ELSA/6-2012-BGO

Proposal to the PAC

Mesurement of the Σ beam asymmetry in $\gamma + p \rightarrow \eta' + p$

The BGO-OD Collaboration

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Abstract

Polarization observables in pseudo scalar meson photoproduction have proved very efficient in pinning down parameters of the resonances involved in the process. In the case of η' photoproduction off the proton, only total and differential cross section values are available in the literature. BGO-OD shows excellent detection efficiency for both neutral and charged final states, allowing for the determination of still unmeasured η' Σ beam asymmetry.

We propose measuring the beam asymmetry Σ from threshold up to 1.7 GeV with error $\Delta\Sigma = 0.07$ in five energy and six angular bins. The experiment is feasible with 1000 hours' beam time, the 6 cm lenght liquid Hydrogen target and a photon beam linearly polarized through coherent Bremsstrahlung with a total tagged intensity of $N_\gamma = 5 \cdot 10^7 s^{-1}$.

The beam time request partly overlaps with the requests of the proposals for η and ω photoproduction measurements. Total and differential cross section for η' photoproduction will also be remeasured and π^0, η and η' Dalitz decays will be analysed as well.

Equipment

Accelerator & target specification

e^- beam:	3.2 GeV e^- unpolarized
beam line:	BGO-OD experimental area
beam intensity:	$\sim 5 \cdot 10^7 s^{-1}$
polarization:	coherent peak at 1.65 GeV
target:	LH_2
trigger:	$E_{BGO} \geq 180$ MeV and Tagging

beamtime request

LH_2-target:	**1000 h**

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Polarization observables in pseudo scalar meson photoproduction have proved very efficient in pinning down parameters of the resonances involved in the process. In the case of η' photoproduction off the proton, only total and differential cross section values are available in the literature. BGO-OD shows excellent detection efficiency for both neutral and charged final states, allowing for the determination of still unmeasured η' Σ beam asymmetry.

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beam intensity:	$\sim 5 \cdot 10^7 s^{-1}$
linear polarization:	coherent peak at 1.65 GeV
target:	LH2 6 cm
beam time request:	1000 hours

1 Motivation

Polarization degrees of freedom in photoproduction processes play a crucial role, offering a complementary approach to the barion spectroscopy, and are particularly important as they are very sensitive to the details of the interaction, via an interference mechanism allowing to access resonance properties that are difficult to extract from differential cross section measurements where a single contribution often dominates the transition amplitude[1, 2, 3, 4]. The detailed description of the photon-nucleon interaction requires a complete data set containing, at least, eight independent observables: the cross section, the three single polarization observables (beam, target and recoil nucleon) and four, appropriately chosen, double polarization observables[5]. The properties of the resonances can then be extracted from the photoproduction data via partial wave analysis and multipole decomposition, in the framework of different approaches[6, 3] and the comparison of the calculated observables with the experimental data becomes a strong constraint to the theoretical models[4, 7] determining the role and the properties of the included resonances.

In the past few years, the CLAS experiment at Jlab and the CB-ELSA-TAPS at Bonn have produced a rich amount of η' cross section data on the proton[8] [9] [10] and, very recently, on the deuteron[11]. The energy region from threshold (1.447 GeV) up to 2.84 GeV was measured and total and differential cross section data were produced.

As a consequence of this huge experimental effort, the following facts were established:
i) the η'N channel couples mainly to S_{11}(1535) and P_{11}(1710). A marginal role is played by J=3/2 resonances namely P_{13}(1720) and D_{13}(1520)[8].
ii) $g_{\eta' NN} = 1.3 - 1.5$, a value consistent with existing theoretical estimates[8].
iii) above 2 GeV, where the process is dominated by ρ and ω exchange, the dynamics of η' photoproduction are similar to those of η photoproduction[10].

Two theoretical approaches were developed to describe these data:
i) in a relativistic meson-exchange model of hadronic interactions[12], Nakayama and Haberzettl include t-channel mesonic (ρ and ω) together with s- and u-channel nucleon and resonances contributions. The resonances included were S_{11}(1535), P_{11}(1710), D_{13}(1520) and P_{13}(1720), the two latter being required to reproduce some of the details of the angular distribution.
ii) in a reggeized model for η and η' photoproduction[13], Tiator and co-workers use essentially the same ingredients but the vector mesons exchanges are treated in terms of Regge trajectories to comply with the correct high-energy behavior.

Both approaches give a reasonable description of the data and in both cases the authors stress that the cross section data alone are insufficient to pin down the resonances parameters, while beam and/or target asymmetries could be very helpful to better determine the partial wave contributions in this reaction, and impose stricter constraints on the parameter values.

In Fig. 1 the results for the differential cross section of the reaction in model[12] are displayed. From the figure we can see how all fits describe the differential cross section well; as a consequence this observable is unsensitive to the details of the calculation and its measurement cannot help in determining the correct approach. The situation is completely different when the polarization variable Σ is considered (see Fig. 2). From the figure we can see that this observable is very sensitive to the details of the calculation: if e.g. the P_{13} resonance is removed from the fit, beam asymmetry changes sign (curves I and IV) and that it is sensitive to the fine details of the calculation as well (see curve V where all the included resonances have the masses and the widths fixed to their PDG values). Some of the curves show high values of Σ, making the measurement simple and certainly significant.

The sensitivity of the beam asymmetry for the MAID reggeized model[13] is shown in Fig. 3 for two photon energies. The model predicts lower asymmetries with respect to the one previously discussed and still shows a good sensitivity to the P_{13} role in the reaction mechanism.

2 Experimental equipment

2.1 Linearly polarized photon beam

The linear polarized photons will be produced by coherent Bremsstrahlung off the crystal lattice of a properly aligned diamond radiator. The use of this method moreover increases the photon flux in the selected polarization region (see Fig. 4). The option to rotate the photons polarization vector by 90° through adjusting the crystals alignment allows to effectively determine the intrinsic detector φ dependence.

The photon tagging system uses a series of 120 adjacent, partially overlapping plastic scintillators with fast photomultiplier readout. It is designed to cover an electron energy range between 10% and 90% of the ELSA energy. A total tagged photon flux of $N_\gamma^{Tot} \sim 5 \cdot 10^7 s^{-1}$ will be produced, corresponding to $N_\gamma^{Pol} \sim 2.5 \cdot 10^6 s^{-1}$ photons under the polarized peak with average polarization $P \sim 0.3$.

The beam energy spectrum and its polarization as required by this proposal are shown in Fig. 4 (red curve).

2.2 BGO-OD detector

The BGO-OD detector setup is a combination of a central detector system and a forward spectrometer for charged particles, completed by a photon tagging system(see Fig.5).

The central detector of the experimental setup is the high resolution and large solid angle ($0.9 \cdot 4\pi$) BGO[a] electromagnetic calorimeter of the former GRAAL experiment.The calorimeter is combined with two multi-wire proportional chambers (MWPC) for inner tracking and a plastic scintillator barrel for particle identification through the measurement of dE/dx. The calorimeter consists of 480 BGO crystals with a length of 24cm ($>$ 21 radiation lengths).

The region between the acceptance of the central detector and the forward spectrometer will be covered by an azimuthally symmetric Multi-gap Resistive Plate Chamber (MRPC), which is a contribution from external BGO-OD collaborators (INFN Rome and University of Rome). The MRPC will be located between the BGO calorimeter and the MOMO detector. It consists of two stacks, which are divided into 16 independent azimuthal sectors with a total of 480 channels.

The forward spectrometer is based on a large open dipole magnet, a permanent loan by DESY. Tracks are reconstructed in front of the magnet by two fiber hodoscopes, MoMo and SciFi2.

[a] $Bi_4Ge_3O_{12}$

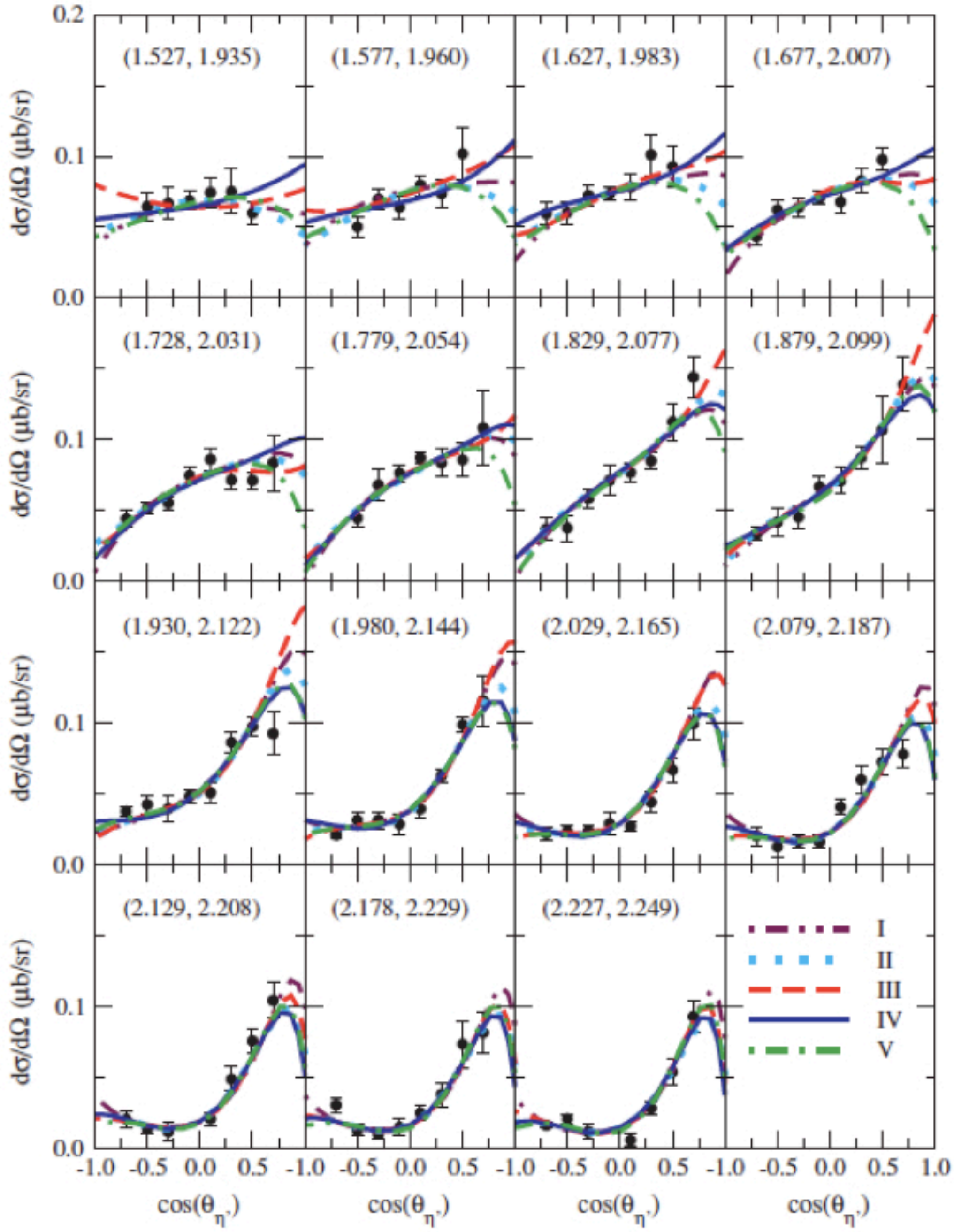

Figure 1 *Differential cross section for $\gamma + p \to \eta' + p$ as a function of the η' emission angle $\theta_{\eta'}$ in the center-of-momentum system frame[12]. The curves correspond to different fit results: I (dash-double-dotted) contains P_{11}, S_{11}, P_{13} and D_{13} resonances, II (dotted) shows the effect of the inclusion of an extra $D_{13}(2085)$ resonance, III (dashed) includes the contribution of higher mass P_{11} and S_{11} states, IV (solid) the P_{13} resonance is removed from the fit and V (dash-dotted) contains all the resonances with masses and widths fixed to their PDG values. The numbers in parentheses represent the incident photon energy and the corresponding s-channel center-of-mass energy in GeV. The data are from Ref[8].*

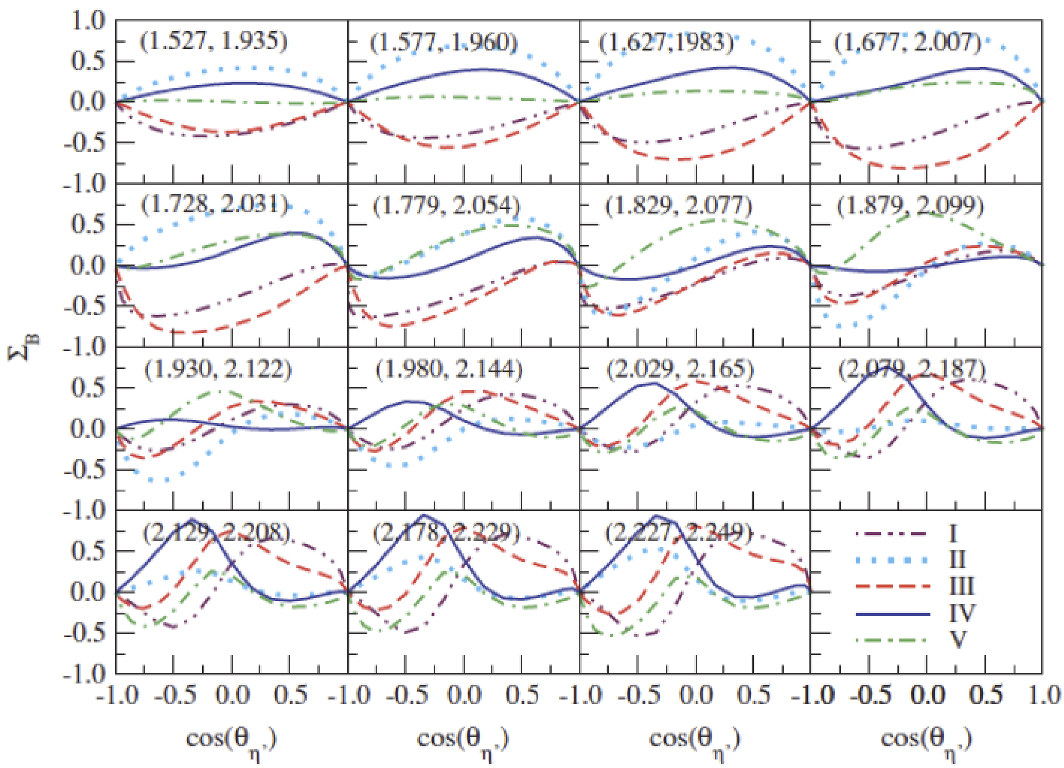

Figure 2 *Beam asymmetry Σ for $\gamma + p \rightarrow \eta' + p$ as a function of the η' emission angle $\theta_{\eta'}$ in the center-of-momentum system frame. Curves as in Fig.1. The numbers in parentheses represent the incident photon energy and the corresponding s-channel center-of-mass energy in GeV.*

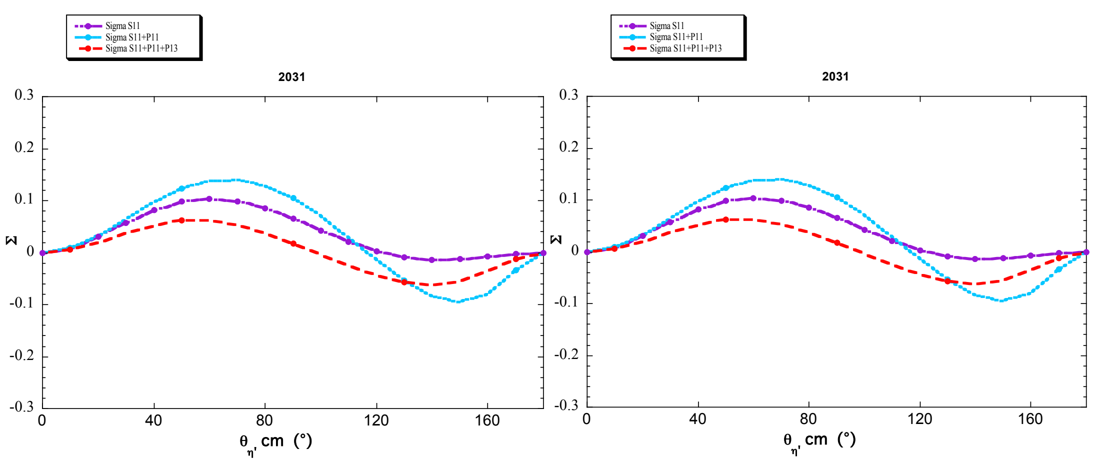

Figure 3 *Beam asymmetry Σ for $\gamma + p \rightarrow \eta' + p$ as a function of the η' emission angle $\theta_{\eta'}$ in the center-of-momentum system frame as predicted in[13].*

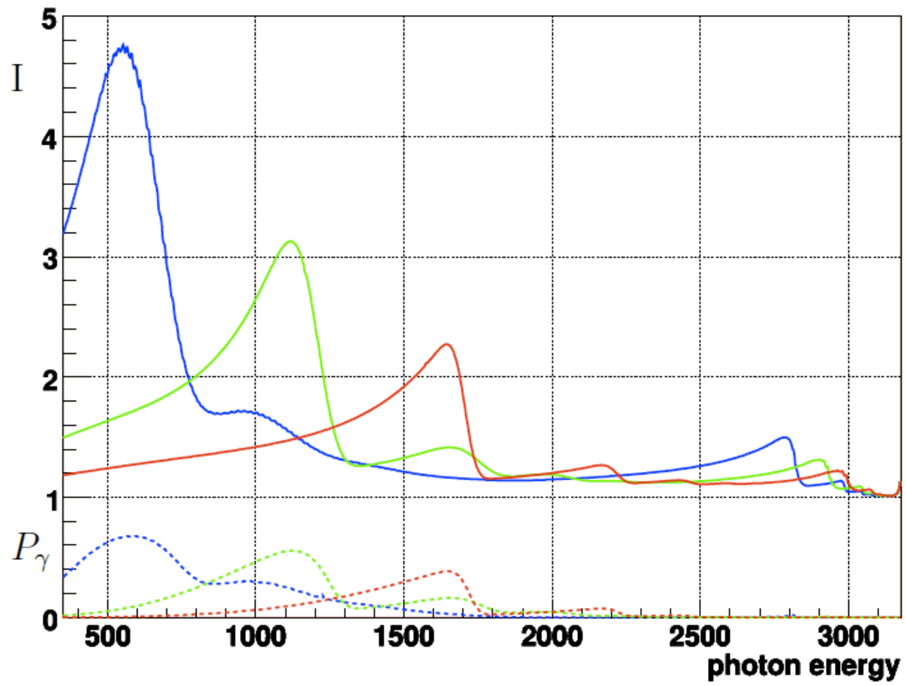

Figure 4 γ *beam energy and polarization. Red curve displays the conditions required by present proposal.*

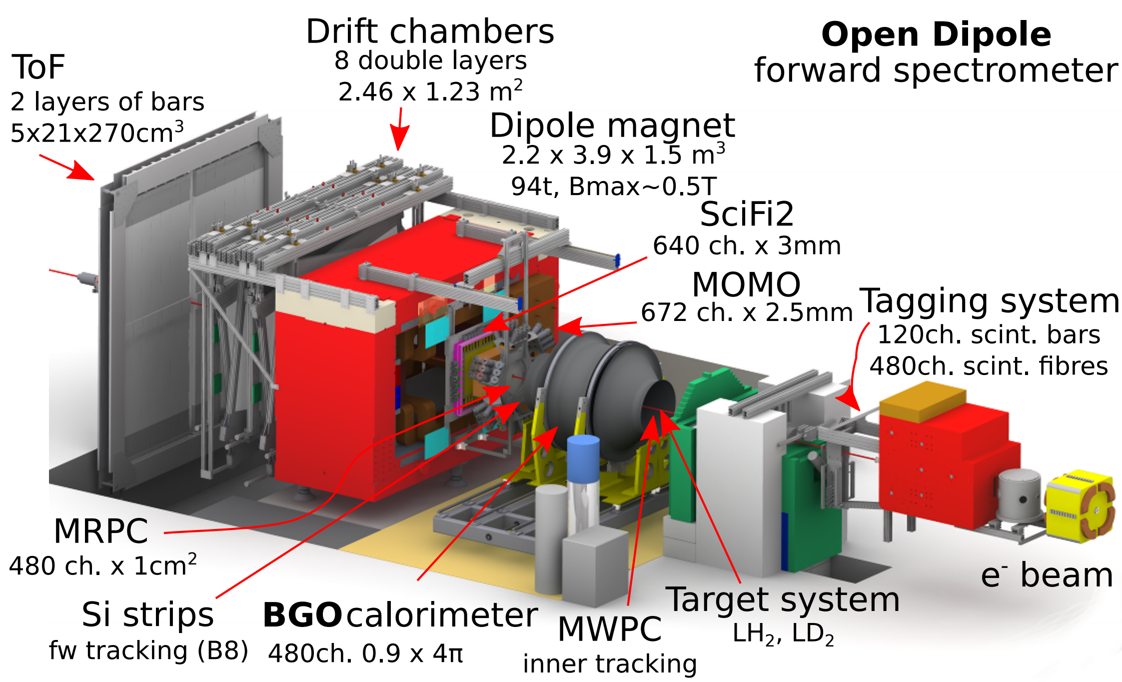

Figure 5 *The BGO-OD experimental setup*

Behind the magnet, tracking is done using a set of 8 double layer drift chambers in four different orientations, vertical wires to measure the x-coordinate, horizontal for the the y-coordinate, and tilted by $\pm 9^\circ$ from vertical, for a u- and v-coordinate.

The forward spectrometer is completed by a set of time-of-flight walls that are used to discriminate the various particles.

Part	Acceptance	angular resolution	time resolution	p/E resolution
BGO Ball	$25^\circ < \Theta < 155^\circ$	$\Delta\Theta < 6^\circ$,$\Delta\Phi < 7^\circ$	$< 3\,\mathrm{ns}$	$\approx 3\,\%$ for $1\,\mathrm{GeV}$ photons
MWPC	$8^\circ < \Theta < 163^\circ$	$\Delta\Theta \approx 1^\circ$,$\Delta\Phi = 2^\circ$	n.a.	n.a.
MRPC	$8^\circ < \Theta < 25^\circ$	$< 1^\circ$	50 ps	n.a.
forward spec.	$\Theta_{vert} < 8^\circ$	$\Delta\Theta_{\Theta<4^\circ} < 0.2^\circ$	n.a.	$< 3\,\%$ for $p < 1.5\,\mathrm{GeV}$
	$\Theta_{hor} < 12^\circ$	$\Delta\Theta_{\Theta<10^\circ} < 0.3^\circ$	n.a.	$< 6\,\%$ for $p < 3\,\mathrm{GeV}$
ToF	$\Theta_{vert} < 8^\circ$,$\Theta_{hor} < 12^\circ$		500 ps	n.a.
Tagger	n.a.	n.a.	275 ps	10 MeV to 40 MeV

Table 1 *Parameters of the BGO-OD setup*

3 Event selection

A very simple trigger is required to perform this measurement: the coincidence between a signal in the tagger and a constraint in the total energy collected by the BGO calorimeter, the latter required to be greater than a threshold value $E_{thr}^{BGO} \sim$ 180-200 MeV. This simple trigger scheme proved to be very efficient in reducing the electromagnetic background (mainly pair production on the target cell and along the photon beam line) without affecting the hadronic count rate.

In Fig. 6 the kinematics of the reaction are displayed. We can see from the figure that, in our required conditions, the recoil proton will always be measured either in the dipole spectrometer, or by the MRPC position chambers. A complete measurement is thus feasible by detecting the recoil proton in the forward direction ($\vartheta_p^{lab} \leq 25^\circ$) and the η' decay products in the BGO calorimeter.

We will detect the η' via the following decay chains:

1. $\eta' \rightarrow 2\gamma$
2. $\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$
3. $\eta' \rightarrow \pi^+\pi^-\eta \rightarrow \pi^+\pi^-2\gamma$

(their respective branching ratios beeing: $\Gamma_1 \simeq 2.18\%$, $\Gamma_2 \simeq 8.28\%$, $\Gamma_3 \simeq 17.05\%$)

4 Simulations

For each decay chain, the detection efficiency ϵ_i must be estimated. We have used a full montecarlo simulation of the detector setup that includes an event generator (updated version of the one described in[14]) containing all known hadronic cross sections off the proton as a function of the photon energy.

The result of the simulation and event selection procedure is summarized in Fig. 7. In the figure we can see the yields (in arbitrary units) at various stages of the selection procedure: the black curve in both graphs represents the starting point of the event selection when at least 2 γ are detected by the BGO. The red curve indicates the resulting spectrum when exactly 2 γ (left) or 6 γ (right) are measured, and finally the blue curve shows the events that fulfil the kinemetical constraints in the recoil proton measurement. In the right graph, invariant mass selection identifies the 2 π^0 and the η from the η' decay (see Fig. 8), as well. The values of the reconstruction efficiencies ϵ_i depend on the percentage of background events that are accepted by the event selection procedure. These are summarised in Table 2 together with the relevant solid angle $\Delta\Omega_i$ (The efficiency values for the detection of the decay $\eta' \rightarrow \pi^+\pi^-2\gamma$ are conservative estimates; the relevant simulations are in progress).

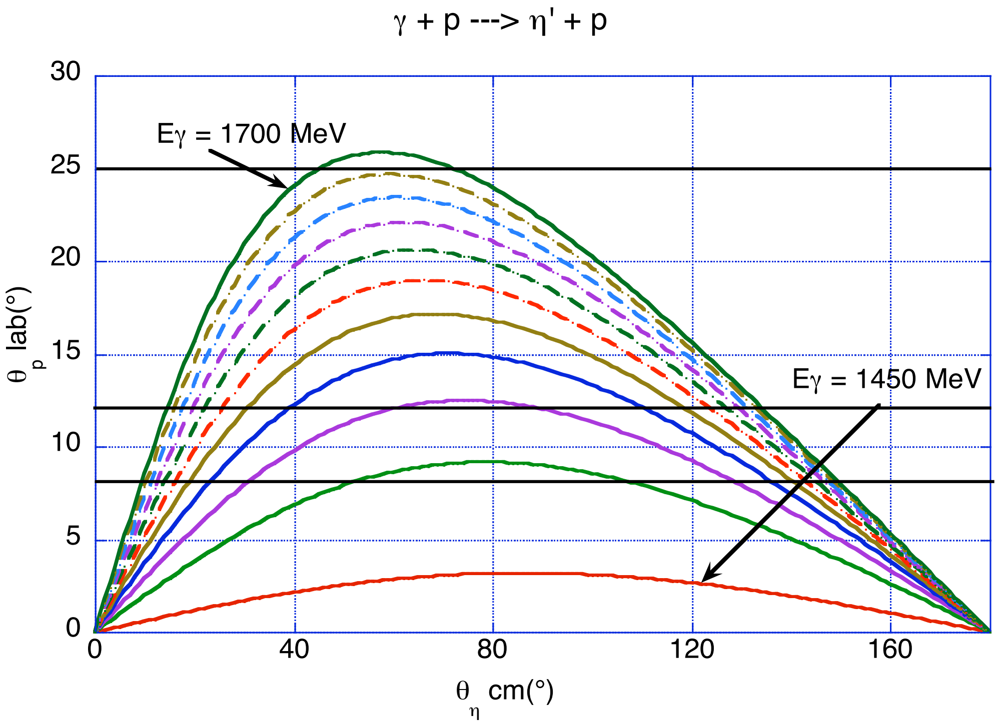

Figure 6 *Kinematics of the reaction $\gamma + p \rightarrow \eta' + p$. The curves show (25 MeV steps for the incident photon energy E_γ) the bahavior of the proton laboratory angle ϑ_p as a function of the η' center-of-mass angle $\vartheta_{\eta'}$. The horizontal lines show the geometrical dipole aperture limits (vertical direction $8°$, horizontal direction $12°$ and the BGO calorimeter lower limit ($25°$).*

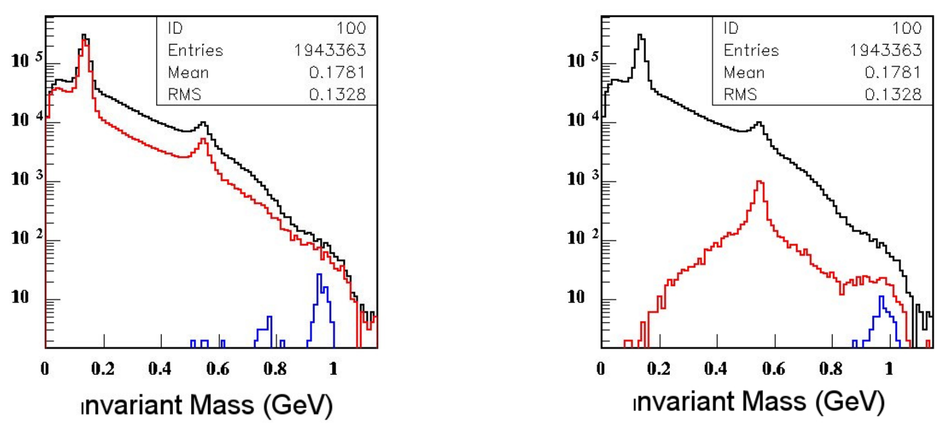

Figure 7 *Event selection: the black curve is identical in both graphs and indicates the invariant mass spectrum of all events containing at least two photons measured in the BGO calorimeter. The red curve shows the same spectrum when exactly 2 photons(left) or six photons(right) are reconstructed in the calorimeter. The blue curve shows the remaining events after the kinematical constraints from the recoil proton measurement are applied. In both cases (two or six photons) the η' peak is cleanly selected. A 3% contamination from concurrent events is allowed under the peak*

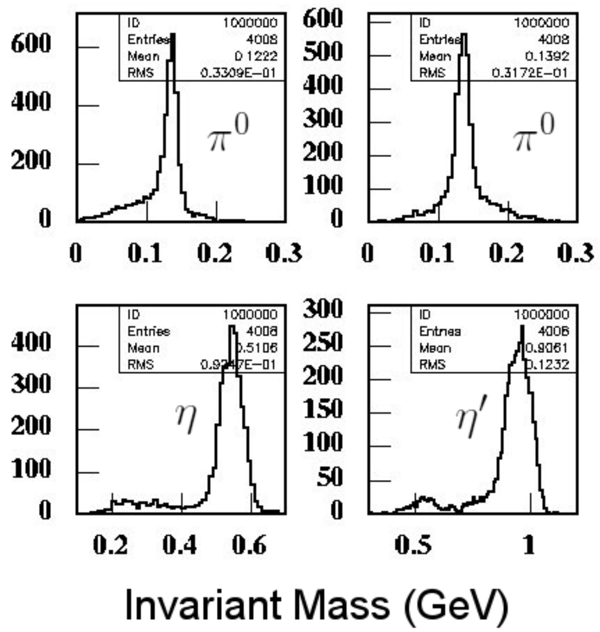

Figure 8 *Identification of the three neutral mesons ($2\pi^0\eta$) from η' decay by invariant mass selection and subsequent η' invariant mass reconstruction.*

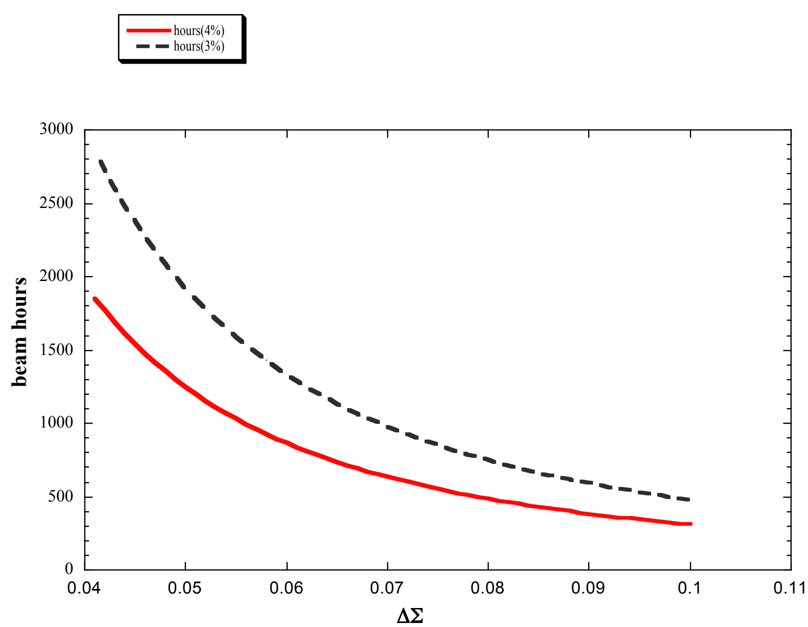

Figure 9 *Time (hours) needed to perform the measurement as a function of the statistical uncertainty $\Delta\Sigma$. Black dashed curve corresponds to 3% background events, while the red full curve corresponds to 4% background events. We can see that the measurement is feasible in $\simeq$ 1000 hours of beam time even with the stricter event selection*

Background level	2γ	6γ	$\pi^+\pi^-\,2\gamma$
$\epsilon(3\%)$	0.25	0.044	~ 0.05
$\epsilon(4\%)$	0.34	0.073	~ 0.08
$\Delta\Omega$ (sr)	10.0	6.7	8.2

Table 2 *Reconstruction efficiencies and solid angles*

5 Count rates

The number $n_{\eta'}$ (detected η' per second) is given by:

$$n_{\eta'} = \frac{N_0 \cdot \rho \cdot x}{A} \cdot N_\gamma^{Pol} \cdot \frac{d\sigma}{d\omega} \cdot \Delta\Omega_i \cdot \Gamma_i \cdot \epsilon_i$$

By using a 6 cm lenght LH2 target, a photon flux under the polarized peak of $N_\gamma^{Pol} \simeq 2.5 \cdot 10^6 s^{-1}$, and assuming an average cross section $< \frac{d\sigma}{d\omega} > \simeq 6.3 \cdot 10^{-2} \mu b/sr$, we obtain:

for $\eta' \to 2\gamma$ $n_{\eta'} = 2.92(2.15) \cdot 10^{-3} s^{-1}$,

for $\eta' \to 6\gamma$ $n_{\eta'} = 1.60(0.96) \cdot 10^{-3} s^{-1}$,

for $\eta' \to \pi^+\pi^- 2\gamma$ $n_{\eta'} = 4.38(2.71) \cdot 10^{-3} s^{-1}$.

where the number in brackets refers to a 3% background contamination. A total running efficiency $\epsilon_{run} \simeq 0.5$ accounting for the macroscopic duty cicle of the accelerator (0.714) and for the expected DAQ lifetime (0.75) must be considered. The total number of η' will be:

$n_{\eta'} \simeq 4.46(2.90) \cdot 10^{-3} s^{-1} = 16.1(10.4) h^{-1} = 385(250) d^{-1}$ for 4%(3%) background events.

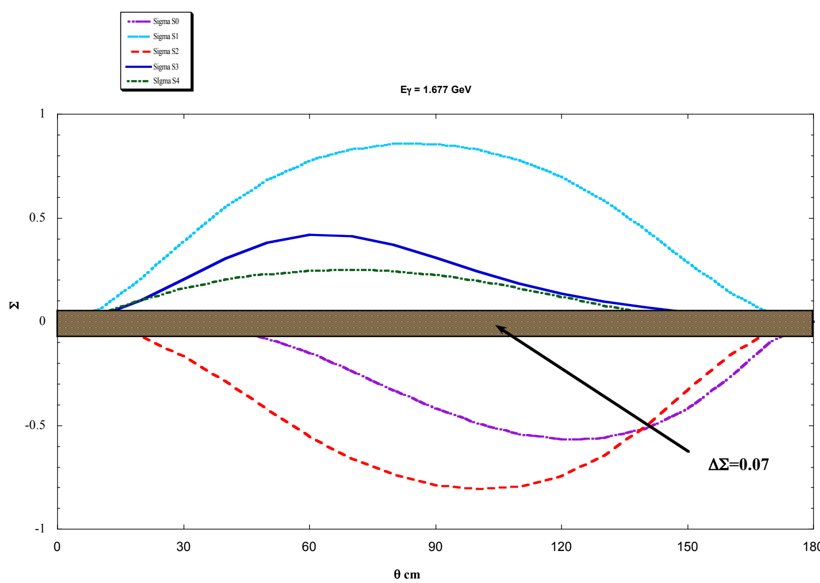

Figure 10 *Projected result of present proposal. The horizontal band shows the $\pm 7\%$ statistical error expected in the measurement. The curves are from model[12] and refer to an incoming photon energy $E_\gamma = 1.677 GeV$.*

We mean to measure the observable Σ in 3 energy and 5 center-of-mass angles bins with an accuracy $\Delta\Sigma = 0.07$. The behavior of the time needed to obtain this statistical uncertainty is shown in Fig. 9. From the figure we can see that the measurement is feasible in 640(980) hours of beam time.

The expected sensitivity of this measurement with respect to the predictions of the model[12] is shown in Fig. 10. We can see that the measurement can discriminate between the different theoretical curves.

6 Conclusion

The measurement of the Σ beam asymmetry for the reaction $\gamma + p \to \eta' + p$ is feasible with a reasonable beam time requirement. The value of this observable is still unknown and its measurement will provide important constraints to the existing theoretical approaches. The data can be partially collected in parallel with other proposed measurements for the BGO-OD beamline, and the trigger configuration will allow for exploratory analyses of not-so-rare decays of the η' meson as well.

The total beam time request for this proposal is 1000 hours.

7 References

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