

Neutral Particle Production in π^+p and pp Collisions at 100 GeV/c

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We have measured the inclusive cross sections for γ , K_s^0 , Λ , and $\bar{\Lambda}$ production in π^+p and pp interactions at 100 GeV/c and compared various inclusive distributions of the produced γ and K_s^0 .

We have used a sample of 100 000 pictures from the Fermi National Accelerator Laboratory 30-in. hydrogen bubble chamber to compare the production of neutral particles (γ , K_s^0 , Λ , $\bar{\Lambda}$) in π^+p and pp interactions at 100 GeV/c. The chamber was exposed to an unseparated tagged beam of positive particles.¹ This allows us to compare π^+ - and proton-induced reactions with minimum biases.

The film was scanned twice, yielding 2418 events which had at least one V visible within a restricted fiducial volume in the chamber. The overall scanning efficiency for the two scans was 96%. The events on about half the film were measured on a spiral reader, the others on a Franckenstein, at Lawrence Berkeley Laboratory. The measurements were processed using the programs POOH and TVGP, and the position of the beam track in the chamber was matched with data from the beam-tagging system to identify the beam track. The incident particle was unambiguously identified as a π^+ or proton in 78% of the events. The program SQUAW was then used to fit the V 's associated with unambiguously identified beam tracks; in each fit the neutral was constrained to come from the measured produc-

tion vertex. Events measured on the spiral reader were re-examined on a scan table and those considered to be possibly measurable were re-measured on a Franckenstein. The overall efficiency of the two measurements for V 's produced by an ambiguously identified π^+ or proton was 89%; for one Franckenstein measurement it was 82%. The scanning and measuring efficiencies were assumed to be the same for all events.

The identity of each neutral track producing a V was assigned, where possible, by using the ionization information from the special scan. Ambiguous events were selected on the basis of the confidence level of the kinematic fit and the transverse momentum of the decay tracks with respect to the line of flight of the neutral. A fiducial volume smaller than that used in scanning was imposed. Also, γ conversion pairs were rejected if they were within 4 cm of the production vertex and strange-particle decays within 2 cm. The number of events remaining after all acceptance criteria were met are given in Table I. The contamination of the γ 's is negligible, and for K_s^0 , Λ , and $\bar{\Lambda}$ it is estimated to be less than 2, 5, and 10%, respectively.

The events were weighted for escape from the

TABLE I. Production of neutral particles.

	Reaction	γ	K_s^0	Λ	$\bar{\Lambda}$
Number of V 's	π^+p	350	190	57 (6f) ^a	4
	pp	492	223	135 (13f) ^a	11
Inclusive cross section (mb)	π^+p	136 ± 11	4.1 ± 0.4	1.1 ± 0.2	0.15 ± 0.08
	pp	174 ± 13	3.8 ± 0.3	3.5 ± 0.4	0.24 ± 0.07
Ratio $\sigma(\pi^+p)/\sigma(pp)$ ^b $\langle P_T \rangle$	π^+p	0.78 ± 0.09	1.08 ± 0.14	≥ 0.32	~0.6
	pp	0.054 ± 0.005	0.30 ± 0.03	0.23 ± 0.06	0.42 ± 0.10
		0.059 ± 0.005	0.23 ± 0.03	0.32 ± 0.04	0.25 ± 0.06

^af is the number detected in forward hemisphere.

^b $\sigma_T(\pi^+p)/\sigma_T(pp) = 0.61$.

chamber, decay close to the production vertex, and neutral decay modes; the average weights were 58, 3.0, 2.7, and 4.2 for γ , K_s^0 , Λ , and $\bar{\Lambda}$, respectively. To investigate our detection efficiency, we looked at the inclusive distributions in the rapidity variable y plotted in Fig. 1 (the Λ and $\bar{\Lambda}$ distributions are not shown because of space limitations). We note that the γ and K_s^0 distributions for pp interactions are approximately symmetric about $y=0$, indicating that our detection efficiency for these processes is similar in both the forward and backward hemisphere. This forward-backward similarity is lacking in observed Λ distributions because many of the Λ 's are produced peripherally and those in the forward hemisphere are very fast and leave the chamber before they decay. For $\bar{\Lambda}$'s it appears that our detection efficiency is adequate in the forward hemisphere. To calculate the total inclusive cross sections for γ , K_s^0 , and $\bar{\Lambda}$ production and for $\pi^+p \rightarrow \Lambda$ we used all events. For the reaction $pp \rightarrow \Lambda$ we used only the backward-going Λ 's and the symmetry of the reaction. The neutral inclusive cross sections are presented in Table I, where we normalize to the measured total cross sections.² The errors include uncertainties in the scanning, measuring, and beam-tagging efficiencies. The neutral inclusive pp

cross sections agree well with those of Chapman *et al.*³ at 102 GeV/c. The π^+p cross sections for K_s^0 , Λ , and $\bar{\Lambda}$ production when compared with those of Sturtebeck *et al.*⁴ at 18.5 GeV/c all show an increase with energy, a trend established at lower energies.⁵ For K_s^0 production the rise is rapid; 1.1 ± 0.07 to 4.1 ± 0.4 mb. On the other hand, the Λ cross section has risen slowly from 0.73 ± 0.05 mb to 1.1 ± 0.2 mb; however, it must be remembered that our inclusive cross section is really a lower limit because of our poor detection efficiency in the forward hemisphere. Increasing cross sections with incident momentum are observed in pp and π^+p interactions⁶⁻⁸; however, the rise in K_s^0 production is much less pronounced than the rise we see in the π^+p reaction. Comparison of our π^+p and pp cross sections is interesting because it shows that the production of γ 's and $\bar{\Lambda}$'s is roughly in the ratio of the total cross sections, whereas K_s^0 's are produced with nearly equal probability in the two reactions, and Λ 's are produced relatively prolifically in pp collisions.

To study in detail the dependence of the neutral-particle production upon its longitudinal momentum, we show in Fig. 1 distributions in rapidity y . Note that, since $(1/\sigma_T)(d\sigma/dy) = (1/N_T)dN/dy$, all distributions have been normal-

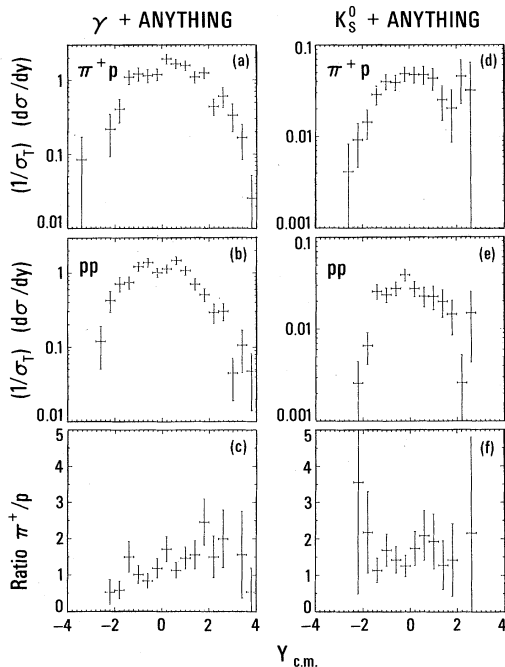


FIG. 1. Inclusive distributions in center-of-mass rapidity. $y_{c.m.} = 0.5 \ln(E + p_L)/(E - p_L)$.

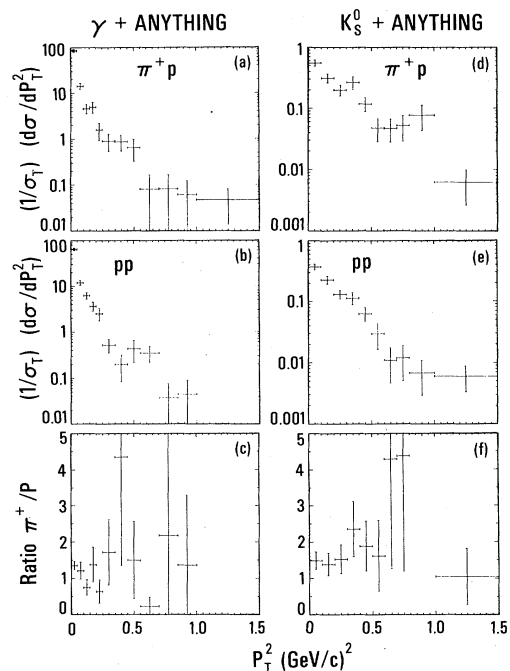


FIG. 2. Inclusive distributions in transverse momentum, P_T^2 .

ized by the total events in our data sample thus reducing biases and making comparison easier. The errors are statistical only. The γ distributions for π^+p and pp reactions show similar shapes in the backward hemisphere. In the forward hemisphere there is a suggestion that the shapes are different and the ratio is greater than 1.0. The K_s^0 distributions show that the ratio (π^+/p) is greater than one both backwards and forwards.

Next we look at the dependence on the square of the neutral-particle transverse momentum, p_T^2 . We see in Fig. 2 the expected exponential fall with increasing p_T^2 and the slope decreasing with increasing neutral-particle mass. We note also that a single exponential term will not describe either γ distribution because the lowest bin contains too many events. The average p_T^2 is given in Table I. The shapes of the π^+p - and pp -induced reactions are similar.

In Fig. 3 we show the average number of π^0 and K_s^0 produced per inelastic interaction as a function of the number of charged prongs produced (n_{ch}). Here we assume that all γ 's come from π^0 's and that $\sigma_{\pi^0} = \sigma_\gamma/2$. We see that the average number of π^0 's is similar for π^+p and pp interactions and rises more or less linearly, as observed in pp collisions at several energies.^{8,9}

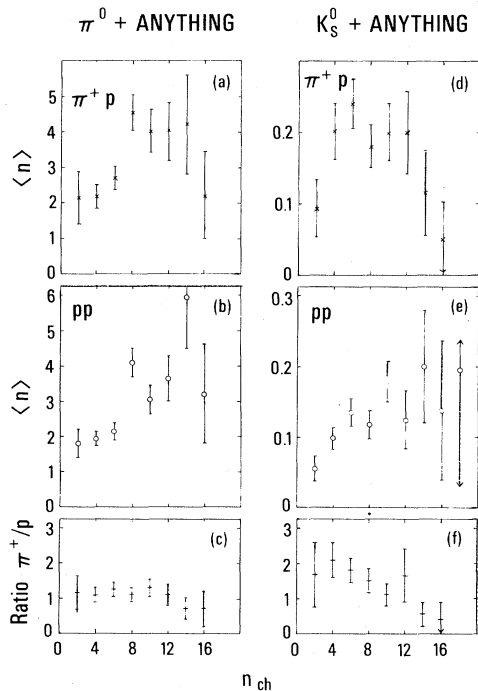


FIG. 3. Average number of neutrals produced.

The average number of K_s^0 shows only weak dependence on the number of charged prongs. For pp interactions the distribution is fairly flat for $n_{ch} \geq 6$, an effect already seen in pp collisions at 102 and 205 GeV/c⁴ and in π^-p at 205 GeV/c.⁶ The π^+p -induced distribution shows some excess at low multiplicity.

We have compared the inclusive cross sections for neutral-particle production in π^+p and pp reactions at 100 GeV/c. We find that when we normalize by the total cross sections the γ production is similar in the two reactions with a slight excess of events in the forward hemisphere for the π^+p interaction, and a depletion backwards. The K_s^0 cross section is rising much more rapidly with energy than it does in pp and π^-p induced reactions.

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Pion-⁴He Scattering around the $\frac{3}{2}, \frac{3}{2}$ Resonance

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We present π^- -⁴He differential cross sections at 110, 150, 180, 220, and 260 MeV, as well as total cross sections at eleven energies between 67 and 285 MeV.

Negative-pion-⁴He scattering has been measured at the CERN synchrocyclotron with the double achromatic spectrometer previously used for pion-¹²C scattering.^{1,2} A liquid-helium target of the supercooled type with a precise temperature regulation was installed for these measurements. Its windows consisted of thin Havar (Co-Fe) foils, except for the very-forward-angle measurements, where Mylar windows were used because of their lower atomic number. Effective target thicknesses are extrapolated from window-bulge measurements made at room temperature under controlled pressure conditions. The relative error of this procedure is $\pm 3\%$. It is the main contribution to the total relative error on the absolute normalization of the data which is estimated to be $\pm 4\%$.

Momentum dispersion of the incident pion beam was $\Delta p/p = \pm 1.8\%$. Overall angular resolution was 1° with use of a setup which included a DISC counter for identifying the forward-scattered pions. It was 2° for the large-angle measurements.

The experimental data are represented in Fig. 1. Differential cross sections are given as a function of the scattering angle in the center-of-mass system.

Cross sections for 180° scattering were measured by observing ⁴He nuclei recoiling in the forward direction. For this purpose, the target

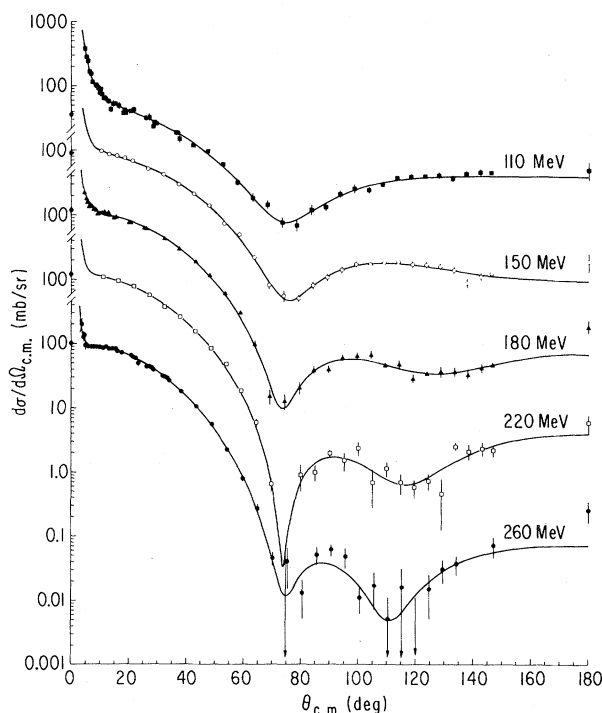


FIG. 1. π^- -⁴He elastic-scattering differential cross sections versus $\theta_{c.m.}$, the pion scattering angle in the c.m. system. Optical points on vertical axis show the value of $(k/4\pi)|\text{Im}f|^2$ as deduced from our measured total cross sections. Only part of the forward data are shown for the sake of clarity. The curves result from fits by a formula given in the text.