NAL PROPOSAL No. 14

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FTS/Commercial 212-280-1754

PROPOSAL TO STUDY INELASTIC HIGH ENERGY PROTON-PROTON COLLISIONS IN THE DIFFRACTIVE REGION

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June, 1970

Proposal to Study Inelastic High Energy Proton-Proton Collisions in the Diffractive Region

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ABSTRACT

We propose to study reactions of the type $p+p\rightarrow X+p$ in the kinematical region where the recoil proton has a laboratory momentum below ~300 MeV/c. A solid state counter hodoscope is used to detect proton recoils and measure their momentum and angle. The doubly differential cross section $\frac{d^2\sigma}{dtdM}$ (M is the mass of X) can thus be measured for a range $-0.100 \leq t \leq -0.0001$ and $1 \leq M \leq 6$ or 10 BeV. It is proposed that a hydrogen jet be used as a target, exposed to the full proton beam.

Data obtained in this way are relevant to various models of high energy collisions, in particular diffraction dissociation and limiting fragmentation. The energy dependence of the cross section should be checked at two energies, at least. The proposal asks for a few cubic feet for the experimental setup, and uses only one part in 10^9 of the beam with no degradation in the quality of the remainder, hence is completely parasitic in nature.

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Introduction

No comprehensive understanding of inelastic hadronic collisions has been reached so far, possibly because among other reasons, a many-particle final state can be studied in its entirety only in highly dimensional spaces. The experimental problem is thus often a question of how to project out some simple one (or two) dimensional distributions which might retain important information which would help towards gaining insight into high energy strong interactions. In order to decide which distributions might be important, it is necessary to use a model as a starting point. In this way the experiment will certainly test the validity of the model. The hope then is that, were the model to turn out to be incorrect, the experimental information might still be relevant to physics and not merely increase our heavy load of incomplete or not-understood data.

To hopefully achieve the above aim, the model should possibly be extremely simple, intuitive and related to as many current ideas about high energy interactions as possible. We feel that such a phenomenonlogical approach is achieved by the diffractive model, originally extended to inelastic processes by Landau, etc. and more recently by Good and Walker. (One might recall how successfully the optical model had been used to describe elastic π-p and p-p scattering by Serber.) Recently, the evidence for inelastic diffractive scattering on free nucleons has been reviewed by one of us (P.F.) at the Stony Brook Conference on High Energy Collisions.

The existence of such processes at presently available energies is well established. For processes of the type $a + b \rightarrow a' + b$, where a' is a state of many particles, with rest energy M and the same charge, I-spin etc. as a, the following properties are approximately valid:

1. $\frac{d\sigma}{dM}$ is independent of incident energy.
2. $d\sigma/dM \sim 1mb/1$ GeV and it is independent of M for $1 < M < 2$ GeV.
3. $\frac{d\sigma}{dt} \sim e^{at}$, $8 \leq a \leq 10$, where t is the momentum transfer to particle b.
4. the number of fragments into which a' breaks is determined by M and the quantum numbers of a.

The above observations are limited to a narrow range of M $\leq$ 2 GeV mainly because of the coherence condition

$$M \leqslant \sqrt{2\ pM_{\pi}}$$

where p is the laboratory incident momentum (up to now $\leq$ 25 GeV/c). Thus with the new energies available at NAL one can study inelastic diffraction for masses up to ~10 GeV. Also point (2) above (assuming no wild dependence of $\frac{d\sigma}{dM}$ vs M appears) suggests that diffraction might saturate the inelastic cross section at energies of 200 to 500 GeV.

We would thus propose to measure the two dimensional distribution function $\frac{d^2\sigma}{dtdM}$ for a collision $a+b \rightarrow a'+b$ where b recoils intact with four momentum transfer t and M is the mass of a'. Particle b is obviously limited to being a proton, while particle a can be any hadron out of which a beam could be made. As a first investigation, it appears that the most straight forward experiment is to study p+p → anything +p where the recoil proton has very small momentum in the laboratory. By limiting the experiment to very small recoil momentum one has the following advantages:

a. Explore the region where diffraction dominates.

b. Improve the kinematical separation between target proton recoiling intact and target dissociation.

c. Simplify greatly the experimental setup.

Since points a and b are self-evident, we will discuss only point c. This will be, in fact, the specific experimental proposal.

Although the above discussion of the justification of the experiment is based on the diffractive model, its results would be highly significant to many other models of hadron collisions. Apart from the obvious connection of the diffractive model to

a. Dominance of Pomeron exchange at high energy

b. Parton model

c. Coherent droplet model

explicit predictions have been made for instance for the distribution of the longitudinal momentum of the recoil proton in the limiting fragmentation model (Benecke et al. Phys. Rev. <u>188</u>, 2159 (1969).) In this model a sharp dip should appear at high energy for very low longitudinal momenta.

In addition, the proposed experiment is an ideal search for high mass, narrow resonances which might be produced coherently in proton-proton scattering.

APPARATUS

Low energy protons are ideally detected with silicon solid state detectors. We propose, in order to identify protons and measure their momentum, to use two overlapping counters; the first one 0.1 cm thick, the second one 1-2 cm thick. A set of 40 such counters are placed ~100 cm away from a hydrogen jet target upon which the entire proton beam impinges. Many counters are used to cover at once a reasonable angular range for the recoil proton, from 90° in the laboratory to as low an angle as compatible with the kinematics of very high mass dissociation. Assuming each counter to be 1 cm^2 in area, the resolution of the spectrometer is

$\Delta\theta \approx 10^{-2}$ rad

$\Delta T \leqslant 50$ KeV (T is kinetic energy)

or $\Delta\ |t| \leqslant 10^{-4}\ (GeV/c)^2$

and $\Delta M \approx 80$ MeV at $M = 2$ GeV

$\Delta M \approx 25$ MeV at $M = 4$ GeV

$\Delta M \approx 20$ MeV at $M = 6$ GeV

The laboratory solid angle for each counter is $\Delta\Omega = 10^{-4}$

and the laboratory momentum range is

$30 < p < 270$ for 1 cm silicon detector

$30 < p < 340$ for 2 cm silicon detector.

For the 1 cm silicon case this represents a range in t of $-0.0009 < t < -0.073$ or a factor of 81 over which $\frac{d\sigma}{dt}$ can be studied.

EXPECTED YIELD

Since nobody knows what value the inelastic cross section will have at NAL energies nor what its t dependence might be, we will assume that the diffractive model is not too far off.

Hence, we will assume that about 1/3 of the total inelastic cross section is dominated by diffractive processes in which the target proton recoils intact, specifically (this cross section is shown as a function of the recoil laboratory angle in Fig. 1)

$$\frac{d\sigma}{d\varphi\, dt\, dM} \sim \frac{10}{2\pi} e^{10t} \quad \mathrm{mb}(\mathrm{GeV}/c)^{-2}(\mathrm{GeV})^{-1}(\mathrm{rad})^{-1}$$

$(1 < M < 10 \text{ GeV})$

Since our hodoscope covers the range

$-0.1 \leqslant t \leqslant -0.001 \; (\mathrm{GeV}/c)^2$

$1 \leqslant M \leqslant 6 \quad \mathrm{GeV}$

$\Delta\varphi \sim \frac{1}{100}$ rad

we can integrate to obtain

$\Delta\sigma = 0.5 \times 10^{-29} \text{ cm}^2$

We assume further that the hydrogen jet target will have an effective thickness of 10^{-7} gr/cm^2 (This is the value reported by the Russian group). We then obtain

$$N_{ev} = N_{beam} \times \Delta\sigma \times t \times N$$

$$N_{ev} = 10^{+13} \times 5 \times 10^{-30} \times 10^{-7} \times 6 \times 10^{23} =$$

$$= 30 \times 10^{-1} \text{ i.e. } 3 \text{ events}/10^{13} \text{ protons}$$

The fraction of beam lost in the hydrogen is

$$\text{Loss} = \frac{N_{int}}{N_{beam}} = 4 \times 10^{-26} \times 10^{-7} \times 6 \times 10^{23} = 2.4 \times 10^{-9}$$

Experimental Arrangement

A sketch is shown in Fig. 2. We would require a vacuum chamber of dimension ~ 1.5 x 1.5 x 0.3 m^3 to be inserted along the beam path. As a first attempt it appears simpler to insert the chamber and run the experiment in the extracted proton beam. This might make it rather complicated to run the experiment at different energies. After some experience with the jet target and the hodoscope, and the experiment has been run at one energy, we would request to insert our apparatus in the machine ring.

To obtain valuable information on $\frac{d^2\sigma}{dtdM}$, at least 10^4 events at each energy are desirable corresponding to a minimum of 3000 machine pulses of 10^{13} protons each. (With the apparatus in the main ring multiple traversal would gain a large factor in number of interactions).

Thus significant results can be obtained in a few hours of running. It might also be desirable at one energy to obtain 10^5 to 10^6 events, possibly at improved angular and energy resolution, especially to study production of old and new resonances.

Thus typically we would request

Energy	Machine pulse at 10^{13} protons	Hours
100 GeV	3,000	2
200 GeV	300,000	200
300 GeV	3,000	?
Highest possible	3,000	?

The energy for the extensive run is chosen at 200 GeV under the assumption that it might be the most convenient one to run the accelerator. A higher energy would be in fact more valuable for the physics involved. We do not explicitly ask for testing and set up time because of the completely parasitic nature of the proposal.

$\frac{d^2\sigma}{d\Omega_{lab}\, dM_x}$ for $p+p \rightarrow X+p$ at 200 Gev

(The two branches in each curve correspond to 2 possible recoil mom. at each angle)

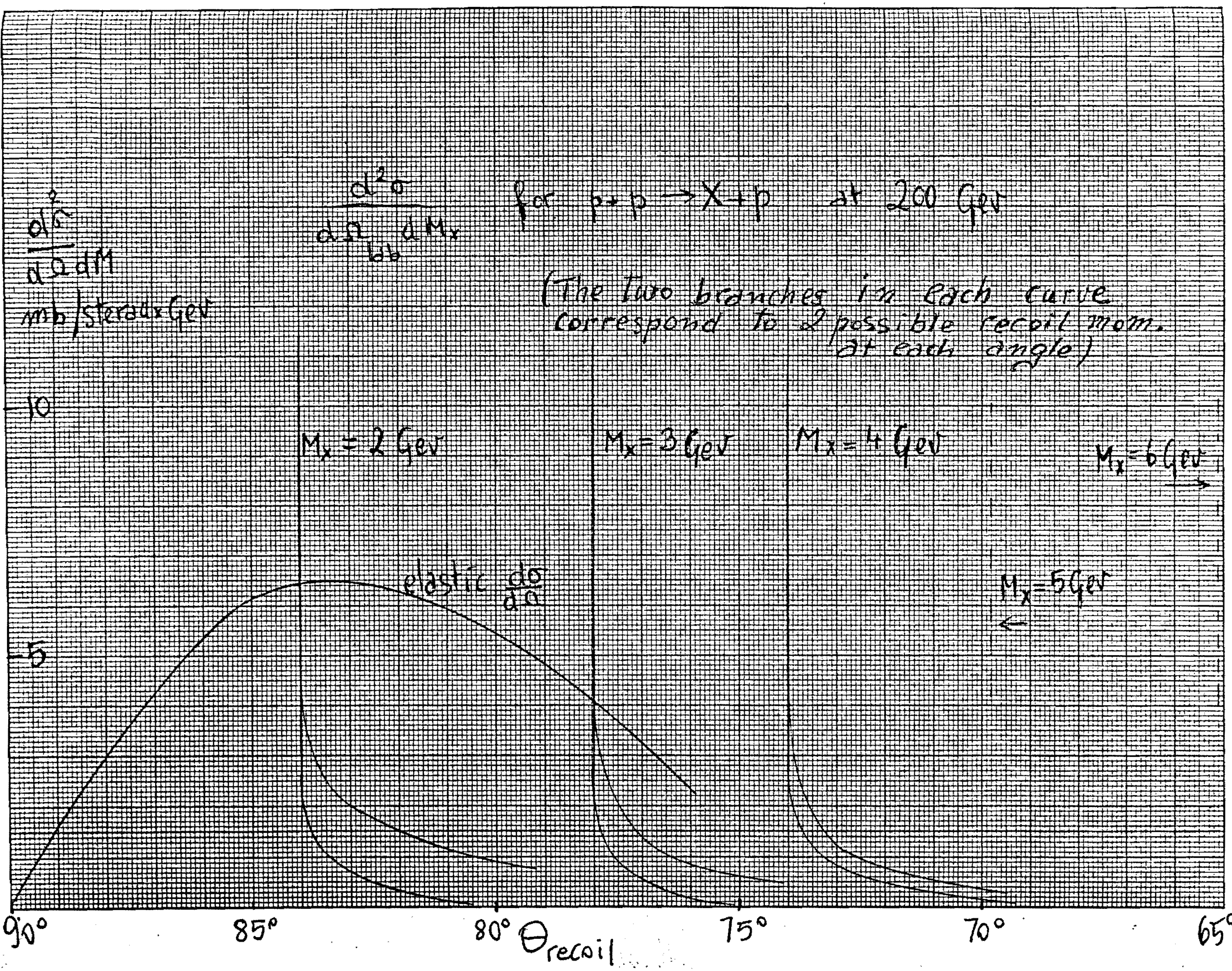


FIG 1

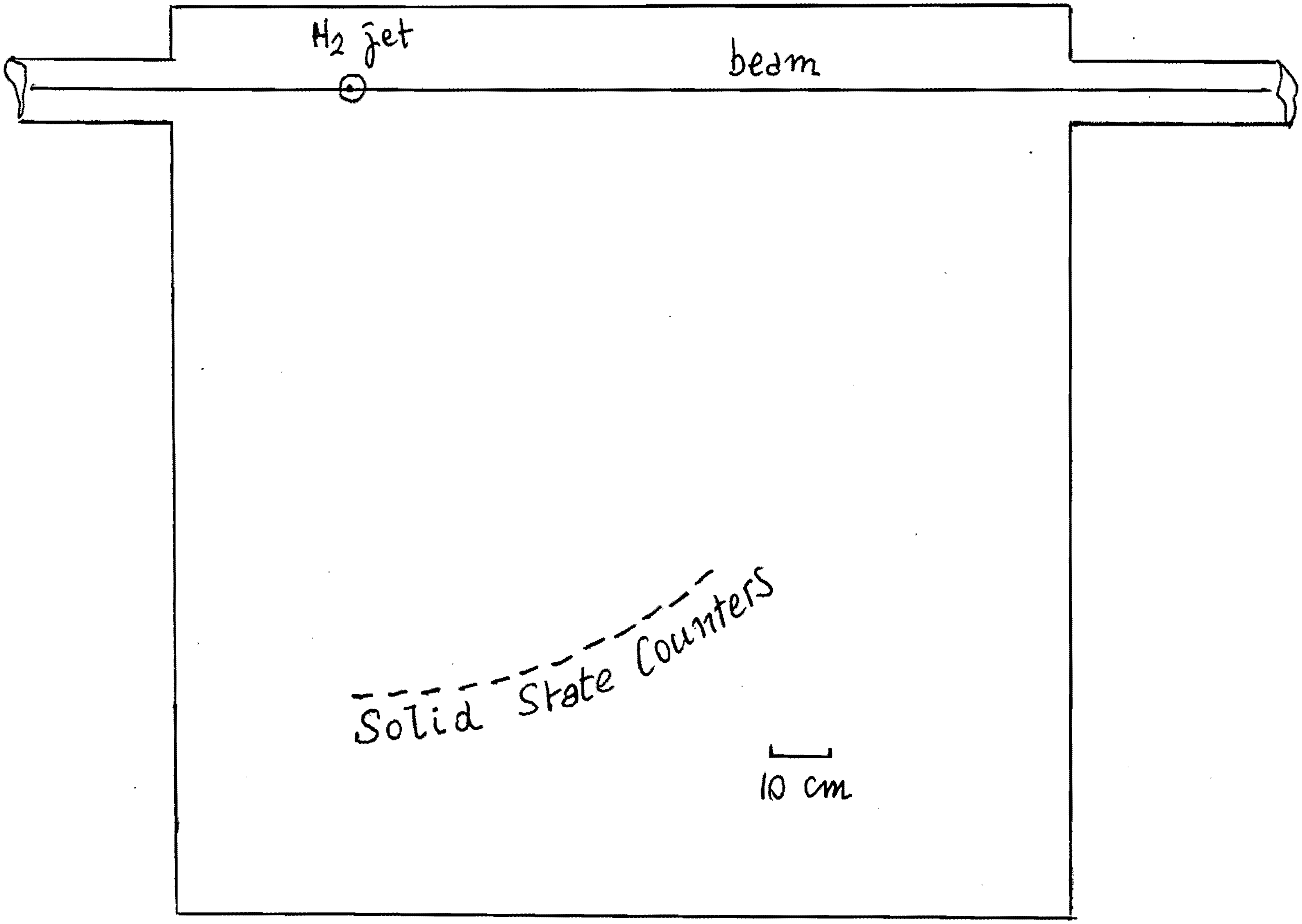


Fig 2

Addendum to Proposal #14
p-p Inelastic Scattering
Columbia-Stony Brook Collaboration

Introduction

The aim of the original proposal was to measure the doubly differential cross section $d\sigma^2/dt\ dM$ for the reaction of the type $p + p \rightarrow p + x$ where t is the momentum transfer to the target proton and M is the mass of x.

We discuss here a preliminary phase of such measurements employing polyethylene-carbon subtraction method, together with a slightly more complete presentation of the solid state counter hodoscope.

Polyethylene-Carbon Subtraction

The obvious advantages of the method are simplicity and increase in event rates; the disadvantage is the inherent uncertainties in the subtraction procedure, which are likely to greatly dominate any other source of error.

The main reason for employing this method is however the impossibility of making any meaningful prediction of the background rates in the vicinity of the very intense NAL beam, to the level of interest for the proposed experiment performed with a hydrogen jet target.

We thus feel it highly worthwhile to accept the problems of the subtraction method and to try to learn to control the background while measuring in this way the physical quantities of interest.

Kinematics of pp → px and Justification of Solid State Hodoscope

The minimum proton recoil momentum is given at high energy by

$$p_{min} = \frac{M_x^2 - m_p^2}{2p_{lab}}$$

For $p_{lab} = 500$ GeV/c and $M_x = 10$ GeV, we have

$$p_{min} = \frac{100-1}{1000} = 99 \text{ MeV/c}$$

which corresponds for protons to a kinetic energy of ~ 5 MeV. A five mm thick silicon detector can stop protons up to 30 MeV and measure the energy deposited in the crystal typically to better than 100 KeV(fwhm) for such energies.

This implies that just measuring the recoil energy one obtains t, the invariant momentum transfer, related to T kinetic energy by $t = 2mT$, to an accuracy typically of 0.2%. Angle and kinetic energy together give a measurement of M. In our experiment with

$$\sqrt{<\Delta\theta^2>} = \pm\ 0.33^\circ \text{ and } \Delta T/T = \pm 0.3\%$$

we obtain $\Delta M = \pm 100$ MeV at $M = 1.5$ GeV, $t = 0.01$
$\Delta M = \pm\ 70$ at $M = 3.5$ GeV, $t = 0.01$
$\Delta M = \pm\ 30$ at $M = 5$ GeV , $t = 0.01$
$\Delta M = \pm\ 60$ at $M = 4$ GeV , $t = 0.04$
$\Delta M = \pm\ 30$ at $M = 8$ GeV, $t = 0.04$.

Experimental Setup

This is shown in Fig. 1.A thin polyethylene wire or ribbon is interposed in the path of the external proton beam.

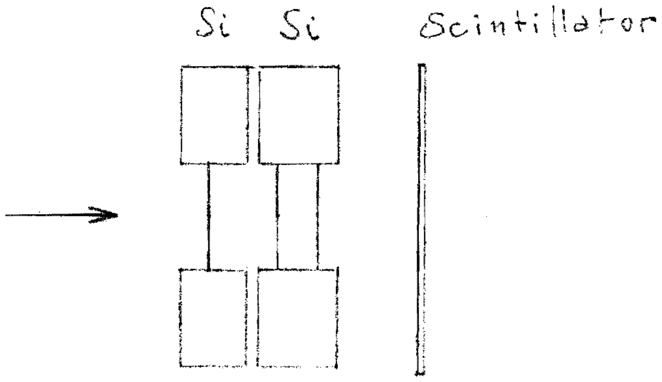
A solid state counter hodoscope covers the laboratory angle range 90° to 45° with a covering efficiency of about 30% in θ at a distance of 1 m from the target (20 channels, 1 cm^2 each).

As discussed later, each counter can measure proton recoils of kinetic energy from about 0.5 MeV to about 100 MeV or t ($=2mT$) of $0.001 (GeV/c)^2$ to $0.2 (GeV/c)^2$. With such a hodoscope, the number of events can be between 10 and 1000 per hodoscope element per 10^{13} incident protons. This range is obtained by using a target which is 10 μ thick and 10 μ to 1 mm wide. The total beam loss in such target is correspondingly 4×10^{-8} to 4×10^{-6}.

We would prefer to run at the lowest event rate possible but all our system is designed to be able to accept the highest rate if this is necessary in order to improve signal to background ratio.

Hodoscope

Each element is a telescope of two solid state counters in transmission mount.



The first counter is a 200 μ surface barrier, totally depleted Li detector. The second is a 5 mm Si lithium drifted detector. A scintillation counter is behind the entire hodoscope. Very low energy protons are detected by the first element only.

This corresponds to $T \leq 5$ MeV/c. Pions stopping in the first counter have $p_\pi \leq 24$ MeV/c, which corresponds to so little phase space, not to constitute a real background. This can be checked against the next energy interval. Medium energy protons $5 < T < 30$, will stop in the second detector thus giving us a dE/dx-E measurement. This allows separation of protons from pions.

For higher energy protons, $30 < T < 100$ MeV, we will have effectively two measurements of dE/dx, integrated over the detector thickness. This still allows separation of π's from p's and a measurement of the proton kinetic energy. See Fig. 2. Two small intervals will in fact be lost. The first is around 29 MeV, because of the uncertainty in counter thickness. The second is around 70 MeV where the pion correlation curve crosses the proton curve. This ambiguity is however removed by a scintillation counter behind. The first interval is of the order of 2 MeV wide and the second about 5 MeV. Both positions are very easily obtained experimentally.

The energy resolution will typically be 0.2% in the energy range 5 to 30 MeV with the lithium drifted detector supplied us by Nuclear Semicond.. We expect the resolution to remain better than 1% up to 50 MeV and better than 2% up to 100 MeV (Fig. 2).

Running Time, Experimental Results and Accuracy

A minimal set of experimental results can be considered a measurement of

a. $d\sigma/dM$ for 10 value of M in the range 2 to 10 BeV, with 20% relative accuracy over the entire range and 5% relative accuracy over a small mass range.

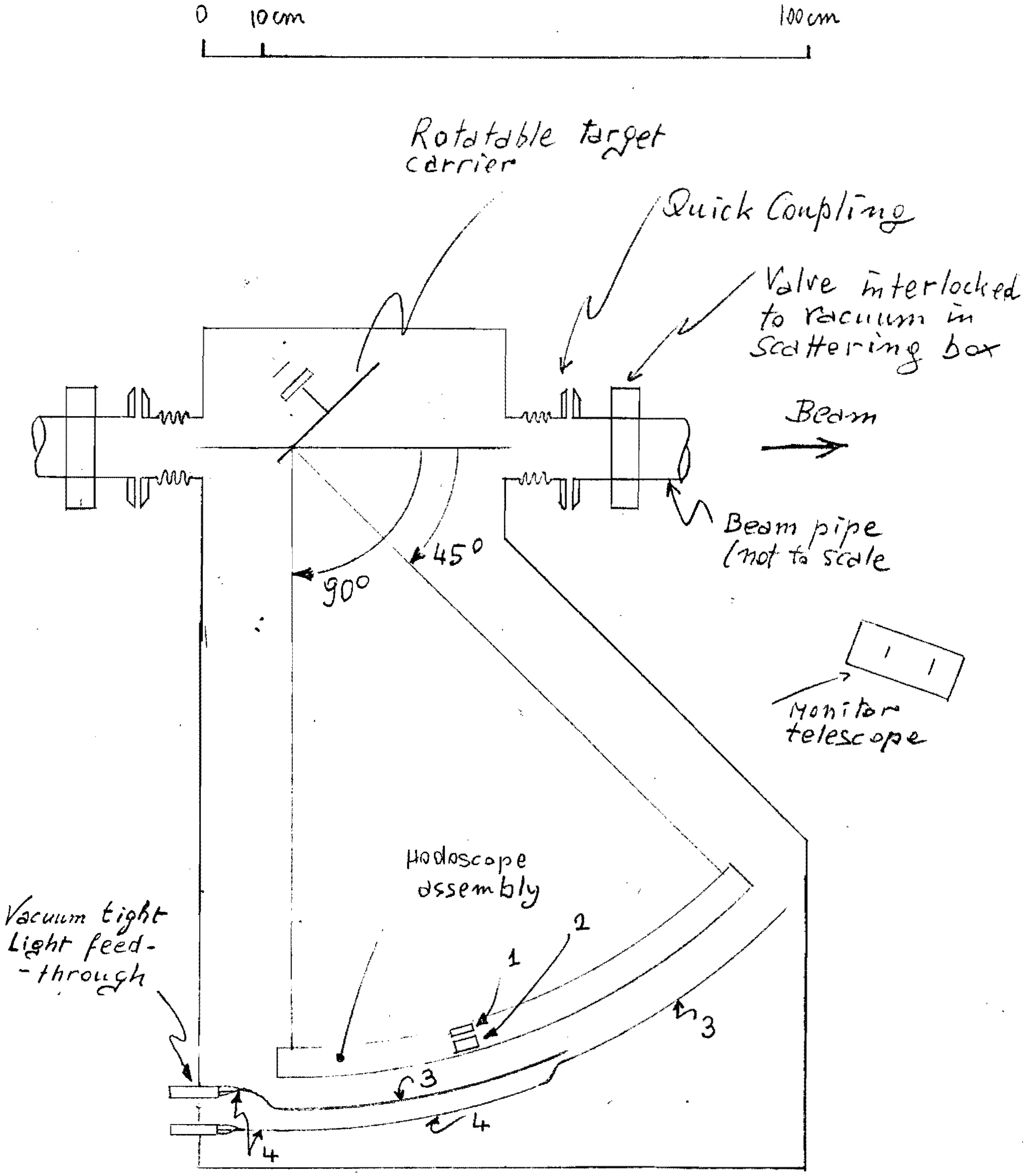
b. Assuming $d\sigma/dt \simeq ae^{-bt}$, a measurement of b for 10 values of M over the same range with an accuracy $\Delta b/b \simeq$ 5%. We assume in the following there are no errors in the subtraction other than statistical. Because of the subtraction, the errors are typically given by $\sqrt{25N}$ where N is the number of hydrogen events, and the total number of events is 25N.

To satisfy a), we need 25 x 10 x 10^4 events or 2.6 x 10^5 events. To satisfy b), we need 10 x 25 x 10^4 events. Our minimum rate is 20 x 20 = 400 events/pulse. This is also the maximum rate that our ~~recoiling~~ recording equipment can accept.

We thus need 2.5 x 10^6 ev/400 = 0.62 x 10^4 pulses = 6.2 x 10^3 pulses at 10^{11} to 10^{13} proton/pulse. We would want to run for approximately ten times as much data with various targets mostly to improve our understanding of backgrounds and to investigate problems connected with hydrogen losses in the target.

Calibration of these losses can be very simply obtained to the accuracy necessary here with standard analytical methods.

As mentioned previously, the most effect on the beam is to remove one part in 10^6, most likely one part in 10^8. Multiple scattering is totally negligible. Hence the experiment is completely parasitic. For this reason, we do not specify the setting up and running time, but leave this to be decided by logistics considerations.



1 200µ Surface barrier Si detector (not to scale)

2 5000µ Si (Li) Detector (not to scale)

3 Plastic Scintillator on Lucite

4 Lucite light pipe

Fig. 1

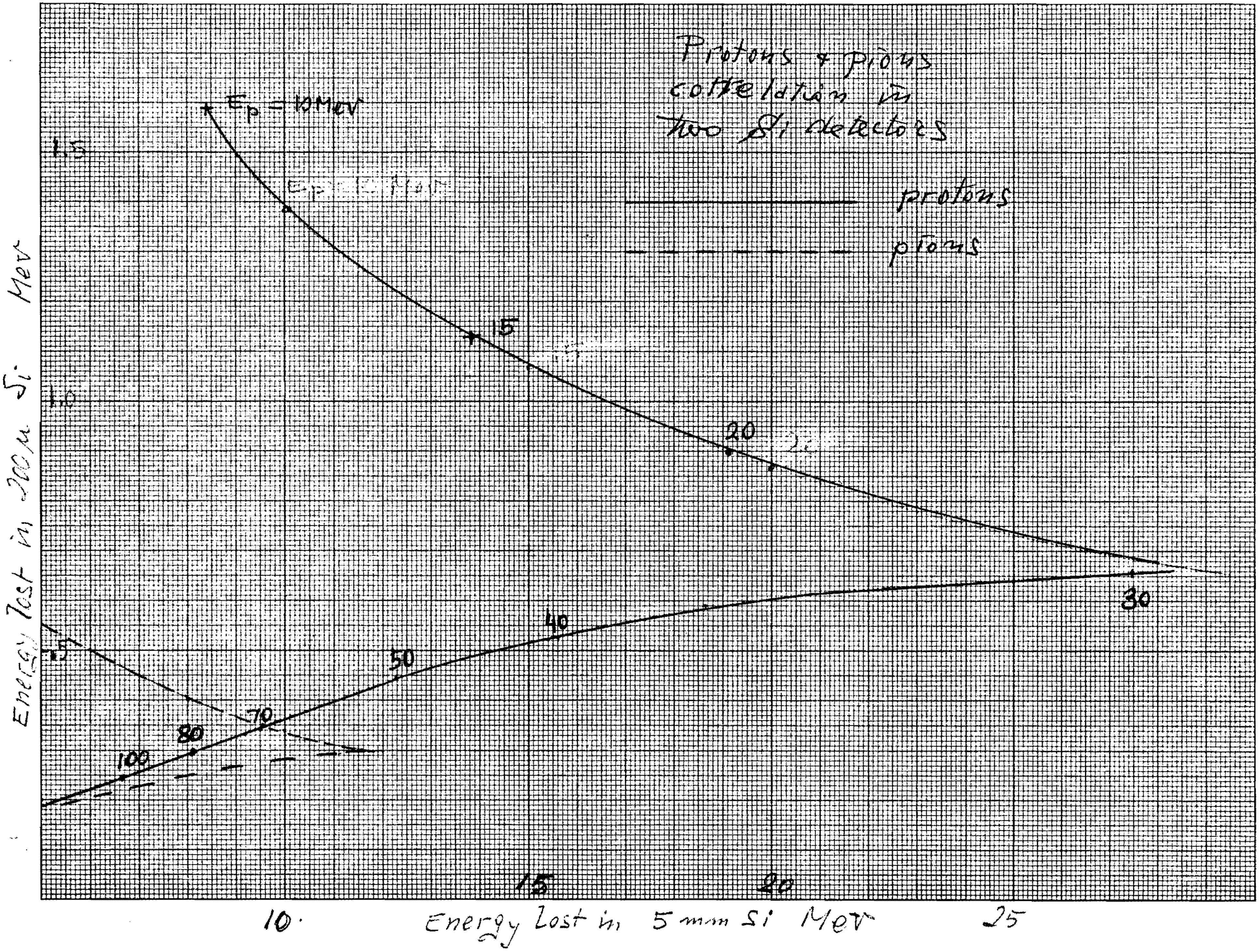

Protons + pions
correlation in
two Si detectors
protons
pions
Ep = 10 Mev
15
20
30
40
50
70
80
100
1.5
1.0
.5
Energy lost in 200μ Si Mev
15
20
10
25
Energy lost in 5 mm Si Mev

Fig 2