NAL PROPOSAL No. 216

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A MEASUREMENT OF THE PION FORM FACTOR BY DIRECT PION-ELECTRON SCATTERING

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Summary:

This is a proposal to measure the charged pion form factor for space like q^2 in the region $q^2 \leq .086\ \mathrm{GeV}^2$ by scattering 100 GeV (negative) pions from electrons in a liquid hydrogen target (∿50 cm long).

A similar experiment conducted at Serpukhov yielded a pion radius of (0.96 ± .06)f which is a value much larger than the 0.64f expected from vector dominance and even larger than the limits that can be set using the known colliding beam data in the time-like region and the requirements of analyticity. The present proposal is designed to check this unexpected result at a significantly higher energy (100 GeV as opposed to 50 GeV at Serpukhov) where the effect of f_π^2 in the cross section will double so that the effects of systematic errors will be at least halved.

The trajectory at the incident pion and the momenta and scattering angles of the recoiling π-e pairs are measured with a combination of proportional chambers, wire spark chambers, and spectrometer magnets (2 BM 109's with 8" x 18" aperture and $\int Bdl$ = 80 kg - m). Electrons and hence the q^2 label for each event are identified through kinematic analysis of the recoiling particles using the high angular precision of the apparatus (±0.2 mr). A redundancy check on the electron identification is supplied by total absorption Pb-glass shower counters.

Using a beam intensity of 2.5×10^5 π's/pulse at 500 pulses/hr., the experiment anticipates 20,000 π-e events in 200 hours of running time at $q^2 > .05\ \mathrm{GeV}.^2$

They also plan to simultaneously measure the radius of the charged kaon to an accuracy of 20% assuming $\langle r_K^2 \rangle^{1/2}$ = 0.58f as given by vector dominance and SU3

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INTRODUCTION

We propose an experiment to measure the pion form factor via direct scattering of negative pions in a beam from electrons in a hydrogen target. This present proposal is intended as a complete document to supercede previous documents that we have submitted to NAL in the hope that by so doing we will minimize confusion and provide a convenient reference for all of our arguments. Resubmission of the pi-e proposal at the present time is motivated by the results obtained from the Serpukhov experiment at 50 GeV. These results indicate a pion radius of 0.96 ± .06 f, a value much larger than the 0.64f expected from vector dominance and even larger than the limits that can be set by using the known colliding beam results in the time-like region and the requirements of analyticity. This unexpected result indicates the importance in repeating the experiment at only a modest increase in energy, from an incident pion energy of 50 GeV at Serpukhov to an energy of order 100 GeV at NAL where the effect being measured will more than double so that systematic errors, even if they are not reduced as a result of our Serpukhov experience, will be halved. Table 1 summarizes the relevant data.

TABLE I

π	$E_{e\ max}$	σ_{point} $(1/2E_{max}$ to $E_{max})$	f_π^2 at $E_{e\ max}$* $r_\pi = 0.64f$	f_π^2 at $E_{e\ max}$* $r_\pi = 1.0f$
50	36.2	2.2 μb	.88	.75
100	84.0	0.9 μb	.75	.54

* This calculation assumes

$$f_\pi^2 = (1 + \frac{1}{6} q^2 \langle r_\pi^2 \rangle)^{-2}$$

It can be seen in Table I that although the cross section is smaller, an experiment at 100 GeV is much more sensitive than at 50 GeV. Backgrounds at the higher energy are predicted from the Serpukhov experiment to be small. If verified, we would then increase the incident beam energy to its highest practical limit set either by beam line limitation or by the strong interaction background.

THEORY

Perhaps the most complete analysis of the pion form factor has been given by Levin and Okubo[1] who derive upper and lower limits on the value of the pion form factor in the space-like region. Their assumptions include analyticity, polynomial boundedness, that $F(\xi) = F^*(\xi^*)$, that $F(t)$ has no poles in a region where the phase shift $\delta_F(t)$ is known, and that $|F(t)|$ is bounded from above by a function known either from experiment (at experimentally available colliding beam energies) or a "reasonable" bound at higher energies. These limits depend most strongly on the unknown π-π phase shift near threshold; the resultant lower bound assuming the phase shift is given by effective range is shown in Figure 1 along with the form factors found in the Serpukhov experiment. We believe that the clear disagreement both in slope and in absolute cross section mandates a repeat of the experiment at slightly higher energy.

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[1] D. Levin and S. Okubo, Phys. Rev. D, 6, 3149 (1972)

EXPERIMENTAL SET UP

Figure 2 summarizes the kinematics relevant for the design of the experiment at 50 GeV and at 100 GeV. Elastic scattering is a four-constraint process. At high energy the energy constraint is not effective and we apply the remaining constraints to coplanarity, transverse momentum, and longitudinal momentum. The latter constraint is not as useful as the first two in rejecting strong interaction backgrounds. For these, precise measurement of the scattering angles is important. In the experimental setup at Serpukhov shown in Figure 3, these angles were measured to ±0.3 mr. This accuracy was sufficient both to reduce strong interaction backgrounds to <1% of the pi-e signal and to identify the scattered pion and electron by measurement of the angles alone (except at the points near 1/2 the beam energy where q^2 is well-defined.) Additional (redundant) identification is provided by the Pb glass Cerenkov shower counters labelled $\check{C}_\pi$ and $\check{C}_E$ in the figure. In fact, the π-e signal is so prominent that some relaxation in the kinematic accuracy can be permitted.

The accuracy required to reject strong interaction backgrounds should scale with the incident energy. We feel that measurement to ±0.2 mr at 100 GeV should be sufficient. Figure 4 shows the transverse momentum peak from the Serpukhov data. The curve labelled "no cuts" represents raw data; the curve labelled "standard cuts" represents the data within a 6 mr cone after application of longitudinal momentum and coplanarity cuts. Electron identification (by the shower counters) interchanges the pion and electron labels on 1% of the events.

As can be seen from the kinematics, the opening angles are nearly the same at 100 GeV as at lower energies, in fact the angles are only slowly varying as a function of recoil electron energy (q^2), and the total angular range is smaller at higher energy so that the required magnet aperture is small. Furthermore, the opening angle does not become excessively small except at the peak electron energy so that track-finding of the narrow opening-angle pair is simplified and introduces no significant q^2 bias. This fact is important because the radius can be measured in two more-or-less independent ways, the "absolute cross section" method and the "slope" method. In the former, the absolute yield at each q^2 is compared to the expected yield. In the latter, the results are fitted and the radius determined only by the data as a function of q^2 but with an arbitrary normalization constant. In the Serpukhov experiment, these methods were in statistical agreement and a final fit was performed to all of the data using a full error matrix.

We propose to use a setup similar to that of Figure 3. Three blocks of spark chambers are used. Blocks I and II in front of and behind the target, respectively, will be proportional chambers $\simeq$ 1 ft. square. Block III, behind the magnet which spatially separates the π-e^- pair, will be magnetostrictive chambers 1 m. square. Two BM 109 magnets (80 Kg-m) with aperture 8" by 18" could be used for momentum analysis. Each of Blocks I, II, and III measure angles over a 10 meter lever arm providing the appropriate angular resolution of ± 0.2 mr. The apparatus accepts momenta from 30 GeV to 70 GeV with high efficiency covering nearly all of the π-e spectrum. A space of $\simeq$35 m. is required along a beam line.

DATA RATES

A 50 cm hydrogen target will be used. Its product of length times density must be known to of order 1%. Targets have been built at Dubna with quoted accuracy of 0.1% and appear to pose no technical problems. We assume a cross section of 0.4 of the point-like value from 1/2 E_{max} to E_{max} in order to take into account the form factor, radiative corrections, and other experimental corrections. This 0.4 μb cross section gives 0.2 event/pulse at 2.5×10^5 π's/pulse. At 500 pulses per hour we obtain 20,000 events in 200 hours of running time. The experiment will need checkout and tuning time to the extent of another 300 hours since clearly the experiment is limited by systematic and not statistical errors. We would expect to occupy a beam line ≈3-6 months. The apparatus is small and narrow; it could, for example, be placed in the 2.5 mr. beam enclosure. Beam to other experiments could either pass through the apparatus (with the shower counters and muon shield moved to the side) or, if this represents too much material for downstream experiments, the chambers could easily be moved to the side and a beam pipe inserted.

TRIGGER RATES AND BACKGROUNDS

Trigger rates can be easily predicted from the Serpukhov experiment. There the trigger rate was 1×10^{-4} per incident pion, and should be almost energy independent. This would imply 25 triggers per pulse which is an acceptable rate. We expect to add the additional trigger requirement of two or more particles present in the Block II

proportional chambers in order to further reduce the rate. We have assumed a 250 msec. effective spill time in our calculations. If this is increased, the beam intensity could be increased proportionally. The instantaneous beam rate is a conservative one pi per μsec. These rates correspond to those at Serpukhov where all three blocks were magnetostrictive chambers and could be increased perhaps a factor of two or three especially if the Block III magnetostrictive chambers are deadened in the area struck by the incident beam. (These chambers had significantly lower backgrounds than the upstream chambers in the Serpukhov experiment.) Of course, the major improvement of the proposed setup is the proportional chambers in Blocks I and II. Their time resolution will greatly reduce unwanted background tracks and, in addition, the chambers will be more efficient for detection of two particles of small spatial separation.

K^- ELECTRON SCATTERING

We hope to simultaneously obtain K-e scattering events. A Cerenkov counter to tag K's in the beam will be required and perhaps it will be necessary to choose a beam energy which optimizes the K/π ratio in the beam. At 100 GeV the maximum electron recoil energy is limited to 30 GeV. Some minor modifications of the geometry of the apparatus may be required to simultaneously observe the scattered kaons and electrons. If electrons between 20 and 30 GeV (corresponding to kaons between 80 and 70 GeV) are observed, the point cross section is 0.5 μb and we might hope to obtain 1-2,000 K-e events corresponding to a 20% measurement of the kaon radius assuming it

is given by the vector-dominance-SU3 relation

$$f_k = \frac{1}{2} \frac{1}{1 + q^2/m_\rho^2} + \frac{3}{8} \frac{1}{1 + q^2/m_\phi^2} + \frac{1}{8} \frac{1}{1 + q^2/m_\omega^2}$$

which gives $r_k = 0.58f$.

DATA ANALYSIS

Data analysis will be greatly aided by the Serpukhov experience. Highly efficient, well studied track finding programs exist. Monte Carlo programs for geometric and track finding efficiencies, fitting routines, and, radiative correction programs exist. All of this software entailed a great number of man hours of effort and can be easily modified for the new experiment.

RADIATIVE CORRECTIONS

The radiative correction for the Serpukhov experiment has been calculated by Micelmacher and Bardin from Dubna using a Monte Carlo technique. This program will require only minor modifications for use at 100 GeV. The total correction including real bremmstrahlung in the target and spectrometer materials is of order 20%.

TIME READY

The apparatus is relatively easy to construct. Most of the equipment is available from previous experiments and could be assembled by summer, 1974.

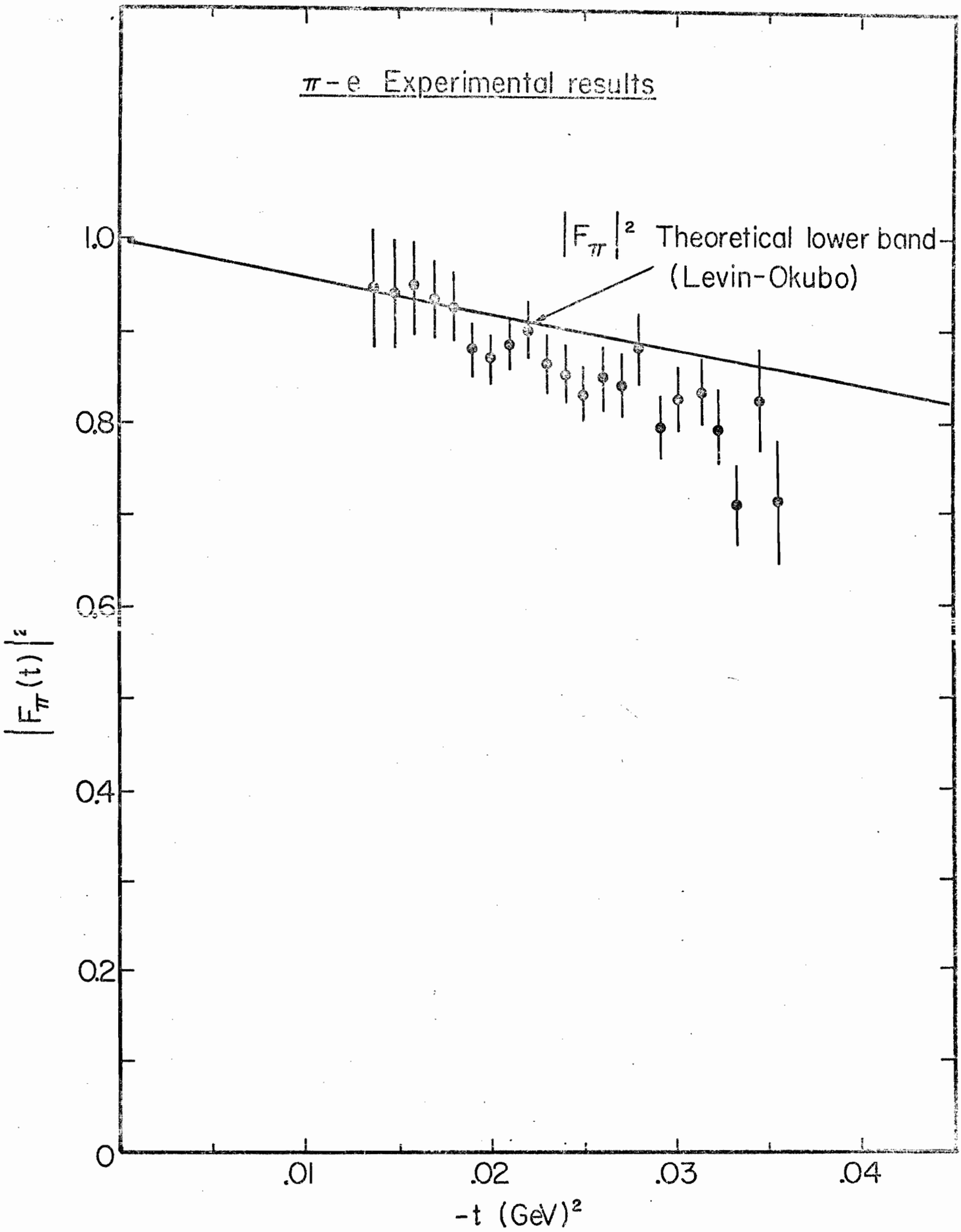
π - e Experimental results
$|F_\pi|^2$ Theoretical lower band
(Levin-Okubo)
1.0
0.8
0.6
0.4
0.2
0
$|F_\pi(t)|^2$
.01
.02
.03
.04
$-t$ (GeV)^2

FIGURE 1

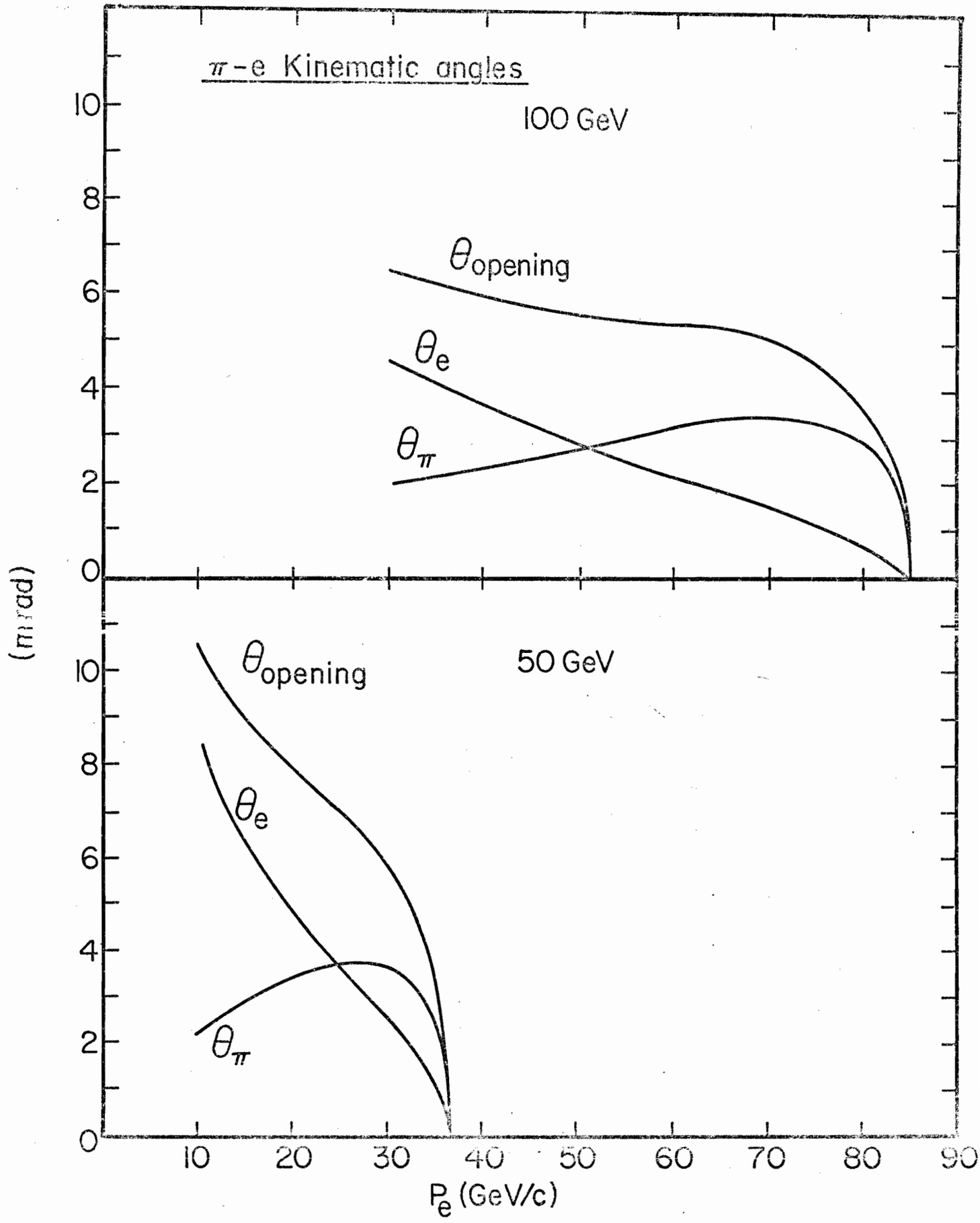
π-e Kinematic angles
100 GeV
θopening
θe
θπ
50 GeV
θopening
θe
θπ
(mrad)
0
2
4
6
8
10
10
20
30
40
50
60
70
80
90
Pe (GeV/c)

FIGURE 2

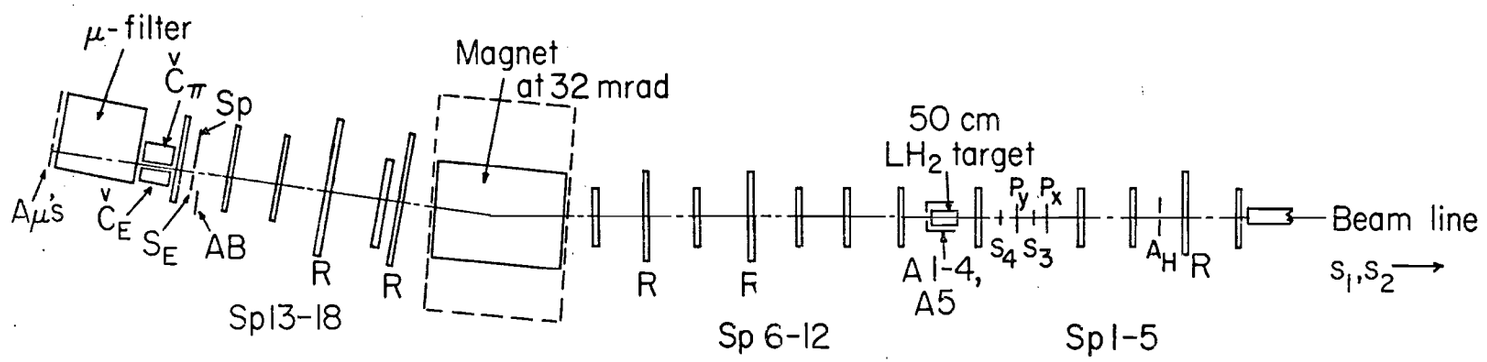
μ-filter
$\check{C}_\pi$
Sp
Magnet
at 32 mrad
50 cm
LH_2 target
P_y P_x
A_μ's
$\check{C}_E$
S_E
AB
R
R
R
R
S_4 S_3
A_H
R
Beam line
S_1, S_2
Sp13-18
Sp 6-12
A 1-4,
A5
Sp1-5

FIGURE 3

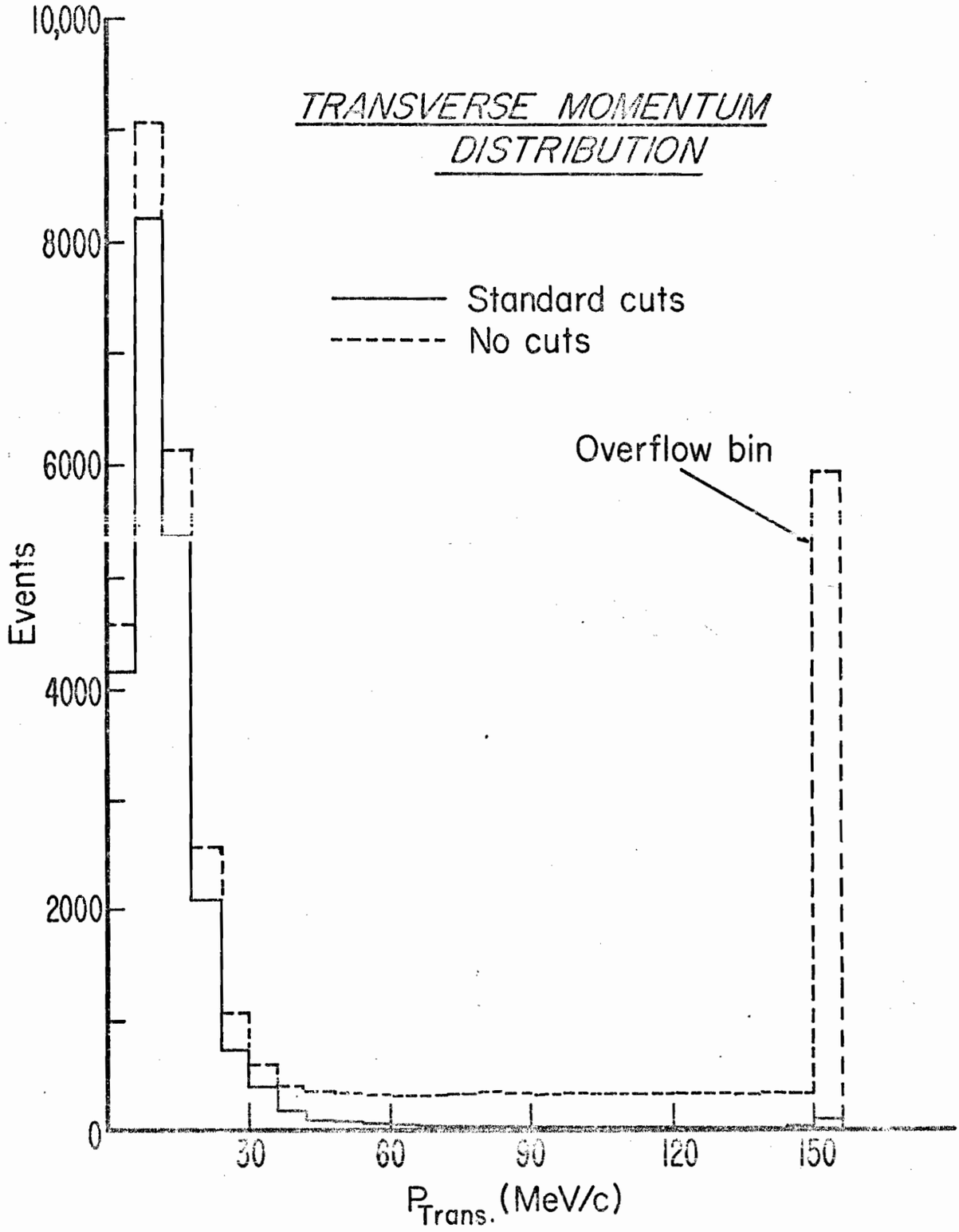
TRANSVERSE MOMENTUM DISTRIBUTION
Standard cuts
No cuts
Overflow bin
Events
10,000
8000
6000
4000
2000
0
30
60
90
120
150
$P_{Trans.}$ (MeV/c)

FIGURE 4