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HYPERON PRODUCTION IN PROTON–PROTON COLLISIONS WITH ANKE AT COSY* **

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The reaction $pp \to pK^+Y$ has been studied with the ANKE spectrometer at COSY-Jülich in order to investigate heavy hyperon production. The missing mass spectra MM(pK^+) have been analyzed and compared with Monte Carlo simulations. Indications for a hyperon resonance $Y^{0*}(1480)$ have been found.

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1. Introduction

The production and properties of hyperons have been studied for more than 50 years, mostly in pion and kaon induced reactions. Hyperon production in pp collisions has been investigated close to threshold at SATURNE (Saclay, France) [1] and COSY-Jülich [2–8]. Reasonably complete information on $\Lambda(1116)$, $\Sigma^0(1192)$, $\Sigma^0(1385)$, $\Lambda(1405)$ and $\Lambda(1520)$ can be found in the Review of Particle Physics [9].

For the $\Lambda(1405)$, in spite of rather high statistics achieved (the total world statistics is several thousand events), there are still open questions concerning the nature of this resonance: is it a singlet qqq state in the frame of SU(3) or a quark–gluon *(uds-q)* hybrid, or a KN bound state? [10–20].

In contrast, the $\Sigma(1480)$ hyperon is not well established yet. In the 2004 Review of Particle Physics [9] it is described as a 'bump' with unknown quantum numbers. Only recently the ZEUS Collaboration has reported [21]

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an indication for a structure in the invariant mass spectrum for $K^0_{\rm s}p$ and $K^0_{\rm s}\bar{p}$ which may correspond to $\Sigma(1480)$ but this structure appears on a steeply falling background, so its significance is difficult to estimate. The Crystal Ball has not seen any indications for the resonance $\Sigma(1480)$ in the $\pi^0\Lambda$ invariant mass distribution measured in the reaction $K^-p \to \pi^0\pi^0\Lambda$ which is dominated by the $\Sigma(1385)$ [22–24].

In Table I a summary of some properties of selected strange baryons is presented.

TABLE I

Properties of strange baryons. *Values with errors from Ref. [9].*

	mass (MeV/c^2)	full width (MeV/c^2)	mean life (s)	status
$\Lambda(1116)$	*1115.683±0.006*	2.501×10^{-12}	*(2.632±0.020)*$\times10^{-10}$	****
$\Sigma(1192)$	*1192.642±0.024*	0.008895	*(7.4±0.7)*$\times10^{-20}$	****
$\Sigma(1385)$	*1383.7±1.0*	*36±5*	1.8×10^{-23}	****
$\Lambda(1405)$	*1406±4*	*50±2*	1.3×10^{-23}	****
$\Sigma(1480)$	1480	*45*	1.5×10^{-23}	*
$\Lambda(1520)$	*1519.5±1.0*	*15.6±1.0*	4.2×10^{-23}	****

Because of this unclear situation we have started to investigate whether additional information on hyperon production might be obtained from proton–proton interactions at low energies. Such an experimental program is very well suited for the ANKE spectrometer operated at COSY–Jülich.

2. Experiment

The experiment has been performed at the COoler SYnchrotron COSY at the Research Center Jülich (Germany) [25].

COSY is a medium energy cooler synchrotron and storage ring for both polarized and unpolarized protons and deuterons. At COSY various targets can be used, *e.g.* solid or cluster-jet. COSY provides proton beams in the momentum range between 0.6 and 3.7 GeV/c (corresponding to energy between 0.175 and 2.880 GeV), available for experiments with the circulating beam (internal) as well as for experiments with the extracted beam (external), see Fig. 1.

ANKE (**A**pparatus for Studies of **N**ucleon and **K**aon **E**jectiles) is a magnetic spectrometer located at an internal target position of COSY [26]. It consists of three dipole magnets, see Fig. 2. The central C-shaped spectrometer dipole D2, placed downstream of the target, separates the reaction products from the circulating COSY beam. The ANKE detection system, comprising range telescopes, scintillation counters and multi-wire proportional

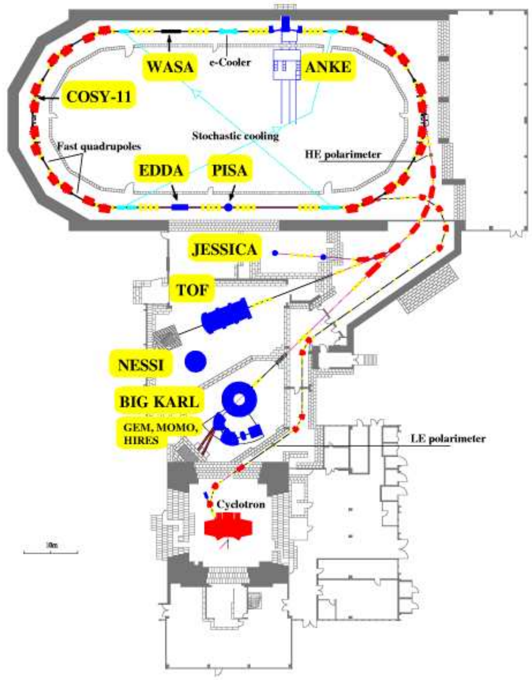

Fig. 1. COolerSYnchrotron at the Research Center Jülich.

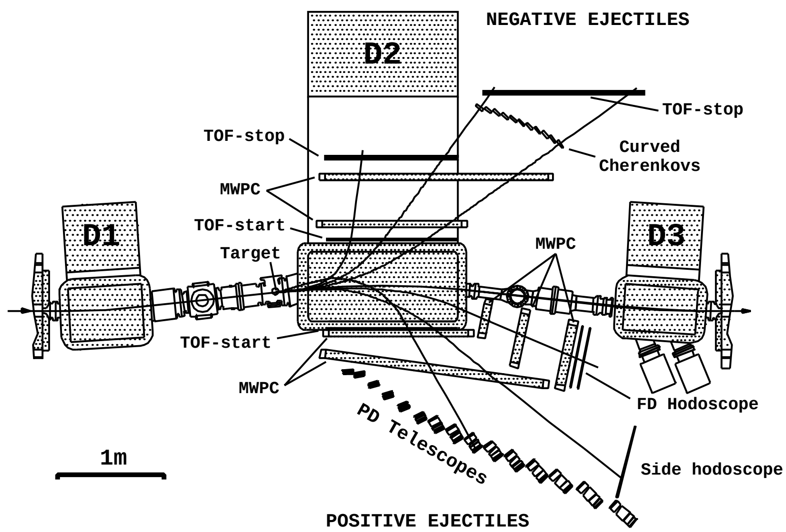

Fig. 2. ANKE spectrometer and detectors.

chambers, simultaneously registers both positively and negatively charged particles and measures their momenta [27].

Positively charged kaons and pions are measured with momenta between 0.2 and 0.9 GeV/c, negatively charged pions between 0.4 and 1.0 GeV/c, and protons from 0.75 GeV/c up to the kinematical limit. The angular acceptance of D2 is $|\vartheta_{\rm H}|\lesssim 12°$ horizontally and $|\vartheta_{\rm V}|\lesssim 5°$ vertically for any ejectile.

In our experiment we have investigated the reaction $pp \to pK^+Y$. The measurements were performed at a proton beam momentum of 3.65 GeV/c incident on a hydrogen cluster-jet target. The average luminosity during the measurements was $L = (1.38 \pm 0.15) \times 10^{31}\,{\rm s}^{-1}\,{\rm cm}^{-2}$. At a COSY beam momentum of 3.65 GeV/c neutral hyperons Y with masses up to ∼1540 MeV/c^2 can be produced in the reaction $pp \to pK^+Y$.

3. Particle identification with ANKE

The ANKE PD telescopes are used to register positively charged particles. They discriminate pions, kaons and protons with the same momenta due to their different energy losses [27]. Passive copper degraders in the telescopes between the scintillation counters enhance the discrimination efficiency. The K^+ mesons are stopped in the ΔE counters or in the second degrader of each telescope, see Fig. 3. Their decay, mainly into $\mu^+\nu_\mu$ and $\pi^+\pi^0$ with a lifetime of $\tau = 12.4$ ns, provides a very effective criterion for

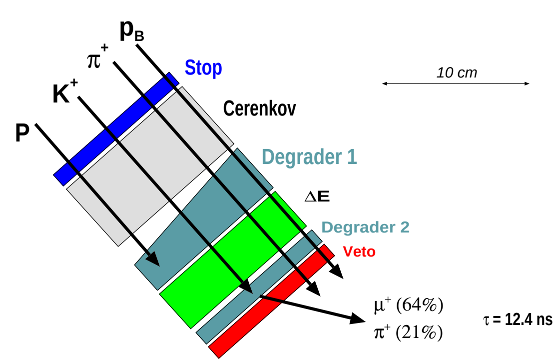

Fig. 3. A schematic top view of one telescope. It is composed of a stop, Cerenkov, ΔE and veto scintillator and two degraders. The degraders are designed to stop protons in the first and kaons in the second one. Kaon decay products are registered in the veto counters with characteristic delay time. The ranges of pions, kaons and protons originating from the target and scattered protons (p_B) with the same time-of-flight as kaons are indicated.

kaon identification via detection of delayed signals in a so-called veto counter (with respect to prompt signals from *e.g.* a π^+ produced in the target passing over all counters of a telescope). By measuring such delayed signals from decay of stopped kaons, positively charged kaons can be identified at ANKE in a background of pions, protons and scattered particles up to 10^6 times more intense [28]. The measured lifetime for K^+ mesons is plotted in Fig. 4, left part. On the right part of Fig. 4, the distributions before and after applying different criteria for a particle selection are shown.

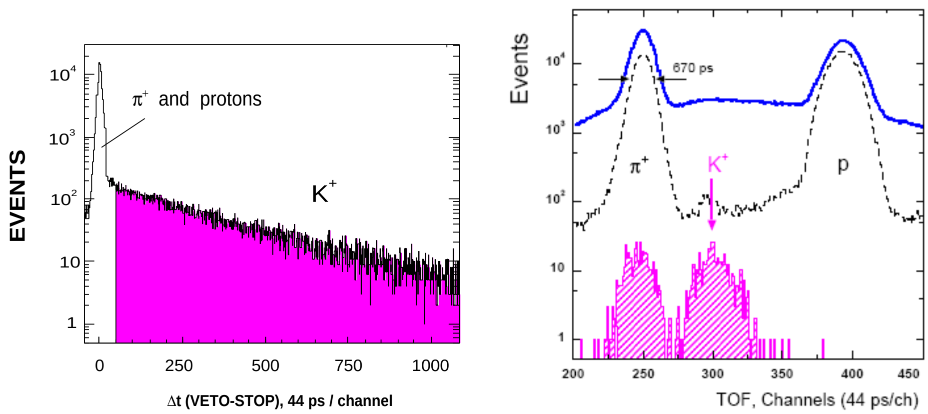

Fig. 4. Left: Time difference between detection of particles in veto and stop counters; the prompt peak is caused by minimum ionising particles (pions, scattered protons). Kaons are decaying with a lifetime of τ=12.4 ns. The criterion for K^+ identification is indicated by the shaded area. Right: The TOF distribution between the start and stop counters. The solid line indicates a raw distribution without any selection criteria, the dashed line shows events after selecting particles from the target, while the shaded histogram are pion and kaon events which are inside gates on the energy losses in the stop and ΔE counters. For the final K^+ identification the combined information from the left and right spectra are used.

In Fig. 5 an example of identification of forward going particles, measured in coincidences with the K^+ mesons, is presented. A clean proton band in the distribution of the time-of-flight versus momenta of forward going particles is seen.

The tracks of the ejectiles, measured with multi-wire proportional chambers (MWPCs), are used to reconstruct momenta of any registered particle.

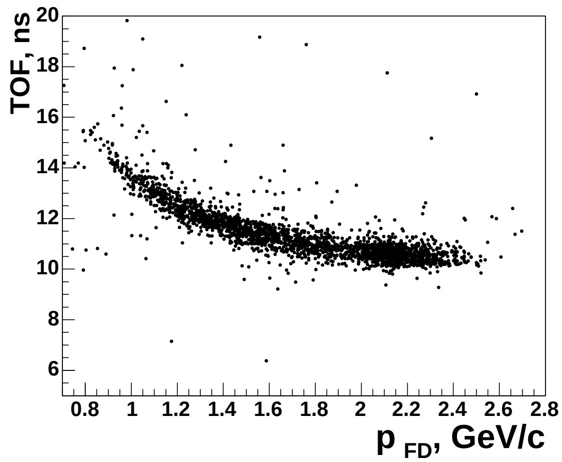

Fig. 5. Time of flight for fast forward-going particles as a function of their momenta in the reaction $pp \to pK^+\pi^-X^+$. A clean proton band is seen.

4. Missing mass technique

The missing mass $\mathrm{MM}(pK^+)$ spectrum measured in the reaction 3.65 GeV/c $pp \to pK^+Y$ is shown in Fig. 6 for the case that a K^+ meson in coincidence with a proton is detected with ANKE [29]. While the ground-state hyperons are clearly seen in the spectrum, the heavier ones are on top of a broad background which can mainly be attributed to the production of additional pions. Thus the unambiguous identification of these hyperons requires the detection of additional coincident particles from their decays.

A final state comprising a proton, a positively charged kaon, a pion of either charge and an unidentified residue X was investigated in the reaction $pp \to pK^+Y \to pK^+\pi^\pm X^\mp$. Kaons from a clean sample, combined with well-defined pions and protons, are used to determine the mass of X.

A missing mass $\mathrm{MM}(pK^+\pi^+)$ spectrum in the reaction $pp \to pK^+\pi^+X^-$ shows a rather flat distribution with a peak at approximately 1195 MeV/c^2 (left part in Fig. 7). This peak corresponds to the decay $Y \to \pi^+\Sigma^-(1197)$. In the charge-mirrored $pp \to pK^+\pi^-X^+$ case, the π^- may originate from different sources, *e.g.* a decay with the $\Sigma^+(1189)$ or a secondary decay of $\Lambda \to p\pi^-$, arising from the major background reaction $pp \to pK^+\Lambda \to pK^+\pi^-p$. Protons from this reaction are easily rejected by cutting the miss-

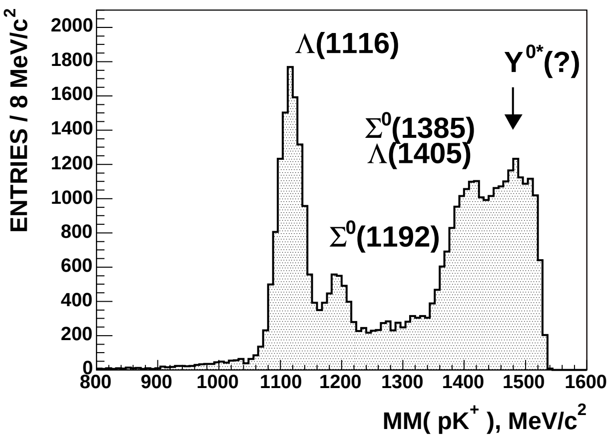

Fig. 6. Missing mass MM(pK^+) distribution measured in the reaction 3.65 GeV/c $pp \to pK^+Y$ with known neutral hyperons.

ing mass MM($pK^+\pi^-$) around the proton mass (right part in Fig. 7). Nevertheless the missing mass distribution for the (π^-X^+)-final state is more complicated.

If only events around the Σ mass are selected, then the missing mass spectrum MM(pK^+) in the reaction $pp \to pK^+\pi^+X^-$ shows two peaks, see left part in Fig. 8. One of them corresponds to the contribution of $\Sigma^0(1385)$ and $\Lambda(1405)$ hyperons. The second peak is located at a mass ~1480 MeV/c^2.

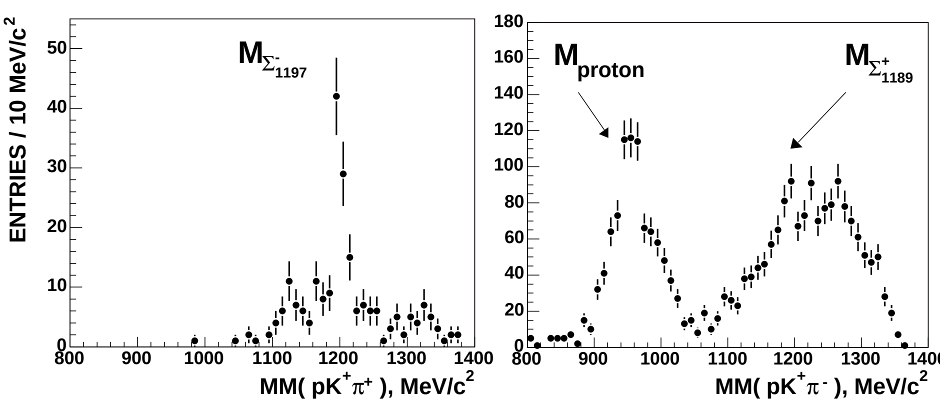

Fig. 7. Missing mass spectra MM($pK^+\pi$) for the reaction $pp \to pK^+\pi^+X^-$(left) and $pp \to pK^+\pi^-X^+$(right).

In the $\pi^- X^+$ case, the distribution also peaks at 1480 MeV$/c^2$, see right part in Fig. 8.

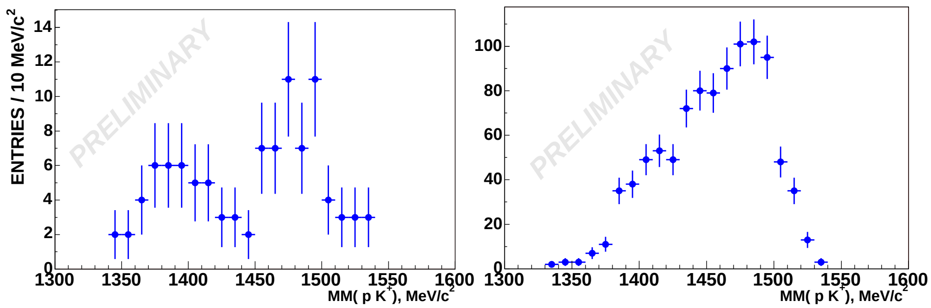

Fig. 8. Experimental missing mass MM(pK^+) distributions measured in the reaction $pp \to pK^+\pi^+X^-$(left) and $pp \to pK^+\pi^-X^+$(right) at the proton beam momentum of 3.65 GeV$/c$.

5. Experimental results and Monte Carlo simulations

We have assumed that the measured missing mass MM(pK^+) spectra can be explained by the production of hyperon resonances and non-resonant contributions. Detailed Monte Carlo simulations have been performed including the production of well established excited hyperons ($\Sigma^0(1385)$, $\Lambda(1405)$, $\Lambda(1520)$) and non-resonant contributions like $pp \to NK^+\pi X$ and $pp \to NK^+\pi\pi X$; X denotes any hyperon which could be produced in the experiment. For both final states the shape of the measured distributions cannot be reproduced by the simulations and an excess of events is observed around the missing mass of 1480 MeV$/c^2$. It is therefore suggested that another excited hyperon is produced and observed through the decay $pp \to pK^+Y^{0*} \to pK^+\pi^\pm X^\mp$.

The Y^{0*} mass M and width Γ have been determined from a fit based on simulations that cover the range from 1460 to 1490 MeV$/c^2$ and from 45 to 75 MeV$/c^2$, respectively, both in steps of 5 MeV$/c^2$. The following parameters of Y^{0*}, consistent for both final states, are obtained: $M(Y^{0*}) = (1480 \pm 15)$ MeV$/c^2$ and $\Gamma(Y^{0*}) = (60 \pm 15)$ MeV$/c^2$. The best fits to the experimental data are shown in Fig. 9. Histograms with different binnings as well as smoothed ones have been used with the likelihood and χ^2 method. The statistical significance of the signal, assuming that this is due to the production of the Y^{0*}, is between 4 and 6 σ depending on a procedure. The production cross section is of the order of few hundred nanobarns.

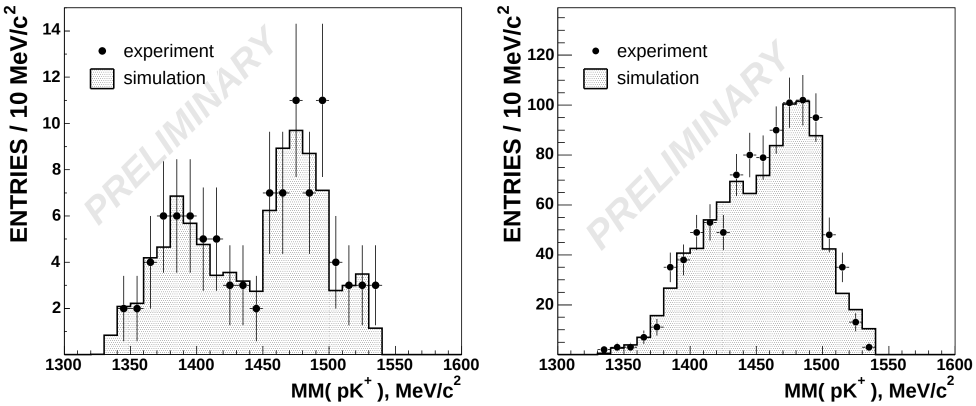

Fig. 9. Experimental missing mass MM(pK^+) distribiutions measured in the reaction $pp \to pK^+\pi^+X^-$(left) and $pp \to pK^+\pi^-X^+$(right). The shaded histogram shows the fitted Monte Carlo simulations.

6. Conclusions

We have found an indication of a neutral hyperon resonance Y^{0*} produced in proton–proton collisions at a beam momentum of 3.65 GeV/c and decaying into π^+X^- and π^-X^+ final states. Because we measured a neutral hyperon, it can be either a Λ or Σ.

If the $Y^{0*}(1480)$ exists indeed, its inner structure presents an important problem. This state cannot be described in a natural way as a conventional 3-quark baryon [30,31]. However, the recent discovery of Θ^+ [32] (still to be reliably confirmed) may open new possibilities. As predicted by the chiral soliton approach [33], the Θ^+ and all other members of its flavor antidecuplet have $J^P = 1/2^+$. In terms of the 5-quark picture, they are P-wave states. It was recently suggested [24] that the $\Sigma(1480)$ and other resonances of the same flavor multiplet [34] correspond to S-wave 5-quark states, thus having $J^P = 1/2^-$. Such a prediction does not contradict existing data, and may be checked by further investigations. At ANKE, using a deuterium cluster target and spectator proton tagging, one can search for the charged Y^{-*} hyperon in the reaction $pn \to pK^+Y^{-*} \to pK^+\pi^-X^0$. The investigation of Y^* decays with photons in the final state is foreseen with the WASA detector at COSY [35].

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