NAL PROPOSAL NO. 308

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

Telephone: 312-753-8747
-8744

A PROPOSAL FOR A DETAILED STUDY OF DIMUON PRODUCTION

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

Enrico Fermi Institute
University of Chicago

and

C. Rubbia and L. Sulak

Harvard University

May 31, 1974

A PROPOSAL FOR A DETAILED STUDY OF DIMUON PRODUCTION

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

Enrico Fermi Institute
University of Chicago

and

C. Rubbia and L. Sulak

Harvard University

May 31, 1974

ABSTRACT

We propose an experiment to study the detailed character of dimuon production in hadron-hadron collisions. We will measure the dimuon mass distribution, angular distribution and density matrix elements as a function of bombarding energy and beam particle species. The study will extend down to low masses, with good resolution to determine the contribution from vector meson production. This detailed, minimum bias study will fully explore the copious yield of prompt muons recently observed at NAL.

ORGANIZATION

1. MOTIVATION

Three recent NAL experiments[1] have observed the emission of single prompt muons from nucleon-nucleon interactions. The yields are $\sim 10^{-4}$ of the pion yields and this ratio of prompt muons to pions appears to be insensitive to variations of the transverse momentum and production angle, at least for the measurements presently available.

This high muon yield can be explained in terms of vector meson production and decay only if most pions themselves arise from vector meson decay. There is little supporting evidence for this interpretation of the muon yield. If it is correct, vector meson production is a dominant feature of the nucleon-nucleon interaction at high energies and a detailed study of their production is indicated. Such a study can be performed by the experiment proposed herein.

An alternative, more speculative approach, is that the NAL observation of leptons in the final state of hadron interactions is intimately related to the SPEAR observations of hadrons from an initial dilepton state. In both cases there is a coupling between leptons and hadrons at the level of α^2. The momentum and angular distribution of the secondaries are similar in the two cases.

Regardless of which picture, if either, is correct the large yield of prompt muons observed at NAL must be investigated in more detail. The study divides itself naturally into two classes of experiments. On the one hand, dilepton production must be measured at the highest masses and transverse momenta attainable at NAL in order to search for new vector particles decaying to two leptons and for the high mass pairs predicted by the parton model. Such a study necessitates the use of an external proton beam and accordingly a well shielded, limited acceptance detector. We believe experiment 70/288 belongs to this category. A second complimentary class of experiment, prompted by the unexpectedly high yields already observed, would use a secondary beam and a large acceptance detector. It would study the details of dilepton production in a minimum bias fashion at lower masses and transverse momenta. Production cross sections would be measured as a function of dimuon mass, momentum, and production angle. Density matrix elements could be measured for the dimuon state. The detector would have good effective mass resolution in order to measure the contribution from vector mesons as well as a possible continuum component in mass spectrum. In such a study the full range of beam and target variables available at NAL would be brought to bear on the understanding of this new phenomenon.

It is this second type of experiment that we are proposing.

2. THE DETECTOR

(a) General Features

We first note that the prompt muon production cross sections already measured lead to very high event rates. Assume that the single prompt muons already observed are one of a pair of muons and that the ratio of 10^{-4} for single prompt muons compared to pions holds for all production angles and momenta. A typical proton-proton collision at 300 GeV produces 10 pions with half of them in the forward hemisphere of the center of mass. Thus for each interaction the number of muon pairs in the forward hemisphere is:

0.5×10^{-4} (probability of a pair per pion) x5 or 2.5×10^{-4}. Accordingly just one machine pulse from a secondary beam giving 10^6 interacting hadrons, yields 250 energetic, forward going, muon pairs. A 10 hour run with a high acceptance detector yields over 10^6 detected μ-pairs. This figure is indicative of the range of cross sections which can be studied. Clearly the experiment would still be viable even if the total production cross section were significantly smaller.

The experimental set-up is shown in Fig. 1. A secondary beam of 10^7 particles/pulse is brought to the experiment's target where 10% of the beam interacts. The primary target materials would be hydrogen and deuterium but initial measurements would be made with targets of a complex nucleus to study the A dependence of the cross section and to quickly map out the gross features of the effect.

Just downstream of the target is a 1.5-meter tungsten hadron shield to absorb secondary hadrons from the target as well as part of the non-interacting component of the beam. The target is separated from the beam dump to ensure that the detected μ-pair did arise from a primary beam particle interacting in the target material. Scintillation counters are placed upstream and downstream of the target so that a pulse height requirement in the counters can be used to identify an interaction. The distance between the target and the shield is variable but for normal data taking it is held fixed for a given beam energy. (e.g. 75 cm at 300 GeV). The probability for two pions to decay to muons in this distance is only a few percent and the mass spectrum for such background is strongly peaked at low masses as shown in Fig. 2. We discuss this background more fully below.

Immediately in front of the hadron absorber are 4 planes of multiwire proportional chambers (MWPC's) to measure precisely the direction of charged particles before they enter the hadron absorber. Using the muon directions seen in the spectrometer and in a plane halfway through the absorber one can extrapolate back to the initial muon trajectories in these upstream chambers and hence measure the muon directions before any multiple scattering takes place in the shield. This feature is necessary to maintain a good mass resolution for the lepton pair. The target chambers also allow a correlation study between the charged particle multiplicity and the other characteristics of the dilepton events.

Following the hadron shield is a large acceptance magnetic spectrometer. Details of the magnet and its acceptance are given below but we note that with the 1.6 m x 1.0 m entrance aperture and high field strength ($\int Bdl$=20 kg-m) the whole center-of-mass forward hemisphere can be studied with a dimuon mass resolution of 5% at the ρ mass in just two settings of the target-to-magnet distance. (The second setting is required to obtain 5% mass resolution for dimuons of high longitudinal momentum.) Should vector mesons not be the dominant mechanism in dimuon production or should the yields be extremely low for high longitudinal momentum then the mass resolution might be relaxed slightly and a single target-to-magnet distance used.

The magnetic spectrometer is equipped with multiwire proportional chambers to allow operation with the highest possible event rates. Moreover, experience in experiment 184, shows that operating behind a hadron shield proportional chambers have a significantly lower counting rate than scintillators of similar area. This feature arises from the insensitivity of the low mass chambers to neutrons.

The lepton character of the two charged particles triggering the system is proven by their penetration of an additional 3 meters of steel downstream from the spectrometer.

The apparatus will be triggered in two modes. (1) the minimum bias mode in which all muon pairs traversing the spectrometer are recorded, (2) the biased mode in which low mass or low P_t muon pairs are not recorded. This latter mode, using radially and azimuthally segmented front counters described below, together with a minimum momentum requirement in the spectrometer, will allow us to reach the smallest cross sections permitted by the beam without being swamped by low P_t events.

3. SPECIFIC DETAILS OF THE DETECTOR

(a) Hadron Shield

We chose the shield to be 1.5 m of tungsten. It is as short as possible so that the magnet subtends the maximum solid angle at the target. With this thickness the probability that a primary pion penetrates the shield without interacting inelastically is 3×10^{-7}. Secondary hadrons emerging from the shield are at a rate of 10^{-2} below the incident flux level.

These shield characteristics are based on measured absorption cross sections[2] and on recent shielding calculations of Ranft.[3] The latter calculations agree well with measurements at lower energies and need only be relied on for the energy dependence of the shield's effectiveness.

The beam enters the shield through a small blind hole coaxial with the beam direction. This reduces the probability of secondaries backscattering into the proportional chambers just upstream.

Except for the small entrance hole, the absorber is uniform in the plane perpendicular to the beam. This ensures uniform detection characteristics as a function of dilepton production angle.

To facilitate correlation of tracks seen in the multiwire proportional chambers (MWPC's) following the target, with muon trajectories in the spectrometer, the shield is split at the midpoint and a single pair of x-y MWPC planes is inserted. The charged particle flux at this point is slightly less than that of the incident beam. Accidental tracks are easily eliminated using the well defined muon trajectories measured in the spectrometer.

As an example, consider the symmetric decay of a dimuon of momentum 30 GeV. For a 15 GeV muon seen in the spectrometer the trajectory extrapolates back to a spot of 6 mm radius in the MWPC midway through the shield. Using this extra point on the trajectory the spot to be searched in the upstream chamber is only 3 mm in radius. The 3 mm size is to be compared with the minimum muon separation at this plane of 50 mm for a μ-pair of 1 GeV mass and 30 GeV momentum. The probability of an additional hadron from the same interaction in this tiny solid angle can be estimated from measured yields.[4] At a bombarding energy of 200 GeV and a very forward production angle of 3.6 mr. the probability is about 4%.

We have considered the problem of an interaction in the target which gives no μ-pair but occurs in accidental coincidence with a beam interaction in the shield giving a μ-pair. This background can be completely eliminated by ensuring that there is no more than one entering beam particle per RF bucket and by using a coincidence resolving time which can separate the buckets. Thus every entering particle can be resolved into one interacting in the target or one interacting in the shield. Only the former would be put in coincidence with the spectrometer logic. The requirement of no more than one beam particle per RF bucket can be easily imposed by pulse height requirements on several scintillators in the beam upstream of the target.

Muons produced in the shield are only important to the extent that they affect the data acquisition rate. The reconstruction accuracy is more than adequate to eliminate them when the events are reconstructed.

The only background which cannot be easily rejected upon reconstruction is that of two pions from the same primary interaction in the target, decaying in the drift space between the target and the shield. We have carefully studied this process by generating multiparticle events, having the proper single particle distributions. For these events we have evaluated the decay probability and mass distribution of the resulting μ-pair.

We find a background of 1% imposing no cuts other than the energy loss in the shield. The mass distribution for the background is shown in Fig. 2. During the running of the experiment a continuous monitor of this background is provided by triggers having two muons of the same sign. The ratio of prompt μ-pairs to decay background can be easily varied by changing the length of the drift space between the target and the hadron shield.

(b) The Magnetic Spectrometer

A key element in the detector is the large magnet used for analysis of the muon momenta. For a minimum bias study of dilepton production we consider a large acceptance magnet essential. The magnet is centered on the beam line in the forward direction where the parent dimuon momenta are presumably the highest and therefore the μ-pair opening angles the smallest for a given mass.

The alternative to a single large magnet is two smaller ones used with a large combination of settings to cover the same solid angle with the same correlation information. The acceptance at each setting of such a system imposes a constraint between dimuon production angle and decay angle. Clearly this constraint can be unfolded with an appropriate number of settings of the arms but such a process is tedious and fraught with systematic errors. For the most efficient use of running time and a minimum of detector biases we choose a single large magnet where all decay configurations can be recorded simultaneously.

We have in our possession the coils for a magnet with a useful aperture of 1.0 m x 1.6 m and a field integral of 20 kg-m. We base our acceptance and resolution calculations on these characteristics. Should the 1.3 M w of power not be available in the experimental area we could use a superconducting magnet of the style being built by NAL's Research Services group.

In this experiment the target-to-magnet distance and lever arms are chosen to suit the particular beam energy. For each energy at most two settings are required to obtain full coverage of the forward hemisphere in the CM system with 5% mass resolution at the ρ mass. Figure 1 shows the detector with the target close to the magnet. For the expanded configuration the drift space and lever arms are scaled up by a factor of 3.

The spectrometer is equipped with 4 x-y modules of MWPC's with a wire spacing of 1.5 mm. A total of 8000 wires are required. The size of this system is similar to that built by some of us for use at the CERN-ISR, and to a system already produced at the Fermi Institute for the NAL muon scattering experiment.

We would like to run the experiment at beam energies of 50, 100, 200, 300, 400 GeV. (See section 5 for a discussion of experimental areas.) The angular coverage in the CM system extends between $1. \geq \cos\theta^* \geq 0$ for all energies above 50 GeV.

Figure 3 shows the acceptance and mass resolution at 300 GeV as a function of x, P_t of the parent dimuon state for both the upstream and downstream target positions. At other bombarding energies the longitudinal detector dimensions are scaled to obtain similar performance. An important element in maintaining good mass resolution is the measurement of muon trajectories before the particles enter the tungsten absorber. Four small planes of MWPC's with 1 mm wire spacing are used. We have already used such chambers in experiment 184.

(c) <u>Trigger</u>

As mentioned above we will trigger in two fashions. The minimum bias method will impose no special constraints on the muon pair and will be used to determine the total cross section for dimuon production and for an analysis of the initial spin state of the dimuon. The triggering requirement, based on counter planes A, B, and C shown in Fig. 1, would be that two muons traverse the spectrometer in coincidence. The experiment's data logging system must be especially fast to handle the high rate associated with this trigger.

The second mode would be more selective. It would reject low mass and small angle dimuons by using the radial and azimuthal structure of the counter plane A shown in Fig. 4.

Consider the impact point of two muons on this plane. The parent dimuon direction must lie on the line segment joining these points. For a symmetric decay it lies at the midpoint of the line segment. Thus a requirement on the 2 counter elements struck in plane A allows one to constrain the parent's production angle.

The dimuon mass can be constrained in the following way:

The effective mass is:

$$M^2_{\mu\mu} = 4P_1P_2 \sin^2 \frac{\theta_{12}}{2}$$

$$\sim P_1P_2\,\theta_{12}^2$$

P_1, P_2 — momenta of muons 1 and 2

θ_{12} — opening angle of the μ-pair

$\theta_{12} = \frac{r}{d}$ — where r is the length of the line segment mentioned above; d is the distance from the target to plane A

By requiring P_1 and P_2 to be above some lower limit through the use of the hodoscope planes B and C behind the magnet, the counter elements struck in plane A can be used to impose a lower bound on the dimuon mass. This triggering mode would be used to explore the lowest cross sections attainable in the beam without any limitation from detector dead time. The logic requirements on the A plane elements can be imposed efficiently with a matrix conincidence system built from emitter-coupled integrated circuit elements.

4. MEASUREMENT PLAN AND EXPECTED EVENT RATES

A summary of the experimental stages and the allocation of running time is given in Table I.

The physics goals of the experiment are a measurement of dimuon production as a function of x, P_t and $M_{\mu\mu}$ from pions, kaons and protons incident on protons and neutrons. We will also measure the decay angular distribution of the dimuon to examine the angular momentum structure of the initial dimuon state. This would be done for localized regions of the variables x, P_t, $M_{\mu\mu}$. Because the expected dimuon rate is several hundred per pulse for 10^6 primary interactions and our acceptance is large, much of the data for this detailed study is recorded simultaneously. Only a few percent of the beam interactions, however, arise from K-mesons and $\bar{p}$'s. The exact disposition of running time will depend strongly on what is found.

As indicated in Table I, the first step in the experiment is detector tune-up in a parasitic mode. Since the hadron absorber can be removed, we will be compatible with any beam conditions chosen by an upstream or downstream user and require only a thin polyethylene target to send charged particles into the detector.

At Step 2 of Table I the physics interest begins. The detector outlined above was configured on the assumption that the dilepton state has properties similar to a hadron except for a factor of $\sim \alpha^2$ in the coupling. This assumption is supported by the NAL experiments 70, 100, and 184 over a range of transverse momenta from 800 MeV/c to 4.5 GeV/c. One of the first and most important steps in the experiment is to quickly verify this assumption over the range of parameters to which the final experiment will have access. This check is vital to verify the suitability of specific detector configurations and to ensure proper allocation of running time to the various conditions. We will also determine whether the dimuons are produced entirely from vector meson decay or have a continuous mass distribution. To this end we propose to run initially with simultaneous carbon and polyethylene targets at 3 beam energies and both beam polarities. Some data will be taken with heavier targets to study the A dependence of the effect. This period will also be a shakedown phase for operation of the detector at peak beam rates. We expect to require approximately 100 hours for this running-in phase. Following this period the prime data taking runs with 70 cm. hydrogen and deuterium targets will begin. We will run at beam energies of 50, 100, 200, 300, 400 GeV and with both positive and negative polarities at each energy. A beam Cerenkov will be used to tag the incoming particles, and to allow triggering selectively should this be desired.

The cross section sensitivity of the experiment, if our acceptance is unity in the region of interest, is 5×10^{-34} cm^2 at the level of 10 events/hr.

5. REQUIREMENTS FROM NAL

The most serious requirement is that of the secondary beam. A beam of 10^7 per sec is needed to fully exploit the capabilities of the detector.

If the event rates are as high as the most optimistic predictions given above, then significant physics might be done with less beam. For the 50, 100, 200 GeV points, the M1 beam in the Meson Lab, operated with 10^{13} protons on target and $\Delta P/P = \pm 1.5\%$ provides both positive and negative fluxes of nearly 10^7. The 300 and 400 GeV energies cannot be achieved there.

The new pion beam in the Proton Lab promises to more than meet our requirements. It's time for completion, however, appears rather distant since an experiment at the CERN-ISR has been approved to study some of the same physics we are proposing.

In order to begin an attack on this physics now, we would propose to use the M1 beam in the mode described above and postpone the high energy points until after some early results have been obtained.

We will need assistance from NAL with the spectrometer magnet. We can provide the coils for a conventional magnet described above if its power load is suitable for the experimental area. Otherwise, we would need assistance in constructing a superconducting magnet.

We need material for the tungsten hadron absorber and the iron muon filter following the spectrometer.

Some standard fast electronics would be required for the trigger. The 70 cm hydrogen target would be built at NAL.

We would plan to provide the proportional chambers, readout electronics, scintillators and mechanical supports.

6. TIME TABLE AND PERSONNEL

This experiment is of immense interest and importance. We are ready to devote full time effort to its preparation as soon as approval is received. Since the detector itself uses standard, well understood components, we estimate that we can be on the experimental floor within 8 months from the date of approval. The time may be determined primarily by the magnet preparation.

The Chicago group will have at least 3 Ph.D. physicists and two graduate students entirely committed to this experiment.

7. SUMMARY

We will fully explore the recently observed, high yield of prompt muons from hadron-hadron collisions. We will measure dimuon production as a function of x, P_t and $M_{\mu\mu}$ from pions, kaons and protons incident on protons and neutrons. We will also study the angular momentum structure of the dimuon state by observing its decay angular distribution. Our detector is designed to have a 5% dimuon mass resolution at the ρ mass, so vector meson production can be accurately studied.

We note that this is an exceptionally attractive experiment to run promptly at NAL. It is a follow-up on a recently observed effect of great potential importance. The final state to be studied is simple and very easy to trigger on. Established detection methods are fully adequate for its study. Also, the means are available at NAL to perform a definitive study in this single experiment by varying beam and target characteristics. Since the anticipated event rates are very high, the data can be acquired promptly and will have exceptional statistical power. We are ready to start construction of the detector immediately.

References

1. J. Apple et al., (NAL E-70) reported at the 1974 Washington APS Meeting;

   J. Cronin et al., (NAL E-100) reported at the 1974 Washington APS Meeting;

   D. Bintinger et al., (NAL E-184) reported at the 1974 Washington APS Meeting.

2. S. Denisov et al., Nuclear Physics B61, 62 (1973).

3. K. Goebel et al., Nuclear Instruments and Methods 113, 433 (1973).

4. W. Baker et al., NAL preprint: NAL-Pub-74/13-EXP.

FIGURE CAPTIONS

1. Experimental set-up for 300 GeV running.
2. Muon pair mass distribution from decay of two pions.
3. Acceptance and mass resolution as a function of x, P_t, $M_{\mu\mu}$ at 300 GeV. Characteristics are shown for the detector configuration of Fig. 1 (downstream target position) and for the elongated configuration (upstream target) which gives 5% mass resolution over the whole x interval at slight sacrifice in acceptance at low x.
4. Structure of counter plane A to aid in triggering on dimuon production angle and effective mass.

TABLE I - RUN PLAN

	Goal	Hours	Events
1.	Detector tune-up - parasitic running - hadron shield removed - thin polyethylene target in beam	-	-
2.	First look at dimuon production and detector shakedown - full beam flux - hadron shield in place - use of poly and carbon targets in tandem - beam energies of 50, 200, 400 GeV at both polarities - use of copper and lead targets for additional information on A dependence	100	10^6 events at each energy and polarity
3.	Definitive runs on hydrogen and deuterium targets - beam energies of 50, 100, 200, 300, 400 at both polarities	400	2×10^6 events at each energy, polarity and target material

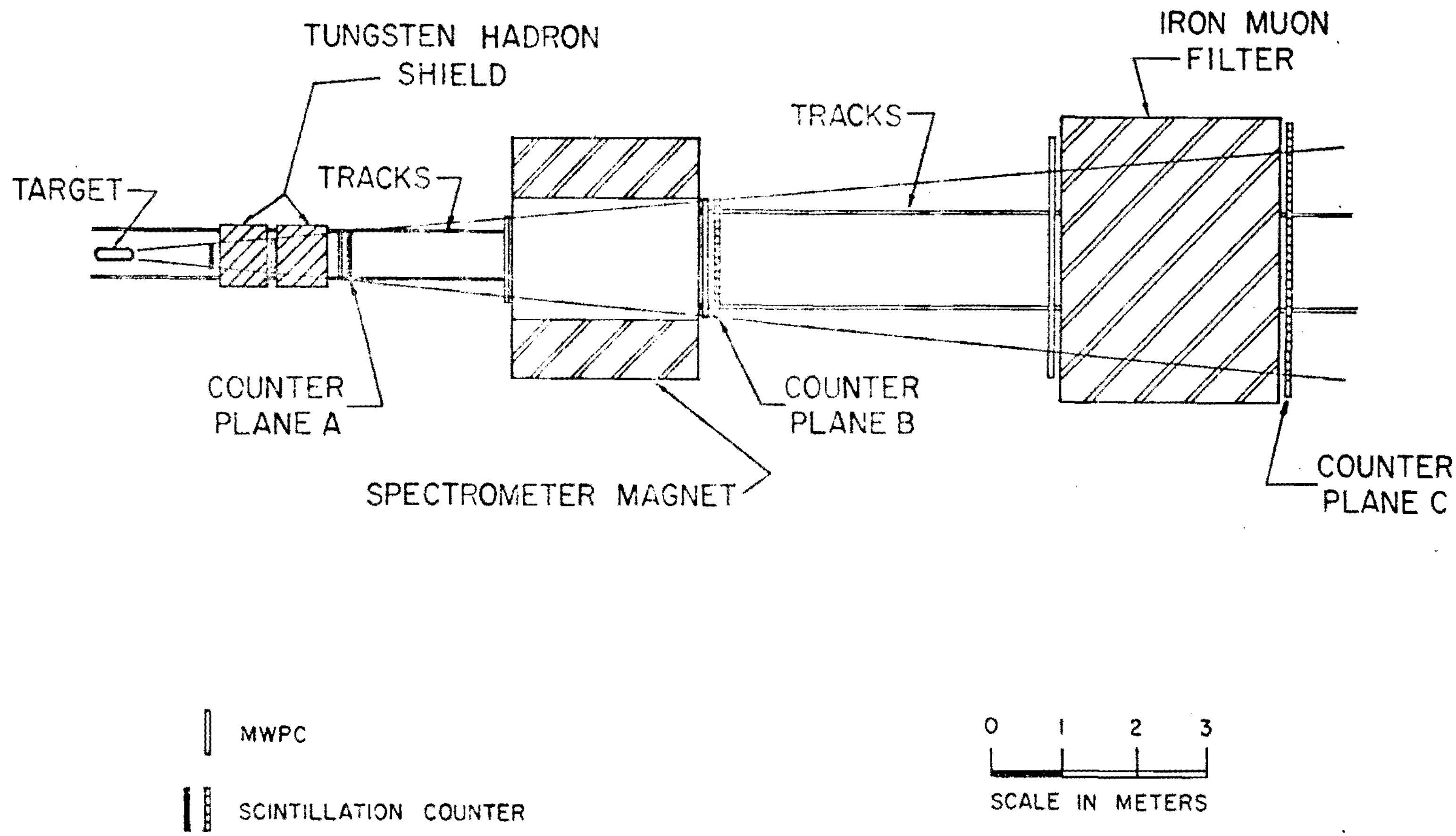
Note: (1) Event rates are calculated under the assumptions given in the text.

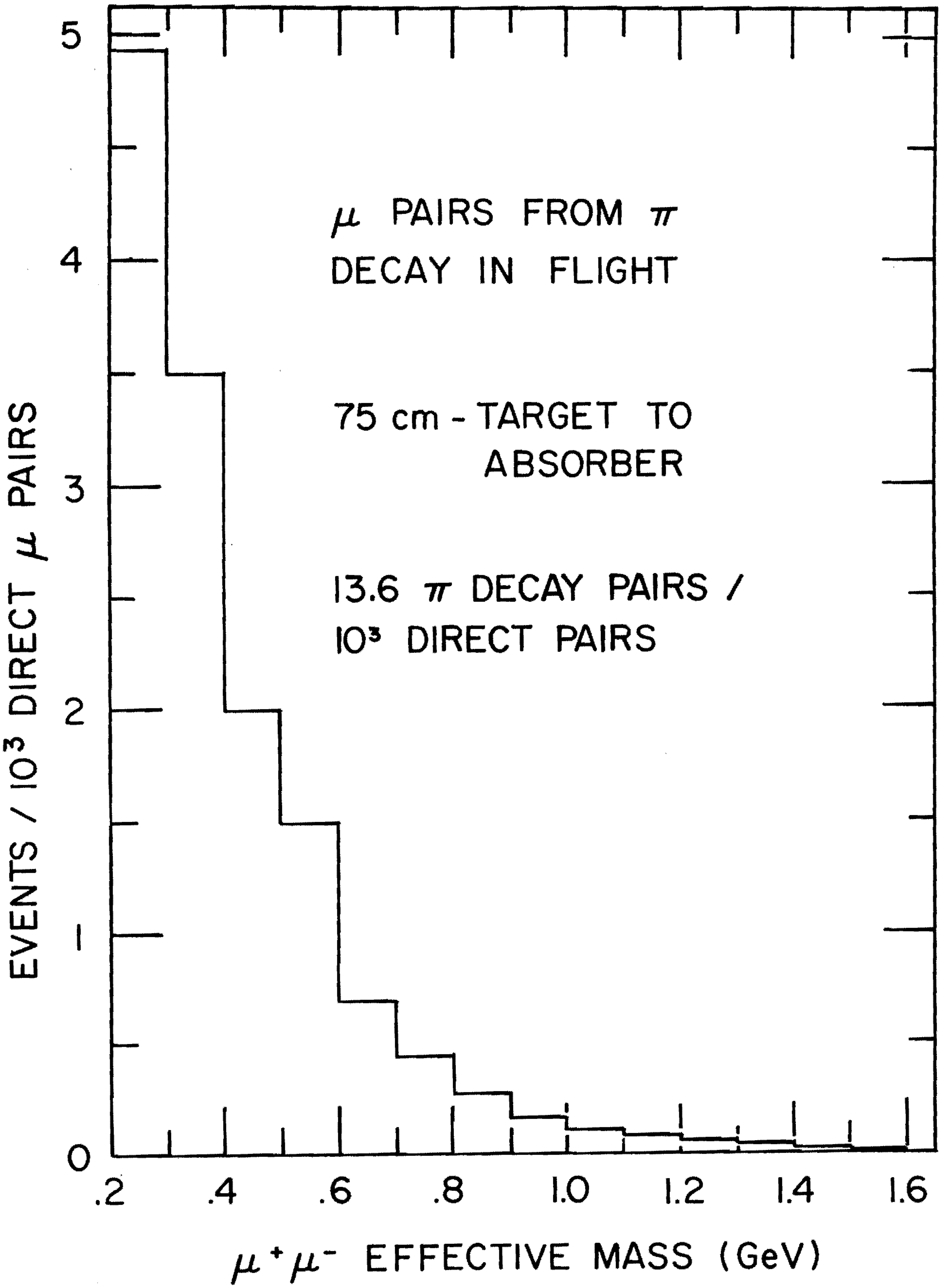
(2) Number of recorded triggers may be limited by our analysis capability. Much of the running time may be spent accumulating data on the $K^\pm$ and $\bar{p}$ interactions and μ-pairs in regions of low cross section. The exact details will depend on what is found.

(3) Our cross section sensitivity is $5 \times 10^{-34} cm^2$ for 10 events/hr.

FIGURE 1

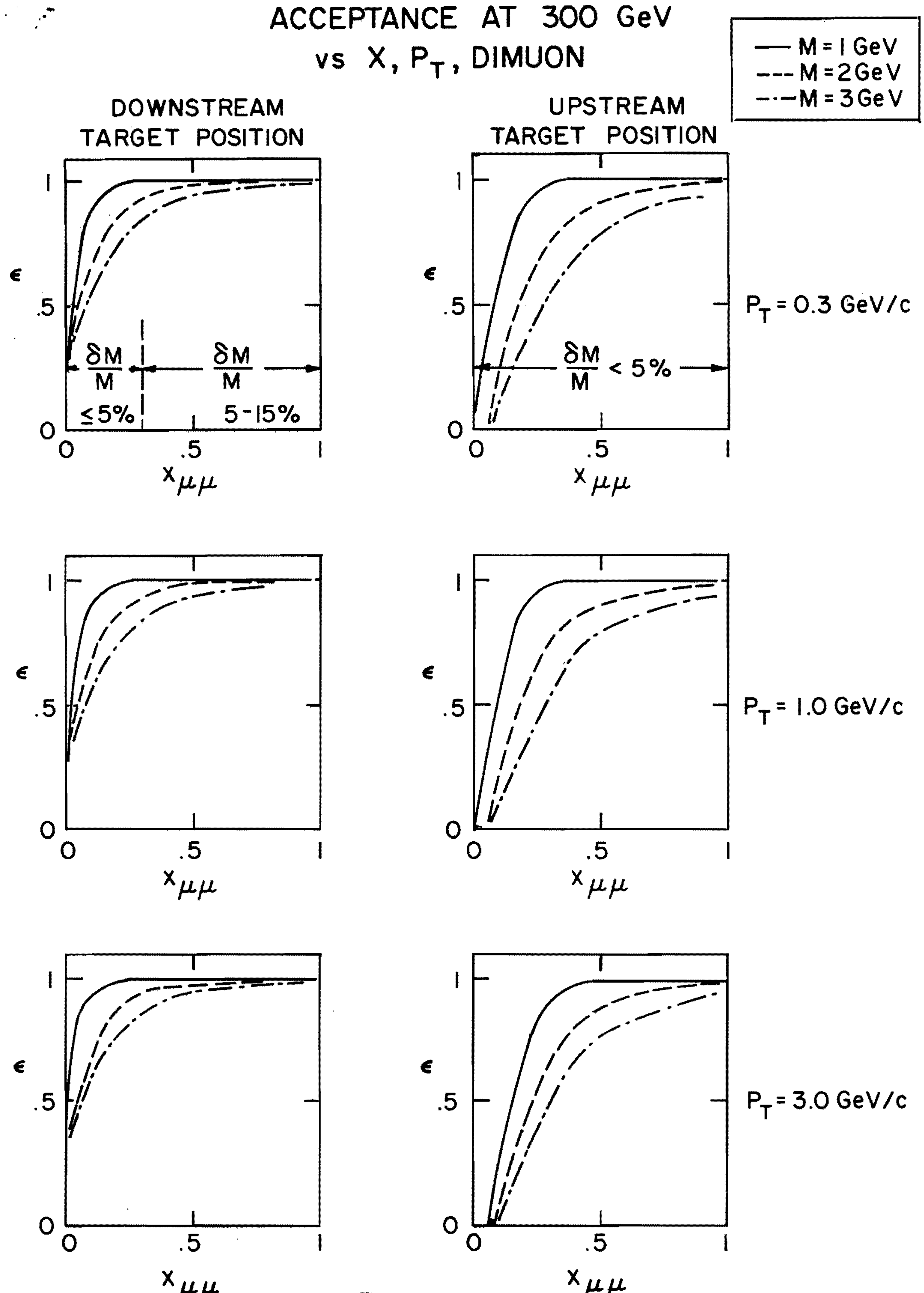
300 GeV CONFIGURATION





μ PAIRS FROM π
DECAY IN FLIGHT
75 cm - TARGET TO
ABSORBER
13.6 π DECAY PAIRS /
10³ DIRECT PAIRS
EVENTS / 10³ DIRECT μ PAIRS
0
1
2
3
4
5
.2
.4
.6
.8
1.0
1.2
1.4
1.6
μ⁺μ⁻ EFFECTIVE MASS (GeV)

FIGURE 2



ACCEPTANCE AT 300 GeV
vs X, P_T, DIMUON
M = 1 GeV
M = 2 GeV
M = 3 GeV
DOWNSTREAM TARGET POSITION
UPSTREAM TARGET POSITION
δM/M ≤5%
δM/M 5-15%
δM/M < 5%
P_T = 0.3 GeV/c
P_T = 1.0 GeV/c
P_T = 3.0 GeV/c
ε
x_μμ

FIGURE 3

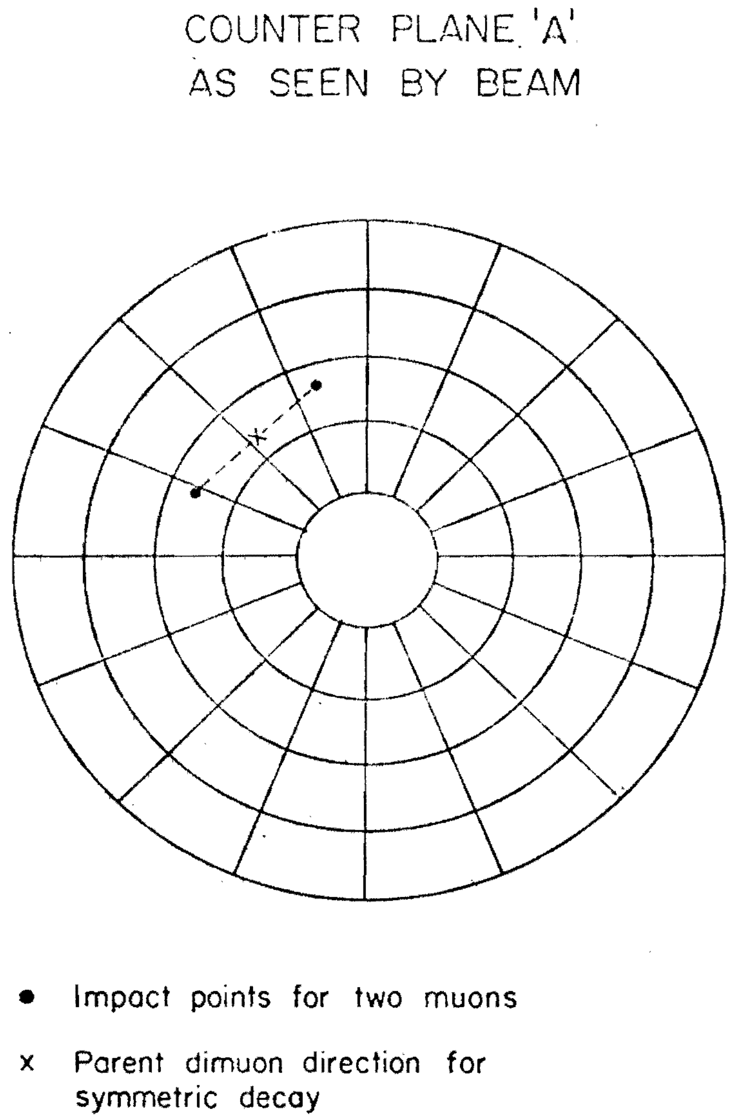

COUNTER PLANE 'A'
AS SEEN BY BEAM
• Impact points for two muons
x Parent dimuon direction for symmetric decay

FIGURE 4

SUPPLEMENT TO PROPOSAL 308

A PROPOSAL FOR A DETAILED STUDY OF DIMUON PRODUCTION

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

Enrico Fermi Institute
University of Chicago

and

C. Rubbia and L. Sulak

Harvard University

This supplement amplifies the capabilities of the detector described in the main body of the proposal. We discuss in more depth the physics to be studied, the detector characteristics for higher mass μ-pairs, and alternative estimates of dimuon production cross sections and their event rates.

I. Physics of the Dilepton State

A detailed study of dilepton production in hadron-hadron collisions may provide vital information towards understanding the hadron. Dileptons in the continuum mass spectrum reflect the coupling of time-like photons to hadronic material, just as lepton-nucleon scattering explores the coupling for space-like photons. Since the electromagnetic behavior of the photon probe is in principle understood, we can gain important insight by studying these processes.

The parton model has been rather successful in explaining the coupling of space-like photons to the nucleon. In this model they couple electromagnetically to point-like constituents inside the nucleon. This same picture of the nucleon has also been successful in explaining early observations of neutrino-nucleon scattering.

The parton model has been less successful in predicting the coupling for time-like photons. It predicts a cross section for $e^+e^- \to$ hadrons which falls like 1/s in contrast to the CEA and SPEAR observations of a constan-cross section. Recent measurements at NAL of single leptons from hadron-hadron collisions give a cross section substantially larger than predicted for lepton pair production by the parton model.

It is crucial to determine if these single leptons arise from vector meson production and decay or from a continuum mass spectrum characteristic of time-like photons coupling to the hadronic material. In either case, because of the unexpectedly large yield, a detailed study is indicated. In the experiment proposed, dimuon production can be studied with very broad acceptance up to $q^2 \sim 100$ GeV^2 or down to cross sections of $\sim 10^{-34}$ cm^2.

To first order in the electromagnetic interaction the cross section for the final dilepton state is described by four real form factors (five if polarizations are measured)[1]. These form factors which contain the physics of the photon-hadron coupling are measured by analyzing the decay angular distribution of the dimuon state.

In the rest system of the dimuon, the angular distribution for fully relativistic decay leptons ($\beta = 1$) is given by:

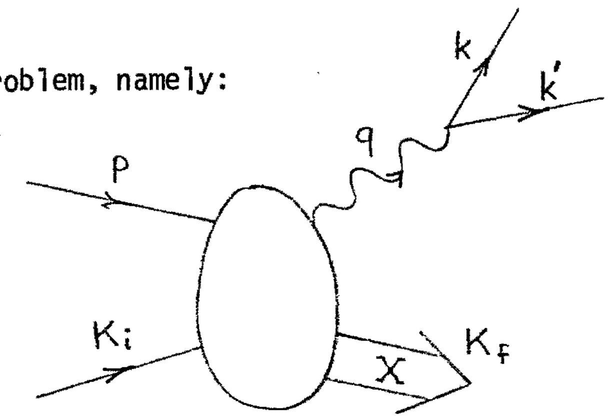
$$W(\theta,\phi) = \{F_1 \sin^2\theta + F_2 (1-\sin^2\theta\sin^2\phi) + F_3 (1-\sin^2\theta\cos^2\phi) -$$
$$F_4 \sin 2\theta \cos \phi\} / (F_1 + F_2 + F_3)$$

where $F_1, \ldots, F_4$ are the form factors

θ is the polar decay angle relative to the incoming beam direction

ϕ is the azimuthal angle of the decay plane relative to the production plane.

The form factors are functions of at most 4 scalar invariants of the problem, namely:



$$s = (p + K_i)^2$$
$$t_{\mu\mu} = (p-q)^2$$
$$q^2 = (k + k')^2 = M_{\mu\mu}^2$$
$$K_f^2 = (p + K_i - q)^2 = M_X^2$$

In practice an alternative combination of form factors may be more suitable for fitting the decay distribution. One such combination is the density matrix elements for the dimuon state.

A measurement of the form factors and production cross section as a function of the invariants allows a study of scaling laws. One can test Feymen scaling, Bjorken scaling and Drell-Yan scaling as they apply to this system. Moreover, specific models for the photon-hadron coupling make predictions about the decay angular distribution. The vector dominance model, for example, predicts a $\sin^2\theta$ distribution, while the Drell-Yan model based on parton-antiparton annihilation gives $1 + \cos^2\theta$.

For all these measurements it is essential to use a detector whose acceptance is large over a wide range of the variables of the problem. Moreover, incident mesons beams, as well as nucleons, may provide valuable insight into the structure of the hadrons.

II. Detector Performance for Higher Masses

Our main proposal describes the detailed performance of the detector for dimuon masses up to 3 GeV. The acceptance is shown as a function of $X_{\mu\mu}$, $P_{T_{\mu\mu}}$, and $M_{\mu\mu}$ assuming an isotropic decay distribution. In this mass range, where the event rate is high and acceptance almost unity, it is clear that the form factors can be well measured. Because of the large detector aperture acceptance decreases only very slowly with increasing mass. Fig. 1 of this supplement shows the acceptance for masses of 5, 8, and 11 GeV with isotropic decay distributions. The source of the modest acceptance loss is asymmetric dimuon decays which lead to large μ-pair opening angles. Fig. 2 shows the acceptance as a function of decay angle for a series of masses. A decay distribution like $\sin^2\theta$ would give a larger acceptance while $1 + \cos^2\theta$ would yield a reduced acceptance. Clearly, for a study of dimuon production by meson and nucleon beams on free nucleons, the detector's acceptance is excellent for masses up to 10 GeV. The ultimate limitation may be imposed by the cross section for production of these high masses rather than acceptance.

III. Alternative Estimates of Production Cross Sections and Event Rates

The main proposal gives μ-pair production cross sections based on the single muon yields measured at NAL near 90° in the CM system. An alternative approach is to use the μ-pair production cross sections measured at BNL by Christenson et al.[2], together with some prescription to scale the cross sections up to NAL energies.

The most pessimistic assumption is that there is no cross section increase at all. That is, the dimuon production cross section is independent of CM energy and the NAL experiments are observing anomalously large vector production. In this case the dimuon production cross section in the region studied in the BNL experiment at 29.5 GeV, namely $1.0 < M_{\mu\mu} < 5.0$, $X_{\mu\mu} > 0.5$, $P_T < 2.0$ is $4.9 \times 10^{-33}\ cm^2$, which corresponds to $\sim$ 100 ev/hr. for the running conditions described in the proposal. Since our acceptance extends much beyond these kinematic boundaries, particularly the $X_{\mu\mu}$ cut-off, our event rate would be substantially higher.

A second point of view, more reasonable than a constant cross section, is that the production cross section scales with increasing CM energy in order to fill the expanded range of accessible q^2. The Drell-Yan scaling law predicts that

$$\frac{d\sigma}{dq^2} = \frac{\alpha^2}{q^4} F(q^2/s)$$

The BNL experiment is reasonably represented by $F(q^2/s) = \exp(-10q^2/s)$.[2] The resulting cross section at 300 GeV as a function of $M_{\mu\mu}$ is shown in Fig. 3. The event rate for $0.75 < M_{\mu\mu} < 3$ GeV is 250 ev/hr. and for $3 < M_{\mu\mu} < 8$ GeV is 10 events per hour.

IV. Conclusions

The physics to be studied is of fundamental importance in understanding the nature of the hadron. The theoretical picture presented by the parton model is ripe for testing and already there are several hints that this model is inadequate, both in the time-like photon domain ($e^+e^- \rightarrow$ hadrons) and for high q^2 muon scattering. Important clues to the nature of the failure may come from the experiment we are proposing.

We wish to perform a definitive study of the detailed characteristics of dimuon production. The data will represent a very tight constraint on both the parton model and any future models seeking to describe the hadron's structure. The results of the measurement can be represented in a simple, unambiguous fashion by the dimuon production cross sections and the form factors describing the dimuon state.

Even the most pessimistic lower bound on the production cross section gives an event rate greater than 100 events/hr. The Drell-Yan scaling formula predicts at least 250 events/hr.

Because of the simplicity of the final state to be studied, considerable insight into the experiment can be gained by early beam tests, without the spectrometer magnet. We propose to begin construction of the magnet immediately. If sufficient time is available before its completion, we wish to perform beam tests of the trigger and to study the μ-pair production rate in the forward direction vs. beam energy, opening angle characteristics, etc. This could be done in the meson lab using the tungsten absorber and steel muon filter as described in the proposal, together with a few planes of hodoscope counters.

REFERENCES

1. R. J. Oakes, Il Nuovo Cimento 44, 440 (1966).
2. J. H. Christenson et al., Physical Review D8, 2016 (1973).

FIGURE CAPTIONS

1. Detector acceptance for μ-pair masses of 5, 8, and 11 GeV. The calculation is based on an isotropic dimuon decay distribution. Results are shown for two detector geometries. The "upstream target" geometry is used for measurements at large $X_{\mu\mu}$ in order to have 5% mass resolution for high momentum dimuons.
2. Acceptance as a function of dimuon decay angle. The curves are for $X_{\mu\mu} = 0.5$ and bombarding energy 300 GeV. The detector is in the "downstream target" configuration.
3. Cross section prediction based on Drell-Yan scaling of the 29.5 GeV BNL data to 300 GeV.

ACCEPTANCE AT 300 GeV
vs X, P_T, DIMUON

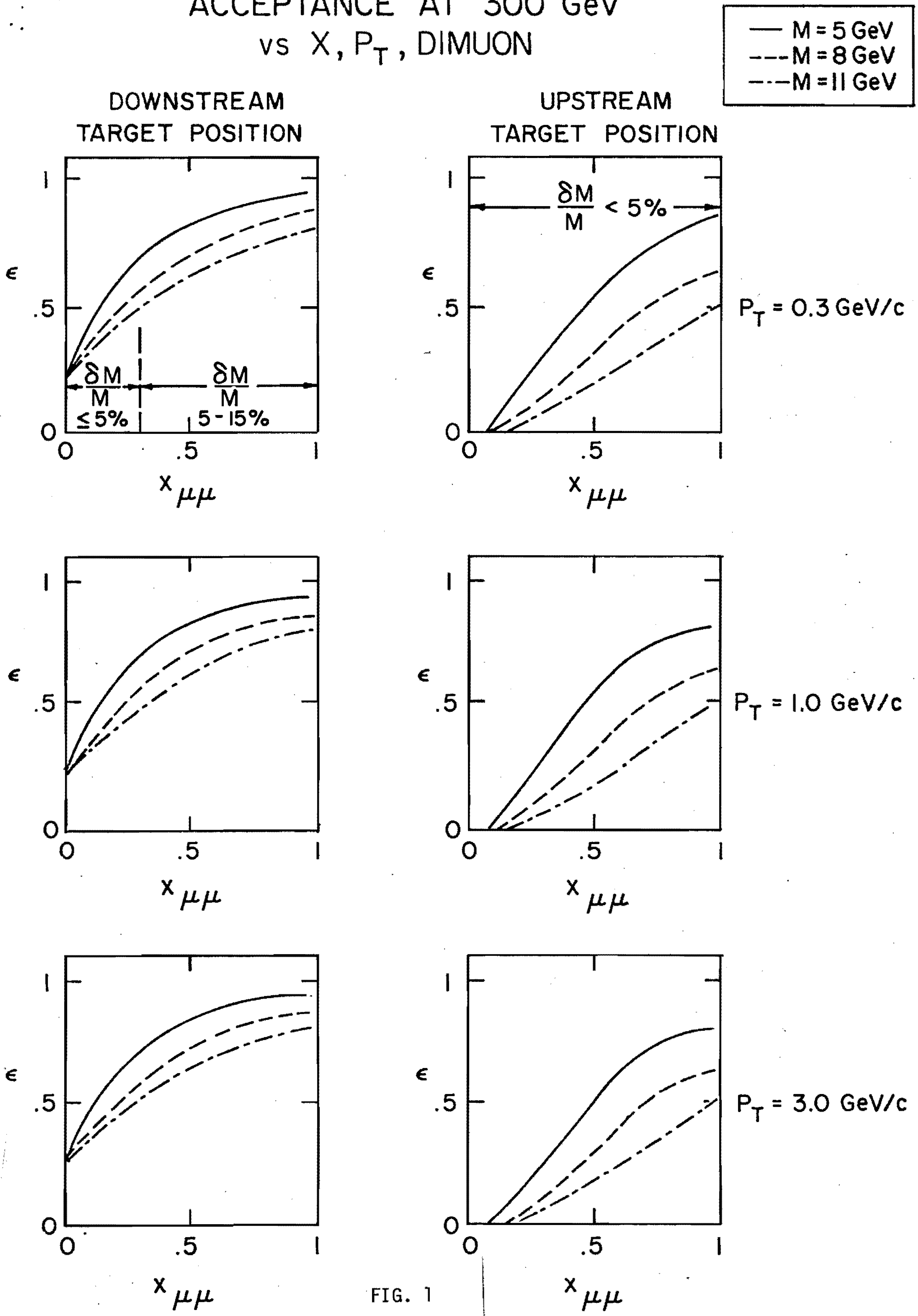


FIG. 1

ACCEPTANCE vs DIMUON DECAY ANGLE ($X_{\mu\mu} = 0.5$)

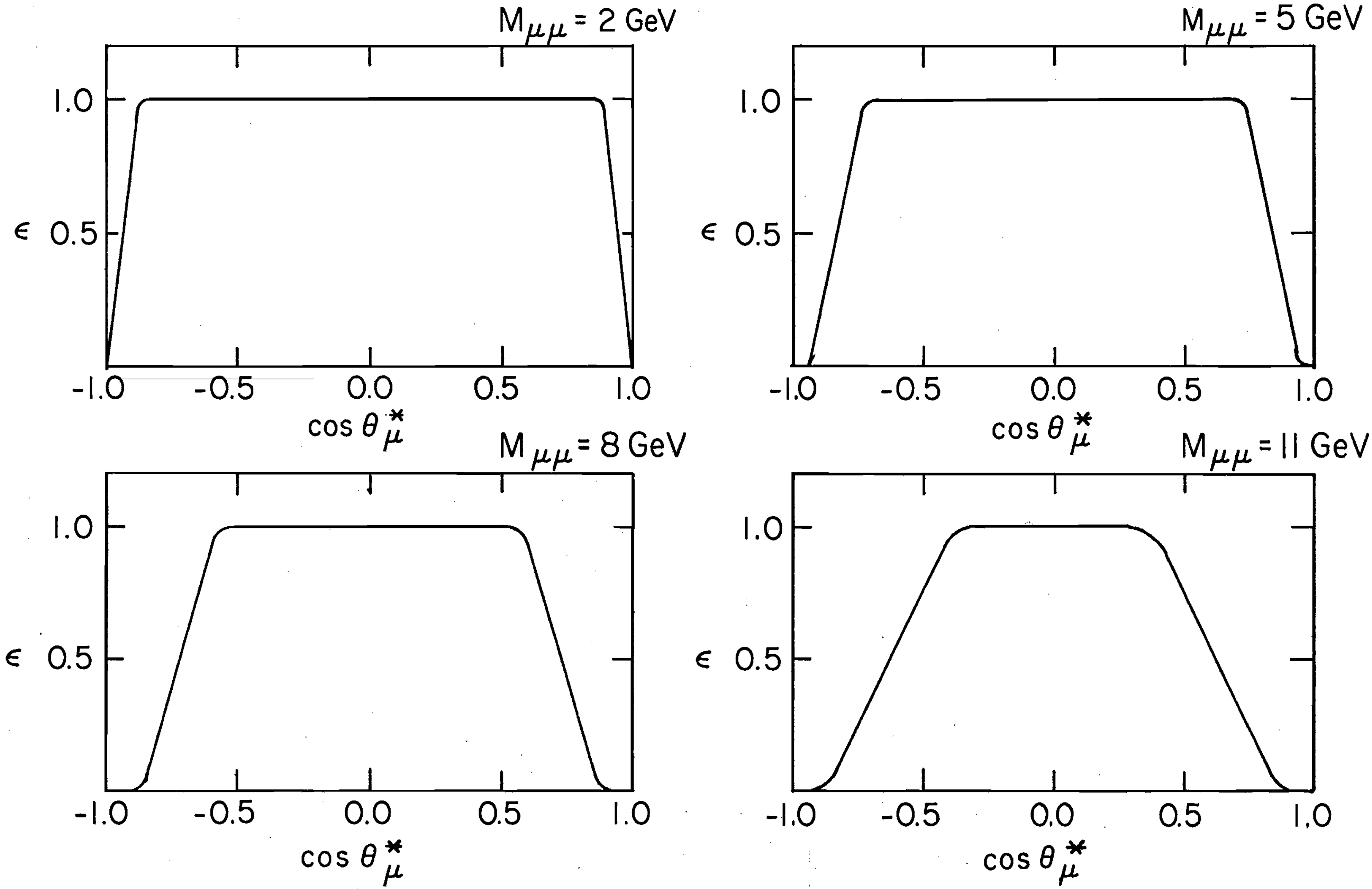
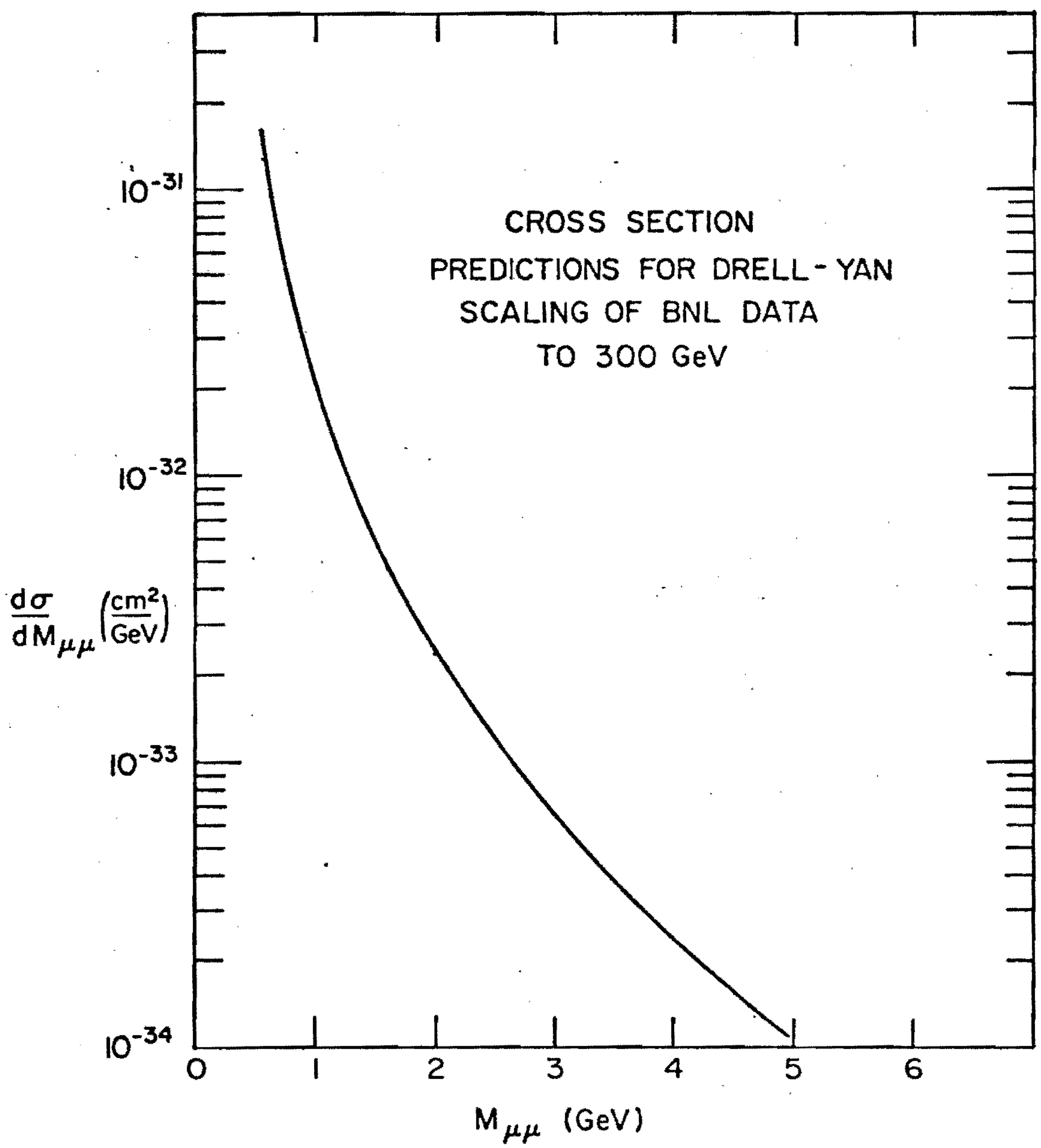


FIG. 2



CROSS SECTION
PREDICTIONS FOR DRELL-YAN
SCALING OF BNL DATA
TO 300 GeV
10^{-31}
10^{-32}
10^{-33}
10^{-34}
$\frac{d\sigma}{dM_{\mu\mu}}\left(\frac{cm^2}{GeV}\right)$
0
1
2
3
4
5
6
$M_{\mu\mu}$ (GeV)

FIG. 3