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HIGH ENERGY PHOTOPRODUCTION OF NEW MASSIVE PARTICLES

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During the last several years a high energy photon beam was designed and constructed at the Fermi National Accelerator Laboratory combined with a detecting system that would allow us to identify and measure the energy of leptons, photons and hadrons. One of the purposes was to look for new massive $J^P = 1^-$ objects. During the last nine months we have had a series of experimental runs using this apparatus in which, among other things, we have studied the high energy photoproduction of the narrow resonance at 3.1 GeV/c^2. I will first describe the beam, then the detecting apparatus, and then I will discuss the results we have obtained on the high energy photoproduction of the new massive particles.

(1) Beam: A neutral beam is created by protons hitting a 30 cm beryllium target; the protons and other charged particles leaving the target region are deflected by a magnetic field into a beam dump. The neutral particles produced in the target include: photons, neutrons, anti-neutrons, and K°_L mesons. In order to change the beam into one that is predominantly photons, we attenuate the neutrons and other neutral hadrons by passing the beam through 34 meters of liquid deuterium. The liquid deuterium which is inside sweeping magnets is separated into two sections, as shown in figure 1. Between the two sections there is a mechanism for remotely inserting 0 to 6 radiation lengths of lead which allows us to attenuate the photons. This permits us to determine the purity of the photon beam and to establish whether events are being produced by other than photons. The results of inserting various radiation lengths of lead with and without the deuterium are shown in figure 2; we have plotted the total energy in the beam measured in a quantameter as a function of radiation lengths of lead. The top curve shows that with no deuterium in the beam

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the lead has a small effect indicating that the beam consists mainly of hadrons. With the first section of the deuterium system filled (approximately 11 meters of liquid deuterium) one obtains the data in the middle curve which shows a component of photons that are being attenuated by the lead. When one has the full length of deuterium, one obtains the lower data which is exponentially decreasing with the slope one expects for an almost pure photon beam. From this one sees that the amount of energy remaining in the beam due to hadrons is probably the order of 1% or less.

(2) Detecting Apparatus: The detecting apparatus which is about 140 meters downstream from the proton target is shown in figure 3. The apparatus consists of a magnetic spectrometer using five multiwire proportional chambers, each containing 3 planes. Downstream of the proportional chambers are a series of particle identifiers. First is an electromagnetic shower detector (shown in figure 4) which is made of 22 alternating layers of lead and scintillator. The left and right banks of counters consist of a front array with 6 radiation lengths and a back array with 16 radiation lengths. The pulse height is constantly monitored with a light pulsing system, and they have been stable within a few percent over periods of many months. The resolution is approximately $0.4/(E)^{1/2}$, where E is in GeV. These shower detectors combined with a thin lead target and a special upstream magnet are used to make and spread apart electron-positron pairs in order to measure the photon spectrum; the same arrangement is used to check the calibration of the shower detectors about once a week. In figure 5 the spectra are shown for the photons produced with 300 GeV and 380 GeV protons on target. The part of the spectra of interest in producing ψ particles is that with $E_\gamma > 70$ GeV.

Following the shower detectors is a hadron calorimeter consisting of 24 sheets of steel 4-1/2 cm thick with 6 mm scintillators sandwiched in between them. There was a hole 15cmx15cm through the hadron calorimeter to allow the neutral beam to pass through and be absorbed in the quantameter. The quantameter was calibrated to better than 1% at SLAC, and it serves as a monitor during the photon experiments. Downstream of the quantameter is a muon identifier, consisting of 1.2 meters of steel followed by a horizontal array of counters, then another 60 cm of steel followed by an array of vertical counters; the steel and counter arrays are 220 cm wide and 240 cm high. In addition to the particle identifiers, there are a variety of counters for triggering and for determining whether additional particles are being emitted from the target and/or are outside the fiducial volume of the multiwire proportional chambers.

The electronic circuitry is set up so that simultaneous data can be taken in eight different channels; for example one channel could be 2μ, another 2e, another μe, another with $E > E_{threshold}$ hadrons, another vee particles, etc. We can also require that the particles be symmetric or asymmetric relative to the beam line.

(3) <u>ψ(3.1) photoproduction</u>: For the processes $\gamma + Be \rightarrow \mu^+\mu^- + X$, and $\gamma + Be \rightarrow e^+e^- + X$ we obtain the mass spectra shown in figure 6 using photons produced by 300 GeV protons. One sees the narrow resonance at approximately 3.1 GeV/c^2 that was simultaneously announced this fall by groups at Brookhaven, SPEAR, and ADONE (J.J. Aubert <u>et</u> <u>al</u>., Phys. Rev. Letters <u>33</u>, 1404 (1974); J.-E. Augustin <u>et</u> <u>al</u>., Phys. Rev. Letters <u>33</u>, 1406 (1974); and C. Bacci <u>et</u> <u>al</u>., Phys. Rev. Letters <u>33</u>, 1408 (1974).

The determination of the mass of the dimuons is the straightforward measurement of the momenta and of the opening angle. However for the e^+e^- events, the determination of the mass is complicated by the finite thickness of the target and the finite probability for the electrons to emit bremsstrahlung in passing through the target. The energy in the bremsstrahlung is also detected in the shower detector and is added to the energy of the electrons. A real example is shown in figure 7.

The continuum of leptons at lower masses is of interest in itself. It should consist of the electromagnetic production of pairs according to the Bethe Heitler theory as well as the decays of vector mesons into lepton pairs. It is being analyzed at the present time to determine whether the ρ' is a kinematic enhancement or a true vector meson which decays into lepton pairs with a width similar to that of other vector mesons.

As will be seen below, one of the most important quantities to be determined from the photoproduction experiment is the $d\sigma/dt$ for photoproduction from so-called "elastic processes". "Elastic processes" include both the coherent production off the beryllium nucleus and the elastic production off of single nucleons. We are in the fortunate position of having counters around the target and downstream of the target as well as the multiwire proportional system which record the emission of any additional particles accompanying the ψ event. Some of the ψ's are a result of the process $\psi'(3.7) \rightarrow \mu^+\mu^- + \pi^+\pi^-$. In our total sample of 105 $\mu^+\mu^-$ events, 6 are candidates for this process; 3 give clean measurements of the ψ' mass. There are another 20 events which are accompanied by the emission of at least one additional particle. When we remove these events, we obtain the t dependence shown in figure 8. At small t one sees the rapid fall-off associated with the coherent production from the beryllium nucleus followed by an apparently slow fall-off from the production by individual nucleons. For comparisons figure 9 shows the type of results we obtain for the ρ meson plotted on the same t scale. For $t < 0.05$ there is the same fall-off as for the ψ associated with coherent Be production. However for $0.1 < t < 0.3$ the ρ has a much more rapid fall-off for the production on a single nucleon.

The interest in obtaining $d\sigma/dt$ for "elastic" photoproduction is that the vector dominance model, with a few other assumptions gives a relationship between $(d\sigma/dt)_0$ and the total cross-section for the interaction of a ψ with a nucleon. The other assumptions are the optical theorem and that the nucleon interaction amplitude is predominantly imaginary. The Feynman diagram going with this model is shown in figure 10.

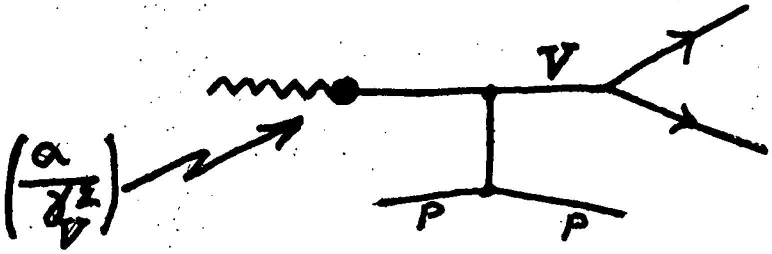

Figure 10. Vector Dominance Model of Photoproduction of Vector Meson

The relationship is

$$\left[\frac{d\sigma}{dt}(\gamma P \to VP)\right]_{t=0} = \frac{1}{16\pi}\left(\frac{\alpha}{\gamma_V^2}\right)[\sigma_{total}(VP)]^2 \quad (1)$$

The constant (α/γ_V^2) is calculated from the partial width of the vector meson to decay into an electron-positron pair $(\Gamma_{V\to ee}/M_V)$. In order to avoid your being uncertain as to normalizations and factors of 4π, I recommend using the ratio of the forward production of the ψ to the known forward production of the ρ meson and then one obtains the expression (2) given below.

$$\frac{\left[\frac{d\sigma}{dt}(\gamma P \to \psi P)\right]_0}{\left[\frac{d\sigma}{dt}(\gamma P \to \rho P)\right]_0} = \frac{(\Gamma_{\psi\to ee}/M_\psi)\ [\sigma_{total}(\psi P)]^2}{(\Gamma_{\rho\to ee}/M_\rho)\ [\sigma_{total}(\rho P)]^2} \quad (2)$$

All of the quantities in this ratio are reasonably well known for the ρ meson; the width $\Gamma_{\psi \to ee}$ is known from the measurements at SPEAR. Therefore from $(d\sigma/dt)_0$ of our photoproduction experiment one can calculate a value for the ψ nucleon total cross section.

We have fitted our data with an expression of the form

$$\left[A^2 \left(\frac{d\sigma}{dt}\right)_{t_{min}} e^{\alpha t} + A \left(\frac{d\sigma}{dt}\right)_{t_{min}} e^{\beta t}\right] \qquad t_{min} < t < 0.5,$$

and we find

$$40\,(\text{GeV})^{-2} < \alpha < 65\,(\text{GeV})^{-2}$$

$$0.5\,(\text{GeV})^{-2} < \beta < 3.5\,(\text{GeV})^{-2}$$

$$40\,\frac{\text{nb}}{(\text{GeV})^2} < \left(\frac{d\sigma}{dt}\right)_{t_{min}} < 63\,\frac{\text{nb}}{(\text{GeV})^2}$$

Using either expression (1) or (2) above with these values, one obtains that $\sigma_{tot}(\psi n)$ is approximately one millibarn. This is a cross-section that is many orders of magnitude above that one would expect if the ψ particle had been the weak intermediate vector boson.

After we had made a preliminary report on this experiment, Freund brought to our attention that Carlson and Freund (Physics Letters 39B, 349 (1972)) had suggested that such an experiment be performed as a test of a 4 quark model and that with their model the total cross-sections for vector mesons will vary inversely as the square of the mass of the vector meson. Their prediction is consistent with our data.

We are currently analyzing a variety of hadronic channels. Channels containing K mesons are identified by the decay of the $K^o_S \rightarrow \pi^+\pi^-$ in flight. We also see an appreciable production of Λ and anti-Λ hyperons. However I wish to remind you that there are some K^o_L mesons present in our beam. Therefore we must analyze the background runs that were made to determine to what extent these strange particle events were produced by photons or by other particles in our beam.

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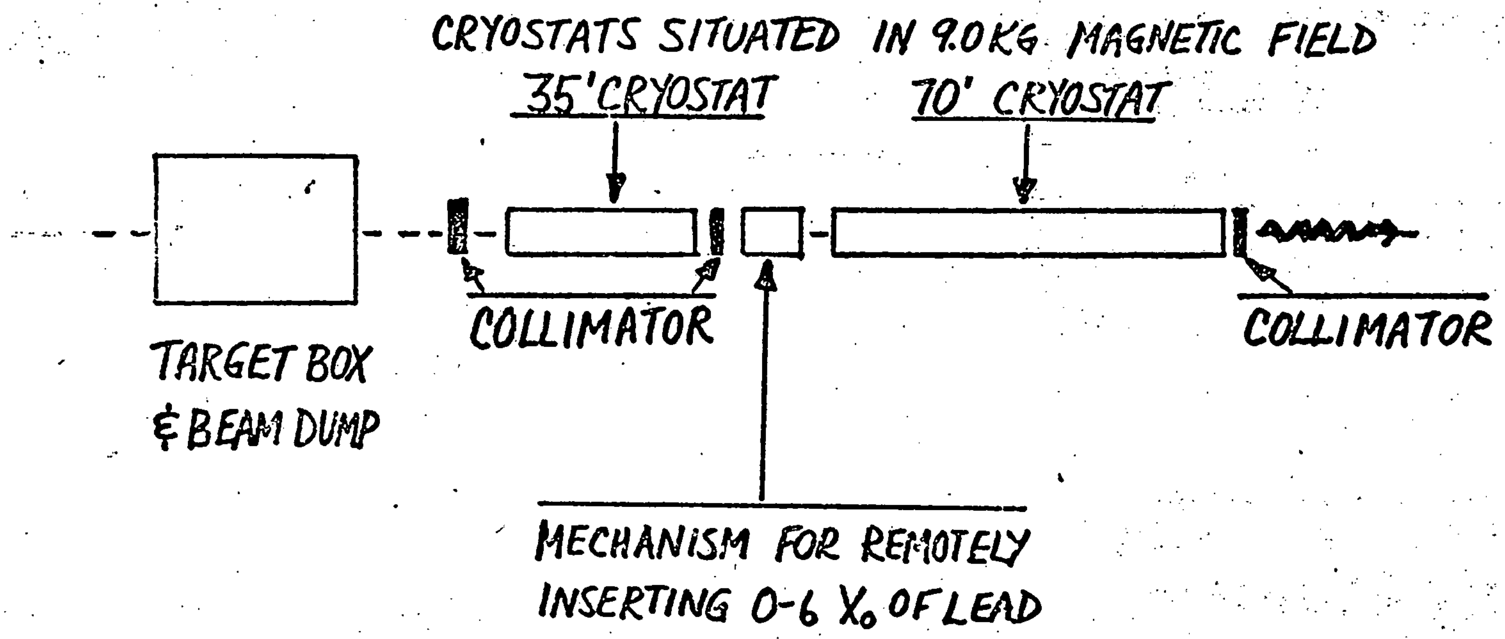


Figure 1. Schematic drawing of photon beam arrangement

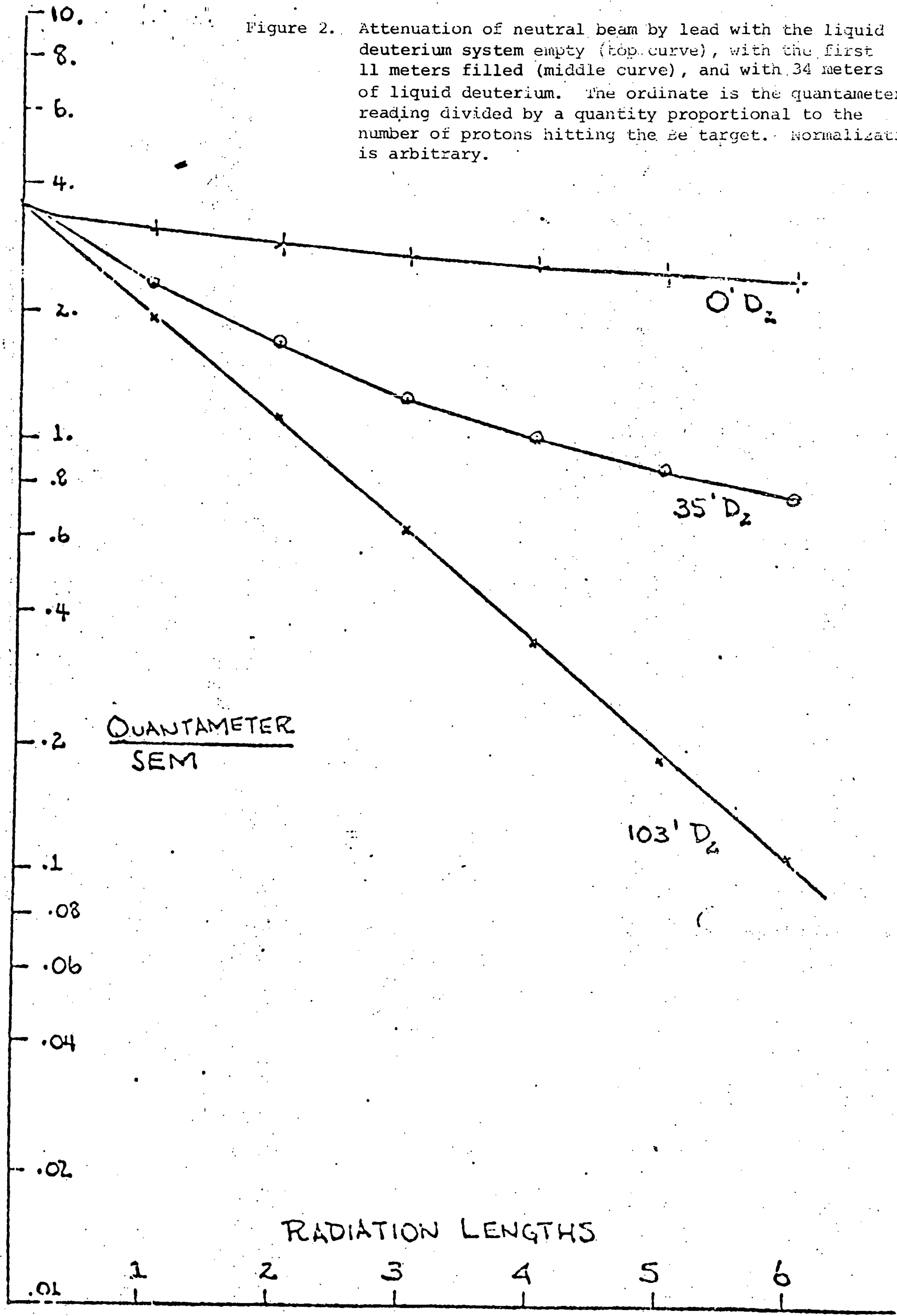


Figure 2. Attenuation of neutral beam by lead with the liquid deuterium system empty (top curve), with the first 11 meters filled (middle curve), and with 34 meters of liquid deuterium. The ordinate is the quantameter reading divided by a quantity proportional to the number of protons hitting the Be target. Normalization is arbitrary.

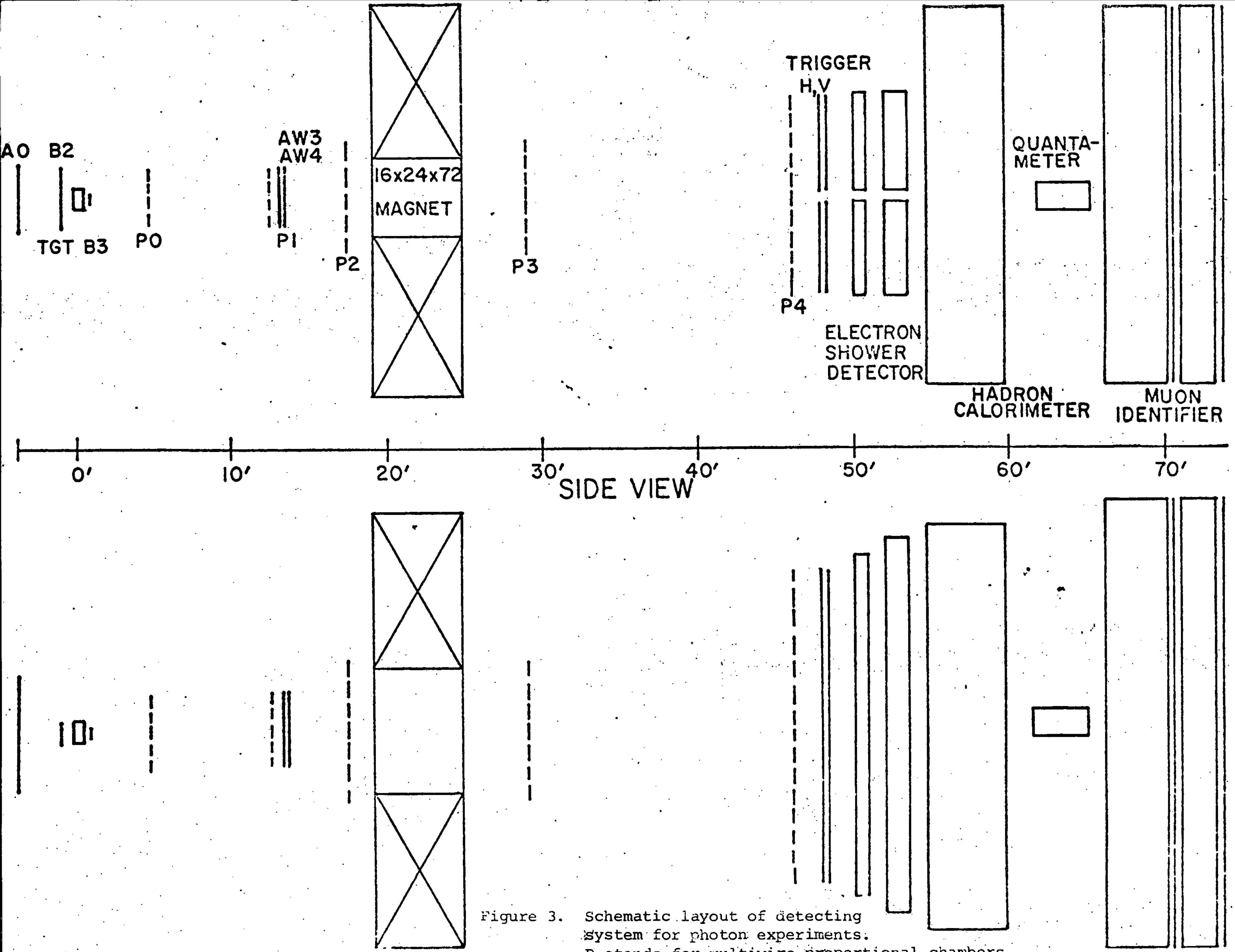


Figure 3. Schematic layout of detecting system for photon experiments. P stands for multiwire proportional chambers.

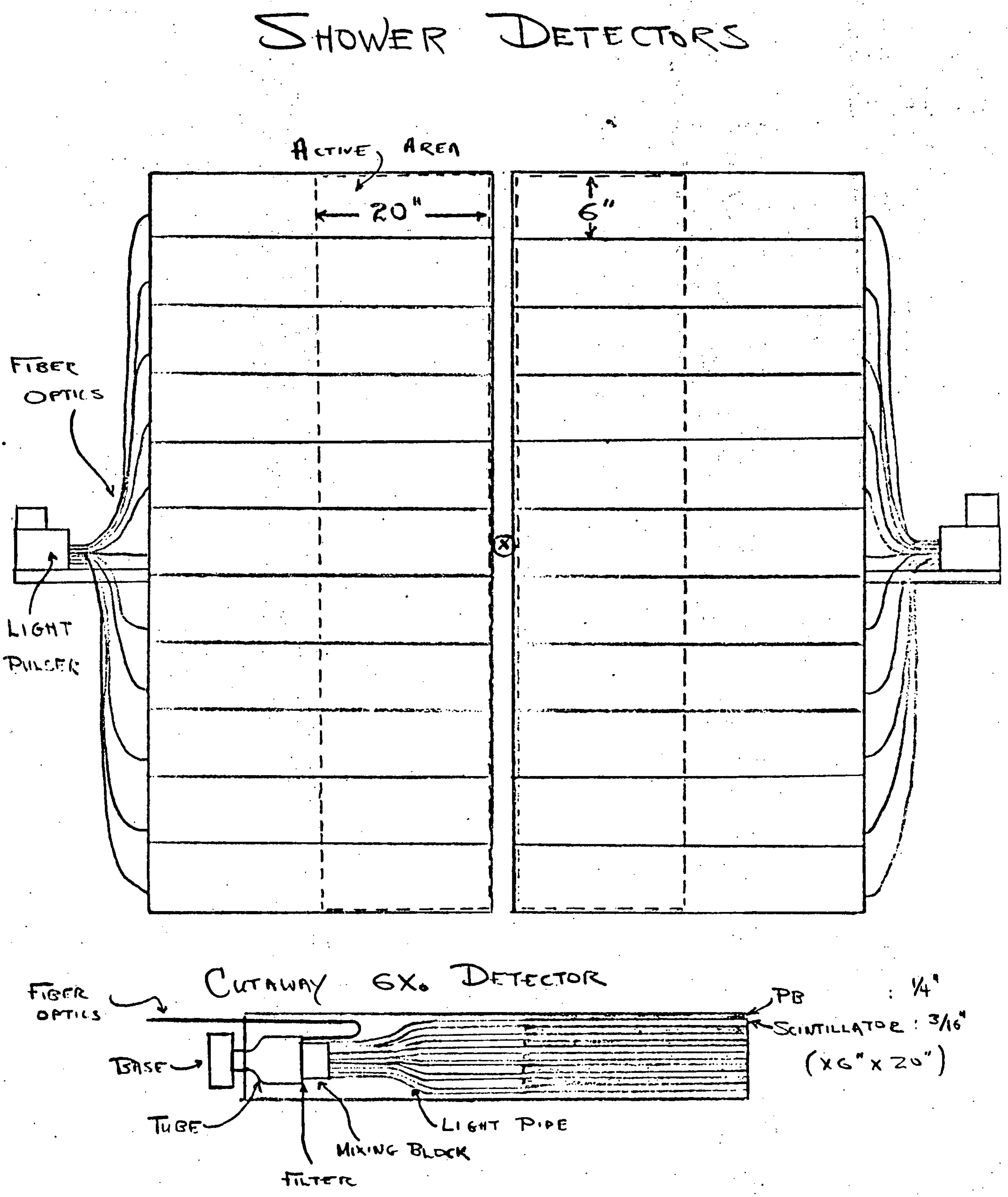


Figure 4. Schematic drawing of electromagnetic shower detectors.

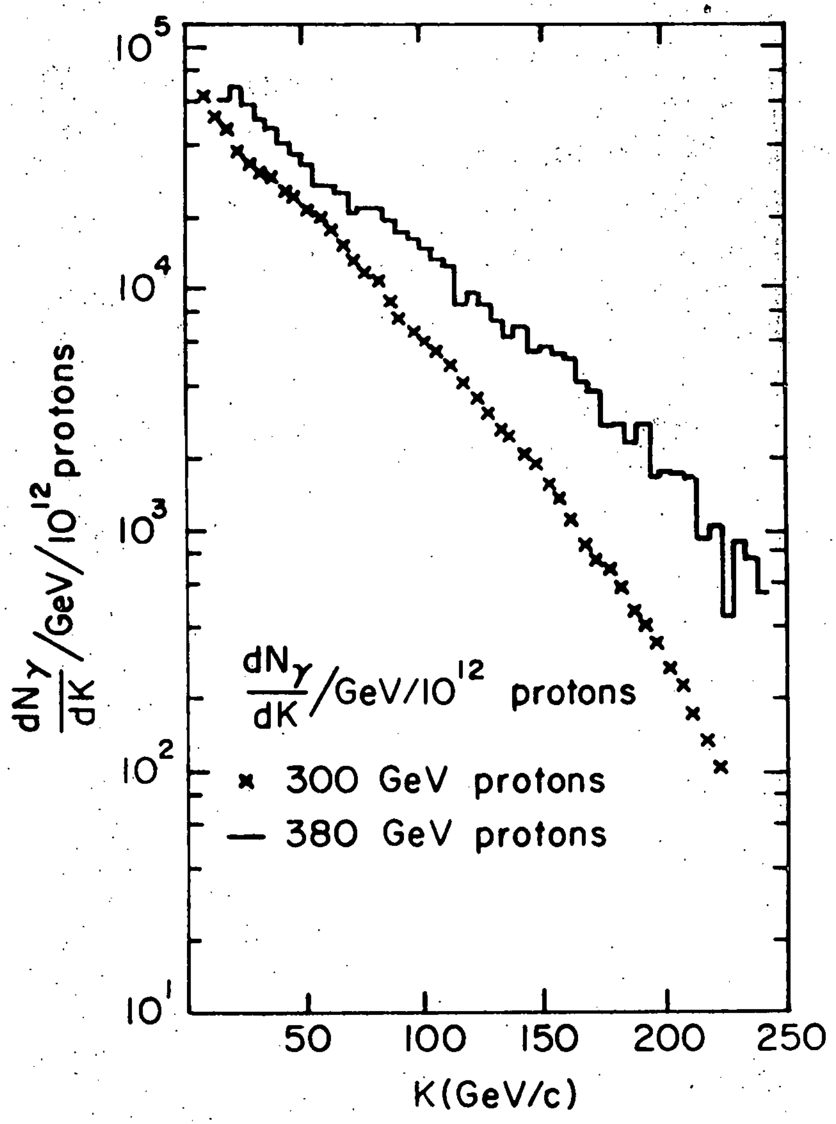


Figure 5. The photon spectra produced at 0 milliradians by 300 and 380 GeV protons on a 30 cm Be target. There is a slight uncertainty in the proton normalization for the 380 GeV data.

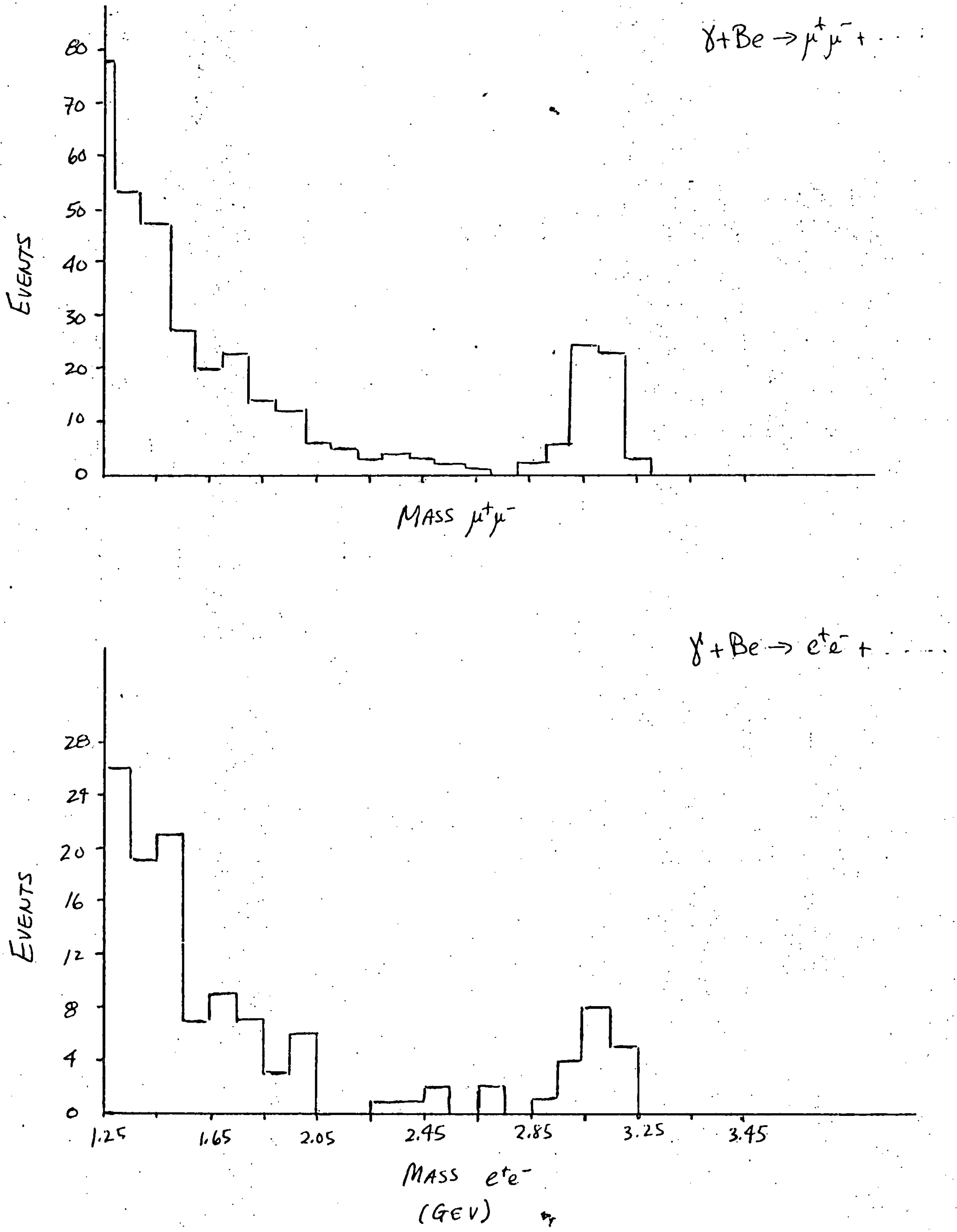
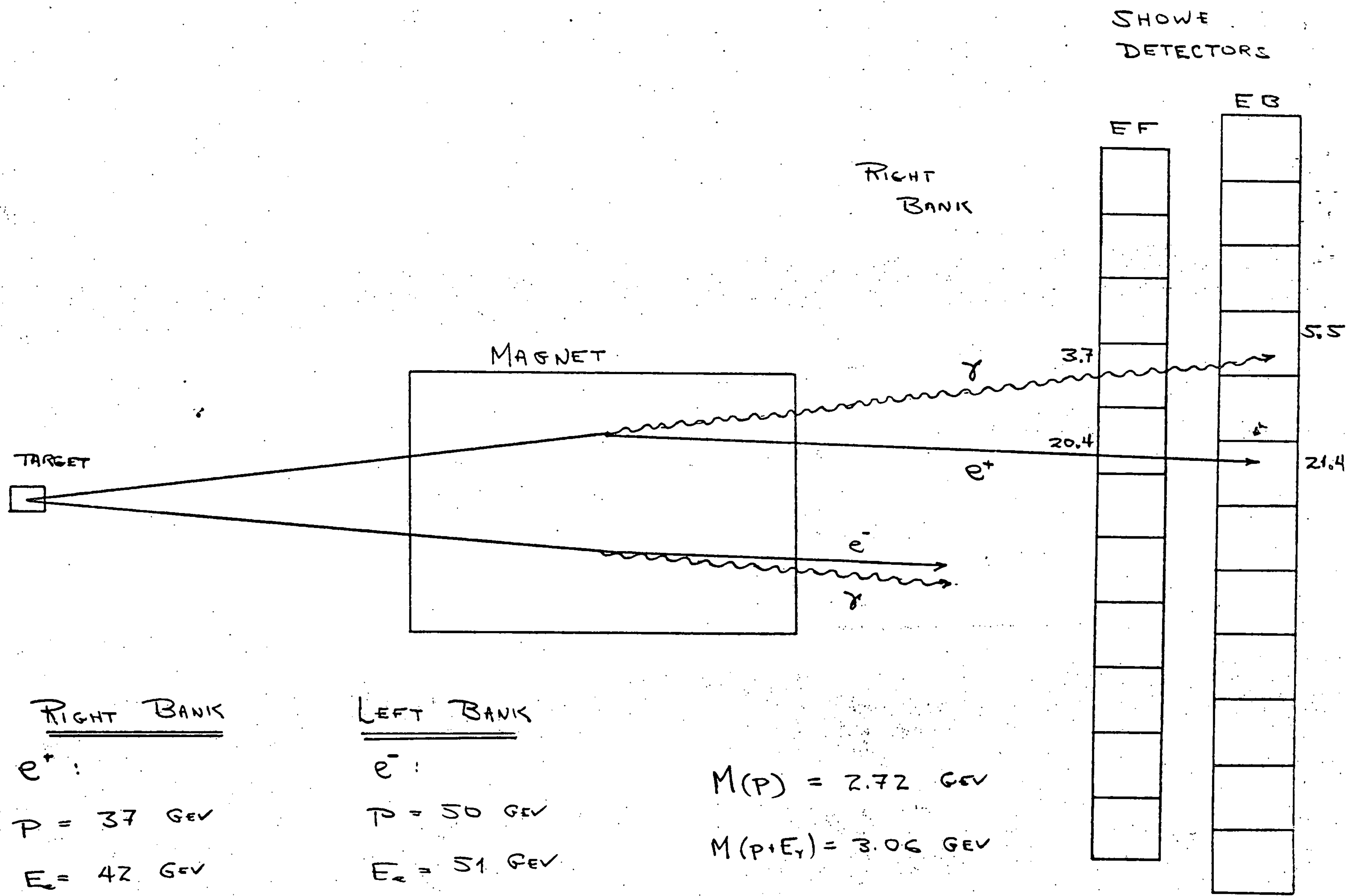


Figure 6. Mass spectra of $\mu^+\mu^-$ pairs (upper) and e^+e^- pairs (lower) obtained from photons on Be.



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e^+ :

$P = 37$ GEV

$E_e = 42$ GEV

$E_\gamma = 9$ GEV

LEFT BANK

e^- :

$P = 50$ GEV

$E_e = 51$ GEV

$E_\gamma = 1$ GEV

$M(p) = 2.72$ GEV

$M(p+E_\gamma) = 3.06$ GEV

Figure 7. An event that illustrates how the bremsstrahlung correction is obtained in order to correct the determination of the mass of an e^+e^- pair.

Figure 8. $\frac{d\sigma}{dt}$ for $\psi(3.1) \rightarrow \mu\mu$. The events which were accompanied by the production of one or more additional particles have been removed.

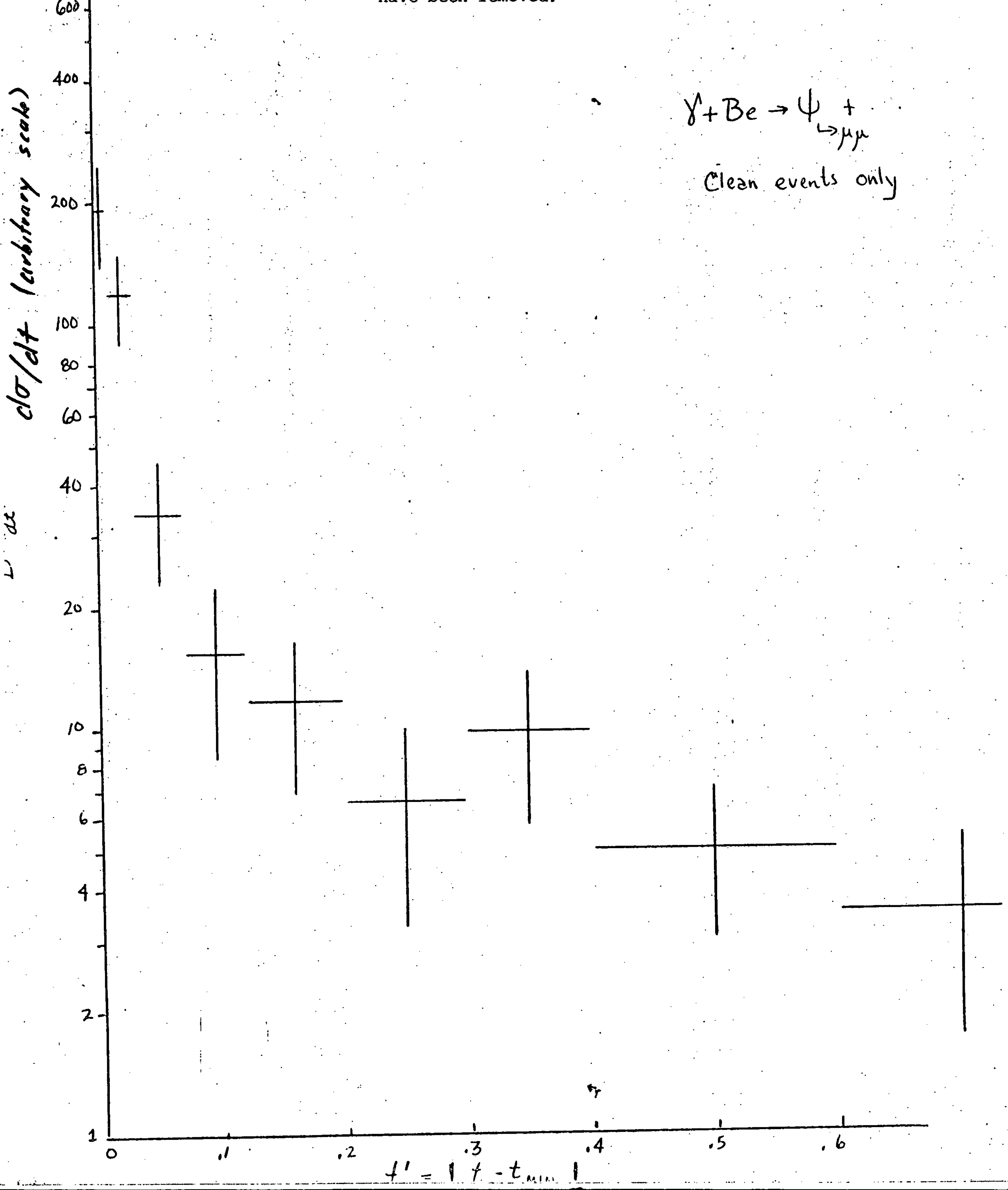

Figure 9. $\frac{d\sigma}{dt}$ for a sample of ρ events.