SMALL-ANGLE PION FLUX PRODUCED IN A THICK BERYLLIUM TARGET BY HIGH-ENERGY ELECTRONS*

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The pion yield produced by 16-GeV electrons in a 0.6-radiation-length beryllium target was studied at laboratory angles of 0.2° to 1.1°. The experimental yields are somewhat larger than those estimated using the Drell and ρ-diffraction models for pion photoproduction, and they do not appear to decrease at small angles as expected from the theoretical models.

High-energy electron beams produce useful beams of strongly interacting particles via bremsstrahlung and subsequent photoproduction in a thick target. Drell originally pointed out that γ-ray pair production of strongly interacting particles with the interaction of one of these particles with the target nucleus could lead to large differential cross sections at small angles.[1] It has also been found that the coherent photoproduction of ρ^0 mesons from complex nuclei makes a large contribution to pion fluxes at high energy.[2] We have studied the pion yields from a 0.6-radiation-length beryllium target and compared the results with a calculation by Tsai[3] based on the Drell and ρ^0 mechanisms. This Letter describes the yields at laboratory angles $\lesssim 1°$; the two accompanying Letters describe results obtained near 0°[4] and at 2° and 3°.[5]

Electron beams of various energies between 10 and 16 GeV were directed into a 0.6-radiation-length beryllium target placed between the end of the Stanford 20-GeV linear accelerator and the beam transport system normally used to carry the electron beam to the experimental area. Secondary particles produced in the target were carried about 300 m by this transport system to the experimental area, and focused at the detector. Steering magnets located in front of the target allowed the angle of the incident beam relative to the transport system to be varied over the range from 0° to 1°. The momentum acceptance of the system was set to values ranging from 1/8 to 2%. The solid-angle acceptance was measured directly by scanning the angular acceptance limits with the electron beam; it was typically 5×10^{-8} sr but varied with secondary particle momentum (±15%), and time (±10%).

A sketch of the detection equipment is shown in Fig. 1. The shower counter consisted of 16 layers of $\frac{1}{4}$-in. plastic scintillator separated by $\frac{1}{4}$-in. lead plates, and had an energy resolution of ±5% for 10-GeV electrons. A coincidence between the small scintillators, T_1 and T_2, caused the SDS-9300 computer to read the range counters and the pulse height in the shower counter. This range versus pulse-height distribution was the basis of the separation of electrons, pions, and muons.

Good e-π separation was necessary since the e^- to π^- ratio at the detectors was typically 400:1 and 20:1 at 0.5° and 1°, respectively. The number of pion events in the 1° runs was obtained by comparing the shower-counter pulse-height spectrum for the 0.5° and 1° runs, using the 0.5° runs with their much larger ratio of electrons to pions to estimate the electron contamination in the 1° runs. For the 0.5° and smaller angle runs, the pion yields were obtained by considering only those events having less than ~1.5-GeV electron-equivalent pulse height in the shower counter and pulses in at least counters R, M_0, and M_1; these data should be quite free of electron contamination. The correction factor for having taken only these "safe" events was obtained by observing the fraction of pions at 1° which satisfied the conditions; this fraction varied somewhat with

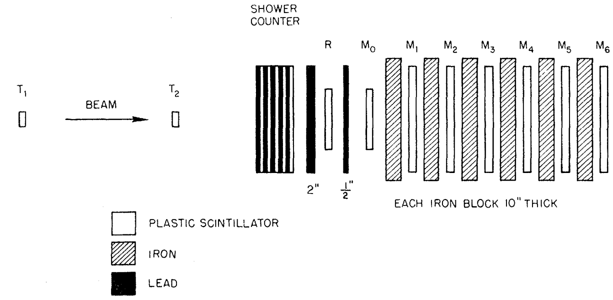

FIG. 1. Sketch of the detection system (not to scale).

momentum, but was typically 50%.

The data were corrected for pile-up in the pulse-height analyzer (typically less than 2%), interactions with material upstream of the shower counter (7%), and pion decay in flight (a factor of 1.70 at 10 GeV/c).

No $\pi K p$ separation was made. The long flight path reduces the K contamination to well under 1%; the antiproton rates are also under 1% of the π^- rate. Based on the results of the other beam survey experiments,[4,5] our π^+ rates have a proton contamination of roughly 6%; no correction has been made for this.

The experimental results are shown in Fig. 2. The errors shown on the points in Figs. 2(a) and 2(b) correspond to counting statistics and ±8% drift uncertainty in the beam monitor, ±10% possible variation in $\Delta\Omega$ for the different momenta, and ±10% uncertainty in the πe separation which may vary with momentum. The normalization of the points is uncertain by ±20% (solid angle and πe separation). The errors shown on the points in Figs. 2(c) and 2(d) correspond only to statistics and ±8% for the monitor, leaving an uncertainty in normalization of ±25% from the other effects.

The curves marked "Drell" in the figures correspond to Drell's original formula[1] with $\sigma(\pi\text{-Be}) = 210$ mb, averaged over the thick target shower. The curves marked "ρ" correspond to the coherent photoproduction of polarized ρ's with a laboratory cross section of

$$d\sigma/d\Omega = 73k^2 A^{1.63} \exp(-10A^{\frac{2}{3}}t)\ \mu\text{b/sr},$$

where k is the photon energy in GeV and $A = 9$ for beryllium. The process is assumed to conserve helicity giving a $\sin^2\theta$ decay distribution where θ is the angle between the decay π in the ρ rest frame and the ρ momentum in the over-all center of mass.[6] The curves marked Crossland were obtained from the Cocconi, Koester, and Perkins (CKP) formula for yields from proton beams, but with constants obtained from the Cambridge Electron Accelerator pion yields.[7]

At a pion momentum of 13 GeV/c the experimental points at 0.52° and 1.07° are in good agreement with both the "Crossland" and the "Drell + ρ" curves. At the lower momenta the experimental yields are larger than expected. The angular distribution for 7-GeV/c π^+ is shown

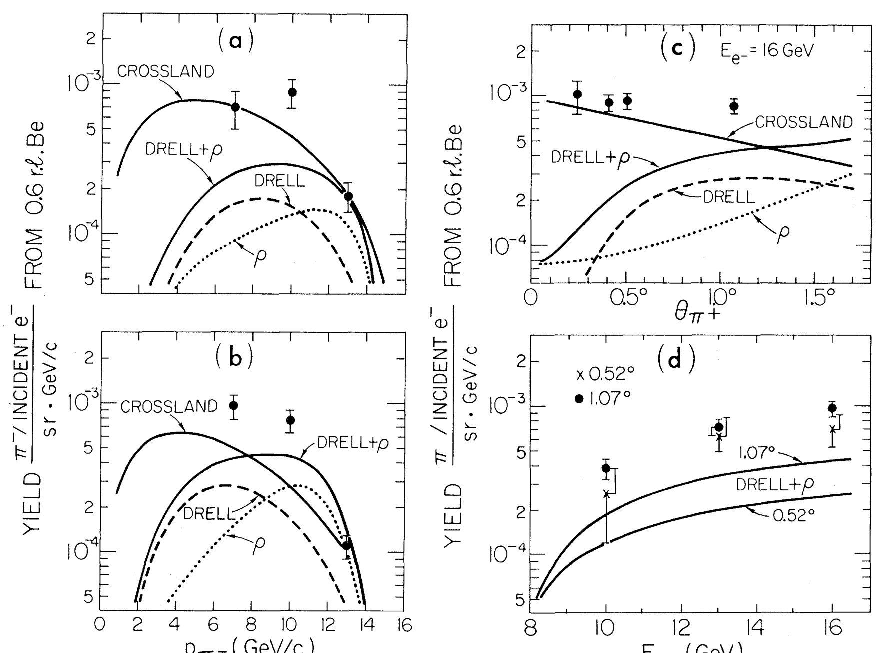

FIG. 2. (a) π^- yields at 0.52° from 16-GeV electrons incident on 0.6 radiation lengths of beryllium. The uncertainties shown are those expected to fluctuate from point to point; in addition there is an uncertainty in normalization of ±20%. The curves are discussed in the text. (b) π^- yields at 1.07°. (c) 7-GeV/c π^+ angular distribution. (d) 7-GeV/c π^- excitation data.

in Fig. 2(c); it is seen that the data do not fall off at small angles as expected from the Drell one-pion-exchange mechanism. The excess pions at 7 GeV thus cannot simply be due to uncertainty in the strengths of the Drell and ρ mechanisms, but are presumably due to other mechanisms.[8] At the present time it is difficult to imagine individual mechanisms which can result in such a large increase of the yield; for example, a crude calculation estimating the pions from the lower vertex of the Drell diagram indicates that this contribution is down from the Drell peak by a factor of 4.

Data taken as a function of electron energy are shown in Fig. 2(d) and indicate that the energy dependence of the cross sections is quite consistent with that expected from the Drell and ρ mechanisms.

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[6]These curves were computed by Van Whitis using computer programs which he wrote using Tsai's formulas.

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[8]Note that certain of the refinements suggested for the Drell mechanism can add to the small-angle yields. In particular, the gauge-invariant model of P. Stichel and M. Scholz, Nuovo Cimento 34, 1381 (1964), effectively adds on a correction which is fairly independent of angle and is roughly 60% of the Drell peak. Caution must be exercised, however, since their calculations were for the specific case $\gamma + p \rightarrow N_{33}^* + \pi$.