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Overview of COSY

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Abstract. The COSY facility is sketched together with its experiments. The hadron physics program is discussed highlighting recent results with particular emphasis on nucleon-nucleon interaction, precision experiments, and meson and strangeness production.

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1 Accelerator and experiments

COSY is a synchrotron at the Research Centre Juelich. It delivers unpolarized as well polarized proton and deuteron beams in the momentum range from $300\,\mathrm{MeV}/c$ up to about $3650\,\mathrm{MeV}/c$. Electronic cooling is used at the injection energy whereas stochastic cooling is provided for higher energies. COSY can be used as a storage ring for internal experiments and delivers external beams by stochastic extraction with spill times between a few seconds and several minutes.

The excellent beam quality of the extracted beam with an admittance of about 0.5 mm mrad allows precise tracking close to the target. This is of special importance for measurements close to reaction thresholds. In fig. 1 a scheme of the COSY facility is shown together with the internal experiments ANKE, COSY-11, EDDA and PISA and the external experiments BIG KARL, COSY-TOF and JESSICA. Both PISA and JESSICA, which have been used for the investigation of spallation processes, are not discussed in this talk. Moreover the place of the WASA detector, which is in the commissioning, is indicated. Information about the COSY-facility and the various experiments can be found at the COSY homepage [1].

ANKE and COSY-11 are magnetic spectrometers with a wide momentum acceptance for charged particles; both well suited for studying meson production processes close to threshold with particle emission into forward direction. Whereas COSY-11 employs one accelerator dipole, ANKE is a chicane consisting of three dipoles with the middle one as analysing part. COSY-11, a scheme of which is shown in fig. 2, has been upgraded during the last years for registering neutrons, deuterons, spectator protons and to extend the acceptance for kaons.

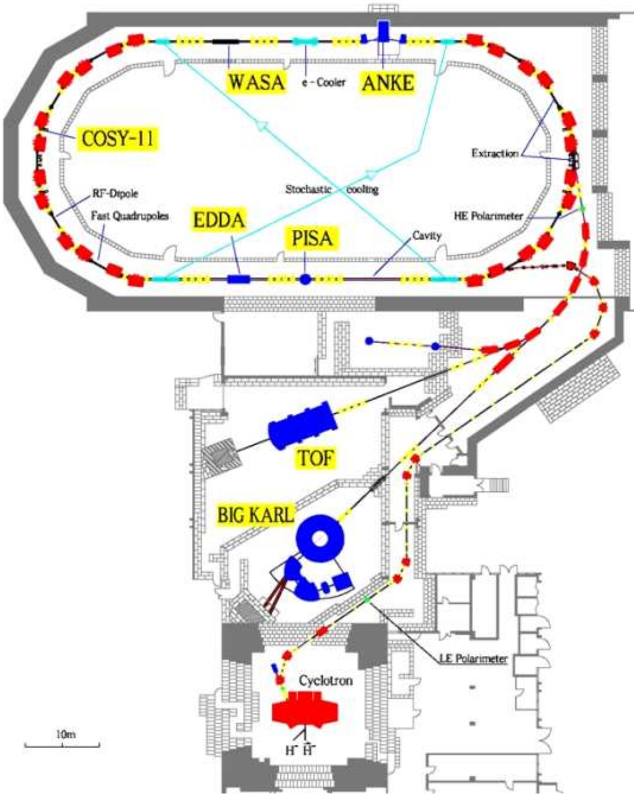

Fig. 1. The COSY facility with internal and external experiments.

As can be seen in fig. 3, the detection system of ANKE comprises tracking detectors and scintillator hodoscopes in forward direction for positive and negative reaction products. In addition, dedicated range hodoscopes and Cherenkov detectors allow the identification of charged

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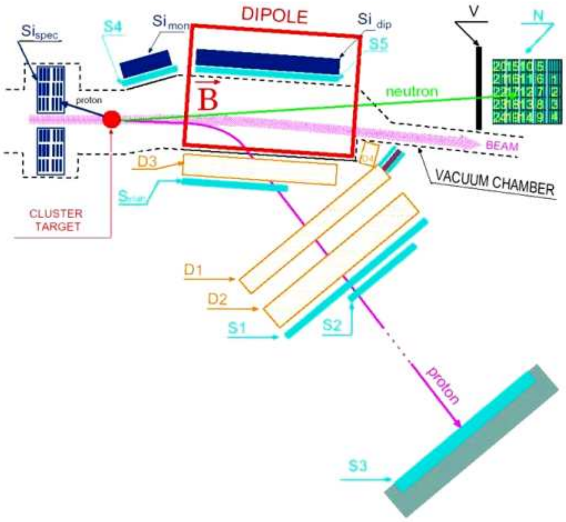

Fig. 2. Scheme of the COSY-11 detection system. D_i denotes drift chambers, S_i and V scintillation, C Cherenkov, N neutron, and Si silicon detectors, whereas the last ones are used for spectator protons and negatively charged particles.

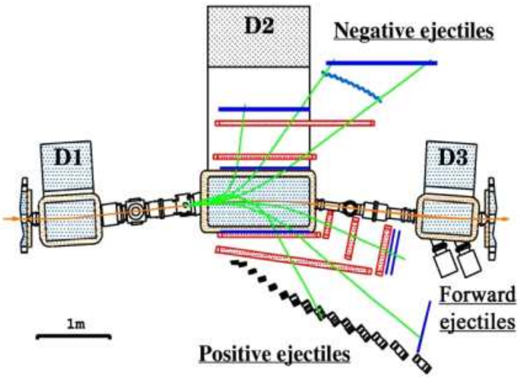

Fig. 3. Scheme of the ANKE detection system.

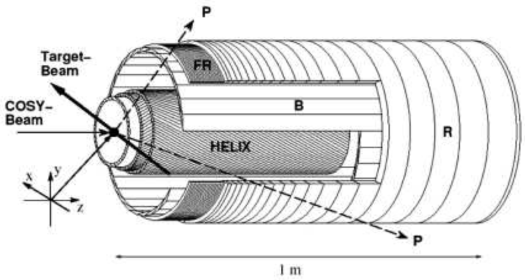

Fig. 4. Scheme of the EDDA detector.

kaons. Around the target silicon detectors allow to detect slow particles.

The non-magnetic EDDA detector, schematically shown in fig. 4, consists of two cylindrical detector shells of overlapping scintillator bars (outer) and helix wounded scintillating fibres (inner). The solid angle coverage is 30° to 150° in $\Theta_{c.m.}$ for elastic proton-proton scattering. It is now used as a very efficient beam polarimeter for the preparation of polarized proton and deuteron beams. All three internal experiments discussed here use gas (cluster) jet targets or, alternatively, thin foils or fibres. In addition, EDDA and ANKE possess polarized atomic beam targets, moreover ANKE has the option to use a storage cell.

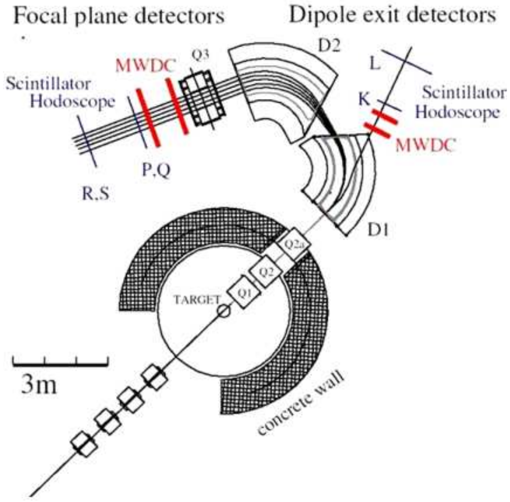

Fig. 5. Scheme of the BIG KARL spectrometer.

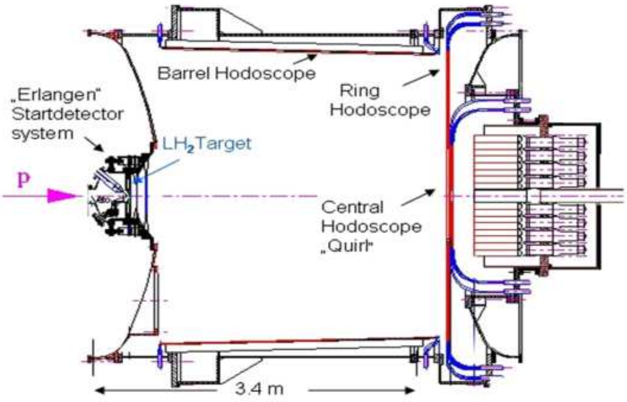

Fig. 6. Scheme of the COSY-TOF detector.

BIG KARL, a setup of which is shown in fig. 5, is a high-resolution magnetic spectrometer of 3Q2D type with a momentum resolution of $\Delta p/p < 5 \cdot 10^{-5}$ and a momentum acceptance of ±4.5%. The ejectiles are detected by multiwire drift chambers. Particle identification is done in combination with time-of-flight measurements using scintillator hodoscopes. In the target region the spectrometer is supplemented at large emission angles by a stack of four highly granulated annular germanium detectors, and a three-layer scintillator detector (ENSTAR).

The non-magnetic COSY-TOF apparatus (see fig. 6) is a huge vacuum vessel covered by several layers of scintillators which are used for tracking and together with the detectors in the target region for time-of-flight measurement. The target area detectors, consisting of a highly segmented annular silicon microstrip detector and two fibre hodoscopes, are suited for tracking and especially the reconstruction of delayed decays. Moreover, the setup comprises a central calorimeter in the end cap of the vessel. The goal is the examination of particle production in proton-proton and proton-deuteron collisions. Due to the kinematical completeness of the measurement the full set of variables can be determined, including total and differential cross-sections, angular distributions, and Dalitz plots.

So far the detectors at COSY are photon-blind. This will change with the WASA detector which was transferred form CELSIUS at Uppsala to COSY in 2005 and will start operation in the second half of 2006. This facility can detect both neutral and charged particles in a large angular and momentum range. Dedicated information on the measurements planned with WASA can be found in [1].

2 Physics at COSY

A broad spectrum of physics is covered by the different experiments at COSY. The excellent cooled beams are especially well suited for precise particle production measurements in the threshold regions. In the following a few recent results from experiments covering different topics are briefly discussed.

2.1 Nucleon-nucleon interaction

Elastic *pp* scattering investigations at EDDA resulted in accurate data for excitation functions [2], analysing power [3] and spin correlation observables [4]. Examples are shown in fig. 7.

These data extend drastically the base for phase shift analysis and are important for an improved understanding of the elementary *pp* interaction. EDDA also looked intensively for dibaryon resonances with a negative result.

ANKE is continuing the study of nucleon-nucleon reactions especially investigating *pn*-observables using the polarized deuteron beam and the polarized target which is now available.

2.2 Precision experiments

The precise COSY beam makes different types of precision experiments feasible. At the BIG KARL spectrometer a precision measurement of the η-mass, which still is poorly known, has been performed. Minimal systematic errors could by achieved by a self-calibrating measurement where the brilliance of the COSY beam plays an important role. The three reactions $p+d \to t+\pi^+$, $p+d \to \pi^+ + t$ and $p+d \to {}^3\text{He}+\eta$ were measured simultaneously with one setting of the spectrometer, where always the first particle produced was detected. In fig. 8 the reconstructed missing-mass spectrum of the η-particle is shown.

The final value of

$$m(\eta) = 547.311 \pm 0.028(\text{stat.}) \pm 0.032(\text{syst.})\,\text{MeV}/c^2$$

(see ref. [5]) is in agreement with older data but in disagreement with a recent result from NA48, which dominates the PDG average. Details of the BIG KARL experiment are discussed in the talks of Daniel Kirilov; very

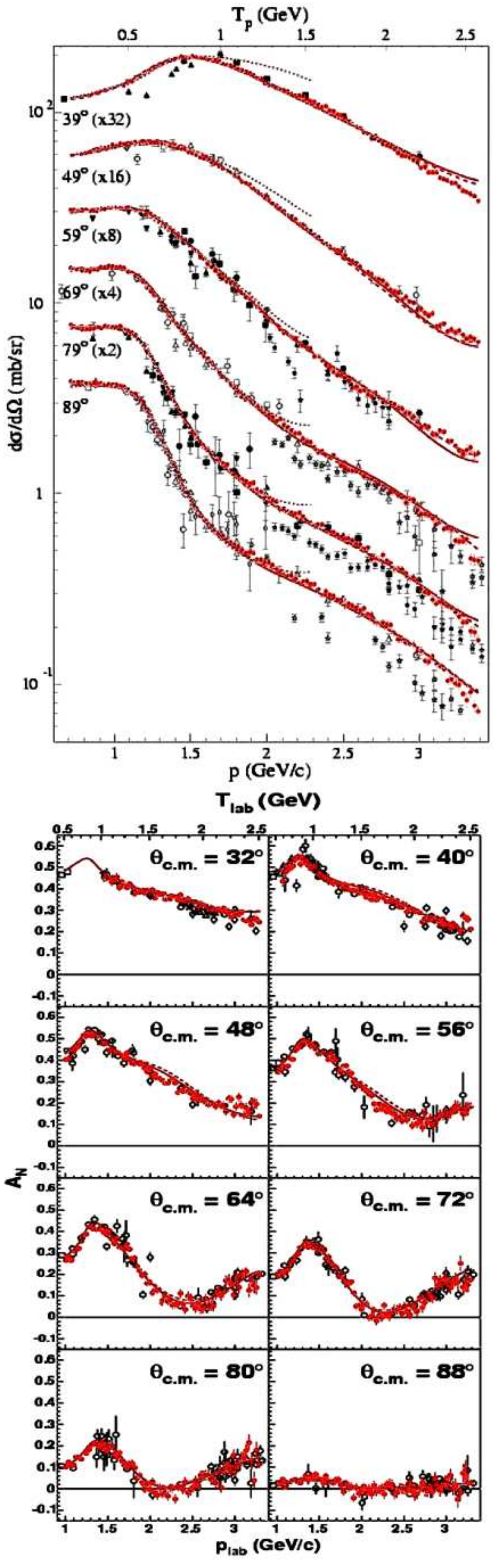

Fig. 7. Excitation functions of *pp* differential cross-sections and analyzing power for several scattering angles; EDDA data (in grey) together with data from former experiments.

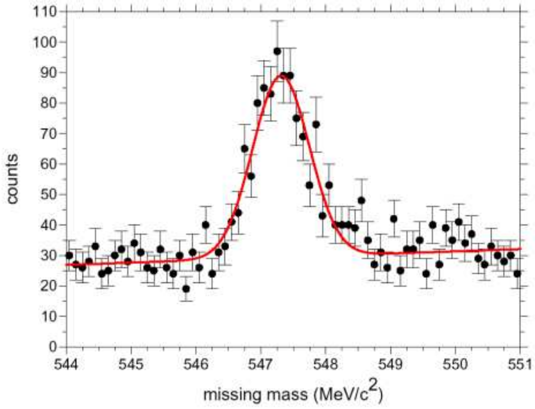

Fig. 8. Missing-mass spectrum of the η-particle obtained by the experiment using BIG KARL.

recent data from the KLOE experiment on this topic are presented by Cesare Bini at this conference.

2.3 Meson production

A large part of the experiments at COSY concentrates on physics of the near-threshold meson production in different flavour and spin channels. Meson production is studied in nucleon-nucleon reactions as well as in nucleon-nuclei reactions. The measurements performed by the various internal and external experiments span from pion- to phi-production. In this paper I will concentrate on the elementary reactions. Medium effects are discussed by Albrecht Gillitzer at this conference.

Of special interest to understand the reaction dynamics in elementary reactions is the role of N^*-resonances, and connected with the production near threshold, the influence of final-state interaction effects. As an example the results of COSY-11 comparing η- and η'-production are sketched here. Near-threshold η-production differs considerably from pion production due to the strong coupling of the $S_{11}(1535)$-resonance to the η-nucleon decay channel, leading to a threshold enhancement of the η-production cross-section. This is compatible with a rather large η-nucleon scattering length. The η'-proton interaction near threshold appears to be much weaker than the η-proton interaction. Using the stochastically cooled proton beam COSY-11 performed measurements for both systems very close to threshold [6]. The energy dependence of the cross-sections are shown in fig. 9. Comparing the data to phase space (dashed line) reveals that for both reactions the final-state interactions enhance the total cross-sections by more than one order of magnitude at small excess energies. While the η'-production data are well described by modulation of the phase space with the pp FSI (solid curve), for the η one this is not sufficient. The remaining discrepancies close to threshold can be explained by the influence of the attractive η-proton interaction. The upmost curve in fig. 9 corresponds to a simple model where an incoherent pairwise interaction between the outgoing particles is used.

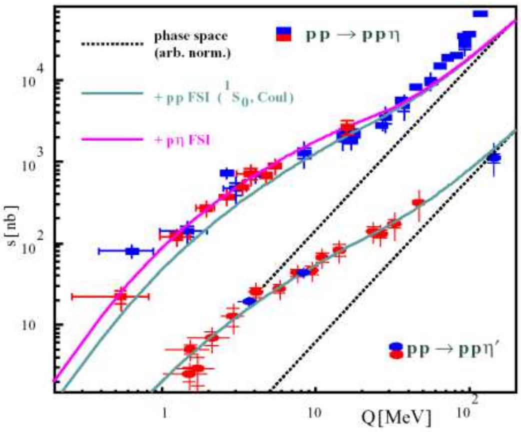

Fig. 9. Excitation functions of the reactions $pp \to pp\eta'$ and $pp \to pp\eta$. The grey points are the COSY-11 results.

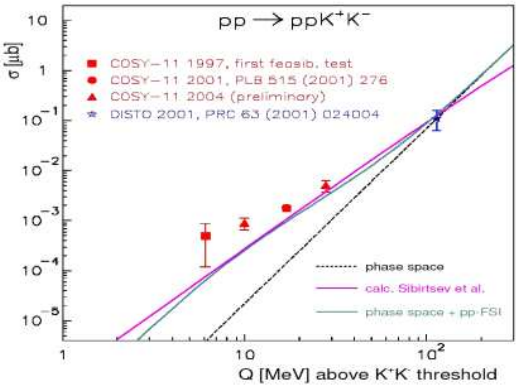

Fig. 10. Excitation functions of the reaction $pp \to ppK^+K^-$ very close to threshold.

COSY-11 also investigated the channel $pp \to ppK^+K^-$ very close to threshold [7]. The extracted excitation function is shown in fig. 10 together with a data point at somewhat higher energy from DISTO. Again there is a strong influence of the pp final-state interaction which leads to a significant enhancement very close to threshold.

Vector meson production is studied at COSY in the reaction $pp \to pp\phi$ by ANKE and in the channel $pp \to pp\omega$ by COSY-TOF. One of the interesting topics in this field is the value of the cross-section ratio of both reactions, which is discussed in the context of the violation of the OZI rule. In fig. 11 the ϕ cross-section is shown, obtained by ANKE for very low excess energies together with a data point from DISTO at somewhat higher energy. The curves correspond to phase space (full) and a calculation including pp FSI (dashed), which is normalized to the data points at higher energies.

COSY-TOF measured total and differential cross-sections of the reaction $pp \to pp\omega$ for various excess energies. Results on the differential cross-sections are shown in fig. 12 together with data on $pp \to pp\phi$ from DISTO. The angular distributions behave similarly for both channels. Combining the data from ANKE and COSY-TOF

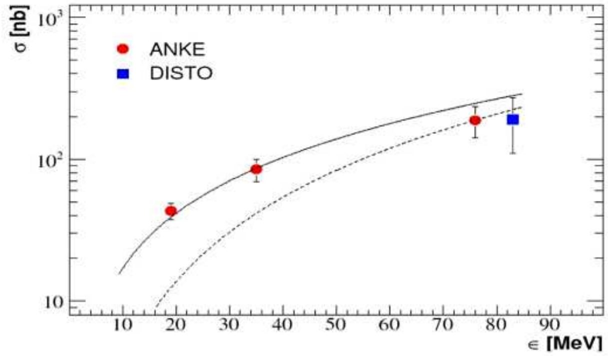

Fig. 11. Cross-section of $pp \rightarrow pp\phi$ obtained by ANKE together with a data point from DISTO.

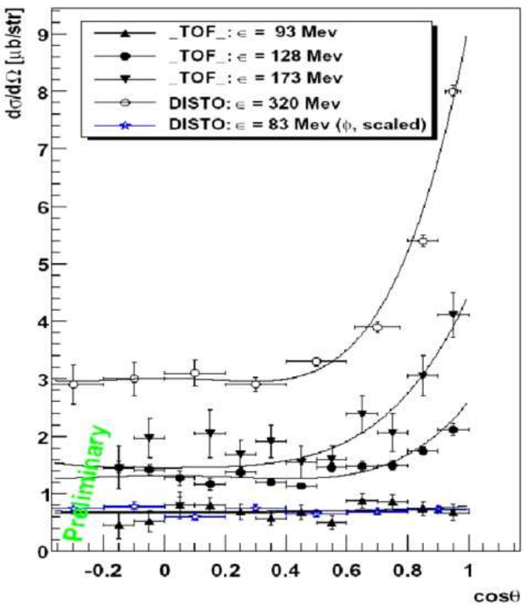

Fig. 12. Angular distributions of the reaction $pp \rightarrow pp\omega$ from COSY-TOF together with DISTO data on the reaction $pp \rightarrow pp\phi$.

the obtained ratio ϕ to ω is about 7 times larger than the ratio obtained from the OZI rule. This value of about 7 close to threshold is larger than the value of about three obtained in average from experiments at higher energies. For final conclusion this has to be discussed by investigating the reaction mechanism.

2.4 Strangeness production

An essential part of the program at COSY-TOF aims at the production of Λ-, Σ^0-, and Σ^+-hyperons in proton-proton collisions and in a further stage also at proton-neutron reactions. The main interest in the investigation of the associated strangeness production in elementary reactions close to threshold is to get insight into the dynamics of the $s\bar{s}$-production. The questions especially concern the role of N^*-resonances and the hyperon-nucleon final-state interaction which is known to be of special importance close to threshold. A further topic is also the search for exotic resonances as the pentaquark Θ^+. To come to conclusive results, precise measurements of the observables are needed, concentrating on exclusive data, covering the full phase space.

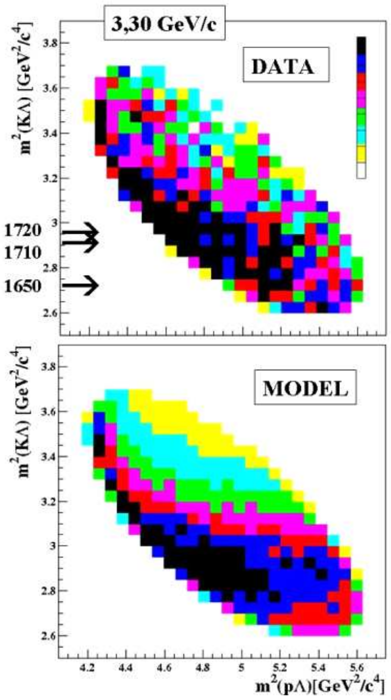

Fig. 13. Dalitz plots of the reaction $pp \rightarrow K^+\Lambda p$ at a beam momentum of 3.30 GeV/c. Top: data from COSY-TOF. Bottom: model of Sibirtsev with adjusted parameters (see text). The arrows indicate the $N^*(1650, 1710, 1720)$-resonances.

The external experiment COSY-TOF is a wide-angle, non-magnetic spectrometer with an inner detector system, which is optimized for strangeness production measurements. This inner system with small beam holes as well as the outer detector system covers the full angular range of the reaction products. It allows the complete reconstruction of the $pp \rightarrow K^+\Lambda p$ and $pp \rightarrow K^0\Sigma^+p$ events, including a precise measurement of the delayed decay of the Λ-hyperon and the K^0-meson, respectively. A more detailed discussion of the strangeness production program at COSY-TOF is given in a talk by Wolfgang Schroeder at this conference.

The reaction $pp \rightarrow K^+\Lambda p$ has been investigated at momenta from threshold up to nearly the COSY limit for the external beam ([8,9]). For reactions with more than two particles in the final state, as in the case of the reaction $pp \rightarrow K^+\Lambda p$, Dalitz plots are a powerful tool to extract information about the reaction mechanism. Whereas pure phase space leads to a homogeneous strength distribution, in particular resonances should lead to significant deviations from this. Figure 13 (top) shows as an example the Dalitz plot extracted from the experiment at the beam momenta of 3.30 GeV/c. It obviously shows strong deviations from phase space. Using a parametrization of

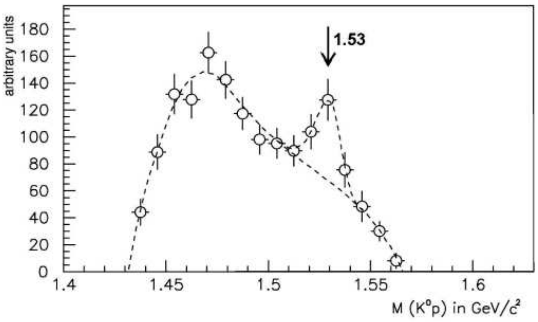

Fig. 14. Invariant-mass spectrum of the K^0p system from the reaction $pp \to K^0\Sigma^+p$ at a beam momentum of $p_{beam} = 2.95\,\mathrm{GeV}/c$.

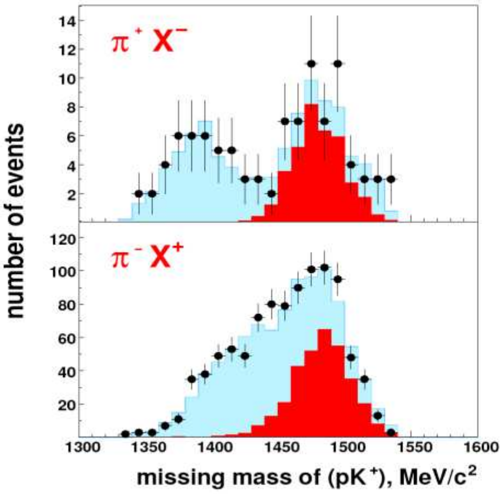

Fig. 15. Missing-mass $MM(pK^+)$ spectra for the reactions $pp \to pK^+\pi^+X^-$ (top) and $pp \to pK^+\pi^-X^+$ (bottom). The contribution of the newly found Y^{0*}-resonance is shown as a solid histogram (dark).

A. Sibirtsev [10], which includes the $N^*(1650, 1710, 1720)$-resonances, a non-resonant term and the $p\Lambda$ final-state interaction on the amplitude base, the strengths of the various contributions were adjusted individually to achieve a best fit for the Dalitz plots. The results are shown on the lower plot of fig. 13. The data are well described by the model fits. Measurements between $2.85\,\mathrm{GeV}/c$ and $3.30\,\mathrm{GeV}/c$ show a pronounced energy dependence of the contributions of the different resonances (see talk of W. Schroeder).

Apart from the Λ-production also the Σ-production is exclusively studied in the COSY-TOF experiment. This includes the search for the exotic pentaquark Θ^+ using the reaction $pp \to K^0\Sigma^+p$. In the K^0p system evidence was found for a narrow resonance at a mass of $1530\pm5\,\mathrm{MeV}/c^2$ with strangeness $S = 1$ [11]. The published spectrum is shown in fig. 14.

To come to a final decision on the existence of the Θ^+ in the investigated reaction very recently COSY-TOF performed a measurement which will give results with strongly improved statistical accuracy. More details on this topic are presented at this conference.

Also at ANKE strangeness production is a very important part of the experimental program. Besides the study of K-production in proton-nucleus reaction strangeness production is also intensively investigated in pp and pn reactions.

One of the most interesting results in this field is a possible new excited hyperon resonance for which evidence was found in the reaction $pp \to pK^+Y$ using a beam momentum of $3.65\,\mathrm{GeV}/c$ ([12]). Analysing the missing-mass $MM(pK^+)$ spectra for the two reaction chains $pp \to pK^+\pi^+X^-$ and $pp \to pK^+\pi^-X^+$, which are shown in fig. 15, and comparing with MC simulations including all known hyperon resonances, the necessity for an additional hyperon resonance Y^{0*} was found. Mass and width have been deduced to be $M(Y^{0*}) = (1480 \pm 15)\,\mathrm{MeV}/c^2$ and $\Gamma(Y^{0*}) = (60 \pm 15)\,\mathrm{MeV}/c^2$.

3 Summary and outlook

Using internal and external beams the various experiments at COSY achieved a broad spectrum of precise results which significantly extend the data base in different fields of hadron physics in the corresponding energy regime. In the future hadron physics at COSY will be performed especially by the three major experiments ANKE, COSY-TOF, WASA. The main topics will be spin physics, spectroscopy and symmetries. Using the precise COSY beam these experiments will contribute on the way to understand how hadrons are made in nature and will help to better understand the strong interaction.

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