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# SECONDARY PARTICLE YIELDS AT $0^{o}$ FROM THE NEW STANFORD ELECTRON ACCELERATOR*

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We have measured the yields of secondary particles produced at zero degrees to the direction of the incident beam in a beryllium target bombarded by 16 GeV/c electrons from the new Stanford Linear Electron Accelerator. The target was 1.8 radiation lengths thick. We had three purposes in making these measurements. First, we believed that the most intense secondary particle beams could be obtained at or near zero degrees, where the flux per unit solid angle would be at or near maximum, and where a thick production target (several radiation lengths) can be used without broadening the effective source. Our second purpose was to see if a zero degree, secondary beam of strongly interacting particles could be useful in view of the fact that in such a beam there are millions of electrons or positrons for every pion. Our third purpose was to provide results to complement the work of others at non-zero angles.[1,2]

The measurements were made as part of a program of building and testing a high energy muon beam at the Stanford Linear Accelerator Center, during tests of equipment and methods to be used in making a search for new particles.

The beam has three sections. The first is a momentum analysis section in which an image of the target is formed in both planes at the momentum slit. In the second stage, momenta are recombined to give a dispersion-free image in both planes at the second focus. The final stage consists of a pair of quadrupoles which form a third double image, 90 meters from the target. The measurements were made at the third focus.

Electron contamination was removed by placing a lead radiator, typically five radiation lengths thick, at the first focus. Electrons which lose an amount of energy greater than the momentum resolution of the beam, in this case less than one percent, are removed from the beam by the bending magnets in the second stage. From the Bethe-Heitler straggling formula, and the thick target bremsstrahlung calculations of Tsai and Van Whitis,[3] it can be shown that rejection factors of the required order of magnitude ($10^7$ to $10^8$) can be obtained with radiators of three to five radiation length thickness.

At the end of the beam were placed, in order, a differential Cerenkov counter of the type described by Kycia and Jenkins,[4] filled with $CO_2$, a lead-lucite sandwich shower counter,[5] and scintillation counters placed at depths up to 1.6 meters in an iron absorber. The telescope which defined the incident beam for all of these consisted of two scintillation counters, one several meters upstream of the Cerenkov counter, and the second about one meter downstream of the Cerenkov, immediately in front of the shower counter.

Measurements of beam composition were made at 12.0, 8.0,and 5.5 GeV/c, for both positive and negative particles. At each momentum, the electron contamination was measured by means of the shower counter. Except for one measurement at 5.5 GeV/c, where it was 2%, the proportion of electrons in the beam was always less than one percent. The $K/_{(\pi + \mu + e)}$ and $p/_{(\pi + \mu + e)}$ ratios were measured by varying the gas pressure in the Cerenkov counter. The proportion of muons in the beam was measured by the number of particles which penetrated the 1.6 meter thick iron absorber. Particle production ratios obtained in this manner are given in Table I, corrected for decay and for absorption in the counters and in the lead radiator.

In addition to measurements of relative abundance, the muon flux was measured at 5.5 and 8.0 GeV/c relative to 12 GeV/c, and absolute measurements were made at 12 GeV/c. The flux was measured with large counters in the iron absorber which intercepted the whole beam. In order to avoid excessive counting rates, it was necessary to operate at a level of electron current in the accelerator too low to be measured accurately by the electron beam current toroid monitor. The flux measurements were therefore referred to a small monitor telescope placed behind the iron absorber at the end of the beam. This intermediate monitor was calibrated for each measurement against the toroid monitor at high current.

The loss of particles from the beam due to coulomb scattering in the radiator was taken into account in the case of the relative flux measurements by changing the radiator thickness to give approximately the same coulomb scattering at each momentum. Small corrections, based on the variation of yield with radiator thickness at 12 GeV/c, were made to obtain the fluxes for equal coulomb scattering. Corrections were made for the presence of muons from $\pi$ decay. The relative muon yields measured in this way are given on the last line of Table I. No difference in the yields of positive and negative muons was observed.

The absolute flux of muons at 12 GeV/c was obtained by reducing the radiator thickness in steps from 23.6 to 2.7 radiation lengths, and extrapolating to zero thickness. Calculations of the loss due to scattering in the radiator are in good agreement with the observed variation of counting rate with radiator thickness. The counting rate at 12 GeV/c for a 2.7 radiation length radiator must be multiplied by a factor of 1.5 to arrive at the rate for zero radiator. The combined uncertainty in the extrapolation and in the beam acceptance with no radiator is estimated to be $\pm$ 30%. All other sources of error are small in comparison. Our result for the 12 GeV/c muon yield is $1.0 \pm 0.3 \times 10^{-4}$ $\mu^{\pm}$ per Steradian per GeV/c per incident electron, averaged over the acceptance of the beam.[6,8] The complete results are shown in Fig. I, normalized to the experimental point at 12 GeV/c.

We have compared our results with calculations made by Tsai and Van Whitis[7] of the muon yields at small angles from a 1.8 radiation length target. When we averaged their results over the acceptance of the beam and made small corrections for energy loss and multiple scattering in the target (about 3% each), we obtained a value of $1.1 \pm .1 \times 10^{-4}$ per Steradian per GeV/c per electron for the muon flux expected at 12 GeV/c compared with our experimental result of $1.0 \pm 0.3 \times 10^{-4}$. The agreement with the energy variation we observe is good. From the expected variation of muon yield with angle we find that our yields at 12.0, 8.0,and 5.5 GeV/c should be multiplied by factors of × 1.43, × 1.15,and × 1.06, respectively, to obtain the yield which would be observed in an infinitesimal solid angle. The yields of the strongly interacting particles are also averaged over the acceptance of the beam, and the correction to the pion yields will depend on the angular distribution.

In order to compare our measurements at $0^\circ$ from 16 GeV/c electrons incident on 1.8 radiation lengths of beryllium with those of Flatté et al.[1], at $2^\circ$ and $3^\circ$ from 18 GeV/c electrons on a 0.3 radiation length target and of Boyarski et al.,[2] at $1^\circ$ and $0.5^\circ$ from 16 GeV/c electrons on a 0.6 radiation length target, it is necessary to make some assumption about the yield as a function of photon energy, and to correct for the appropriate photon track length, and for absorption in our much thicker target.

These corrections have ± 30% uncertainties. We feel, however, that an even greater difficulty is the separate normalization for the three different experiments, and that there is no common point at which to test the relative normalizations. Therefore, comparisons demanding more precision than a factor of two should not be made.

With this in mind we make the following conclusions:

1. The secondary particle flux at zero degrees is, within a factor of two, the maximum obtainable at the Stanford Linear Accelerator Center.

2. Secondary beams at zero degrees from thick (or thin) targets can be used at this accelerator because the electrons or positrons can be removed without seriously affecting the secondary beam quality.

Acknowledgements

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## REFERENCES


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2. A. Boyarski, F. Bulos, W. Busza, D. Coward, R. Diebold, J. Litt, A. Minten, B. Richter and R. Taylor, Phys. Rev. Letters (this issue).
3. Tsai and Van Whitis, SLAC-PUB-184, 1966, and private communication.
4. T. F. Kycia and E. W. Jenkins, Nuclear Electronics (International Atomic Energy Agency, Vienna, 1962), Vol. I, p. 63.
5. Kindly lent by C. Heusch.
6. The beam acceptance is ± 6.3 mr in the vertical plane, ± 3.9 mr in the horizontal plane, and ± 1.2% in momentum.
7. Y. S. Tsai and Van Whitis, private communication. The muon pair production cross sections used in this calculation were obtained from the formulae given in Y. S. Tsai, Proc. Int. Conf. on Nucleon Structure, Stanford, 1963 (Hofstadter and Schiff, editors, Stanford University Press, 1964), p.221, by the application of the substitution rule. The thick target bremsstrahlung spectrum was obtained from the work described in Ref. 3.
8. Measurements were also made of the muon flux at 12 GeV/c with a small counter telescope, with all quadrupoles turned off. In this case, the electron contamination had to be removed by placing twenty radiation lengths of lead close to the target. The resulting corrections for the additional muon production in lead were made using the results of Tsai and Van Whitis.[7] Corrections also have to be made for multiple scattering in the lead. These results are also consistent with the predictions of Tsai and Van Whitis within similar limits of error.

9. The Stanford Linear Accelerator is designed to give about $2 \times 10^{14}$ electrons per second. Peak electron currents corresponding to about $7 \times 10^{13}$ electrons per second at full repetition rate have been obtained in its initial operation. (G. A. Loew, Proc. 1966 Int. Conf. on Instrumentation for High Energy Physics, p.365, 1966). However, practical considerations of target shielding and the absorption of the power in the electron beam may limit the current which can be used in any specific case. More details may be obtained from the SLAC Users Handbook.

TABLE I - Particle Production Ratios at $0^{\circ}$

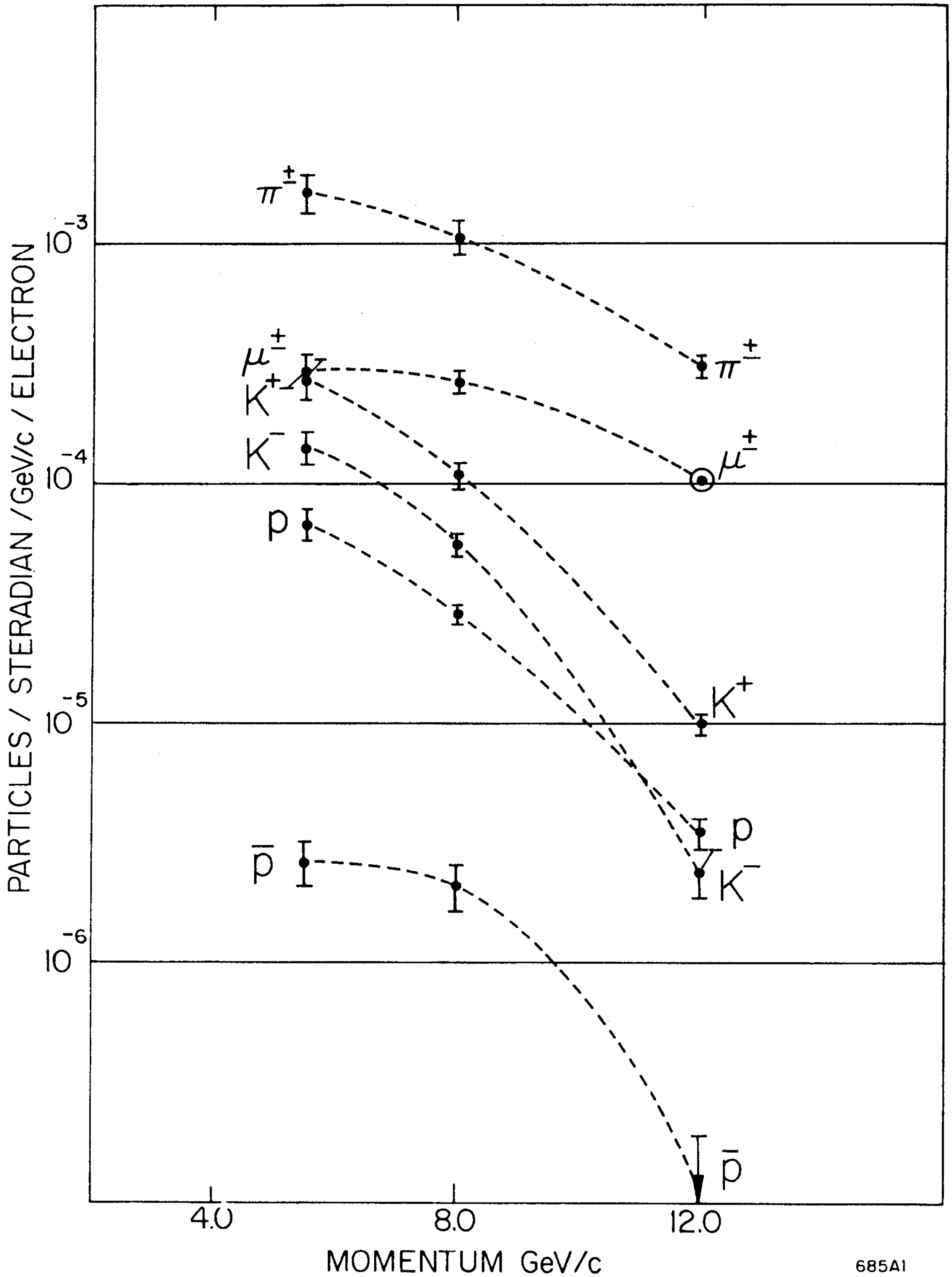
| Momentum (Gev/c) | 5.5 | 8.0 | 12.0 |
|---|---|---|---|
| $\pi^-/\mu^-$ | $5.6 \pm .8$ | $4.1 \pm .4$ | $3.1 \pm .3$ |
| $\pi^+/\mu^+$ | $5.5 \pm .8$ | $4.0 \pm .4$ | $3.0 \pm .3$ |
| $K^-/\mu^-$ | $0.48 \pm .07$ | $0.21 \pm .02$ | $0.024 \pm .005$ |
| $K^+/\mu^+$ | $0.90 \pm .13$ | $0.41 \pm .04$ | $0.10 \pm .01$ |
| $\bar{p}/\mu^-$ | $(0.90 \pm .13) \times 10^{-2}$ | $(0.82 \pm .16) \times 10^{-2}$ | $\leq 2 \times 10^{-3}$ |
| $p/\mu^+$ | $0.23 \pm .03$ | $0.11 \pm .01$ | $.036 \pm .006$ |
| $\mu^{\pm}$ flux per GeV/c relative to 12 GeV/c | $2.9 \pm .5$ | $2.6 \pm .3$ | 1.0 |

| | |
|---|---|
| Target | 1.8 radiation lengths, beryllium |
| Electron Energy | 16 GeV |
| Beam Acceptance* | $\pm$ 6.3 mr vertical, $\pm$ 3.9 mr horizontal |

*All results in this table are averages over the angular acceptance of the beam. See text.

## FIGURE CAPTION

1. Complete results at $0^{\circ}$ for 16 GeV/c electrons incident on a 1.8 radiation length beryllium target. Fluxes are averages over the acceptance of the beam (see text). The results are normalized to the observed muon flux at 12 GeV/c. The normalization is uncertain by ± 30%. Error bars on the muon flux are uncertainties relative to the 12 GeV/c point. Other error bars are uncertainties relative to the muon flux at the same momentum. The curves are freehand through the points.



PARTICLES / STERADIAN / GeV/c / ELECTRON
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$\pi^{\pm}$
$\pi^{\pm}$
$\mu^{\pm}$
$\mu^{\pm}$
$K^{+-}$
$K^{-}$
$K^{+}$
p
p
$K^{-}$
$\bar{p}$
$\bar{p}$
4.0
8.0
12.0
MOMENTUM GeV/c
685A1