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A PROPOSAL TO EXPLORE MULTI MUON PRODUCTION IN HADRON COLLISIONS

(MUlti Muon Spectrometer--MUMS the word)

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ABSTRACT

An exploration of the cross section behavior for producing three or more muons in hadron hadron collisions is proposed. Associated production of the new narrow particles, heavy lepton production, pseudoscalar meson spectroscopy, constituent annihilation to four muons, and other processes will be probed with good sensitivity. A beam intensity of 10^{10}p or π/pulse is used with a detector whose acceptance is close to 3π steradians in the center of mass system.

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0. Introduction

The hadronic production of new narrow states which promptly decay to muon pairs has been observed in recent experiments at BNL[1] and Fermilab.[2] At the same time anomolous production of dimuons is indicated by the Fermilab results[3] of neutrino experiments. This may be evidence for the production of heavy leptons or new hadron states. In addition, there is evidence from SPEAR[4] that muons and electrons are being produced in association. Again, production of new particles of some kind is indicated.

The above experiments suggest that a sensitive exploration of multiple muon production will probably produce more surprises and insights.

Presently approved muon production experiments are of two configurations. The first configuration is the use of high beam intensity ($> 10^{10}$/pulse) and small acceptance, E-70/288 and E-372 are examples of this approach. The second configuration involves the use of a large acceptance detector and low beam intensity ($< 10^{7}$/pulse); E-331, using the cyclotron magnet, is an example of this approach.

The expected low cross sections for multi ($\gtrsim 3$) muon production require both a detector with large acceptance and an intense ($\gtrsim 10^{10}$ particles/pulse) beam. It is this type of detector that we are proposing.

1. Physics Justification

The reaction we propose to investigate is

$$p + Z \rightarrow \geq 3\mu + \text{"X"}$$

We give examples of processes resulting in particular muon multiplicities.

Associated Production with a Charm Like Quantum Number

Consider associated production of J (3.1) or ψ' (3.7) with charmed pseudoscalar mesons (D). It is assumed[5] that the leptonic decay branching ratios of pseudoscalar states will be appreciable. Three muons are produced in the case:

$$(1) \qquad p + Z \rightarrow J + D^{\pm} + \text{"X"}, \quad J \hookrightarrow \mu^+ + \mu^-, \quad D^{\pm} \hookrightarrow \mu^+ + \nu + \text{"X"}$$

whereas four muons appear in the final state of the reaction

$$(2) \qquad p + Z \rightarrow J + D^+ + D^- + \text{"X"}, \quad J \hookrightarrow \mu^+ + \mu^-, \quad D^+ \hookrightarrow \mu^+ + \nu + \text{"X"}, \quad D^- \hookrightarrow \mu^- + \nu + \text{"X"}$$

Rates for the above processes can be estimated from the fact that approximately 3,000 ($J \rightarrow 2\mu$) events occur per pulse.

We expect the J and D's to be produced close together in rapidity space. In this case the transverse momentum of the J will mostly be balanced by the transverse momentum of the D's. This argument is probably true for any assumption regarding the new quantum number (charm, color etc.) associated with J production. Observation of J production at large $p_\perp$ correlated with

one or two muons at large $p_\perp$ on the other side would be good evidence for the production of particles of an entirely new kind. Conversely, non-observation (to the level of 10^{-4}) of muons in association with J production would be a severe blow to present ideas on charm states.

We will also explore J production with large $p_\parallel$. This process may be a useful trigger for a study of charmed baryon production. We expect a fast J to be produced in association with a D and a C (charmed baryon). Both the D and C are expected[5] to have appreciable leptonic decay branching ratios.

The systematics of J and ψ' production with additional muons will be explored and provide insight on the mechanism of associated production.

<u>Associated Production where the J has a New Non-Zero Quantum Number.</u>[6]

The J is produced in association either with its anti-particle or another particle with this new quantum number. This case is analogous to associated production for strange particles. The analogies are $K^o \leftrightarrow J$ and $\bar{K}^o \leftrightarrow \bar{J}$, while the observable particles J_L and J_s are similar to K_L and K_s. We are interested in the processes

(3) $\quad p + Z \rightarrow J + \bar{J} + \text{"X"}$

(4) $\quad p + Z \rightarrow J + \textcircled{H} + \text{"X"}$

analogous to $p + Z^o \rightarrow K^o + \bar{K}^o + \text{"X"}$ and $p + Z \rightarrow K^o + \Lambda + \text{"X"}$.

Here Θ is a baryon with this new quantum number of $\bar{J}$. In both reactions (1) and (2), we expect to see $\mu^+\mu^-\mu^+\mu^-$, because

$$\Theta \rightarrow p + \mu^+ + \mu^-$$

is a permissible electromagnetic or weak decay mode of Θ via a virtual $\bar{J}$. If Θ is a narrow resonance, all decays must be electromagnetic or weak and the mass of Θ must be less than the sum of the masses of J and proton. Thus the invariant mass of the $\mu^+\mu^-$ pair is less than 3.1 GeV. In this way, the processes (3) and (4) can be distinguished. If such a narrow resonance indeed exists, the cross sections for both processes will be measured with good sensitivity.

Heavy Lepton Production

The production of charged heavy leptons may give rise to 2, 3, 4, 5 or 6 muons. The process is

$$p + Z \rightarrow \ell^+ + \ell^- + \text{"X"}$$
$$\hookrightarrow \mu^+ + \nu_\mu + \bar{\nu}_\mu \qquad \hookrightarrow \ell^o + \mu^- + \nu_\mu$$
$$\hookrightarrow \mu^+ + \mu^- + \nu_\mu$$

The ℓ^+ can also decay via an ℓ^o giving rise to a possible six muons in the final state.

Similar muon signatures can arise from the production of heavy leptons whose lepton number is different from muons.[7] For example a possible reaction is

$$p + Z \rightarrow \ell^+ + \ell^- + \text{"X"}$$
$$\hookrightarrow \mu^+ + \nu_\mu + \nu_\ell \qquad \hookrightarrow \ell^o + \mu^- + \nu_\mu$$
$$\hookrightarrow \mu^+ + \mu^- + \nu_\ell$$

It should be noted that it is not possible in neutrino (ν_μ) experiments at Fermilab to produce new leptons of this kind. Detection of the muons from these new heavy leptons is probably easier than detection of the new type of neutrinos (ν_ℓ) in a neutrino detector.

The search for threshold effects and correlated high $p_\perp$ anomalies would be of great interest in this regard. In addition, there is the possibility[8] of the ℓ^o having a lifetime long enough (> 10^{-10} secs) to see the resulting muon pair as a V whose vertex is well downstream of the target.

Pseudoscalar Meson Spectroscopy

The mass spectrum of massive pseudoscalar states can be investigated through their double Dalitz decay into four muons. Each pair of muons would have a characteristic low invariant mass.

eg. $\eta_c \rightarrow$ "γ" + "γ"

$\hookrightarrow \mu^+ + \mu^-$ $\hookrightarrow \mu^+ + \mu^-$

The mass of each state (eg. η_c) would then be reconstructed and the full mass range up to > 20 GeV would be studied.

The experiment is exploratory in nature and will undoubtedly lead to results for muon production which cannot be anticipated at this time. The above discussion describes some of the more obvious physics potential of the detector.

2. Detector System

A. General

A schematic of the detector is shown in Fig. 1. A beam of

10^{10} protons/pulse strikes a hevimet beam stop. The diameter of the beam is about 60 cms for reasons described later. The hevimet is surrounded by steel which is 4.5 m long in the beam direction. The total charged hadron rate[9] emerging from the back face of the steel is $\leq 10^5$/pulse and the total neutron rate[9] is $\lesssim 10^8$/pulse.

Muons coming out of the steel go through proportional chambers PC1 and PC2, then enter a uniform horizontal magnetic field produced by a solid iron magnet dipole, D1. Proportional chamber PC3 detects the position of muons at the back of D1. Associated with these proportional chambers are scintillation counter hodoscopes S_1, S_2 and S_3. Each of these hodoscopes has 50 counters in the x, y and u direction giving a spatial resolution of ± 2.5 cms. Each plane is separated from another by a 1" thick steel plate to minimize the effects of delta rays giving rise to a spurious trigger. The proportional chambers are 2.5 m x 2.5 m in size and have 2 mm wire spacing. The directions and momenta of muons are determined by the proportional chambers.

Three toroidally magnetized iron slabs T1, T2 and T3 and three proportional chambers PC4, PC5 and PC6 are used to make accurate (9%) momentum measurements on the muons. The P.C.'s are used to detect the positions of the muon trajectories behind each toroid. The information from these chambers is used only for off-line analysis of the data. Chambers PC4, PC5 and PC6 are 2.5 m x 2.5 m in size and have 2 mm wire spacing. Alternate wires in all chambers are connected to high voltage to improve the time resolution and amplifiers are connected to the other wires.

The acceptance in both the horizontal and vertical planes is 16 degrees. The expected mass resolution for dimuons is about ± 16% at 3 GeV, ± 11% at 5 GeV and ± 8% at 10 GeV. This resolution should be quite adequate to separate the J from background because we demand at least one other muon in the final state.

B. Background Rates in Counters

We consider several sources of muon background.

1. Muons from π decay

A typical proton-proton collision at 400 GeV produces 10 charged pions. About 10^{-4} of the pions decay into muons before interacting. A muon must have at least 7 GeV to reach S1. Only about 40% of these pions have an energy sufficient to produce a 7 GeV decay muon within the acceptance of the detector. For each pulse 10^{10} interacting protons we will therefore produce 4×10^{6} muons going through the detectors.

2. Muons from Kaon decay

We assume that the kaon to pion production is about 10%. Then a calculation analogous to the above gives a muon rate from kaon decay of 3×10^{6}/pulse through the detectors.

3. Single Prompt Muons

The preliminary result[10] of E-48 gives an upper limit of 10^{-4} of prompt muon relative to pion production at small $p_{\perp}$ and intermediate $p_{\parallel}$. We take 0.5×10^{-4} for this ratio and obtain a total prompt muon flux through

the detectors of $\approx 2 \times 10^6$ μ/pulse.

The total single muon rate is then $(4 + 3 + 2) \times 10^6 \approx 10^7$/pulse. We assume a 2 second flat top and obtain 5×10^6 muons per second instantaneous rate in the detectors.

In addition to muons, there are, integrated over all energies, about 10^8 neutrons emerging from the back face of the dump and passing through S1 and PC1. This will produce $\approx 5 \times 10^5$ events/second in S1 and probably somewhat fewer in PC1 due to its lower mass. The size of the dump was chosen to ensure the rate from hadron background to be much less than the rate from single muons.

C. Trigger

There are two aspects of the design of the experiment which are very important for the success of the trigger. These aspects are

a) Use of a beam of large cross sectional area which allows unambiguous rejection of muons from different events.

b) The simplicity afforded by the dipole field D1 which gives bending in one plane only and allows straight line track identification in the other plane.[11] Pattern recognition is relatively simple and therefore fast.[12]

The trigger occurs in three stages with successively more stringent requirements. The first level of the trigger employs scintillation counter hodoscopes S_1, S_2, and S_3. A minimum of three pulses is required in each plane of the hodoscopes. We

denote[13] the occurrence of such an event as $S_1(3)$, say. The background accidental triples rates contributing to $S_1(3)$ and $S_2(3)$ are computed from the 5×10^6 uncorrelated single muons/second and 20 nanosecond resolving time,

$$S_1(3) = S_2(3) = 10^7 \times 10^{-1} \times 10^{-1} = 10^5/\text{pulse}.$$

The S_3 singles rate is about a factor of 2 less than that for S_1 or S_2 because of the magnetized steel D1. Hence, the rate for $S_3(3)$ accidental triples is given by

$$S_3(3) = 5 \times 10^6 \times 5 \times 10^{-2} \times 5 \times 10^{-2} \approx 10^4/\text{pulse}.$$

The uncorrelated muon contribution to $S_1(3)S_2(3)S_3(3)$ will then be about 10^4/pulse.

There is also an important correlated muon contribution to the first level trigger. The results of E-87/358 suggest that the dimuon production cross section is consistent with being dominated by leptonic decay of vector mesons. The principal contribution is from ρ^o mesons. We consider a μ pair from a ρ^o in random coincidence with another muon. The rate for this to occur is determined from the observed[14] ratio of 10% for ρ/π production and we obtain $2 \times 10^5 \times 2 \times 10^{-8} \times 5 \times 10^6 = 2 \times 10^4$/pulse. Allowing for an additional factor of two due to possible continuum and contributions from the other vector mesons we obtain $\sim 4 \times 10^4$/pulse from this source. We denote this type of correlated event as $(2\,\mu, \mu)$.

When an event of the type $S_1(3) \cdot S_2(3) \cdot S_3(3)$ occurs the impact points of the muons on one plane (x say) of S_3 are determined

along each of the struck counters by the time difference of the light arriving at the two ends of the counters. Figure 2 shows some results[15] obtained using this technique and it appears that in our case the impact points can be identified with a spatial resolution of 4 cm full width at half maximum. The same results show that the time resolution using this spatial information can be improved to about 1 nanosecond. We shall assume that an on-line resolving time of 5 nanoseconds can be achieved. Hence, processing of the information contained in the timing of the photomultiplier pulses decreases the effective resolving time and reduces the number of $S_1(3) \cdot S_2(3) \cdot S_3(3)$ triggers. This processing occurs in about 1 μsecond and contributes about 3% dead time to the system. The rate of events of the type $S_1(3) \cdot S_2(3) \cdot S_3(3)$ (uncorrelated) reduces from 10^4/pulse to about 10^3/pulse and the correlated (2 μ, μ) contribution goes from 4×10^4 to 10^4/pulse. The final rate for $S_1(3) \cdot S_2(3) \cdot S_3(3)$ is dominated by events of the type (2 μ, μ) and is about 10^4/pulse. We define this first level of trigger as T1.

When a T1 event occurs the wire chambers PC1, PC2 and PC3 are latched and read out from those areas defined by the struck scintillation counter elements. The struck wire information can be obtained in about 1 μsecond. A pattern recognition routine is applied using PC1, PC2 and PC3 to identify straight trajectories in the undeflected plane and only PC1 and PC2 in the other plane. This trajectory information is obtained in about 3 μseconds. Finally, the trajectories are extrapolated back to the front face of the hevimet beam dump where a unique

creation point is required to an accuracy of ± 7 cm in each plane compared to a beam diameter of 60 cms. This takes a further 3 μseconds. It is estimated that this criterion rejects uncorrelated T1 events by a factor of 3×10^2 and correlated events (2 μ, μ) by a factor of 20. Events which survive these criteria are then called triggers at the second level, T2.

The rate of T2 is about 500/pulse and is dominated by events in which a pair of muons has been produced promptly in some reaction, such as ρ^o creation, and a third muon is in random coincidence with that pair (i.e., 2 μ, μ) type events. The dead time for T1 due to source reconstruction and application of rejection criteria is about $10^4 \times 7 \times 10^{-6} \times 0.5 = 4\%$.

If an event satisfies the T2 source criteria then full track reconstruction is performed and the production angles and momenta are obtained for each muon. The invariant dimuon mass is calculated for each combination of a pair of muons:

$$m_{12}^2 = p_1 \, p_2 \, \theta_{12}^2$$
$$m_{13}^2 = p_1 \, p_3 \, \theta_{13}^2$$
$$m_{23}^2 = p_2 \, p_3 \, \theta_{23}^2$$

Figure 3 shows the dimuon mass distribution observed in E-87. In this data, 0.1% of the events are above a mass of 2 GeV. In addition, Fig. 4 shows the calculated[16] μ pair effective mass for μ pairs produced from π decay in flight.

For an event to pass the T3 level we require that at least

one of the $\sqrt{m^2}$ be above 2 GeV. It is estimated that the event processing for the T3 trigger can be performed in a further 50 μsec. There is therefore no more than about 5% dead time for data acquisition from this level of the trigger. Less than one T3 event/pulse is therefore expected from background processes.

When a T3 event occurs all of the wire chamber data from PC1.....PC6 and the hodoscope information are written on to tape.

We conclude that it is quite feasible to design a trigger system which will effectively eliminate background at a beam intensity of 10^{10} protons/pulse and allow the acquisition of the desired data. Table 1 provides a summary of the trigger requirements.

We have briefly considered additional trigger possibilities. In particular, it appears feasible to trigger on a single high $p_\perp$ ($\gtrsim$ 2 GeV/c) muon by using scintillation counters strategically placed at the rear of the detector. Similarly, it is possible to trigger on a high $p_\perp$ ($\gtrsim$ 2 GeV/c) pair of muons whose invariant mass is greater than 2 GeV, say. The importance of these and other possible trigger options will be reexamined as new physics results are obtained from present experiments and as our design develops.

3. Rates

In the following we consider two modes of running the experiment.

A. Full Sensitivity Mode of Running (As discussed up to this stage.)

We shall first calculate the rate of $J(3.1) \rightarrow 2\mu$ production.

E-87/358 has measured the cross section for the reaction

$$n + B_e \rightarrow J + \text{"X"}$$
$$\hookrightarrow \mu^+ + \mu^-$$

for $|x| > 0.24$ as 3.6×10^{-33} cm^2/nucleon. The observed x distribution for J production is given in Fig. 5. We make the conservative assumption that the J cross section remains constant in the interval $0 \leq |x| \leq 0.24$ and integrate over our acceptance (i.e., $x > -.2$) to obtain a cross section of about 1.2×10^{-32} cm^2/nucleon. Compared to the total nucleon nucleon cross section of 40 mb, that for $J \rightarrow 2\mu$ production is a factor of $\frac{1.2 \times 10^{-32}}{40 \times 10^{-27}} \sim 3 \times 10^{-7}$ smaller. Therefore, with a beam of 10^{10} protons/pulse interacting in the hevimet beam dump, there are $3 \times 10^{-7} \times 10^{10} = 3 \times 10^3$ $(J \rightarrow 2\mu)$ events/pulse produced.

If J particles are predominantly produced in association with a Ⓗ particle or a $\bar{J}$ then the event rate for 4 muons would be 150/pulse. Alternatively, J's may be produced in association with pseudoscalar charmed mesons. These latter may have a 20% total muon decay giving $3 \times 10^3 \times 20 \times 10^{-2} \times 2 = 1200$ events/pulse with three muons and $3 \times 10^3 \times 20 \times 10^{-2} \times 20 \times 10^{-2} = 120$ events/pulse with four muons.

The rate for pseudoscalar meson detection via four muons can be estimated if we assume the same production cross section as that of the J and a 10^{-4} branching ratio into four muons. In this case we obtain about 3000 events/day for each new particle in the spectrum.

An estimate (Paschos, private communication) has been made for the cross section of parton anti-parton annihilation into four

muons. The resulting rate for the beam and detector described is about 200 events/day. This process contributes to the continuum and is of interest in its own right. Other background processes such as two photons each producing muon pairs, muon trident production, etc., appear to produce acceptably low backgrounds of multi ($\geq$ 3) muons. Special runs will be made to study backgrounds with a) the hevimet replaced by a lower atomic number material and b) the hevimet distributed so that its effective density is reduced, thereby enhancing the $\pi \rightarrow \mu$ decay probability.

It is clear from the above analysis that the proposed experiment is sensitive to small cross sections for multi-muon production. In fact, a cross section of 10^{-38} cm^2/nucleon results in about one multi ($\geq$ 3) muon event per hour. It now becomes possible to explore new regions where entirely new effects could appear. Whatever interesting effects are found, there will be interest in knowing whether they yield information on the structure (for example, anti-parton constitution) of the beam particle. For this reason, we believe it is highly desirable to locate the detector in an intense proton/pion beam.

B. Reduced Sensitivity Mode of Running

It is probably much simpler to find a location for the apparatus where the proton beam has normal dimensions ($\approx$ 1 cm) rather than those discussed in this proposal. In this case, the maximum acceptable proton beam intensity is $1/\sqrt{20} \times 10^{10} \approx 2 \times 10^9$ protons per pulse. Thus there is a factor of 5 reduction in rate. We propose that this is still an acceptable initial running condition particularly if the beam has the potential to be increased in size

at a later time. In this running condition, there is no ability to extrapolate back to the target region to eliminate background of the type (2 μ, μ), but there are fewer random triggers of this kind. There is a compensation, however, in this case. The constraint of the "point" source of muons gives a dimuon mass resolution of about ± 12% instead of ± 16% at 3 GeV/c^2.

4. Requirements from Fermilab

The most important requirement is that of the beam. As our primary objective is exploration for new particle production, the most desirable situation is a proton beam of 10^{10}/pulse and diameter which is controllable up to at least 60 cms. If this beam can be switched to become a pion beam with the same characteristics that would be advantageous but not essential. The reduced sensitivity mode of running calls for a proton beam intensity of 2 x 10^9/pulse and diameter of about a cm.

Fermilab will be required to construct the beam dump and iron magnets. Fermilab and Northern Illinois Physics Departments will supply the proportional chambers, hodoscopes and microprocessors. Special purpose microprocessors are currently being developed in the Research Services Division of Fermilab and we expect to make use of this expertise.

Some of the setting up of the experiment may be accomplished while other experiments are running upstream of our beam dump detector. We therefore request 100 hours of final set up time, 400 hours of proton beam and 200 hours of pion beam operation to do a first exploratory search.

5. Time Schedule and Personnel

From time of approval we could construct the detector in 12 months. For this reason, if prompt approval is given to this proposal we would prefer to locate in a suitable proton beam at the earliest possible time and consider the use of a pion beam at a later time.

The personnel involved are currently taking data for E-284 in P-West. They have no other experimental commitments.

6. Summary

We have proposed a study of multi-muon production in hadron collisions. The detector has a large acceptance and is designed to operate with a high interaction rate. The sensitivity of the detector is characterized by the fact that approximately 3×10^3 $(J \rightarrow 2\mu)$ events/pulse will be produced. A sensitive search for associated production of the new particles, heavy lepton production, pseudoscalar meson spectroscopy, constituent annihilation into two virtual photons, and other new phenomena will be pursued. High transverse momentum muons and dimuons will be studied with an emphasis on discovering threshold effects for large invariant mass states. There is no other proposal to search for these phenomena at either Fermilab or CERN II with a thousandth the sensitivity of this proposal. It is a natural sequel to the present experiments on dimuon production. Recent discoveries of anomalous lepton production in several laboratories strongly suggest that the proposed experiment may yield new and exciting results. We are ready to start construction of the detector immediately upon prompt approval.

Table I

Summary of Trigger Requirements

Trigger Level	Requirements	Background Trigger Rate/Pulse
T_1	Three pulses required in each plane of S_1--denoted by $S_1(3)$. Similarly for S_2 and S_3. Trigger level T_1 is then the triple triple coincidence denoted by $S_1(3)S_2(3)S_3(3)$.	10^4
T_2	Track extrapolation back to the front of the beam dump and a common origin to ± 7cms is required for all tracks.	500
T_3	M_{12}^2, M_{13}^2, and M_{23}^2 are calculated, and one of the three masses is required to be greater than 2 GeV/c^2.	0.5

References

1. J. J. Aubert et al., Phys. Rev. Lett. 33, 1404 (1974).
2. B. Knap et al., Phys. Rev. Lett. 34, 1044 (1975).
3. D. Cline, SLAC Lepton and Photon Conference, August, 1975.
4. M. Perl, SLAC Lepton and Photon Conference, August, 1975.
5. M. K. Gailliard, B. Lee, J. Rosner FNAL-THY-86 (1974). Recent experimental results suggest that the total muon decay branching ratio could be as high as 20%.
6. H. T. Nieh, T. T. Wu, C. N. Yang, Phys. Rev. Lett. 34, 49 (1975).
7. This possibility and the advantage of the hadronic production mechanism rather than by neutrinos was emphasized to us by C. Albright.
8. This possibility was suggested to us by M. Gellman.
9. A. Van Ginneken (private communication).
10. R. Adair, SLAC Lepton and Photon Conference, August, 1975.
11. The advantage of the uniform field configuration was first suggested to us by T. T. Wu.
12. We would like to acknowledge useful contributions to the development of the trigger logic by L. Holloway and T. O'Halloran.
13. The pair of muons from J decay have a chance (eg., 10% at x = 0) of going into the same counter in the x plane of S_1 say. In this case, the two muons strike different counters in the y and u planes. The muon pair together with the additional muon associated with J production will then give rise to two counters registering in the x plane and three counters in the y and u planes. Thus the trigger requirement from a hodoscope (S_1 say) is :--at least two counters firing in one plane plus at least

three counters firing in the other two planes. This is the general definition of $S_1(3)$.

14. Singer et al., Results from the 30" Bubble Chamber (private communication).

15. B. Ghidini et al., N.I.M. 125, 357 (1975).

16. J. Pilcher (Proposal 331).

Figure Captions

1. Experimental set up.
2. Position resolution versus distance between photomultipliers in a long scintillation counter.
3. Results of E-87/358 on the observed dimuon mass spectrum. Some of the observed events at masses less than 0.6 GeV could be from pion decay in flight.
4. Muon pair mass distribution from decay of two pions.
5. Results of E-87/358 on the $p_{\parallel}$ dependence of J production in neutron Be collisions.

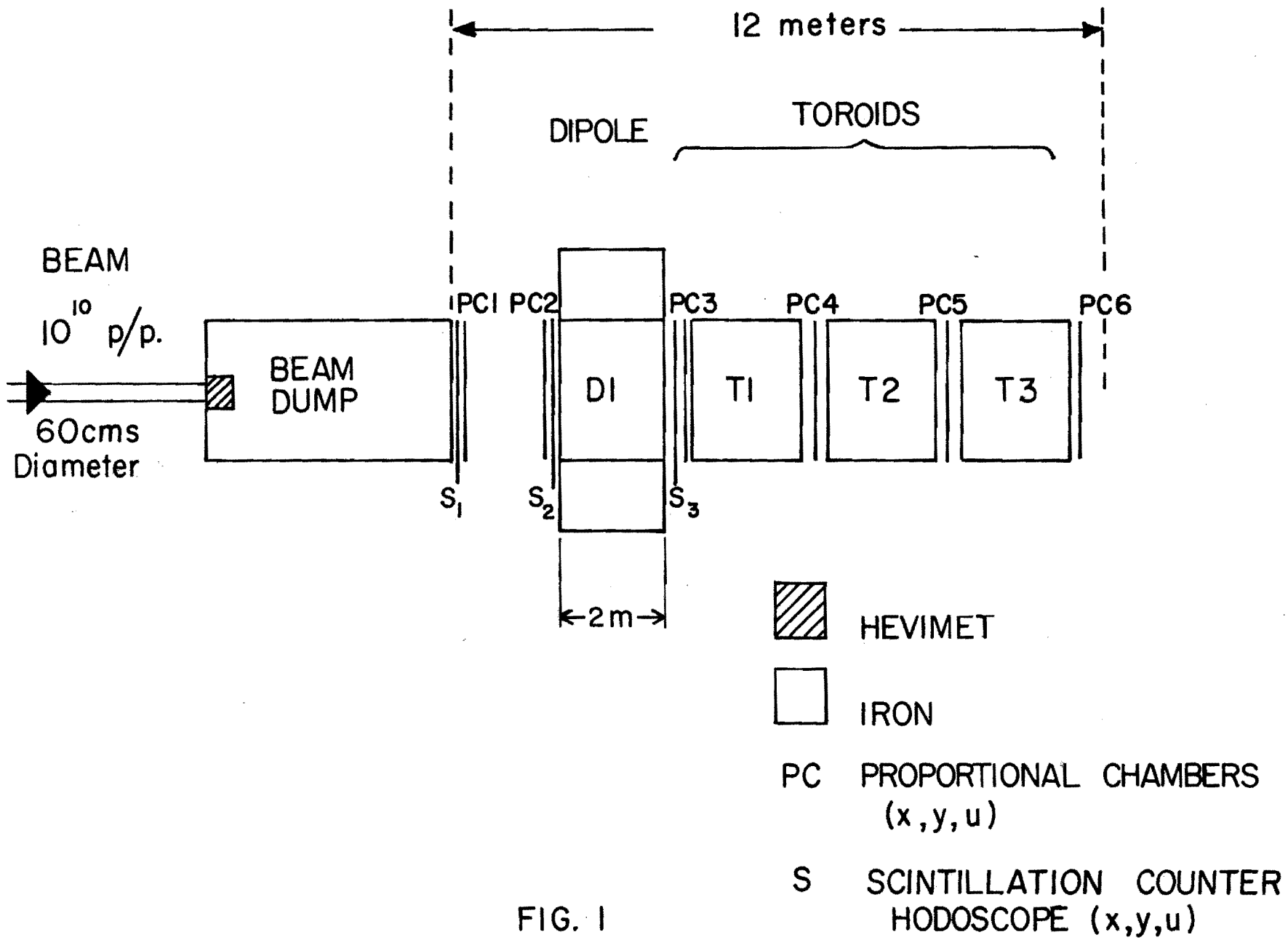
12 meters
DIPOLE
TOROIDS
BEAM
10^{10} p/p.
60cms
Diameter
BEAM
DUMP
PC1
PC2
PC3
PC4
PC5
PC6
D1
T1
T2
T3
S_1
S_2
S_3
2m
HEVIMET
IRON
PC PROPORTIONAL CHAMBERS
(x, y, u)
S SCINTILLATION COUNTER
HODOSCOPE (x,y,u)

FIG. 1

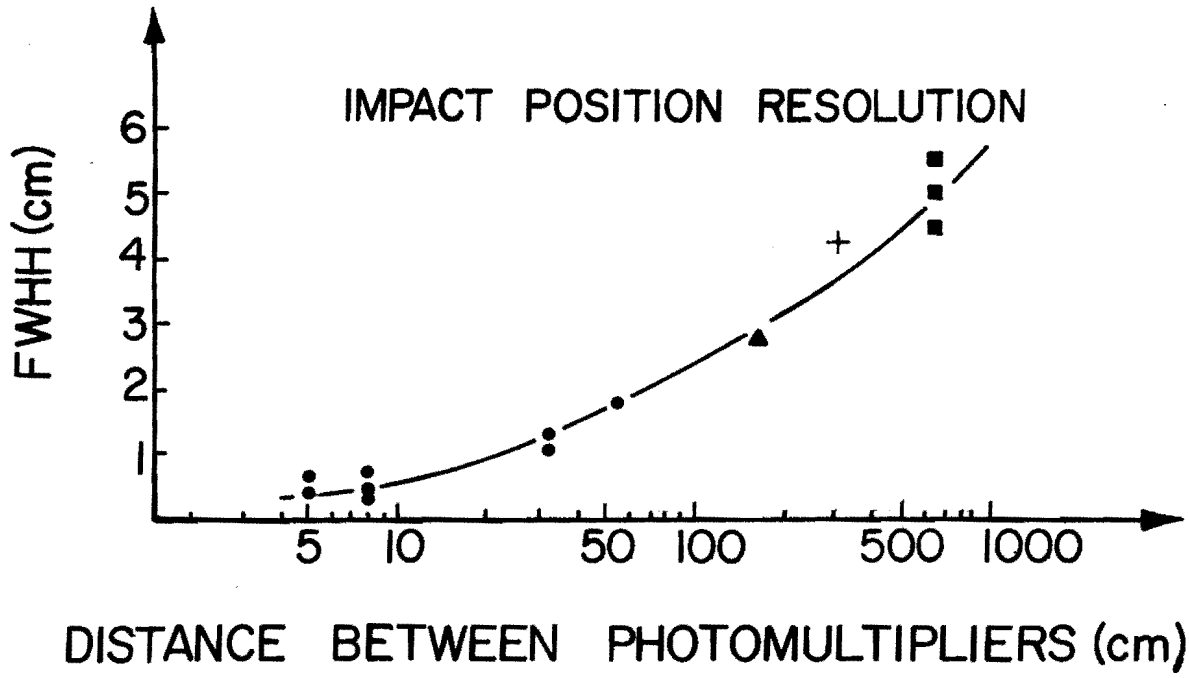
IMPACT POSITION RESOLUTION
FWHH (cm)
6
5
4
3
2
1
5
10
50
100
500
1000
DISTANCE BETWEEN PHOTOMULTIPLIERS (cm)

Fig. 2

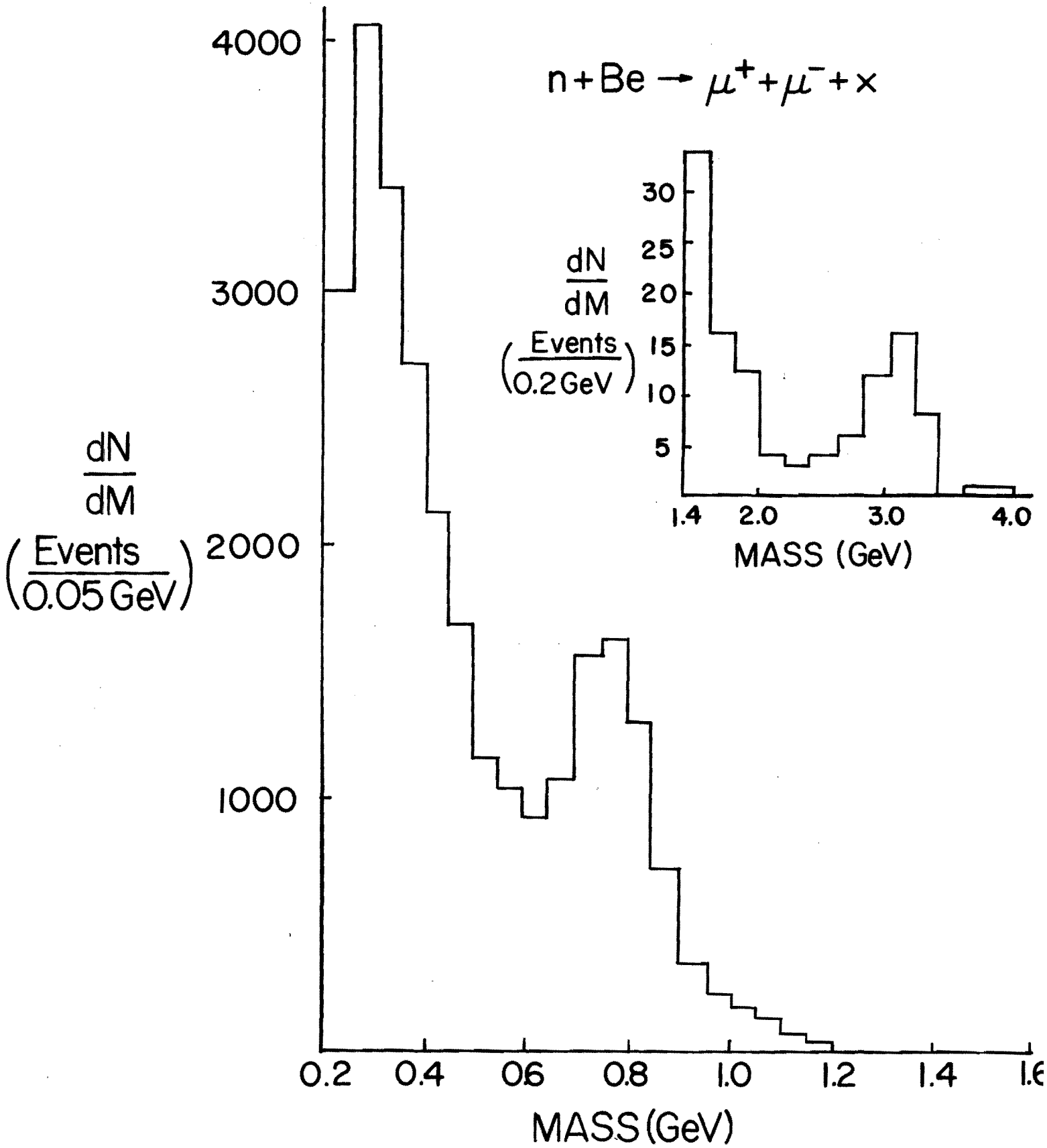
n+Be → μ⁺+μ⁻+x
4000
3000
2000
1000
dN/dM (Events/0.05 GeV)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
MASS (GeV)
30
25
20
15
10
5
dN/dM (Events/0.2 GeV)
1.4
2.0
3.0
4.0
MASS (GeV)

Fig. 3

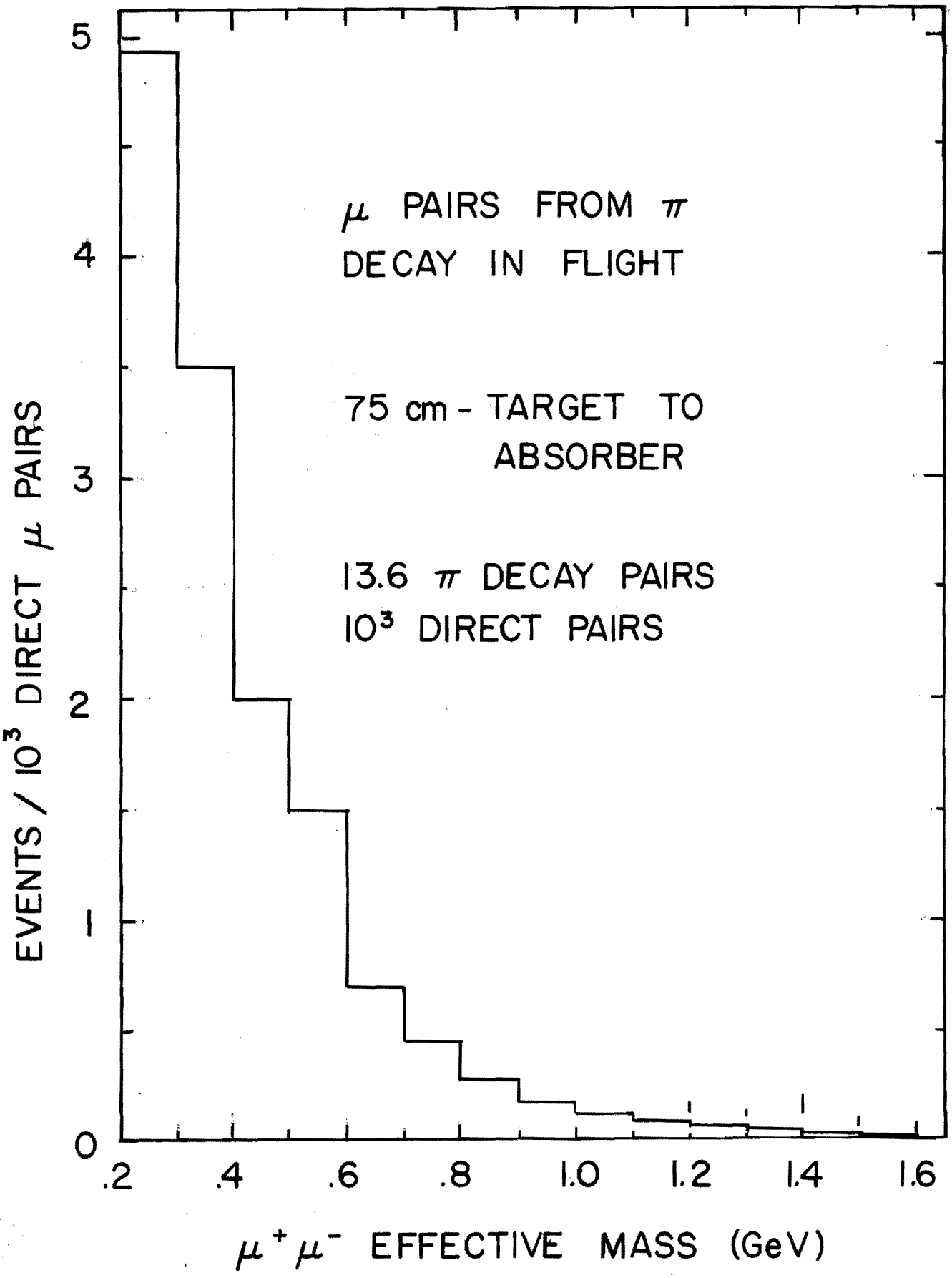
μ PAIRS FROM π
DECAY IN FLIGHT
75 cm - TARGET TO
ABSORBER
13.6 π DECAY PAIRS
10³ DIRECT PAIRS
EVENTS / 10³ DIRECT μ PAIRS
0
1
2
3
4
5
.2
.4
.6
.8
1.0
1.2
1.4
1.6
μ⁺μ⁻ EFFECTIVE MASS (GeV)

Fig. 4

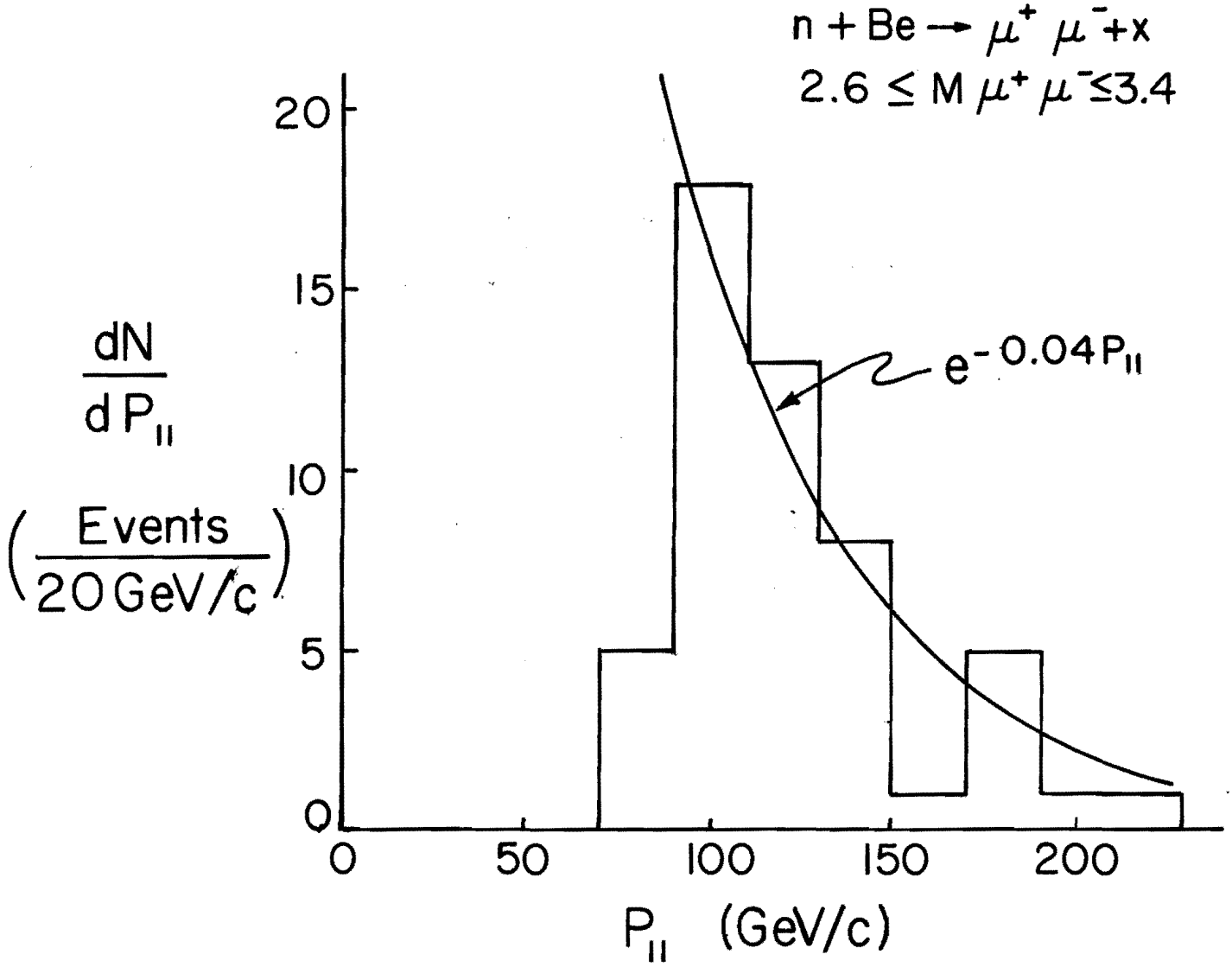
n + Be → μ⁺ μ⁻ + x
2.6 ≤ M μ⁺ μ⁻ ≤ 3.4
e^-0.04 P∥
dN/dP∥
(Events/20 GeV/c)
20
15
10
5
0
0
50
100
150
200
P∥ (GeV/c)

Fig. 5