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MESON PRODUCTION FROM DIFFRACTIVE PION DISSOCIATION AT COMPASS

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FOR THE COMPASS COLLABORATION

Diffractive dissociation reactions at COMPASS provide clean access to mesons with masses below $\approx 2.5\,\mathrm{GeV}/c^2$. This paper presents a partial wave analysis of about 420 000 $\pi^-\mathrm{Pb} \to \pi^-\pi^-\pi^+\mathrm{Pb}$ events at $190\,\mathrm{GeV}/c$ beam momentum and with four-momentum transfer $t' \in [0.1, 1]\,\mathrm{GeV}^2/c^2$. The well-known $a_1(1260)$, $a_2(1320)$ and $\pi_2(1670)$ mesons are resolved with high quality. Also the less established states $\pi(1800)$ and $a_4(2040)$ are seen. In addition, a resonance in the spin-exotic $J^{PC} = 1^{-+}$ wave is observed. A mass-dependent fit results in a mass and width of $1.660^{+0.010}_{-0.074}$ and $0.269^{+0.063}_{-0.085}\,\mathrm{GeV}/c^2$, respectively, which is consistent with the disputed hybrid candidate $\pi_1(1600)$.

Keywords: Exotic mesons; diffractive dissociation; partial wave analysis; COMPASS.

1. Introduction

COMPASS (COmmon Muon and Proton Apparatus for Structure and Spectroscopy)[1,2] is a fixed-target experiment at the CERN SPS, which investigates the structure and the spectrum of hadrons. In 2004, a pilot run using a $190\,\mathrm{GeV}/c$ π^- beam and nuclear targets took place. Diffractive dissociation reactions of the type $\pi^-\ \mathrm{Pb} \to X\ \mathrm{Pb} \to \pi^-\pi^-\pi^+\ \mathrm{Pb}$ were recorded, from which resonance X production is analyzed. The primary goal is to search for exotic states lying outside the constituent quark model. Quantum Chromo Dynamics (QCD) and derived models predict in particular the existence of $q\bar{q}g$ hybrids, which are difficult to identify experimentally due to mixing with ordinary $q\bar{q}$ mesons. However, some of them might have quantum numbers forbidden for $q\bar{q}$ systems, e. g. $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}$. Their observation would therefore provide a fundamental confirmation of QCD. Spin-exotic states were searched for in the past mostly in the light-quark sector, and a candidate for a light 1^{-+} hybrid, the $\pi_1(1600)$, was observed in diffractive production and decaying to $\rho\pi^-$. These results are still heavily disputed[3–5] and the experimental situation needs to be clarified.

2. Data Sample

The results presented are based on about two days of data taking with lead targets and a dedicated trigger[1] to select diffractive dissociation events. Primary vertices with one incoming negative and three outgoing $(-,-,+)$ particles are required in the offline analysis[6]. An exclusivity cut ensures that, taking into account also the momentum transfer $t' = |t| - |t|_{\rm min}$ to the target, the total energy of the three outgoing pions sums up to the beam energy. A t' range of $0.1 < t' < 1.0\,\mathrm{GeV}^2/c^2$ has been chosen, since there the discussed $\pi_1(1600)$ signals were observed in the past. At such high values of t' scattering on the nucleons inside the lead nuclei dominates. The final event sample comprises about 420 000 events. Fig. 1 presents their invariant 3π mass spectrum, which exhibits the dominantly produced mesons $a_1(1260)$, $a_2(1320)$ and $\pi_2(1670)$. In Fig. 2 the (non-squared) Dalitz plot for the $\pi_2(1670)$ mass region is shown, visualizing the $\rho\pi$ and the $f_2\pi$ decay modes.

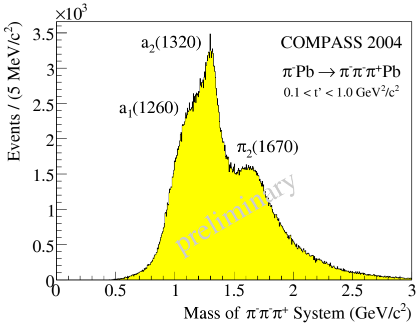

Fig. 1. Invariant mass of $\pi^-\pi^-\pi^+$ final states for $0.1 < t' < 1.0\,\mathrm{GeV}^2/c^2$.

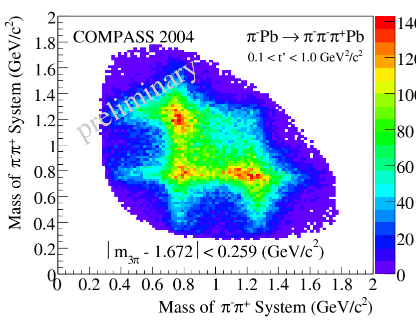

Fig. 2. Dalitz plot for $\pi_2(1670)$, selected by a $\pm 1\Gamma$ cut around its nominal mass.

3. Partial Wave Analysis (PWA) and Results

The PWA is based on the isobar model and the Zemach formalism. One partial wave is characterized by a set of quantum numbers $J^{PC}M^{\epsilon}[isobar]L$, where J^{PC} represents the spin, parity and C-parity of the resonance X, respectively. M and ϵ (reflectivity) describe the spin projection. X is assumed to decay into an *isobar* and a bachelor π^-, which have a relative orbital angular momentum L. The *isobar* further decays into a $\pi^+\pi^-$ pair. The PWA is divided into two steps, namely a mass-independent and a mass-dependent fit[6]. The former has been carried out in $40\,\mathrm{MeV}/c^2$ mass bins and employing a set of 42 waves (including the 27 listed in Ref. 3). An extended maximum likelihood method is used (based on the "Ascoli" fitter[7]), comprising acceptance corrections. COMPASS has an excellent acceptance for diffractive 3π events, which is of the order of 55-60%. A maximum rank $N_r = 2$ has been set for the spin density matrix. The results from the mass-independent fit are visualized as data points with (statistical) error bars in the following. Enlarged errors (thick green part) indicate multiple solutions within one unit of $\ln \mathcal{L}$. For the subsequent mass-dependent fit a subset of seven waves has been selected: $0^{-+}0^{+}[f_0(980)\pi]S$, $1^{-+}1^{+}[\rho\pi]P$ (spin-exotic), $1^{++}0^{+}[\rho\pi]S$, $2^{-+}0^{+}[f_2\pi]S$, $2^{-+}0^{+}[f_2\pi]D$, $2^{++}1^{+}[\rho\pi]D$ and $4^{++}1^{+}[\rho\pi]G$. The intensities and interferences of these waves are parameterized with relativistic Breit-Wigner (BW) and eventually background functions. From this fit, which is shown as red curve overlayed to the mass-independent fit results, resonance masses and widths have been obtained. In Figs. 3, 4 and 5 the intensity of the three dominant partial waves in the mass-dependent fit is presented, corresponding to the production of $a_1(1260)$, $\pi_2(1670)$ and $a_2(1320)$. Figs. 6, 7 and 8 show the spin-exotic 1^{-+} signal and its phase motion with respect to $\pi_2(1670)$ and the tail of $a_1(1260)$. A background and a BW function have been used to describe this wave, for which no significant ($< 5\%$) leakage was found in a dedicated study. The BW parameters of all fitted resonances are listed in Tab. 1, including also results for $\pi(1800)$ and $a_4(2040)$.

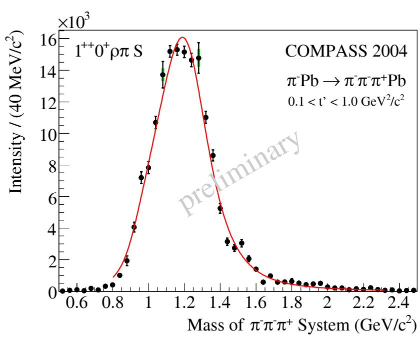

Fig. 3. Intensity of the $1^{++}0^{+}[\rho\pi]S$ wave.

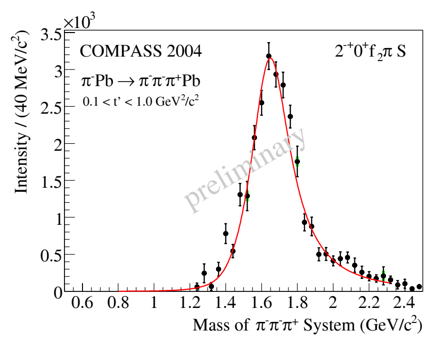

Fig. 4. Intensity of the $2^{-+}0^{+}[f_2\pi]S$ wave.

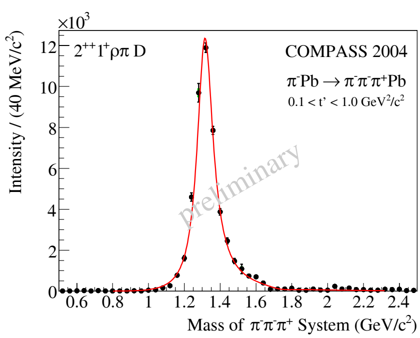

Fig. 5. Intensity of the $2^{++}1^{+}[\rho\pi]D$ wave.

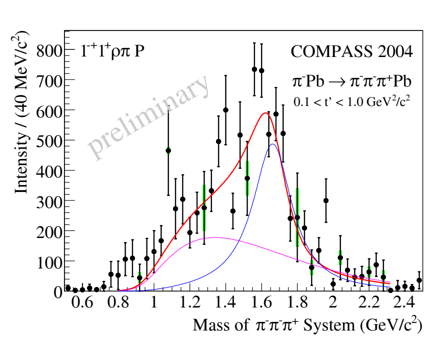

Fig. 6. The exotic $1^{-+}1^{+}[\rho\pi]P$ wave; BW (blue) and background (purple) part.

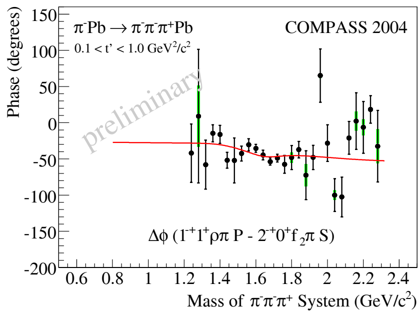

Fig. 7. Phase difference between the exotic $1^{-+}1^+[\rho\pi]P$ and the $2^{-+}0^+[f_2\pi]S$ wave.

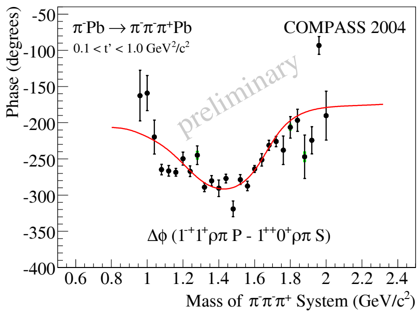

Fig. 8. Phase difference between the exotic $1^{-+}1^+[\rho\pi]P$ and the $1^{++}0^+[\rho\pi]S$ wave.

Table 1. Resonance masses and widths with statistical and systematic errors; preliminary.

State	Mass ± stat. +− syst. (GeV/c^2)	Width ± stat. +− syst. (GeV/c^2)
$a_1(1260)$	1.256 ± 0.006 + 0.007 - 0.017	0.366 ± 0.009 + 0.028 - 0.025
$a_2(1320)$	1.321 ± 0.001 + 0.000 - 0.007	0.110 ± 0.002 + 0.002 - 0.015
$\pi_1(1600)$	1.660 ± 0.010 + 0.000 - 0.064	0.269 ± 0.021 + 0.042 - 0.064
$\pi_2(1670)$	1.659 ± 0.003 + 0.024 - 0.008	0.271 ± 0.009 + 0.022 - 0.024
$\pi(1800)$	1.785 ± 0.009 + 0.012 - 0.006	0.208 ± 0.022 + 0.021 - 0.037
$a_4(2040)$	1.884 ± 0.013 + 0.050 - 0.002	0.295 ± 0.024 + 0.046 - 0.019

4. Conclusion and Outlook

The obtained parameters for the resonance found in the spin-exotic $1^{-+}1^+[\rho\pi]P$ partial wave are consistent with the disputed hybrid candidate $\pi_1(1600)$. In addition, established mesons are observed. COMPASS resumes data taking for diffractive meson production during summer 2008 with a liquid-hydrogen target[2].

Acknowledgments

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