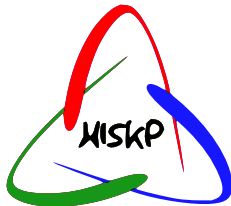


Measurement of the double polarization observables E and G at the Crystal Ball experiment at MAMI

Farah Noreen Afzal
for the
A2 collaboration

HISKP, University of Bonn

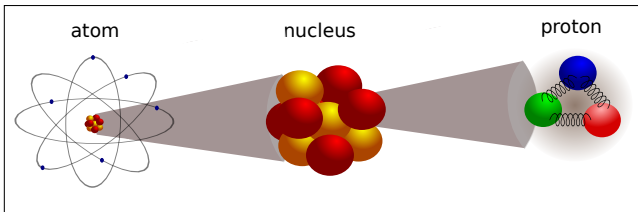
09/17/2015



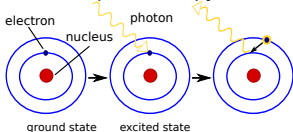
Outline

- 1 Motivation
- 2 The Crystal Ball experimental setup
- 3 Event selection
- 4 Determination of G and E
- 5 Preliminary results

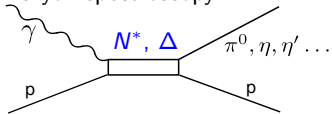
Why baryon spectroscopy?



Atomic spectroscopy:



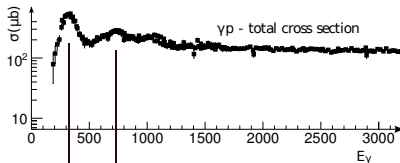
Baryon spectroscopy:



Argon:



E.D. Bloom et. al., SLAC-PUB-653 (1969)



Difficulty: Due to short lifetime, resonances are broad and strongly overlap

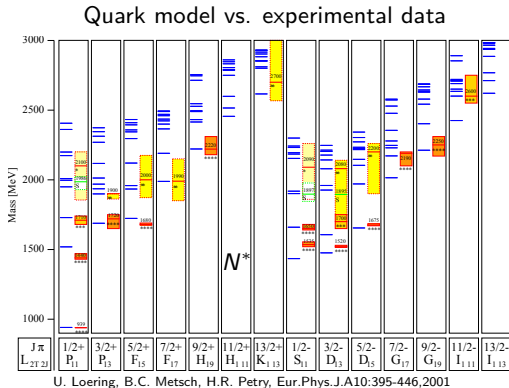
$\Delta(1232)$
 $N^*(1520), N^*(1535), \dots$

Why baryon spectroscopy?

Goal: Understanding nucleon excitation spectra

↔ Understanding dynamics of the constituents inside the nucleon

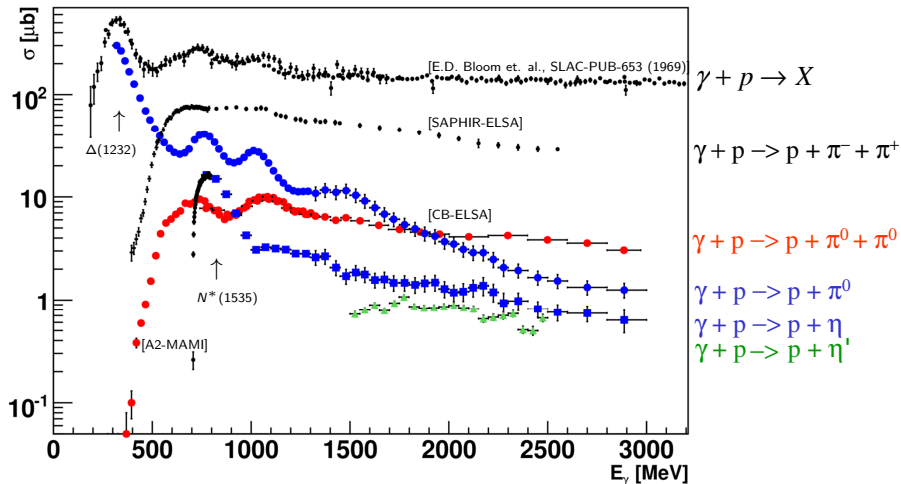
- many more resonances expected in quark models or lattice QCD than experimentally observed
- What are the relevant degrees of freedom?
- most resonances observed in $\pi N \rightarrow$ some resonances might not couple to πN



Photoproduction reactions are excellent tool to probe excitation spectra!

Photoproduction reactions

Study of different reaction channels gives access to different resonant structures
⇒ Worldwide effort to get high precision data (ELSA, JLab, MAMI,...)



Importance of polarization observables

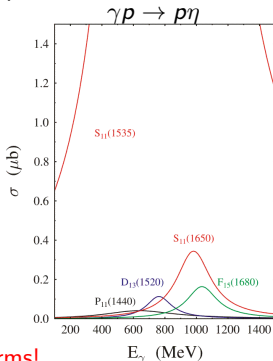
- Scattering amplitude $f \longleftrightarrow$ 4 complex amplitudes (CGLN amplitudes)
 $f(F_1(W, \cos \theta_{cm}), F_2(W, \cos \theta_{cm}), F_3(W, \cos \theta_{cm}), F_4(W, \cos \theta_{cm}))$
- PWA: $F_1 = \sum_{l=0}^{\infty} (lM_{l+} + E_{l+})P'_{l+1} + [(l+1)M_{l-} + E_{l-}]P'_{l-1}$
 - $E_{l\pm}(W), M_{l\pm}(W)$: Multipoles
 - $P'_{l\pm 1}(\cos \theta_{cm})$: Legendre polynomials
- Measurable observables \longleftrightarrow Multipoles \longleftrightarrow Resonance parameters

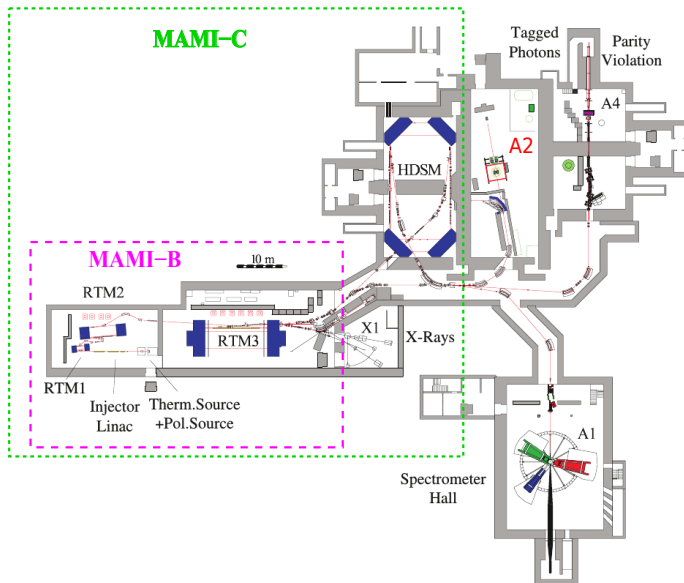
Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
		X	Y	Z(beam)	X'	Y'	Z'	X'	X'	Z'	Z'
unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
linear	Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{x'})$	$(-T_{x'})$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

$$\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \dots$$

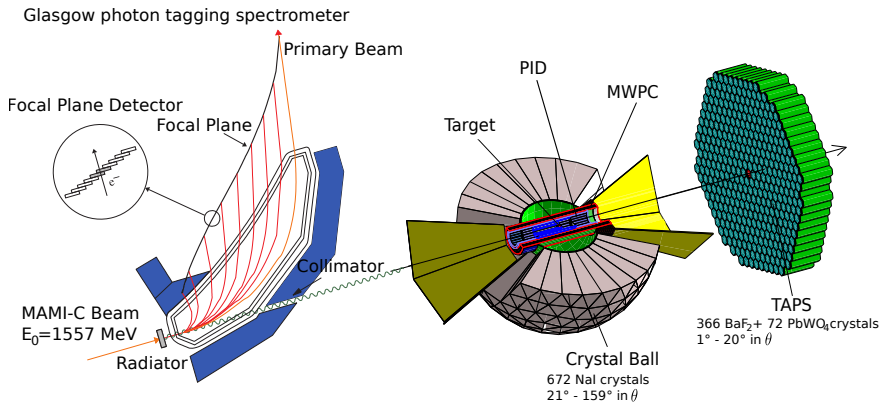
$$\Sigma \sim -2E_{1+}^* M_{1+} + 2M_{1-}^* E_{1+} - 2M_{1-}^* M_{1+} + \dots$$

\Rightarrow Polarization observables are sensitive to interference terms!





The Crystal Ball experiment at MAMI in Mainz

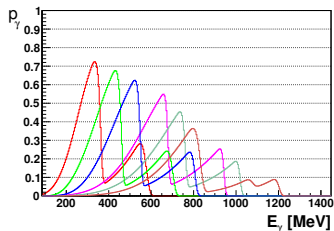


Polarized e^- beam on diamond radiator

First experimental attempt to measure with longitudinally polarized electron beam in combination with a diamond crystal!

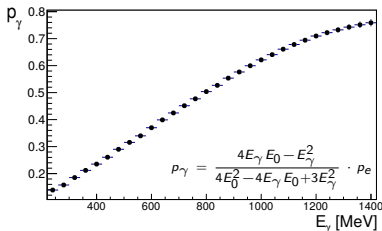
Linearly polarized photons

- diamond radiator needed
- coherent bremsstrahlung
- coherent edges at:
350 MeV, 450 MeV, 550 MeV,
650 MeV, 750 MeV and 850 MeV



Circularly polarized photons

- longitudinally polarized electrons needed
- Mott measurement:
 $p_e \approx 75\% - 78\%$
- helicity transfer to photons

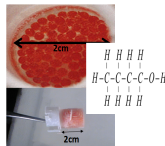


Dubna-Mainz frozen spin polarized target

- polarization via Dynamic Nuclear Polarization DNP
- 70 GHz microwave irradiation at 2.5 T is used to transfer the electrons polarization to protons
- $^3\text{He}/^4\text{He}$ dilution cryostat with 25 mK holding coil and 0.63 T
- relaxation time $\tau \approx 2000$ h
- $9 \cdot 10^{22}$ pol. protons per cm^2 in the target cell
- $p_T \approx 65\%$
- carbon target needed for background studies



Butanol Target



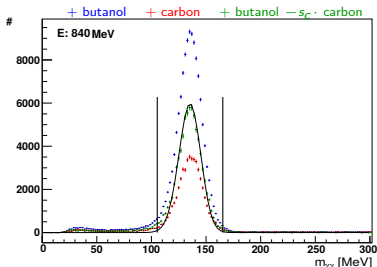
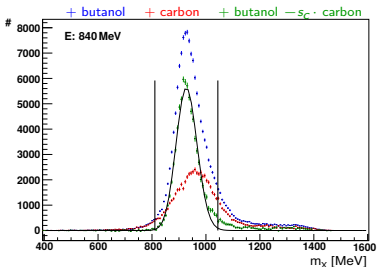
Carbon Target



Selection process of $\gamma p \rightarrow \gamma\gamma p$

Selected events had to fulfill kinematic constraints:

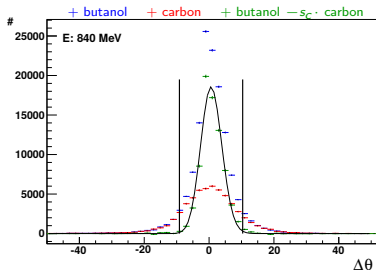
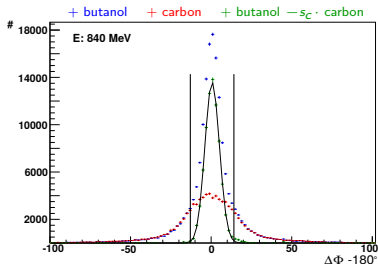
- 3 hits in calorimeters ($p+2\gamma$)
- time coincidence of beam photons and final state meson
- energy dependent 3σ -cuts:
 - Proton: calculated as missing particle of $\gamma p \rightarrow \gamma\gamma X$
 - Invariant mass of $\gamma\gamma$
 - Agreement of missing mass and measured charged particle in θ
 - Coplanarity-cut: $\Delta\Phi = |\Phi_{\gamma\gamma} - \Phi_p| = 180^\circ$



Selection process of $\gamma p \rightarrow \gamma\gamma p$

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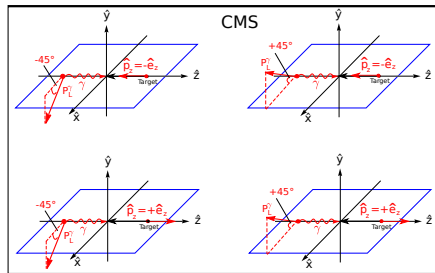
Determination of G and E

Differential cross section for pseudo-scalar meson photoproduction using linearly and circularly polarized photons in combination with a longitudinally polarized target:

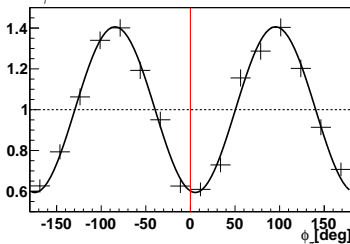
$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{d\sigma}{d\Omega_0}(\theta) [1 - P_{lin} \Sigma \cos(2(\alpha - \phi)) - P_z (-P_{lin} G \sin(2(\alpha - \phi)) + P_{circ} E)]$$

Integrating over all possible helicity states:

$$N_B \Big|_{\pm\alpha}^{\pm p_z}(\theta, \phi) = N_B(\theta) \cdot [1 - P_{lin} \Sigma_B \cos(2(\alpha - \phi)) + d P_{lin} P_z G \sin(2(\alpha - \phi))]$$



All 4 settings are normalized, shifted to 0° and added up
 $E_\gamma = 464 \text{ MeV}, \cos \theta = -0.15$



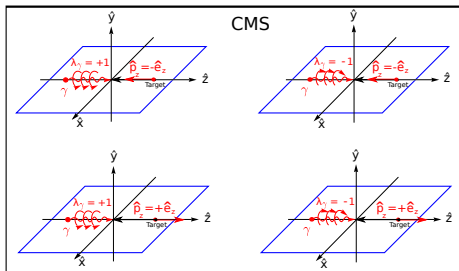
Determination of G and E

Differential cross section for pseudo-scalar meson photoproduction using linearly and circularly polarized photons and longitudinally polarized target:

$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{d\sigma}{d\Omega_0}(\theta) [1 - P_{lin} \Sigma \cos(2(\alpha - \phi)) - P_z (-P_{lin} G \sin(2(\alpha - \phi)) + P_{circ} E)]$$

Integrating over ϕ :

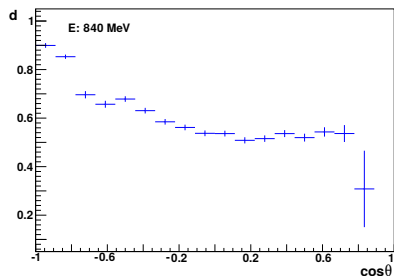
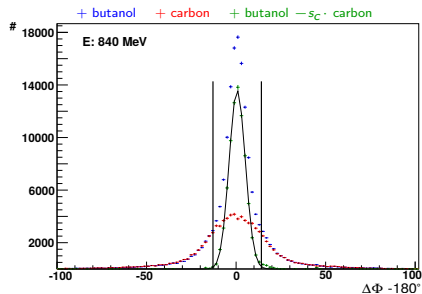
$$N_B \Big|_{\pm 1}^{\pm p_z}(\theta) = N_B(\theta) \cdot [1 - d P_{circ} P_z E]$$



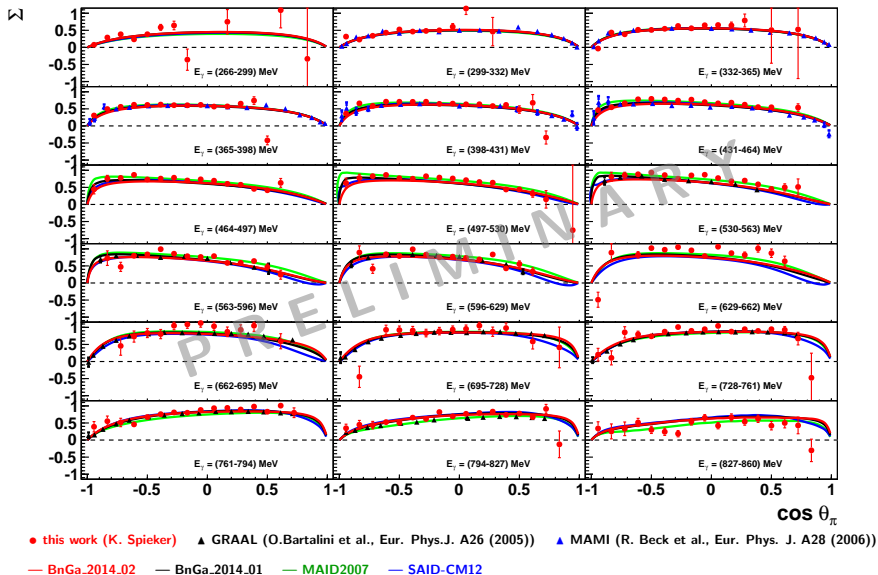
$$\begin{aligned} E &= \frac{\sigma^{1/2} - \sigma^{3/2}}{\sigma^{1/2} + \sigma^{3/2}} \\ &= \frac{N_B^{1/2} - N_B^{3/2}}{N_B^{1/2} + N_B^{3/2}} \cdot \frac{1}{d} \cdot \frac{1}{p_z P_{circ}} \end{aligned}$$

Determination of the dilution factor

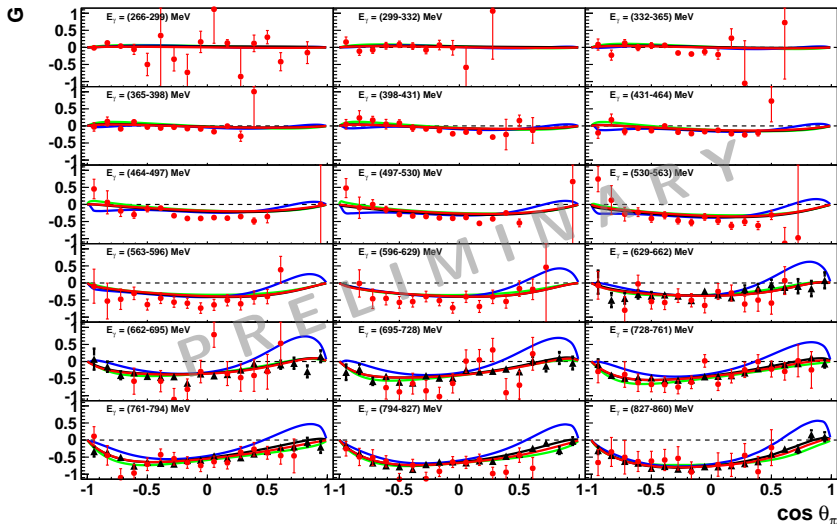
- dilution factor: amount of polarizable protons in the selected data
- $d = 1 - s_c \cdot \frac{N_C}{N_B}$
- scaling factor s_c takes acceptance and flux differences of butanol and carbon beam times into account



Beam asymmetry Σ_B (260 MeV - 860 MeV)



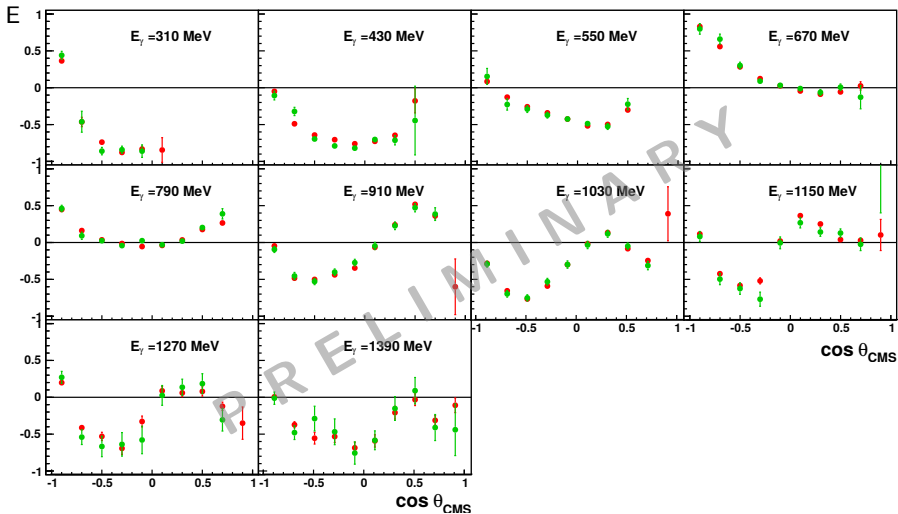
Double polarization observable G (260 MeV - 860 MeV)



● this work (K. Spieker) ▲ CBELSA/TAPS (A. Thiel et al., Phys. Rev. Lett. 109 (2012) 102001)

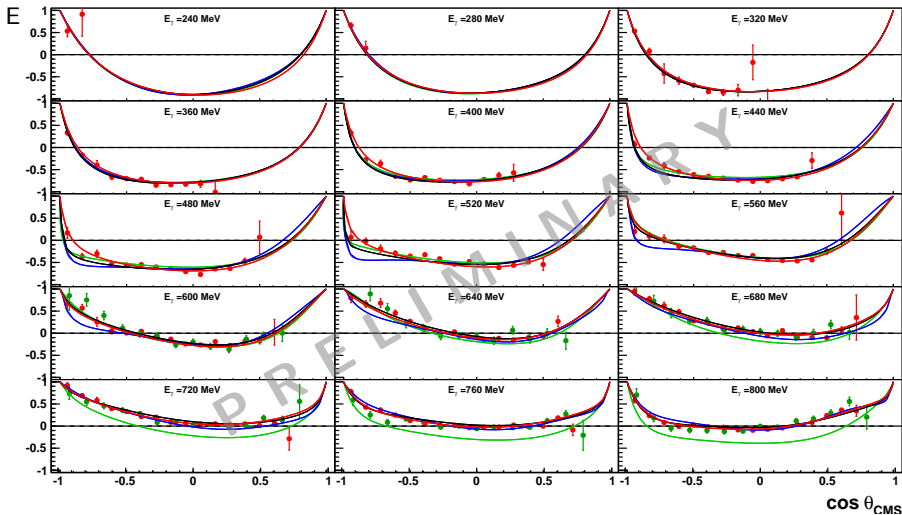
— BnGa_2014_02 — BnGa_2014_01 — MAID2007 — SAID-CM12

The double polarization observable E in π^0 -photoproduction



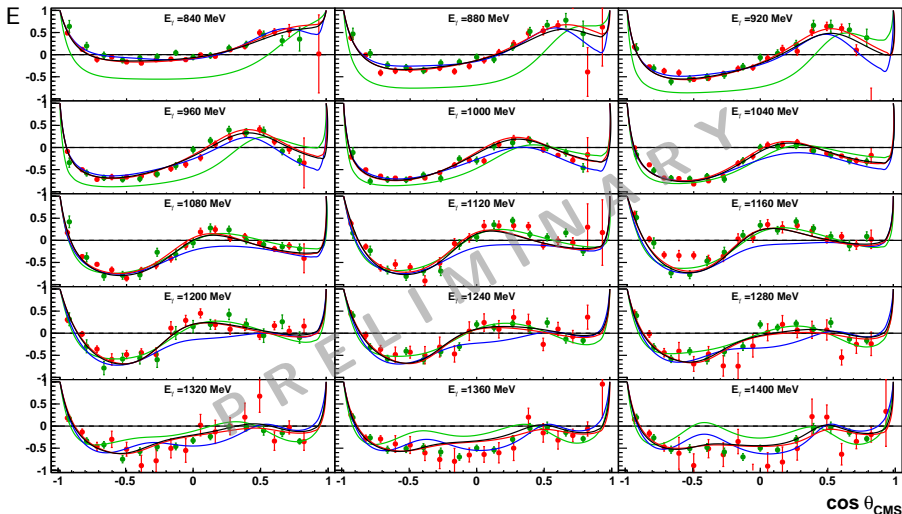
● this work (diamond runs) ● this work (Moeller runs)

E results for π^0 -photoproduction (240 MeV - 800 MeV)



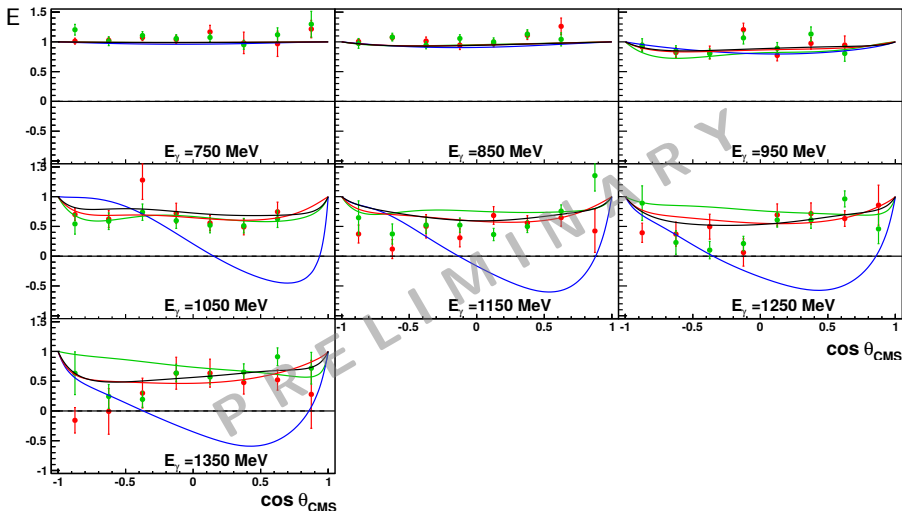
- this work (diamond runs) ● CBELSA/TAPS (M. Gottschall et al., Phys. Rev. Lett. 112 (2014) 012003)
- BnGa_2014_02 — BnGa_2014_01 — MAID2007 — SAID-CM12

E results for π^0 -photoproduction (840 MeV - 1400 MeV)



● this work (diamond runs)
 ● CBELSA/TAPS (M. Gottschall et al., Phys. Rev. Lett. 112 (2014) 012003)
— BnGa_2014_02
 — BnGa_2014_01
 — MAID2007
 — SAID-CM12

E results for η -photoproduction

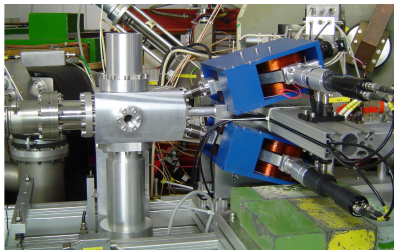
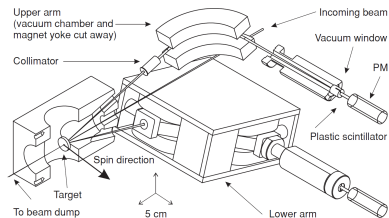


- this work (diamond runs) ● CBELSA/TAPS (J.Müller et al., to be published soon)
— BnGa_2014_02 — BnGa_2014_01 — η -MAID — SAID-GE09

- The double polarization observables G and E were measured at the Crystal Ball experiment at MAMI within the same beam time
- The preliminary results in $\gamma p \rightarrow p\pi^0$ are looking promising:
 - Our data cover energy range down to $\Delta(1232)$ resonance region
→ complementary to CBELSA/TAPS and CLAS data
 - Good agreement between our results for Σ_B , G and E and existing data
 - Good agreement between data obtained with a Moeller and a diamond radiator
- Outlook
 - Not the entire data was shown → More data was/will be taken
 - Analysis of $\gamma p \rightarrow p\eta$, $\gamma p \rightarrow n\pi^+$...

Thank you!

Mott measurement



- Mott-scattering: electrons in gold ($Z=79$) interact via spin-orbit coupling with the longitudinally polarized electrons from MAMI \rightarrow asymmetry in backscattering!
 \rightarrow polarization degree of electrons
- helicity transfer from electrons to photons \rightarrow circularly polarized photons

Linearly polarized photons

- coherent bremsstrahlung produced on diamond crystal
- Bragg: if $\vec{q} = n \cdot \vec{g} \rightarrow$ constructive interference

