INCLUSIVE K^* 's AND Σ^* 's PRODUCTION IN 360 GeV/c pp INTERACTIONS

USING THE EUROPEAN HYBRID SPECTROMETER

EHS-RCBC Collaboration

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ABSTRACT

We have studied the inclusive production of strange meson and baryon resonances in 360 GeV/c pp interactions. Cross sections for $K^{*+}(892)$ and $K^{*-}(892)$ are estimated to be 4.42 ± 0.62 mb and 2.54 ± 0.47 mb respectively and those for $\Sigma^+(1385)$ and $\Sigma^-(1385)$ are 0.67 ± 0.11 mb and 0.26 ± 0.07 mb respectively. Longitudinal and transverse momentum distributions for $K^*(892)$ and $\Sigma(1385)$ are presented, as well as for their decay products K^0 and Λ . An estimation is given on the $K^*(1430)$ and $\Sigma^*(1915)$ productions.

1. INTRODUCTION

There have been several studies of resonance production in hadron-hadron collisions during the past several years. These studies have led to the conclusion that a major fraction of the pions and the kaons are the decay products of various resonances. Since resonances are dominantly produced directly, they are more useful to test the various production mechanisms such as quark recombination/fusion, the quark fragmentation or the perturbative QCD approach etc., see ref. [1-14]. The present experimental and theoretical situations are well summarised in a recent review [15]. However, strange resonance production from p-p interactions is much less studied [16-25]; a special interest in this study lies in the fact that there are no strange quarks in the initial state. Thus the strangeness label might help to reveal the underlying quark dynamics. In the present work we report results from an experiment on strange meson (K^*) and strange baryon (Σ^*) resonance production in 360 GeV/c pp interactions based on statistics which is about 4 times larger than the published results [21,22] around this energy. The plan of the paper is as follows. In sect. 2 we give the experimental details; the method of analysis is presented in sect. 3. Results on K^* and Σ^* production are presented in sects 4 and 5 respectively. In sect. 6 we summarize the results and conclusions.

2. EXPERIMENTAL DETAILS

The present study is based on the experiment NA23 performed at CERN using the Rapid Cycling Bubble Chamber (RCBC) and the European Hybrid Spectrometer (EHS) set-up. The RCBC, filled with liquid hydrogen was exposed to a 360 GeV/c proton beam. The relevant details about the spectrometer and the procedure of triggering the events is given elsewhere [26,27]. A sample of 160 K pictures has been scanned and measured for inelastic interactions with at least one associated V^0 or γ seen in the bubble chamber. The resulting sample of 10672 interactions corresponds to a sensitivity of ~ 1.6 events/ μb . The events were measured by automatic and/or manual measuring devices. The measurements were processed through the hybrid geometry program GEOHYB and through a kinematics program to reconstruct the V^0 's and γ 's. Among the uniquely fitted V^0 's (3-constraint fits, with a probability bigger than 10^{-4} for one

hypothesis and less than that for all the others), we have 1382 K^0 's, 635 Λ and 106 $\bar{\Lambda}$. Approximately 22% of the V^0 's were found to be ambiguous among the different hypotheses by the kinematics fitting program. The sources of ambiguities have been studied in great detail [28,29] by looking at various kinematic distributions. In this paper the ambiguities were solved by using cuts on p_T of the decay products and effective masses. In what follows only fully reconstructed events were used. In addition a cut on the fit probability distribution at 2% was imposed to the V^0 's. Among the remaining events the V^0 's were asked to have a Feynman x-value $x_F \leq 0$, since in the bubble chamber we cannot detect most of the forward hemisphere produced K^0 and Λ .

After all these cuts we are left with a total of 894 K^0 's and 482 Λ 's.

For the $(V^0, \pi^\pm)$ combinations we ask that the charged track has a $\Delta p/p < 20\%$. Each of the mass combinations has been appropriately weighted not only by the V^0 visibility weight, but by the weights which take into account the losses due to the fully reconstructed requirement (which is a function of the event topology) and the losses due to the $\Delta p/p$ cut.

3. METHOD OF ANALYSIS

The major aim in this paper is to extract K^* and Σ^* resonance production from effective mass distributions of $K_S^0 \pi^\pm$ and $\Lambda \pi^\pm$ respectively. For this, the experimental effective mass distributions are fitted to the following expression

$$\frac{d\sigma}{dM} = A * BG(M) + E * BG(M) * BW(M) \quad (1)$$

where $BG(M)$ represents the background and $BW(M)$ a Breit-Wigner function

$$BG(M) = M_x^b * e^{-cM_x - dM_x^2} \quad (2)$$

where $M_x = M - M_{th}$, $M_{th} = M_{V^0} + M_{\pi^0}$.

$$BW(M) = \frac{M M_R \Gamma_R}{(M^2 - M_R^2)^2 + M_R^2 \Gamma_R^2} \quad (3)$$

M_R and Γ_R are the mass and width of the resonances, and M is the effective mass of the combination.

The error in the $K_S^0 \pi^\pm$ and $\Lambda \pi^\pm$ effective mass determination as function of the mass (fig. 1) give a good indication of the experimental resolution. These values are equal to 6 and 19 MeV/c² at $K^*(892)$ and $K^*(1430)$ masses and 2.6 and 9.3 MeV/c² at $\Sigma(1385)$ and $\Sigma(1915)$ masses, respectively. The small errors found in the resonant region allow to fit the data using fixed values for the widths and masses.

An approximation to the shape of the background can be obtained by combining a V^0 (K_S^0 or Λ) from one event and a charged pion from another event having the same primary charged multiplicity. The normalization of the combinations for a given primary charged multiplicity is so adjusted as to reproduce the observed V^0 topology distribution. A χ^2 fit to those background distributions allows to determine the values of the parameters b , c , and d in (2), thus fixing the shape of the background. This background shape is then combined with the appropriate Breit-Wigner to fit the experimentally observed $V^0 \pi^\pm$ distribution. The only parameters now fitted are A and E in (1) which fix the amounts of the background and Breit-Wigner respectively.

The above method of determining the shape of the background ignores any physical reflections which may be present in real events. In an alternative approach we have directly fitted the experimental $V^0 \pi^\pm$ distribution to a combination of background and Breit-Wigner as specified in (1)-(3) allowing all the parameters A , b , c , d , E to be determined from the best fit. The cross sections presented in this paper represent the average of the results obtained using these two methods.

Note that in (1) only a Breit-Wigner is used and this is due to the fact that in the mass spectra only one resonance is clearly seen: K_{892}^* in the $K_S^0 \pi^\pm$ combinations, and Σ_{1385}^* in the $\Lambda \pi^\pm$. The presence of the K_{1430}^* and Σ_{1915}^* is investigated later.

Finally, all the cross sections, but for the Σ_{1915}^* , obtained in the subsequent sections have been corrected for the unobserved decay modes, and for the fact that only V^0 's with $x_F \leq 0$ were used.

4. RESULTS ON K^* PRODUCTION

The $K^0\pi^+$ and $K^0\pi^-$ effective mass distributions are shown in figs 2(a) and 2(b). Signal of K_{892}^{*-} is clear in both distributions. We have then fitted the experimental distributions to the eq. (1) where the mass and the width of the resonance are taken from the PDG tables [30]. The result of the fits are also shown in figs 2(a) and 2(b).

The K_{1430}^{*-} signal is not clear at all. Fig. 2(c) shows the $K_S^0\pi^\pm$ mass distribution. We have made a fit to that distribution in the region above $1.1 \text{ GeV}/c^2$ where the effect from K_{892}^{*-} is already negligible. The result of the fit is shown in fig. 2(c).

4.1 Cross sections

The total number of K_S^{0*} events in the experiment correspond to $8.55 \pm 0.51 \text{ mb}$ [28]. The K_{892}^{*-} cross sections thus obtained are listed in table 1.

The energy dependence of K_{892}^{*-} cross sections is shown in fig. 3 [18,19,22,25]. The results from this experiment agree reasonably well with those obtained at other energies. At lower energies the K^{*-} cross section is significantly lower than the K^{*+} cross section. However this difference decreases with increasing energy.

It is interesting to compare our data with the predictions made by V. Anisovich and V. Shekhter [1] within the framework of the additive quark model. This model predicts the equality

$$\frac{K^{*+} + K^{*-}}{K^0 + \bar{K}^0} = \frac{K^{*+} + K^{*-}}{2K_S^0} = \frac{3 + 4\alpha_F}{4 + \lambda + 4\alpha_F}$$

where $\lambda = 1/3$ is the strange quark suppression factor. Here we take into account the proton fragmentation and assume that it is suppressed by a factor α_F with respect to the central production. The above ratio varies from 0.69 to 0.84 when α_F increases from 0. to 1.:

$$\frac{K^{*+} + K^{*-}}{2K_S^0} = 0.69 \div 0.84$$

From our data it is equal to 0.41 ± 0.07 . Similarly, [1] predicts

$$K^{*+}/K_S^0 = 0.69 \div 1.32$$

$$K^{*-}/K_S^0 = 0.69 \div 0.36$$

$$K^{*+}/K^{*-} = 1.0 \div 3.7.$$

In our data these ratios are found to be 0.52 ± 0.08 , 0.30 ± 0.08 and 1.74 ± 0.28 respectively. Hence we can conclude that asymptotic conditions assumed in [1] are not yet reached at our energy. The energy dependence of the ratios K^{*+}/K_S^0 and K^{*-}/K_S^0 are shown in fig. 4. The comparison with the data at other energies indicates that the first ratio seems to have a constant value of 0.47 ± 0.03 over the wide range of momentum from 12 to 405 GeV/c. The second ratio is increasing towards the same value.

The signal for $K^{*+}(1430)$ as mentioned earlier is rather poor; nevertheless, the fit to the mass distribution yields a cross section of (2.86 ± 0.78) mb (table 1). It may be mentioned that the $K^{*}(1430)$ cross section as measured in 405 GeV/c pp experiment [22], based on smaller statistics than ours, was found to be 3.4 ± 1.7 mb in the limited region of $|x_f| = (0.1-0.2)$.

Fig. 5 shows the cross sections for K^0 , $K^{*}(892)$ and $K^{*}(1430)$ as function of the mass. An exponential behaviour is seen. The value for the slope is found to be 2.06 ± 0.28 .

In the multiperipheral resonance production model by Fukugita et al. [31], the production ratios for pseudoscalar, vector and tensor mesons are $1. : 0.53 \div 0.62 : 0.13 \div 0.15$. These predictions are in fair agreement with our data: $1. : 0.41 \pm 0.07 : 0.17 \pm 0.04$.

4.2 x_F and p_T^2 dependence of K_{892}^{*}

The Feynman x_F distributions for K_{892}^{*+} are shown in fig. 6(a). The shape of the distributions is very similar for both K^{*+} and K^{*-} . They are both consistent with central production.

We have calculated the x_F distributions for $K_{892}^{*\pm}$ in the Lund fragmentation model [32] and the results are shown as smooth curves in fig. 6(a). The same distributions have been obtained in the quark fusion model of refs [10-12], where the structure functions for the valence and the sea quarks in proton are taken from the parametrisation given in ref. [33]. The results are given in fig. 6(b).

One can see that the experimental distributions are quite well reproduced by both models.

The p_T^2 distributions for $K_{892}^{*\pm}$ are shown in fig. 6(c). They show a sharp fall with increasing p_T^2 . A fit to the form

$$\frac{d\sigma}{dp_T^2} = A e^{-bp_T^2} \quad (4)$$

leads to values of $b = 3.0 \pm 0.6 \text{ (GeV/c)}^{-2}$ for K_{892}^{*+} and $b = 2.2 \pm 0.6 \text{ (GeV/c)}^{-2}$ for K_{892}^{*-} .

4.3 K_S^0 from K_{892}^{*} decays

From the estimated cross sections of K_{892}^{*} , we have evaluated the contribution of indirectly produced K_S^0 from $K_{892}^{*\pm}$ decays to be $2.32 \pm 0.37 \text{ mb}$. Thus $\sim 27\%$ of the K_S^0 are produced indirectly through $K_{892}^{*\pm}$ decays. If we assume the charge invariance in K^* production, i.e.,

$$\sigma(K^{*+}) + \sigma(K^{*-}) = \sigma(K^{*0}) + \sigma(\bar{K}^{*0}) \quad (5)$$

then we can conclude that $\approx 41\%$ of the K_S^0 's come indirectly through K_{892}^{*} decays. If we include $K^*(1430)$, this value becomes $\sim 54\%$.

Fig. 7(a) shows the x_F distribution of the K_S^0 's produced indirectly through K_{892}^{*} decays. For comparison the same figure also shows the x_F distribution of the total inclusive K_S^0 sample. The line shows the expectations from the Lund model [32]. The agreement is evident.

The p_T^2 distributions of the indirectly produced K_S^0 as well as the total inclusive sample are shown in fig. 7(b). No clear difference is observed. An exponential fit of the form (4) gives rise to a slope of

$b = 4.7 \pm 0.6 \text{ (GeV/c)}^{-2}$ for the indirectly produced K_s^0 sample. The total inclusive K_s^0 sample can be best fitted by a sum of two exponentials [28] with slopes $5.28 \pm 0.62 \text{ (GeV/c)}^{-2}$ and $3.69 \pm 0.84 \text{ (GeV/c)}^{-2}$.

5. RESULTS ON Σ^* PRODUCTION

The $\Lambda\pi^+$ and $\Lambda\pi^-$ mass distributions are shown in figs 8(a) and 8(b). Signal for Σ_{1385}^* is seen in both distributions.

In the $\Lambda\pi^\pm$ effective mass distribution (fig. 8(c)) one can also observe some enhancement in the mass region 1800-1950 MeV, suggesting the production of Σ_{1915}^* .

In order to extract the cross sections for these resonances, we have adopted the procedure outlined in sect. 3. For the fit, the mass and width of Σ^* 's have been kept fixed to the nominal values as given in ref. [30].

For the Σ_{1915}^* we have only used the mass distribution region starting at 1.6 GeV/c^2 .

The results of the fits are summarized in table 2 and shown in figs 8(a-c).

5.1 Cross sections

We have corrected the observed number of Σ^* events for Σ^* produced in the forward hemisphere. In case of Σ_{1385}^* we have also corrected for unobserved decay modes whereas for Σ_{1915}^* we have only calculated $\sigma \cdot \text{BR}(\Sigma \rightarrow \Lambda\pi)$ since the branching ratio for this resonance is not well known. The total number of Λ events in this experiment correspond to $4.08 \pm 0.40 \text{ mb}$ [28]. The resulting Σ^* cross sections are summarized in table 2.

The cross sections of Σ_{1385}^+ and Σ_{1385}^- have been plotted as a function of p_{lab} in fig. 9 [17,22,25]. It is seen that the cross section increases rather slowly with the increasing p_{lab} . The ratio $\Sigma_{1385}^\pm/\Lambda$ from this experiment is 0.23 ± 0.08 to be compared with the measurement of 0.15 ± 0.12 at 300 GeV/c [21].

5.2 x_F and p_T dependence of $\Sigma_{1385}^{\pm}$

The x_F dependence for $\Sigma_{1385}^{\pm}$ is shown in fig. 10(a). The smooth curves in the figure refer to the Lund model [32] predictions. The trend of the data is reasonably well explained by the model for the Σ_{1385}^- production. In the case of Σ_{1385}^+ a disagreement is observed for $|x_F| < 0.3$.

The same distributions are calculated on the basis of the quark-diquark fusion model [13] and displayed on fig. 10(b). The trend of the data is more or less explained by the model, although this time, there is a small disagreement both for Σ_{1385}^+ and Σ_{1385}^- in the same $|x_F| < 0.3$ region.

Fig. 10(c) shows the p_T^2 distribution for Σ_{1385}^* . Σ_{1385}^+ is well represented by an exponential distribution, eq. (4), with the slope $1.41 \pm 0.22 \text{ (GeV/c)}^{-2}$. The data for Σ_{1385}^- , comparatively poor, shows a slope of $0.54 \pm 0.40 \text{ (GeV/c)}^{-2}$.

5.3 Λ from Σ^* decays

Using the cross sections obtained for Σ^* production, see table 2, we estimate the fraction of indirectly produced Λ from Σ^* decay to be 0.28 ± 0.07 .

The x_F and p_T^2 distributions for the indirectly produced Λ from the decay of Σ_{1385}^* are shown in figs 11(a) and 11(b). On the same figures we have also shown the total inclusive distributions of Λ [28]. Within errors, the trends of the data for indirectly produced Λ and the total inclusive Λ have been found to be similar. The curve represents the expectation from the Lund model [32] that reveals again good agreement.

An exponential fit of the form (4) to the p_T^2 distribution of the indirectly produced Λ data gives rise to a slope of $b = 2.28 \pm 0.17 \text{ (GeV/c)}^{-2}$.

6. SUMMARY

In this paper we have studied the inclusive production of $K^{*\pm}$ and $\Sigma^{*\pm}$ resonances in 360 GeV/c pp interactions. The sensitivity of the present data sample corresponds to 1.6 events/ μ b. We have obtained the following results:

- Production cross sections for K_{892}^{*+} and K_{892}^{*-} are found to be 4.42 ± 0.62 mb and 2.54 ± 0.47 mb respectively. From a marginal signal of $K_{1430}^{*\pm}$ we have estimated a cross section of 2.86 ± 0.78 mb.
- Cross sections for Σ_{1385}^{+} and Σ_{1385}^{-} are 0.67 ± 0.11 mb and 0.26 ± 0.07 mb respectively. We have observed an enhancement in the $\Lambda\pi^{\pm}$ distribution around 1915 MeV which yields $\sigma \cdot \text{BR}(\Sigma \rightarrow \Lambda\pi) = 0.31 \pm 0.11$ mb.
- Inclusive spectra as a function of x_F and p_T^2 for $K_{892}^{*\pm}$ and $\Sigma_{1385}^{\pm}$ are presented. Trends of the x_F distributions for these resonances are reasonably represented by the Lund model.
- About 54% of the K^0 's arise as decay products of K^{*} resonances and $> 28\%$ of the Λ 's come from $\Sigma^{*\pm}$ decays. The x_F and p_T^2 distributions of the indirectly produced K_S^0 and Λ are not significantly different from the respective total inclusive distributions. The x_F shapes are well described by the Lund model.

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TABLE CAPTIONS

Table 1 Results from fits to $K_s^0 \pi$ distribution.

Table 2 Results from fits to $\Lambda \pi$ mass distributions.

TABLE 1

Resonance	$K^{*+}(892)$	$K^{*-}(892)$	$K^{*\pm}(1432)$
Number of weighted events	341 ± 46	194 ± 35	96 ± 26
Cross section (mb)	4.42 ± 0.62	2.54 ± 0.47	2.86 ± 0.78

TABLE 2

Resonance	$\Sigma^+(1385)$	$\Sigma^-(1385)$	$\Sigma^+(1915)$
Number of weighted events	151 ± 24	57 ± 16	79 ± 28
Cross section (mb)	0.67 ± 0.11	0.26 ± 0.07	$0.31 \pm 0.11^{(a)}$

(a) Here cross section refers to $\sigma \cdot \text{Br}(\Sigma \rightarrow \Lambda\pi)$.

FIGURE CAPTIONS

- Fig. 1 The error of effective mass determination as function of the $K_S^0 \pi^\pm$ and $\Lambda \pi^\pm$ effective mass
- Fig. 2 (a) Effective mass distribution of $K_S^0 \pi^+$ system. The solid curve is the result of the fit as given in eq. (1). The dashed curve represents the contribution of the background and the dash-dotted curve shows the contribution of the resonance.
- (b) Effective mass distribution of $K_S^0 \pi^-$ system. The curves are as in fig. 1(a).
- (c) Effective mass distribution of $(K_S^0 \pi^\pm)$. The curves are as in fig. 1(a).
- Fig. 3 Inclusive cross section of $K^{*+}(892)$ and $K^{*-}(892)$ as a function of incident laboratory momentum.
- Fig. 4 Laboratory momentum dependence of the production rates $K^{*+}(892)/K_S^0$ and $K^{*-}(892)/K_S^0$.
- Fig. 5 Particle cross section as function of the mass. The line represents a fit to the form $e^{-2.06M_R}$.
- Fig. 6 (a) x_F distribution for $K^{*+}(892)$ and $K^{*-}(892)$. The smooth curves are the predictions of the Lund model.
- (b) x_F distribution for $K^{*+}(892)$ and $K^{*-}(892)$. The smooth curves are the predictions of fusion model.
- (c) p_T^2 distribution for $K^{*+}(892)$ and $K^{*-}(892)$. The solid and dashed lines are exponential fits to the data.
- Fig. 7 (a) x_F distribution of the indirectly produced K_S^0 from K_{892}^{*} decays. On the same plot a similar distribution of total inclusive K_S^0 sample is shown. The curve is the prediction from the Lund model.
- (b) p_T^2 distribution of the indirectly produced K_S^0 from K_{892}^{*} decays together with similar distribution of total inclusive K_S^0 sample. The solid line is the result from an exponential fit to the indirectly produced K_S^0 data.

FIGURE CAPTIONS (Cont'd)

Fig. 8 (a) Effective mass distribution of $\Lambda\pi^+$ system. The solid curve is the result of the fits, eq. (1). The dashed and dash-dotted curves represent contributions from the background and the resonance respectively.

(b) Effective mass distribution of $\Lambda\pi^-$ system. The curves are as in fig. 8(a).

(c) Effective mass distribution of $\Lambda\pi^0$ system. The curves are as in fig. 8(a).

Fig. 9 Combined cross section of $\Sigma^+(1385)$ and $\Sigma^-(1395)$ as a function of incident laboratory momentum.

Fig. 10 (a) x_F distributions for $\Sigma^+(1385)$ and $\Sigma^-(1385)$. The smooth curves are the predictions of the Lund model.

(b) x_F distributions for $\Sigma^+(1385)$ and $\Sigma^-(1385)$. The smooth curves are the predictions of quark-diquark fusion model.

(c) p_T^2 distribution for $\Sigma^+(1385)$ and $\Sigma^-(1385)$. The solid and dashed lines are fits to the Σ_{1385}^+ and Σ_{1385}^- data using an exponential parametrization.

Fig. 11 (a) x_F distributions of the indirectly produced Λ and total inclusive Λ sample. The curve represents the Lund model expectations.

(b) p_T^2 distributions of the indirectly produced Λ and total inclusive Λ sample. The solid line is the result from an exponential fit to the indirectly produced Λ data.

Fig. 1

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 3

Fig. 4

Fig. 5

Fig. 6a

Fig. 6b

Fig. 6 c

Fig. 7a

Fig. 7b

Fig. 8a

Fig. 8b

Fig. 8c

Fig. 9

Fig. 10 a

Fig. 10 b

Fig. 10 c

Fig. 11 a

Fig. 11b