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Observation of a resonance in the $K_S p$ decay channel at a mass of 1765 MeV/c^2

WA89 Collaboration

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Abstract. We report on the observation of a $K_S p$ resonance signal at a mass of 1765±5 MeV/c^2, with intrinsic width $\Gamma = 108 \pm 22$ MeV/c^2, produced inclusively in Σ^--nucleus interactions at 340 GeV/c in the hyperon beam experiment WA89 at CERN. The signal was observed in the kinematic region $x_F > 0.7$, in this region its production cross section rises approximately linearly with $(1 - x_F)$, reaching $BR(X \to K_S p) \cdot d\sigma/dx_F = (5.2 \pm 2.3)\,\mu b$ per nucleon at $x_F = 0.8$. The hard x_F spectrum suggests the presence of a strong leading particle effect in the production and hence the identification as a Σ^{*+} state. No corresponding peaks were observed in the $K^- p$ and $\Lambda\pi^\pm$ mass spectra.

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1 Introduction

Baryon spectroscopy has seen great progress in the charmed baryon sector during the last years, but almost nothing

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has happened in the non-strange and strange baryon sectors since about 1990 (see, for instance, the review articles in the Review of Particle Physics [1]). In the strange baryon sector, the review lists 13 Λ^*, 9 Σ^* and 5 Ξ^* resonances classified as "established" (3 or 4 stars).

In particular in the Σ^* sector, almost all known states above the $\Sigma(1385)$ have been observed through partial wave analyses only, with often widely varying estimates of the masses and widths of the observed resonances. So far, there has been only one observation of a Σ^* above the $\Sigma(1385)$ in an invariant mass spectrum: we have observed a wide peak at 1660 MeV/c^2 in the mass spectra of $\Lambda\pi^-$ pairs and, less prominently, $\Lambda\pi^+$ pairs. These pairs were produced inclusively in a copper/carbon target by a Σ^- beam of 340 GeV/c momentum [2].

We have also undertaken a high-statistics search for the pentaquark candidate $\Theta^+(1540)$ in the $K_S p$ decay channel [3]. While no resonance signal was seen in the $K_S p$ mass spectrum around 1540 MeV/c^2, we observed a $K_S p$ resonance signal at 1765 MeV/c^2, which is the topic of this publication.

2 Event Selection

The hyperon beam experiment WA89 at CERN ran from 1990 to 1994 in the West Hall. The results presented here are based on the data collected in the years 1993 and 1994. Details on the hyperon beam and the experimental apparatus can be found in [4–6].

The events were selected as described in detail in our previous search for the $\Theta^+(1540)$ pentaquark [3]. K_S were reconstructed in the decay $K^0_S \to \pi^+\pi^-$, using all pairs of positive and negative particles which formed a decay vertex in the decay zone. The contamination caused by $\Lambda \to p\pi^-$ decays was reduced by excluding candidates with a reconstructed $p\pi^-$ mass within $\pm 2\,\sigma_m(\Lambda)$ of the Λ mass ($\sigma_m(\Lambda)$ was 1.8 MeV/c^2 at low momenta and 2.8 MeV/c^2 at 200 GeV/c). This requirement reduced the K_S signal by 3% and the background by 1/3 to less than 1%.

The reconstructed $\pi^+\pi^-$ mass distribution of the remaining K_S candidates is shown in fig. 1. The peak from K_S decays contains about 13 million events, their momentum spectrum extends from 10 GeV/c to about 200 GeV/c. Candidates with a reconstructed $\pi^+\pi^-$ mass within $\pm 2\,\sigma_m$ of the K_S mass were retained for further analysis.

Proton candidates were selected from all additional positive particles with a reconstructed track extending from the microstrip counters downstream of the target to the wire chambers beyond the spectrometer. Requiring track reconstruction in the microstrip counters rejected most of the protons from Λ decays. The RICH counter was used to purify the proton candidate sample. We required the proton momentum to be $p_p > 45$ GeV/c, well above the proton threshold of the RICH at 38 GeV/c [3].

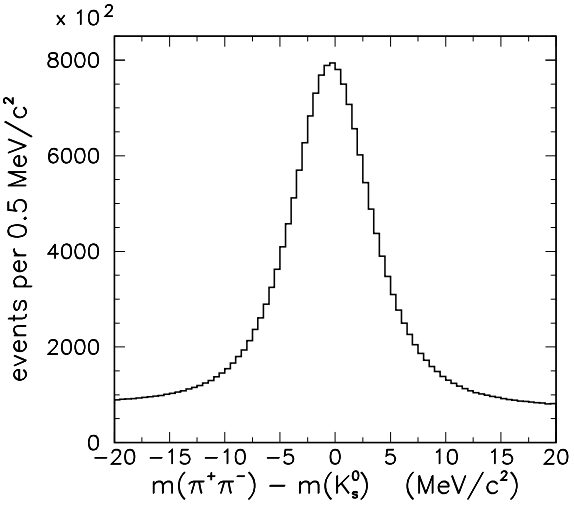

Fig. 1. Reconstructed $\pi^+\pi^-$ mass distribution of the K_S candidates

3 Results

Even without using proton identification by the RICH, we noted a clear $K_S p$ mass peak at large values of Feynman–x. Fig. 2a shows the $K_S p$ mass spectrum for $x_F > 0.8$. In Fig. 2b we show the mass spectrum after application of the RICH-cut for proton identification (see above). The peak again is clearly visible, with approximately equal statistics, while the background is reduced by 25%. This proves the identification as a $K_S p$ resonance signal. The signal still appears as a less significant shoulder in the region $0.7 < x_F < 0.8$, with comparable statistics, as shown in fig. 2c. At $x_F < 0.7$, the signal disappears in the rapidly increasing background.

The distributions were fitted by the sum of a S-wave Breit-Wigner function for the signal and a function $f(m) = C \cdot (m - m_0)^a \cdot e^{-(m-m_0)/b}$ for the background, where m_0 is the $K_S p$ threshold and C, a and b are fit parameters. The solid lines show the fit result for signal plus background and the dashed lines show the background. In the region $x_F > 0.8$, the resonance contains N = 1380 ± 260 events, where the error includes the errors from the choice of background parametrization and fit window. The mass of the resonance is $m = 1765 \pm 5$ MeV/c^2 and its width is $\Gamma = 108 \pm 22$ MeV/c^2. The fit has $\chi^2/NDF = 106/89$. Fitting the distribution to the background function $f(m)$ only, we obtained $\chi^2/NDF = 226/92$. For $0.7 < x_F < 0.8$, we obtained N = 1560 ± 340 events and values of m and Γ compatible with those for $x_F > 0.8$. Replacing $f(m)$ in the fit with the observed shape of the $K_S p$ mass distribution of "mixed" events, leaving only the background normalization as a fit parameter, we found, for $x_F > 0.8$, an increase of the number of events by 8%, well within the errors from the fit using $f(m)$.

The production cross section per nucleon was calculated assuming its dependence on the mass number A of the target nucleus to be $\sigma(A) \propto A^{2/3}$. The result is $BR(X \to K_S p) \cdot d\sigma/dx_F = (5.2 \pm 2.3)\,\mu b$ *per nucleon*, at x_F=0.8. The error on the cross section includes the un-

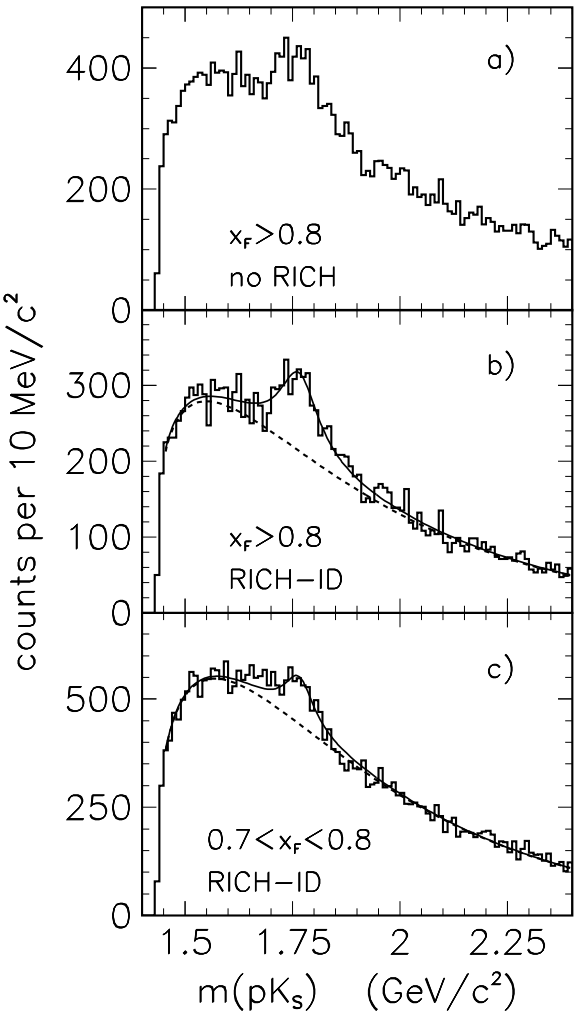

Fig. 2. K_Sp invariant masses at high x_F. Proton identification was required for b) and c).

certainties of the trigger efficiency for this decay mode. The x_F dependence can be parametrized as $d\sigma/dx_F \propto (1-x_F)^n$, with $n = 1.0 \pm 0.5$.

We have searched for an isospin partner of this resonance in the K^-p decay channel. Candidates for this decay had to have a K^- and a proton candidate with their resp. tracks emerging from the target and with RICH identification. For the proton candidates we used the same momentum and RICH cuts as those used for the K_Sp sample. For the K^- we used analogous cuts, $p_K > 25$ GeV/c and a RICH-cut with the same efficiency. The resulting K^-p mass spectra are shown in fig. 3. They are dominated by the $\Lambda(1520)$ peak. Less significant structures are visible around 1650 and 1800 MeV. These structures have also been observed by the SPHINX collaboration [7] and can be attributed to known Λ^* or Σ^* resonances [1]. No evidence for a resonance around 1765 MeV/c is visible, also not at lower x_F. Upper limits for the cross section were calculated treating the mass and width of the resonance with their experimental errors as nuisance parameters (see e.g. [8]). We obtained a limit of

$$\sigma \cdot BR(K^-p)/\sigma \cdot BR(K_Sp) < 0.6\,(95\%\,CL).$$

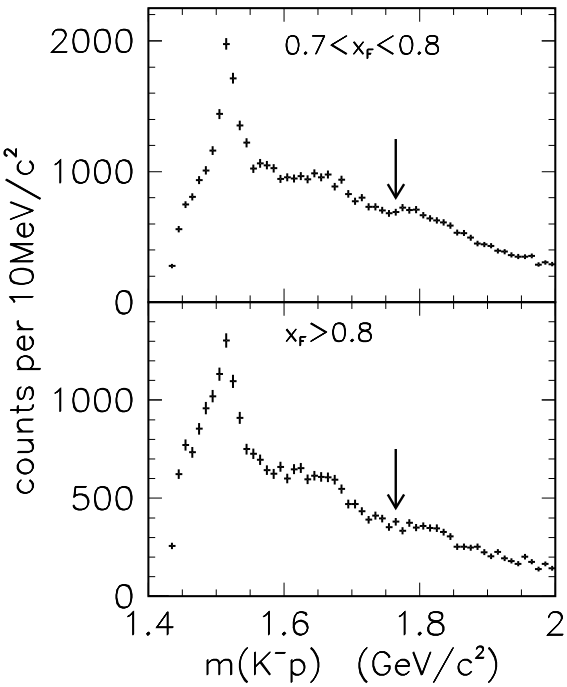

Fig. 3. K^-p invariant masses at high x_F. The arrows indicate the position of the K_Sp peak.

We have also searched for this resonance and a possible isospin partner in the $\Lambda\pi^\pm$ decay channels. Candidates for $\Lambda \to p\pi^-$ decays were selected with criteria analogous to those used in the selection of $K_S \to \pi^+\pi^-$ candidates. All additional charged particles emerging from the target with a reconstructed track in the microstrip counters were considered as pion candidates. Since this sample contained a large fraction of low-momentum pions, a cut $\cos\vartheta^*(\pi) > -0.8$ was applied, which rejected about 50% of the $\Lambda\pi^+$ and 25% of the $\Lambda\pi^-$ candidates at $x_F > 0.7$ and $1700 < m(\Lambda\pi) < 1820$ MeV/c^2. The resulting samples are shown in fig. 4. Again, no evidence for a resonance around 1765 MeV/c^2 is visible, also not at lower x_F. The following upper limits were obtained:

$$BR(\Lambda\pi^+)/BR(K_Sp) < 1.8\,(95\%\,CL),$$
$$\sigma \cdot BR(\Lambda\pi^-)/\sigma \cdot BR(K_Sp) < 3.4\,(95\%\,CL).$$

4 Discussion

The strangeness of the observed resonance could be S=+1 or S=–1. In the first case, this would be an exotic state like the pentaquark candidate $\Theta^+(1540)$. The assignment S=–1 leads to the more likely interpretation as a Σ^{*+}, which we will discuss further.

In table 1 we list the differential cross sections *per nucleon* at $x_F = 0.75$ for production of $\Sigma^\pm$ and $\Sigma^{*\pm}$ measured in our experiment [2]. The x_F-dependence of the

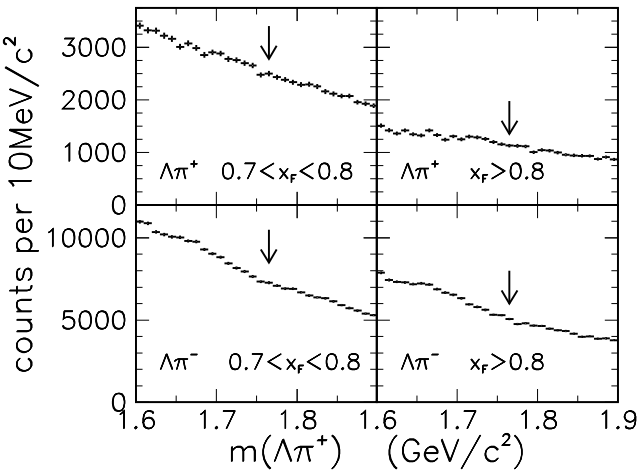

Fig. 4. $\Lambda\pi$ invariant masses at high x_F. The arrows indicate the position of the K_Sp peak.

$\Sigma^+(1765)$ production cross section is very similar to that of the Σ^+ and $\Sigma^+(1385)$ production. This fact suggests that also in $\Sigma^+(1765)$ production at high x_F, a strange quark is transferred from the beam projectile to the outgoing hyperon, which supports the S=–1 assignment to this state. (For a detailed discussion of the "leading particle effect" in hadronic hyperon production, see ref. [2]).

	$d\sigma/dx_F$	$BR \cdot d\sigma/dx_F$	
	$[\mu b]$		n
Σ^+	850±200		1.7±0.2
Σ^-	15500±1500		-0.2±0.2
$\Sigma^+(1385)$	600±100		1.0±0.2
$\Sigma^-(1385)$	1500±200		0.5±0.1
$\Sigma^+(1660) \to \Lambda\pi^+$		100±50	4±1
$\Sigma^-(1660) \to \Lambda\pi^-$		550±100	0.5±0.1
$\Sigma^+(1765) \to K_Sp$		6±3	1.0±0.5
$\Sigma^0(1765) \to K^-p$		< 3.5	
$\Sigma^+(1765) \to \Lambda\pi^+$		< 11	
$\Sigma^-(1765) \to \Lambda\pi^-$		< 20	

Table 1. Σ and Σ^* production cross sections at $x_F = 0.75$, measured in WA89. $d\sigma/dx_F$ is per nucleon and is parametrized as $d\sigma/dx_F \propto (1 - x_F)^n$.

Numerous candidates for Σ^* states have been found in PWA analyses [1]. There are two known states in the region of 1765 MeV/c^2, which are shown in table 2. The parameters of our observed signal are compatible with either state, so it could well be one of both or a combination of them. Our limit on the $\Lambda\pi^+$ decay mode is too high to enable a separation of the two states.

So far, no Σ^* resonance above the $\Sigma(1385)$ has been observed directly in a mass plot with the exception of the $\Lambda\pi^\pm$ resonances observed at lower x_F in our experiment at around 1660 MeV/c^2 [2]. This $\Lambda\pi^-$ resonance is visible even at $x_F > 0.8$, as shown on the bottom right of fig. 4.

	$\Sigma(1750)\ S_{11}$	$\Sigma(1775)\ D_{15}$
status	***	****
mass (MeV/c^2)	1760±10	1775±10
width Γ (MeV/c^2)	60 - 160	135±20
BR(NK)	0.1 - 0.4	0.40±0.03
BR($\Lambda\pi$)	seen	0.17±0.03

Table 2. The basic data of the $\Sigma(1750)$ and $\Sigma(1775)$ from the Particle Data Group [1].

From the data on $\Sigma^\pm(1385)$ and $\Sigma^\pm(1660)$ production, which exhibit a strong leading particle effect [2], we would expect the production cross section for $\Sigma^-(1765)$ to be three to five times larger than for $\Sigma^+(1765)$. $\Sigma^0(1765)$ production then would probably also be enhanced w.r.t. $\Sigma^+(1765)$ production. In the relevant kinematic range the acceptance for $\Sigma(1765) \to \Lambda\pi$ is about a factor 0.65 lower than for $\Sigma(1765) \to K_Sp$. This difference is mainly due to the different decay lengths of Λ and K_S and to the fact that the Λ momenta resulting from the $\Lambda\pi$ decays are larger than the K_S momenta from the K_Sp decays. Thus the missing peak in the $\Lambda\pi$ channel can not be attributed to a very different acceptance. However, since the branching ratios to the various decay modes of the Σ^* isospin triplet are poorly known, our limits on the K^-p and $\Lambda\pi^\pm$ decays (Tab. 1) cannot be translated into cross section limits significant enough for a statement on the leading particle effect.

To summarize: We have observed a K_Sp resonance signal at 1765±5 MeV/c^2, with an intrinsic width Γ = 108±22 MeV/c^2. The x_F-dependence of the production cross section favors the assignment of S=–1 to the resonance. Therefore the most likely interpretation is that it is one or both of two Σ^* resonances of similar mass and width, which are known from PWA. We have not found this resonance or its possible isospin partners in the K^-p and $\Lambda\pi^\pm$ decay channels, but the poor knowledge of the branching ratios involved prevents any further conclusions about the nature of this resonance.

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