Fermilab Proposal No. 331

Scientific Spokesman

J. E. Pilcher
Enrico Fermi Institute
University of Chicago
Chicago, Illinois 60637

PH: 312 - 753-8747 or 8744

Formerly
Addendum to Proposal 308

A PROPOSAL FOR A DETAILED STUDY OF DIMUON PRODUCTION

K. Anderson, D. Bintinger, J. Curry, J. Pilcher, J. Sidles

Enrico Fermi Institute
University of Chicago

and

C. Rubbia and L. Sulak

Harvard University

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I. Introduction

We have proposed an experiment to investigate the detailed characteristics of direct muon pair production in hadron-hadron interactions. This experiment emphasizes good mass resolution down to the ρ-mass, the use of an incident beam of mesons as well as nucleons, and an extremely large acceptance detector for the muon pair. The broad acceptance will allow an unbiased study of the production and decay angular distributions of the dimuon state. A more restrictive acceptance would couple the observed production and decay characteristics through the detector geometry.

This detector is not designed to reach the very small cross section levels of NAL dilepton experiment E-70/288 which employs a much smaller acceptance detector but uses the intensity of the extracted proton beam. Experiment 308 will, however, have a cross section sensitivity of 10^{-34} cm^2 at the rate of a few events per hour.

The physics motivation, experimental method, background estimates, event rates, and run plan are all given in the original proposal. The proposal requests a pion beam of 10^7/pulse up to as high an energy as possible and proposes to use a large magnetic spectrometer. At the request of the Program Advisory Committee and the FNAL administration, we have considered the suitability of the Chicago cyclotron spectrometer in the Muon Laboratory. We conclude that this spectrometer would be fully adequate and the meson beam available there is excellent for our purposes. This addendum describes the experiment using the cyclotron spectrometer. We consider below, those features of the beam, experimental configuration, acceptance, and backgrounds which differ from the original proposal.

II. Hadron Beam to the Muon Laboratory

We have discussed the possibility of using the N1 beam for hadrons, with P. Limon of NAL and several members of the E-98 muon scattering experiment. The present beam using the quad-triplet train delivers 10^6 muons at 150 GeV/c with $\Delta p/p = \pm 2\%$ for 6×10^{12} protons of 300 GeV on target. The μ/π ratio at 150 GeV/c is $\sim 3\%$ so a pion intensity of over 10^7 is attainable simply by removing the hadron absorber. The proposed experiment has no special demands on momentum resolution or spot size.

This large solid angle, 0° beam, is the most intense pion source available at NAL and will remain so until the new Proton-West pion beam comes into operation. Its only shortcoming for this experiment is the maximum momentum attainable. It is presently limited to 150 GeV/c although simple modifications would allow it to reach 200 GeV/c. We would urge its upgrading to 300 GeV/c to allow operation on pions from 400 or 500 GeV protons.

The changeover from muons to pions is a simple one and Limon estimates it could be done in one day.

III. The Detector

The detector layout is shown in Fig. 1. As described in the proposal we would operate with a beam of 10^7 pions or protons into a target approximately 1 m upstream from a dense hadron shield. The pulse height from scintillators in the beam would be used to ensure no more than one particle per RF beam bucket and a scintillator just downstream of the target would identify beam particles interacting in the target. One would trigger on interactions in the target producing two particles which traverse the 18 absorption length hadron shield and also penetrate the 2.5 m steel muon filter downstream from the spectrometer.

For some of the running, if the trigger rate were high, we would operate with an effective mass threshold in the trigger. A segmented counter plane between the hadron shield and spectrometer would be sensitive to the opening angle of the pair while the hodoscopes downstream from the magnet would impose a lower limit on the momentum. Further details of this trigger are discussed in the original proposal.

Small multiwire proportional chambers (MWPC's) would record track trajectories between the target and hadron shield and part way through the hadron shield. Trajectories seen in the spectrometer would be used to identify the muon tracks in these chambers. For good mass resolution at low masses it is important to measure the μ-pair opening angle before the multiple scattering of the hadron shield

Initial measurements would be made with a very short, low Z target to map out the general features of the dimuon signal and any background effects. If the rates were suitable as expected, the detailed measurements would be taken with hydrogen and deuterium targets. The present hydrogen target represents too distributed a source so the present hydrogen flask would be replaced by one of half the length.

We have evaluated the detection efficiency of the system for muon pairs. Figure 2 shows the detection efficiency at 200 GeV as a function of dimuon transverse momentum, longitudinal momentum, and effective mass. The efficiency shown is for a dimuon decay angular distribution which is isotropic in the dimuon rest system. The efficiency fall-off at low $X_{\mu\mu}$ values arises from forward-backward decays in the dimuon rest frame.

The principal modifications to the present muon spectrometer would be: (1) the introduction of a 1.5 m hadron shield of tungsten or depleted uranium upstream from the spectrometer, together with triggering scintillators and MWPC's for the muon trajectories. (2) the introduction of a counter plane between the hadron shield and spectrometer in order to obtain a prompt estimate of the pair opening angle and to thereby develop a trigger based on effective mass. (3) the widening of the present vertical hodoscope plane to improve acceptance at wide angles and the addition of a second plane of vertical counters behind the steel μ-filter.

We estimate that these new elements could be produced in three months once the go-ahead were given.

The original proposal called for scaling the longitudinal dimensions of the detector with bombarding energy. Moreover, at each energy, two configurations were required for 5% mass resolution over the full range of longitudenal dimuon momentum ($X_{\mu\mu}$). Because of the very large apperture and enormous field integral available with the cyclotron spectrometer, changes in the spectrometer lever arms are no longer required. One setting of geometry and magnetic field gives 5% mass resolution over the range $0 < X_{\mu\mu} < 0.7$.

IV. Backgrounds

We have considered special backgrounds which might be associated with the muon spectrometer.

Multi-track ambiguities should be negligible downstream from the 18 absorption length hadron shield. The flux of charged secondaries out of the shield is a factor of 100 below the incident flux and the energy spectrum is very strongly degraded. Thus the incident beam of 10^7 is reduced to 10^5 low energy secondaries. The MWPC's in front of the spectrometer can easily take this rate. The field of the spectrometer magnet (22 kg-m or ΔP_T = 660 MeV/c) provides an effective clearing of low energy charged secondaries and so further reduces the charged flux into the spark chambers behind the spectrometer.

The event topology in the spectrometer is exceptionally simple with just two charged particles which both penetrate 18 absorption lengths of uranium, a clearing field of 22 kg-m, and an additional 2.5 m of steel. Thus the basic trigger on a pair of muons should be simple and clean. In addition, the two particle requirement in each of the large hodoscope planes should be very effective in reducing accidental coincidences associated with high singles rates or muons in the beam halo. There is sufficient space in front of these planes to introduce some additional low Z shielding material should this be required because of neutron background.

The 3% muon contamination of the beam and the muon halo of comparable intensity should produce no problems. Accidental muon tracks in the large spark chambers can be eliminated during reconstruction by tagging tracks with the hodoscope counters which fired.

In summary we can find no background effects which would render the muon spectrometer or its hadron beam unsuitable for our experiment.

V. Conclusions

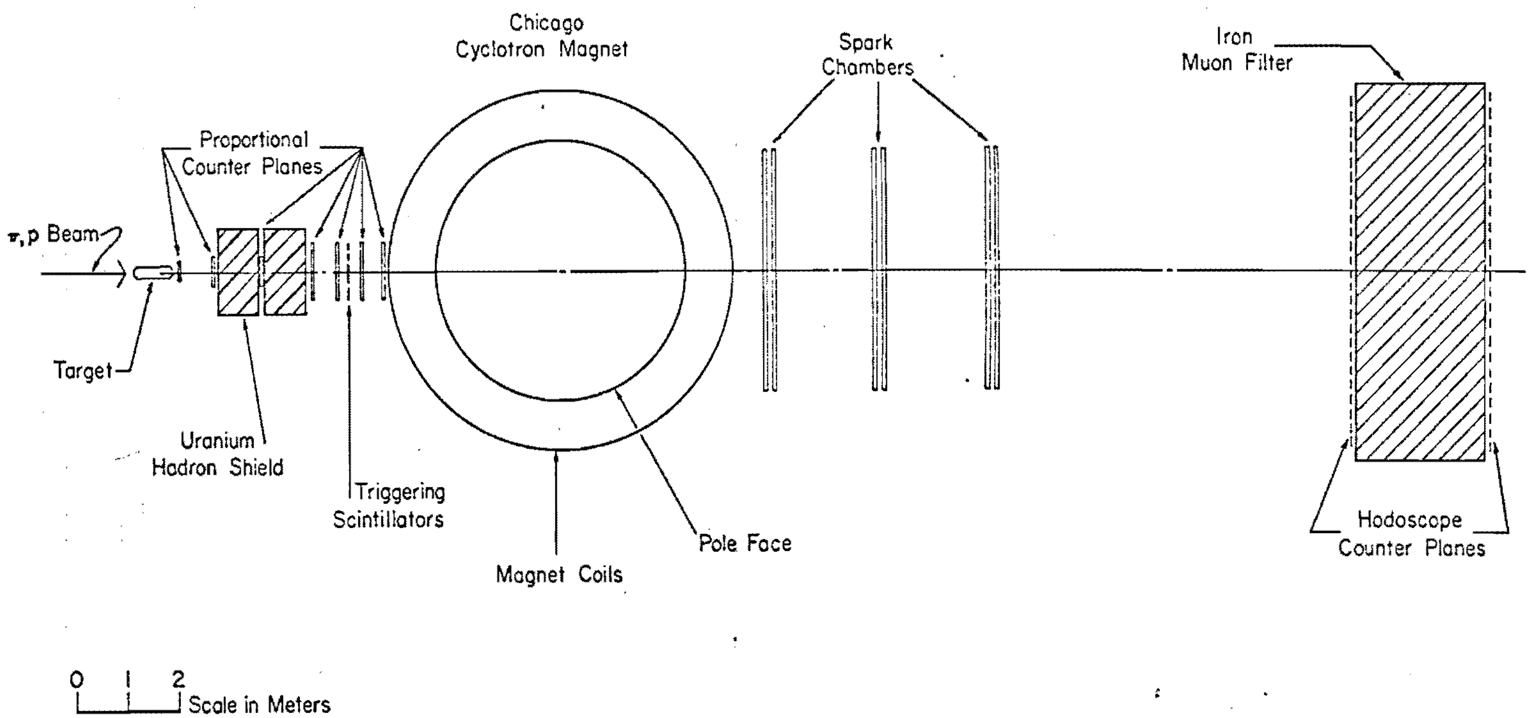
The muon spectrometer and its associated hadron beam appear to be ideal for studying dimuon production in hadron-hadron collisions. The detector's acceptance is exceptionally large and the pion beam available there is the most intense at FNAL. The spectrometer is already equipped with most of the detector elements required. We have discussed their use with the present owners and have met with full cooperation.

A problem of scheduling does exist. At present the E-98 group has a running experiment and are in the midst of a measurement with this detector. To minimize conflicts and interference we hope that their use of the detector in its present configuration can be satisfactorily completed before the commencement of E-308.

We feel that the experiment of proposal 308 is both topical and of fundamental importance. We are anxious to begin data taking as soon as possible and can be fully prepared with the additional detector elements in 3 months from the date of approval.

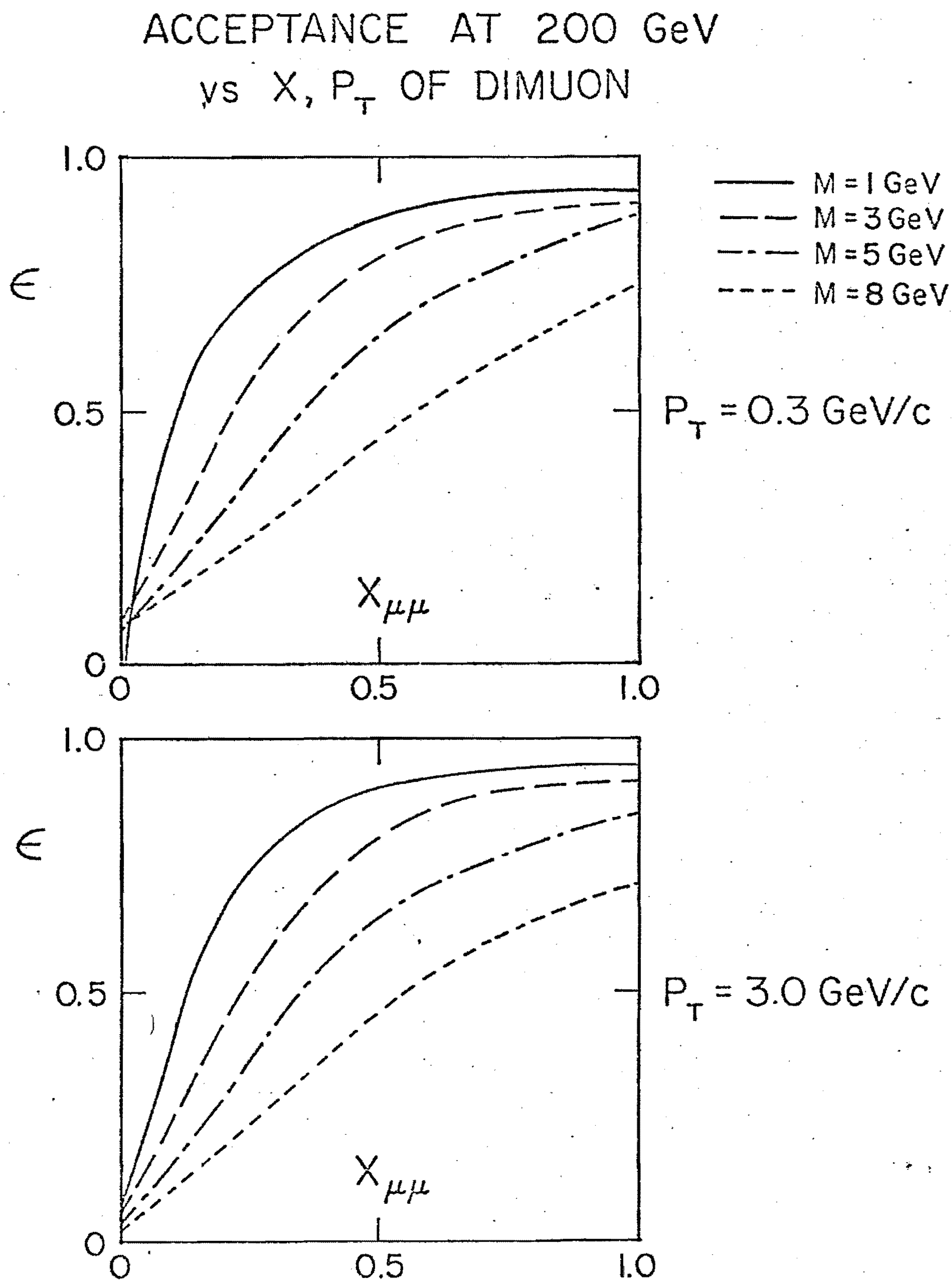
FIGURE CAPTIONS

1. Detector set-up using the Chicago cyclotron spectrometer.
2. Detection efficiency for a 200 GeV beam as a function of fractional longitudinal momentum ($X_{\mu\mu}$), transverse momentum (P_T) and effective mass of the dimuon state.



Chicago
Cyclotron Magnet
Spark
Chambers
Iron
Muon Filter
Proportional
Counter Planes
π, p Beam
Target
Uranium
Hadron Shield
Triggering
Scintillators
Magnet Coils
Pole Face
Hodoscope
Counter Planes
0
1
2
Scale in Meters

Figure 1



ACCEPTANCE AT 200 GeV
vs X, P_T OF DIMUON
M = 1 GeV
M = 3 GeV
M = 5 GeV
M = 8 GeV
ε
P_T = 0.3 GeV/c
X_μμ
P_T = 3.0 GeV/c
0
0.5
1.0

Figure 2

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A PROPOSAL FOR A DETAILED STUDY OF DIMUON PRODUCTION

K. Anderson, D. Bintinger, J. Curry, J. Pilcher, J. Sidles

Enrico Fermi Institute
University of Chicago

ABSTRACT

This addendum documents our presentation at the dilepton workshop and treats some points in more depth. It also reports on our recent studies in the M2 beam.

ADDENDUM TO PROPOSAL 331

In this addendum we elaborate on points discussed at the dilepton workshop. We also draw inferences for the final experiment from our recent studies in the M2 beam. Details of this test are contained in a technical memorandum included as Appendix I.

This addendum assumes familiarity with the proposed experiment.

A. Points Discussed at the Dilepton Workshop

(1) Ability to Determine Muon Trajectories Before The Hadron Shield

In our proposed experiment two modules of proportional chambers (MWPC's) are used to record the trajectories of charged particles between the target and the hadron shield. Trajectories of the muons seen after the shield permit extrapolation back to the expected muon positions in the upstream chambers and the closest track is taken as the muon track. The extrapolation is aided by an MWPC halfway through the shield.

We have studied the suitability of this method by generating with the computer μ-pair events with accompanying hadrons and then reconstructing the events. Muon pairs were produced with a mass of 1 GeV and the same x, p_T distribution as pions. The dimuon was allowed to decay isotropically in its CM system and the resulting muons were followed through the hadron shield and detector. Ten charged tracks were generated at the primary interaction vertex to accompany the muon trajectories in both the upstream MWPC's and the ones halfway through the shield. These charged hadrons were chosen from the same x, p_T distribution as the parent dimuon. Reconstruction procedures were then applied to the events.

The resulting mass distribution, corresponding to a 200 GeV incident beam and a drift space of 75 cm between the target and shield, is shown in Fig. 1.

The slight tail below the peak corresponds to cases where one of the charged hadrons lies closer to the expected muon position in the upstream chambers than does the muon itself. This situation is almost completely eliminated if one uses a drift space of 1.5 m instead of 75 cm. Moreover, such events could be separated from the rest of the sample in the analysis, since they have at least 2 particles in the search zone for the muon.

We believe we have effectively demonstrated the feasibility of measuring the muon trajectories before the hadron shield.

(2) Background from Double Pion Decay

This background rate is proportional to the square of the available decay path and is inversely proportional to the square of the average pion energy. Consider the Columbia μ-pair experiment at Brookhaven. It used an effective decay path of 12 cm (1 absorption length of uranium) and a bombarding energy of 30 GeV. No change in signal was observed in runs with 3 times the decay path (9 times the background rate) so no background subtraction was performed. Increasing the bombarding energy and decay path by a common factor should lead to an analogous situation. This scaling procedure suggests a decay path of 60 cm at 150 GeV or 120 cm at 300 GeV. Our design calculations are based on a drift space of 75 cm. The large factor still in hand, according to the Columbia-BNL results, should permit operation with an extended hydrogen target and measurements at lower $x_{\mu\mu}$ values than the BNL experiment. The decay background will be continuously monitored both by like-sign-muons, and by the variation in rate over the length of the target. With a 75 cm-long target and a 75 cm drift space between target and shield, the decay background varies by almost a factor of 4 over the length of the target.

(3) Problems Associated With The Muon Halo

The muon contamination of the N1 beam running with the hadron filter removed is expected to be 3% at 150 GeV. The muon halo is of comparable intensity. Thus a beam of 10^7 hadrons is accompanied by a muon halo of 3×10^5. To reduce triggering difficulties associated with the halo, the E-98 muon scattering experiment uses a large plane of veto counters around the beam. Clearly, halo problems are more severe when triggering on a single muon than on a pair.

We, too, would plan to incorporate a halo veto. Muons within the beam spot itself are potentially dangerous only if accompanied by another muon or hadron in the same RF bucket. Care is taken to veto such occurrences as described in the original proposal. The dead time produced by the halo veto for a beam of 10^7 hadrons over a 1 sec. spill is only 0.6% if the anti vetos only a single RF bucket.

(4) Cross Section Sensitivity

The sensitivity quoted in the original proposal is approximately 1 ev/hr at the level 10^{-34} cm^2. Thus, a 100 hr run could reach cross sections of 10^{-36} cm^2. This sensitivity assumes an interaction rate of 10^6/pulse or a beam flux of 10^7/pulse. The beam flux is limited by the detector at 10^7 if one is to observe the muon trajectories between the target and the shield. This requirement is essential for good resolution at low masses. Once the low mass region had been thoroughly studied, however, one could remove all detectors upstream of the shield. With an iron hadron shield the mass resolution at 5 GeV would be $\sim$ 5%. The cross section sensitivity now could be increased by at least an order of magnitude by increasing the beam flux. A fraction of the recorded events would originate in the hydrogen or deuterium target, and these could be identified by extrapolating back along the trajectories observed in the spectrometer. For μ-pair masses of a few GeV there is ample spatial resolution to discriminate muon pairs originating in the target from those originating in the shield. To run in this mode, a reliable suppression of low mass pairs would be essential. Such a mode of operation could exploit the full pion flux available from the N1 beam.

B. Conclusions From The M2 Tests

Details of the studies performed with 150 GeV/c negative pions are reported in Appendix I. Muons were identified by penetration of 48 nuclear absorption lengths of material, and pairs were selected with a 3-fold coincidence on each arm. The muon-pair production rates and opening angle distributions were measured, as were the charged particle fluxes associated with the hadron absorber.

The most important conclusion is that there is a substantial, but manageable, μ-pair trigger rate. The measured rate corresponds to $\sim$ 30 events/10^6 interacting pions. Because of these results we are proceeding with the development of simple trigger logic which can cleanly discriminate against low mass triggers. Such a logic scheme was discussed in the original proposal. We will also try to ensure that the final detector is capable of operating with a substantial trigger rate.

The observed μ-pair opening angle distribution is flatter than expected if all μ-pairs arise from ρ decay.

Charged particle fluxes associated with the hadron absorber were directly measured with a proportional chamber. The data indicate that the fluxes are approximately a factor of 3 higher than estimated in the original proposal, but are entirely acceptable. For an incident beam of 150 GeV the MWPC halfway through the shield will see an average of 3 charged tracks or stars, accompanying the muon pair. Our studies of event reconstruction problems have assumed 10 extra charged tracks. Typical single wire counting rates in the MWPC following the shield are 5 kHz. For the MWPC halfway through the shield, the highest rate is ∿ 350 kHz.

Experience gained in this test emphasizes the importance of ensuring two distinct muons following the final muon identifier as opposed to a single muon with a δ-ray. During the test we took steps to avoid this problem and, at present, are directly measuring the δ-ray frequency and angular distribution by using spark chamber film from the E-1A muon spectrometer.

To suppress this effect in the final experiment, we will position the rear hodoscope counters as close as possible to the steel and will trigger on non-adjacent pairs of counters.

C. Use of The N1 Beam and Cyclotron Spectrometer for Hadron Studies

The N1 beam is a large acceptance 0^{o} beam and represents the most intense pion source presently available at Fermilab. Moreover, the beam is delivered to the largest acceptance magnetic spectrometer at the Lab. This combination offers a unique opportunity for small cross section, minimum bias studies. Since the spectrometer cannot be used for muon physics during neutrino running, this time is available for set-up, tuning and preliminary data taking. The obvious problem is one of interference with the muon program.

Since the spectrometer has been developed by the E-98 muon scattering group, they must have clear priority to complete their approved program without interference. A natural time to use this spectrometer for our studies would be between muon experiments when time is required for analysis or preparation of the next experiment.

Discussions with members of the E-98 group have been extremely positive. The Fermi Institute members of the E-98 collaboration offer their full support in lending us their equipment and helping us to understand, operate and service it. Since we share common support facilities, the engineers and technicians who have built and serviced the apparatus in the past will be directly available to assist us. We strongly believe that a vigorous, experienced group, with the full cooperation of the physicists who built the detector, can master its operation.

In conclusion, we emphasize again that this beam and spectrometer are ideally suited to the proposed experiment. The very large acceptance will allow a study of μ-pair production with a minimum of detector bias. The large magnet is vital since the hydrogen target must be located far enough upstream to allow a drift space and a hadron shield before the front chambers of the spectrometer. This spectrometer is also expressly equipped for muon studies with a halo anticoincidence shield upstream and a 400 ton steel muon identifier downstream. Since we will use a hadron filter between the target and spectrometer the high beam intensity for both nucleons and mesons can be exploited without encountering problems in the spectrometer from counting rates or pattern recognition.

We feel this is a significant, topical experiment. Counting rates and backgrounds have been directly studied in beam tests and found to be reasonable. The bulk of the detecting apparatus already exists. We urge for prompt approval.

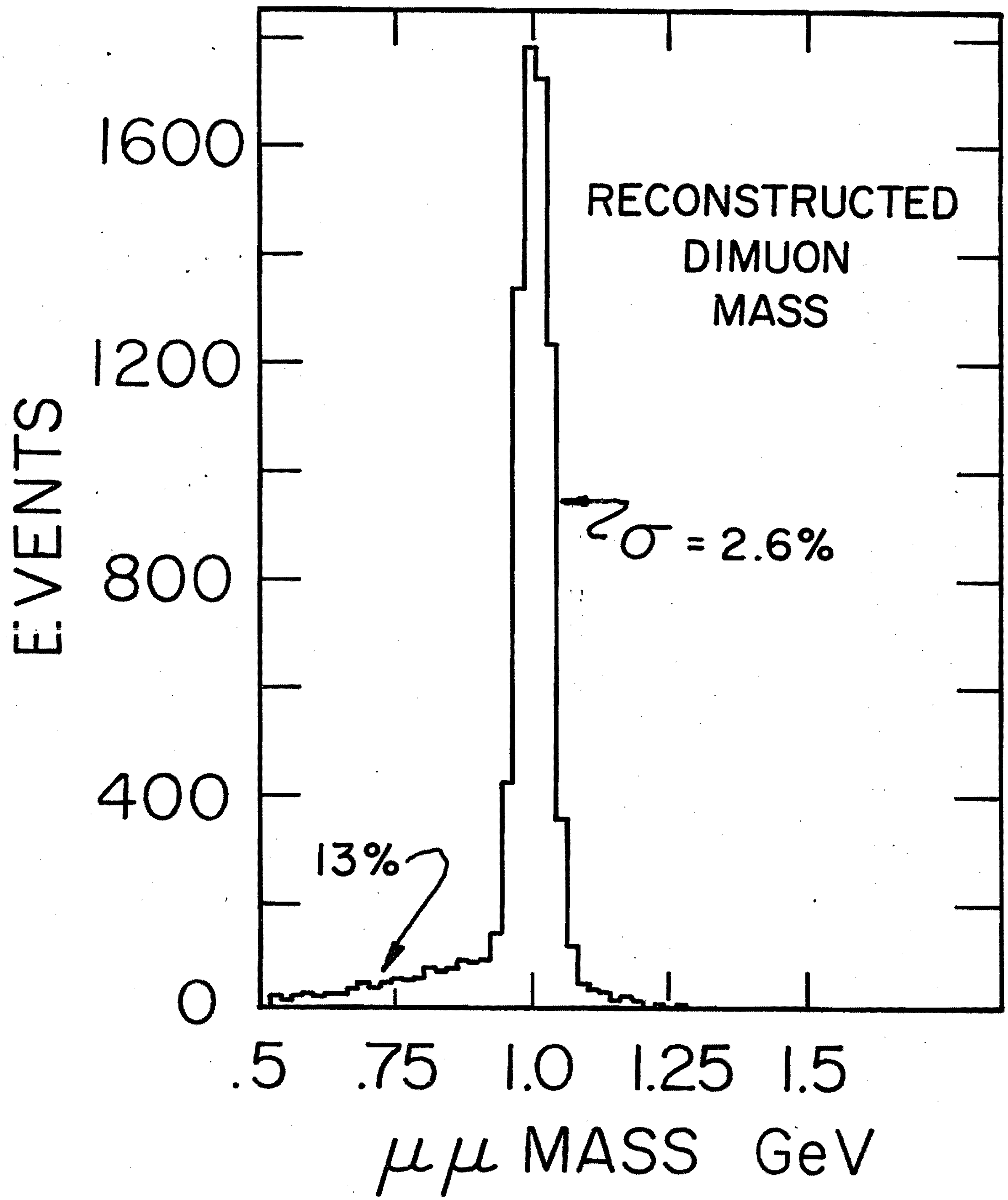

RECONSTRUCTED
DIMUON
MASS
σ = 2.6%
13%
EVENTS
0
400
800
1200
1600
.5
.75
1.0
1.25
1.5
μμ MASS GeV

FIGURE 1

APPENDIX I

Subject: Report on Tests in the M2 Beam Line for NAL Proposal 331

From: K. Anderson, J. Curry, J. Pilcher, J. Sidles

We have performed beam studies to estimate the trigger rate in the final experiment, to determine the opening angle distribution of the triggering muon pairs, to search for background processes, and finally, to determine the charged particle fluxes associated with a 15-absorption length hadron shield used as a beam stop.

The studies were performed in the M2 beam line tuned for 150 GeV/c negative particles. The test set-up is shown in Fig. 1. The beam was defined by a 3 counter telescope and a halo anti-coincidence counter to veto interactions upstream. In our apparatus the pions were incident on a steel beam stop of 24 slabs, each 2-ft. square and 4-in. thick. For charged particle flux measurements, individual slabs were removed and a multi-wire proportional chamber inserted. Immediately downstream from the shield two 10-in.-square counters were positioned on opposite sides of the beam (counter plane A). This plane was followed by 3 feet of concrete shielding and a second pair of counters, either 10-in.-square (B-counters) or 10-in.-high by 1.75-in.-wide (C-counters), depending on the test. Finally, particles were required to traverse an additional 18 feet of steel in the form of the large sweeping magnet for the neutral hyperon experiment. This magnet had a steel yoke of cross section 6-ft.-high by 9.7-ft.-wide and the 3.5-in.-high gap was solidly packed with zinc. The 1-cm-diameter beam hole was closed with a brass rod. Following the hyperon magnet, a plane of four counters (E-plane), each 48-in.-high by 18-in.-wide, signalled two charged particles downstream of the magnet.

To traverse the entire system, single muons needed an energy of 12 GeV. They traversed 48 nuclear absorption lengths of material.

The beam telescope and anti-counter defined a beam spot 2 cm in diameter. During normal operation the incident flux was approximately 80K/pulse. Without the halo veto the rate was a factor of 2.0 times higher, consistent with the interaction probability in the 0.65 absorption lengths of material in the E-111 detector upstream. Two particles within the beam spot were vetoed by imposing an upper limit on the pulse height in one of the beam telescope counters.

(1) Muon-pair Rate vs. Opening Angle

For these studies the C-plane counters were used to define the opening angle upstream of the magnet. They were placed symmetrically on either side of the beam and coincidence rates were studied for four different distances to the beam. The hyperon magnet was not energized for these studies.

Only two counters were used in the E-plane behind the magnet. For each opening angle the E-counters were positioned to cover the shadow of the C-counter and to extend an extra four inches towards the beam.

This choice was made to allow maximum separation between the counters behind the magnet. For the largest opening angle this separation was greater than 20 inches. The geometrical solid angle subtended by each C-counter was 0.33 mster.

The coincidence logic was $(T \cdot A_L \cdot C_L \cdot E_L) \cdot (T \cdot A_R \cdot C_R \cdot E_R)$ where T denotes a signal from the beam telescope. Single arm rates were also recorded and were typically a factor of 100 larger than the pair rates.

The measured rate versus opening angle is shown in Fig. 2. We have estimated the background from processes in the hadron filter, such as muon pair production by photons and double pion decays. The acceptance of the apparatus, folded with the production probability for these backgrounds is shown in Fig. 2. We have estimated the contribution from several forms of accidentals and find them to be negligible.

Background processes associated with the E-counters were studied with the four counters shown in Fig. 1 positioned edge to edge, and with the requirement of a pair of particles upstream of the magnet in the widest opening angle configuration. The probability that any three E-counters were struck,compared with any two, was 6.2%. The single μ rate behind the magnet was a factor of 11 higher than the pair rate. Thus, contamination of the data by a single muon plus locally produced debris is certainly less than 33% for the opening angle with the smallest signal. It is expected to be substantially less since specific, separated E-counters were used for the pair data of Fig. 2.

We have compared the observed opening angle distribution with the prediction of several models. We use a Lorentz invariant dimuon production cross section characteristic of hadrons, namely $Ed^3\sigma/d^3p = A\, e^{-6p_T}(1 - x)^4$. In addition, we assume a dimuon decay angular distribution which is isotropic in its CM system. Results for a mass spectrum which is Gaussian at the ρ-meson mass and for a spectrum falling like $1/m^2$ are shown in Fig. 2.

For the experimental results discussed above, the muons were required to be symmetric in the horizontal plane to ± 7.5 mr. and were coplanar with respect to the beam to within ± 43 mr. If the observed rates under these constraints are integrated over opening angle and azimuthal angle, they correspond to 1.3 triggers/10^6 interacting π's or 930 events/hour for the proposed experiment.

(3) Fluxes Associated with the Hadron Shield

For these studies a small proportional chamber 2.5-in.-square was used to systematically measure the charged particle flux as a function of depth in the absorber and distance from the beam axis. Logic signals from each wire of the chamber were added to obtain a signal with amplitude proportional to the detected charged particle multiplicity. To avoid spurious multiplicities, adjacent wires struck were treated by the electronics as just a single wire. The final signal was gated by the coincidence requirement of an incident beam particle and was recorded on a pulse height analyser. Thus, for each chamber position the probability of various charged multiplicities was measured. To avoid counting muons, the four E-counters were used in anti-coincidence. At the end of the hadron filter, muons accounted for 90% of the charged particle flux when the MWPC was centered on the beam axis. In general, the probability of several charged particles was much higher than the product of single particle probabilities, as would be expected for multi-prong nuclear stars.

The combined flux of single tracks and stars is shown in Fig. 3 as a function of depth in the absorber integrated over the area of the slabs to a radius of 30 cm. Figure 4 shows the radial flux density for five different depths. The curves are slightly flatter at large depths, but as expected, even a depth of 640 gm/cm^2 of absorber produces a broad distribution compared to the profile of the incident beam. These flux measurements agree to within a factor of 3 with Monte Carlo predictions by Ranft.

They suggest that, on an average, in the center of the shield, three extra single tracks or stars would be observed together with the muon-pair. Actually, in the final experiment, this rate might be substantially less, since the interactions to be studied will be constrained to originate in the target and deep penetration of the beam particle in the shield will be eliminated. To the above figure for in-time charged particle background must be added the accidental background arising from the beam stopping in the shield. With an MWPC resolving time of 50 ns and 10^7 incident particles during a 1 sec. spill, the accidental background is $\sim$ 1 wire/event. These background rates are entirely compatible with the proposed experimental configuration. There is adequate margin for operation with a 300 GeV beam and/or a somewhat poorer duty cycle.

Summary

(a) We have measured an upper limit on the trigger rate for μ-pairs symmetric with respect to the beam to within ± 7.5 mrs. It is 1.3 events/pulse of 10^6 interacting pions.

(b) The observed opening angle distribution for these muon pairs falls off much more slowly with opening angle than the expected background mechanisims and the process $\rho \rightarrow \mu^+\mu^-$.

(c) A looser triggering requirement on the muon pair which covers the whole forward hemisphere, out to 50 mr in the lab, gives μ-pair trigger rate of 33 events/pulse of 10^6 interacting pions.

(d) The measured charged particle fluxes within and downstream of the hadron shield are fully compatible with operating in a beam of 10^7 particles during a pulse of 1 sec.

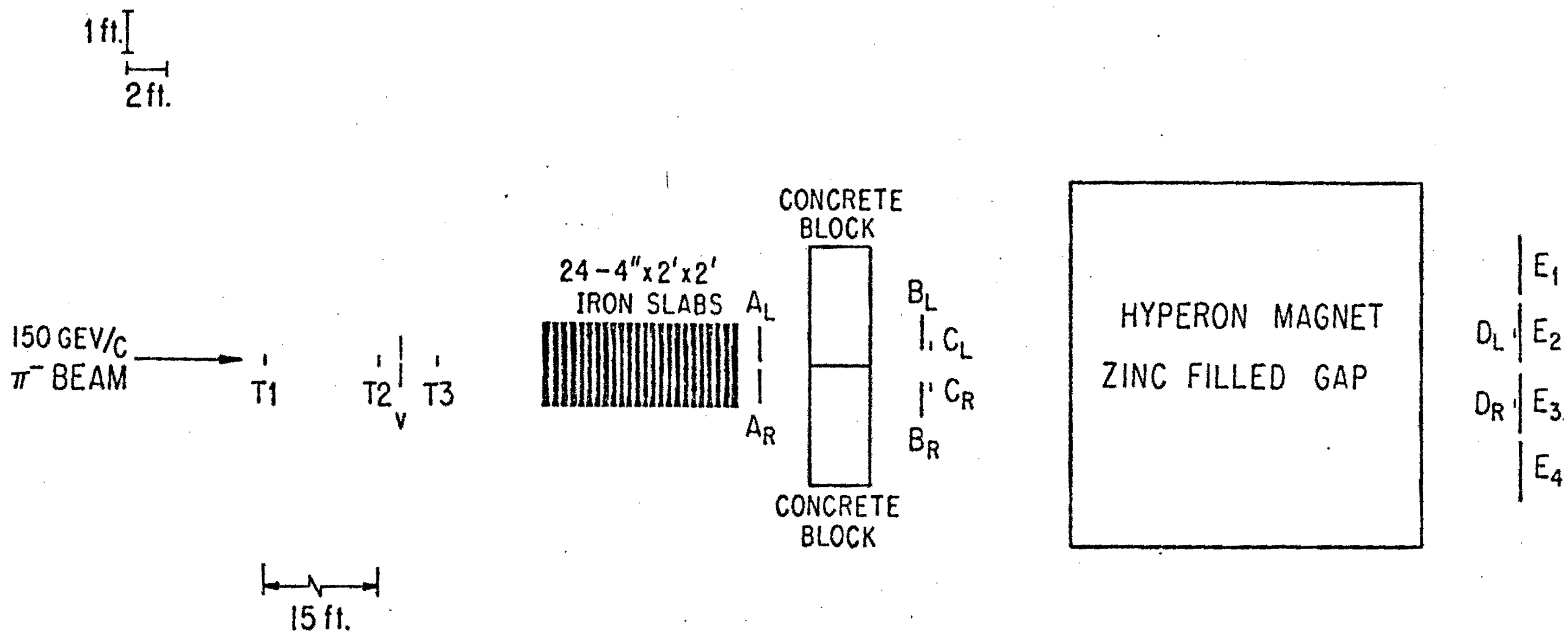
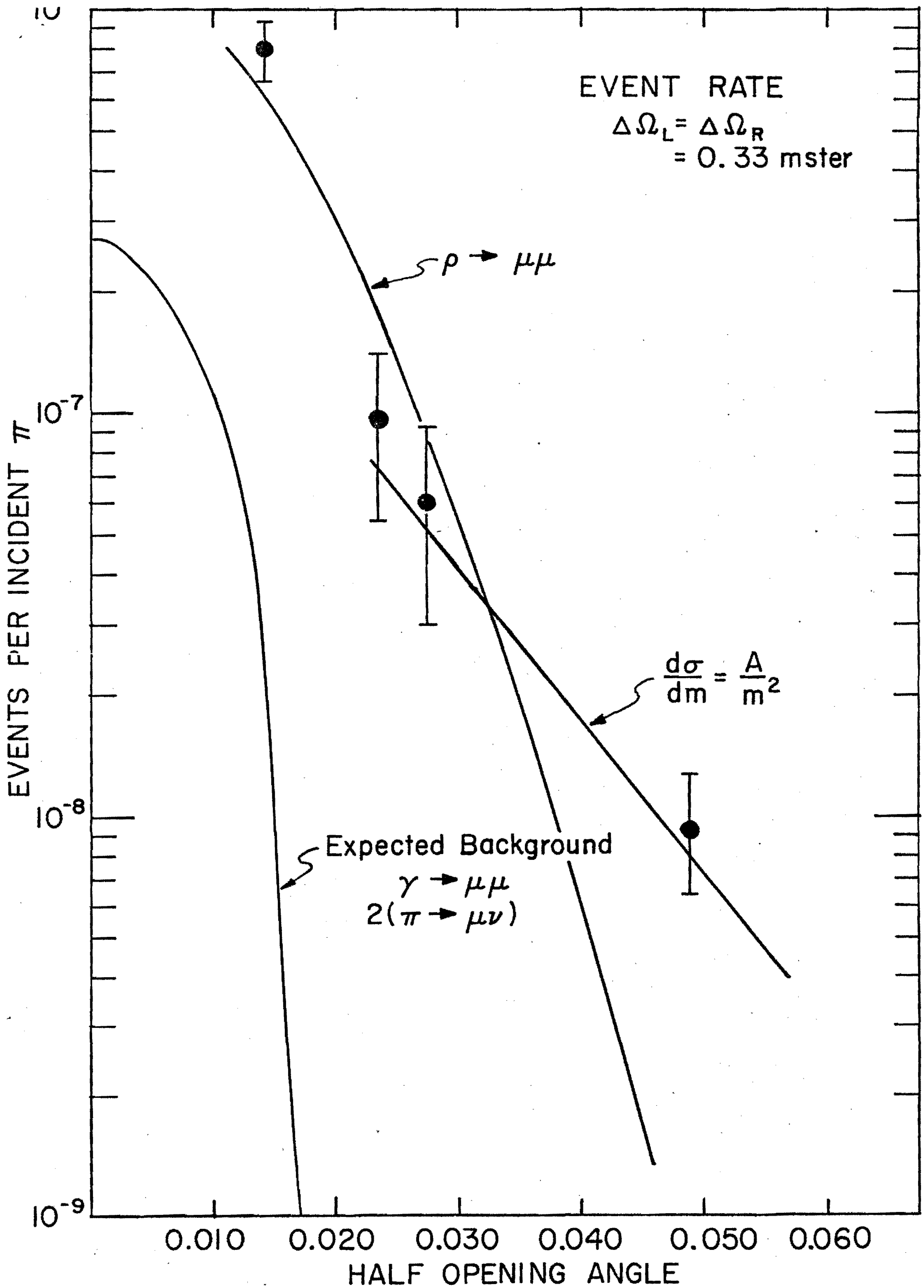

1 ft.
2 ft.
150 GEV/C
π⁻ BEAM
T1
T2
V
T3
15 ft.
24 - 4"x2'x2'
IRON SLABS
A_L
A_R
CONCRETE BLOCK
CONCRETE BLOCK
B_L
C_L
C_R
B_R
HYPERON MAGNET
ZINC FILLED GAP
D_L
D_R
E_1
E_2
E_3
E_4

Fig. 1



EVENT RATE
$\Delta\Omega_L = \Delta\Omega_R$
= 0.33 mster
$\rho \rightarrow \mu\mu$
$\frac{d\sigma}{dm} = \frac{A}{m^2}$
Expected Background
$\gamma \rightarrow \mu\mu$
$2(\pi \rightarrow \mu\nu)$
EVENTS PER INCIDENT π
10^{-7}
10^{-8}
10^{-9}
0.010
0.020
0.030
0.040
0.050
0.060
HALF OPENING ANGLE

Fig. 2

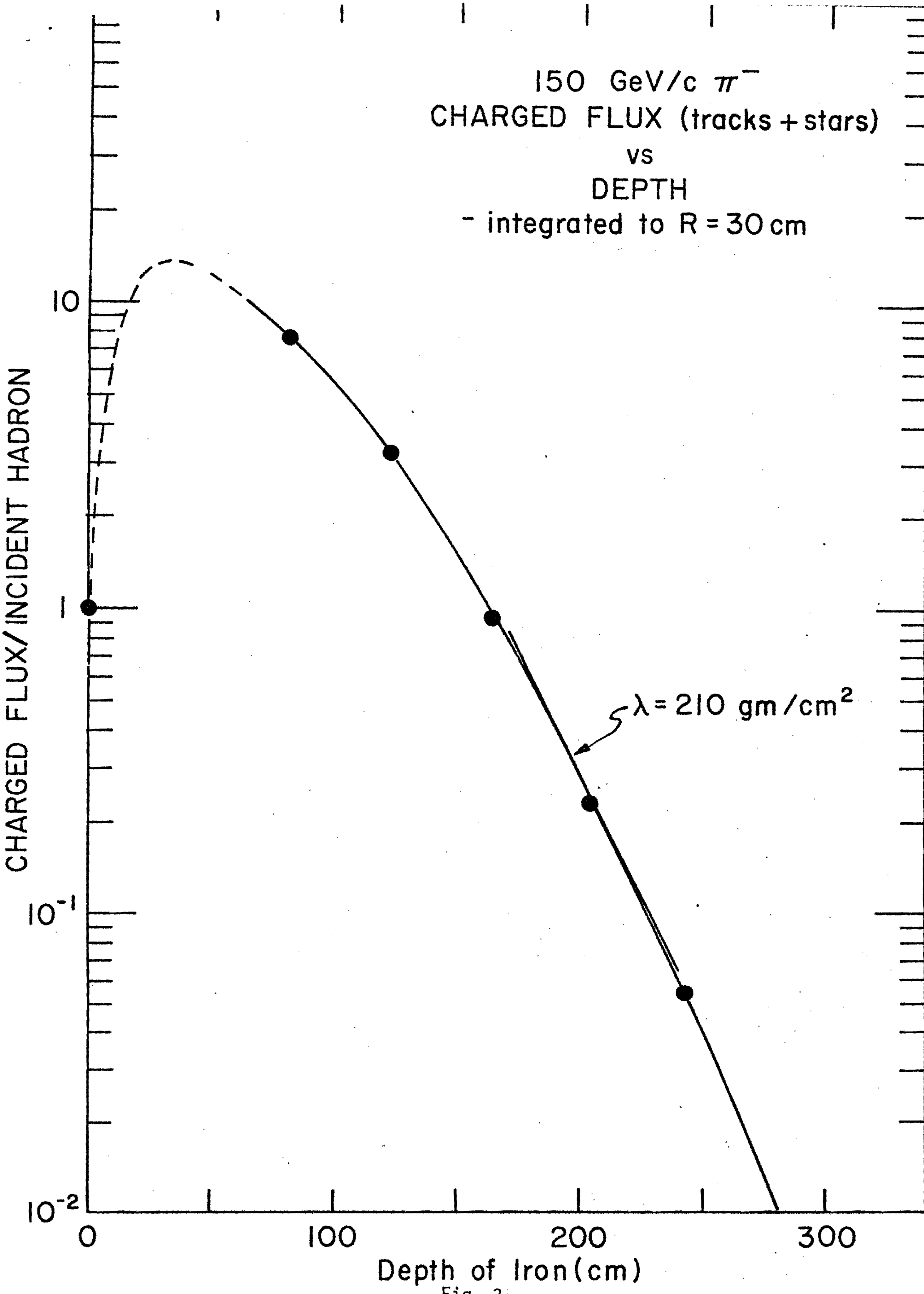

150 GeV/c π^-
CHARGED FLUX (tracks + stars)
vs
DEPTH
- integrated to R = 30 cm
$\lambda = 210$ gm/cm^2
CHARGED FLUX/INCIDENT HADRON
10
1
10^{-1}
10^{-2}
0
100
200
300
Depth of Iron (cm)

Fig. 3

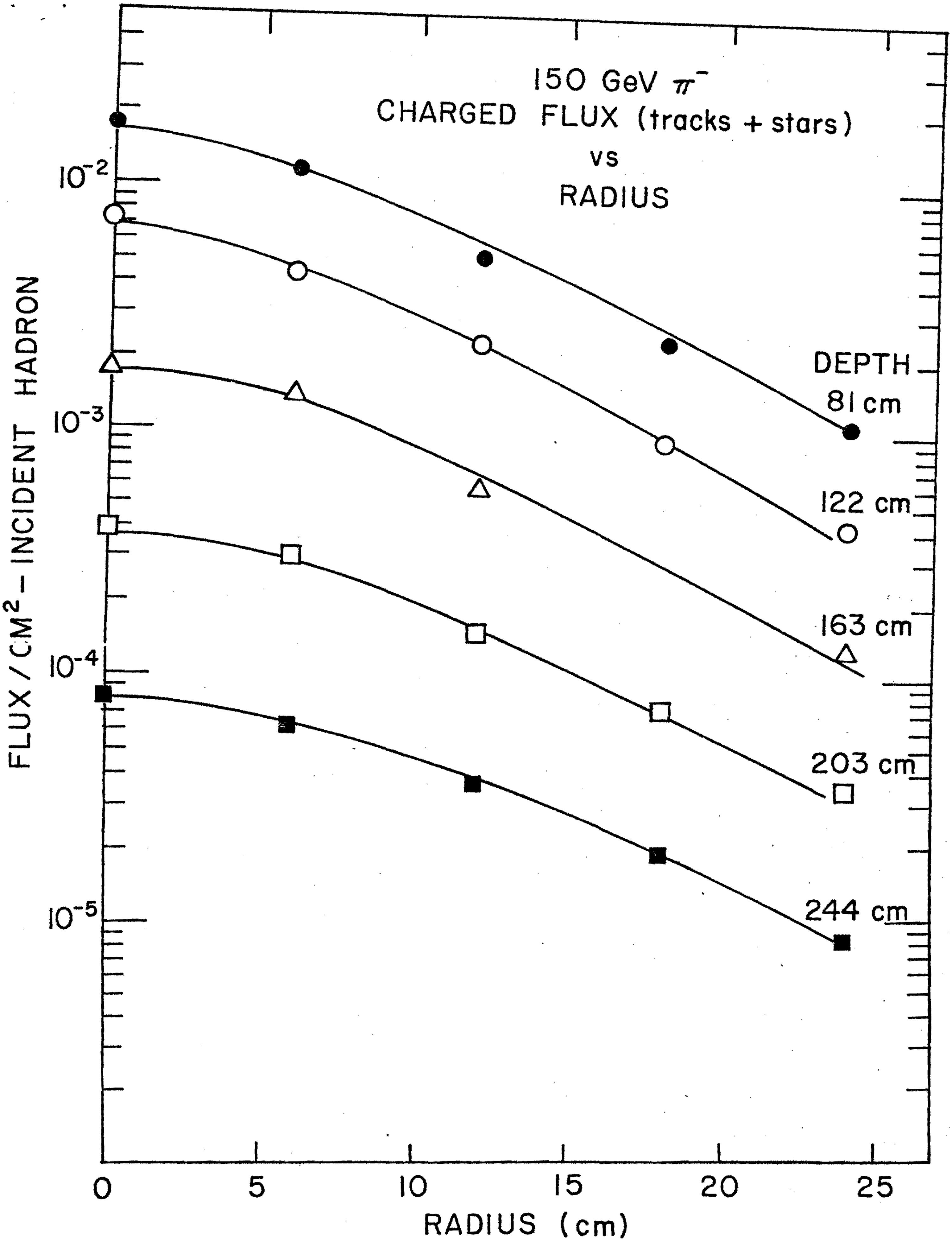

150 GeV π^-
CHARGED FLUX (tracks + stars)
vs
RADIUS
DEPTH
81 cm
122 cm
163 cm
203 cm
244 cm
10^{-2}
10^{-3}
10^{-4}
10^{-5}
FLUX / CM² – INCIDENT HADRON
0
5
10
15
20
25
RADIUS (cm)

Fig. 4