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DIMUON PRODUCTION BY NEUTRONS

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ABSTRACT

The proposal is a request to measure the invariant cross section of dimuons produced by 300 and 400 GeV neutrons. An exploratory run has established the feasibility of the technique. A preliminary discussion of those results is presented. The experiment uses the existing E-87 detectors in EE-4 and the broad band photon beam in Proton East. Three hundred hours of beam time are requested for these measurements in order to reach 25 $(GeV/c^2)^2$ in the square of the dimuon mass and 20 $(GeV/c^2)^2$ in the momentum transfer to the dimuon.

I. INTRODUCTION

We have observed dilepton production in both photon-nucleon and neutron-nucleon interactions. A summary of what we have learned about the reactions thus far is as follows:

1. The neutron induced events indicate the presence of a rho-meson signal.
2. The neutron induced dimuon events are not dominated by vector meson production.
3. The neutron induced dimuon events extend to higher transverse momenta and masses than the photon-induced events.
4. Dimuon events have similar momentum distribution as that of a single π and the ratio is $\sim 10^{-4}$.

These observations are based on a short exploratory run which was concluded just over a month ago. The data analysis has progressed far enough so that we could make the preceding statements. In the next month we will complete the calculation of the apparatus acceptance. When that work is finished we will be able to present an analysis of the invariant cross section in terms of the dynamical variables such as S, M^2, and $P_{\perp}^{2}$. In addition, we expect to have completed a comparison of the photo production of muon pairs with the theoretical predictions. In the regions of kinematic variables where previous reliable data exists, the comparison will serve as a check on the biases in our analysis. Since the data will extend beyond those limits it will add new information.

We believe that the committee is well acquainted with the reasons for measuring the yield of directly produced leptons by hadrons. For that reason we have omitted such a discussion and instead we emphasize our ability to measure the cross sections for the neutron production of muon pairs and the photoproduction of muon pairs. It is important to note that the geometric acceptance corrections for both reactions are the same.

The diffractive photoproduction process is well understood from current theoretical knowledge. Our data will enlarge the domain of the dynamical variables over which the theory can be tested. Perhaps there will be surprises! We will be able to compare the non-diffractive part of the photo-produced dimuons with the neutron produced dimuons.

In the following sections we will emphasize only the results and the new requests which are relevant to the neutron production, since the photoproduction work is part of Experiment 87, which is approved. Our group has an identical composition for both experiments. Our main requirement is for more running time with the neutron absorbers empty.

We will describe in some detail the following topics. A description of the apparatus which was built for E-87; the modifications, completed and planned, which make the apparatus an ideal detector for dimuon studies; the status of our current data analysis from which we drew our preceding conclusions; and a description of the additional measurements which we wish to make and the requirements for running time which the new measurements imply.

II. DESCRIPTION OF BEAM AND THE E-87 DETECTOR

The neutral beam in Proton East is produced at 0 mr. The beam is a pure hadron beam when six radiation lengths of lead are inserted. It is a high purity photon beam when the lead is removed and the two neutron absorbers are filled with liquid D_2. The details of this beam will be published soon and a preliminary report was forwarded to the Fermilab.*

The apparatus for Experiment 87A was designed to study the photoproduction of a variety of final states, one of which was muon pairs. The essential features of the detector are shown in Fig. 1. There are 5 multiwire proportional chambers which have 3 independent planes, x, u, and v. Each plane, with the exception of the large downstream plane, P_4, has 2 mm wire spacing. The u and v planes of P_4 have 2 mm wire spacing while the x plane has 3 mm spacing. A magnet placed between P_2 and P_3 gives each charged particle a vertical deflection of 640 MeV/c. The momentum resolution at 50 GeV/c is estimated to be 2%. Angles are measured to a precision of 100 μr.

The magnet has a depth of 6 feet and an aperture of 24 inches vertical by 16 inches horizontal. For the arrangement shown in Fig. 1, the solid angle subtended from the target by the magnet aperture is 80 mr by 54 mr. In the center of mass of a 200 GeV particle this solid angle is 1/2 steradian.

After chamber P_4, there are two counter hodoscopes, H and V. H consists of 12 horizontal counters, arranged so that half are on one side of the beam and half are on the other side. There are 8 vertical counters, arranged so that half are above the horizontal plane containing the beam and half are below. These counters, together with a counter B immediately after the target, are used in coincidence to generate a master gate. This gate causes the multiwire proportional chamber wire signals, as well as the status of the scintillation counters, the shower counters, and the hadron calorimeter counters, to be stored in coincidence registers.

*Enclosure No. 2 of the October 14, 1974 letter to Dr. Goldwasser from Wonyong Lee.

At this point, additional requirements are imposed on an event before the decision to transfer the data to 32 K word buffer memory is made.

Following the H and V counter hodoscopes, there is an array of 22 horizontal shower counters, arranged so that 11 are on one side of the beam line and 11 on the other. Each shower counter consists of six sheets of plastic scintillator and six sheets of one radiation length thick lead. Behind these counters, there is a second set of 24 horizontal counters which are arranged and constructed in a similar manner. The second set of counters consists of 16 layers of lead and 16 layers of scintillator. The total charge from the signal from each counter is measured separately.

Following the shower counter, there is a hadron calorimeter. It consists of 24 plates of steel, each of which is 7 feet by 9 feet, with a thickness of 1-3/4 inches. Twenty counters are placed in the steel. Each counter consists of 12 leaves of scintillator which are viewed by a single phototube. As with the shower counter, the charge from each counter which is in coincidence with the master gate is separately measured. The counters were not installed during the exploratory run.

Following the hadron calorimeter, there is a muon identifier. It consists of an additional 48 inches of steel, an 18 counter vertical hodoscope, and a 22 counter horizontal hodoscope. The steel is subdivided so that the last twenty-four inches separates the two planes of counters. There is an 8 inch x 8 inch hole in the muon identifier along the beam line.

III. MODIFICATIONS MADE TO THE E-87 DETECTOR FOR THE DILEPTON MEASUREMENTS

When the dimuon measurements were made, a hadron calorimeter, UHC, was placed immediately after P_o. This counter consisted of 12 leaves of scintillator, each of which was 36 inches x 18 inches x 1/4 inch. Between each pair of leaves there was a block of steel which was 12 inches x 12 inches x 2 inches. Following the calorimeter there was a steel shield which was 47-1/2 inches thick, 32 inches wide, and 32 inches high.

During a special run this calorimeter was used to measure the neutron momentum spectrum. While the absolute energy scale will only be known accurately after the counter is calibrated in a monoenergetic beam, it is possible to estimate the scale from the location of the end point energy of 300 GeV. The momentum spectrum, with this qualification, can be inferred from the pulse height spectrum. The results are shown in Figure 2. The energy resolution at 300 GeV is consistent with 12% FWHM.

The calorimeter was used throughout the data runs to measure the hadronic energy of the interaction products and to monitor the beam flux. When the energy carried by the muon pair is added to the energy absorbed in the calorimeter, the resulting neutron spectrum between 200 GeV and 300 GeV agrees very well with the spectrum of Figure 2 without adjustment of the energy scale. Since this portion contains the rapid fall of the neutron spectrum, the agreement establishes that the neutron energy can be measured on an event by event basis.

The improvements which we would make for the next run would be to increase the size of the steel in the upstream hadron calorimeter to 36 inches x 30 inches. Rather than using one 12-leaf counter, two would be used. The solid angle subtended from the target by this calorimeter would be 0.7 sr. Two additional chambers would be added in front of P_o, replacing the small single plane 1 mm chamber which was used for part of the data taking. No other additional equipment would be required.

Data was taken using the following trigger. The event gate was generated when there was a coincidence among all of the following counters; the B counter, the AW_3 and AW_4 counters, at least one H counter, and one V counter. The status of the counter registers was checked to be sure that there was no count in the A counter, the beam veto, or the wall antis. There were additional requirements for each of the three following types of events.

1. 1-μ events: one or more muons on one side.
2. 2-μ asymmetric events: two or more muons on the same side.
3. 2-μ symmetric events: one or more muons on one side and one or more muons on the other side.

A particle is called a muon if a horizontal and vertical muon counter on the same side register. The three types of events were recorded simultaneously. However, only one out of every eight single muon events were recorded since they were so numerous.

IV. STATUS OF THE ANALYSIS

Neutron data and photon data were taken with three types of targets; polyethylene, aluminum and copper. These targets were placed at 18 inches, 40 inches, 60 inches, and 80 inches from the upstream hadron calorimeters. Over one hundred thousand two track events have been reconstructed which are candidates for being dimuons. In addition, more than one million single track events have been reconstructed which are candidates for single muons. The following comments are based on a smaller, more well understood sample of the data.

In order to demonstrate that the two track events which we have observed are indeed the direct production of dimuons, we show that:

1. the tracks come from the target,
2. the tracks are muons,
3. the tracks are not due to $\pi \to \mu$ decay,
4. the tracks are not produced indirectly by known processes.

1. The tracks come from the target

The multiple scattering introduces an rms error of only .8" when the 25 GeV particle track is projected back to the target. A target cut is imposed which requires both tracks to come from the target. For the events which were obtained from target positions which were 60" or more from the dump, the resolution is good enough when the mass is greater than .3 GeV/c^2 to determine that the events could have only come from the target. For these conditions, non-target background is less than 10%.

2. The tracks are muons

In order for a muon to count in both horizontal and vertical muon counters it must traverse seventy inches of steel between P_0 and P_1, have at least 5 GeV/c momentum to prevent being bent away from the muon identifier, and finally it must traverse an additional 114 inches of steel to reach the muon counters. In the analysis, we require that the particle track must project into the muon counters which were in coincidence with the master gate before it is called a muon. Allowance is made for multiple scattering.

A muon pair requires that at least one member of the pair traverse two of the correct counters and the other member must traverse at least the first of the two correct counters. A significant number of the muons are ranged out. It is possible to examine these events in more detail by looking at the pulse heights in the hadron calorimeter and the muon counters. Large pulse heights denote hadrons. During the exploratory run the shower counters were used for this purpose.

3. The tracks are not due to $\pi \to \mu$ decay

The average number of charged particles per events which go through P_0 is measured to be six. If two pions decay at random from such a sample one expects that the total number of pairs which have particles of like charge will be as numerous as pairs of particles which have opposite charge. The data contains more than ten times as many pairs of opposite charge as pairs of identical charge. Closer inspection shows that most of the identical charge pairs have one low momentum track which did not count in the muon counter. These pairs actually came from the one muon category of events. We are able to eliminate virutally all of the like charge pairs by reasonable criteria.

We have checked the dependence of the yield of lepton pairs on the target position and we find that it does not depend on the position.

4. The tracks are not produced indirectly by known processes.

4a. $n + N \to \pi^o + X;\ \pi^o \to \gamma\gamma;\ \gamma + Z \to \mu^+ \mu^- Z$

A possible source of background could come from the two step process associated with π^o's which are produced by neutron interactions in the target. The neutron interaction causes B to count, subsequently the photons from the π^o's produce $\mu^+ \mu^-$ pairs in the steel shield through the Bethe Heitler mechanism.

We can calculate the contribution for this process from the single muon data in such a manner that the normalization errors and accidentals are accounted for properly. By analyzing the dependence of the single muon events on the target position, the yield of muons from pion decays can be established. From these numbers, the yield of π^+ and π^- per neutron interaction can be determined. In turn, from the yield of charged mesons, the yield of π^o's and hence γ's can be determined. The γ spectrum is then used as an input to a Monte Carlo program which determines the yield of μ^+ and μ^- pairs produced in the steel which can be detected in the apparatus. A preliminary version of this calculation established that this indirect process is less than 20% of the observed rate. The assumptions which were made to make the problem tractable caused the process to be overestimated. The more accurate calculation is almost finished.

As a check of our estimates of the π^+ and π^- yields from the single muon data, a separate run was taken with the steel shield and the calorimeter (UHC) removed. The master gate served as the trigger. The calculated π^- yield agrees quite well with the π^- yield from this measurement.

4b. Decays of known particles

$\eta \rightarrow \mu^+ \mu^- \gamma$

Other than the decay of the vector mesons into $\mu^+ \mu^-$ pairs, the most likely particle decays is $\eta \rightarrow \mu^+ \mu^- \gamma$.

We estimate the branching ratio of $\eta \rightarrow \mu^+ \mu^- + \gamma$ to $\eta \rightarrow$ all to be 2×10^{-4}. If the production of η in the kinematic range over which we have observed dileptons is 10% or less of the production of pions in the same range, then the contribution to the background is less than 20%. Based on our calculations, we find the distribution in energy of dimuon is similar to that of pion and the ratio is $\sim 10^{-4}$. As is shown in the mass distribution, the distribution in mass of dilepton from neutron is substantially different from that of photon. Therefore, we believe we observed direct production of dimuon via neutrons.

In Figure 3 we show dimuon mass distributions for a sample of neutron and photon induced events. The distributions are raw data, uncorrected for acceptance, but restricted to events with more than 50 GeV dimuon energy. Our acceptance is then reasonably independent of mass, and similar for neutrons and photons. From these distributions we see a strong suggestion of rho mesons in the neutron induced events.

V. ADDITIONAL MEASUREMENTS

The main aspect of the new measurements is to study dimuon production with neutrons of up to 400 GeV. 400 GeV should make it possible to extend the limits of mass squared and momentum transfer to 25 $(\text{GeV}/c^2)^2$ and 20 $(\text{GeV}/c)^2$, respectively. We would propose to take the data under the following conditions:

1. Low intensity at 400 GeV

   These measurements would be made in a manner similar to the measurements which were made previously at 300 GeV. The neutron beam intensity would be about 2×10^6 neutrons per second. From this data we would expect to determine the invariant cross section for dimuon pairs with squared masses less than

10 $(GeV/c^2)^2$ and momentum transfer of less than 10 $(GeV/c)^2$. The hadron calorimeter will make it possible to measure the energy of the neutrons on an event by event basis. When the 300 GeV data is combined with 400 GeV data we will have useful data which spans a neutron energy range of 150 to 360 GeV/c.

2. High intensity at 400 GeV

   In order to have a sensitivity for higher mass and higher momentum transfer events, we need a greater integrated flux and, therefore, we propose to run at higher intensity (of the order of 10^{12} protons/pulse).

   Our goal would be to take useful data at neutron intensities which are at least an order of magnitude greater than in the first part of the run. Under these conditions the hadron calorimeter could not be used. If we can achieve our objective, we can extend the values of dimuon mass squared and momentum transfer to 25 $(GeV/c^2)^2$ and 20 $(GeV/c^2)^2$, respectively.

3. Running with a 300 GeV front porch

   If the accelerator is operating with a 300 GeV slow spill front porch simultaneously with a 400 GeV slow spill, we would plan to take data at 300 GeV simultaneously with 400 GeV. We have successfully taken data at two energies, when Proton East operated with a 200 GeV slow spill front porch and a 300 GeV slow spill.

At low intensity we would like to be able to check any problems which the present analysis may uncover and to reestablish the normalization of our data associated with the minor modification of geometry and detectors which we are planning.

At high intensity, it would enable us to establish the energy dependence of the cross section since we cannot use the hadron calorimeter.

We request 300 hours of running time at 400 GeV.

VI. LONG RANGE PLAN

We hope that we will answer many of the outstanding questions in dimuon physics when we complete the run. However, we may end up with more questions than answers when we complete the next run. Looking far ahead, we are thinking about improvements we would like to make in our detectors. One such improvement would be a larger analyzing magnet.

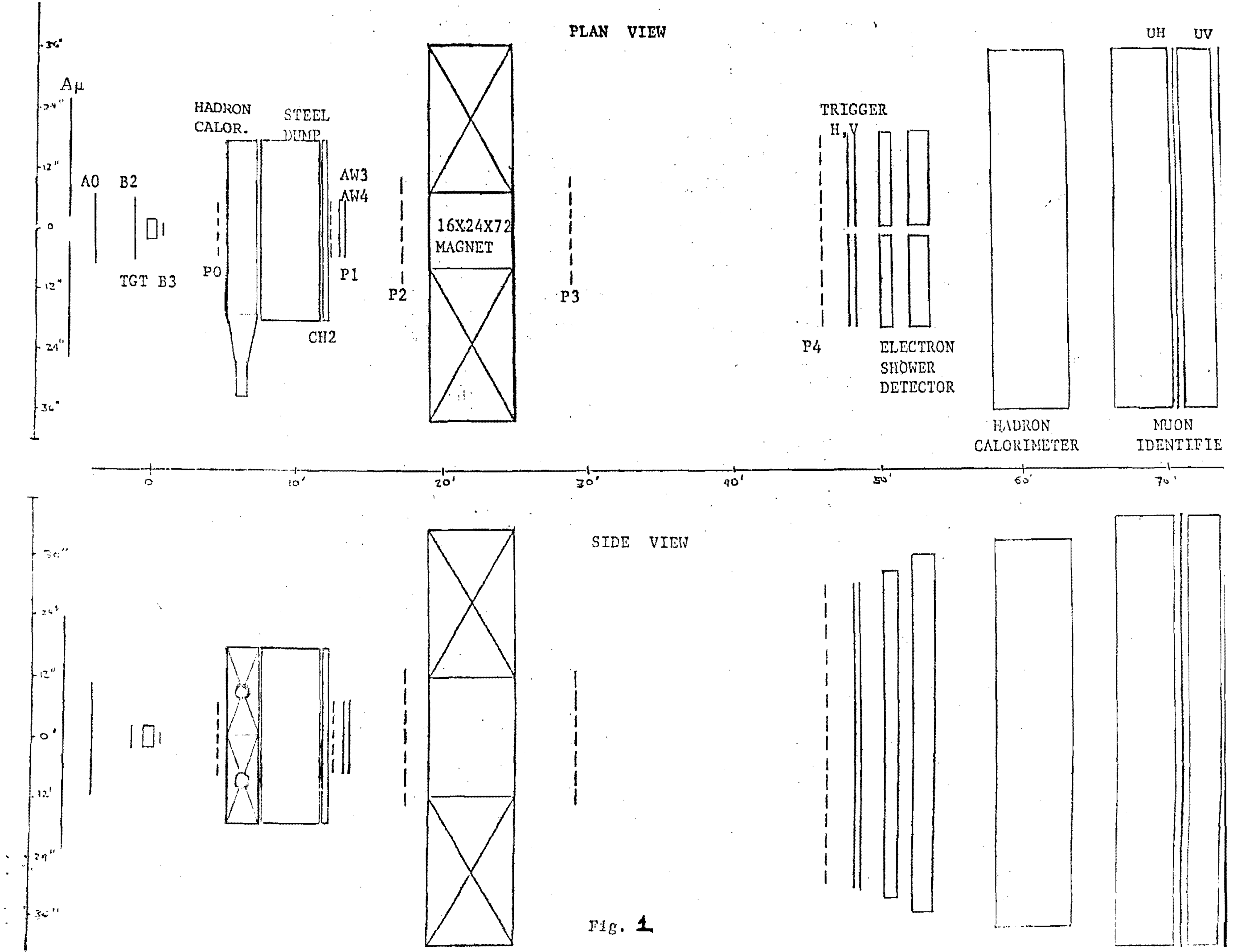
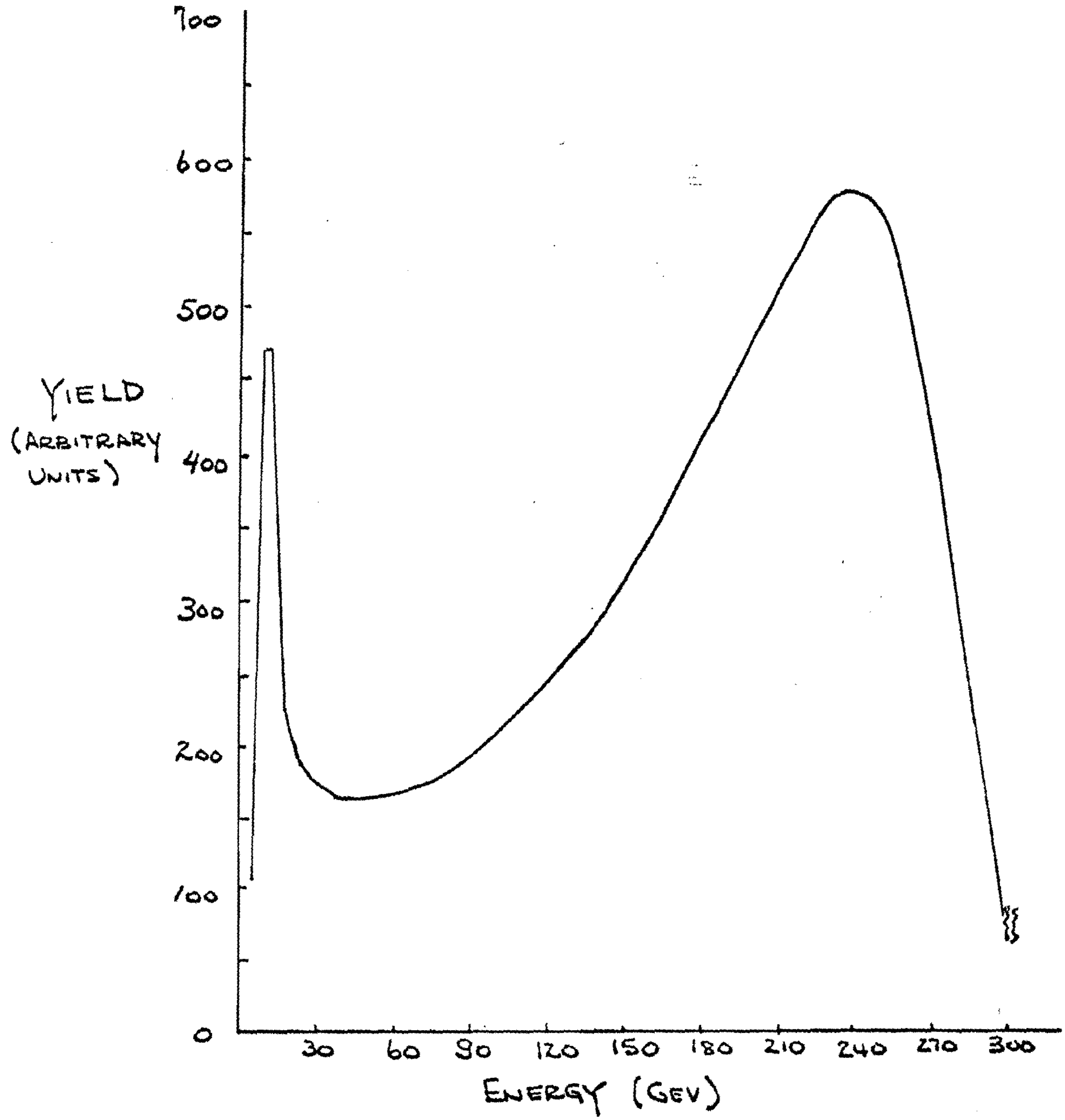
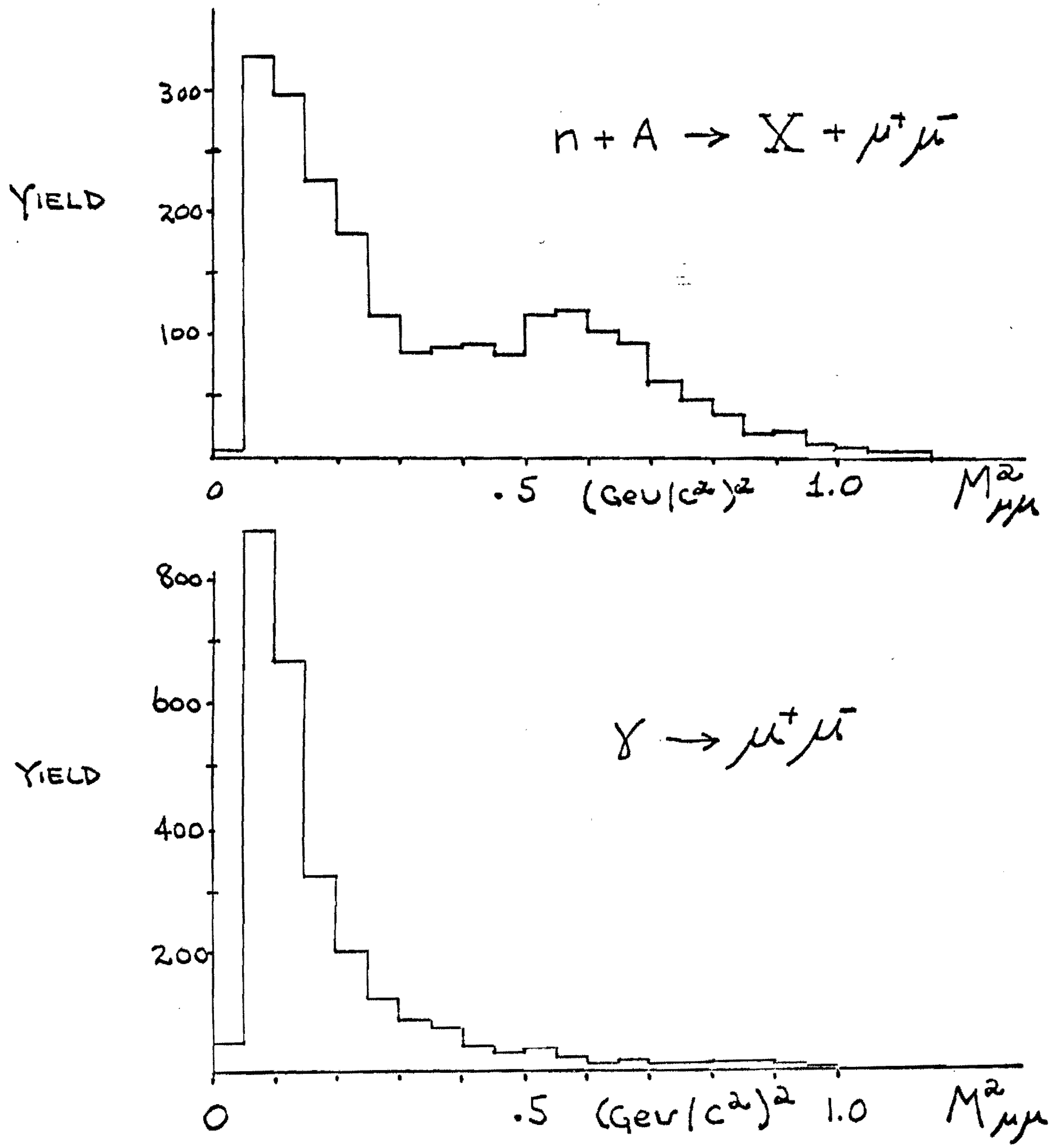

PLAN VIEW
UH
UV
Aμ
HADRON
CALOR.
STEEL
DUMP
TRIGGER
H,V
A0
B2
AW3
AW4
16X24X72
MAGNET
P0
TGT B3
P1
P2
P3
P4
CH2
ELECTRON
SHOWER
DETECTOR
HADRON
CALORIMETER
MUON
IDENTIFIE
0
10'
20'
30'
40'
50'
60'
70'
SIDE VIEW

Fig. 1

FIGURE 2

O MR NEUTRON ENERGY SPECTRUM FROM 300 GEV PROTONS ON Be.





YIELD
300
200
100
n + A → X + μ⁺μ⁻
0
.5
(GeV/c²)²
1.0
M²μμ
YIELD
800
600
400
200
γ → μ⁺μ⁻
0
.5
(GeV/c²)²
1.0
M²μμ

Figure 3.