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INVERSE DIPROTON PHOTODISINTEGRATION WITH ANKE AT COSY

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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). It presents and discusses the results of recent measurements of the reaction pp $\rightarrow$ $\{pp\}_s$ γ (inverse diproton photodisintegration) which were obtained with ANKE/COSY and subsequently at WASA-Promice/TSL.

Introduction:

Photoabsorption on two-nucleon systems in nuclei at intermediate energies (a few 100 MeV) allows one to probe fundamental properties of nuclei at short distances, for example through the photo-disintegration of the simplest nucleus, the deuteron. Much less is known about the other simplest process, i.e. $\gamma + \{pp\}_s \rightarrow p + p$, where $\{pp\}_s$ is a proton pair in the $^1S_0$ state. It is obvious that different features of the underlying dynamics will be revealed by studying both systems since different amplitudes contribute to deuteron and diprotons, respectively. In the absence of a free diproton, the cleanest way to study the above reaction is the inverse channel with the production of a free $^1S_0$ diproton: $p + p \rightarrow \{pp\}_s + \gamma$.

Such an experiment has been performed with the ANKE detector system at an internal beam of the Cooler Synchrotron COSY that will be discussed further below; before, however, a brief overview of the COSY facility is provided.

Apparatus:

- COSY [Ref. 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 90´s 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.

- Detectors
  - ANKE [Ref. 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").
  - TOF [Ref. 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 detection 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.
  - WASA [Ref. 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).
- Targets
  - Cluster Jet [Ref. 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)x10^{14} atoms/cm^2 for deuterium. It is used at ANKE.
  - Pellet [Ref. 6]

    For high luminosity unpolarized experiments with internal targets, a stream of frozen pellets (diameter ~ 20-50 µm, 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.

- Polarized atomic beam source [Ref. 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 [Ref. 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 µm Mylar foil.

Recent results on inverse diproton photodisintegration:

The fundamental reaction $pp \rightarrow \{pp\}_s \gamma$ was observed in an experiment of an incident beam of unpolarized protons (T_p = 353, 500, and 550 MeV; note that the corresponding γ-energy is equivalent to about $T_p/2$) on an unpolarized proton cluster jet target inside the COSY ring [Ref. 9]. The produced two protons in the final state were registered in the forward detection system of the magnetic spectrometer ANKE. To identify diprotons, it was requested that the excitation energy E_{pp} of the two protons was less than 3 MeV. The photon final state was selected through a missing mass analysis, i.e. $pp \rightarrow pp\,X$ ($X = \gamma$): at the lowest beam energy a clean separation between γ and π^0 was achieved. For larger beam energies the photon peak was sitting on top of the much larger π^0-contribution, which, however, could be easily subtracted.

The differential cross sections measured for c.m. angles θ_{pp} between 0° and 20° exhibit a steep increase with angle that is compatible with E1 and E2 multipole contributions. The ratio of measured cross sections to those of $np \rightarrow d\gamma$ is on the 10^{-3} to 10^{-2} level. The observed cross section increase with T_p might reflect the influence of the $\Delta(1232)$ resonance. It should be noted that there is no direct contribution from S-wave ΔN intermediate states and M-odd multipoles are forbidden. In addition only the spin-flip contribution to the E1 operator survives.

Motivated by this result, an experiment performed at TSL CELSIUS (Uppsala, Sweden) with the WASA-Promice set-up has been analyzed and published [Ref. 10]. The measurement was performed at the incident proton beam energy of 310 MeV, and the $^1S_0$ diproton state was identified by a final state pp missing mass peak where the excitation energy was less than 3 MeV. The advantage of this measurement is the complete coverage of the photon c.m. angle θ_γ. The linear behaviour observed in $\cos^2\theta_\gamma$ indicates that there is almost no influence of an E2 multipole at this energy, and that the E1 and M2 must be of similar size.

For more details, I refer to the orginal publications [Refs. 9, 10].

Summary, Outlook:

Two recent experiments [Ref. 9, Ref. 10] have been performed to investigate inverse diproton photo-disintegration at intermediate energies, i.e. in the region of the Δ-resonance. Such an approach (pp $\rightarrow$ $\{pp\}_s\,\gamma$) is advantageous compared to other techniques, for example studying the photoabsorption (γ, pp)-reaction with emission of two fast protons on light nuclei. Due to the different quantum numbers and involved multipoles compared to deuteron photodisintegration, this reaction provides valuable additional information about NN-systems.

More recently, the excitation function has been studied at ANKE throughout the Δ-resonance region, and a clear indication for its excitation has been observed [Ref. 11].

There are also analysis efforts going on for ANKE data to enlarge the angular range [Ref. 12].

Finally, it is planned to exploit polarized COSY proton beams for this reaction.

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