NAL PROPOSAL No. 63

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SURVEY OF PARTICLE PRODUCTION IN PROTON COLLISIONS AT NAL

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June 15, 1970

SURVEY OF PARTICLE PRODUCTION IN PROTON COLLISIONS AT NAL

ABSTRACT

A spectrometer which can analyze up to 2.4 GeV/c particles is proposed for a high-energy survey at NAL of the reactions:

$$p + p \rightarrow p + \text{anything}$$
$$\bar{p} + \text{anything}$$
$$\pi^{\pm} + \text{anything}$$
$$K^{\pm} + \text{anything}$$
$$\mu^{\pm} + \text{anything}$$
$$e^{\pm} + \text{anything}$$
$$\gamma + \text{anything}$$

The information obtained will be useful for:

a. calculating the high-energy neutrino spectrum. (This has been our basic motivation in this work.)

b. predicting secondary hadron beam intensities.

c. input data for radiation shielding purposes.

d. intrinsic physics interest.

Names of Ph.D. Experimenters:

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Date: June 15, 1970.

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Brief Discussion of Reactions: 3

a) $pp \rightarrow \pi^{\pm}$ + anything

b) $pp \rightarrow K^{+}_{-}$ + anything

c) $pp \rightarrow p$ + anything

d) $pp \rightarrow \bar{p}$ + anything

e) $pp \rightarrow \mu^{\pm}$ + anything
$\rightarrow e^{\pm}$ + anything

f) $pp \rightarrow \gamma$ + anything

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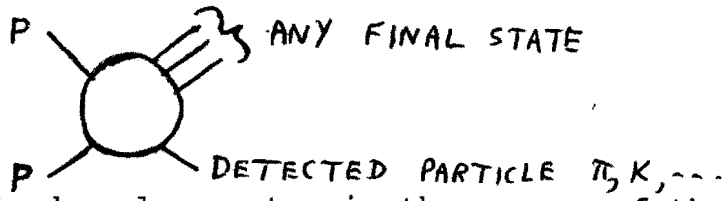
2. General Discussion

We are interested in the reactions



Due to the forward-backward symmetry in the c.m.s. of the pp collision the detection of a particle produced backwards in the c.m.s. (low laboratory energy) or forwards in the c.m.s. (high laboratory energy) is equivalent. The importance of this fact at N.A.L. was pointed out several years ago by D. Jovanovic. The experimental study of the yield of high energy particles at very small angles involve severe problems of particle identification and great precision in alignment. These problems become increasingly severe in the range 200-500 GeV. We propose, instead, to study the yield of particles in the backward hemisphere in the center of mass system. In this case, the angular alignment is trivial and particle identification for momenta less than 2.4 GeV/C is relatively easy.

Figure 1 is a plot of the kinematic relation between forward and backward production of pions and kaons in 200 GeV p-p collisions. It is clear that detection of backward mesons limits the accessible range of forward pions to $\geq$ 40 GeV/C and for kaons $\geq$ 120 GeV/C. Extending the range for pions to less than 40 GeV/C will be done by detecting low energy forward going pions. The limit of a pion having zero longitudinal momentum in the center of mass corresponds to a forward going

1.4 GeV/C pion in 200 GeV p-p collisions. The corresponding figure for 500 GeV p-p collisions is 2.4 GeV/C forward pions which sets the upper limit of momentum analysis for the spectrometer. In a similar way, the range for kaons can be extended.

Figure 2 is a plot showing the relation between forward and backward production angles for several pion momenta.

3. Spectrometer

Figure 3 shows a schematic of the proposed spectrometer layout. At the hydrogen target the vertical size of the proton beam is made $\leq$ 0.1 mm. Particles emitted from the effective line source in the target are bent in the vertical plane by the 24" magnet. The trajectory of a particle at the exit of the magnet is measured by 2" X 2" planes of wire chambers a spatial accuracy of $\approx$ 0.1 mm. The momentum resolution of the spectrometer is about 2% and has a total momentum acceptance of several percent $\Delta p/p$. The geometric acceptance is defined by a 0.01" thick and 1 cm X 1 cm scintillation counter giving a solid angle of acceptance of 4×10^{-4} steradian.

Particles are detected with thin scintillation counters and identified with a Čerenkov counter, time of flight, specific ionization loss, range and pulse height in an electromagnetic shower detector.

4. Brief Discussion of Reactions:

a) $pp \rightarrow \pi^{\pm}$ + anything

If we define $\theta_c = \frac{0.3}{p \text{ (GeV/C)}}$

as the characteristic angle for the production of high energy secondaries of momentum p (GeV/C) then we will obtain information on the yield of these secondaries in the angular range $\theta_1 \rightarrow \theta_2$

where $\theta_1 << \theta_c << \theta_2$. The counting rates are very high. The existence and momentum distribution of low energy pions in the center of mass system (sometimes called pionization process) is of some current theoretical interest. This process should be able to be studied.

b) $pp \rightarrow K^{\pm}$ + anything

Similar remarks to a) can be applied here. Of course we will not be able to study kaons which have very low center of mass momenta.

By fitting the data to a reasonable particle production model (say that due to Hagedorn and Ranft) we will be able to extrapolate across the range of momenta in which particles do not get out of the target. This applies to all of the reactions studied.

c) $pp \rightarrow p$ + anything

Perhaps, the dominant feature here is the diffractive elastic scattering. However, the deep inelastic proton spectrum will be used in various ways for secondary beams. This process has been extensively studied at CERN and BNL. In both cases the high energy outgoing proton was detected. Fig. 4 shows the kinematics relationship between the slow recoil proton momentum and angle against the mass of the "anything" for 200 GeV pp collisions. We should be able to obtain useful proton spectra and interesting physics information from these mass distributions.

d) $pp \rightarrow \bar{p}$ + anything

Predictions on antiproton yields at very high energy are particularly unreliable. These measurements will greatly assist in the design of secondary beams.

e) $pp \rightarrow \tilde{\mu}^{\pm}$ + anything

$\rightarrow e^{\pm}$ + anything

It is likely that the detection of these particles is dominated by the decay, of π and K mesons. On the other hand it may be interesting to look at the yield of high transverse momentum ($\leq$ 2.4 GeV/C) leptons as a function of incident proton energy. Any threshold effect might signal the production of the intermediate boson followed by leptonic decay.

f) $pp \rightarrow \gamma$ + anything

The gamma rays will mostly come for the decay of π^{o} mesons produced in the pp collisions. We propose surveying the yields of gamma rays with energy greater than a few GeV corresponding to transverse mementa greater than about 1 GeV/C. this data should be useful for designing a gamma ray beam in Area 2 or 3 and at the same time look for anomalous large transverse momentum behavior.

5. Logistics and Scheduling

The physical requirements of the apparatus are not great. On the other hand, the early determination of particle fluxes in a reliable and simple way is of importance to our development program. Thus, if we wish to have the spectrometer ready by the summer of 1971, work will have to start rather soon on its construction.

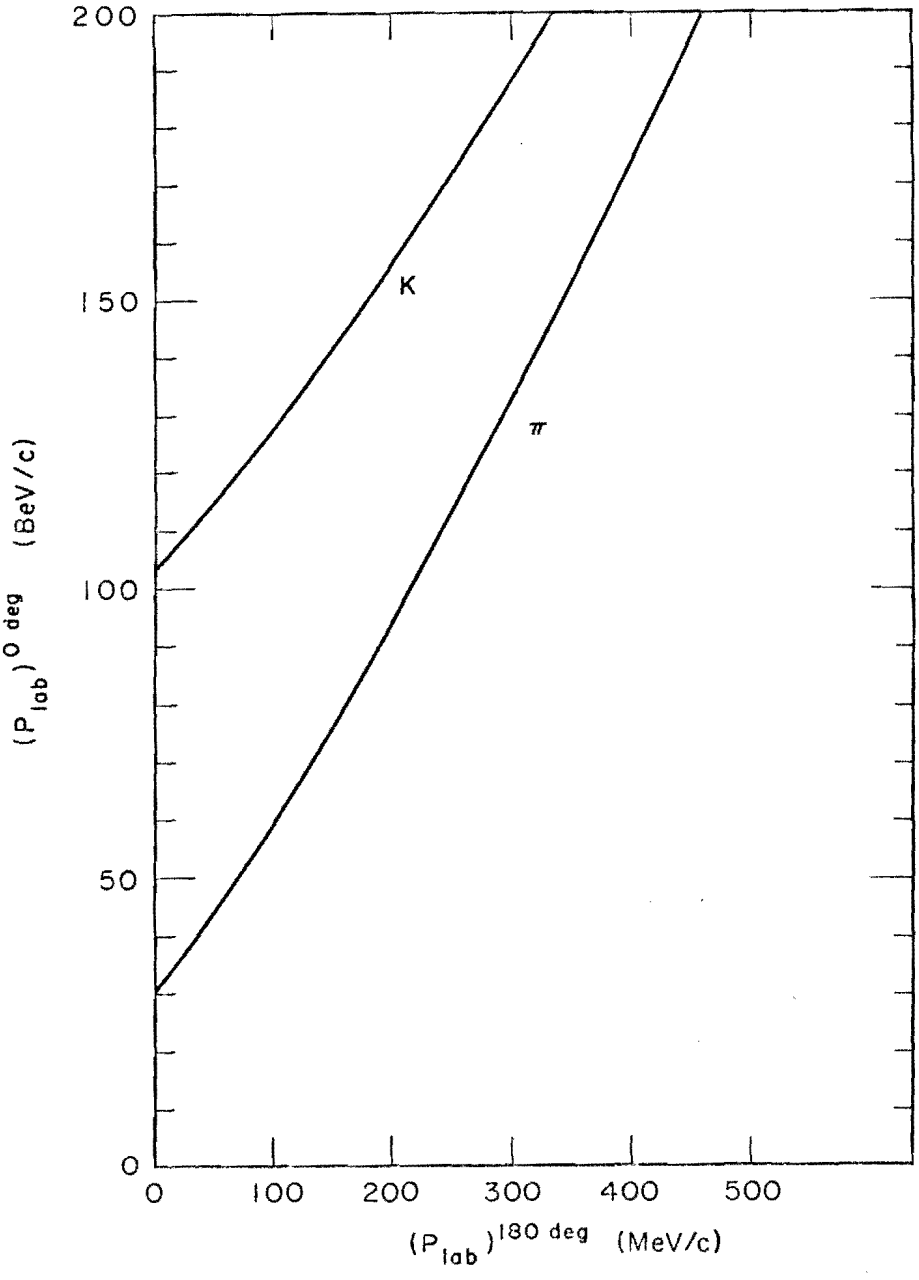


Fig. 1. Relation between particle momenta at 180 deg and particle momenta at 0 deg for pions and kaons produced in 200-BeV p-p collisions.

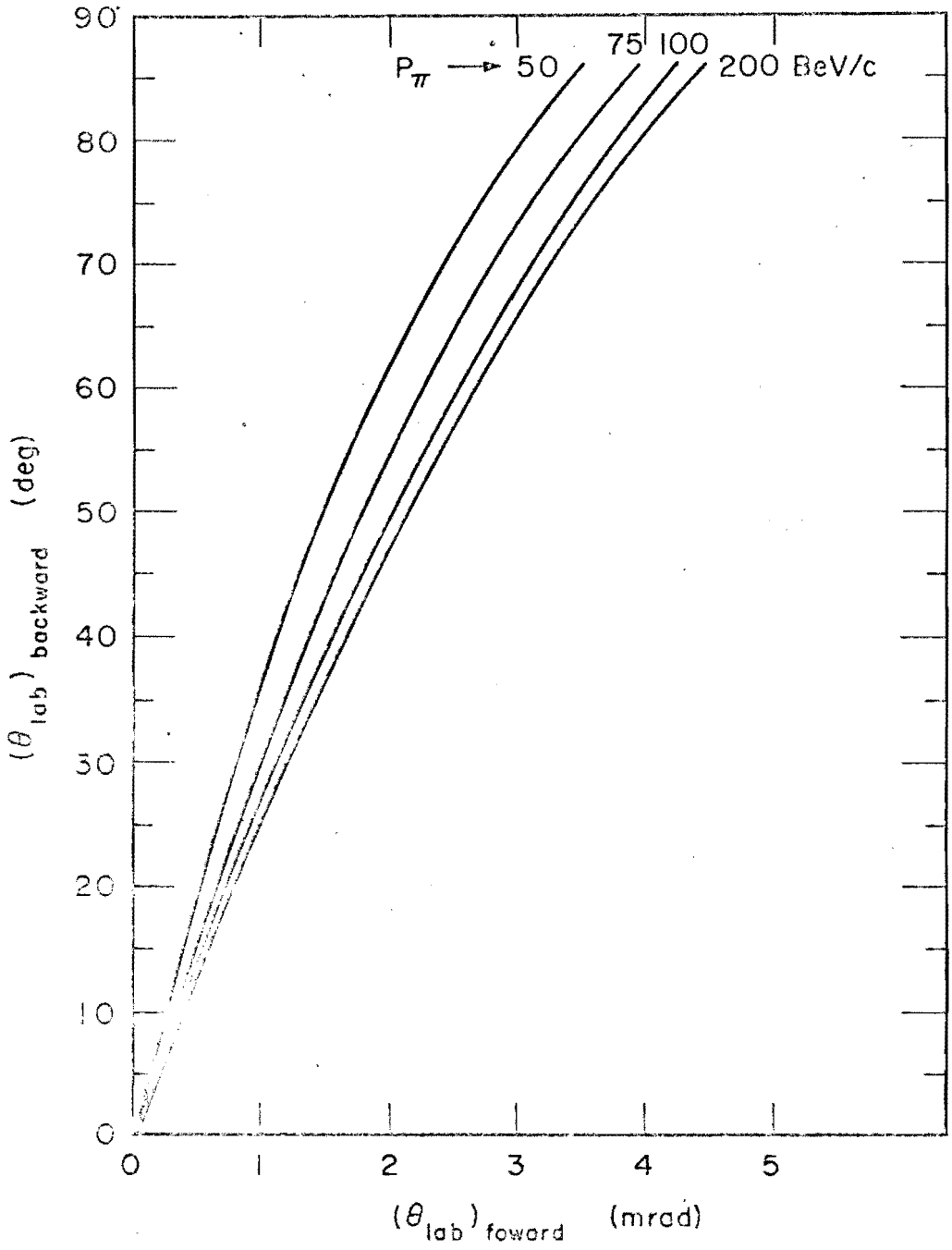


Fig. 2. Relation between forward and backward production angles for several pion momenta in symmetric p-p collisions.

Spectrometer Layout

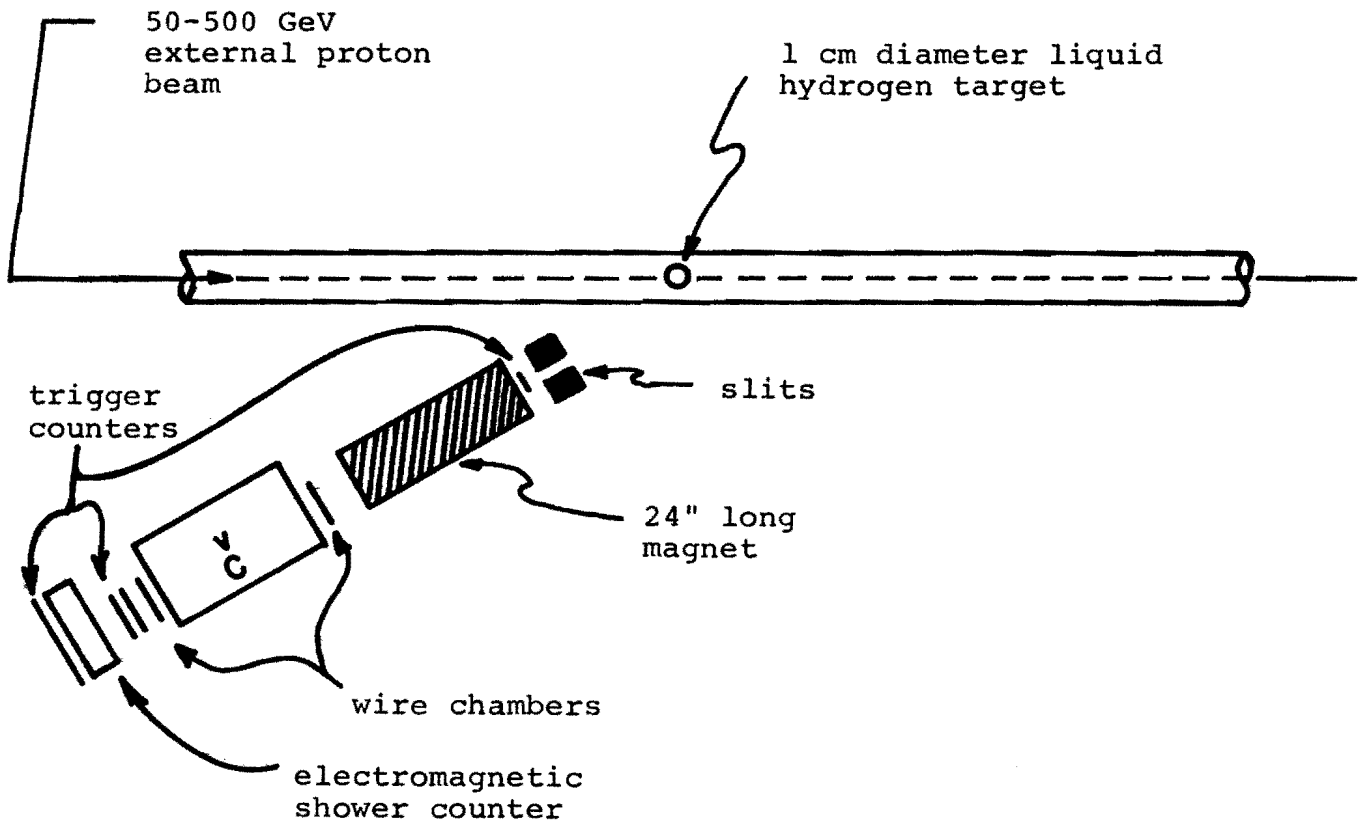


Fig. 3

Total length of spectrometer = 6' located in proton beam transport tunnel leading to beam dump.

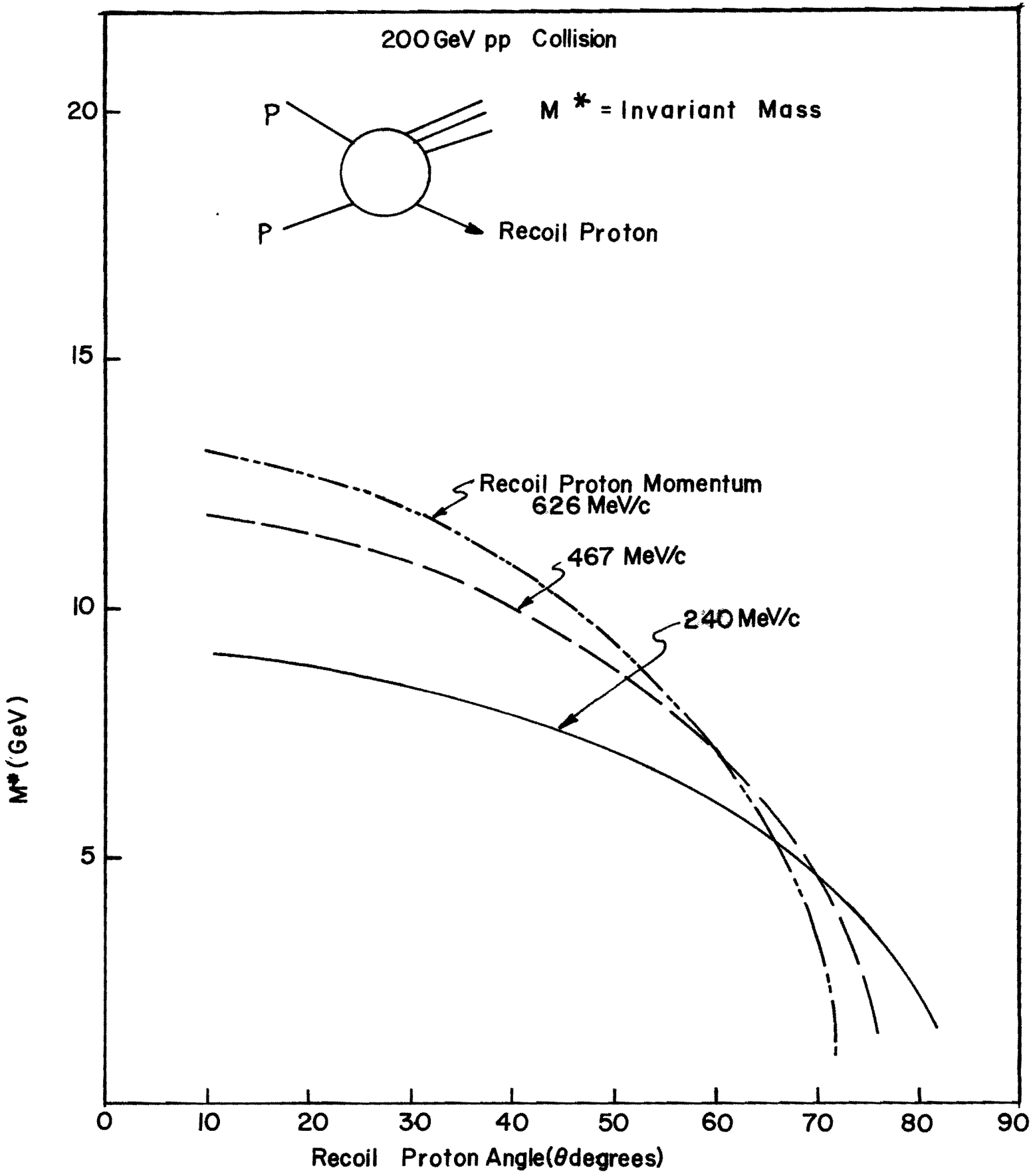

200 GeV pp Collision
P
P
M * = Invariant Mass
Recoil Proton
Recoil Proton Momentum
626 MeV/c
467 MeV/c
240 MeV/c
M* (GeV)
20
15
10
5
0
10
20
30
40
50
60
70
80
90
Recoil Proton Angle(θ degrees)

Fig. 4

December 9, 1970

APPENDIX TO NAL PROPOSAL 63

We have proposed an experiment to study particle production in proton proton collisions between 70 GeV and 500 GeV incident proton energy. The yields of stable secondary particles will be obtained up to their highest possible momentum, and at transverse momenta less than about 2 or 3 GeV/c.

The results of this experiment will provide the basic information for:

a) predicting secondary hadron and neutrino beam intensities.

b) input data for shielding purposes.

In addition, these single particle spectra are of profound intrinsic physics inherent by themselves as tests of models of high energy hadron dynamics.

In the past few years, several studies of particle production have been made above 10 GeV. The best of these studies is probably that reported in April 1970 by a CERN group.[1] The over-all absolute error quoted in this work is ±15%. The history of models purporting to describe the particle production process is a long one. Recent contributions have been made by Hagedorn and Ranft,[2] Wayland,[3] Caneshi and Pignotti,[4] Sanford and Wang,[5] Wang,[6] Liland and Pilkuhn,[7] Benecke, Chou, Yang, Yen[8] and finally by Drell.[9] These models have been adjusted to fit the production data below 30 GeV.

In the last few months it has become quite clear (and emphasized most recently at the Argonne Symposium on High Energy Interactions, November 19, 1970) that these models when extrapolated to 70 GeV are in striking disagreement with the available data of the CERN-SERPUKOV collaboration. The predicted yields for essentially all the models average to about a factor of five above the observed yields. Extrapolations of the models to several hundred GeV probably results in much larger errors.

It is clear, that careful absolute measurements of these particle production spectra up to 500 GeV should be performed as soon as possible, due to the great uncertainty in the anticipated yields of particles at NAL.

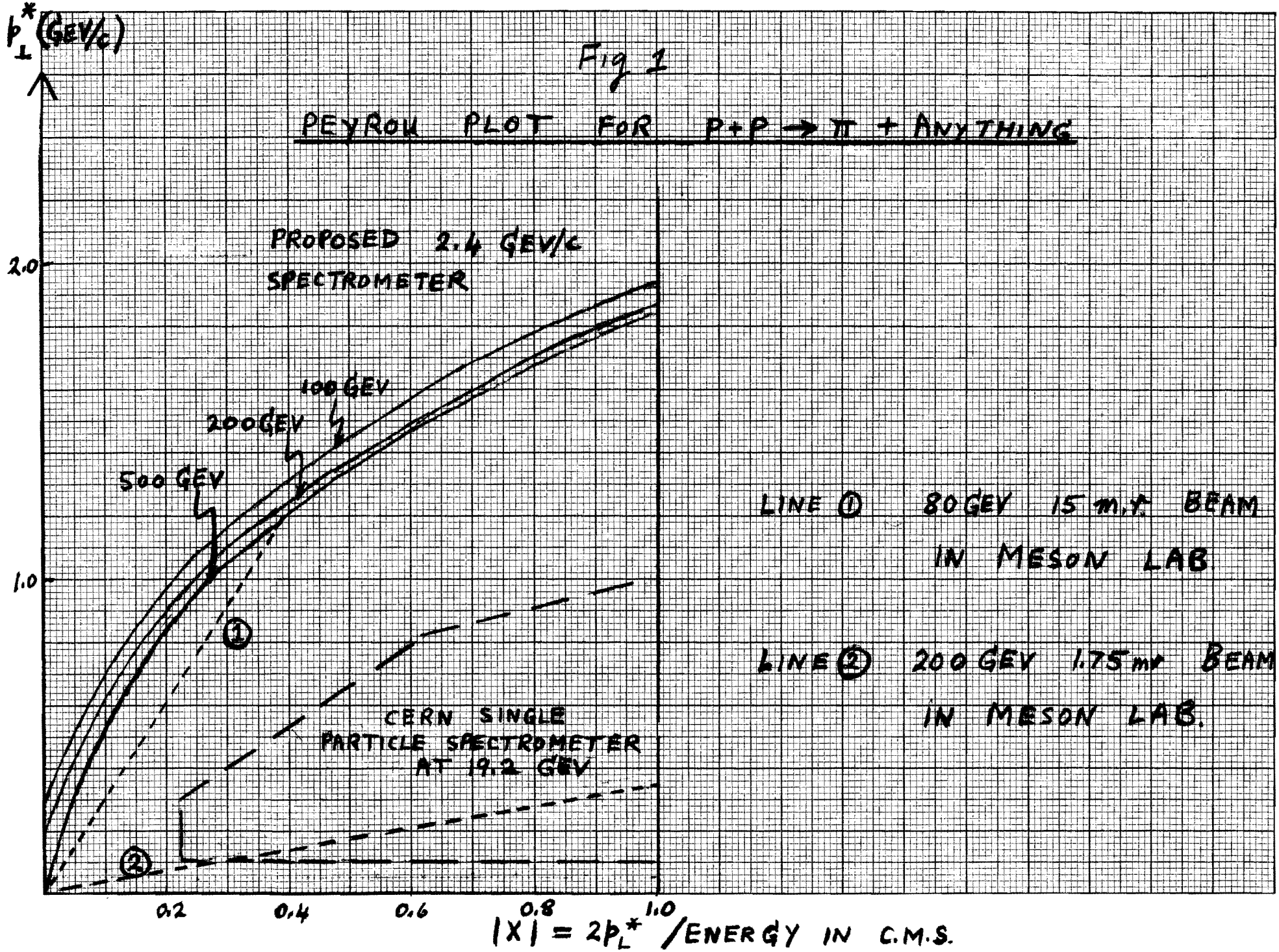
Kinematic Region to be Covered

Figure 1 shows a Peyrou Plot for the reaction

$$p + p \rightarrow \pi + \text{anything}$$

This plot is convenient for the following reasons:

1. Plotted in units of center of mass transverse momentum $p_\perp^*$ and normalized longitudinal momentum $|x| = 2\, p_L^*/\text{Energy}$ in c.m.s. the contours become approximately energy independent. The area below the contour is that kinematic region accessible to the proposed spectrometer.
2. Shown for comparison is the area covered by the recent CERN particle survey.
3. Two typical beam lines being constructed in the Meson Laboratory at NAL are shown as the dashed lines.



4. The plot shows the ability of the spectrometer to reach down even to very small values of $|x|$ as well as the maximum possible $|x|$. An expanded graph of the small $|x|$ region is shown in Figure 2. Thus pion production can be studied even below the mass unit of the pion in both variables $p_{\perp}^{*}$ and $|x|$.

Figure 3 shows the coverage of the proposed survey for the charged beams in the Meson Laboratory. Almost the full range of angles and momenta utilized in the Meson Lab can be conveniently covered by the spectrometer. The small region of no coverage in the most forward beams is due to the mesons being difficult to detect below 100 MeV/c.

Figure 4 shows a similar plot for the K meson survey.

Figure 5 shows the corresponding Peyrou Plots for the reaction

$$p + p \rightarrow p + \text{anything}$$

Similar remarks can be made as before, however, the only significant difference here is the missing bottom $\sim$20% of the momentum coverage of the proton survey. Otherwise, the coverage is excellent.

We have emphasized in our proposal that in addition to the basic proton beam survey, the data can be interpreted as a study of the mass distribution of the "anything". Figure 6 shows the spectrometer acceptance superimposed on a kinematics plot of this reaction. The shape of this continuum mass distribution as well as its energy and momentum transfer

Fig 2

PEYROU PLOT AT 200 GEV

FOR $P + P \rightarrow \pi +$ Anything

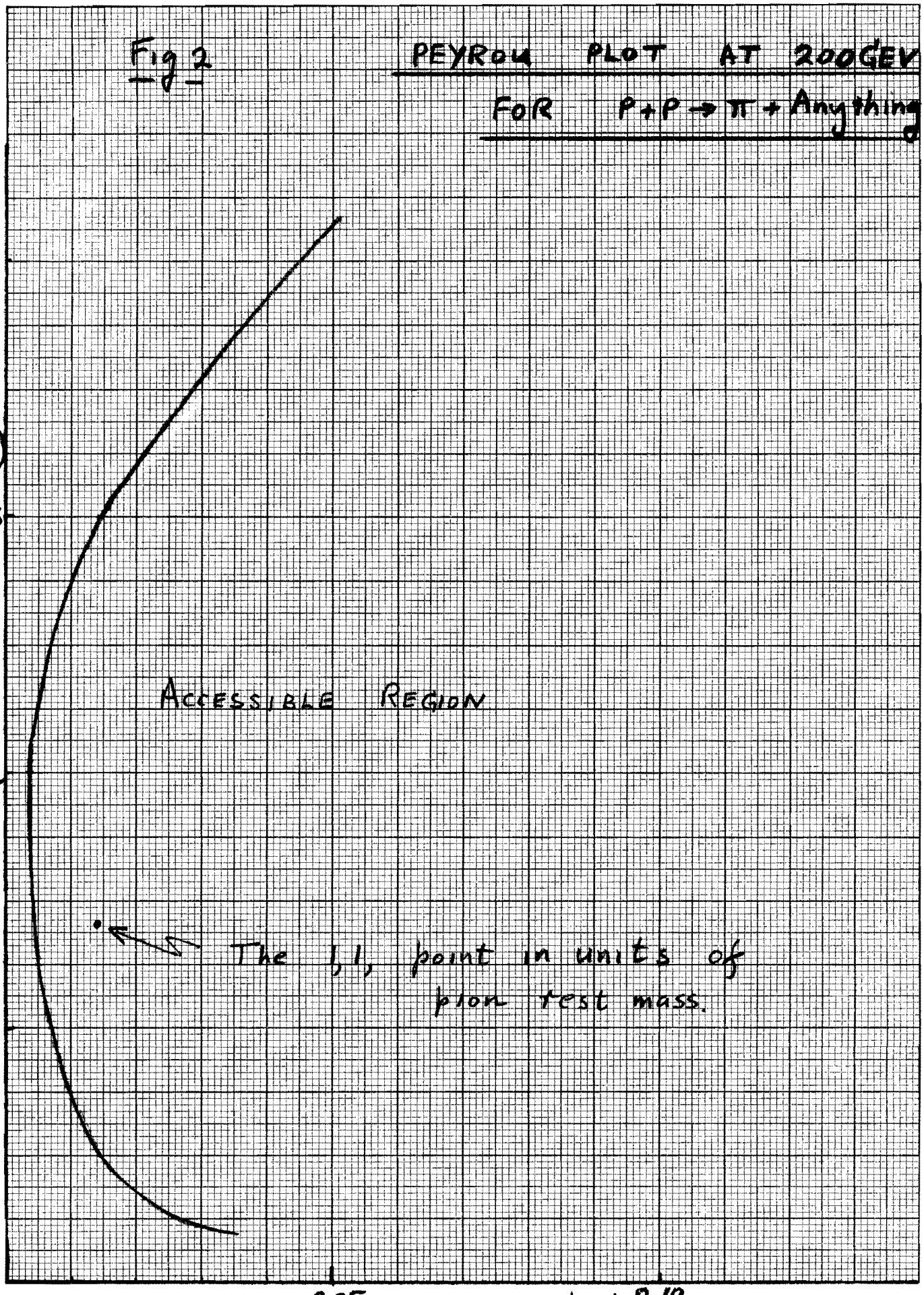


FIG 3

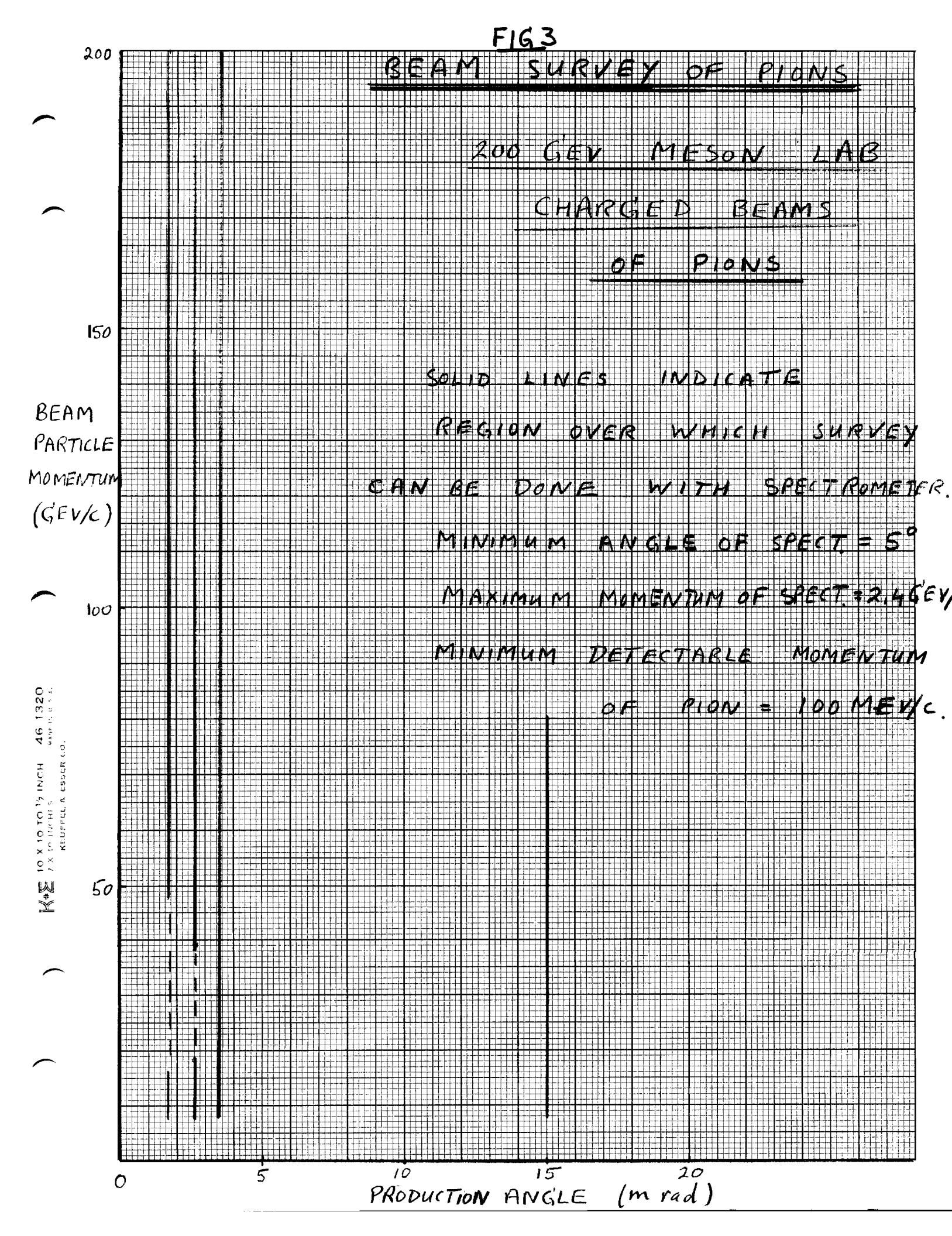

BEAM SURVEY OF PIONS
200 GEV MESON LAB
CHARGED BEAMS
OF PIONS
SOLID LINES INDICATE
REGION OVER WHICH SURVEY
CAN BE DONE WITH SPECTROMETER.
MINIMUM ANGLE OF SPECT. = 5°
MAXIMUM MOMENTUM OF SPECT. = 2.4 GEV/
MINIMUM DETECTABLE MOMENTUM
OF PION = 100 MEV/c.
BEAM PARTICLE MOMENTUM (GEV/c)
200
150
100
50
0
5
10
15
20
PRODUCTION ANGLE (m rad)
10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES
KEUFFEL & ESSER CO.

FIG. 4

BEAM SURVEY OF KAONS

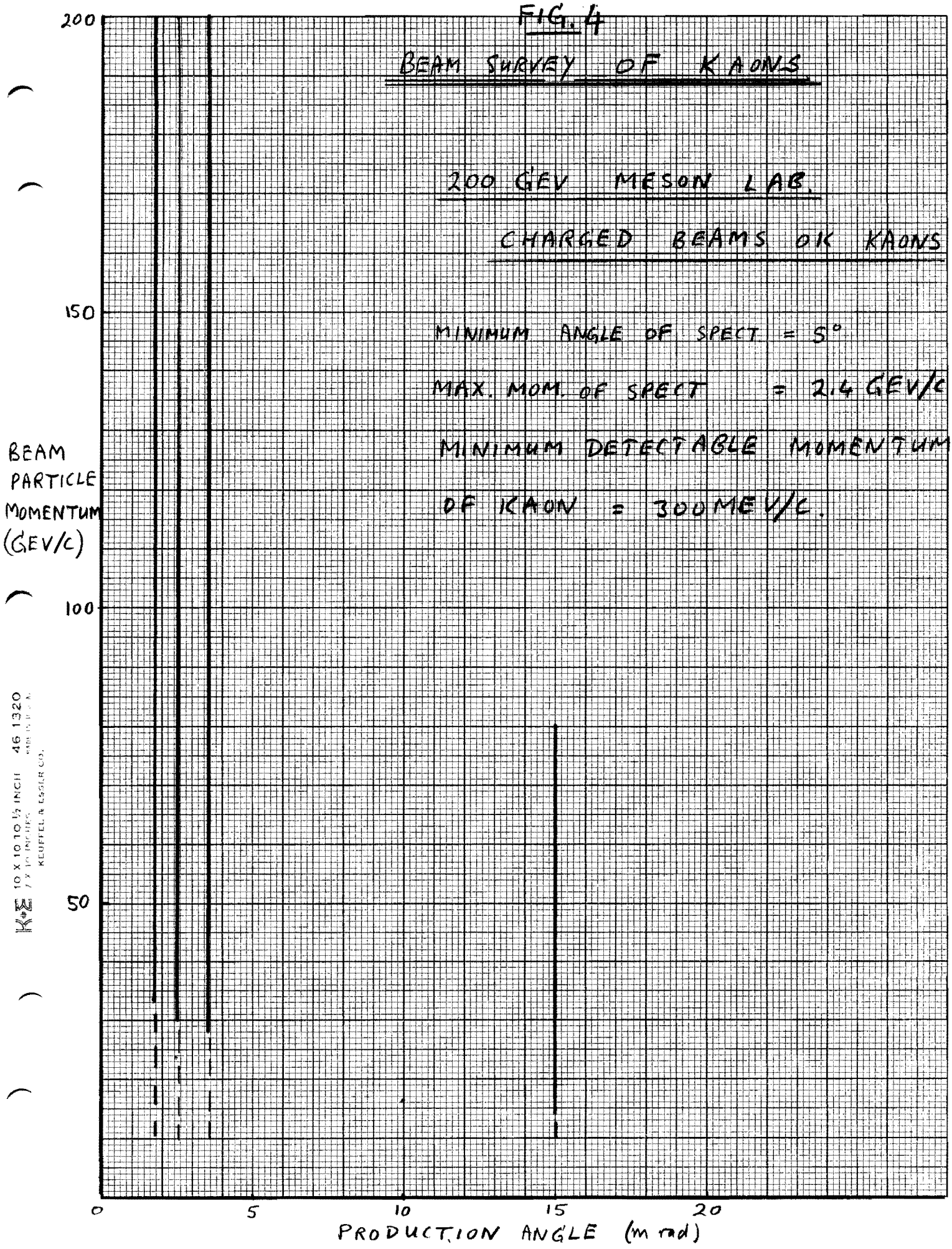
200 GEV MESON LAB.

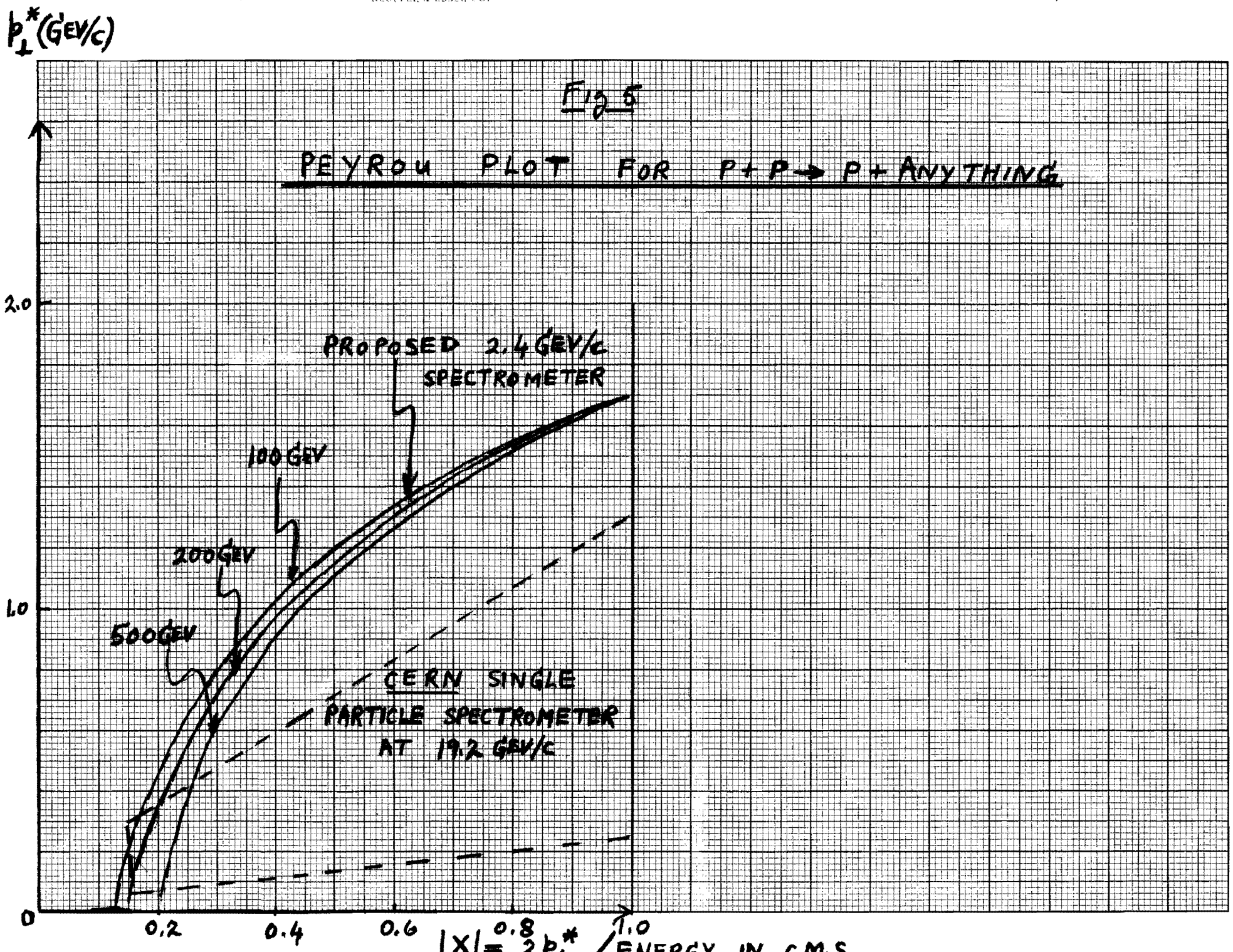
CHARGED BEAMS OF KAONS

MINIMUM ANGLE OF SPECT = 5°

MAX. MOM. OF SPECT = 2.4 GEV/c

MINIMUM DETECTABLE MOMENTUM OF KAON = 300 MEV/c.





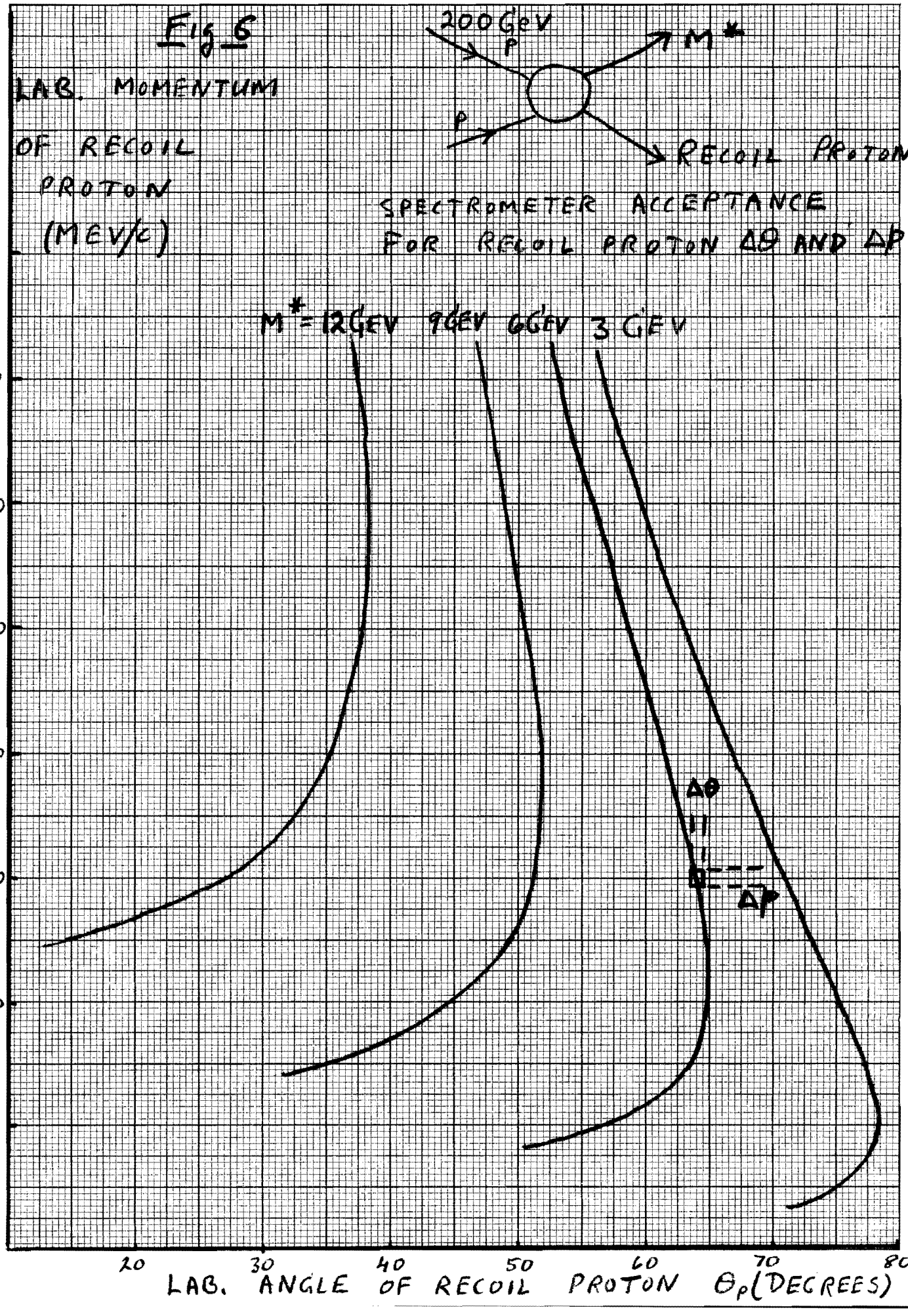


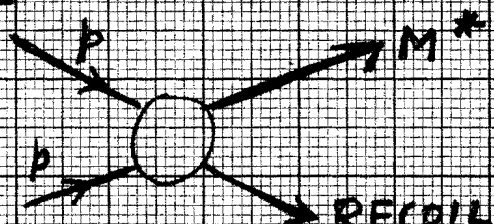
Fig 6
LAB. MOMENTUM OF RECOIL PROTON (MEV/c)
200 GeV
p
p
M*
RECOIL PROTON
SPECTROMETER ACCEPTANCE FOR RECOIL PROTON Δθ AND Δp
M* = 12GEV 9GEV 6GEV 3 GEV
Δθ
Δp
1400
1200
1000
800
600
400
200
20
30
40
50
60
70
80
LAB. ANGLE OF RECOIL PROTON θp (DEGREES)

dependence is of great interest to hadron dynamics. The experimental mass resolution as a function of momentum transfer for various masses of the "anything" is shown in Fig. 7 The mass resolution is minimum at the Jacobian peak where it is dominated by the angular resolution of the proton detection. Effectively, multiple scattering of the proton in the target, walls, gas and counter limit the available resolution. A mass resolution of 20 to 30 MeV can be achieved over a quite broad range of momentum transfers. This is due to our relatively good momentum resolution, which begins to be important quite rapidly as one moves away from the Jacobian peak. If any structure is observed in the continuum mass distribution of the "anything" then its significance above the background can be optimized by varying the momentum transfer and keeping the mass fixed. The available data of the Collins group at BNL indicate large variations of the momentum transfer distribution of different N^* production compared with the continuum background. This data suggests that close to an order of magnitude improvement of signal to noise of structure effects may be achieved by controlling the momentum transfer in the reaction.

We wish to emphasize the great strength of this technique is its equal ability to study particle production in proton proton collisions at 500 GeV as 70 GeV.

To give more feeling for an actual survey of a beam, let us consider the 3.0 mrad beam in the Meson Laboratory. Table 1 shows the angles and energies of the detected π mesons involved in the survey. Figure 8 shows the Hagedorn-Ranft

Fig 7 MASS RESOLUTION



200 GEV INCIDENT

MeV

$\pm\Delta M^*$

100
90
80
70
60
50
40
30
20
10

$M^* = 3$ GEV

$M^* = 6$ GEV

$M^* = 9$ GEV

$M^* = 12$ GEV

0 0.5 1.0 1.5 2.0

RECOIL PROTON MOMENTUM (GEV/C)

MESON LAB. 3 mrad Beam Survey

$p_{forward}$ (GeV/c)	p_{back} (GeV/c)	θ_{back} (degrees)	Counts/ second
20	.097	38.2	32
40	.120	91.7	48
60	.186	105.1	64
80	.255	109.5	96
100	.322	111.4	80
120	.390	112.5	62
140	.457	113.1	16
160	.523	113.5	4
180	.590	113.8	1

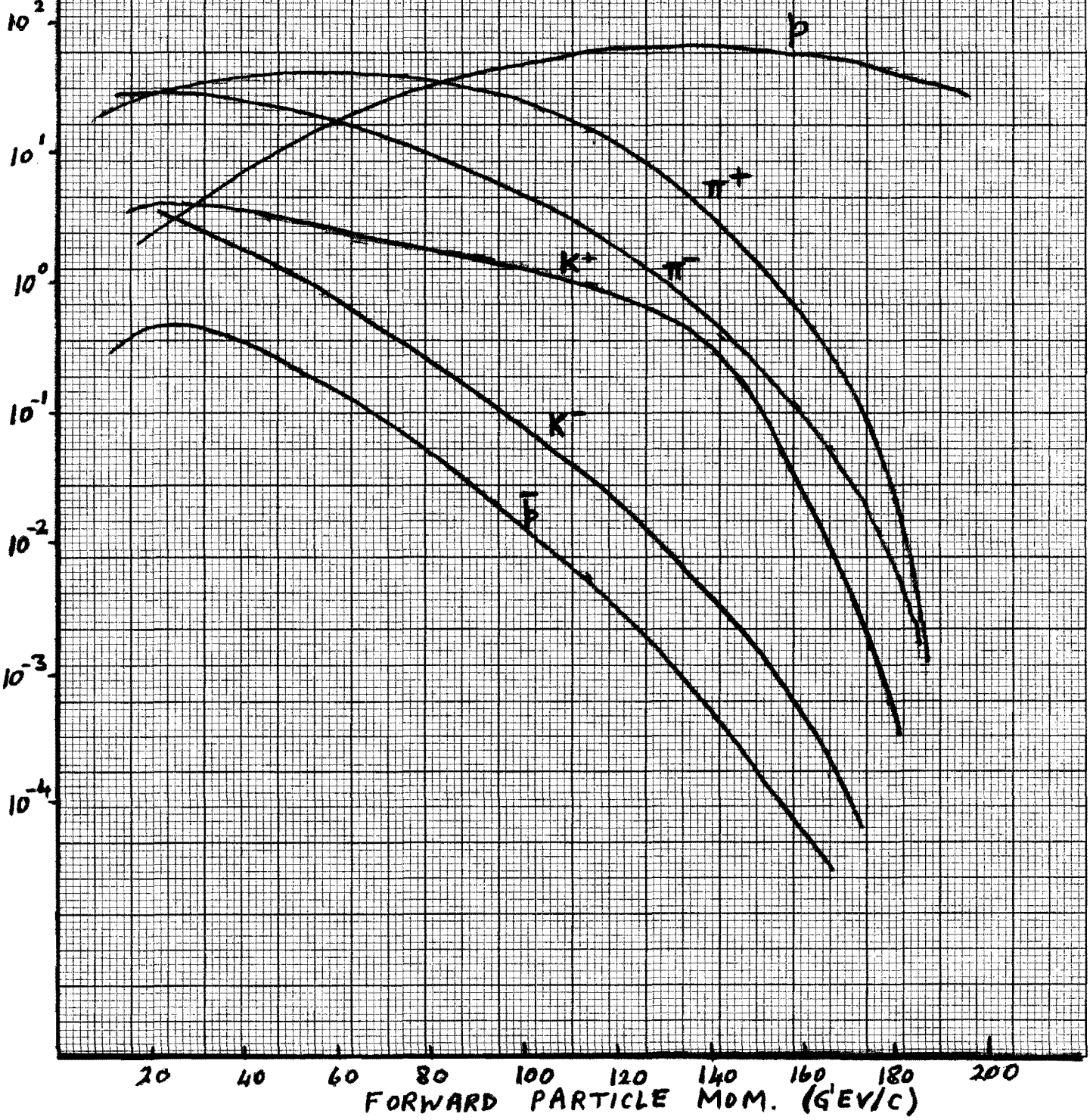
The event rate is for π^+ mesons in a ±2% $\Delta p/p$ and 10^{-4} steradian solid angle acceptance of the spectrometer. The beam intensity is assumed to be 10^{12} protons per second and a liquid hydrogen target is 1 cm thick.

TABLE 1.

Fig 8

H.R. PREDICTION IN 3.0 m.T. BEAM

Number of Particles PER GEV/c PER SR. PER INTERACT. PROTON



particle production predictions for this beam. The antiproton rates are down by about a factor of 1000 from the π^* rates. The Jacobian for transforming the forward to backward cross sections is favorable to the antiproton production compared to pion production by roughly a factor of 2. Thus, rates for antiprotons will be down by about 500 from that for π^+ given in Table 1, giving one antiproton per 5 to 10 seconds as typical.

We propose surveying the particle yields at several angles to cover the area of the Peyrou Plots as well as possible at 70 GeV, 200 GeV and 500 GeV, or whatever is the highest stable machine energy that is available.

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ADDENDUM TO NAL PROPOSAL #63: STUDY OF TWO PARTICLE CORRELATIONS IN THE SECONDARIES PRODUCED IN PROTON PROTON COLLISIONS

ABSTRACT

We propose extending the study of single particle spectra in p-p interactions, to study correlation effects in the two particle spectrum of secondaries. The proton-proton interaction is unique in two respects compared with other hadron proton interactions. The proton beam intensity is about 10^5 times greater than any secondary beam intensity. Secondly, in proton-proton collisions due to the symmetry in the center of mass system, observations of the low energy secondaries in the laboratory system permit a complete study of the process. Particle identification up to about 2.4 GeV/c is adequate and allows a simple and relatively inexpensive setup to be used.

The object of this experimental proposal is to find clear cut qualitative features of high energy hadron-hadron collisions as they are displayed in particle-particle correlation effects. These results coupled with our presently approved study of single particle spectra will provide many of the basic qualitative features of high energy strong interaction dynamics.

1. Justification

There does not exist a real theory of strong interactions at present. The models of high energy processes that one studies are no substitute for such a theory. It is the aim of this experimental proposal, coupled with proposal #63 to help to characterize the general features of multiple particle production independently of any model.

We propose studying

$$p + p \rightarrow a + b + \text{anything}$$

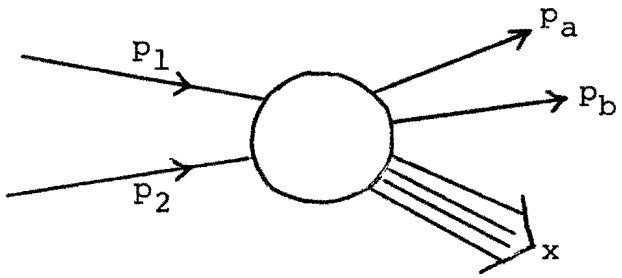
where a, b can be any one of the following particles π^+,π^-, K^+,K^-,p or $\bar{p}$. For the purpose of this proposal we shall concentrate on a discussion where a and b are charged pions. The detection and identification of the other types of particles of course will be done.

There is a well known analogy which links multiparticle production cross sections to the multiparticle distribution functions of a classical gas. The scaling laws predicted by the multiperipheral model may be introduced via this analogy. In addition, the conceptual development of the Feynman parton model of high energy collisions depended to a significant extent on this analogy. Finally, the thermodynamic model of Fermi and Hagedorn is largely based upon the analogy. In a real gas, a knowledge of the density and density correlation functions (as a function of temperature and pressure, say) determines all the properties of the gas of practical interest. By analogy, a knowledge of the density and density density correlations of the "elementary particle gas" at high energy

should be invaluable in characterizing its properties.

The density of the gas is simply the invariant single particle spectrum for the scattering problem (this will be different for the different species of secondary particle π^+, K^---). The density-density correlations of the gas correspond to the two particle correlation function (again this will be different for different species of particles). In this way, the gas analogy makes clear that any attempt to study multiple production should include experiments on the single particle distributions and the two-particle correlation functions.

We shall now try to be more specific and give examples of the type of qualitative features that nature may reveal in these experiments. Consider the diagram



where p_1, p_2 are proton 4-vectors, p_a, p_b are the 4-vectors of the detected particles and x is the undetected hadron state.

The measured differential cross section

$$\frac{d\sigma}{d^3p_a/E_a \; d^3p_b/E_b}$$ is a function (F) of six variables.

We may write these six variables as

$$S = (p_1 + p_2)^2$$

$$x_a = 2p_a''/\sqrt{S}$$

$$x_b = 2p_b''/\sqrt{S}$$

$$\vec{p}_{a\perp}$$

$$\vec{p}_{b\perp}$$

and $\quad \vec{p}_{a\perp} \cdot \vec{p}_{b\perp}$

The basic question is: what simple features does the function F exhibit at high energy?

We list some features that have been suggested in the last year. At this stage we should acknowledge stimulation by the ideas of Ken Wilson of Cornell on possible experiments on multiple production.

1. Scaling Hypothesis:

$$\frac{d\sigma}{\sigma_T}\Bigg|_{\substack{S\to\infty \\ x_a,\ x_b \text{ fixed} \\ \vec{p}_{a\perp},\ \vec{p}_{b\perp} \text{fixed}}} \sim \frac{d^3p_a}{E_a}\frac{d^3p_b}{E_b} F\left(x_a, x_b; \vec{p}_{a\perp}, \vec{p}_{b\perp}; \vec{p}_{a\perp}\cdot\vec{p}_{b\perp}\right)$$

In other words, at high enough energy the function F becomes a function of 5 rather than 6 variables; --the S dependence drops out.

2. dx/x Proposed Law:

$$\frac{d\sigma}{\sigma_T}\Bigg|_{\substack{\text{large fixed } S \\ \vec{p}_{a\perp},\ \vec{p}_{b\perp} \text{ fixed}}} \sim \frac{d^3p_a}{E_a}\frac{d^3p_b}{E_b} F$$

where it is proposed that F may be a constant for x_a, $x_b \lesssim 0.3$

3. Proposed Factorization Law:

$$F(S, x_a, x_b; \vec{p}_{a\perp}, \vec{p}_{b\perp}, \vec{p}_{a\perp} \cdot \vec{p}_{b\perp})$$

$$= I(S)\, G(x_a, x_b)\, H(|\vec{p}_{a\perp}|, |\vec{p}_{b\perp}|, \vec{p}_{a\perp} \cdot \vec{p}_{b\perp})$$

4. Correlation Lengths:

Here one studies, for example

$$\left.\frac{d\sigma}{\sigma_T}\right| \begin{array}{l} S \text{ large and fixed} \\ \vec{p}_{a\perp}, \vec{p}_{b\perp} \\ x_a \text{ fixed} \end{array}$$

as a function of x_b.

One can compute the two particle correlation function g from this data.

We define

$$g(S, x_a, x_b, |\vec{p}_{a\perp}|, |p_{b\perp}|, \vec{p}_a \cdot \vec{p}_b)$$

$$= F(S, x_a, x_b, |\vec{p}_{a\perp}|, |\vec{p}_{b\perp}|, \vec{p}_a \cdot \vec{p}_b)$$

$$- f_a(S, x_a, |\vec{p}_{a\perp}|) f_b(S, x_b, |\vec{p}_{b\perp}|)$$

where $f_a(S, x_a, |\vec{p}_{a\perp}|)$ and $f_b(S, x_b, |\vec{p}_{b\perp}|)$ are the single particle spectra functions of particles a and b. Qualitatively, the most interesting property of the correlation function is if it exhibits a correlation length, i.e., see if it goes to zero for $S_{+-} = (p_a + p_b)^2 >> m_\rho^2$ for the case of the particles a and b being oppositely charged π mesons.

These are some examples of clear cut qualitative features that may emerge for the structure of the production

amplitude F in this type of experiment. Of course, similar qualitative features should emerge from the study of the single particle spectra. No doubt nature is more subtle than we can anticipate and will provide us, after much hard experimental effort, with different but more rich insights into the structure of the hadron hadron scattering amplitude. We believe that discovering the general characteristic features of these processes is more important than having precise numerical data on particular processes (e.g. 5 body final states) just to test a particular model. Finally, we hope these characteristic features that are discovered will give a profound insight into our understanding of strong interaction theory.

II. Apparatus

A double focussing magnetic spectrometer is being constructed for studying the single particle distributions in proton-proton interactions. The solid angle accepted by the spectrometer is about 1 millisteradian and the maximum operable momentum is 2.4 GeV/c. The momentum band pass of the spectrometer is about 10% and individual particle momenta will be determined to about ±0.5%. The angular resolution for particles traversing the spectrometer is about ±1 milliradian. The angular range over which the spectrometer operates is 5^{o} to 175^{o} in the laboratory system. The angular range corresponds to covering essentially all of the backward hemisphere in proton-proton collisions up to 500 GeV incident protons.

A 1 cm thick liquid hydrogen target will be used.

The proton beam intensity will be measured using several monitors and it is anticipated that eventually reliable absolute monitoring of the beam will be achieved at the ±1% level of accuracy at all proton beam energies. Good beam monitoring is required to study the energy dependence of the distribution functions (breaking of the scaling laws).

The design of the spectrometer is such that all of the counters are located behind shielding out of sight of the liquid target and the proton beam line. In this way we anticipate, based on experience with presently available beam energies and spectrometers, that we will be able to operate the spectrometer at up to 10^{13} protons per second passing through the liquid hydrogen target. Liquid targets have been built and used at SLAC which allow successful operation at beyond this beam intensity.

For the purpose of the study of the two particle correlations, we propose the use of a second similar spectrometer with an upper momentum limit of about 2.4 GeV/c and about 25 feet long. The detailed design of the second spectrometer will depend on further calculations of multiparticle event simulations. In particular, it is possible that a larger solid angle of acceptance for the second spectrometer would be appropriate. For the present we consider the design of the two spectrometers to be identical. These two spectrometers would rotate about a common axis centered below the liquid hydrogen target. They would normally, but not always, be on opposite sides of the incident proton beam line. The

length of each spectrometer is 25' and is remotely controlled in all of its functions.

III. Experimental Procedure

We consider, to be specific, the π^+,π^- correlation function. Let S_{+-} be the invariant mass squared of the π^+,π^- pair; in terms of the measured laboratory quantities $|\vec{p}^{+}||\vec{p}^{-}|$, θ^+, θ^- with an obvious notation

$$S_{+-} = 2m_\pi^2 + 2\sqrt{m_\pi^2 + p^{+2}}\ \sqrt{m_\pi^2 + p^{-2}} - 2p^+p^- \cos(\theta_+ - \theta_-)$$

One expects strong correlation between the π^+ and π^- when $S_{+-} \sim m_\rho^2$ (m_ρ is the ρ mass). The correlation function may become small when $S_{+-} >> m_\rho^2$. The experiment then consists of measuring the cross section at various x_b as described earlier.

Figures 1, 2 and 3 show the regions of the Peyrou plot at incident proton energies of 70 GeV, 200 GeV and 500 GeV which can be covered by the proposed experimental setup for $S_{+-} = m_\rho^2$ and $S_{+-} = 3m_\rho^2$. For the case of $S_{+-} = m_\rho^2$ the accessible region covers essentially the complete range of x and $p_\perp$ where we expect the vast bulk of the vents will fall. The dual model, the double Pomeron exchange model, parton model etc. all make interesting and different predictions for this type of data. It is likely that new scaling laws will emerge from these results and the range of their validity will be explored in detail.

Rates

An event simulation Monte Carlo program is being used to study the effective acceptance of the two spectrometer

arrangement for dipion systems over the complete kinematic range that is accessible. This is a complicated and lengthy procedure and is sensitive to the model of particle production that is used. We do not yet have results from this work.

As a first step towards evaluating rates we have simply calculated the single pion rates in each spectrometer when they are symmetrically located on either side of the beam at some representative angles for 200 GeV incident proton energy. The transverse momentum of the dipion system is therefore zero and the values of x $(= 2\ p_{11}/\sqrt{S})$ of the dipion system are given in Fig. 4. The invariant dipion mass is approximately constant at 0.4 GeV^2, the actual values are shown in Fig. 1. For this dipion mass the range $0 \leq x \leq 1$ can be covered for all proton energies up to 500 GeV. In addition, transverse momenta in the range $0 \leq p_\perp \lesssim 2$ GeV/c can be covered (the upper limit is correlated with the value of x as indicated in Figs. 2, 3, 4).

Scaling and factorization can be explored over a wide range of the variables. In addition, the cross section dependence on the choice of pion charges i.e. $\pi^+\pi^+$, $\pi^-\pi^+$, $\pi^-\pi^-$ can be investigated.

It can be seen that the counting rates in each spectrometer are very large, typically about 10^5/sec at the above settings. To enhance the true coincidence rate above the uncorrelated or random coincidence rate it may be appropriate to run at lower incident beam intensity for these low invariant dipion masses where rates are high. A detailed study of the

anticipated correlated coincidence rate for various models will be done in the coming months.

Of course, it should be emphasized that in this example of two pions we have picked out only one of a number of the qualitative questions which can be investigated with this technique. The rates with kaon pairs and proton, anti-proton pairs will presumably be considerably less than for pion pairs. The correlations of unlike particles such as pions and protons will also be of interest.

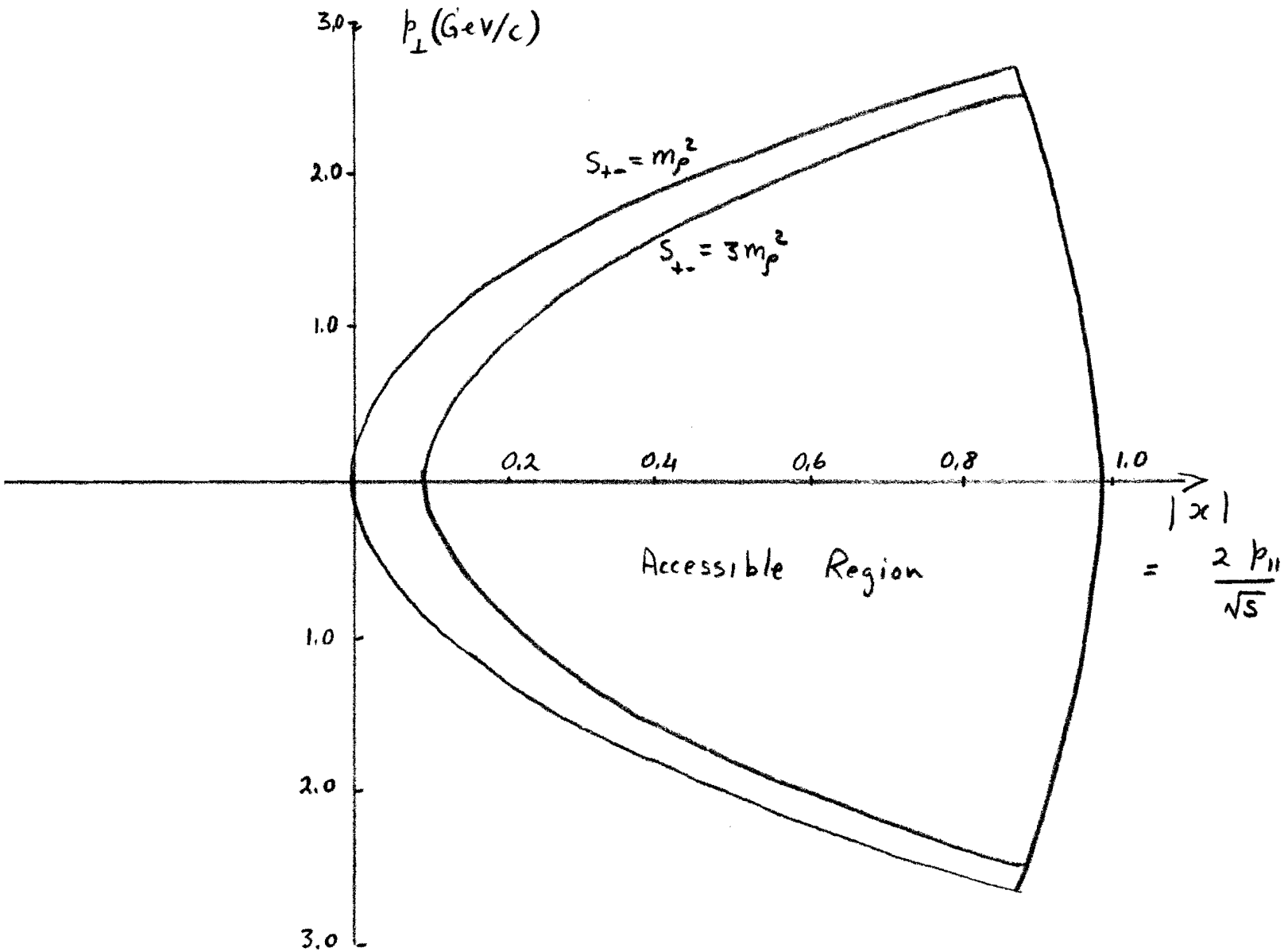
Time Schedule

We anticipate that the major portion of the single particle spectra will be taken by December 1972. We propose that installation of the second spectrometer should proceed at this time and that data taking can begin sometime in the spring of 1973.

Summary

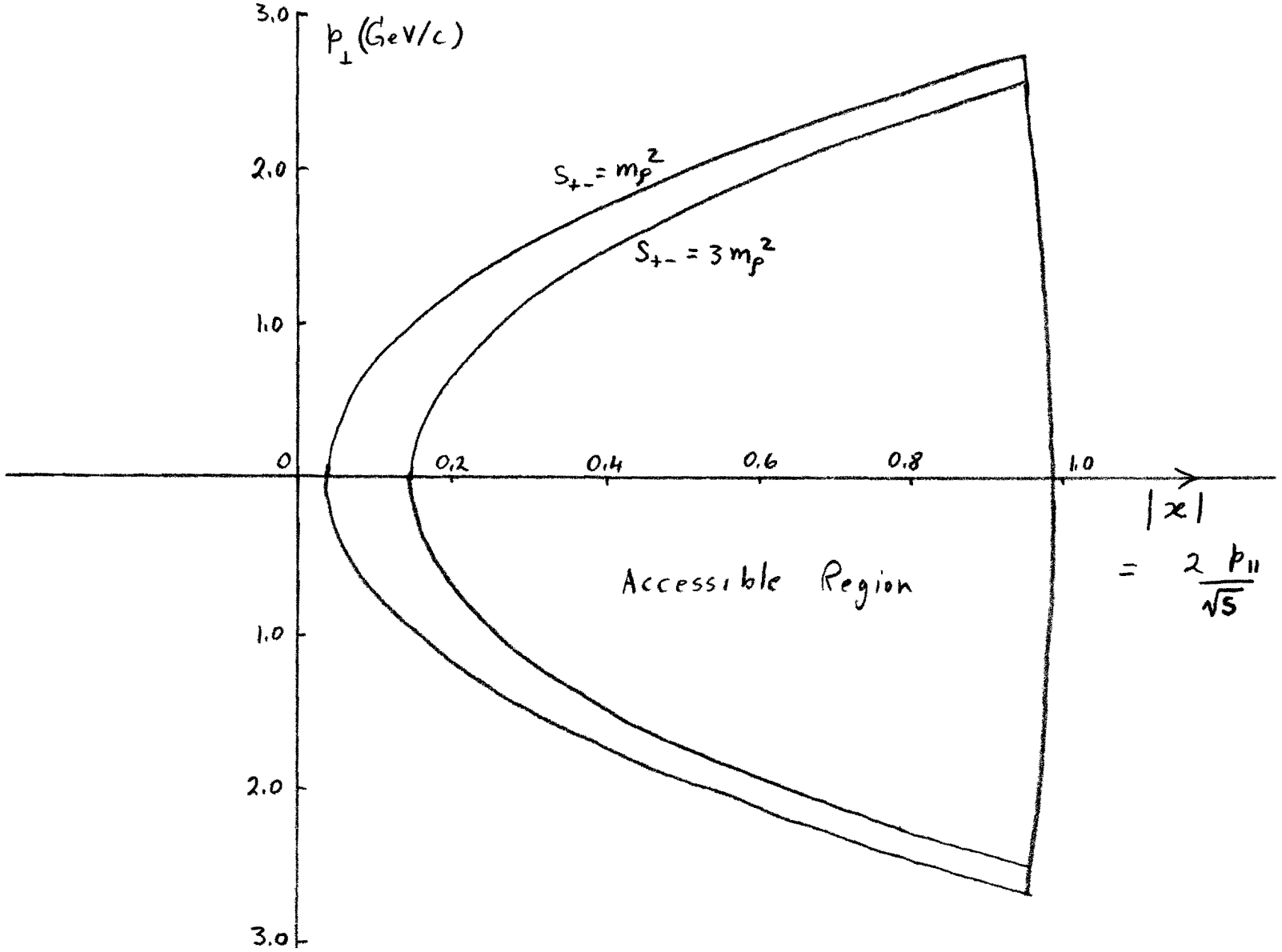
At this stage, we believe the physics justification to study two particle correlations in hadron-proton collisions is very strong. The proton-proton scattering is a particularly appropriate first case for studying these correlations due to high beam intensity and very simple, inexpensive and well tried detection techniques being required. We believe it is important at this stage that the design of the Proton Laboratory should take into account a thin transmission target at the pivot of the two spectrometers which can swing from $\sim 5^{o}$ to 175^{o}.

We intend submitting a detailed addendum to this proposal on the subject of two particle coincidence rates. It is our conviction that these two phases of the experiment, namely, single particle spectra and two particle correlation spectra, will yield many of the most important qualitative characteristics of high energy hadron dynamics.



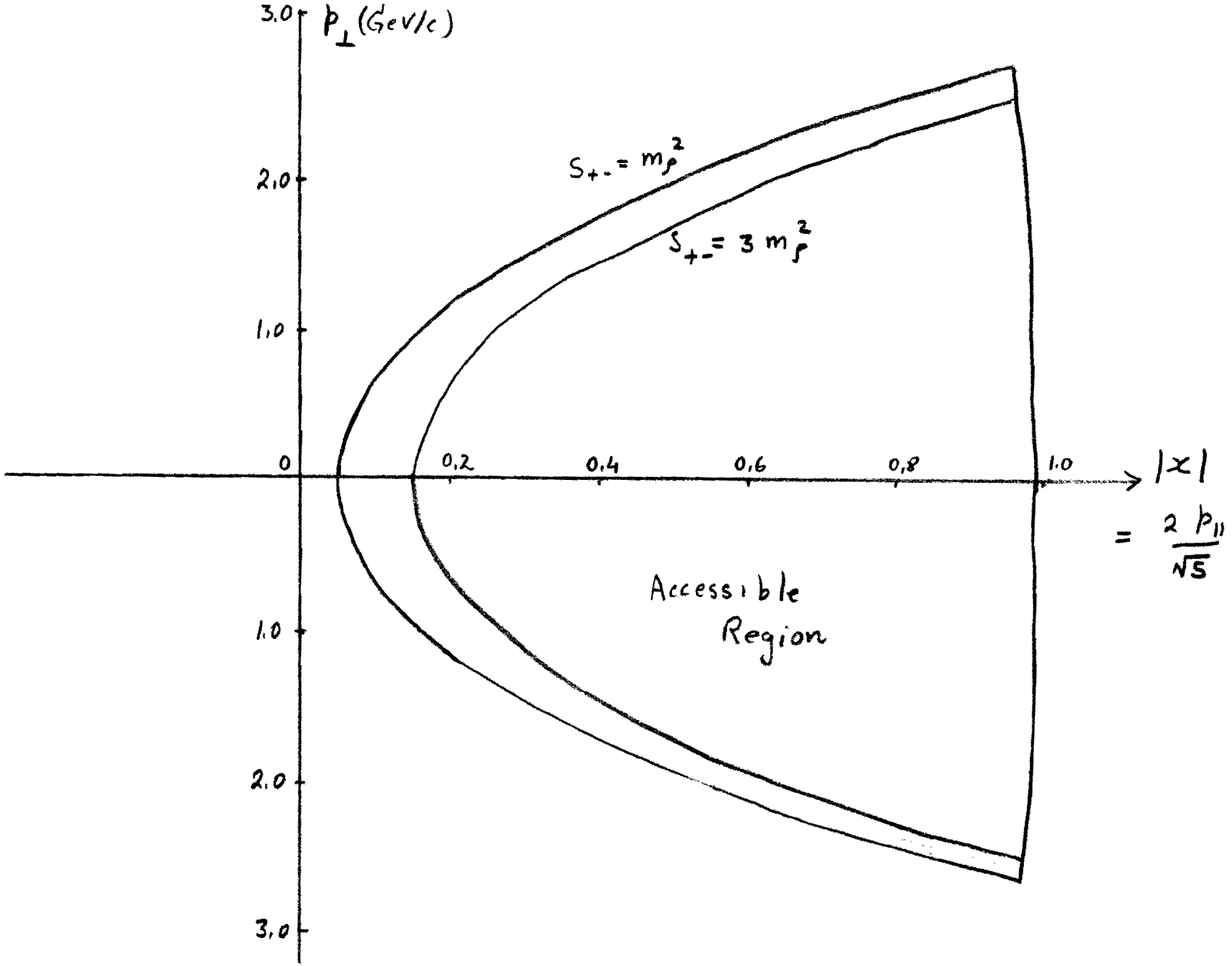
C.M.S. Region within which measurements can be performed on dipion system of $(\text{mass})^2 = S_{+-}$. Incident Energy = 70 GeV.

Fig. 1



C.M.S. Region within which measurements can be performed on dipion system of $(\text{mass})^2 = S_{+-}$. Incident Energy = 200 GeV.

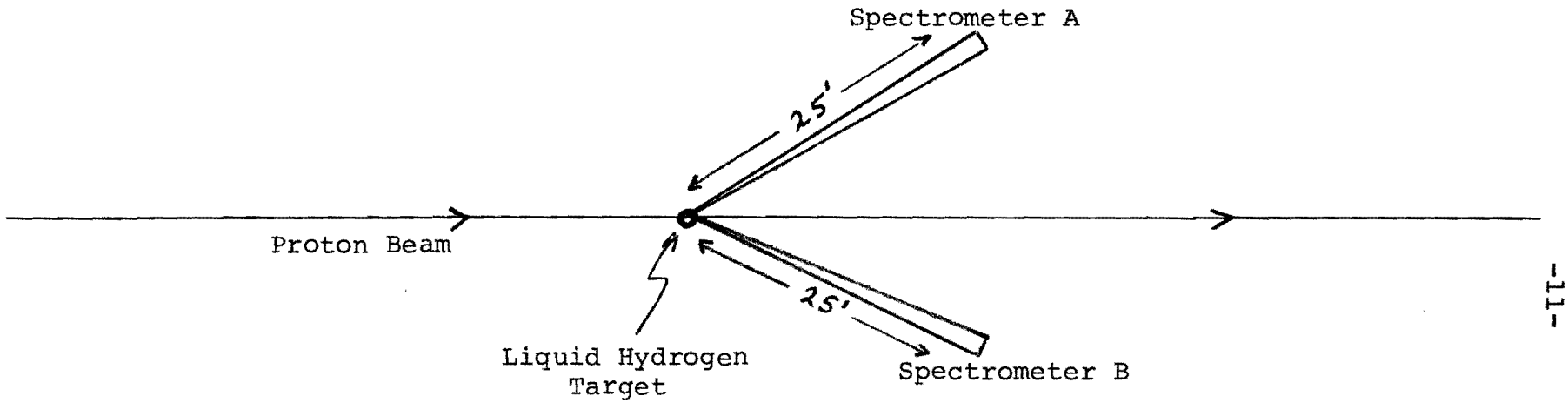
Fig. 2



C.M.S. Region within which measurements can be performed on dipion system of $(\text{mass})^2 = S_{+-}$. Incident proton energy = 500 GeV.

Fig 3

Equivalent Forward Pion Mom. (GeV/c)	Transverse Mom. GeV/c	Backward Pion Mom. GeV/c	Backward Pion Angle Degrees	Invariant Mass of Dipion System $(GeV)^2$	Value of $x = 2p_{11}/\sqrt{s}$ of Dipion System GeV/c)	Counting Rate of Pions in Spectrometer A or B/Second
25	±0.3	0.507	±36.3°	0.44	0.25	1.6×10^5
50	±0.3	0.322	±68.8°	0.39	0.50	2×10^5
75	±0.3	0.30	±93.8°	0.44	0.75	1.7×10^5



Kinematics and Counting Rates for Each Spectrometer.

Fig. 4.