

**ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY**

**Proceedings of the Exotic
Nuclei Symposium**

D. Moltz, Editor
Nuclear Science Division

April 1996
Presented at the
Exotic Nuclei Symposium,
Bodega Bay, CA,
April 14-15, 1996,
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the Proceedings

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D. Moltz, Editor

Nuclear Science Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

April 1996

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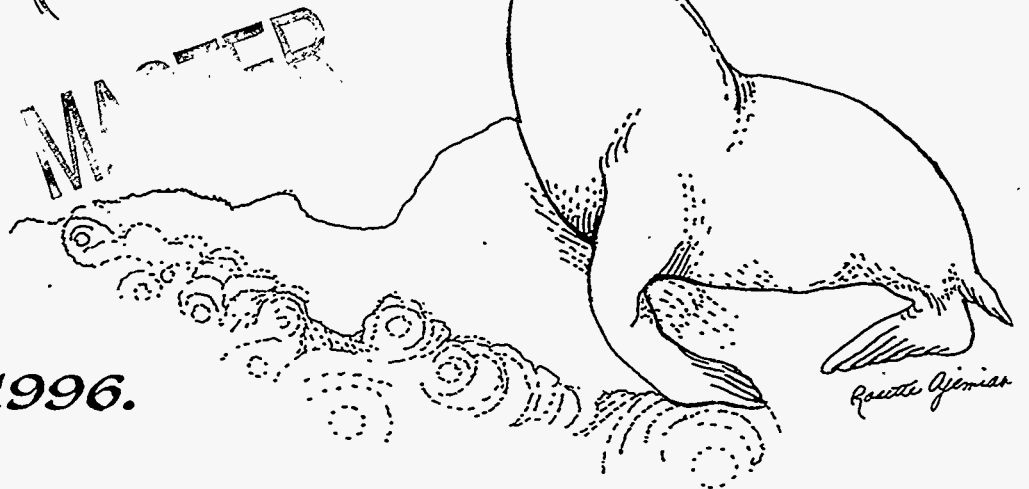
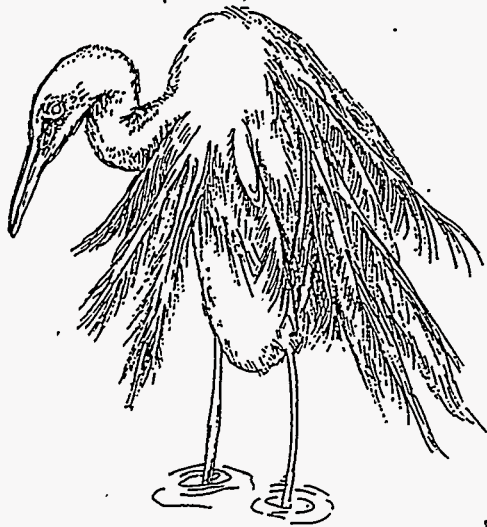
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Exotic Nuclei Symposium

Bodega Bay, Ca.



April 14-16, 1996.

Rosette Agerman

Foreword

This document constitutes the proceedings of the Exotic Nuclei Symposium held in Bodega Bay, California from April 14-16, 1996. All of the speakers were invited and were past associates either as visitors, postdocs or graduate students of Joseph Cerny. The timing of this symposium was such that it coincided closely with Joe's 60th birthday. Although a university professor can measure his own research productivity in a rather straightforward manner, probably the best overall measure is the research accomplishments of those who were directly influenced either as postdocs or graduate students. Almost all of those associated with Joe over the years are still active in research in one form or another. Furthermore, the majority of these individuals are still in nuclear physics and chemistry. The breadth of just the work presented herein is indicative of this point.

Many individuals either planned to attend and cancelled at the last minute or the April timing conflicted with other meetings or teaching duties. Since a couple of hundred people were invited including all of Joe's past associates (to the best of my knowledge), I obviously have a rather complete list of the whereabouts of these individuals. Since I have had numerous requests for this information, I have appended both regular mail and electronic mail addresses to the end of this document.

The banquet was particularly memorable because of the many humorous presentations by both volunteers and conscripts. I am grateful to all who participated. I wish to thank all those who responded so promptly to my initial queries and all of those who were able to attend. I am particularly thankful to everyone for keeping the entire affair as a surprise to Joe. In this light, I am especially grateful to Susan Cerny for arranging for Joe's presence. I also want to thank Linda Lopez for creating a credible work schedule for April 15 and 16. I wish to thank the Bodega Bay Lodge for making the organization rather trivial from my perspective. Finally, I would like to thank my wife Rosette for designing the cover page art. I believe everyone had a good time, while still managing to learn a bit.

Dennis M. Moltz

16:05 - 17:20 Session IV Rainer Jahn, Chairman

16:05 - 16:30	John Hardy CRL, Canada	<i>Superaligned beta-decay: a Nuclear Probe of the Standard Model</i>
16:30 - 16:55	Juha Äystö, U. of Jyväskylä, Finland	<i>Beta-Delayed Neutron Emission</i>
16:55 - 17:20	Gordon Wozniak LBNL	<i>From Exotic Reactions to Multifragmentation</i>

Banquet 19:30

EXOTIC NUCLEI SYMPOSIUM SCHEDULE

Day 2

April 16, 1996

9:00 - 9:05 Introduction

9:05 - 10:20 Session V David Vieira, Chairman

9:05 - 9:30	Mike Rowe LBNL	<i>Beta-Delayed Particle Decays of Light Nuclei</i>
9:30 - 9:55	Dennis Moltz LBNL	<i>Dark Matter Axions</i>
9:55 - 10:20	Claude Detraz IN2P3, France	<i>Nuclear and Particle Physics in Europe; A View from the Skipper</i>

Break 10:20 - 10:45

10:45 - 12:30 Session VI Juha Äystö, Chairman

10:45 - 11:10	Creve Maples Musetech	<i>A New Dimension in Human-Computer Interaction</i>
11:10 - 11:35	Mike Cable LLNL	<i>Nuclear Measurement Techniques for Inertial Confinement Fusion</i>
11:35 - 12:00	Peter Haustein BNL	<i>Nuclear Stimulated Desorption from Surfaces and Thin Films</i>
12:00 - 12:15	Joseph Cerny	<i>The Final Word</i>

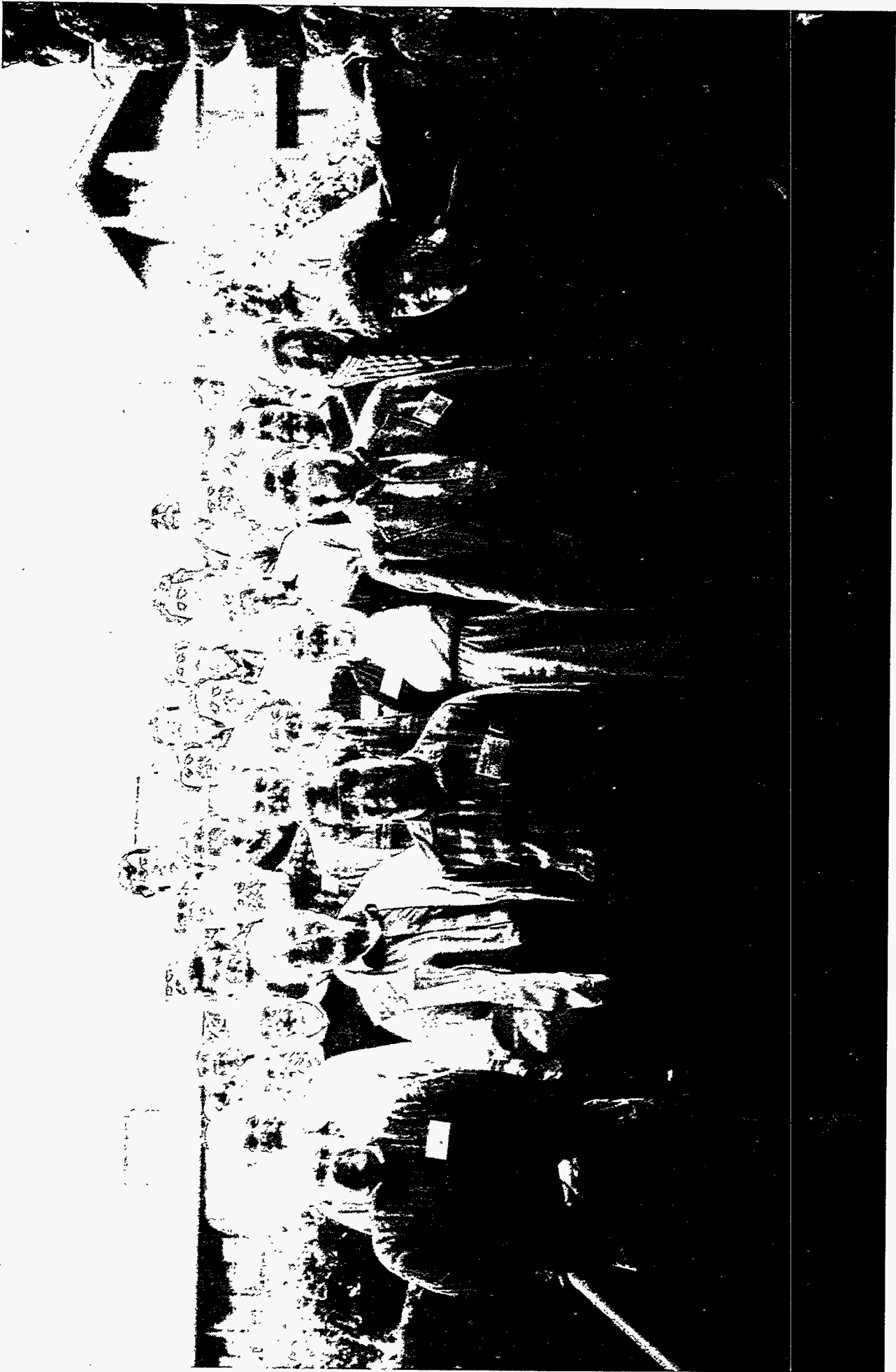
Conference Photograph

First Row- Gordon Ball, Lee Schroeder, Dennis Moltz, Joe Cerny,
Susan Cerny

Second Row- John Hardy, Bernard Harvey, Norman Glendenning, Peter
Haustein, Ruth-Mary Larimer, Janis Dairiki, Rick Gough,
Alan Shotter

Third Row- Mike Zisman, Jorgen Randrup, Juha Äystö, Eric Norman,
Bob McGrath, Claude Detraz, Rainer Jahn, Bob Weisenmiller

Fourth Row- Creve Maples, Peter Jackson, David Vieira, James Powell,
Mike Cable, Jon Batchelder, Ted Ognibene, Mike Rowe,
Gordon Wozniak



Registered Conference Attendees not making Presentations

Bernard Harvey, LBNL

Lee Schroeder, LBNL

Norman Glendenning, LBNL

Ruth-Mary Larimer, LBNL

Janis Dairiki, LBNL

Ned Dairiki, LLNL

Jorgen Randrup, LBNL

Eric Norman, LBNL

James Symons, LBNL

John Rasmussen, LBNL and UC Berkeley

Gabor Somorjai, LBNL and UC Berkeley

Sam Markowitz, LBNL and UC Berkeley

Ian Carmichael, UC Berkeley

Carol Christ, UC Berkeley

Dan Mote, UC Berkeley

Bob McGrath, SUNY Stony Brook

Peter Jackson, TRIUMF

Robert Weisenmiller

MRW & Associates
Oakland, CA

EXOTIC ENERGY POLICY

How I Spent from 1977-96

by

Dr. Robert B. Weisenmiller

Morse, Richard, Weisenmiller
& Associates, Inc.

April 12, 1996



OVERVIEW

- 1977 - PhD in Chemistry
- 1977 - M.S. in Energy & Resources
- 1977 - California Energy Commission
- 1982 - Independent Power Corporation
- 1986 - Morse, Richard, Weisenmiller, & Associates, Inc..

California Energy Commission

- Established in 1975 by the Warren-Alquist Act (signed by Governor Reagan)
- Act Implemented by Commissioners Appointed by Governor Jerry Brown
- Roughly 500 person staff with about \$50 million budget
- Located in Sacramento

California Energy Commission Responsibilities

- Forecasting future electricity and energy needs
- Licensing energy facilities to meet these needs
- Promoting energy efficiency
- Developing alternate energy technologies
- Planning for energy emergencies

Energy Context in 1975

- It was assumed energy requirements rose in lock step with economic growth
- It was assumed that over the next twenty years, California would require about 20 1000 MW coal or nuclear power plants
- These plants could be either located along the California coast with seismic issues or inland with water issues

Energy Context (cont'd)

- Nuclear plants were perceived to have safety and waste disposal issues
- Coal plants had obvious air quality concerns
- Electric utilities were monopolies from power plant to meter
- Natural gas prices were regulated and low, so regulation rationed supply. Shortages were common.

Energy Context (cont'd)

- Nuclear plants were perceived to have safety and waste disposal issues
- Coal plants had obvious air quality concerns
- Electric utilities were monopolies from power plant to meter
- Natural gas prices were regulated and low, so regulation rationed supply. Shortages were common.

Energy Context (cont'd)

- Natural gas service was also generally provided by monopolies, aside from production
- Domestic oil supplies were also price controlled, while foreign oil supplies were controlled by OPEC
- California's energy needs would require the sacrifice of its environmental quality

California Energy Commission

- 1977 -- Advisor to Commissioner Ron Doctor
- 1978-79 -- Office Manager of the Special Project Office (Overall RDD Policy, Cogeneration, Small Power, Power Pooling)
- 1980-82 -- Director of the Office of Policy and Program Evaluation

CEC Accomplishments

- Developed Comprehensive Energy Policy Package for Brown in 1978, which included legislation and administrative actions
- Blocked utility commitments to coal plants
- Developed energy services concept which lead to utility conservation programs
- Developed avoided cost concept which lead to cogeneration and renewable industry



State of California

GOVERNOR'S OFFICE
SACRAMENTO 95814

EDMUND G. BROWN JR.
GOVERNOR

November 10, 1982

Dr. Robert B. Weisenmiller
Director,
Policy and Programs
California Energy Commission
Sacramento, CA 95825

Dear Dr. Weisenmiller:

On the occasion of your departure from the California Energy Commission, I want to congratulate you for your accomplishments in the energy field and wish you success in the future.

I understand your efforts have left a mark of excellence at the Commission and been a critical component of California's progressive energy policy.

Thank you for your service to the people of California.

Sincerely,


Edmund G. Brown, Jr.
Governor

Consulting Career

- Co-founded and managed two nationally known energy consulting firms
- Testified as an expert witness in about 100 proceedings
- Representing Dow, Arco, Chevron, Simpson Paper, Proctor & Gamble, etc.. established framework for cogeneration industry in California

Consulting Career (cont'd)

- Established bankable reputation with the financial community for their investments in energy projects
- Lead witness for the City of San Diego to block SCE/SDG&E merger
- Lead witness for El Paso, Mojave, and Kern River pipelines in pipeline rates and expansion cases

Current Energy Realities

- California's (and U.S.) economic growth has occurred with little energy growth
- Beyond their earlier commitments California utilities have built limited resources since 1977 (i.e., Palo Verde)
- Conservation limited need for additional utility power plants.

Current Energy Realities (cont'd)

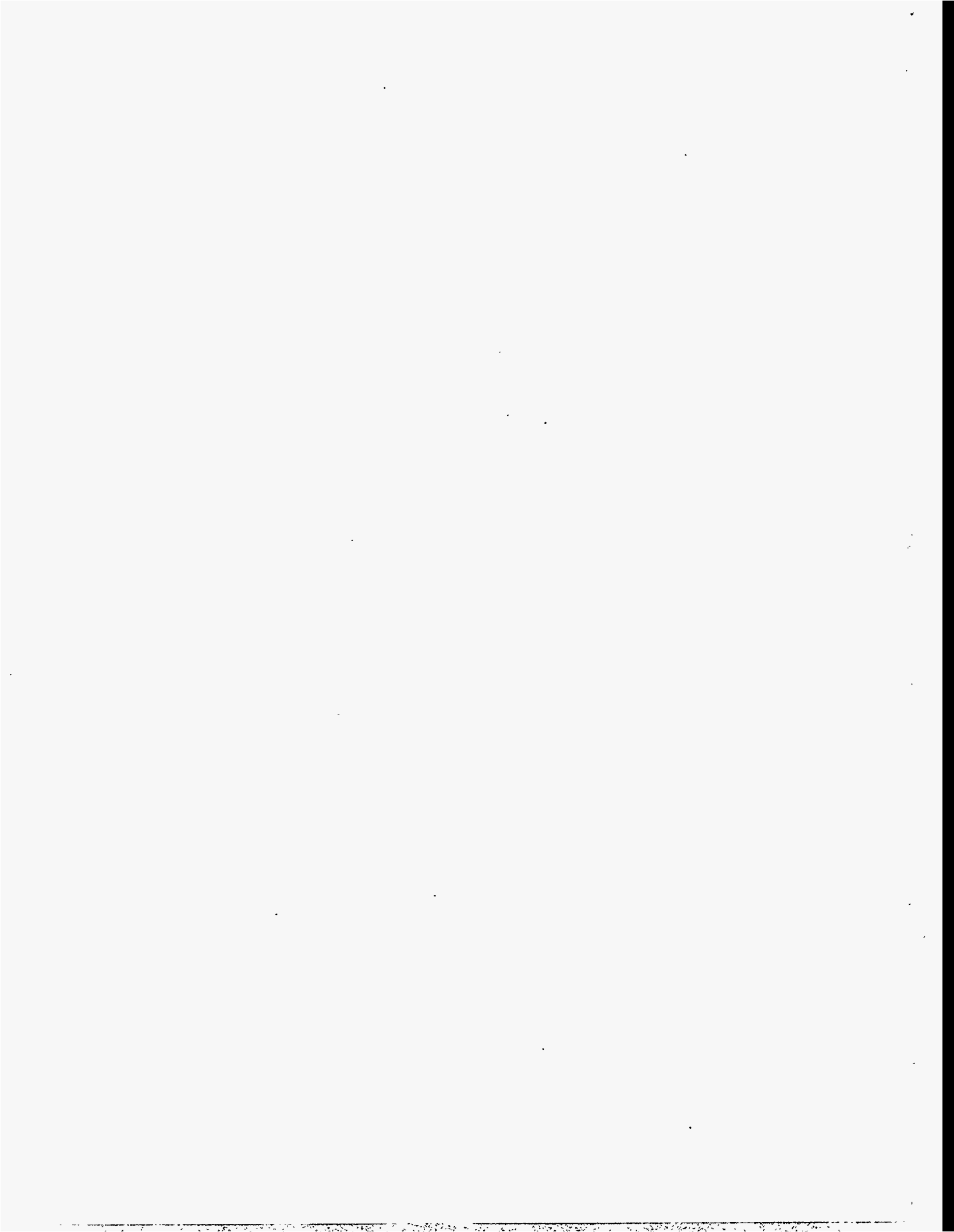
- Cogeneration dissolved utility monopoly on generation services.
- California gets between 20 and 30% of its power from cogeneration
- California has surplus power situation
- Natural gas is cheap and plentiful

Current Energy Realities (cont'd)

- Gas and power markets on a national and international level are being restructured by competitive forces
- Higher oil prices depressed demand, increased alternatives, and broke OPEC stranglehold at least in the near-term

Rainer Jahn

University of Bonn
Bonn, Germany



Two - Mason - Production

at

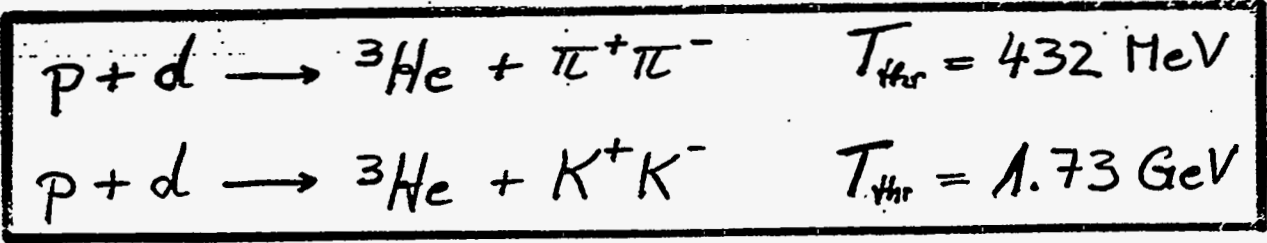
COSY

Basics + Exotics

Rainer Jahn

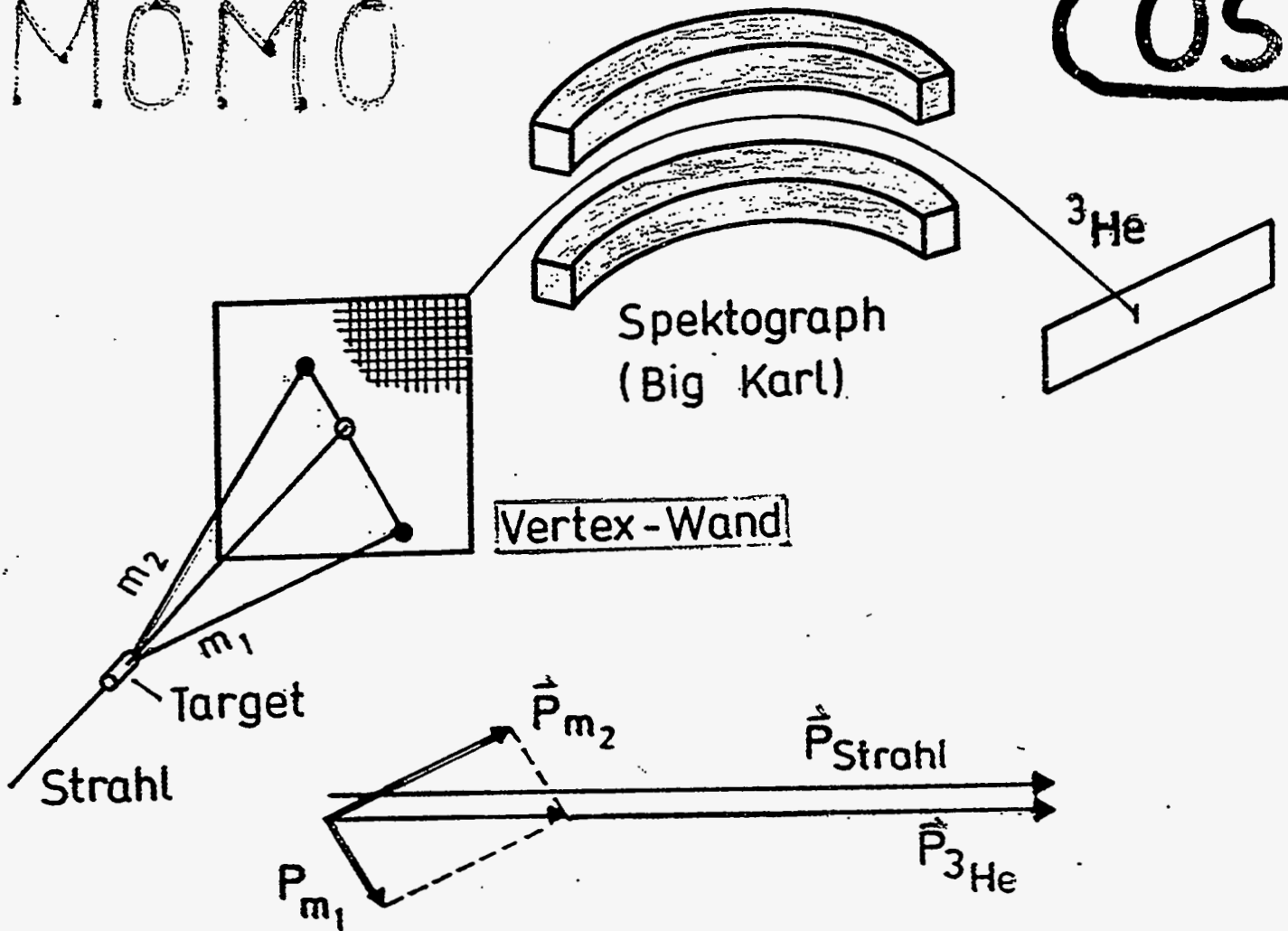
Bodega Bay Meeting

10/196



MOMO

COSY



detected: $\vec{P}_{{}^3\text{He}} \rightarrow T_{{}^3\text{He}}$
 $\vec{P}_{m_1} \rightarrow T_{m_1}$
 $\vec{P}_{m_2} \rightarrow T_{m_2}$

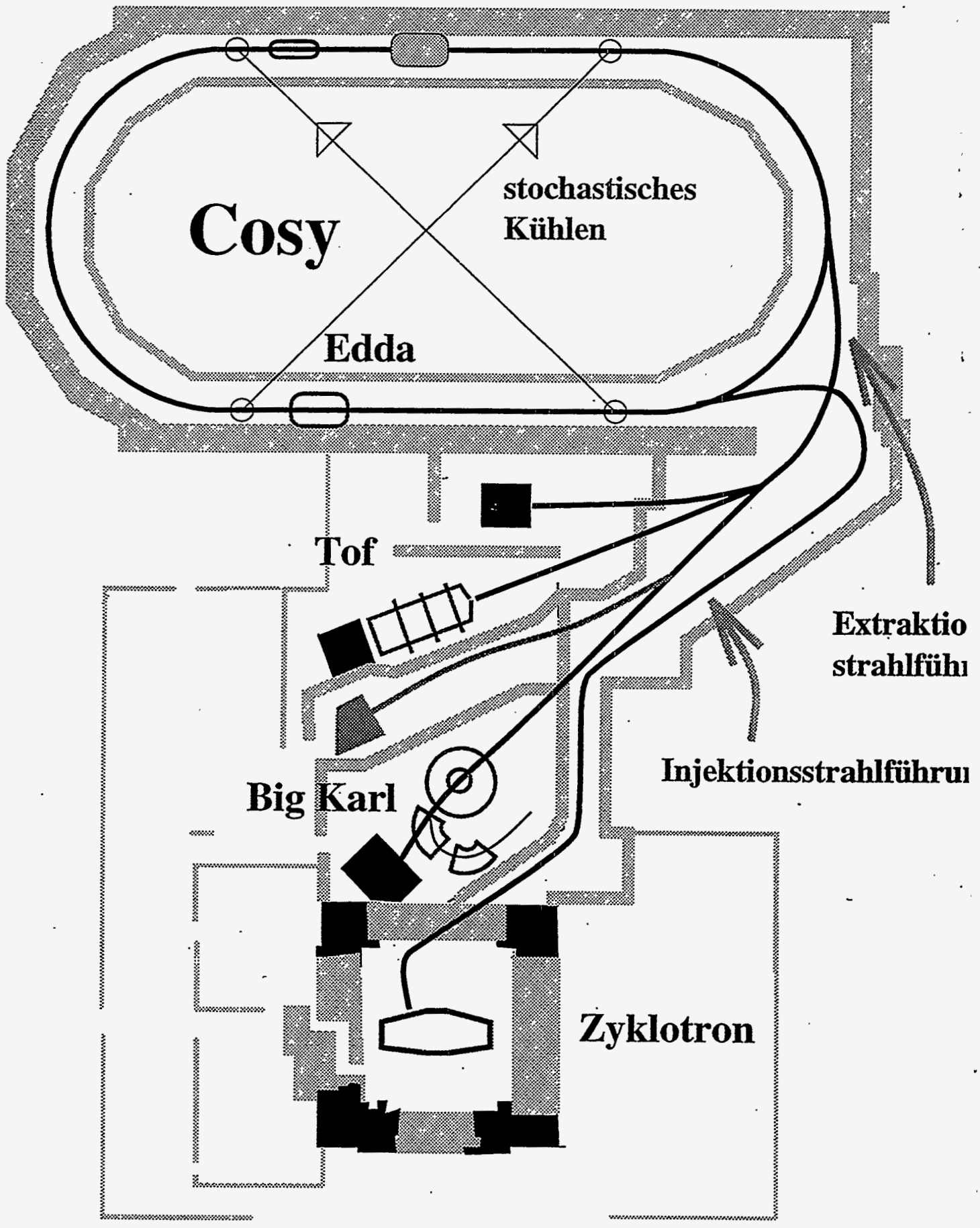
Energy conservation $\rightarrow m_1 + m_2$

kinematically complete

Physics with MOMO

- low energy $\pi^+\pi^-$ and K^+K^- interaction
 - KK molecules
 - meson nucleon Resonances $d^1?$
- in near threshold two meson production

HF Elektronen Kühler



Cosy

**stochastisches
Kühlen**

Edda

Tof

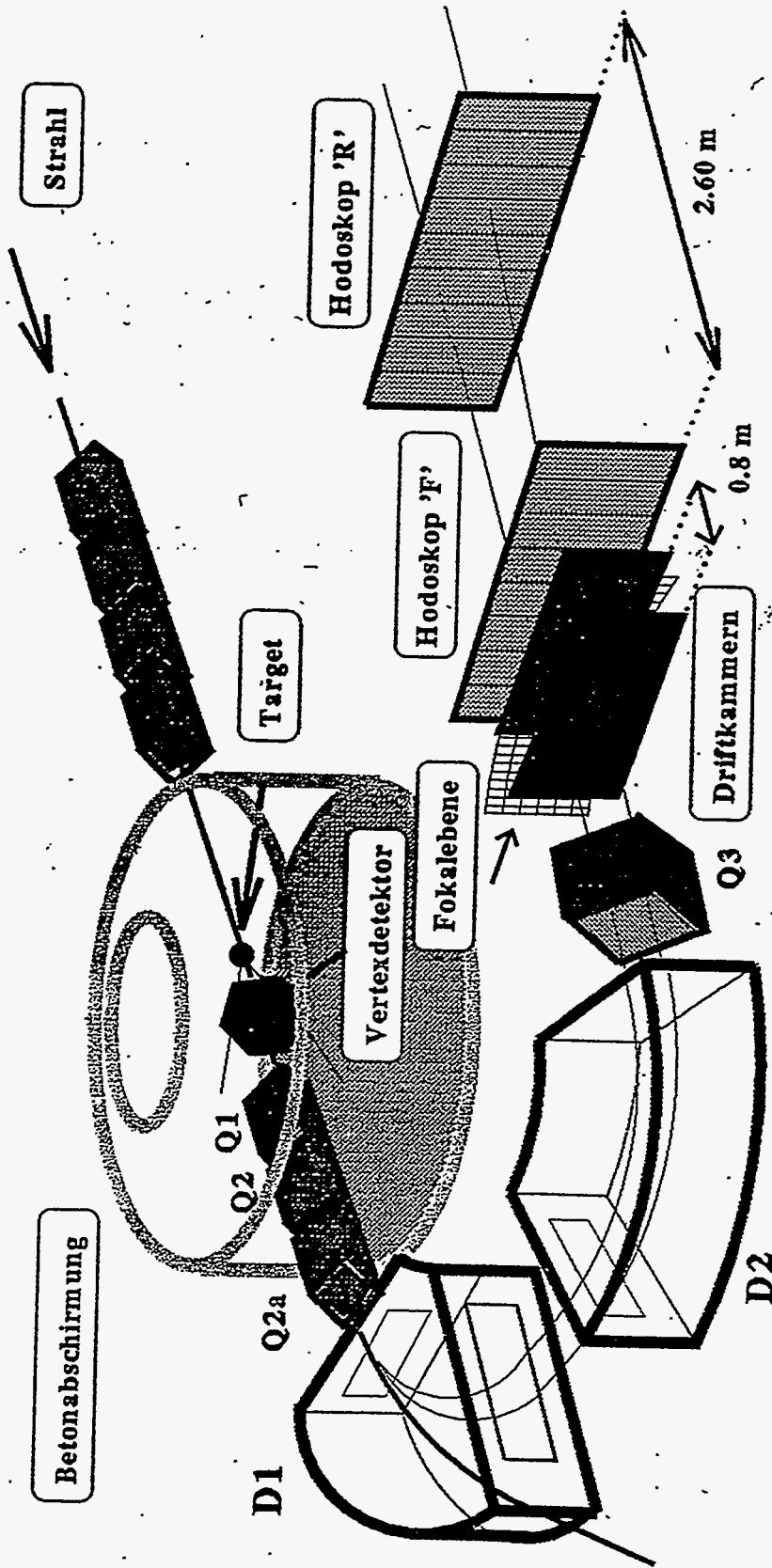
**Extraktio
strahlführu**

Big Karl

Injektionsstrahlführu

Zyklotron

Strahlplatz BIG KARL



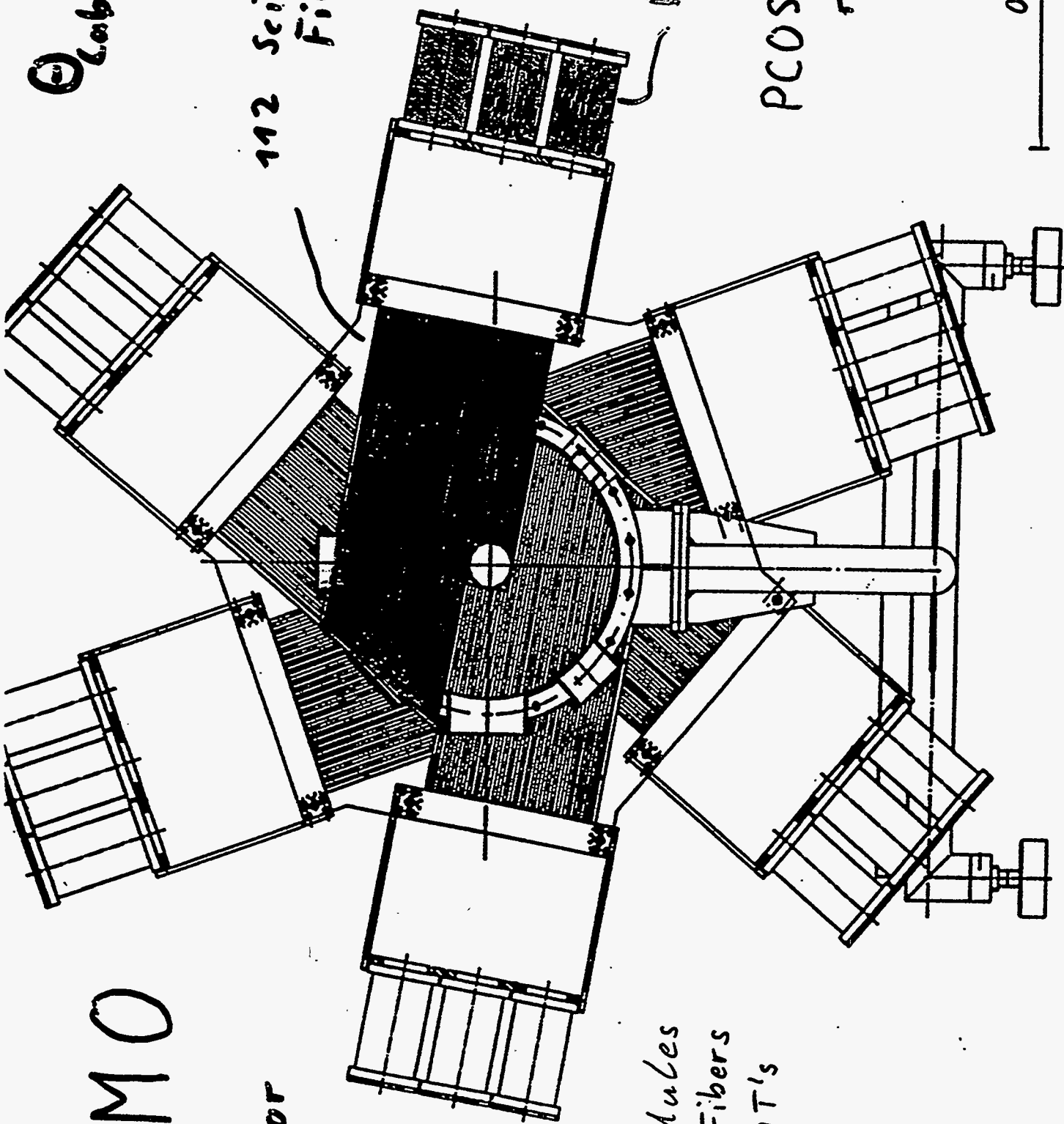
$\Theta_{Lab} \cong \pm 45$

112 Scintillator
Fibers

R4760
PMT's

PCOS III -
readout

0.5 m

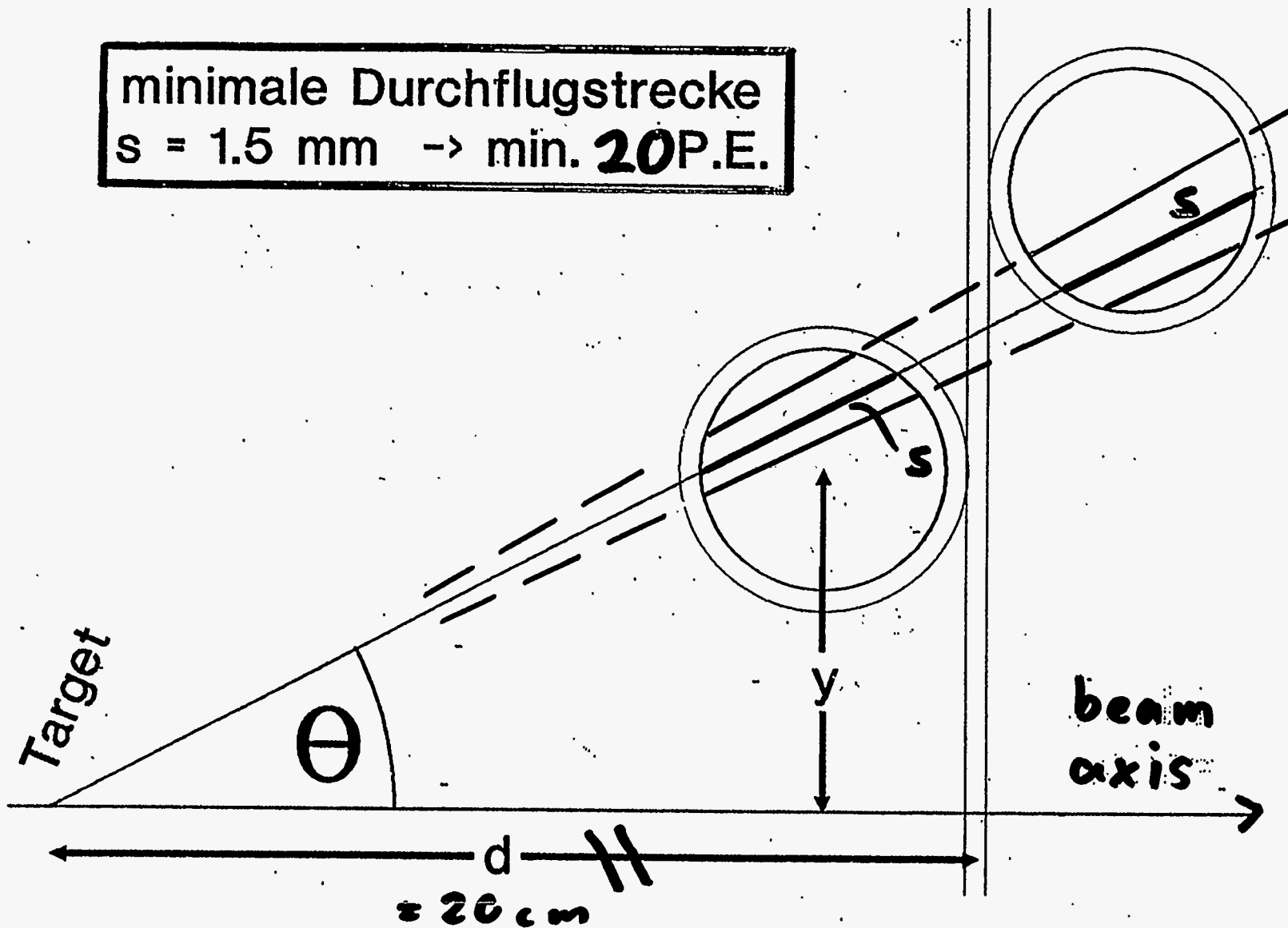


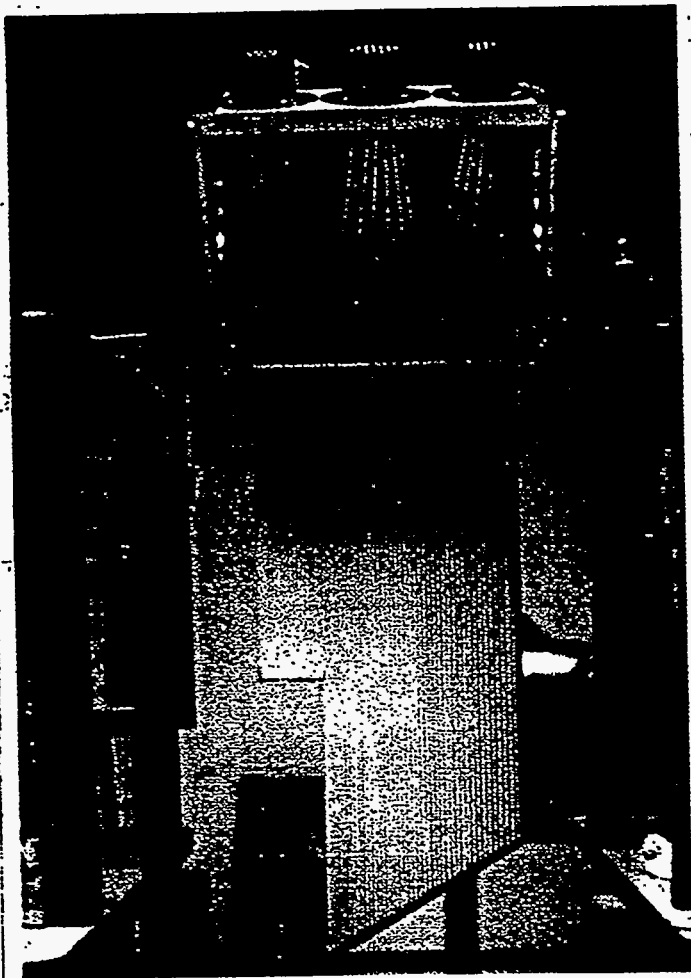
MOMO

Vertex
Detector

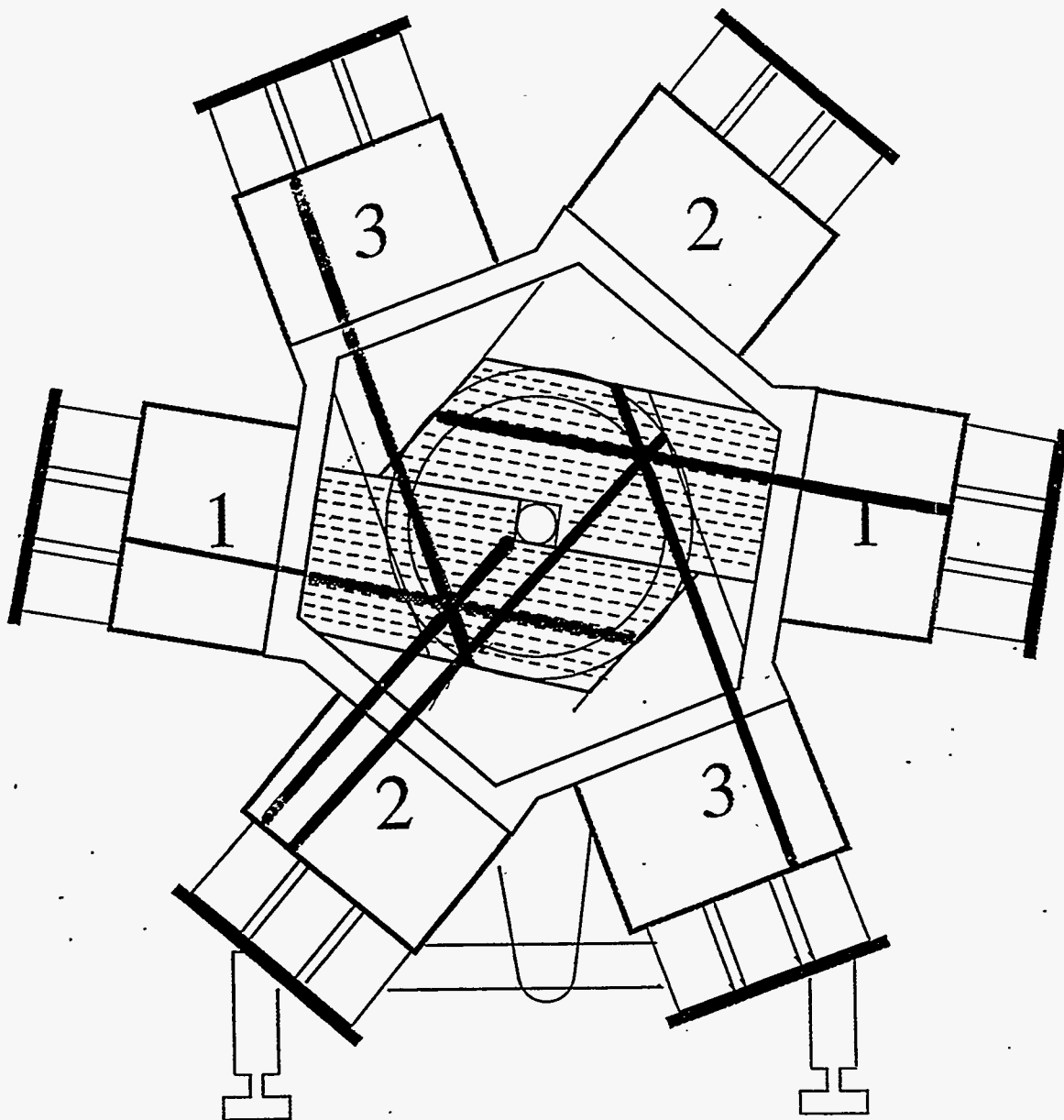
6 Modules
672 Fibers
54 PMT's

minimale Durchflugstrecke
 $s = 1.5 \text{ mm} \rightarrow \text{min. } 20\text{P.E.}$



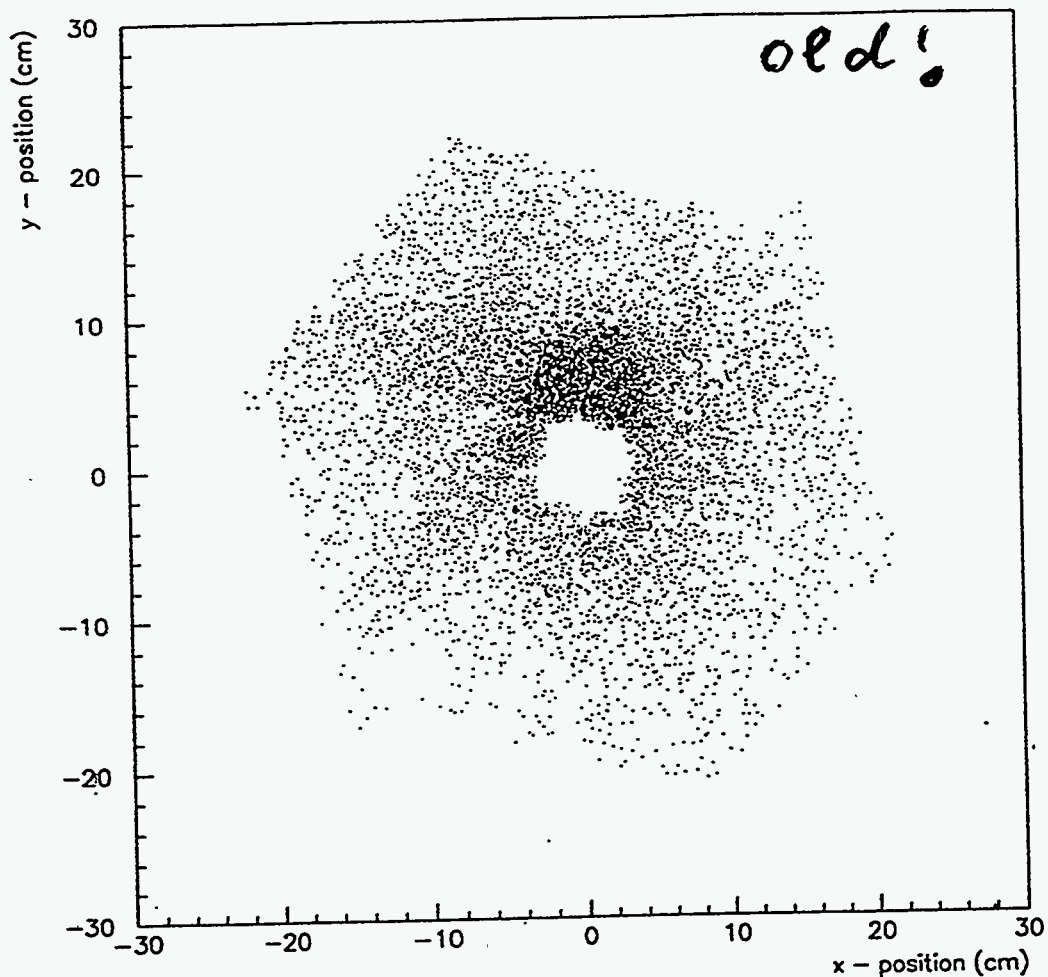


Vertexrekonstruktion



Beam Halo

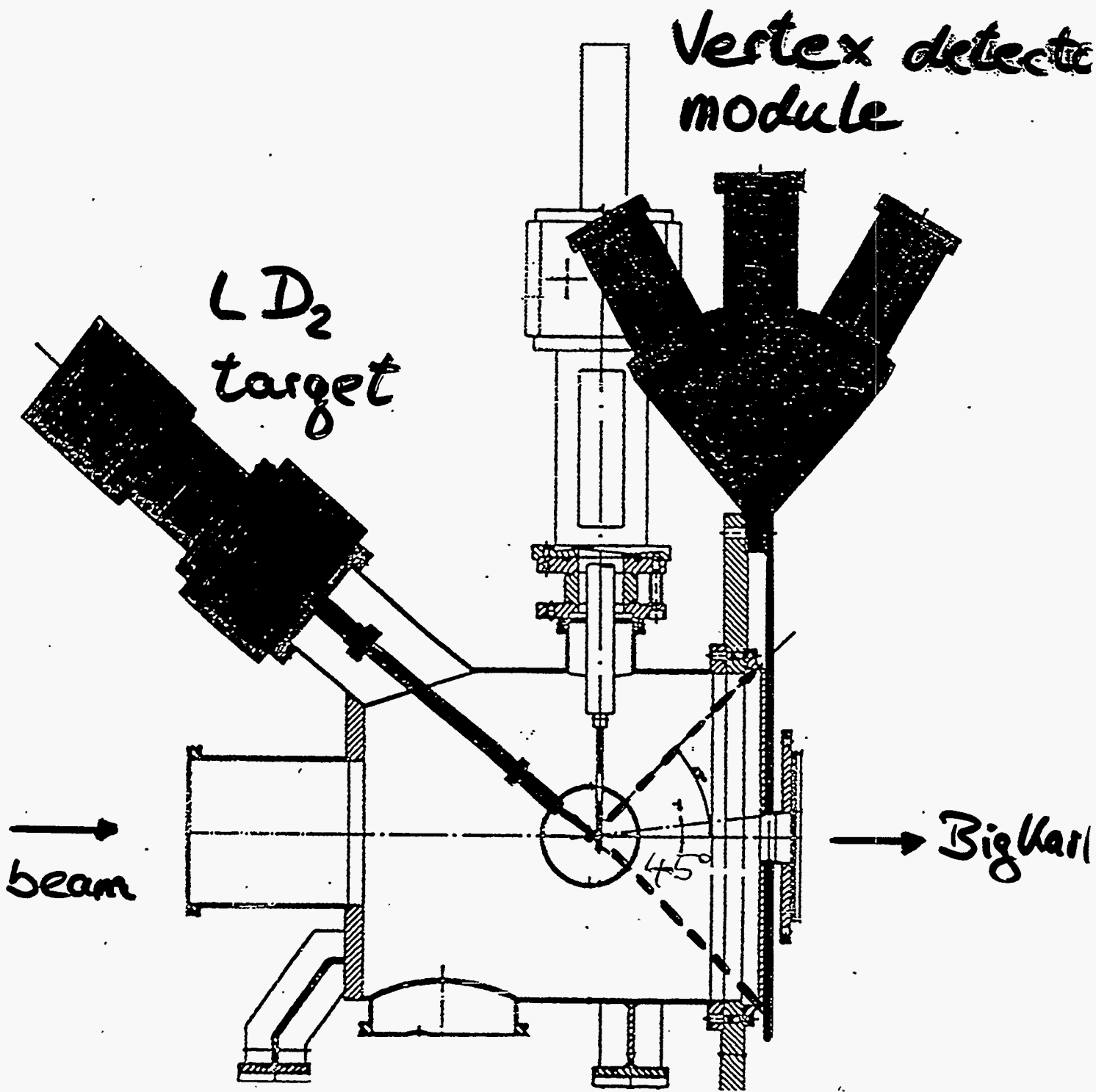
The vertex wall is
used as monitor
triggered on all events, not only



all hits

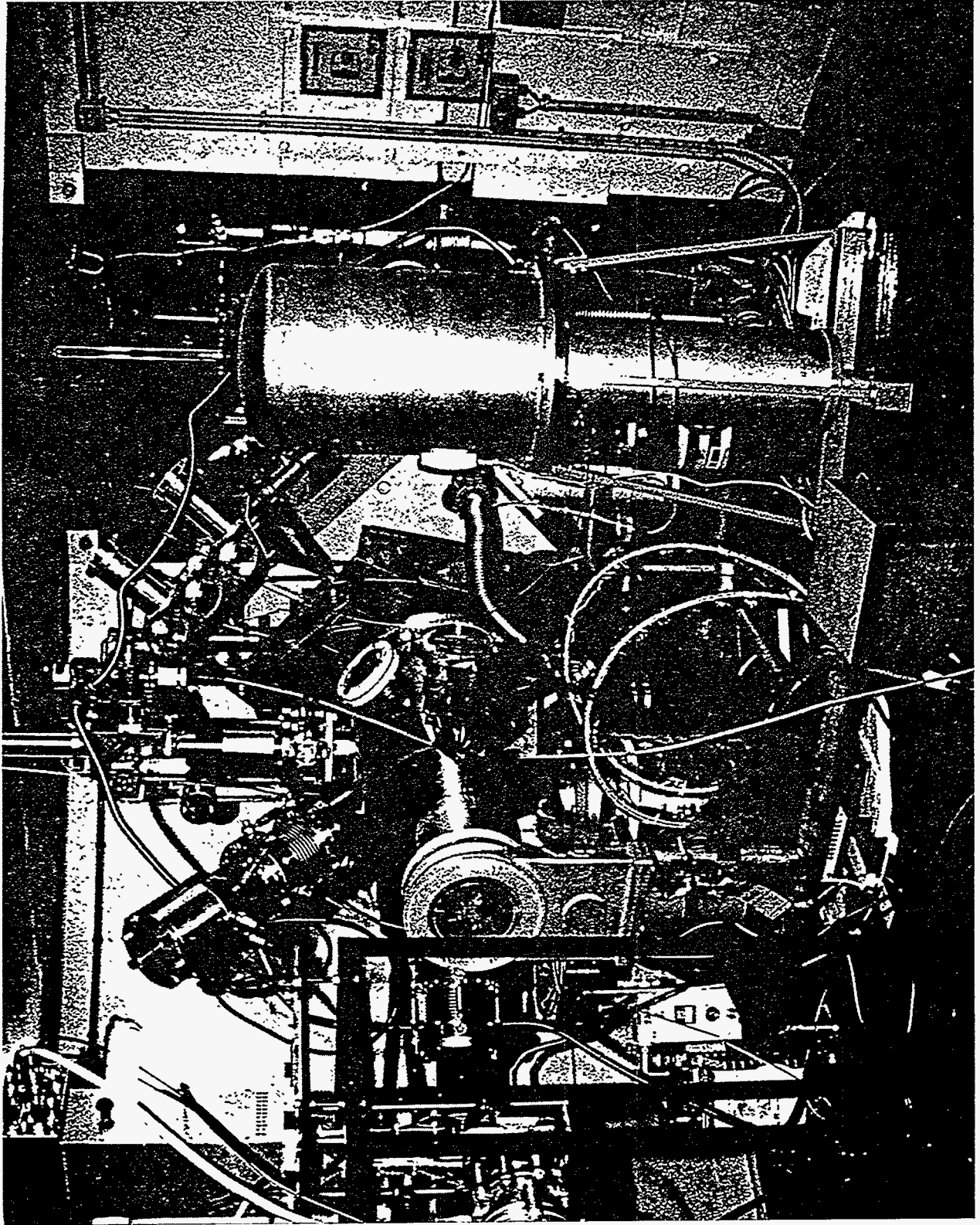
1150 MeV/c

$\sim 10^7$ p/c



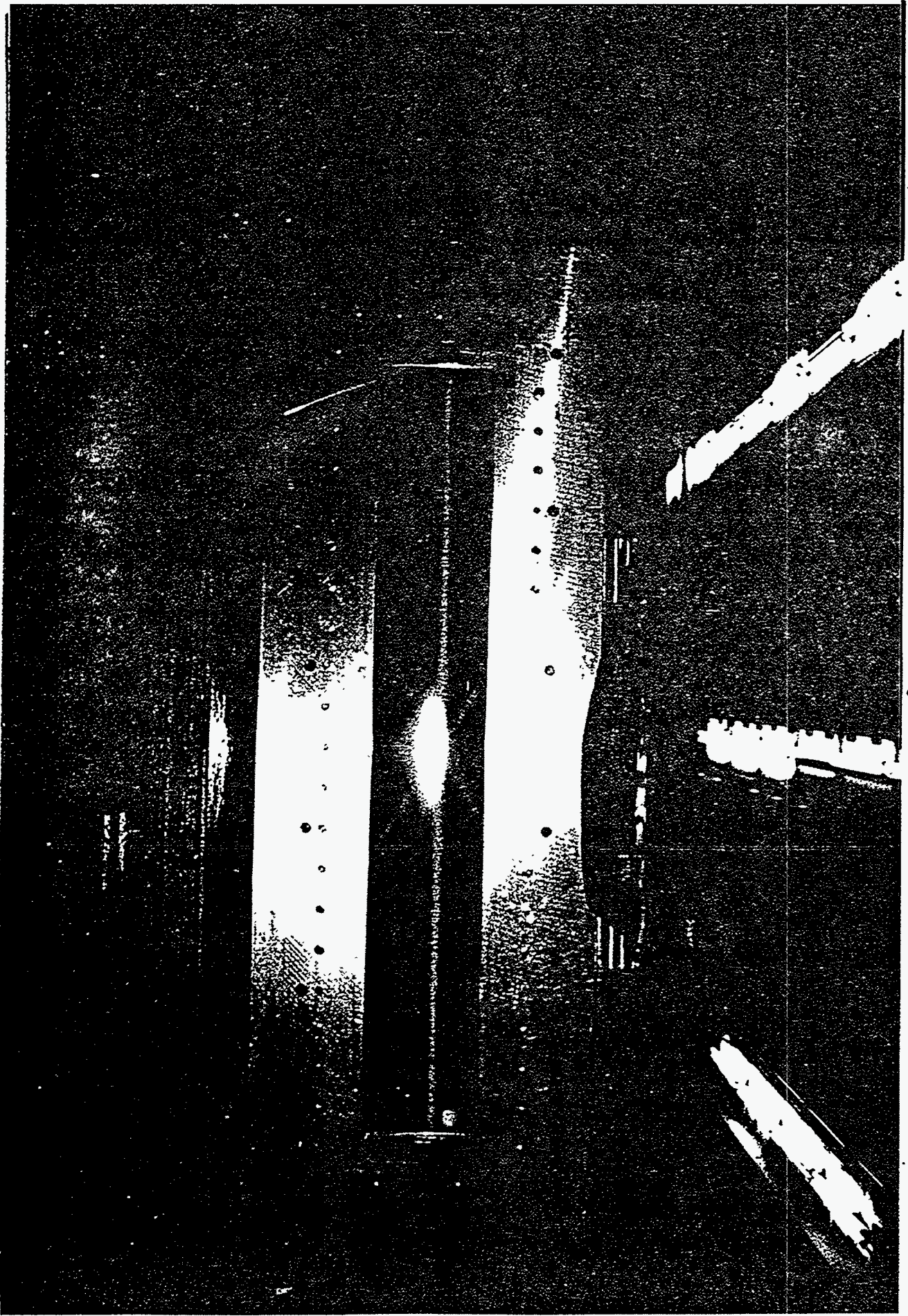
MOMO Target area

M O M O



1/11/55

В И С Т У П Л Е Н И Е

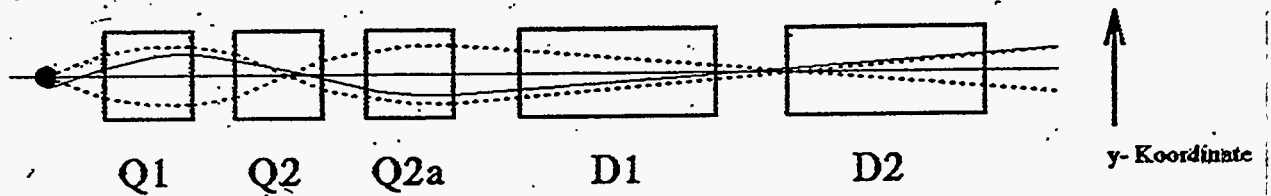


КРАКОВ - ЗÜLICH - БОНН

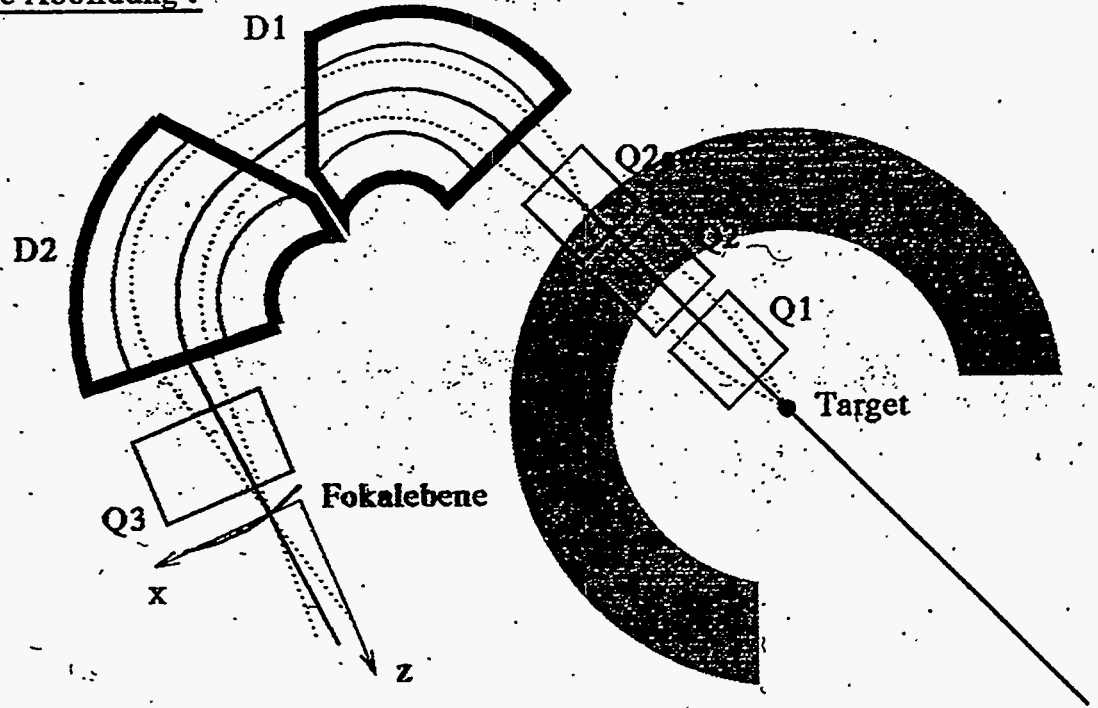
Abbildungseigenschaften von Big Karl

vertikale Abbildung :

vertikaler Winkel \rightarrow y Position in der Fokalebene

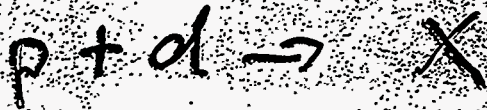


horizontale Abbildung :



Gesamtimpuls \rightarrow x Position in der Fokalebene

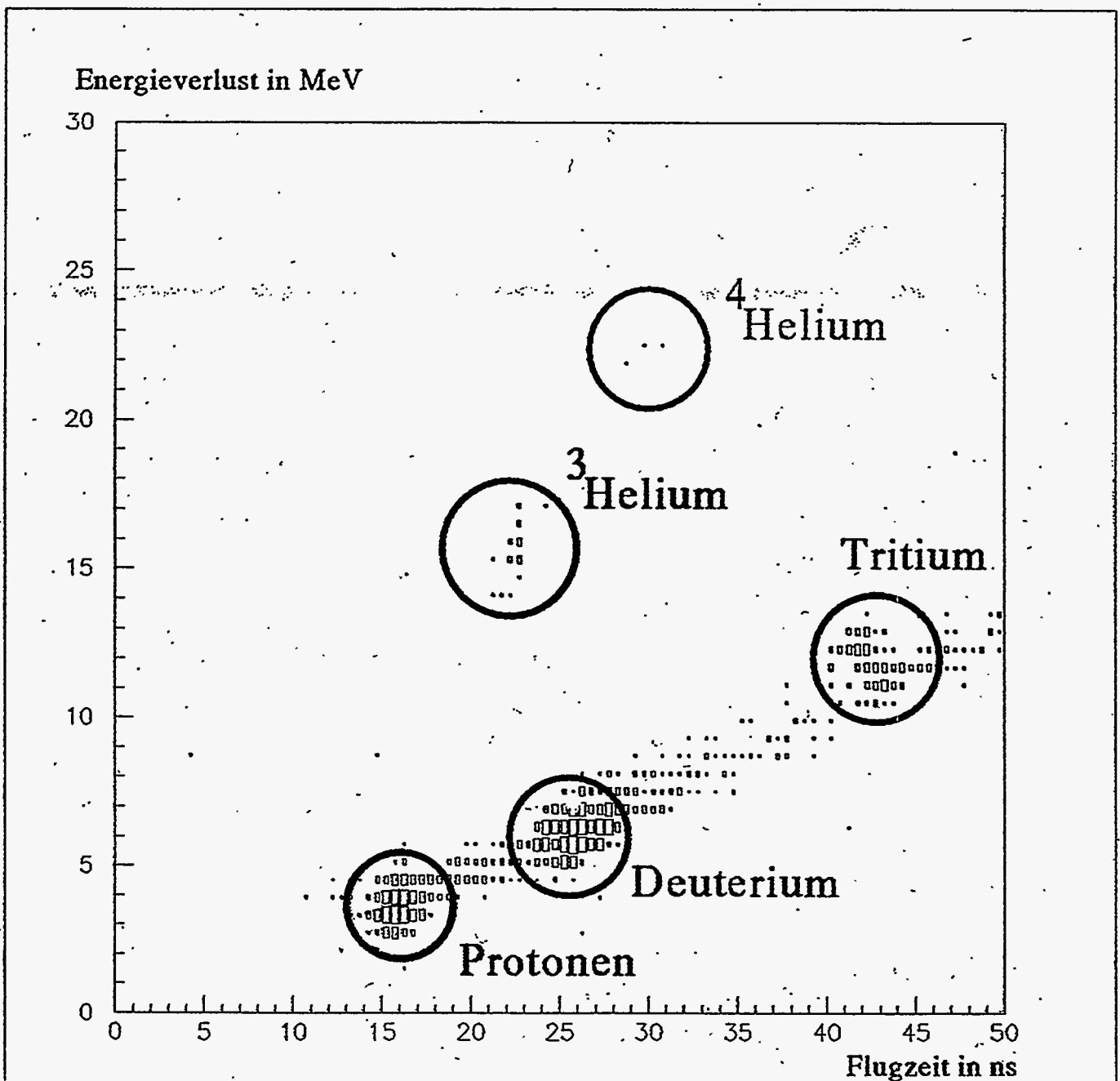
horizontaler Winkel \rightarrow horizontalen Winkel in der Fokalebene



1150 MeV/c

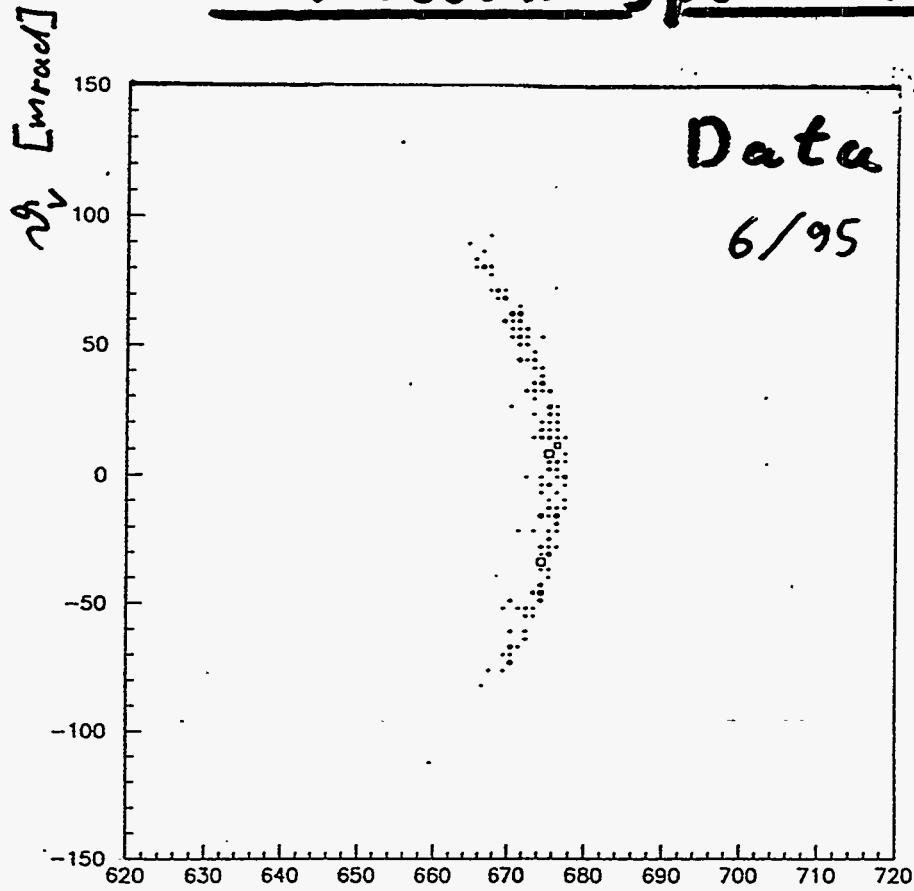
Teilchenidentifikation

Energieverlust im ersten Szintillatorhodoskop
gegen Flugzeit zwischen den beiden Hodoskoplagen



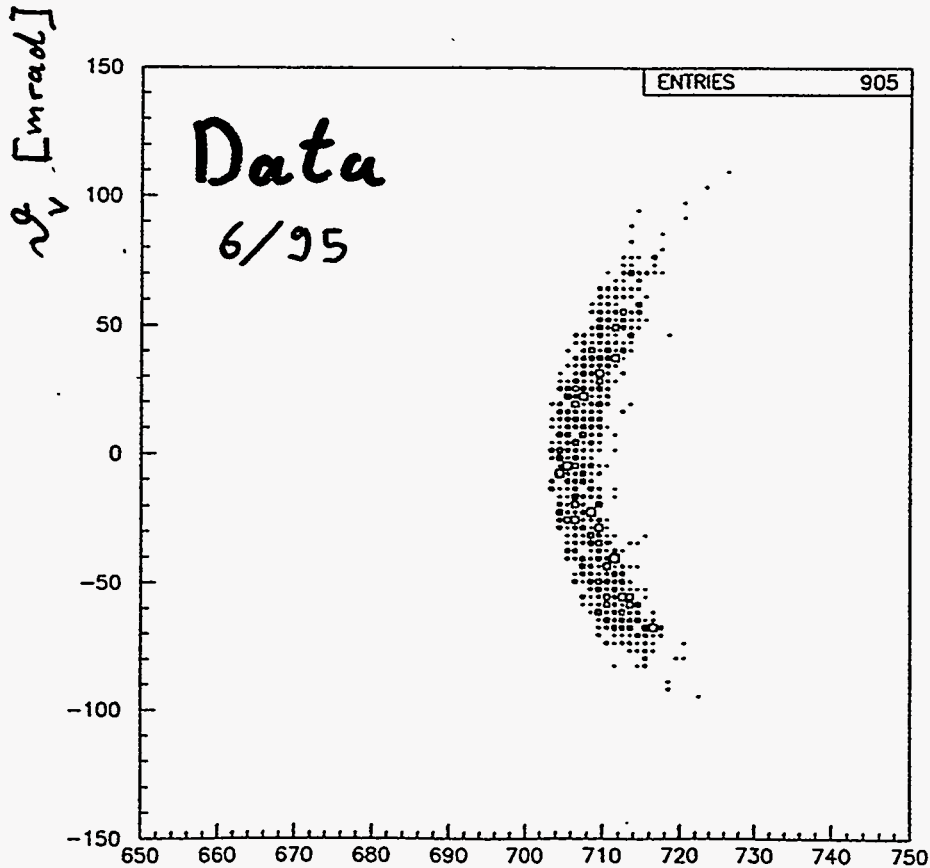
Fokalebene Spektren

BIG Ki



$pd \rightarrow {}^3\text{He}$

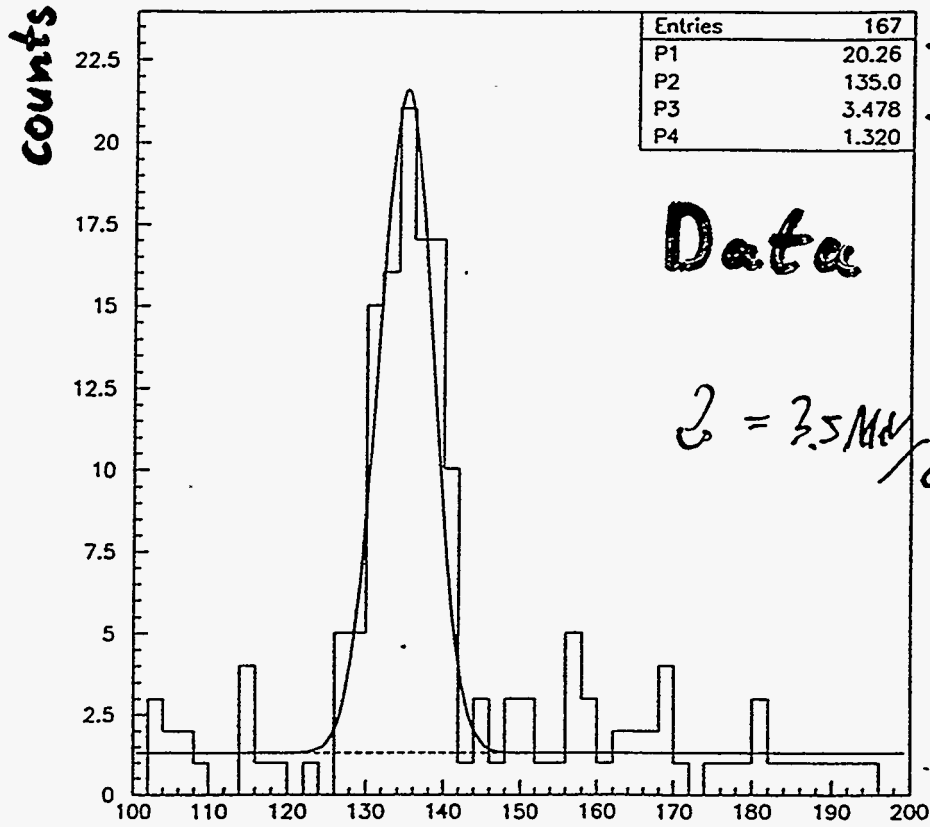
P/Z [MeV/c]



$pd \rightarrow {}^3\text{H}\pi$

missing mass

5/95

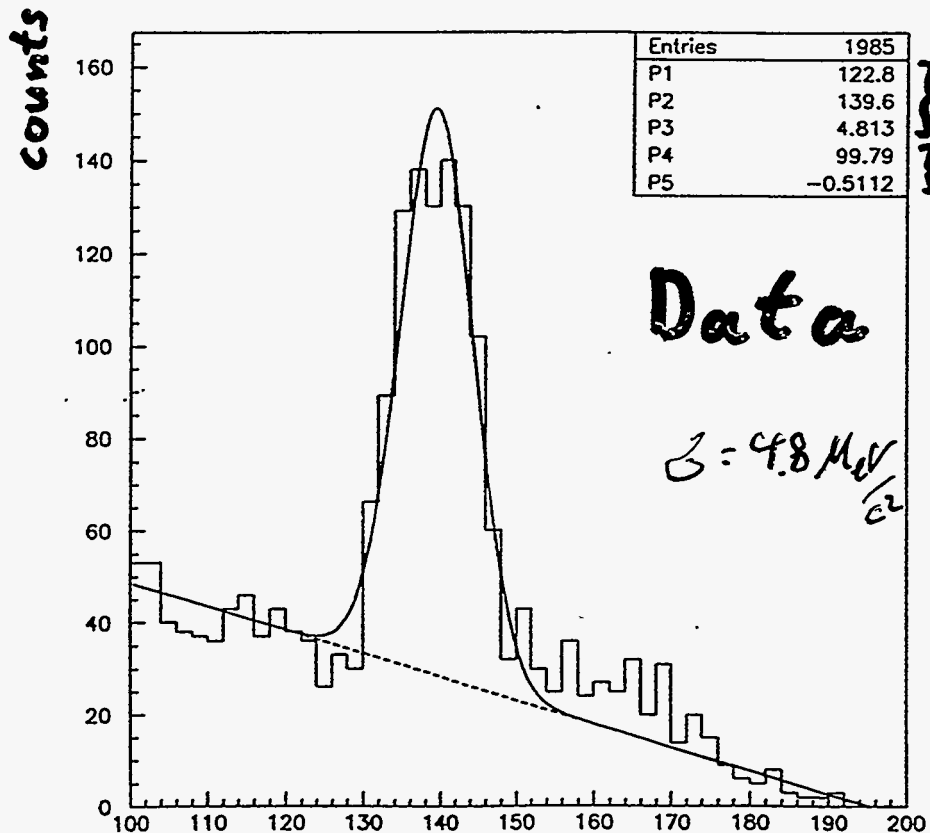


} Gauß
const

pd \rightarrow $^3\text{He} \pi^0$

$$\beta = 3.5 \text{ MeV}/c^2$$

$m_{\pi^0} [\text{MeV}/c^2]$



} Gauß
Line

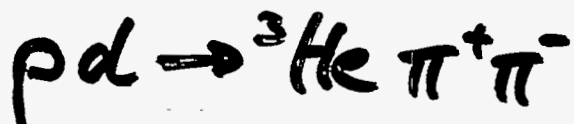
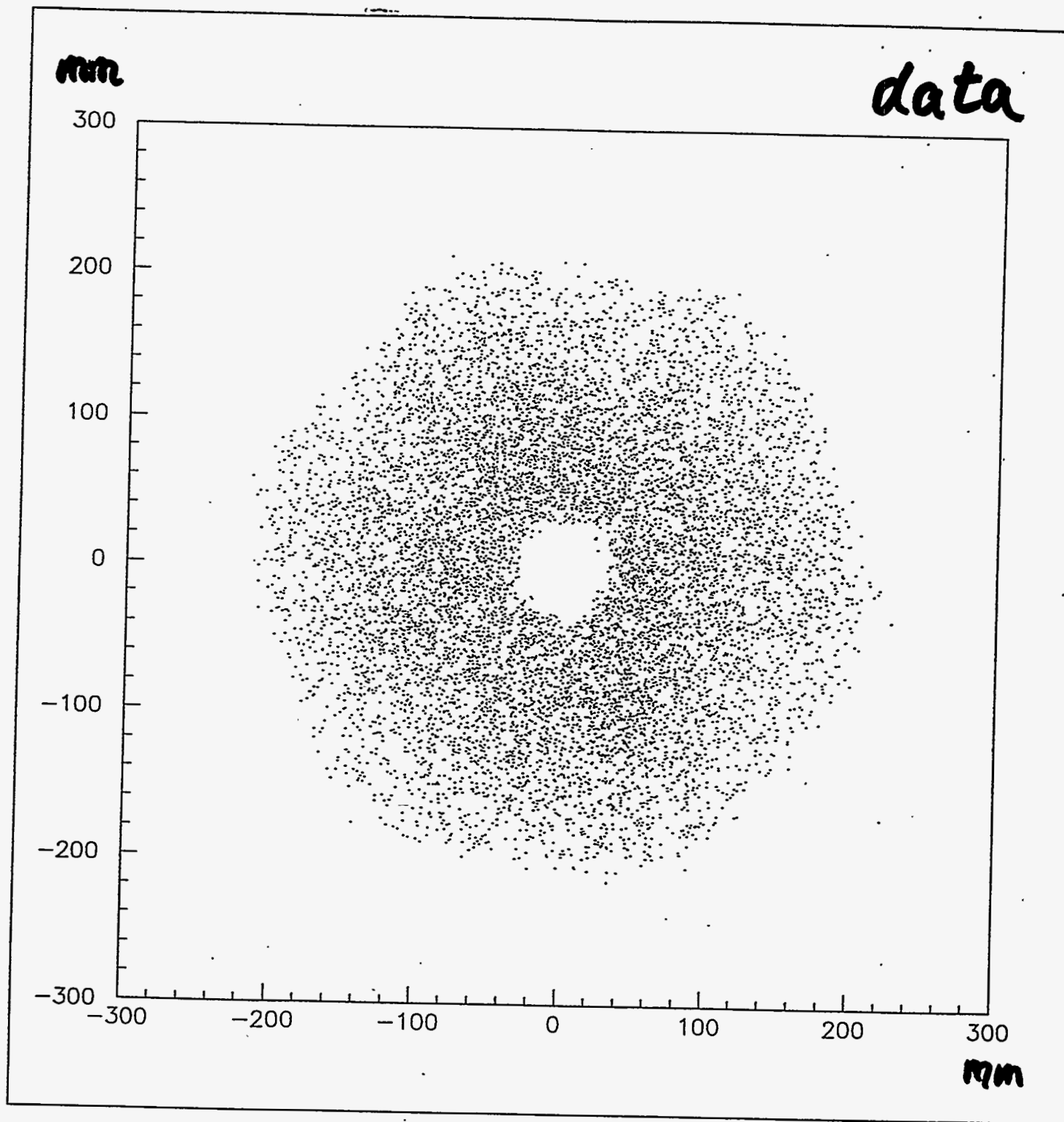
pd \rightarrow $^3\text{He} \pi^+$

$$\beta = 4.8 \text{ MeV}/c^2$$

$\Gamma \text{ MeV}$

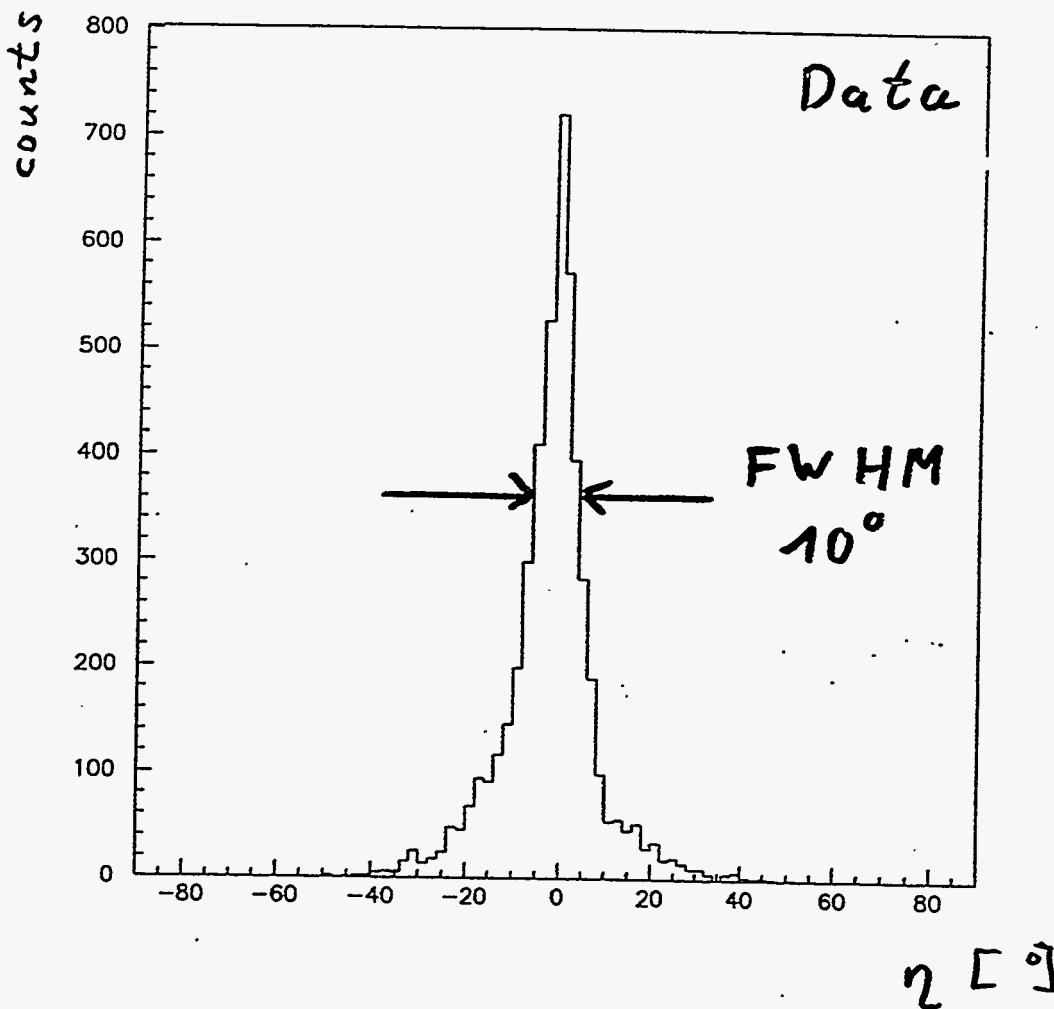
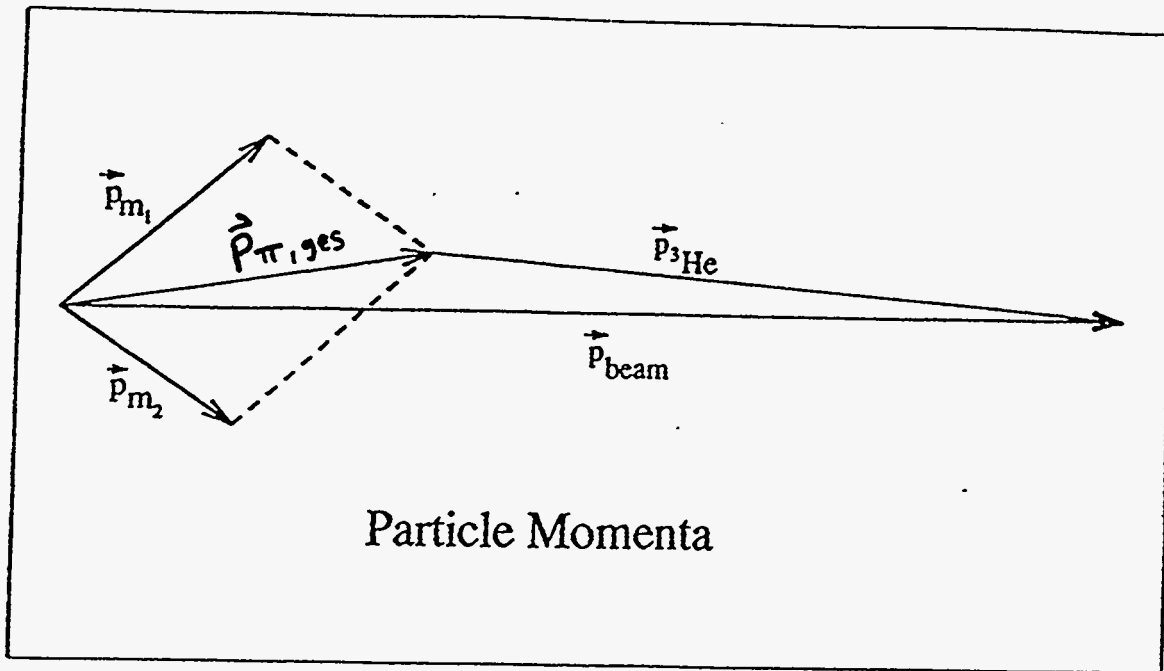
Two Pion Hits

4/19/66



$$P_D = 1150 \text{ MeV}/c$$

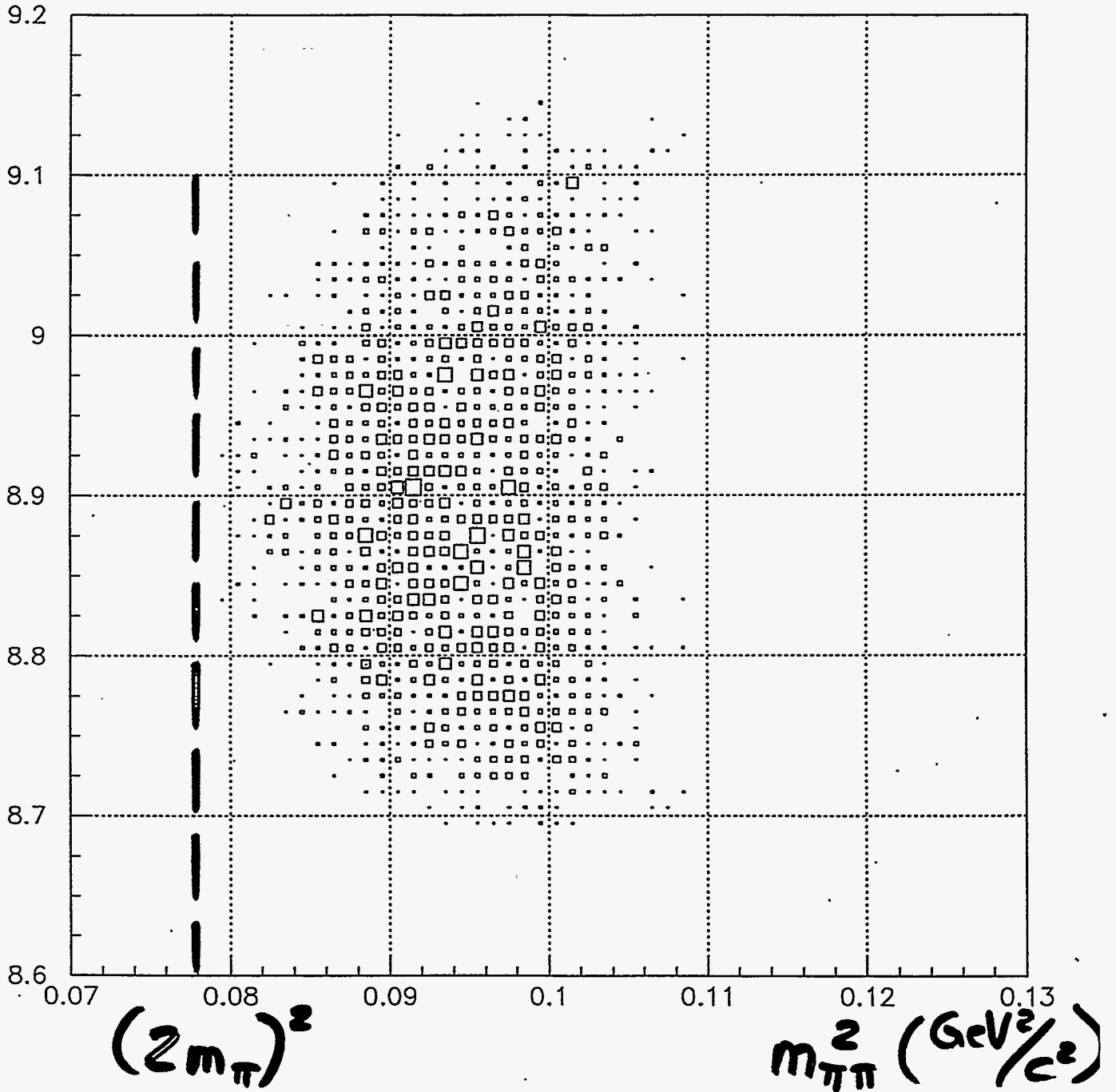
Koplanaritäts test



DALITZ PLOT

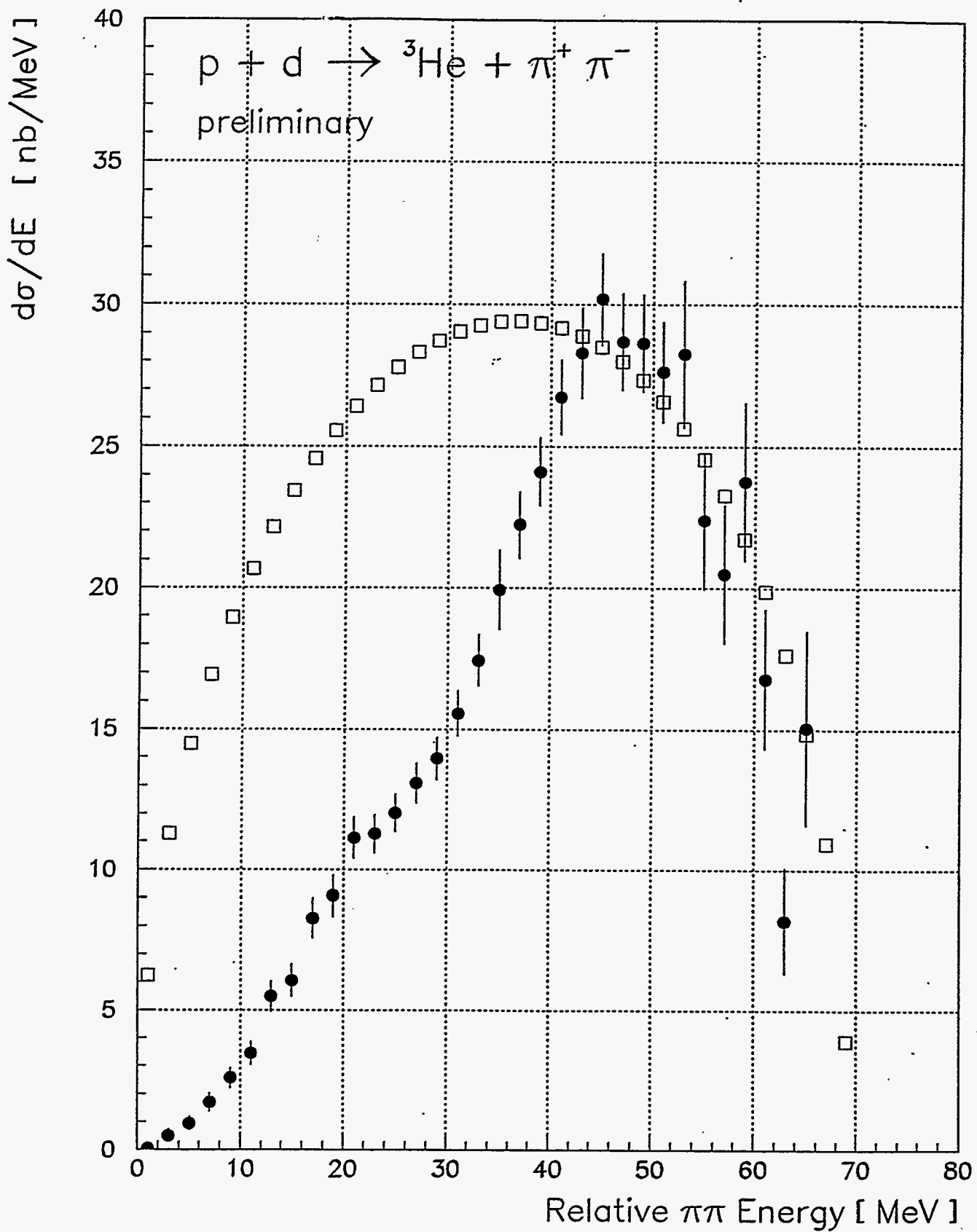
$m_{\pi He}^2$ (GeV^2/c^2)

data 02/96



11/196

differential cross section



'Exotics' at MOMO

e.g. $\pi^- - {}^3\text{He}$ resonances

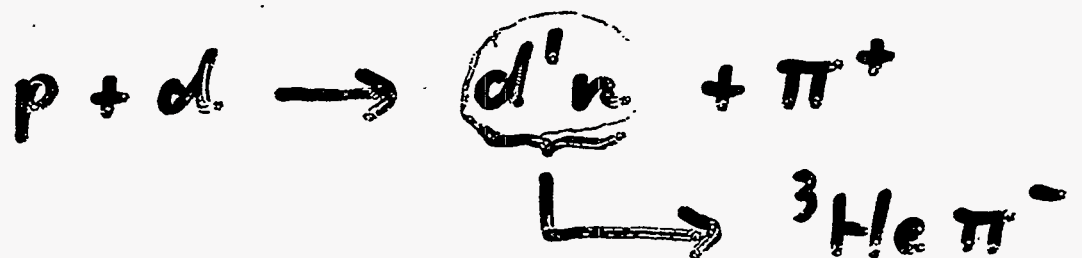
d' Hypothesis

$d' \equiv \pi NN$ resonance

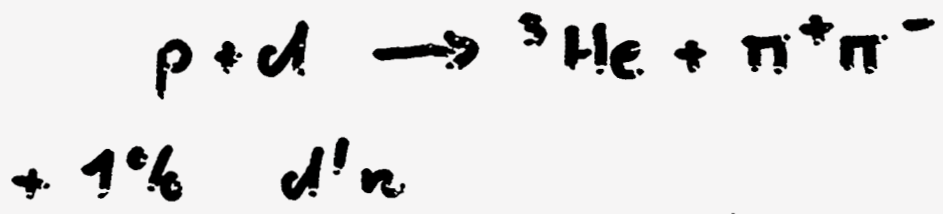
$$M = 2.06 \text{ GeV}/c$$

$$\Gamma = 0.5 \text{ MeV}$$

d' in the reaction.

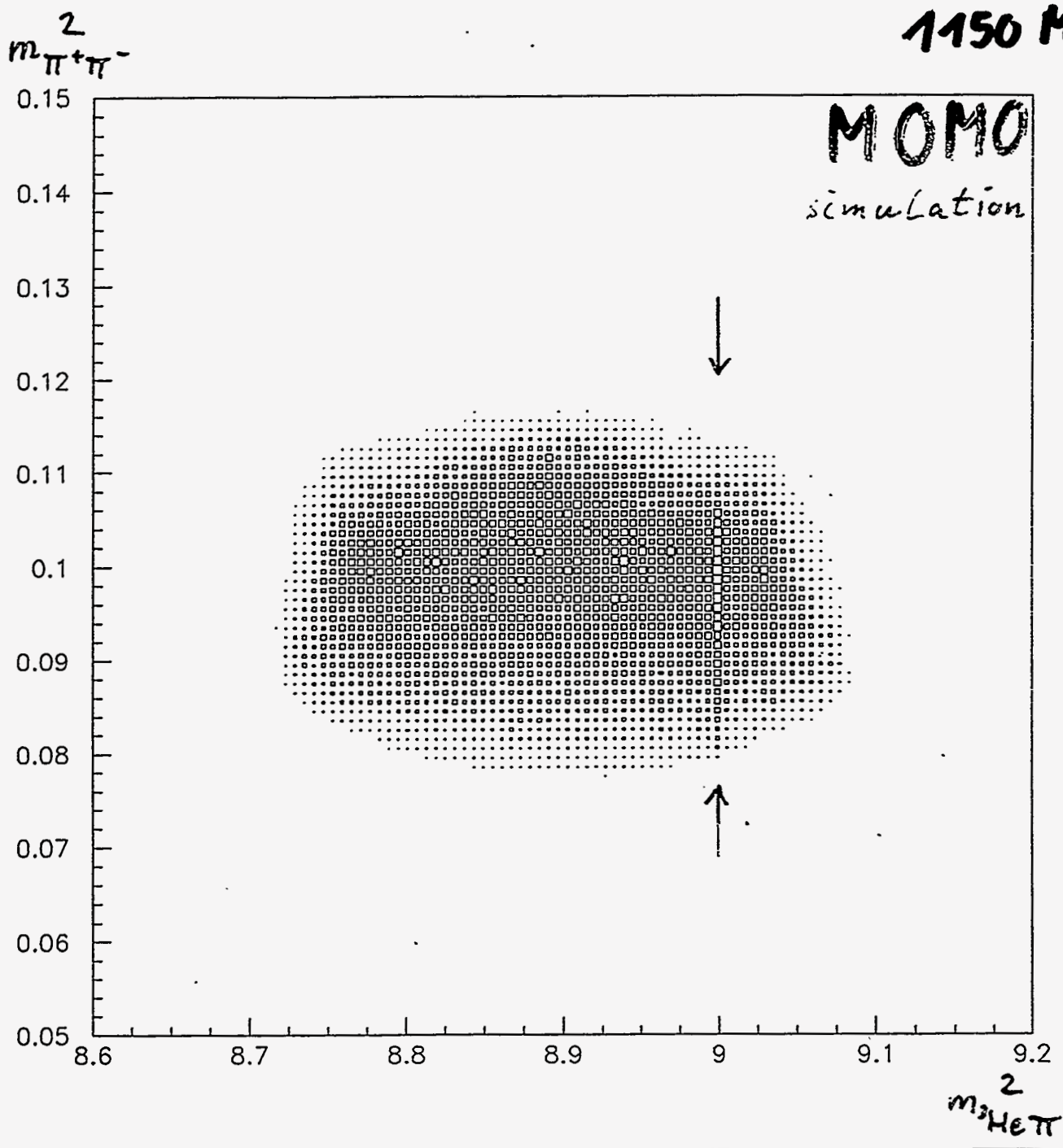


as a ${}^3\text{He} \pi^-$ resonance

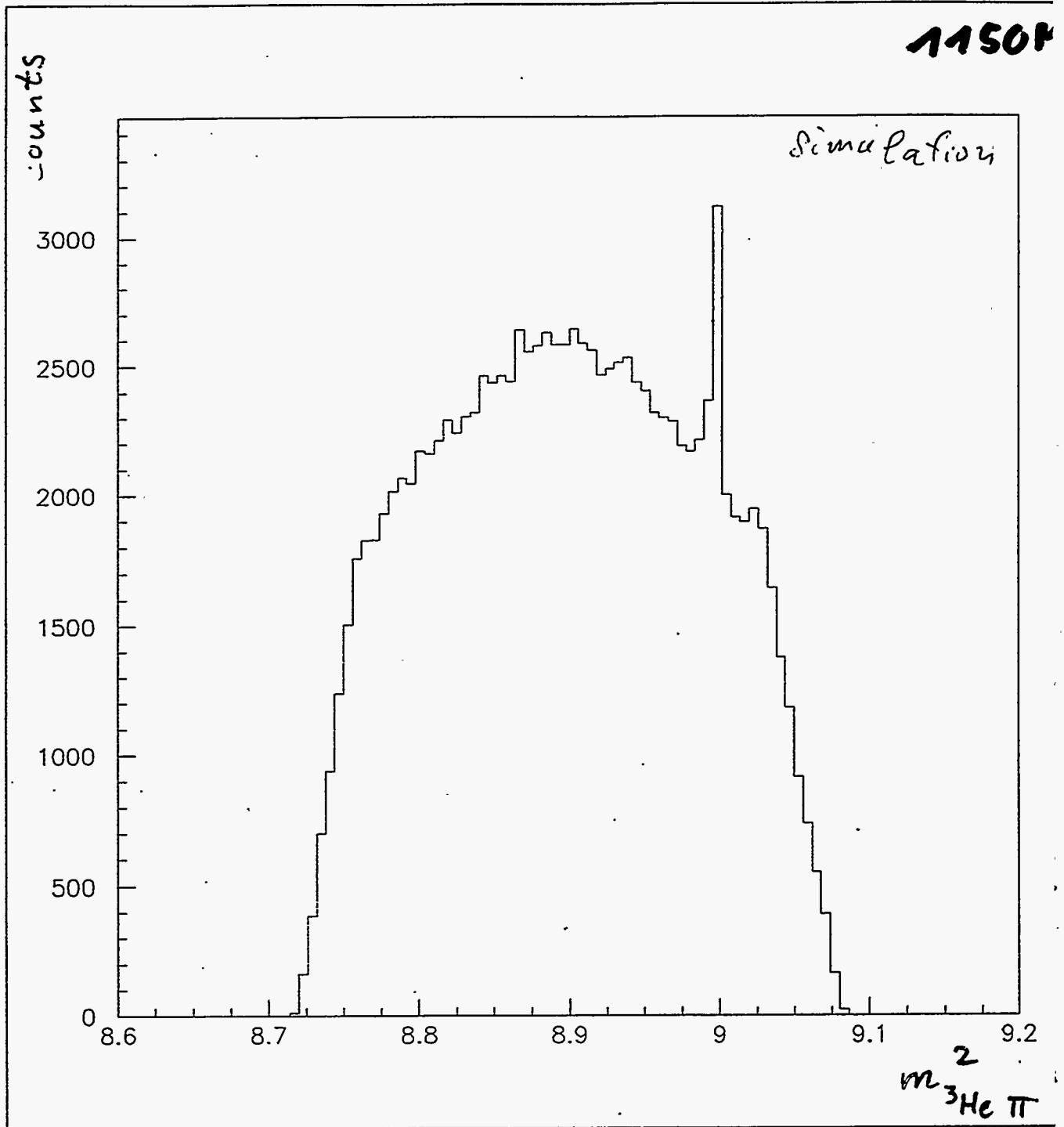
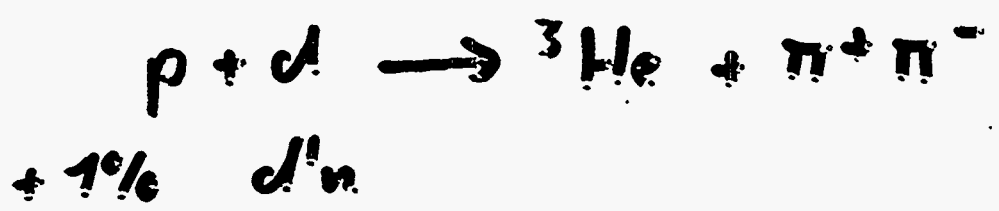


1150 MeV/c

MOMO
simulation



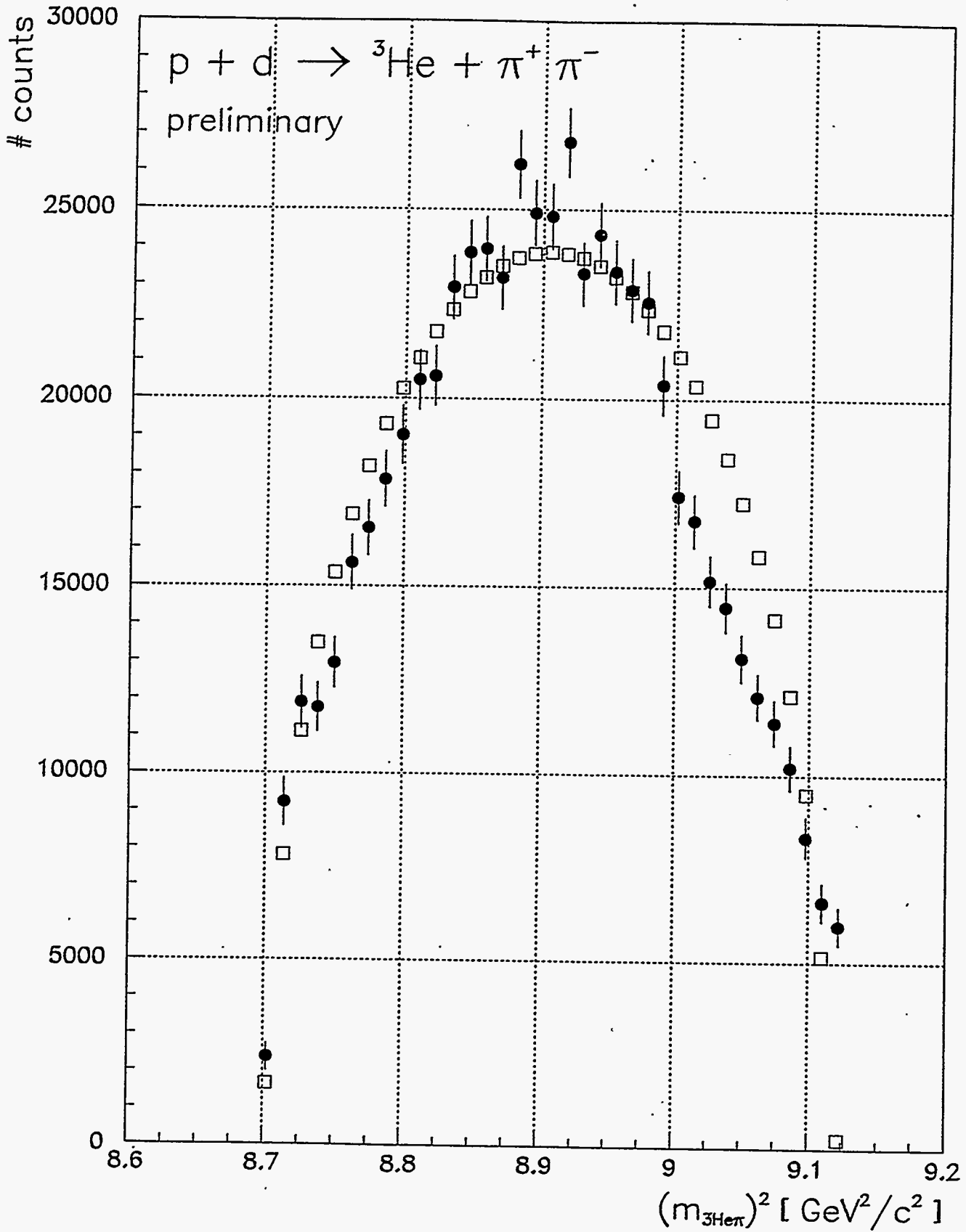
GISMO



GISMO

11/96

Invariant mass $(m_{3\text{He}\pi})^2$ data



M a n y

O n l i n e

M e s o n s

O n t i m e

Die MOMO - Kollaboration

F. Bellemann¹, A. Berg¹, J. Bisplinghoff¹, G. Bohlscheid¹, J. Ernst¹, R. Frascaria⁶,
C. Henrich¹, F. Hinterberger¹, R. Ibal¹, R. Jahn¹, L. Jarczyk², R. Joosten¹,
A. Kozela², U. Kuhn¹, H. Machner³, R. Maschuw¹, T. Mayer-Kuckuk¹,
G. Mertler¹, B. Metsch⁴, J. Munkel¹, P. v. Neumann-Cosel⁵, T. v. Oepen¹,
H. R. Petry⁴, D. Rosendaal¹, P. v. Rossen³, K. Scho¹, F. Schwandt¹, R. Siebert⁶,
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R. Ziegler¹

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³ Institut für Kernphysik, Forschungszentrum Jülich

⁴ Institut für theoretische Kernphysik, Universität Bonn

⁵ Institut für Kernphysik, Technische Hochschule Darmstadt

⁶ IPN Orsay, France



Jon Batchelder

Louisiana State University
Baton Rouge, LA

**The study of Intruder States
Near $Z = 82$ via Alpha Emission:
The Decays of $^{187,189}\text{Bi}$**

J. C. Batchelder

Louisiana State University

presented at the Exotic Nuclei Symposium,

Bodega Bay, Ca, April 14-16, 1996

Argonne National Laboratory

C. N. Davids, D.J. Blumenthal, D.J. Henderson, D. Seweryniak

University of Edinburgh

P. J. Woods, R. J. Irvine

Louisiana State University

J. C. Batchelder, E. F. Zganjar

University of Tennessee

C. R. Bingham, B. E. Zimmerman, J. Wauters

Oak Ridge National Laboratory

K. S. Toth

University of Maryland

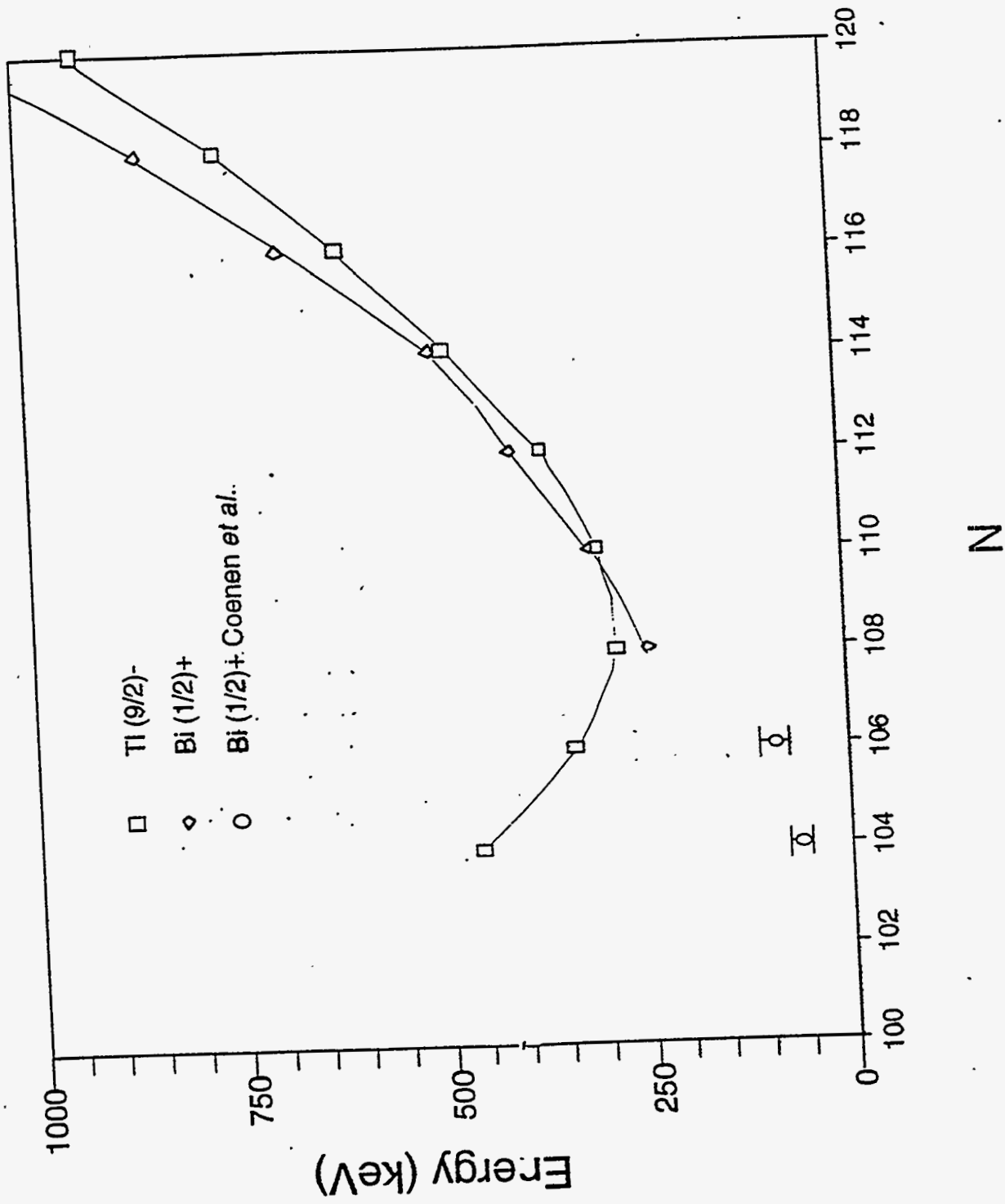
W. B. Walters, L. F. Conticchio

Vanderbilt University

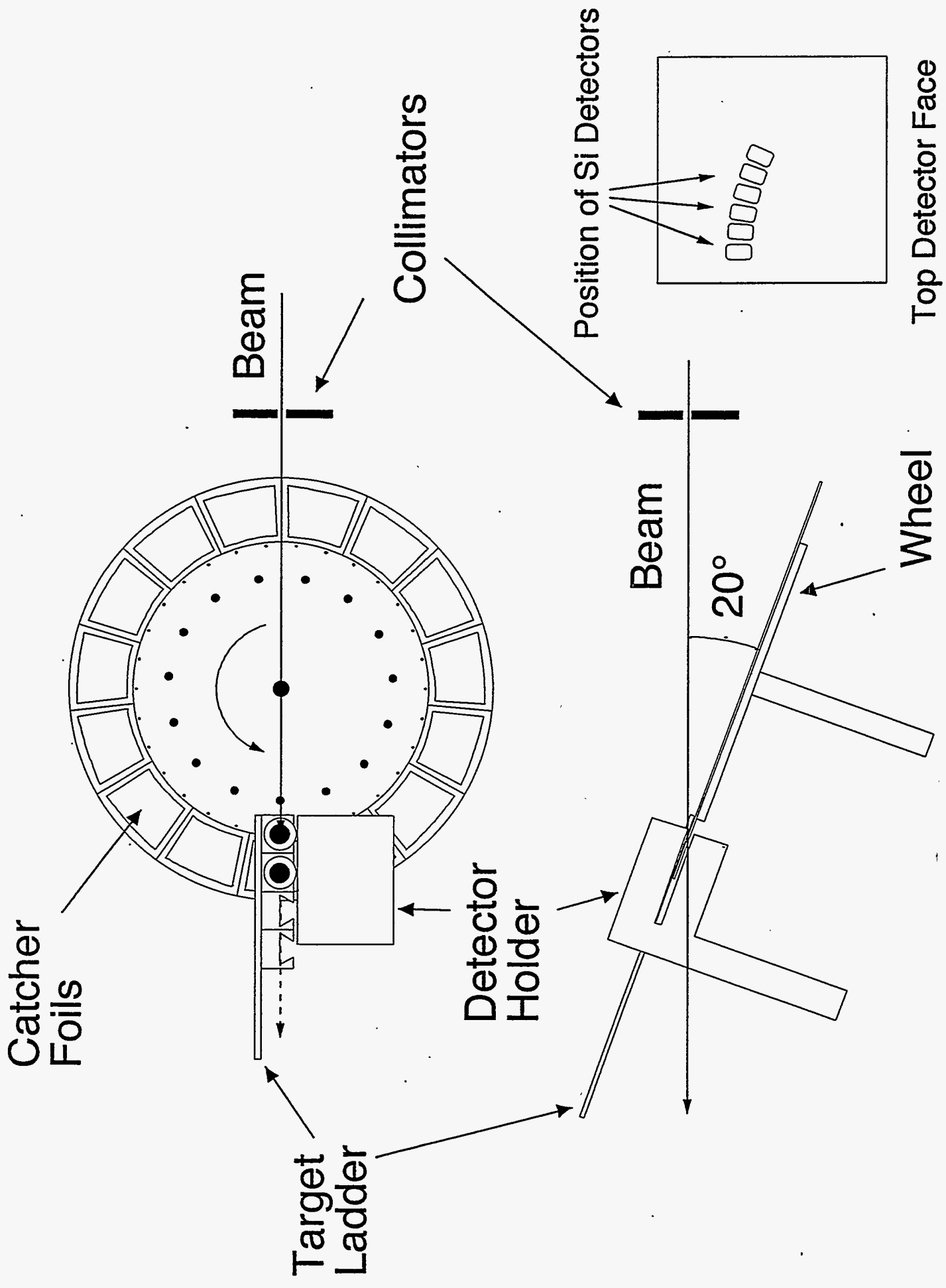
L. T. Brown

University of California, Berkely

D. M. Moltz, T. J. Ognibene, J. Powell, M. W. Rowe, R. J. Tighe



Plot of the intruder state excitation energies versus N for odd-mass Tl ($\pi h_{9/2}$) and Bi ($\pi s_{1/2}$) isotopes.



Catcher Foils

Beam

Collimators

Position of Si Detectors

Beam

20°

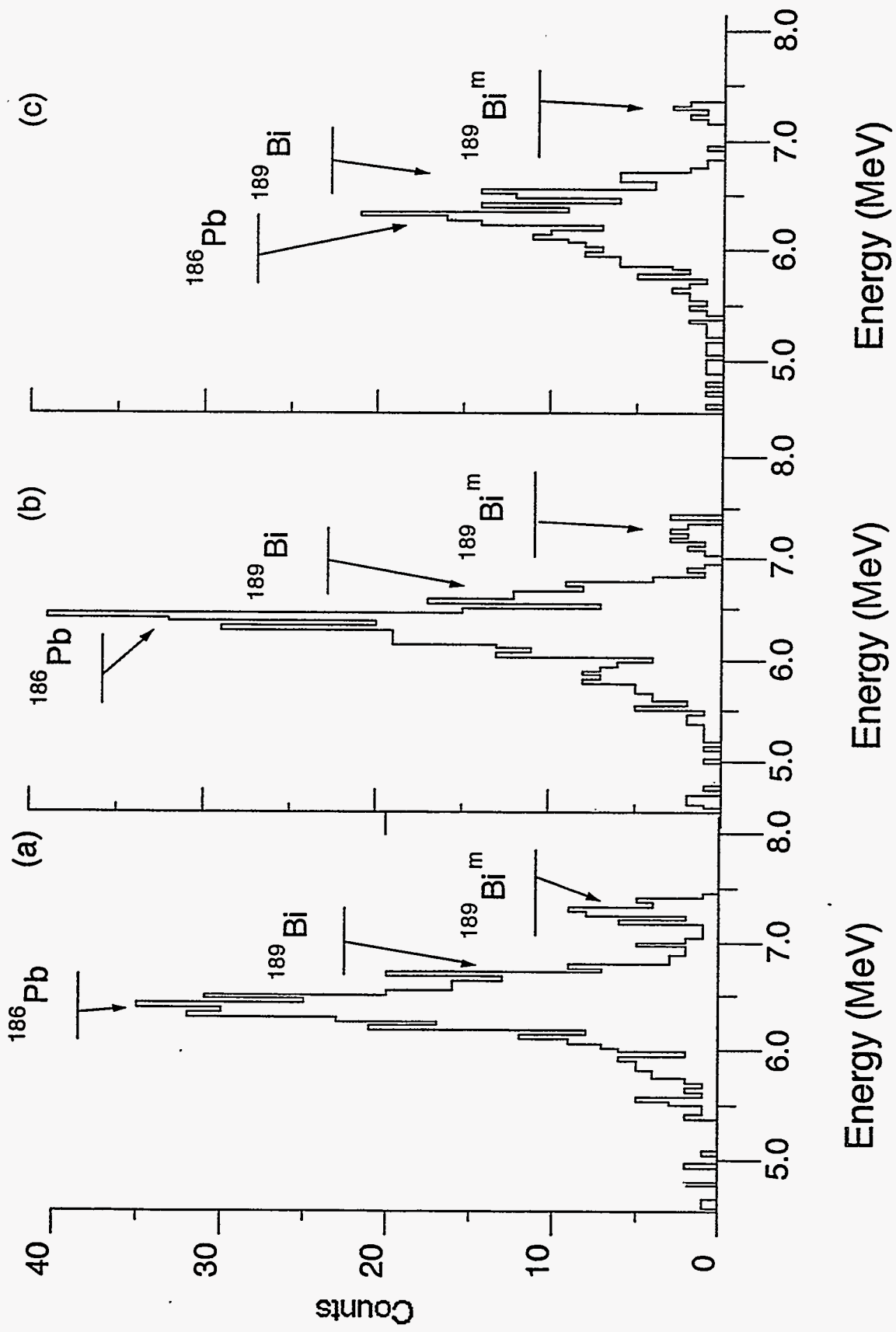
Wheel

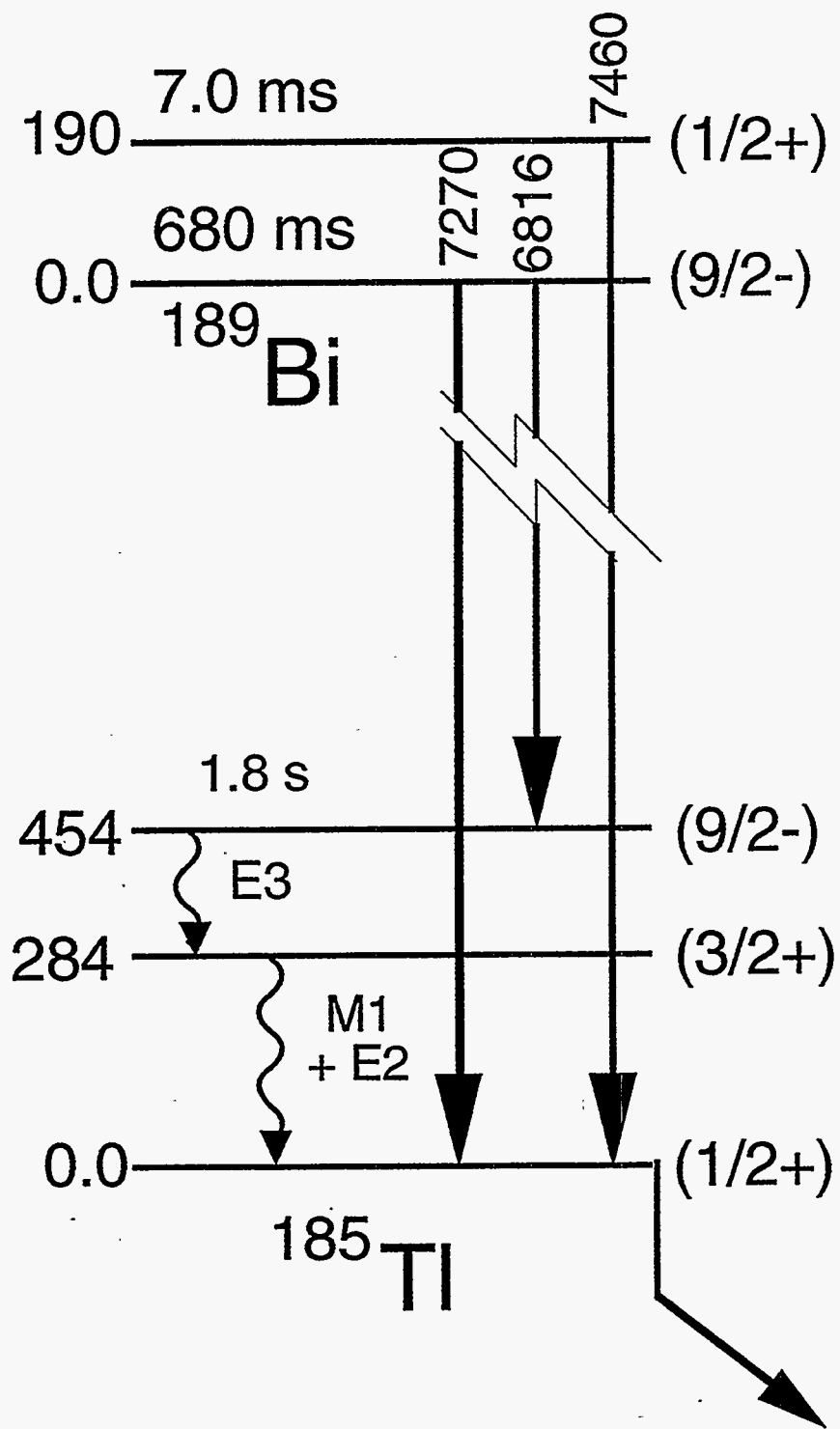
Top Detector Face

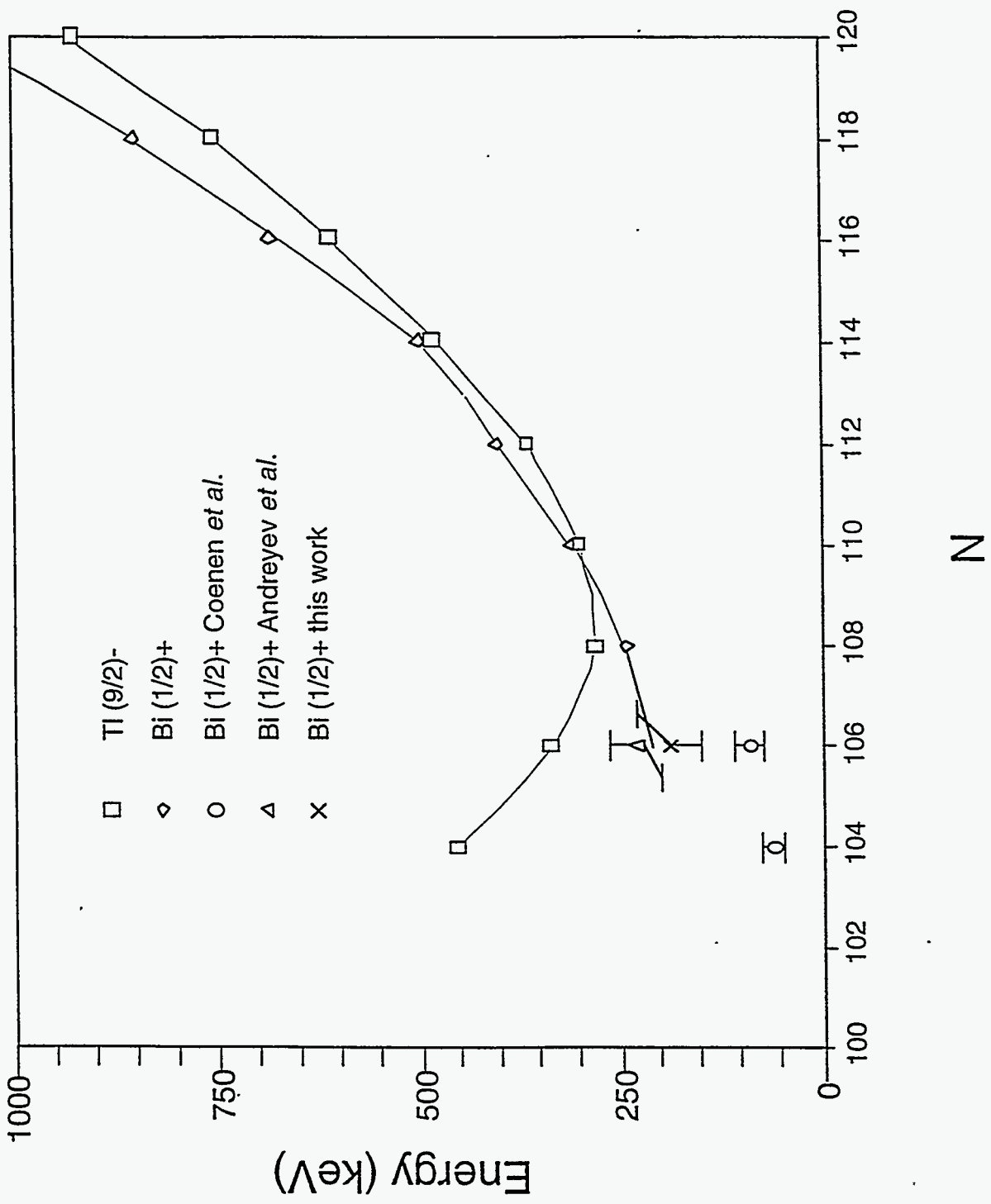
Target Ladder

Detector Holder

Si Detectors







Plot of the intruder state excitation energies versus N for odd-mass Tl ($\pi h_{9/2}$) and Bi ($\pi s_{1/2}$) isotopes.

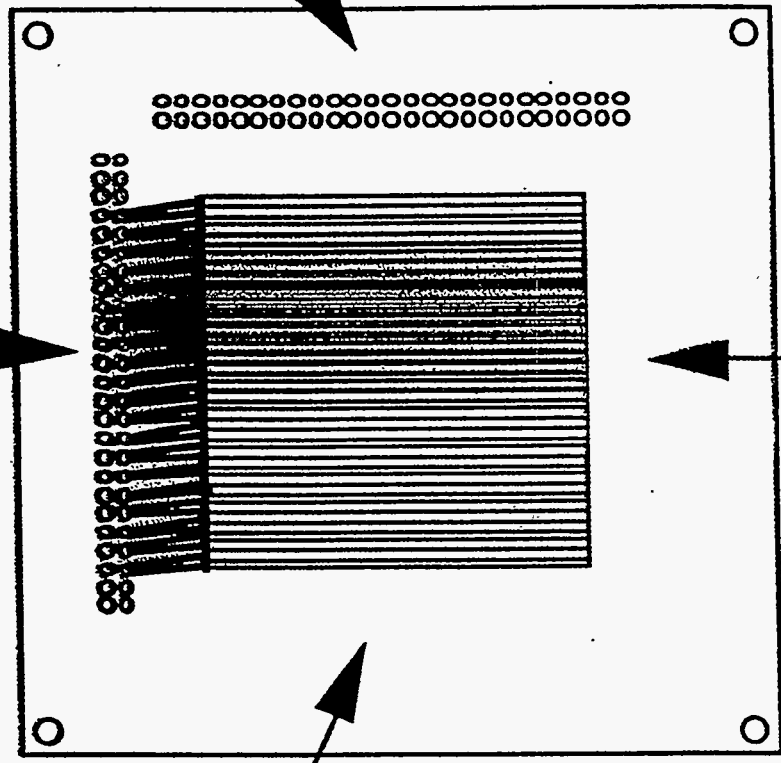
Connector For Front Strips

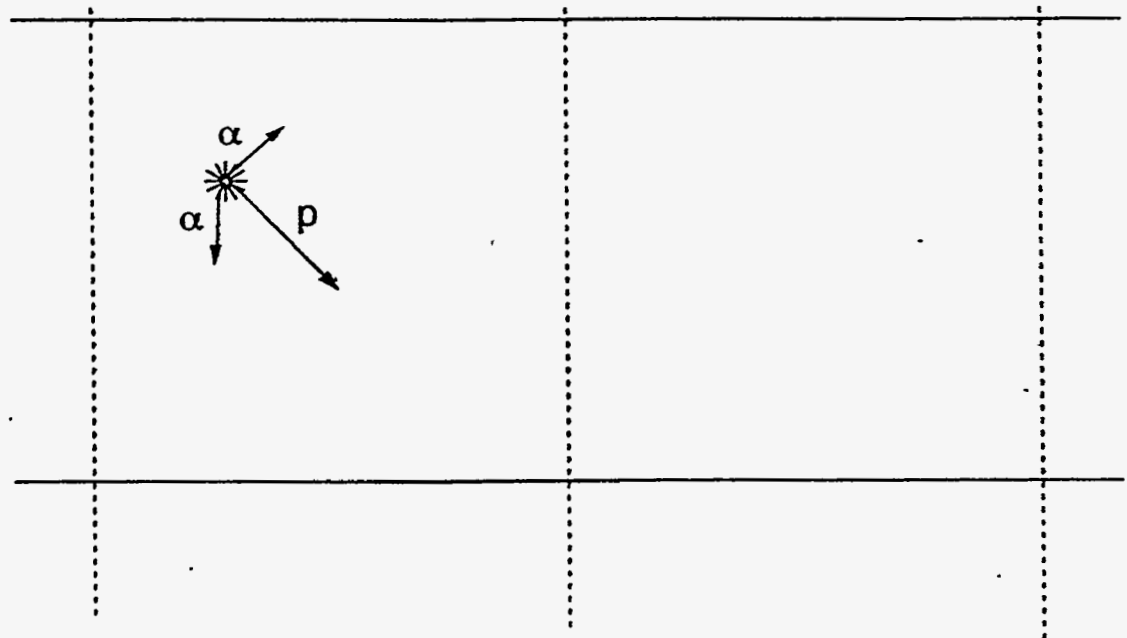
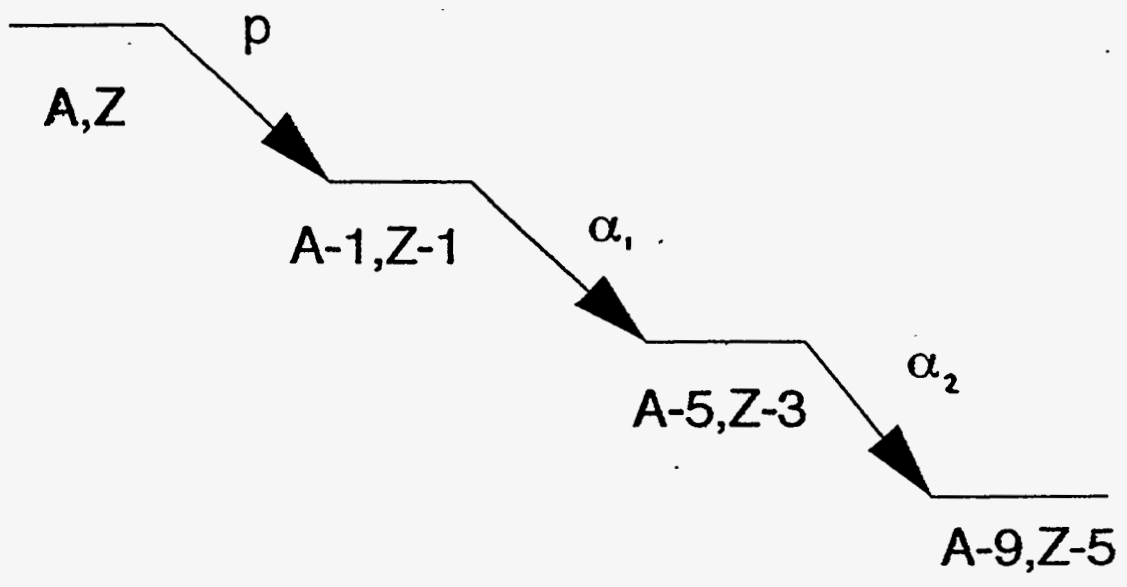
Connector for Rear strips

Printed Circuit Board

Mounting Holes

Si wafer (40 vertical strips)





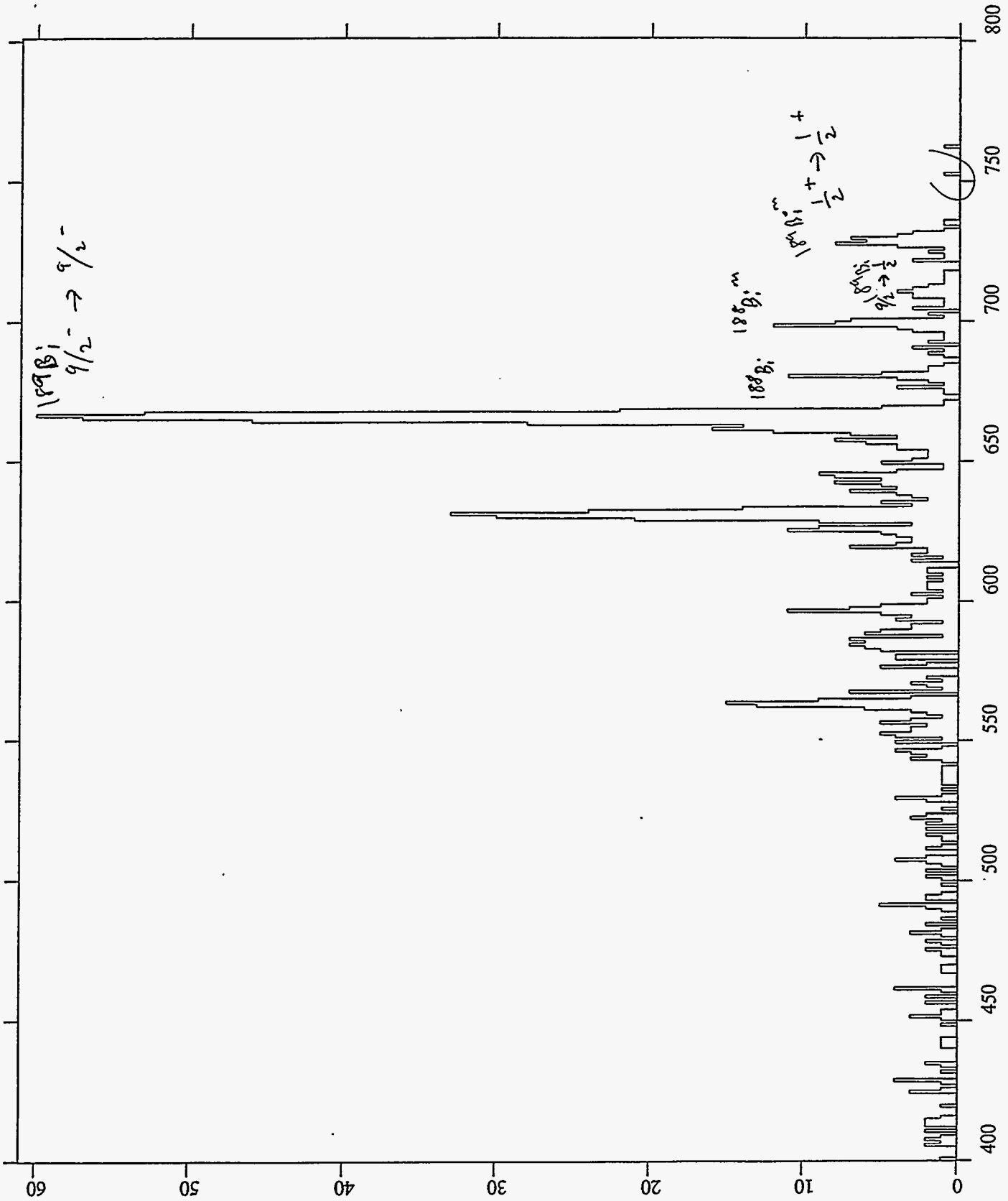
Advantages over a standard $\Delta E-E$ Si telescope

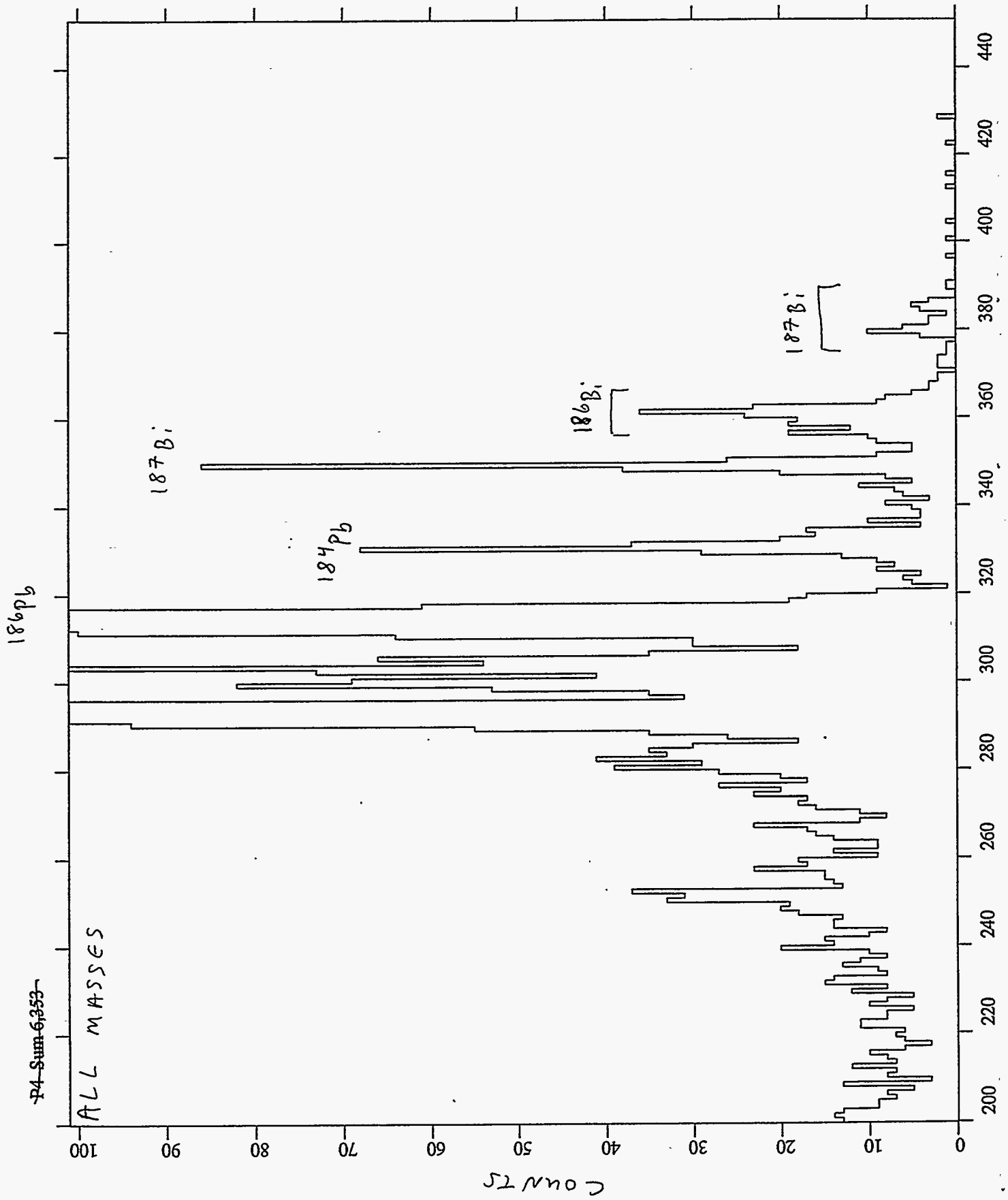
- 1). Virtually invisible to beta particles (i.e. betas are unlikely to leave much energy in such a small area).
- 2). Excellent resolution (~ 30 keV for alpha particles).
- 3). When particles are implanted, the solid angle is nearly 50%.
- 4). Small pixelation effectively results in many independent detectors
 - a). Timing correlations between recoil and decay
 - b). Parent-daughter correlations (both energy and timing information).
- 5). Combining with PSAC allows determination of the previous recoil's mass.

Limitations

- 1). Low energy threshold ~ 600 keV for protons.
- 2). No event by event particle identification
- 3). Half-life measurement threshold limited to ~ 10 μ s.
- 4). Low beam rates.

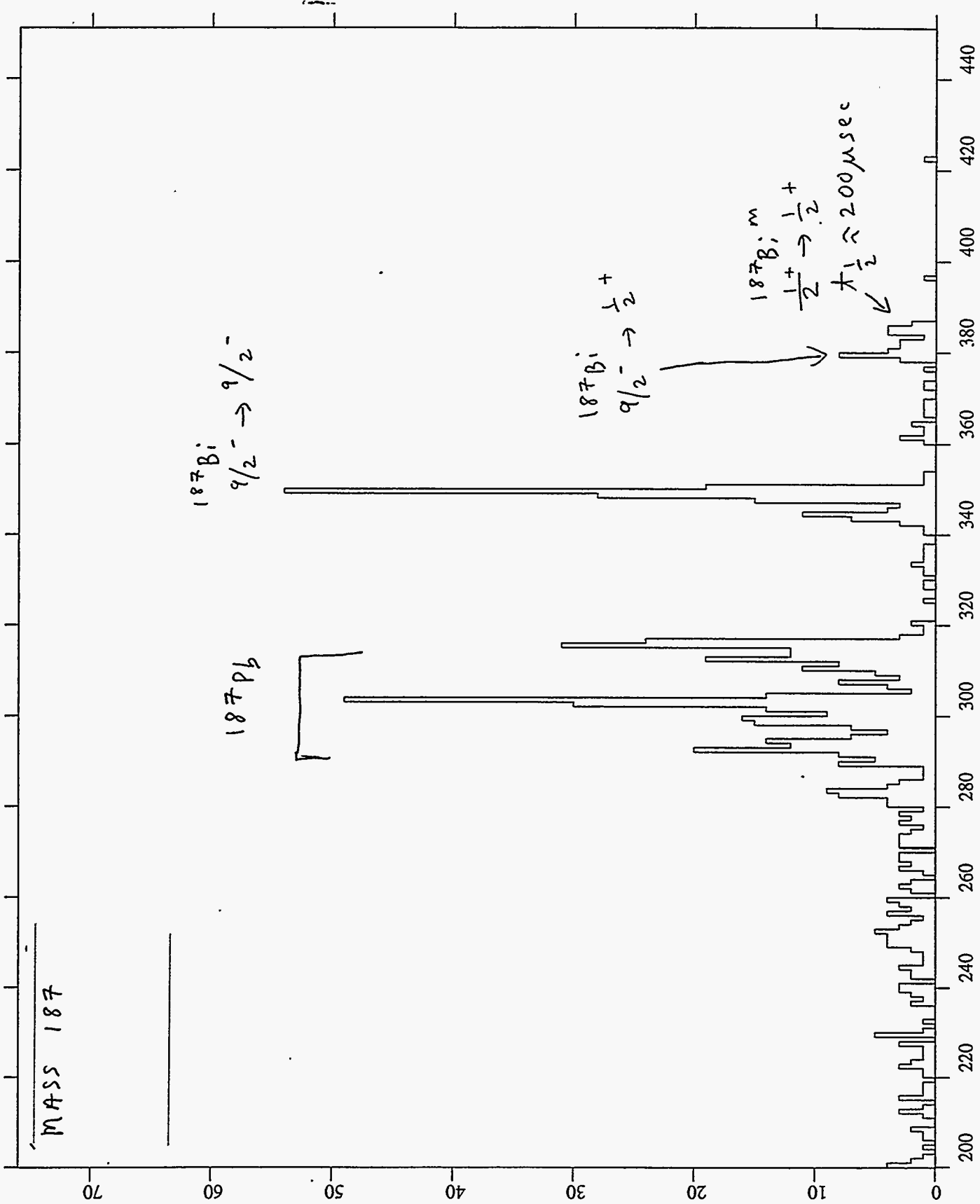
EDF Run 14 Sum 1,140



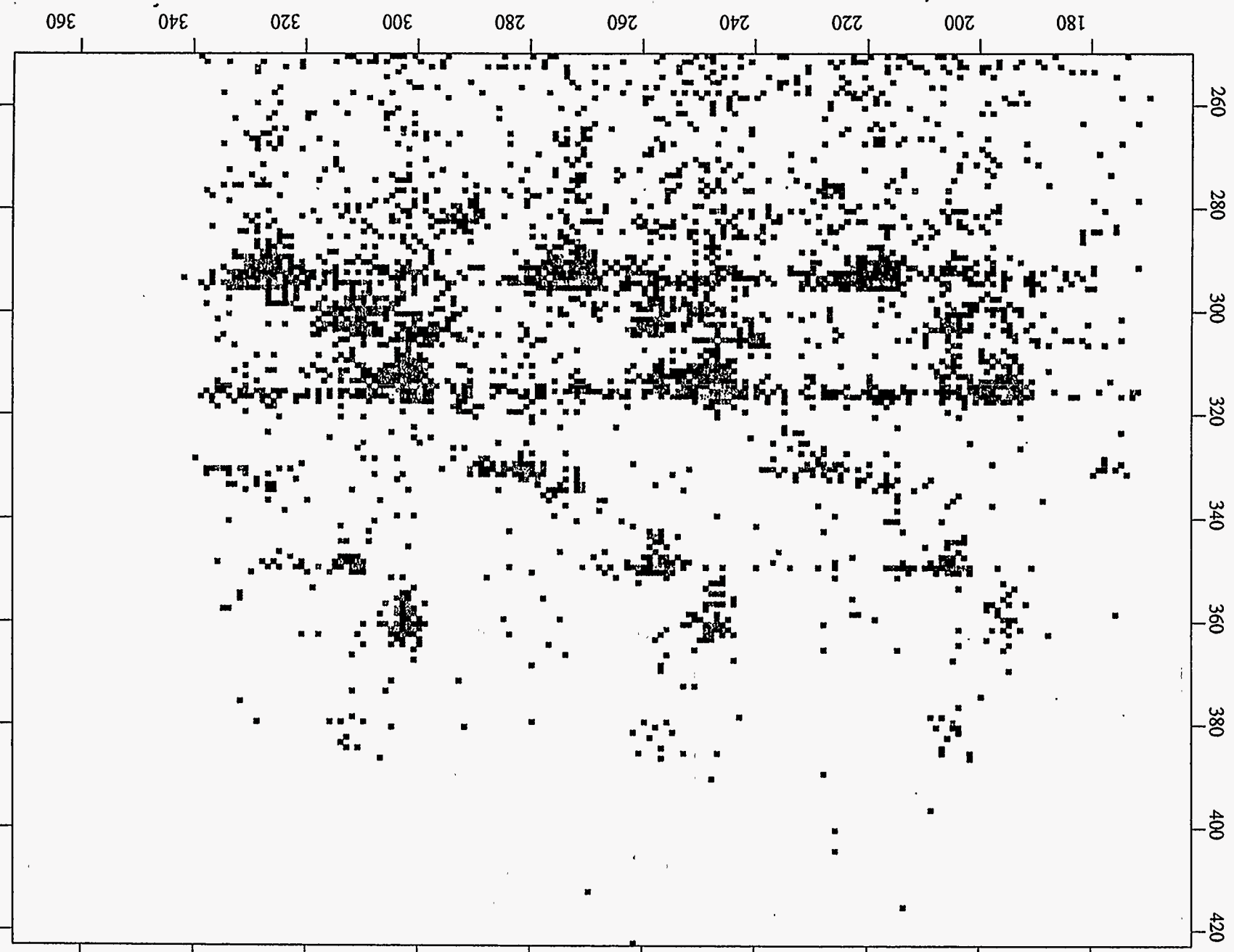


P2 Sum 764

MASS 187

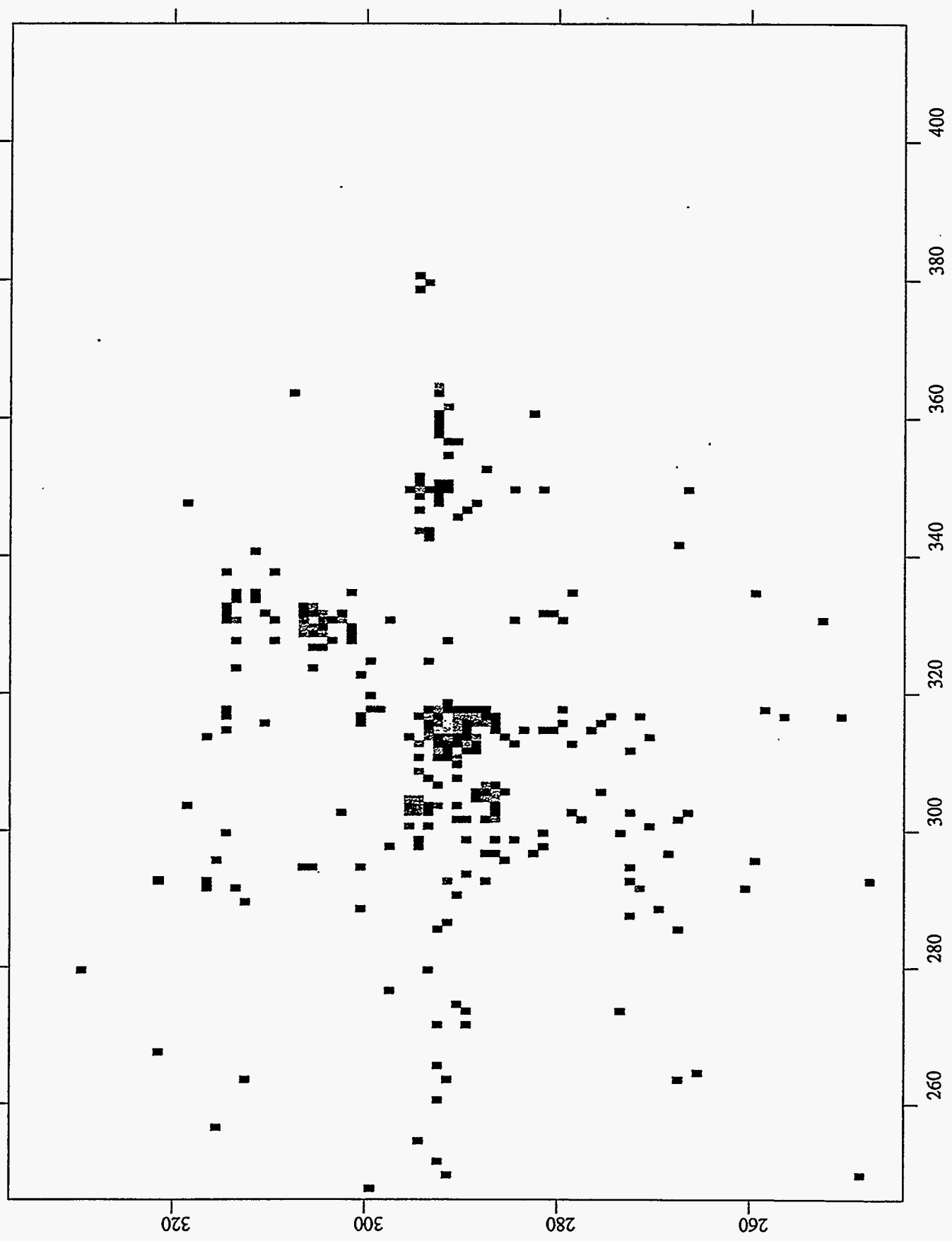


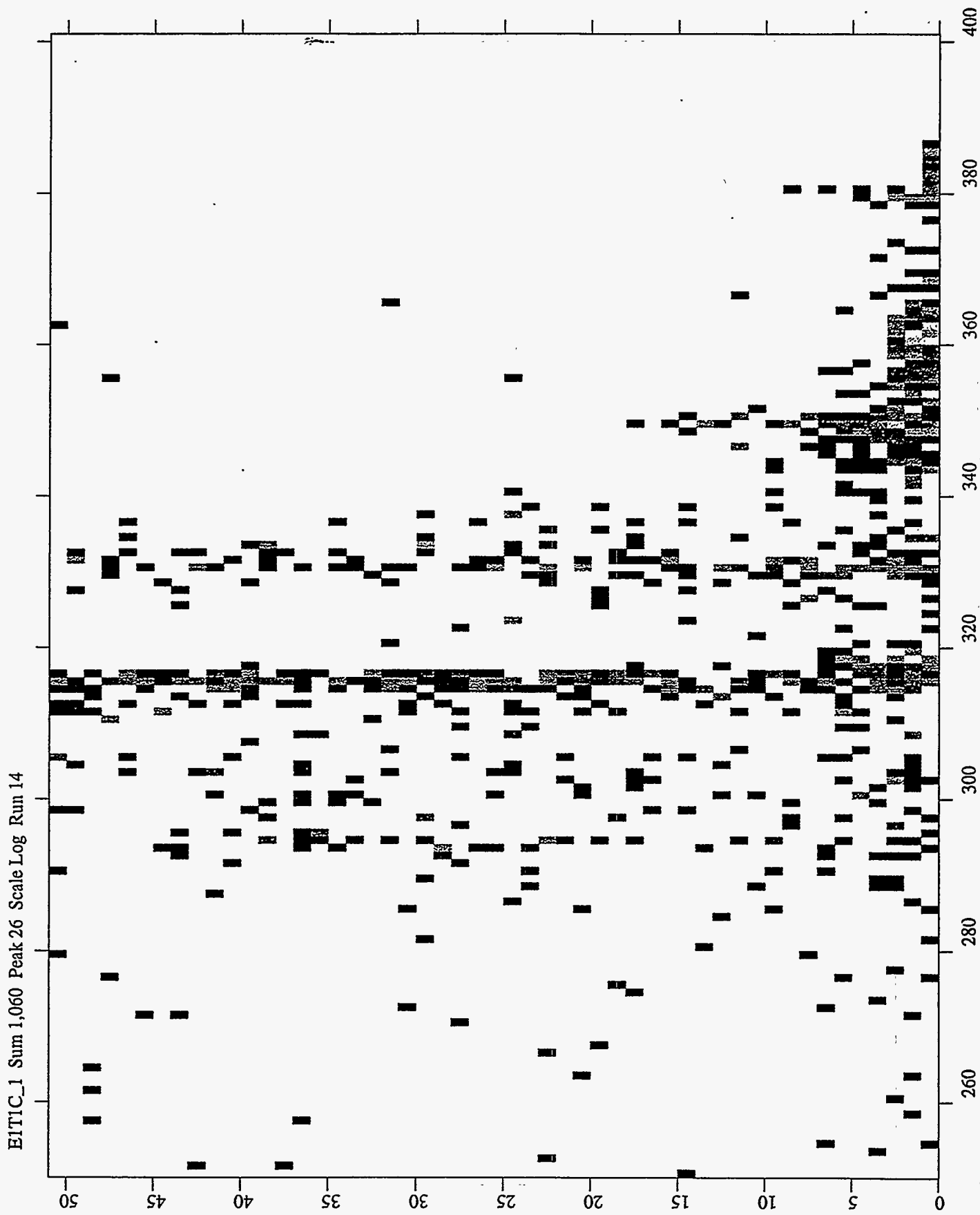
XE1 Sum 5,838 Peak 55 Scale Log Run 14

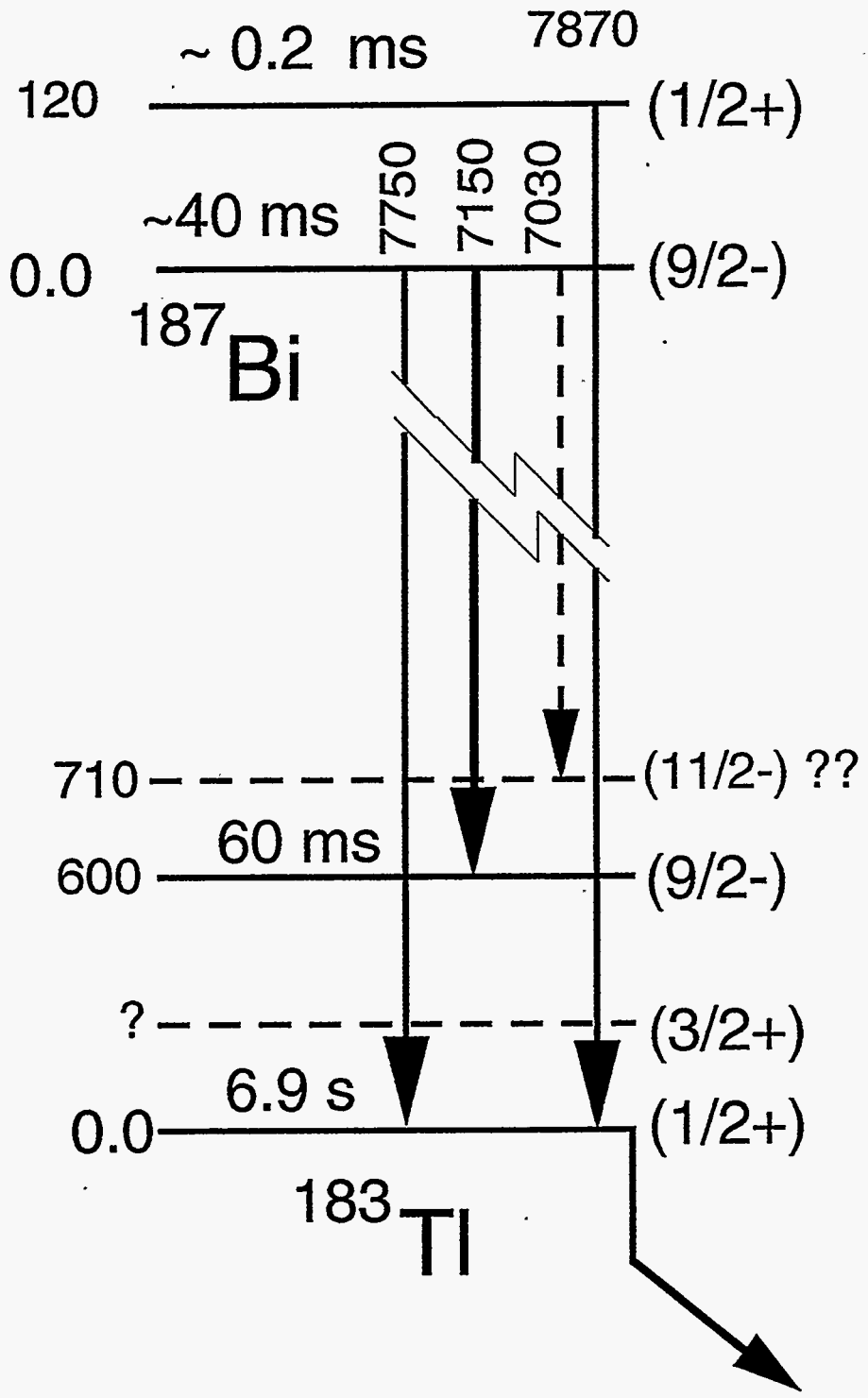


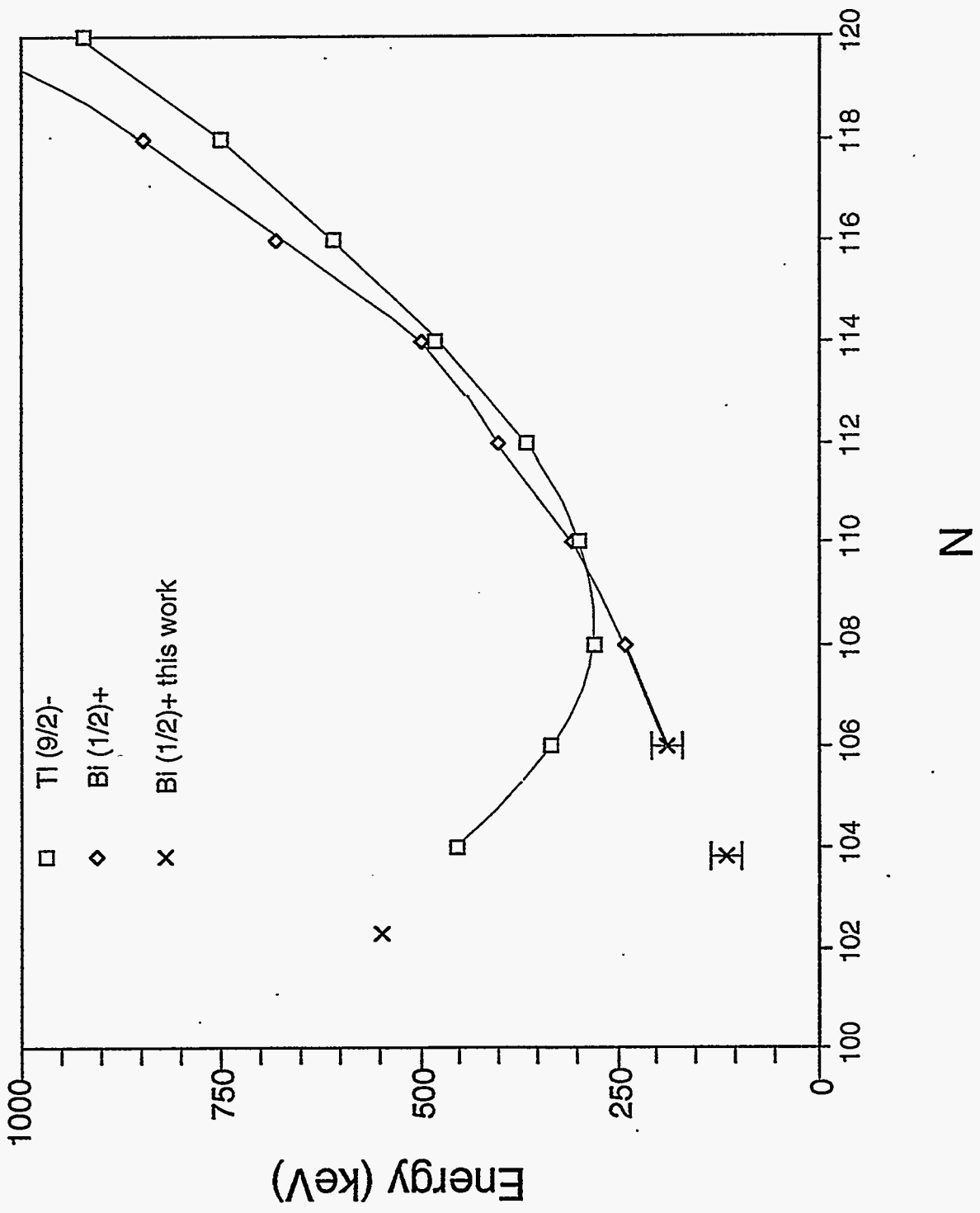
22:40 11-Apr-96

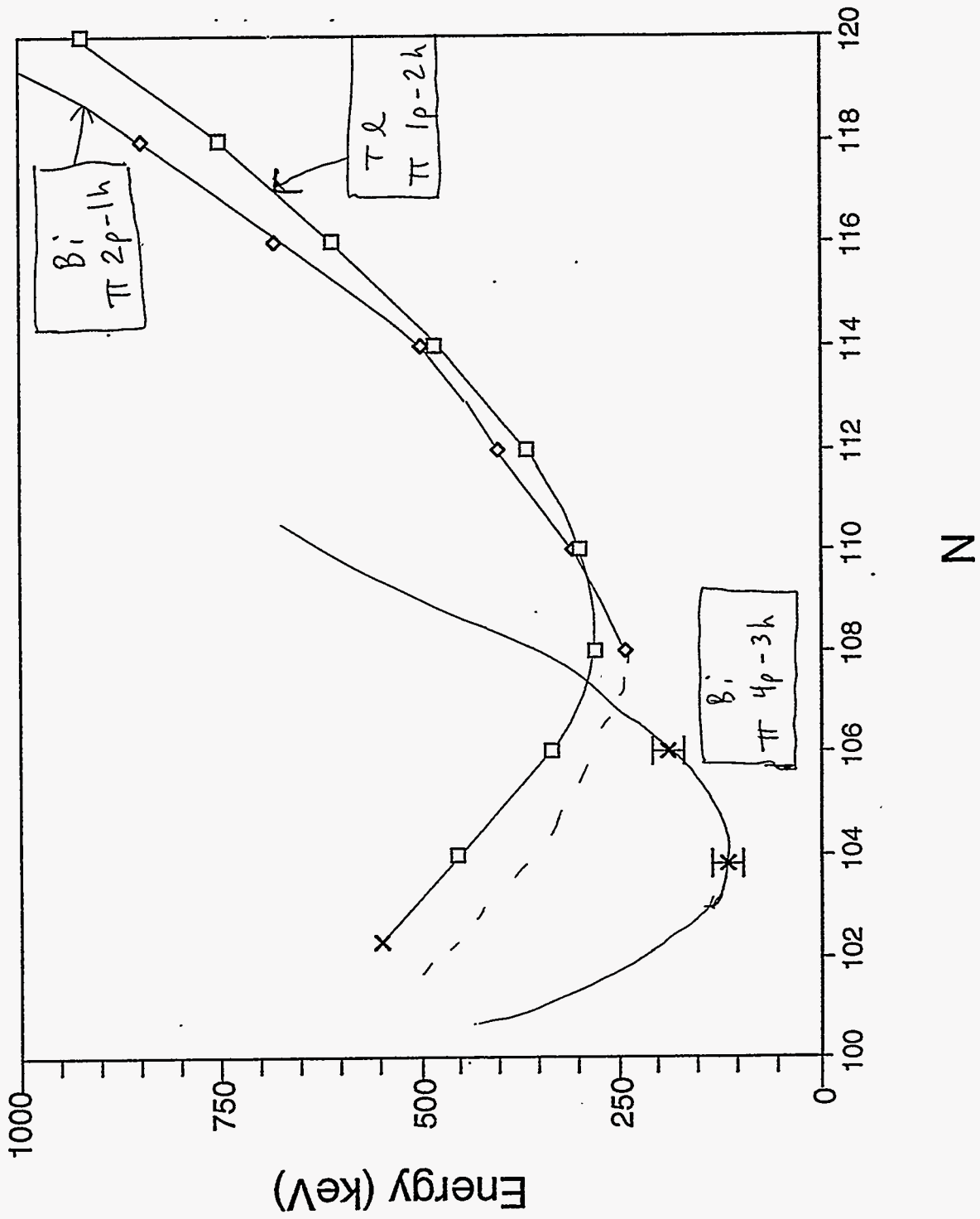
E1E2 Sum 452 Peak 22 Scale Log Run 14

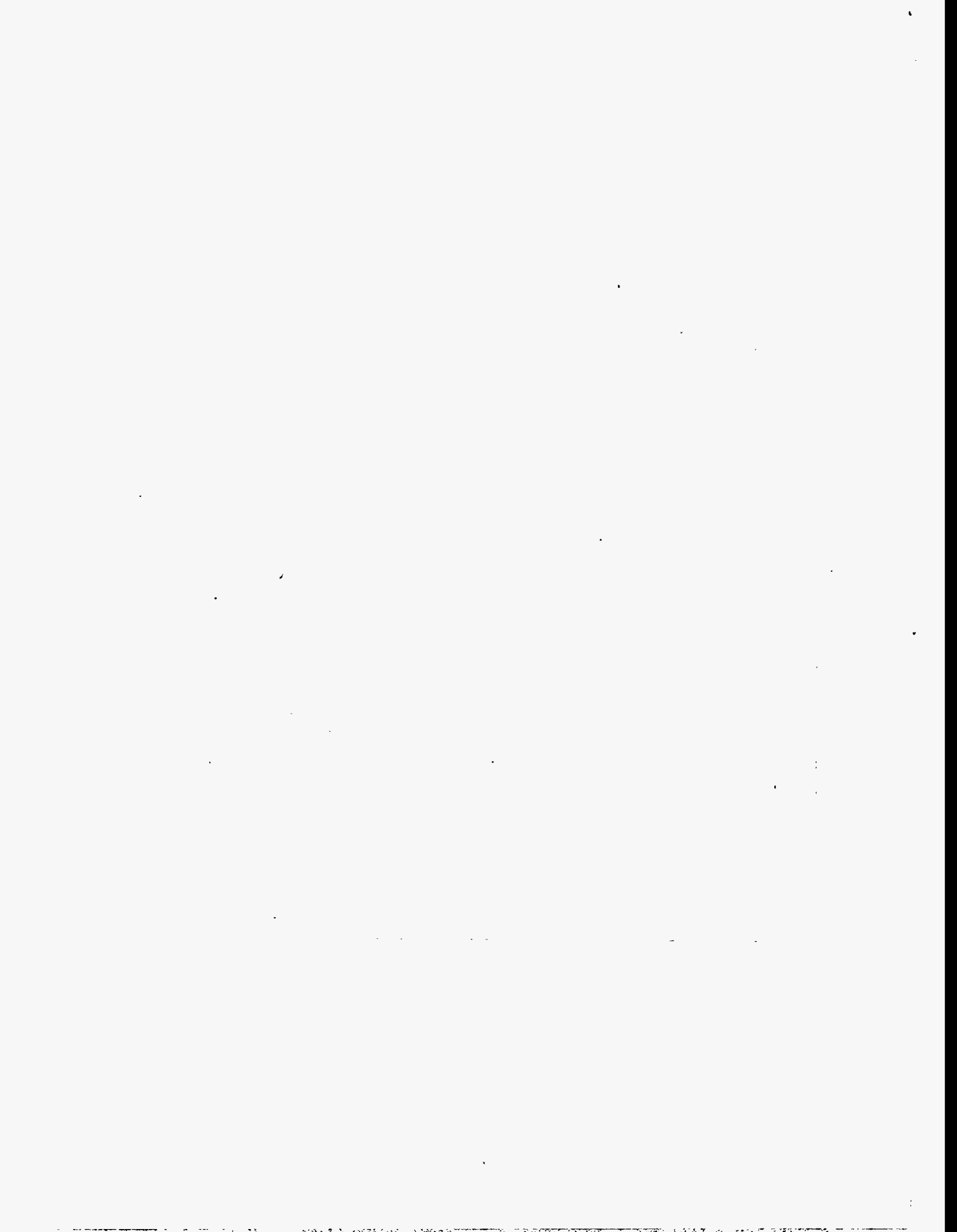






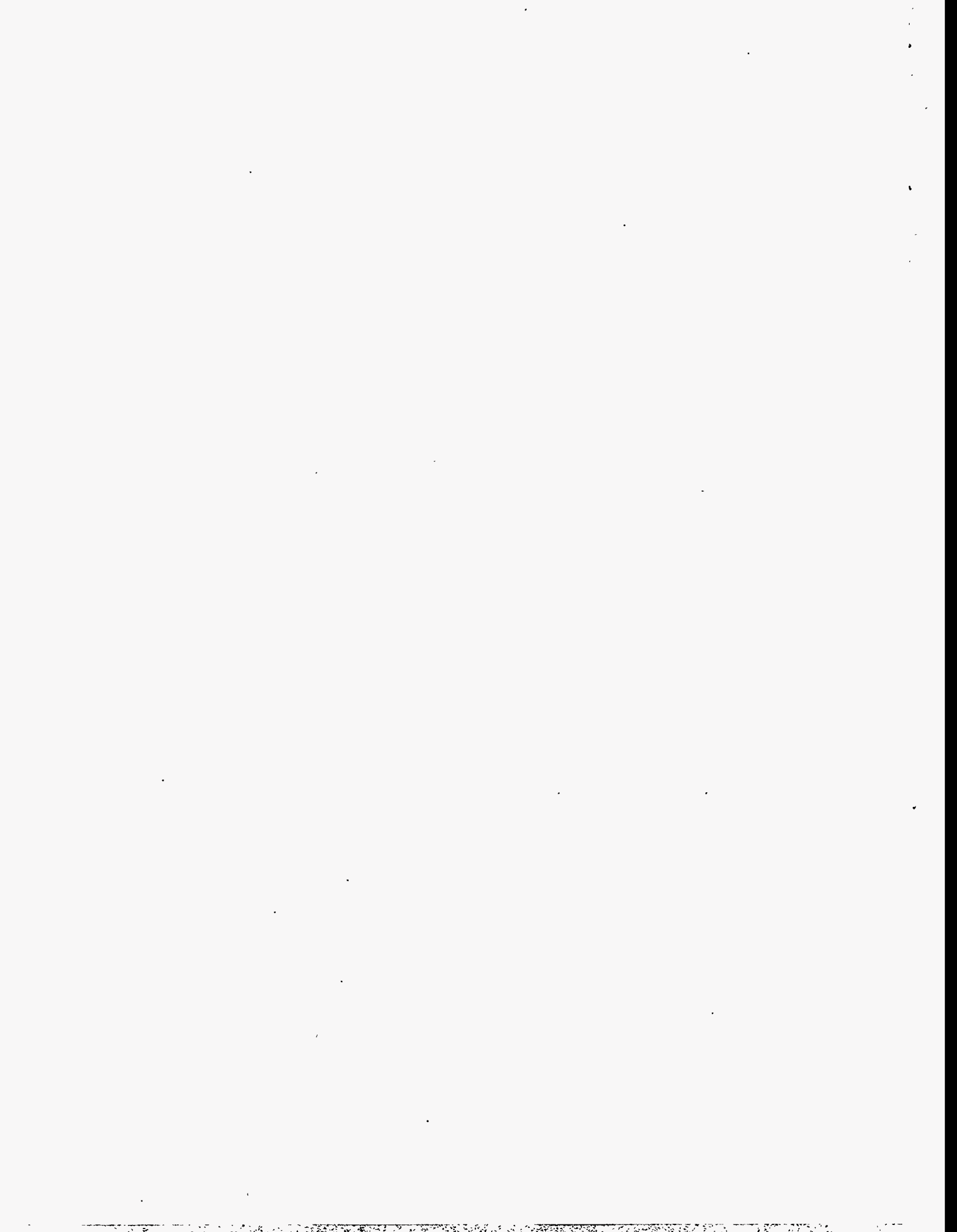






James Powell

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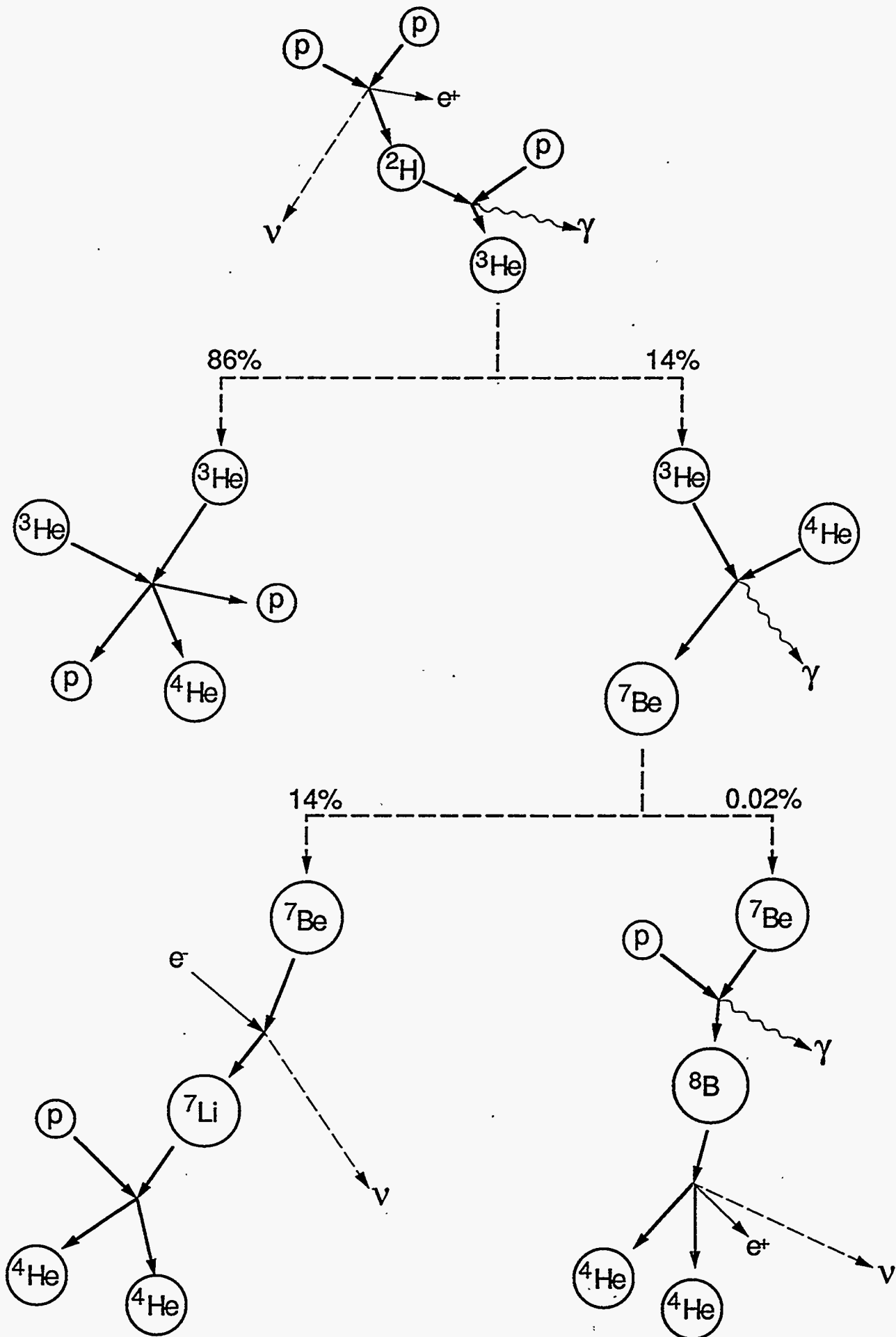


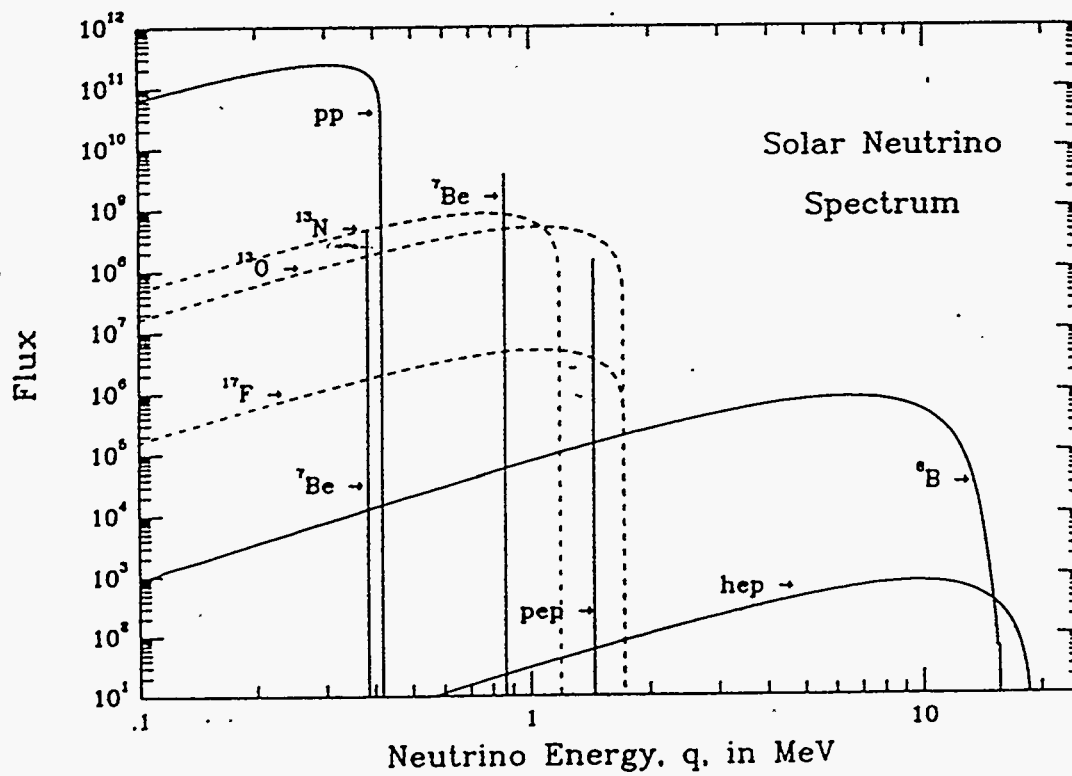
**A New Measurement of ${}^7\text{Be}(p,\gamma)$
and the
Solar Neutrino Problem**

J. Powell, D.M. Moltz, A. Rice
M. W. Rowe and J. Cerny
LBNL

A. Champagne, J. Guillemette
V. Hansper and H. Weller
TUNL

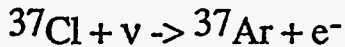
M. Hofstee
Colorado School of Mines





Neutrino Detectors:

Homestake Mine



- Expected rate due to ν 's from ${}^8\text{B}$ (77%), ${}^7\text{Be}$ (14%) and other sources (9%)

--> Observe only $1/4$ to $1/3$ of rate calculated from the standard solar models

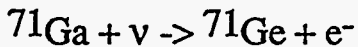
Kamiokande

water Cherenkov experiment

- Sensitive to high-energy neutrinos, mostly ${}^8\text{B}$

--> Observe only about $1/2$ of the ${}^8\text{B}$ flux expected

SAGE and GALLEX



- Expected rate due to ν 's from p-p (54%), ${}^7\text{Be}$ (26%), ${}^8\text{B}$ (11%) and other sources (10%)

--> Observe about $1/2$ of calculated rate

"Solar Neutrino Problem"

Several other detector facilities being constructed (SNO, Super-Kamiokanda) or developed (BOREXINO, etc.).

Solutions to the Solar Neutrino Problem?

1) Neutrino Oscillations $\nu_e \leftrightarrow \nu_x$

- vacuum oscillations
- MSW effect

2) Inaccuracies in some of the Input Quantities

- stellar reaction rates
- neutrino capture rates
- details of the solar models

${}^7\text{Be}(p,\gamma){}^8\text{B}$

- rate directly affects the high energy ${}^8\text{B}$ neutrino flux that is the dominant component seen by many types of neutrino detectors
- one of the most significant uncertainties remaining in the solar models

Measuring ${}^7\text{Be}(p,\gamma){}^8\text{B}$ Directly:

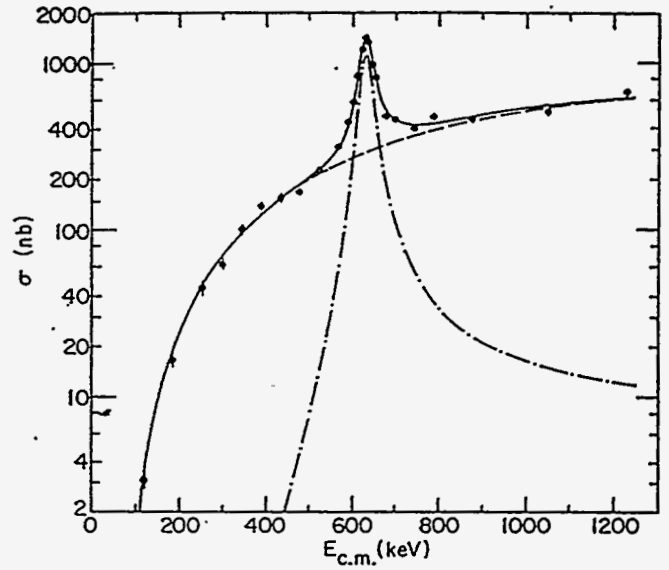
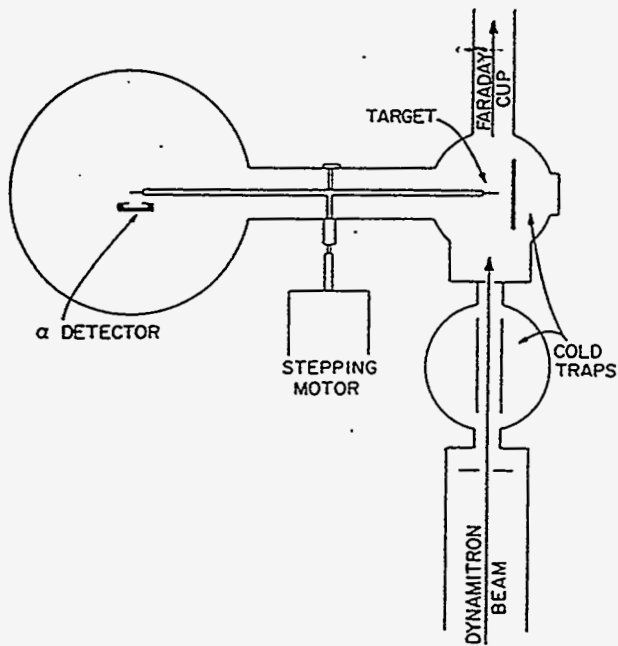
${}^7\text{Be}$ Target:

- { ${}^7\text{Be}$ electron captures to ${}^7\text{Li}$: $t_{1/2} = 53$ days }
- produced through ${}^7\text{Li}(p,n){}^7\text{Be}$
- chemically separated and formed into a thin target
- 11% of decays emit 478 keV γ rays

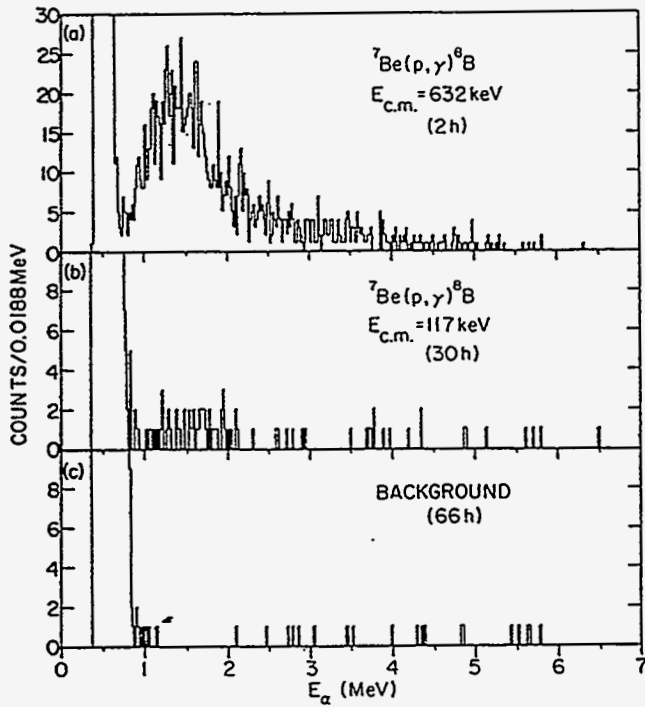
Observe ${}^8\text{B}$ produced:

- { ${}^8\text{B}$ β decays to ${}^8\text{Be} \rightarrow 2\alpha$: $t_{1/2} = 0.77$ s }
- detect either the β or α particles in a suitable detector

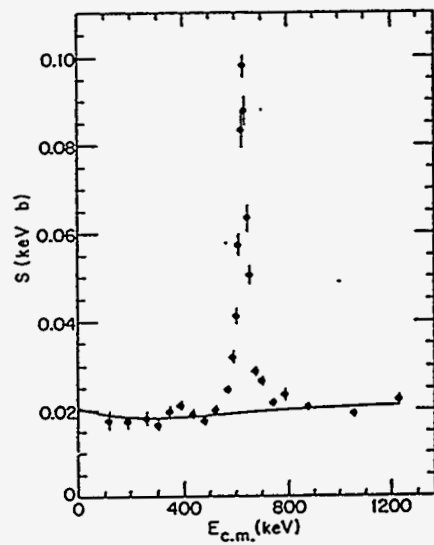
Trace reaction over a range of higher energies,
where the cross section is large enough to measure,
and extrapolate down to the energy most relevant for
solar hydrogen burning (about 20 keV)



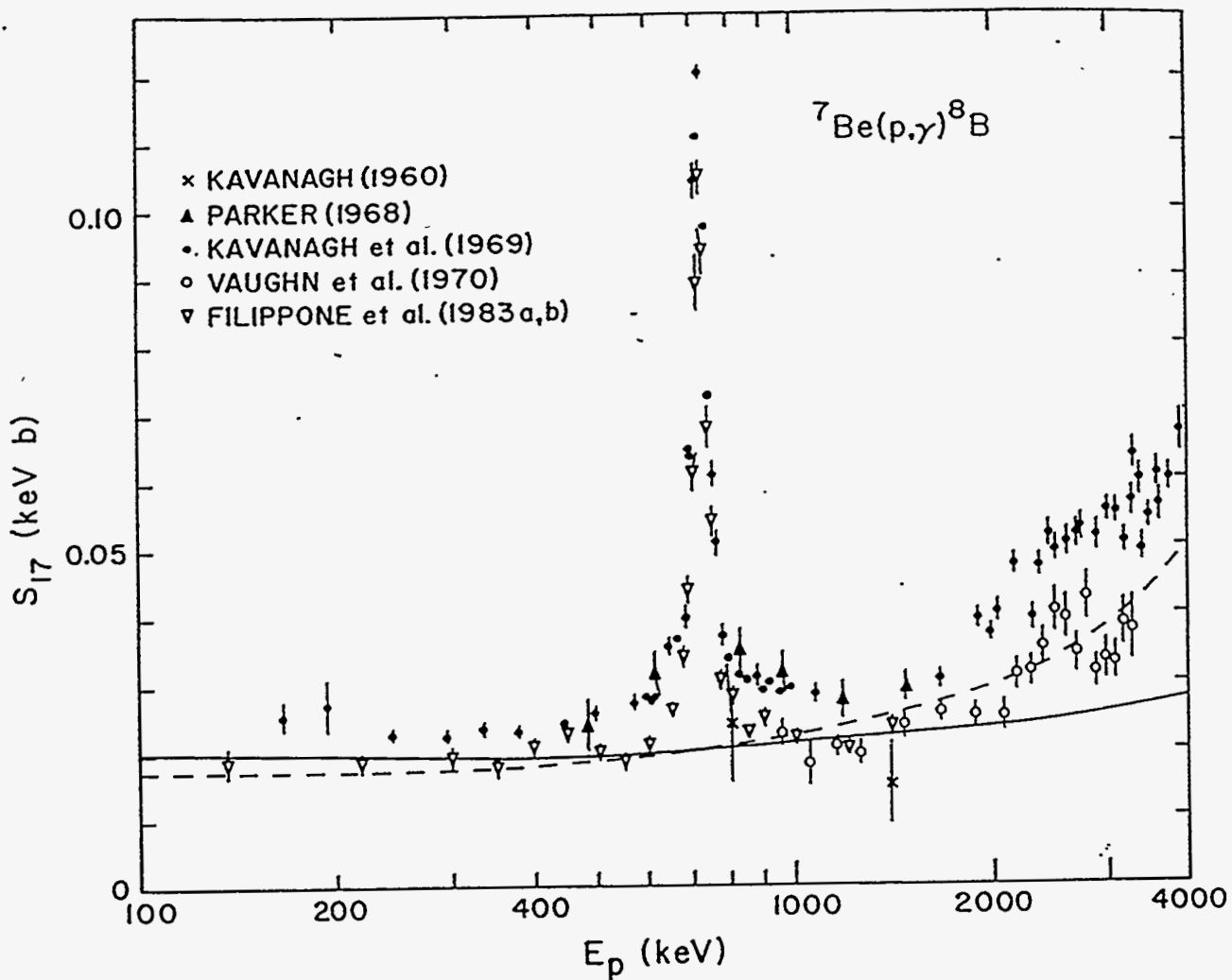
Total ${}^7\text{Be}(p, \gamma){}^8\text{B}$ cross section



α -particle spectra



S factor for ${}^7\text{Be}(p, \gamma){}^8\text{B}$
 $\{ S(E) = \sigma(E) E \exp(2\pi\eta) \}$

${}^7\text{Be}(p, \gamma){}^8\text{B}$ CROSS SECTIONRecent Calculations:

Johnson *et al.*:
 ApJ 392(1992)320

$S_{17}(0) = 20.2 \pm 2.3$ eVb (Filippone *et al.* data)
 $= 25.2 \pm 2.4$ eVb (Kavanagh *et al.* data)
 adopted $S_{17}(0) = 22.4 \pm 2.1$ eVb

Barker, NP A588(1995)693:

$S_{17}(0) = 17 \pm 3$ eVb

Xu *et al.*, PRL 73 (1994)2027:

$S_{17}(0) = 17.6$ eVb estimated

Descouvemont and Baye, NP A567(1994)341: $S_{17}(0) \geq 24$ eVb

Kim *et al.*, PRC 35(1987)363:

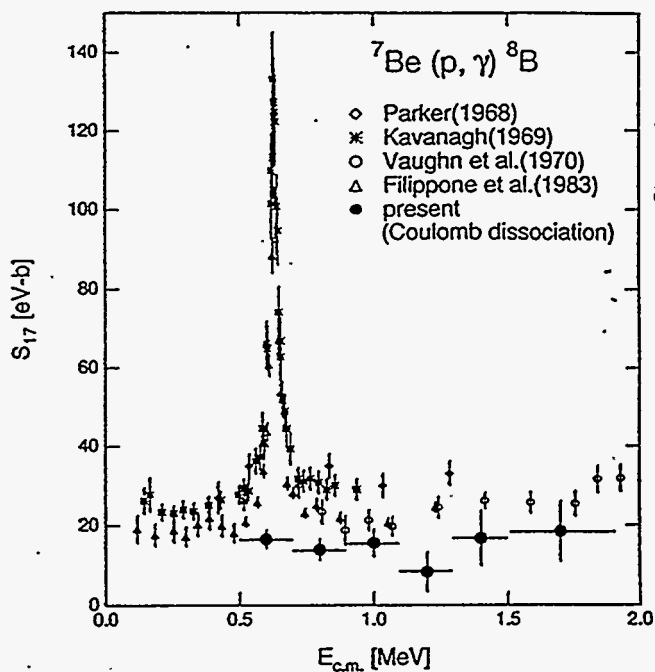
$S_{17}(0) = 24$ eVb

Ongoing Experimental Work:

1) Coulomb Dissociation, ^8B (Pb) \rightarrow ^7Be + p

RIKEN

Motobayashi et al., PRL 73(1994)2680



2) p + ^7Be

TRIUMF and U. of Washington (1997?)

TRIUMF (inverse reaction, $^7\text{Be}+p$, 2000?)

LBNL and TUNL (1996)

Bochum and Karlsruhe (?)

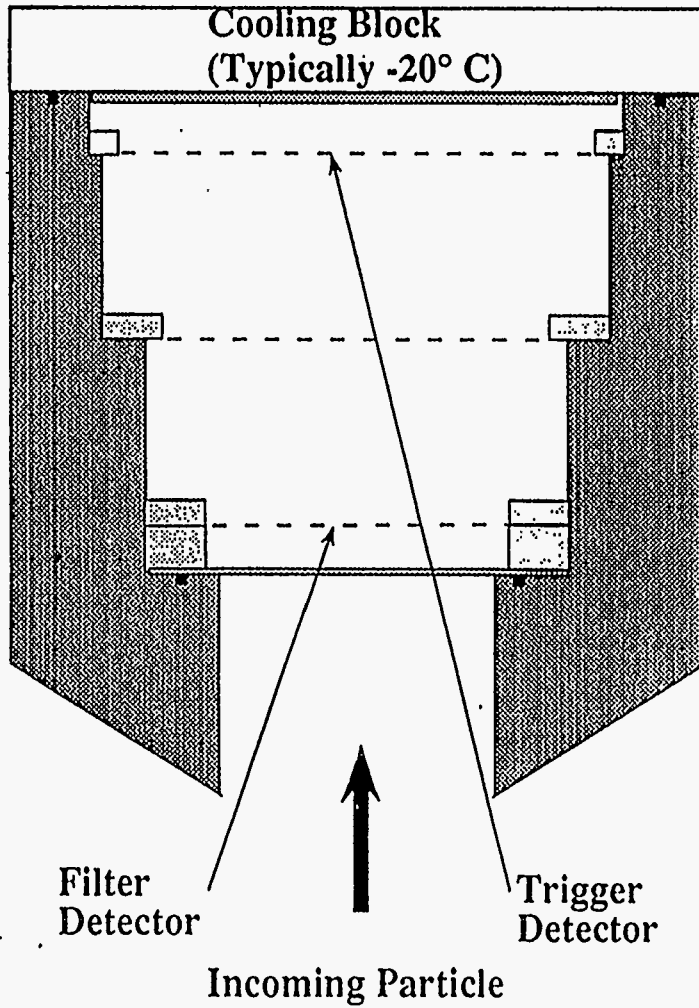
3) $^{10}\text{B}(^7\text{Be}, ^8\text{B})^9\text{Be}$

Texas A&M

4) Possible large p-wave component suggested by $^7\text{Li}(p, \gamma)$ being explored at TUNL and CalTech

The LBNL + TUNL Experiment:

- > produce ${}^7\text{Be}$ via the ${}^7\text{Li}(p,n){}^7\text{Be}$ reaction
at the new medical cyclotron at LBNL (10 MeV)
- > separate ${}^7\text{Be}$ chemically and electroplate onto a
platinum backing (5 mm diam. spot)
- > use accelerators at TUNL
 - Tandem
 - ion implanter (high currents at the lowest energies)
- > use a large area version of the low-energy
charged-particle detector telescopes pioneered by
the Cerny group at LBNL.



Distance
(in mm)

1

4

4

1

380 mm² silicon detector

--- Floating ground grid

--- Electrode grid (+600 V)

--- Floating ground grid

50 μg/cm²
polypropylene window

Improvements Over Previous Experiments:

- > 10 times more ^7Be in the target
 - 1 full Curie as compared to the 0.08 Ci used by Filippone et al.

- > low-energy detector telescopes
 - precise identification of α particles with reduced background

- > an improved energy calibration
 - accurate to about 1 keV compared to 3 keV

Together, the above improvements will allow the measurement of much smaller cross sections leading to an extension of the $^7\text{Be}(p,\gamma)$ measurement down to lower energies (60 keV as compared to ≥ 117 keV)

- improves the extrapolation down to solar energies
- tests the predicted energy dependence

Timeline:

Ongoing:

- | | |
|--|------------|
| --> detector station design | LBNL, TUNL |
| --> detector design and purchase | LBNL |
| --> electroplating development and tests with stable ^9Be | LBNL |
| --> develop scheme for energy calibration and current integration of proton beam | TUNL |

August, 1996:

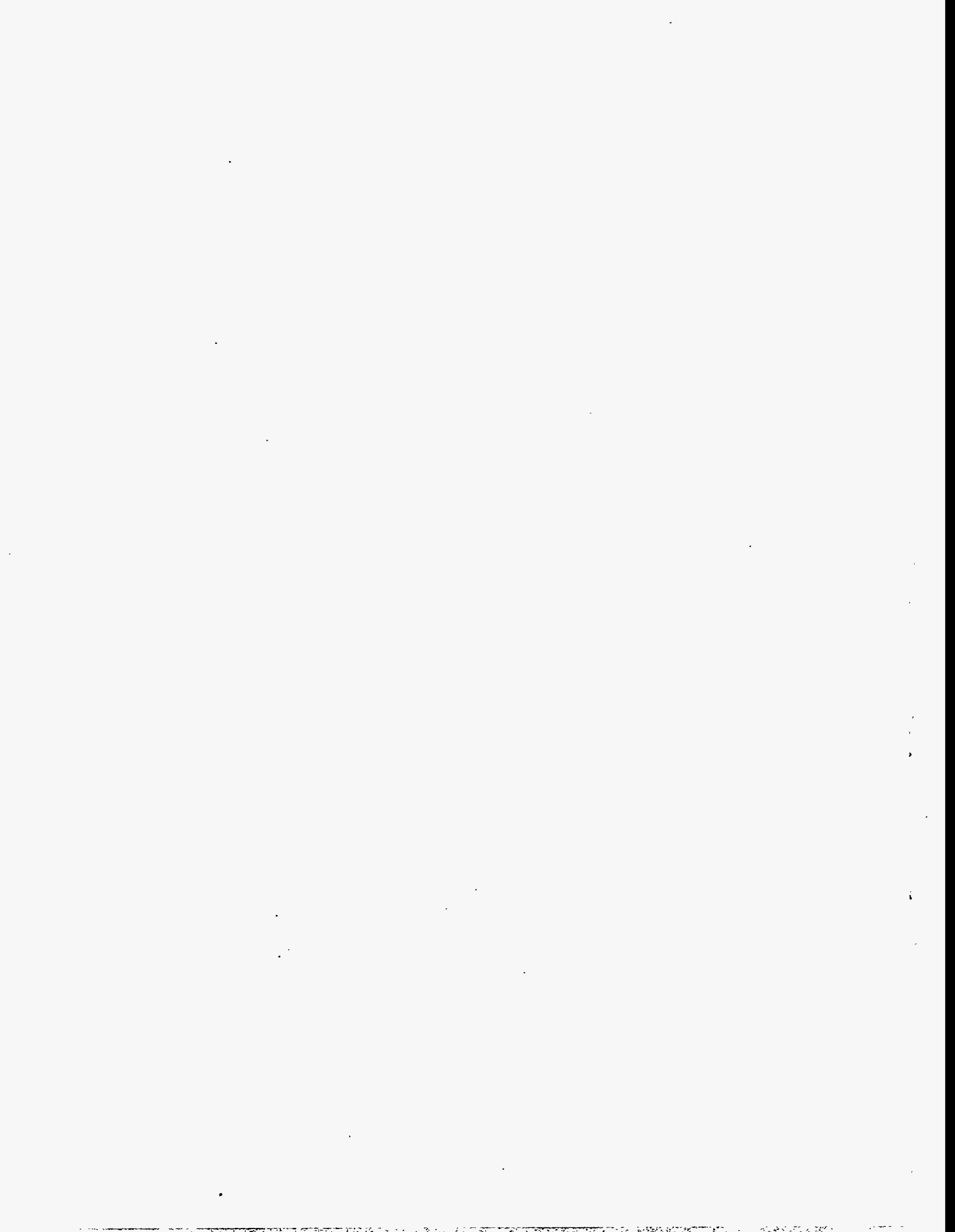
- > produce and perform test run on weaker ^7Be target (~ 0.1 Ci)
- > do higher energy measurements
- > investigate systematic errors

Early 1997:

- > Full experiment on hot target (1 Ci)

Mike Zisman

Lawrence Berkeley National Laboratory
Berkeley, CA



Building a Factory

for B's:

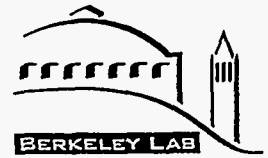
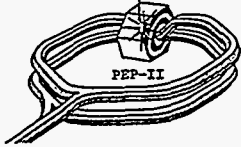
The

PEP-II

Project

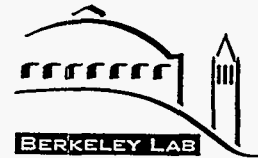
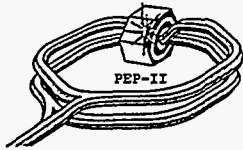
**Michael S. Zisman
LER System Manager
PEP-II B Factory Project
Accelerator & Fusion Research Division
Ernest Orlando Lawrence
Berkeley National Laboratory**

**Cerny Symposium
April 15, 1996**



Outline

- **Introduction**
- **PEP-II history**
- **Typical parameters**
- **Design challenges**
- **Project overview**
- **Project status**
- **Cost and schedule**
- **Summary**

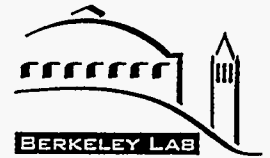
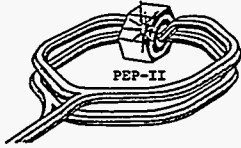


Introduction

- **Strong interest (worldwide) in past few years in design of high- \mathcal{L} e^+e^- collider for a “ B factory”**

 - **primary motivation: study origin of CP violation**
 - **effect expected to be large in $B\bar{B}$ system**

- **Experiment will probe the origins of the universe**
 - **why do we live in a matter dominated world?**
- **At Big Bang, equal amounts of matter and anti-matter**
 - **slight asymmetry in reaction rates caused matter to dominate**
 - **this is thought to be related to CP violation**
 - **we know it happens, but not why**
- **Machine to answer this question requires several novel features compared with existing colliders**



- ***CP*-violation studies benefit from moving $B\bar{B}$ c.m.**

⇒ “asymmetric” collider, $E_1 \neq E_2$

— permits spatial resolution of B and \bar{B} decays

- energy asymmetry has broad optimum

$$\frac{7}{4} \leq \frac{E_1}{E_2} \leq \frac{12}{2.3}$$

- **Statistics for decay channels of interest, require high collision rate (“luminosity” in collider parlance)**

— $R = \mathcal{L} \sigma$

- **Need $\mathcal{L} = 3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ for *CP* violation study**

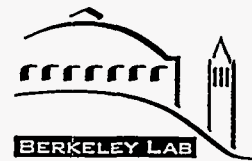
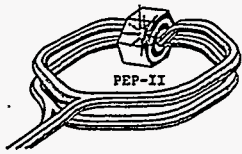
- **Actual figure of merit is integrated \mathcal{L}**

— must produce abundant sample of $B\bar{B}$ pairs

- meaning (and challenge) of “factory”

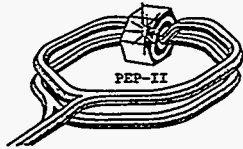
— aim for $\int_{\text{year}} \mathcal{L} \cdot dt = 3 \times 10^{40} \text{ cm}^{-2} = 30 \text{ fb}^{-1}$

- based on canonical “year” of 10^7 seconds



PEP-II History

- **Concept for asymmetric e^-e^+ collider to serve as *B* factory due to Oddone (1987)**
 - initial accelerator design studies at LBNL led by Chattopadhyay (1988–1989)
 - SLAC-LBNL-LLNL design study done in 1990
- **Original CDR for project completed February '91**
 - to avoid stigma of new machine, ours was an “upgrade,” whence PEP-II
- **Design extensively reviewed over 3-year period**
 - Cornell put forth competing proposal “CESR-B”
- **Ultimate hurdle was Joint DOE/NSF *B* Factory Review in 1993**
- **After Joint Review, President Clinton announced SLAC as site for U.S. *B* factory**
- **Japan is building an equivalent machine: “KEKB”**
 - ⇒ we have a race on our hands!



Typical Parameters

- Luminosity is

$$\mathcal{L} = \frac{N_+ N_- f_c}{4\pi\sigma_x^* \sigma_y^*}$$

- For machine design purposes write \mathcal{L} as

$$\mathcal{L} = 2.17 \times 10^{34} \xi (1 + r) \left(\frac{I \cdot E}{\beta_y^*} \right)_{+,-} [\text{cm}^{-2}\text{s}^{-1}]$$

where

I = total current [A]

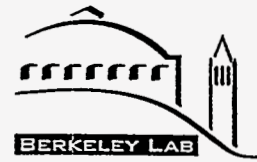
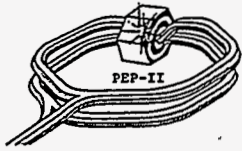
β_y^* = vertical beta function at IP [cm]

r = aspect ratio (σ_y/σ_x) (detector constraint)

E = beam energy [GeV] (physics constraint)

ξ = $\Delta V_{\text{bb,max}}$ (accelerator physics constraint)

- Justification for writing \mathcal{L} as above is empirical limit on ξ



- **Must improve luminosity by a factor of 15**
 - **need higher I and smaller beam sizes at IP!**
 - **both are challenging**
- **Typical parameters for $\mathcal{L} = 3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ are:**

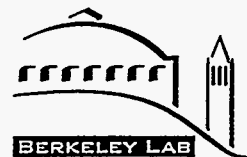
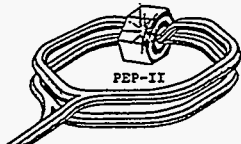
$$I_b \approx 1 - 5 \text{ mA}$$

$$\varepsilon_x \approx 100 \text{ nm}\cdot\text{rad}$$

$$\sigma_\ell \approx 1 \text{ cm}$$

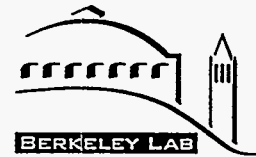
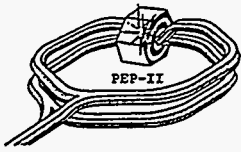
$$I \approx 1 - 3 \text{ A}$$

$$k_B \approx 100 - 2000$$

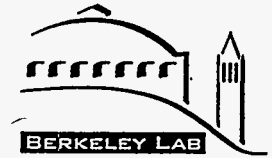
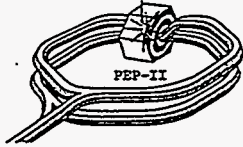


Design Challenges

- **Design of high- \mathcal{L} asymmetric B factory gives both physics and technology challenges**
 - **design choices are interrelated**
 - **proper optimization is the “art”**
- **BF parameter regime forces two-ring collider**
 - **different energies, high currents, many bunches**
- **Two-ring collider gives physics challenges in**
 - **collider design**
 - **beam separation and common focusing of unequal energy beams; keeping beams in collision**
- **Multibunch instabilities severe for B factory**
 - **wakefields induced by displaced bunches (mainly in RF cavity HOMs) can cause other bunches to be displaced**
 - **for certain bunch patterns, get exponential growth of amplitude, leading to beam loss**
 - **growth rates scale with total current, which we require to be very high**

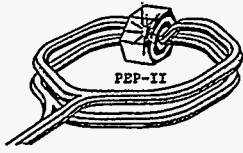


- **Physics issues just discussed make certain implicit assumptions about B factory hardware**
- **Technology challenges can be summarized as:**
 - Don't make a liar out of the accelerator physicists!***
- **Examples:**
 - **lifetime estimates assume low P in rings despite copious photodesorption**
 - **\mathcal{L} estimates assume that high beam currents can be supported without melting anything**
 - **coupled-bunch instability estimates assume RF cavities with heavily damped HOMs**
 - **performance estimates assume components are sufficiently reliable that the machine does not “spend all its time in the shop”**
- **For any BF design, main technological challenges lie in the following areas:**
 - **vacuum system**
 - **RF system**
 - **feedback system**
 - **even with heavily damped cavity modes, must combat growth times ≈ 1 ms**



Project Overview

- **High-energy ring (HER)**
 - 9 GeV e^- in PEP ($C = 2200$ m)
 - reuses all magnets; new RF & vacuum system
 - some new magnets required
- **Low-energy ring (LER)**
 - 3.1 GeV e^+ in new ring ($C = C_{\text{PEP}}$)
 - located above PEP ring in same tunnel
- **Injection system based on present SLC injector**
 - world's most powerful positron source
 - run in “top-off” mode to maintain high average luminosity
 - time to top-off operating collider is 3 minutes;
time to fill from zero is 6 minutes
- **LBL is lead lab for design, construction, commissioning of LER**
 - I serve as LER System Manager

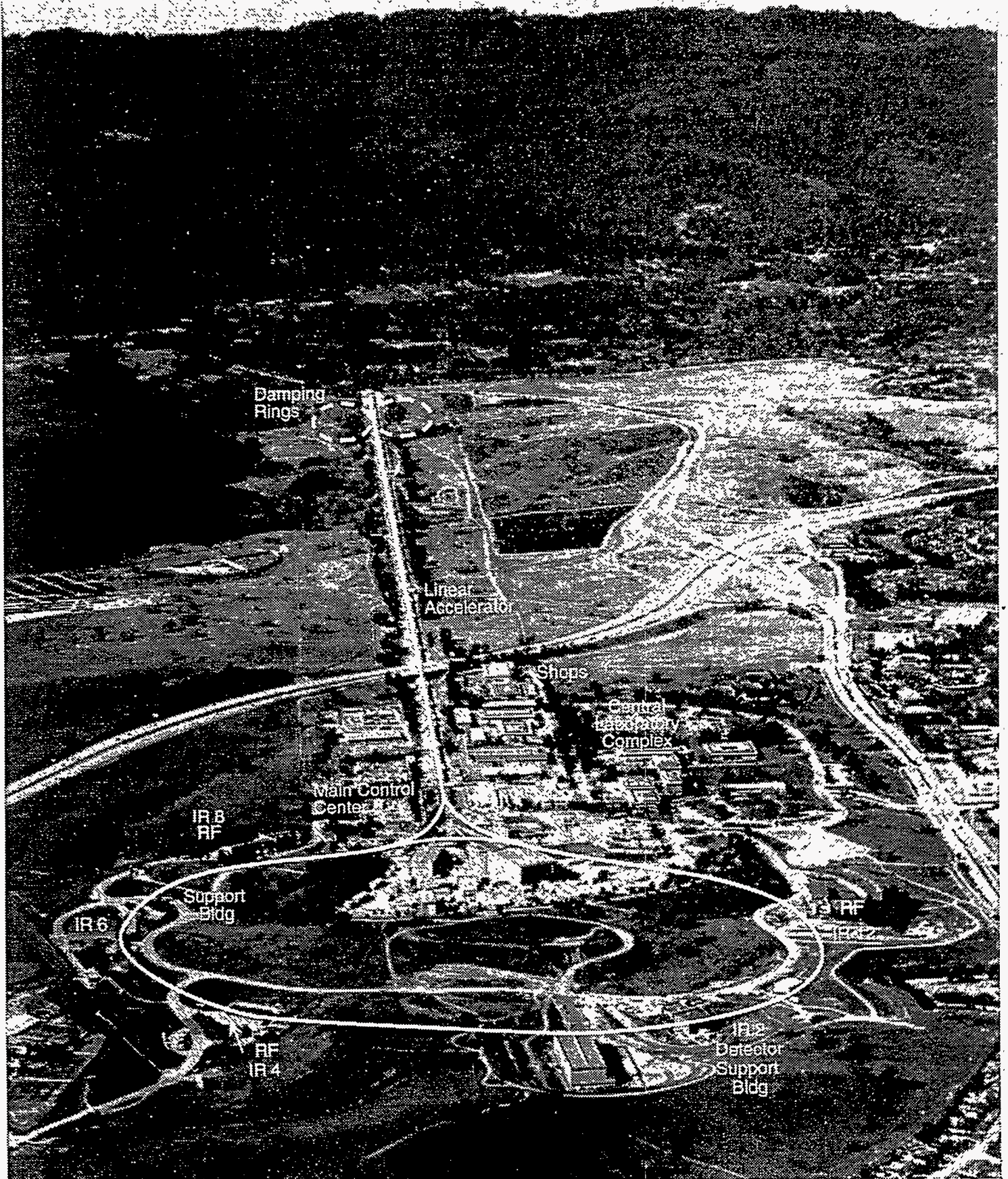
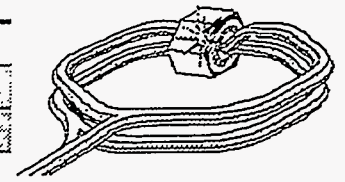


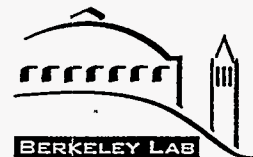
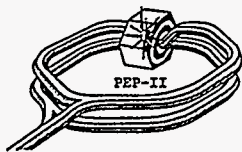
PEP-II Main Collider Parameters

	LER	HER
Energy, E [GeV]	3.1	9
Circumference, C [m]	2199.32	2199.32
ϵ_y/ϵ_x [nm·rad]	2.0/66	1.5/49
β_y^*/β_x^* [cm]	1.5/50.0	2.0/66.7
$\xi_{ox,oy}$	0.03	0.03
f_{RF} [MHz]	476	476
V_{RF} [MV]	5.1	14.0
Bunch length, σ_ℓ [mm]	10	11.5
Number of bunches, k_B	1658†	1658†
Bunch separation, s_B	1.26	1.26
Damping time, τ_E/τ_x [ms]	30.0/62.5	18.3/37.0
Total current, I [A]	2.16	1.00
U_0 [MeV/turn]	0.75	3.59
Luminosity, \mathcal{L} [cm⁻²s⁻¹]	3×10^{33}	

†includes gap of $\approx 5\%$ for ion clearing

PEP-II B-Factory





Project Status

- **Injection**

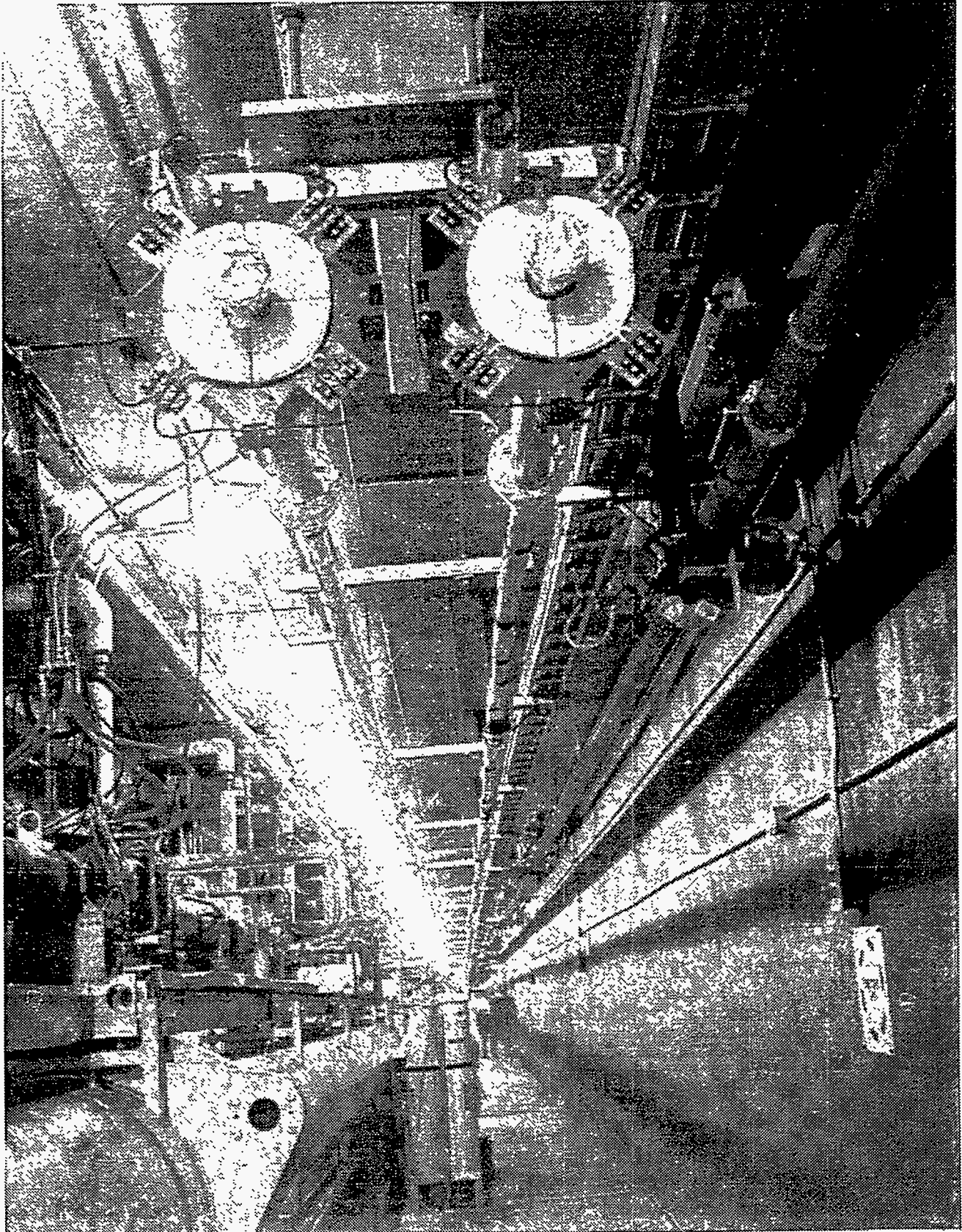
- **electron extraction and both bypass lines installed**
 - **electron line being commissioned**
- **components for positron extraction line being fabricated for installation in Summer '96**

- **HER**

- **magnet refurbishment and remeasurement completed**
 - **arc dipoles reinstalled**
 - **quadrupole rafts being installed**
 - **vacuum chamber production under way**
 - **arcs use in-house e-beam welder**



Installation of the e^+ and e^- Bypass Lines in LINAC Housing



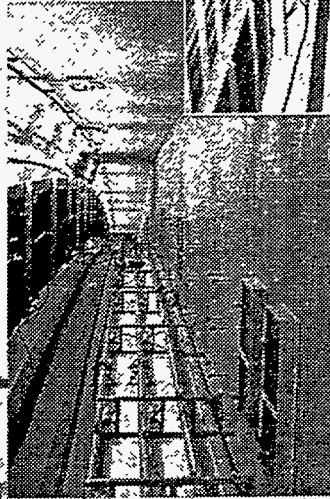
High Energy Ring ARC Section History



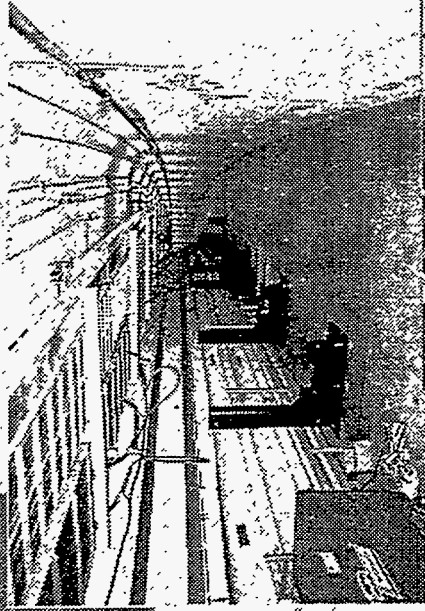
Jan. 94



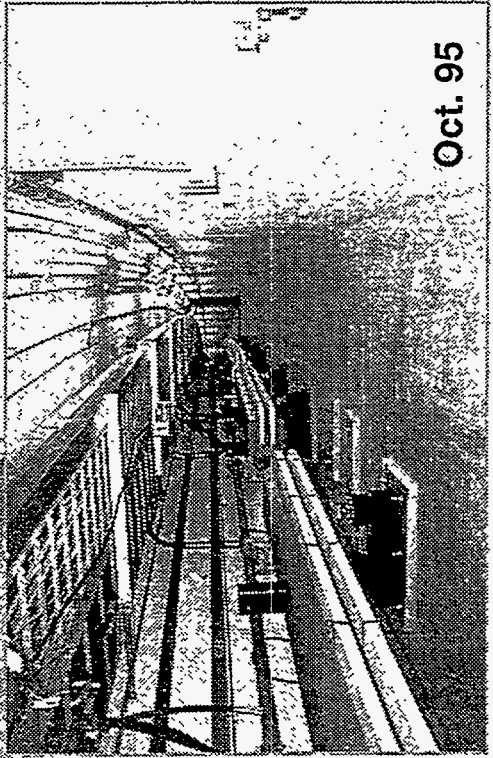
Jul. 94



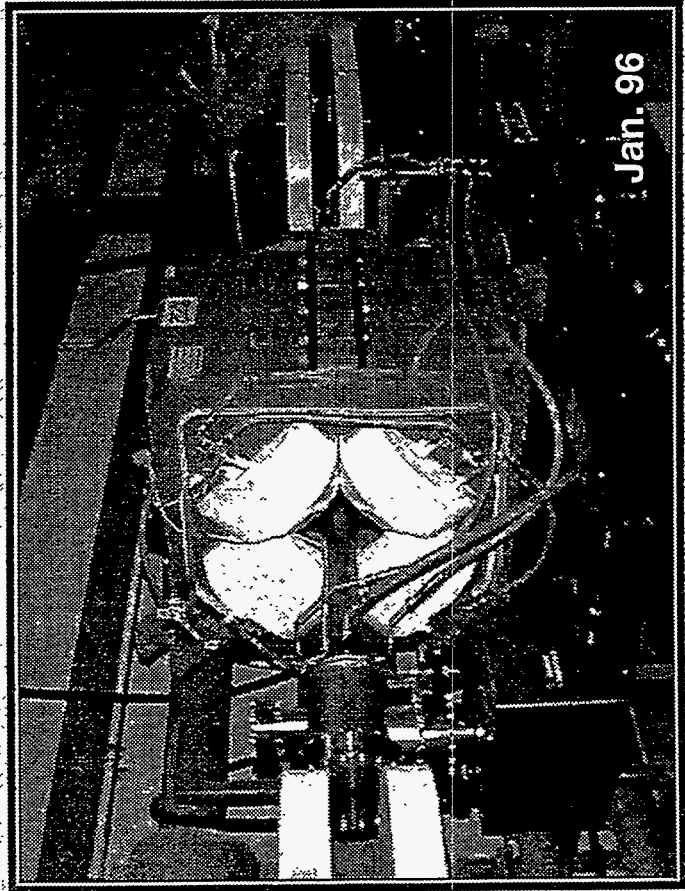
Feb. 95



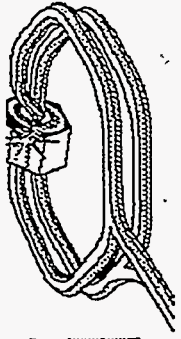
Apr. 95



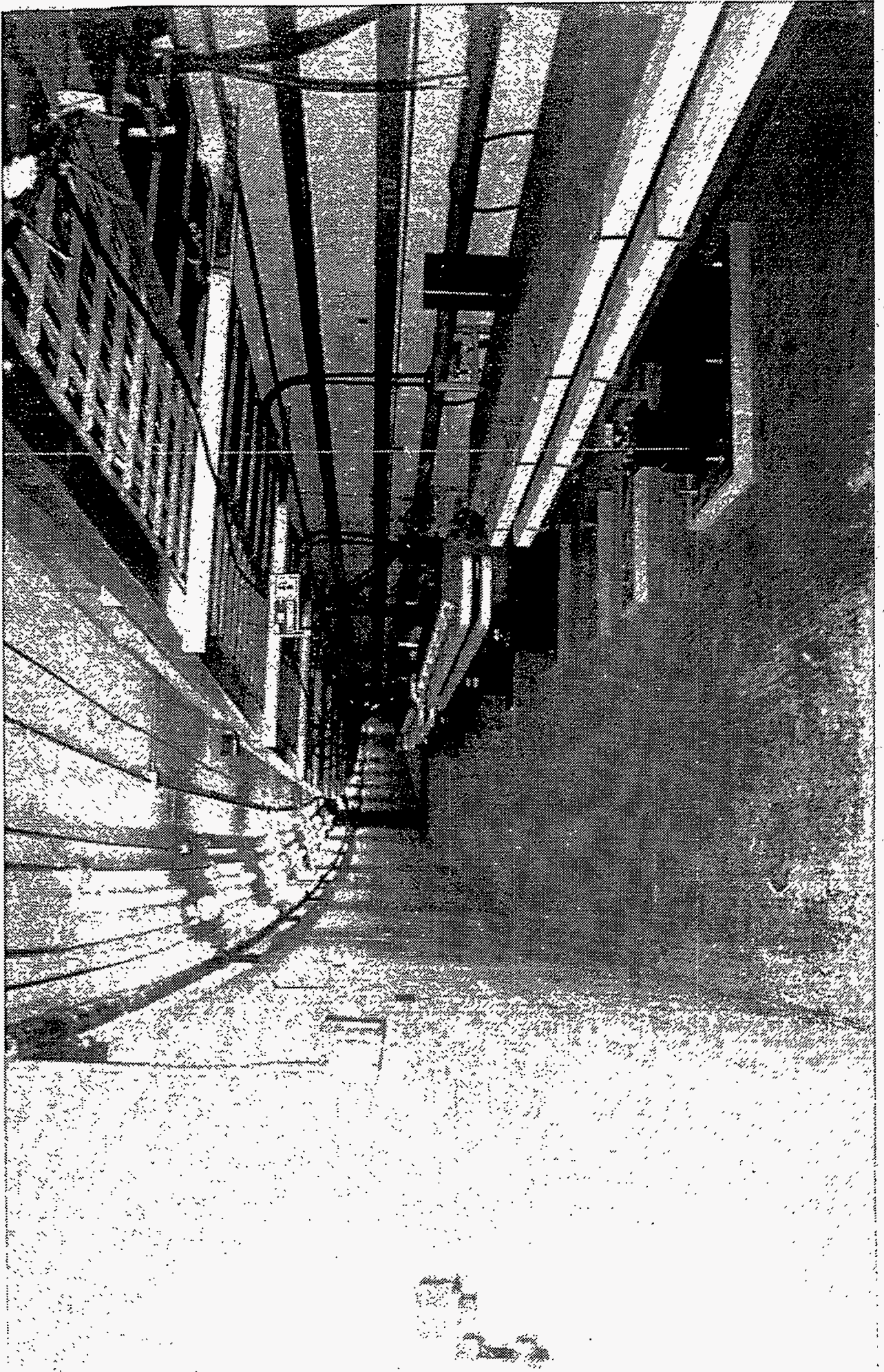
Oct. 95

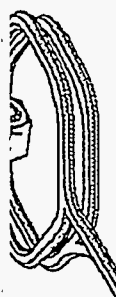


Jan. 96

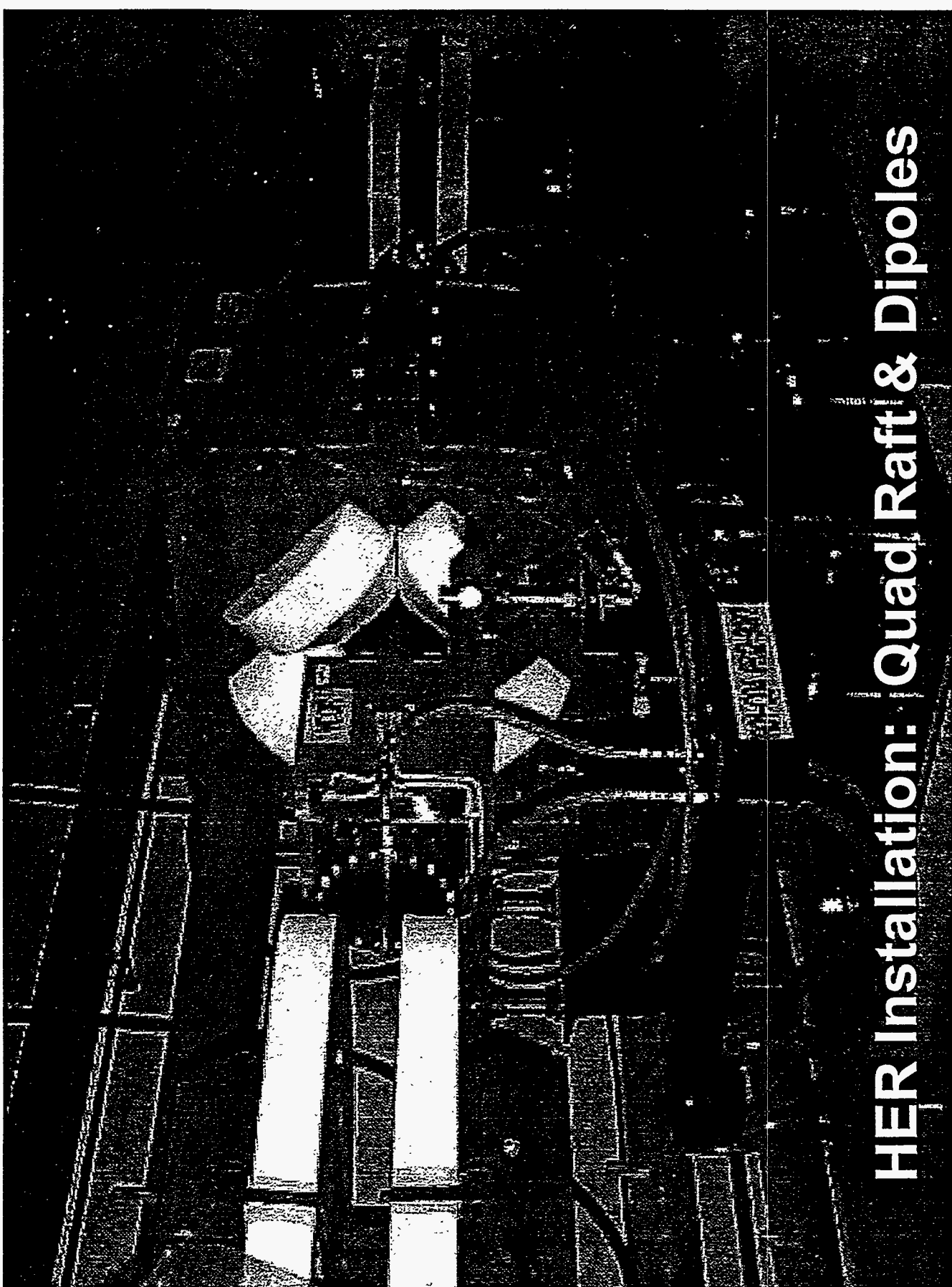


HER First Arc Dipole Installation



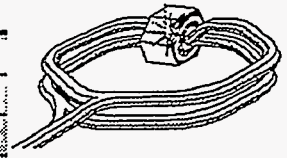


PEP-II B-Factory

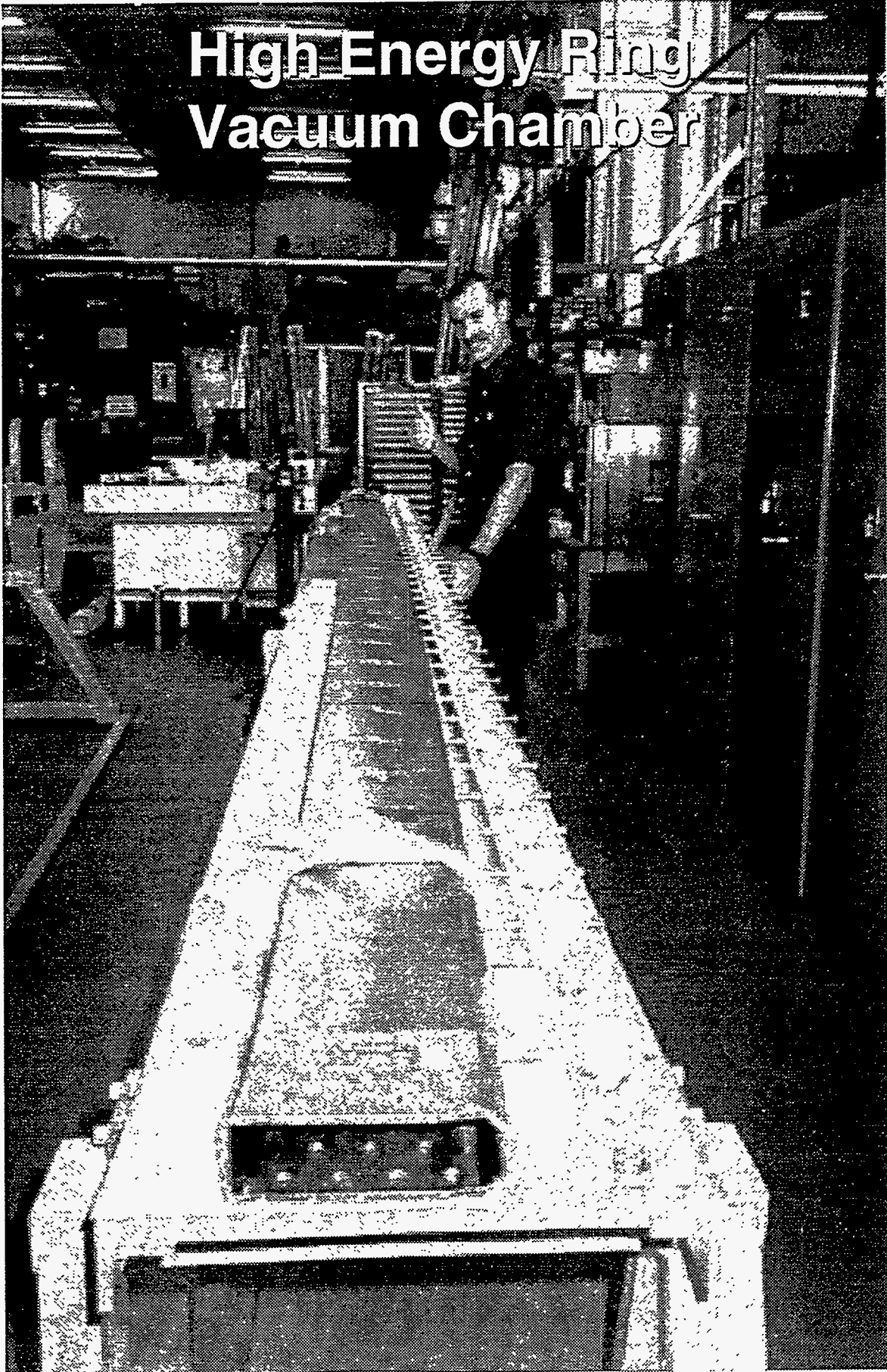


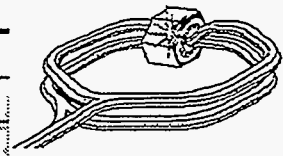
HER Installation: Quad Raft & Dipoles

PEP-II B-Factory

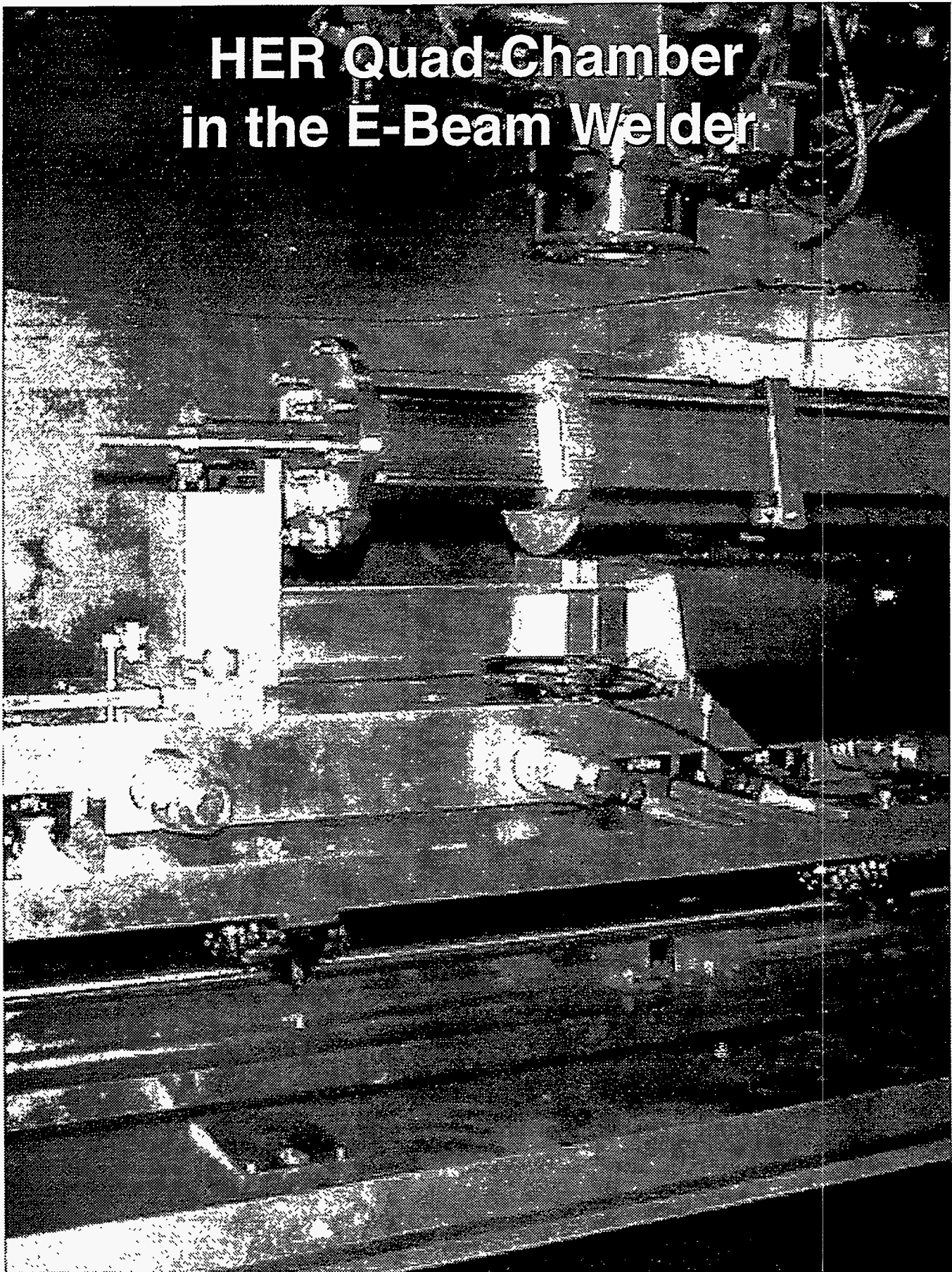


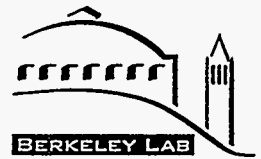
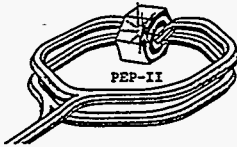
High Energy Ring Vacuum Chamber





HER Quad Chamber in the E-Beam Welder





- **LER**

- **quad and dipole production under way in collaboration with IHEP (Beijing)**
 - **quad quality exceeds design specs**
 - **prototype dipole approved for production**
- **corrector magnets being constructed in industry**
- **sextupoles being refurbished from PEP (new coils)**
- **prototype arc and straight section rafts completed**
- **arc vacuum chamber extrusions in hand**

- **IR**

- **intricate region to design and build**
- **prototype of Q1 being developed**
- **design of supports under way**

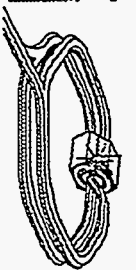


PEP-II B-Factory

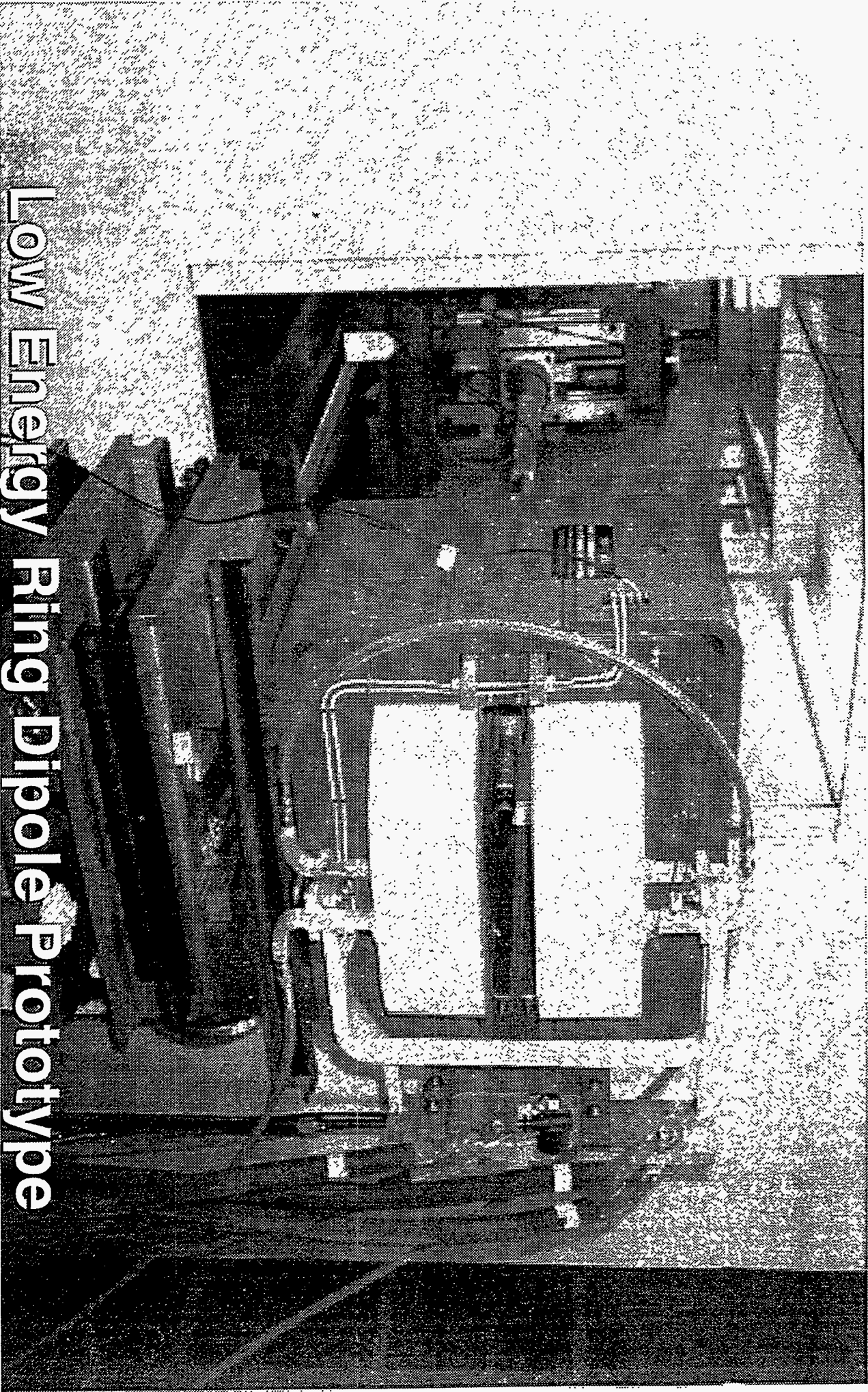


LER Quads Awaiting Measurement at IHEP

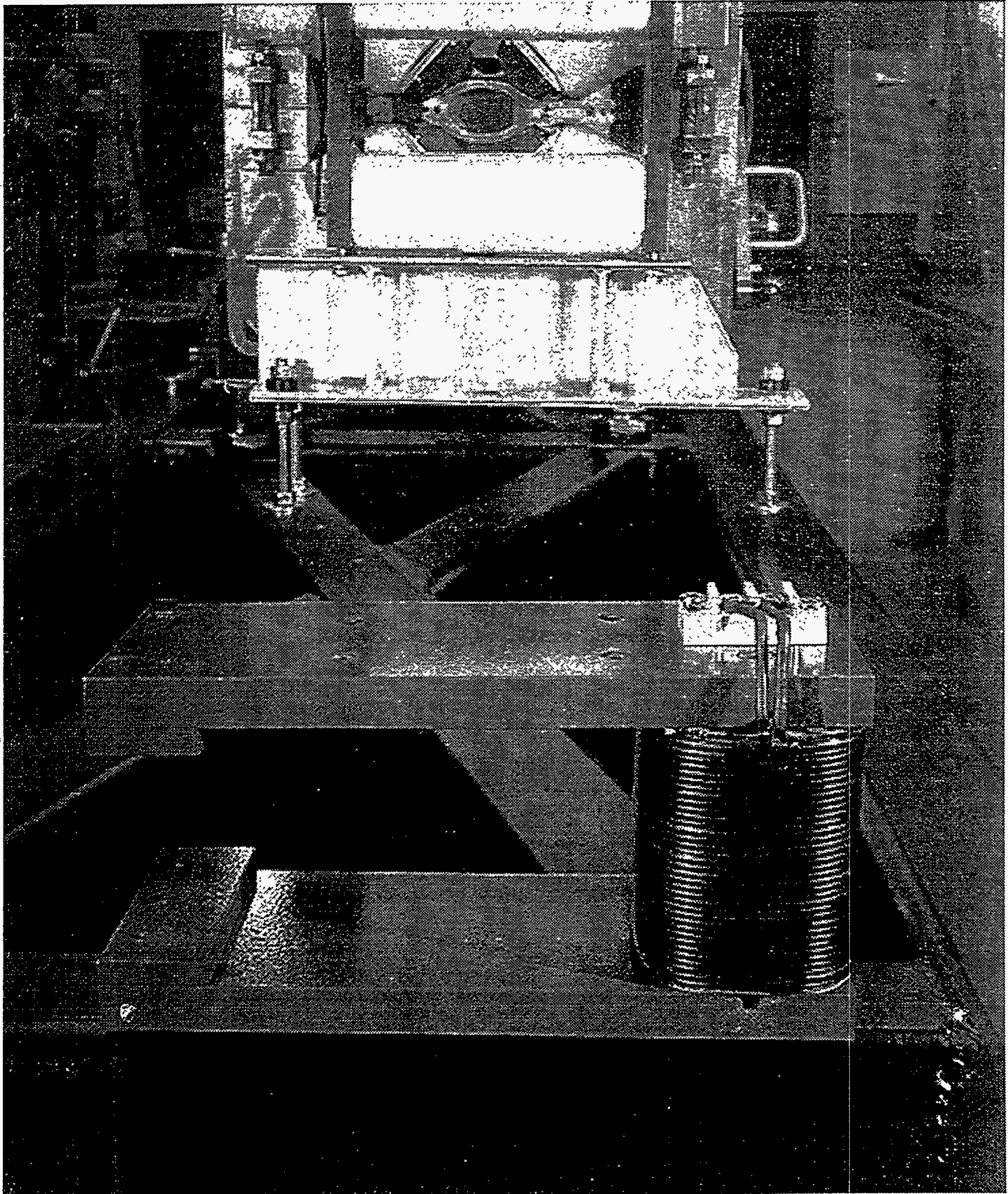
PEP-II B-Factory



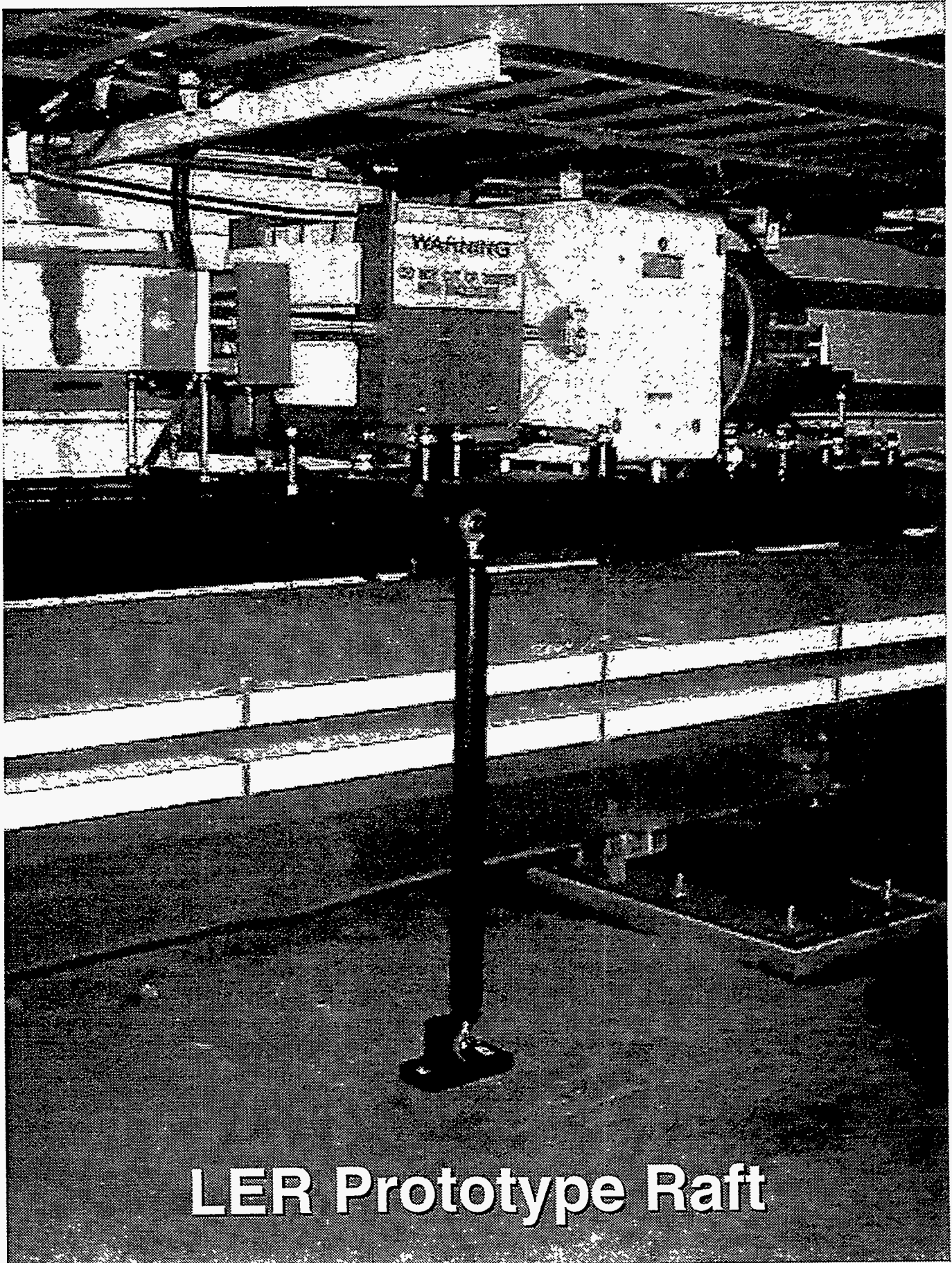
Low Energy Ring Dipole Prototype



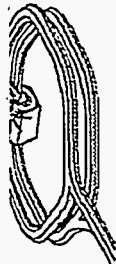
PEP-II B-Factory



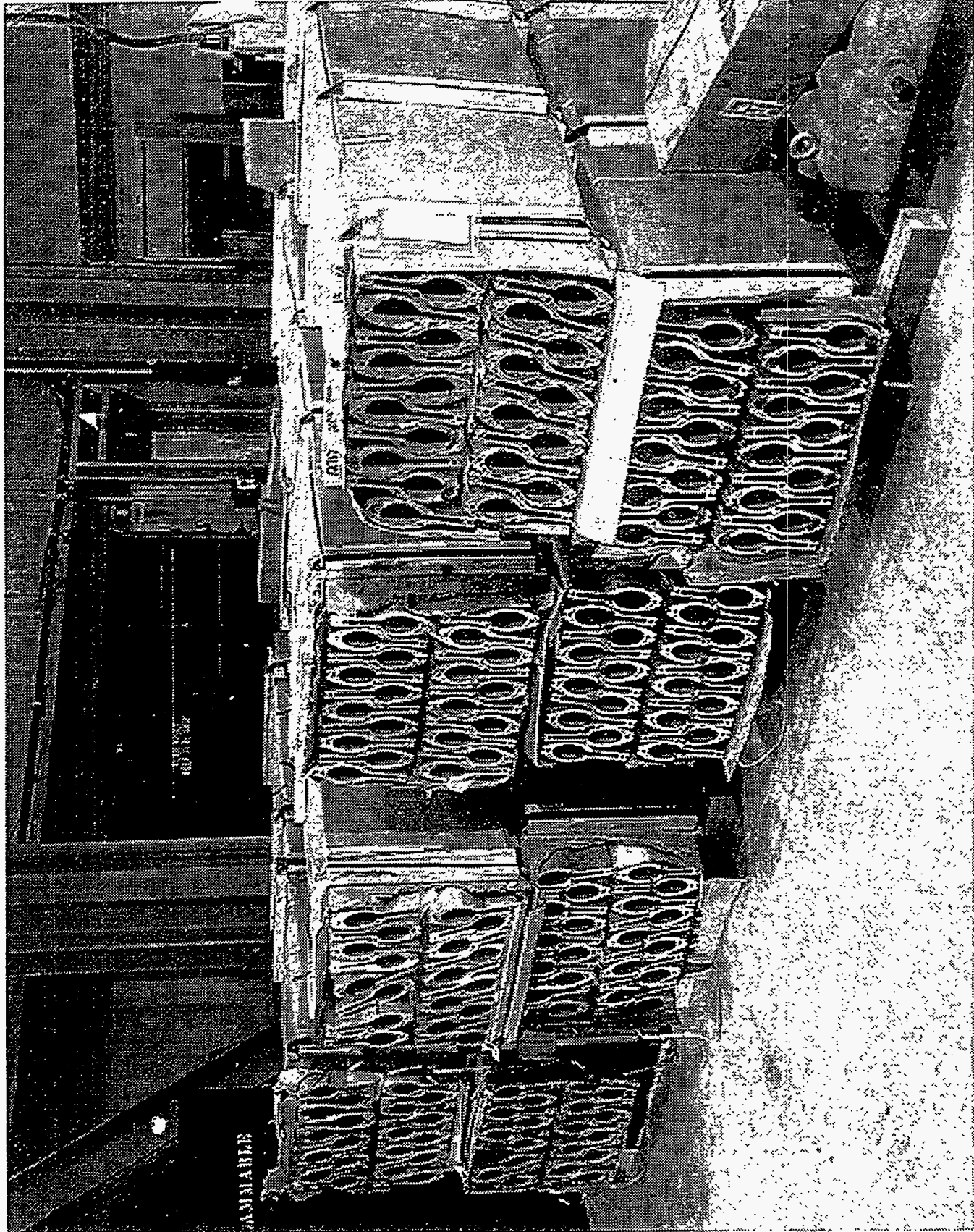
PEP-II B-Factory



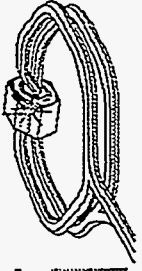
LER Prototype Raft



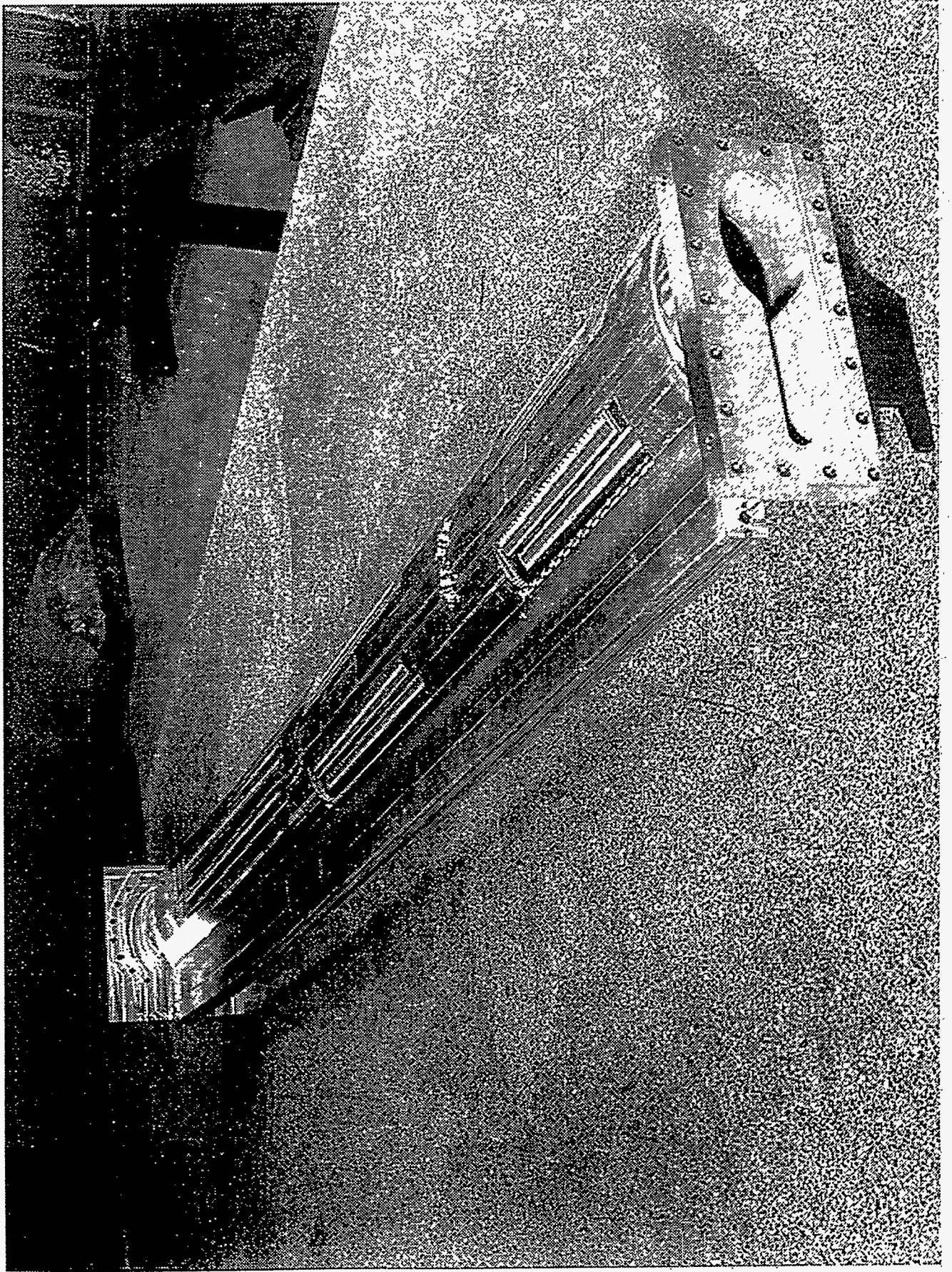
PEP-II B-Factory

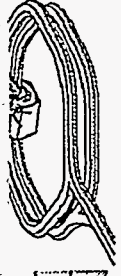


AVAILABLE

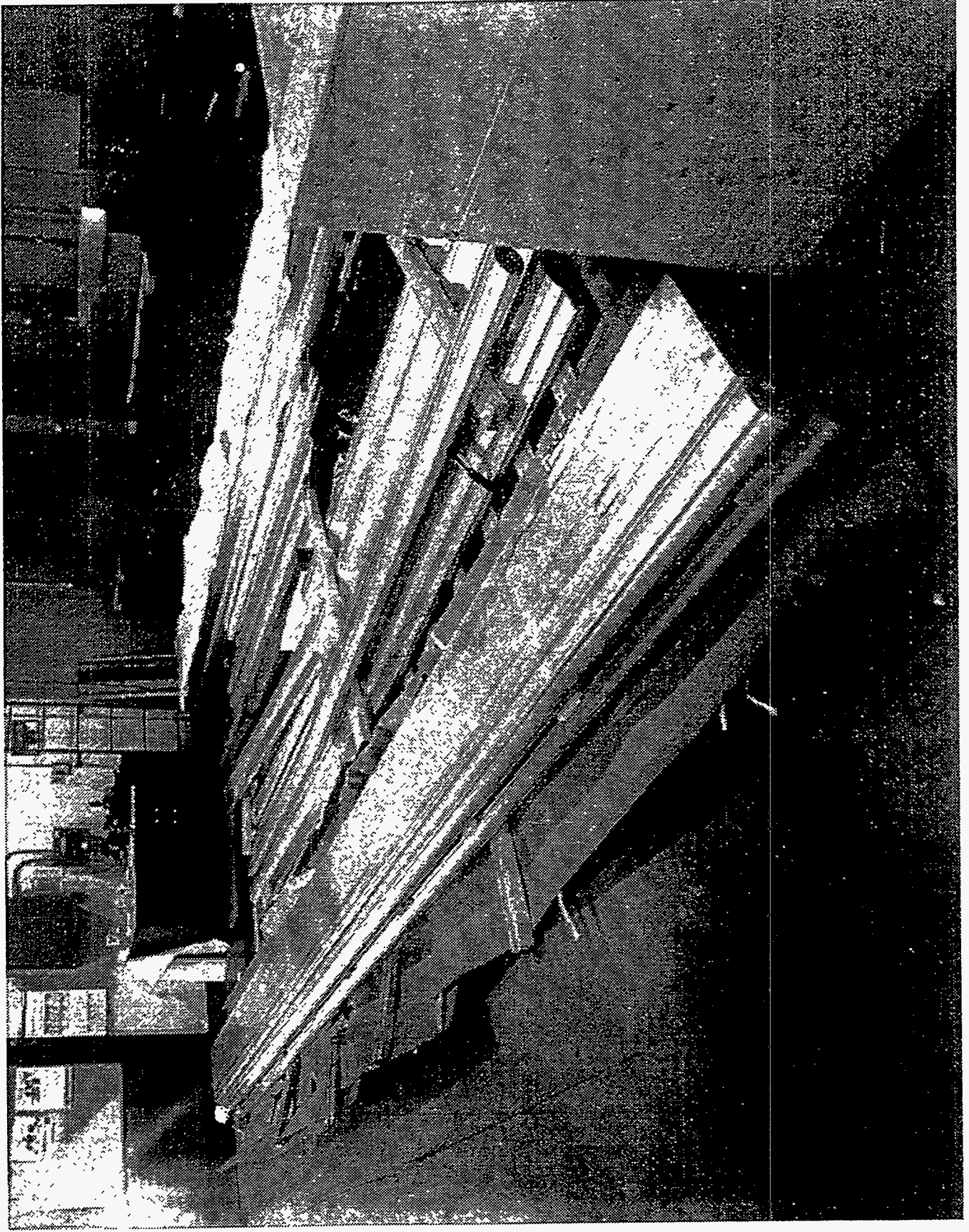


PEP-II B-Factory

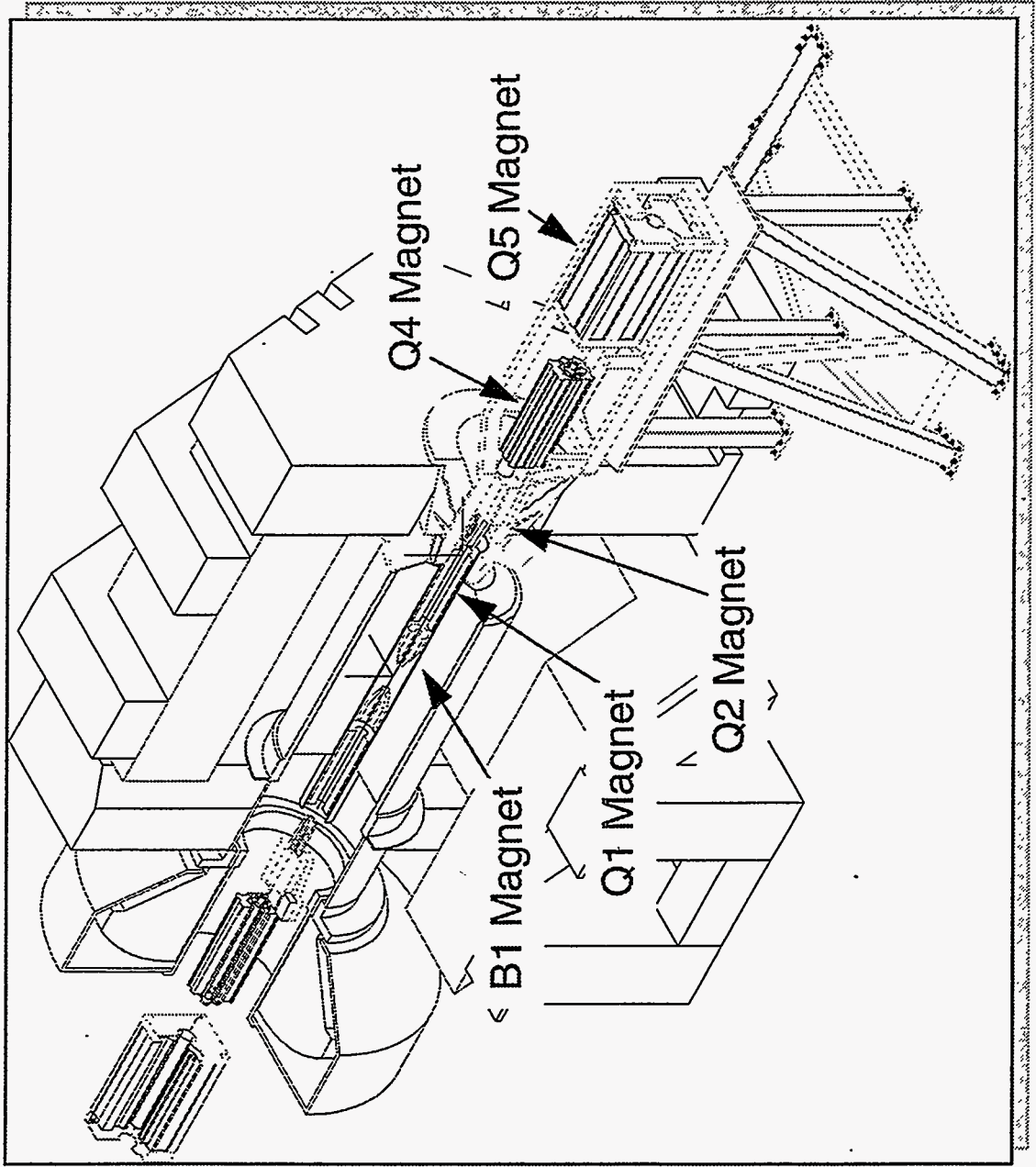




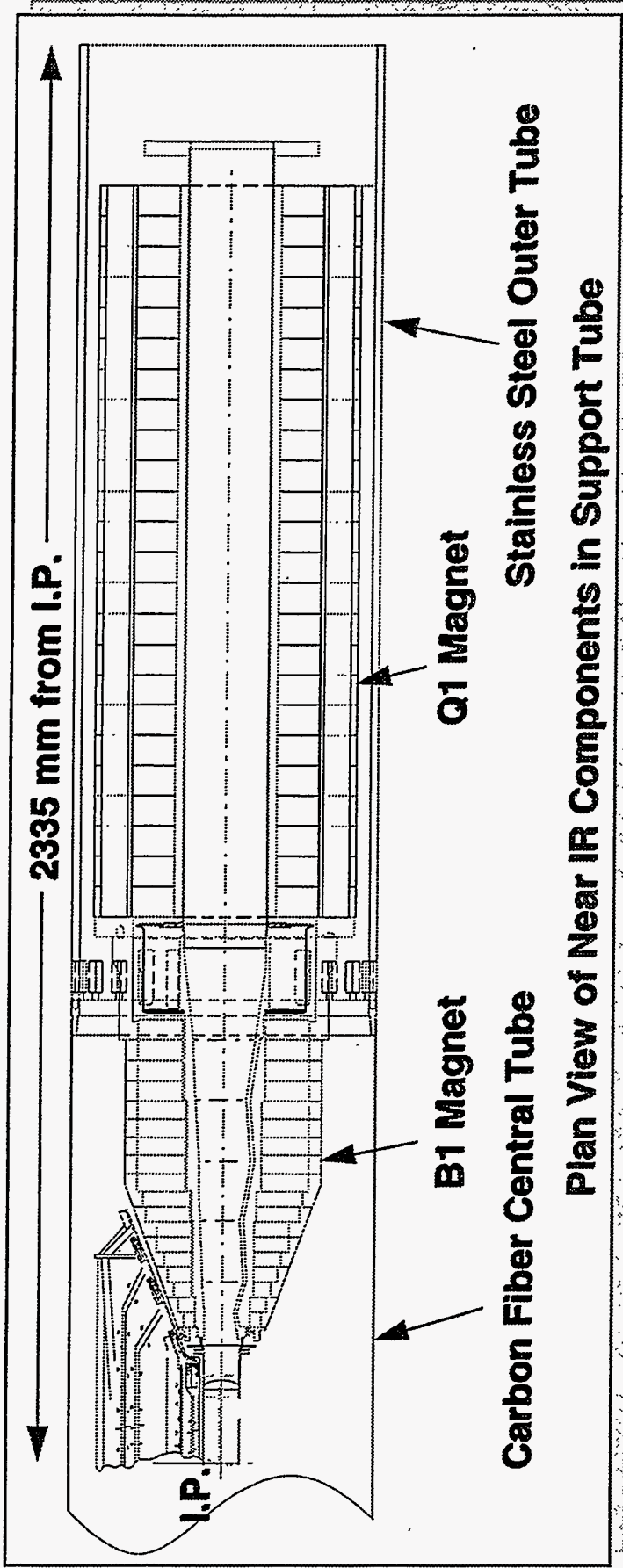
PEP-II B-Factory



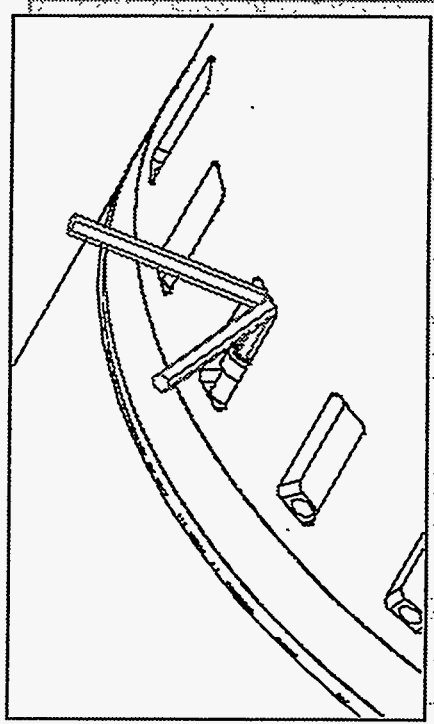
Magnet Design



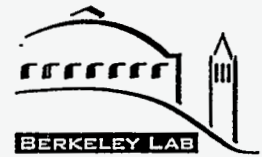
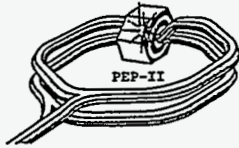
Support Tube Design



Plan View of Near IR Components in Support Tube



Detail of C.F.C.
Bolted Joint



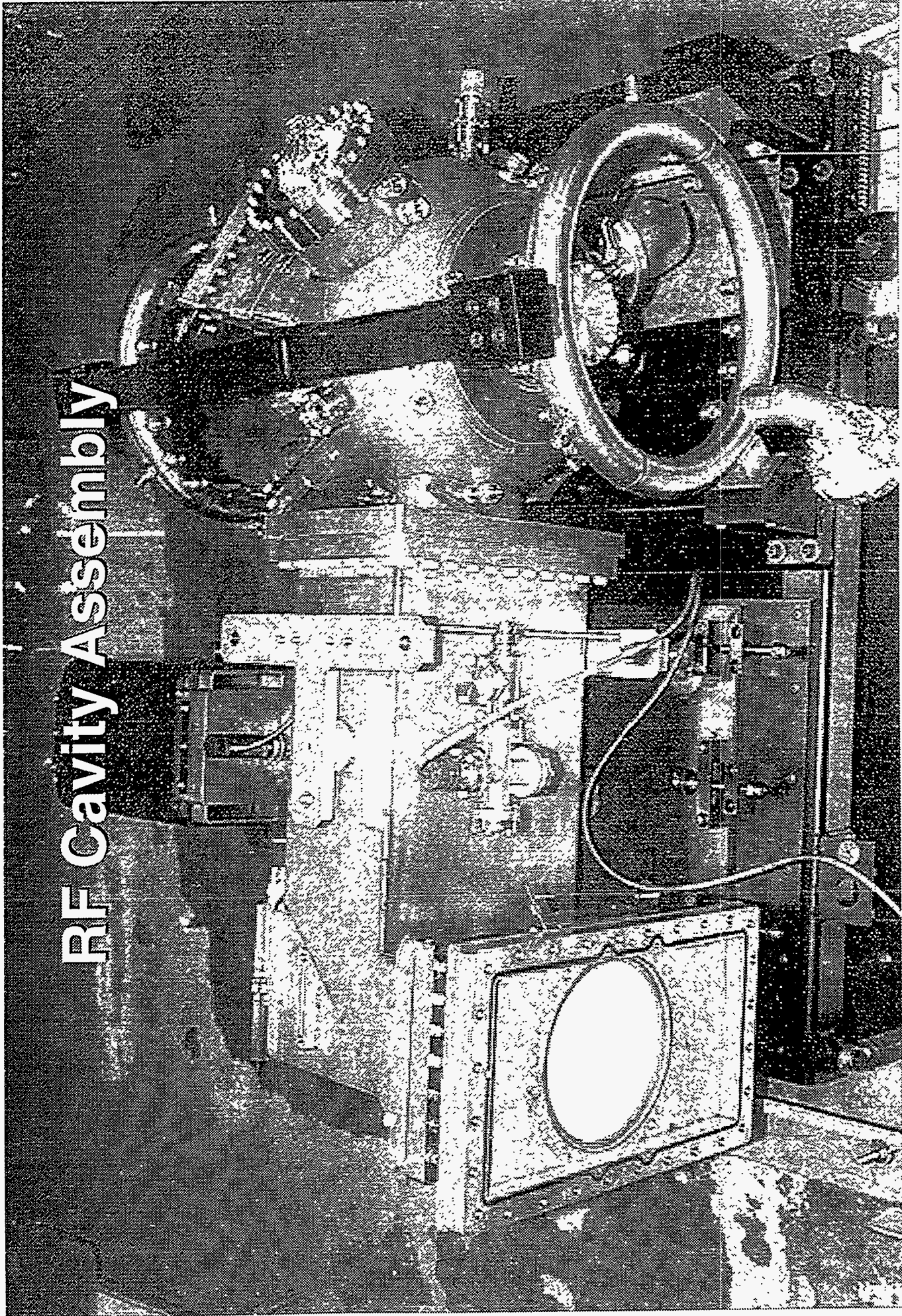
- **RF system**
 - test cavity demonstrated wall power of 120 kW
 - RF window demonstrated 500 kW power
 - first-article klystron produced required 1.2 MW
 - damping loads undergoing tests at 714 MHz

 - **Feedback systems**
 - preferred approach is bunch-by-bunch feedback in time domain
 - detect bunch displacement, kick it back where it belongs
 - considerable design verification done at ALS
 - both longitudinal and transverse systems work as expected
 - ALS requirements are comparable to PEP-II needs
- ⇒ doing realistic “battlefield” testing

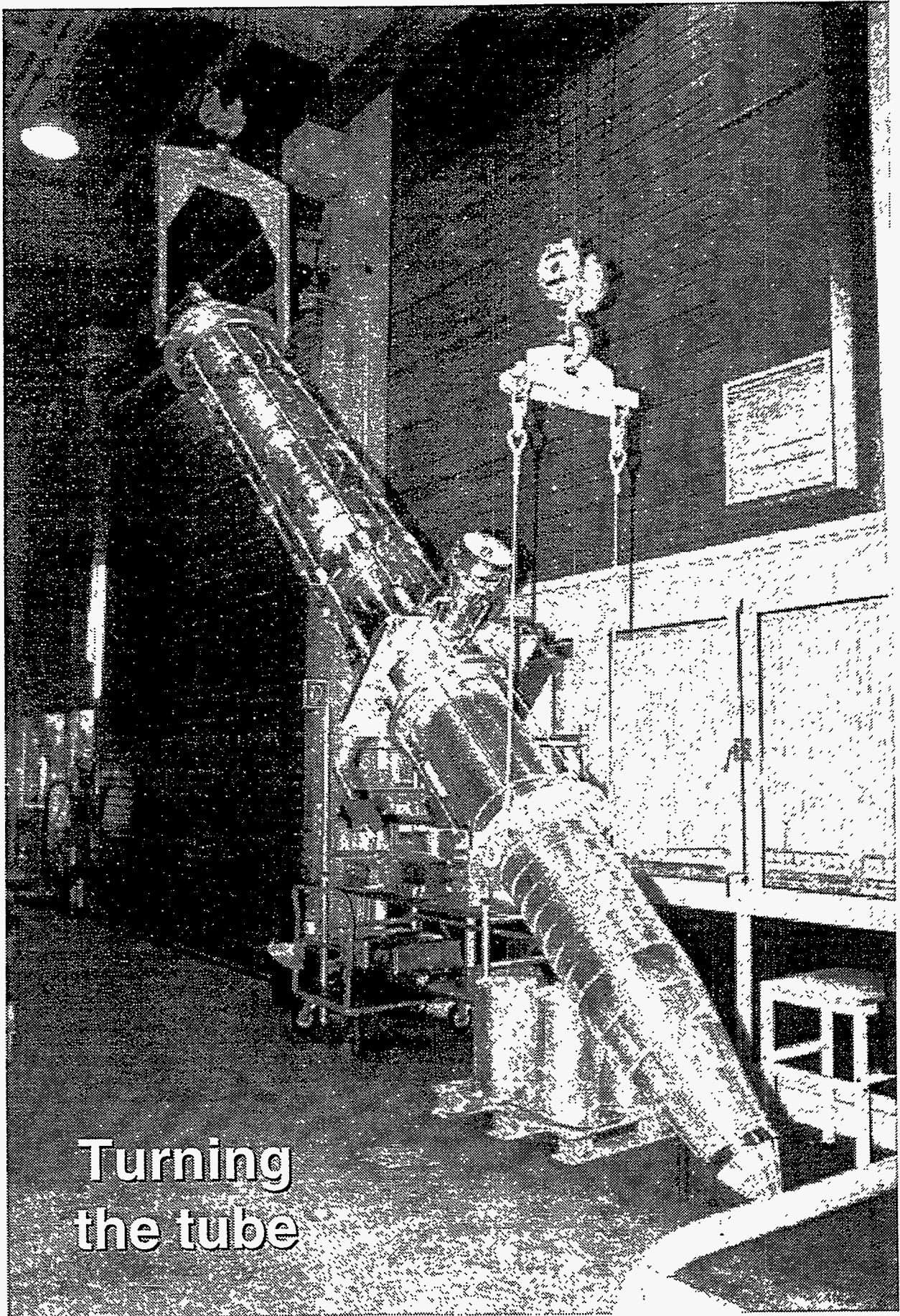
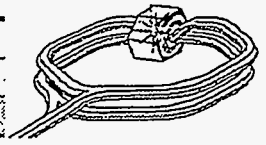


PEP-II B-Factory

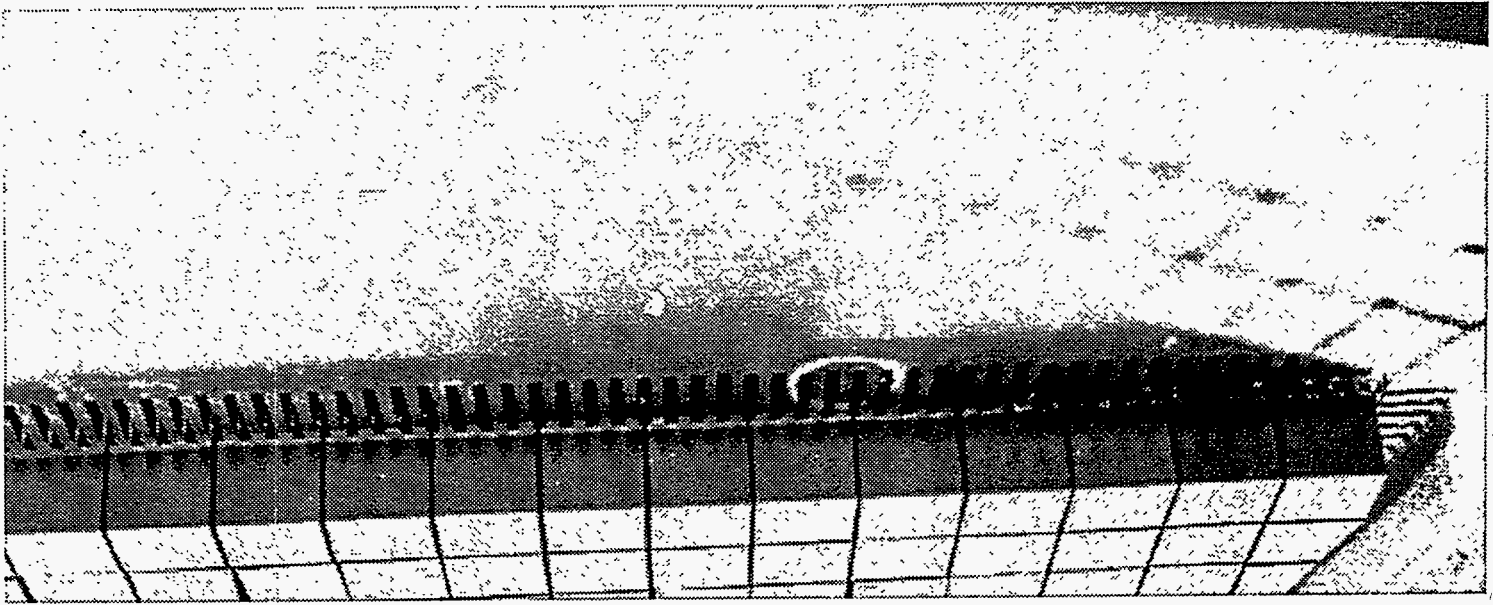
RF Cavity Assembly



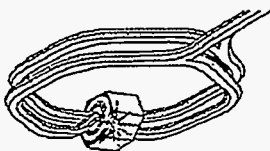
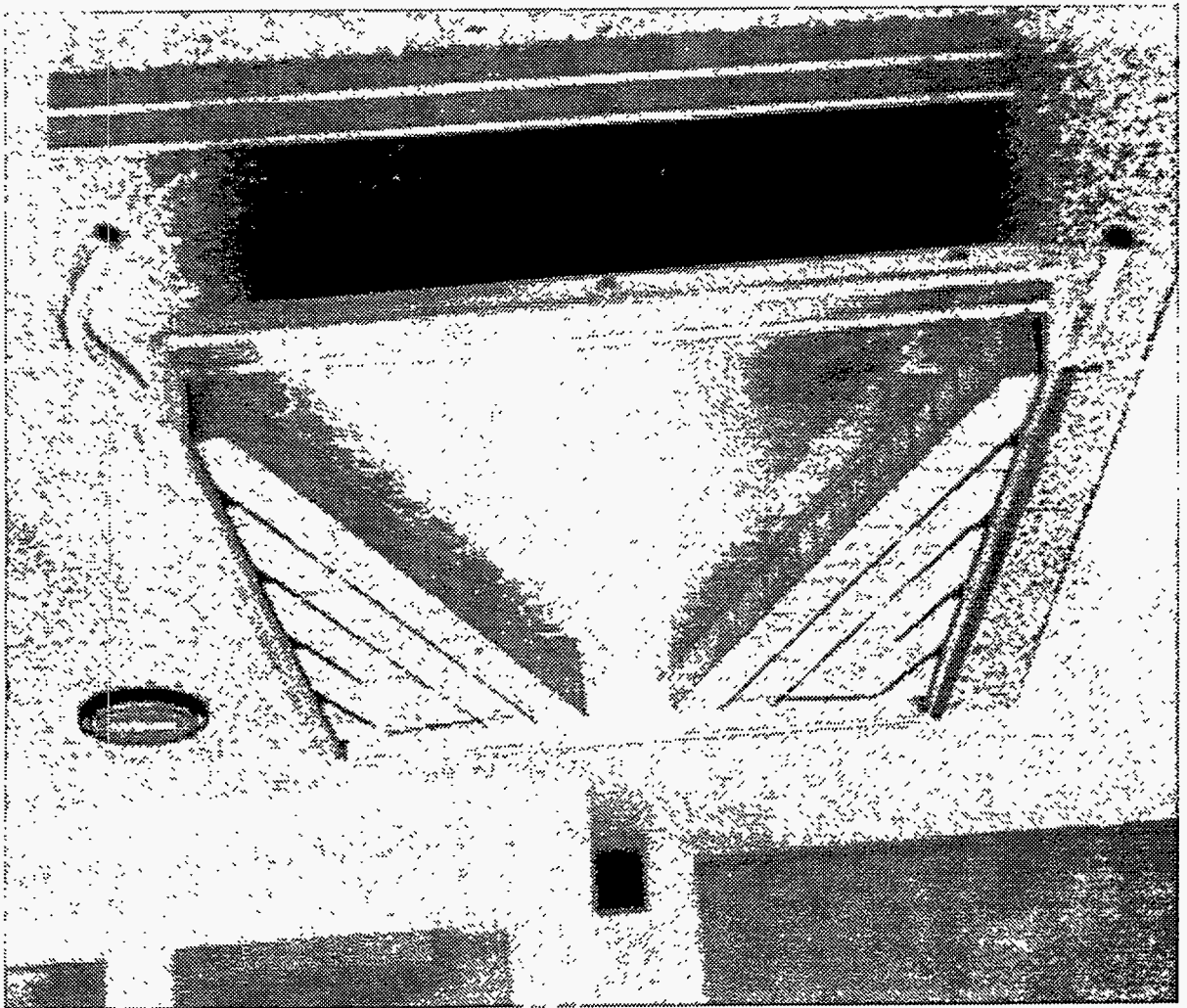
YK 1360 - Tube #1



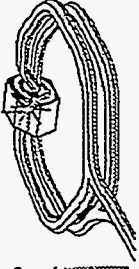
Turning
the tube



HOM Load High-Power Prototype

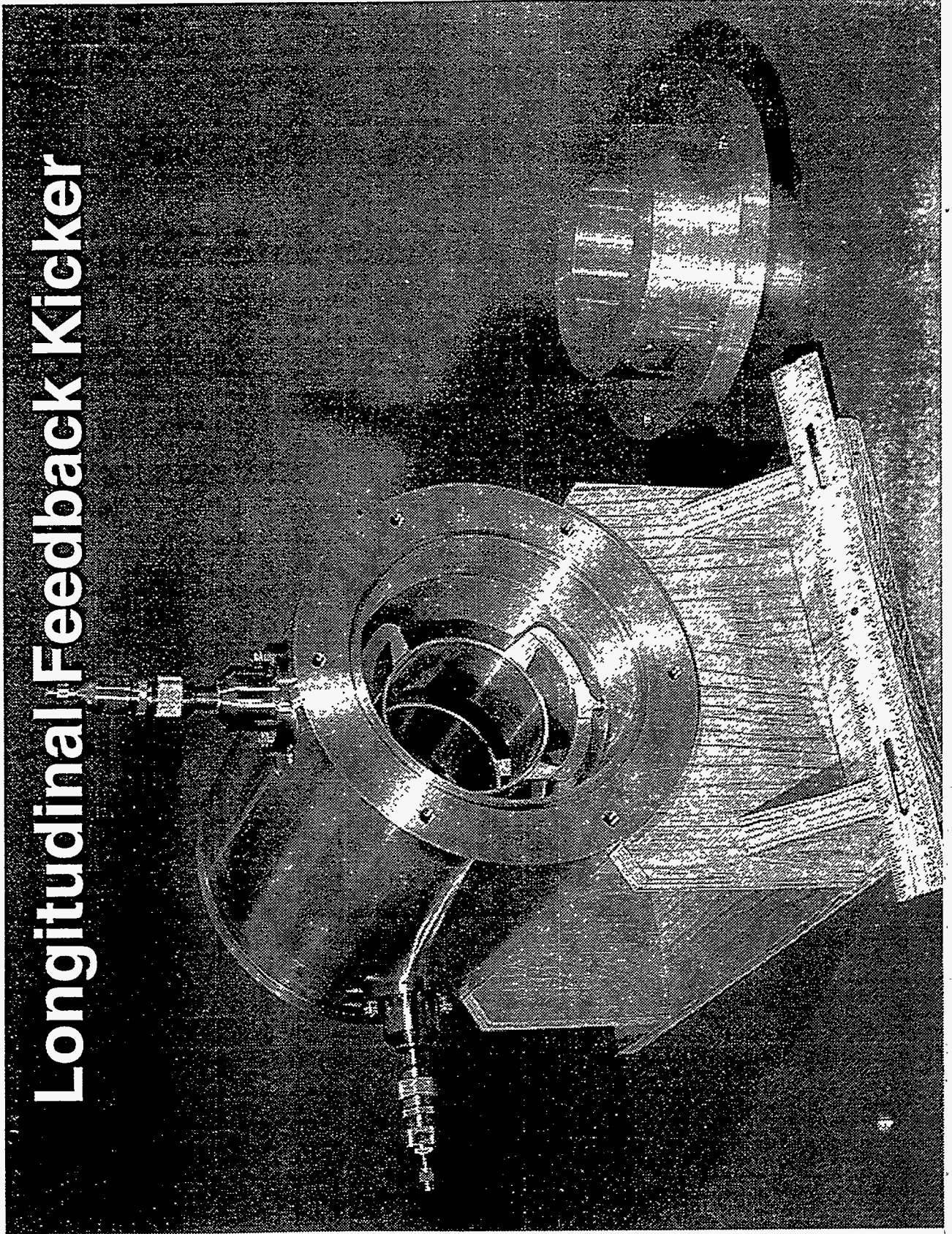


PEP-II B-Factory



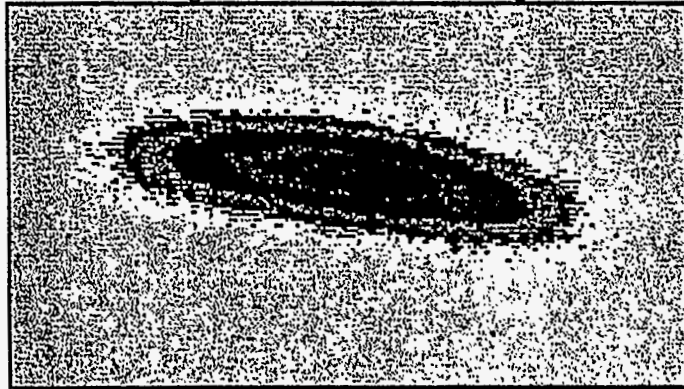
PEP-II B-Factory

Longitudinal Feedback Kicker

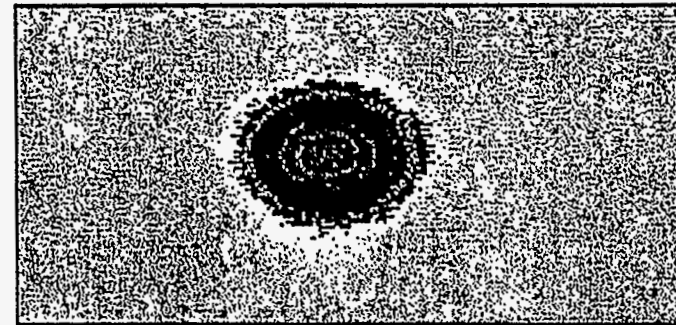


ALS Longitudinal Feedback System

Diagnostic beamline images



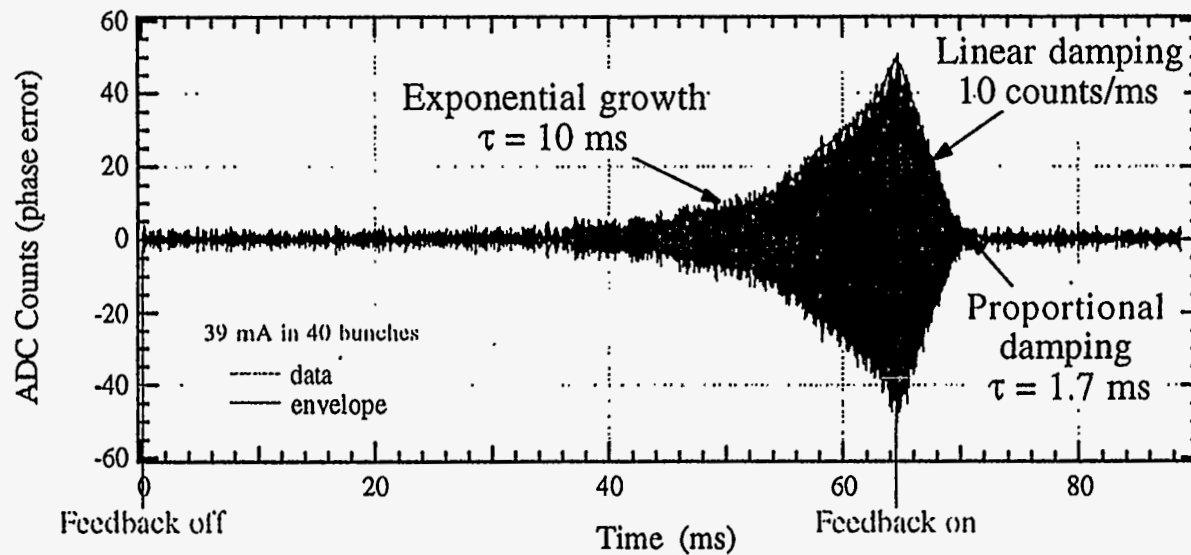
LONGITUDINAL FEEDBACK OFF
Vertical and Horizontal feedback on
Horizontal blow-up & tilt due to dispersion

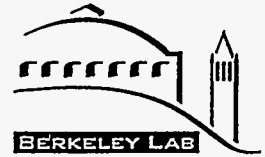
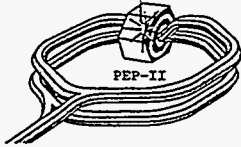


175 mA in 40 bunches

LONGITUDINAL FEEDBACK ON
Vertical and Horizontal feedback on

Feedback system time domain data





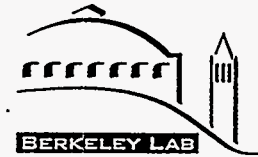
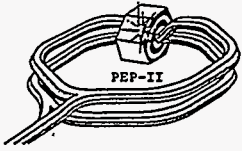
Cost and Schedule

- **Cost estimate is \$177M**
 - activities split among SLAC, LBNL, and LLNL
- **DOE plan calls for 5-year construction schedule**

PEP-II Funding Profile

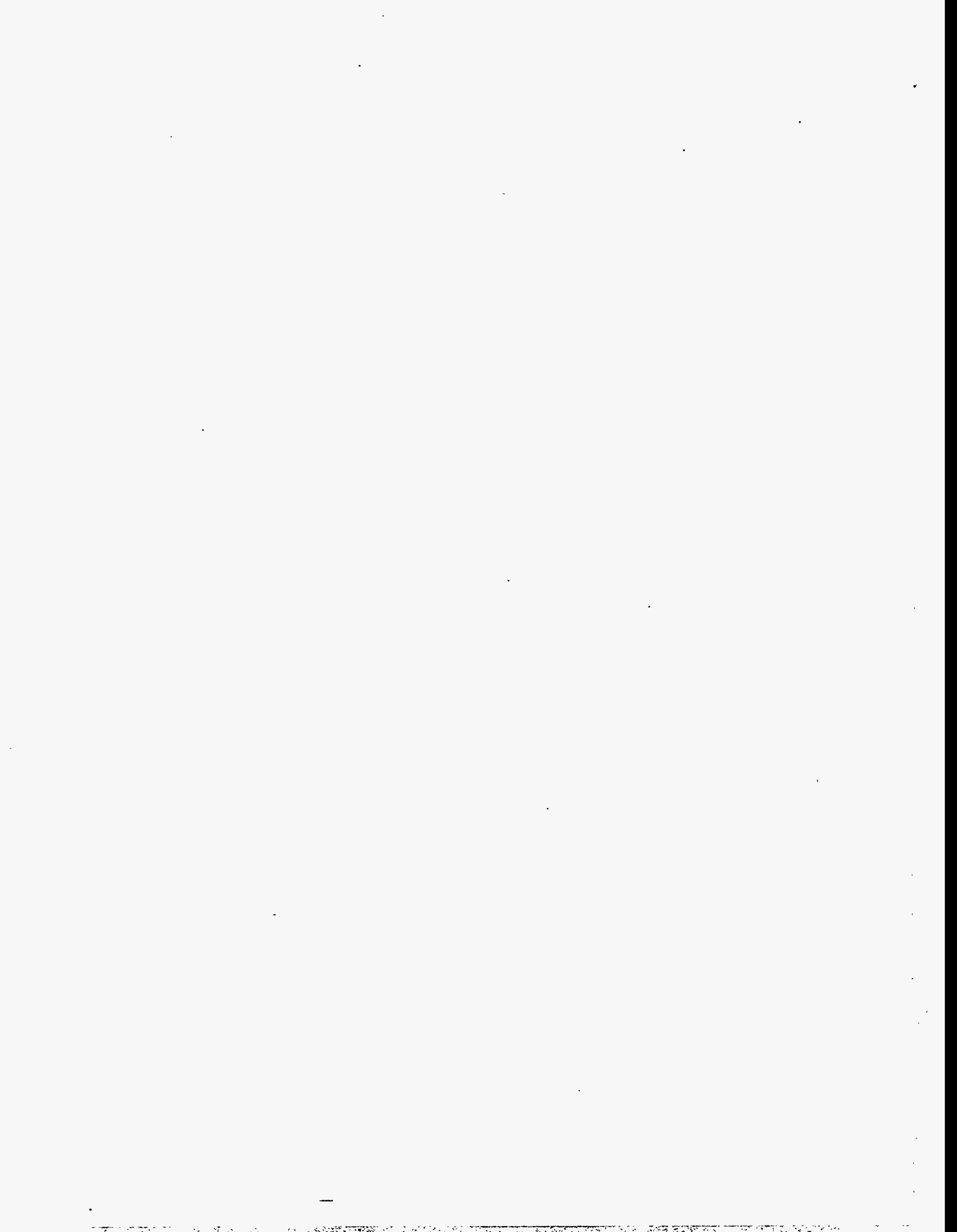
	FY94	FY95	FY96	FY97	FY98
	(\$M)	(\$M)	(\$M)	(\$M)	(\$M)
Budget authority	36	44	52	45	--
Budget outlay	27	42	50	47	11

- **Strategy**
 - complete HER first
 - study injection and high-current multibunch operation
 - then finish LER
 - study beam-beam collision issues



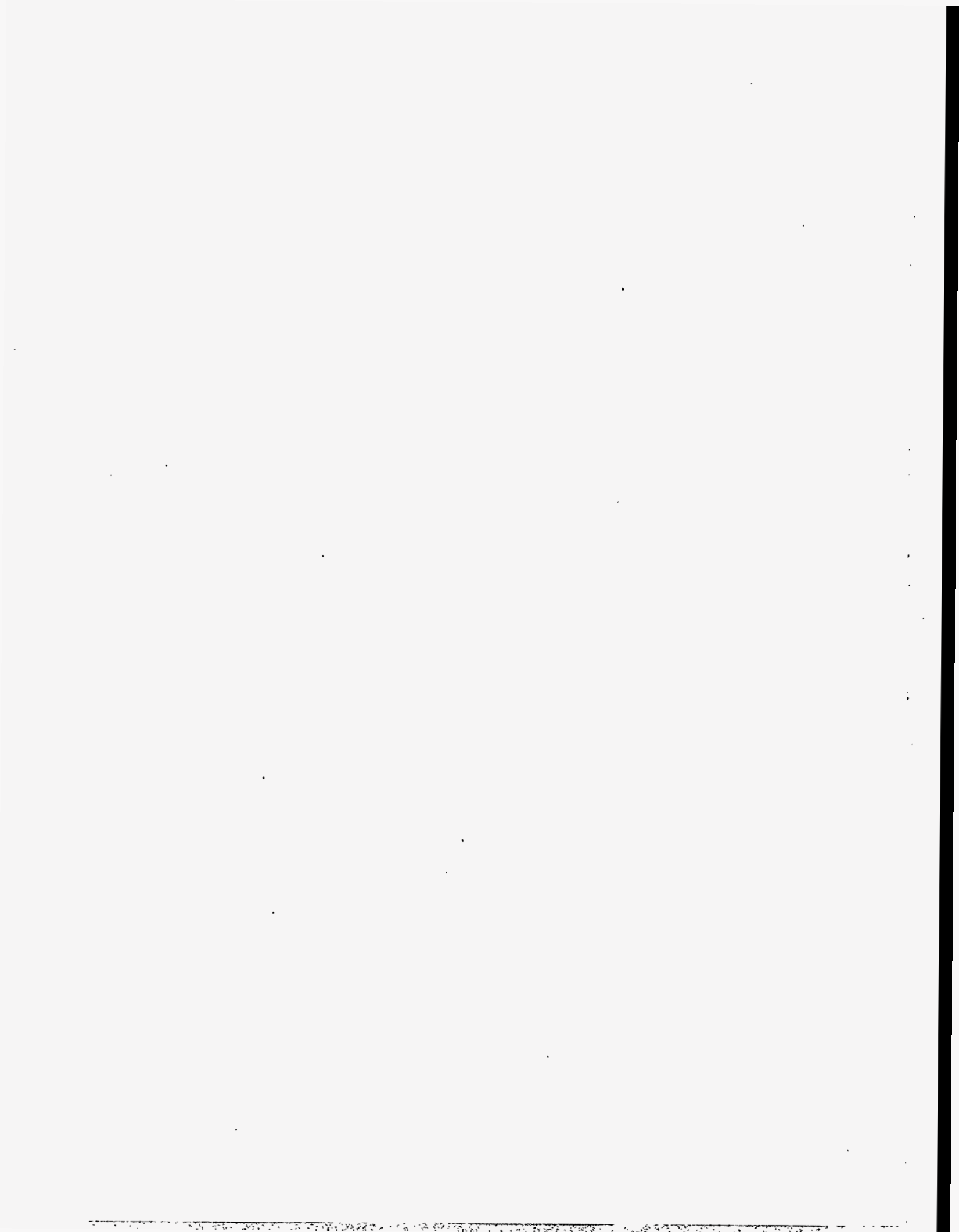
Summary

- **After 5 years of R&D, PEP-II project funded beginning FY94**
- **Project addresses a fundamental outstanding problem in HEP**
- **Considerable progress made**
 - **injection system mostly installed**
 - **HER components being installed**
 - **LER components in production**
 - **IR components in final design and prototyping**
- **PEP-II team is looking forward to continuing our phased commissioning process with HER in about one year!**



Gordon Ball

Chalk River Laboratories
Chalk River, Ontario, Canada



“PIONIC FUSION OF HEAVY IONS”

G.C. BALL

Presented At

Exotic Nuclei Symposium

Honoring The 60th Birthday Of Joseph Cerny

April 14-16, 1996

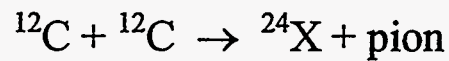
1. *Introduction*

- a) Subthreshold pion production in heavy ion collisions.

$$E_{\text{cm}} \leq 135A \text{ MeV}$$

- b) Coherent mechanisms at low E_{cm}

2. *Experiment—Pionic Fusion*

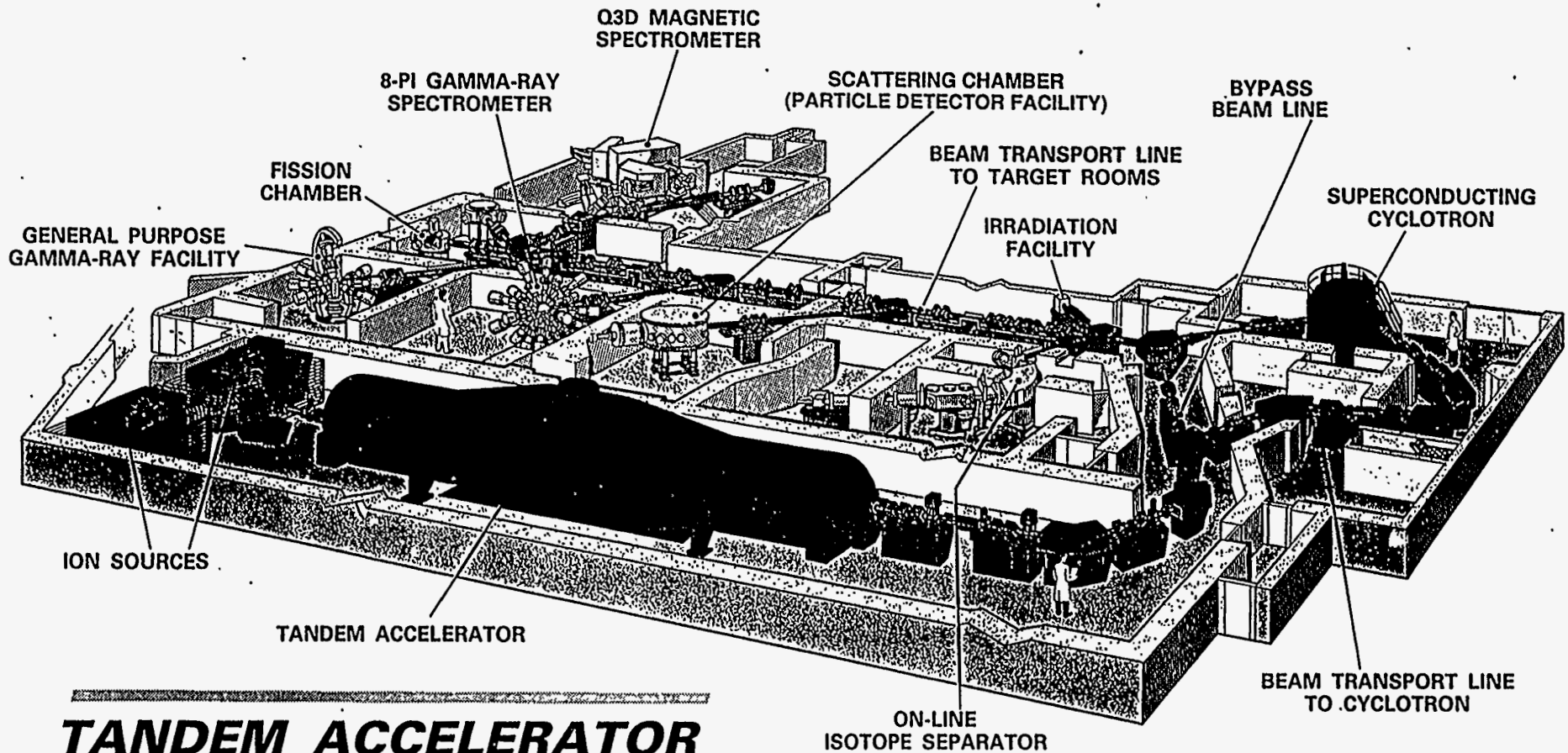


3. *Results*

4. *Summary*

Collaborators:

Chalk River		University Laval
G.C. Ball	A.C. Hayes	L. Beaulieu
D.R. Bowman	D. Horn	Y. Larochelle
W.G. Davies	G. Savard	C. St. Pierre
D. Fox		



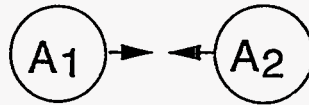
**TANDEM ACCELERATOR
SUPERCONDUCTING
CYCLOTRON (TASCC)**

Chalk River, Canada.



Pion Production in Heavy-ion Reactions

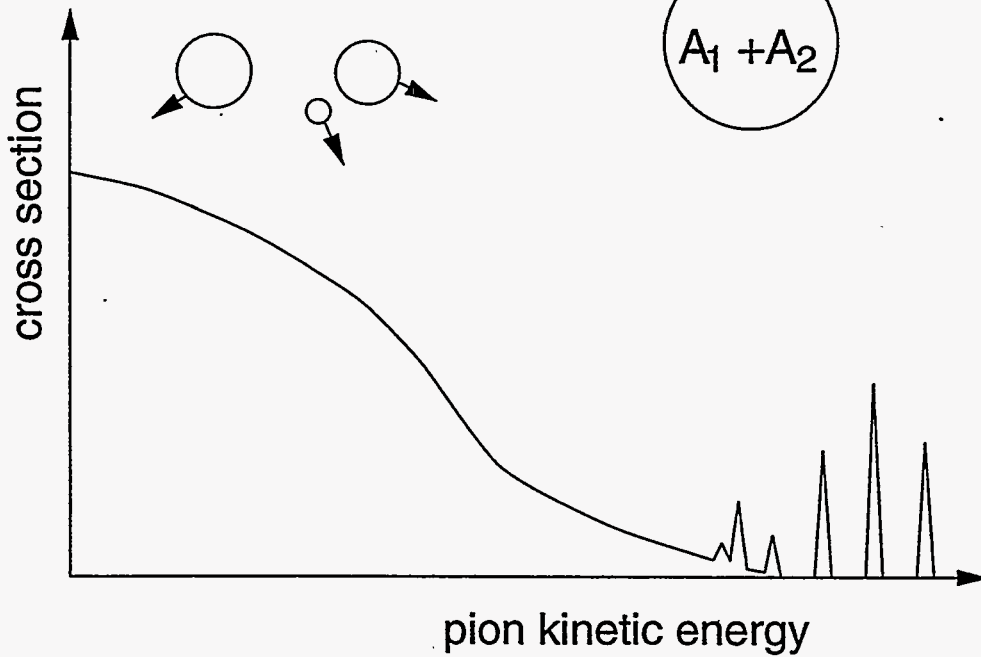
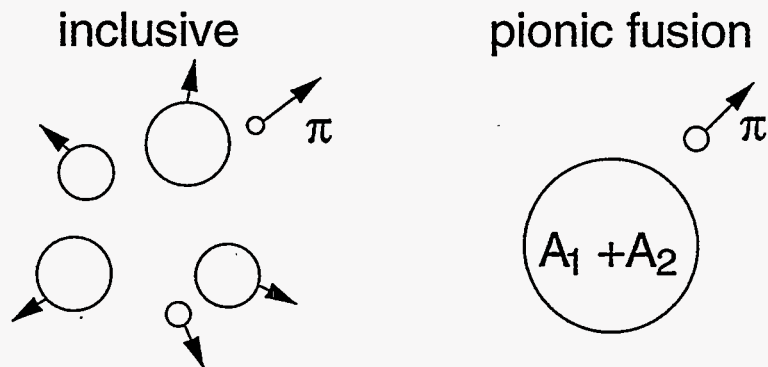
ENTRANCE CHANNEL:



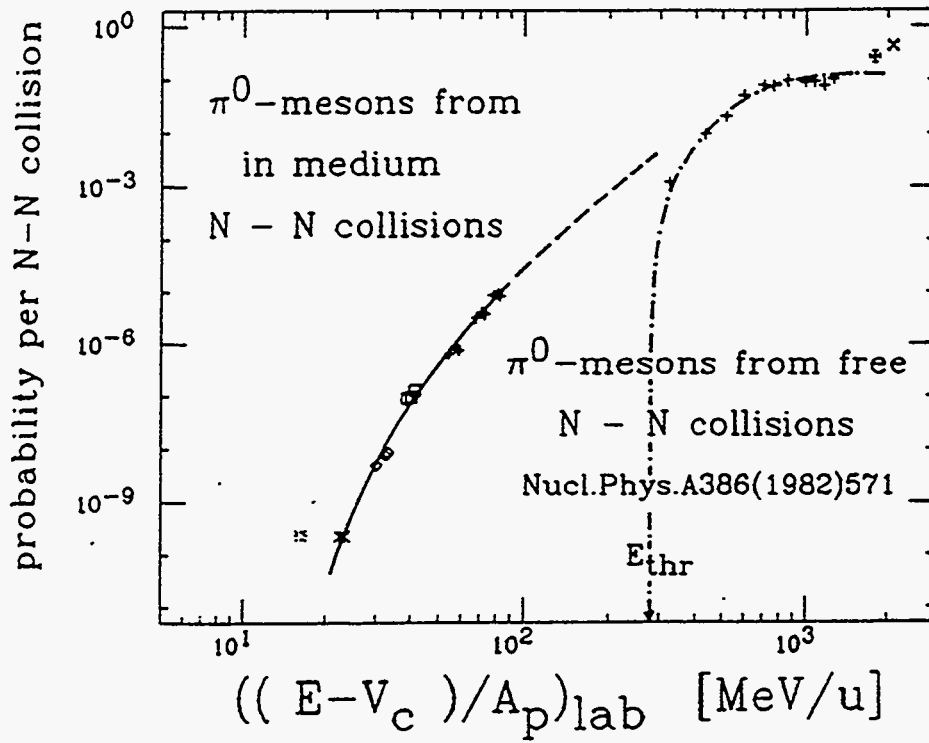
MECHANISM:



FINAL STATE:



W. Cassing et al., Production of energetic particles in heavy-ion collisions



“SUBTHRESHOLD PION PRODUCTION IN HEAVY-ION COLLISIONS”

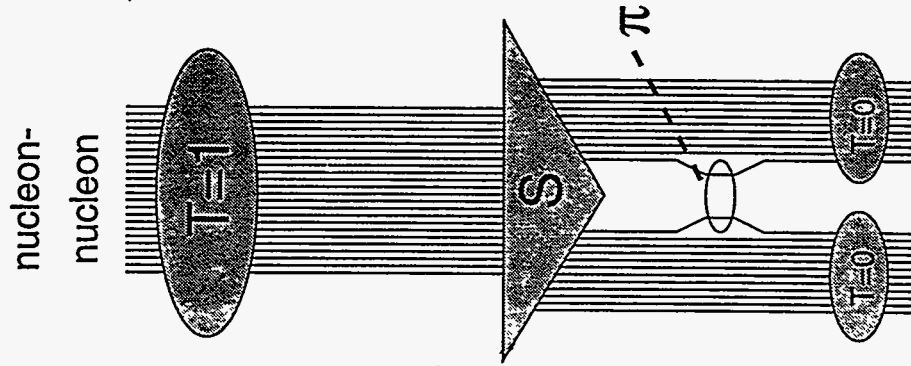
- Incoherent summation of nucleon-nucleon collisions

- “Coherent” models
 1. Pionic bremsstrahlung model

 2. Statistical or compound nucleus models
(—model of reaction dynamics to define source)

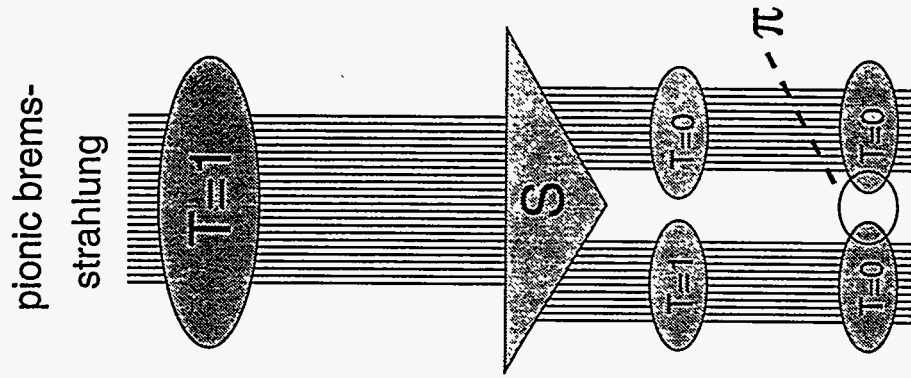
 3. Microscopic models

"SUBTHRESHOLD" PION PRODUCTION MECHANISMS

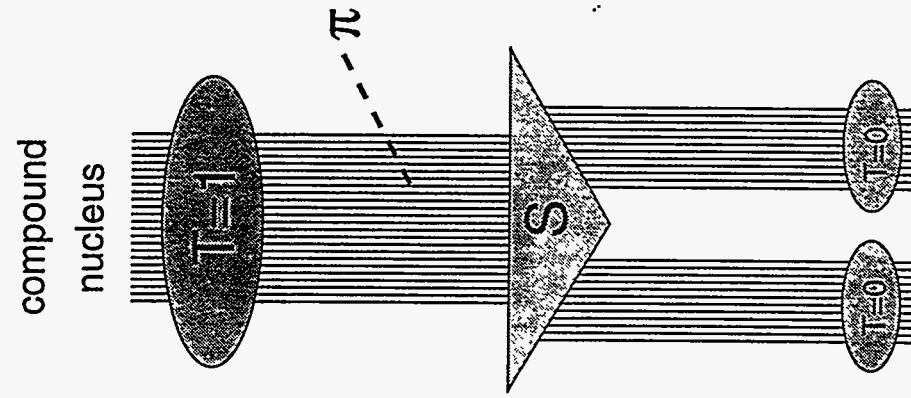


Cassing et al.

Bertsch



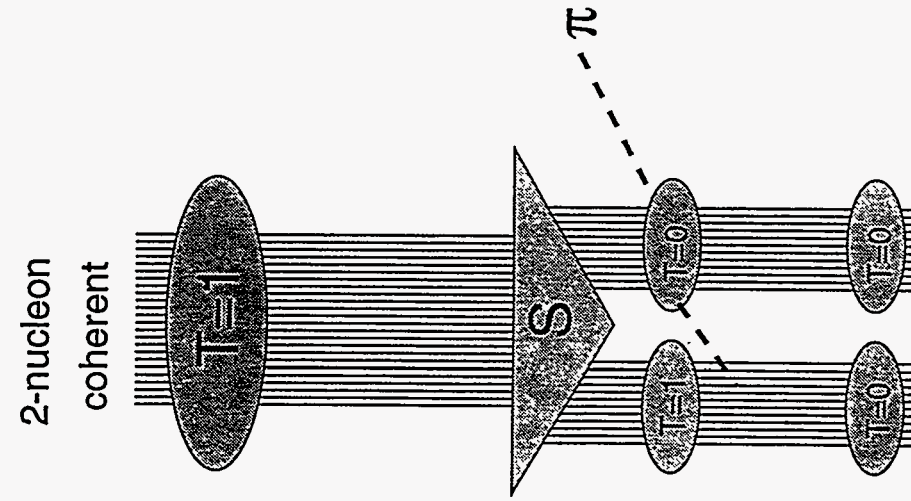
Vasak et al.



Aichelin-Bertsch

Prakash et al.

Potvin et al.



Huber et al.

Gibbs-Hayes

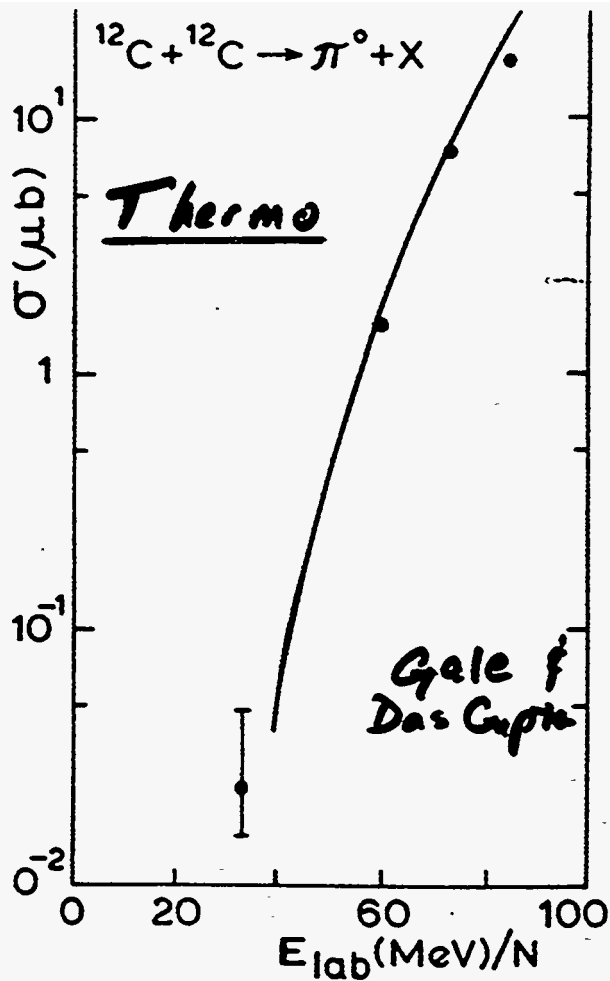


FIG. 1. Total inclusive π^0 cross section. The curve is our thermodynamic calculation. The parameters of the calculation are given in the text. The data are from Ref. 1.

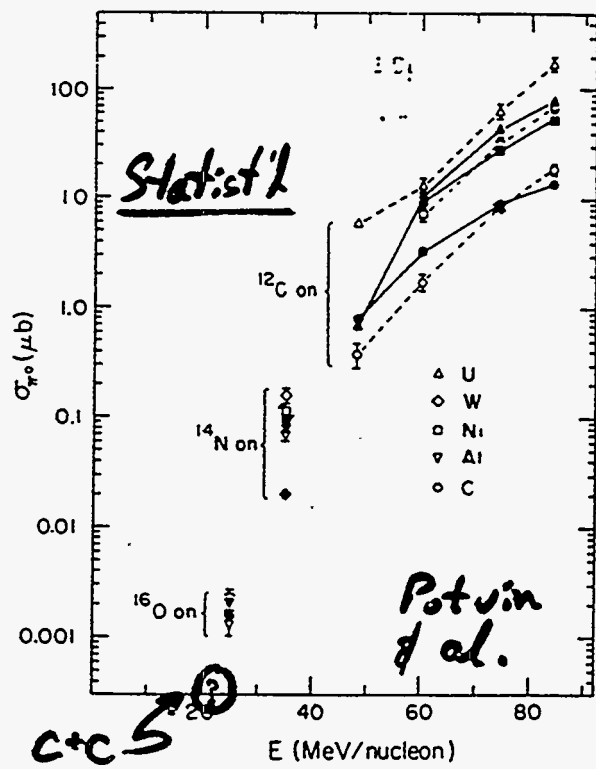


FIG. 1. Experimental and calculated σ_{π^0} total cross sections of ^{12}C , ^{14}N , and ^{16}O beams on different targets as a function of energy. The open symbols are used for the experimental data (Refs. 1 and 3) and the calculated yields are shown by solid symbols. In the case of ^{12}C beams, the values are linked by lines to guide the eye.

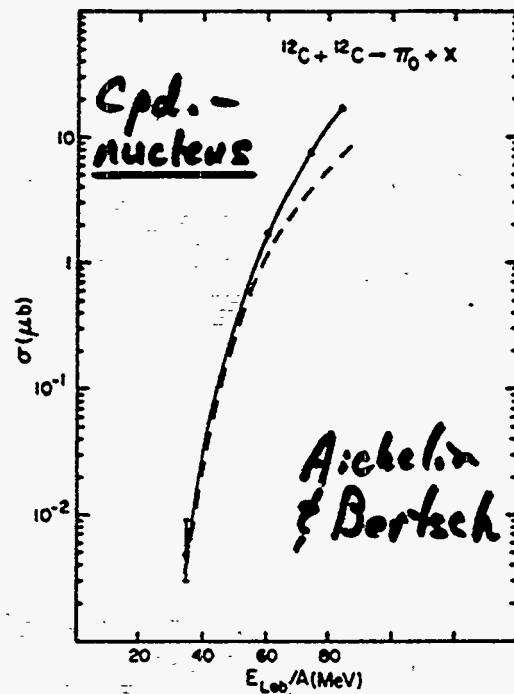
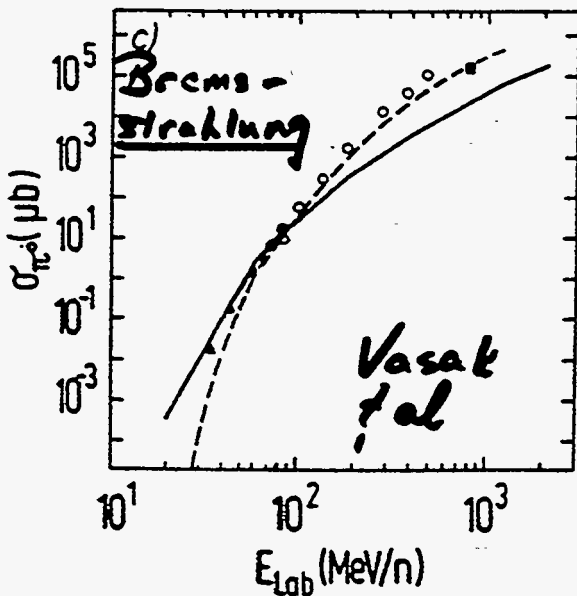


Fig. 1. Calculated total π_0 cross section and the data of ref. [1]. The point at 35 MeV/N is extracted from the reaction $^{14}\text{N} + ^{27}\text{Al} \rightarrow \pi_0 + X$ as explained in the text. The cross section for forming the compound system in the reaction $^{12}\text{C} + ^{12}\text{C}$, which finally emits a pion, is taken as $\sigma_0 = 160$ mb. The dotted line shows the cross section of pions emitted in the first step, the full line represents the sum over all steps

Pionic Fusion

- E_{cm} near absolute threshold limit

- *Previous data*

${}^3\text{He} ({}^3\text{He}, \pi^+) {}^6\text{Li}$ — Le Bornec *et al.* (1981)

${}^{12}\text{C} ({}^3\text{He}, {}^{15}\text{N})\pi^+$ — Homolka *et al.* (1988)

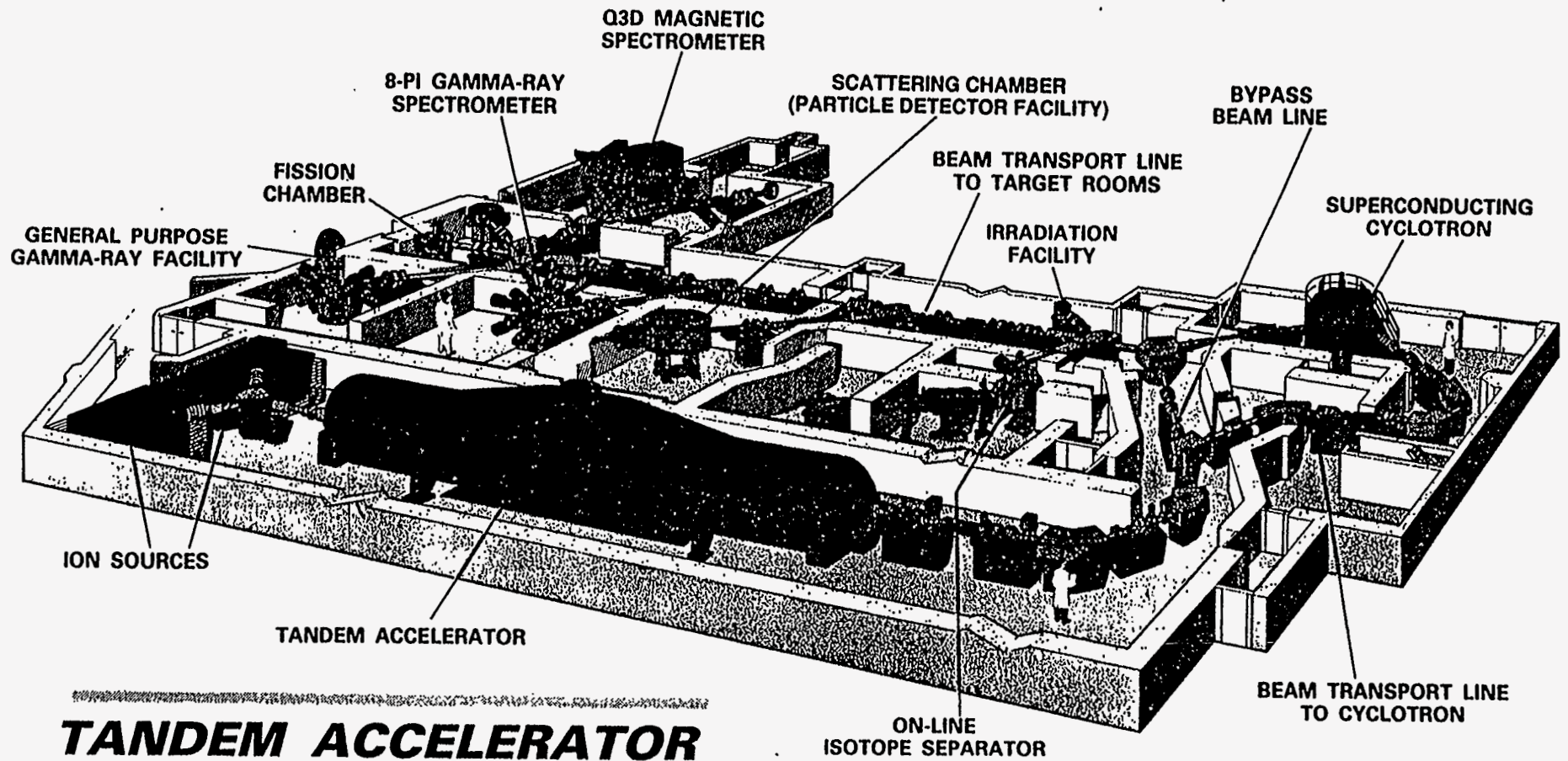
- *Present experiment*

${}^{12}\text{C} + {}^{12}\text{C} \rightarrow {}^{24}\text{X} + \text{pion}$

$E_{cm} \sim 137 \text{ MeV}$

σ (expected) $\sim .01 - 1.0 \text{ nb}$

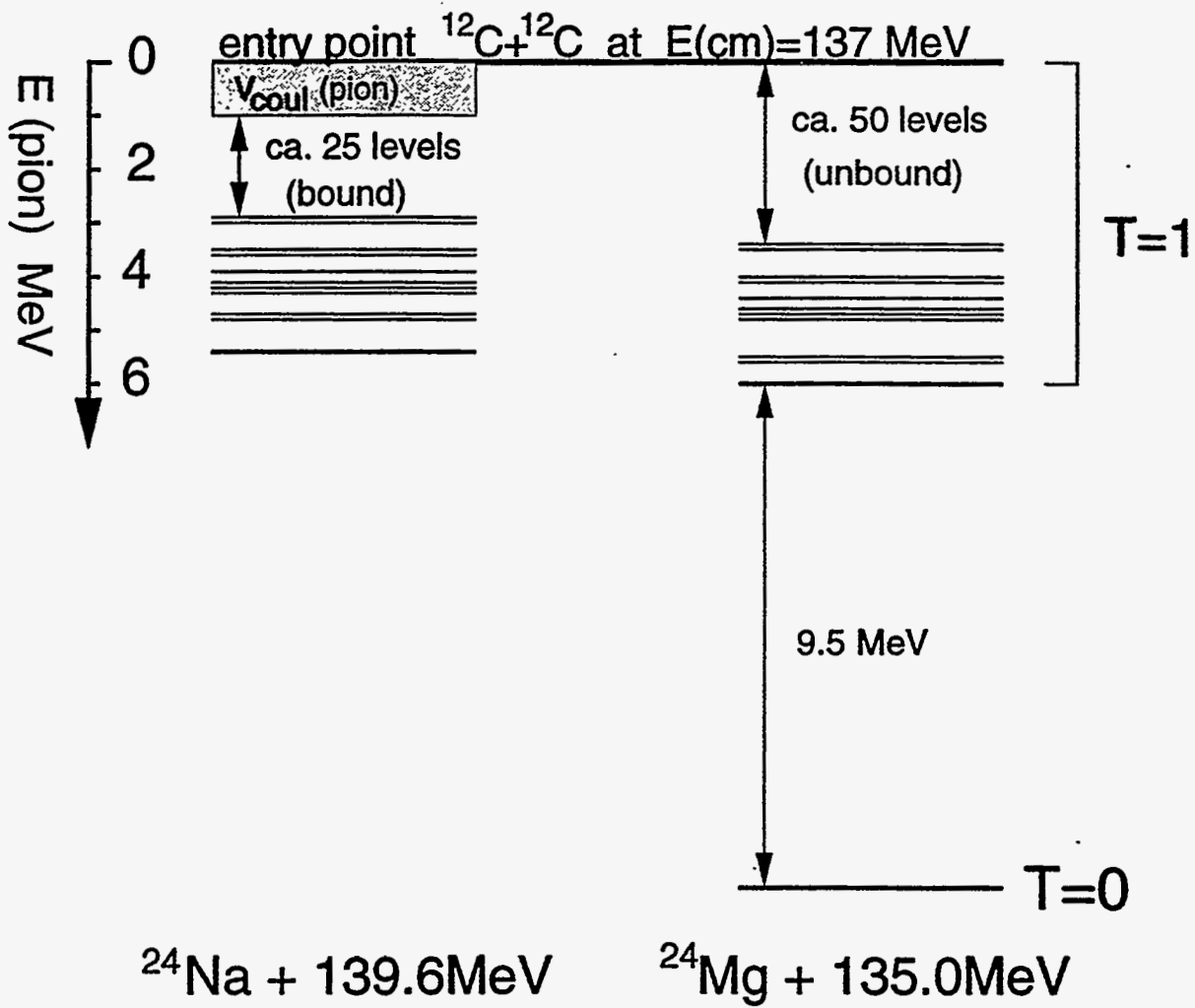
detect A=24 residues

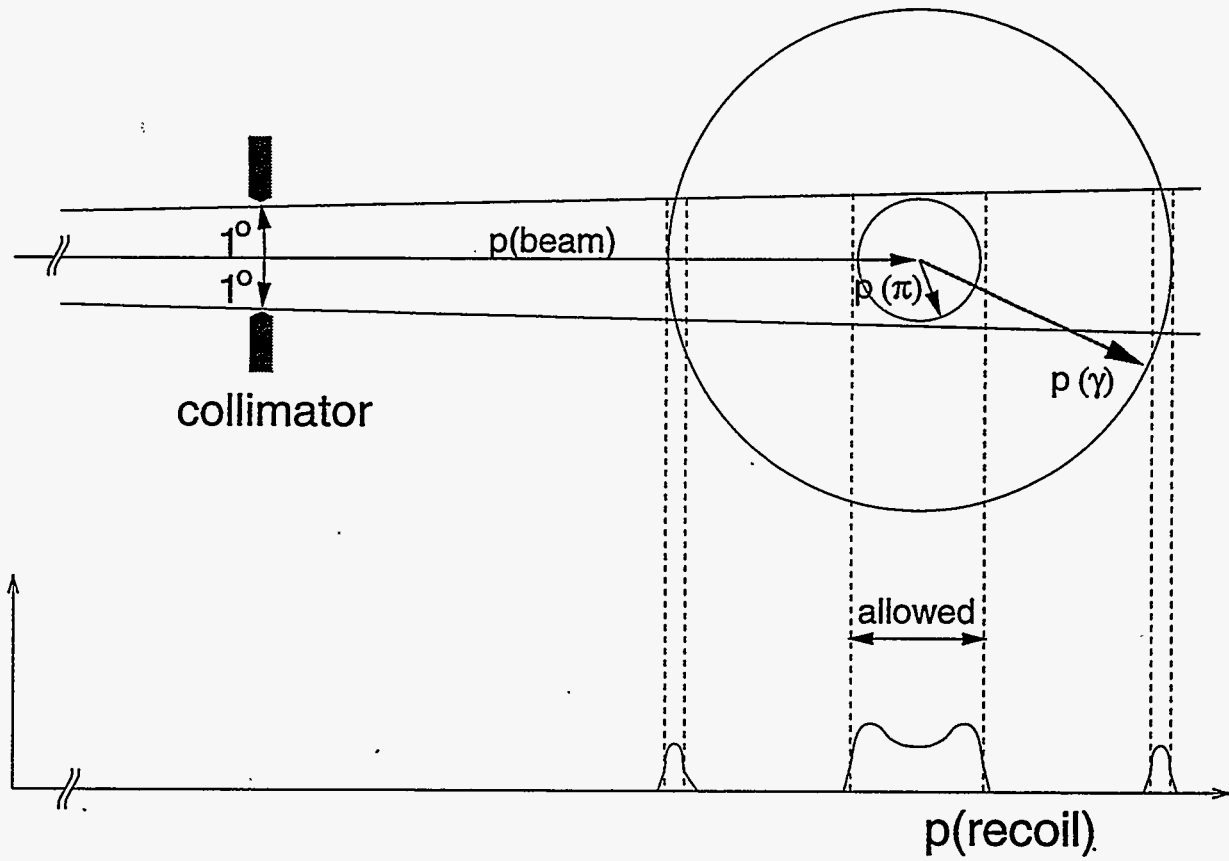


**TANDEM ACCELERATOR
SUPERCONDUCTING
CYCLOTRON (TASCC)**

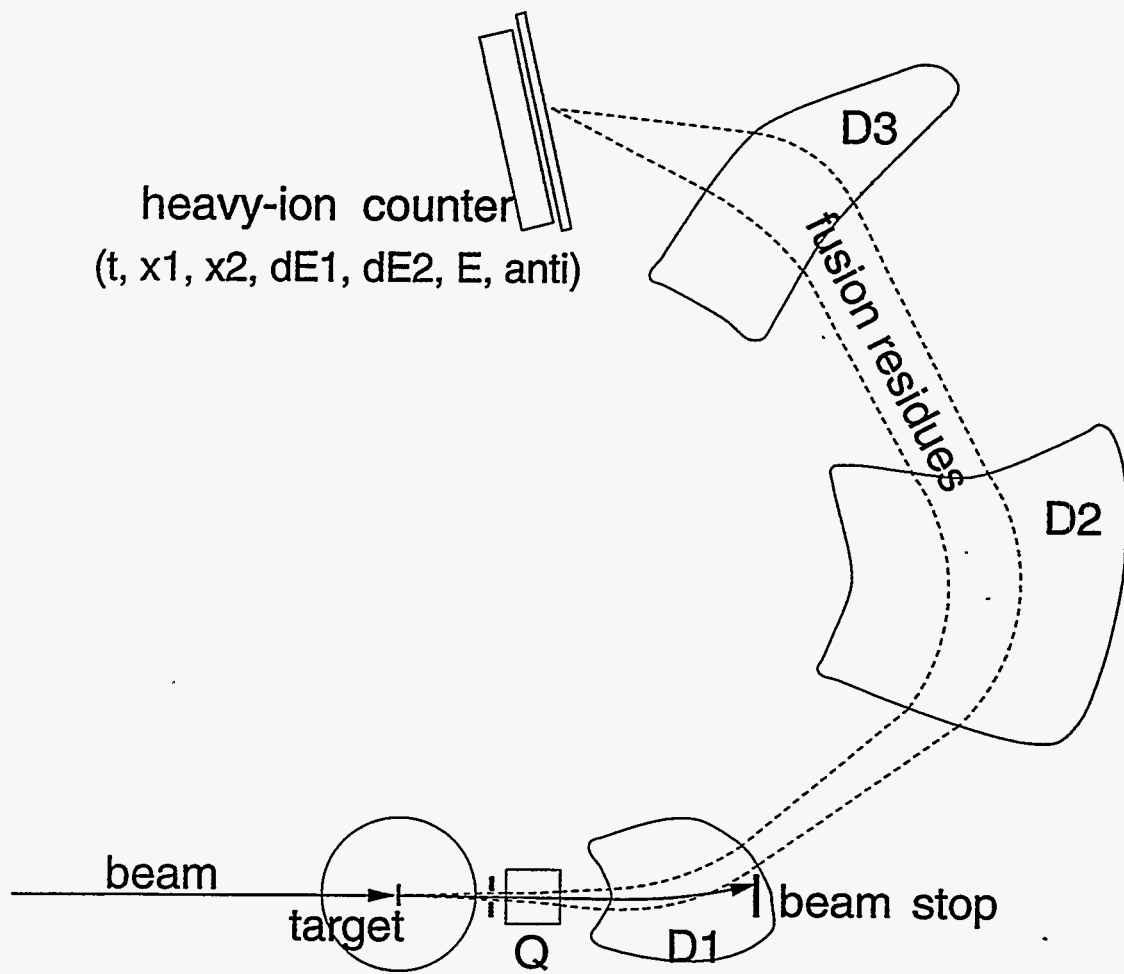
Chalk River, Canada



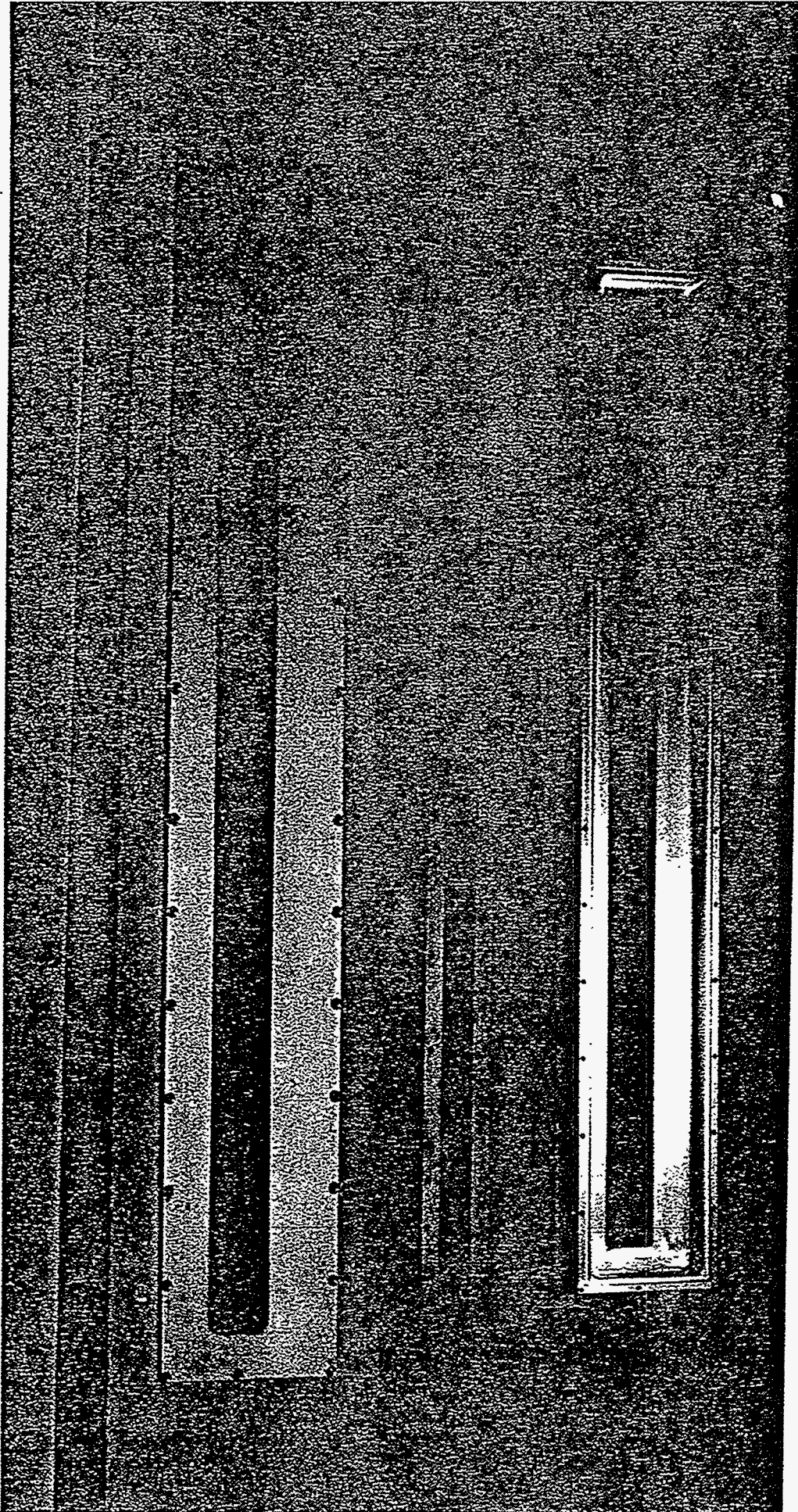




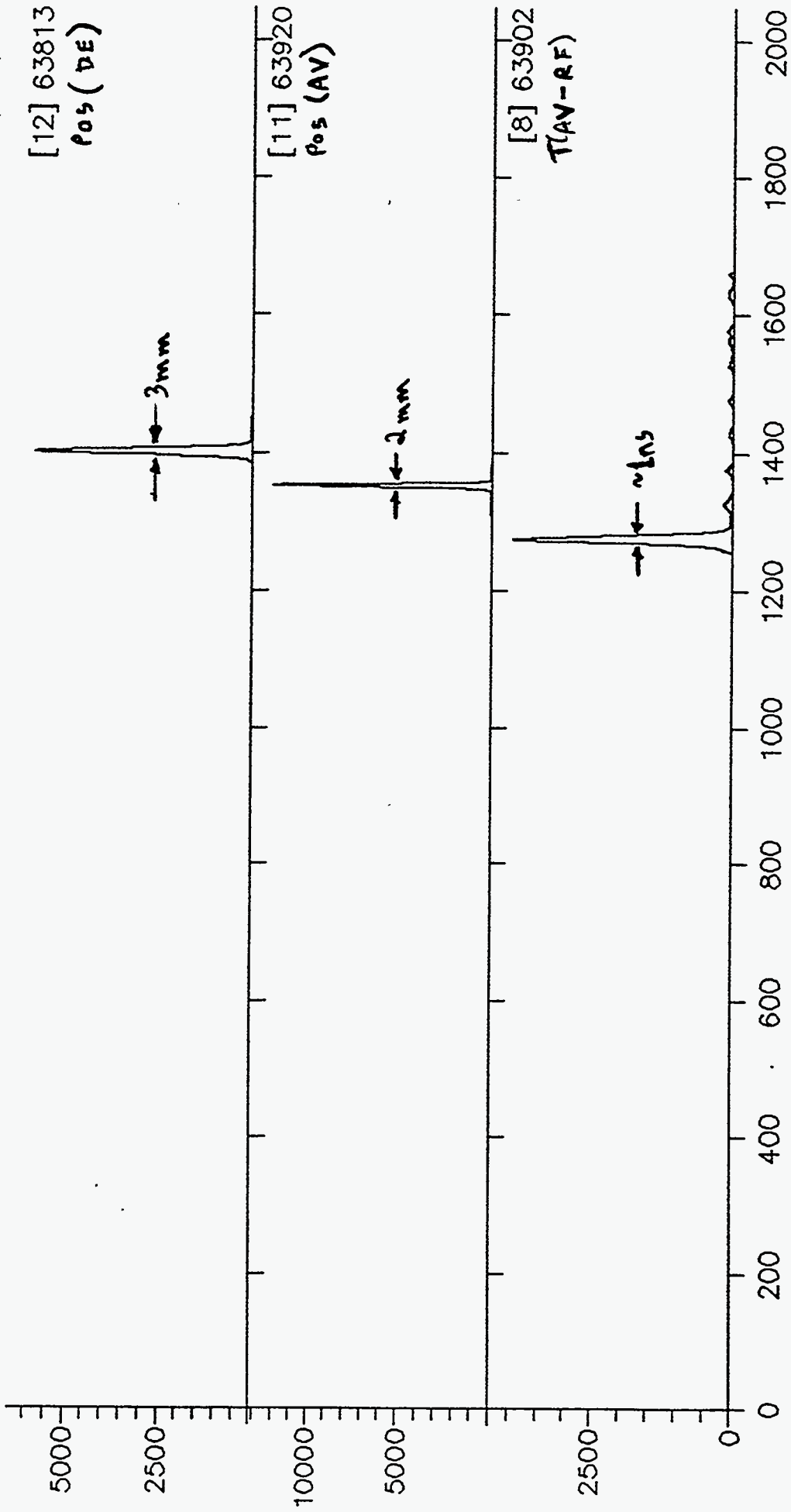
RECOIL KINEMATICS

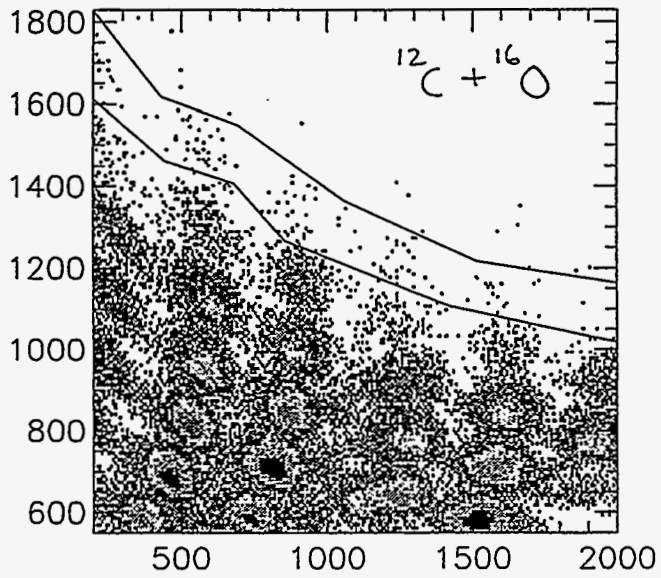


QDDD SPECTROMETER

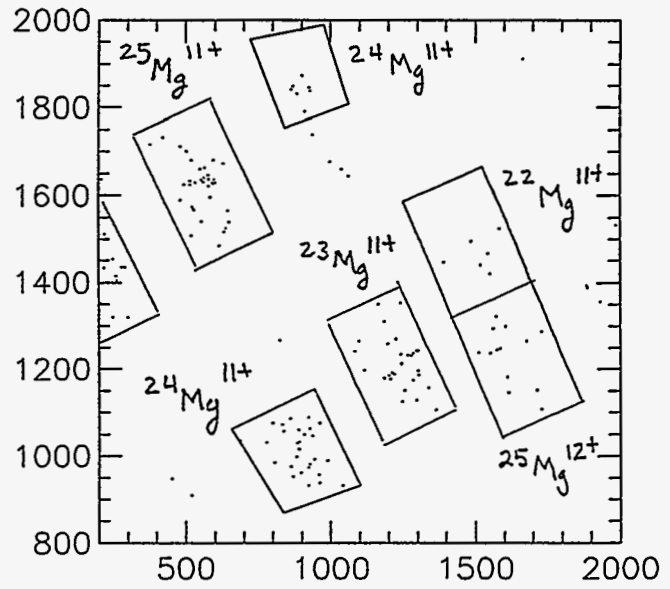


(21931 = 7

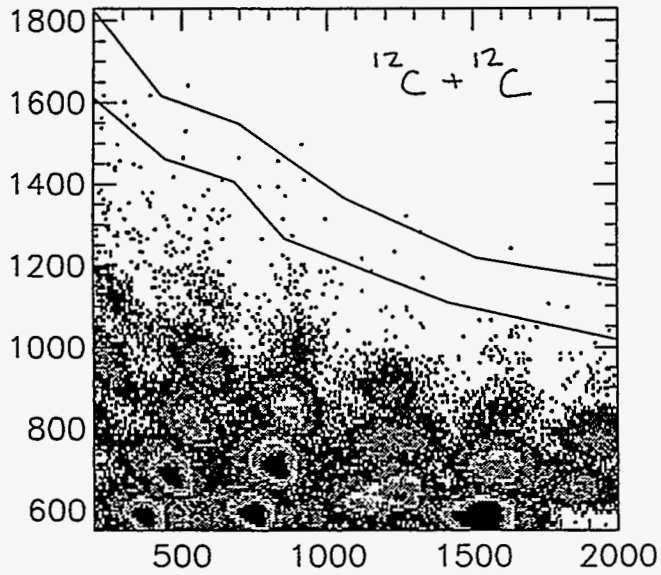




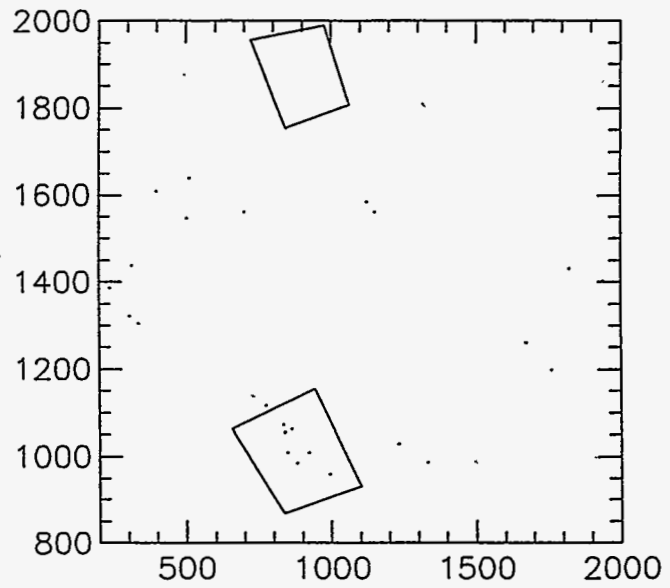
ΔE_2 vs E



RFAV VS E



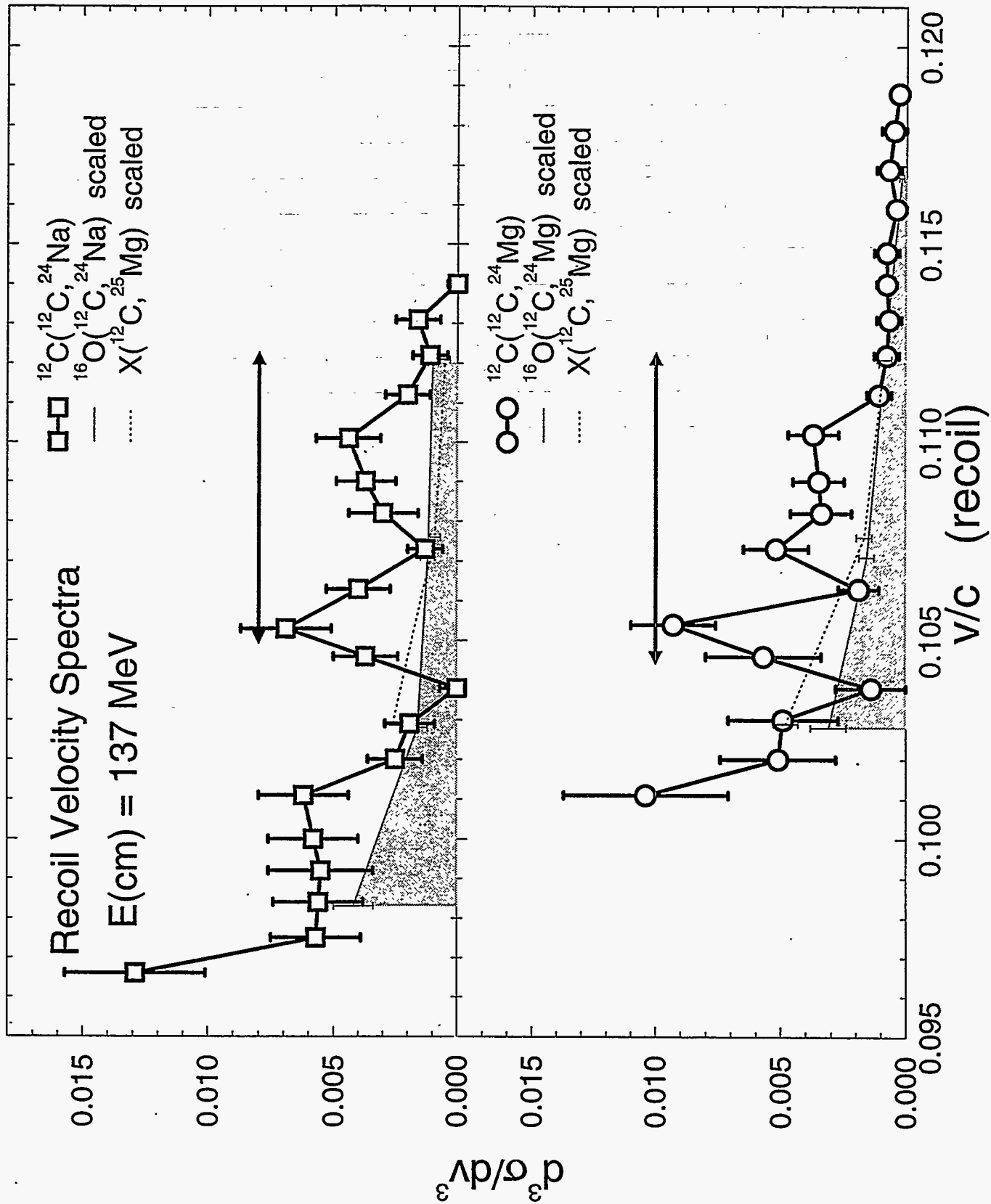
ΔE_2 vs E

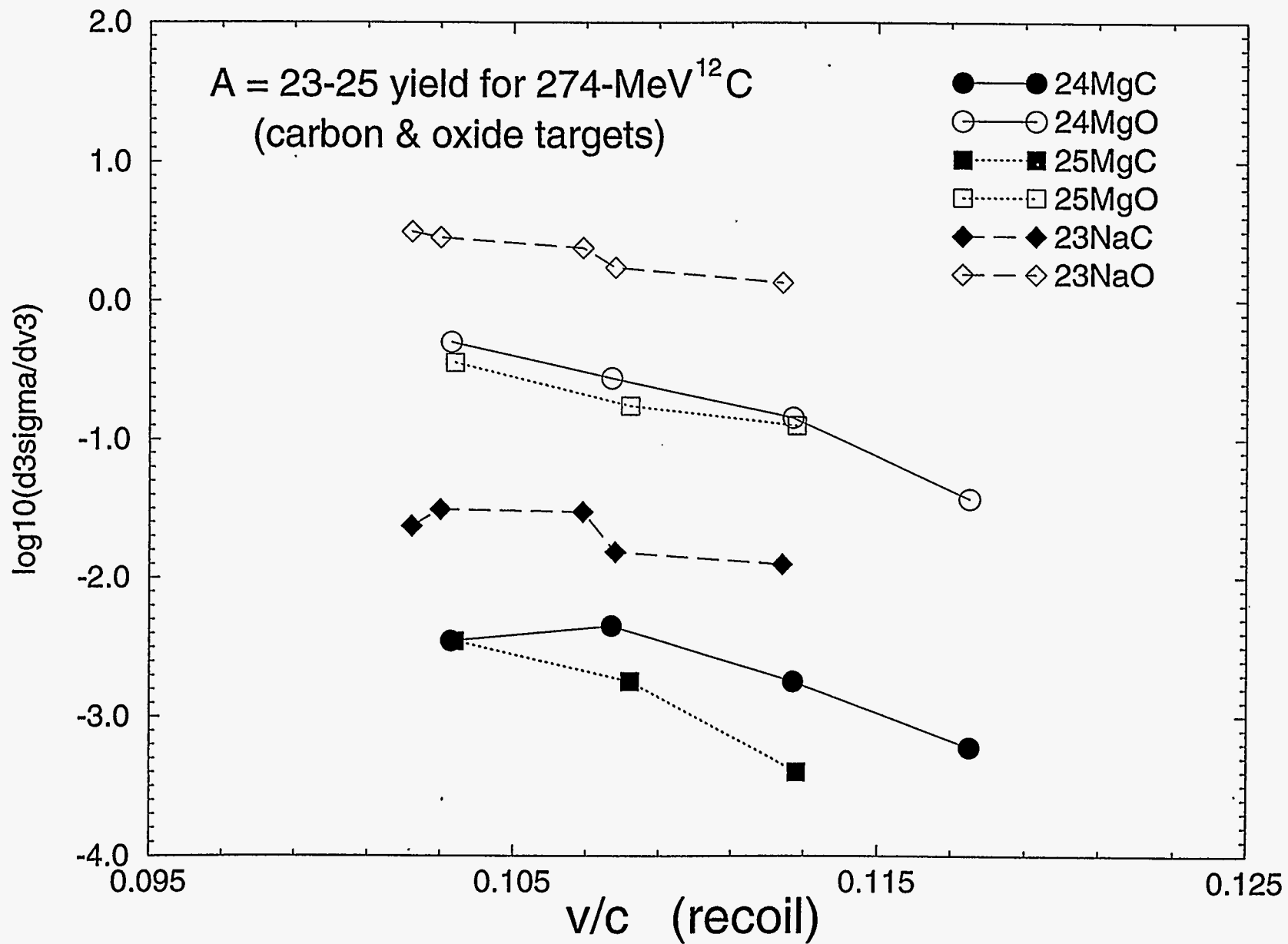


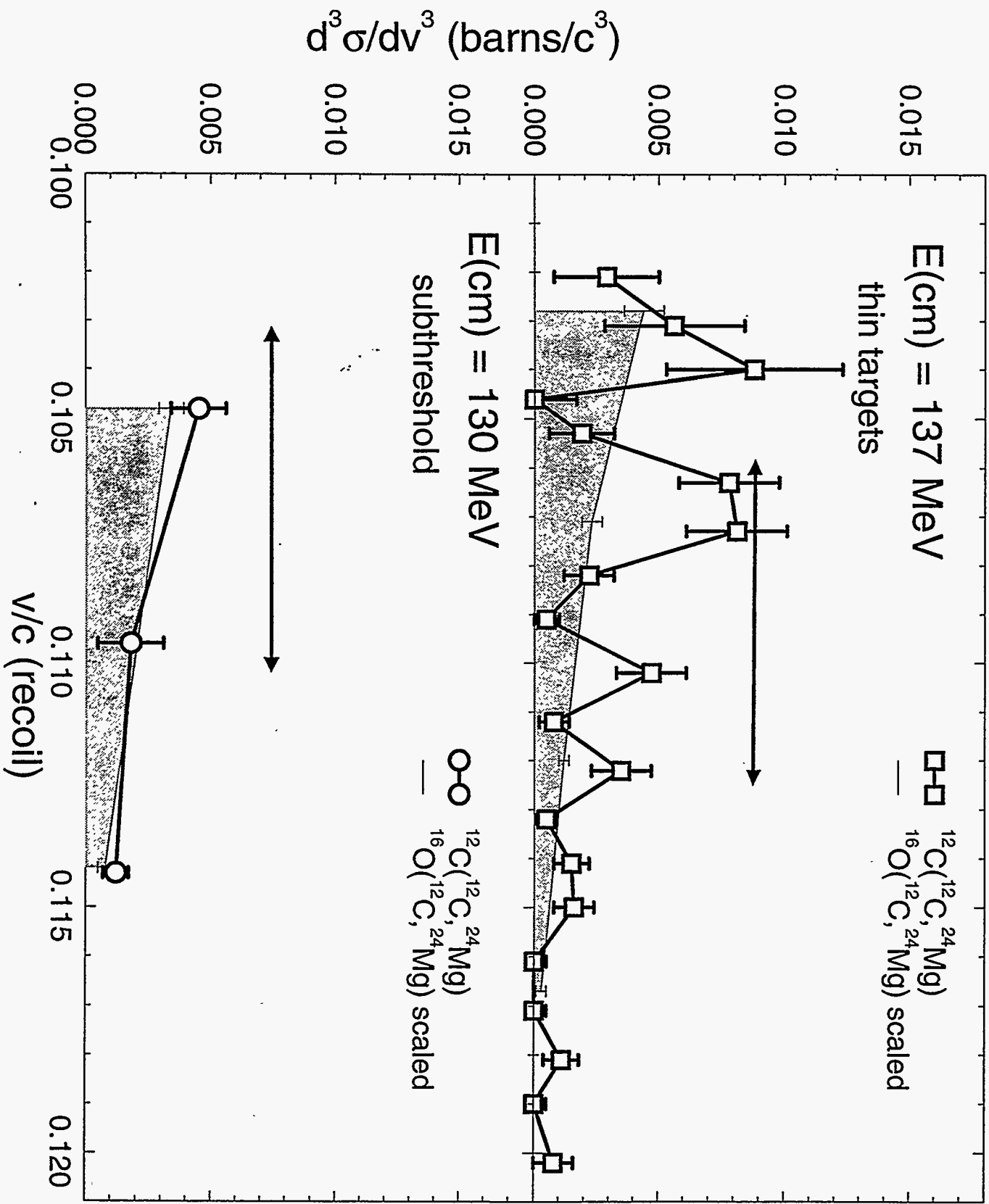
RFAV VS E

Experimental Difficulties

challenge	solution
low cross section	$I_{beam} \geq 200\text{nA}$ (charge)
target E loss	0.5mg/cm^2 ^{12}C
$B\rho$ calibration	^{24}Mg tandem beam
charge state fractions unknown	measure 62% 12^+ ; 33% 11^+
$\Delta p/p > 4.7\%$ (ctr limit)	measure at 4 field settings
scattered beam particles	tune; slits after 90° magnet; anti p/t
high-energy gamma decay	collimate to 1°
target impurities	isotopic target; vacuum oven; Ar transfer
knowing impurities	oxide run; assay target
pileup	fast multiple hit reject; TOF
ion ID	TOF



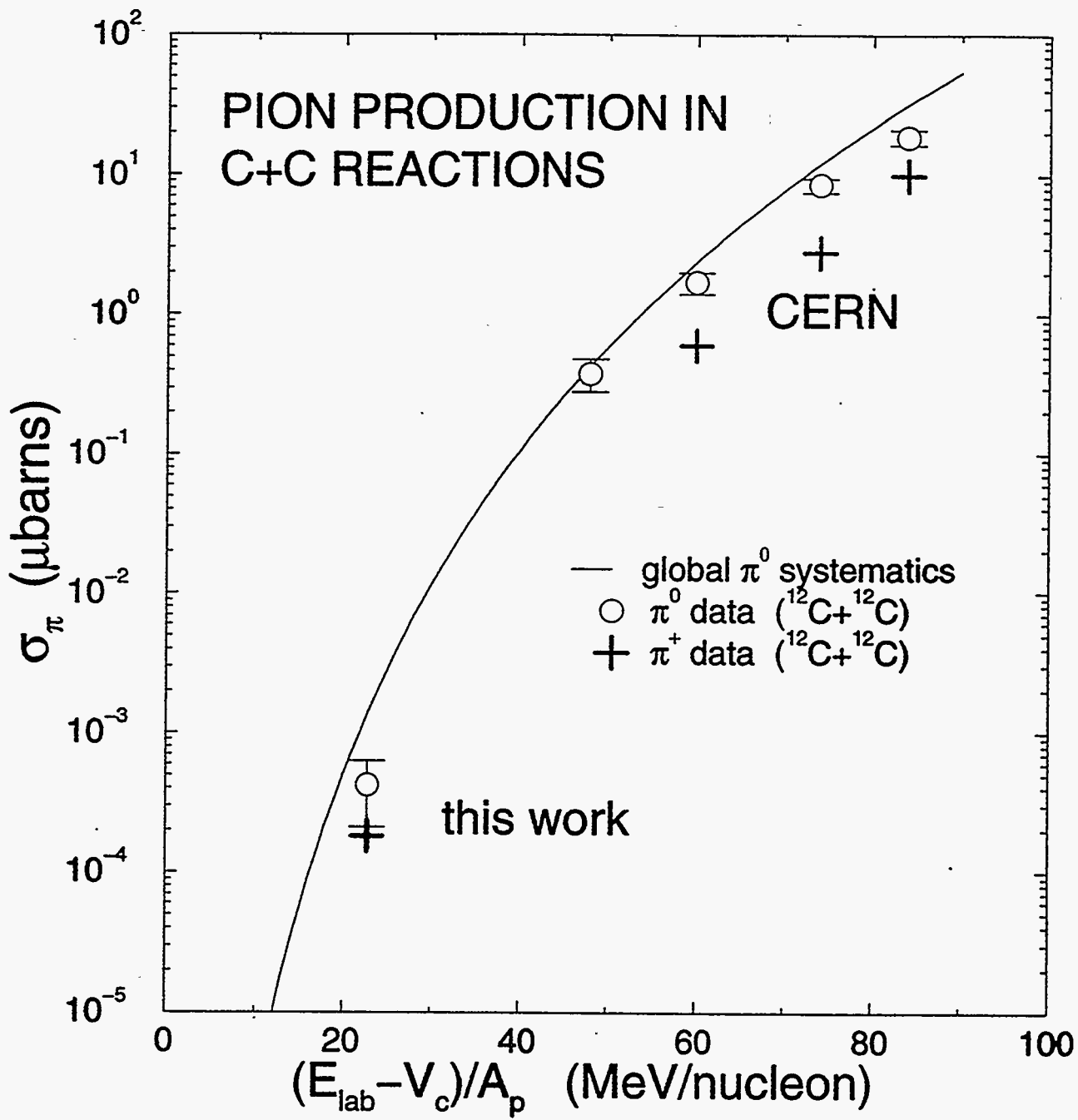




Measurement	Counts	σ_{gross} (pb)	σ_{bkgd} (pb)	σ_{net} (pb)
^{24}Mg (thick)	98	397(40)	166(25)	231(47)
^{24}Na (thick)	68	353(43)	126(22)	227(48)
^{24}Mg (thin)	58	329(43)	163(46)	166(63)
^{24}Mg (subthresh)	14	279(90)	220(62)	59(109)

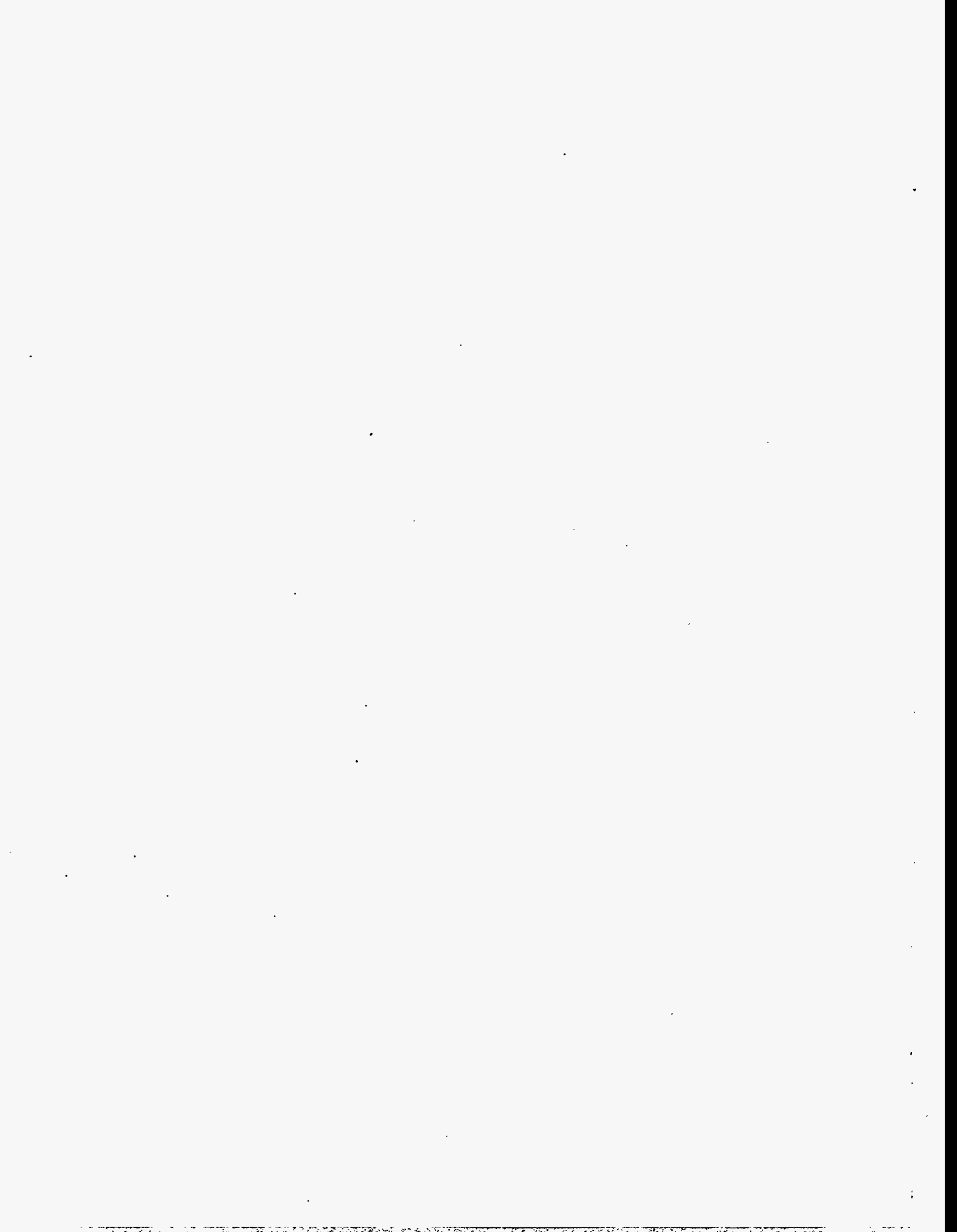
Theory

- $\sigma(^{24}\text{Mg} + \pi^0)/\sigma(^{24}\text{Na} + \pi^+) = 2.0$
- Estimate that \approx half the ^{24}Mg yield goes to unbound levels



Summary of Pionic Fusion Results

- We have measured the $^{12}\text{C}(^{12}\text{C},^{24}\text{Mg})\pi^0$ and $^{12}\text{C}(^{12}\text{C},^{24}\text{Na})\pi^+$ reactions at $E_{cm} = 137$ MeV.
- The ^{24}Na velocity spectrum in the “allowed” region displays the double-lobed structure characteristic of a forward-backward emission pattern.
- Backgrounds interpolated from “forbidden” velocity regions and from explicit background measurements account for approximately one-half the observed A=24 yield.
- The net ^{24}Mg yield, representing part of the total π^0 production cross section was 208 ± 38 picobarns.
- The net ^{24}Na yield, representing all of the π^+ production cross section was 182 ± 84 picobarns.
- Observation of pion production so near threshold places constraints on the mechanisms, requiring that they incorporate the kinetic energy of the entire 24-nucleon system as well as the binding energy gained in fusion.



Joseph Cerny

University of California
and
Lawrence Berkeley National Laboratory
Berkeley, CA

? The Very Poor Man's Beralac?

- Develop some radioactive beams at the 88" by producing radioactive nuclides at Budinger's

medical isotope cyclotron.

When: Bevatron floor

What type of cyclotron: 10-11 MeV H^- , 20-40 μA

Focus: light, short-lived gaseous isotopes

Transfer: By a long capillary to the 88" (trap unwanted activity at the cyclotron area)

Examples:

	$T_{1/2}$	Reaction	Q-value
^{11}C	20 min	$^{11}B(p,n)$	-2.8 MeV
^{13}N	10 min	$^{13}C(p,n)$	-3.0 MeV
^{18}F	1.8 hours	(they make this now)	

and there are more!

Nuclear Astrophysics

($^{14}\text{O} + ^4\text{He} \rightarrow ^{17}\text{F} + \text{p}$)

E. Norman, T. Wang

Reactions and Structure of Mirror Nuclei

($^{11}\text{C} + ^{11}\text{B}$ and $^{13}\text{N} + ^{13}\text{C}$)

J. Cerny, D. Moltz

Nuclear Physics at the Proton Drip Line

(e.g., studies of ^{11}N , ^{15}F)

F. Ajzenberg-Selove, H. Weller

Isospin Mixing in the GDR

($^{16}\text{O} + ^{12}\text{C}$, $^{15}\text{O} + ^{13}\text{C}$)

K. Snover

Spectroscopy of Proton-rich 1f-2p Nuclei

(e.g., $^{14}\text{O} + ^{40}\text{Ca} \rightarrow$)

J. Becker, P. Haustein, F. Stephens

Subbarrier Fusion and Transfer

($^{15,16}\text{O} + ^{143,144}\text{Nd}$)

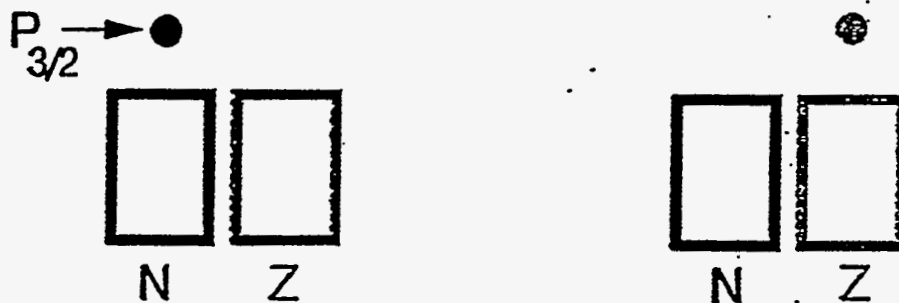
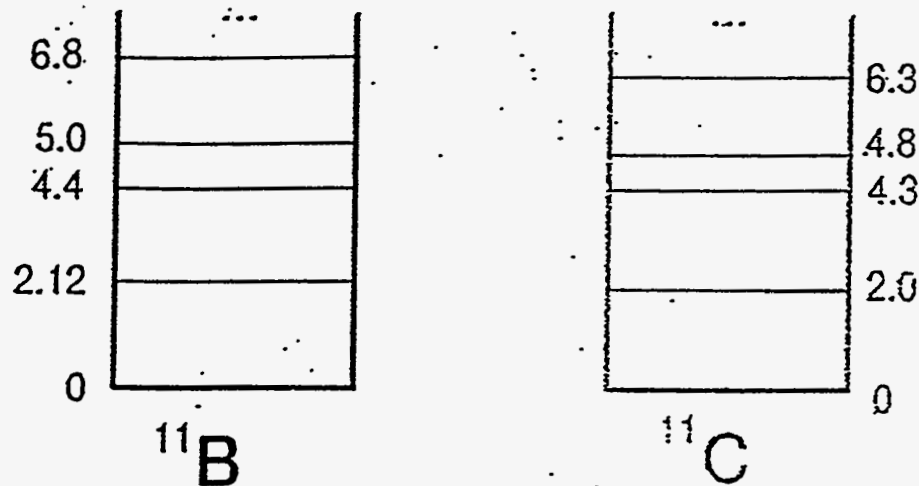
D. Di Gregorio, Y. Chan, R. Stokstad

Mass Measurements of Nuclei Five Neutrons from Stability

(e.g., the (^{10}C , ^{15}C) Reaction)

J. Cerny, D. Moltz

Charge Exchange in Elastic Scatt. of Mirror Nuclei (Inelastic)



Resonant Charge Exchange Effects between Mirror Nuclei
M.A. Nagarajan and J.P. Vary (1984)

{ Mean Field } and Charge Exchange Amplitudes both
Direct contribute to elastic scattering

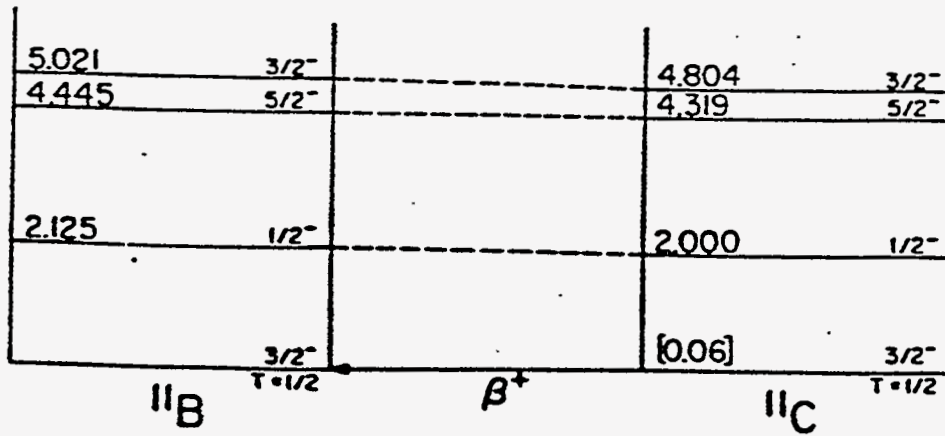
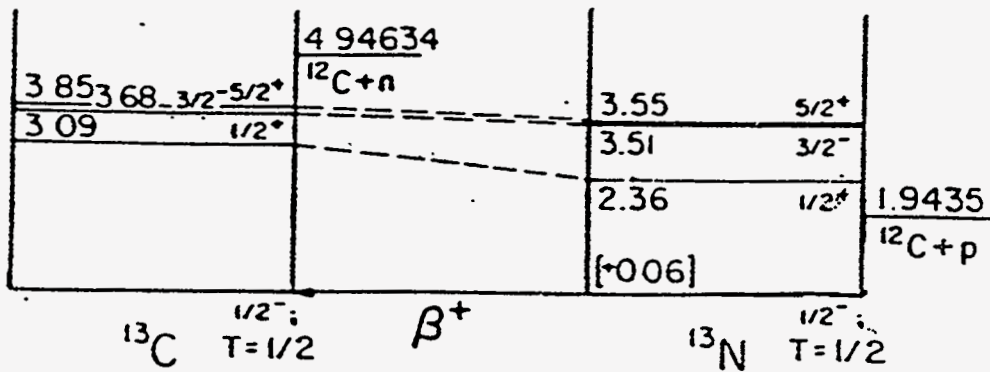
$Q=0$ cross sections large near Coulomb Barrier

Cores (^{10}B) are identical, so calculation is simple(r)

{ Coupled Channel formalism } are in hand
Microscopic Wave Functions
Optical potentials

Goal : new knowledge of g.s. wave functions

Figure xx. Low-lying level structure of the A = 11, 13 $T_z = \pm 1/2$ mirror nuclei.



^{11}C Production Yields

Helium Jet Targets

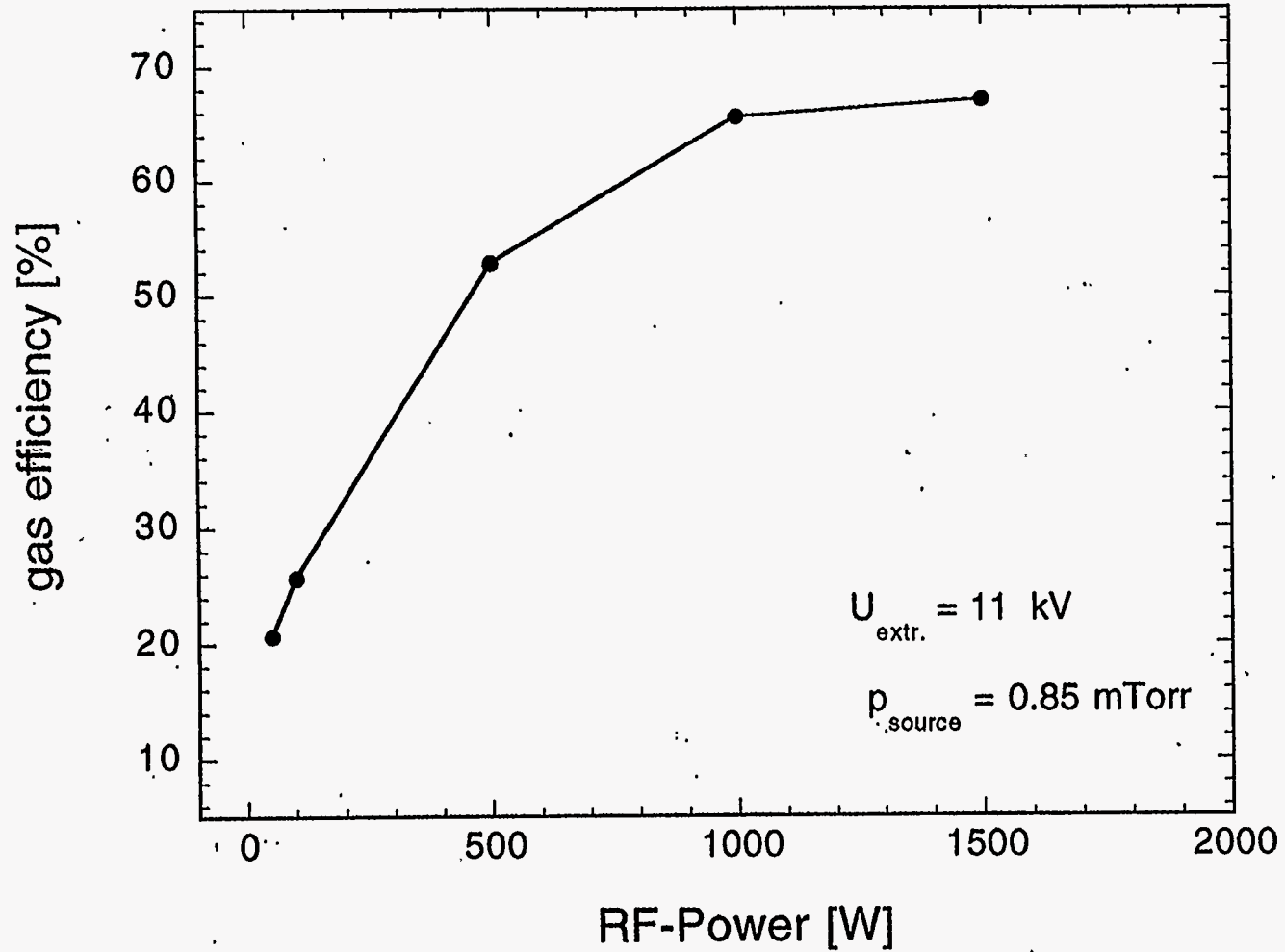
$20 \times 220 \mu\text{g}/\text{cm}^2$

Production	$1.4 \times 10^9 \text{ sec}^{-1}$
Target Efficiency	50 %
Initial Rate	$7 \times 10^8 \text{ sec}^{-1}$
Transit Time (200 m)	~ 30 sec
Yield for 20 min Activity	$7 \times 10^8 \text{ sec}^{-1}$
Skimmer Efficiency	50 %
Yield into ECR	$3.5 \times 10^8 \text{ sec}^{-1}$
Yield out of ECR (~ 1 %)	$3.5 \times 10^6 \text{ sec}^{-1}$
Cyclotron Efficiency (~ 30 %)	$1.2 \times 10^6 \text{ sec}^{-1}$
Optics (80 %)	$1 \times 10^6 \text{ sec}^{-1}$

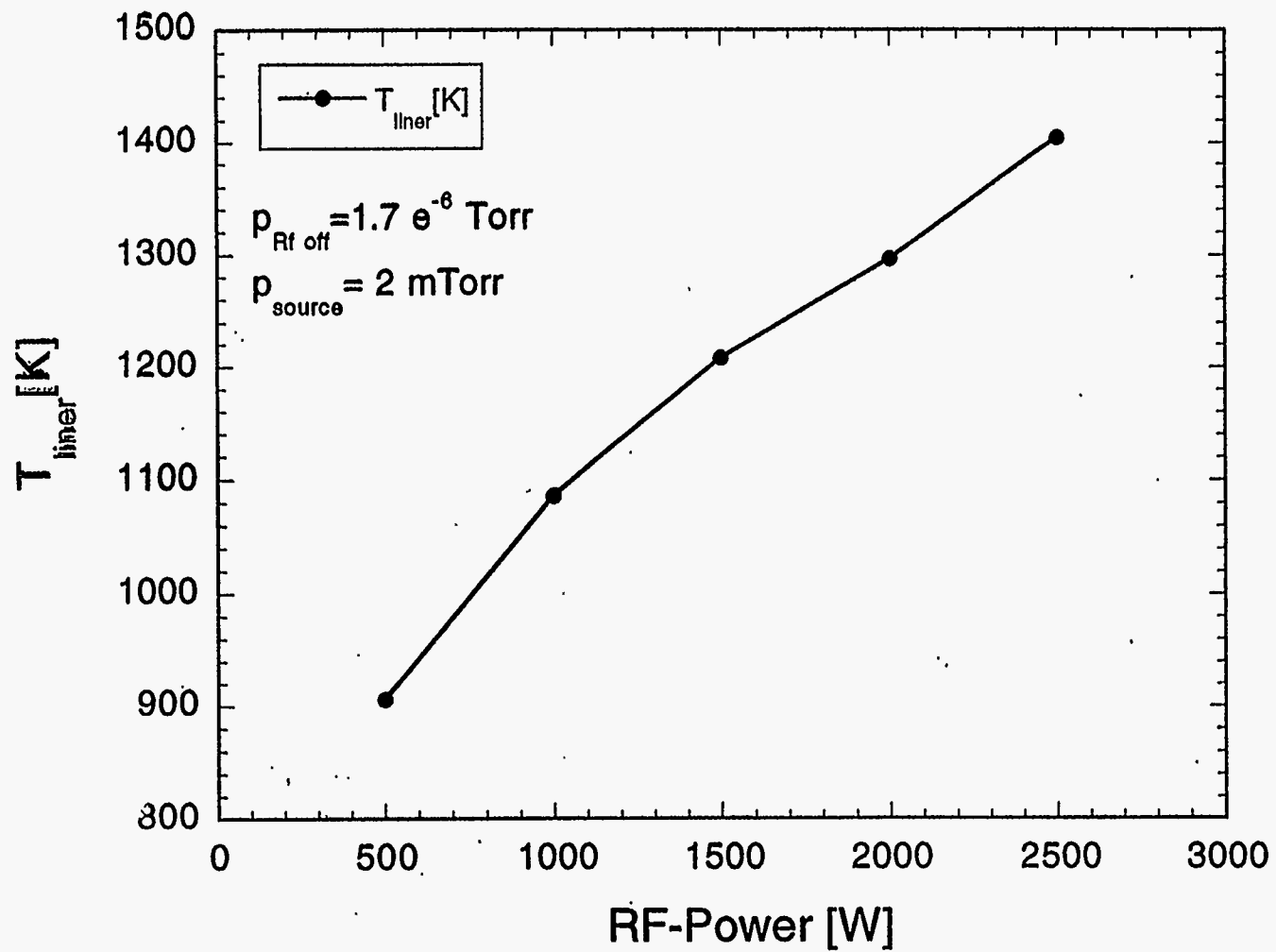
Outlook

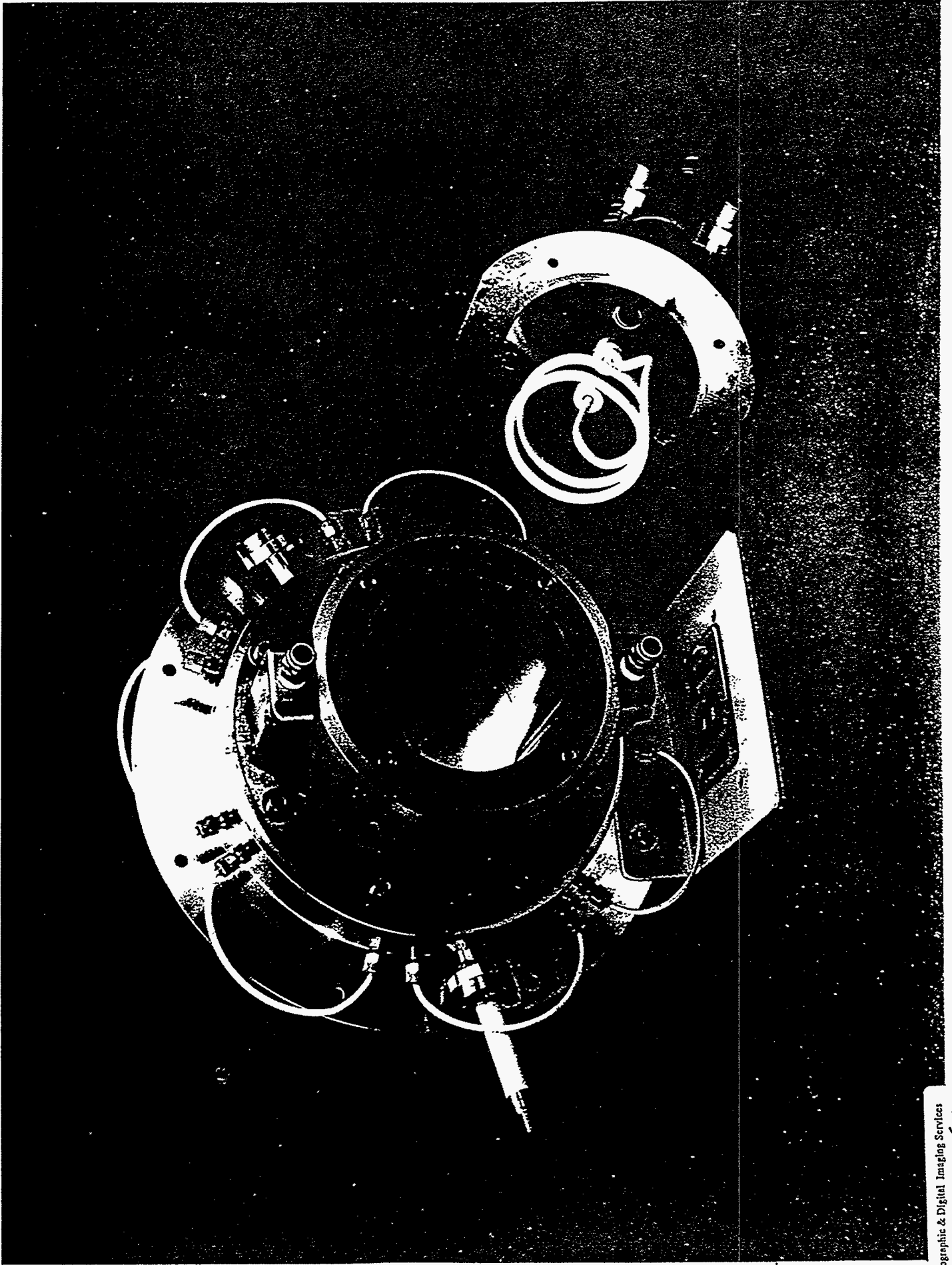
- Beam intensities of $10^6 - 10^8$ /s are adequate for many experiments.
- Selective exciting experiments in nuclear astrophysics.
- A wide-open field in Nuclear Reactions and Spectroscopy
with
highly exothermic Q -values (at least relatively)
and
transfers of unusual spin and isospin

**gas efficiency Argon
vs.
RF Power**



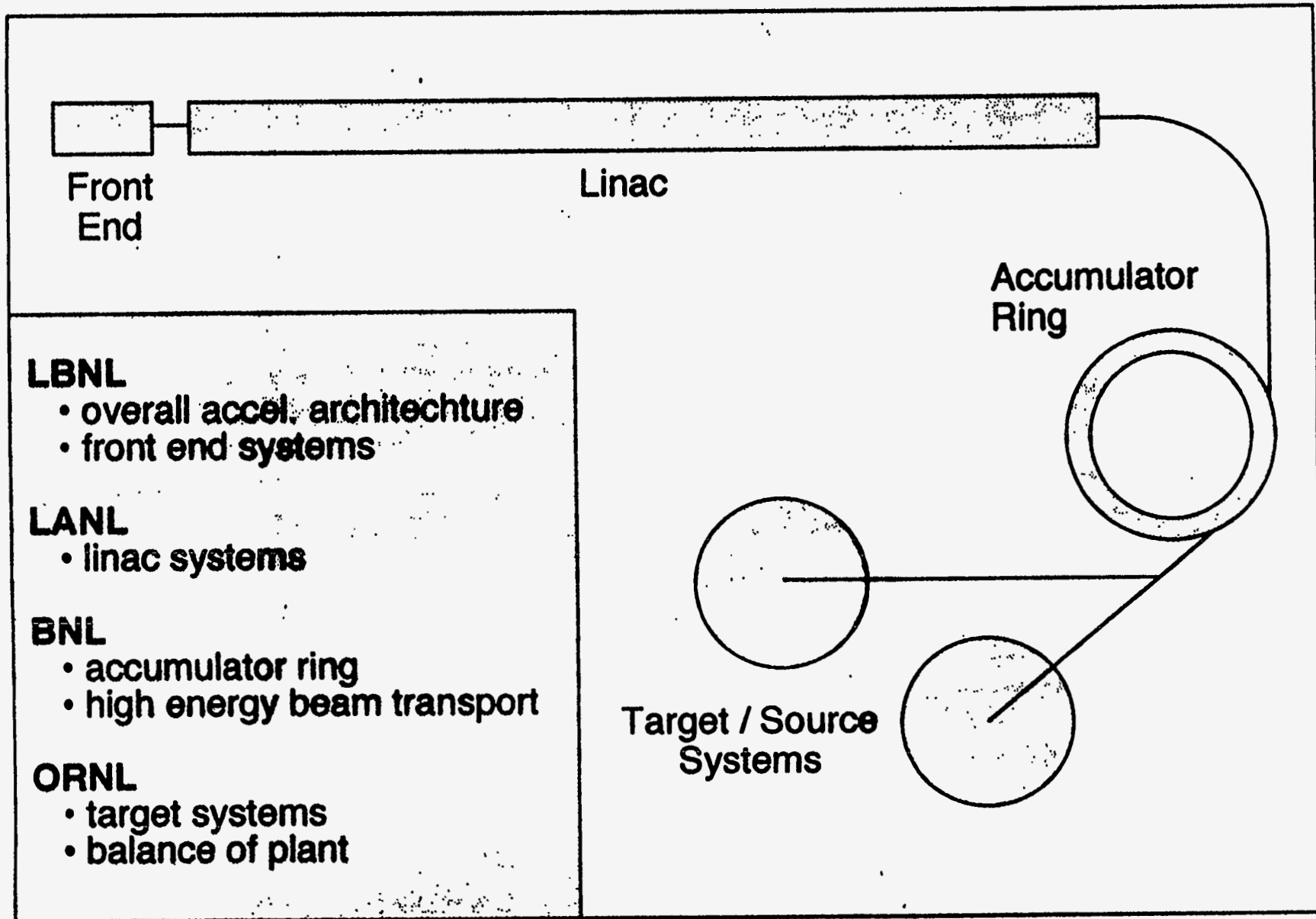
Liner Temperature vs. RF Power





The Oak Ridge Spallation Neutron Source

– a Multi - Laboratory Partnership –



Steering at Second Einzel Lens as a function of % Steering Strength

Notice the 95% entrance contour (yellow) moving with respect to the stationary neutrals background (red).



Phase Space Plot Format

Phase Space Plot
x vs. x'

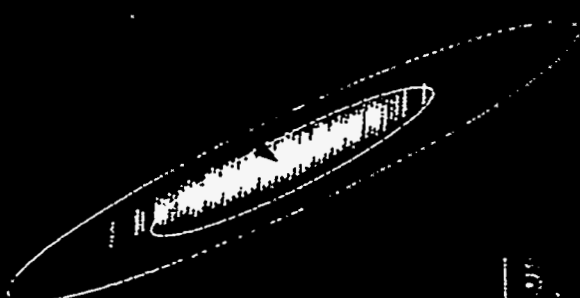
Beam Intensity Distribution
in Phase Space

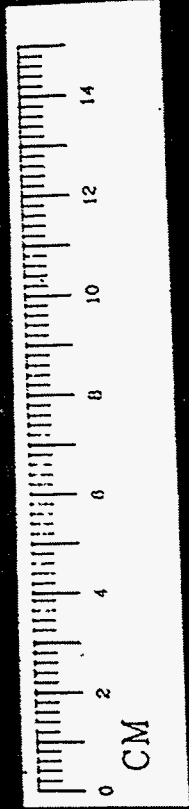
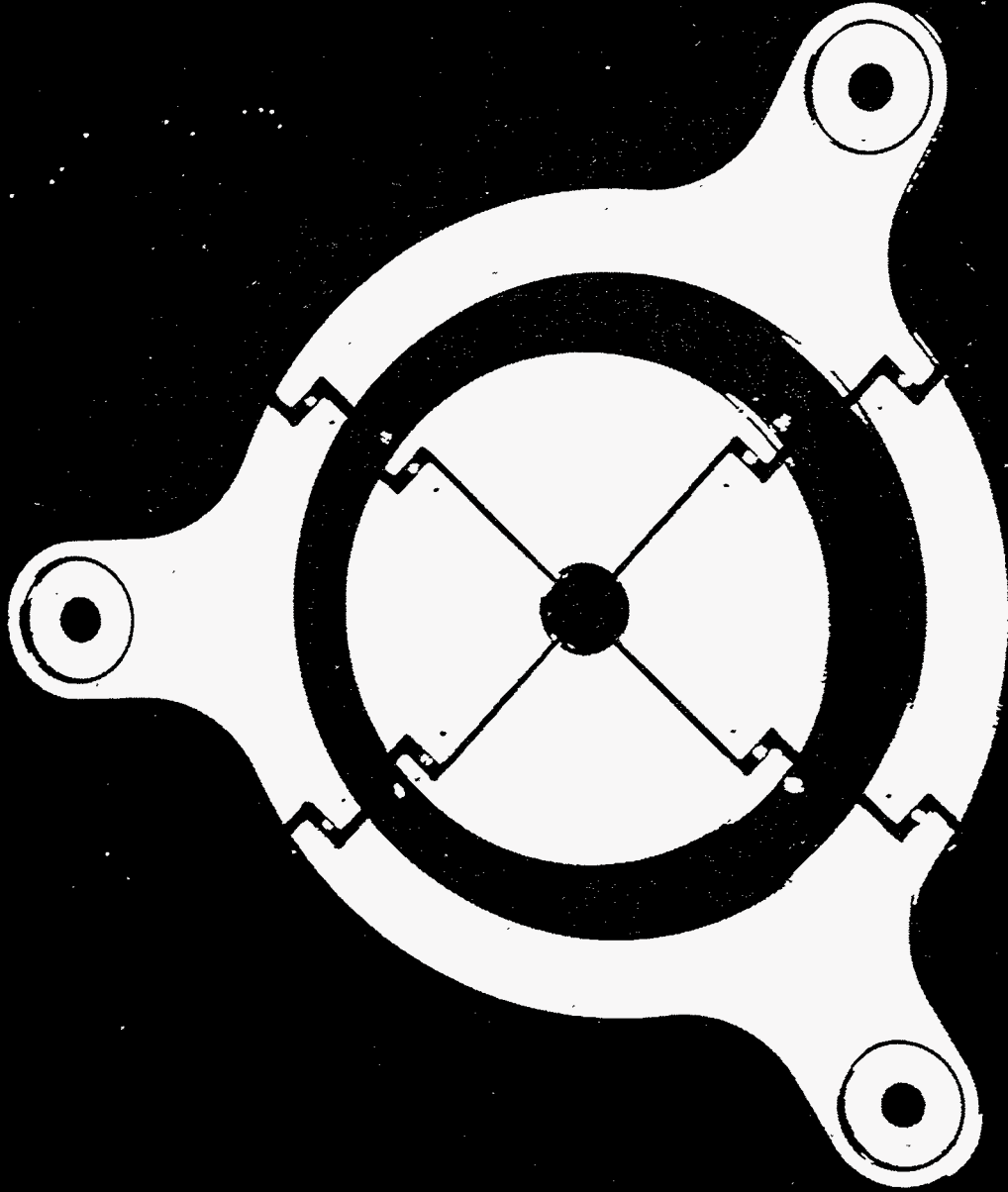
(Red Background): Signature of
Neutrals in the Beam

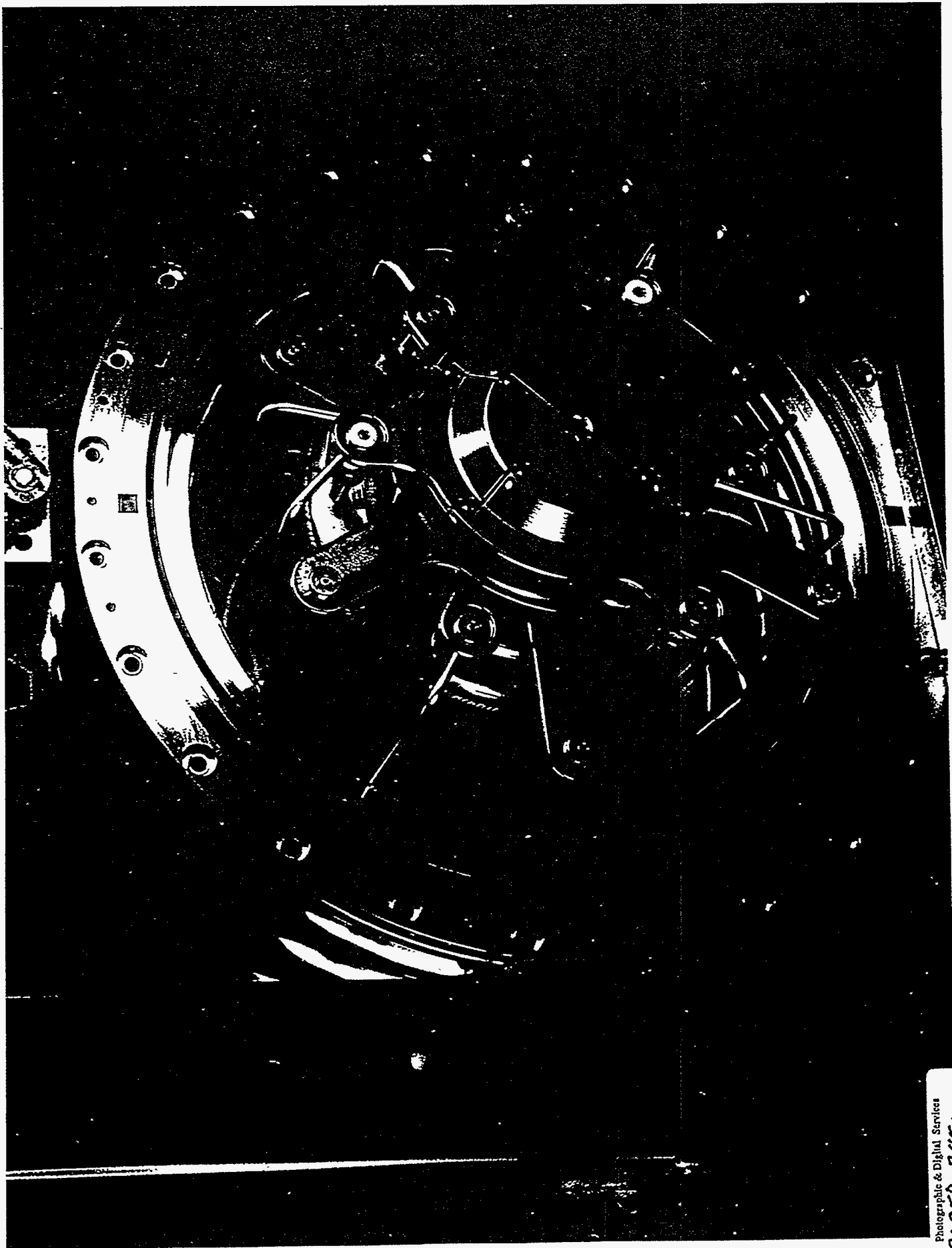
(Yellow Ellipse): 95% and 50%
Beam Emittance Contours

Origin of
Scanner Axis

(Green Ellipse): Shape of
the Acceptance

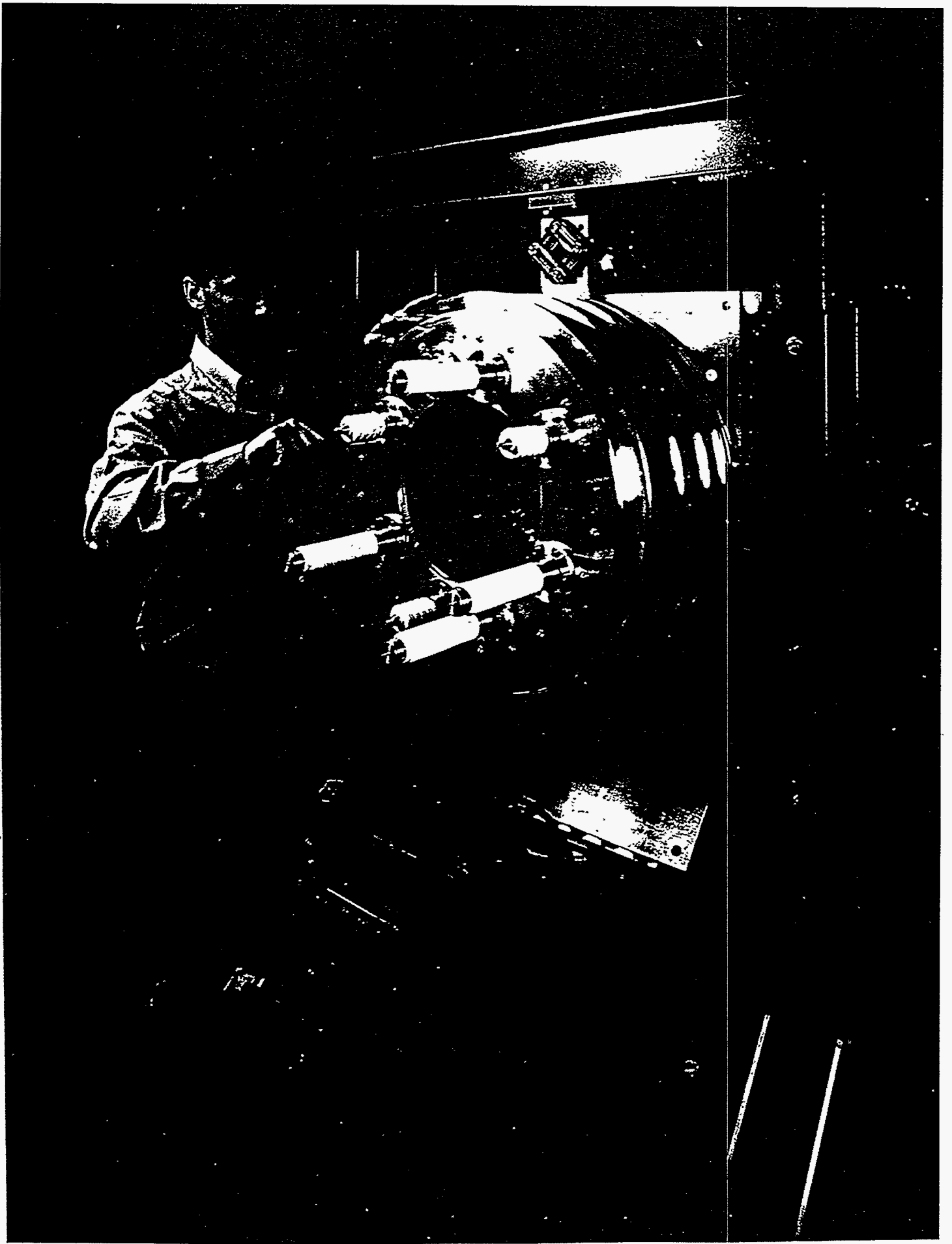






Photographic & Digital Services

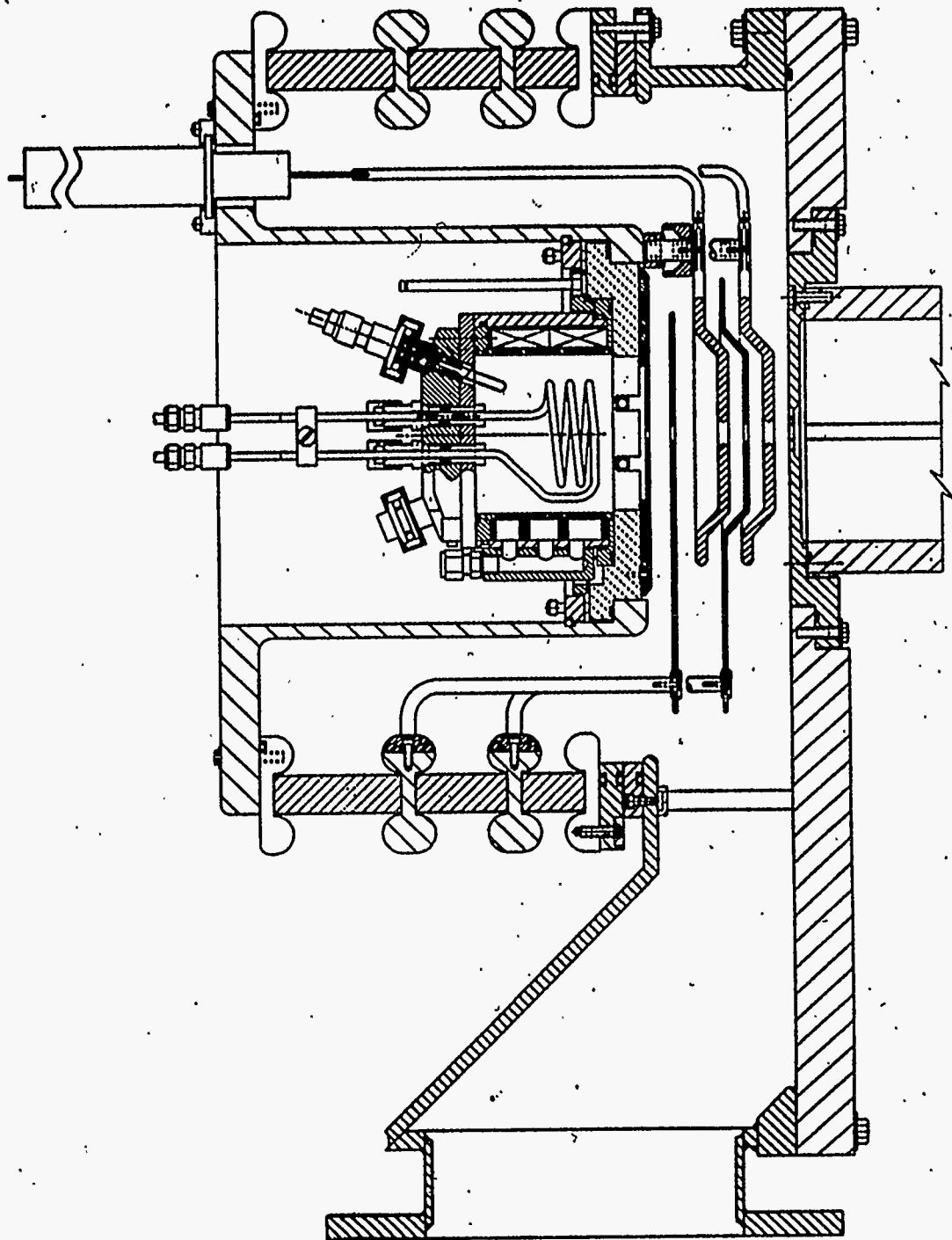
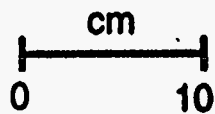
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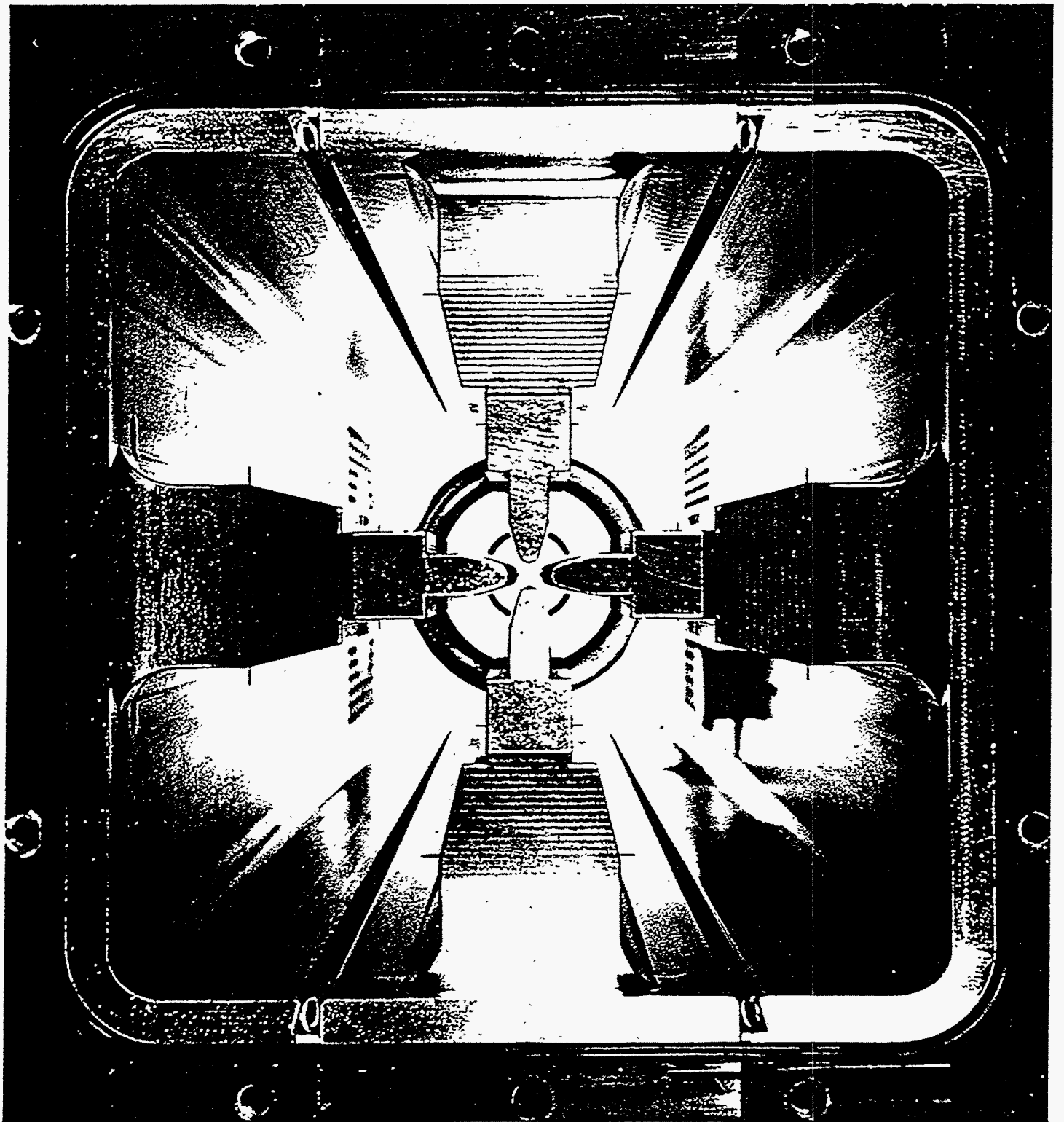


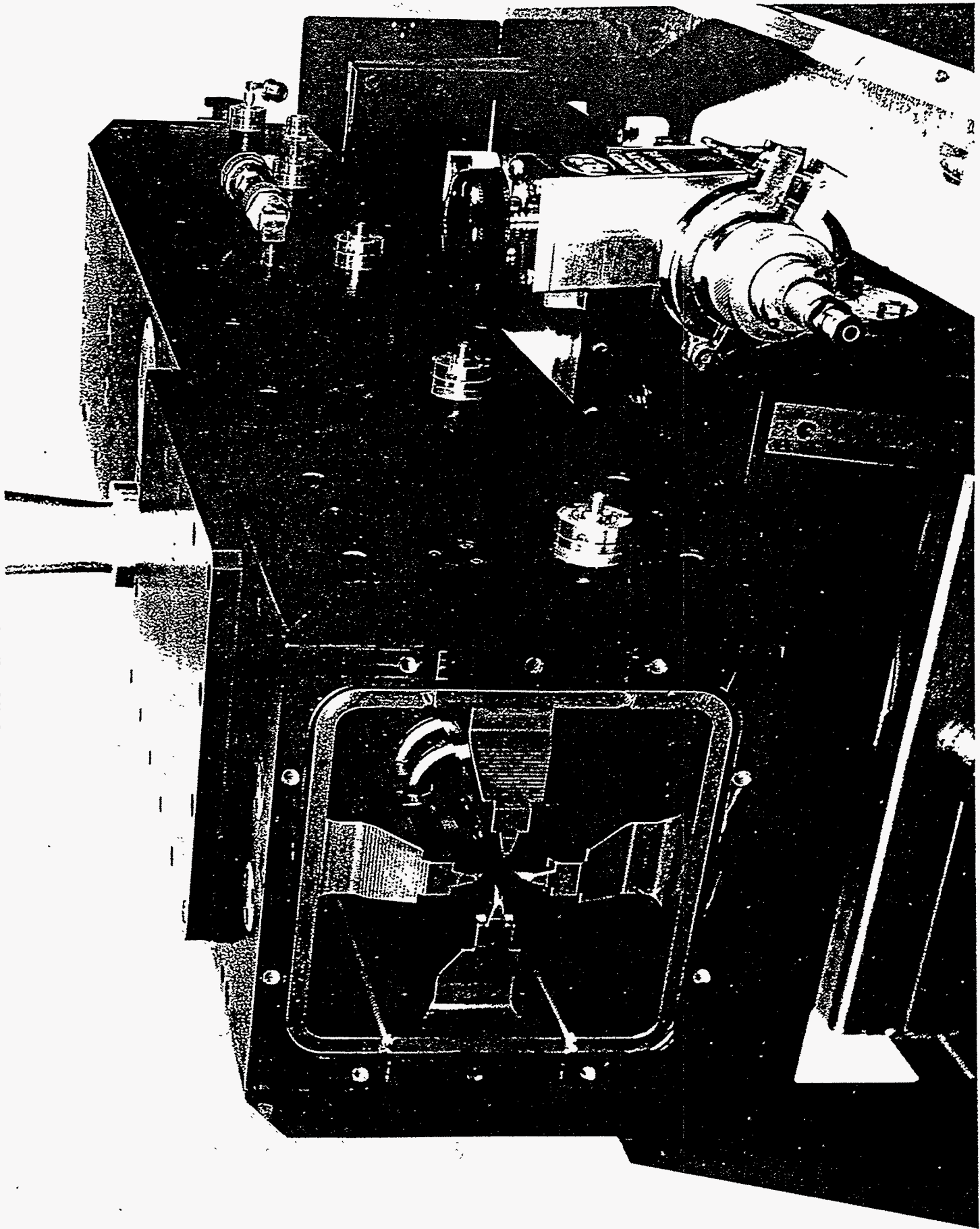
Photographic & Digital Services

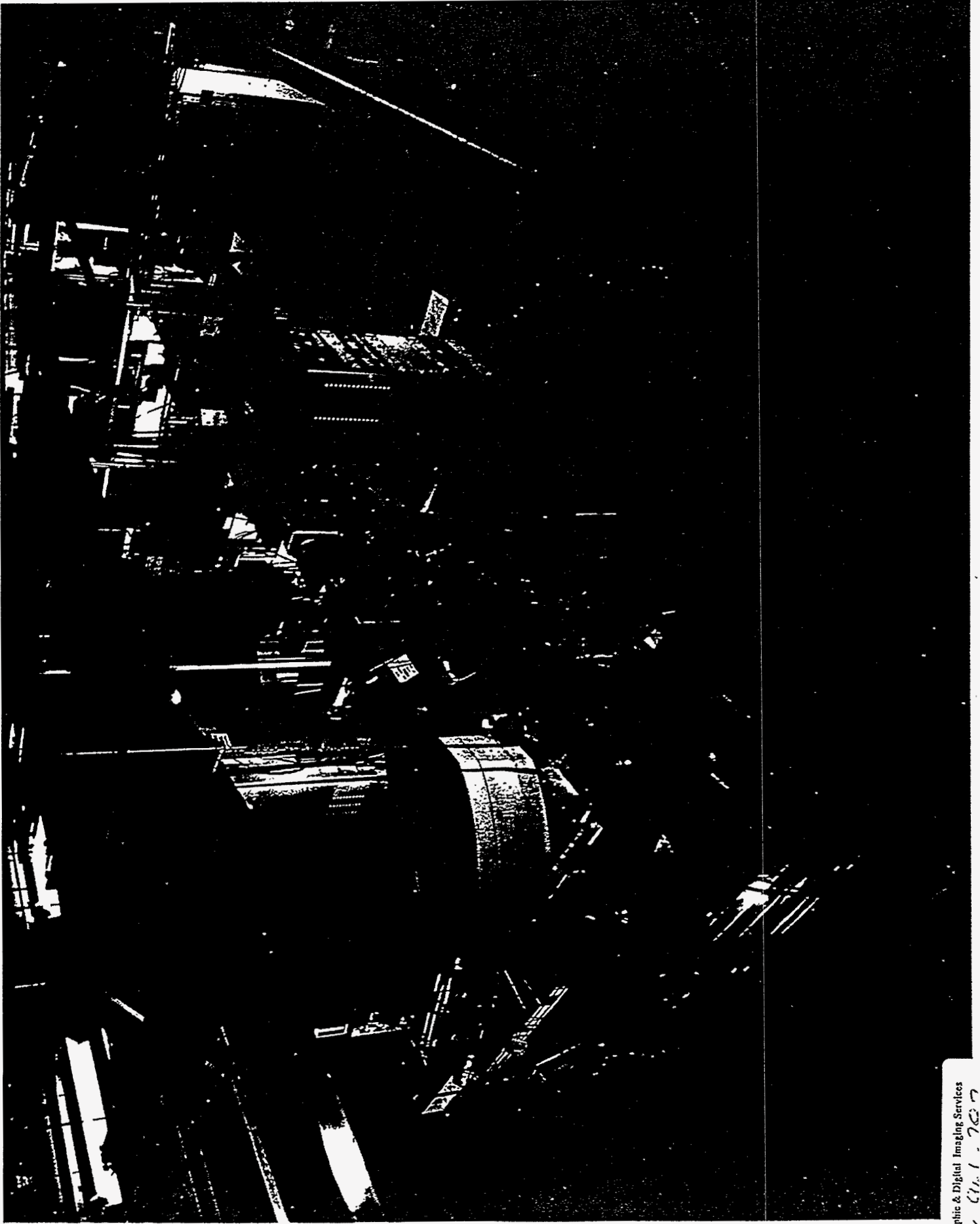
XBC 957-3448

**Integrated
Source - LEBT - RFQ
Experiment with 30 mA
Proton Beam**









R&D Topics in the Ion Beam Technology Program

- Ion Source Development
- RFQ Linac Development

Integrated Ion Source / RFQ Testing

- Stochastic Cooling (with CBP)
 - Beam Optics
- **Pulsed Spallation Neutron Source**
- **Boron Neutron Capture Therapy**
 - Proton Therapy

- Surface Modification Studies
 - Biocompatible Materials
 - Neutron Logging
 - MeV Implantation
 - Ion Beam Lithography
 - Ion Doping
- Flat Panel Display Technology
 - Diamond Coatings
 - MuliLayers

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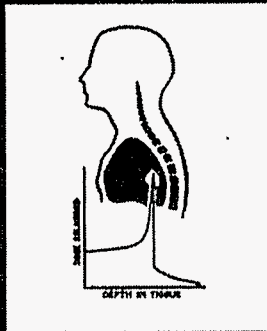
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Vilaithong, Rummiya
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Wutte, Daniela

Ion Beam Technologies



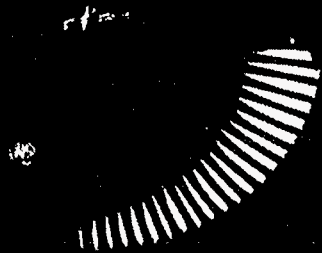
Technology for the DOE

- ion source development
- advanced accelerator structures
- heavy ion beam cooling



Medical Applications

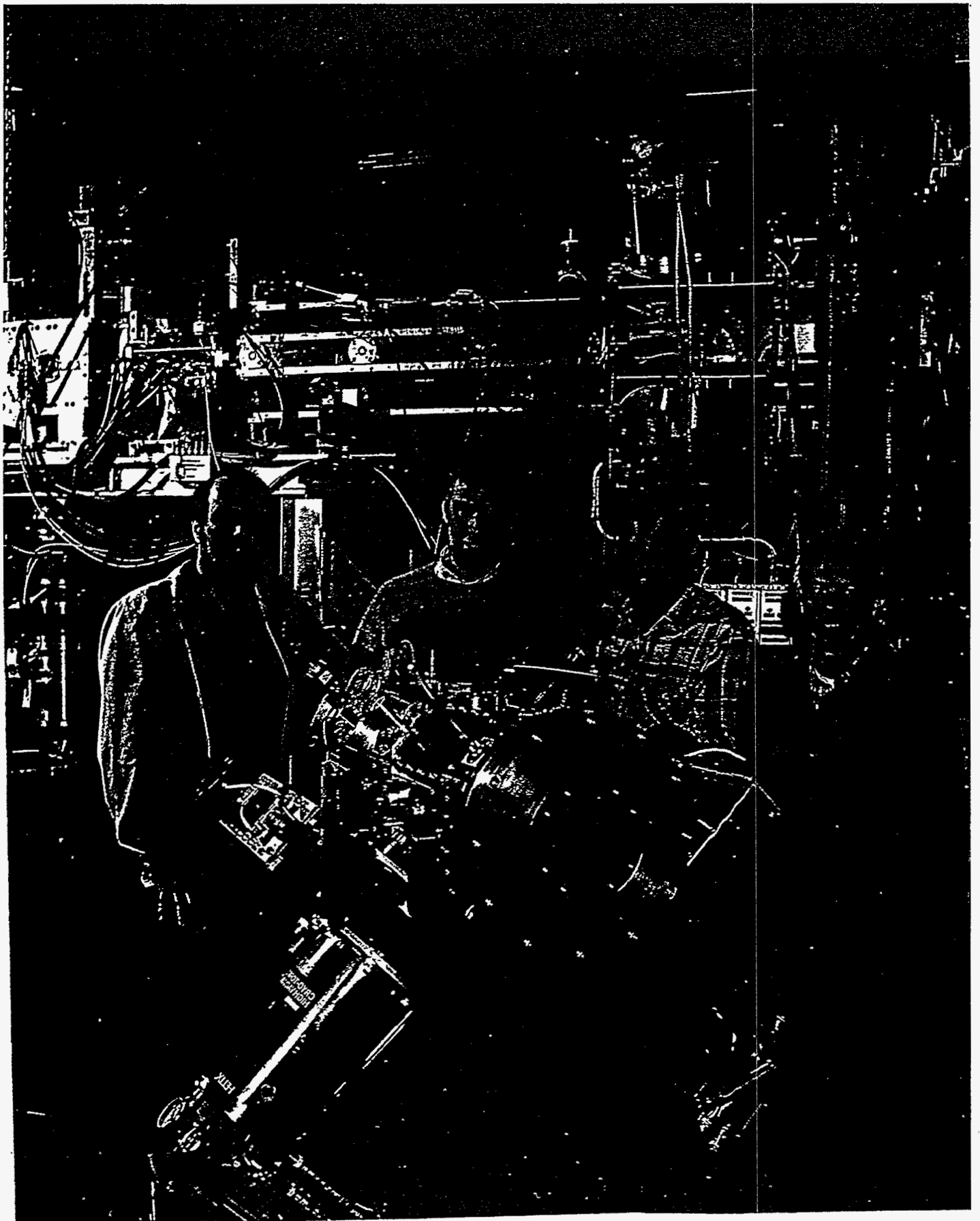
- radiotherapy
- radioisotope production
- instrumentation



Materials Applications

- ion implantation
- surface modification
- ion beam lithography





• BB 855-4195

48710

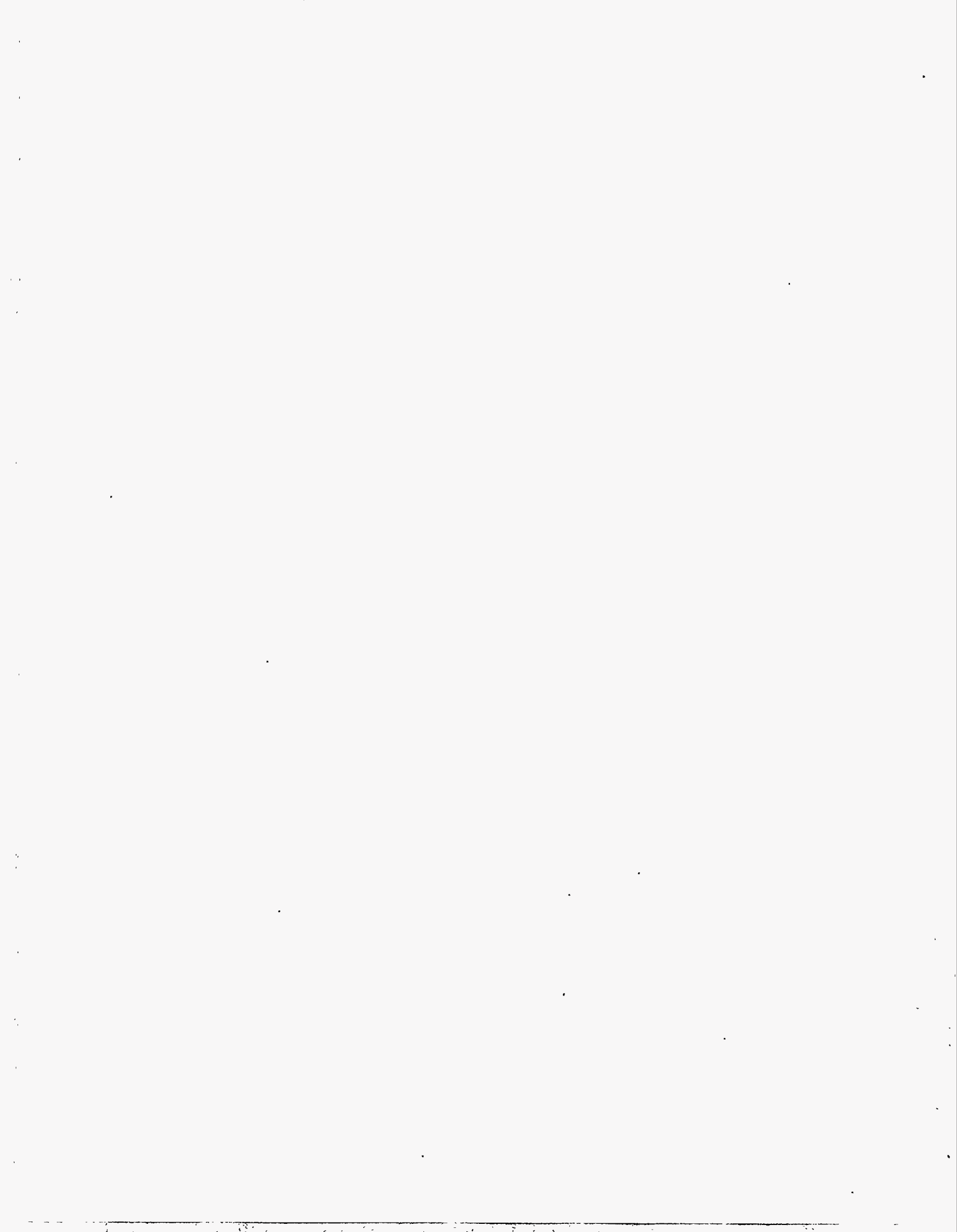
CONF 884

Selected Accelerator Applications

Richard A. Gough

**Exotic Nuclei Symposium
Bodega Bay, California
April 15-16, 1996**



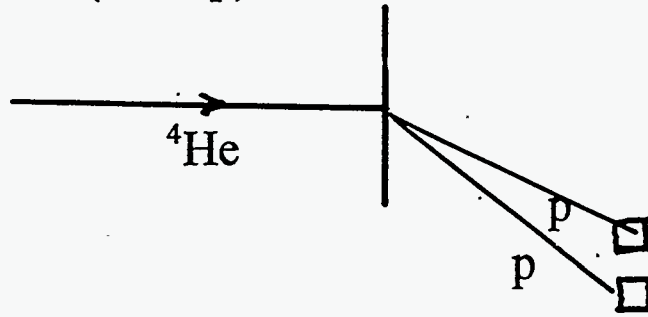


Rick Gough

Lawrence Berkeley National Laboratory
Berkeley, CA

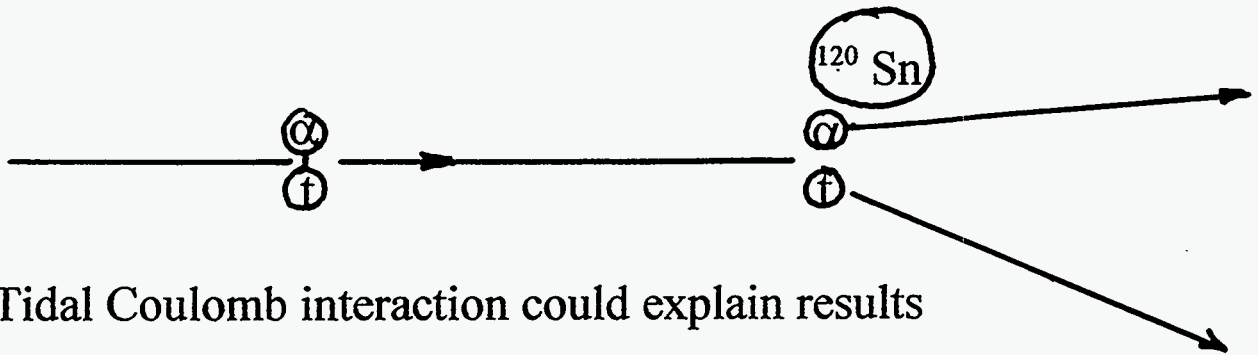
1978 -1980

$(^4\text{He}, 2p)$



Used apparatus for : $(^{12}\text{C}, ^8\text{Be} + \alpha)$
 $(^7\text{Li}, \alpha + t)$

-----> Direct Breakup



* Tidal Coulomb interaction could explain results

* Relates $\begin{cases} ^7\text{Li} + \gamma \text{ ----} \rightarrow \alpha + t \\ \alpha + t \text{ ----} \rightarrow ^7\text{Li} + \gamma \end{cases}$

Larger detectors

Ideal for Radioactive
beam experiments

Breakup σ_b
Capture σ_c

Deduce σ_c from σ_b

e.g. $^{14}\text{O} \text{ --} \rightarrow ^{13}\text{N} + p$

Summary

- * At LLN several beams are available :

${}^6\text{He}$ ${}^{11}\text{C}$ ${}^{13}\text{N}$ ${}^{18}\text{F}$ ${}^{18}\text{Ne}$ ${}^{19}\text{Ne}$ ${}^{35}\text{Ar}$

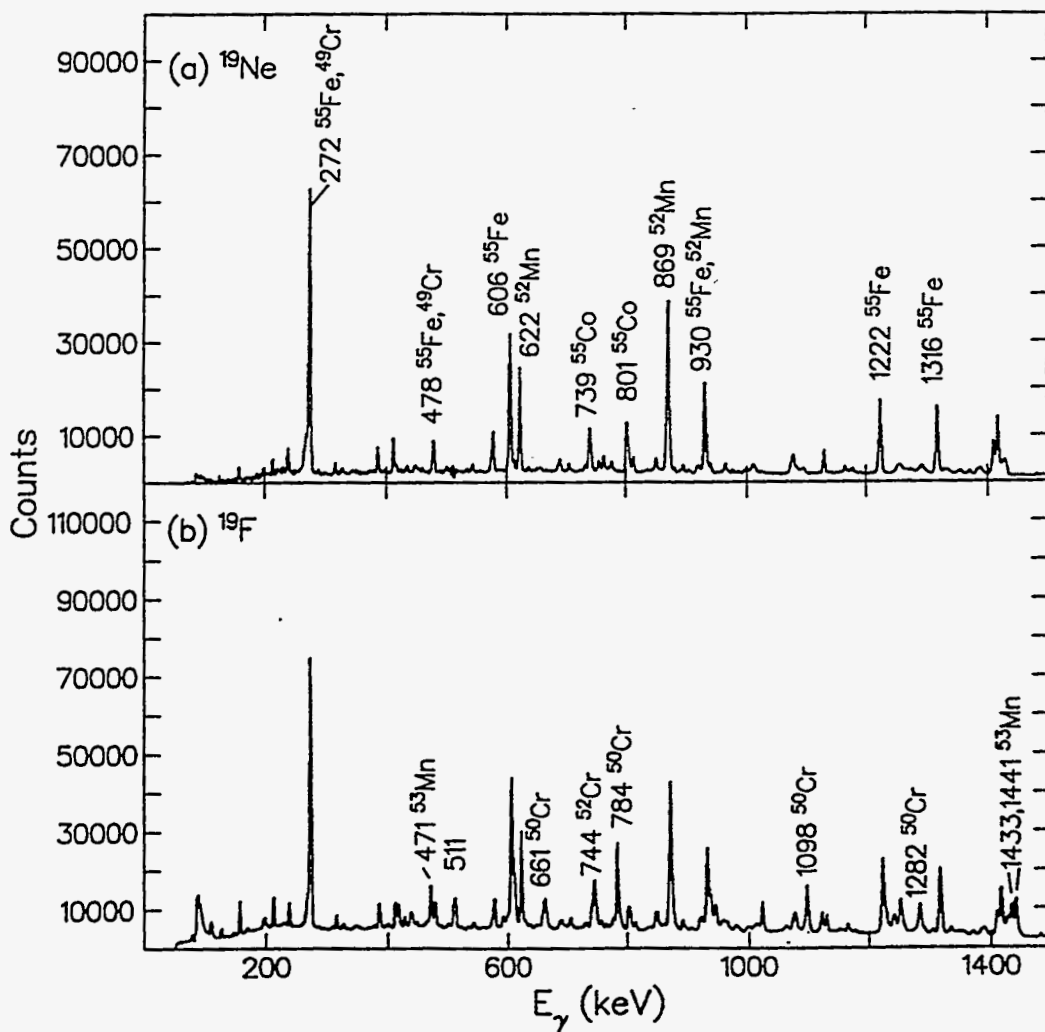
(${}^{10}\text{C}$ ${}^7\text{Be}$ ${}^{15}\text{O}$ ${}^{34}\text{Ar}$ under consideration)

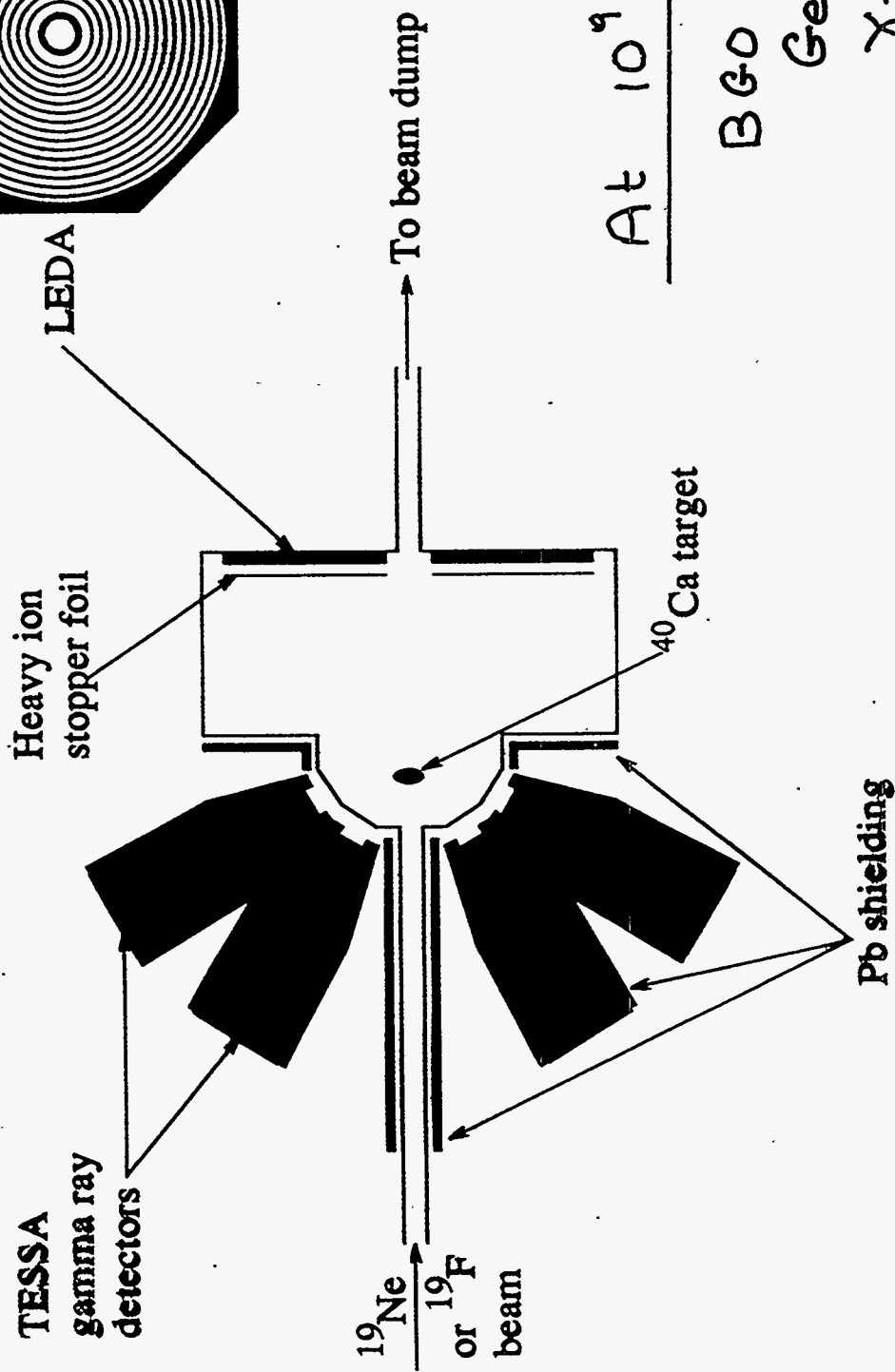
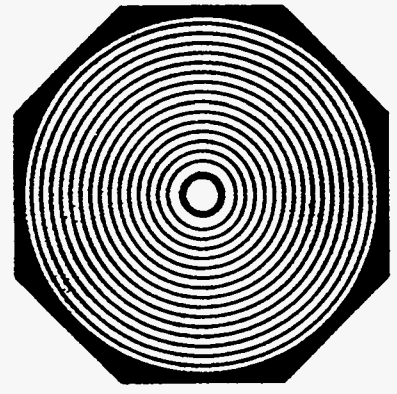
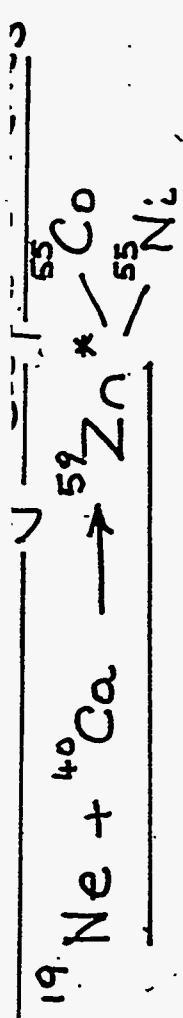
- * Beams used for a variety of nuclear and nuclear astrophysics experiments

experience shows a lot of innovation is needed
both for production and exploitation

- * New cyclotron will increase intensity by $\times 10$

Figure 10: Comparison of the background subtracted gamma-ray singles spectra for (a) the ^{19}Ne beam, and (b) the ^{19}F beam data. Data from all 90° Ge detectors.





At $10^9 \text{ s}^{-1} \text{ } ^{19}\text{Ne}$

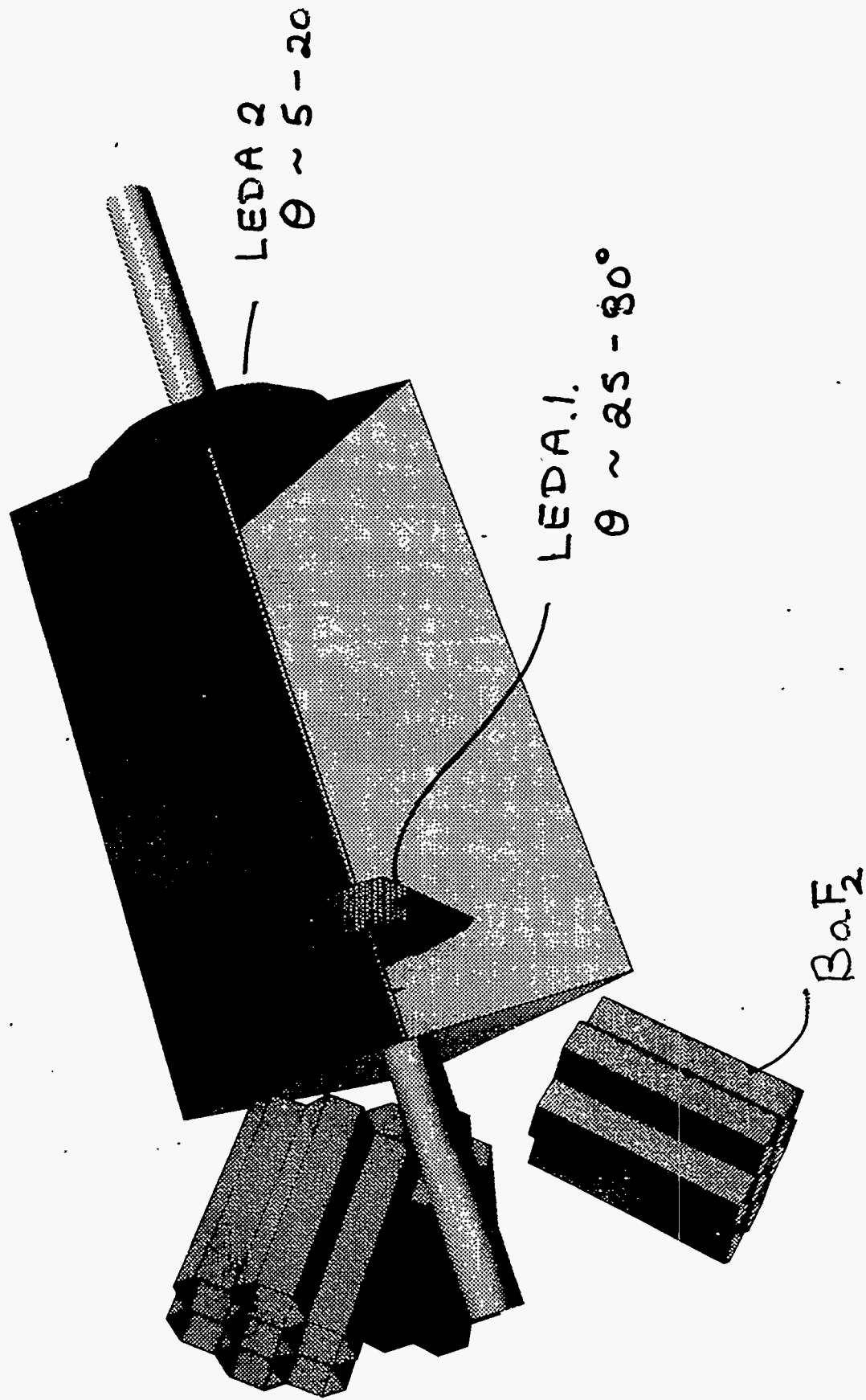
BGO shield $\sim 50\text{k s}^{-1}$

Ge $\sim 1000 \text{ s}^{-1}$

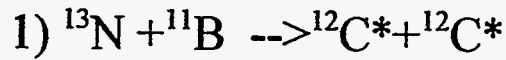
γ - γ $\sim 20 \text{ s}^{-1}$

γ -LEDA $\sim 800 \text{ s}^{-1}$

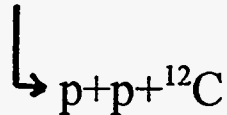
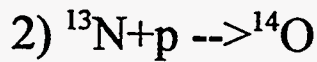
Reaction studies experimental configuration.



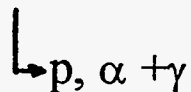
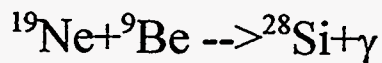
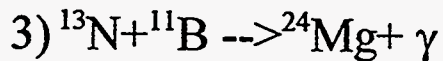
Some Nuclear Physics experiments with LEDA



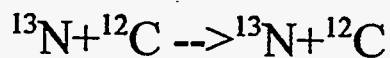
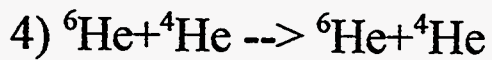
Transfer :
 ^{13}N Proton wavefunction



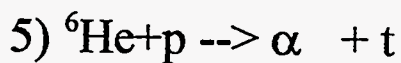
2 p decay mechanism



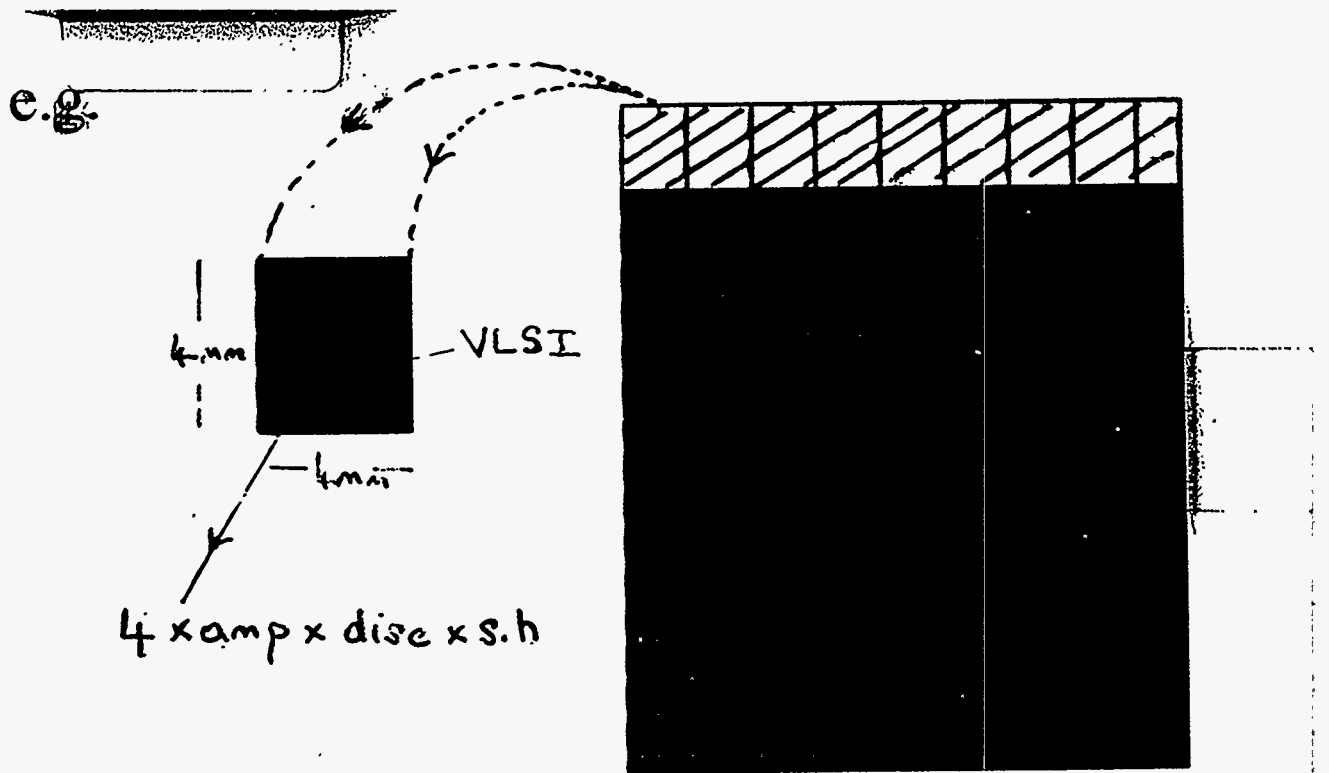
Fusion :
T dependence of GDR



Exchange scattering

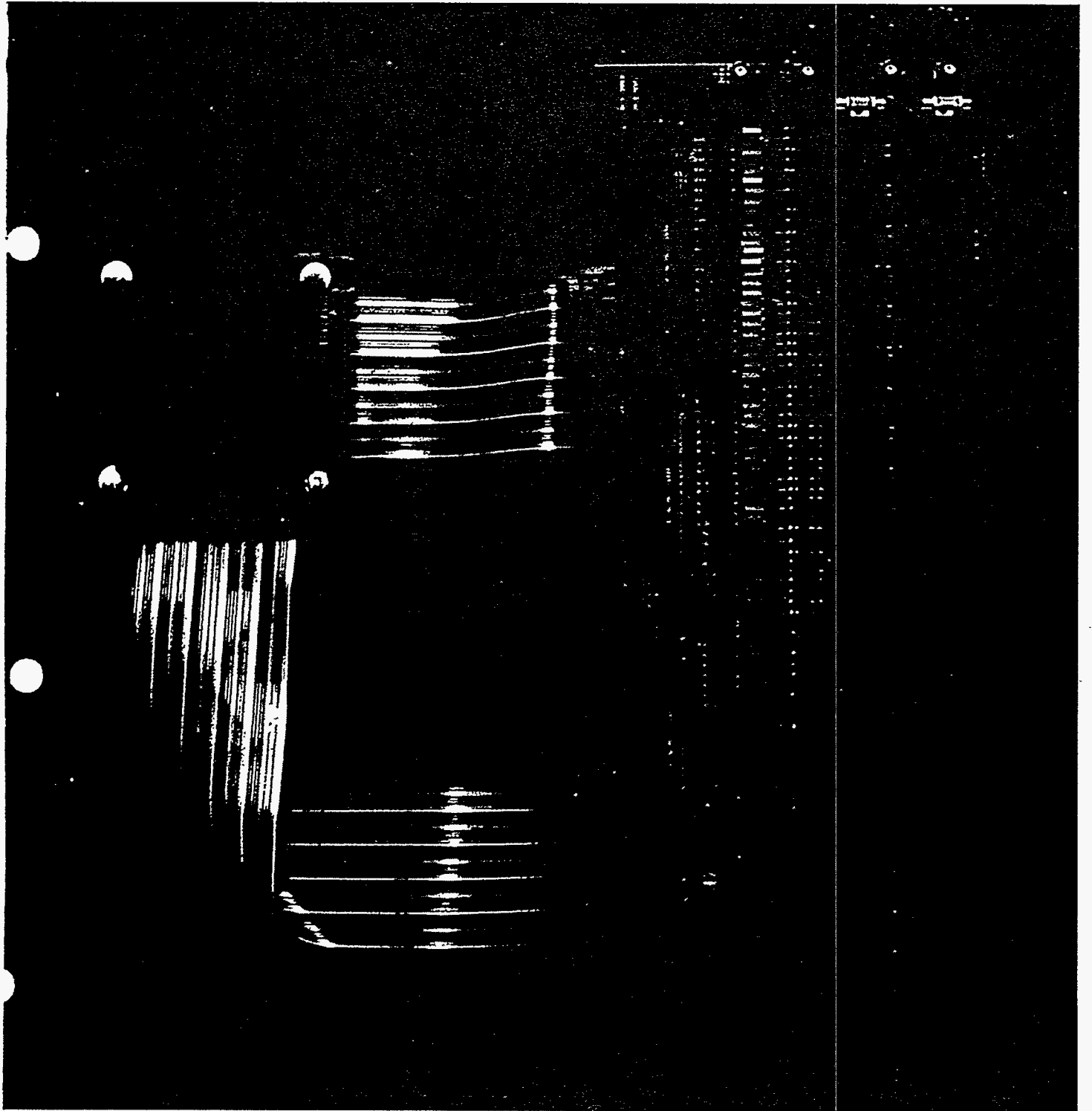


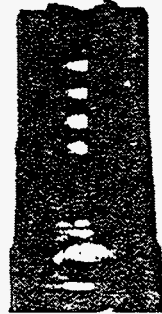
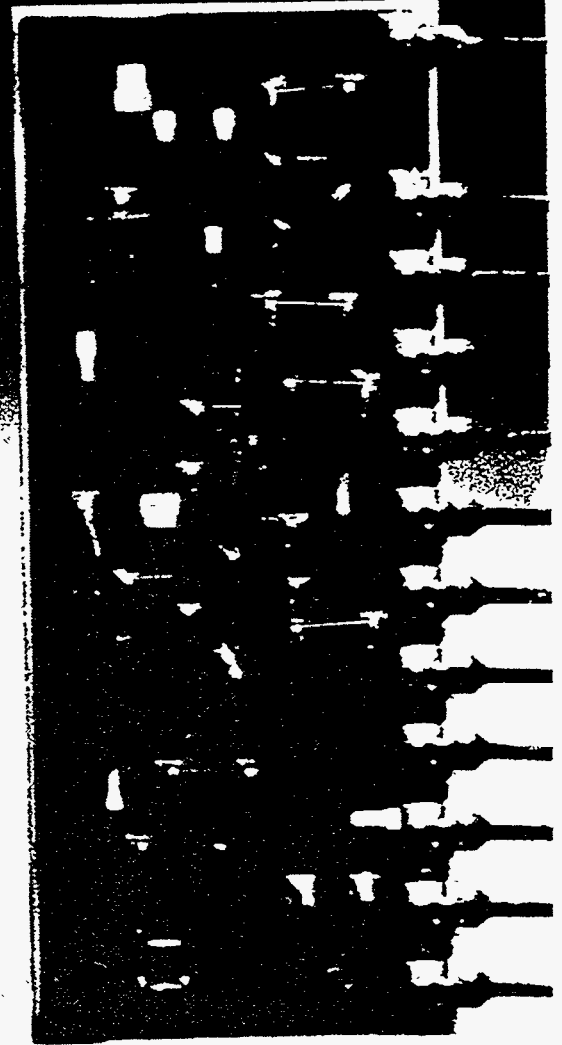
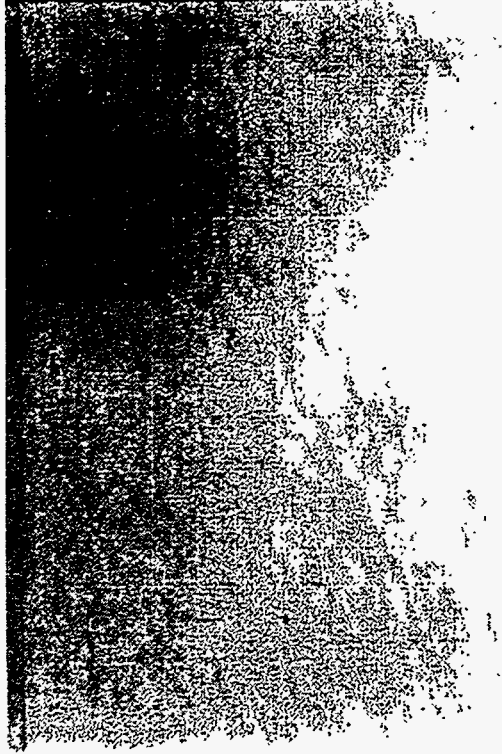
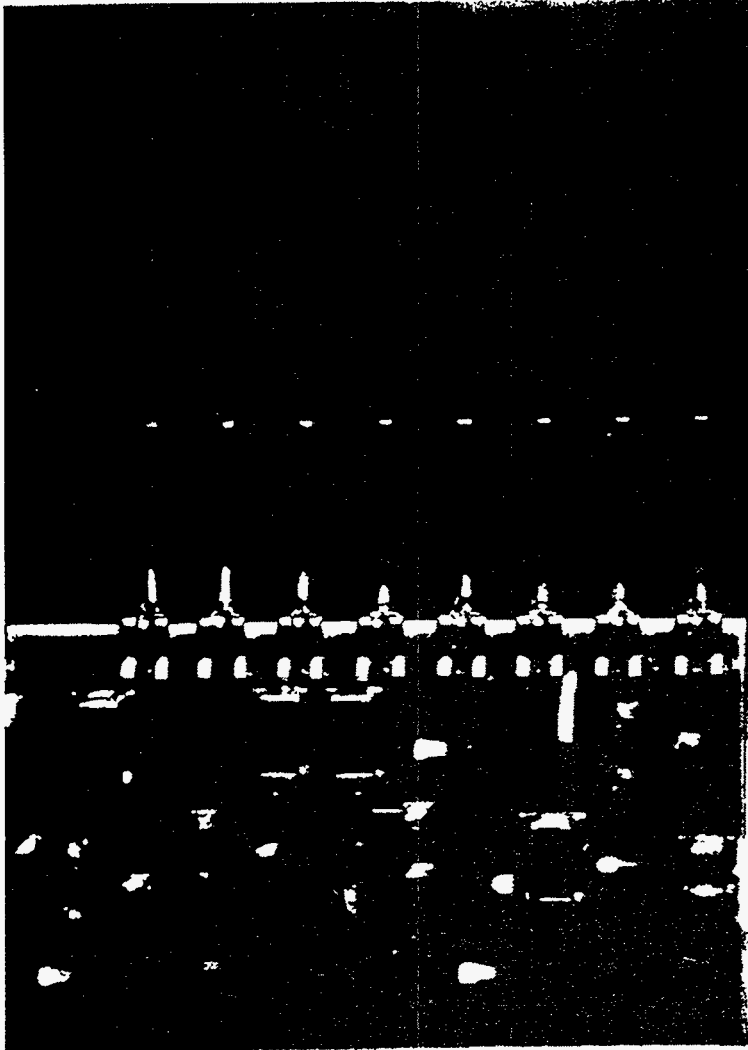
2 n structure of ^6He



122 Schreff 69001-821

SCHROFF 69001-865





In general for radioactive beam experiments



Low beam intensities / High backgrounds



Use Large segmented detectors



Need many hundreds channels of electronics

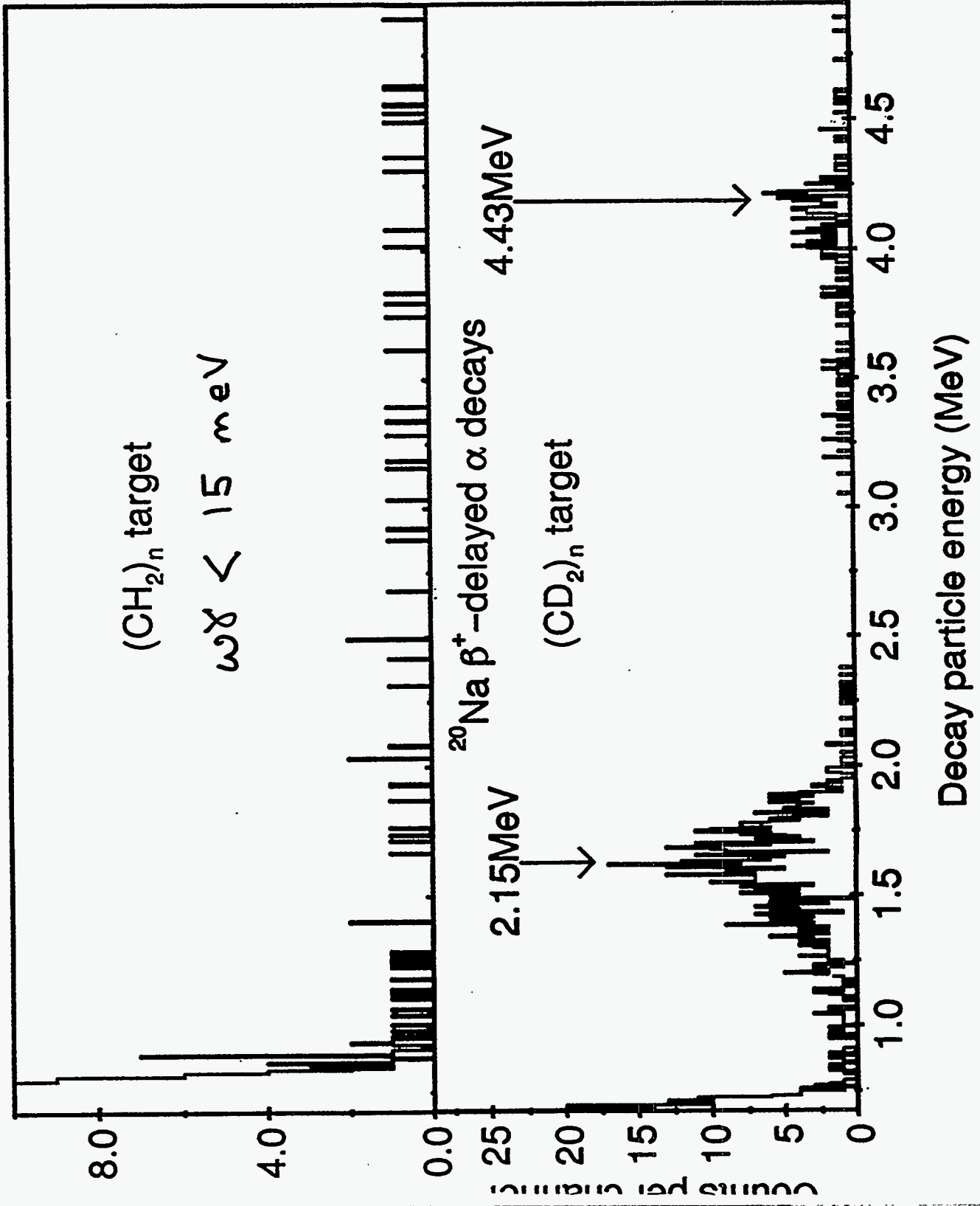


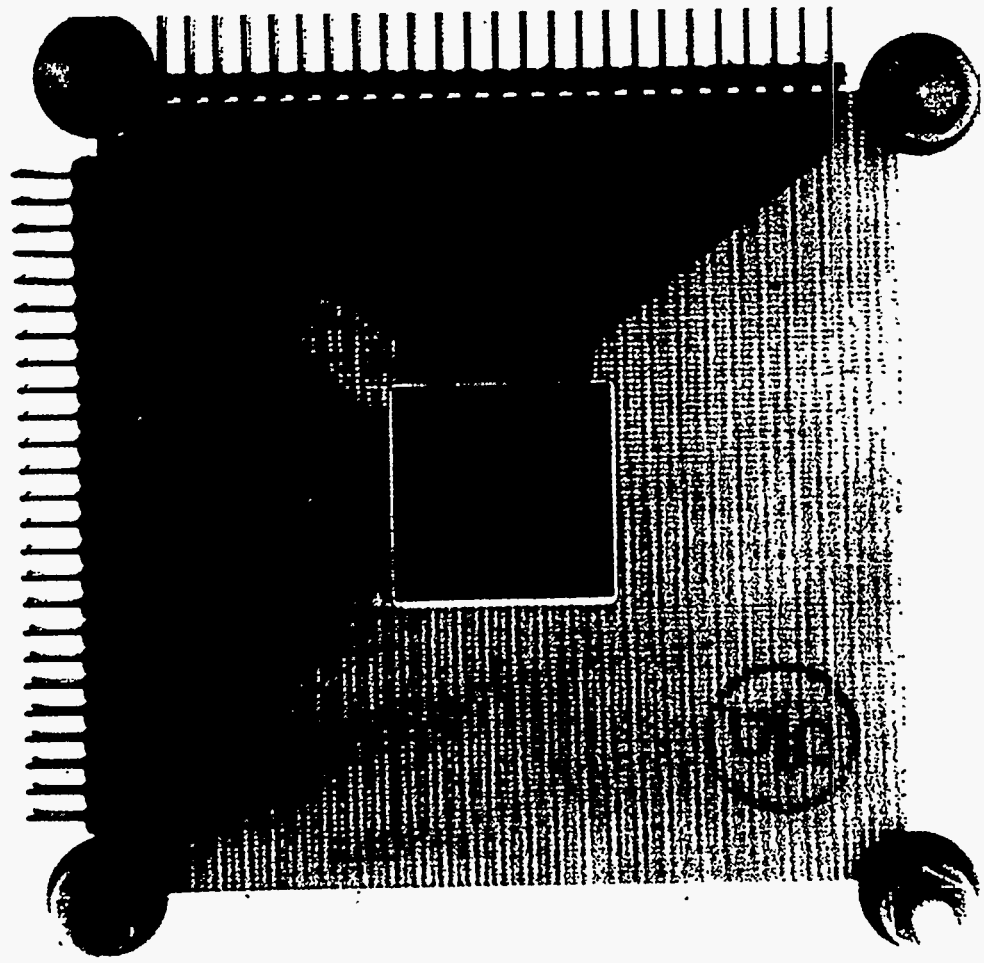
problems: Space / Cost



LEDA microelectronics overcomes these problems

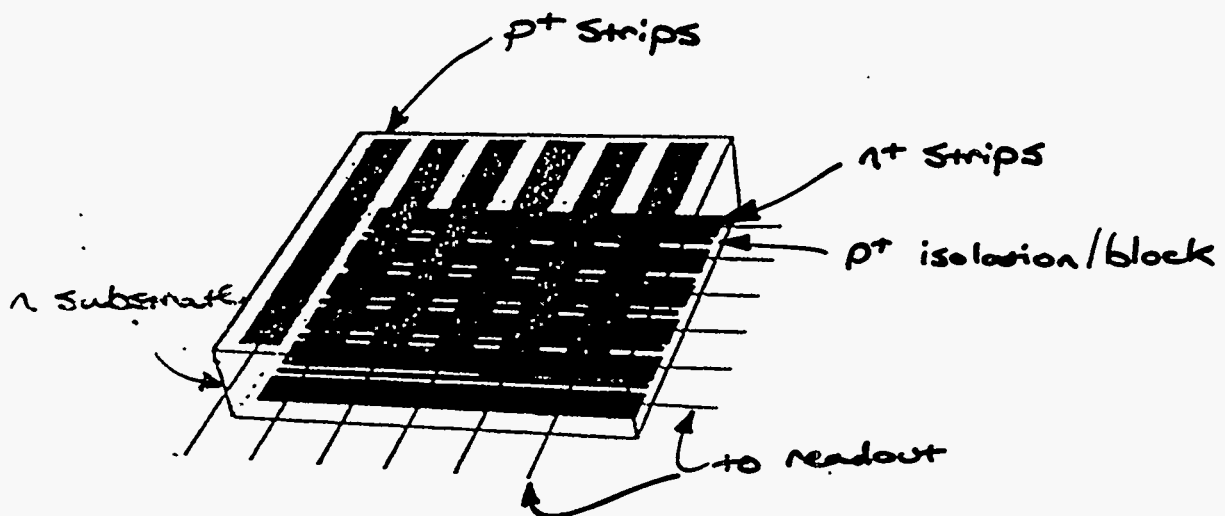
PRL 73(1994)
3066



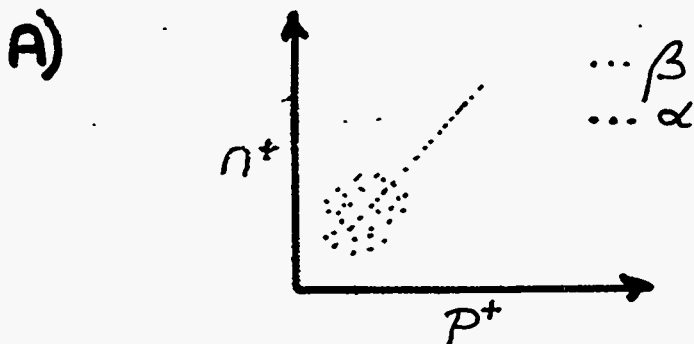


Rejection of β 's

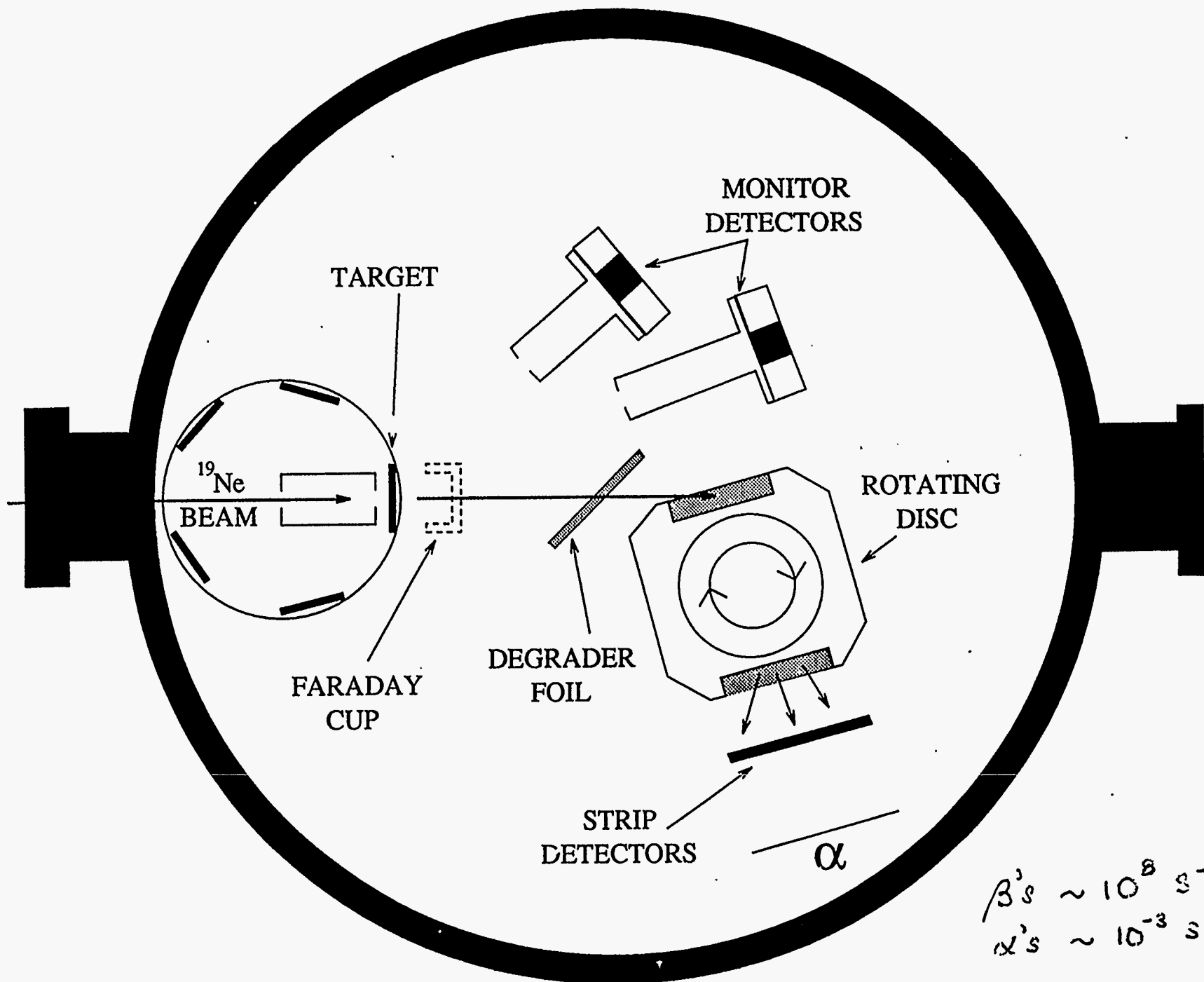
- 1) Use thin detectors
- 2) Use DSSSD

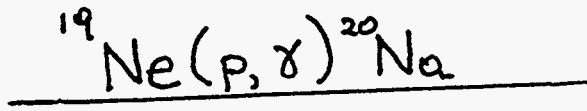


DOUBLE SIDED SILICON STRIP DETECTOR
(DSSSD)



B) Demand multiplicity .l. n^+, p^+

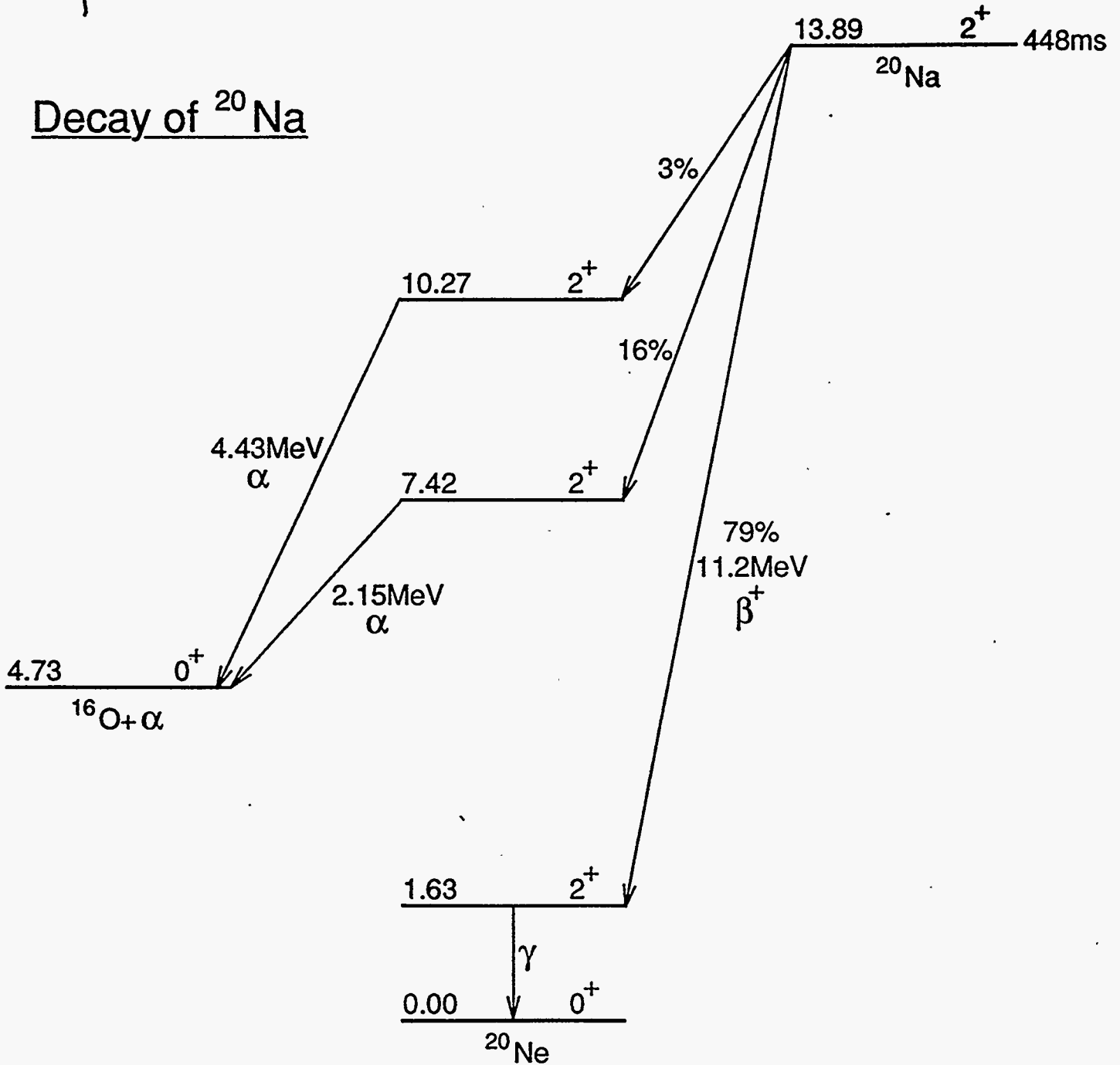




(Large B.G.
↓
segmentation)

$E_p \sim 450 \text{ keV}$

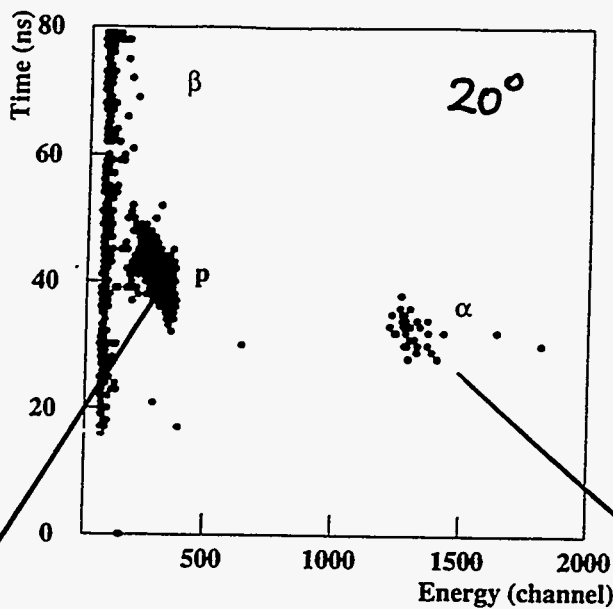
Decay of ^{20}Na



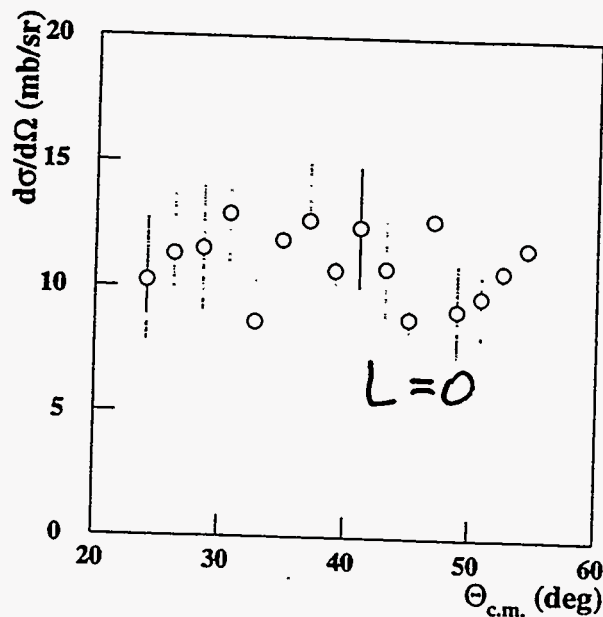
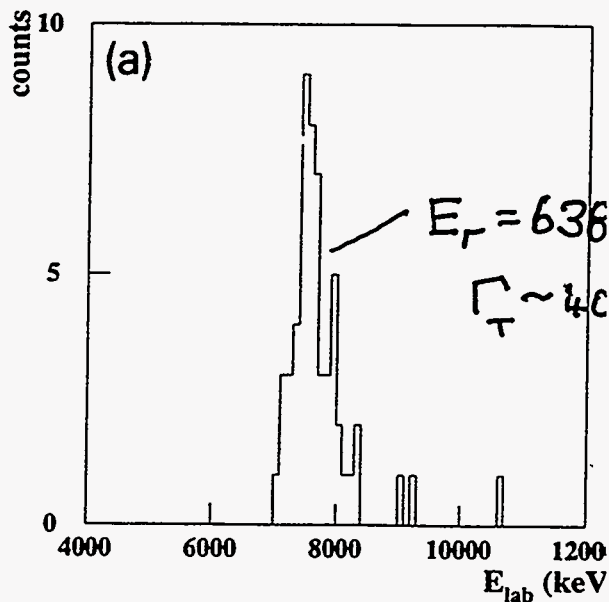
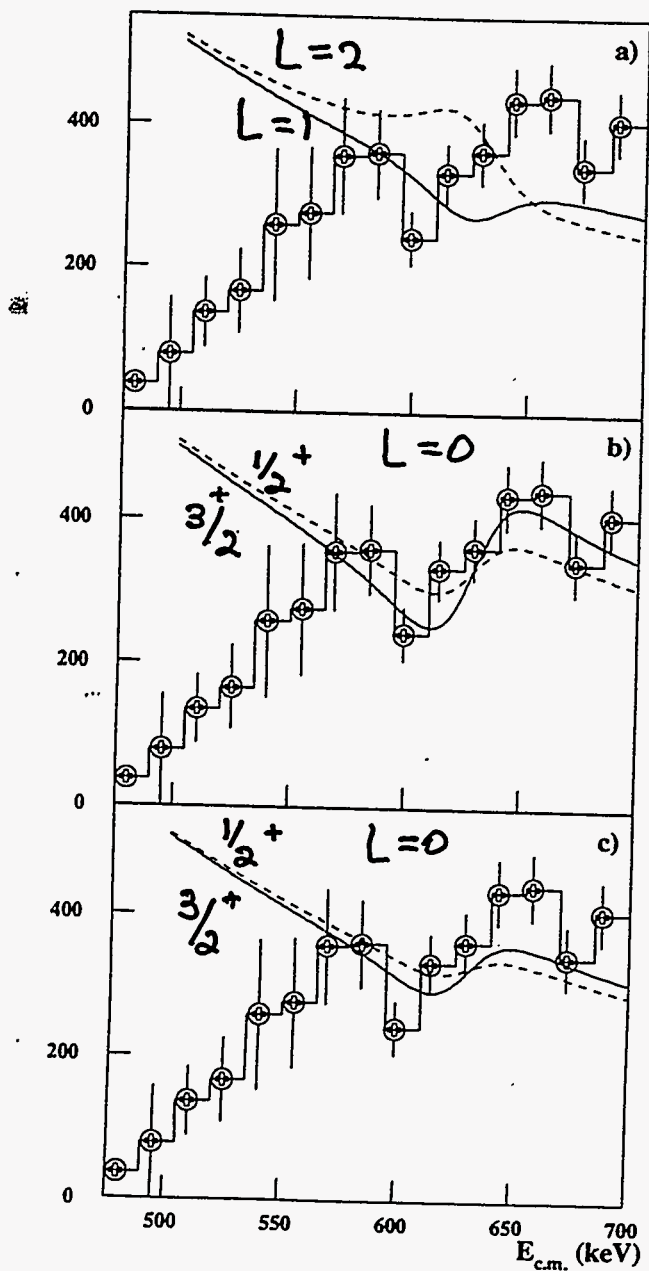
$^{18}\text{F}(p, \alpha)$

thick target scan 550 - 740 keV
above threshold

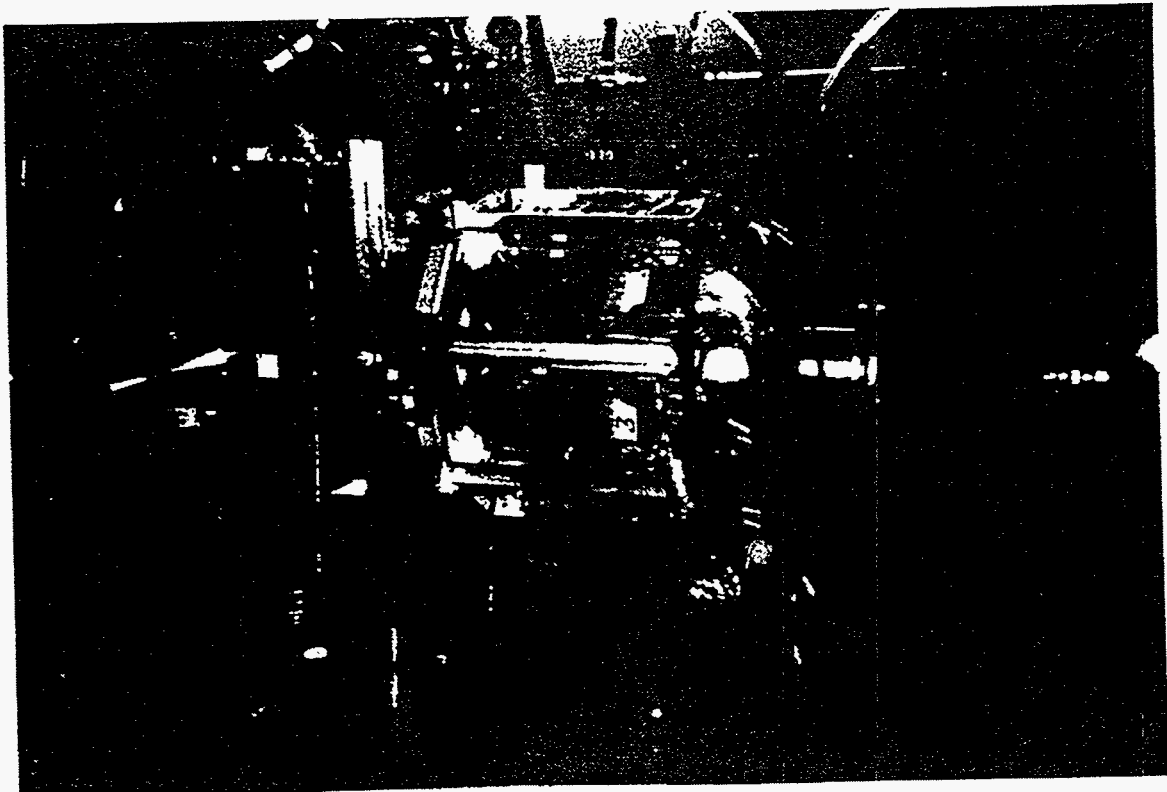
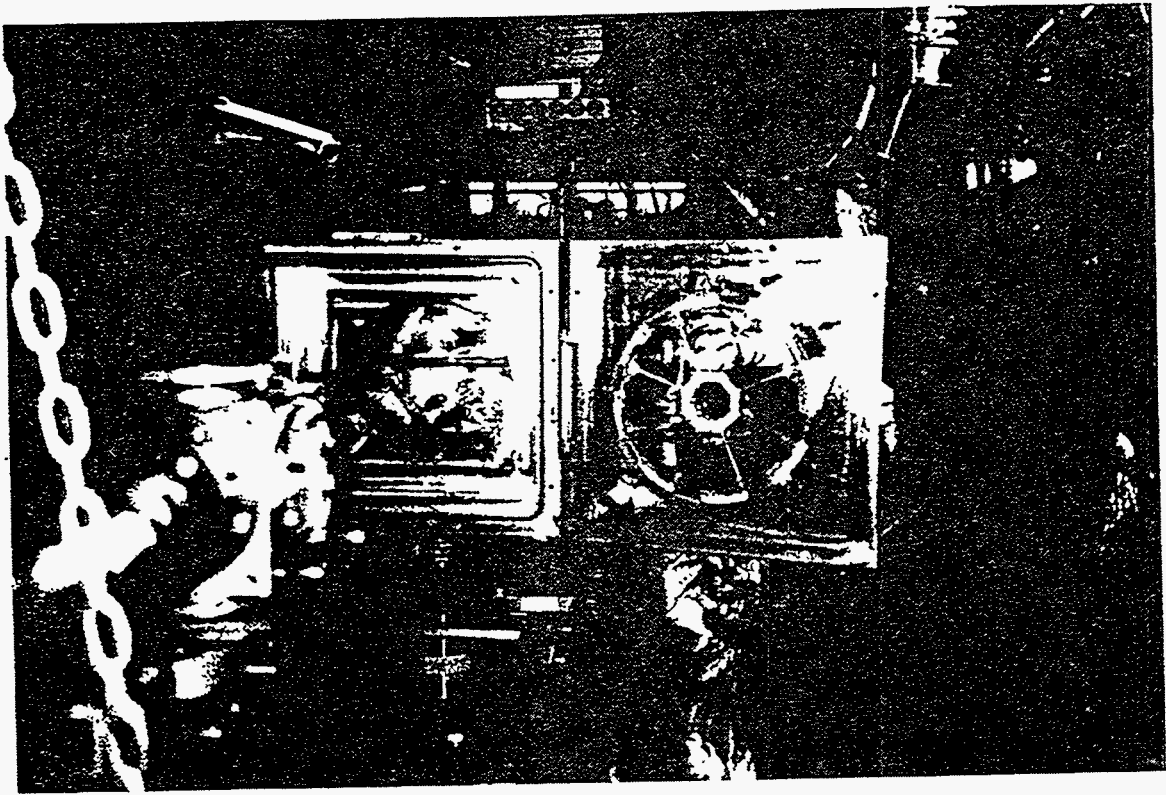
$^3\text{F} \sim 10^6 \text{ s}^{-1}$
for 4 hours

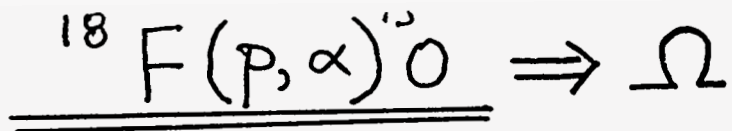


P.L. 353 (11)
184



$\dots - (E \dots)$



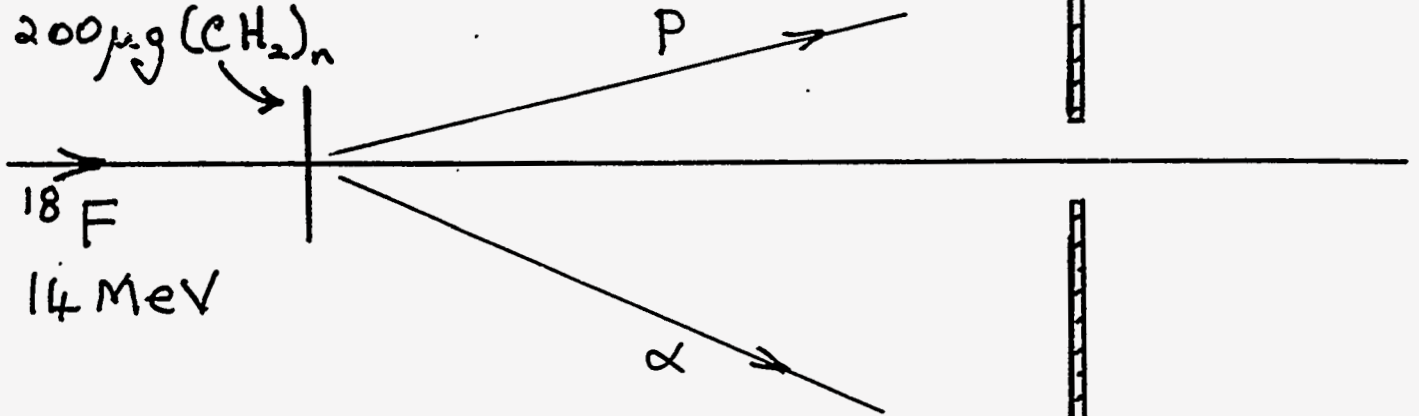


Target

$200\mu\text{g}(\text{CH}_2)_n$

^{18}F

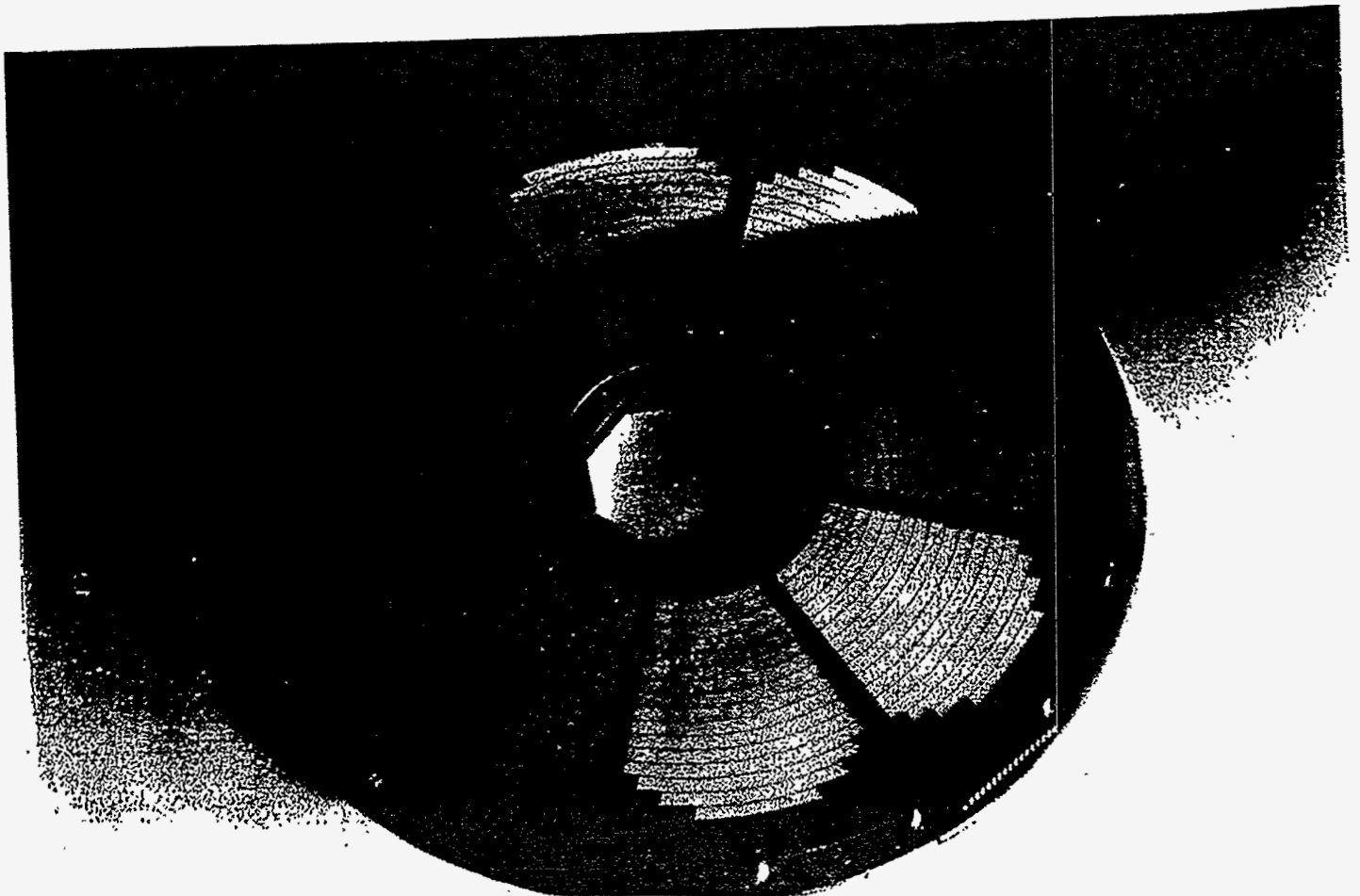
14 MeV

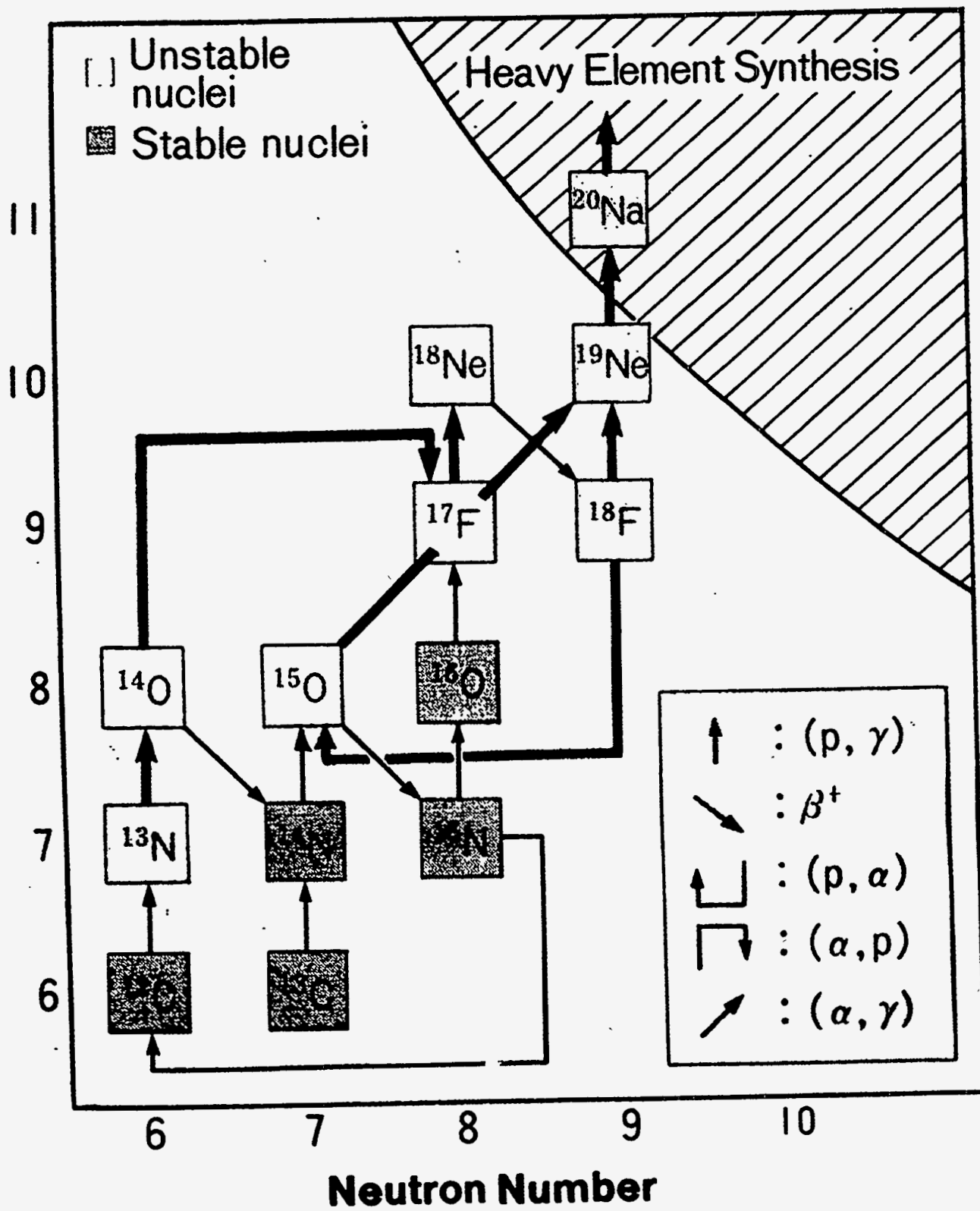


$\sim 10^6 \text{ s}^{-1}$ for $\alpha \times 2 \text{ hr}$

L.E.D.A.

(Louvain - Edinburgh - Detector - Arr.)



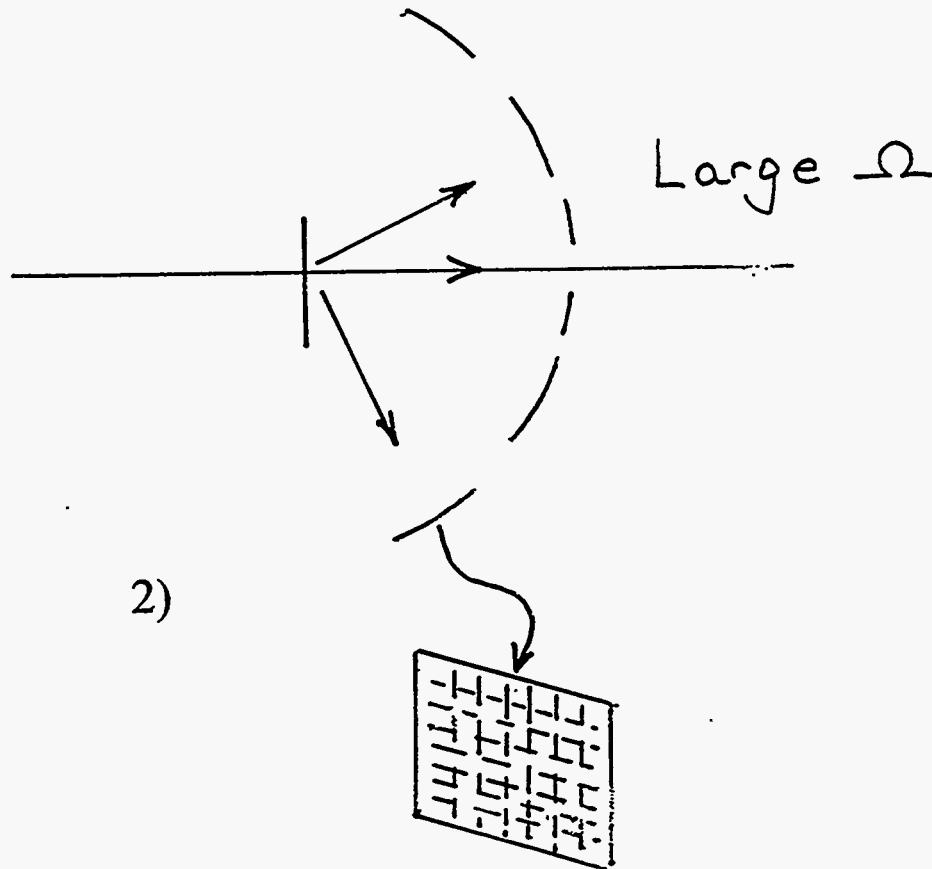


Experimental problems

1) Radioactive beam intensity \ll stable beams

2) Radioactive beams produce more background radiation

To overcome 1) --- use high efficiency detector systems



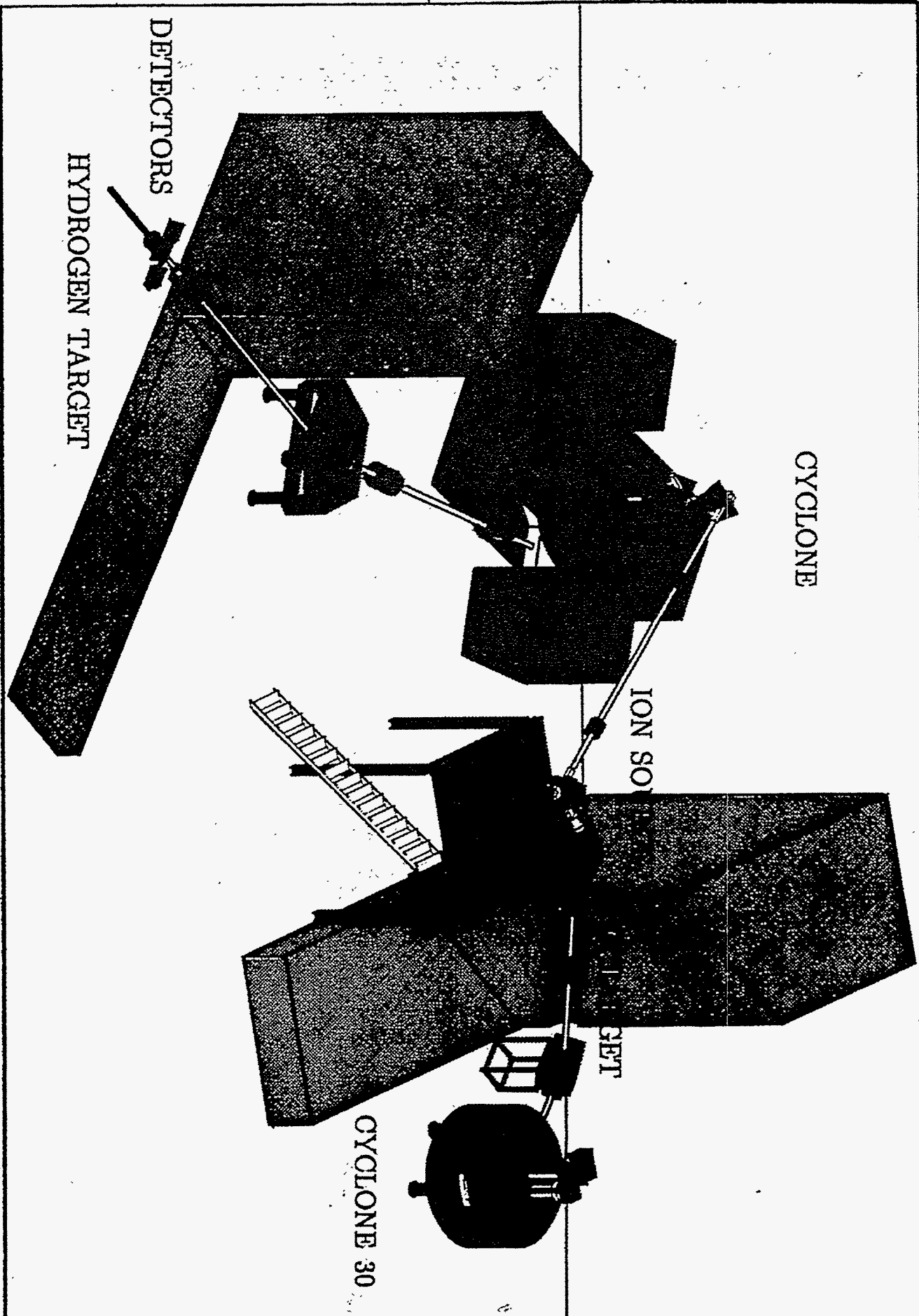
2)

segmented detector

Beams available:

Element	$T_{1/2}$	Q	Intensity (pps)	Maximum energy (MeV)
${}^6\text{He}$	0.8 s	1 ⁺	1.2×10^6	18
${}^{11}\text{C}$	20 min	1 ⁺	1.0×10^7	10
${}^{13}\text{N}$	10 min	1 ⁺	4.0×10^8	8.5
		2 ⁺	3.0×10^8	34
		3 ⁺	3.0×10^7	70
${}^{18}\text{Ne}$	1.7 s	3 ⁺	4.2×10^5	55
${}^{19}\text{Ne}$	17 s	2 ⁺	1.9×10^9	23
		3 ⁺	1.5×10^9	50
		4 ⁺	5.0×10^8	93
${}^{35}\text{Ar}$	1.8 s	5 ⁺	10^5	79
${}^{18}\text{F}$	110 min	2 ⁺	1×10^6	24

LOUVHANI

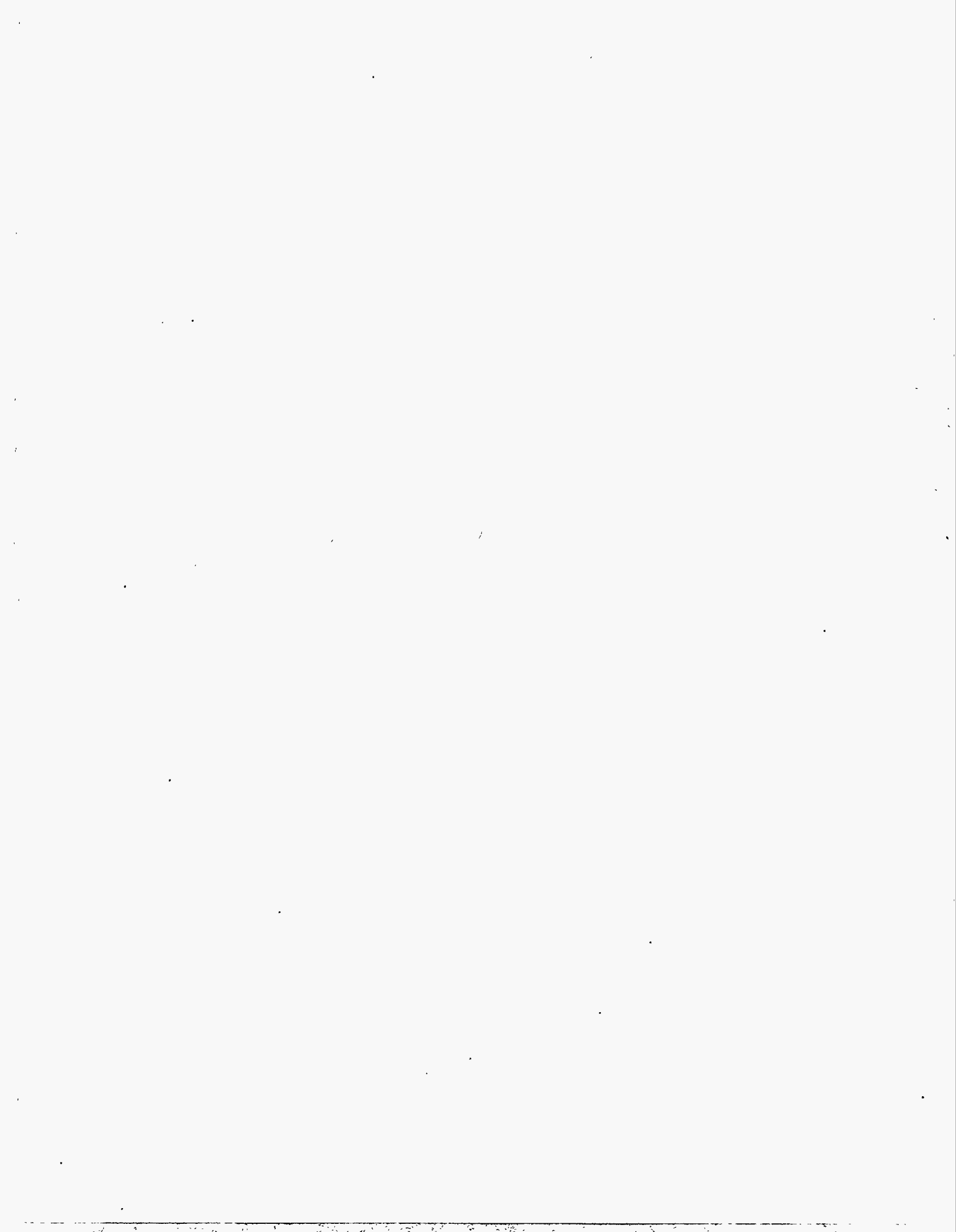


P.A.I. - 08-02-91 - HG

Radioactive Beam Research at Louvain la Neuve

- a) Brief word about facility
- b) General experimental problems with intense radioactive beams
- c) Examples of Nuclear Astrophysics experiments
- d) List of Nuclear physics experiments
- e) Instrumentation

Collaboration: Brussels-Budapest-Edinburgh-Leuven -LLN-Notre Dame



Alan Shotter

University of Edinburgh
Edinburgh, UK

Measured Yields- 25 m capillary

10 MeV p + ^{14}N , 10 small capillaries

^{11}C

^{14}O

1.9×10^8 /sec/ μA

6.35×10^9 /sec/ μA

Situation at ORNL

Beams: (alleged) ^{74}As , ^{72}As , ^{70}As

possibly ^{17}F

possibly ^{33}Cl , ^{34}Cl

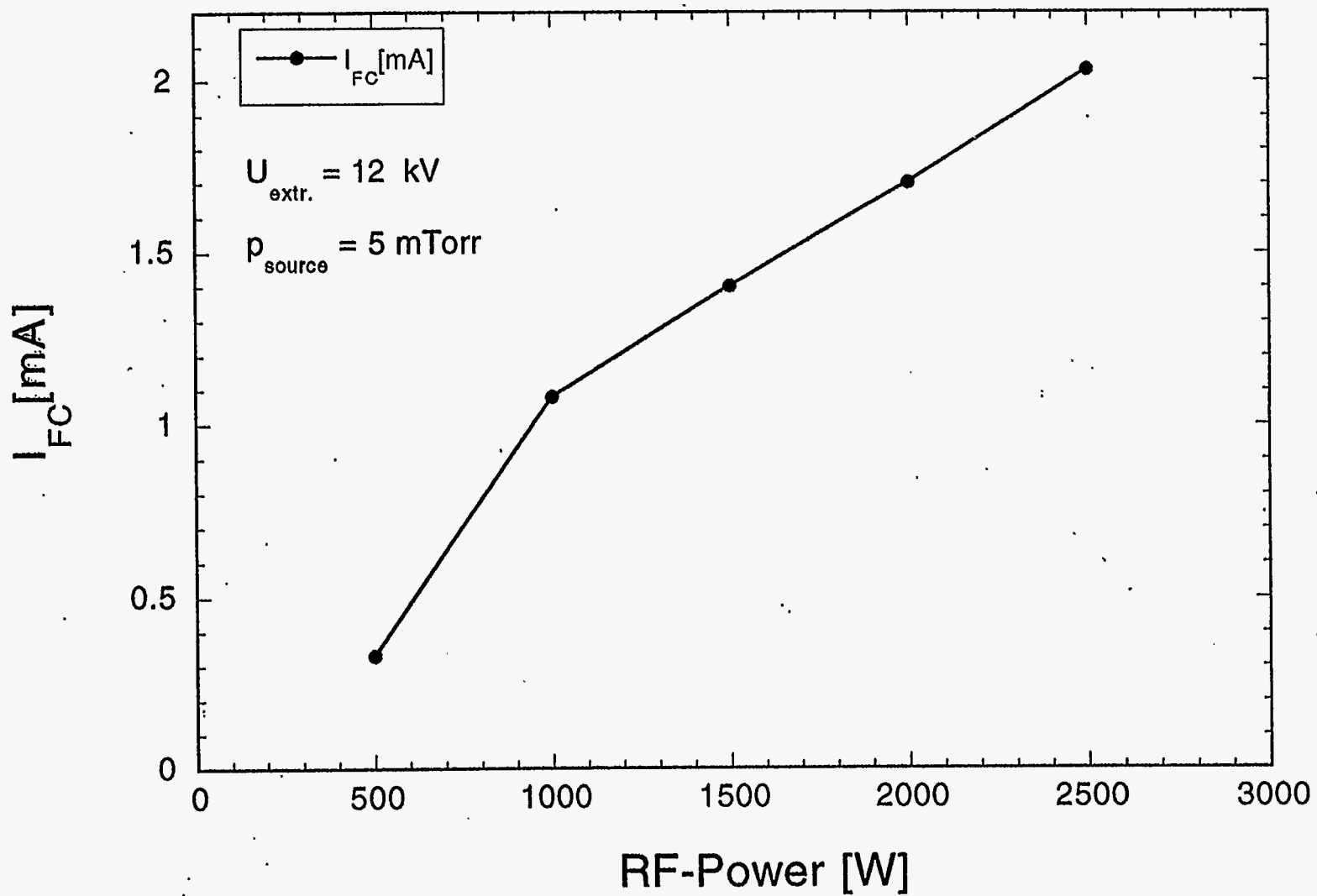
They received 34 Letters of Intent

7 Reaction Studies

9 Nuclear Astrophysics

18 Nuclear Structure

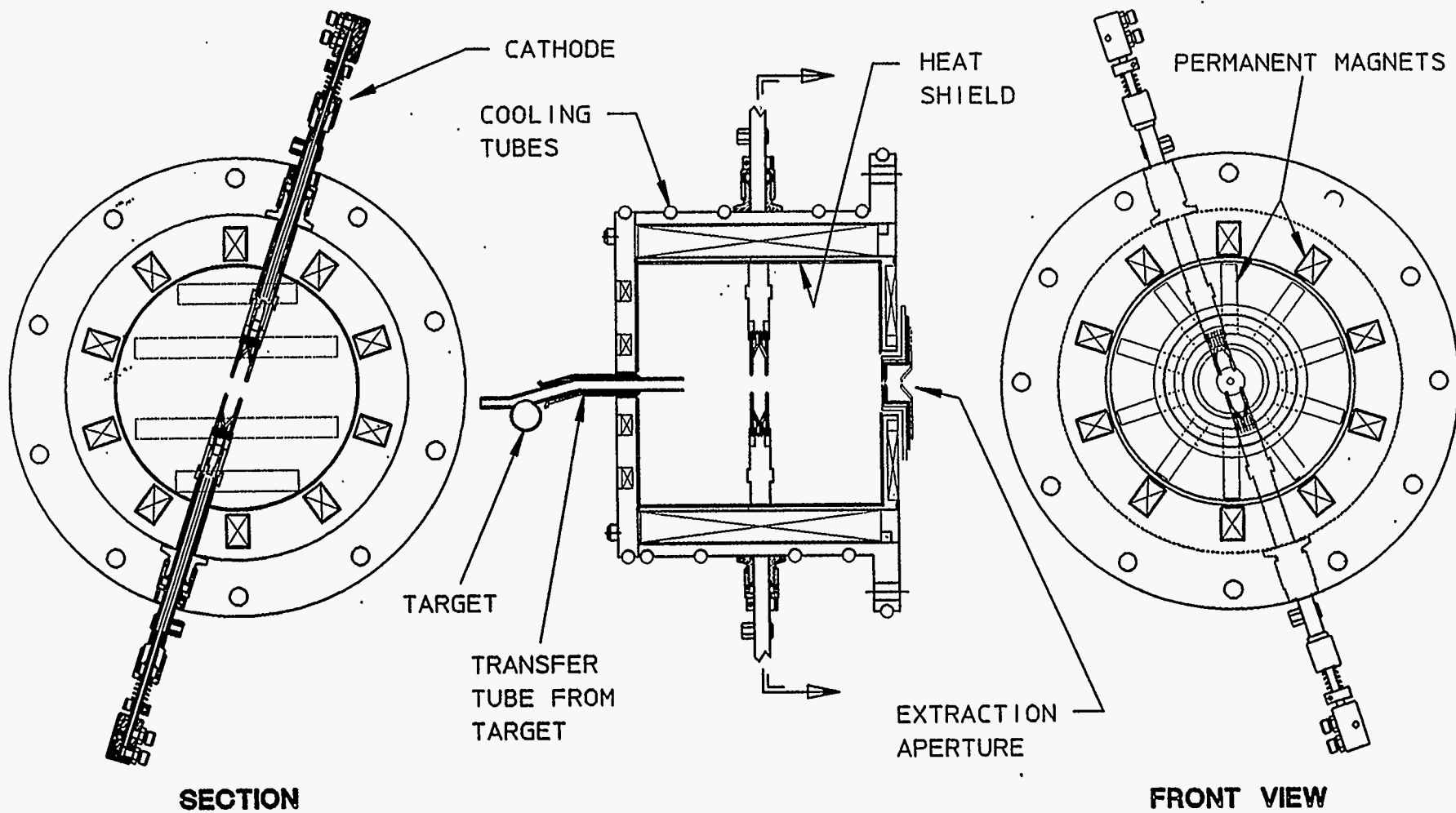
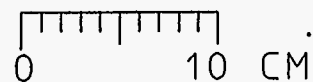
Extracted ion current vs. RF Power

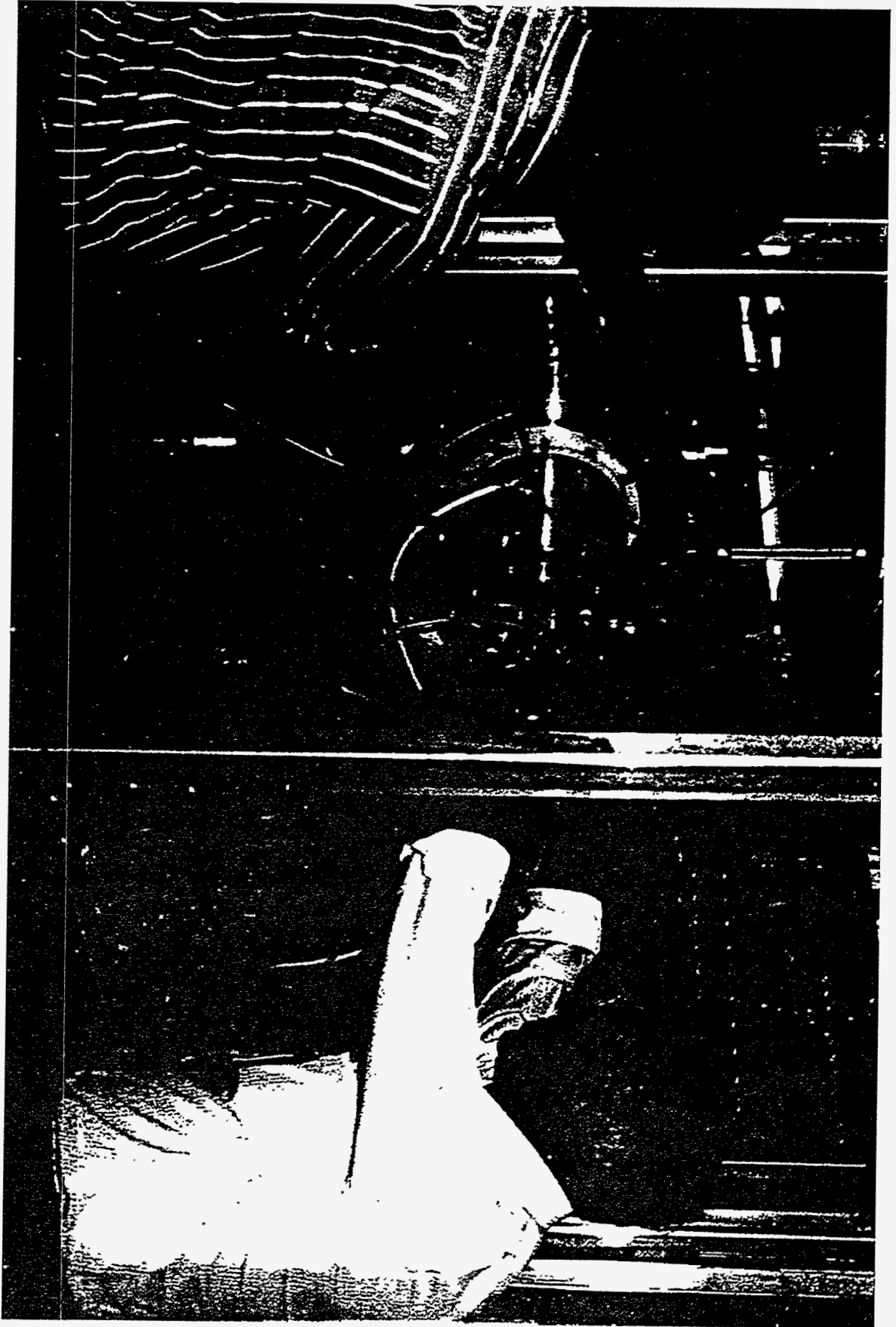




TRIUMF SOURCE

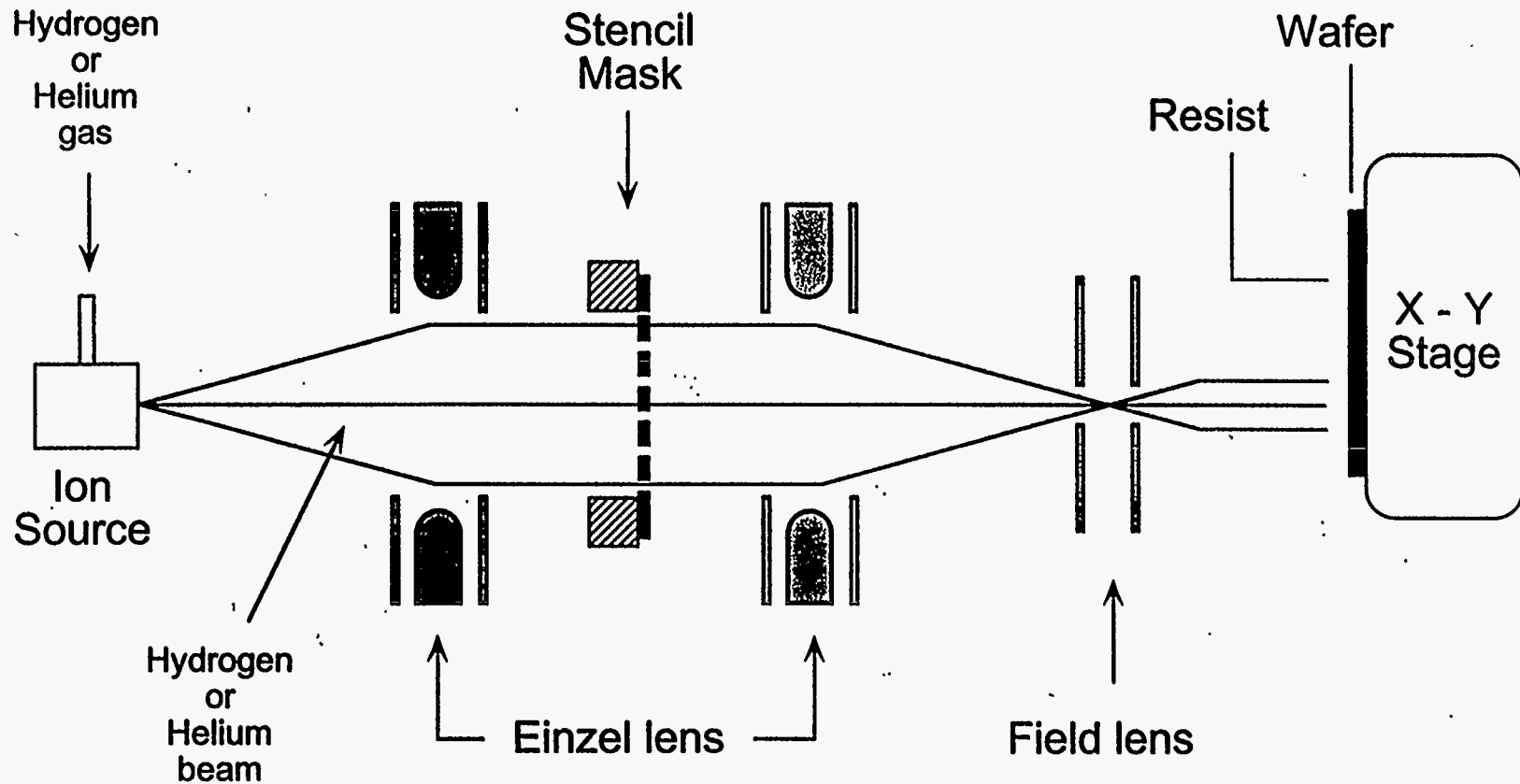
(FOR RADIOACTIVE ION BEAM PRODUCTION)



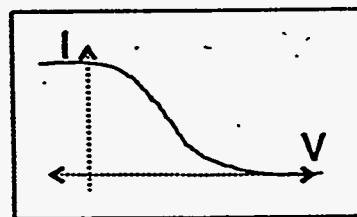
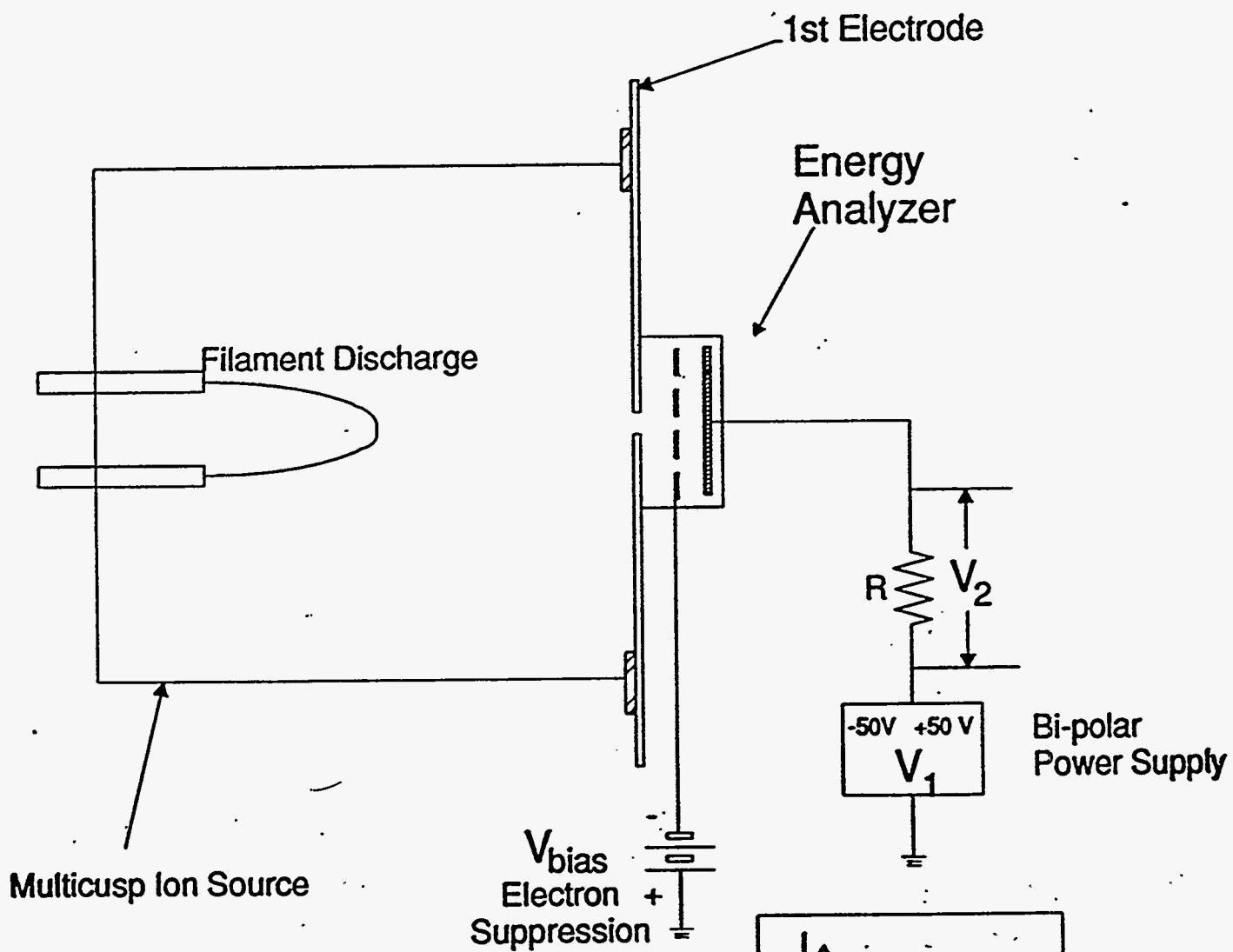


Alpha – 5x Ion Projection Exposure

Ion Microfabrication Systems (IMS)



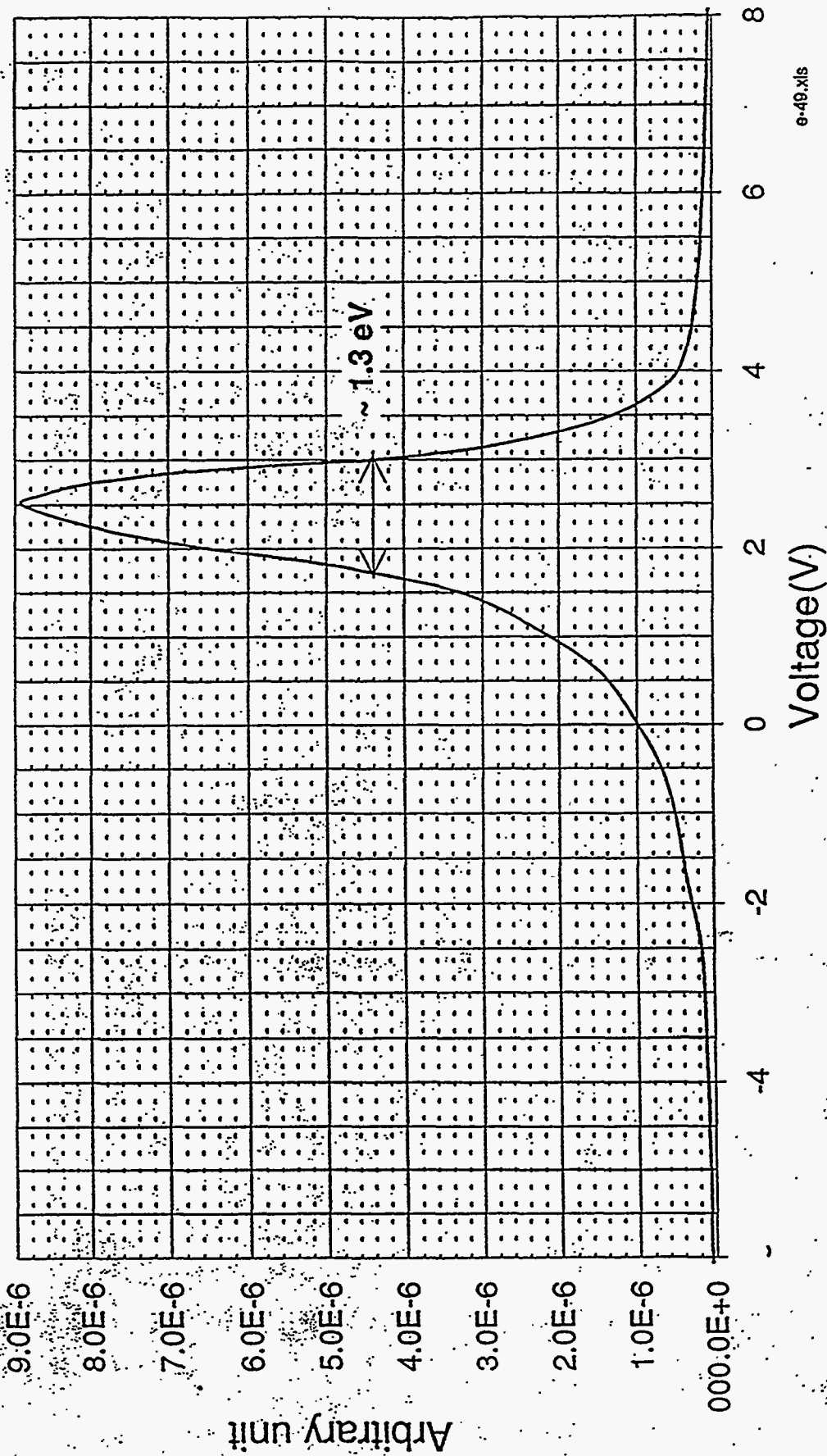
ENERGY ANALYZER SCHEMATIC



Data Acquisition System

$$V = V_1 + V_2; I = \frac{V_2}{R}$$

10 cm ALG Source, Filament Operation With filters, first electrode floating



Mevva ion sources

- Vacuum-arc-based ion sources have virtue of producing ion beams that are
high current
metal
- Important applications are
ion implantation
accelerator injection
tool for fundamental vacuum arc physics
- It is feasible to make a giant ion beam device (implanter)
- A new ion source looking for new applications

Accelerator Injection Applications

For synchrotron injection

- Bevalac, LBL – Limited tests
- Unilac & SIS, GSI – Program is ongoing
- ITEP, Moscow – Limited tests

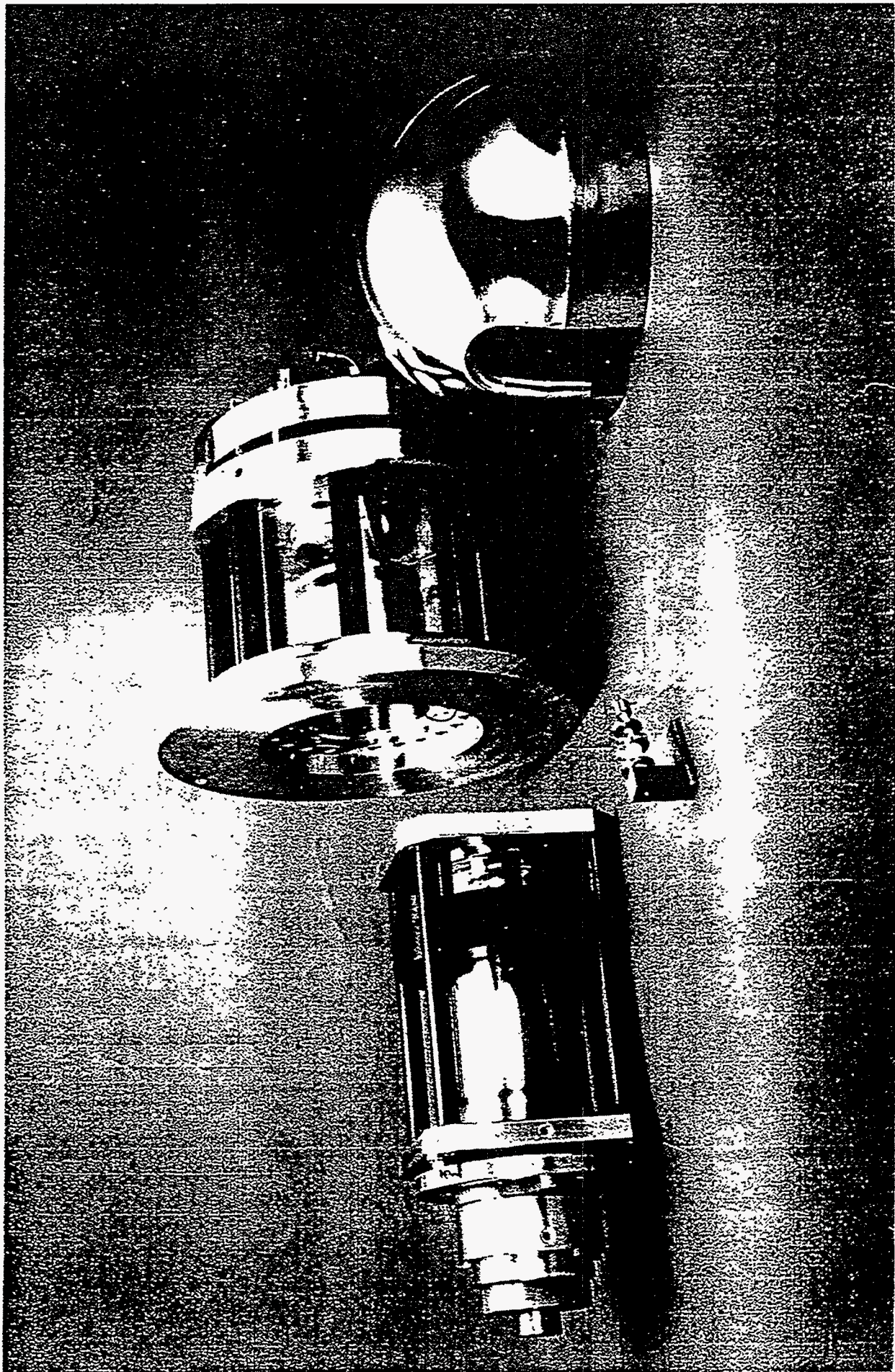
For heavy ion fusion

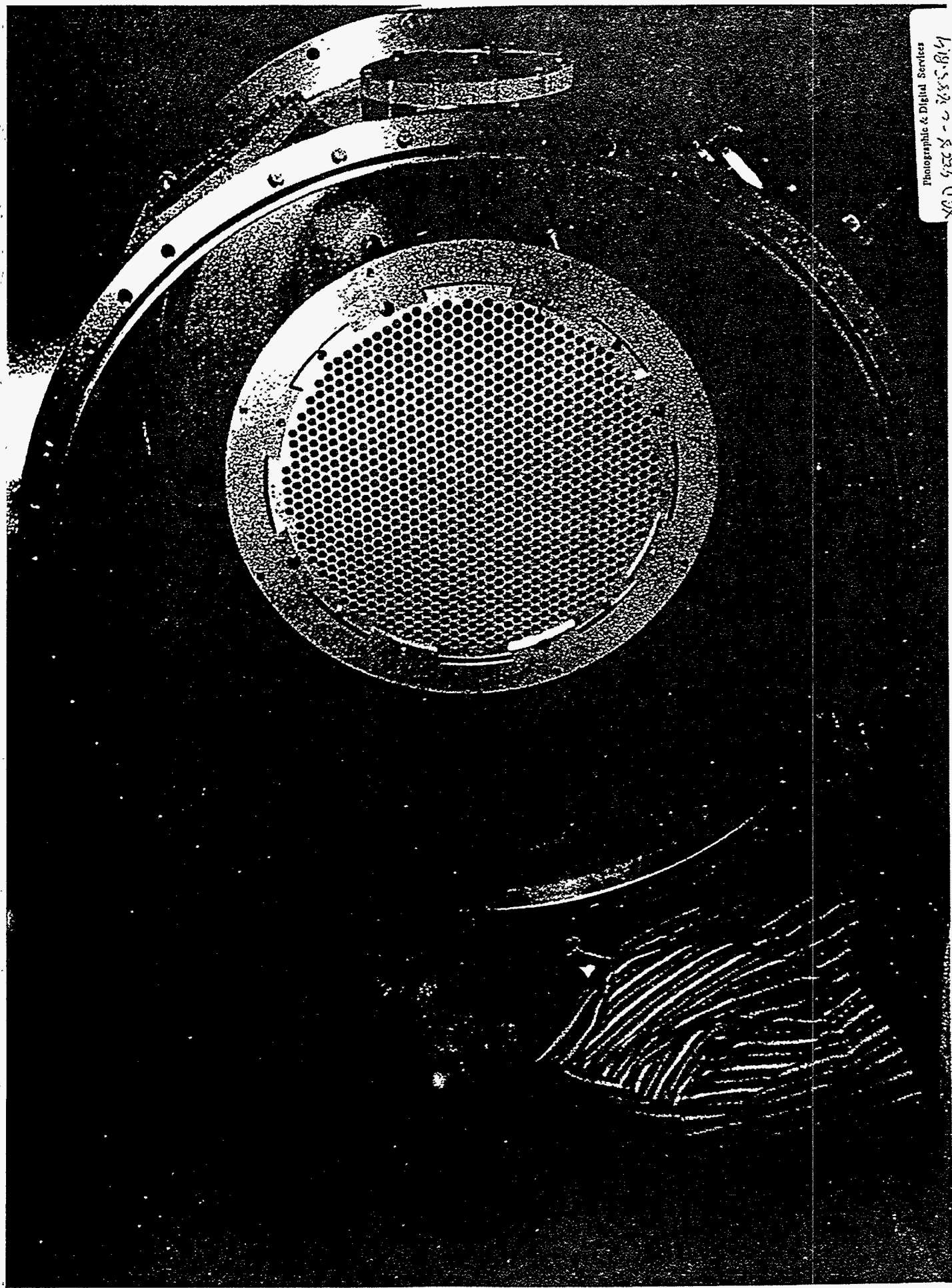
- ITEP, Moscow – In development

Problem: Transport of high current beams

Source & beam characteristics

Extraction voltage	10 – 100 kV
Beam current	10 mA – 20 A
" diameter	0.1 – 50 cm
" divergence	$\geq 2^\circ$
" emittance	$\geq 0.05 \pi$ cm.mrad.
" length	10 μs – dc
Ion species	Li, C, Mg, Al, Si, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ge, Sr, Y, Zr, Nb, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Ce, Pr, Nd, Sm, Gd, Dy, Ho, Er, Tm, Yb, Hf, Ta, W, Ir, Pt, Au, Pb, Bi, Th, U
Ion charge state	1 – 6
ion energy	10 - 600 keV





Photographic & Digital Services
XSD 4558-2 3685-B14
PREPARED BY NATIONAL LABORATORY

ELEMENT	Z	Q=1+	2+	3+	4+	5+	6+	\overline{Q}_p
Li	3	100						1.0
C	6	100						1.0
Mg	12	46	54					1.5
Al	13	38	51	11				1.7
Si	14	63	35	2				1.4
Ca	20	8	91	1				1.9
Sc	21	27	67	6				1.8
Ti	22	11	75	14				2.1
V	23	8	71	20	1			2.1
Cr	24	10	68	21	1			2.1
Mn	25	49	50	1				1.5
Fe	26	25	68	7				1.8
Co	27	34	59	7				1.7
Ni	28	30	64	6				1.8
Cu	29	16	63	20	1			2.0
Zn	30	80	20					1.2
Ge	32	60	40	*				1.4
Sr	38	2	98					2.0
Y	39	5	62	33				2.3
Zr	40	1	47	45	7			2.6
Nb	41	1	24	51	22	2		3.0
Mo	42	2	21	49	25	3		3.1
Pd	46	23	67	9	1			1.9
Ag	47	13	61	25	1			2.1
Cd	48	68	32					1.3
In	49	66	34	*				1.4
Sn	50	47	53					1.5
Ba	56		100					2.0
La	57	1	76	23				2.2
Ce	58	3	83	14				2.1
Pr	59	3	28	69				2.7
Nd	60		83	17				2.2
Sm	62	2	83	15				2.1
Gd	64	2	76	22				2.2
Dy	66	2	66	32				2.3
Ho	67	2	66	32	*			2.3
Er	68	1	63	35	1			2.4
Yb	70	3	88	8				2.1
Hf	72	3	24	51	21	1		2.9
Ta	73	2	33	38	24	3		2.9
W	74	2	23	43	26	5	1	3.1
Ir	77	5	37	46	11	1		2.7
Pt	78	12	69	18	1			2.1
Au	79	14	75	11				2.0
Pb	82	36	64					1.6
Bi	83	83	17					1.2
Th	90		24	64	12			2.9
U	92		12	58	30			3.2

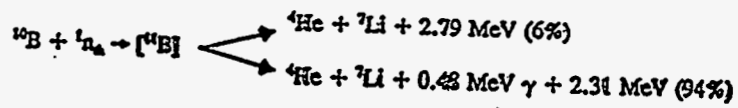
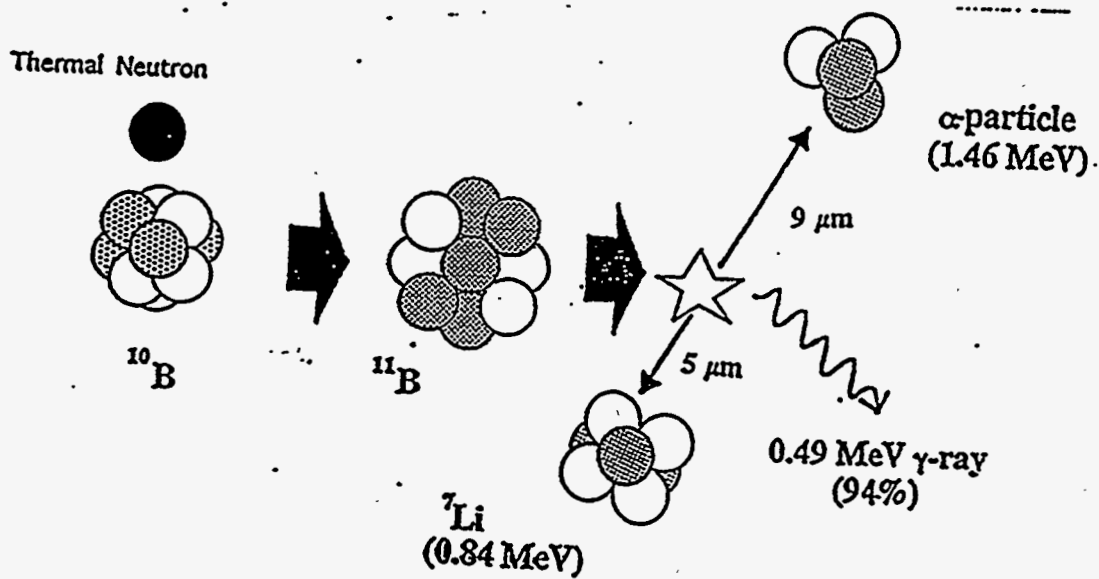
Ion implantation research applications

Some examples of research projects done:

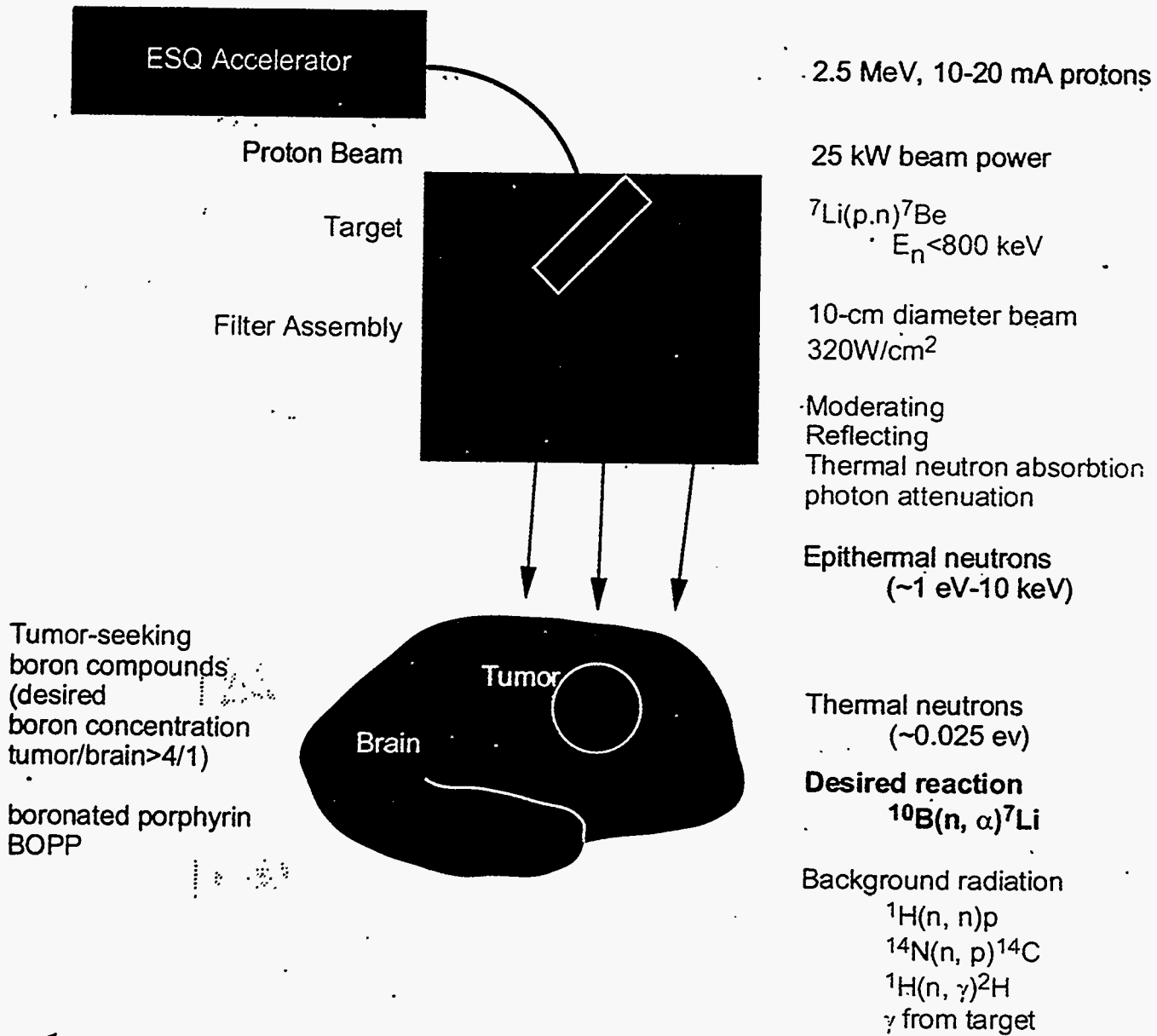
- High temperature oxidation inhibition
- Corrosion resistance
- Hardening of ceramics
- Buried conducting layers in Si (IrSi_3)
- Buried strained layers in Si ($\text{Si}_{1-x}\text{Ge}_x$)
- Hi- T_c film compositional "tuning": Y, Cu into YBaCuO
- Fundamental study of implantation ranges in C
- Effect of implantation on diamond nucleation
-

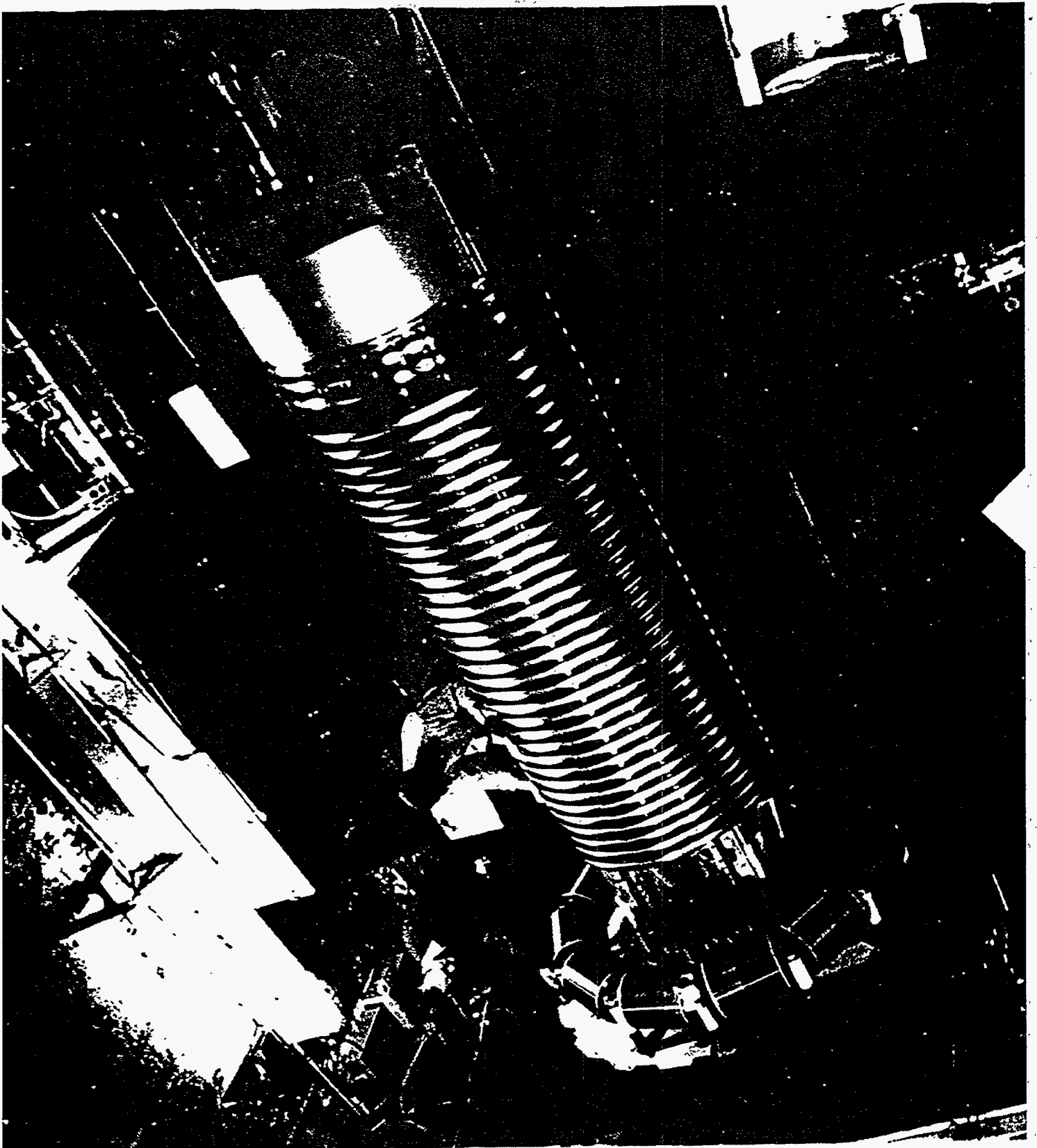
PHYSICS AND BIOLOGY OF BNCT

WHAT IS BNCT



BORON NEUTRON CAPTURE THERAPY (BNCT)

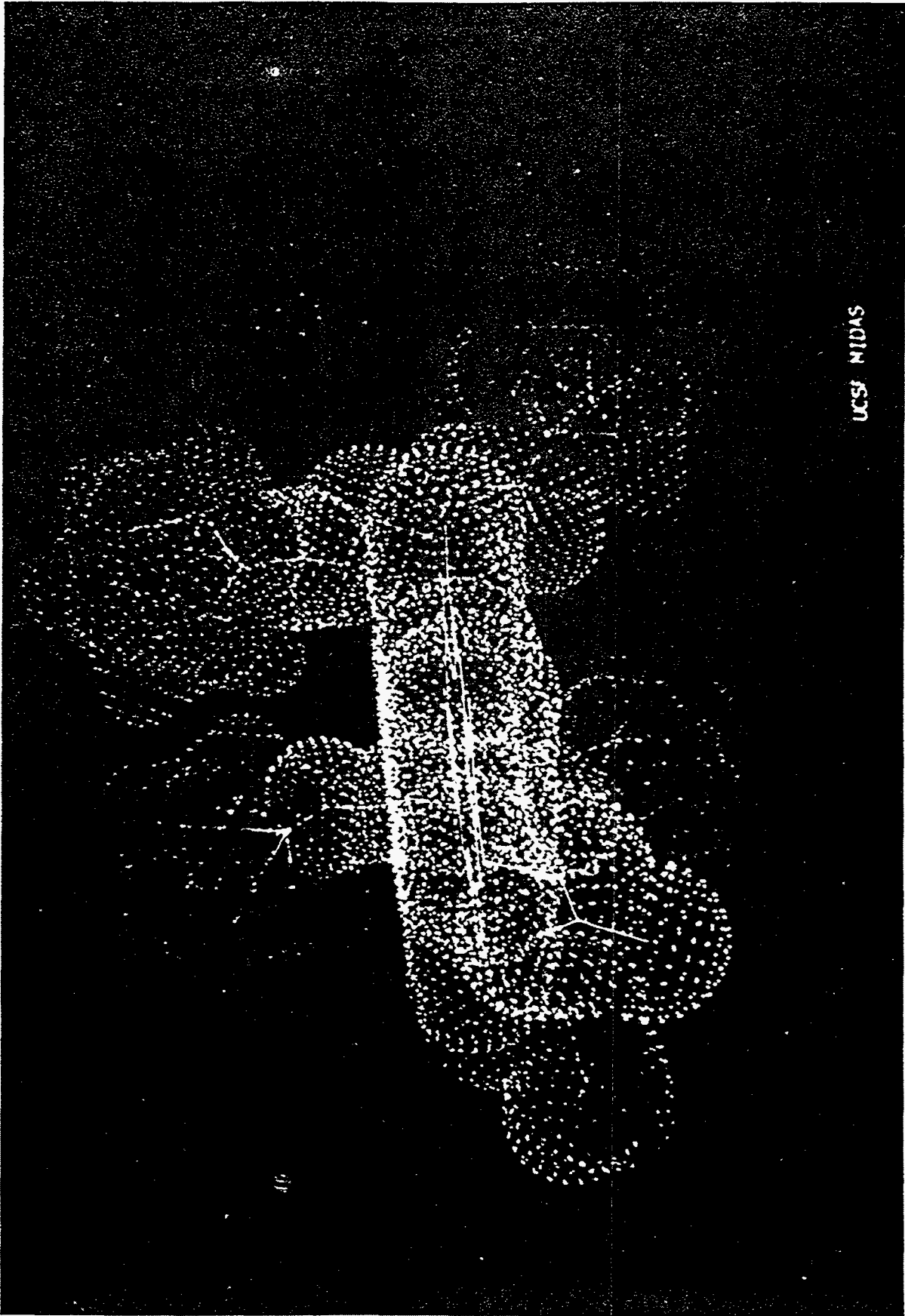




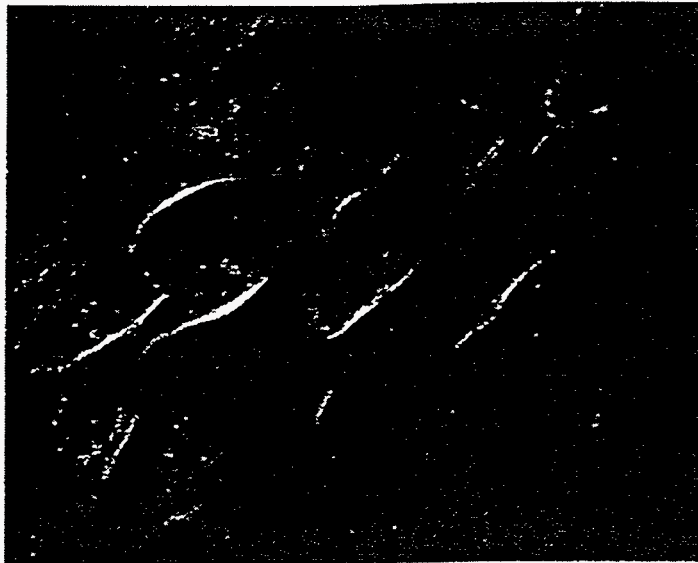
STUDIES FOR BNCT RADIOBIOLOGY

BOPP Boronated protoporphyrin

- 30% boron by weight**
- highly water soluble**
- 10 boron atoms / cage**
- 40 boron atoms / molecule**
- tumor/normal tissue ratio in mice: 400/1**



LCSF MIDAS



PHYSICS AND BIOLOGY OF BNCT
POTENTIAL TUMORS
FOR BNCT TREATMENT

INITIAL TARGETS

- **GLIOBLASTOMA MULTIFORME**
- **ANAPLASTIC ASTROCYTOMAS**
- **SQUAMOUS CELL CANCER OF THE HEAD AND NECK**
- **MELANOMA**
- **PANCREATIC CANCER**

Purpose:

- Prepare an ESQ-based BNCT facility *at Berkeley Lab.*
- Perform multi-faceted *science-based* Phase I/II BNCT clinical trials starting in 1999.
- Advanced accelerator studies leading to the design of *hospital-based* BNCT facilities.
- Technology transfer of BNCT to medical centers for Phase III clinical trials.

Ted Ognibene

Lawrence Berkeley National Laboratory
Berkeley, CA

Beta-Delayed Proton Decays of ^{27}P and ^{31}Cl

T. J. Ognibene, J. Powell, D. M. Moltz,
M. W. Rowe and Joseph Cerny

88-Inch Cyclotron

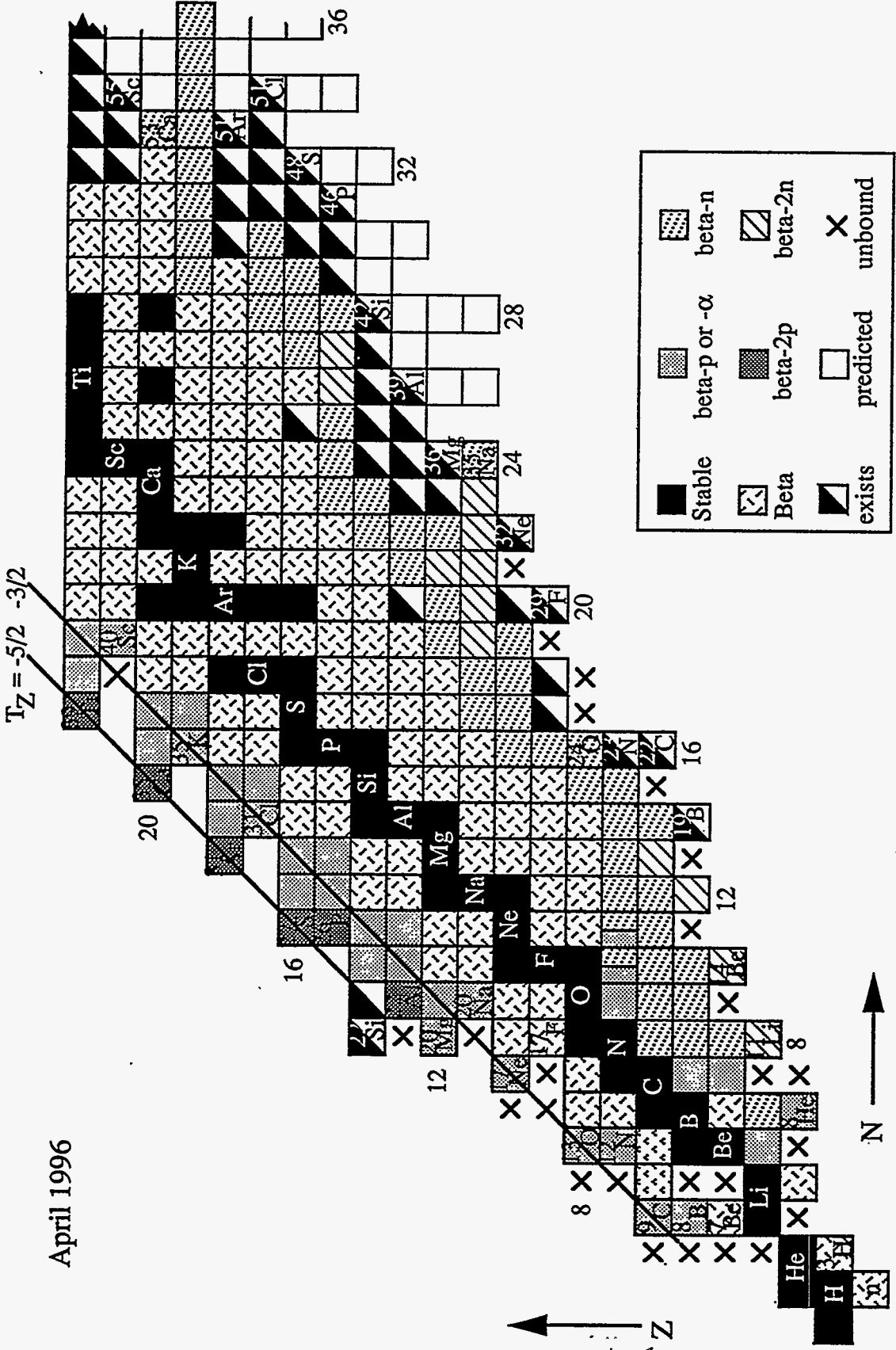
Department of Chemistry,
Lawrence Berkeley National Laboratory,
University of California, Berkeley

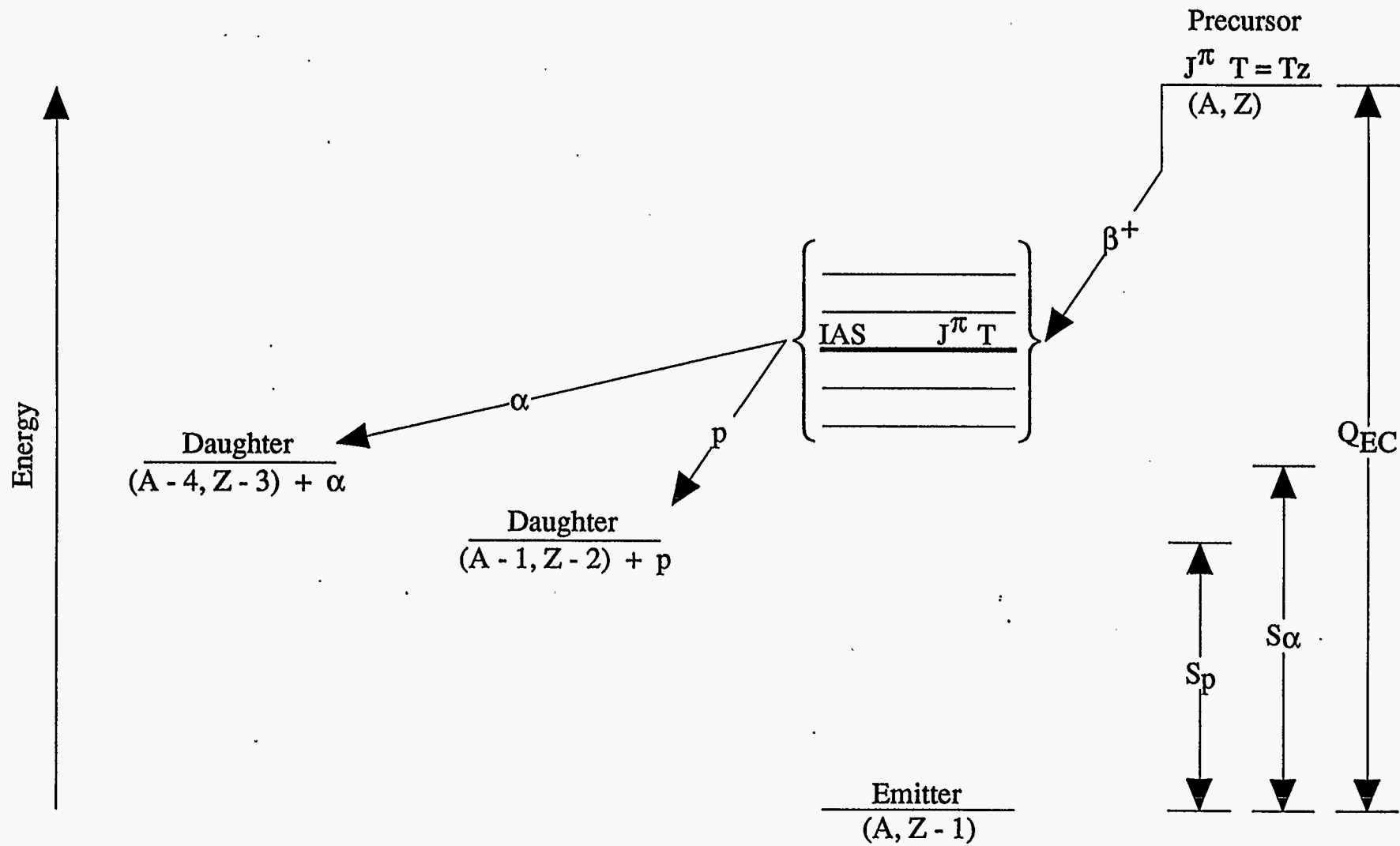
Outline

- Introduction
- Experimental Techniques
- Results
 - ^{27}P
 - ^{31}Cl
- Conclusions

$$T_Z = \frac{N-Z}{2}$$

April 1996



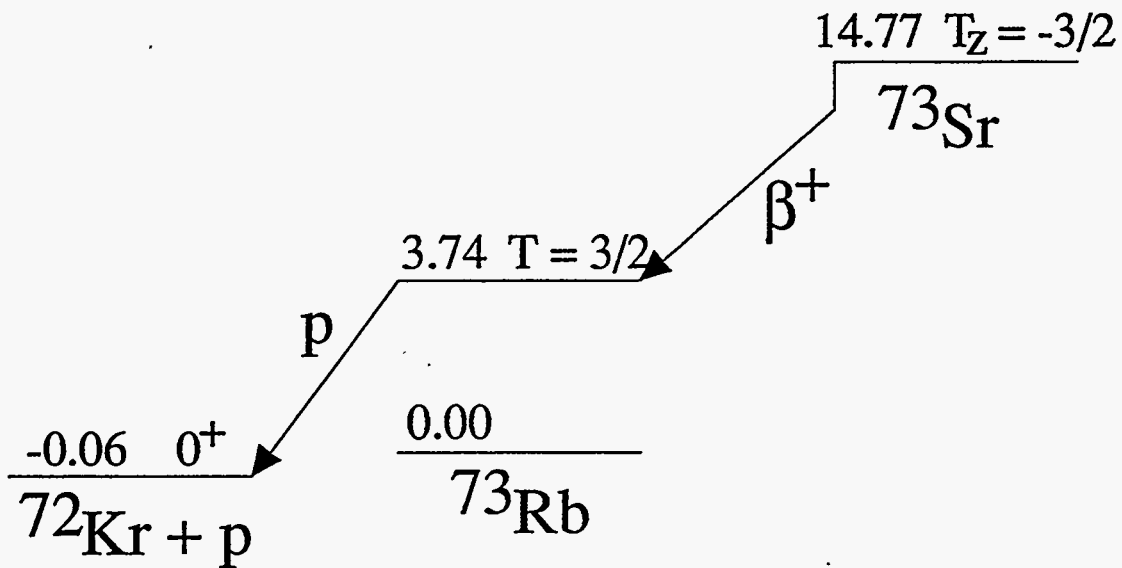


Goals

- Shell Model Tests

$$ft = \frac{K}{g_V^2 \langle 1 \rangle^2 + g_a^2 \langle \sigma \tau \rangle^2}$$

- Mass Models

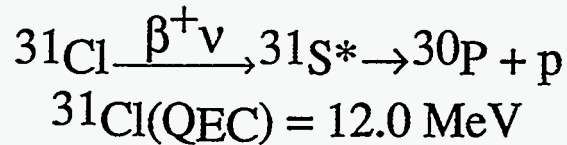
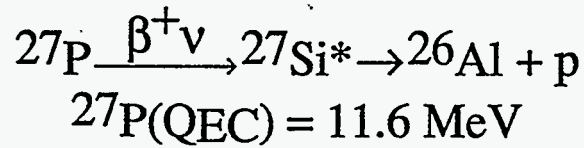


- Nuclear Astrophysics

^{23}Al	^{24}Al	^{25}Al	^{26}Al
^{22}Mg	^{23}Mg	^{24}Mg	^{25}Mg
^{21}Na	^{22}Na	^{23}Na	
^{20}Ne	^{21}Ne	^{22}Ne	

Arrows indicate transitions: $^{20}\text{Ne} \rightarrow ^{21}\text{Na}$, $^{21}\text{Na} \rightarrow ^{22}\text{Mg}$, $^{22}\text{Na} \rightarrow ^{23}\text{Mg}$, and $^{22}\text{Mg} \rightarrow ^{23}\text{Al}$.

The Beta-Delayed Proton Emission of ^{27}P and ^{31}Cl



$$ft = \frac{6170 \text{ sec}}{B(\text{F}) + B(\text{GT})}$$

$$B(\text{F}) = (T - T_z)(T + T_z + 1) \text{ for } \Delta T = \Delta J = 0$$

$$= 0 \text{ for } T_i \neq T_f, J_i \neq J_f$$

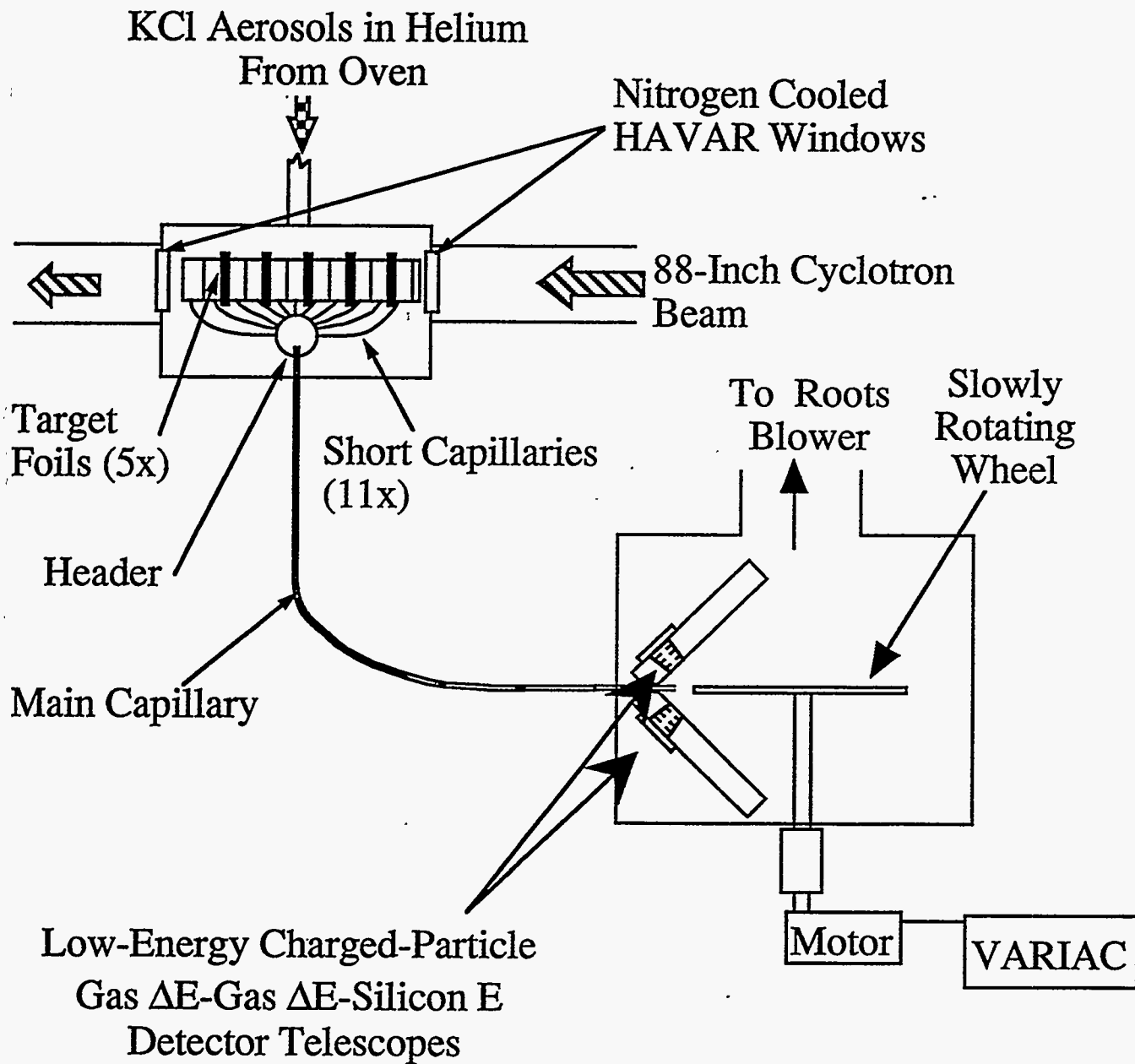
$$B(\text{GT}) = \frac{g_a^2}{g_v^2} \langle \sigma \tau \rangle^2 \text{ for } \Delta J = 0, \pm 1$$

$$f = \int_1^{W_0} F(Z, W) W(W^2 - 1)^{1/2} (W_0 - W)^2 dW$$

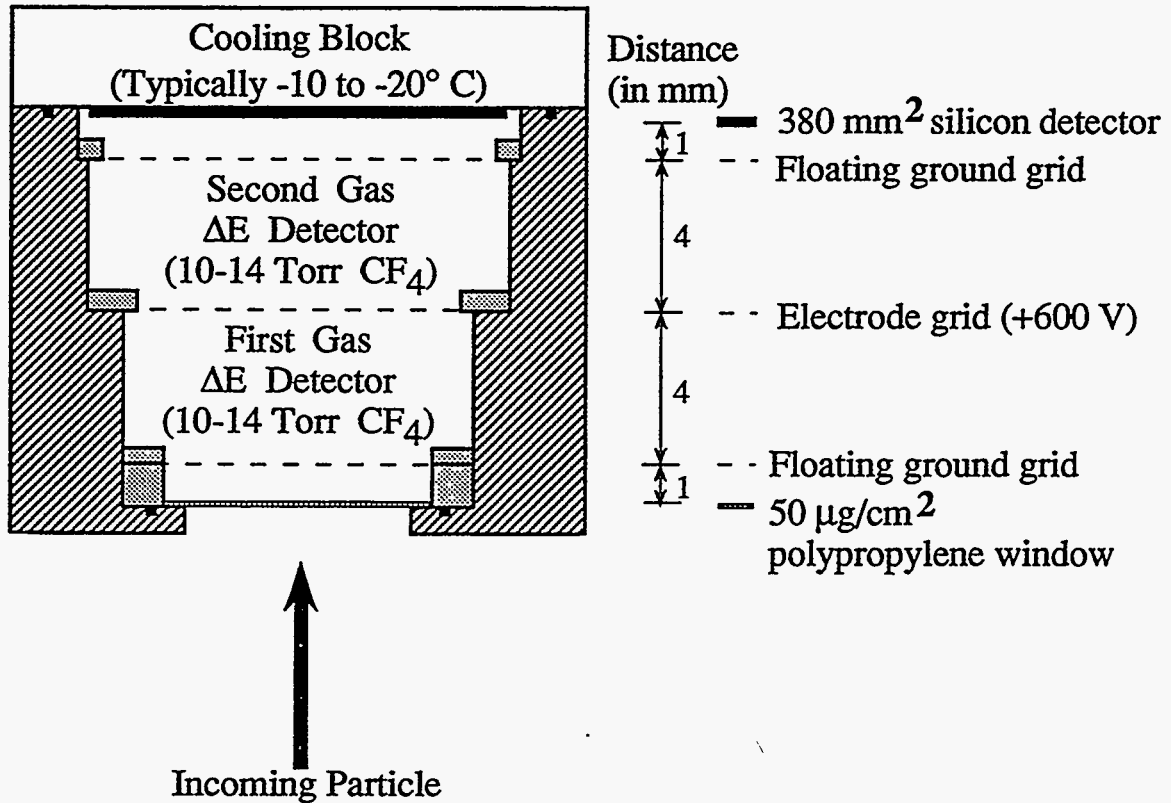
W = positron energy in units of mec^2

$$F(Z, W) = \frac{2\pi Z e^2}{\hbar v \left(1 - \exp\left(\frac{2\pi Z e^2}{\hbar v}\right) \right)}$$

SETUP FOR THE PHOSPHORUS AND CHLORINE β_p EXPERIMENTS



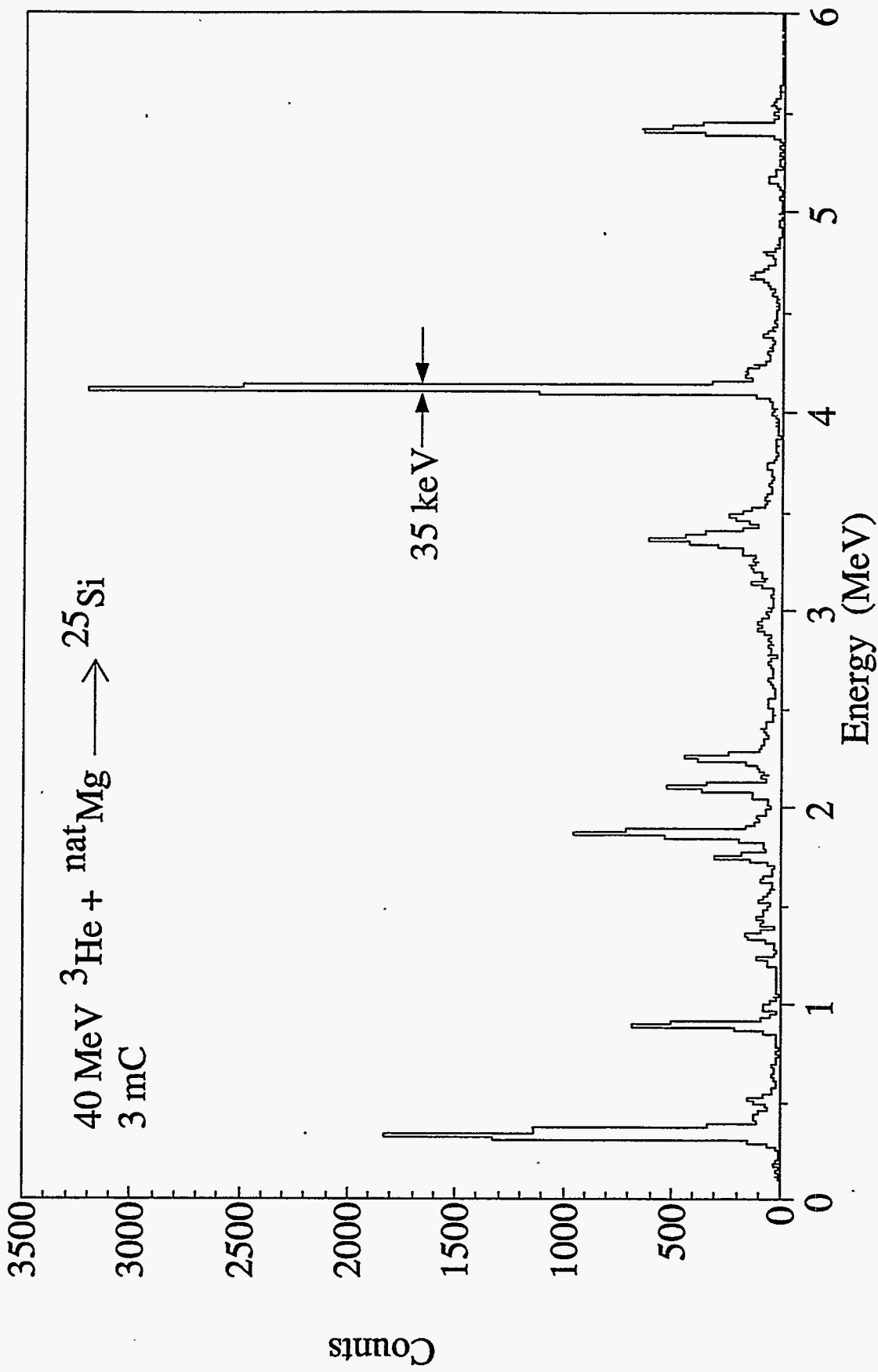
Cross Section Low-Energy Charged-Particle Gas ΔE -Gas ΔE -Silicon E Detector Telescope

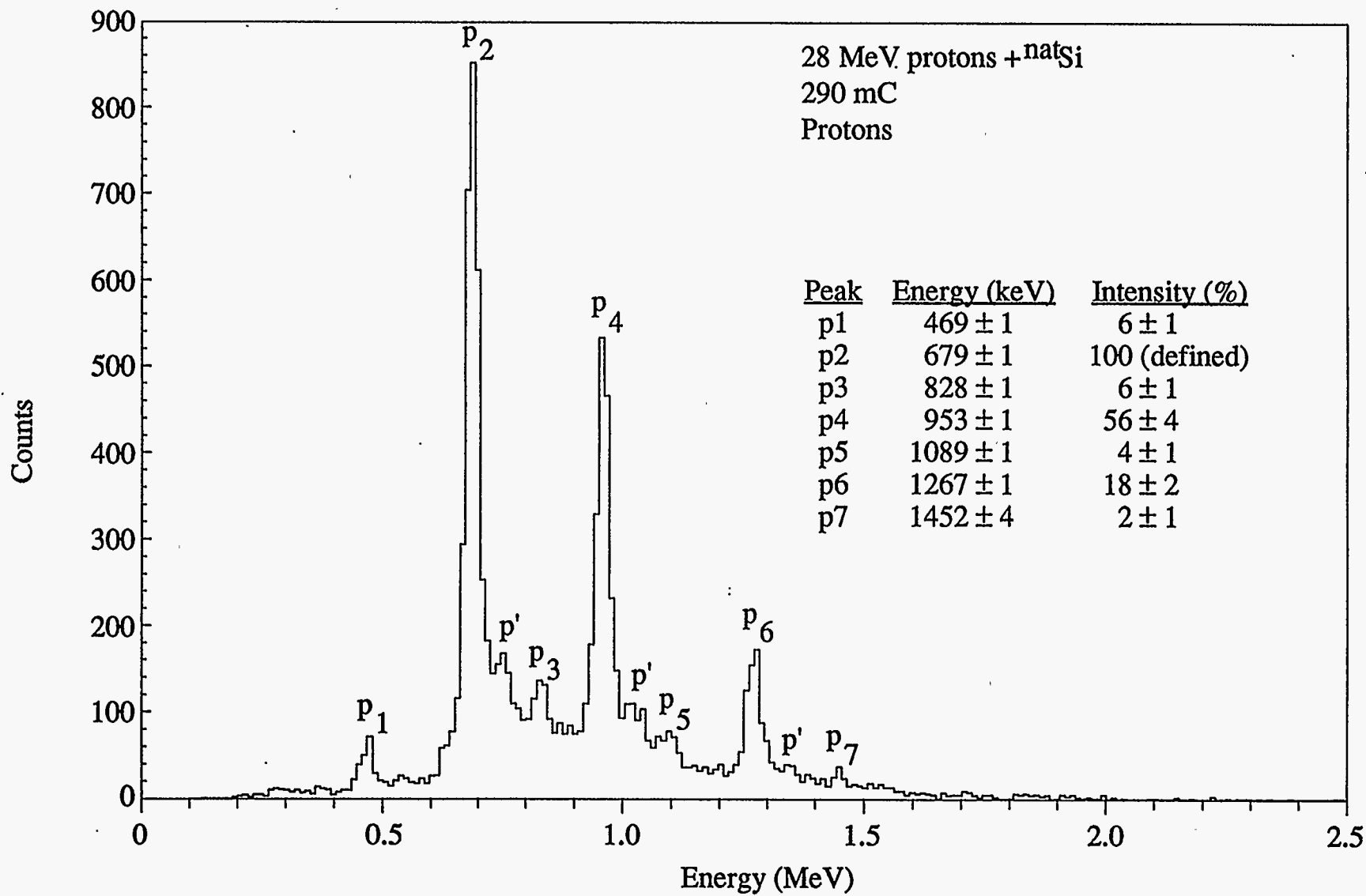


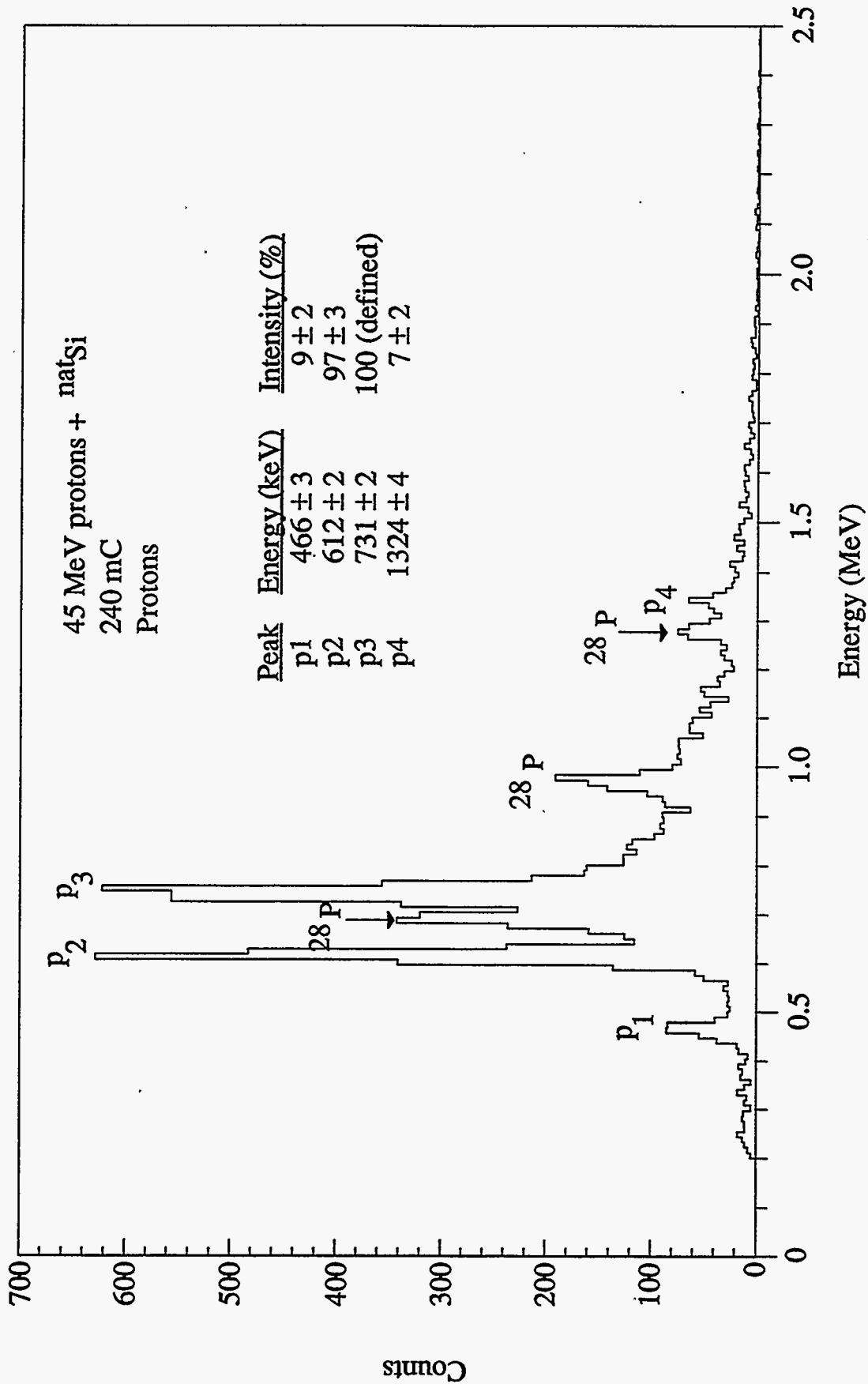
Features

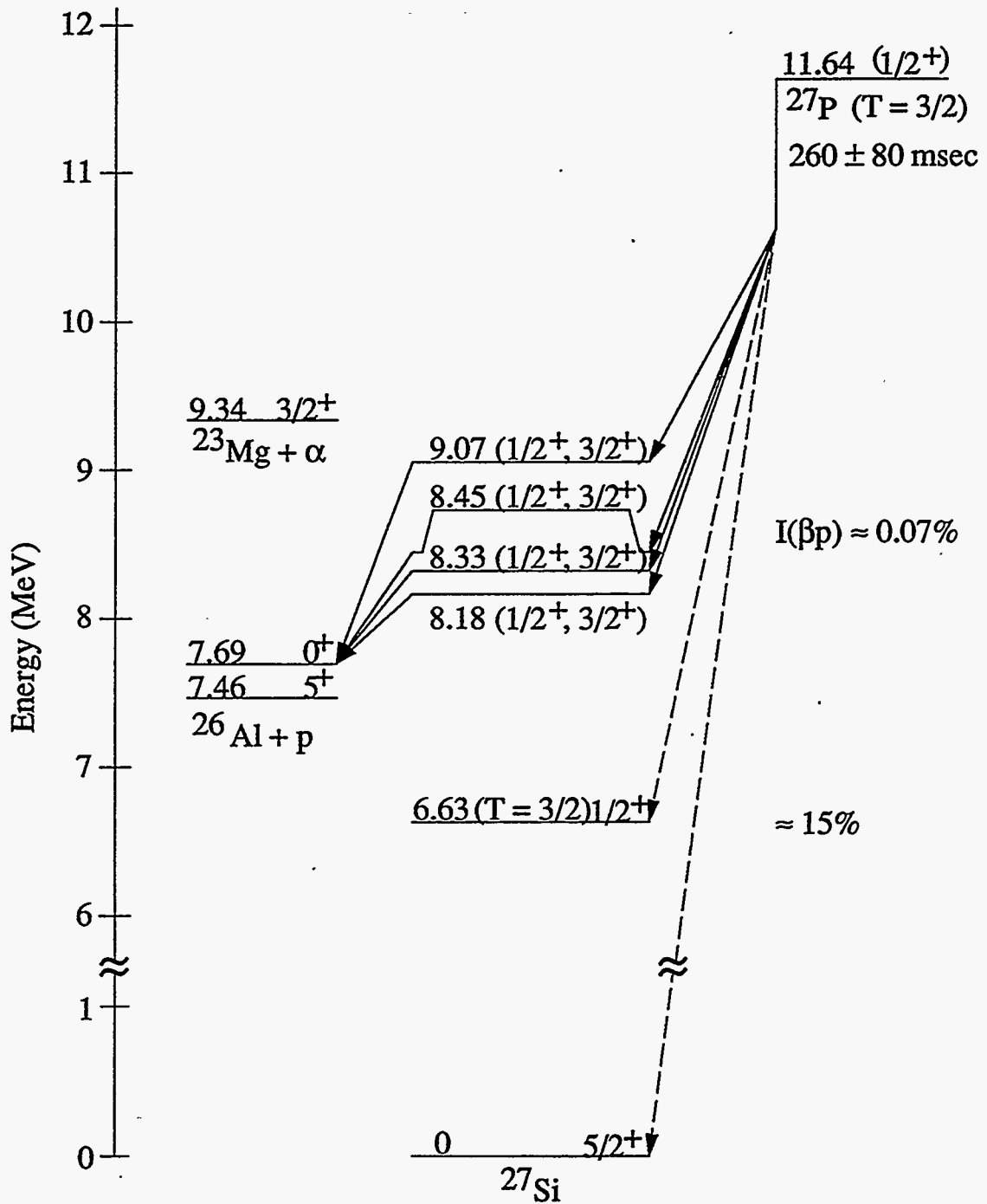
- Low Energy Threshold
- Particle Identification In High Beta Backgrounds

Triple Coincidence Gating

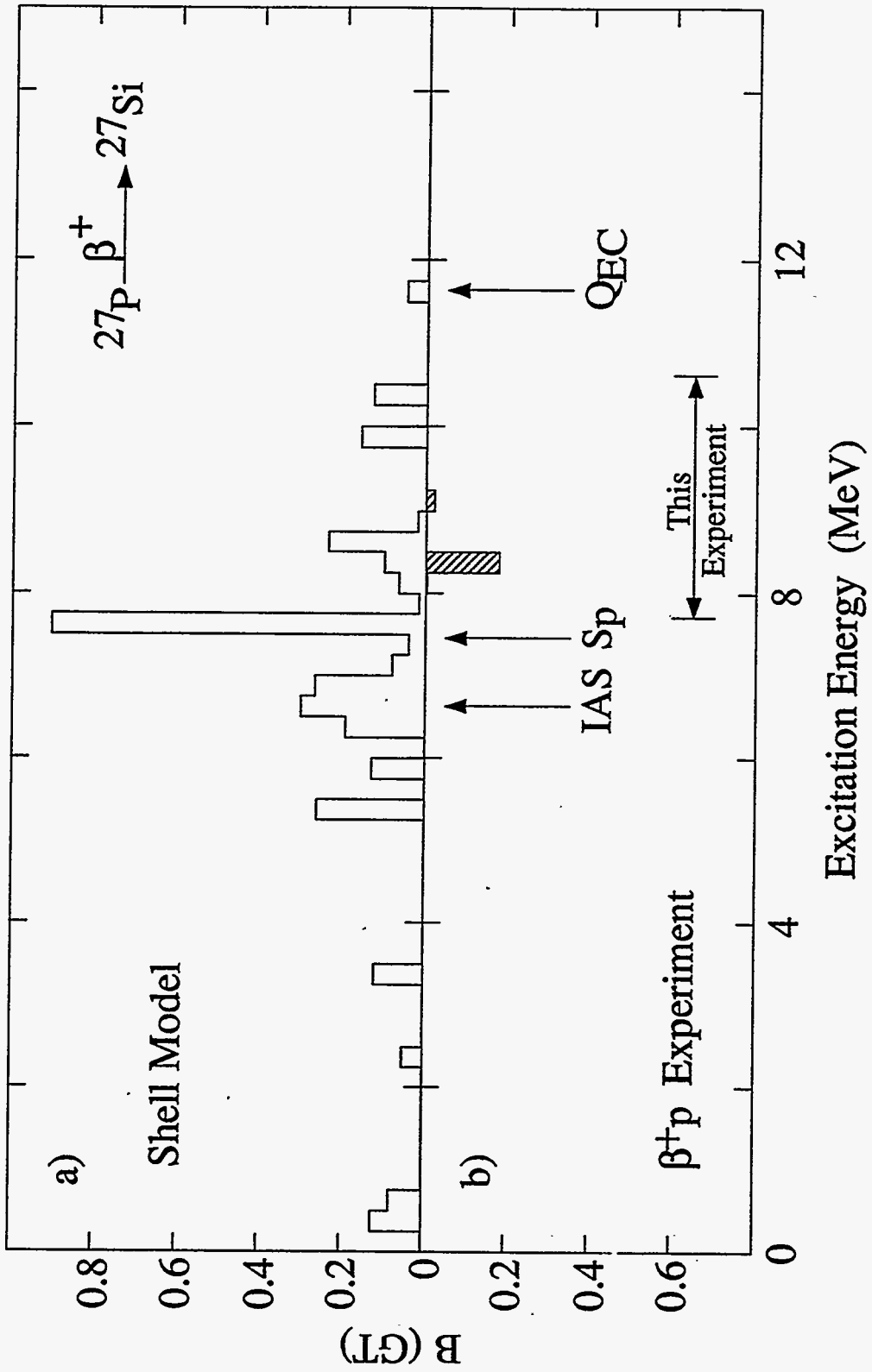


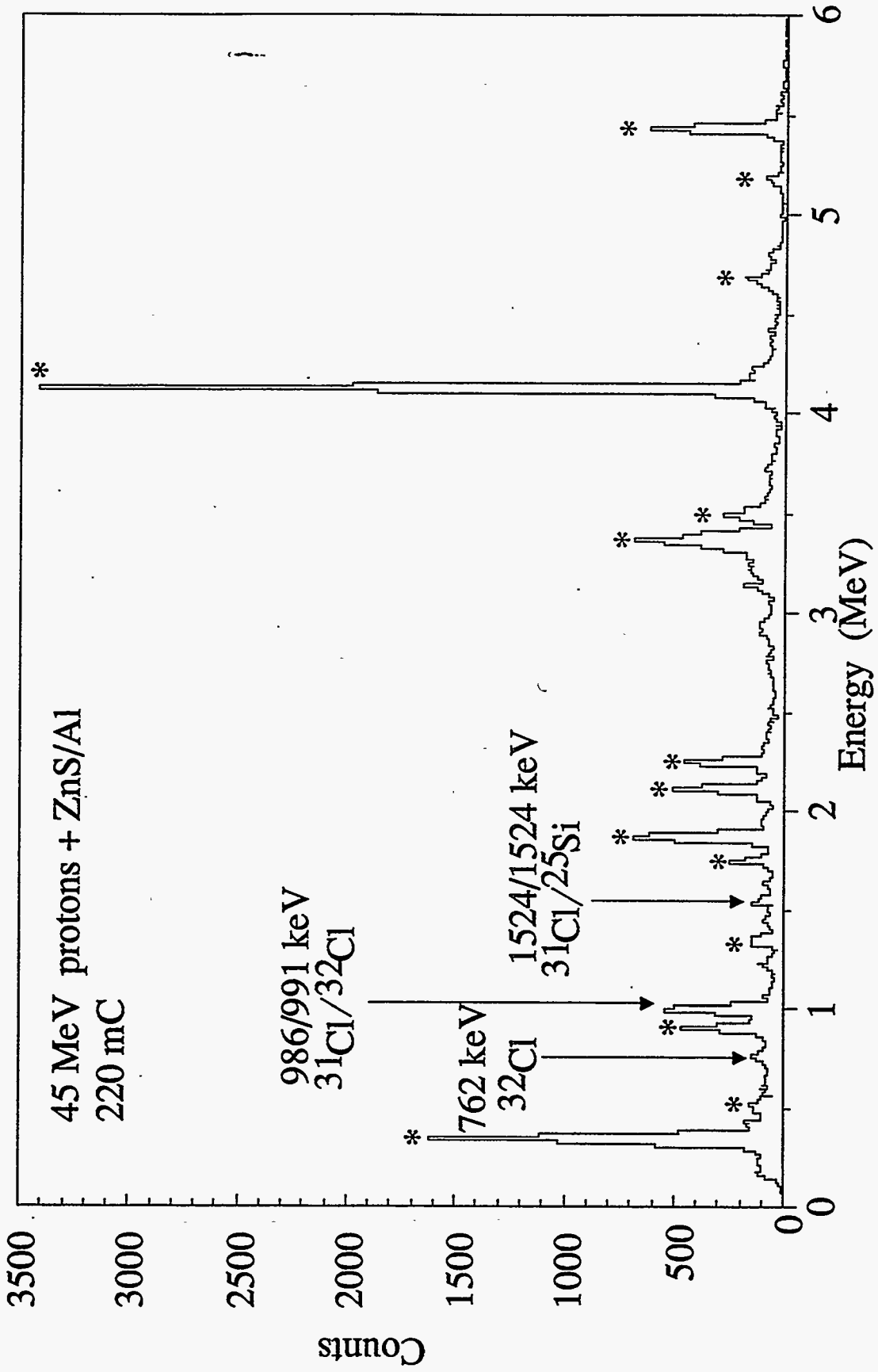






Peak	Energy (keV)	Intensity (%)	$E^*(^{27}\text{Si})$
p1	466 ± 3	9 ± 2	8176 ± 3
p2	612 ± 2	97 ± 3	8328 ± 2
p3	731 ± 2	100 (defined)	8451 ± 2
p4	1324 ± 4	7 ± 2	9067 ± 4





31Cl Beta-Delayed Proton Groups.

$E_p^{a)}$	Relative Proton Intensity	
	This Work	<i>Äystö et al.</i>
845 ± 30	b)	3 ± 2
986 ± 10	100 ^{c)}	$100 \pm 2^c)$
1173 ± 30	b)	3 ± 2
1520 ± 15	11 ± 5	23 ± 6
1695 ± 20	≤ 1	10 ± 3
1827 ± 20	≤ 1	13 ± 4
2113 ± 30	≤ 1	7 ± 3
2204 ± 30	≤ 1	6 ± 3

a) Energies are reported in keV in the laboratory system and are from *Äystö et al.*

b) These proton groups could not be positively identified because of the significant levels of contamination of ^{25}Si beta-delayed protons.

c) Defined.

- Conclusions

New proton groups in $^{27,28}\text{P}$

Shell Model Tests

βp groups in ^{31}Cl

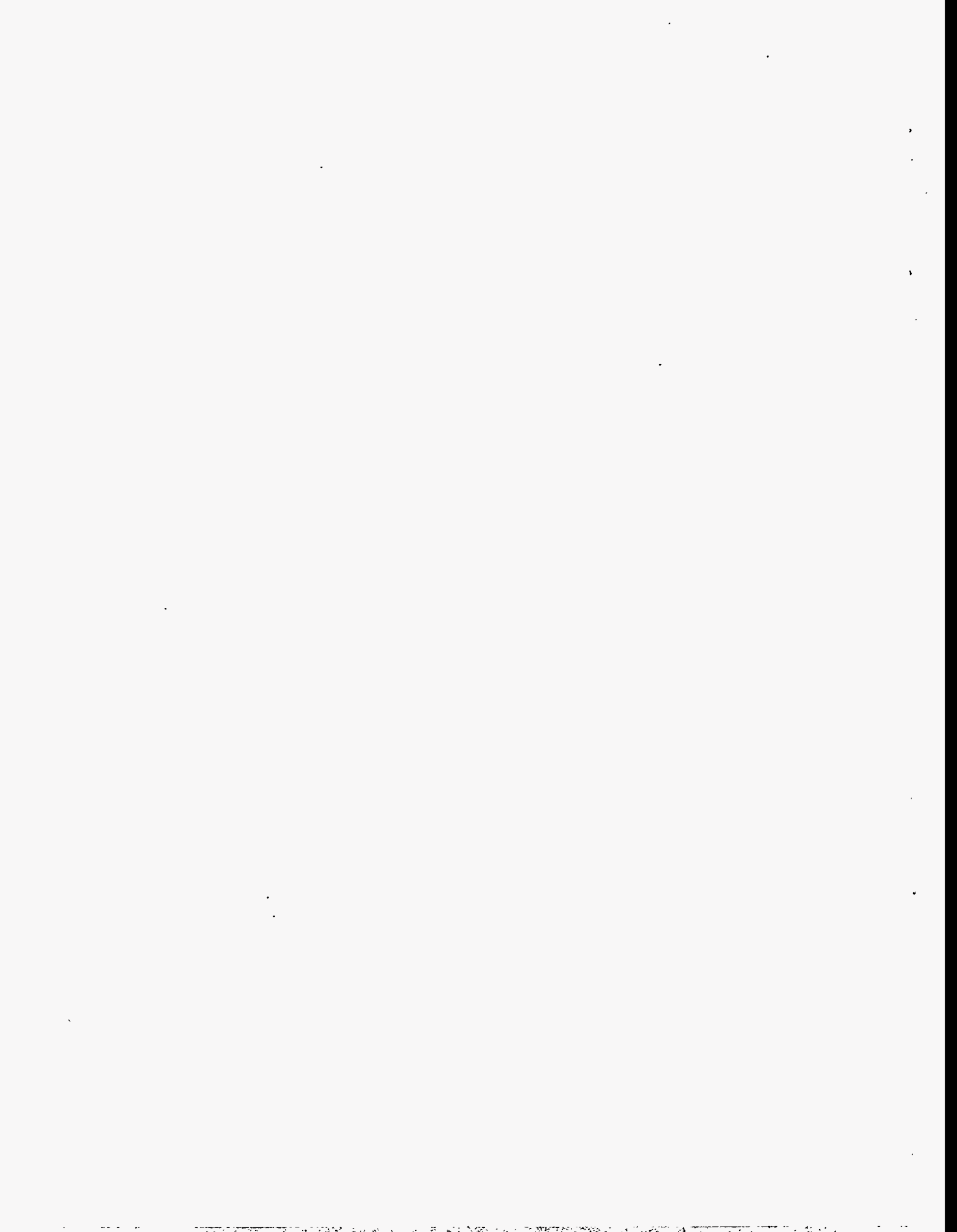
- Future Work

^{27}P and ^{31}Cl $\beta\gamma$ decay studies

Targets for ^{31}Cl

David Vieira

Los Alamos National Laboratory
Los Alamos, NM



Joe's 60th

Dave Vieira
April 15, 1996

UCB/LBL graduate student days

Cerny's group: '73 - '77

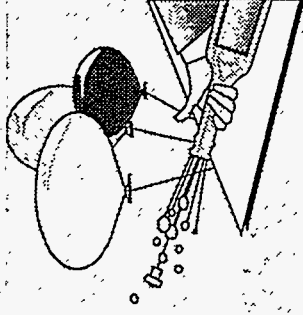
- post-docs: Rick Gough, Mike Zisman, Nick Jelley, Gary Kekelis, Rainer Jahn, Hugh Evans (visitor from Queen's Univ.)
- grad. students: Rich Sextro, Gordon Wozniak, John McDonald, Ken Wilcox, Bob Weisenmiller, DJV, Dieter Stahel, Dennis Moltz, Jan Wouters, Alden Bice, Mike Cable

Good times / set the stage for a career

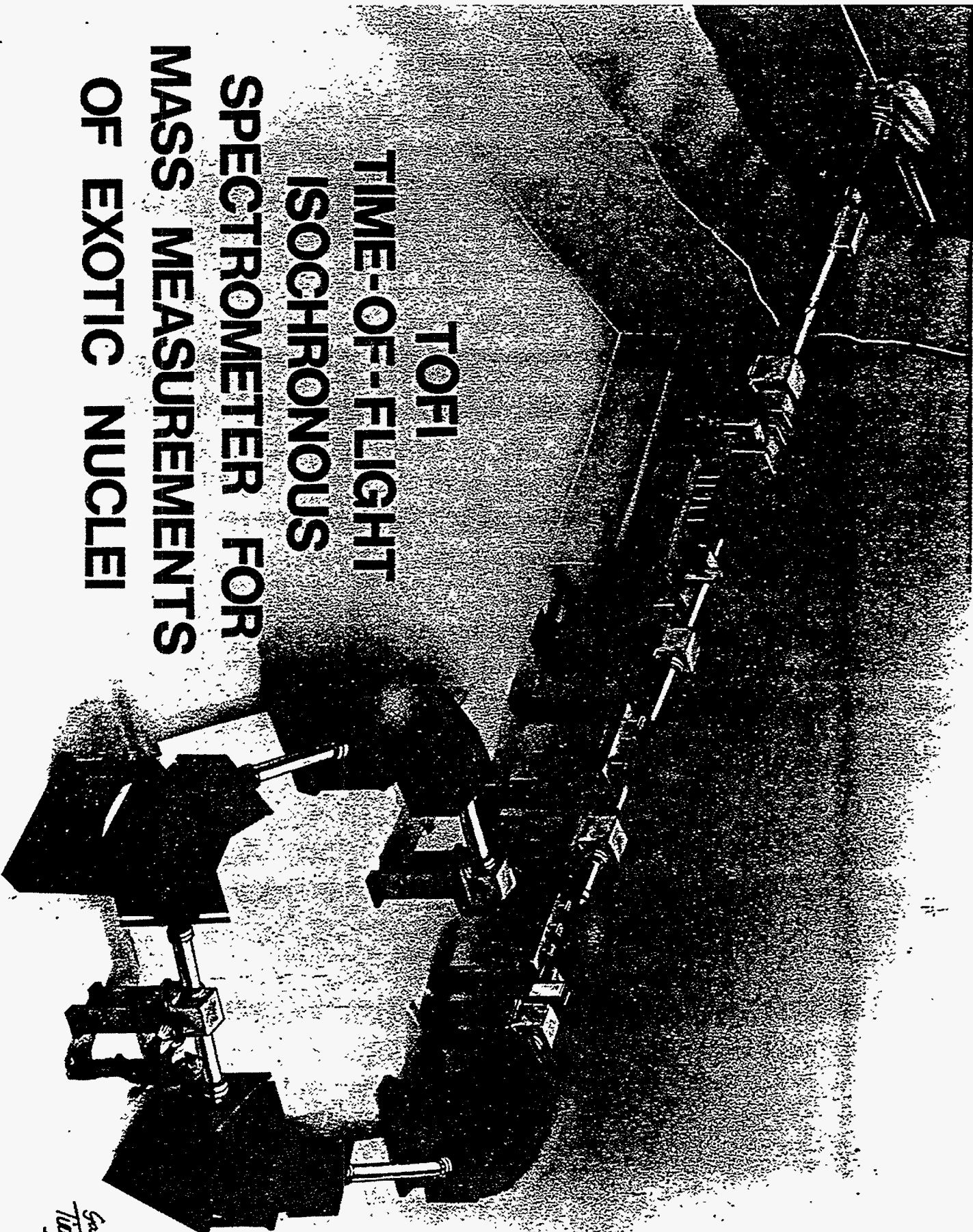
- stimulating environment
- working with others
- designing, fabricating & doing experiments
- Ray Burton, Jack Walton & the 88" shop
- developed the taste for small, but very challenging exps.
"ones which you can get your hands around"

Outline (25 min.):

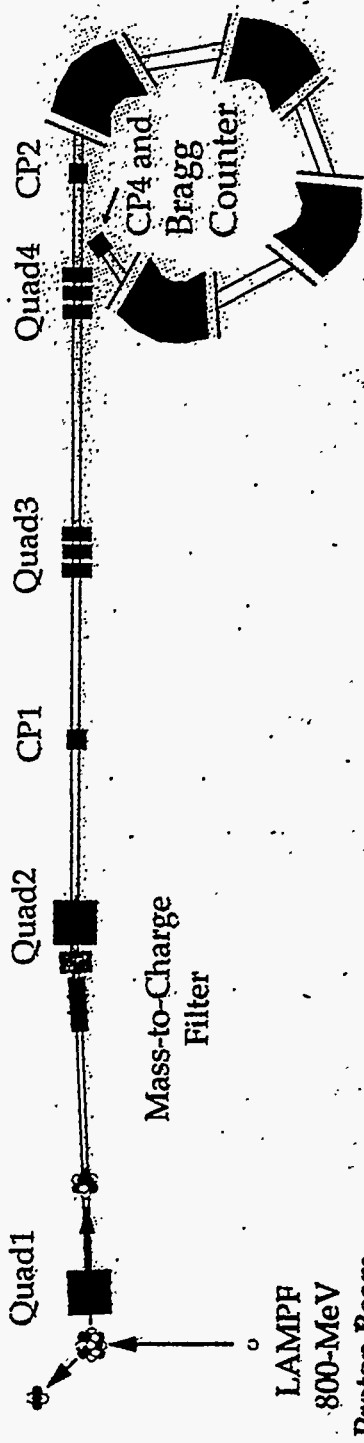
1. TOFI spectrometer - mass & decay properties of exotics
2. High-intensity, He-jet thin-target tests - radioactive beams
3. Trapping radioactive atoms - electroweak interaction exps.



**TOF
TIME-OF-FLIGHT
ISOCHRONOUS
SPECTROMETER FOR
MASS MEASUREMENTS
OF EXOTIC NUCLEI**



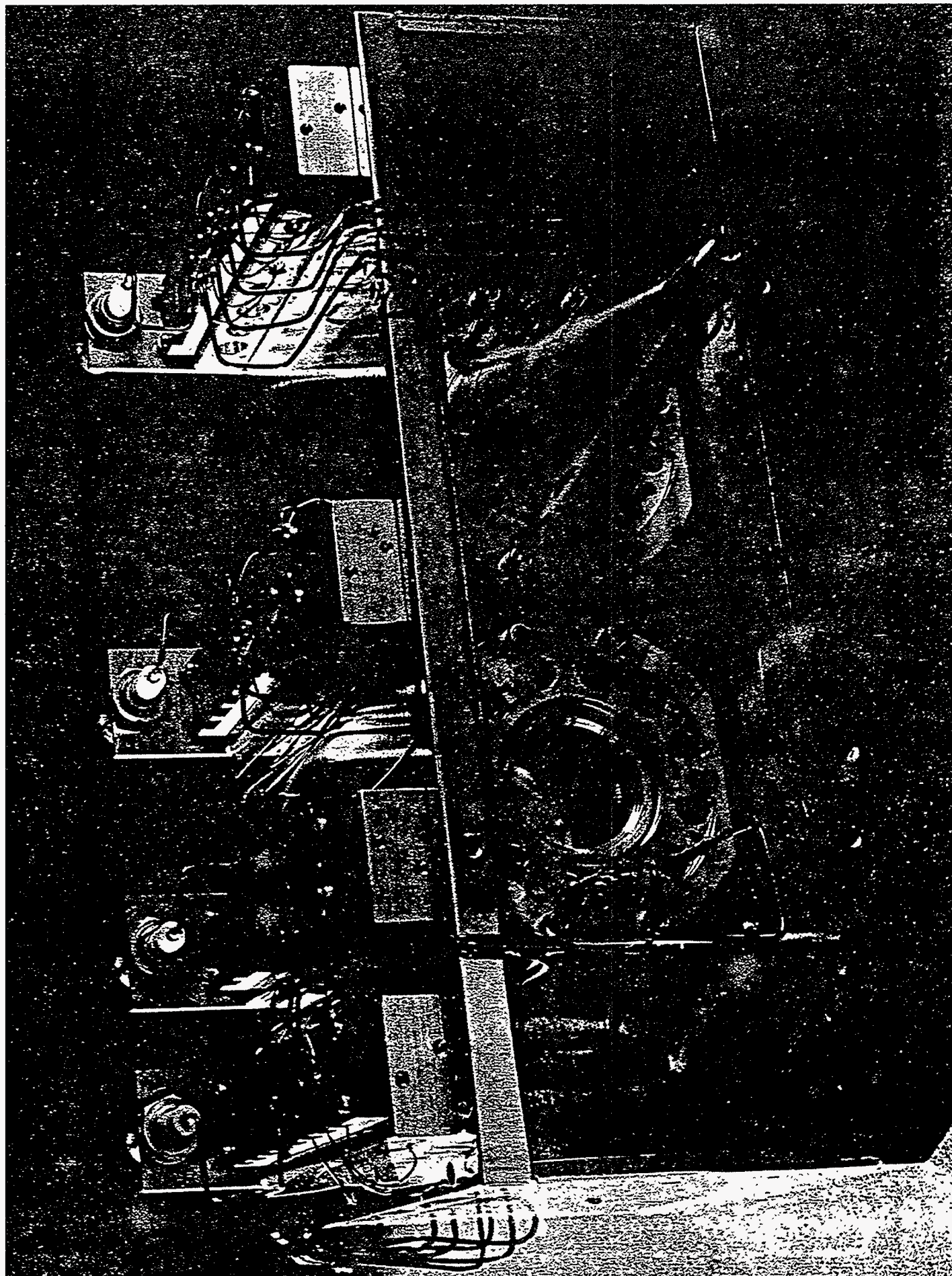
*Scott
Tajima*

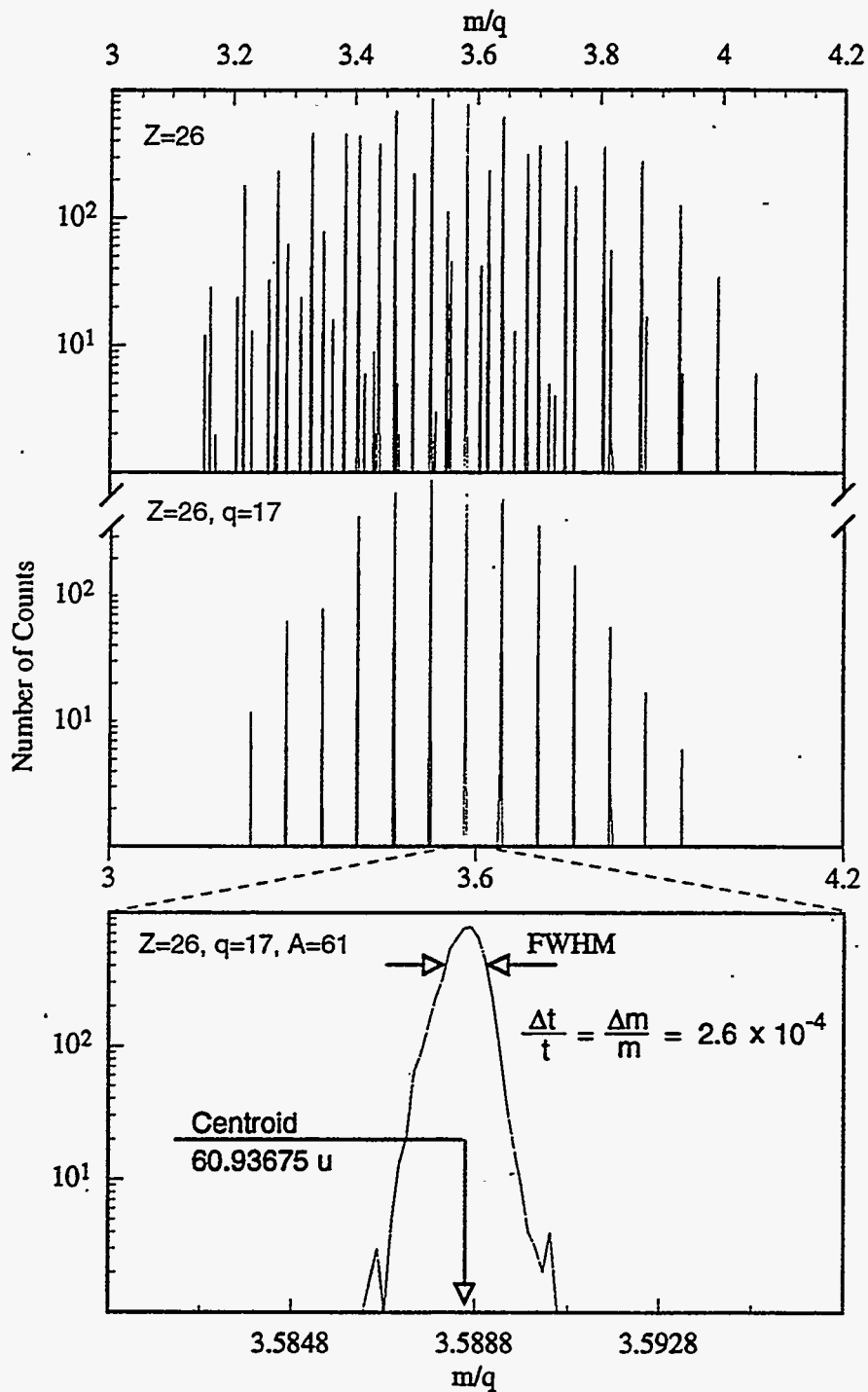


Experimental Setup

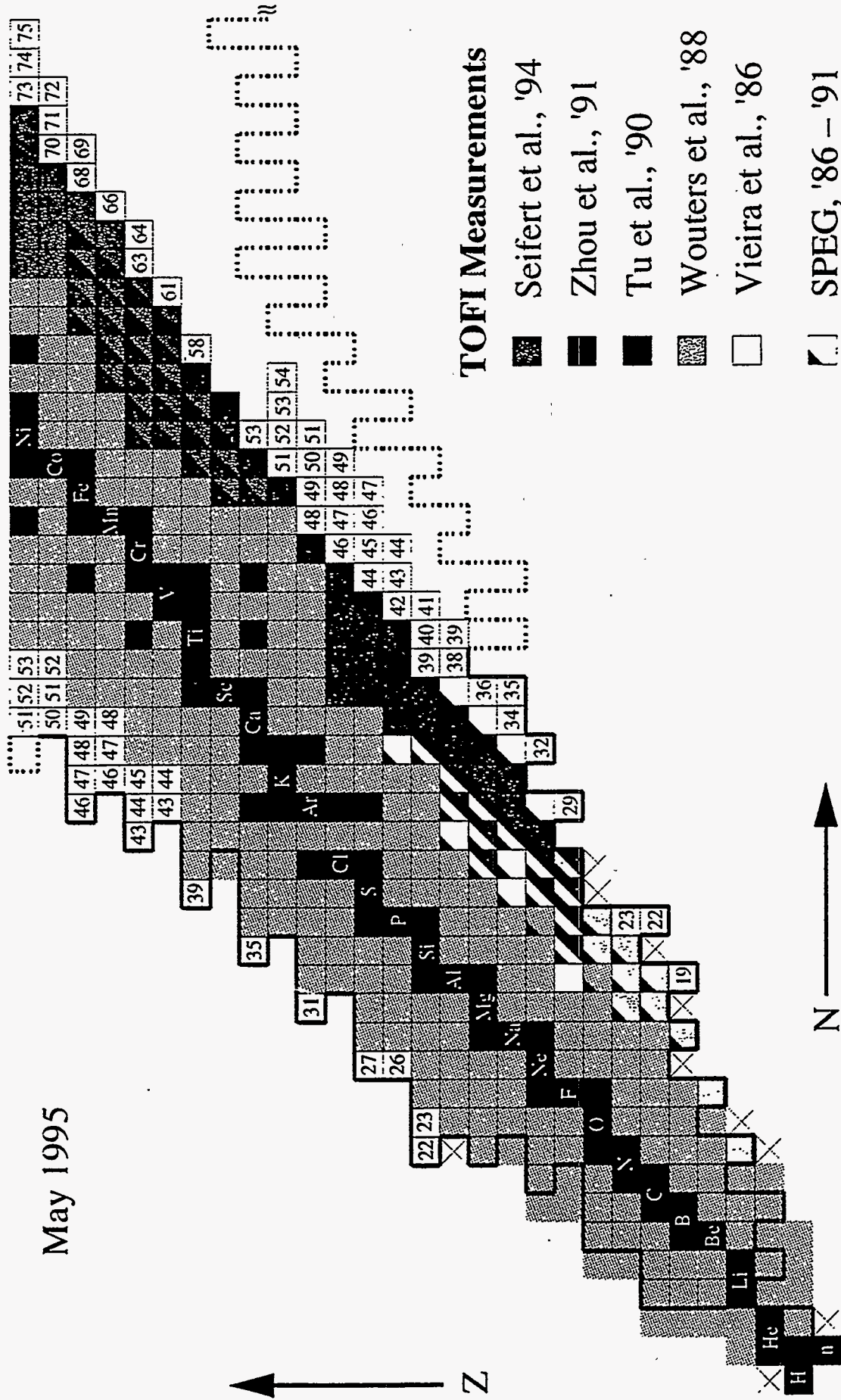


$$\left. \begin{aligned}
 T_{12} &= CP_1 - CP_2 \\
 Vel &= D_{12} / T_{12} \\
 m_{low} &= 2 \times E_{tot} / Vel^2
 \end{aligned} \right\} q = m_{low} / (m/q)$$





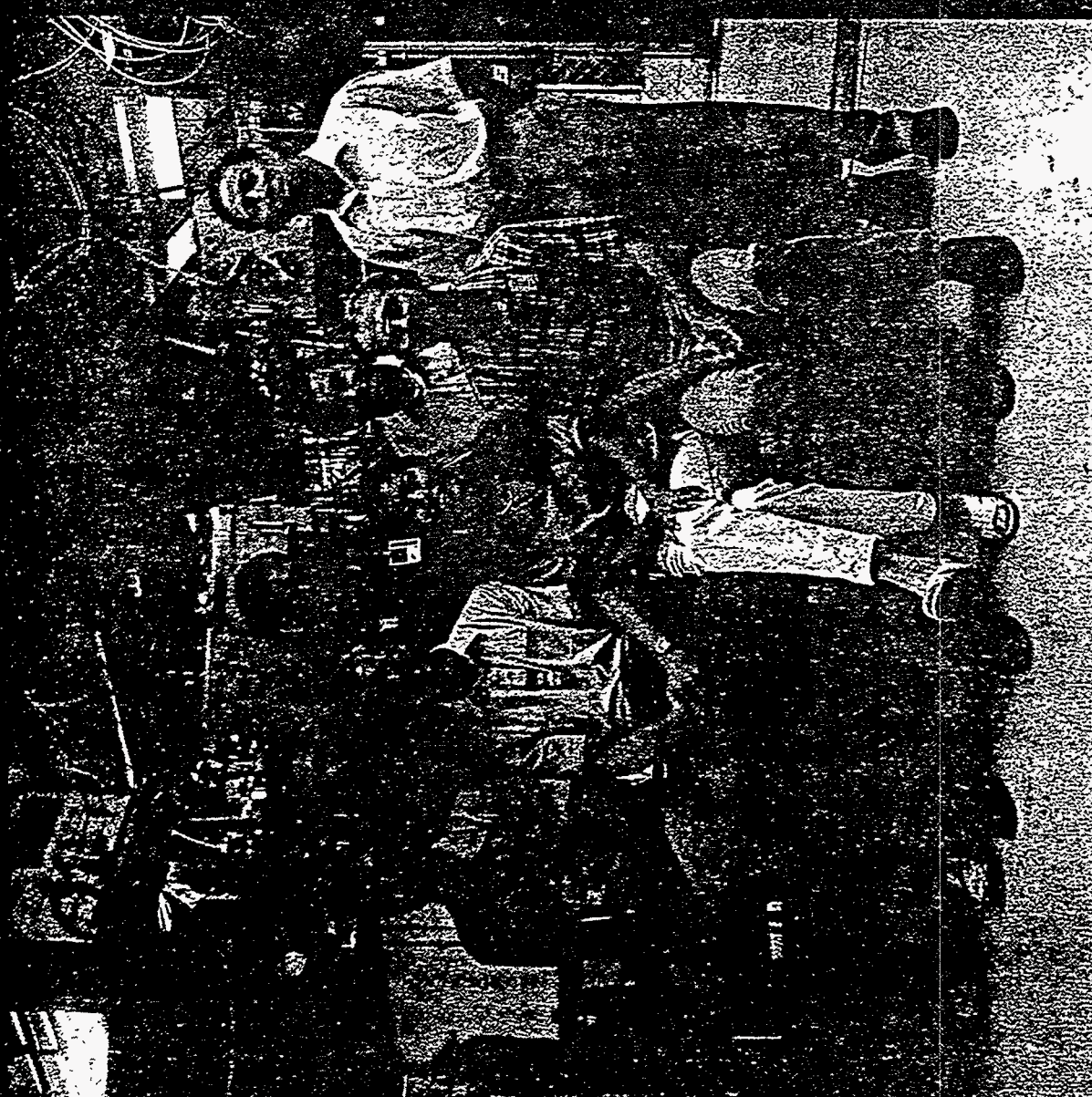
May 1995



TOFI Measurements

- Seifert et al., '94
- Zhou et al., '91
- Tu et al., '90
- Wouters et al., '88
- Vieira et al., '86
- SPEG, '86 - '91

TOFI COLLABORATION



Los Alamos

- Lil Butler*
- Larry Ulibarri*
- Dave Vieira*
- Fan Wouters*

Utah State Univ.

- London Lind*
- * *Xiao-Lin Fu*
- * *Xiao-Long Zhou*

Battelle Northwest

- Walt Hensley*
- Paul Reeder*
- Ray Warner*

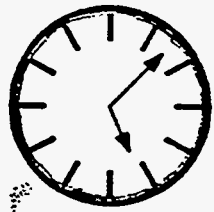
Visitors

- * *Hardy Seifert*
- Tong-Yuan Zhou*

INC DIVISION
Los Alamos

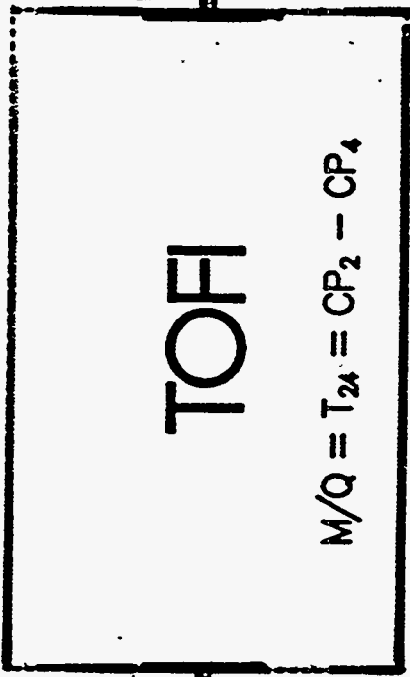
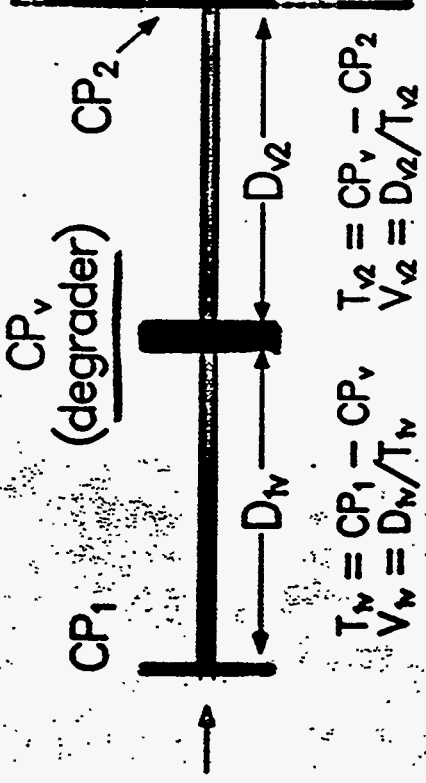
Recoil Tagging - p-n - Delayed Coin. Exp.

Clock Time

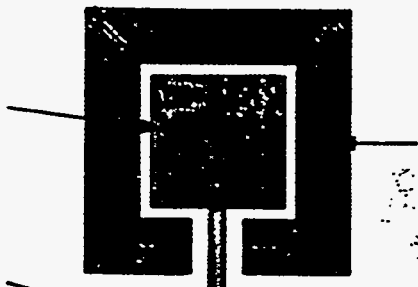


Detector Geometry

6 x 0.4 mg/cm²
nitrocellulose foils



Total E
CP₄ detector



CP: Channel-plate timing detector

Z: ⁴⁰ moderated ³ He prop. ctrs.

Charge:

$$M_{low} = 2 \times E_{tot} / V_{v2}^2$$

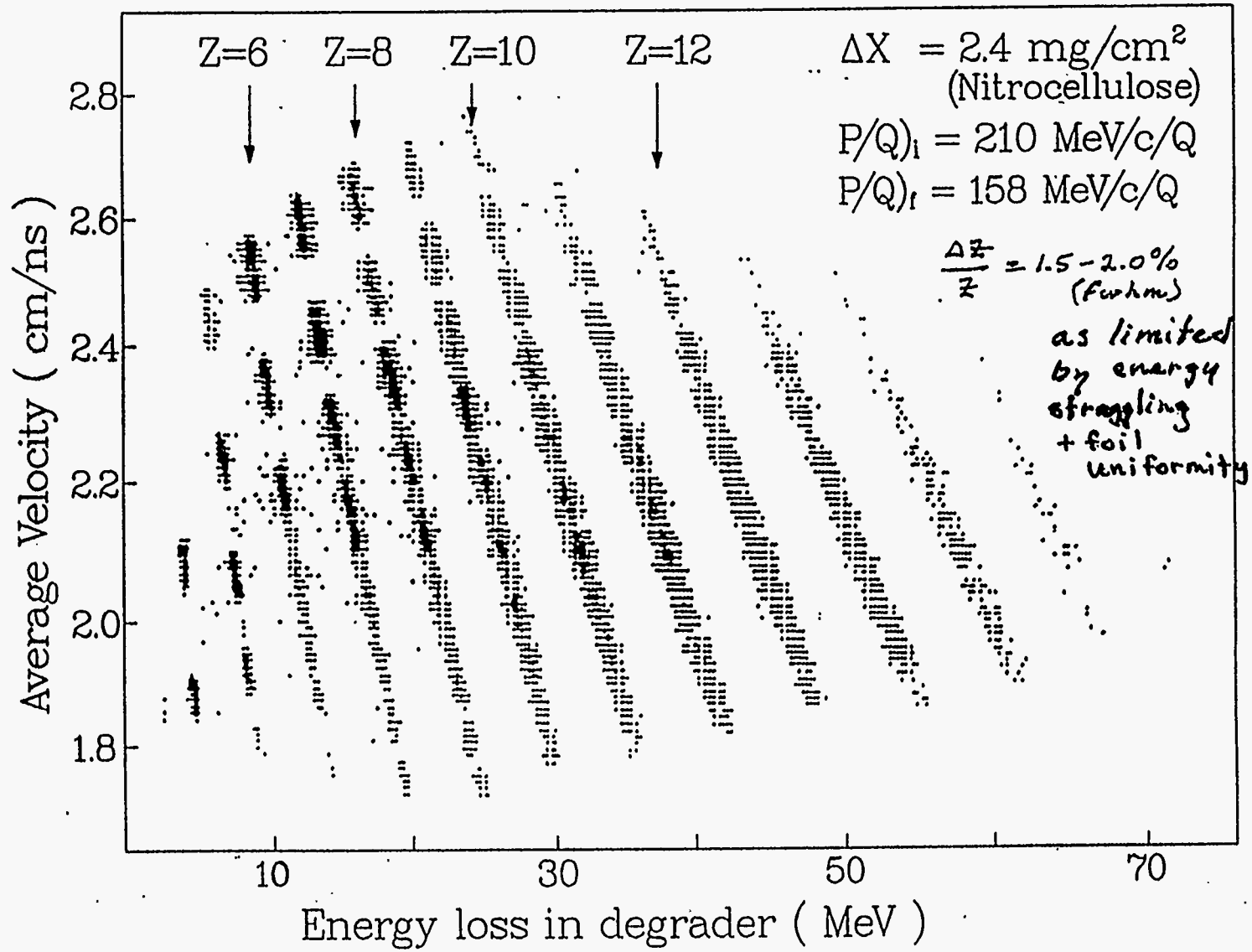
$$Q = M_{low} / (M/Q)$$

$$\Delta E = M \times (V_{v2}^2 - V_{v1}^2) / 2$$

$$Z = f(V, \Delta E)$$

INC DIVISION

Massive Degradator - ΔZ Technique

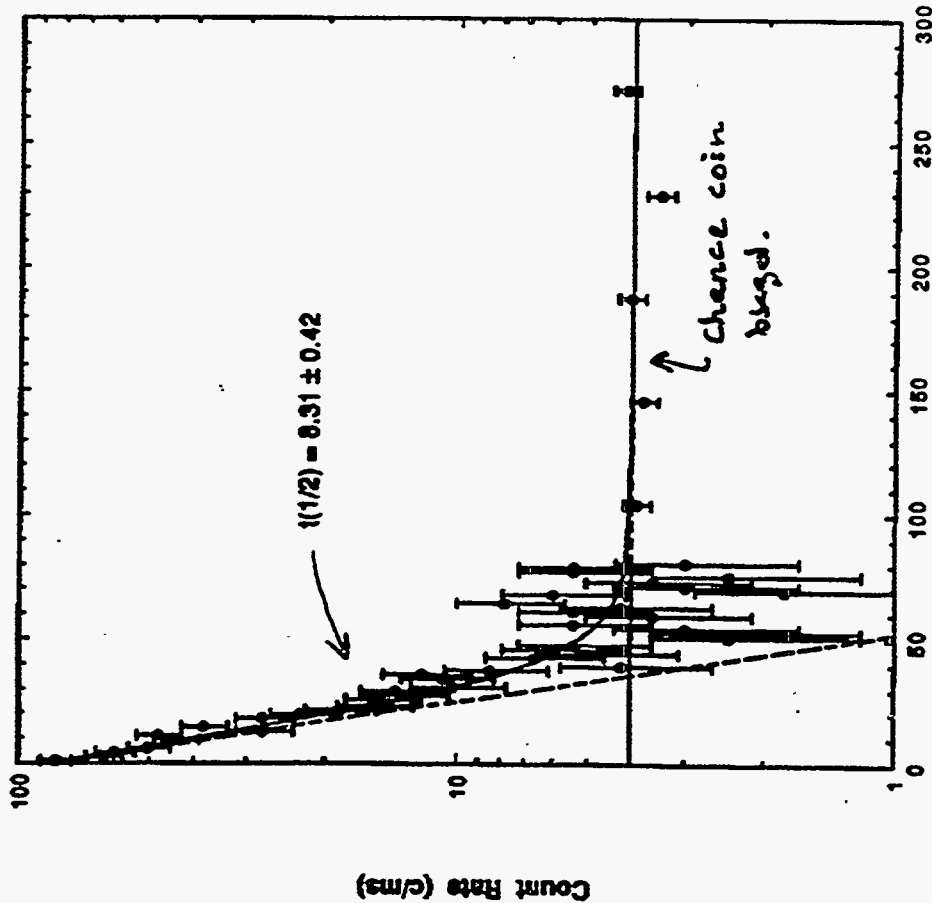


M.S. thesis - Y.-K. Kim

(Utah State, 1989)

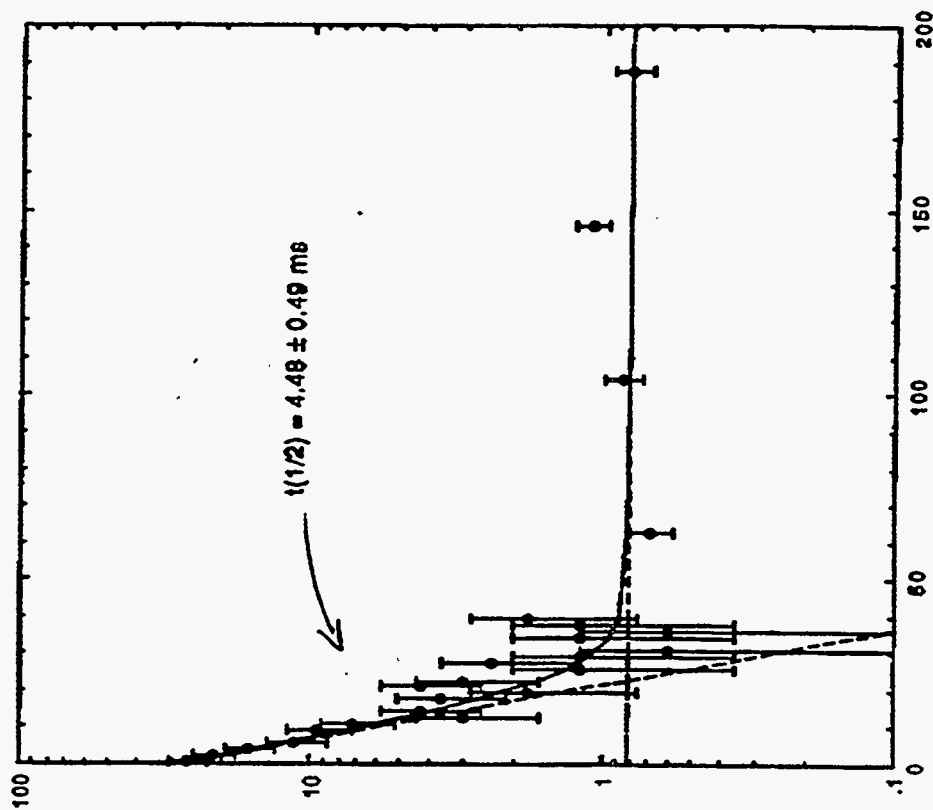
Delayed ion - neutron counting technique

¹¹Li Beta-Neutron Coinc. Decay Curve



Time (ms)

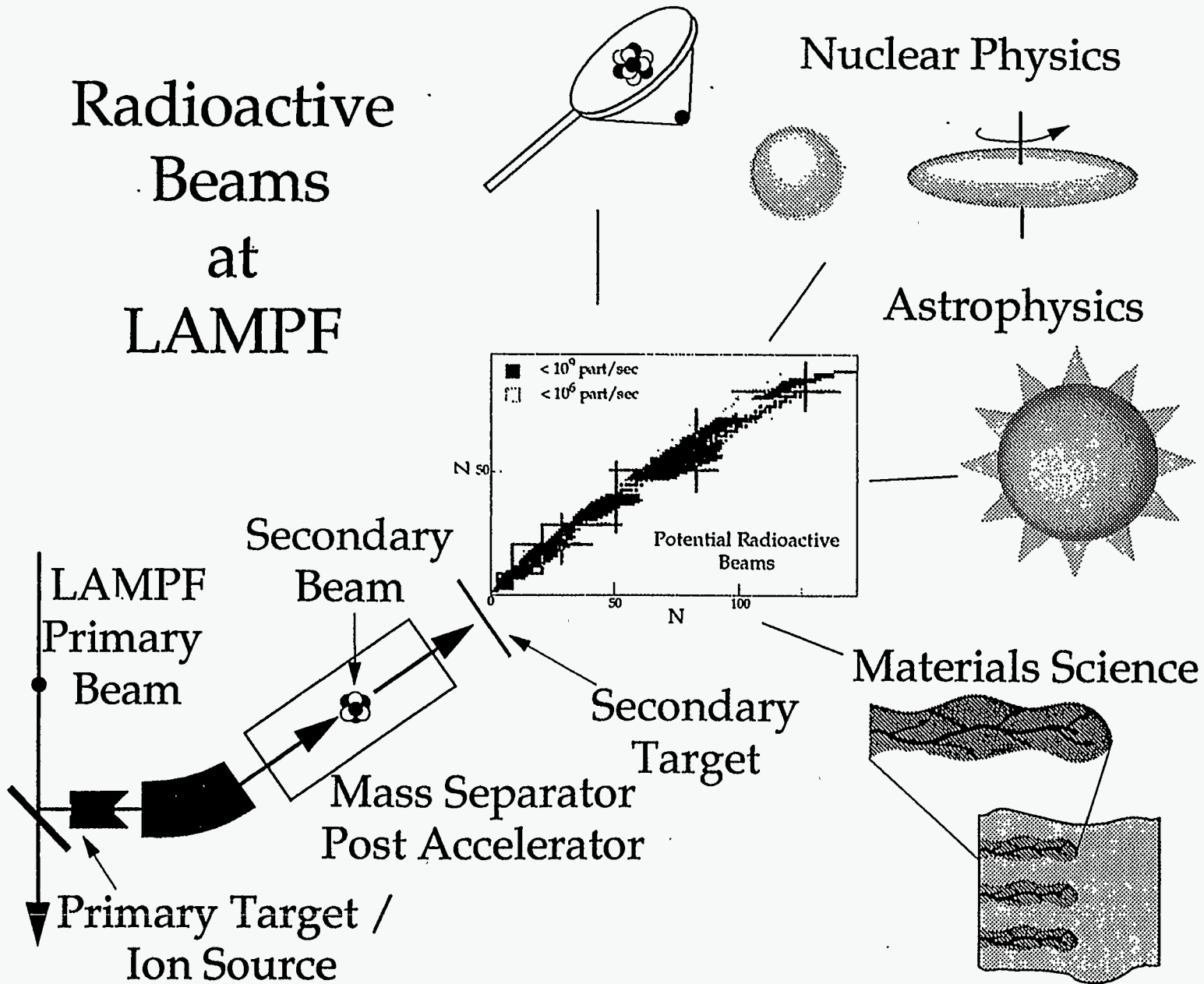
¹⁴Be Beta-Neutron Coinc. Decay Curve



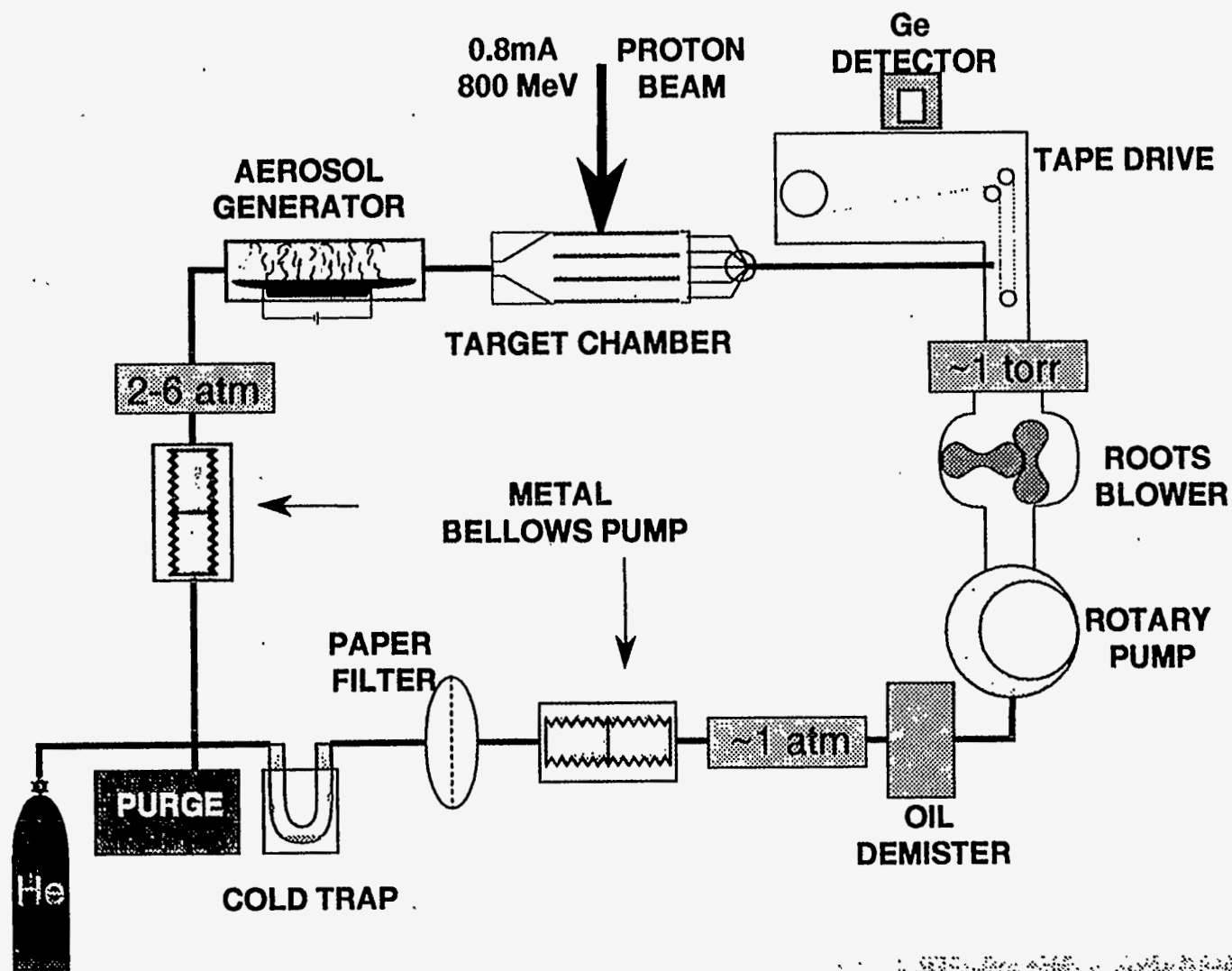
Time (ms)

P. Reeder, et al. - 1992 data

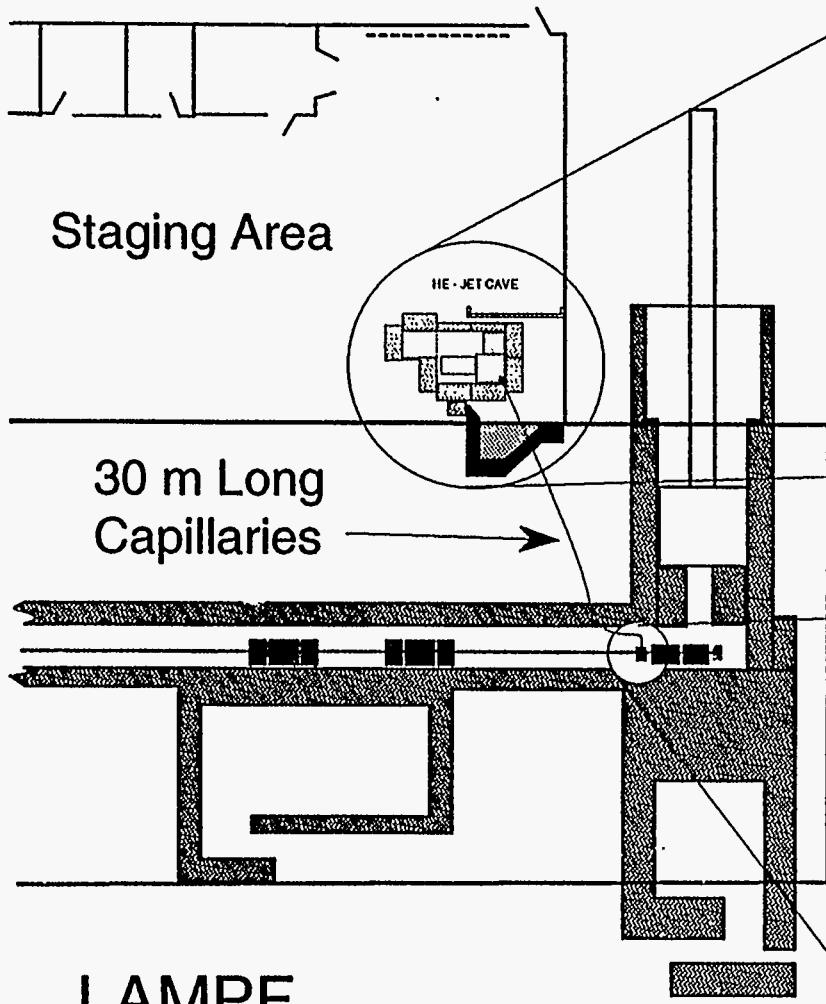
Radioactive Beams at LAMPF



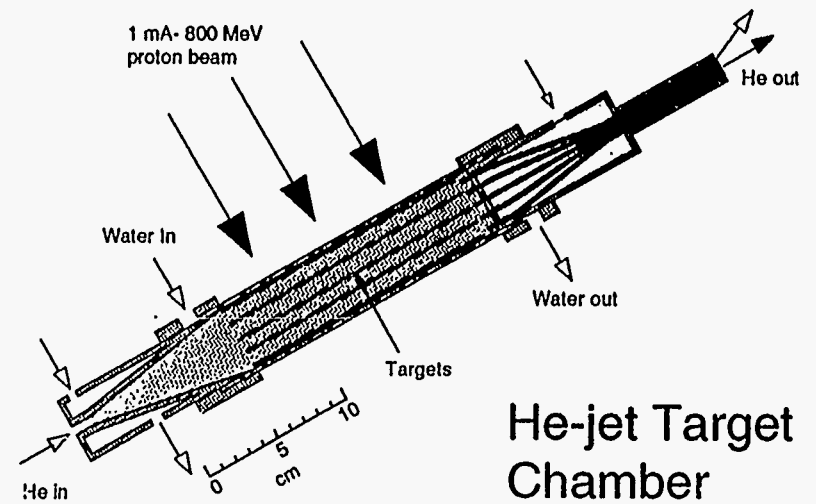
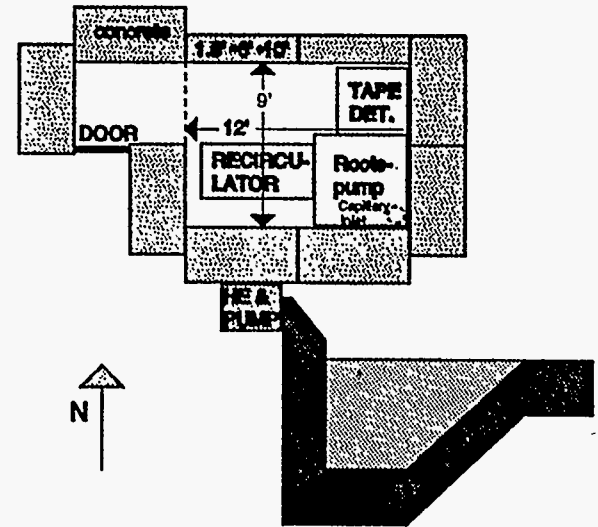
He-jet Test Experiment



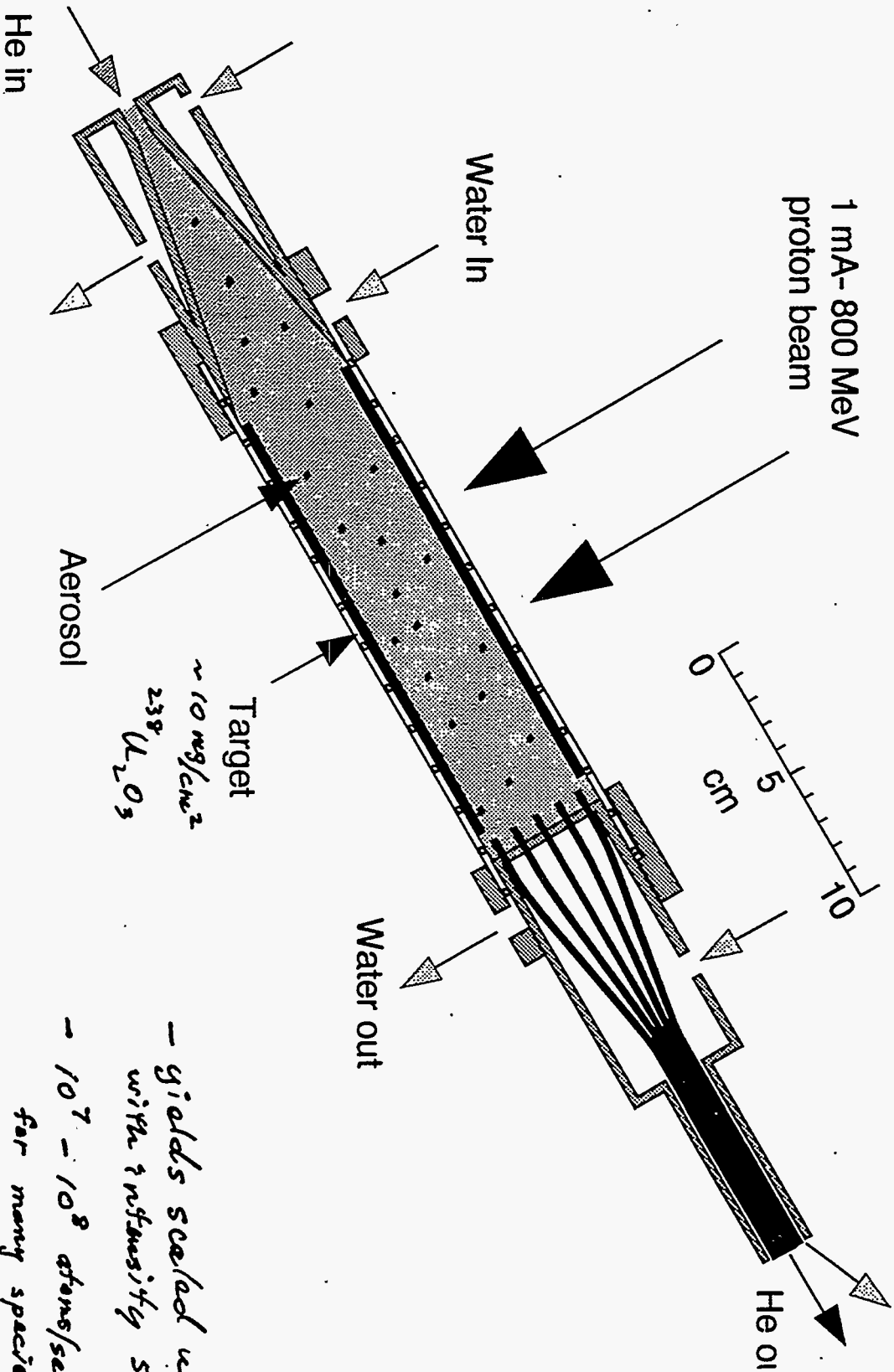
0 15
Meters



He-jet Cave

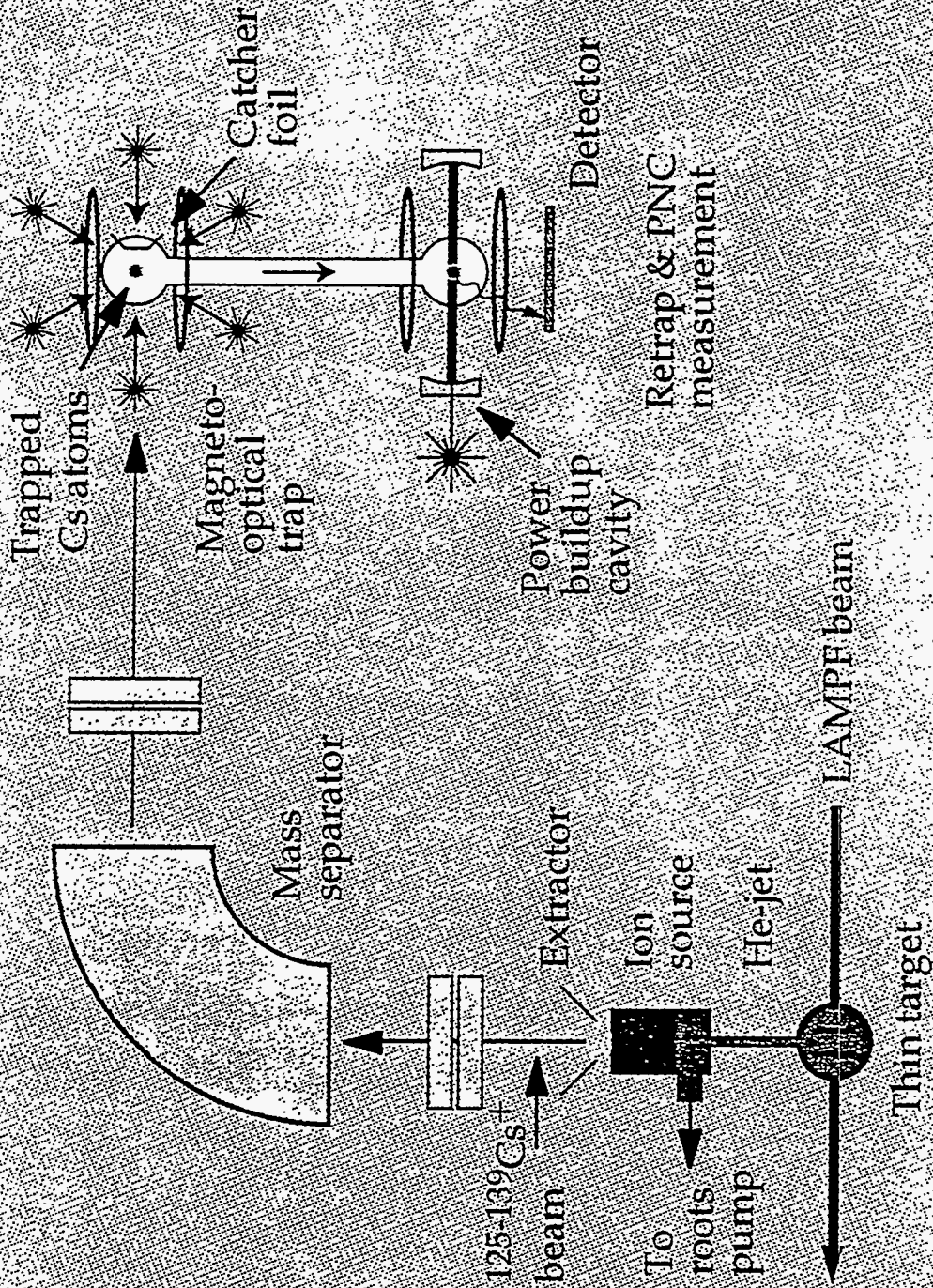


High-Intensity He-jet Tests at Los Alamos



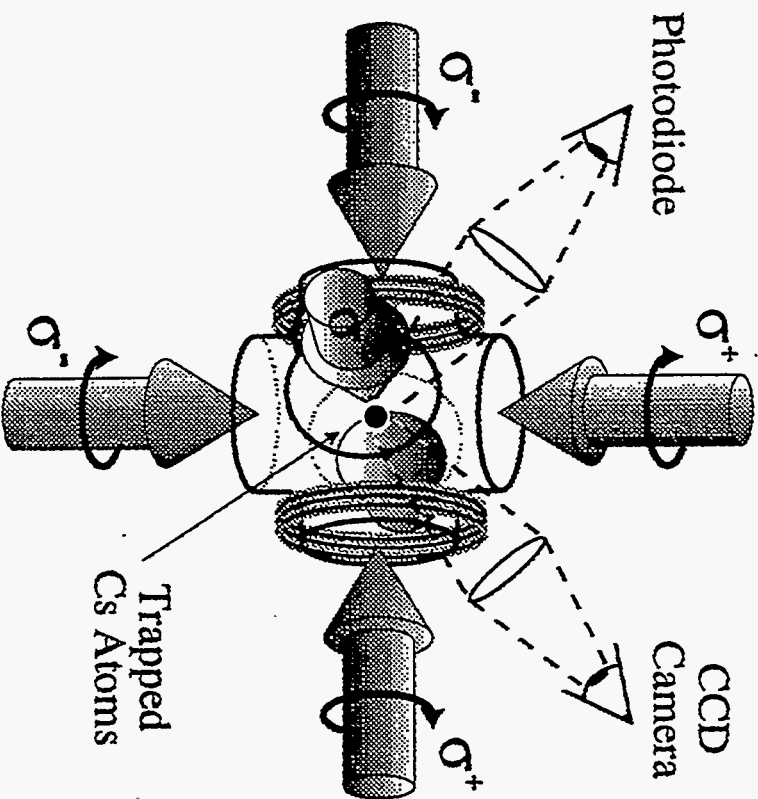
- yields scaled up with intensity $5 \rightarrow 700 \times$
- $10^7 - 10^8$ atoms/sec/isotope for many species
- He-jet eff. of 15-20%

Overview of the multi-isotope Cs - PNC experiment



Atomic Trapping

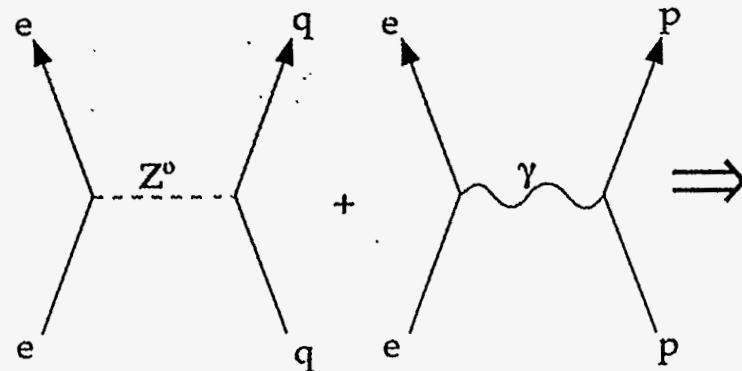
Magneto-Optical Trap (MOT)



- Highly-concentrated, point-like source (10^8 atoms / 2 mm ϕ)
- Long trapping times (1-100 sec)
- Cold sample (< 1 mK)
- UHV environment (10^{-8} - 10^{-9} torr)
- Atoms/nuclei can be easily polarized & manipulated

Atomic PNC Experiment in Cs (Fr): A Low-Energy Test of the Standard Model

Neutral current e-q coupling leads to parity mixing of atomic states.



Weak neutral current
(parity violating)

Coulomb interaction
(parity conserving)

W.-S.-G. Electroweak theory
Standard Model

predicts mixing of S + P states

$$|S'\rangle = |S\rangle + \delta_{\text{PNC}} |P\rangle$$

$$\delta_{\text{PNC}} \propto Q_w \gamma_5$$

weak charge

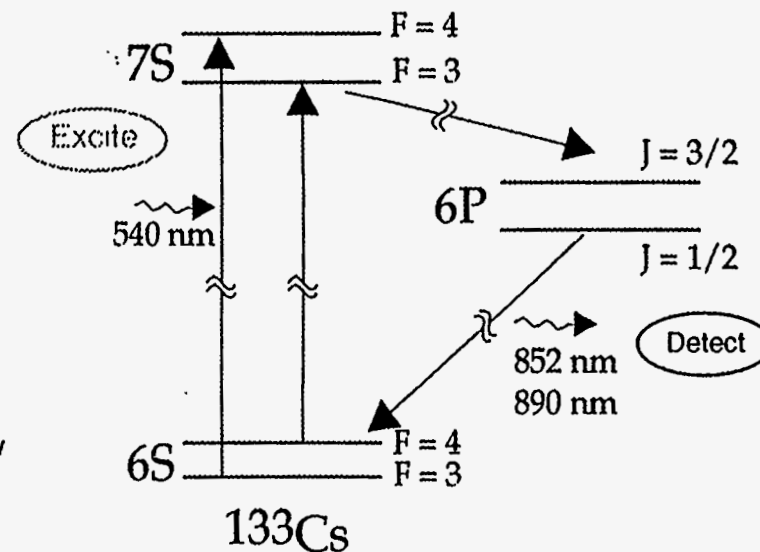
atomic matrix element $\propto Z^3$

$$Q_w = -2[(2Z+N)C_{1u} + (Z+2N)C_{1d}] + \% \text{ rad. corr.}$$

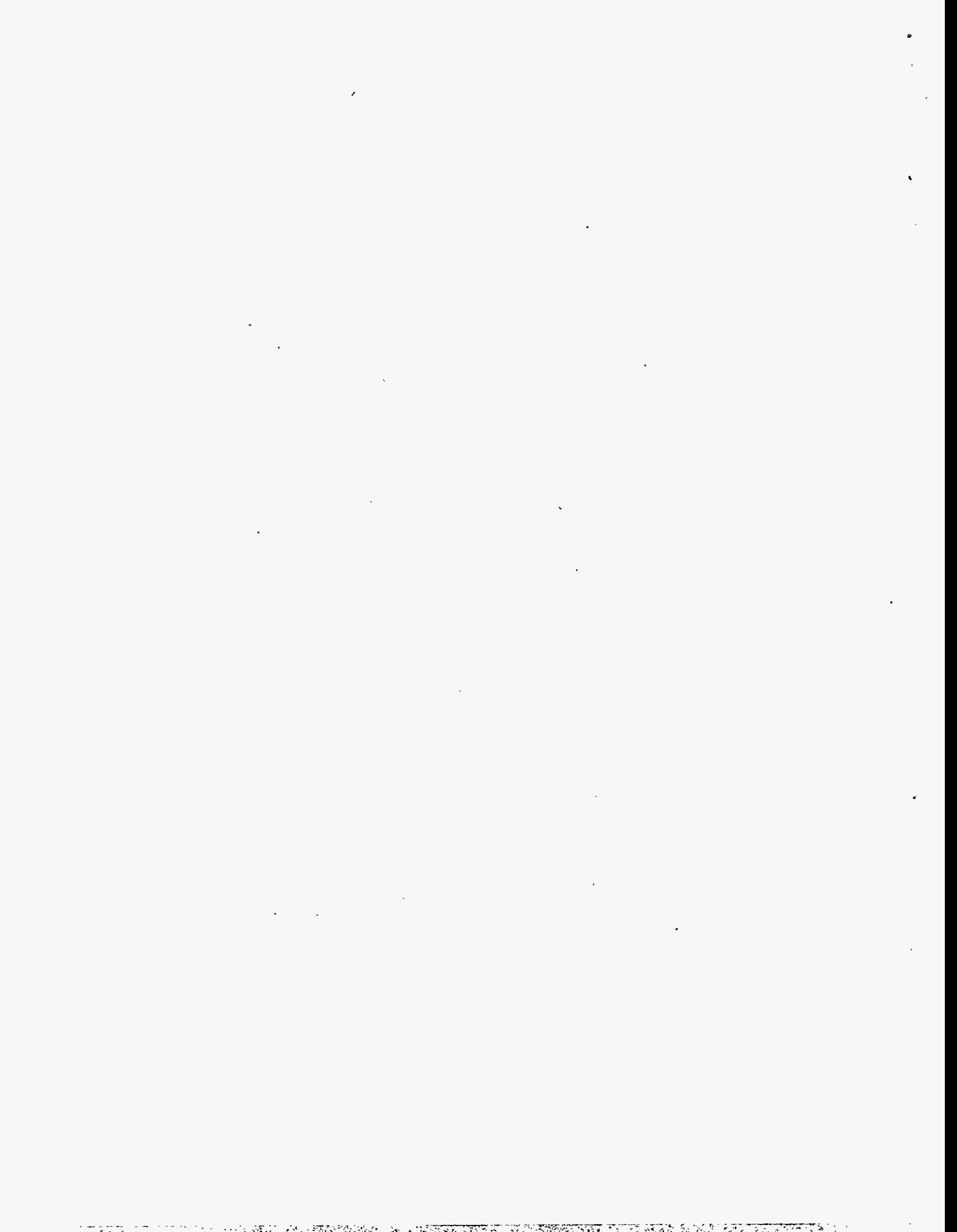
$$\text{with } C_{1u} = -1/2 + 4/3 \sin^2 \theta_w$$

$$C_{1d} = 1/2 - 2/3 \sin^2 \theta_w$$

$$= -N + Z(1 - 4 \sin^2 \theta_w) \\ (0.076 \text{ from } Z^0)$$

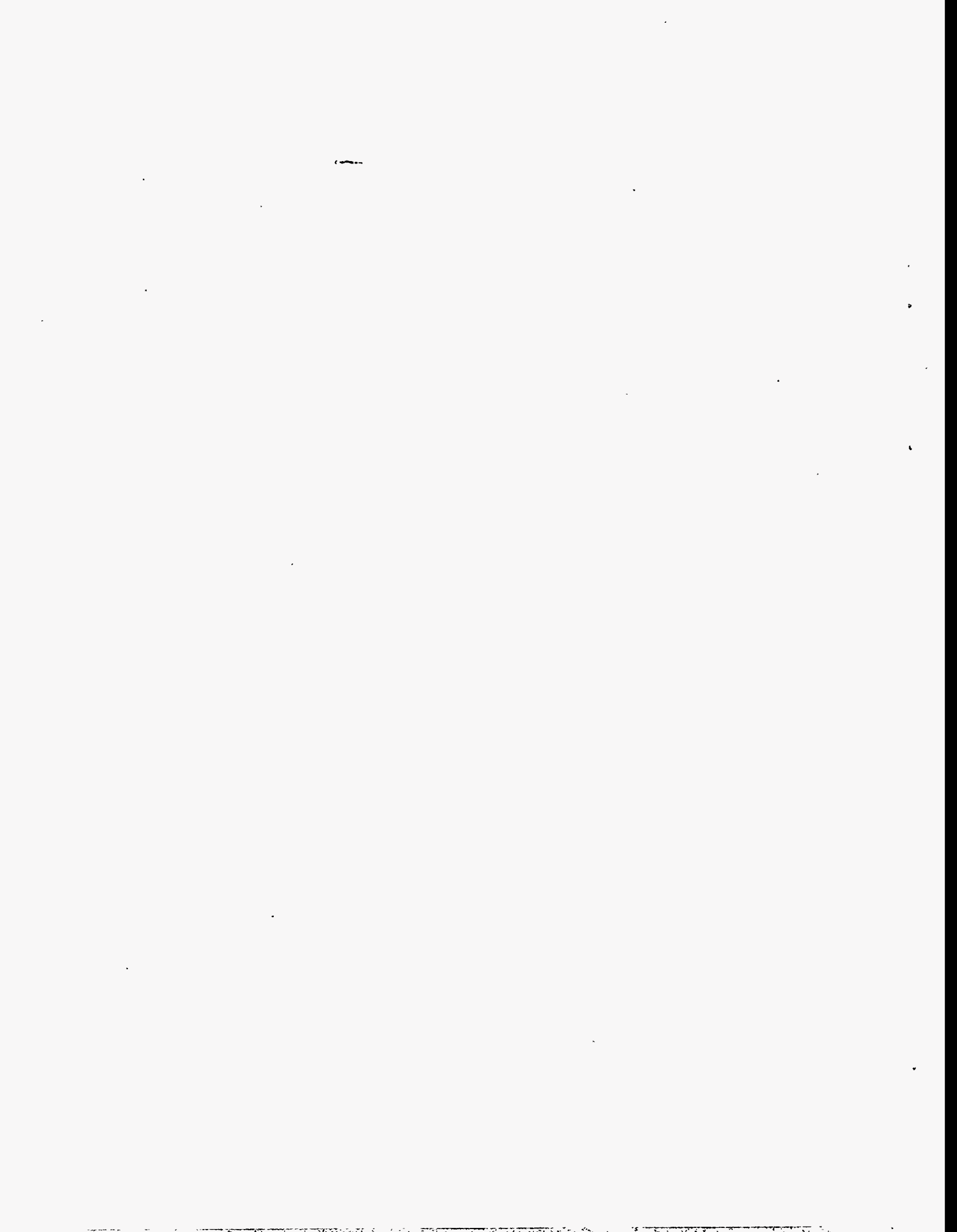


U. Colo. & LANL



John Hardy

Chalk River Laboratories
Chalk River, Ontario, Canada



SUPERALLOWED BETA-DECAY:

A Nuclear Probe of the Electroweak Standard Model

J.C. Hardy

E. Hagberg

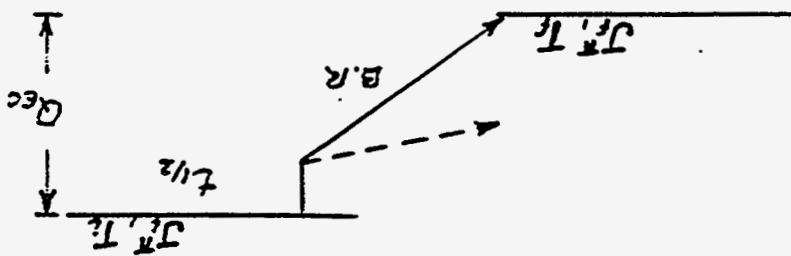
V. Koslowsky

G. Savard

I.S.Towner

Chalk River Laboratories

ALLOWED NUCLEAR BETA DECAY



EXPERIMENT

WEAK DECAY EQUATION

$$ft = \frac{G_V^2 \langle 1 \rangle^2 + G_A^2 \langle \sigma \tau \rangle^2}{K}$$

$f = f(Z, Q_{\beta c})$
 $t = f(t_{1/2}, B.R.)$
 $G_{V,A}$ = coupling constant
 $\langle \rangle$ = matrix element

SELECTION RULES

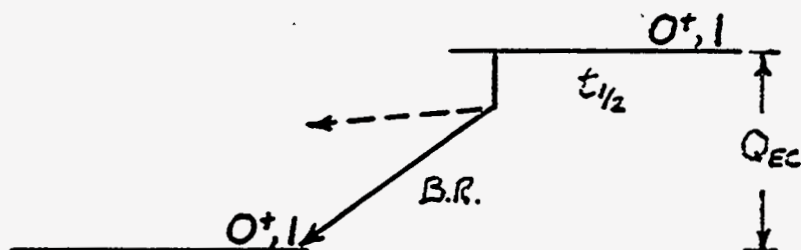
	$\langle 1 \rangle$	$\langle \sigma \tau \rangle$
ΔJ	0	0, 1 (not 0 to 0)
ΔT	0	0, 1
$\Delta \pi$	no	no

PURE VECTOR DECAY

$$O^+ \rightarrow O^+, \Delta T = 0$$

SUPERALLOWED $0^+ \rightarrow 0^+$ BETA DECAY

EXPERIMENT



WEAK DECAY
EQUATION

$$ft = \frac{K}{G_V^2 \langle 1 \rangle^2}$$

RADIATIVE
CORRECTIONS

$$t \rightarrow t(1 + \delta_R)$$

$$G_V^2 \rightarrow G_V^2(1 + \Delta_R)$$

$$\delta_R = f(Z, Q_{EC}, \text{nuclear structure})$$

$$\Delta_R = f(\text{interaction})$$

CHARGE
CORRECTIONS

$$\langle 1 \rangle^2 \rightarrow 2(1 - \delta_c)$$

$$\delta_c = f(\text{nuclear structure})$$

CVC TEST

$$\mathcal{F}t \equiv ft(1 + \delta_R)(1 - \delta_c) = \frac{K}{2G_V^2(1 + \Delta_R)}$$

CONSTANT

UNITARITY TEST

CABIBBO - KOBAYASHI - MASKAWA
QUARK-MIXING MATRIX

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

THREE-GENERATION
UNITARITY

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

$$V_{ud} \sim 0.97$$

$$V_{us} \sim 0.22$$

$$V_{ub} \sim 0.003$$

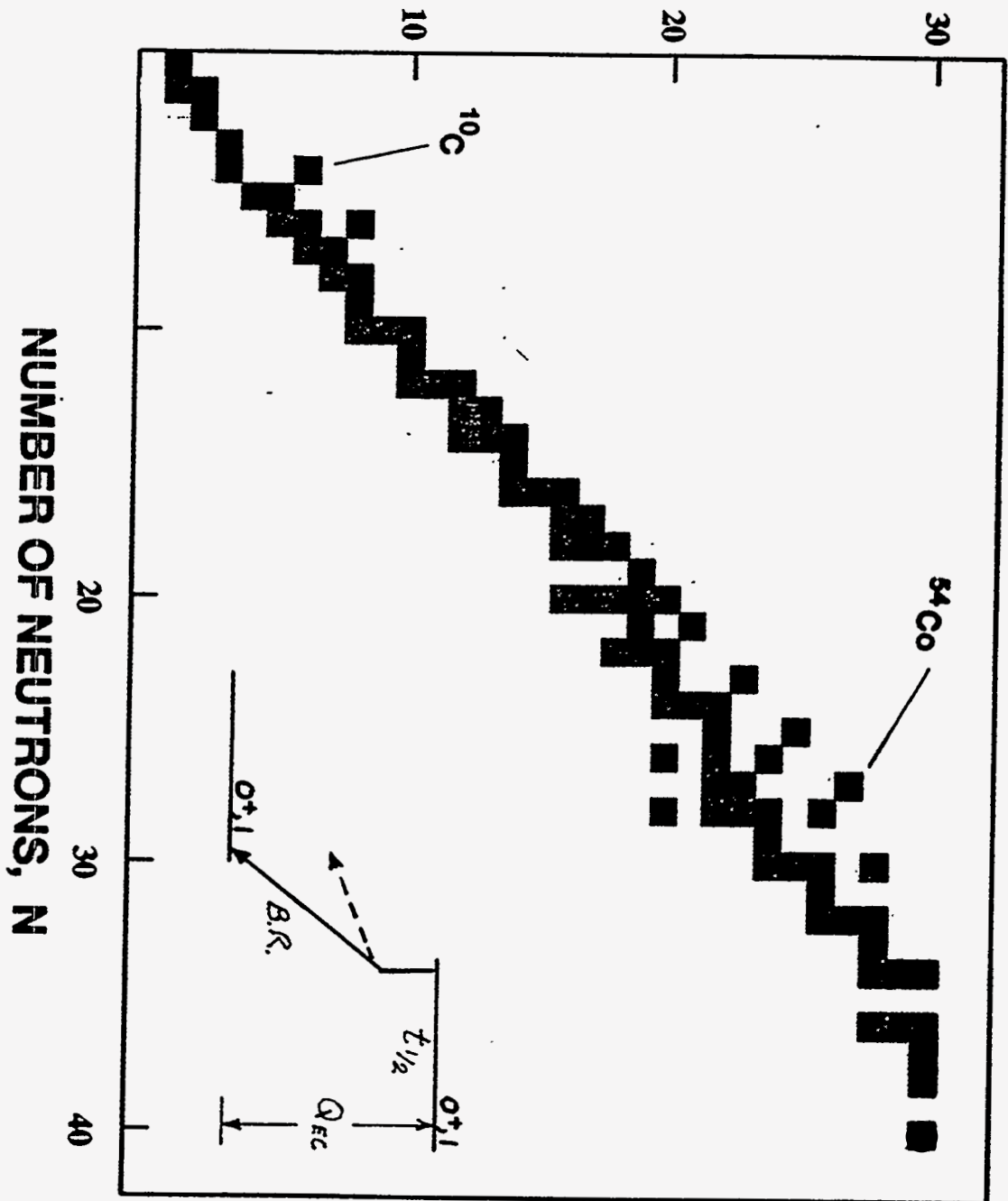
NUCLEAR
CONTRIBUTION

$$\begin{aligned} |V_{ud}| &= G_V / G_\mu \\ &= \left(\frac{K}{2(1+\Delta_R) \overline{F}_t} \right)^{1/2} G_\mu^{-1} \end{aligned}$$

\overline{F}_t = AVERAGE $D^+ \rightarrow 0^+$
NUCLEAR RESULT

G_μ = MUON COUPLING
CONSTANT

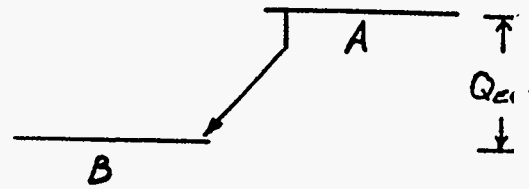
NUMBER OF PROTONS, Z



EXPERIMENTAL RESULTS

1. Q_{EC} VALUE

precision ≈ 100 eV



- $B(p,n)A$ threshold (Auckland)
- $C(p,\gamma)A$ & $C(n,\gamma)B$ Q values (Oak Ridge/UT)
- $B(^3\text{He},t)A$ & $B'(^3\text{He},t)A'$ Q-value doublet (Chalk River)

2. LIFETIME

precision $\approx 0.03\%$

- Isotope-separated samples (Chalk River)

3. BRANCHING RATIO

- ^{10}C , direct measurement with γ -ray spectrometer (Chalk River, LBL)
- All others indirect: $BR > 99\%$ (Chalk River)

BRANCHING-RATIO MEASUREMENTS

1. DIRECT MEASUREMENT OF SUPERALLOWED BRANCH

- ^{10}C branching ratio = 1.46%

2. MEASUREMENT OF OTHER WEAK BRANCHES

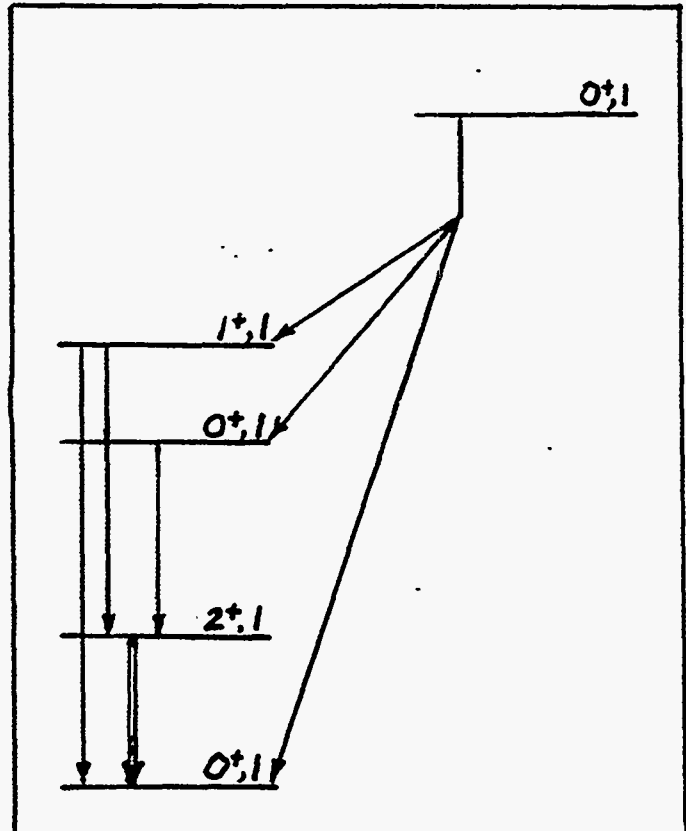
- All other cases, superallowed branching ratio > 99%

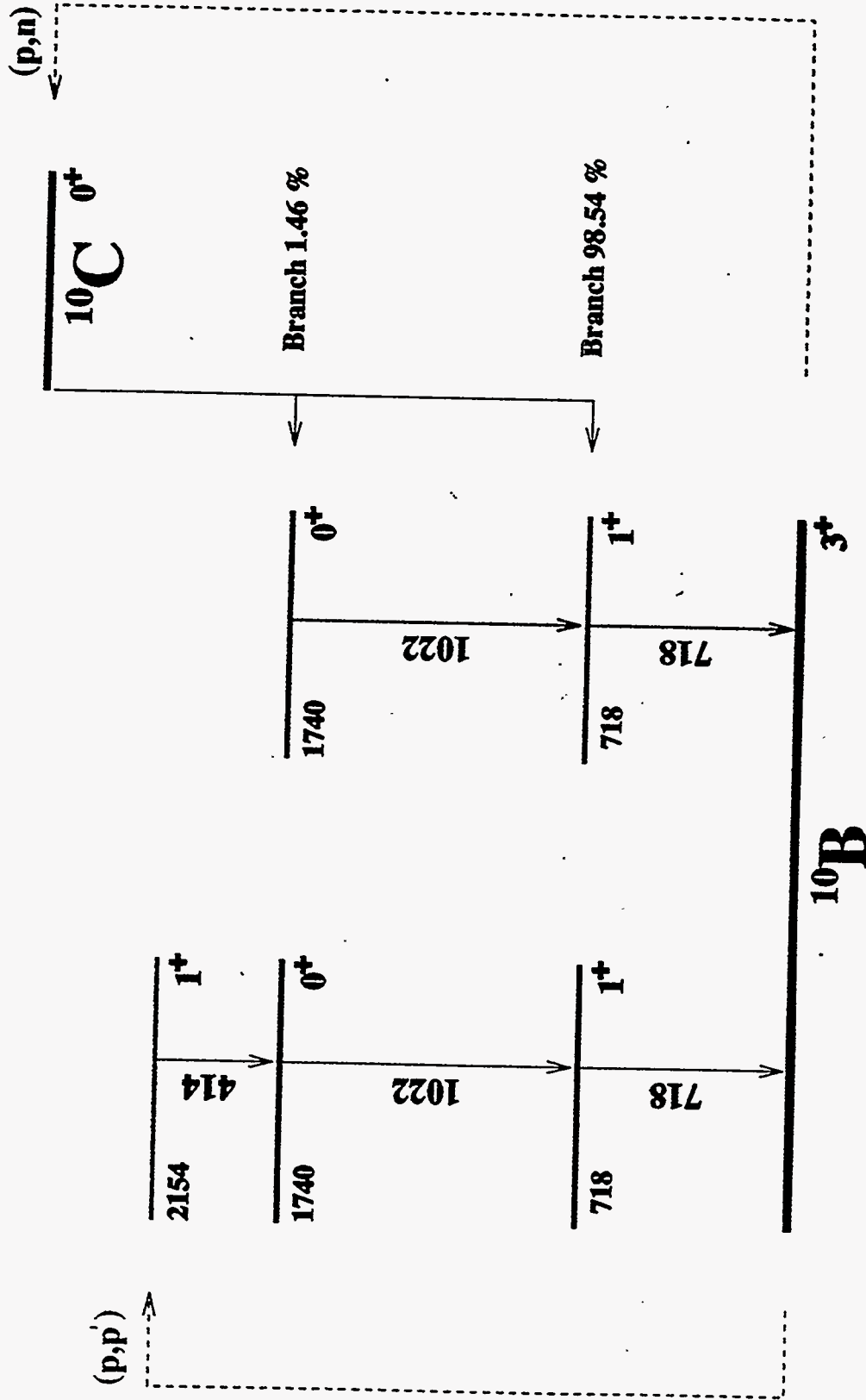
- $0^+ \rightarrow 1^+$ Axial-vector decay branches

- affects superallowed branching ratio
- sensitivity required $\sim 500\text{ppm}$

- $0^+ \rightarrow 0^+$ Non-analogue vector-decay branches

- tests charge corrections
- locates relevant 0^+ states
- sensitivity required $\sim 1\text{ppm}$





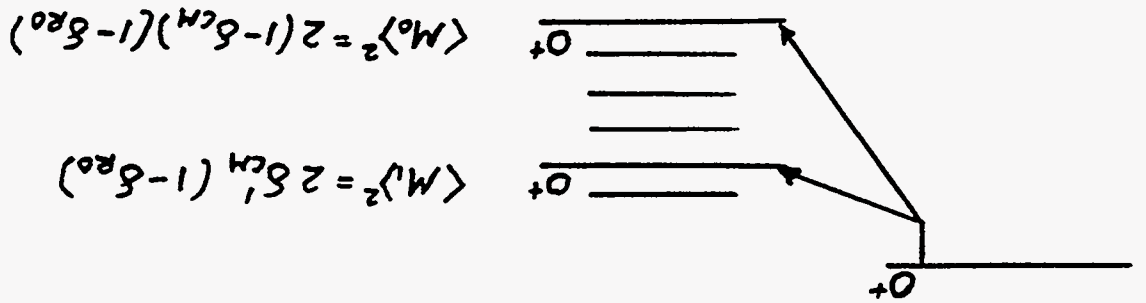
$$BR = 1.4625 \pm 0.0020 \pm 0.0015 \% \quad (\text{stat}) \quad (\text{sysz})$$

CHARGE CORRECTION

$$\delta_c = \delta_{cm} + \delta_{RO}$$

- Difference in config-uration mixing between parent and daughter.
- Shell-model calculation fitted to 0^+ states, IAME & non-analogue branch.
- $\sim 0.1\%$
- Mismatch in radial wave function between parent and daughter
- Woods-Saxon wave function matched to experimental binding energy and shell-model percentage
- $\sim 0.4\%$

EXPERIMENTAL TEST

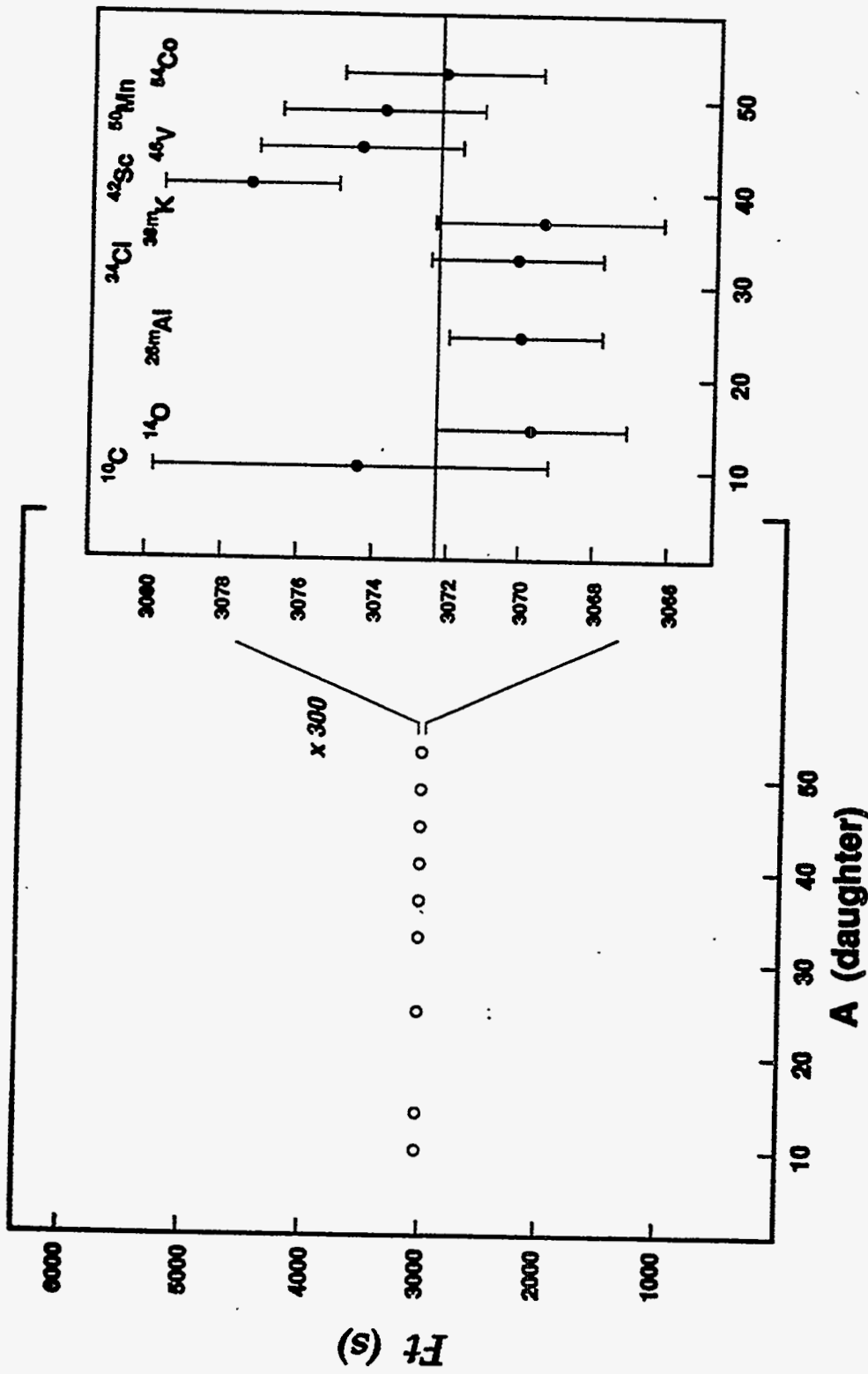


(Hagberg et al., P.R.L. 75 (1994) 396)

BRANCHING RATIOS TO NON-RNANALOGUE 0^+ STATES

PARENT	EXPERIMENTAL RESULTS (ppm)	CALCULATION (ppm)
38mK	<19	6 ± 1
46V	39 ± 4	34 ± 4
50Mn	<3	10 ± 4
54Co	45 ± 6	48 ± 10

CVC TEST - WORLD DATA, 1995



$$\overline{Ft} = 3072.3 \pm 1.0\text{s}$$

- "STATISTICAL" UNCERTAINTY ON δ_2
 - $\chi^2/N = 1.90$

UNITARITY TEST - WORLD DATA, '94

- NUCLEAR $0^+ \rightarrow 0^+$ DECAYS

$$\overline{Ft} = (3072.3 \pm 1.0 \pm 1.0) \text{ s}$$

- MUON LIFETIME

$$G_{\mu} / (\hbar c)^3 = (1.16639 \pm 0.00002) \times 10^{-5} \text{ GeV}^{-2}$$

- RADIATIVE CORRECTION (Z MRSS,...)

$$\Delta_R = (2.46 \pm 0.09) \%$$

$$V_{ud} = \left(\frac{K}{2(1+\Delta_R)\overline{Ft}} \right)^{1/2} G_{\mu}^{-1}$$
$$= 0.9740 \pm 0.0005$$

± 0.0002 experimental

- K_{e3} & HYPERON DECAYS

$$V_{us} = 0.2205 \pm 0.0018$$

- B-MESON DECAY

$$V_{ub} = 0.0032 \pm 0.0009$$

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9972 \pm 0.0013$$

EXPLANATIONS OF "NON-UNITARITY"

TRIVIAL

- INADEQUATE CHARGE CORRECTIONS TO NUCLEAR $0^+ \rightarrow 0^+$ DECAYS: RESIDUAL Z -DEPENDENCE IN F_t VALUES.

$$\Sigma = 0.9985 \pm 0.0015$$

- REANALYSIS OF HYPERON DECAYS (V_{ud})

$$\Sigma = 0.9987 \pm 0.0013$$

NON-TRIVIAL

- RIGHT-HAND CURRENTS
- ADDITIONAL NEUTRAL GAUGE BOSONS
-
-

Juha Äystö

University of Jyväskylä
Jyväskylä, Finland

Beta-delayed neutron emission
in the $A \sim 100$ region

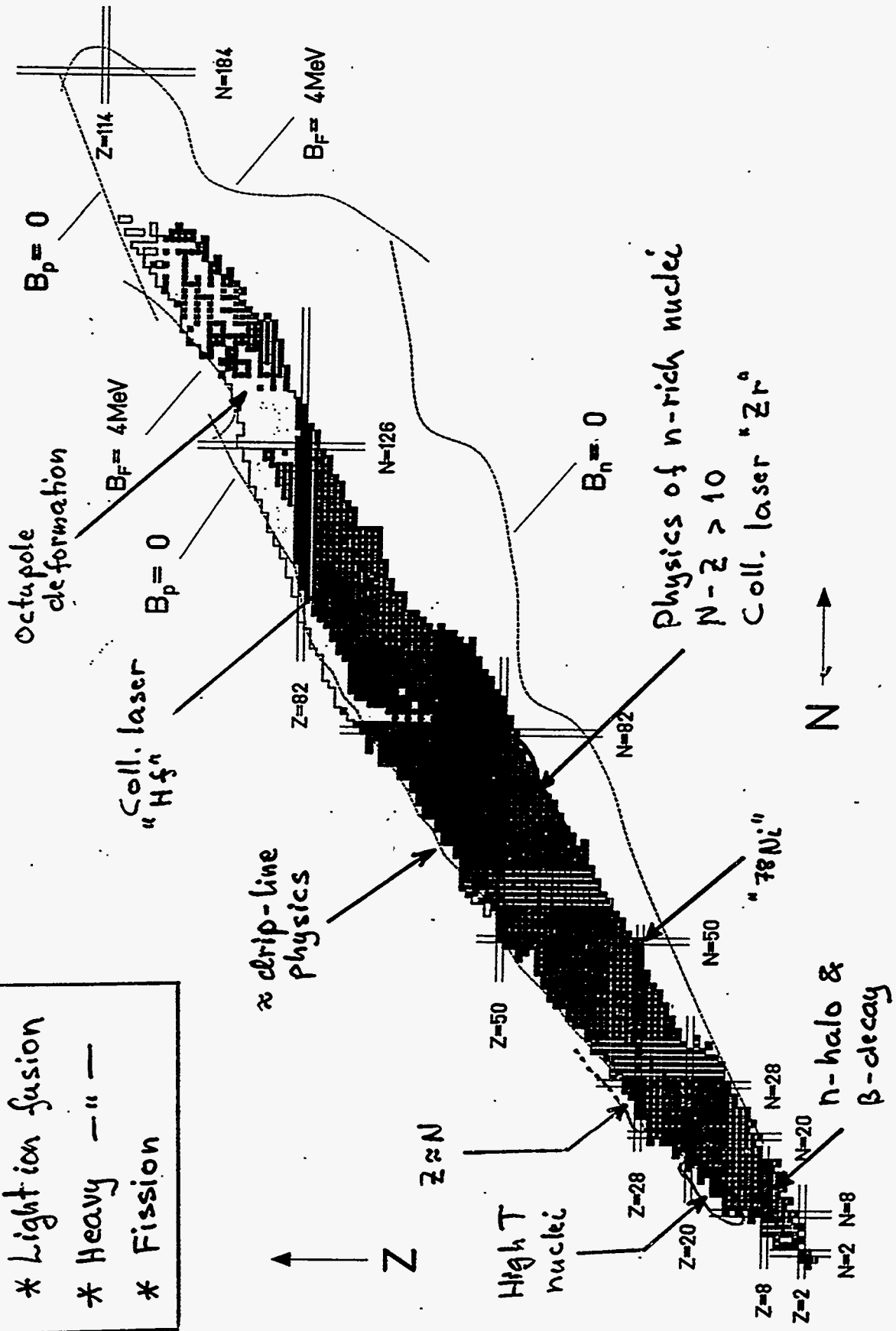
Juha Äystö

University of Jyväskylä

Finland

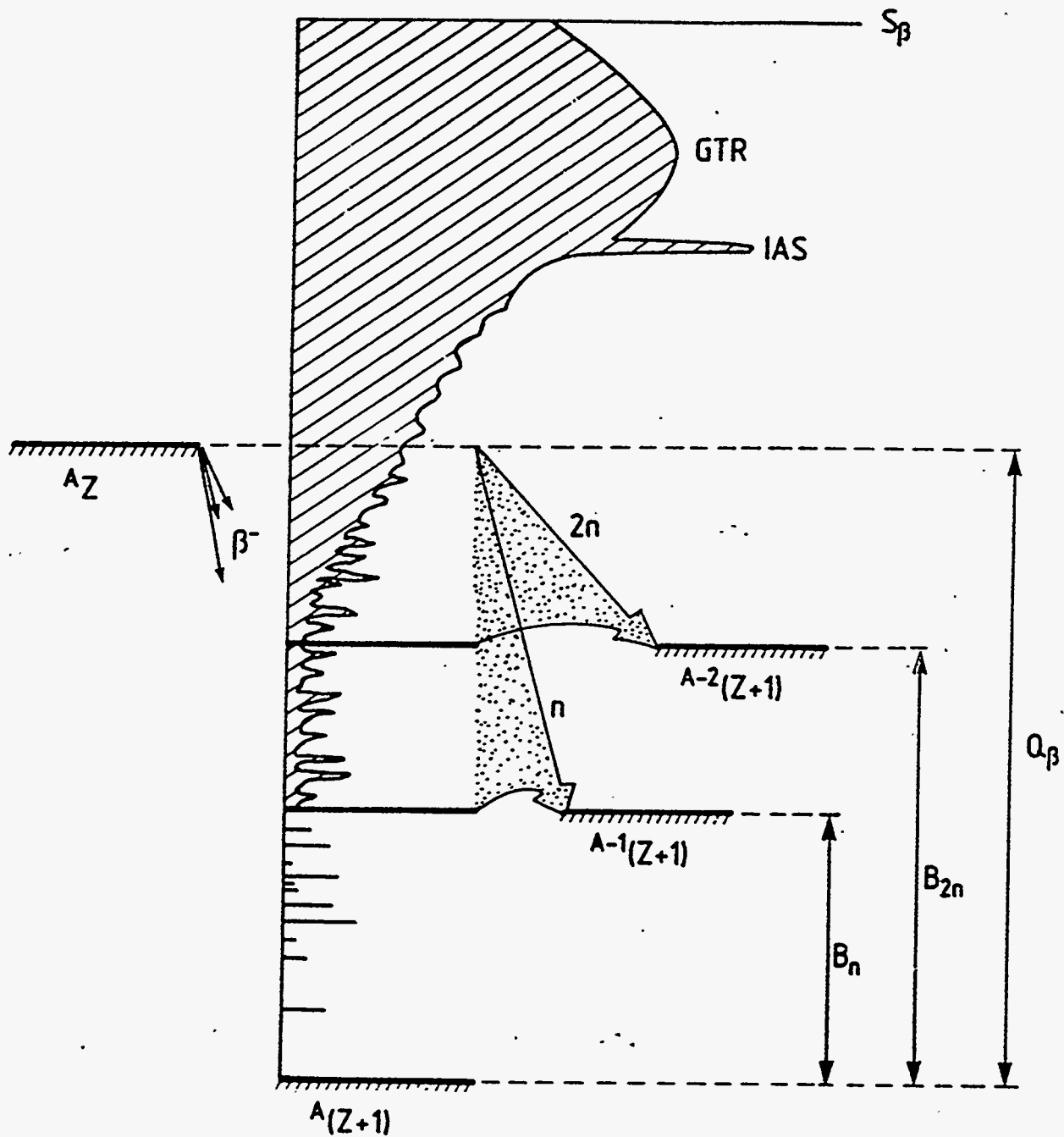
PHYSICS AT IGISOL in 1996-97

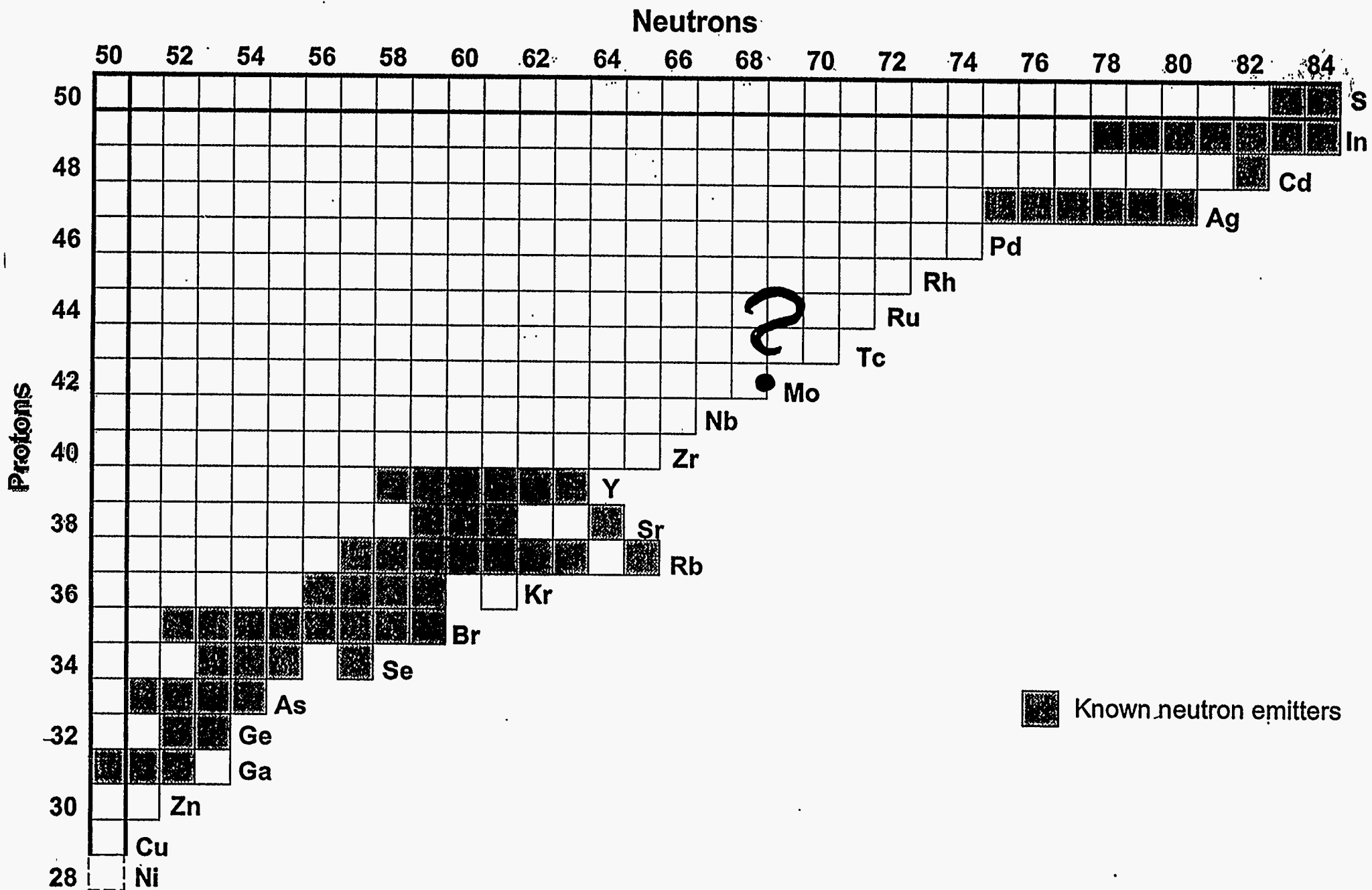
- * Light ion fusion
- * Heavy — " —
- * Fission

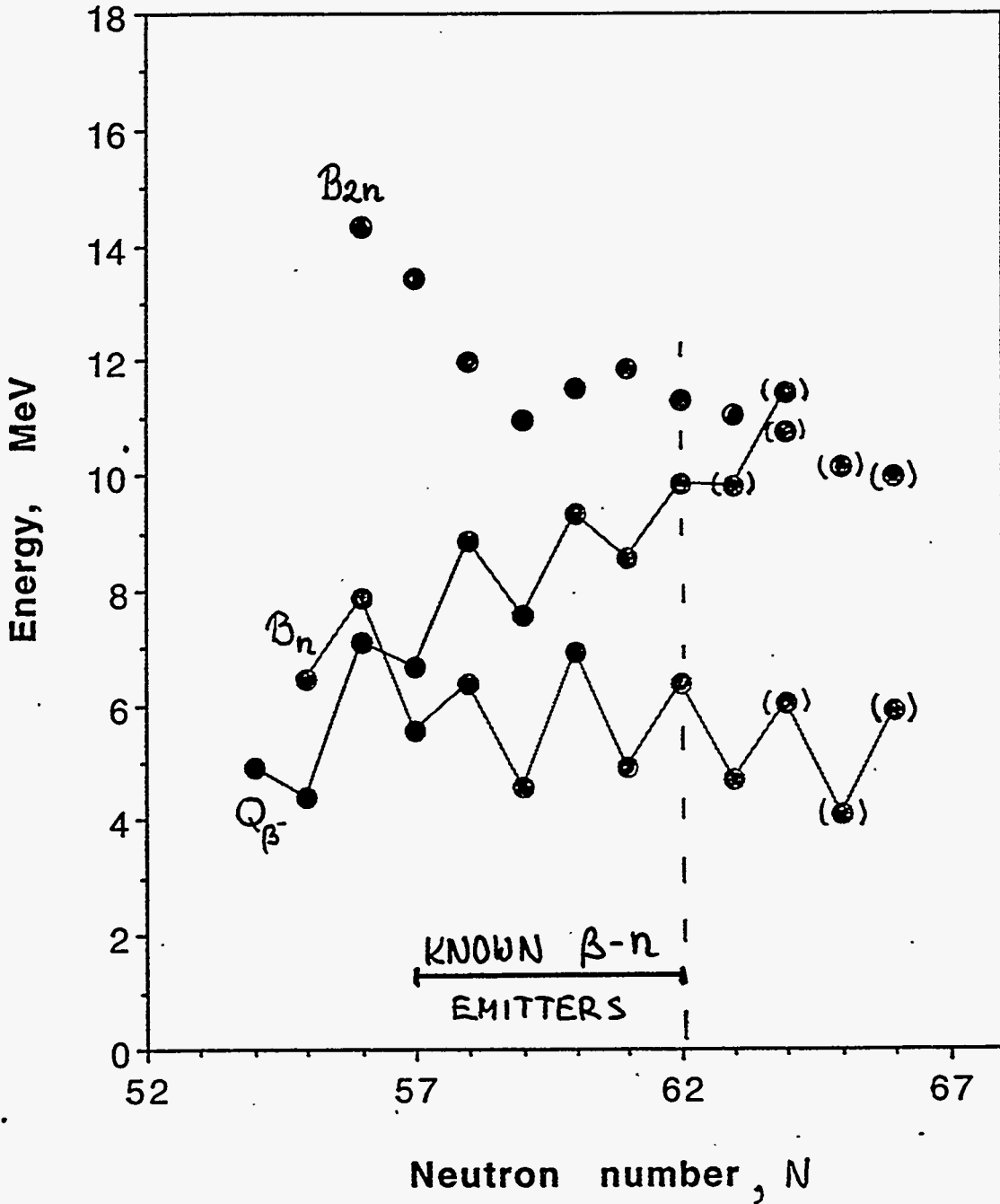
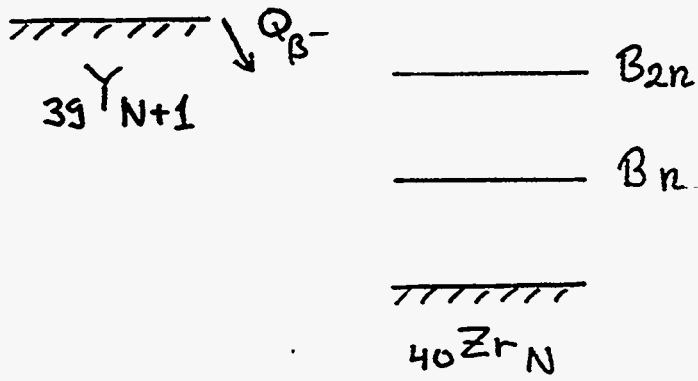


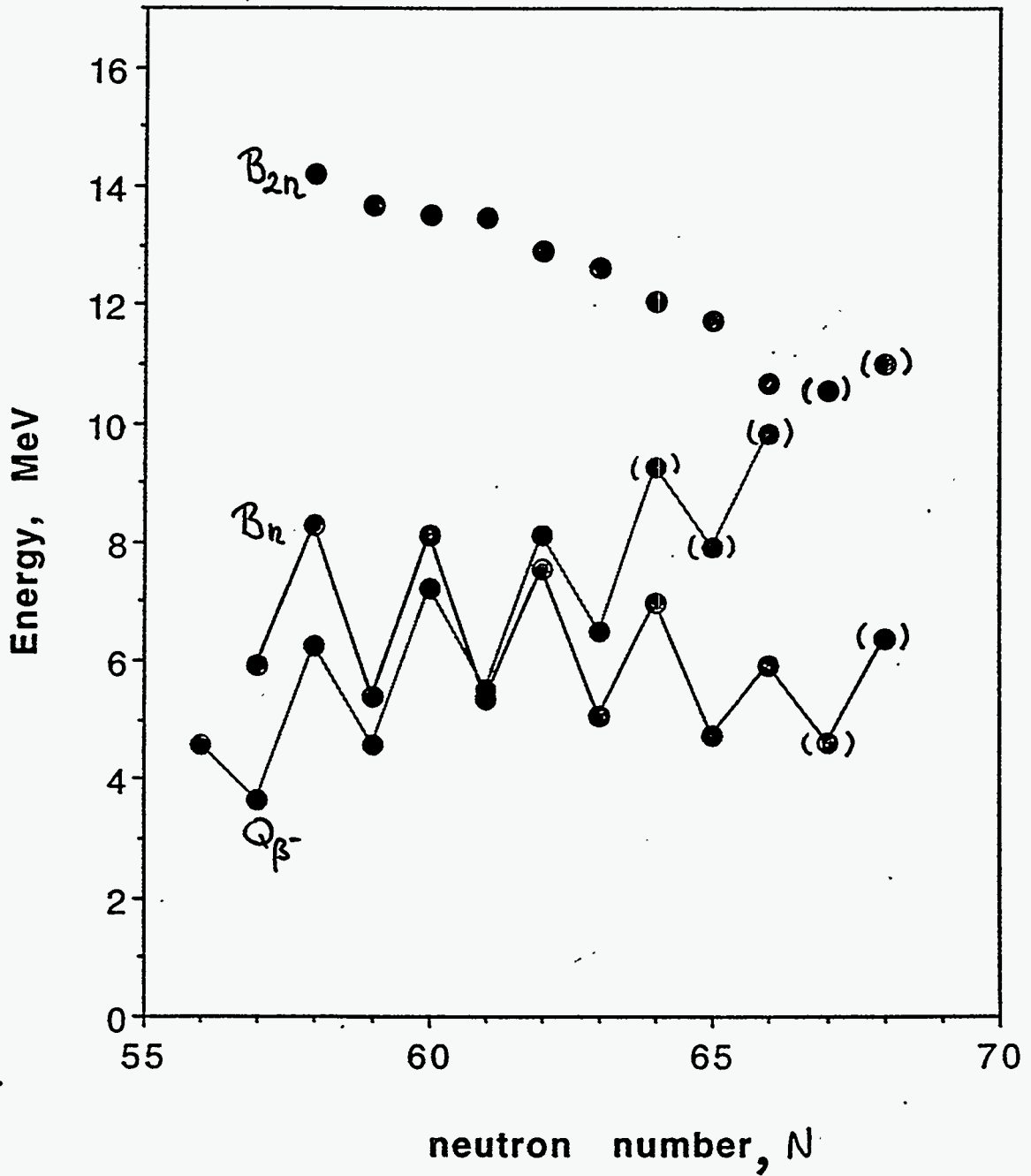
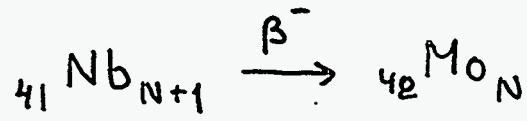
BETA-DELAYED NEUTRON EMISSION

(probe for new n-rich nuclei)









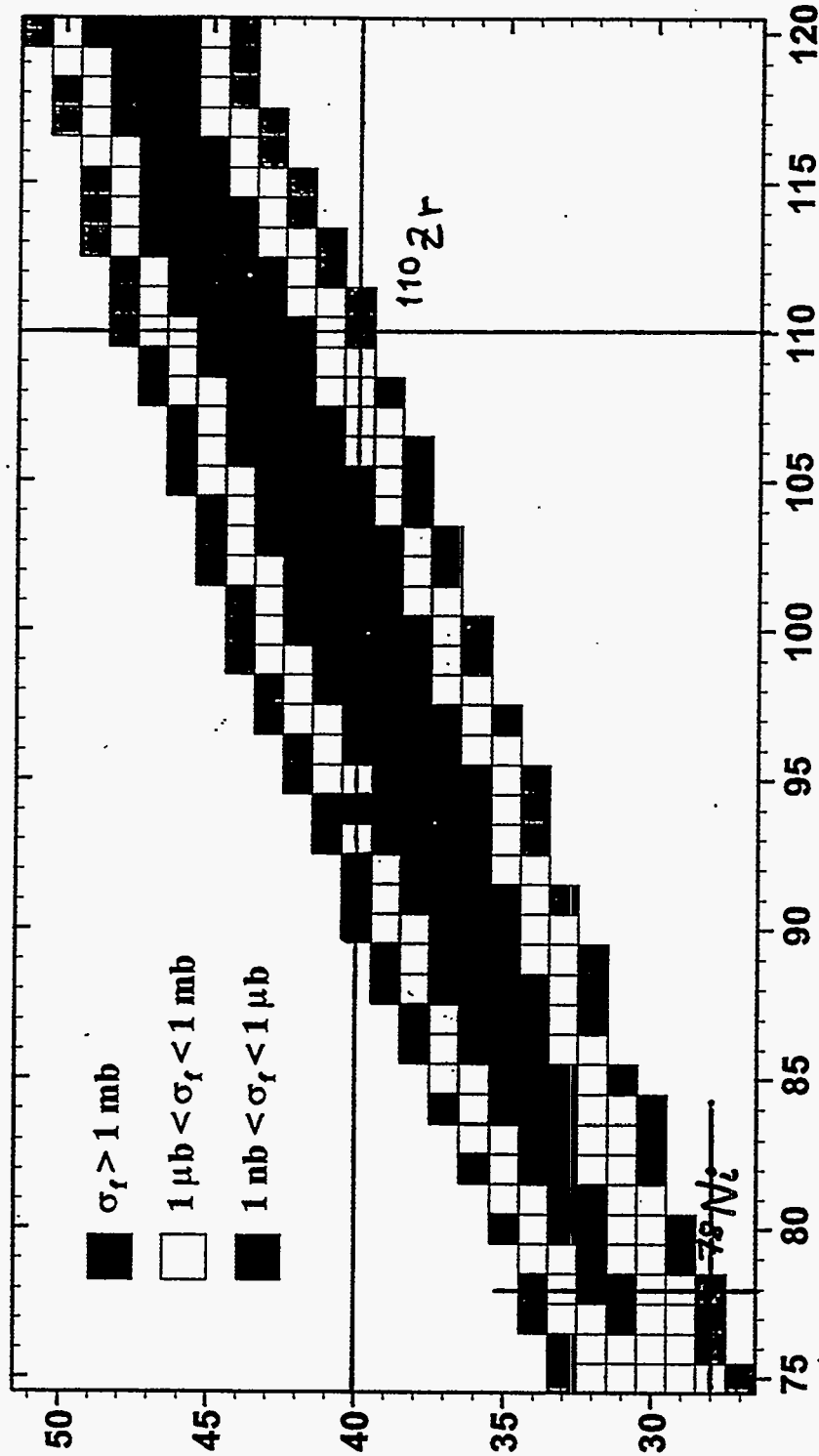
Reactions:

(p,xnf), (d,xnf) & (d,pf)

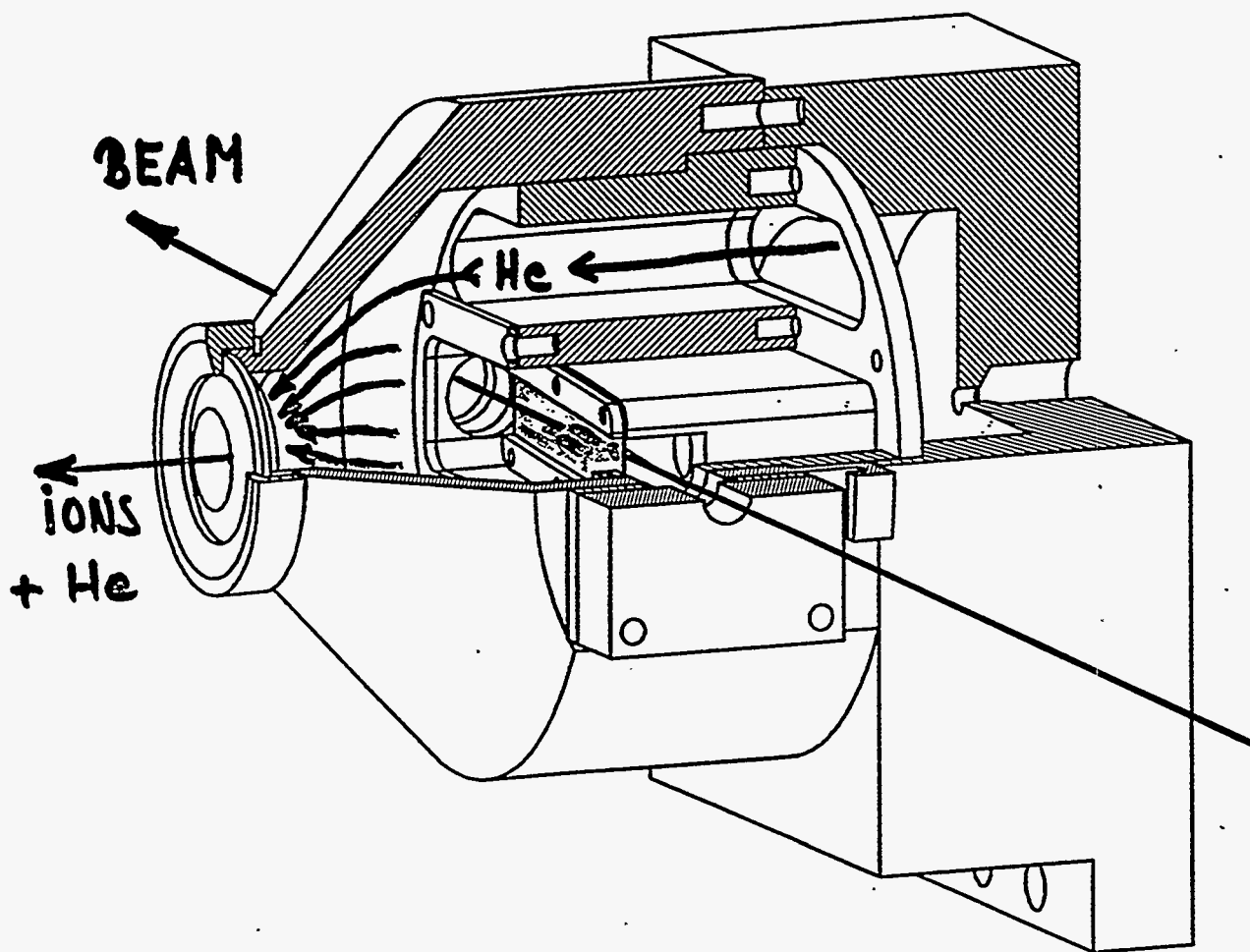
$$\left[\begin{array}{l} p + {}^{238}\text{U} \\ p + {}^{232}\text{Th} \end{array} \right. \quad \begin{array}{l} E_p = 20 - 90 \text{ MeV} \\ I_p = 40 \mu\text{A} \text{ (up to 30 MeV)} \\ I_p = 10 \mu\text{A} \text{ (above 30 MeV)} \end{array}$$

$$\left[\begin{array}{l} d + {}^{238}\text{U} \\ d + {}^{232}\text{Th} \end{array} \right. \quad \begin{array}{l} E_d = 15 - 65 \text{ MeV} \\ I_d = 20 \mu\text{A} \end{array}$$

$^{238}\text{U} + ^1\text{H}, E_p = 25 \text{ MeV}$



ION GUIDE TARGET CHAMBER



- target angle to the beam

$$\theta \geq 80^\circ$$

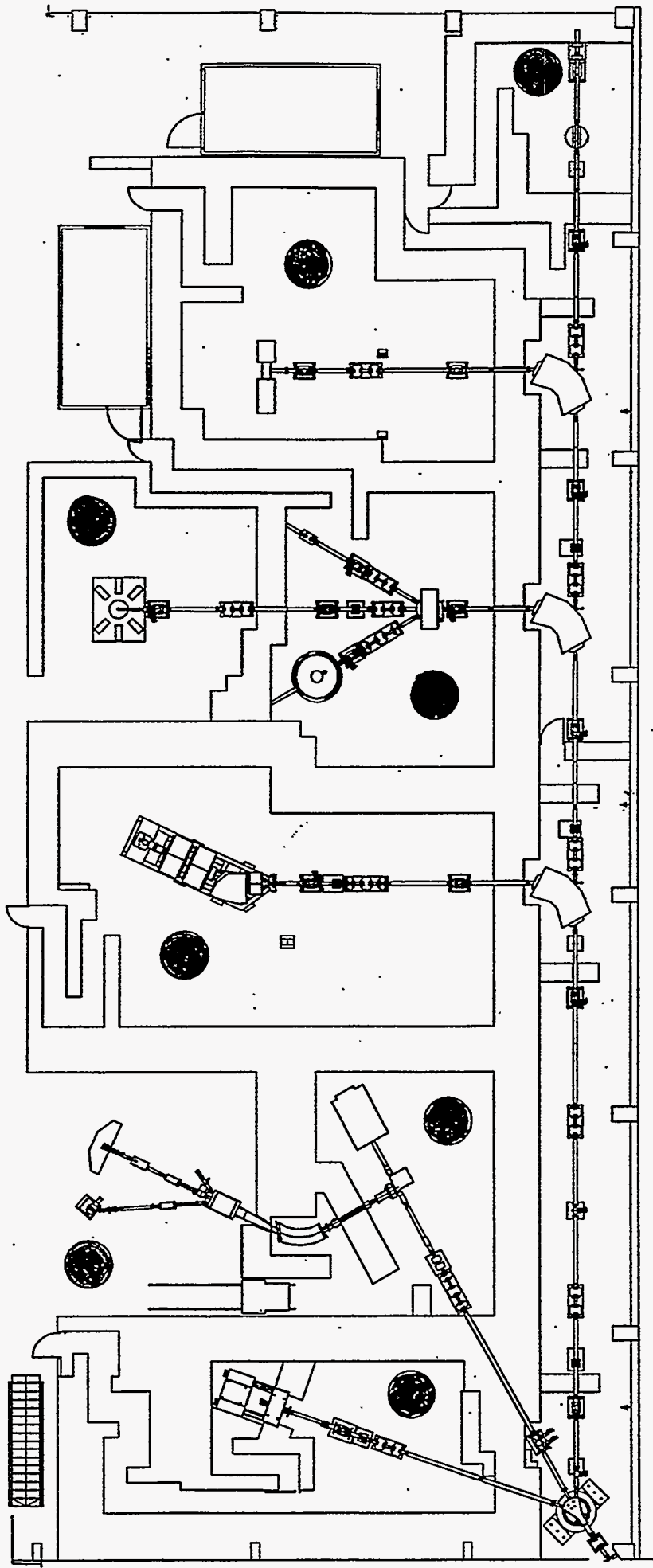
- extraction voltage

$$V_{sk}: 0 - 1000 \text{ V}$$

③ ISOTOPE PRODUCTION (MAP) ⑤ RECOIL SPECTROMETER (RITU)

④ ISOTOPE SEPARATOR (IGISOL)
+ LASER

⑥ ION BEAM APPLICATIONS

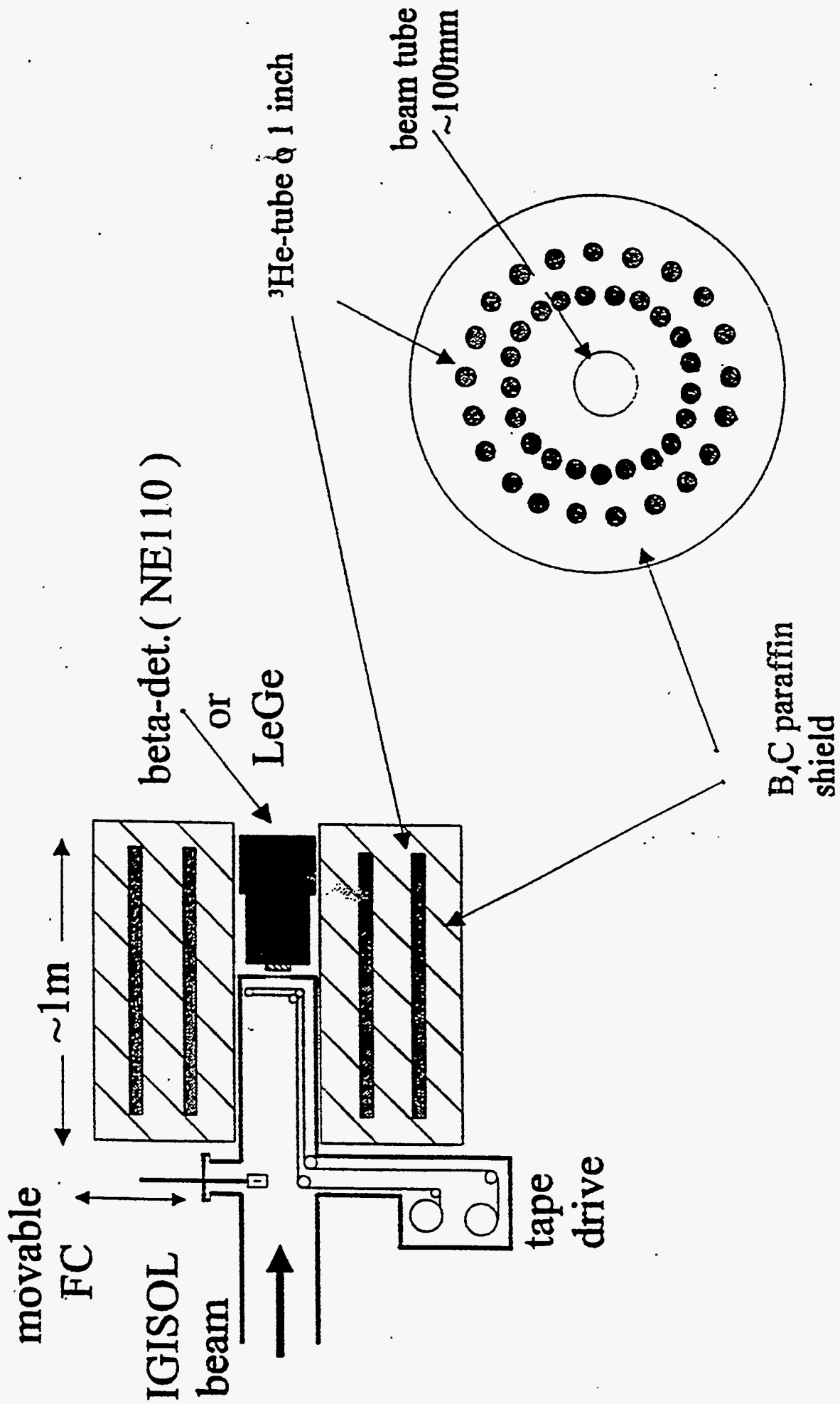


0 5 10m

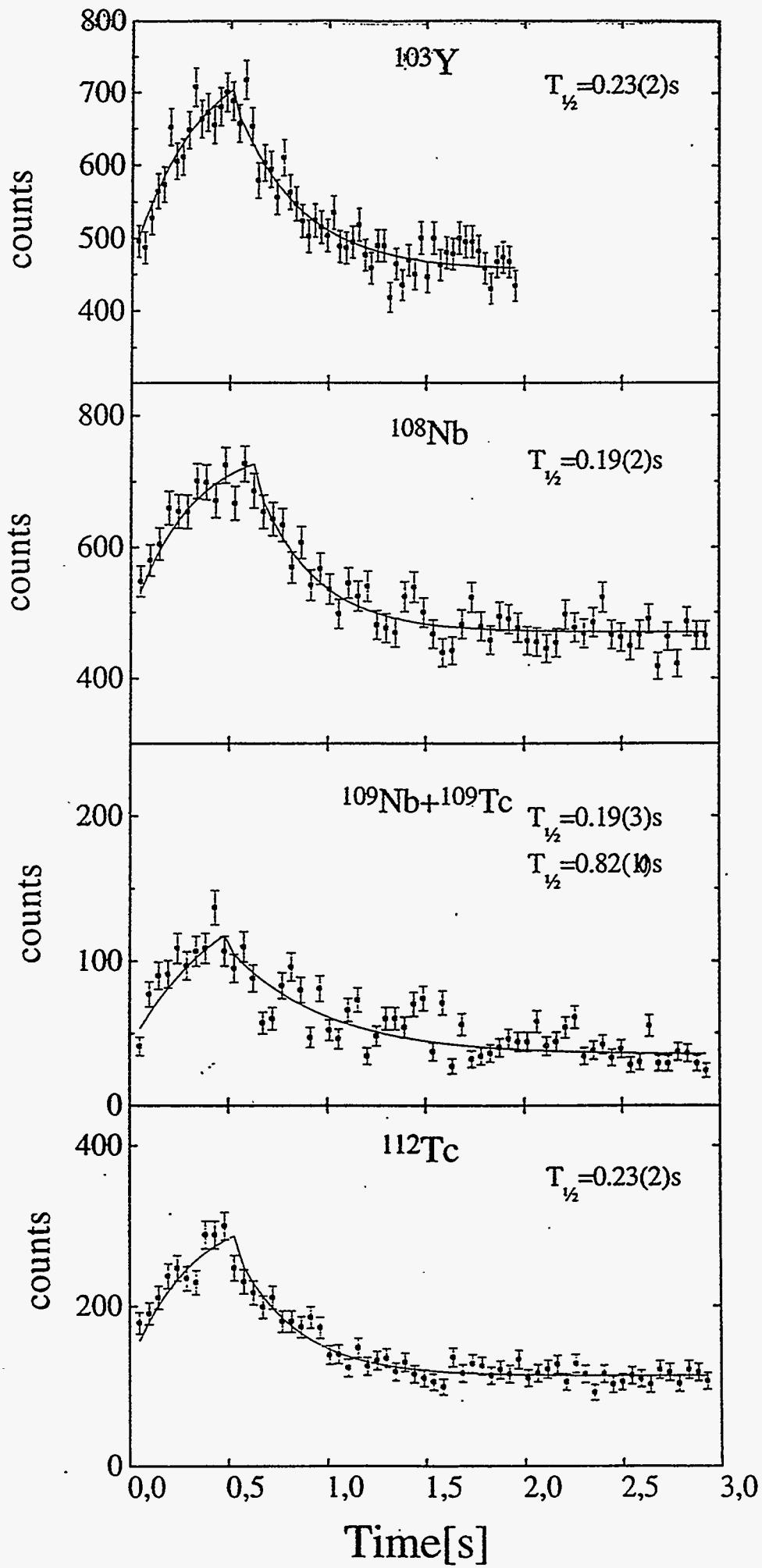
⑦ GAMMA BALL (TESSA)

⑨ NEUTRON DETECTOR (HENDES)

⑧ ELECTRON SPECTROMETER



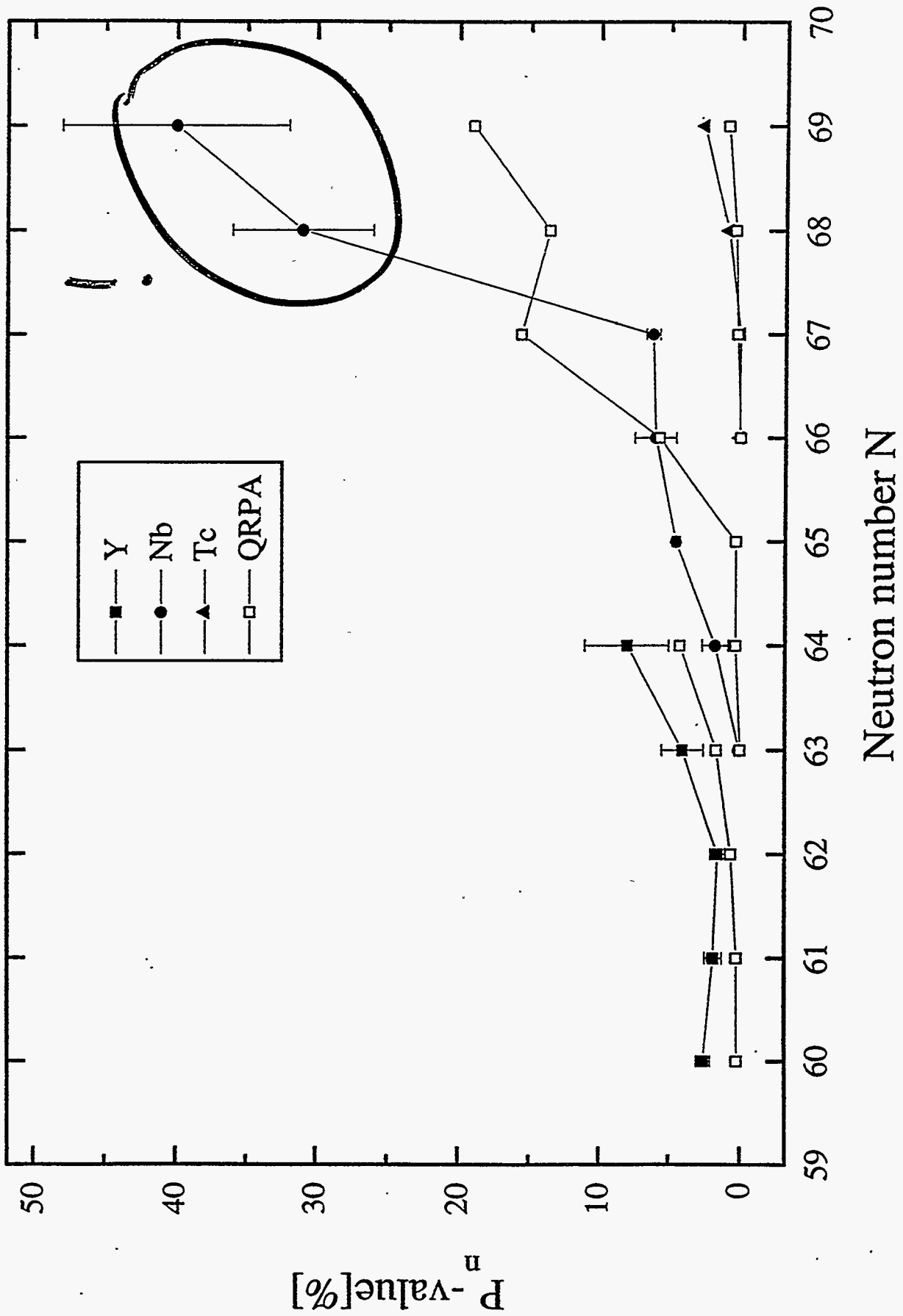
" NOT IN SCALE "



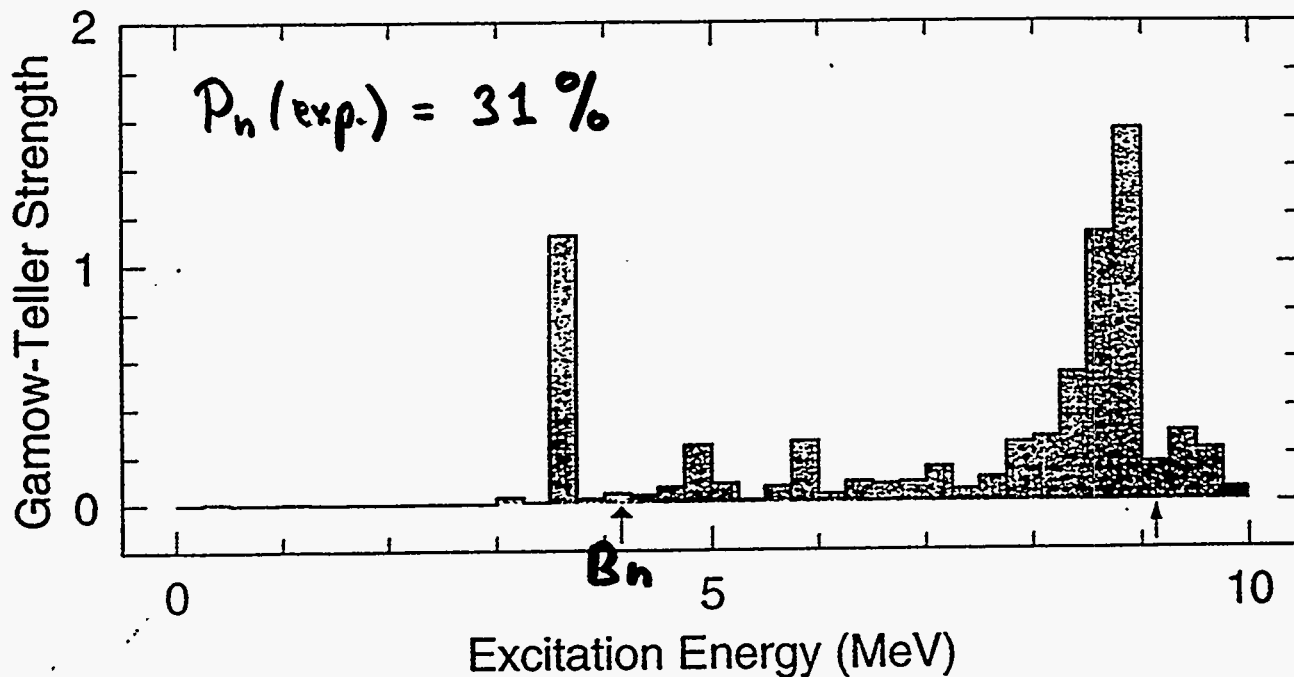
New beta-delayed neutron-emitters observed at IGISOL

● Decay observed for the first time

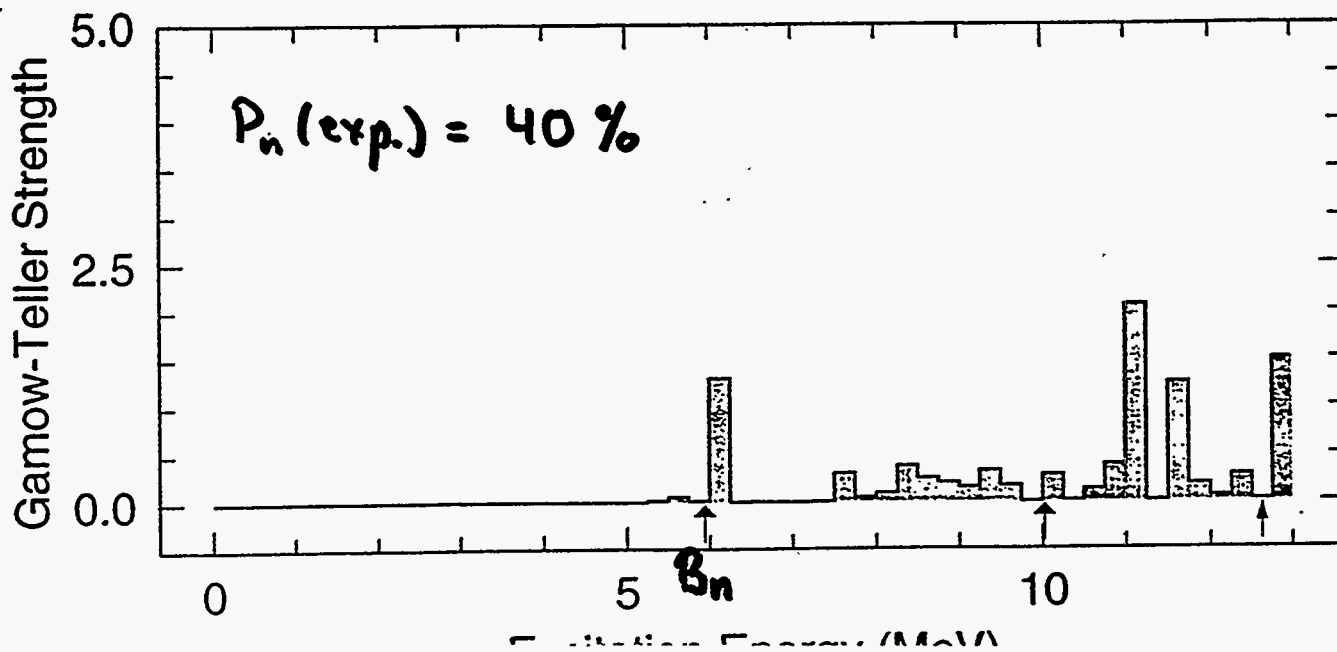
Nuclide	$T_{1/2}$ (s)	P_n -value (%)
<hr style="border-top: 1px dashed black;"/>		
● 103-Y	0.23	8
104-Nb(gs)	5.0	0.06
104-Nb(m)	1.0	0.05
105-Nb	2.8	1.7
106-Nb	0.90	4.5
107-Nb	0.30	6.0
● 108-Nb	0.19	6.2
● 109-Nb	0.19	31
● 110-Nb	0.17	40
109-Tc	0.82	0.08
110-Tc	0.78	0.04
111-Tc	0.29	0.85
112-Tc	0.23	2.6
<hr style="border-top: 1px dashed black;"/>		



Folded-Yukawa potential		$\varepsilon_2 = 0.317$	$\Delta_n = 0.88$ MeV	$\lambda_n = 33.54$ MeV
$P_n = 13.60\%$	$T_{1/2} = 460.99$ (ms)	$\varepsilon_4 = 0.087$	$\Delta_p = 1.14$ MeV	$\lambda_p = 30.73$ MeV
$^{109}_{41}\text{Nb} \rightarrow ^{109}_{42}\text{Mo} + e^-$		$\varepsilon_6 = -0.037$	(L-N)	$a = 0.80$ fm

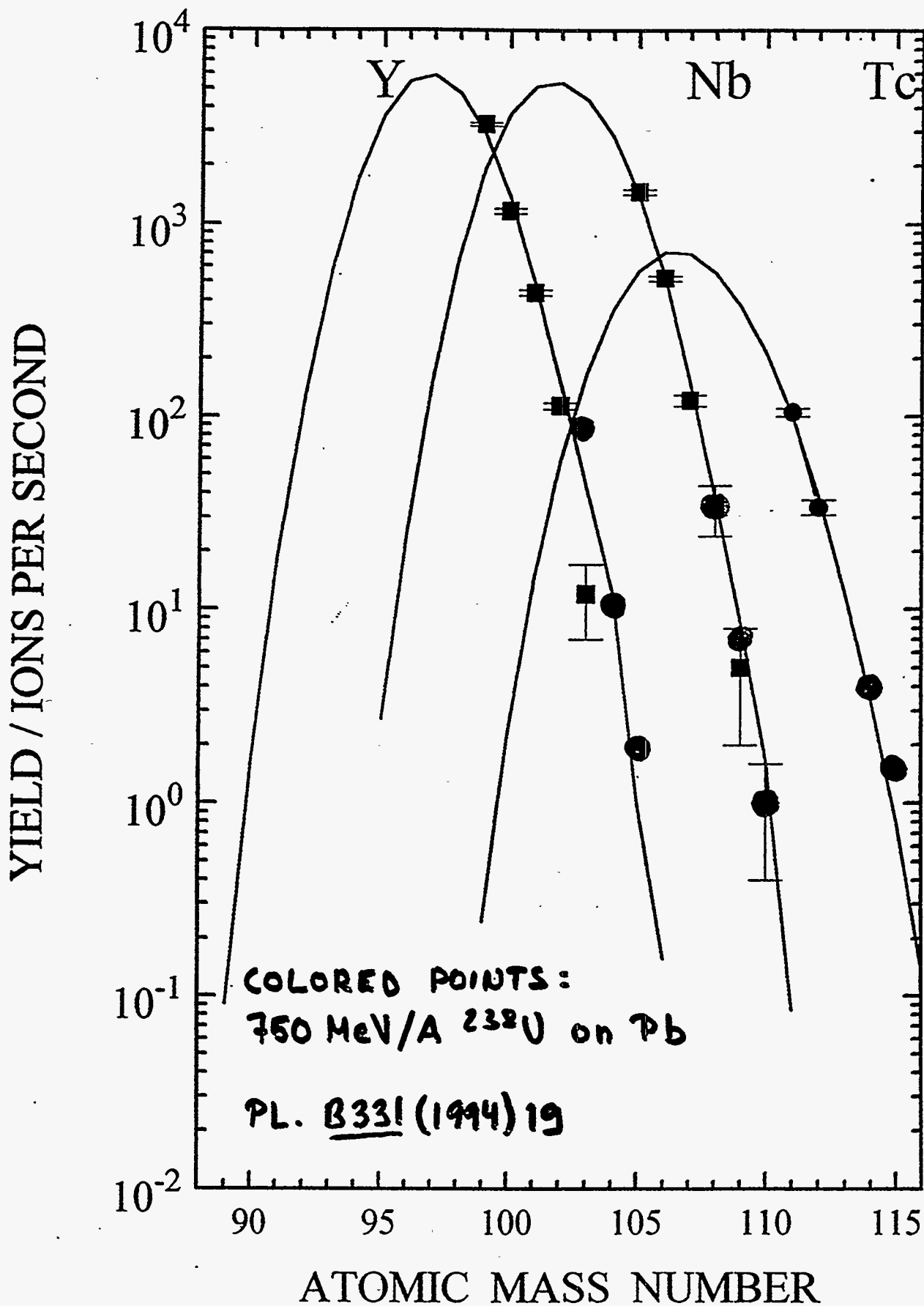


Folded-Yukawa potential		$\varepsilon_2 = 0.298$	$\Delta_n = 0.98$ MeV	$\lambda_n = 33.56$ MeV
$P_n = 91.99\%$	$T_{1/2} = 190.56$ (ms)	$\varepsilon_4 = 0.017$	$\Delta_p = 1.18$ MeV	$\lambda_p = 30.75$ MeV
$^{110}_{41}\text{Nb} \rightarrow ^{110}_{42}\text{Mo} + e^-$		$\varepsilon_6 = 0.000$	(L-N)	$a = 0.80$ fm



PROD. RATES IN β_n -EXPERIMENT

25 MeV p + uranium



Nuclear Shell Structure at Particle Drip Lines

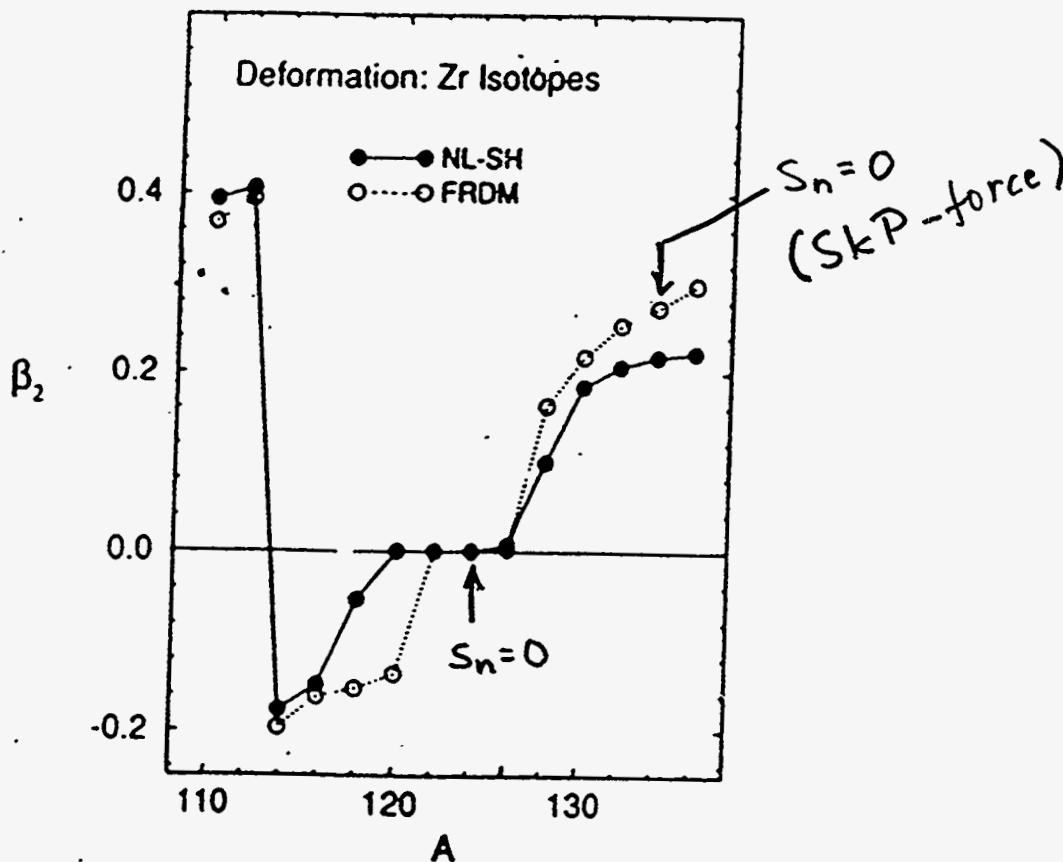
J. Dobaczewski,* I. Hamamoto,† W. Nazarewicz,* and J. A. Sheikh†
 Joint Institute for Heavy-Ion Research, Physics Division, Oak Ridge National Laboratory,
 P.O. Box 2008, Oak Ridge, Tennessee 37831
 and Department of Physics, University of Tennessee, Knoxville, Tennessee 37996
 (Received 1 September 1993)

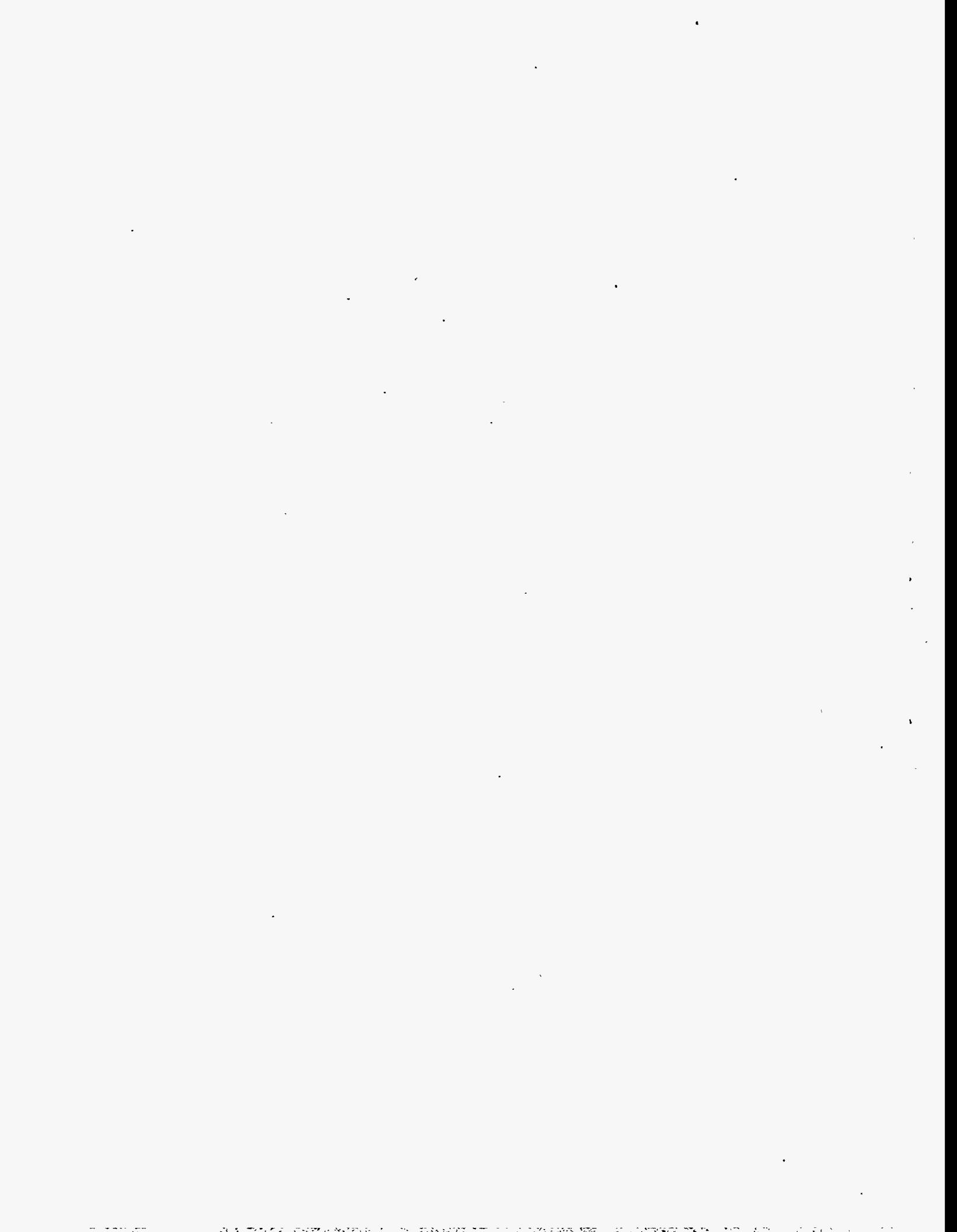
The shell structure of exotic nuclei near proton and neutron drip lines is discussed in terms of the self-consistent mean-field theory. It is demonstrated that when approaching the neutron drip line, the neutron density becomes very diffused and the single-particle spectrum shows similarities to that of the harmonic oscillator with spin-orbit term. Interaction between bound orbitals and continuum is shown to result in quenching of shell effects in light and medium systems.

Shell Effects in Nuclei near the Neutron-Drip Line

M. M. Sharma,¹ G. A. Lalazissis,² W. Hillebrandt,¹ and P. Ring²
¹Max Planck Institut für Astrophysik, Karl-Schwarzschildstrasse 1, D-85740 Garching, Germany
²Physik Department, Technische Universität München, D-85747 Garching, Germany
 (Received 20 October 1993)

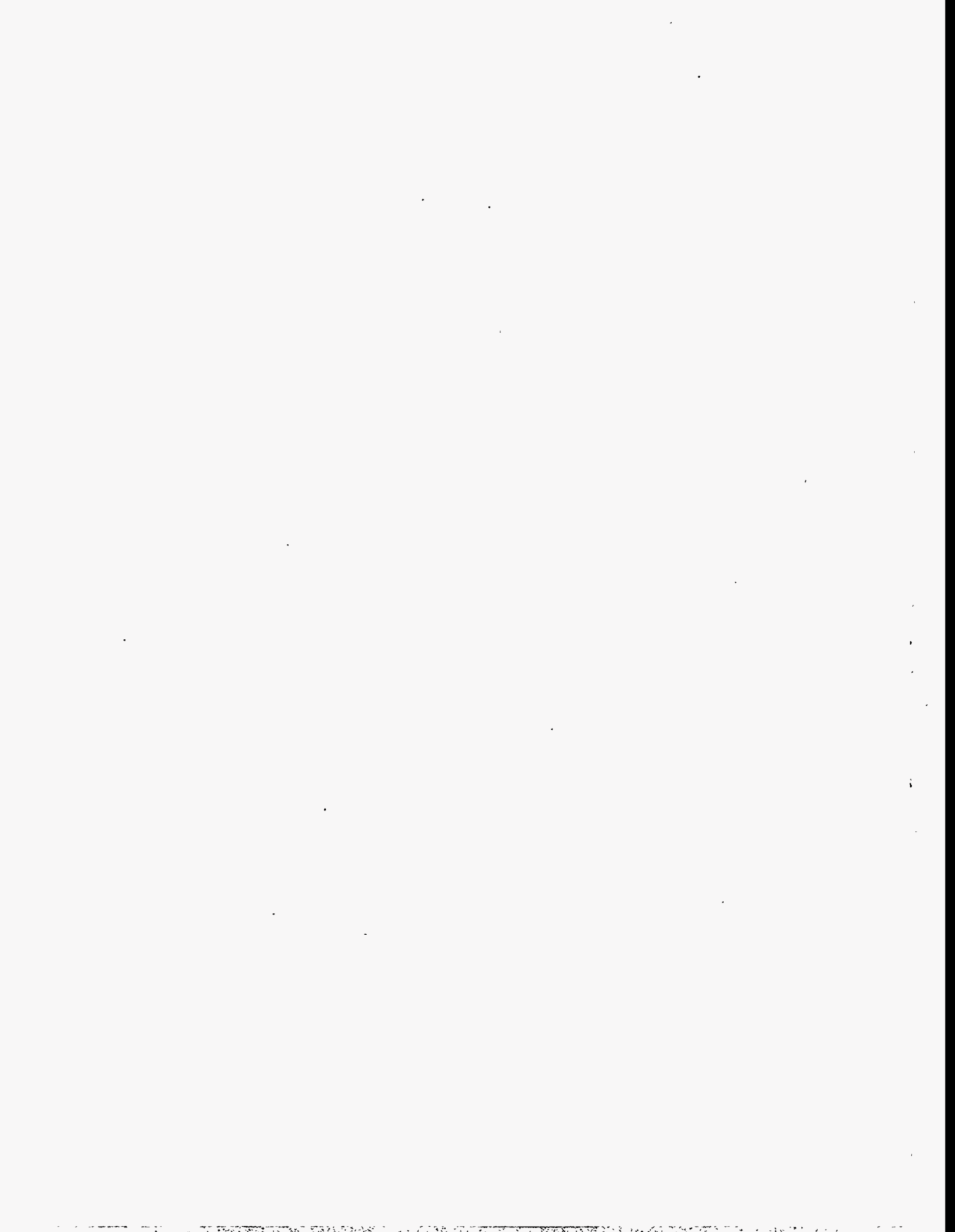
Shell effects in nuclei close to the neutron-drip lines have been investigated. It has been demonstrated in the relativistic mean-field theory that nuclei very far from stability manifest the shell effects strongly. This behavior is in accord with the predictions of nuclear masses in the finite-range droplet model including shell corrections. The shell effects predicted in the existing Skyrme mean-field theory in comparison are significantly weaker than those of the other approaches.

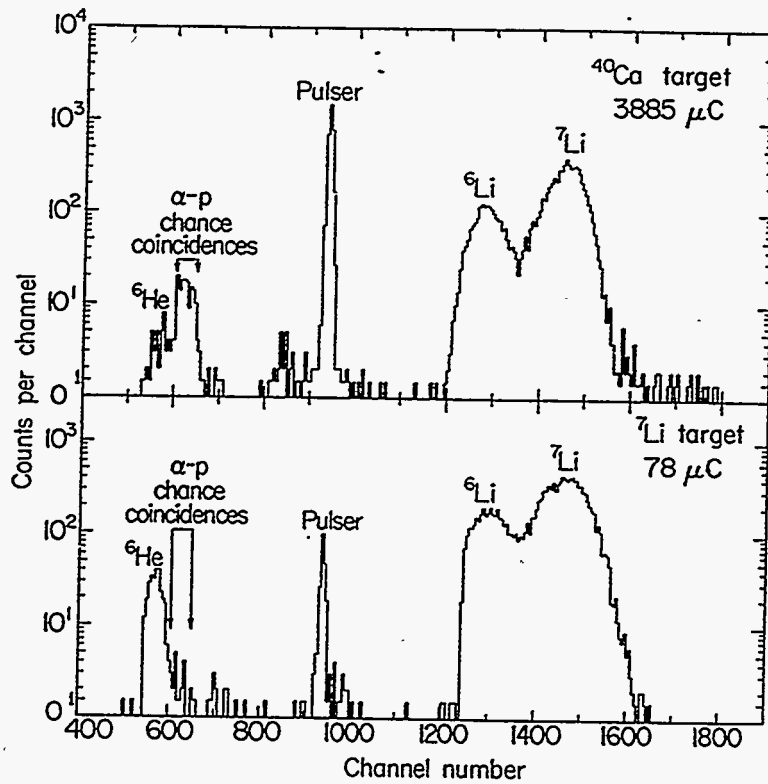




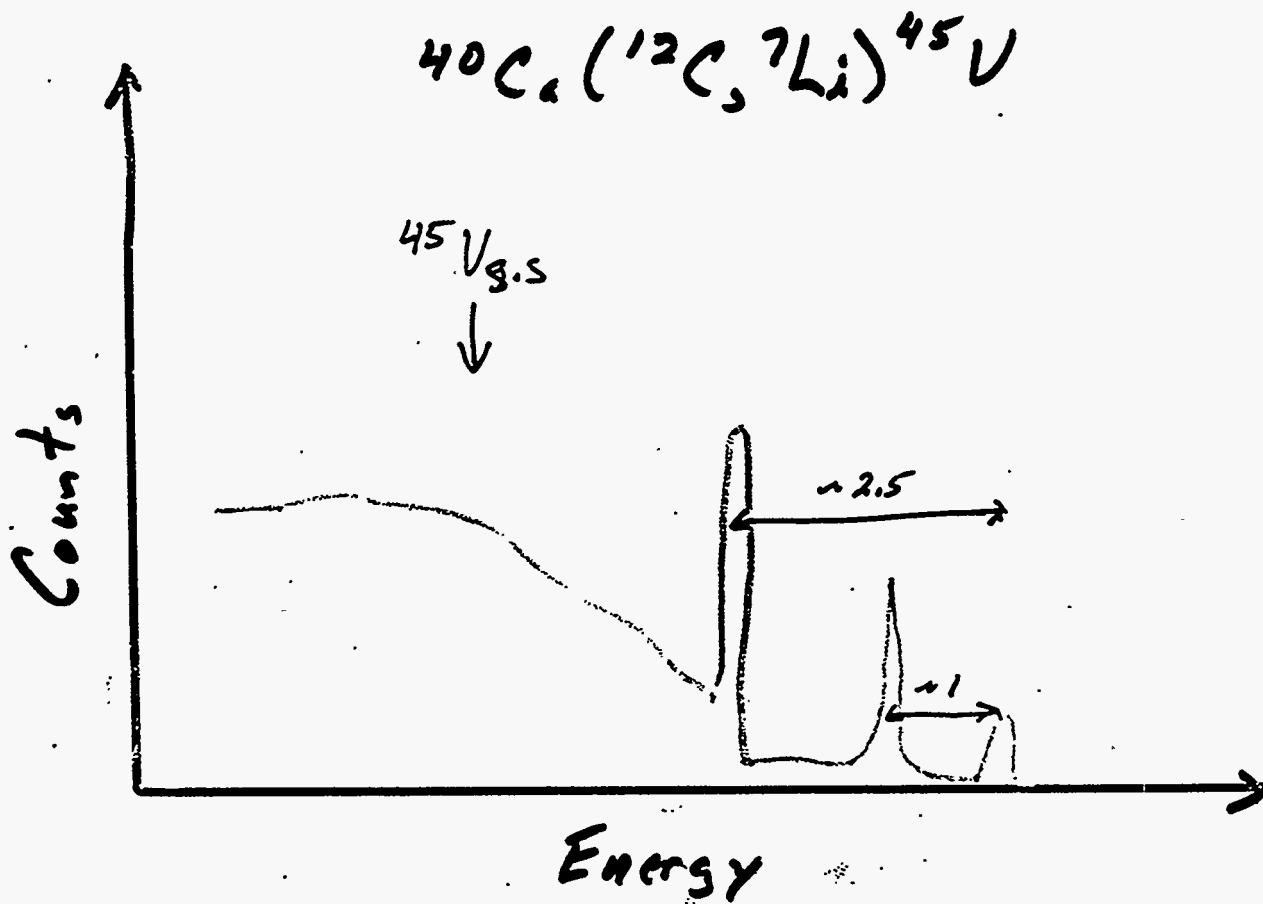
Gordon Wozniak

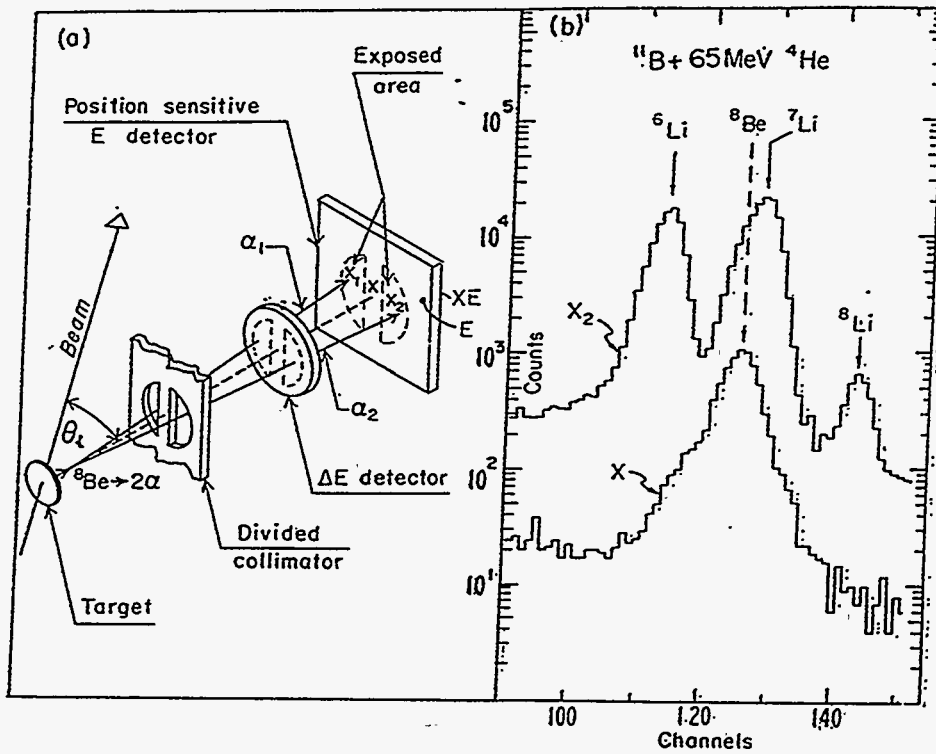
Lawrence Berkeley National Laboratory
Berkeley, CA



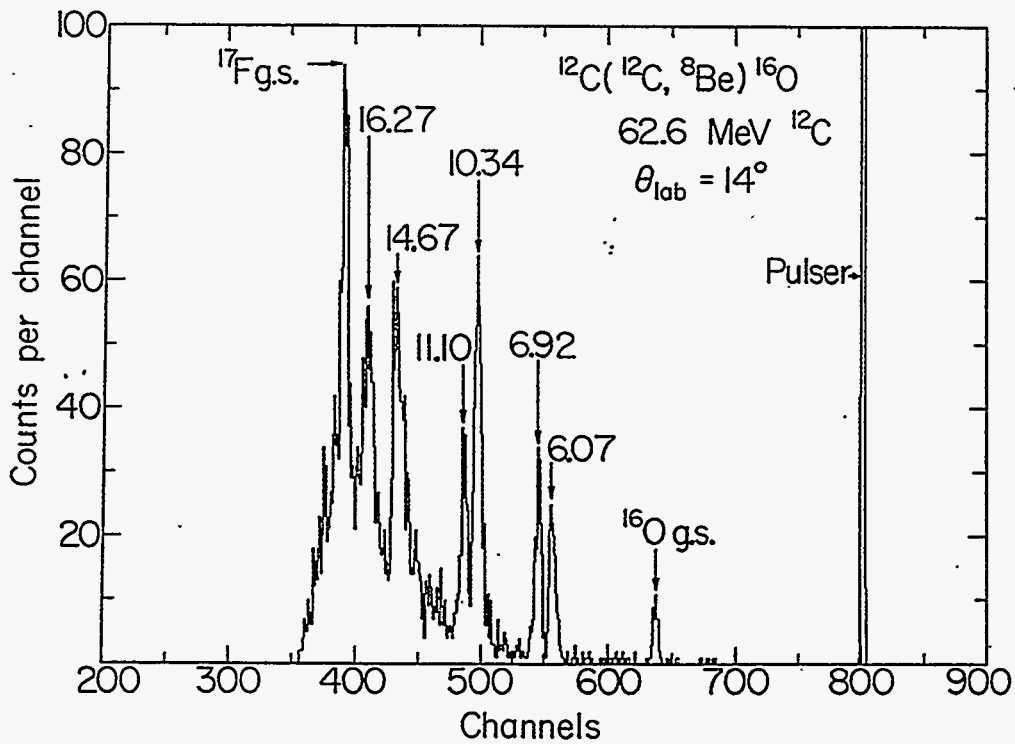


E E_c
 ΔE_2 ΔE_1

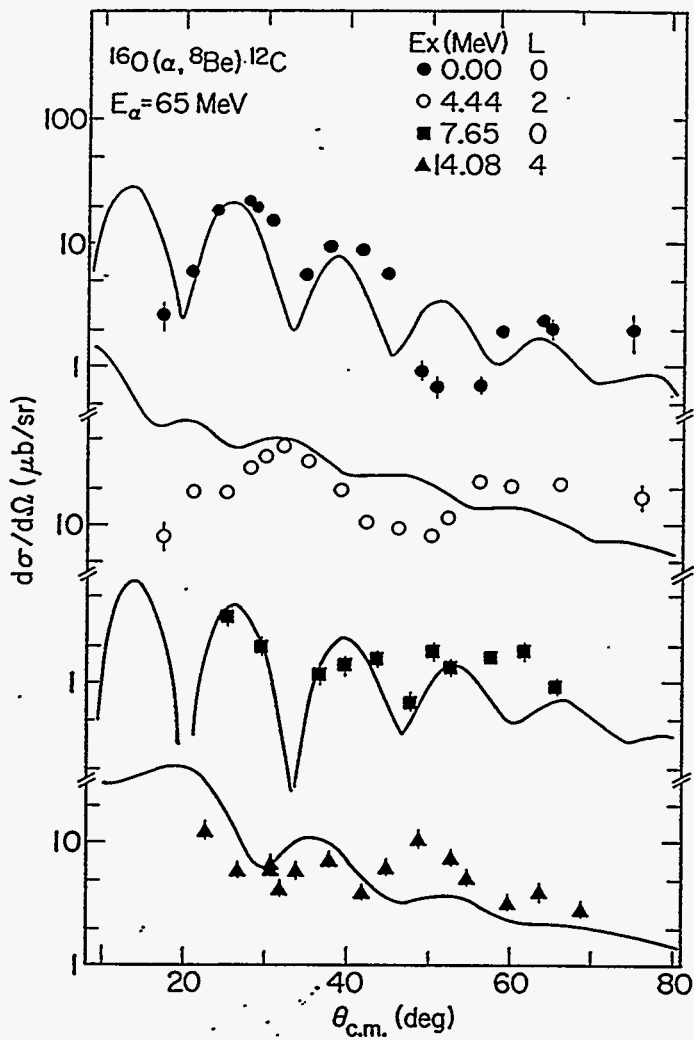
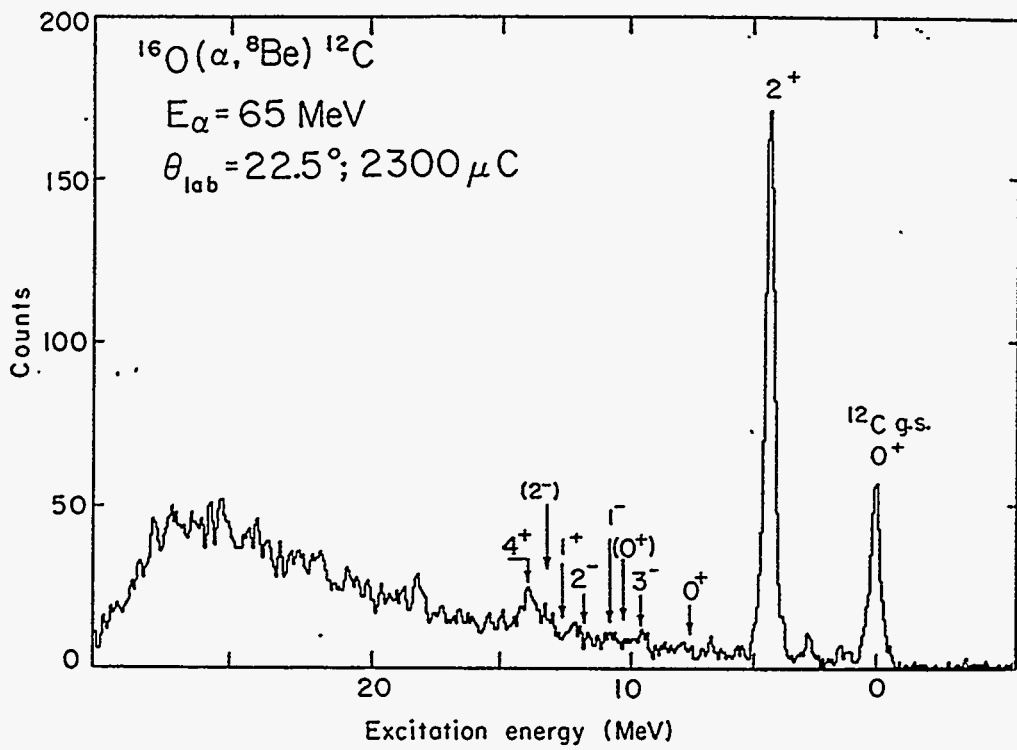




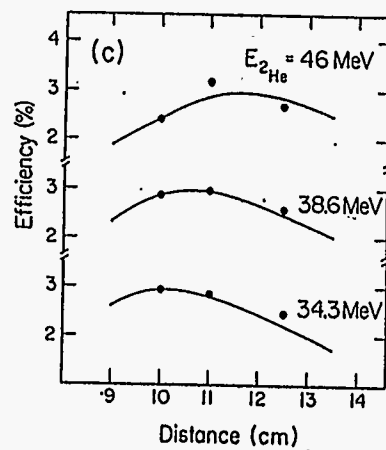
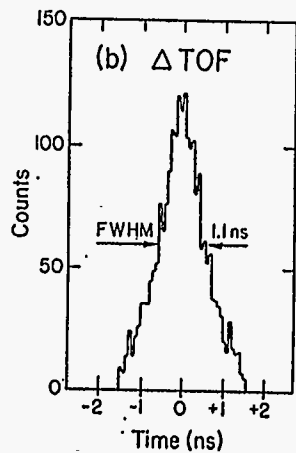
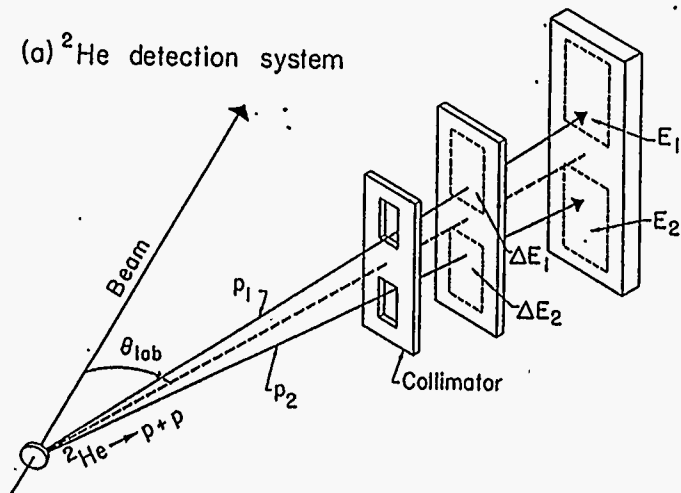
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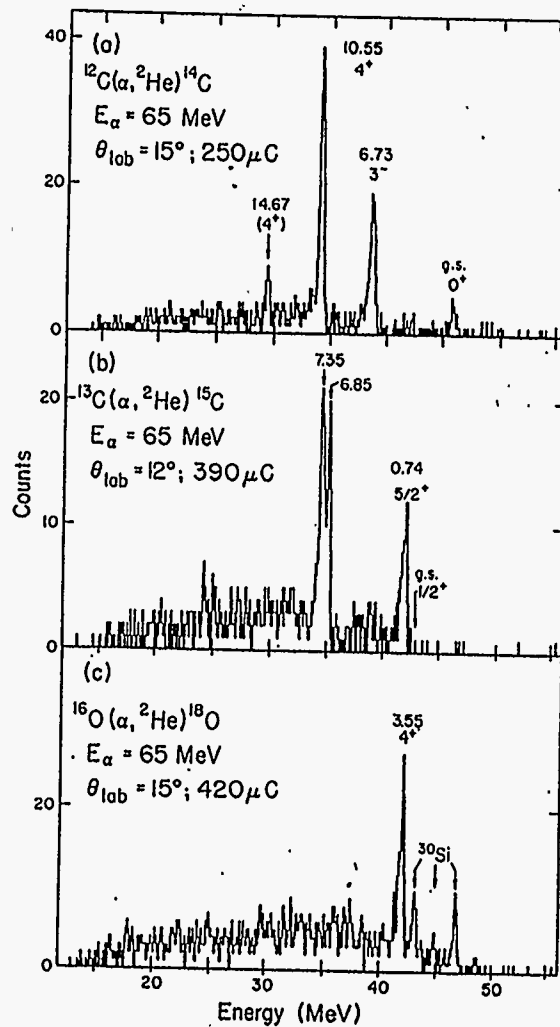
XBL721-2175



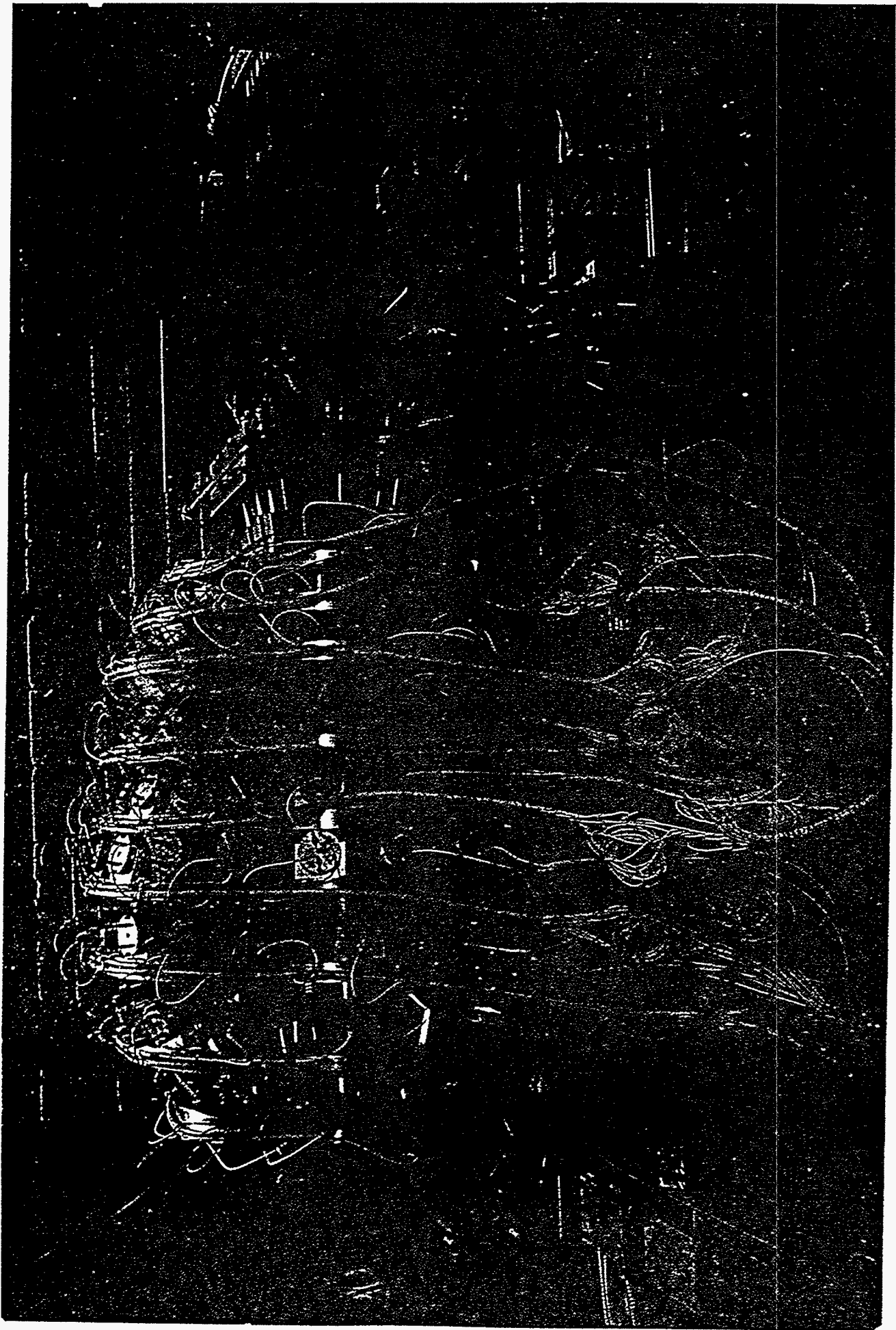
(a) ^2He detection system

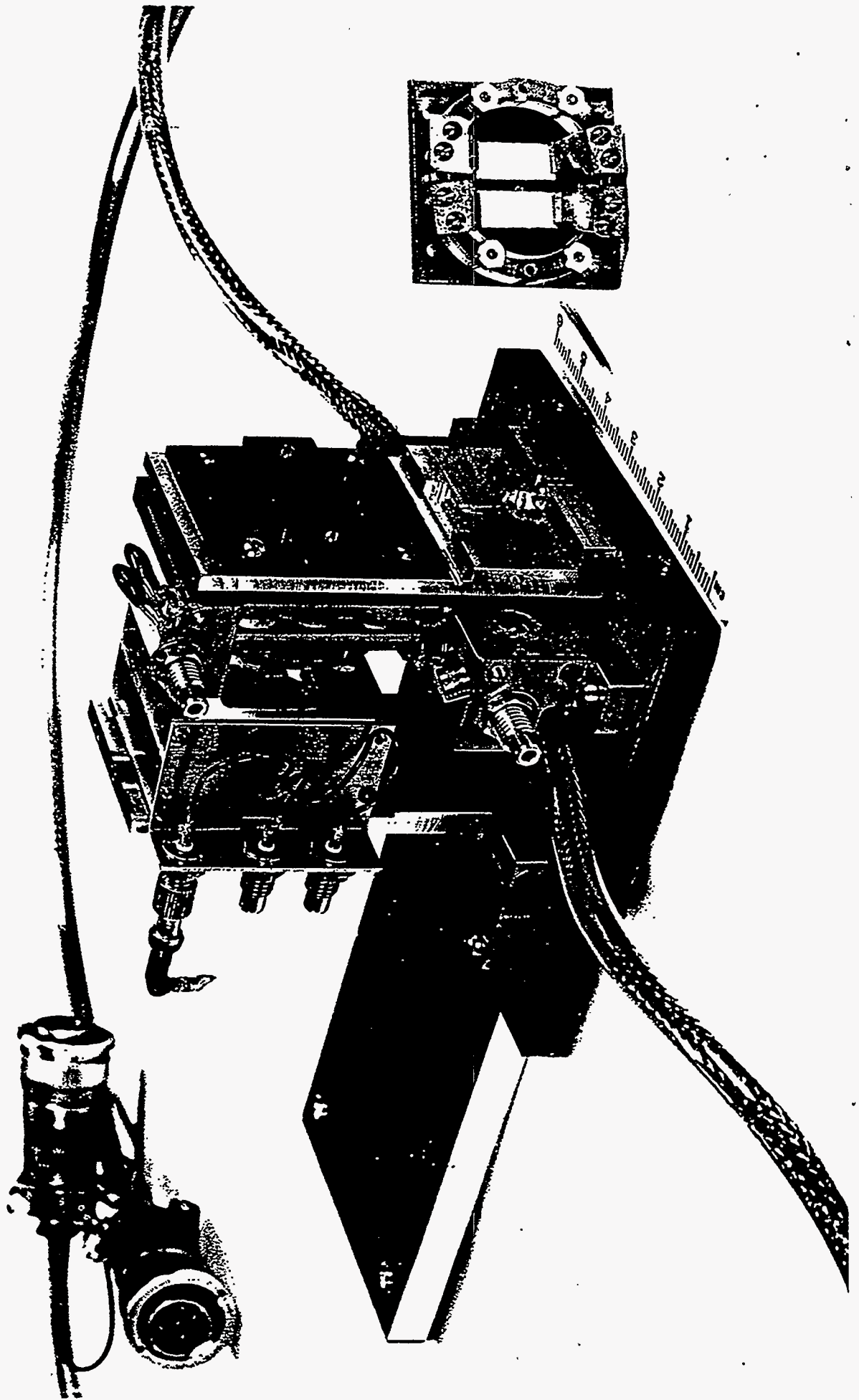


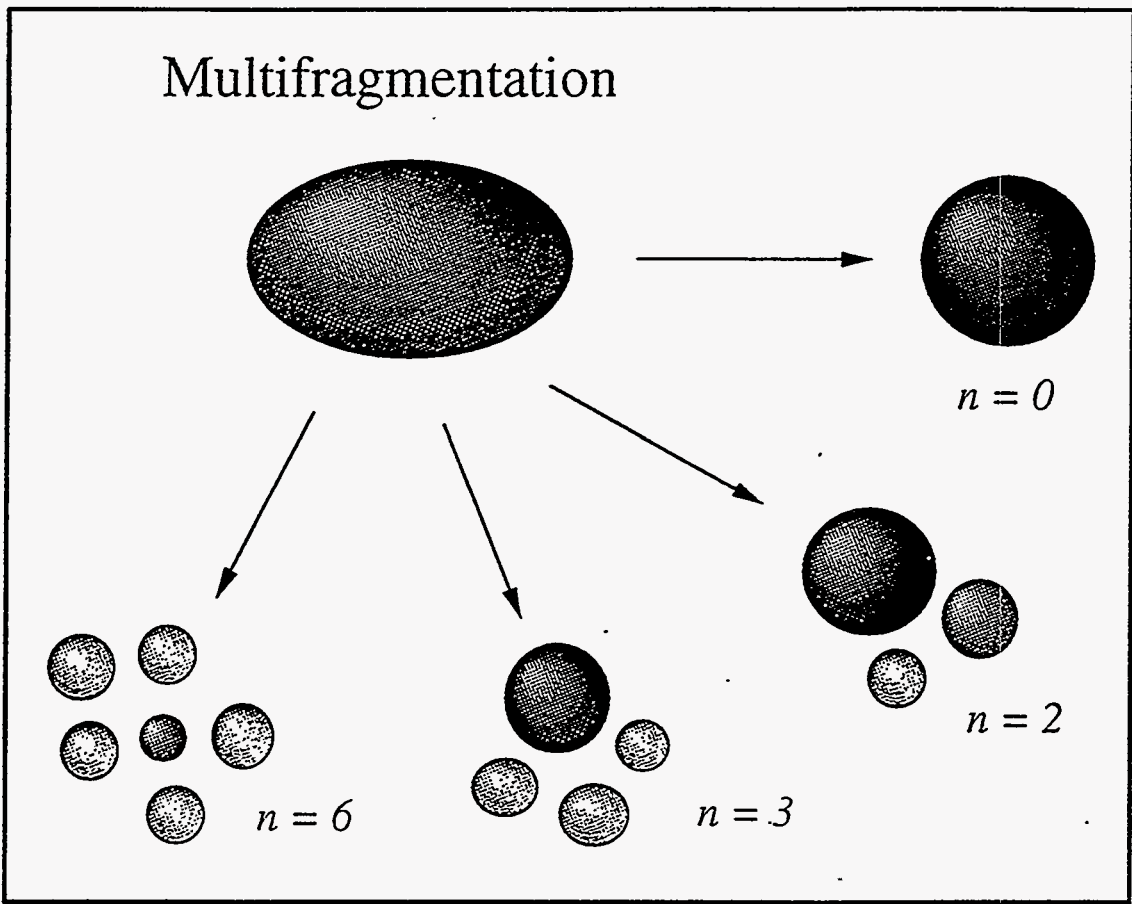
XBL 766 2941



XBL 766 2940





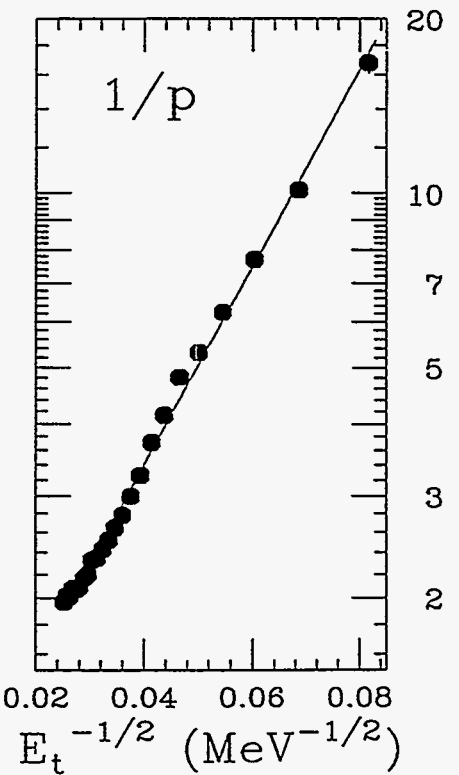
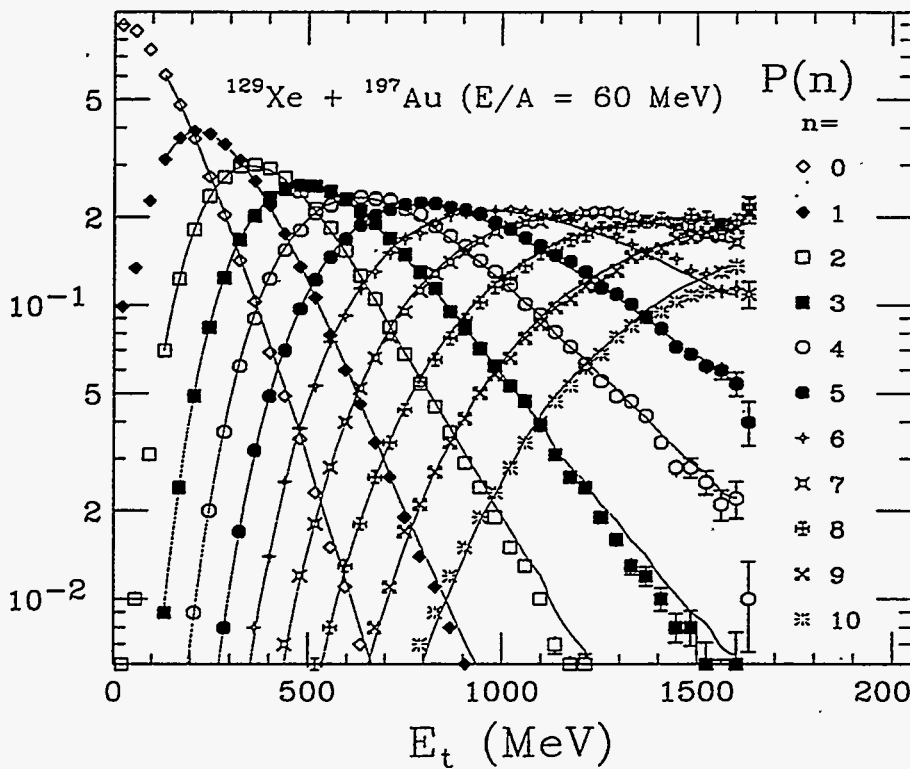


Binomial Reducibility

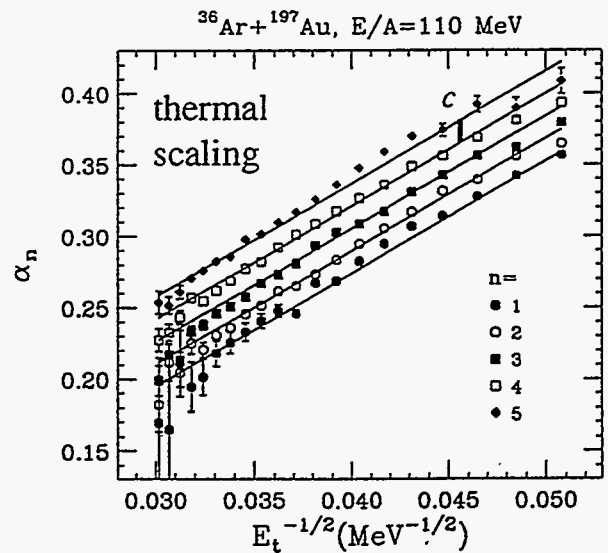
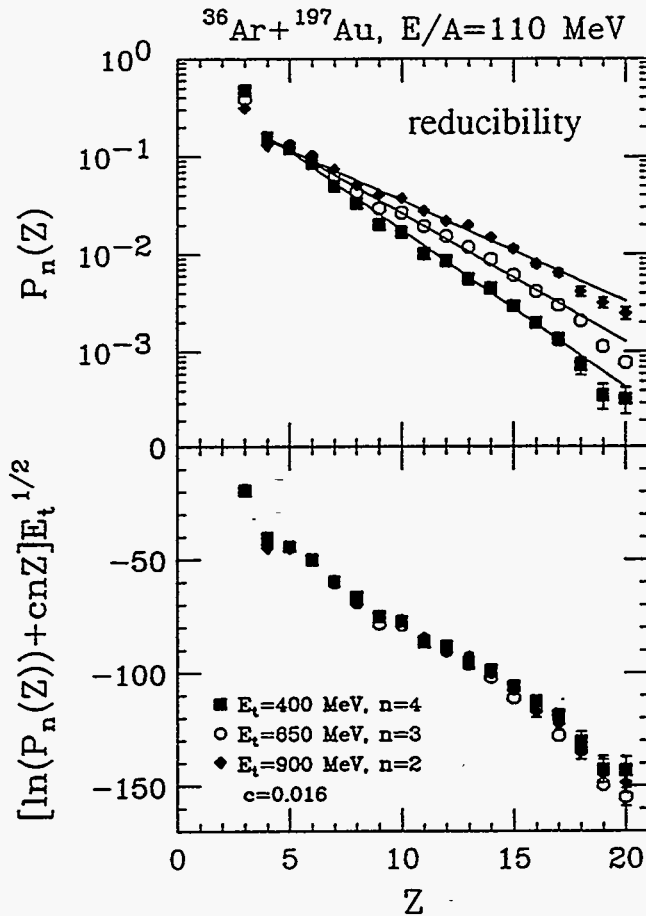
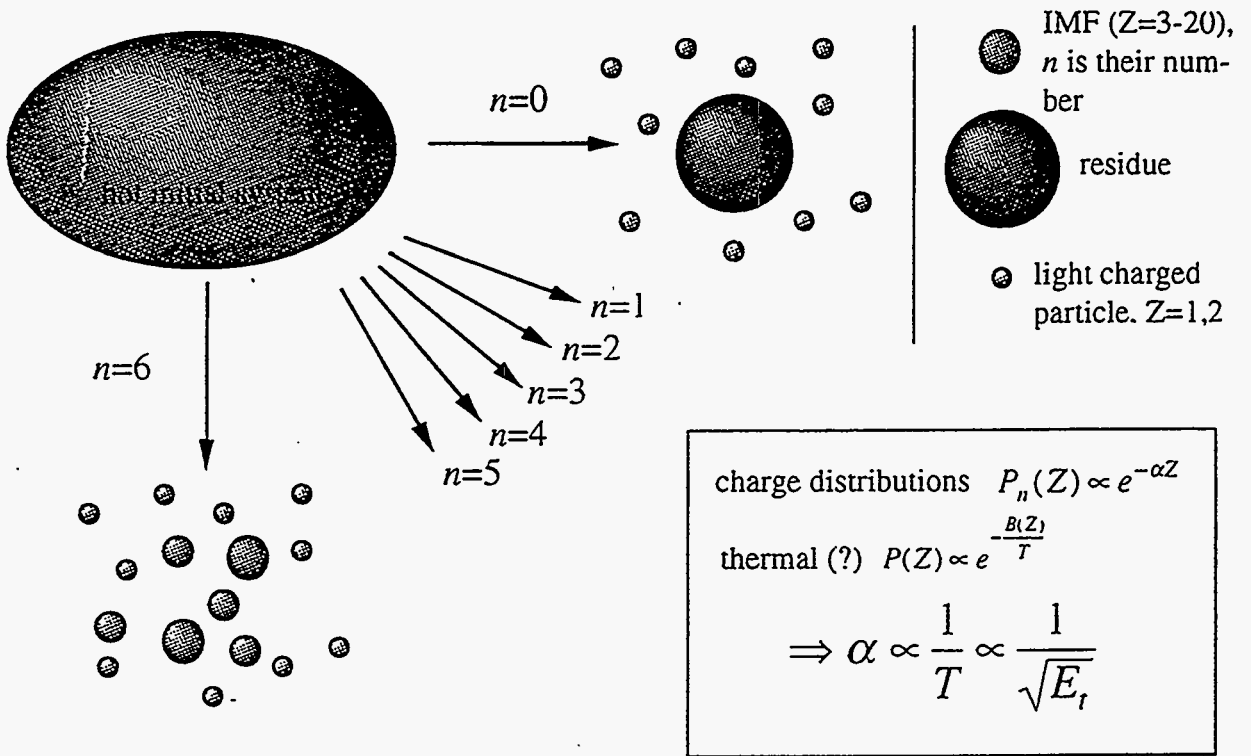
$$P_n^m = \frac{m!}{n!(m-n)!} p^n (1-p)^{m-n}$$

Thermal Scaling

$$p \propto e^{-B/T}$$



Reducible and Thermal Nature of the Charge Distributions



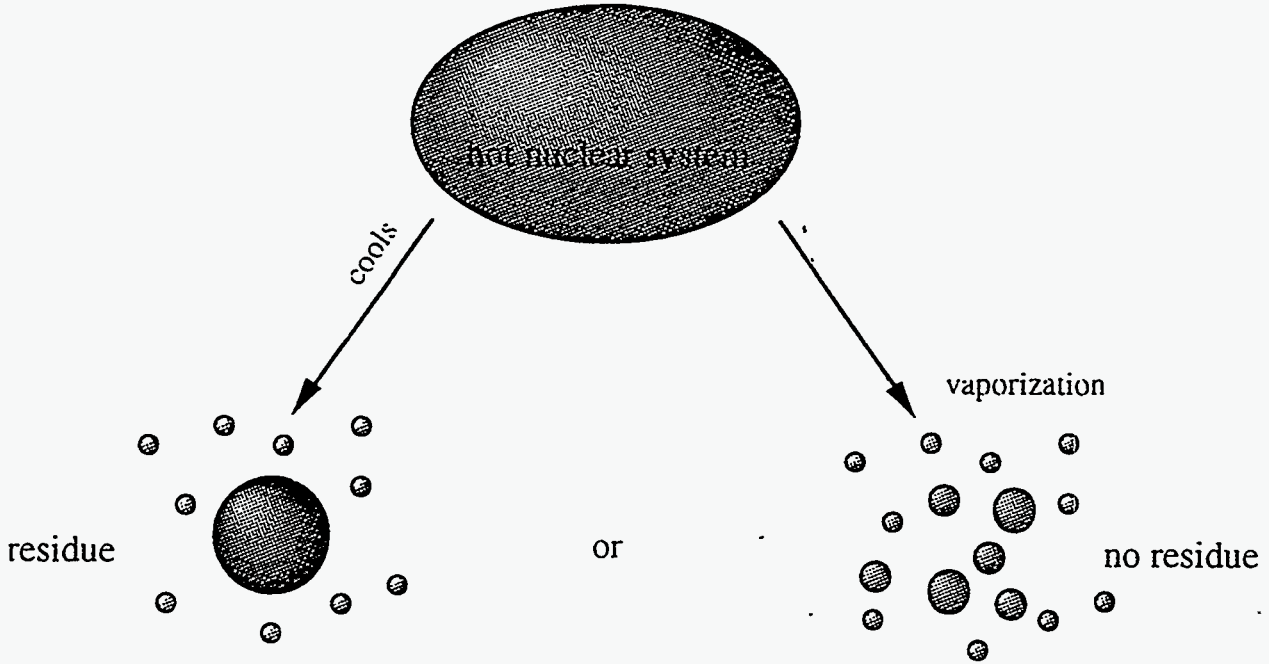
$$\alpha_n = \frac{K}{\sqrt{E_t}} + nc \Rightarrow P_n(Z) \propto \exp\left[-\frac{B(Z)}{T} - ncZ\right]$$

Euler's problem, break Z_0 into n smaller pieces

$$nZ = \frac{n^2}{Z_0} \exp\left[-\frac{nZ}{Z_0}\right]$$

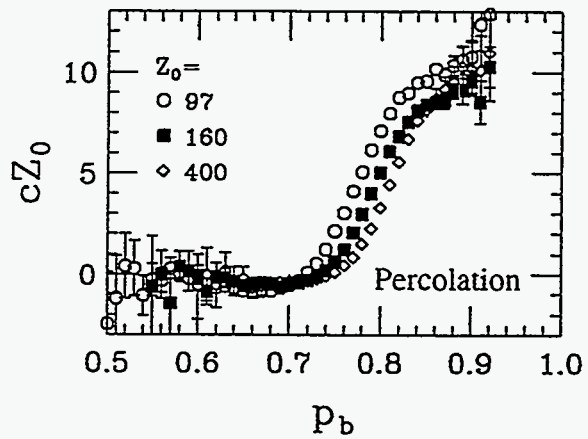
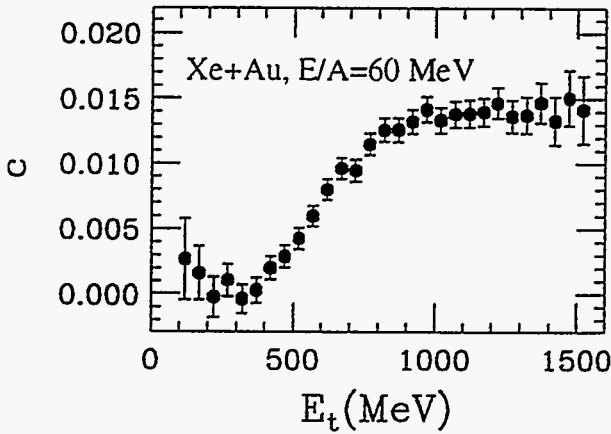
$$c \propto \frac{1}{Z_0}$$

Phase Coexistence in Multifragmentation?



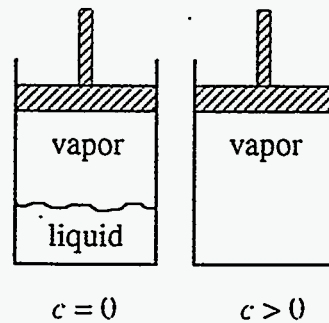
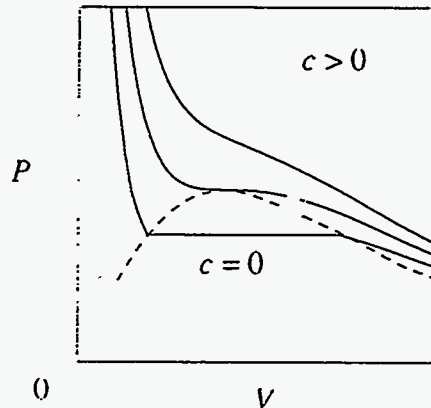
Charge distributions: $P_n(Z) \propto \exp\left[-\frac{B(Z)}{T} - nCZ\right]$

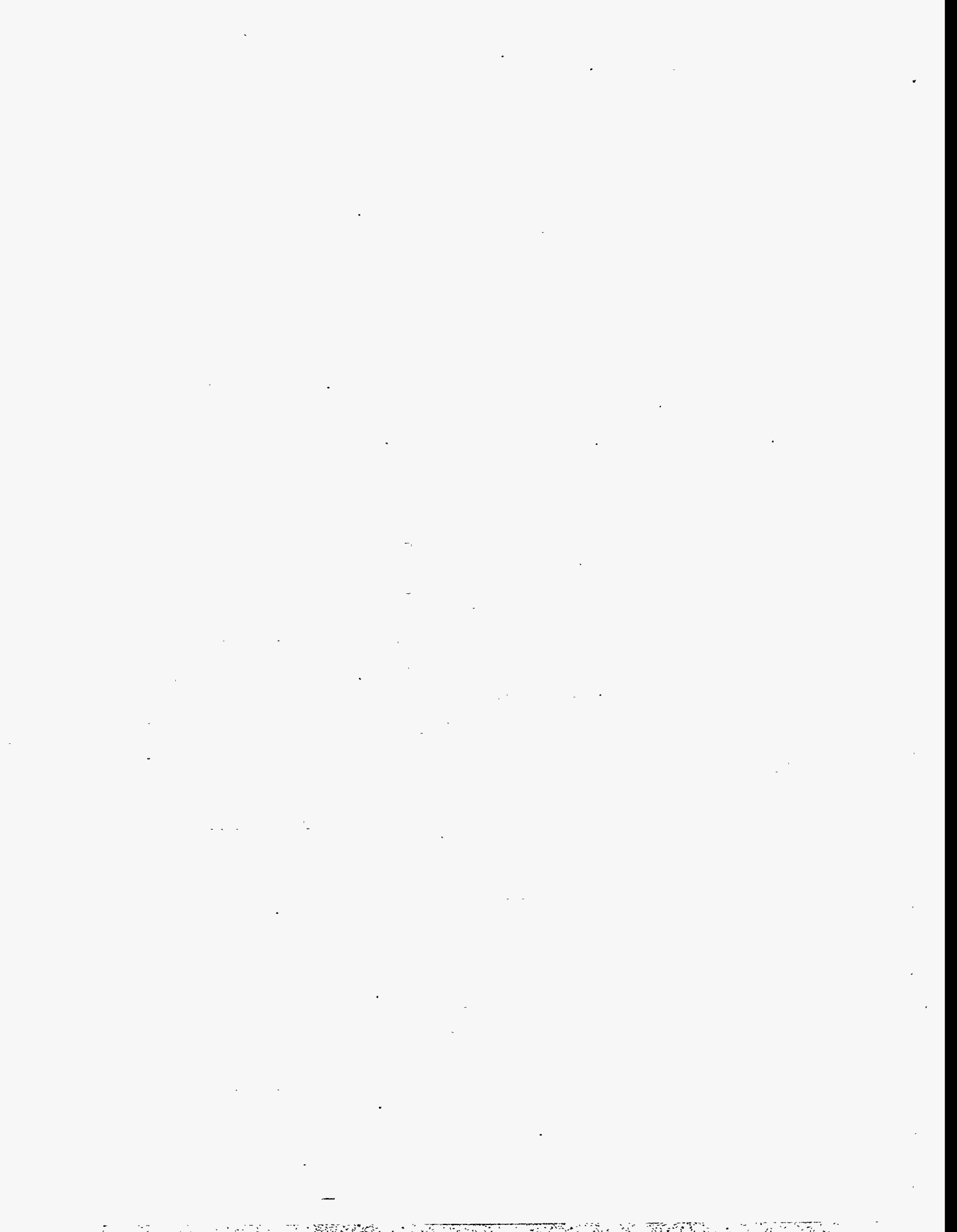
enthalpy entropy



Classical Liquid-Gas
Phase Diagram

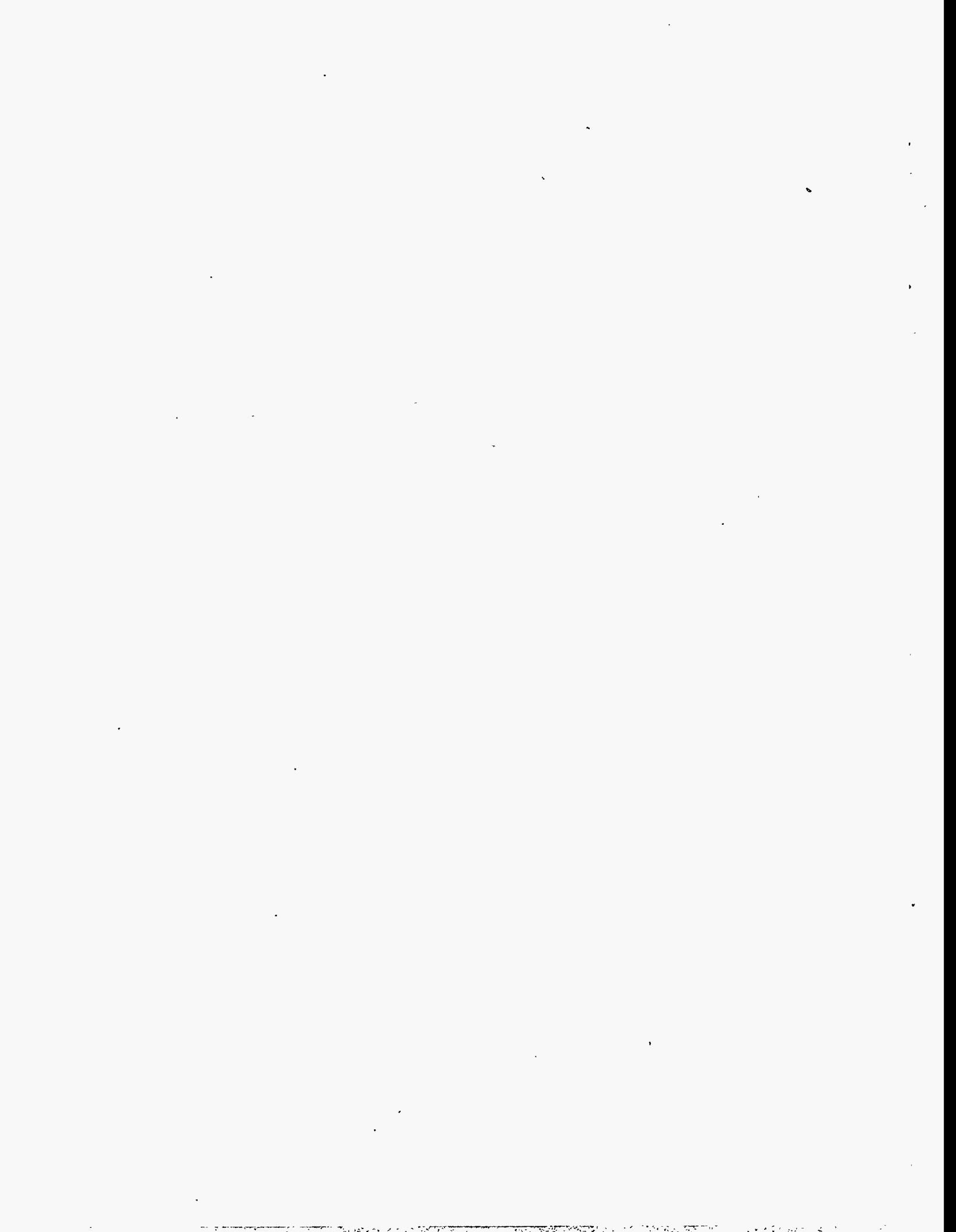
$$c \propto \mu_L - \mu_V$$





Mike Rowe

Lawrence Berkeley National Laboratory
Berkeley, CA



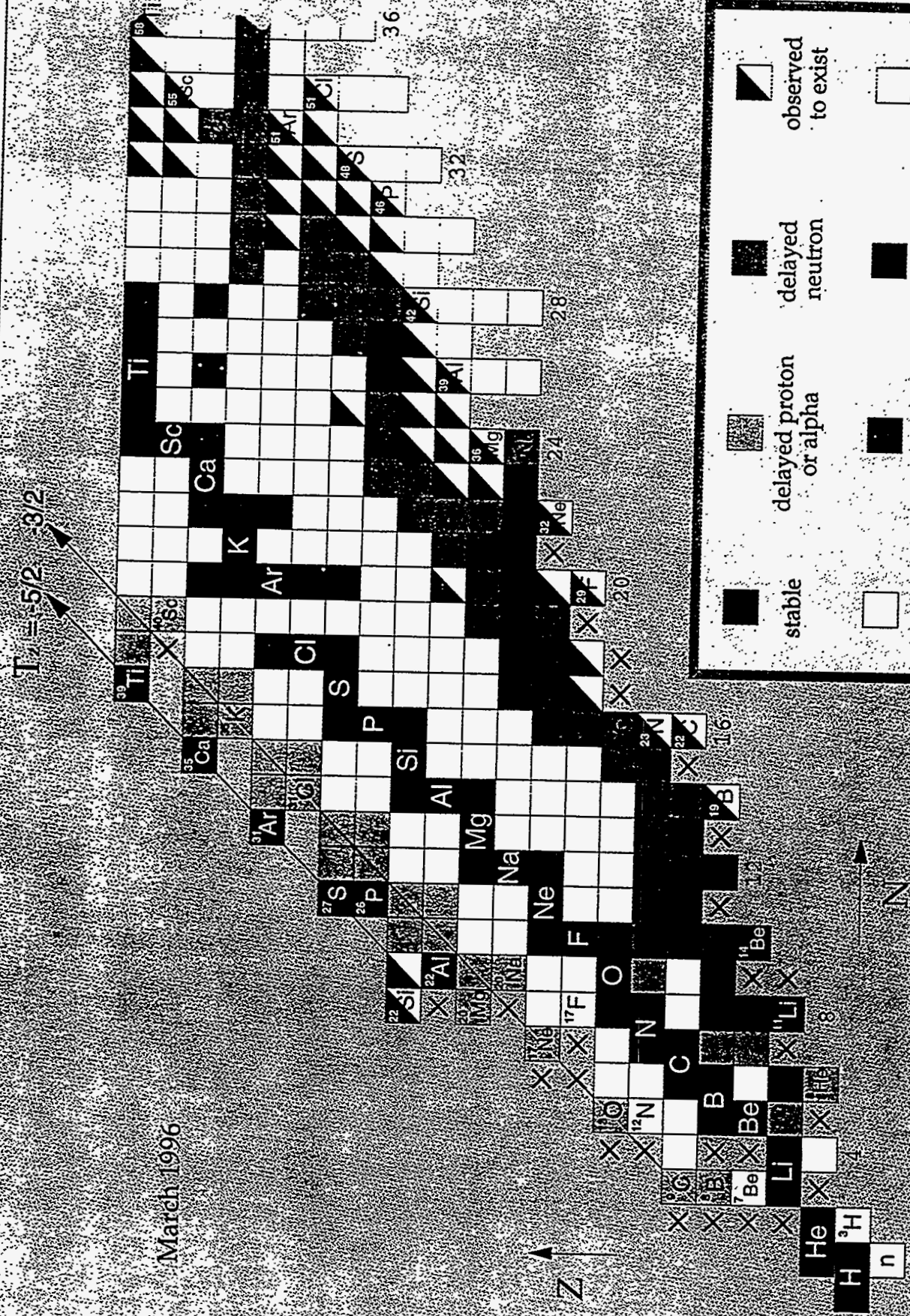
Beta-Delayed
One- and Two- Proton
Decay Studies
of
 ^{23}Si and ^{22}Al

M. W. Rowe, T. J. Ognibene, J. Powell,
J. C. Batchelder, D. M. Moltz
and Joseph Cerny

88-Inch Cyclotron
Lawrence Berkeley National Laboratory

March 1996

$$T_1 = 5/2 \quad 3/2$$



Z

N

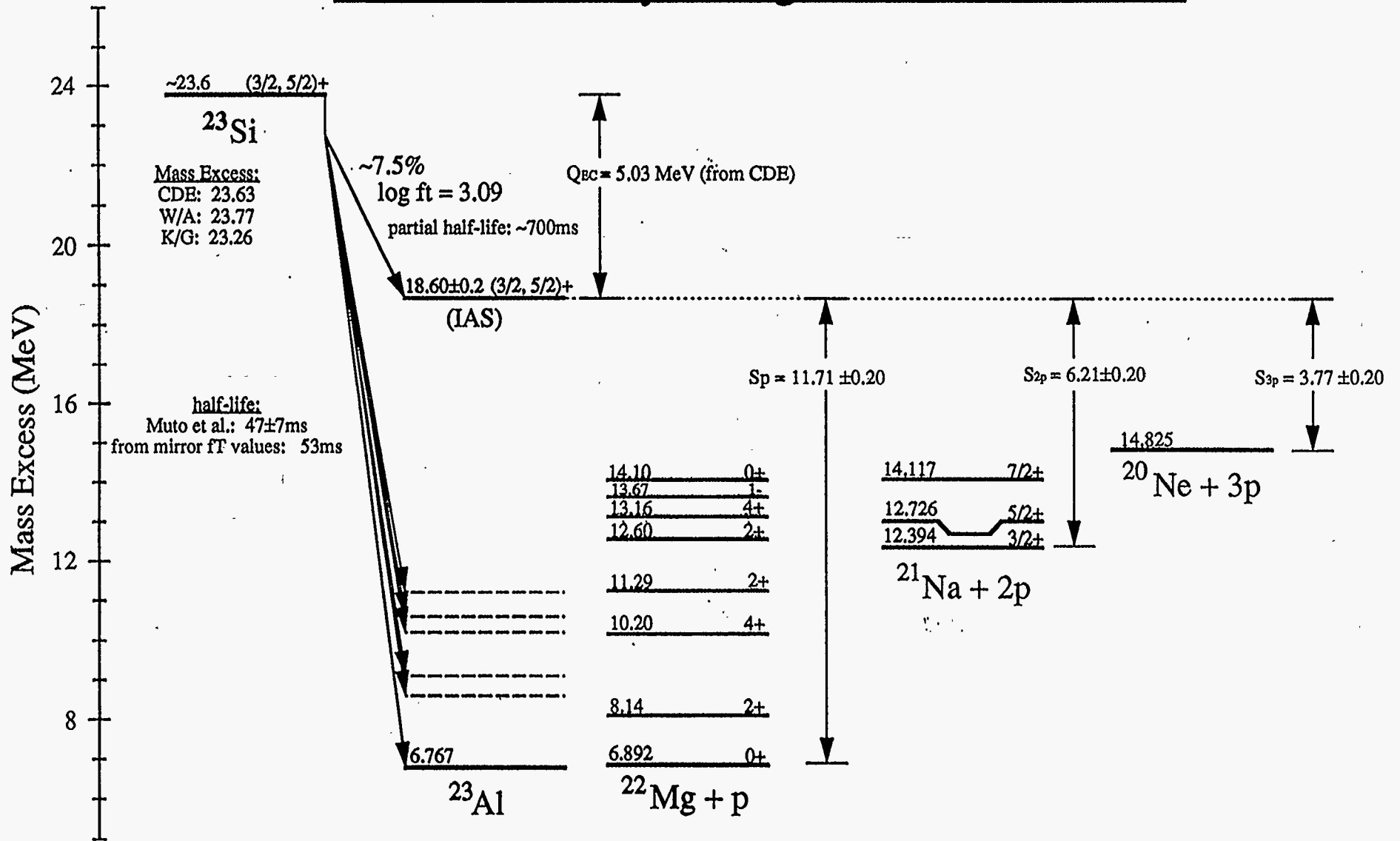
Si-23 Mass Predictions

Mass Model Authors	Method of Prediction	Mass Excess (MeV)	Lab. Proton Energy* (IAS-->g.s.; MeV)
Satpathy-Nayak	Infinite nuclear matter model	25.37	13.69
Tachibana et al.	Empirical liquid drop with odd/even and shell corrections	23.84	11.17
Moeller et al.	Finite-range droplet with shell/pairing corrections	24.39	12.22
Moeller-Nix	Yukawa+exponential model with shell/pairing corrections	23.86	12.52
Masson-Jaenecke	Inhomogeneous partial difference equation with isospin	23.94	11.74
Jaenecke-Masson	Transverse Garvey-Kelson mass relation	23.43	10.88
Comay-Kelson-Zidon	Transverse and longitudinal Garvey-Kelson relationships	23.51	10.76
Pape-Antony	Isobaric Mass-Multiplet Equation (IMME)	23.44	10.95
Wapstra-Audi	Experimental data and systematic trends	23.77	11.33

* Proton energy calculated using Coulomb Displacement Energy of 5.03 MeV and predicted Mg-22 ground-state masses

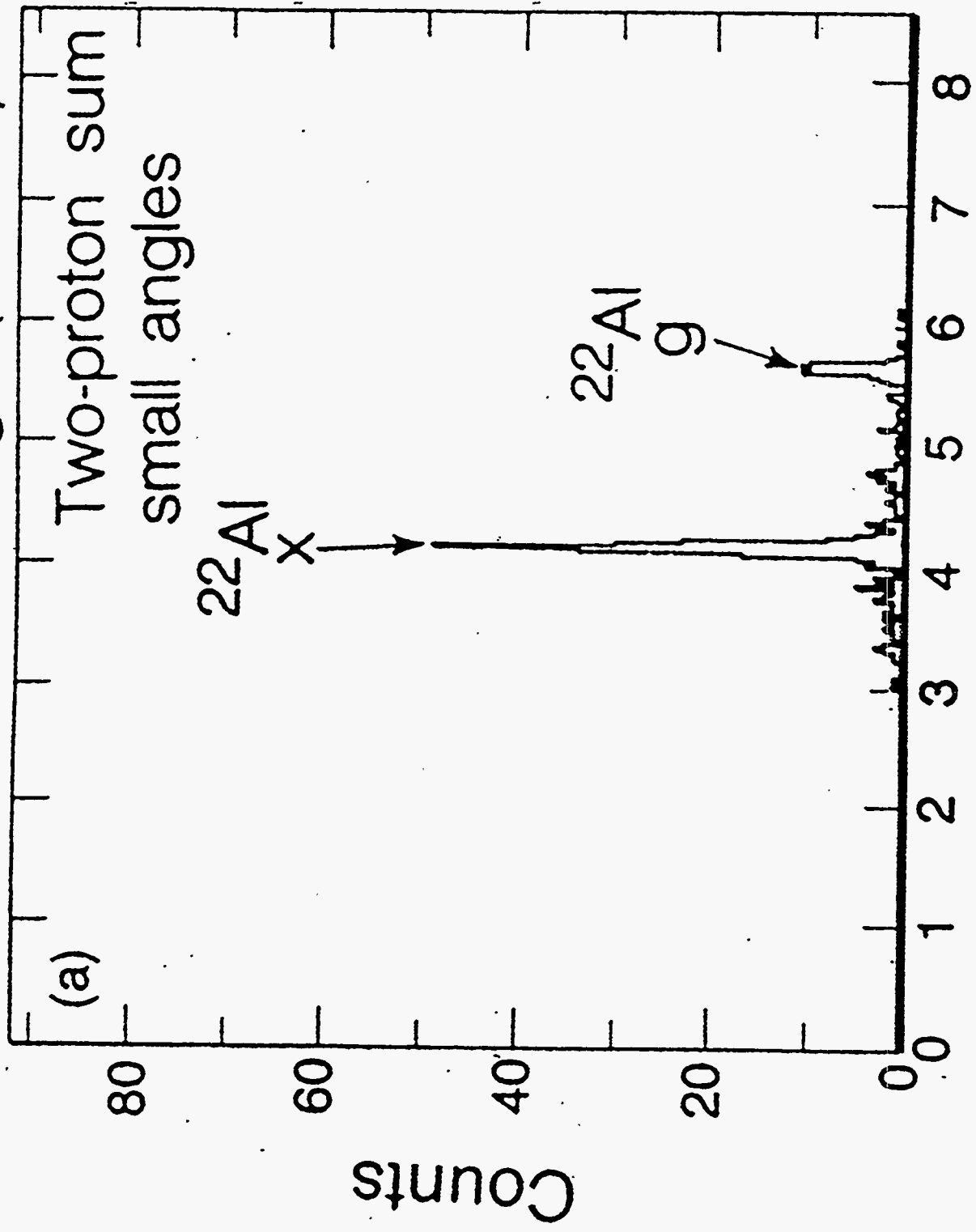
All predictions taken from Atomic Data and Nuclear Data Tables, vol. 39, 186 (1988)
except for Wapstra-Audi, which is from Nuclear Physics A565, 1 (1993).

Predicted Decay Energetics for Silicon-23



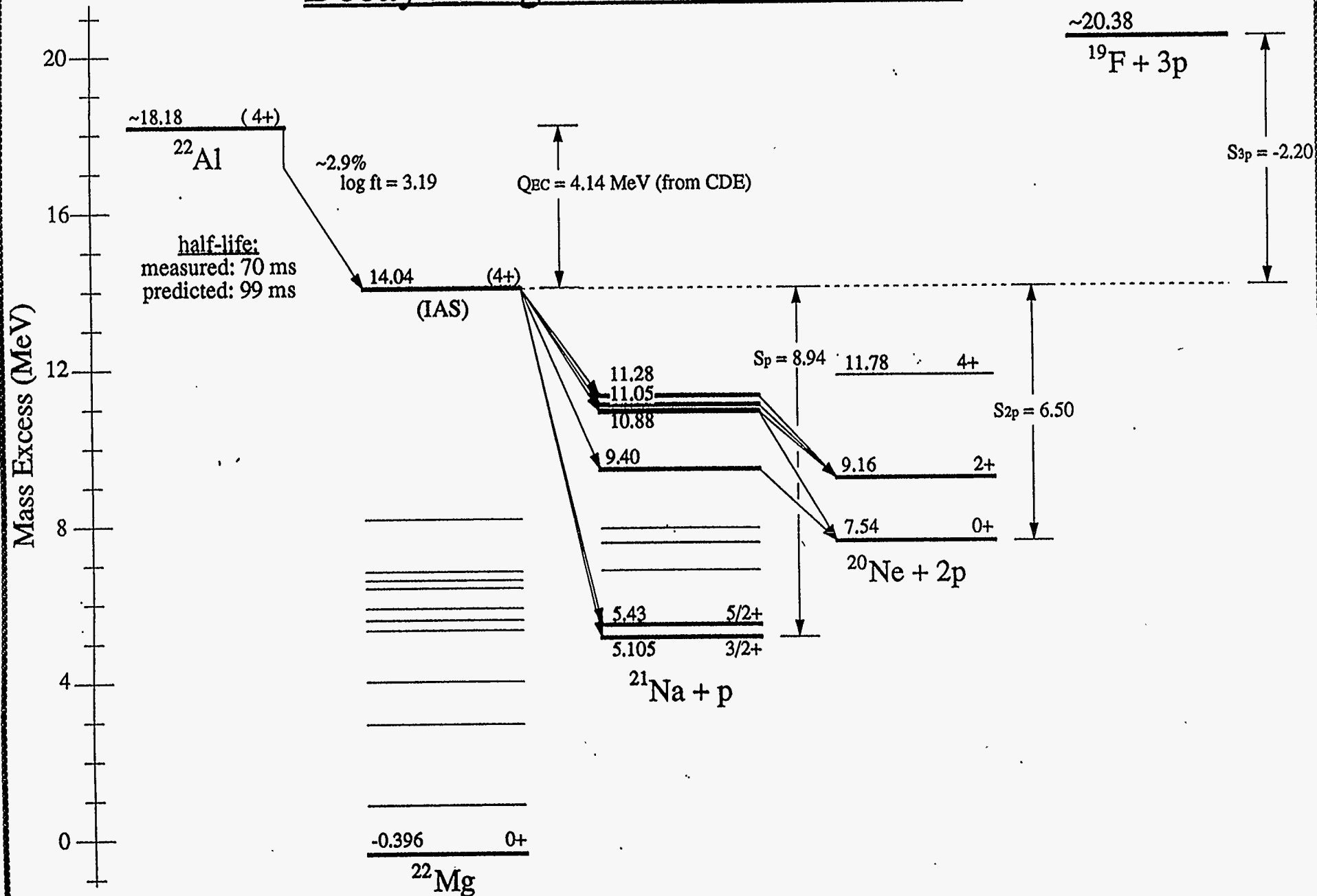
$^{110}\text{He} + \text{natMg}$ (2.30 C)

Two-proton sum
small angles



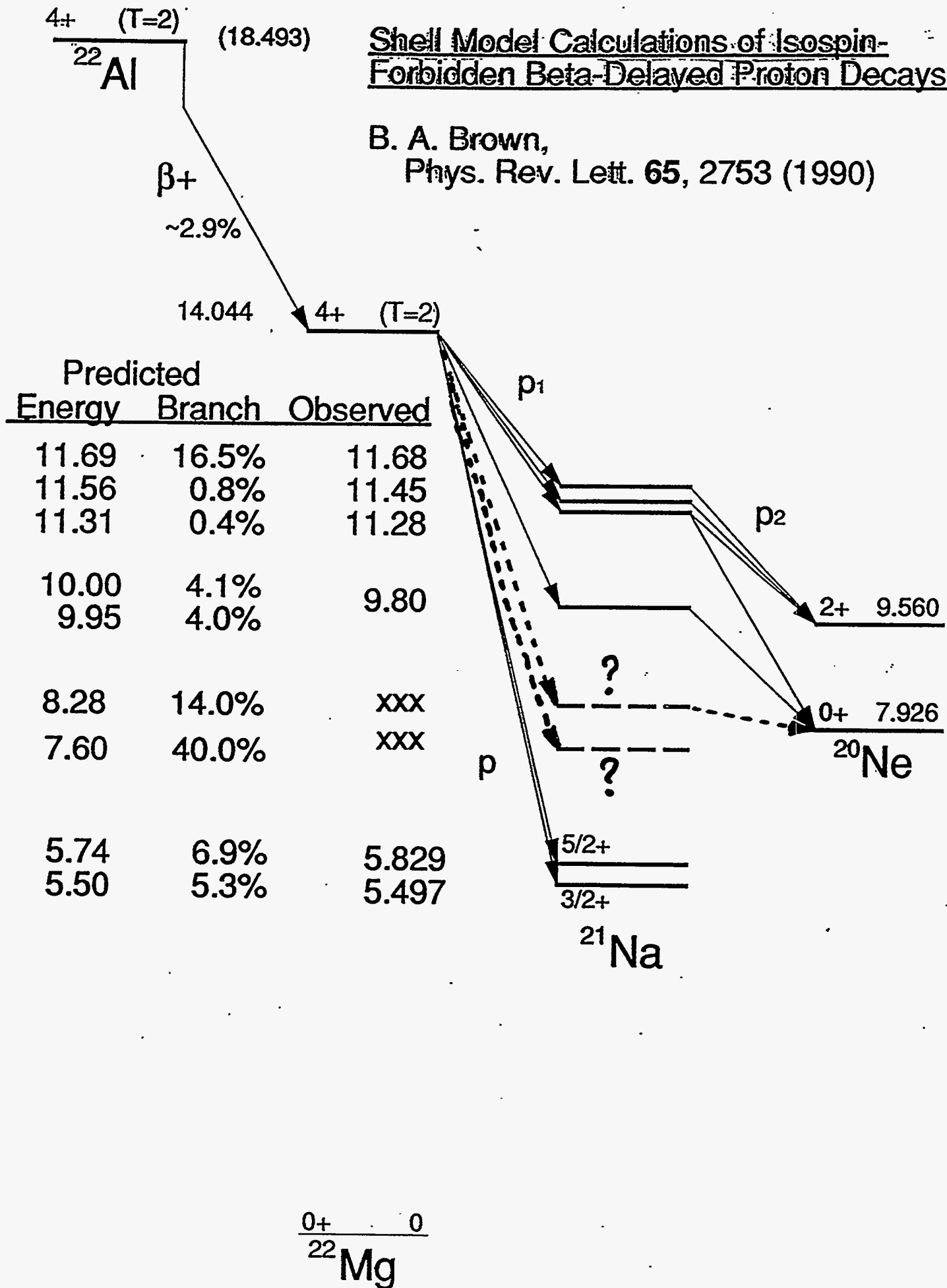
Energy (MeV)

Decay Energetics for Aluminum-22



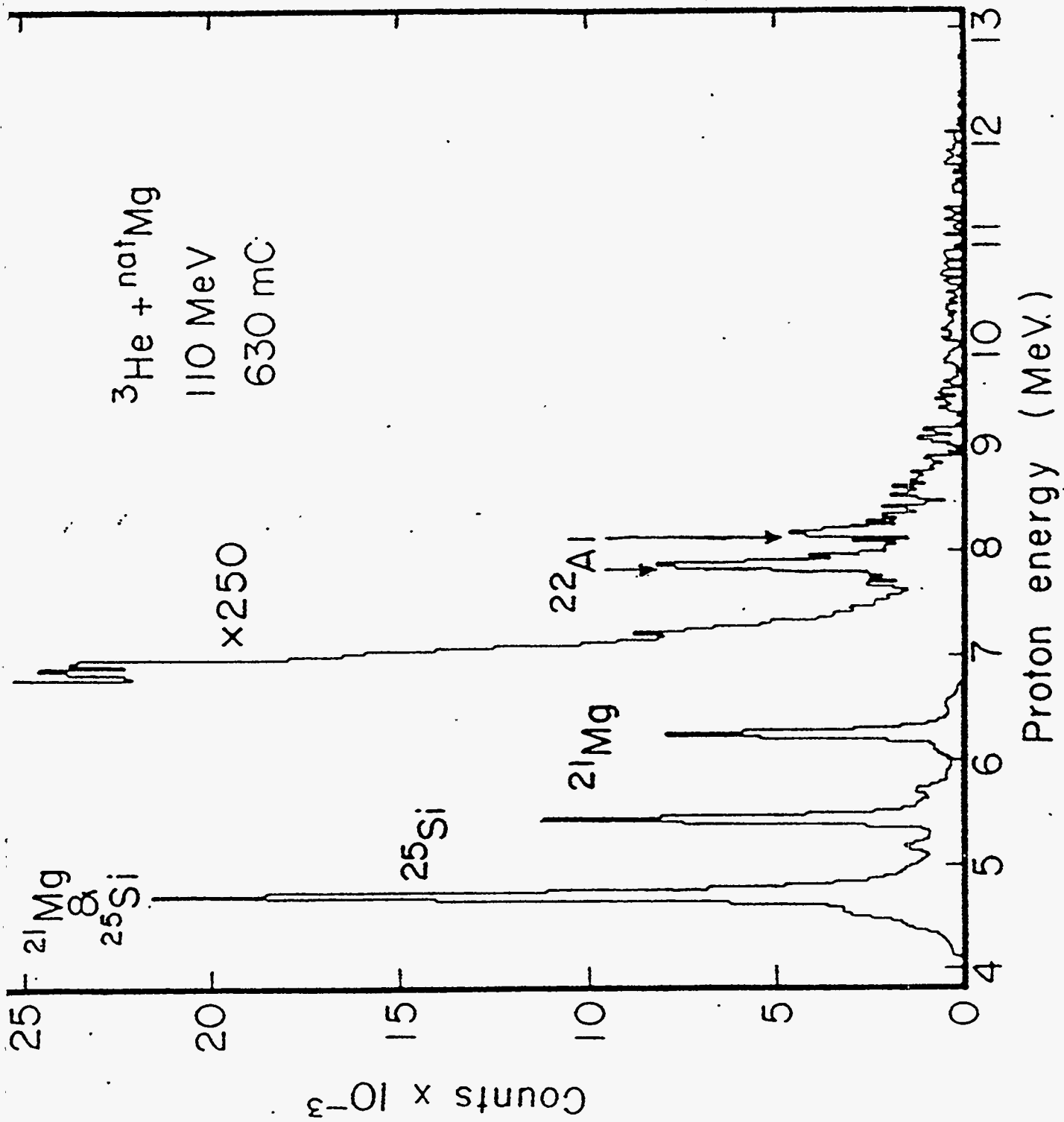
Shell Model Calculations of Isospin-Forbidden Beta-Delayed Proton Decays

B. A. Brown,
Phys. Rev. Lett. **65**, 2753 (1990)



Experimental Goals

- Observe ^{23}Si beta-delayed proton decay
 - Determine masses of ^{23}Si IAS and ^{23}Si
 - Look for ^{23}Si beta-delayed two-proton decay
- Observe beta-delayed two-proton decay branch of ^{22}Al through predicted 2.78 MeV ^{21}Na state
 - Measure ^{23}Si half-life

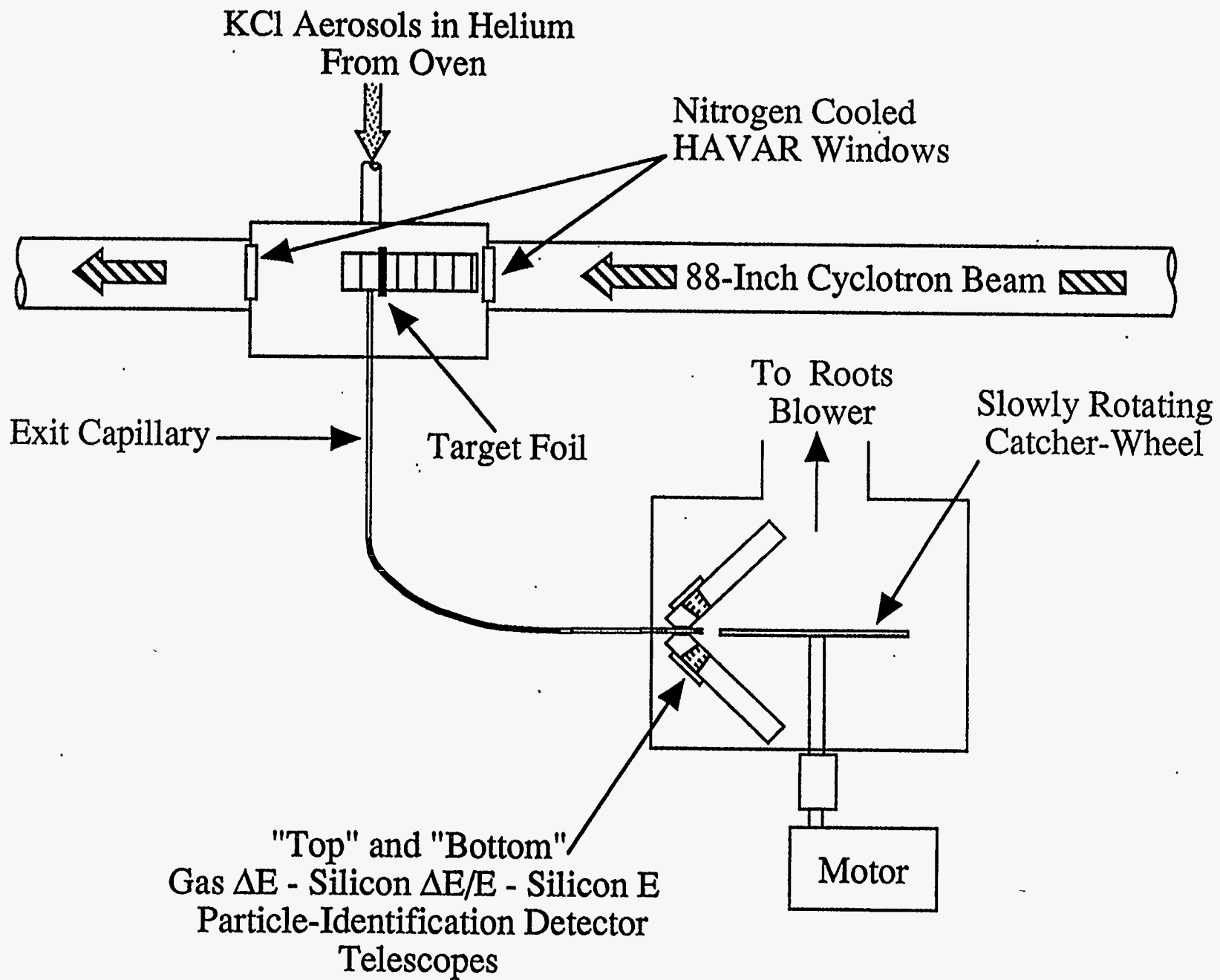


Comparison of Experimental Parameters

	^{22}Al		^{23}Si
	Predicted	Observed (Cable et al.)	Predicted
Cross Section	6.75 μb (ALICE)	116-260 nb	450 nb (ALICE)
Half-Life	99 \pm 4 ms (Muto et al.)	70 ⁺⁵⁰ ₋₃₅ ms	47 \pm 7 ms (Muto et al.)
He-Jet Transport Time	~100 ms	N/A	~20 ms
IAS Feeding	4% (Muto et al.)	~2.9%	4.9% (Muto et al.)
Beta-Delayed p/2p Ratio	0.2 (Detraz)	0.52 - 0.18	1 (Detraz)
Proton Feeding to Ground and First-Excited Daughter States	21.6% (Brown)	N/A	36.4% (COCAGD3)

Experimental Requirements

- Large proton-energy range: $\sim 300 - 13000$ keV
 - Ability to observe two-proton decay events
- Tolerate high beta-decay count rates (>30 kHz)
- Unambiguous identification of decay events
 - Minimize background events
 - Minimize transport time
- Reliable calibrations at both high and low energies

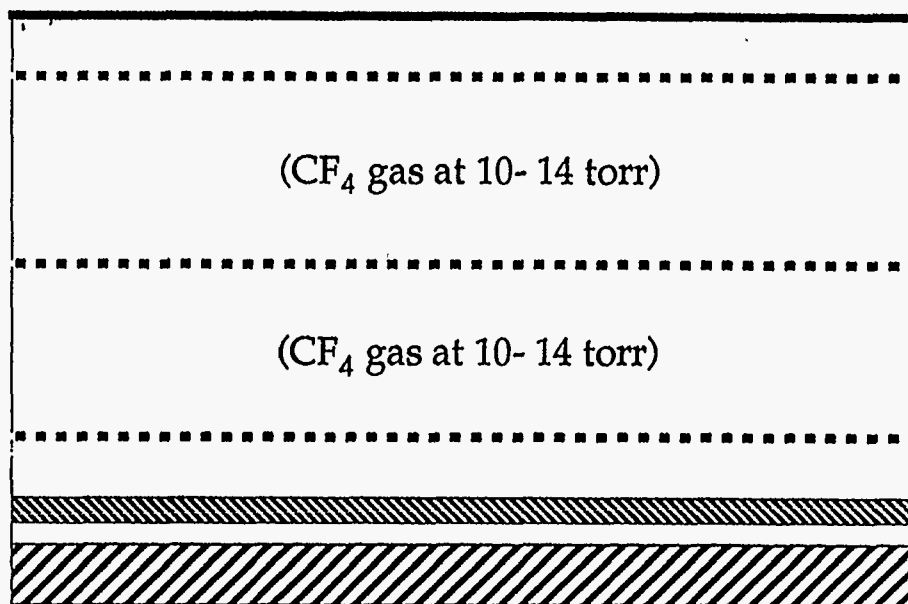
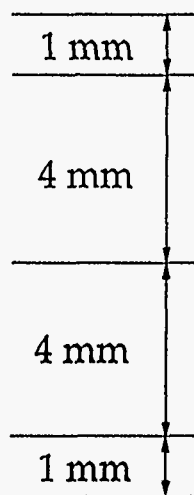


Gas ΔE - Silicon $\Delta E/E$ - Silicon E

Large Energy-Range Particle Identification Telescope

Capable of detecting protons with energies from ~ 300 keV to ~ 14 MeV

Incident radiation



$400 \mu\text{g}/\text{cm}^2$ aluminum window

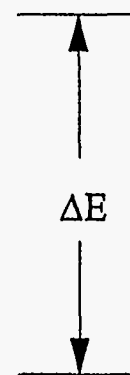
Wire grid at ground

Wire grid at 525 V

Wire grid at ground

$300 \mu\text{m}$ silicon detector

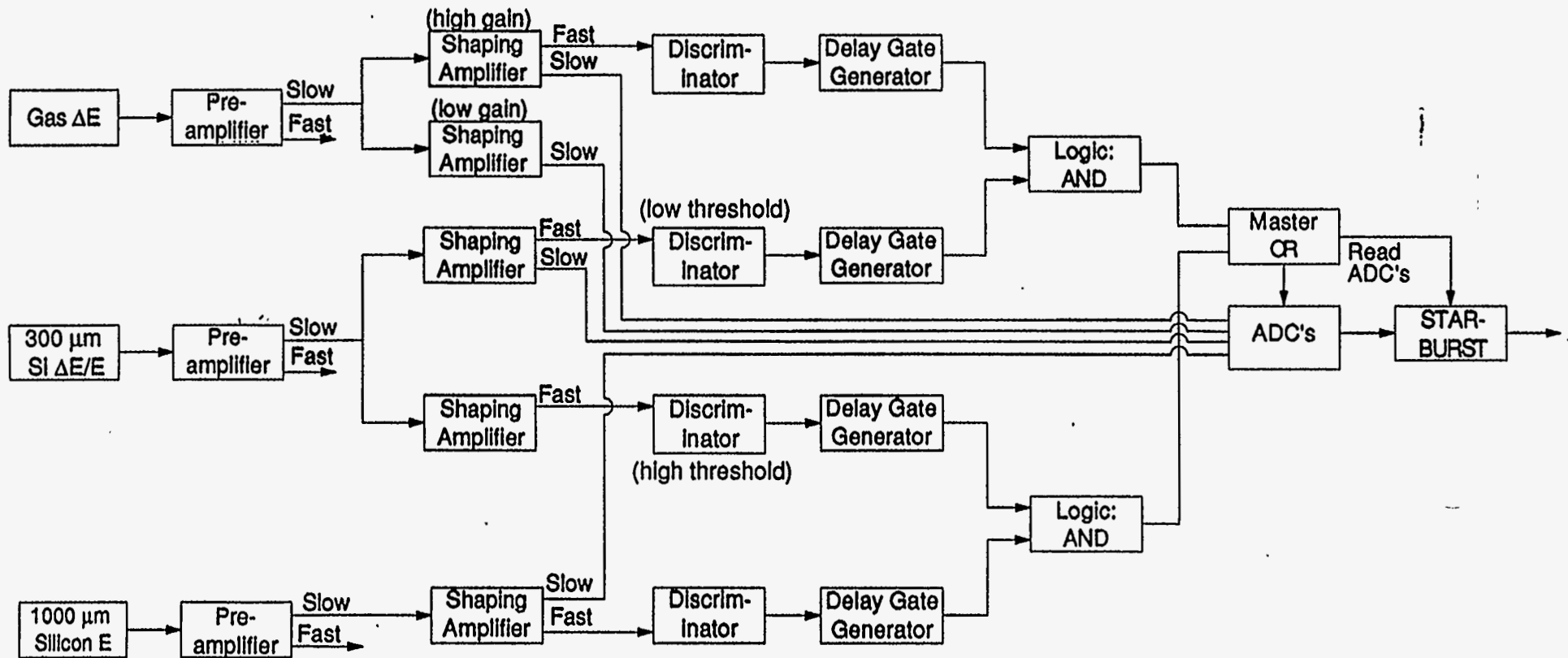
$1000 \mu\text{m}$ silicon detector



$\Delta E/E$

E

Electronics Set-up for Large Energy-Range Telescopes



Pre-amplifier fast outputs are used for fast-timing measurements.

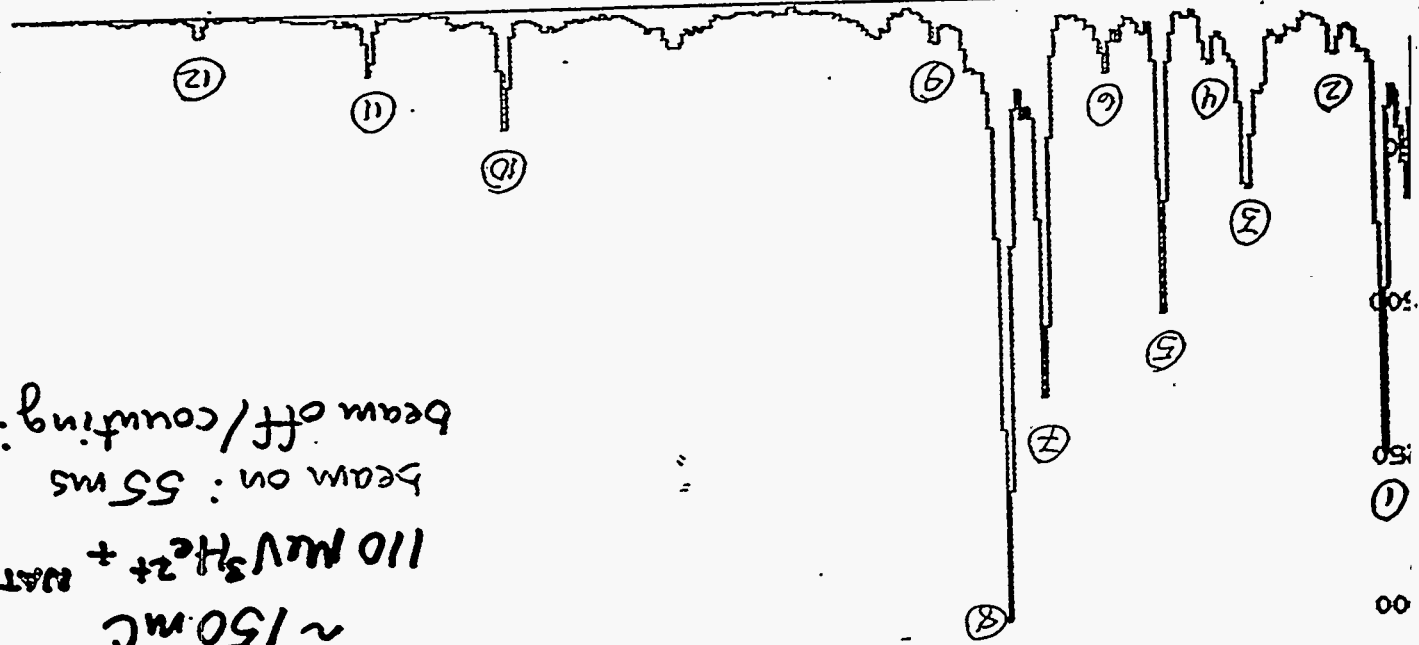
TAC signals are measured between gas- ΔE and Si- $\Delta E/E$ and between Si- $\Delta E/E$ and Si-E for each telescope and between the Top and Bottom Si- $\Delta E/E$'s

protons, run 3195-3199
300 μm $\Delta E/E$ detector

$\sim 150 \text{ mC}$
110 $\mu\text{V}^3 \text{He}^{2+}$ + NAT Mg
beam on: 55 ms
beam off/counting: 70v

$^{21}\text{Mg} + ^{25}\text{Si}!$

20-1TOP SI DE/E
110 MeV 3He on nat Mg
RUN 3195



Predicted E detected *

E incident

Peak #

Peak #	E incident	Predicted E detected *
1	386	174
2	534	363
3	907	786
4	1060	951
5	1257	1160
6	1495	1409
7	1773	1697
8	1939	1867
9	2219	2154
10	4091	4049
11	4670	4632
12	5405	5371

* $85 \mu\text{g}/\text{cm}^2$ deadlayer
 $66 \mu\text{g}/\text{cm}^2$ gas
 $469 \mu\text{g}/\text{cm}^2$ Al window

High Energy (>6 MeV) Proton Spectrum

3/28/96

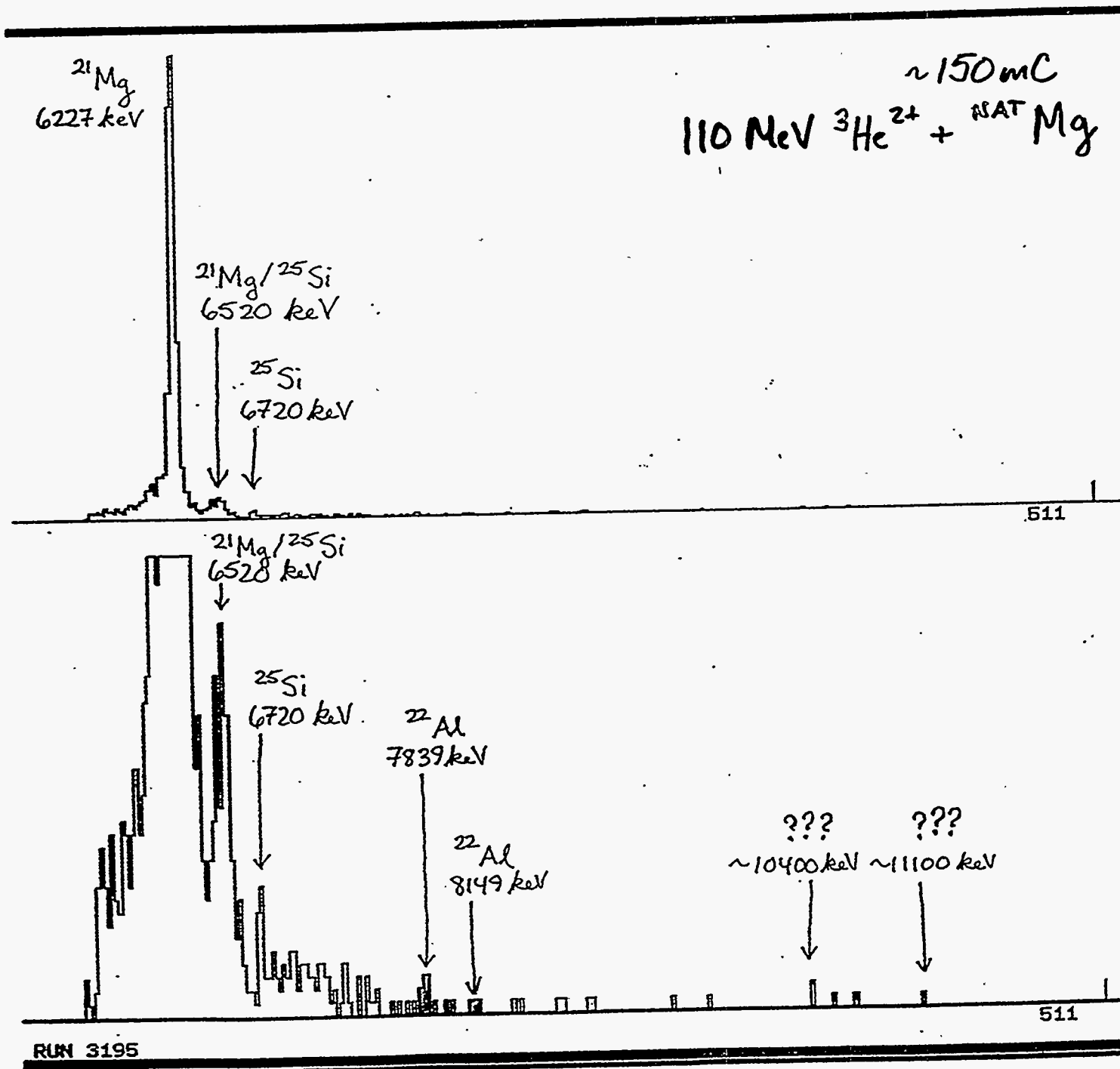
runs 3195-3196

Bottom Detector Telescope

^{23}Si β -p search test

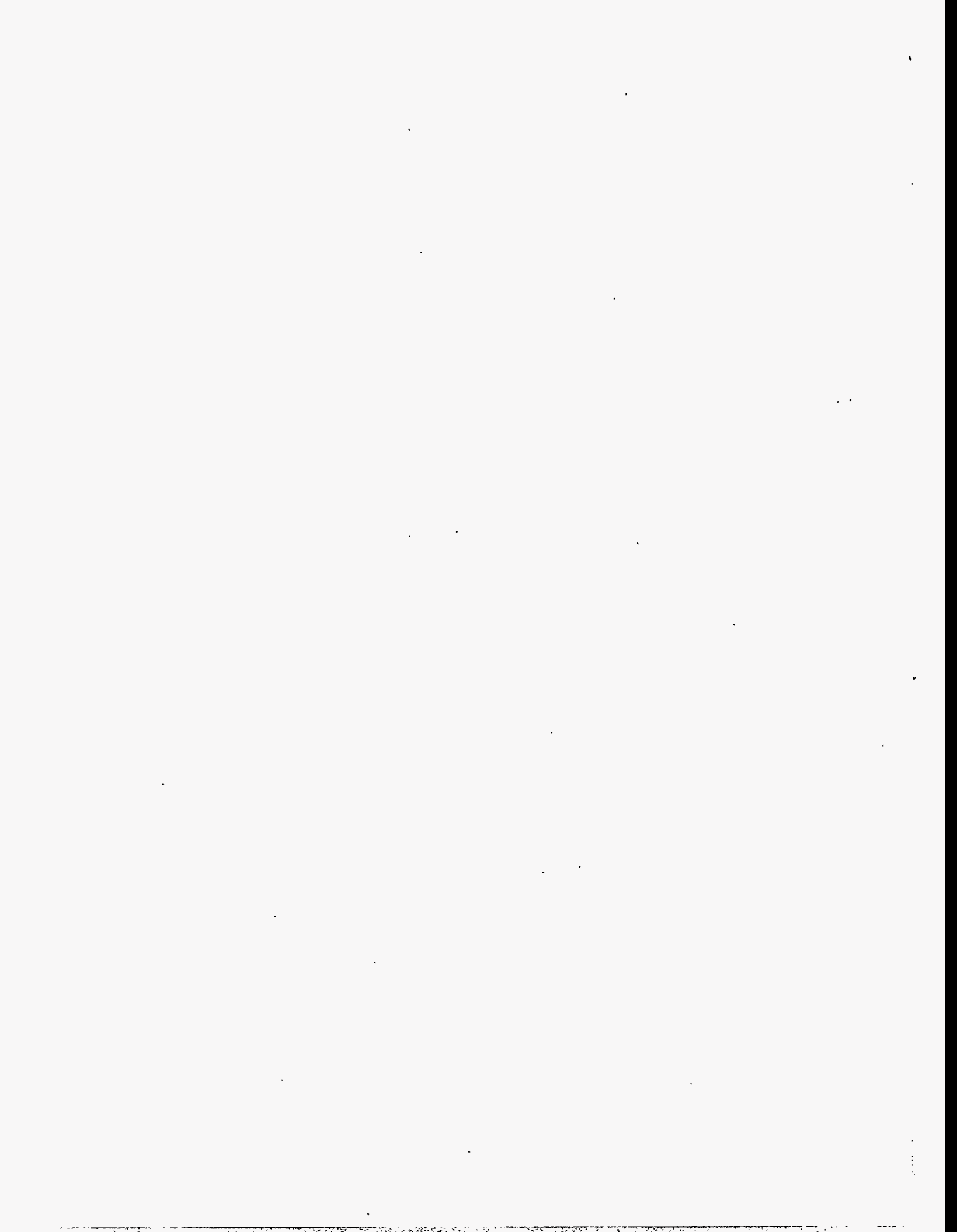
gated on:

- PI
- TAC
- AND small gas- ΔE signal



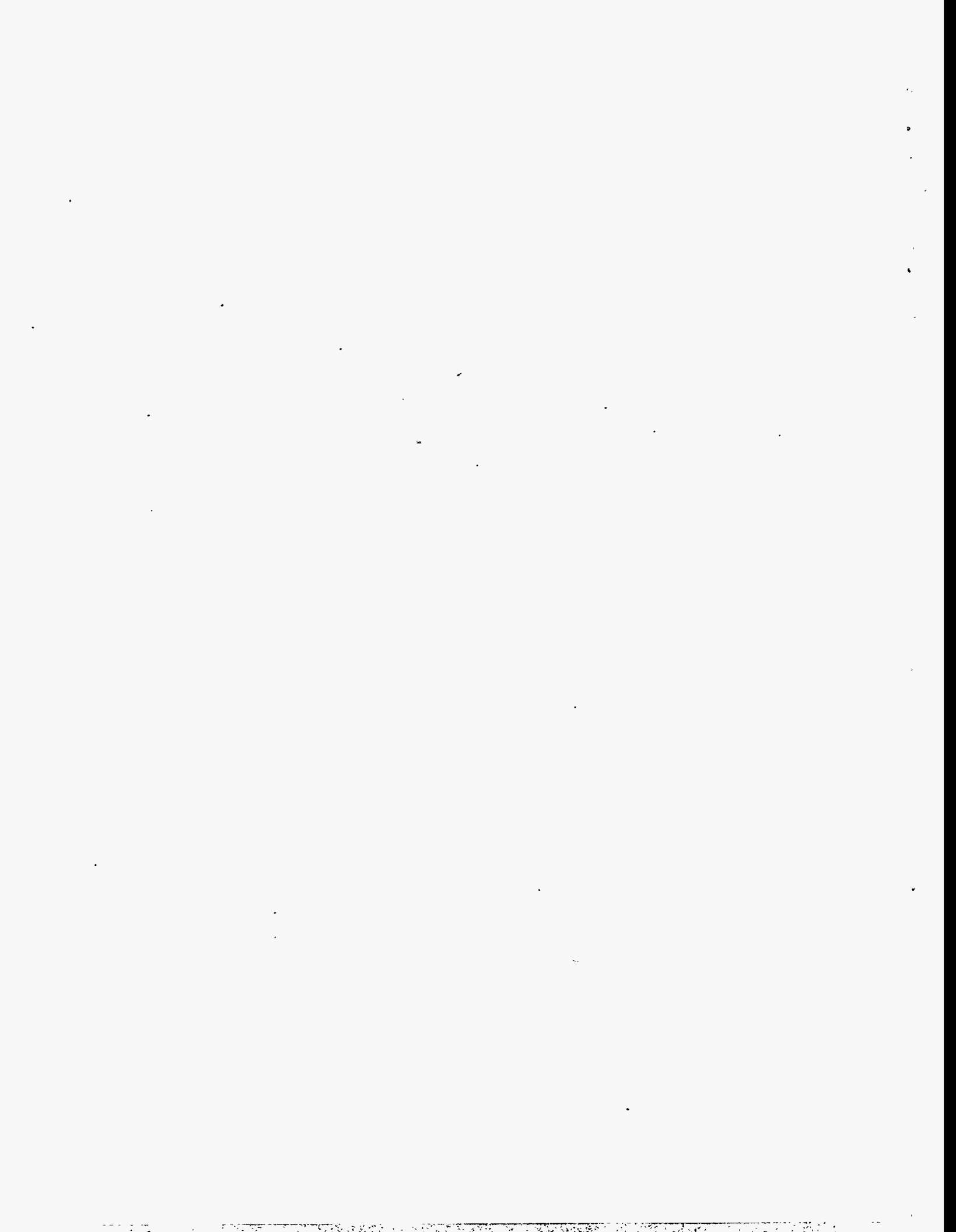
Modifications in the Experimental Set-up for the Main Run

- Fix the cyclotron!!!
 - Switch to 1000 μm SiLi E detectors;
negative detector biases on E detectors
- Increase solid angle by repositioning telescopes
 - Improve activity catcher-wheel efficiency
- Change pulsing structure for faster transport
 - Improve on-line analysis capabilities
 - Use separated-isotope ^{24}Mg target



Dennis Moltz

Lawrence Berkeley National Laboratory
Berkeley, CA



Status of the Large-Scale Dark-Matter Axion Search

K. van Bibber, C. Hagmann, W. Stoeffl
LLNL

L. Rosenberg, E. Daw
MIT

P. Sikivie, N. Sullivan, D. Tanner
Univ. Florida

F. Nezrick, M. Turner
FNAL

D.M. Motz, R. Tighe, J. Powell
LBNL

J. Clarke
U.C. Berkeley

N. Golubev, L. Kravchok
Moscow

Strong CP Problem.

$$\mathcal{L}_{QCD} = \left(\begin{array}{c} \text{Gluonic} \\ \text{Field} \\ \text{strength} \end{array} \right) + \left(\begin{array}{c} \text{Quark} \\ \text{Fields} \end{array} \right) + \text{4-Divergence}$$

DOES NOT CONTRIBUTE IN PERTURBATION THEORY

DOES CONTRIBUTE LOW-PERTURBATIVE EFFECTS

OR

WHY IS THERE NO LIGHT PSEUDO-NAMBU-GOLDSTONE BOSON (LIKE THE PIONS) PRODUCED IN SPONTANEOUS BREAKING OF THE $U_A(1)$ QUARK FLAVOR SYMMETRY.

→ SOLVED ONLY FOR $\theta = 0$.

$$\bar{\theta} = \theta - \arg \det m_q = \theta - \arg (m_1 m_2 \dots m_n)$$

IF $\bar{\theta} \neq 0$, QCD VIOLATES P AND CP

Experimental Observation

$$d_n \approx 10^{-16} \bar{\theta}$$

$$\leq 10^{-24} \text{ e cm}$$

$$\Rightarrow \bar{\theta} \leq 10^{-8}$$

But P and CP Violation of the Weak Interaction Tends to Feed the Strong Interaction. (e.g. $K_L \rightarrow 2\pi$)

Why is $\bar{\theta}$ so small.

PELLEE + QUINN MAKE $\bar{\theta}$ a

Dynamical Variable; Strong Interaction

Will Align $\bar{\theta} \ni$

$$\bar{\theta} = 0 \pmod{\pi}$$

Neutral

\Rightarrow Pseudoscalar or **AXION**

Where to look for Axions?

ORIGINAL SUGGESTIONS BASED UPON

$$f_a \geq 250 \text{ GeV}$$

(From Weinberg & Wilczek)

- ① Axion exchange would give make the gyromagnetic ratio of the muon of the order $G_F m_\mu^2 \pi^2 \approx 10^{-8}$
- ② Axion exchange \rightarrow Spin-Spin Interaction in Atoms & Molecules
- ③ Expect a spike in $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ spectrum
- ④ Since a_0 is analogous to π_0 (Same quantum numbers)
 - $\circ \rightarrow \pi^0 + \square$
 - $\circ \rightarrow a_0 + \square$
- ⑤ Nuclear reactors
 10^{-6} axion / prompt γ since 1 eV / prompt
- ⑥ Any predominantly M1 Nuclear Transition,

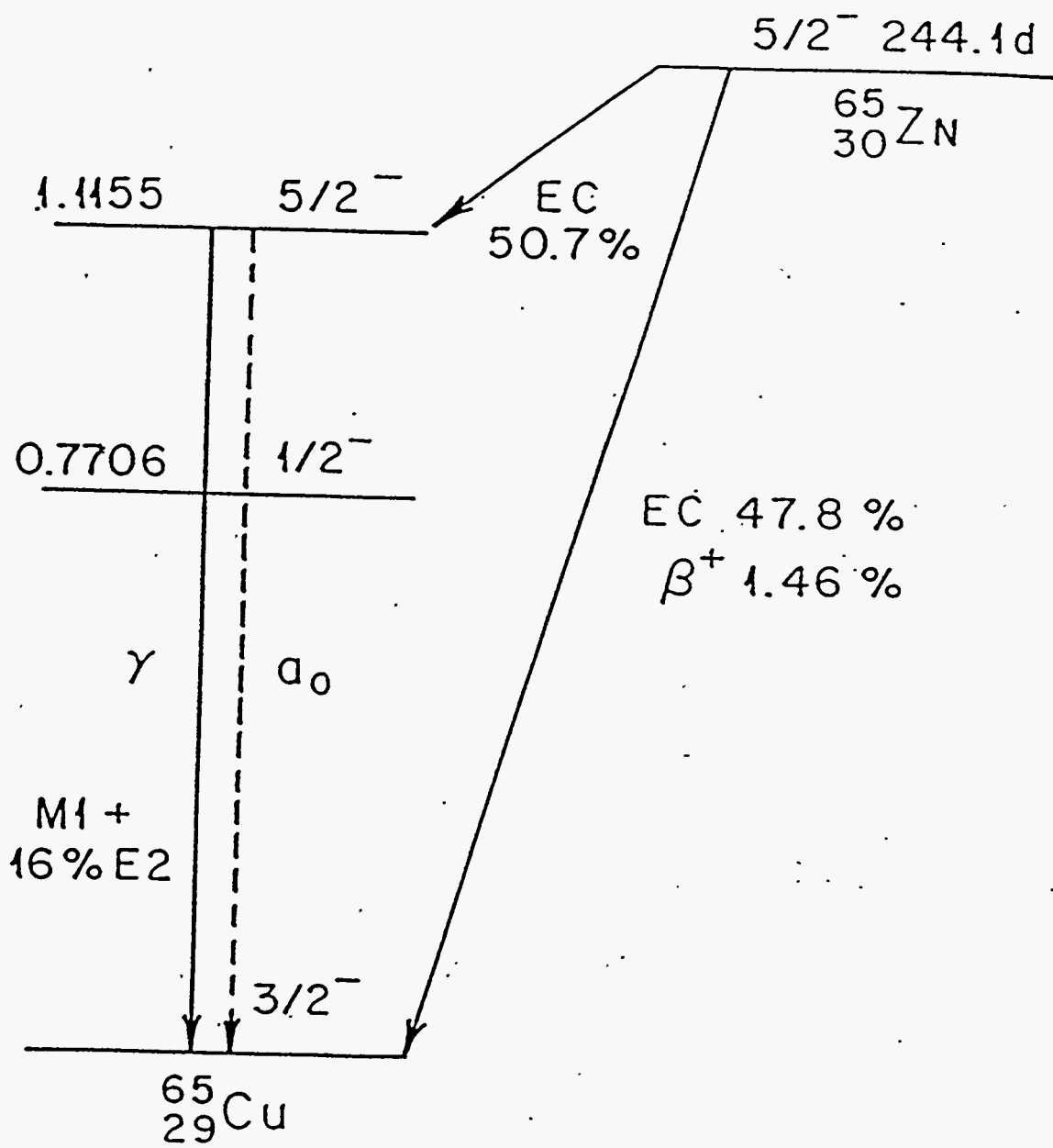
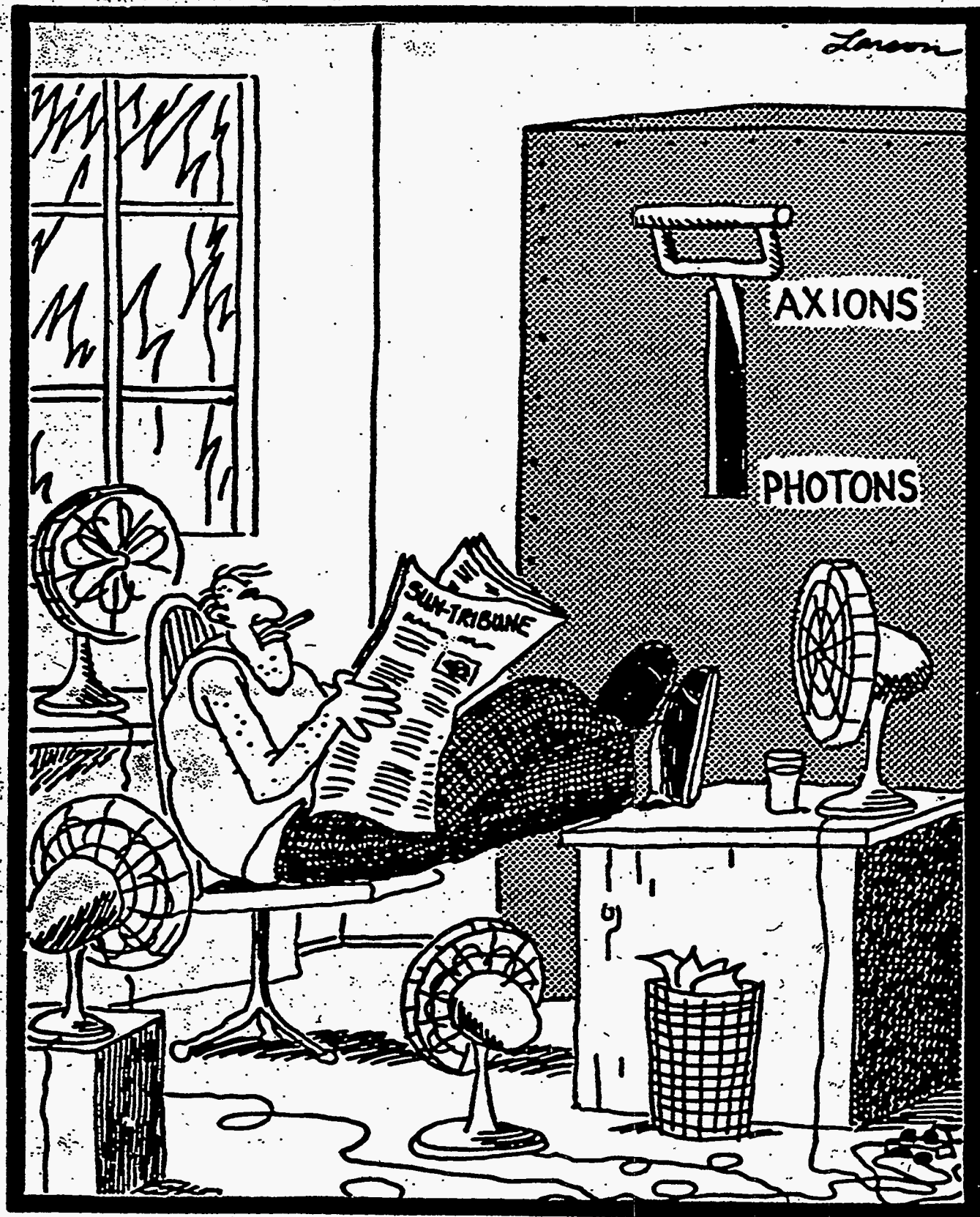


Figure 1



Inside the sun

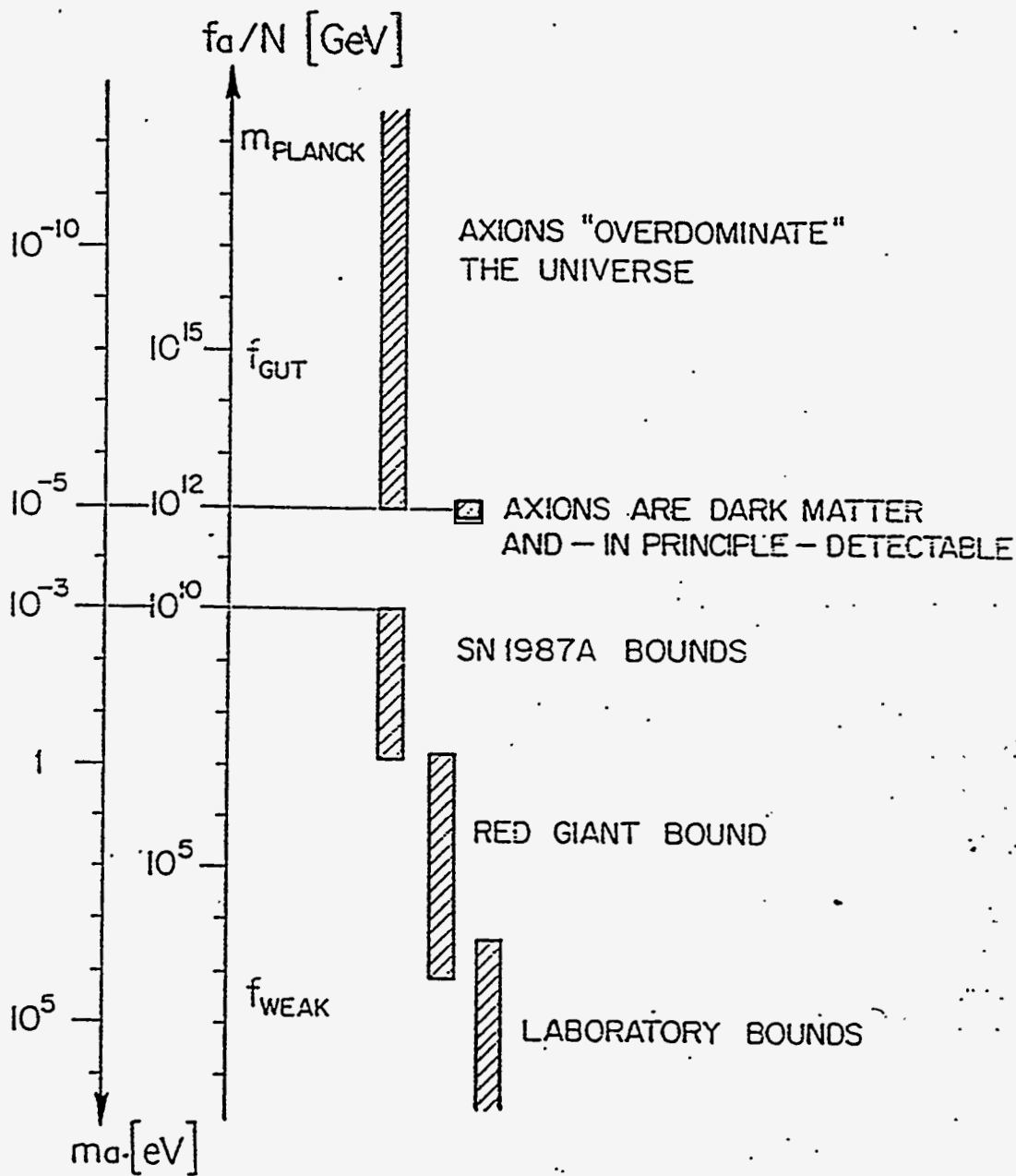
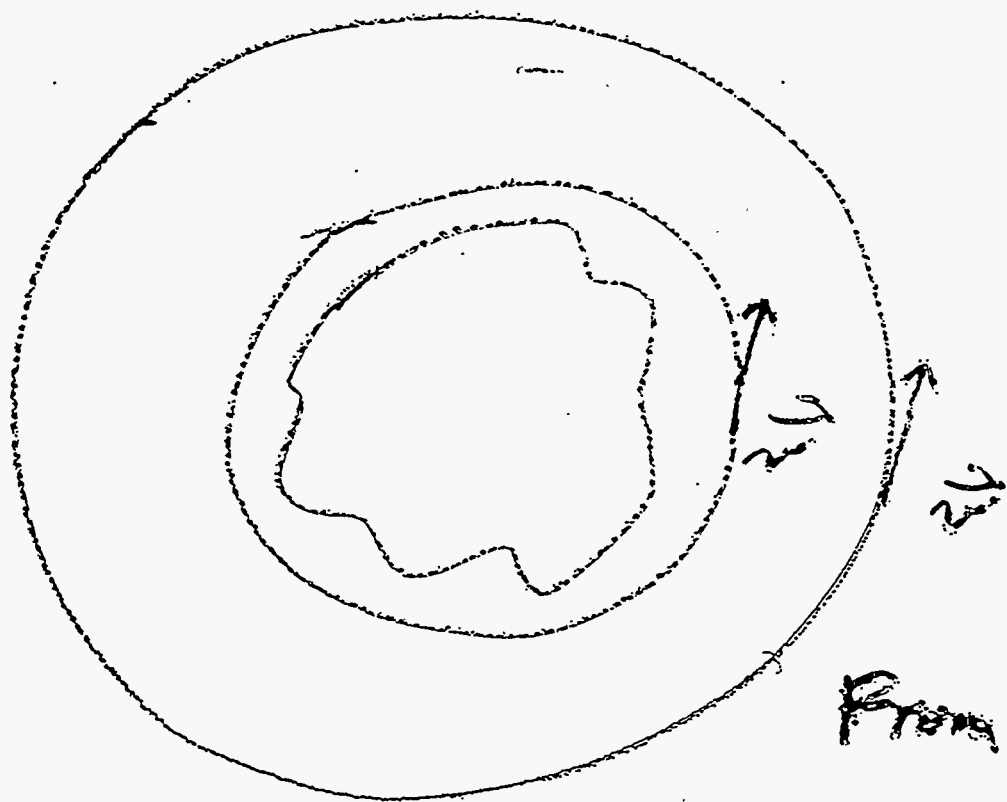


Figure 1

Axion parameters excluded by cosmological, astrophysical, and laboratory bounds. We only show results obtained from the generic axion couplings to nucleons and radiation.

clear bremsstrahlung, $N_1 + N_2 \rightarrow N_3 + N_4 + a$. This volume emission would compete



From Kepler's

3rd Law

$$GM = v^2 \times r$$

$$v \propto r^{-\frac{1}{2}}$$

Found $v = \text{constant}$

NOT ENOUGH PHOTONS

" " " " " " HADRONONS

LOOK TO THE DARK SIDE

DARK
MATTER

DARK/LUMINOUS ≥ 10

DARK/Baryonic ~ 10 ?

Velocities of Stars in Galaxies
Not consistent.

$$\langle P \rangle = \langle n_{\text{GAL}} \rangle \langle M_{\text{GAL}} \rangle$$

Need to find out how much
matter in a galaxy.

WHO'S MINDING THE STORE?

Leading Dark-Matter Candidates:

- **WIMP's :** NSF Science Center for
 (Weakly Interacting Particle Astrophysics, Berkeley;
 Massive Particles) Europe ...
- **Massive Neutrinos :** SAGE, GALLEX, SNO,
 Homestake Mine, LLNL ...
- **Axions :** ?!

(Limits to the Baryonic Component in terms of Massive Compact Halo Objects – MACHO's—is being carried out by an IGPP/CfPA/Australia collaboration, and the French.)

Yet of the 3 leading candidates, Axions are:

- The only one for which we can achieve the required sensitivity today
- The only one for which the signal would be completely unambiguous
- At least as well motivated as m_ν , WIMP's.

COSMIC AXION

PRODUCTION

- 1) Thermal (Turner, Raffelt)
- 2) Misalignment (Preskill, Wilczek, Wise, Abbot-Sikine, Dine-Fischler)
- 3) Axionic String Decay (Davis)

Thermal:

For $m_a \geq 10^{-3}$ eV, axions in thermal equilibrium.

Relic Axions - $\rho_a \sim \rho_\nu$

Many formation mechanisms



Phase Space Structure of Cold Dark Matter Halos (Sikivie + Ipser)

$$t_1 \approx 10^{-6} \text{ s} \quad (\text{Axion acquires mass})$$

For $m_a \approx 10^{-5} \text{ eV}$, (a small initial velocity dispersion due to inhomogeneous axion field)

$$d_{a_1 \rightarrow a_2} \approx 10^{11} \text{ cm}$$

whereas galactic scales $\approx 10^{23} \text{ cm}$

thus dark matter is a thin sheet spread uniformly over \vec{r} -space. As time increases, the energy momentum spectrum has a series of peaks (sheets wind up).

Detection of cold dark matter particles would form a record of our galaxy formation. Sheet Structure follows from Liouville's theorem and that trajectories cannot cross in phase space (and that dark matter is collisionless)

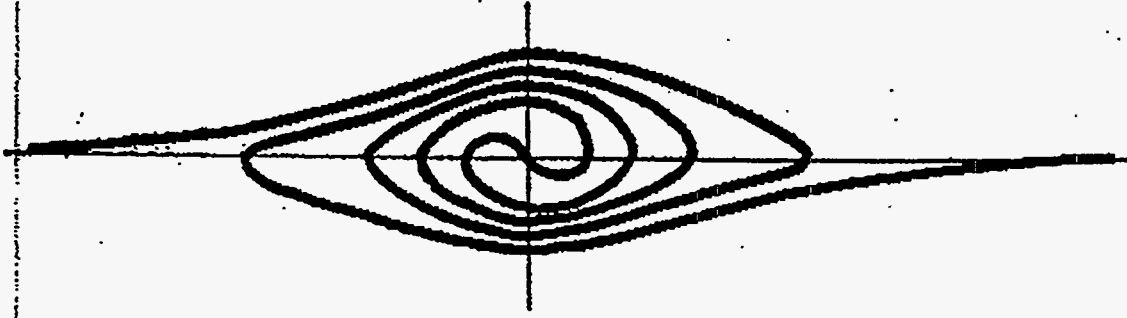
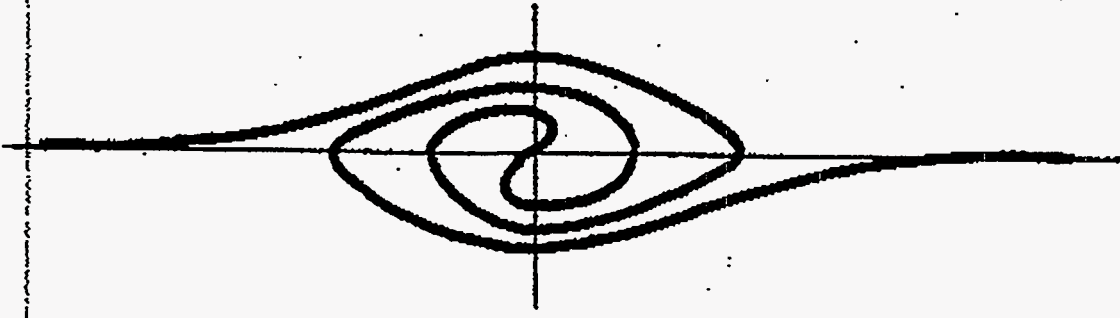
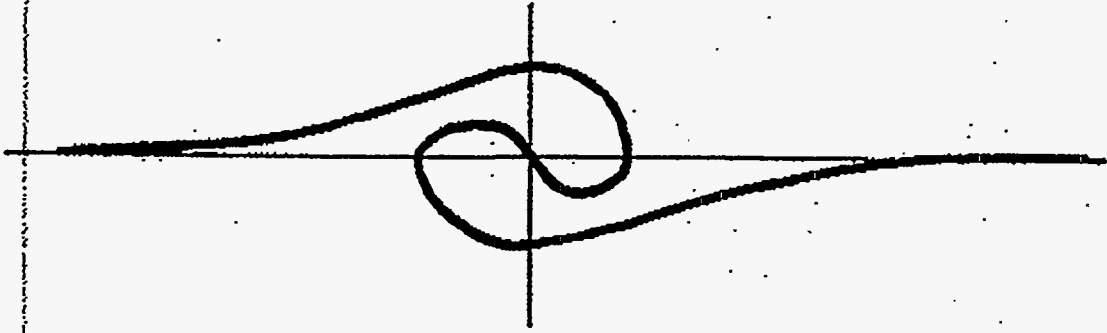
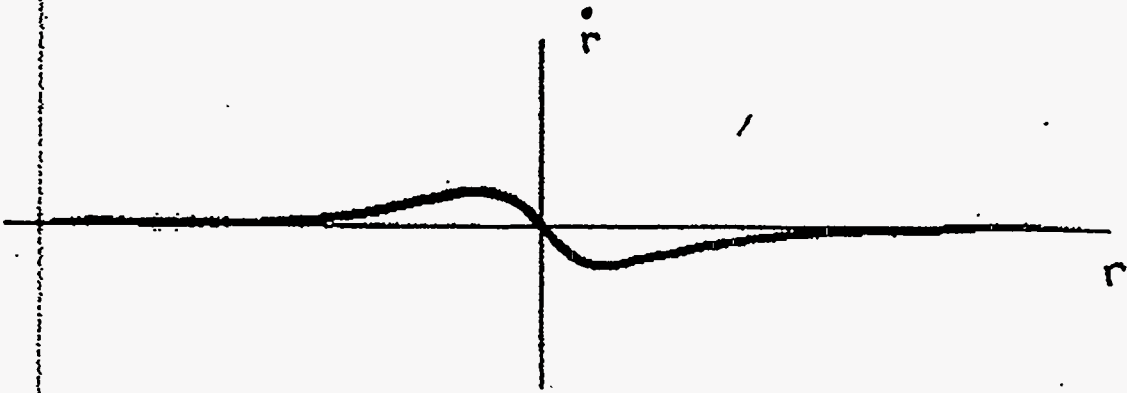
$N \equiv$ number of crossings

for neutrinos, N is very large

\therefore peaks not distinguishable

$N \approx 200$ for axions or WIMPs

Angular momentum changes the location, but not the number of folds!



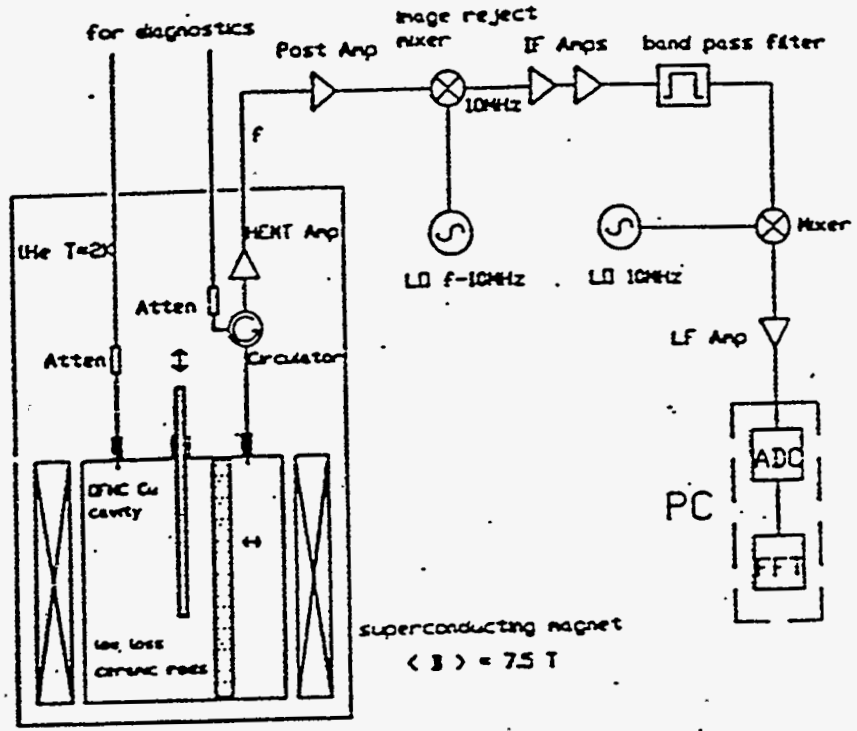
HOW TO SEARCH FOR DARK MATTER AXIONS

(Sikivie, 1983)

MAKOFF

PROCESS:

γ
 μ
 ν
 ω
 σ
 ρ
 τ
 θ
 ϕ
 χ
 ψ
 ω
 ν
 μ
 γ
 X
 A^{μ}



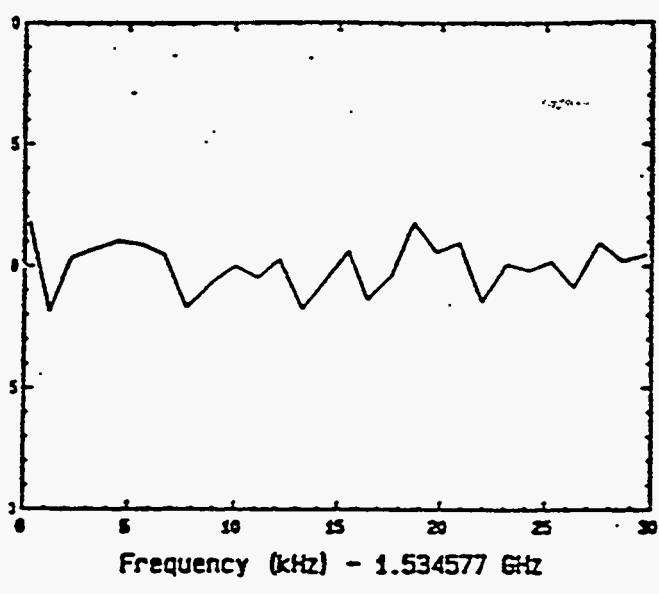
$$P_{nl} = \left(\frac{\alpha}{\pi} g_{\gamma} \frac{1}{f_a} \right)^2 V B_0^2 \rho_a C_{nl} \frac{1}{m_a} \text{Min}(Q_L, Q_a)$$

$$= 3 \times 10^{-26} \text{Watt} \left(\frac{V}{3 \text{ m}^3} \right) \left(\frac{B_0}{7 \text{ Tesla}} \right)^2 C_{nl} \left(\frac{g_{\gamma}}{0.36} \right)^2$$

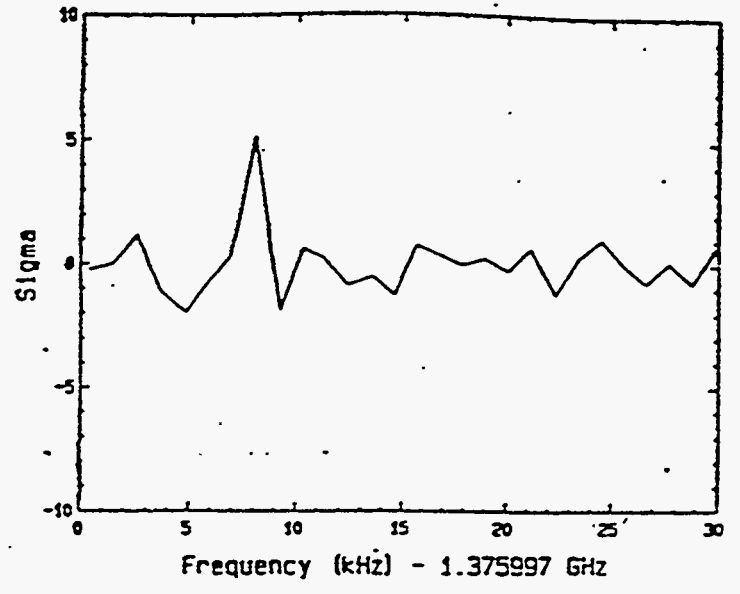
$$\cdot \left(\frac{\rho_a}{\frac{1}{2} \times 10^{-24} \text{ gr/cm}^3} \right) \left(\frac{m_a}{2\pi(1\text{GHz})} \right) \text{Min}(Q_L, Q_a)$$

Q_L = LOADED Q OF TUNABLE MICROWAVE CAVITY ($\geq 10^5$)

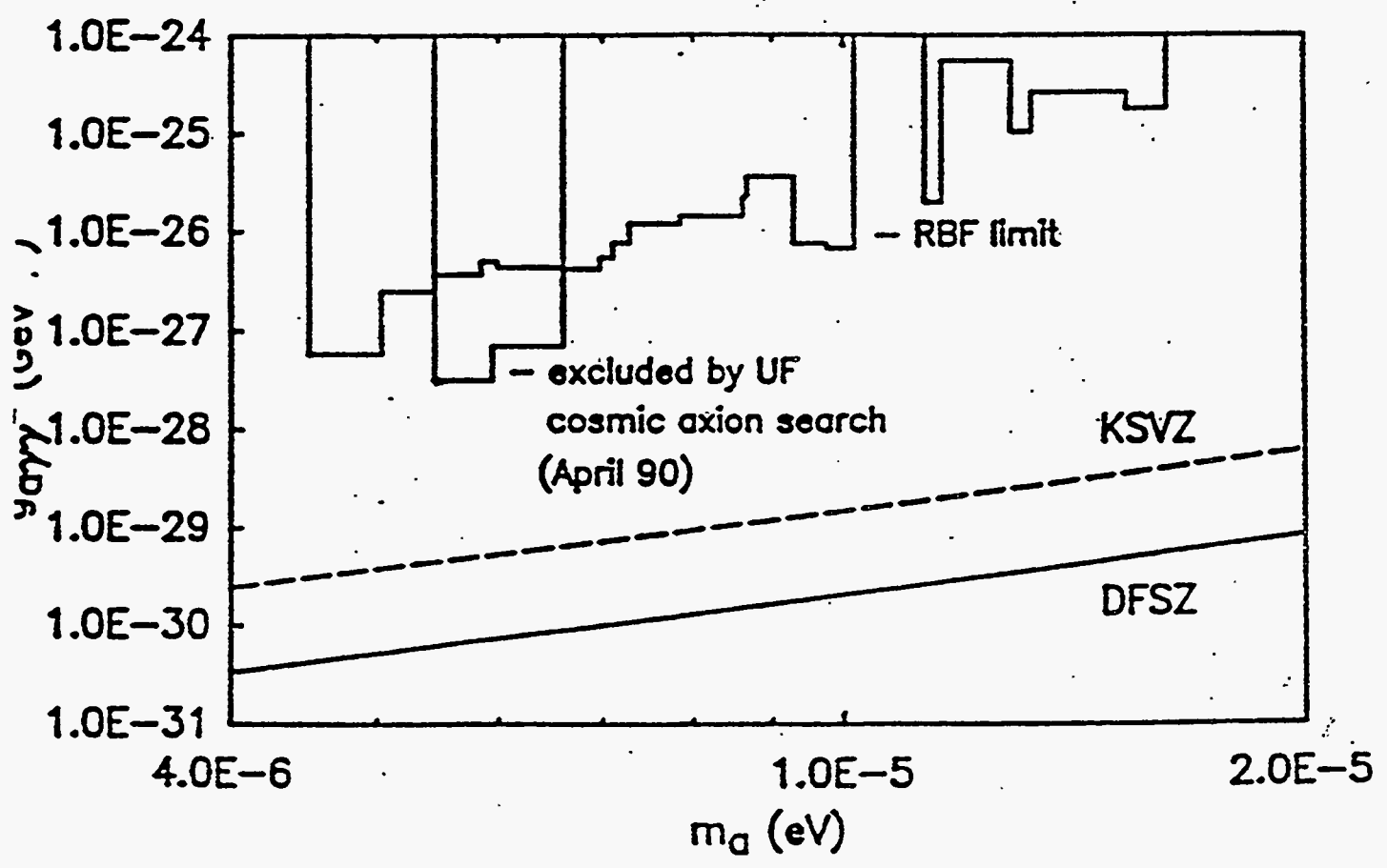
Q_a = "QUALITY FACTOR OF AXION" ($> 10^5$)

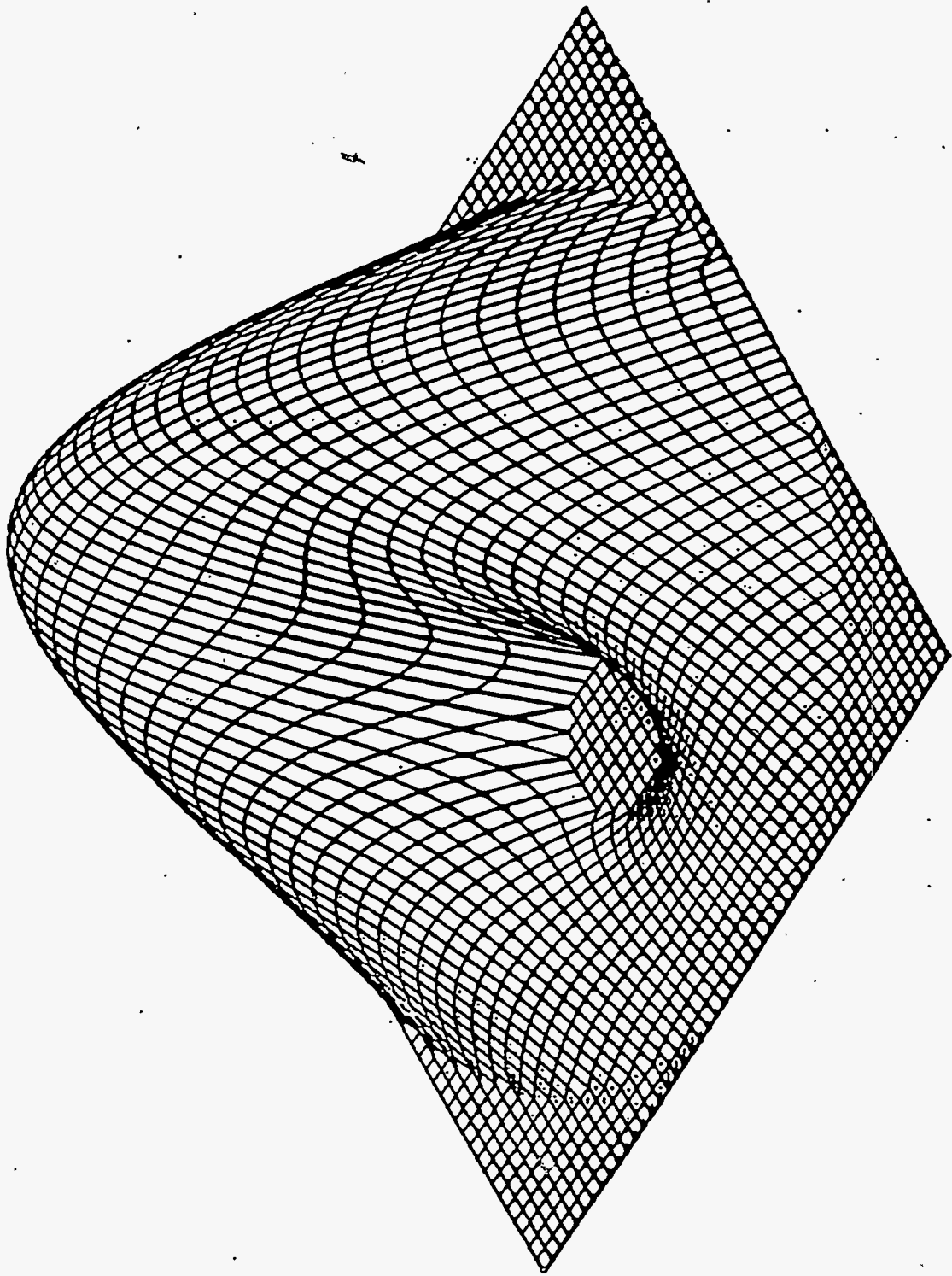


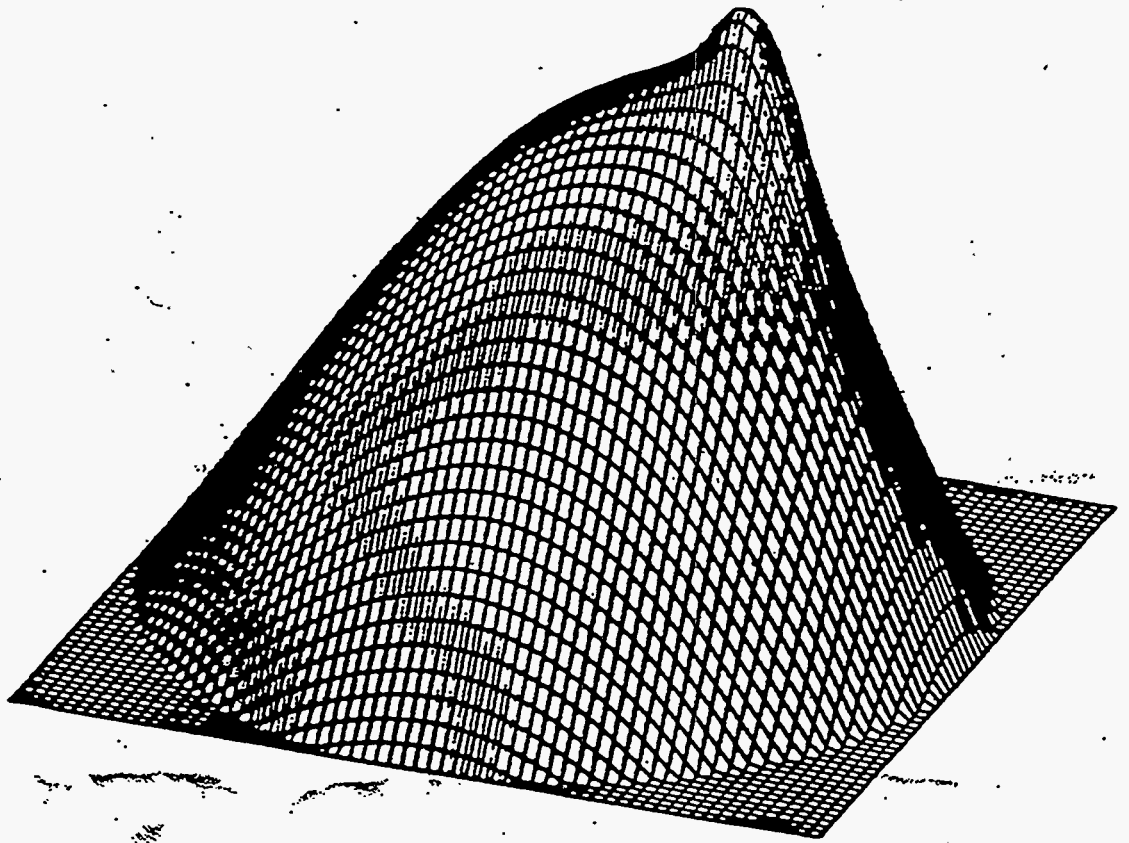
Typical power spectrum.



Power spectrum with candidate peak.







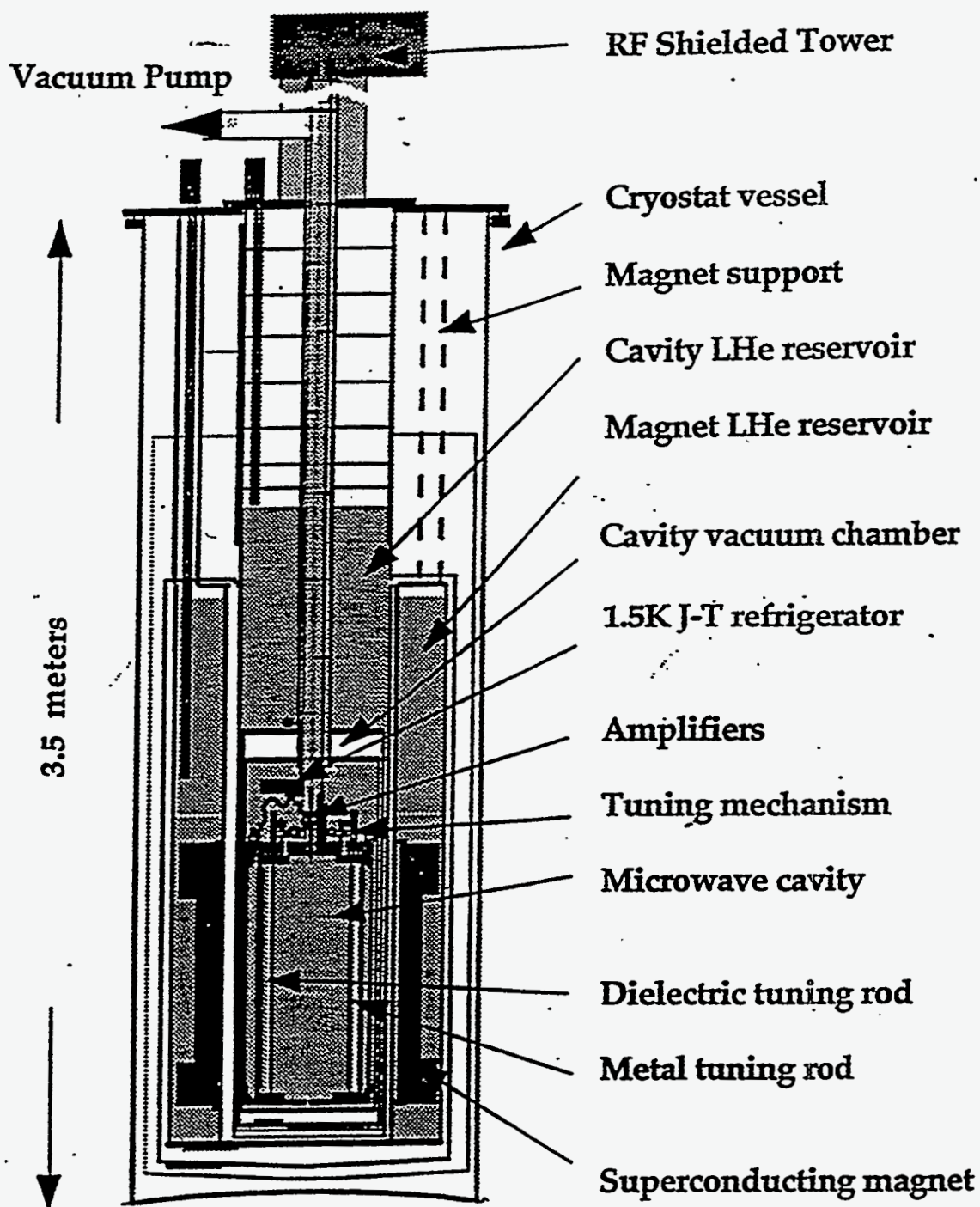
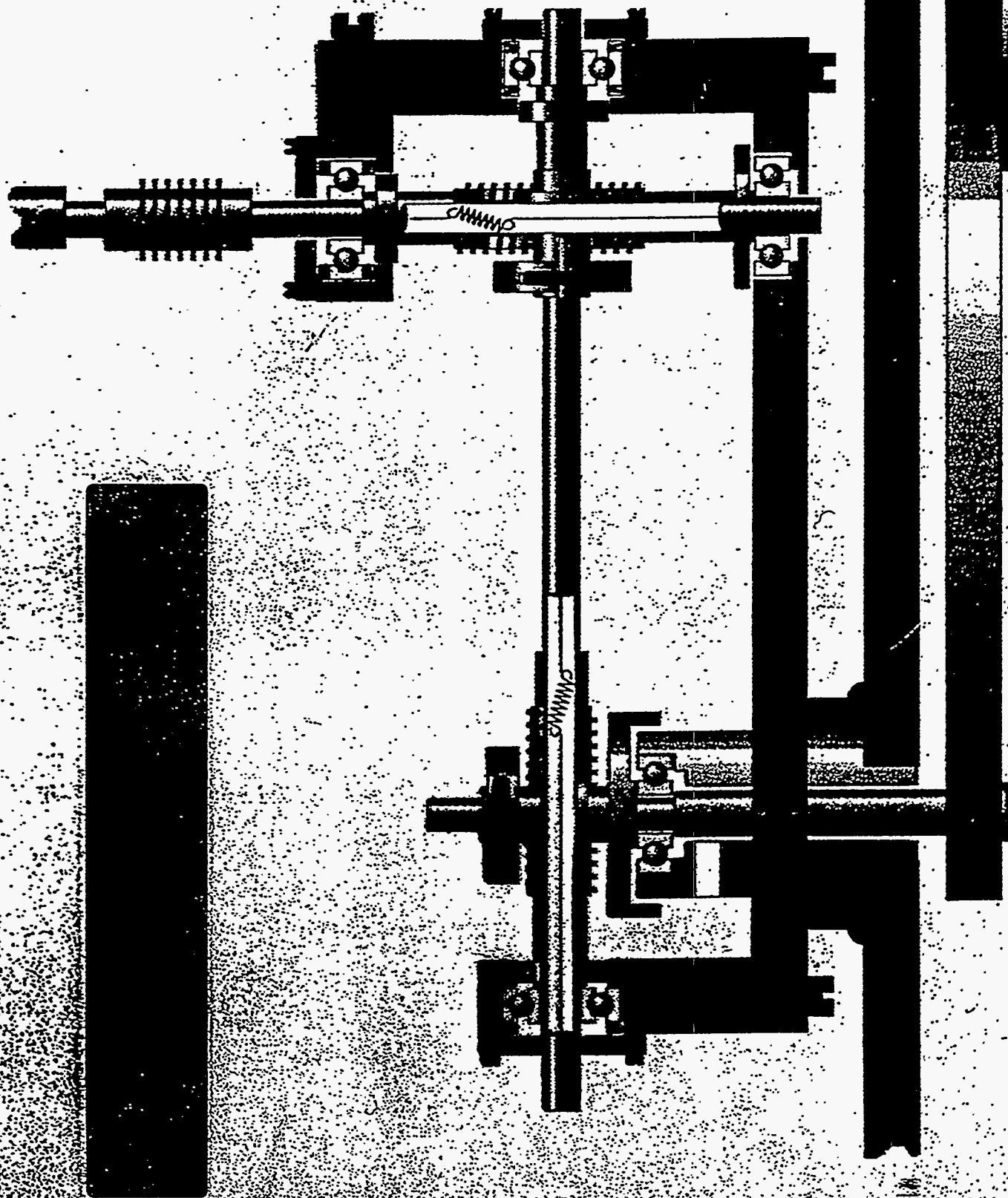
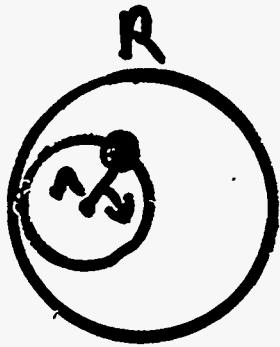


Figure 3. Schematic of the magnet and cryostat, with the physics package inserted.

Correct Experiment



Parameter Space for Piezo Motion



Motion must be
consistent

$\times 4$ or 16 or $64 \equiv N$

1 Master Cavity

+ $N-1$ Slave Cavities

Goal: $0.1 \mu\text{m} / \text{movement}$

Accept: $1.0 \mu\text{m} / \text{movement}$

Must operate at 3°K in 8T Field!

134.5 kHz Driver

g Voltage 200 - 500 V.

Break down in He at 1 Torr in 8T

Expansion / Contraction

from Warming / Cooling

Everything is elastic at μm !

Gears have memory!

Piezoes do not!

Micro Pulse Systems, Inc.

LINEAR MICROPOSITIONING WITH MICRO PULSE SYSTEMS' PIEZOELECTRIC ACTUATORS

FEATURES

- Direct microinch resolution
- Unlimited travel
- Power-off position locked without drift
- No lost motion — bearings and gears can be eliminated
- Simple drive circuitry with fast response
- High vacuum compatibility and non-magnetic options

The patented direct drive technology of MPS provides the advantages of piezoelectric actuators without the complexity and costly mechanics of conventional devices. MPS actuating drivers are simple and reliable; in most applications they are mounted kinematically, eliminating the need for critical tolerances and adjustment.

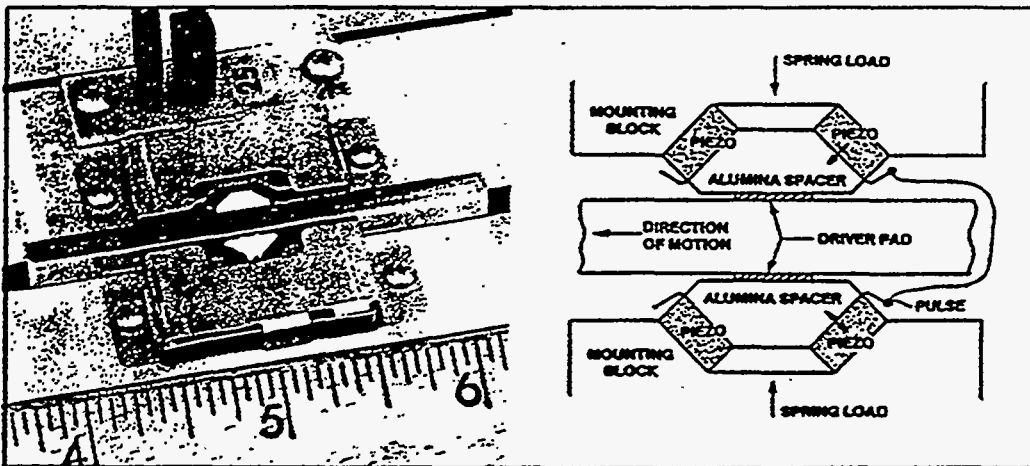


Figure 1

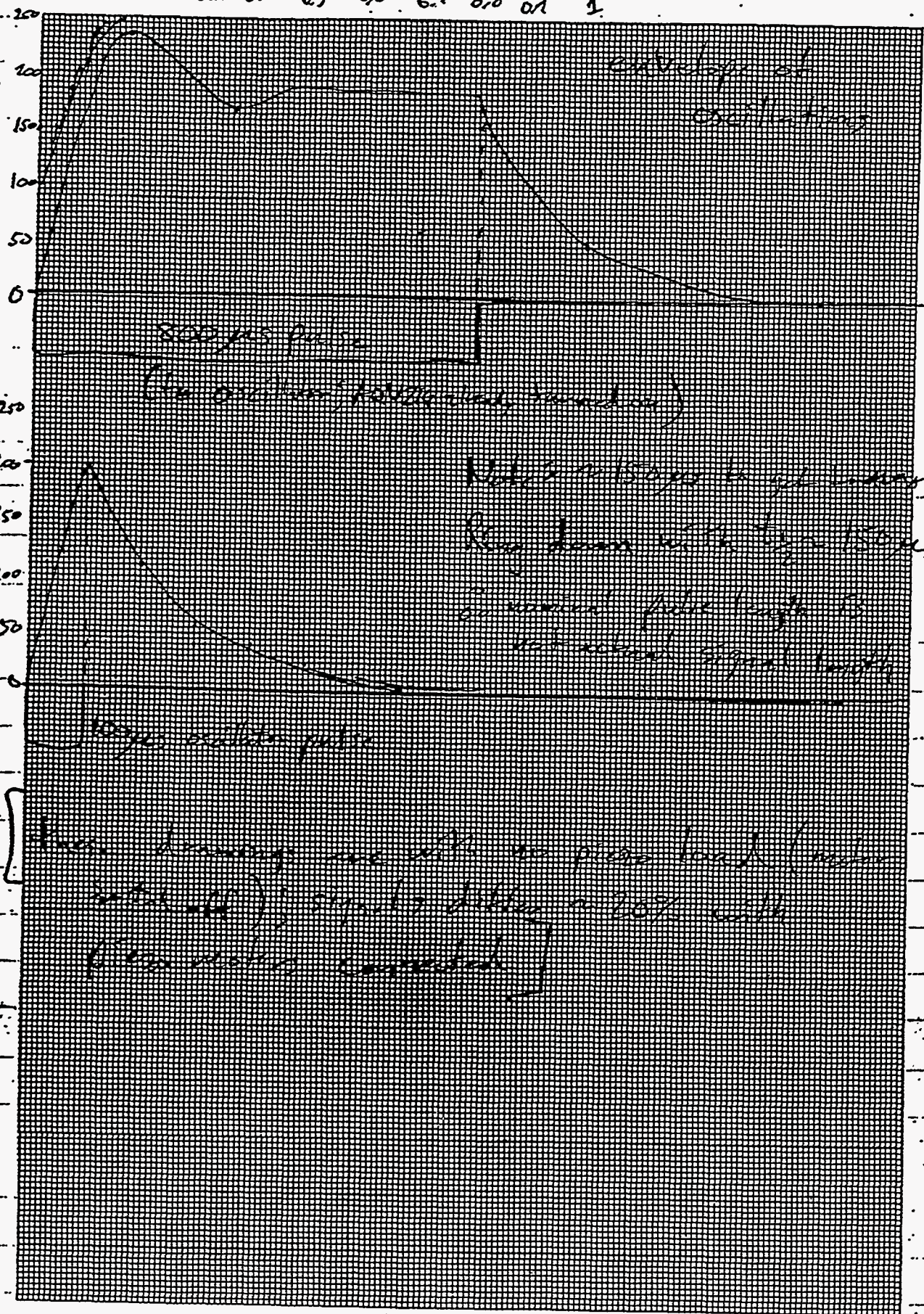
Figure 1 illustrates the direct drive principle in the linear mode using L-104 components. The actuator incorporates four piezoelectric elements which are excited in pairs to drive a hardened steel bar. When the thickness of the piezo element expands and contracts in response to pulses of the excitation voltage, the resultant motion has a component along the length of the bar, and the bar is moved in steps. By adjusting the width of the pulses the size of the steps can be varied. The bar can be driven in either direction with a minimum step of approximately 1 microinch.



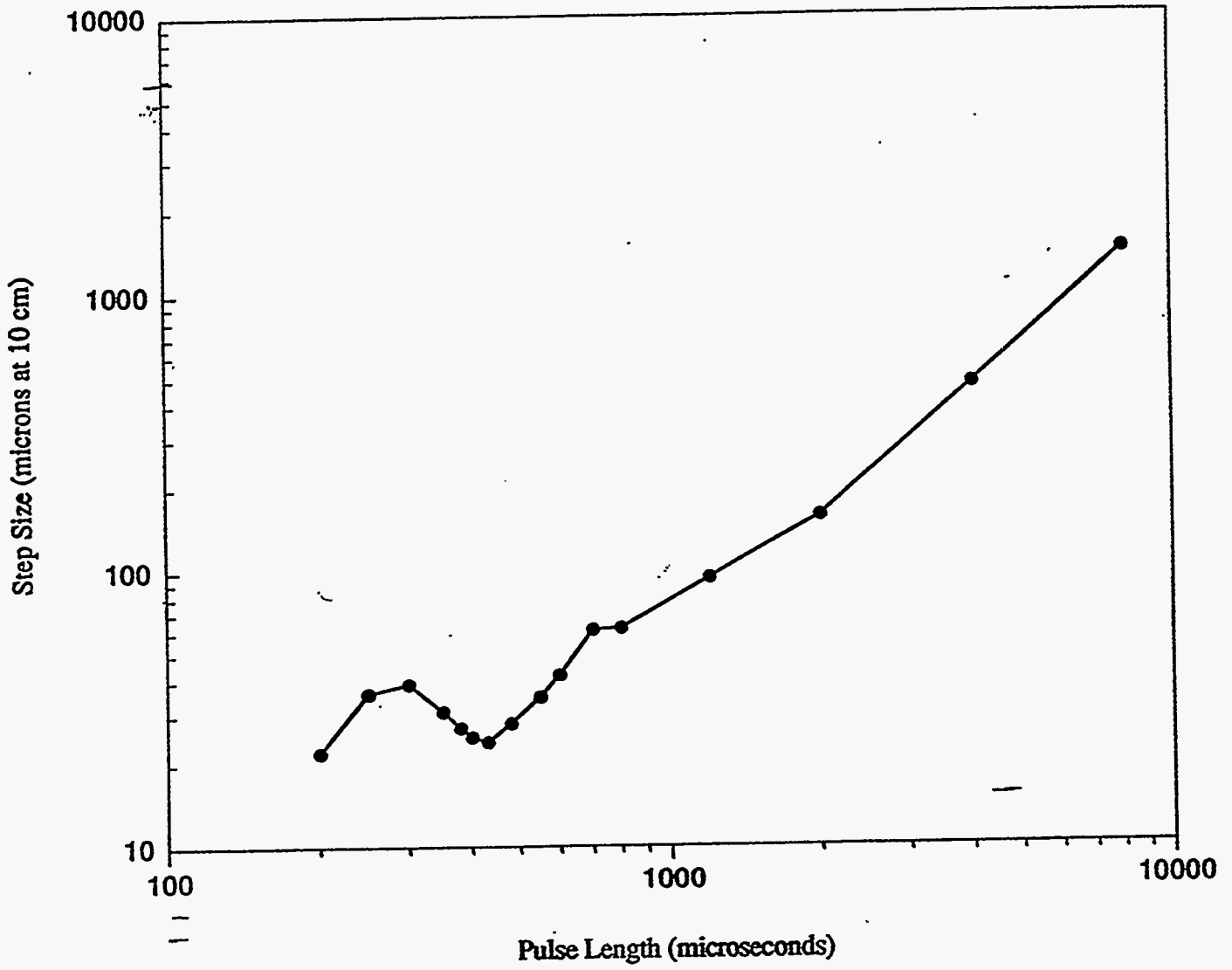
Time (ms)

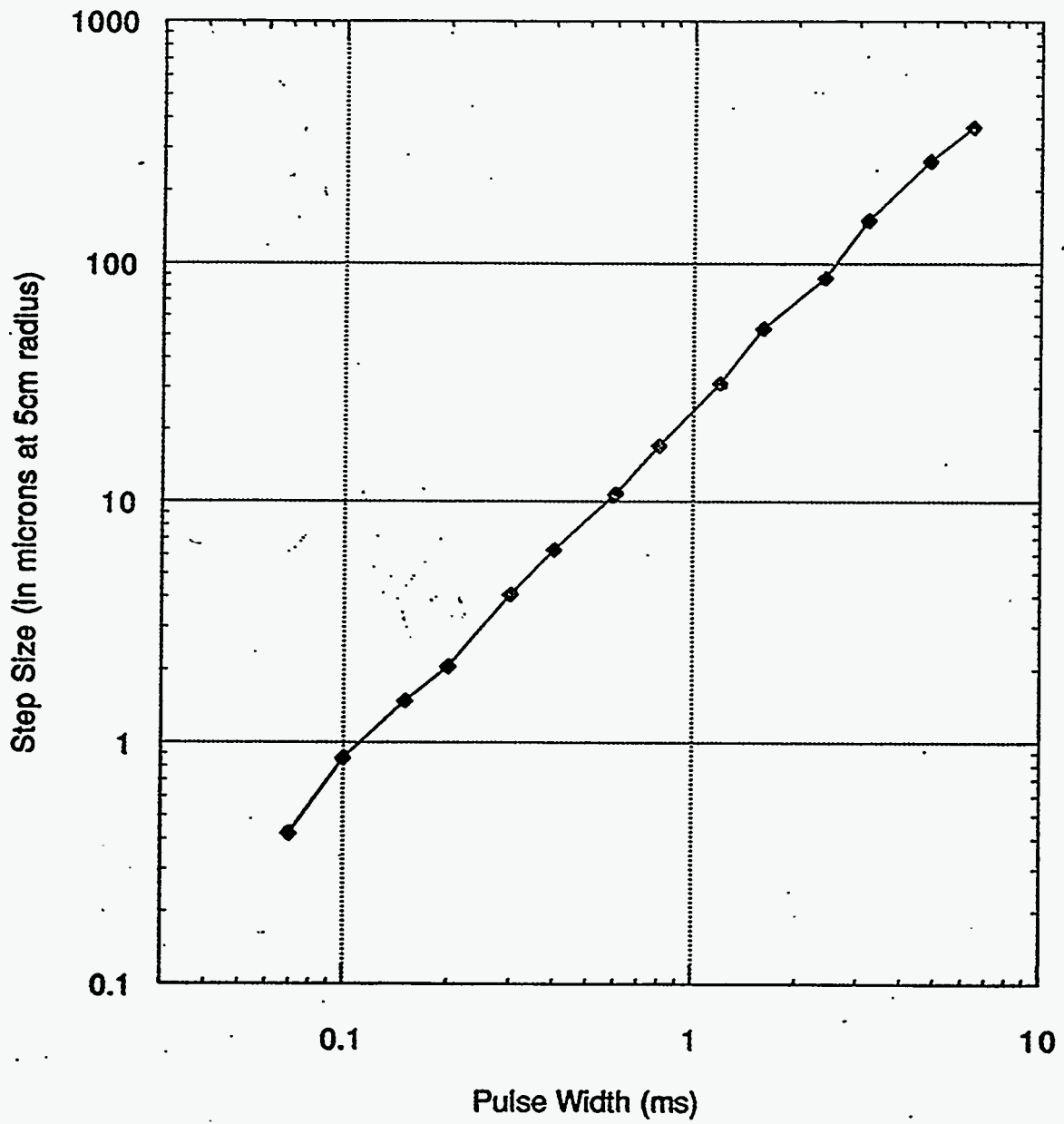
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

V_{AC} (VOLT) $\times 10^4$

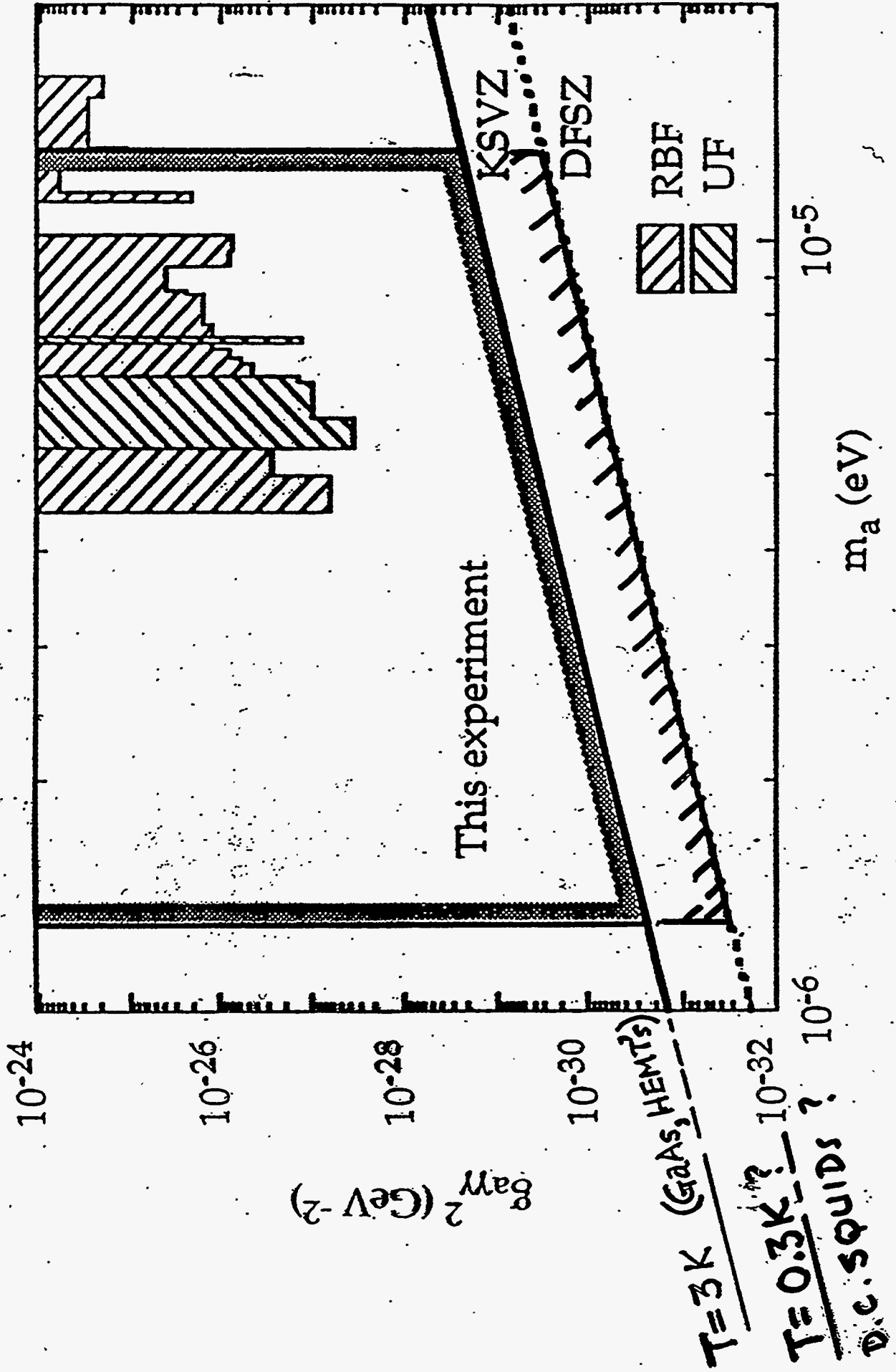


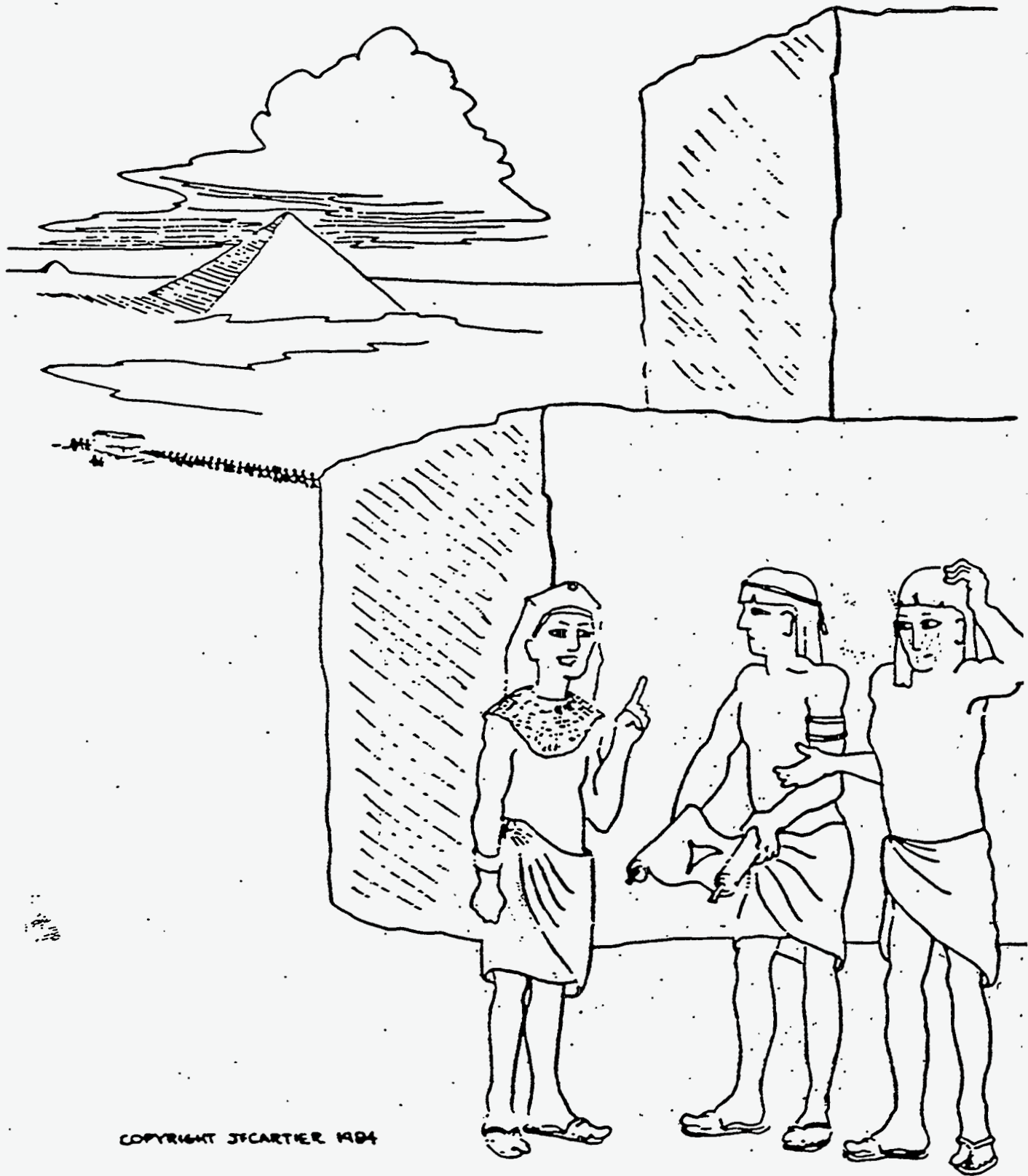
Run down with $t_p = 150 \mu s$
to avoid pulse length B
intended signal bands






THE REACH OF THE EXPERIMENT



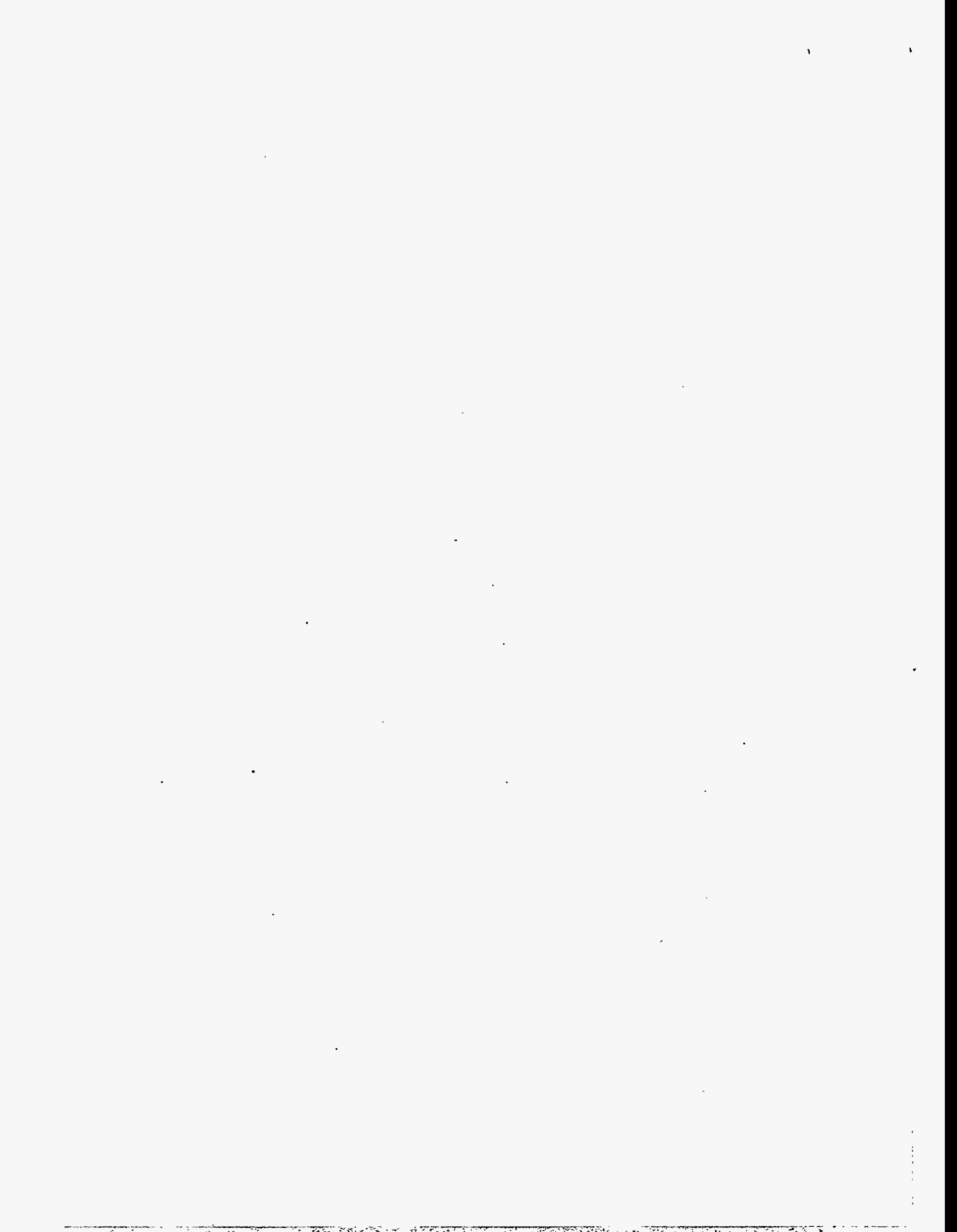


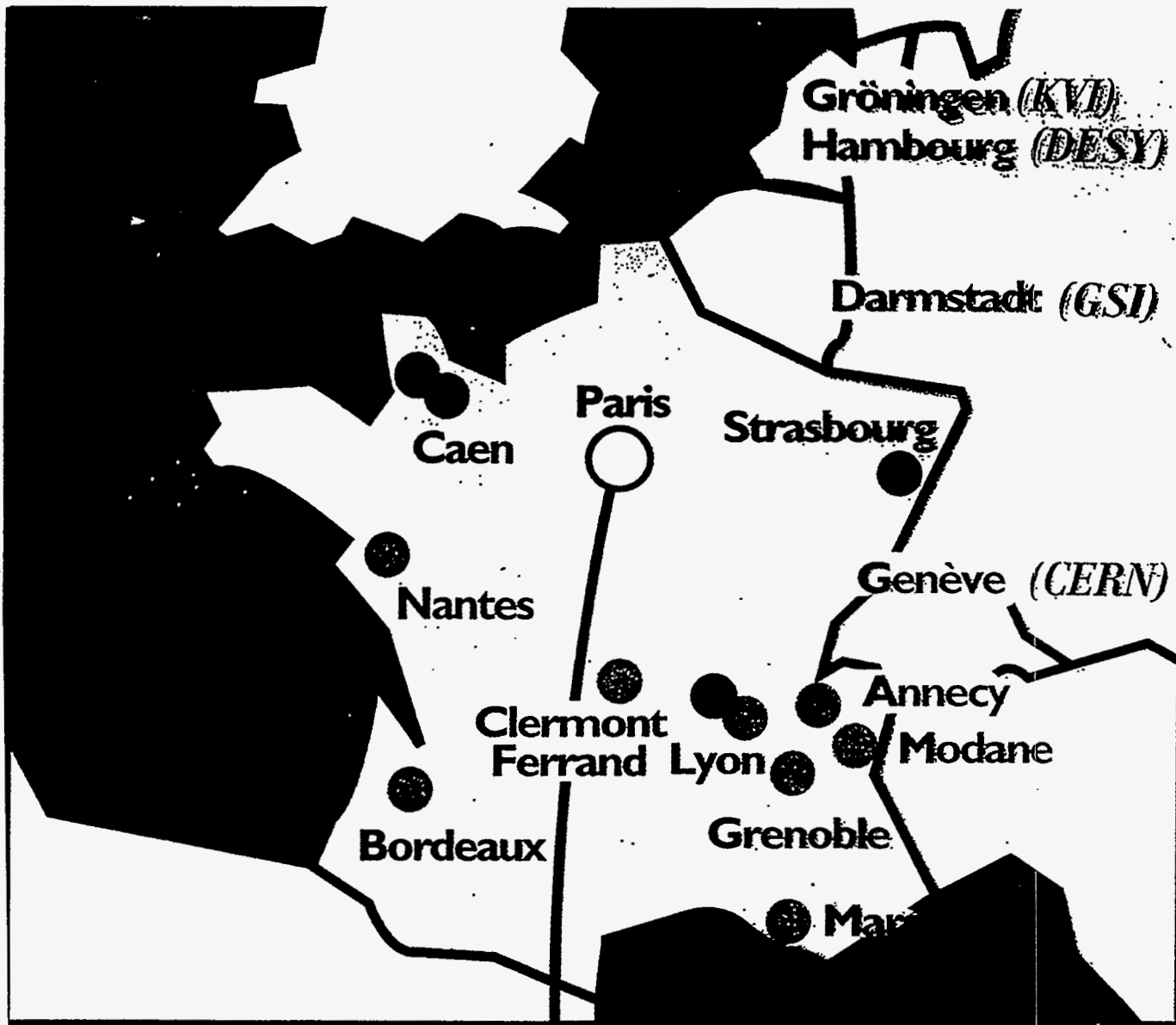
COPYRIGHT JFCARTIER 1984

It's been over 700 years
and we haven't observed a single  event.
We will have to make it BIGGER.

Claude Detraz

IN2P3
Paris, France





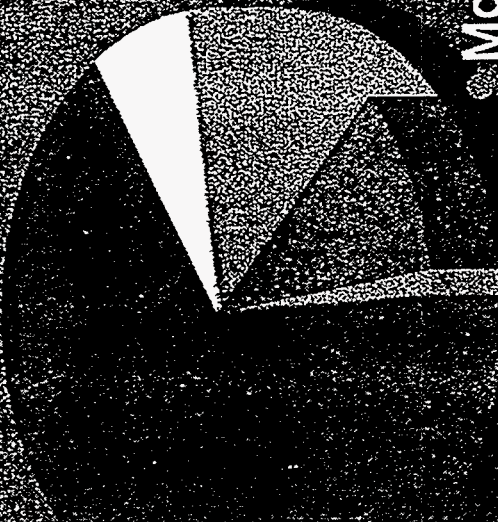
IN2P3

BUDGET ET EFFECTIF (1994)

Budget total :

1 036 MF HT

Répartition



● Grands équipements
8,7%

● Moyens des laboratoires
19,1%

● Moyens de calcul
9%

● Personnel
63%

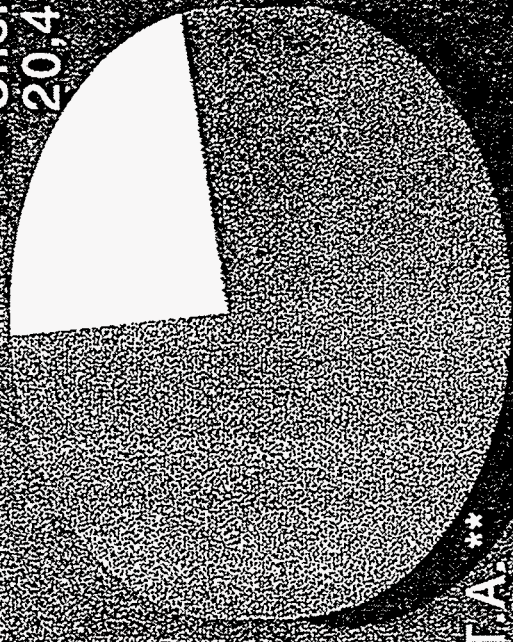
● Immobilier
0,2%

Effectif total :

2 339 personnes*

Catégories

● Chercheurs
20,4%



● I.T.A. **
79,6%

* Personnel permanent

** Ingénieurs Techniciens Administratifs :
personnels d'appui à la recherche + TPN :
(Techniciens de Physique Nucléaire)

NUCLEAR MATTER

QUARKS AND LEPTONS

HADRONIC PHYSICS

FIELDS, PARTICLES, NUCLEI IN THE UNIVERSE

PERSPECTIVES

1. EVOLUTION

LEP (e^+e^-)

----->

LHC (pp)

HERA (ep)

SATURNE (hadrons)

----->

CEBAF, etc, ... ELFE
(electrons)

2. NEW FIELDS

Neutrinos

Radioactive
beams

Astro
particles

B or τ
Factories

3. MAJOR PROGRAMS FOR THE DECADE

LEP 200

HERA

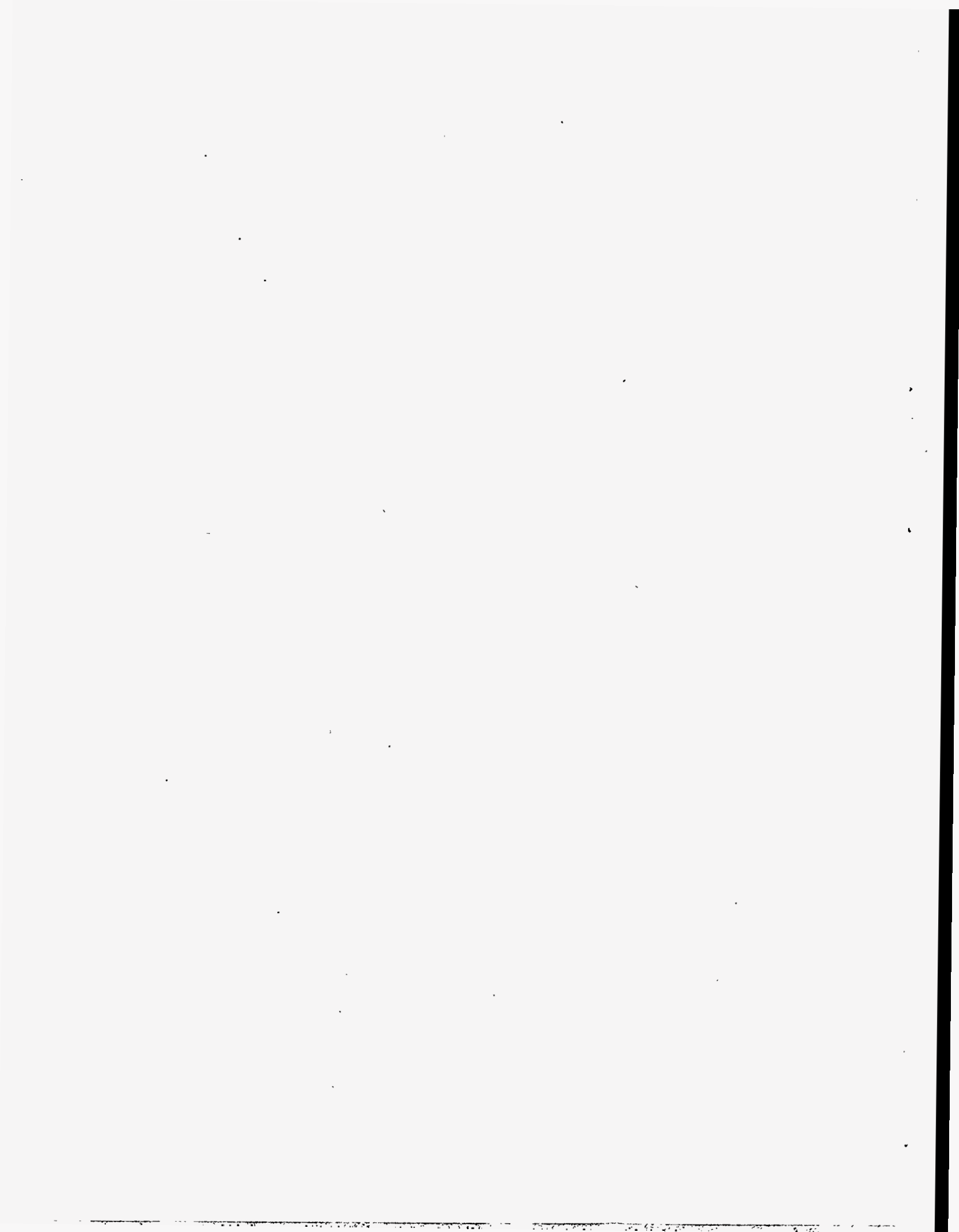
GANIL

VIVITRON

SATURNE

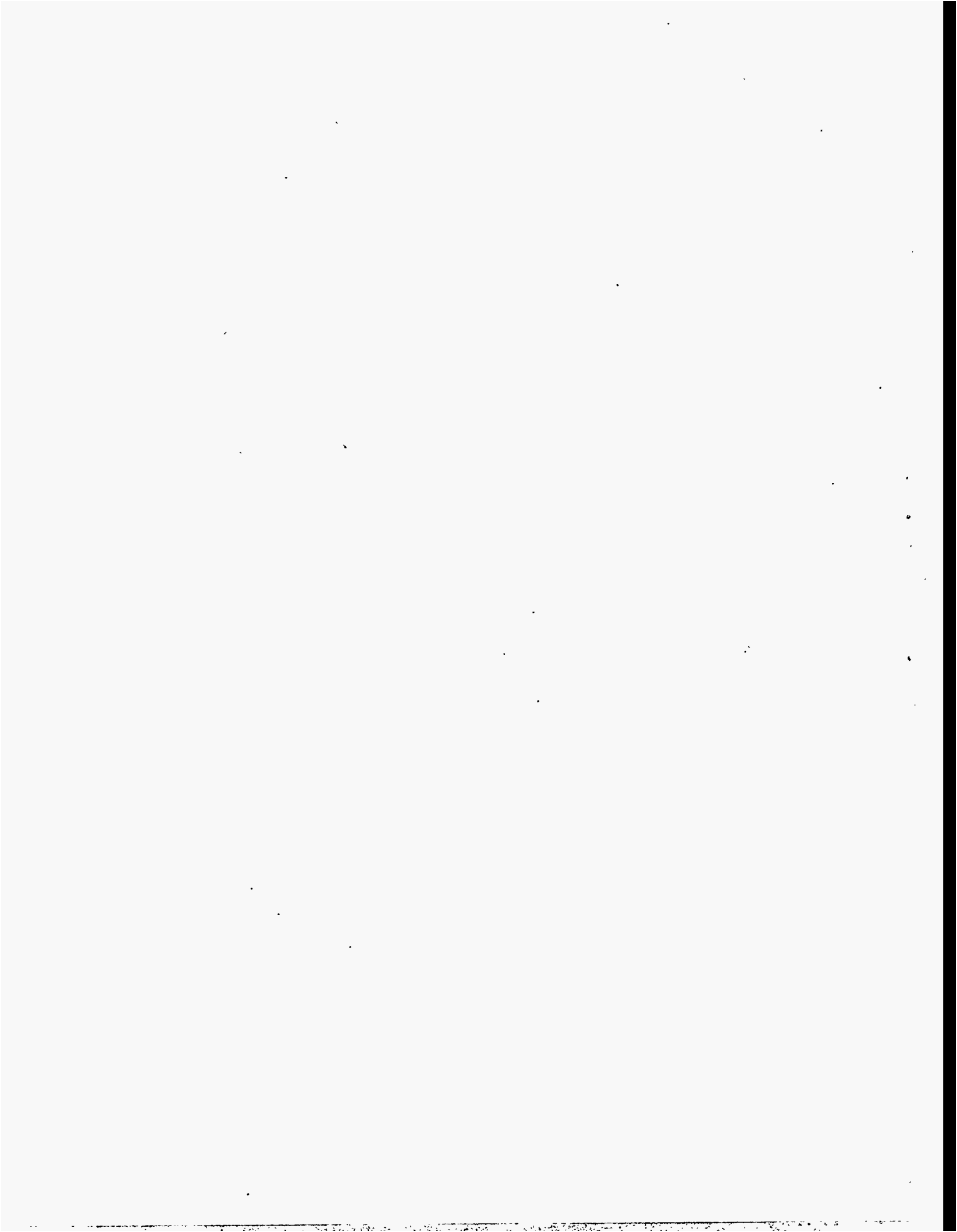
SHARED MULTI-DETECTORS

<u>DETECTOR</u>	<u>PARTICIPATING COUNTRIES</u>	<u>PARTICIPATING LABORATORIES</u>	<u>SUCCESSIVE SITING</u>
TAPS (Two arm Photon Spectrometer)	France Germany Netherlands	GANIL Caen GSI Darmstadt Univ. Giessen KVI Groningen	GANIL Caen GSI Darmstadt KVI Groningen MAMI Mainz LEAR CERN
EDEN (Neutrons)	France Netherlands	IPN Orsay KVI Groningen	Tandem Orsay GANIL Caen KVI Groningen
DEMON (Neutrons)	France Belgium	LPC Caen; CRN Strasbourg U.L. Bruxelles, U.C. Louvain-la-Neuve	U.C. Louvain-la-Neuve GANIL Caen Viviron Strasbourg
EUROGAM (Photons)	France United Kingdom	IPN Orsay CSNSM Orsay CEN Bordeaux GANIL CRN Strasbourg IPN Lyon ISN Grenoble NSF Daresbury Univ. Manchester Univ. Liverpool Univ. Birmingham	NSF Daresbury Viviron Strasbourg (GANIL)
will evolve towards EUROBALL	+ Germany Italy Scandinavian Countries		



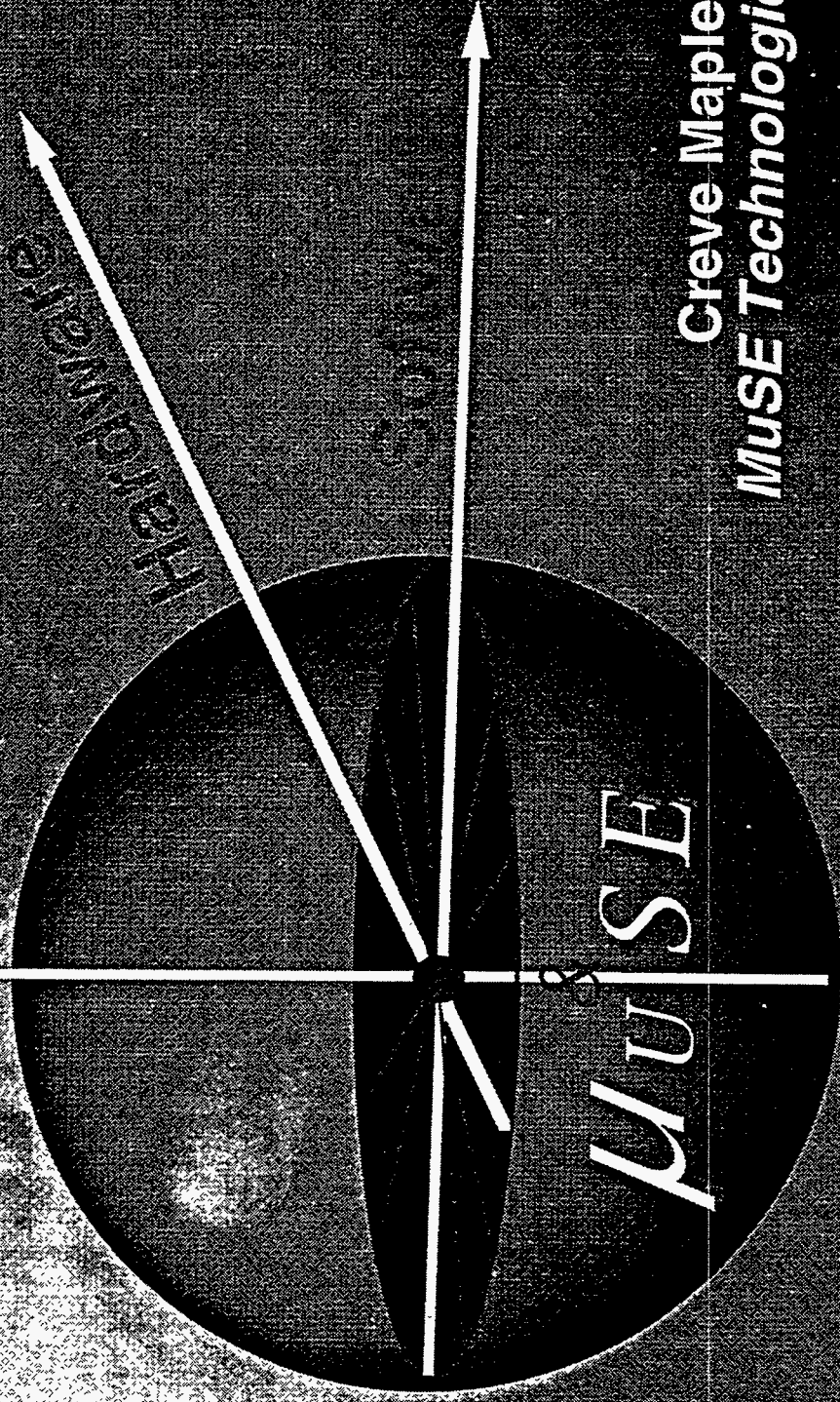
Creve Maples

Musetech
Albuquerque, NM



A New Dimension in Human-Computer Interaction

Users



Creve Maples
MUSE Technologies, Inc.

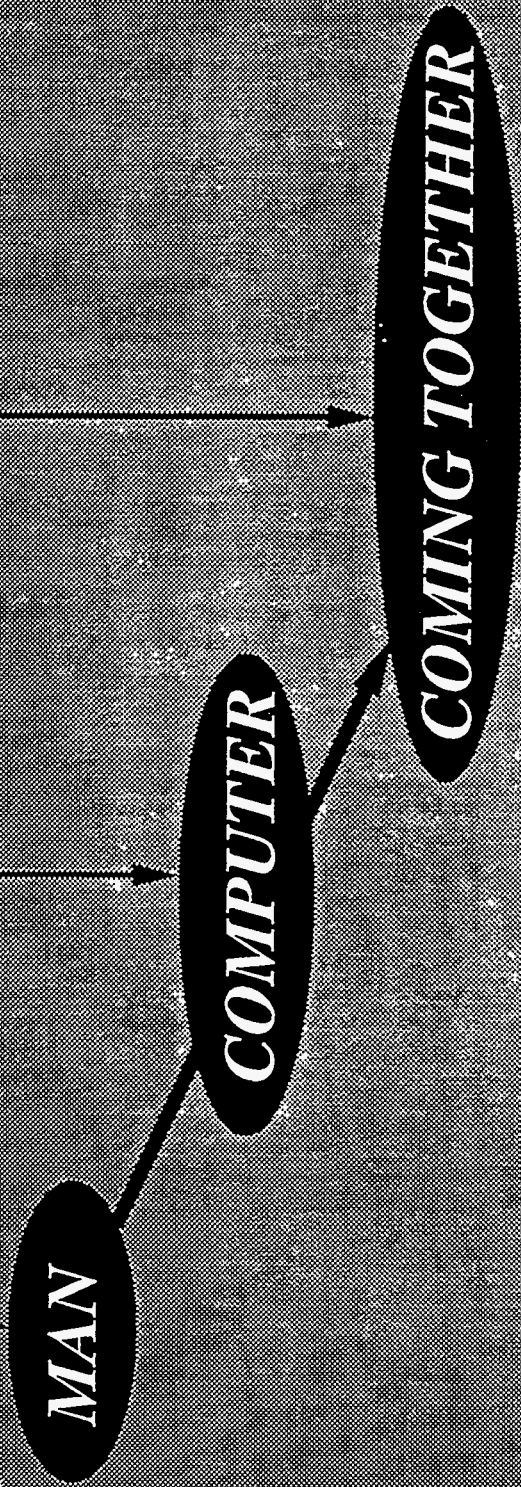
1601 Ranpolph, Suite 210, Albuquerque, NM
(505) 843-6873 cmuples@musetech.com

**"The purpose of
computing is
*insight,***

not numbers"

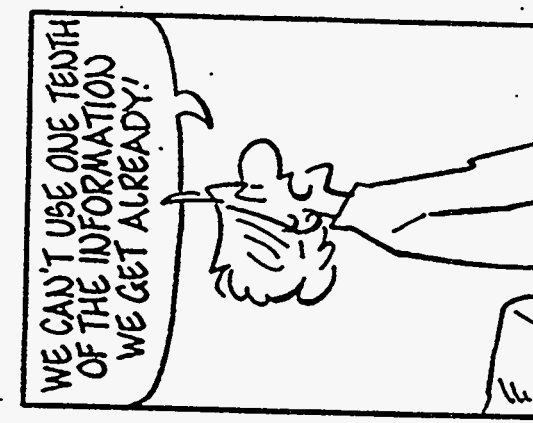
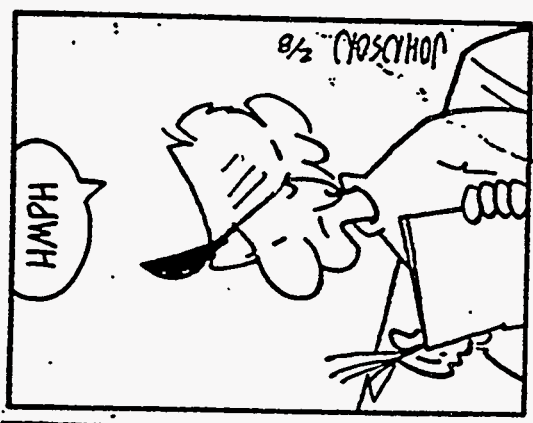
Richard Hamming

ANTHROPOCYBERSYNCHRONICITY



MUSE Technologies, Inc.

ARLO AND JANIS



The Dimension of

HUMAN SENSES

SIGHT

*length
width
height*

*color
motion
objects*

SOUND

*loudness
pitch
voice*

*location
motion
speech*

TOUCH

*texture
pressure
temperature*

*location
motion*

ODOR

*type
degree*

direction

TASTE

*type
degree*

The Dimension of SOUND

SPEECH

*Voice recognition
Synthetic speech*

**DISCRETE
DATA**

*amplitude
frequency
voice*

LOCATION

*x, y, and z
coordinates*

**SENSORY
QUEUES**

*associated
with events*

MOTION

direction

AREAS OF HUMAN-COMPUTER INTERACTION

PRESENTATION

Approaches for representing complex, multi-dimensional information.

EXPLORATION

Techniques for moving within and between various representations and models.

NAVIGATION

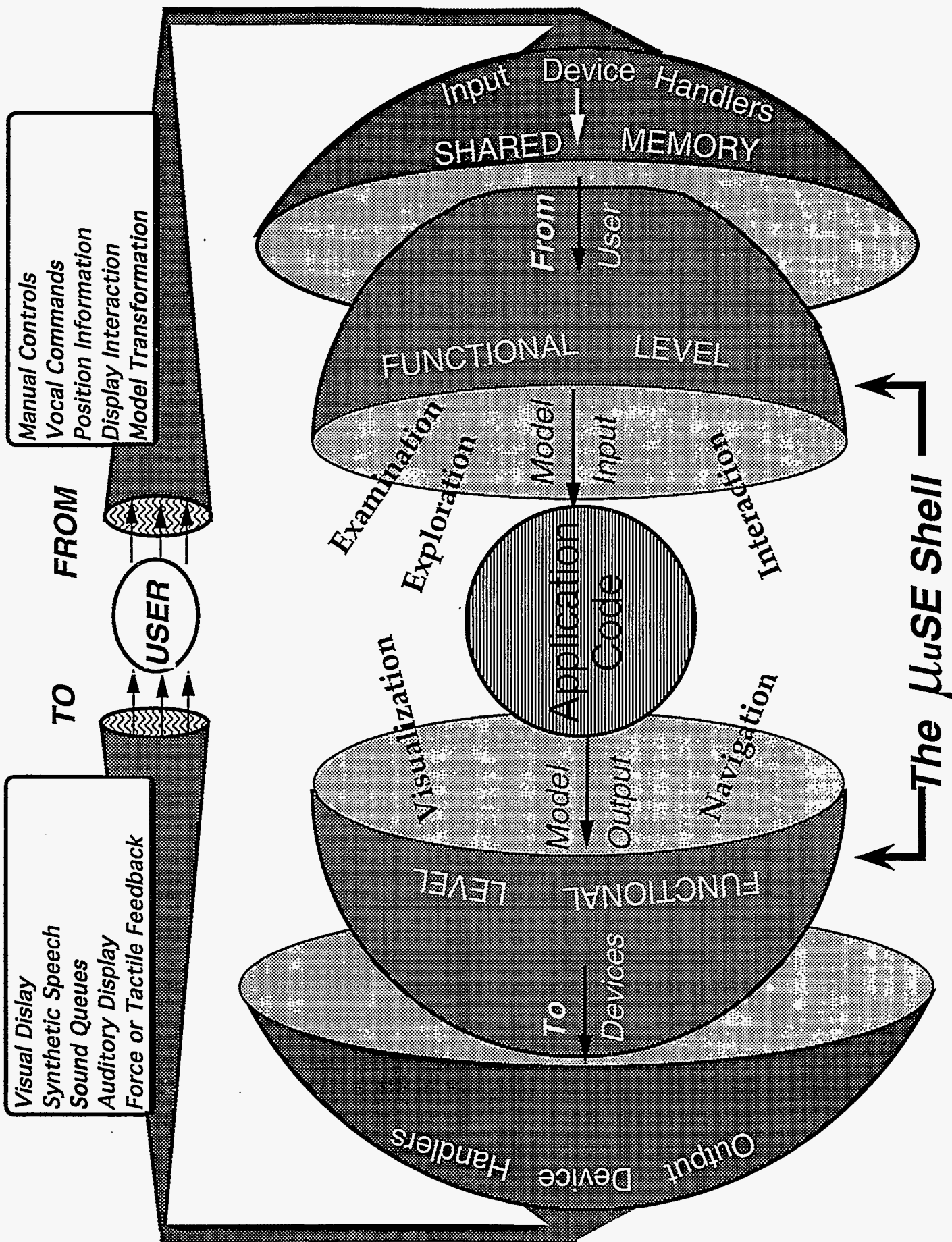
Methods for maintaining location and reference within representations.

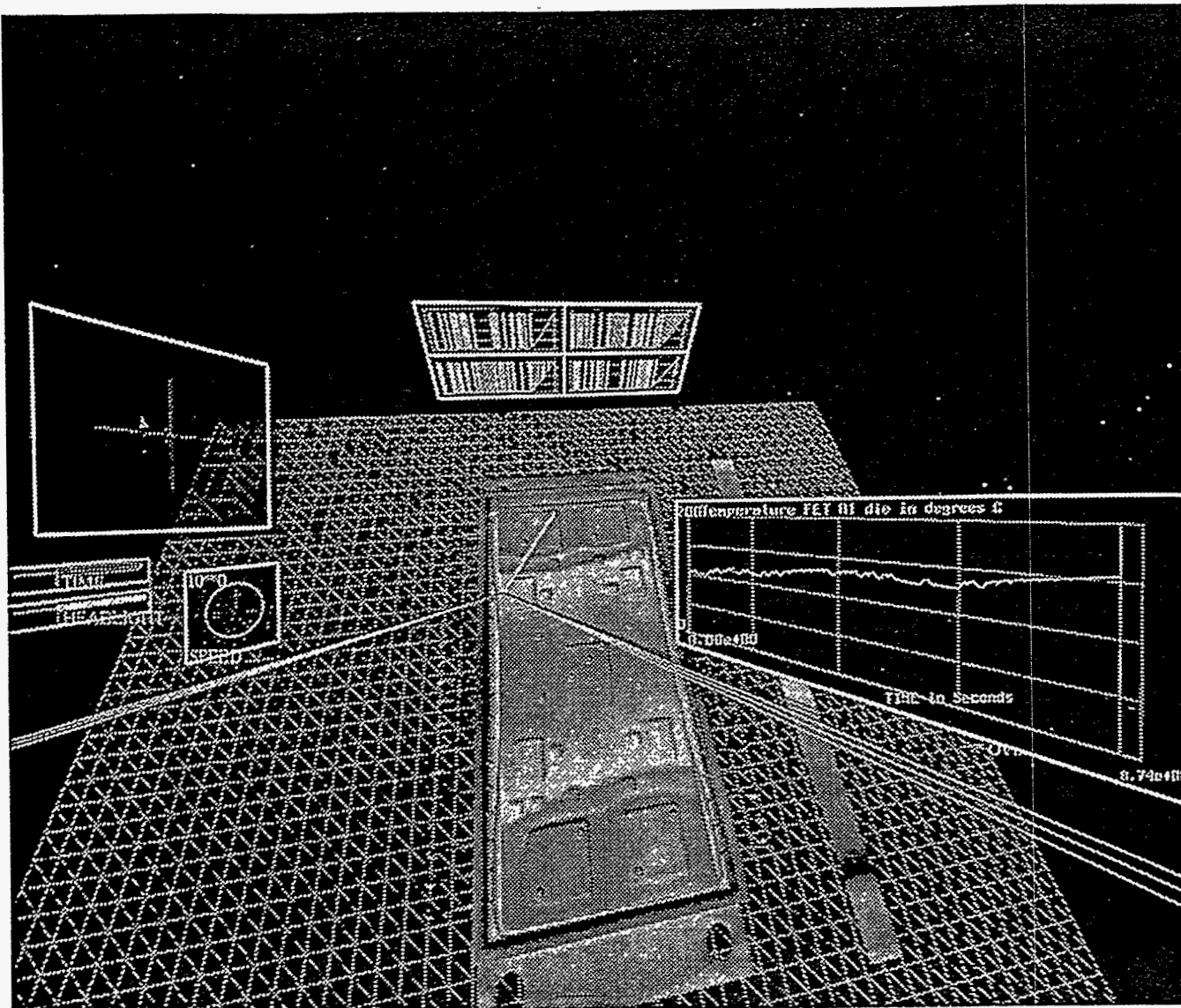
MANIPULATION

Control mechanisms for interacting with displays and information.

EXAMINATION

Control mechanisms for interacting with displays and information.



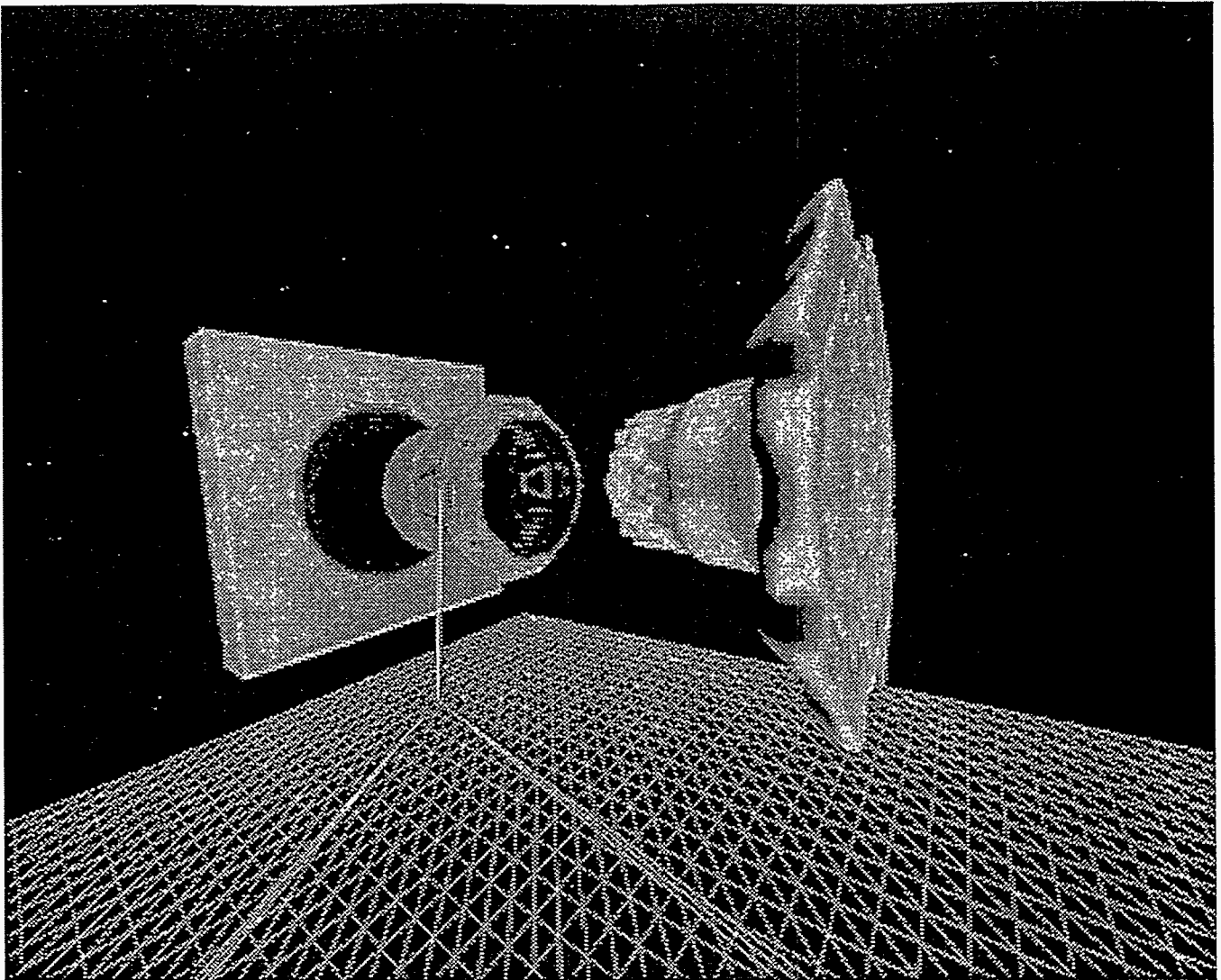


Operation of a Multichip Module

APPLICATIONS: Finite element analysis; Thermal conductivity; Circuit simulation; Stress analysis; CAD models; Data sonification.

DESCRIPTION: This model integrates diverse information associated with the electrical and thermal operation of a Modular Adaptable Controller. This multichip module contains various electrical components and controls the mechanical operation of a complex maze-wheel discriminator.

The system displays CAD and finite element models, and permits any of 25 points to be probed during the operation of the chip. Data from the probes may be displayed on the craft side wall, as spatial graphs, or transformed into sound output. Time-dependent thermal information is shown as color overlays to the finite element grid. Thermal conductivity of substrates may be altered, and electrical and thermal effects examined.

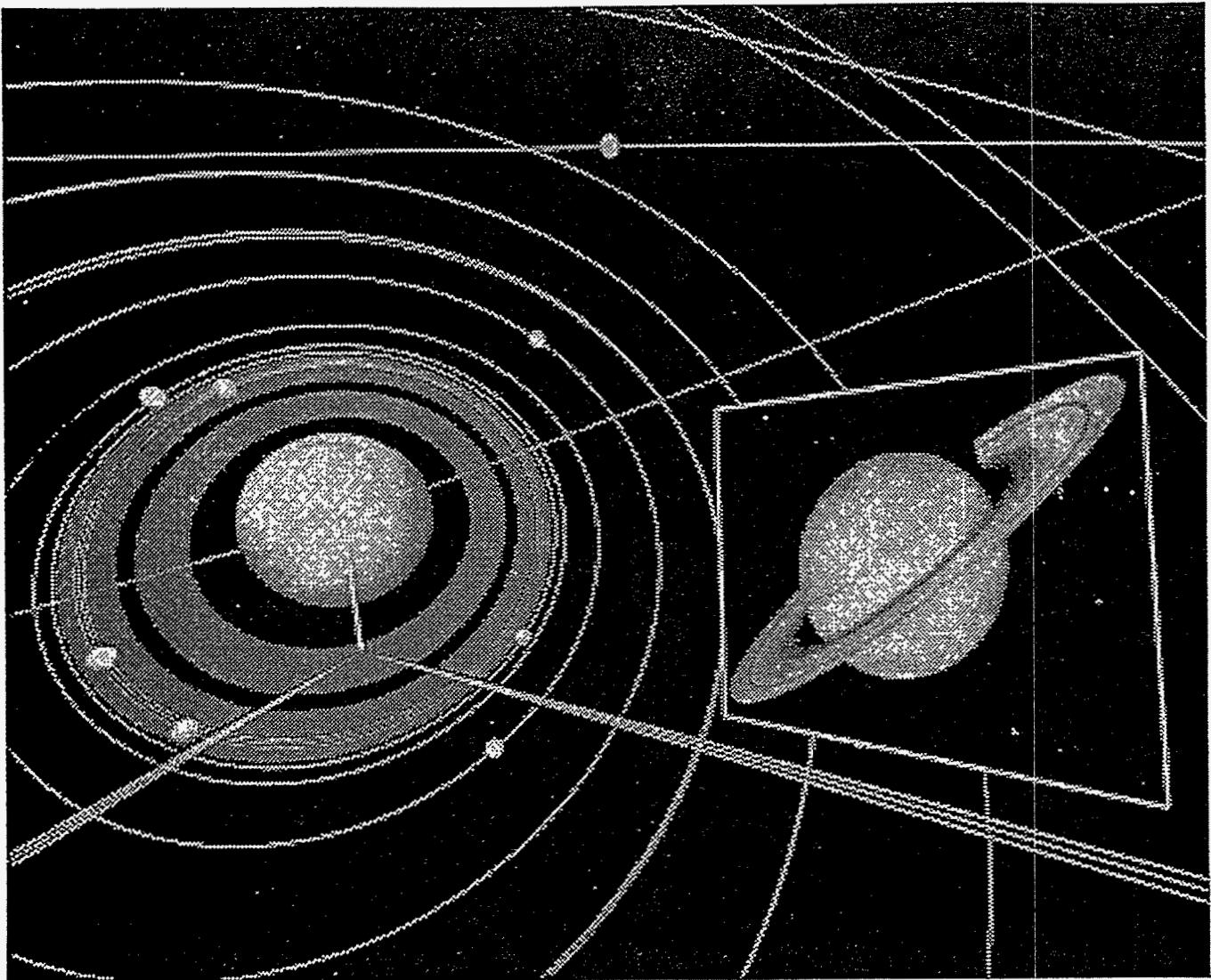


Explosive Welding

APPLICATIONS: Dynamic simulations (e.g.: stress, shock or impact analysis); Mass distribution analysis.

DESCRIPTION: The model represents a simulation of an attempt to simultaneously weld and force-fit a copper pipe to a beveled steel plate by setting off an explosive charge in the pipe. The simulation was run using the Parallel CTH code on the Paragon Super-computer in 95 time steps.

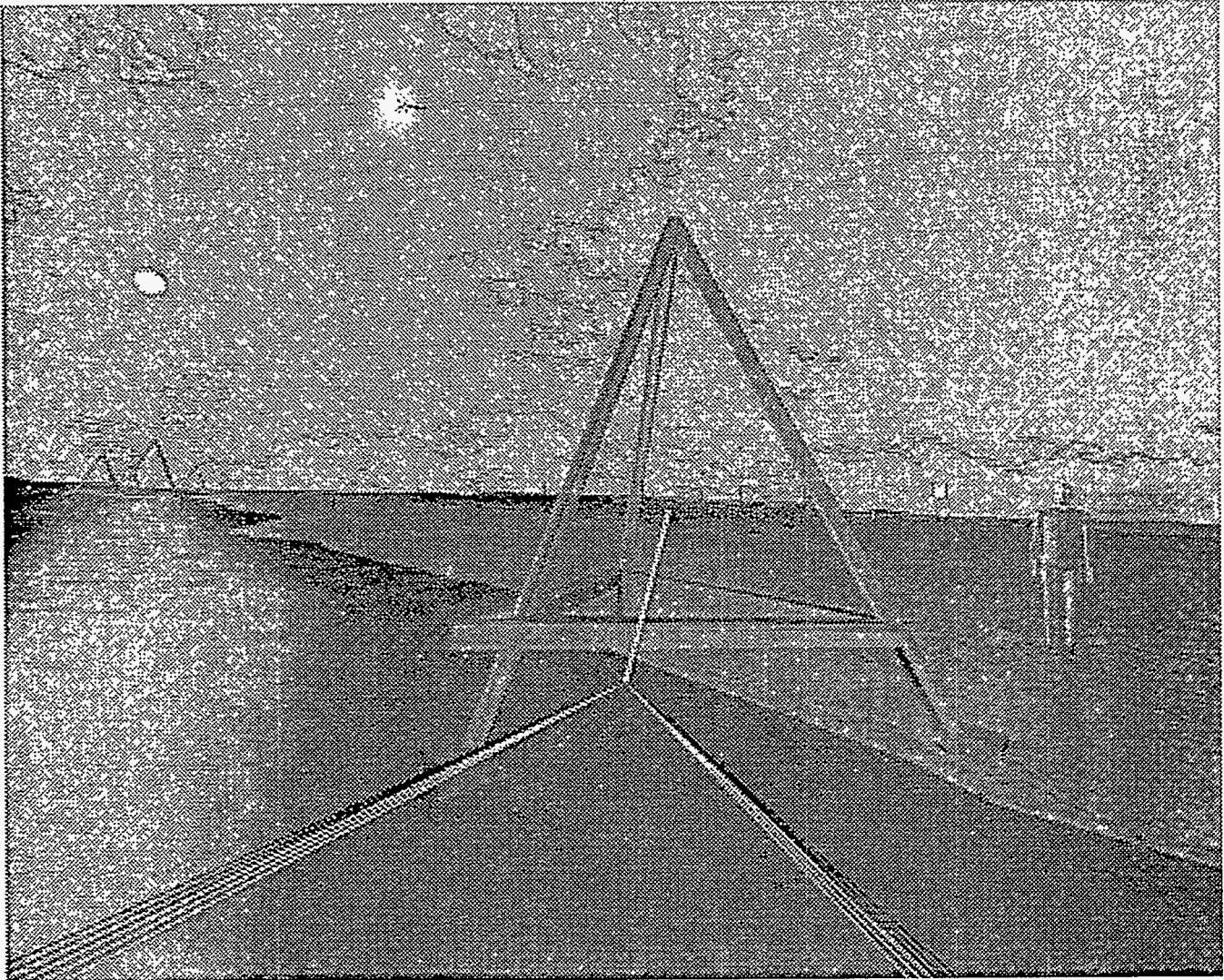
Spatial and temporal teleportation to specific marked locations, coupled with the ability to manipulate dynamically changing data sets, permits detailed examination of the welding process and its effect on materials.



Dynamic Solar System

APPLICATIONS: Time-dependent models; Fusion of different types of correlated information (e.g., pictures, trajectories); Real-time interaction with dynamic models.

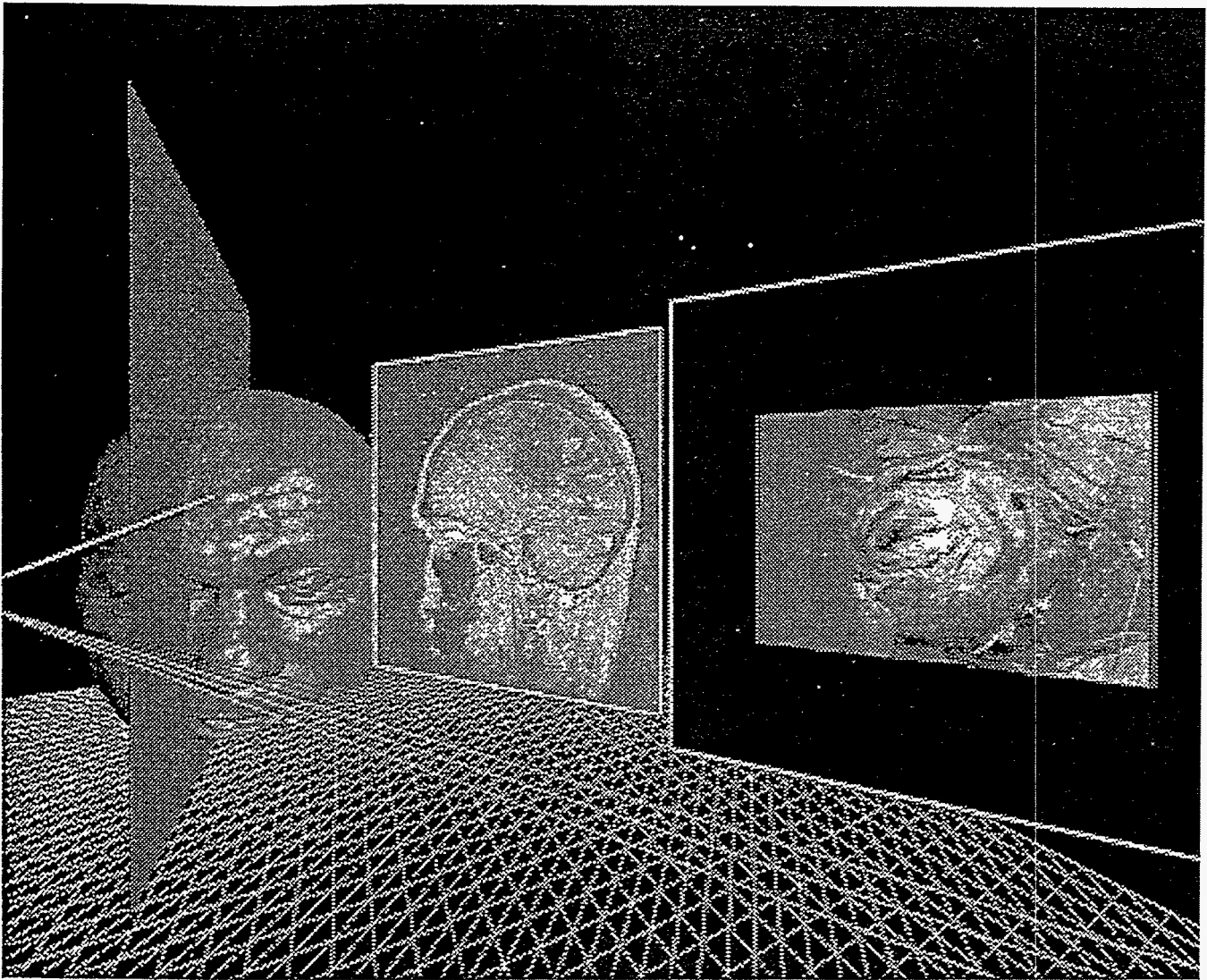
DESCRIPTION: The scale model of the solar system covers a spatial range of 1010 km with an individual positioning resolution of ~20km. It contains 73 objects, each with appropriate motion. Tethering or locking permits a viewer to attach to an object and travel with it, duplicating all or part (e.g., center of mass) of its inertial motion while retaining the ability to move independently. Here, tethering also triggers a search of available NASA data. Photographs and associated text information are displayed on the craft wall while tethered.



Environmental Evaluation

APPLICATIONS: Transportation, Construction, Planning, Architecture, Training, Environmental impact, Command and Control, Tactical and strategic analysis.

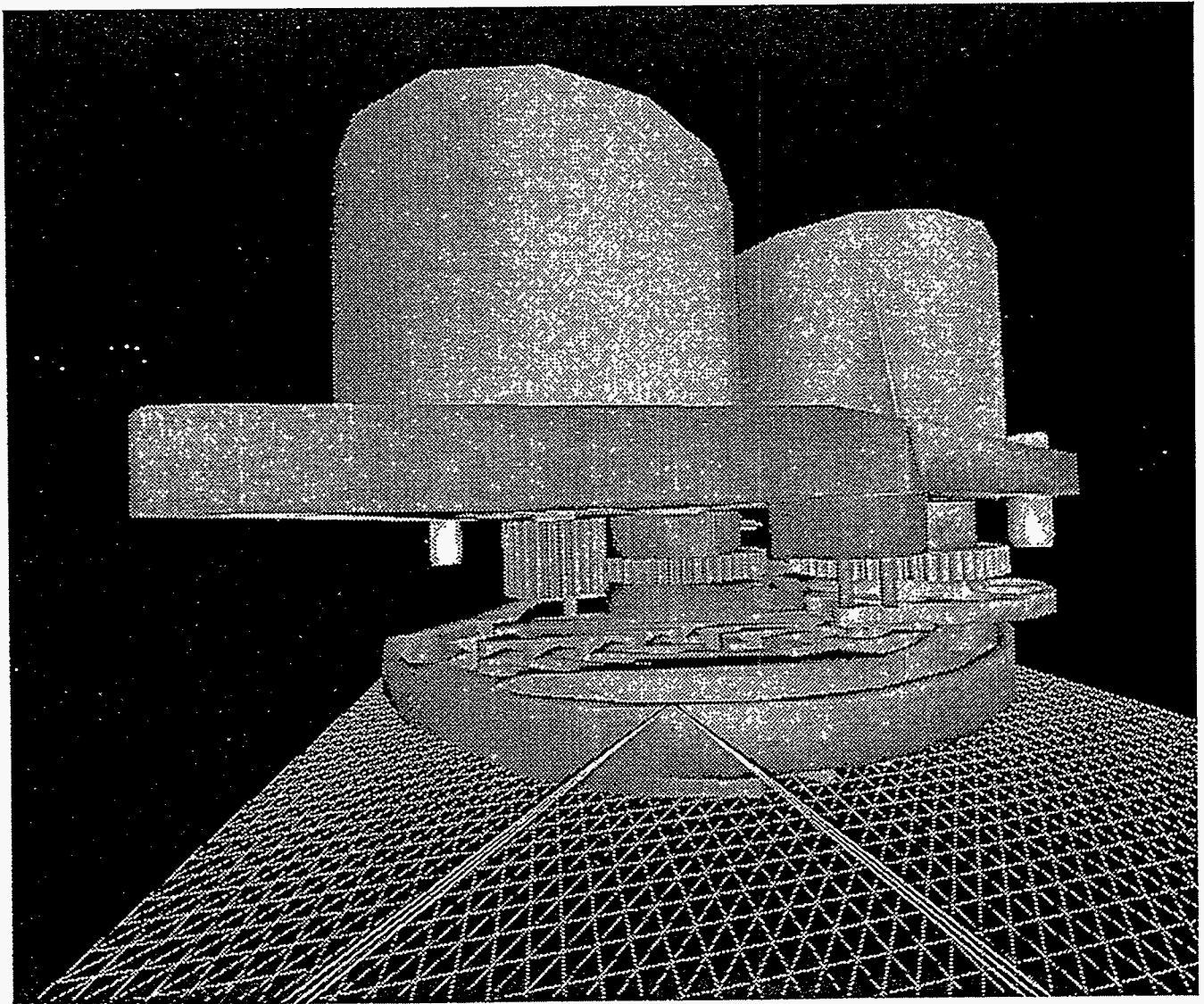
DESCRIPTION: Topographic, geometric, photographic, and observational information was combined to recreate a section of an actual beach over a three month period. The reconstruction included the dynamic lighting variation, actual weather and surf conditions, and changes in terrain and structures due to climate effects. The user has complete freedom of movement through both time and/or space, either by moving location and controlling the rate of time, or by teleporting to different spacial and temporal locations set by the viewer. A user can rapidly assess and evaluate the complete situation, and make informed decisions and plans that take all the various factors into account. The MuSE system was used both by the designers to actually construct this model, as well as by users to interact with it.



MRI Scan and Related Patient Data

APPLICATIONS: Medical imaging; Complex data evaluation; Analysis of 3-D volumetric data; Operation planning; Structural analysis

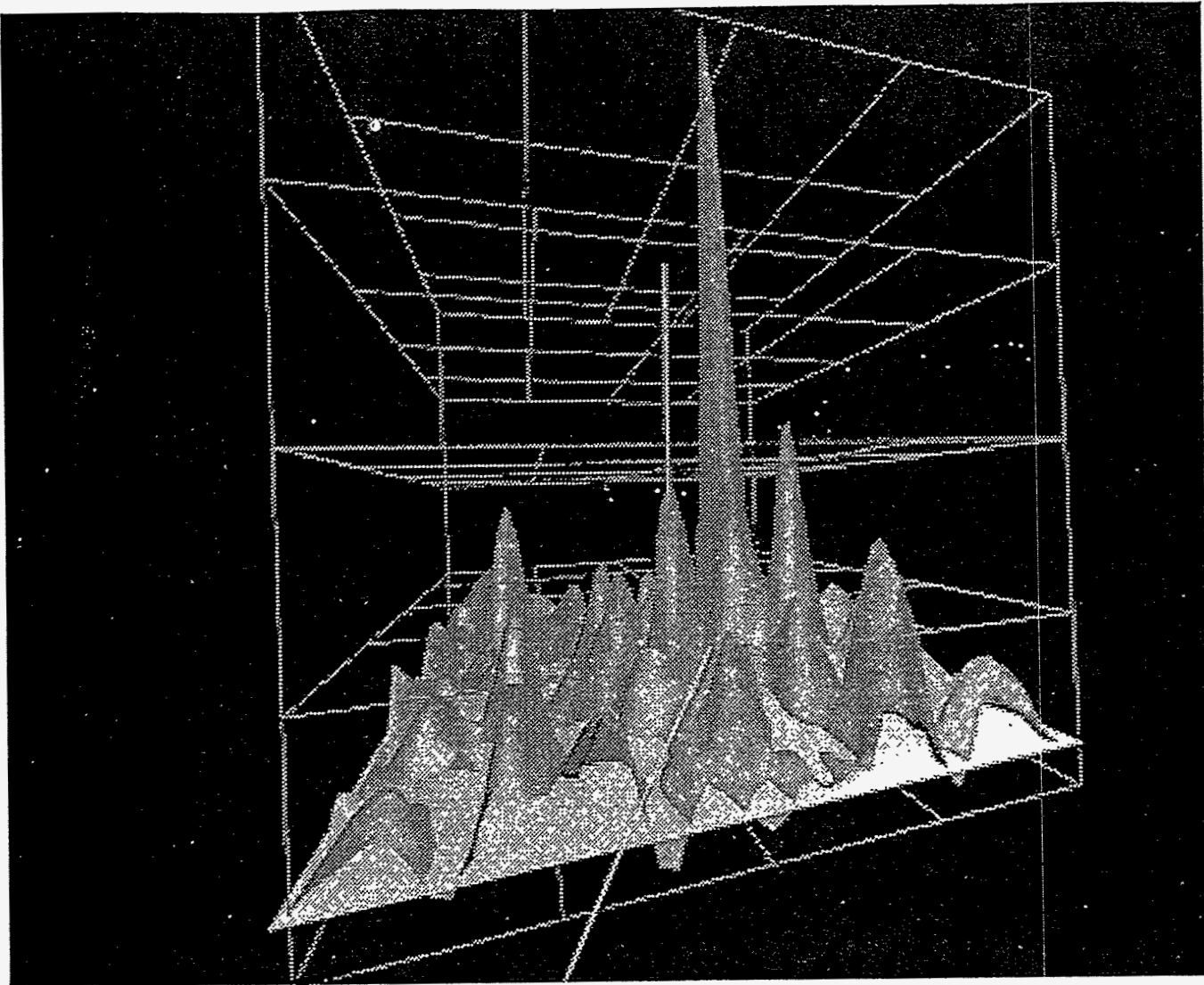
DESCRIPTION: Model is based on 128 MRI cranial scans. A dynamic cutting plane may be invoked to project cross sections on the wall of the craft. Additional patient information (e.g. actual photographs, test result) can be accessed as needed on the craft wall, or selectively mapped into sound (e.g. systolic pressure, heart rate, respiration rate, temperature).



CAD Analysis and Operation

APPLICATIONS: Design analysis and verification; Component integration; Training.

DESCRIPTION: A synthetic working model of a complex electromechanical maze-wheel discriminator, designed and built at Sandia National Laboratories. MuSE integrates CAD information with functional kinematic calculations from commercial software. The actual device is approximately 2" x 1" x 2". MuSE permits the user to vary size ratios to explore the internal operation of the system. Users can control the speed and direction of time, manipulate components, examine subsystems, and disassemble the model, all while the motor is running. Cutting planes permit cross-sectional views during operation and side displays can access schematics or test result information.

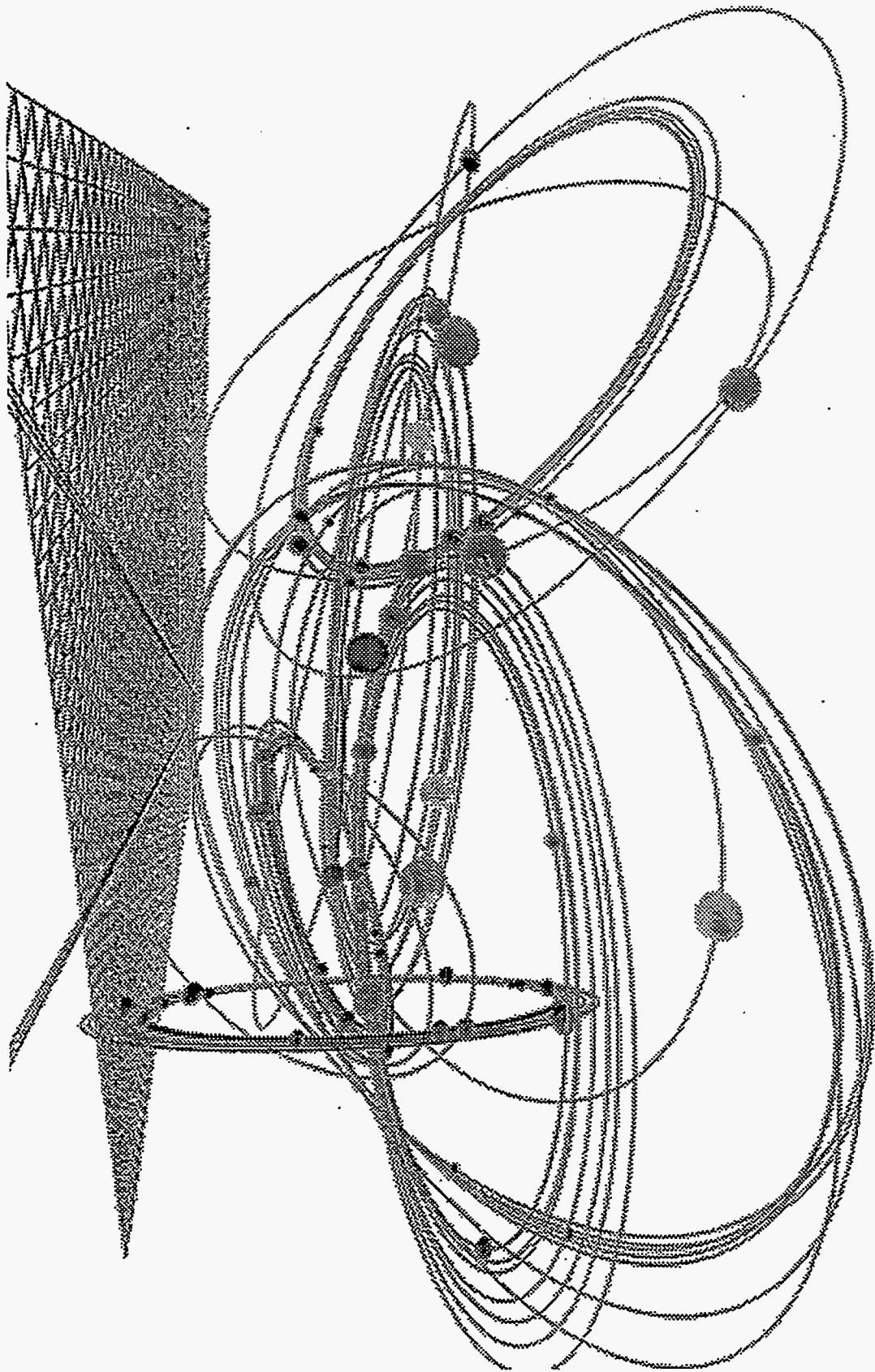


Seismic Information

APPLICATIONS: Investigation and evaluation of financial, economic, statistical or scientific data.

DESCRIPTION: Information was obtained from the ARCESS seismic detector array in Norway. The data is based on a fusion of individual detector information distributed over a roughly 1 km square area. The sensor information is transformed into time-dependent frequency wave number (F_k) data. The display shows the amplitude of seismic events. The location of a peak in this display is related to the direction and velocity of the approaching seismic wave. Interacting with this time-varying information in a synthetic environment enhances the ability to understand and separate independent seismic events which occur at different locations but are closely spaced in time.

The same technique can be applied to other numeric information, allowing a rapid evaluation of financial, economic, statistical, or scientific data.







LESSON # 1

**TO BE SUCCESSFUL IN A FIELD
REQUIRES THAT 90%
of all waking efforts
BE DEVOTED to the PURSUIT
of that field!**

COROLLARY # 1

*It helps enormously, however,
if you can convince others to
buy-in to your potential success
and devote 90% of their time
to helping you achieve it !*

LESSON # 2

**THE AMOUNT OF MONEY ONE
MAKES IS IMMATERIAL!**

**Since expenses increase
in proportion to income,
DISPOSABLE INCOME REMAINS
RELATIVELY CONSTANT.**

COROLLARY # 2

*Indentured servitude is viable,
if people can be convinced to
voluntarily accept it!*

LESSON # 3

Devoting a portion of one's life to
HELPING the LESS ADVANTAGED,
is important to society, and is a
WORTHWHILE UNDERTAKING!

COROLLARY # 3

*This lesson may conflict with Lesson # 1.
The conflict may be resolved, however,
by convincing others to devote
their time to bettering society
under your sponsorship !*

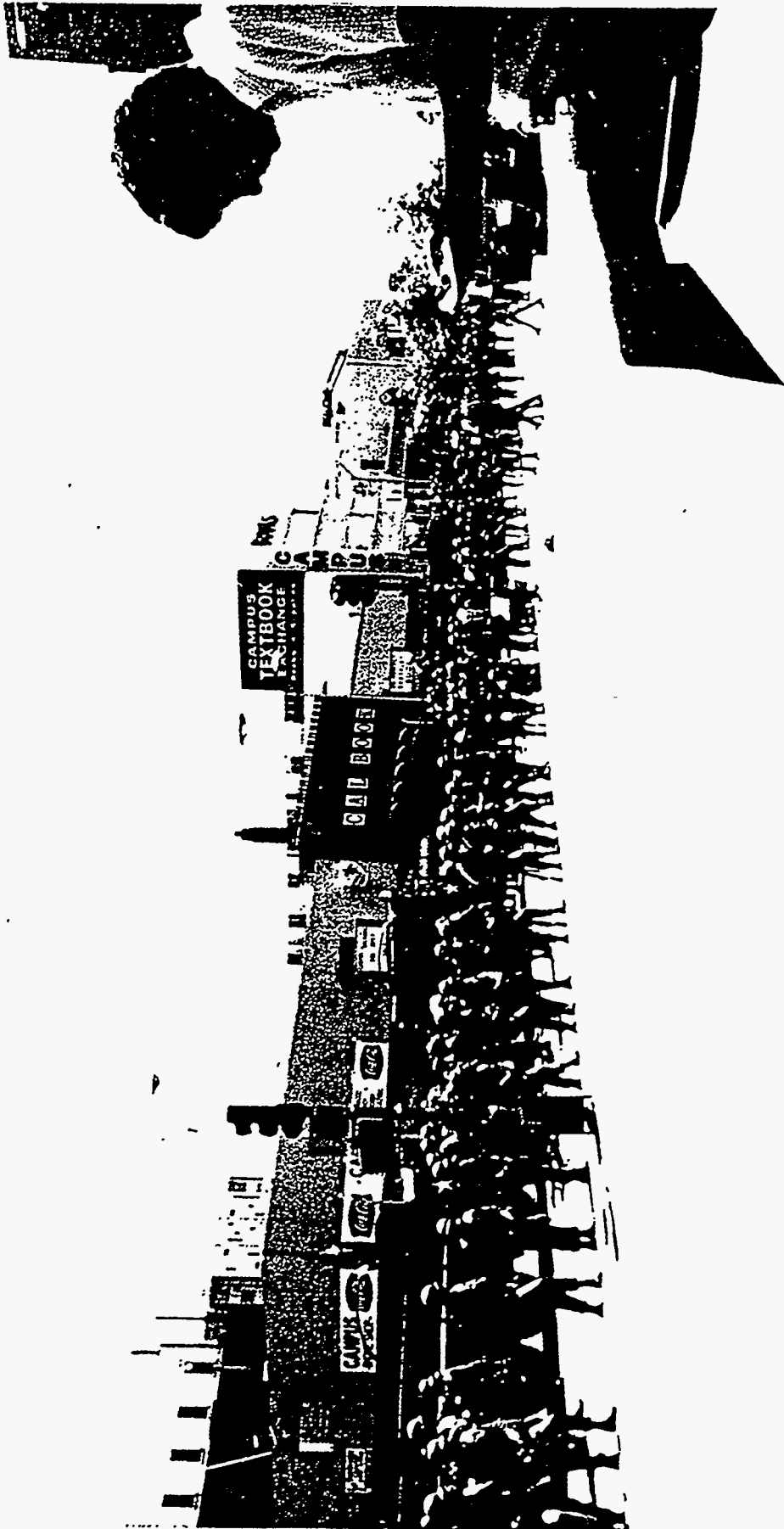
LESSON # 4

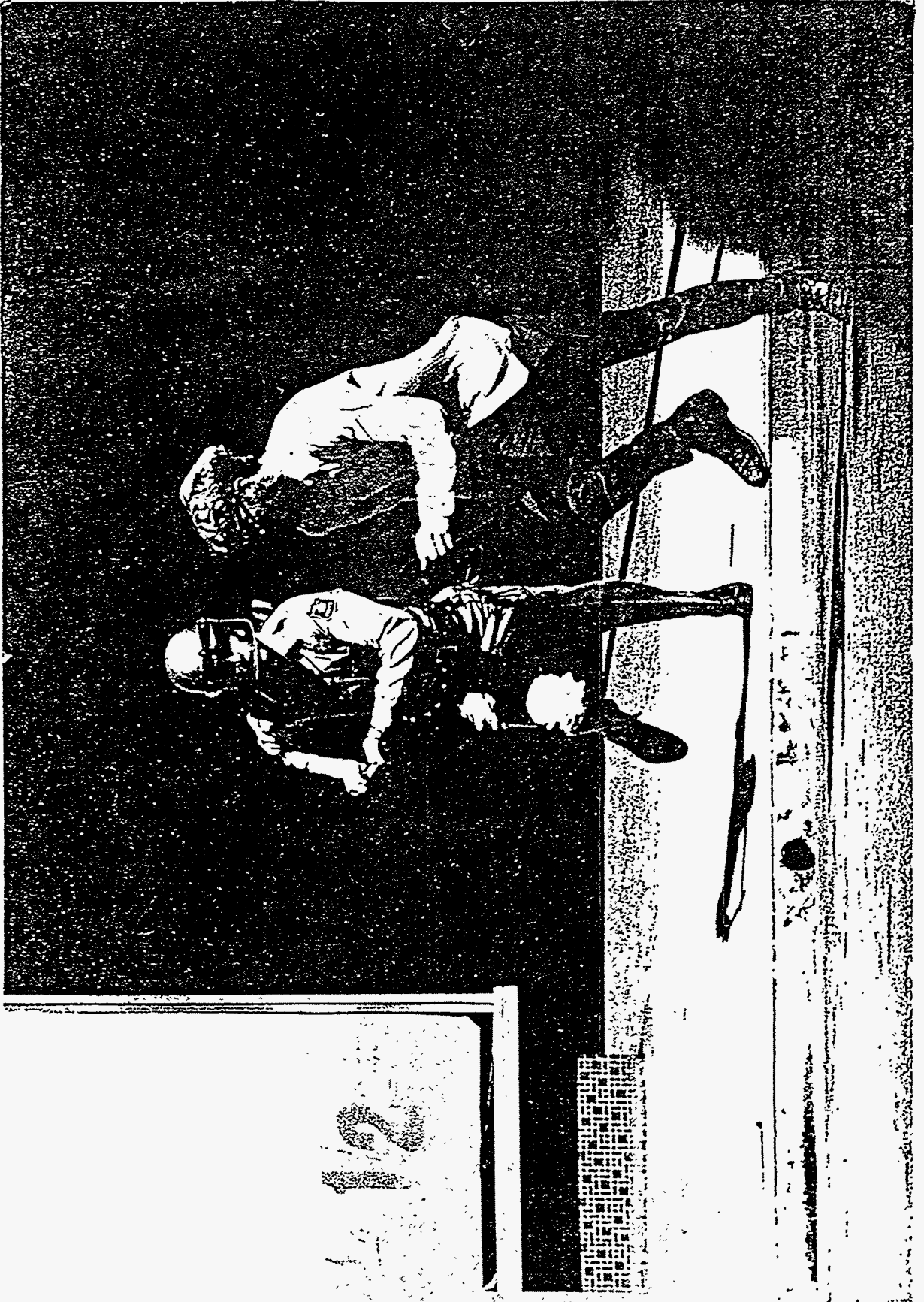
SUCCESS REQUIRES A
CLEARLY DEFINED OBJECTIVE
and the
PATIENCE and PERSISTENCE TO
STICK WITH IT !

COROLLARY # 4

IT IS NOT NECESSARY TO SHARE
YOUR REAL OBJECTIVE WITH
OTHERS,

*They are free to draw their own
conclusions !*



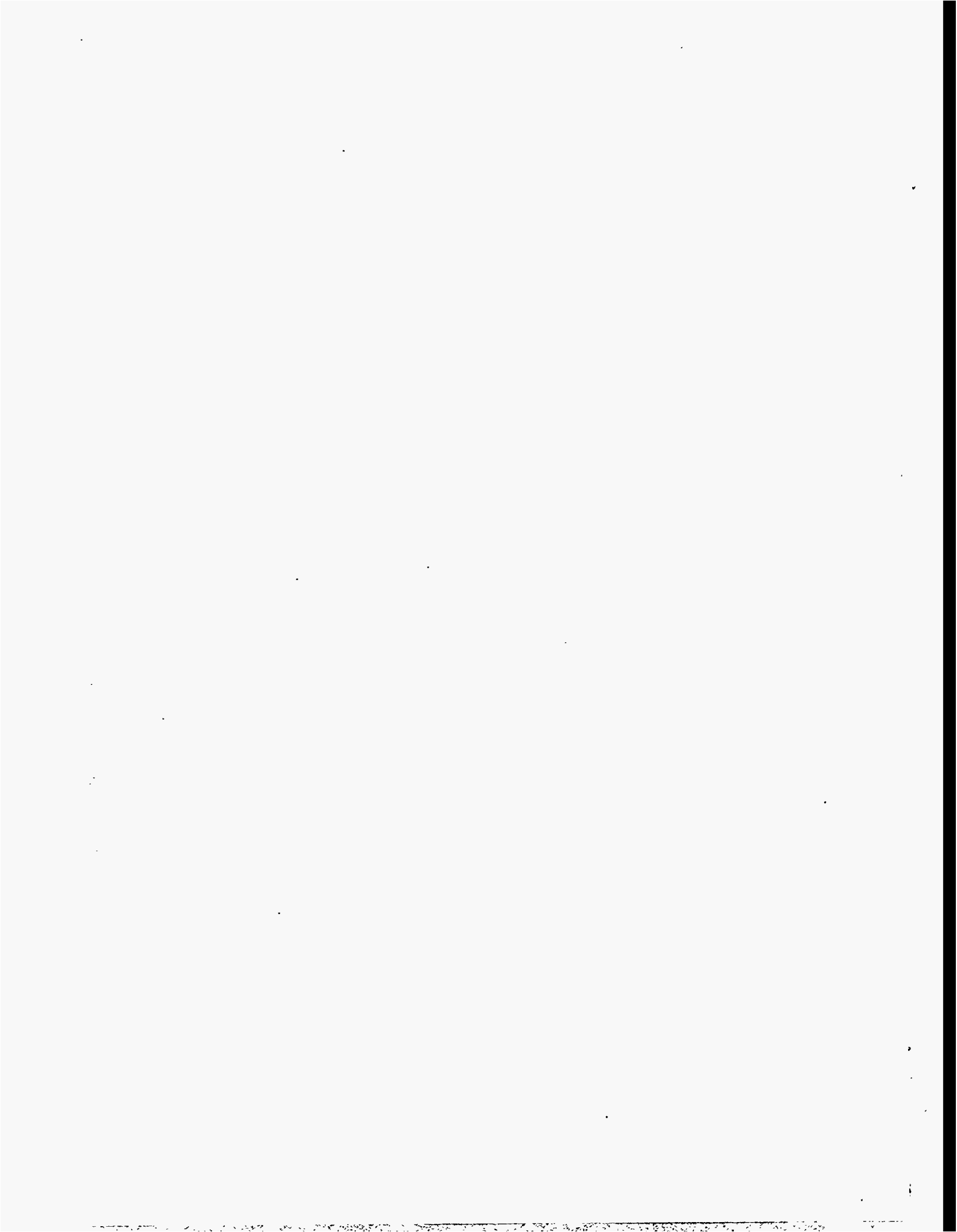




CHAOS – Where Brilliant Dreams are Born™ – I CHING IMAGE™, image #3

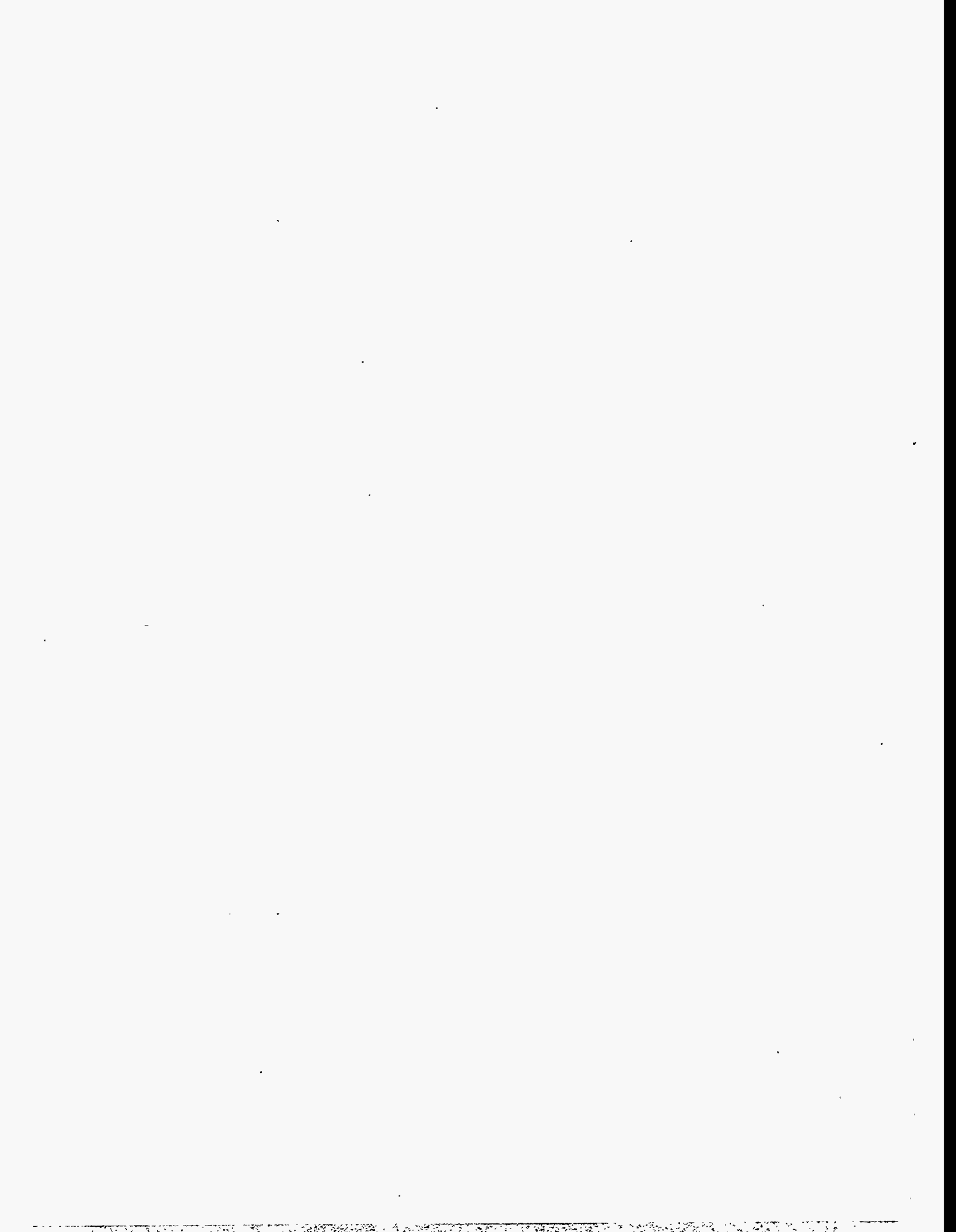
Before the beginning of great brilliance, there must be Chaos.

Before a brilliant person begins something great, s/he must look foolish to the crowd.



Mike Cable

Lawrence Livermore National Laboratory
Livermore, CA



Nuclear Measurement Techniques for Inertial Confinement Fusion*



Michael D. Cable
NIF Diagnostics
Development Group

University of California



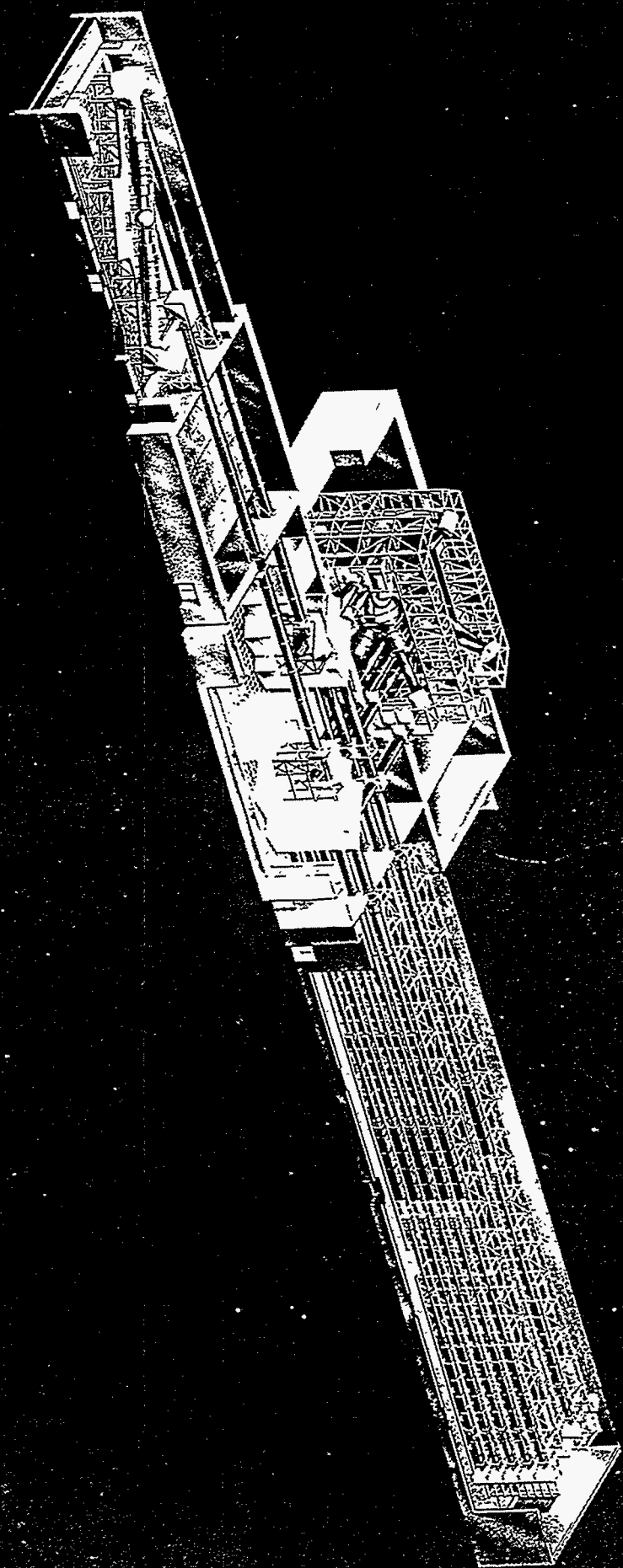
Lawrence Livermore
National Laboratory

Exotic Nuclei Symposium

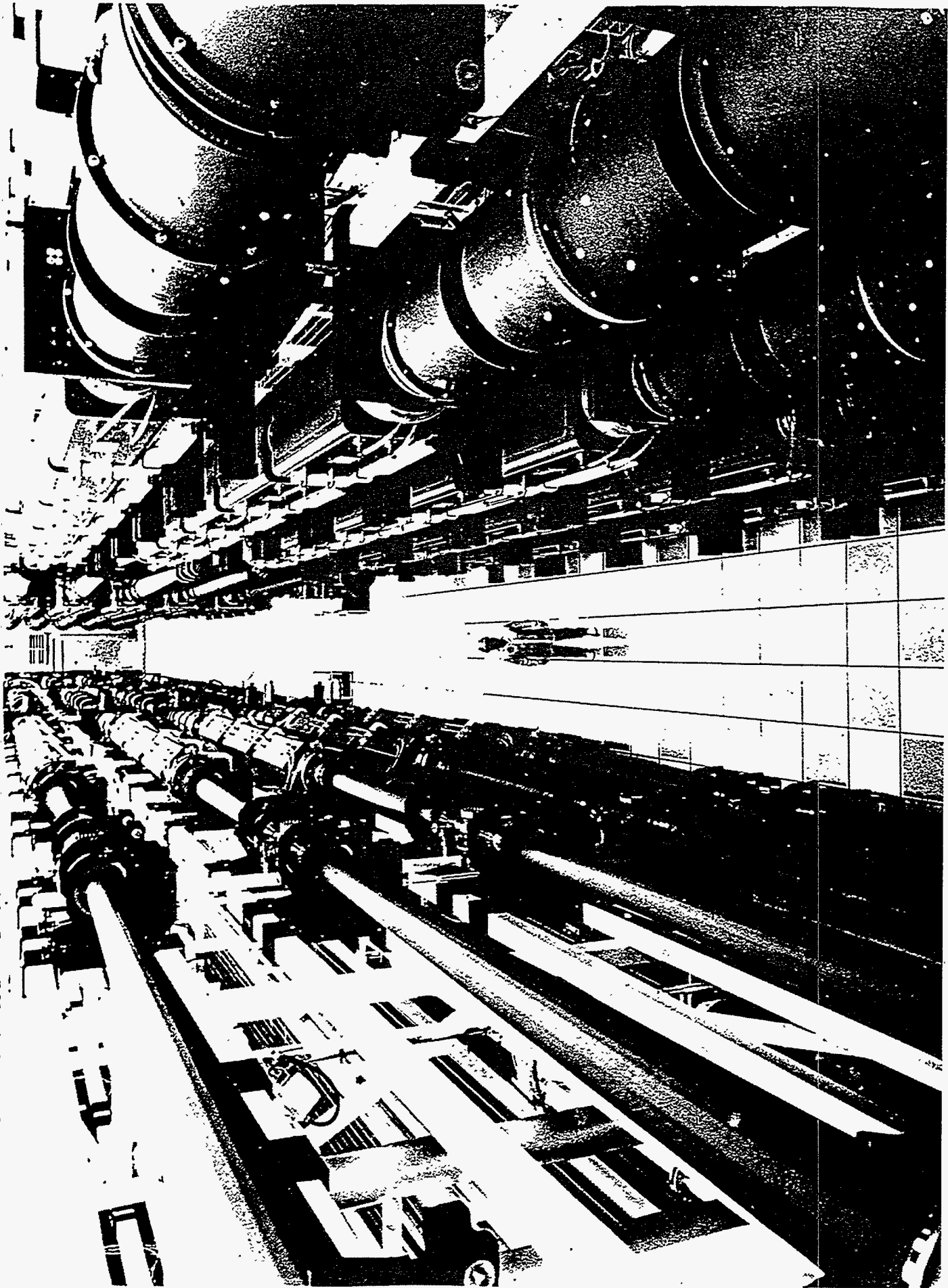
Bodega Bay, CA
April 14-16, 1996

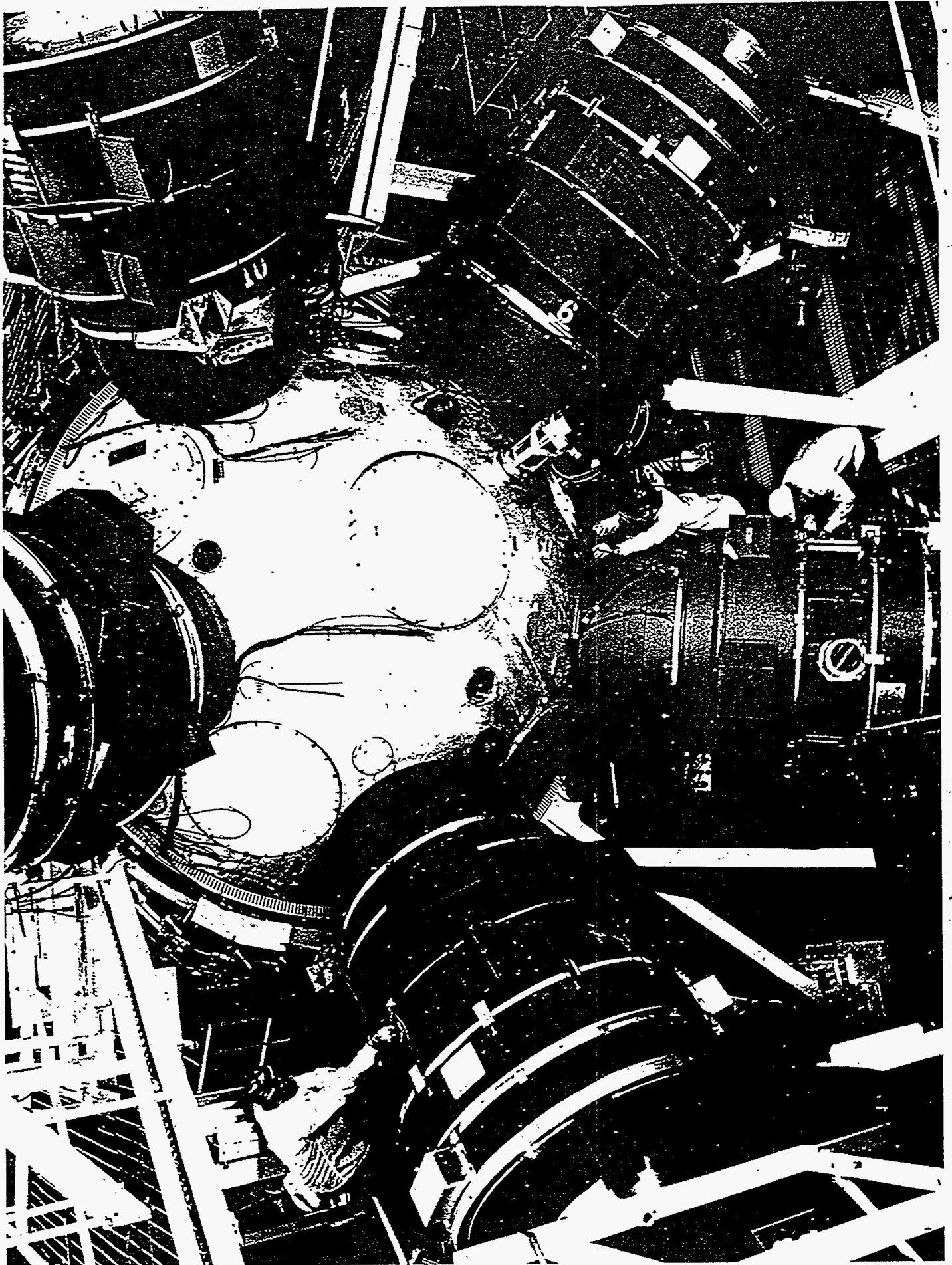
***This work was performed under the auspices of the U.S. Department of Energy
by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.**

Nova System

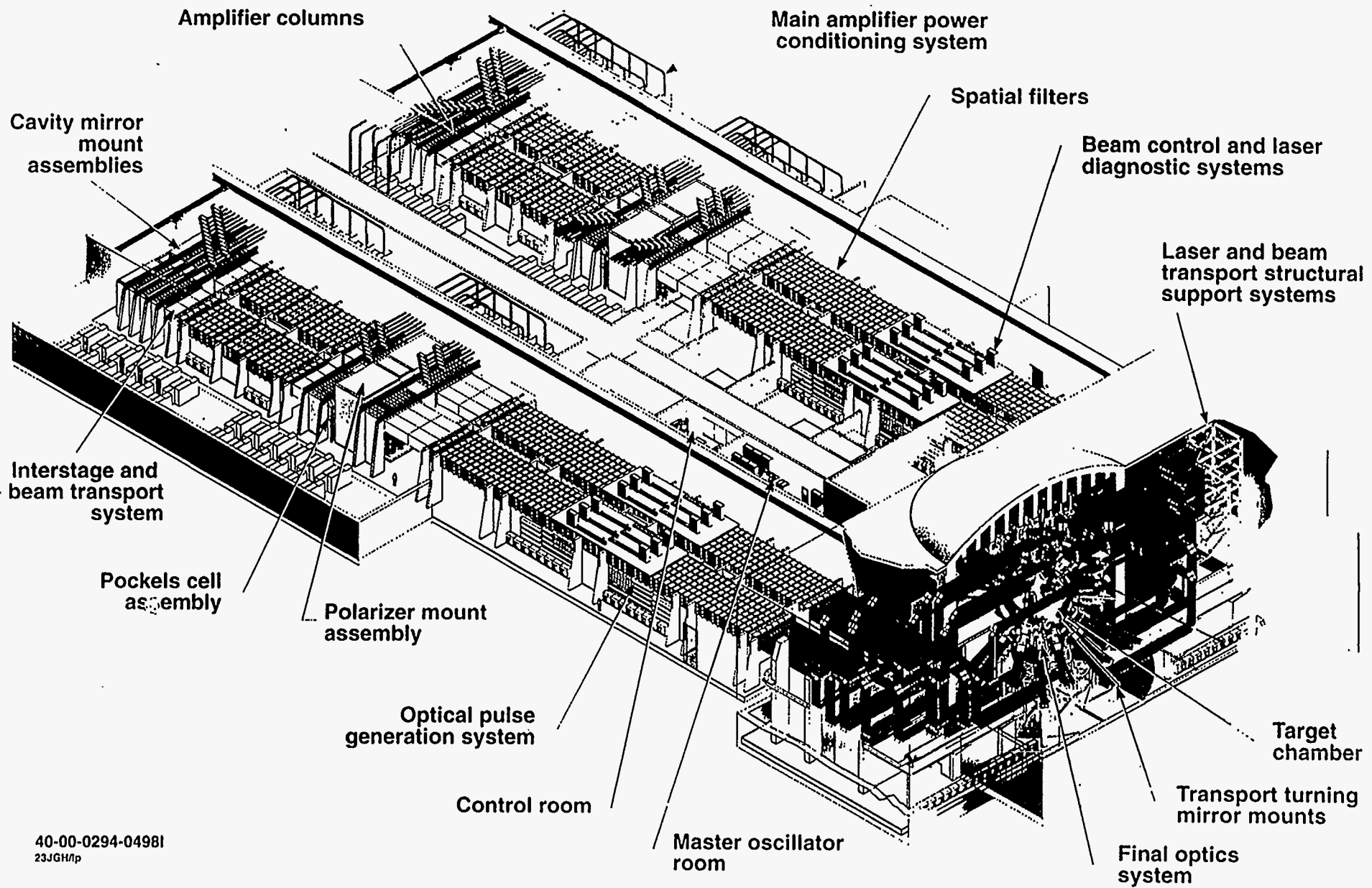


02-31-0385-1279





The National Ignition Facility—192 Beam

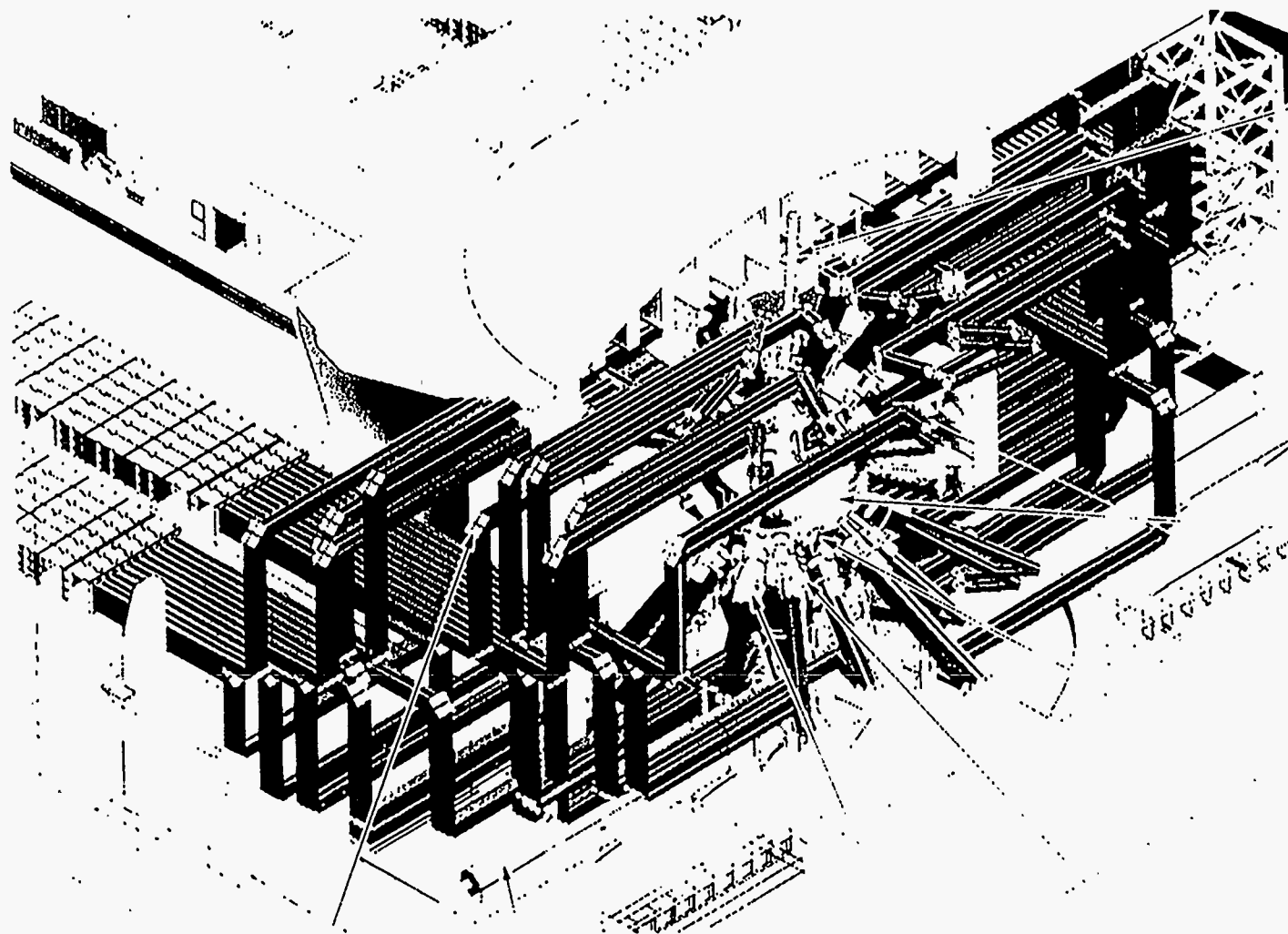


40-00-0294-04981
23JGH/p

The National Ignition Facility target area

NIF

The National Ignition Facility



Static x-ray chamber

Mirror support structure

Target chamber

Vacuum pump

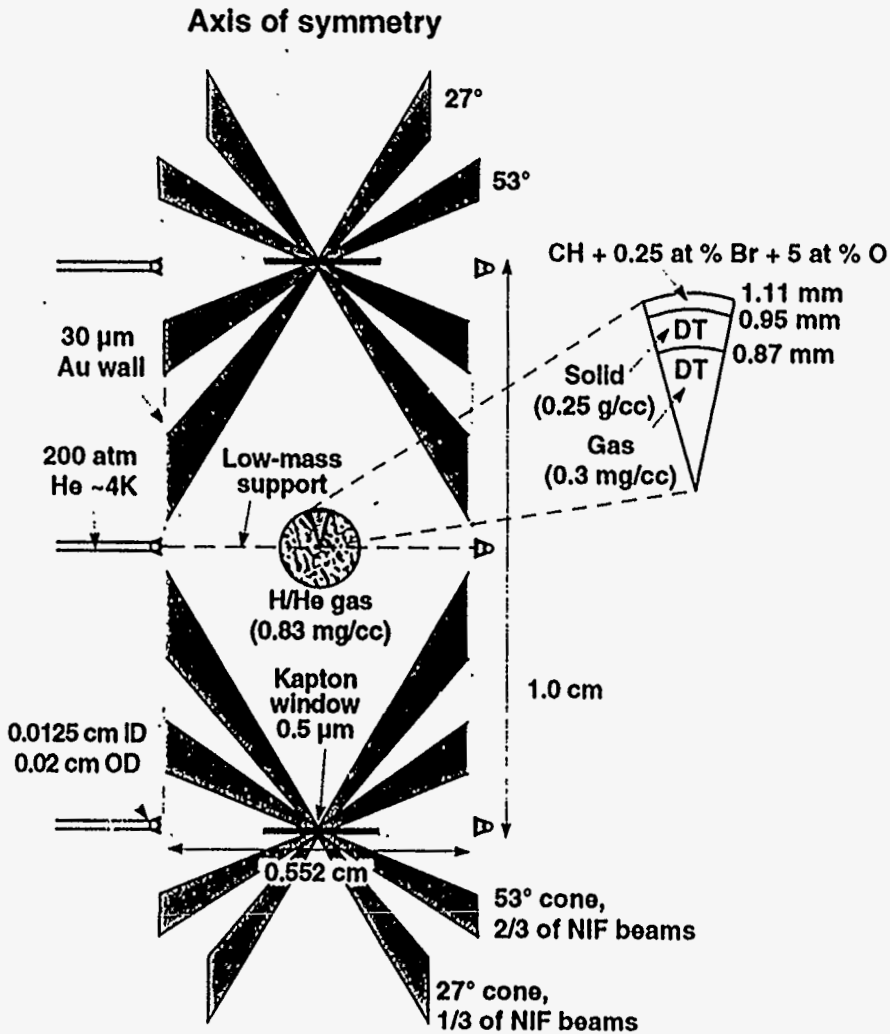
Turning mirror assembly

Target plane diagnostic station

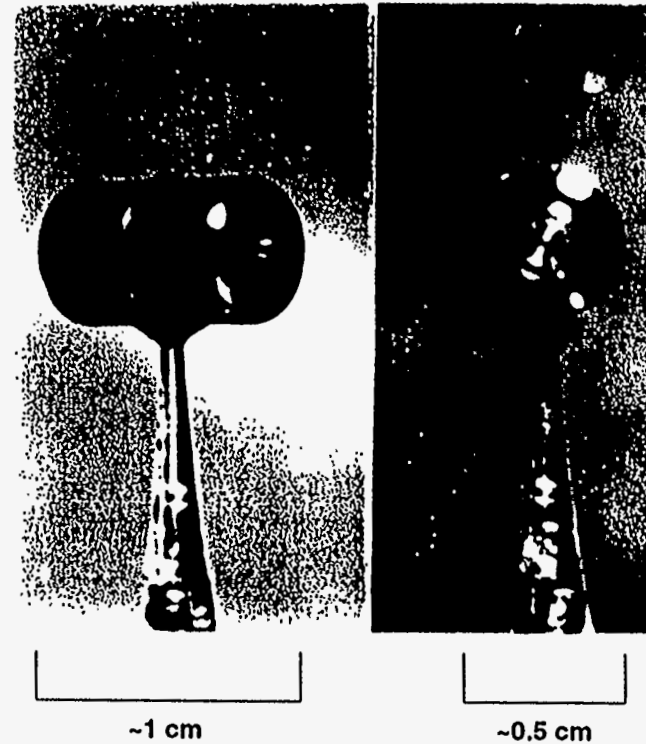
Final optics assembly

Twelve-inch manipulator

NIF beam number and orientation (>192) meets implosion symmetry requirements for baseline target design



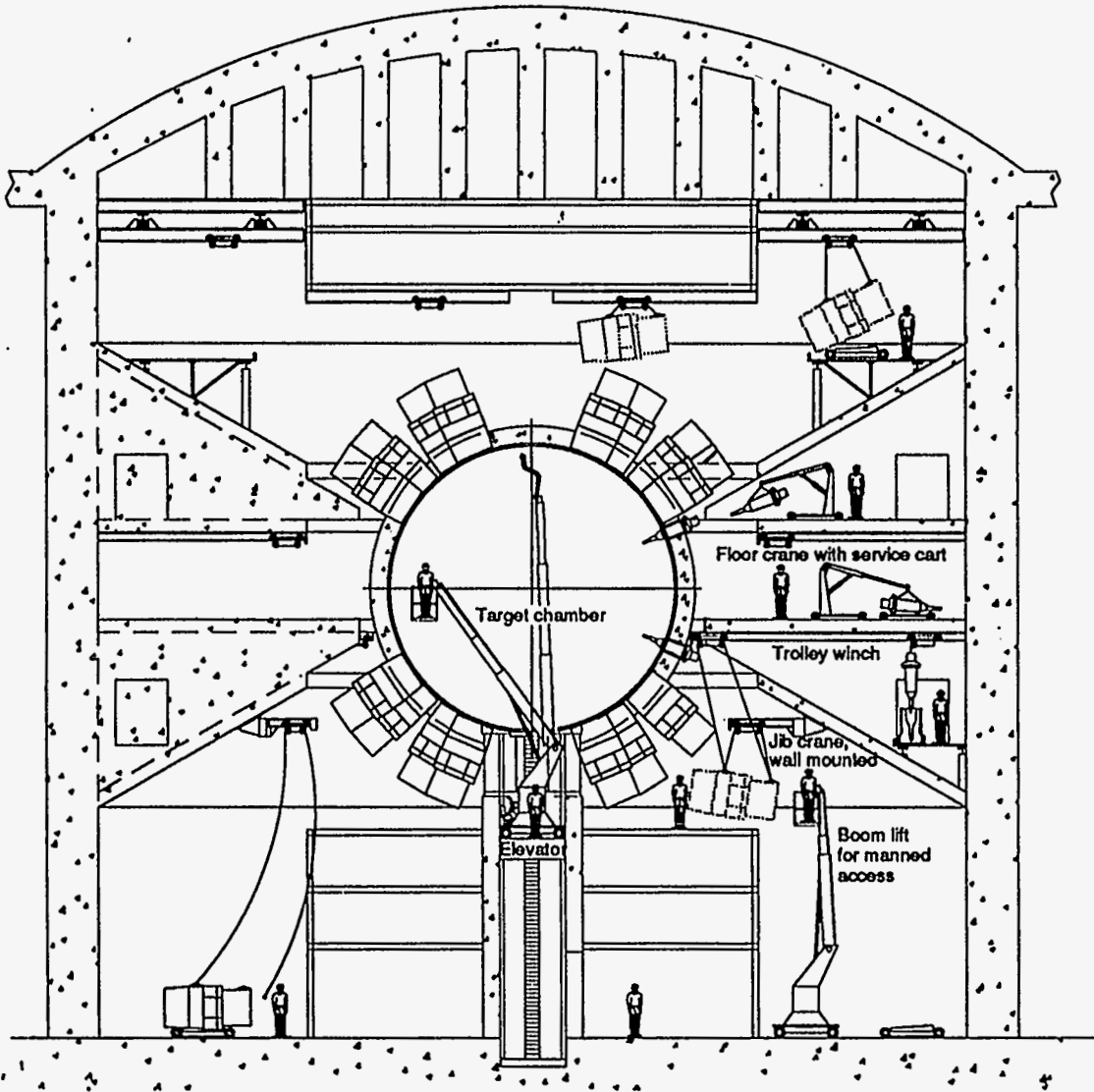
Representative NIF target



The target area is configured for accessibility and ease of maintenance

NIF

The National Ignition Facility



Nuclear reaction products can be used as penetrating "probes" for the central region of large ICF implosions.

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Pros

Multi-MeV particles (particularly neutrons) can escape from the center of the implosion and carry out information about that region.

Nuclear reaction products are produced at burn time and are useful for probing the final fuel conditions - know when and where produced.

Cons

Early stages of implosion (pre-burn) can't be studied since no reactions occur during this time.

Failed implosions (no burn) provide little useful information.

Relatively small number of reactions historically has been technically limiting, but this situation has changed at Nova and is expected to change even more at NIF.

Comparison of NIF and Nova

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Quantity	Nova	NIF
Laser energy on target	40 kJ	1.8 MJ
Capsule diameter	2.5 mm	9 mm
Hohlraum length	0.45 mm	1.1 mm
Implosion velocity	3.5×10^7 cm/s	4×10^7 cm/s
Convergence ratio	up to 24	25-35
Fuel areal density	20 mg/cm ²	1-2 g/cm ²
Fuel density	20 g/cm ³	800 g/cm ³
Fuel temperature	1-3 keV	5-20 keV
Confinement time	50 ps	100 ps
Neutron yield	10^{11}	10^{18}

High NIF neutron yields will make a variety of new nuclear diagnostic techniques possible.

A simple model for ICF shows some important properties to measure

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$$Y_n = n_d n_t \langle \sigma v \rangle \tau V$$

This model of a spherical fuel with uniform density and temperature burning for time, τ , illustrates how the following quantities are fundamental to an ICF implosion.

- Neutron yield** - Gives the amount of fusion energy released.
- Fuel density** - Determined by the amount of fuel compression.
- Fuel temperature** - Determines the reaction rate (along with density).
- Confinement time** - Length of burn, the τ in $n\tau$.

More detailed simulations show other interesting properties that can be measured by nuclear techniques

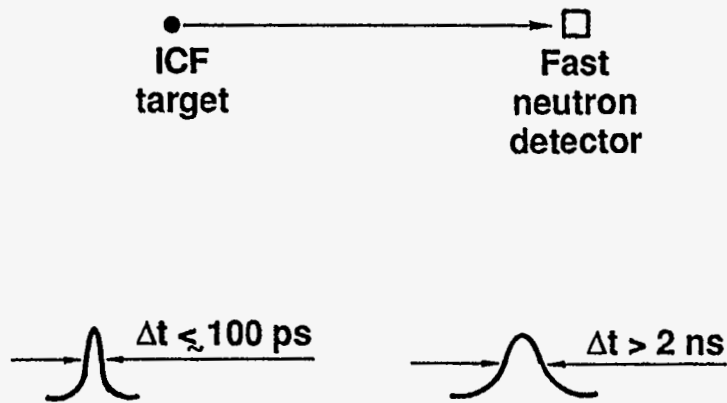
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- Fuel areal density** - Must be sufficient to stop alphas for ignition.
- Pusher density** - Useful for evaluating implosion dynamics.
- "Bang" time** - Can be compared to simulations with differing drive dynamics.
- Neutron image** - Directly shows distribution of burning fuel region.
- Charged particle slowing** - important for alpha heating.
- Mix** - Fuel and pusher mixing due to hydro dynamic instabilities.

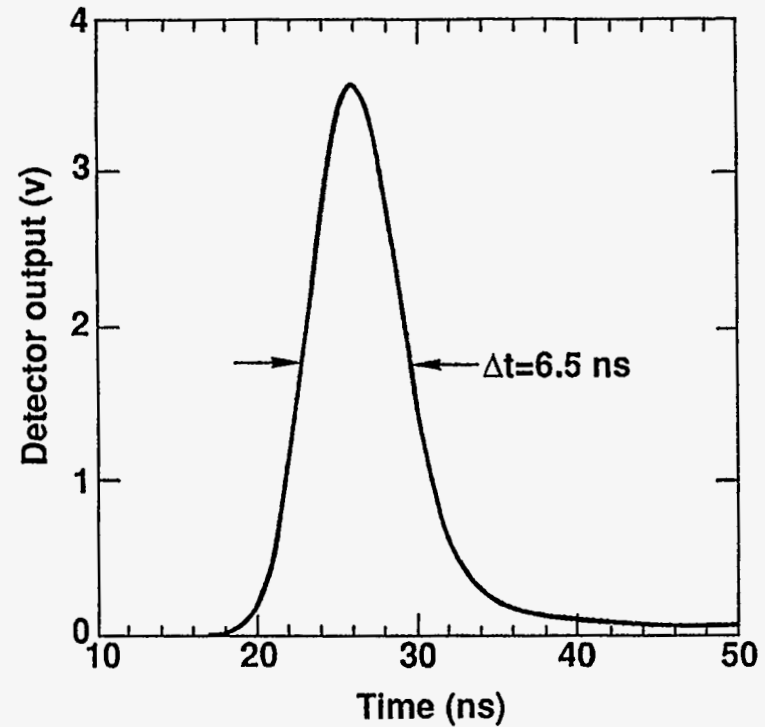
Neutron energy spectra, measured with a time-of-flight technique, are used to determine fuel ion temperature



$$\Delta E \propto \Delta t$$

$$\Delta E = 176 \sqrt{\theta_1} \quad dt \text{ n}$$

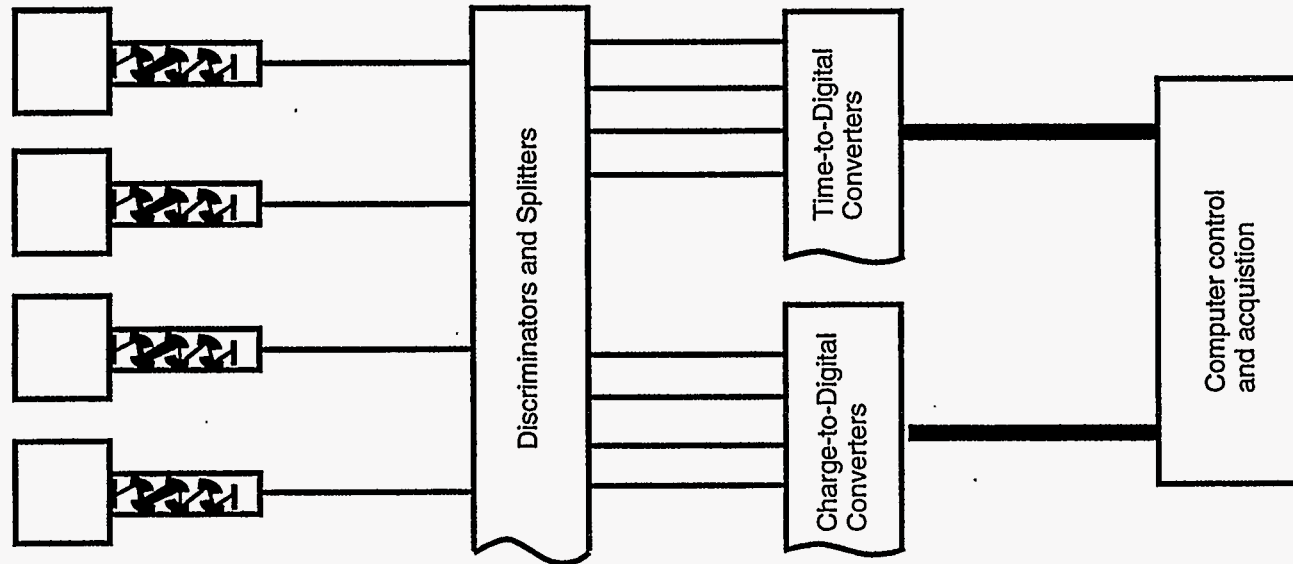
$$\Delta E = 82.4 \sqrt{\theta_1} \quad dd \text{ n}$$



Shot # 17122303

$\theta_1 = 8 \text{ keV}$

Neutron energy spectra are measured using an array of single-particle time-of-flight detectors.

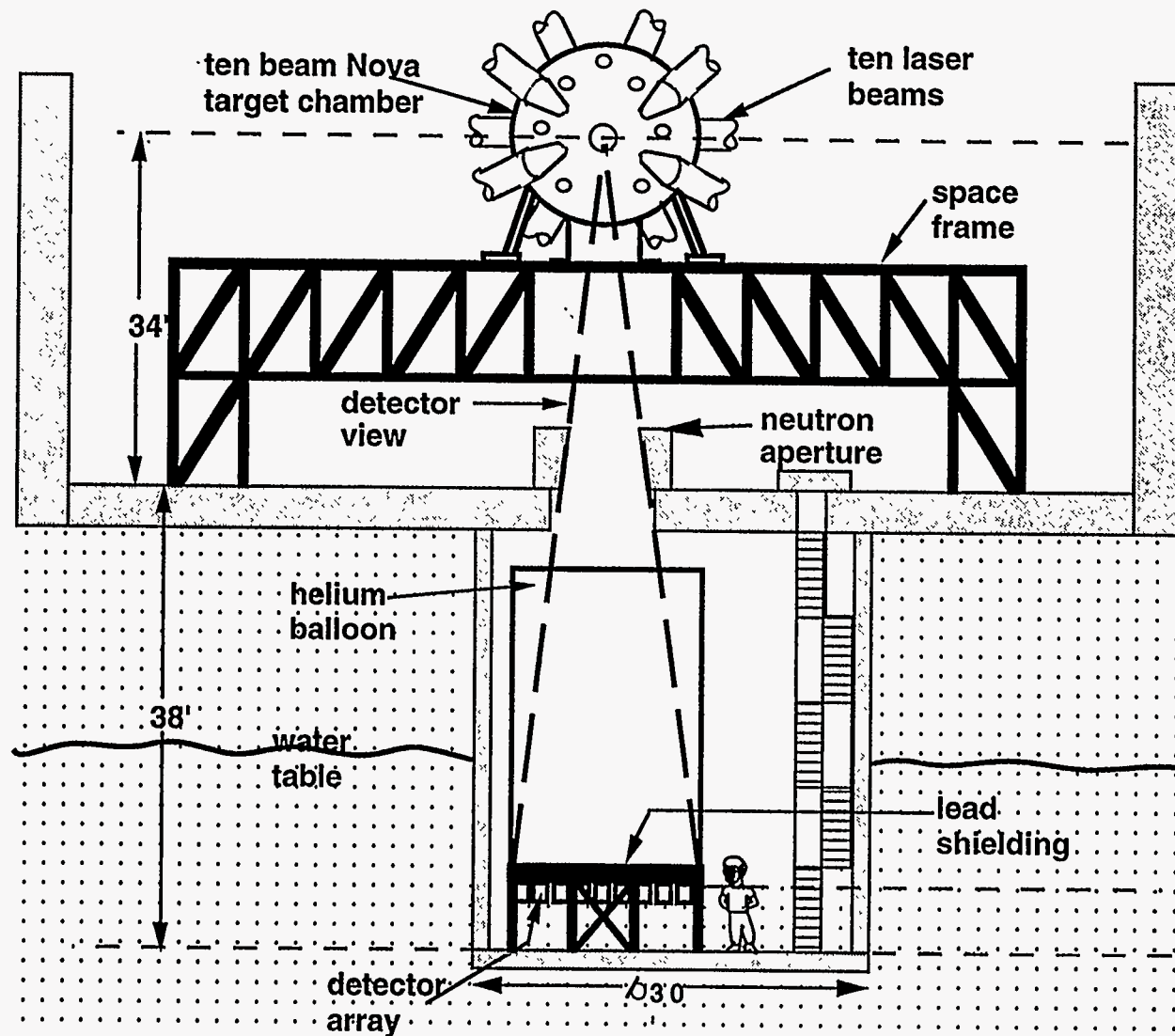


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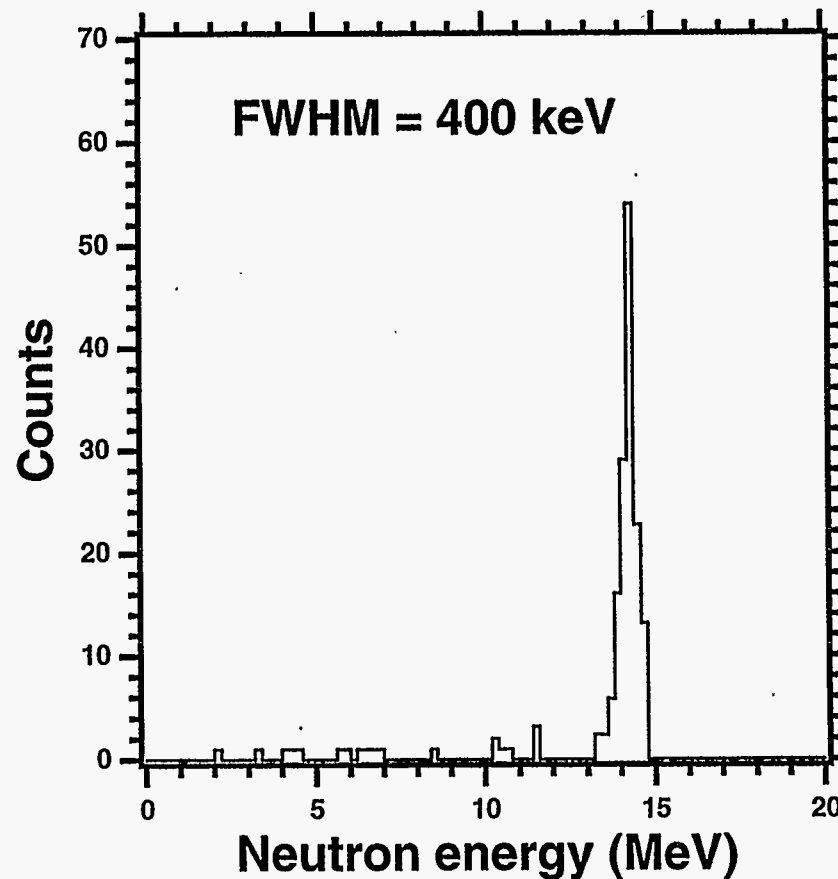
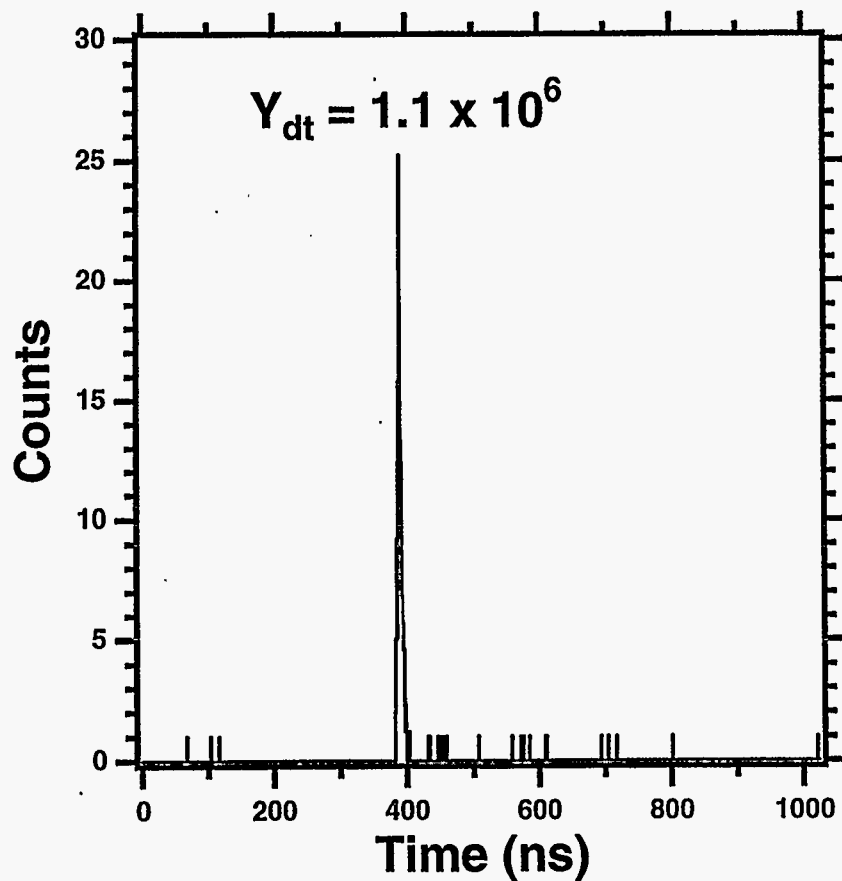
The Large Neutron Scintillator Array (LaNSA) consists of 960 scintillator-phototube detectors and associated electronics.

Each detector is capable of recording the arrival time (relative to the time at which the laser is fired) of at least one neutron. An energy spectrum is obtained by summing the results of all detectors.

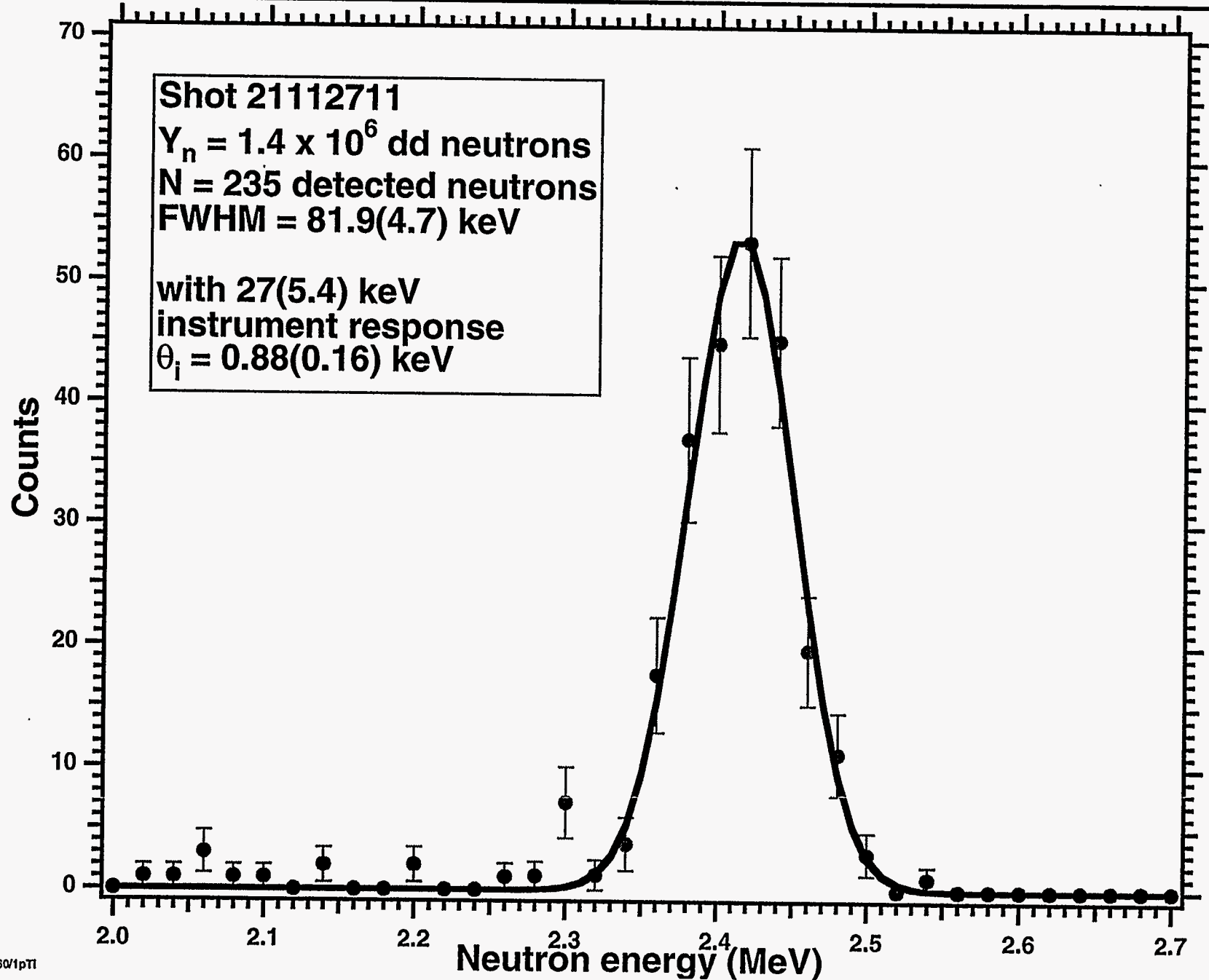
Secondary neutron energy spectra are measured with an array of neutron time-of-flight detectors.



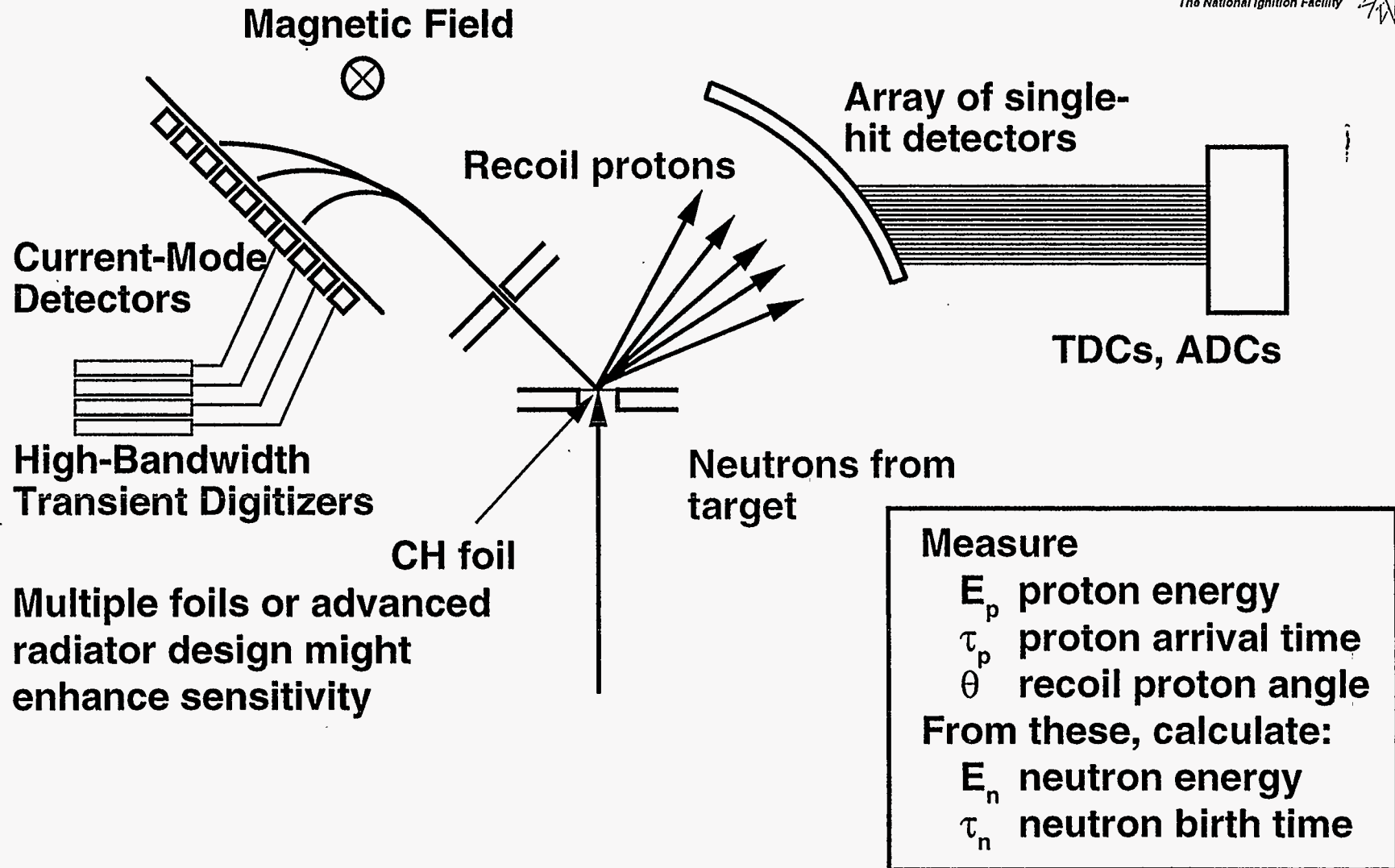
A low yield calibration shot shows the 14.1 MeV dt neutron peak.



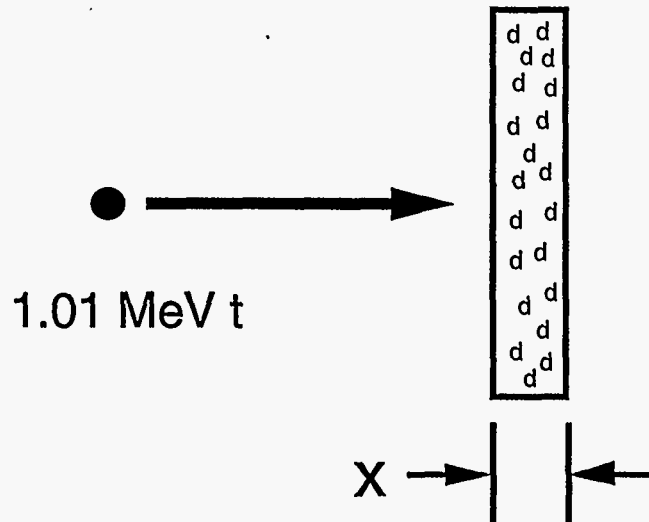
For low yield implosions, LANSA can be used to determine ion temperatures in single particle mode.



The higher neutron yields at NIF may allow time-resolved ion temperature measurements.



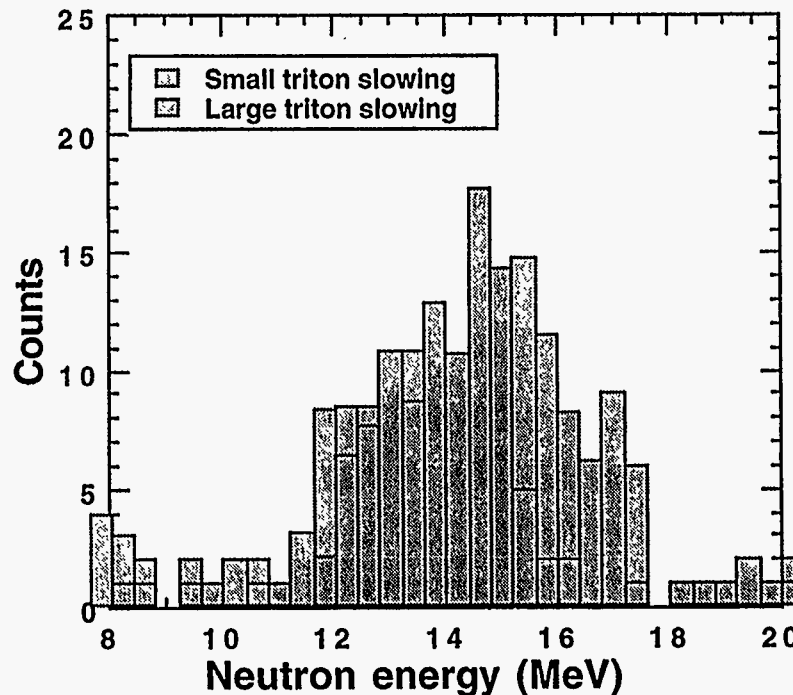
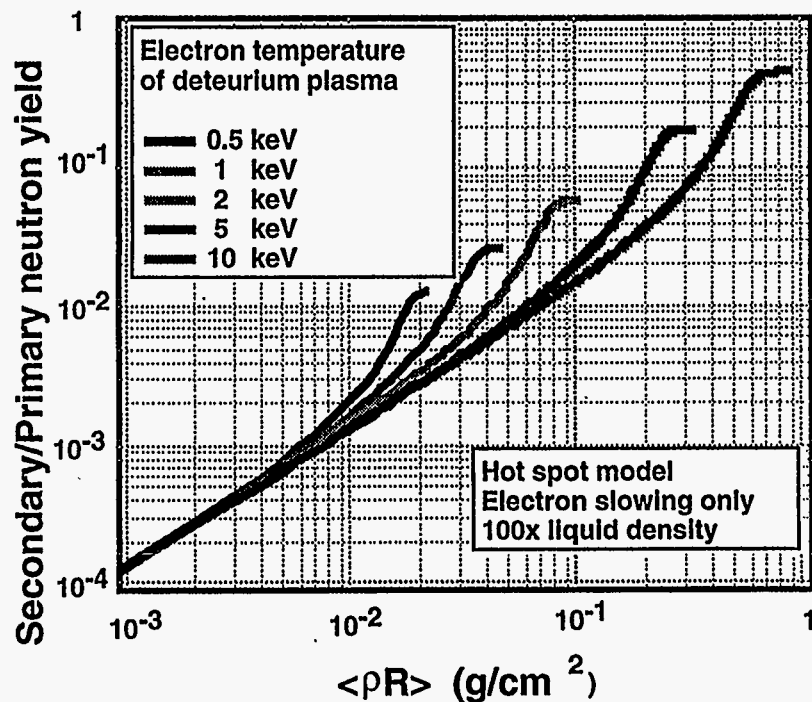
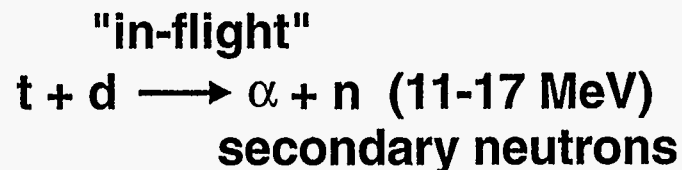
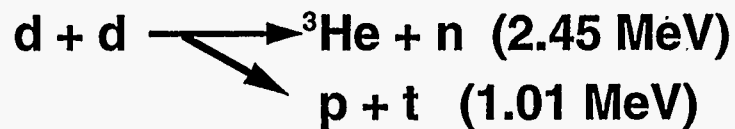
The measurement of fuel areal density can be illustrated with a simple example.



Probability of triton reaction in a thin slab of deuterium is $P = n_d \sigma x$. Since σ is known, ratio of reacting tritons to incident tritons gives $n_d x$.

$$\frac{\text{Number reacting tritons}}{\text{Number incident tritons}} = \sigma(E_t) n_d x$$

Secondary neutron measurements can be used to determine areal density for pure deuterium fuel.

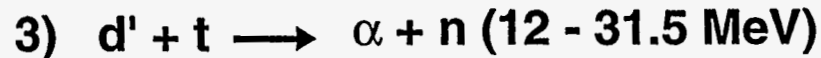
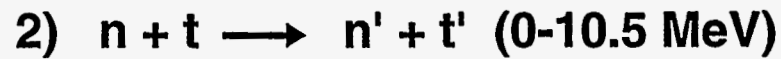
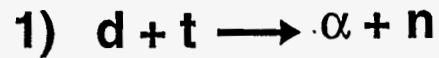


The spectrum width can be used to determine the amount of triton slowing. Triton slowing is sensitive to fuel/pusher mix.

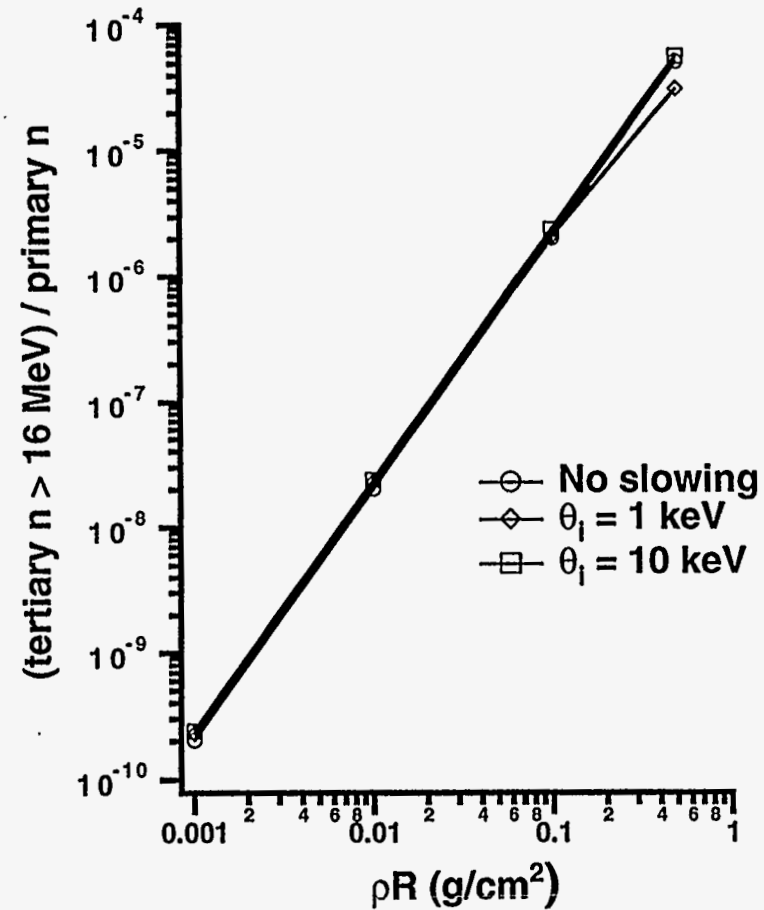
Tertiary neutrons can be used to measure large fuel areal densities.

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For negligible ion slowing
(no energy dependent cross-section
effects) tertiary production is
proportional to $\langle \rho R \rangle^2$.



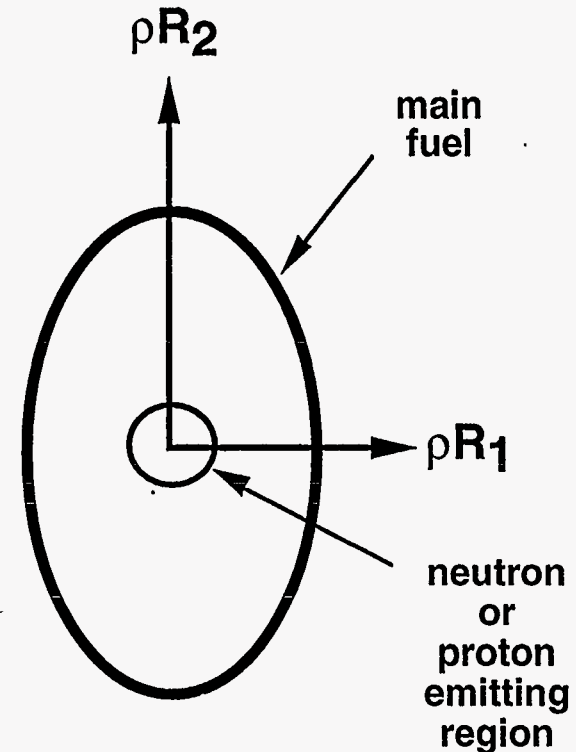
High energy tertiary neutrons or protons (>28 MeV) may be used to determine capsule symmetry at NIF.



- 1) $d + t \longrightarrow \alpha + n$ (14 MeV)
 - 2) $n + d \longrightarrow n' + d'$ (0-12.5 MeV)
 - 3) $d' + t \longrightarrow \alpha + n$ (12-31 MeV)
- $d + {}^3\text{He} \longrightarrow \alpha + p$

Reaction sequence must be nearly collinear (momenta aligned) to reach high energies.

ρR measurements in different directions can be used to determine if the final fuel configuration is round.

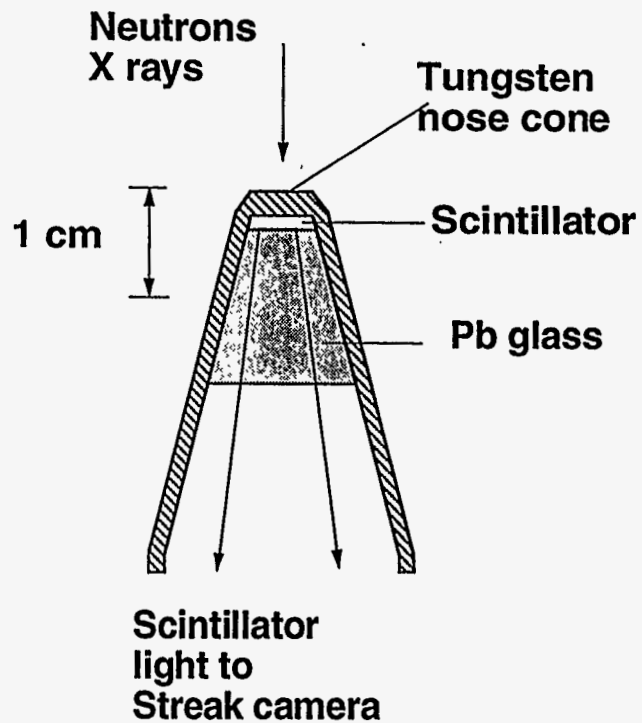


neutron version
Welch, Kislev and Miley, 1985

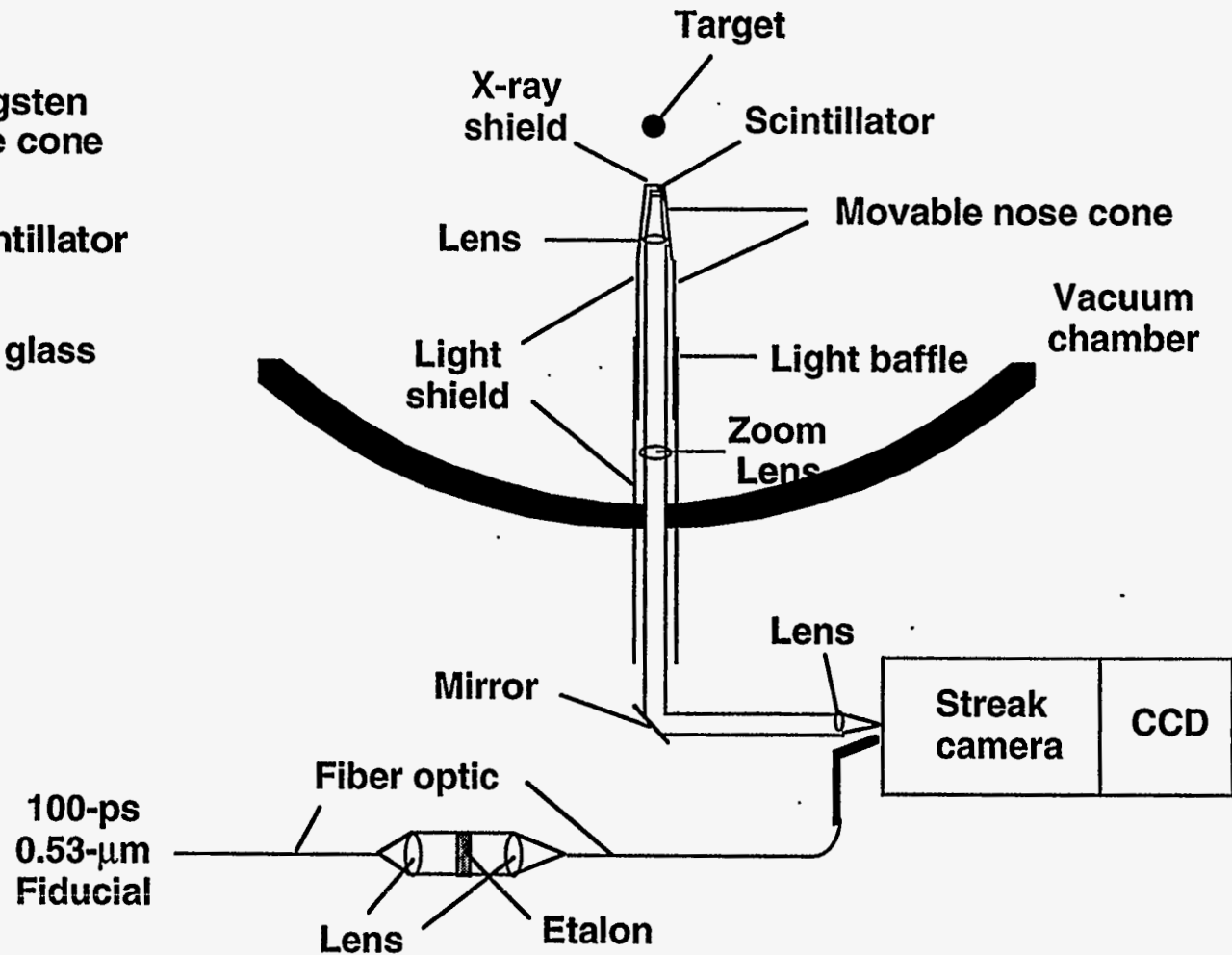
We use fusion neutrons to measure burn history for Nova ICF targets



(a) Nose cone



(b) Detector system



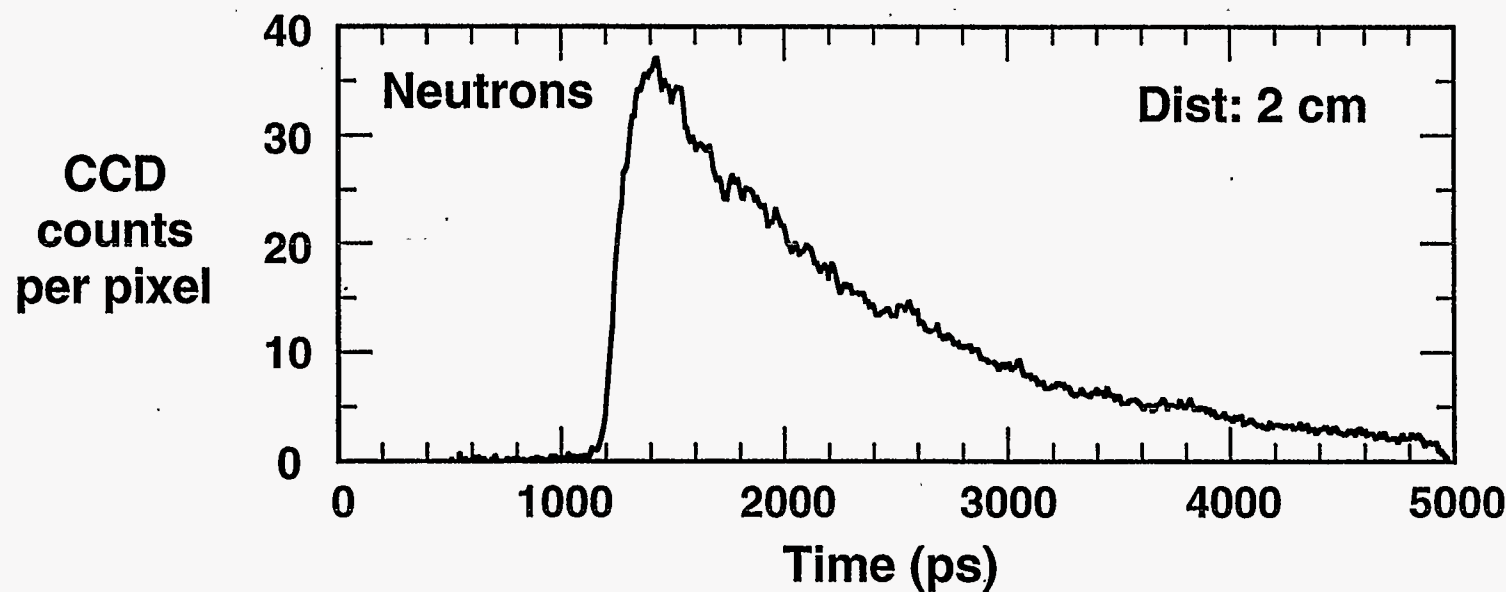
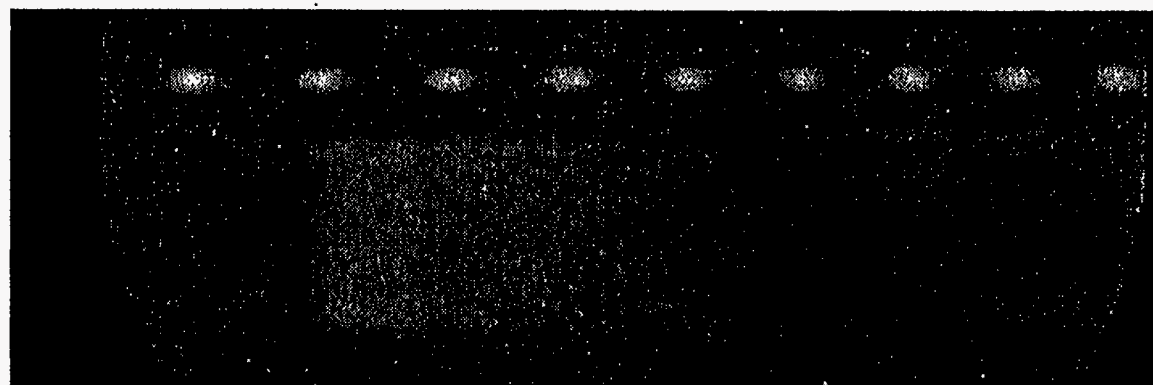
Excellent signals are recorded for targets producing only 5×10^8 DT neutrons



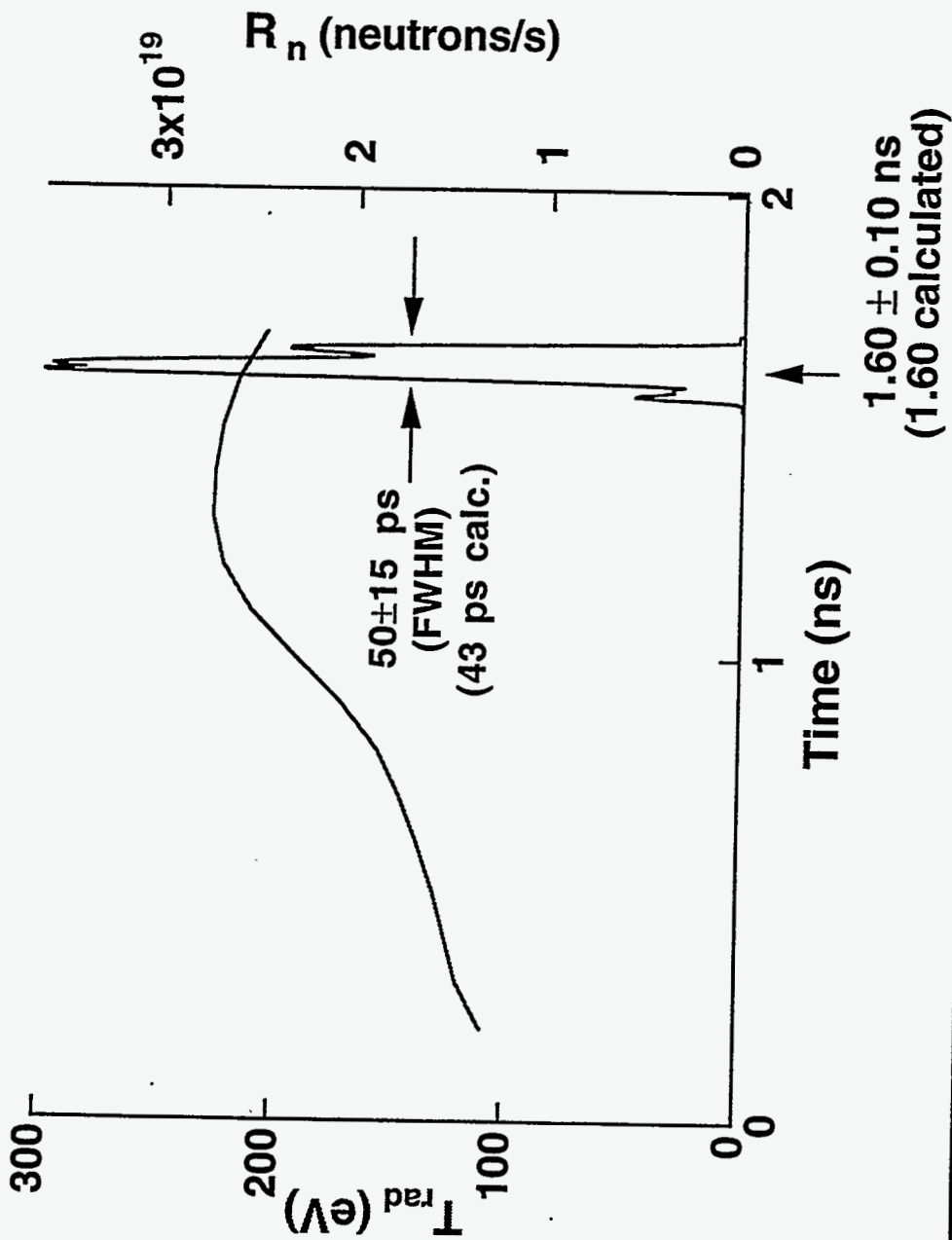
Fiducial

Neutrons

6 mm



Measured bang time and burn width agree with calculations.

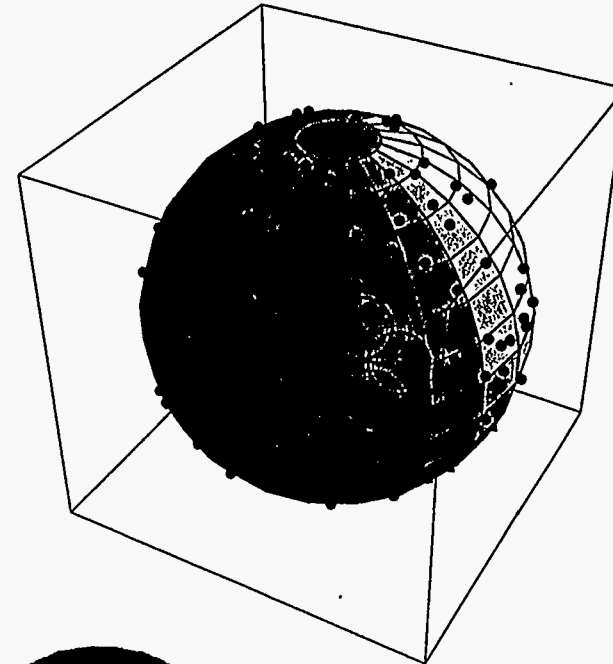
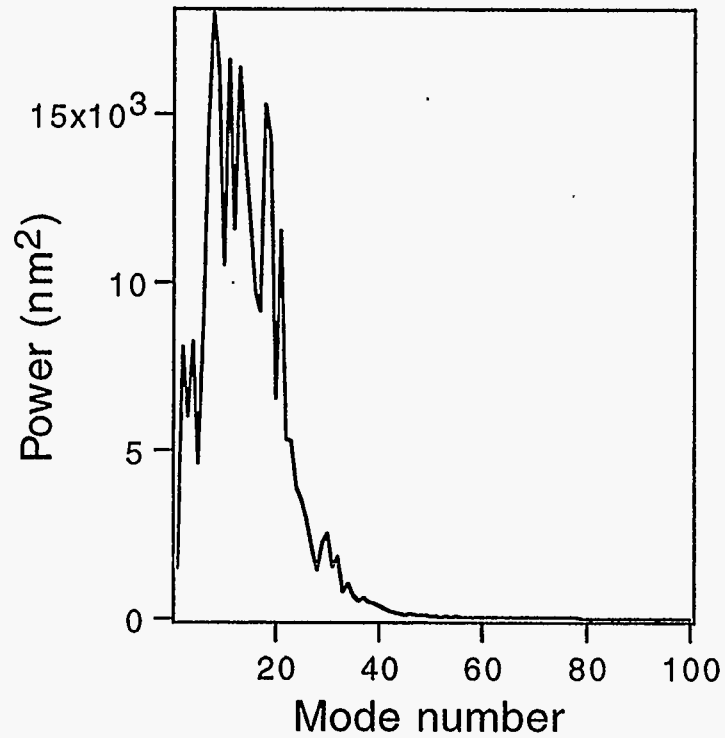


**Bang time agreement supports implosion kinematics.
Burn width agreement supports mix sensitive cooling rate.**

Laser-ablated ICF capsule: multimode surface



Mode Spectrum



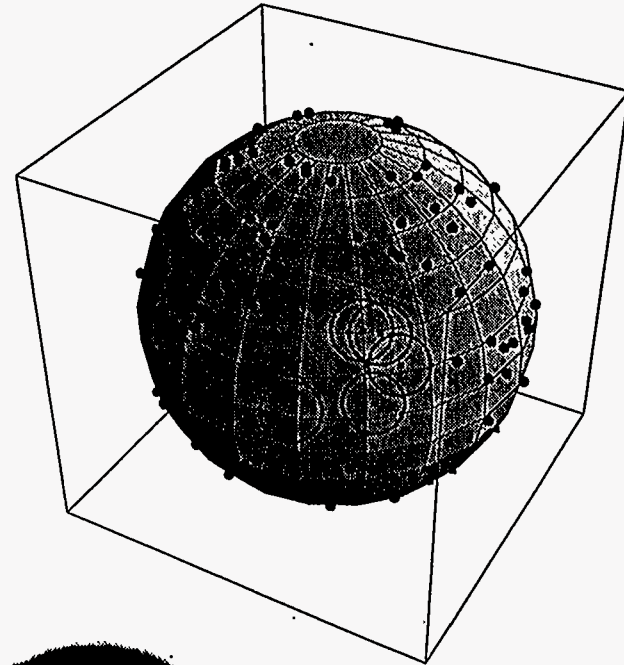
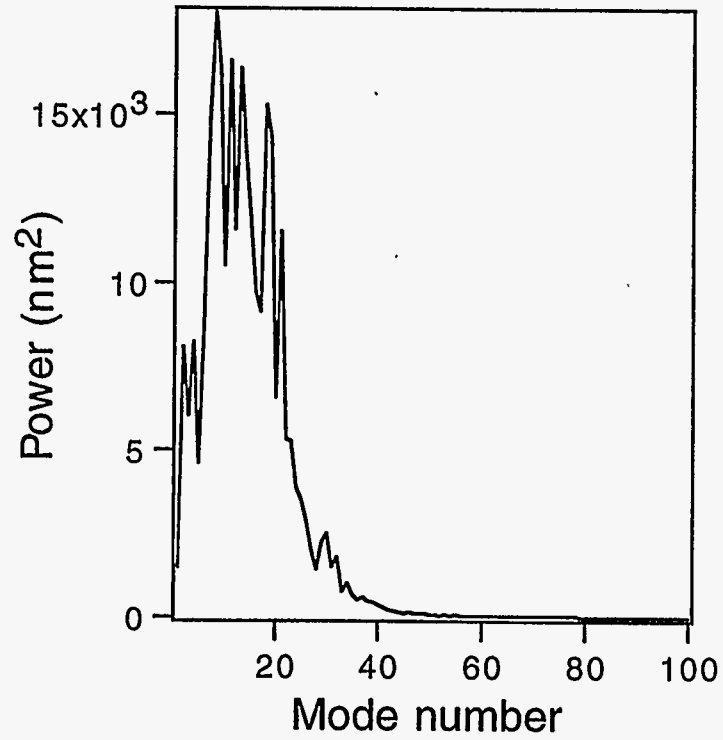
200 randomly-placed pits

75 μm diameter, gaussian profile

Laser-ablated ICF capsule: multimode surface

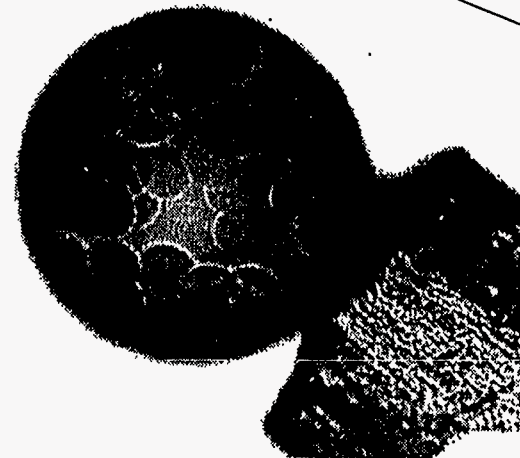


Mode Spectrum

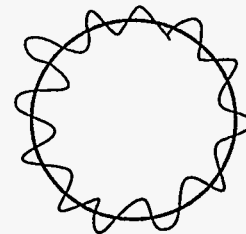
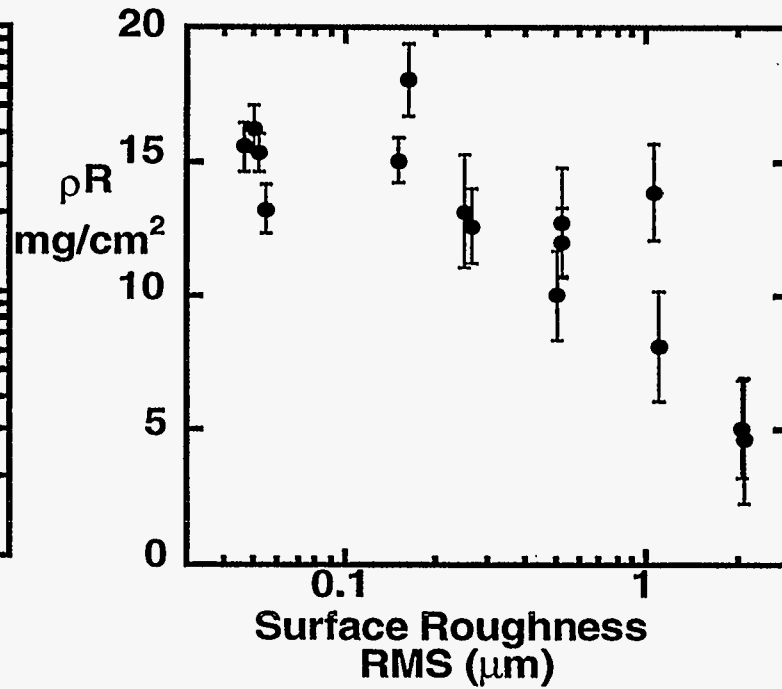
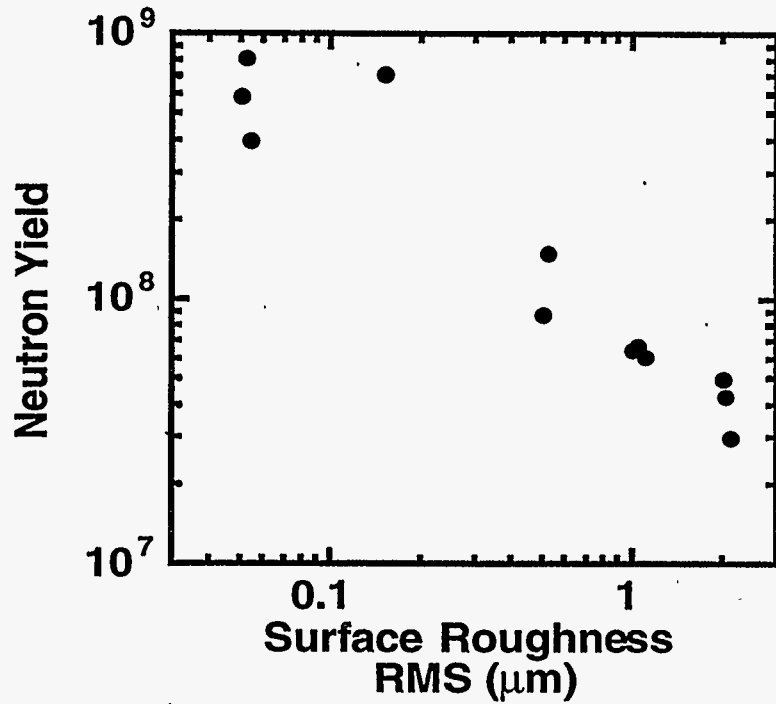


200 randomly-placed pits

75 μm diameter, gaussian profile

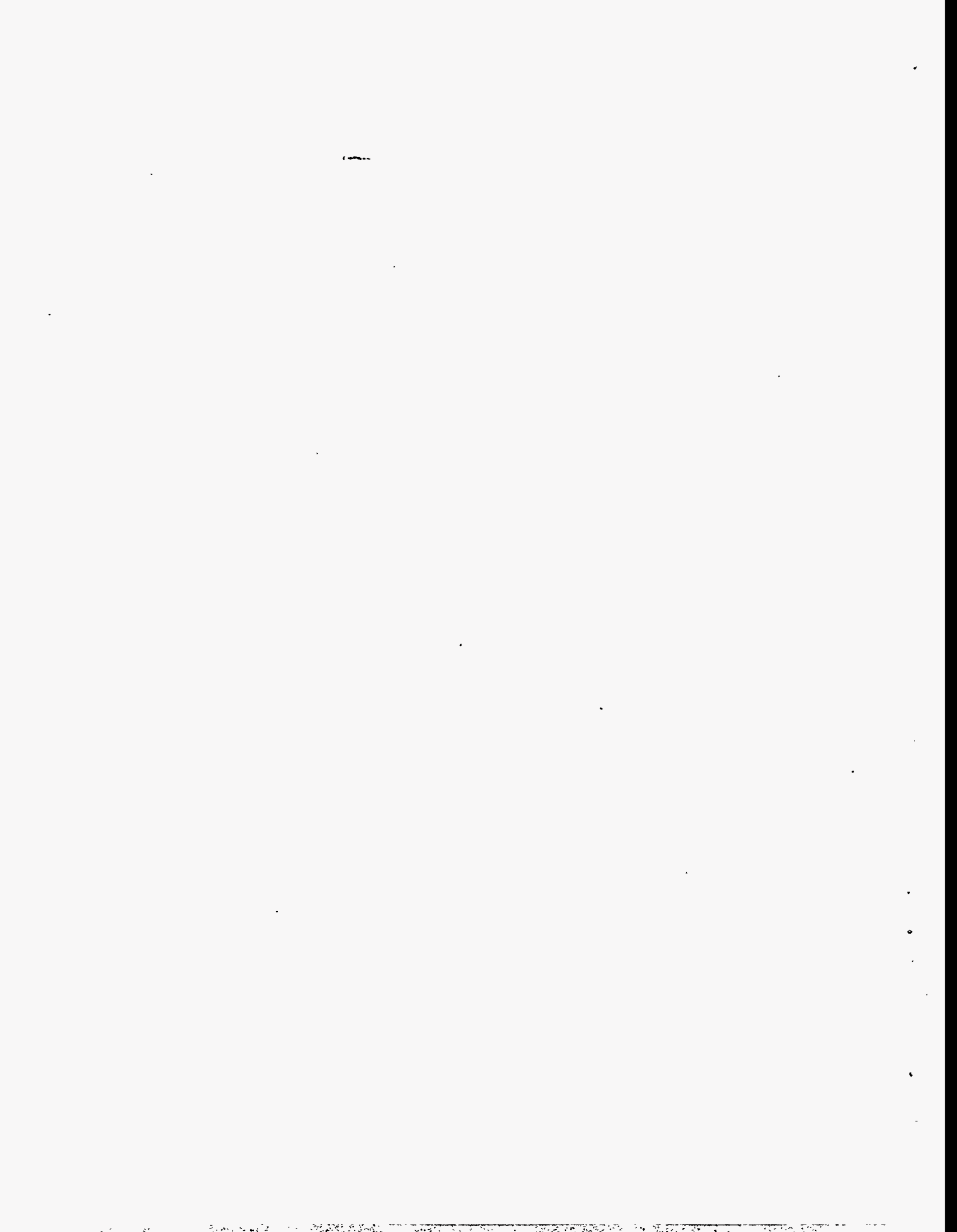


Neutron yield and final fuel areal density decrease with increasing surface roughness.

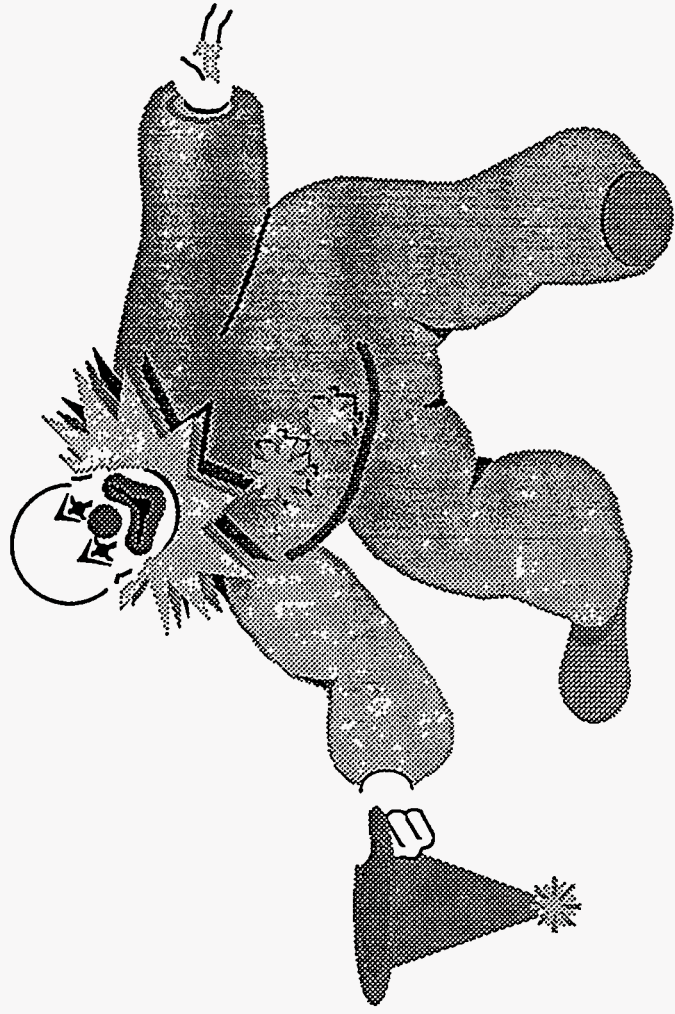
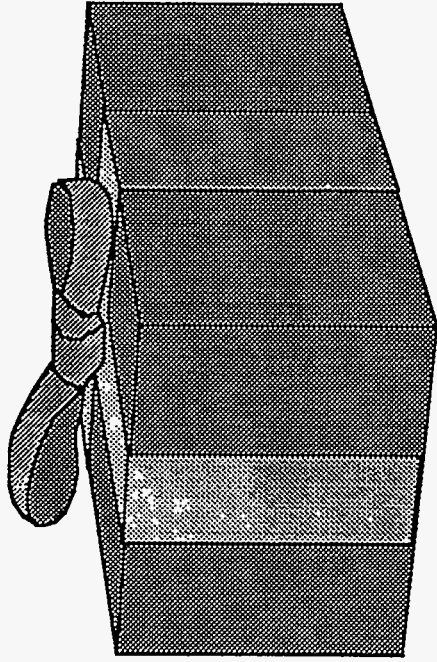


Peter Haustein

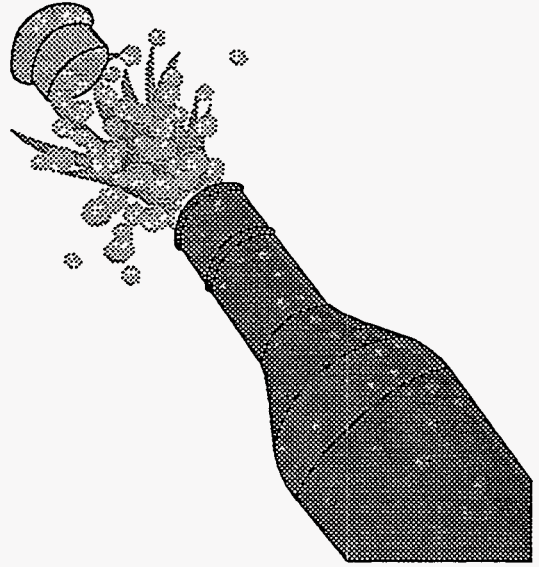
Brookhaven National Laboratory
Upton, NY



Cerny Fest



Happy Birthday
Joe!



April 14-16, 1996

Cerny Fest

My connections with Joe Cerny and his group

1965-66 UC Berkeley Undergraduate Days:

**Maples, Fleming, Butler, Goth, Ball, McGrath,
Cosper**

1979 Sabbatical from BNL:

**Aysto, Moltz, Wouters, Cable, Perry, Byce,
Shotter**

1989-90 Sabbatical from BNL:

**Moltz, Lange, Ognibene, Batchelder (Stokstad
for EB88)**

April 14-16, 1996

Cerny Fest

NSD

Nuclear Stimulated *D*esorption

*(Not the Nuclear Science Division of the
Ernest Orlando Lawrence Berkeley
National Laboratory)*

*Peter Haustein, Chemistry Dept.,
Brookhaven National Lab.*

April 14-16, 1996

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Nuclear Stimulated Desorption - -

***A technique for studies of surfaces
and thin films with relevance to
the remediation of high level
radioactive waste***

April 14-16, 1996

Outline:

What is NSD? Why study it?

Consequences of nuclear recoil

Basic premise used in NSD interpretation

Typical events and experiments to study them

**Relevance of NSD to remediation of High Level Radio-
active Waste (HLW)**

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What is Nuclear Stimulated Desorption?

Nuclear decays or reactions generally impart some recoil energy to the heavy participant. This can range from eV (IT, low energy β) to keV (β , α or n-capture) to multi-Mev (fission).

This recoil energy is sufficient to promote the desorption of atoms from surfaces or thin films. It can also promote the desorption or dislocation of atoms near the NSD site.

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Basic Premise of NSD and Goals in Studying NSD

Premise: The temporal, energetic and angular aspects of the process carry with them information about the desorbing species and its environment.

Goals: A basic quantitative understanding of the process for representative systems and, where possible, mathematical modeling of it. Application of this to development of remediation strategies for HLW.

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Typical NSD Scenario:

Nuclear event occurs (n-capture, β -decay, etc.)

Recoil energy is imparted to nucleus, which starts to move in a random direction and eventually is stopped.

Nucleus motion is affected by surface binding and may be hindered by the presence of adjacent atoms or over-layers.

Besides the primary recoiling atom, other atoms may be dislodged and/or desorbed.

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A Sampler of Typical NSD Events

- 1. Topmost atom on a surface**
- 2. An atom just below the surface**
- 3. An atom in the bulk**
- 4. Primary and secondary events**
- 5. Complicated cases with surface irregularities or dynamic surface conditions**

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Nuclear Techniques to Initiate NSD and Follow its Evolution

Initiate: Some type of nuclear transformation, e.g. beta decay or neutron capture

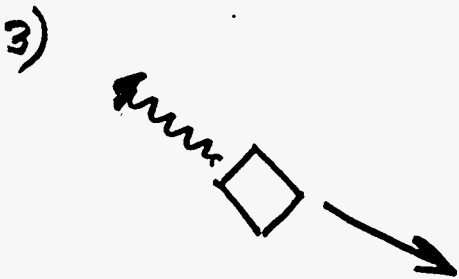
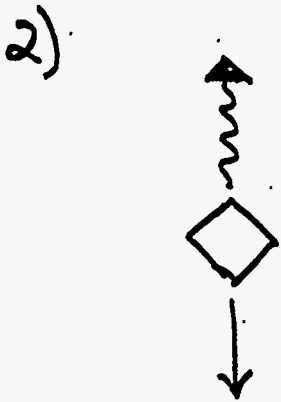
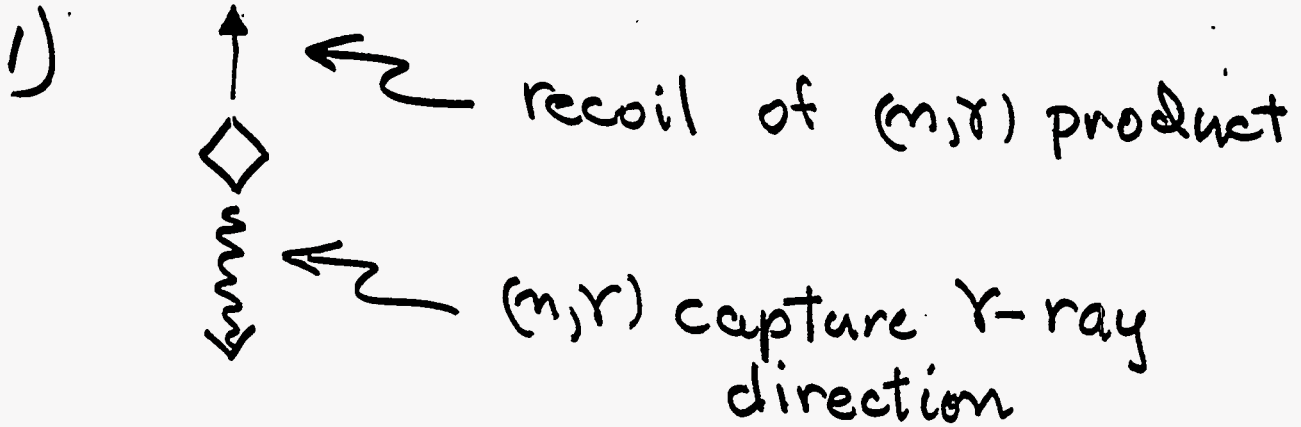
Follow:

Primary desorbing species becomes (and remains) radioactive and can be followed (location, amount, etc.) with very high sensitivity.

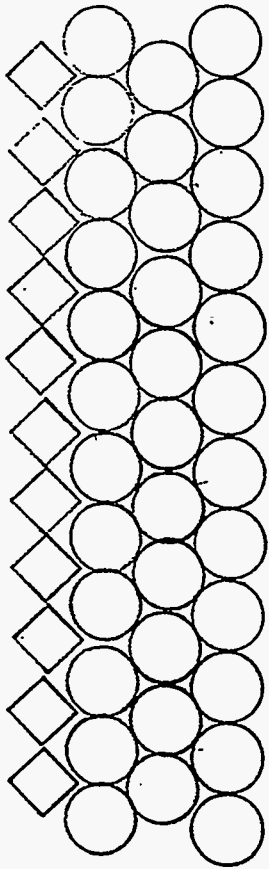
Secondary stable atoms which also desorb can be assayed via neutron activation after the assay of primary species.

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(n, γ) Events of \diamond atoms

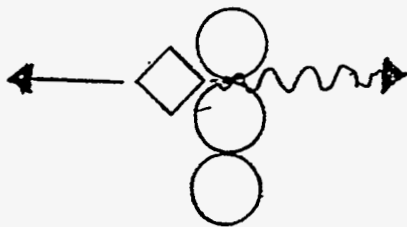
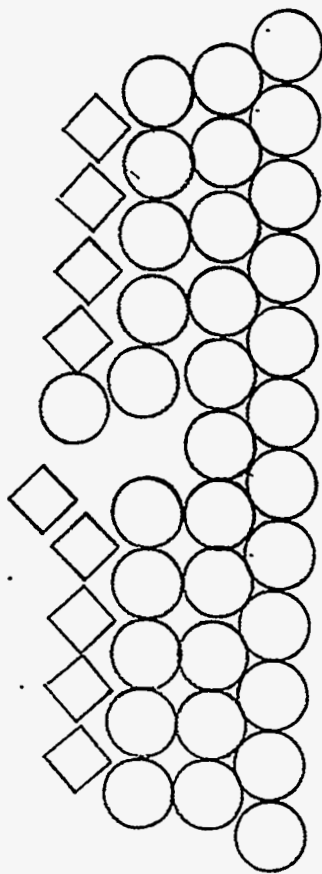
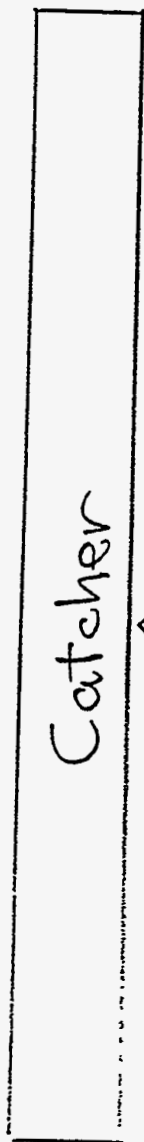


Catcher

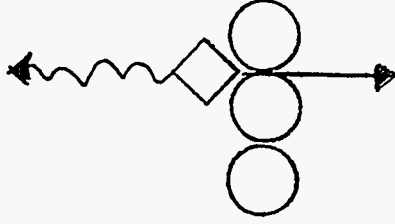
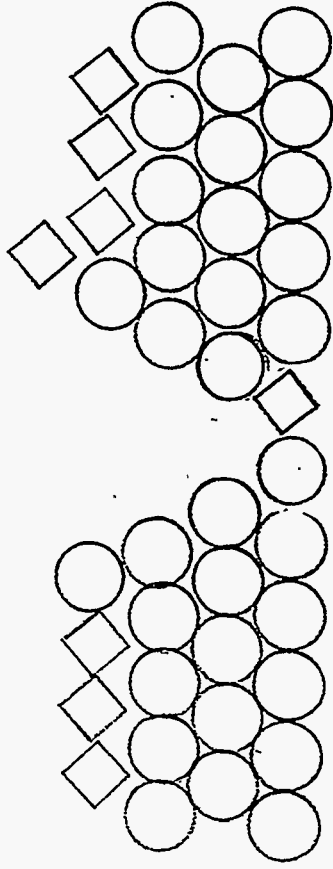
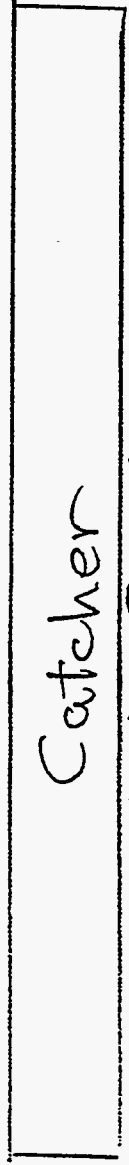


○ = Substrate ◇ = Monolayer Film

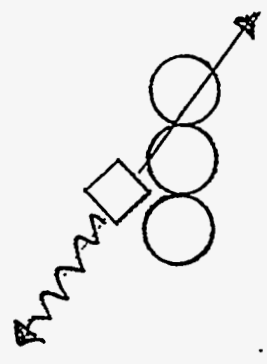
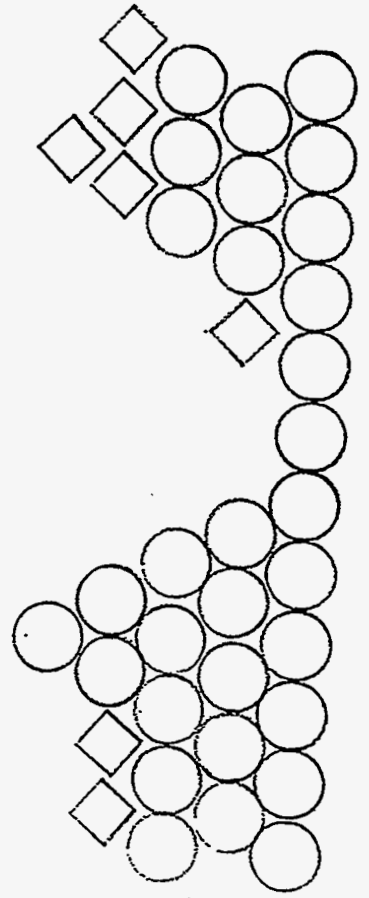
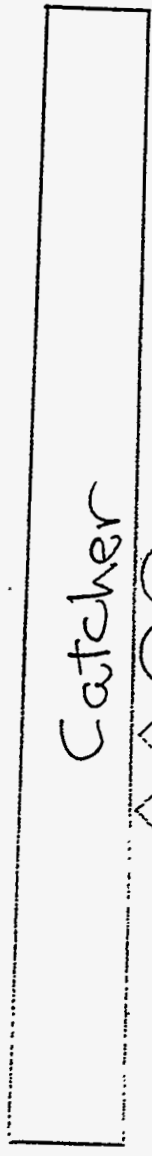
Event 1



Event 2



Event 3



Activation of \diamond atom
causes NSD and allows
one to follow where \diamond went.

(stable)
Fate of dislodged \wedge atoms,
 \diamond or \circ , can be followed by
neutron activation analysis
after the assay of the
primary \diamond atoms from NSD

**NSD and the Remediation of High Level
Radioactive Waste (HLW)**

HLW will contain high concentrations of many radio-nuclides (1.3 weight % ^{137}Cs for example), and will generate *intense* radiation fields, 20 watts/liter, 10^9 Rads/year self dose).

HLW surfaces and interfaces will contain high con-centrations of radioactive species and NSD pro-cesses will be a major source of surface degradation and loss of interfacial integrity. At these NSD sites radiolysis promoted corrosion and unwanted chemical reactions, e.g. H_2 evolution are major problems.

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H₂ Evolution from HLW and Spent Nuclear Fuel

“Wet option”: Process with minimal removal of H₂O; essentially all waters of hydration remain.

“Dry option”: Heat (to 50°C) and evacuate (to ~100 torr) to remove significant amounts of water; waters of hydration remain.

These options and H₂ evolution from radiolysis (promoted by NSD, photon stimulated desorption (PSD) and electron stimulated desorption (ESD)) dictate strategies for vented or non vented containers.

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**Long term collaborator: Prof. Itzhak Kelson, Physics Dept.,
Tel Aviv University, Israel**

**New collaborators (for the FY96 Environmental Management
Sciences Program Initiative:**

**Prof. Ted Madey, Depts. of Chemistry & Physics, Rutgers
University, Piscataway, NJ (Electron Stimulated Desorption)**

**Dr. Thomas Orlando, Environmental Molecular Sciences
Laboratory, Pacific Northwest National Laboratory, Richland,
WA (Photon Stimulated Desorption)**

April 14-16, 1996

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Dr.	George	Goth	1601 Kains Avenue	Berkeley	CA	94703	USA	goth@aol.com
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Dr.		Jorma	Honkanen	Kulmakuja 3 A1	Varkaus			FINLAND	watol@pspt.fi
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