New Results in Meson-Photoproduction at ELSA

R. Beck, University Bonn

MENU 2010, 31.5-4.6, 2010, Williamsburg

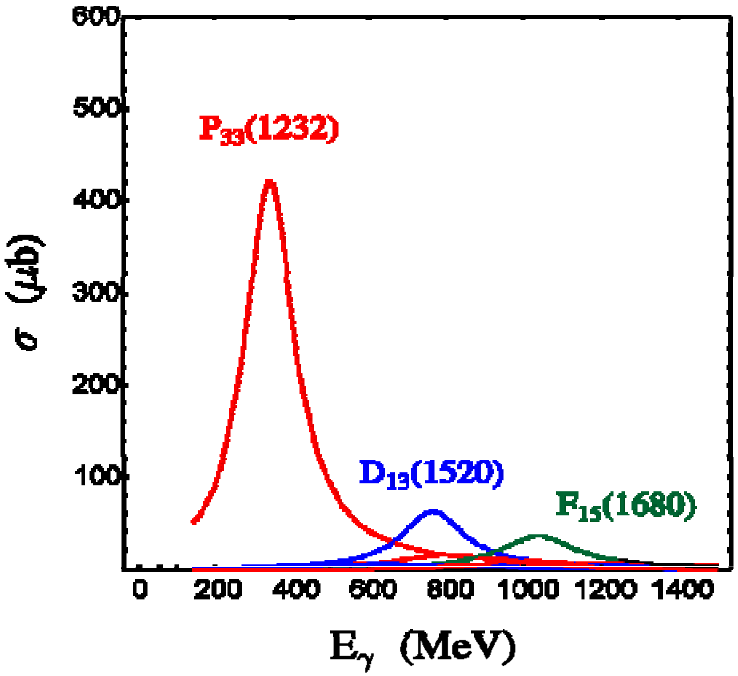
- Motivation
- Crystal Barrel experiment
- Recent Results
- Summary and Outlook

supported by the DFG within the SFB/TR16

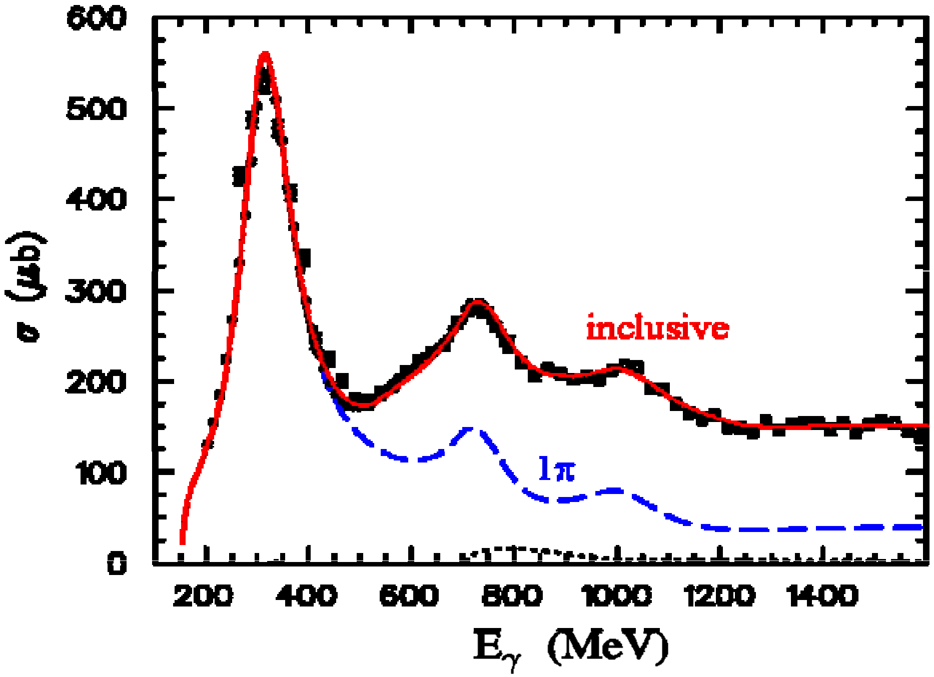
Introduction

- 3.2 GeV photon beam at ELSA used to study meson photoproduction
  - study the nucleon resonance spectrum

Breit Wigner Resonances



Total Photon Absorption Cross Section



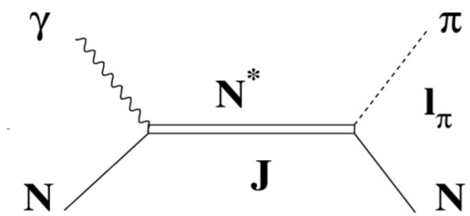
Spectroscopic Notation

$$X_{2I\ 2J}$$

Isospin

Spin

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

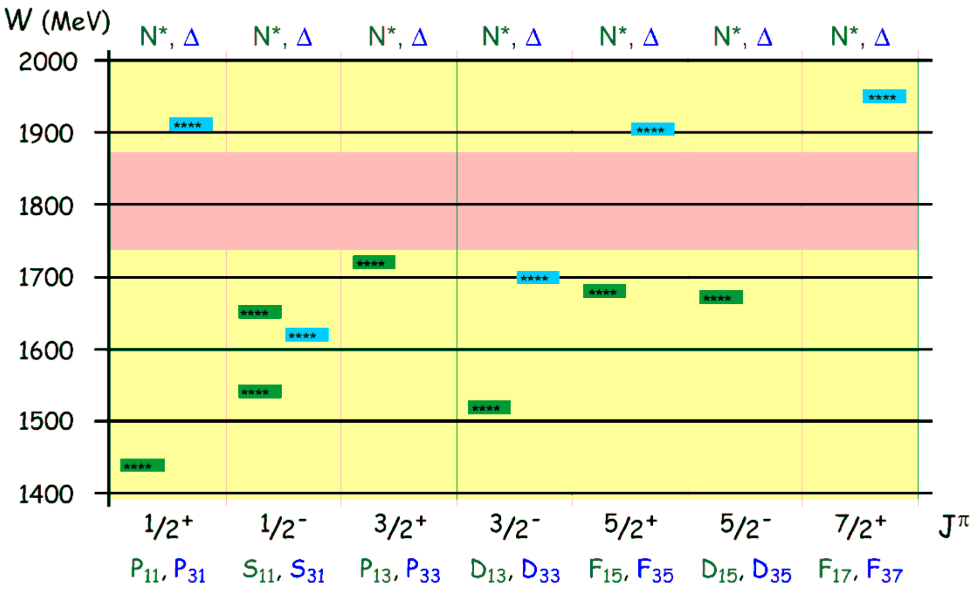


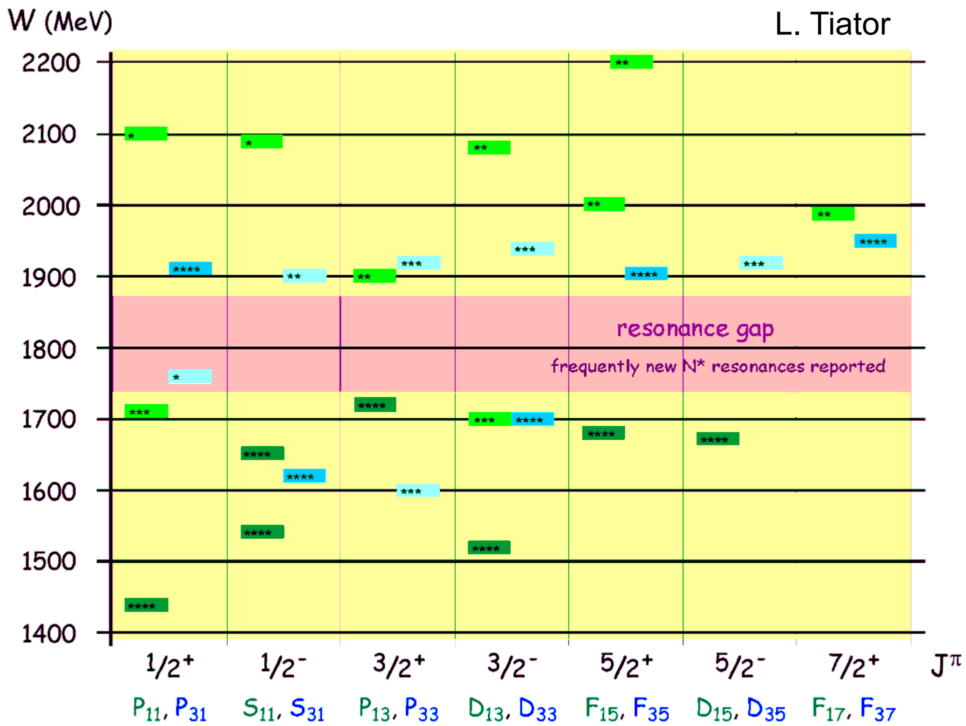
Introduction

PDG 2010: Status on nucleon resonances

only 7 N* and 5 Δ*

established in the region 1400 MeV < W < 2000 MeV





- Energy pattern for the dominant states

  Constituent Quark Models

  Dynamical Models

  Lattice QCD

- Various nucleon models predict many more states

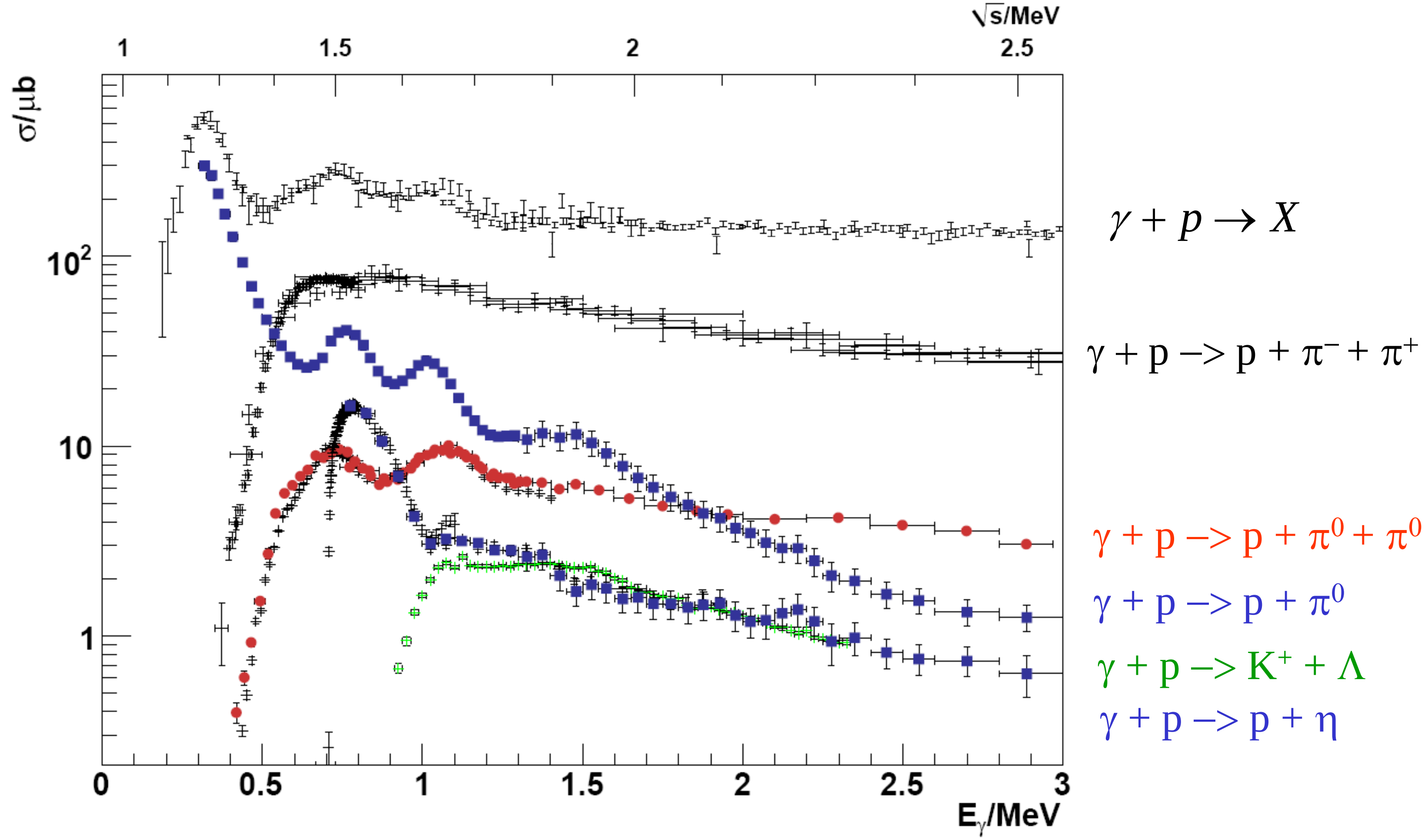
  weak coupling to πN final state

  insufficient data base

Experimental program for N*

Common effort at ELSA, JLab and MAMI,

- Precision data for different final states ($p\pi^0$, $p\pi^0\pi^0$, $p\eta$, ...)
- Polarization experiments (beam, target and recoil)
  "complete experiment"



Complete Experiment

$$\vec{\gamma} + \vec{N} \rightarrow N + \pi$$

8 well chosen observable have to be measured to determine the production amplitudes (F_1,F_2,F_3 and F_4)

- π- threshold until $\Delta^+(1232)$- region

  additional constraints:

  (a) s- and p- wave approximation

  (b) Fermi- Watson theorem

$$\gamma + N \rightarrow N + \pi$$
$$\pi + N \rightarrow N + \pi$$

same I, J in the final state
→ same scattering phase δ_{IJ}

two observable sufficient for "complete experiment"

differential cross section : $d\sigma/d\Omega$

beam asymmetry : Σ

- above $\pi\pi$- threshold

  Fermi- Watson theorem not valid any more
  More observable needed to find unique partial wave solution

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	-	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	-	-	-	-

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

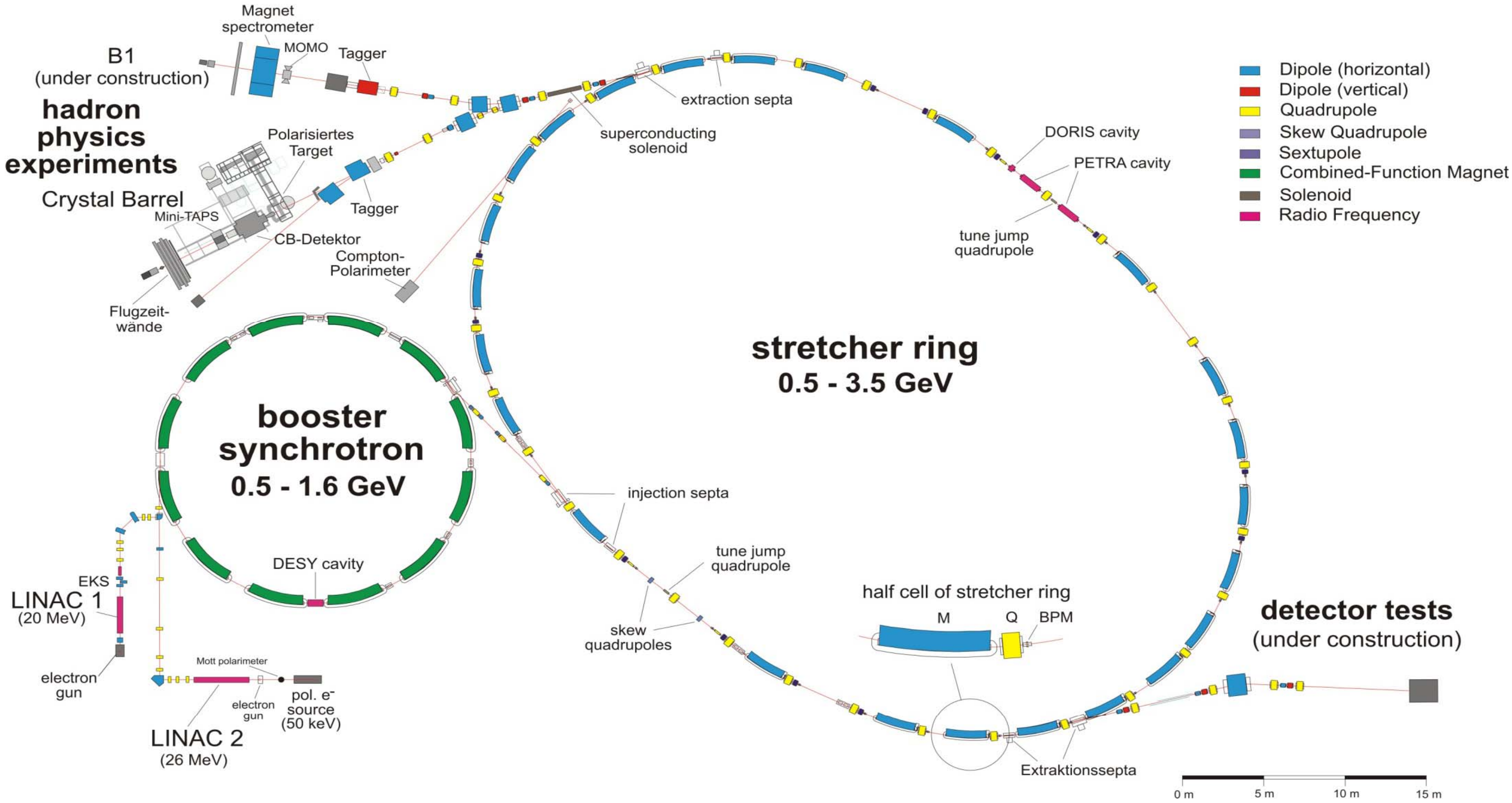
Recoil polarization: P

Double polarization: G

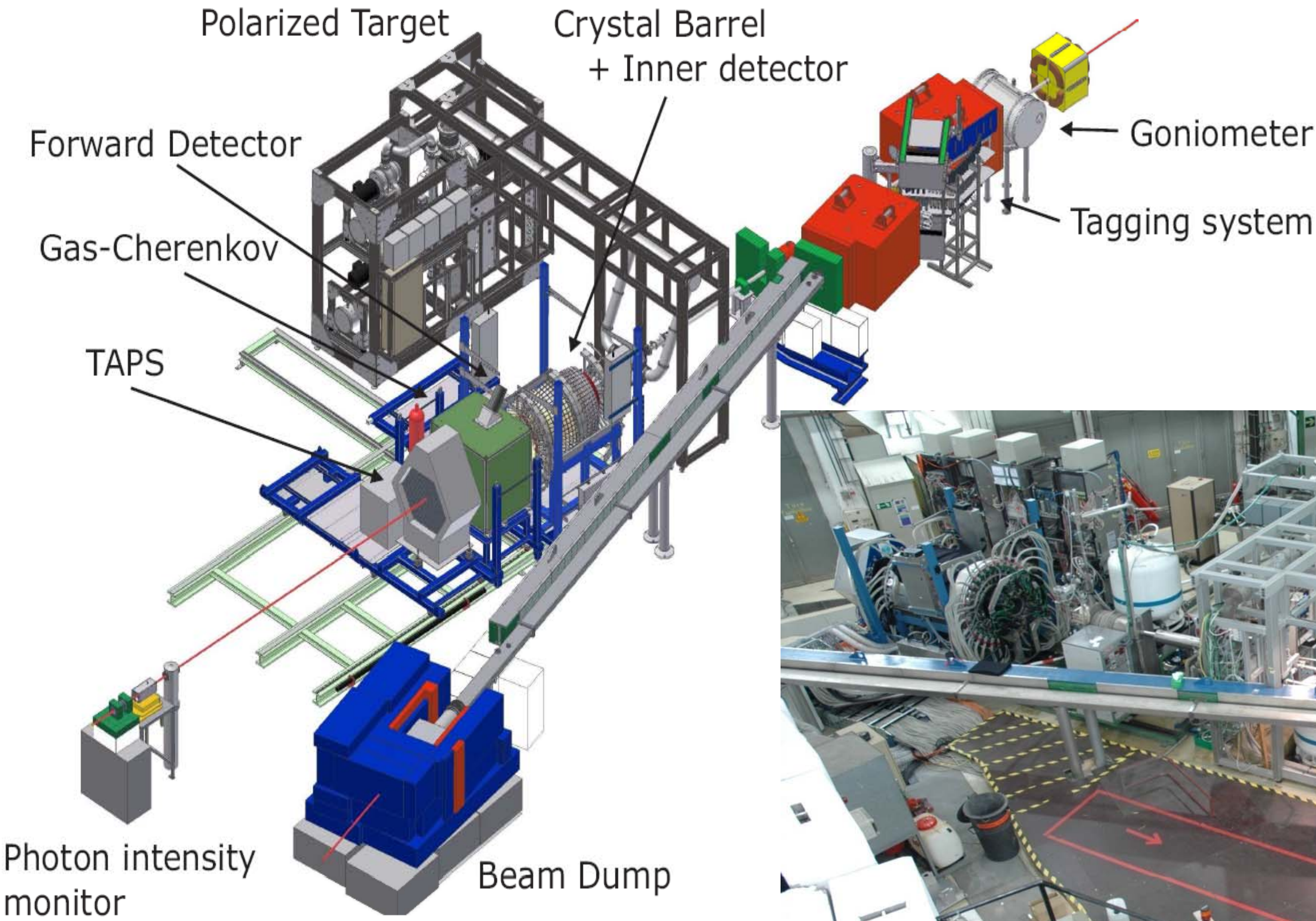
Sensitive to: $\mathrm{Im}(P_1 \cdot P_2)$

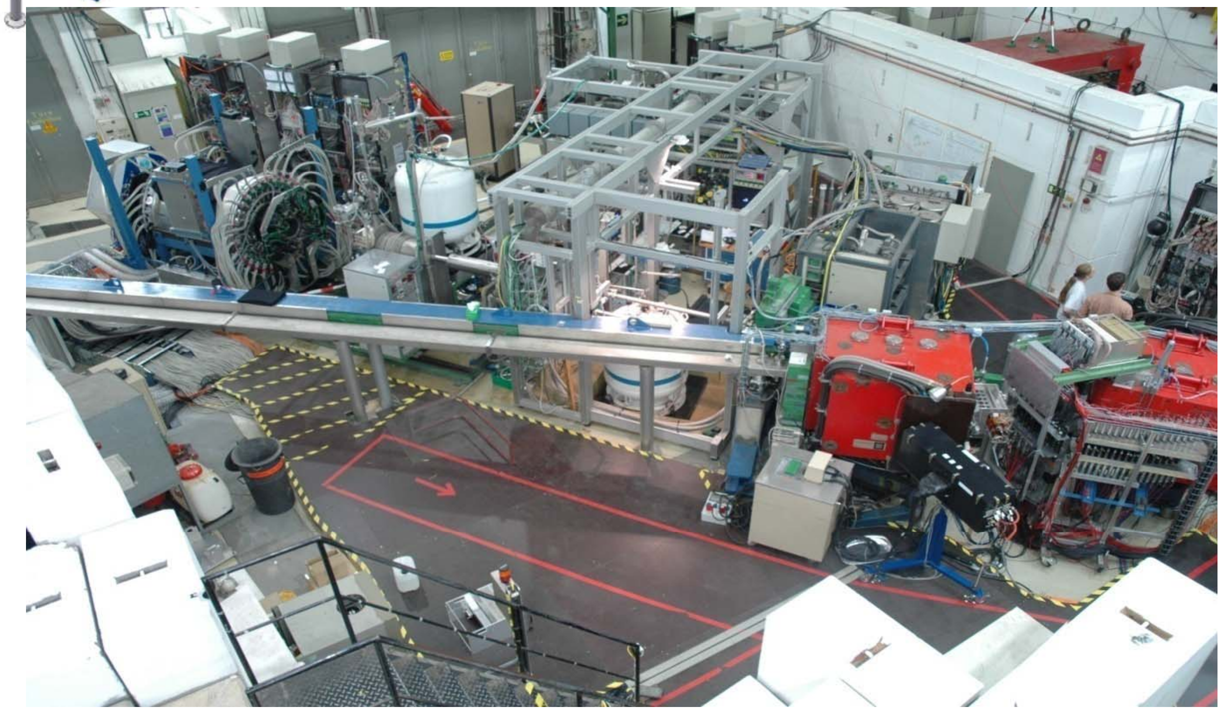
Crystal Barrel experiment at ELSA: polarized photons, polarized targets and 4π acceptance

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

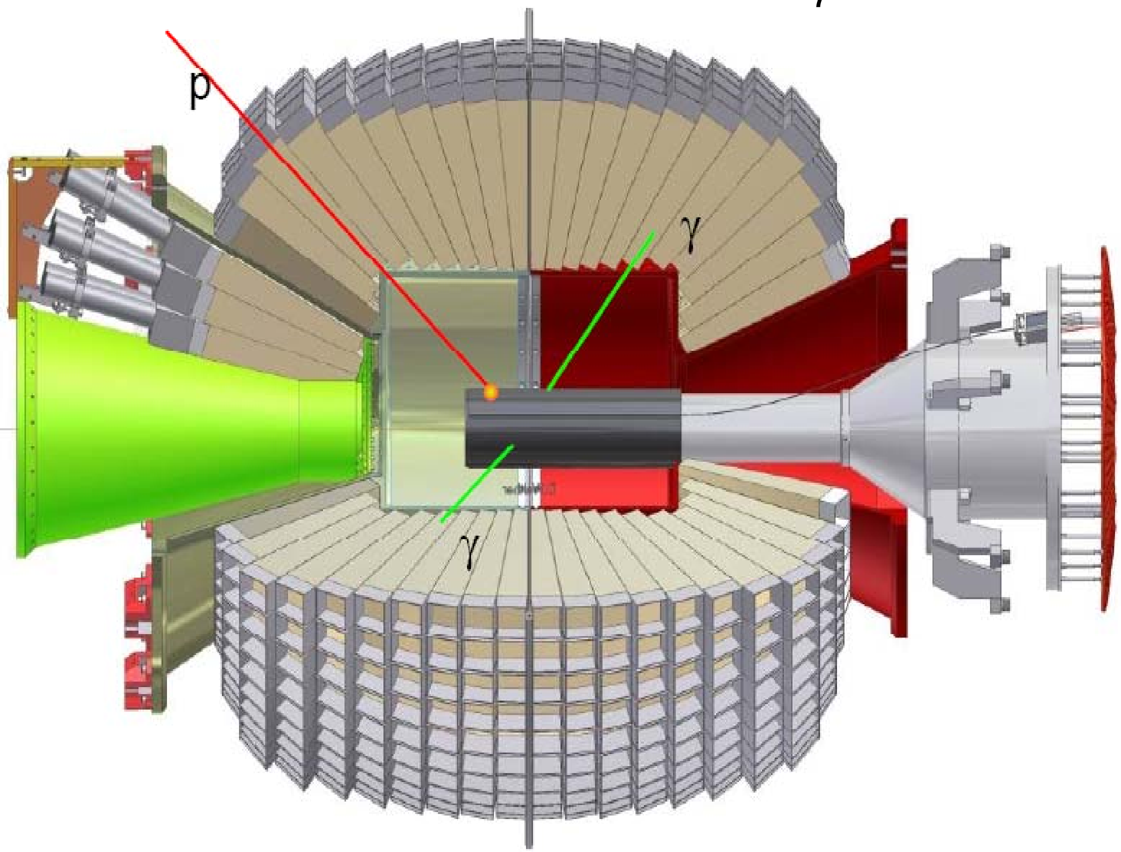
- forward detector (FWPlug)
  90 CsI crystals with PM's, 12^0-30^0

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

Close to 4π coverage

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

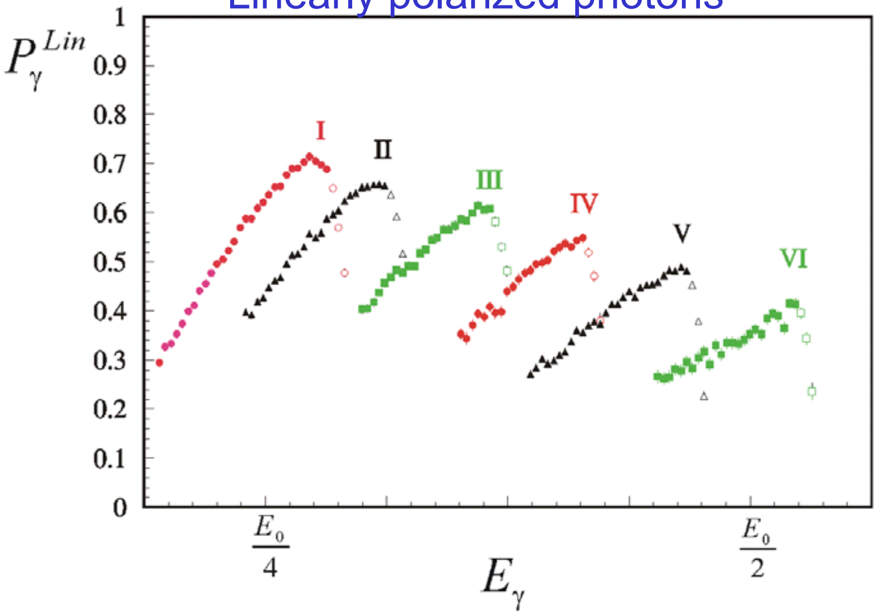
$\eta \to 3\pi^0$

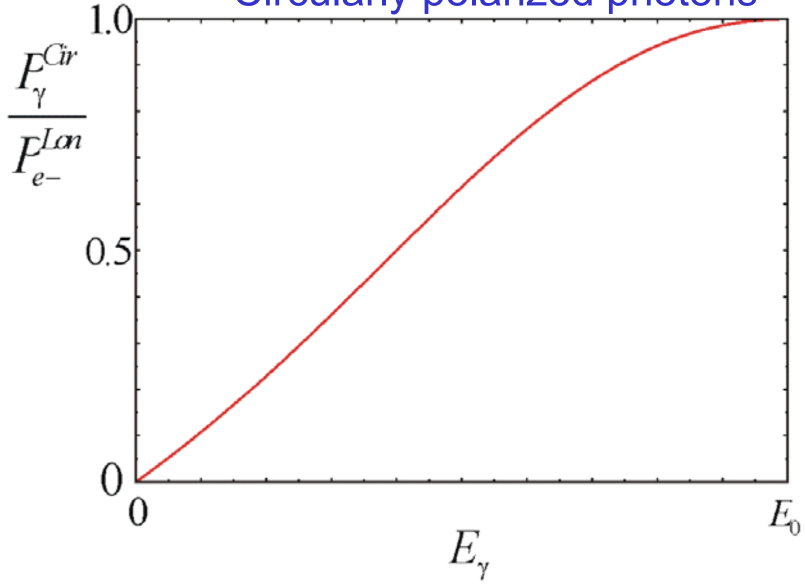


Polarized Photons

Linearly polarized photons:
- coherent bremsstrahlung
- diamond radiator

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





high polarization at
low photon energies

$p_\gamma^{Lin} = 70\%$

high polarization at
high photon energies

$p_\gamma^{Cir} = 65\%$

(H. Eberhard)

(S. Kammer)

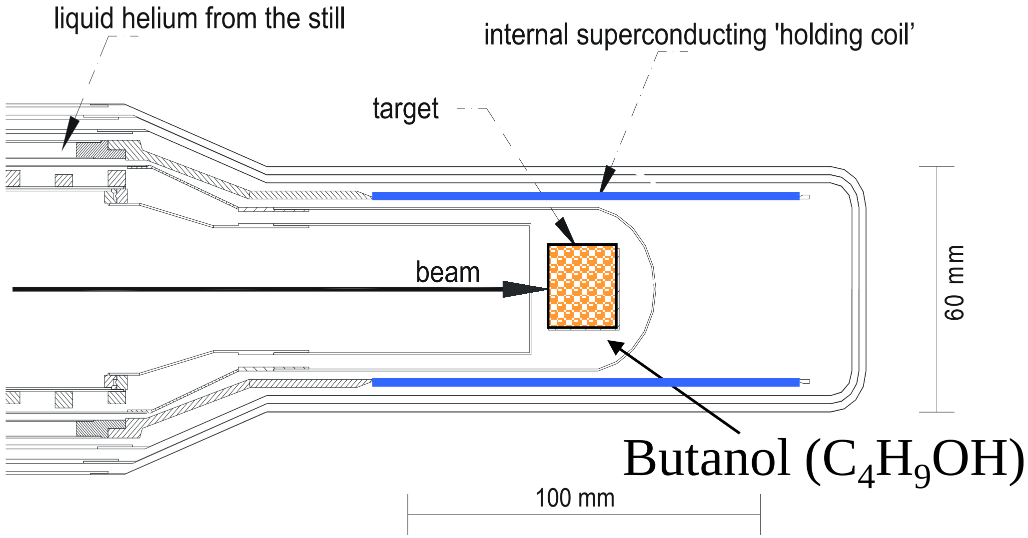
Polarized Target

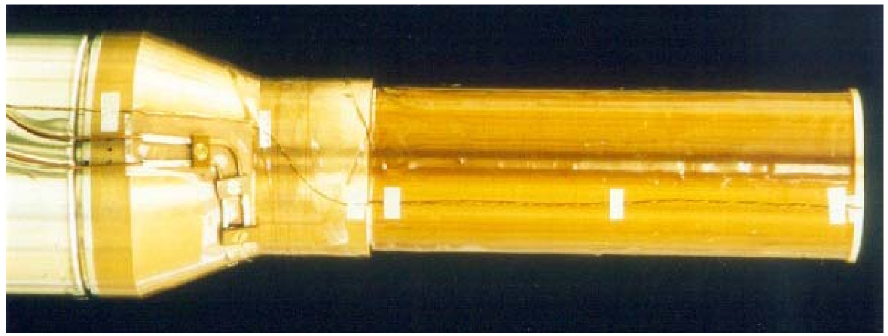
„Frozen Spin Target“

horizontal cryostat with integrated solenoid
to freeze up the spin

Target: Butanol (C_4H_9OH)

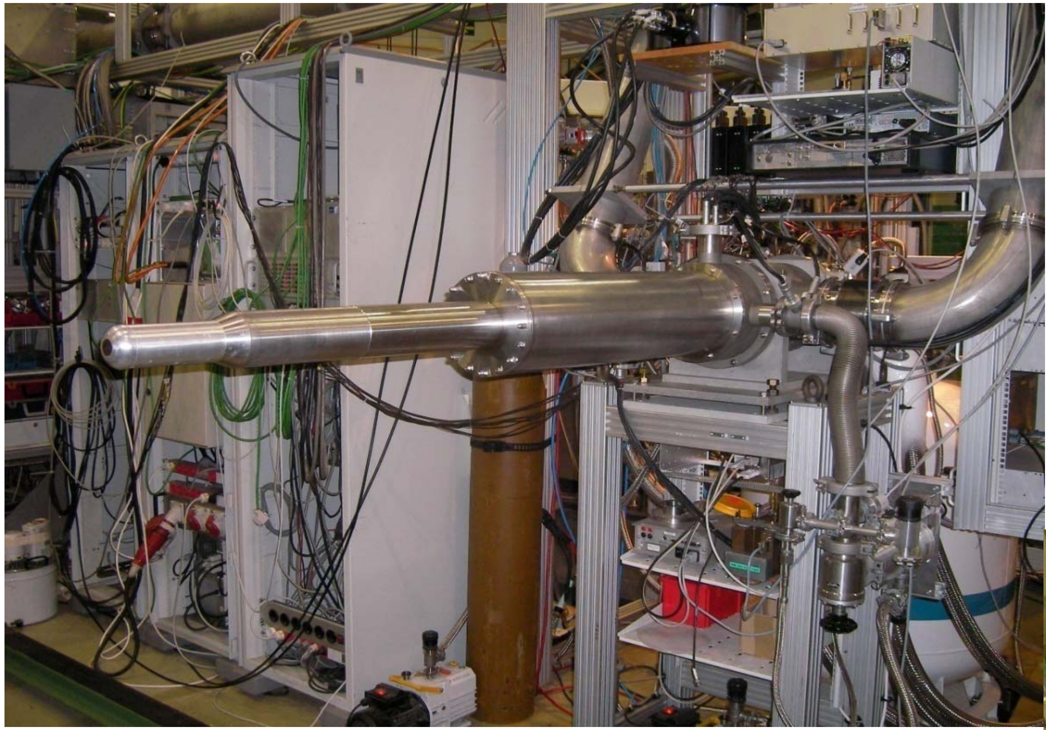
Polarization: DNP at high B-field (2.5 T)
„freeze“ up the spin (0.4 T)
relaxation time T~500h





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

Polarized Target

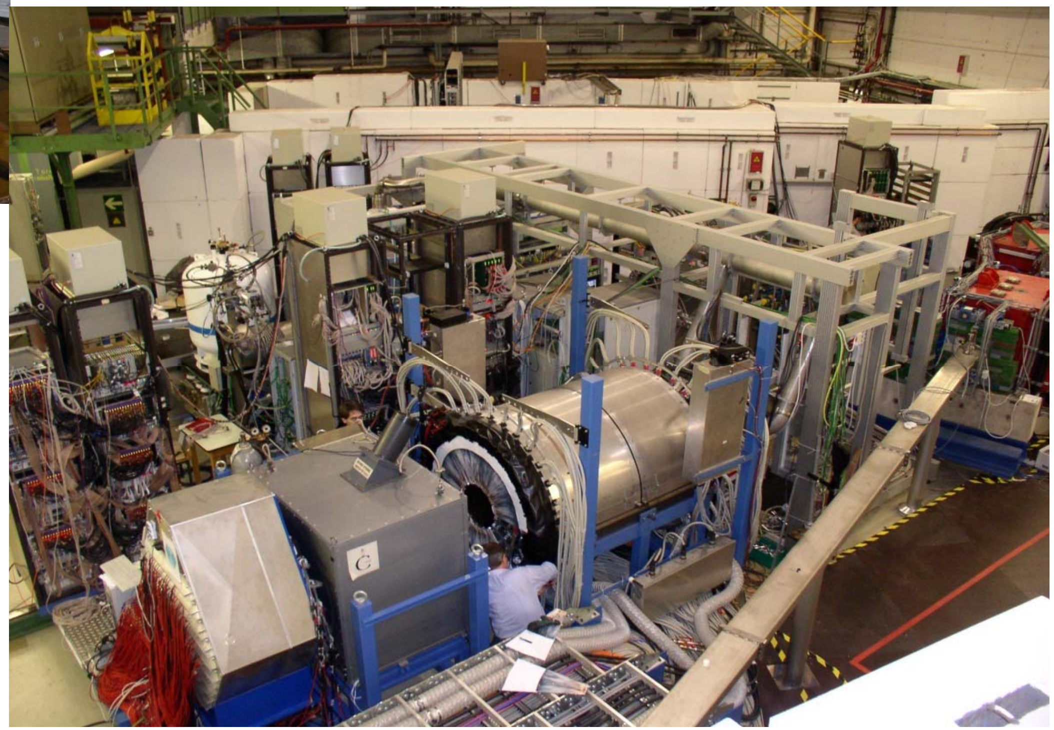


Running time over 2500 hours in year 2008
over 2200 hors in year 2009

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

horizontal cryostat
in experimental area

data taking →



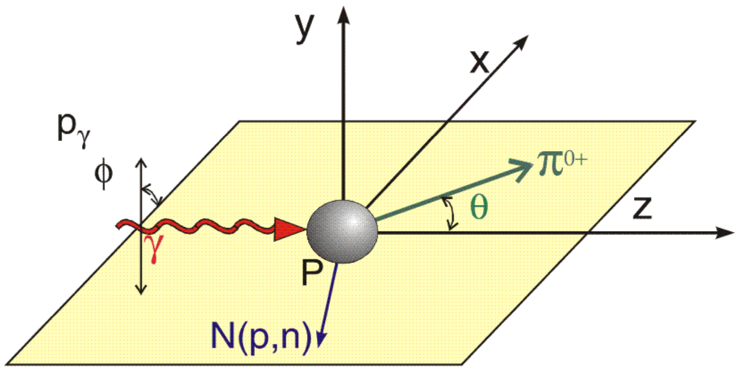
Polarization Observables

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

Linearly polarized photons: p_γ^{Lin}

Circularly polarized photons: p_γ^{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 preliminary results for *G* and *E*

Crystal Barrel/TAPS Results

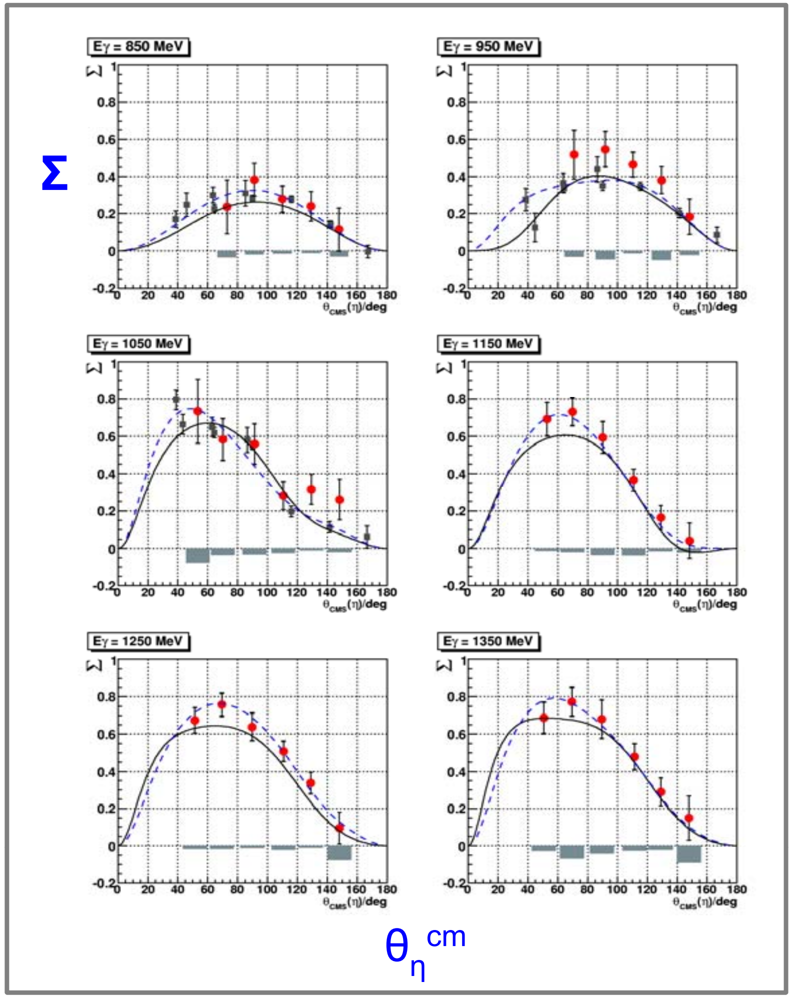
Beam asymmetry: Σ

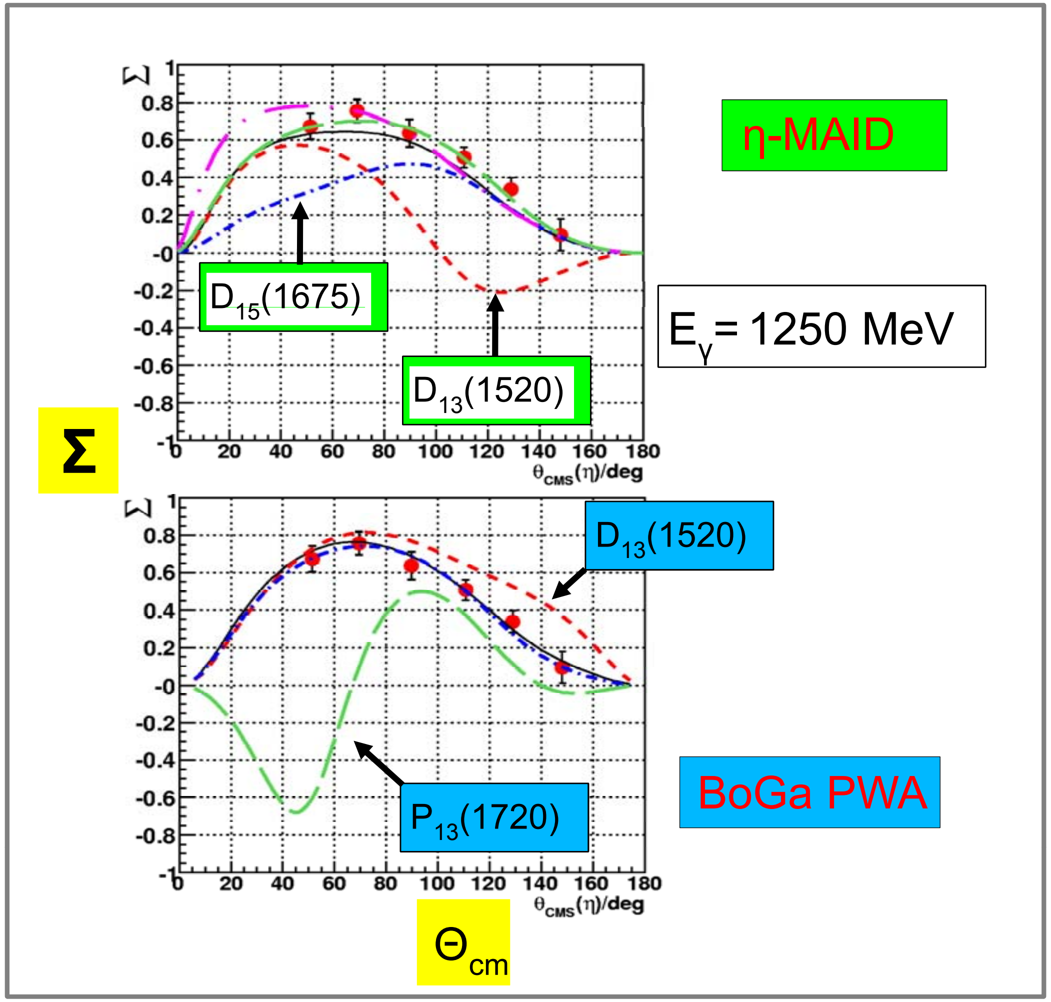
$\vec{\gamma} + p \rightarrow p + \eta$

Higher sensitivity because of interference between different resonance contributions

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

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



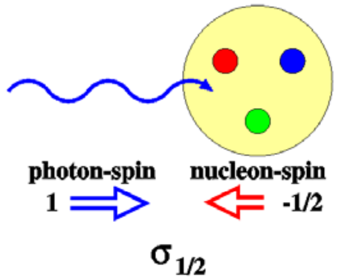


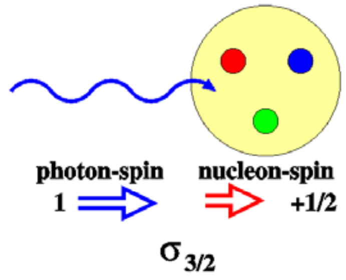
Helicity dependent total cross section

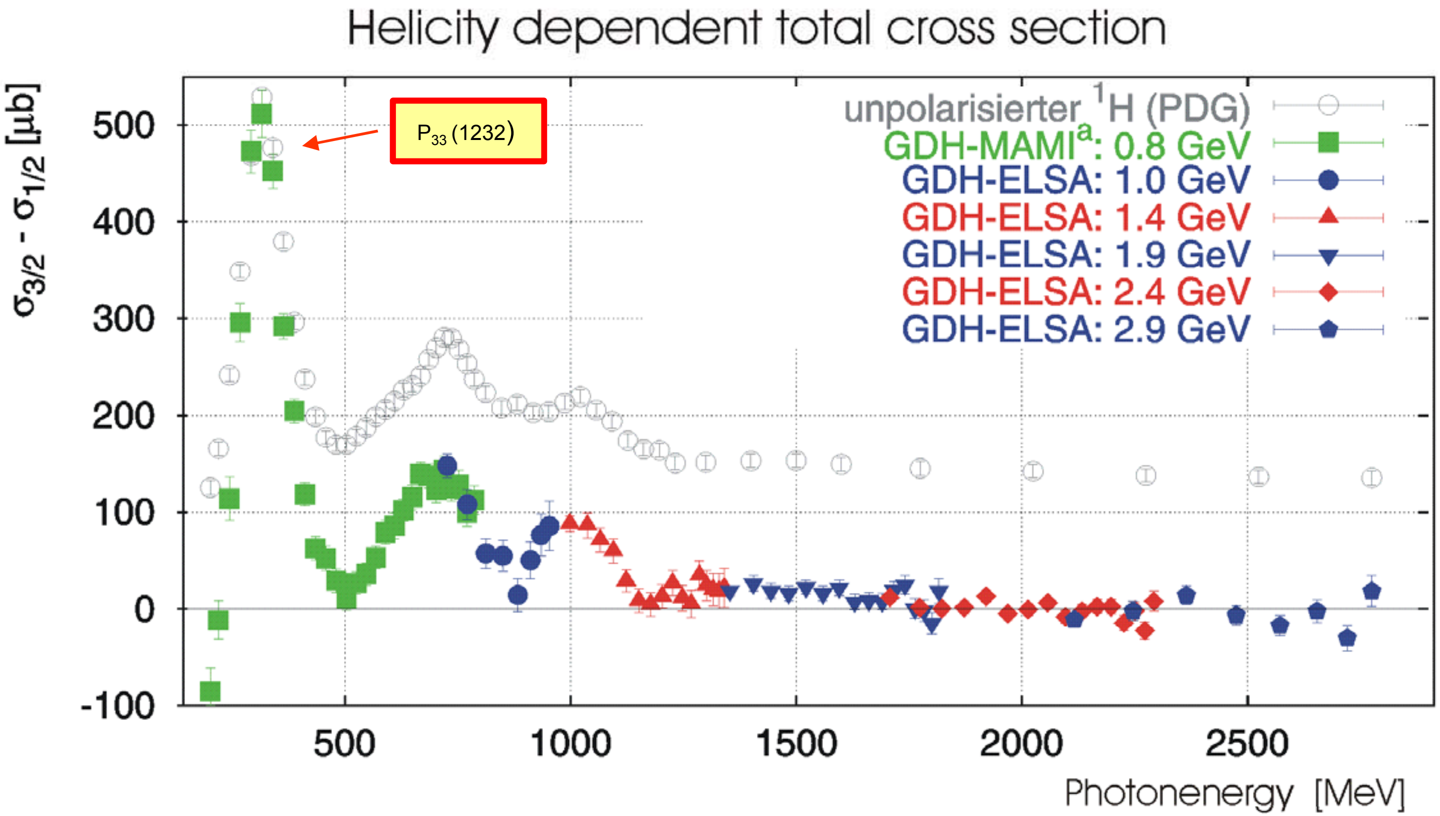
reaction: $\vec{\gamma} + \vec{p} \rightarrow X$

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

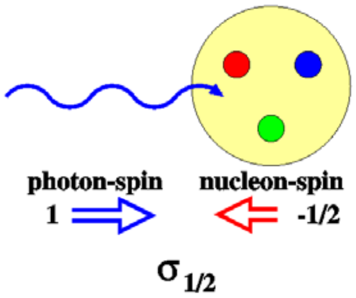
Helicity dependent cross section

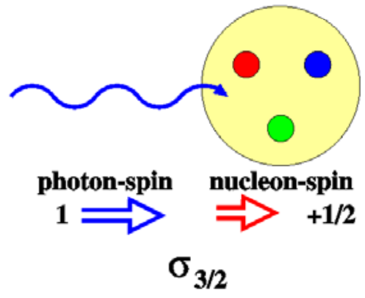
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

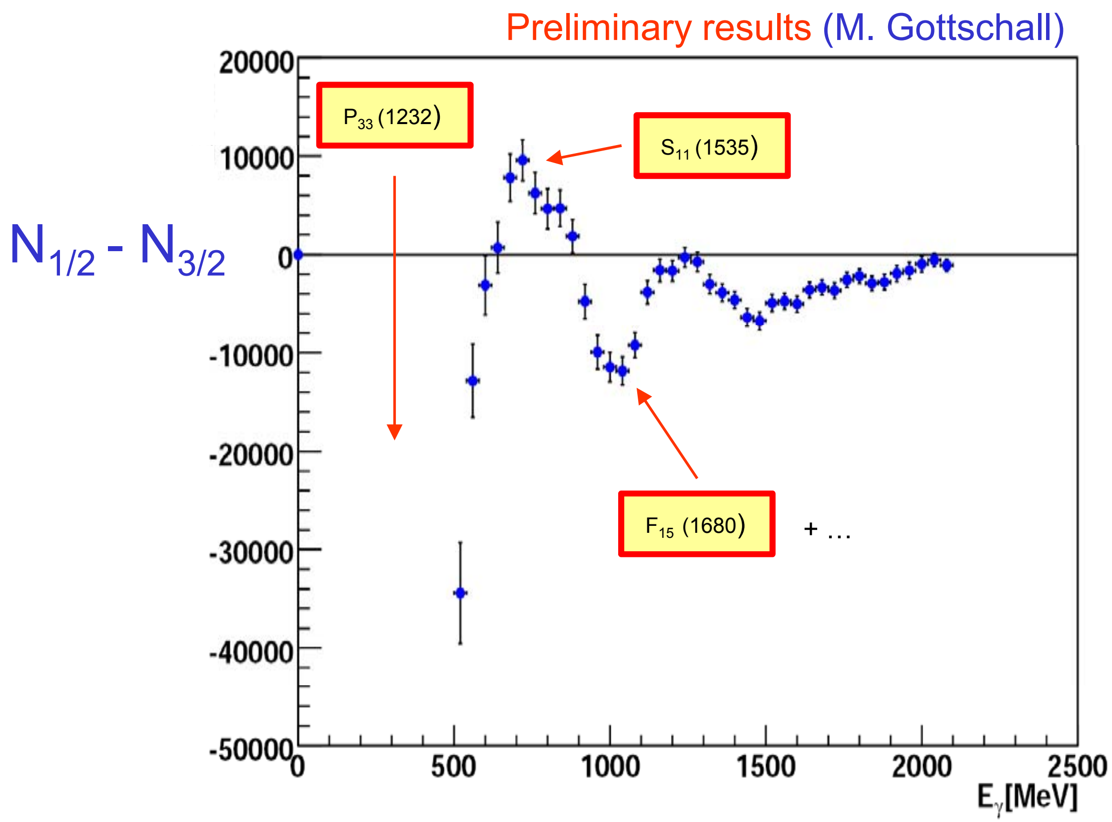
circularly polarized photons

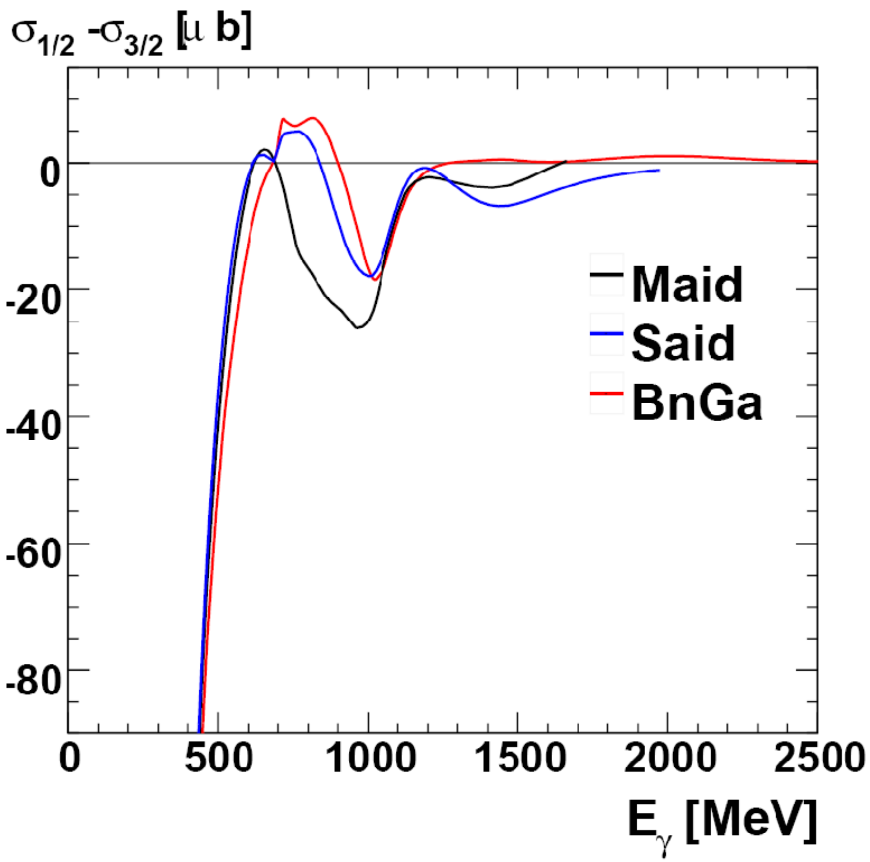
longitudinally polarized proton

count rate difference
preliminary acceptance correction









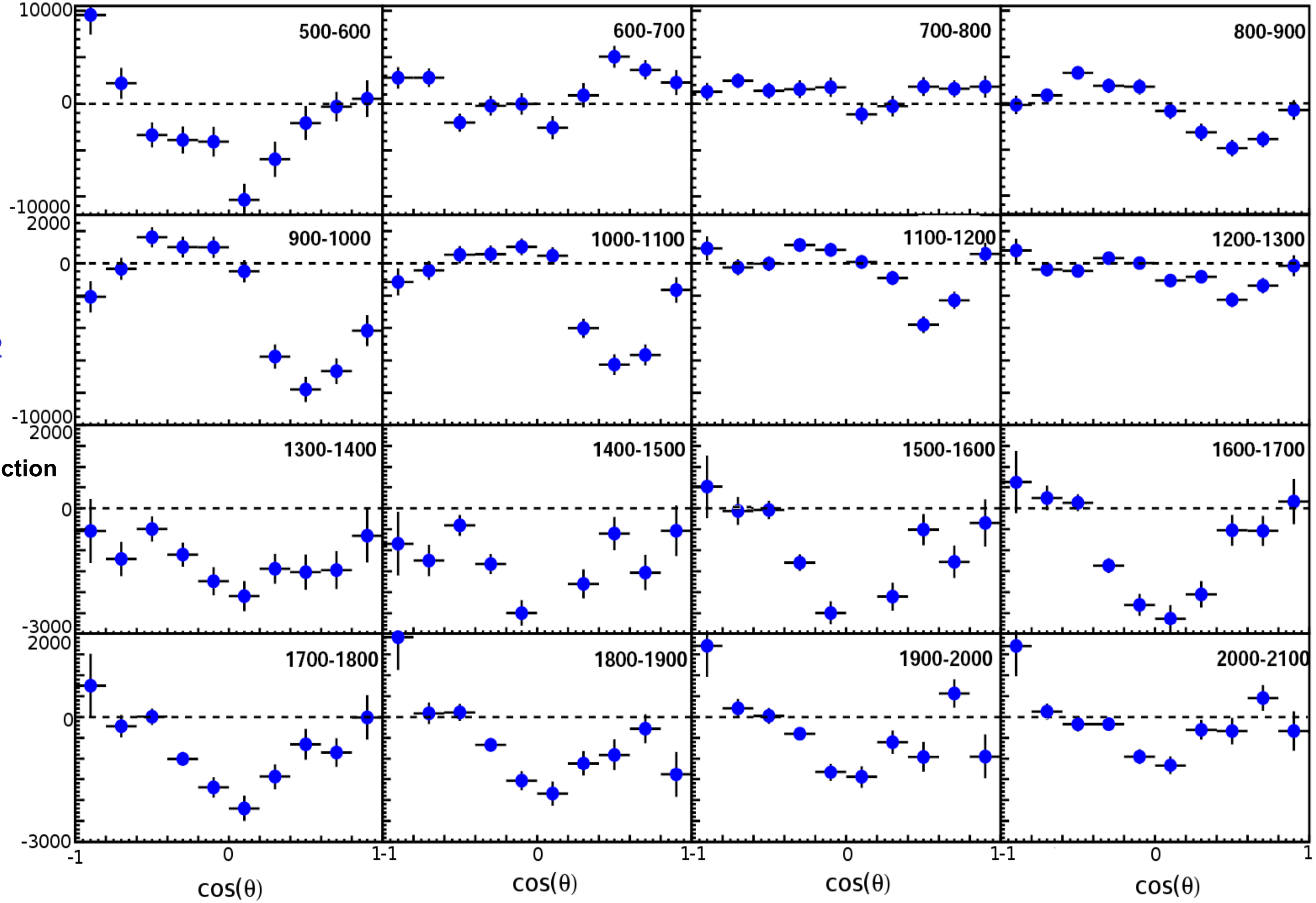
Helicity dependent cross section

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

Preliminary results (M. Gottschall)

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

count rate difference
with acceptance correction

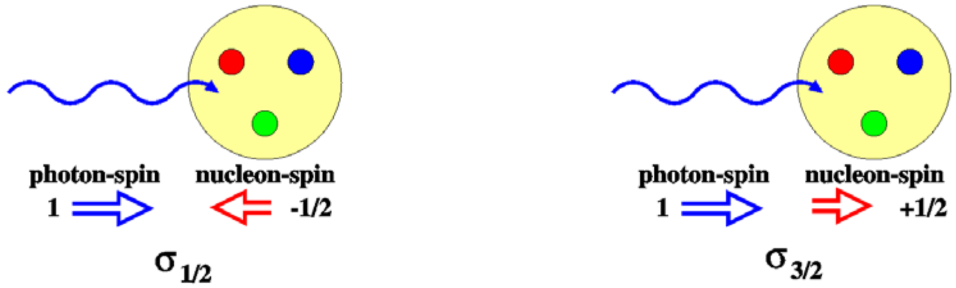


Helicity dependent cross section

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

circularly polarized photons

longitudinally polarized proton



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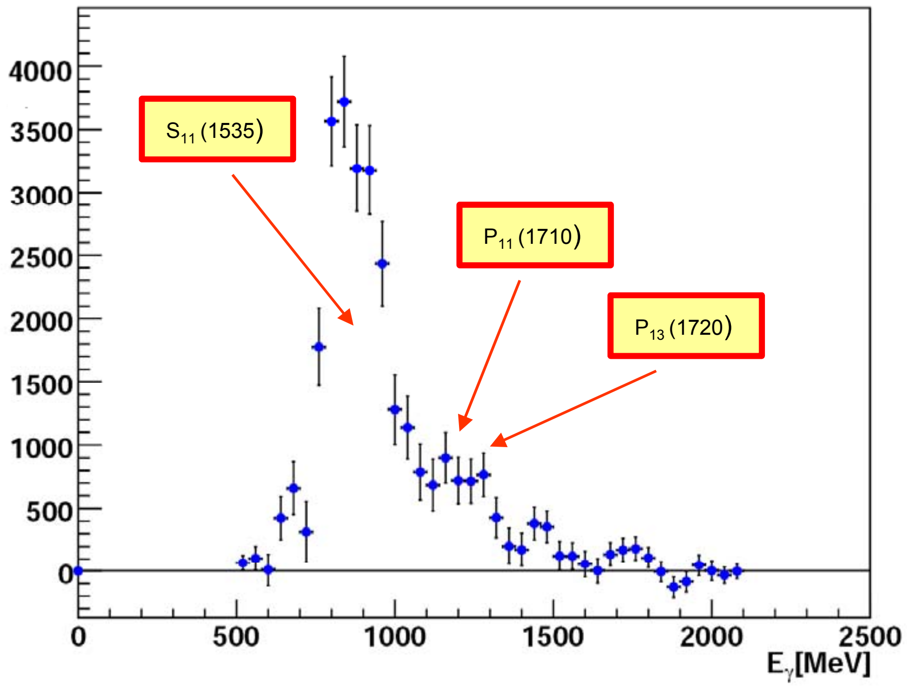

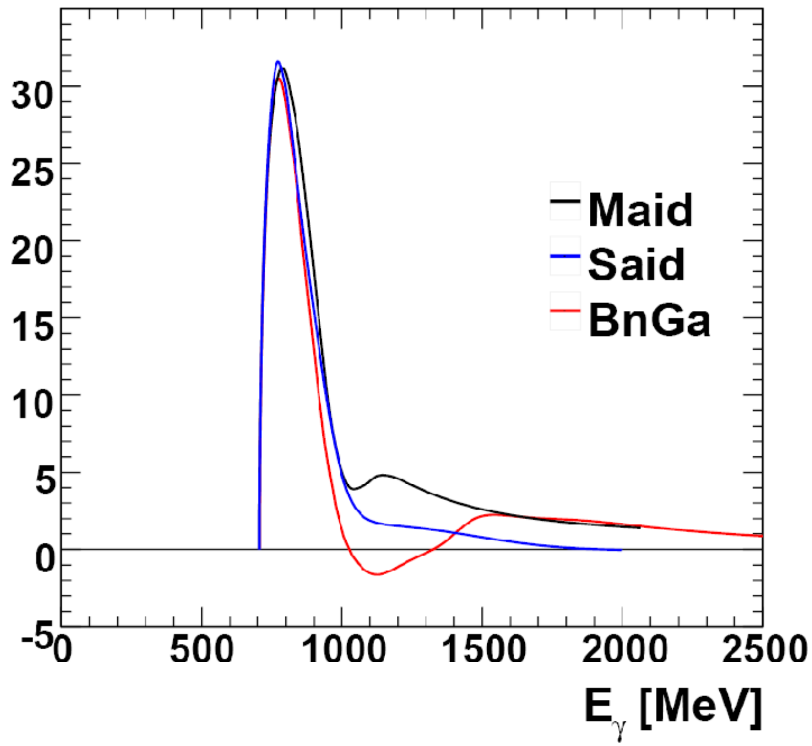

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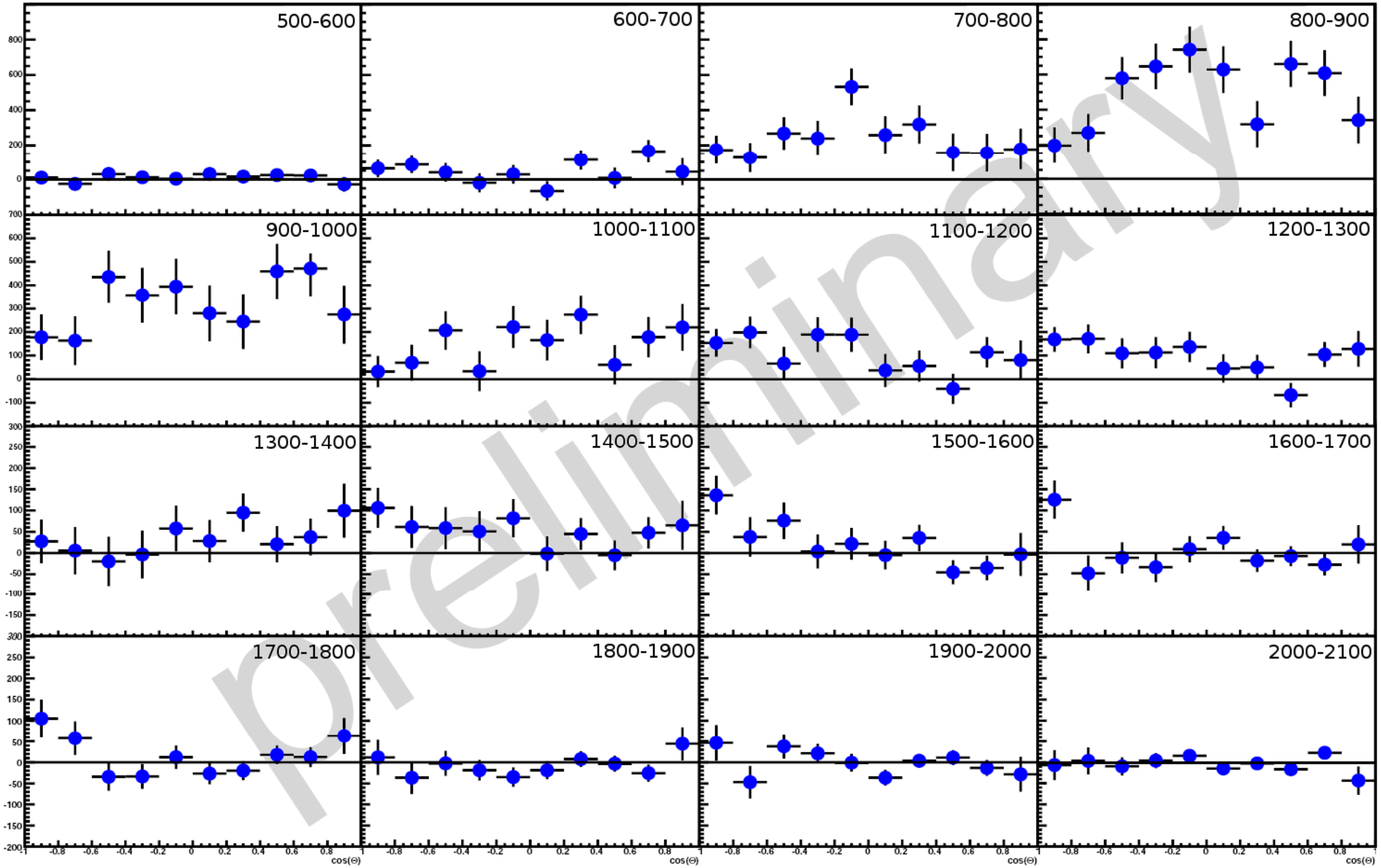

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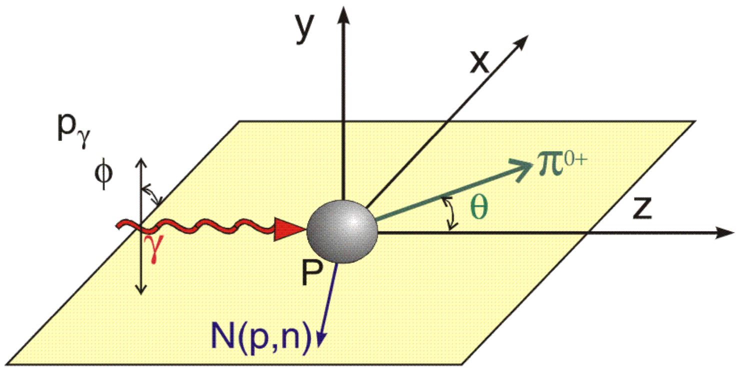


$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta)\left(1 - p_\gamma^{Lin}\Sigma\cdot\cos(2\phi) - p_\gamma^{Lin}\,p_z\,G\cdot\sin(2\phi) + p_\gamma^{Cir}\,p_z\,E\right)$$

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)

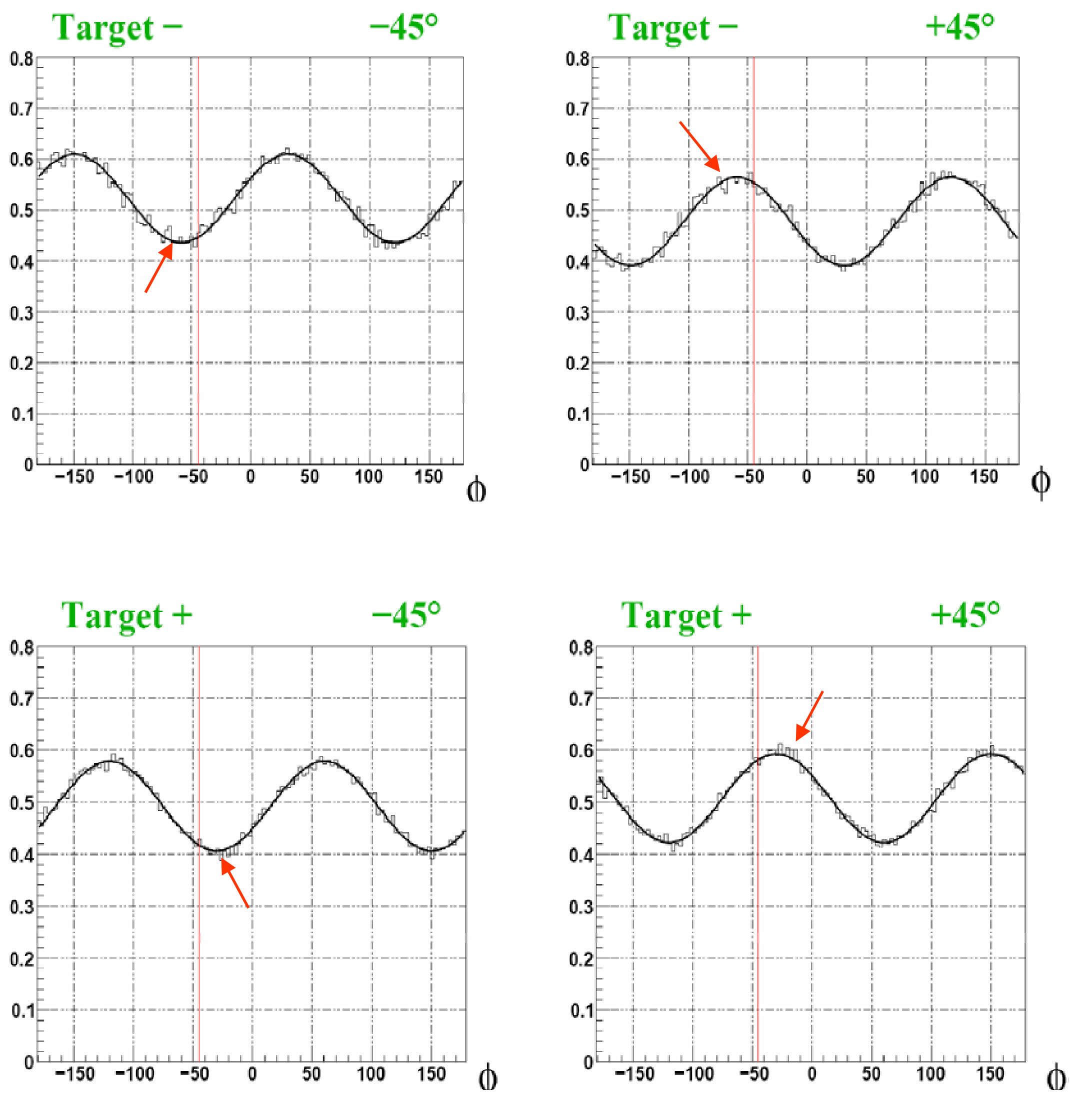
Double Polarization Experiment for G

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

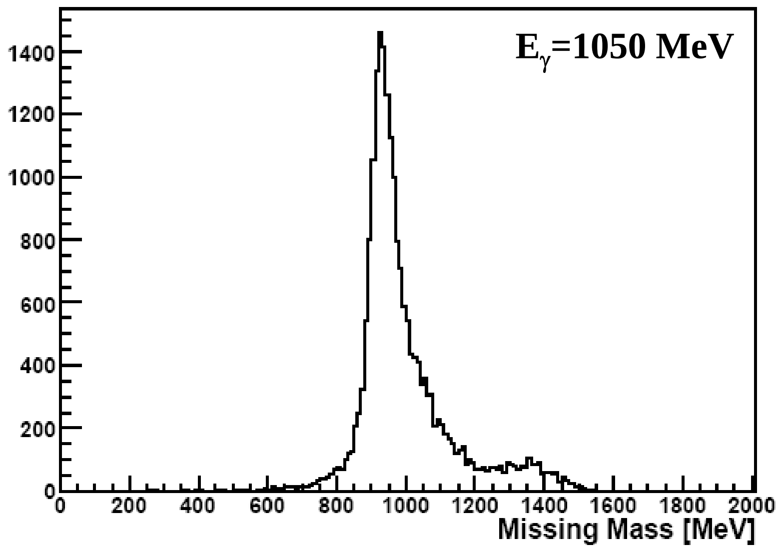
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

linearly polarized photons
longitudinally polarized proton

Clear effect from G observed



G-Asymmetry for $p\pi^0$



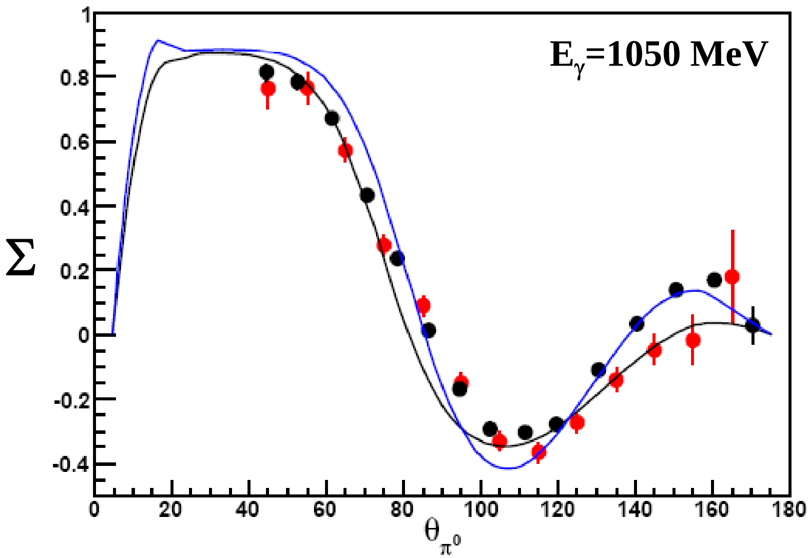
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

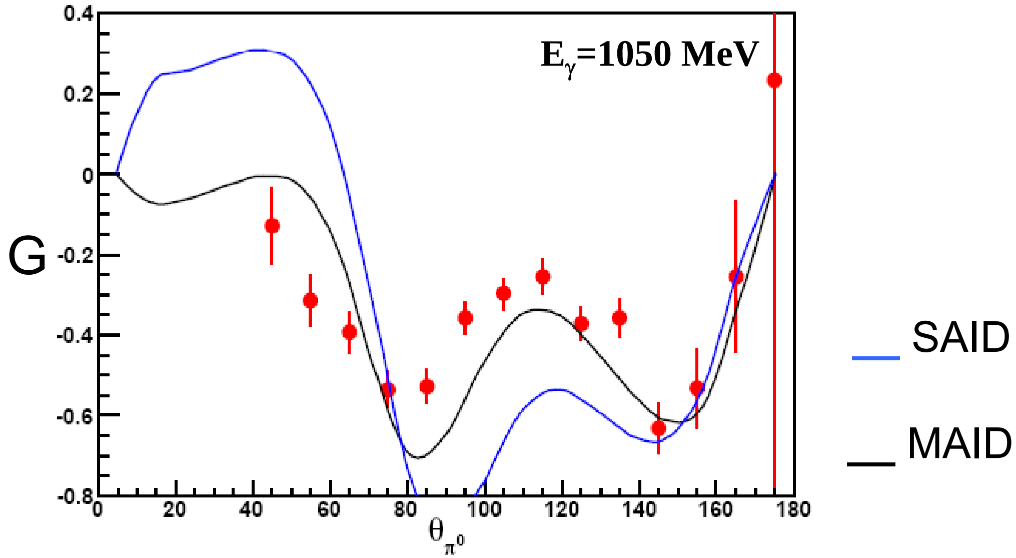
missing mass cut

fit to the ϕ-distribution

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

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



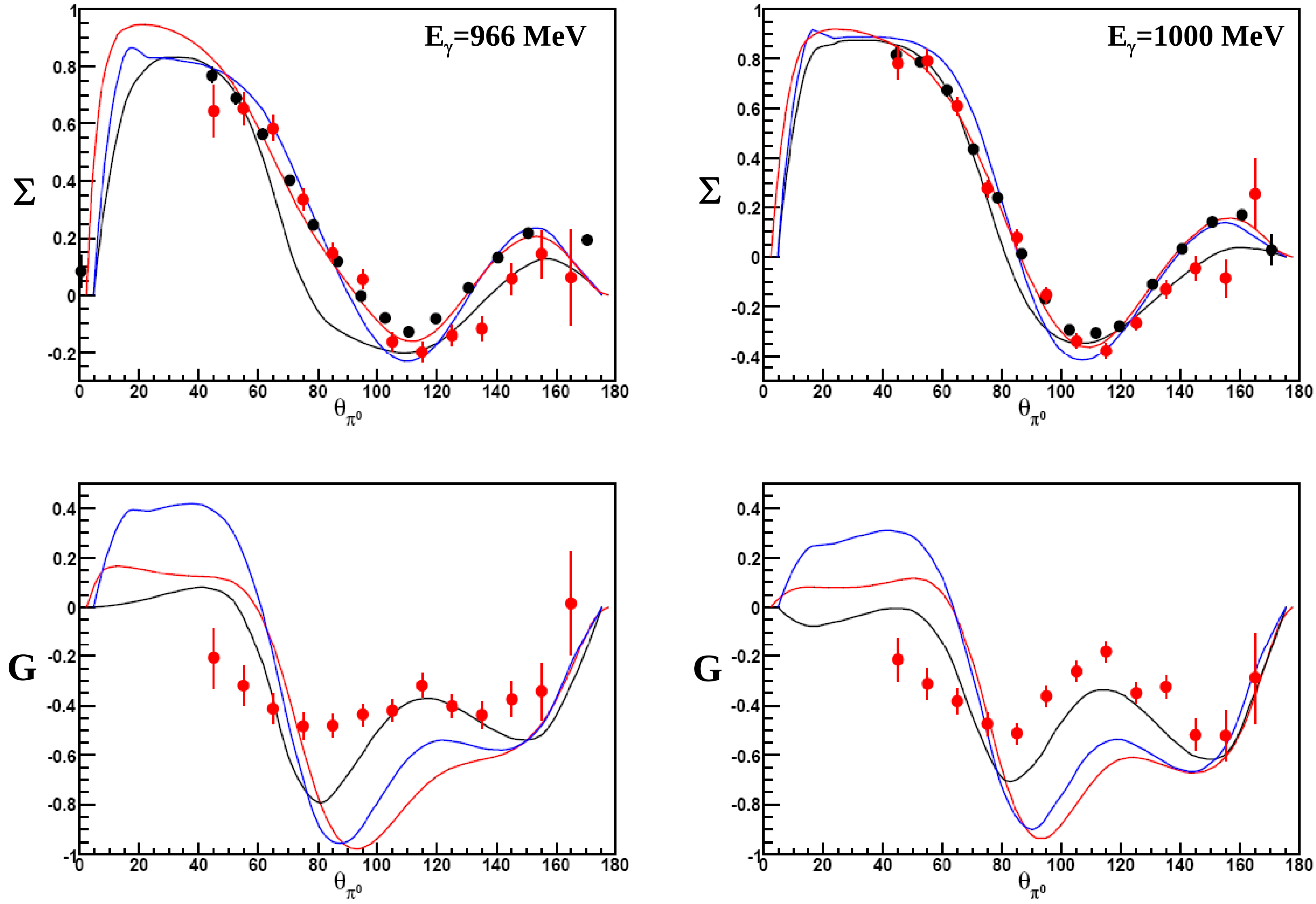


Asymmetries for $p\pi^0$

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

linearly polarized photons

longitudinally polarized proton



● Preliminary results (A. Thiel)

● GRAAL data

prediction partial wave analysis

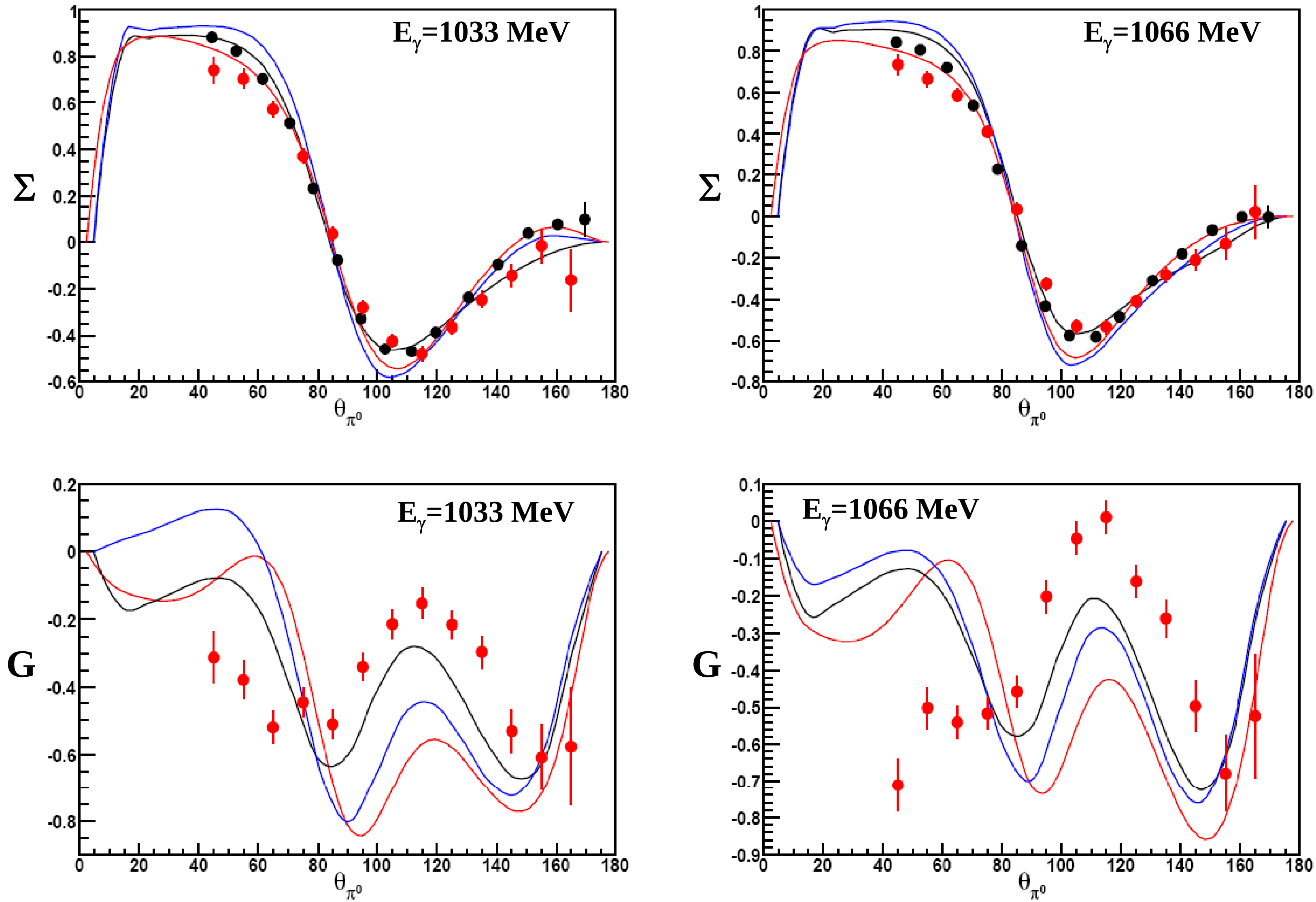
BoGa

SAID

MAID

Asymmetries for $p\pi^0$

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



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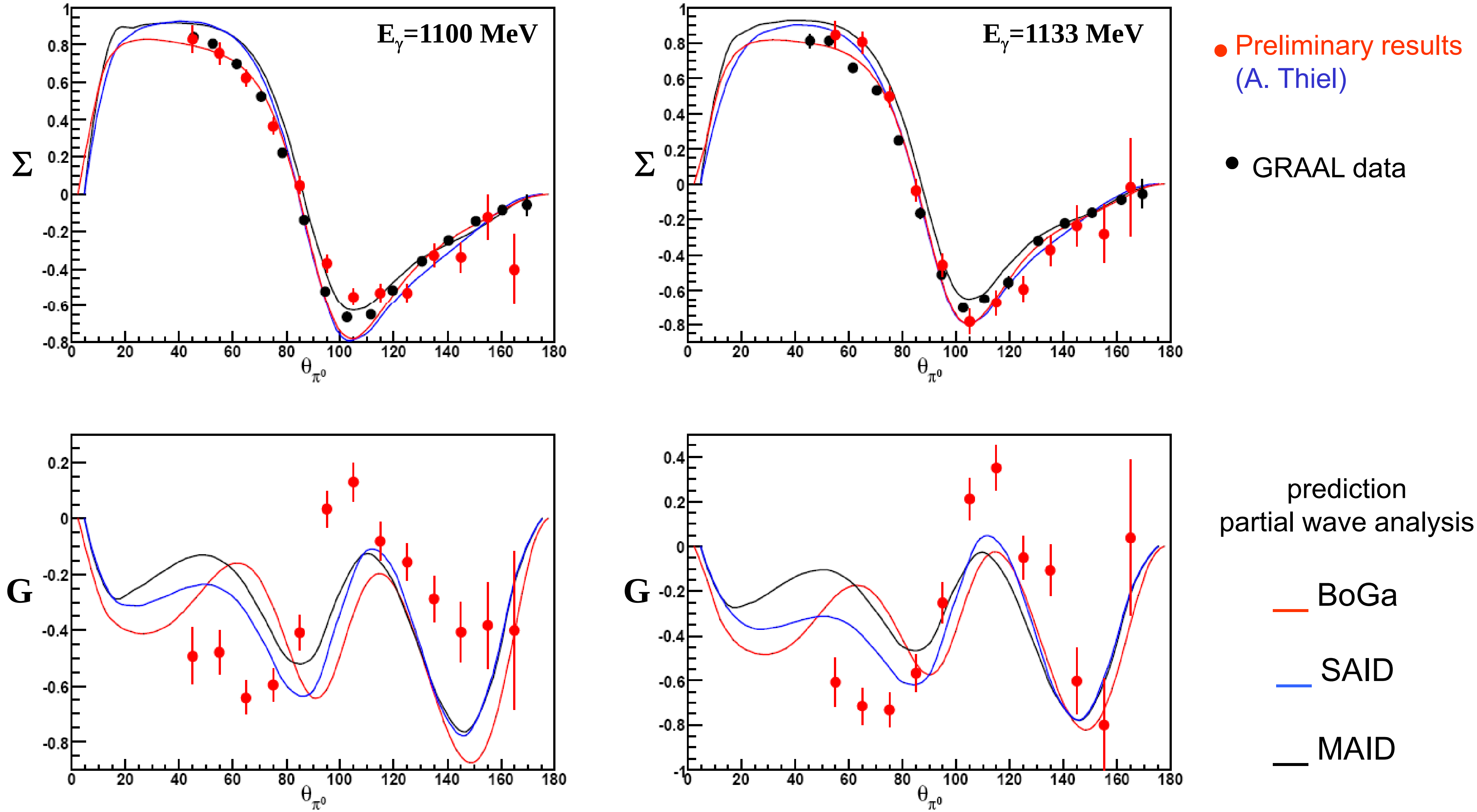
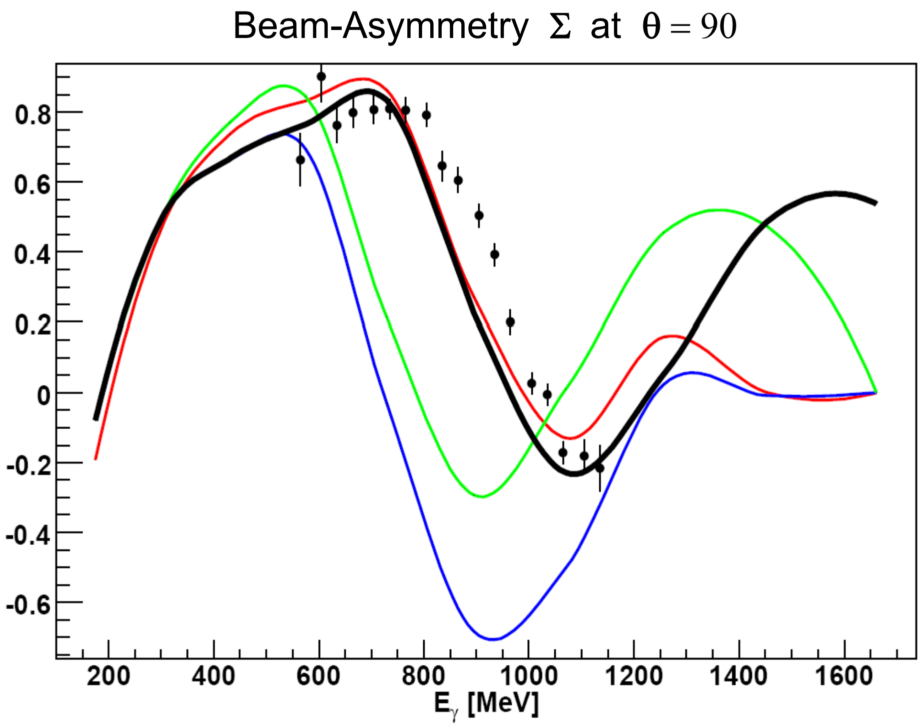


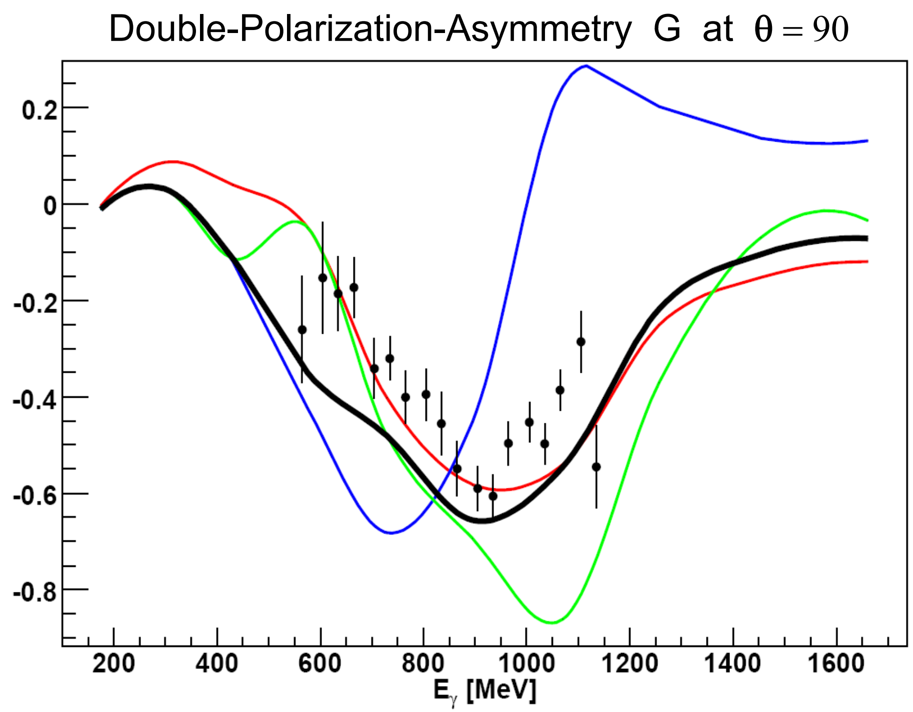
Energy dependence



without P_{11} (1440)

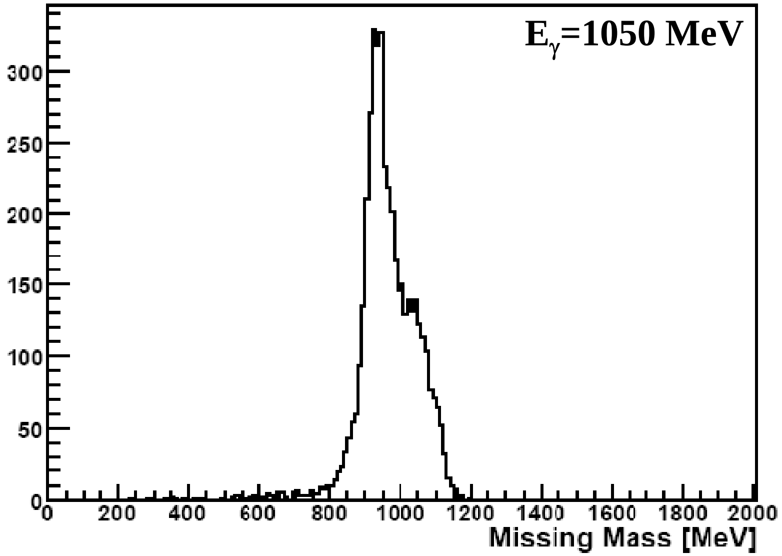
without D_{13} (1520)

without F_{15} (1680)



Preliminary results
(A. Thiel)

Asymmetries for pη

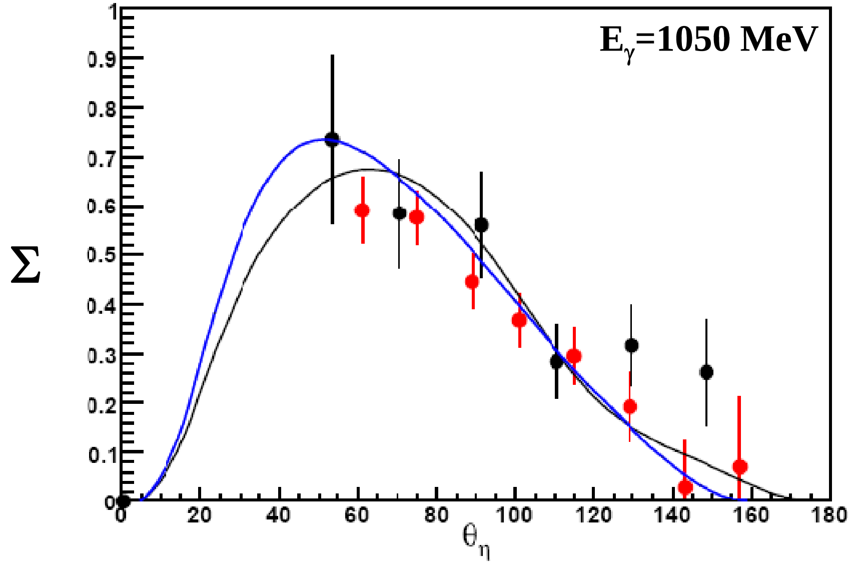


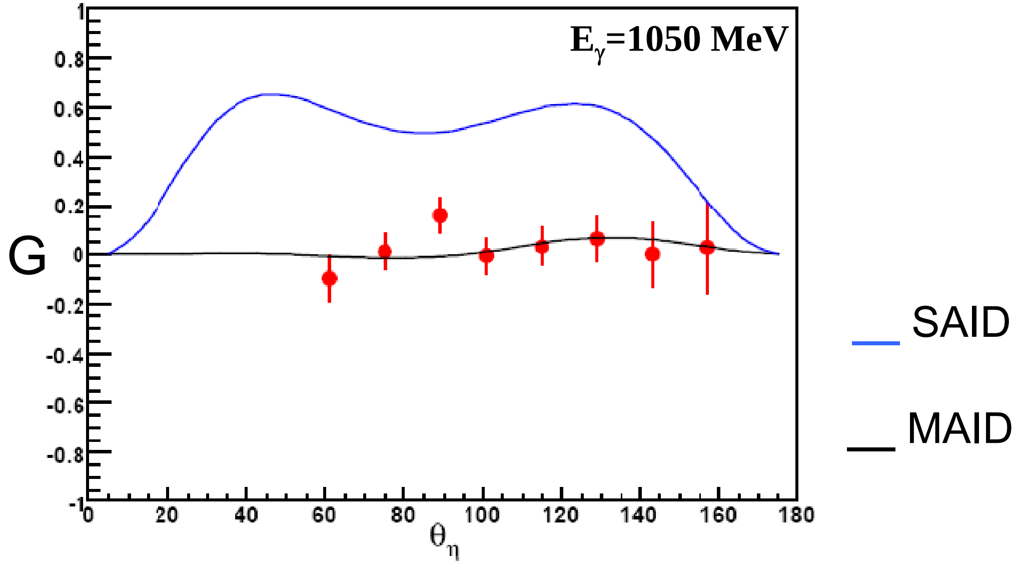
reaction: $\vec{\gamma} + \vec{p} \rightarrow p + \eta$

missing mass cut

fit to the ϕ-distribution

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



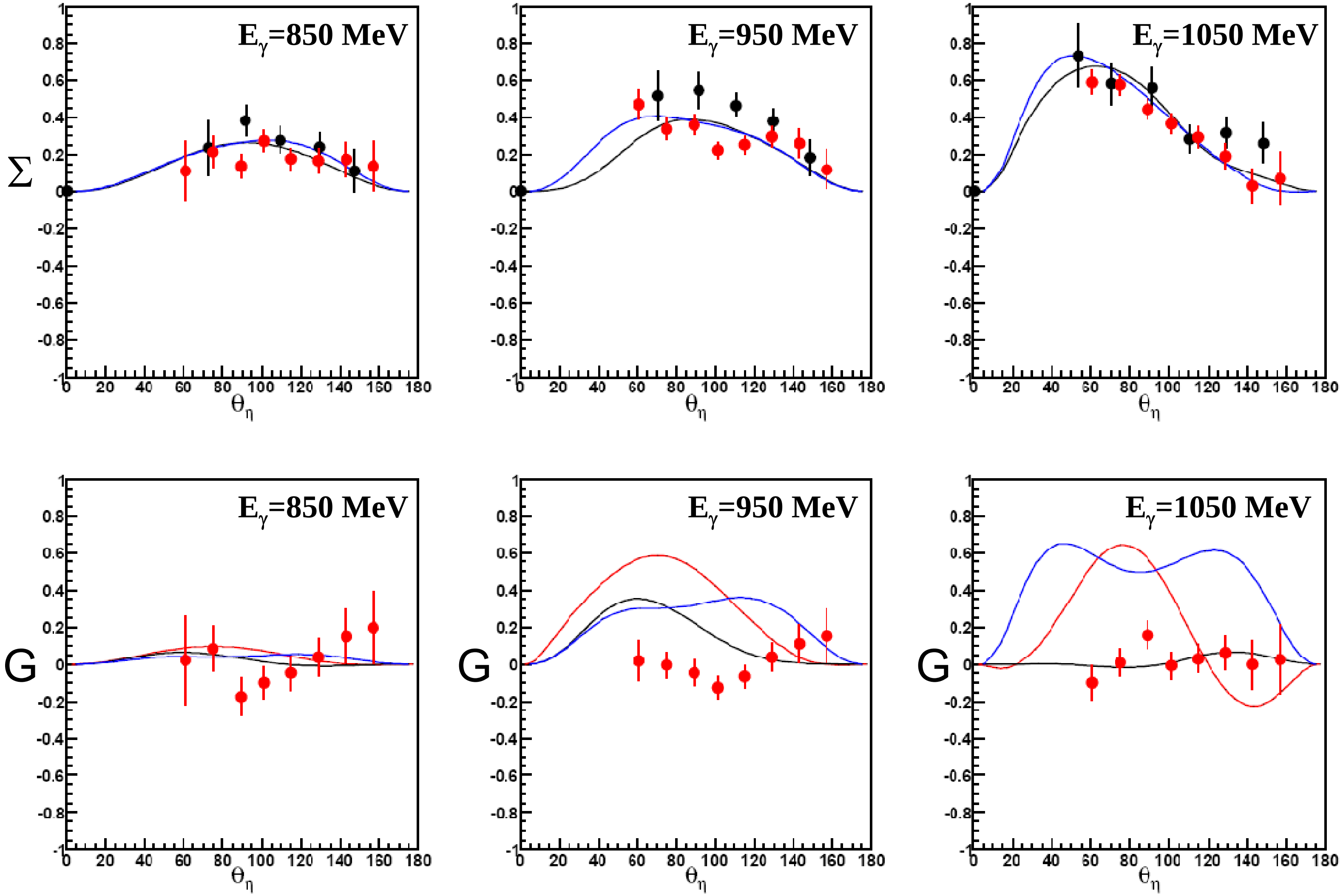


Asymmetries for pη

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

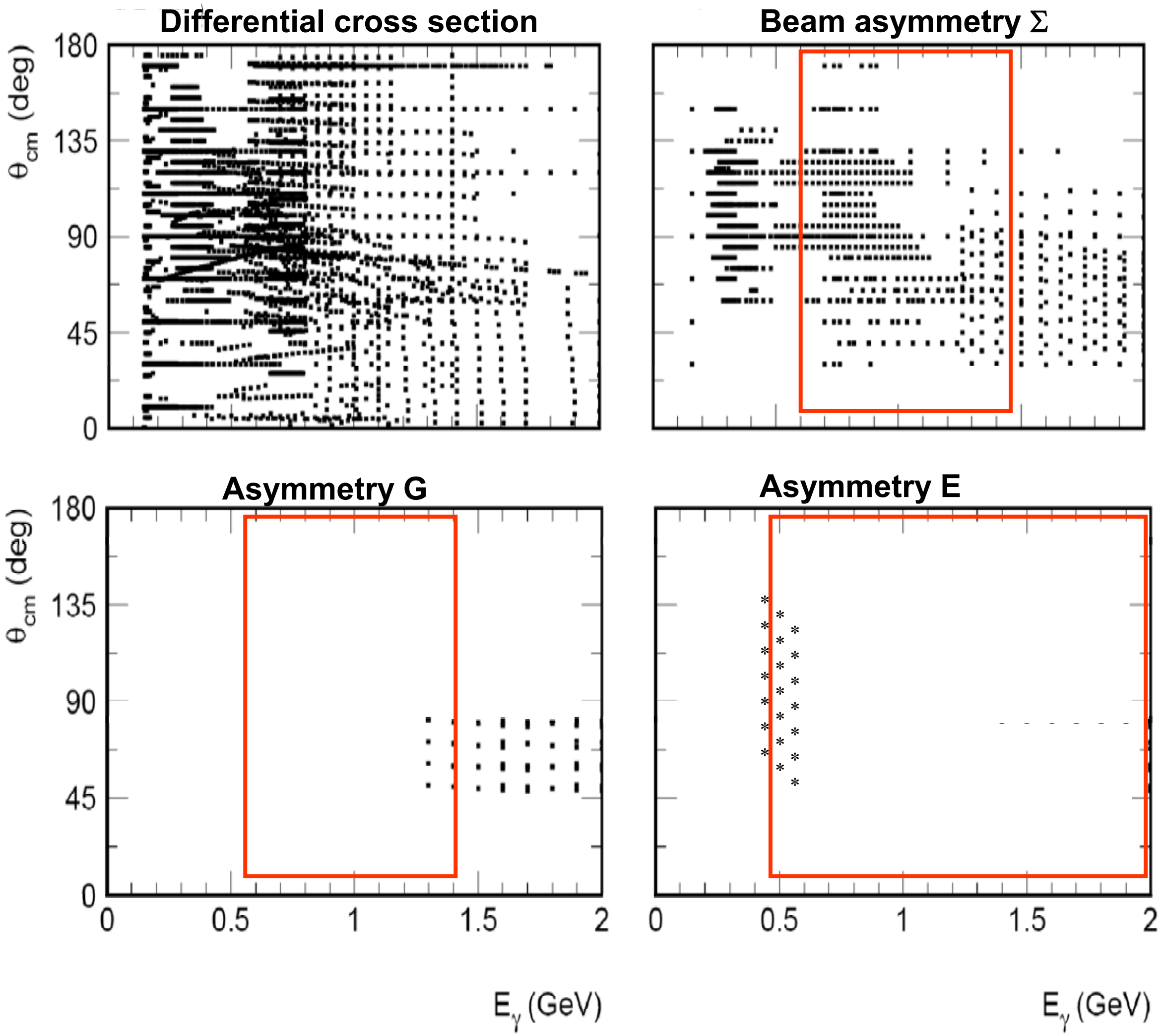
BoGa

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 for CB at ELSA:

Extend energy range to 3 GeV

Transversally polarized target
Installed and tested

Measurements on the neutron
polarized deuteron target

Targetasymmetry in η Production

only few partial–
waves contribute

threshold → Δ (1232)–region

increasing number of partial waves → E_γ

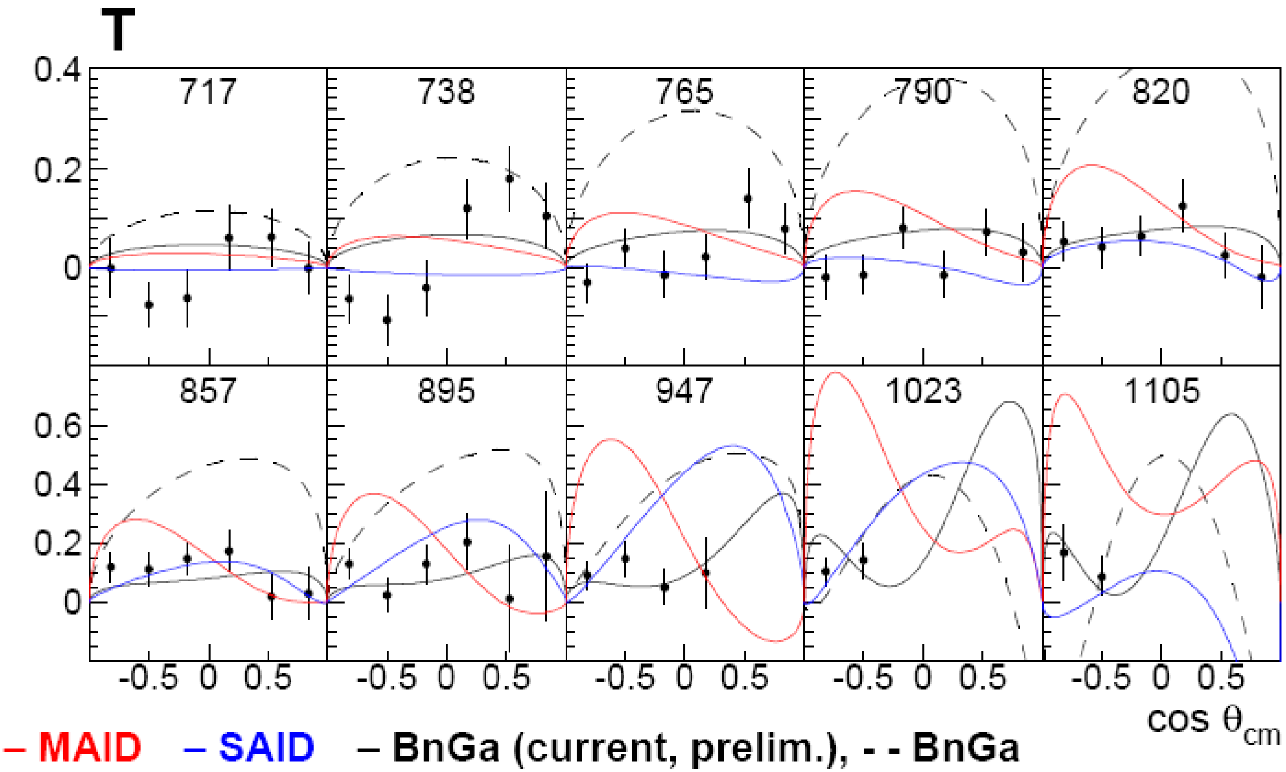
Low energy regime:

$\gamma p \longrightarrow p\eta$:

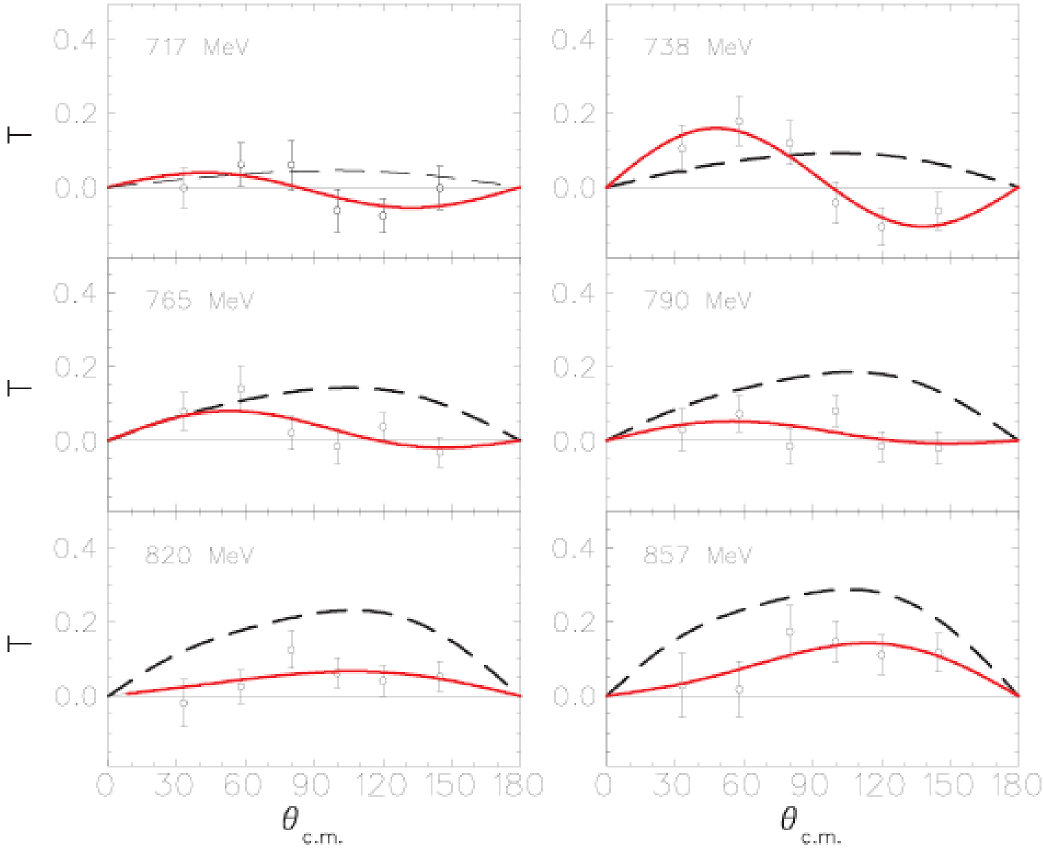
PHOENICS data on T

⇒ isobar models fail
to describe the data

⇒ big differences
between the different
solutions

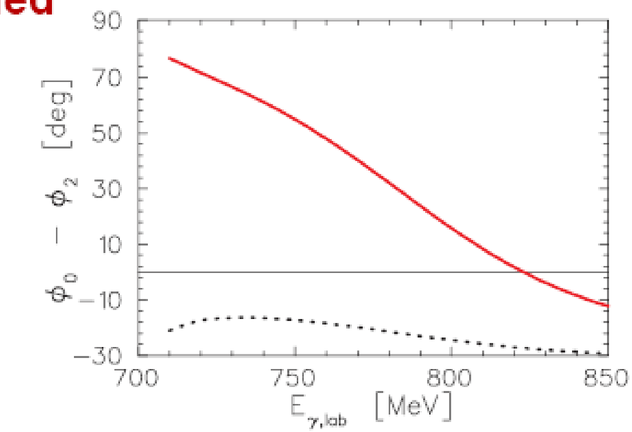


Low energy regime $\vec{\gamma}\vec{p} \longrightarrow p\eta$:



— Tiator et al.:
Model independent fit, assuming S-wave multipoles and their interference with p- and d-waves sufficient (E_γ $\leq$900 MeV)

$\Rightarrow$ Energy dependent phase between S_{11}(1535) and D_{13}(1530) needed



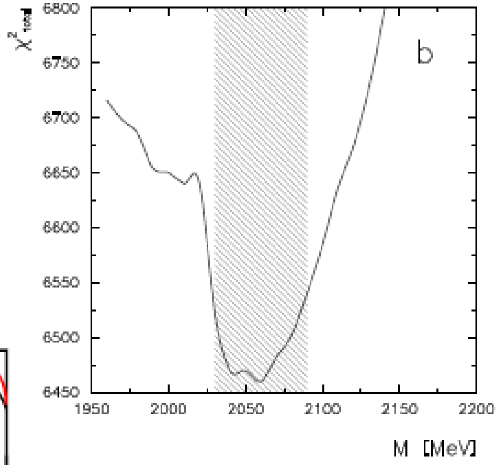
$\Rightarrow$ Energy dependent phase $\leftrightarrow$ origin presently not understood

- nature of the S_{11}(1535) ?
- interpretation of the data ?

$\Rightarrow$ Cross check and improve the precision of the existing data !

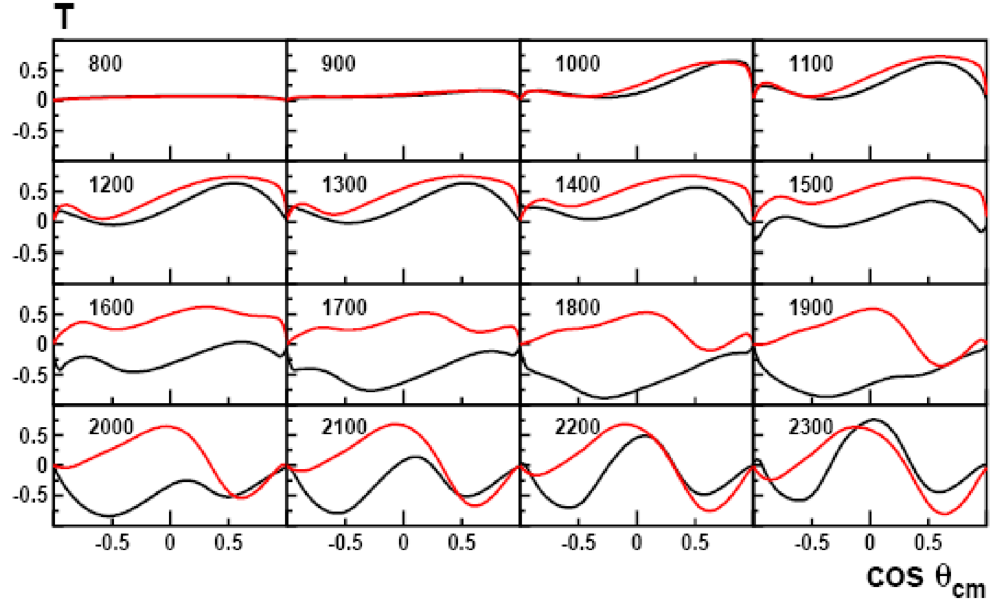
High energy regime $\vec{\gamma}\vec{p} \longrightarrow p\eta$:

$D_{15}(2060 \pm 30, 340 \pm 50)$:



Observation of a new D_{15}(2070) in the BnGa-analysis of $\gamma p \longrightarrow p\eta$ - data fitted together with various other reactions

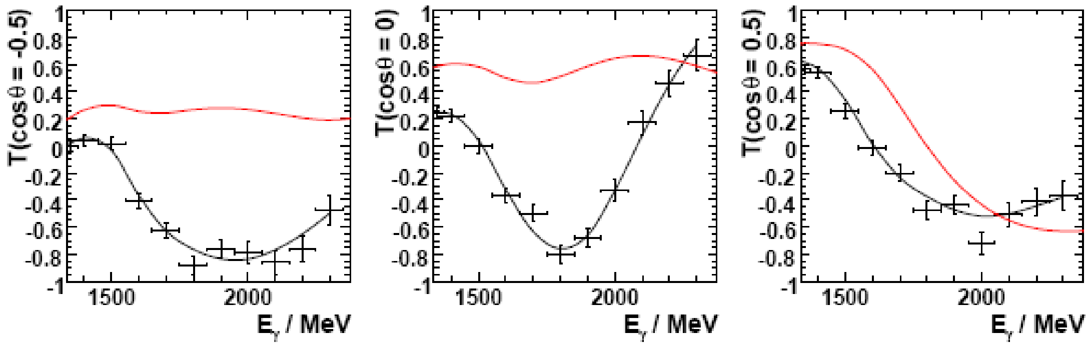
$\Rightarrow$ **Confirmation in polarisation experiments urgently needed !**



– BnGa (current, prelim.)

– no D_{15}(2070) (refitted)

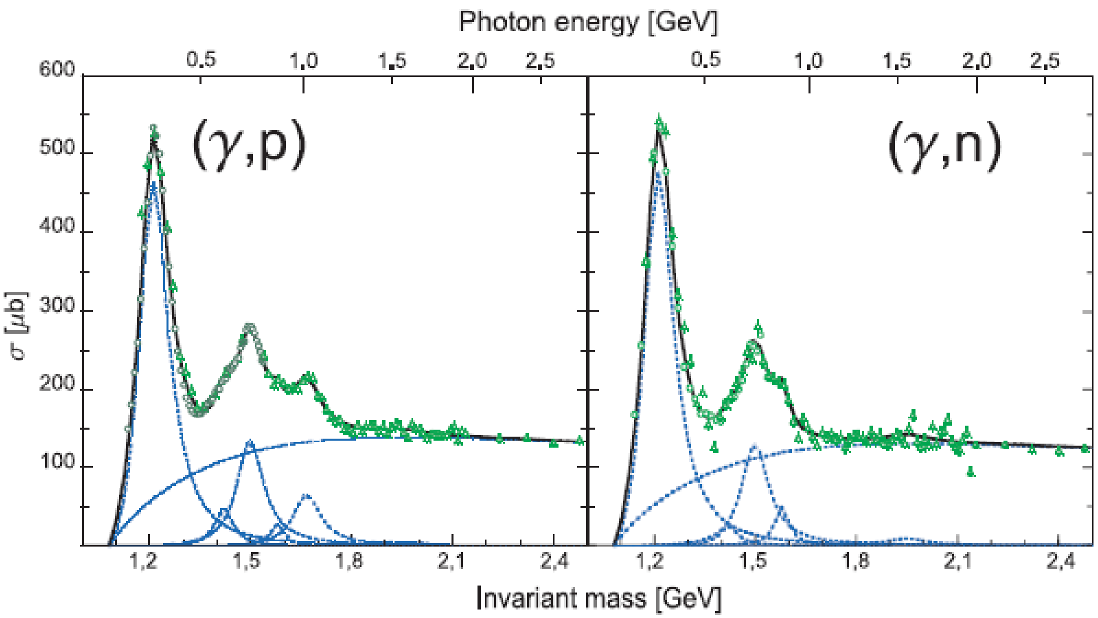
precision expected:



$\Rightarrow$ **further information to constrain the resonance contributions**

Electromagnetic excitation off the neutron

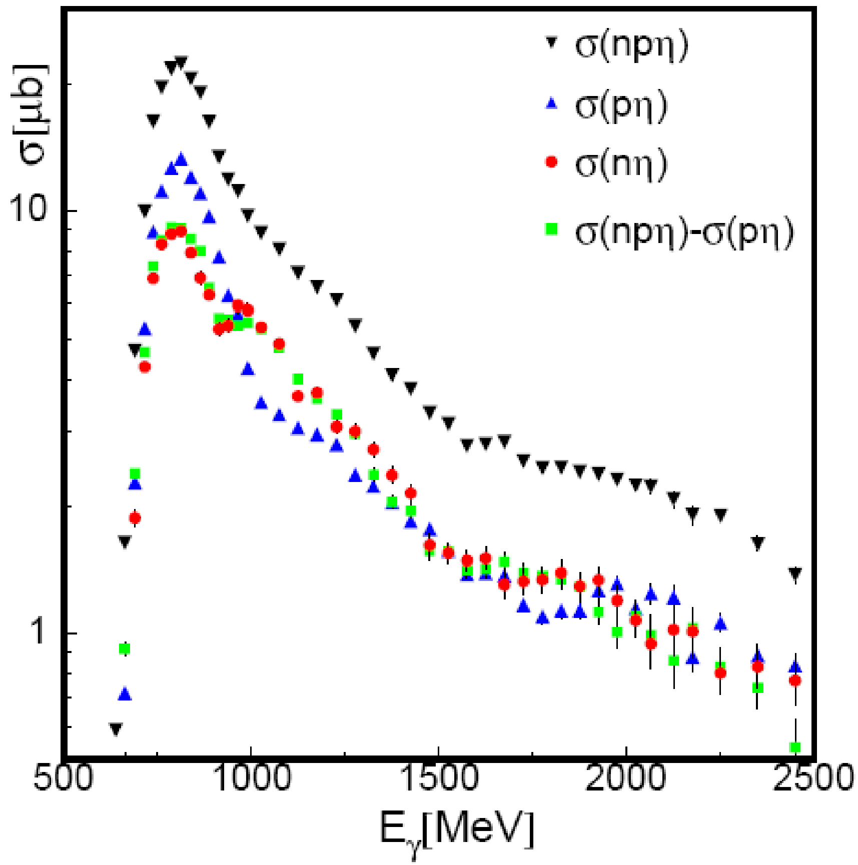
- **importance of measurements off the neutron:**
  - **different resonance contributions**
  - **needed for extraction of iso-spin composition of elm. couplings**

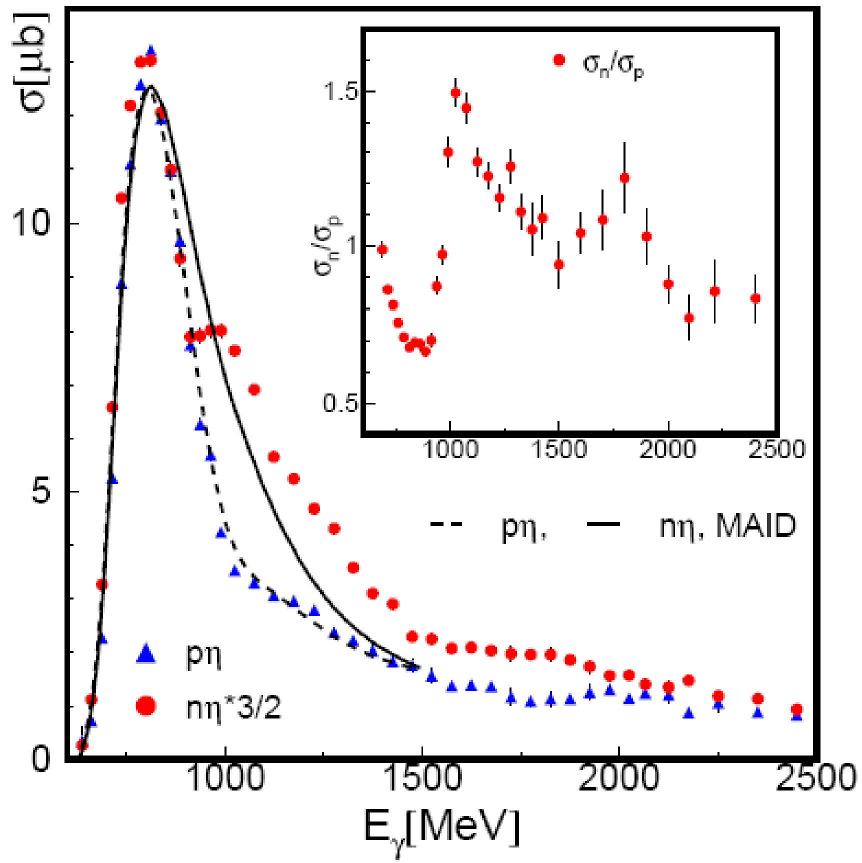


- **complications due to use of nuclear targets (deuteron):**
  - **Fermi motion**
  - **nuclear effects like FSI, re-scattering, coherent contributions**

Electromagnetic excitation off the neutron

- cross section for $\gamma n \rightarrow \eta n$ from analyses with very different systematics:
  (1) η in coincidence with recoil neutrons
  (2) difference of inclusive data and η in coincidence with recoil protons

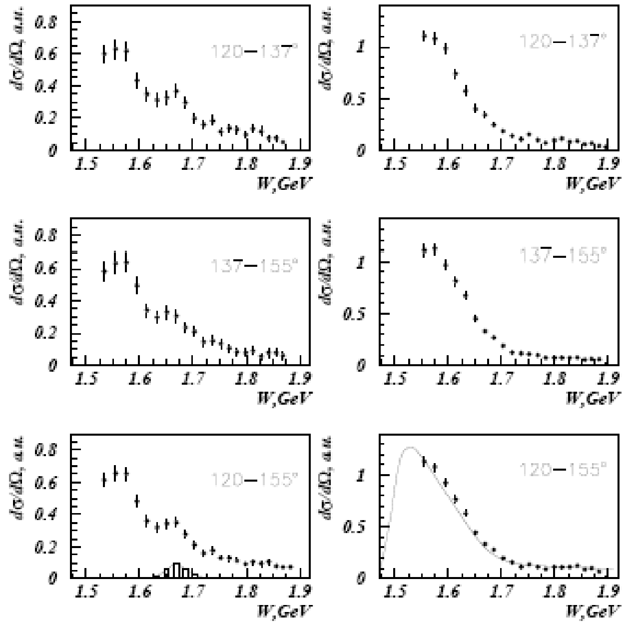


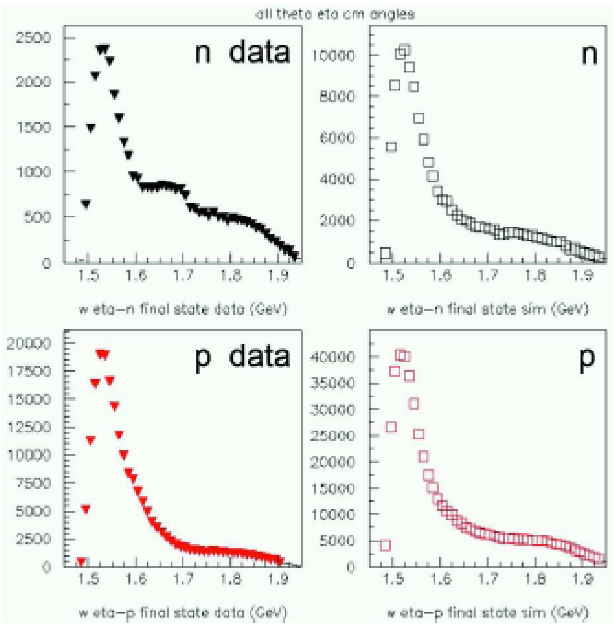


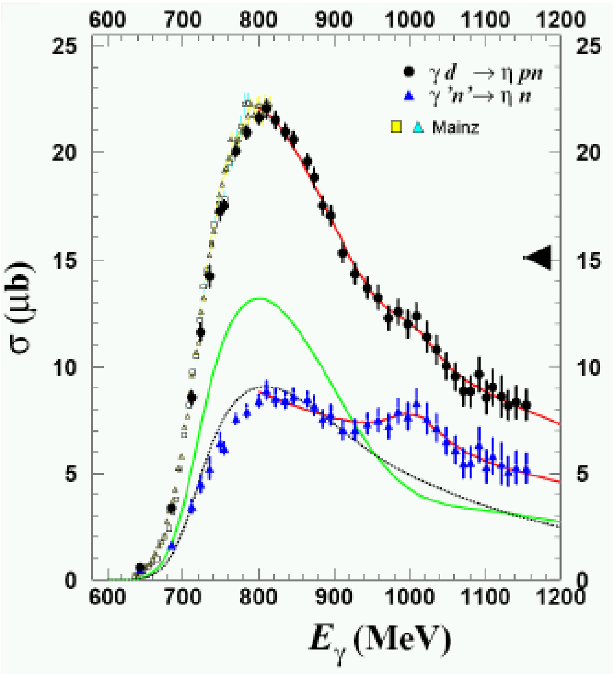
ELSA data, I. Jaegle, B. Krusche

experimental evidence (for η-n bump) from other labs

- GRAAL (Kuznetsov 04)
- GRAAL (Schaerf 09)
- Sendai 07







Comparison Narrow Structure

- narrow structure in excitation function of $\gamma n \rightarrow n\eta$:
- GRAAL: $W \approx$ 1680 MeV, $\Gamma <$30 MeV
- Tohoku-LNS: $W \approx$ 1666 MeV, $\Gamma <$40 MeV
- ELSA: $W \approx$ 1685 MeV, $\Gamma <$60 MeV
- MAMI-C: $W \approx$ 1675 MeV, $\Gamma <$40 MeV
- so far no information about quantum numbers
  of possible resonance
  or whatever nature of the structure

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