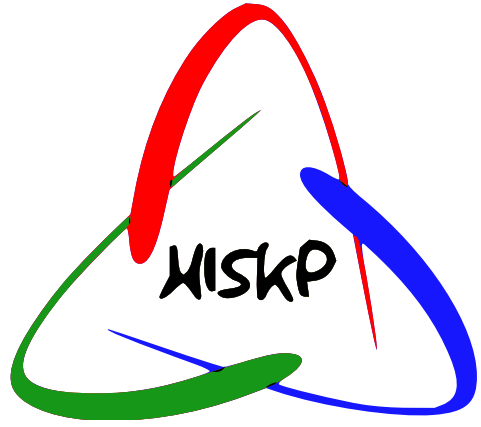
Measurement of the double polarization observables E and G at the Crystal Ball experiment at MAMI

Farah Noreen Afzal
for the
A2 collaboration

HISKP, University of Bonn

05/19/2016



Outline

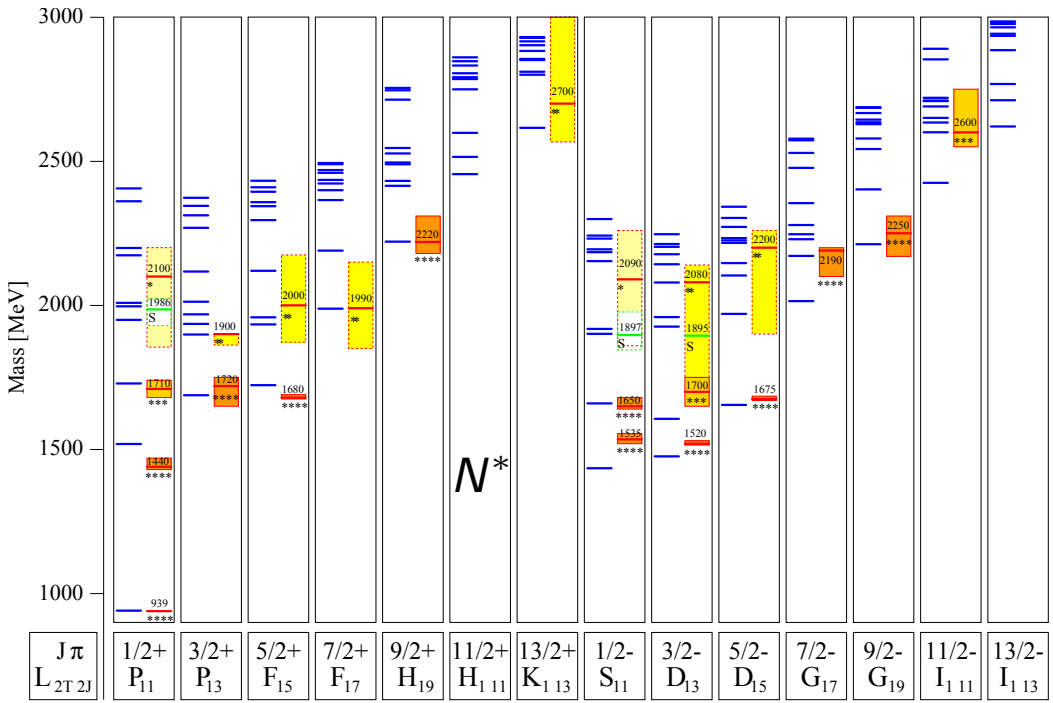
Why baryon spectroscopy?

Goal: Understanding nucleon excitation spectra
$\leftrightarrow$ 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

$\rightarrow$Talk by Jan Hartmann, Monday 11:30
$\rightarrow$Talk by Prof. Leinweber, Tuesday 10:00

Quark model vs. experimental data

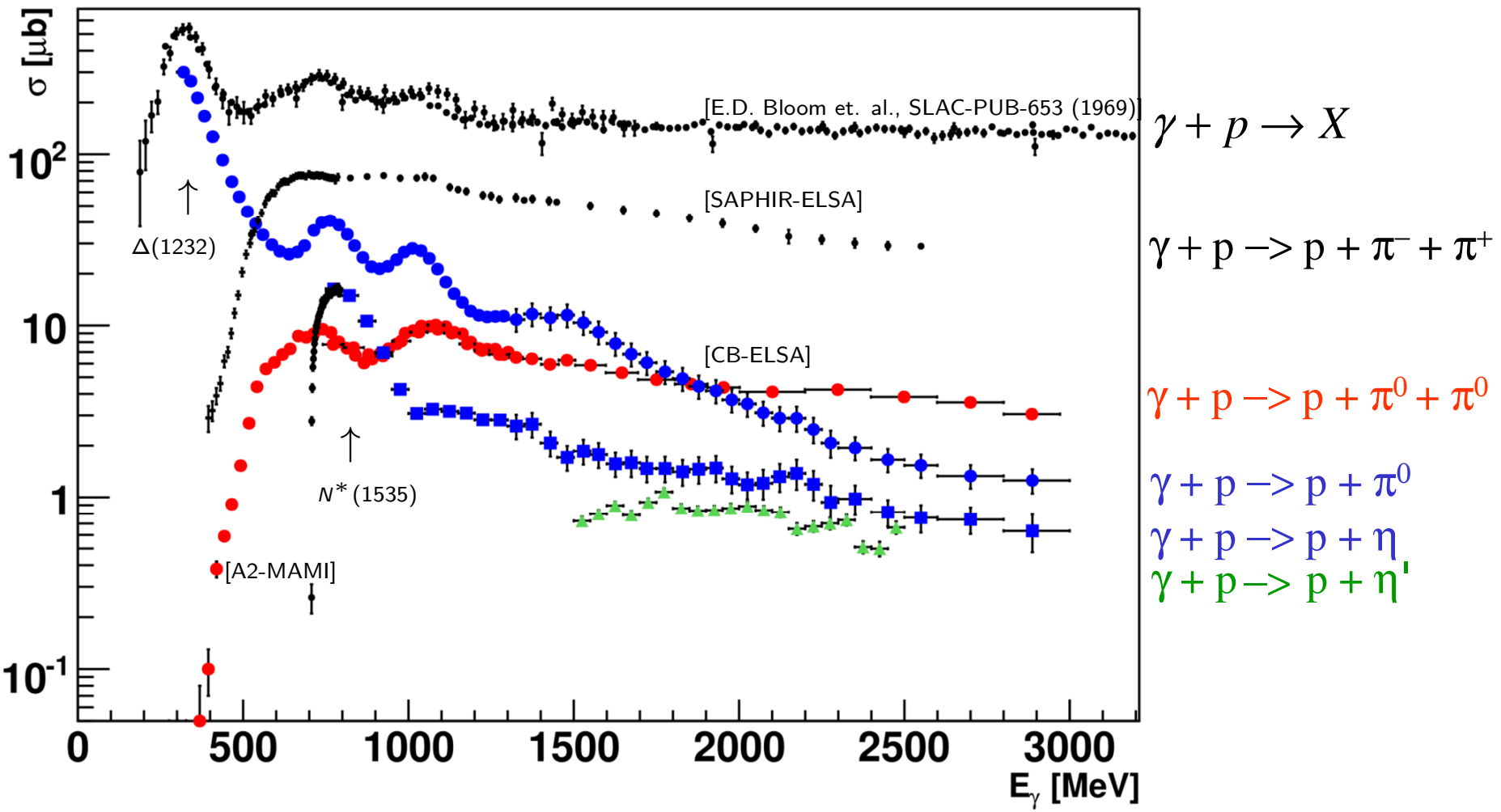


U. Loering, B.C. Metsch, H.R. Petry, Eur.Phys.J.A10:395-446,2001

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,...)



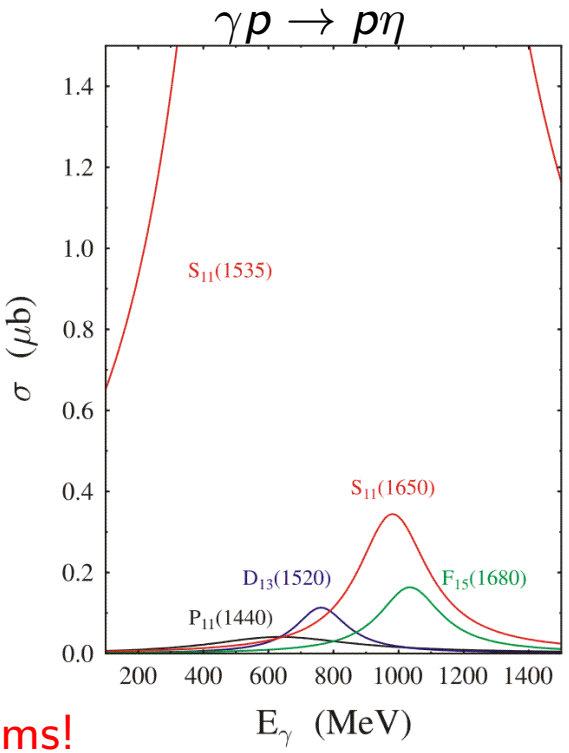
Importance of polarization observables

- 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
  - $P'_{l\pm1}(\cos\theta_{cm})$: Legendre polynomials

→Talk by Yannick Wunderlich (Monday 14:30)

- 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' X Z X 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	$C_{x'}$ - $C_{z'}$	- - - -

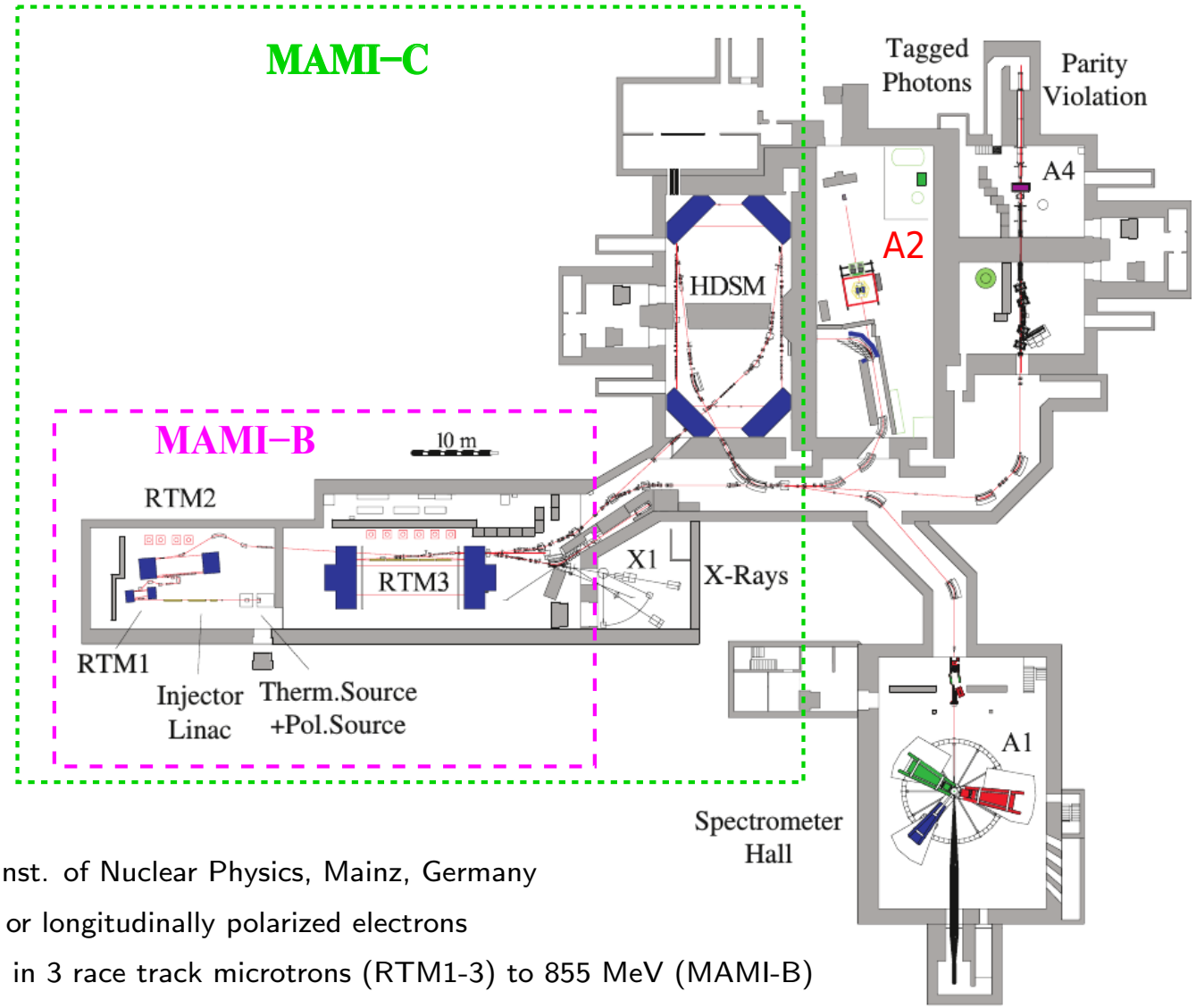


$$\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \ldots$$

$$\Sigma \sim -2E^*_{1+}M_{1+} + 2M^*_{1-}E_{1+} - 2M^*_{1-}M_{1+} + \ldots$$

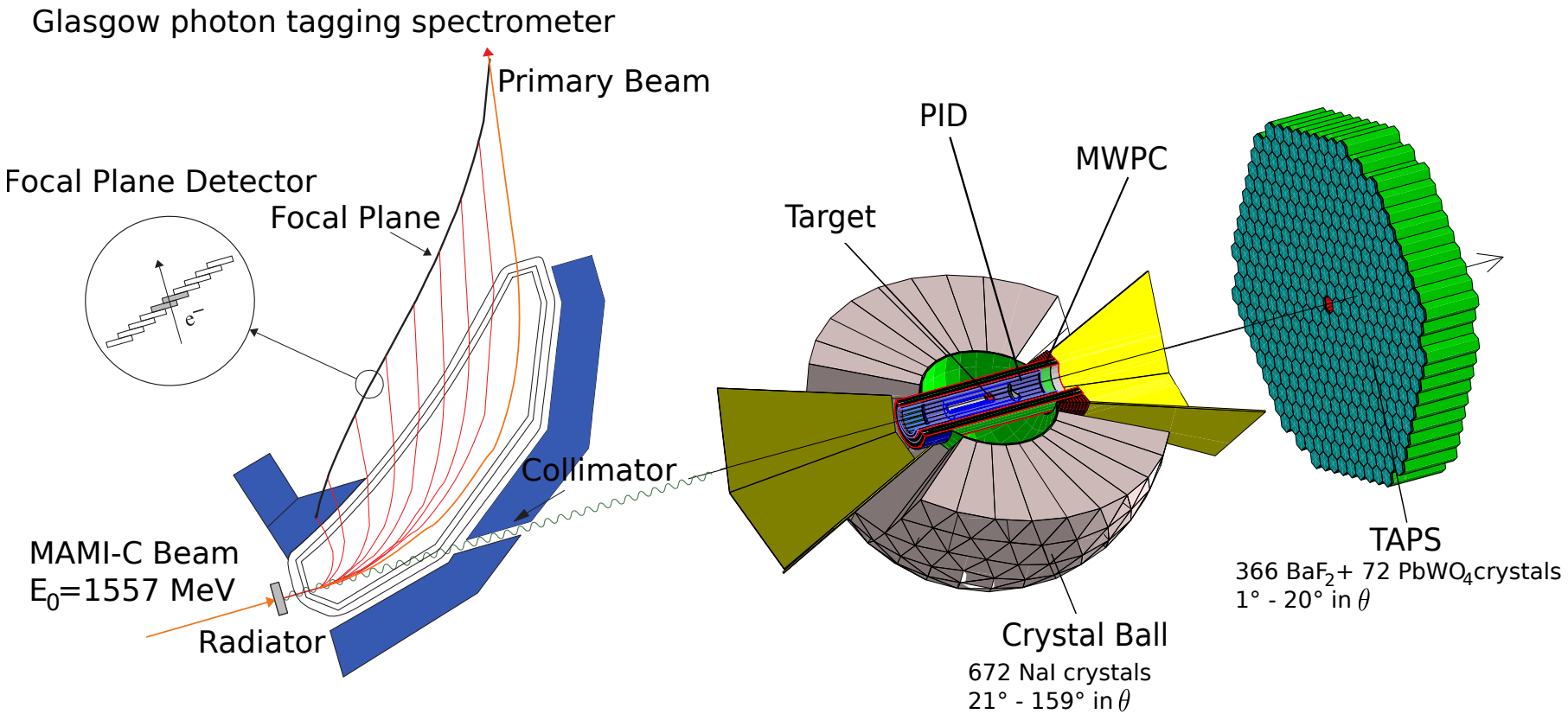
⇒Polarization observables are sensitive to interference terms!

MAinz MIcrotron MAMI



- Located at Inst. of Nuclear Physics, Mainz, Germany
- Unpolarized or longitudinally polarized electrons
- Acceleration in 3 race track microtrons (RTM1-3) to 855 MeV (MAMI-B)
- Acceleration in harmonic double-sided microtron (HDSM) to 1600 MeV (MAMI-C)

The Crystal Ball experiment at MAMI in Mainz



More talks from A2:

- Prof. Bernd Krusche, Monday 14:55
- Dr. Sergey Prakhov, Tuesday 15:00
- Dr. Vahe Sokhoyan, Thursday 11:00
- Dr. Dominik Werthmueller, Thursday 12:00

Polarized e^- beam on diamond radiator

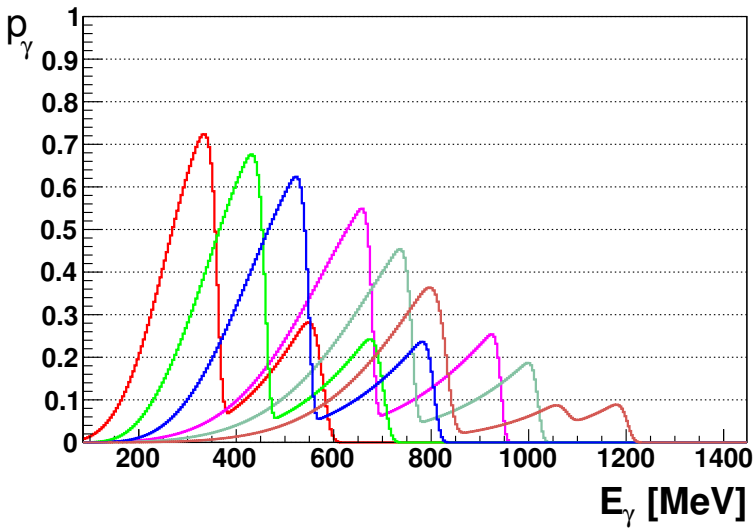
First experimental attempt to measure E and G with longitudinally polarized electron beam in combination with a diamond crystal → using linearly and circularly polarized photons within same beam time!

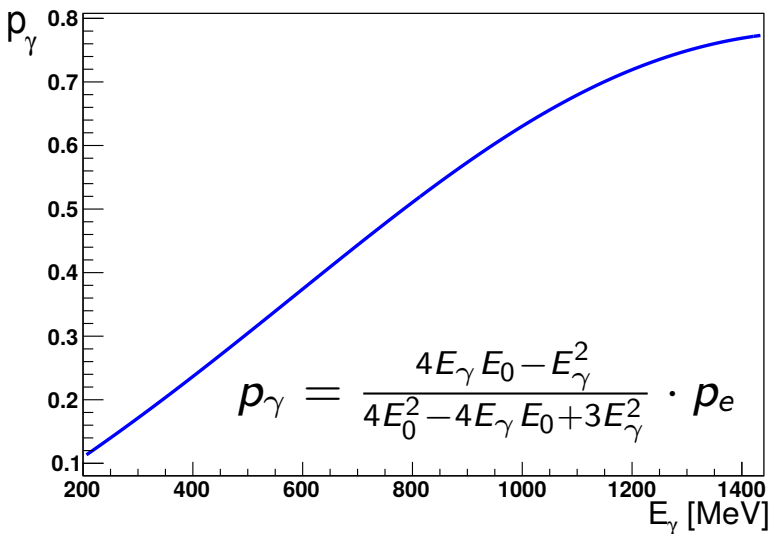
Linearly polarized photons

- 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
- helicity transfer to photons
- Mott/Møller measurement:
  $p_e \approx 75\% - 78\%$

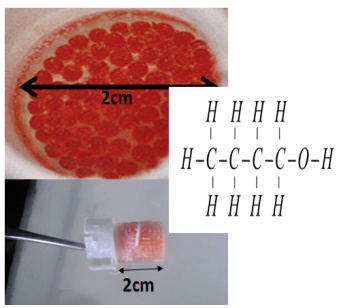




Dubna-Mainz frozen spin polarized target

- polarization via Dynamic Nuclear Polarization DNP
- 70 GHz microwave irradiation at 2.5 T is used to transfer the electrons polarization to protons
- ^{3}He/^{4}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 up to 90%
- carbon target needed for background studies

Butanol Target

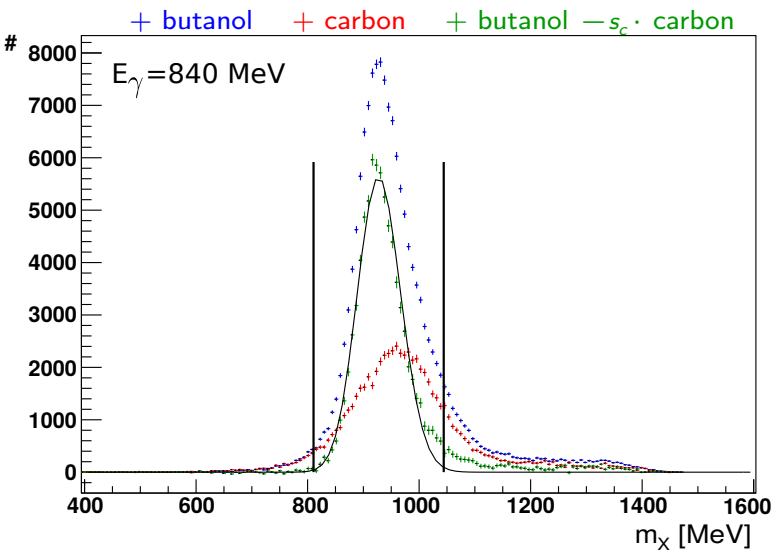


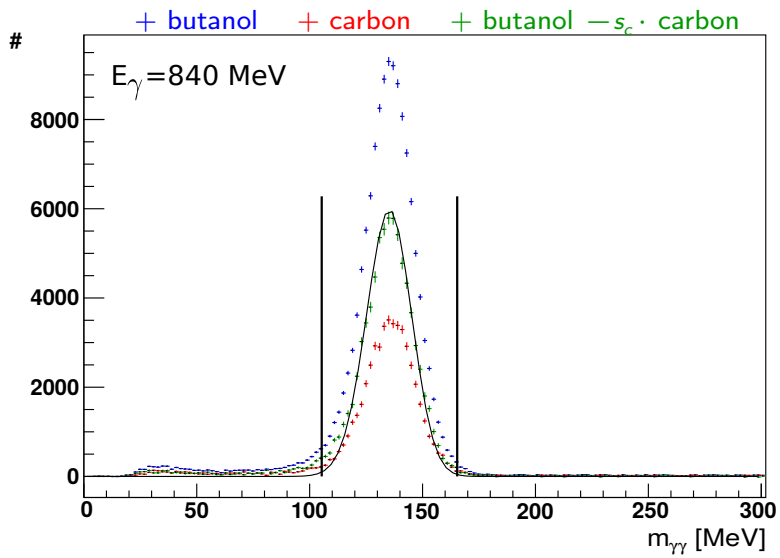
Carbon Target

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

Selected events had to fulfill kinematic constraints:

- 3 hits in calorimeters (p+2γ)
- 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: $\Delta\Phi = |\Phi_{\gamma\gamma} - \Phi_p| = 180°$





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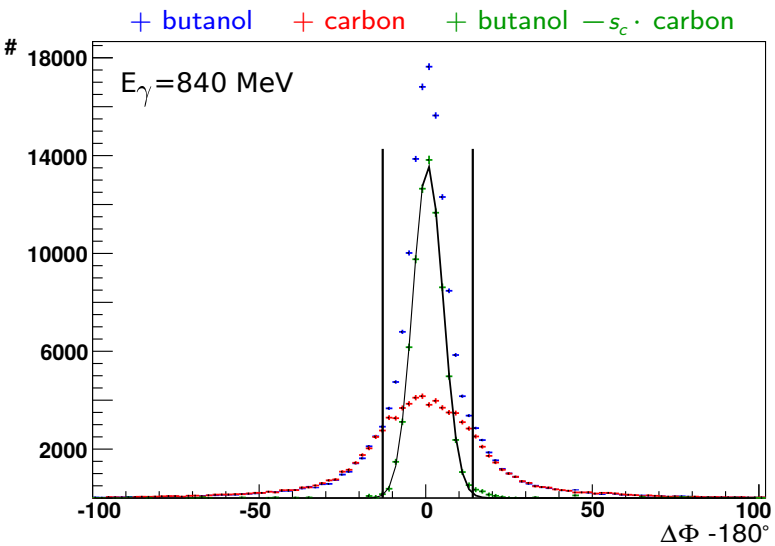
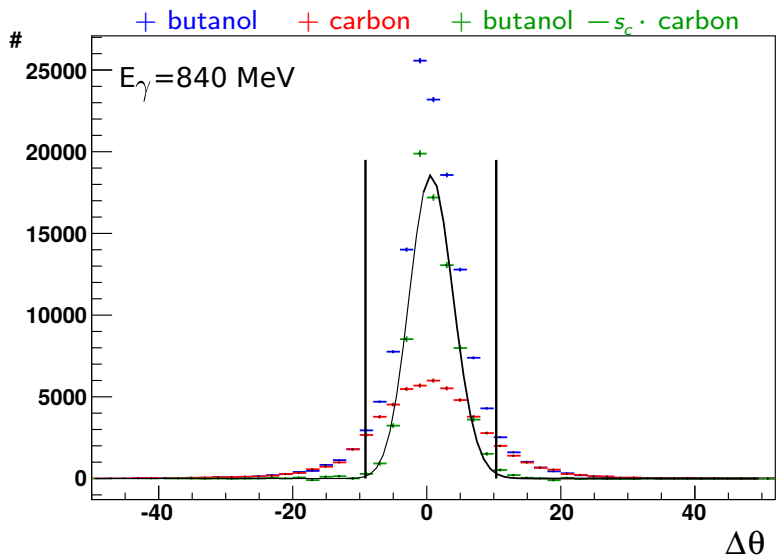




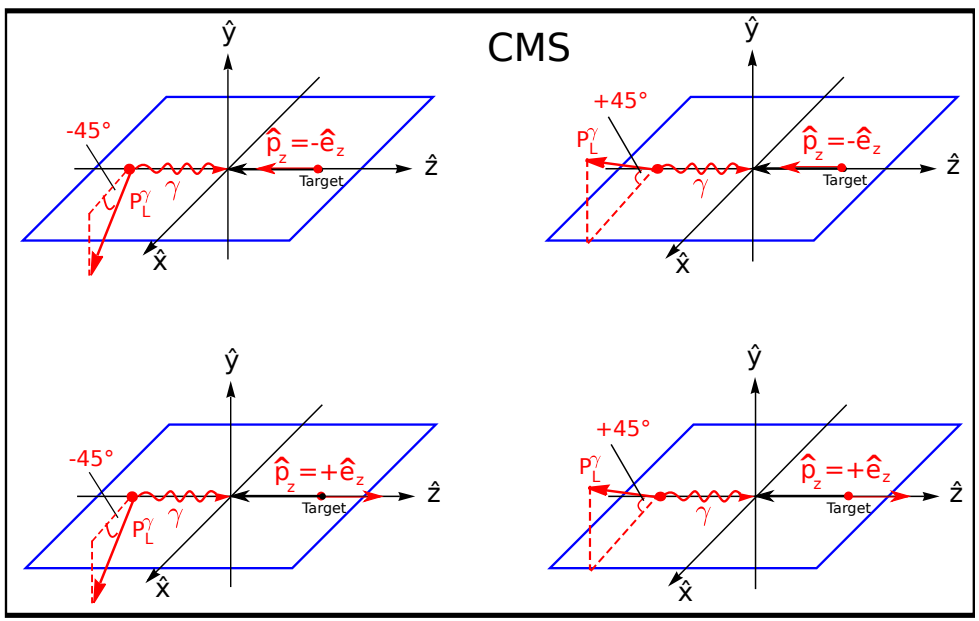
Determination of E and G

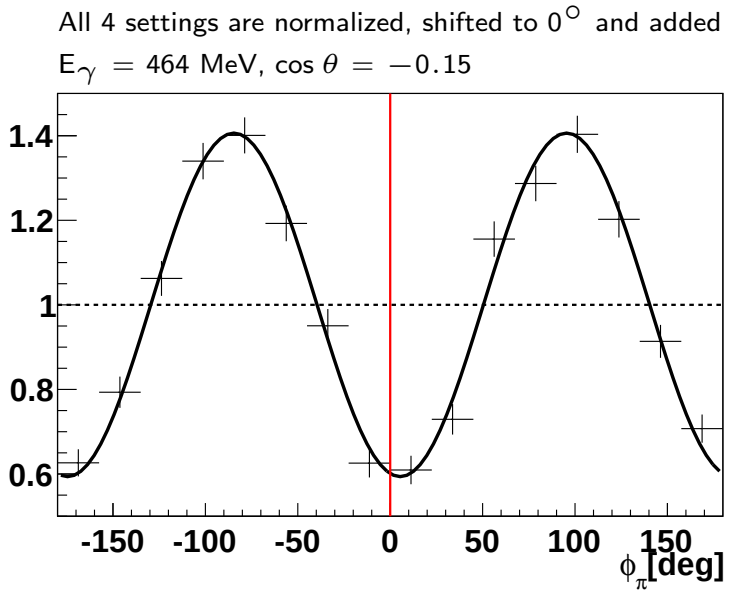
Differential cross section for pseudo-scalar meson photoproduction using elliptically polarized photons in combination with a longitudinally polarized target:

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}_0(\theta)\left[1 - P_{lin}\mathbf{\Sigma}\cos(2(\alpha-\phi)) - P_z\left(-P_{lin}\mathbf{G}\sin(2(\alpha-\phi)) + P_{circ}\mathbf{E}\right)\right]$$

Integrating over all possible helicity states:

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





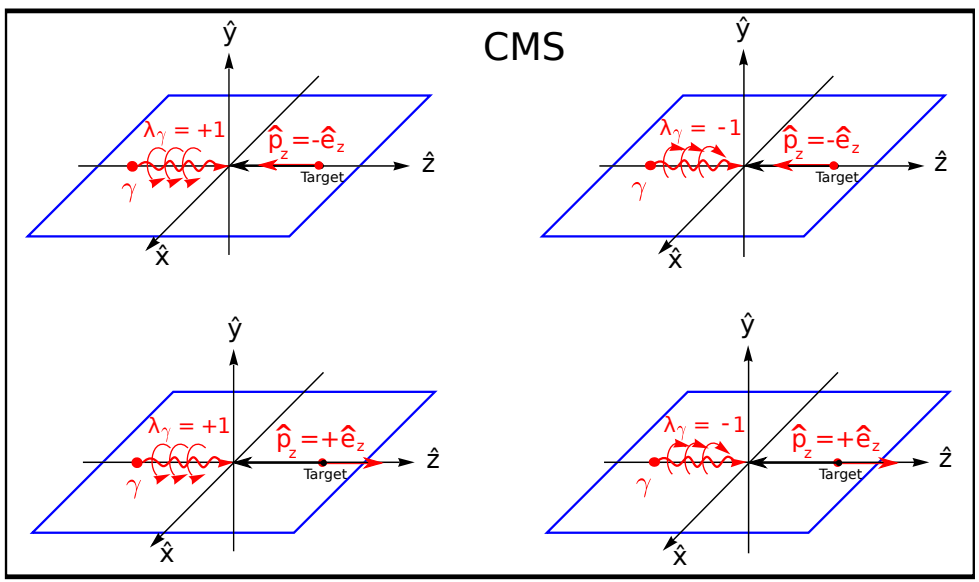
Determination of E and G

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

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}_0(\theta)\big[1 - P_{lin}\mathbf{\Sigma}\cos(2(\alpha-\phi)) - P_z\big(-P_{lin}\mathbf{G}\sin(2(\alpha-\phi)) + P_{circ}\mathbf{E}\big)\big]$$

Integrating over ϕ:

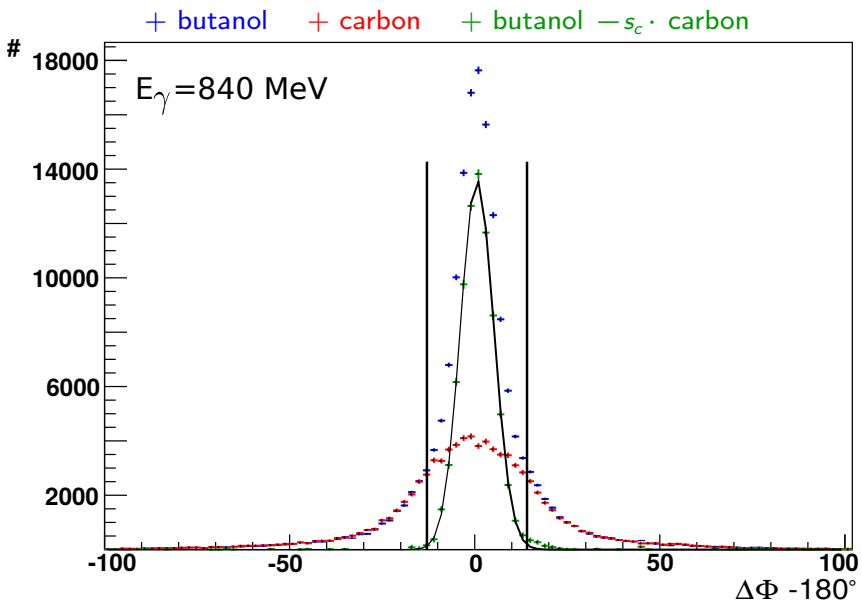
$$N_B\Big|_{\pm 1}^{\pm P_z}(\theta) = N_B(\theta)\cdot\big[1 - dP_{circ}P_z\mathbf{E}\big]$$

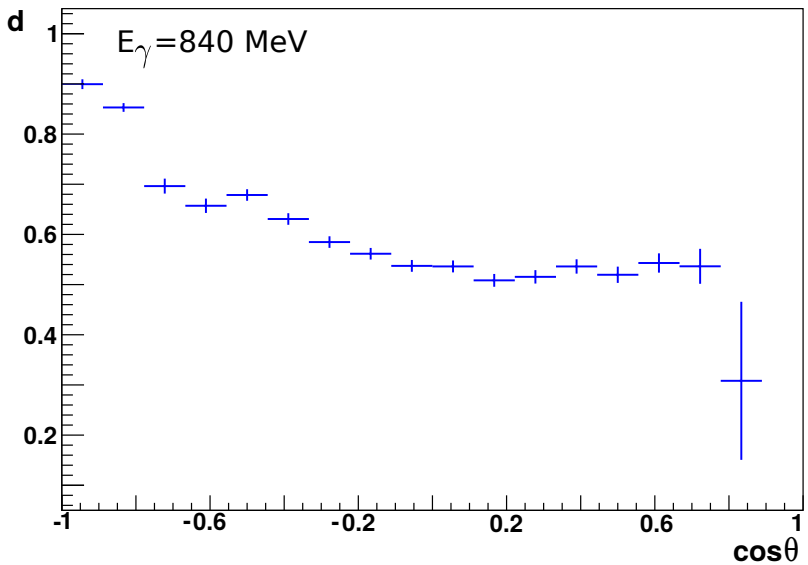


$$\mathrm{E} = \frac{\sigma^{1/2} - \sigma^{3/2}}{\sigma^{1/2} + \sigma^{3/2}} = \frac{N_B^{1/2} - N_B^{3/2}}{N_B^{1/2} + N_B^{3/2}} \cdot \frac{1}{d} \cdot \frac{1}{P_{circ}P_z}$$

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

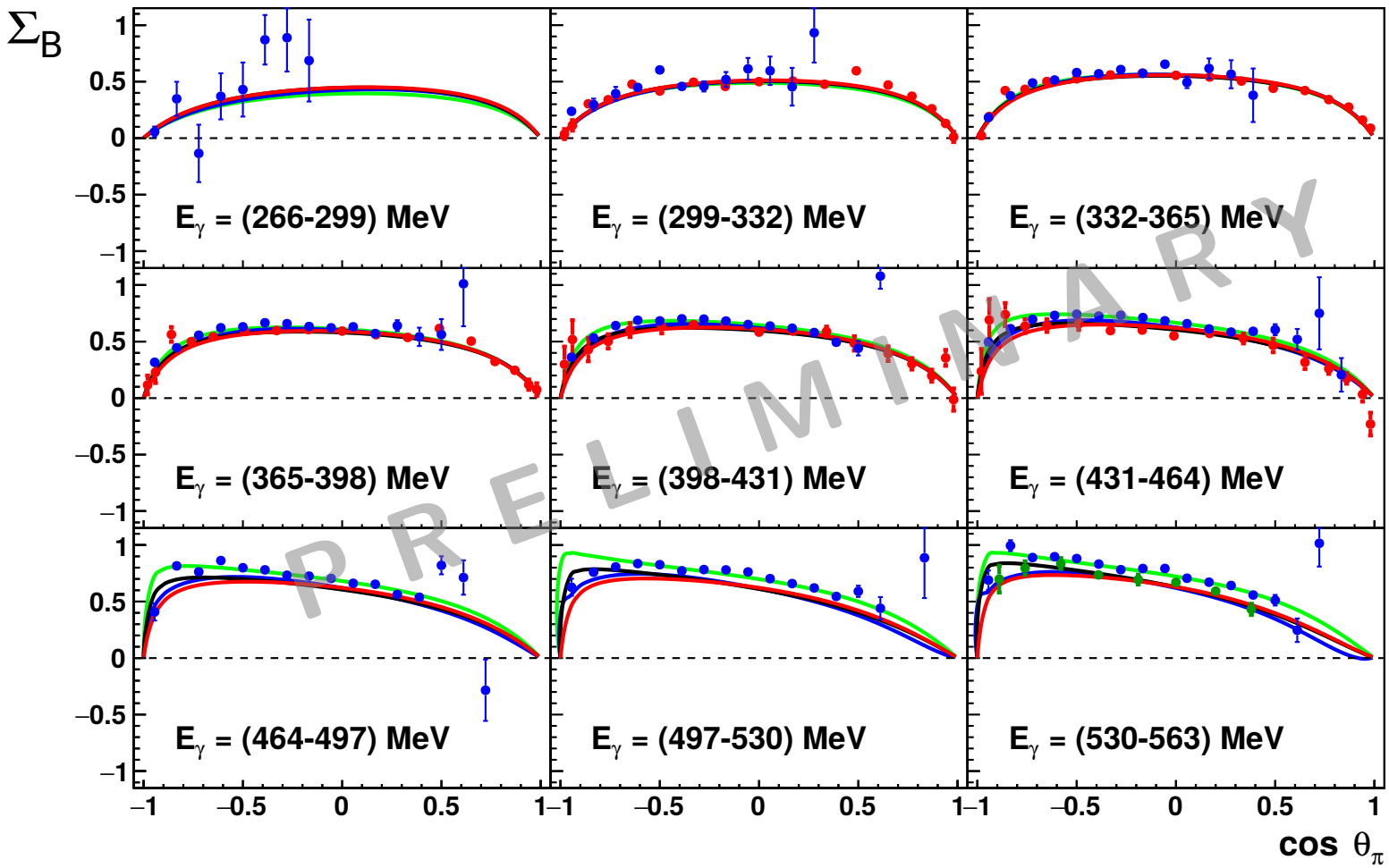




Beam asymmetry Σ_B (266 MeV - 563 MeV)

- this work (butanol data, K. Spieker)
- GRAAL (O.Bartalini et al., Eur. Phys.J. A26 (2005))
- MAMI (R. Beck et al., Eur. Phys. J. A28 (2006))

— BnGa_2014_02 (PWA fit) — BnGa_2014_01 (PWA fit) — MAID2007 (PWA fit) — SAID-CM12 (PWA fit)



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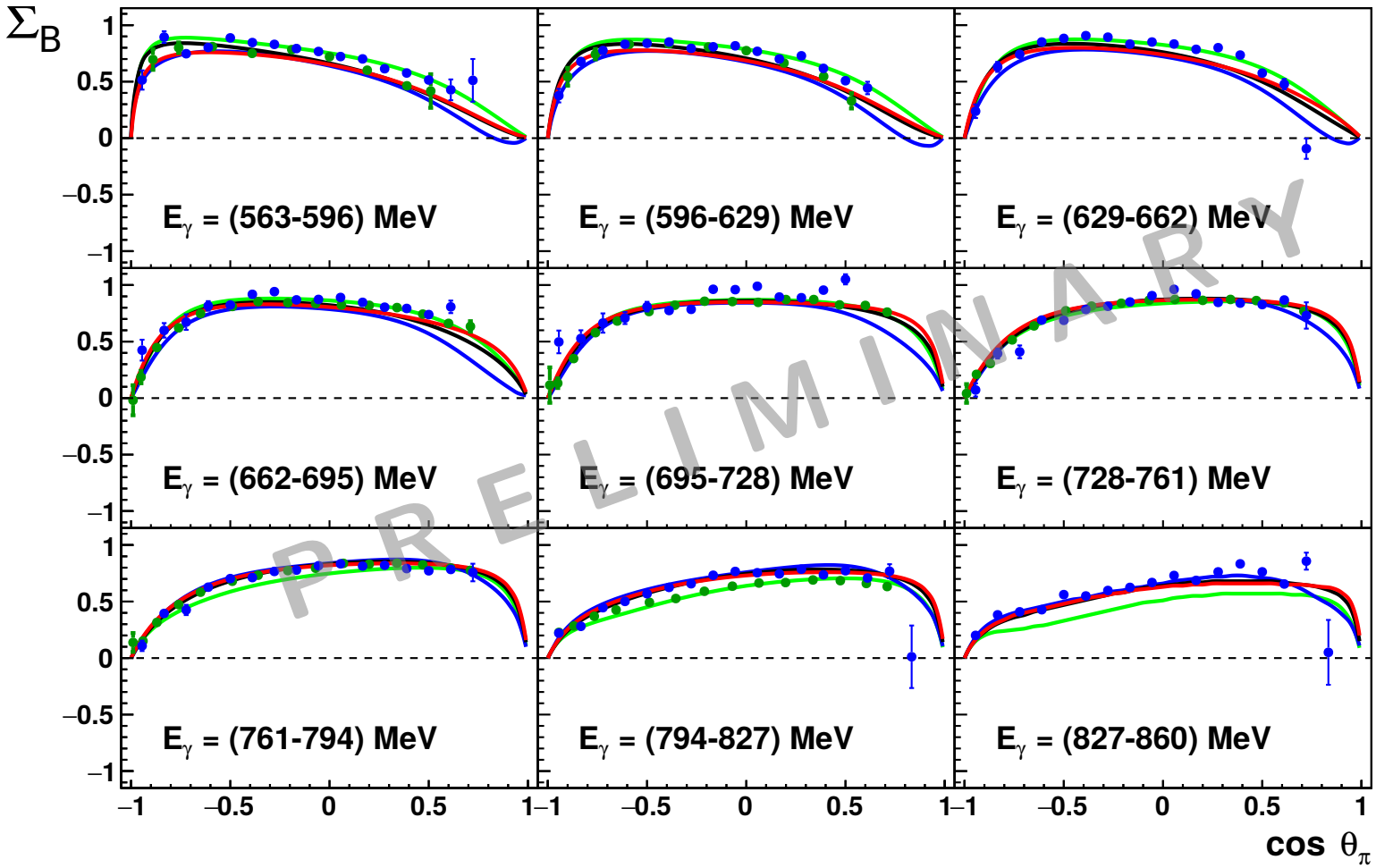
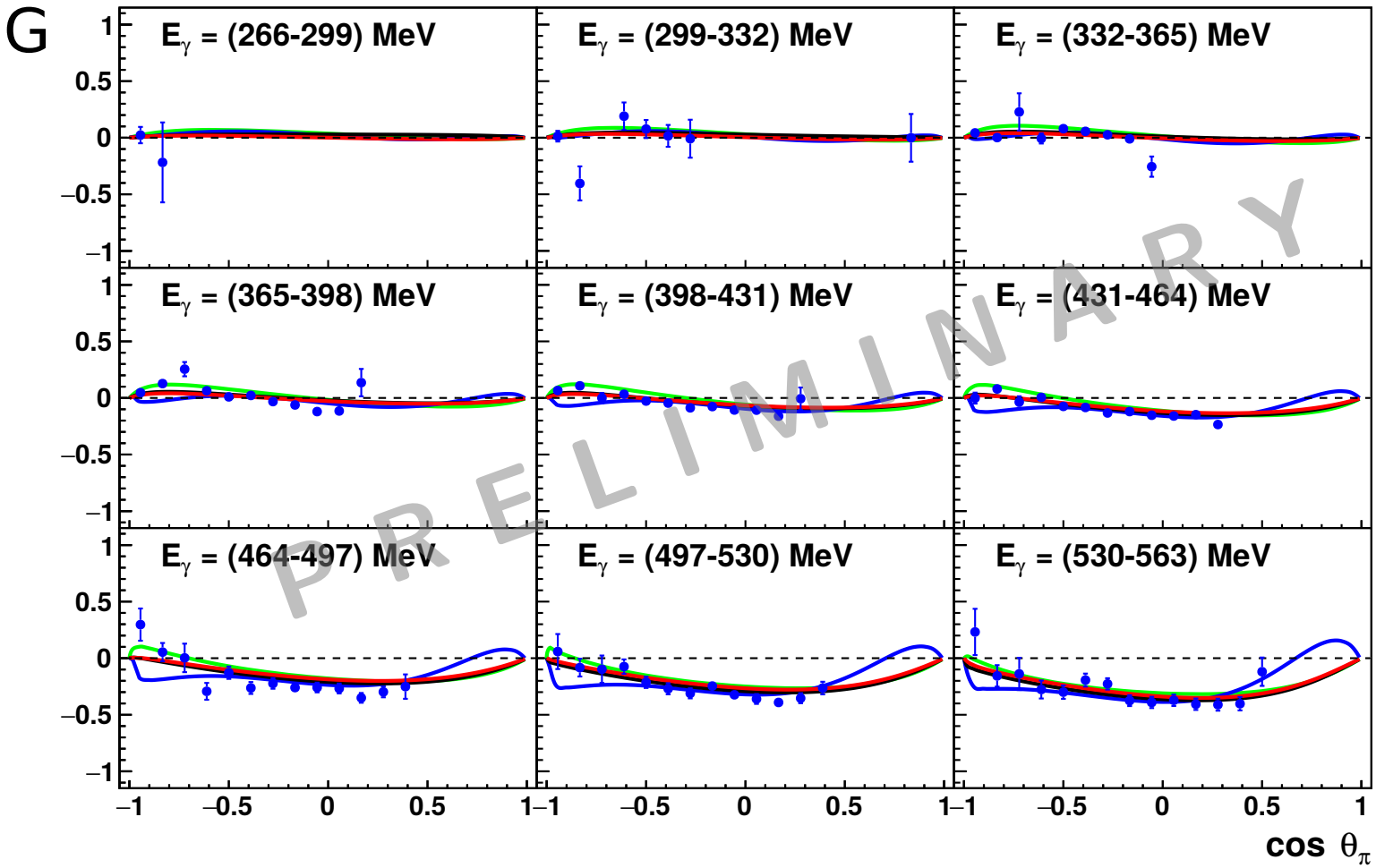


Double polarization observable G (266 MeV - 563 MeV)

- this work (longitudinally polarized electrons + diamond radiator K. Spieker)
- CBELSA/TAPS data (using unpolarized electrons, A. Thiel et al., Phys. Rev. Lett. 109 (2012) 102001)

— BnGa_2014_02 (PWA fit) — BnGa_2014_01 (PWA fit) — MAID2007 (PWA pred.) — SAID-CM12 (PWA pred.)



Double polarization observable G (563 MeV - 860 MeV)

- this work (longitudinally polarized electrons + diamond radiator, K. Spieker)
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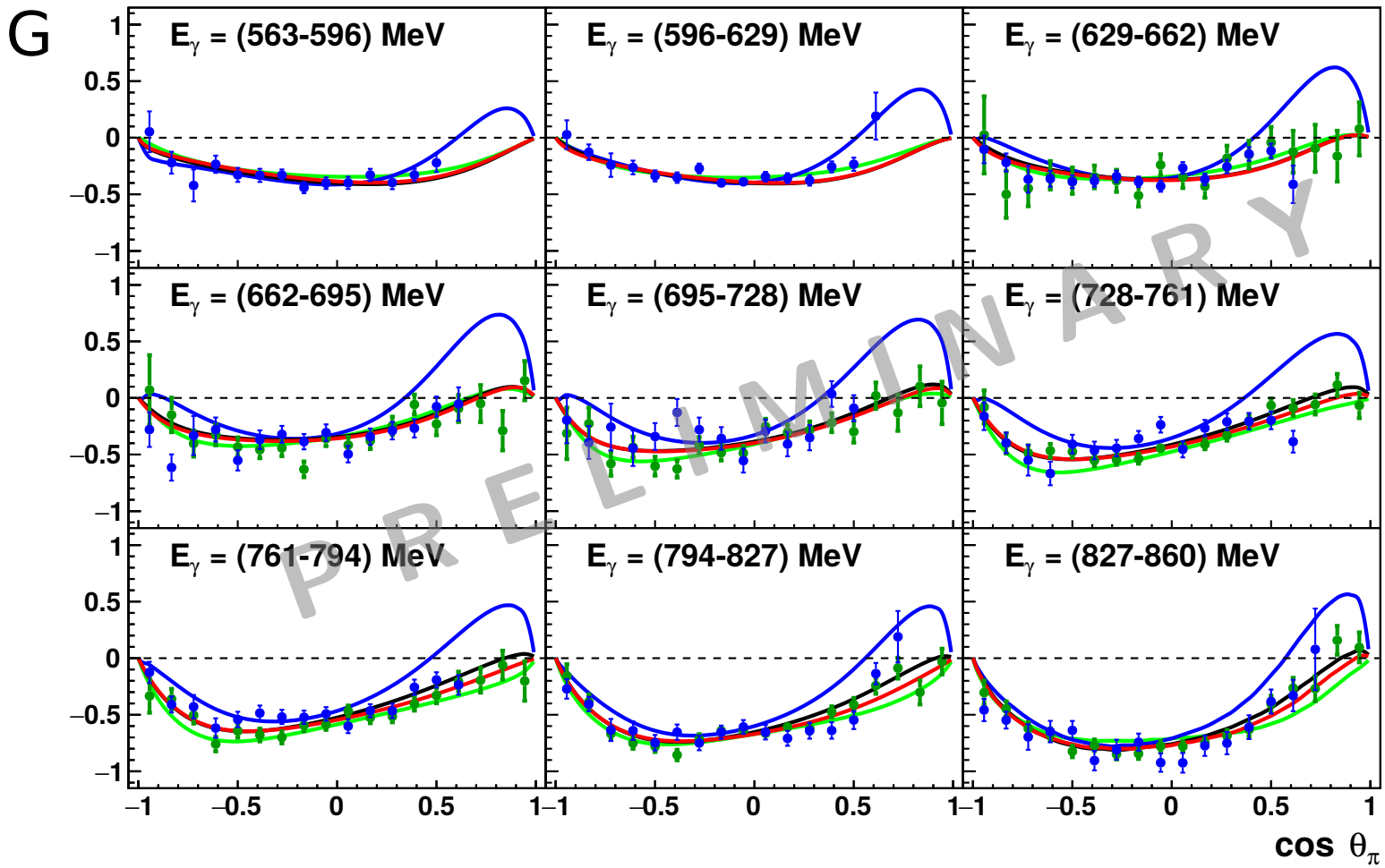
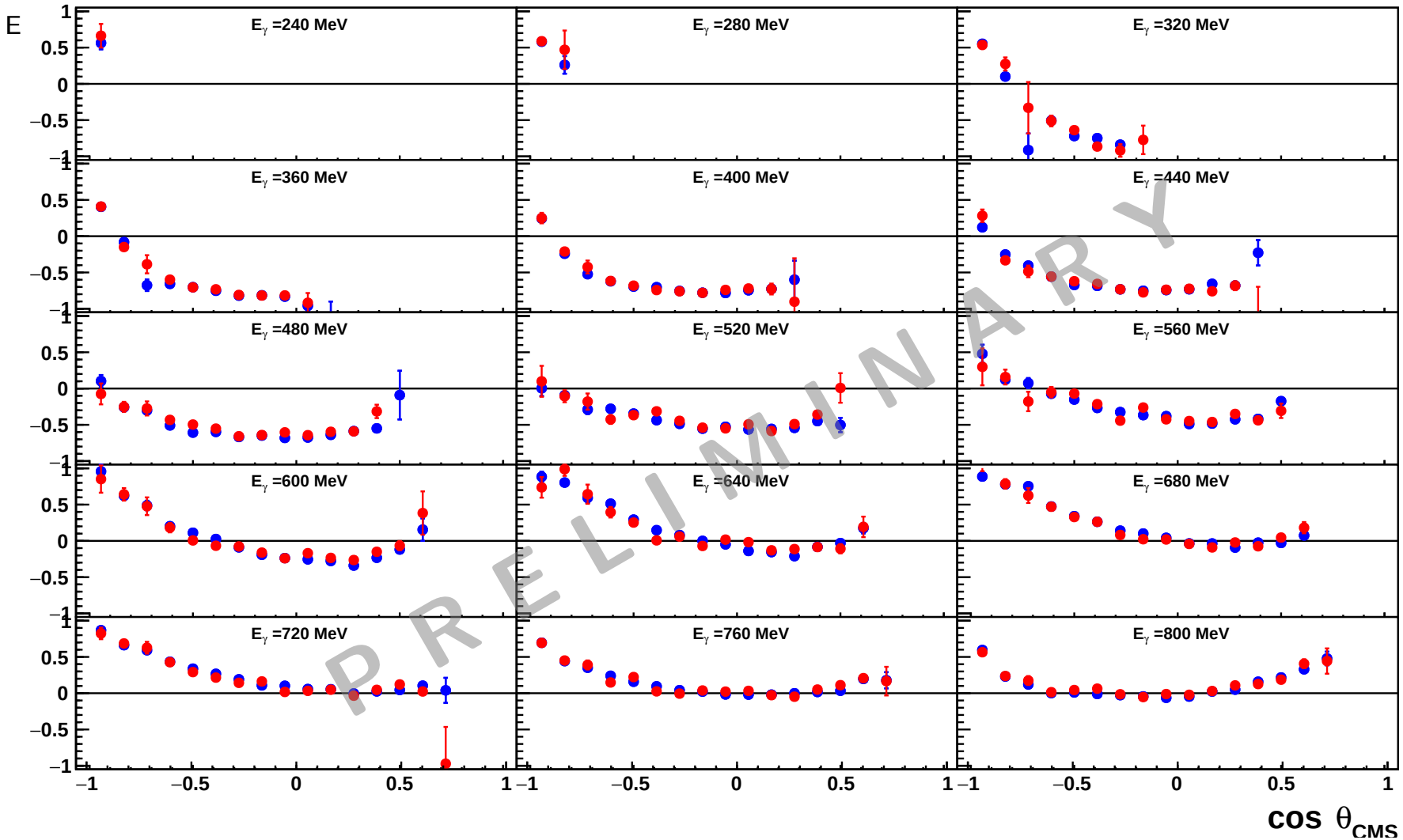


Results for E in π^0-photoproduction (240 MeV - 800 MeV)

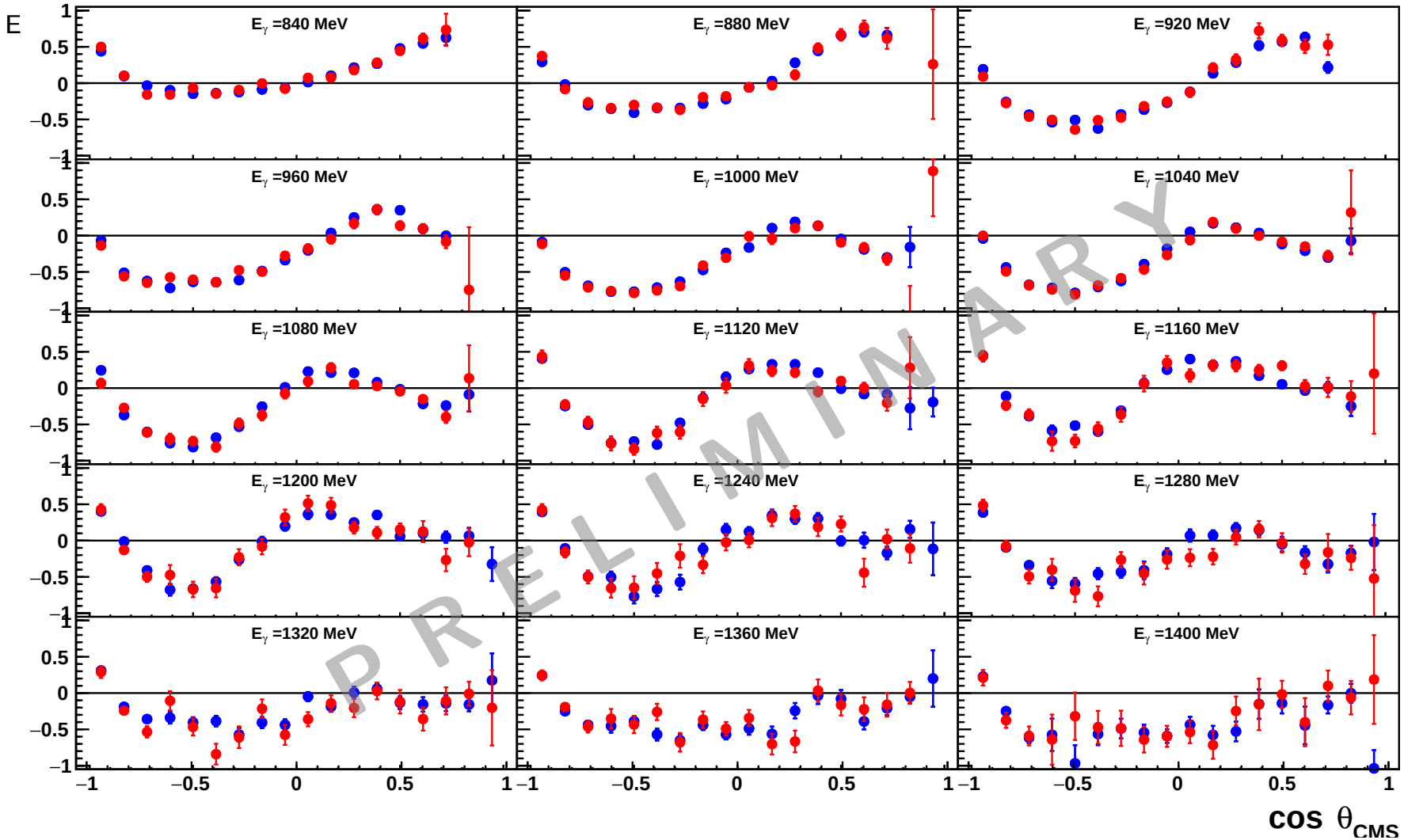
- **this work (longitudinally polarized electrons + diamond radiator → elliptically polarized photons)**
- **this work (longitudinally polarized electrons + amorphous radiator → only circularly polarized photons)**



Very good agreement between data obtained with a diamond and an amorphous radiator!

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

- this work (longitudinally polarized electrons + diamond radiator $\rightarrow$ elliptically polarized photons)
- this work (longitudinally polarized electrons + amorphous radiator $\rightarrow$ only circularly polarized photons)



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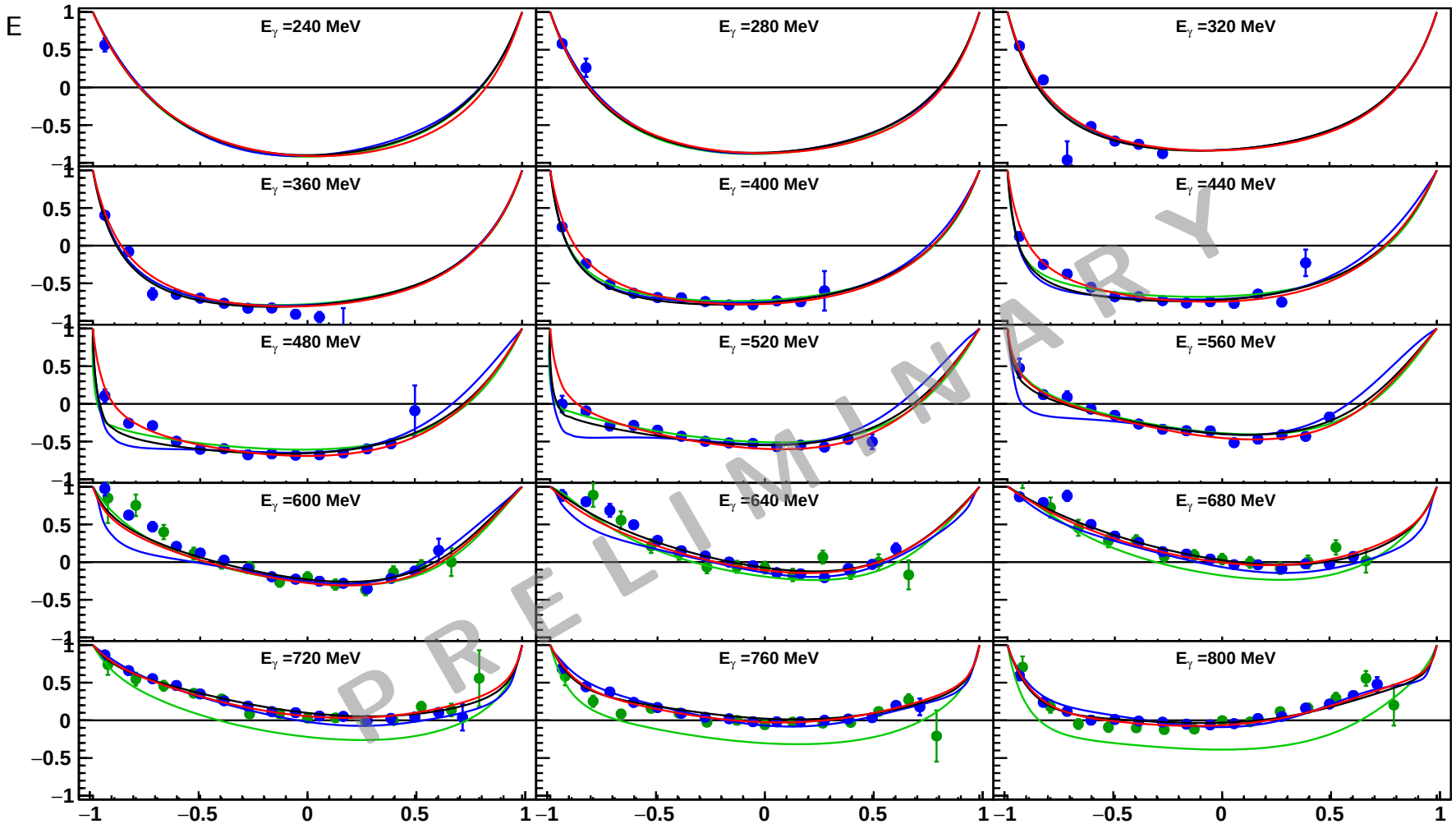

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Results for E in π^0-photoproduction (840 MeV - 1400 MeV)

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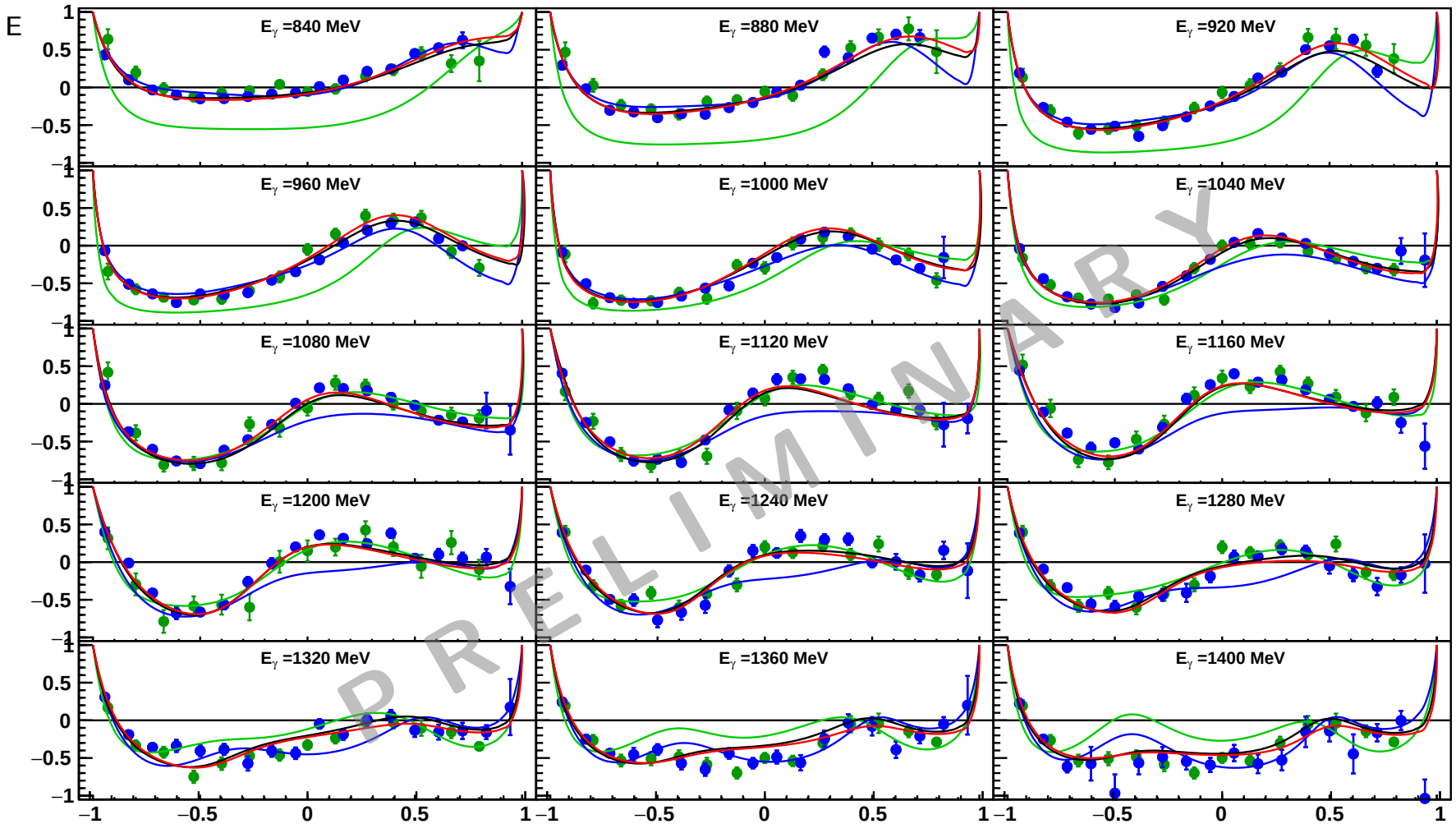
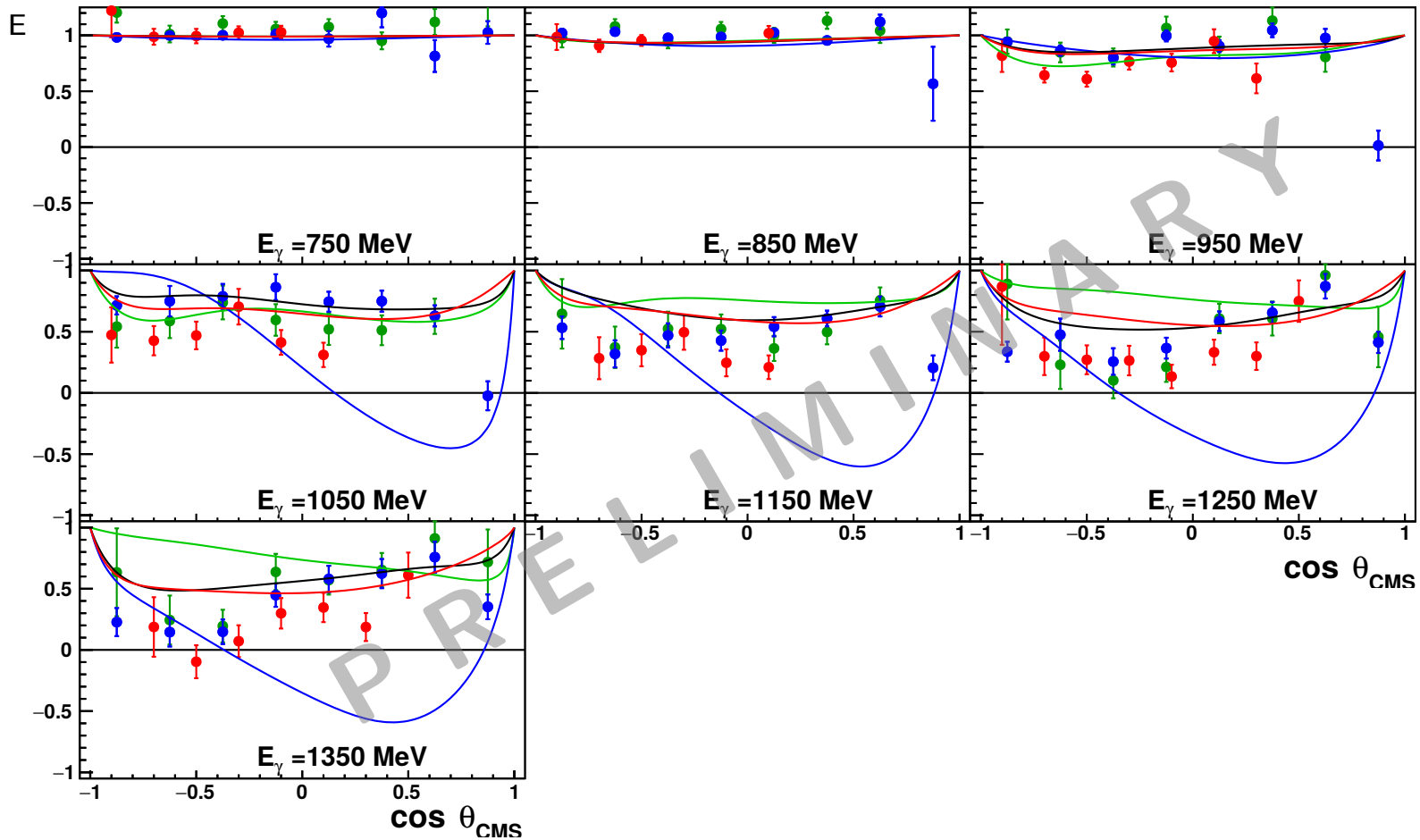


Very good agreement to existing data!

Results for E in η-photoproduction

- this work (longitudinally polarized electrons + diamond radiator $\rightarrow$ elliptically polarized photons)
- CBELSA/TAPS data (taken with amorphous data, J.Müller et al., to be published soon)
- CLAS data (taken with amorphous data, I. Senderovich et al., Phys. Lett. B 755 (2016)

— BnGa_2014_02 (PWA pred.) — BnGa_2014_01 (PWA pred.) — η-MAID (PWA pred.) — SAID-GE09 (PWA pred.)

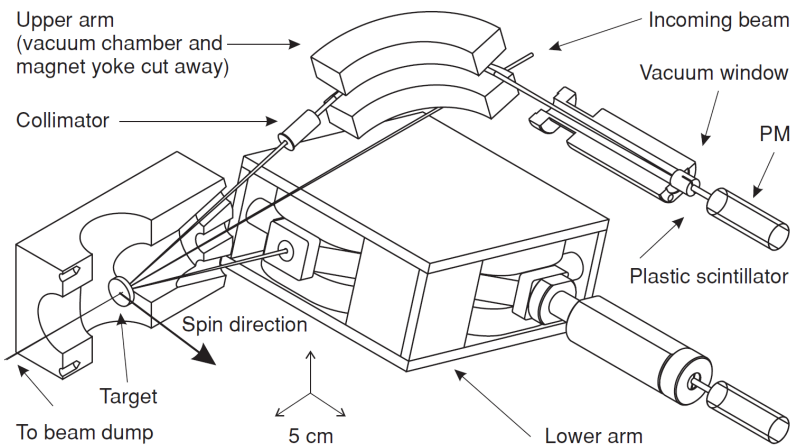


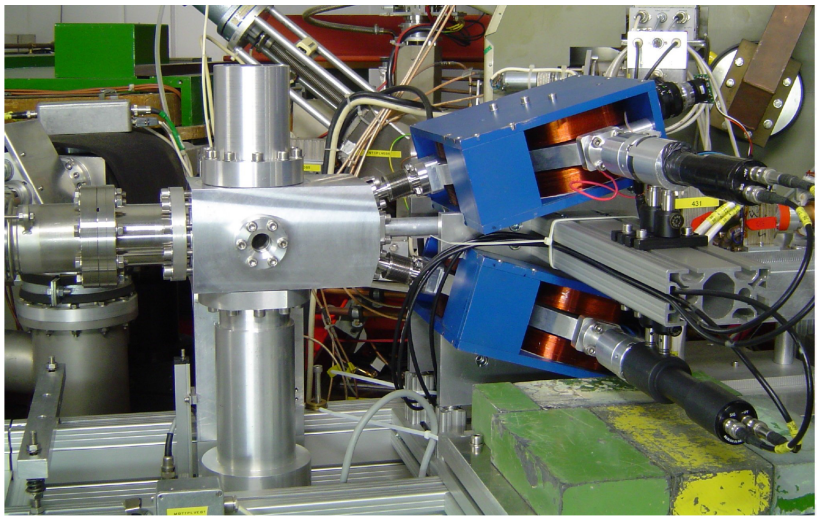
Summary and Outlook

- The double polarization observables E and G were measured at the Crystal Ball experiment at MAMI within the same beam time using longitudinally polarized electrons on a diamond radiator $\rightarrow$ linearly and circularly polarized photons
- The preliminary results in $\gamma p \rightarrow p\pi^0$ are looking promising:
  - Our data cover energy range down to $\Delta(1232)$ resonance region $\rightarrow$ complementary to CBELSA/TAPS and CLAS data
  - Good agreement between our results for E ($E_\gamma = (220 - 1420)$ MeV), Σ_B and G ($E_\gamma = (266 - 860)$ MeV) and existing data
  - Good agreement between data obtained with a Moeller and a diamond radiator
- Outlook
  - 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