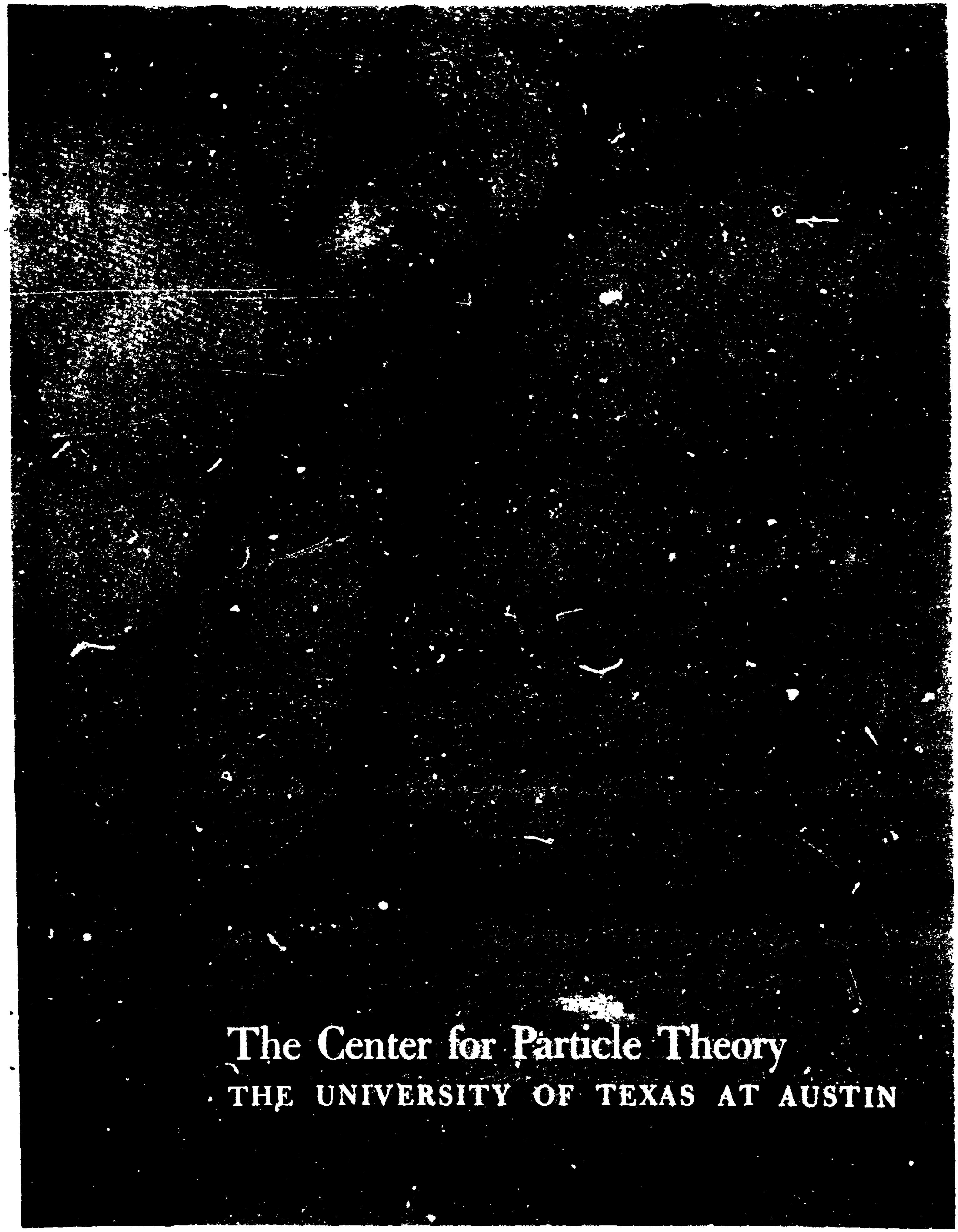

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The Recombination Model and Baryon Production by pp and πp Collisions

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ABSTRACT

The recombination model predictions for baryon production, using modified Kuti-Weisskopf structure functions are in good agreement with the pp and πp collision data. The indistinguishability of sea quarks naturally accounts for the difference in the p and $\bar{p}$ spectra in the pion fragmentation region.

The recombination model[1] has been quite successful in explaining low p_T meson production in hadronic collisions. In this note we examine, within the framework of the recombination model, the production of fast, low p_T baryons by p-p and π-p collisions. A particularly interesting feature of the p and $\bar{p}$ inclusive production[2,3] in the fragmentation domain of the pion is that although the x $(= 2p_{\parallel}/\sqrt{s})$ spectra for both cases are similar in shape, proton production exceed $\bar{p}$ production by a factor of about 2. Naive recombination model considerations suggest that $\frac{x}{\sigma}\frac{d}{dx}(\pi^+p \to pX) = \frac{x}{\sigma}\frac{d\sigma}{dx}(\pi^+p \to \bar{p}X)$ because the probability of picking out two u and a d quark from the pion (these constitute the proton) is considered to be equal to that of picking out two $\bar{u}$'s and a $\bar{d}$ quark. This led Migneron and Robinson[4] to suggest that whenever two (or more) sea quarks of the same species are picked out of a hadron, an additional correlation arises as a result of the exclusion principle. They argued that for the reaction $\pi^+p \to pX$ the specified quarks, u_v (valence u), u_s (sea u) and d_s are distinguishable whereas the two $\bar{u}$ quarks that go to form the $\bar{p}$ in the reaction $\pi p \to \bar{p}X$ are indistinguishable since they are both picked out from the sea. To include this effect, they introduced an ad hoc form for the two (identical) sea quark structure function. Thus, their scheme, although consistent in itself, suffers from a lack of anyspecific prediction.

In this letter, we discuss this problem within the framework of the recombination model[1] associated with structure functions constructed using the modified Kuti-Weisskopf (KW) method.[5,6,7] We recall that in the KW model the sea quarks of each species are considered to be indistinguishable and hence a statistical weight $\prod_q \frac{1}{n_q!}$ arises whenever n_q sea quarks of type q are designated within the structure function (see Eqs. (4), (6), (7)). In the limit in which the triple sea recombination is negligible, it follows (from Eqs. (2), (6) and (7)) that

$$\frac{x}{\sigma}\frac{d\sigma}{dx}(\pi^+ p \to pX) = 2\,\frac{x}{\sigma}\frac{d\sigma}{dx}(\pi^+ p \to \bar{p}x) \ . \tag{1}$$

The asymmetry between p and $\bar{p}$ production referred to earlier is naturally explained in the KW model (without the introduction of additional correlations) as arising due to the indistinguishable nature of sea quarks. This may be regarded as evidence for a physical distinction between the valence (distinguishable) and sea (indistinguishable) quarks.

In the recombination model, the baryon inclusive spectrum, assuming three-body recombination is dominant, is given by[8]

$$\frac{x}{\sigma}\frac{d\sigma}{dx} = \int_0^1 f(x_1,x_2,x_3)\,R(x_1,x_2,x_3;x)\,dx_1dx_2dx_3 \ , \tag{2}$$

where x and x_i are the longitudinal momentum fractions of the observed baryon and the i^{th} quark, respectively, and σ is the inelastic scattering cross section. For the recombination we choose[a] the form recently predicted by Hwa[9] on the basis of the valon hypothesis, viz.

$$R(x_1,x_2,x_3;x) = \alpha_B \left(\frac{x_1 x_2 x_3}{x^3}\right)^{3/2} \delta\left(\frac{x_1+x_2+x_3}{x} - 1\right) \quad . \qquad (3)$$

Hwa predicted $\alpha_B = 105/2\pi$. $f(x_1,x_2,x_3)$, the three-quark (antiquark) structure function, is the probability density of finding three "independent"[b] quarks (antiquarks) with specified momentum fractions. For the cases of $\bar{p}$ and $\bar{\Lambda}^0$ production in the fragmentation domain of the proton, the required three-antiquark structure functions are given (in the modified KW model) by

$$f^p_{\bar{u}\bar{u}\bar{d}}(x_1,x_2,x_3) = \frac{h^p_{\bar{u}_S}(x_1)\, h^p_{\bar{u}_S}(x_2)}{2!}\, h^p_{\bar{d}_S}(x_3)\, G^p_{\{0\}}(1-x_1-x_2-x_3) \quad , \qquad (4)$$

and

$$f^p_{\bar{u}\bar{d}\bar{s}}(x_1,x_2,x_3) = h^p_{\bar{u}_S}(x_1)\, h^p_{\bar{d}_S}(x_2)\, h^p_{\bar{s}_S}(x_3)\, G^p_{\{0\}}(1-x_1-x_2-x_3) \quad . \qquad (5)$$

Here, $h_{\bar{q}}$'s, the primitive structure functions, represent the probability densities of finding an antiquark $\bar{q}$ in the absence of any correlations. The correlation function $G_{\{V\}}(1-x_1-x_2-x_3)$ depends only on the valence content[7] of the designated quark system (e.g. in Eqs. (4), (5) no valence quarks are specified and hence $\{V\} = \{0\}$) and represents the effect of longitudinal momentum conservation. The statistical weight[b] $\frac{1}{2!}$ in Eq. (4) takes into account the indistinguishability of the two $\bar{u}_S$ antiquarks. For the case of p and $\bar{p}$ production in the fragmentation domain of the pion the required structure functions are

$$f^{\pi}_{uud}(x_1,x_2,x_3) = h^{\pi}_{u_V}(x_1)h^{\pi}_{u_S}(x_2)h^{\pi}_{d_S}(x_3)G^{\pi}_{\{u\}}(1-x_1-x_2-x_3) + \frac{h^{\pi}_{u_S}(x_1)h^{\pi}_{u_S}(x_2)}{2!}h^{\pi}_{d_S}(x_3)G^{\pi}_{\{0\}}(1-x_1-x_2-x_3) , \tag{6}$$

and

$$f^{\pi}_{\bar{u}\bar{u}\bar{d}}(x_1,x_2,x_3) = \frac{h^{\pi}_{\bar{u}_S}(x_1)h^{\pi}_{\bar{u}_S}(x_2)}{2!}h^{\pi}_{\bar{d}_V}(x_3)G^{\pi}_{\{\bar{d}\}}(1-x_1-x_2-x_3) + \frac{h^{\pi}_{\bar{u}_S}(x_1)h^{\pi}_{\bar{u}_S}(x_2)}{2!}h^{\pi}_{\bar{d}_S}(x_3)G^{\pi}_{\{0\}}(1-x_1-x_2-x_3) . \tag{7}$$

The existence of the factor $\frac{1}{2!}$ in the first term of Eq. (7) but not in that of Eq. (6) leads to the approximation, Eq. (1) when the triple sea recombination is neglected. (This follows because we have[10] $h^{\pi}_{u_V} = h^{\pi}_{d_V}$ and $h^{\pi}_{u_S} = h^{\pi}_{d_S}$.)

In our previous papers[7,10] we have used the single meson inclusive production data by pp, πp and Kp collisions as an input to determine the multiquark structure functions in the proton, the pion and the kaon. In addition, we extracted[10] the intrinsic p_T distributions of the quarks in the p, π and K assuming them to be normalized Gaussians. The parameters thus determined have all been listed in Tables I and II. These p_T-dependent structure functions were subsequently used for the analysis of multimeson production by pp,[11] πp and Kp collisions. The parameter-free predictions for the shapes and the absolute magnitudes were found[10,11] to be in agreement with the available data.[12] Since the modified KW[7,10] model allows the unambiguous generation of the correlation functions $G_{\{V\}}$ once the primitive functions are specified, we are able to make parameter-free predictions for the shapes of the baryon spectra both in pp and πp collisions. Moreover, once the recombination strength, α_B is fixed by fitting say the $pp \to \bar{p}X$ data, the cross sections for all other reactions involving baryon production can be predicted without any free parameters. We remark, however, that since a fundamental assumption of the KW model is that the quarks are statistically distributed and the only correlation is assumed to be due to momentum conservation, the model is not applicable for those reactions involving strong correlations among the quarks, such as $pp \to pX$ (leading particle effect) or $pp \to \Lambda^0 X$ (multivalence recombination—two of the three valence quarks tend to remain bonded together and thus cannot be treated independently). In both these cases the observed spectrum is much flatter than the recombination model prediction.

Our predictions for the baryon-inclusive spectra are shown in figs. (1-4). The value of α_B which determines the overall normalization is fixed from the data in fig. 1.[13] We find, using σ^{pp}_{inel} = 32 mb that α_B = 8.2 in contrast to $105/2\pi$ predicted by Hwa.[9] In figs. 2 and 3 we compare our completely parameter-free predictions with the πp collision data[2] using $\sigma^{\pi p}_{inel}$ = 20.5 mb. We note that the $\pi^+ \to p$ data differ slightly from $\pi^- \to \bar{p}$ as do the $\pi^+ \to \bar{p}$ from the $\pi^- \to p$. Our predictions, using the isospin flipped structure functions for π^+ and π^- are in fair agreement with both sets of data. Accumulation of more data would serve to test the validity of the assumed independence of particle production in the target and projectile fragmentation regions. Our predictions are also in agreement with the data in ref. 3. In fig. 4, we comapre our prediction for the reaction $pp \to \bar{\Lambda}^0 X$ with the data of Kichimi et al.[14] We also comment that our predictions of the p_T distributions for the reaction $pp \to \bar{p}X$ are consistent with the data of ref. 12 as also are those for $\pi p \to p(\bar{p})X$.[2]

To summarize, we have studied baryon production by pp and πp collisions within the framework of the recombination model[1] associated with the modified KW structure functions.[7,10,11] The only free parameter, α_B, the recombination strength for baryon formation, is determined by normalizing our predictions to the $pp \to \bar{p}X$ data[13] at p_T = 0.25 GeV/c. Our parameter-free predictions for the x and p_T spectra for the reactions $pp \to \bar{p}(\bar{\Lambda}^0)X$ and $\pi^+ p \to p(\bar{p})X$ are in agreement with the data. The difference in the magnitudes of p and $\bar{p}$ production by πp collisions is naturally explained as the manifestation of the indistinguishable nature of the sea quarks. This may be considered as evidence for a qualitative distinction between the valence and sea quarks; for instance, the valence quarks are distinguishable but the sea quarks are not. We remark that because the KW model has been constructed to explain reactions involving uncorrelated systems of quarks, the model in its present form naturally does not account for reactions involving the leading particle effect or multivalence recombination. Other predictions of the model such as the study of momentum correlations in baryon-meson and multibaryon inclusive production by hadronic collisions will be treated elsewhere.

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TABLE I - PRIMITIVE STRUCTURE FUNCTIONS

Proton: $h^{p}_{u_V}(x) = x^{-\alpha}(1+\beta x)$

$$h^{p}_{d_V}(x) = x^{-\alpha}(1-x)(1+\gamma x)$$

$$h^{p}_{u_S}(x) = h^{p}_{\bar{u}_S}(x) = g_u x^{-1}(1-x)^{n_u}$$

$$h^{p}_{d_S}(x) = h^{p}_{\bar{d}_S}(x) = g_d x^{-1}(1-x)^{n_d}$$

$$h^{p}_{s_S}(x) = h^{p}_{\bar{s}_S}(x) = g_s x^{-1}(1-x)^{n_s}$$

$$h^{p}_{g}(x) = g_g x^{-1}(1-x)^{n_g}$$

$\alpha = 0.5$, $\beta = 3.5$, $\gamma = 5.0$, $g_u = 0.5$, $g_d = 0.6$, $g_s = 0.075$,
$g_g = 1.45$, $n_u = n_d = 2$, $n_s = n_g = 0$

Pion: $h^{\pi^+}_{u_V}(x) = h^{\pi^+}_{d_V}(x) = h^{\pi^-}_{u_V}(x) = h^{\pi^-}_{d_V}(x) = x^{-\alpha}(1+\beta x)$

$$h^{\pi^+}_{u_S}(x) = h^{\pi^+}_{d_S}(x) = h^{\pi^-}_{u_S}(x) = h^{\pi^-}_{d_S}(x) = g_u x^{-1}(1-x)^{n_u}$$

$$h^{\pi^+}_{s_S}(x) = h^{\pi^-}_{s_S}(x) = g_s x^{-1}(1-x)^{n_s}$$

$$h^{\pi^+}_{g}(x) = h^{\pi^-}_{g}(x) = g_g x^{-1}(1-x)^{n_g}$$

Table I (continued)

Pion (continued):

$h_{q_S}(x) = h_{\bar{q}_S}(x)$ for π^+ and π^-

$\alpha = 0.5,\ \beta = 0,\ g_u = 0.545,\ g_s = 0.08,\ g_g = 0.0$

$n_u = n_d = 2,\ n_s = 1,\ n_g = 0$

TABLE II - INTRINSIC p_T DISTRIBUTIONS

General form: $\frac{1}{\pi a_q^2} \exp(-p_T^2/a_q^2)$

	a_q (GeV/c)^2 when q is the		
	valence	Non Strange Sea	Strange Sea
PROTON	0.12	0.17	0.14
PION	0.07	0.18	0.12

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Footnotes

[a] The shapes of the spectra are quite insensitive to the particular form of the recombination function.

[b] By "independent" we mean that the combinatorial factors that arise due to the indistinguishable nature of sea quarks are included in the structure function.

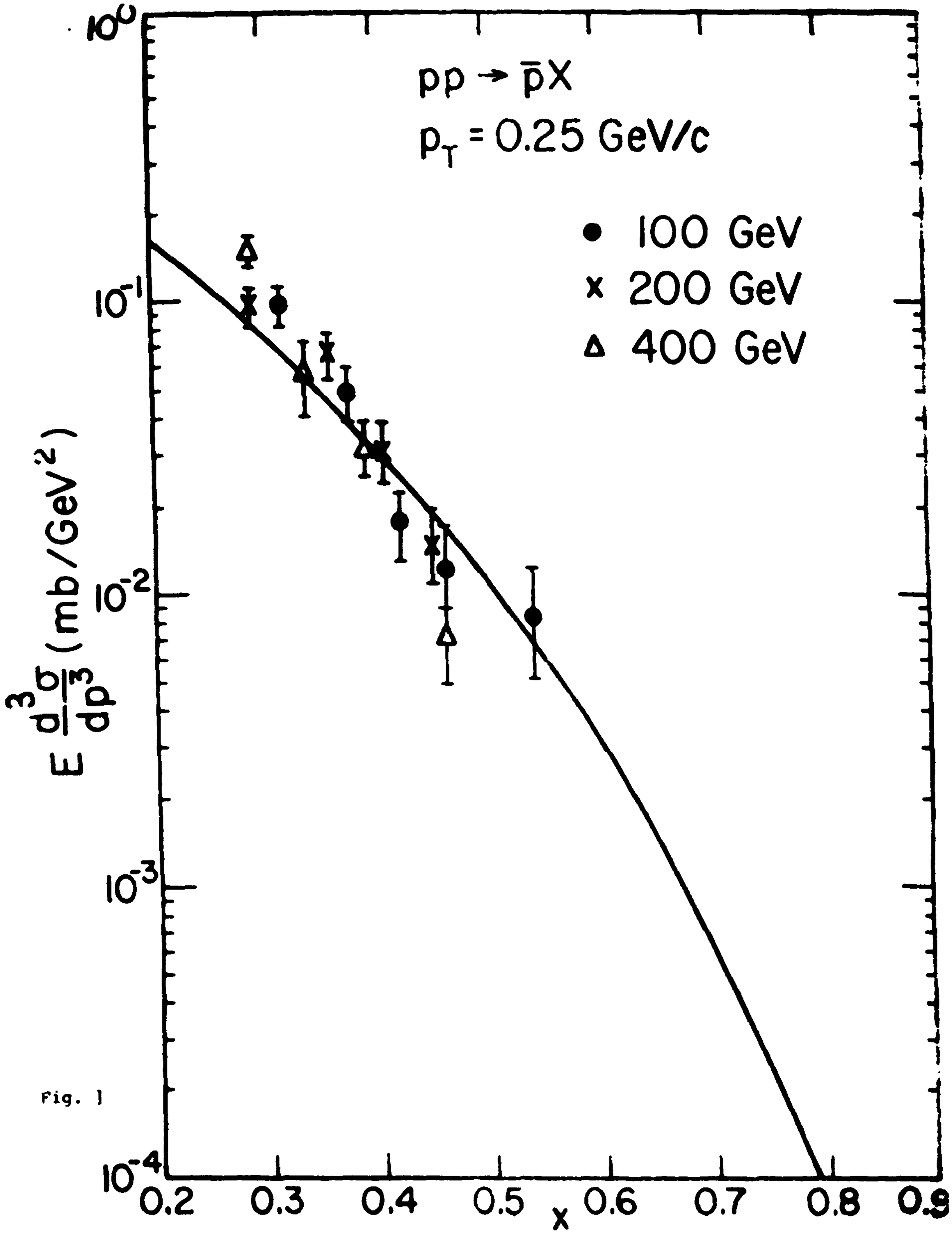
Figure Captions

Fig. 1. The comparison of the recombination model predictions for the reaction $pp \to \bar{p}X$ with the data of the Fermilab-Illinois collaboration (Ref. 13). This data yields $\alpha_B = 8.2$.

Fig. 2. The parameter-free prediction of the invariant cross sections for the reactions $\pi^+p \to pX$ and $\pi^-p \to \bar{p}X$ at $p_T = 0.3$ GeV/c. The data are from ref. 2.

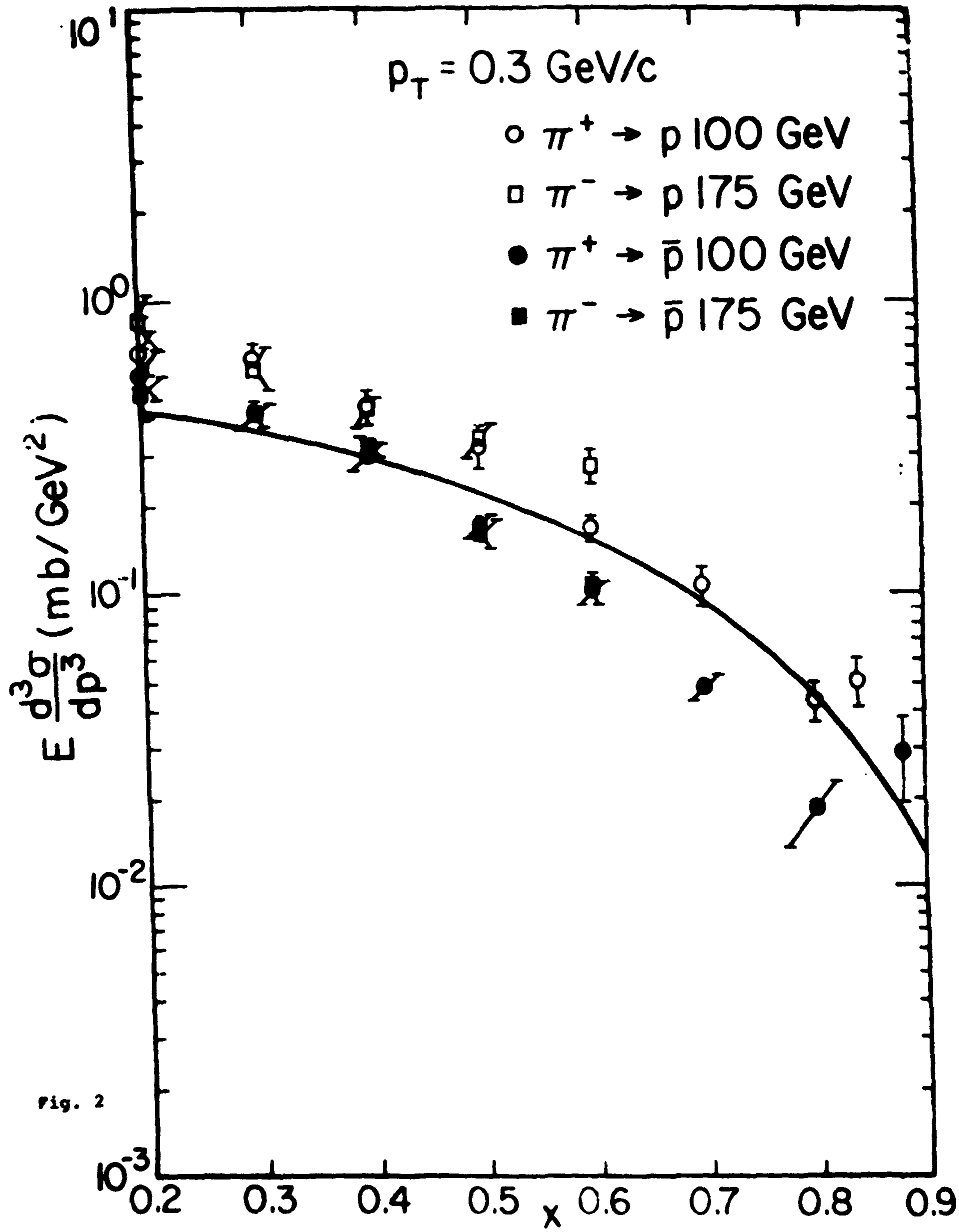
Fig. 3. The parameter-free prediction of the invariant cross sections for the reactions $\pi^+p \to \bar{p}X$ and $\pi^-p \to pX$ at $p_T = 0.3$ GeV/c. The data are from ref. 2.

Fig. 4. The parameter-free prediction for $x\frac{d\sigma}{dx}$ for the reaction $pp \to \bar{\Lambda}^0X$. The data are from ref. 14.



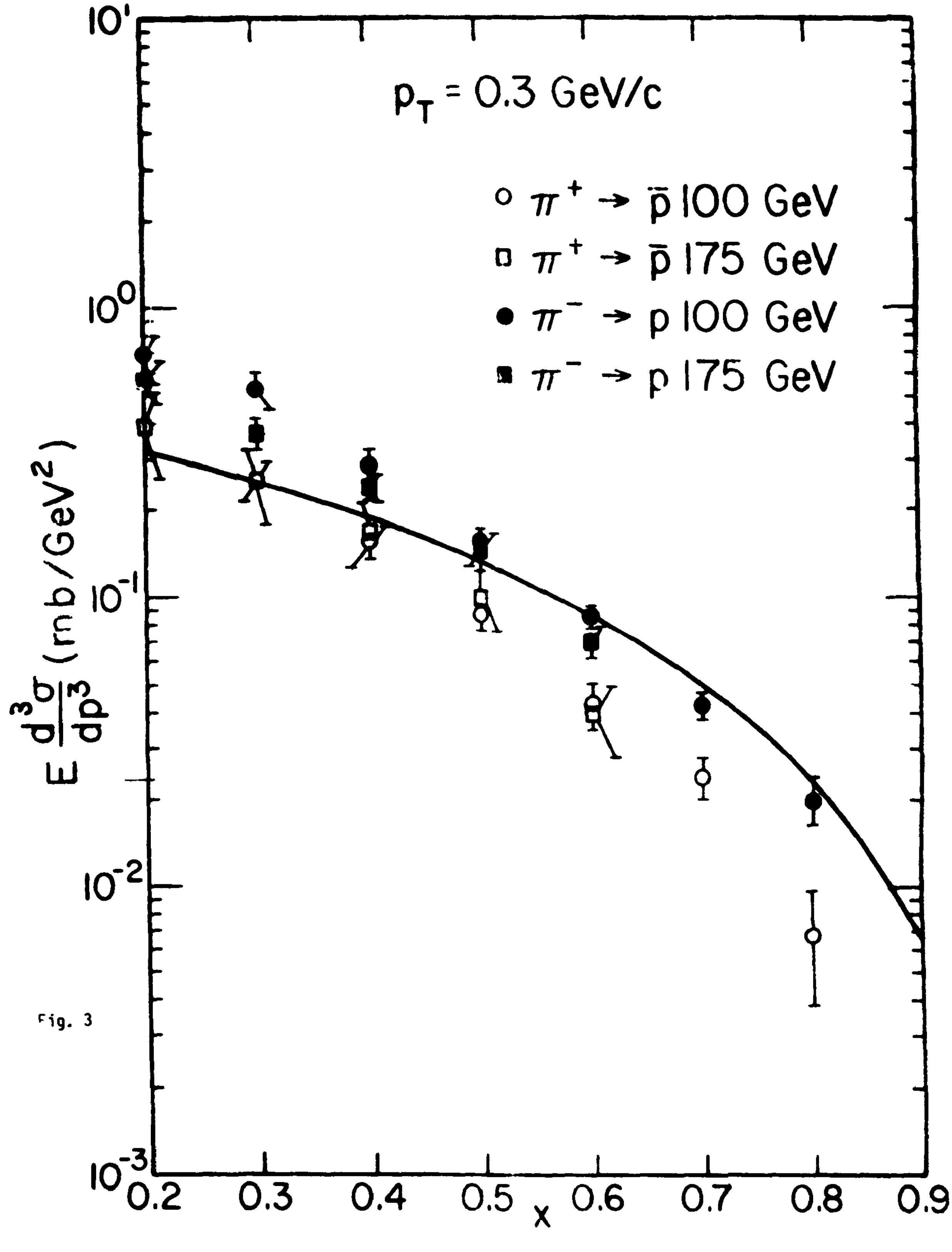
pp → $\bar{p}$X
p_T = 0.25 GeV/c
● 100 GeV
x 200 GeV
Δ 400 GeV
$E\frac{d^3\sigma}{dp^3}$ (mb/GeV^2)
x
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Fig. 1



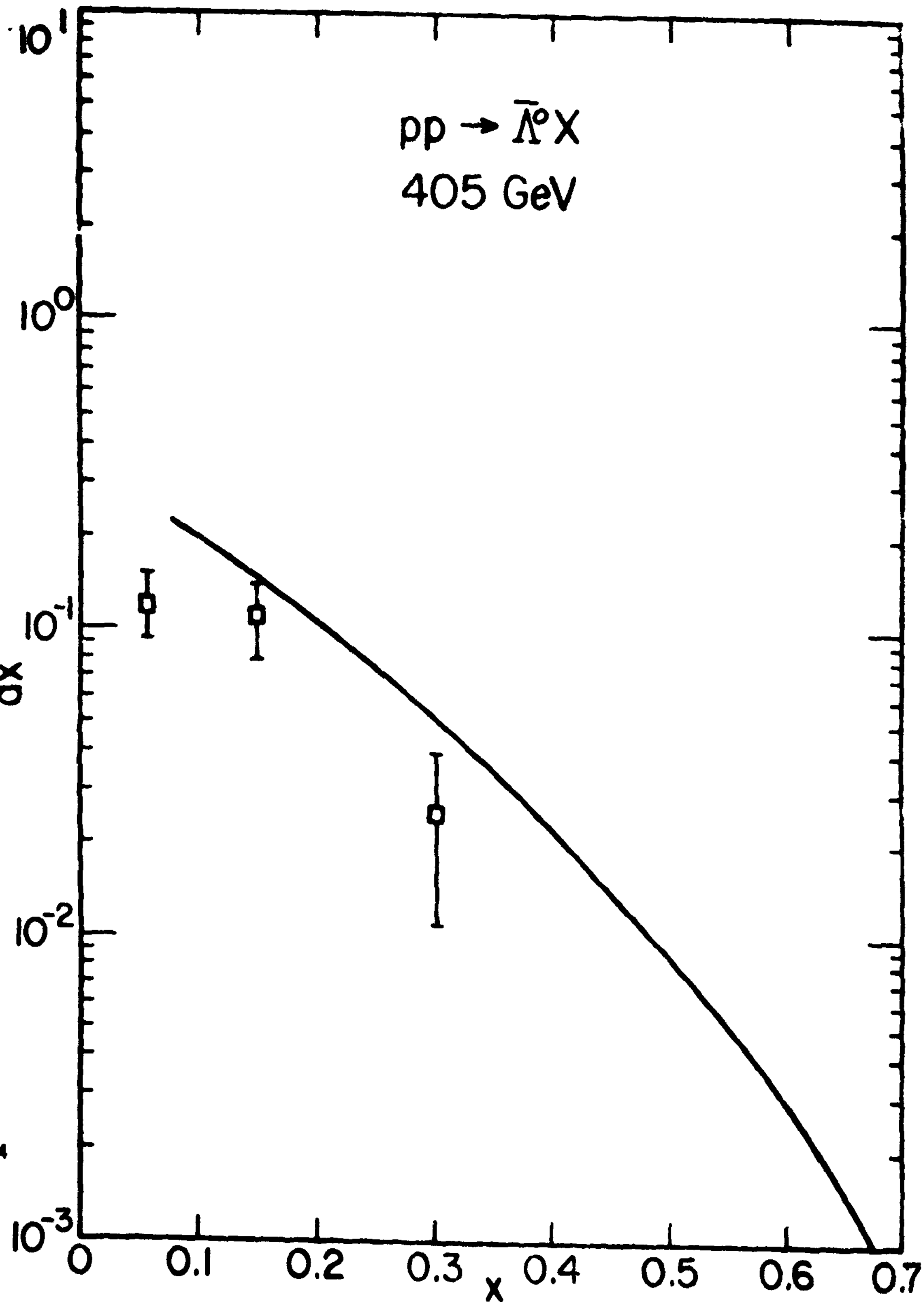
p_T = 0.3 GeV/c
○ $\pi^+ \rightarrow p$ 100 GeV
□ $\pi^- \rightarrow p$ 175 GeV
● $\pi^+ \rightarrow \bar{p}$ 100 GeV
■ $\pi^- \rightarrow \bar{p}$ 175 GeV
$E\frac{d^3\sigma}{dp^3}$ (mb/GeV^2)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0.2
0.3
0.4
0.5
x
0.6
0.7
0.8
0.9

Fig. 2



p_T = 0.3 GeV/c
○ $\pi^+ \rightarrow \bar{p}$ 100 GeV
□ $\pi^+ \rightarrow \bar{p}$ 175 GeV
● $\pi^- \rightarrow p$ 100 GeV
■ $\pi^- \rightarrow p$ 175 GeV
$E\frac{d^3\sigma}{dp^3}$ (mb/GeV^2)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x

Fig. 3


pp → $\bar{\Lambda}^0$X
405 GeV
$x\frac{d\sigma}{dx}$ (mb)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
x

ig. 4