Measurement of the vector analyzing power of the reaction at intermediate energies at ANKE/COSY

To cite this article: D Tsirkov and the ANKE collaboration 2011 *J. Phys.: Conf. Ser.* **295** 012079

View the article online for updates and enhancements.

Related content

- Near-threshold pion production in diproton reactions at ANKE
  Sergey Dymov and the ANKE collaboration

- Spin physics at COSY and beyond
  Frank Rathmann

- Spin-dependent *pd* cross sections at low and intermediate energies
  Yu N Uzikov and J Haidenbauer

Recent citations

- The role of spin in *NN NN*
  Vadim Baru

Measurement of the vector analyzing power of the $\vec{p}p \to \{pp\}_s\pi^0$ reaction at intermediate energies at ANKE/COSY

D Tsirkov for the ANKE collaboration

Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, 141980 Dubna, Russia
Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany

E-mail: `cyrkov@jinr.ru`

Abstract. The reaction $\vec{p}p \to \{pp\}_s\pi^0$, where $\{pp\}_s$ is a proton pair with an excitation energy $E_{pp} < 3$ MeV, has been observed with the ANKE spectrometer at COSY-Jülich using a polarized beam with energies 353, 500, 550 and 700 MeV. The data have been processed to obtain the vector analyzing power A_y of the reaction. The setup acceptance covers most of the angular range at 353 MeV and forward angles at the higher beam energies, allowing one to obtain the A_y angular dependence. From the results of the analysis at 353 MeV, one can extract information on the pion d-wave contribution, which is important for Chiral Perturbation Theory tests at this energy. At higher energies the results are compared with a phenomenological model and this gives additional information about Δ-nucleon dynamics.

1. Introduction

Single pion production in nucleon-nucleon collisions from threshold to the region of the lowest nucleon resonances is one of the basic processes of hadron physics in the intermediate energy range. It has received much attention near threshold as a promising exploratory test bench for the applicability of chiral perturbation theory (ChPT) [1,2]. This effective field theory of QCD is essentially a low energy approach and its use for pion production, which involves relatively high momentum transfers, has only been developed in recent years (see [3] and references therein). The theory involves a contribution in the effective chiral Lagrangian from a so–called $(\bar{N}N)^2\pi$ contact operator, the strength of which is denoted by a low energy contact parameter d, which must be determined from experimental data. The contact operator allows one to compare a wide set of low-energy reactions and this makes the determination of a reliable value of d a task of the highest importance.

The short-range operator $(\bar{N}N)^2\pi$ does not contribute to p–wave pion production and hence to the $pp \to \{pp\}_s\pi^0$ amplitude. On the other hand, it was shown [3] that the $pp \to d\pi^+$, $pp \to pn\pi^+$ and $pn \to \{pp\}_s\pi^-$ reactions are sensitive to the value of d. The last one is particularly well suited for this aim. A successful ChPT analysis of the pion production process is currently focused on a set of experimental data at 353 MeV, already existing from TRIUMF [4,5] and being in progress at COSY [6]. However, there are contaminations in these processes from pion d–waves that are not yet included in the ChPT analysis [3]. Hence the π^0 production data will provide information on the pion d–waves that can be used in the extraction of the p–wave from, for example, $pn \to \{pp\}_s\pi^-$ [7].

The effects of the d–waves have been seen in the $pp \to \{pp\}_s\pi^0$ differential cross section measured at WASA–CELSIUS [8]. Here $\{pp\}_s$ represents a diproton where the excitation energy $E_{pp} < 3$ MeV, so that it is dominantly in the $^1S_0$ state. The Ss/Sd interference distorts significantly the angular distribution but a partial–wave analysis of the data shows that the Sd contribution to the total cross section is $(0.4\pm0.1)\%$ at 340 MeV and $(1.6\pm0.15)\%$ at 360 MeV. Thus, the strength of the contamination at 353 MeV will have a large statistical uncertainty. In addition, the partial–wave results depend to some extent on the pion–exchange model, used in the analysis. A more direct estimation of the d-wave contribution is worthwhile and it was one of the main aims for the present A_y measurement at 353 MeV [9].

At higher energies, in the $\Delta(1232)$ resonance region, the reaction $pp \to \{pp\}_s\pi^0$ was studied for the first time at ANKE [10]. The experiment revealed a wide peak in the energy dependence of the cross section at small angles. This is very similar to the well studied $pp \to d\pi^+$ reaction. However, the dominant contribution to the latter reaction in the 500–800 MeV range is connected with the $^5S_2$ state of the intermediate ΔN system. But this state is forbidden in the diproton channel. Higher orbital angular momenta would therefore be required to yield the observed peak. A consistent picture of the process is still lacking and the only detailed theoretical estimation, carried out in a coupled channel approach [11], does not agree with the experimental data.

Further experimental information is needed to elucidate the dynamics of π^0 production and, with this in mind, we have performed measurements of the cross section and A_y in the energy region 500–700 MeV where the forward cross section is maximal. The particular choice of beam energies was also aimed to improve the determination of the energy dependence in regions that are most sensitive for comparison with the model [11], as explained in more detail in [9].

2. Measurement and analysis

The experiment was performed in April 2009 at the ANKE magnetic spectrometer [12] that is positioned inside the ring of the synchrotron COSY–Jülich. The transversely polarized proton beam, with energies $T_p = 353, 500, 550$ and 700 MeV, interacted with the hydrogen cluster-jet target. The polarization was flipped between "spin–up" to "spin–down" (perpendicular to the plane of the accelerator) and no measurements were made with an unpolarized beam. The charged secondary particles were registered by the ANKE forward detector system, consisting of a set of multiwire chambers and a scintillation hodoscope. The setup and procedure for data handling are described in detail in references [10, 13, 14].

The polarization of the beam was evaluated using the $pp \to pp$ and $pp \to d\pi^+$ reactions that were detected in parallel. The required A_y values for these reactions were taken from the SAID analysis program, solutions SP07 for pp elastic and SP96 for $pp \to d\pi^+$ [15]. The two methods agreed within measurement errors and resulted in an average polarization of $P = 0.67 \pm 0.01$.

To start to identify the $pp \to \{pp\}_s\pi^0$ reaction, proton pairs were first selected from all the registered two–track events. This was done using the measured momenta of the both particles and their time-of-flight difference [16]. The resolution ΔE_{pp} in the diproton excitation energy is better than 0.5 MeV in the E_{pp} energy range 0–3 MeV for all the beam energies. This allowed us to apply the cut $E_{pp} < 3$ MeV to identify pairs where the $^1S_0$ state dominates.

After selecting $^1S_0$ events, where the momenta of both protons are known, we can reconstruct the kinematics of the $pp \to \{pp\}_s X$ process event–by–event and obtain a missing–mass spectrum. The distribution of M_X^2 over the c.m. polar angle of the pair θ_{pp}^{cm} is shown in Fig. 1. In addition to giving an impression about the angular acceptance of the setup for this reaction at different energies, it shows the main sources of the background, namely random coincidences and a signal from the $pp \to \{pp\}_s\gamma$ channel.

The γ and π^0 signals are well separated at 353 MeV and begin to overlap as the beam energy increases. To find the numbers of $\{pp\}_s\pi^0$ events, we fitted the M_X^2 distributions by the sum of a linear accidental background and simulated peak shapes for γ and π^0. A sample of the
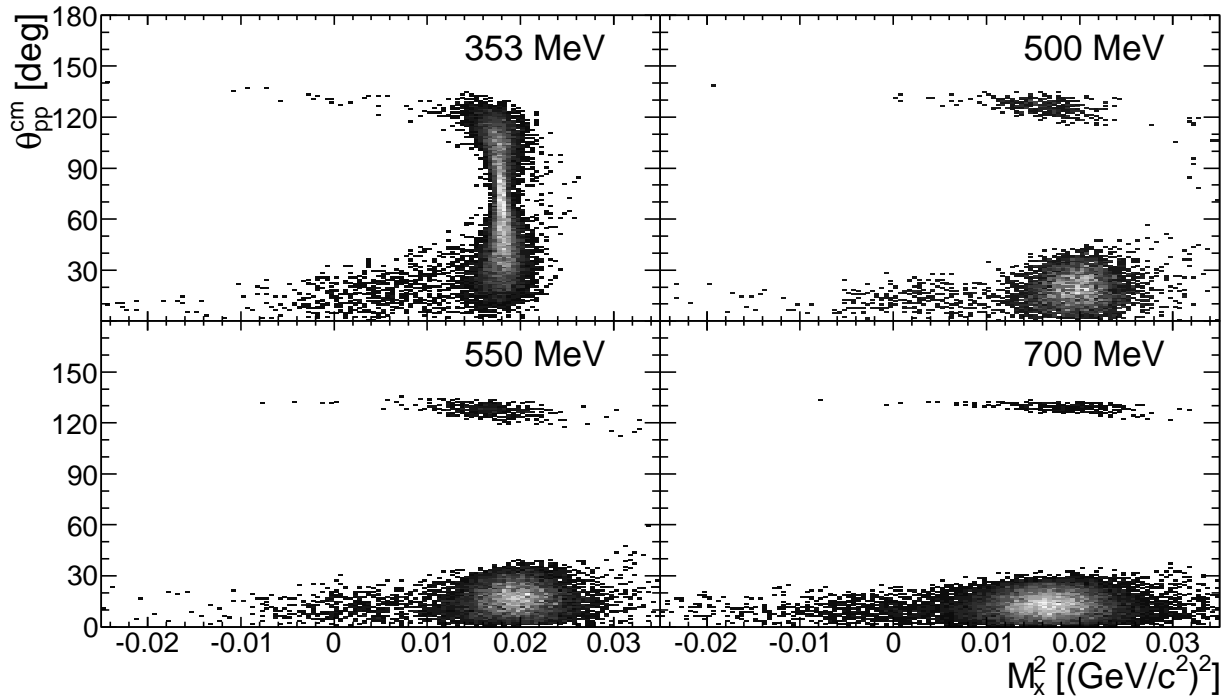
Figure 1. Two–dimensional distributions of the the c.m. polar angle θ_{pp}^{cm} of the $^1S_0$ diproton versus the missing–mass–squared M_X^2 for the $pp \to \{pp\}_s X$ reaction.

fitting in the most complicated case, 700 MeV, is presented in Fig. 2. The fitting procedure is described in more detail in [16].
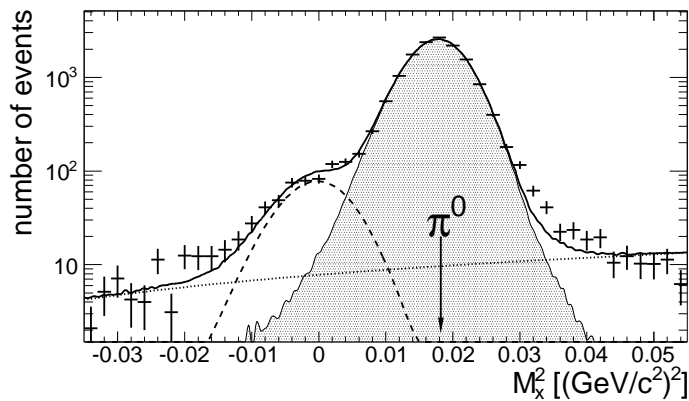

Figure 2. Sample fit of the missing–mass–squared distribution for the $pp \to \{pp\}_s X$ reaction at 700 MeV. The expected π^0 position is indicated by the arrow. The shaded area corresponds to the π^0 peak, the dashed line to the γ peak, the dotted to the linear accidental background, and the solid to the sum of these three contributions.

The polarization asymmetry is given by

$$\varepsilon = \frac{N_\uparrow^* - N_\downarrow^*}{N_\uparrow^* + N_\downarrow^*},$$

where $N_\uparrow^* = N_\uparrow/L_\uparrow$, $N_\downarrow^* = N_\downarrow/L_\downarrow$, $N_\uparrow$ and $N_\downarrow$ are the numbers of $\{pp\}_s\pi^0$ events with spin up and down, respectively, $L_\uparrow$ and $L_\downarrow$ are the corresponding luminosities. The luminosity uncertainty added about a 2% systematic error to ε.

The analyzing power A_y is connected to the asymmetry through:

$$A_y = \frac{\varepsilon}{P \left\langle \cos \phi_{pp}^{\mathrm{cm}} \right\rangle} \, ,$$

where P is the transverse polarization of the beam and $\left\langle \cos \phi_{pp}^{\mathrm{cm}} \right\rangle$ is the average of the diproton azimuthal angle over all events in the corresponding $\theta_{pp}^{\mathrm{cm}}$ interval. Since the $\cos \phi_{pp}^{\mathrm{cm}}$ acceptance is concentrated near 1, essentially all the statistics collected effectively contribute to A_y.
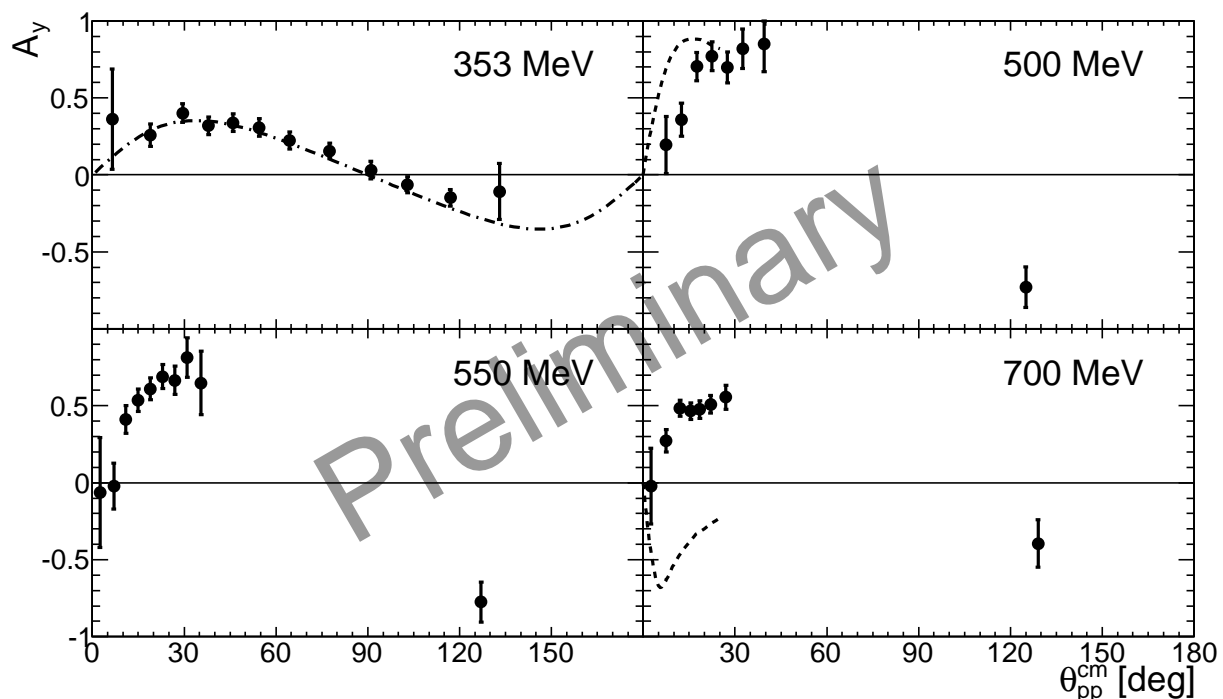
3. Results and discussion

Figure 3. Preliminary values of A_y for the $\vec{p}p \to \{pp\}_s \pi^0$ reaction at all the measured energies. The errors shown are purely statistical; the overall systematic uncertainty from the beam polarization and luminosity is about 3%. The angular uncertainty is about 5° near 90° at 353 MeV and less than 1.5° at other energies. The dash-dotted line represents the fit using CELSIUS data for the cross section [8]. The dashed line corresponds to the predictions by Niskanen [11, 17].

Our 353 MeV measurement reveals a rather high analyzing power, of up to about 0.4 in the forward hemisphere. If only waves up to $\ell = 2$ are retained, then A_y must originate from a $Ss{:}Sd$ interference. The product of the differential cross section and A_y should then be proportional to $\sin 2\theta_{pp}^{\mathrm{cm}}$ [18]. Quite generally, since odd partial waves are forbidden, this means that A_y must be antisymmetric about 90°. Therefore the data in a single hemisphere are sufficient for a full analysis. The cross section can be described with $a + b \cos^2 \theta_{pp}^{\mathrm{cm}}$ [18]. Interpolating the CELSIUS data [8] gives the values of $a = 204 \pm 10$ nb/sr and $b = -112 \pm 23$ nb/sr. Then fitting the A_y distribution with

$$A_y = \frac{c \sin 2\theta_{pp}^{\mathrm{cm}}}{a + b \cos^2 \theta_{pp}^{\mathrm{cm}}}$$

leads to $c = 48 \pm 4$ nb/sr. When the results of the full model [3] are available, the current data will provide a valuable test of the theoretical approach.

In the $\Delta(1232)$ region, our setup has a high acceptance only in a narrow angular range from $0°$ to $40°$ ($30°$) at 500 (700) MeV. The analyzing power grows steeply from zero to high values of about 0.8 (0.5) at 500 (700) MeV. It is positive in the forward direction and negative near $125°$, as it has to be in the absence of odd partial waves. The small angle predictions of the Niskanen model [17] approach the data at 500 MeV but are in full disagreement at 700 MeV. The reason for the disagreement in respect of both the cross section [10] and analyzing power is unclear.

The differential cross sections of the $pp \rightarrow \{pp\}_s\pi^0$ reaction are in the process of being obtained which, together with earlier ANKE data [10], will define better the energy dependence of the $pp \rightarrow \{pp\}_s\pi^0$ forward cross section. In order to refine the results presented here, the setup geometry will be defined more precisely in order to improve the angular uncertainty at 353 MeV from $5°$ to $\approx 2°$. The systematic uncertainties will also be reduced by applying more precise dead-time and luminosity corrections.

References

[1] Weinberg S 1979 *Physica* A **96** 327
[2] Gasser J and Leutwyler H 1984 *Ann. Phys.* **158** 142
[3] Baru V *et al* 2009 *Phys. Rev.* C **80** 044003
[4] Duncan F *et al* 1998 *Phys. Rev. Lett.* **80** 4390
[5] Hahn H *et al* 1999 *Phys. Rev. Lett.* **82** 2258
[6] Dymov S *et al* 2008 Institut für Kernphysik/COSY proposal 192
      http://fz-juelich.de/ikp/anke/en/proposal/pppiMinusProposal.pdf
[7] Baru V 2010 private communication
[8] Bilger R *et al* 2001 *Nucl. Phys.* A **693** 633
[9] Kulikov A *et al* 2006 Institut für Kernphysik/COSY proposal 158
      http://fz-juelich.de/ikp/anke/en/proposal/New_proposal_pi0.pdf
[10] Kurbatov V *et al* 2008 *Phys. Lett.* B **661** 22
[11] Niskanen J A 2006 *Phys. Lett.* B **642** 34
[12] Barsov S *et al* 2001 *Nucl. Instrum. Methods Phys. Res.* A **462** 354
[13] Dymov S *et al* 2004 *Part. Nucl. Lett.* **1** (2) 40
[14] Dymov S *et al* 2006 *Phys. Lett.* B **635** 270
[15] Arndt R A *et al* 2007 *Phys. Rev.* C **76** 025209; http://gwdac.phys.gwu.edu
[16] Tsirkov D *et al* 2010 *J. Phys.* G **37** 105005
[17] Niskanen J A 2008 private communication
[18] Hanhart C 2004 *Phys. Rep.* **397** 155