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DIMUON PRODUCTION BY HIGH ENERGY NEUTRONS

B. Knapp, W. Lee, P. Leung, S. D. Smith, A. Wijangco, Columbia Univ.*,
J. Knauer, D. Yount, Univ. of Hawaii†, D. Nease, Cornell Univ.*,
J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley,
R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler,
Univ. of Illinois†, and M. Binkley, R. Orr, J. Peoples, L. Read, FNAL†

This is a report on measurements studying the reaction $n + Be \rightarrow \mu^+\mu^- + X$ using high energy neutrons produced by 300 GeV and 380 GeV protons at the Fermi National Accelerator Laboratory. A preliminary report has already been published on the 300 GeV data (Phys. Rev. Letters 34, 1044 (1975)); therefore emphasis will be placed on the more recent results obtained at higher energies.

The neutrons are produced about 120 meters away from the detecting apparatus by allowing protons to hit a 30 cm. long beryllium target. The charged particles are swept out by a magnet field; the neutral particles pass through a series of collimators and sweeping magnets and 18 radiation lengths of lead in order to remove the photons that are present. The resultant beam consists predominantly of neutrons with a few percent of K_L^o mesons of lower energy than the neutrons. The type of neutron spectrum that we have obtained is shown in figure 1. For the two runs, the average energy of the neutrons is considered to be 250 GeV and 340 GeV.

The detecting apparatus shown in figure 2 includes veto counters, the Be target, monitoring counters, a hadron calorimeter consisting of 24 steel plates 4-1/2 cm. thick with 6 mm. thick scintillators between them. This hadron calorimeter was used in determining the neutron spectrum. It had been previously calibrated in a proton beam. There are an additional 60 centimeters of steel in order to further attenuate hadrons. Therefore with this arrangement, we can only study muon production.

The momentum of the muons is measured in a magnetic spectrometer consisting of 4 multiwire proportional chambers each containing three planes. Downstream of the spectrometer is a series of vertical and horizontal counters which are used as part of the trigger. The remaining apparatus of interest is a muon identifier. There are about 1900 gms./cm.^{2}, mainly of steel, followed by a horizontal array of 24 counters,

followed by an additional 450 gms./cm.^{2} of steel, and then a vertical array of 22 counters. The trigger for a dimuon event required 3 out of 4 of these counters in order to avoid losing those events where two of the muons passed through the same counter; the efficiency of this system for four out of four counters was approximately 93%.

The aperture in the magnet was the basic limitation on our acceptance; it was $\Delta\theta/2 \sim 30$ milliradians in the laboratory. The minimum momentum muon which could reach the muon hodoscope is about 7 GeV/c. For particles of the mass of the $\psi(3.1)$, the acceptance is non-zero for the sum of the momentum of the particles above 70 GeV/c.

Results

Figure 3 shows the mass of the dimuons in the lower mass region for the run with $\bar{E}_n = 340$ GeV. One sees a continuum with a pronounced peak at the mass of the ρ meson. Figure 4 shows the higher mass region with 49 events in the interval of the $\psi(3.1)$, 2.8 GeV/c^2 < $M_{\mu\mu}$ < 3.4 GeV/c^2. There is also one event that is at a mass consistent with that of the $\psi'(3.7)$. For the run with 250 GeV neutrons, there were 2 events at about 3.7 compared with 40 events at the mass of the $\psi(3.1)$.

We have an appreciable amount of steel in our apparatus, which is excellent for being certain that you have muons; however, the multiple scattering smears out the mass resolution and creates a good deal of uncertainty especially in the low mass continuum. A variety of ways to correct for the multiple scattering were studied in a series of Monte Carlo calculations. The usual way to obtain the mass is to use the vectors as measured in the upstream multiwire proportional chamber to determine the opening angle and to calculate with the measured momentum using the relationship $M_v^2 = (E_1+E_2)^2 - (\vec{p}_1+\vec{p}_2)^2$. ($M_v$ designates mass obtained with vectors.) It was found that we could obtain a better determination of the mass (designated "corrected mass" M_c) by reconstructing the vectors to the center of the upstream hadron absorber and by then using the separation of the particles at that position extrapolated to the center of the target to determine θ, the opening angle. This is then used in $M_c^2 = m_\mu^2(2 + p_1/p_2 + p_2/p_1) + p_1 p_2 \theta^2$; the data in figures 3 and 4 are M_c.

If one demands that $|M_c - M_v| \lesssim .3$, then one is making an uncertain but selective cut on events which have a small amount of multiple scattering. An analysis is currently underway using such cuts to see if the data contains evidence for dimuon production in the mass regions of the ϕ and the ρ'.

The number of events as a function of $p_{\parallel}$ of the dimuon pair is shown in figure 5. The dotted line is the result of a Monte Carlo calculation which includes the acceptance and the assumption that the $p_{\parallel}$ distribution is of the form e^{-10X} where $X = \frac{p_{\parallel}^*}{p_{max}^*}$ (center of mass). In figure 5 the lack of events at lower $p_{\parallel}$ is due to our acceptance. The distribution of events in terms of $p_\perp^2$ is shown in figure 6. The dotted line is the result of a Monte Carlo program that assumes $E^{-2p_\perp^2}$. These distributions are very similar to those that were obtained using 250 GeV neutrons.

It is interesting to compare the $p_\perp$ distribution of dimuons from the ρ and the $\psi(3.1)$. We have done this with the data obtained using 300 GeV protons, and it is shown in figure 7. One sees that there is an appreciably slower falloff with $p_\perp$ for the ψ than for ρ, indicating that different mechanisms may be involved in the production of the ψ than in the production of the ρ mesons. The more obvious explanations are that the ψ is produced accompanied by the production of other massive particles and/or that some of the ψ events are the decay products of more massive particles.

In principle it is very easy to obtain a cross-section. In our experiment, simultaneously with the measurement of the production of the ψ's, we measure the total number of neutron interactions in the target. If one assumes that each interaction of a neutron corresponds to 40 millibarns per nucleon, then we can divide the total number of ψ events, 49, by the total number of interactions, and we get a number. However, the number is really (the cross-section) x (the branching ratio) x (the acceptance). For the above data $\sigma BA = 0.35$ nanobarns/nucleon for our region of measurement. Using the value of the branching ratio $\Gamma_{\psi\to\mu\mu}/\Gamma_{\text{total}} = .069$, reported by the SPEAR Group at the Washington APS meeting and using our measured distribution in $p_\perp$ and a calculated acceptance we obtain for the production of $\psi(3.1)$ by 340 GeV neutrons $\sigma = 62$ nb/nucleon for $|X| > 0.25$ and $\sigma = 32$ nb/nucleon for $|X| > 0.32$. When we write the absolute value of X, we are multiplying by 2 to account for the backward and forward hemisphere production. For our previous run with 250 GeV neutrons, $\sigma = 26$ nb/nucleon for $|X| > 0.32$. Statistical uncertainties in each case would be those associated with about 50 events; thus there is no statistically significant change in the cross-section between 250 GeV and 340 GeV. We are currently running Monte Carlos to get a better determination of the uncertainties in the acceptance calculations.

Without a knowledge of the mechanisms involved in the production of these particles, for example whether they are accompanied by other particles or are decay products, it is dangerous to extrapolate from $|X| > 0.32$ down to zero. The correction would be greater than a factor of 20. The groups at BNL and at ISR who have been measuring cross-sections for this process have been operating in different regions of X. Our results are several orders of magnitude above those reported from the proton production at BNL at much lower energies. Therefore the possibility exists that the mechanisms involved in the production at lower energies may be different from the mechanisms involved in the production at our energies and those at ISR. The results given by the ISR group at the APS meeting appeared to be about a factor of 2 or 3 greater than the cross-section we obtained. Whether one should consider this a real increase with energy is not clear until we have a more precise understanding of the distributions.

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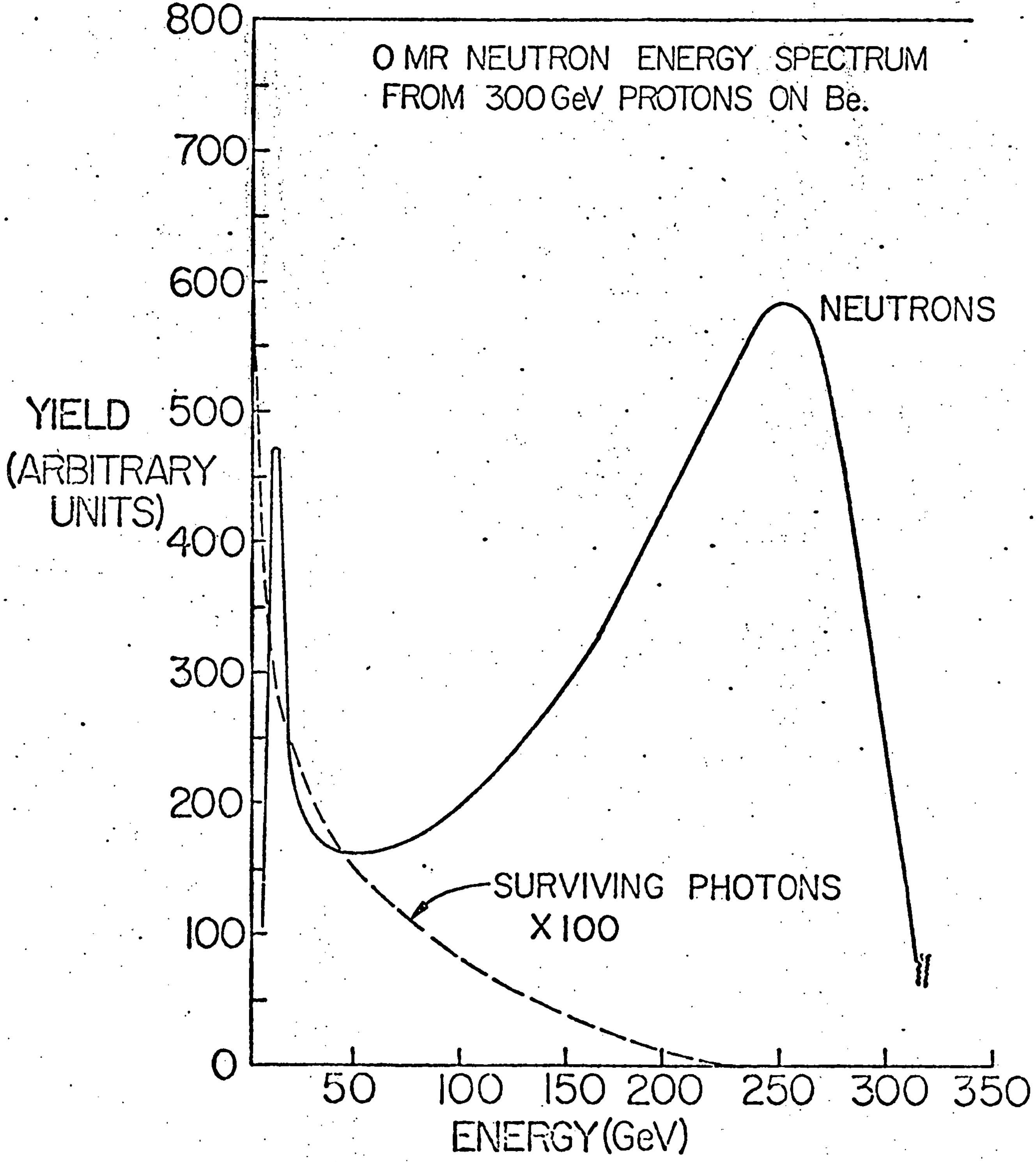

Figure 1. The Neutron Spectrum from 300 GeV Proton on Be as measured in a hadron calorimeter which previously had been calibrated in a proton beam.

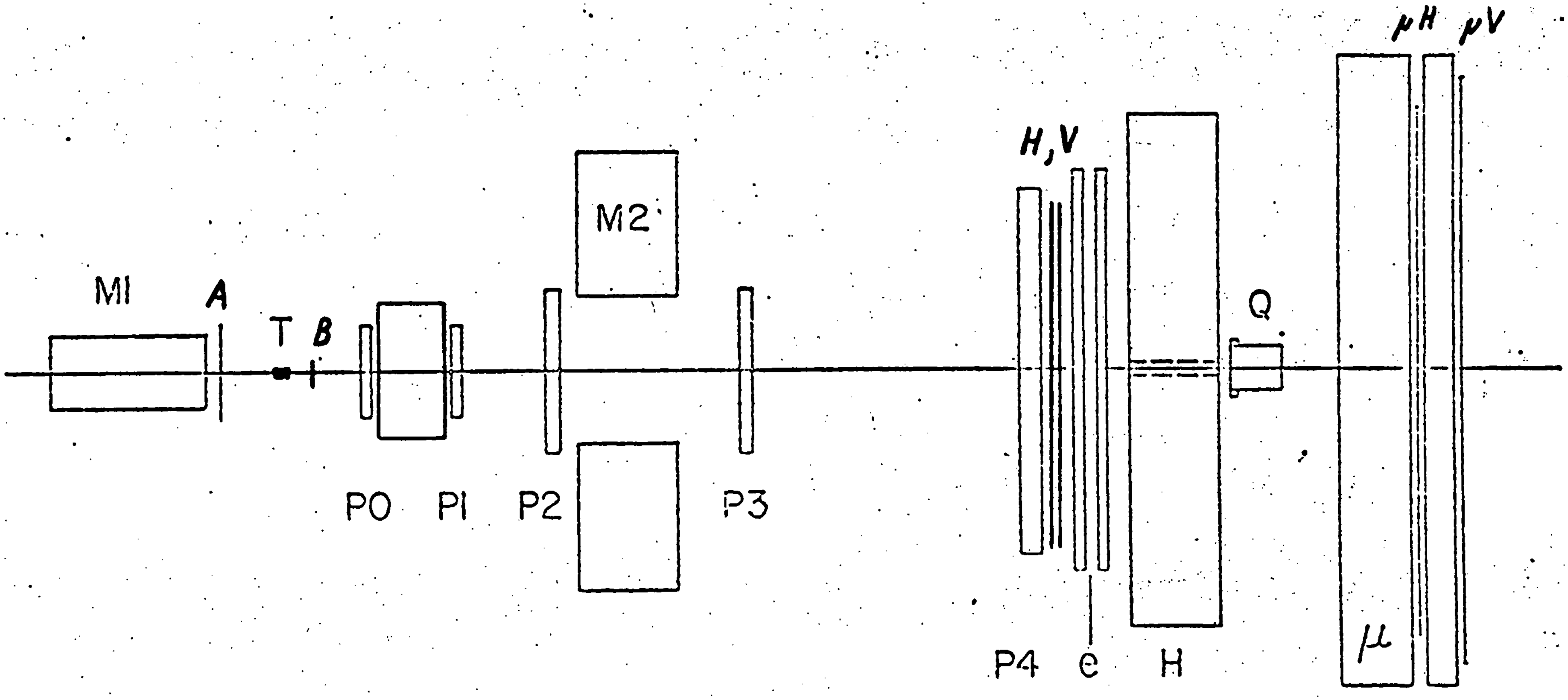

Figure 2. Schematic drawing of apparatus used to study n + Be → μμ + X

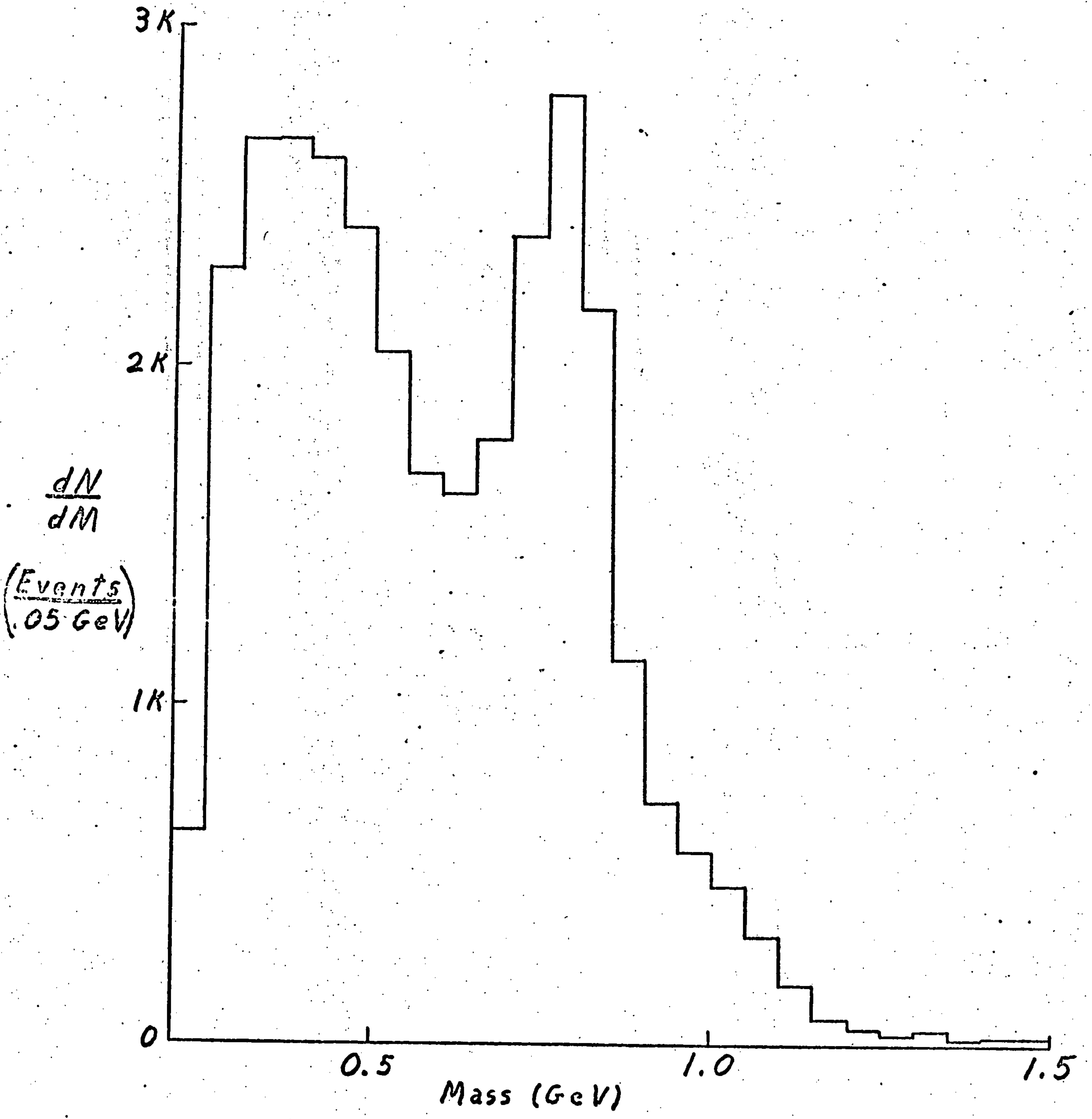

Figure 3. Dimuon mass distribution for M < 1.5 GeV/c^2 (using 380 GeV proton to produce neutrons).

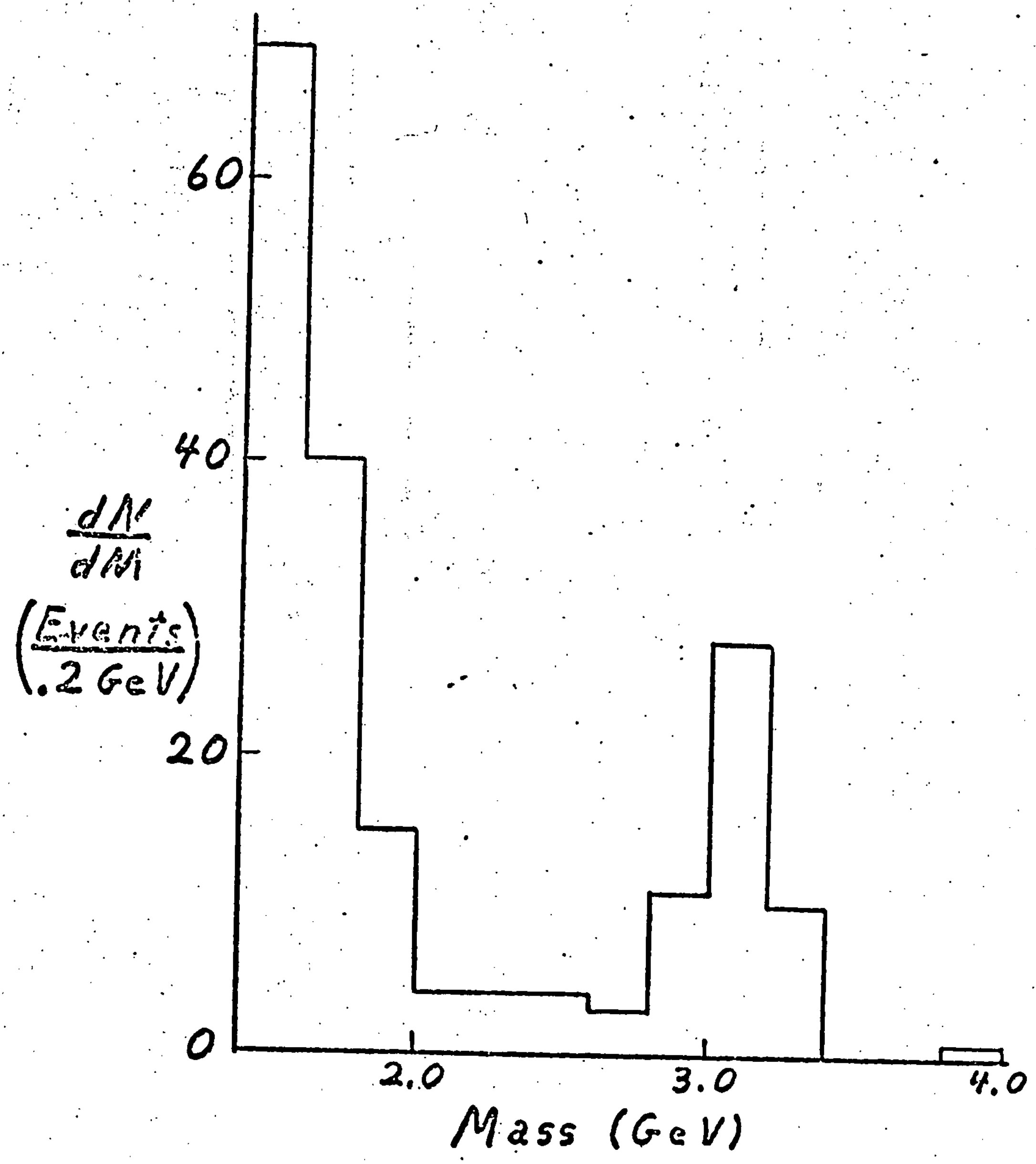

Figure 4. Dimuon mass distribution for $M > 1.4\ \mathrm{GeV}/c^2$ (using 380 GeV proton to produce neutrons).

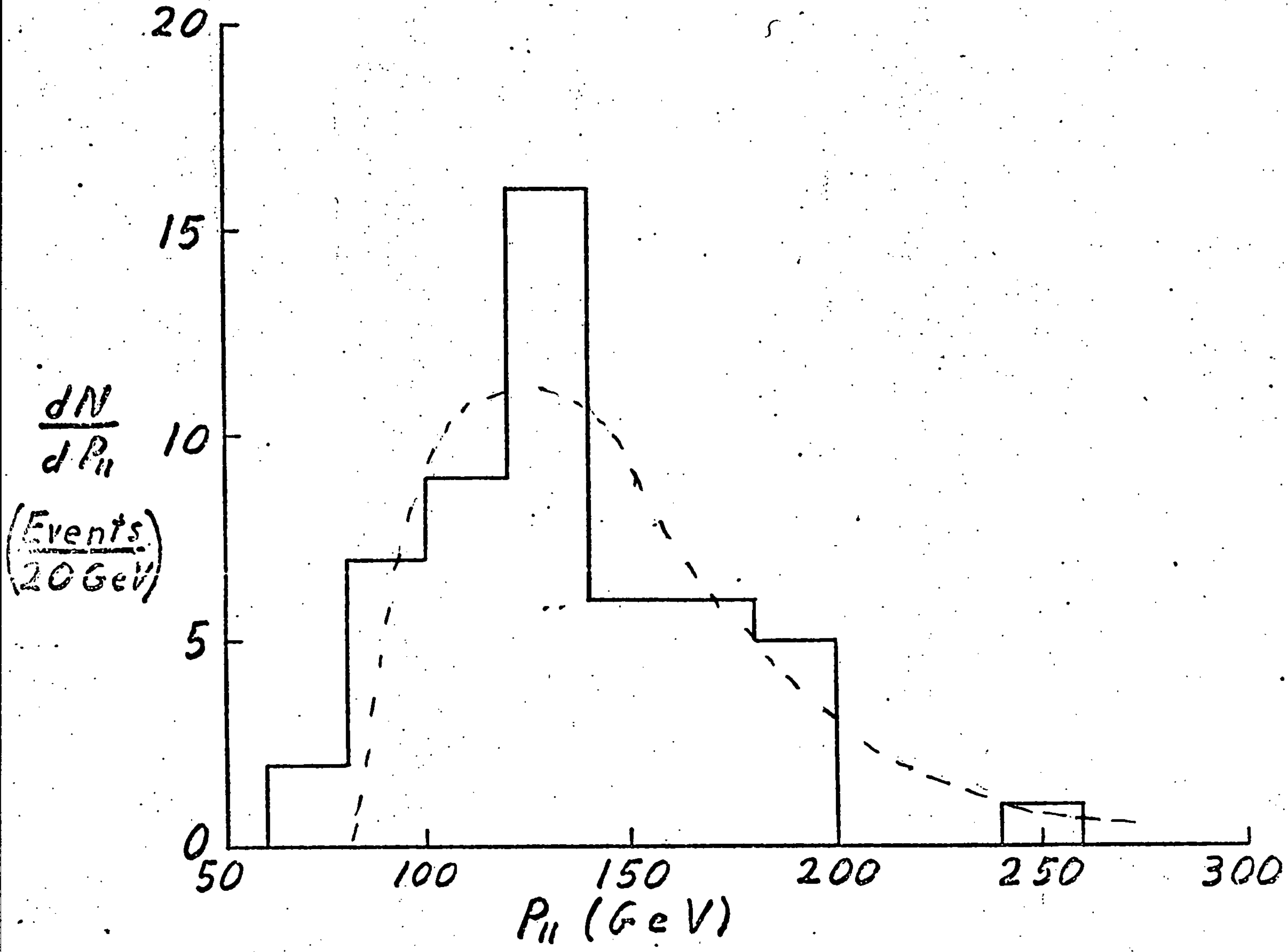

Figure 5. The distribution in $p_{\parallel}$ of dimuon pairs with $2.8 < M_{\mu\mu} < 3.4$ GeV/c^2 (using 380 GeV protons to produce neutrons). The dotted curve is from a Monte Carlo calculation of the acceptance assuming e^{-10x}

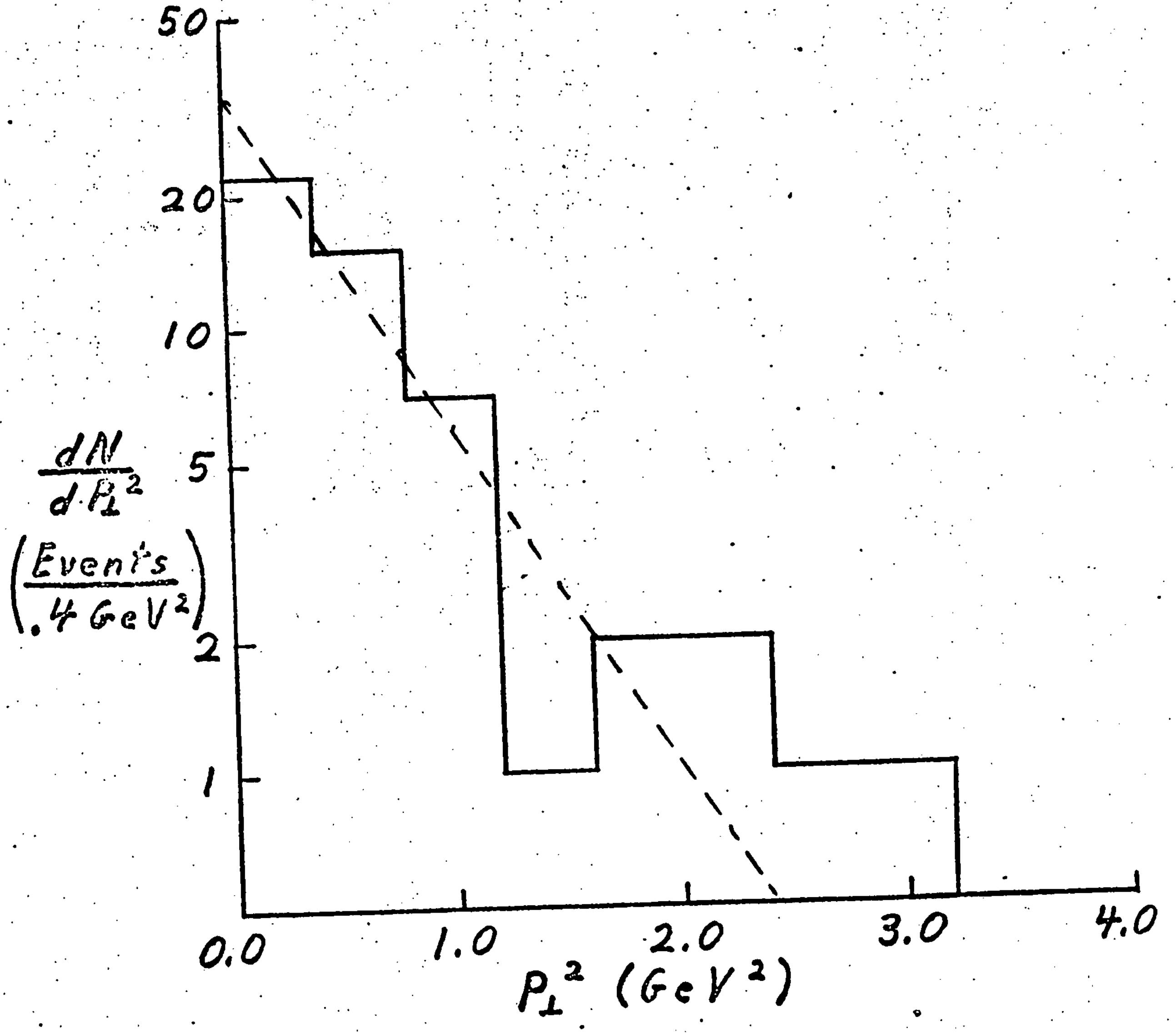

Figure 6. The distribution in $p_\perp^2$ of the dimuon pairs with $2.8 < M_{\mu\mu} < 3.4$ GeV/c^2 (using 380 GeV protons to produce neutrons). The dotted line is from a Monte Carlo calculation of the acceptance assuming $e^{-2p_\perp^2}$.

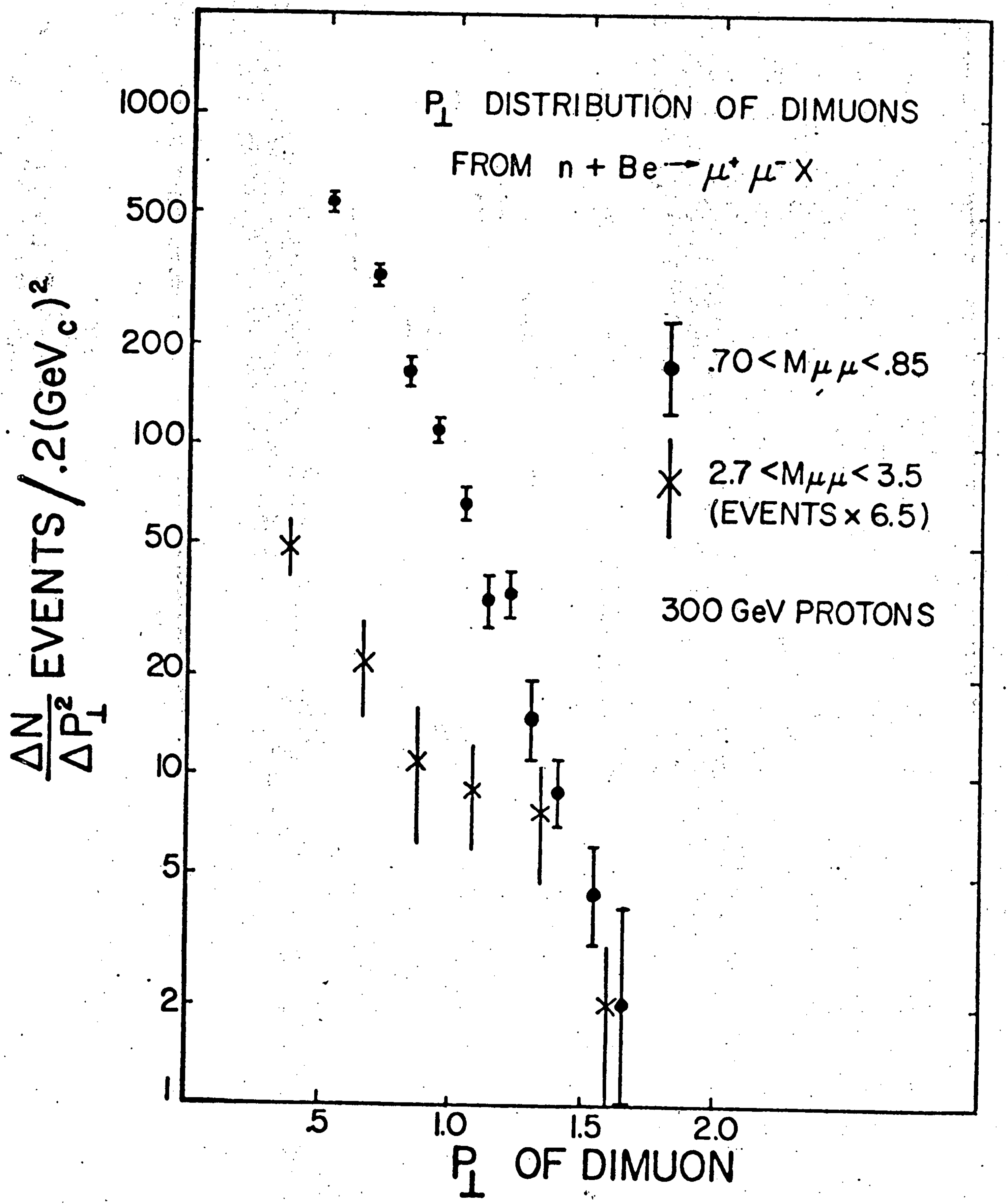

Figure 7. A plot of $\Delta N/\Delta p_\perp^2$ vs. $p_\perp$ for dimuon pairs in the mass region of the ρ and the $\psi(3.1)$ from data obtained using 300 GeV protons to produce neutrons.