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$K^{*\pm}$ (892) PRODUCTION IN $\pi^- N$ INTERACTIONS AT 200 GeV/c

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ABSTRACT

$K^{*\pm}(892)$ production is studied in the reaction $\pi^-N \to K^\circ_S K^\circ_S + X$ where X includes up to five observed charged particles. An excess of K^{*-} over K^{*+} is observed for Feynman-x > 0.1. The ratio of K^{*+} to K^{*-} decreases with x as predicted by QCD counting rules. K°_S and K^* production are compared to recent D and D^* data from other experiments.

Recently, there has been considerable interest in the production and decay properties of charm mesons from hadron beams[1] on fixed targets. These experiments are difficult because charm mesons are massive and possess many decay modes. Perhaps the easiest and most direct search is for events with decays occurring within at most a few centimeters of the primary interaction point.[2,3] The same argument can be made for strange particles, however the decay region extends over distances of meters at Fermilab energies. Like the charm quark, the strange quark is not present as a valence quark in a pion or in a nuclear target, and since it is also relatively massive compared to u and d quarks, it is of interest to compare inclusive $K^{*\pm}$ data with high statistics to recent $D^{*\pm}$ data from pion beams.

This experiment (E580) carried out in the Fermilab Multiparticle Spectrometer allows a study of K^{*+} and K^{*-} via the decays to a K_s^0 and a $\pi^\pm$. The K_s^0 decays to $\pi^+\pi^-$ occur within a two-meter helium-filled decay region downstream of an active 20-layer scintillator target.[4] Using an incident beam of 200 GeV/c π^-, a total of 1.4 million triggers were recorded in final states containing two or more neutral strange particles and less than 6 charged particles. These were processed through a pattern recognition program, a spline fit to particle trajectories which included hits from proportional wire chambers within the magnet, and finally a multi-vertex kinematic fit. A total of 70,500 two vee events remained. Of these, 62% were best fit as $K_s^0K_s^0$, 29% fit $K_s^0\Lambda$ or $K_s^0\overline{\Lambda}$, and 8% fit $\Lambda\overline{\Lambda}$, with the remainder being identified as $\Lambda\Lambda$ or $\overline{\Lambda}\overline{\Lambda}$. Further details of the apparatus and the experiment have been published elsewhere.[4,5,6,7,8] In this paper we examine the $K^{*\pm}$ production distributions as a function of the Feynman variable, x, and the K^* momentum squared transverse to the beam direction, p_t^2. The ratio of K^* to K_s^0 is also determined. Finally, these results are compared with predictions of QCD counting rules and with D^* data from other experiments.[2,3]

The curves in Fig. 1 are fits to the inclusive distributions for $K_s^0\pi^-$ and $K_s^0\pi^+$ combinations for $x > 0$ and all p_T^2. The events have been escape weighted to account for K_s^0 decays occurring outside the decay volume. A clear excess of K^{*-} over K^{*+} is observed. The fits used a P-wave Breit-Wigner[6] for the K^* and a non-polynomial background of the form: $A(M-M_0)^B \exp(-CM-DM^2)$ where M is the $K\pi$ mass and A,B,C,D are fit parameters. Only the mass region below 1.3 GeV was included in the fits, but there is no evidence of $K^*(1430)$ in the inclusive distributions and the parameterization is satisfactory beyond 2 GeV. However, a $K^*(1430)$ signal was observed when cuts were made to isolate the diffractive component in the $K_s^0K_s^0\pi^-$ data.[5] The mass and width obtained from Fig. 1 for the K^{*-} were $M = 0.891 \pm 0.001$ and $\Gamma = 0.056 \pm 0.004$, and for the K^{*+} were $M = 0.888 \pm 0.003$ and $\Gamma = 0.054 \pm 0.009$, which agree with currently accepted values.[10] Fig. 1 shows the effect of requiring the $K_s^0\pi^-$ combination to have $x > 0$, 0.2, 0.4, 0.6, and 0.8 successively. The K^{*-} peak is evident for all x values (Fig. 1a), while the K^{*+} is significant only at low x values (Fig. 1b). This x behavior is expected on the basis of QCD counting rules.[9] Given a π^- containing $\bar{u}$ and d valence quarks, one obtains a fast valence quark by gluon exchange. A $(1-x)^1$ distribution is obtained for $x \to 1$ and low transverse momentum of the struck quark. For π^- fragmentation to a sea quark, the sea $q\bar{q}$ pair is produced by gluon bremsstrahlung and a $(1-x)^3$ distribution is obtained. If the π^- wave function contained a hard $q\bar{q}$ component initially, a $(1-x)^5$ distribution would be obtained. The general rule is:

$$G(x) = (1-x)^{2n_H+n_{PL}-1}$$

where $G(x)$ is the hadronization function of the quark, proportional to $x(dN/dx)$, n_H is the number of quark spectators in the initial hadron and n_{PL} is the number of spectators arising from point-like bremsstrahlung. When our K^* data is parameterized by $(1-x)^n$ we obtain $n = 0.64 \pm 0.12$ for the K^{*-} with chi-squared per degree of freedom of 0.98 and $n = 2.76 \pm 0.32$ for the K^{*+} with a chi-squared per degree of freedom of 1.19. The invariant x distributions $x(dN/dx)$, are shown in Fig. 2 for $x > 0.2$, the region where our acceptance is large. Acceptance corrections for K^{*+} and K^{*-} are almost identical for equal x values of the $K^\circ{}_S\pi^+$ and $K^\circ{}_S\pi^-$combinations. A 2 cm by 2 cm beam veto counter gives a small asymmetry. Taking the ratio of the $x(dN/dx)$ distributions, $R(x)$, allows cancellation of these acceptance terms. $R(x)$ is shown Fig. 3 (filled circles) for all data with $x > 0$. If $R(x)$ is parameterized by $R_0(1- x)^n$, the counting rules predict $n = 2$. The fit results were $n = 2.24 \pm 0.34$ and $R_0 = 0.89 \pm 0.19$ with chi-squared per degree of freedom of 0.67. One might expect the numbers of K^{*+} and K^{*-} to be nearly equal at $x = 0$. If R_0 is set to unity the best fit is $n=2.40 \pm 0.25$.

The ACCMOR collaboration [11] has recently studied $\overline{K}^{*\circ}$ and $K^{*\circ}$ production by 175 GeV π^-incident on a beryllium target. Fig. 3 (open circles) also presents their $\overline{K}^{*\circ}$ to $K^{*\circ}$ ratio obtained from the invariant x distributions in Table 2 of Ref. 11. When these data are fit to the form $R_0(1-x)^n$, we obtain $n=1.11 \pm 0.27$ and $R_0 = 0.86 \pm 0.08$. This R_0 value is equal within errors to that for the K^{*+}/K^{*-} ratio, that is, the ratios of $\overline{K}^{*\circ}/K^{*\circ}$ and K^{*+}/K^{*-} are equal at $x=0$. At higher x values the $\overline{K}^{*\circ}/K^{*\circ}$ ratio is consistently larger than the K^{*+}/K^{*-} ratio.

The transverse momentum dependence of K^* production has been parameterized as $e^{-bp_T^2}$. Best fits to our data using six equal bins with $\Delta p_T^2 = 0.2$ over the interval $0 \leqslant p_T^2 \leqslant 1.2$ gave $b = 2.25 \pm 0.08$ for the K^{*-} and

and 2.01 ± 0.13 for the K^{*+}. No other significant difference in p_T^2 behavior is observed between K^{*+} and K^{*-}. The ACCMOR collaboration[11] found $b = 2.42 \pm 0.25$ for $K^{*\circ}$ and 2.39 ± 0.37 for $\overline{K}^{*\circ}$ in the range $0 \leqslant p_T^2 \leqslant 1.0$.

The dependence of $K^{*\pm}$ production on the number of observed charged particles from the primary vertex may also be examined. Table 1 displays the fraction of events for each multiplicity, N, that contain a $K^{*\pm}$. Also given are the ratios of the number of K^{*+} to K^{*-} and of the number of π^+ to π^- for each value of N, assuming charged tracks to be pions. Note that N = 1 data contain a large diffractive component[5] of $K^{*-}K^\circ_s$ and few of these events contain a positive track. Neglecting this special case, a slow rise is observed for the K^{*+}/K^{*-} ratio and also for the π^+/π^- ratio, as N increases. This is in accord with naive expectations from charge conservation since the charge of the beam π^- becomes less significant for large N. The value of N would be given by $2n_+ + 1$ if the π^- fragmented into n_+ positively charged particles and $n_+ + 1$ negatives. Since some slow particles may be undetected, a given N is not uniquely related to the total multiplicity of charged particles in the event. The observed rise of R with multiplicity is also in agreement with the x dependence. An increase in the associated charge multiplicity is expected as $x \to 0$ for single particle inclusive distributions. A Fermilab bubble chamber experiment[12] with 205 GeV/c π^- incident on hydrogen finds an average total charged particle multiplicity of 8.0 ± 0.1. Our data sample should be representative of roughly half of the total $K^{*\pm}$ cross section, since it includes forward charge multiplicities less than six. Taking into account that each event contains two K°_s, we find the ratio of K^{*+} to K°_s is 0.049 ± 0.015 and the ratio of K^{*-} to K°_s is 0.104 ± 0.017. If it is assumed that production of $K^{*\circ}$ and $\overline{K}^{*\circ}$ occurs at a rate equal to that of K^{*+} and K^{*-}, a total K^*/K°_s ratio of ~30% is obtained. Bubble chamber experiments[13] also indicate that about one-third of the $K^\circ{}_s$ come from K^* decay. A Monte Carlo dataset was generated to test the entire analysis chain. These events were propagated through the spectrometer, reconstructed, and written to a data summary tape. The K^* to $K^\circ{}_s$ ratios determined from these data agreed with the generated values to better than 5%, the statistical error of the sample.

The x distributions of inclusive $K^\circ{}_s$ and $K^\pm$ have been determined elsewhere. Our inclusive x(dN/dx) distribution for $K^\circ{}_s$ gave a fit[8] of $n = 1.61 \pm 0.03$. Edwards et al.[14] studied the inclusive spectrum of $K^\circ{}_s$ from 200 GeV/c π^- incident on beryllium at $p_T = 0$. They applied a $(1-x)^n$ parameterization from the constituent interchange model (CIM) and found $n = 0.26 \pm 0.01$. They attribute the slope change near $x = 0.5$ to an excess of K° over $\overline{K}^\circ$ at large x. The Fermilab Single Arm Spectrometer[15] studied K^+ and K^- production at 100 GeV/c and 175 GeV/c at numerous fixed x and p_T values for $0.12 \leqslant x \leqslant 0.94$ and $0.15 \leqslant p_T \leqslant 0.75$ GeV/c. Results were $n = 2.06 \pm 0.25$ for $\pi^- \to K^-$ $(x < 0.5)$ and $n = 2.85 \pm 0.22$ for $\pi^- \to K^+$ at 175 GeV/c; the $\pi^- \to K^-$ distribution becomes less steep for $x > 0.5$. The $K^\circ{}_s$ and $K^\pm$ distributions have values of n which are generally intermediate between the K^{*+} and K^{*-} values, as expected if resonance decay is significant.

We now compare the production of $K^{*+}(u\bar{s})$ with $D^{*+}(\bar{d}c)$ data from other experiments using π^- beams.[2,3] Neither particle contains a valence quark from the π^- and both contain a heavy quark. Similarly, one may compare K^{*-} $(\bar{u}s)$ and $D^{*-}(d\bar{c})$, where both particles contain one π^- valence quark. A LEBC experiment[2] studied charm production in $\pi^- p$ interactions at 360 GeV/c and found $(dN/dx) \sim (1-x)^n$ with $n = 2.8 \pm 0.8$ for all D's. However, within statistics, the data are consistent with two components, one $n = 1$ and the other $n = 6$. The $n = 1$ component accounts for about 30% of all D's and consists only of D's which contain a valence quark. An ACCMOR experiment[3] used a

π^- beam incident on beryllium at 120, 175, and 200 GeV/c. They find n = 3.2 ± 1.5 for D^* ($\rightarrow D^\circ\pi$), and n = 0.8 ± 0.4 for inclusive D°, $\overline{D}^\circ$, D^+, and D^-. An excess of D^- and D° over D^+ and $\overline{D}^\circ$ is reported; the ratio of valence quark D's to non-valence quark D's is 2.0 ± 1.0. Both experiments clearly report an excess of D's with one valence quark over D's with no valence quark, especially at larger values of x.

In summary, we find an excess of K^* with one valence quark compared to K^* which contain no valence quark, approximately twice (2.12 ± 0.16) as many K^{*-} as K^{*+} for $x > 0.1$. The production ratios for $x > 0.2$ and $N \leq 5$ are found to be 0.049 ± 0.015 for $K^{*+}/K^\circ{}_s$ and 0.104 ± 0.017 for $K^{*-}/K^\circ{}_s$. The invariant x distributions for K^*'s may be parameterized as $(1-x)^n$ with n = 2.76 ± 0.32 for the K^{*+} and n = 0.64 ± 0.12 for the K^{*-}, compared with QCD counting rule predictions of three and one respectively. ACCMOR[11] obtained n = 1.47 ± 0.51 for $\overline{K}^{*\circ}$ production and n = 0.56 ± 0.13 for $K^{*\circ}$ production in the range $0.3 \leq x \leq 0.9$. The individual values of n for K^{*+}, $\overline{K}^{*\circ}$, $K^{*\circ}$, and K^{*-} are all systematically lower than the QCD counting rule predictions. However, the value of n = 2.24 ± 0.34 for the K^{*+}/K^{*-} ratio agrees with the prediction of 2. These results demonstrate the significant role of valence quarks in strange resonance production suggested by the more limited data presently available on charm meson production.

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REFERENCES AND FOOTNOTES

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TABLE 1

Selected particle ratios as a function of N, the number of observed charged particles from the primary interaction vertex.

N	K^{*+}/EVENT	K^{*-}/EVENT	K^{*+}/K^{*-}	π^+/π^-
1	.005	.151	.032	.106
2	.056	.173	.321	.509
3	.086	.197	.435	.595
4	.086	.164	.524	.665
5	.103	.179	.576	.729

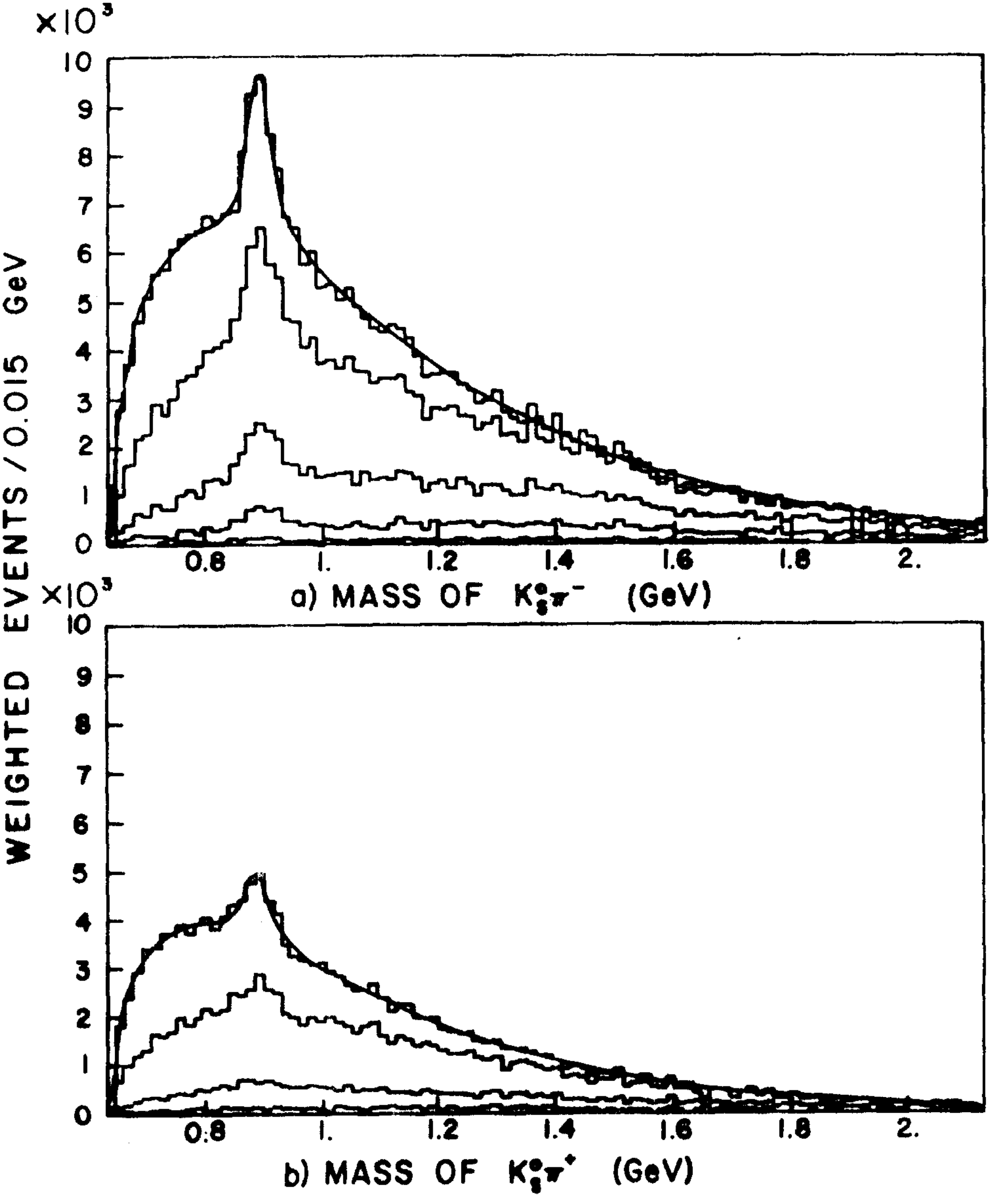
Figure Captions

Fig. 1 a) Invariant mass distributions for all $K^{\circ}{}_{s}\pi^{-}$ combinations with $x>x_{min}$ where x_{min} = 0, 0.2, 0.4, 0.6, and 0.8.

b) Corresponding distributions for all $K^{\circ}{}_{s}\pi^{+}$ combinations.

Fig. 2 Distributions of x (dN/dx) obtained from mass fits to the data in Fig. 1 for the K^{*-} (points on solid curves) and the K^{*+} (points on dashed curve). The curves are best fits to $A(1-x)^{n}$.

Fig. 3 The K^{*+} to K^{*-} ratio for this experiment (filled circles) and the $\overline{K}^{*\circ}$ to $K^{*\circ}$ ratio from the data of Ref. 11 (open circles). The curve is $R_0(1-x)^{n}$ with n = 2.24.


×10³
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9
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1.8
2.
a) MASS OF $K^0_s\pi^-$ (GeV)
×10³
10
9
8
7
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3
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1
0
0.8
1.
1.2
1.4
1.6
1.8
2.
b) MASS OF $K^0_s\pi^+$ (GeV)
WEIGHTED EVENTS / 0.015 GeV

Fig. 1

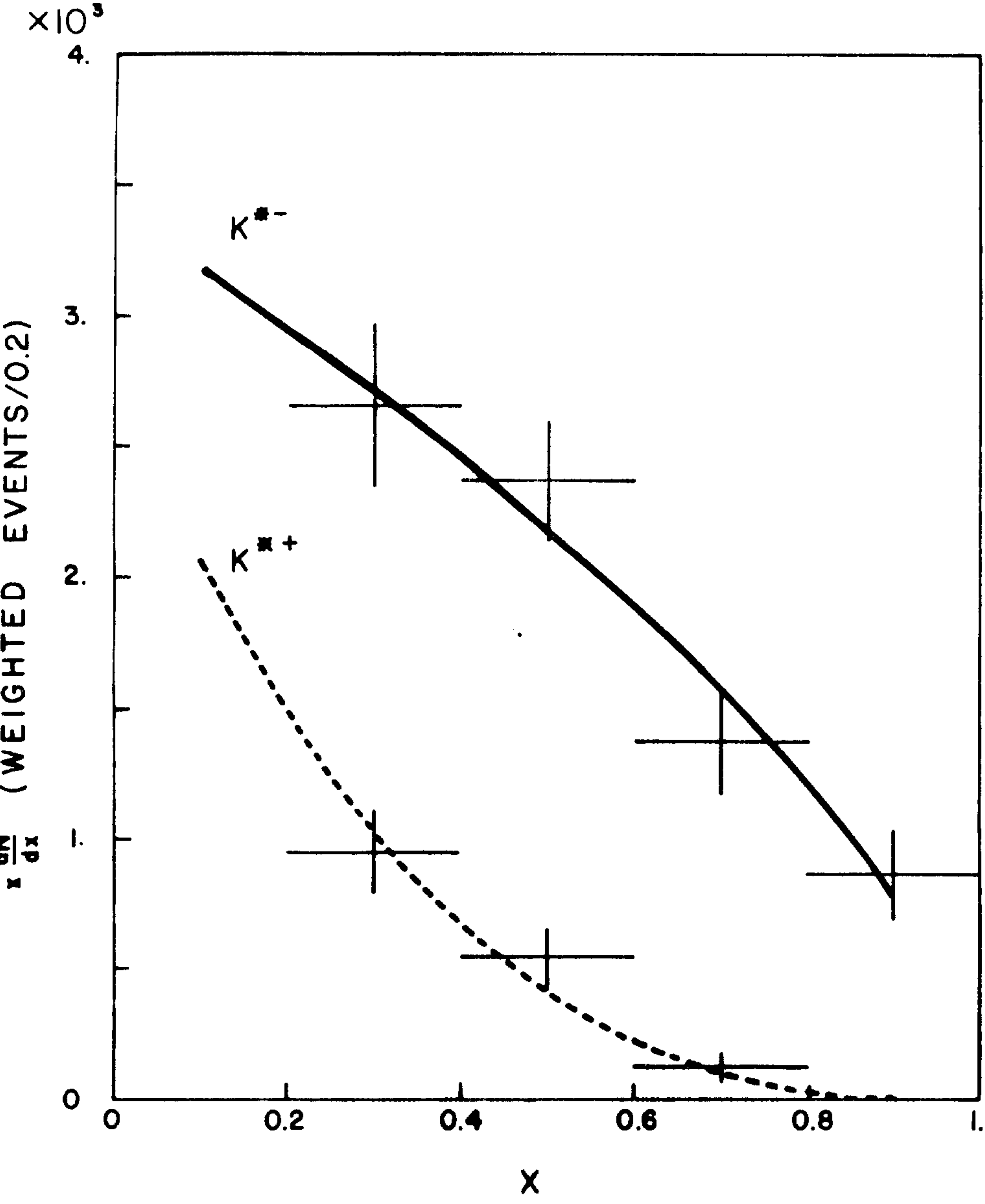

Fig. 2

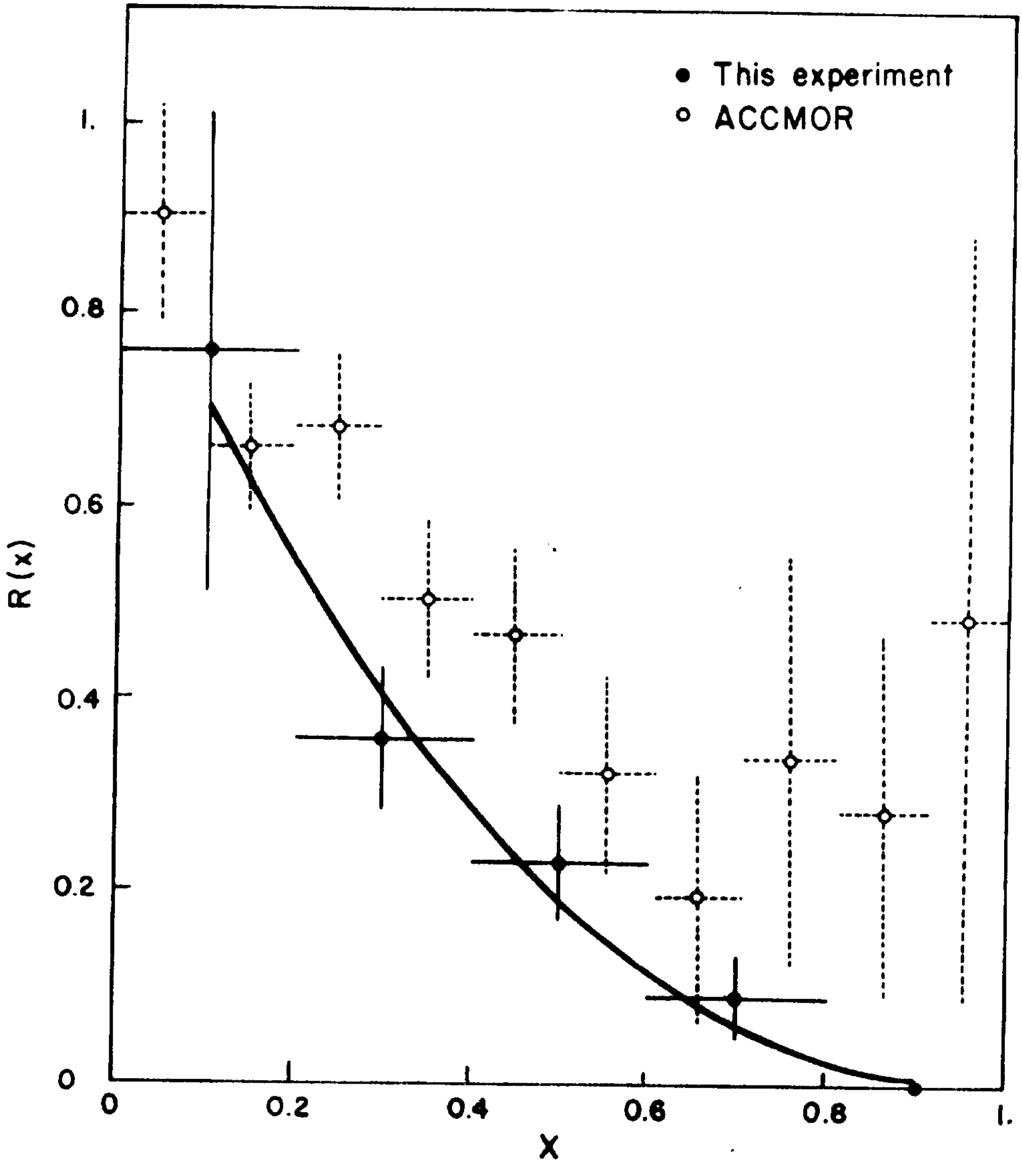

Fig. 3