

η' beam asymmetry at threshold using the BGO-OD experiment

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Abstract.

The unexpected nodal structure of the beam asymmetry recently reported by the GRAAL collaboration in η' photoproduction very close to threshold could be explained by a previously unobserved narrow resonance.

The BGO-OD experiment is ideally suited to verify this measurement via the detection of forward going charged particles which in the threshold region of interest allows the identification of the reaction $\gamma p \rightarrow \eta' p$ solely based on the proton going in the forward direction. This yields unprecedented statistics if, in the missing mass analysis of the η' meson, the background can be sufficiently well controlled. Preliminary results using a linearly polarised photon beam are shown. The reaction $\gamma p \rightarrow \eta' p$ was identified in the BGO forward spectrometer, with simulated data used to separate signal and background.

1 Introduction

As can be seen in figure 1 the η' beam asymmetry has already been measured by the GRAAL experiment [1]. There an unexpected nodal structure was observed in the $\Theta_{\eta'}^{CMS}$ (polar angle of the η' in the centre of mass frame) dependance of the beam asymmetry that vanishes rapidly with higher beam energies.

The polarised cross section for the reaction can be written as the unpolarised cross section including an additional term as shown in equation 1.

$$\left(\frac{d\sigma}{d\Omega}\right)^{\text{pol}} = \left(\frac{d\sigma}{d\Omega}\right)^{\text{unpol}} (1 - P_{\gamma}(E_{\gamma})\Sigma(E_{\gamma}, \Theta_{\eta'}^{CMS})\cos(2\phi_{\eta'})) \quad (1)$$

$P_{\gamma}(E_{\gamma})$ is the photon beam polarisation, $\Sigma(E_{\gamma}, \Theta_{\eta'}^{CMS})$ the beam asymmetry and $\phi_{\eta'}$ the azimuthal angle of the η' . An expansion of $\Sigma(E_{\gamma}, \Theta_{\eta'}^{CMS})$ in partial waves can be done, leading to the expression shown in equation 2-4 [2]. This

is valid for a truncation at $l_{max} = 3$ (F-waves).

$$\Sigma = (1 - x^2) \sum_{k=0}^4 a_k x^k \quad (2)$$

$$x = \cos(\Theta) \quad (3)$$

$$a_1 = a_1^{SF} + a_1^{PD} + a_1^{DF} \quad (4)$$

For the lowest order (k=0) this results in a $\sin^2(\Theta)$ modulation of Σ which is not observed in the data. k=1 yields the observed $\sin^2(\Theta) \cdot \cos(\Theta)$ modulation. The corresponding coefficient a_1 consists of interference terms between S-F, P-D and D-F-wave.

The observed behaviour can be explained by a narrow resonance close to threshold. This is further supported by results from the Bonn-Gatchina partial wave analysis group which show that including a narrow resonance ($D_{13}(1900)$) with a mass of $M_{\eta'p} = 1900 \pm 1$ MeV and a width of $\Gamma_{\eta'p} < 3$ MeV close to threshold much more accurately describes the experimental data [3], see figure 2. EtaMAID can describe the observed behaviour as well us-

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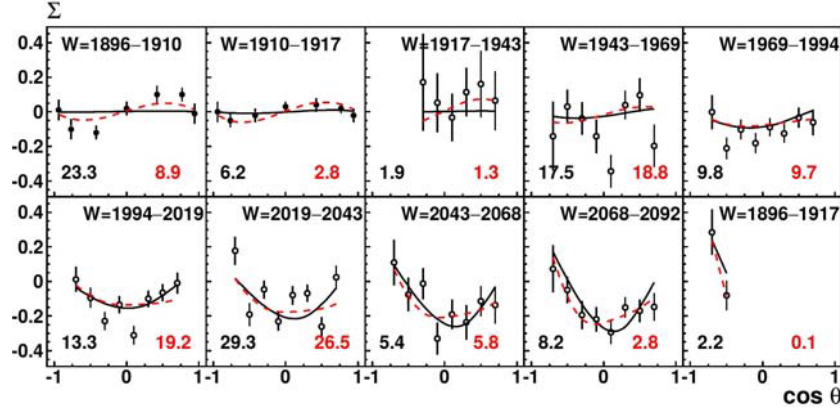


Figure 2. Partial wave analysis results from the Bonn-Gatchina partial wave analysis group. The red dotted lines show the fits with a narrow resonance close to the η' threshold included whereas the solid black lines show the same fits without the resonance included [3].

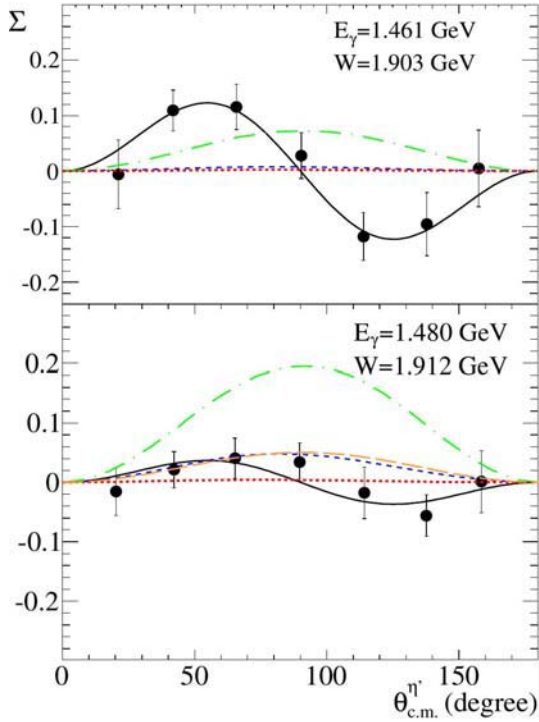


Figure 1. η' beam asymmetry results from the GRAAL experiment. The colored lines are different theoretical calculations, references found in [1]. Figure taken from [1].

ing a narrow S_{11} (1900) resonance [2].

Experimentally the determination of the beam asymmetry is done by extracting the normalised η' yields for two perpendicular polarisation planes (+ and -), subtracting the two and dividing out the sum to remove detector inefficiencies. This is shown in equation 5.

$$A = \frac{N_+ - N_-}{N_+ + N_-} = P_\gamma(E_\gamma) \Sigma(E_\gamma, \Theta_{\eta'}^{CMS}) \cos(2\phi_{\eta'}) \quad (5)$$

From this the beam asymmetry can be calculated by applying a $\cos(2\phi_{\eta'})$ fit to the $\phi_{\eta'}$ distribution of A in different $\cos(\Theta_{\eta'}^{CMS})$ bins.

2 The BGO-OD experiment at ELSA

The BGO-OD experiment is located at the ELSA [4] (Electron-Stretcher-Accelerator) facility at the physics institute of the University of Bonn. ELSA is a three stage accelerator which can boost electrons up to 3.2 GeV. The electrons are produced via a thermionic gun, from which they are first accelerated using a linear accelerator. Subsequently they enter a booster synchrotron, where they are accelerated up to 1.6 GeV. Several runs of the synchrotron are used to fill the stretcher ring, where the electrons reach their final energy of up to 3.2 GeV. From there they are fed to one of the two hadron physics experiments (BGO-OD and Crystal Barrel) or into an area for detector tests.

At BGO-OD (see figure 3) the electron beam enters the goniometer tank at which point bremsstrahlung is produced via a thin copper or diamond radiator. The copper radiator is employed to produce an unpolarised photon beam whereas the diamond radiator is used to create a linearly polarised photon beam through coherent bremsstrahlung. Using a magnet and a hodoscope (the tagging system) the post-bremsstrahlung electron's energy can be determined. The produced real photon beam passes two collimators and enters the central part of the setup. It consists of the target filled with liquid hydrogen surrounded by two cylindrical Multi-Wire-Proportional-Chambers for charged particle tracking, a plastic scintillator barrel for particle ID and the BGO ball, consisting of 480 $Bi_4Ge_3O_{12}$ crystals. The ball covers nearly 4π in acceptance and is ideally suited for the detection of neutral particles. In polar angle it covers $22^\circ - 155^\circ$.

The central detectors are complimented by the forward spectrometer which is well suited for the identification and momentum determination of charged particles. It consists of tracking detectors in front and behind a large open dipole magnet and time-of-flight walls at the end. The forward spectrometer covers polar angles up to 12° which leaves an acceptance gap between the central detectors and the forward spectrometer. This is filled by the SciRi (Scintillating-Ring) detector.

Two detectors are located at the very end of the experiment for flux measurement.

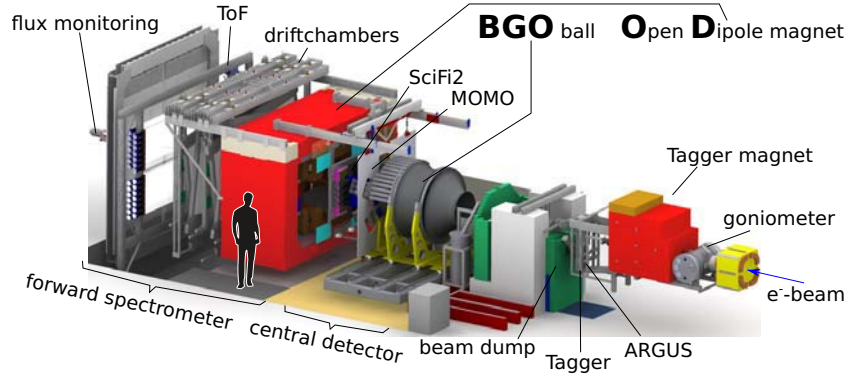


Figure 3. The BGO-OD setup.

3 Analysis of $\gamma p \rightarrow \eta' p$

Due to the Lorentz boost, protons will be boosted in a forward direction close to threshold, thus entering the forward spectrometer, where their momentum and direction can be determined. No other particles are reconstructed in this analysis, resulting in high statistics at the expense of a significant background.

After identifying the proton, the missing mass, m_{miss} , to the proton can be calculated as shown in 6.

$$m_{\text{miss}}^2 = (p_\gamma + p_{\text{target}} - p_p)^2 \quad (6)$$

p_γ is the 4-momentum of the incoming photon, p_{target} the 4-momentum of the target proton and p_p the momentum of the forward going proton.

The resulting missing mass spectrum is shown in figure 4. On top of a continuous background, the peak of the η' is clearly visible alongside peaks from others mesons. The spikes around 600 MeV in the spectrum are binning artifacts from the tagging system.

For the determination of the beam asymmetry the data is

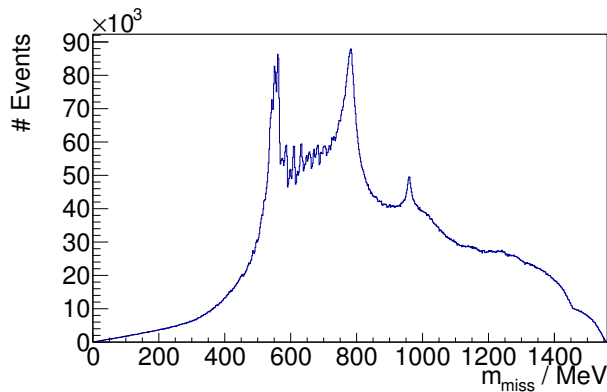


Figure 4. Spectrum of the missing mass to the forward going proton.

subsequently binned as shown in table 1.

Table 1. Binning for the beam asymmetry determination

Parameter	Minimum	Maximum	Bins
E_γ	1446 MeV	1466 MeV	1
$\cos(\Theta_{\eta'}^{CMS})$	-1.0	1.0	7
$\Phi_{\eta'}$	-180°	180°	7

4 η' number extraction

In figure 4 the η' peak is clearly visible above background. This is not the case anymore if the data is split up into the aforementioned bins (see table 1) as can be seen in figure 5.

The missing mass spectra of several simulated reactions are fit simultaneously to the missing mass spectrum of the real data, which makes it possible to determine the contributions of the different reactions to the total spectrum¹.

To ensure that there is an η' contribution in the real data, the fits have been performed with and without the η' included. Figure 5 shows two example bins to demonstrate that this channel is needed for a proper fit.

5 Preliminary beam asymmetry results

Having extracted the η' yields from the different bins, the beam asymmetry can be calculated.

Ideally the polarisation is equal for both polarisation planes, however the polarisation degree varies slightly with orientation and time, so a weighted mean, $P_\gamma(E_\gamma, \pm)$, is determined for each orientation and divided out, see equation 7-9.

$$\frac{N_+ - N_-}{N_+ + N_-} = P_\gamma(E_\gamma) \Sigma(E_\gamma, \Theta_{\eta'}^{CMS}) \cos(2\phi_{\eta'}) \quad (7)$$

$$\tilde{A} = \frac{\tilde{N}_+ - \tilde{N}_-}{\tilde{N}_+ + \tilde{N}_-} = \Sigma(E_\gamma, \Theta_{\eta'}^{CMS}) \cos(2\phi_{\eta'}) \quad (8)$$

$$\tilde{N}_\pm = \frac{N_\pm}{P_\gamma(E_\gamma, \pm)} \quad (9)$$

By fitting a $\cos(2\phi_{\eta'})$ to \tilde{A} the beam asymmetry can be extracted. The particle numbers are carefully flux normalised.

Figure 6 shows the fits to the $\phi_{\eta'}$ distribution of \tilde{A} in the

¹The fits were performed using the RooFit library of Root [5].

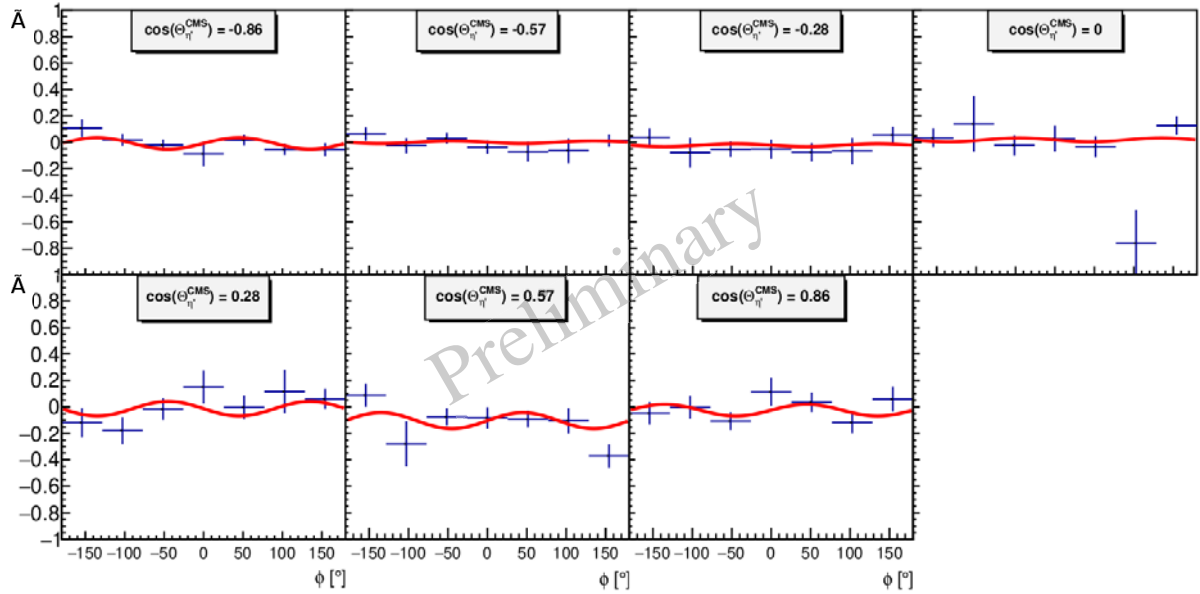


Figure 6. Fits to the $\phi_{\eta'}$ distribution of \tilde{A} in the different $\cos(\Theta_{\eta'}^{CMS})$ bins. Only statistical errors shown.

different $\cos(\Theta_{\eta'}^{CMS})$ bins. These fits are preliminary and represent a snapshot of the current status of this work. The resulting beam asymmetry is shown in figure 7.

6 Conclusion

It has been shown, that the reaction $\gamma p \rightarrow \eta' p$ can be identified at the BGO-OD experiment using only proton identification in the forward spectrometer and fitting the resulting missing mass spectrum.

This technique yields high statistics, but results in a large amount of background. Despite this, the data can be well described in the chosen energy range close to threshold with several simulated reaction channels. These fits are challenging due to the similar nature of signal and background and work is still ongoing.

Furthermore systematic checks on the signal/background extraction will be performed in the future.

A very preliminary first look at the resulting beam asymmetry is also given.

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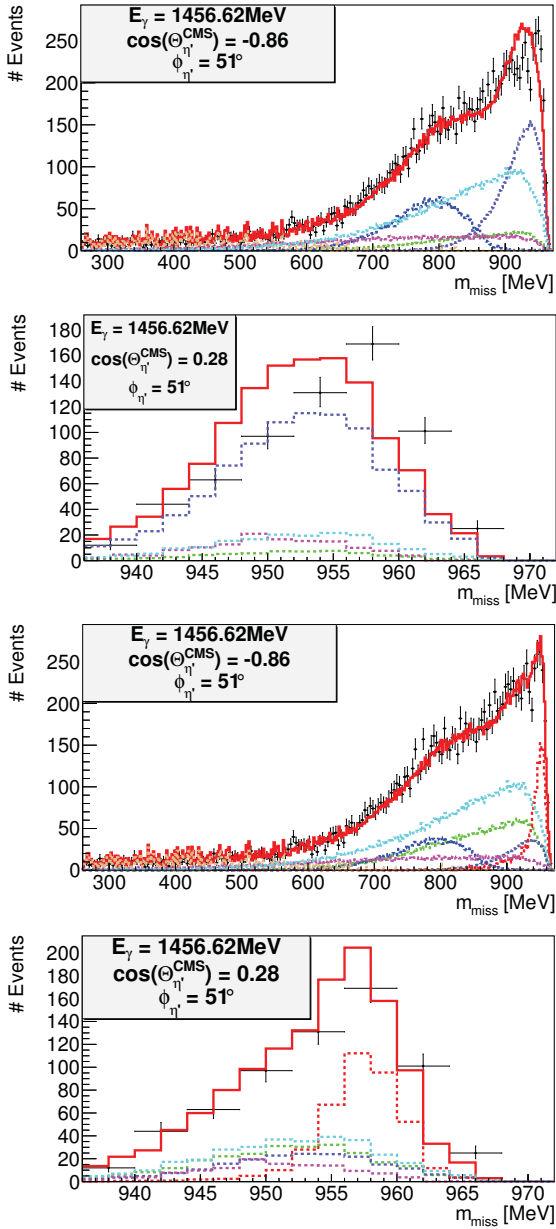


Figure 5. Fits in two different bins without the η' (top two plots) and the same bins with the η' included (bottom two plots). The black data points are the real data, the total fit is shown in solid red, the $\eta' p$ contribution in dotted red, $2\pi p$ in purple, $3\pi p$ in light blue, $\eta\pi^0 p$ in green, $\eta\pi^0\pi^0 p$ in dark purple, ωp in dark blue and $\pi^0 p$ in brown. Note that ωp and $\pi^0 p$ only contribute in the most backward $\cos(\Theta_{\eta'}^{CMS})$ bins.

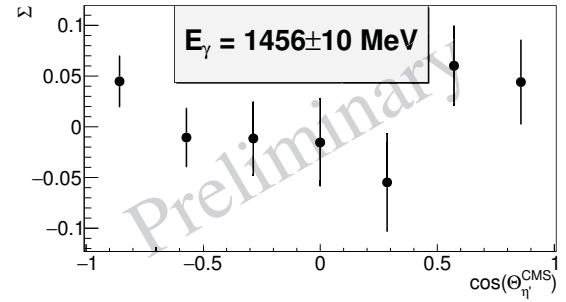


Figure 7. Beam asymmetry results. The errors are the errors of the $\cos(2\phi_{\eta'})$ fit.