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Isospin effects in the exclusive $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction

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Abstract. The differential cross section for the exclusive $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction has been measured with high resolution and large statistics over a large fraction of the backward ^{3}He hemisphere at the excess energy 265 MeV using the COSY-ANKE magnetic spectrometer. Though the well-known ABC enhancement is observed in the $\pi^+\pi^-$ spectrum, the differences detected between the π^{+3}He and π^{-3}He invariant-mass distributions show that there must be some isospin-one $\pi\pi$ production even at relatively low excess energies. The invariant-mass differences are modeled in terms of the sequential decay $N^*(1440) \to \Delta(1232)\pi \to N\pi\pi$.

PACS. 25.40.Qa (p, π) reactions – 25.45.-z ^{2}H-induced reactions – 25.40.Ve Other reactions above meson production thresholds (energies > 400 MeV)

1 Introduction

Two-pion production in proton-deuteron collisions has a long history. Abashian, Booth, and Crowe [1] measured the inclusive cross sections for $pd \to {}^3\mathrm{He}\,X^0$ and $pd \to {}^3\mathrm{H}\,X^+$ at a beam energy of $T_p = 743$ MeV. This corresponds to an excess energy with respect to the $\pi^+\pi^-$ threshold of $Q = W - M_{^3\mathrm{He}} - 2M_{\pi^+} = 184$ MeV, where W is the total energy in the centre-of-mass system (CMS). In addition to the expected single-pion peaks, a striking enhancement was seen in the ^{3}He case at a missing mass of about 310 MeV/c^2 with a width ≈ 50 MeV/c^2. This has since become known as the ABC effect or enhancement. However, these parameters change with the experimental conditions and a lot of evidence has since emerged to show that the ABC is a kinematic effect, related to the presence of nucleons, rather than an s-wave $\pi\pi$ resonance [2].

The lack of a similar signal in the ^{3}H case proves that the effect has to be dominantly in the $\pi\pi$ isospin $I_{\pi\pi} = 0$ channel. Apart from phase space effects, one would then expect that the $\pi^+\pi^-$ component in the production of the ABC should be twice as strong as the $\pi^0\pi^0$.

The original ABC data were obtained at a fixed laboratory angle of 11.8° and only covered forward production of the ^{3}He with respect to the proton beam direction in the CMS [1]. By using a deuteron beam with an energy about twice as high, the acceptance was increased significantly and allowed the reaction to be studied inclusively at Saclay in both hemispheres [3].

The first exclusive measurements of the $pd \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction were made at much lower energies and the data there look very different. The COSY-MOMO results at $Q = 76$ MeV, which did not differentiate between the charges on the two pions, actually show a suppression of events at low $\pi^+\pi^-$ invariant masses $M_{\pi^+\pi^-}$ [4]. This was mistakenly taken as evidence for the production of p-wave pion pairs. There is also no sign of an ABC effect even closer to threshold in data obtained at $Q = 27$ MeV at CELSIUS [5] or at 8 and 28 MeV at COSY-MOMO [6].

Much more extensive information was provided by the CELSIUS-WASA collaboration, where the production of both $\pi^+\pi^-$ and $\pi^0\pi^0$ pairs was measured at $Q = 269$ MeV[1] in coincidence with the detection of the ^{3}He [7]. Only fast ^{3}He were registered and so the kinematics are similar to those of the first inclusive experiment [1]. The large acceptance of WASA for the pions allowed the measurement

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[1] All values of Q are quoted with respect to the $^3\mathrm{He}\,\pi^+\pi^-$ threshold

of a wide variety of angular distributions as well the two-particle invariant masses.

The ABC effect was clearly seen in the WASA $\pi^0\pi^0$ spectrum but perhaps somewhat less in that of $\pi^+\pi^-$. However, in the comparison of the two final states there are significant effects at low $M_{\pi\pi}$ that arise from the mass difference between the charged and the neutral pions. There are also some ambiguities in the fraction of $I_{\pi\pi} = 1$ $\pi^+\pi^-$ pairs extracted from these data due to uncertainties in the evaluation of the relative $\pi^0\pi^0/\pi^+\pi^-$ acceptance in WASA. However, if one normalises the phase-space-corrected ratio to the isospin factor of two in the low mass region, it appears that there could be a little $I_{\pi\pi} = 1$ production at very high $M_{\pi\pi}$. This is not in contradiction to the $pd \to {}^3\mathrm{H}\,X^+$ measurement [1] since there are uncertainties in this case connected with possible background contributions.

Both the $\pi^0\pi^0/\pi^+\pi^-$ and $pd \to {}^3\mathrm{He}\,X^0/{}^3\mathrm{H}\,X^+$ cross section ratios are sensitive to the relative $I_{\pi\pi} = 1/I_{\pi\pi} = 0$ production intensities. In contrast, the difference in the ${}^3\mathrm{He}\,\pi^+$ and ${}^3\mathrm{He}\,\pi^-$ invariant mass distributions in the $pd \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction depends upon the interference of the amplitudes for producing $I_{\pi\pi} = 1$ and $I_{\pi\pi} = 0$ $\pi^+\pi^-$ systems. There is therefore greater sensitivity and, moreover, no uncertainty regarding the relative normalisations for producing two different final states.

The CELSIUS-WASA collaboration evaluated experimental ${}^3\mathrm{He}\,\pi^+$ and ${}^3\mathrm{He}\,\pi^-$ distributions [7] but did not draw firm conclusions from their difference. We present here data taken at COSY-ANKE in inverse kinematics, with a deuteron beam incident on a hydrogen target. This approach increases significantly the overall acceptance and hence the statistics. The use of a magnetic spectrometer also improves the resolution relative to WASA, though this has to be balanced against the greater geometric acceptance at the WASA facility.

The conditions for the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ experiment are described in sect. 2, where the kinematics and the luminosity determination are discussed. The event selection of sect. 3 required the detection of the ${}^3\mathrm{He}$ and at least one of the two pions. The reaction, or the kinematics of the missing pion, was then identified with the help of the missing-mass technique. By making judicious cuts on the data, it is believed that fewer than 0.5% of events were lost in the process but that the background under the 81,500 good events was also below $\approx 1\%$.

The ANKE spectrometer has a very non-uniform acceptance and corrections for this were estimated using a Monte Carlo model, where the input was taken from two very different reaction models. These resulted in differences that were typically less than 5% and this was checked in sect. 4 in a model-independent multidimensional approach.

The results shown in sect. 5 are broadly in line with the CELSIUS-WASA data [7] and are not incompatible with the inclusive measurements at Saclay [3]. Apart from the ABC peak seen in the $\pi^+\pi^-$ invariant mass distribution, both the ${}^3\mathrm{He}\,\pi^+$ and ${}^3\mathrm{He}\,\pi^-$ distributions show broad peaks that are reminiscent of $\Delta(1232)$ excitation in nuclei. However, the high resolution of the current experiment demonstrates quantitatively the shift in the peak position between the ${}^3\mathrm{He}\,\pi^+$ and ${}^3\mathrm{He}\,\pi^-$ data. This difference can be understood as arising from the different coupling strengths of the π^+ and π^- to the $\Delta(1232)$ isobar, but this does not explain why this effect remains so strong at low $M_{\pi^+\pi^-}$.

The mere existence of a ${}^3\mathrm{He}\,\pi^+/{}^3\mathrm{He}\,\pi^-$ mass difference requires that there must be some $I_{\pi\pi} = 1$ production. In our conclusions of sect. 6, we also discuss the relative $I_{\pi\pi} = 1/I_{\pi\pi} = 0$ production intensities within the model used to describe the ${}^3\mathrm{He}\,\pi^+$ and ${}^3\mathrm{He}\,\pi^-$ differences and also consider what information is available on this ratio from the comparisons of $pd \to {}^3\mathrm{He}\,\pi^+\pi^-/\pi^0\pi^0$ and $pd \to {}^3\mathrm{He}\,X^0/{}^3\mathrm{H}\,X^+$ data.

2 Experiment

The measurements were performed at the COoler SYnchrotron and storage ring COSY [8] using the magnetic spectrometer ANKE [9] that is located inside the ring. Two dipole magnets (D1, D3) deflected an unpolarised deuteron beam onto a hydrogen cluster-jet target [10] and back onto the nominal orbit, respectively (see Fig. 1). The third dipole magnet (D2) separated the charged reaction products from the deuterons in the beam. The ${}^3\mathrm{He}$ nuclei from the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction were registered in the forward detection (FD) system, the pions in the two side detectors for positively (PD) and negatively (ND) charged particles. Each of the detector systems is equipped with multiwire proportional chambers and scintillator hodoscopes.

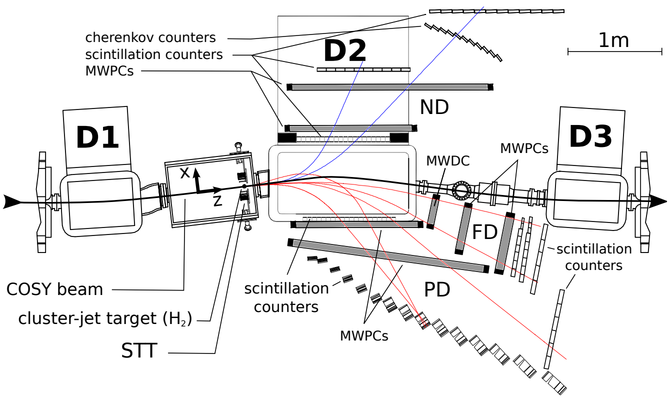

Fig. 1. The ANKE spectrometer setup showing the positions of the three dipole magnets (D1,D2,D3), the hydrogen cluster-jet target, the Silicon Tracking Telescope (STT), and the Positive (PD), Negative (ND), and Forward (FD) detectors.

The principal aim of the experimental proposal was the determination of the mass of the η meson [11] and, for this purpose, the measurements were carried out at 17 closely-spaced beam energies near the η production threshold. The experiment was divided into three supercycles, each involving up to seven different machine settings. The energy range covered is far above the threshold for two-pion production and little variation is expected for this reaction over the narrow energy interval $\Delta Q \sim 15$ MeV. The data presented in this work were therefore those taken for background studies below the η threshold, at a beam momentum of $p_d = 3.12$ GeV/c, where the highest statistics were collected[2]. This corresponds to $Q = 265$ MeV, which is effectively the same excess energy as that used in the CELSIUS-WASA experiment [7].

The kinematical range of the reaction measured at ANKE was restricted to CMS ^{3}He production angles from 143° to 173°. In this region there was practically full coverage of the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ Dalitz plot.

The integrated luminosity that was necessary for the evaluation of normalised cross sections was determined through the simultaneous measurement of deuteron-proton elastic scattering, following the procedure described in Ref. [12]. After registering the scattered deuterons in the forward detector, the reaction was isolated by identifying the proton with the missing-mass peak. Calibration data from Refs. [13] were used in the four-momentum-transfer region $0.08 < |t| < 0.26$ (GeV/c)^2. The resulting normalisation has an overall systematic uncertainty of ±6%.

3 Event selection

The events used in the analysis required a hit in the forward detector associated with a hit in at least one of the two side detectors. In cases where only one of the pions was detected in coincidence with the ^{3}He, the second pion was identified through the missing mass in the reaction.

Various steps were applied in the selection in order to identify the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction. In the forward system a clear ^{3}He band is apparent in the energy-loss-versus-momentum scatter plot shown in Fig. 2a. As seen in Fig. 2b, a large fraction of the background was suppressed by making cuts on this band for each of the three hodoscope layers. Identical cuts were applied to the Monte Carlo data used in the estimation of the acceptance corrections (see section 4).

The initial selection in the side detectors was made on the basis of the time of flight (TOF) between start and stop counters. An example of this time difference is shown in Fig. 3a for a counter combination involving the positive detector. A further cut on the TOF between the start counters of the side detectors and the counters of the forward detector was also imposed. To improve the resolution, the values of the times recorded in the first two forward hodoscope layers were averaged and, as shown in Fig. 3b, this led to a good separation of the ^{3}He from the residual proton background. A 3σ limit was used for all TOF selections.

The final selection of the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction was made using a missing-mass cut of ±0.03 (GeV/c^2)^2 on the undetected pion. This is illustrated in Figs. 4a and 4b for unobserved π^- and π^+, respectively. When all three particles were detected a 4σ cut on the invariant mass of 3.35 GeV/c^2 was applied. Fewer than 0.5% of the events from the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction were lost by making these selections. The total number of events, after making all cuts, was $\approx 81,500$, with a background that is estimated to be below 1%.

[2] The data actually used were taken from two supercycles with identical settings at this energy.

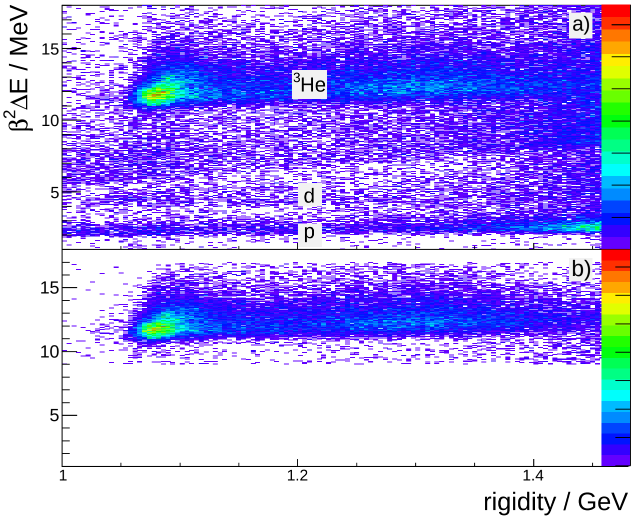

Fig. 2. (a) $\beta^2\Delta E$ versus rigidity before cuts. The reconstructed particle rigidity is recorded on the abscissa. The ordinate shows the energy deposited in the first scintillator wall of the forward detector multiplied by the square of the particle velocity, on the assumption that this is a ^{3}He nucleus. The edge, which moves between 5.5 and 8.5 MeV, is a consequence of the hardware trigger cut of about 16 MeV on ΔE. (b) The same spectrum after making cuts on the ^{3}He band for each of the three hodoscope layers.

4 Acceptance correction

In order to evaluate the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ cross sections, a correction is required to account for the limited acceptance of the ANKE detector. This has been estimated through the use of Monte Carlo simulations. Due to the strong deviation of the cross section from a simple phase space behaviour, combined with a non-uniform detector acceptance, it is necessary to find a description which reproduces adequately the main characteristics of the data.

There is no agreed model for the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction and the ansatz used here is based loosely on the idea of the Roper resonance emitting a p-wave pion and decaying into the $\Delta(1232)$ resonance, which also emits a p-wave pion when it decays [14]. Neglecting recoil effects, the simplest scalar that reflects the double p-wave transition is $\boldsymbol{k}_1 \cdot \boldsymbol{k}_2$, where the $\boldsymbol{k}_i$ are the pion momenta in centre-of-mass frame. We are therefore led to consider the form

$$\sigma \propto \left|[M_\pi^2 + B\boldsymbol{k}_1 \cdot \boldsymbol{k}_2](3\Delta^{++} + \Delta^0)\right|^2 , \qquad (4.1)$$

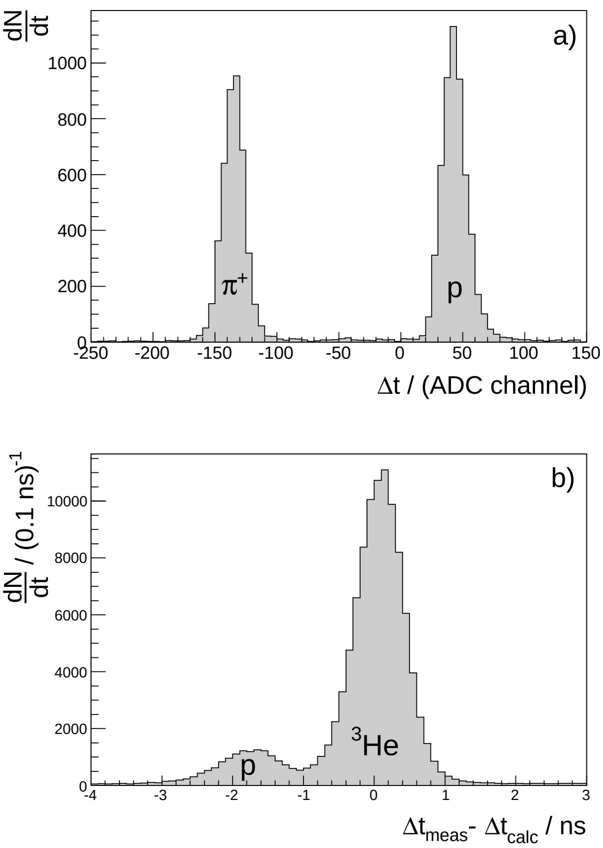

Fig. 3. (a) Time of flight difference between start and stop counters in the positive detector. Pions are clearly separated from a background that consists mainly of protons. (b) Difference between the times of flight measured between the forward hodoscope and the start counter of a side detector and that calculated from momentum information, on the assumption that the particle is a ^{3}He. The ^{3}He peak, which is centered at the origin, is well separated from a background that is composed mainly of protons.

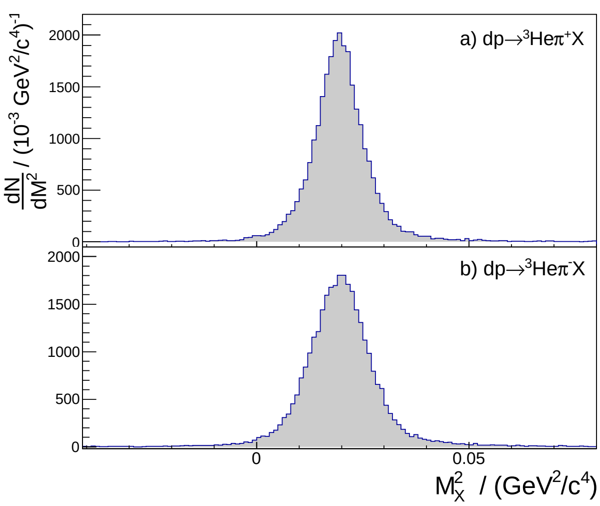

Fig. 4. Distributions in the squares of the missing masses for (a) $dp \to {}^3\mathrm{He}\,\pi^+X$ and (b) $dp \to {}^3\mathrm{He}\,\pi^-X$ reactions. Two-pion production can be clearly identified in both cases with minimal background.

where the factors 3 and 1 result from the isospin couplings. The $\Delta(1232)$ propagators are taken as [15]

$$\Delta = \frac{\sqrt{M_\Delta \Gamma / k_{\pi N}}}{M_{\pi N}^2 - M_\Delta^2 + iM_\Delta \Gamma}, \tag{4.2}$$

where the width is parameterised by

$$\Gamma = b\frac{\gamma R^2 k_{\pi N}^3}{1 + R^2 k_{\pi N}^2}, \tag{4.3}$$

with $k_{\pi N}$ being the momentum in the πN system.

Pion-nucleon data can be fitted with the values $M_\Delta = 1.238$ GeV$/c^2$, $\gamma = 0.27$, and $R = 6.3$ c/GeV [16] but, in order to account for a larger width of the isobar inside the ^{3}He nucleus, a factor $b = 1.35$ is also introduced [17]. Our $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ data can then be reasonably well described by Eq. (4.1) by choosing $B = 0.2 + 0.3i$.

The primary purpose here is to provide a plausible ansatz in order to estimate the necessary acceptance corrections. In order to study the model dependence that this introduces, we consider also the more extreme assumption;

$$\sigma \propto \left|3\Delta^{++} + \Delta^0\right|^2 P(M_{\pi^+\pi^-}). \tag{4.4}$$

The p-wave decays are omitted and a polynomial $P(M_{\pi^+\pi^-})$ included to reproduce the shape of the $M_{\pi^+\pi^-}$ invariant mass spectrum;

$$P(x) = 1.00 - 6.05x + 12.52x^2 - 8.65x^3, \tag{4.5}$$

where the masses are measured in GeV$/c^2$.

Despite the very marked differences between the forms of Eqs. (4.1) and (4.4), the acceptance-corrected distributions in the two models differ by at most 5%. Effects of a similar size are observed for modest variations of the 3:1 factor for the Δ^{++} and Δ^0, as well as the parameters M_Δ and b in Eqs. (4.2) and (4.3).

In order to investigate these corrections further, estimates were also made using a multidimensional approach in terms of the relevant degrees of freedom, as described in Ref. [18]. For a three-particle final state produced in an unpolarised reaction, there are four independent observables. These were chosen to be the invariant masses of the $^3\mathrm{He}\,\pi^-$ and the $\pi^+\pi^-$ systems, the ^{3}He production angle, and the polar angle of the normal to the ejectile plane, though the latter had minimal influence on the results. The invariant masses were each divided into ten bins and the ^{3}He angle into six.

In certain kinematical regions, where there is very low and strongly fluctuating acceptance, the multidimensional matrix method was not reliable. Thus, when comparing the acceptance corrections with those based on Eq. (4.1), the region where 3.03 GeV$/c^2 < M_{^3\mathrm{He}\,\pi^-} < 3.09$ GeV$/c^2$ and $M_{\pi^+\pi^-} > 0.43$ GeV$/c^2$ was excluded. Away from this region, both methods are in very good agreement, which suggests that Eq. (4.1) could provide a useful basis for evaluating one-dimensional acceptance corrections for the complete invariant mass region.

The systematic uncertainties associated with the choice of model used for the acceptance corrections were evaluated individually for each data point in the respective invariant mass spectrum. This was done by comparing the correction factors resulting from Eq. (4.1) with those obtained with various model variations that are essentially also in agreement with the data. These are Eq. (4.4) and the modifications of the Breit-Wigner functions that are mentioned above. For each correction factor the maximum relative deviation was taken as a measure of the systematic uncertainty.

5 Results

After correcting for inefficiencies in the data acquisition system and the MWPCs, the value of the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ differential cross section has been extracted at the excess energy $Q = 265$ MeV. Averaged over the ^{3}He production angle interval $143^\circ < \vartheta^{CMS}_{^3\mathrm{He}} < 173^\circ$, this gave $\langle d\sigma/d\Omega^{CMS}\rangle = 480 \pm 3 \pm 35$ nb/sr, where the first error is statistical and the second systematic. The latter arises mainly from the 6% uncertainty in the luminosity, though there is also some contribution coming from the ambiguity in the evaluation of the acceptance. The CELSIUS-WASA collaboration quoted a value of $\langle d\sigma/d\Omega^{CMS}\rangle = 660 \pm 60$ nb/sr when averaged over $141^\circ < \vartheta^{CMS}_{^3\mathrm{He}} < 180^\circ$ [7]. However, their cross section normalisation was derived from a comparison with $dp \to {}^3\mathrm{He}\,\pi^0$ data, which introduces a $\approx 20\%$ systematic uncertainty [19].

The comparison with the Saclay inclusive data [3] is less straightforward because only 180° results are available in our energy region and the quoted 560 ± 70 nb/sr corresponds to only the ABC peak over the hand-drawn background. However, after taking into account the $\approx 60\%$ $\pi^+\pi^-$ branching ratio, no obvious discrepancy is evident with the present data.

Double differential cross sections for the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction are shown in Fig. 5 as functions of the three possible invariant mass combinations, where the acceptance corrections have been made on the basis of Eq. (4.1). In addition we also show the difference between the $M_{^3\mathrm{He}\,\pi^+}$ and $M_{^3\mathrm{He}\,\pi^-}$ distributions.

The curves corresponding to Eq. (4.1) in Fig. 5 describe well the two $M_{^3\mathrm{He}\,\pi}$ spectra and their difference but the ABC peak in the $\pi^+\pi^-$ mass distribution is not quite sharp enough, though this could be adjusted through the introduction of a modest $\pi^+\pi^-$ form factor.

In the approach proposed here, the isospin factors of 3 and 1 in Eq. (4.1) ensure that the $\Delta(1232)$ plays a more important role in the $M_{^3\mathrm{He}\,\pi^+}$ distribution than in that of the $M_{^3\mathrm{He}\,\pi^-}$, with the latter being mainly a kinematic reflection of the $\Delta^{++}(1232)$ in the available phase space. If this is true, it would mean that a very different picture would emerge if the experiment were repeated at significantly lower or higher energy, where the kinematic reflections would be very different.

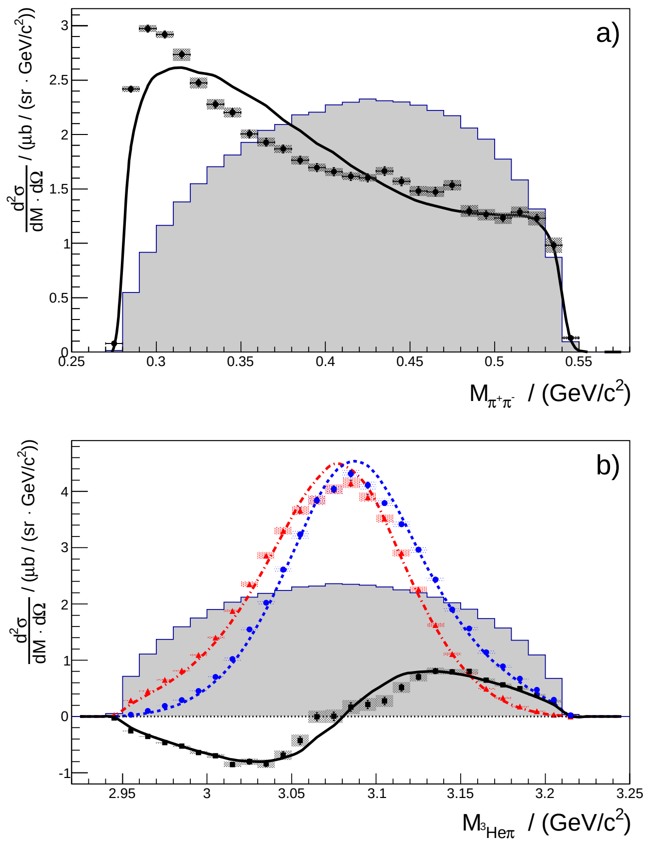

Fig. 5. Centre-of-mass double differential cross sections for the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction averaged over $143^\circ < \vartheta^{CMS}_{^3\mathrm{He}} < 173^\circ$ in terms of (a) $M_{\pi^+\pi^-}$ and (b) $M_{^3\mathrm{He}\,\pi^+}$ (blue circles) and $M_{^3\mathrm{He}\,\pi^-}$ (red triangles). The differences between the two $M_{^3\mathrm{He}\,\pi}$ distributions are plotted as black squares. Horizontal error bars show the bin width, vertical ones the statistical uncertainty. The shaded rectangles around the points reflect systematic uncertainties in the acceptance correction. There is in addition an overall normalisation uncertainty of 6%. The curves correspond to Eq. (4.1) and the shaded areas are phase-space distributions normalised to the integrated cross section.

However, it is clear from Fig. (6) that Eq. (4.1) does not describe well the whole of the charge dependence of the spectra. When events only in the ABC peak, $M_{\pi^+\pi^-} < 340$ MeV$/c^2$, are retained, the charge difference becomes even more pronounced than that predicted by the ansatz. The model must therefore underestimate the strength of $I_{\pi\pi} = 1$ production at low $M_{\pi^+\pi^-}$.

6 Discussion and Conclusions

Using the COSY-ANKE spectrometer, we have measured the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction over a significant angular range at an excess energy of 265 MeV. About 81,500 fully reconstructed events were obtained with negligible background. The results are broadly consistent with those found at CELSIUS by the WASA collaboration [7], though their larger geometric acceptance must be weighed against the

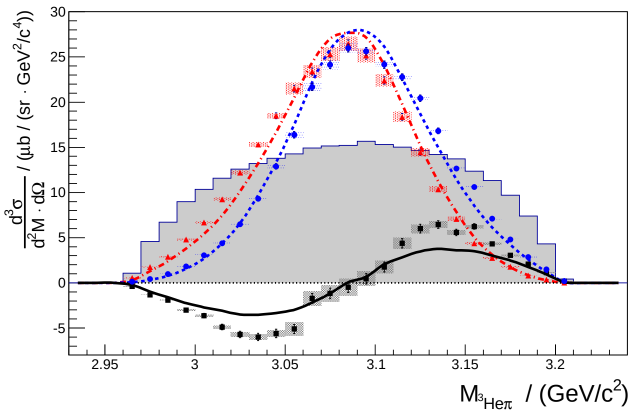

Fig. 6. $M_{^3\mathrm{He}\,\pi}$ cross section spectra for the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction as in Fig. 5 but only for those events where $M_{\pi^+\pi^-} <$ 340 MeV/c^2.

higher resolution and greater statistics achieved in the current experiment.

Although ANKE has limited acceptance, the three different approaches that have been used to compensate for this resulted in distributions that were remarkably similar, with differences on the 5% level. Reliable differential cross sections could therefore be extracted for $143^\circ < \vartheta^{CM}_{^3\mathrm{He}} < 173^\circ$. Over this range the differential cross section is consistent with that found at CELSIUS [7].

Apart from the ABC structure, which was already well known from the inclusive measurements [1,3], the most striking feature of the data is the peaking in the $M_{^3\mathrm{He}\,\pi^\pm}$ distributions. Their difference, which was deduced with high precision, shows that there must be some $I_{\pi\pi} = 1$ $\pi^+\pi^-$ production that interferes with the dominant $I_{\pi\pi} = 0$ of the ABC enhancement. We have tried to explain this effect in terms of a $N^*(1440) \to \Delta(1232) \to N$ decay chain and, although this can describe the total results, it is seen from Fig. 6 that this approach does not give sufficient isovector strength at low $M_{\pi^+\pi^-}$. The $\Delta(1232)$ propagator model of Eq. (4.1) also has the problem that it predicts no $I_{\pi\pi} = 1$ production at maximum $M_{\pi^+\pi^-}$.

Turning now to earlier experimental data, the $I_{\pi\pi} = 1$ production rate could be studied by comparing the cross sections for final $\pi^+\pi^-$ and $\pi^0\pi^0$ states in the CELSIUS data [7]. There are some uncertainties in the relative normalisation and, in an attempt to avoid this problem, the data can be scaled slightly so that there is no $I_{\pi\pi} = 1$ production in the phase-space-corrected data at very low $M_{\pi\pi}$. However this then suggests little $I_{\pi\pi} = 1$ production below about 450 MeV/c^2 and this is certainly insufficient to explain our $M_{^3\mathrm{He}\,\pi^\pm}$ difference, which require an $I_{\pi\pi} = 1$ amplitude for $M_{\pi^+\pi^-} < 340$ MeV/c^2. A very reliable relative normalisation for $\pi^0\pi^0$ and $\pi^+\pi^-$ detection is therefore a prerequisite if one wants to use this approach to deduce the $I_{\pi\pi} = 1/I_{\pi\pi} = 0$ production ratio.

If information is sought instead from the original inclusive $pd \to {}^3\mathrm{H}\,X^+/{}^3\mathrm{He}\,X^0$ measurements [1], there is the difficulty of identifying the background. If this is taken to be constant at the level found at around 270 MeV/c^2, then the $I_{\pi\pi} = 1/I_{\pi\pi} = 0$ production ratio is over 10% by 340 MeV/c^2. Similar indications are found in the Saclay data at a deuteron momentum of ≈ 3.4 GeV/c [3]. This might be sufficient to explain the observed $M_{^3\mathrm{He}\,\pi^\pm}$ difference, but this conclusion does depend upon the background assumptions.

In summary, by measuring carefully the differences in the $M_{^3\mathrm{He}\,\pi^+}$ and $M_{^3\mathrm{He}\,\pi^-}$ invariant mass spectra produced in the $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ reaction, we have shown that there must be some $I_{\pi\pi} = 1$ production, even in the ABC region of $\pi^+\pi^-$ masses. Similar effects cannot exist for $dd \to {}^4\mathrm{He}\,\pi^+\pi^-$ [20] because only the $I_{\pi\pi} = 0$ channel is there allowed. In the other case where the ABC effect is clearly seen, $np \to \mathrm{d}\,\pi^+\pi^-$, the π^+d and π^-d systems are both purely $I = 1$ so that little difference is to be expected in the M_{π^+d}/M_{π^-d} mass distributions, and none is observed in the WASA data [19].

The simple isobar production model suggested to describe our $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ data underestimate the $I_{\pi\pi} = 1$ strength at low $M_{\pi\pi}$. The effects seem much larger than anything resulting from isospin violation and call for a renewed effort to clarify the production mechanism in this reaction. Further exclusive measurements at much higher or lower energy could be very illuminating in this respect.

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