Physics at COSY

H. Machner

Inst. für Kernphysik, FZ Jülich, 52425 Jülich, Germany

The COSY accelerator in Jülich is presented together with its internal and external detectors. The physics programme performed recently is discussed with emphasis on strangeness physics.

1. THE ACCELERATOR COMPLEX

COSY is a synchrotron with electron cooling at injection energy and stochastic cooling at higher energies. It provides beam of unpolarised as well as polarised beams of protons and deuteron up to 3700 MeV/c momentum. COSY can be used as a storage ring to supply internal experiments with beam. The beam can also be stochastically extracted within time bins ranging from 10 s to several minutes to external experiments. The emittance of the extracted cooled beam is only $\epsilon = 0.4\pi$ mm mrad. This allows excellent close to target tracking. Hence a large fraction of the experimental programme is devoted to meson production close to threshold.

Here we will concentrate on hadron physics thus leaving out detectors built for different purposes. These are COSY-11, ANKE and EDDA internally and TOF and BIG KARL externally. The physics at EDDA will be presented in the contribution by Hinterberger [1] and is therefore neglected here. COSY-11 and ANKE are magnetic detectors. The former [3] employs an accelerator dipole magnet while the latter [2] is a chicane consisting of three dipoles with the middle one as analysing magnet. TOF [4] is a a huge vacuum vessel with several layers if scintillators. Time of flight is measured between start detectors in the target area and the scintillators. The target area detectors are especially suited for the identification of delayed decays and TOF is thus a geometry detector. BIG KARL [5,6] is a focussing magnetic spectrograph of the 3Q2D-type. Particle tracks are measured in the focal plane area with packs od MWDC's followed by scintillator hodoscopes allowing for a time of flight path of 3.5 m. Additional detectors exist. MOMO [7] measured the emission vertex of charged particles. The Germanium Wall [8] is a stack of four annular germanium diodes being position sensitive. It acts as a recoil spectrometer.

2. STRANGENESS PHYSICS

One strong item in COSY physics is the study of strangeness production in various processes in pp, pd and pA interactions. Here we have to concentrate on a few of these reactions.

The $pp \to pK\Lambda(\Sigma)$ reactions, associated strangeness production were measured by COSY-11 [9–11] and TOF [12]. In Fig. 1 the ratio $\sigma(pK^+\Lambda)/\sigma(pK^+\Sigma^0)$ is shown as function of the excess energy. The ratio rises strongly to threshold. This unex-

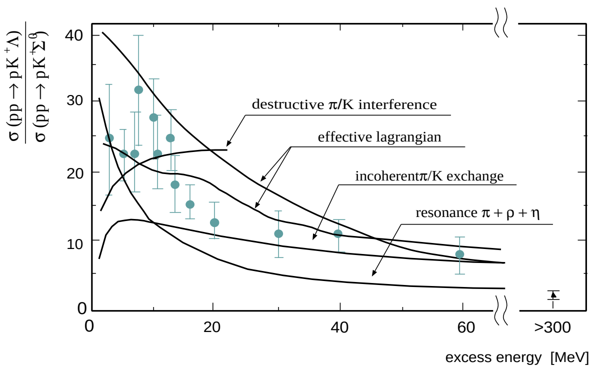

Fig. 1. Ratio of the cross sections for the indicated associated strangeness production. The curves are model calculations discussed in the text.

pected behaviour is studied within several models, including pion and kaon exchange added coherently with destructive interference [13] or incoherently [16], the excitation of nucleon resonances [14, 15] (labeled effective lagrangian), resonaces with heavy meson exchange (π, ρ, η [17] and heavy meson exchange (ρ, ω and K^*) [14,15]. The corresponding curves are also shown in the figure. All models show a decrease of the ratio with increasing excitation energy but none of them accounts for all data.

The associated strangeness production is also a useful tool to study the nucleon–hyperon interaction via FSI. At present a high resolution study of this interaction runs at BIG KARL. The measurement of Dalitz diagrams enables even the investigation of the importance of intermediate N^* excitation.

Connected with the associated strangeness production is the quest for the existence of a pentaquark. Most of the experimental searches were performed with electromagnetic probes on the neutron, which, of course, is embedded in a nucleus. A cleaner environment is the pp interaction. The reaction studied with TOF is the

$$pp \to K^0\Sigma^+p \tag{1}$$

reaction. The K^0 is identified via its decay into two pions and the Σ via its delayed decay. The data are shown in Fig. 2 [18]. There is evidence on a 4σ level for the production of a pentaquark

$$pp \to \Theta^+\Sigma^+ \tag{2}$$

with a subsequent decay of the Θ^+ into $K^=$ and p. For the enormous body of papers related to pentaquark we refer to the talk by Stancu [19].

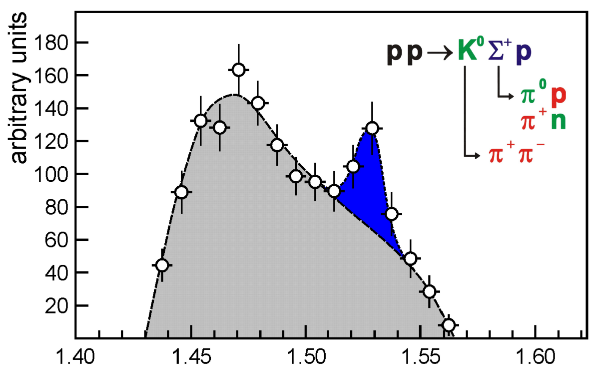

Fig. 2. Evidence for a pentaquark produced in pp collision.

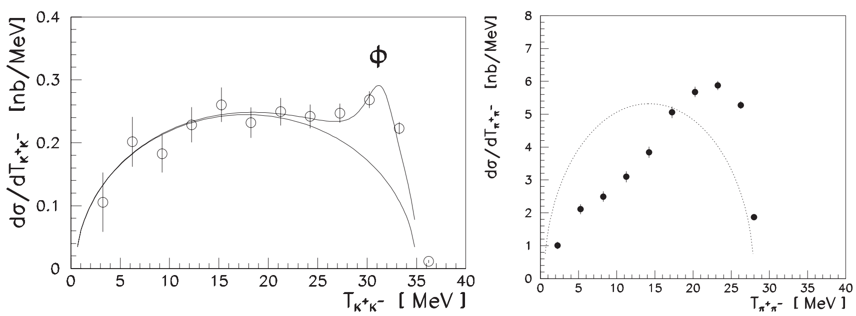

Fig. 3. Left: Energy spectrum of the two kaons at a maximal excess energy of 35 MeV. Right: Same as left but for two pions for a maximal excess energy of 28 MeV.

Another intersting reaction is

$$pp \to dK^+\bar{K}^0. \tag{3}$$

On order to reach the threshold of this reaction the maximal energy of COSY had to be lifted above its design value of 2.5 GeV. The data were taken at an energy of 2.65 GeV. The analysis of the data [21] resulted in a dominance of the channel

$$pp \to da_0^+ \tag{4}$$

with a subsequent decay $a_0^+ \to K^+\bar{K}^0$.

At the BIG KARL spectrograph the reaction

$$pd \to^3 HeK^+K^- \tag{5}$$

was studied with the MOMO vertex wall. The interest in this reaction stems from the surprising behaviour of two pions in the

$$pd \to^3 He\pi^+\pi^- \tag{6}$$

reaction [22]. The latter reaction showed a p-wave between the two pions even close to threshold. In Fig. 3 the energy spectrum of two kaons for a maximal energy of 35 MeV are shown. Besides a smooth continuum the production of ϕ-mesons is visible. The energy distribution follows phase space, hence it is s-wave. The same conclusion holds for the KK–^3He system. Also the excitation function for the ϕ production is an accord with the assumption of s-wave. To summarise: the KK–^3He behaves as expected while the $\pi\pi$–^3He system shows an unexpected behaviour. In order to proof the findings for this system the experiment was repeated but with inverse kinematics. The advantage of doing so is less settings of the spectrograph. A result of this measurement is also shown in Fig. 3. It supports the previous findings.

One aspect of strangeness physics is the $s\bar{s}$ content in the nucleon. This is connected to a violation of the OZI-rule in the ratio

$$R = \frac{\sigma(pp \to pp\phi)}{\sigma(pp \to pp\omega)}. \tag{7}$$

These two mesons have almost ideal quark mixing and hence the ω has negligible $s\bar{s}$ content while the ϕ is an almost pure $s\bar{s}$ state (see previous reaction). TOF measured ω production at exactly the same excess energy as previous ϕ production, thus allowing the deduction of R as function of excess energy. This yields $R = (3 \pm 1) \times 10^{-2}$ while the OZI-rule predicts $R = 4 \times 10^{-3}$. This may point to a serious content of $s\bar{s}$ pairs in the nucleon.

3. THRESHOLD PRODUCTION, SYMMETRIES, PRECISION EXPERIMENTS

There is a wealth of data of light meson production measured at COSY in the threshold region. The data were taken mainly by the COSY-11 and GEM collaborations for the nucleon-nucleon channel [24–26]. The η and η' production were discussed by Moskal [27] at this meeting. Here we will concentrate on $pd \to {}^3AX$ reactions with $A = H$ or He and $X = \pi, \eta$. The latter reaction is of interest since the η-nucleus interaction might be attractive. From the differential cross sections one can deduce a matrix element f as

$$|f\,(\theta)\,|^2 = \frac{k^2}{q^2}\frac{d\sigma}{d\Omega}\,(\theta) = |f_p|^2 |T\,(q)\,|^2. \tag{8}$$

This quantity is shown in the left part of Fig. 4 as function of the of the η momentum q. Close to threshold the final state interaction is an s-wave and one can apply the Watson–Migdal theorem (right side of Eq. 8) to extract the FSI amplitude $T\,(q)\,|$ and from this the η-^3He scattering length. Sibirtsev et al. [28] performed such an analysis with the result a=|4.3±0.3|+i(0.5±0.5) fm. This result is also shown in the figure. The second curve is from A. Khoukaz which includes the preliminary COSY-11 data.

The GEM collaboration studied isospin symmetry breaking by comparing neutral and charged pion production in $pp \to d\pi^+$ and $np \to d\pi^0$ ([5]) reactions, and

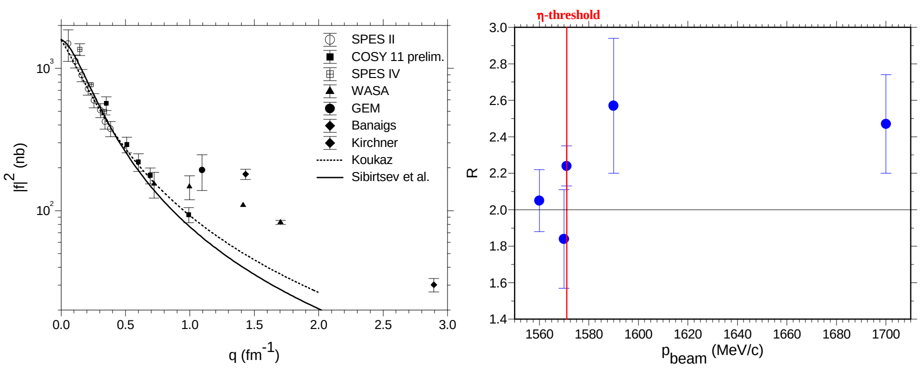

Fig. 4. Left: Excitation function of the matrix element squared for the $pd \to {}^3He\eta$ reaction. The references can be found in [28]. Right: Excitation functions for the ratio of the two pion production reactions at maximal momentum transfer (zero degree in the lab. system). The η-prodiction threshold is indicated as line.

$pd \to {}^3H\pi^+$ and $pd \to {}^3He\pi^0$ reactions [29]. For the latter reactions it was found that the angular distribution of the matrix elements consists of two parts. an exponential part showing scaling which is attributed to a one step reaction. This part shows isospin symmetry breaking. The second component is isotropic and is related to two step processes. It does not show isospin symmetry breaking. The origin of isospin symmetry breaking is in addition to the Coulomb force a difference in the masses of the up and down quark. It was suggested [30] to study the $pd \to {}^3He\pi^0$ reaction at maximal momentum transfer around the η-production threshold. This channel should be sensitive to π^0-η mixing with the mixing angle being dependent on the different quark masses. On the contrary the $pd \to {}^3H\pi^+$ reaction should not show such an interference effect. This was indeed found in an experiment [31] and the ratio of both reactions is shown in Fig. 4. Baru et al. [32] claimed this effect to be most probably to FSI. However, if the data are analysed on terms of the model from Ref. [30] the mixing angle results into $\theta = 0.006 \pm 0.005$. Green and Wycech used a K-matrix formalism and derived $\theta = 0.010 \pm 0.005$. From this formalism a rather large η-nucleon scattering length is extracted making a bound η-nucleus very likely. The search for such a system is in progress. Also the question of π^0-η mixing will be further studied via isospin forbidden decays of η and η' mesons with WASA at COSY.

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