

ORO-3065-43

MASTER

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Subject: Progress Report for Contract E-(40-1)-3065 between the Department of Energy and Duke University

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I. INTRODUCTION — OVERALL PROGRESS

We have continued studying high energy π^\pm -proton, and π^\pm -Neon interactions in the SLAC 82" bubble chamber and in the Fermilab 30" bubble chamber. The present work is aimed at studying the production and interaction of pions and other particles in hydrogen and nuclei over the momentum range of 10 to 200 GeV/c. The observation of the energy dependence of multiplicity and single particle spectra gives us very useful data and a better understanding of processes going on in a heavy nucleus. We have a newly approved proposal to run the 30" chamber at Fermilab with π 's incident on a variety of nuclei at 100 GeV. The heavy nuclei would give approximately two times the nuclear path lengths as compared to neon.

In January, 1977, we made a proposal to SLAC for the use of the "Lead-Glass Wall" in conjunction with the SLAC 40" bubble chamber. Fortunately, our proposal was accepted. The experiment was proposed in collaboration with groups from the University of Tennessee at Knoxville and Florida State University. Since that time we have reconfigured the wall and run it using 16 GeV/c π^+ into deuterium. Our work on the direct production of electrons has nearly been completed and has been quite successful. We will probably want to continue measuring some of the events associated with the pairs.

We have continued our work on the direct production of γ 's in hadronic interactions. Dr. Evans has worked out some of the details of this process with us. This work is of considerable interest and helps illuminate some of the puzzling results from work at ISR and the A. G. S. as well as our own work on direct electron production.

II. PROJECTS UNDERWAY

A. Direct Electrons

We completed this year our study of direct electron production. The results of this work are given in a Physical Review Letter and a preprint is attached. The basic results are that we find that essentially all the electrons seen (excluding Dalitz pairs from π^0 's) are members of pairs. Of the directly produced non-Dalitz electrons (and positrons) less than one in one hundred is singly produced. This fact sets a low limit on charm production. The directly produced pairs can be separated from π^0 Dalitz pairs by their invariant mass ($> m_{\pi^0}$) or possibly by their p_L and p_T values. Figure 1 shows a kinematic separation. The peak at very small p_T cannot be understood in terms of π^0 production.

Another interesting result has to do with the fact that for high mass pairs ($m_{ee} > 135 \text{ MeV}/c^2$) more seem to be produced in π^- -p collisions than in π^+ -p collisions although the number of events is not overwhelming.

The fact of pair production indicates electromagnetic origin of these pairs. We have investigated the direct production of γ -rays. The results

of these investigations are given in the paper submitted to the Tokyo Conference on High Energy Physics. The crux of the idea used in this investigation was to separate the π^0 induced γ -rays from the directly produced ones by kinematic means. We show the Feynman X and the p_T distributions of the γ -rays of interest (Figs. 2 and 3).

B. Lead-Glass Wall Experiment

One of the major efforts of our group this year has been the work on the lead-glass wall experiment. The wall was removed from SPEAR in the latter part of June, 1977. It was transported to the building that we used in the beam area at SLAC. Last summer was taken up with the process of reconfiguring the wall. As used at SPEAR, the wall consisted of single blocks of lead-glass, 6" x 6" x 12", which were stacked in a rectangle which was essentially ten blocks high and twenty blocks wide. We required nearly the same configuration of glass but we needed the long dimension to be vertical rather than oblong. Our configuration consisted of a stack which was eight blocks wide and nineteen blocks high. The other major change was that we required that at least the central part of the wall be more than the 10 radiation lengths that was used at SPEAR. The central part of the wall has been made of double blocks. Two of the standard size blocks were stuck together with a pliable transparent cement. This proved to be quite a successful technique. In front of the back blocks we have active converter blocks which are long blocks of somewhat smaller cross sections. These blocks are stacked up horizontally about two feet in front of the back blocks. The

configuration of the blocks, and the hodoscope between the active converter blocks and the back blocks, is shown in Fig. 4. This work on reconfiguring the wall required our group effort until about January 1. During the month of January and the first couple of weeks of February, we ran extensive tests on the characteristics of the double glass blocks. This test required that we run a test beam into the blocks and then record the pulse heights from the interaction of the high energy electron in the blocks. This test was not only a useful calibration of the blocks but also gave our group valuable experience in the operation of the various components of the experiment.

We have had personnel at SLAC continuously since a year ago this last June. I myself spent most of the summer of 1977 there. Dr. Lucas was there during the fall, Dr. Goshaw was the prime mover in the test that occurred in January and February and one of our graduate students has been there since December. We also have had the services of various members of the SLAC engineering and technical staff. The engineering work of designing and construction of the mountings which hold the wall in the active converter were done by Mr. Charles Hoard, who is a staff engineer at SLAC. Our collaborators from Tennessee and Florida State University each furnish a person at SLAC. Thus we have had three people, at least, present for the last sixteen months or so. The wall, the hodoscope and the active converter were completely cabled and in their proper position inside of their box by May 15 of this year. After a slight delay, the box was moved into a final resting place behind the 40" chamber. This occurred on about June 20.

In the next week the cables connecting the photomultiplier tubes to their high voltage supply and the photomultiplier to the computing area were all laid. Our student, Mr. Glanzman, over a period of several months, had already constructed the software necessary for being able to read in the pulses from the lead-glass photomultiplier tubes. Our group also did all of the work on developing a trigger for indicating the occurrence of an event of interest.

We began to calibrate the wall during the last week of June. It was necessary to have a well defined beam of electrons in order to do this. This turned out to be a rather difficult problem since the electrons had to traverse about $1/4$ radiation length before reaching the front of the lead-glass array. We were able to produce an acceptable beam by using the bubble chamber magnet. The difficulty in getting a suitable beam of electrons into the wall required that we only illuminate one block at a time. This automatically required a large amount of time for the calibration since we had an array of 152 back blocks. The result was that it required over one week of running to calibrate about 80% of the wall. The calibration is a calibration not only of the pulse height from the wall, but also the whole system up to the recording of the pulse height on magnetic tape. The computer software allows one to cycle through about 400 channels of analog to digital converters. Most of these converters are in a device known as the Large Scale Digitizer which was constructed at the Lawrence Berkeley Laboratory. This device had its own peculiarities which took considerable effort for us

to understand. Since the correct operation of this device is an absolute necessity for the success of the experiment, we hope to have better cooperation with the Berkeley Laboratory during our fall run.

Another difficulty was encountered before the run began, namely, that the electronics for the fairly extensive PWC system associated with the bubble chamber was flooded as a result of the malfunction of the air conditioning and subsequent over-heating of the room in which the electronics are kept. The result was that the experiment was started with only a small fraction of the PWC system operable. By the time the run was completed, about 80% of the PWC system was operable. The apparatus was finally calibrated and operational for about five running days at the end of the accelerator cycle. During this period of time we recorded about 100,000 pictures which were triggered by the lead-glass wall. In order to take a picture we required that the wall have about 8 GeV of electromagnetic energy deposited in it. This seemed to be a fairly conservative trigger, yet we hope to be able to improve the operation of the system before we begin our final run during the fall cycle of the accelerator. The art of the hybrid bubble chamber system is to obtain just the pictures that you want without hopelessly biasing the result that you obtain from the pictures. In our case, we had calculated that about 1 pion in 20 which interacted in the bubble chamber would deposit enough energy in the wall to produce a trigger. As it was, about 1 interaction out of 4 or 5, in fact, deposited enough energy to trigger the system. This was caused by the interaction of the secondary pions with the lead-glass of the wall to produce π^0 's. We are in the process

of designing hardware to cut down this effect and to produce a superior trigger.

At the present time, the three institutions are in the process of scanning the pictures obtained, and also Florida State has begun to measure some of the events. In the next month we hope to measure 1000 or so events and also, of course, to correlate the results of the bubble chamber measurements with the information obtained from the energy deposition in the lead-glass wall. At the present time, we have been approved for a ten-million expansion in the 40" bubble chamber. In order to carry on the experiment as originally proposed, we will request an additional ten to twenty-million expansions which we would hope to be able to take during the October, November, December experiment cycle at SLAC.

C. π -Neon at 200 GeV

We have continued our measurement program on our old 200 GeV π -Ne data measured at Albany. This proved to be unsatisfactory as far as obtaining a detailed and balanced picture of the interactions. We began a series of measurements aimed at completing the measurements begun at Albany. The results were reported at the Washington meeting of the American Physical Society but were still rather incomplete. The high multiplicity events were often never attempted at all. These events are in some sense the most interesting of all in that they are most different from the simple π -nucleon interactions. We are now completing a sample of events of relatively high multiplicity. This will complete our sample obtainable from the 200 GeV π^- -Ne pictures.

D. Our Collaboration with SUNY at Albany

Our collaboration with C. R. Sun's group at the State University of New York - Albany has continued to be fruitful. As in the past, we have made use of the scanning and measuring system at SUNY to increase the flexibility of our research effort and to help handle short term peak loads. In addition, C. R. Sun and I. Kim have provided the physicist expertise necessary to carry out certain independent projects in our expanded joint research effort (see details below). The mutual benefits derived from this collaboration have been obtained at a low cost in contract funds (\$25K last year).

Some details of the work done at SUNY are given below:

1) Direct γ production in π^+p Interactions.

The physics details of this subject are discussed elsewhere in this report. The major contribution of SUNY to this research has been a careful study of the subtle backgrounds that occur in this process. This required a large number of physicist man-hours devoted to examining the $\gamma \rightarrow e^+e^-$ pairs on film. In addition, special scans were done to evaluate random coincidences of γ 's with events.

2) The Pb-glass Wall Experiment at SLAC (BC-67)

Sun and Kim have taken the responsibility for monitoring the stability of the ~ 400 photomultipliers used in this experiment. The high voltages are computer monitored and a LED flashing system is used to check for changes in gains of the tubes. The CAMAC interfacing of these systems to a NOVA

computer and the software programs used for diagnostics have been largely developed by the group at SUNY.

E. The Theory of Direct γ and Electron Production

Larry Evans has made an important contribution to our understanding of the theory of direct γ production. He has observed that internal bremsstrahlung from hadronic interactions can be calculated directly, using a low energy photon theorem derived by F. E. Low, if the hadronic charged track measurements are known completely for each interaction. Several theorists have previously obtained approximate inclusive expressions for direct photon and electron production from inner bremsstrahlung. We can now calculate the results exactly and, more importantly, differentially for various different types of hadronic interactions. This calculation has been carried out and will be compared in detail to our direct γ measurements.

The internal conversion of inner bremsstrahlung γ 's will produce a source of direct electrons with low p_T . This may be related to reported increases in the direct e to π ratio at low p_T . This calculation has been started and will be compared to results obtained in the Duke-SLAC-Imperial College direct electron experiment.

F. High Energy Compton Electron Scattering

We have completed a measurement of the Compton electron spectrum produced by high energy photons. The production cross section for Compton electrons with energies between 0.1 and 5.0 GeV agrees well with QED calculations. This is the first measurement that has been made of this process above 1.0 GeV. The result of this research has been accepted for publication in Physical Review D (see attached preprint).

G. Additional Projects

In addition to participating in several of the Duke originated projects mentioned elsewhere in this report, Dr. Peter W. Lucas has continued work on three experiments in which he was involved before his arrival here.

1. The Diffraction Dissociation $n \rightarrow p\pi^-\pi^0$ Induced by 12 GeV/c K^- Mesons. A final draft of this work has been completed and accepted for publication in Physical Review D. (Since most of this work was performed while Dr. Lucas was employed by the Johns Hopkins University, publication credit rests with that institution.) The chief points of interest in this work are the fact that the final state $K^- \pi^- \pi^0$ pp_S in K^-d interactions can be isolated at this beam momentum through careful ionization studies, and then that a three body target break-up can be observed into a final state in which Δ^{++} , Δ^- , and σ (s-wave, $T = 0$, dipion) are all forbidden. Direct N^* production and a multiperipheral mechanism dominate the cross section.

2. Leading Particles and Diffraction Dissociation in π^-p Collisions at 150 GeV/c. This study, performed in the FNAL 30" BC-PWC hybrid spectrometer, represents the most comprehensive examination yet performed on diffractive processes at FNAL energies. Beam dissociation is observed through clear leading proton signals in the bubble chamber while target dissociation is isolated through leading pion effects observed in proportional wire chambers, with the aid of an advanced version of a Van Hove sector cut unique to the hybrid spectrometer. The results on

cross sections and diffractive break-up dynamics are presented as a function of charged particle multiplicity and of whether or not neutral particles are produced.

This work has been submitted to Nuclear Physics with Dr. Lucas' share of the publication credit residing with Duke.

3. Study of the reaction $K^+ n \rightarrow K^+ \pi^+ \pi^- n$ at 12 GeV/c. This study performed in collaboration with A. Firestone of Iowa State University, uses the data of the large exposure of 12 GeV/c K^+ on deuterium in the SLAC 82" bubble chamber taken by the Berkeley group. The work is proceeding with the most interesting result so far being confirmation of the fact that neutron diffraction dissociation induced by kaons proceeds with a slope in momentum transfer much less steep than that seen in the dissociation of protons. This effect has been seen previously by Lucas in $n \rightarrow n \pi^+ \pi^-$ and $n \rightarrow p \pi^- \pi^0$ induced by 12 GeV/c K^- .

In the course of pursuing these projects many programs originally written for the Johns Hopkins SIGMA-7 computer have been brought on-stream on the Duke SIGMA-5, making that computer a very useful tool in data reduction.

III. STATUS OF RIPPLE AND SIGMA COMPUTERS

The usefulness of the SIGMA computer has been dramatically increased during this contract period. A CDC line printer and card reader obtained from the ADP excess property lists have been successfully interfaced to the computer in a manner which is compatible with the RBM monitor system. The system has been operable since about January and RIPPLE became operational under the new monitor during July.

The SIGMA now has 48K memory, a 3M byte fixed head disk, two 9-track, 800 bpi tape drives, a 1000 cpm reader, and a 1000 lpm printer as its major general purpose peripherals. The RBM monitor supports foreground/background activities but RIPPLE requires the entire memory which eliminates this feature at present. The RIPPLE program also dominates the disk space making general purpose programming quite limited in both time and variety.

The RIPPLE system is presently measuring high multiplicity events with converted gammas in FNAL 30" chamber H-Ne photographs. These events, which have up to 30 outgoing tracks at the primary vertex and up to 6 converted gammas, are preselected as being "possible to measure" and traced in one view. About 250 such events have been measured in the last four weeks. We hope to measure 1000 such events before switching to BC-67 film.

Duke University

HIGH ENERGY PHYSICS

PUBLICATIONS LIST

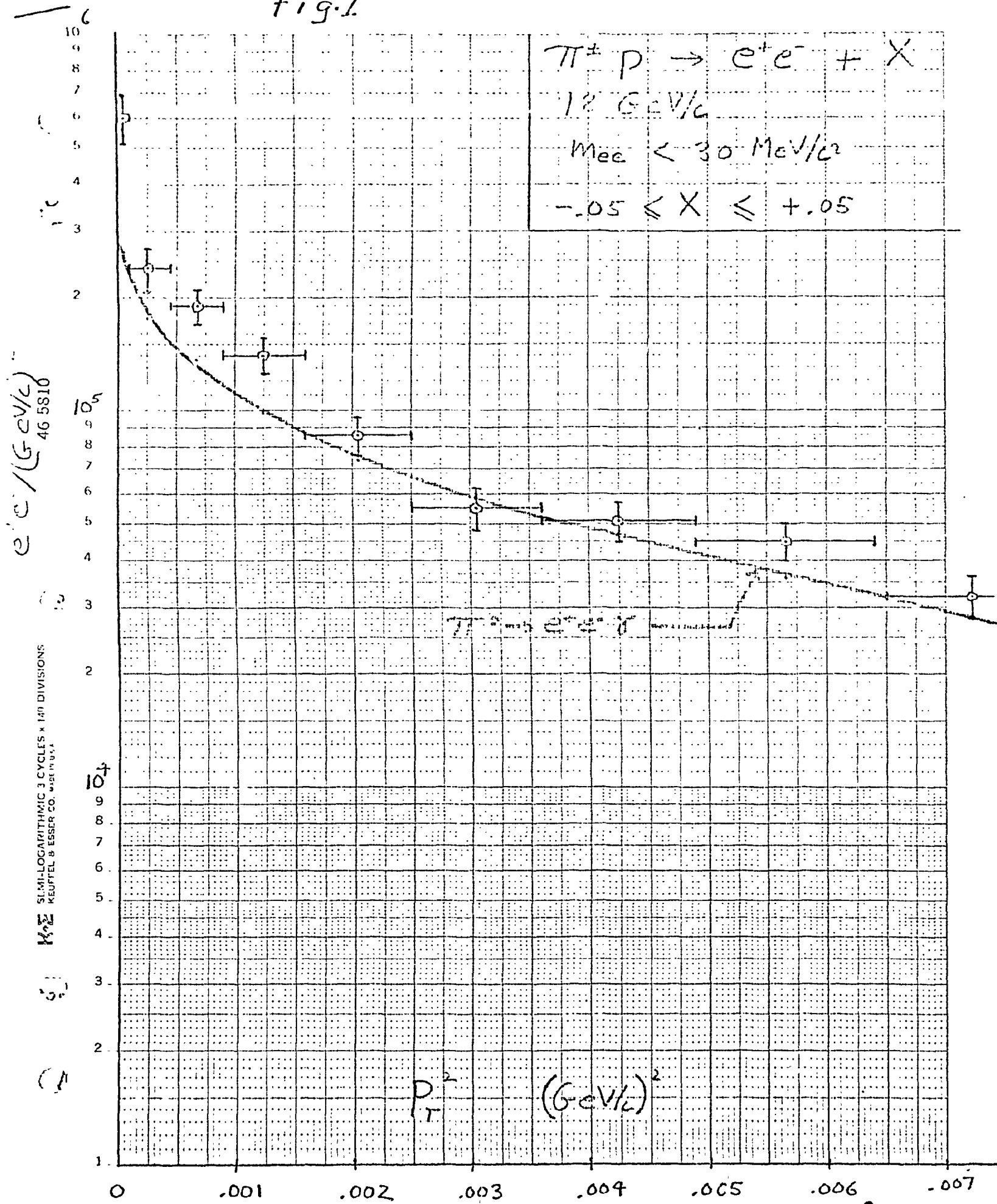
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Reprints Removed

fig. 1



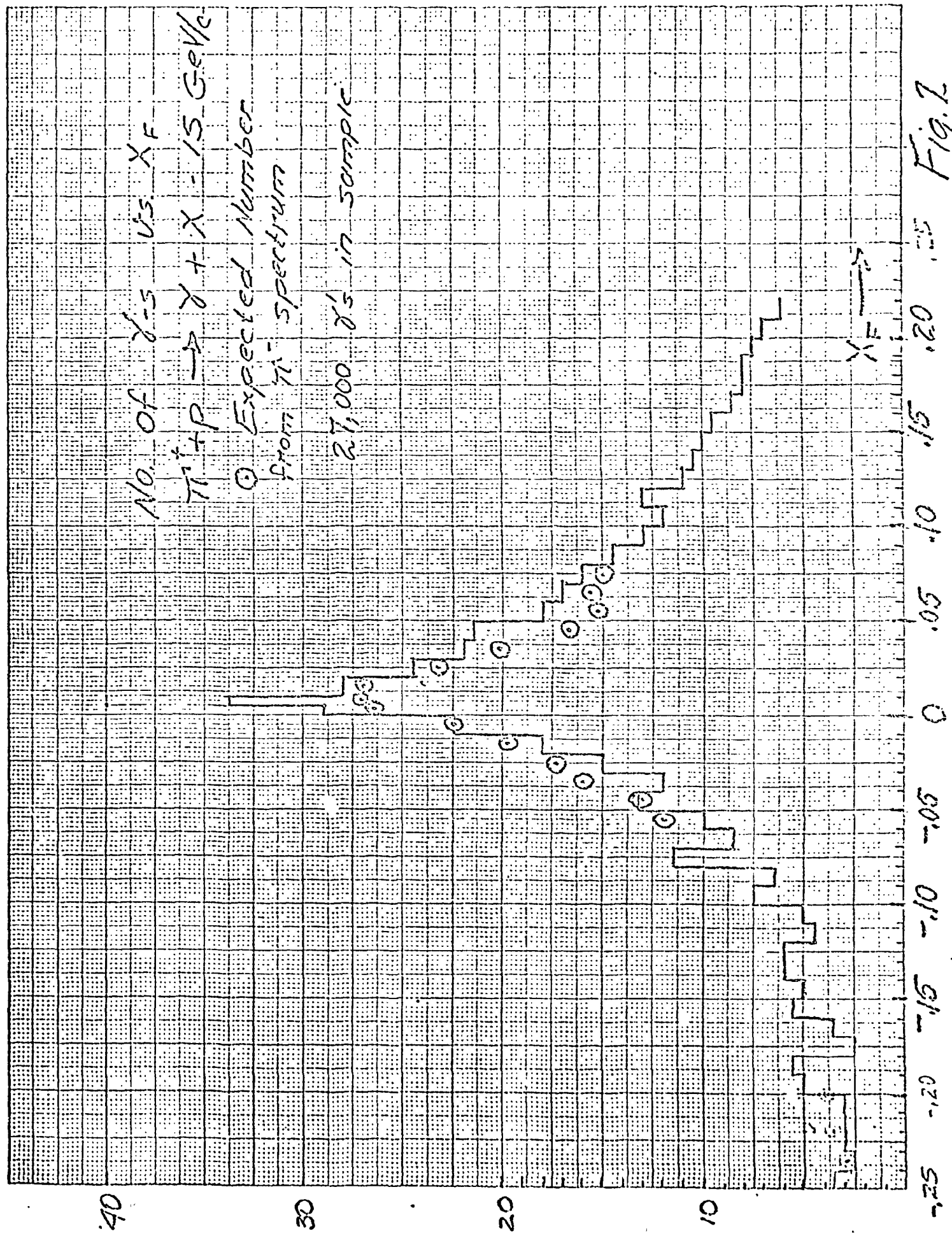


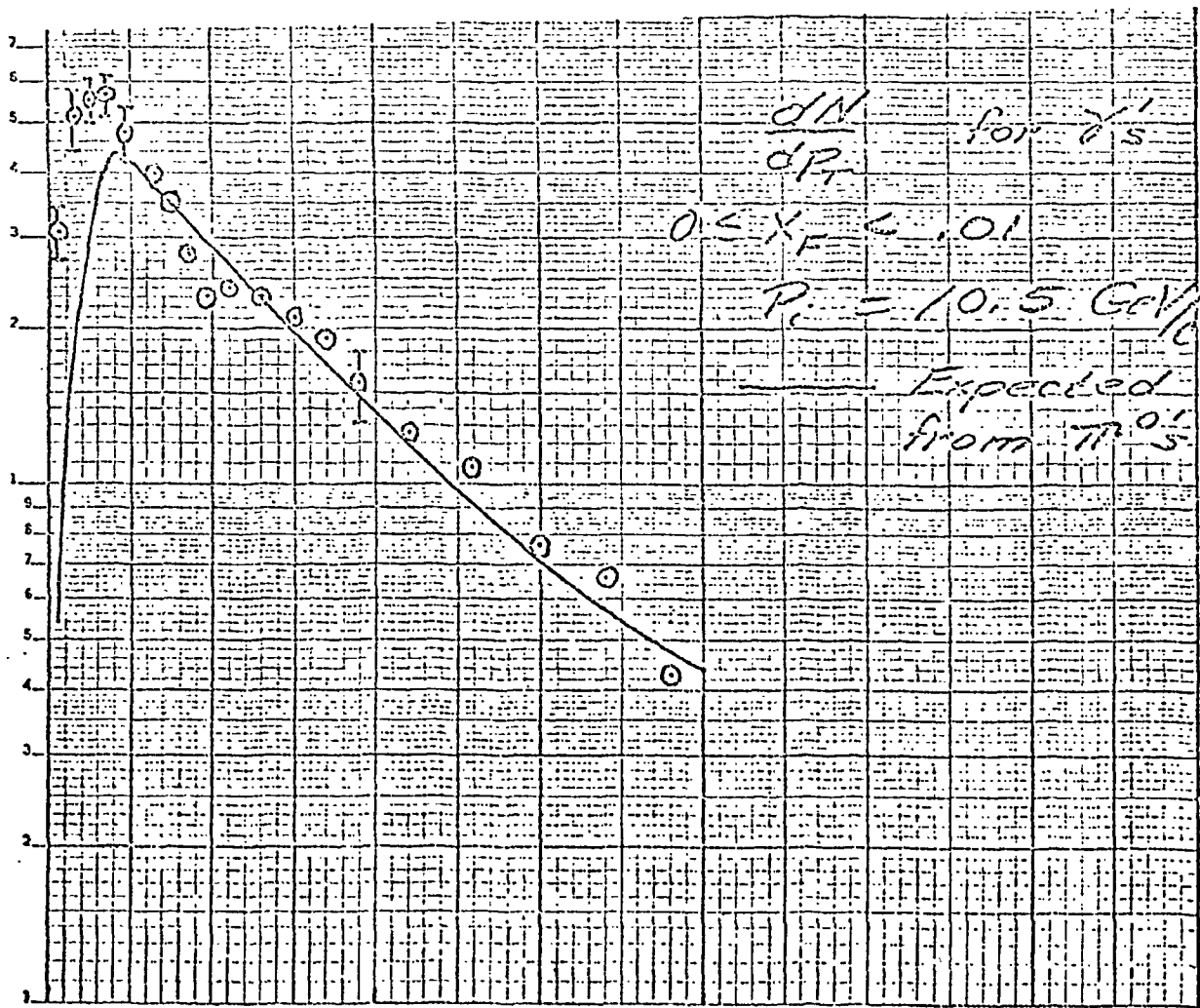
Fig. 2

Fig. 3

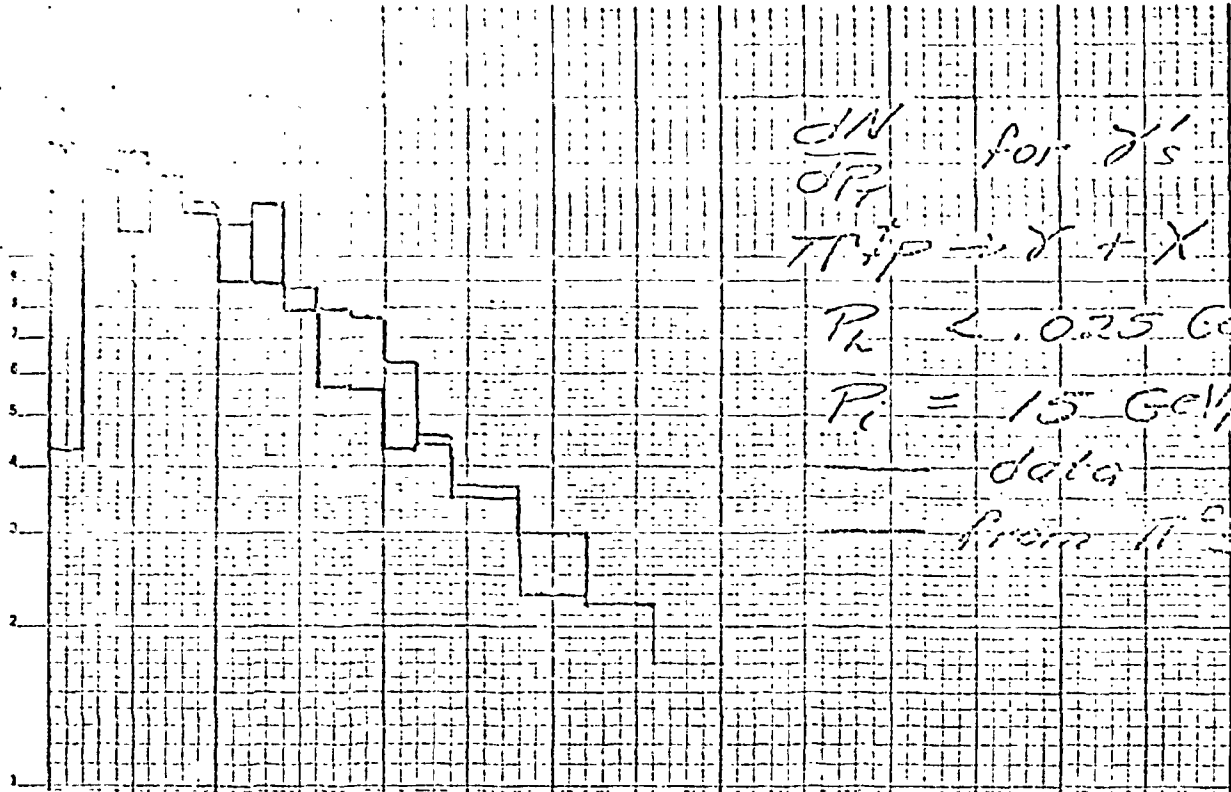
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$\frac{dN}{dP_r}$ for γ 's
 $0 \leq X_T \leq 1.01$
 $P_i = 10.5 \text{ GeV/c}$
 Expected from π 's



$\frac{dN}{dP_r}$ for γ 's
 $\pi^+ \pi^- \rightarrow \gamma + X$
 $P_i = 0.25 \text{ GeV/c}$
 $P_i = 15 \text{ GeV/c}$
 data from π 's

0 .1 $P_r \rightarrow$.2 GeV/c Fig. 2

Figure 4

Beam layout

