Physics with diproton final states at ANKE-COSY

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Abstract. The study of the processes with production of proton pairs with small excitation energy (diprotons) provides a new approach to the hadron interactions at intermediate energies. It is especially instructive due to comparison with the processes where a deuteron is produced in the same kinematics. Provided that the momentum transfer is high enough the diprotons are found presumably in the $^1S_0$ state, what simplifies the theoretical analisys. The ANKE spectrometer gives a possibility to select the diprotons with sufficiently high excitation energy resolution. A number of processes including $pd \to \{pp\}_s n$, production of single and two pions in pN collisions, and the $pp \to \{pp\}_s\gamma$ process, have been investigated.

1 Experiments with diproton final states at ANKE

Few nucleon systems have long been a subject of intensive theoretical and experimental study. Especially important role in this study have played the processes with production of deuteron, a bound state of proton and neutron. In this respect, a particular interest arises for the investigation of the diproton, an unbound system of two protons with small excitation energy. The diproton, being the isospin partner of the deuteron, possesses different quantum numbers. Selection of the excitation energy of the proton pair $E_{pp} < 3$ MeV ensures dominance of the $^1S_0$ state of the diproton, which simplifies significantly the theoretical interpretation. The reactions with formation of a diproton involve transitions in the NN system, different from the case of the deuteron, and, in particular, the role of the Δ isobar is expected to be much suppressed because the S-wave ΔN intermediate state is forbidden.

Detection of the proton pair with $E_{pp} < 3$ MeV in an experiment requires an excellent excitation energy resolution and the ability to resolve the two spatially close trajectories of the protons. The ANKE spectrometer [1] provides a resolution of $\sigma(E_{pp}) = 0.2 - 0.6$ MeV in the $E_{pp} = 0 - 3$ MeV range and is particularly well suited for this purpose.

The diproton program at ANKE involves several experiments:

- Study of mesonless deuteron break-up $pd \to \{pp\}_s n$ in collinear kinematics:
  - at high momentum transfer [2–4],
  - at low momentum transfer (charge-exchange reaction) [5].
- Study of meson production in $pN \to \{pp\}_s X$, where X is:
  - a single pion [6],
  - the $(\pi\pi)$ system, used to study of the ABC effect in pp collisions [7],
  - a heavier meson like η and ω.
- the inverse diproton photodisintegration $pp \to \{pp\}_s\gamma$ [8].

Single pion production and the charge-exchange reaction are the key double polarization experiments in the future physics program at ANKE.

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2 Deuteron break-up reactions

2.1 High momentum transfer

The process $pd \to \{pp\}_s n$ with a forward emitted diproton is proposed for study. The kinematics of the process is the same as in pd-backward scattering and the same mechanisms can be considered for its description. In contrast to $pd \to dp$, the amplitude of excitation of Δ in the intermediate state is expected to be suppressed by a factor of 3 due to selection of the diproton in S-wave. Thus, the one nucleon exchange mechanism, which is sensitive to the short range part of the NN-interaction potential and to the high momentum part of the deuteron wave function, is expected to play more important role.

The differential cross-section of $pd \to \{pp\}_s n$ with a forward emitted diproton has been measured in the range of $T_p = 0.5 - 2.0$ GeV [2]. Comparison of the results with a model-calculation including Δ-production, one nucleon exchange and single scattering mechanisms, shows a clear advantage in using the modern CD Bonn NN-potential over the Paris and RSC potentials in the region 0.4 – 0.6 GeV/c of the internal deuteron momentum [2]. Preliminary results of a new high statistics measurement of the cross section [4] are presented in Fig. 1. The increased statistics let one obtain the angular distributions and test that the diproton

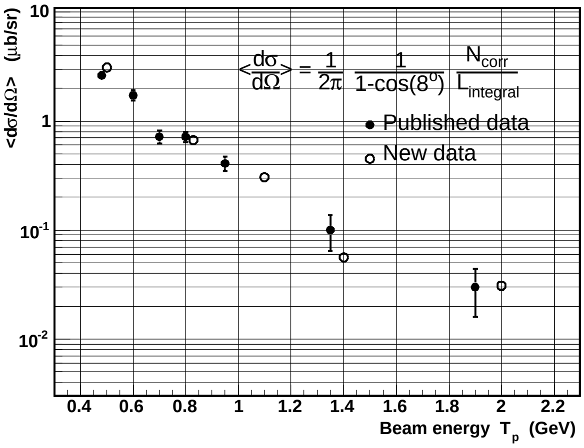

Fig. 1. Forward differential cross section of $pd \to \{pp\}_s n$ process averaged in the range $\cos\theta_{pp} = (0-8)^o$.

is endeed found in the $^1S_0$ state. For further insight, additional data, in particular polarization measurements, are needed to provide a complete set of observables.

2.2 Deuteron charge-exchange break-up reaction

The processes $\mathbf{dp} \to \{pp\}_s n$ with a forward emitted diproton proceed with low momentum transfer. One can extract the elementary charge-exchange spin amplitudes of *pn*-scattering from the measured polarization observables in the deuteron charge-exchange break-up process. The existing information on these amplitudes above 800 MeV is scarce. The equivalent neutron beam momentum available for COSY ranges up to 1.1 GeV in the case of deuteron beam, and up to 2.8 GeV in the case of deuteron target.

As a first step of the study, a measurement at T_n = 585 MeV was done, where information on the np spin-dependent amplitudes is available. The analysis showed excellent agreement of the extracted np amplitudes with the existing data [5]. Currently, the data obtained at T_d = 2.3 GeV are being analyzed. New double polarization measurements of the spin correlation coefficients $C_{y,y}, C_{x,x}$ have been conducted in the end of 2009.

3 Pion production in $pN \to \{pp\}_s\pi$

3.1 π^0 production in $0.5-2.0$ GeV region

The single pion production in nucleon-nucleon collisions, $NN \to NN\pi^0$, is one of the principial tools used in the investigation of NN dynamics at intermediate energies. Because of large momentum transfers involved, even close to threshold, such a meson production is sensitive to the short-range part of the NN-interaction. The $pp \to (pp)_s\pi^0$ differential cross section has been measured with the ANKE spectrometer at COSY-Jülich for seven proton beam energies T_p between 0.5 and 2.0 GeV [6]. In the measured region of $\theta_{pp}^{cm} = \pm 18°$, the data reveal a forward dip for $T_p \leq 1.4$ GeV whereas a forward peaking is seen at 1.97 GeV. The energy dependence of the forward cross section shows a broad peak in the 0.6-0.8 GeV region, probably associated with $\Delta(1232)$ excitation, and a minimum at 1.4 GeV.

The ratio of $pp \to (pp)_s(0°)\pi^0$ to $pp \to d(0°)\pi^+$ cross sections can provide information on the relative strength of spin-singlet to spin-triplet production. The resulting ratio shows that singlet production in the forward direction remains small at energies even above the $\Delta(1232)$ excitation region. Below 1.4 GeV the ratio is typically a few per cent, which is significantly smaller than the trivial spin-statistics factor of 1/3.

3.2 Near threshold region

The spin structure of the process $pn \to \{pp\}_s\pi^-$ (or $pp \to \{pp\}_s\pi^0$) with the diproton in $^1S_0$ state is $\frac{1}{2}^+\frac{1}{2}^+ \to 0^+0^+$, and there are only two spin amplitudes involved in this process. From this it follows that the measurement of the differential cross section, the analyzing power and one spin correlation coefficient is sufficient to extract magnitudes of the two amplitudes and their relative phase. A combined study of several observables in $pp \to \{pp\}_s\pi^0$ and $pn \to \{pp\}_s\pi^-$ could be used to isolate the important strength parameter d of the four-nucleon-pion contact interaction in χPT [9].

3.3 New measurements

In october 2007, the unpolarized cross section of $pp \to (pp)_s(0°)\pi^0$ process has been measured at 6 new beam energies: 353, 500, 550, 700, 1700 and 2400 GeV. These data will let one study the cross section energy dependence in the extended range and with a higher statistics.

In 2009, the vector analysing power in the process $\mathbf{p}p \to (pp)_s(0°)\pi^0$ has been obtained at 353, 500, 550 and 700 MeV, and a high precision measurement of the $\mathbf{p}n \to (pp)_s(0°)\pi^-$ process has been preformed. The results at 353 MeV will be used for defining the four-nucleon-pion contact term in χPT.

In addition, a double-polarized experiment for obtaining of $A_{y,y}$ and $A_{x,x}$ in $\mathbf{p}n \to (pp)_s(0°)\pi^-$ at 353 MeV is planned [10].

4 Inverse diproton photodisintegration

The fundamental reaction $pp \to \{pp\}_s\gamma$ has been observed using the missing-mass technique at proton beam energies of $T_p = 0.353, 0.5$, and 0.55 GeV [8]. This is equivalent to photodisintegration of a free $^1S_0$ diproton for photon energies $E_\gamma \approx T_p/2$.

The differential cross sections measured for c.m. angles $\theta_{pp}^{cm} < 20°$ exhibit a steep increase with angle that is compatible with E1 and E2 multipole contributions. The ratio of the measured cross sections to those of $np \to \gamma d$ is on the $10^{-3} - 10^{-2}$ level. The increase of the $pp \to \{pp\}_s\gamma$

cross section with T_p might reflect the influence of the $\Delta(1232)$ excitation.

In addition, analysis of data obtained at the beam energies 625, 700 and 800 MeV reveals a signal of $pp \to \{pp\}_s\gamma$ process on a rather large background from $pp \to \{pp\}_s\pi^0$. This result together with the published data at $T_p = 353, 500$, and 550 MeV lets one investigate behavior of the forward cross section of diproton photodisintegration in the Δ-isobar excitation region.

5 ABC effect in pp collisions

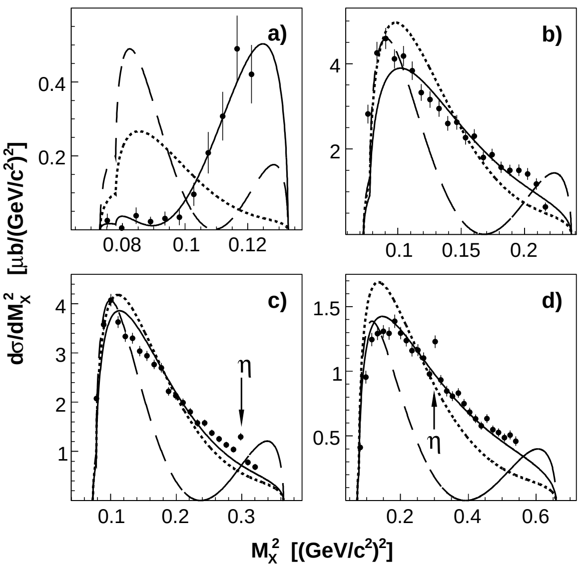

Fig. 2. The $pp \to ppX$ differential cross section as a function of the square of the missing mass M_x at (a) 0.8, (b) 1.1, (c) 1.4, and (d) 2.0 GeV for $E_{pp} < 3$ MeV and $\cos_{pp} > 0.95$. The η peaks are indicated. The curves correspond to the double Δ model [7] with the initial pp system in the pure S-wave $A_D = 0$ (long dashes), pure D-wave $A_S = 0$ (short-dashed), and with the best fit of A_S/A_D ratio (solid line).

The cross section for inclusive multipion production in the $pp \to ppX$ reaction was measured at four beam energies, 0.8, 1.1, 1.4, and 2.0 GeV, for low excitation energy in the final pp system [7]. At the three higher energies, the missing-mass M_x spectra show a strong enhancement at low M_x, corresponding to an Abashian-Booth-Crowe effect that moves steadily to larger values as the energy is increased (see Fig. 2). Despite the missing-mass structure looking very different at 0.8 GeV, the variation with M_x and beam energy are consistent with two-pion production being mediated through the excitation of two Δ (1232) isobars, coupled to S and D states of the initial pp system. There is no sign of any resonancelike structure in the energy dependence of the type recently observed for the $pn \to d\pi^0\pi^0$ total cross section [12].

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6 Bibliography

References

1. S. Barsov *et al.*, NIM **A 462** (2001) 364
2. V. Komarov *et al.*, Phys. Lett. **B 553** (2003) 179
3. S. Yaschenko *et al.*, Phys. Rev. Lett. **94** (2005) 072304
4. S. Dymov *et al.*, submitted to Phys. Rev. **C** (2009)
5. D. Chiladze *et al.*, Phys. Lett. **B 637** (2006) 170
6. V. Kurbatov *et al.*, Phys. Lett. **B 661** (2008) 22
7. S. Dymov *et al.*, Phys. Rev. Lett. **102** (2009) 192301
8. V. Komarov *et al.*, Phys. Rev. Lett. **101** (2008) 102501
9. C. Hanhart, Phys. Rep. **397** (2004) , 155
10. Spin Physics From COSY To FAIR, COSY proposal # 152, nucl-ex/0511028
11. COSY proposal # 192, http://www.fz-juelich.de/ikp/anke/en/proposals.shtml
12. M. Bashkanov *et al.*, Phys. Rev. Lett. **102** (2009) 052301