Observation of a resonance in the $K_{sp}$ decay channel at a mass of 1765 MeV/c$^2$

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Received: 10.12.2000

Abstract. We report on the observation of a $K_{sp}$ resonance signal at a mass of 1765±5 MeV/c$^2$, with intrinsic width $\Gamma = 108 \pm 22$ MeV/c$^2$, produced inclusively in $\Sigma^-$-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 $BR(X \rightarrow K_{sp}) \cdot d\sigma/dx_F = (5.2 \pm 2.3)$ μb 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 $\Sigma^{*+}$ state. No corresponding peaks were observed in the $K^-p$ and $\Lambda p$ mass spectra.


1 Introduction

Baryon spectroscopy has seen great progress in the charmed baryon sector during the last years, but almost nothing
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 $Σ(1385)$ 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 $Σ(1385)$ in an invariant mass spectrum: we have observed a wide peak at 1660 MeV/c$^2$ in the mass spectra of $Λπ^−$ pairs and, less prominently, $Λπ^+$ 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 $Θ^*(1540)$ in the $K_S^p$ decay channel [3]. While no resonance signal was seen in the $K^+$ mass spectrum around 1540 MeV/c$^2$, we observed a $K^0_S$ 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 $Θ^*(1540)$ pentaquark [3]. $K_S^0$ were reconstructed in the decay $K^0_S → π^+π^−$, using all pairs of positive and negative particles which formed a decay vertex in the decay zone. The contamination caused by $Λ → pπ^−$ decays was reduced by excluding candidates with a reconstructed $pπ^−$ mass within $±2\sigma_m(Λ)$ of the $Λ$ mass ($σ_m(Λ)$ was 1.8 MeV/c$^2$ at low momenta and 2.8 MeV/c$^2$ at 200 GeV/c). This requirement reduced the $K_S^0$ signal by 3% and the background by 1/3 to less than 1%.

The reconstructed $π^+π^−$ mass distribution of the remaining $K_S^0$ candidates is shown in fig. 1. The peak from $K_S^0$ decays contains about 13 million events, their momentum spectrum extends from 10 GeV/c to about 200 GeV/c. Candidates with a reconstructed $π^+π^−$ mass within $±2\sigma_m(Λ)$ of the $K_S^0$ 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].
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 $K^0_Sp$ 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 $\Lambda^*$ or $\Sigma^*$ resonances [1]. No evidence for a resonance around 1765 MeV/c² is visible, also not at lower $x_F$. The following upper limits were obtained:

- $\text{BR}(\Lambda^+) / \text{BR}(K^0_Sp) < 1.8 (95\% CL)$,
- $\sigma \cdot \text{BR}(\Lambda^+) / \sigma \cdot \text{BR}(K^0_Sp) < 3.4 (95\% CL)$.

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 $\Sigma^{*+}$, which we will discuss further.

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

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

<table>
<thead>
<tr>
<th>$\Sigma^+$</th>
<th>$d\sigma/dx_F$ [nb]</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma^+$</td>
<td>850±200</td>
<td>1.7±0.2</td>
</tr>
<tr>
<td>$\Sigma^-$</td>
<td>15500±1500</td>
<td>-0.2±0.2</td>
</tr>
<tr>
<td>$\Sigma^+$(1385)</td>
<td>600±100</td>
<td>1.0±0.2</td>
</tr>
<tr>
<td>$\Sigma^+$(1385)</td>
<td>1500±200</td>
<td>0.5±0.1</td>
</tr>
<tr>
<td>$\Sigma^+$(1660) $\rightarrow \Lambda\pi^+$</td>
<td>100±50</td>
<td>4±1</td>
</tr>
<tr>
<td>$\Sigma^+$(1660) $\rightarrow \Lambda\pi^-$</td>
<td>550±100</td>
<td>0.5±0.1</td>
</tr>
<tr>
<td>$\Sigma^+$(1765) $\rightarrow K\pi^+$</td>
<td>6±3</td>
<td>1.0±0.5</td>
</tr>
<tr>
<td>$\Sigma^+$(1765) $\rightarrow K^-p$</td>
<td>&lt; 3.5</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^+$(1765) $\rightarrow \Lambda\pi^+$</td>
<td>&lt; 11</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^+$(1765) $\rightarrow \Lambda\pi^-$</td>
<td>&lt; 20</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>$\Sigma(1750)$</th>
<th>$\Sigma(1775)$</th>
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<tbody>
<tr>
<td>$S_{11}$</td>
<td>$D_{12}$</td>
</tr>
<tr>
<td>mass (MeV/$c^2$)</td>
<td>1760±10</td>
</tr>
<tr>
<td>width $\Gamma$ (MeV/$c^2$)</td>
<td>60 - 160</td>
</tr>
<tr>
<td>BR($NK$)</td>
<td>0.1 - 0.4</td>
</tr>
<tr>
<td>BR($A\pi$)</td>
<td>seen</td>
</tr>
</tbody>
</table>

From the data on $\Sigma^+$(1385) and $\Sigma^+$(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) $\Sigma^+$(1665) production then would probably also be enhanced w.r.t. $\Sigma^+$(1765) production. In the relevant kinematic range the acceptance for $\Sigma(1765) \rightarrow \Lambda\pi$ is about a factor 0.65 lower than for $\Sigma(1765) \rightarrow K\pi$. This difference is mainly due to the different decay lengths of $\Lambda$ and $K_S$ and to the fact that the $\Lambda$ momenta resulting from the $\Lambda\pi$ decays are larger than the $K_S$ momenta from the $K\pi$ 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 $\Sigma^*$ isospin triplet are poorly known, our limits on the $K^-p$ and $\Lambda\pi^\pm$ decays (Tab. 2) cannot be translated into cross section limits significant enough for a statement on the leading particle effect.

To summarize: We have observed a $K\pi$ resonance signal at 1765±5 MeV/$c^2$, with an intrinsic width $\Gamma = 108±22$ 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 $\Sigma^*$ 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.

### Acknowledgements

We are indebted to J. Zimmer and the late Z. Kenesei for their help during all moments of detector construction and setup. We are grateful to the staff of CERN’s EBS group for providing an excellent hyperon beam channel, to the staff of CERN’s Omega group for their help in running the $\Omega$-spectrometer. We thank S.U. Chung for valuable discussions.

### References

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