EXPERIMENTAL INCLUSIVE γ, K^o, Λ, and $\overline{\Lambda}$ PRODUCTION

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ABSTRACT

Recent results of six experiments studying inclusive neutral particle production are summarized and compared. The beam momentum ranges from 10.5 GeV/c to 205 GeV/c.

INTRODUCTION

This paper reports on the results of six experiments studying inclusive neutral particle production. These six experiments submitted papers to the Berkeley meeting[1-6] and Table I shows the institutions and experimental parameters involved. Note that the incident particles studied are positive pions, negative pions and protons; the beam momentum ranges from 10.5 GeV/c to 205 GeV/c; and the produced particles studied are gammas (pi zeros in some cases), neutral kaons, lambdas and lambda bars. In general this paper will consider only the "highlights" of the experimental results, and, following the lead of the six papers, theoretical remarks will be sparse. Experimental details will be ignored except for the following points. Five of the experiments were done in hydrogen bubble chambers, while the 10.5 GeV/c π^+p experiment was done in a neon-hydrogen mixture. This mixture was used in order to increase the probability of observing gamma pair production in the chamber. The 12.4 GeV/c pp experiment also wanted to study multiple gamma production, and in their case it was done by using a very large bubble chamber (the ANL 12-ft). In comparing experiments it is important to remember that the number of events observed varies considerably. The 10.5 and 12.4 GeV/c experiments both observed approximately 4000 gammas and the 18.5 GeV/c experiment studied 11,000 vees. At the higher energies the three NAL experiments scratched the bottom of the barrel (bubble chamber?) to find 400 to 900 events (gammas plus vees). The small number of events at NAL energies coupled with the high escape probability of neutral kaons and lambdas going forward in the center of mass means that most of the information on neutral decays at these energies is from the backward hemisphere. In order to organize all the results this paper is presented in four sections:

1) total inclusive cross sections
2) average number of neutral particles produced, $< n_o >$, per inelastic collision (as a function of the number of charged particles produced, n_{ch})
3) differential cross sections as a function of longitudinal momentum
4) differential cross sections as a function of transverse momentum, p_T.

TABLE I: Experiments Reported On

Institution	Momentum (GeV/c)	Beam	Produced Particles Studied
Duke University, University of North Carolina	10.5	π^+	π^o
IIT, ANL, SLAC, University of Maryland, Concordia Teachers College, NAL	12.4	p	π^o
Notre Dame University	18.5	π^+, π^-	$K_S^o, \Lambda^o, \overline{\Lambda}^o$
University of Michigan, University of Rochester	102	p	$\gamma, K_S^o, \Lambda^o, \overline{\Lambda}^o$
ANL	205	p	"
NAL, University of California, Berkeley, LBL	205	π^-	"

TOTAL INCLUSIVE CROSS SECTIONS

Each experiment has calculated $\sigma(a + b \rightarrow \text{neutral} + X)$. Remember that in inclusive cross sections there is a multiple counting of individual events. For example if one event produces two K_S then it is counted twice. Figure 1 shows the inclusive π^0 cross section for pp interactions as a function of laboratory momentum.[7] The 12.4 GeV/c point was calculated from events with two gammas fitting a pi zero, while the other points are just one half the experimental single gamma cross sections. The straight line[8] shows that the cross section appears to go as log p_{lab} in this energy region. The papers also remark that the relationship $\sigma(\pi^0) = 1/2\,[\sigma(\pi^+) + \sigma(\pi^-)]$ holds in this energy range.

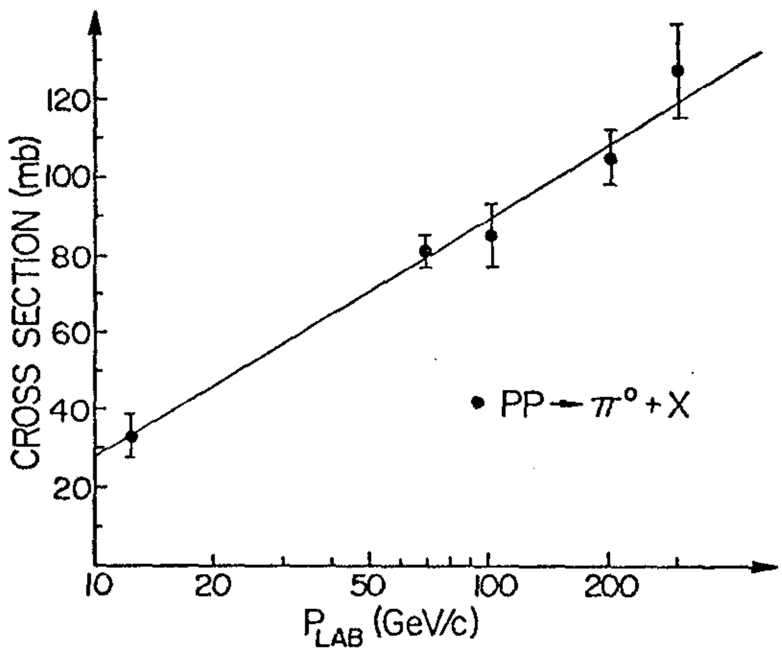

Fig. 1. Total inclusive π^0 cross sections for pp interactions.

Figure 2 shows the K_S^o, Λ^o, and $\overline{\Lambda}^o$ cross sections for pp interactions. Here note that above about 50 GeV/c the Λ^o (and possibly the $\overline{\Lambda}^o$?) cross section has leveled off while the K_S^o cross section appears to rise sharply.[9] Why should these cross sections behave differently? At this point your guess is as good as any. Note that above 10 GeV/c,

$$\sigma(\pi^o) >> \sigma(K_S^o) > \sigma(\Lambda^o) > \sigma(\overline{\Lambda}^o) .$$

The above inequalities as well as the increase in cross section in going from lower energies to NAL energies also hold for pion-proton collisions. In general π^- cross sections are slightly above π^+, and proton-proton cross sections are one to two times pion-proton cross sections at the same energy.

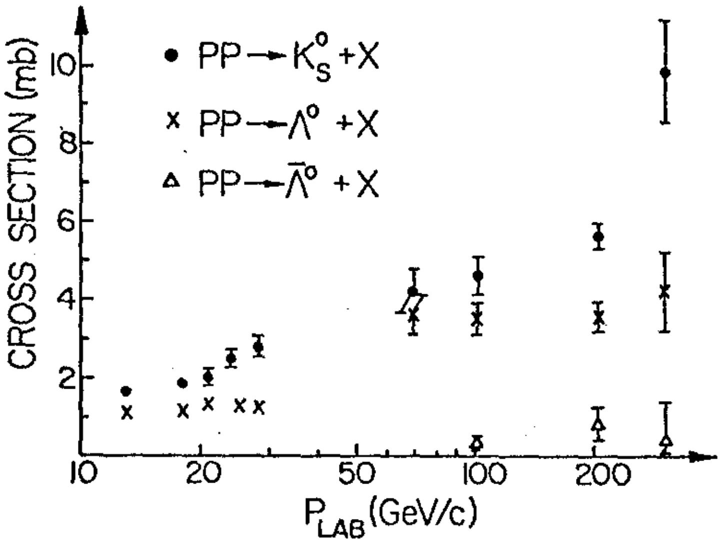

Fig. 2. Total inclusive K_S^o, Λ^o, $\overline{\Lambda}^o$ cross sections for pp interactions.

$<n_o>$ PER INELASTIC INTERACTION

In an attempt to discover correlations between the production of charged particles (mostly pions) and neutral particles (π^o's, K_S^o's or Λ's) several experiments have determined the average number of a particular neutral particle produced per inelastic interaction as a function of the number of charged particles produced. Figure 3 shows data on $<\pi^o>$ per inelastic pp interaction for three energies. Note that at 12.4 GeV/c the number of pi zeros produced shows almost no dependence on the number of charged particles. However at NAL energies, $<\pi^o>$ has a stronger dependence on n_{ch}. The exact dependence is not clear from the two proton experiments. Two possibilities are a linear increase as n_{ch} increases to six prongs and then a flattening off, or else a linear increase all the way to n_{ch} approximately 14 with a drop off due to total energy conservation.

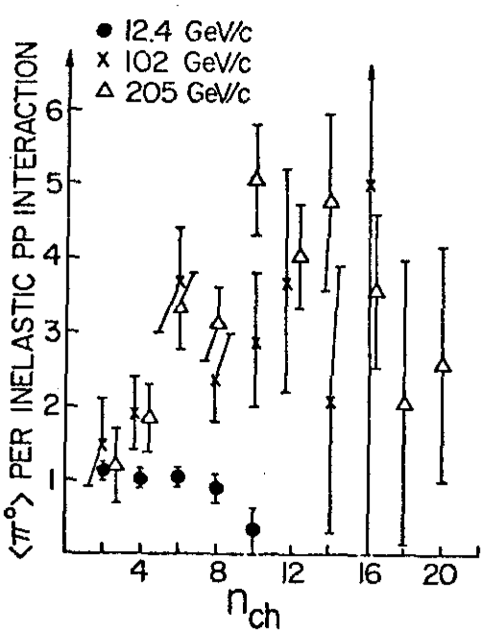

Fig. 3. Average number of π^o's produced per inelastic pp interaction.

Figure 4 shows $<\pi^o>$ for pion-proton interactions. Again note the independence of $<\pi^o>$ from n_{ch} at low energy (at least for n_{ch} greater than two), and the strong dependence at NAL energies. Clearly, here the dependence favored is a linear increase all the way to n_{ch} of twenty. Figure 5 shows K_S^o production data. All

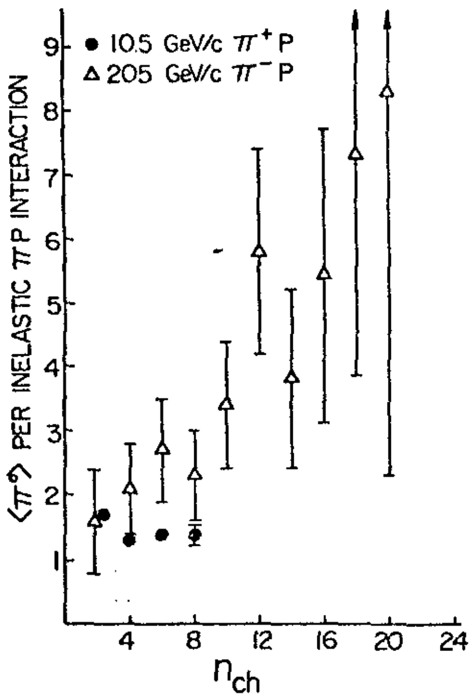

Fig. 4. Average number of π^0's produced per inelastic πp interaction.

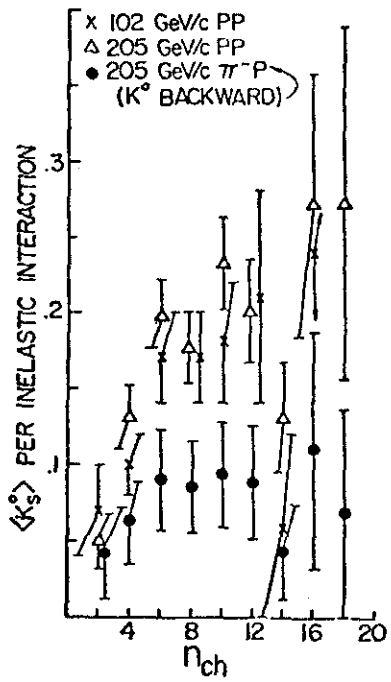

Fig. 5. Average number of K^0's produced per inelastic interaction.

three experiments at NAL energies are consistent with $< K_S^0 >$ being independent of n_{ch} except for a drop off in 2 and 4 prongs. This drop off could be related to the large amount of diffraction that is known to exist in low charged multiplicity events. Perhaps $< n_0 >$ should be calculated per nondiffractive interaction. Data on lambda production indicates that $< \Lambda^0 >$ is like $< K_S^0 >$ in showing little dependence on n_{ch}.

The 10.5 GeV/c $\pi^+ p$ experiment was able to determine for the first time the total number of produced particles per event counting both charged and neutral particles. Figure 6 shows their cross sections as a function of total produced multiplicity. The curve is a Poisson fit to their data.

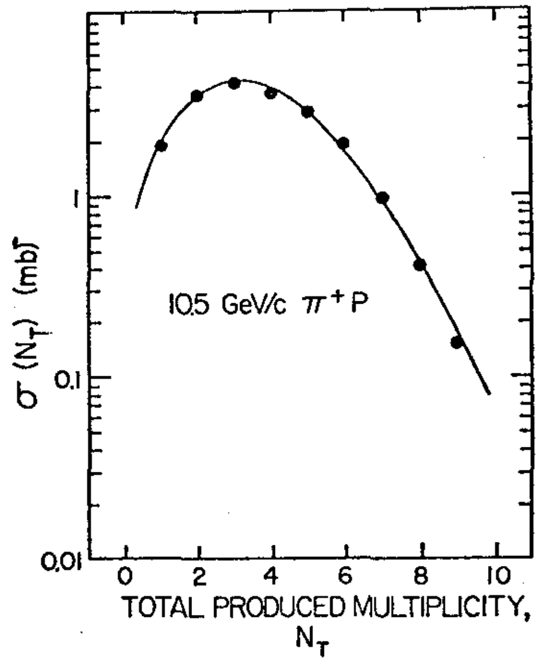

Fig. 6. Total produced multiplicity distribution for 10.5 GeV/c π^+p interactions. The curve is a Poisson fit.

The π^-p experiment at 205 GeV/c compares their results with the 205 GeV/c pp experiment. If one assumes one can "factorize" an interaction into a forward part associated with the beam particle and a backward part associated with the target, then the backward results on particles produced per inelastic interaction for π^-p at a given momentum should be approximately the same as backward results for pp interactions at the same momentum. Table II shows the two experiments agree very well.

TABLE II: Comparison of Neutral Particles Produced Per Inelastic Interaction for 205 GeV/c π^-p and pp

Neutral Particle, n	$\langle n \rangle$ π^-p	$\langle n \rangle$ pp
K_S^o (backward)	0.077 ± 0.014	0.085 ± 0.005
Λ (backward)	0.044 ± 0.11	0.055 ± 0.005
$\overline{\Lambda}$ (backward)	0.01 ± 0.01	0.013 ± 0.004

LONGITUDINAL MOMENTUM

The dependence of neutral particle production on the longitudinal momentum of the produced particle has also been studied. The following variables are most frequently used; the Feynmann scaling variable,

$$x \equiv \frac{2p_L}{\sqrt{s}}$$

and the invariant double differential cross section integrated over p_T^2,

$$F_1(x) \equiv \frac{2}{\pi\sqrt{s}} \int_0^\infty \frac{E\, d^2\sigma}{dx\, dp_T^2}\, dp_T^2 ,$$

where all quantities are calculated in the center of mass. In general the longitudinal distributions depend on the particle produced, sometimes depend on the energy (i.e. non-scaling), and sometimes depend on transverse momentum (i.e. non-factorization).

First, consider γ and π^0 production. Figure 7a shows the longitudinal momentum distribution for γ's produced by 12.4 GeV/c pp interactions. The exponential type drop-off seen here is typical of γ production. In this case the distribution was fit to a sum of three exponentials (the curve on Fig. 7a). This γ fit was transformed into a π^0 distribution as shown in Fig. 7b. For comparison,

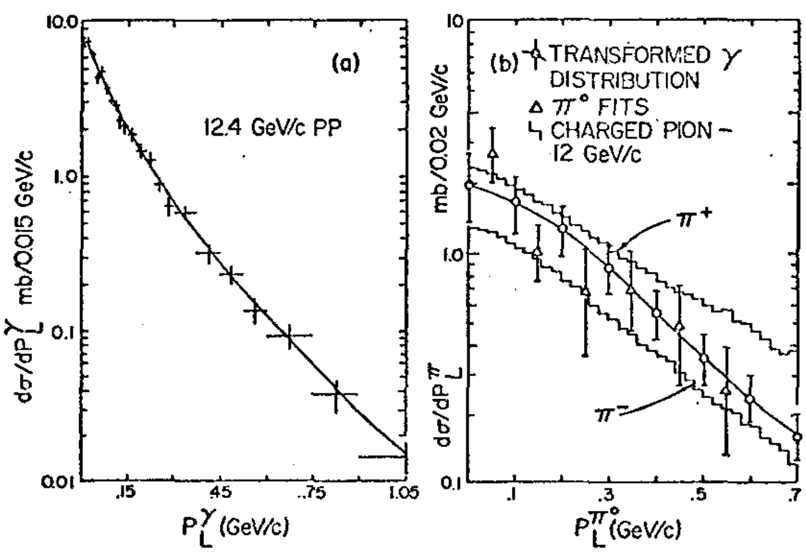

Fig. 7. (a) Longitudinal momentum distribution for γ's produced by 12.4 GeV/c pp interactions.
(b) Corresponding π^0 longitudinal momentum distribution.

the charged pion distributions are also shown, and the authors point out that the relation $\sigma(\pi^0) = 1/2[\sigma(\pi^+) + \sigma(\pi^-)]$ works for differential cross sections as well as total. Figure 8 shows the energy dependence of $F_1(x)$, by comparing 12.4 GeV/c and 205 GeV/c pp data.

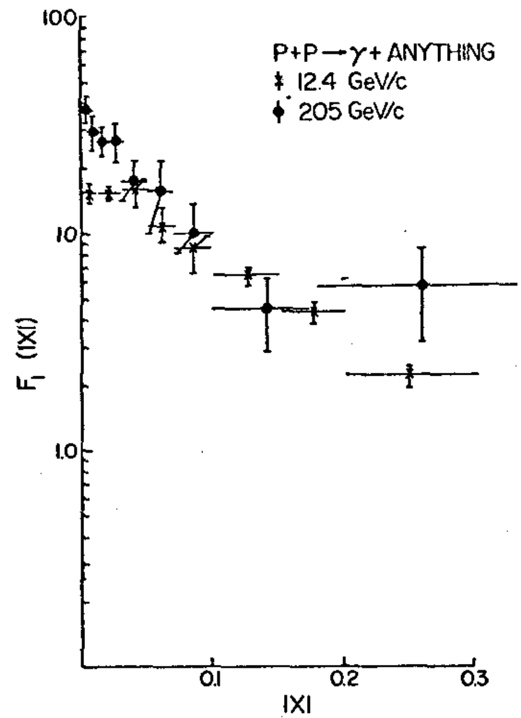

Fig. 8. Comparison of $F_1(x)$ versus x for two energies.

Note $F_1(x)$ appears to be energy independent (scale) in the fragmentation region while scaling has not set in at 12.4 GeV/c for the central region ($|x| < 0.05$). The authors point out this approach to scaling is similar to π^- inclusive production. However, the question of scaling behavior is not completely settled. The 102 GeV/c pp experiment compares their $F_1(x)$ distribution with an interpolation formula suggested for ISR data by Neuhofer et al.[10] (see Fig. 9a). They conclude that scaling may not have set in at 102 GeV/c even for $|x|$ up to 0.15.

Figure 9b shows $F_1(x)$ for K_S^0 production. The curve is exponential with a slope of 4.7 ± 2.0, and is compatible with meson production data at higher energies. Finally, Fig. 9c shows an $F_1(x)$ distribution that is definitely not exponential. Lambda production is seen to occur in the fragmentation region.

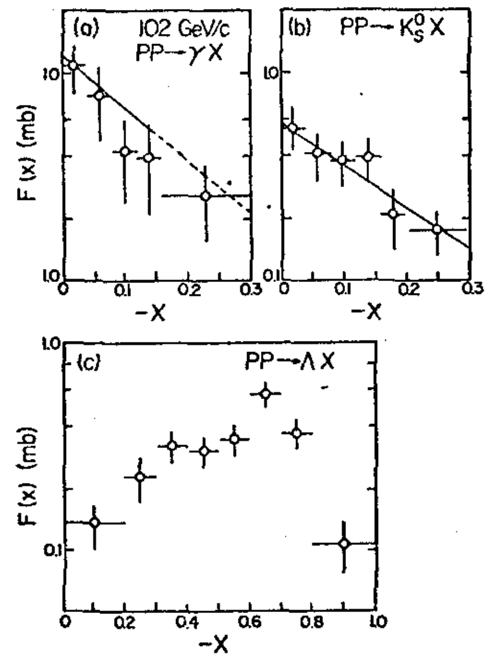

Fig. 9. $F_1(x)$ versus x for 102 GeV/c pp interactions. The curves are described in the text.
(a) γ production
(b) K_S^o production
(c) Λ^o production.

Next consider factorization. That is, can the differential cross section be written as $f(x)g\ (p_T^2)$? Figures 10 and 11 show the 205 GeV/c pp $F_1(x)$ distributions for γ and K^o production. The γ data is clearly non-factorizable as shown by the difference in slopes for different p_T regions, while the K^o data appears to be factorizable.

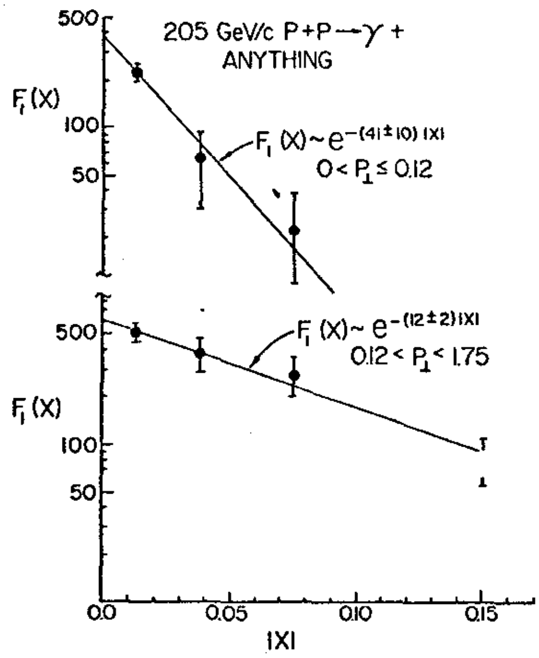

Fig. 10. Evidence for non-factorization of γ differential cross section at 205 GeV/c.

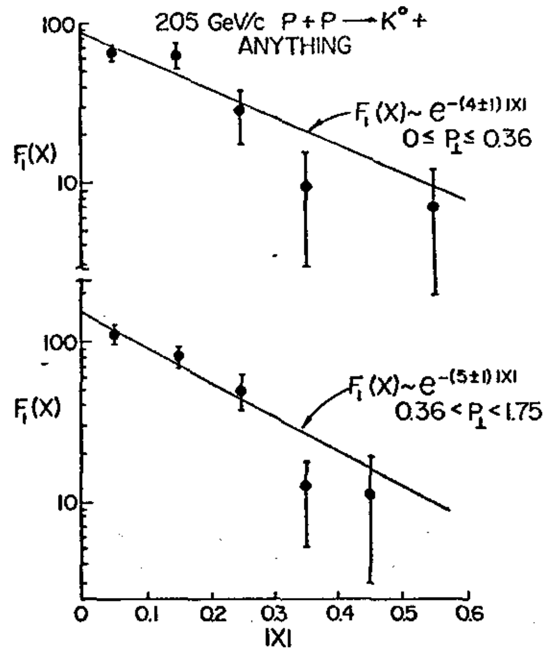

Fig. 11. Evidence for factorization of K_S^o differential cross section.

If one leaves the symmetry of the pp system and considers pion-proton interactions, one can get an asymmetry in the differential cross section about x = 0. Figure 12 shows 18.5 GeV/c $\pi^{\pm}p$ data. For K^o production note the tendency to be produced in the forward direction (positive x, beam fragmentation), while Λ^o production is mainly backward (target fragmentation) and $\overline{\Lambda}^o$ production is possibly in the central region. The backward directions in $\pi^{\pm}p$ for K^o and Λ^o production show similar behavior to the F(x) distributions for K^o and Λ^o production in pp interactions (compare Fig. 12 with Figs. 9b and 9c respectively).

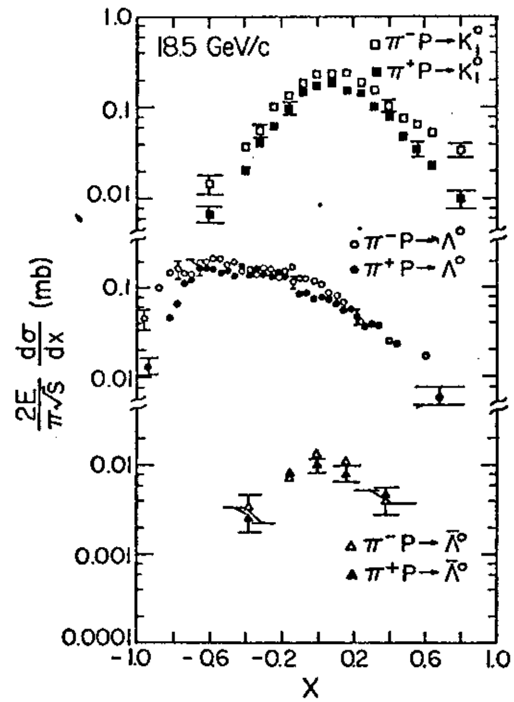

Fig. 12. x distributions for neutral particle production at 18.5 GeV/c.

TRANSVERSE MOMENTUM

Unlike the situation for longitudinal momentum distributions one finds an approximate exponential fall off in all cases for transverse momentum distributions. To study the dependence on transverse momentum one often calculates the invariant double differential cross section integrated over x,

$$F_2(p_T^{\,2}) \equiv \frac{2}{\pi\sqrt{s}} \int_{-1}^{+1} \frac{E\, d^2\sigma}{dx\, dp_T^{\,2}}\, dx \; .$$

Figure 13 shows the similarity of F_2 for γ production for pp interactions at two energies. Figure 14 shows the differential cross sections as a function of $p_T^{\,2}$ for γ, K_S^o, and Λ^o production with 102 GeV/c pp interactions. Note the flattening of the data points as the mass of the produced particle increases. This flattening

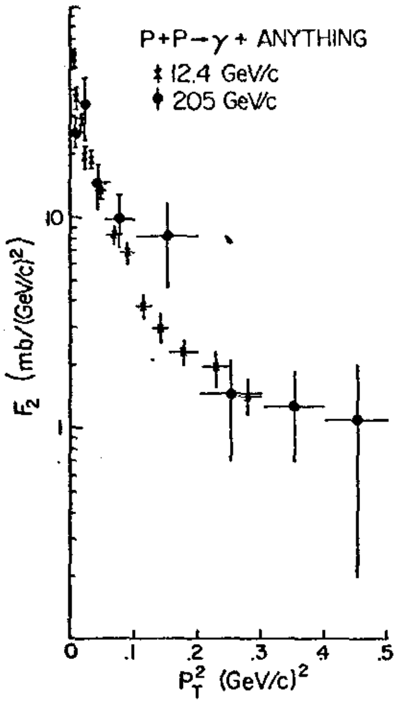

Fig. 13. Comparison of $F_2(p_T^2)$ versus p_T^2 for two energies.

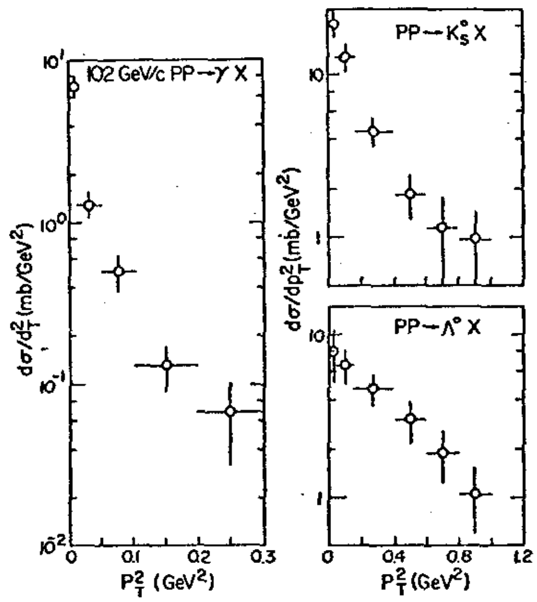

Fig. 14. p_T^2 distributions at 102 GeV/c for γ, K_S^o and Λ^o production.

reflects itself in an increase in average p_T, $<p_T>$, as the mass of the produced particle increases. At 102 GeV/c the values of $<p_T>$ are 0.175 ± 0.020, 0.424 ± 0.043, and 0.541 ± 0.060 GeV/c for γ, K_S^o, and Λ production respectively. This increase in $<p_T>$ was also observed in the 18.5 GeV/c $\pi^{\pm}p$ experiment. In fact, this latter experiment also found a variation in $<p_T>$ for K^o production with the number of charged prongs (see Fig. 15).

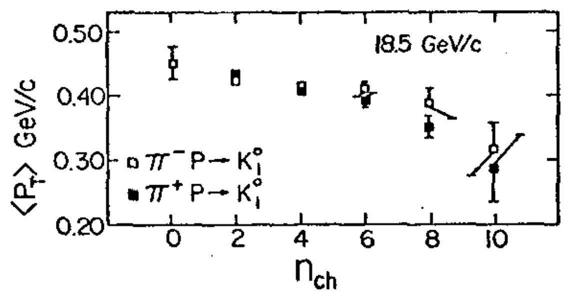

Fig. 15. Average transverse momentum as a function of number of charged prongs at 18.5 GeV/c.

In conclusion, the study of inclusive neutral particle production has yielded a nice variety of experimental facts. One has just about all combinations of independence and dependence occurring among the various variables such as energy, beam particle, target particle, produced particle, x, and p_T. It seems all this information is just waiting for some theory to explain it.

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7. Various figures in this paper have data points from the following papers as well as the six papers (Refs. 1-6) being summarized here. B. Y. Oh and G. A. Smith, "Inclusive Study of Λ^o and $\Sigma^\pm$ Hyperons Produced in Proton-Proton Collisions from 6.6 to 28 GeV/c," (submitted to XVI International Conference on High Energy Physics, Batavia, 1972).

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   F. T. Dao et al., Phys. Rev. Letters 30, 1151 (1973).

8. The five data points fit $\sigma(\pi^o) = (61.5 \pm 4.1) \log p_{lab} - (33.7 \pm 7.5)$ with a 74% probability.

9. During this talk Tom Ferbel stated that preliminary results on the 405 GeV/c pp experiment indicate that the K_S^o cross section at 405 GeV/c is lower than the 303 GeV/c point. Thus it is not at all clear what is happening.

10. G. Neuhofer et al., Phys. Letters 38B, 51 (1972).