NAL PROPOSAL No. 23

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INCLUSIVE PION-PROTON SCATTERING

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Abstract:

The reactions $\pi + p \rightarrow \pi + \cdots$ and $\pi + p \rightarrow K + \cdots$ will be studied over a wide range of the Feynman variables X, Q and S in order to test the conjectured scaling law for hadron collisions and study the form of the yield distributions. Particular attention will be paid to the vicinity of X = 0. The experiment will be carried out with a simple one-magnet spectrometer which takes full advantage of the kinematics and has wide acceptance and the capability of high precision.

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I Introduction

Some recent conjectures[1] on the nature of high energy hadron collisions have led to quantitative predictions as well as to a heuristic picture of these interactions. The predictions have not been tested at high energies; much of the older data at low energies is not of high statistical quality and not all of it was taken with the proper choice of kinematic variables. New experiments at lower energies are under way and the results will be available for comparison with high energy data.

The reactions with which we are concerned here which are expected to give some understanding of hadron structure and high energy collision processes are $\pi+p\to\pi+$anything and $\pi + p \to K +$ anything.

Inclusive Proton-Proton scattering has been studied at ANL,[2] BNL[3] and CERN[4] over a limited range of kinematic conditions buthas already yielded some interesting generalizations about high energy collisions and some significant comparisons[5] with very high energy cosmic ray data.[6] Inclusive Pion-Proton reactions have thus far been studied only in bubble chamber experiments.[7] A University of Washington group has an experiment in progress[8] at SLAC to study πp Scattering at energies up to 16 Gev. Single pion yields with 2% accuracy for a variety of kinematical conditions should be available within a year. (Figure 1)

Feynman[1] has proposed a scaling law for the yield of hadrons in high energy hadron collisions. As s becomes large the yield is expected to approach

$$\frac{dx\,dP_{\perp}^{2}\,f(Q,x)}{\sqrt{x^{2}+\frac{Q^{2}+m^{2}}{s/4}}}$$

where $x = P_{z}^{*}/\sqrt{s}/2$; $Q = P_{\perp}$.

Aside from the 1/E* factor the yield becomes independent of s and depends only on the transverse momentum and the longitudinal momentum suitably scaled. If existing accelerator data is multiplied by E* it can be seen that the function f(Q,x) is nearly factorable into f(Q)g(x) and in fact can be fit over a limited region, at least, by functions of the form

$$e^{-b(Q+\frac{Q^{2}}{M})}\;e^{-ax^{2}}$$

If the yield is integrated over x and Q we expect to obtain the average multiplicity of final pions times the inelastic cross section. If the x dependence of g(x) in the immediate vicinity of x=0 is ignored then the integrated yield and hence the multiplicity can be seen to be proportional to g(0) log s/s_o. Thus g(0) can be compared with data taken at other energies, in particular with low energy data and with cosmic ray data and the onset of the asymptotic region (i.e. no s-dependence) can be found. On the basis of existing 30 Gev p-p data[2-6] we believe that the "scaling" is already in effect at least to within 15 or 20%. Data to be taken at NAL at 50, 100 and 170 Gev/c should confirm the scaling law and provide values for g(0) and s_o as well as giving the limiting form of f(x,Q).

A number of models have been proposed to fit and interpret high energy data[9]; among these are the thermodynamic model and the multiperipheral model which is under active study[10] at U. of W. The latest version will soon be able to fit π^{-}p data.

It would be of very great interest to carry out an experimental test of these conjectures in a simple direct way at the start of NAL experimental operations. The experiment is quite straight forward; for fixed incoming pion energy one measures the distribution in x of outgoing pions at several selected values of Q. This measurement is carried out for three or four beam energies and the function f(x,Q) can be extracted.

II Pion Proton Scattering

We propose a measurement of π^+ and π^- yields with better than 1% statistical accuracy under the kinematic conditions given below. Data for the two charges should be interesting for distinguishing leading pions from pionization.

Table I

Beam momentum = P_i	50, 100, 170 Gev/c
Q	.2, .3, .4, .5 Gev/c
x	$0<x<.4$

Data in this range of x can be obtained with one spectrometer setting. Eight combinations of P_i and Q would be chosen for major data taking runs. The beam momentum need not be especially well defined for this experiment; $\Delta P/P$ of several percent would be fine. We would accept data over a range of about 10% in Q for each magnet setting. Actual values of Q and x for each event would be determined with a magnet-wire chamber spectrometer to be described below.

The precision requirements are modest by NAL standards; we will need angle measurements good to about $\frac{1}{2}$ mrad and momentum measurements to several percent depending on production angle; at small production angles where the momentum, in our scheme is not well determined, the poor precision does not affect the quality of the data (see figure 2). We are, after all, looking for the smooth behavior of the yield as a function of P_i and x and not for structure. Threshold Cerenkov counters would distinguish pions from kaons and protons and a shower-wire spark chamber at the downstream end of the apparatus would tag electrons. A simple hodoscope system will be used to select triggers and to tag spark chamber tracks.

The apparatus to be described below will accept pions over a range of x roughly from x = o to .4 for a fixed value of Q and kaons over most of that range; it is designed so that a range in Q of about 10% is accepted for all these values of x. To compute an approximate data rate we assume a 60 cm long liquid hydrogen target, a maximum scattering angle of 140 mrad and an average azimuthal angular acceptance of the detector of 2%; for small scattering angles of the o acceptance will be comparable although the Cerenkov counter is longer. The event rate per pion is

$$\begin{array}{cccccccc} 30\ \ 10^{-27} & \times\ 6\ \ 10^{23} & \times\ 4 & \times\ .02 & \times\ .50 & \times\ .05 & = .36\ \ 10^{-4} \text{ per pion} \\ \sigma & N_o & \overset{\text{gms}}{LH_2} & \Delta\phi & \Delta x & \Delta Q & \end{array}$$

where we have estimated an acceptance of 50% in x and 5% in Q. The azimuthal acceptance will be limited by the Cerenkov counters and will be somewhat different for different ranges of production angle. The cross section varies with Q but not too rapidly for small Q: The cross section for pion yield has been obtained from the inelastic cross section[7] and the multiplicity of pions of a given charge with the leading pion excluded since it tends to have a larger x. (Figure 3)

At a pion rate of 10^7 per pulse we will get about 360 events per pulse which is convenient from the point of view of data handling and deadtime. At this rate we can collect 325,000 events/hour at each spectrometer setting.

Background rates in the upstream spark chambers can be estimated by using the entire charged particle multiplicity and unit acceptance in Q. This gives about 2 x 10^4 per second or about 50 μsec average spacing between background events; this is much greater than the sensitive timer of any chambers that might be used. Suitable trigger hodoscopes will select secondaries in the desired range of Q.

III. The Spectrometer

1. Beam

A conventional 2 foot long liquid hydrogen target will be placed in a high intensity wide momentum acceptance pion beam. By making fast coincidences with very small counters we hope to be able to utilize a rate of up to 10^7 pions per pulse; if a lower intensity appears to be necessary the event rate is still more than adequate. Each incoming pion will be tagged for angle but not for momentum. Incoming angles will be measured to better than $\frac{1}{2}$ mrad with a pair of fine hodoscopes.

We would expect that the beam and target would be constructed by NAL while the hodoscope and electronics would be supplied by us.

2. Magnet

A bending magnet with approximately a 2 foot wide aperture, an eight inch gap and a value for $\int B \cdot dl$ of 1000 Kg-inches would meet our needs. (Fig. 4)

The magnet is being used in a mode in which pions with a fixed value of Q emerge in parallel rays independent of production angle[11]; rays with a few mrad of divergence are also accepted to give an appropriate range of acceptance in Q. The magnet is placed sufficiently for downstream of the target to permit the production angle to be measured to better than $\frac{1}{2}$ mrad. The magnet's horizontal aperture then limits the range of production angles accepted to about 140 mrad. This is sufficient to allow us to get to $x \doteq 0$ for a wide range of Kinematical conditions.

A magnet with just the parameters we need is being considered for a very similar spectrometer by W. Baker.[12] Many components including target, magnets, hodoscopes, chambers and the 40 meter Cerenkov counter could be shared.

3. Wire Chambers

We will use a system of wire chambers for the angle determinations. The small chambers before the analysis magnet will be run in the proportional mode; The chambers are relatively small and the multitrack rate may be sufficiently high to warrant the good time resolution and multi-spark efficiency that can be obtained with proportional chambers.[13] With the separations chosen the spatial resolution will be adequate. The downstream chambers could probably be wire spark chambers. A total of about 12 coordinate planes will be needed, the largest dimensions are about 1 meter. We are prepared to build these or to collaborate with other groups in this.

4. Cerenkov Counters

In order to cover our desired range of x values for beam momenta from 50 Gev/c to 170 Gev/c, we must be able to detect pions from 1.5 up to 80 Gev/c. To cover this large range we will require three separate but similar Cerenkov counters. Counters C_1 and C_3 are of such length that it probably will prove necessary to build them in modular sections. But since these two counters are the same diameter, this means that they are essentially the same counter, with C_3 merely having more modules.

The working index of refaction for C_1 and C_3 can be taken from figure . Hydrogen has been chosen as the radiator because of the relatively high number of photons/cm produced (0.11 photons/cm/atmosphere between 3500 A and 5000 A for $\beta = 1$, compared to 0.027 photons/cm/atmos. for helium)[14]. The index is not as high as some of the heavier gases, but the multiple scattering and interaction probability are considerably smaller for hydrogen. The amounts of hydrogen involved in the two counters are not large, corresponding to about 6 liters of liquid hydrogen in each case. As C_1 is a one atmosphere counter, there should be minimal safety hazard. C_3 will have to have adequately strong windows for its working pressure of .15 Atm. This is not serious, as C_3 is downstream of our last spark chamber. As indicated on figure 5 , C_1 covers the region from 10-30 Bev/c and C_3 from 30-80 Bev/c. The lengths and diameters of these counters are then determined by the angular acceptance of the analyzing magnet, the angle of the Cerenkov cone, and the number of photons/cm of length. Each of the counters will be viewed by a single 5" phototube. We hope to use a 4522 with a quartz or fused silica face so that we can detect light down to 1800 A. The walls of the pipes will be rough and black, and baffles will be inserted at regular intervals to reduce the effects of delta rays[15]. A proposed design for C_1 is given in figure 6 .

Counter C_2 is designed to separate π's from K's below 10 Bev/c. Thus it is a much more conventional counter. It will use Freon 12 as a radiator, with a pressure varying from 1 to 5 atmospheres (absolute), depending on the lower momentum limit desired. Again this counter is placed downstream of our last spark chamber so that multiple scattering in the windows or in the gas will not affect our determination of angles.

Since the momenta of the secondaries are being determined the two higher pressure Cerenkov counters C_1 and C_2 can be used to tag kaons; together they will count kaons from about 10 Bev to the top of the interesting range; by subtraction we can obtain the yield of pions and kaons over most of the x region with adequate statistical accuracy.

The C_1 counter would be built as a prototype for C_3 and itself poses no special problems; its design and construction can easily be carried out at the University of Washington. We will also design C_3 and construct the mirror and photomultiplier sections; final assembly will have to be done at NAL. The low momentum counter C_2 requires a pressure window of fairly large diameter but similar pressure windows for a Cerenkov counter have already been built[16] and we anticipate no difficulty.

5. Shower Spark Chamber

Electrons among the secondaries will be tagged by a shower-wire spark chamber array at the extreme downstream end of the spectrometer. Preliminary estimates show that it is not difficult to intersperse layers of high Z materials with wire chambers to have high efficiency for generating an electromagnetic shower but low probability for hadron collisions (in particular for π° production). Such a shower detector is currently in use by a University of Washington group doing $n + p \rightarrow d + \gamma$ at the Berkeley cyclotron. The system works well but a different readout mode may have to be developed for the NAL experiment where data rates are relatively high.

6. Trigger Hodoscopes

Three hodoscope arrays will be used to select output angles to generate chamber triggers and gates. The output angles that we want to select are those angles within a few mrad of 0°. With the separations shown in the figure the hodoscope counters could be approximately one inch wide so that the total number of counters is not excessive. An alternate method would be to use proportional chambers in a self gating mode, doing fast logic on the wire outputs before storing the data. In either case the trigger rate should be no more than about 30% higher than the desired event rate. The hodoscope design would be conventional and they could be built at U. of W.

7. Computer

An on line computer will accumulate data from the wire chambers, hodoscopes, Cerenkov counters etc. The data storage rate per event will be approximately:

Hodoscopes (trigger)		100 bits
Hodoscopes (beam)		12 bits
Cerenkov counters		21 bits
Wire chamber banks	S_1	120
	S_2	120
	S_3	120
	S_4	80
	SC	300

for a total of about 900/event or 50 18 bit words. The computer will edit the data, form histograms, compute trajectories and store a condensed version on magnetic tape. With an event rate of close to 500/sec the transfer rate is about 75,000 6 bit bytes per second so high speed, high density tape drives will be needed as well as substantial data condensation. We would expect that a suitable computer would be available at NAL. Detailed specifications remain to be worked out.

Much of the soft-ware development effort could be shared with other spectrometer users. U. of W. is particularly strong in this respect since an automated bubble chamber analysis system is now being built here and we have a number of experts who would participate in this experiment at a later stage.

IV. Conclusion

The Spectrometer outlined here is the most appropriate type for a study of inclusive reactions. It has a wide kinematic acceptance band and takes full advantage of the kinematics to collect data in the interesting region in terms of the Feynman variables directly. It has the important advantage that without the use of quadrupoles the analyzed beam going into the Cerenkov counters is parallel making particle identification easy. The simplicity of the system means that acceptance and solid angle can be calculated with high reliability. The spectrometer can utilize a single magnet which could be found at any existing accelerator while much of the ancillary apparatus such as spark chambers, hodoscopes etc. are completely conventional. The high momentum Cerenkov counter C_3 alone is unique to the NAL energy range but the specifications are such that it would find a multitude of uses; indeed many people are considering just such a counter.

We view this experiment as an important but simple one which should be carried out early in the NAL experimental program. It can use a beam and spectrometer shared by many users with only minor modifications. We would need a few additions such as the shower chamber, counter C_2, some hodoscopes etc. which we would provide. Members of our group have some experience in building Cerenkov Counters and we would like to undertake to build the large one for general use in this type of spectrometer. Table II shows the personnel available for this effort; we are prepared to commit a Research Associate and a student full time and a faculty member part time to begin design at the end of the summer with increased personnel available as time goes on.

The data taking phase could probably be completed in100 hours of beam with 10^7 pions per pulse; this will permit a variety of energies, and both charge states and will provide some kaon data; an extention might be useful if the kaon data seemed interesting. The statistical accuracy will be sufficient to permit distributions to be studied as a function of center of mass energy (or beam momentum). The detection efficiency is likely to change only very slightly with incident beam energy so comparisons can be made with high reliability. It is hard, at this stage to predict the accuracy required since one doesn't know to what extent the distributions limit, but we would guess that 1% results would be useful. In addition to data taking time, a substantial amount of testing time at low beam intensity will be needed to study the various Cerenkov counters and other apparatus; perhaps 200 hours will be needed but some of this can be shared with other experiments on the same spectrometer.

Table II

Personnel for inclusive πp scattering experiment at NAL

A. Faculty

1. Prof. R. W. Williams
2. Prof. J. Rothberg
3. Prof. V. Cook
4. Prof. K. K. Young
5. Prof. D. Wolfe

B. Research Associates

1. Dr. A. S. Schenck
2. Dr. L. Sompayrac
3. Dr. H. Romer
4. to be named

C. Graduate Students

1. to be named
2. to be named

D. Technical Staff

1. T. Proctor (Computer Engineer)
2. A. J. Jaske (Physicist)
3. Mechanical Engineer (to be named)
4. S. Shankman (Electronics Technician)

1. R. P. Feynman, Phys. Rev. Letters, 23, 1415 (1969); High Energy Collisions - Stony Brook 1969 Gordon and Breach (N.Y. 1969) p. 237

   C. N. Yang, Stony Brook 1969 High Energy Collisions; p. 509

   J. Benecke, Chou, Yang, Yen, Phys. Rev. 188, 2159 (1969)

2. J. L. Day, Johnson, Krisch, Marshak, Randolph, Schnueser, Marmer, and Ratner, Phys. Rev. Letters, 23, 1055 (1969)

   G. J. Marmer, Ratner, Day, Johnson, Kalvace, Krisch, Marshak, Randolph, Phys. Rev. Letters, 23, 1469 (1969)

3. E. W. Anderson, Bleser, Collins, Fujii, Menes, Turkot, Carrigan, Edelstein Hien, McMahon, Nadelhaft, Phys. Rev. Letters, 19, 198 (1967); a new experiment is being planned: BNL proposal No. 396

4. J. W. Allaby, et. al., Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna (Austria) 1968.

5. N. F. Bali, Brown, Peccei and Pignotti, Scaling Behaviour in pp + anything at High Energy: Submitted to Phys. Rev. Letters

6. L. W. Jones, Proceedings of the International Conference on Expectations for Particle Reactions at the New Accelerators, University of Wisconsin, April 1970; K. N. Erickson, Thesis, University of Michigan, April 1970 (unpublished).

7. O. Czyzewski in 14th International Conference on High Energy Physics (Vienna 1968) p. 367

   Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw, Nuclear Physics B13, 571 1969. also Nuclear Physics B8, 471 1968

   C. Caso, et. al., Geneva-DESY-Hamburg-Milan-Saclay, DESY report 69/37 (1969)

   J. Bartke and O. Czyzewski, Nuclear Physics B5, 582 1968

   P. Daronian, Daudin, Gandois, Kochowski, Mosca, Topical Conference on High Energy, Collisions of Hadrons, CERN 1968

   T. Hofmokl, Michejda, Otwinowski, Sosnewski, Szeptycka, Wojcik, Wroblewski, Nuclear Physics B4, 573 1968

   W. D. Walker: Stony Brook Conference on High Energy Collisions, September 6, 1969 p. 295

   also Wisconsin Thesis: J. Waters

   There also exists πp film taken at BNL and SLAC which has not yet been analyzed for checking for limiting behavior.

8. SLAC experiment number 68 which is scheduled to run in Spring 1971. Many of the present authors are involved in the SLAC experiment.

9. R. Hagedorn, Nuovo Cimento Suppl. 3, 147 (1965)
   R. Hagedorn and Ranft, Nuovo Cimento, Suppl. 6, 169 (1968)
   J. Orear, Physics Letters, 13, 190 (1964)
   G. Cocconi, Nuovo Cimento, 57A, 837 (1968)
   L. Caneschi and A. Pignotti, Phys. Rev. Letters, 22, 1219 (1969)

10. A. Pignotti, N. Bali and D. Steele; private communication and N. Bali International Conference on Particle Reactions at the New Accelerators, Madison, Wisconsin (March 1970)

11. We take advantage of the observation that $P_{\perp} = P\ \mathrm{Sin}\,\theta_p$ and that for a magnet of field B we can have approximately $BL_{eff} = 1313\ p\ \mathrm{Sin}\,\theta_p = 1313\ P_{\perp}$ where the constant 1313 has dimensions K gauss-in/Bev. Thus we have

Q Bev/c	$\int BdL$ Kg-in
.2	267
.3	400
.4	534
.5	667

12. Private Communication: W. Baker

13. Time resolutions of up to 35 nsec have been achieved. Private communication: D. Nygren (Columbia). Our group is in the process of building proportional chambers for an experiment at SLAC.

14. Poirier and Romanowski, Threshold Cerenkov Counters in Secondary Beams at NAL 1968 NAL Summer Study Vol. 3

15. Yu. Gorin, et. al., High Resolution Cerenkov Counter: submitted to Instruments and Experimental Methods

16. H. Hinterberger, Lavoie, Nelson, Sumner, Watson, Winston, Wolfe, R. S. I. 41, 413 1970

Figure Captions

Fig. 1 Peyrou plots for 16 Gev π^-p collisions into a typical channel

Fig. 2 Pion production angle vr. laboratory momentum 100 Gev incident pions, various values of X are shown. Curves for P = .2, .3, .4 are plotted.

Fig. 3 Cross section as function of incident momentum for various multiplicities

Fig. 4 Plan of the spectrometer and showing Cerenkov counters C_1, C_2, C_3; spark chambers S_1 S_4, Shower chamber SC; hodoscopes BH_1, BH_2, H_1, H_2, H_3

Fig. 5 1-β and Hydrogen pressure as function of laboratory momentum for detecting various particles

Fig. 6 A sketch of counter C_1 ahowing the spherical mirror, baffles and photomultipler moment.

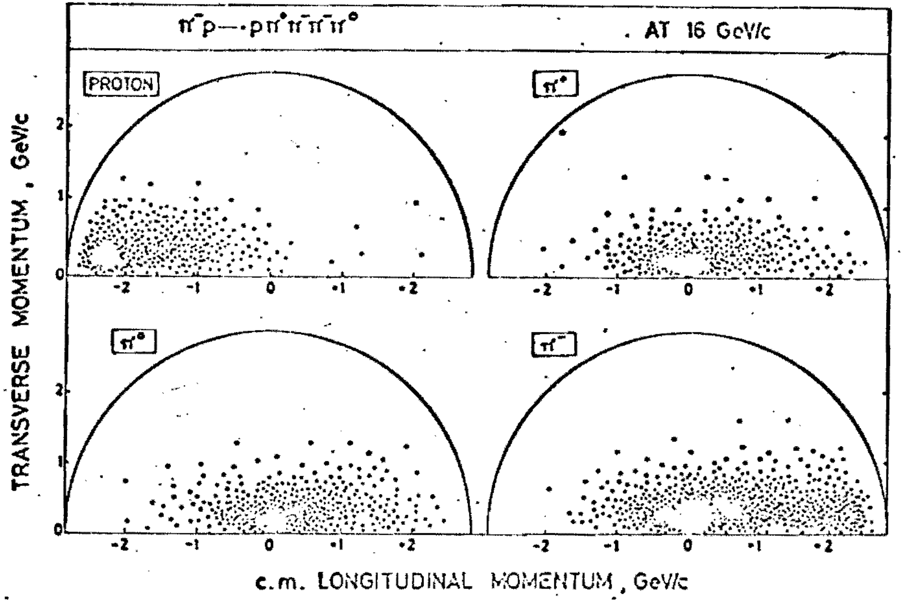


Fig. 1. Distribution of transverse momentum versus c.m. longitudinal momentum for the protons and pions produced in the reaction $\pi^- p \to p\pi^+\pi^-\pi^-\pi^0$ at 16 GeV/*c*.

Fig 1

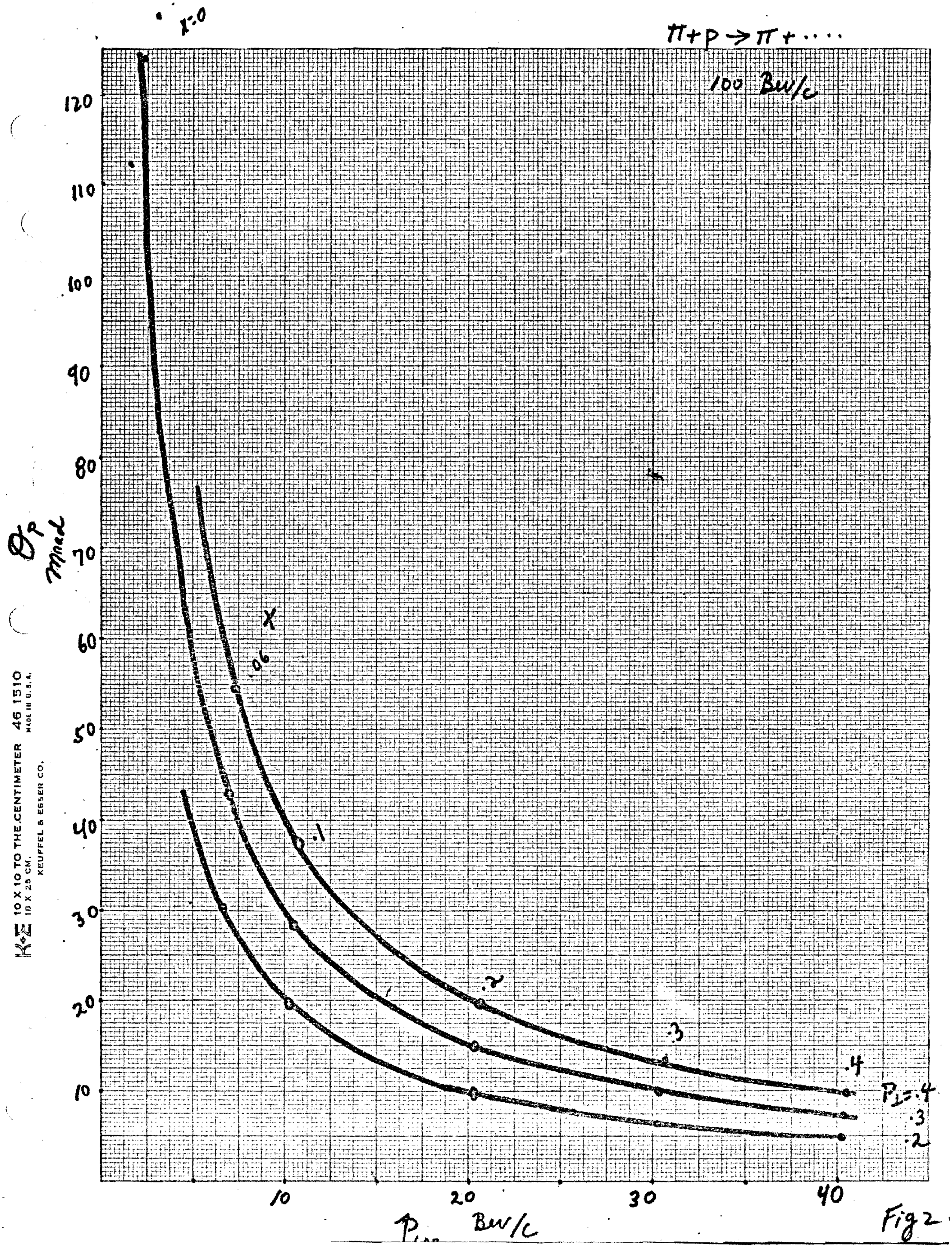
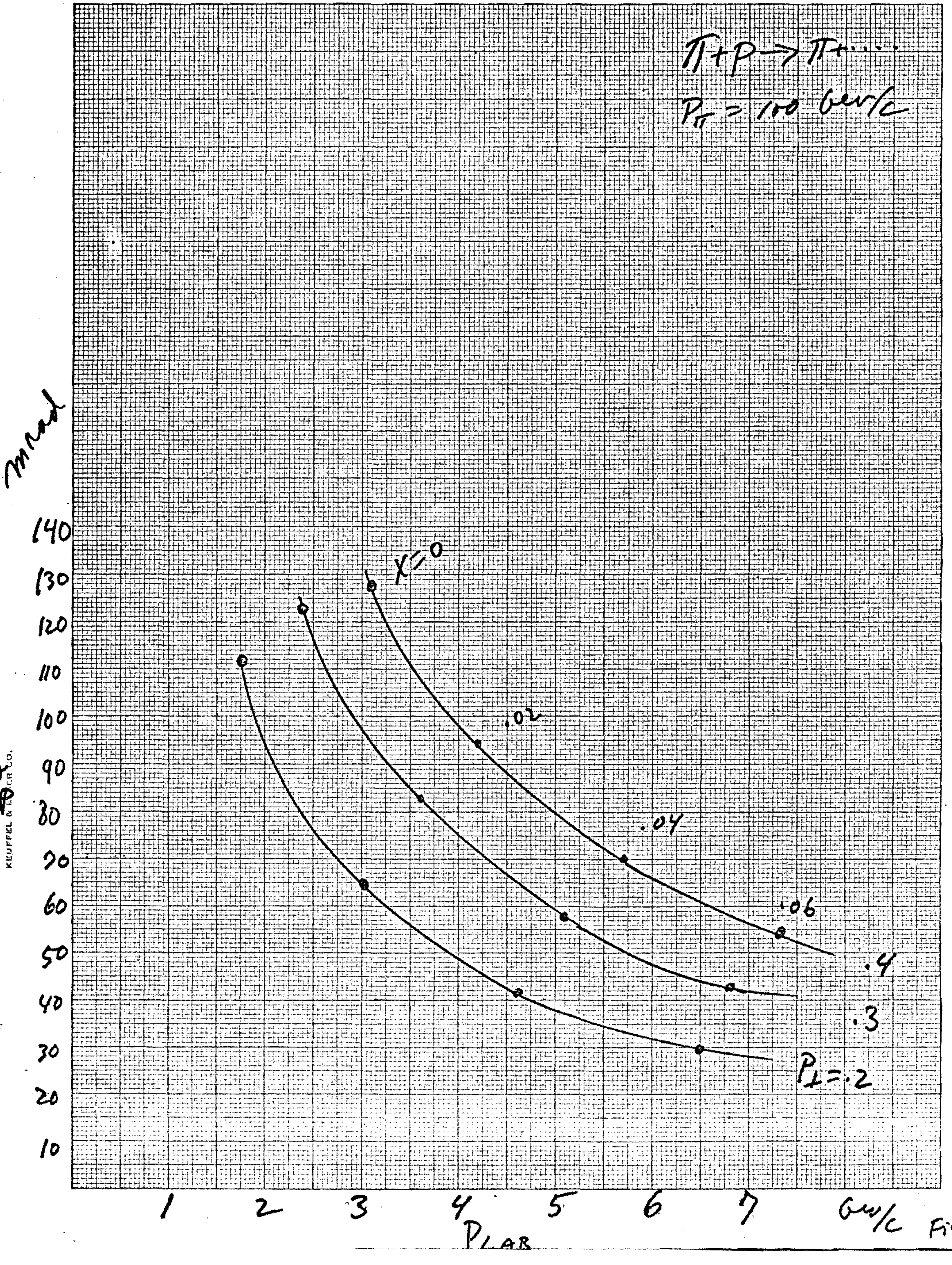

π+p → π + ...
100 Bev/c
x=0
x
.06
.1
.2
.3
.4
P⊥=.4
.3
.2
θp mrad
120
110
100
90
80
70
60
50
40
30
20
10
10
20
30
40
P lab Bev/c

Fig 2


$\pi + P \rightarrow \pi + \cdots$
$P_\pi = 100$ Gev/c
mrad
140
130
120
110
100
90
80
70
60
50
40
30
20
10
X=0
.02
.04
.06
.4
.3
$P_\perp = .2$
1
2
3
4
5
6
7
Gev/c
P_{LAB}

Fi

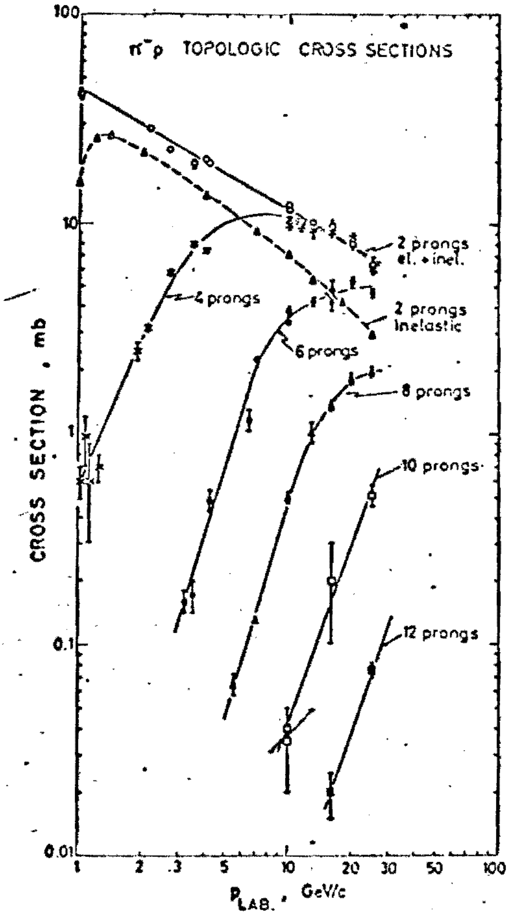


Fig. 3. Variation of the topologic π^-p cross sections, from 2- to 12-prongs as a function of the momentum p_{lab} of the incoming pion, in the range from 1 to 25 GeV/c. The curves drawn are only to guide the eye.

Fig 3

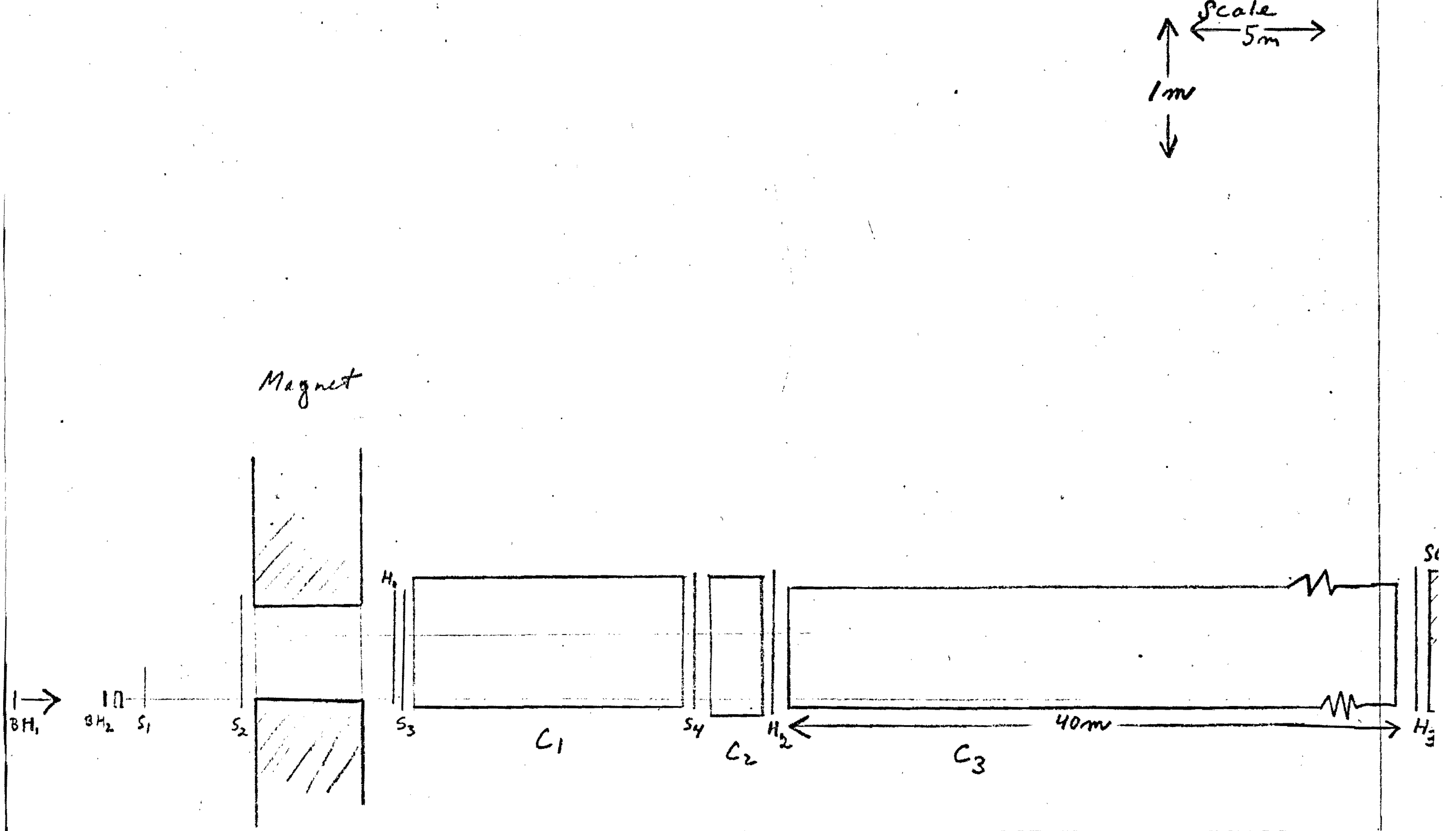


Fig 4

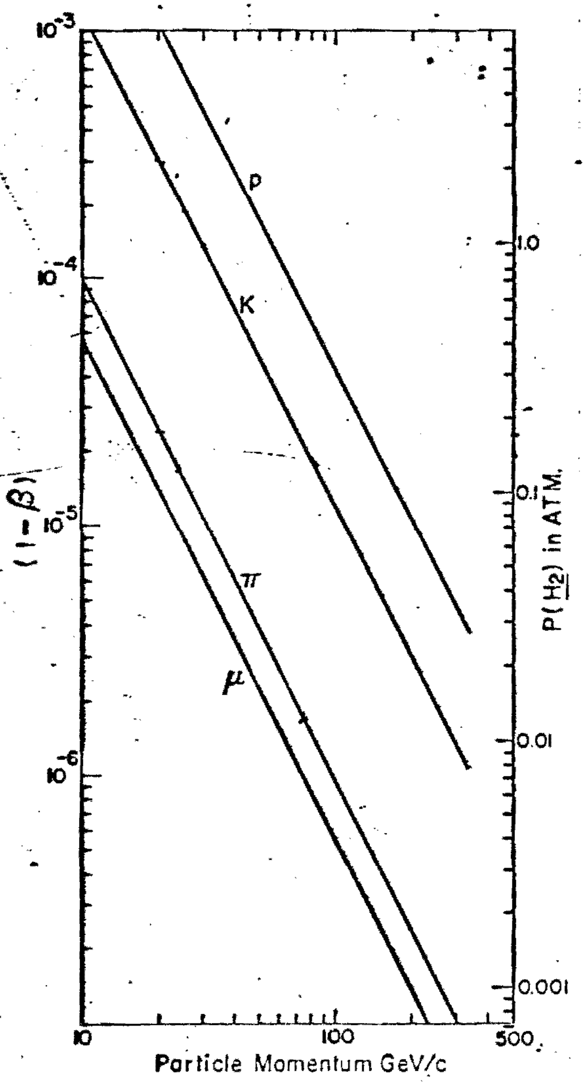
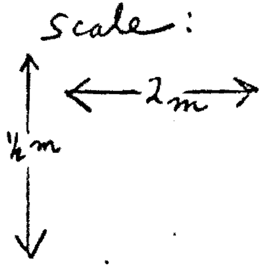
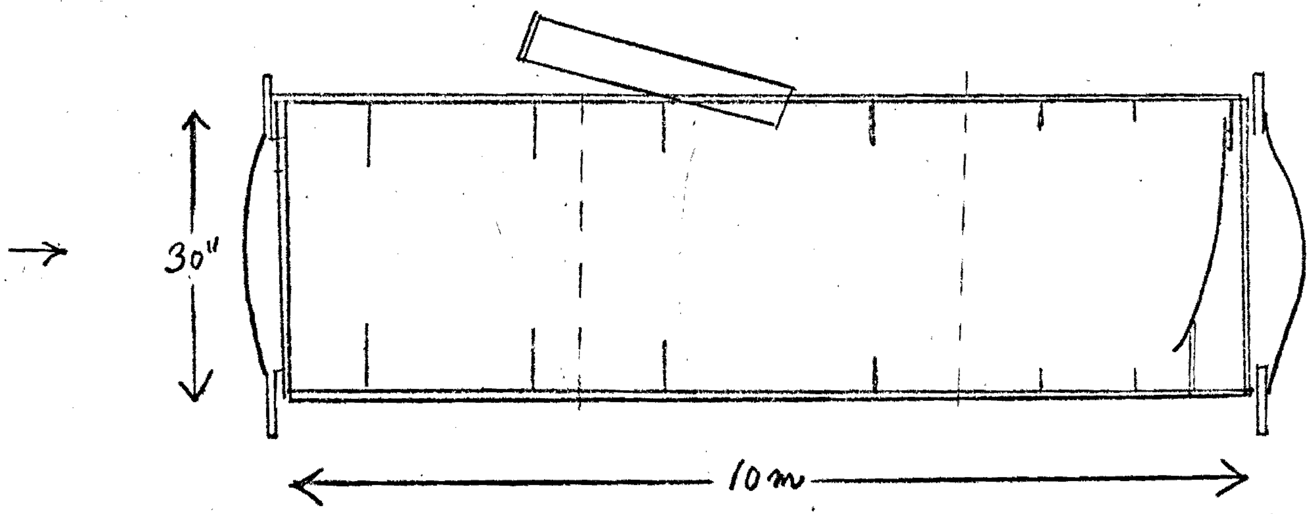

10^-3
10^-4
10^-5
10^-6
(1 - β)
p
K
π
μ
1.0
0.1
0.01
0.001
P(H2) in ATM.
10
100
500
Particle Momentum GeV/c

Fig. 5





Cerenkov Counter C_1

Fig 6

NAL Proposal 23A

Inclusive πp and Kp Scattering

(Revised Version of NAL #23)

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5 May, 1971

Abstract: Our proposal to do inclusive scattering in the wee-x and positive-x region is revised to take advantage of the nearly total compatibility with NAL Exp. 7, elastic πp scattering. We show that the basic results offered by inclusive scattering experiments can be obtained by an increment of less than four weeks at the end of Exp. 7.

The scheduled experiment on πp elastic scattering, #7, leads by a natural extension to a powerful and very interesting body of data on inclusive reactions, $\pi^{\pm}p\rightarrow\pi$+anything, with simulataneous information on $\pi p\rightarrow K$ and $K\ p\rightarrow\pi\ (K)$ inclusive reactions. Our proposal (NAL #23), with supplement of Nov. 16, 1970, emphasizes that inclusive scattering at high energies is expected to be a main road to new insights about the structure of hadrons and that the data is easily and quickly acquired. Very recently there has been a quite impressive outpouring of theoretical interest in these processes; we discuss this briefly in the Appendix, and give a partial bibliography.

The emphasis of this note is that with careful planning the major objectives of Proposal 23 can be achieved with the forward arm of the Exp. 7 setup, used nearly intact, in less than four weeks'extra time at the end of Exp. 7's run. We have explored this idea in some detail with various members of that experiment, especially with Prof. D. I. Meyer. Experiment 7 will obtain data in the resonance region of nearly-elastic scattering. We focus instead on the large-energy-loss region which is related to the "deep-inelastic" region of lepton scattering. In terms of the parton picture, one is exploring the constituents of the hadrons.

The kinematic regions of interest for single-particle spectra in πp or Kp inclusive scattering are: a) The positive-x region $(x\equiv(p_{/\!/}/p_{\text{incident}})_{\text{cm}})$ supposed to represent fragments of the beam particle; b) The negative-x region, fragments of the target; c) The wee-x or "pionization" region, near x=0, setting in at about $|x|\sim\left(\frac{p_{\perp}^{2}+m^{2}}{p_{\text{cm}}^{2}}\right)^{\frac{1}{2}}$. This is the trickiest, and probably the most interesting, region. The arrangement of Exp. 7, which has the incident beam passing down the side of the magnet aperture, is ideal for regions (a) and (c). The principal changes from the Exp. 7 setup, in addition to switching off the recoil leg, are to accomodate secondaries of low momenta and both signs; and to increase the production-angle range. We would accomplish the first by adding a third Cerenkov counter to the two now planned in the Exp. 7 detection scheme; this third counter is quite standard, a 1-meter 5-atmosphere Freon counter which discriminates π's from K's in the <10 GeV/c region (see Supplement to Proposal 23 for details). The second change, to obtain larger angular and momentum acceptance, would be in two steps:

a) With the elements of Exp. 7 essentially intact, run with the magnet set to bend the desired secondaries toward the beam; this is sometimes called "kinematic focussing", and collects a large band of longitudinal momenta with $p_\perp$ near a selected value. The maximum production angle in this position would be 40 mrad giving much of the x> wee-x region. Call this Position I.

b) Move the target to 1.8 meters from the front face of the magnet, Position II, (Fig. 1). This permits up to 200 mrad for the low-momentum particles, and it can be seen (Fig. 2; see also the Supplement) that the remainder of the x region to $x=-.04$ for 150 GeV incident π's, or $x=0$ for 50 GeV/c π's, is covered.

To be able to run off a good experiment on inclusive scattering with high efficiency in a short time, we must use the Exp. 7 equipment with as few changes as possible. The University of Michigan-Argonne-NAL group has indicated that everything in their set-up which is under their control would become available to us. The Argonne 6050 computer, however, might be urgently needed at Argonne. Our own wire-chamber system (now in use in our inclusive πp experiment at SLAC) utilizes an SAC wire-chamber data system into a Hewlett-Packard computer (we plan to upgrade this to a 2116). The U. of Michigan uses the same SAC system. We would work out in advance the details of getting the Michigan SAC running quickly into our computer, should that become necessary (rates are low enough that we could buffer all information onto tape, using only a modest amount of on-line checking). In any case we would work closely with the Exp. 7 group before the change-over.

Changes required for 23A.

The changes required to adapt Exp. 7 to inclusive scattering are the following:

1. Cerenkov counters. The two long counters now planned for Exp. 7 (20 ft. and 40 or 60 ft.) must have longitudinal vanes installed to prevent particles outside our azimuthal acceptance from counting. (We rely on a small azimuthal acceptance, $\sim 2\%$, to prevent confusion from high-multiplicity events). These vanes are simple flat surfaces of any light opaque material. We plan to test the vane system in advance. In addition, the low-momentum Cerenkov counter must be installed behind the last wire chamber. A hodoscope to assist in triggering may also be installed.

2. Hydrogen target. The Michigan target assembly will accept an 18" long flask, which is the size we would want to use in Position I. If Exp. 7 was using a smaller flask we would change this.

We estimate that these changes, including any computer change that might be necessary, could be done in 5 or 6 days.

3. Position II. Move target downstream to within 1.8 m of magnet entrance. Change Exp. 7 counter hodoscope (adjacent to target) to one of finer spacing.

The U. of Michigan group believes that their target set-up can be moved very quickly. Allow 2 days for this.

Physics Objectives.

We want to get everything of interest out of the positive-x and wee-x inclusive scattering of π's and K's, utilizing the high rates available, and choosing parameters carefully. Writing the one-particle cross section as

$$\frac{d^2\sigma}{dx\,dp_\perp^{\,2}} = \frac{\sigma_{\text{Inel.}}}{\sqrt{x^2 + \dfrac{p_\perp^{\,2}+m^2}{p_{cm}^{\,2}}}} \quad F(s,x,p_\perp),$$

we want to see if F (the normalized invariant cross section)becomes independent of the energy s. If so, we can interpret it (loosely) as the distribution of partons in the pion or kaon (x>0); for wee x, F may have structure, such as a dip at x=0 (two fireballs); cusps have even been suggested; in any case it must contain clues to the structure of hadrons. To measure, in a short time, a function of three variables we have two essential aids:

a) Our own measurements on πp inclusive scattering at lower energies, at SLAC. We will have good-statistics data at 12 and 16 GeV, over a range of x, for several distinct values of $p_\perp$. By covering the *same* ranges of x, and using the same values of $p_\perp$, we get the best information on the energy dependence of F.

b) Existing data and theoretical models. The energy variation of F is slow (perhaps[7] as slow as $A+Bs^{-1/2}$), so we want large intervals of $s^{1/2}$. Thus E_0 = 16, 50, and 150 GeV would be $s^{1/2}$ = 5.5, 9.7, and 16.7 GeV; nicely spaced; two energies at NAL (50 and 150 GeV) will be enough. Also the data so far, including $pp\to\pi$ data from the ISR,* indicate that the variation of F with $p_\perp$ is smooth and approximately factorable. With our spectrometer arrangement one magnet setting gives a continuum in x and a restricted band of $p_\perp$ around the chosen $p_\perp$. We therefore choose only three values of $p_\perp$: 0.2, 0.4, and 0.6 GeV/c, covering the same range as in our SLAC experiment.

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*Preliminary data from A.D. Krisch.

Finally, the choices of particles and signs: in the incident beam, K's and π's will be tagged so we have both at once. In the spectrometer we tag π's positively, with less accurate identification of K's. A principal objective is the comparison of the F's for different particle combinations. Excellent data on $pp \to \pi$ will be available from NAL Exp. 63. The four charge combinations available to us ($+ \to +$, $+ \to -$, $- \to +$, $- \to -$) all should have real differences, particularly when the question of exotic channels[7,9r] is raised. We find that our own questions, and those raised by references 7 and 9r, will essentially be answered by doing only the first three, which is what we propose.

Run Plan.

From the foregoing, we have 2 target positions, 2 energies, 3 magnet settings ($p_\perp$ bands), and 3 charge combinations, for a total of 36 runs. With 10^6 pions per pulse we expect an average of $(5-10) \times 10^3$ events/hour.

$\pi \to \pi$ data with statistical accuracy comparable with our SLAC experiment would require runs averaging 8 hours for a total of 300 hours of beam. Adding the changeover and tuneup time of 6 days, and target-moving time of 2 days, we propose to have all the data in 3½ weeks from the end of Exp. 7 data-taking.

We request a decision now, since we should work closely with the Exp. 7 people as their plans take final form.

RECENT DEVELOPMENTS IN EXPERIMENT AND PHENOMENOLOGY IN MULTIPARTICLE PRODUCTION.

Alberto Pignotti

University of Washington

The interest in inclusive experiments has increased steadily during the past year and a half. This new trend probably originated at the 1969 Stony Brook Conference on High Energy Collisions of Hadrons, where R.P. Feynman[1] and C.N. Yang and collaborators[2] discussed regularities that they expected to be found in the spectra of particles produced at high energy. Of course, there had been earlier discussions of such experiments in the framework of various models, but the new ideas injected a refreshing feeling of simplicity in the intricate world of strong interactions.

Simplicity is, indeed, the attractive feature of inclusive experiments for measurement as well as theoretical interpretation of the results. A typical exclusive experiment at NAL energies will depend on roughly twenty variables, whereas a single-particle distribution depends only on three (If the scaling hypotheses of Feynman[1] and Benecke et al.[2] hold, only two variables will suffice to describe single-particle distributions at high energies.) In addition, because of the proliferation of channels at high energy, each exclusive process - except, probably, the elastic one - becomes a small fraction of the total cross section. Furthermore, most channels contain neutral particles, that are difficult to detect. Because of these difficulties and the paucity of inclusive data, we have, in recent months, observed that several experimental groups have reanalyzed old bubble chamber experiments in an inclusive way.[3] This is not, of course, the most economical way to obtain inclusive information.

In spite of its simplicity and the amount of theoretical effort that has gone into the subject, inclusive experiments, and, in particular, single particle distributions, are by no means fully understood. This is partly so because the energies of existing accelerators are not high enough, and can only suggest some trends. As an example, it is instructive to compare the predictions of Feynman's scaling law with those of a recent CERN preprint by Cocconi,[4] in which the ten-year-old model of Cocconi, Koester and Perkins[5] is reexamined. Whereas Feynman scales the c.m. longitudinal momentum of the produced pions by the total c.m. energy, (except for a kinematical factor that does not scale this way), Cocconi scales the same quantity by the square root of the total c.m. energy. We thus have two fundamentally different models, both of which are compatible with present data, and only experiments at higher energies can discriminate between them, and, in doing so, throw light on some basic aspects of strong interactions.

The theoretical interest in inclusive experiments has received further impulse as a consequence of the work of Mueller[6], which relates the high-energy behaviour of inclusive cross sections to Regge behaviour. Some properties that follow from factorization of Regge residues and from the presence of channels with exotic quantum numbers have been discussed by Hong-Mo Chan et al[7], and by Veneziano.[8] The amount of theoretical work in inclusive processes in recent months has become quite impressive.[6-9]

As a final consideration, we would like to discuss an argument of Kenneth Wilson,[10] which shows an advantage in using an incident beam of pions, rather than protons. In the case of an incident proton, pions do not tend to be produced with velocities larger than the proton velocity. This is a dynamical statement, which is verified experimentally, and can be reproduced in various models. (By the same token, with a proton target, rather fast backward pions are kinematically allowed, but not often produced). If we therefore assume the final pion velocity to be limited by that of the incident proton, and its transverse momentum to be of approximately 300 MeV/c, the final pion longitudinal momentum is forced to be less than 1/3 of the momentum of the incident proton. No such limitation exists for an incident pion. Therefore, at comparable energies, an incident pion is more effective at producing more pions: the longitudinal "cloud" of final pions stretches out more, and there is a chance of observing asymptotic effects that could only be observed at proton energies roughly three times as large.

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Other papers at Washington APS/71.
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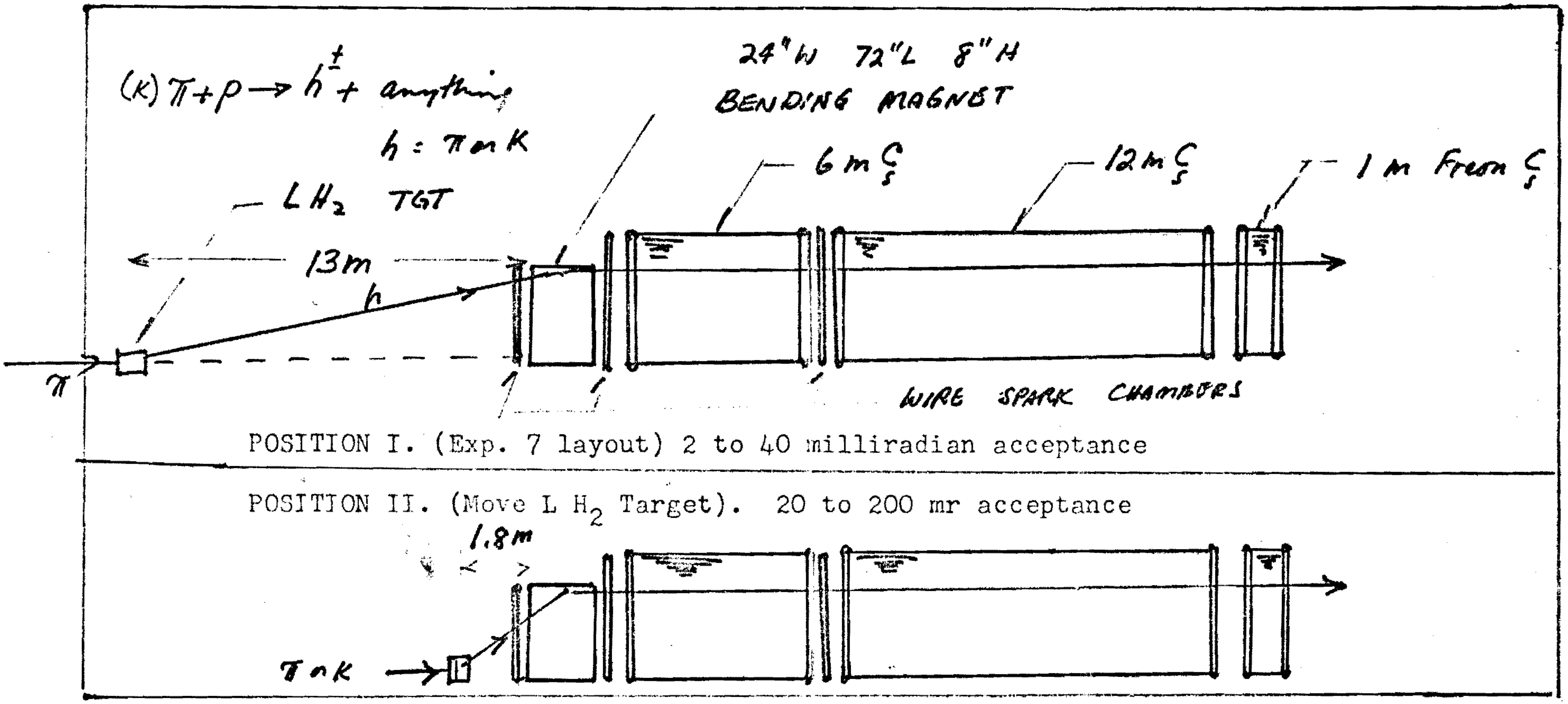
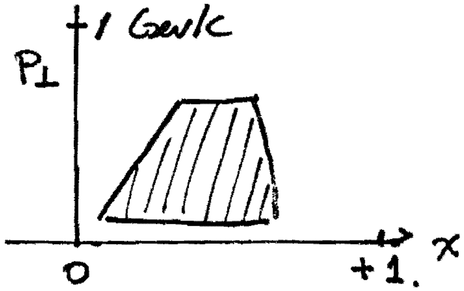
Jn 7 Kinsey, Morris, Panvini, Elbert, Erwin, p. 833.

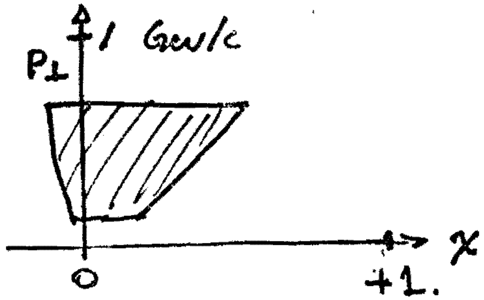


POSITION I. (Exp. 7 layout) 2 to 40 milliradian acceptance

POSITION II. (Move L H_2 Target). 20 to 200 mr acceptance

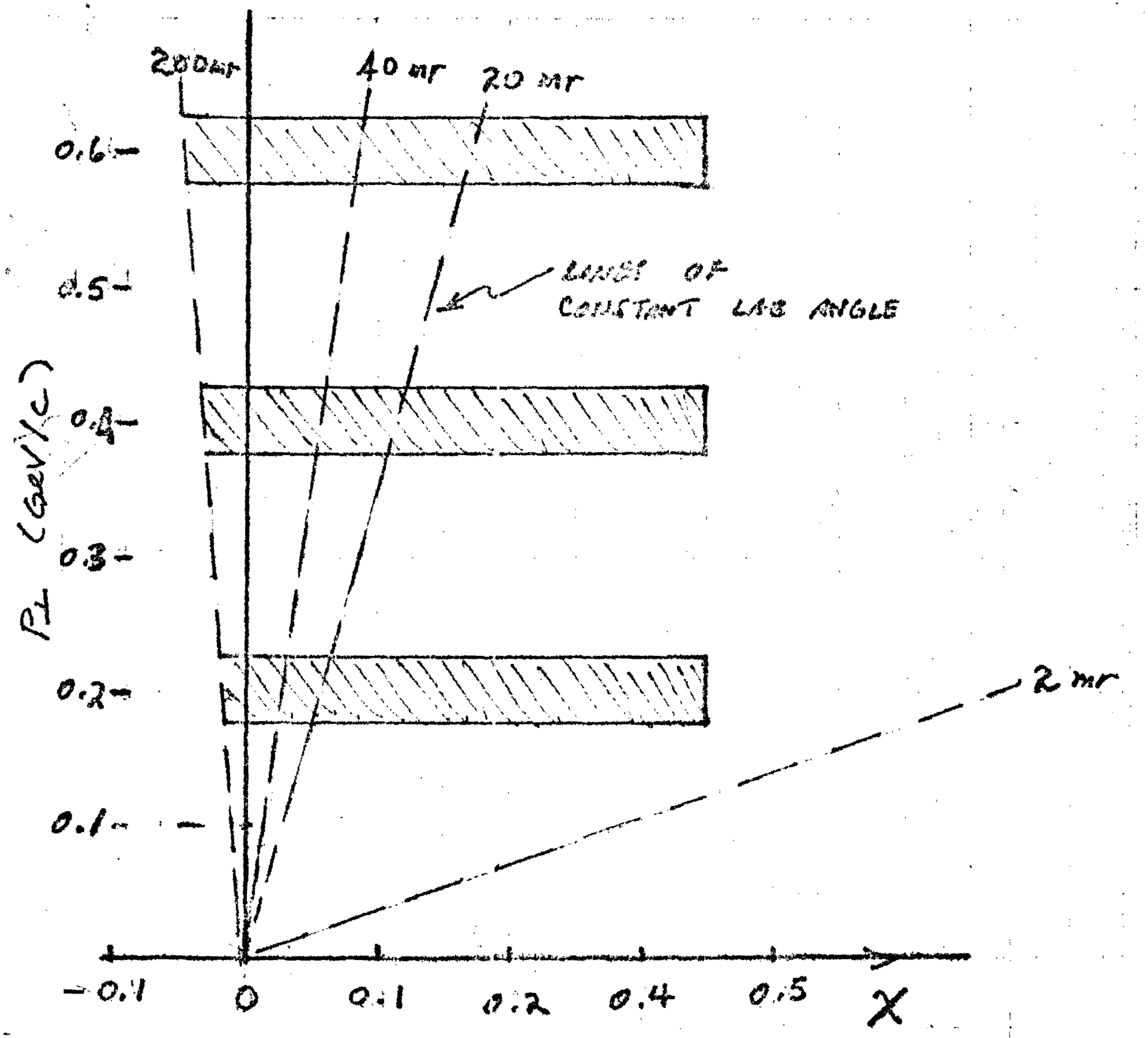


kinematical region covered by position I.



kinematical region covered by position II.

SCHEMATIC of SPECTROMETER LAYOUT FOR PROPOSAL 23A



Kinematical region in x and $P_\perp$ to be covered by NAL proposal 23A.

NAL PROPOSAL No. 23-A

Addendum to NAL Proposal 23-A

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Inclusive πp and Kp Scattering
(Revised Version of NAL #23)

H. Romer, J. E. Rothberg, R. W. Williams, K. K. Young

University of Washington

July 22, 1971

Your letter of 7 June indicates that immediately following the completion of experiment 7, Meyer's equipment could be used for a few short experiments if a computer were made available to replace the computer which must be returned to ANL. We had indicated in proposal 23A that our computer system will be available for this experiment. We will make this computer available for other short experiments in the interval between experiments 7 and 61.

The core of our system is a Hewlett Packard 2115A computer (8K) (16 bit word memory, 2 micro sec. cycle time) with

a) two magnetic tape units (HP 2020, slow; Potter 2648, fast)

b) teletype

c) fast paper-tape reader

d) a SAC spark-chambered data acquisition system (MIDAS)

e) a software-controlled multiplexer of our own design (very flexible)

f) CRT display

This system is well matched to make a switchover from experiment 7 to experiment 23A as experiment 7 also uses the SAC spark-chambered data acquisition system for piping all of their data into their Argonne EMR6050 computer. We have been in contact with the Michigan people to determine that a switchover from their computer to our computer could be done quite expeditiously. Should we be approved to do experiment 23A, we shall exercise the switchover of the computers well in advance of the actual date of the experiment. Figure 1 is a schematic of the data acquisition system of experiment 7. The figure shows how the computers can easily be changed from the EMR 6050 to the HP 2115A. It requires switching one 18-pin cable.

W. Baker indicates that making space available at the E7 experimental site for testing the HP 2115A should be easily accomplished.

Needs from PREP

NAL E7 will have from PREP: a) 20 scaler channels, b) 40 discriminator channels and c) a 564 scope. We shall need this apparatus for P23A. E7 will leave the electronics in tact for the use of P23A.

Changes to Experiment 7 for 23

Besides the possibility of switching computers, we will also:

a) change the angle of the detectors downstream of the spectrometer magnet.

b) mask the Cerenkov counters. The system will be worked out for experiment 7. Also we will try it out on the short Cerenkov counter which we will build for this experiment.

c) installation of a scattered particle hodoscope ($\sim$8 elements).

These are shown in Figure 2.

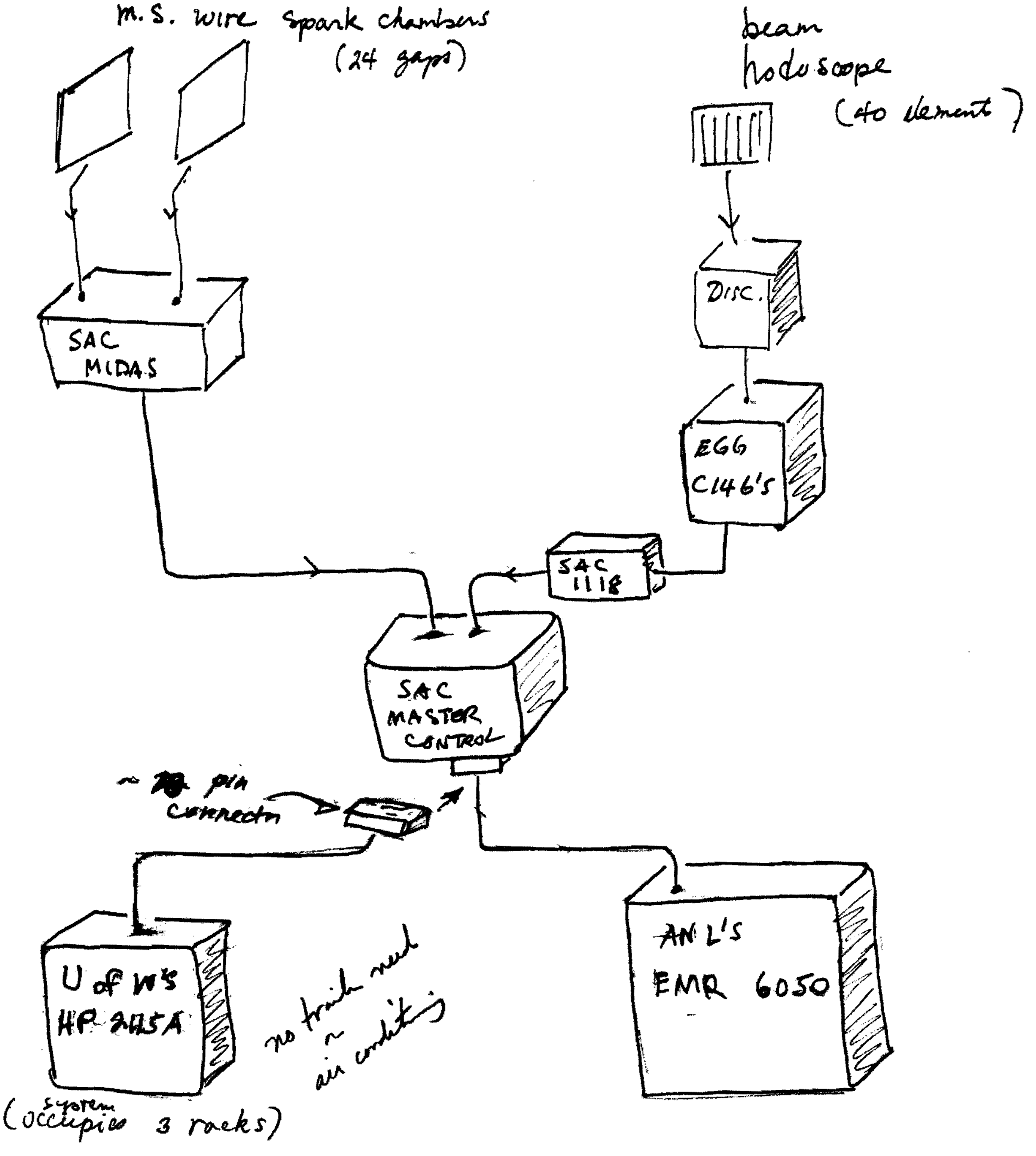
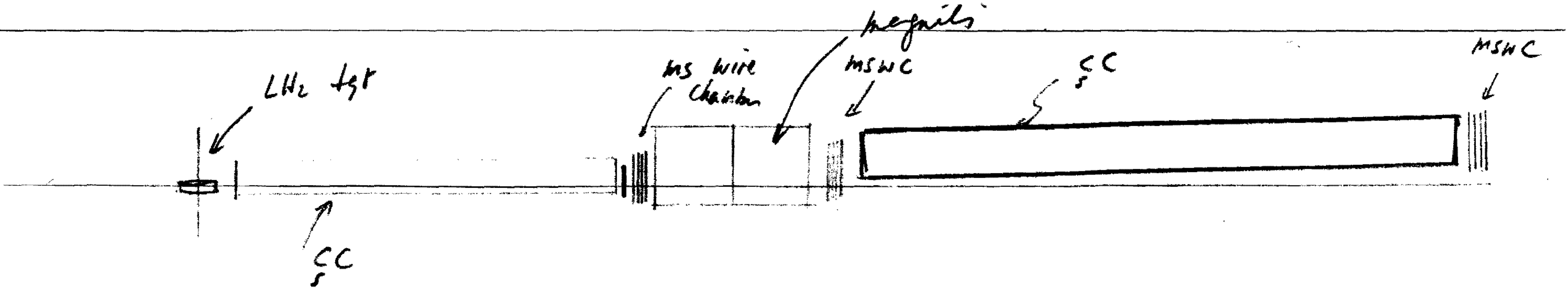
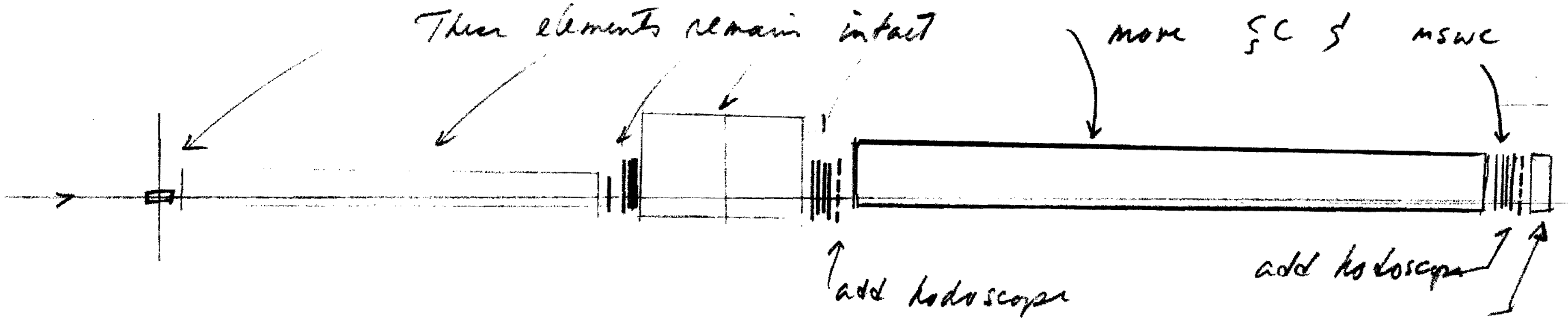


FIG. 1 . TO SWITCH THE UW COMPUTER TO RUN EXP. P23, ONLY ONE 78 PIN CONNECTOR NEEDS TO BE CHANGED.



FOWARD ARM OF E 7



CHANGE TO P23 (position I)

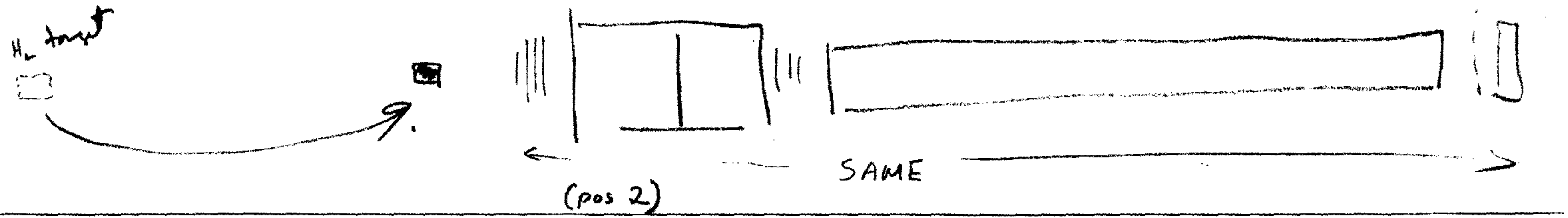


Fig 2. Changes to E7 for E 23A.

Supplement to Proposal #23, Inclusive πp Scattering

University of Washington, 16/Nov./70

In view of the present status of proposals 7 and 61 we are submitting a revision of our proposal for the study of inclusive pion-proton collisions. We have modified our original proposal in several respects and are now able to specify in greater detail some of the apparatus, set-up and backgrounds.

We plan to study secondary pions and kaons and have extended the kinematic region which we will investigate. The region will be bounded by the laboratory variables p, momentum and θ_p production angle as follows:

$$3 < \theta_p < 200 \text{ mrad.}$$
$$1.5 < p < 60 \quad \text{Gev/c}$$

These bounds will permit us to accept events within a wide range of x and Q (depending on incident momentum p_i) as given in figure 1. To justify the choice of these boundaries we note that a production angle of 200 mrad. is as large as one can get to easily with a relatively small aperture magnet. This choice of angle includes the interesting x=0 region for all of the transverse momenta and incident momenta that are expected to be interesting. Looking at secondary momenta below 1.5 Gev/c then adds little useful range.

At the upper momentum end the limitations are clear if we write the approximate kinematic relations: $p\theta_p = Q$ and $x = p/p_i$; the first relation holds for our entire region and the second for $x > 0.06$. We have thus imposed a limit on x of $60./p_i$. which allows us to go beyond x=0.6 in most cases. This obviates the necessity for doing particle identification beyond a momentum of 60. Gev/c meaning shorter, more effective Cerenkov counters and larger solid angle. Looking at the leading pion in the forward direction seems at this point less interesting anyway.

The minimum production angle is determined by the ability to measure that angle precisely enough with a short lever arm; of less significance is the limitation imposed by beam spot size. A transparent view of the requirements on precision can be obtained using the above kinematic approximations as well as the relation:

$$p\,\theta_p = Q = \bar{Q} + P\,\theta_M$$

where $\bar{Q}$ is the effective field of the magnet in units of transverse momentum and θ_M is the measured angle of the secondary particle leaving the magnet. Then we have, in terms of measureable quantities:

$$Q = \frac{\bar{Q}\,\theta_p}{\theta_p - \theta_M} \quad \text{and} \quad x = \frac{\bar{Q}}{P_i\,(\theta_p - \theta_M)}$$

$$p = \frac{\bar{Q}}{\theta_p - \theta_M}$$

The magnet is used in a mode in which $\bar{Q}$ matches the desired value of Q so θ_M is nearly zero but must be measured of course.

$$\text{So:} \quad \frac{\Delta x}{x} \approx \frac{\Delta P}{P} \qquad \frac{\Delta Q}{Q} \approx \frac{\Delta\theta_p}{\theta_p} + \frac{\Delta P}{P}$$

$$\text{and} \quad \frac{\Delta P}{P} \approx \frac{\Delta\theta_p}{\theta_p}$$

since θ_M is small compared to θ_p and since θ_M can usually be measured to higher precision than θ_p; a long lever arm is available downstream of the magnet. The contribution to measurement error from multiple coulomb scattering depends on momentum both directly and through the Cerenkov gas pressure.

Determination of x and Q to 10% at the very smallest production angles and to about 2% at other angles seems attainable and is consistent with checking scaling behavior as a function of incident energy at the several-percent level.

1. Beam

The requirements set by proposal #7 are very suitable for our purposes. We will require at least 10^6 useful beam particle per pulse with Cerenkov counters to identify incident particles and a scintillation counter hodoscope to tag incident angles. An angular resolution of 0.1 mrad is quite adequate and is not as stringent as the requirements of Prop. 7. A momentum spread of several percent is acceptable without the need for momentum tagging. The angular divergence requested by the memo of Nov. 4 from Novey (Prop. 61) is also adequate but we can accept a lower intensity and would prefer to tag particles. The beam spot size is not critical if it can be made smaller than 2 cm diameter. The maximum rate that we can tolerate depends on factors to be considered below but also depends somewhat on contamination of electrons etc.

2. Spectrometer

a) A suitable magnet would resemble the Argonne BM-109 discussed by both Prop. 7 and 61. A magnet with the dimensions 8" x 24" wide x 72" long with an effective field up to about 1000 Kg-inches uniform to about 0.5% over at least 20" horizontally would be consistent withour spectrometer.

With a magnet of such dimensions we will need to place it at three different distances (d) from the hydrogen target to enable us to cover the range of production angle (θ_p) needed and at the same time get the necessary precision in production angle. The error in measuring production angle will come both from error in beam divergence $\Delta\theta_B$ and from position error ΔS in proportional chambers before magnet. Thus we would like $\frac{\Delta S}{d} \lesssim .1$ mrad or $\sim 2\%$ of $\Delta\theta_p$ whichever is larger. θ_p is needed for reconstructing secondary momentum and to find X and Q. For values of $X \gtrsim .06$ the approximate relation $\frac{\Delta X}{x} = \frac{\Delta p}{p}$ hold. Furthermore the momentum error $\frac{\Delta p}{p}$ is approximately $\frac{\Delta\theta_p}{\theta_p}$ if we assume that the angle of the secondary after the magnet can be measured as precisely as necessary. For $0<x<.06$ the requirements on angle measurement are not severe; $\Delta\theta_p = 5$ mrad is good enough. (See fig. 2)

The three magnet positions which will cover the range of production angles $3<\theta_p<200$ mrad and which will simultaneously permit a sufficiently long lever arm to keep $\Delta\theta_p$ small are tabulated below.

d	$\Delta\theta_p$	Range of θ_p (mrad)	Typical Momentum range
2.5 m.	1 mrad	50-200	1.5 - 10 Gev
4.5 m.	.3 mrad	20-65	3-20 Gev
11.5 m.	.1 mrad	3-25	8-40 Gev

The lever arm which can be used for angle measurement and which has been used to compute $\Delta\theta_p$ is, of course, smaller than the tabulated distances d. In each position the magnet is oriented perpendicular to the original beam direction, it is simply translated downstream. The movement can be carried out either by rigging or by rails but will need to be performed only a very few times during the run.

The distances have been chosen so that only about one foot of the magnet aperture is used for the higher momenta and somewhat more is used below 10 Gev. The Cerenkov counter which will identify high momentum secondaries will have an aperture limited to one foot or less while the much shorter Cerenkov counter which we will construct for the low momentum region will have an acceptance of about twenty inches.

b) Secondary particle trajectories will be established by a sequence of proportional wire chambers. Two sets of these will be situated before the magnet and three sets beyond. The chambers will have desensitized regions where the primary beam traverses them and also for excessive azimuthal angles; we will hold the azimuthal acceptance nearly constant over the range of production angles. We have been building proportional chambers at U. of W. for another experiment and have successfully desensitized regions of the chamber without affecting the wedge-shaped useful region. Despite our own development program we would hope to be able to use the chambers which will presumably have been installed in such a spectrometer. Proposal 50, for example, calls for chambers of a size and spatial resolution very well suited to our purposes; their chambers already exist. We need chambers with a maximum dimension of about 24 inches and with a spatial resolution of about 0.7 mm. If this resolution cannot be achieved with a single wire plane we would consider staggering planes which do not add much to cost of readout and do not materially increase multiple scattering. It is only near the forward direction that we have severe requirements on resolution.

c) The Cerenkov counters are expected to distinguish between secondary pions and kaons over a very wide range of momenta. It will not be possible to cover the entire range at a single gas pressure using only three Cerenkov counters so we plan to take several runs changing only gas pressure. No more than three runs should be needed to cover the requisite range, although this depends somewhat on the length and quality of the Cerenkov counters. We have made the conservative assumption that the number of photoelectrons per cm (N_e) is given by $100 \sin^2\theta$ and have prepared charts showing the momentum range that can be covered. The momentum range is limited on the low end by requiring some minimum number of photoelectrons from pions, and on the upper end by the onset of the kaon threshold. These curves together with the required index of refraction ($\eta = n-1$) are shown in figure 3 . We conclude that the counter could be made to work in the ranges 10-20 Gev, 20-40 Gev, 40-60 Gev. The low momentum counter can work simultaneously in the ranges 1.5 to 4; 4-9; 9-11. Only part of this momentum range is needed for any one value of incident momentum; see figure 2 . We shall be able to use the pion and kaon counters discussed in Proposal 61 for detection of secondary pions and kaons in the upper momentum ranges and will provide a low momentum freon filled counter in addition. The Cerenkov counters will have to be desensitized along the beam direction, for production angles less than about 3 mrad., and for large azimuthal angles; this should be possible with the use of an optical septum or baffles. If these precautions are taken we don't expect a significant number of multiple tracks.

d) An elaborate Monte Carlo program has been written to simulate inclusive scattering. Events are generated with multiplicities given by a Poisson distribution with the mean appropriate to the energy. For each channel longitudinal and transverse momenta of secondaries are chosen from distributions obtained from existing accelerator data; the charged secondaries are traced through the apparatus. More detailed data should be available soon and we plan to refine the calculation but present indications are that the number of events with multiple tracks within the sensitive area of the proportional chambers or Cerenkov counter is less than 5%. Figure 4 shows a typical distribution of secondaries in a chamber before magnet. The characteristics of this sort of background (which comes largely from the secondaries of a single interaction) can be studied in detail with the proportional chambers and we will certainly not have a systematic error from this source as big as 1%. The beam intensity will be held to 10^6 per second (about 7×10^4 interactions per second) so accidental background in proportional chambers (assuming even 50 nsec resolution) is no problem. The real multiparticle background is kept down by a limited azimuthal angle acceptance of about 2%. Since multiplicity does not grow very fast with energy (log s) existing data gives a fairly reliable picture. Background is dependent on beam spot size and we would prefer to reduce it as much as possible, even at the expense of some reduction in intensity. Correlations in secondaries near the forward direction can be studied with the spectrometer in its normal position and will be used to provide corrections for multiple tracks. The beam itself will go through the spectrometer for precise angle calibration.

We can estimate the time required for data taking on the basis of 10^6 pions per second and a two foot target. We will need three magnet positions to cover the angular range and three Cerenkov pressure settings for each run. Data will probably be taken at about four or five beam energies from 50 Gev to 170 Gev. The energies to be run can be determined after more existing data has been evaluated. Approximately 10^4 events per hour will be accepted. A five hour run for each condition should be adequate for pions while for kaons poorer statistical accuracy will be tolerated. Assuming a total of sixty runs, permitting some extra energies in the most interesting region we would use 300 hours for data taking. Adding to this some checkout time for items specific to this experiment and some time for contingency we would expect to need 350 hours of beam time.

Concluding Remarks

We wish to emphasize that the proposed experiment is a direct extension of the measurements we are now preparing to do, at SLAC, at 8, 12 and 16 Gev/c. The same group, augmented in size, using some of the same instrumentation and the same data-handling techniques, would carry out measurements from 50 to 170 Gev/c. The range of kinematic variables to be covered is either the same (in the sense of Feynman or Yang[*]) or wider, at the NAL energies. We do not propose a survey of inelastic reactions - that will be available from bubble-chamber studies - but an accurate set of measurements over a region selected in such a way as to have a maximum impact on the emerging picture of high-energy hadronic interactions. It is fortunate that this region can be covered, at NAL, using facilities which will already be present for experiments 7 and 61, with only two changes of magnet position.

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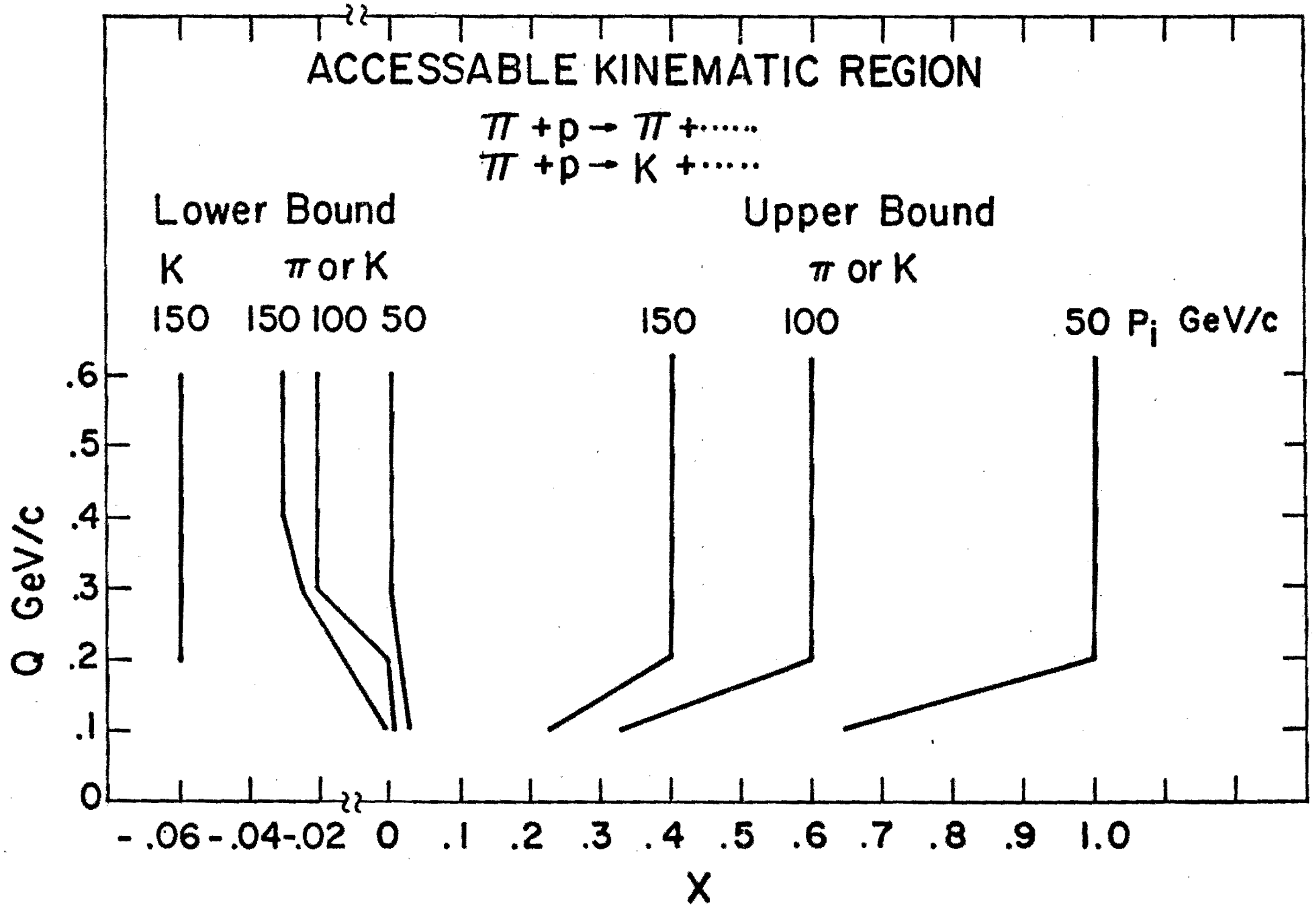
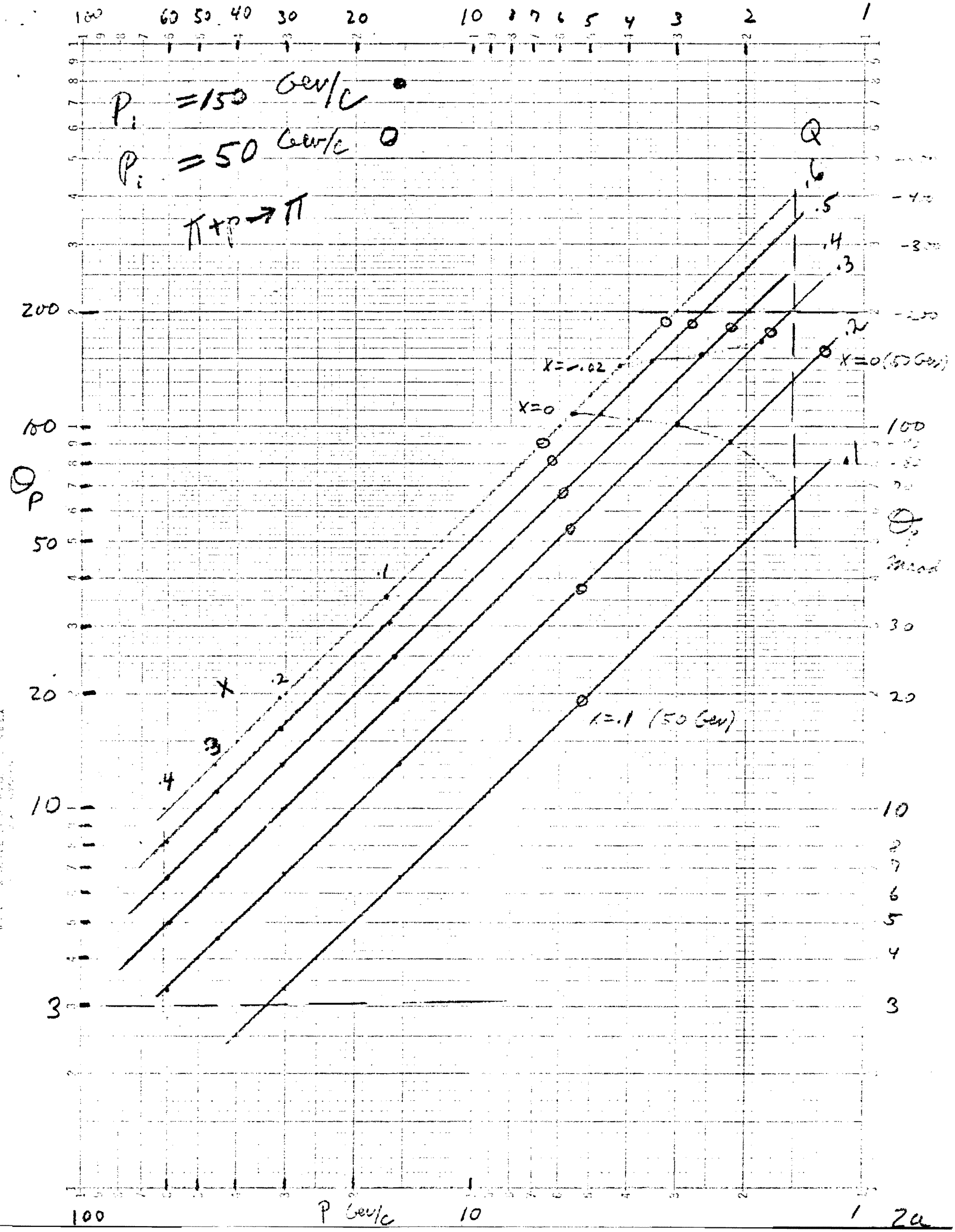
[*] C. N. Yang has recently pointed out that the scaled variable "x" is appropriate to his "limiting-fragmentation" picture even though he does not emphasize the center of mass. Phys. Rev. Letters 25, 1072 (1970).



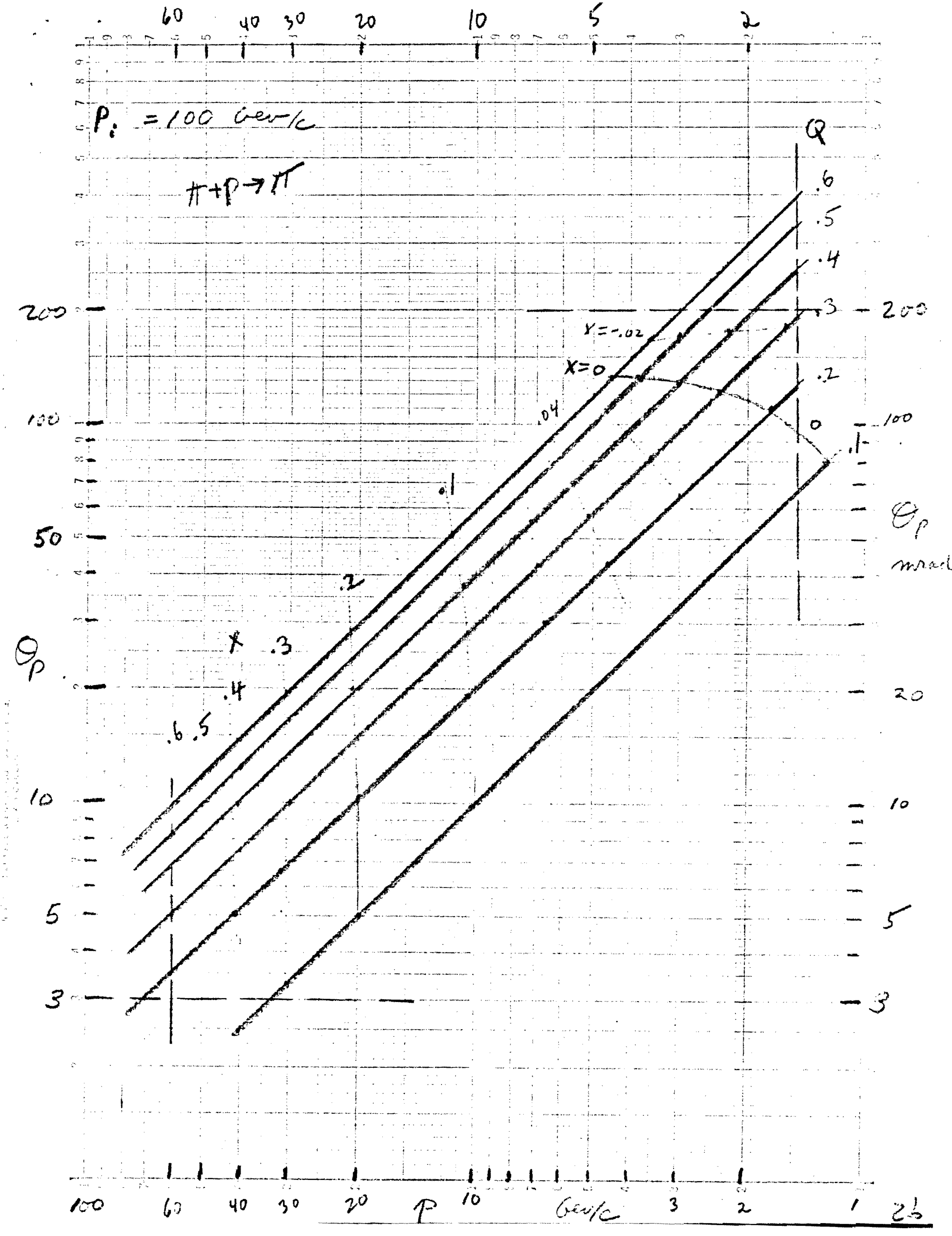
ACCESSABLE KINEMATIC REGION
$\pi + p \rightarrow \pi + \cdots\cdots$
$\pi + p \rightarrow K + \cdots\cdots$
Lower Bound
K
π or K
150
150 100 50
Upper Bound
π or K
150
100
50 P_i GeV/c
Q GeV/c
.6
.5
.4
.3
.2
.1
0
-.06 -.04 -.02 0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
X

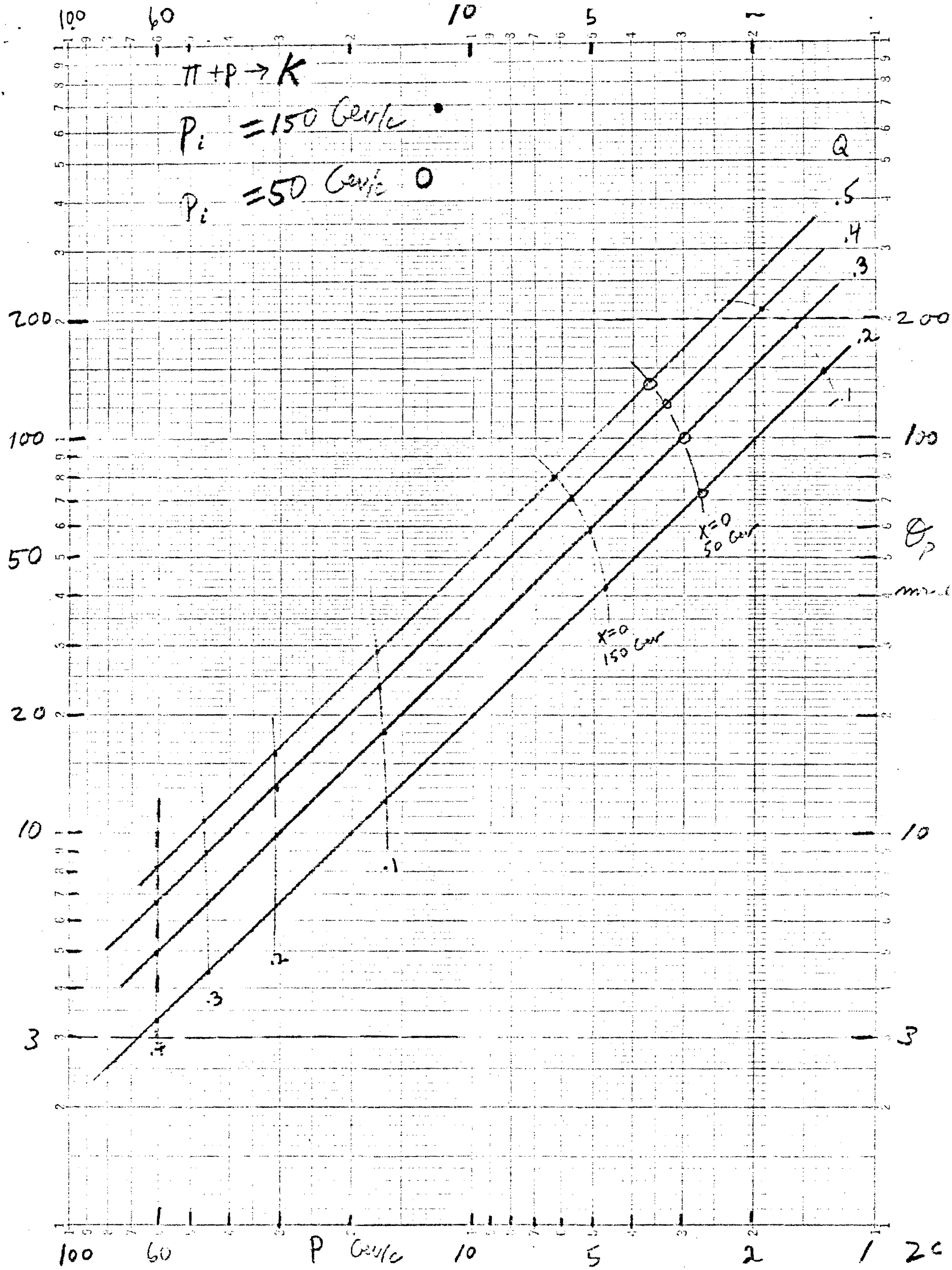
Fig 1



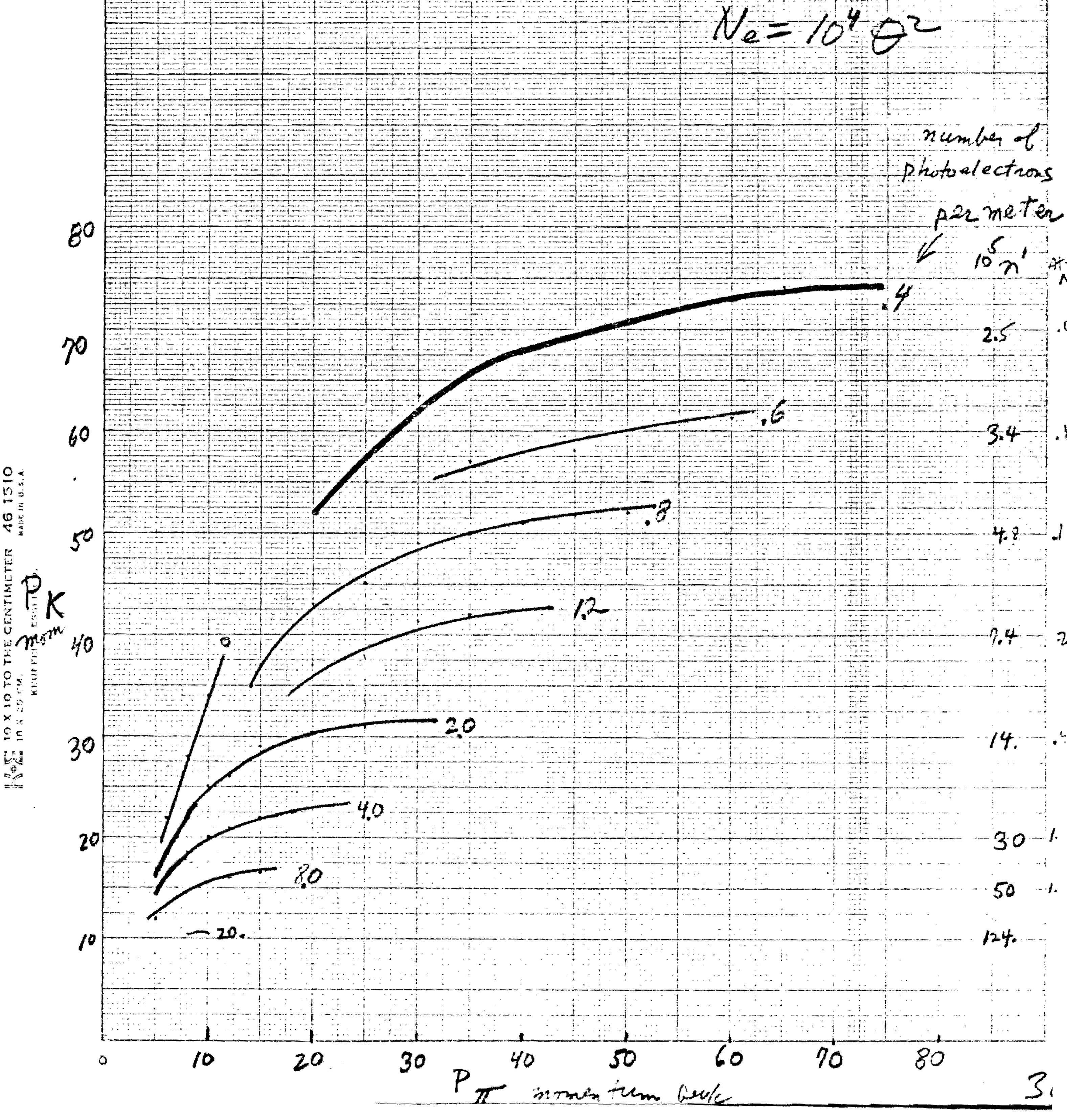
100
60
50
40
30
20
10
8
7
6
5
4
3
2
1
P_i = 150 GeV/c ●
P_i = 50 GeV/c O
$\pi + p \rightarrow \pi$
Q
.6
.5
.4
.3
.2
.1
X = -.02
X = 0
X = 0 (50 GeV)
X = .1 (50 GeV)
X
.1
.2
.3
.4
θ_p
200
100
50
20
10
3
-400
-300
-200
100
90
80
70
θ_p
mrad
30
20
10
8
7
6
5
4
3
100
P GeV/c
10
1

2a

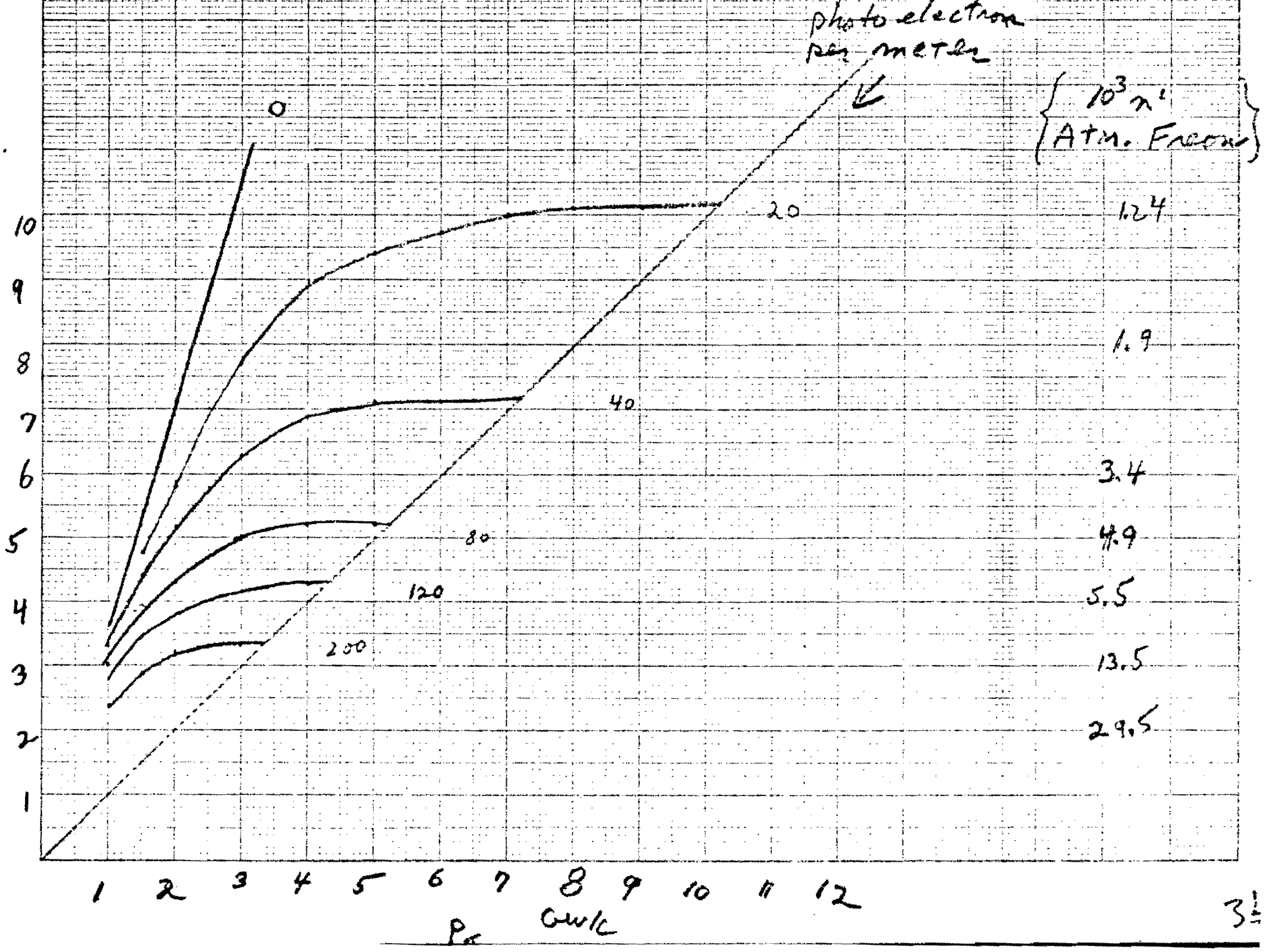

60
40
30
20
10
5
2
P_i = 100 Gev/c
$\pi + p \to \pi$
Q
.6
.5
.4
.3
.2
0
.1
200
100
50
20
10
5
3
200
100
20
10
5
3
Y = -.02
X = 0
.04
.1
.2
X .3
.4
.6 .5
θ_p
θ_p mrad
100
60
40
30
20
P
10
Gev/c
3
2
1
2b

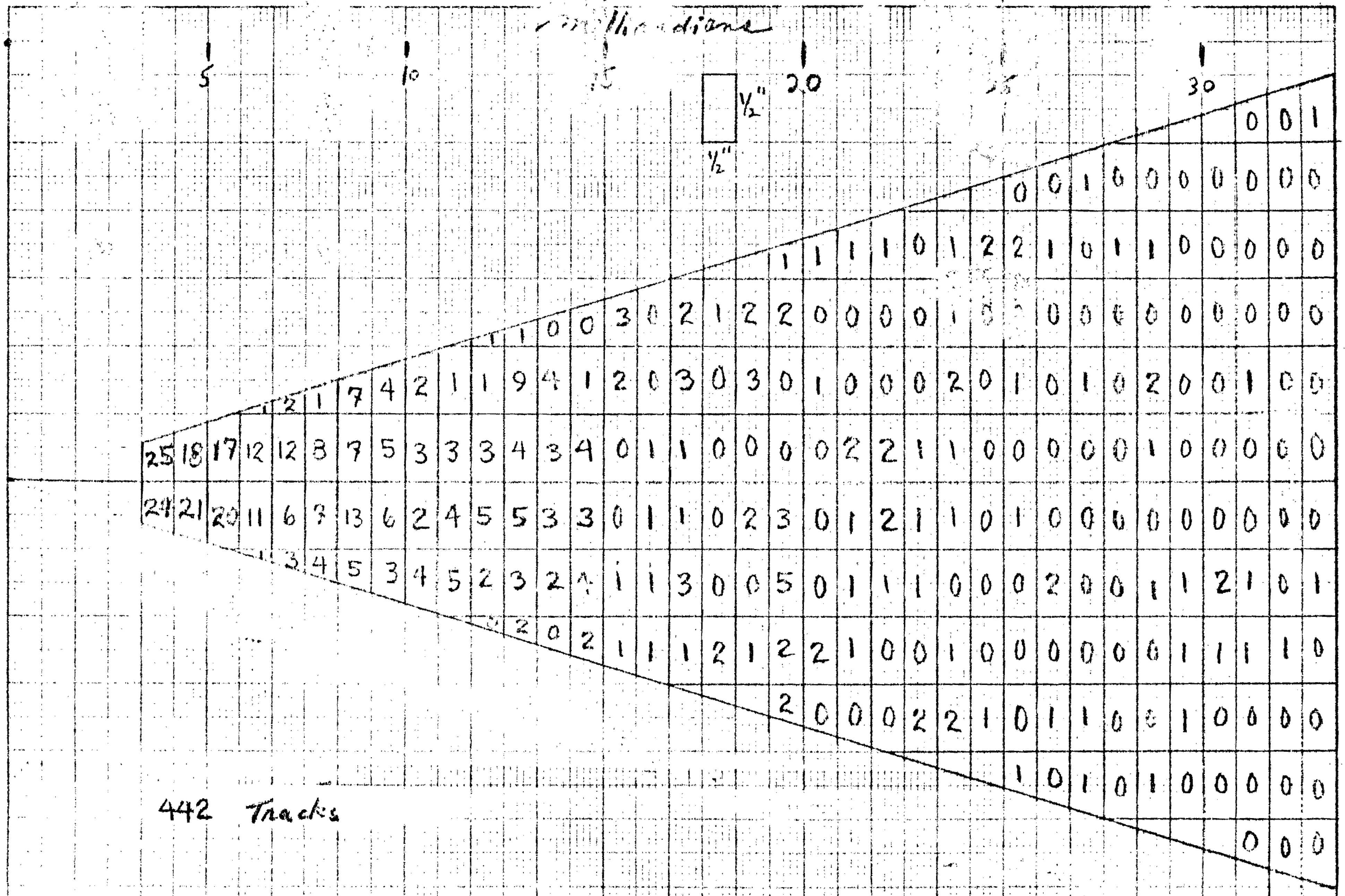

π + p → K
P_i = 150 GeV/c •
P_i = 50 GeV/c O
Q
.5
.4
.3
.2
.1
x=0 50 Gev
x=0 150 Gev
θ_p mrad
100
60
10
5
2
1
200
100
50
20
10
3
200
100
10
3
.1
.2
.3
.4
100
60
P GeV/c
10
5
2
1
20

Čerenkov Counter performance
of ph-el. for various momentum bands



$N_e = 10^4 \theta^2$





																																	0	0	1
																										0	0	1	0	0	0	0	0	0	0
																			1	1	1	1	0	1	2	2	1	0	1	1	0	0	0	0	0
										1	1	0	0	3	0	2	1	2	2	0	0	0	0	1	0	[illegible]	0	0	0	0	0	0	0	0	0
			1	2	1	7	4	2	1	1	9	4	1	2	0	3	0	3	0	1	0	0	0	2	0	1	0	1	0	2	0	0	1	0	0
25	18	17	12	12	8	7	5	3	3	3	4	3	4	0	1	1	0	0	0	0	2	2	1	1	0	0	0	0	0	1	0	0	0	0	0
24	21	20	11	6	7	13	6	2	4	5	5	3	3	0	1	1	0	2	3	0	1	2	1	1	0	1	0	0	0	0	0	0	0	0	0
			1	3	4	5	3	4	5	2	3	2	4	1	1	3	0	0	5	0	1	1	1	0	0	0	2	0	0	1	1	2	1	0	1
										0	2	0	2	1	1	1	2	1	2	2	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0
																			2	0	0	0	2	2	1	0	1	1	0	0	1	0	0	0	0
																										1	0	1	0	1	0	0	0	0	0
																																	0	0	0

442 Tracks

DISTRIBUTION of TRACKS
in Proportional Chamber