PROCEEDINGS OF SCIENCE

Leading Modes of $3\pi^0$ production in proton-proton collisions at incident proton momentum of $3.35\ \mathrm{GeV/c}$

Benedykt R. Jany[*†]
Jagiellonian University, Cracow Poland
E-mail: jany@if.uj.edu.pl

The $pp \to pp3\pi^0$ reaction was measured for the first time by the WASA-at-COSY collaboration at a proton beam momentum of $P_b = 3.35$ GeV/c. All reaction products were measured. Around 1 million events were reconstructed. The 3π production causes one of the most severe types of background, specially for the decays of η, ω, η‘ mesons. The total cross section has been measured and will be compared with existing theoretical predictions and available data. The dynamics of the production was also studied by a Dalitz plot technique, which indicates the dominant role of the $\Delta(1232)$ and the $N^*(1440)$ in the production mechanism.
The $pp \to pp\eta$ reaction reaction was also measured for the same momentum as a reference signal. The experimental data suggest the momentum dependence of the angular distributions.
The preliminary high statistics results on a Total Cross Section and Dalitz plots will be presented.

XLIX International Winter Meeting on Nuclear Physics, BORMIO2011
January 24-28, 2011
Bormio, Italy

*Speaker.
†for the WASA-at-COSY Collaboration

PoS(Bormio 2011)049

1. The $pp \to pp3\pi^0$ reaction

Direct $pp \to pp3\pi^0$ production in the region of narrow mesonic states (like $\eta, \omega, \eta', \phi$) form the main background contribution for studies of meson production and decays. The reaction has not yet been studied at high beam kinetic energies, the cross section and the reaction dynamics are not known, only few data points at low energies were measured [1]. The knowledge about the dynamics of the reaction is very interesting especially since there is enough energy to excite various baryon resonances and their dynamics can also by studied. This is also of special interest for production and decays of ω and η' mesons. The $3\pi^0$ production causes one of the most severe types of background, specially for the leptonic and semileptonic decay channels of the mesons since π^0 mesons can undergo Dalitz decays and conversion from $\gamma\gamma$ decay.

The reaction was measured by the WASA-at-COSY collaboration [2] at a proton beam momentum of $P_b = 3.350$ GeV/c (which corresponds to a kinetic energy of $T = 2.541$ GeV and excess energy $Q = 598$ MeV). All reaction products were measured, two protons in the Forward Detector and six photons, which form three neutral pions, in the Central Detector of the WASA-at-COSY setup. Around 1 million events were reconstructed.

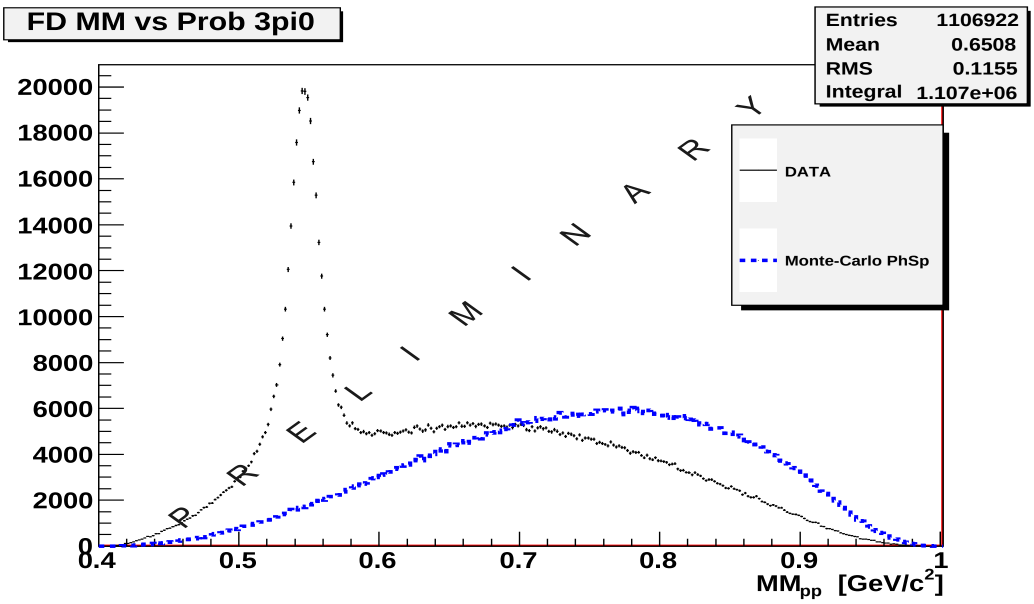
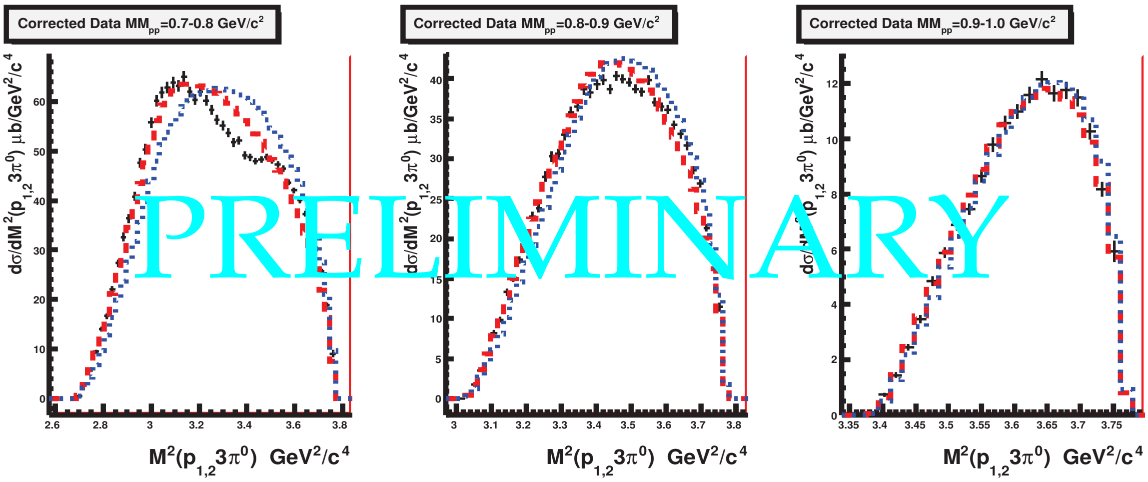
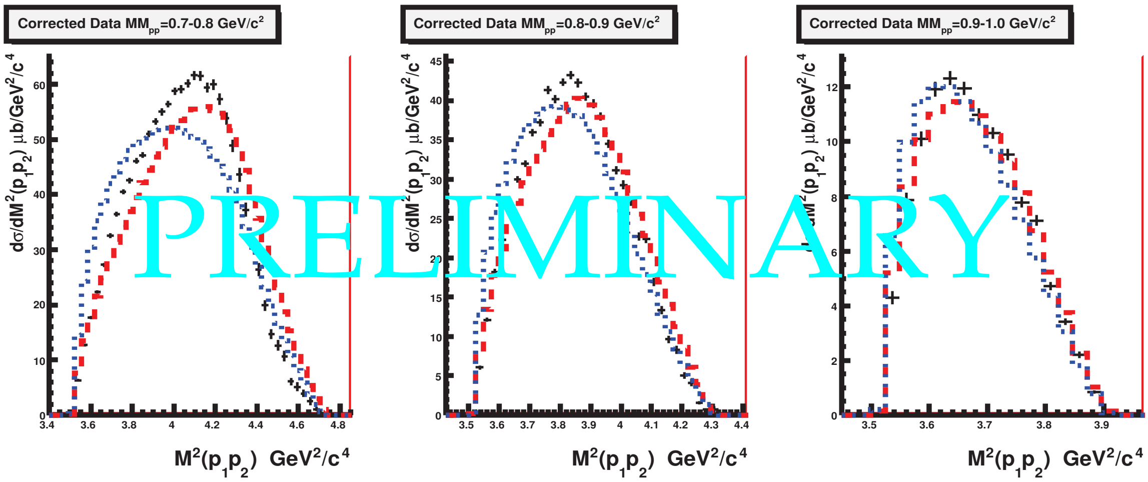


Figure 1: Missing mass of the two protons for the $pp \to pp3\pi^0$ reaction. Experimental data (black), Monte-Carlo homogeneous and isotropic phase space (blue).

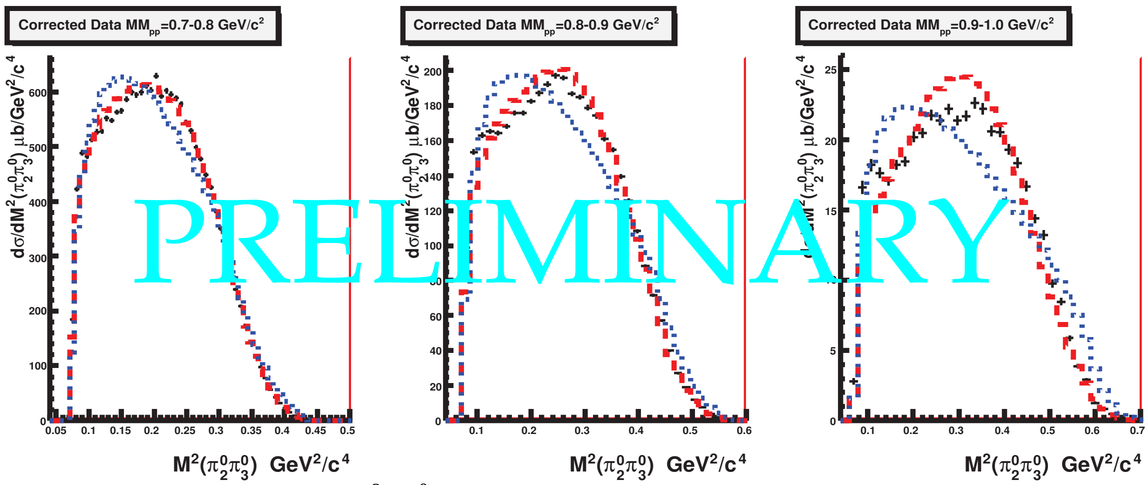
The missing mass distribution of the two protons is presented in Fig. 1 for the case of two protons and three neutral pions. A clear signal for $\eta \to 3\pi^0$ is seen above the direct $pp \to pp3\pi^0$ production. The Monte-Carlo simulation which is based on a homogeneous and isotropic populated Phase Space is plotted for comparison. It is seen that the experimental direct missing mass distribution strongly deviates from the simulation. The homogeneously and isotropically populated phase space does not describe the experimental data.



(a) $M^2(p3\pi^0)$ distribution, each event is filled two times.

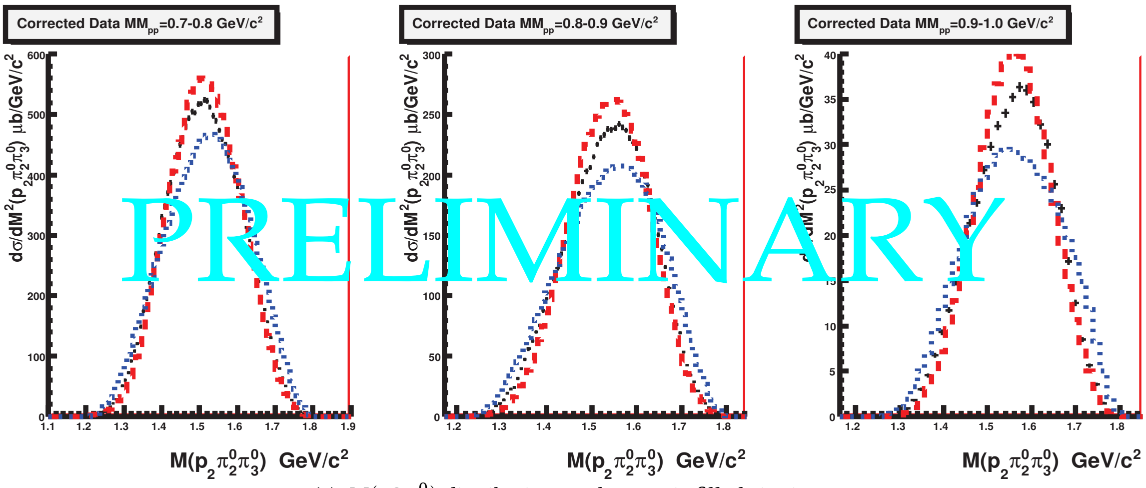


(b) $M^2(pp)$ distribution, each event is filled two times.

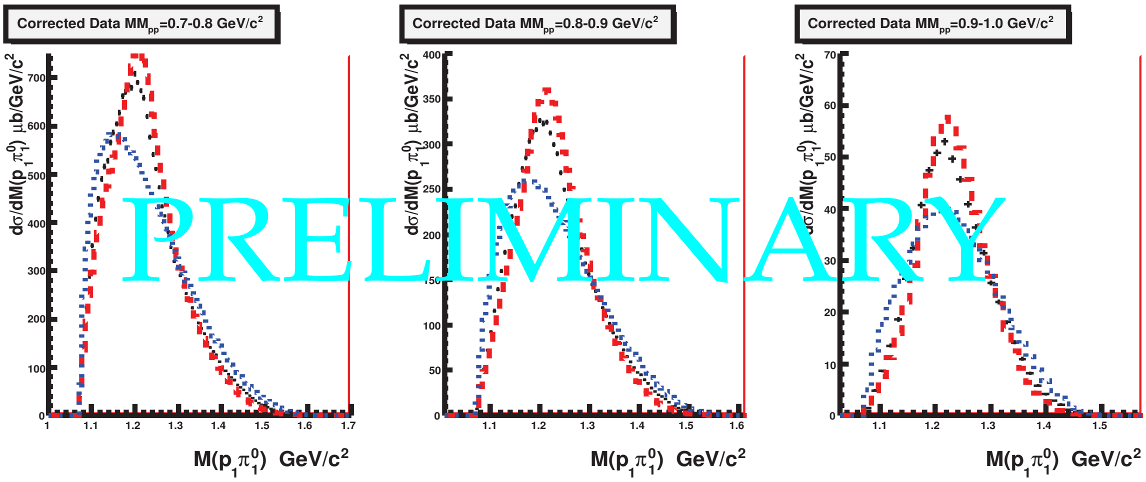


(c) $M^2(2\pi^0)$ distribution, each event is filled six times.

Figure 2: Dalitz Plot projections for the $pp \to pp3\pi^0$ reaction, acceptance and efficiency corrected experimental data (black) compared with Monte-Carlo model assuming simultaneous excitation of $\Delta(1232)$ and $N^*(1440)$ (red) and Monte-Carlo homogeneous and isotropic phase space (blue) simulation. The columns from left to right correspond to the selection of the following missing mass of two proton region: $MM_{pp} = 0.7-0.8$ GeV/c^2, $MM_{pp} = 0.8-0.9$ GeV/c^2, $MM_{pp} = 0.9-1.0$ GeV/c^2. The simulations are normalized to the same number of events as the experimental data. It is seen that the model describes the data significantly better than the homogeneous and isotropic phase space.



(a) $M(p2\pi^0)$ distribution, each event is filled six times.



(b) $M(p\pi^0)$ distribution, each event is filled six times.

Figure 3: Nyborg Plot projections for the $pp \to pp3\pi^0$ reaction, acceptance and efficiency corrected experimental data (black) compared with Monte-Carlo model assuming simultaneous excitation of $\Delta(1232)$ and $N^*(1440)$ (red) and Monte-Carlo homogeneous and isotropic phase space (blue) simulation. The columns from left to right correspond to the selection of the following missing mass of two proton region: $MM_{pp} = 0.7-0.8\,\mathrm{GeV/c^2}$, $MM_{pp} = 0.8-0.9\,\mathrm{GeV/c^2}$, $MM_{pp} = 0.9-1.0\,\mathrm{GeV/c^2}$. The simulations are normalized to the same number of events as the experimental data. It is seen that the model describes the data significantly better than the homogeneous and isotropic phase space.

The dynamics of the production was studied by a Dalitz and Nyborg plot analysis. The experimental distributions were compared with the homogeneous and isotropic phase space and the Monte-Carlo model assuming the following reaction mechanism:

$$pp \to \Delta(1232)N^*(1440) \to pp3\pi^0 \tag{1.1}$$

where the $\Delta(1232)N^*(1440)$ decays later into protons and pions via:

- $\Delta(1232) \to p\pi^0$ and $N^*(1440) \to p\pi^0\pi^0$ (direct decay)

- $\Delta(1232) \to p\pi^0$ and $N^*(1440) \to \pi^0\Delta(1232) \to \pi^0 p\pi^0$ (sequential decay).

From the fit of the two decay branches of the $N^*(1440)$ to the experimental distributions, the fraction of the sequential decay contributing to the $pp3\pi^0$ final state was estimated to be $\sim 94\%$.

It is seen in Figs. 2, 3 that the model describes the data significantly better than the homogeneous and isotropic phase space.

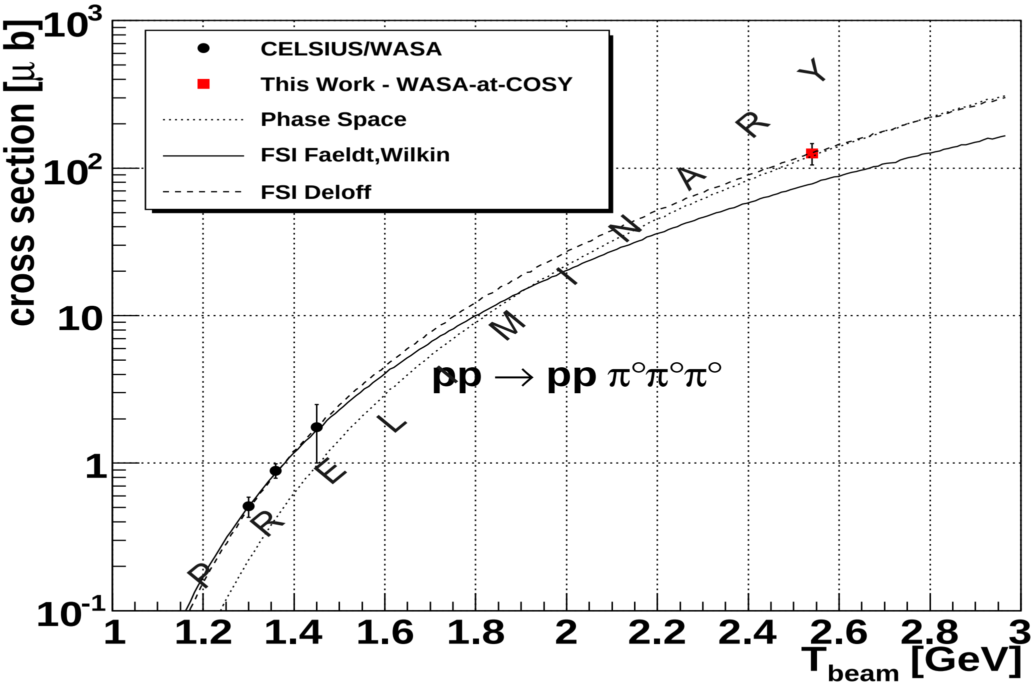


Figure 4: Cross Section for $pp \to pp3\pi^0$ as a function of beam energy. Experimental data [1] and different theoretical predictions are indicated [3, 4, 5]. The WASA-at-COSY result is shown as a solid square.

The total cross section has been obtained by a normalization to the known $pp \to pp\eta$ cross section resulting in

$$\sigma_{pp\to pp3\pi^0} = 123 \pm 21\ \mu\text{b} \tag{1.2}$$

The cross section has been compared with the existing data [1] and theoretical predictions [3, 4, 5], presented in Fig. 4. The data favors the cross section scaling model based on the Delof final state interaction [4].

2. The $pp \to pp\eta$ reaction

Many previous high statistics experimental studies of the reaction dynamics in the threshold region [6, 7, 8, 9], for beam kinetic energies less than 2 GeV, show an important role of the $N^*(1535)$ baryon resonance. The near threshold data were interpreted mostly in the framework of the one-boson exchange models [10, 11, 12, 13, 14, 15, 16] (by exchange of various mesons like π, η, ρ, ω) and a dominant role of the $N^*(1535)S_{11}$. In the threshold region also the Final State Interaction plays an important role [5, 4].

For higher energies above 2 GeV beam kinetic energy, there are only few studies [17, 18] which consider two dominant production mechanisms: the resonant production (via excitation of $N^*(1535)$) and the non resonant production.

The $pp \to pp\eta$ reaction at an incident proton momentum 3.35 GeV/c ($T = 2.541$ GeV), which corresponds to the excess energy $Q = 455$ MeV, was also measured with the WASA-at-COSY detector setup [2] via η meson decay into three neutral pions. All final state particles were detected, the two protons were registered in the Forward Detector of the WASA, while the three pions were reconstructed from the decay into six photons in the Electromagnetic Calorimeter.

The reaction was measured for the momentum of the η meson in the CM system in the rage of $q_\eta^{CM} = 0.45 - 0.7$ GeV/c and for the cosine of the scattering angle of the η meson in the CM frame in range of $\cos(\theta_\eta^{CM}) = -1.0 - 0.0$. The detail investigations of the reaction dynamics were performed to understand the production process.

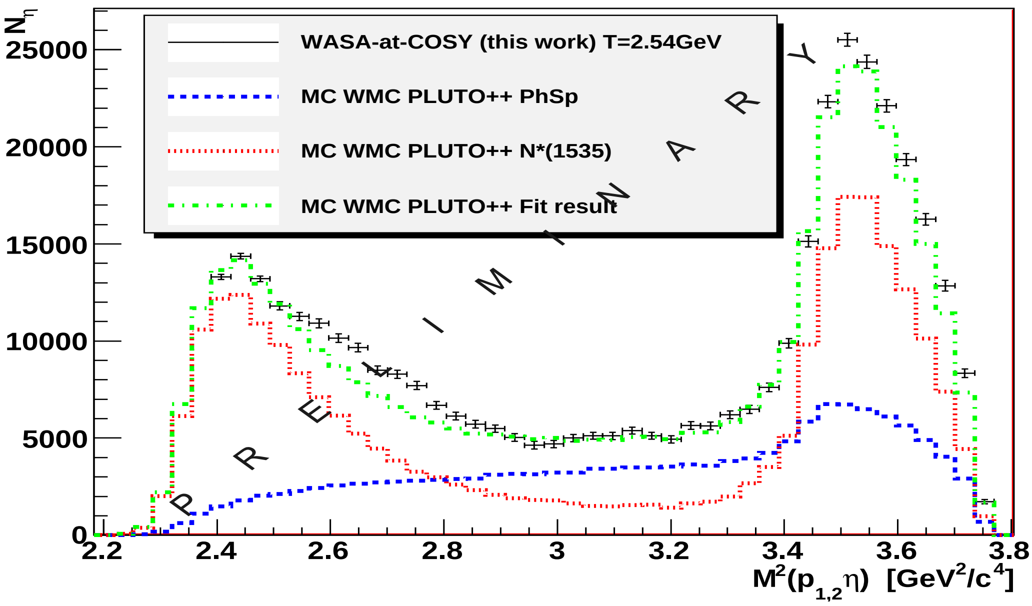


Figure 5: Invariant mass squared of the proton-η system, the lines correspond to the Monte-Carlo simulation assuming different production mechanism. The experimental data are described by the 43% contribution of the $N^*(1535)$ and 57% contribution of the homogeneous and isotropic phase space. The spectra are not corrected for acceptance or efficiency.

PoS(Bormio 2011)049

The invariant mass squared of the proton-η system was investigated (Fig. 5) to study the dynamics of the reaction. The experimental data were compared with the Monte-Carlo predictions based on the Pluto++ simulations [19] where the WASA-at-COSY detector response was simulated by GEANT3 [20]. The following production scenarios were considered:

- The resonant part - modeled by the excitation of the $N^*(1535)$
- The non resonant part - modeled by homogeneously and isotropically populated phase space

Assuming that only these two scenarios participate in the production of the η meson, the relative contribution of these two parts were fitted to the experimental data, fitted curve see Fig. 5. The fit results in a 43% contribution of the $N^*(1535)$ (resonant part) and 57% of the non resonant part (phase space) in the production mechanism.

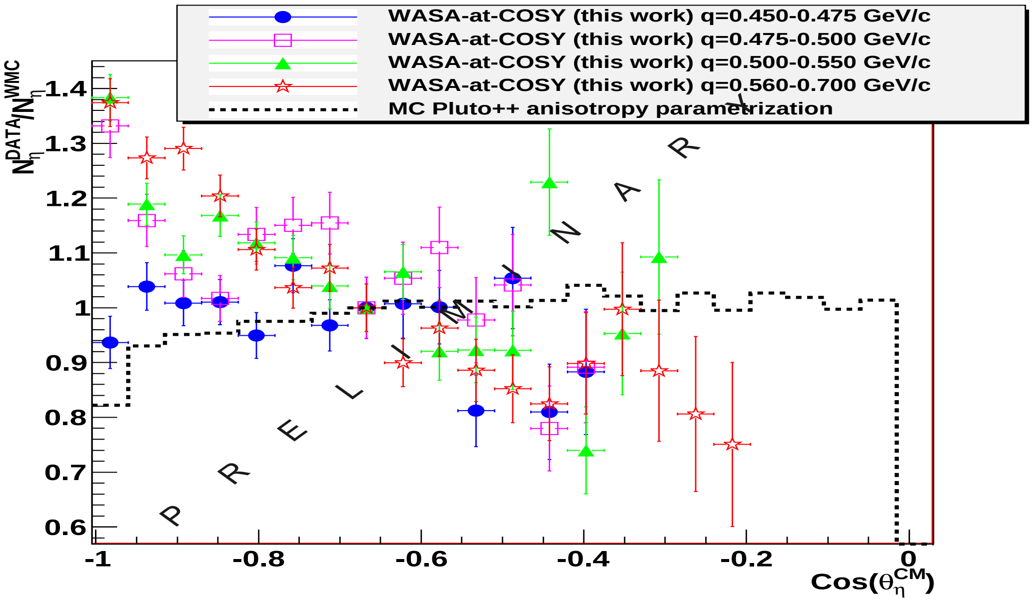


Figure 6: The angular distribution of the η meson in the CM system for the different η meson momentum in the CM frame, the line corresponds to the Monte-Carlo model [19] based on experimental measurements [17]. The angular distribution changes while the η momentum increases.

Also the angular distribution of the η meson was investigated by studying the cosine of the scattering angle of the η meson in the CM frame $\cos(\theta_\eta^{CM})$ for different momenta of the η meson in the CM system q_η^{CM} (Fig. 6). It is seen that when the momentum q_η^{CM} increases the angular distribution of $\cos(\theta_\eta^{CM})$ changes from almost flat one to highly anisotropic. This effect have never been measured before. The experimental data were also compared with the existing Monte-Carlo model [19], based on the experimental measurements [17]. It is seen that the Monte-Carlo model follows only the angular distribution for the lowest momentum range $q_\eta^{CM} = 0.450 - 0.475$ GeV/c. The angular distribution for the higher momentum range is not described by the model since it does not include the changes of the distribution as a function of the momentum.

PoS(Bormio 2011)049

The production dynamics of the η meson was studied in details. It is shown that the production mechanism proceeds via excitation of the $N^*(1535)$ baryon resonance in 43%. For the first time the momentum dependence of the angular distribution of the η meson was observed.

References

[1] C. Pauly et al., *Phys. Lett. B* **649**, 122-127, 2007.

[2] H. H. Adam, et al., 2004, `nucl-ex/0411038`.

[3] E. Fermi, Prog. Theor. *Phys. 5* **570**, 1950.

[4] A. Deloff, *Phys. Rev. C* **69** 035206, 2004.

[5] G. Faeldt, C. Wilkin, *Phys. Lett. B* **382** 209, 1996.

[6] J. Smyrski et al., *Phys. Lett. B*, **474**, 182âĂŞ187, 2000.

[7] F. Hibou et al., *Phys. Lett. B* , **438**, 41âĂŞ46, 1998.

[8] E. Chiavassa et al., *Phys. Lett. B*, **322**, 270âĂŞ274, 1994.

[9] R. Czyzykiewicz et al.,*Phys. Rev. Lett.*, **98**, 2007.

[10] J. Germond and C. Wilkin, *Nucl. Phys. A* , **518**, 308âĂŞ316, 1990.

[11] T. Vetter et al., *Phys. Lett. B*, **263(2)**, 153âĂŞ156, 1991.

[12] J. Laget, *Phys. Lett. B*, **257**, 254âĂŞ258, 1991.

[13] M. Batinic et al., *Phys. Scr.*, **56(4)**, 321, 1997.

[14] A. Sibirtsev and W. Cassing, 1999, `nucl-th/9904046`.

[15] G. Faeldt and C. Wilkin, *Phys. Scr.*, **427**, 2001.

[16] K. Nakayama, J. Speth, and T. S. H. Lee, *Phys. Rev. C*, **65(4)**, 2002.

[17] F. Balestra, et al. *Phys. Rev. C*, **69(6)**, 064003, 2004.

[18] K. Teilab, *IJMP A*, **26**, 694âĂŞ696, 2011.

[19] I. Frohlich, et al. *PoS*, ACAT2007 **076**, 2007, `nucl-ex/07082382`.

[20] R. Brun, F. Bruyant, M. Maire, A.C. McPherson, and P. Zanarini. *CERN-DD-EE-84-1*, 1984.