SLAC Proposal No. 13

SLAC Proposal 13 C.2

A PROPOSAL TO MEASURE WIDE ANGLE ELECTRON PAIRS

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SUMMARY

It is proposed to measure the photoproduction of wide angle electron-positron pairs at energies and angles such that the virtual fermion momentum is in the range from 300 MeV to 1200 MeV. The apparatus consists of two large total absorption shower counters, two counter hodoscopes, two threshold gas Cerenkov counters, and a two meter bending magnet. This experiment can be ready for execution in the summer of 1967.

I INTRODUCTION

It is proposed to study the photoproduction of wide angle electron pairs[1] using a high energy bremsstrahlung beam from the Stanford Linear Accelerator. The purpose of this experiment is to study further the anomaly found in wide angle electron pair production in experiments at the Cambridge Electron Accelerator[2] both as a function of photon energy and as a function of the momentum of the virtual fermion. In particular it is planned to study electron-positron pairs in the region where the mass of the electron-positron system is greater than the rho mass and one is free from the troublesome correction due to rho mesons decaying into electron positron pairs.

Because of the lower duty cycle it is much more difficult to do this experiment at SLAC than at an electron synchrotron such as the Cambridge Electron Accelerator. In order to overcome this problem we have made an extensive study of what techniques could be used and we have arrived at an apparatus which uses total absorption shower counters for the final energy measurement and gas Cerenkov counters for particle identification. On the basis of our experience at the Cambridge Electron Accelerator we feel this proposal is conservative and that in practice we will be able to do better. If things should turn out to be much worse than we anticipate, we feel we can reduce the beam intensity even further and still do a meaningful experiment.

II MOTIVATION

Figure 1 shows the two dominant Feynman diagrams for electron-positron pair production. In the experiment at the Cambridge Electron Accelerator wide angle pair production measurements were made for symmetrical pairs with the angle between one member of the pair and the incident photon 4.6^{o}, 6.25^{o}, and 7.5^{o}.[2] For each opening angle the total energy of the electron-positron system varied from 1 to 5 BeV. In this experiment the mass of the virtual fermion varied from 50 to 425 MeV; the mass of the electron-positron pair varied from 80 to 580 MeV. The data showed an excess of electron pairs at high energies and large masses for the virtual fermion. There was also a failure to obtain the proper cross section for low virtual fermion masses where quantum electrodynamics is known to be valid. It is now believed that this difficulty is due to the inefficiency of the Cerenkov counters ~~and to an improper~~ treatment for the radiative corrections. The ratio of the theory to experiment can be expressed as

$$R = 0.62 \left(1.00 \pm 0.05 + \frac{k^2}{(4.31 \pm 0.17)^2}\right) \quad (1)$$

where k is the energy in BeV of the photon which produced the pair, or by

$$R = 0.67 \left(1.00 \pm 0.04 - \frac{Q_f^2}{(313 \pm 13)^2}\right) \quad (2)$$

where Q_f^2 is the four momentum of the virtual fermion in $(\text{MeV})^2$. Equation (1) gives the best fit to the data; equation (2) is more satisfying to theorists.

A group at Cornell has repeated this experiment using a somewhat different technique.[3] They made measurements for an average pair half angle of 7.5° with photon energies up to 1.8 BeV. Their results are consistent with the anomaly observed at the CEA. Their effect, however, is much smaller and requires more careful attention to detail than the CEA experiment.

The present analysis of experiments on the photoproduction of μ pairs at the CEA suggests a cross section which at constant energy ($\sim$4.4 BeV for the initial photon) is somewhat greater than the theoretical cross section and which decreases slowly with increasing mass of the virtual fermion.[4] These measurements also show that the decay of rho mesons into mu pairs gives a contribution which is roughly the same size as the Bethe-Heitler cross section.

An experiment is now being prepared to repeat the measurements on wide-angle electron pairs at the Cambridge Electron Accelerator. This experiment will repeat with many improvements the old measurements, will extend the measurements to small opening angles (2.5°) and will measure the Compton amplitude and the decay of rhos into electron-positron pairs. Thus this experiment will attempt to settle all of the outstanding questions for virtual fermion masses less than 500 MeV and photon energies less than 6 BeV.

The purpose of the SLAC experiment is to extend these measurements to higher energy and higher virtual fermion masses. It is planned to make measurements at the same angles as employed in the CEA experiment but extending to higher energies so that we can obtain virtual fermion masses in the range from 300 MeV to 1200 MeV. This corresponds to electron-positron pair masses from below the rho mass to twice the rho mass. Thus this data will tie onto the CEA data below the rho mass and then extend through the rho mass into the completely unexplored region above the rho mass. This together with the CEA should give complete measurements of the cross section as a function of angles, energy, and virtual fermion mass.

III EXPERIMENTAL SETUP

Figure 2 shows a drawing of the general setup. The main parts are the following:

(1) Collimated photon beam of 10^9 equivalent quanta (Q) per second and the availability of an electron beam of roughly ten times this size.

(2) Hydrogen target

(3) A large magnet such as Mozley's magnet or its equivalent

(4) Two large threshold type gas Cerenkov counters

(5) Four counter hodoscopes

(6) Two large lead sandwich type shower counters with built in

trigger counters

(7) Quantameter or an equivalent device for monitoring the beam

(8) Beam dump

(9) Electronic apparatus

(10) Shielding

The Cerenkov counters will be 20 feet long gas counters set at the threshold for 10 BeV/c pions. This corresponds to an electron cone angle of 0.8° and gives the same amount of light as the counters we are at present using with greater than 95% efficiency at the CEA. The main purpose of these counters is the rejection of pions. We find that the pion rejection ratio for our Cerenkov counters at the CEA is limited by knockons in the scintillation counters in front of the Cerenkov counter. In the experiment at the CEA the effective pion efficiency was 8×10^{-3}. We plan at SLAC to use a smaller amount of material in front of the Cerenkov counters and hence we assume in this proposal that we can obtain an effective pion efficiency of 3×10^{-3}.

The primary devices which will be used to detect the electrons and to measure their energy are the two total absorption shower counters. These counters are ideal for this experiment. The electron pair cross section is such that there is an optimum energy resolution $\Delta p/p$ of $4\ \theta$ where θ is the angle one member of the symmetrical pair makes with the incoming photon. The optimum is determined by the width of the peak for symmetrical pairs. In the experiment at the CEA our resolution was smaller than the optimum. For $\theta = 4.6^{\circ}$ (0.08 radians),

$$\left(\frac{\Delta p}{p} \right) \text{optimum} = 32\%.$$

With shower counters tested at the CEA we have been able to obtain a full width at half maximum of 22% for 1 BeV photons. Measurements show that this scales as the square root of the energy so at 5 BeV we expect a full width at half maximum of 10%. This resolution is more than adequate.

The other advantage of the shower counter is its low background and its ability to reject pions and muons. In order to determine the background problem we made a test run with our prototype shower counter. It was placed on one of the two arms so that it saw a three inch long hydrogen target through two half quadrupole magnets. The arm was at an angle of 9° with respect to the emergent electron beam. The counter was shielded on the beam side by 6 inches of iron and an 8 inch thick lead wall. With an external electron beam of 0.1 μ amp and a duty cycle of 1.5% the instantaneous counting rate was only 3×10^{4}/sec. With this counter we were able to see the elastic peak for electron proton scattering when the quadrupoles were turned off. We are now rebuilding this shower counter with internal separate trigger counters so that coincidence techniques can be used to reduce further the instantaneous counting rate. For the design of the SLAC electron pair experiment we have assumed that we can obtain the same performance at higher energies with scaled up counters and that we can also obtain with such a counter a pion rejection ratio of 30. We are now making measurements to determine whether it is best to use lucite, scintillator, or some combination of the two.

The counter hodoscopes will be used to break up the aperature into smaller bins. Their exact design will depend upon the background problems. If necessary one of them could be placed inside the shower counter.

Experience at the CEA indicates that the quantameter hut is the main source of background in the large scintillation counters and even in the gas Cerenkov counters. The design of the CEA experimental Hall makes it difficult to locate the hut far away. We would like to take advantage of SLAC's size and locate the hut remotely so that we can adequately shield the rear of the counters.

In order to permit operation at as high a beam intensity as possible we wish to use fast electronics and computor data logging. We would also like to use the RF bucket timing to permit tighter timing curves and better rejection of chance coincidences. Thus it will be desired to reduce the beam by rejecting a certain fraction of the buckets.

IV COUNTING RATES

A. BASIC DESIGN PHILOSOPHY

In recent experiments at the Cambridge Electron Accelerator we have had a duty cycle of 1.6×10^{-2} with an intensity of roughly 10^{10} equivalent quanta/second. The SLAC duty cycle is expected to be 5.4×10^{-4} (360 pulses/sec, 1.5 μ sec/pulse) or a factor of thirty worse. Experience shows that at a fixed angle and with the same number of equivalent quanta/sec as one goes to higher energy the background problems decrease. Thus we assume that if we lower the beam so that at SLAC the beam is 1/10 of the beam we now use at the CEA we will have the same instantaneous rates at SLAC as we now have in our large counters at the CEA. This gives a SLAC beam of 10^{9} equivalent quanta/sec. We have not been successful in calculating our background rates at the CEA so we feel this design philosophy is more realistic than an unverified calculation. We have also calculated all of the electron and pion rates and we find that they are smaller than this estimate of background rates. We feel that this design philosophy is conservative; with careful attention to shielding we should be able to do better.

All of the calculations reported here have been made for a 0.5 cm thick carbon target. In practice we plan to do the major running with a hydrogen target. Since a high intensity beam is available at SLAC the target thickness can always be chosen so that the single channel electron rates are dominated by processes that go as the target thickness and the contributions that go as target thickness squared can be neglected.

B. COUNTING RATE CALCULATIONS

We have calculated electron pair rates and background rates for a typical, but not necessarily optimum geometry. The arms are placed symmetrically and each has an angular acceptance of 2.7 msr, from 2° to 5° in the vertical direction and from 4° to 7° in the horizontal direction. A 2 meter magnet with a field of 11.7kG bends particles in the horizontal direction. (A 10 BeV particle bends 4°.) For this geometry the average mass of the virtual fermion (Q_f) is 520 MeV; this corresponds to an average invariant pair mass of 730 MeV.

We have estimated single pion rates by assuming the dominant processes are peripheral production[5] and the decay of ρ mesons produced by a diffraction process.[6,7] The calculated angular distributions of pions are shown in Figure 3. This cross section averaged over the acceptance is $1.0 \frac{\text{mb}}{\text{sr BeV Q}}$. At a beam intensity of 2.8×10^{6} Q/pulse this yields a pion flux of 2.3 particles/arm pulse. A rough, but conservative estimate of single electron rates is 2×10^{-3} particles/arm pulse and an accurate calculation of the electron pair rates yields a counting rate of 1.5×10^{-4} counts/pulse or 200 counts/hr.

The distribution of Q_f for this geometry is

Q_f (MeV)	counts/hr
300	15
400	53
500	71
600	37
700	16
800	5
900	1.8
1000	.9
1100	.2
1200	.1

Preliminary studies of other geometries show that it will be possible to increase the counting rate for $Q_f \geq 900$ MeV by at least a factor of 3.

It is of some interest to note how the counting rates vary over the angular acceptance. For nearly symmetric events, the electron pair cross sections (in arbitrary units) are

Vertical Angle \ Horizontal Angle	7°–6°	6°–5°	5°–4°
5°–4°	.02	.02	.01
4°–3°	.12	.10	.07
3°–2°	.73	.61	.42

A map of the average Q_f (in MeV) for nearly-symmetric pairs is (top number for 8-10 BeV pairs, middle number for 6-8 BeV pairs and bottom number for 4-6 BeV pairs)

Vertical Angle	7°–6°	6°–5°	5°–4°
5°–4°	1060 760 580	990 760 640	980 790 700
4°–3°	860 590 470	780 590 530	750 630 600
3°–2°	670 420 360	560 420 420	530 470 510

Horizontal Angle

If it is assumed that the resolving time is 3n sec and the single arm rejection factor for pions is 10^4 all chance coincidence rates are completely negligible, the largest being the electron-electron chance rate of 10^{-2}/hr.

V SLAC FACILITIES NEEDED

1) Mozley magnet and power supply
2) Collimated photon beam
3) Beam monitoring devices
4) Use of computor for on-line data handling
5) Availability of coincidence circuitry

6) Provision for filling only certain RF buckets so that the RF structure can be used for timing

7) Hydrogen target

8) Assorted lead and concrete for shielding

The large Cerenkov counters, the shower counters, and the counter hodoscopes will be built at the Harvard cyclotron.

VI PERSONNEL

The names listed on this proposal do not signify that they are the only participants but only that they are responsible for what is said in this proposal. Other people in the CEA WAPP group are interested and will be involved. We would also like to join with the Mozley group since much of our initial testing can be done while they are running and we will be able to make use of some of their techniques and know how.

VII RUNNING TIME REQUEST

a) 100 hours preliminary testing of apparatus - in this period we will not require all the pulses nor complete control over the machine parameters. Part of this testing can be done while Mozley is running.

b) 400 hours prime time for data taking. During this period we will need control over the machine parameters and the machine energy. We will want to do RF timing and accordingly throw out a certain fraction of the RF buckets. We will require the machine to run with as long a duty cycle as possible. We would like a large fraction of the time with the machine energy above 16 BeV. We will also need some runs with the electron beam for the calibration of the counters and the measurements of the counter efficiencies. It may be desireable to break this running time up into two large blocks.

VIII WHEN EXPERIMENT READY TO RUN

We are at present building the final prototype shower counter and we will test it sometime this summer. We can be ready to make preliminary test measurements this fall and to run the experiment late next summer.

IX PERIOD REQUIRED TO ANALYZE THE EXPERIMENT

The WAPP group has a great deal of experience with the analysis of this kind of an experiment. Final results should be available within two or three months after the data is taken.

REFERENCES

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6. S. M. Berman and S. D. Drell, Phys. Rev. 133, B791 (1964).

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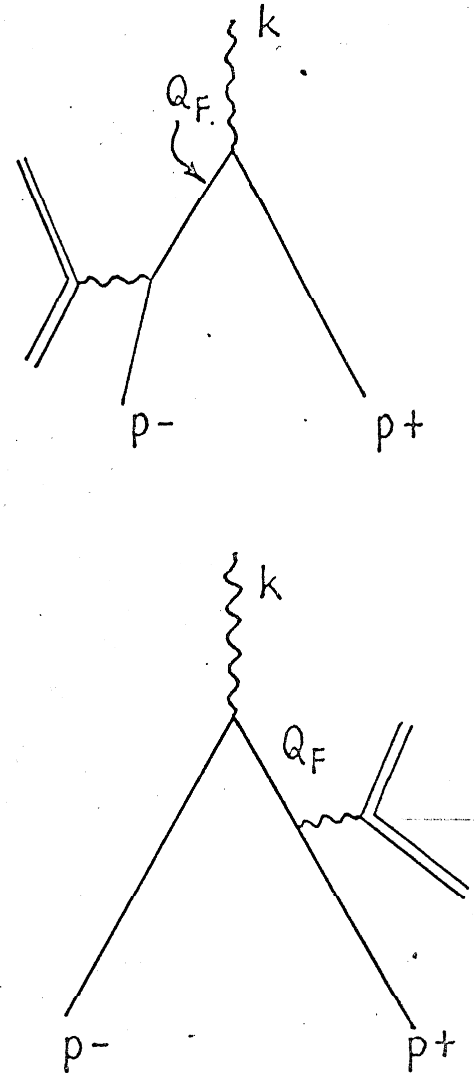

Figure 1

Feynman Diagrams for Electron Positron Pair Production

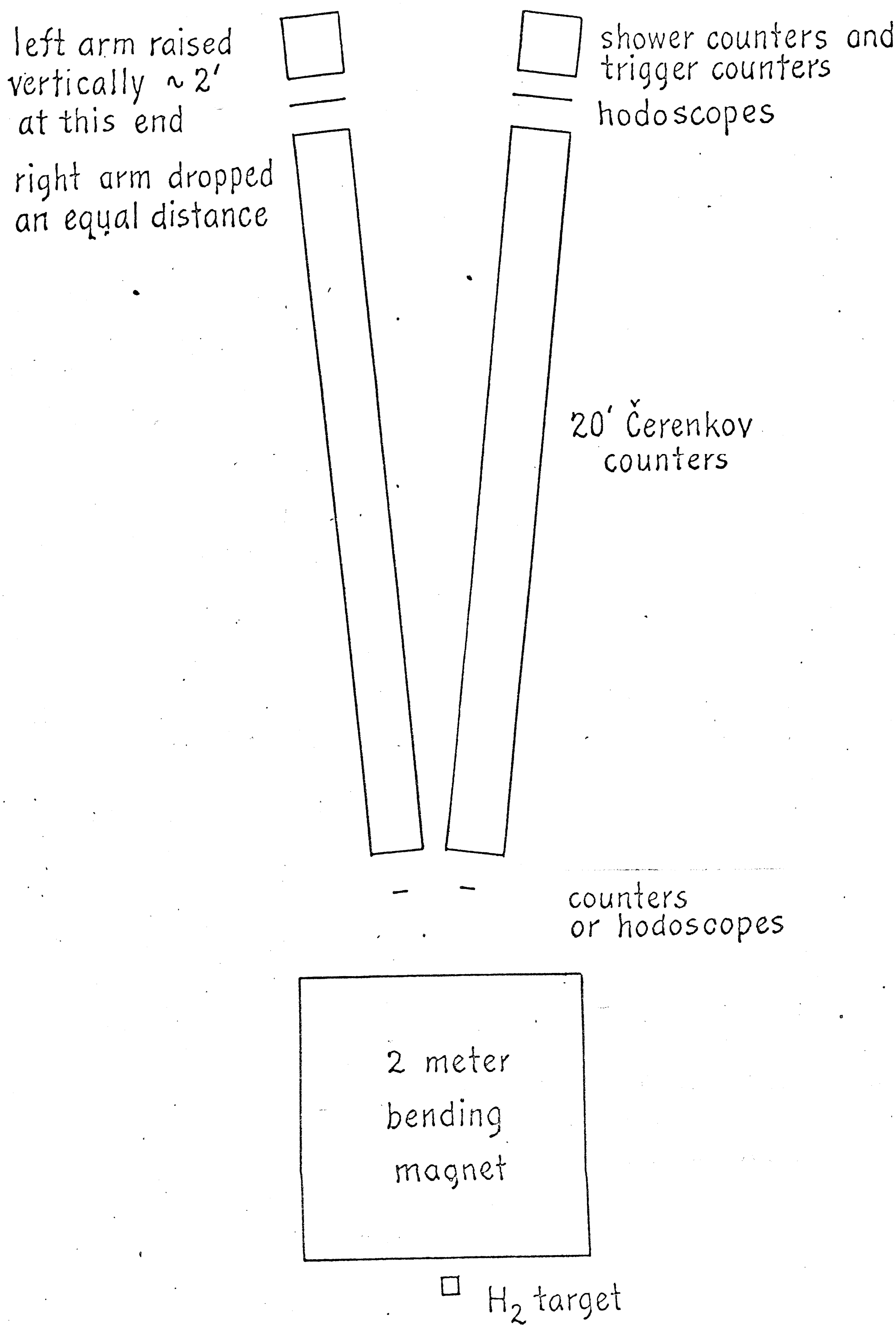

Figure 2
Schematic Drawing of Apparatus

1/4" = 1'

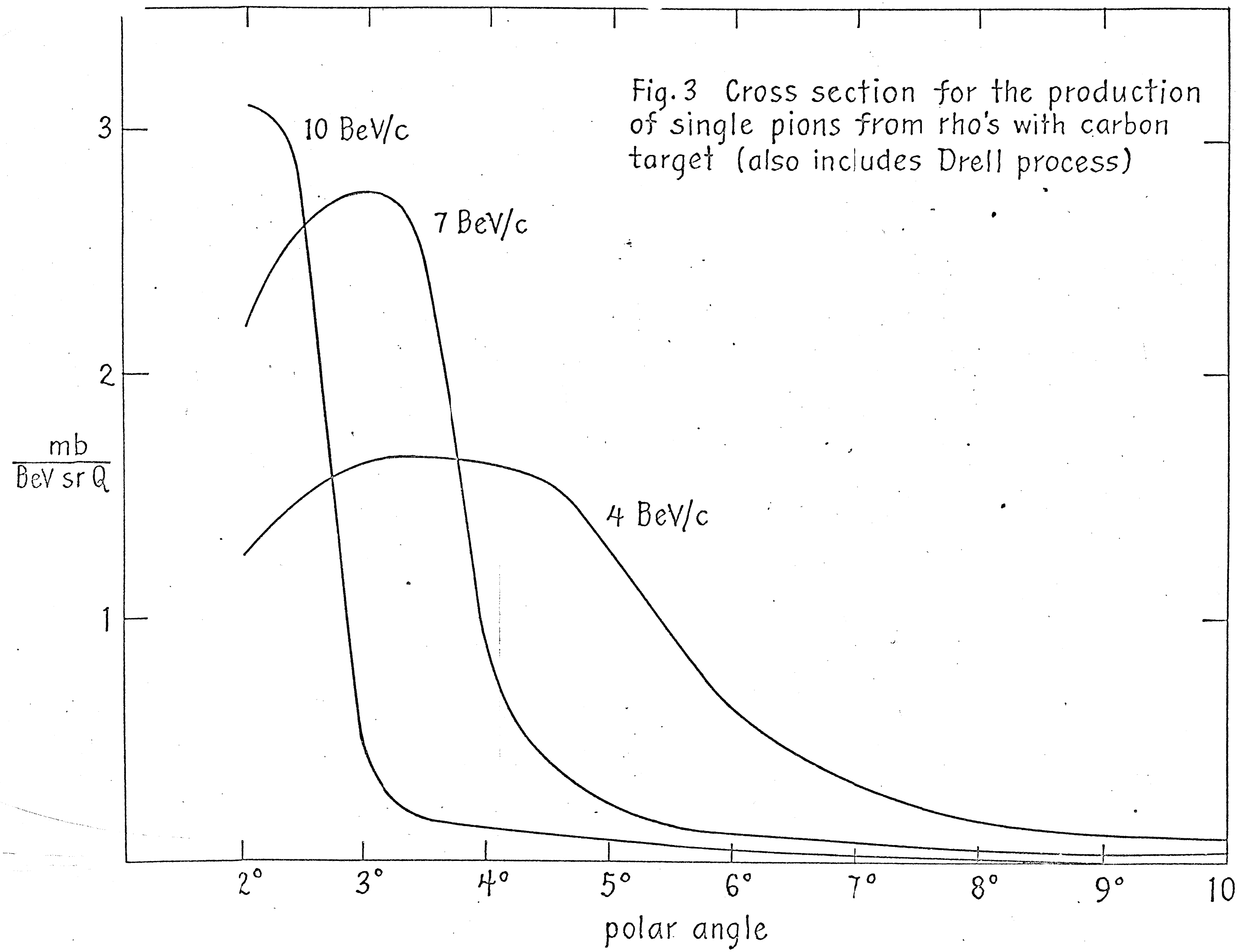

Fig. 3 Cross section for the production of single pions from rho's with carbon target (also includes Drell process)

SLAC Proposal 13 Supp.

~~SUPPLEMENT TO~~

PROPOSAL ~~NUMBER 13~~ TO MEASURE

WIDE ANGLE ELECTRON PAIRS

R. B. Blumenthal, G. Feldman,

F. M. Pipkin, and J. Tenenbaum

This supplement was written to supply further experimental details which were arrived at after a trip to SLAC in June, 1966. During this period we conferred with the Mozley group, calculated some additional background rates, and investigated the availability of certain kinds of apparatus.

A. NEW BACKGROUND CALCULATIONS

In our previous calculations we did not include the rate in the hodoscope counters due to low energy Compton scattered photons. We have now calculated these rates assuming that we have a hardened photon beam. With 2.8×10^6 equivalent quanta/pulse, the total rates in the hodoscope counters for a 15 cm long hydrogen target are:

(a)	Low energy photons	9.5/pulse..
(b)	Pions	2.3/pulse.
(c)	Single electrons	2×10^{-3}/pulse.

For the Compton scattered photons we used the calculation of Thiebaux (TN-64-80). This calculation assumes a hardened photon beam (65 gm/cm^2 Be). We have assumed that the hodoscope counters were 1/8" thick scintillator and that 1% of the low energy photons materialized in the counters. With a pulse length of 1.5 μsec, these calculations give an instantaneous rate of 8 Mc/sec in the hodoscope (total counts--not counts in the bins). One could work with this rate--we have chosen, however, to improve the apparatus so that we can eliminate the Compton scattered photons.

We also used the calculations of Thiebaux to determine the rates in our CEA counters which look directly at the hydrogen target. We found that if we assumed hardening the photon beam reduced the number of low energy photons by a factor of 10, we could calculate the rates encountered at the CEA. Thus we now feel that we have a reliable calculation of the rates in the hodoscope. This is quite encouraging, as it means we can run with a higher beam intensity than 2.8×10^6 Q/pulse.

The beam dump at SLAC is located so remotely from our apparatus that we feel that neutrons from it will not be a problem. Thus we expect that the rates in the large counters will be dominated by target associated processes.

B. CHANGES IN THE APPARATUS

In order to overcome the Compton photons we have decided to use a SLAC type 18D72 bending magnet in front of the Mozley magnet. With this arrangement we can get a total bend of 12° and we can put a slit between the 18D72 magnet and the Mozley magnet. This slit can be made so that all of the counters are shadowed by the slit in such a manner that the counters cannot see the target and hence the source of low energy Compton photons. This slit can also be used to improve the energy resolution of the bending magnet system. One can also insert a set of hodoscope counters between the two magnets and by reducing the beam somewhat use this system to measure the rho photoproduction at high energy.

This application requires a magnet with a somewhat larger vertical aperture than the conventional 18D72 magnet. We would need one of these magnets modified so that it has a vertical gap of 12".

C. USE OF A COMPUTER

Our experience at CEA indicates that a computer is essential to a multi-counter experiment. The computer: (1) logs the data on an event-by-event basis onto magnetic tape, (2) performs simple bit counting and histogram displays to aid in setting up and diagnosing the hodoscopes, (3) does simple calculations--for example, the calculation of the dipion mass in a pi pair experiment. We have implemented these features for our CEA experiments using a PDP-1 on a time-shared basis.

For the SLAC experiment our requirements can be summarized as follows:

Either I. A small stand alone computer (SDS-92, PDP-8, or equivalent) with the following features:

(a) 8K 18 bit word (12K 12 bit word) memory.

(b) One or more IBM compatible magnetic tape units (7 track).

(c) Oscilloscope display feature.

(d) Program controlled input and output lines (sufficient to read in or out a full machine word).

(e) "DECTAPE" or equivalent.

(f) Standard input/output device consisting of paper tape reader, paper tape punch, teletype.

Or II. A larger computer (SDS-9300, IBM 1800, etc.) already existing at SLAC on a stand alone basis. This computer would operate solely on our experiment when we were running. Adequate checkout time when we were not running would also have to be made available.

Or III. Same as II operating under a time-sharing monitor.

Any one of the above solutions could be enhanced by having an on-line connection to a larger computer, i.e. SLAC's 360/75. According to Bill Miller of the computation group, such a hookup is not likely to be operational for some time after the running time of this experiment (second half of 1967).

D. OTHER APPARATUS

(1) Photon beam

We would like a hardened photon beam of 2.8×10^6 to 2.8×10^7 equivalent quanta/pulse and with a spot size as small as feasible. It was our conclusion from discussions with the Mozley group that the spot size could be 1 or 2 mm in diameter.

(2) Beam monitoring devices

It appears that one of the quantameters now being developed by the Mozley group for use at SLAC will be satisfactory for our application.

(3) Modification of Mozley magnet

We plan to use the Mozley magnet in the symmetric configuration with both pole pieces present. Thus the magnet will have to be rebuilt and remeasured after the Mozley experiment and prior to this experiment. The main reasons for going over to this configuration are to obtain a more symmetrical field and a larger bending angle.

(4) Hydrogen target

We will want a target 15 cm long built in the standard SLAC configuration. It seems wiser to use a SLAC target than to try to build one outside and modify it so as to meet SLAC safety standards.

(5) Modification of Mozley house

In order to make use of the Mozley magnet in its present location, it will be necessary to rebuild one of the supporting columns so that the Cerenkov counters can extend out through the rear of the house at the proper angle.

(6) Additional shielding

In order to reduce the radiation hazard, it may be necessary to build a shield wall around the apparatus. The perimeter is estimated to be 180 feet. Standard SLAC three foot thick shielding block should be adequate for shielding.

(7) Modification of SLAC type 18D72 magnet

We would like one of the standard SLAC bending magnets modified so that it has a 12" vertical gap instead of the standard 6" gap.

(8) Fast electronics

The following list represents the fast electronics (EGG, Chronetics) required for this experiment. They assume six hocoscopes of six counters each. The "bit gates" refer to 10-15 nsec gates which output a level suitable for the computer. All hodoscope counter outputs and most coincidence circuit outputs are sent to the computer.

20 discriminators
8 fourfold coincidence circuits
12 twofold coincidence circuits
4 linear gates
1 amplitude-to-time converter
2 gate generators
66 bit gates with discriminator inputs
(48 hodoscope counters, 6 scintillation counters within shower counter, 4 shower counter phototubes, 2 Cerenkov counters, 6 trigger counters)
24 bit gates with normal inputs (all coincidence outputs)
1 sampling scope
1 Tektronix 585 oscilloscope or equivalent

It is estimated that this much electronics will cost roughly $80,000. In addition, we will require such items as delay boxes, coaxial cables, and small power supplies.

E. RELATIONSHIP TO MOZLEY GROUP

The Mozley group has expressed the desire to collaborate with us on this experiment upon the completion of their present streamer chamber experiment. We have made a tentative division of tasks. The Mozley group will concern themselves with the beam design, beam monitoring, and the work on the large pieces of apparatus which can best be done at Stanford; we will design the rest of the apparatus and build the hodoscopes and shower counters.

F. DESIRABILITY OF THE RF TIMING SIGNAL

In our proposal we expressed interest in having available the RF timing signal and a reduction in the number of filled buckets. This feature is not necessary for the execution of the experiment, and the design of the experiment is not based on having it available.

Supplement to Proposal No. 13

#2

SLAC Propos-l 13 Supp 1 c.2

A PROPOSAL TO MEASURE WIDE ANGLE ELECTRON PAIRS

July 1966

Submitted by:

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Supplement to Proposal No. 13

A PROPOSAL TO MEASURE WIDE ANGLE ELECTRON PAIRS

Group D is planning to join the Pipkin group in a collaboration on the above-proposed experiment if it is accepted.

We have studied the proposal and discussed it with members of the Pipkin group, and we are in agreement on the basic feasibility and importance of the experiment. In particular we have studied the problems relating to location of the apparatus, the photon beam, and magnetic analysis of the events.

The photon beam and beam measuring equipment under development for Area A should be suitable for the experiment. The large 2m magnet can be used in its symmetrical configuration with 2 poles. We feel that it will be possible to perform the experiment in the Group D building behind target Area A. The experiment will extend beyond the building and will require concrete shielding walls not yet designed. The total radiation from the experiment should be much less than that at Mark III since only 10^9Q per second are required (approximately 1 watt), and the beam can be dumped in beam dump east.

In the collaboration, Group D would take responsibility for obtaining and measuring the photon beam and preparing and measuring the magnets. The Group D control trailers can be used, and a large part of the trigger electronics for the Group D experiment No. 5 would be useful. In addition Group D would plan to build the hydrogen target.

Responsibility for the remainder of the experiment has not been determined in detail.

SUPPLEMENT NO. 3
SLAC PROPOSAL NO. 13

HARVARD UNIVERSITY

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December 13, 1966

Professor Matthew Sands
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Stanford University
Stanford, California

Dear Matt:

Enclosed you will find 12 copies of supplement number three to SLAC proposal number 13 (Wide Angle Electron Pairs). At the time of the Berkeley meeting it was suggested that we should add spark chambers to the electron pair experiment and increase the mass resolution so that we could simultaneously look at the decay of the vector mesons into lepton pairs. We have since then looked into the feasibility of doing this and we have concluded that it is possible and desireable. The rate for $\omega \rightarrow e^+e^-$ and $\varphi \rightarrow e^+e^-$ is greater than 5 events per hour. In the course of 100 hours (360 pulses/sec), we could get 500 events of each type. If we were to add a muon counter we could also obtain 500 events where each particle decays into a muon pair. This would not only give us a good measurement of the branching ratio for the decay of the vector mesons into two electrons, but would also give us a check on μ-e universality at the φ and ω masses and we might be able to study the ρ-ω interference.

For the muon experiment we will need some large pieces of iron to filter out muons; this is an additional request that we now wish to make. In order to further explore the background problems and to determine whether or not the background permits us to use spark chambers, we would like to make a trial run using a mock up of one arm as soon as the Mozley magnet is assembled and ready for operation.

Sincerely yours,

F. M. Pipkin

MS 12/19/66

enclosures (12)

Supplement 3 to
A Proposal To Measure Wide Angle Electron Pairs
(SLAC Proposal No. 13)

by

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and

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A. Odian, F. Villa, and D. Yount

Stanford Linear Accelerator Center

1 December 1966

In this Supplement we show that by improving the mass resolution of our apparatus, we cannot only measure Bethe-Heitler e^+e^- production more precisely, but also simultaneously measure the decays of vector mesons into e^+e^- and $\mu^+\mu^-$. The improved mass resolution will be obtained by adding spark chambers to our apparatus. The μ's will be detected with counters described in Section III.

I. Mass Resolution

Calculations have shown that, ignoring hodoscope resolution, bins of less than 10 MeV in the effective mass of the electron pair are easily obtainable. There are two major contributions:

1) Magnets: a lack of knowledge of the fields from the two magnets used of up to 1/2% will lead to a mass uncertainty of less than .2%. (This is a rough result obtained by assuming uniform fields which fall off sharply.)

2) Target Length: the uncertainty as to where an event takes place along the 15cm hydrogen target leads, for our present experimental configuration, to a mass uncertainty of less than .5%(full-width) over most of our angular acceptance. (The target width and height do not affect the mass resolution to lowest order.)

The mass resolution due to the hodoscopes would be about 100 MeV. This can be greatly reduced by using visual spark chambers in one of the two following configurations:

a) Thin chambers immediately adjacent to each of the four hodoscopes (2 per arm); or
b) One wide-gap chamber in front of each rear hodoscope.

The hodoscopes will be retained in order to pick out the correct spark in multiple-track photographs.

In configuration (a), spark-chamber resolution (including effects of multiple-scattering) is negligible compared to the uncertainties due to magnets and target-size. Thus the resultant mass resolution will be better than 1% (full-width).

In (b) multiple scattering in the Čerenkov tank becomes important and the spark chamber resolution becomes more important because the single chamber is considerably shorter than the distance between the two chambers in (a). These two effects (especially the latter) make the contribution of the chambers to the mass resolution up to ten times as large as for (a), or about 2%. This clearly becomes the major factor here. But 2% (or about 20 MeV) is still far better than the 10 % or so possible without any spark chambers. As discussed below, 20 MeV should be adequate to observe the 2-lepton decays of ω's and φ's. We will also be able to scan the e^+e^- spectrum for other narrow resonances up to about 1.8 BeV.

II. Vector Meson Decays Into Electron-Pairs

We will assume that at the energies of our experiment ρ, ω and φ-mesons are diffraction-produced[1] in the forward direction; and that away from the forward direction the production cross-section falls off as $e^{\alpha q^2}$ (q^2 is the momentum transfer squared to the recoil nucleon). If k is the incident photon energy, experimental data are fairly-well fit by a form

$$\frac{d\sigma}{d\Omega} = c\, k^2\, e^{\alpha q^2} \tag{1}$$

where $\alpha \approx 9.5\ \mathrm{BeV}^{-2}$. ($c\,k^2$ is proportional, in Berman and Drell's model[1], to the differential πN forward cross-section; and c is proportional to the total πN cross-section squared.)

Using a simple form for the current coupling a vector meson to two leptons[1,2], one obtains a six-fold differential cross-section per equivalent quantum of

$$\frac{d^6\sigma}{dE_+ dE_- d\Omega_+ d\Omega_-} \approx \frac{3}{16\pi^2}\, \frac{\Gamma_{V\to ee}}{m_V}\, \frac{1}{s^2}\, \frac{1-A^4}{\left(1-\frac{s^2}{m_V^2}\right)^2+\left(\frac{\Gamma_V}{m_V}\right)^2}\, kG(k)\, \frac{d\sigma}{d\Omega_V} \tag{2}$$

for $\gamma + N \longrightarrow V + N$, $\quad V \hookrightarrow e^+ + e^-$

where V can be ρ, ω or φ. Here

s^2 = invariant mass-squared of e^+e^-;
Γ_V = full-width of V;
$\Gamma_{V\to ee}$ = partial-width of V in e^+e^- channel;
G(k) = Bremsstrahlung spectrum;
$A = \frac{E_- - E_+}{E_- + E_+}$ is an asymmetry parameter (which also $= \frac{\theta_+ - \theta_-}{\theta_+ + \theta_-}$

for forward-produced V's); and $\frac{d\sigma}{d\Omega_V}$ is given by equ. (1).

The model runs into theoretical difficulties for non-forward vector-meson production; so we allow for this largely through the experimental $e^{\alpha q^2}$.

We have used recent bubble chamber data for the total ρ, ω, and φ photoproduction cross-sections[3,4] to determine the constants c in equ.(1). For the partial widths, we used a combination of the scanty experimental data[5,6,7] and the predictions of an SU(3) ω-φ mixing model.[8] The numbers used are listed in Table I.

We have integrated equ.(2) over our acceptance. The total counting rates for nominal momenta of 6 Bev/arm and 8 Bev/arm are given in Table II, along with the Bethe-Heitler rates. Figures 1 and 2 show the total number of counts per 10 MeV mass bins. The ω and φ clearly stand out; and with our estimated counting rates, we will easily be able to measure their e^+e^- decays, even with 20 MeV resolution. With enough events, we may also be able to observe $\rho \to e^+e^-$.

III. Muon Pairs

We plan to place six feet of iron with a counter telescope behind the shower counter in each arm, to detect high-energy muon pairs. For this purpose, we are requesting 200 cubic feet of iron.

The major background to target-produced muon pairs is due to pion pairs in which both members of the pair decay in flight. For 8 BeV pions, this occurs once every 1300 times. At the ρ mass we expect about 4000 pion pairs for every target-produced muon pair; and at masses well above the ρ mass, the ratio will drop to 1000 or less. Moreover, the apparent invariant mass of a muon pair arising from a pion pair will be less than that of the pion pair if either of the pions decays in the magnet system. This will tend to shift the background muon pair mass spectrum significantly downward.

Thus it should be possible to obtain a rough measurement of the Bethe-Heitler cross-section for $\mu^+\mu^-$ with invariant mass above the ρ mass. (This is the region of greatest interest.)

Most significantly, the decays of ω and φ into $\mu^+\mu^-$ will be visible as narrow peaks above the combined Bethe-Heitler and background muon pairs; and thus a direct measurement of $\frac{\Gamma_{V \to \mu^+\mu^-}}{\Gamma_{V \to e^+e^-}}$ will be possible. In the region of the ω, about 25% of the muon pairs will be from ω-decays; in the region of the φ, about 60% of the muon pairs will be from φ-decays.

IV. Requests from SLAC

The only additional request is for the 200 cubic feet of iron (6 ft. by 4 ft. by 4 ft. for each arm) for use with the mu counters.

References

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(4) Cambridge Bubble Chamber Group, Phys. Rev. 146, 994(1966); and to be published.

(5) D. M. Binnie et.al., Phys. Letters, 18, 348(1965).

(6) R. A. Zdanis et.al., Phys. Rev. Letters, 14, 721(1965).

(7) J. K. dePagter et.al., Phys. Rev. Letters, 16, 35(1966).

(8) R. F. Dashen and D. H. Sharp, Phys. Rev. 133, B1585(1964).

Table I

	ρ	ω	φ
Total Photoproduction σ (μb)	16.0	3.0	0.4
Total Width (MeV)	150	12.0	3.3
Partial Width for e^+e^- (KeV)	8.0	2.0	4.0

Table II

Counts per hour (e^+e^-)

Nominal Momentum	Bethe-Heitler	ρ-decay	ω-decay	φ-decay	total
6 BeV/c	230.8	9.3	8.7	4.5	253.3
8 BeV/c	115.1	4.4	4.2	11.3	135.0

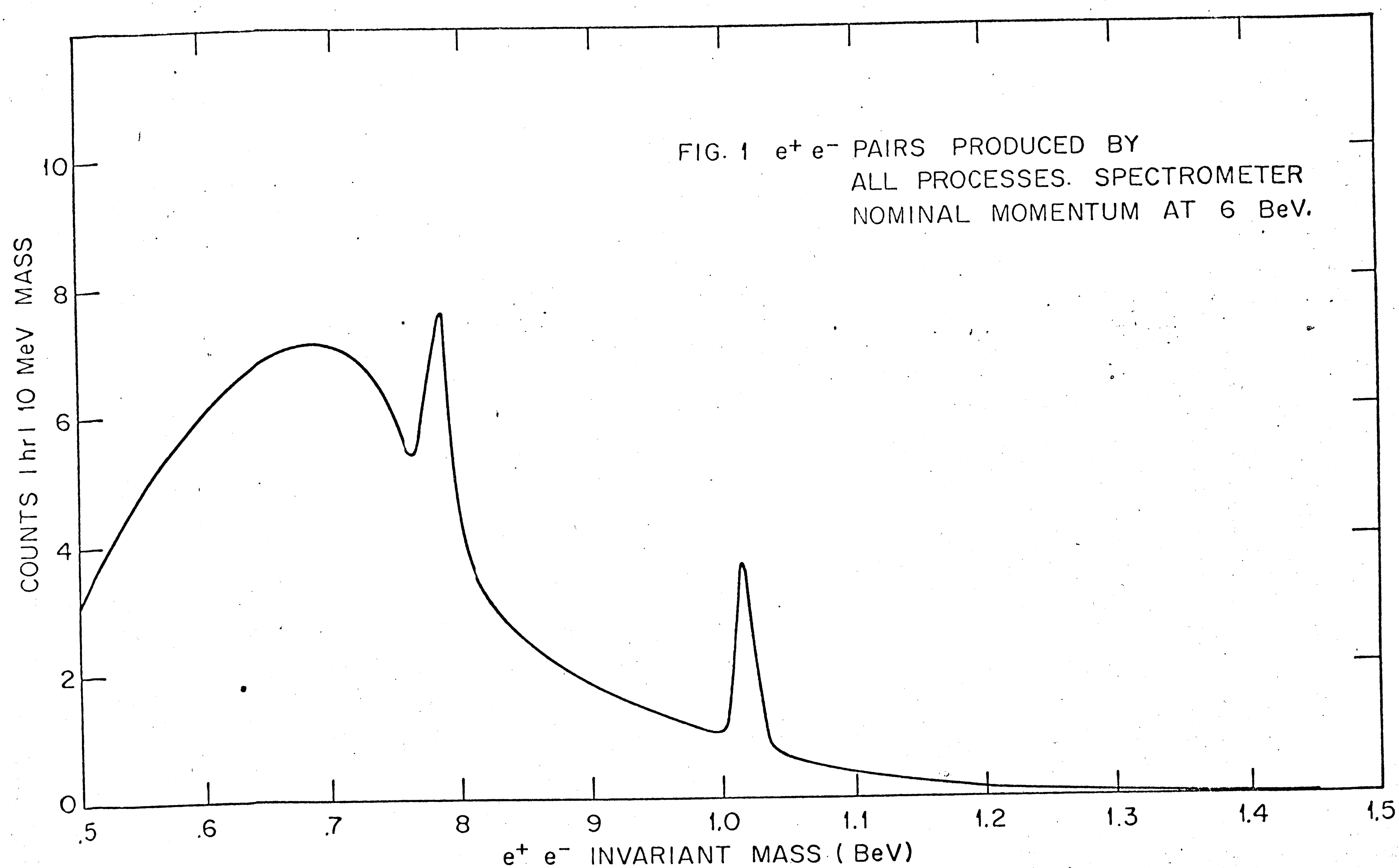

FIG. 1 e^+e^- PAIRS PRODUCED BY ALL PROCESSES. SPECTROMETER NOMINAL MOMENTUM AT 6 BeV.

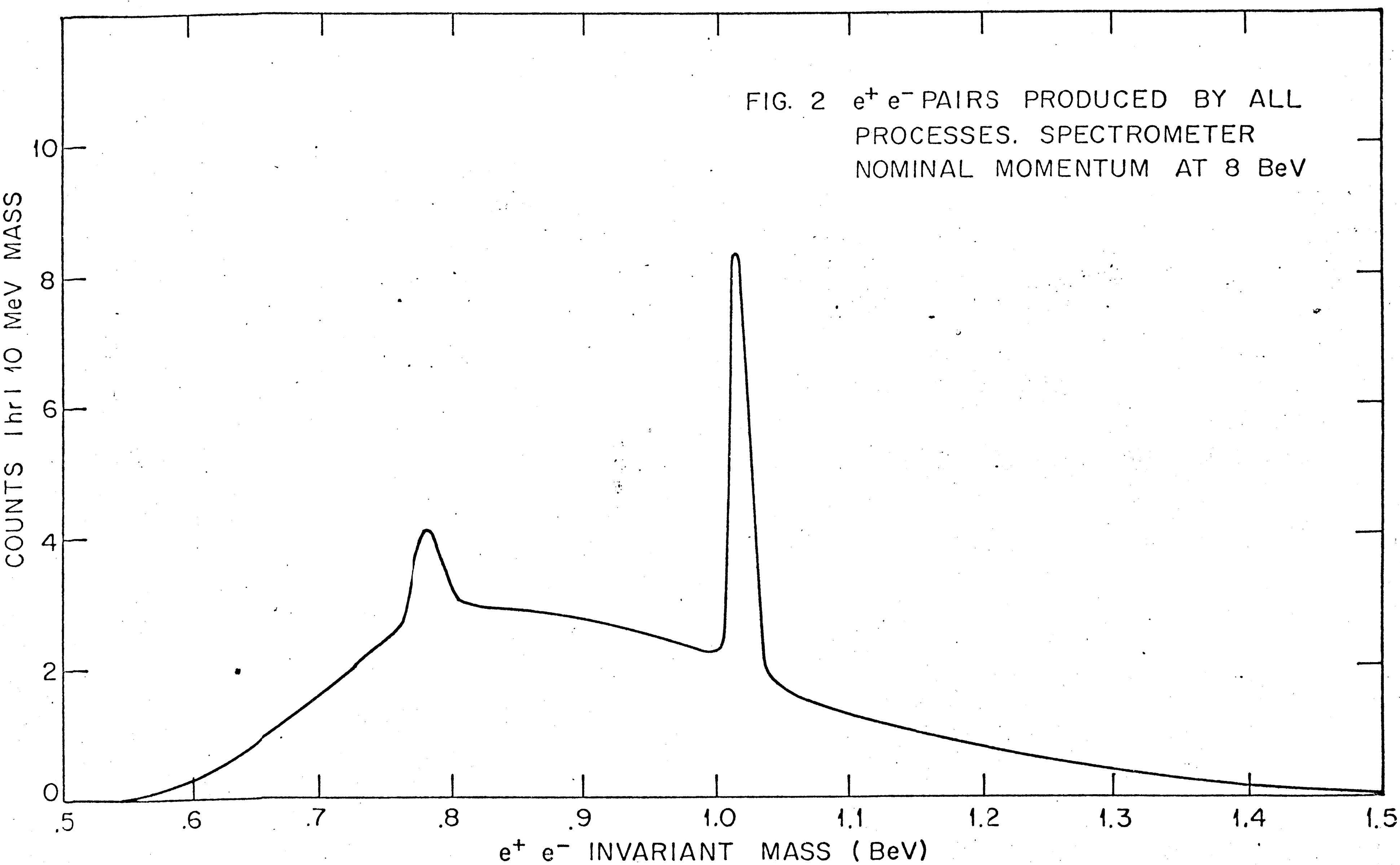

FIG. 2 e^+e^- PAIRS PRODUCED BY ALL PROCESSES. SPECTROMETER NOMINAL MOMENTUM AT 8 BeV