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Search for Direct Production of Mu-pairs at C0

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Summary

We propose to extend our measurements of the s and t dependence of direct muon production in E-184 by making a modest addition to our present spectrometer which will allow us to search for muon pairs. The second muon would be identified in a detector placed above the E-184 apparatus. With the modified apparatus we would be sensitive to mu pairs produced at the level predicted by models for parton-antiparton annihilation. Given prompt approval, the second arm could be constructed and installed at C0 during the late September shutdown. Testing would take place during the fall, and data-taking would commence in the winter. The time required for testing and data-taking will be comparable to that used in E-184 (800 hours).

Physics Justification

Measurement of muons produced directly in high-energy nucleon-nucleon collisions, or produced in the decay of short-lived secondaries, can contribute to our understanding of particle interaction in important ways. A signature for the production of exotic particles, such as the Intermediate Vector Boson or the Lee-Wick heavy boson, would likely be single decay muons at large transverse momentum. In the parton model of the nucleon, parton-antiparton annihilation is expected to produce heavy virtual photons, which then decay into mu pairs of large invariant mass. The cross-section for this process has been calculated from measurements made in neutrino and

electron interactions, plus some assumptions about antiparton momentum distributions.[1] Measurement of these mu pairs can then serve as a check of the validity of the parton model or, less optimistically, can provide important constraints on it.

The fluxes of direct leptons measured in the first round of experiments at Fermilab (E-70, E-100, and E-184) have been found to be $\sim 0.8 \times 10^{-4}$ of the pion flux, at high energies and for transverse momenta in the range of 1.0 to 5.5 GeV/c.[2] These fluxes are greatly in excess of the parton-model predictions and are compatible with the numbers of muons that would arise from the decays of the vector mesons, if vector mesons are produced about the level of pions. The suggestion that the origin of these muons (or electrons) is hadronic is reinforced by the fact that the ratio of leptons is constant over a large range of bombarding energy and muon momentum. If the muons do come from the prompt decays of vector mesons into mu pairs, the implied level of vector meson production is much larger than expected. If both muons are detected, the mass of the parent particle can be calculated. Such an experiment could determine if the source of the present muon signal is vector meson decay. It would also permit a test of the parton model predictions, since the known vector mesons would not contribute to any signal observed in the region of large invariant mass for which the parton model predictions are valid. On the basis of the first-round results, we have

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[1] Parton model calculations of single muon spectra have been made by H. Paar and E. A. Pachos, Fermilab preprint NAL-Pub-74/29 - THY (1974) and by G. R. Farrar, Cal Tech preprint CALT-68-422 (1974).

[2] J. P. Boymond et'al, University of Chicago Enrico Fermi Institute preprint EFI-74-24; talks given by Fermilab experiment 70 at April 1974 APS Meeting.

concluded that a search for the second muon is essential for an understanding of the present measurements and for a meaningful test of the parton model.

The unique facility at C0 enables the mu-pair invariant mass distribution to be measured (or searched for) as a function of s, from ∿ BNL energies up to the maximum available at Fermilab. To deliver this range of energies to experiments in the Proton Lab would likely involve the use of the "front porch" and would certainly be complicated by the requirements of the other experiments in the Proton Lab. The interaction rate available for experiments at C0, which is constrained by radiation and shielding limitations, is lower than the interaction rates available in the Proton Lab. Consequently, experiments done in the Proton Lab and at C0 tend to be complementary rather than competing in character. As an illustration of this, it is useful to compare parameters of the three first round experiments:

Experiment	solid angle	range of $p_\perp$ (GeV/c)	range of E_p (GeV)
E-70	81 μsr	0.75 to 4.0	300
E-100	17 μsr	1.6 to 5.5	300 (plus some data at 400)
E-184	21 μsr	0.85 to 2.5	30-300

In addition, the most important corrections to the data are different for the three experiments: E-70 (electrons) contains large subtractions for π^0 Dalitz decay. E-70 (muons) subtracts substantial charged pion backgrounds. E-100 has large (greater than a factor of 2) multiple scattering corrections at low transverse momentum. E-184 multiple scattering corrections are as large

as 30%. Presumable the second round of direct-lepton experiments would complement one another in a similar way.

Measurements of the direct production of lepton pairs may yield substantial information about nucleon interactions and should be pursued vigorously. With the apparatus discussed below, we will be able to detect mu pairs of invariant mass greater than 1 GeV/c^2, which originate from symmetric decays of forward going vector mesons. This allows us to investigate the large invariant mass region where the parton model is thought to apply and to look for anomalously large production of the ϕ and heavier mesons.

Apparatus Needed

Since the present E-184 spectrometer arm forms the starting point of our proposed experimental setup, it is useful to begin with a brief description of it, along with a discussion of the (minor) changes we would make in it. Also, our experience with the present setup has given us a good idea of the most important considerations in the design of a second arm.

The present apparatus, shown in Fig. 1, has proved to be an excellent device for detecting single muons. Muons produced by the interaction of protons in the main ring of the accelerator with the rotating fiber target proceed through variable hadron absorbers A1, A2, and A3, through iron magnets B1 and B2, and into the spectrometer. Hadrons are absorbed in $\sim$30 interaction lengths of material placed between the target and the spectrometer. Momentum analysis of the muons is performed by air-gap magnet B3, which bends particles in the vertical plane. Pions are identified by their pulse height in the lead-glass Cherenkov counters. The fast logic trigger is a six-fold coincidence between scintillators S3-S8. A PDP-11/45--Camac system records time of flight and pulse height information for each scintillator S1-S8, the pulse heights of the four Cherenkov counters, and information from the multiwire proportional chambers (PC1-4). Each MWPC consists of two planes of wires with 1 mm spacing, at 45° to the horizontal. Trajectories reconstructed with the eight MWPC planes are essentially free of accidental backgrounds. Particles detected in the spectrometer have hadronic contamination of a few percent. Target out rates are about 2%.

E-184 apparatus has been extremely reliable. The MWPC have required no attention at all. The photomultiplier tubes are subject to radiation damage on a time scale of about a year. Such reliability is essential for working at CO.

In E-184, we are using less than 1% of the available interaction rate. This interaction rate is limited by the singles counting rate in the MWPC. However, the shielding of scintillators and the MWPC is not extremely tight, due to the presence of the gas Cherenkov counters on both sides of the analyzing magnet. During E-184 we gradually hardened the shield by substituting uranium for lead in the wedge-shaped volume between the beam pipe and the apparatus in the vicinity of the first two MWPC, by placing lead and iron alongside the apparatus, and so forth. As a result of this work, the maximum interaction rate was increased by about a factor of four. We believe it should be possible to do even better by removing the gas Cherenkov counters and filling the space with lead or concrete shielding, leaving just a hole for the muons.

The MWPC used in E-184 are 100mm by 100mm in area, but only the central region 32mm by 32mm (80mm by 80mm in PC4) is used now. This area is roughly matched to the 1" gap in the spectrometer magnet B3. By activating the remaining wires of the chambers, and by increasing the gap in B3 to 2", we gain a substantial factor in the solid angle acceptance of the spectrometer arm. Trigger scintillators will be correspondingly enlarged. In addition, we will probably tilt the spectrometer so that it points directly at the target.

These modifications can be carried out in piecemeal fashion (one day a week plus accelerator downtime) without interfering with the accelerator. They can be completed this summer.

Parton-antiparton annihilation models for mu-pair production suggest that the virtual photon is produced with little transverse momentum (cf. Fig. 2). Since the first muon would be detected near 90° in the proton-proton center of mass frame in the present E-184 spectrometer, the second muon is most likely to appear at the same angle on the opposite side of the beam. Consequently, a second spectrometer arm must be mounted over the present arm. Our design of a second arm incorporates important lessons learned in E-184: (1) Detectors should have as little mass as possible. The singles counting rate in the plastic scintillators has been substantially higher than the rate in the MWPC placed next to them. (2) Good spatial resolution is helpful in eliminating accidental tracks. (3) Detectors must be well shielded and operate reliably. For the detection of muon pairs at the low levels predicted by parton models, it is also important that the detector have as large a solid angle as is practical. We describe a second spectrometer arm which meets these requirements. A final design for the arm will be chosen after Monte Carlo studies with programs used for the analysis of the E-184 data. The final design should not differ significantly from that discussed here.

The second arm of the spectrometer (Fig. 3) will be made up of iron blocks mounted on a sturdy platform over the main ring of the accelerator. The first three blocks serve to identify the muons by penetration and to absorb hadrons produced in the target. Following the initial absorber are two solid iron magnets. Muons

are detected by segmented plastic scintillators and MWPC inserted in front of the first magnet, between the magnets, and following the second magnet. The first chamber determines the muon production angle to within 10 mr for 10 GeV muon energy. The muon energy is determined from the energy loss in the iron plus the amount of bend in the iron magnet. Multiple scattering in the magnet introduces an uncertainty of ±16% in the measurement of the muon momentum. The area of the detectors is typically 40cm x 40cm with 2mm wire spacing, matched to the aperture of the iron magnet. The iron also shields the detectors from stray secondaries. Lead placed between the beam and the iron provides additional shielding. The solid angle of the detector is 2.5msr. For the spectrometer as a whole, the resolution in mu-pair invariant mass is 13%.

Structures to support the iron will be designed after consulation with the appropriate people in the Fermilab Accelerator Division. Magnetic shielding for the accelerator beam pipe will consist of the soft-iron plates and the mu-metal that was satisfactory for the E-184 magnets.

The two-arm spectrometer can be modified to detect the two-muon decay mode of the ϕ meson by removing a modest amount of range material in both arms. Alternatively, the upper arm can be used alone to detect pairs of muons. Triggering on two particles, the acceptance for symmetric decays is good for transverse momenta above 1.5 GeV/c.

If some fraction of the direct muons observed thus far in E-184 are due to ϕ decays, the proposed second arm in coincidence with the present spectrometer arm will likely yield several x 10^{13}

events in a short period of time. In our present sample of data, we have about 10^4 directly-produced muons, at the level of 10^{-4} of the pion flux. Parton-model predictions are for single-muon production at approximately 1/200 of this level. A rougn integration of the expected angular distribution for the second muon over the acceptance of our proposed second arm indicates that we might detect about 33% of them. Thus, for a several x 10^3 event experiment at levels predicted by parton models, we need to gain a factor of 200 to 600 over the sensitivity of E-184. Our E-184 Monte Carol programs indicate that the addition of the remaining MWPC electronics to the present arm, plus widening of the magnet gap to 2", should give a factor of 20 increase in acceptance. Thus, we need to gain a factor of 10 to 30 in the maximum interaction rate, by improving the shielding of the present detectors. Based on our experience with E-184 we think that it is possible but by no means certain that we can gain a factor as large as this. Accordingly, we ask for approval in two steps: (1) Permission to conduct shielding tests during the remainder of June and July. We guess that ten shifts of testing will be sufficient. These will be taken one or two at a time and possibly in a parasitic mode with E-186. (2) Permission to continue the experiment itself, if our efforts to improve the shielding are successful.

A detailed list of our equipment requirements for this experiment is contained in an appendix. We ask for a level of support from Fermilab comparable to that provided E-184.

Personnel

Some of the proponents of this experiment have also submitted proposal 308 to study dimuon production in one of the external areas. Their primary commitment is to that experiment. If E-308 is approved for running in the near future, additional collaborators will be sought for this C0 experiment.

Appendix: Equipment Needed

I. Existing Equipment (needed for this experiment also)

1. Supplied by experimenters

   Computer, CAMAC crate, tape drive, CAMAC-computer interface
   MWPC system including readout
   Fast electronics
   Air gap magnet, fabrication of iron magnets
   Scintillators
   High voltage supplies
   Power supply for iron magnets
   Movable hadron absorbers
   Gas, lead glass Cherenkov counters
   Magnetic shielding for beam pipe

2. Supplied by Fermilab

   CAMAC modules
   Fast electronics (discriminators, logic circuits)
   Lead and iron shielding
   Cables for MWPC signals
   Power supply for air-gap magnet
   Rotating target mechanism
   Rotating targets
   Iron for iron magnets

II. Additional Equipment

1. Supplied by experimenters

Additional electronics for existing MWPC system (possibly some can be borrowed from CERN)	$ 8K
MWPC for new spectrometer arm	7K
Fabrication of iron magnet	8K
Scintillators	3K
Support for iron	2K

2. Supplied by Fermilab

Additional CAMAC modules from PREP (2 TOF, 2 PHA, 1 pattern unit)	
Additional fast electronics from PREP (discriminators, logic for 9 scintillators)	
Cables for MWPC signals	$ 7K
Iron for absorbers, iron magnets (from stockpile by railroad trucks)	

Figures

1. Existing E-184 spectrometer arm, located below the accelerator beam pipe.

2. Figure 9 from the preprint of Paar and Paschof, ref. 1. The incident proton has energy 300 GeV. One muon is detected at 50 mr. For symmetric decays, the other muon appears at 3.10 in this plot. In this log plot, the distribution of the second muon is centered in a narrow region near 3.10.

3. Sketch of the second spectrometer arm, positioned over the accelerator beam pipe. The dimensions and weights of the first three absorber blocks are: 10" x 12" x 64" (1.1 tons), 16" x 16" x 36" (1.35 tons), 24" x 24" x 48" (4 tons). Each of the two iron magnets is 28" x 28" x 36" and weighs 4 tons.

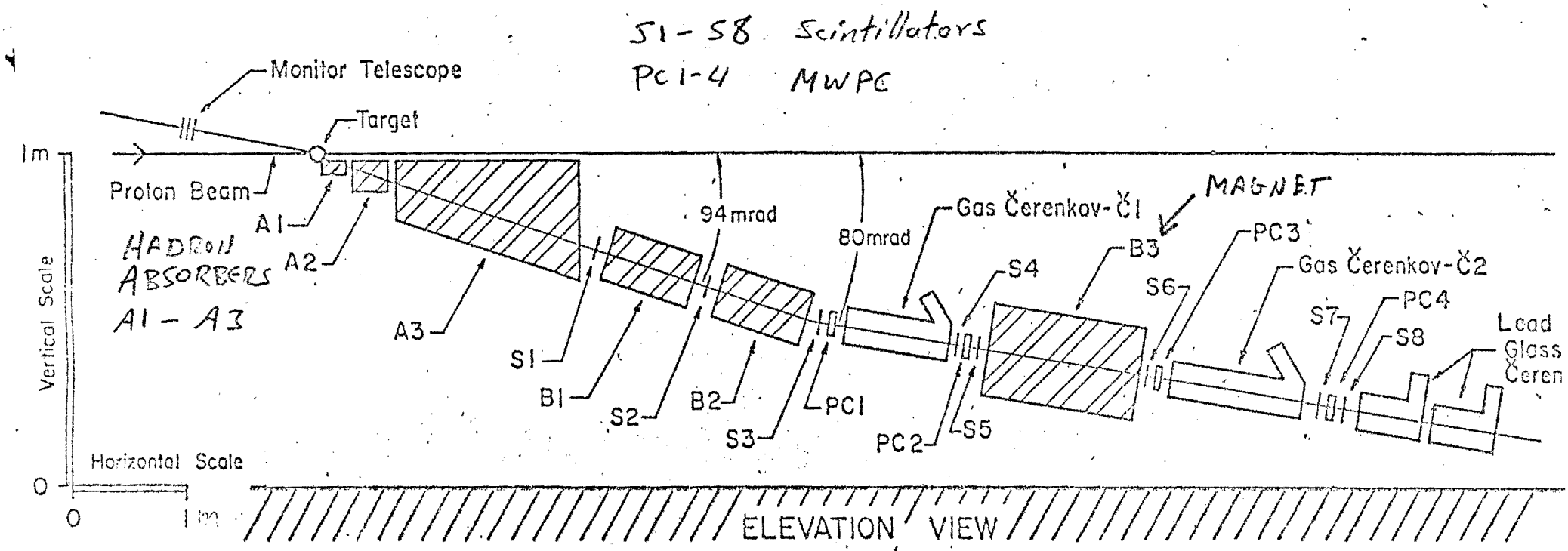
S1 - S8 Scintillators
PC1-4 MWPC
Monitor Telescope
Target
Proton Beam
A1
A2
A3
HADRON ABSORBERS A1 - A3
S1
B1
S2
B2
S3
PC1
94 mrad
80mrad
Gas Čerenkov-Č1
PC2
S4
S5
MAGNET
B3
S6
PC3
Gas Čerenkov-Č2
S7
PC4
S8
Lead Glass Ceren
1m
Vertical Scale
0
Horizontal Scale
0
1m
ELEVATION VIEW

FIGURE 1

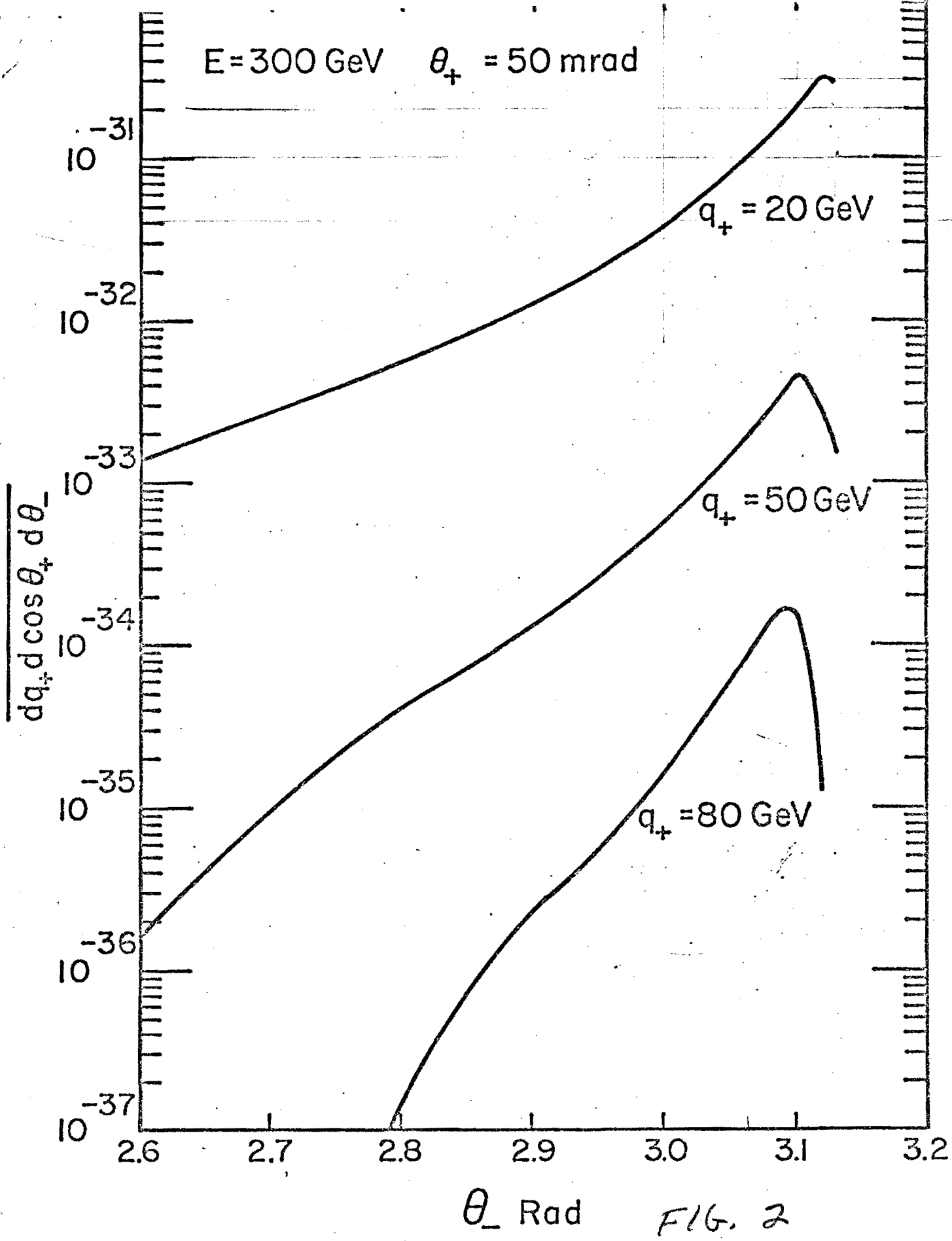
E = 300 GeV
θ_+ = 50 mrad
q_+ = 20 GeV
q_+ = 50 GeV
q_+ = 80 GeV
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
$\frac{d\sigma}{dq_+ d\cos\theta_+ d\theta_-}$
2.6
2.7
2.8
2.9
3.0
3.1
3.2
θ_- Rad

FIG. 2

Fig. 4

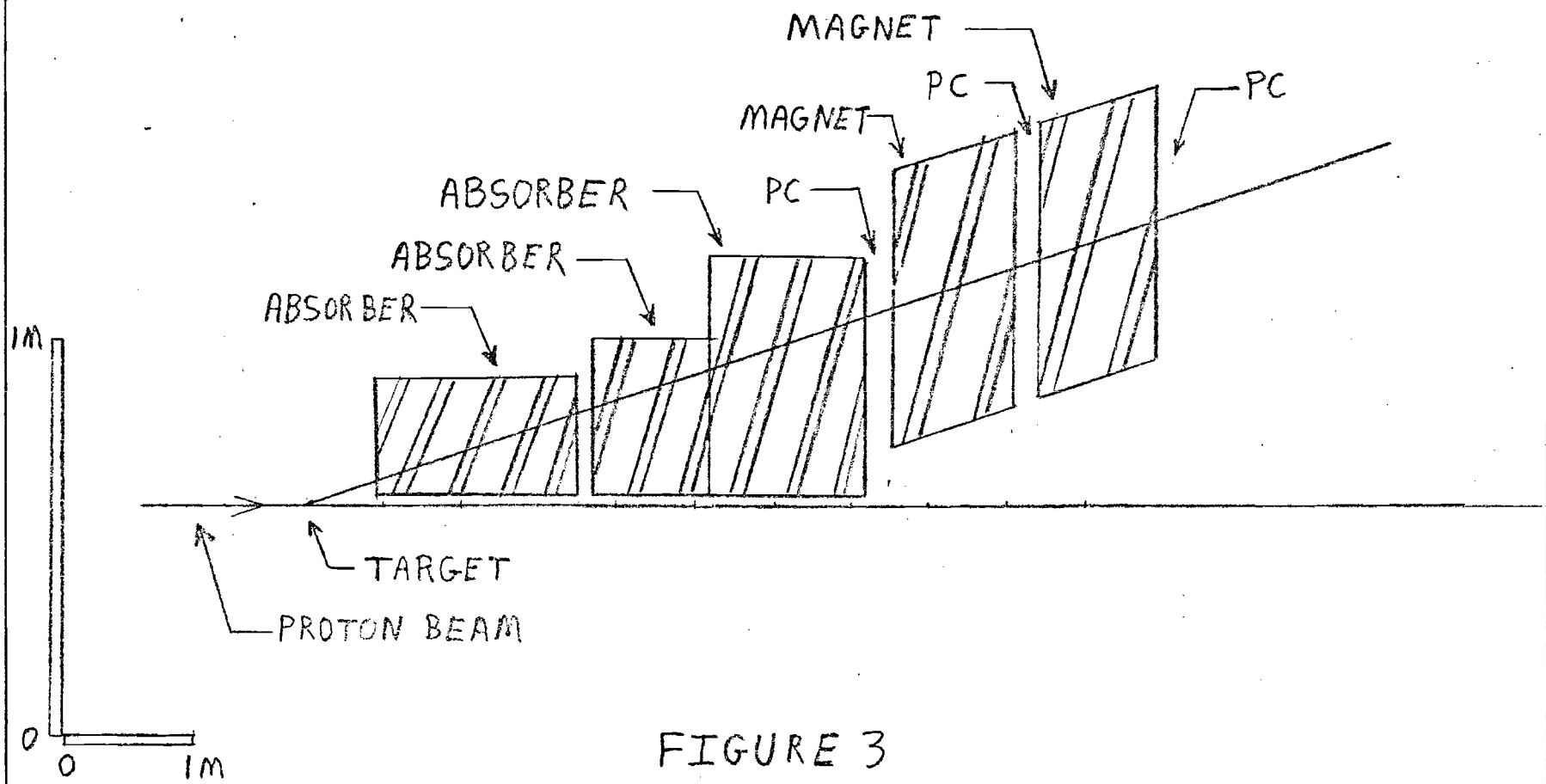

FIGURE 3

SUBJECT

NAME

DATE

REVISION DATE