Spin Physics with Photon Beams

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A2

SUMMARY

- Physics motivations

  Why (real) Photons ? Why Spin ?

  ⇓

  Study of the nucleon internal structure

  - Determination of the N* properties $\gamma N \rightarrow N\pi, N\eta, N\pi\pi, \ldots$
  - Determination of the proton polarizabilities $\gamma N \rightarrow \gamma' N$

- Experimental set up (A2 tagged photon facility)

- Selected Results

$$\vec{\gamma}\ \vec{p}(\vec{n}) \rightarrow \begin{cases} \pi N\ (\eta \mathrm{N}) \\ \gamma' N \end{cases}$$

- Outlook

Why photons ?

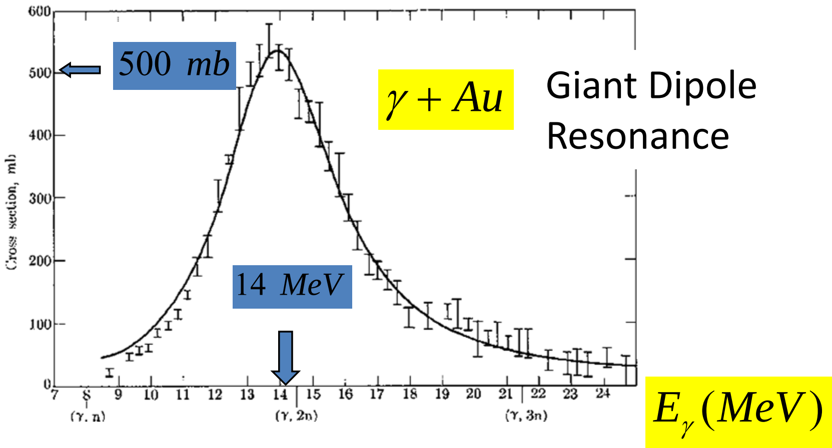
One powerful way of experimentally investigating the strongly interacting particles **(hadrons)** is to look at them, <u>**to probe**</u> them with a known particle, in particular the photon <u>**(no other is known as well)**</u> ***(R.P.Feynman)***

The hadronic structure is explored with a resolution depending of the photon energy (wave length)

$$\lambda_\gamma \cong \frac{200(\mathrm{MeV \cdot fm})}{E_\gamma(\mathrm{MeV})}$$

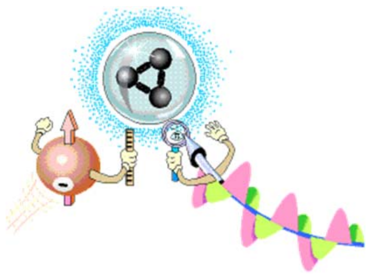
Study of the collective nuclear motions

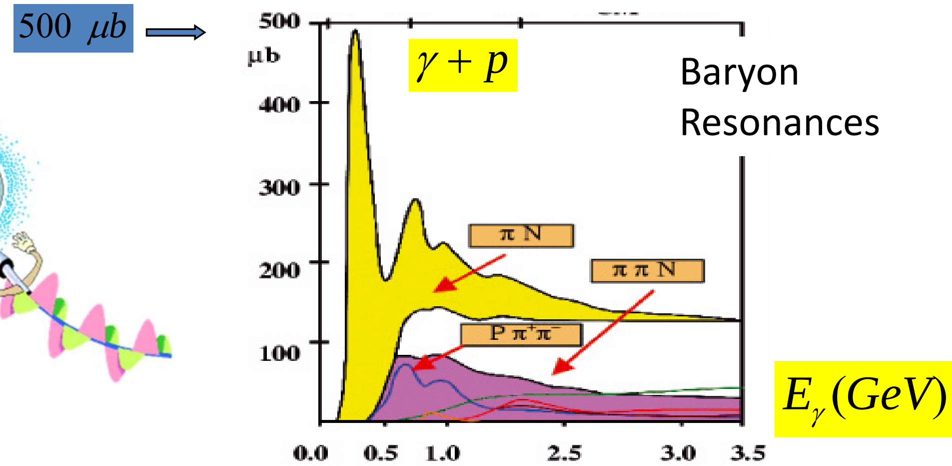
$E_\gamma \approx 20\ \mathrm{MeV} \Rightarrow \lambda_\gamma \approx 10\,\mathrm{fm}$



Study of the nucleon internal structure

$E_\gamma > 200\ \mathrm{MeV} \Rightarrow \lambda_\gamma < 1\,\mathrm{fm}$



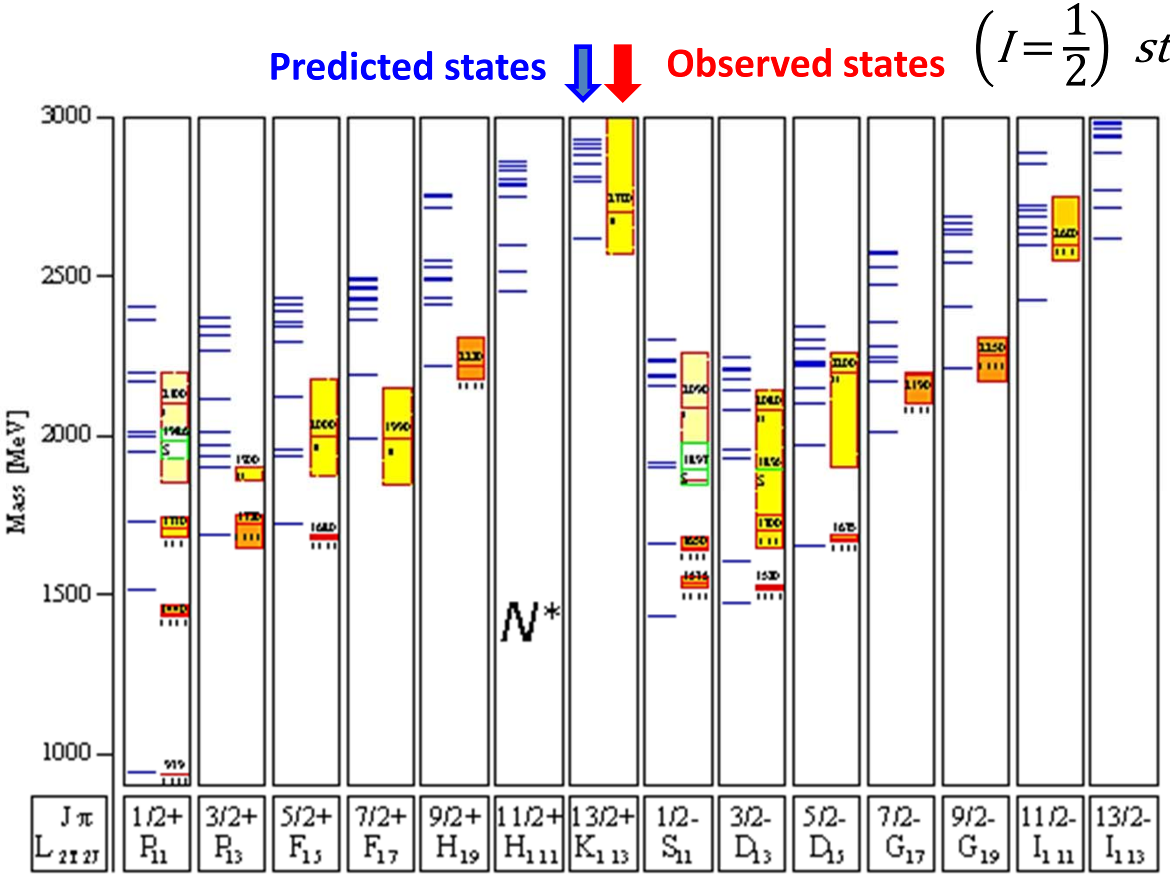


How well do we understand the nucleon excitation spectrum ?

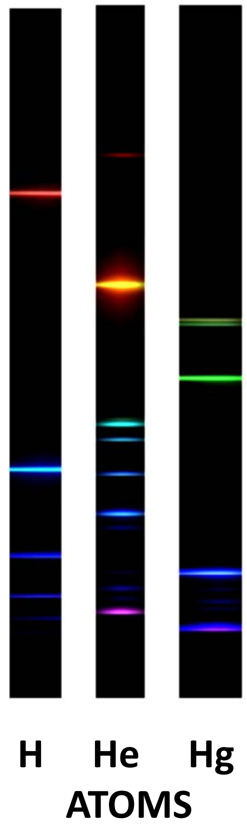
- many more resonances expected in quark models (all based on SU6 symmetry) or lattice QCD than seen experimentally

- What are the relevant degrees of freedom ?

- Most resonances observed in πN scattering but some resonances might not couple to πN

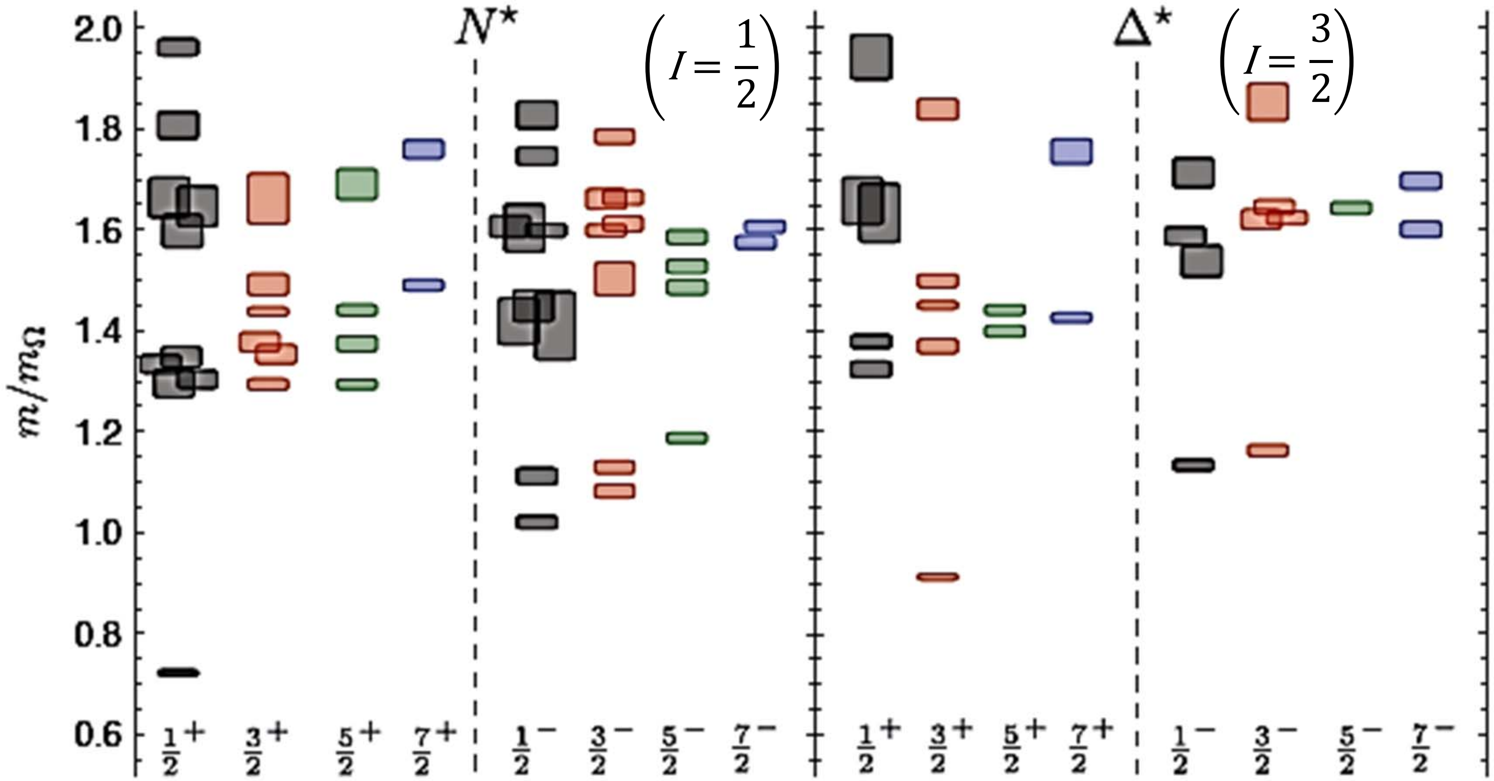


CQM: U. Loering et al, EPJA 10, 395 (2001)



A Lattice QCD model

Edwards et al, PRD 84 074508 (2011)



- **Results for m_π = 396 MeV**
- State-of-the art methods still yield a (too) large number of states

Why spin ?

$$\gamma N \rightarrow \pi N \text{ (or } \eta N)$$

Spin states	±1 ±1/2	0 ±1/2	
DoF	2 x 2	x 2	

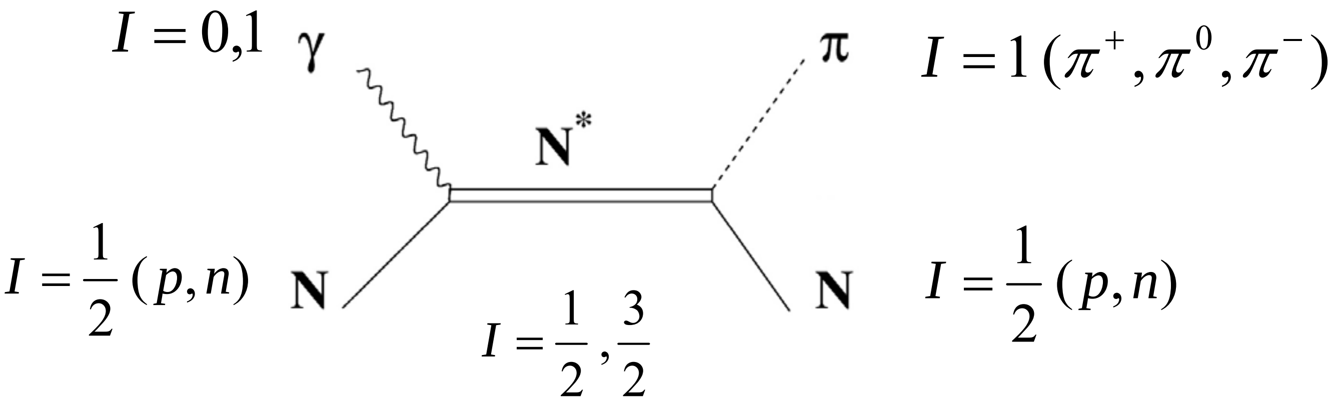
8 matrix elements needed describe the scattering amplitude

- **Parity conservation ⇒ only 4 complex amplitudes are independent (*F_1 … F_4* CGLN amplitudes)**
- **16 independent observables <u>(at least 8 -well chosen-to be measured)</u>**

1 unpolarized observable **3 single polarization observables** **12 double polarization observables**

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_x**	($-L_z$)	(T_z)	(L_x)	($-T_x$)
Circular	-	**F**	-	**E**	**C_x**	-	**C_z**	-	-	-	-

An additional complication: Isospin



✓ N* resonances are in states of definite isospin

Empirical rule

✓ πN (strong) interaction conserves isospin but e.m. interactions do not conserve isospin $|\Delta I| \leq 1$

A^0 isoscalar transition to $I = 1/2$ and $\Delta I = 0$

$A^{1/2}$ isovector transition to $I = 1/2$ and $|\Delta I| = 1$

$A^{3/2}$ isovector transition to $I = 3/2$ and $|\Delta I| = 1$

$$A(\gamma p \to \pi^+ n) = \sqrt{\frac{2}{3}} A^0 + \frac{1}{3}\sqrt{2} A^{1/2} - \frac{1}{3}\sqrt{2} A^{3/2}$$

$$A(\gamma p \to \pi^0 p) = \sqrt{\frac{1}{3}} A^0 + \frac{1}{3} A^{1/2} + \frac{2}{3} A^{3/2}$$

$$A(\gamma n \to \pi^- p) = \sqrt{\frac{2}{3}} A^0 - \frac{1}{3}\sqrt{2} A^{1/2} + \frac{1}{3}\sqrt{2} A^{3/2}$$

$$A(\gamma n \to \pi^0 n) = -\sqrt{\frac{1}{3}} A^0 + \frac{1}{3} A^{1/2} + \frac{2}{3}\sqrt{2} A^{3/2}$$

(at least) 3 different reactions have to be measured ⇒ experiments both on proton and neutron needed (no free neutron target)

➢ Partial Wave Analysis (*l* =pion angular momentum)

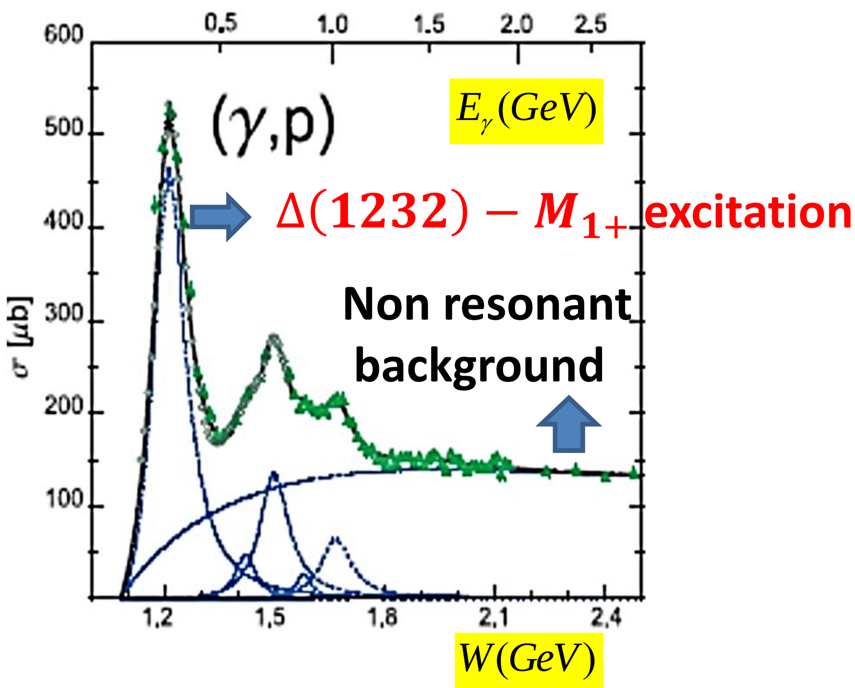
$$F_1 = \sum_{l=0}^{\infty} \left(l M_{l+} + E_{l+} \right) P'_{l+1} + \left[(l+1) M_{l-} + E_{l-} \right] P'_{l-1}$$

multipoles

$$\sigma = |E_{0+}|^2 + |M_{1-}|^2 + 6|E_{1+}|^2 + 2|M_{1+}|^2 + \ldots$$

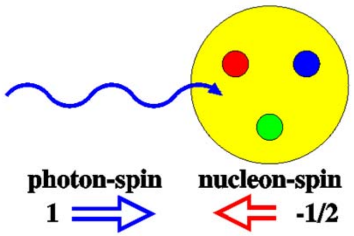
$$E = |E_{0+}|^2 + 3|E_{1+}|^2 - |M_{1+}|^2 + 6E^*_{1+} M_{1+} + \ldots$$

Change of sign and interference terms between multipoles

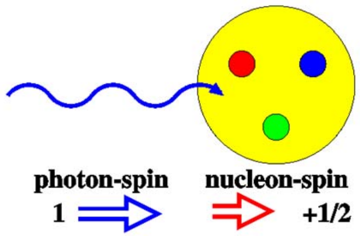


***E* Asymmetry**

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



$\sigma_{1/2}$



$\sigma_{3/2}$

Absorption of circularly polarized photons by longitudinally polarized nucleons

Why spin ?

$$\gamma N \rightarrow \pi N \text{ (or } \eta N)$$

	γN		πN (or ηN)	
Spin states	±1	±1/2	0	±1/2
DoF	2 x	2	x	2

8 matrix elements needed describe the scattering amplitude

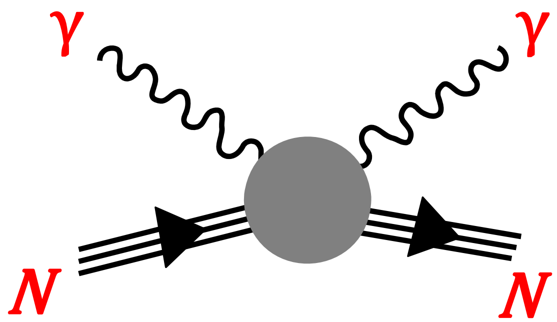
- Parity conservation ⇒ only 4 complex amplitudes are independent (F_1 … F_4 CGLN amplitudes)
- 16 independent observables (at least 8 -well chosen-to be measured ⇒ «complete experiment»)

1 unpolarized observable — 3 single polarization observables — 12 double polarization observables

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_x	$(-L_z)$	(T_z)	(L_x)	$(-T_x)$
Circular	-	F	-	E	C_x	-	C_z	-	-	-	-

Measured or planned at A2 ◯

Real Compton Scattering



Expansion of the Hamiltonian in incident photon energy (ω)

0th order ⟹ **charge, mass**

1st order ⟹ **magnetic moment**

} «point-like» nucleon (Born terms)

2nd order ⟹ **2 scalar polarizabilitites** (not well known)

$$H^{(2)}_{eff} = -4\pi\left[\frac{1}{2}\alpha_{E1}\vec{E}^2 + \frac{1}{2}\beta_{M1}\vec{H}^2\right]$$

Baldin's sum rule: $(\alpha_{E1}+\beta_{M1}) \sim$ **known**

From A2

P. Martel et al, PRL 114, 112501 (2015)

3rd order ⟹ **4 spin (vector) polarizabilitites** **only one direct measurement**

$$H^{(3)}_{eff} = -4\pi\left[\frac{1}{2}\gamma_{E1E1}\vec{\sigma}\cdot\left(\vec{E}\times\dot{\vec{E}}\right) + \frac{1}{2}\gamma_{M1M1}\vec{\sigma}\cdot\left(\vec{H}\times\dot{\vec{H}}\right) - \gamma_{M1E2}E_{ij}\sigma_i H_j + \gamma_{E1M2}H_{ij}\sigma_i E_j\right]$$

$$E_{ij} = \frac{1}{2}(\nabla_i E_j + \nabla_j E_i)$$
$$H_{ij} = \frac{1}{2}(\nabla_i H_j + \nabla_j H_i)$$

$$\gamma_0 = -\gamma_{E1E1} - \gamma_{E1M2} - \gamma_{M1M1} - \gamma_{M1E2}$$
$$\gamma_\pi = -\gamma_{E1E1} - \gamma_{E1M2} + \gamma_{M1M1} + \gamma_{M1E2}$$

(not well known)

Spin Polarizabilities: predicted and measured values

	K-mat.	HDPV	DPV	L_χ	HBχPT	BχPT	A2 Experiment
γ_{E1E1}	-4.8	-4.3	-3.8	-3.7	-1.1 ± 1.8 (th)	-3.3	-3.5 ± 1.2
γ_{M1M1}	3.5	2.9	2.9	2.5	2.2 ± 0.5 (st) ± 0.7 (th)	3.0	3.16 ± 0.85
γ_{E1M2}	-1.8	-0.02	0.5	1.2	-0.4 ± 0.4 (th)	0.2	-0.7 ± 1.2
γ_{M1E2}	1.1	2.2	1.6	1.2	1.9 ± 0.4 (th)	1.1	1.99 ± 0.29
γ_0	2.0	-0.8	-1.1	-1.2	-2.6	-1.0	$-1.01 \pm 0.08 \pm 0.1$
γ_π	11.2	9.4	7.8	6.1	5.6	7.2	8.0 ± 1.8

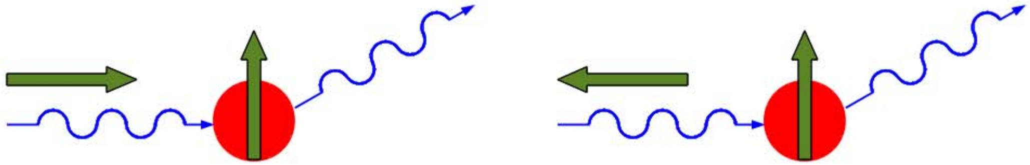
other data

- **Spin polarizabilities in units of 10^{-4} fm^4**
- K-matrix: calculation from Kondratyuk et al., Phys. Rev. C 64, 024005 (2001)
- HDPV, DPV: dispersion relation calculations, B.R. Holstein et al., Phys. Rev. C 61, 034316 (2000) and B. Pasquini et al., Phys. Rev. C 76, 015203 (2007), D. Drechsel et al., Phys. Rep. 378, 99 (2003)
- L_χ chiral lagrangian calculation, A.M. Gasparyan et al., Nucl. Phys. A 866, 79 (2011)
- HBPT and BPT are heavy baryon and covariant, respectively, chiral perturbation theory calculations, J.A. McGovern et al., Eur. Phys. J. A 49, 12 (2013), V. Lensky et al., Phys. Rev. C 89, 032202 (2014)

Spin Polarizabilities: how can they be measured ?

- Circularly polarized photons, transversely polarized protons.

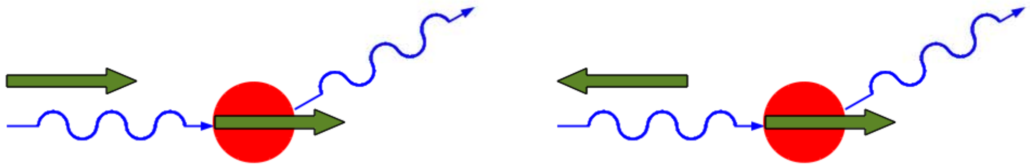
$$\Sigma_{2x} = \frac{N^R_{+x} - N^L_{+x}}{N^R_{+x} + N^L_{+x}}$$



Sensitive to γ_{E1E1}

- Circularly polarized photons, longitudinally polarized protons.

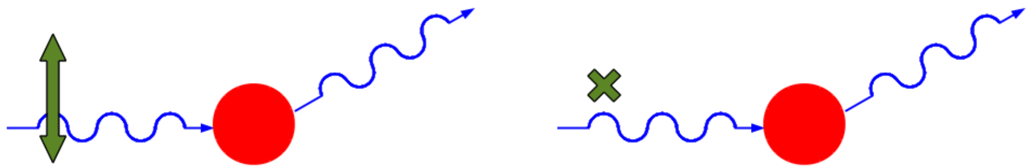
$$\Sigma_{2z} = \frac{N^R_{+z} - N^L_{+z}}{N^R_{+z} + N^L_{+z}}$$



Sensitive to γ_{M1M1}

- Linearly polarized photons, unpolarized protons.

$$\Sigma_3 = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$

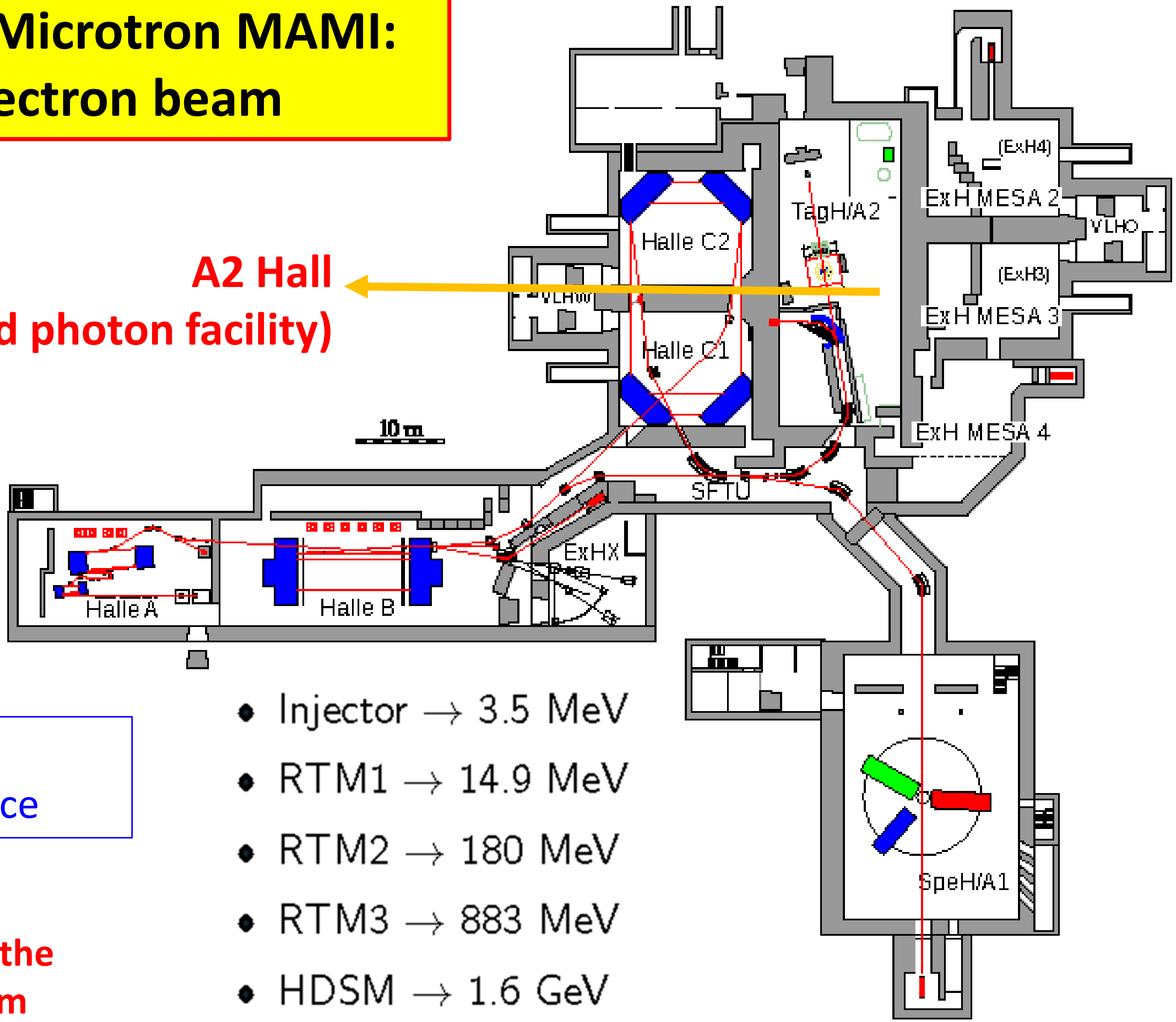


Sensitive to γ_{E1E1} <u>and</u> γ_{M1M1}

Experimental Set up

Mainz Microtron MAMI: electron beam

A2 Hall
(Tagged photon facility)

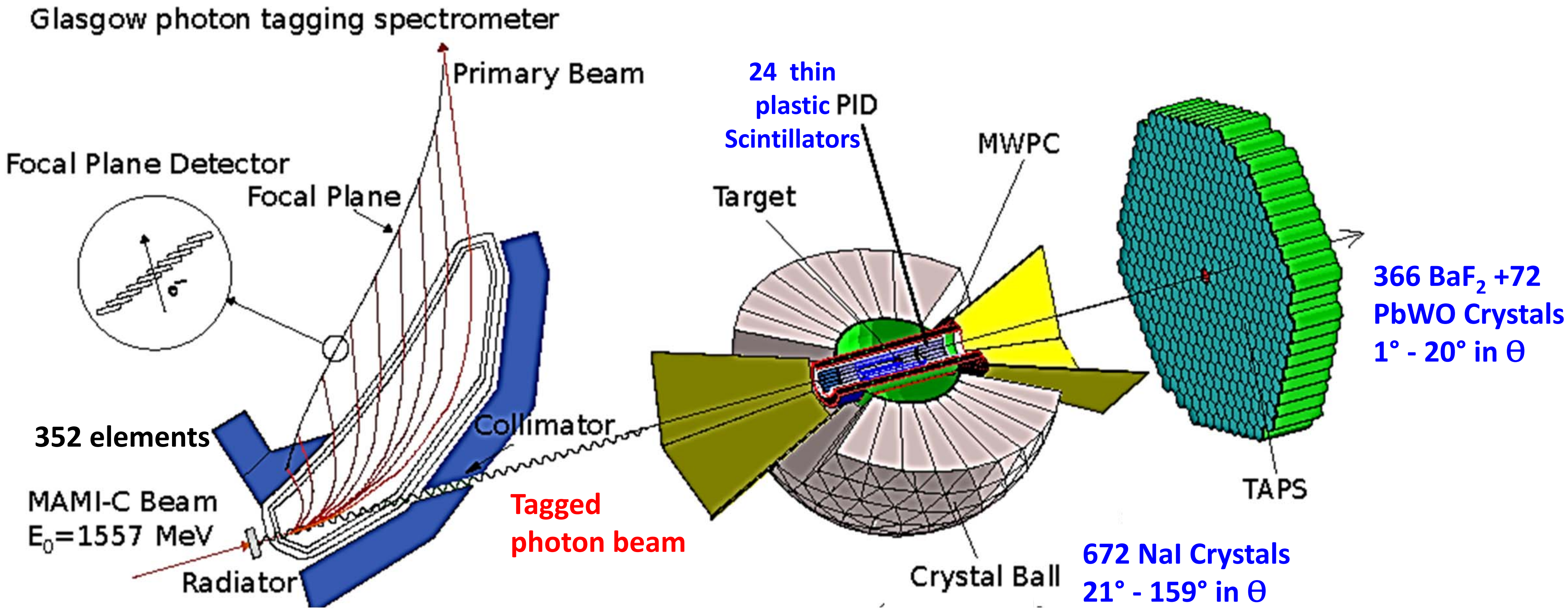


- Injector → 3.5 MeV
- RTM1 → 14.9 MeV
- RTM2 → 180 MeV
- RTM3 → 883 MeV
- HDSM → 1.6 GeV

High stability
Low beam divergence

Very good properties of the secondary photon beam

A2@MAMI: Detector overview



Nucleon polarimeter (graphite cylinder) also available

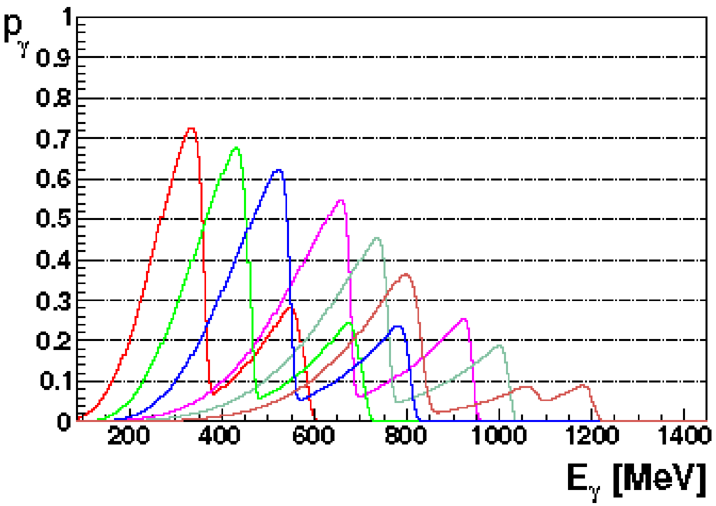
Photon beam produced by bremsstrahlung and tagged by a magnetic spectrometer

$$E_\gamma = E_0 - E_{e^-} \quad ; \quad \Delta E_\gamma = 2 - 4 \text{ MeV}$$

Beam Polarization

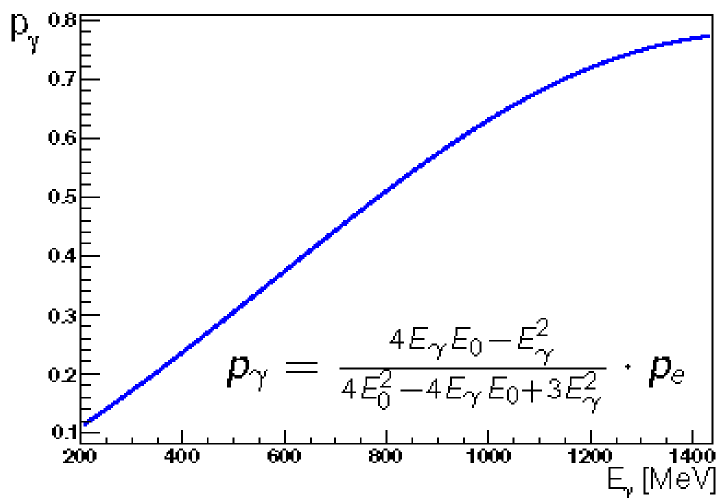
Linearly polarized photons

- Diamond radiator needed
- Coherent Bremsstrahlung
- Coherent edges at
  350 MeV, 450 Mev, 550 MeV,
  650 MeV, 750 Mev, 850 MeV,



Circularly polarized photons

- Longitudinally polarized electrons needed
- Helicity transfer to photon
- Mott/Moeller measurements: beam polarisation $p_e \approx$ 75-85%



Target Polarization

Longitudinally and Transversally polarized protons/deuterons **(Mainz-Dubna target)**

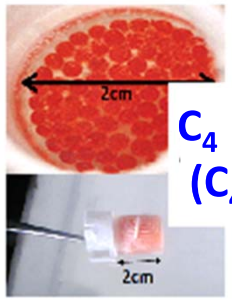
- Polarized material: (deuterated) butanol **(Bochum)**

- Polarization via DNP process
- 70 GHz microwave irradiation at 2.5 T us used to transfer the electron polarization to p/d
- 3He/4He dilution cryostat at 25 mK and holding coil at 0.63 T

- Relaxation time ≈ 2000 hours
- $\approx 10^{23}$ polarized protons (deuterons) $/\mathrm{cm}^2$
- $P_{proton} \approx 90\%$; $P_{deuteron} \approx 50\%$

- Carbon target needed for background studies

Butanol Target



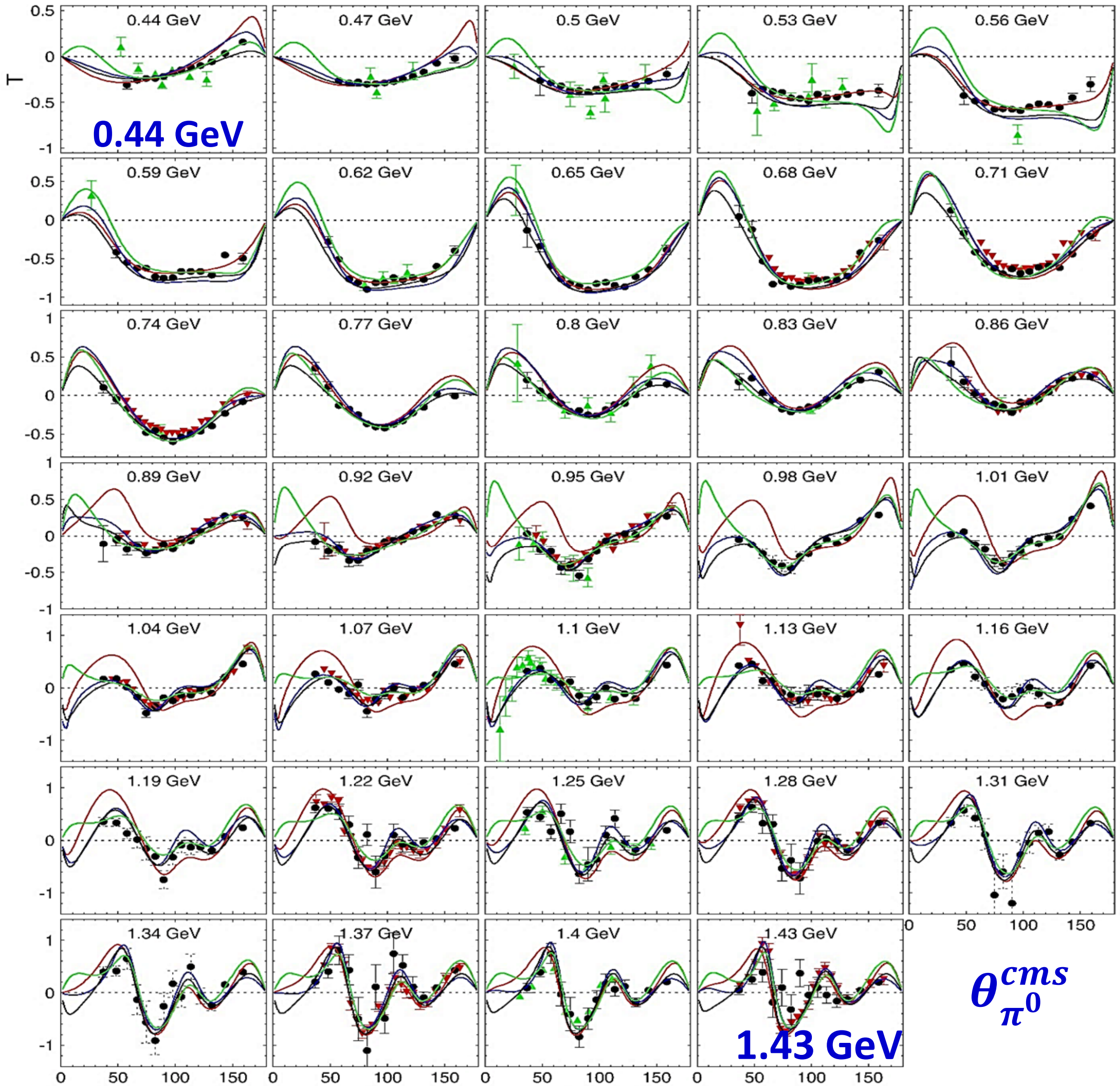
C_4 O H_{10}
(C_4 O D_{10})

Carbon Target

Selected results

T asymmetry for $p\pi^0$

Transverse target pol.
Unpolarised beam



J. Annand et al., PRC 93, 055209 (2016)
also F asymmetry data given in the same paper

(34 energy bins over a 1 GeV-wide photon beam range)

Data in the energy range 150 – 400 MeV will be also published

Black circles: A2 data
Red triangle CBELSA (Bonn)
Green Triangle Older points

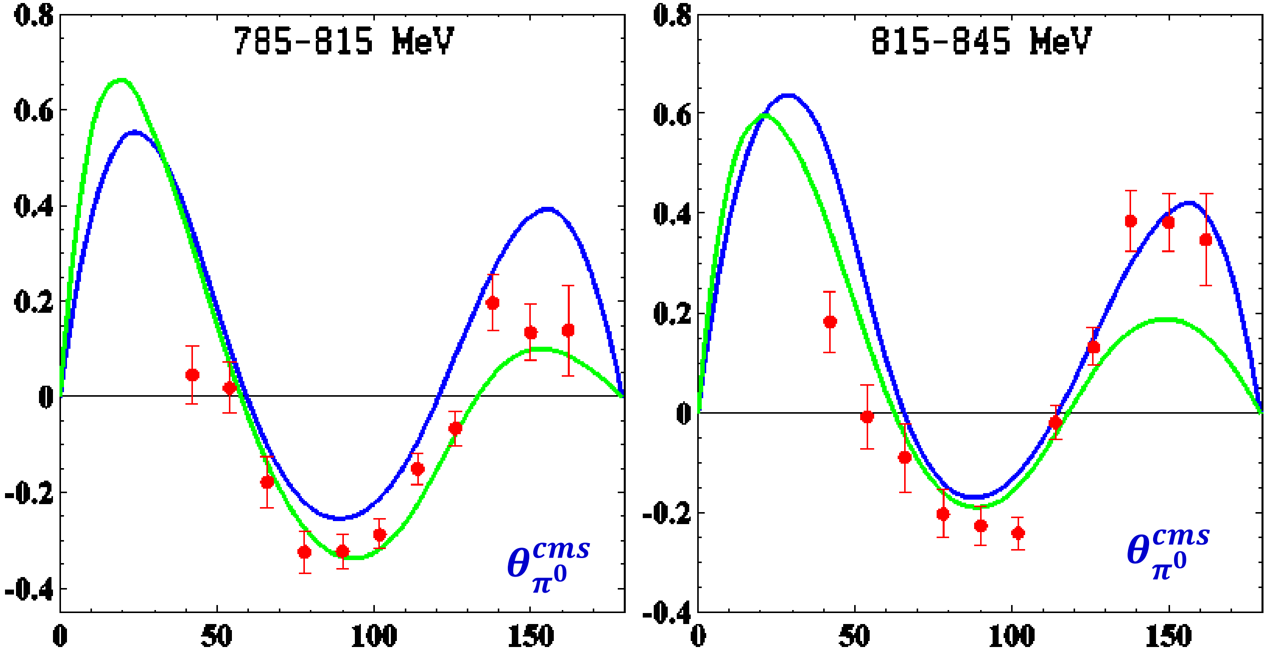
Red line: MAID 2007
Blue line SAID PR15
Green line JUBO2015-B
Black line BG2014-2

PWA Analyses

T asymmetry for $p\pi^0$

Transverse target pol.
Unpolarised beam

$$T \approx Im(E^*_{0+} (E_{2-} + M_{2-}) - 6E^*_{2-}M_{2-})$$



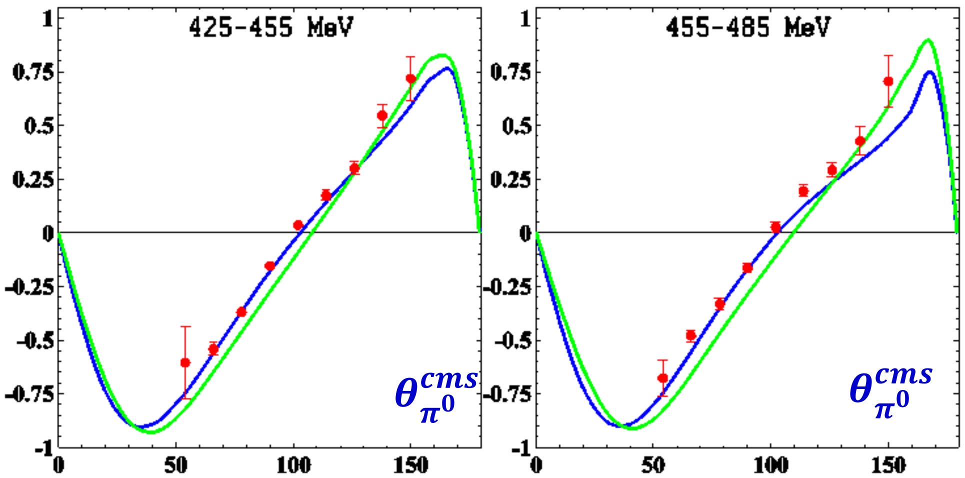
• A2 data J. Annand et al., PRC 93, 055209 (2016)

– MAID 2007 (PWA pred) – SAID-CM12 (PWA pred)

Strong D-wave contribution from D_{13}(1520)

F asymmetry for $p\pi^0$

Transverse target polar.
Circular beam polarization

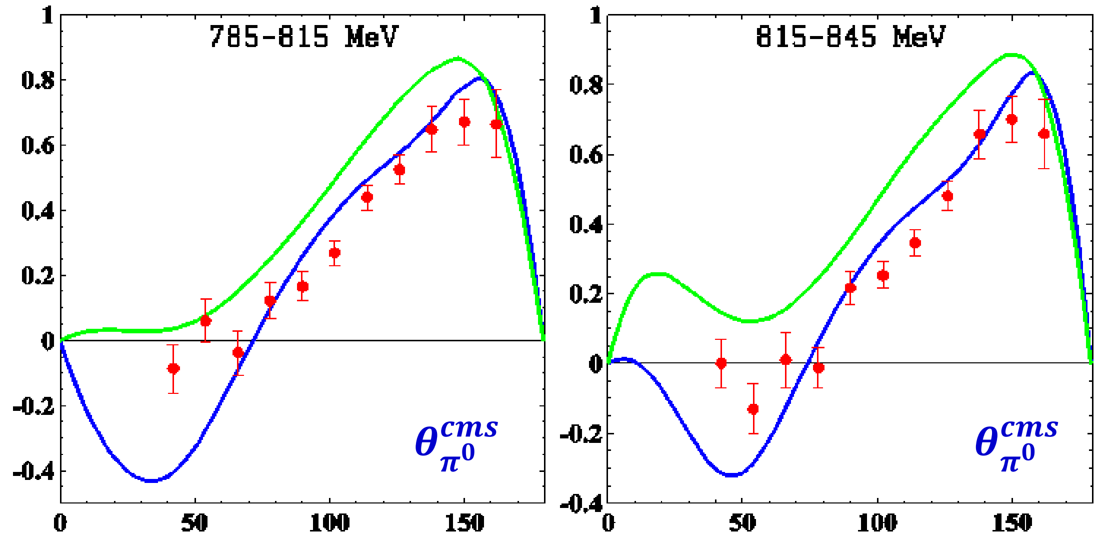


J. Annand et al., PRC 93, 055209 (2016)

$F \approx -\sin(\vartheta)\cos(\vartheta)\,|M_{1+}|^2$

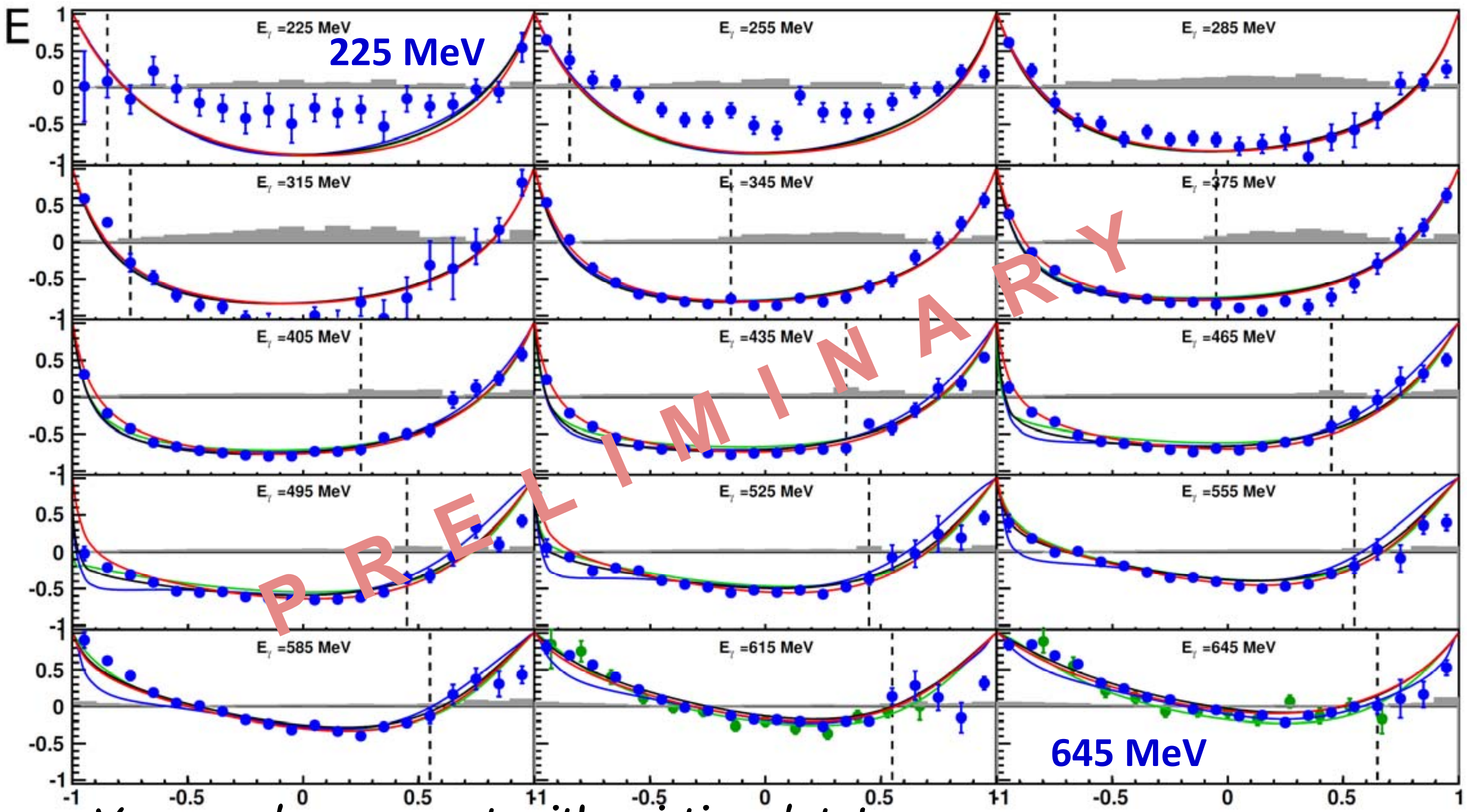
(well known)

$$F \approx \sin(\vartheta)\cos(\vartheta)\cdot(|E_{2-}|^2 - 3|M_{2-}|^2 + E^*_{0+}(E_{2-} + M_{2-}) - 2E^*_{2-}M_{2-})$$



- A2 data J. Annand et al., PRC 93, 055209 (2016)
- MAID 2007 (PWA pred.)
- SAID-CM12 (PWA pred)

E asymmetry for $p\pi^0$



Very good agreement with existing data!

Longitudinal target polar.
Circular beam polarization

→ *small* M_{1+}

→ $E \approx |M_{1+}|^2$

(well known)

$(\sigma_{1/2} - \sigma_{3/2})$

Previously measured in Mainz by the GDH collab.

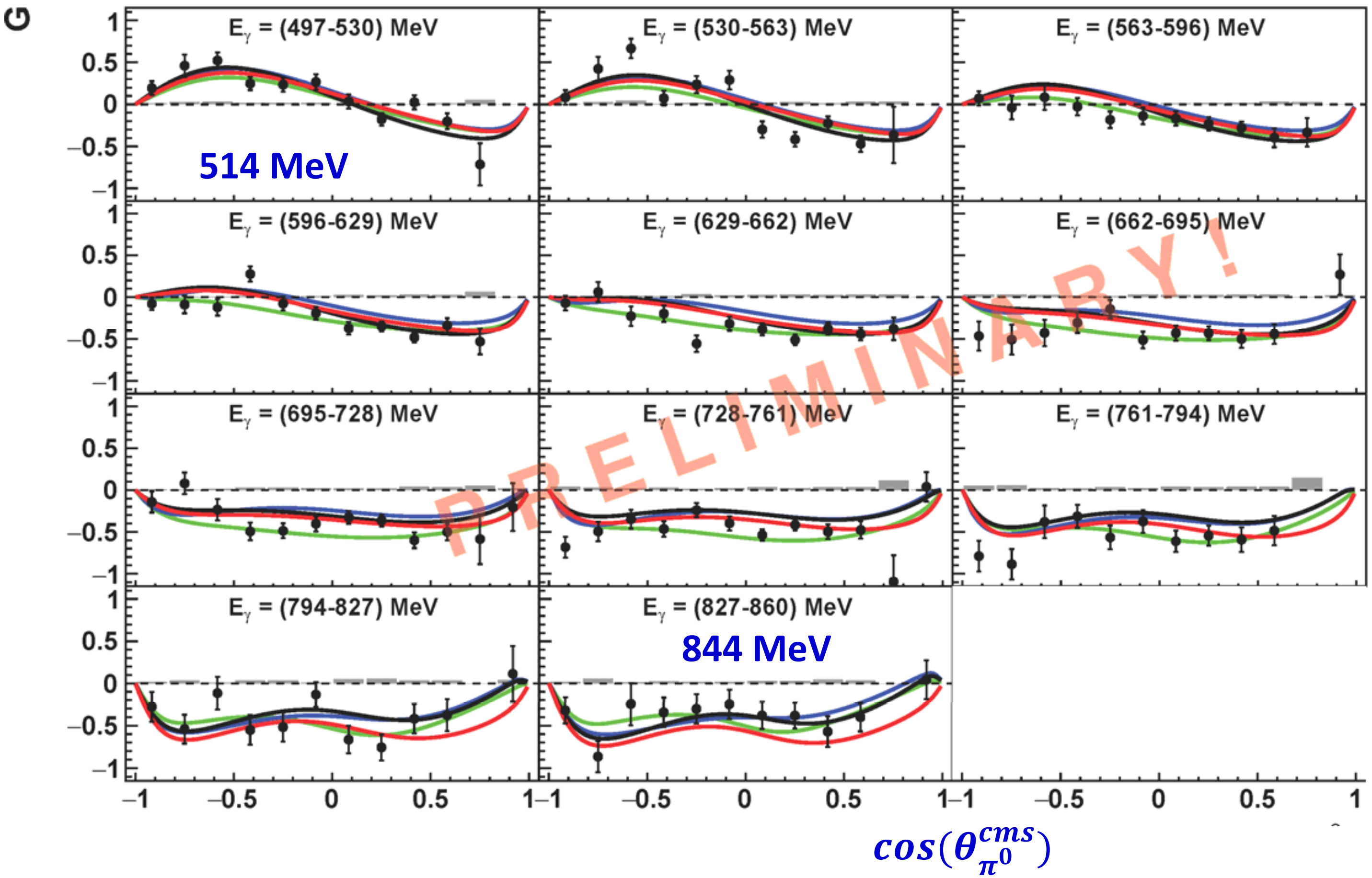
- M. Gottschall et al., Phys. Rev. Lett. 112 (2014) 012003)

– BnGa_2014_02 (PWA fit)
– BnGa_2014_01 (PWA fit)
– MAID 2007 (PWA pred.)
– SAID-CM12 (PWA pred)

Measured energy range
225 MeV – 645 MeV

G asymmetry for $n\pi^+$

Longitudinal target polar.
Linear beam polarization



$$G \approx Im\, M_{1-} \cdot Re\, M_{1+}$$

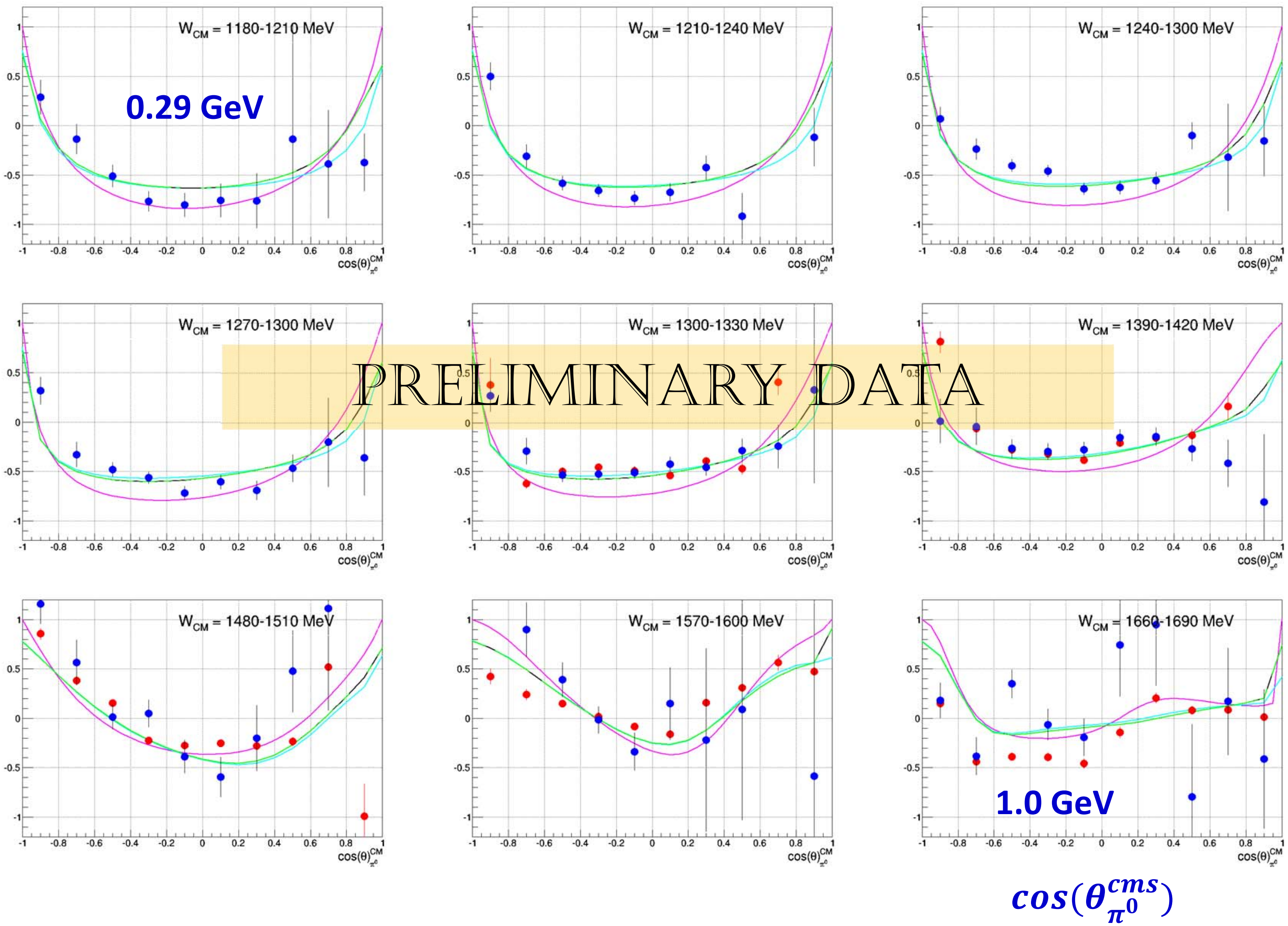
- sensitive to the M_{1-} partial wave
- **sensitive to** P11(1440) (Roper resonance)

– BnGa_2014_02 (PWA fit)
– MAID 2007 (PWA pred.)
– BnGa_2014_01 (PWA fit)
– SAID-CM12 (PWA pred)

E asymmetry for $n\pi^0$

Longitudinal target polar.
Circular beam polarization

deuteron target



● A2 Preliminary data

● A2 Published data
M.Dieterle et al.,
PLB 770, 523 (2017)

MAID 2007
(Free neutron)

Deuteron nuclear model:
A. Fix et al,
PRC 72 064005 (2005)

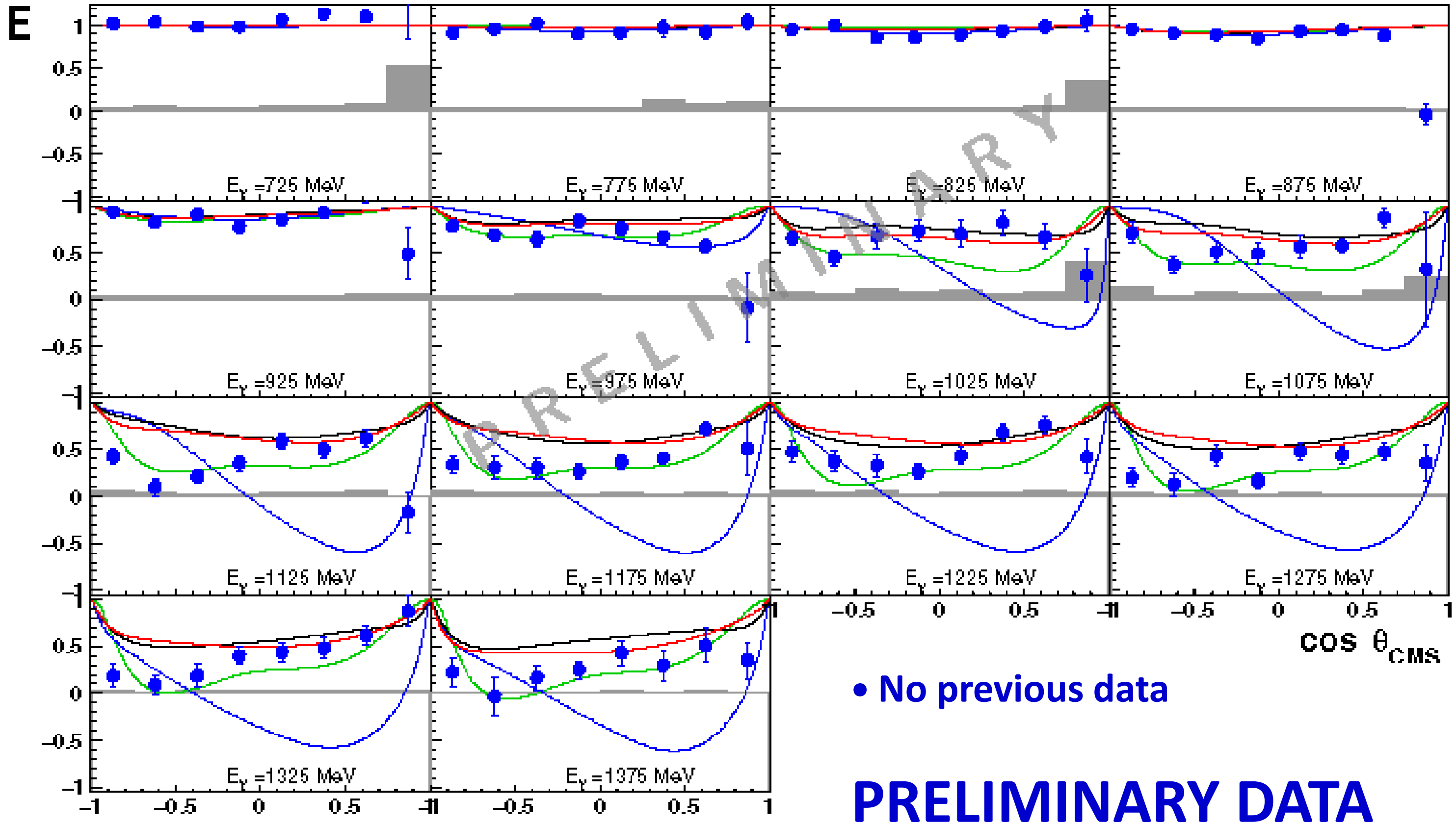
MAID + IA

MAID + IA +FSI

Nuclear effects are small

E asymmetry for pη

η meson (I=S=0) can be used as isospin filter to isolate a part of the total resonance spectrum



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

$$E = +\left|E_{0+}\right|^2 + 3\left|E_{1+}\right|^2 - \left|M_{1+}\right|^2 + \ldots$$

JuBo2016-3.1 (FIT)

SAID GE09 (PRED)

BnGa 2014-01 (PRED)

BnGa 2014-02 (PRED)

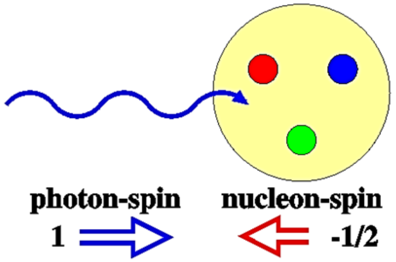
• No previous data

PRELIMINARY DATA

$\gamma N \rightarrow N\eta$ helicity dependent cross-section

$\sigma_{1/2}$; $\sigma_{3/2}$

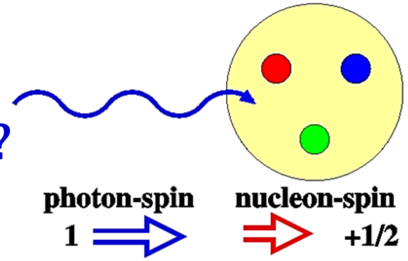
- helicity component 1/2



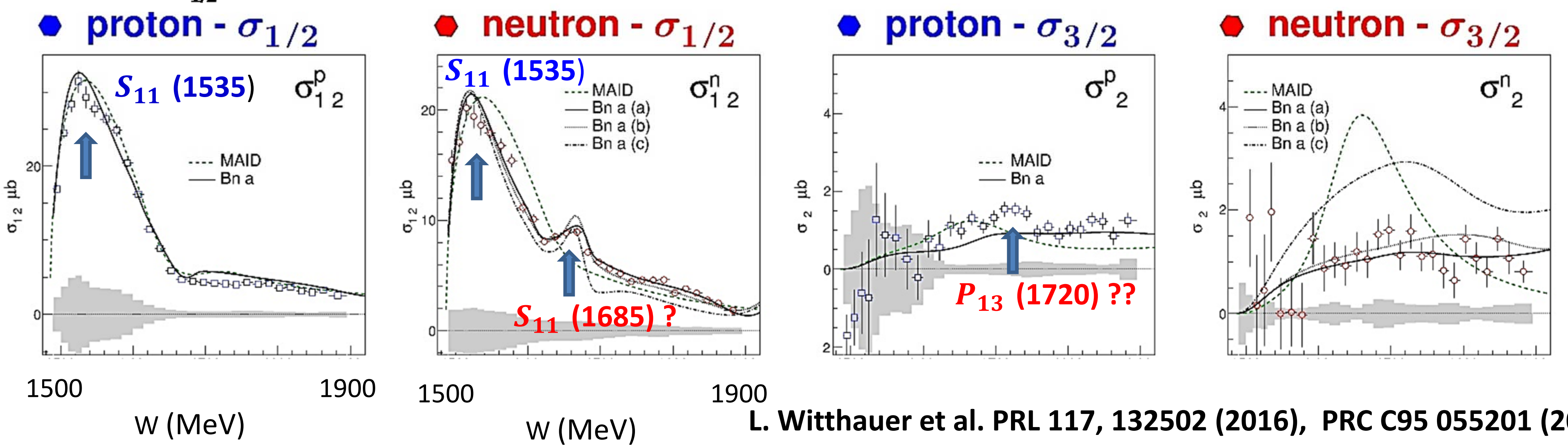
$\sigma_{1/2}$

- **No previous data**
- **Neutron: new excited state** $S_{11}(1685)$?
- **Proton: new excited state** $P_{13}(1720)$??

- helicity component 3/2



$\sigma_{3/2}$



L. Witthauer et al. PRL 117, 132502 (2016), PRC C95 055201 (2017)

Is all this useful for anything ?

Eur. Phys. J. A (2016) **52**: 284
DOI 10.1140/epja/i2016-16284-9

THE EUROPEAN PHYSICAL JOURNAL A

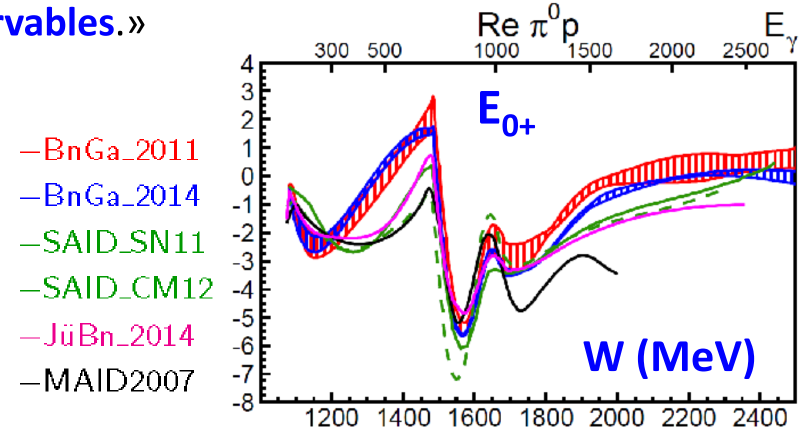
Regular Article – Experimental Physics

A. Anisovich et al. EPJA 52, 2284 (2016)

The impact of new polarization data from Bonn, Mainz and Jefferson Laboratory on $\gamma p \longrightarrow \pi N$ multipoles

A.V. Anisovich[1,2], R. Beck[1,a], M. Döring[3,4], M. Gottschall[1], J. Hartmann[1], V. Kashevarov[5], E. Klempt[1], Ulf-G. Meißner[1,6,7], V. Nikonov[1,2], M. Ostrick[5], D. Rönchen[1,6,b], A. Sarantsev[1,2], I. Strakovsky[3], A. Thiel[1], L. Tiator[5], U. Thoma[1], R. Workman[3], and Y. Wunderlich[1]

«We find that the new data force the multipoles to get closer to each other, the variance is reduced by about a factor of two. Even more important seems to be that the multipoles converge to similar values in the region of leading resonances while the "background" and the contribution of higher-mass resonances remain less constrained by the new data……
High-lying, broad resonances require precise data due to many non-vanishing partial waves, motivating further experimental effort. **The task on the experimental side will require more precise data, in particular more precise data on polarization observables.**»



BnGa: Without polarization observables

BnGa: With polarization observables

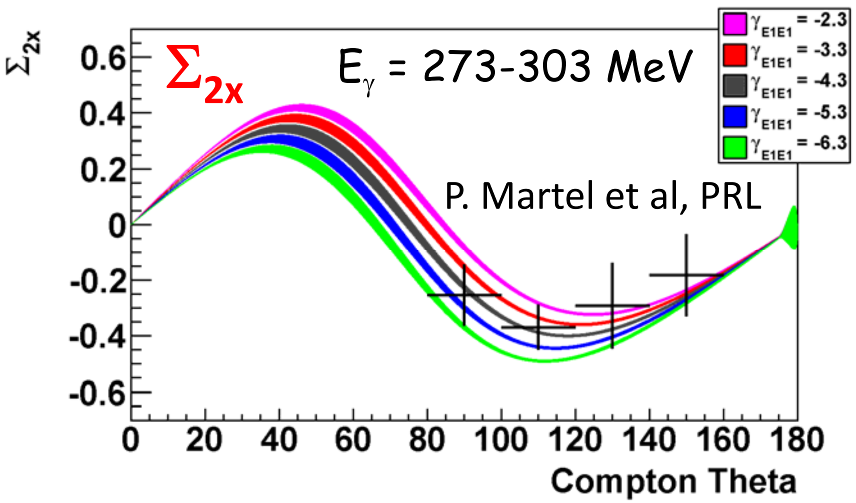
J. Hartmann et al.,
Phys. Lett. B 748, 212-220 (2015)

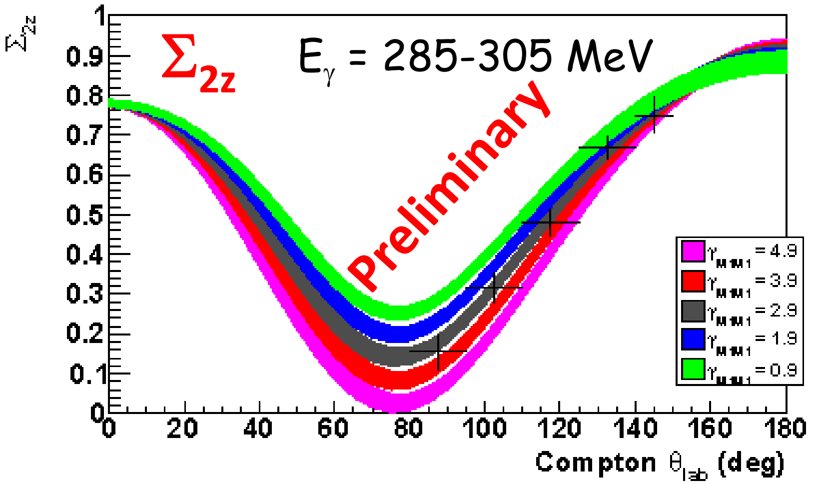
YES, but ….

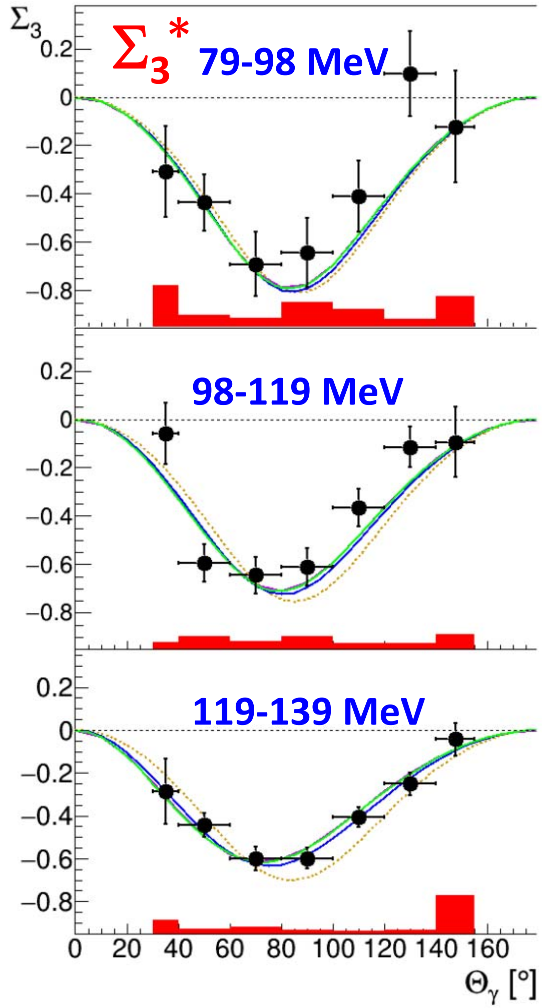
Discrepancies between the different PW analyses exist. Inclusion of more polarization observables will converge all analyses to the same solution

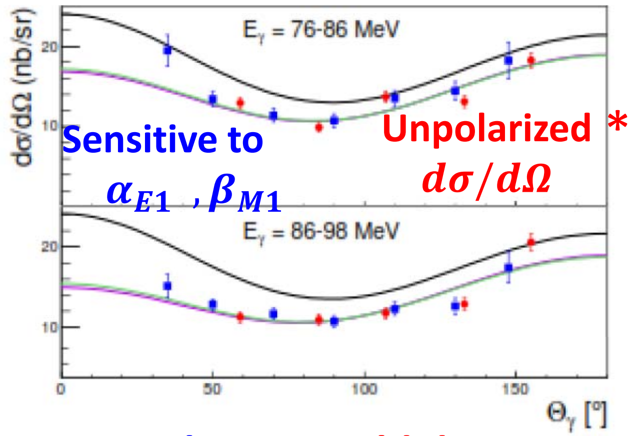
(Un)Polarized Compton Scattering

V. Sokhoyan et al., EPJA 53, 14 (2017)









•A2 data •old data

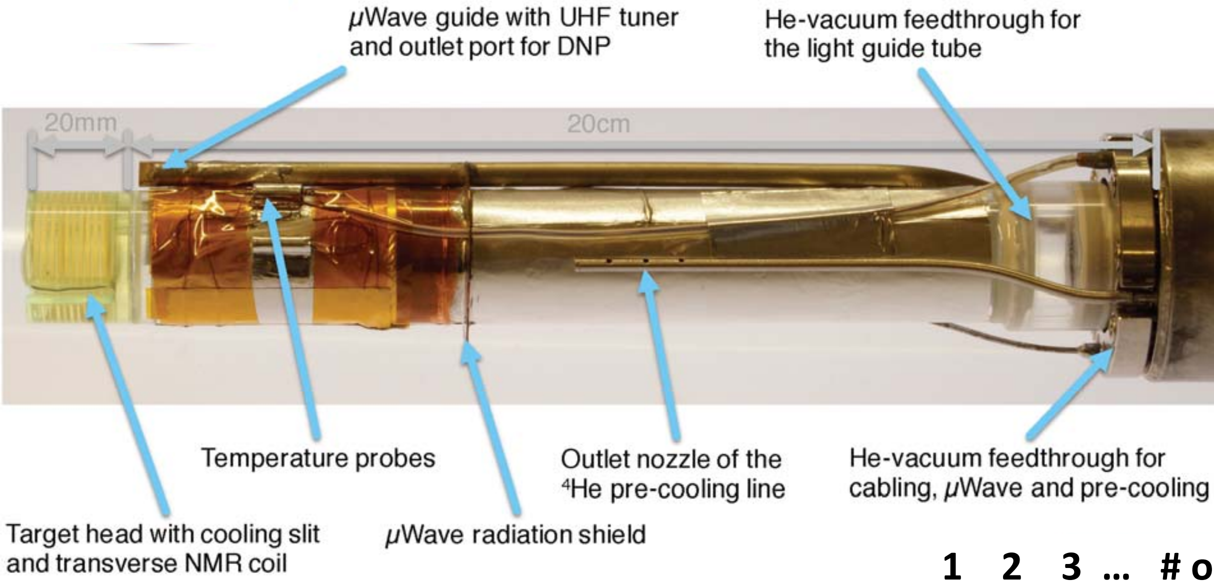
* ≃ 5 times more statistics on disk

First simultaneous fit of all 6 polarizabilites using all 4 obervables

(our dream: error on spin polarizabilities -at least- halved)

The near future: an active and polarized target

Thin slices of polarized (doped) scintillator material (T= 30 mK)

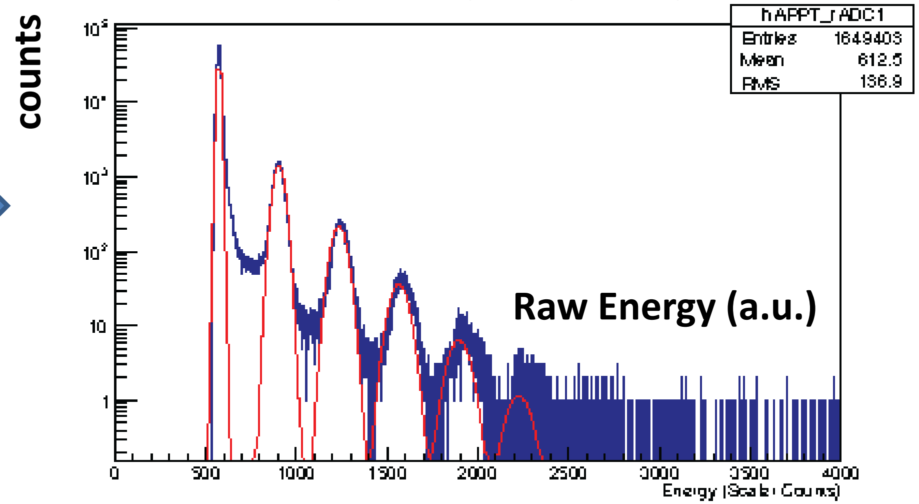


Target nose

(Mainz-Dubna)

M. Biroth at al, PoS PSTP2015 (2016) 005

- First beam test successful (some physics results will also be published)
- A relevant improvement (especially for Compton scattering) in the accessible polar angular and photon energy range
- Data takings planned next year



Conclusions

- Rutherford discovered the proton in 1917 and since 1933 (Stern-Gerlach experiment) we know that it is not an elementary particle

- **Understanding the proton (neutron) internal structure is a very severe challenge both on the theoretical and on the experimental side**

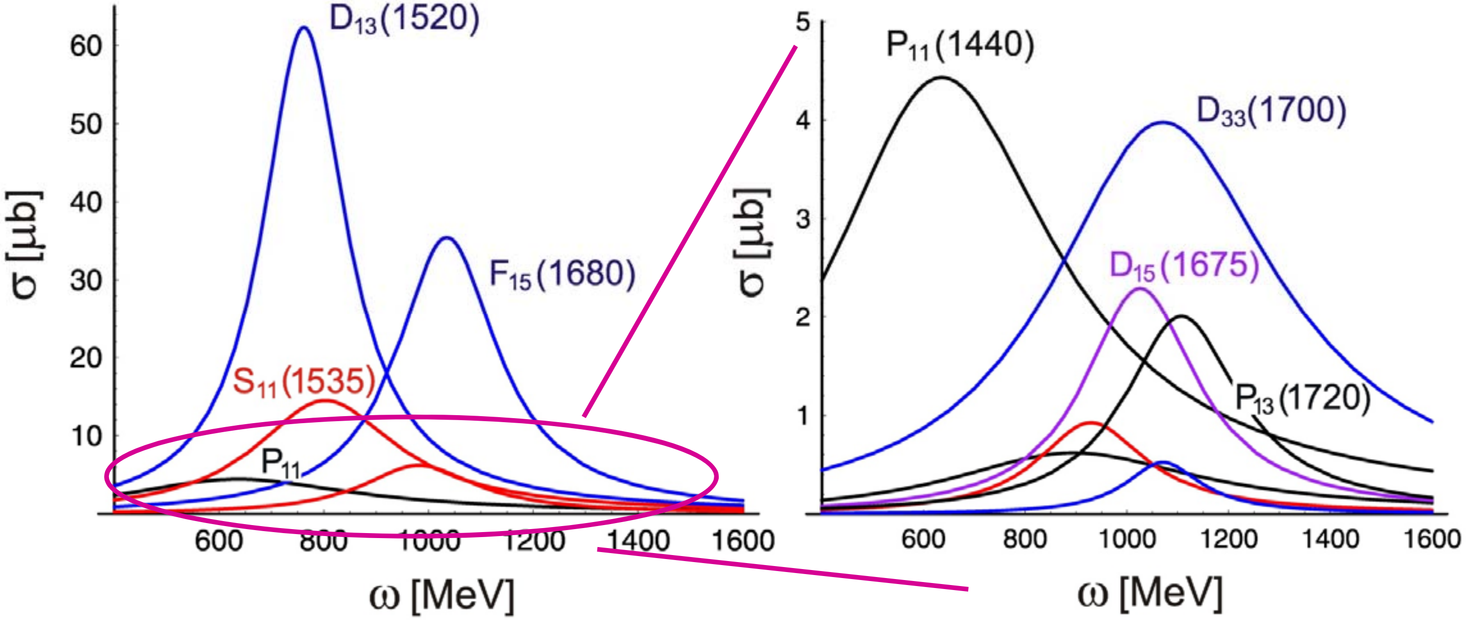
- The joint effort of several laboratories (Mainz, Bonn, JLAB, …) and the technological development in polarized beam and target techniques can solve some long-standing problems (how many baryon resonances are there?, accurate determination of the polarizabilities, …)

- **The A2 collaboration is an important player of this game: many published data, many more to come and to be collected.**

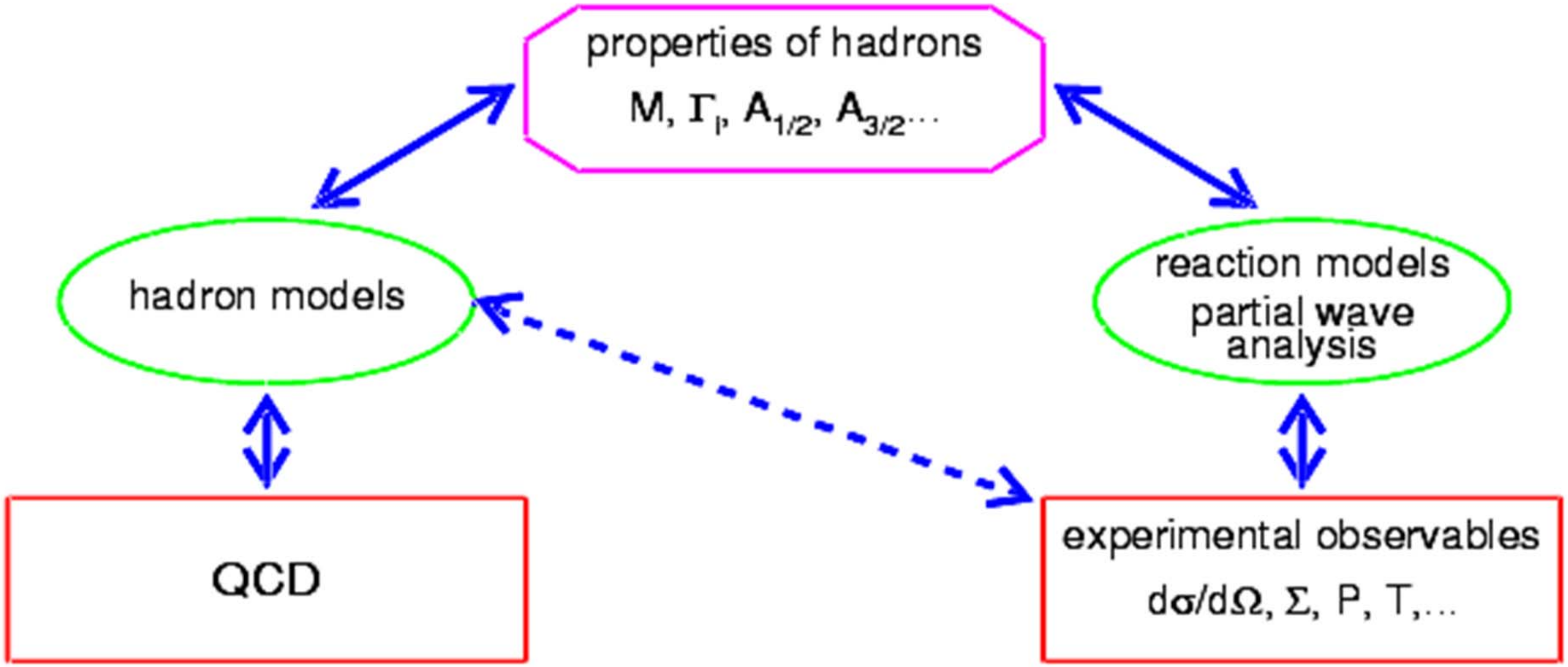
A2 Collaboration	Participating Institutions
$\simeq$ 80 researchers	**Europe: Universities of Mainz, Basel, Bochum, Bonn, Glasgow, Giessen, York, INFN-Pavia, INR-Moscow, JINR-Dubna, RBI-Zagreb; Israel: University of Jerusalem** **North-America: Universities of Mount-Allison (Canada), Regina (Canada), Saint Mary's (Canada), Washington-DC (USA), Kent-OH (USA), Amherst-MASS (USA), Los Angeles (USA).**

You Want more…

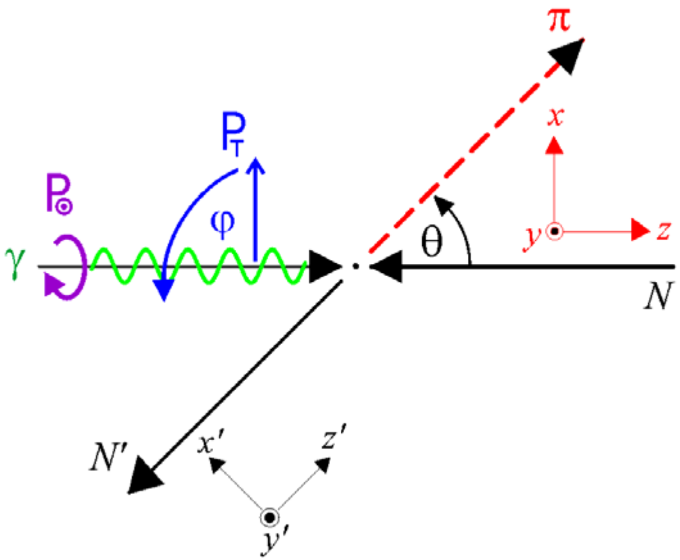
total photoabsorption
in the 2nd and 3rd resonance regions (MAID model)



Polarization observables are necessary to disentangle the broad and overlapping resonances at higher excitation energies and to separate resonant mechanisms from non-resonant background


properties of hadrons
M, Γi, A1/2, A3/2...
hadron models
reaction models
partial wave
analysis
QCD
experimental observables
dσ/dΩ, Σ, P, T,...

16 polarization observables
in photoproduction
of pseudoscalar mesons
π, η, η', K



- polarized photons and polarized target

$$\frac{d\sigma}{d\Omega} = \sigma_0 \Big[1 - P_T \Sigma \cos 2\varphi + P_x(-P_T H \sin 2\varphi + P_\odot F) - P_y(-T + P_T P \cos 2\varphi) - P_z(-P_T G \sin 2\varphi + P_\odot E) \Big]$$

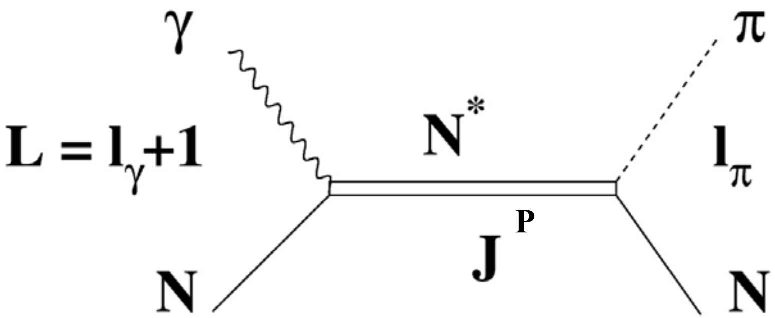
- polarized photons and recoil polarization

$$\frac{d\sigma}{d\Omega} = \sigma_0 \Big[1 - P_T \Sigma \cos 2\varphi + P_{x'}(-P_T O_{x'} \sin 2\varphi - P_\odot C_{x'}) - P_{y'}(-P + P_T T \cos 2\varphi) - P_{z'}(P_T O_{z'} \sin 2\varphi + P_\odot C_{z'}) \Big]$$

- polarized target and recoil polarization

$$\frac{d\sigma}{d\Omega} = \sigma_0 \Big[1 + P_{y'} P + P_x(P_{x'} T_{x'} + P_{z'} T_{z'}) + P_y(T + P_{y'} \Sigma) - P_z(P_{x'} L_{x'} - P_{z'} L_{z'}) \Big]$$

Connection between resonances and multipoles



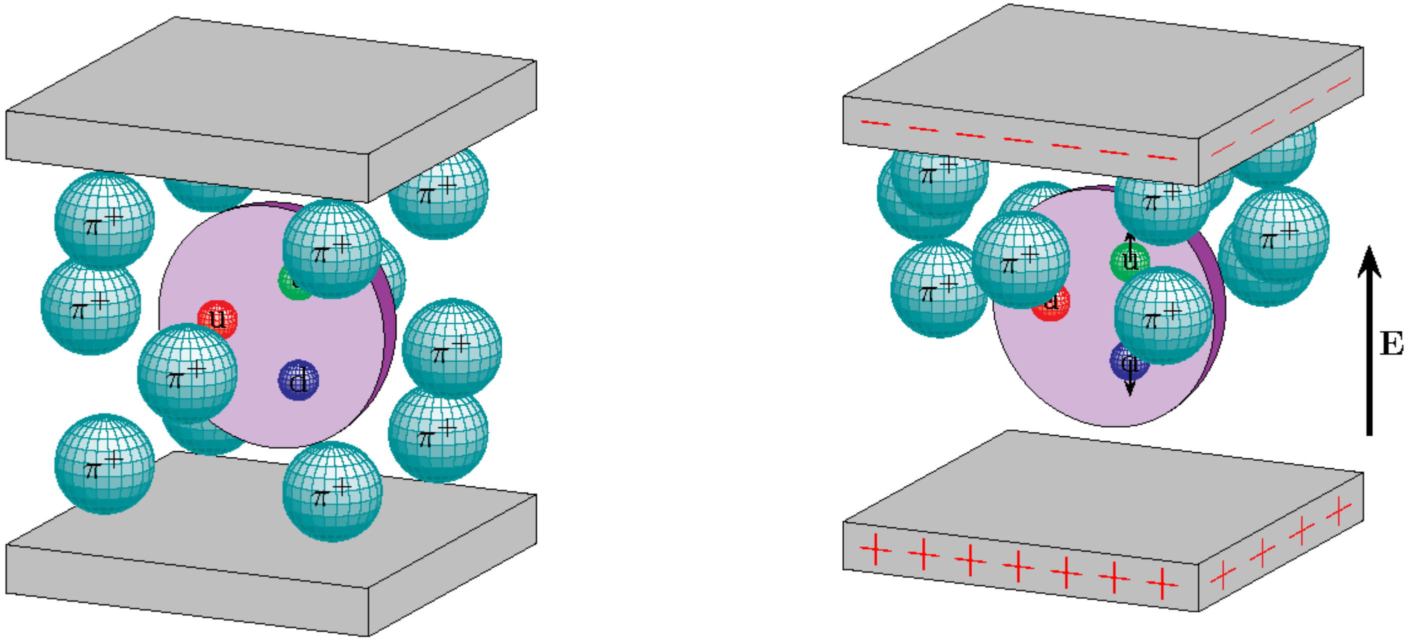
$$X_{2I\,2J}$$

isospin

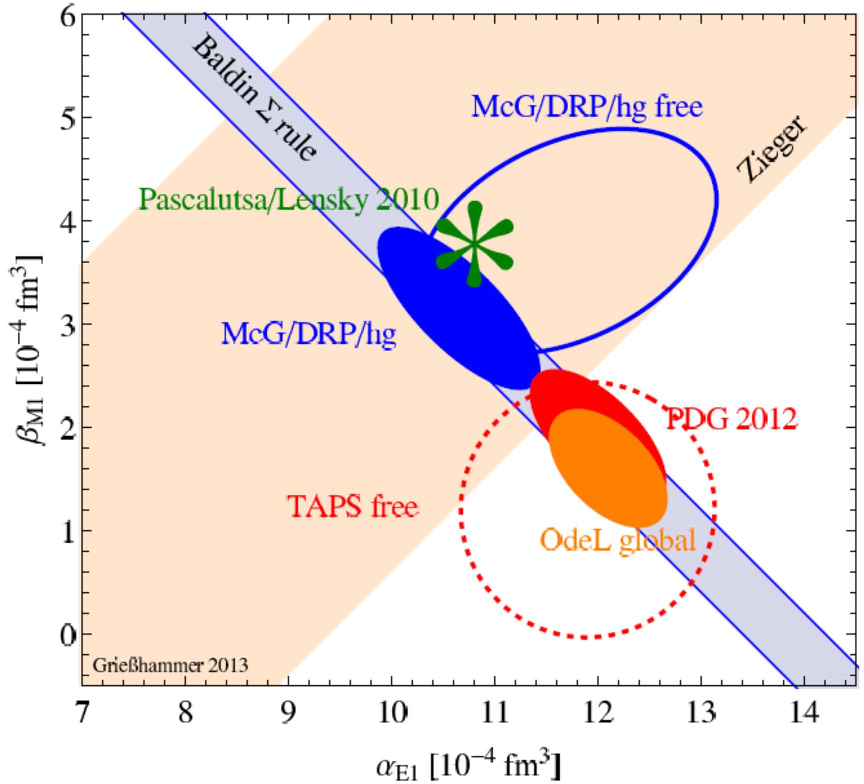
spectroscopic notation

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

Photon L	Photon Multipole	J	P	Pion lπ	Pion Multipole	Resonance
1	E1	1/2	-	0	E_{0+}	S_{11}
		3/2	-	2	E_{2-}	D_{13}
	M1	1/2	+	1	M_{1-}	P_{11}
		3/2	+	1	M_{1+}	P_{33}
2	E2	3/2	+	1	E_{1+}	P_{33}
		5/2	+	3	E_{3-}	F_{15}
	M2	3/2	-	2	M_{2-}	D_{13}
		5/2	-	2	M_{2+}	D_{15}

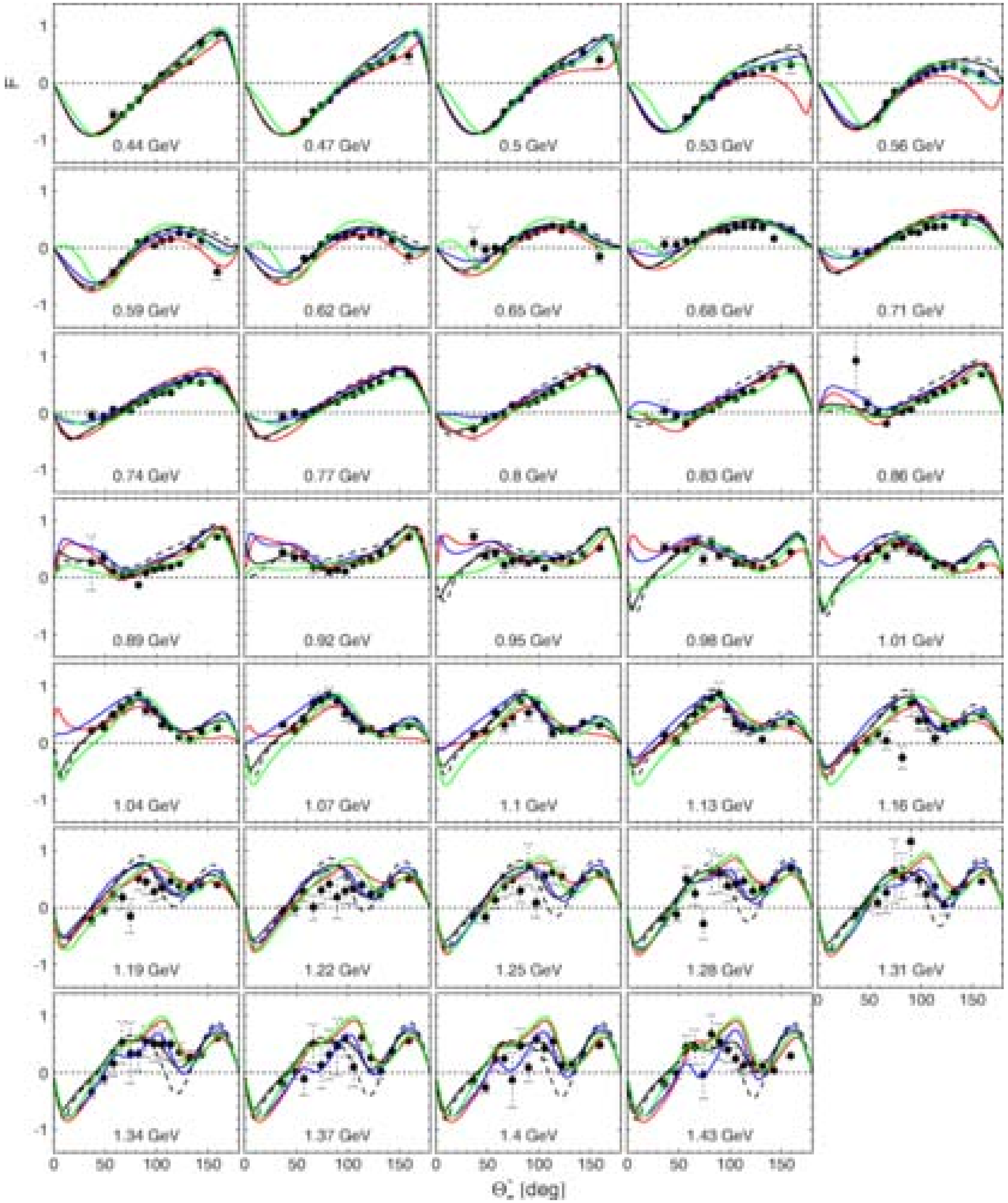


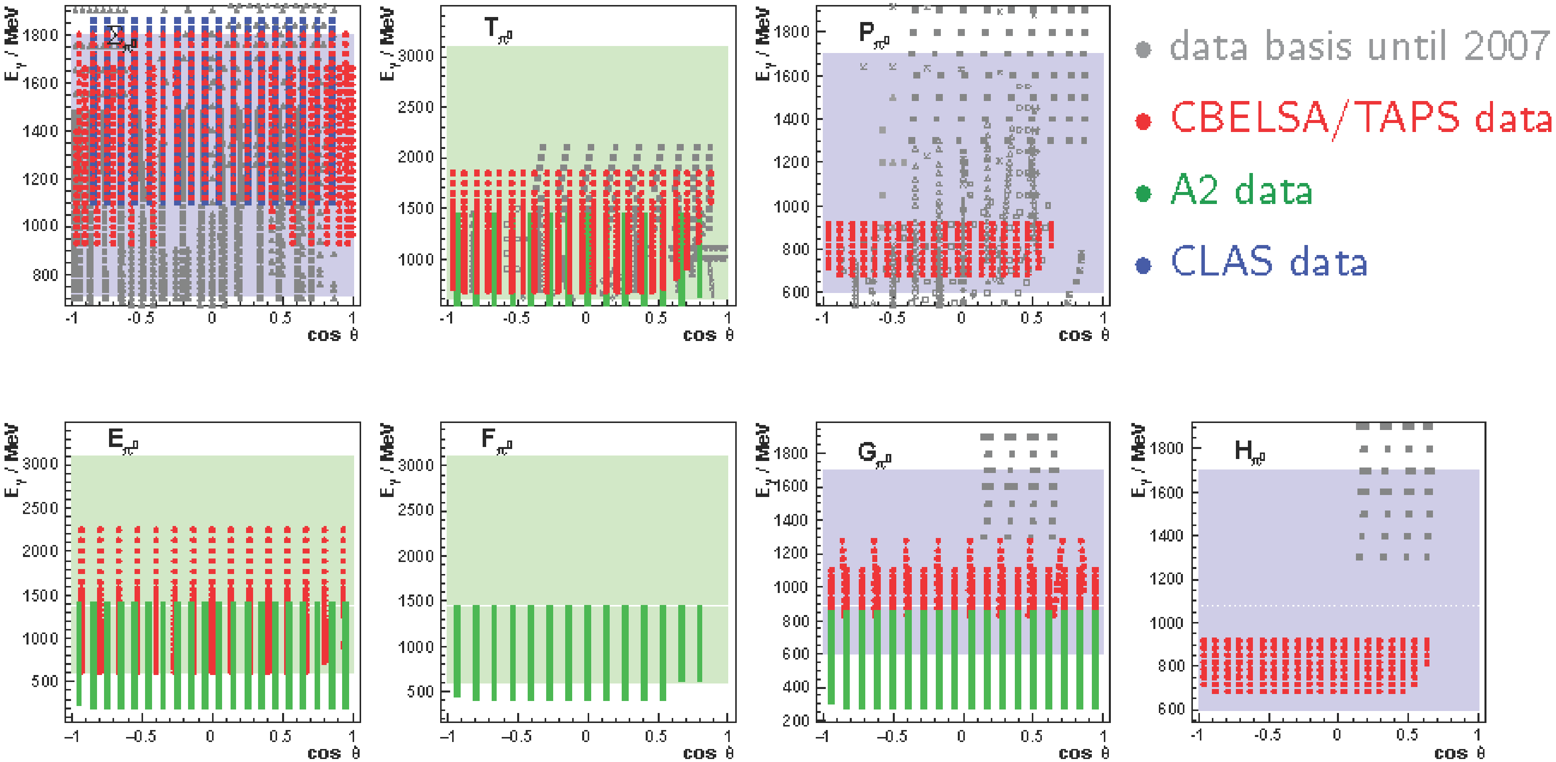
π^+
u
d
E



Baldin Σ rule
McG/DRP/hg free
Zieger
Pascalutsa/Lensky 2010
McG/DRP/hg
PDG 2012
TAPS free
OdeL global
Grießhammer 2013
β_{M1} [10^{-4} fm^3]
α_{E1} [10^{-4} fm^3]

F asymmetry pi0





CBELSA/TAPS publications:

G: A.Thiel et al., PRL 109 (2012) 102001

E: M. Gottschall et al., PRL 112 (2014) 012003

T,P,H: J. Hartmann et al., PRL 113 (2014) 062001

Σ: F. Afzal et al. (preliminary)

A2 publications:

σ: P. Adlarson, Phys. Rev. C 92, 024617 (2015)

T,F: J.R.M. Annand et al., Phys. Rev. C 93, 055209 (2016)

E: F. Afzal et al. (preliminary)

G: K. Spieker et al. (preliminary)

Experimental verification of the GDH sum rule

- Proposed in 1966 by Gerasimov-Drell-Hearn
- Prediction on the absorption of circularly polarized photons by longitudinally polarized nucleons/nuclei

$$I_{GDH} = \int_{\nu_{thr}}^{\infty} \frac{\sigma_p(E_\gamma) - \sigma_a(E_\gamma)}{\nu} d\nu = 4\pi^2 S \frac{e^2}{M^2} k^2$$

Anomalous magnetic moment

$$\nu_{thr} = \begin{cases} \pi \text{ production threshold (nucleon)} \\ \text{photodisintegration threshold (nuclei)} \end{cases}$$

GDH sum rule:

✓ Fundamental check of our knowledge of the γN interaction

The only "weak" hypothesis is the assumption that **Compton scattering $\gamma N \rightarrow \gamma' N'$ becomes spin independent when $\nu \rightarrow \infty$**
A violation of this assumption can not be easily explained

✓ Important comparison for photoreaction models

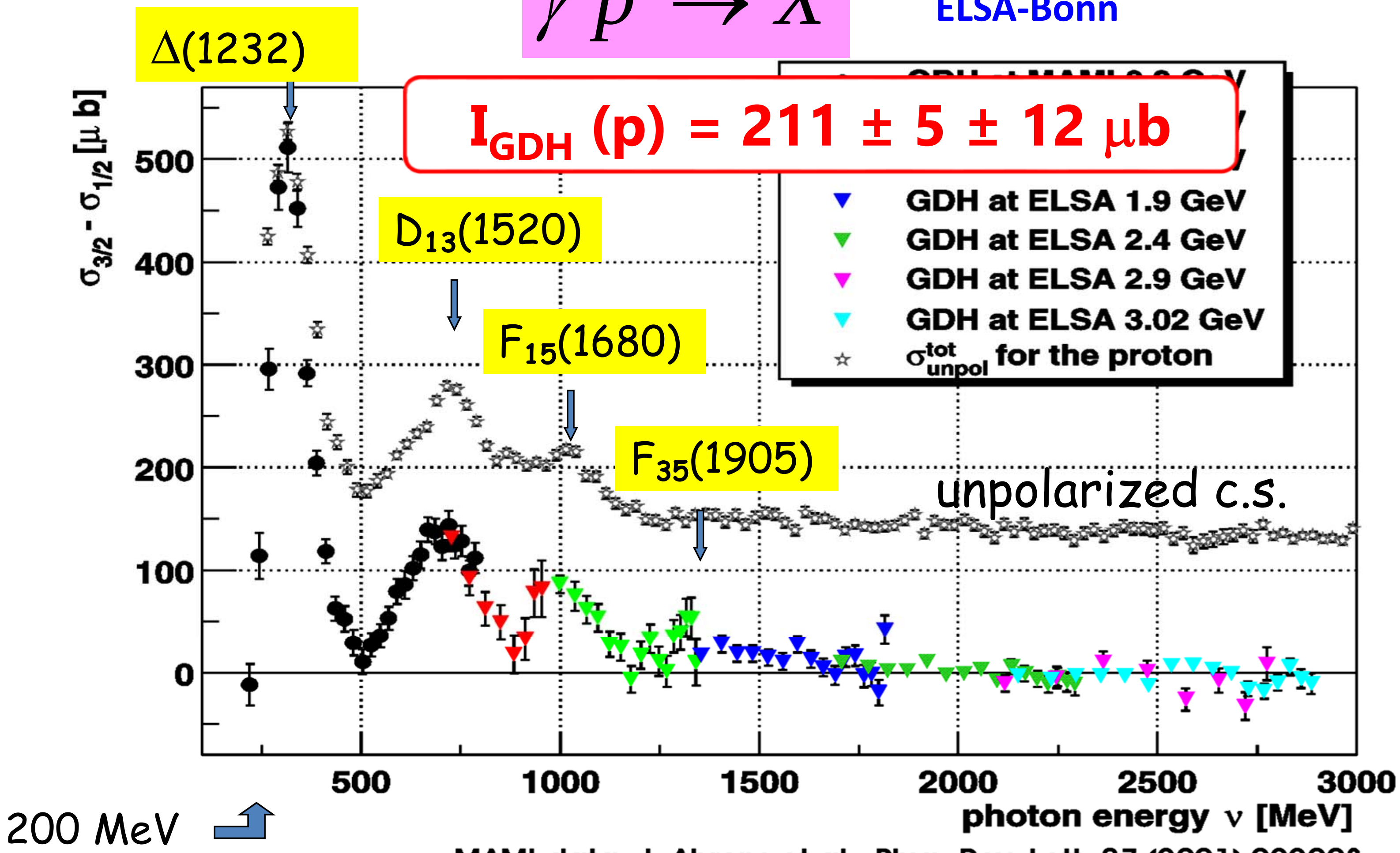
✓ Helicity dependence of partial channels (pion photoproduction) is an essential tool for the study of the baryon resonances (interference terms between different electromagnetic multipoles)

✓ Valid for any system with $\mathbf{k} \neq 0$ (^2H, ^3He) . "Link" between nuclear and nucleon degrees of freedom

Experimental status

$$\vec{\gamma}\,\vec{p} \rightarrow X$$

MAMI-Mainz
ELSA-Bonn



MAMI data: J. Ahrens et al., Phys. Rev. Lett. 87 (2001) 022003
ELSA data: H. Dutz et al., Phys. Rev. Lett 91 (2003) 192001
H. Dutz et al., Phys. Rev. Lett 93 (2004) 032003