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ABSTRACT

We have studied the properties of the inclusive $pp \to \gamma X$, $K_S^0 X$, $\Lambda^0 X$, and $\overline{\Lambda^0} X$ reactions in an exposure of the NAL 30-in. bubble chamber to a 303 GeV/c proton beam. From an analysis of V events observed in this experiment, we have obtained the following results: 1) the average number of particles produced per inelastic collision $\langle n_\gamma \rangle = 7.90 \pm 0.75$, $\langle n_{K_S^0} \rangle = 0.31 \pm 0.04$, $\langle n_{\Lambda^0} \rangle = 0.13 \pm 0.03$, and $\langle n_{\overline{\Lambda^0}} \rangle = 0.01 \pm^{0.03}_{0.007}$; 2) $\langle n_{\pi^0} \rangle$ rises approximately linearly with n_- implying that neutral and charged pions are strongly coupled, while $\langle n_{K_S^0} \rangle$ is less coupled to n_-; 3) γ, K_S^0, and Λ^0 production cross sections have reached a scaling limit by 303 GeV/c; and 4) $d\sigma/dy$ is relatively flat in the central region for K_S^0 and low multiplicity γ events.

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In this letter we report on our study of V^o events from an exposure of 303 GeV/c protons in the 30-inch hydrogen bubble chamber at the National Accelerator Laboratory. Results on multiplicity, total cross section, and inclusive Δ^{++} production have already been reported.[1] A total of 311 V^o events were recorded in a fixed fiducial volume.[2] These events were processed through TVGP and SQUAW and fitted to the following hypotheses: $K_S^o \to \pi^+\pi^-$, $\Lambda^o \to p\pi^-$, $\overline{\Lambda}^o \to \pi^+\overline{p}$ and $\gamma(p) \to e^+e^-(p)$. After two measurements, 71% of the 311 events had satisfactory fits, 19% did not point to the primary vertex, and 10% were unmeasurable. The events were examined on a scan table by physicists. Of the 311 fitted events, 18% had more than one satisfactory fit. A selection on the transverse momentum of the negative outgoing track with respect to the neutral particle[3] was effective in resolving all the γ ambiguities. The small number of K_S^o/Λ_o ambiguities was resolved by ionization and χ^2. These were edited on the scan table using ionization information.

After all selections there were 119 γ, 50 K_S^o, 20 Λ^o, and 2 unique $\overline{\Lambda}^o$.[4] The data for K_S^o, Λ^o, and $\overline{\Lambda}^o$ were restricted to the backward hemisphere in the pp center of mass as the detection efficiency in the forward direction was extremely low. The average weighting factors[5] are: 71.9 for γ, 3.44 for K_S^o, 4.25 for Λ^o, and 4.69 for $\overline{\Lambda}^o$. The final sample was further corrected by a scanning efficiency of 0.93. The inclusive cross sections measured (that is, the product of the average number of particles produced per inelastic collision and the total inelastic cross section) are: $\sigma(\gamma) = 253 \pm 24$ mb, $\sigma(K_S^O) = 9.8 \pm 1.3$ mb, $\sigma(\Lambda^O) = 4.2 \pm 1.0$ mb and $\sigma(\overline{\Lambda}^O) = 0.4 \pm {}^{1.0}_{0.3}$ mb. Assuming that all γ's come from $\pi^O \rightarrow 2\gamma$, we get $\sigma(\pi^O) = (127 \pm 12)$ mb.

The dependencies of these cross sections on the incident laboratory momentum[6,7,8,9] are shown in Figs. 1(a), (b), and (c). Note that $\sigma(\Lambda^O)$ has increased threefold from 28 GeV/c to 303 GeV/c and remains much larger than $\sigma(\overline{\Lambda}^O)$ at 303 GeV/c. The K_S^O cross section has increased more than eight times from 28 GeV/c to 303 GeV/c. However, the rapid rise in $\sigma(K_S^O)$ may level off at energies beyond 303 GeV/c as indicated by the ISR data.[10] The π^O cross section in Fig. 1(c) is consistent with a logarithmic growth with incident momentum and is equal to $\sigma(n_-)$ or $\sigma(\pi^-)$ if we assume all negatively charged particles to be π^-'s. This is in accord with multiperipheral models that predict $\langle n_{\pi^O} \rangle = \langle n_{\pi^-} \rangle = \langle n_{\pi^+} \rangle$,[11] where $\langle n_x \rangle$ is the average number of particles of type x produced per inelastic pp collision.

The topological cross sections and $\langle n_{\pi^O} \rangle$ and $\langle n_{K_S^O} \rangle$ vs topology for inclusive π^O and K_S^O production are listed in Table I.

In Fig. 2(a) and (b) $\langle n_{\pi^O} \rangle$ and $\langle n_{K_S^O} \rangle$ are plotted as a function of charged multiplicity, n_c. Two possible dependencies are shown: $\langle n_{K_S^O} \rangle = 0.31$ assumes K_S^O production is independent of topology; $\langle n_{K_S^O} \rangle = 0.09\, n_-$ is based on $\sigma_{K_S^O}/\sigma_{\pi^-}$ being independent of topology. In contrast $\langle n_{\pi^O} \rangle$ tends to rise linearly with n_c for $n_c \leq 18$. The latter linear dependence which has been observed here and earlier at 205 GeV/c is very different from the low energy pp data.[12] The broken straight line in Fig. 2(b) is given by $< n_{\pi^0} > = n_-$. If we assume all the negative particles to be pions, the data imply that the isospin states of the pion are strongly correlated. Berger, Horn and Thomas[13] conclude that a linear rise of $< n_{\pi^0} >$ versus n_c at high energies rules out models in which pions are independently emitted but is in accord with fragmentation models and multiperipheral models in which ρ or ω type meson clusters are emitted. The weaker dependence of $< n_{K_S^0} >$ on n_c may reflect the lack of strong-correlation between kaons and pions.

In Figs. 3(a) and (b), we show the invariant single particle distribution in Feynman variable x for the inclusive K_S^0 and Λ^0 reactions. Our results combined with the 205 GeV/c data[7] give evidence that the inclusive K_S^0 and Λ^0 reactions have reached their scaling limits from below, with Λ^0 approaching the limit at a much faster rate than K_S^0.

Figures 4(a) and (b) show $d\sigma/dy$ versus the rapidity variable y for the K_S^0 and γ reactions. There is evidence for a plateau with widths of two units in y for the K_S^0 and low multiplicity γ events; $d\sigma/dy$ seems to peak at $y = 0$ for high multiplicity γ events. The average longitudinal momentum in the center of mass $<|p_L|> = 2.90 \pm 0.56$, 1.11 ± 0.17, and 0.88 ± 0.12 GeV/c for Λ^0, K_S^0, and π^0 respectively.[14] Thus, neutral pions and kaons are produced more frequently in the central region than Λ^0's.

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References

[1] F. T. Dao et al., Phys. Rev. Letters 29, 1627 (1972).

F. T. Dao et al., Phys. Rev. Letters 30, 34 (1973).

[2] The fiducial volume for the primary interaction vertex was chosen to be smaller than the ones mentioned in Ref. 1 to allow enough track length for decay or conversion. The fiducial volume for the V^o vertex was defined as $(x_v - 3)^2 + y_v^2 \leqslant (28\text{ cm})^2$ and $0 \leqslant z_v \leqslant 37.72$ cm, where (x_v, y_v, z_v) are spatial coordinates for the V^o vertex.

[3] The following cuts on the transverse momentum p_T in MeV/c were made: $0 \leqslant p_T \leqslant 15$ for γ, $15 \leqslant p_T \leqslant 210$ for K_S^o, and $15 \leqslant p_T \leqslant 105$ for Λ^o and $\overline{\Lambda}^o$.

Note that these cuts are equivalent to making a very small cut (0.3%) in the cosθ distribution in the center of mass of K_S^o, Λ_o, and $\overline{\Lambda}_o$ decays.

[4] Ten $\overline{\Lambda}^o \to \overline{p}\pi^+$ candidates were found and edited on the scan table using ionization information. The result was: 2 unique $\overline{\Lambda}^o$, 3 unique K_S^o, and 5 events that fit $\overline{\Lambda}$ and at least one other hypothesis (usually K_S^o).

[5] Each event was weighted by a factor calculated from the potential decay length and neutral decay branching ratio. The minimum length for efficient detection was 4 cm for γ and 2 cm for K_S^o, Λ^o, and $\overline{\Lambda}^o$. The pair conversion cross section for γ was calculated by T. M. Knasel, DESY Reports Nos. 70/2 and 70/3.

[6] 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", paper

submitted to XVI International Conference on High Energy Physics, Batavia (1972).

[7]G. Charlton et al., Phys. Rev. Letters 30, 574 (1973).

[8]G. Charlton et al., Phys. Rev. Letters 29, 1759 (1972).

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[10]The ISR data points in Fig. 1(b) were computed on the assumption that neutral kaon emission is as frequent as charged kaon emission. Thus,

$$\sigma(K_S^{\,0}) = \left(\frac{R\left(\frac{K^+}{\pi^+}\right) + R\left(\frac{K^-}{\pi^-}\right) \; R\left(\frac{\pi^-}{\pi^+}\right)}{1 + R\left(\frac{\pi^-}{\pi^+}\right)} \right) \sigma(\pi^0)$$

where the ratios were obtained from A. Bertin et al., Phys. Letters 41B, 201 (1972) and the π^0 cross section from Ref. 9.

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[12]H. Boggild et al., Nucl. Phys. B27, 285 (1971).

[13]E. L. Berger, D. Horn, and G. H. Thomas, ANL/HEP Report 7240 (1972).

[14]G. I. Kopylov, Nucl. Phys. B52, 126 (1973), derives $< p_L (\pi^0) > = 2 < p_L (\gamma) >$.

[15]H. J. Mück et al., Phys. Letters 39B, 303 (1972).

TABLE I

Cross Sections for $p\bar{p} \rightarrow \pi^o X$ and $K_S^o X$

n = Number of Charged Particles	$\sigma_n(pp \rightarrow \pi^o X)$* in mb	$< n_{\pi^o} >$	$\sigma_n(pp \rightarrow K_S^o X)$ in mb	$< n_{K_S^o} >$
2	1.7 ± 1.2	1.0 ± 0.7	0.2 ± 0.2	0.1 ± 0.1
4	11.8 ± 3.1	2.4 ± 0.7	0.8 ± 0.4	0.2 ± 0.1
6	19.4 ± 4.1	3.4 ± 0.8	2.9 ± 0.7	0.5 ± 0.1
8	16.0 ± 3.7	3.0 ± 0.7	1.4 ± 0.5	0.3 ± 0.1
10	22.8 ± 4.4	4.8 ± 1.0	1.6 ± 0.5	0.4 ± 0.1
12	20.3 ± 4.1	4.8 ± 1.4	1.3 ± 0.4	0.3 ± 0.1
14	15.7 ± 2.5	7.2 ± 1.5	0.6 ± 0.2	0.3 ± 0.1
16	9.3 ± 2.8	6.7 ± 2.2	0.8 ± 0.4	0.6 ± 0.3
18	7.2 ± 2.5	8.3 ± 3.2	---	---
20	1.6 ± 1.1	5.3 ± 2.4	0.2 ± 0.2	0.3 ± 0.3
22	---	---	---	---
24	---	---	---	---
26	0.9 ± 0.9	17.0 ± 17.0	---	---
TOTAL	126.7 ± 12.0	3.95 ± 0.38	9.8 ± 1.3	0.31 ± 0.04

*Calculated from $\sigma_n(pp \rightarrow \pi^o X) = \sigma_n(pp \rightarrow \gamma X)/2$.

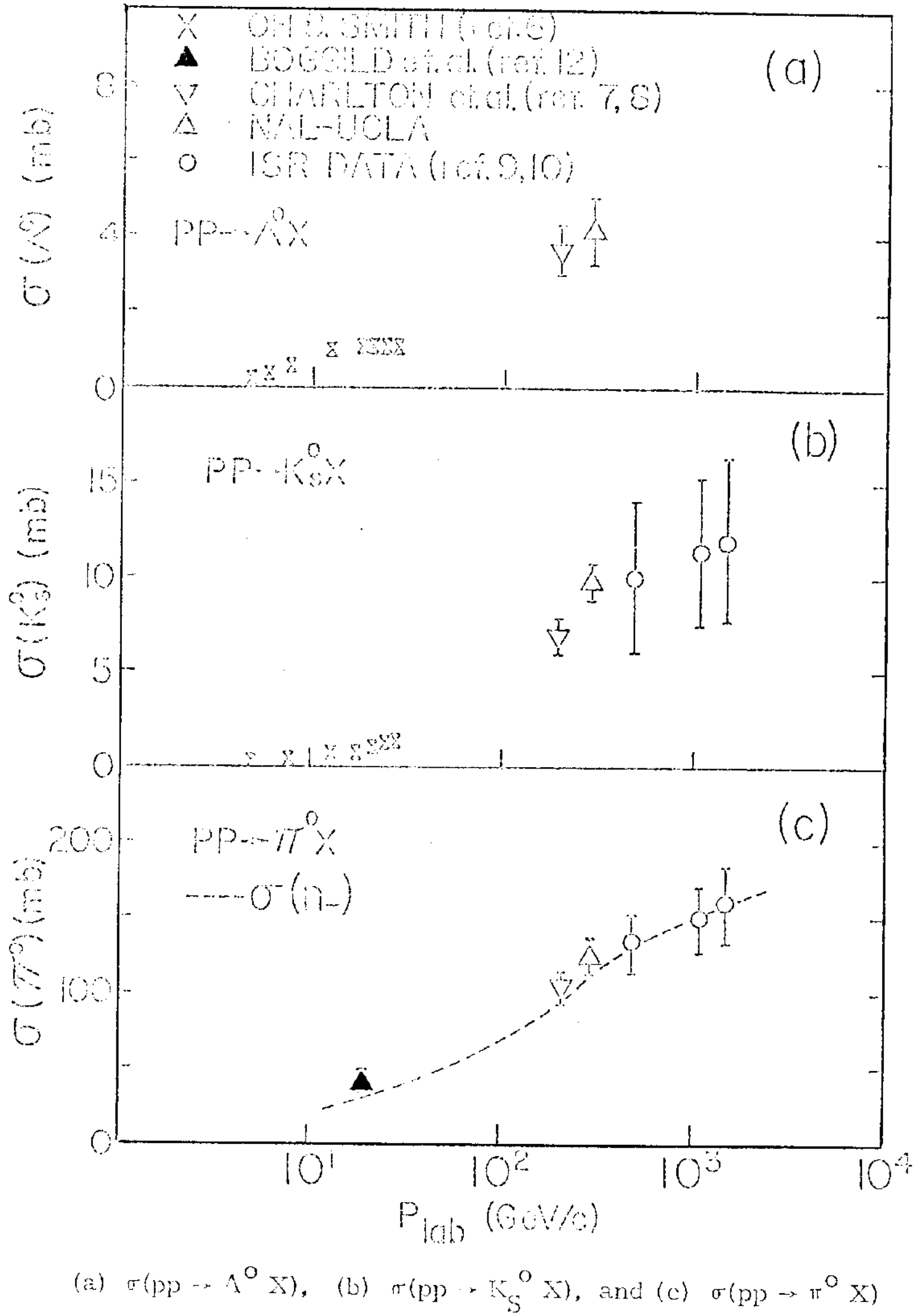

Fig. 1 (a) $\sigma(pp \to \Lambda^0 X)$, (b) $\sigma(pp \to K_S^0 X)$, and (c) $\sigma(pp \to \pi^0 X)$ versus incident laboratory momentum P_{lab}. See Ref. 10 for derivation of data points beyond 303 GeV/c.

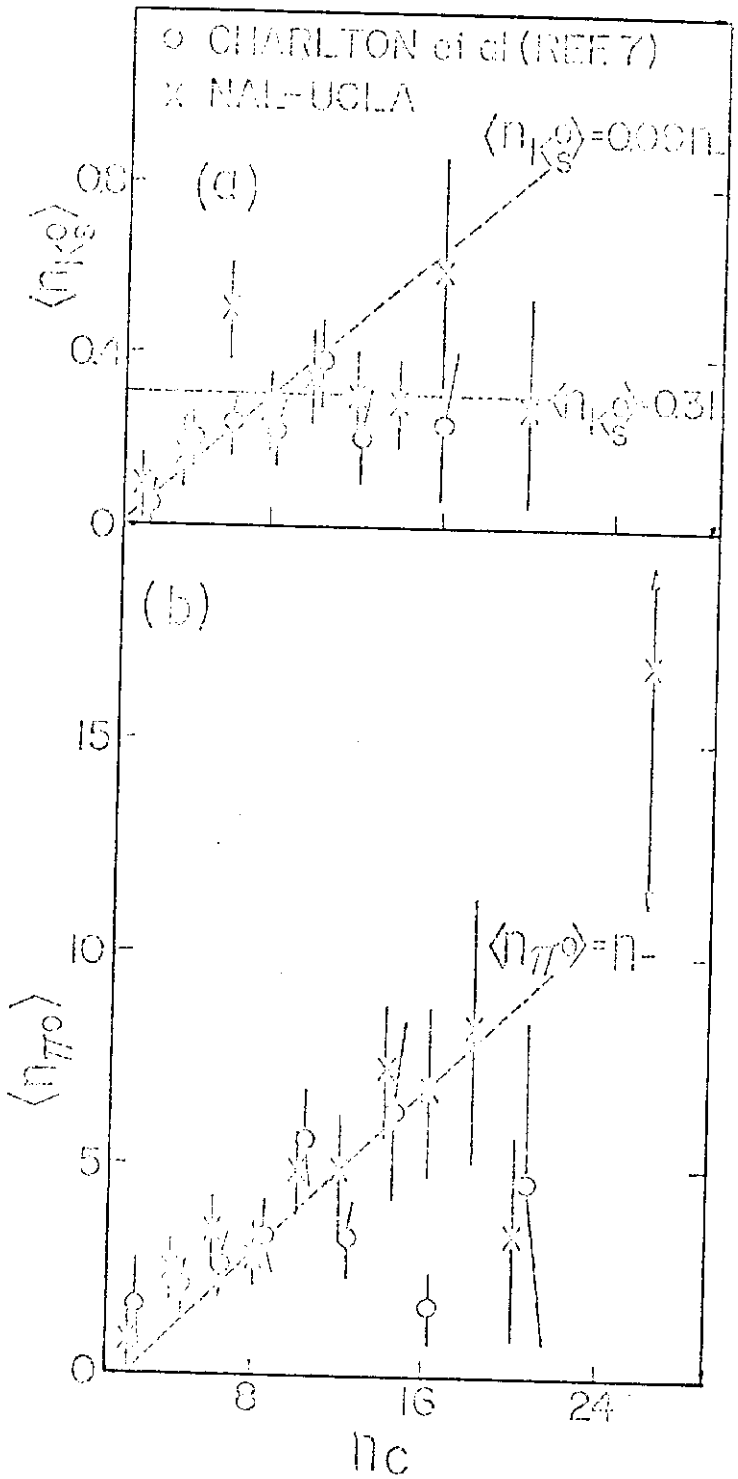

Fig. 2 (a) Average number of K_S^o and (b) average number of π^o's produced per inelastic pp collision versus charged multiplicity. The curves are described in the text.

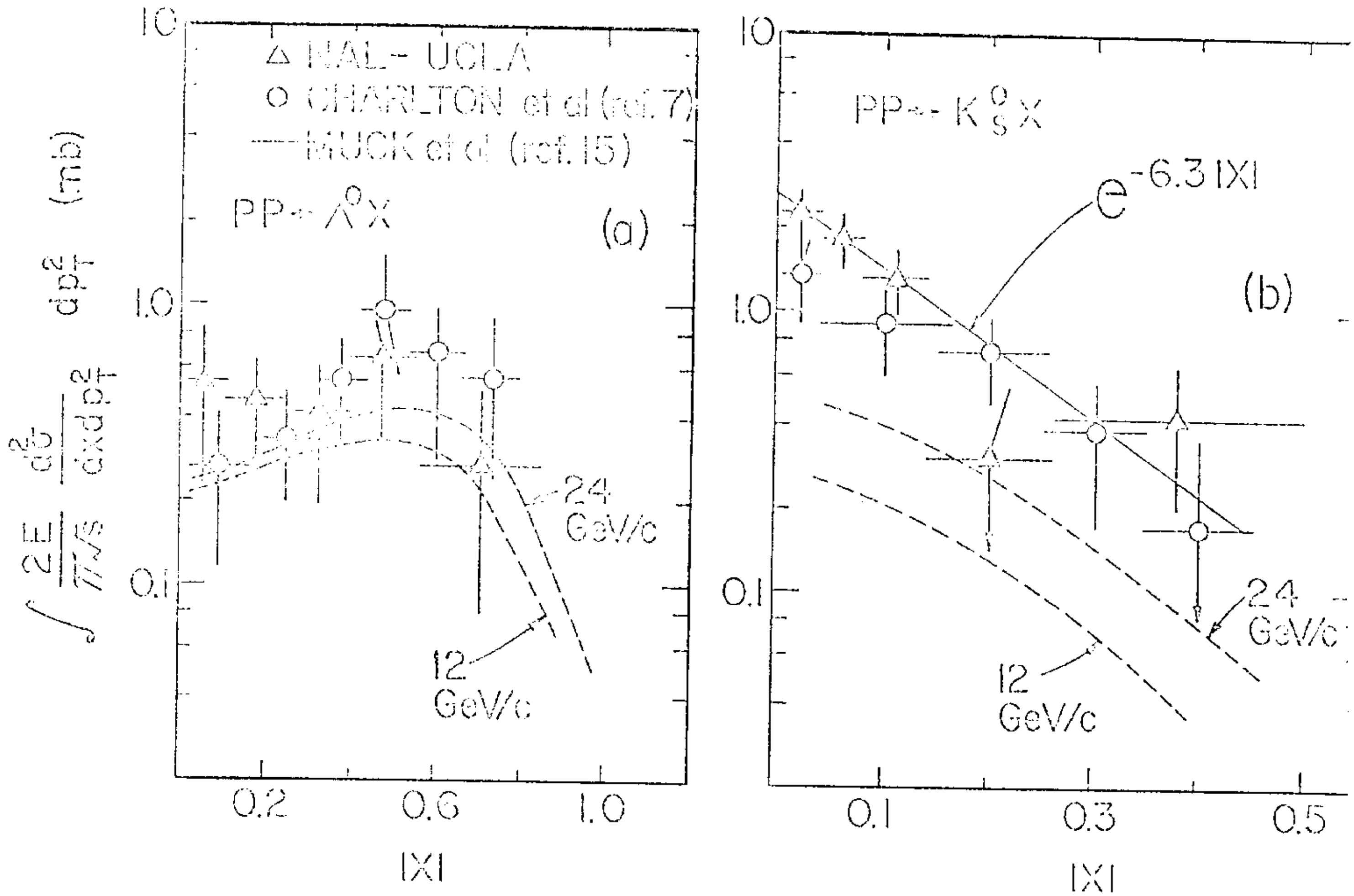

Fig. 3 Invariant distribution

$$\int \frac{2E}{\pi \sqrt{s}} \frac{d^2\sigma}{d\,x\,dp_T{}^2}\, dp_T{}^2$$

versus x for (a) $pp \rightarrow \Lambda^o X$

and (b) $pp \rightarrow K_S^o X$,

and E, p_T, and p_L are the energy, transverse, and longitudinal momentum of the particle in the center of mass

and $x = 2\,p_L/\sqrt{s}$.

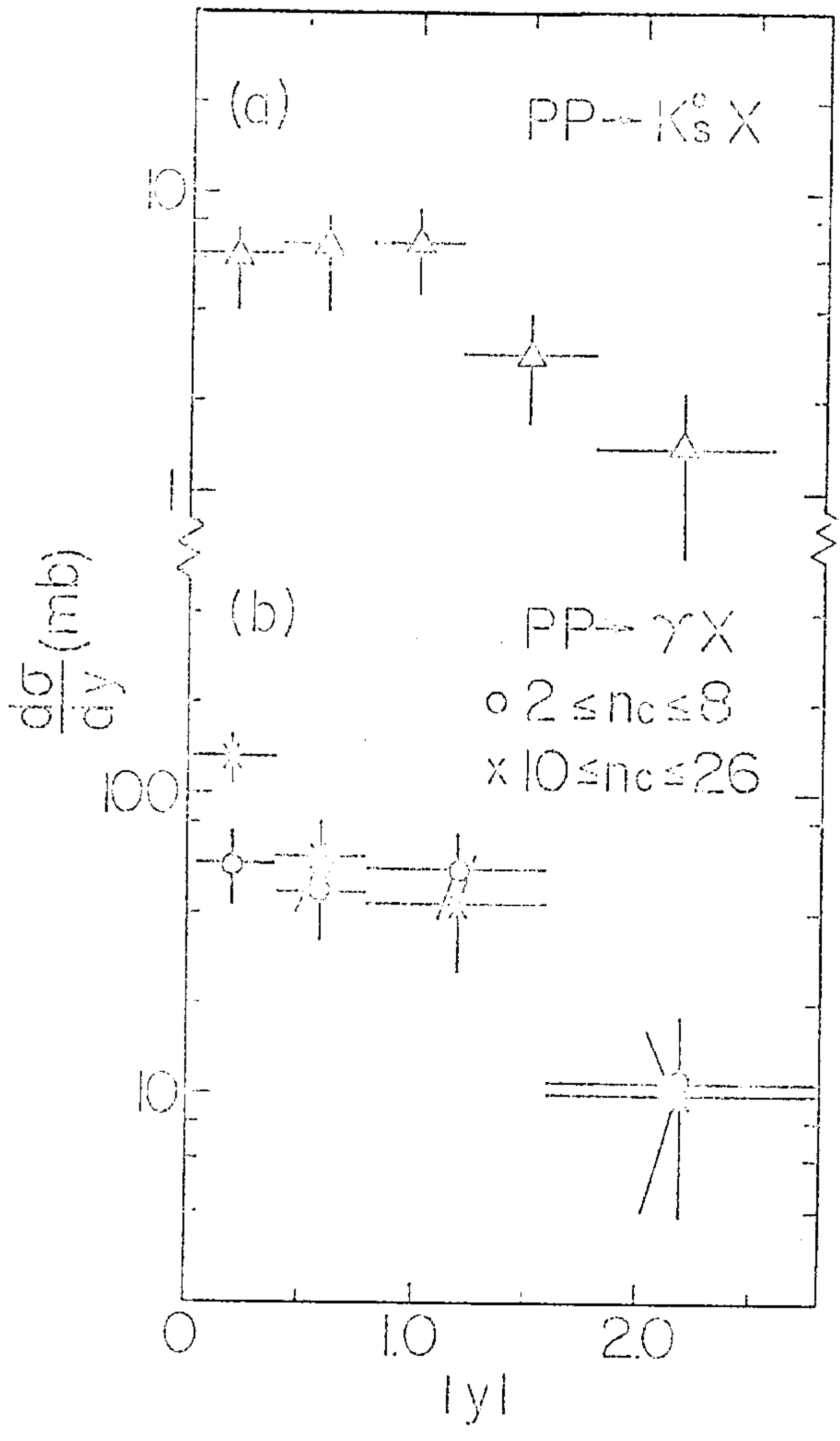

Fig. 4 dσ/dy versus y for (a) pp → K_S^0 X and (b) pp → γX.