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N*-Program at COSY-Jülich

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Abstract The paper gives a brief introduction into the COSY-facility, the currently used detector systems (ANKE, TOF and WASA) and the targets (cluster jet, pellet and ABS), and it presents some recent results, which were obtained in the field of baryon excited states.

Key words handron-induced reactions, nucleon and hyperon resonances

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1 Introduction

One of the aims of hadron physics is to unravel the excitation spectrum of the nucleon and to characterize these states (baryon resonances) and/or to understand their nature. This is a major challenge for both experimental investigations and corresponding theoretical descriptions/models or for fundamental theories. In order to make progress, different probes – hadronic and electromagnetic – have to be employed, and in recent times, the polarization of beams and targets (and of the decay products) has come into the focus. In the following, I give a brief account of what has been achieved recently at COSY-Jülich with (polarized) proton beams and (un-)polarized hydrogen and deuterium targets. I first describe the COoler SYnchrotron COSY, then discuss the used detector systems and the targets, and finally give a few recent examples.

2 Apparatus

1) COSY[1]

The COoler SYnchrotron COSY is an accelerator and storage ring at the Institute for Nuclear Physics (IKP) of the Forschungszentrum Jülich (FZJ). It is in operation since the beginning of the 90s and is now in a mature state, providing high intensity proton and deuteron beams, which may also be polarized, for both internal experiments (ANKE, WASA (see below), in previous times also COSY-11 and EDDA) and to external target stations (now TOF (see below), earlier also BIG KARL (GEM, MOMO)). The maximum beam momentum is 3.7 GeV/c, typical beam intensities are a few times 10^{10} for unpolarized particles, and about an order of magnitude less, if the beams are polarized.

2) Detectors

ANKE[2]

ANKE is the name of a magnetic forward spectrometer inside the ring of the Cooler Synchrotron COSY. It comprises 3 dipole magnets D1-D3, which impose a small chicane to the COSY ring. D1 deflects the beam out of the nominal orbit onto a target (see below) in front of D2, and D3 reflects the magnet back onto the nominal orbit. D2 is the large spectrometer magnet, which separates the reaction products from the beam. The magnet is movable perpendicular to the beam direction in order to detect particle momenta independent of the beam momentum. Forward, positive and negative side detection systems allow to track, identify and momentum analyze the particles. For experiments with deuterium (used as effective neutron targets), silicon tracking telescopes near the target are implemented to detect slow recoil protons (spectator protons). ANKE is the place where double-polarized experiments are performed at COSY.

TOF[3]

The time-of-flight spectrometer TOF is a non-magnetic detector at an external target position, combining excellent tracking capabilities with large acceptance and full azimuthal coverage. It consists of a large vacuum tank, covered with scintillators inside, and a near target tracking system for decay vertex de-

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tection and triggering. Recently, a low-mass budget tracking detector, based on straw-chambers has been implemented to improve the momentum resolution. TOF is optimized for detection of final states with strangeness. The investigation of hyperon resonances is thus one of its pillars.

WASA[4]

The wide Angle Shower Array, originally set up at the CELSIUS accelerator in Uppsala (Sweden), is a close-to-4π detector for neutral and charged particles, which is operated at the internal COSY beam. WASA comprises an electro-magnetic calorimeter (∼1000 CsI crystals), a very thin superconducting solenoid (∼ 0.18 X_0), inner and forward tracking detectors and a frozen pellet target (see below). The physics program focuses on symmetries and symmetry breaking in nuclear reactions and meson decays, but it also involves the ABC effect (see below).

3)Targets

Cluster Jet[5]

For measurements with unpolarized hydrogen or deuterium targets, a cluster jet is used, crossing the circulating COSY beam at right angles. The density of the target reaches 10^{15} atoms/cm^2 for hydrogen and $(2-5)\times10^{14}$ atoms/cm^2 for deuterium. It is now used at ANKE, in previous times COSY-11 also ran such a target.

Pellet[6]

For high luminosity unpolarized experiments with internal targets, a stream of frozen pellets (diameter 20—50 m, pellet rate up to 10 kHz) through the circulating beam is the target of choice. The vertex is well defined, but the interaction rate is not as smooth as with cluster jets. In addition the large energy loss leads to fast heating of the beam, which must be compensated by cooling methods. This target is employed at WASA and is foreseen for PANDA at FAIR.

Polarized atomic beam source[7]

The polarized internal target for the ANKE experiment utilizes a polarized atomic beam source to feed a storage cell with polarized hydrogen or deuterium atoms. The nuclear polarization is measured with a Lamb-shift polarimeter. The commissioning of the target in the COSY ring has been done, and first double polarized experiments are scheduled for 2009.

Liquid hydrogen/deuterium target[8]

The TOF liquid hydrogen/deuterium target has been constructed with an extremely small amount of passive material. The standard target cell is 6 mm in diameter and has a length of 4 mm. The working pressure is 200 mbar, which allows to use very thin target windows of only 0.9 m Mylar foil.

3 Recent experimental N*-results:

General

Studies of baryon resonances in nucleon-nucleon collisions are difficult, since the final state often comprises three- or more particles, and hadronic backgrounds in such reactions are large. Except for two-body reactions like pn → dπ^+ or special cases like pp → pp$\pi^0\pi^0$, where the Roper resonance is seen as a shoulder in the excitation function, usually smooth non-resonant energy dependences are observed, and contributing resonances can only be disentangled by partial wave analyses. In addition final state interactions significantly influence the observables near threshold.

pp → p $K^+\Lambda$[9]

Hyperon production in the threshold energy region has been studied in the reaction pp → p $K^+\Lambda$ using the TOF spectrometer. The full phase space was covered, and from an analysis of the Dalitz-plots, a dominant contribution of the N*(1650)-resonance was deduced. In order to resolve existing ambiguities, future experiments will make use of polarized proton beams.

pp → N$K^+\Sigma$[10—12]

Surprisingly large near-threshold cross sections for the reaction pp → N$K^+\Sigma$ have recently been reported by the COSY-11 collaboration. In order to accommodate this very strong threshold enhancement, contributions from the previously ignored sub-$K^+\Sigma^+$-threshold resonance $\Sigma^{++}(1620)$ have been invoked. A follow-up experiment at ANKE, using a different technique, has, however, not confirmed the previous finding.

$Y^{*0}(1480)$[13]

Indications for the production of a neutral excited hyperon have been found in the reaction pp → pK^+Y^{*0} with parameters $M(Y^*) = (1480 \pm 15)$ MeV/c^2 and $\Gamma = (60 \pm 15)$ MeV/c^2 in both final states $Y^* \to \pi^+X^-$ and π^-X^+. The Y^* could be the one-star $\Sigma(1480)$ of the PDG.

$\Sigma(1385)/\Sigma(1405)$[14]

The lineshape of the $\Lambda(1405)$ hyperon has been measured through its $\Sigma^0\pi^0$ decay in the reaction pp → pK^+Y^0. Final states comprising two protons, one positively charged kaon and one negatively charged pion have been identified. A clean separation between the $\Sigma(1385)$ and the $\Lambda(1405)$ has been achieved by a cut on the missing mass. The lineshape, which is supposedly sensitive to the nature of the state, is found to be the same in all $\Sigma\pi$ final states within the statistical accuracy achieved.

ABC effect[15, 16]

The observations of a peak in the $\pi\pi$ spectrum (ABC-effect) have presented a puzzle since its first discovery almost fifty years ago. If the ABC anomaly is not a resonance it must be a kinematic reflection of the production mechanism, which should be investgated in the simplest systems, i.e. nucleon-nucleon collisions. The conventional view is that ABC production in nucleon-nucleon collision is mediated by the excitation and decay of two separate Δ isobars. Recently, however, a CELSIUS experiment has found a striking energy dependence (ABC-resonance) in the reaction $\mathrm{pn}\rightarrow \mathrm{d}\pi^0\pi^0$, which seems difficult to reconcile in the $\Delta\Delta$-scenario. A different isospin channel, $\mathrm{pp}\rightarrow \mathrm{pp_s}(\pi\pi)$ (with $\{\mathrm{pp}\}_\mathrm{s}$ being the $^1S_0$ diproton system), does not see such a sharp energy dependence. Thus, additional measurements have to be performed in order to clarify the ABC puzzle.

4 Summary, outlook

The cooler synchrotron COSY can make valuable contributions in the field of baryon resonances, exploiting (polarized) NN-collisions and detecting final states with one of the installed detection systems (ANKE, TOF, and WASA). While ANKE and WASA are mainly focussed on different topics (reaction mechanisms, symmetry (breaking)), TOF has a dedicated program to study hyperons and the excited nucleon states contributing to this. It is foreseen to exploit polarized proton beams in the upcoming experiments.

The results presented in this paper have been obtained by the ANKE-, TOF-, and WASA-collaborations, in close and successful cooperation with the COSY accelerator crew and other members of the Jülich Center for Hadron Physics (JCHP), ZAT, ZEL, and IAS. The many different contributions by members of these groups are gratefully acknowledged.

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