MEASUREMENT OF $\pi^{\pm}$, $K^{\pm}$, p AND $\bar{p}$ PRODUCTION BY 200 AND 300 GeV/c PROTONS ☆

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Data are presented on the yields at 3.6 mr of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ with momenta between 23 and 197 GeV/c produced by 200 and 300 GeV/c protons incident on beryllium.

Studies of secondary particle yields produced by protons have been carried out in the past at most accelerators [1–3], not only to gain information on beam properties and particle identification methods, but also to gain insight into the physical mechanism of particle production at increasingly higher momenta.

In this experiment, secondary particle yields have been measured using the extracted proton beam from the Fermi National Accelerator Laboratory synchrotron. Results are presented here for the production of positive and negative hadrons by protons of incident laboratory momentum (P_0) of 200 and 300 GeV/c striking a beryllium target. The production angle was 3.6 mr and the laboratory momenta (p_{lab}) of the secondary particles observed were between 23 and 197 GeV/c. The proton beam, typically 5×10^{11} per pulse, was focused to a spot of about 1/16 inch diameter on a beryllium bar 1/8 inch wide, 1/8 inch high and 12 inches long. The M1 beam in the Meson Area [4] was used to study the particles produced in the target; the final counter of our detector system was 1353 feet from the target.

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A secondary emission monitor in the incident proton beam, together with a counter telescope looking at the production target and an ionization chamber, were used as monitors. Absolute calibrations were obtained by radiochemical means and a toroid current monitor. The fraction of the proton beam hitting the target was determined at both primary momenta by sweeping the beam vertically across the target, and by moving the target horizontally through the beam. Effects of any proton beam halo were studied by comparing the yields from two different cross sectional area targets. In order to minimize any changes in the fraction of the proton beam hitting the target, absolute secondary fluxes were measured over as short a time period as possible.

The secondary beam line was operated in two modes: non-focusing and focusing. In the first mode, only dipole magnets were energized in order to measure the absolute total fluxes with well known defining apertures. These total flux measurements were made at typically eight secondary particle momenta for each beam polarity and each primary proton momentum. Four scintillation counters placed along the beam line were used in coincidence for these studies. The total acceptance was

$$\Delta\Omega\, \Delta p/p = 3.8 \times 10^{-11}\,\text{sr}\,.$$

In the second mode, quadrupole magnets were energized in order to increase the flux and to obtain an approximately parallel beam through two simple differential Cerenkov counters [5] filled with helium, air, or freon. One counter was used to measure relative particle abundances, while the other was used to determine the efficiency or the first.

Table 1

Particle production at 3.6 mr by 200 and 300 GeV/c protons on a 12 inch beryllium target. Values are given of $d^2N/[d\Omega(dp/p)]$ per steradian per incident proton. Point to point errors are ± 5% except where noted. See text for systematic errors.

Momentum (GeV/c)	200 GeV/c π	K	p	300 GeV/c π	K	p
+ 23	138	16.6	26.9 ± 2.7	–	–	–
−23	101	8.29	–	–	–	–
+ 35	–	–	–	258	34.1	44.4 ± 4.4
−35	–	–	–	192	17.2	4.99
+ 50	384	38.0	197	–	–	–
−50	215	16.0	4.41	–	–	–
+ 70	333 ± 33	42.7 ± 4.3	456 ± 46	537	61.0	253 ± 25
−70	164	12.0	2.40	265	22.1	7.27
+ 100	218	37.8	932 ± 93	440	61.0	573 ± 57
−100	83.1	4.08	0.452	195	15.4	4.05 ± 0.41
+ 120	107 ± 11	24.2 ± 2.4	1160 ± 116	–	–	–
−120	37.1	1.50	0.110	–	–	–
+ 140	39.2	13.5 ± 1.4	1180	246	42.2 ± 4.2	886
−140	10.0	0.174 ± 0.035	0.00972	84.9	4.69 ± 0.47	0.680
+ 174.4	–	–	1520	–	–	–
−174.4	0.658	–	–	–	–	–
+ 175	–	–	–	101	26.0 ± 2.6	937
−175	–	–	–	30.9	1.21 ± 0.12	0.118
+ 189.4	–	–	1900	–	–	–
−189.4	0.0693	–	–	–	–	–
+ 194.3	–	–	4440	–	–	–
+ 196.8	–	–	17000	–	–	–

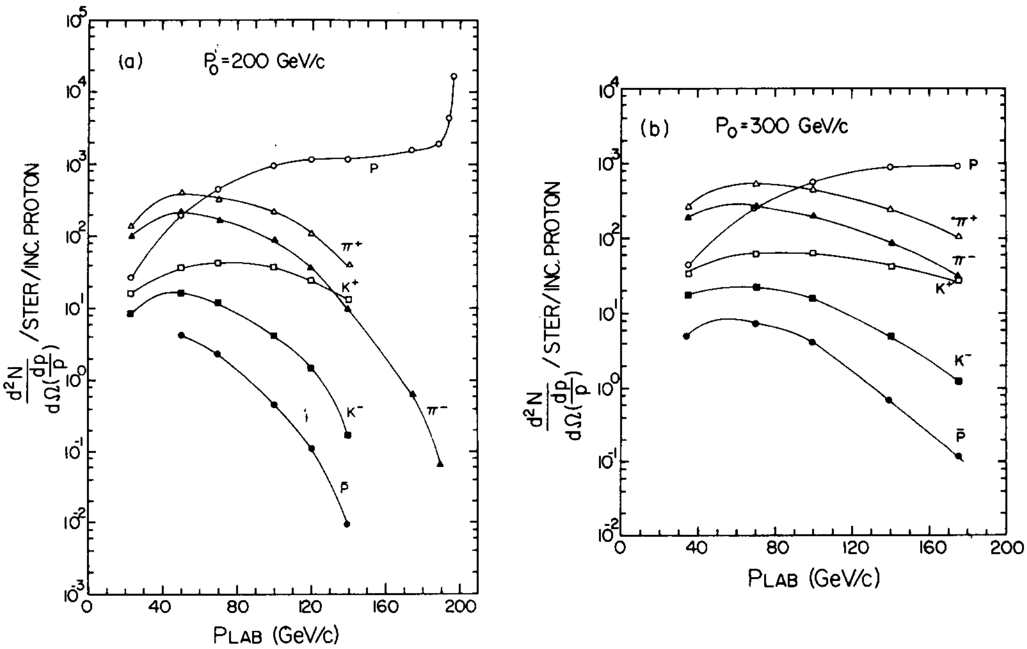

Fig. 1. Yields of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ at 3.6 mr produced in beryllium by protons of a) p_0 = 200 GeV/c; b) p_0 = 300 GeV/c. Curves are shown to guide the eye.

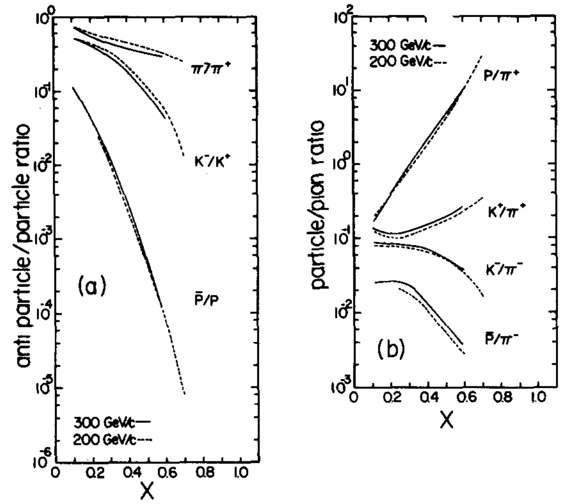

Fig. 2. Ratios of particle yields at 3.6 mr produced in beryllium by p_0 = 200 and p_0 = 300 GeV/c protons.

The electron contamination in the secondary beam was measured using a 22 radiation length lead glass Cerenkov counter. The contamination varied from ~ 1% at 23 GeV/c to less than 0.1% above 100 GeV/c. Muons were identified by their ability to penetrate a thick absorber; the muon contamination was between 1 and 5% of the total flux.

All data have been corrected for particle decays and for absorption by material in the beam line to obtain the yields at the downstream end of the 12 inch beryllium target. The absorption correction was made using the cross sections of ref. [6], assuming that the cross sections varied as $A^{2/3}$ and had no momentum dependence. In the worst case, for antiprotons, the correction was 8%. A small correction ($\lesssim$ 1%) was applied to the data to account for the slightly different (0.3%) mean momenta of the two modes of beam operation.

Point-to-point errors in our results are ± 5%, except in a few cases. There is an uncertainty in the 300 GeV/c fluxes relative to those taken at 200 GeV/c of −20, +10%. In addition, there is an absolute scale error estimated to be about ± 30%. The uncertainty in the momentum of the secondary particles is ~ 1%.

Our results are given in table 1, and displayed in figs. 1 and 2. Fig. 1 shows the yield of each particle for both 200 and 300 GeV/c protons; fig. 2 shows various particle ratios as a function of the variable x ($\approx p_{\rm lab}/p_0$). In fig. 2, we see that the particle ratios show a strong dependence on x, but a little primary momentum dependence. Note that the data at the two momenta correspond to different transverse momenta; however, the dependence of the particle ratios on transverse momentum is known to be weak [3, 7].

We can compare our (thick target) data with the predictions of models for particle production. The model of Hagedorn and Ranft [8] (for a thin target) gives spectra in general agreement with the shapes of the curves of fig. 1, but predicts absolute values in most cases too large by a factor of 2−3. The empirical formula of Wang [9] for pion production differs somewhat more from the data than Hagedorn and Ranft.

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References

[1] W.F. Baker et al., Phys. Rev. Letters 7 (1961) 101.
[2] Yu.B. Bushnin et al., Phys. Lett. 29B (1969) 48; 30B (1969) 506.
[3] J.V. Allaby et al., CERN 70−12 (1970), and paper presented at the 4th Int. Conf. on High-Energy Collisions, Oxford (1972).
[4] Meson Laboratory preliminary design report, J.R. Orr and A.L. Read, National Accelerator Laboratory (1971) (unpublished).
[5] S.M. Pruss, NAL report #TM-470 (1974) and to be published.
[6] S.P. Denisov et al., Nucl. Phys. B61 (1973) 62.
[7] A. Bertin et al., Phys. Letters B42 (1972) 492; Nuclear Physics, to be published.
[8] H. Grote, R. Hagedorn and J. Ranft, Atlas of Particle Production Spectra, CERN (1970) (unpublished). This reference gives results from the more recent strong bootstrap thermodynamic models can be compared when the required computer programs are available.
[9] C.L. Wang, Brookhaven National Laboratory report BNL 15893 (1971) (unpublished).