Baryon-Spectroscopy - Recent results -

U.Thoma, Bonn University

- Introduction
- Polarisation observables
- Results
- Current double polarisation experiments
- η- photoproduction at the neutron

  ($\longrightarrow$ talk of B. Krusche)
- Summary

funded by the DFG
within the
SFB/TR16

universitätbonn

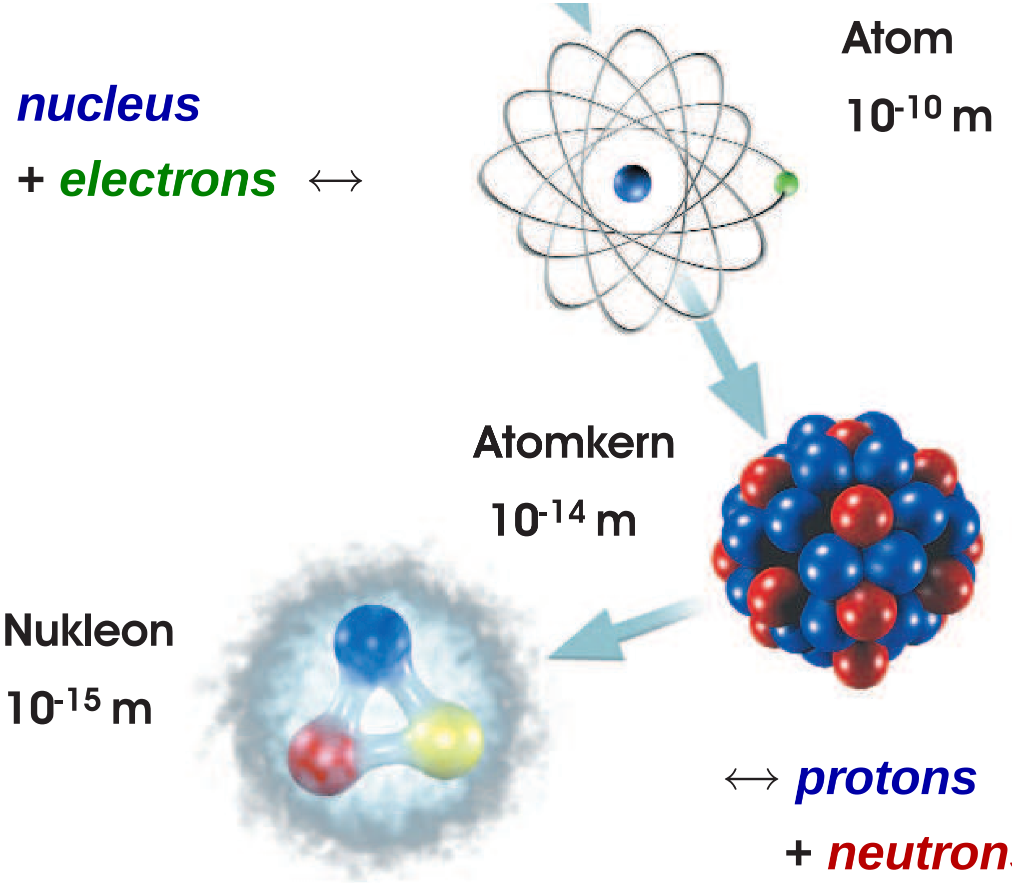
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

RVHR-VNIVERSITAT BOCHVM

Introduction

nucleus

+ *electrons* $\leftrightarrow$



$\leftrightarrow$ *protons*

+ *neutrons*

$\leftrightarrow$ *quarks*

$\leftrightarrow$ Electromagnetic Force

* Atom: $M \approx \sum m_i$

Effect of the binding energy: 10^{-8}

$\leftrightarrow$ Strong Force

* Nucleus: $M \approx \sum m_i$

Effect of the binding energy: 10^{-3}

* Nucleon: $M >> \sum m_i$

3+3+7 MeV $\neq$ 938 MeV

The LHC might explain about 2% of the nucleon mass

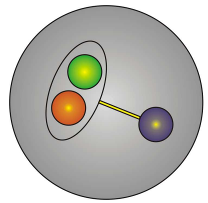
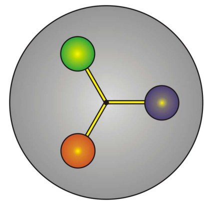
Rest: strong interaction (field energy)

How does QCD give rise to hadrons ?

Baryon spectroscopy

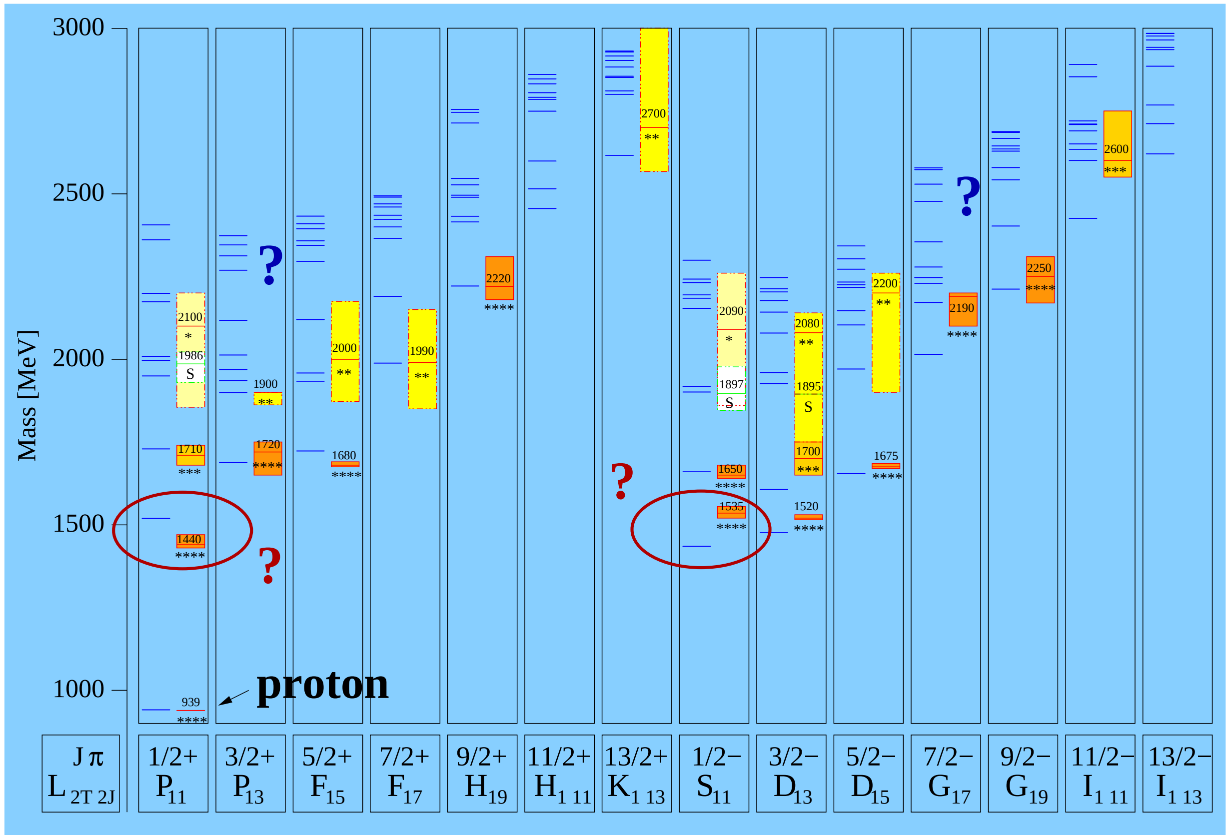
Aim: Good understanding of the spectrum and the properties of baryon resonances ↔ bound states of strong QCD

- What are the relevant degrees of freedom ?
- Effective forces between them ?

e.g.:  or  ?

Symmetric quark models:

→ many more resonances expected than observed yet



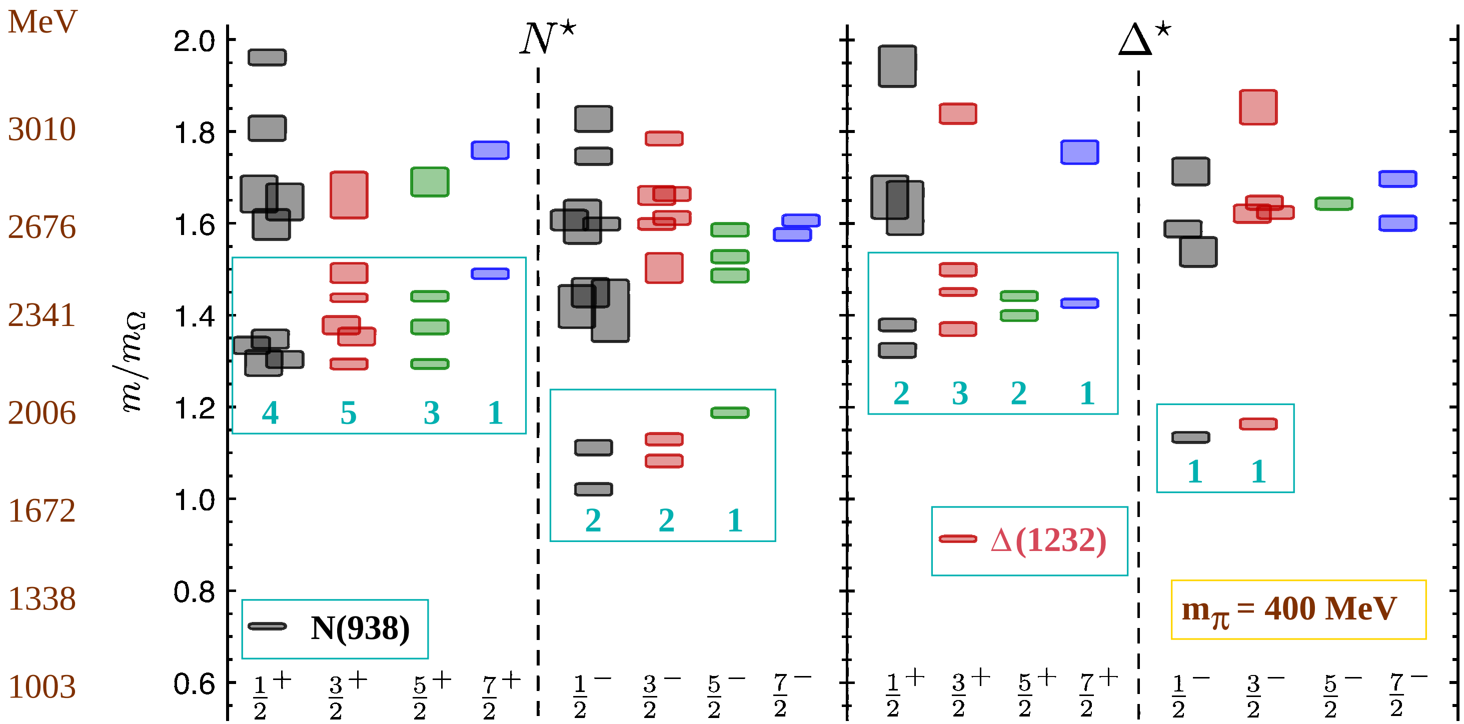
U. Loering, B. Metsch, H. Petry et al.

Constituent quarks
confinement potential
+ residual interaction

non-strange N^*-resonances

↔ wrong degrees of freedom ?

Excited baryons from Lattice QCD



R.Edwards et al., arXiv:1104.5152 [hep−ph]

Exhibits the broad features expected from SU(6)⊗O(3)-symmetry

⟶**Counting of levels consistent with non-rel. quark model**

⟶ **no parity doubling**

Of course there are also approximations made by lattice QCD (e.g. m_π=400 MeV)

Baryons may also be: $\mathrm{N}^* = \alpha \cdot |\mathrm{qqq} > + \beta \cdot |\mathrm{Baryon\ Meson} > + \ldots.$

⟷ **some resonances can be dynamically generated (Λ(1405), ...)**

Baryon spectroscopy

Symmetric quark models:

$\longrightarrow$ **many more resonances expected than observed yet**

- certain configurations completely missing !

- **Certain configurations not realised by strong QCD ?   Why ?**
- **Experimentally not found yet   (resonances might decouple from πN)**

$\Leftrightarrow$ **Photoprod. experiments e.g. $\gamma p \longrightarrow N\eta,\ N\eta',\ N\omega,\ \Delta\pi,\ N\rho,\ \Delta\eta,\ \ldots$**

(give access to the inelastic channels: black box in $\pi N \longrightarrow \pi N$-analyses)

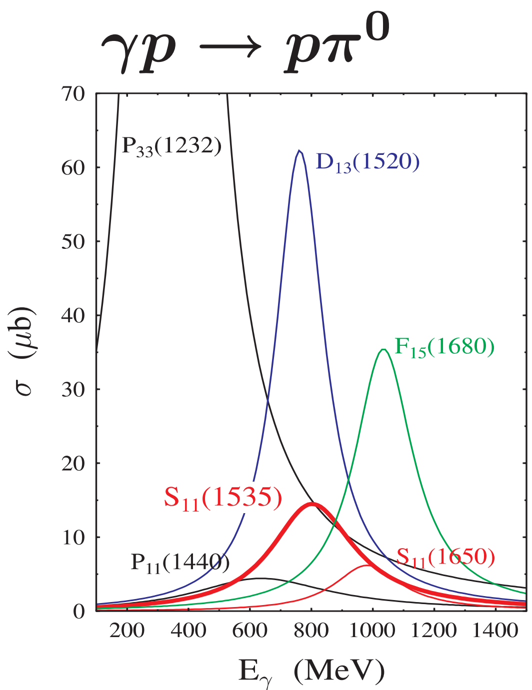
Experimentally:

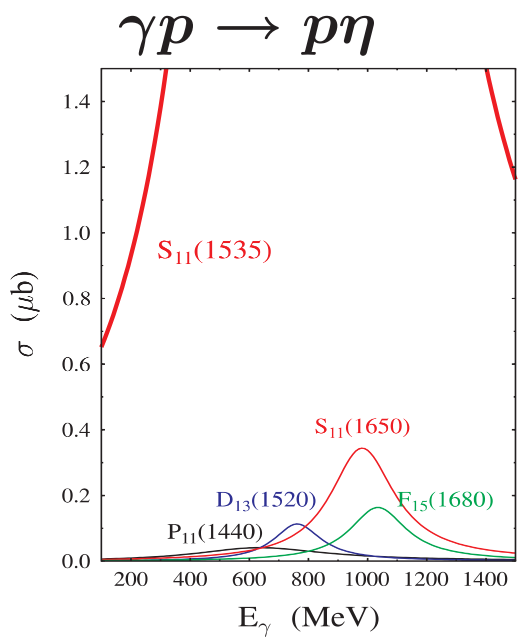
Broad strongly overlapping resonances

Important:

$\longrightarrow$ **Measurement of polarisation observables (unambigiuos PWA)**

$\longrightarrow$ **Investigation of different final states**





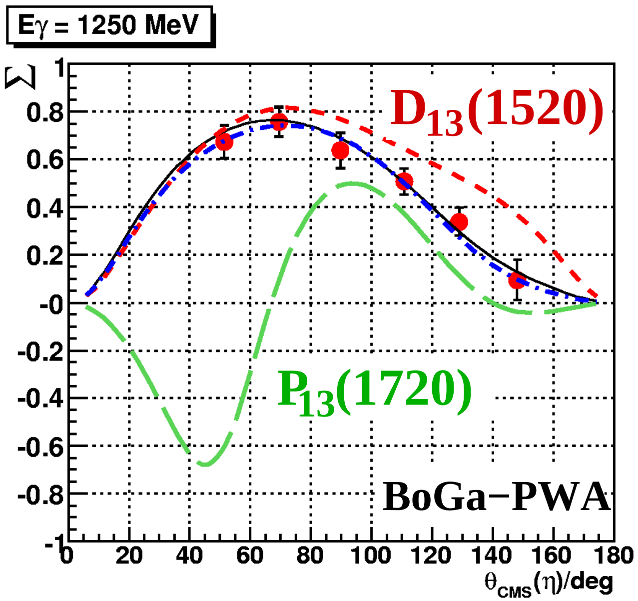
Measurement of polarisation observables

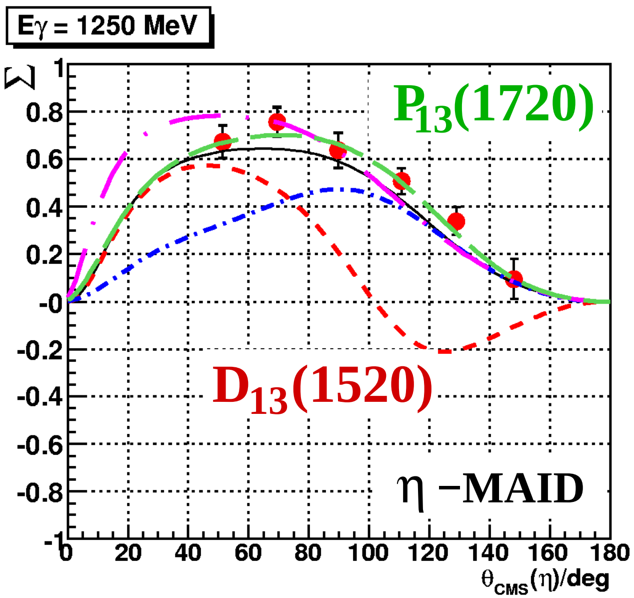
Example : $\gamma p \longrightarrow pM$ **(M: pseudoscalar meson):**

8 well chosen observables need to be measured to determine the contributing amplitudes = basis for an unambigious PWA

Problem otherwise: e.g. for $\gamma p \longrightarrow p\eta$**:**

Two different PWA-solutions: both describing $d\sigma/d\Omega$ **and** Σ **nicely, but:**





$\longrightarrow$ **quite different resonance contributions ...**

$\longrightarrow$ **solution not unambiguous**

$\Rightarrow$ **further polarisation observables needed !**

CBELSA/TAPS:
D.Elsner et al.,EPJ. A33 (2), 147 (2007)

Measurement of polarisation observables

Complete experiment: Measurement of 8 well chosen observables

(e.g. $\gamma p \longrightarrow p\eta$)

Photon		Target			Recoil			Target–Recoil			
					x'	y'	z'	x'	x'	z'	z'
		x	y	z				x	z	x	z
unpolarized	σ	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear	-Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	(-$L_{z'}$)	($T_{z'}$)	(-$L_{x'}$)	(-$T_{x'}$)
circularly	0	F	0	-E	$C_{x'}$	0	$C_{z'}$	0	0	0	0

Double polarisation program started at:

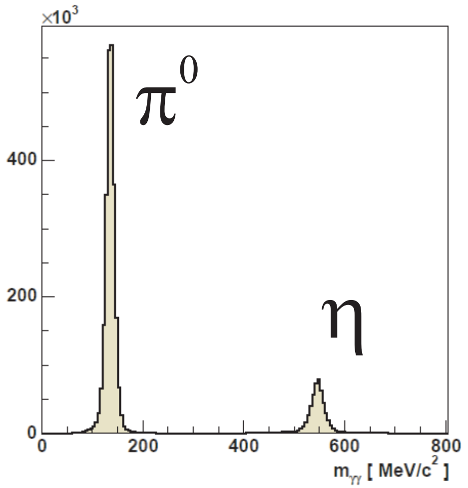
In addition:
LEGS, Spring-8

MAMI:	**up to M$_{res}$ = 1.9 GeV**	**trans. + long. pol. target**	**pol. beam**
ELSA:	**up to M$_{res}$ = 2.5 GeV**	**trans. + long. pol. target**	**pol. beam**
JLAB:	**up to M$_{res}$ = 2.6 GeV**	**trans. + long. pol. target**	**pol. beam**

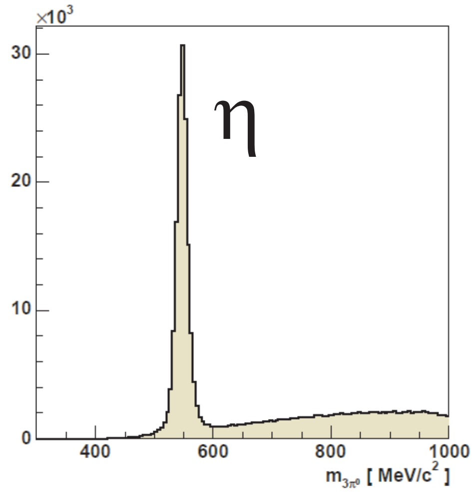
Detector systems partially complementary

CBELSA/TAPS: η - Photoproduction off the proton

$\eta \rightarrow \gamma\gamma$

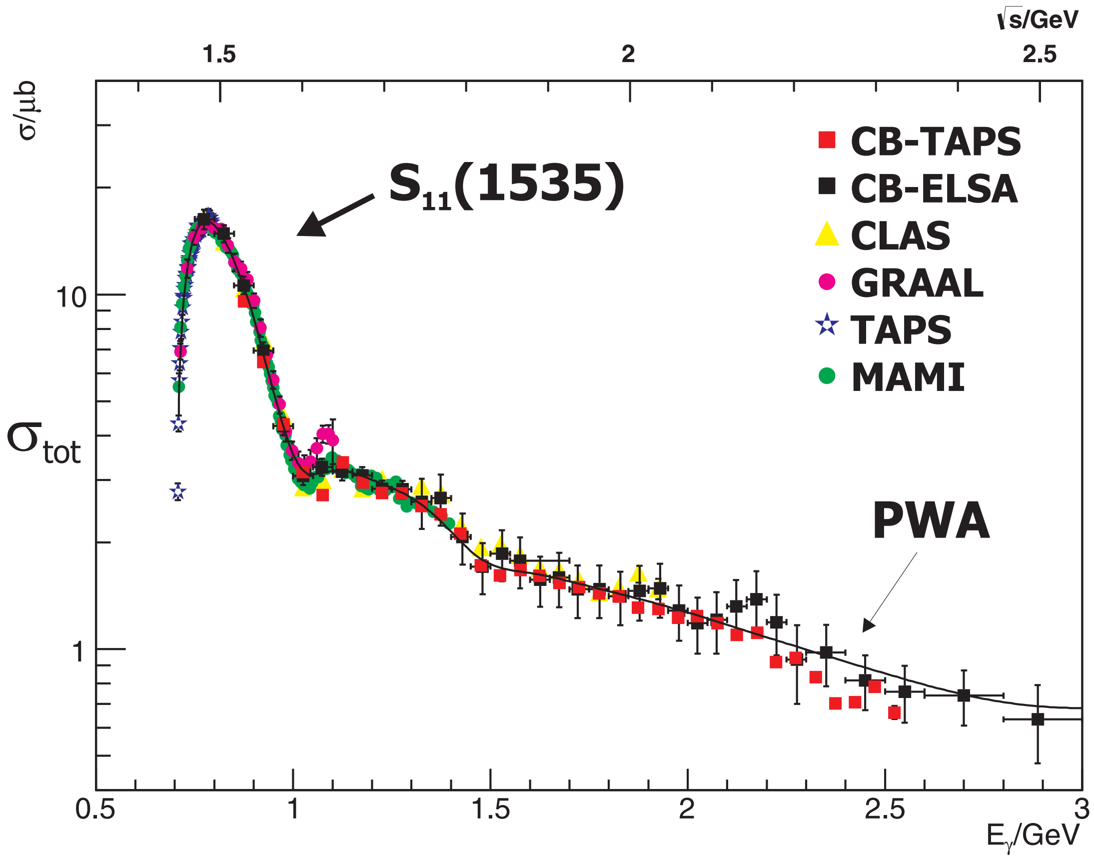


$\eta \rightarrow 3\pi^0$



$d\sigma/d\Omega$

PWA



S_{11}(1535), D_{13}(1520), S_{11}(1650), F_{15}(1680), P_{13}(1720), D_{13}(2080) + ... + ρ -, ω -t-channel exchange

+ new D_{15}: m = 2068 $\pm$ 22 MeV,

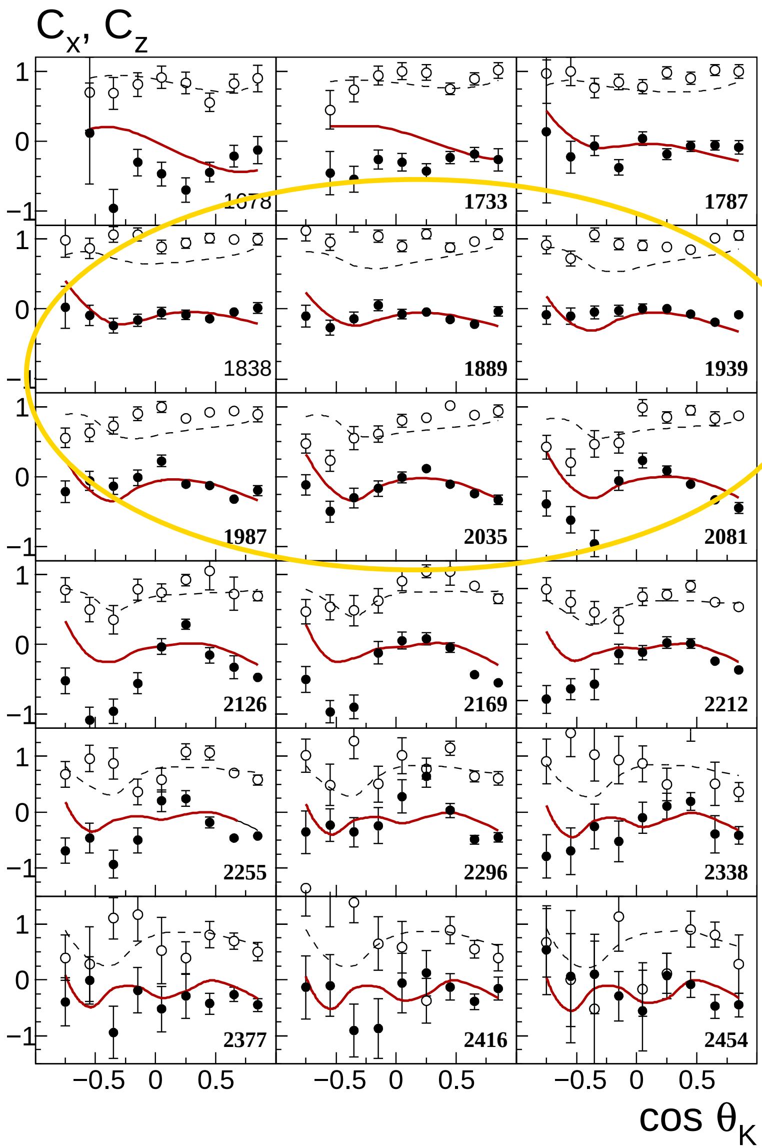
Γ = 295 $\pm$ 40 MeV

(needed: confirmation in polarisation exp.)

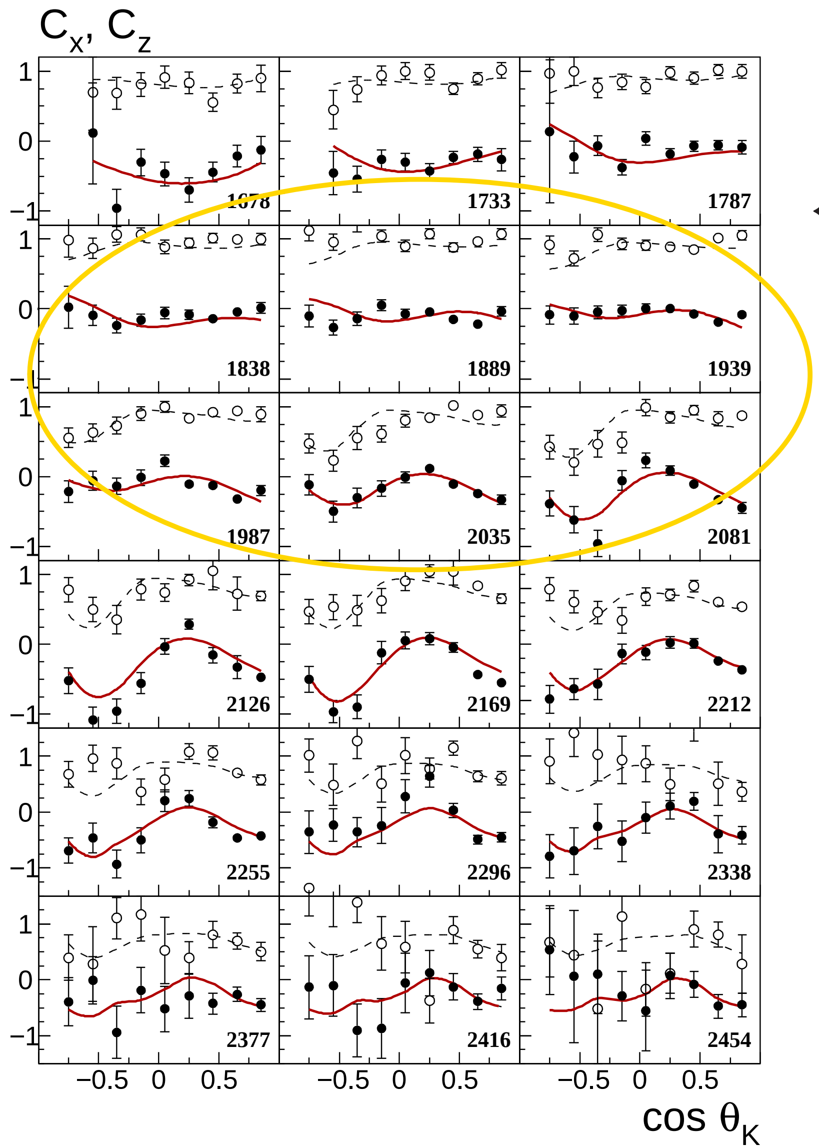
V.Crede et al. PRL 94 (2005) 012004

CLAS: $\vec{\gamma} p \rightarrow K \vec{\Lambda}$ polarisation transfer

best fit without $P_{13}(1900)$

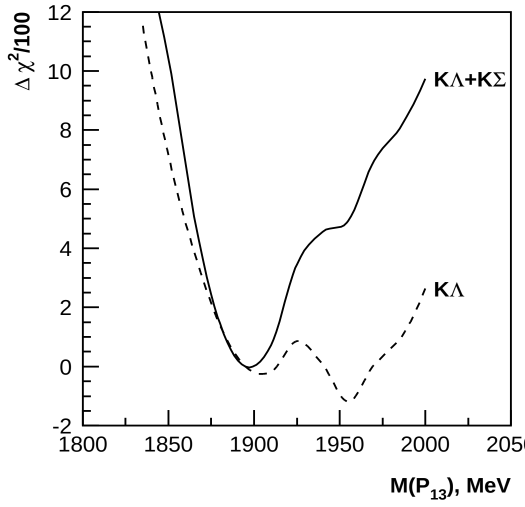


with $P_{13}(1900)$



$\leftrightarrow$ **Bonn-Gatchina PWA:**

favours existence of second P_{13}-state !

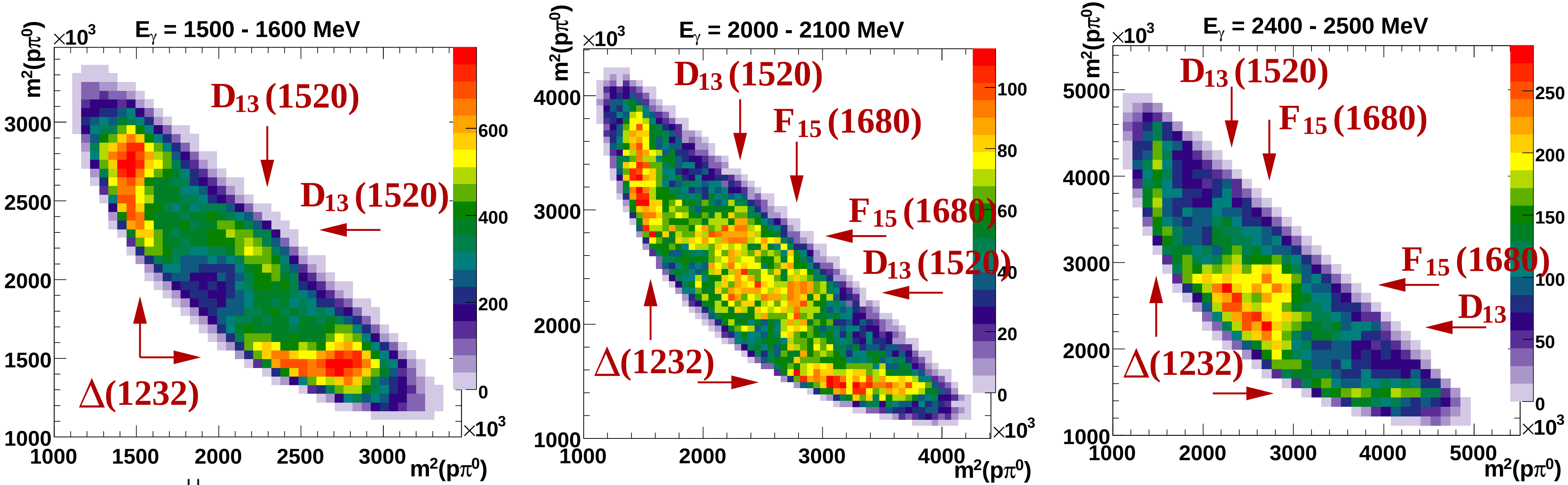


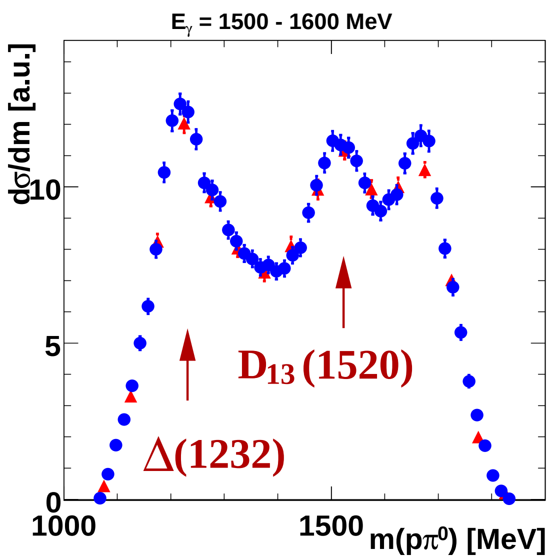
R.Bradford et al. PRC 75 (2007) 035205

V.Nikonov et al. PLB 662 (2008) 245

$P_{13}(1900)$: Evidence against the quark-diquark model

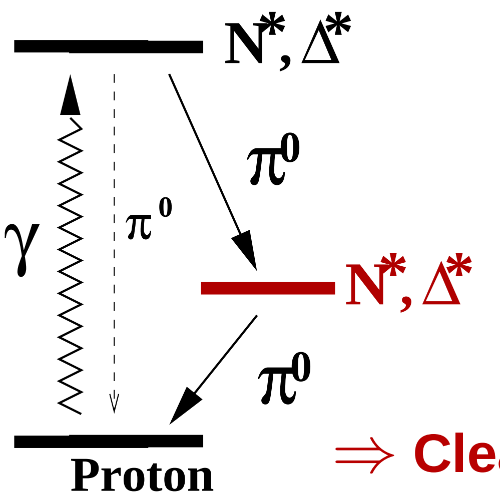
CBELSA/TAPS: $\gamma p \longrightarrow p\pi^0\pi^0$ (V.Sokhoyan, Bonn)





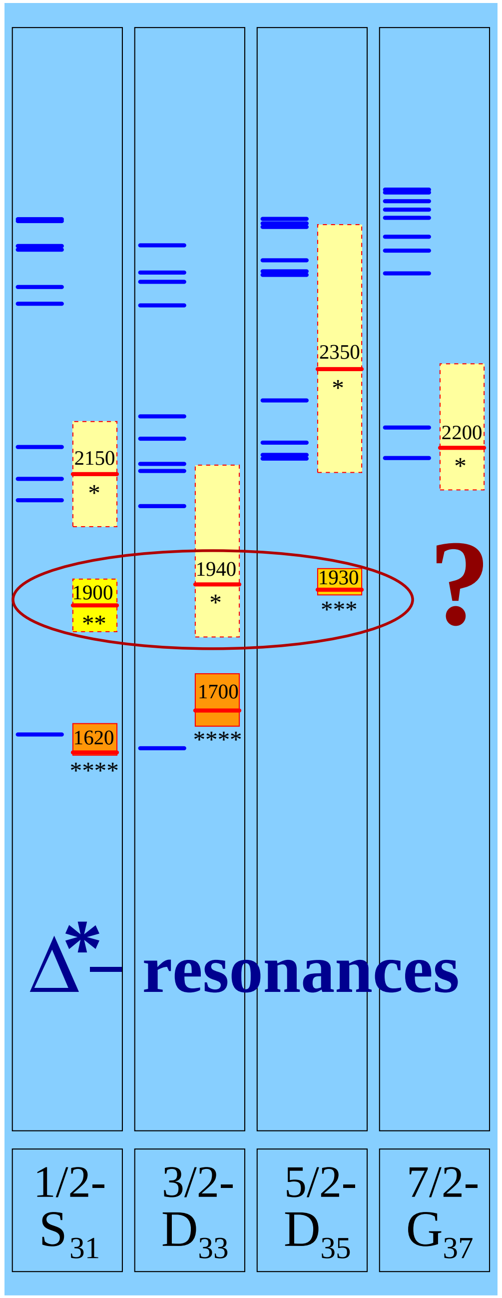
CB-ELSA data

CBELSA/TAPS data



$\Rightarrow$ Clear observation of baryon cascades !

Partial Wave Analysis - results

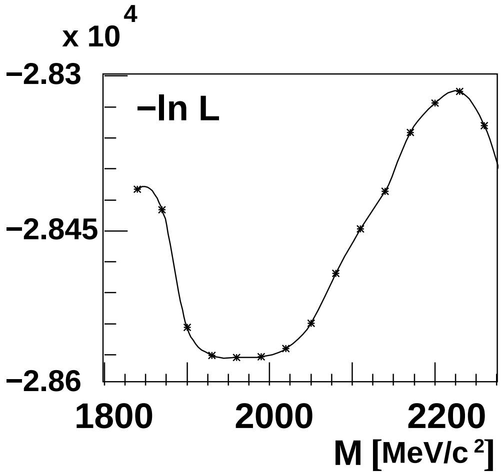


U. Loering et al.

BnGa-PWA:

Evidence for the $\Delta^*(1940)$ found

PWA Likelihood scan

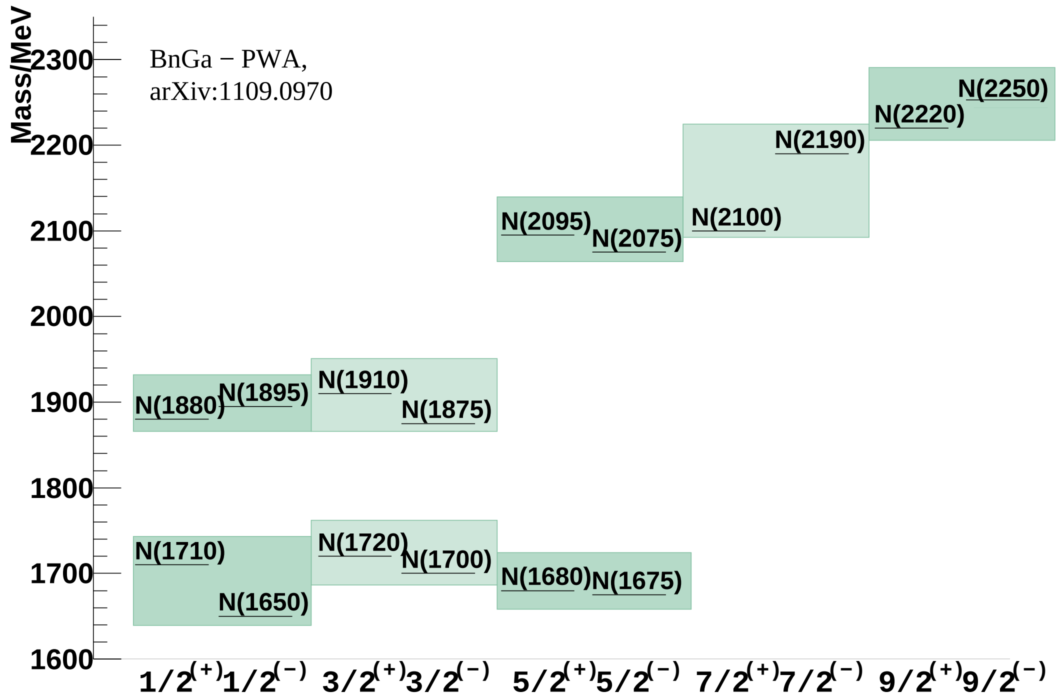


- evidence based on CBELSA-data on $\gamma p \rightarrow p\pi^0\eta$-data

$$\gamma p \rightarrow \Delta^*(1940)$$
$$\rightarrow \Delta\eta$$

I.Horn et al. PRL 101 (2008) 202002

Parity doublets occur:



Not expected by:

- lattice QCD, constituent quark-models

Baryons may also be:

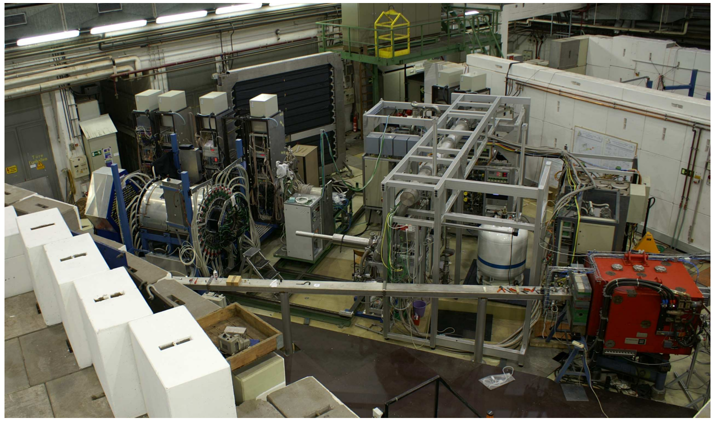
$$N^* = \alpha \cdot |qqq> +$$
$$\beta \cdot |\text{Baryon Meson} > + \ldots.$$

New data taken with polarised target

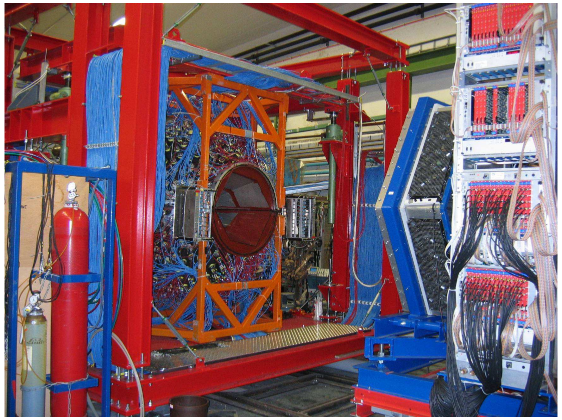
Double polarisation program at: CLAS, ELSA, MAMI

CLAS

ELSA



MAMI

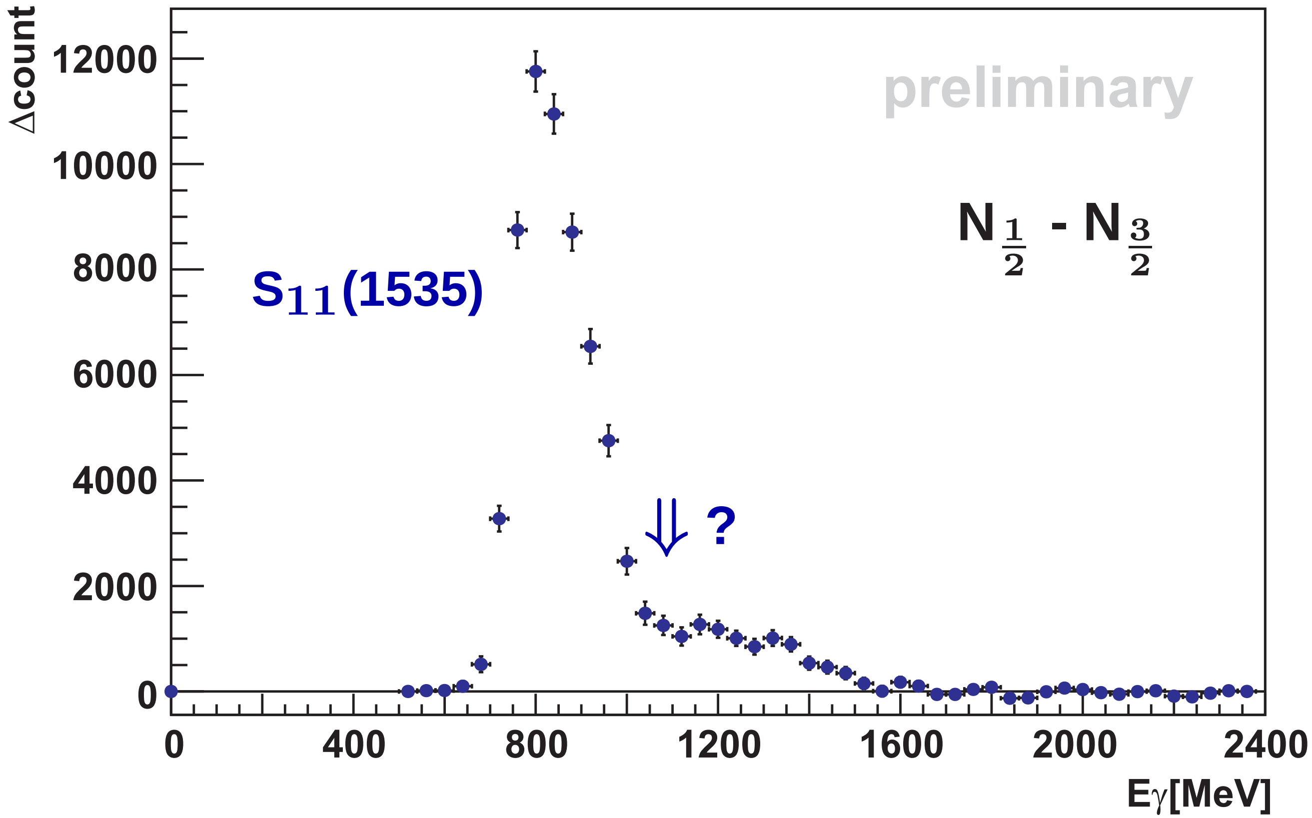


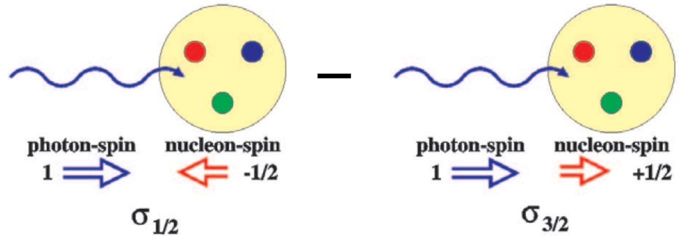
an important step forward towards a complete experiment

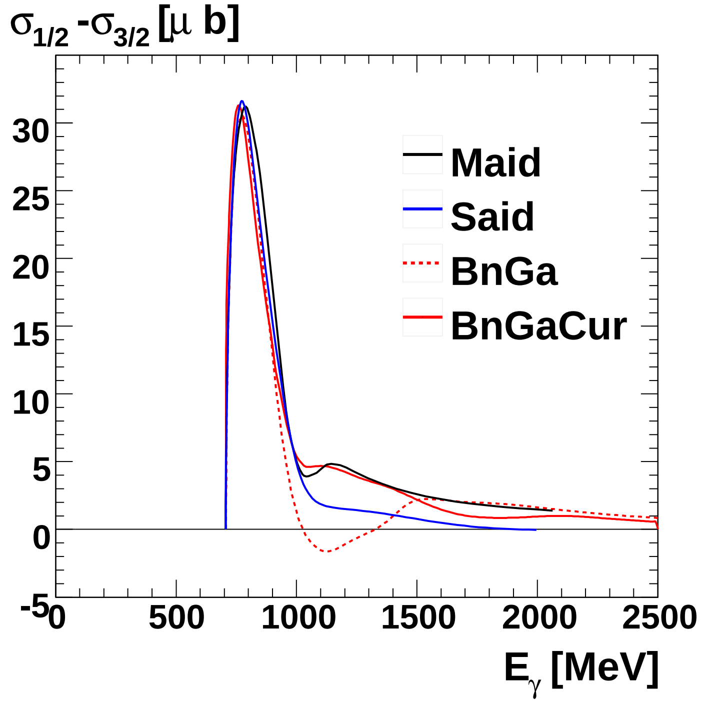
CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\eta$ (J. Müller, Bonn)

Circularly polarised photons, longitudinally polarised target

Count rate differences plotted:







Clear asymmetries observed !

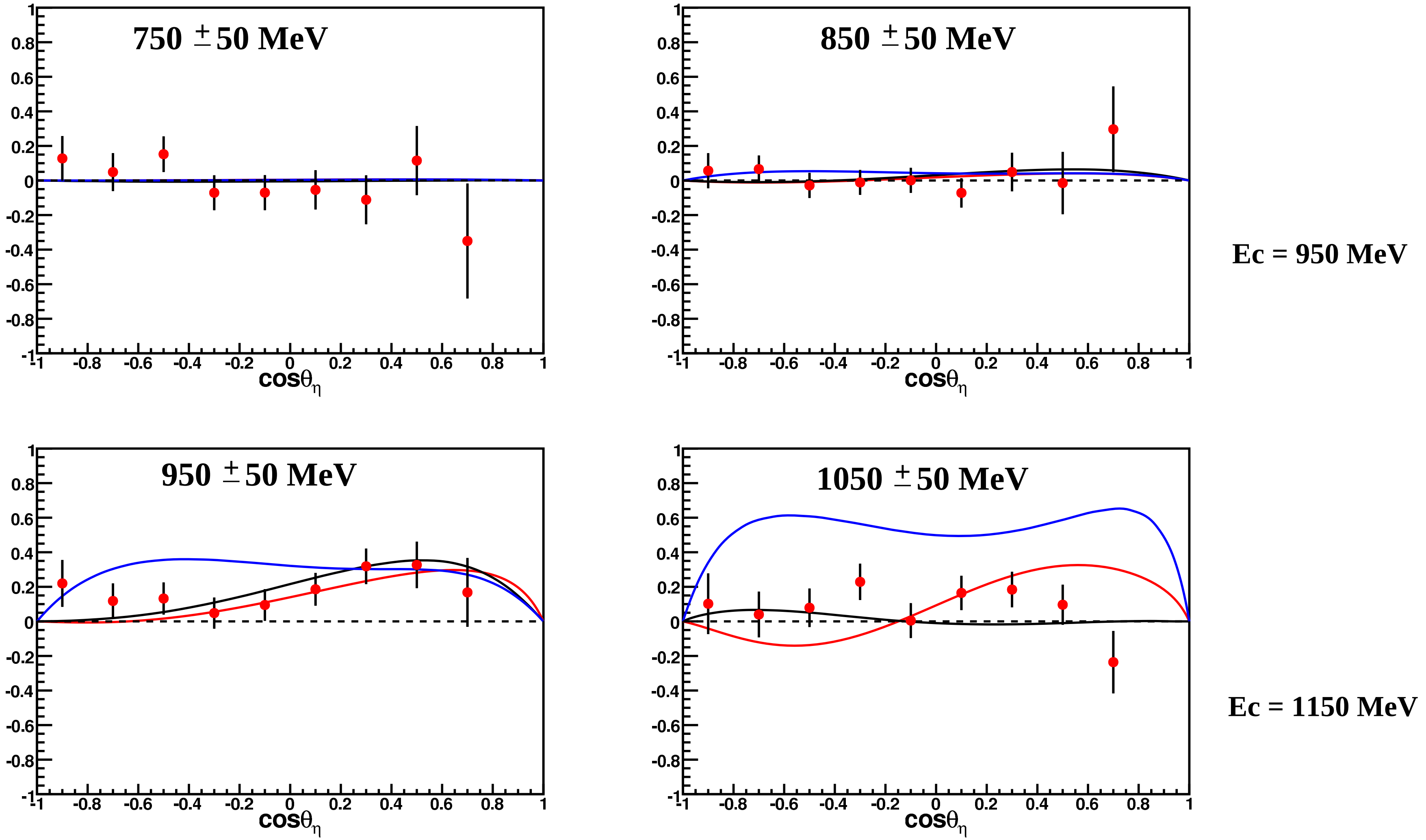
∼ complete angular coverage

⇒ New and important information for the PWA

CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\eta$ (A. Thiel, Bonn)

Linearly polarised photons, longitudinally polarised target

$$\frac{d\sigma}{d\Omega}(\Phi) = \frac{d\sigma}{d\Omega_0} \cdot \left(1 - P_\gamma^{lin} \Sigma \cos(2\phi) + P_\gamma^{lin} P_z G \sin(2\phi)\right)$$



– MAID – BnGa – SAID

CLAS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow n\pi^+$ (S.Strauch, SC)

$\gamma p \longrightarrow p\eta$:

only N^*-resonances:

isospin selective

$\gamma p \longrightarrow N\pi$:

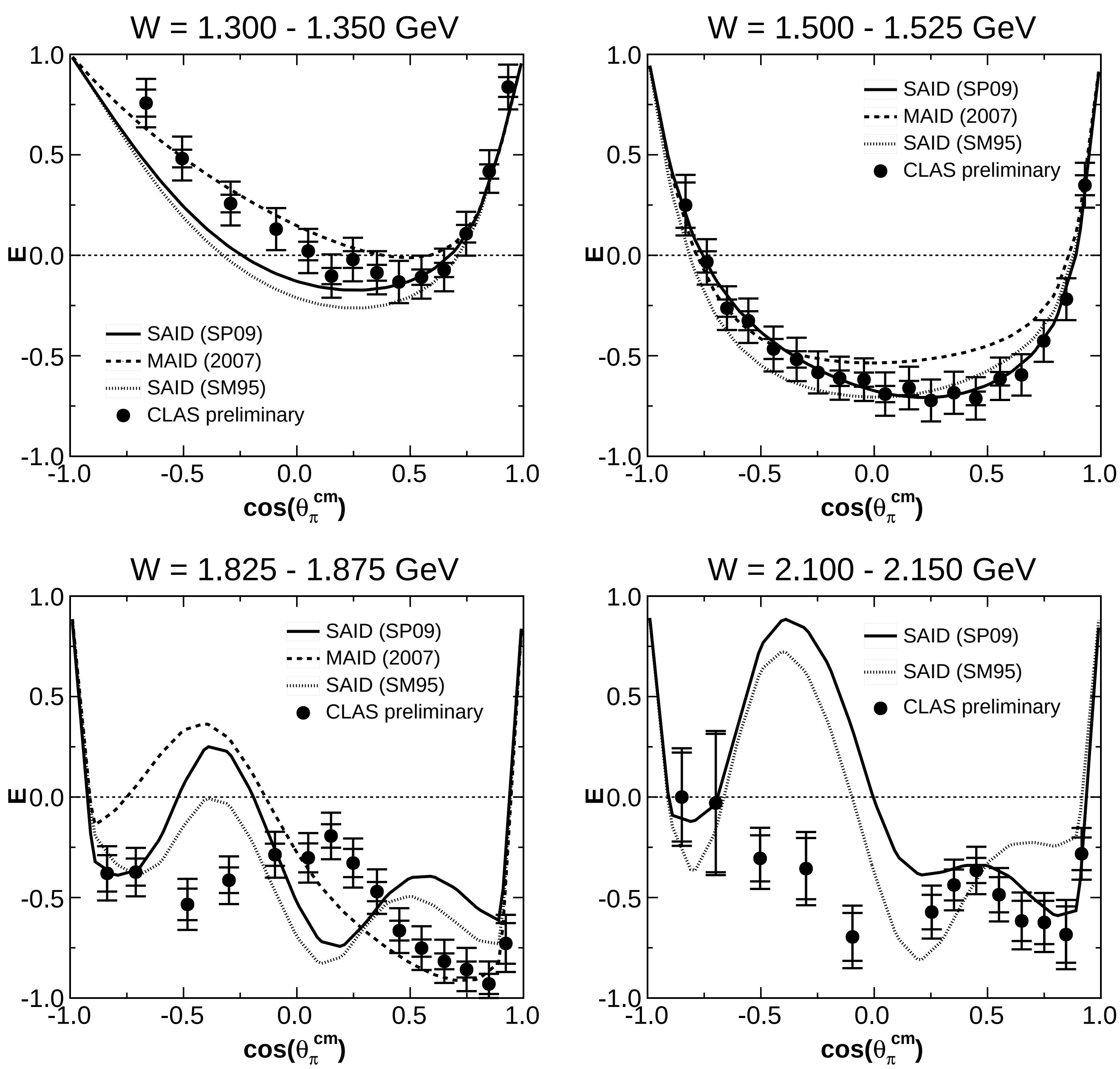
N^* and Δ^*-resonances

contribute:

$$p\pi^0 : \sqrt{\tfrac{2}{3}}|I = \tfrac{3}{2}, I_3 = \tfrac{1}{2}> - \sqrt{\tfrac{1}{3}}|I = \tfrac{1}{2}, I_3 = \tfrac{1}{2}>$$

$$n\pi^+ : \sqrt{\tfrac{1}{3}}|I = \tfrac{3}{2}, I_3 = \tfrac{1}{2}> + \sqrt{\tfrac{2}{3}}|I = \tfrac{1}{2}, I_3 = \tfrac{1}{2}>$$

circ. pol. photons on long. pol. protons

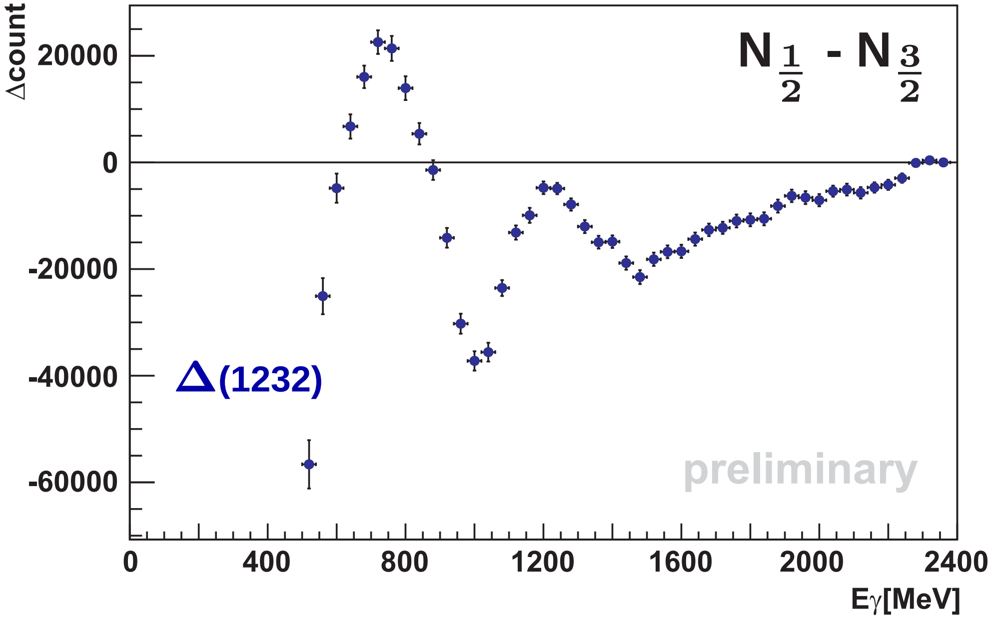


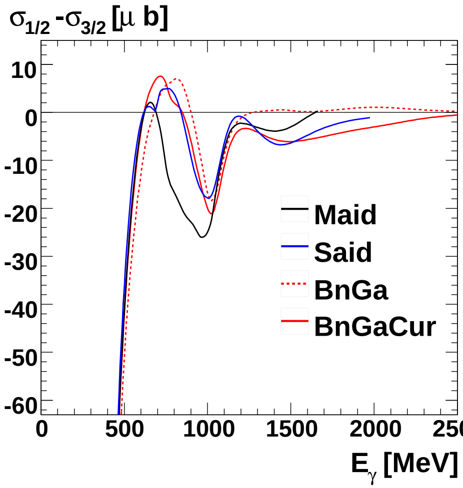
PWA predictions not too bad at lower energies

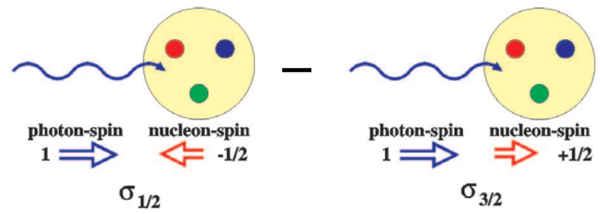
but: quite unsatisfactory at higher energies

CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\pi^0$ (M.Gottschall, Bonn)

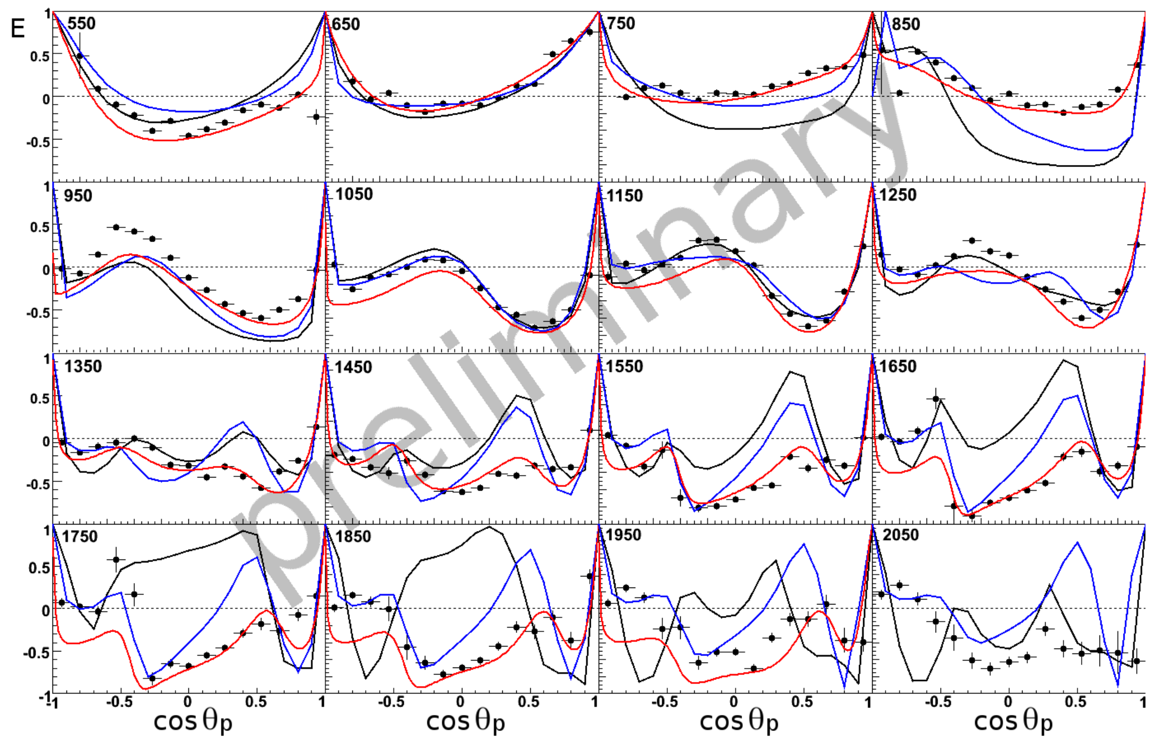
Circularly polarised photons, longitudinally polarised target







$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} :$$



∼ complete angular coverage

PWA not too bad at lower energies

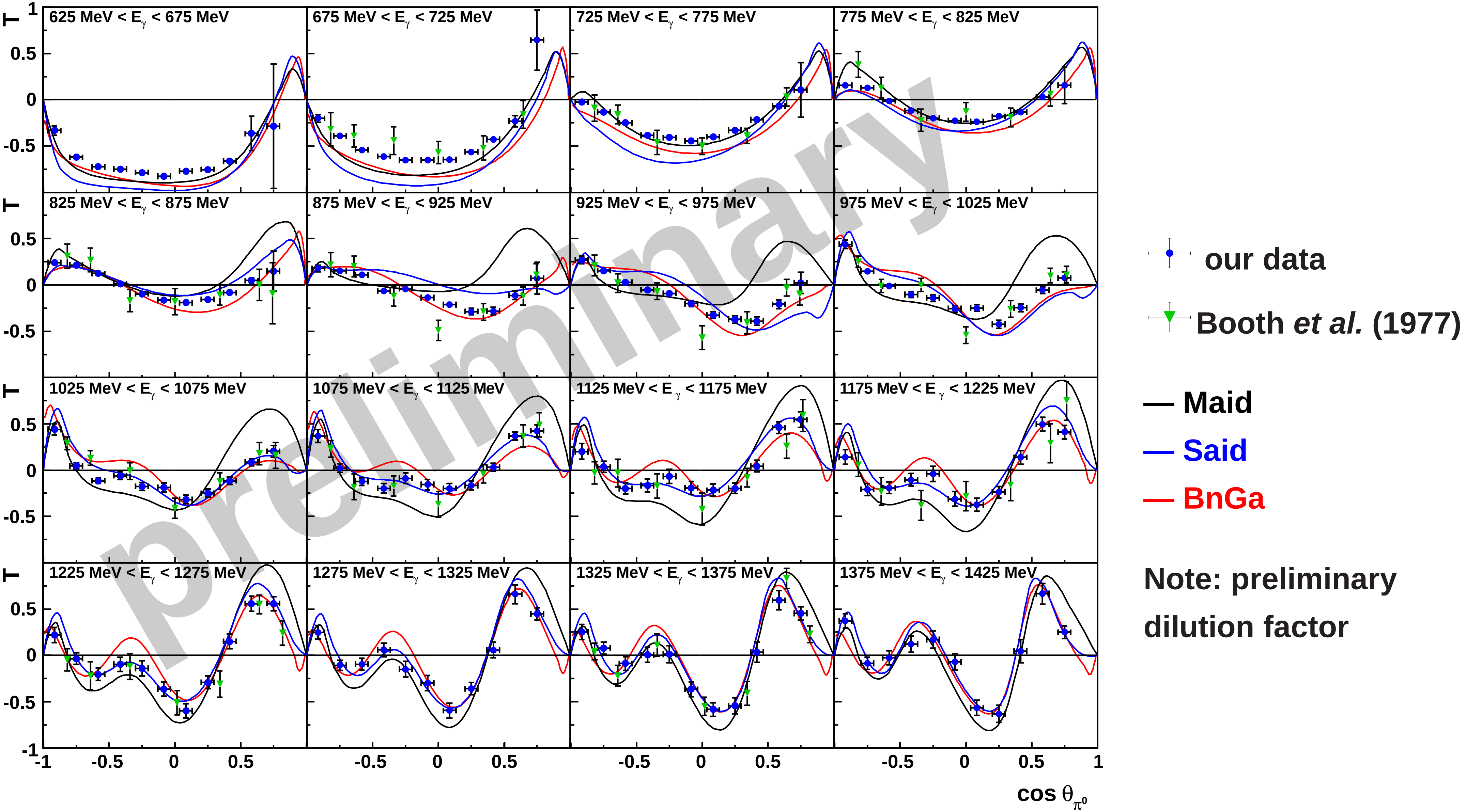
but: quite unsatisfactory

at higher energies

⇒ New and important information

CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\pi^0$ (J. Hartmann, Bonn)

Transversally polarised target



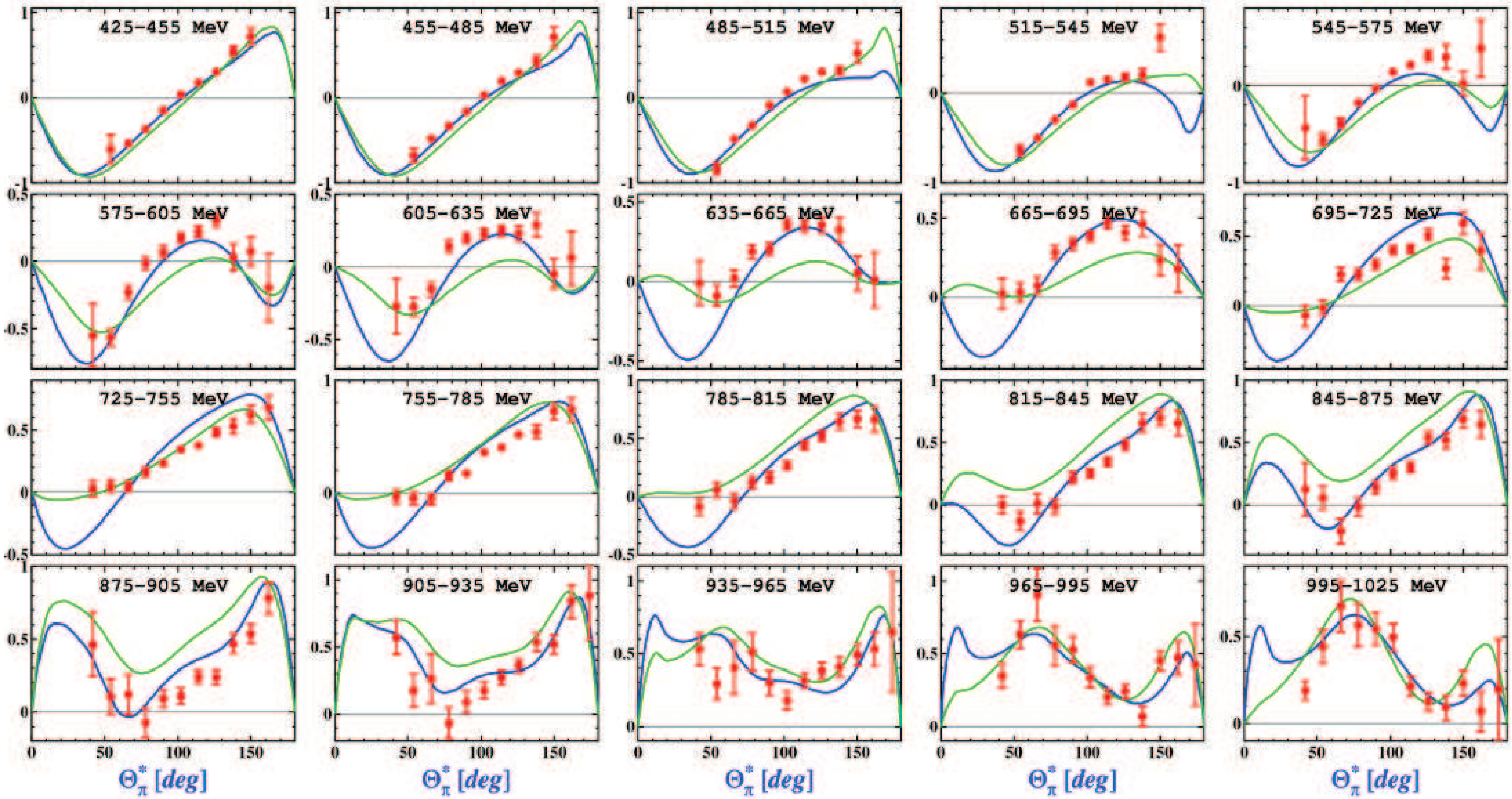
Note: preliminary dilution factor

CBALL (MAMI) $\vec{\gamma}\vec{p} \longrightarrow p\pi^0$ (H.-J. Arends at NSTAR)

Circularly polarised photons, transversally polarised target

Double polarization observable F

blue line – MAID-2007
green line – SAID

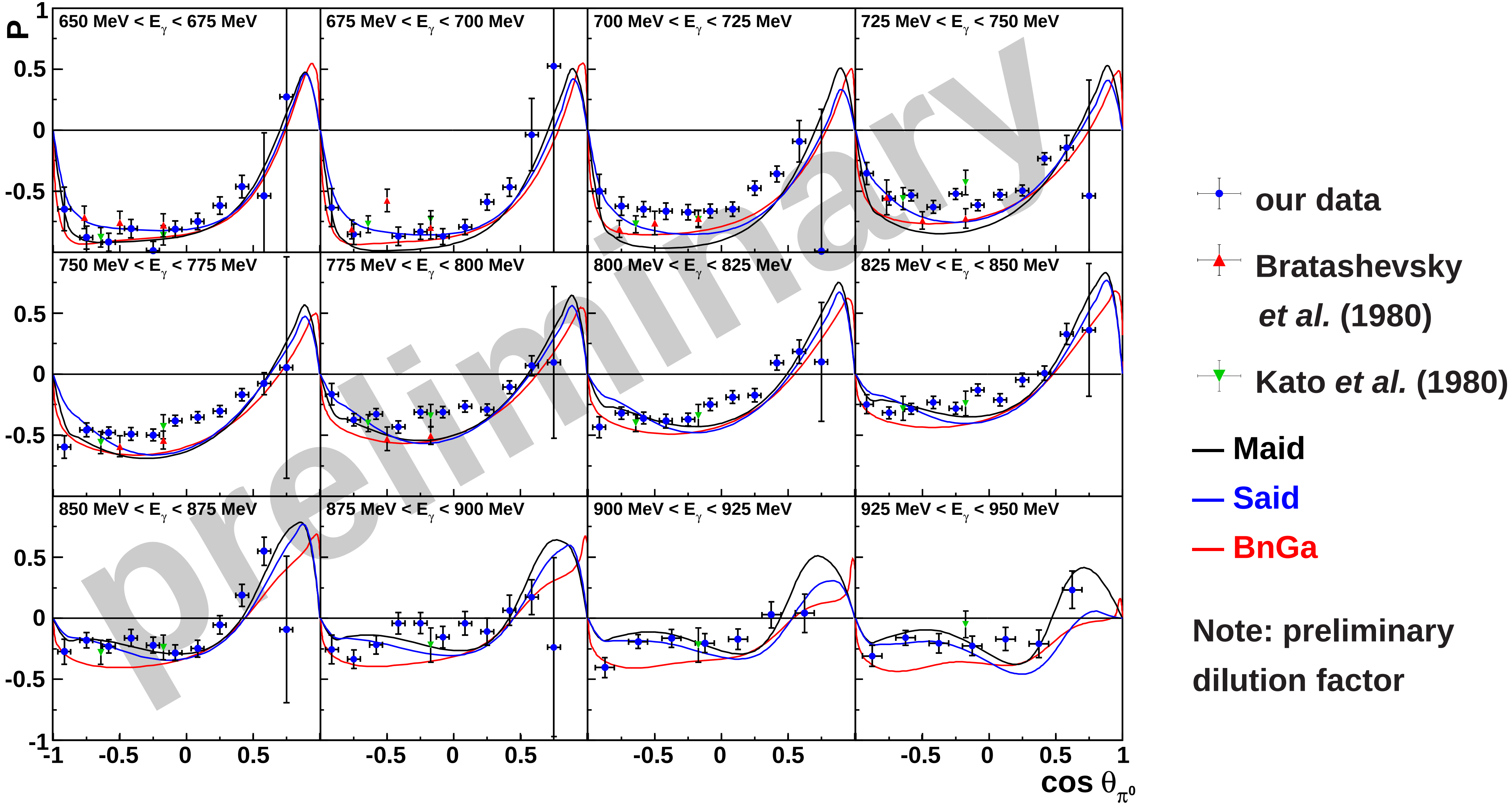


preliminary results

CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\pi^0$ (J. Hartmann, Bonn)

Linearly pol. photons, transversally polarised target

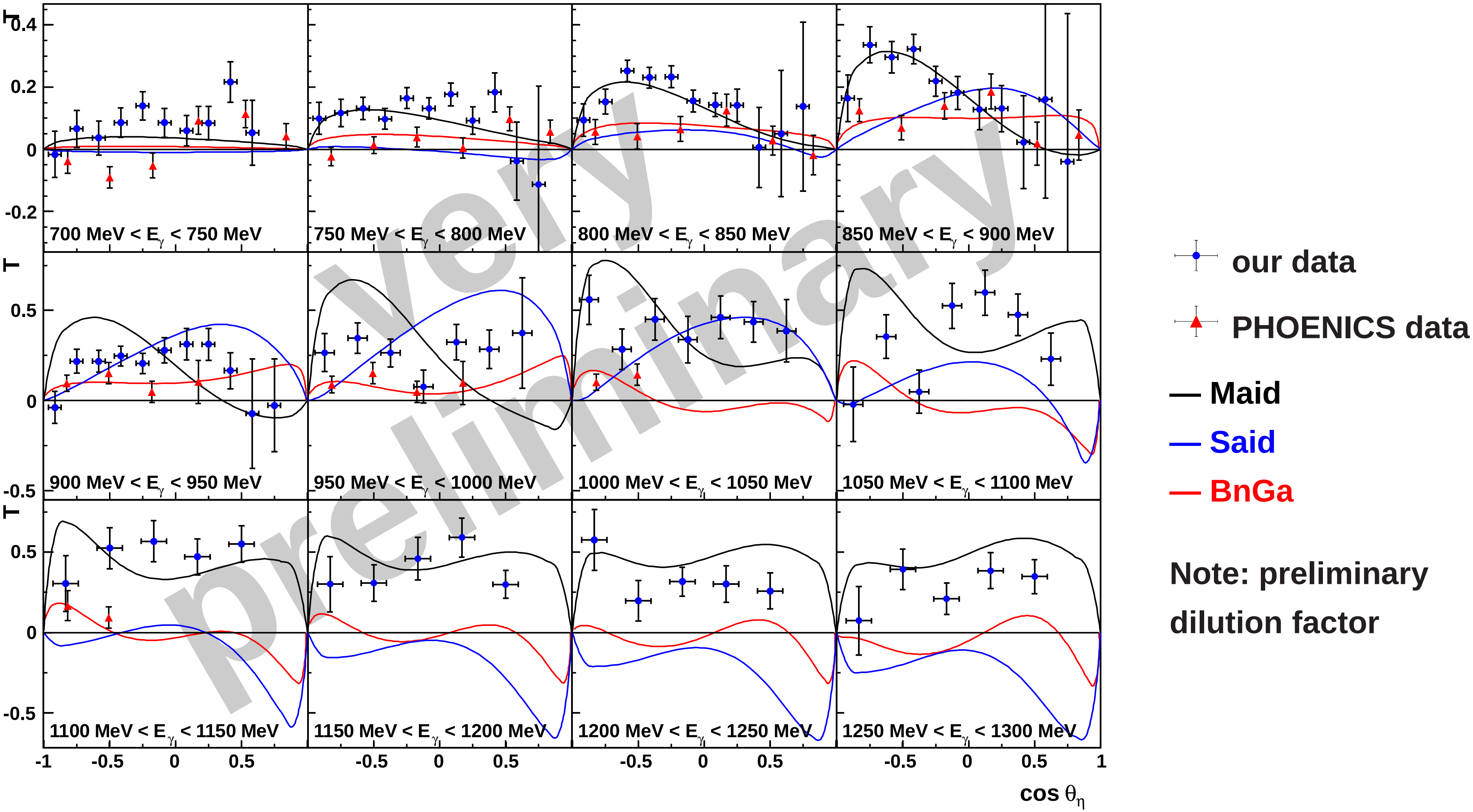
Measurement of the recoil polarisation



Note: preliminary dilution factor

CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\eta$ (J. Hartmann, Bonn)

Transversally polarised target



Note: preliminary dilution factor

Strong deviations between PWAs and pol. obs. also for P and H

Summary

- Our experimental knowledge of the spectrum and the properties of baryons is steadily increasing !

$\longleftrightarrow$ Important contributions from photo-(electro-) production experiments
(single and double polarisation experiments)
- allow in contrast to $\pi N \longrightarrow \pi N$ the measurement of inelastic channels !

Experiment: - no alternating pattern of positive and negative parity states
- parity doublets observed (not for all states (?))
- Baryons fall on Regge-trajectories, Why ?

$\Longrightarrow$ Quarkmodels/first lattice calculations do not provide the expected systematics in the spectrum

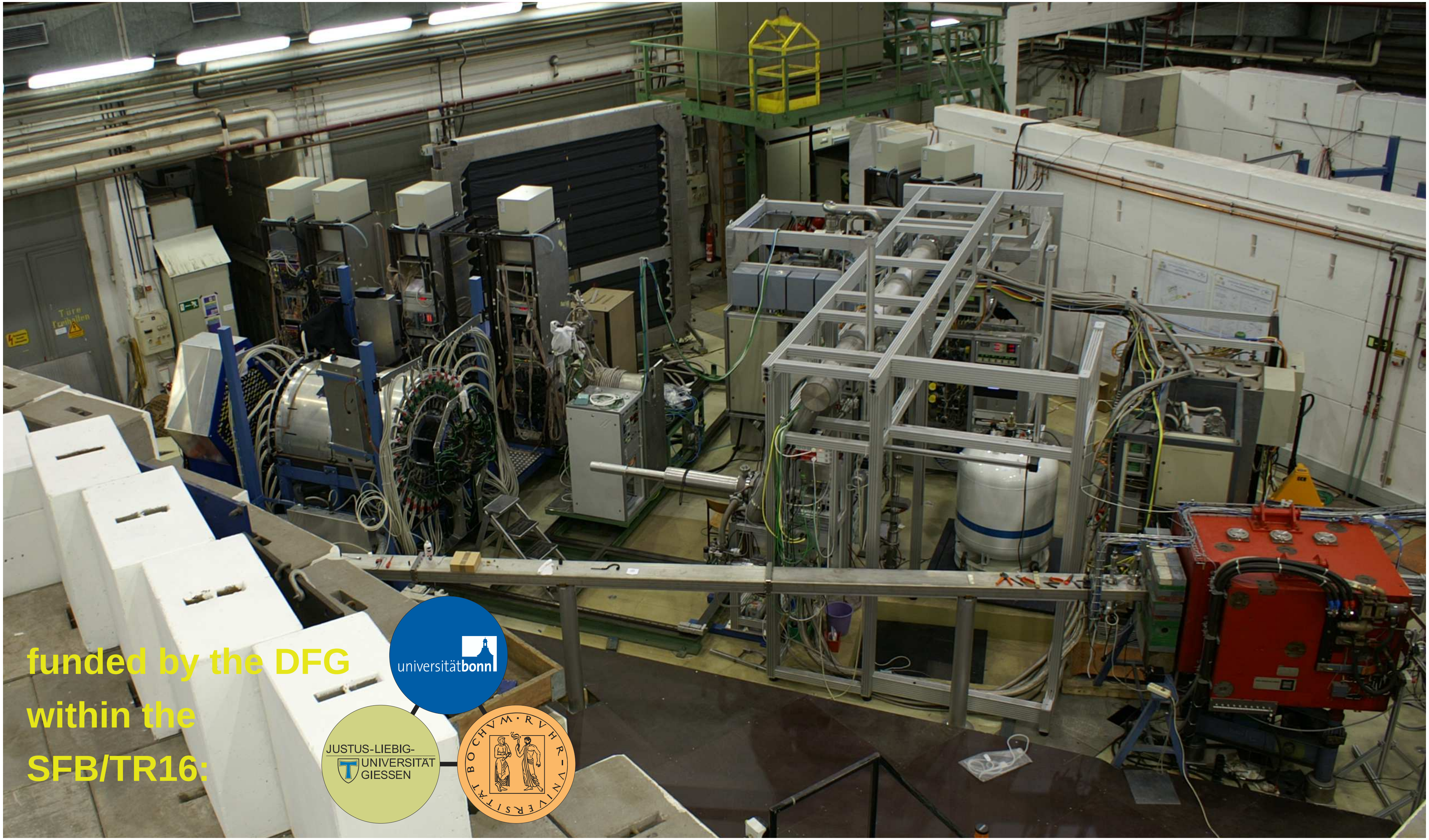
- some states can be generated dynamically from their decays ....
do they occur in addition to the expected 3q-states (SU(3)) ?

New experimental information from the double polarisation experiments

$\Longrightarrow$ provide a more complete picture of the baryon spectrum !

= Detailed testing ground for models (e.g. dynamically generated resonances) and lattice QCD.

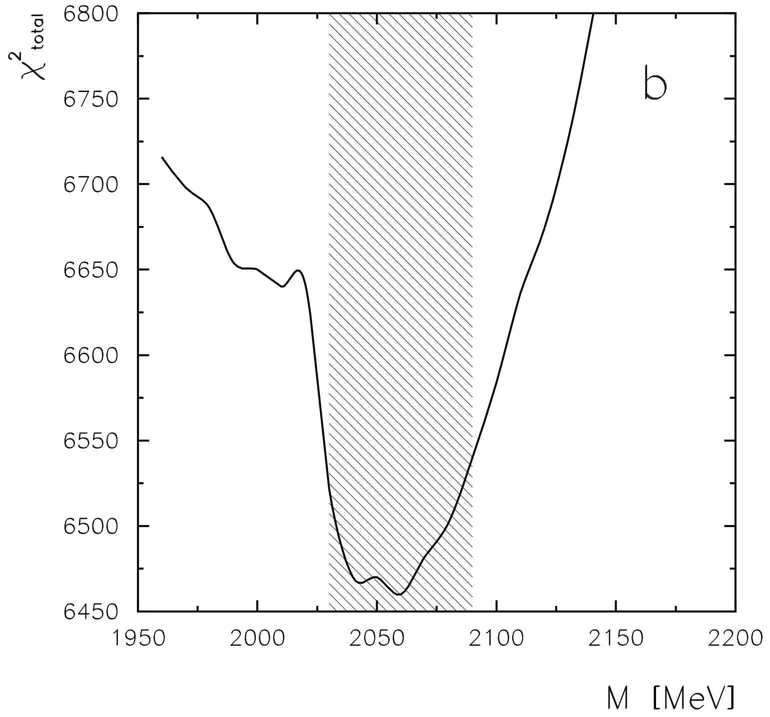
Thank you for your attention!



funded by the DFG
within the
SFB/TR16:

New D_{15} -state

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



$N(2200)$ D_{15} $I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ Status: ∗∗

OMITTED FROM SUMMARY TABLE

The mass is not well determined. A few early results have been omitted.

$N(2200)$ BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2200 OUR ESTIMATE				
1900	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
2180±80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1920	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
2228±30	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2240±65	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$

varies strongly !

$N(2200)$ BREIT-WIGNER WIDTH

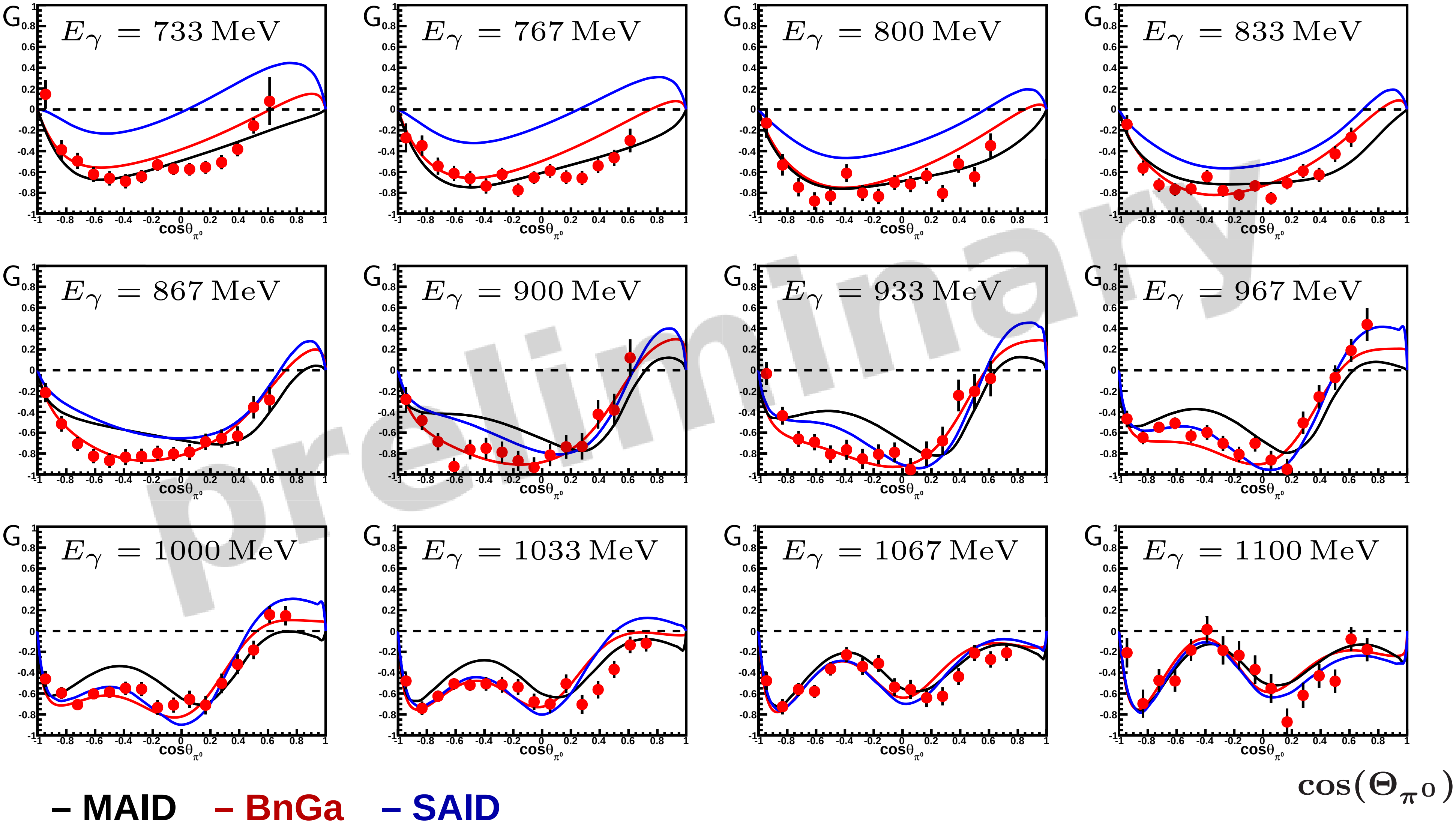
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
130	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
400±100	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
220	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
310± 50	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
761±139	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$

⇔ Results vary strongly!

CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\pi^0$ (A. Thiel, Bonn)

Linearly polarised photons, longitudinally polarised target

$$\frac{d\sigma}{d\Omega}(\Phi) = \frac{d\sigma}{d\Omega_0} \cdot \left(1 - P_\gamma^{lin} \Sigma \cos(2\phi) + P_\gamma^{lin} P_z G \sin(2\phi)\right)$$

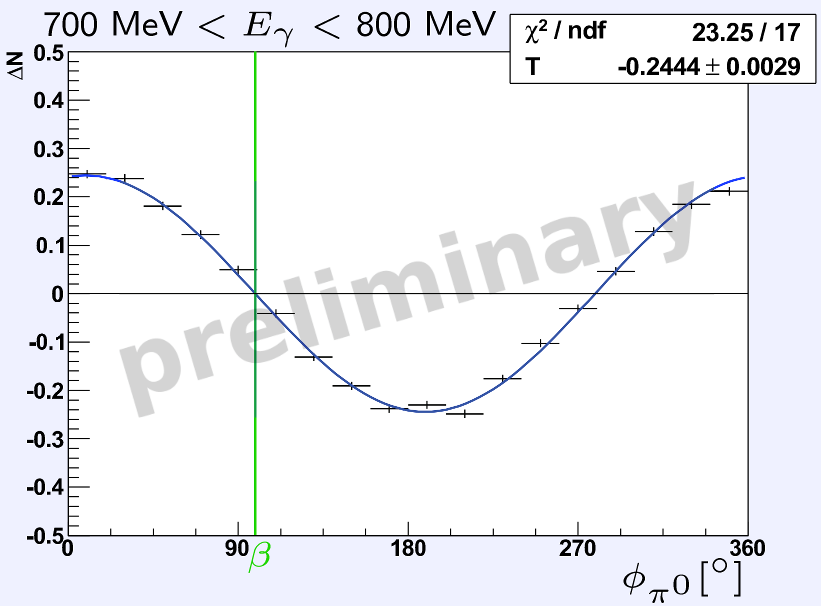


Target Asymmetry T

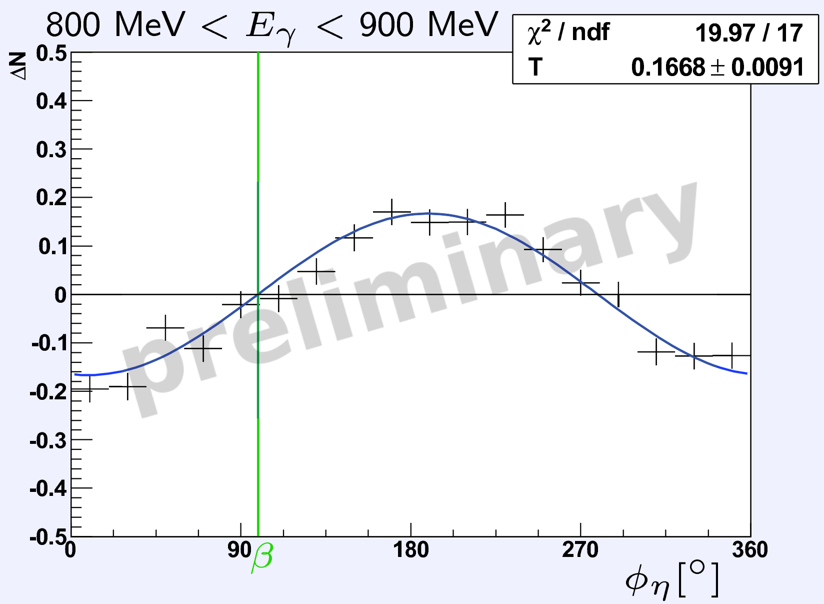
- unpolarized beam
- transversely polarized target (direction of pol.: $\beta = 99^\circ$)

$$\Delta N(\phi) = \frac{1}{f P_{\text{target}}} \cdot \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = T \cdot \sin(\phi - \beta)$$

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



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



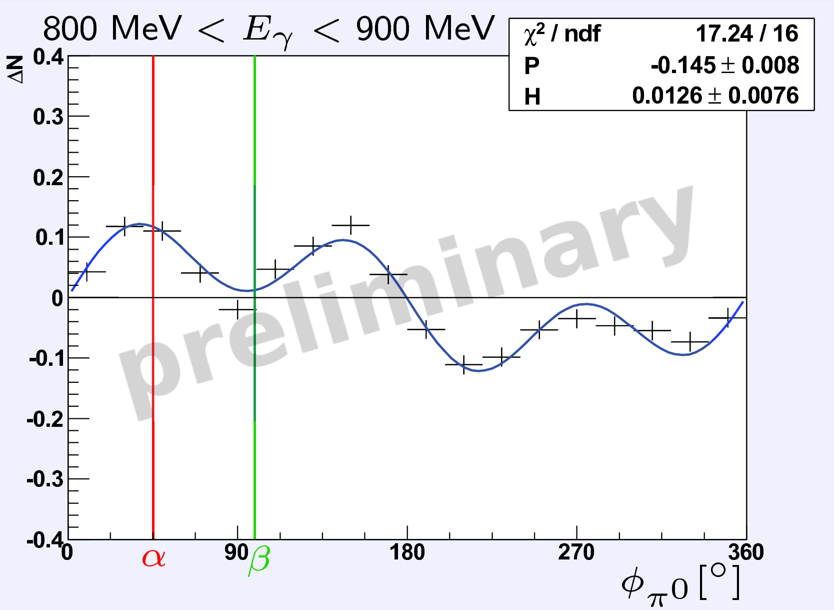
Recoil Polarization P and Observable H

- linearly polarized photon beam (angle of pol. plane: $\alpha = 45°$)
- transversely polarized target (direction of pol.: $\beta = 99°$)

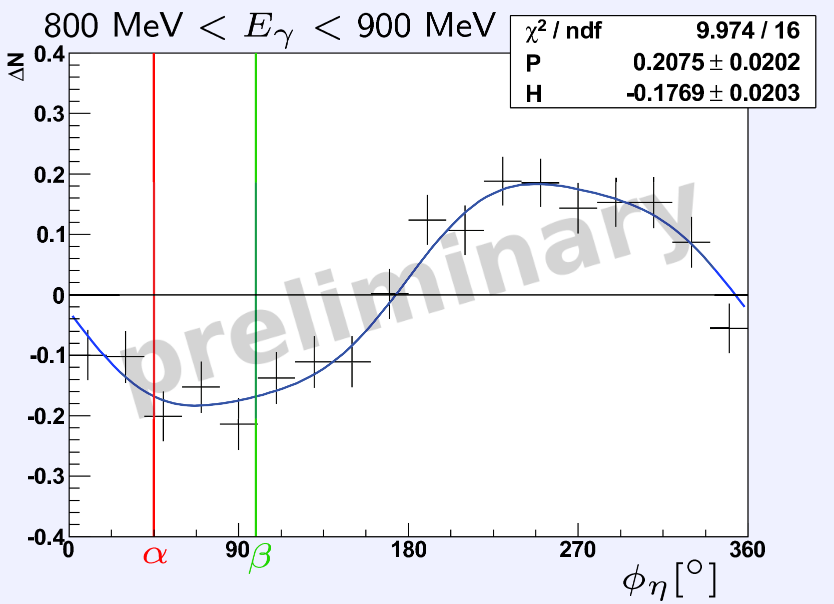
$$\Delta N(\phi) = \frac{1}{f P_{\text{beam}} P_{\text{target}}} \cdot \frac{(N_{\perp\uparrow} - N_{\perp\downarrow}) - (N_{\parallel\uparrow} - N_{\parallel\downarrow})}{(N_{\perp\uparrow} + N_{\perp\downarrow}) + (N_{\parallel\uparrow} + N_{\parallel\downarrow})}$$

$$= (P \sin(\phi - \beta)\cos(2(\phi - \alpha)) + H \cos(\phi - \beta)\sin(2(\phi - \alpha)))$$

$\vec{\gamma}\vec{p} \to p\pi^0$

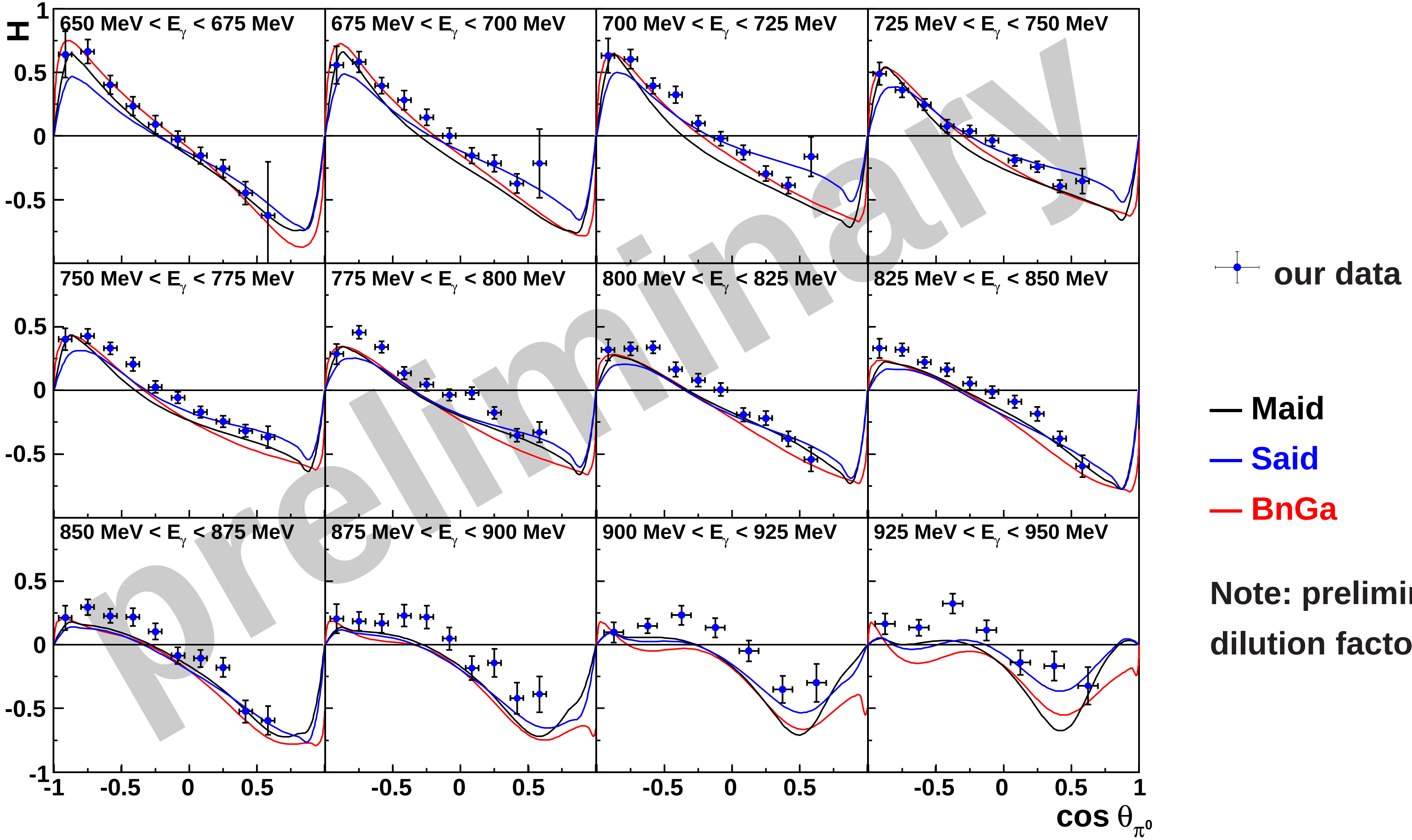


$\vec{\gamma}\vec{p} \to p\eta$



CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\pi^0$ (J. Hartmann, Bonn)

Linearly pol. photons, transversally polarised target

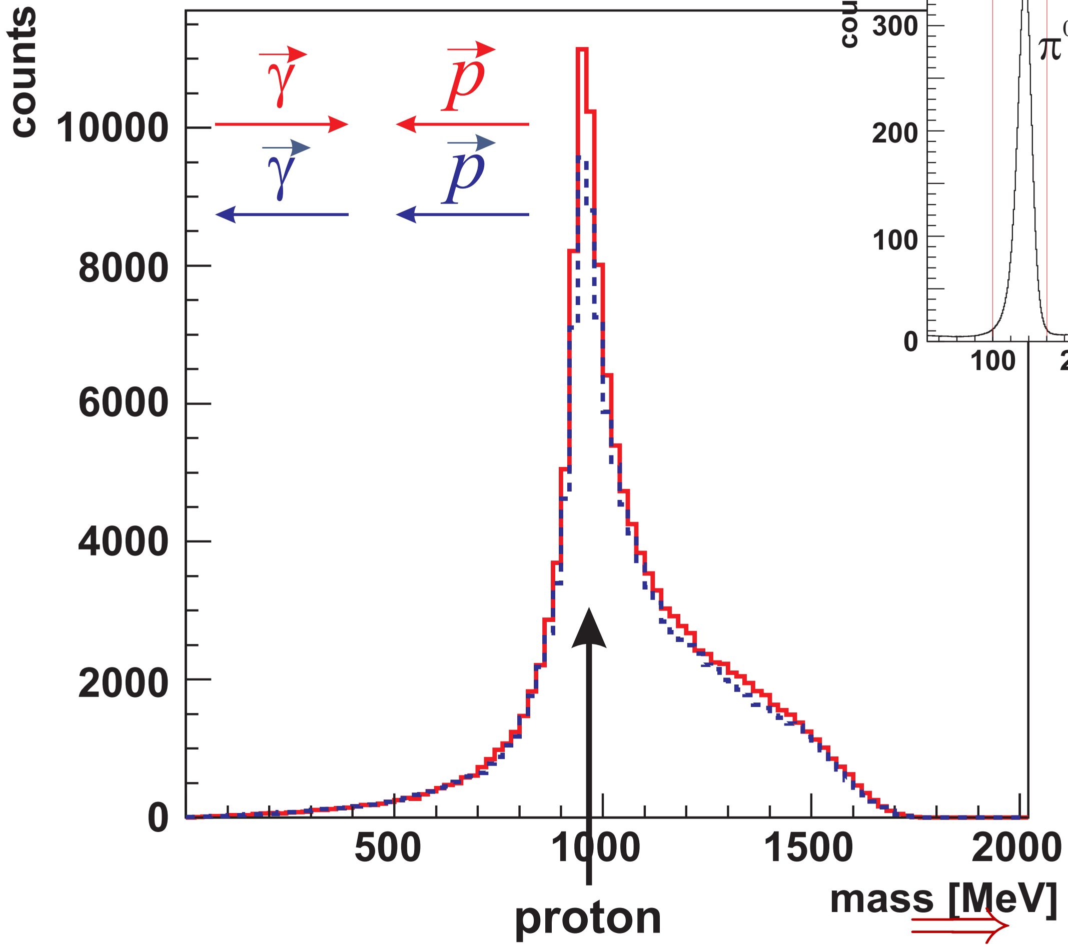


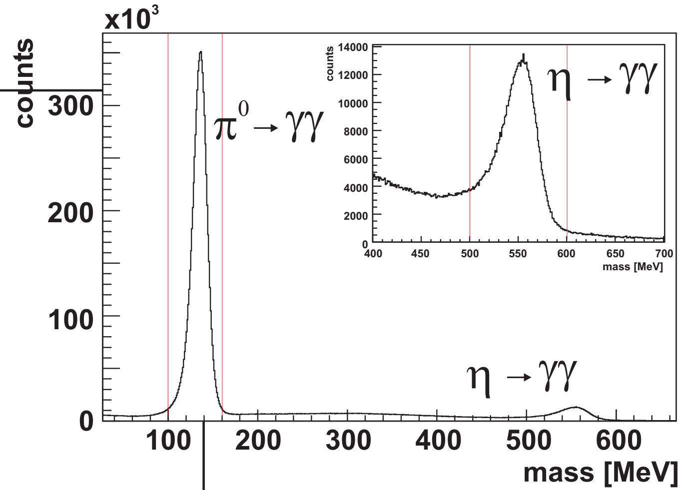
Note: preliminary dilution factor

Double Polarisation Experiments at ELSA

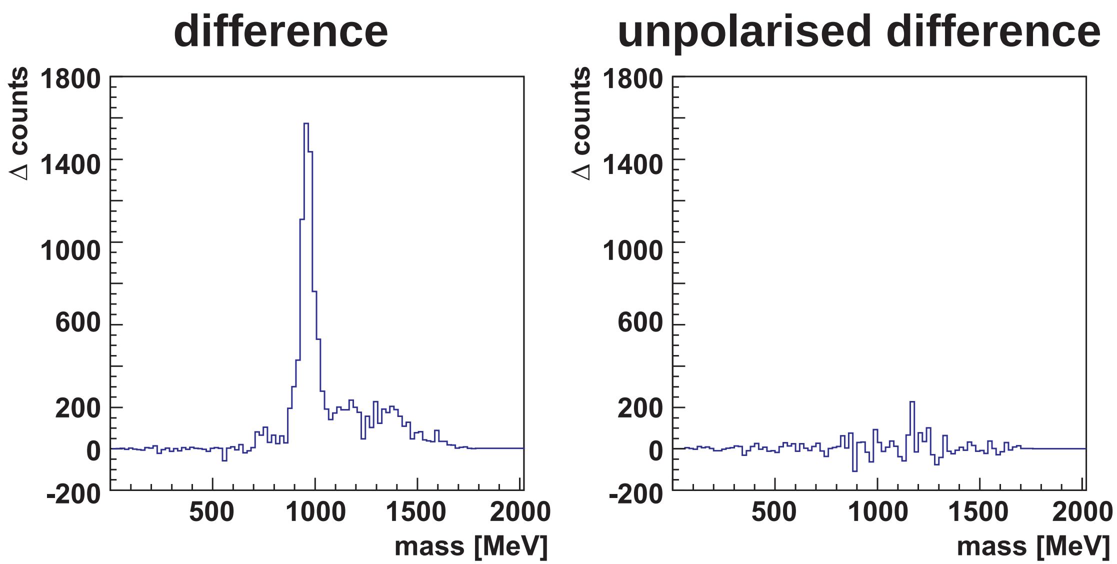
Online spectra: circularly polarised beam, longitudinally polarised target

$\gamma p \longrightarrow p\eta$:





$\gamma p \longrightarrow p\gamma\gamma$

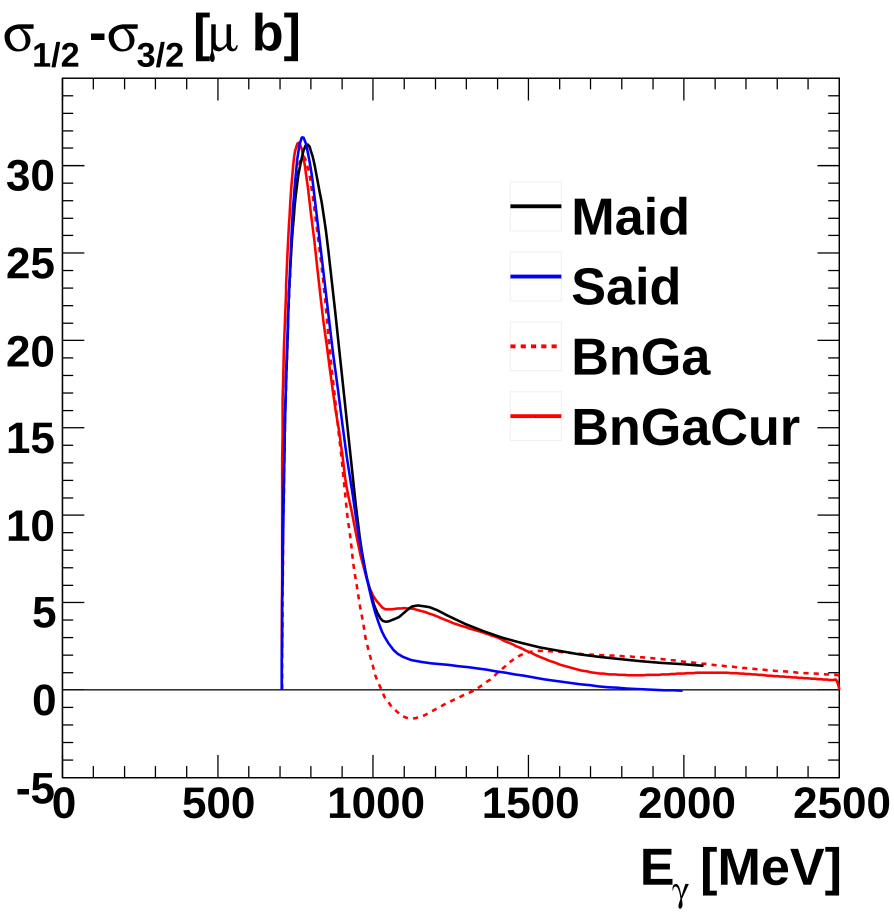


$\Rightarrow$ **Clear asymmetries observed**

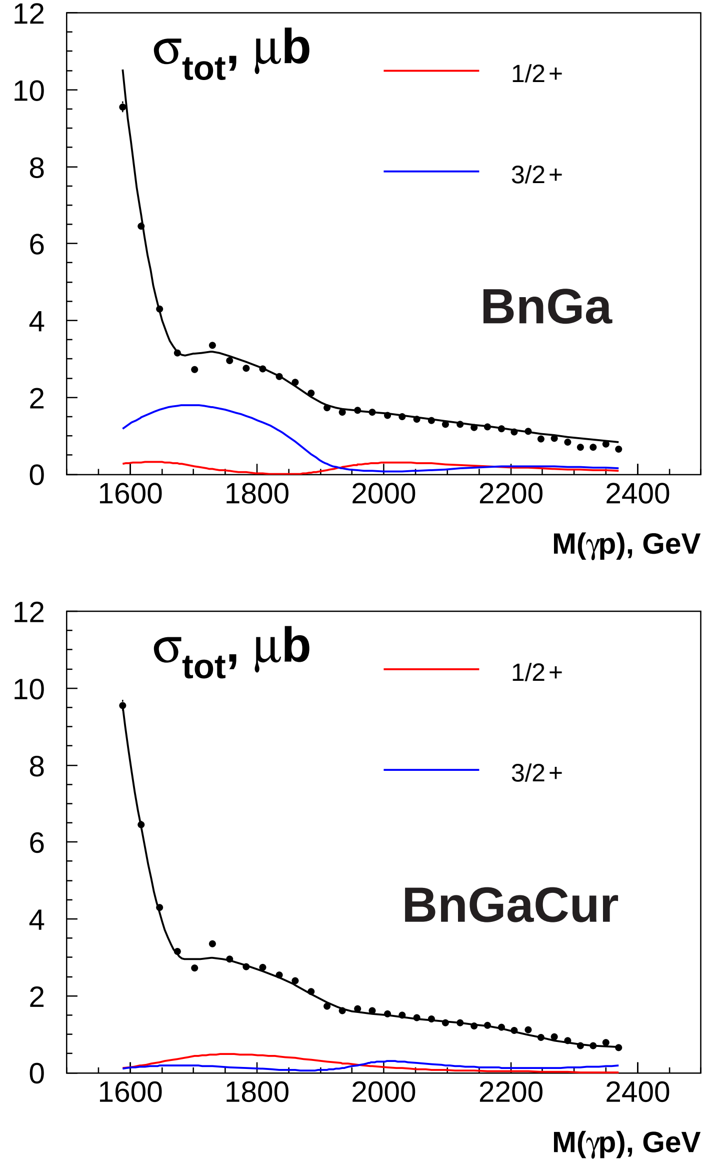
Double polarisation experiments $\vec{\gamma}\vec{p} \longrightarrow p\eta$

Circularly polarised photons, longitudinally polarised target

BnGa-PWA:

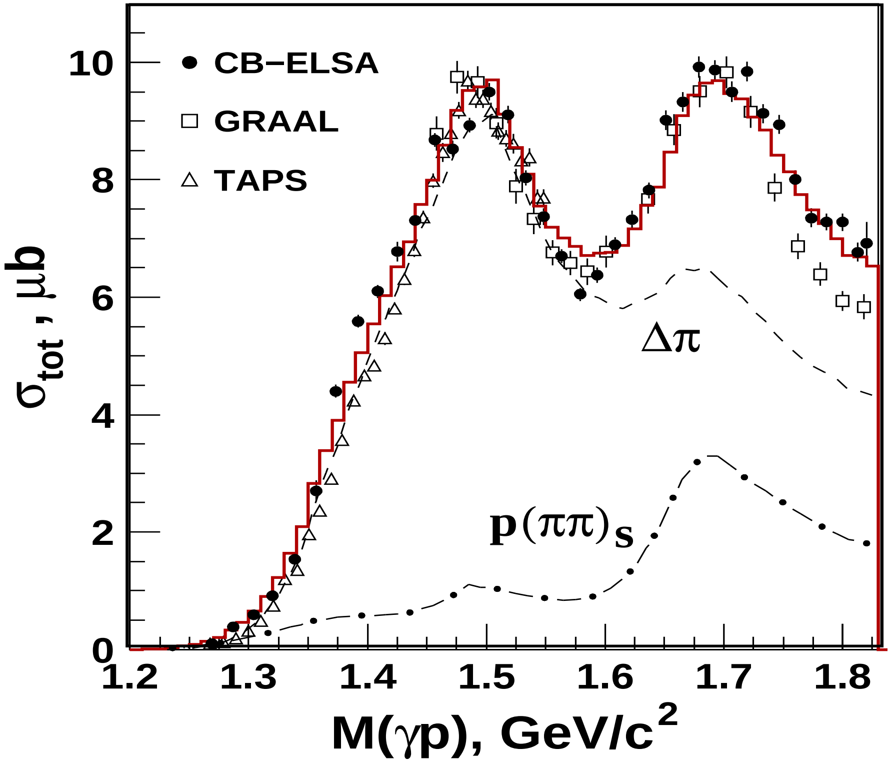


$\gamma p \longrightarrow \eta p$



$\gamma p \longrightarrow p\pi^0\pi^0$

U. Thoma et al., PLB 659 (2008) 87



CB-ELSA Fit including additional data from:

- single meson photoproduction,
- $\pi^- p \longrightarrow n 2\pi^0$ (CBall),
- P_{11}, S_{11}, P_{33}, D_{33}- πN-partial waves

$\longleftrightarrow$ **Event based maximum likelihood fit**

$\Rightarrow$ **Determination of resonance properties:**

m , Γ_i $(\Delta\pi^0, N\sigma, P_{11}\pi, D_{13}\pi, +...)$

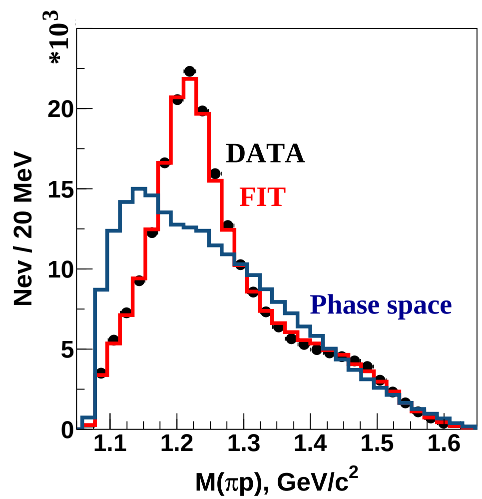
Results contradicting naive expectation:

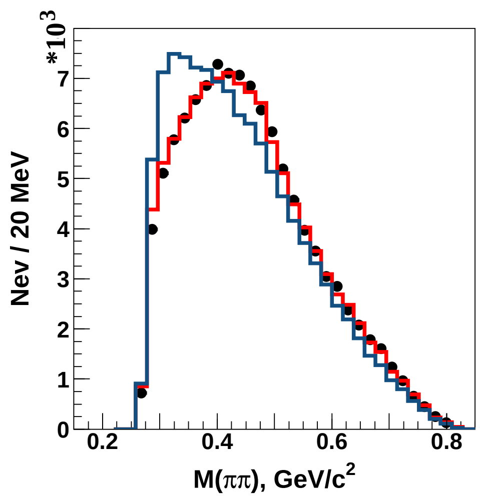
e.g.: $D_{13}(1520) \longrightarrow \Delta\pi$ decay with L=0 $\approx$ L=2

$D_{13}(1700) \longrightarrow \Delta\pi$ decay with L=0 $<$ L=2

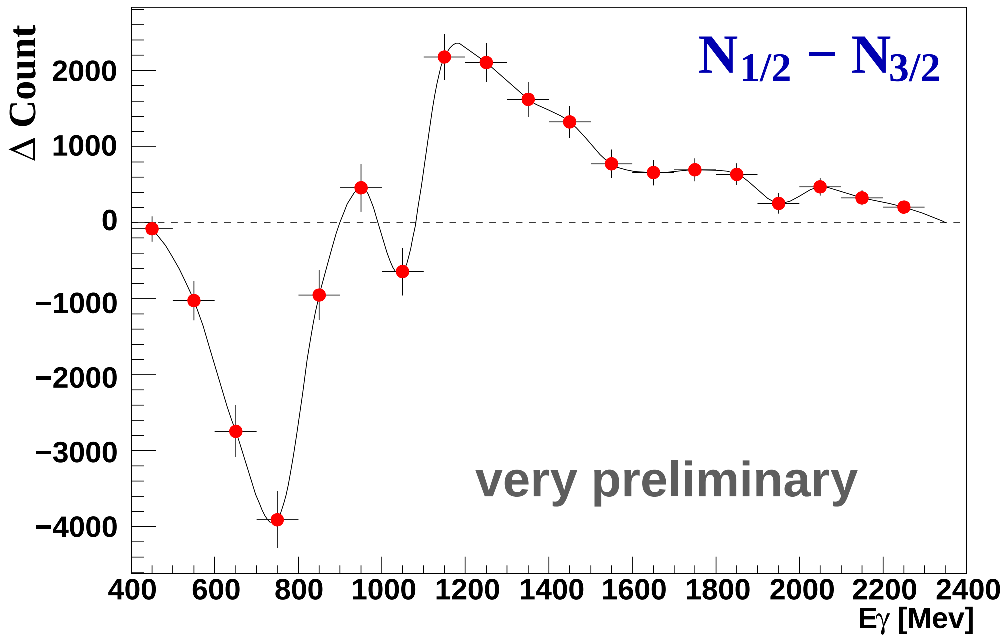
$D_{33}(1700) \longrightarrow \Delta\pi$ decay with L=0 or L=2

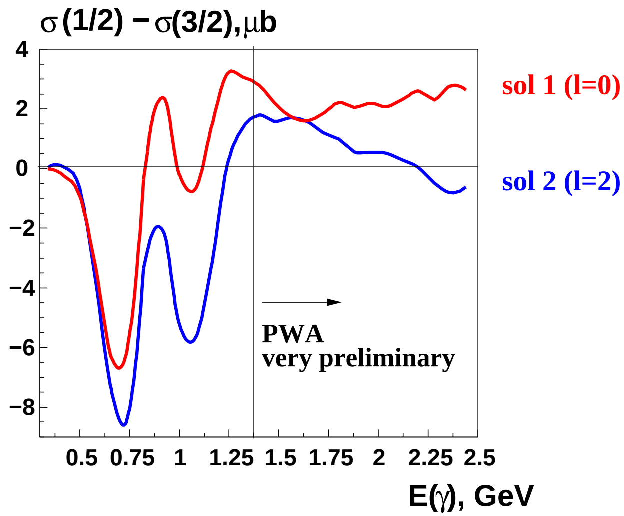
$\longrightarrow$ **Measurement of double polarisation observables necesarry**



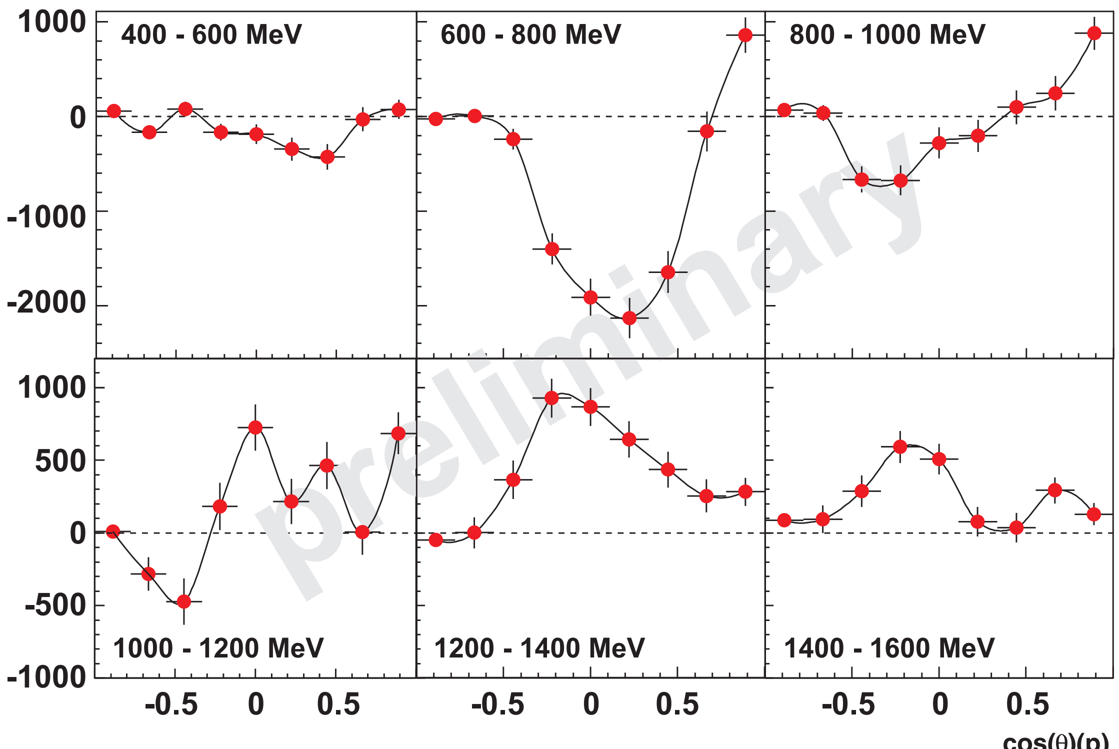


CBELSA/TAPS data $\vec{\gamma}\vec{p} \longrightarrow p\pi^0\pi^0$ (D.Piontek, Bonn)





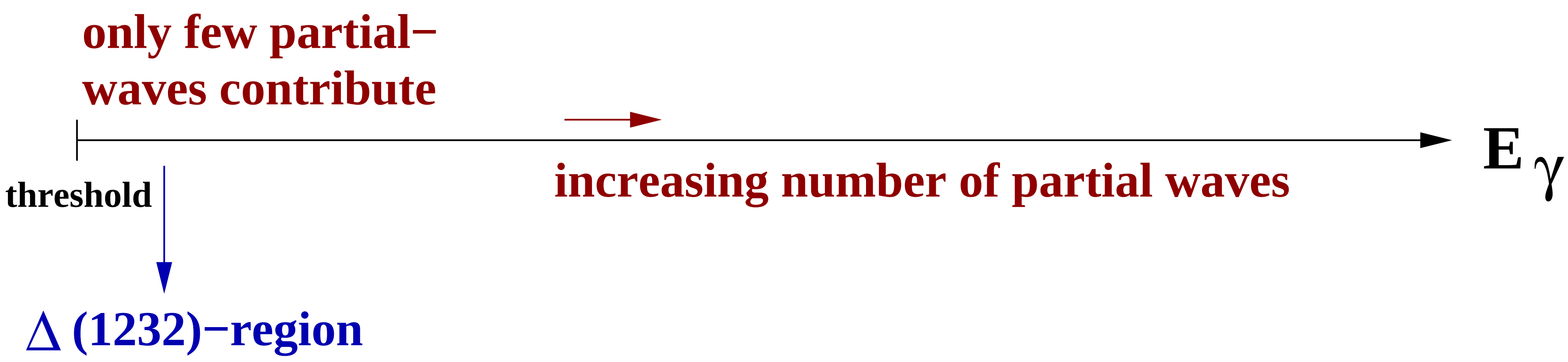
$\cos\theta_p$-distributions:



Count rate differences plotted

first look into differential distributions (preliminary)

Motivation



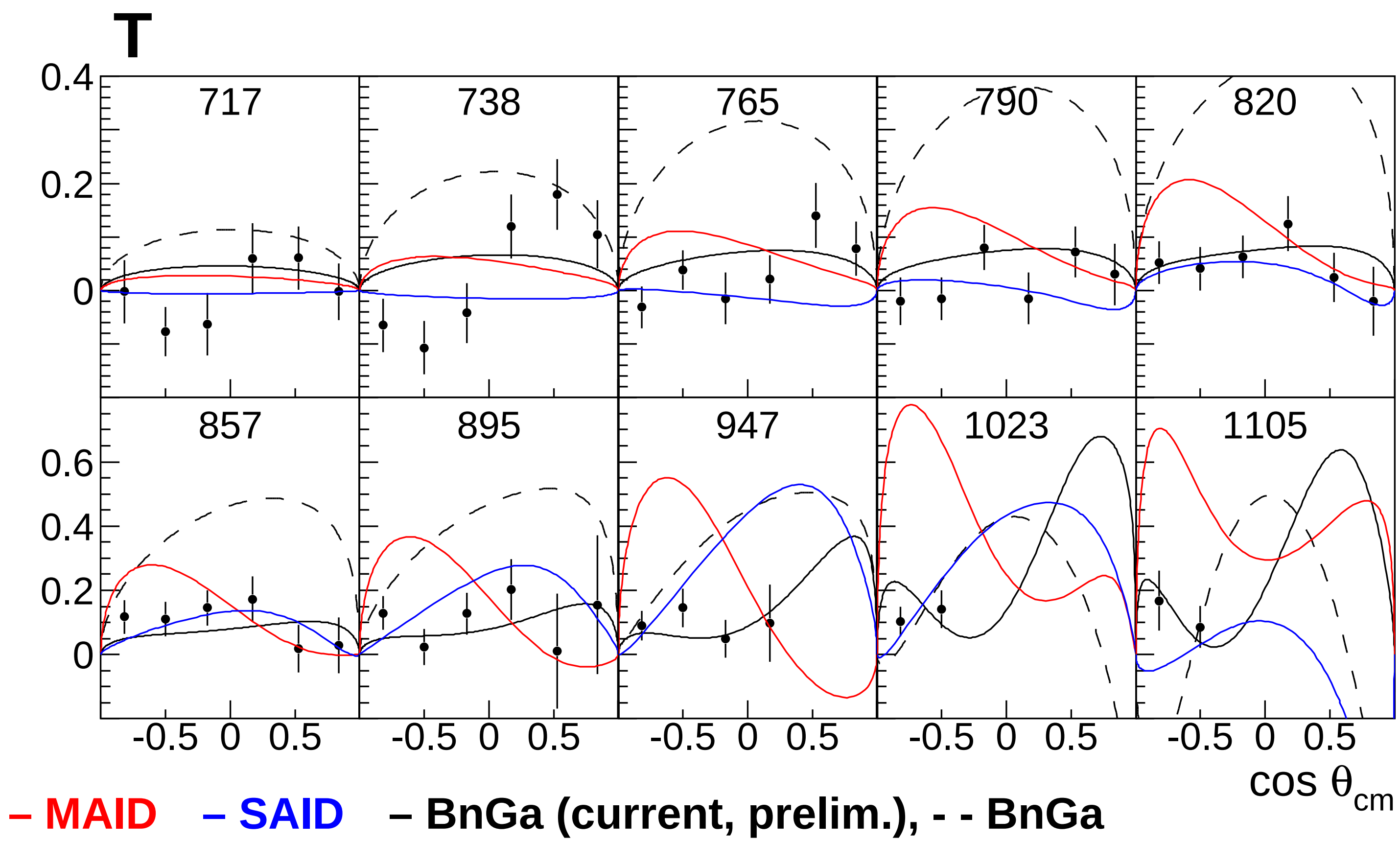
Low energy regime:

$\gamma p \longrightarrow p\eta$:

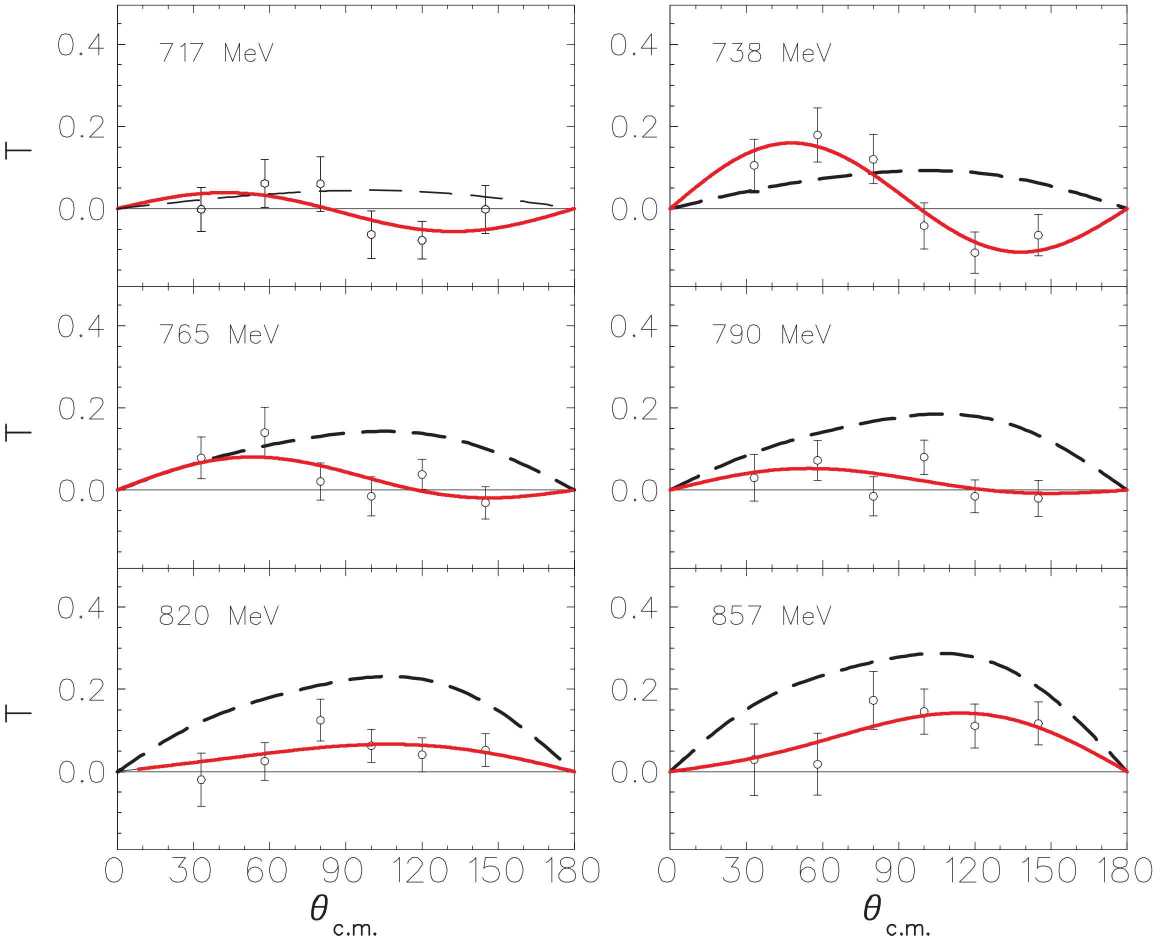
PHOENICS data on T

⇒ **isobar models fail to describe the data**

⇒ **big differences between the different solutions**

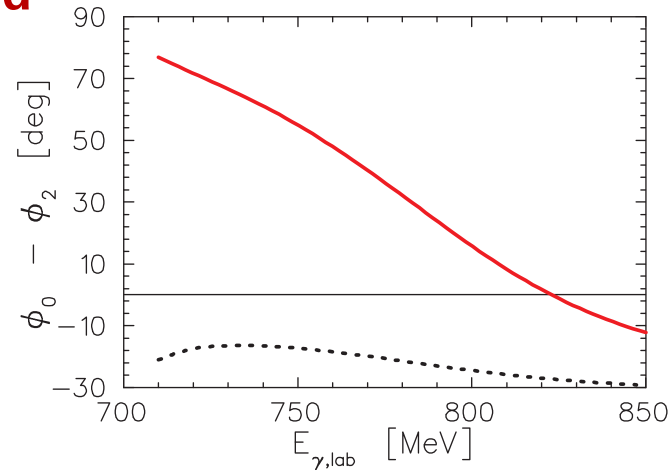


Polarisation observable T in η-photoproduction



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

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



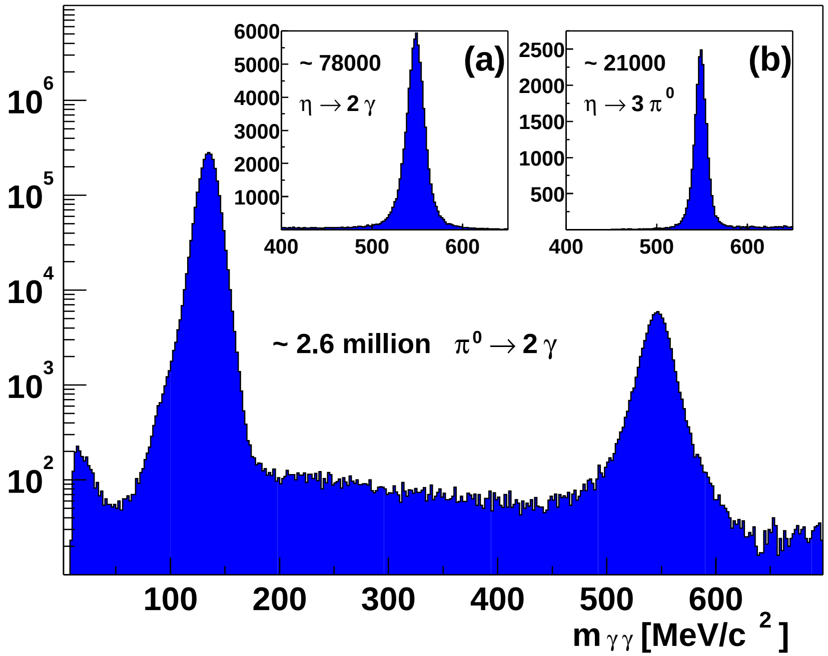
$\Rightarrow$ Energy dependent phase $\leftrightarrow$ origin presently not understood

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

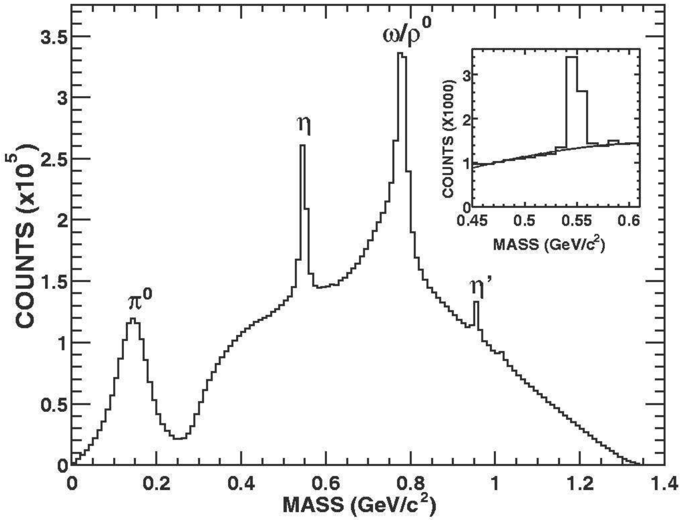
$\Rightarrow$ Cross check and improve the precision of the existing data !

η - Photoproduction

CB-ELSA:



CLAS:



$\gamma p \longrightarrow p\,\eta$:

$\eta \longrightarrow \gamma\gamma$

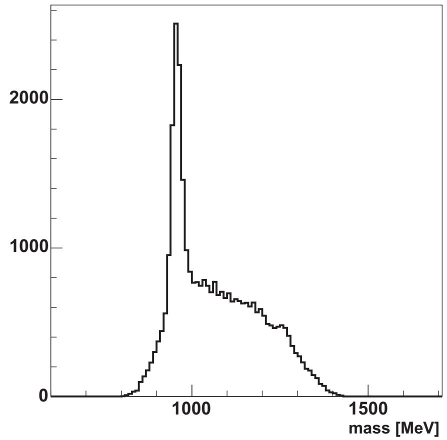
$\eta \longrightarrow 3\pi^0$

$\longrightarrow$ Proton detected

$\longrightarrow$ η from missing mass

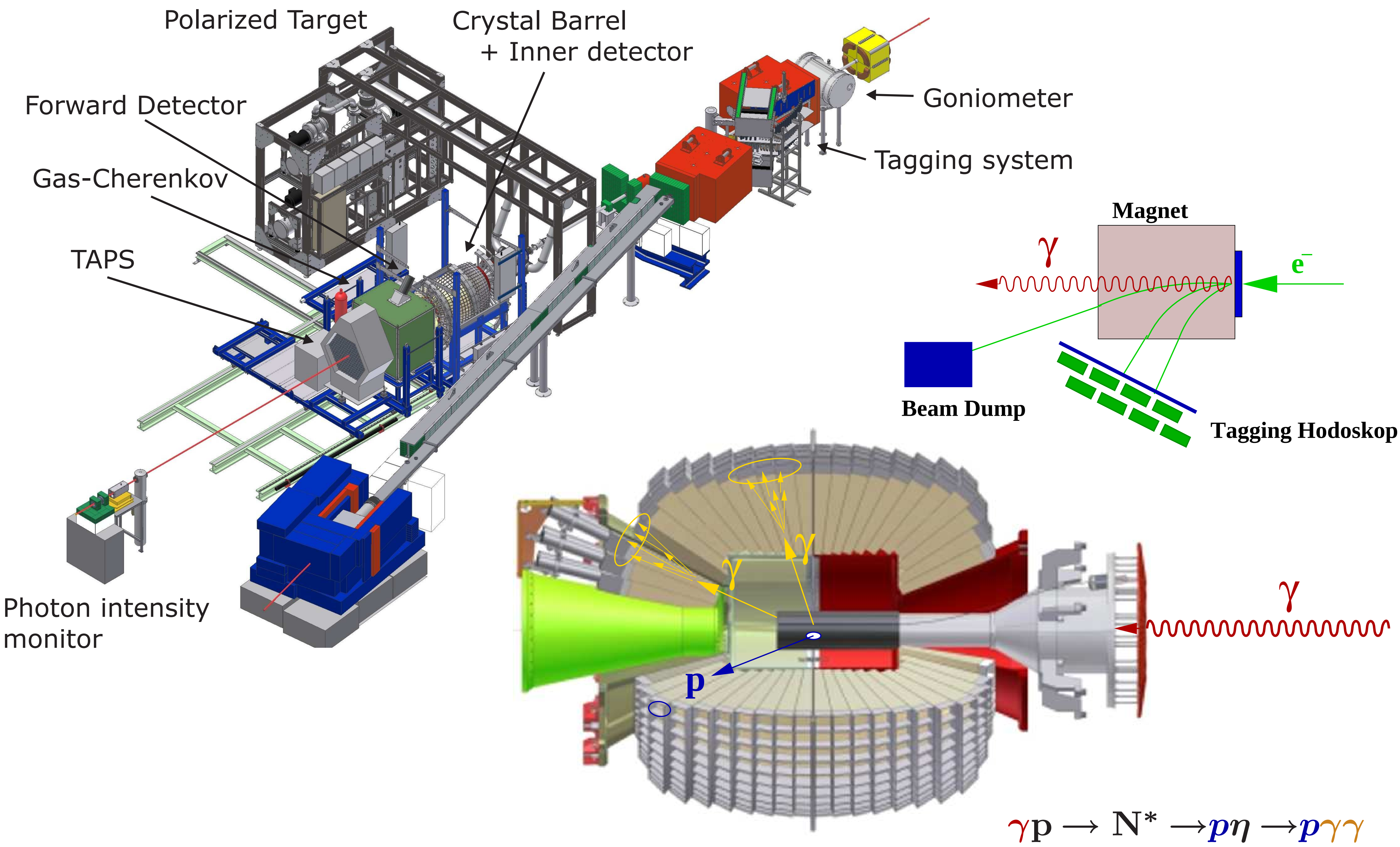
$\longrightarrow$ Photons are detected

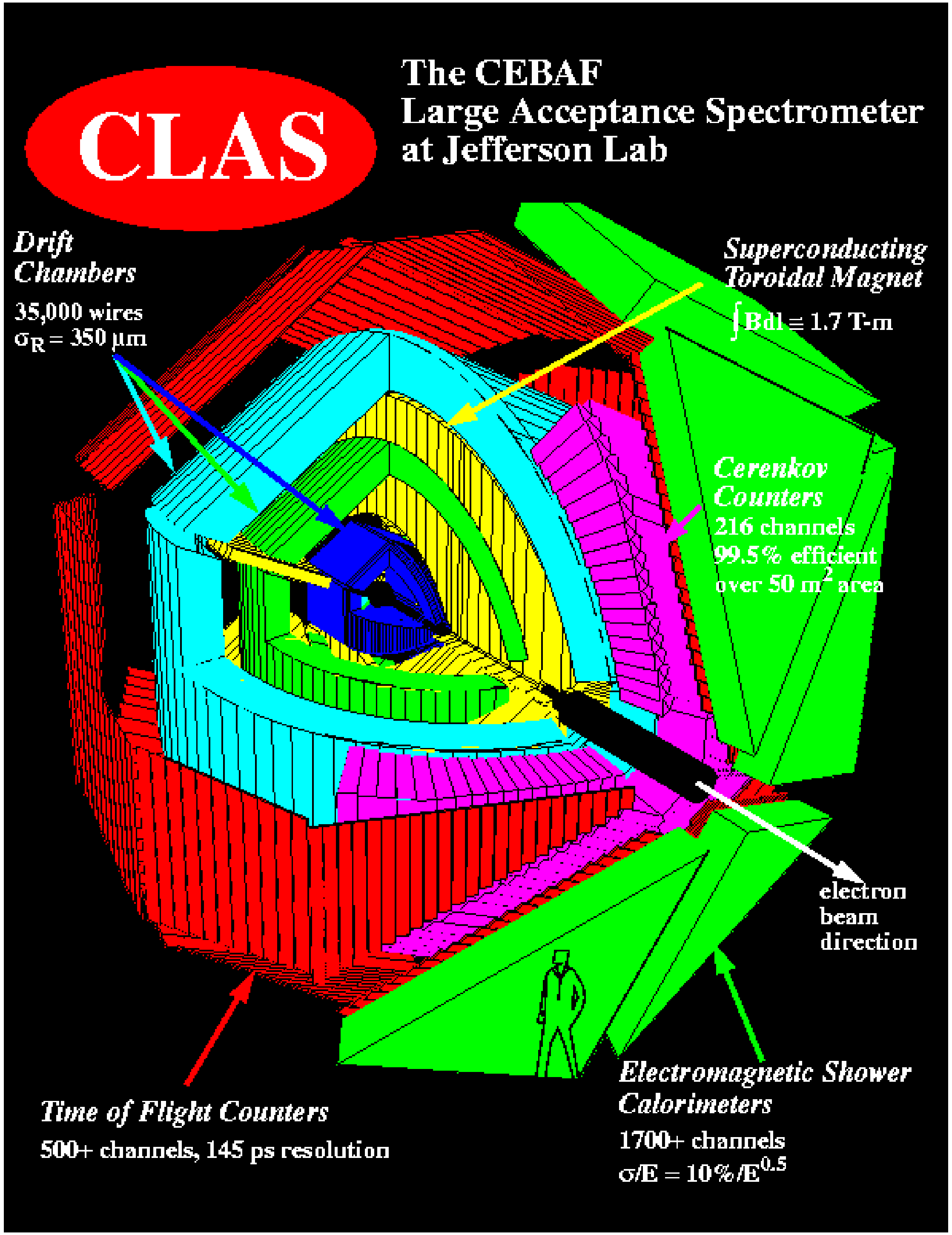
$\longrightarrow$ Proton direction measured



$\eta' \longrightarrow \pi^0\pi^0\eta$

The Crystal Barrel Experiment at ELSA





The CLAS Experiment at Jefferson Lab

- very well suited to measure charged particles

- photo- and electroproduction experiments

Number of polarisation amplitudes needed

differential cross section:

$$\frac{d\sigma}{d\Omega} \sim \sum_{f,i} | < f|T|i > |^2$$

using helicity amplitudes: $H^{f}_{\gamma,i} =< \lambda_f|T|\lambda_i >$

$$H_1 = H^{1/2}_{1,1/2} \quad = \quad < 1/2 \quad |T| \quad 1 \quad 1/2 >$$

$$H_2 = H^{1/2}_{1,-1/2} \quad = \quad < 1/2 \quad |T| \quad 1 \quad -1/2 >$$

$$H_3 = H^{-1/2}_{1,1/2} \quad = \quad < -1/2 \quad |T| \quad 1 \quad 1/2 >$$

$$H_4 = H^{1/2}_{-1,1/2} \quad = \quad < 1/2 \quad |T| \quad -1 \quad 1/2 >$$

$$H_5 = H^{-1/2}_{-1,-1/2} \quad = \quad < -1/2 \quad |T| \quad -1 \quad -1/2 >$$

$$H_6 = H^{-1/2}_{-1,1/2} \quad = \quad < -1/2 \quad |T| \quad -1 \quad 1/2 >$$

$$H_7 = H^{1/2}_{-1,-1/2} \quad = \quad < 1/2 \quad |T| \quad -1 \quad -1/2 >$$

$$H_8 = H^{-1/2}_{1,-1/2} \quad = \quad < -1/2 \quad |T| \quad 1 \quad -1/2 >$$

Parity transformation:

$$\vec{x} \longrightarrow -\vec{x}$$

$$\vec{p} \longrightarrow -\vec{p}$$

$$\vec{s} \longrightarrow \vec{s}$$

$$\Rightarrow \lambda \longrightarrow -\lambda$$

(λ: projection of the spin on the momentum axis)