Baryon-Spectroscopy

Recent results from the Crystal Barrel/TAPS experiment at ELSA

U.Thoma, Bonn University

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

funded by the DFG
within the
SFB/TR16

universitätbonn

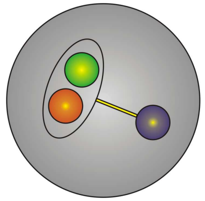
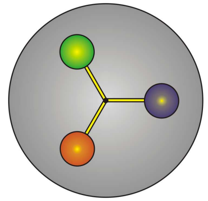
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

BOCHVM · RVHR-VNIVERSITAT

Baryon spectroscopy

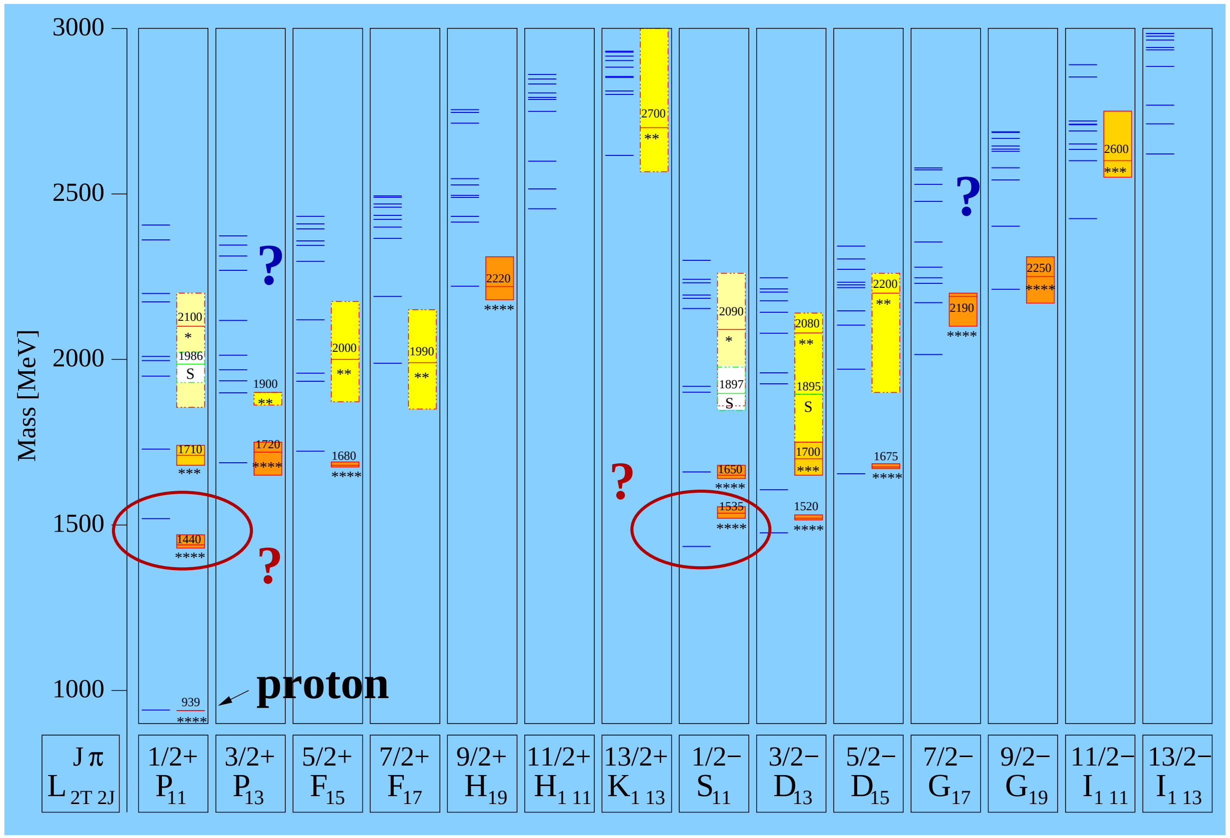
Aim: Good understanding of the spectrum and the properties of baryon resonances $\leftrightarrow$ bound states of strong QCD

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

e.g.:  or  ?

Symmetric quark models:

$\longrightarrow$ many more resonances expected than observed yet



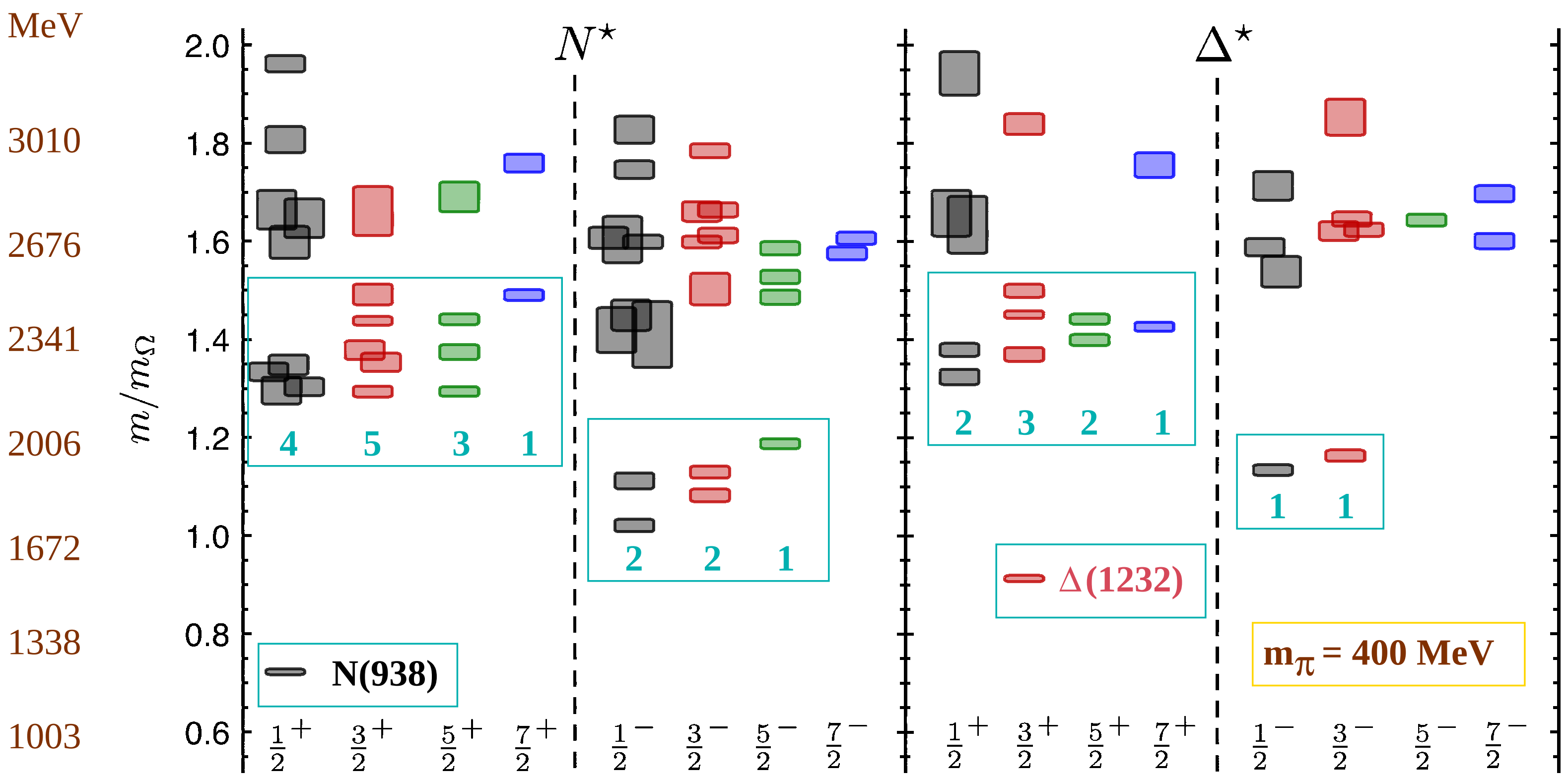
U. Loering, B. Metsch, H. Petry et al.

Constituent quarks
confinement potential
+ residual interaction

non-strange N^*-resonances

$\longleftrightarrow$ **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

$\longrightarrow$ Counting of levels consistent with non-rel. quark model

$\longrightarrow$ no parity doubling

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

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

$\longleftrightarrow$ 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. γp $\longrightarrow$ $\mathbf{N\eta,\ N\eta',\ N\omega,\ \Delta\pi,\ N\rho,\ \Delta\eta,}$ ...

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

Experimentally:

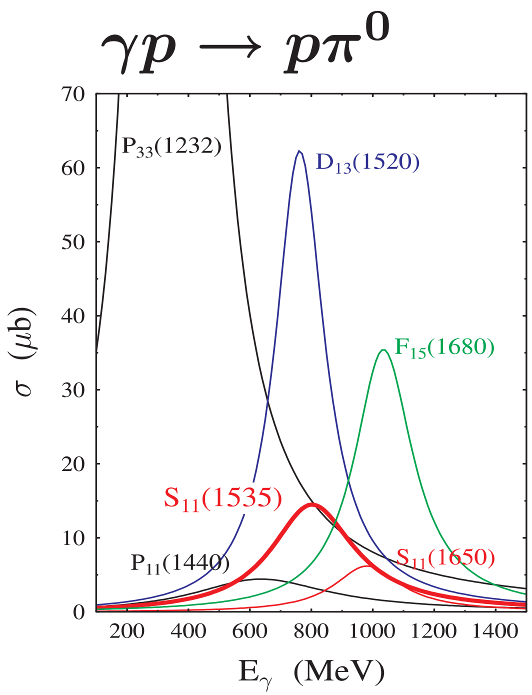
Broad strongly overlapping resonances

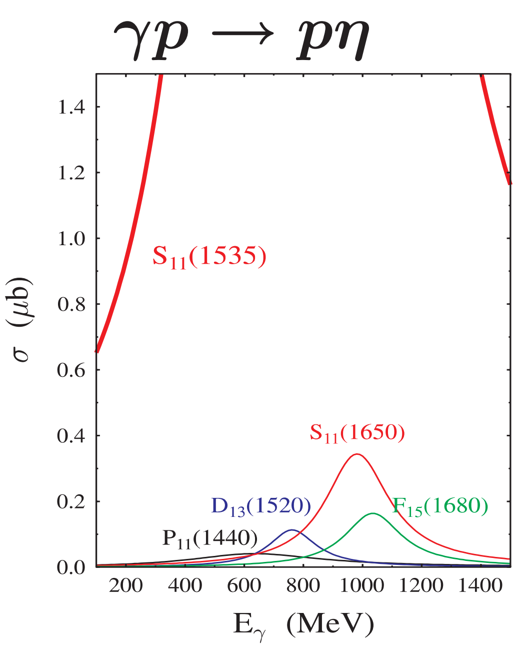
Important:

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

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

(multi-channel partial wave analysis)





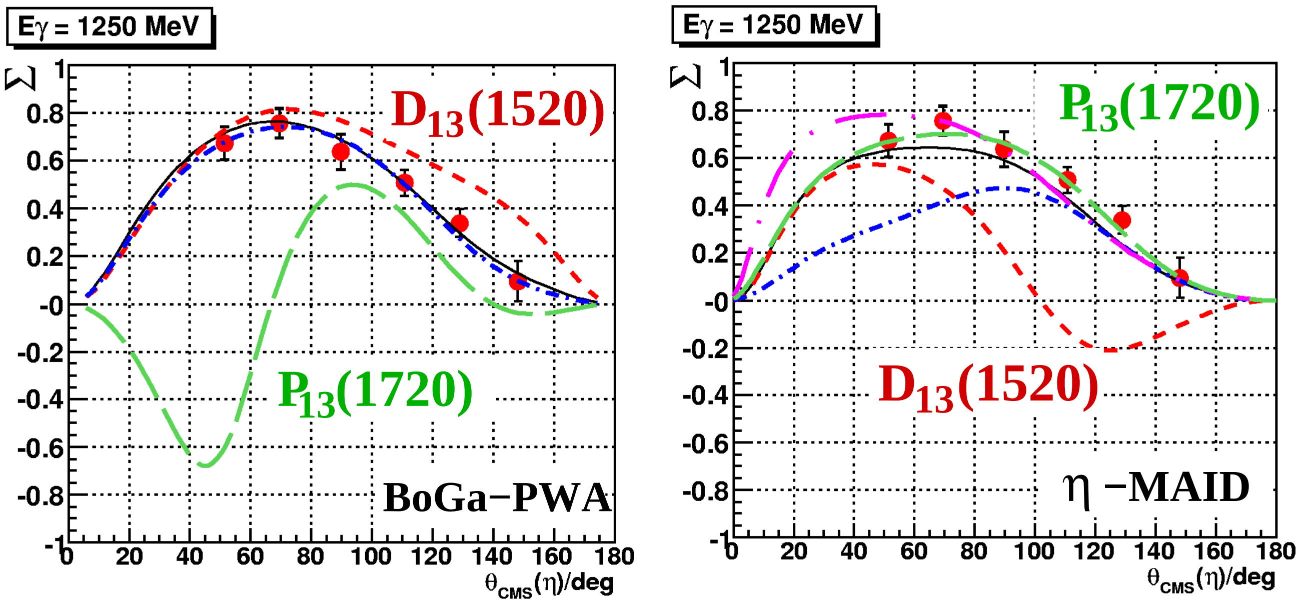
Measurement of polarisation observables

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. $\gamma p \longrightarrow p\eta$)

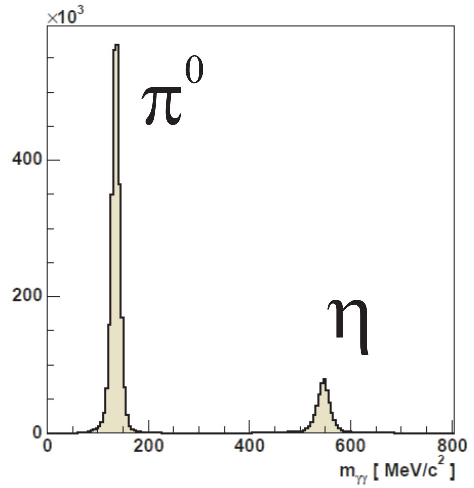
Photon		Target			Recoil			Target–Recoil			
					x'	y'	z'	x'	x'	z'	z'
		x	y	z				x	z	x	z
unpolarized	σ	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear	-Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	(-$L_{z'}$)	($T_{z'}$)	(-$L_{x'}$)	(-$T_{x'}$)
circularly	0	F	0	-E	$C_{x'}$	0	$C_{z'}$	0	0	0	0

At ELSA : Double polarisation experiments with polarised beam and polarised target

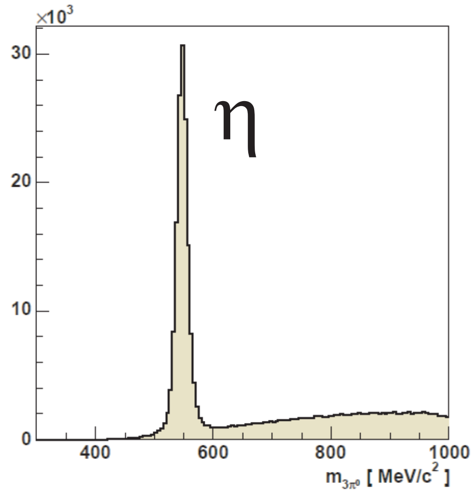
... but first some other results:

CBELSA/TAPS: η - Photoproduction off the proton

$\eta \longrightarrow \gamma\gamma$

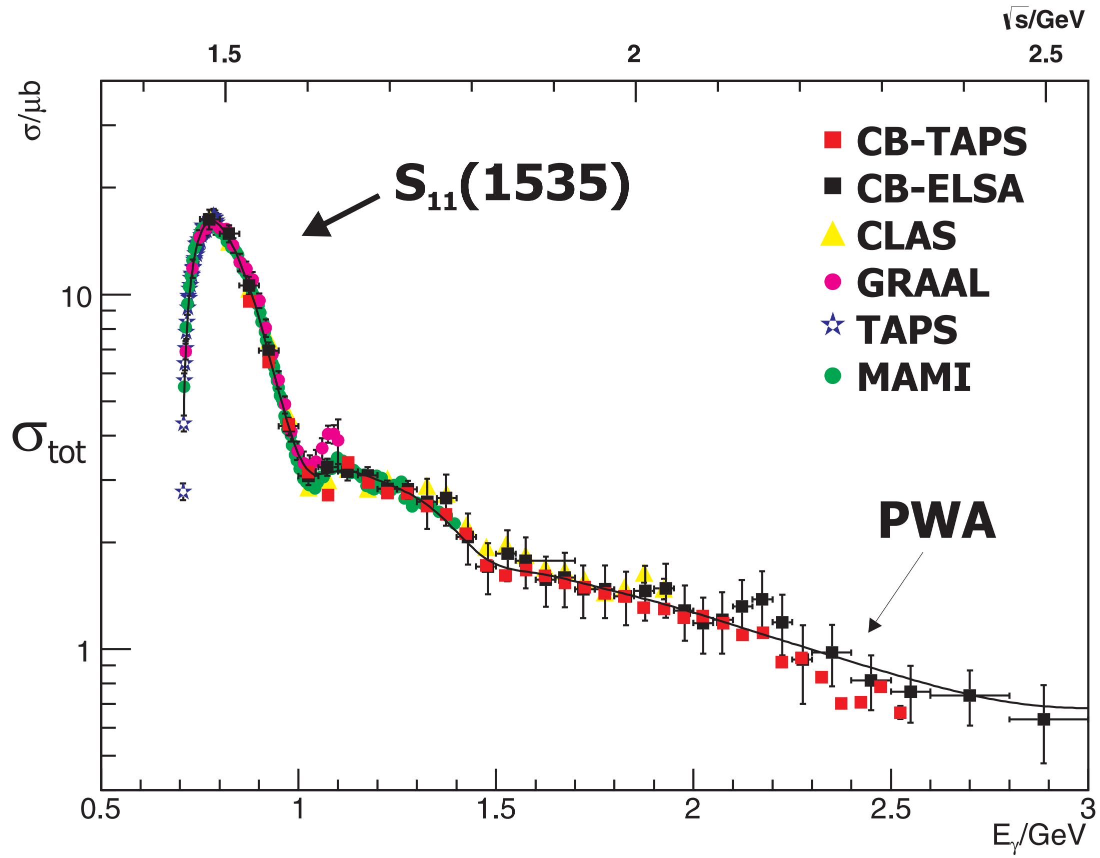


$\eta \longrightarrow 3\pi^0$



$d\sigma / d\Omega$

PWA



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

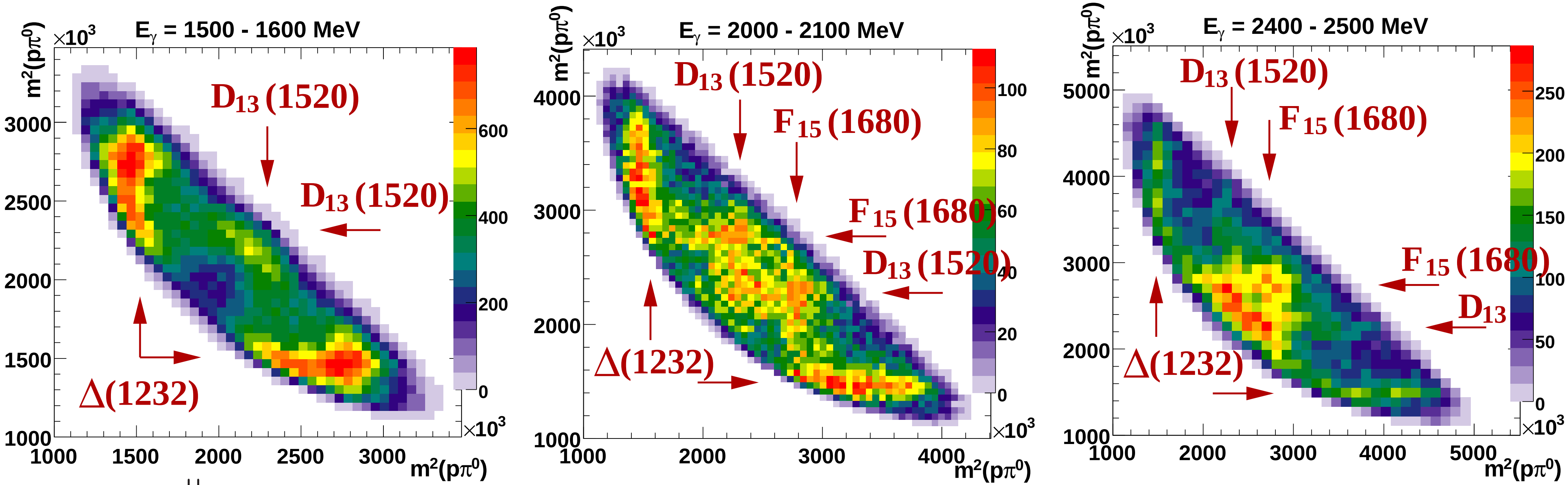
+ new D_{15}: m = 2068 $\pm$ 22 MeV,

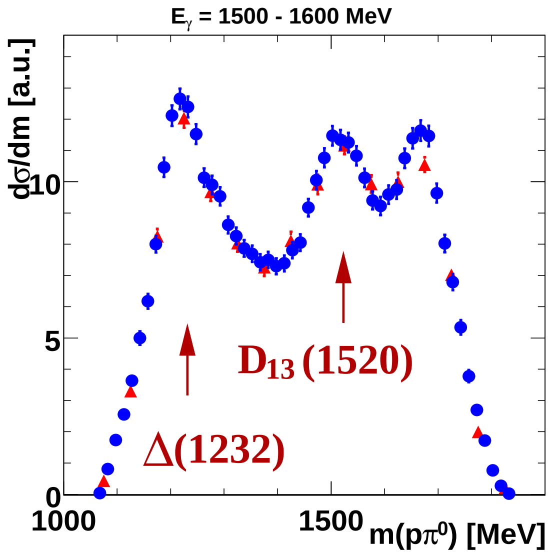
Γ = 295 $\pm$ 40 MeV

(needed: confirmation in polarisation exp.)

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

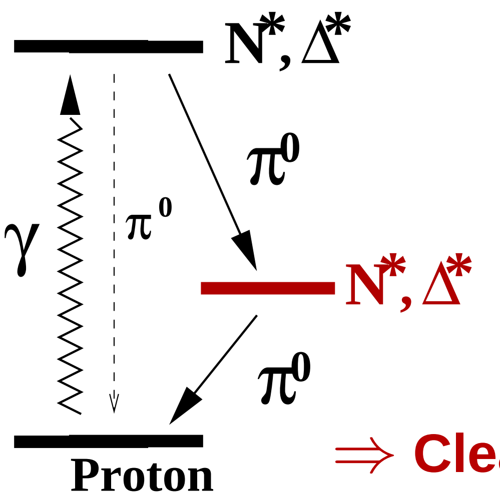
CBELSA/TAPS: $\gamma p \longrightarrow p\pi^0\pi^0$ (V.Sokhoyan, Bonn)





CB-ELSA data

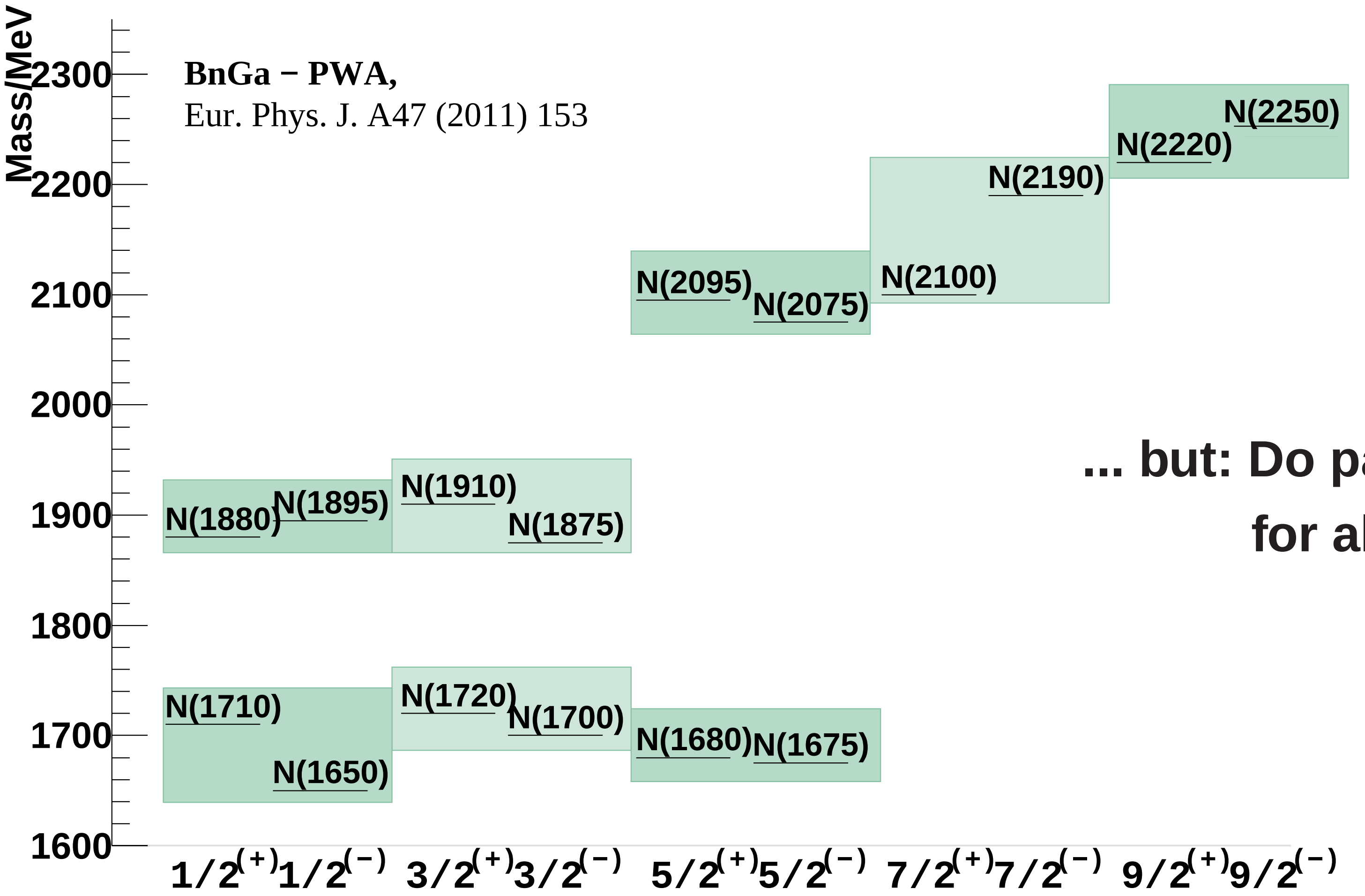
CBELSA/TAPS data



$\Rightarrow$ **Clear observation of baryon cascades !**

Partial Wave Analysis - results

Parity doublets occur:



... but: Do parity doublets exist for all high mass states ?

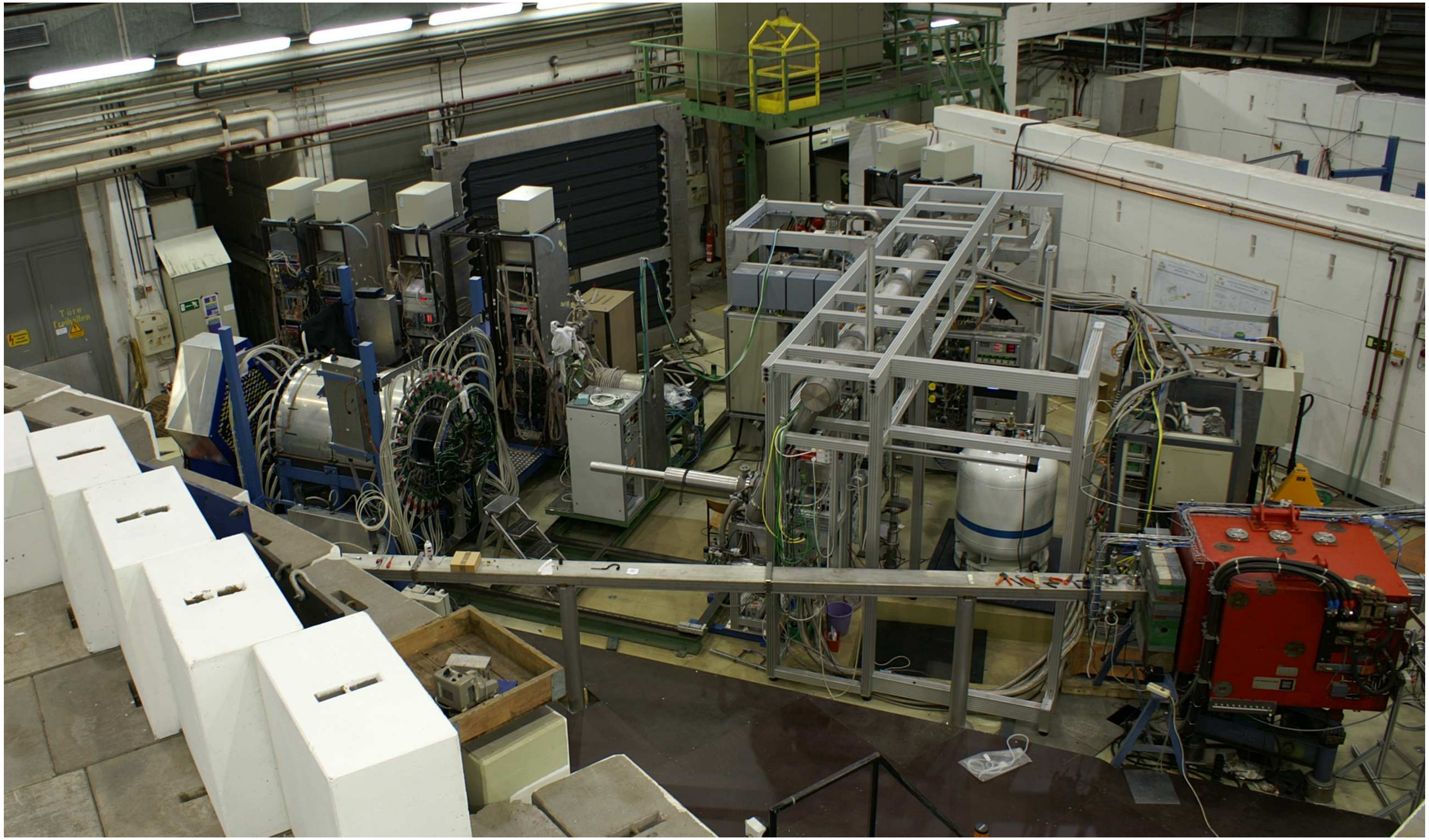
Not expected by:

- present lattice QCD calculations or constituent quark-models

New data taken with polarised target

Double polarisation program at: JLAB, ELSA, MAMI

ELSA

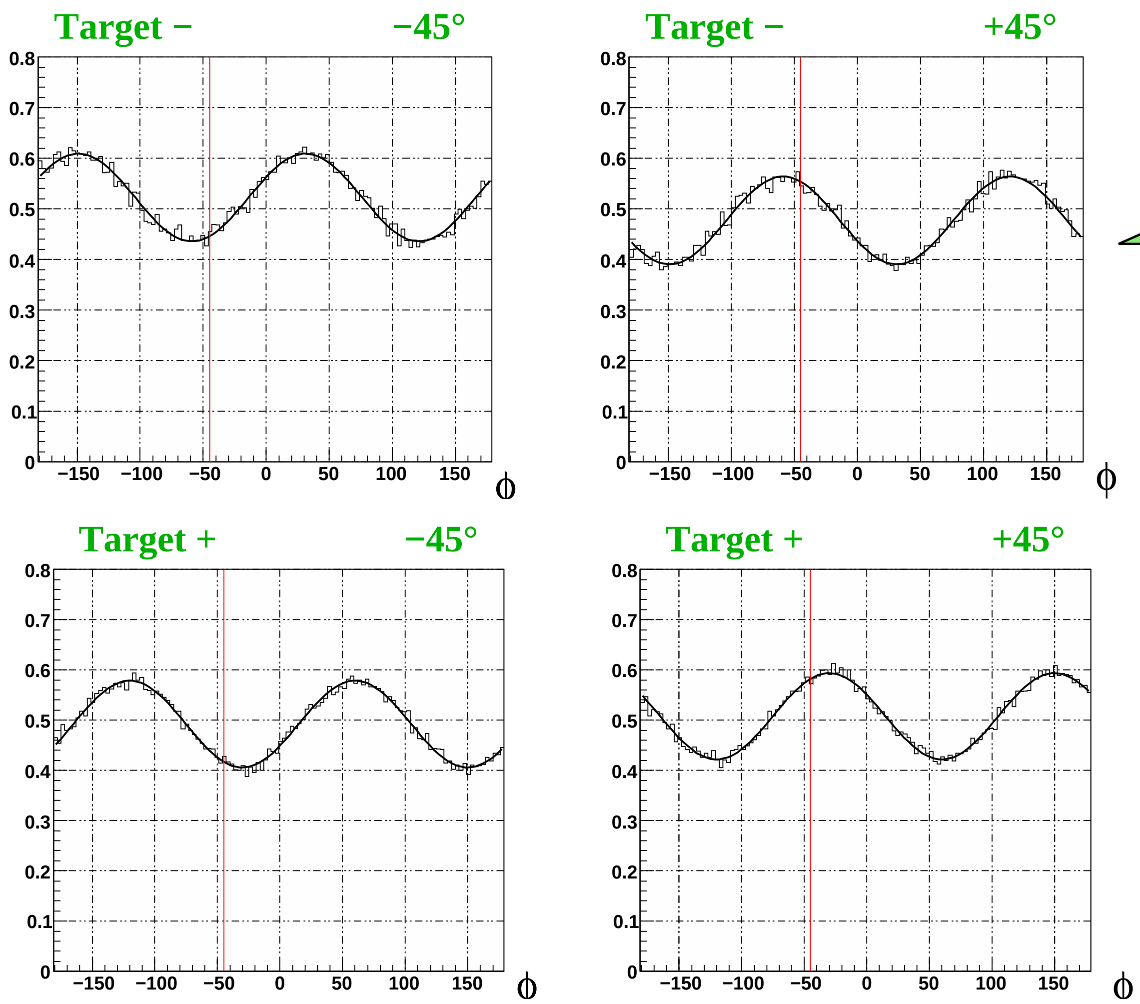


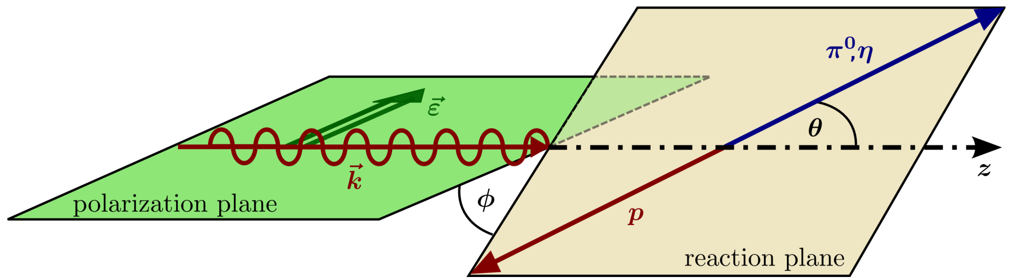
an important step forward towards a complete experiment

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

Linearly polarised photons, longitudinally polarised target

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





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

(E_γ=750-1200 MeV)

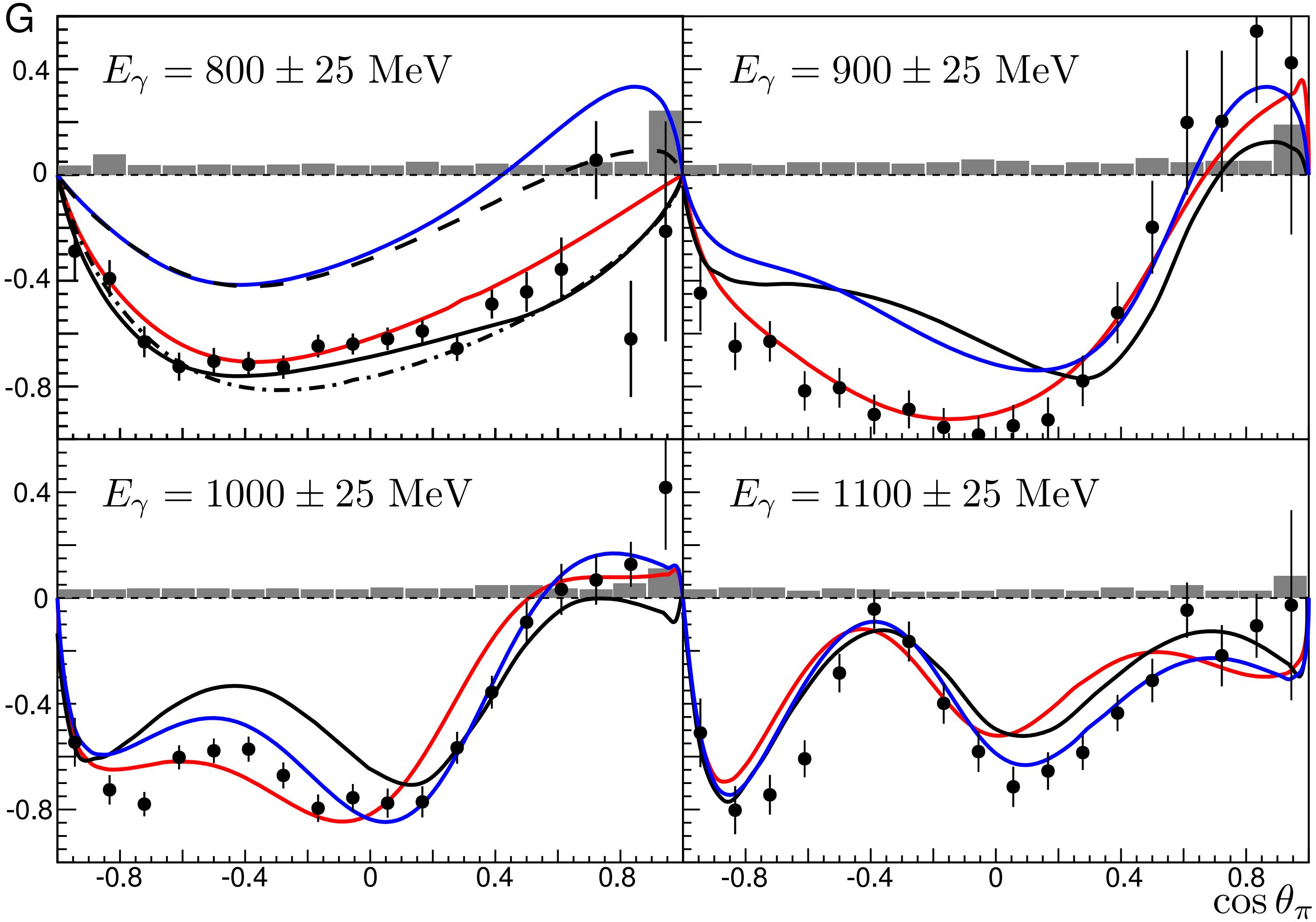
$\Rightarrow$ Clear effect

from $\underline{\underline{G}}$ observed

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

Linearly polarised photons, longitudinally polarised target

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



– MAID – BnGa – SAID

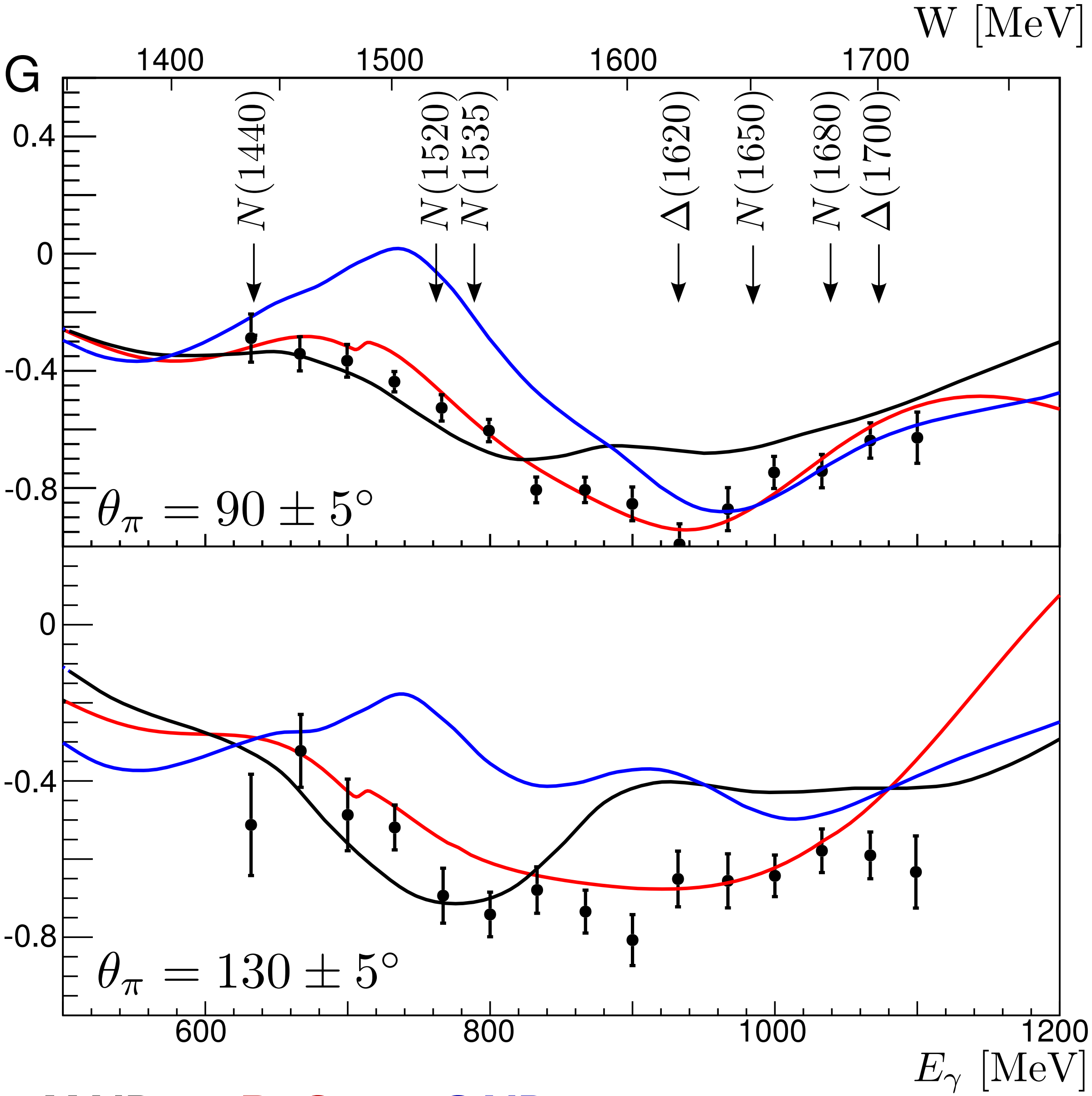
already in the second resonance region:

significant differences !

related to the E_{0+}, E_{2-} -multipoles

$\leftrightarrow 1/2^-, 3/2^-$ -partial waves

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



– MAID – BnGa – SAID

Linearly polarised photons, longitudinally polarised target

already at low energies:

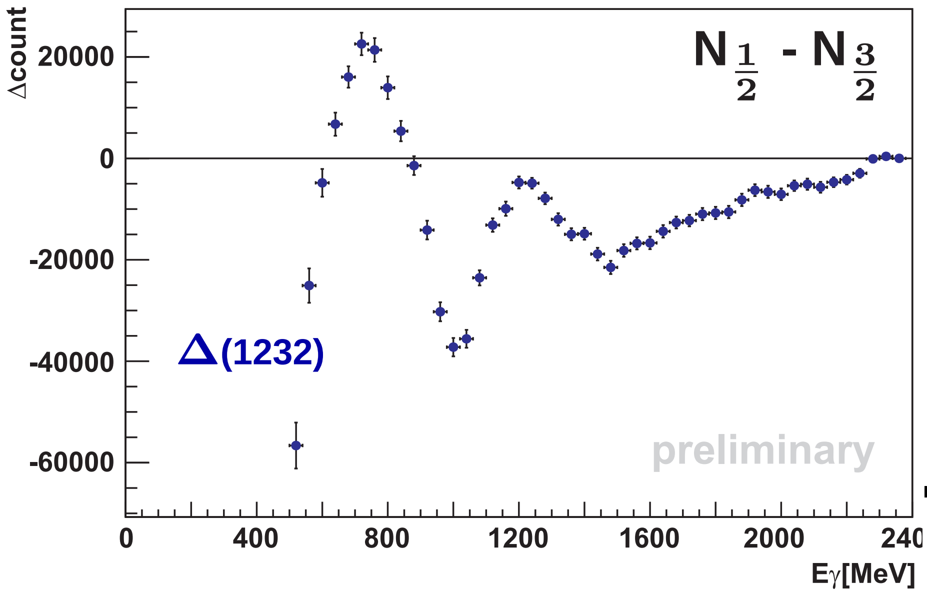
significant differences !

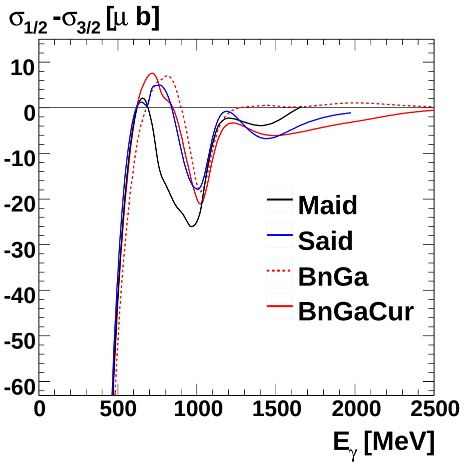
related to the E_{0+}, E_{2-} -multipoles

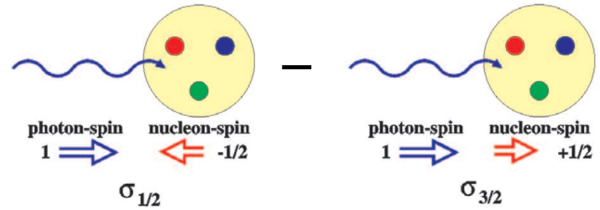
$\leftrightarrow$ $1/2^-$, $3/2^-$ -partial waves

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

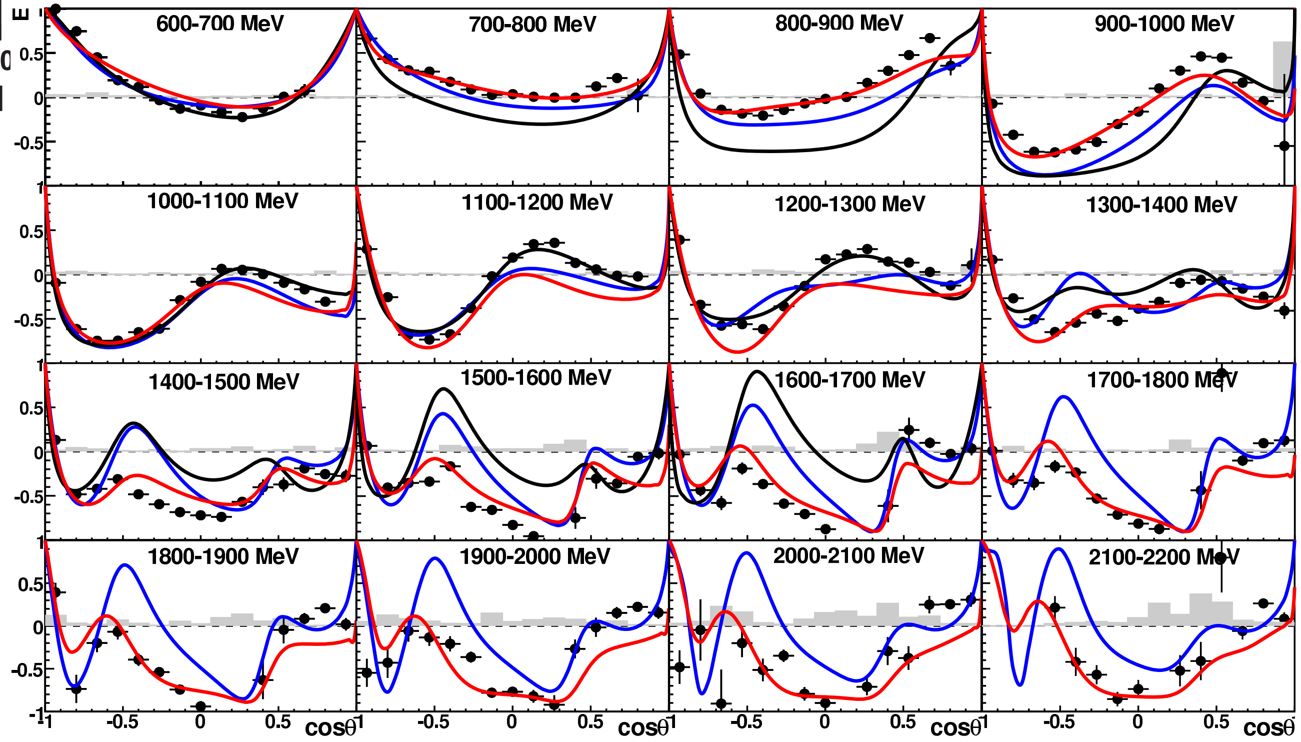
Circularly polarised photons, longitudinally polarised target







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



Different PWAs :

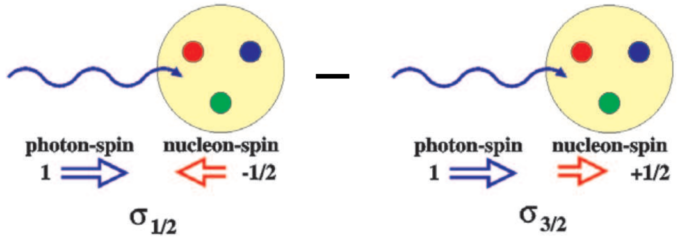
- **deviations already at lower E_γ**
- **quite unsatisfactory at higher energies**

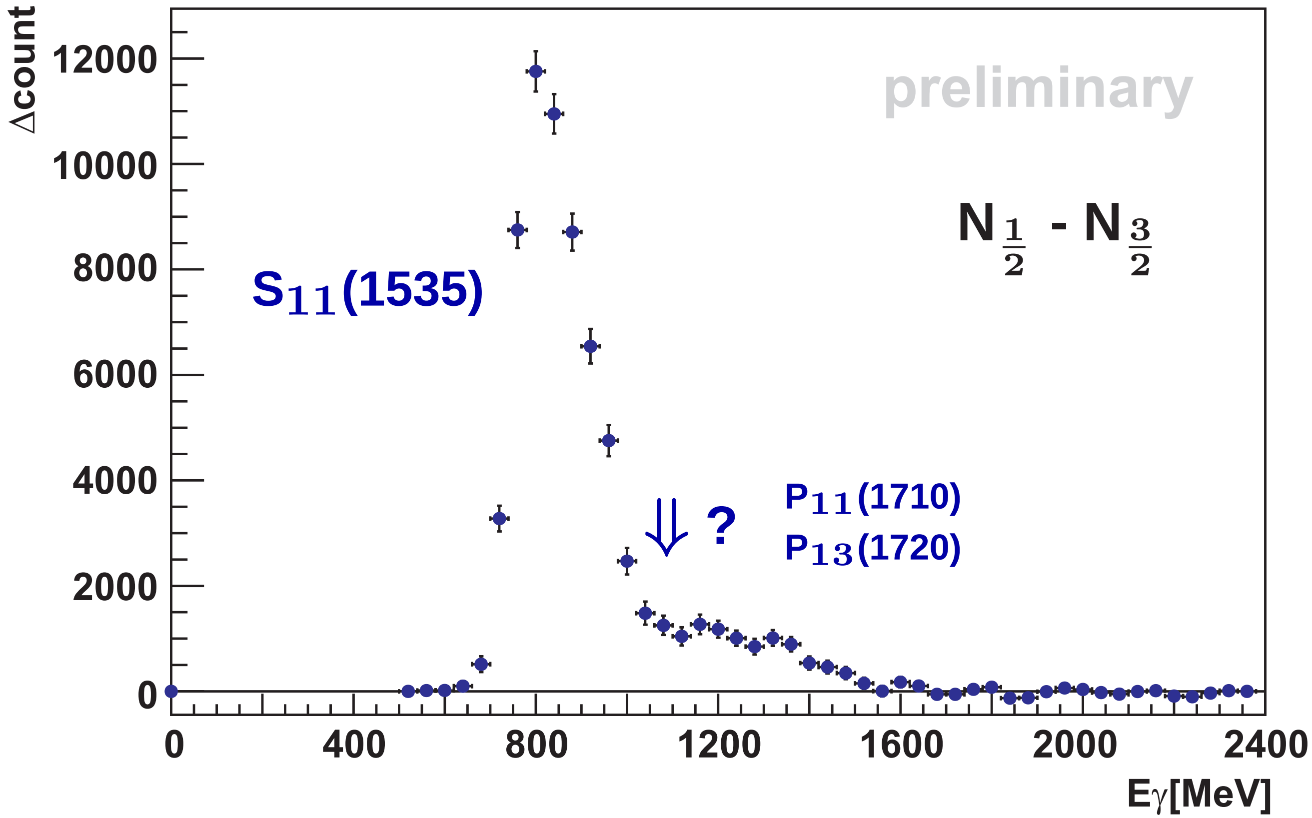
⇒ New and important information

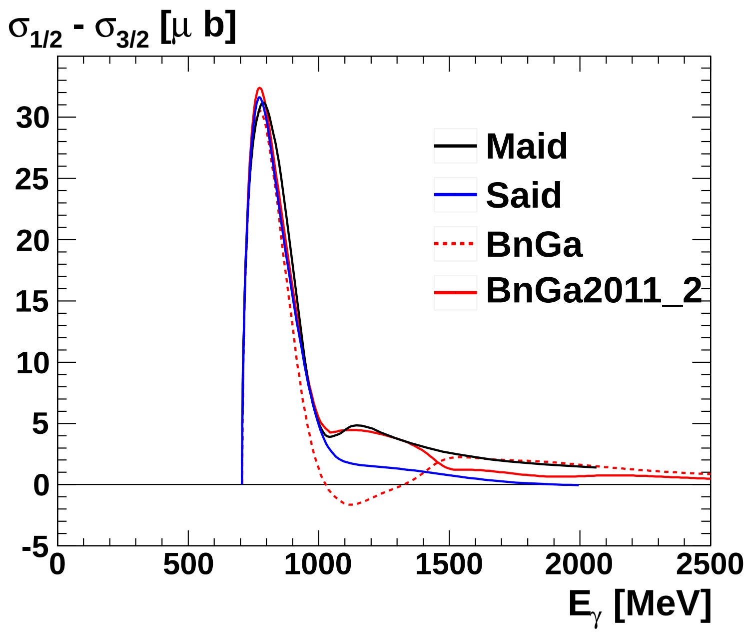
CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\eta$ (J. Müller, Bonn)

Circularly polarised photons, longitudinally polarised target

Count rate differences plotted:







Clear asymmetries observed !

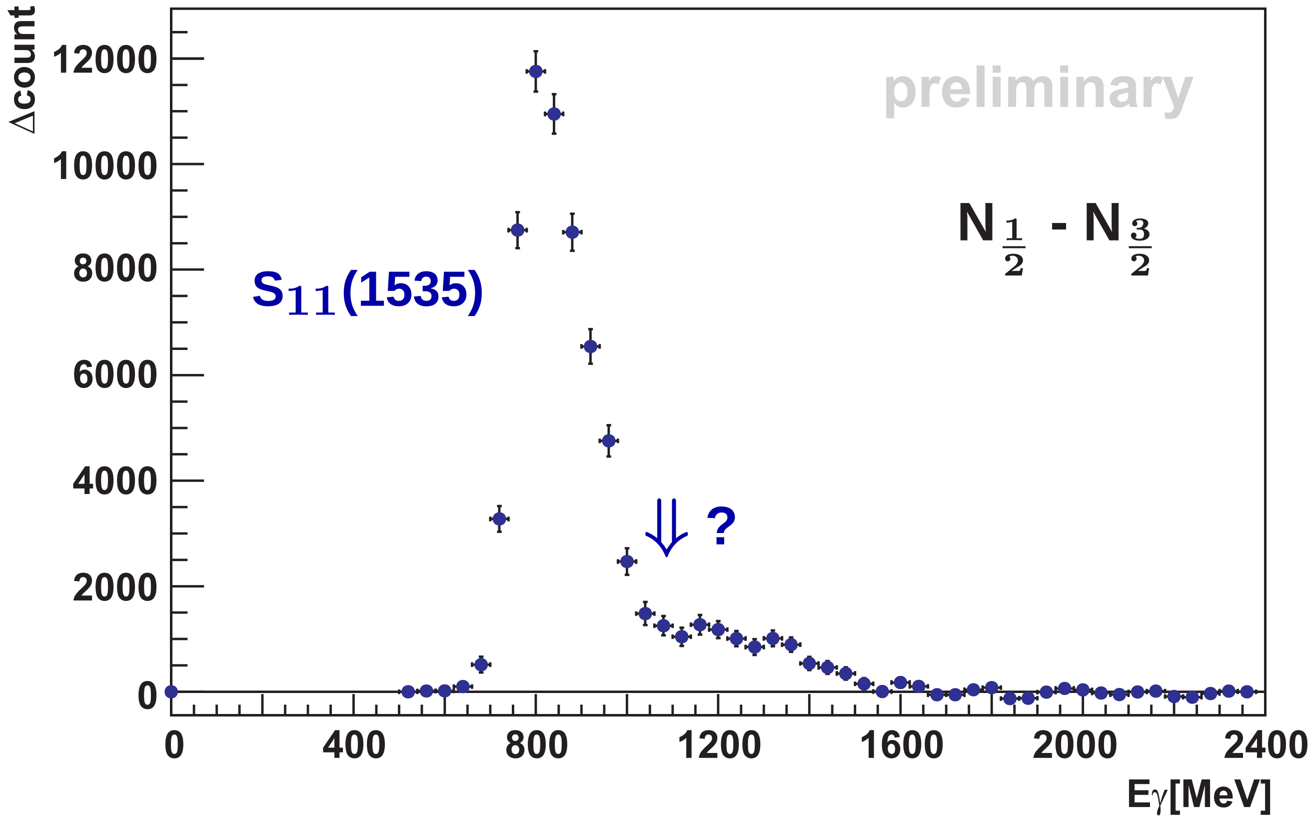
$\sim$ complete angular coverage

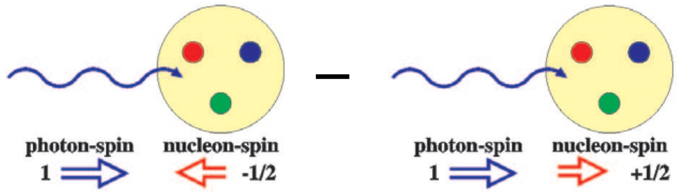
$\Longrightarrow$ New and important information for the PWA

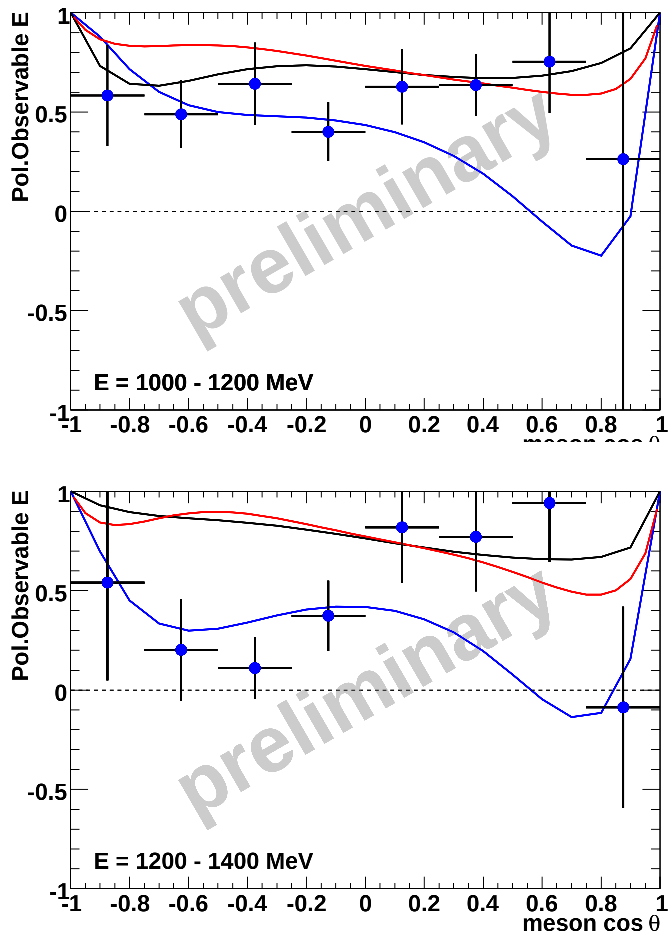
CBELSA/TAPS: Double pol. exp. $\vec{\gamma}\vec{p} \longrightarrow p\eta$ (J. Müller, Bonn)

Circularly polarised photons, longitudinally polarised target

Count rate differences plotted:







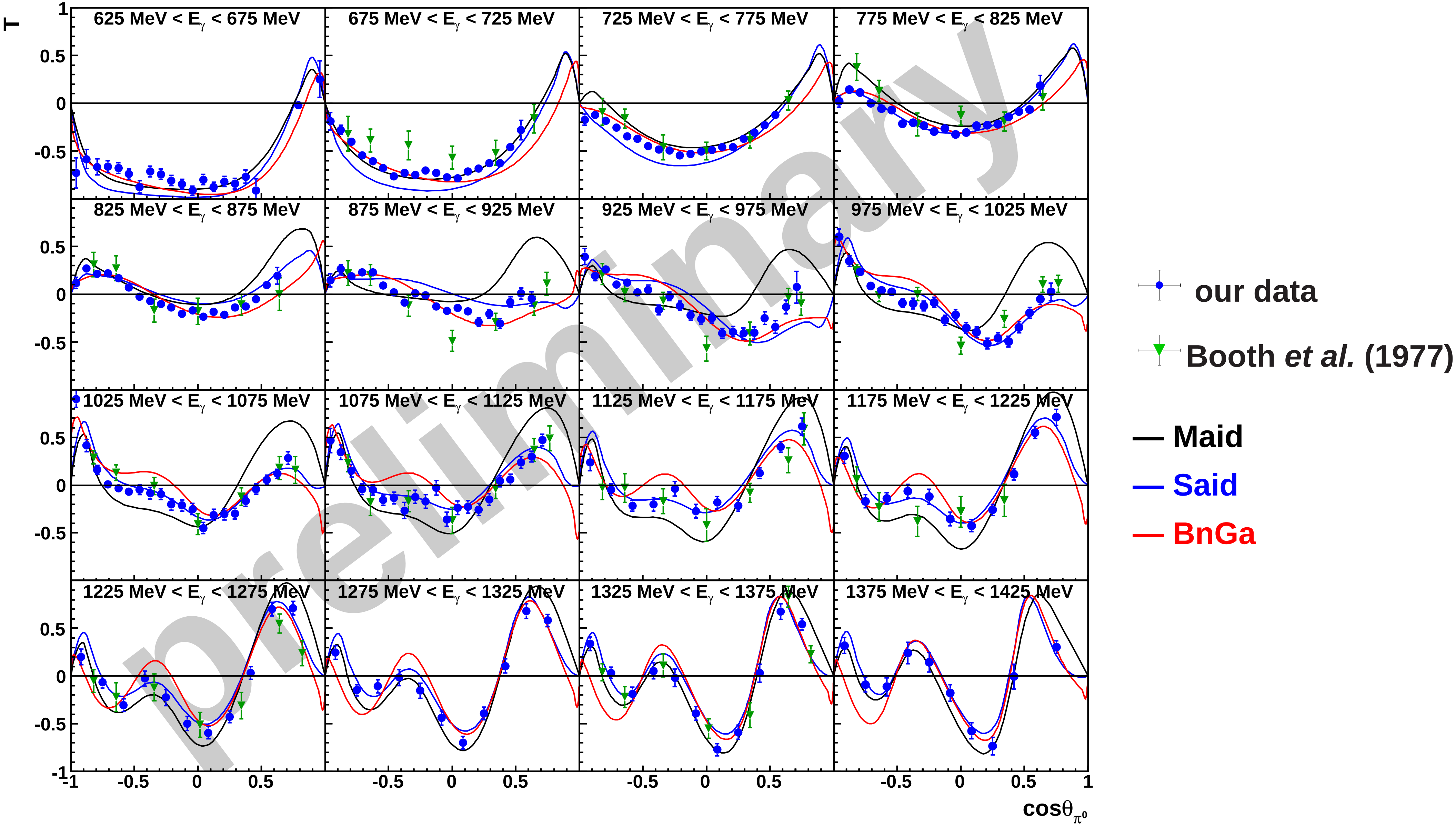
Clear asymmetries observed !

∼ complete angular coverage

⟹ New and important information for the PWA

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

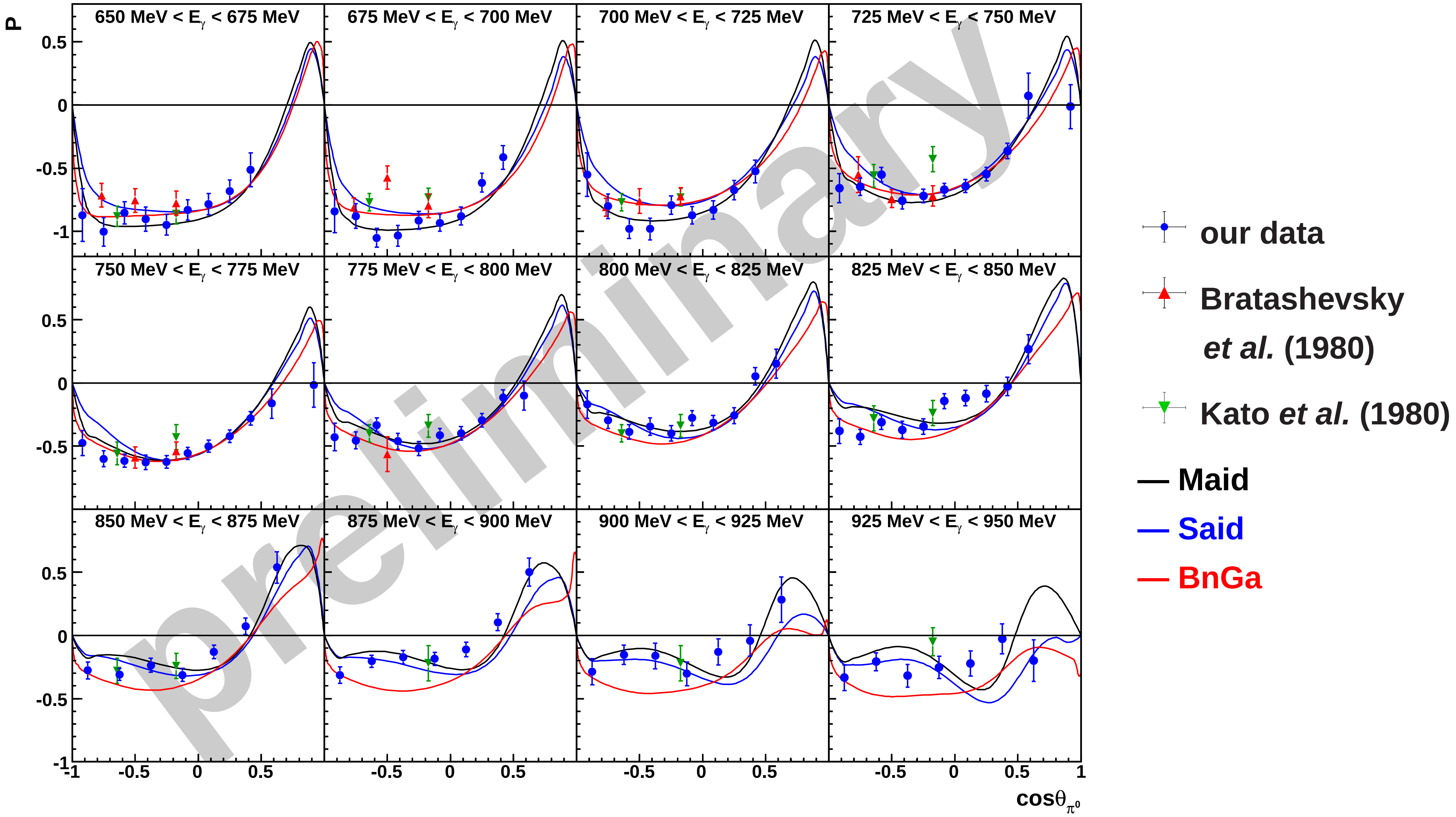
Transversally polarised target



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

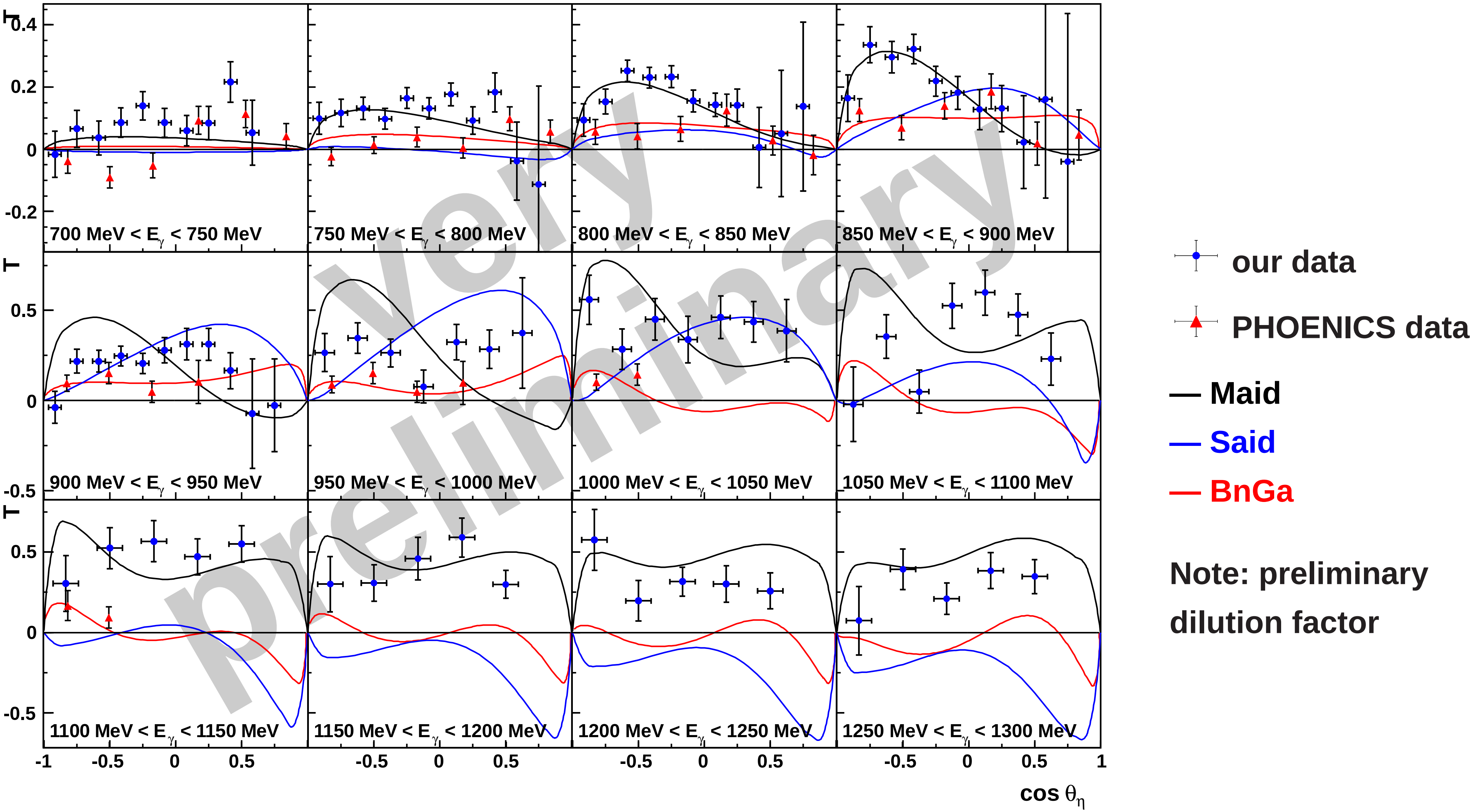
Linearly pol. photons, transversally polarised target

⇒ Measurement of the recoil polarisation



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

η - Photoproduction off the neutron (I.Jaegle, Basel)

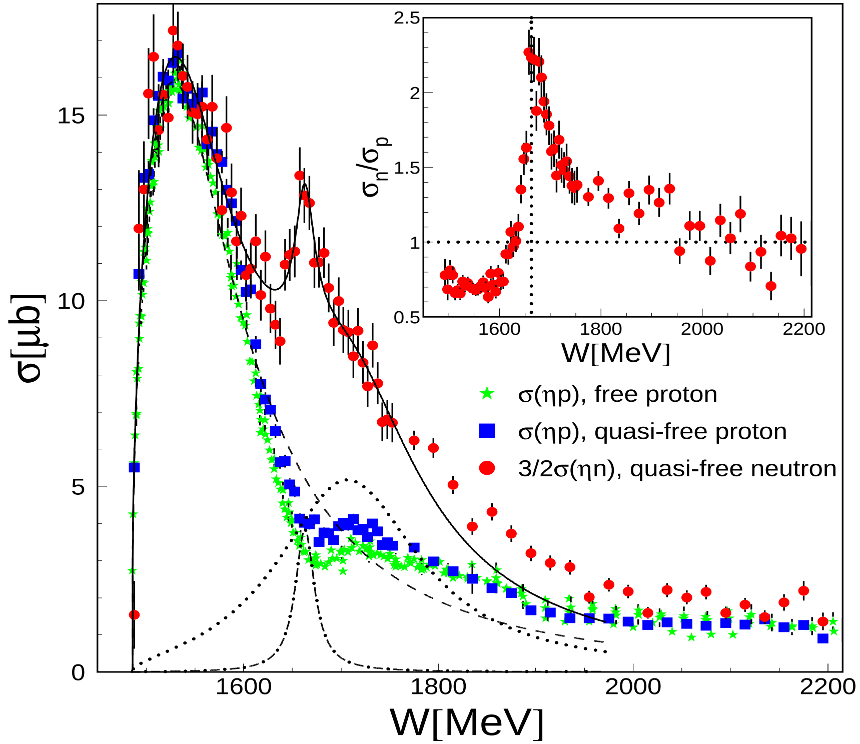
$\leftrightarrow$ **Use kinematics to calculate neutron momentum:**

$n\eta$-invariant mass can be calculated
(no Fermi-motion)

phenomenological fit of total cross section data (Breit-Wigner-resonances only)

Narrow structure: mass $\approx$ 1670 MeV,
width $\lesssim$ 50 MeV

- **role of the D_{15}(1675) ?, narrow P_{11}(1670) ?**
- **explainable by S_{11}-states + P_{11}(1710) ?**
- **interference of S_{11}(1535)/S_{11}(1650) + background ?**



Challenge for the PWA
$\leftrightarrow$ conventional interpretation possible
or narrow state needed ?

also observed by GRAAL, Tohoku-LNS, MAMI-C

For a final interpretation:

Additional information needed $\leftrightarrow$ polarisation observables
$\Rightarrow$ interpretation of the origin of the observed structure

First double polarisation data (E) presently analysed ($\leftrightarrow$ quantum numbers)

Summary

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

$\leftrightarrow$ Important contributions from photo-(electro-) production experiments (single and double polarisation experiments)

- allow in contrast to $\pi N \rightarrow \pi N$ 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 ?

$\Rightarrow$ Quark models/first lattice calculations do not provide the expected systematics in the spectrum

- some states can be generated dynamically from their decays ....

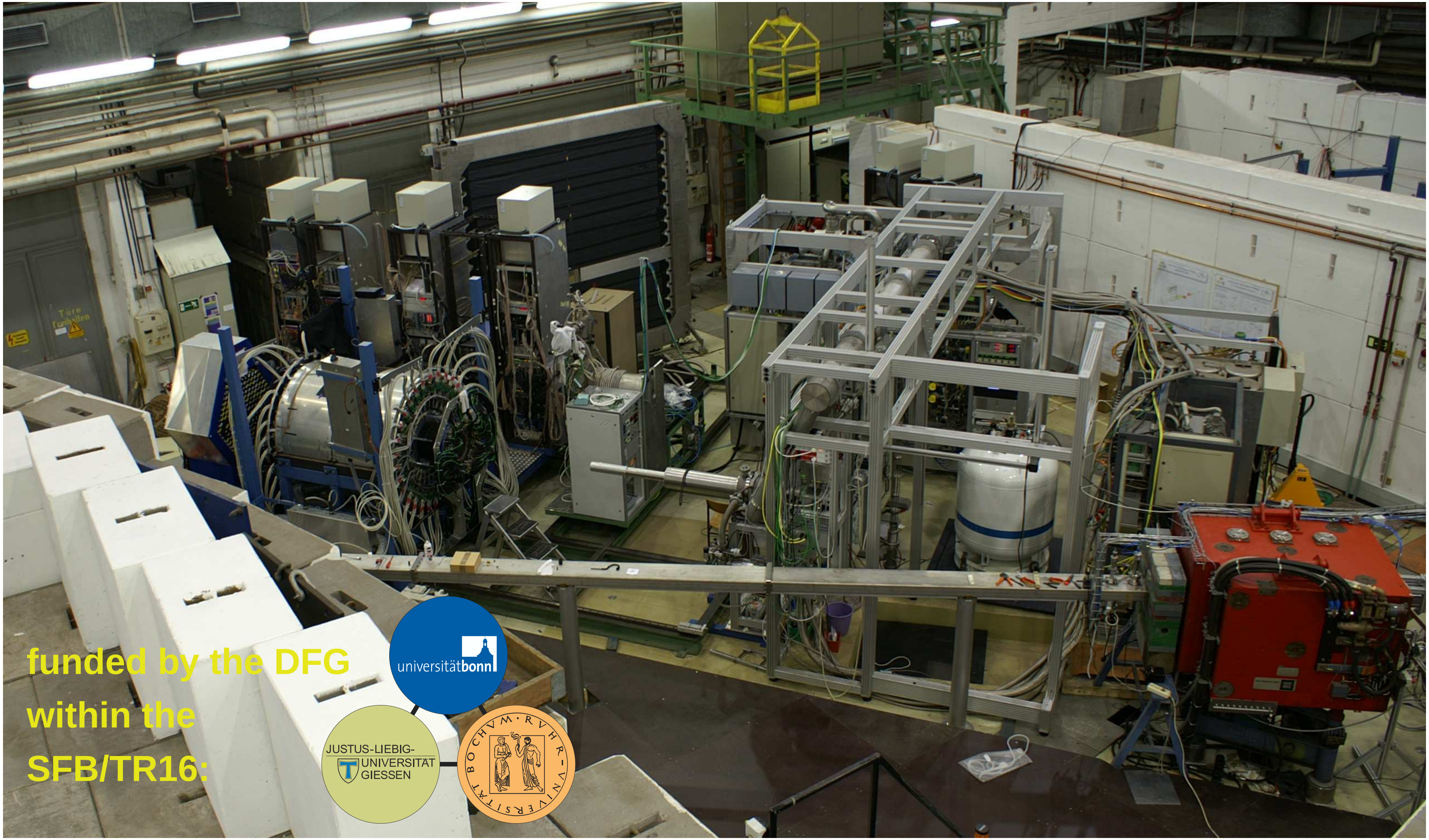
narrow structure in η-photoproduction off the neutron observed

New experimental information from the double polarisation experiments

$\Rightarrow$ 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: