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A PARASITIC ELECTRON BEAM AND TAGGED PHOTON BEAM*

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ABSTRACT

A parasitic electron beam facility has been developed at the Mark III linear accelerator, Stanford University.

The beam has been used both for physics experiments and for counter and spark chamber tests, even though the beam intensity is very low. A tagged photon beam was installed as part of the facility. A description of the two beams and a short discussion of the applications of these beams is included.

INTRODUCTION

Several years ago it became apparent that the utility of the Stanford Mark III Linear Accelerator could be increased if a low intensity parasitic beam were made available. Such beams were traditionally used only for counter testing; however, the advent of 4π detectors and in particular the streamer chamber,[1] made weak beams of more than academic interest. An important class of physics experiments could actually be performed with these parasitic beams. (For example, the SLAC Streamer Chamber Group uses a beam for photoproduction studies of 100 Q per pulse or about 10^{-8} of the maximum available photon beam current.) Subsequently it was decided to attempt to activate such a beam at Mark III in the then recently constructed switchyard area. Midway through the checkout of this beam, it became clear that one could also add a tagged photon beam[2] to the facility so that both photons and electrons of known energy would be available in the beam. Because of background problems, it was not clear initially whether or not the tagged photon beam could operate parasitically; in practice we have found these backgrounds to be severe, so that the tagged beam operates only marginally unless the user has direct control of the accelerator. Nevertheless, this beam has been successfully used in one experiment and has also been used for counter and spark chamber tests.

BEAMS

Parasitic Electron Beam

Completion of the Switchyard and End Station II experimental area at Mark III in early 1965 provided a unique facility for parasitic operation. Figure 1 shows a layout of the bunker and End Station I areas, and the Switchyard and End Station II areas. The basic idea behind this parasitic beam was not new and, in fact, had been previously used at Mark III. Typically, 10 to 20% of the electrons in the accelerator beam strike the defining collimator located at the entrance to the bunker. If either the "15-foot side" analyzing system or the "9-foot side" analyzing system is turned on, the electron beam is deflected,

analyzed and used in an experiment in End Station I. Photons produced in the collimator are emitted into a rather large forward cone, the major flux being produced near 0° . These photons are then collimated, pass through End Station I and strike the radiation RO. Electrons or positrons from pairs made in this radiator are focused by quadrupole Q3 and Q4. They are energy-analyzed by the three magnet analyzing system in the switchyard, and emerge from the collimator to form the beam in End Station II where they may be used.

Several characteristics of this beam are apparent. It is truly parasitic; the use of it in no way interacts with use of the primary beam. Since photons of all energies are present, the beam energy may be varied from a very low energy up to the energy in the primary beam, the momentum resolution being controlled by the slits in the energy analyzing system. Finally it should be pointed out that this beam required only activation, not construction, since all components were already in existence.

Major modifications were however needed in the radiation interlock scheme. Since this beam is very weak, it presents no significant radiation hazard and one could consider a scheme where the experimenter has access to the "new end station" experimental area, an area denied access under normal conditions. The problem was to guarantee that, for example, in the event of a magnet failure, the primary beam (or even some small fraction) could not appear in this experimental area. This problem was solved by G. Gilbert who devised the necessary electrical interlocks that permit access under the following conditions:

1. The switchyard is locked and in a "no access" condition.
2. A permanent magnet is installed in the 0° beam-line in the "bunker" so that charged particle beams are deflected.
3. The switchyard magnet polarity is set to analyze positrons.

As another convenience, access is allowed to the switchyard when stoppers sufficient to attenuate the primary beam are inserted upstream in the beam-line. Appropriate interlocks guarantee that the stoppers are indeed inserted.

The beam current available in this beam is highly variable, depending directly on primary beam conditions. Not only is it a function of

primary current, but also it varies with the amount of beam being scraped off on CO. This variation is a little disconcerting at times; however, we have found that beams of a few electrons per minute up to as many as six electrons per 60-cycle pulse are available. Parasitic beam current can be controlled simply and reliably over a large range either by changing the converter thickness at RO or by changing the analyzing slit width. (The maximum $\Delta P/P$ acceptance is about 2% ; since a nearly flat spectrum strikes these slits, beam current is proportional to this width.) Calculations show that beam current could be increased by a large factor if quadrupoles were added to contain more of the large phase space present in this beam. In fact, one could convert near CO and transport the beam with a quadrupole system all the way to the new end station. This method was not attempted because it was expensive and because the present beam currents have been adequate for all requirements to date.

Figure 2 shows the parasitic beam current observed when a 400 MeV beam was being used in End Station I. The current is small at low energies because of multiple scattering and the large emission angles in the converter RO. The beam current decreases near the maximum energy because few high energy photons are available for conversion.

Figures 3 and 4 show some characteristics of this parasitic electron beam. Since the beam is rather poorly defined spatially because of the large phase space, a 3/8-inch-diameter collimator was used at C4 to limit beam spot size. These results come from an exposure of a small streamer chamber to single passing tracks in the parasitic beam. Figure 3 shows the cross-section of the beam to be a circle of about 1-cm diameter. Figure 4 shows the momentum width of the beam with a full width at half maximum of 6%. This number seems surprisingly large, but is nevertheless adequate for most experiments. The observed 6% width may be due to errors in the streamer chamber measurements, although internal consistency tests indicate that this is not the case. Alternatively, it may be that the source of the beam is not as well defined as one might hope and that relatively large angle particles can be transmitted by the system. Our feeling is that the first conjecture is the proper

one and that the beam momentum spread is well defined by the energy analyzing slits. (In this case, the slits were set to $\Delta P/P = 1/2\%$.)

Tagged Photon Beam

Figure 5 shows the arrangement of equipment used to tag photons in this experimental area. The energy analyzed electron beam emerging from the final magnet in the three-magnet analyzing system impinges on the radiator R1 (typically a 20 mil aluminum foil equal to about 0.007 radiation lengths). The charged beam is then deflected by the tagging magnet and dumped into a "beam catcher" made from lead bricks and having a re-entrant geometry to minimize backgrounds. Recoil electrons from bremsstrahlung events in the radiator are emitted at such small laboratory angles that they remain in the beam until deflected by the tagging magnet. In the most common arrangement, three counter channels are used to tag 30% of the bremsstrahlung beam in three 10% wide intervals. This choice is dictated by the experiment being performed; clearly, other choices including smaller photon energy intervals are possible and have been made, depending upon the experiment being performed. Photon energy is then, of course, given by the difference between the incident beam energy and the observed final electron energy. Typically a 1-GeV incident beam is used to generate tagged photons centered at 650-700 MeV. Since the tagging magnet was chosen to be only four inches long, a 1-GeV beam is deflected only about 3° and dumped about 12 inches from the beam-line. This narrow angular bend means that the primary beam struck the side of the vacuum chamber at a narrow grazing angle, producing large backgrounds in the nearby tagging counters. These backgrounds were greatly reduced when the aluminum window in the chamber was replaced by 0.003-inch mylar.

The tagging counters also detected background counts coming from the beam catcher. In practice, these background counts plus the general switchyard background precluded use of the tagging counter as an absolute beam monitor. Furthermore, the solid angle available to the photon beam is small so that photons which are emitted at large angles with respect to the beam direction strike obstructions and are lost. These effects

are particularly severe when the parasitic beam is used to generate the tagged beam. Tagging efficiencies of about 5% to 8% have been measured for these conditions[3] by comparing the tagging counter rate with the coincidence rate between the tagging counter and a NaI counter in the photon beam. Efficiencies of up to 30% have been observed when the primary electron beam coming from the accelerator is used, and its small phase space and energy spread (typically 1% without definition by the energy-defining slits) reduces backgrounds.

Even if these general backgrounds are removed, a number of physical processes remain which reduce the tagging efficiency. A successful beam design must minimize these processes if the tagging counters are to be used as absolute monitors. These processes are listed in Table I as calculated for this beam, assuming a 1-GeV electron beam incident and three tagging counters centered at 800 MeV , each defining $\Delta k/k$ of 10%. Specifically, the photon ranges are 720 ± 40 MeV, 800 ± 40 MeV, and 880 ± 40 MeV while the counters actually detect electrons of energy 280 ± 40 MeV, 200 ± 40 MeV, and 120 ± 40 MeV, or $\Delta P/P \approx 28\%$, 40%, and 65%, respectively. Thus, while the momentum resolution of the electrons is very bad, the resultant energy resolution of the photons is quite good, the two being related by the ration P/k where P is the electron energy and k is the photon energy, $\left(\frac{\Delta k}{k} = \frac{P}{k}\frac{\Delta P}{P}\right)$. The radiator R1 was a 20 mil aluminum foil, the beam aperture being $\simeq \pm 10$ m/E. Figure 6 shows the tagged photon energy spectrum for these conditions as reconstructed from pairs produced in a streamer chamber. This spectrum has a full width at half maximum of 30% as expected, but with rather large tails in the distribution.

The tagged photon intensity is severely limited in this beam by the low duty cycle of the Mark III accelerator. Beams of ≈ 3 photons per pulse have been used giving ≈ 200 photons per second with about a 10% accidental probability. This seems the chief limitation of this beam at present although future improvements in the accelerator will increase the available duty cycle and thereby increase the available tagged photon intensity. Nevertheless, this beam has proved to be useful for experiments even at the present low intensity.

APPLICATIONS

It seems relevant at this point to list some of the applications in which these beams have been used. The intent here is only to stimulate ideas for possible future uses; therefore, no attempt will be made to be complete. The most extensive use of the tagged photon beam has been made by Benaksas and Morrison[4] who studied electron triplets and pairs produced by the tagged photons using the neon gas in a streamer chamber as a target. In this experiment the tagged photons were used as a part of the trigger to ensure observation of high energy ($\approx$ 650 MeV) events. This tagged beam has also been used by F. F. Liu to study the response of shower spark chambers to photons in the energy range 50 to 175 MeV. The parasitic positron beam was used to generate the photons in this calibration. The parasitic beam has been used in two streamer chamber experiments still being analyzed. Benaksas and Morrison observed bremsstrahlung events in a sulphur target inserted in the streamer chamber in an investigation of the shape of the high energy region of the bremsstrahlung spectrum. The point here was to observe directly the event and to measure the low energy electrons resulting from a high energy bremsstrahlung. This beam was also used by Benaksas, Drickey, Kilner, and Rinehart to measure characteristics of electron showers produced by 1-GeV positrons in lead and to compare them with the results of a Monte Carlo calculation. Finally, the beam has been used in numerous counter tests including a test of the use of a PbF crystal as a shower counter by Dally and Hofstadter.[5]

ACKNOWLEDGMENTS

A number of people were involved in the construction and operation of the parasitic electron and tagged photon beams. Doctors David Benaksas and Robert Morrison participated fully in all phases of this work. The support of Professors Carl Barber and Robert Mozley is gratefully acknowledged. Dr. Dieter Fries collaborated in the momentum studies of the parasitic beam using the streamer chamber. Doctors E. B. Dally and F. F. Liu and Mr. Richard Zdarko have also particpated

in the study and use of these beams. Finally, the help of the accelerator crew under Gordon Gilbert and the electrical maintenance crew under Melvin Swift in, at times, trying conditions is gratefully appreciated.

REFERENCES

* Work supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research Contract [Nonr 225(67)].

1. F. Bulos, A. Odian, F. Villa, and D. Yount, "Streamer Chamber Development," SLAC Report No. 74, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1967).

2. D. Drickey, "Tagged Photons," SLAC-TN-65-35, Stanford Linear Accelerator Center, Stanford University, Stanford, California (April 1956); and D. O. Caldwell, J. P. Dowd, Klaus Heinloth, and M. D. Rousseau, Rev. Sci. Inst. 36, 283 (1965). The latter also contains references to the extensive previous work.

3. F. F. Liu, private communication, 1967.

4. D. Benaksas and R. Morrison, Phys. Rev. 160, 1245 (1967).

5. E. B. Dally and Robert Hofstadter, HEPL Report No. 531, High Energy Physics Laboratory, Stanford University, Stanford, California, to be published.

TABLE I

Contributions to Tagging Counter Rates

Process	Relative Rate In Tagging Counters
1. Bremsstrahlung	1.00
2. Wide angle bremsstrahlung × multiple scattering	1.30×10^{-2}
3. Double bremsstrahlung	0.80×10^{-2}
4. Bremmstrahlung × pair production	0.60×10^{-2}
5. Tridents	0.30×10^{-2}
6. Electron-electron scattering	
(a) electrons incident	4.00×10^{-2}
(b) positrons incident	0.15×10^{-2}
7. Bremsstrahlung × Compton scattering	$<0.10 \times 10^{-2}$
8. Bremsstrahlung × electron-electron scattering	$<0.10 \times 10^{-2}$

LIST OF FIGURES

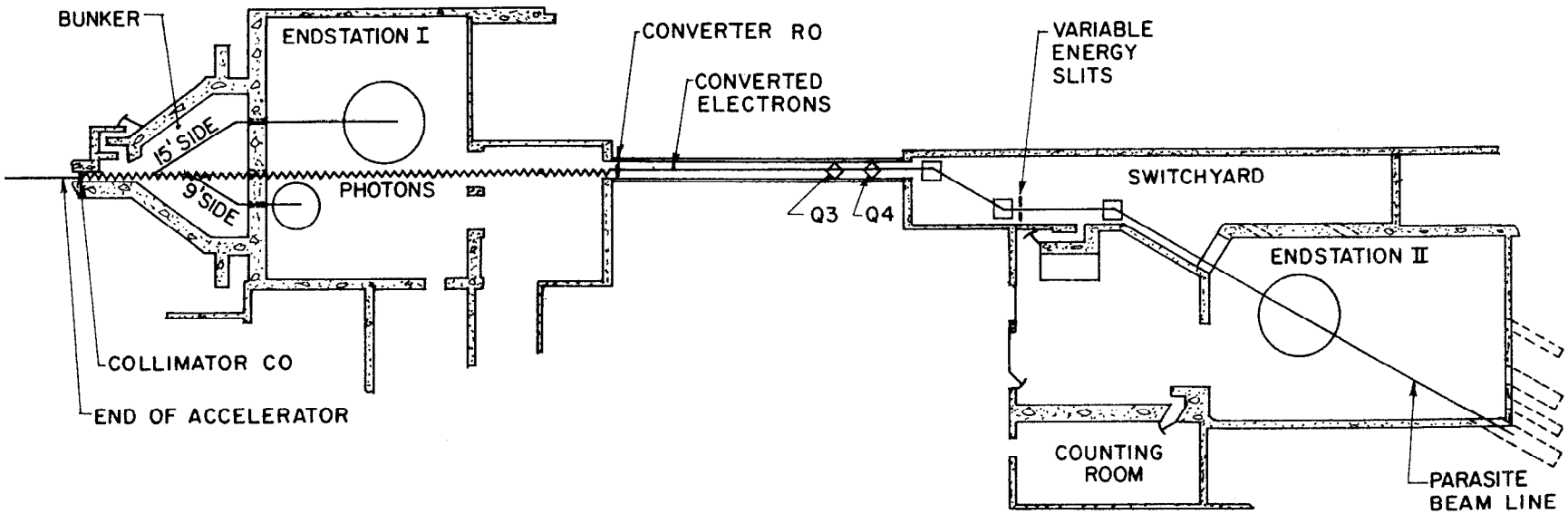

BUNKER
ENDSTATION I
CONVERTER RO
CONVERTED ELECTRONS
VARIABLE ENERGY SLITS
15' SIDE
9' SIDE
PHOTONS
Q3
Q4
SWITCHYARD
ENDSTATION II
COLLIMATOR CO
END OF ACCELERATOR
COUNTING ROOM
PARASITE BEAM LINE

Figure 1

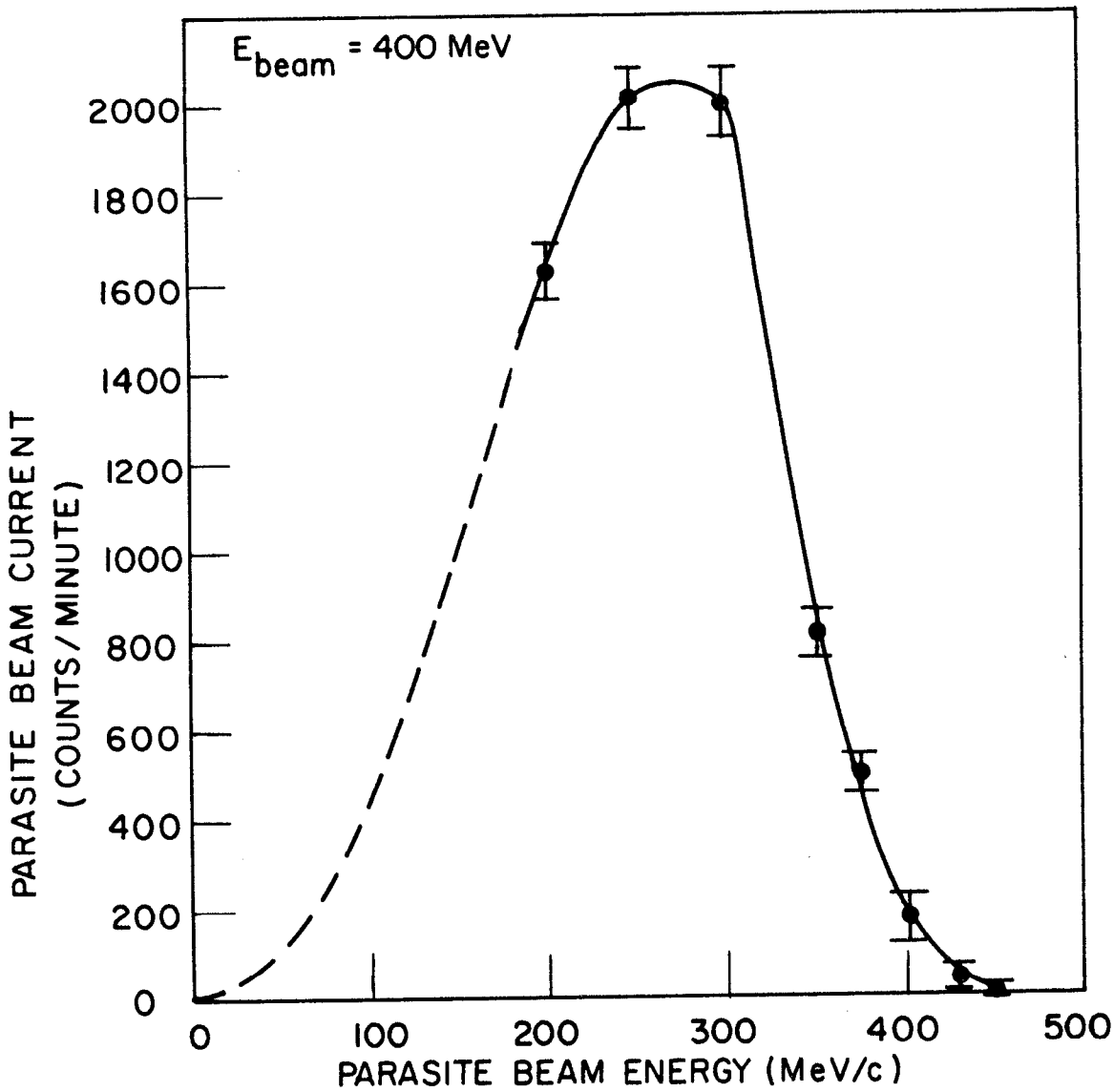
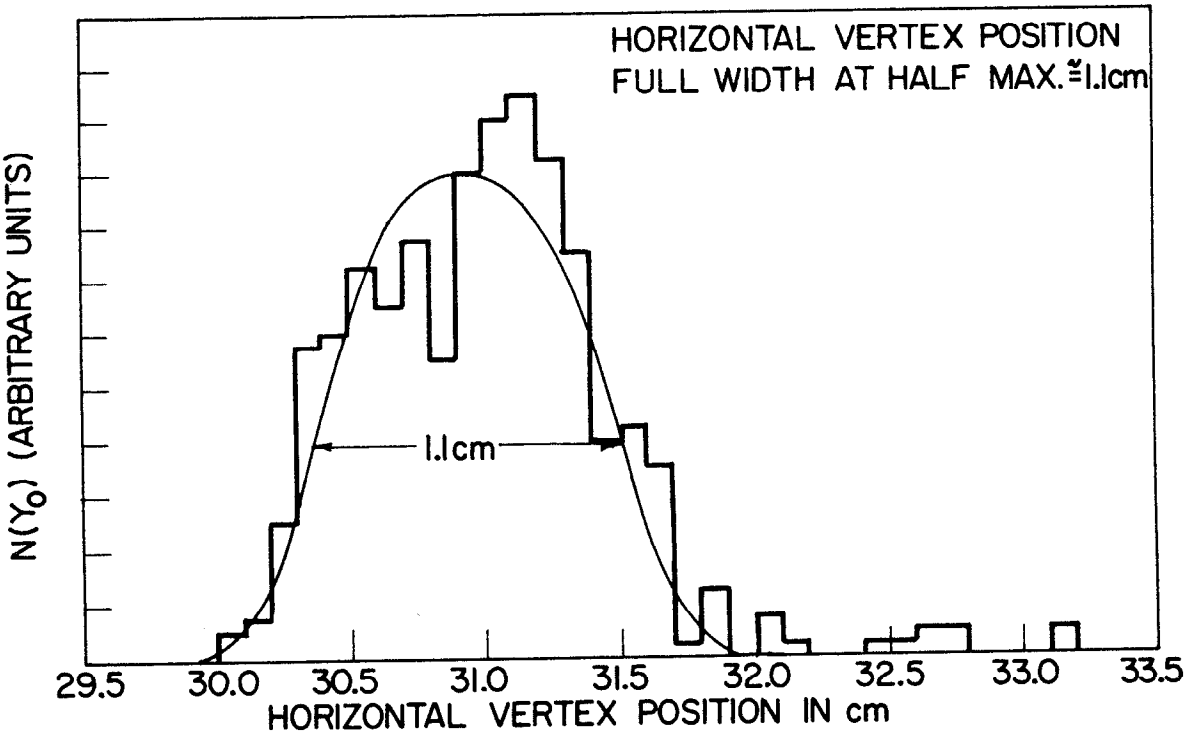

E_{beam} = 400 MeV
PARASITE BEAM CURRENT
(COUNTS/MINUTE)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
PARASITE BEAM ENERGY (MeV/c)

Figure 2


HORIZONTAL VERTEX POSITION
FULL WIDTH AT HALF MAX.≅1.1cm
1.1cm
N(Y0) (ARBITRARY UNITS)
29.5
30.0
30.5
31.0
31.5
32.0
32.5
33.0
33.5
HORIZONTAL VERTEX POSITION IN cm

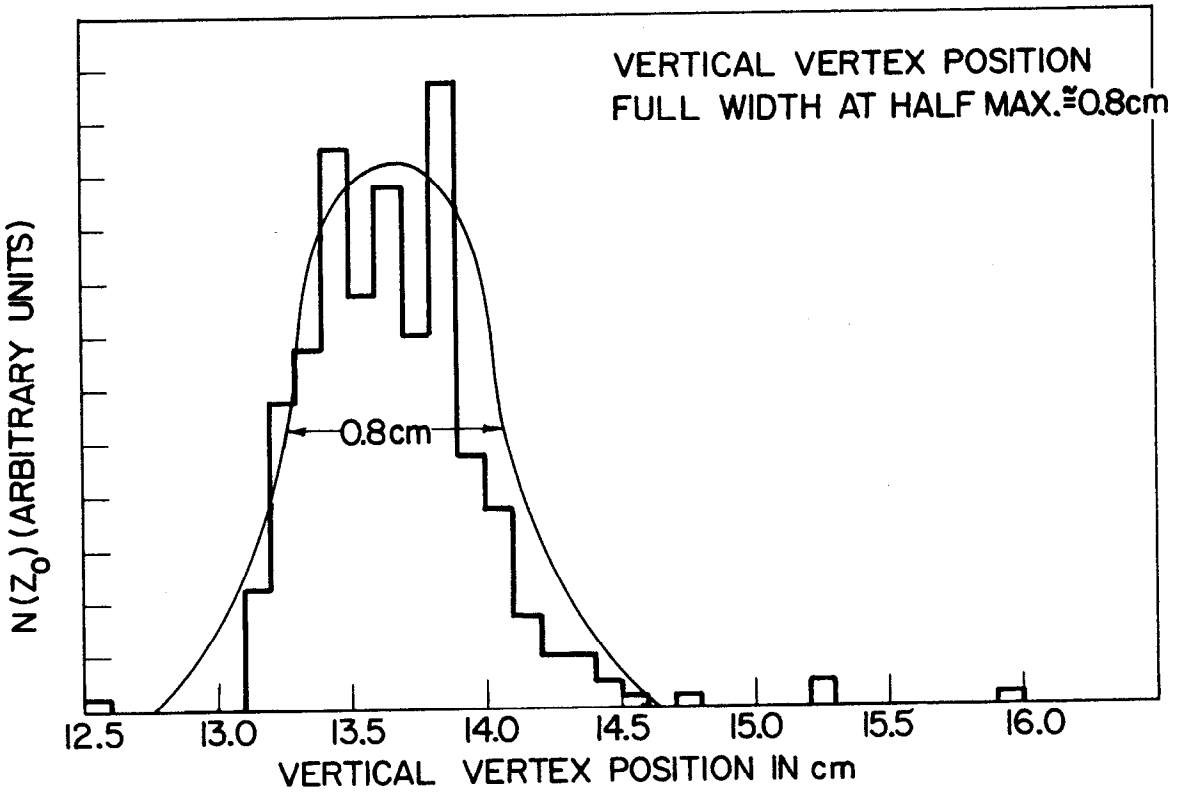

VERTICAL VERTEX POSITION
FULL WIDTH AT HALF MAX.≅0.8cm
0.8cm
N(Z0) (ARBITRARY UNITS)
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
VERTICAL VERTEX POSITION IN cm

Figure 3

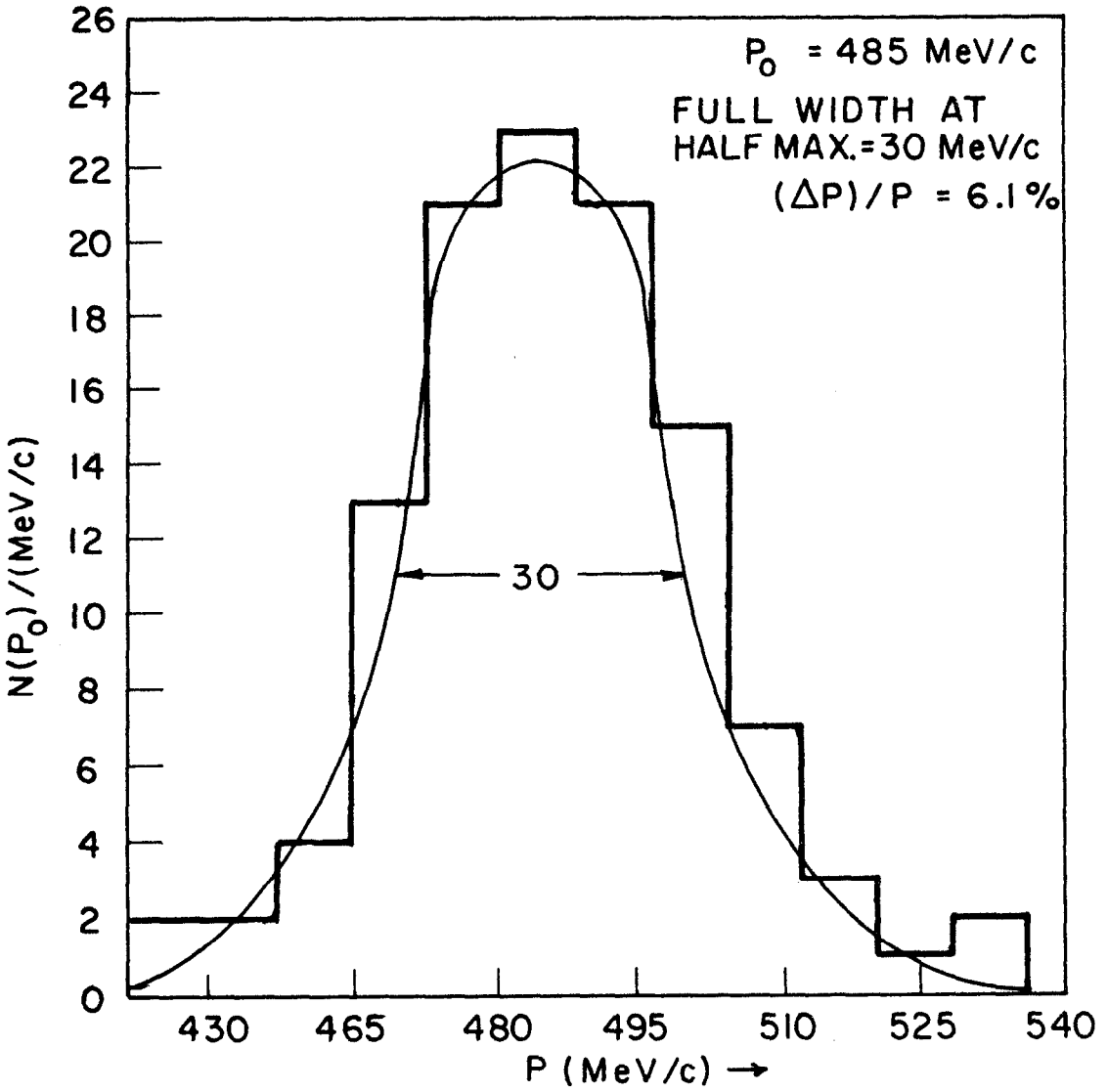

P_0 = 485 MeV/c
FULL WIDTH AT
HALF MAX.=30 MeV/c
(ΔP)/P = 6.1%
30
N(P_0)/(MeV/c)
P (MeV/c) →
0
2
4
6
8
10
12
14
16
18
20
22
24
26
430
465
480
495
510
525
540

Figure 4

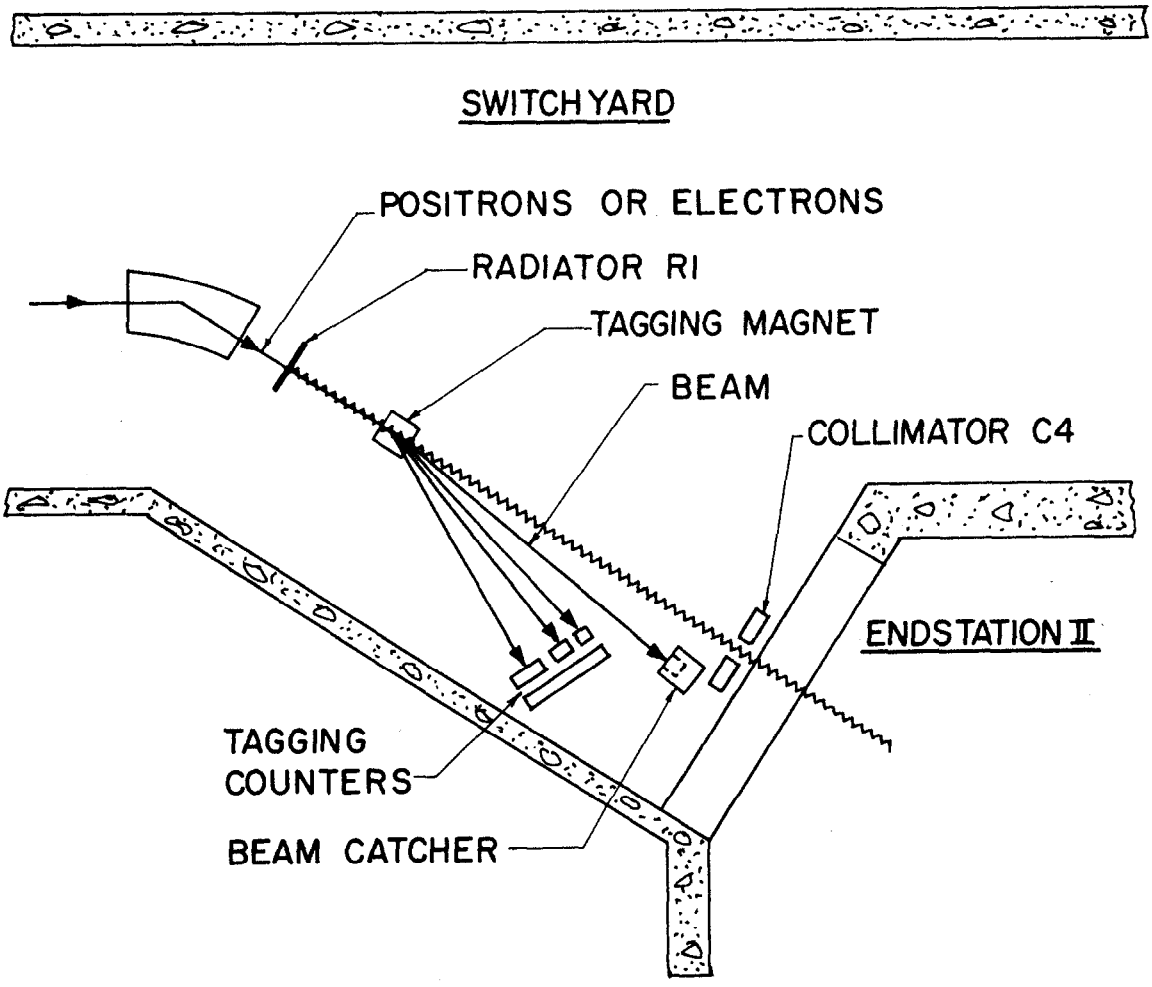

SWITCHYARD
POSITRONS OR ELECTRONS
RADIATOR RI
TAGGING MAGNET
BEAM
COLLIMATOR C4
ENDSTATION II
TAGGING
COUNTERS
BEAM CATCHER

Figure 5

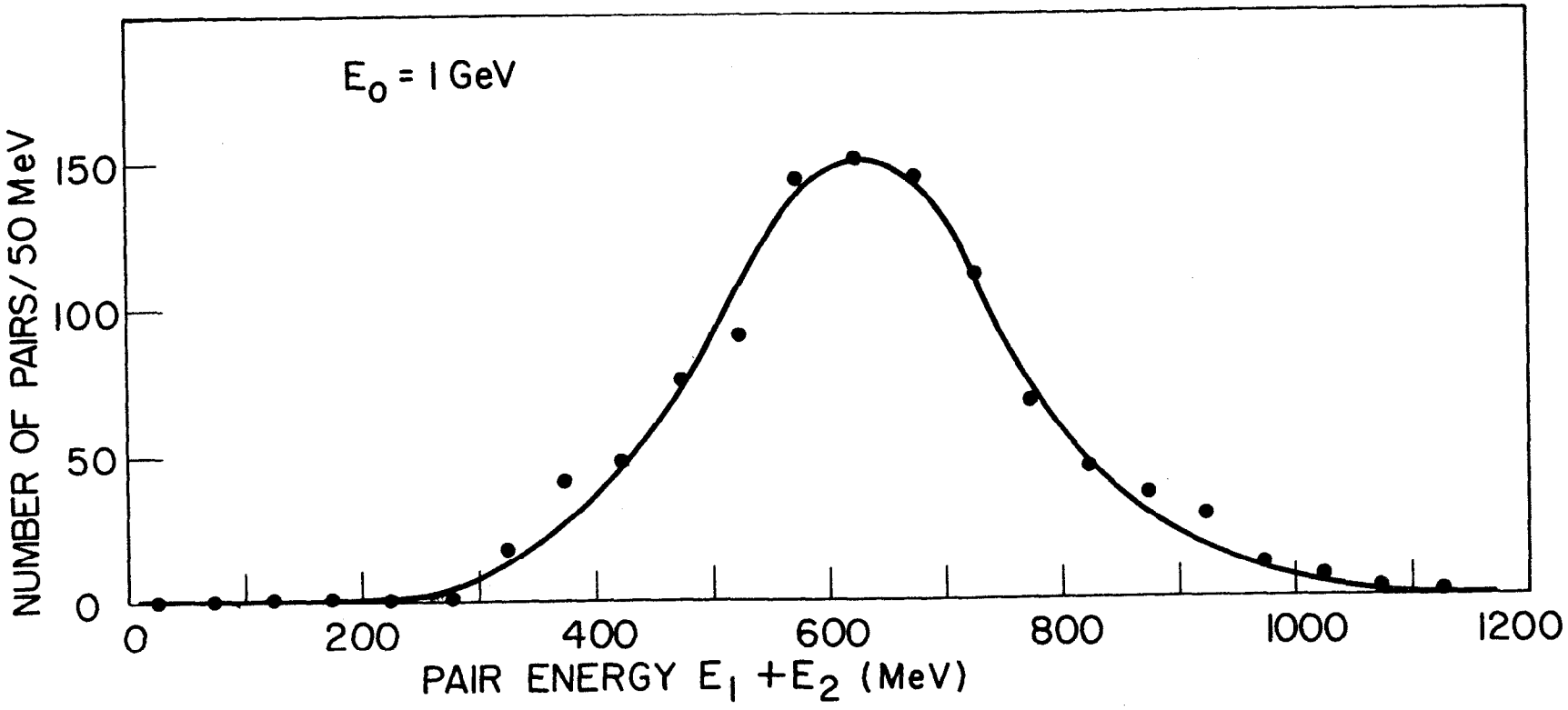

E_0 = 1 GeV
NUMBER OF PAIRS/50 MeV
150
100
50
0
0
200
400
600
800
1000
1200
PAIR ENERGY $E_1 + E_2$ (MeV)

Figure 6