Preliminary Proposal No. 14

PROPOSAL FOR TESTING OF QUANTUM ELECTRODYNAMICS BY PHOTOPRODUCTION OF ASYMMETRIC MUON PAIRS

Submitted

By

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A. Introduction

We propose an experiment to test the validity of muon electrodynamics by studying the photoproduction of asymmetric muon pairs from protons. The experiment was suggested and discussed by S. D. Drell[1].

In the proposed experiment only one muon, the negative one, is detected and its momentum and angle measured. The detection system is arranged to select muons which carry nearly all the energy of the incoming photon, leaving the proton and the positive muon almost at rest. The main contribution to the process comes from the Feynman graph in fig. 1a. The four-momentum transfer squared of the muon propagator is

$$t = (k - p_1)^2$$

$$= m_\mu^2 - 2kE_1(1 - \beta_1 \cos(\vec{k}, \vec{p}_1))$$

where index 1 refers to the muon escaping from the upper vertex.

Detecting the muon from the lower vertex (fig. 1a), we fix the upper one to $\beta_1 \cong 0$ and $E_1 \cong m_\mu$, so

$$t \cong -2\,k\,m_\mu$$

which is $t = -4(\text{BeV}/c)^2$ for a photon of 20 BeV. Detecting the upper muon in the forward direction fixes $\beta_1 \cong 1$, $\cos(\vec{k}, \vec{p}_1) \cong 1$

$$t \cong -m_\mu^2$$

As discussed by Drell[1] the amplitude of this "bad diagram" is reduced by the scattering from the proton to a contribution which is comparable to the "good diagram." The obtainable momentum transfer allows a test of QED far beyond the limits obtained so far from other accelerators.[2]

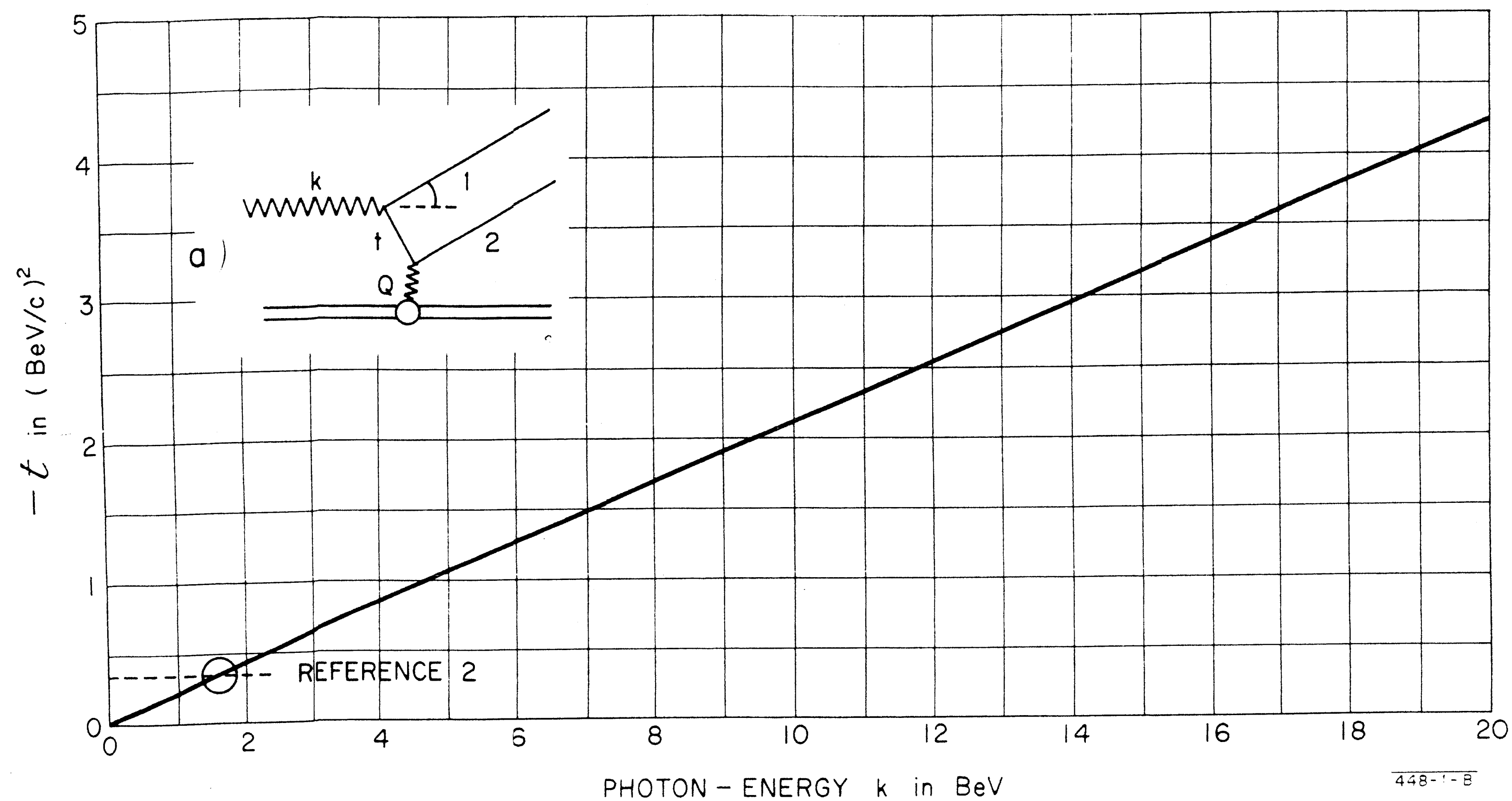


FIG. 1 - FOUR – MOMENTUM SQUARED OF THE VIRTUAL MUON

From the experimental result we hope to check the quantum electrodynamic description of the pair-production process and in particular to look for deviations from the conventional expression for the muon propagator. If no deviation is observed, we will be able to set an upper limit for the cut-off parameter, Λ, in the Feynman-Pauli regulator

$$\frac{1}{\gamma_\mu z_\mu + m_\mu} - \frac{1}{\gamma_\mu z_\mu + \Lambda}$$

which is often used to represent a breakdown model for the conventional muon propagator. We feel that this experiment is capable of placing a limit on Λ of about $\Lambda > 8$ BeV or $\frac{1}{\Lambda} < 3 \times 10^{-15}$cm which will considerably extend the limit from the latest wide angle muon-pair measurements carried out at the CEA[2]. Because of the differing results of the wide angle electron-pair[7] and muon-pair[2] experiments, it is important to extend experimental tests of quantum electrodynamics to higher energies and momentum transfers than have previously been possible.

We propose to measure the photo-production cross section of asymmetric muon pairs at photon energies of 10, 15, and 20 BeV. As we will show later, the result will be the relative cross section with respect to the production of asymmetric electron pairs, which occurs at low values of t.

The experimental set-up we propose consists of a 0.03 radiation length copper converter, which after collimation is followed by a 100 cm long hydrogen target, and the 20 BeV spectrometer operating at 0°.

The following discussion will show, that the expected counting rates are adequate. We believe that 150 hours of machine time will be sufficient to do the experiment. The time would be divided about equally between calibrations and background surveys and data-taking at three different energies, based on 3% statistical errors.

B. Kinematics and Cross Sections

The minimum photon energy, k_o, for μ-pair photoproduction in which a negative muon of energy E_- is detected is given by the expression

$$k_o = \frac{E_- + m_\mu}{1 - \frac{E_-}{M}(1 - \beta_\mu \cos\theta)}$$

which gives $E_- + 0.112$ [BeV] for a photon of 20 BeV and $\theta = 0$. For a particular particle momentum selected by a spectrometer, the difference in the minimum energies for μ-pair and π-pair photoproduction is given approximately by the expression

$$\Delta k \cong \frac{m_\pi - m_\mu}{1 - \frac{2p_-}{M}\sin^2\frac{\theta}{2}}$$

The difference is approximately 34 MeV for the energies of interest at SLAC. In principle, if the spectrometer were operated with a momentum bite of about 34 MeV, the experiment would be completely free from the pion background. However, the cross section for μ-production is small and, in order to obtain satisfactory statistics within a reasonable time, we have to increase the momentum bite of the spectrometer. The final selection of the interval is made by consideration of pion and electron background and the effectiveness of background discrimination by the detection system.

To obtain the cross section, the two Feynman amplitudes of Fig. 1a are added and squared. Since only one particle, the negative muon, is detected, we find the experimental yield by integration over all unobserved variables. The small-angle approximation formula given by Drell[1] is the following:

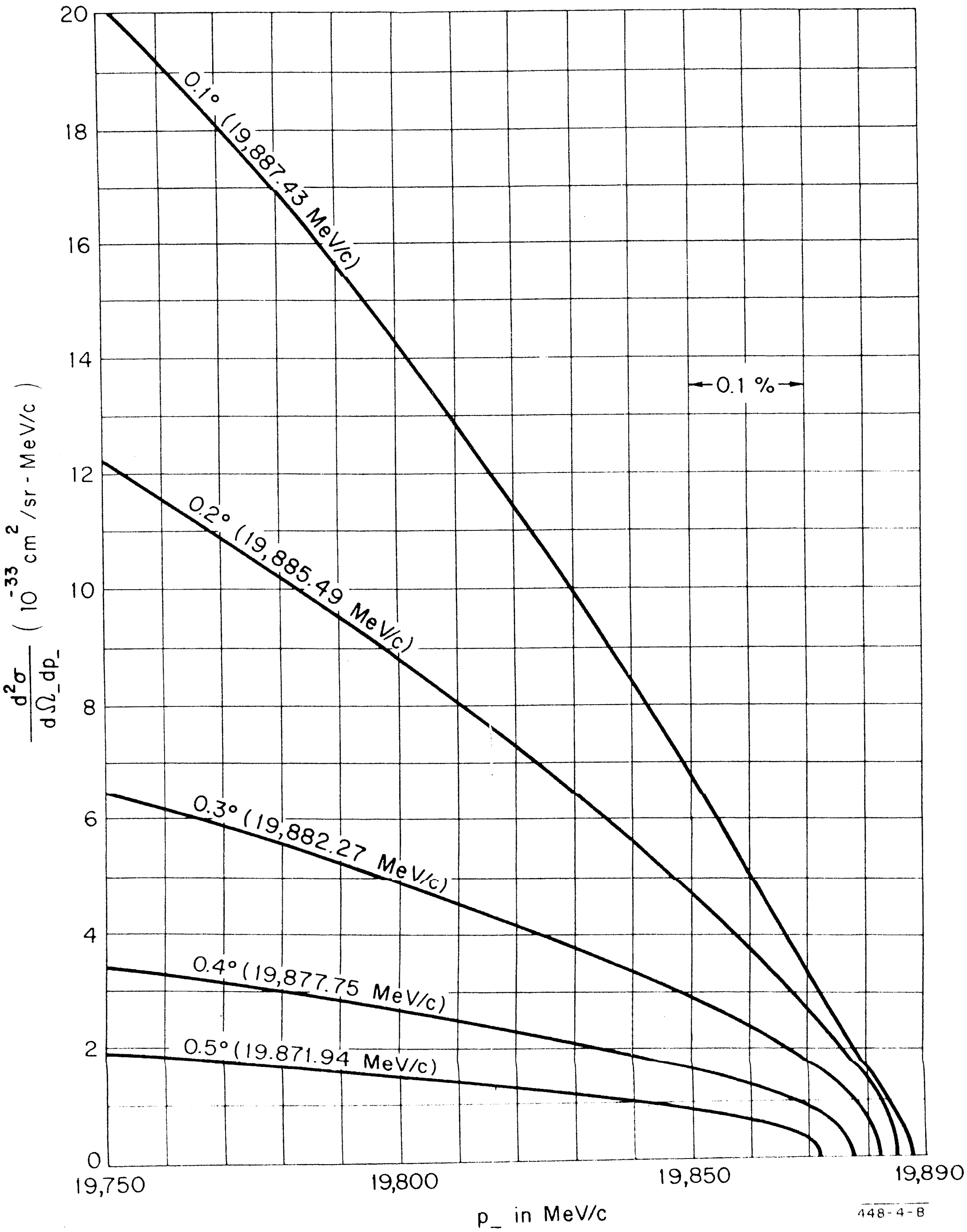
$$\frac{d^2\sigma}{dE_- d\Omega_-} = \frac{4\alpha}{\pi} r_e^2 \left(\frac{m_e}{m_\mu}\right)^2 \frac{kp_+}{m_\mu^3} \left\{ \frac{\varphi^2 + \frac{2}{3}\left(\frac{p_+}{m_\mu}\right)^2 - \frac{1}{6}\varphi^2\left(\frac{p_+}{m_\mu}\right)^2 \left[1 + \frac{4}{1+\varphi^2} + \frac{24}{(1+\varphi^2)^2}\right]}{(1+\varphi^2)^3} \right\}$$

with $r_e = 2.8 \times 10^{-13}$ cm and $\varphi = \frac{k\theta_-}{m_\mu}$. In the above formula only the corrections due to the finite momentum of the slow μ^+ are included. Parsons[3] included also the effect of the proton recoil and form factors. We evaluated Parsons' cross sections for different photon energies and angles using a computer. Fig. 2 shows the muon spectrum for 20-BeV photons and Fig. 3 the differential cross sections for several photon energies, using a bremsstrahlung spectrum.

The expected muon counting rates are given in Table I:

TABLE I

Electron Energy (in BeV)	Muons/hour
8	107
10	126
12	135
14	141
15	143
16	142
18	142
20	139



$\frac{d^2\sigma}{d\Omega_- dp_-}$ (10^{-33} cm^2/sr - MeV/c)

FIG. 2 - ASYMMETRIC μ-PAIR PRODUCTION WITH 20-BeV PHOTONS

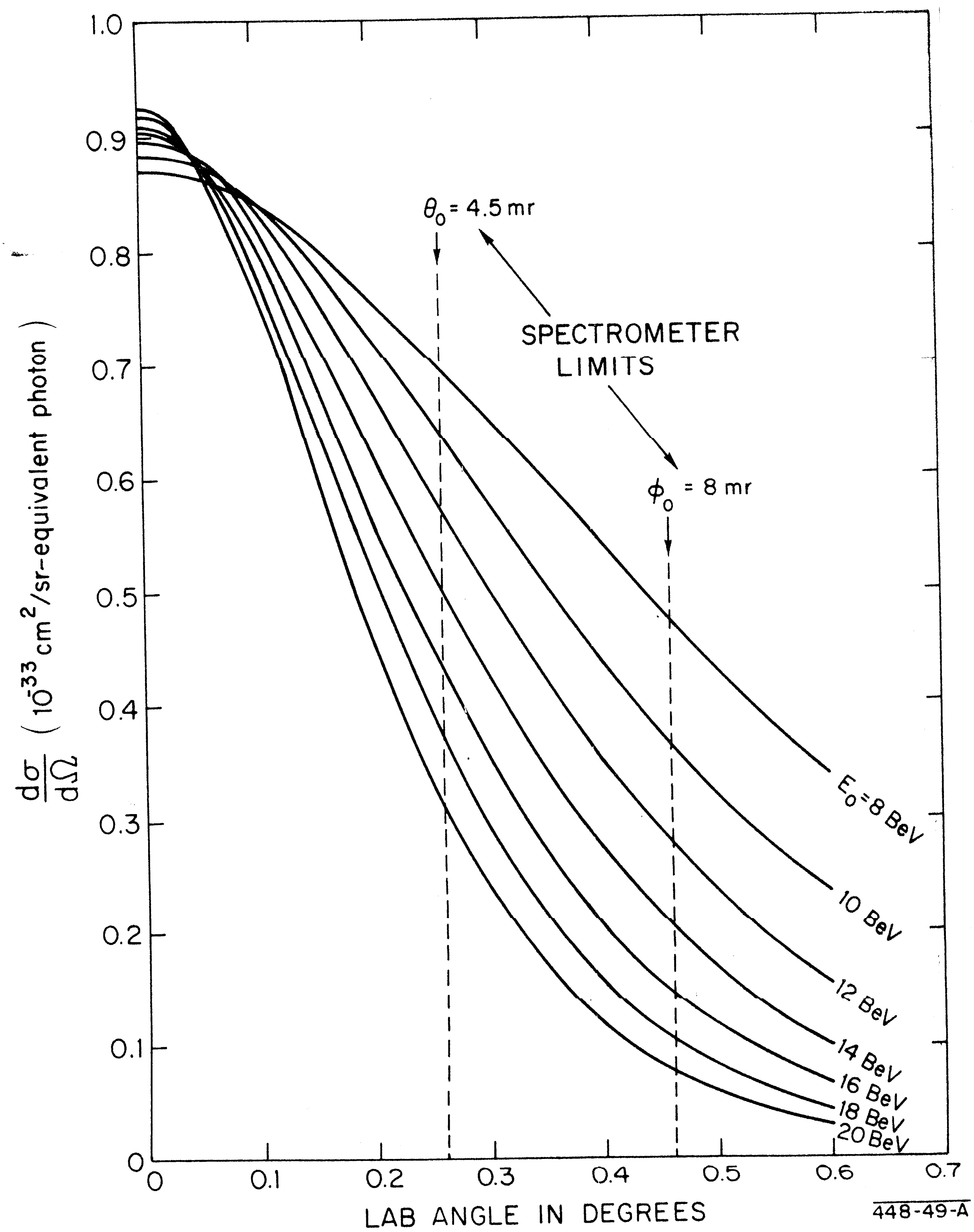


FIGURE 3 -- ANGULAR DISTRIBUTIONS OF THE ASYMMETRIC MUON-PAIRS PHOTOPRODUCED BY ELECTRON BREMSSTRAHLUNG.

These numbers are obtained assuming 2×10^{13} electrons/sec of a $\pm 0.05\%$ momentum spread and a 100 cm long liquid hydrogen target. The 20-BeV spectrometer is operating at 0° and its momentum bite is about 110 MeV/c i.e., the muon cross section is integrated from $p_{max} = k - 0.112$[BeV/c] down to $p_{min} = p_{max} - 0.110$[BeV/c]. The calculation has included the effects due to the shape of the thick-target bremsstrahlung spectrum and losses due to collimation of the photon beam. The detail is given in Appendix I.

C. Backgrounds

The backgrounds to this experiment are mainly from the photoproduction of π- and e- pairs. We will use part of the pair-produced electrons to make an energy calibration as is discussed in the next section. In this section we discuss only the backgrounds arising from photoproduction of pions.

Figure 4 shows the relative magnitude of the cross sections for e-, μ-, and π-pair[4] production at 0.2° with monoenergetic photons of energy 15 BeV. The π-pair production cross section calculations were based on the Drell one pion exchange model.

At zero degree, the numbers of pions expected are given in the following table:

TABLE II

Electron Energy	Pions / hour	Daughter muons which could reach the detector per hour
8	17	0.52
10	26	.62
12	34	.68
14	41	.68
15	45	.68
16	48	.70
18	53	.68
20	57	.65

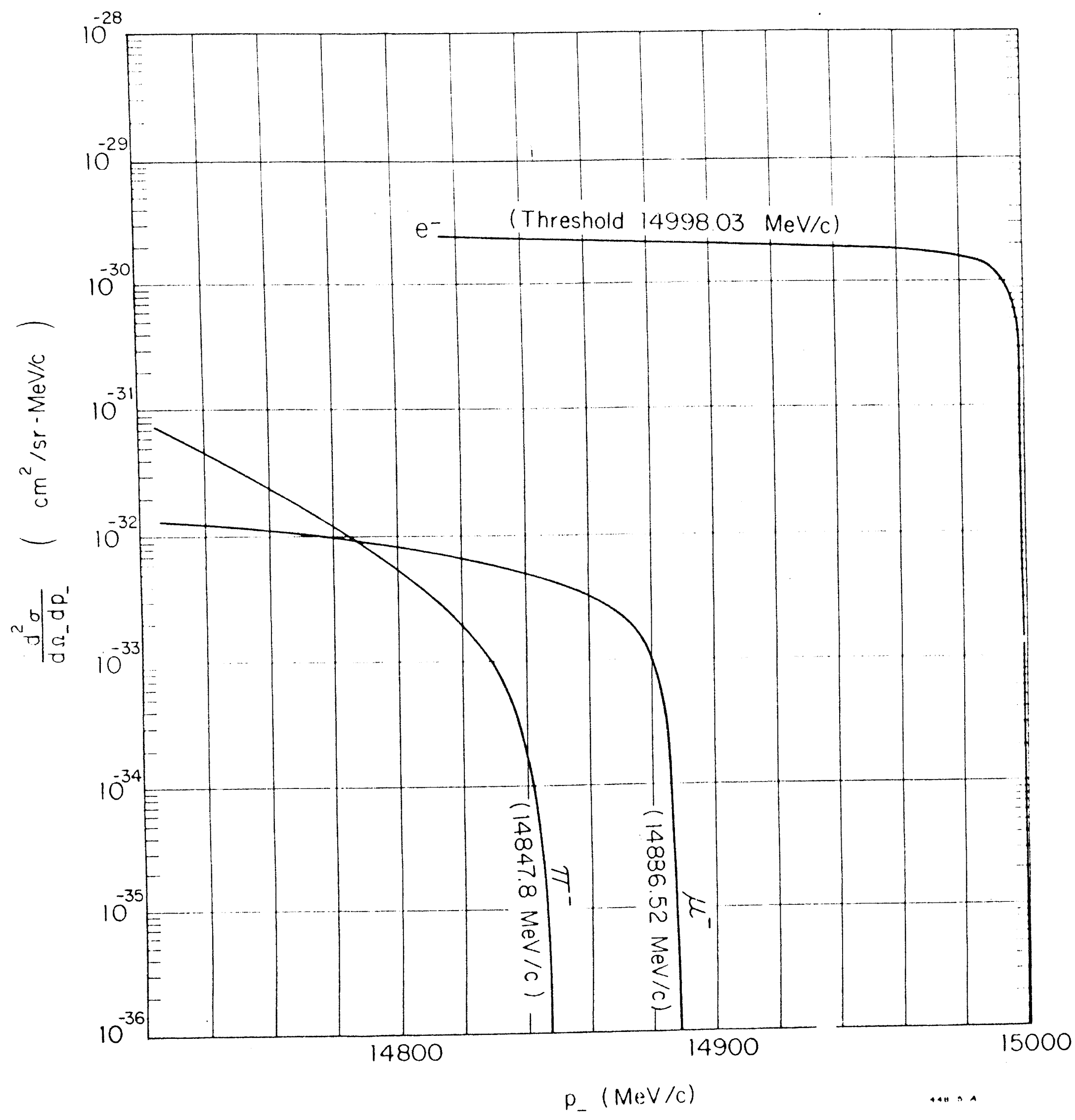


FIG. 4 -- ASYMMETRIC LEPTON AND PION PAIR PHOTOPRODUCTION CROSS SECTION. PHOTON ENERGY k = 15 BeV, θ = 0.2° (lab.)

These numbers are obtained with the same assumptions as were used for the muons. The cross section is that given by Drell[(4)] for the peripheral process:

$$\frac{d^2\sigma}{d\Omega dp} = \frac{\alpha}{8\pi^2} \frac{\sin^2\theta}{(1 - \beta\cos\theta)^2} \frac{p\sqrt{(k - E)^2 - m_\pi^2}}{k^3} \sigma^{total}_{\pi^+ p}(k-E-m_\pi)$$

Angular distributions are shown in Fig. 5. At photon energies above 5 BeV many pions arise from the decay of ρ^o,[(5)] which is produced by a diffraction mechanism. However, because of kinematics the maximum pion energy from ρ^o decay is too low to allow the pions to be accepted in the planned momentum interval.

The decay length of charged pions is 55m/(BeV/c), compared to a distance of 43 meters between target and detector in the 20-BeV spectrometer. An exact calculation of the contamination by decay muons is difficult because of the complexity of the spectrometer optics involved. The estimates given in Table II represent upper limits and, as in no case they exceed 0.5% of the genuine muon yields, their contribution is negligible.

D. Detection System

1. Elimination of Electron-Pair Events

Under the conditions for which the muon-pair counting rate is about 140 counts per hour the electron-pair counting rate is about 3×10^8 per hour, which is an instantaneous rate of over 10^8/sec for a duty cycle of $\frac{1}{2000}$. This rate is too high to accept in the detection system. The factor which determines the upper limit for the electron rate in the detection system

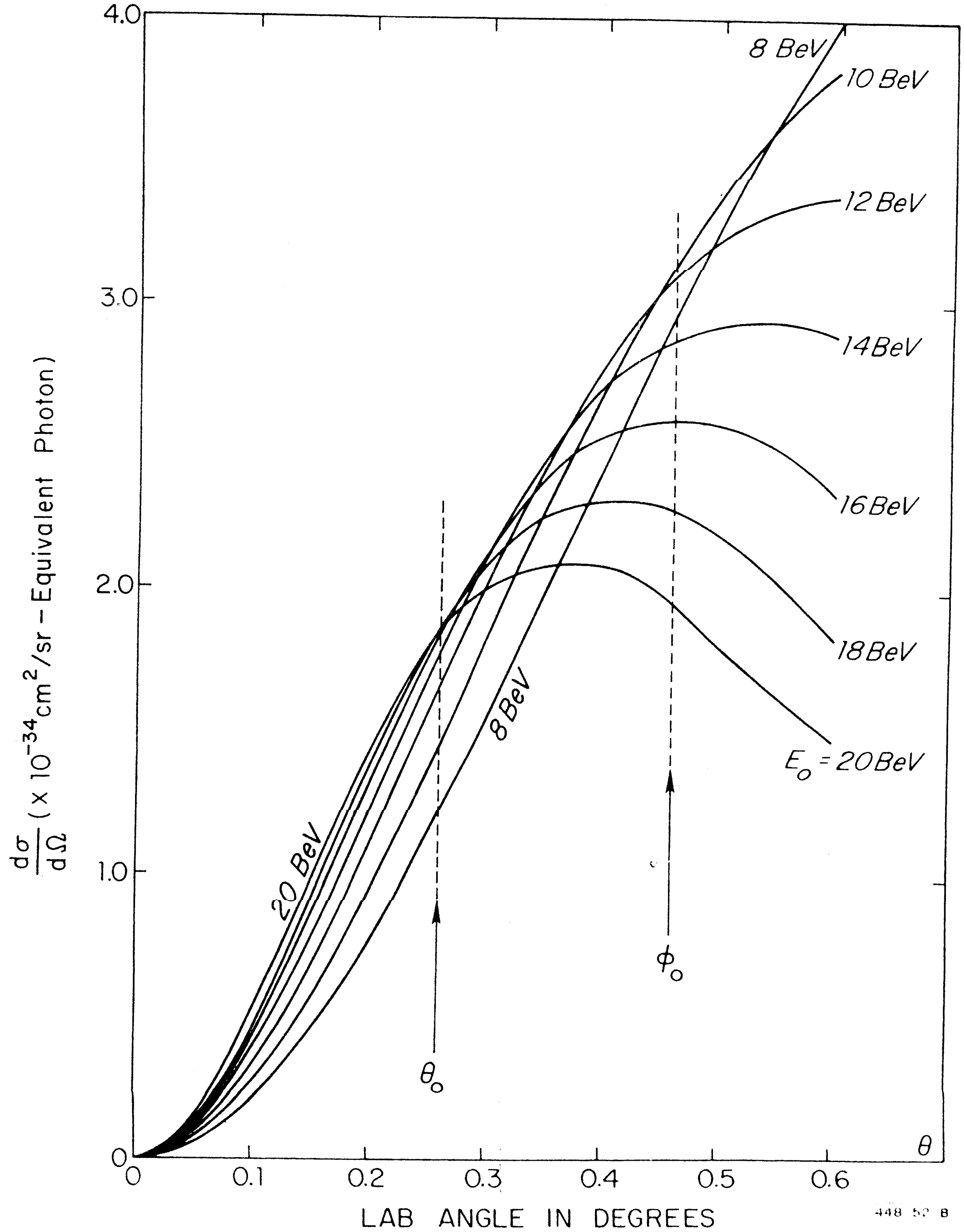


FIG. 5--ANGULAR DISTRIBUTIONS OF THE PERIPHERAL PIONS PHOTOPRODUCED BY ELECTRON BREMSSTRAHLUNG.

is the loss of genuine muon events due to an electron traversing the hodoscopes while the coincidence gate is open. If the coincidence gate is open for approximately 10 nanoseconds, a 1% loss in genuine events due to a spurious particle arises from an instantaneous counting rate over the entire hodoscope of 10^6 electrons/sec. This requires a reduction of the instantaneous electron counting rate in the hodoscopes by a factor of 300.

Behind the momentum and angular hodoscopes will be placed a muon detector which will have an efficiency for detecting electrons of less than 10^{-6}. Thus the background events arising from electrons will constitute about 0.5% of an event.

The electrons will be eliminated from the hodoscopes by utilising the very narrow angular distribution of the electron-pair production process. Fig. 6 shows the angular distribution of the yield of electrons from asymmetric pair production integrated over the momentum of the energetic particle (between the limits of 20.00 BeV/c and 19.78 BeV/c) for a photon end point energy of 20.00 BeV. Figure 7 shows the fraction of all electron events that occurs at angles greater than θ. From this graph we see that roughly 2×10^{-3} of all electron events lie outside of 0.9 mr. If this range of angle were excluded from the hodoscope the desired reduction factor would be achieved. This could be accomplished by not using the central six bins in the angular hodoscope of the 20-BeV spectrometer. In addition, the momentum hodoscope counters would have to be split to avoid the high electron yields within this angular range. The hodoscope design is shown in Fig. 8. The exclusion of this angular range reduces the asymmetric muon-pair counting rate by about 25%, resulting in a rate, for example, of about 105 counts/hr for k = 20 BeV.

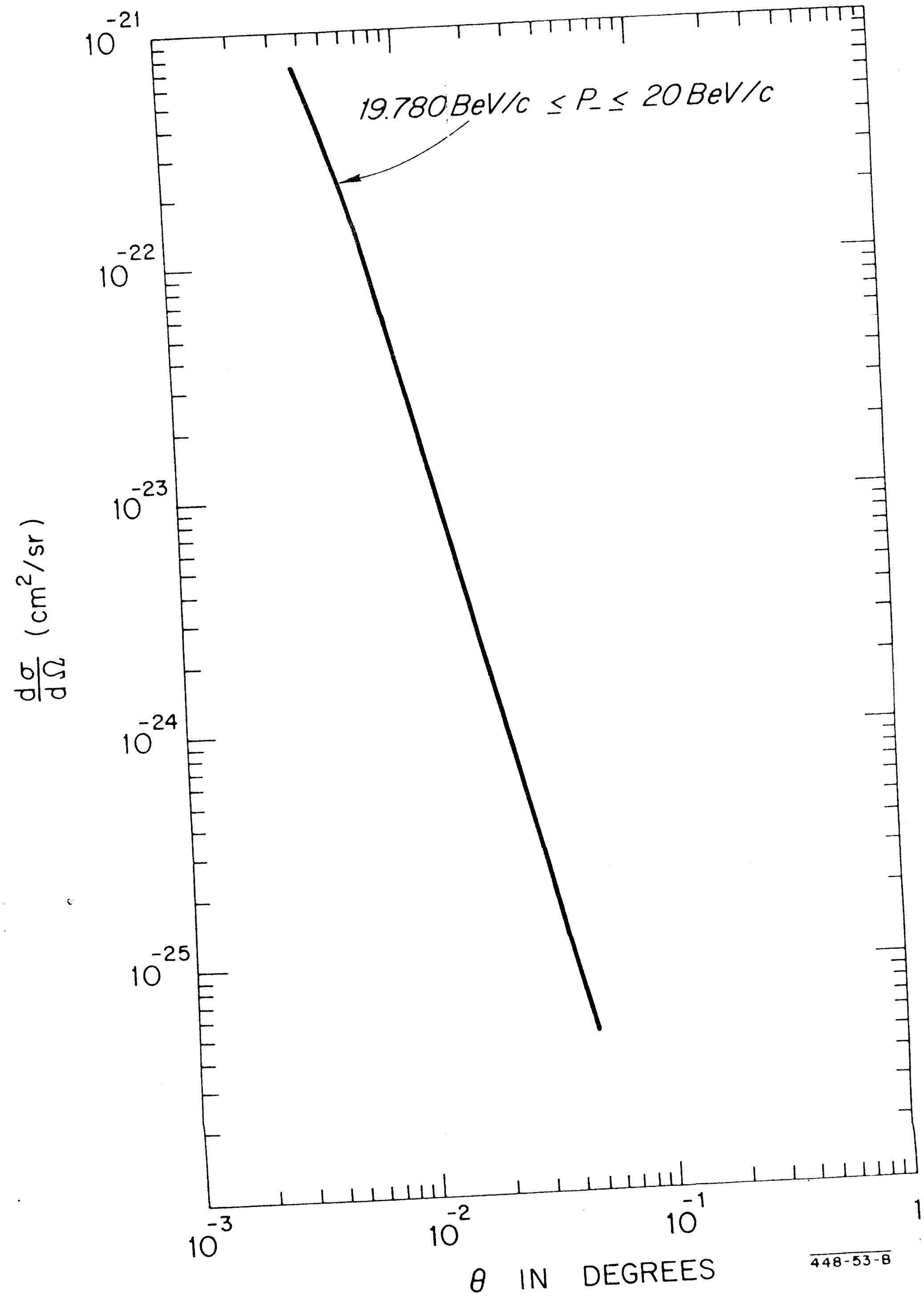


Fig. 6 - DIFFERENTIAL CROSS SECTION FOR ASYMMETRIC e-PAIR PRODUCTION WITH 20 BeV PHOTONS

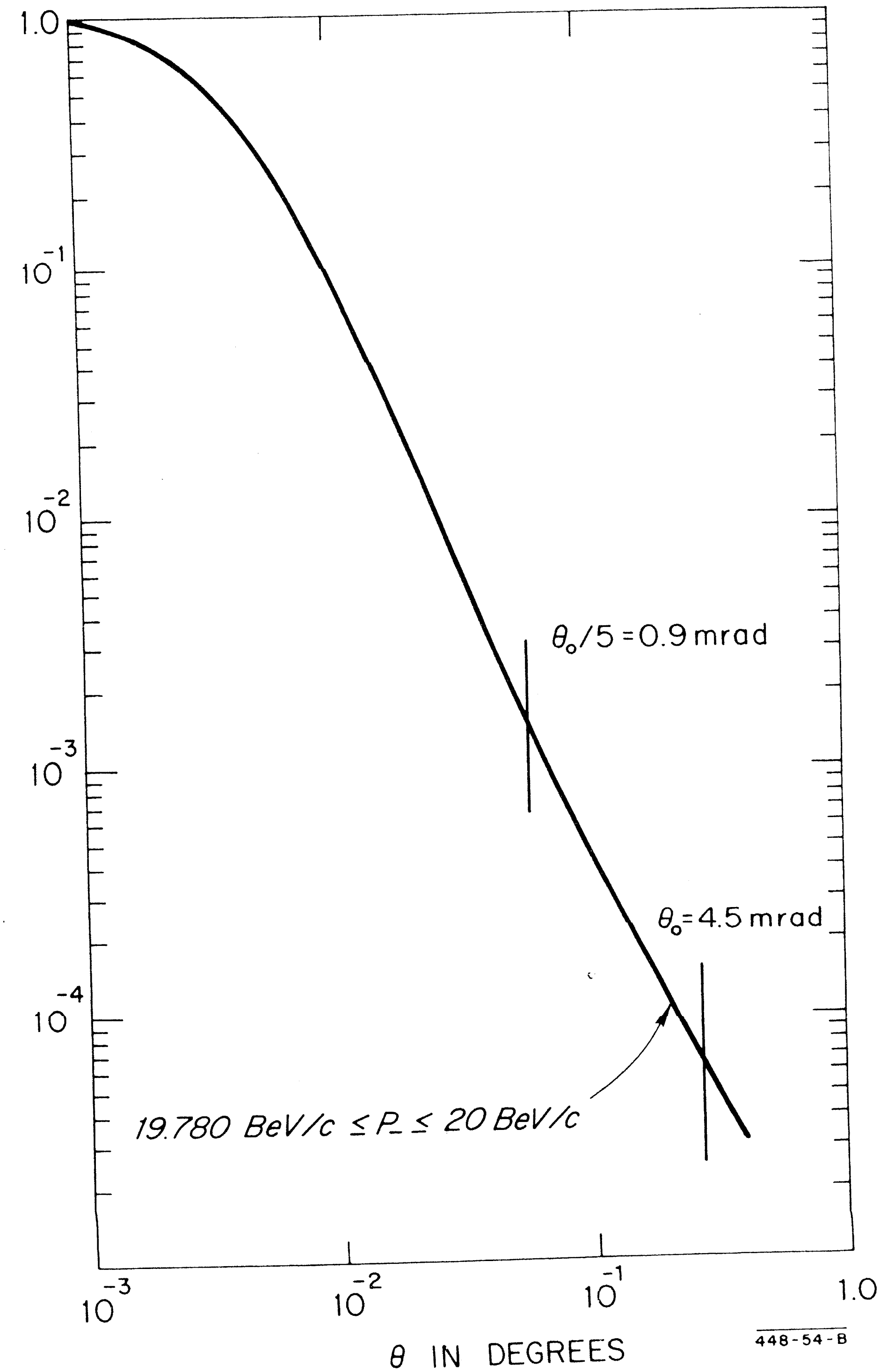


Fig. 7 -- THE FRACTION OF EVENTS AT AN ANGLE > θ FOR ASYMMETRIC e-PAIR PRODUCTION WITH 20 BeV PHOTONS

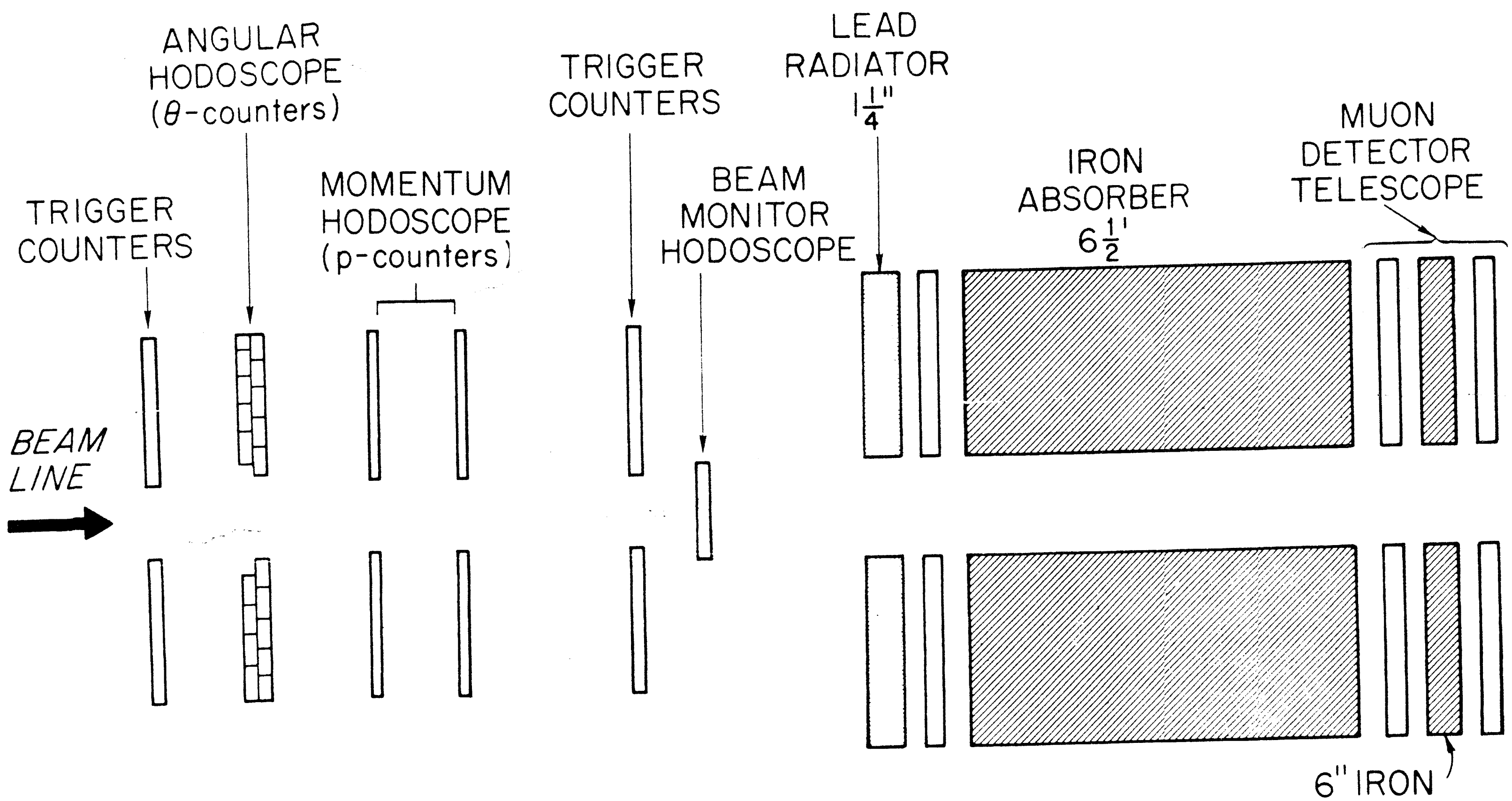


Fig. 8 - DETECTION SYSTEM

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2. Requirements on Stability of Beam Energy and Spectrometer.

Since the muons detected in this experiment are produced by photons near the tip of the bremsstrahlung spectrum, a small change in the primary beam energy or the central momentum of the spectrometer will produce a large change in the counting rate.

If the central momentum of the spectrometer or the beam momentum changes by δ_p it results in a change in the muon-pair rate of approximately

$$\frac{\Delta R}{R} = \frac{2\delta_p}{110 \text{ MeV/c}}$$

In order to limit the error from this effect to be less than 5%, the values of δ_p must be $\lesssim 3$ MeV/c which requires a stability of about 0.015% for the spectrometer and the beam switchyard system at a beam energy of 20 BeV. Since neither system will have this capability in the initial stages of operation, it will be necessary to monitor the δ_p during the experiment in order to ensure that the desired accuracy is achieved. This can be done by monitoring the momentum spectrum of the electron-pair events while muon data are being collected. Because of the extremely high rates, some central counters in the hodoscopes will deliver dc-currents proportional to the electron rates. The current from each counter will be integrated over each beam pulse to determine the total number of electrons incident on the counter during the pulse. The information from each element of the electron hodoscope will be stored in the SDS 9300 computer after each pulse. After a small number of pulses enough information will be accumulated to determine a statistically significant electron spectrum averaged over a short interval of time. Thus spectra will be continuously recorded during the measurement.

The position of this monitor hodoscope is shown in Fig. 8. It should be stressed that the split geometry of the muon hodoscope permits this type of monitoring without subjecting the muon detection system to unreasonably high rates.

3. Design of Monitor Hodoscope

Fig. 9 shows the momentum spectrum of electrons within an angle of 0.05° calculated with thick-target corrections to the bremsstrahlung spectrum and folded with resolution functions of ± .05% half-widths for (a) the energy spread due to the beam switchyard (b) the momentum spread in the spectrometer resulting from the beam height. Because this experiment is to be carried out at 0°, there are no significant momentum spreads resulting from angular spreads. The endpoint portion of the momentum distribution curve shown in Fig. 9 has the following approximate dependence on the momentum, p

$$\frac{dN}{dp} = A\,(p_o - p)^{1.8} \quad \text{where} \quad p_o \simeq K - m_e$$

Consider the yield Y from the endpoint portion of the spectrum falling into a counter of momentum acceptance $\Delta p/p = 0.1\%$ for $k_{max} = 20$ BeV.

$$Y = \int_{p_o}^{p'} \frac{dN}{dp}\, dp = \frac{A}{2.8}\,(p_o - p')^{2.8}$$

The percentage change in Y resulting from a change δp_o is given by

$$\frac{\Delta Y}{Y} = 2.8\,\frac{\delta p_o}{(p_o - p')} = \frac{2.8\,\delta p_o}{20(\text{MeV}/c)}$$

In order to limit the error in the μ-pair cross section from this effect to be ≤ 5%, we must know p_o to an accuracy of better than 3 MeV/c. A variation of p_o by 2.5 MeV/c leads to a value of

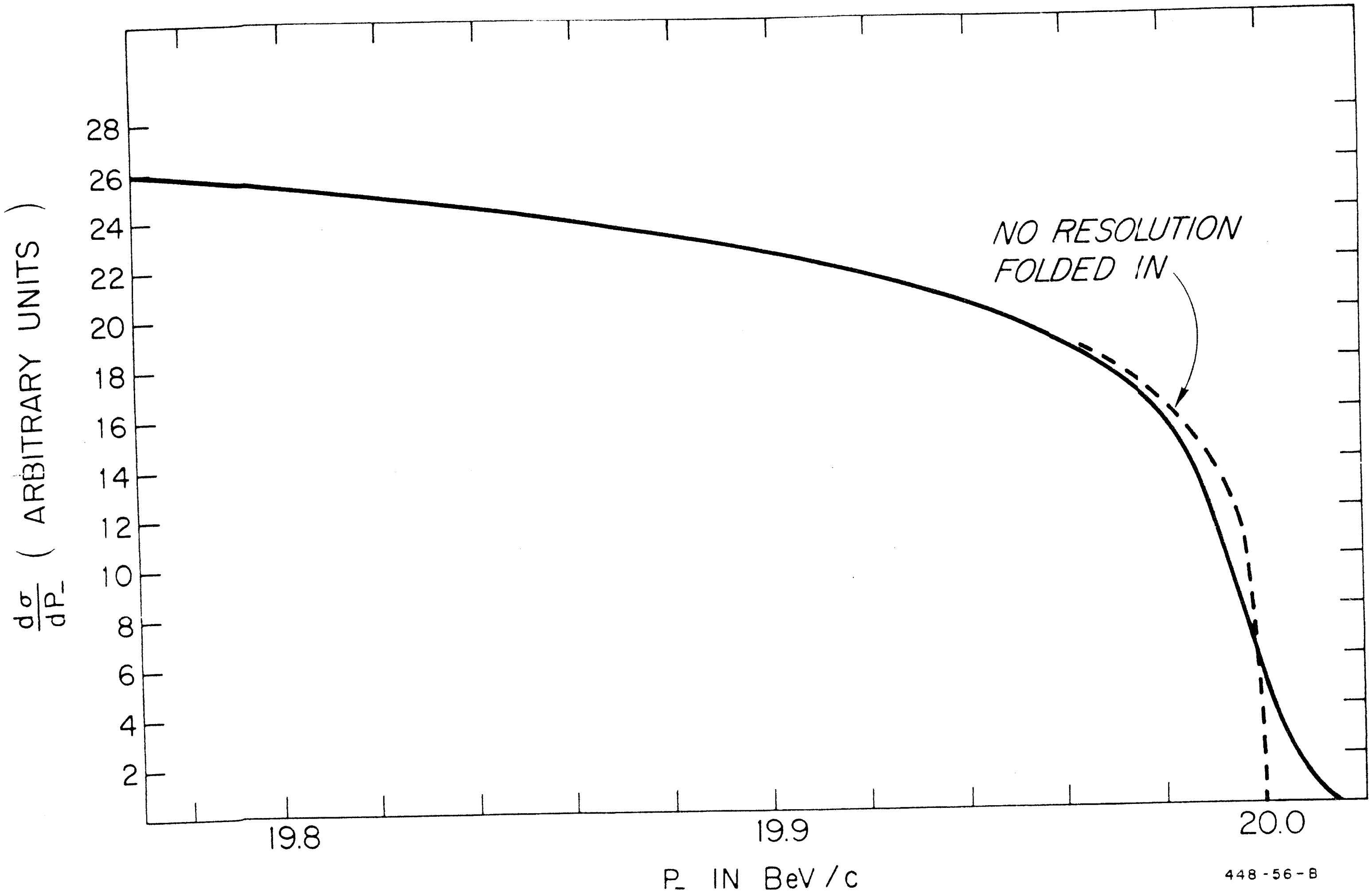

Fig. 9 - MOMENTUM DISTRIBUTION OF ELECTRONS FROM ASYMMETRIC e-PAIR PRODUCTION WITH K=20 BeV AND $\theta \leq 0.05°$ (Resolution fold included.)

$$\frac{\Delta Y}{Y} = 0.35$$

Hence, if we measure Y to an accuracy of better than 35%, we will monitor p_o to sufficient accuracy. We will nominally aim for a measurement of Y which is accurate to within 20%, with the error primarily arising from the statistics of the electron yield. The expected yield in this counter is about 7 particles/pulse. Thus if we integrate the total current from this counter for roughly 10 pulses, we will be able to monitor with sufficient accuracy the value of p_o averaged over a time interval of .028 sec. This time interval corresponds to an uncertainty in the μ-pair cross section from energy fluctuations of 2.8%. If it is necessary, we can reduce this time interval by about a factor of two by relaxing our requirements on the accuracy of the determination of Y. It is not likely that the large magnet systems involved will have sizeable fluctuation in their central momenta in such short time intervals. Since a change in Y can result from either a fluctuation in p_o or a fluctuation in beam intensity, it is necessary to monitor the average intensity during the same time interval. This can be done conveniently by monitoring the total electron-pair yield, Y_T, integrated over a momentum interval of 220 MeV/c. A change in p_o of 2.5 MeV/c results in a change in Y_T of only 2.5% as compared to a 35.0% change in Y. Thus the ratio Y/Y_T is highly sensitive to the value of p_o and is independent of beam intensity. The statistical error in Y_T is expected to be about 2.2% for 10 beam pulses.

Compared to the relative calibration of the spectrometer with respect to the beam switchyard, the absolute energy calibration is of minor importance. 1% is sufficient in order to eliminate the energy dependence of the cross sections.

4. The Muon Detector.

The muon detector has to reject the pions and electrons produced at the target. The pion yield is roughly 0.35 pions per muon, i.e., the π-μ discrimination should have a rejection efficiency of 10^2. The electron yield beyond 0.05° is about 0.5×10^4 electrons per muon, which postulates an electron rejection of 10^6. Electrons below 0.05° pass through the hole in the detector arrangement. A diagram of the muon detector is shown in Fig. 8. The detector consists of a lead radiator of 6 radiation lengths, an intermediate scintillator, an absorber of 6-1/2' of iron, and a counter telescope. The total amount of radiator amounts to 120 radiation lengths.

The absorber suppresses the purely electromagnetic part of the cascade by a factor of 10^8. A possible source of background is the photoproduction of muons and pions. In Appendix II we calculate these reactions and obtain a probability of 3.5×10^{-5} and 3.5×10^{-8} per incident electron, which transforms to probabilities of 0.14 and 2×10^{-4} per incident muon. In order to reduce this background we degrade the energy of the shower particles in the initial lead radiator, which is followed by a scintillator. All shower-accompanied counts are considered as electron-initiated and are rejected.

We finally consider the rejection of primary pions from the hydrogen target. Disregarding the pionic cascade their frequency is described by

$$N(\pi) = 0.35 \times e^{-n}$$

where $n = 10$ is the number of interaction lengths. After 6.5' of iron we obtain $N(\pi) \cong 1.6 \times 10^{-5}$.

APPENDIX I

The counting rate of muons is calculated in the following way:

1. Bremsstrahlung Spectra

We used the thick-target bremsstrahlung program originally due to R. Alvarez and improved by R. Early[9] to calculate the photon spectra from a 0.03 r.l. copper radiator at different electron energies. The photon spectrum is given by

$$n(k)\, dk = 0.03\ \Phi(k)\ \frac{dk}{k}$$

The shape factor $\Phi(k)$ is calculated on a computer with a Fortran IV program.

2. Cross Sections

The cross section per equivalent photon, integrated over the momentum and angular acceptances of the spectrometer is given by

$$\sigma = \int d\Omega \int_{p_{min}(\theta)}^{p_{max}(\theta)} dp \int_{k_{min}(p,\theta)}^{E_o - m_e} \Phi(k)\ \frac{d^2\sigma(k,p,\theta)}{d\Omega dp}\ \frac{dk}{k}$$

where E_o is the primary electron energy; $p_{min}(\theta)$, the lower limit of the momentum acceptance of the magnetic spectrometer; $k_{min}(p,\theta)$, the minimum photon energy to produce a muon with momentum p at angle θ; $p_{max}(\theta)$, the maximum muon momentum at angle θ. The first two integrations are carried out on a computer using the Gauss-Legendre quadrature formula. The result gives the angular distribution, $\frac{d\sigma(\theta)}{d\Omega}$. Figure 3 shows results for different primary electron energies and $p_{min} = (E_o - 0.22)$ BeV/c.

The angular acceptance of the 20 BeV spectrometer is approximately elliptical with horizontal and vertical acceptance half angles of $\theta_o = 4.5$ mrad and $\Phi_o = 8.0$ mrad and

$$\Delta\Omega = \pi\, \theta_o\, \Phi_o \cong 1.1 \times 10^{-4}\ \text{sr}$$

The last integration over the aperture is carried out on a computer with the trapezoidal rule according to the formula

$$\sigma = \int_0^{\theta_o} 2\pi\,\theta\,\frac{d\sigma(\theta)}{d\Omega}\,d\theta + \int_{\theta_o}^{\Phi_o} 4\theta\,\alpha(\theta)\,\frac{d\sigma(\theta)}{d\Omega}\,d\theta \quad [\text{cm}^2/\text{equivalent photon}]$$

where

$$\alpha(\theta) = \tan^{-1}\frac{\theta_o}{\Phi_o}\left[\frac{(\Phi_o+\theta)(\Phi_o-\theta)}{(\theta+\theta_o)(\theta-\theta_o)}\right]^{\frac{1}{2}}$$

3. Collimation of Photon Beams

Since the copper radiator is designed to be located 168 feet upstream from the liquid hydrogen target, only part of the bremsstrahlung can be use to do the photoproduction process under consideration. In order to keep the momentum resolution of the spectrometer to the designed value, the photon beam produced from a 0.03 radiation length radiator is collimated at the target position to a size of 0.3 cm in the vertical direction. The fractions of the bremsstrahlung F_γ, which could reach the target are given in the following table:

TABLE III

Primary Electron Energy (BeV)	F_γ (%)
8	14.6
10	18.1
12	21.8
14	25.3
15	27.1
16	28.8
18	32.2
20	35.2

The numbers in the above table are calculated (numerically) with a Fortran IV program by folding together the angular distributions from bremsstrahlung[9] and from multiple Coulomb scattering of the primary electrons in the radiator[10].

4. Counting Rate

Using a 100 cm long liquid hydrogen target, the number of protons is

$$N_p = 100(0.07)(6 \times 10^{23}) = 4.2 \times 10^{24} \text{ protons/cm}^2.$$

Using 2×10^{13} primary electrons/sec and a 0.03 r.l. copper radiator the number of equivalent photons is

$$N_\gamma = (2 \times 10^{13}) \times (0.03) = 6 \times 10^{11} \text{ equivalent photons/sec.}$$

The final counting rate for muons, N_μ, is given by

$$N_\mu = N_\gamma F_\gamma N_p \sigma \text{ muons/sec.}$$

APPENDIX II

Here we estimate the effectiveness of the muon detector to electromagnetic shower and the probability to photoproduce muons and pions. The energy of the initial electron is $E_o = 20$ BeV, the detector consists of 6 radiation lengths of lead and 1550 g cm^{-2} of iron, which is 110 radiation lengths and 10 interaction lengths.

1. Electromagnetic Shower.

According to Nagel's[11] calculations the number of shower particles after 25 radiation lengths is for $E = 1.5$ MeV

$$\Pi(E_o, E, t) = 0.6$$

We extrapolate the attenuation using the minimum slope, and obtain

$$\Pi(20, 10^{-3}, 110) \cong 10^{-8}$$

2. Photoproduction of Muon Pairs.

We compute the probability that an electron of $E_o = 20$ BeV initiates the production of a muon pair, and that at least one of the muons has sufficient energy to penetrate the iron absorber. Then the range must be > 1550 gcm^{-2}, corresponding to a muon energy of 2.4 BeV. This results in a cutoff between 2.4 and 4.8 BeV in the photon energy. The number of muons produced is

$$N_\mu \, dE_\mu = \int N_\gamma(E_o, k, t) \cdot N_N \cdot \sigma(k, E_\mu, Z) \, dt \, dE_\mu$$

where the integration goes to a cutoff at $t_{max} = \ell n \frac{E_o}{k_{min}}$. Using poor-man's shower theory, where

$$N_\gamma(20, k, t) \cong \frac{1}{3} e^t \quad \text{with} \quad k \cong E_o e^{-t}$$

$$N_N = \frac{x_o}{A \, m_p} \ [\text{cm}^{-2}] \quad \text{with} \quad x_o = 5.8 \text{ gcm}^{-2}, \ A = 207, \ m_p = 1.66 \times 10^{-24} \text{g}$$

$$\int \sigma \, dE_\mu = Z^2 r_e^2 \alpha \left(\frac{m_e}{m_\mu}\right)^2 \left\{ \frac{28}{9} \ell n \left(\frac{183}{Z^{1/3}}\right) - \frac{2}{27} \right\}$$

we obtain with $k_{min} = 3.6$ BeV

$$N_\mu(E_\mu > 2.4) \cong 3.5 \times 10^{-5}$$

3. Photoproduction of pions

i) The total cross section for pion photoproduction(12) is $\sigma_{\gamma\pi} \leq 10^{-28}$ cm^2 independent of k. We further assume a peripheral mechanism with $E_\pi = k$. Then the number of pions is:

$$N_\pi = \int N_\gamma(E_o, k, t) \times N_n \times \sigma_{\gamma\pi}(k, E_\pi) \, dt$$

with

$$N_\gamma(20, k, t) \cong \frac{1}{3} e^{t} \quad \text{and} \quad k = E_o e^{-t}$$

$$N_n = \frac{x_o}{m_p} \quad [\mathrm{cm}^{-2}]$$

$$\sigma_{\gamma\pi} \cong 10^{-28} \ \mathrm{cm}^2$$

Using the same range cutoff as in the muon case, but with $k_{min} - 2.5$ BeV, we obtain

$$N_\pi(E_\pi > 2.5 \ \mathrm{BeV}) \leq 7. \times 10^{-4} .$$

ii) We assume that pions are absorbed with a mean free path of 155 gcm^{-2}. This is about the value measured at several BeV at Brookhaven in connection with shielding for the muon beam, and it is somewhat longer than the absorbtion length measured at 19.3 BeV[13].

We obtain for 6.5' of iron

$$N_\pi \leq 7 \ 10^{-4} \times e^{-10} = 3.5 \times 10^{-8} .$$

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SUMMARY OF SLAC
Preliminary Proposal No. 14.

July 1966.

PROPOSAL FOR TESTING OF QUANTUM ELECTRODYNAMICS BY PHOTOPRODUCTION OF ASYMMETRIC MUON PAIRS

1. Experimenters:

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2. Experiment:

a) Physics.

The essence of the experiment is to detect μ^- from $\gamma p \to p\mu^+\mu^-$ near 0^o with $p \approx k_{max}$, and to compare the muon yield with the electron yield under the same conditions of target, γ beam and magnets and with similar detectors. The "good" Feynman diagram has for the lepton propagator $t \approx -2\ km$ which at 20 BeV is $(2\ BeV/c)^2$ for the muon and $(0.14\ BeV/c)^2$ for the electron. We would measure the relative yields at several energies (say, 10, 15, 20 BeV) and look for a deviation from QED. Very roughly, for a 5% experiment that showed no deviation the limit on the usual Λ would be $\Lambda^{-1} \gtrsim 3 \times 10^{-15}$ cm (67% confidence).

The muon rate is about 100 counts per hour.

b) Technique

The 20-BeV spectrometer is at 0^o. The normal p and θ hodoscopes are spread away from the spectrometer axis to let the blast of electrons through. A special p hodoscope measures the electron spectrum. Measuring the muons and electrons at the same time reduces sensitivity to magnet drifts. Muons are identified by a coincidence telescope after 6.5 feet of steel. Electron rejection is enhanced by a shower counter at the front of the steel. Muon and electron counts are selected on the bases of their p, θ distributions and the responses of the identification counters. Rejection of pions depends in large part on kinematics as well as on nuclear absorption in the steel.

c) Some Points to Verify

i) The γ beam is dumped inside the first quadrupole of the spectrometer. Does this cause too much background?

ii) Will the required rejection ($\sim 10^{-6}$) of muon counts from electrons be easily achieved?

iii) The operation of the split hodoscopes depends critically on the wings of the angular distribution of the electrons.

iv) Good over all resolution in p and θ is important. This depends on the spectrometer optics (including source height effects), the γ beam size and spectrum, and the BSY energy resolution.

3. Experimental Requirements

a) SLAC Equipment
20 BeV spectrometer
SDS 9300
Liquid hydrogen fill and vent system
Photon radiator, beam dump and photon collimators.

b) Major Equipment Furnished by Group.
Split p hodoscope for muons
Special p hodoscope for electrons
Muon filter and telescope
Shower counter
Hydrogen target (100 cm).

c) Machine Requirements
Good current into narrow energy band
(we assume 2×10^{13} e/s into $\pm$ .05%)
Good energy stability $\lesssim$ 0.1%/hour
Modest energy calibration (1%)
Energy 10-20 BeV (convenient maximum)

4. Running Time Estimate.

Hard to estimate because most is for testing and checking. Guess:

100 hours - Debugging - 60 or 180 cps
50 hours - Data (at 3 energies) - 180 or 360 cps.

We could be ready to start this experiment in the Summer of 1967.