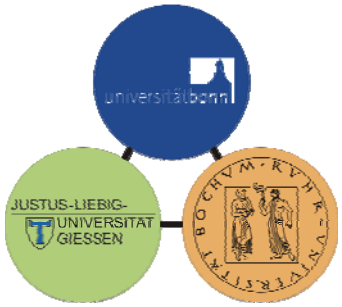
# Baryon Spectroscopy at ELSA

R. Beck, University Bonn
CBELSA/TAPS-collaboration
EuNPC, March 15-20, 2009, Bochum

- Motivation
- ELSA accelerator
- Crystal Barrel experiment
- Recent Results
- Summary and Outlook



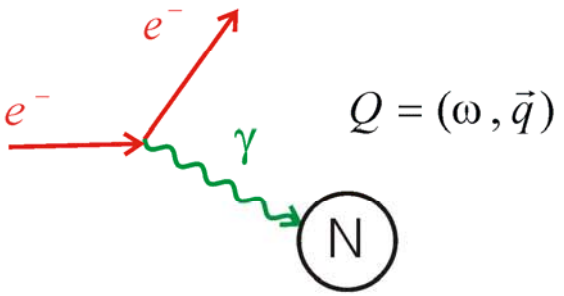

**supported by the DFG within the SFB/TR16**

# Introduction

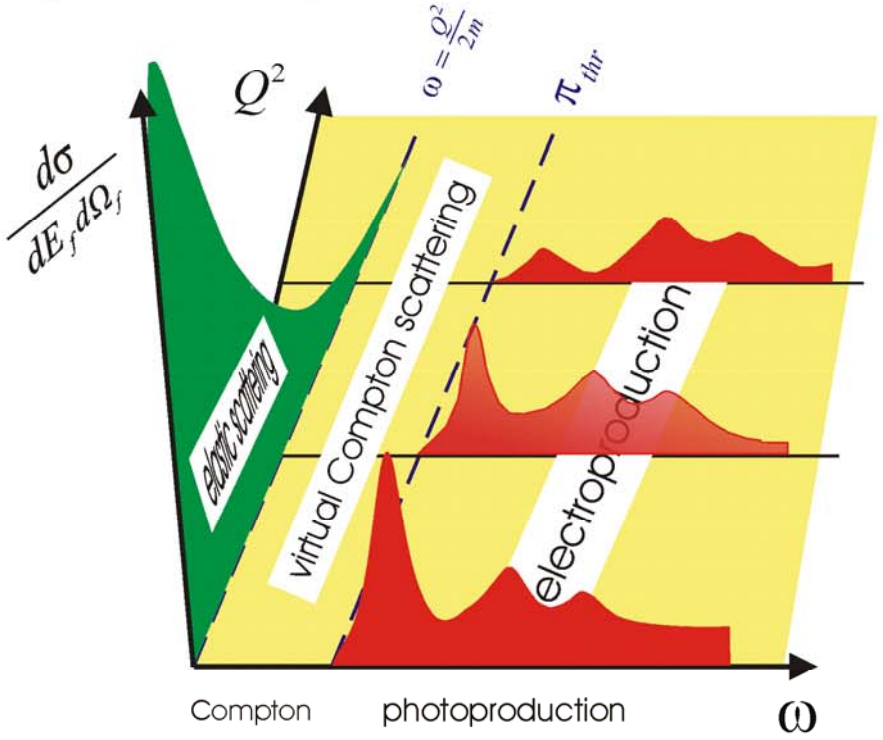
Baryons are extended objects with internal structure :

electron scattering:

$e^- + N \rightarrow e^- + N$




(schematic view)




## Nucleon properties to be measured

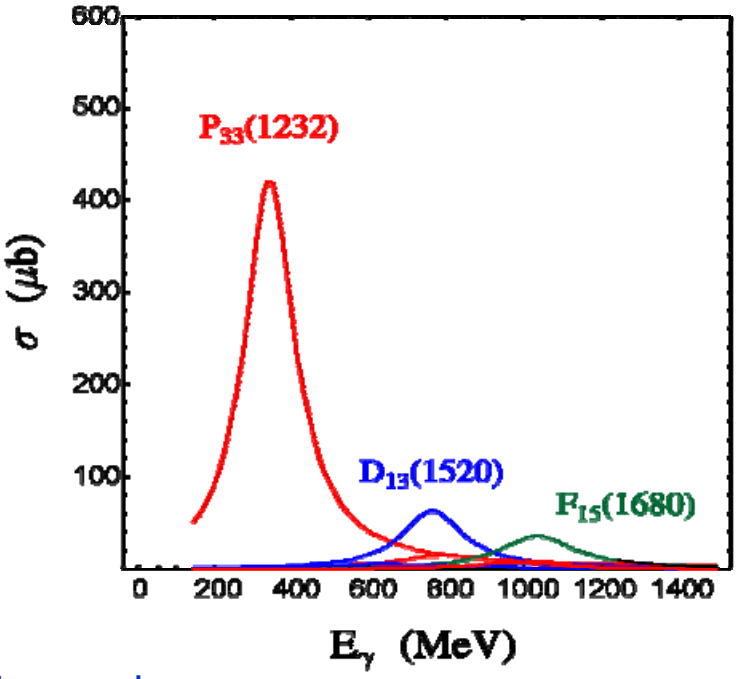
| | |
|---|---|
| $\mu$ | magnetic moment |
| $\langle r^2 \rangle$ | radius (elect. -, mag. -, axial) |
| | form factor |
| $\alpha, \beta, \gamma_i$ | polarizabilities + form factor |
| $M^*$ | excitation spectrum |
| $\mu^*$ | transition moment + form factor |
| $A_{1/2}, A_{3/2}, S_{1/2}$ | helicity amplitude |

ELSA: focus on excitation spectrum

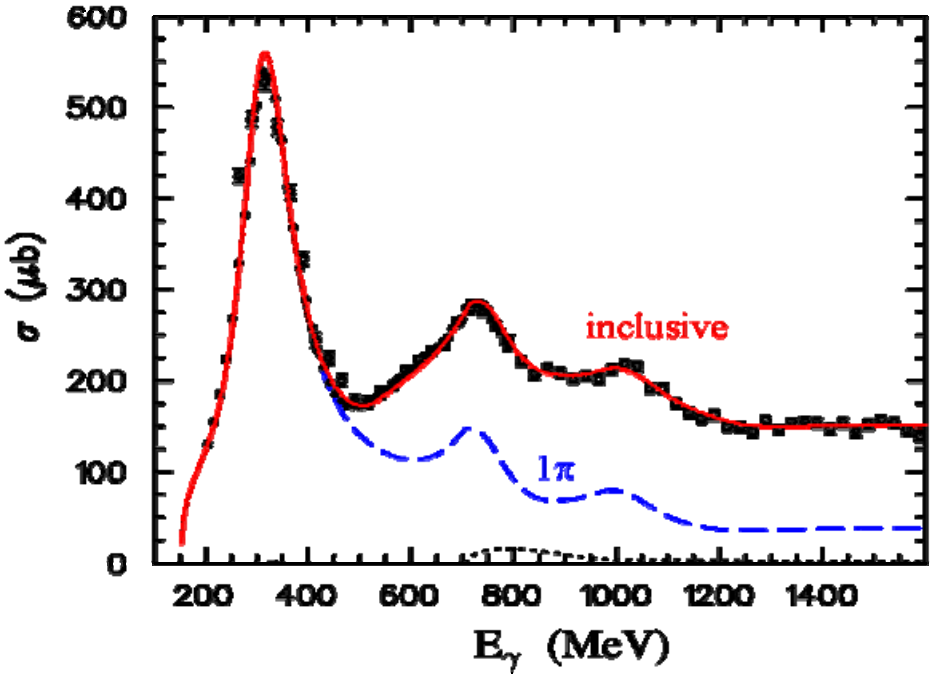
# Introduction

- 3.2 GeV photon beam at ELSA used to study meson photoproduction

Breit Wigner Resonances




Total Photon Absorption Cross Section



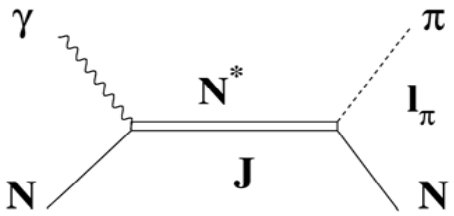

Spectroscopic Notation

$X_{2I\,2J}$

Isospin

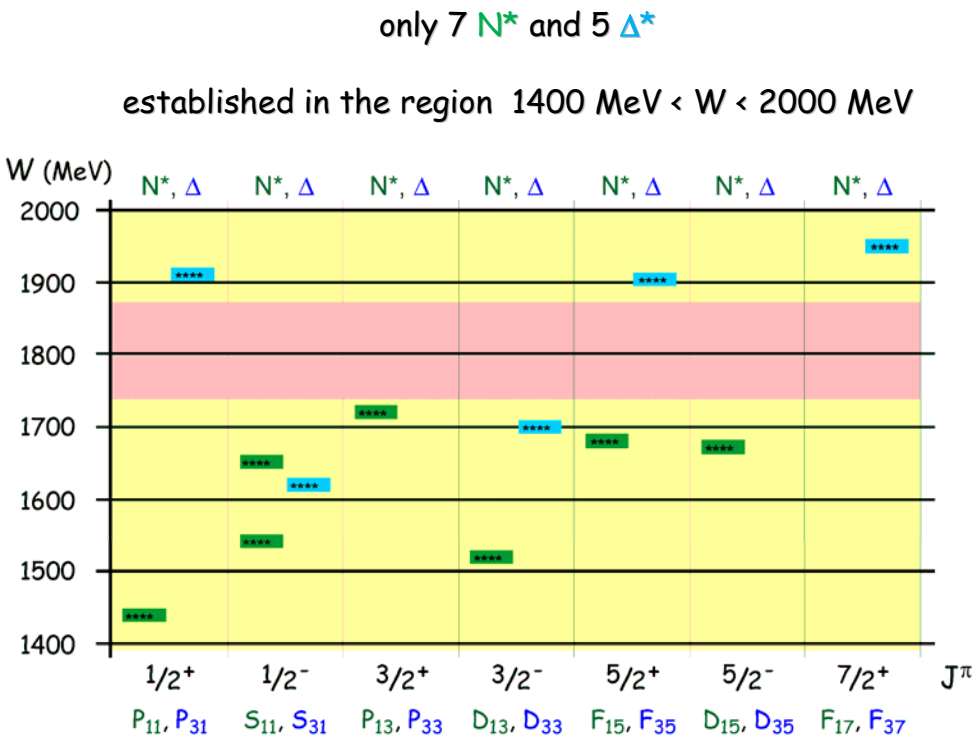
Spin

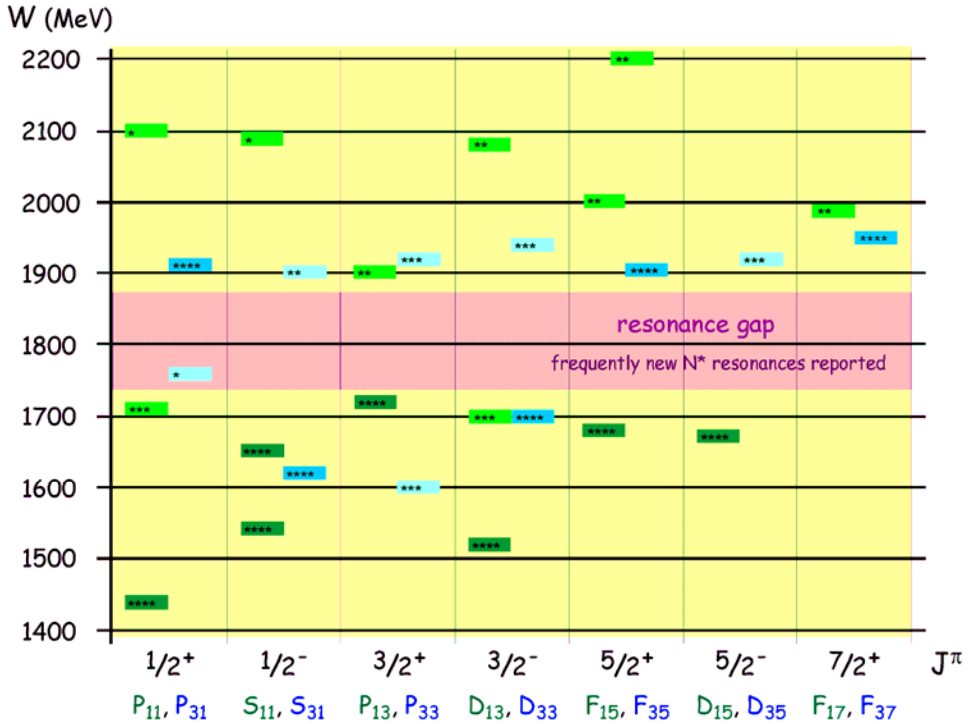
$X = S(l_\pi = 0); P(l_\pi = 1); \ldots$



# Introduction

PDG 2008: Status on nucleon resonances



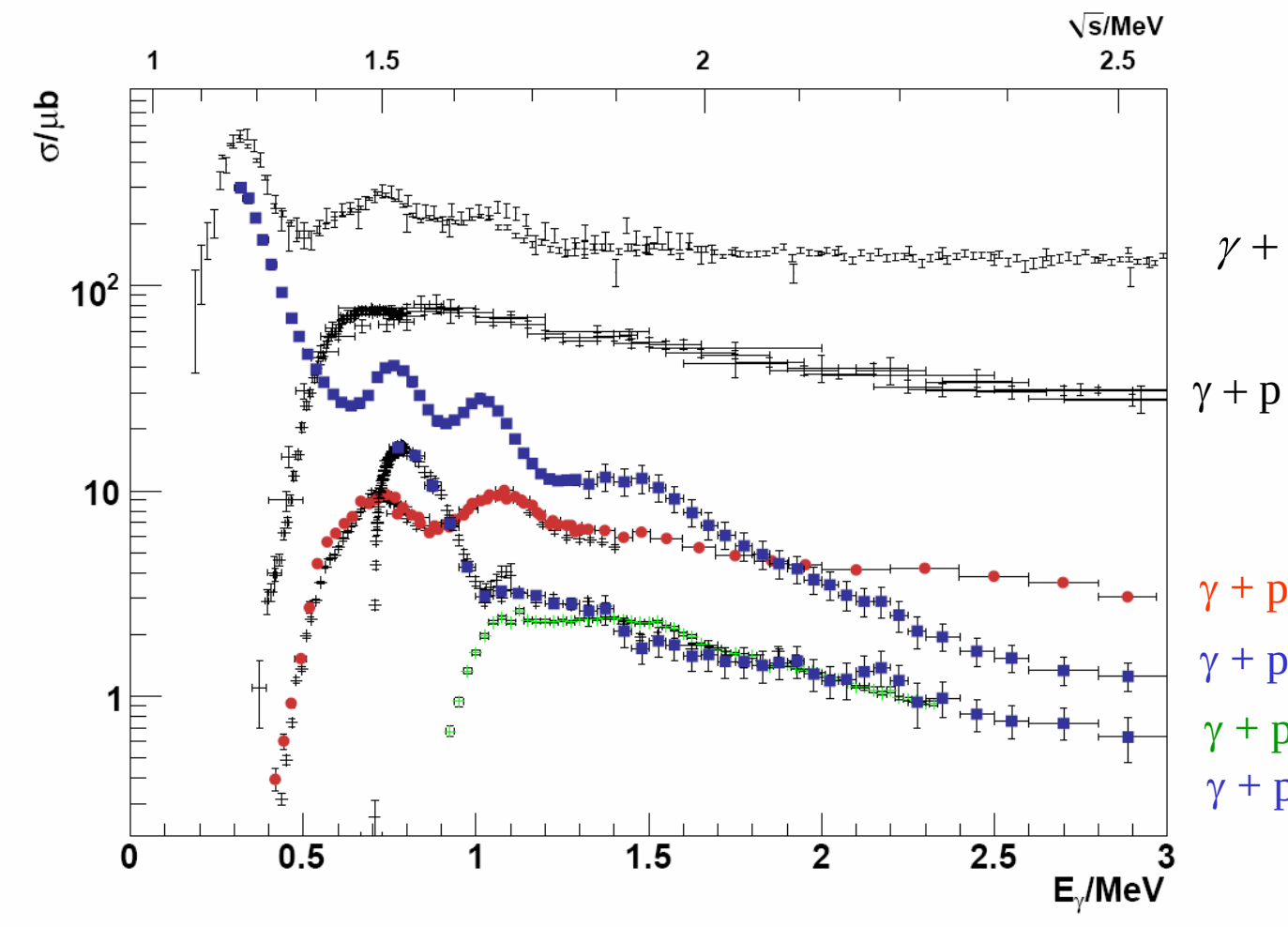




- Energy pattern for the dominant states
  - Constituent Quark Models
  - Dynamical Models
  - Lattice QCD
- Various nucleon models predict many more states
  - weak coupling to $\pi$N final state
  - insufficient data for PWA

# Experimental program for N*

Common effort at ELSA, JLab and MAMI,

- Precision data for different final states
- Polarization experiments (beam, target and recoil)



# Observables in Meson Photoproduction

| Photon polarization | | Target polarization | | | Recoil nucleon polarization | | | Target and recoil polarizations | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X | Y | $Z_{(beam)}$ | X' | Y' | Z' | X' X | X' Z | Z' X | Z' Z |
| unpolarized | σ | - | **T** | - | - | **P** | - | $\mathbf{T_x}$ | $\mathbf{L_x}$ | $\mathbf{T_z}$ | $\mathbf{L_z}$ |
| linear | Σ | **H** | (-P) | **G** | $\mathbf{O_x}$ | (-T) | $\mathbf{O_z}$ | $(-L_z)$ | $(T_z)$ | $(L_x)$ | $(-T_x)$ |
| circular | - | **F** | - | **E** | $\mathbf{C_x}$ | - | $\mathbf{C_z}$ | - | - | - | - |

data only for:

Differential cross section: σ

Beam asymmetry: Σ

Double polarization: **E**

Sensitive to: $\mathrm{Re}(P_1 \cdot P_2)$

data needed for:

Target asymmetry: **T**

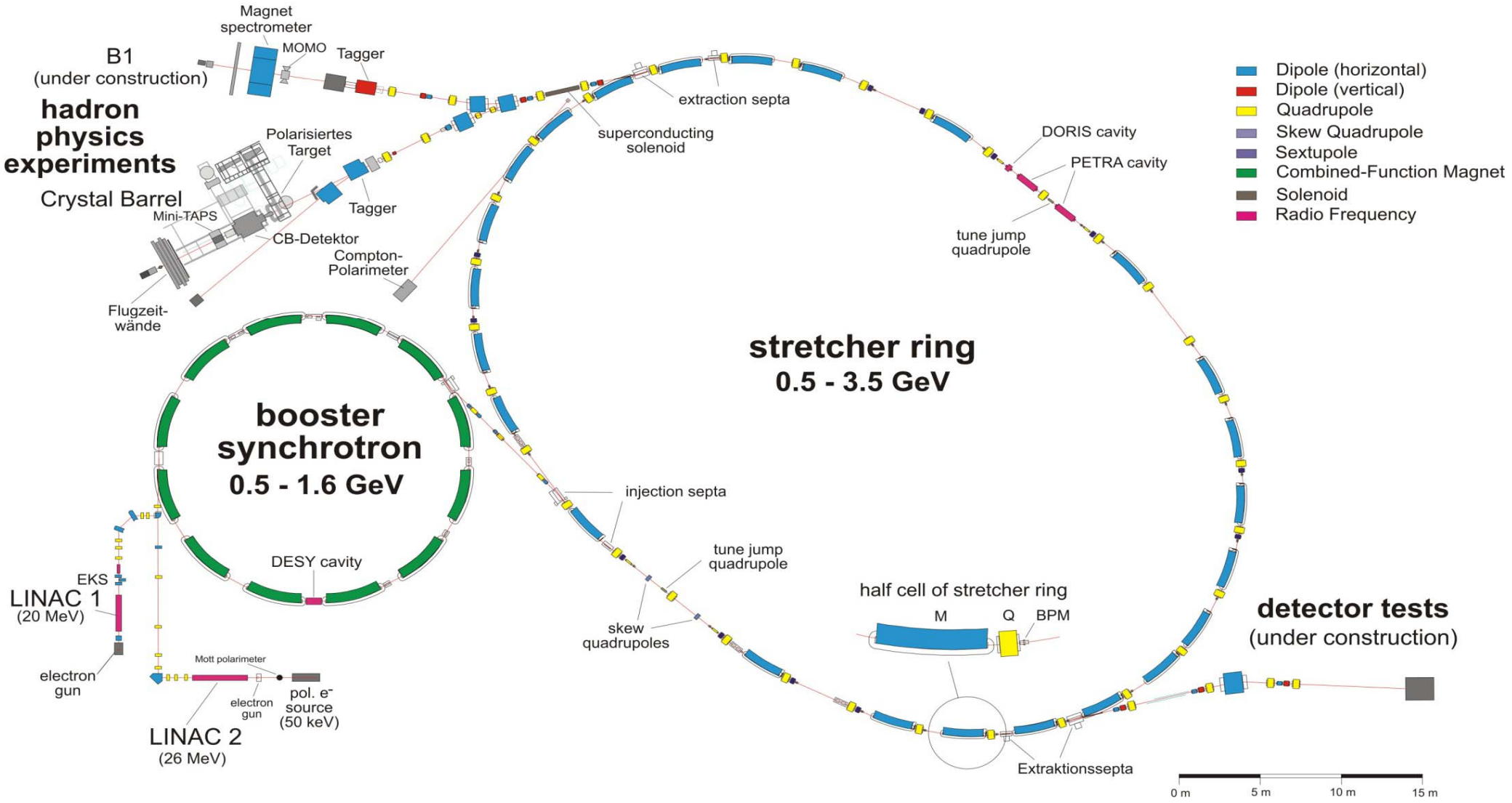
Recoil polarization: **P**

Double polarization: **G**

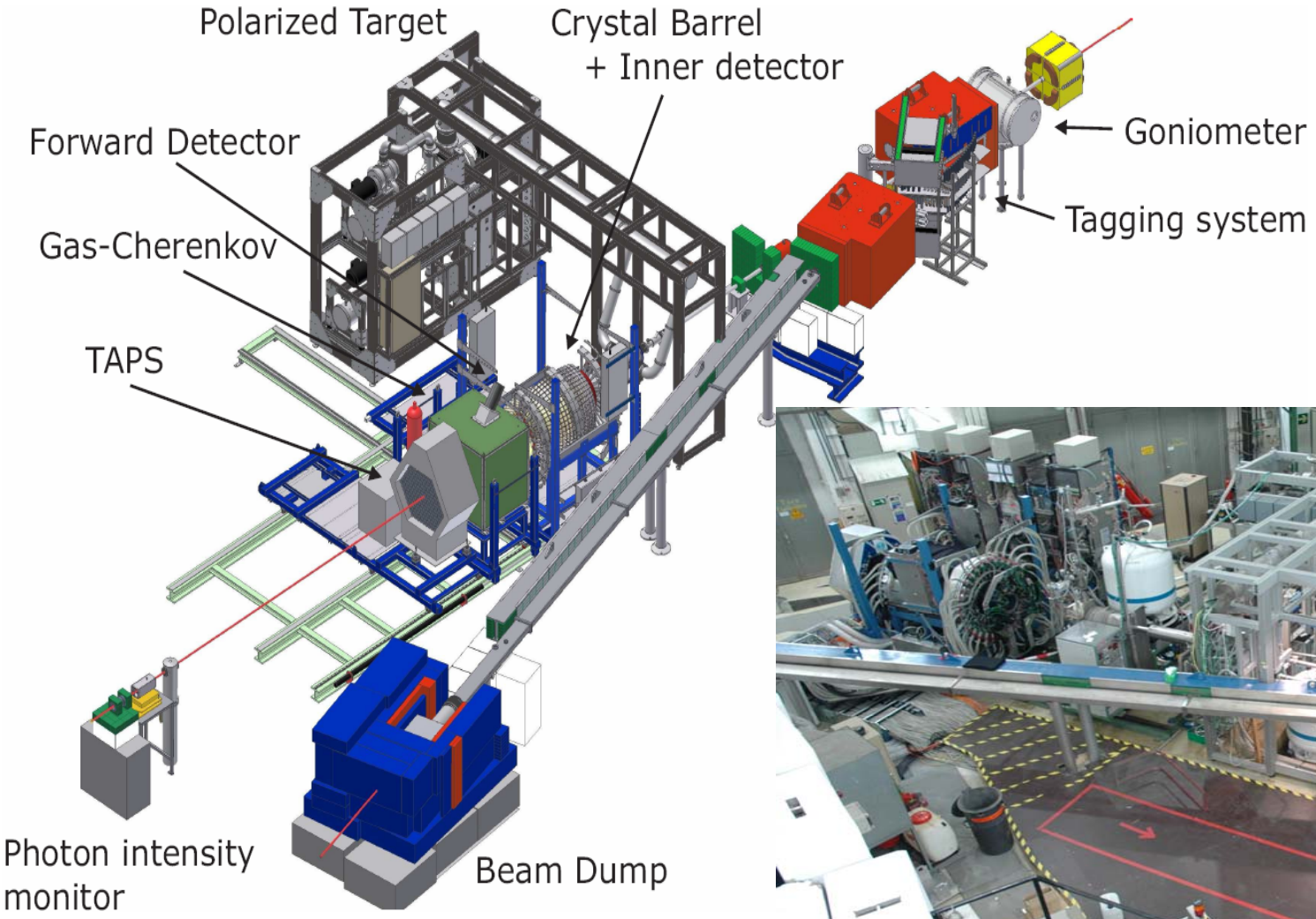
Sensitive to: $\mathrm{Im}(P_1 \cdot P_2)$

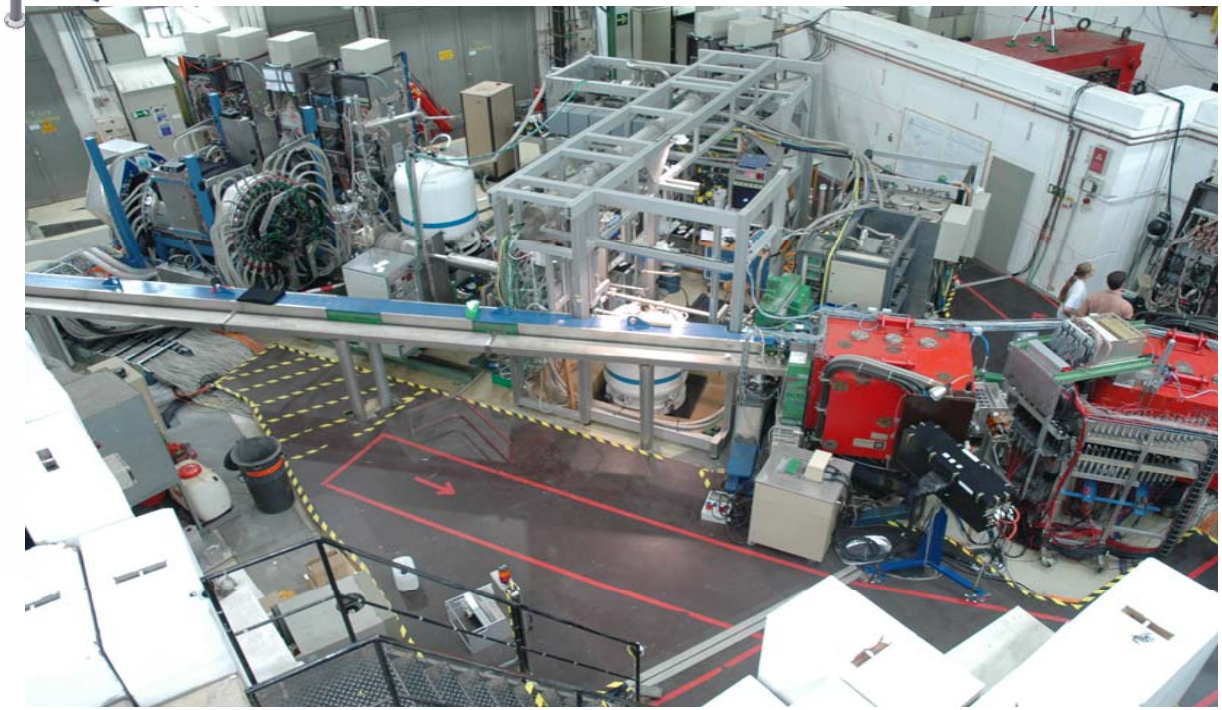
Crystal Barrel experiment at ELSA: polarized photons, polarized targets and 4π acceptance

# Electron Stretcher Accelerator (ELSA)



# Crystal Barrel Set Up at ELSA



# Crystal Barrel Set Up at ELSA

- Crystal Barrel detector
  1230 CsI crystals

- Inner-detector
  cylinder of 513 scintillating fibers

- forward detector (FWPlug)
  90 CsI crystals with PM's, $12^0$-$30^0$

- forward detector (MiniTAPS)
  216 $BaF_2$ , $1^0$-$12^0$

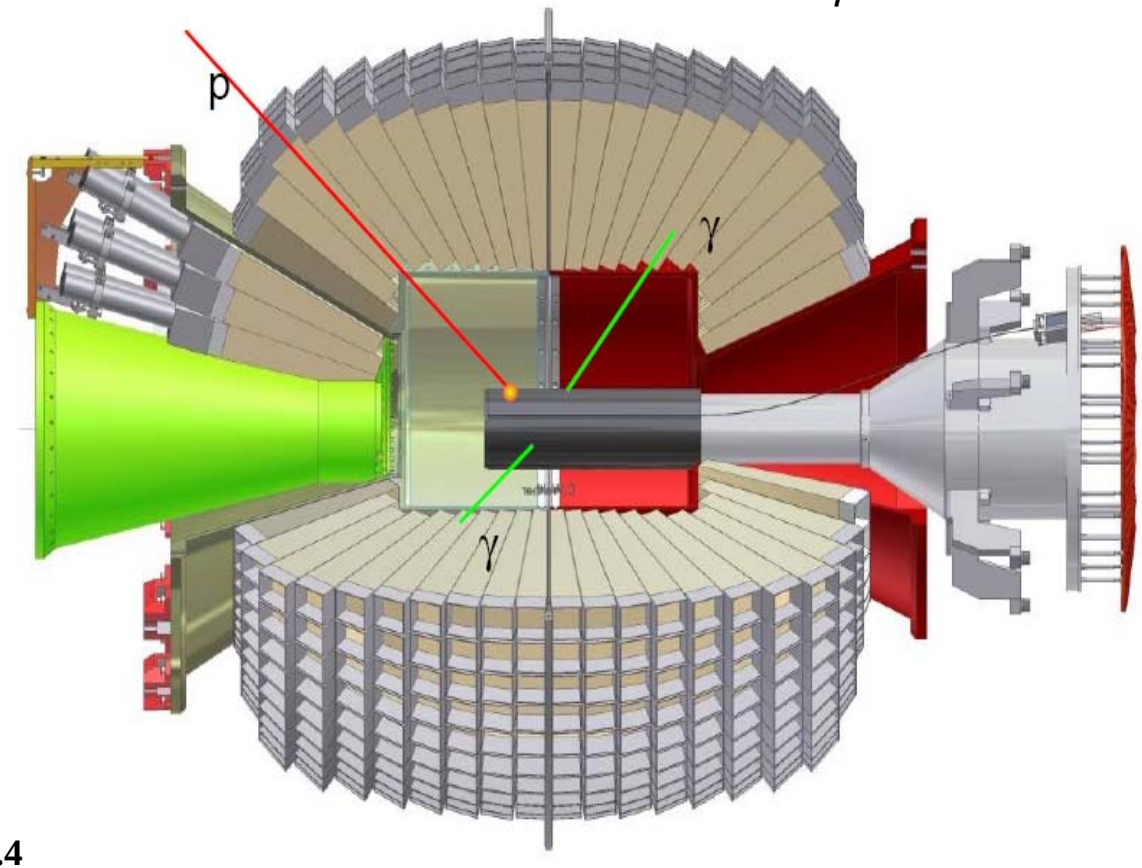
Close to 4π coverage

more details about performance and future upgrade:

**HK 52.4, HK 62.2, HK 62.3, HK 62.5 und HK 75.4**

$\pi^0 \to \gamma\gamma$ $\eta \to \gamma\gamma$

$\eta \to 3\pi^0$

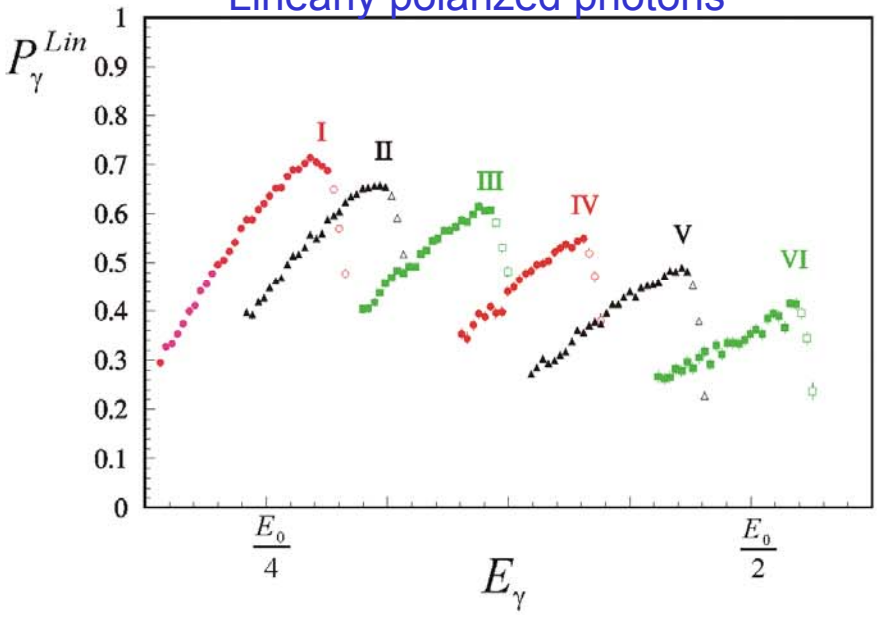


# Polarized Photons

Linearly polarized photons:
- coherent bremsstrahlung
- diamond radiator

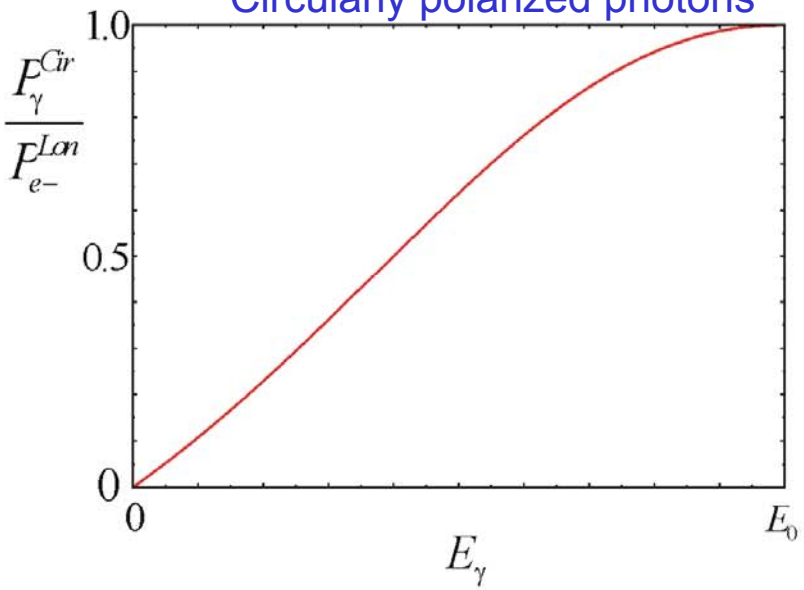
Circularly polarized photons:
- longitudinally polarized electrons
- helicity transfer to photon

Linearly polarized photons




high polarization at low photon energies $p_\gamma^{Lin} = 70\%$

Circularly polarized photons




high polarization at high photon energies $p_\gamma^{Cir} = 65\%$

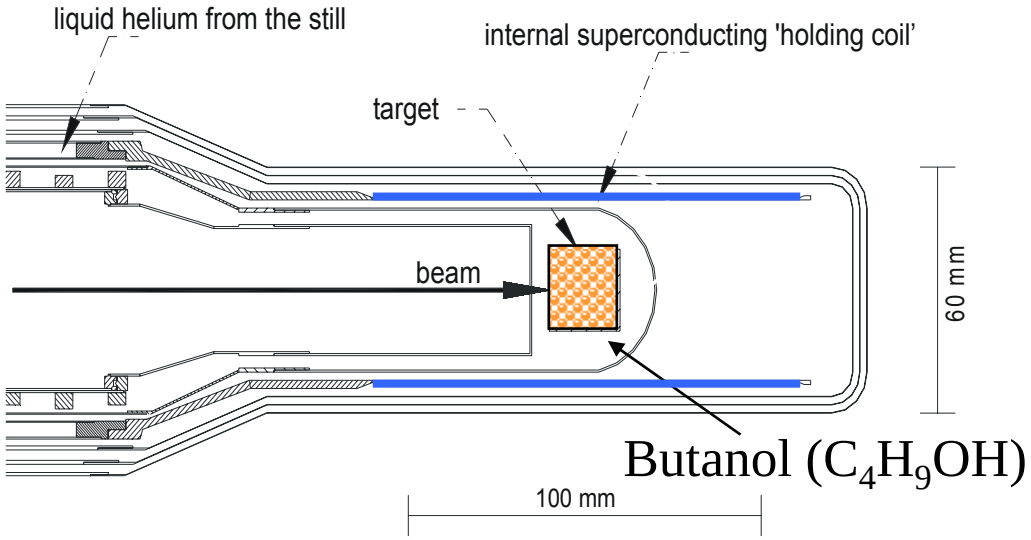
(H. Eberhard HK69.8)

(S. Kammer)

# Polarized Target

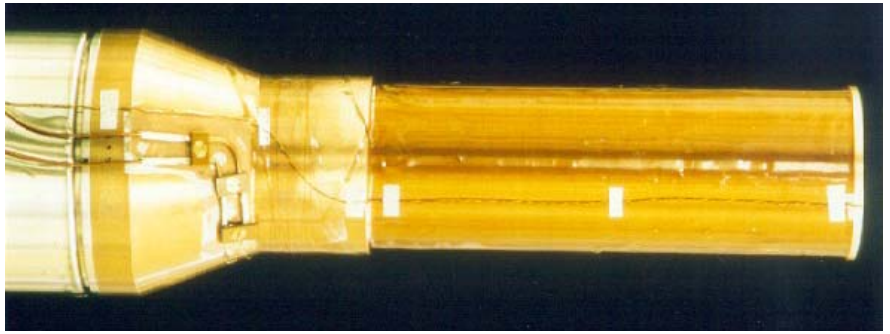
## „Frozen Spin Target“

horizontal cryostat with integrated solenoid
to freeze up the spin



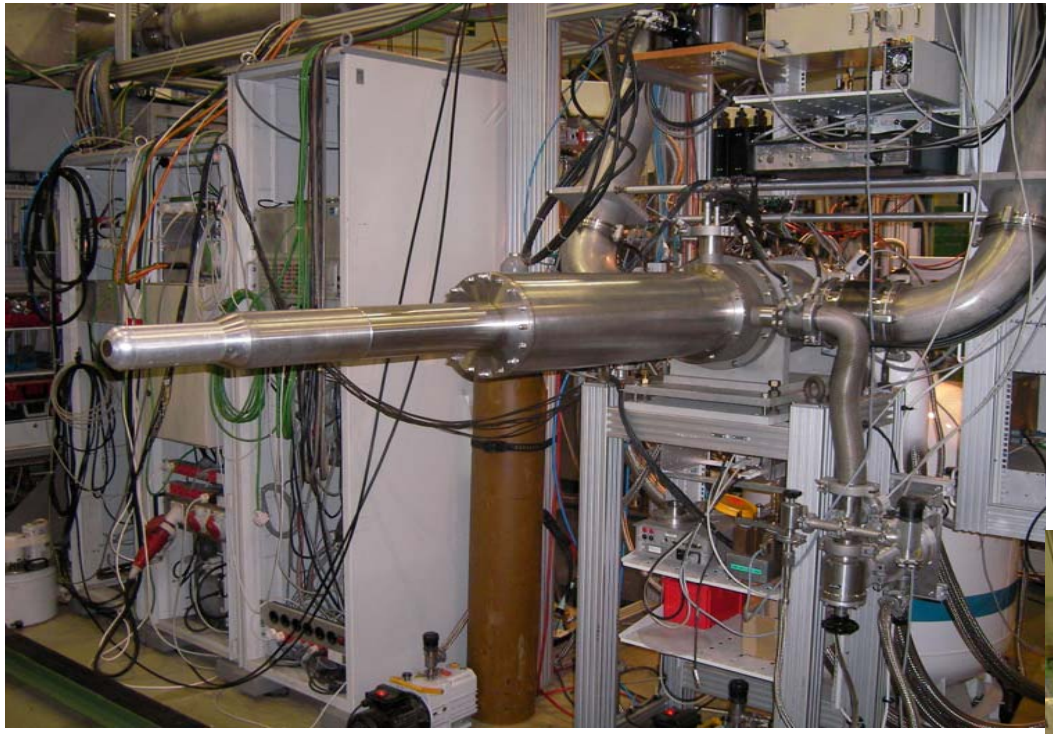

Target: Butanol ($C_4H_9OH$)

Polarization: DNP at high B-field (2.5 T)
„freeze“ up the spin (0.4 T)
relaxation time T~500h



Bonn: H. Dutz, S. Goertz
Bochum: W. Meyer, S. Reichertz

# Polarized Target

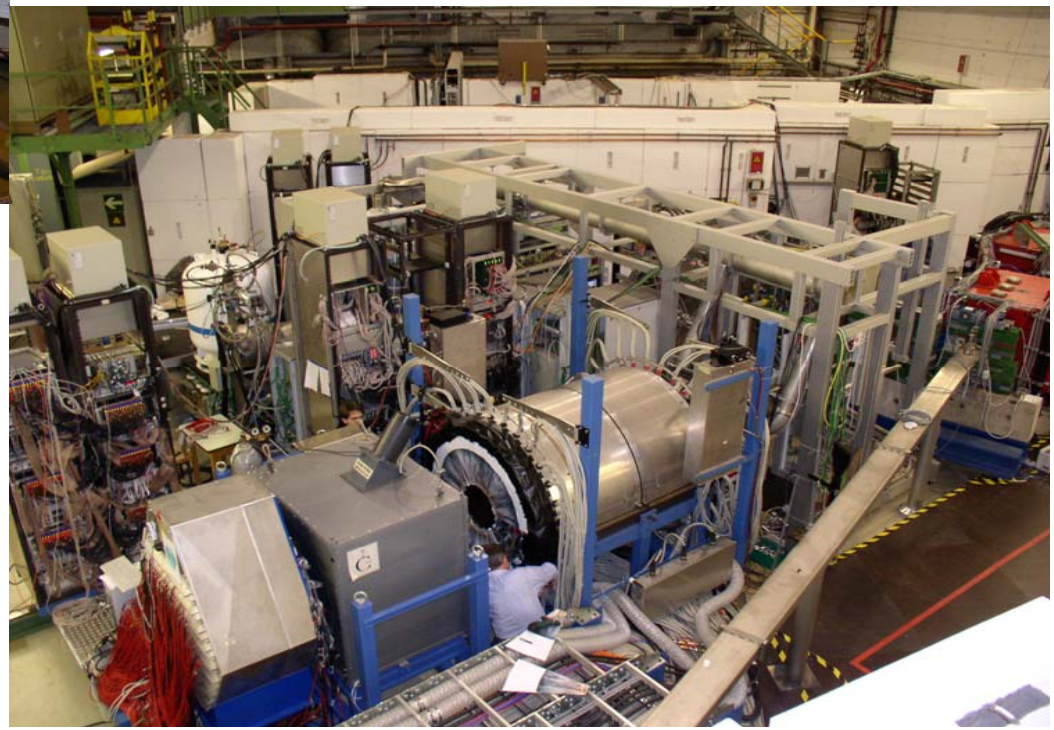


horizontal cryostat
in experimental area

data taking →

Running time over 2500 hours in year 2008

| | |
|---|---|
| High. polarization | $P_+ =$ 83.4 % |
| | $P_- = -$ 80.9 % |
| fast build-up | 05h04min (May/June) |
| | 05h39min (August) |
| Pol.-time | 06h10min |



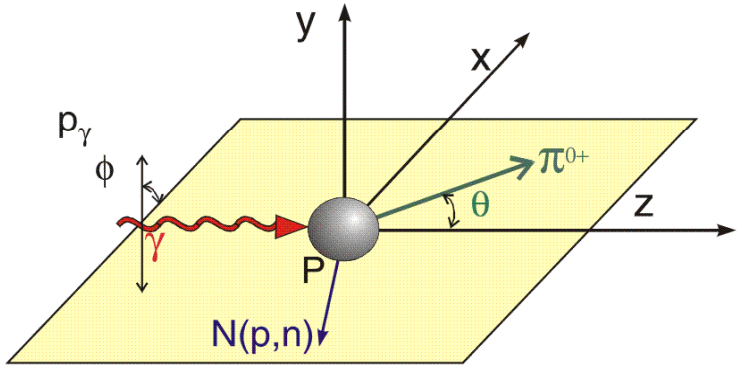
# Polarization Observables

$$\vec{\gamma}\,\vec{p} \rightarrow p\,\pi^0$$

Linearly polarized photons: $p_\gamma^{Lin}$

Circularly polarized photons: $p_\gamma^{Cir}$

Longitudionally polarized protons: $p_z$




$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\left(1 - p_\gamma^{Lin}\,\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\,p_z\,G\cdot\sin(2\phi) + p_\gamma^{Cir}\,p_z\,E\right)$$

Linearly polarized photons –> beam asymmetry Σ

Circularly polarized photons
Longitud. polarized protons
–> double polarization asymmetry *E*

Linearly polarized photons
Longitud. polarized protons
–> double polarization asymmetry *G*

Crystal Barrel experiment at ELSA:

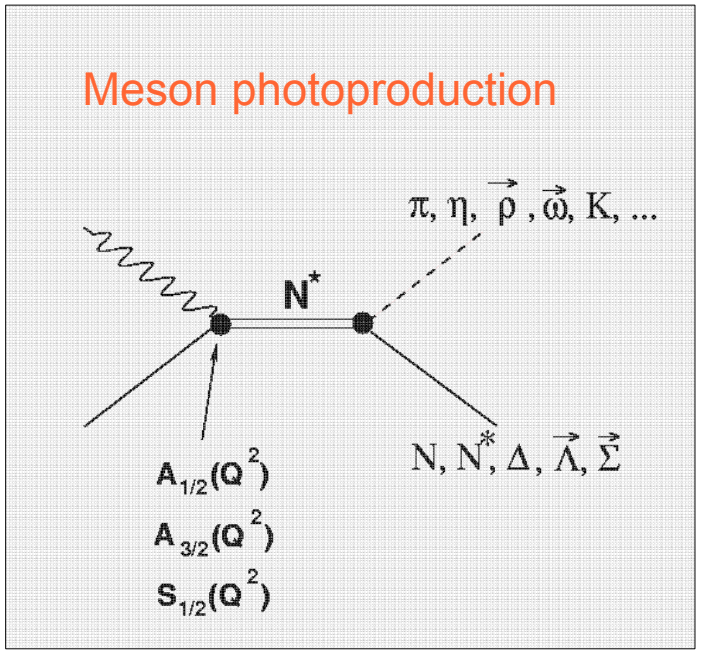
New results for different final states
New preliminary results for *G* and *E*

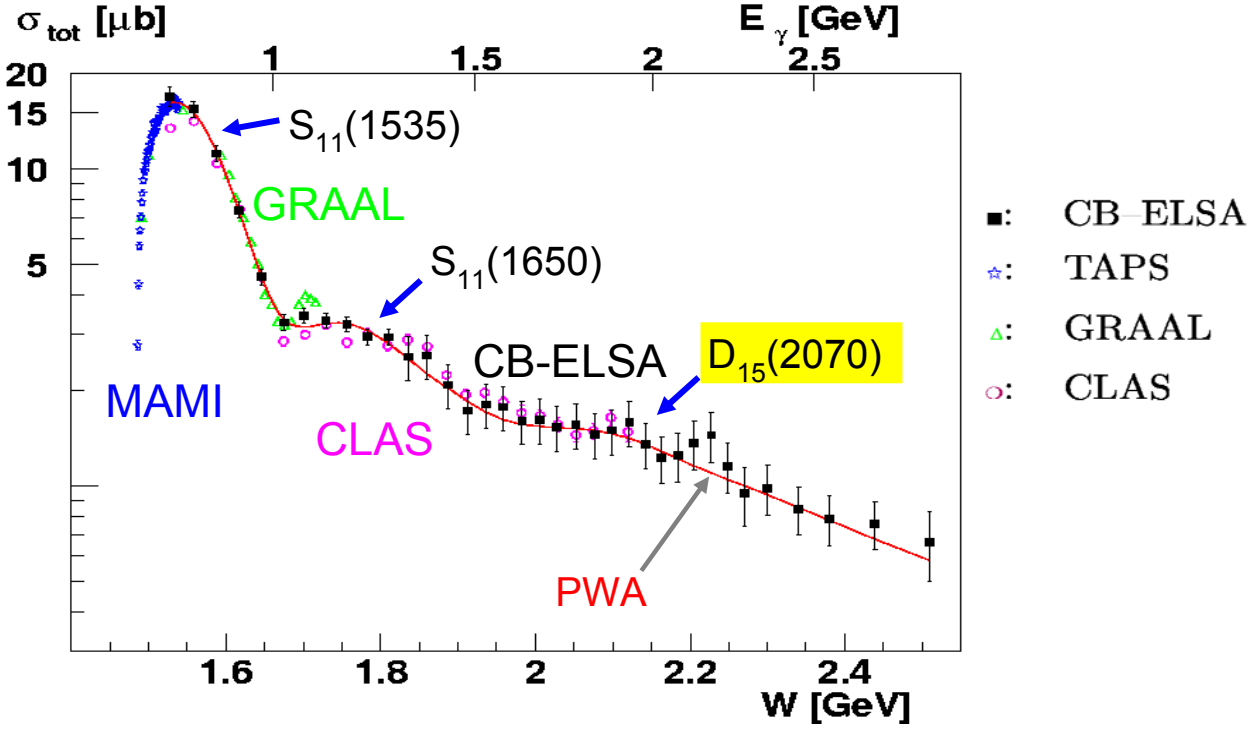
**HK 14.7, HK 14.8, HK 25.4, HK 56.3,**
**HK 57.9, HK 69.3, HK 69.4, HK 69.6, HK 69.8**

# Crystal Barrel/TAPS Results

$$\vec{\gamma} + p \rightarrow p + \eta$$

V. Crede, O. Bartolomy et al.,
PRL 94 (2005) 012004,
EPJ A33 (2007) 133




Photon helicity couplings: $A_{1/2}$ und $A_{3/2}$

$S_{11}(1535)$ : $A_{1/2}(S_{11}(1535))$ only

$D_{13}(1520)$ : $A_{1/2}(D_{13}(1520))$ and $A_{3/2}(D_{13}(1520))$

Total cross section:

$\sigma_{tot} \sim |A_{1/2}(S_{11})|^2 + |A_{1/2}(D_{13})|^2 + |A_{3/2}(D_{13})|^2 + \ldots..$

# Crystal Barrel/TAPS Results

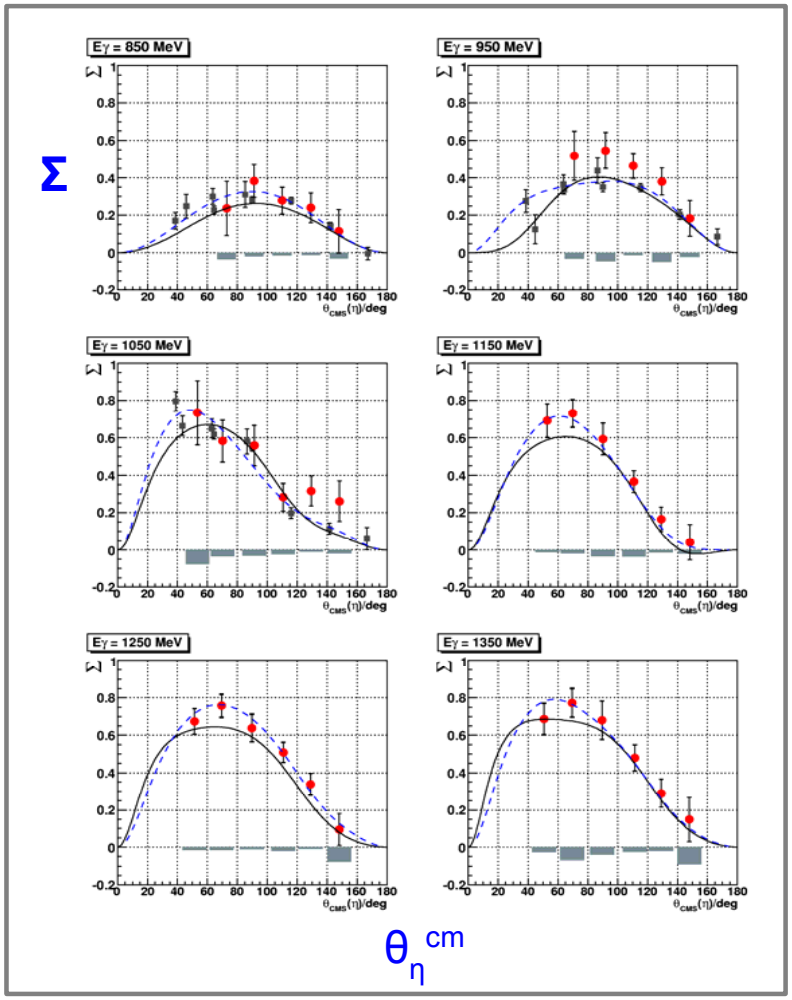
Beam asymmetry: $\Sigma$

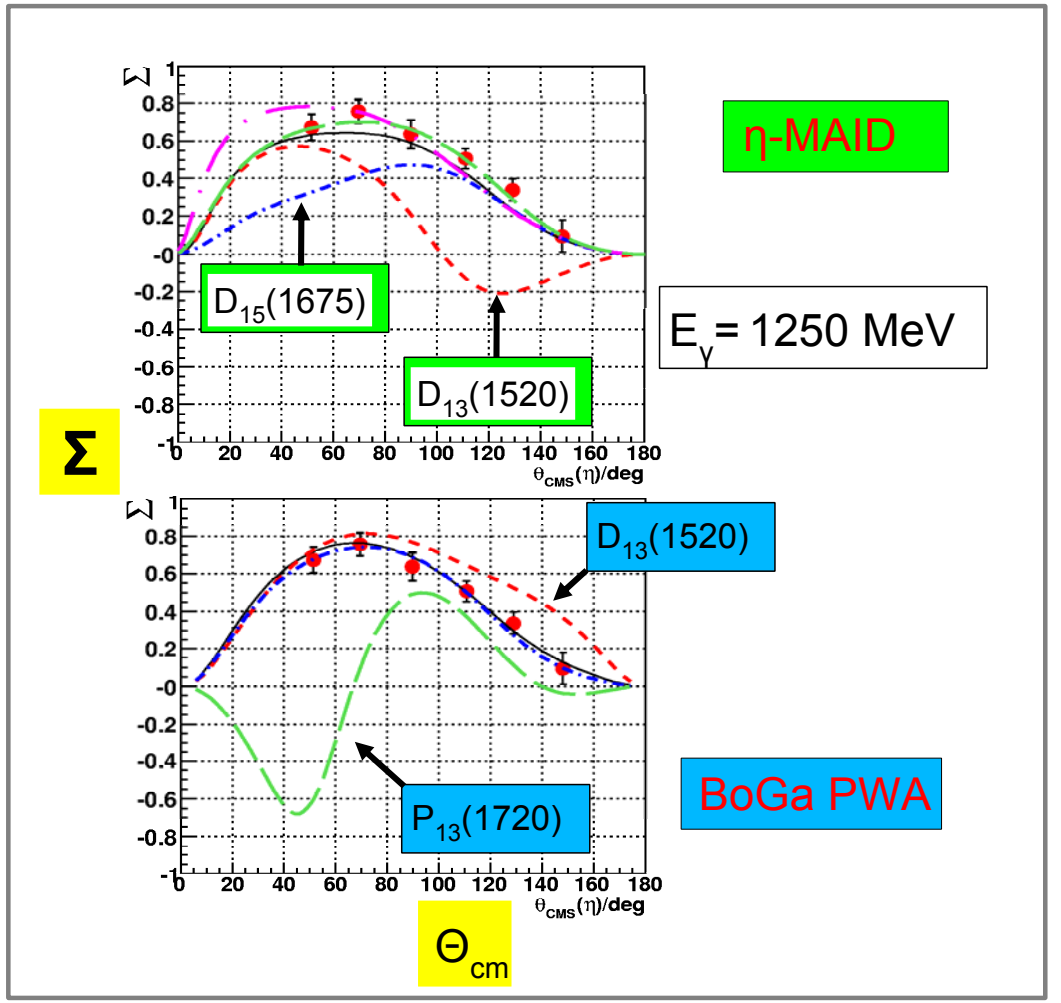
$\vec{\gamma} + p \rightarrow p + \eta$

Higher sensitivity because of interference between different resonance contributions

$\Sigma \sim A_{1/2}(S_{11}) * A_{1/2}(D_{13}) + \ldots..$

D. Elsner et al., EPJ A33 (2007) 147



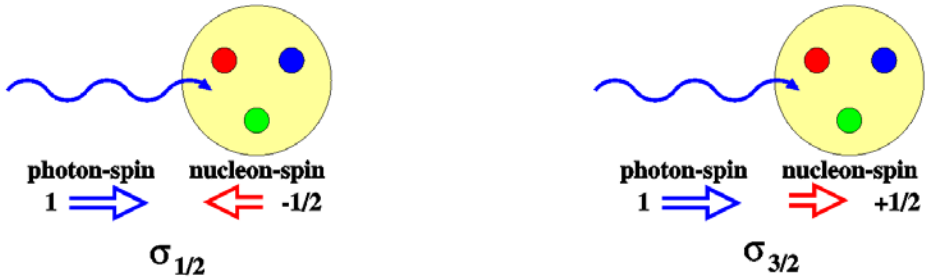



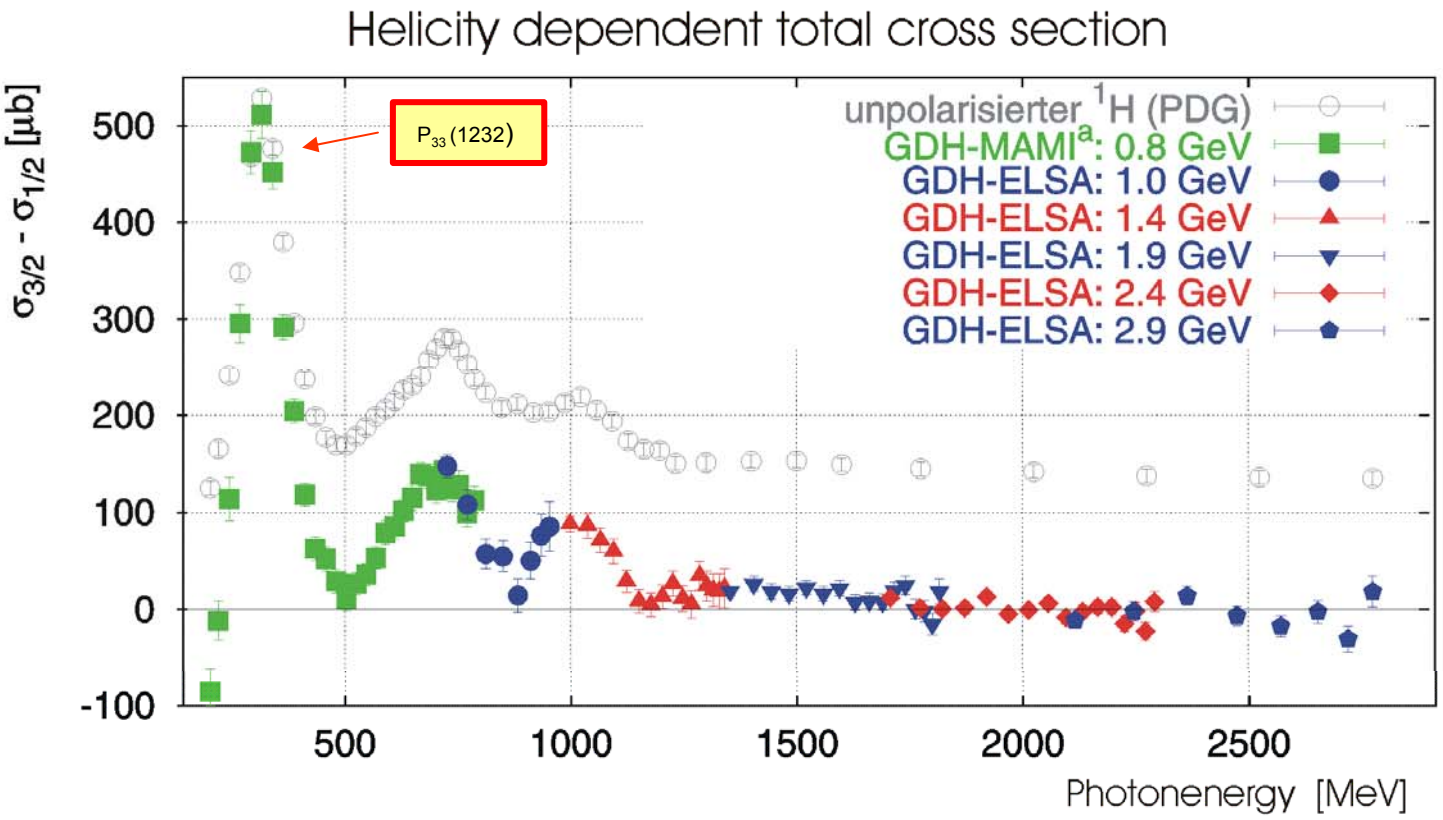
# Helicity dependent total cross section

reaction: $\vec{\gamma} + \vec{p} \rightarrow X$

circularly polarized photons

longitudinally polarized proton



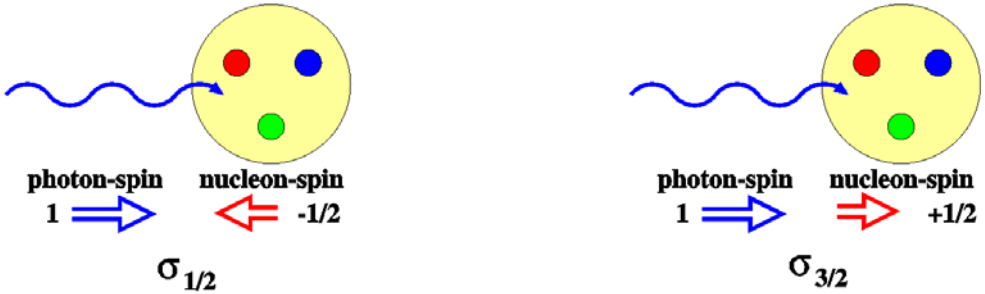

MAMI data: J. Ahrens et al., Phys. Rev. Lett. 87 (2001) 022003
ELSA data: H. Dutz et al., Phys. Rev. Lett 91 (2003) 192001

# Helicity dependent cross section

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

circularly polarized photons

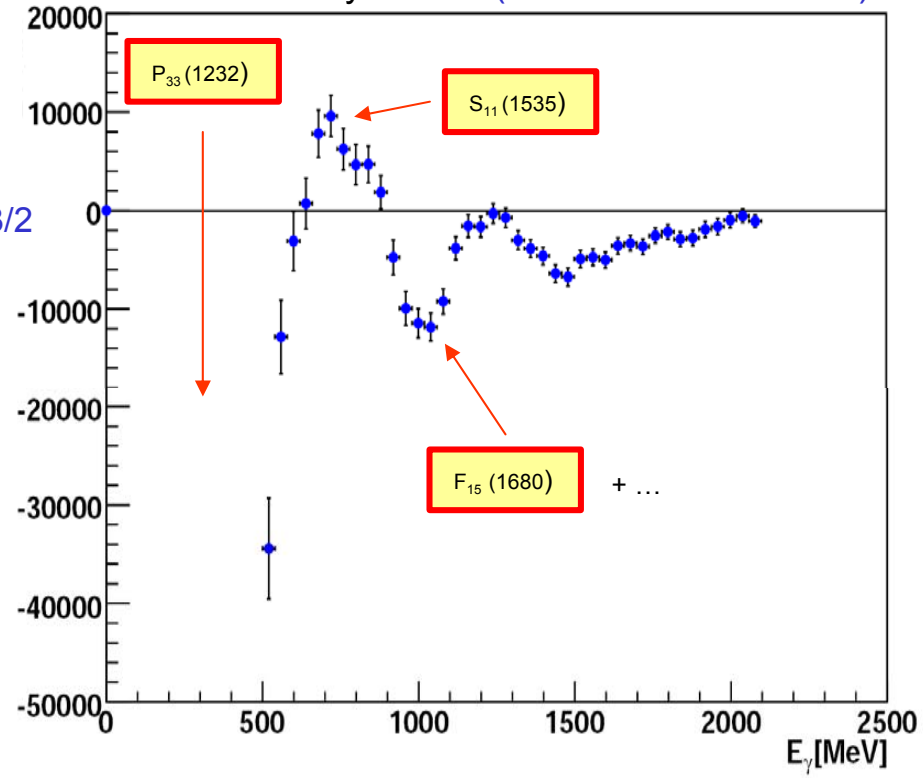
longitudinally polarized proton

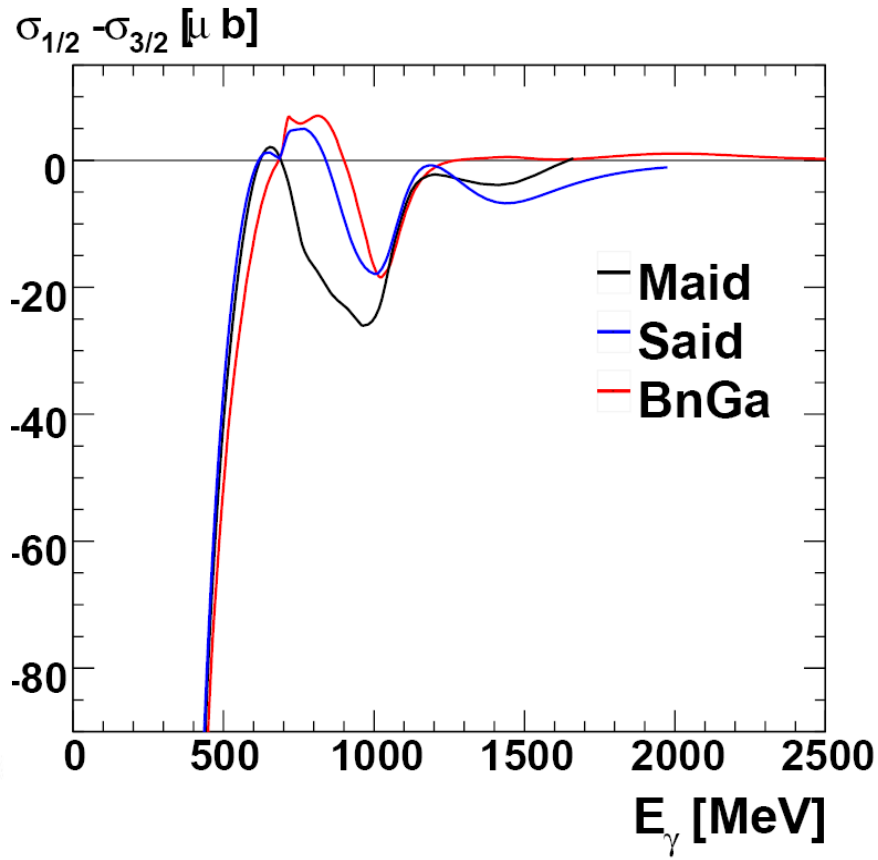



count rate difference
preliminary acceptance correction

Preliminary results (M. Gottschall HK14.7)

$N_{1/2} - N_{3/2}$



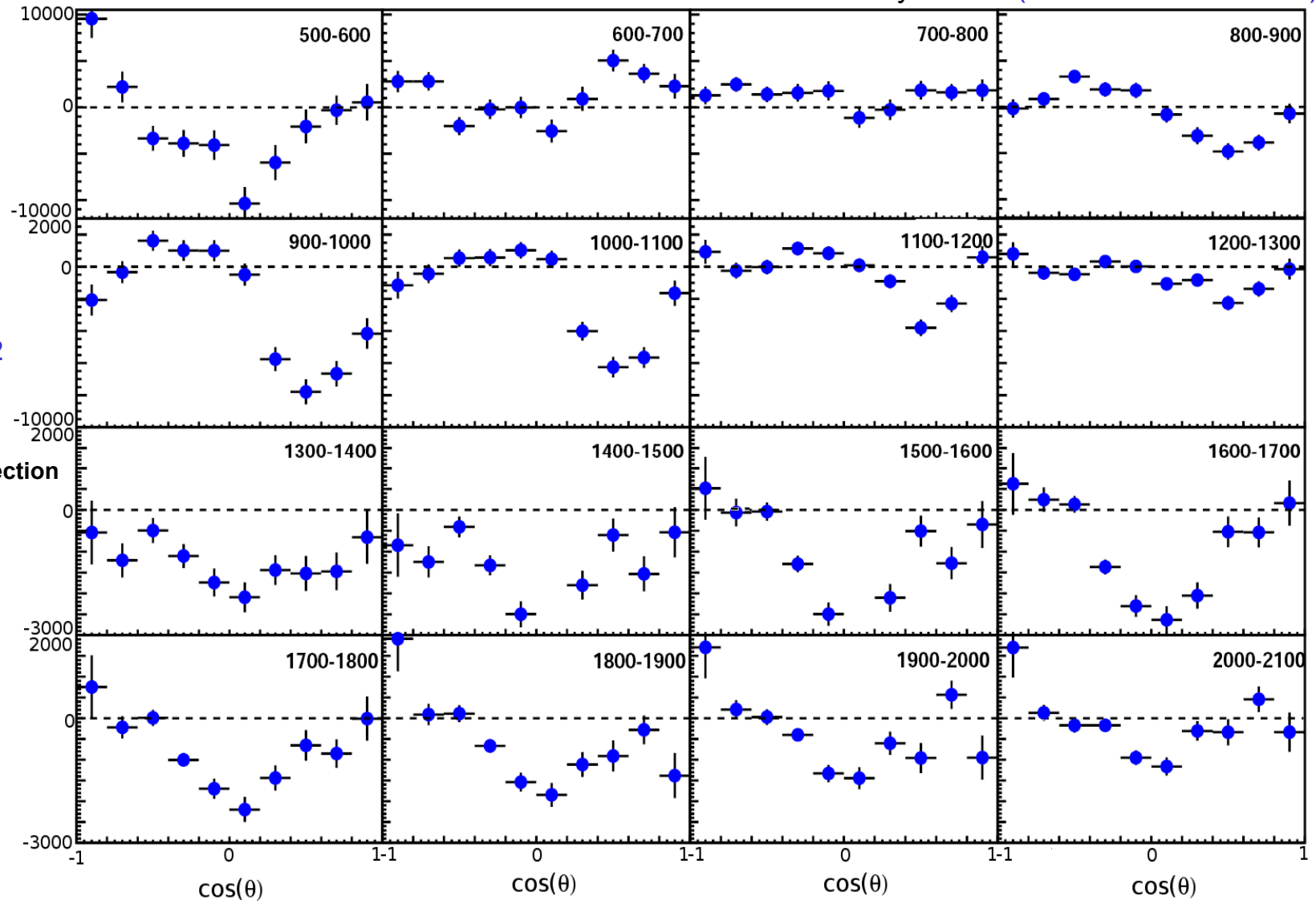
# Helicity dependent cross section

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$ Angular distributions sensitive to interference between resonances

Preliminary results (M. Gottschall HK14.7)

$N_{1/2} - N_{3/2}$

**count rate difference with acceptance correction**

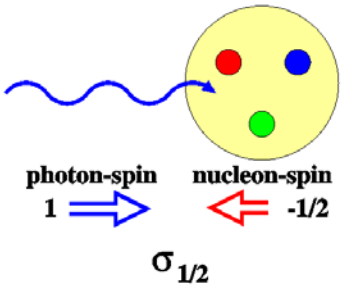


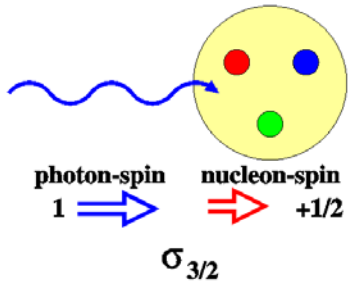
# Helicity dependent cross section

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \eta$

circularly polarized photons

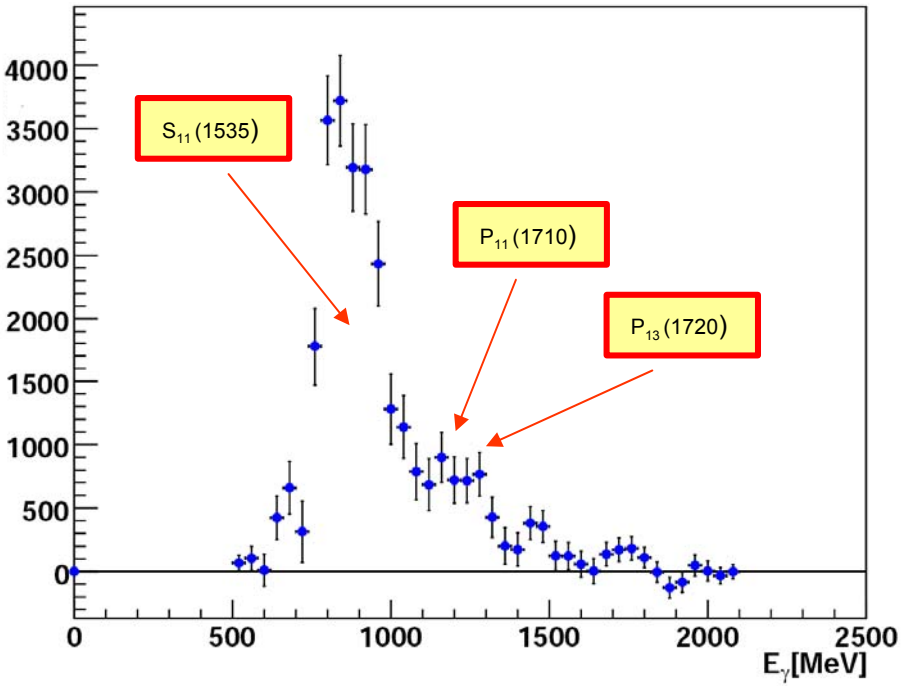
longitudinally polarized proton

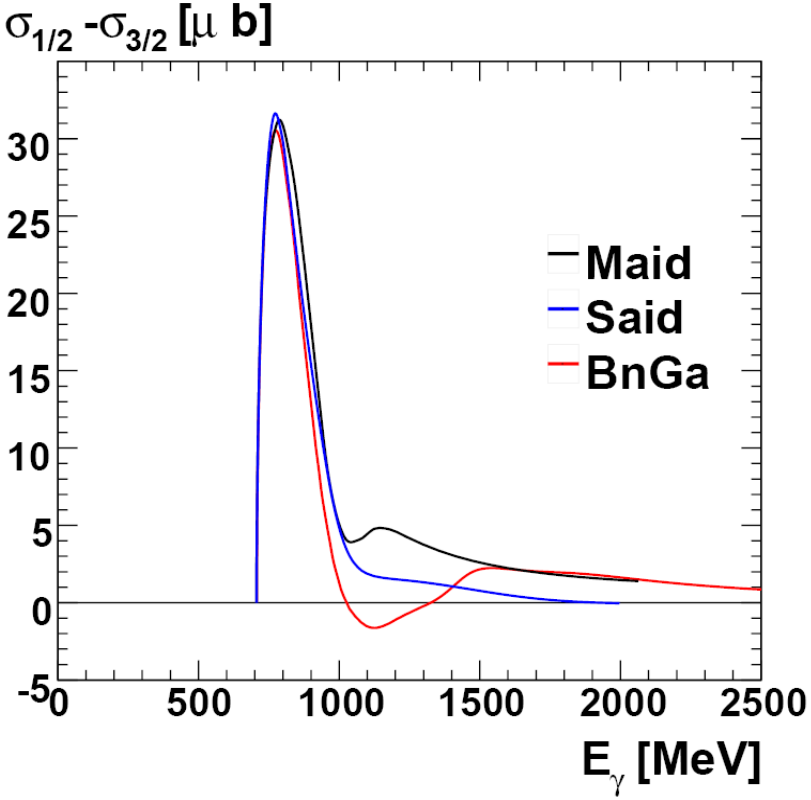



Preliminary results (M. Gottschall HK14.7)

$N_{1/2} - N_{3/2}$



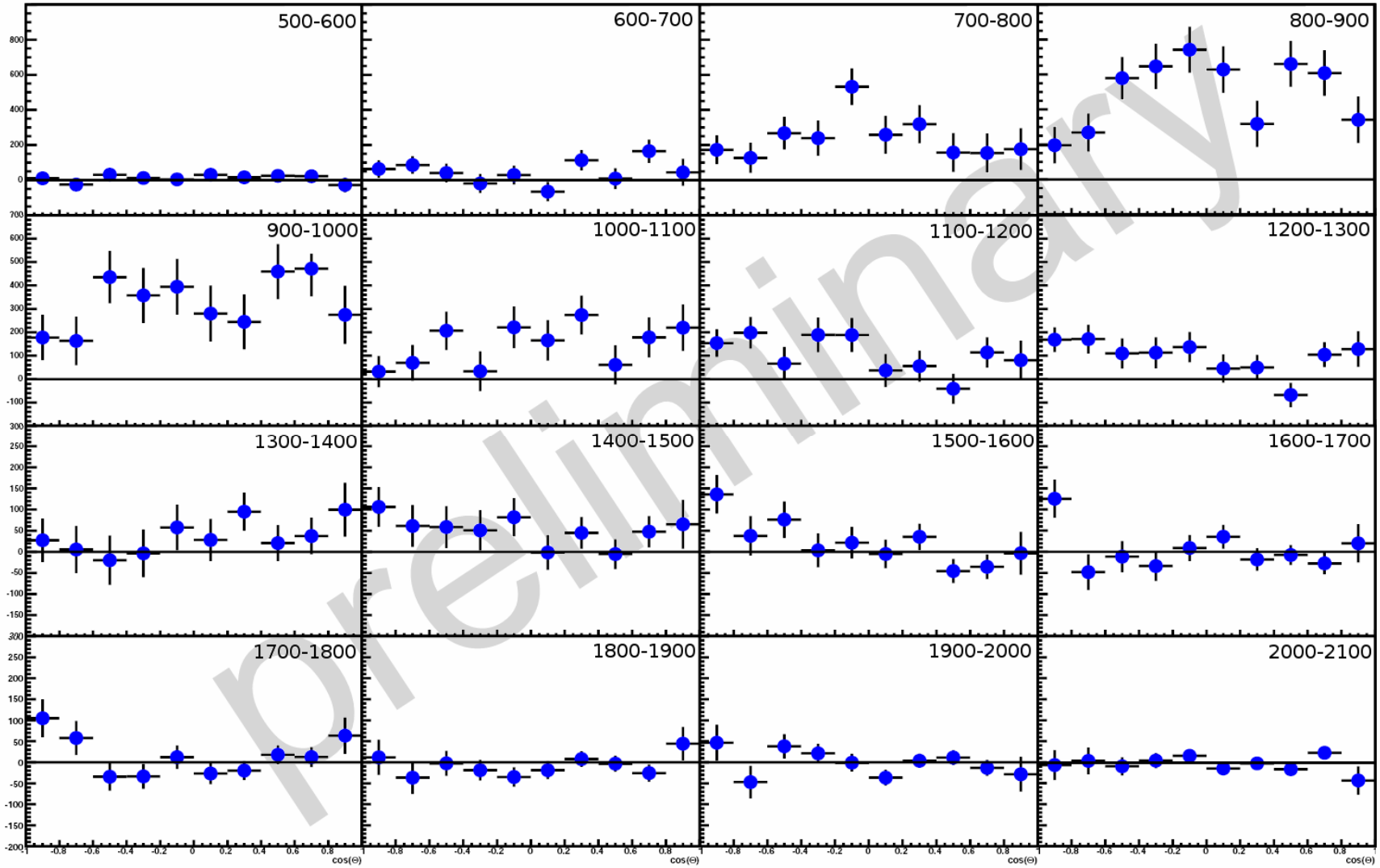
# Helicity dependent cross section

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \eta$

Preliminary results (M. Gottschall HK14.7)

$N_{1/2} - N_{3/2}$

**count rate difference**

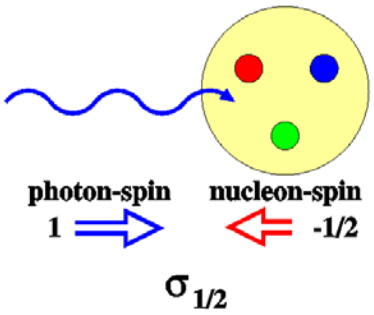


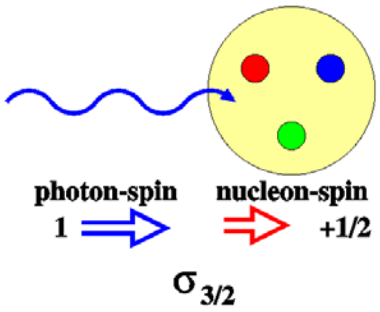
# Helicity dependent cross section

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0 + \pi^0$

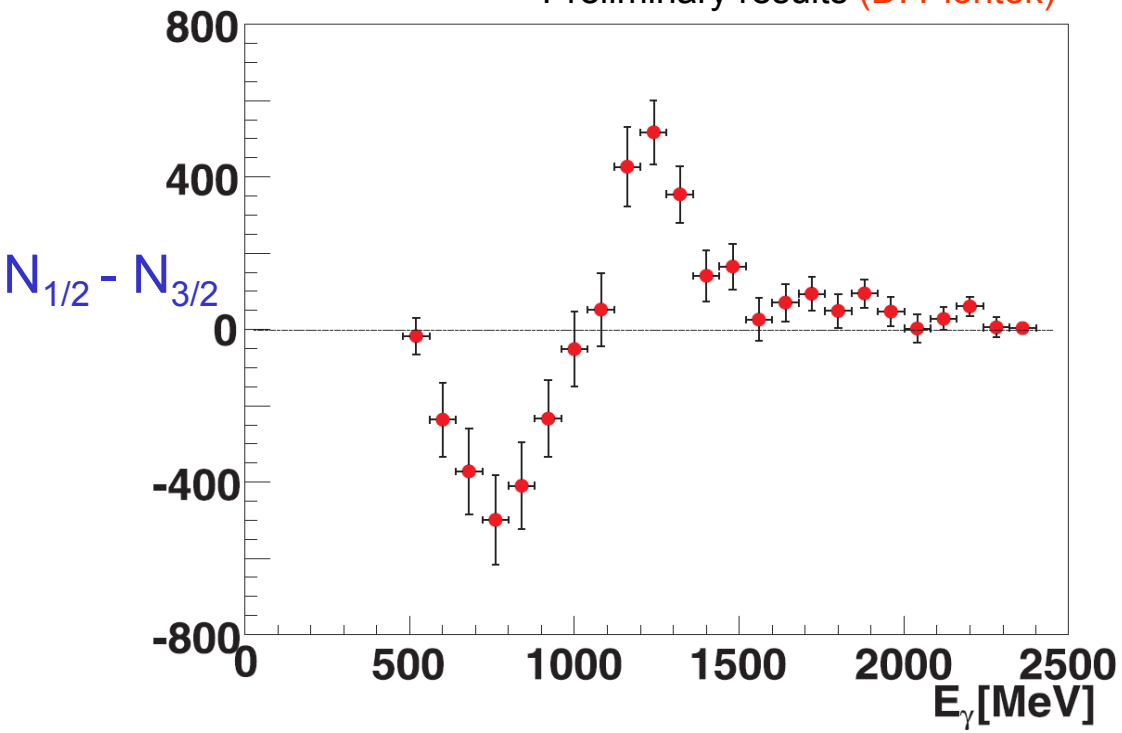
circularly polarized photons

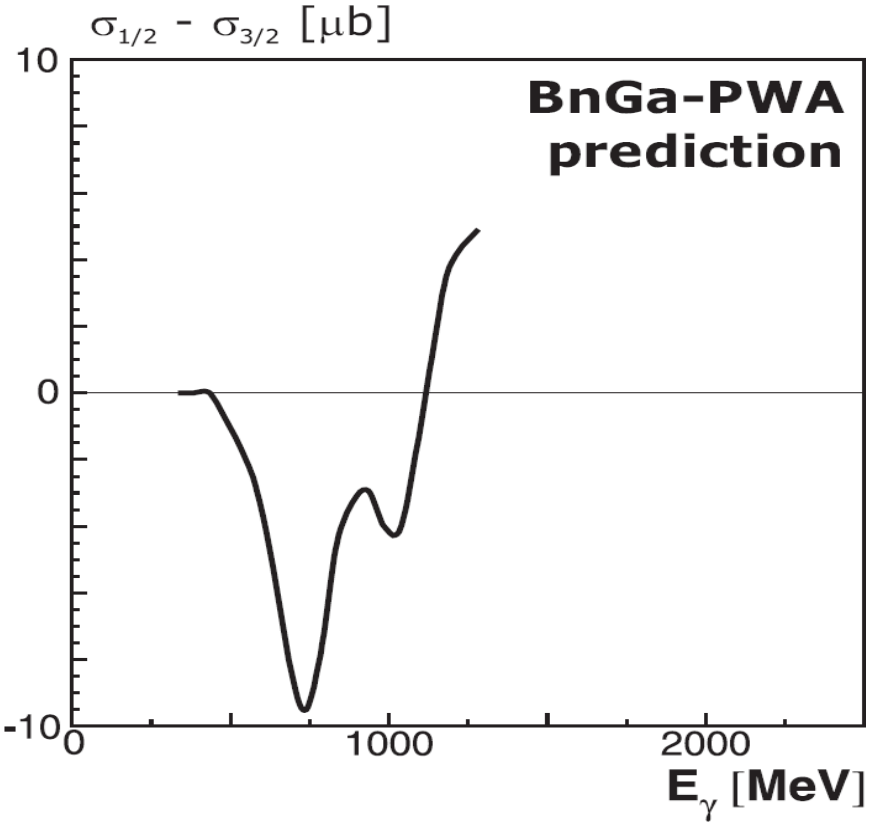
longitudinally polarized proton




Preliminary results (D. Piontek)



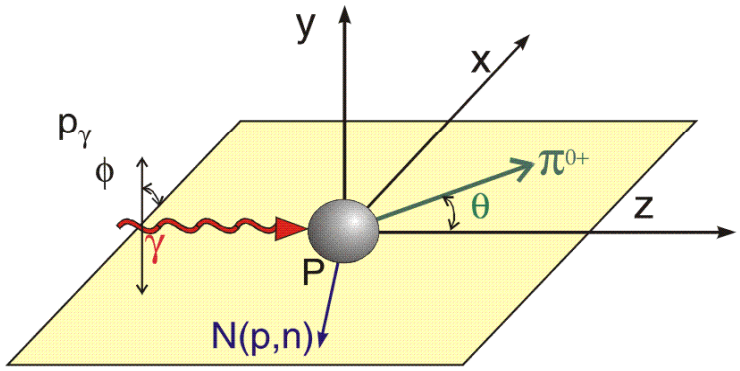
# Polarization Observables

$$\vec{\gamma}\,\vec{p} \rightarrow p\,\pi^0$$

Linearly polarized photons: $p_\gamma^{Lin}$

Circularly polarized photons: $p_\gamma^{Cir}$

Longitudionally polarized protons: $p_z$




$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\left(1 - p_\gamma^{Lin}\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\,p_z G\cdot\sin(2\phi) + p_\gamma^{Cir}\,p_z E\right)$$

G-measurement : linearly pol. photons and long. pol. Target

1.) Coherent peak at 600 MeV, $\vec{\gamma}\,\vec{p} \rightarrow p\,\pi^0$
interference between P33(1232) and P11(1440)

2.) Coherent peak at 1100 MeV, $\vec{\gamma}\,\vec{p} \rightarrow p\,\pi^0$ and $\vec{\gamma}\,\vec{p} \rightarrow p\,\eta$
interference between P13(1720) , P11(1710) and D13(1520)

3.) Coherent peak at 1700 MeV, $\vec{\gamma}\,\vec{p} \rightarrow p\,\pi^0$ and $\vec{\gamma}\,\vec{p} \rightarrow p\,\eta$
interference between P13(1720) , P11(1710) and D15(2070)

# Double Polarization Experiment for G

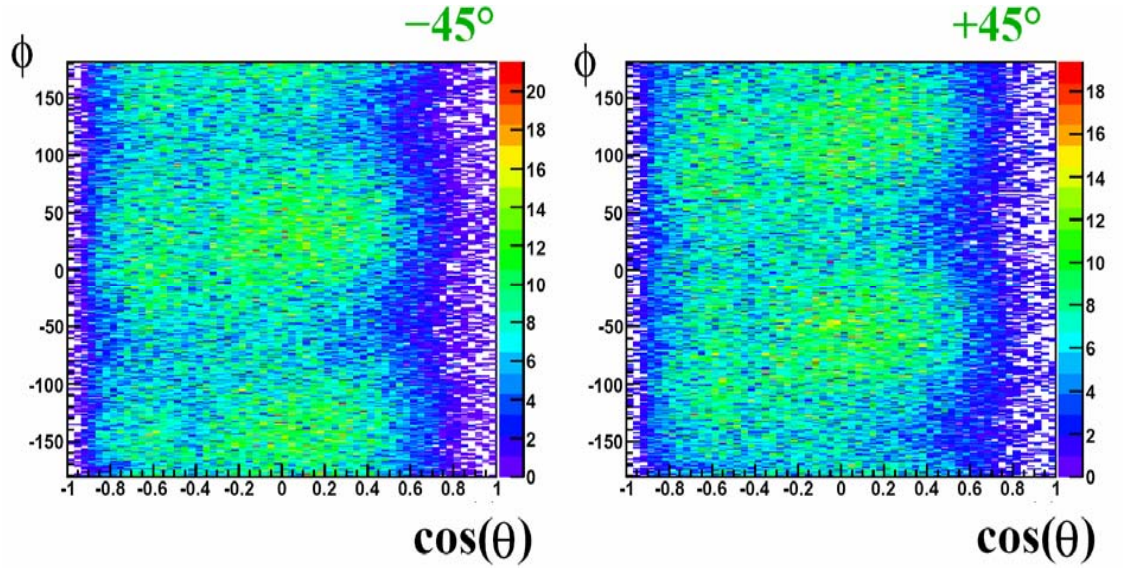
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

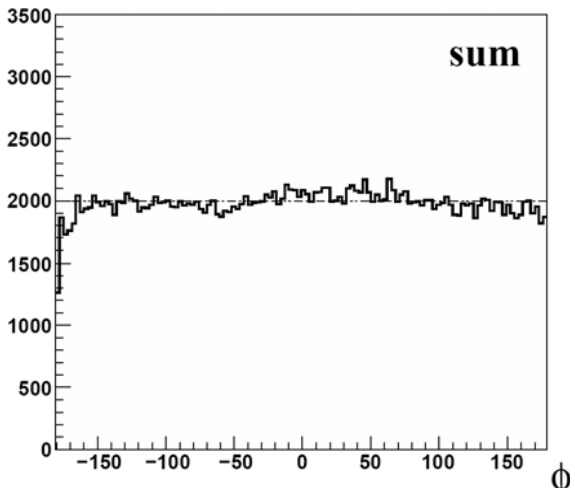
$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\,(1 - p_\gamma^{Lin}\,\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\;p_z\,G\cdot\sin(2\phi))$$

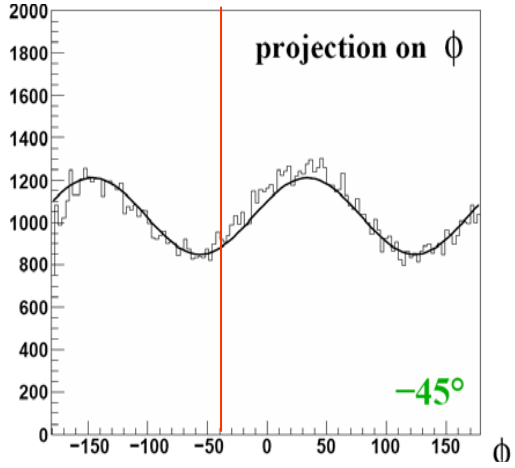
first online spectra with

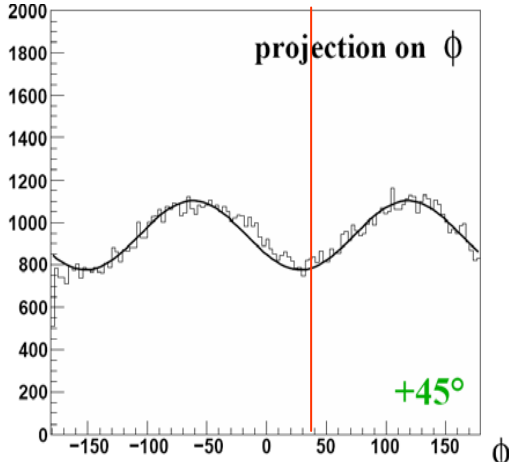
linearly polarized photons

longitudinally polarized proton



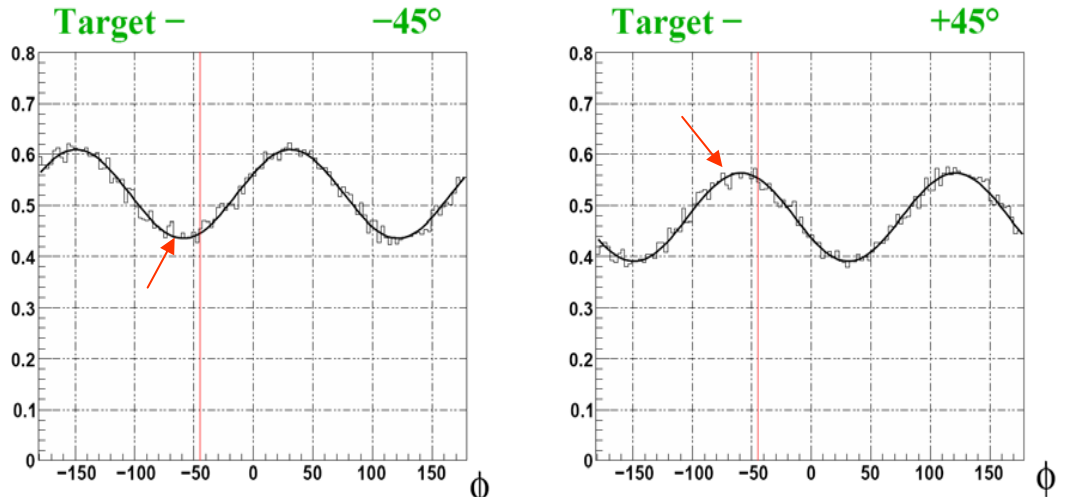



# Double Polarization Experiment for G

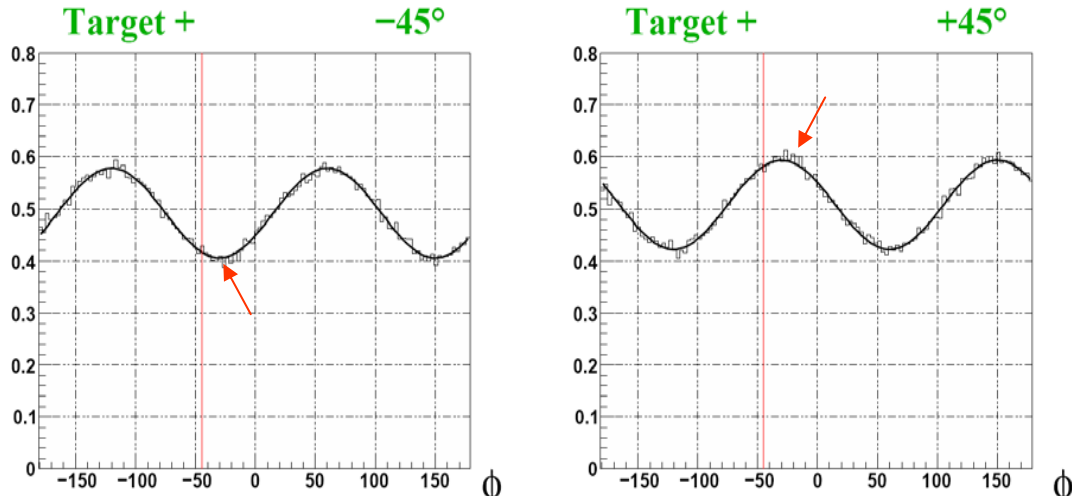
$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\,(1 - p_\gamma^{Lin}\,\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\;p_z\,G\cdot\sin(2\phi))$$

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

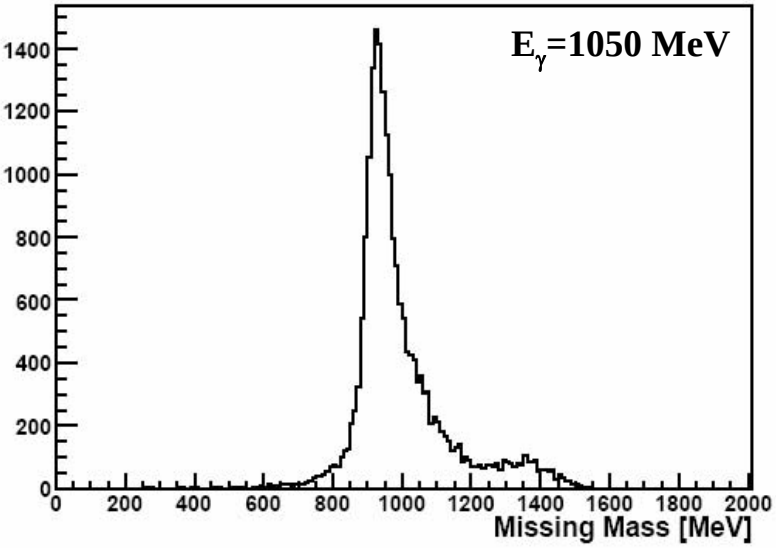
linearly polarized photons
longitudinally polarized proton




Clear effect from G observed



# G-Asymmetry for $p\pi^0$



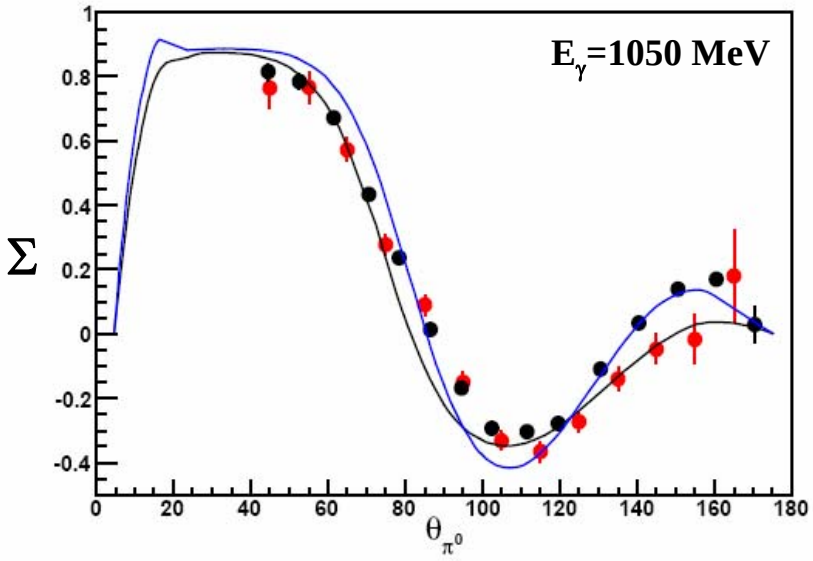

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

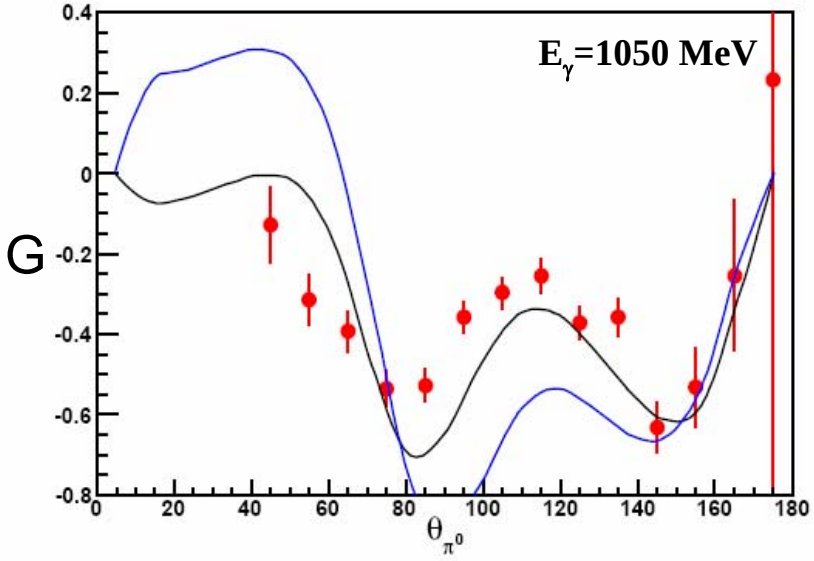
missing mass cut

fit to the $\phi$-distribution

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\,(1 - p_\gamma^{Lin}\,\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\;p_z\,G\cdot\sin(2\phi))$$

- Preliminary results CB (A. Thiel HK69.6)
- GRAAL data




SAID

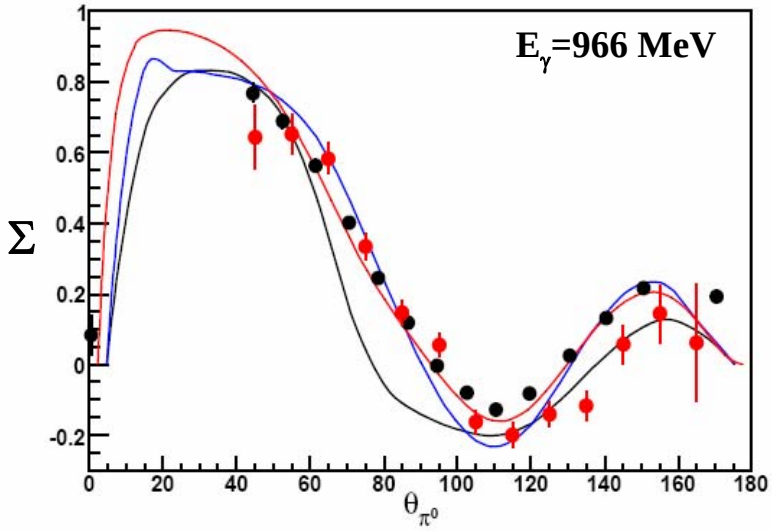
MAID

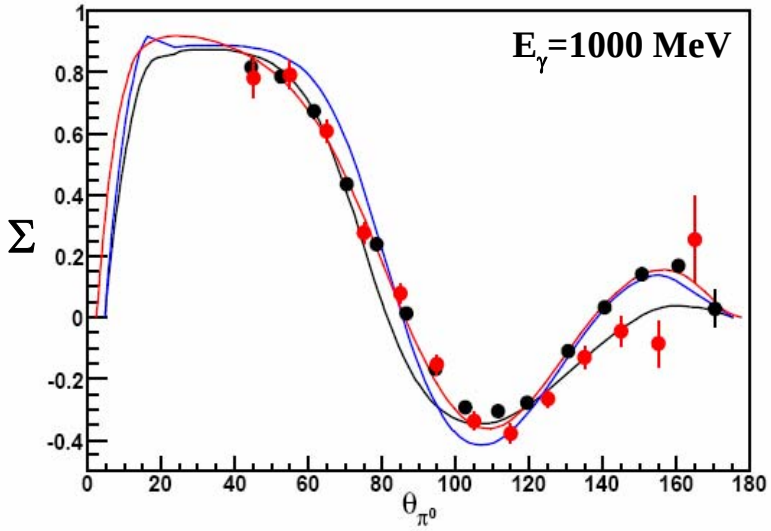
# Asymmetries for $p\pi^0$

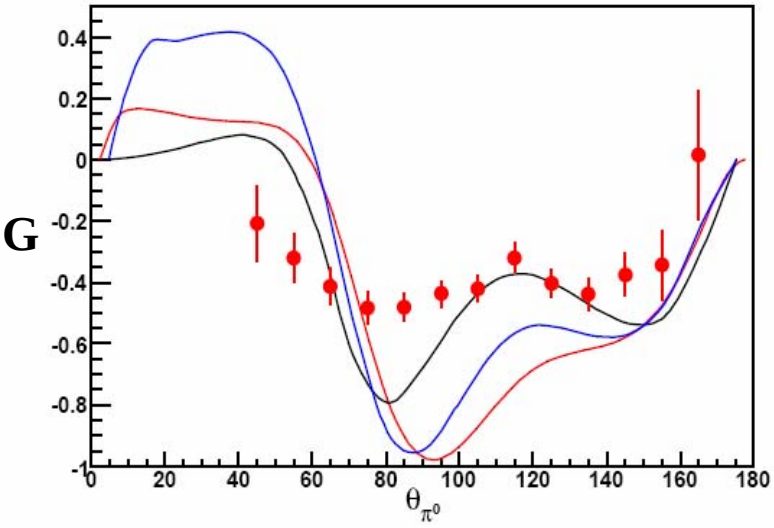
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

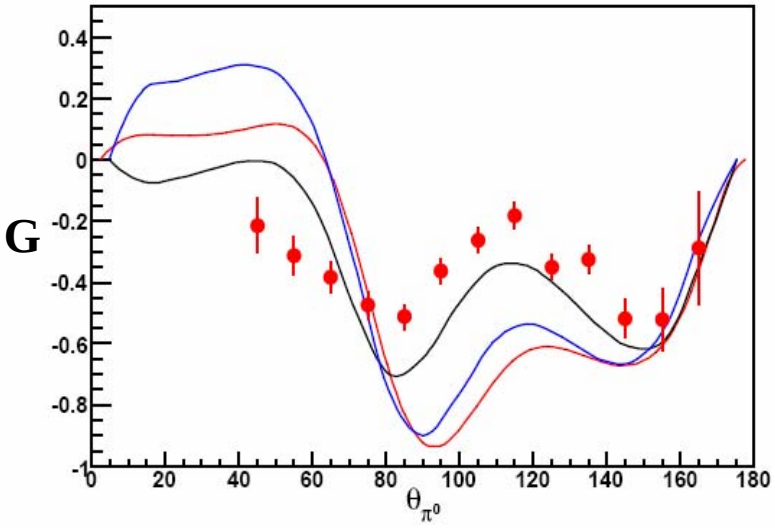
linearly polarized photons

longitudinally polarized proton



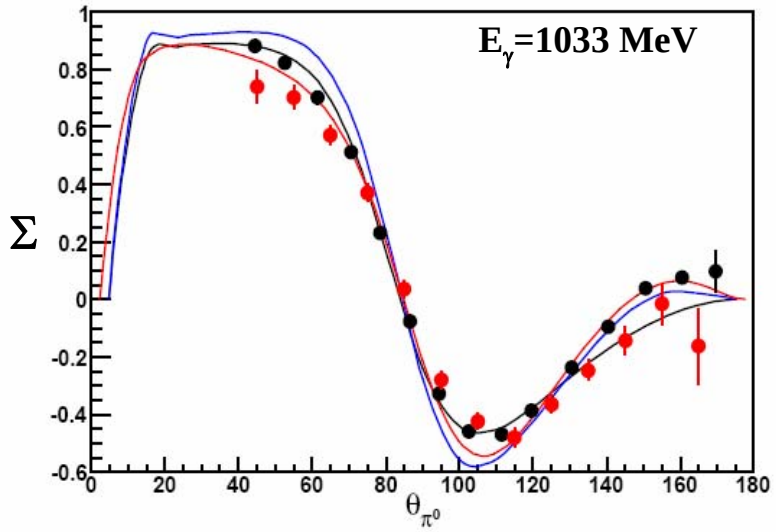

- Preliminary results (A. Thiel HK69.6)
- GRAAL data

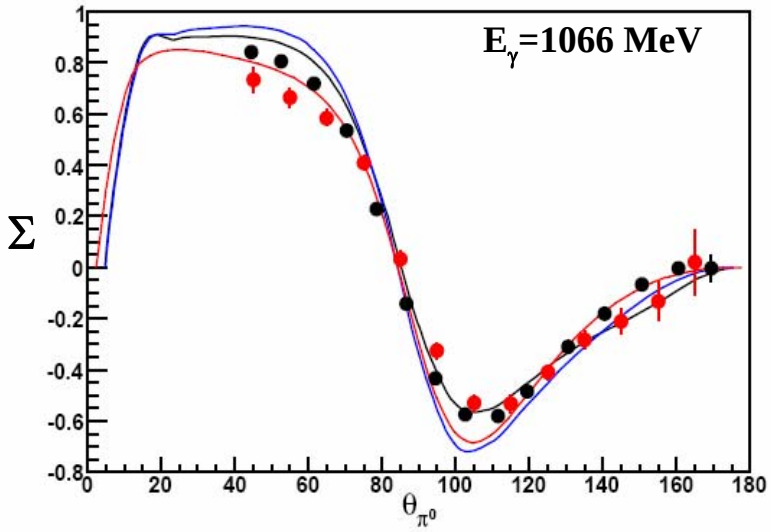
prediction partial wave analysis

- BoGa
- SAID
- MAID

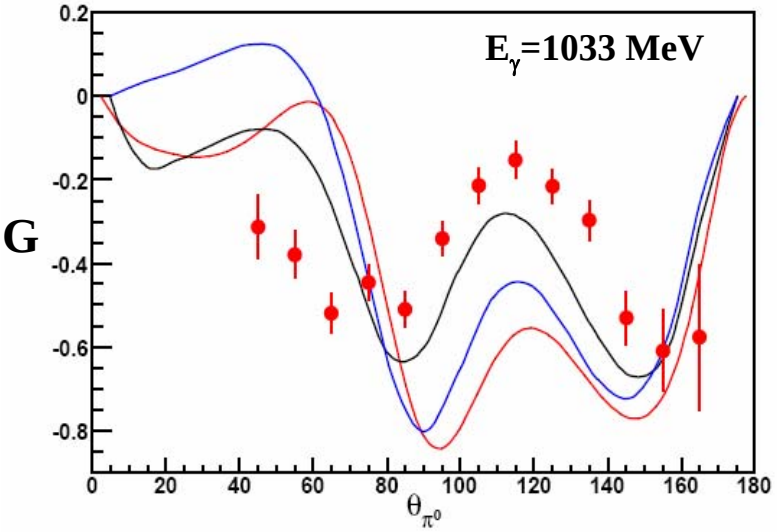
# Asymmetries for $p\pi^0$

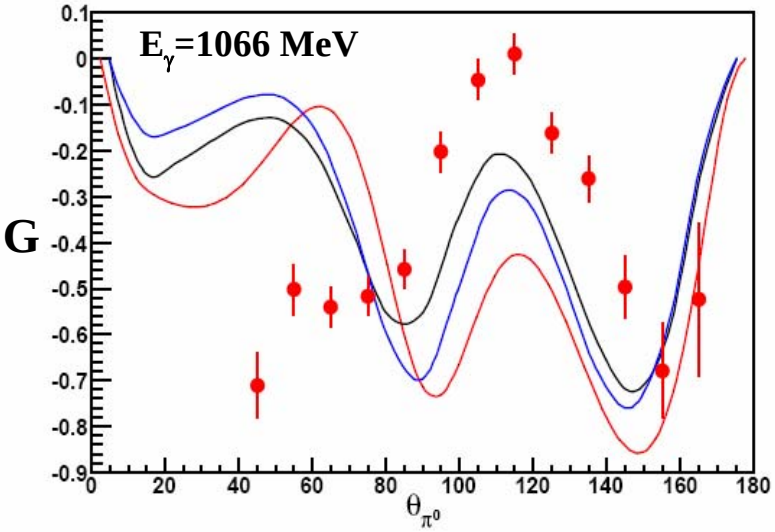
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$




- Preliminary results (A. Thiel HK69.6)
- GRAAL data



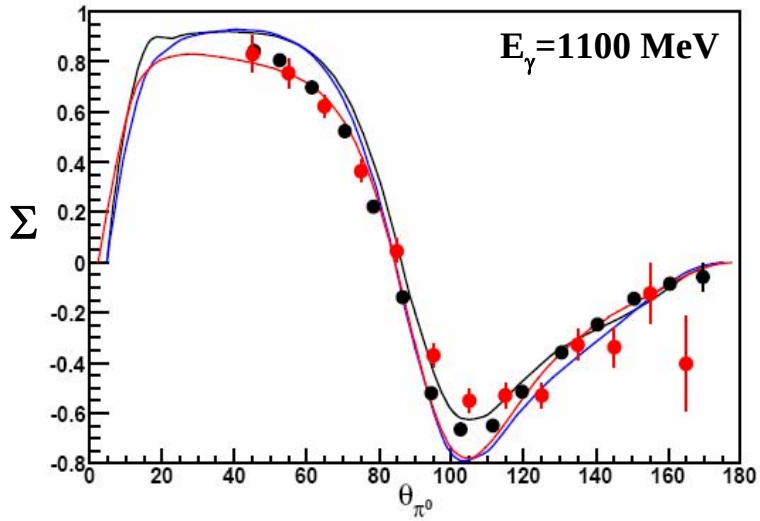



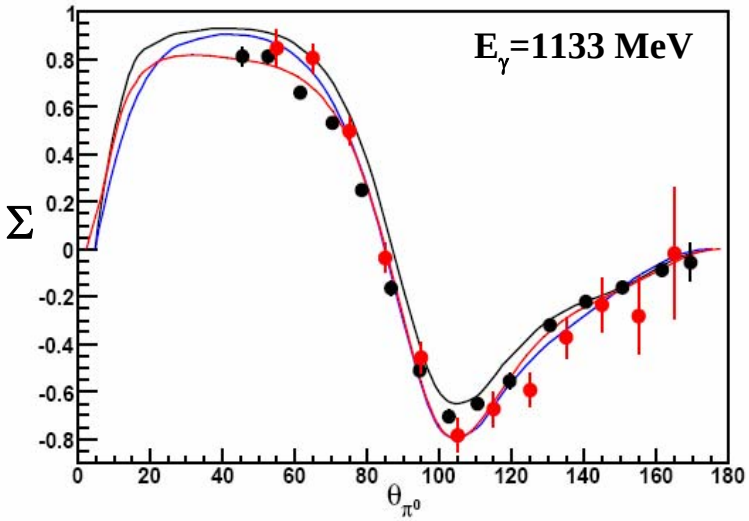

prediction
partial wave analysis

- BoGa
- SAID
- MAID

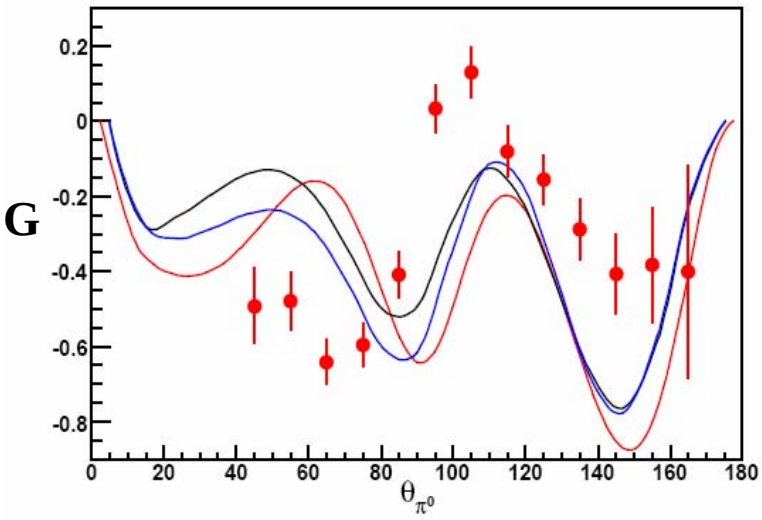
# Asymmetries for $p\pi^0$

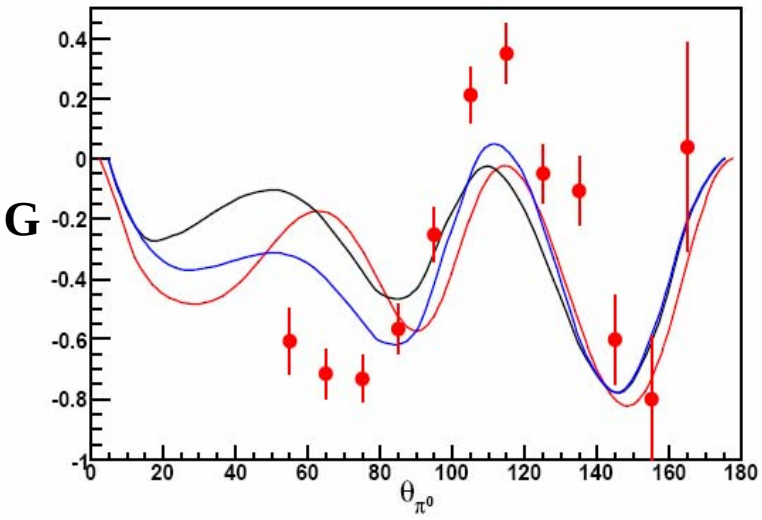
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$




- Preliminary results (A. Thiel HK69.6)
- GRAAL data



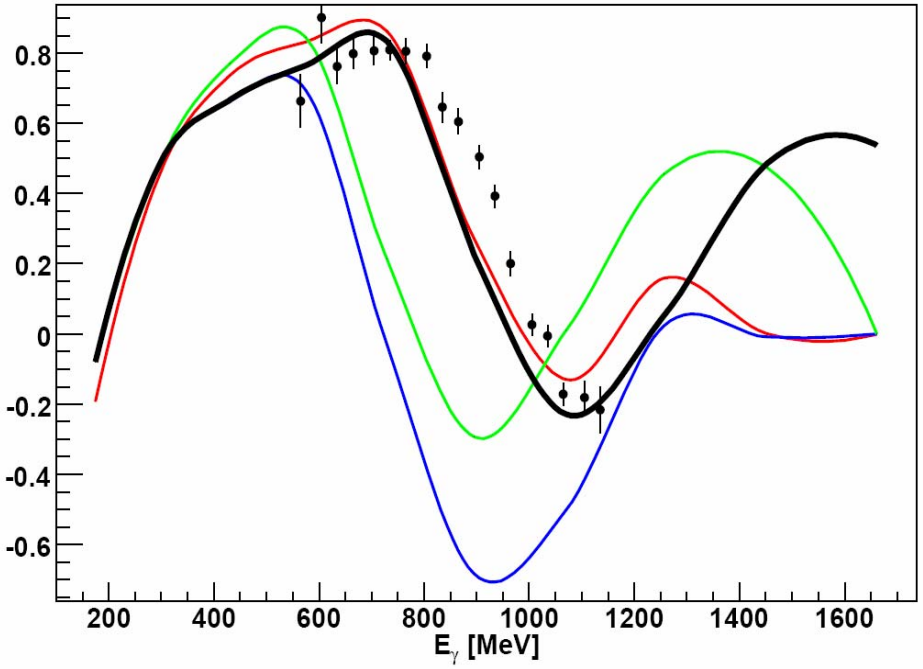




prediction
partial wave analysis

- BoGa
- SAID
- MAID

# Energy dependence

Beam-Asymmetry $\Sigma$ at $\theta = 90$

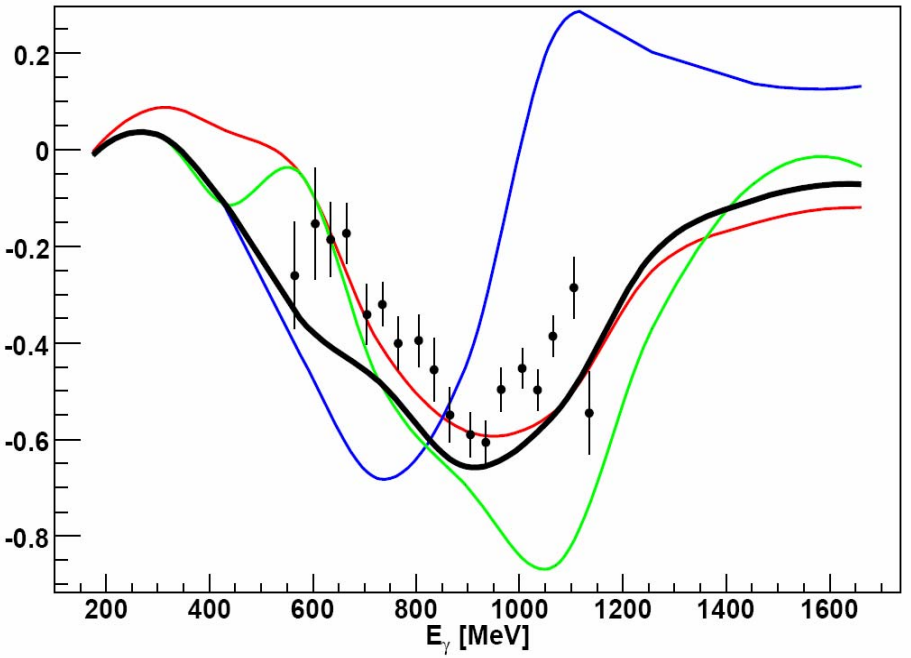



without $P_{11}$ (1440)

without $D_{13}$ (1520)

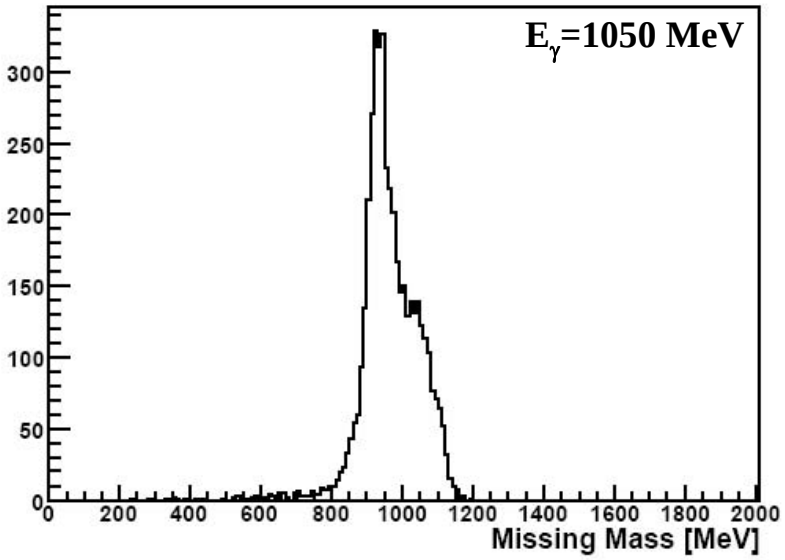
without $F_{15}$ (1680)

Double-Polarization-Asymmetry G at $\theta = 90$




Preliminary results
(A. Thiel HK69.6)

# Asymmetries for pη

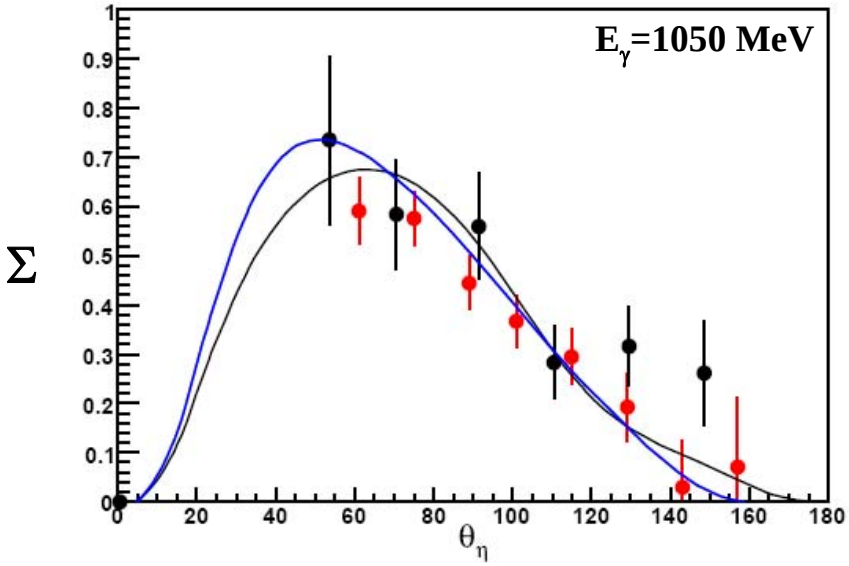


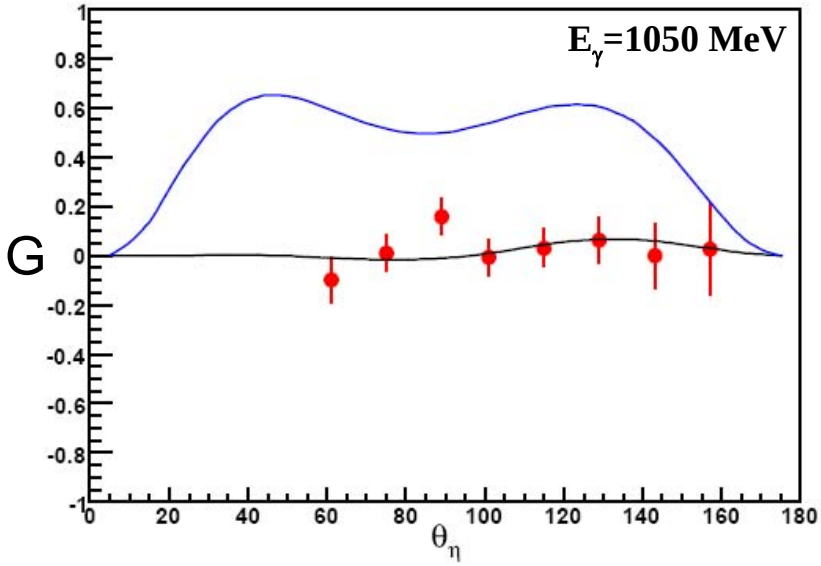

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \eta$

missing mass cut

fit to the ϕ-distribution

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\,(1 - p_\gamma^{Lin}\,\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\;p_z\,G\cdot\sin(2\phi))$$




SAID

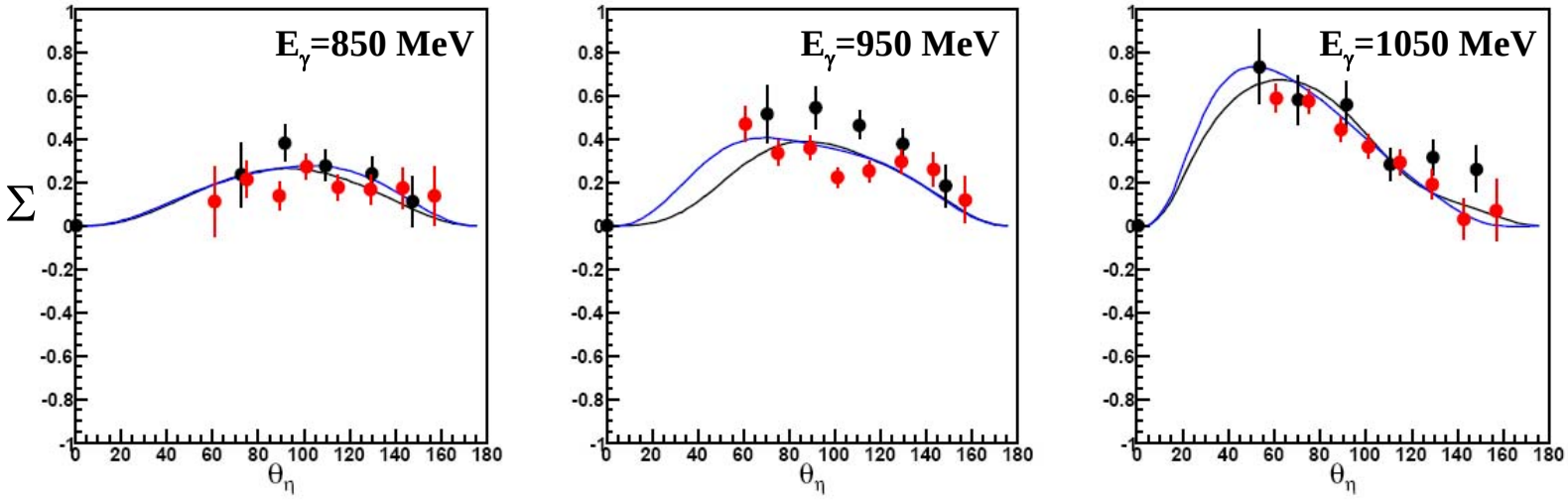
MAID

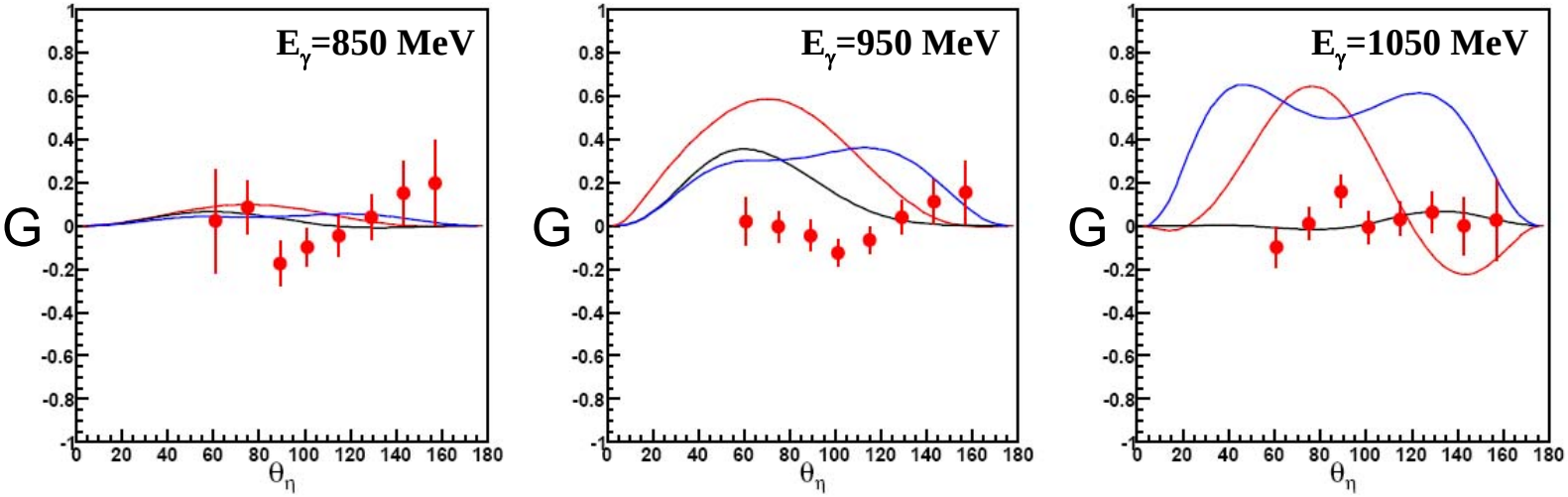
# Asymmetries for pη

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \eta$

linearly polarized photons

longitudinally polarized proton



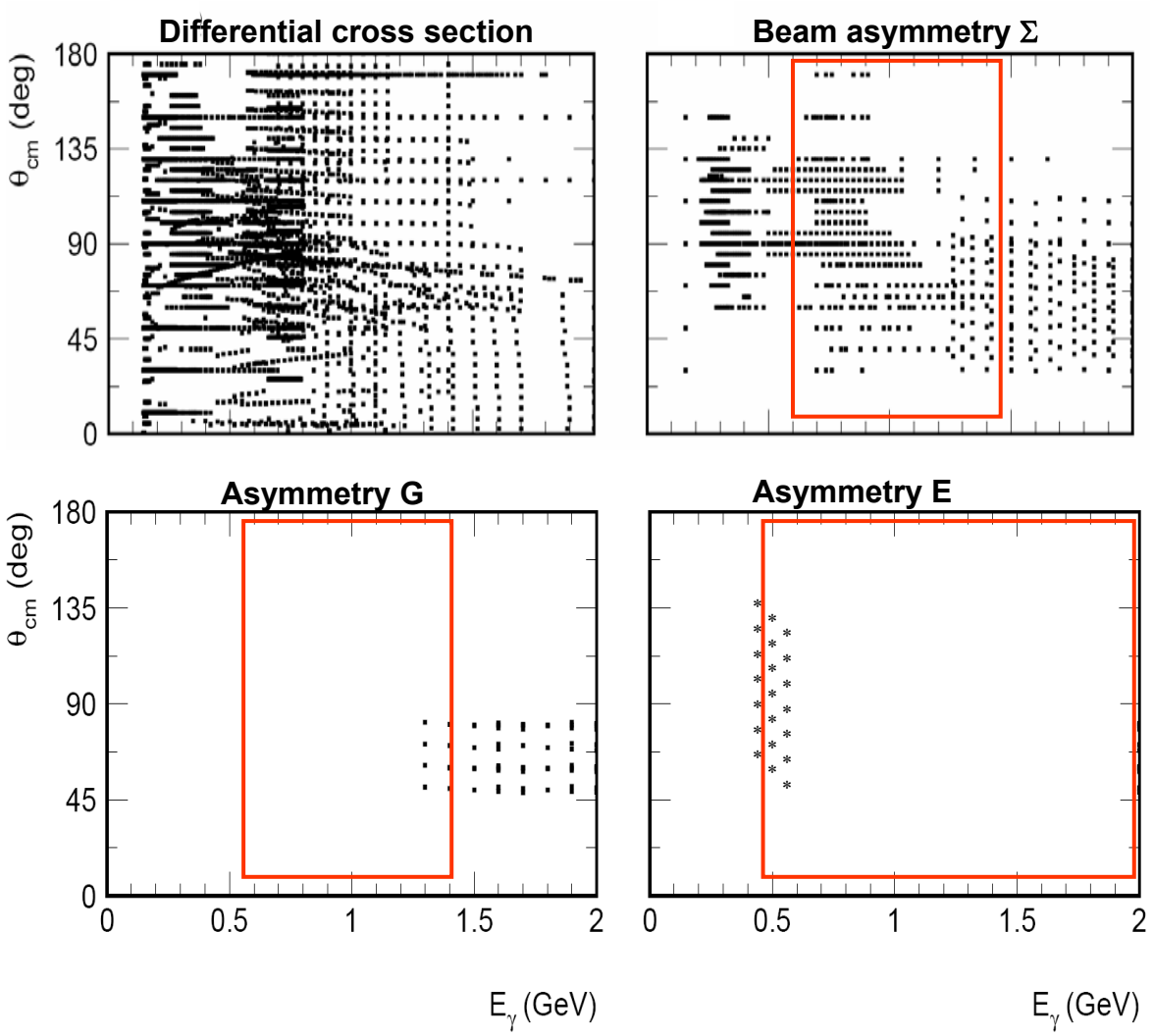

- Preliminary results (A. Thiel HK69.6)
- CB (D. Elsner)

prediction
partial wave analysis

- BoGa
- SAID
- MAID

# World Data Base

reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$




First round of double polarization experiments with CB at ELSA:

Energy range for G: 600- 1300 MeV

Energy range for E: 500- 2100 MeV

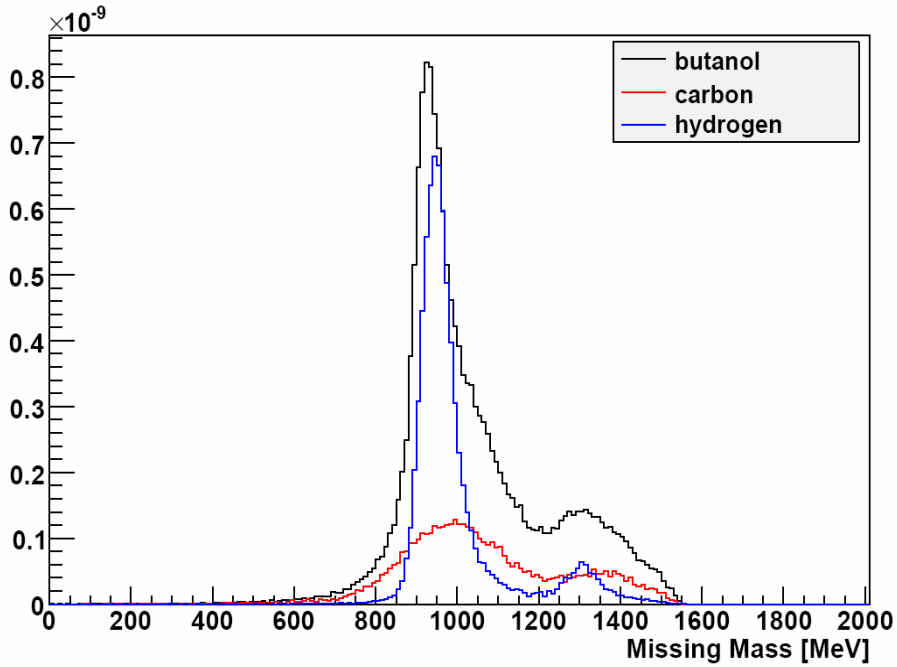
Future plans:

Extend energy range

Transversally polarized target in preparation

# Summary

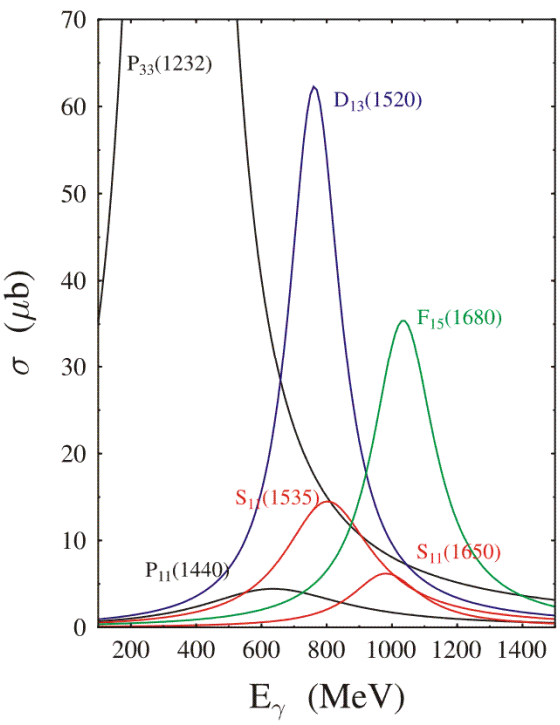
- First round of double polarization experiments with Crystal Barrel at ELSA
- Preliminary results for the double polarization observable G and E
- Aim: reach “complete” experiment
- Model independent partial wave analysis
- Will shed new light on the nucleon excitation spectrum


×10^-9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Missing Mass [MeV]
butanol
carbon
hydrogen

# Nucleon Resonances

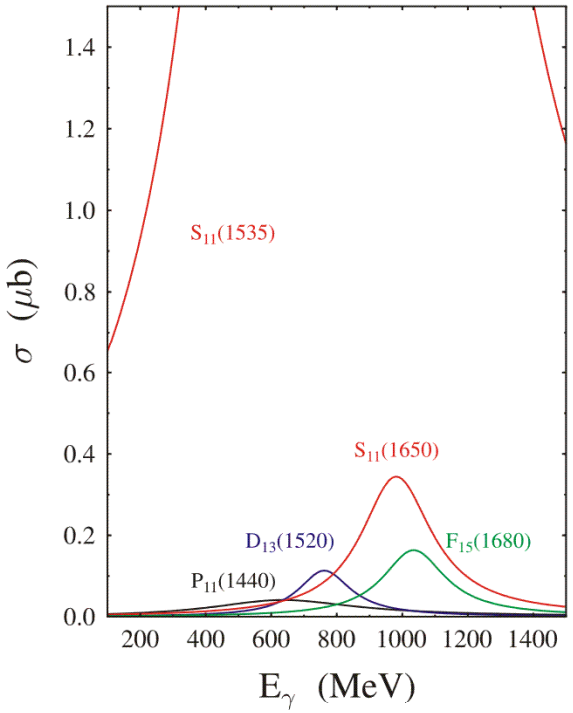
## Pion-Production

$$\gamma + N \rightarrow N^* \rightarrow N + \pi$$



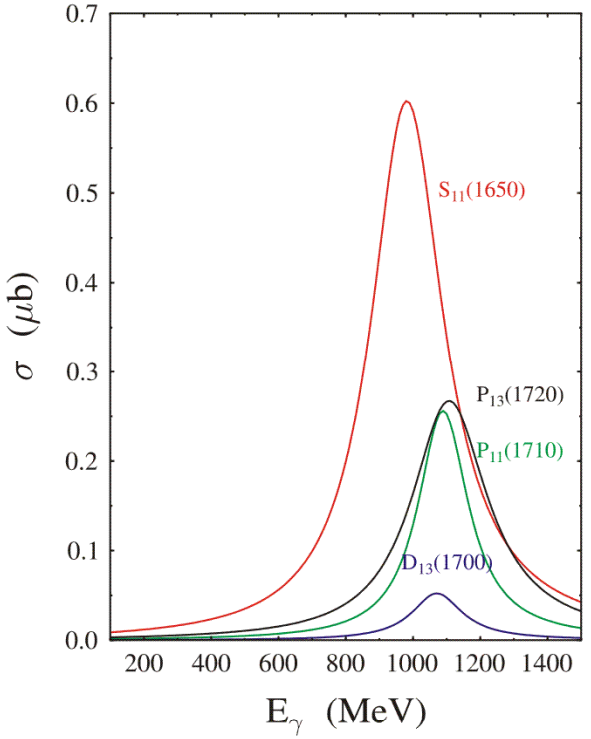

## Eta-Production

$$\gamma + N \rightarrow N^* \rightarrow N + \eta$$




## Kaon-Production

$$\gamma + N \rightarrow N^* \rightarrow K^+ + \Lambda$$




Problem : overlapping resonances
Polarization observable

ELSA and MAMI : polarized photons and polarized targets