PROCEEDINGS OF SCIENCE

High precision η meson mass determination at COSY-ANKE

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Measurements of the mass of the η meson performed at different experimental facilities over the last decade have resulted in very precise data which differ by up to 0.5 MeV/c^2, i.e. more than eight standard deviations. In order to clarify this situation a new measurement of the $d\,p \to {}^3\mathrm{He}\,\eta$ reaction near threshold was proposed at the COoler SYnchrotron - COSY - of the Forschungszentrum Jülich with the aim to achieve a mass resolution of $\Delta m < 50$ keV/c^2. In order to measure the η meson mass with high accuracy through the $d\,p \to {}^3\mathrm{He}\,\eta$ reaction, the momentum of the circulating deuteron beam in COSY has to be determined with unprecedented precision. This has been achieved by studying the spin dynamics of the polarised deuteron beam. By depolarising the beam through the use of an artificially induced spin resonance, it was possible to determine the beam momentum p_d with an accuracy of $\Delta p_d/p_d < 10^{-4}$ for $p_d \approx 3$ GeV/c. In parallel the CMS momenta of the produced ^{3}He-nuclei have to be determined with high precision with the ANKE spectrometer. The method for determination of the η mass, as well as current results will be discussed in this presentation.

8th International Conference on Nuclear Physics at Storage Rings-Stori11,
October 9-14, 2011
Laboratori Nazionali di Frascati, Italy

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†This work is supported by FZ Jülich FFE

Recent measurements on the η meson mass performed at different experimental facilities (i.e. CERN-NA48, COSY-GEM, CESR-CLEO, DAΦNE-KLOE, MAMI-Crystall Ball) resulted in very precise data but differ by up to more than eight standard deviations, i.e. $0.5\,\mathrm{MeV/c^2}$ [1]. In order to clarify this situation a high precision measurement using the ANKE spectrometer at the COoler SYnchrotron COSY has been realized.

Using the two-body reaction $d\,p \to {}^3\mathrm{He}\,\eta$ at low excess energies the η mass can be determined only from pure kinematics by the determination of the production threshold. Therefore, twelve data points at fixed excess energies in the range of $Q = 1-12\,\mathrm{MeV}$ were investigated. The final state momentum p_f of the ^{3}He-particles in the Center of Mass System (CMS)

$$p_f(s) = \frac{\sqrt{\left[s-(m_{^3\mathrm{He}}+m_\eta)^2\right]\cdot\left[s-(m_{^3\mathrm{He}}-m_\eta)^2\right]}}{2\cdot\sqrt{s}}\,, \tag{1}$$

measured with the ANKE spectrometer, is very sensitive on the η mass and the total energy $\sqrt{s}$, where the latter one is completely defined in a fixed target experiment by the masses of the initial particles and the momentum of the deuteron beam p_d:

$$\sqrt{s} = \sqrt{2m_p\sqrt{m_d^2+p_d^2}+m_d^2+m_p^2}\,. \tag{2}$$

For a precise determination of the production threshold both quantities, the final state momenta of the ^{3}He-particles and the corresponding deuteron beam momenta have to be measured with highest accuracy. Fitting the dependency of the final state momentum p_f on the beam momentum p_d and the η mass, $p_f = p_f(p_d, m_\eta)$, for the twelve points the mass can be extracted as fitting parameter (see Fig. 4).

The beam momentum for each fixed excess energy was determined using a method developed at the electron-positron machine VEPP-2M at Novosibirsk using the spin dynamics of a polarized beam [2]. Thereby the spin precession frequency of a relativistic particle is disturbed by an artificial spin resonance induced by a horizontal rf-magnetic field of a solenoid leading to a depolarization of the polarized accelerator beam. The depolarizing resonance frequency f_r depends on the kinematical γ-factor (i.e. the beam momentum $p = m\sqrt{\gamma^2-1}$) and the beam revolution frequency f_0 via the resonance condition:

$$f_r = (k+\gamma G)\,f_0\,, \tag{3}$$

where k is an integer and G the gyromagnetic anomaly of the beam particle. By measuring these two frequencies the beam momentum of the polarized beam can be determined with a precision below $\Delta p/p < 10^{-4}$. For the first time this method was used at COSY with a vector polarized deuteron beam and the beam momentum accuracy could be increased by more than an order of magnitude compared to the conventional method. The momenta in the threshold range of 3.1 - 3.2 GeV/c were determined with an accuracy of $\Delta p/p < 6\cdot 10^{-5}$, i.e. with 170 keV/c [3].

The correct final state momenta for the twelve different energies of the ^{3}He-nuclei of the reaction $d\,p \to {}^3\mathrm{He}\,\eta$ can only be extracted fulfilling two conditions: a clear identification of the reaction of interest and a precise detector calibration. At ANKE the produced ^{3}He-nuclei can be identified using the energy loss and time of flight information. By this, the background, consisting mainly of protons and deuterons of the dp elastic scattering and the deuteron break-up, can be suppressed effectively. For a two-body reaction at a fixed center of mass energy $\sqrt{s}$ the final state momenta in the CMS are distributed on a momentum sphere with constant radius p_f, which can be visualized by plotting the transversal versus the longitudinal reconstructed momentum, as shown

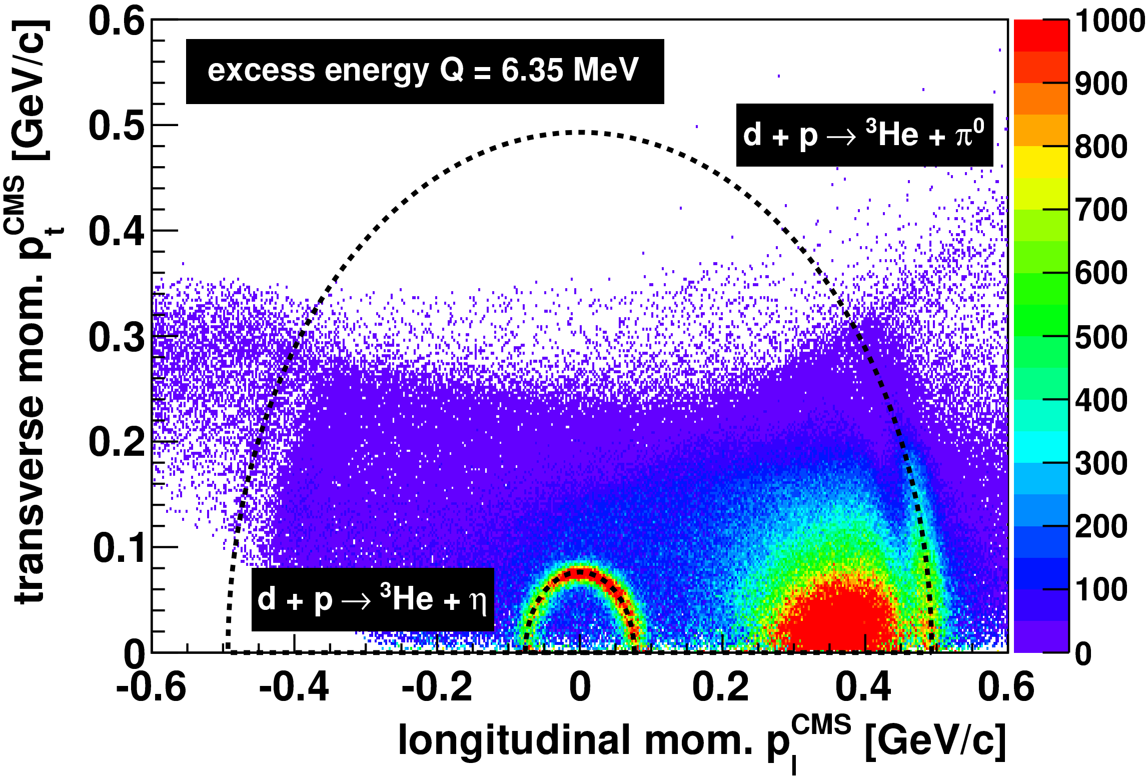

Figure 1: The momentum loci for the $^3\mathrm{He}\,\eta$ and $^3\mathrm{He}\,\pi$ channels. For the $^3\mathrm{He}\,\eta$ channel ANKE covers near threshold the full solid angle, while for the $^3\mathrm{He}\,\pi$ channel only forward scattered ^{3}He-nuclei are detected.

According to Eq. 1, one expects a centered momentum locus with a fixed radius $p_f = (p_x^2 + p_y^2 + p_z^2)^{1/2}$, indicated in Fig. 1 as dashed line. The feature that the ANKE facility has full geometrical acceptance for the reaction $d\,p \to {}^3\mathrm{He}\,\eta$ near threshold up to 15 MeV allows to verify and improve the detector calibration by studying the kinematics of this two-body reaction. The main idea to verify the calibration is that the momentum sphere has to be completely symmetric in p_x, p_y and p_z (or ϑ and ϕ) so that the final state momentum p_f should be constant in all directions. By a careful investigation of the momentum dependency on the cosine of the polar angle ϑ and the azimuthal angle ϕ

$$p_f = p_f(\cos\vartheta) \tag{4}$$

$$p_f = p_f(\phi) \tag{5}$$

the shape of the momentum sphere or locus can be studied in more detail. Deviations from this symmetric shape will indicate the need of an improvement of the calibration. Therefore the ^{3}He η signal has to be extracted background free.

The background left after cutting on ^{3}He-nuclei (see Fig. 1 and 2), originating mainly from the multi pion production, can be subtracted by data taken below the η production threshold at an excess energy of $Q \approx -5$ MeV, but analyzed as if they were taken above. In [4] the successful applicability of this approach on missing mass spectra is shown, but it is also applicable to final state momentum spectra as shown in Fig. 2 for different $\cos\vartheta$ bins for the data point closest to threshold, i.e. Q $\approx$ 1 MeV. Similarly the final state momentum dependency on ϕ can be studied.

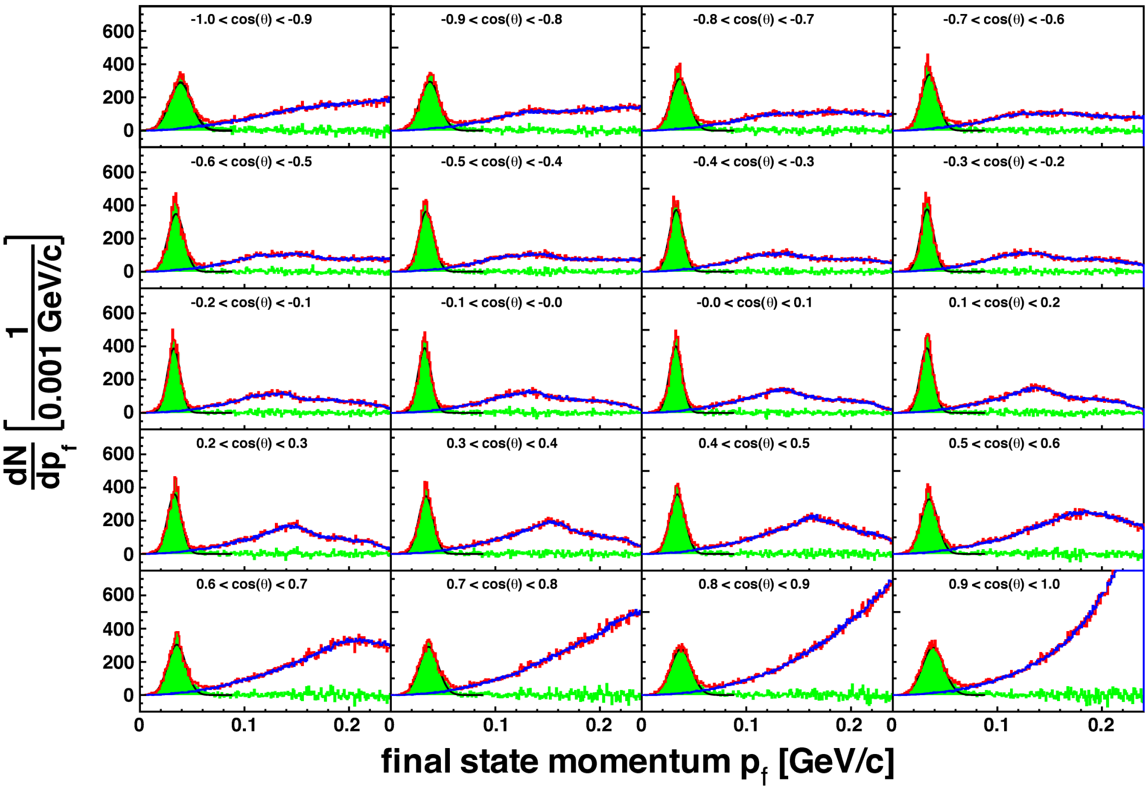

Figure 2: Final state momentum signal $p_f = p_f(\cos\vartheta)$ for different $\cos\vartheta$ bins (red) at an excess energy of $Q \approx 1$ MeV, the background description using data taken below threshold (blue) and the extracted background free ^{3}He η signal (green).

The background free ^{3}He η distribution allows to extract the mean final state momentum $p_f(\cos\vartheta)$ and $p_f(\phi)$ as shown in Fig. 3. In contrast to Monte-Carlo simulations on $p_f(\cos\vartheta)$ and $p_f(\phi)$ without momentum smearing (black line) the obtained data points, indicated as red circles, show a dependency of the final state momentum in $\cos\vartheta$ and ϕ. The shape of the momentum sphere is stretched to values $\cos\vartheta \to \pm 1$ and shows an oscillation in ϕ. This behavior is caused by a kinematic effect due to different momentum resolutions of the ANKE detector for p_x, p_y and p_z. Assuming that the p_x, p_y and p_z distributions are gaussian distributed with different widths σ, it is possible to reproduce the final state momentum dependency on $\cos\vartheta$ and ϕ with Monte-Carlo simulations shown as black squares. However for a precise calibration the shape should be still

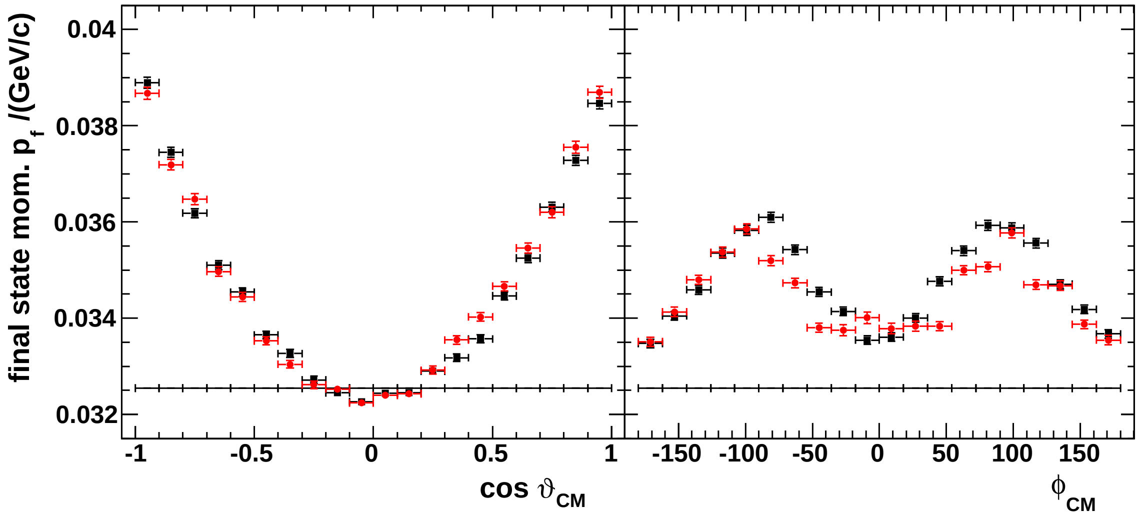

Figure 3: Final state momentum dependency on $\cos\vartheta$ and ϕ: $p_f = p_f(\cos\vartheta)$ and $p_f(\phi)$ for data (red circles), Monte-Carlo simulations without momentum smearing (black line) and with momentum smearing (black squares).

symmetric in $\cos\vartheta$ and ϕ (i.e. p_x, p_y and p_z).

For the final state momentum determination the plots shown in Fig. 3 are of high importance because of following three reasons:

1. Improvement of the calibration. Asymmetric shapes in $\cos\vartheta$ and ϕ originated by a "unpolished" calibration can be corrected by minor changes of the ANKE calibration parameters. These changes are so small that they have no impact on typical calibration quantities like missing masses of different reactions. That means by studying the $\cos\vartheta$ and ϕ dependency the sensitivity for the different calibration parameter can be increased.

2. Extraction of the correct momentum resolution in (p_x, p_y, p_z). Assuming gaussian distributions with different widths we found for ANKE $(\sigma_x, \sigma_y, \sigma_z) = (3.2, 7.8, 16.4)$ MeV/c.

3. Correction of the reconstructed final state momentum. Because of the finite momentum resolution the extracted average momentum over all $\cos\vartheta$ and ϕ bins (see Fig. 3 red circles) is larger compared to the original one (black line). This has to be considered in the determination of the twelve final state momenta.

Currently the final state momentum analysis is still in progress but already now the twelve momenta in the range of $30-100\,\mathrm{MeV/c}$ can be determined with a precision below $400\,\mathrm{keV/c}$. Fitting the $p_f = p_f(p_d, m_\eta)$ dependency, as shown in Fig. 4, the η mass is determined preliminary to

$$m_\eta = (547.869 \pm 0.007 \pm 0.040)\,\mathrm{MeV/c^2}. \qquad (6)$$

The accuracy, which will be achieved at ANKE, will be comparable and competitive to the precision achieved at other recent experiments.

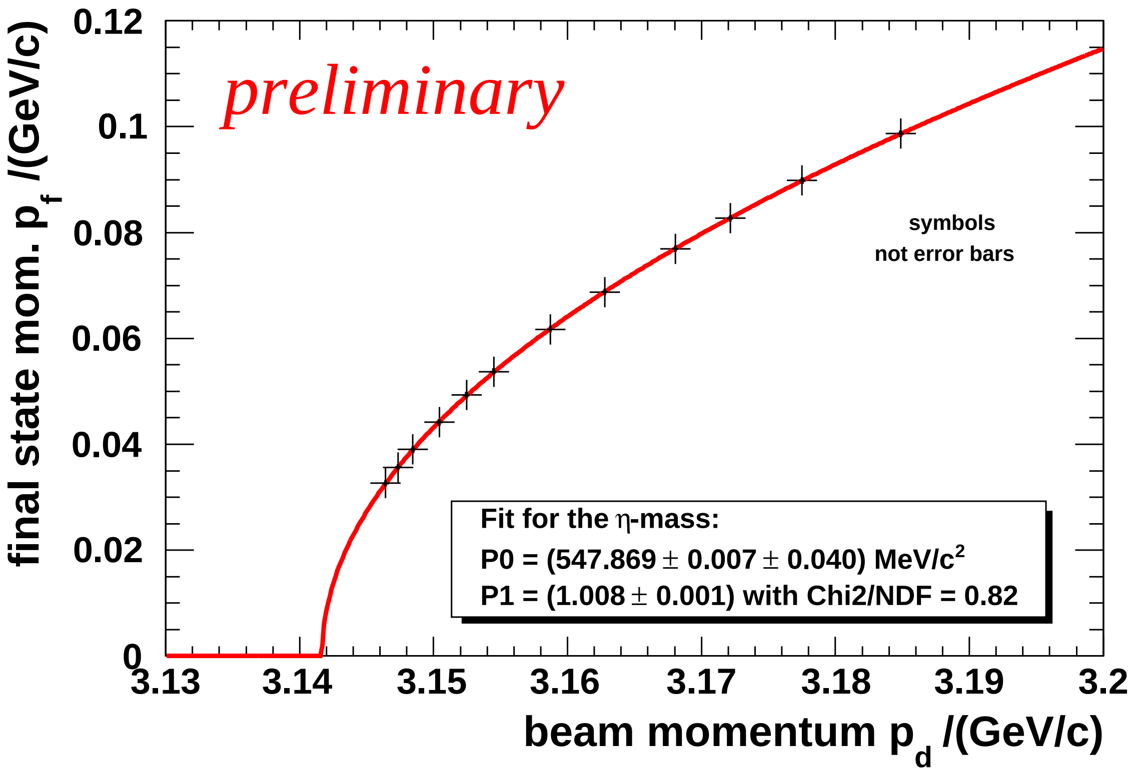

Figure 4: Preliminary determination of the η mass by fitting the dependency $p_f = p_f(p_d, m_\eta)$. The η mass is extracted as fitting parameter to $m_\eta = (547.869 \pm 0.007 \pm 0.040)\,\mathrm{MeV/c^2}$.

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