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Search for an isospin $I = 3$ dibaryon

The WASA-at-COSY Collaboration

P. Adlarson [a,1], W. Augustyniak [b], W. Bardan [c], M. Bashkanov [d,*], F.S. Bergmann [e], M. Berłowski [f], H. Bhatt [g], A. Bondar [h,i], M. Büscher [l,2,3], H. Calén [a], I. Ciepał [c], H. Clement [j,k], E. Czerwiński [c], K. Demmich [e], R. Engels [l], A. Erven [m], W. Erven [m], W. Eyrich [n], P. Fedorets [l,o], K. Föhl [p], K. Fransson [a], F. Goldenbaum [l], A. Goswami [l,q], K. Grigoryev [l,r,4], C.-O. Gullström [a], L. Heijkenskjöld [a], V. Hejny [l,1], N. Hüsken [e], L. Jarczyk [c], T. Johansson [a], B. Kamys [c], G. Kemmerling [m,5], F.A. Khan [l], G. Khatri [c], A. Khoukaz [e], O. Khreptak [c], D.A. Kirillov [s], S. Kistryn [c], H. Kleines [m,5], B. Kłos [t], W. Krzemień [c], P. Kulessa [u], A. Kupść [a,f], A. Kuzmin [h,i], K. Lalwani [v], D. Lersch [l], B. Lorentz [l], A. Magiera [c], R. Maier [l,w,x], P. Marciniewski [a], B. Mariański [b], H.-P. Morsch [b], P. Moskal [c], H. Ohm [l], E. Perez del Rio [j,k,6], N.M. Piskunov [s], D. Prasuhn [l], D. Pszczel [a,f], K. Pysz [u], A. Pyszniak [a,c], J. Ritman [l,w,x,y], A. Roy [q], Z. Rudy [c], O. Rundel [c], S. Sawant [g,l], S. Schadmand [l], I. Schätti-Ozerianska [c], T. Sefzick [l], V. Serdyuk [l], B. Shwartz [h,i], K. Sitterberg [e], T. Skorodko [j,k,z], M. Skurzok [c], J. Smyrski [c], V. Sopov [o], R. Stassen [l], J. Stepaniak [f], E. Stephan [t], G. Sterzenbach [l], H. Stockhorst [l], H. Ströher [l,w,x], A. Szczurek [u], A. Trzciński [b], R. Varma [g], M. Wolke [a], A. Wrońska [c], P. Wüstner [m], A. Yamamoto [aa], J. Zabierowski [ab], M.J. Zieliński [c], A. Zink [n], J. Złomańczuk [a], P. Żupránski [b], M. Żurek [l]

[a] Division of Nuclear Physics, Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden
[b] Department of Nuclear Physics, National Centre for Nuclear Research, ul. Hoza 69, 00-681, Warsaw, Poland
[c] Institute of Physics, Jagiellonian University, ul. Reymonta 4, 30-059 Kraków, Poland
[d] School of Physics and Astronomy, University of Edinburgh, James Clerk Maxwell Building, Peter Guthrie Tait Road, Edinburgh EH9 3FD, United Kingdom
[e] Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany
[f] High Energy Physics Department, National Centre for Nuclear Research, ul. Hoza 69, 00-681, Warsaw, Poland
[g] Department of Physics, Indian Institute of Technology Bombay, Powai, Mumbai 400076, Maharashtra, India
[h] Budker Institute of Nuclear Physics of SB RAS, 11 akademika Lavrentieva prospect, Novosibirsk, 630090, Russia
[i] Novosibirsk State University, 2 Pirogova Str., Novosibirsk, 630090, Russia
[j] Physikalisches Institut, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany
[k] Kepler Center for Astro and Particle Physics, Eberhard Karls University Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany
[l] Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany
[m] Zentralinstitut für Engineering, Elektronik und Analytik, Forschungszentrum Jülich, 52425 Jülich, Germany
[n] Physikalisches Institut, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
[o] Institute for Theoretical and Experimental Physics, State Scientific Center of the Russian Federation, Bolshaya Cheremushkinskaya 25, 117218 Moscow, Russia
[p] II. Physikalisches Institut, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany
[q] Department of Physics, Indian Institute of Technology Indore, Khandwa Road, Indore 452017, Madhya Pradesh, India
[r] High Energy Physics Division, Petersburg Nuclear Physics Institute, Orlova Rosha 2, Gatchina, Leningrad district 188300, Russia
[s] Veksler and Baldin Laboratory of High Energiy Physics, Joint Institute for Nuclear Physics, Joliot-Curie 6, 141980 Dubna, Moscow region, Russia
[t] August Chełkowski Institute of Physics, University of Silesia, Uniwersytecka 4, 40-007, Katowice, Poland
[u] The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, 152 Radzikowskiego St, 31-342 Kraków, Poland

* Corresponding author.
E-mail address: mikhail.bashkanov@ed.ac.uk (M. Bashkanov).
[1] Present address: Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Johann-Joachim-Becher Weg 45, 55128 Mainz, Germany.
[2] Present address: Peter Grünberg Institut, PGI-6 Elektronische Eigenschaften, Forschungszentrum Jülich, 52425 Jülich, Germany.
[3] Present address: Institut für Laser- und Plasmaphysik, Heinrich-Heine Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany.
[4] Present address: III. Physikalisches Institut B, Physikzentrum, RWTH Aachen, 52056 Aachen, Germany.
[5] Present address: Jülich Centre for Neutron Science JCNS, Forschungszentrum Jülich, 52425 Jülich, Germany.
[6] Present address: INFN, Laboratori Nazionali di Frascati, Via E. Fermi, 40, 00044 Frascati (Roma), Italy.

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[v] Department of Physics, Malaviya National Institute of Technology, Jaipur, 302017, Rajasthan, India
[w] JARA-FAME, Jülich Aachen Research Alliance, Forschungszentrum Jülich, 52425 Jülich, Germany
[x] RWTH Aachen, 52056 Aachen, Germany
[y] Institut für Experimentalphysik I, Ruhr-Universität Bochum, Universitätsstr. 150, 44780 Bochum, Germany
[z] Department of Physics, Tomsk State University, 36 Lenina Avenue, Tomsk, 634050, Russia
[aa] High Energy Accelerator Research Organisation KEK, Tsukuba, Ibaraki 305-0801, Japan
[ab] Department of Astrophysics, National Centre for Nuclear Research, Box 447, 90-950 Łódź, Poland

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ABSTRACT

Various theoretical calculations based on QCD or hadronic interactions predict that in addition to the recently observed dibaryon resonance $d^*(2380)$ with $I(J^P) = 0(3^+)$ there should also exist a dibaryon resonance with mirrored quantum numbers $I(J^P) = 3(0^+)$. We report here on a search for such a NN-decoupled state in data on the $pp \to pp\pi^+\pi^+\pi^-\pi^-$ reaction. Since no clear-cut evidence has been found, we give upper limits for the production cross section of such a resonance in the mass range 2280–2500 MeV.

1. Introduction

Recently, exclusive and kinematically complete measurements of the reactions $pn \to d\pi^0\pi^0$ and $pn \to d\pi^+\pi^-$ revealed a narrow resonance-like structure in the total cross section [1–3] at a mass $m \approx 2380$ MeV with a width of $\Gamma \approx 70$ MeV and quantum numbers $I(J^P) = 0(3^+)$. Additional evidence for it had been traced subsequently in the two-pion production reactions $pn \to pp\pi^0\pi^-$ [4], $pn \to pn\pi^0\pi^0$ [5] and $pn \to pn\pi^+\pi^-$ [6–8]. Finally, analyzing power measurements of np elastic scattering established this structure to represent a true s-channel resonance, which produces a pole in the $^3D_3$ partial wave – denoted since then by $d^*(2380)$ [9–12].

Such a dibaryon resonance, which asymptotically resembles a deeply bound $\Delta\Delta$ system, was predicted first – and astonishingly precise as it turns out now – by Dyson and Xuong [13] in 1964 based on $SU(6)$ symmetry breaking. Later-on, Goldman et al. [14] called this state the "inevitable dibaryon" pointing out that due to its particular quantum numbers and its associated special symmetries, such a state must be predicted in any theoretical model based on confinement and one-gluon exchange. Indeed, there are now quite a number of QCD-based model calculations available, which find $d^*(2380)$ at about the correct mass [15–22]. Also, relativistic Faddeev-type calculations based on hadronic interactions find this state at the observed mass [23,24]. The observed relatively narrow width of about 70 MeV is obviously more difficult to understand theoretically. Until recently, Gal and Garcilazo came closest with about 100 MeV [24]. Dong et al. [18] succeeded in reproducing the experimental width by accounting for hidden color effects – as had been speculated already in Ref. [25].

Part of the theoretical calculations, which successfully obtain the $d^*(2380)$ state, predicts also a dibaryon state with mirrored quantum numbers $I(J^P) = 3(0^+)$ at a similar mass [13,15,16,24]. In tendency, this state, which is expected to be again a $\Delta\Delta$ configuration asymptotically, appears to be somewhat less bound than $d^*(2380)$, but still below the $\Delta\Delta$ threshold of $2m_\Delta$. The predicted width varies from about 90 MeV [24] to about 180 MeV [15]. Only the calculation of the Nijmegen group [22] predicts this state to be far above the $\Delta\Delta$ threshold.

2. Experiment

In order to investigate this issue experimentally, we follow the suggestion of Dyson and Xuong (who called the state in question the D_{30}, where the first index denotes the isospin and the second one the spin) and consider the four-pion production in proton-proton collisions, in particular the $pp \to pp\pi^+\pi^+\pi^-\pi^-$ reaction. Because of its isospin $I = 3$ such a state is isospin-decoupled from the nucleon–nucleon (NN) system. Therefore, in order to be able to reach such a state by NN collisions, its production in the collision process needs to be associated by the generation of particles, which take away two units of isospin. This appears to be accomplished most easily by the production of two extra pions. So the process we aim at reads as $pp \to D_{30}\pi^-\pi^- \to \Delta^{++}\Delta^{++}\pi^-\pi^- \to pp\pi^+\pi^+\pi^-\pi^-$. Due to $I = 3$ the $\Delta^{++}\Delta^{++}$ configuration is the most preferred $\Delta\Delta$ combination, where D_{30} decays into – see next section.

The measurements of this reaction have been carried out with the WASA detector including a hydrogen pellet target [26,27] at the cooler synchrotron COSY (Forschungszentrum Jülich) using proton beams with energies of $T_p = 2.063$ and 2.541 GeV. These correspond to center-of-mass energies of $\sqrt{s} = 2.72$ and 2.88 GeV, respectively. The latter denotes the highest energy used with WASA at COSY.

The trigger was set to two (and more) charged hits both in the forward and in the central detector. Since the main goals of these runs, which comprise 3 weeks of beam-time, was not the four-pion production, but ω and η' production, also a missing mass trigger was active during the measurements at 2.541 GeV. It required the deposited energy of each of the two protons detected in the forward detector to be larger than 150 MeV – a condition, which did not affect the four-pion production events.

The four-momenta of the two emitted protons were detected in the Forward Detector, whereas the four-momenta of the four charged pions were recorded in the Central Detector, where a magnetic field allowed for charge identification and momentum determination. That way, the reaction was measured kinematically complete with four overconstraints, which allowed a corresponding kinematic fit of the events. Finally, a total of 136 (1017) events at $T_p = 2.063$ (2.541) GeV passed the χ^2 criterion of the kinematic fit, which is a cut of the probability function at 10%. Despite the kinematic fit condition, Monte Carlo (MC) simulations suggest that the final sample at $T_p = 2.063$ GeV is contaminated with about 50 events originating from three-pion production, where the photons from π^0 decay have undergone conversion or Dalitz decay. The distribution of those events is not noticeably different from the other events. The acceptance of the WASA detector for $pp\pi^+\pi^+\pi^-\pi^-$ events has been determined by MC simulations to be about 15%

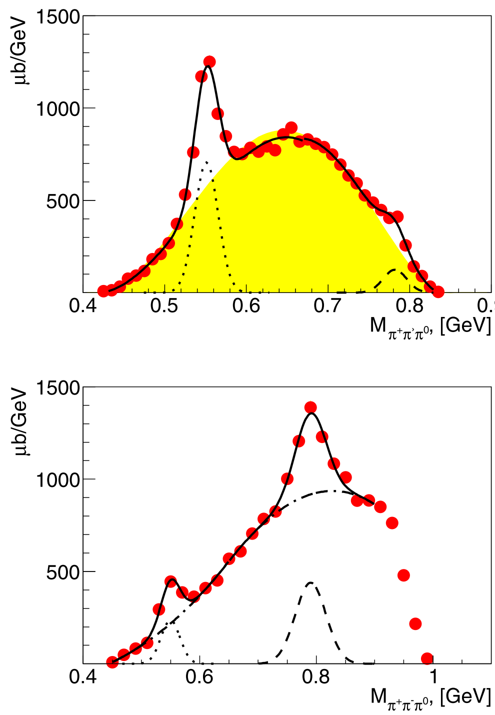

Fig. 1. (Color online.) Measured spectrum of the $pp \to pp\pi^+\pi^0\pi^-$ reaction at $T_p = 2.063$ (top) and 2.541 GeV (bottom). The filled circles represent the data from this work. Dotted and dashed lines give the fitted η and ω contributions, whereas the shaded area in the top panel shows the pure phase-space distribution. The dash-dotted line in the bottom panel is a polynomial fit of direct three-pion production. The solid line is the sum of η, ω and direct three-pion production.

with an uncertainty of less than 1%. The detection efficiency for $pp\pi^+\pi^+\pi^-\pi^-$ events has been 0.1 % at $T_p = 2.063$ GeV and 0.5% at $T_p = 2.541$ GeV, also evaluated via comprehensive MC simulations of the detector performance.

The absolute normalization of the four-pion production data has been done via the simultaneous measurement of the three-pion production ($\pi^+\pi^-\pi^0$ with π^0 decay into two photons) including η and ω production in this channel. The spectra of the three-pion invariant mass $M_{\pi^+\pi^0\pi^-}$ at $T_p = 2.063$ GeV and $T_p = 2.541$ GeV are shown in Fig. 1. Since the cross section for three-pion production is two orders of magnitude larger than that for four-pion production, it was sufficient to use only a small sample of the available three-pion production data for this procedure.

At $T_p = 2.063$ GeV, the data for the three-pion production (including η and ω production) have been normalized to the value of 220 μb obtained in Refs. [28,29] for this reaction at $T_p = 2$ GeV. As a result, the fitted contributions from η and ω production (dotted and dashed lines in Fig. 1) correspond to production cross sections of 111 ± 20 μb and 5.6 ± 1.0 μb, respectively. The first value agrees reasonably well with the value of 142 ± 22 μb obtained at $T_p = 2.2$ GeV by the HADES Collaboration [30]. The second value is in good agreement with the value of 5.7 μb obtained in Ref. [31].

At $T_p = 2.541$ GeV, where ω production provides already a substantial contribution to three-pion production, the data have been normalized to this process using for the ω production cross section the value 35 μb interpolated from the values given in Refs. [32,33].

As a result of this normalization procedure, we obtain total four-pion cross sections of 0.7 ± 0.3 and 5.2 ± 1.0 μb at $T_p = 2.063$ and 2.541 GeV, respectively, which are two orders of magnitude smaller than the three-pion production cross sections at these energies.

The quoted uncertainties originate predominantly from systematic uncertainties in the determination of background beneath the

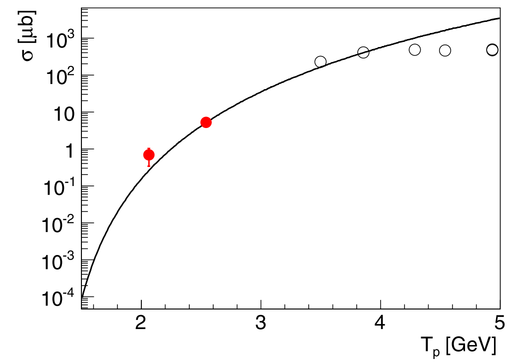

Fig. 2. (Color online.) Energy dependence of the total cross section for the $pp \to pp\pi^+\pi^+\pi^-\pi^-$ reaction. The filled circles are from this work, the open symbols from Refs. [34–38]. The drawn line gives the energy dependence of pure phase space normalized to the data point at $T_p = 2.541$ GeV.

η and ω peaks, the determination of the WASA acceptance and efficiency and the extrapolation of cross sections to full phase space, which has been done by MC simulations assuming phase-space or model distributions – see next section.

Due to the small statistics for the four-pion production reaction, all systematical effects had to be evaluated by Monte Carlo simulations only. However, some of these systematic effects, like influence of missing-mass trigger could be cross-checked with the $pp \to pp\pi^+\pi^0\pi^-$ reaction due to much higher statistics, same multiplicity (π^0 decays into two photons, hence there are also six particles detected in the final state) and very similar kinematics. Therefore systematical errors related to triggering, errors parameterization, kinematical fitting, etc. were evaluated based on large samples of three-pion production data.

The widths of about 30 MeV for the η and ω lines in the three-pion spectrum give a measure of the mass resolution achieved in this data analysis.

3. Results and discussion

The energy dependence of the total cross section for the $pp \to pp\pi^+\pi^+\pi^-\pi^-$ reaction is displayed in Fig. 2, where our results are compared to earlier published data [34–38] obtained a higher energies. The solid line represents the energy dependence of pure phase space. It accounts at least qualitatively for the trend of the data.

Having measured the four-pion production kinematically complete, we are able to construct all kinds of differential distributions. Of relevance in the search for the $I = 3$ dibaryon D_{30} are the spectra of the $pp\pi\pi$-invariant masses $M_{pp\pi^+\pi^+}$, $M_{pp\pi^-\pi^-}$ and $M_{pp\pi^+\pi^-}$. For the latter the statistics quadruples due to combinatorics. These spectra are displayed in Fig. 3 for both incident energies. They are shown within WASA acceptance, *i.e.* not acceptance corrected, in order to avoid any model dependence introduced by the corresponding correction procedure.

The spectra in Fig. 3 show very smooth mass distributions and do not exhibit any unusual structures. However, they deviate systematically from pure six-body phase-space distributions, which are shown (again within WASA acceptance) by the shaded histograms in Fig. 3. This is not surprising, since already single- and two-pion productions are known to be dominated by baryon excitations starting right from threshold [39–45].

The lowest-lying baryon resonance, which decays by emission of two pions, is the Roper resonance $N^*(1440)$ with its two-pion decay routes $N^* \to N\sigma \to N\pi\pi$ and $N^* \to \Delta\pi \to N\pi\pi$. It is known to dominate the two-pion production for energies $T_p < 1$ GeV – before the $\Delta\Delta$ excitation by t-channel meson ex-

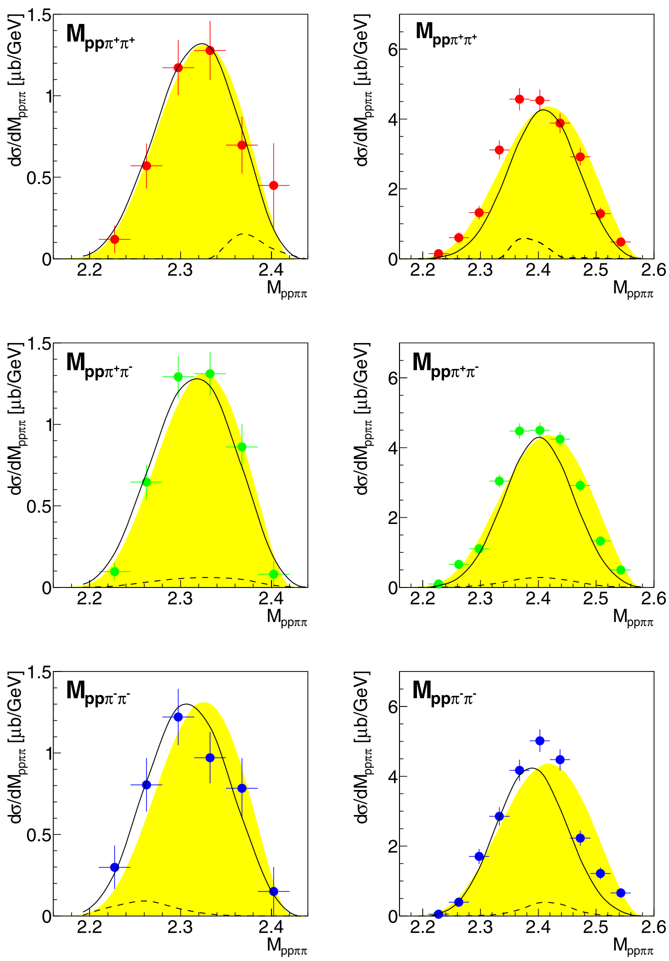

Fig. 3. (Color online.) Distributions of invariant masses $M_{pp\pi^+\pi^+}$ (top), $M_{pp\pi^+\pi^-}$ (middle) and $M_{pp\pi^-\pi^-}$ (bottom) for $\sqrt{s} = 2.72$ GeV (left) and 2.88 GeV (right) within WASA acceptance. Solid dots denote the data from this work, the shaded histograms represent phase-space distributions, whereas the calculated t-channel $N^*(1440)N^*(1440)$ distribution is shown by the solid lines. The dotted curves show the effect of an $I = 3$ resonance with mass $m = 2380$ MeV and width $\Gamma = 70$ MeV scaled arbitrarily in height to a 5% contribution of the total cross section.

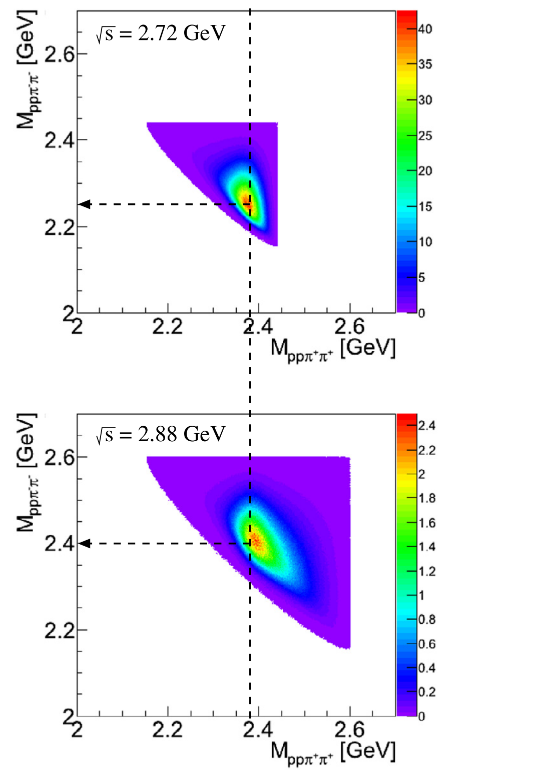

Fig. 4. (Color online.) Distribution of MC-simulated events plotted in the plane of $M_{pp\pi^-\pi^-}$ versus $M_{pp\pi^+\pi^+}$ for an $I = 3$ resonance with mass $m = 2380$ MeV and width $\Gamma = 70$ MeV. The top panel exhibits the situation at $\sqrt{s} = 2.72$ GeV, the bottom panel that at $\sqrt{s} = 2.88$ GeV.

change starts to dominate at energies above 1 GeV. Since the latter configuration can produce only two pions in its decay, the only resonance process eligible for four-pion production is the double $N^*(1440)$ excitation, *i.e.* the $N^*(1440)N^*(1440)$ excitation by t-channel meson exchange between the colliding incident nucleons. Also, the nominal mass of $2m_{N^*(1440)}$ for this configuration fits very well to the center-of-mass energies of the measurements discussed here. A model calculation based on an extended version of the modified Valencia model [44,42] reproduces the measured total cross sections within 30%.

The solid lines in Fig. 3 show a calculation of the $N^*(1440)N^*(1440)$ process adjusted in height to the data. For the lower energy, $\sqrt{s} = 2.72$ GeV, this calculation gives already a practically perfect description of all three invariant-mass spectra within uncertainties.

For the higher energy this description is not quite as good, since it misses strength at low $pp\pi^+\pi^+$ and high $pp\pi^-\pi^-$ invariant masses. The situation could possibly be improved, if we would fit a contribution from the next higher-lying N^* excitation (providing a $N^*(1520)N^*(1440)$ configuration in the intermediate state) to the data. But we refrain here from a fine tuning of the background description due to the much increased complexity of the theoretical description, which necessarily introduces new uncertainties. We just note that the behavior of the shapes given by the solid lines is characteristic for a dominance of the $\Delta^{++}\Delta^{++}$ excitation insofar as the $M_{pp\pi^+\pi^+}$ spectrum is narrower than the pure phase-space spectrum and peaking around $2m_\Delta$, whereas the $M_{pp\pi^-\pi^-}$ spectrum exhibiting dominantly the reflection of the $\Delta^{++}\Delta^{++}$ excitation peaks at substantial lower mass.

Next, we investigate, how an $I = 3$ resonance would show up in these spectra. From isospin coupling arguments, we deduce the relative cross sections, with which such a resonance should show up in the various invariant-mass spectra, namely:

$$\sigma_{pp\pi^+\pi^+} : \sigma_{pp\pi^+\pi^-} : \sigma_{pp\pi^-\pi^-} = 1 : \frac{2}{225} : \frac{1}{225}. \qquad (1)$$

I.e., such a resonance contributes practically only to the spectrum with the highest charge in a direct way. However, since the three invariant-mass spectra are interrelated, reflections of such a resonance also appear in the $M_{pp\pi^+\pi^-}$ and $M_{pp\pi^-\pi^-}$ spectra – as illustrated in Fig. 4, where MC generated events are plotted in the plane $M_{pp\pi^-\pi^-}$ versus $M_{pp\pi^+\pi^+}$. It displays the results of a simulation of an $I = 3$ resonance with $m = 2380$ MeV and $\Gamma = 70$ MeV. The simulated resonance is shown in Fig. 3 by the dashed curves scaled in height corresponding to a 5% contribution of the resonance to the total cross section. Whereas in the $M_{pp\pi^+\pi^-}$ spectrum the reflection causes a broad phase-space like continuum, it produces a peak-like structure in the $M_{pp\pi^-\pi^-}$ distribution, though somewhat broader than the original peak in the $M_{pp\pi^+\pi^+}$ spectrum and located in the complementary region of the kinematical mass range.

Knowing now the kinematic behavior of such an $I = 3$ resonance, we further inspect the data shown in Fig. 3. We observe no obvious narrow structures, which fulfill the kinematical conditions for a possible $I = 3$ resonance. However, we immediately also notice that a contribution of a dibaryon resonance as illus-

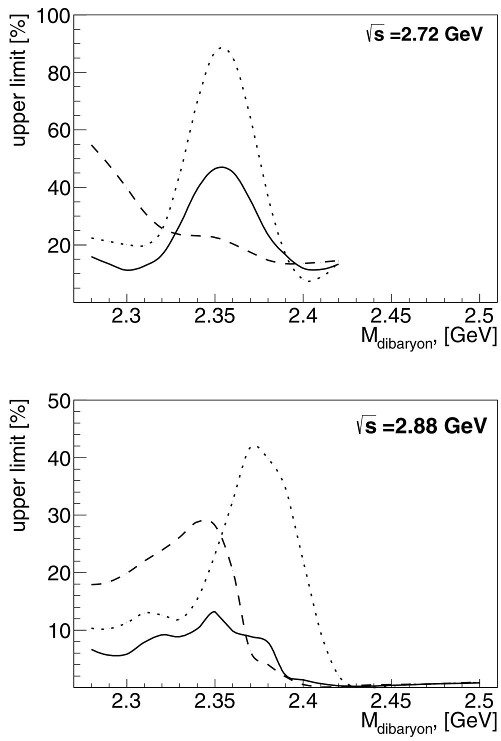

Fig. 5. (Color online.) Upper limits (C.L. 95%) in percentage of the total cross section from the search for an $I = 3$ resonance structure conducted on the invariant mass spectra of Fig. 3 at $\sqrt{s} = 2.72$ GeV (top) and 2.88 GeV (bottom) assuming the conventional processes to behave like the $N^*(1440)N^*(1440)$ distributions. The solid, dotted and dashed lines refer to a fit search with a line width of $\Gamma = 50$, 100 and 150 MeV, respectively.

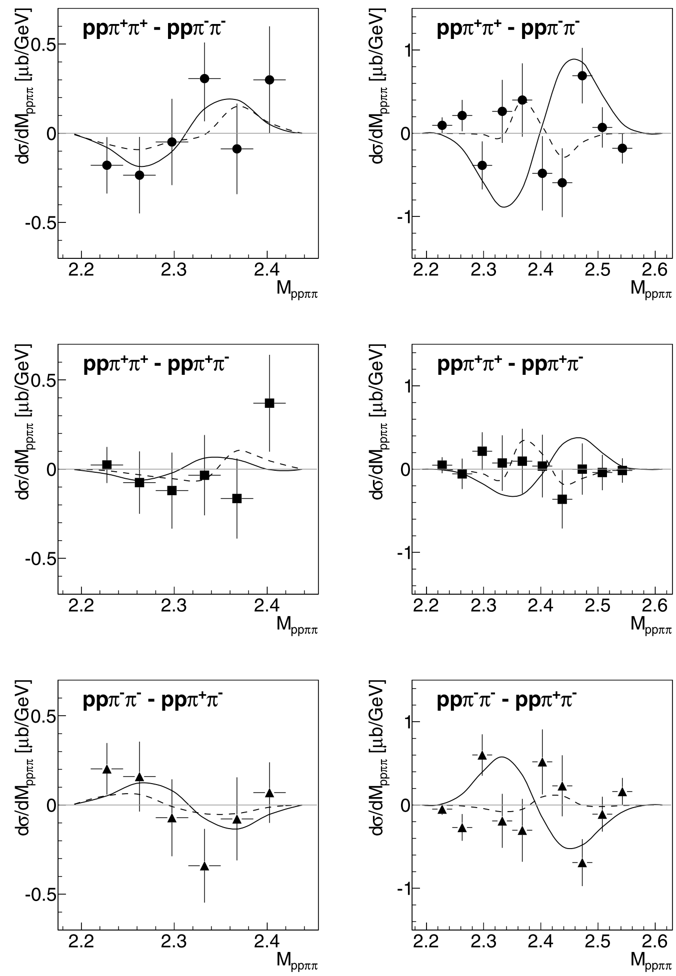

Fig. 6. (Color online.) Difference spectra as defined in the text in dependence of $M_{pp\pi\pi}$. The dashed curve represents the simulation of an $I = 3$ resonance with mass $m = 2380$ MeV and width $\Gamma = 70$ MeV, the solid line the t-channel $N^*(1440)N^*(1440)$ excitation. The left panel exhibits the situation at $\sqrt{s} = 2.72$ GeV, the right panel that at $\sqrt{s} = 2.88$ GeV.

trated by the dashed lines in Fig. 3 would certainly give an improved description of the data. Though this is certainly a model-dependent statement, it demonstrates the difficulty of excluding a dibaryon resonance contribution of smaller than 5% of the total cross section – in particular for dibaryon masses smaller than 2380 MeV.

In an ideal case the peak to be searched for is expected to sit upon a flat or smoothly rising or falling background with a curvature, which is small compared to the peak width. This is far from being the case here. On theoretical grounds we can not expect the dibaryon resonance to have a width much smaller than 50 MeV, more likely is a width in the region of 100 MeV or even above, if this resonance happens to be close to the $\Delta\Delta$ threshold. The background due to conventional processes is not flat or smoothly rising/falling in the range of interest as we see from the distributions displayed in Fig. 3. Moreover shape and strength of the background can not be calculated sufficiently reliable within contemporary theoretical approaches. Though the width of these distributions is still broader than the dibaryon signal we look for, it is not broader by an order of magnitude. We are not aware of any model-independent peak search analysis for such a case. Hence we will proceed by assuming two scenarios, where the background is accounted for either by phase space-like processes (meaning processes, which give identical contributions in all $M_{NN\pi\pi}$ spectra, e.g. chiral terms, various contact terms, etc.) or by the $N^*(1440)N^*(1440)$ process displayed in Fig. 3. The $N^*(1440)N^*(1440)$ scenario represents a theoretically-motivated background description, though possibly oversimplified as discussed above.

As usual in such peak searches, we assume interferences to be small and add the resonance term incoherently to the background term. Under these assumptions the shapes of both resonance and background can be considered to be known (also within WASA acceptance). Then for given mass and width of the resonance only the relative contributions of resonance and background enter the simultaneous fit of all three invariant mass spectra. The upper limits (95% C.L.) resulting from these single-parameter fits are displayed in Fig. 5 in dependence of a hypothetical dibaryon mass $M_{dibaryon}$ for assumed resonance widths of 50 MeV (solid lines), 100 MeV (dotted) and 150 MeV (dashed).

In order to investigate the case, where the background is assumed to be distributed phase-space like, we consider the following difference spectra constructed out of the three invariant-mass spectra: $\sigma_{pp\pi^+\pi^+} - \sigma_{pp\pi^-\pi^-}$, $\sigma_{pp\pi^+\pi^+} - \sigma_{pp\pi^+\pi^-}$ and $\sigma_{pp\pi^-\pi^-} - \sigma_{pp\pi^+\pi^-}$, since they have the advantage that there the contributions from phase-space like distributions cancel. Note that any possible contaminations from misreconstructed background, like three-pion production with subsequent π^0 Dalitz decay, cancels out in the difference spectra as well.

In these difference spectra, which are plotted in Fig. 6 for both beam energies, double baryon excitations due to t-channel meson exchange produce an antisymmetric pattern (see solid lines in Fig. 6), whereas an $I = 3$ resonance in the $pp\pi^+\pi^+$ subsystem should show up in general by an asymmetric pattern formed by its direct peak and its reflection – as indicated by the dashed curves in Fig. 6.

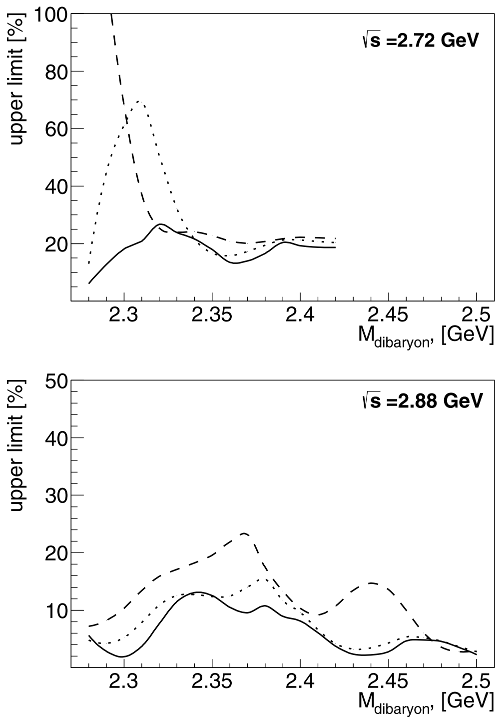

Fig. 7. (Color online.) Upper limits (C.L. 95%) in percentage of the total cross section from the search for an $I = 3$ resonance structure conducted on the difference spectra defined in eqs. (2)–(4) at $\sqrt{s} = 2.72$ GeV (top) and 2.88 GeV (bottom). The solid, dotted and dashed lines refer to a fit search with a peak width of $\Gamma = 50$, 100 and 150 MeV, respectively.

Since we know the expected signature of such a resonance in the difference spectra, we can perform again single-parameter peak finding fits simultaneously to all three difference spectra per beam energy and thus obtain upper limits for such a resonance in dependence of its mass and width. The results for the 95% C.L. upper limits of this peak finding search are displayed in Fig. 7.

Both in Fig. 5 and in Fig. 7 the 95% C.L. upper limits are plotted in percentage of the total cross section. The extrapolation of our results obtained within the WASA acceptance to total cross sections introduces systematic uncertainties, as discussed in the experimental section. They amount to 40% for the lower energy and 20% for the higher energy.

For both scenarios – $N^*(1440)N^*(1440)$ and phase-space like background – we obtain qualitatively similar results. Due to the much superior statistics at the higher energy, the resulting upper limits are much more stringent there. As expected, the data are most sensitive to the signature of a narrow resonance. Also, for large dibaryon masses the upper limits are in general substantially lower than for small masses. The largest upper limit happens in the $N^*(1440)N^*(1440)$ background scenario for a dibaryon mass of about 2380 MeV and a width of 100 MeV, where the upper limit reaches 40% of the total cross section.

Compared to the formation cross section of 1.7 mb found for $d^*(2380)$ [46], the upper limits found here for the production of an $I = 3$ dibaryon resonance are smaller by three to four orders of magnitude.

More informative should be the comparison to formation/production of a $\Delta\Delta$ system by conventional t-channel meson exchange. In two-pion production (isoscalar part) the peak cross section for $d^*(2380)$ formation is roughly one order of magnitude larger than the one for the conventional $\Delta\Delta$ process [2] at the $d^*(2380)$ peak energy. If we assume that the four-pion production at the beam energies considered here is dominated by $N^*(1440)N^*(1440)$ formation as shown in Fig. 3, then we know also the cross section for conventional $\Delta^{++}\Delta^{++}$ production via the route $pp \to N^*(1440)N^*(1440) \to \Delta^{++}\Delta^{++}\pi^-\pi^-$. The calculations shown in Fig. 3 contain the two-pion decay routes of the Roper resonance $N^*(1440) \to N\sigma \to N\pi\pi$ and $N^*(1440) \to \Delta\pi \to N\pi\pi$ with the branching ratio obtained in Refs. [44,47,48]. From these calculations we find that at $\sqrt{s} = 2.72$ GeV about 6% of the total cross section are due to conventional $\Delta^{++}\Delta^{++}$ production. For $\sqrt{s} = 2.88$ GeV the corresponding number is 32%.

Whereas for the lower incident energy the upper limits obtained for D_{30} production are in general larger than the cross section for conventional $\Delta^{++}\Delta^{++}$ production, the upper limits obtained at the higher incident energy are in general significantly smaller – with the exception of the case $M_{dibaryon} \approx 2380$ MeV and $\Gamma = 100$ MeV for the $N^*(1440)N^*(1440)$ scenario, where the upper limit is of the same order as the conventional $\Delta^{++}\Delta^{++}$ production. The results for the higher incident energy appear to be quite significant. If the interaction between the two Δ^{++} particles produced side-by-side in the decay of the intermediate $N^*(1440)N^*(1440)$ system would be attractive, then the probability to form a dibaryon should be substantially larger than for the conventional process – as it is obviously the case for $d^*(2380)$ formation in the presence of an isoscalar $\Delta^+\Delta^0$ system. However, our results suggest that the probability for dibaryon formation in the presence of a $\Delta^{++}\Delta^{++}$ system in the intermediate state is smaller (with the possible exception of the above mentioned case). This is in support of the findings of Ref. [14], which predicted an attractive interaction between the $\Delta\Delta$ pair in case of $d^*(2380)$, but repulsion in case of D_{30} and hence no dibaryon formation.

4. Summary and conclusions

We have searched for an $I = 3$ dibaryon resonance, which has been predicted by Dyson and Xuong as well as by various QCD-based and hadronic model calculations to decay into the $NN\pi\pi$ system. The mass range of our search covers the region from 2.2–2.5 GeV, *i.e.* from near-to two-pion threshold to the nominal $\Delta\Delta$ threshold of $2m_\Delta$ and above. To our knowledge this has been the first such search – with the exception of some earlier attempt by use of proton–nucleus collisions [49].

We have found no apparent indication for such a resonance in our data. The deduced upper cross section limits for the production of such a resonance are three to four orders of magnitude smaller than the formation cross section of 1.7 mb found for $d^*(2380)$. They also are up to one order of magnitude smaller than the cross section for conventional $\Delta^{++}\Delta^{++}$ production in the $pp \to pp\pi^+\pi^+\pi^-\pi^-$ reaction – again in sharp contrast to the corresponding situation for $d^*(2380)$ formation, where this is an order of magnitude larger than in conventional $\Delta\Delta$ formation.

An improved, reliable background description by conventional t-channel meson exchange processes would certainly have the potential to lower these upper limits considerably.

With only upper limits at present we, of course, cannot exclude the existence of such a resonance. However, if existent, either the production process of the $I = 3$ resonance associated with the emission of two pions has an unusually small cross section or such a resonance has a mass above the energy region investigated here – as predicted, *e.g.* in Ref. [22]. However, in such a case, when the resonance lies significantly above the $\Delta\Delta$ threshold, its width is expected to be very broad due to its fall-part decay and hence it will be very hard to distinguish such a resonance from conventional processes.

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