NAL PROPOSAL No. 110

Correspondent: J. Pine
P. O. Box 961
Mammoth Lakes, Cal.

714-934-6412

THE PEOPLE'S SPECTROMETER

A. Dzierba, G. Fox, R. Gomez, Y. Nagashima, J. Pine
California Institute of Technology

E. Malamud, R. Lundy
National Accelerator Laboratory

H. R. Bleiden
State University of New York at Stony Brook

W. Hoogland, M. Rabin, P. Schlein, W. Slater
University of California, Los Angeles

R. Abrams, S. Bernstein, H. Goldberg, S. Margulies, D. McLeod, J. Solomon
University of Illinois, Chicago Circle

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October 15, 1971 New Scientific Spokesman and Revised Participants

NAL PROPOSAL No. 110

Correspondent: M. Gettner
Department of Physics
Northeastern University
Boston, Mass 02115

FTS Offnet 617-223-2100
437-2938

THE PEOPLE'S SPECTROMETER

A. Dzierba, R. Gomez, Y. Nagashima, J. Pine
California Institute of Technology

E. Malamud, R. Lundy
National Accelerator Laboratory

D. Bowen, D. Earles, W. Faissler, D. Garelick, M. Gettner, B. Gottschalk
G. Lutz, E. Shibata, E. von Goeler, R. Weinstein
Northeastern University

H. R. Bleiden
State University of New York at Stony Brook

W. Hoogland, P. Schlein, W. Slater
University of California, Los Angeles

R. Abrams, S. Bernstein, H. Goldberg, S. Margulies, D. McLeod, J. Solomon
University of Illinois, Chicago Circle

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PROPOSAL TO STUDY MULTIPARTICLE PERIPHERAL HADRON PHYSICS AT NAL

Abstract

We propose to build a large wire chamber magnetic spectrometer at NAL to measure multi-body forward-going hadronic systems produced by π's, K's and protons up to 80 GeV/c. Specific reactions will be isolated in order to study the s and t dependences of the cross sections for peripheral processes, search for new resonant states and attempt to measure $\pi\pi$ and $K\pi$ inelastic scattering. We propose a physics program for the spectrometer which is initially limited to those processes easiest to measure and which nevertheless spans a large range of strong interaction problems. Technically, the proposed spectrometer is a relatively modest extension of presently operating systems in the 10-20 GeV/c region, and does not present a challenge of uncertain magnitude to construct.

A. Dzierba, R. Gomez, Y. Nagashima, J. Pine
California Institute of Technology, Pasadena, California

E. Malamud, R. Lundy
National Accelerator Laboratory, Batavia, Illinois

D. Bowen, D. Earles, W. Faissler, D. Garelick, M. Gettner, B. Gottschalk, G. Lutz, E. Shibata, E. von Goeler, R. Weinstein
Northeastern University, Boston, Massachusetts

H. R. Bleiden
State University of New York at Stony Brook, New York

W. Hoogland, P. Schlein, W. Slater
University of California, Los Angeles, California

R. Abrams, S. Bernstein, H. Goldberg, S. Margulies, D. McLeod, J. Solomon
University of Illinois, Chicago Circle, Chicago, Illinois

Correspondent: J. Pine - Caltech

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I. INTRODUCTION AND PHYSICS JUSTIFICATION

A. Introduction

We propose to build a large magnetic spectrometer at NAL to measure forward-going hadronic systems between 20 and 80 BeV/c. The particle detectors are a series of wire spark chambers, appropriately distributed before and after the magnet to optimize measurement resolution and solid angle acceptance and a large downstream hodoscopic Cerenkov counter to distinguish π's, K's and protons. Details of the spectrometer are described in Section II of this proposal.

Spectrometers of this type already exist at CERN,[1] BNL[2] and SLAC[3] to study physics in beams of momentum up to ~20 GeV/c. They have shown themselves capable of recording highly interesting data in a rapid and efficient way for a large number of reactions. We are proposing to extend measurements of this type up to P_{Lab} = 80 GeV/c beam momentum at NAL both in order to study the dependence of various reaction mechanisms on beam momentum and momentum transfer and also to search for higher mass states which decay into multi-body systems.

Although spectrometers of the type described here do not possess an intrinsic 4π solid angle detection capability, due to the peripheral nature of high energy reactions such 4π capability is approached and, in many cases, obtained in the rest frame of forward going systems. With detection of a recoil nucleon not required, the apparatus is almost entirely free of bias in momentum transfer. The type of physics studied with the spectrometer depends on the particular trigger used. With the aid of a downstream hodoscopic counter array which can select a predetermined

number of particles, we will be able to study systems of 2, 3, 4, 5, etc., forward-going particles (see Section III B for a detailed discussion of the different trigger modes of operation).

Table I contains a partial list of reactions which the spectrometer will be able to detect, grouped according to the beam particle and number of forward-going charged particles. In all cases only proton and neutron recoil reactions are shown.

Table I Examples of Multiparticle Reactions to be Studied

	$\pi^{\mp}$ beam	$K^{\mp}$ beam	P(or $\bar{P}$) beam
2	$(\pi^{\mp}\pi^{+})n$ $(K^{-}K^{+})n$	$(K^{\mp}\pi^{+})n$	$(P\pi^{+})n$
$3'_{(a)}$	$(K^{o}K^{\mp})P$ $\rightarrow(\pi^{-}\pi^{+}K^{\mp})P$	$(K^{o}\pi^{\mp})P$ $\rightarrow(\pi^{-}\pi^{+}\pi^{\mp})P$	—
3	$(\pi^{\mp}\pi^{-}\pi^{+})P$ $(\pi^{\mp}K^{-}K^{+})P$	$(K^{\mp}\pi^{-}\pi^{+})P$ $(K^{\mp}K^{-}K^{+})P$	$(P\pi^{-}\pi^{+})$ P $(PK^{-}K^{+})$ P
4	$(\pi^{\mp}\pi^{+}\pi^{-}\pi^{+})n$	$(K^{\mp}\pi^{+}\pi^{-}\pi^{+})n$	$(P\pi^{+}\pi^{-}\pi^{+})n$
4'	$(K^{o}\bar{K}^{o})n$	$(K^{o}\pi^{\mp}\pi^{+})n$	-

(a) 3' triggers are 2-body events which are detected as 3-body because of the K^{o} decay.

Reactions involving production of one or more π^{o} mesons have intentionally been left out of the table because we feel that, while interesting in their own right, their measurement with acceptable resolution involves another degree of complexity in the apparatus. We thus defer their consideration to a possible "second-phase" experiment.

For the present, detection of both fast and slow π^o's is done only as a means of excluding "background" processes.

Since the recoil nucleon is in general not detected, the purity of a given sample of events essentially depends on the electronic rejection of other recoil nucleon-pion systems with the same charge. This is accomplished with the use of a set of proportional wire chambers, plastic scintillator counters and lead sandwich shower counters which surround the liquid hydrogen target (see description in Section II of this proposal).

The physics analyses of the reactions contained in Table I can be discussed under the following broad catagories although there are unavoidable partial overlaps in the physics content of several of the sections.

B. s and t-dependence of Quasi-two-body Processes

A large number of such processes are contained in the reactions of Table I. The processes are of essentially two types, which differ according to whether there is or is not charge exchange to the recoil nucleon. The non-charge exchange reaction events (i.e., proton recoils) further subdivide into two groups depending on whether or not they are dominated by diffraction scattering.

(1) Non-charge exchange non-diffractive processes

Examples of these processes which are characterized by natural spin-parity meson systems are $\pi^{\pm}P \rightarrow A_2^{\pm}P \rightarrow K^oK^-P$ and $K^{\pm}P \rightarrow K^{*\pm}P$. These processes are interesting for many reasons. The recent CERN-Munich results[1] on the K^-K^oP reaction at 17 GeV/c show it to be dominated by A_2 production ($J^P = 2^+$) apparently from ρ-exchange (although f^o exchange may also contribute

and the relative amounts of each is presently an open question). A study of the momentum transfer dependence and decay angular correlation properties of the $\pi^- P \rightarrow A_2 P$ reactions as a function of beam momentum up to 80 GeV/c will yield information on the production mechanism. The CERN-Munich data also show evidence for g-meson production ($J^P = 3^-$) in the same final state. It will be possible to study this state as well as other presently unknown higher mass states.

It will also be possible to study the K^* production mechanism in the $(K^0\pi^\pm)^- P$ reaction. At present, for example, $K^*(890)^\pm P$ production ($J^P = 1^-, 2^+$) is believed to be dominantly produced by ω-f^0 exchange[4] although a relatively small amount of π-exchange also contributes. A study of this process and a comparison with the π-exchange dominated $K^{*0} n$ reaction at high momentum will provide useful clues to the unraveling of the different exchange contributions and their dependence on total-s.

(2) Diffraction processes.

Since the diffraction mechanism itself is so poorly understood theoretically, it will be extremely valuable to measure the s- and t-dependencies of various diffractive processes such as

$$\pi^\pm P \rightarrow A_1^\pm P \quad \text{and} \quad K^\pm P \rightarrow Q^\pm P.$$

The increased collimination of the forward meson systems at 80 GeV/c and the good acceptance of our proposed spectrometer (as discussed in Section III C) will also allow us to study the 3-pion system up to much higher mass (up to $M_{3\pi} \sim 6$ GeV with greater than 50% acceptance at 80 GeV/c) than is possible with exising spectrometer systems.

Current analyses of such processes using bubble chamber data

are attempting to determine the partial-wave structure of the 3-meson systems. The non-4π solid angle acceptance of our spectrometer (80% and 93% for $A_1^{\pm}P$ at 40 and 80 GeV/c, respectively) can be corrected for with the use of orthogonal functions of the internal variables in the 3-meson system.[5] Thus, we will be able to extend such analyses to higher beam momenta.

Furthermore, higher multiplicity diffraction processes such as $\pi P \rightarrow (5\pi^{\pm})P$, about which almost nothing is presently known may be studied up to $M_{5\pi} \sim 3.5$ GeV with greater than 50% acceptance. PP diffraction processes such as $PP \rightarrow (P\pi^+\pi^-)P$ can also be easily studied with the spectrometer.

(3) Charge exchange to recoil nucleon.

Examples of these processes are $\pi^-P \rightarrow \rho^0 n$, $K^-P \rightarrow K^{*0}n$, and $PP \rightarrow \Delta^{++}n$. They are believed to be dominated by one-pion exchange up to the highest momenta studied thus far. Studies of the s and t dependences of their differential cross sections and density matrix elements will allow us to question the validity of this picture more deeply than has previously been possible. For example, measurements of $d\sigma/dt$ at fixed t as a function of s should allow us to determine the effective Regge trajectory of a process. Dominance of pion exchange in all three reactions would require that they all yield the same results for this trajectory.

Whether or not pion exchange dominates these processes at high energy, a knowledge of their differential cross sections and density

matrix elements is certain to provide an important challenge to the theoretical models of their dynamics. One of the things we will want to study is the structure of $d\sigma/dt$ in the t-range $\sim$ 0.6-1.0 GeV^2, some variety of which is predicted by almost all models.

C. Search for New Resonances

Aside from general dynamical questions having to do with the dependence of processes on beam momentum (P_{Lab}), an important reason for operating at high P_{Lab} is that the angular acceptance of the spectrometer for a given mass multi-body system is larger. This fact will allow us to look for new resonance structure in 2π, 3π, 4π, 5π, etc., at higher mass values than has hitherto been possible. Highly inelastic resonances may only be seen in their multi-body decay modes. There are also some theoretical reasons[6] for believing that exotic resonances (e.g. T = 2 or 3/2 meson systems), if they exist, may preferentially decay into multi-body final states.

D. $\pi\pi$ and $K\pi$ Scattering

Because of the good multi-body acceptance characteristics of the spectrometer it will also be possible to study $\pi\pi$ and $K\pi$ inelastic scattering. For example, the differential cross section for the process $\pi^- P \rightarrow (4\pi^{\pm})n$ at fixed $M_{4\pi}$ may be extrapolated to the pion-exchange pole to obtain the cross section for $\pi^-\pi^+ \rightarrow 4\pi^{\pm}$. In order to test the validity of such procedures, $P\pi^-$ and $P\pi^+$ inelastic cross sections have been obtained[7] from studies of the processes $PP \rightarrow \Delta^{++}(P\pi^-)$, $\Delta^{++}(n\pi^-\pi^+)$, $\Delta^{++}(P\pi^-\pi^o)$, Δ^{++} (all neutrals) and $PP \rightarrow n(P\pi^+)$, $n(P\pi^+\pi^-\pi^+)$ at 6.6 GeV/c. Similar results have also been obtained[8] from the $PP \rightarrow \Delta^{++}(X)$ reactions at

28.5 GeV/c beam momentum.

A recent analysis of the reactions $\pi^- P \rightarrow n(K^+K^-)$, $n(K_1^oK_1^o)$, $n(4\pi^\pm)$ by a CERN-Munich-Zurich-Hawaii collaboration [9] has shown that the $T = 0$ s-wave $\pi\pi$ interaction becomes highly (perhaps fully) inelastic within the first ~30 MeV above $K\bar{K}$ threshold. The limitation of this analysis was the poor statistics in the $4\pi^\pm$ reaction; further studies of this type must be with high statistics electronics experiments with good acceptance for the $4\pi^\pm$ system above 1 GeV mass. This would be possible with our apparatus.

II. APPARATUS

A. Introduction

The spectrometer, as depicted in Figure 1, consists of two main parts: (a) the detectors which surround the hydrogen target, and (b) the forward spectrometer itself, with its wire planes, magnet and gas Cerenkov counter.

The overall scale of the apparatus is set by the magnet size, which in turn is established by considerations of solid angle acceptance and momentum resolution. As will be pointed out in Section III (Performance Parameters) the spectrometer solid angle coverage in the rest frame of a forward-going peripherally produced system is excellent, as is the mass resolution for this system. The target house, and its detectors will be movable, so that the distance to the magnet can be varied over the range of about 1.5 to 5 meters. As a result a trade-off between mass resolution and solid angle coverage will be possible, as dictated by specific physics goals.

The momentum measuring accuracy does not make it possible to infer the presence of missing neutrals with mass 140 MeV, from energy balance for the charged particles. To make this possible would be costly, in that the magnet and detector sizes would increase by more than a factor of two, and is not justified in our opinion. In the proposed experiment, missing π^{o}'s are detected by energy balance for energies greater than about 1 GeV and by gamma ray detection and transverse momentum balance at lower energies.

Included among those proposing this experiment are people who are interested in extending the capabilities of the apparatus in various ways.

For example, more detailed measurements of slow particles emerging from the target, or of gamma rays from forward π^o's and η^o's, would both be interesting. We believe, however, that the primary need is for a forward spectrometer of high quality, and that the physics learned solely with this instrument will be an important guide in pursuing further studies and in designing more detailed experiments.

B. Beam Measurements

The experiment is planned for the 15 mrad., 80 GeV, beam. Beam Cerenkov counters will be used to identify π's, K's or protons in the beam. Furthermore, beam hodoscopes will be needed to fully utilize energy and momentum balance. One hodoscope will be at the last momentum focus, to determine P_{Lab} to $\pm 0.1\%$. A second hodoscope will be used to measure the position of each beam particle at the exit of the last quadrupole. Since the beam will focus to about 3 mm width or less at the H_2 target (more than 30 meters downstream) this last measurement determines the angle of each beam particle ± 0.1 mrad.

C. Target and Anti-counter House

In addition to a 30 cm long and 6 mm wide H_2 target, this consists basically of two parts: (i) A charged particle detector, in the form of a cylindrical array of proportional wires, parallel to the target. (ii) A lead sandwich shower counter array to veto γ's, which surrounds the above assembly, except for a forward opening to permit charge particles to emerge. Other γ-vetoes are placed just before the magnet to intercept and reject some γ's which can emerge through the forward aperture of the target house. Additional downstream γ-veto counters, behind the last wire planes,

will also be added if more detailed design calculations indicate that they are necessary.

The cylindrical proportional chamber, with roughly 100 wires, will be used to count the number of particles emerging from the target at large angles, while a downstream proportional chamber, labeled H2 on Figure 1, counts the number of forward particles. Together, these provide information for triggering the wire chamber system.

The cylindrical chamber around the target also provides a measurement of azimuthal angle for large-angle charged particles, which is useful in later kinematical analysis. A small set of proportional chambers, H1, is used to measure the beam coordinates in order to improve the accuracy of the azimuthal angle measurements.

The gamma ray vetoes are formed by a cylindrical array of counters. In order to avoid vetoing on charged particles, fast logic will remove from the veto circuit the sandwich counters behind proportional wires which have signals. With twenty-four sandwich counters in the array, we expect that for one charged particle the gamma ray veto will on the average be greater than 90% efficient.

D. Forward Spectrometer

Four groups of 6 to 12 wire planes each are positioned relative to the magnet and gas Cerenkov counter at C_1, C_2, C_3, and C_4, as shown in Figure 1. The proportional chamber H2, positioned downstream of the target serves as a trigger hodoscope and measures the number of forward charged particles emerging from the hydrogen target. A second trigger hodoscope H3 (consisting of an array of proportional counters or scintillation counters)

is positioned just after C_3 to measure the number of charged particles which emerge from the magnet. By requiring that the number of charged particles emerging from the target and from the magnet be equal, we hope to avoid lining the inside surfaces of the magnet with anti-counters. Furthermore, a forward Vee trigger, for K^o's or Λ^o's, is made by requiring that the number of particles at H3 is two greater than at H2.

The magnet has pole faces 2 m wide x 3 m long, with a gap spacing of 1.5 m. The field has been assumed to be 18 Kgauss. A superconducting magnet appears feasible and economical. Figure 2 shows a sketch of the cross section of such a magnet. The magnet yoke should probably be constructed of ground low carbon steel plates, arranged as coarse laminations (about 12" thick). This results in low iron cost and gives flexible access to the inner region through vertical slots in the top and bottom faces.

The box shaped cryostat embodies tension members which cross the pole faces at low temperature, and which take the major coil forces. The cryostat for these members should have periodic openings above which access slots in the iron can be located. As a result of this cryostat design, the load which must be supported by structural supports which terminate at room temperature is essentially limited to the dead weight of the cryostat and coil. The much larger magnetic forces are not carried by these supports. As a result the heat leak is much reduced, and the refrigeration cost greatly lowered.

A smaller magnet embodying the main features described above has been designed at NAL and is soon to be built. It will serve as a very good check on the actual feasibility of using low cost steel and a box cryostat.

The large gas Cerenkov counter will be used to identify π's, K's, and protons. The desired refractive index for a given beam momentum and type of operation can be obtained over the range of this experiment by an appropriate mixture of gases at atmospheric pressure, thus greatly simplifying the structure. Furthermore, the Cerenkov light is so well collimated along the direction of particle motion that a small array of phototubes can collect all the light and provide separate information on each of two or more particles traversing the counter along different paths. The counter is discussed in more detail in Appendix II.

E. Computers

A minimum on-line computer requirement is that we be able to monitor the performance of the wire chambers and counters and to log the data on tape for later off-line event reconstruction and analysis. It would, however, be very undesirable if this experiment were limited to this minimum on-line capability. During the setup of triggers it will be very important to receive rapid and detailed information about the actual events selected by the trigger. Some events should be reconstructed on line, effective mass and missing mass calculations made, and histograms of interesting kinematical quantities made available. The data rates are high enough so that such information can often be available after a very small amount of running time.

The on-line computer should also be able to fully analyze a sample of the data during steady running, to establish that the overall behavior of the apparatus is correct, and to give useful physics information to guide the planning of succeeding runs. There is such a broad

spectrum of possible operating conditions for the spectrometer that run planning will require the maximum amount of rapidly available information on the physics which is being observed.

In order to provide adequate on-line computer power we plan to utilize the Northeastern University PDP-9 system and the Chicago Circle Super Nova. The PDP-9 is well equipped to log the data onto tape and to perform diagnostic checks of the experimental apparatus, while the Super Nova will provide good on-line analysis capability. The full details of the two-computer system need to be worked out, but we feel sure that the necessary computer power for efficient running will be availalbe. Strong off-line analysis capability exists at several of the participating institutions. We can also look forward to off-line batch processing with short turnaround times when needed.

III. PERFORMANCE PARAMETERS

The usefulness of this spectrometer as an experimental tool is characterized by the rate at which data can be collected without saturating the capabilities of the apparatus as well as by the mass resolution. The rate at which we expect to collect data in turn is dependent on the estimated flux of each type of beam particle, the geometrical detection efficiency, the triggering scheme, and the dynamics of the process being studied. These are discussed below.

A. Rates

The event rates per unit cross section for each type of beam particle are given in Table II. The beam yields were estimated from a Hagedorn-Ranft calculation for the 15 mrad. beam (A. Wehmann, private communication), with $\delta p/p = .4\%$, assuming a 30 cm hydrogen target and 3×10^{12} protons/pulse in the primary beam. An upper limit to the beam flux was set by requiring that the probability of an interacting beam particle within 2 μsec of a trigger be $\leq 10\%$.

Table II: Estimated Yields Expressed as Interactions/Hour/μbarn

Beam Energy	Charge	Beam Particle p	π	K
40	+	500	700	50
40	-	60	1400	60
80	+	800	300	40
80	-	14	200	14

In trying to estimate the cross sections for processes being studied here we have made use of the experimentally observed power law dependence of cross section on lab momenta, i.e., p_{lab}^{-n} . Only a few specific reactions will be discussed here to give an idea of what typical cross-sections will look like.

(i) $\underline{\pi^- p \to \rho^o n}$

At 17 GeV/c this cross section is ~50 μb and follows a p_{lab}^{-2} law. Thus at 40 and 80 GeV/c we expect ~9 and ~2 μb respectively. It should be noted that the $\rho^o n$ final state which leads to $\pi^-\pi^+ n$ is less than 10% of the total $\pi^-\pi^+ n$ cross section at these energies. Thus we expect the cross section for producing the $\pi^-\pi^+ n$ final state to be $\gtrsim$20 μb at 80 GeV/c. Included in these non- ρ^o events are the f^o, g^o and as yet undiscovered higher-mass 2π resonances as well as non-resonant ππ data.

(ii) $\underline{pp \to \Delta^{++}(1238)n \to p\pi^+ n}$

At 17 GeV/c this cross section is ~230 μbarn and also has a p_{Lab}^{-2} dependence on beam momentum. Since we only detect that half of the cross section which corresponds to fast forward Δ^{++} in the laboratory, we have ~21 and ~5 μbarn at 40 and 80 GeV/c respectively.

(iii) $\underline{\pi^- p \to (\pi^-\pi^+\pi^-)\ p}$

It is known that the cross section for this reaction in specific 3π mass ranges is approximately independent of beam momentum in the range 8-20 GeV/c with the cross sections given in Table III.

Table III 3π P cross Sections from 8-20 GeV/c

3π Mass Range	Cross Section
0.8---1.0 GeV	50 μb
1.0--1.2	150 μb
1.2--1.4	150 μb

The $Kp \rightarrow (K\pi\ \pi)p$ and $pp \rightarrow (p\pi\ \pi)p$ reactions in Table I have comparable behavior and cross section.

(iv) $\underline{\pi^- p \rightarrow A_2^- p \rightarrow K^o K^- p \rightarrow \pi^- \pi^+ K^- P}$

At 17 GeV/c this cross section is about 2 μbarn. Although the dependence on P_{Lab} is not reliably known, if we assume P_{Lab}^{-2} we get 0.4 and 0.1 barn at 40 and 80 GeV/c respectively.

B. Triggering

The trigger requirements will mainly be established in terms of numbers of "forward" tracks, in hodoscopes H2 and H3, and total number of tracks, found from H2 and the cylindrical proportional chamber around the target. Four typical triggers, which are among the most important ones, are specified below. The entries in the table are numbers of particles detected, where N is the total.

Trigger	H2	H3	N	Sample Final State
(a)	2	2	2	$(\pi^+\pi^-)n$
(b)	4	4	4	$(\pi^+\pi^-\pi^+\pi^-)n$
(c)	1	3	1 or 2	$(K^-\ K^o)p$
(d)	3	3	3 or 4	$(\pi^+\pi^-\pi^+)p$

The number N must be allowed to have two values for events with recoil protons, since at very low t the protons will not leave the target.

For all triggers, the gamma ray vetoes are expected to reduce triggering on processes with slow π^{o}'s by a factor $\gtrsim 100$, leading to trigger rates determined by the cross section for all-charged states. For fast forward π^{o}'s, there may or may not be a veto from counters after the gas Cerenkov counter. If not, triggers will be up on the average, perhaps a factor 3 over the all-charged rates.
The presence of fast π^{o}'s will of course be detected in the later analysis by energy balance.

A major problem is to control the acceptance of triggers generated by diffractive processes. Since the cross sections are so large, they would swamp the data logging and analysis. Triggers a-c above reject diffractive processes effectively by requirements noted below:

(a) N requirement (High t elastic scattering accepted, but not a problem)

(b) H2 and H3 protect against 4-prong diffractive events, while N protects against 6-prongs.

(c) H2 and N

Diffractive data can be collected by using trigger (d) with a preset limit on the number accepted per beam spill.

There are a great variety of "dirt" effects which also need to be examined to be sure the triggering is effective. For example, owing to physics and geometry, N may be recorded in excess of its true value. This does not, however, lead to any "leakage" of diffractive processes into non-diffractive triggers. We have examined a variety of such fine

points and have concluded that clean triggering is no problem. Experience with operating systems at 10-20 GeV confirms the expectation that triggering can be effectively achieved for the types of reactions of primary interest in this proposal.

C. Acceptance

In order to illustrate the acceptance properties of the proposed spectrometer for multi-body events, we present in Figure 3-6 the acceptance vs mass of the multi-pion systems in the following reactions:

$$\pi p \rightarrow (2\ \pi^{\pm})n$$

$$\pi p \rightarrow (3\ \pi^{\pm})p$$

$$\pi p \rightarrow (4\ \pi^{\pm})n$$

$$\pi p \rightarrow (5\ \pi^{\pm})p$$

for minimum momentum transfer t from proton to final state nucleons (since the acceptance is only weekly dependent on t, this selection is of little importance). Figures 3 and 4 contain the acceptances vs mass of the multi-pion system for the 2 $\pi^{\pm}$ and 3 $\pi^{\pm}$ reactions respectively. In each case curves are shown for 20, 40 and 80 GeV/c beam momentum and for two extreme target-magnet spacings, 1.5 and 5.0 meters. The acceptance for higher multiplicity events at 80 GeV is shown in Figure 5a, b for the 1.5 and 5.0 meter target-magnet spacing respectively; the curves show how the acceptance depends on the number of pions for several masses of the multi-pion system.

These acceptances were calculated for phase space distribution of the internal variables in the multi-pion system. For purposes of

surveying the acceptance properties of the spectrometer, this is of relatively little importance for most multi-pion reactions, but for the $(2\ \pi^{\pm})n$ reaction this means that the acceptance is given for a di-pion reaction with an isotropic distribution in the di-pion rest frame. Since the θ distribution in this rest frame is observed to be peaked forward at large mass (characteristic of diffraction scattering), whereas the acceptance falls off near $\cos\theta = 1$, the effective acceptance of the spectrometer for this reaction is actually less than is shown in Figure 3. It is thus interesting to examine the acceptance function vs $\cos\theta$. This is shown in Figure 6 for several different di-pion mass values (1.8, 2.8 and 3.8 GeV). Although the polar part of the distribution is cut off quite severely at large mass, thus removing most of the diffractive peak, the variation of large ℓ Legendre coefficients with mass can still be detected in the observed part of the angular distribution given sufficient statistics.

In order to study forward θ (i.e., diffractive) part of the $\pi\pi$ angular distributions, we will use the smaller 1.5 m target-magnet separation which has the much improved polar acceptance. The resulting loss of mass resolution (for the 1.5 m configuration) is of little importance for the study of diffraction scattering(high mass resolution is mainly interesting in the study of resonance effects).

D. Mass Resolutions

(i) Effective mass resolution: For the experimental layout of Figure 1 (5 meter target-magnet separation) and 54 Kg meters of field integral, we show in Table IV estimated net mass uncertainties for several di-pion mass values at both 40 and 80 GeV/c beam momentum (see Appendix I for derivation).

Table IV Estimated Di-pion Mass Resolutions (Standard errors, in MeV)

P_{Lab} \ eff. mass	1 GeV	2 GeV	4 GeV
40 GeV/c	±6	±7	±9
80 GeV/c	±7	±9	±13

The mass resolution is found to be exceedingly good. The uncertainty arises about equally from momentum errors and multiple scattering.

(ii) Missing Mass Resolutions: In this type of spectrometer, the missing mass measurement error (δM_x) is too large to identify the nature of the recoiling (slow) nucleon system without additional electronic suppression of pion-production events as described in Section II A. Nevertheless, it is desirable to keep δM_x as small as possible to aid in the separation. δM_s can be shown to depend on the uncertainty in beam and forward particle system energies as (see Appendix I):

$$\delta M_x = \left(\frac{m_p}{M_x}\right)\left[(\delta E_{beam})^2 + (\delta E_{\substack{forward \\ system}})^2\right]^{\frac{1}{2}}$$

With the aid of one of the beam hodoscopes mentioned in Section II D, $\delta E_{beam} \sim 0.1\%$ while $\delta E_{forward}$ in $\sim 0.5\%$ (see Appendix I). Typical uncertainties in Missing Mass are given in Table V:

Table V Uncertainties in Missing Mass M_x

P_{Lab}	M_k = 938	M_x = 1240	M_x = 2000 MeV
40 GeV/c	±80 MeV	±60	±40
80 GeV/c	±320 MeV	±240	±160

IV. PERSONNEL AND ORGANIZATION

There are twenty-five people from six institutions involved in this proposal. Originally we submitted three separate proposals (numbers 35, 51, and 54), and were brought together by NAL to see whether we would find a significant area of common interest. We have had two long meetings and have found the group to be both personally congenial and united behind the forward spectrometer physics of this proposal.

The organization we envision is an involvement of all of us in building the forward spectrometer and studying the physics of this proposal, followed by a period when subsets of the total group can expect to be able to pursue specialized interests. The main spectrometer will remain central to these later runs, perhaps with additions, modifications of geometry, or other changes.

When we investigate the manpower available to work on the spectrometer and this experiment, the estimated number of full time people rises smoothly from about four in spring 1971 to 24 by summer 1972. With this manpower, plus our resources in both money and equipment, we feel confident that the forward spectrometer can be built to coincide with the earliest availability of the magnet.

We expect that others, as well as ourselves, will be interested in continuing to use the spectrometer after the initial experiment described in this proposal is completed. It would be very wasteful to construct such a setup and then dismantle it before it had been fully

utilized. We will therefore be prepared to work out arrangements under which the apparatus can be made available for open use. However, we request a period of time, following the initial experiment, during which we will have priority in the use of the apparatus. Considering our efforts in building the spectrometer, and our interests in more specialized uses of it, a total running time of about a year during which we enjoy priority seems reasonable.

V. MATERIAL RESOURCES

The main items of equipment needed for the experiment are listed below. For each item, either NAL Experimental Facilities (NALXF), or one or more of the participating institutions (initials NAL indicate NAL experimenters, in distinction to NALXF), is listed as the source. The list reflects presently owned equipment as well as equipment to be purchased or built by the experimenters.

We have estimated that the total of new equipment funds available from the participants is about 150K dollars, while the amount needed exceeds this by about 20%. At this early stage in the planning, this mismatch is within the estimated error. In particular we anticipate reduced costs due to improvements in the technology of wire chambers and readout systems.

BEAM

Momentum and angle hodoscopes	UICC, NAL
Gas Cerenkov counters	NAL
Beam defining counters	NAL

TARGET REGION

Target	NALXF
Proportional planes	UICC, NE
Gamma Ray Vetoes	CIT

WIRE CHAMBER SYSTEM	
Chambers	NE, NAL
Magnetostrictive Readout System	NE, CIT
Gas recirculator	CIT
High Voltage Pulsing system	SUNY
MAGNET	
Cryostat and superconducting Coils	NALXF
Iron	NALXF
Support structure and assembly fixtures	NALXF
TRIGGER SYSTEM	
Counter hodoscopes	SUNY, UCLA
Electric Logic	CIT, UCLA
GAS CERENKOV COUNTER	CIT

ON-LINE COMPUTERS: NE(PDP-9, 8K, with interface, tape, other peripherals), data logging and diagnostics

IUCC (Super Nova, 16K, 800nsec, 256K disc, tape, display scope, other peripherals), on-line reconstruction and analysis.

VI. RUN PLAN

We expect to run the apparatus with a variety of triggers in parallel, and for all types of beam particles of a given sign simultaneously. It is still necessary to run sequentially at different beam energies, different signs of the beam, and different Cerenkov counter settings.

Initially, we would expect to run briefly near 20 GeV/c to verify that our cross sections are consistent with previous data. Then we would want to make an initial exploration of the full energy range by running for about 200 hours each at 40 and 80 GeV/c, with both signs of beam and with the Cerenkov counter set for both π-k separation and proton-meson separation. To keep an optimum combination of mass resolution and solid angle acceptance, the target to magnet distance will vary from about 1.5 meters at 20 GeV/c to about 5 meters at 80 GeV/c. The total running of about 400 hours, split among beam settings and Cerenkov counter settings will provide an overview of the most accessible physics, including a chance to see any obvious surprises.

Further running will be dictated by the results of this first series of runs, as well as by desires to study selected reactions with smaller yields or acceptances. (Processes occurring with incident K's and anti-protons are particularly likely to require further time.) It is reasonable to expect that a calendar time of about six months from the start of real running will suffice to accumulate enough data with the spectrometer configuration shown in Figure 1.

Following this phase of the running, we anticipate that various members of the large group making this proposal will want to pursue

exploratory runs with modifications of the apparatus, and to request beam time for serious data taking if such runs are successful. We would like to allocate a total time of one year after the start of data taking for such runs, and to request priority on the use of the apparatus during this time.

An outline of the plan discussed above, in terms of calendar months, including checkout, is given below, on the assumption that beam is available without any long interruptions and at a reasonable average intensity:

Elapsed Time	Operation
0	Begin checkout, following setup of apparatus.
3 mos.	Begin first round of running at 40 and 80 GeV.
6 mos.	End first round of runs; begin more specialized second round runs.
9 mos.	End of runs covered by this proposal; begin runs with modifications and additions to the forward spectrometer.
15 mos.	End of period when proposers enjoy priority.

APPENDIX I Calculations of Mass Resolutions

A. The effective mass of the forward-going particles is given by the expression

$$M^2 = \left(\sum_i E_i\right)^2 - \left(\Sigma p_i\right)^2$$

For two particles at high energies, with small values of θ_{12} , the angle between the two particles, this formula is well approximated by:

$$M^2 \approx p_1 p_2 \theta_{12}^2$$

$$\frac{\Delta M}{M} = \left\{ \frac{1}{4}\left[\left(\frac{\delta p_1}{p_1}\right)^2 + \left(\frac{\delta p_2}{p_2}\right)^2\right] + \left(\frac{\delta \theta_{12}}{\theta_{12}}\right)^2 \right\}^{1/2}$$

In estimating the performance of the spectrometer this two body small angle case is a good guide.

The geometry of the experiment is assumed to be as in Figure 1. The uncertainties in the wire chamber measurement at the group of chambers immediately after the target is taken to be ±0.2 mm., and the uncertainty at the other measuring stations, which require large chambers, is taken to be ±0.4 mm. With these uncertainties, and 54 kg-meters of field integral, the momentum uncertainty for measurements utilizing the four sets of planes is given by:

$$\left(\frac{\delta p}{p}\right)_4 = \left(0.007\, p_{\mathrm{GeV}/c}\right)\%$$

If only the first three sets of wire chambers are used, the precision is about three times worse:

$$\left(\frac{\delta p}{p}\right)_3 = (0.02\ P_{\text{GeV/c}})\ \%$$

For lower energy particles, which occur at larger angles, it is not necessary that they reach the last set of chambers in order to achieve satisfactory accuracy. Furthermore, these particles are also of such low momenta that the Cerenkov counter is not well tuned for them. Therefore, the size of the gas counter and final set of wire planes need not be set by the solid angle required for these particles.

The angular error introduced by the wire chamber data introduces a mass uncertainty negligible in comparison with that from momentum errors. The di-pion effective mass uncertainty is then found to be approximately given by the following result, when averaged over the spectrometer acceptance:

$$\frac{\delta M}{M} = (0.004\, p^{\text{BEAM}}_{\text{GeV/c}})\ \%$$

Where P_{Beam} is the di-pion energy (or beam energy) in the lab.

The effect of multiple scattering in the target materials is estimated to introduce a mass error of about ±6 MeV, essentially independent of incident energy and di-pion mass. These considerations lead to the results shown in Table IV, Section III B.

B. Missing Mass Resolution

The mass of the recoiling nucleon system M_x is given by:

$$M_X^2 = |(p_{BEAM} - p_{FORWARD}) + p_{TARGET}|^2$$

$$= t + m_p^2 + 2(p_{BEAM} - p_{FORWARD}) - p_{TARGET}$$

$$= t + m_p^2 + 2m_p(E_{BEAM} - E_{FORWARD})$$

$$\delta M_X \cong \frac{m_p}{M_X}\left[(\delta E_{BEAM})^2 + (\delta E_{FORWARD})^2\right]^{1/2}$$

with $\delta E_{beam} \approx 0.1\%$ of 80 GeV and $\delta E_{forward} \approx 0.5\%$ of 80 GeV we obtain the results given in Table V. The error in the missing mass is dominated by the error in measuring the energy of the forward going system.

APPENDIX II Gas Cerenkov Counter

The general layout of this counter is shown in Figure 7. It consists of a 10 meter long gas radiator, a 4 meter by 3 meter area of concave mirrors, and twelve 2" photomultipliers. All the light produced by particles which reach the last set of spark chambers is focused on an area about 40 cm x 5 cm. The optics are arranged in such a way that there is a fairly good correlation between the particle momentum, its charge (sign), and the position on the photomultiplier plane where the light is focused. This arrangement permits the simultaneous and independent measurement of the Cerenkov light produced by two particles with opposite charge, or with the same sign of charge, but significantly different momentum (20 GeV/c and 40 GeV/c, for example).

The n-1 (index of refraction minus one) for the radiator is 10^{-4} for a pion threshold of 10 GeV/c and 4.5×10^{-5} for a threshold of 15 GeV/c. These low indices will be obtained by using a mixture of helium and argon at atmospheric pressure, so that the gas container only has to be light tight but does not have to have any significant mechanical strength. The large concave mirror can be a combination of smaller mirrors.

In order to estimate the performance of the counter, the Cerenkov light spectrum has been folded over the published response of the RCA C31000D photomultiplier.

At 80 GeV/c, a reasonable operating point for the counter is with the threshold at 15 GeV for pions. Figure 8a shows the number of photoelectrons as a function of pion and kaon momentum for this case. The π-K separation becomes most difficult at high momentum, and Figure 8b shows

the integral photoelectron distributions at 70 GeV/c. The integral probabilities are for greater than the indicated number of photoelectrons for kaons and less than the number of photoelectrons for pions.

In discussing threshold pulse height criteria for the counter, we envision establishing the criteria after the wire chamber data have been analyzed, so that momentum-dependent criteria are possible. The pulse height will be recorded for each phototube. If it is desired to select pions, Figure 8b shows that a threshold of 9 photoelectrons at 70 GeV/c gives 60% pion efficiency and 2% kaon efficiency. Even at this high momentum the counter performs usefully, and the π-K separation becomes much better for lower values of momentum.

There are three types of two-meson combinations which the counter is intended to identify: π-π, π-K, and K-K. To select π-π events the pulse height required will be set low for momenta below K-threshold, and relatively high above this momentum, to minimize the chance that a K appears to be a π. For the π-K state the pulse height required above K-threshold should be set relatively low, to minimize a chance that a pion is identified as a kaon.

In order to distinguish protons from kaons, the counter must be run at a higher index of refraction, which is accessible without exceeding a pressure of one atmosphere. Good separation can be obtained for a wide range of proton momentum. At beam momenta lower than 80 GeV/c it will be necessary to lower the Cerenkov threshold. In this case the performance of the counter will be improved because of better photon statistics.

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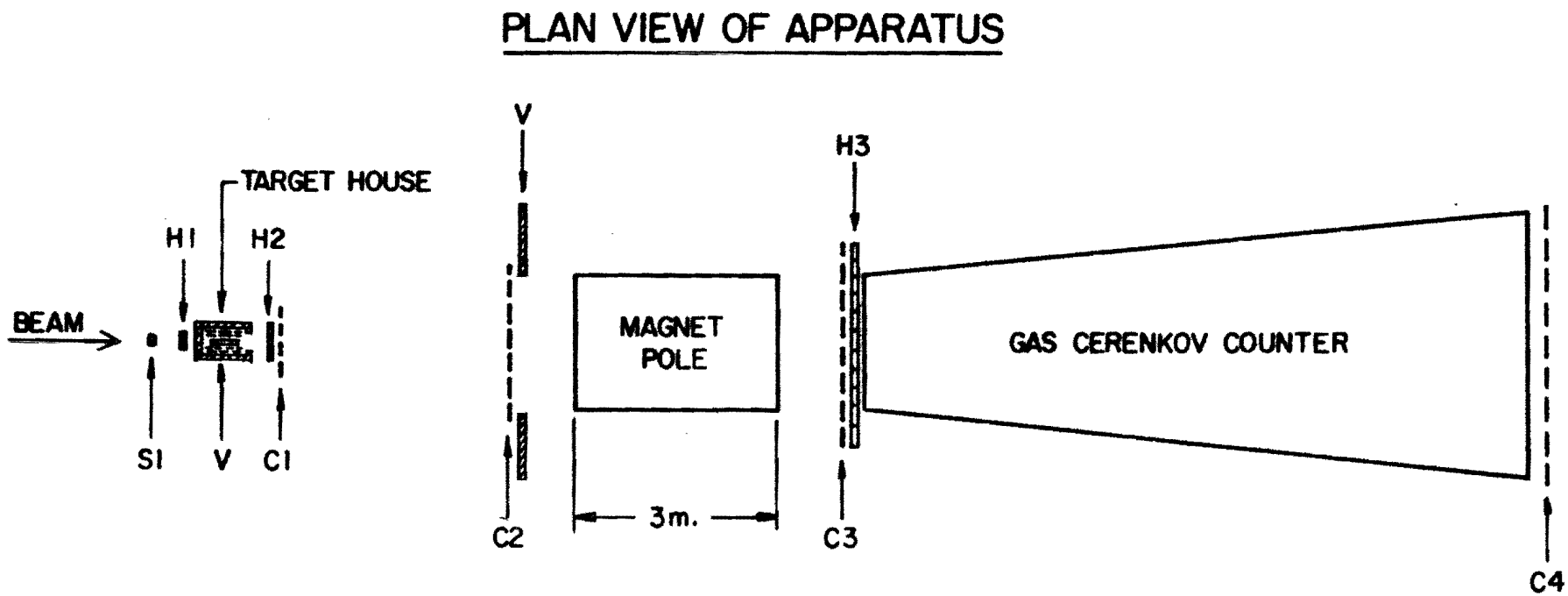


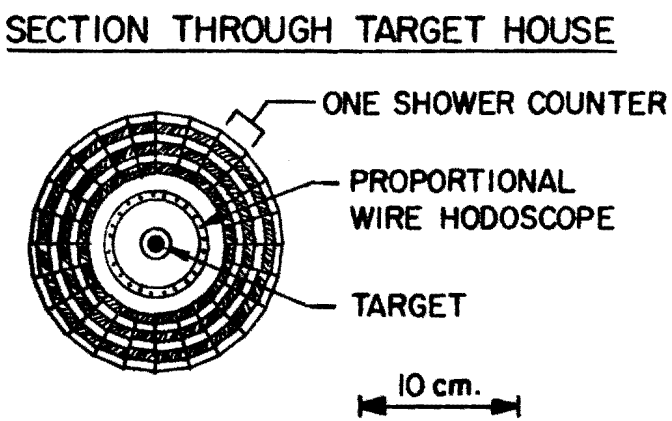


Figure 1. Schematic view of spectrometer.

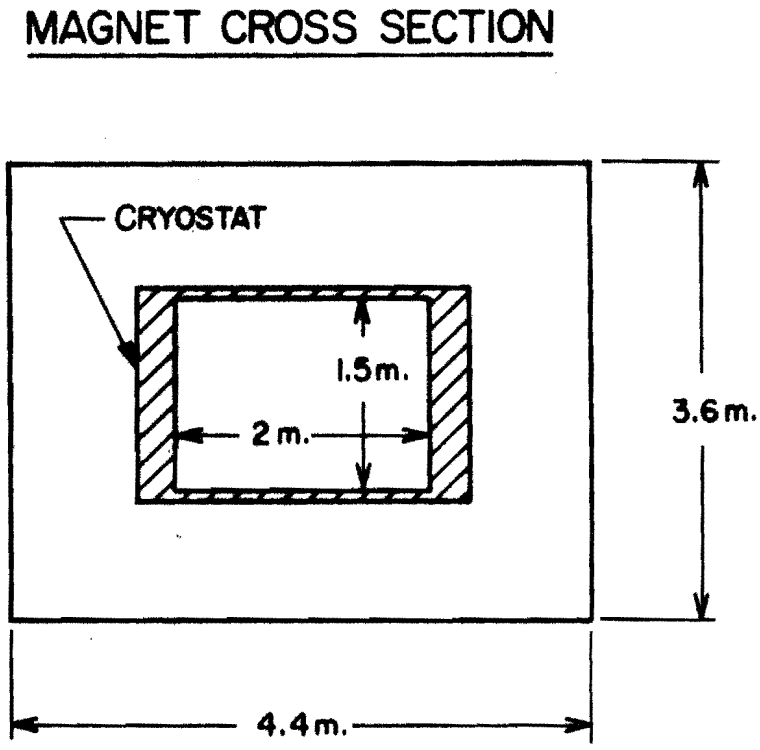
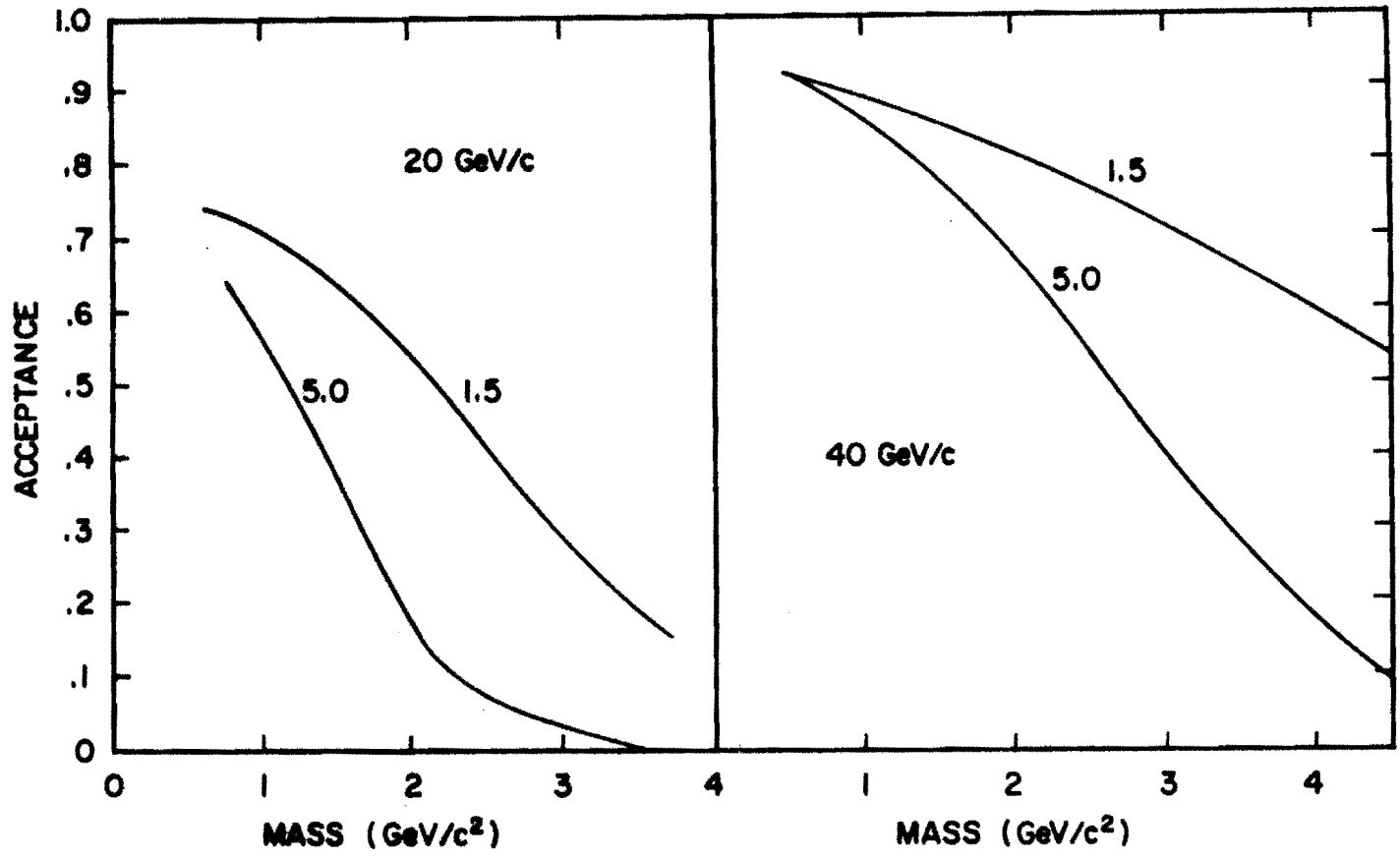


Figure 2. Cross section of a possible superconducting magnet configuration.



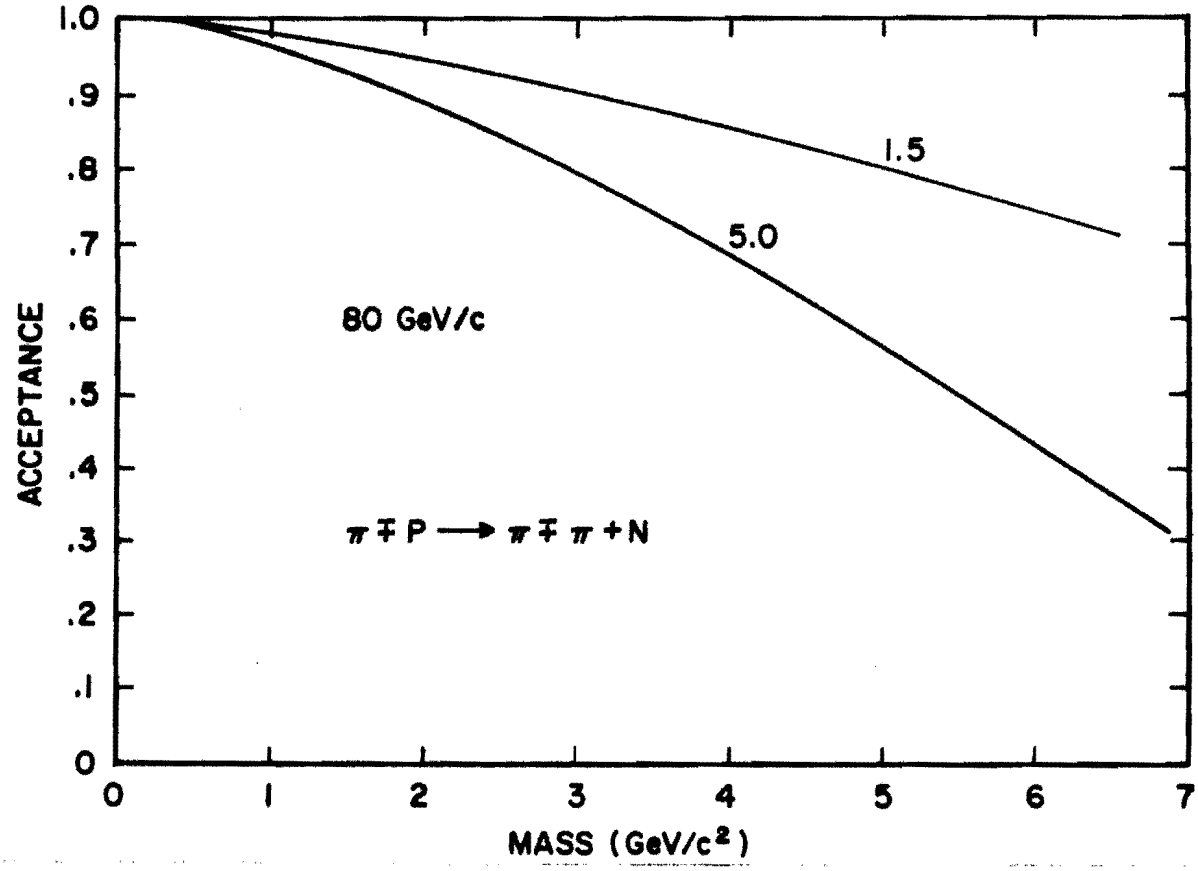
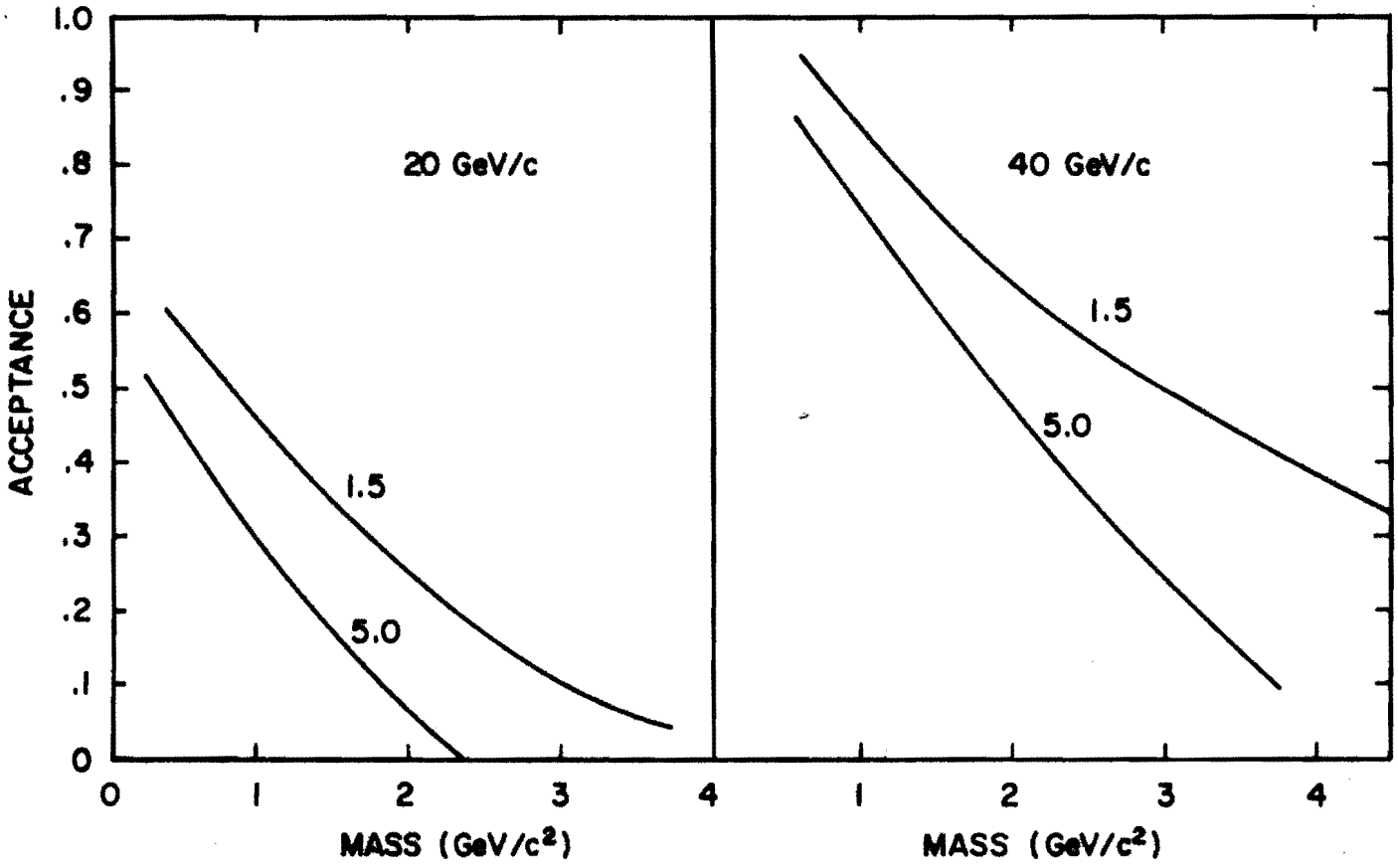


Figure 3. Spectrometer acceptance for $\pi^{\mp}P \rightarrow (\pi^{\mp}\pi^{+})N$ at 20,40,80 GeV vs. mass $(\pi\pi)$ (for 1.5 and 5.0 meter target-magnet separation).



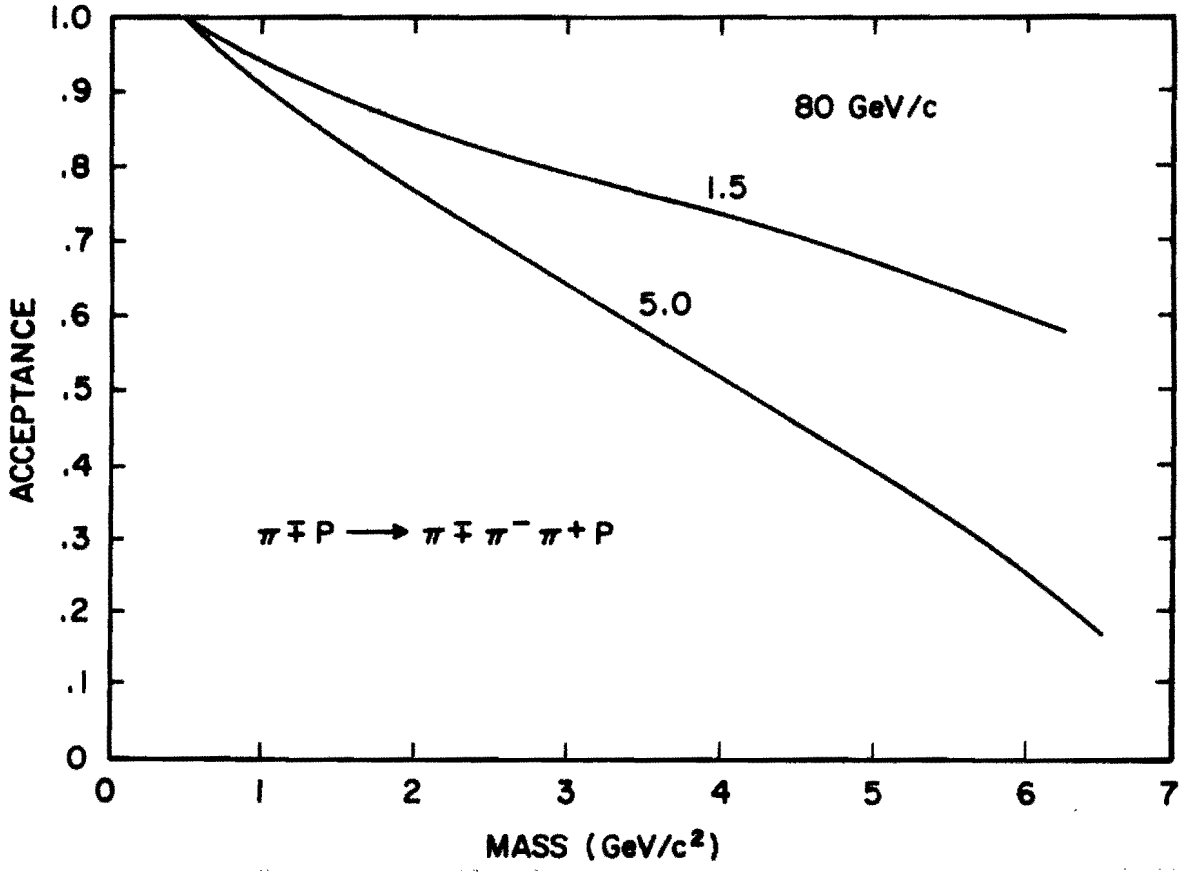
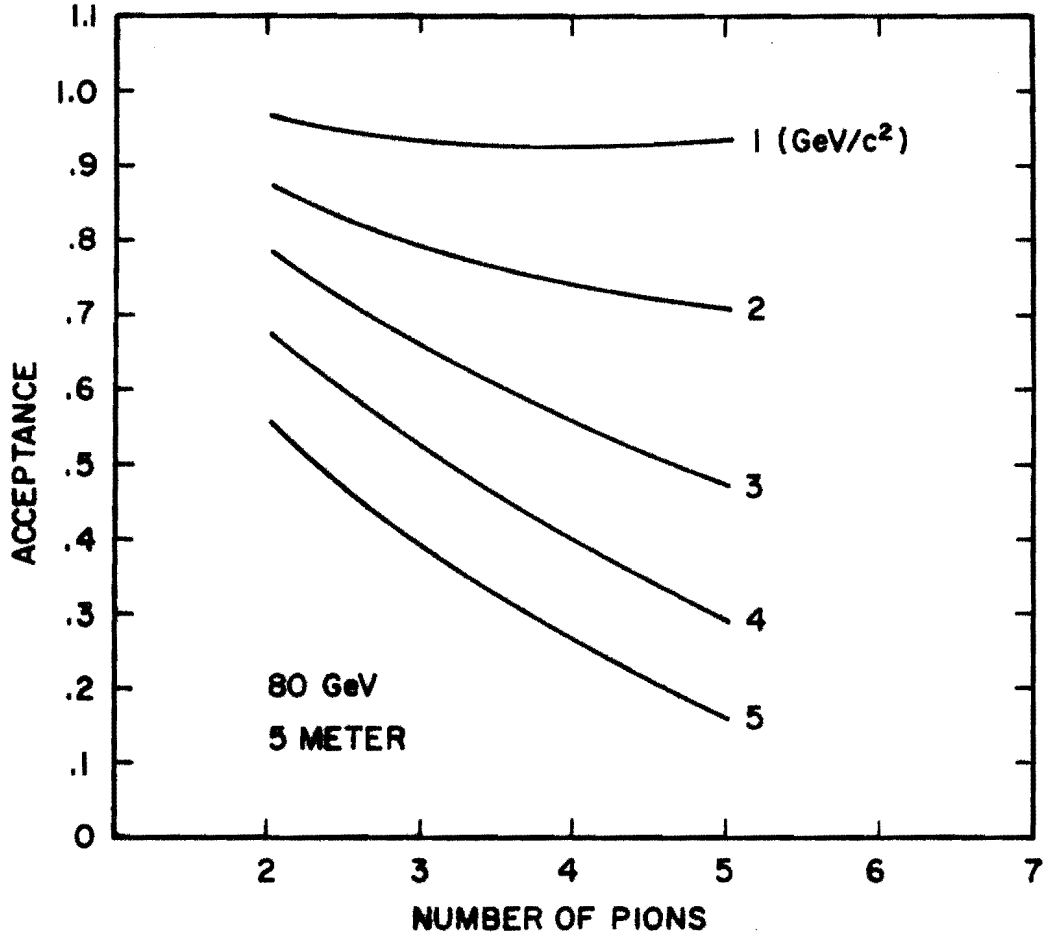


Figure 4. Spectrometer acceptance for $\pi^{\pm}P \rightarrow (\pi^{\pm}\pi^{+}\pi^{-})N$ at 20, 40, 80 GeV vs mass (3π) (for 1.5 and 5.0 meter target-magnet separation).



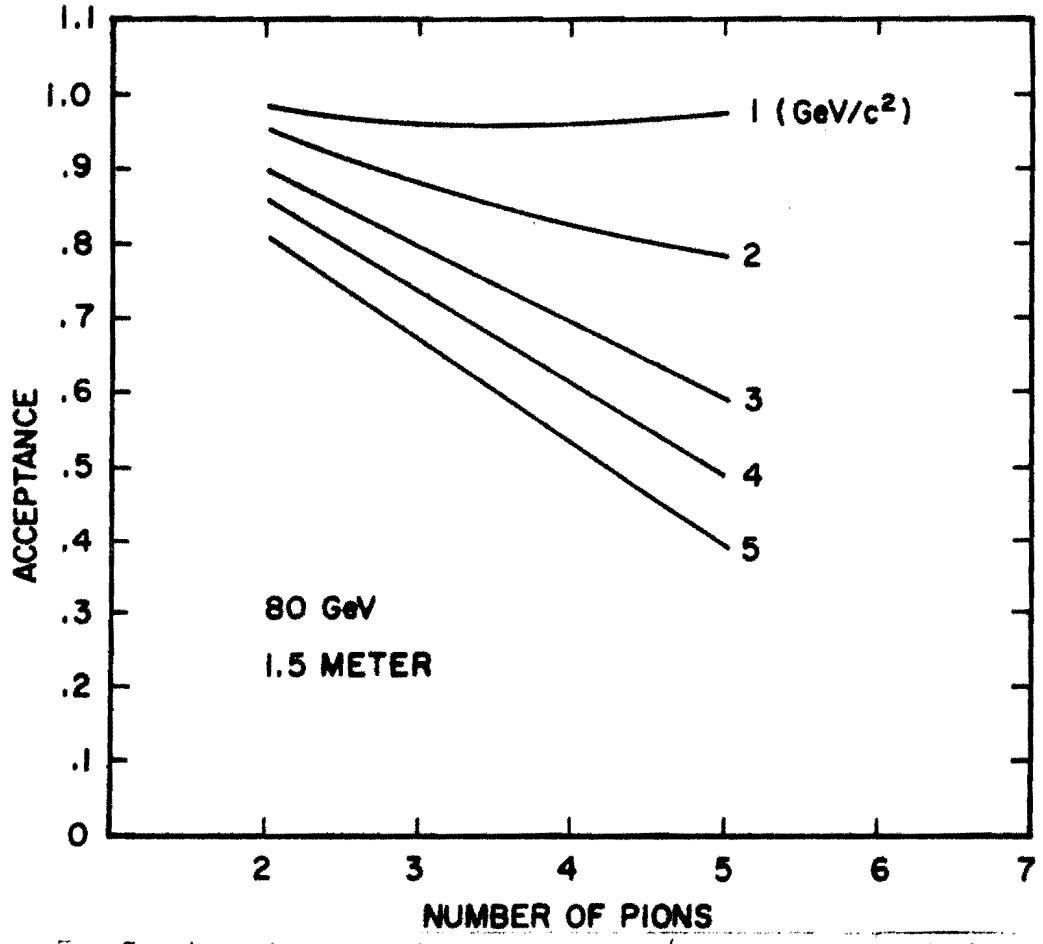
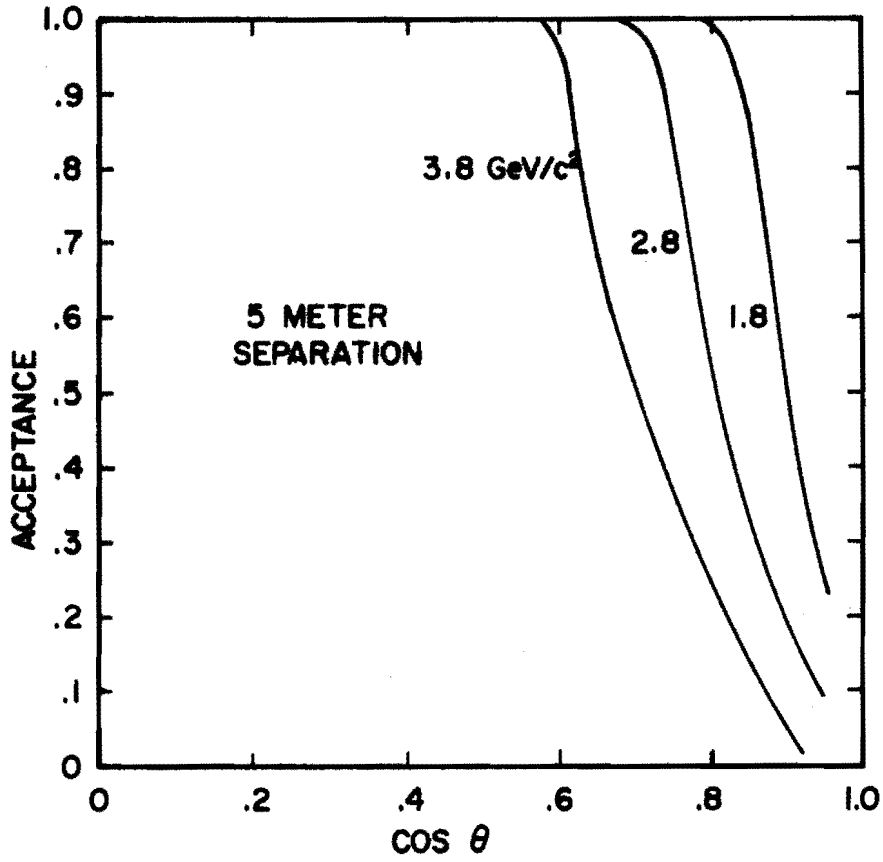


Figure 5. Spectrometer acceptance at 80 GeV/c vs n in $\pi P \rightarrow (n\pi)P$ for fixed mass $(n\pi)$. (For 1.5 and 5.0 meter marget-magnet separation.)



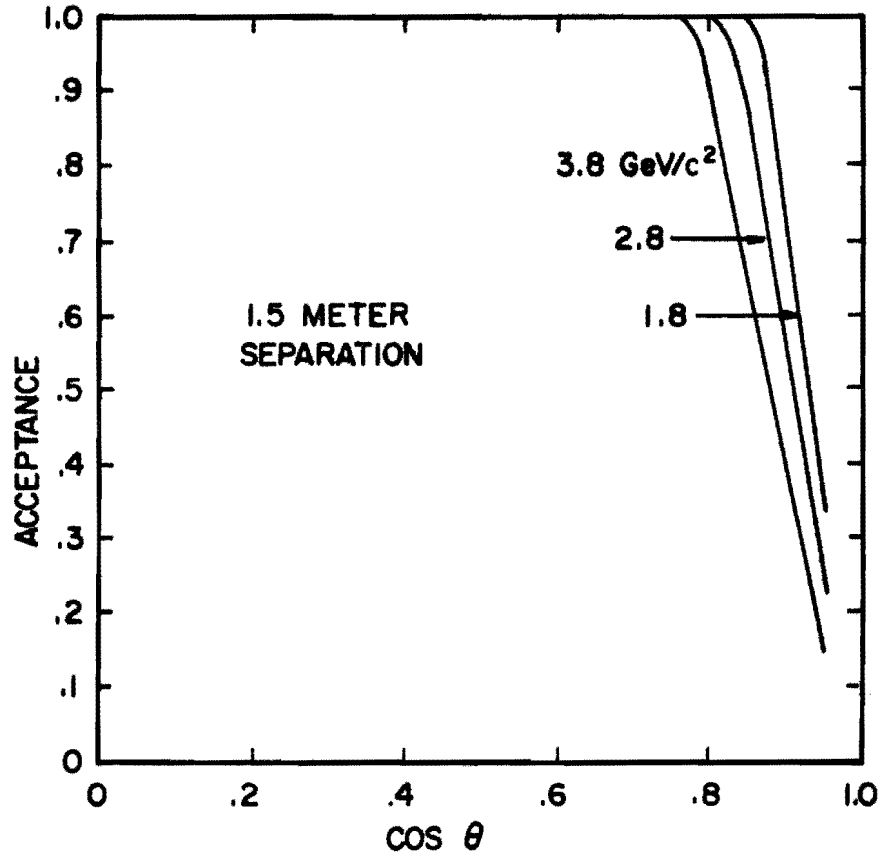


Figure 6. Spectrometer acceptance at 80 GeV/c vs $\pi\pi$ helicity angle in π P $\rightarrow$ $(\pi\pi)$N (for 1.5 and 5.0 meter target-magnet separation).

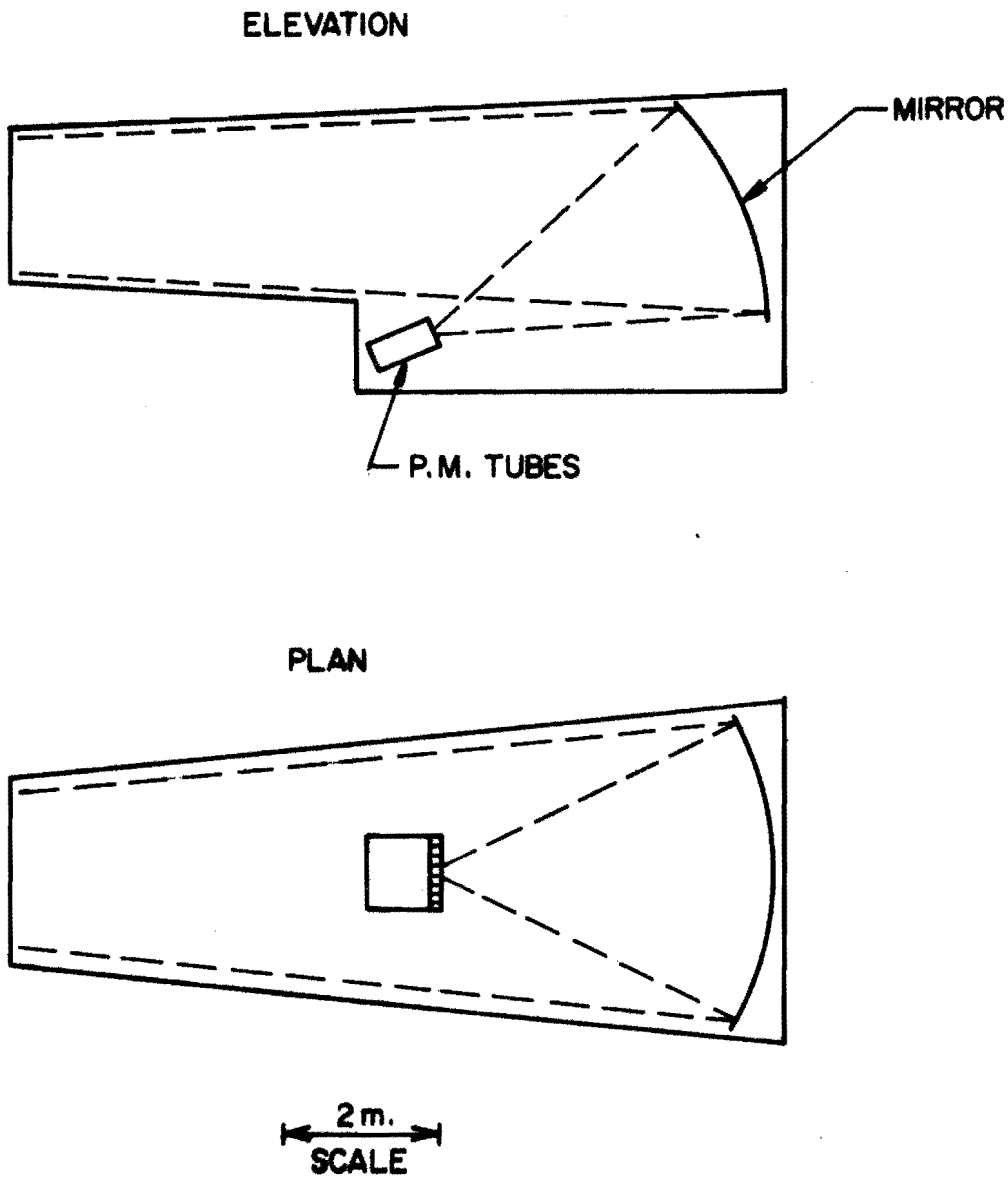
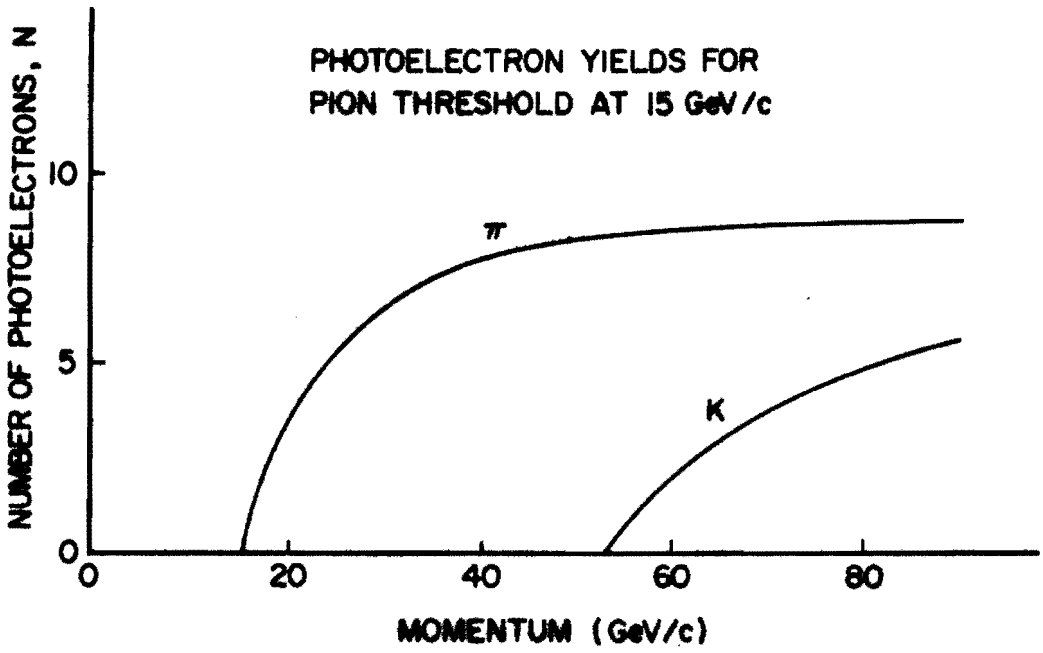


Figure 7. Schematic drawing of spectrometer Cerenkov Counter.

a)



b)

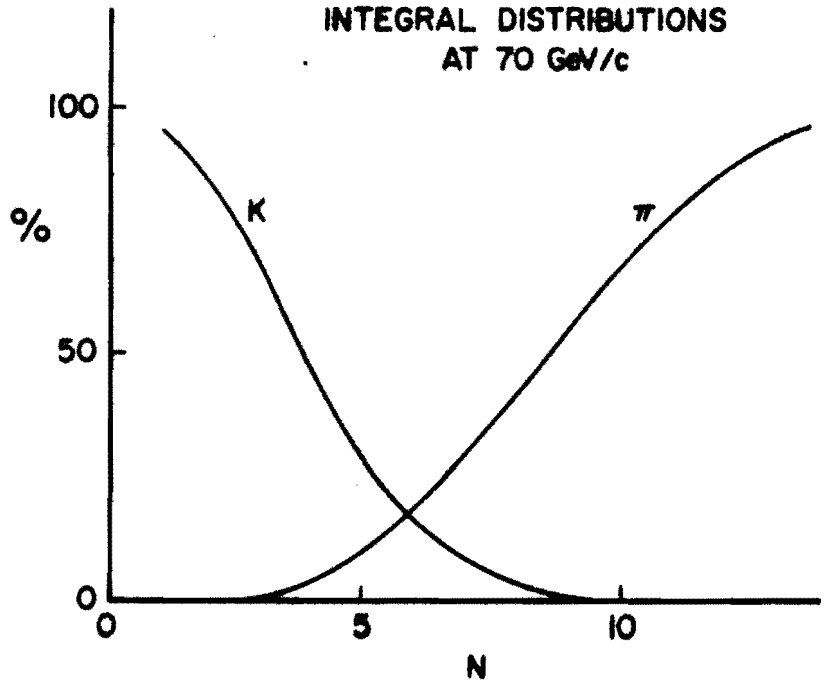


Figure 8. a) Photoelectron yields (RCA C31000D phototube) for ten meter Cerenkov counter with pion threshold at 15 GeV.
b) Probability for fewer than N photoelectrons for π's and greater than N for K's, for 70 GeV/c momentum, with pion threshold at 15 GeV/c.

Experiment 110A Amended 5-5-74

PROPOSAL TO STUDY MULTIPARTICLE PERIPHERAL PHYSICS AT NAL

Abstract

The proposal as last amended, on May 1, 1972, remains the same, except for two changes. The senior personnel and their institutions are updated, as listed below. And the attached addendum is added to the proposal.

The addendum adds to the experiment:

a) Quasi two body reactions in which a two-body system is produced at the target vertex (a Δ^{++} for example).

b) Inclusive studies of two or more body correlations, for (Feynman) $x \geq 0$.

c) Some peripheral reactions of particular current interest involving Pomeron exchange.

G. Fox, R. Gomez, J. Pine (Spokesman), J. Scheid
California Institute of Technology, Pasadena, California

E. Lorenz, P. Schlein, W. Slater, R. Webb
University of California, Los Angeles, California

A. Dzierba, J. Mott
University of Indiana, Bloomington, Indiana

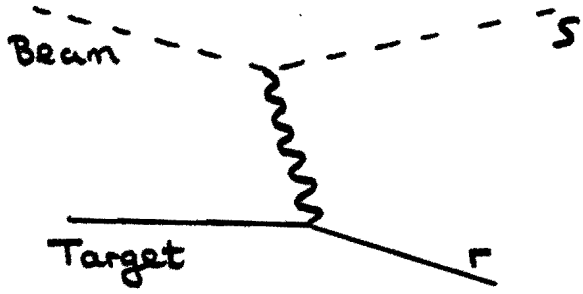
R. Abrams, S. Bernstein, H. Goldberg, S. Margulies, D. McLeod, J. Solomon
University of Illinois, Chicago Circle, Chicago, Illinois

V. Ashford, H. Haggerty, R. Juhala, E. Malamud, S. Mori
National Accelerator Laboratory, Batavia, Illinois

ADDENDUM TO EXPERIMENT 110

A. Two Body Recoil Systems -

The original experiment 110A proposal called for a study of the reaction:



for any fast scattered system s that decays into charged particles and a recoil system r restricted to

(r1) r = neutron

(r2) r = proton (or more generally a single charged particle)

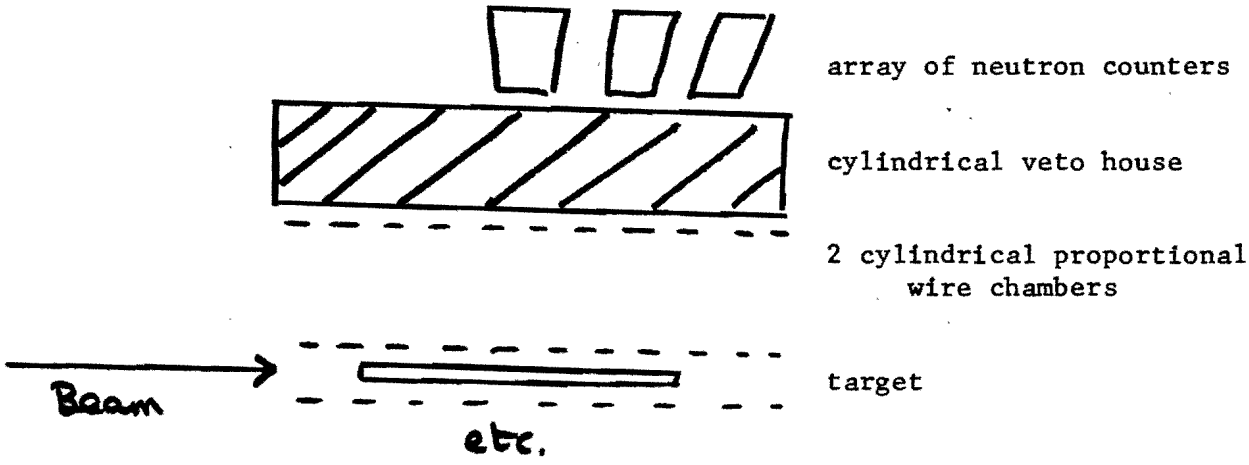
A detailed study of the hardware around the target necessary to acheive this, revealed that the following recoil systems could also be studied

(r3) r = Λ° decaying into $p\pi^-$

(r4) r = $p\pi^+$ - typically decay of Δ^{++} (1234)

(r5) r = $n\pi^+$ - typically decay of N^{*+} (1688)

(r1) to (r5) are studied by the following schematic target configuration:



Many examples of interesting physics for recoils (r1, r2) can be found in the experiment 110 proposal. These can be trivially extended for the new recoil triggers as fast system s and recoil r triggers are independent. Generally, we are studying energy and momentum transfer dependence of the reaction: beam + target → s + r with a simultaneous investigation of properties of resonances produced in s or r system. More specifically, we isolate below one particularly interesting/typical reaction for each recoil:

(r1) $\pi^- p \to \rho^\circ n$, $\pi^- p \to \pi^+\pi^- n$. Study of $\pi\pi$ scattering up to 6 GeV $\pi\pi$ mass.

(r2) Diffractive processes, $pp \to N^{*+}(\to p\pi^+\pi^-)p$.

(r3) Hypercharge exchange, $\pi^- p \to K^\circ \Lambda$ with measurement of Λ polarization.

(r4) $\pi^+ p \to \rho^\circ \Delta^{++}$. Correlated decay of ρ° and Δ^{++} plus study of π exchange in a kinematically favorable place. (See G. Fox, ANL/HEP-7028, p. 545.)

(r5) $pp \to N^{*+}(\to p\pi^+\pi^-$: fast) $N^{*+}(\to n\pi^+$: slow). Study of double diffractive and Pomeron factorization.

B. Inclusive Studies -

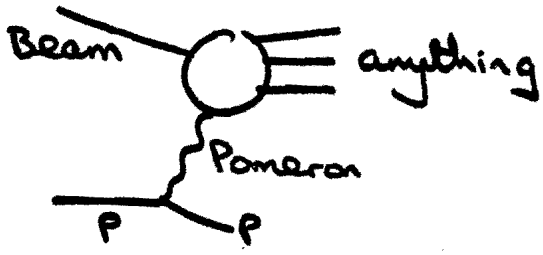
The high p_T experiment 260 has reminded us of the trivial fact (mention of which was omitted in original E110 proposal) that one can also run the apparatus, like a bubble chamber but with much higher statistics, in the untriggered mode to study the general multiparticle reaction beam + target → charged particles + (essentially unobserved neutrals). Some running of this sort must be done to fully understand the biases and backgrounds for the various exclusive triggers, in any case.

For this data, we will study single particle and ($\geq$) two particle (correlation) inclusive distributions. The memo "Response of E110 Spectrometer to Multiparticle Events" (by G. C. Fox) studies acceptance for charged particles as a function of (Feynman) x and p_T^2. To summarize this work (at p_{lab} = 180 GeV/c), acceptance is excellent for $x \geq 0$ and poor for $x < 0$. Here we require particles to pass through magnet and be momentum-analyzed. (Directions are found for charged particles with $x < 0$.)

C. Pomeron Exchange

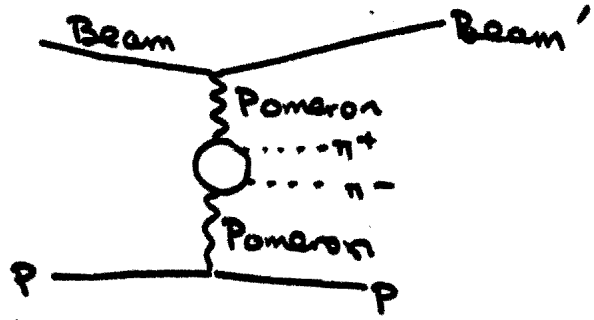
We hope to generate effective triggers to study particlarly interesting peripheral multiparticle final states when we analyze the untriggered data. One obvious possibility is to use "neutron counters" as "total absorption proton counter" to study diffraction scattering (Veto house removed).

beam + p → p($x_{cms} \lesssim -.9$, proton slow in lab) + anything (fast in lab due to proton selection)



which emphasizes we are studying "Pomeron-beam" scattering. (See G. C. Fox in last Stonybrook Conference proceedings.)

In particular, we can study



which has been suggested by 200 GeV/c pp and π^-p NAL bubble chamber exposures.

NAL PROPOSAL No. 110-B

Scientific Spokesman:
J. Pine
P. O. Box 961
Mammoth Lakes, Calif. 93546

FTS/Off-Net: 213-688-2000
714-934-6412

PROPOSAL TO STUDY MULTIPARTICLE PERIPHERAL PHYSICS AT NAL

A. Dzierba, G. Fox, R. Gomez, J. Pine
California Institute of Technology, Pasadena, California

E. Lorenz, P. Schlein, W. Slater, R. Webb
University of California, Los Angeles, California

R. Abrams, S. Bernstein, H. Goldberg
S. Margulies, D. McLeod, J. Solomon
University of Illinois, Chicago Circle, Chicago, Illinois

R. Lundy, E. Malamud, A. Wehmann
National Accelerator Laboratory, Batavia, Illinois

May 1, 1972

Proposal 110A

Amended 5/1/72

PROPOSAL TO STUDY MULTIPARTICLE PERIPHERAL PHYSICS AT NAL

Abstract

We propose to build a wire chamber magnetic spectrometer at NAL to measure multi-particle forward-going hadronic systems produced by π's, K's, protons, and antiprotons up to 200 GeV. Specific reactions will be isolated in order to study the s and t dependences of the cross sections for peripheral processes, search for new resonant states, and attempt to measure $\pi\pi$ and $K\pi$ inelastic scattering.

The proposed physics program is initially limited to those processes easiest to measure which nevertheless span a large range of strong interaction problems. Technically, the proposed spectrometer is similar to systems already in use in the 10-20 GeV region. Its construction does not require a very large commitment of funds, nor does it represent a challenge of uncertain magnitude.

This amended proposal differs from the original proposal 110 mainly in size of magnet, beam to be used, some details of instrumentation, and personnel. The section immediately following describes the changes in detail.

A. Dzierba, G. Fox, R. Gomez, J. Pine
California Institute of Technology, Pasadena, California

E. Lorenz, P. Schlein, W. Slater, R. Webb
University of California, Los Angeles, California

R. Abrams, S. Bernstein, H. Goldberg, S. Margulies, D. McLeod, J. Solomon
University of Illinois, Chicago Circle, Chicago, Illinois

R. Lundy, E. Malamud, A. Wehmann
National Accelerator Laboratory, Batavia, Illinois

Spokesman: J. Pine

AMENDMENT TO PROPOSAL 110

In the spring of 1971, proposal 110 was approved. However, in the summer of that year, in view of limited funds available, it was decided at NAL that neither the beam nor the large magnet envisioned in that proposal would be built. Soon after that decision, the Northeastern University group withdrew from experiment 110 to press for approval of their original proposal 51. The four groups remaining with proposal 110 investigated in detail the feasibility of performing the experiment with two alternative arrangements: the Chicago cyclotron magnet plus a new hadron beam; or a smaller magnet in the M6 beam of the meson lab. Along with NAL, we came to favor the latter alternative, which is the basis of this amended proposal.

The small-magnet spectrometer is shown in plan view in Figure A1. Groups of wire spark chamber planes are symbolized by each of four measuring stations labeled W1-W4. The magnet pole face is 1.2 m square, corresponding to a 48D48 magnet which constitutes a modest demand on equipment funds. The magnet gap is envisioned to be in the range 24 to 30 inches, a question to be discussed further below.

In Figure A1, the distance D has been chosen so as to duplicate the excellent solid angle acceptance of the original proposal 110 spectrometer operating at its short, 1.5 meter, target-to-magnet distance. In view of our physics goals, we feel that this acceptance should not be compromised if possible. The consequence of choosing the relatively short distance D is that the baseline distance L_1, which largely determines the angle and momentum uncertainties of the spectrometer, becomes quite short.

In view of the short baseline L_1 and the relatively small $\int B\, dl$ for the magnet (assumed to be 22 kg-m), it is essential that the highest possible positional accuracy be attained at the measuring stations W1 and W2. However, since the wire chambers involved are quite small, we anticipate using the most modern techniques for achieving good spatial resolution (e.g., high pressure and/or low temperature to achieve high gas density). For these chambers it will also be relatively easy to maintain extremely tight alignment and construction tolerances. Therefore, in assessing the expected performances of the spectrometer we will assume the following positional accuracies (standard errors) at the four measuring stations (based on averaging two to four individual measurements at each station):

W1: 80 microns

W2: 150 microns

W3: 300 microns

W4: 300 microns.

Figure A1 is drawn to scale for operation at 100 GeV/c. For a forward-going multiparticle system with a given mass, the distance D should scale linearly with beam momentum if the acceptance of the spectrometer, in the rest frame of the forward-going system, is to remain invariant. However, as beam momentum increases the interesting mass range extends to higher maximum mass, proportional to the square root of the beam momentum. As a result, for good acceptance at the maximum mass the distance D is then also found to scale like the square root of the beam momentum. Between 100 and 200 GeV/c, the table shown in Figure A1 indicates such scaling of the spectrometer. Note that the mass resolution at 200 GeV/c remains as

good as at 100 GeV/c. This is because the resolution is dominated by the accuracy of measurement over the L_1 baseline, which doubles as the spacing of the front end of the spectrometer is stretched, just meeting the more stringent demands of the higher momentum. Because D is increased less than linearly with beam momentum, the acceptance for a given mass at 200 GeV/c is even better than at 100 GeV/c.

For momenta below 100 GeV/c, the distance D should be decreased to maintain very high acceptances. However, at 50 GeV/c the decrease in D by $\sqrt{2}$ would reduce L_1 essentially to zero. We thus indicate in the table that below 100 GeV/c the distance D is held constant. Correspondingly, the mass resolution becomes better and the acceptance worse at lower momentum.

Before considering numerical values calculated for the resolutions and acceptances, note the last column of the table on Figure A1. The quantity Y_K^o listed there is the probability for a K_S^o decay in the region between W1 and W2, assuming production at the target center with one half the beam momentum. While a somewhat longer decay path might be desirable, these probabilities indicate that good data can be obtained for the K^o decay modes of forward-going systems.

Figure A2 shows mass resolutions and acceptances for various forward-going multipion systems, from Monte Carlo calculations made on the following basis: Total momentum of the system either 100 GeV/c (solid curves) or 50 GeV/c (dashed curves); momentum transfer squared t to the target nucleon of 0.1 $(GeV/c)^2$; wire chamber resolutions as given above; no multiple scattering; 24" magnet gap, with the exception of two curves labeled 30"; phase space decay distribution of the multipion system in its rest frame.

The neglect of multiple scattering will not appreciably affect the mass resolutions, except for extremely low values of 5 MeV or less.

Looking first at the mass resolutions, they are comparable with these for the large magnet spectrometer. The assumed high-precision measurements at W1 and W2 have nearly compensated for a reduction by a factor 2.4 in the value of $\int B\, dl$. Note that the resolutions presented in Table IV, page 21, of proposal 110 are for the 5 meter-high resolution-front spacing. While the 2π, 100 GeV/c resolutions in Figure A2 are about twice those at 80 GeV/c in Table IV, they essentially match those for the original spectrometer operated with the short front spacing and high acceptance.

The 2π acceptance of the small magnet spectrometer at 50 and 100 GeV/c matches that for the large magnet at the 1.5 meter front spacing, as was built into the small magnet design. However, the 4π and 6π acceptances are somewhat improved, owing to less loss of low momentum particles inside the magnet. From Figure A2, the 100 GeV/c acceptances are seen to be excellent up to masses of about 5 GeV/c^2, while at 50 GeV/c the acceptances begin to be poor near 3 GeV/c^2. Here, the effect of increasing the magnet gap is quite significant, as shown by the two 50 GeV/c 4π curves. In general, the magnet gap increase to 30" moves a given acceptance out to a mass value about 1 GeV/c^2 greater. Although we prefer the better acceptance given by the larger gap, the spectrometer performance with the 24" gap is seen to be quite good.

In essence we have argued above that the small spectrometer can be made completely competitive with the larger originally proposed magnet by using the best possible detector technology. This approach reflects that

of the original proposals 54 and 35 of the presently collaborating groups. The large magnet setup was influenced by the extremely stringent needs of the Northeastern proposal 51, and by a desire at NAL to build a consensus magnet which would appeal to the largest number of users of a spectrometer facility.

To continue with changes in proposal 110, we are now requesting that the experiment run in the M6 beam, along the branch not used by the focussing spectrometer, downstream of the setup for experiment 69A. Compared with the old 15 mr. beam, the M6 beam offers competitive fluxes up to nearly 200 GeV/c. Table A1, below, replaces, for the M6 beam, Table II, page 16, of proposal 110. In a new column, N, the assumed number of interacting protons on target has been added.

Table A1. Estimated yields expressed as interactions per hour-micrbarn. Assumptions are as in Table II, page 16, of proposal 110, except for the M6 beam and numbers of interacting protons specified by N in this table.

Energy	Charge	P		K	N
50	+	300	1,000	150	5×10^{11}
50	-	20	1,500	80	10^{12}
100	+	1,000	250	35	5×10^{11}
100	-	1	300	5	10^{12}
150	+	1,000	5	3	3×10^{11}
150	-	10^{-3}	0.6	4×10^{-3}	10^{12}

Except for negative particles at 100 and 150 GeV/c, the values of N are limited by our design maximum beam flux. Thus, much of the experiment runs very well at a small fraction of the design NAL beam. Our running time request must at this early date be considered highly provisional, since the most interesting problems to be studied with so flexible an apparatus can be expected to change between now and when the experiment starts. However, as a guide, we propose:

Check runs at 20-50 GeV/c -	150 hours
Surveys at 50, 100, and 150 GeV/c, each with both beam polarities and two or more fillings of the gas Cerenkov counter -	450 hours
Running on selected problems -	300 hours
TOTAL	900 hours.

Because of the volume of data and the variety of physics which we expect to study, we request that this time be spread over one calendar year.

Contrary to the original request in proposal 110 we do not request any prior approval for extensions of the running by subgroups of the proposers. However, since this experiment represents a logical first step toward the goals of proposals 35 and 54 we request that they remain active, though deferred, for consideration after experiment 110 begins.

This concludes the major amendments to proposal 110. With regard to other key items, such as physics goals, target and anti-counter house, triggering, and the gas Cerenkov counter, the original proposal stands essentially unchanged at this time.

P_o (GeV/c)	D (m.)	L_1 (m.)	σ_{mass}	Acc	Y_{K^o}
50	2.70	1.0	$\frac{\sigma_o}{2}$	$< A_o$	.38
100	2.70	1.0	σ_o	A_o	.27
200	3.70	2.0	σ_o	$> A_o$	.29

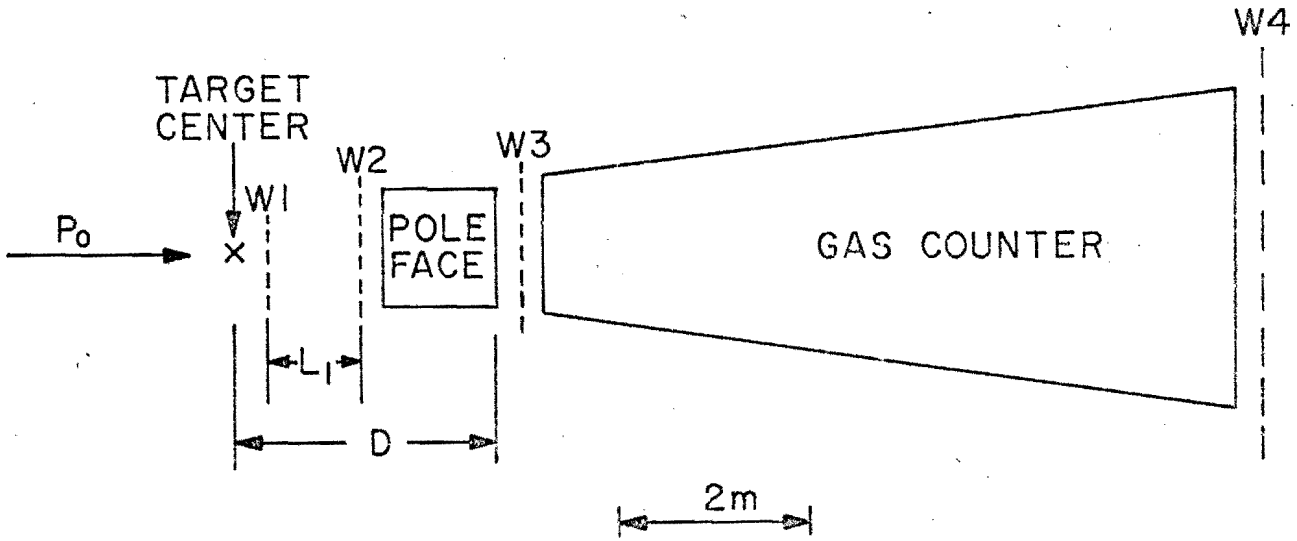


Figure A1. Spectrometer Plan View with table of dimensions, relative mass resolutions, acceptances, and K_o decay probabilities.

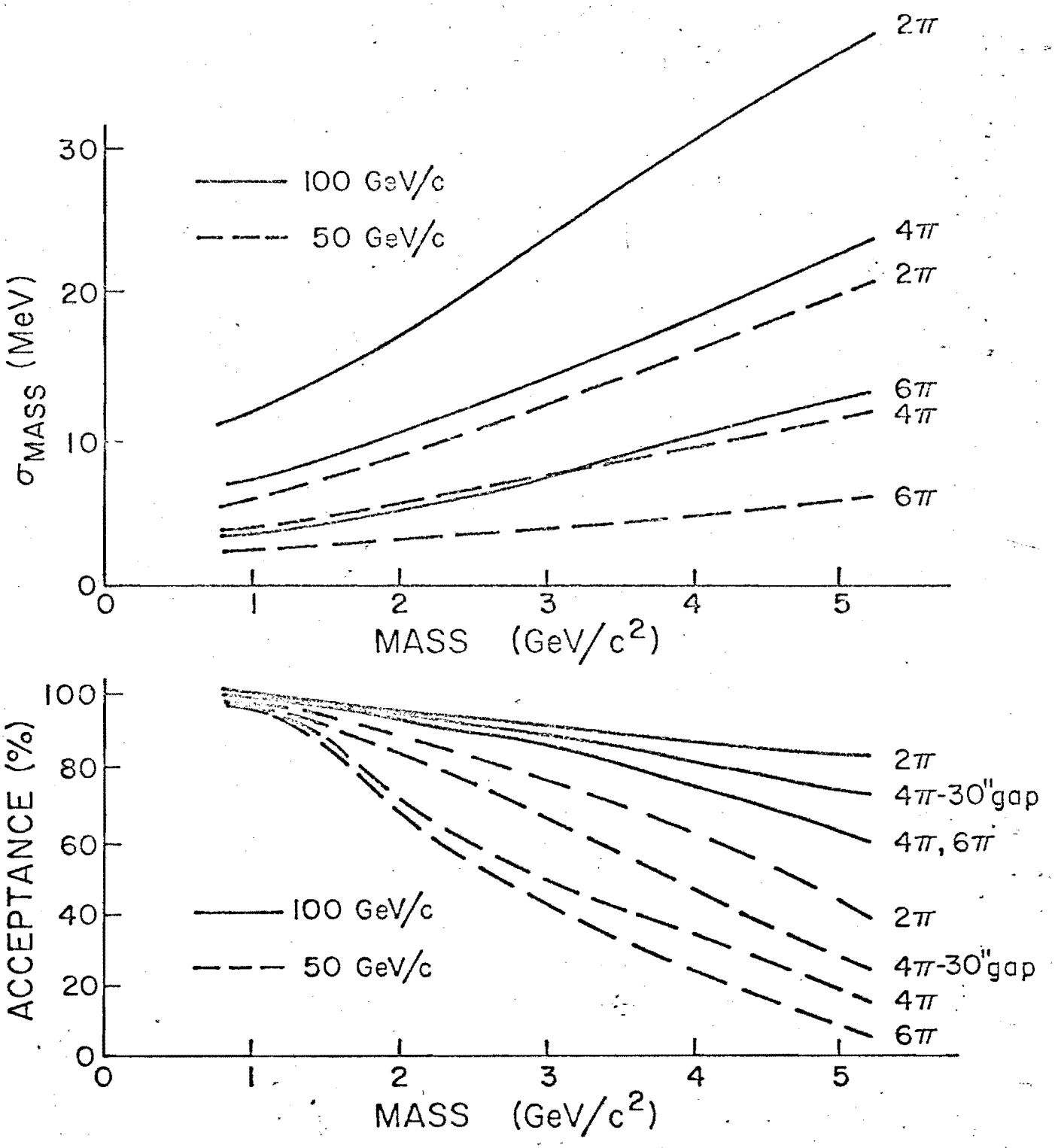


Figure A2. Mass resolutions and acceptances at 50 and 100 GeV/c incident momenta, for D = 2.70 m. and L_1 = 1.0 m.