Spin In Hadronic Reactions At Medium Energy

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Abstract. In this contribution a brief write-up of the presentation given at SPIN´06 is provided.

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INTRODUCTION

Hadron physics aims at a fundamental understanding of all matter comprised of quarks and gluons; one may focus this aim into the question "How does Nature *make* hadrons?" In order to find a convincing answer, combined efforts from both experimental and theoretical groups working in this field are necessary, and in fact essential progress has been achieved in recent years – thus, a satisfactory reply seems to be in reach in the near future.

In this contribution, results obtained of late with *hadronic* probes will be presented, exploiting proton and deuteron beams at COSY-Jülich – the non-observance of the many and highly important experiments using photon and lepton beams is accounted for by a number of other contributions to this conference and the proceedings.

After a brief discussion of the experimental tools (accelerator, targets, detectors) with special emphasis on *polarization*, a few selective results will be discussed. In a second part a new project for the to be built FAIR (Facility for anti-proton and ion research) at GSI (Darmstadt, Germany) will be introduced, namely the production of *polarized* anti-protons by means of spin-filtering.

EXPERIMENTAL TOOLS

COSY Facility

The Cooler Synchrotron COSY [1] is a unique accelerator, cooler and storage ring for protons and deuterons up to momenta of 3.65 GeV/c. It exploits electron cooling at injection energy and stochastic cooling between 800 MeV/c and the maximum momentum to provide precision beams for both internal and external target stations. Since many years it also supplies polarized beams up to the maximum energy. In

Fig.1, an overview of the COSY facility – injector cyclotron, cooler ring, and detection systems – is shown:

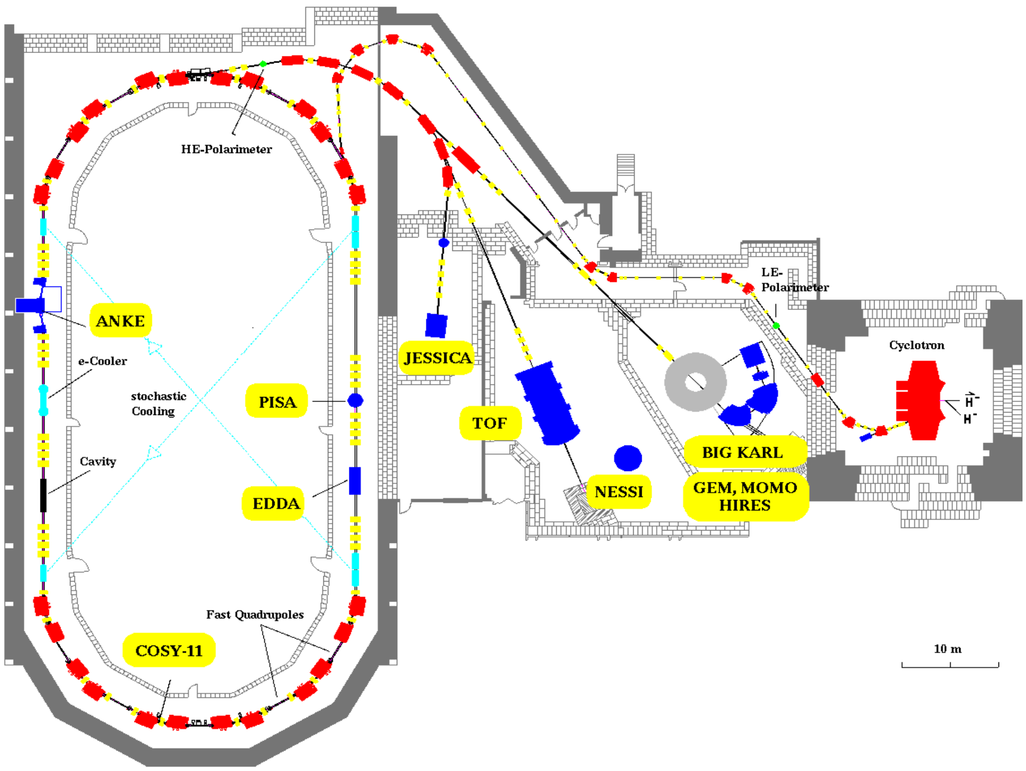

FIGURE 1. The COSY Facility at the Research Center Jülich (Germany). It comprises the injector cyclotron JULIC, the Cooler Synchrotron COSY and detector systems at internal beam positions (ANKE, COSY-11, EDDA, and PISA) and at extracted beam lines (BIG KARL and TOF). The new WASA detector has recently been installed in front of the electron cooler ("cavity").

Detector Systems At COSY

For some years, COSY has harbored four experiments at internal target stations – ANKE [2], COSY-11 [3], EDDA [4] and PISA – as well as two external facilities – BIG KARL [5] (with the subsystems ENSTAR, GEM, and HIRES), and COSY-TOF [6].

ANKE [2] and COSY-11 [3] are magnetic spectrometers with a wide momentum acceptance for charged particles. While COSY-11 exploits a dipole magnet of the COSY ring to deflect the produced positively charged reaction products out of the beam, ANKE comprises three dipole magnets: D1 and D3 deflect the circulating beam onto a target in front of D2, and back into the nominal orbit, D2 is the spectrometer magnet. ANKE imposes a chicane to the orbit and allows to vary the magnetic rigidity independent of the beam within certain limits by changing the size of the chicane. Furthermore, ANKE has the capability to detect both positive and negative charged final-state particles, and it uses solid targets as well as unpolarized gas jet and polarized jet or storage cell targets, based on an atomic beam source (ABS) [7]. Both detectors are well suited to study meson-production processes close to threshold (see below).

EDDA [4] is a non-magnetic, φ-symmetric detector, employing scintillation detectors. It has been used to study proton-proton elastic scattering, and it is now used as a beam polarimeter inside the COSY ring. The PISA detector is used for the investigation of spallation processes which are not discussed further in the current context.

COSY-TOF [6], located at one of the extracted beam lines, is also a non-magnetic spectrometer, which measures velocities and directions of the charged particles with very large acceptance, thus allowing for a kinematically complete reconstruction of events with up to one neutral final state particle via missing mass. Due to its φ-symmetric design, it is very well applicable for experiments with polarized beams. BIG KARL [5] is a high resolution magnetic spectrometer, for which dedicated supplementary subsystems around the target position can be added. Both TOF and BIG KARL use unpolarized liquid hydrogen and deuterium targets.

So far, all detectors at COSY are "photon-blind", i.e. they have no capability to detect γ-rays. This has changed recently with the transfer of WASA [8] from CELSIUS (Uppsala, Sweden) to COSY: WASA can detect both neutral and charged particles with large acceptance; it is currently (autumn 2006) commissioned and will start its experimental program (see below) in early 2007. WASA employs a novel unpolarized pellet target of frozen hydrogen and deuterium for highest luminosity.

BIG KARL, COSY-11, EDDA and PISA will finish their experimental programs by the end of 2006, thus ANKE, COSY-TOF, and WASA will be the only operational detectors at COSY from 2007 on. In addition, new ideas are being brought up in connection with the efficient production of polarized antiprotons for FAIR (see below).

EXPERIMENTAL PROGRAM AT COSY

Overview

The hadron physics program at COSY can be summarized as spectroscopy, spin, and symmetry. Under the headline spectroscopy the foremost research object is the nucleon an its mutual interactions as well as its excited states (N*´s and Δ´s) and possible exotics. The role and manifestation of the strange quark is an issue studied in associated production of hyperons and strange mesons. Recently symmetries and their breaking have come into the focus of investigations, after the WASA detector has been brought to and installed at COSY. Finally medium modifications in the form of final state interactions or possible bound states are also being investigated. With proton and deuteron beams, isospin and polarization of beam and target are used as a tool, and photons serve as a selective (final state) probe.

In the following, a few selective examples of recent results are presented.

Recent Research Highlights

Nucleon-Nucleon Interaction – The EDDA Legacy

The EDDA collaboration has studied proton-proton elastic scattering over a wide range of energies and angles with unprecedented accuracy and internal consistency: (i) unpolarized cross sections between 500 and 2500 MeV and 35° to 90° (cm) with an internal CH_2 fiber target during the acceleration cycle (ramping mode) [9], (ii) excitation functions of the analyzing power for projectile momenta from 1000 to 3000 MeV/c with a polarized atomic hydrogen target [10], and (iii) spin-correlation parameters at a fixed momentum of 2100 MeV/c, and between 1000 and 3300 MeV/c [11], respectively.

With these data, a precise characterization of the pp interaction for energies up to 2500 MeV has been achieved in terms of partial wave analyses. A search for possible dibaryons resulted in no significant signal [12].

These investigations are now being extended to the pn-case at ANKE [13].

ϕ-Production In Nucleon-Nucleon Collisions

At ANKE, the production of ϕ-mesons in the reactions pp $\rightarrow$ pp ϕ and pn $\rightarrow$ d ϕ has been investigated for energies close to the production threshold at excess energies of 18, 34, and 76 MeV (for pp) [14] and between 0 and 80 MeV (for pn) [15]. The production on the neutron is found to be stronger than on the proton, although not as much as for the η meson. In combination with corresponding data on ω vector-meson production, a significant enhancement of the ϕ/ω ratio by about a factor of 8 compared to predictions based on the Okubo-Zweig-Iizuka rule has been obtained.

The Tale Of The Pentaquark

At TOF, evidence for a narrow resonance at 1520 MeV/c^2 had been found in the (K^0p)-subsystem, studying the reaction pp $\rightarrow$ Σ^+K^0p at a beam momentum of 2.95 GeV/c [16]. The peak was interpreted as an indication for the so called θ^+ pentaquark, since the subsystem has strangeness S = +1. Although the significance of the structure is claimed to be 4 – 6 standard deviations, it was felt – also in view of the conflicting results that have been published in the meantime – to repeat the measurement with significantly improved statistical accuracy. Such an experiment has been performed at TOF and is currently being analyzed with final results being expected by the end of 2006.

It should be noted that a model independent determination of the parity of the θ^+ would be possible by a measurement of the energy dependence of the spin-triplet production cross section in NN → θ^+Y (Y = Λ, Σ) [17]. These results are applicable for the parity determination of any narrow spin-½ baryon resonance in NN-collisions.

Future Program

Symmetry And Symmetry Breaking

With the possibility to detect final state photons with the WASA detector, a new window is open at COSY to investigate symmetries and their breaking [18]. The envisioned program includes measurements of: (i) production reactions like dd → $\alpha\,\pi^\circ$ and dd → $\alpha\,\pi^\circ\eta$ (isospin symmetry, mixing) and (ii) all kinds of η and η´-decays (C, P, T symmetries). WASA has been refurbished with new electronics and it was installed at COSY during the 2006 summer shut-down. In the meantime it has been successfully commissioned, and the experimental program is expected to start in 2007.

Future Projects

The FAIR project to be constructed at GSI (Darmstadt, Germany) [19] will comprise a hadron physics part at the "High Energy Storage Ring" (HESR) [20] for antiprotons and a dedicated detection system at an internal target position, called PANDA [21]. In addition to this, the PAX collaboration has proposed to make use of the unique possibilities offered by polarization of the antiprotons [22]. Polarized anti-protons provide access to a wealth of single- and double-spin observables, from which outstanding physics questions like "What is the transversity distribution of the valence quarks in the proton?" may be answered. Although the physics case has been very highly rated by the corresponding FAIR review committee, the technical challenges are enormous, to begin with finding an answer to the question "How to (effectively) polarize antiprotons?".

Although a number of different approaches were investigated in the past and new ideas have been put forward recently, the only viable way for producing polarized antiprotons for FAIR at present is via "spin filtering"[23]. This method exploits the spin-dependent scattering of an unpolarized beam of antiprotons on a polarized hydrogen target. Technically this will have to be done be repeatedly sending the stored beam in a cooler cyclotron through a storage cell containing the polarized target. In fact, such an experiment (FILTEX) has been performed some time ago with protons at the TSR (Test Storage Ring; at MPI, Heidelberg, Germany) [24], proving the feasibility of the method. One of the (many) still open questions is, however, how spin filtering actually works, since two different interpretations of the FILTEX-result have been put forward [25, 26], which need to be scrutinized.

The PAX-collaboration is prepared to perform new and additional test experiments, including: (i) a measurement of the depolarization of a polarized stored COSY-proton beam at injection energy (T_p = 45 MeV) interacting with electrons in a ^{4}He gas target [27], (ii) an extension of the FILTEX-experiment with an unpolarized proton beam and a polarized hydrogen target at COSY [28], and eventually (iii) a corresponding measurement with antiprotons at the AD of CERN [29]. In parallel it is preparing the technical proposal for FAIR/HESR, including a polarizer ring and an asymmetric collider as well as the PAX-detector [22].

SUMMARY

COSY is the only facility worldwide which provides polarized beams of protons and deuterons in the intermediate energy range for internal and external experiments. Together with existing and new detection systems, it is an indispensable facility for studies of hadron physics with hadronic probes. Its importance is further strengthened by the need to perform preparatory tests for the upcoming FAIR project at GSI.

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