Light Baryon Spectroscopy

R. Beck
University of Bonn

Hadron 2023 , Genova, June 5th to 9th 2023

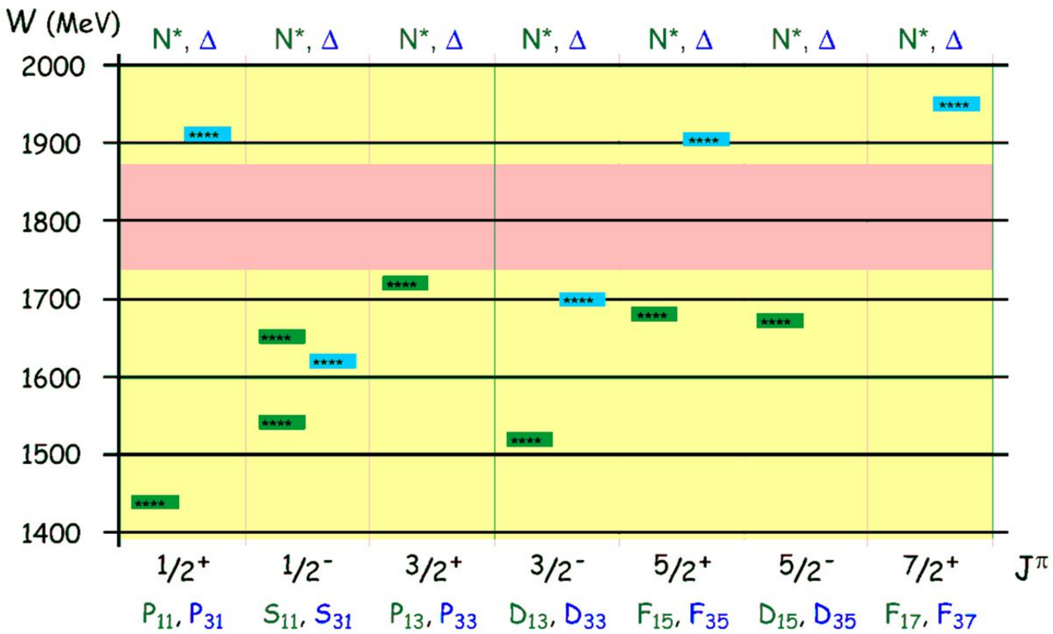
- Introduction
- Impact of the new polarization data
- Some highlights
- Summary

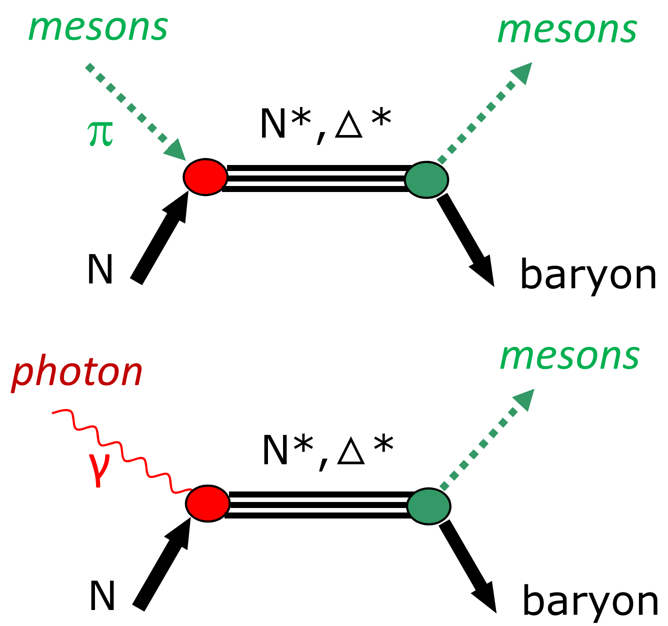
Introduction

Excitation spectra: information about interaction and dynamics between constituents

Experiments: focus on baryon spectroscopy, meson photoproduction

Nucleon Excitation Spectrum





$$J^P = \text{Spin}^{\text{Parity}}$$

only a few well established in the mass region 1400 MeV < W < 2000 MeV

- Energy pattern for the dominant states
  - Constituent Quark Models
  - Dynamic Models, EFT, Lattice QCD
- Various nucleon models predict many more states
  - weak coupling to πN final state
  - incomplete data base

Talk: D. Leinweber, C. Morningstar, M. Mai, R. Molina Peralta…

Introduction

- **Status 2022: Light Baryon Resonances**

$J^P = \text{Spin}^{\text{Parity}}$

final states

Particle	J^P	overall	PWA	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****											
$N(1440)$	$1/2^+$	****	○ $\diamond_g$ ★ ▷	****	****	****	***	-			-		
$N(1520)$	$3/2^-$	****	○ ◇ ★ ▷	****	****	****	**	****			- - - -		
$N(1535)$	$1/2^-$	****	○ ◇ ★ ▷	****	****	***	*	****			- -		
$N(1650)$	$1/2^-$	****	○ ◇ ★ ▷	****	****	***	*	****	* - -	- -	- -		
$N(1675)$	$5/2^-$	****	○ ◇ ★ ▷	****	****	****	***	*	*	*	-		
$N(1680)$	$5/2^+$	****	○ ◇ ★ ▷	****	****	****	***	*	*	*	- - - -		
$N(1700)$	$3/2^-$	***	○ ▷	**	***	***	*	*	- -	-	-		
$N(1710)$	$1/2^+$	****	○ ◇ ▷	****	****	* -		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	○ ◇ ★ ▷	****	****	***	*	*	****	*	* -	*	
$N(1860)$	$5/2^+$	**	▷	*	**		*	*					
$N(1875)$	$3/2^-$	***	○ ▷	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	○ ▷	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	○ ▷	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	○ ◇ ▷	****	**	**	*	*	**	**	-	*	**
$N(1990)$	$7/2^+$	**	○ ◇ ▷	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	○ ★	**	* -	**	*	*	-	-	- -	*	
$N(2040)$	$3/2^+$	*	▷		*								
$N(2060)$	$5/2^-$	***	○ $\diamond_g$ ▷	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	○ ▷	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	○ ▷	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	○ ◇ ★ ▷	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	○ ◇ ★	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	○ ◇ ★ ▷	**	****			*	*	*			
$N(2300)$	$1/2^+$	**			**								
$N(2570)$	$5/2^-$	**			**								
$N(2600)$	$11/2^-$	***	★		***								
$N(2700)$	$13/2^+$	**			**								

- Until 2010: only results from πN scattering used in the PDG

- PWA groups:
  BnGa, JüBo. SAID, MAID
  include photoproduction data

- Now: new values from the PWA fits are entering the PDG

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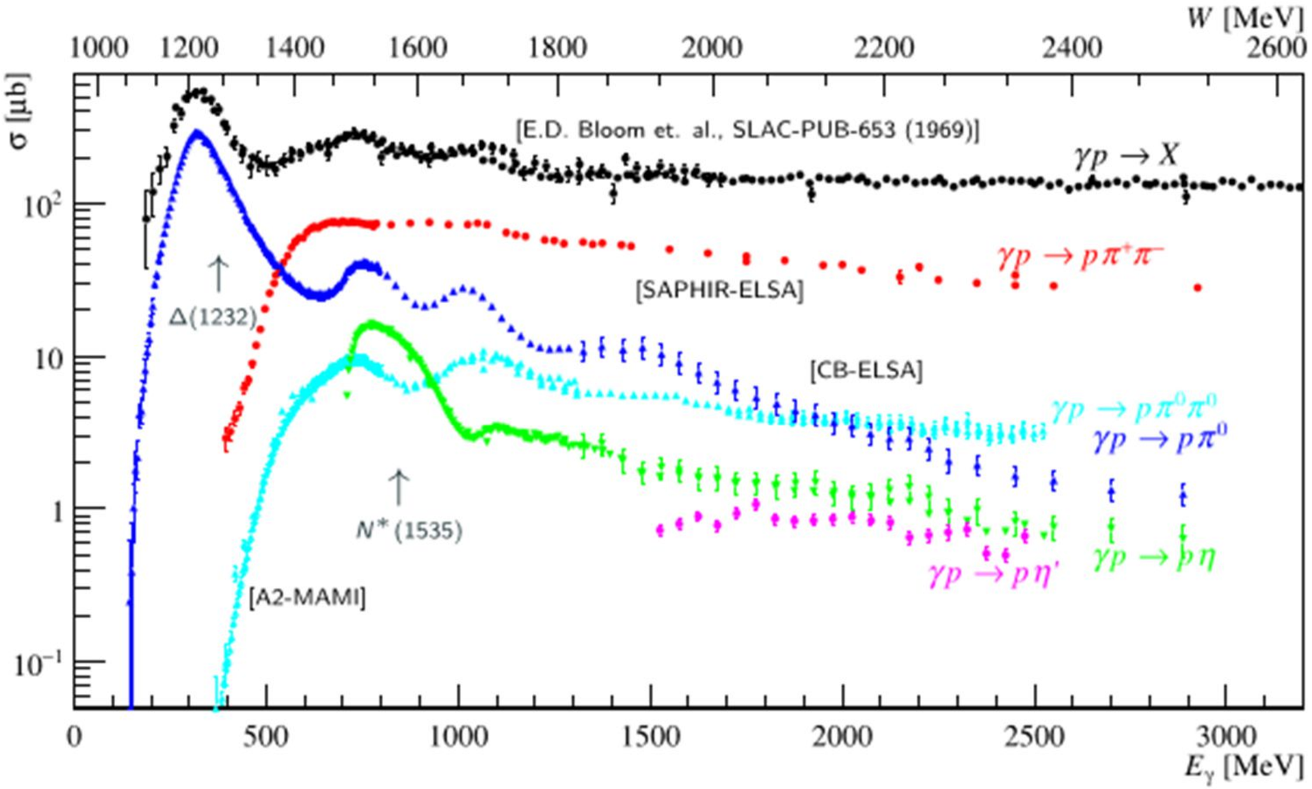
Introduction

Worldwide effort at ELSA (Bonn), JLab (USA), MAMI (Mainz), Spring8 (Japan), ……….

- Precision data for different final states ($p\pi^0$, $n\pi^+$, $p\eta$, $K^+\Lambda$, $p\pi^0\pi^0$....)
- Polarization experiments (beam, target and recoil) "complete data base"
- To constrain PWA –> unique PWA solution



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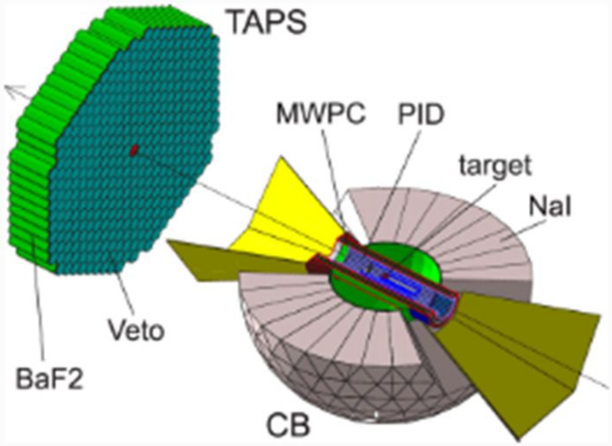
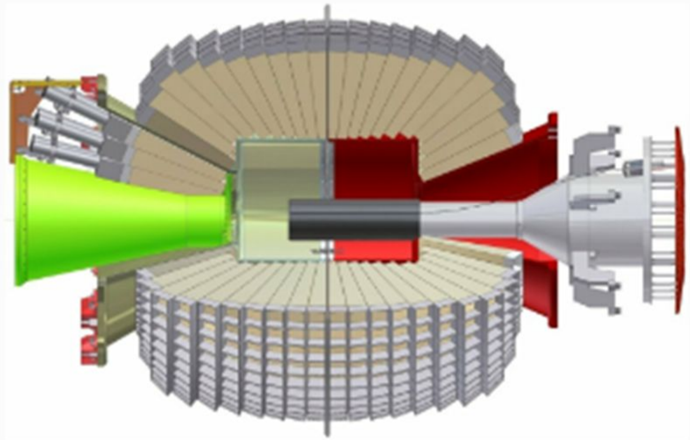
- Photoproduction reactions are an excellent toll to probe excitation
- Resonances contribute with different strength to distinct channels

Introduction

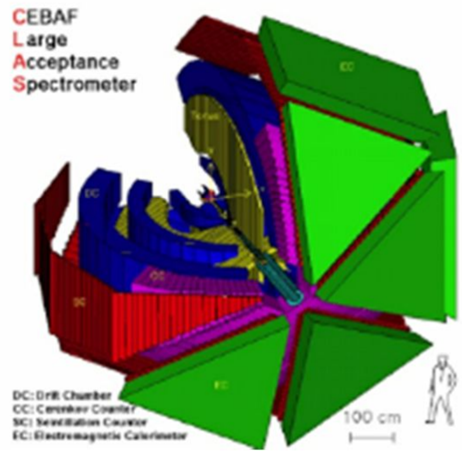
A2 experiment at MAMI Mainz, Germany



CBELSA/TAPS experiment at ELSA, Bonn, Germany



CLAS experiment at JLAB Newport News, US



Common features :

- Good angular coverage of detector systems
- Polarized photons and polarized targets

Important differences :

- Different sensitivities for charged or neutral particles
- Different photon energies

Introduction

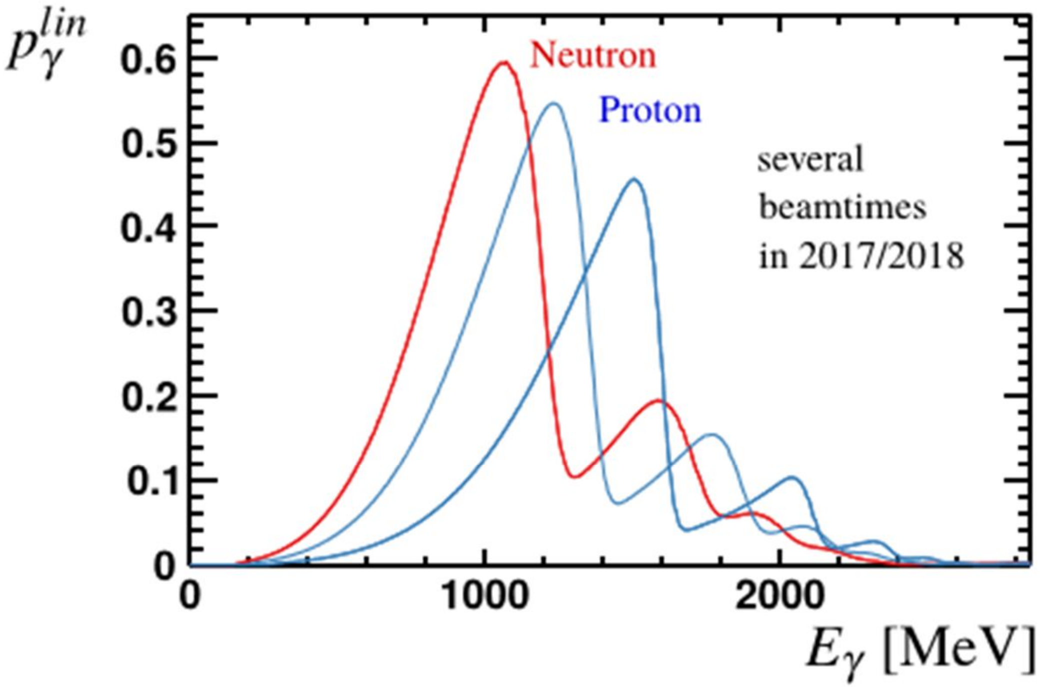
Linearly polarized photons:

- coherent bremsstrahlung
- diamond radiator

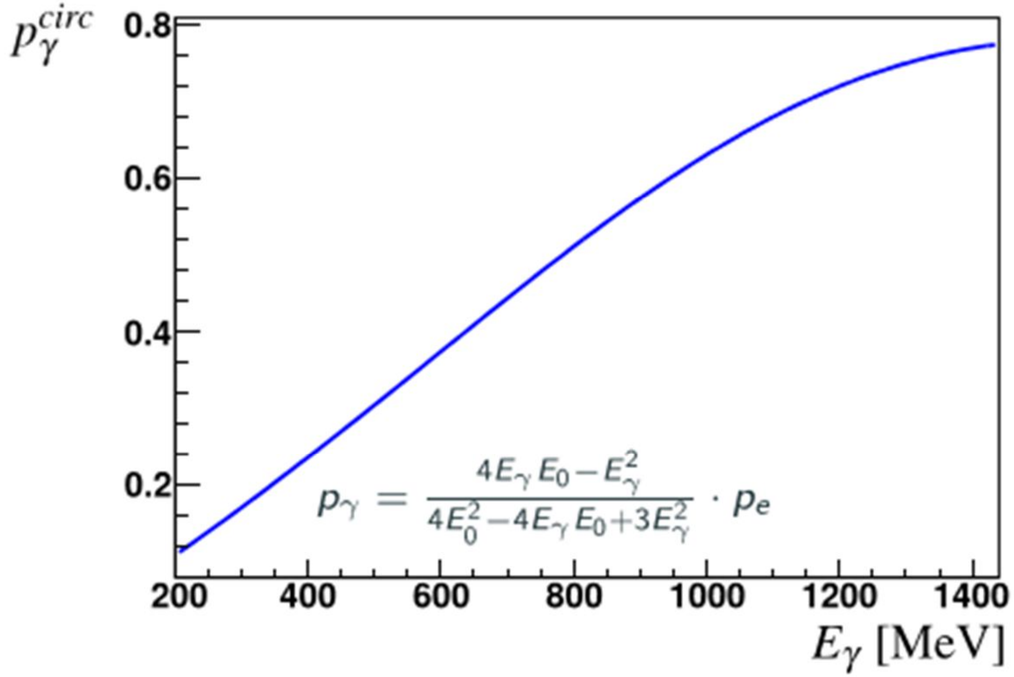
Circularly polarized photons:

- longitudinally polarized electrons
- helicity transfer to photon

Linearly polarized photons



Circularly polarized photons



high polarization at low photon energies

high polarization at high photon energies

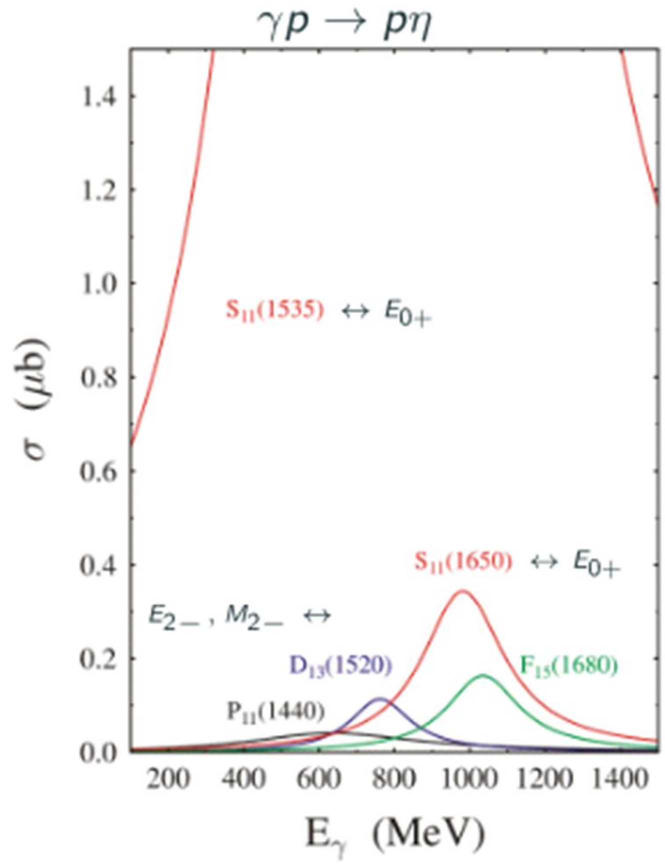
Polarization Observables

Polarization observables in the 2-body kinematic system for the photoproduction of a pseudoscalar meson

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	$-\Sigma$	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{x'})$	$(-T_{x'})$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

$\sigma, \Sigma, T, P + 4$ double pol. observables needed for a unique solution

[W. Chiang and F. Tabakin, Phys. Rev., C55 (1997) 2054-2066]



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circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

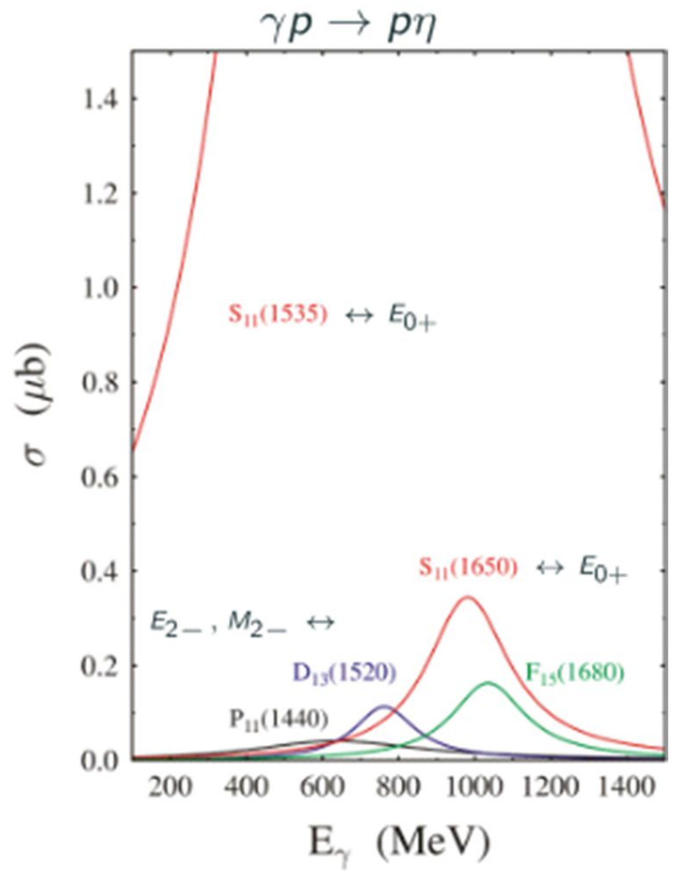
σ, Σ, T, P + 4 double pol. observables needed for a unique solution
[W. Chiang and F. Tabakin, Phys. Rev., C55 (1997) 2054-2066]

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

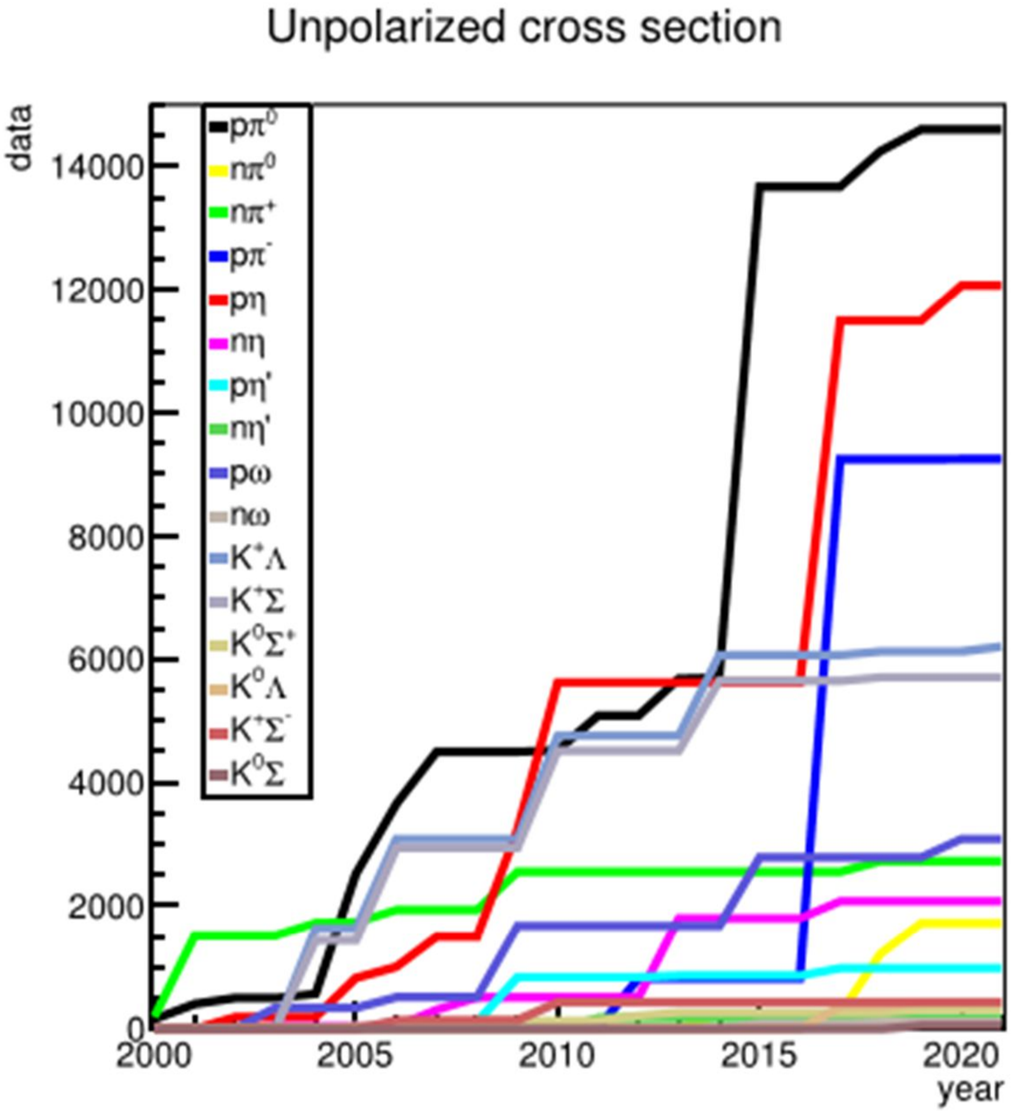
$$\Sigma \sim \underbrace{-2E_{0+}^{*}E_{2+} + 2E_{0+}^{*}E_{2-} - 2E_{0+}^{*}M_{2+} + 2E_{0+}^{*}M_{2-}}_{<S,D>} + \ldots$$

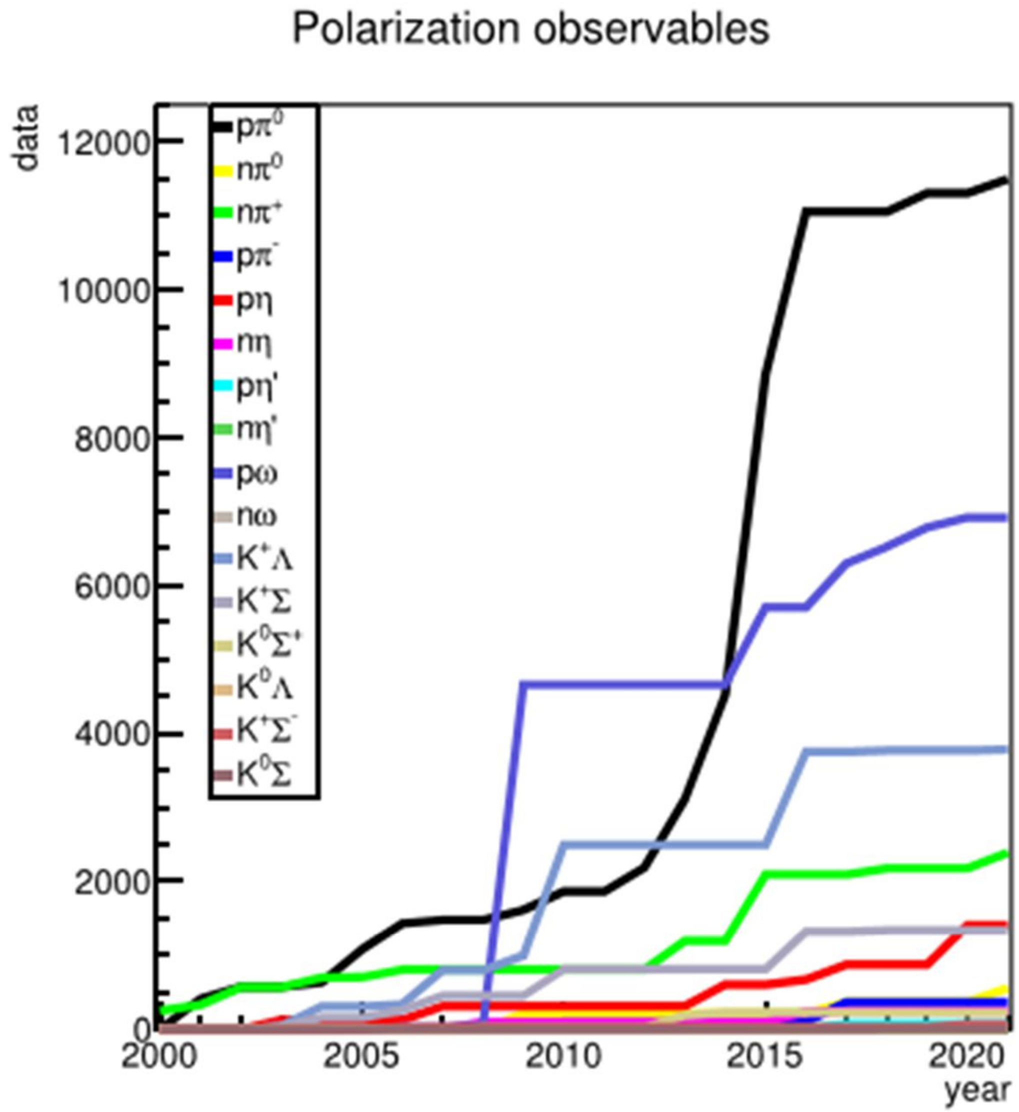
→Polarization observables are sensitive to interference terms!

→Interferences with the dominant S-wave (E_{0+}) important in η photoproduction!



The new data base





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The new data base

- **Contribution of CLAS**

	σ	Σ	T	P	E	F	G	H	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$
								Proton targets								
$p\,\pi^0$	✔	✔	✓	(✓)	✓	✓	✓	✓								
$n\,\pi^+$	✔	✔	✓	(✓)	✔	✓	✓	✓								
$p\,\eta$	✔	✔	✓	(✓)	✔	✓	✓	✓								
$p\,\eta'$	✔	✔	✓	(✓)	✓	✓	✓	✓								
$p\,\omega\,(\phi)$	✔	✔	✔	(✔)	✔	✔	✓	✔								
$K^+\,\Lambda$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^+\,\Sigma^0$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^0\,\Sigma^+$	✓	✓	✓	✔	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
								Neutron (deuteron) targets								
$p\,\pi^-$	✔	✓			✔		✓									
$K^+\,\Sigma^-$	✓	✓	✓	✓	✓	✓	✓									
$K^0\,\Lambda$	✔	✓	✓	✓	✔*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\,\Sigma^0$	✓	✓	✓	✓	✔*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✔ published

✓ acquired or under analysis

Tensor polarization, SDMEs, $I^{\odot}$, I^{s}, I^{c}, etc.

Courtesy V. Crede

Problem with a Unique PWA Solution

Total cross section:

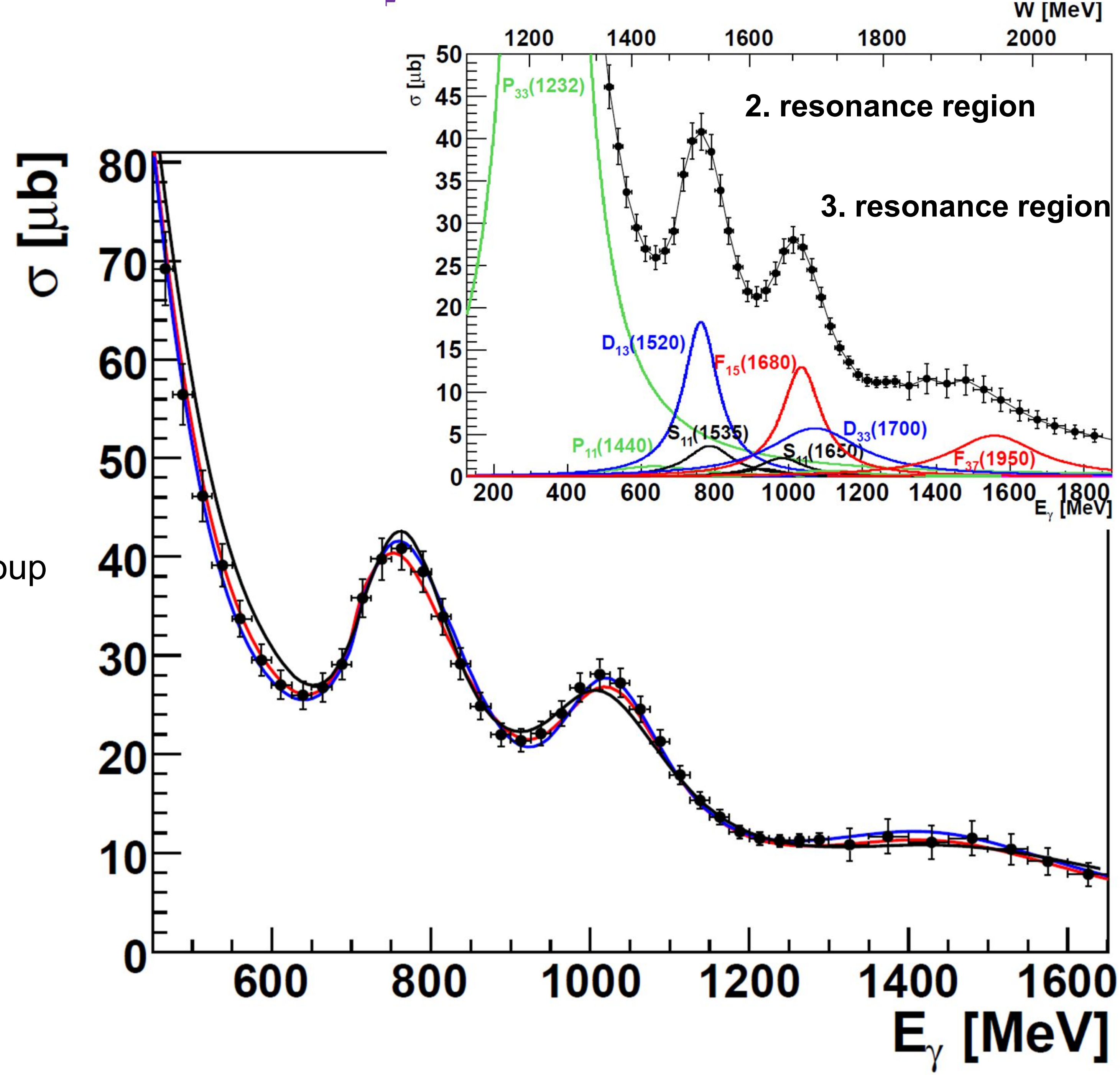
$$\gamma + p \rightarrow p + \pi^0$$

Partial wave analysis:

BnGa — Bonn-Gatchina group

SAID — Washington group

MAID — Mainz group



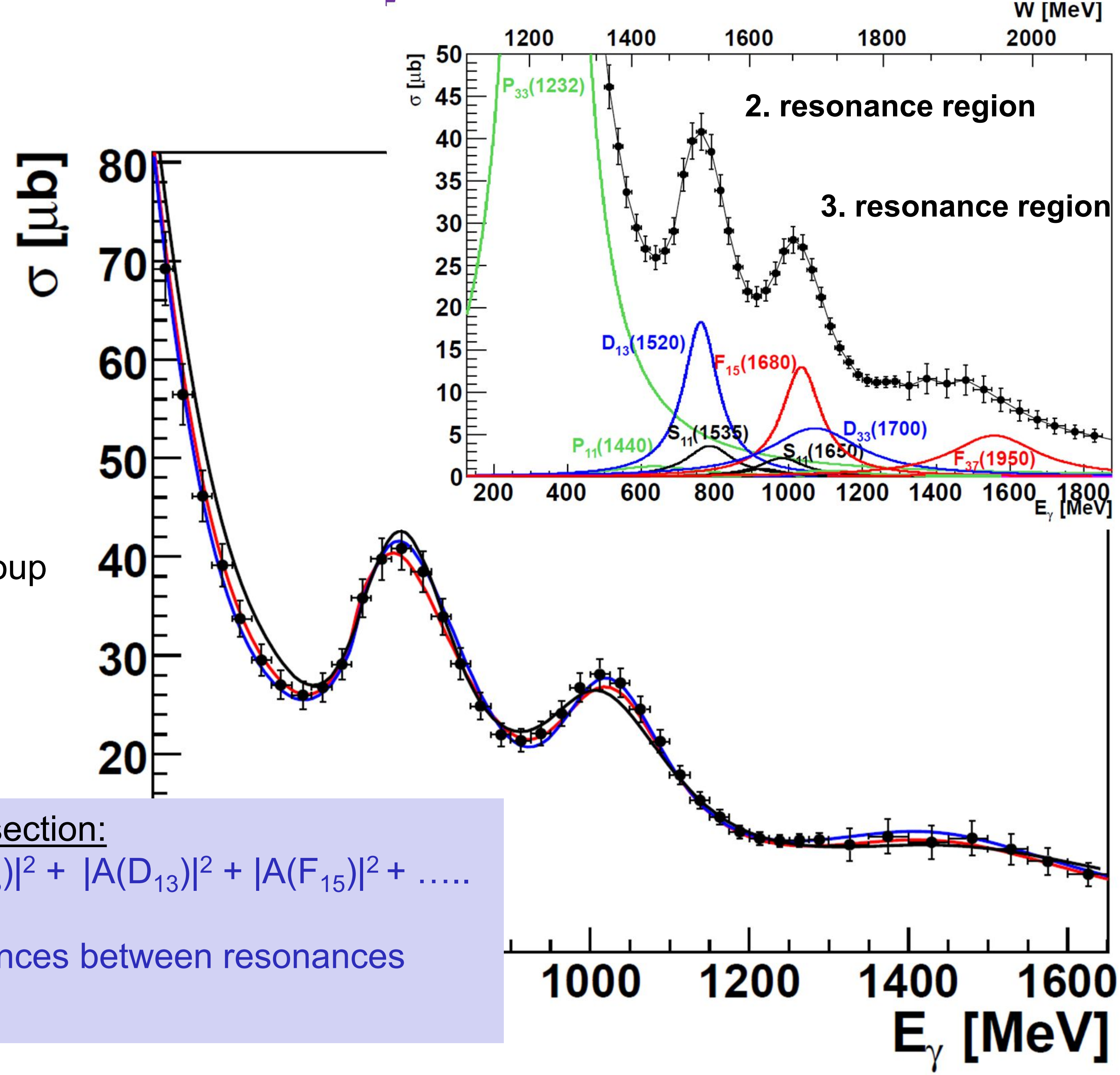
Problem with a Unique PWA Solution

Total cross section:

$$\gamma + p \rightarrow p + \pi^0$$

Partial wave analysis:

— (red)	BnGa	Bonn-Gatchina group
— (blue)	SAID	Washington group
— (black)	MAID	Mainz group



Total cross section:

$\sigma_{tot} \sim |A(P_{33})|^2 + |A(D_{13})|^2 + |A(F_{15})|^2 + \ldots..$

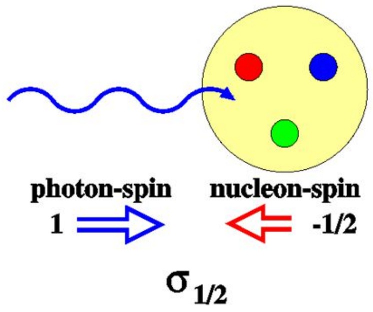
no interferences between resonances

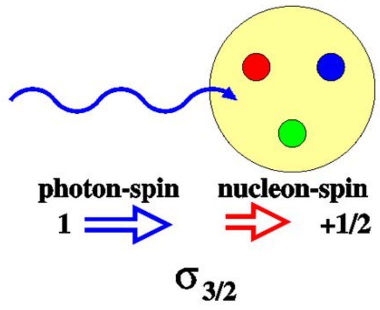
Helicity Dependent Cross Section for $p\pi^0$

<u>reaction:</u> $\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$

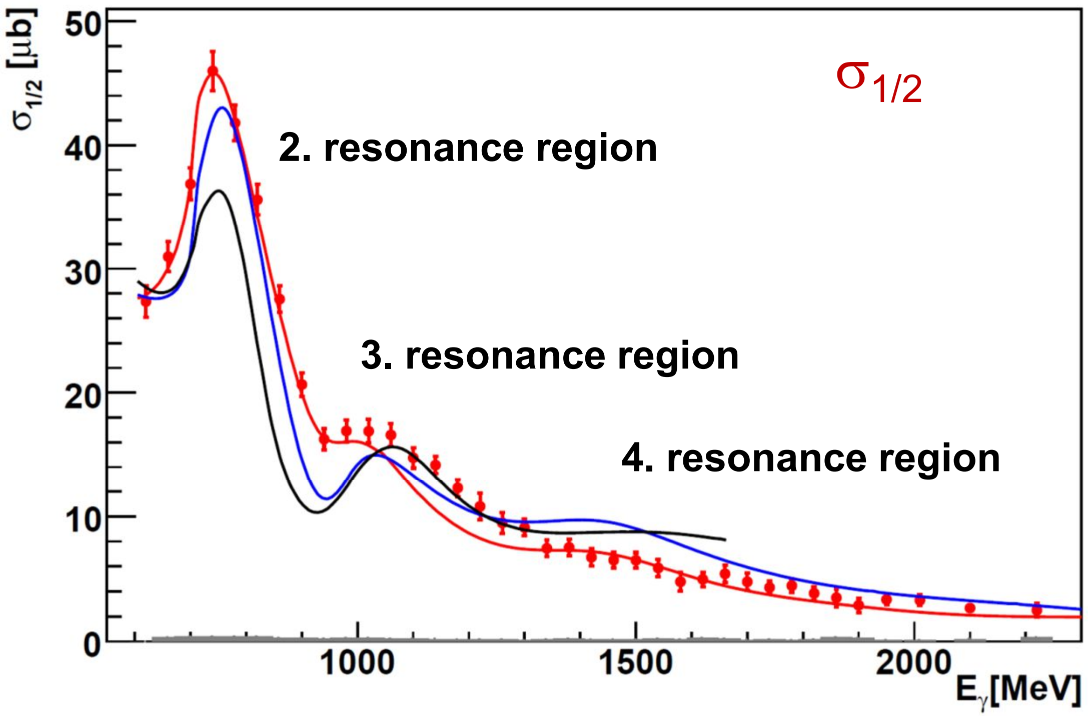
circularly polarized photons

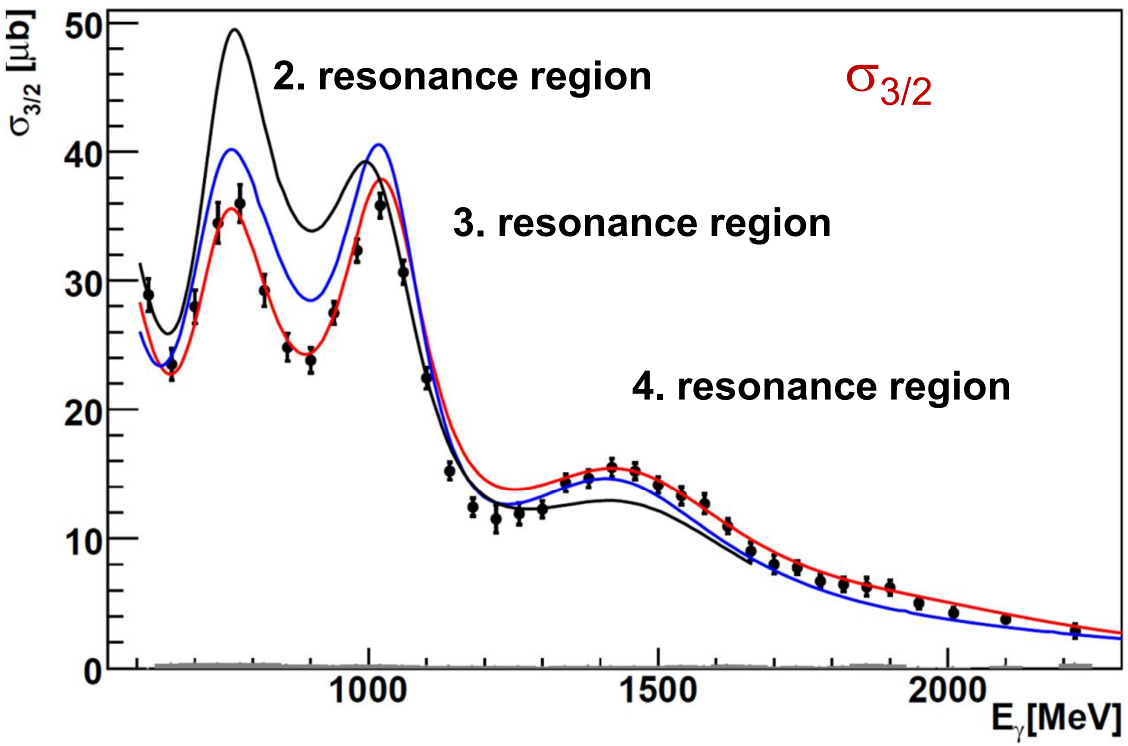
longitudinally polarized proton





CBELSA/TAPS , *M. Gottschall, PRL 112 (2014), 012003*





<u>Partial wave analysis predictions :</u> BnGa SAID MAID

Helicity Dependent Cross Section for $p\pi^0$

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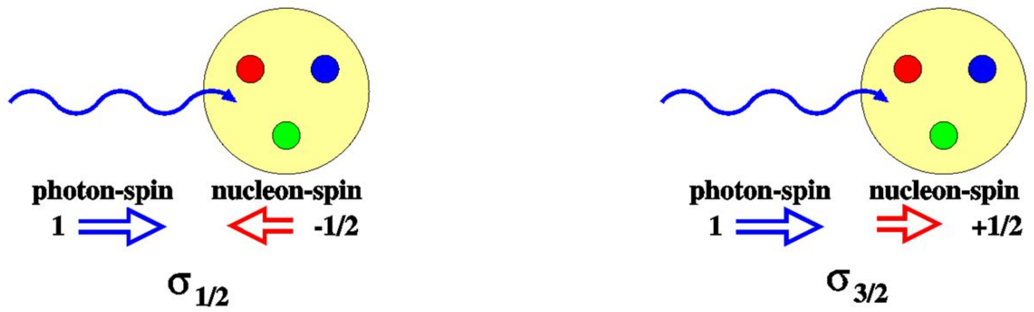

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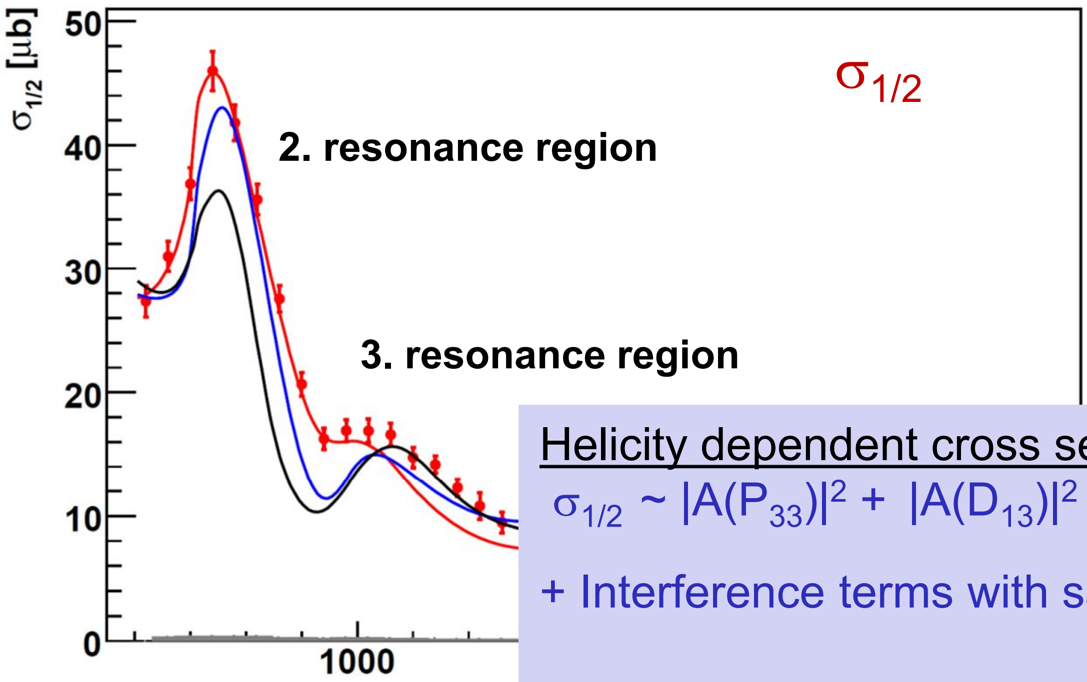
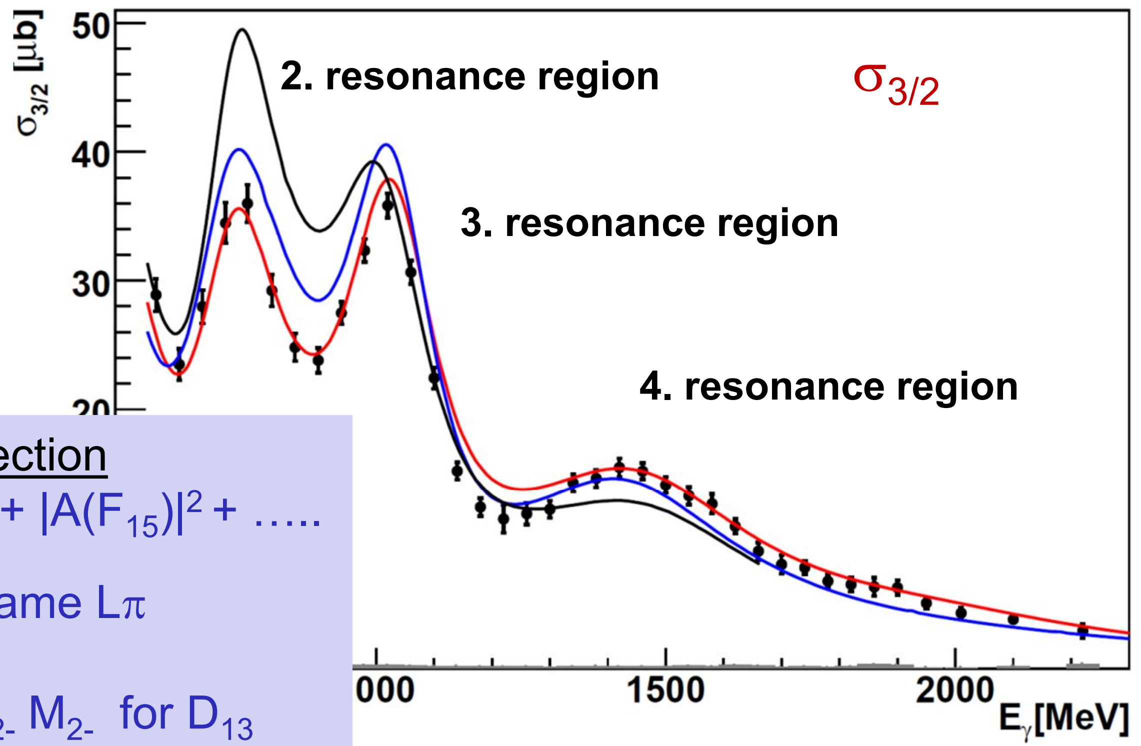




Helicity dependent cross section

$\sigma_{1/2} \sim |A(P_{33})|^2 + |A(D_{13})|^2 + |A(F_{15})|^2 + \ldots..$

+ Interference terms with same L_π

like E_{1+} M_{1+} for P_{33} or E_{2-} M_{2-} for D_{13}

Partial wave analysis predictions : BnGa SAID MAID

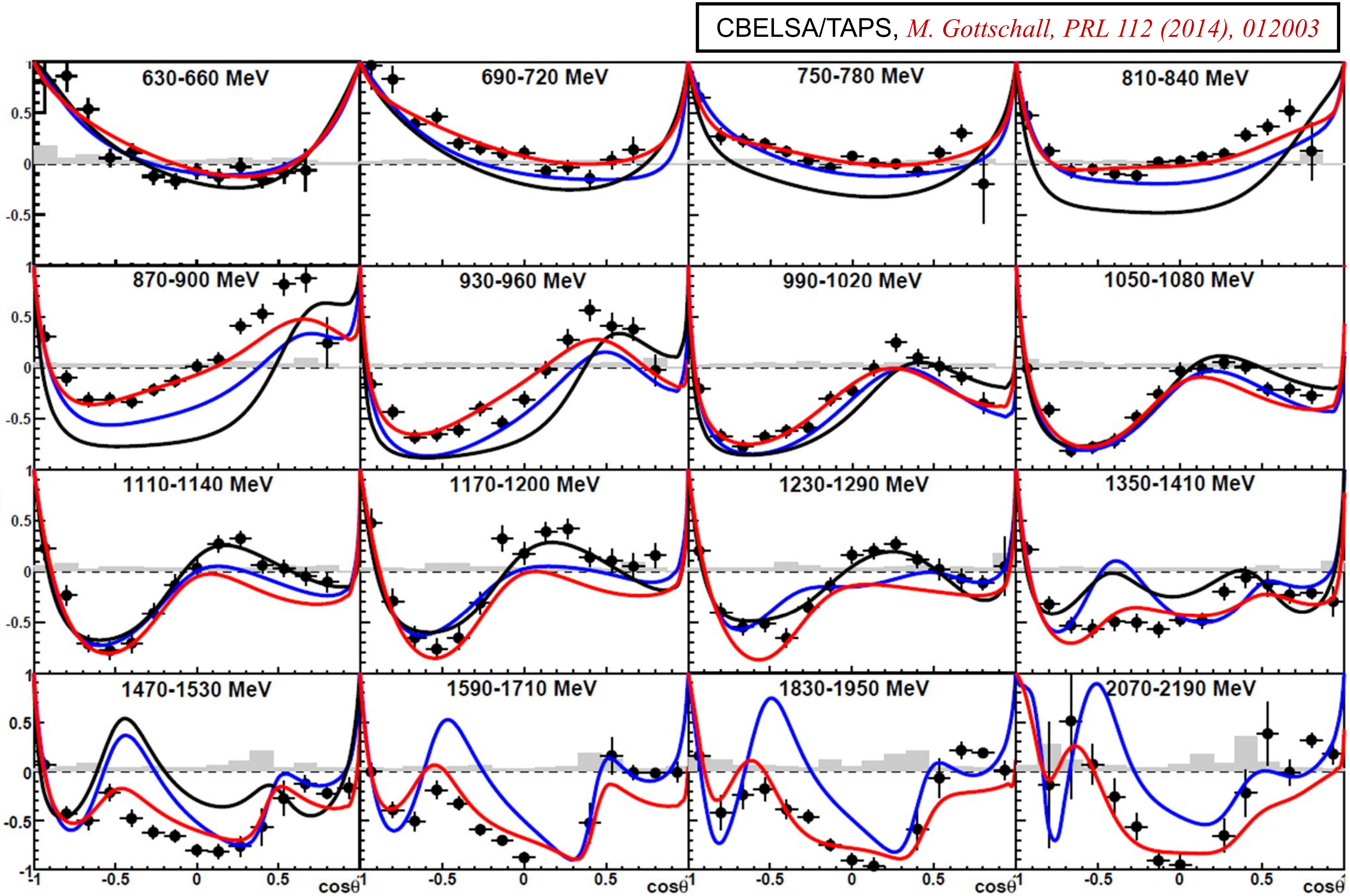
CBELSA/TAPS: Helicity Asymmetry E for $p\pi^0$

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

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

Partial wave analysis prediction:

- BnGa (red)
- SAID (blue)
- MAID (black)



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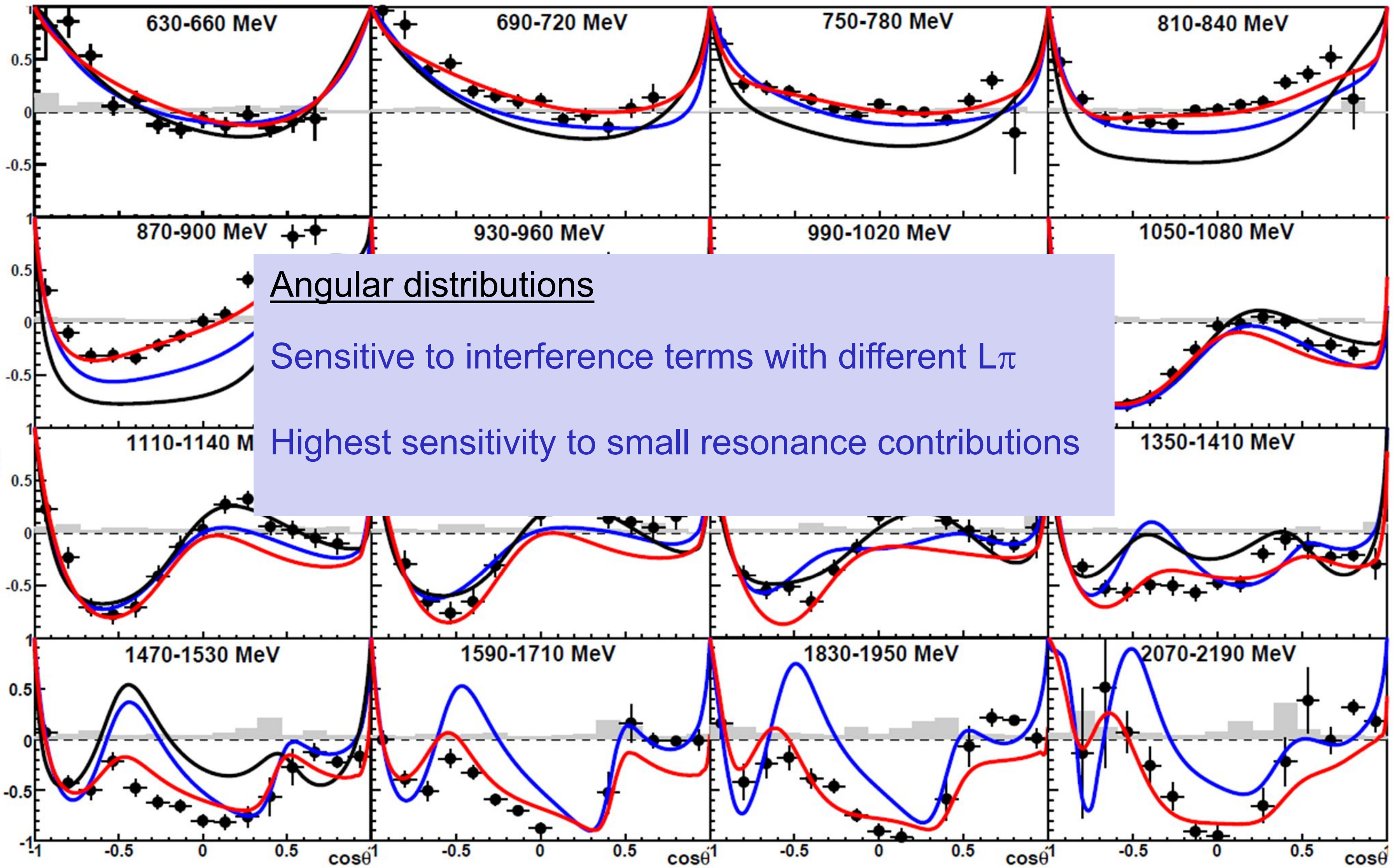
CBELSA/TAPS, *M. Gottschall, PRL 112 (2014), 012003*



Angular distributions

Sensitive to interference terms with different L_π

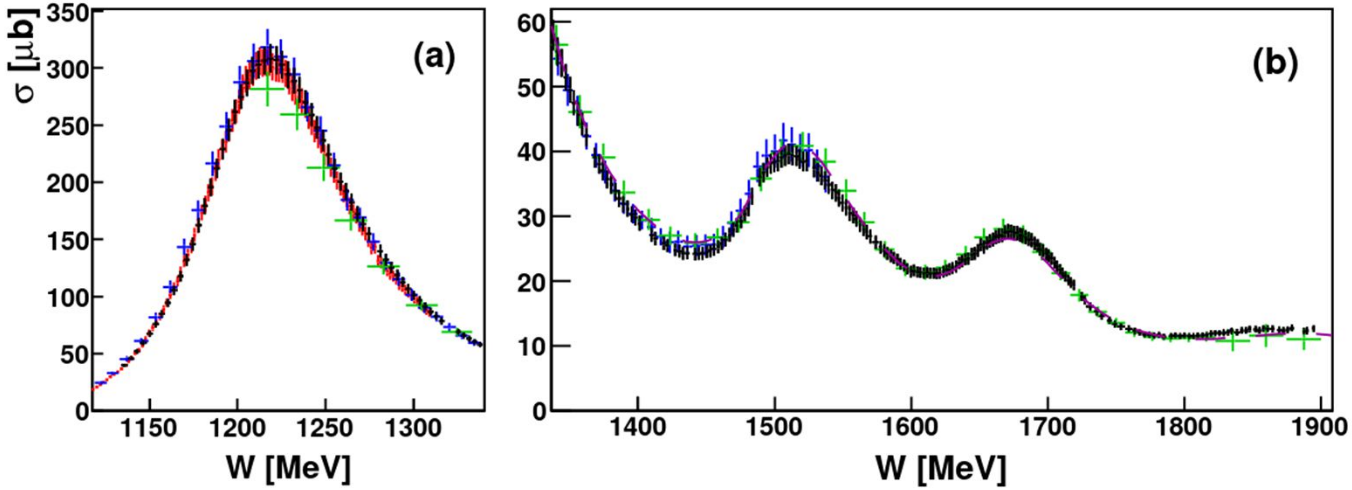
Highest sensitivity to small resonance contributions

Partial wave analysis prediction:

- BnGa
- SAID
- MAID

Measurements off protons ($\gamma p \rightarrow p\pi^0$)

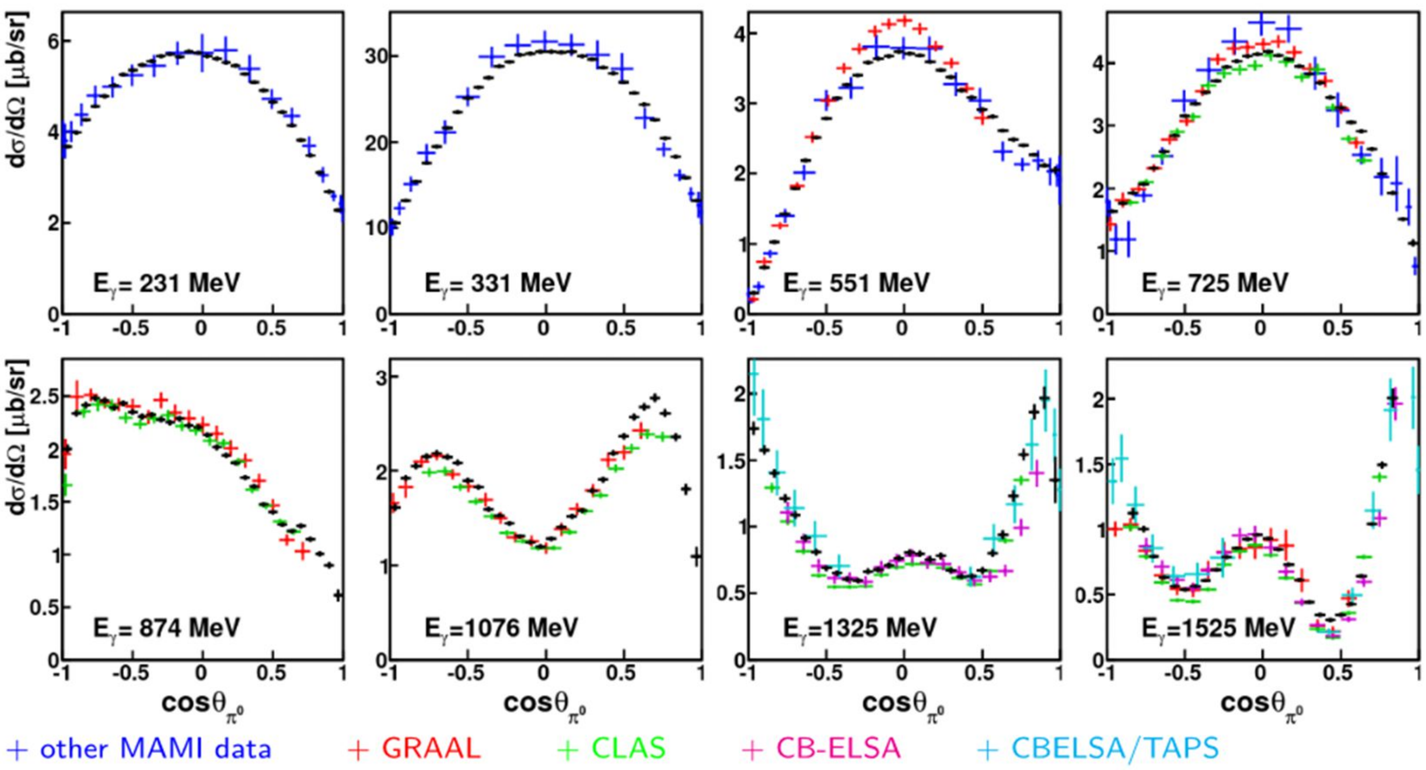
$\gamma p \to p\pi^0$: MAMI measurements of cross sections



Total cross section of

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

P. Adlarson et al. Phys. Rev C 92.2 (2015) 024617



Differential cross section :

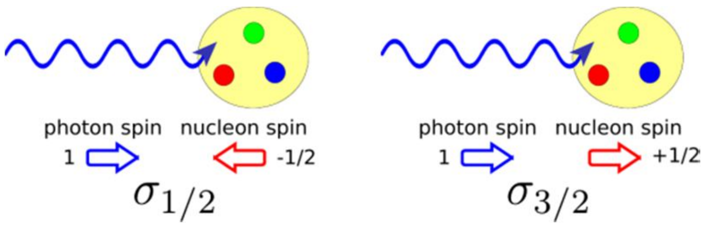
$$\vec{\gamma} + \vec{p} \rightarrow p + \pi^0$$

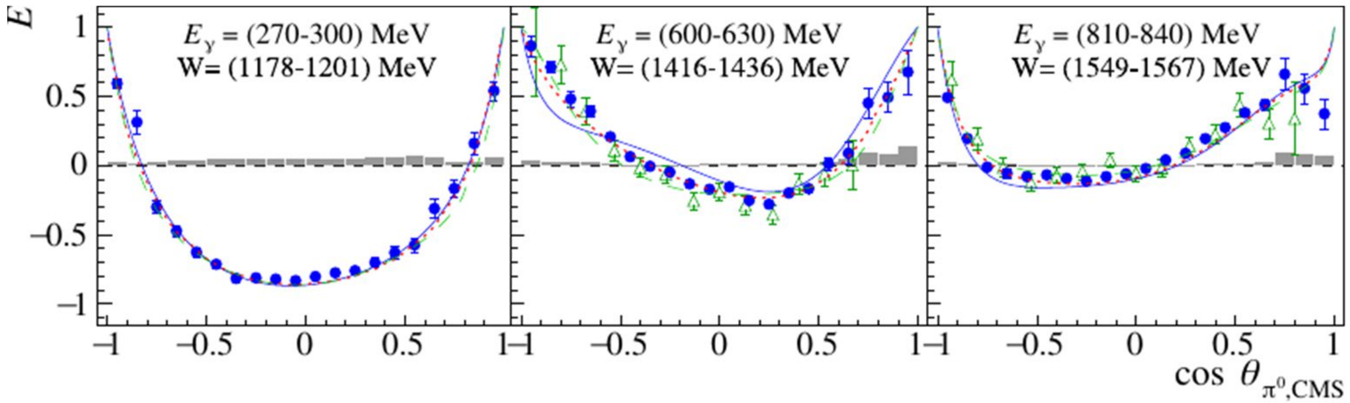
- fine photon energy binning
- full angular coverage
- Increases existing data by 47%

$\gamma p \to p\pi^0$: Simultaneous Measurment of G and E

Elliptically polarized photons (long. polarized electrons + diamond) and longitudinally polarized target

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega_0}(\theta)\left[1 - P_{lin}\mathbf{\Sigma}\cos(2(\alpha-\phi)) - P_z\left(-P_{lin}\mathbf{G}\sin(2(\alpha-\phi)) + P_{circ}\mathbf{E}\right)\right]$$





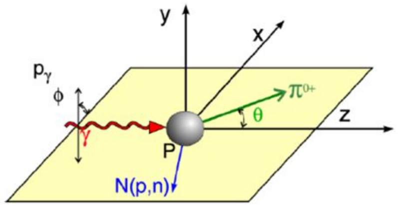
ELSA: M. Gottschall et al. EPJA 57.1 (2021) 40

MAMI: F. Afzal submitted to PRL

- Excellent agreement between MAMI (diamond radiator) and ELSA (amorphous) measurements
- Measuring with linearly and circularly polarized photons at the same time
- Time an cost efficient measurement possible

$\gamma p \rightarrow p\pi^0$: Simultaneous Measurment of G and E

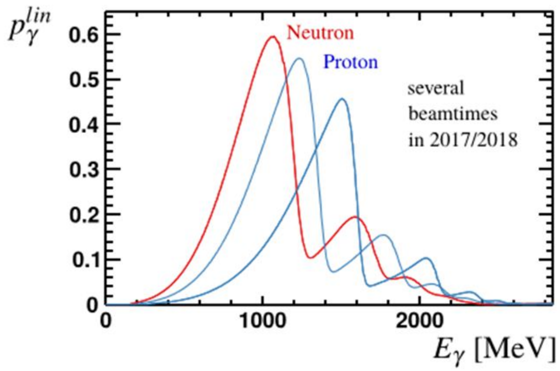
Elliptically polarized photons (long. polarized electrons + diamond) and longitudinally polarized target



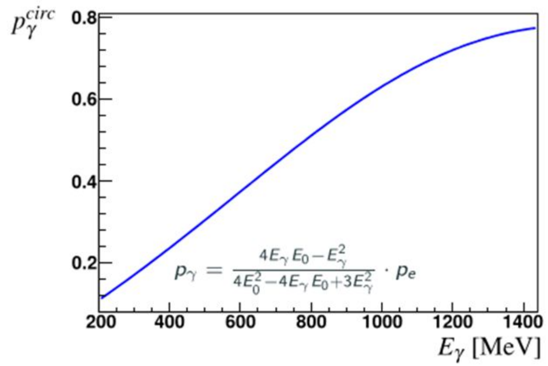
photon pol.		target pol. axis x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \Big[1 - P_\gamma^{\text{lin}}\,\Sigma(\theta)\cos(2\phi)$$
$$+P_x \cdot \left(-P_\gamma^{\text{lin}}\,H(\theta)\,\sin(2\phi) + P_\gamma^{\text{circ}}\,F(\theta)\right)$$
$$+P_y \cdot \left(+P_\gamma^{\text{lin}}\,P(\theta)\,\cos(2\phi) - T(\theta)\right)$$
$$-P_z \cdot \left(-P_\gamma^{\text{lin}}\,G(\theta)\,\sin(2\phi) + P_\gamma^{\text{circ}}\,E(\theta)\right)\Big]$$

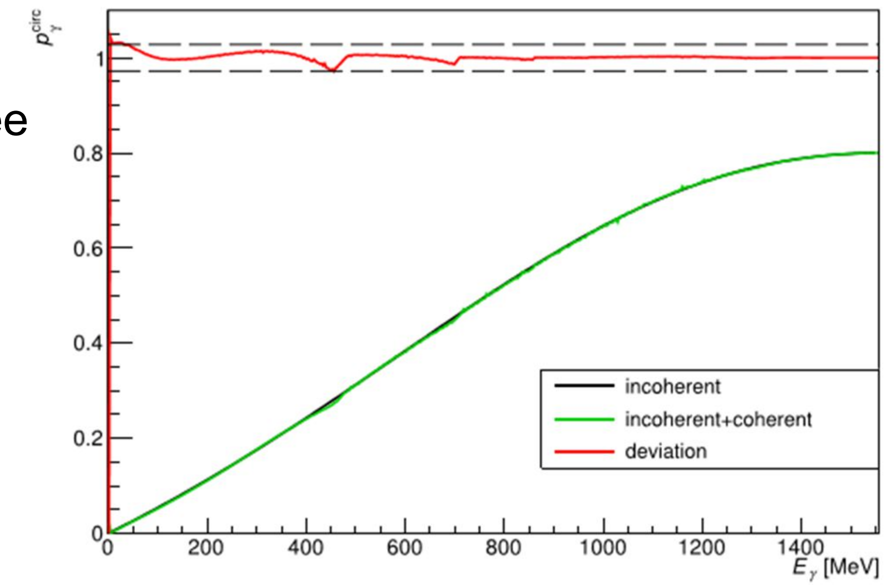
Linearly polarized photons



Circularly polarized photons

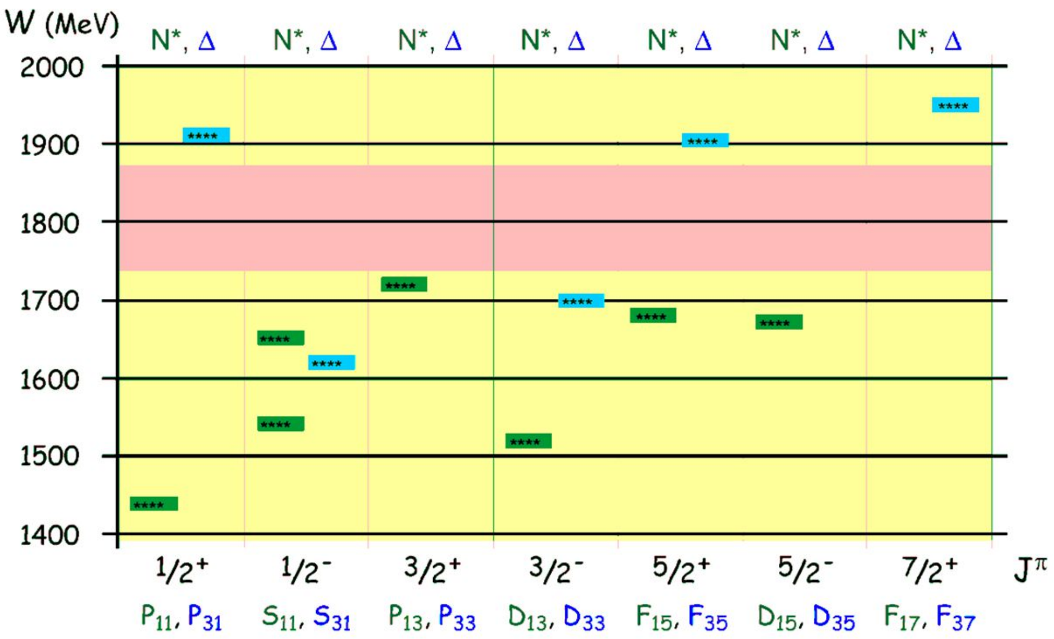


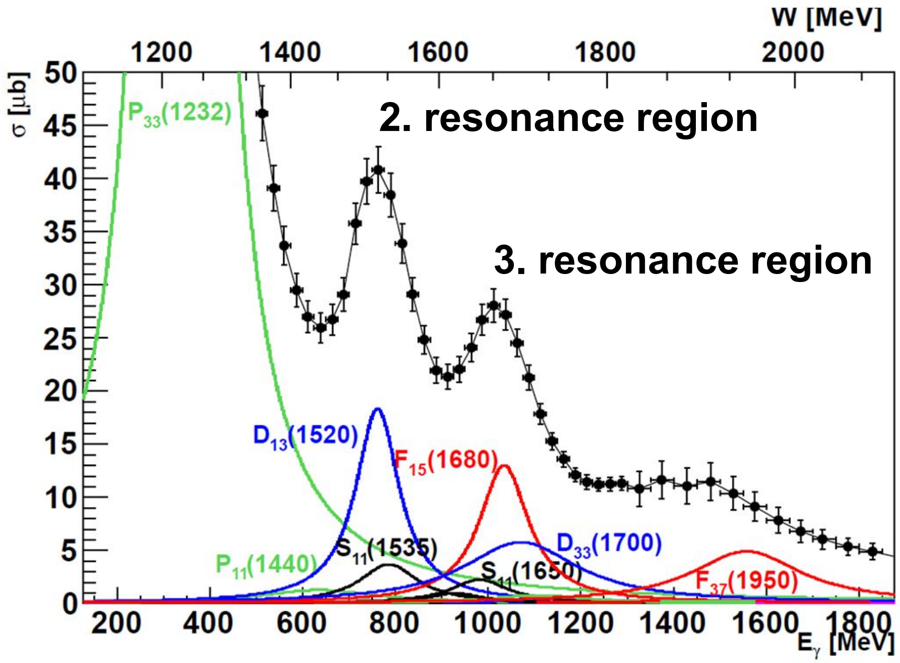
- Crystal lattice has a small influence on polarization degree
- Measuring of different polarization at the same time



To be published by : F. Afzal, R. Beck, R. Jones

Impact of the new polarization data





Which L_{max} is seen in the new polarization data ? –> Truncated partial wave analysis possible

$L_{max} = 0$, S-wave , resonances in S-wave: $S_{11}(1535)$, $S_{11}(1650)$, $S_{31}(1620)$

$L_{max} = 1$, P-wave , resonances in P-wave: $P_{11}(1440)$, $P_{13}(1710)$, $P_{33}(1232)$, $P_{31}(?)$,

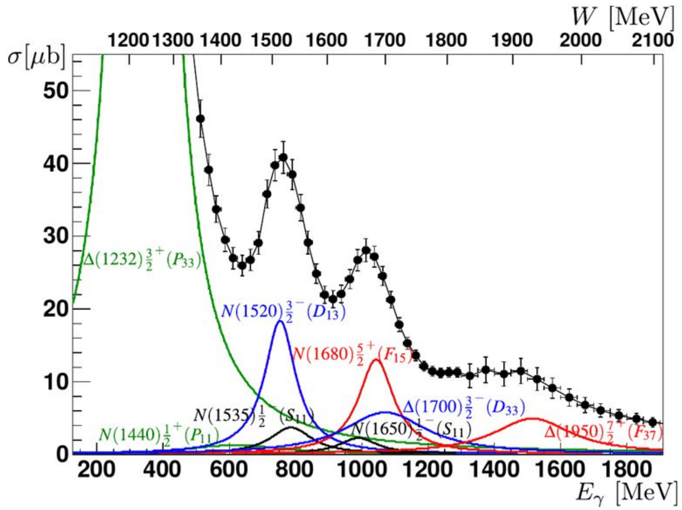
$L_{max} = 2$, D-wave , resonances in D-wave: $D_{13}(1520)$, $D_{15}(1680)$, $D_{33}(1700)$, $D_{35}(?)$,

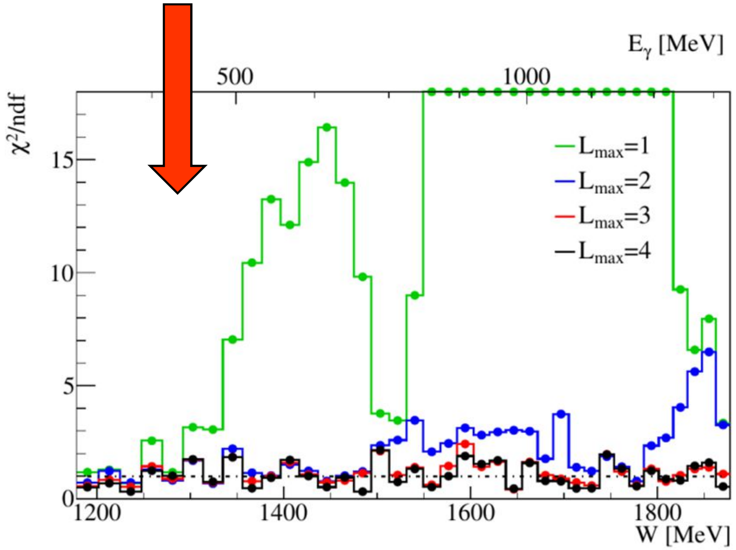
$L_{max} = 3$, F-wave , resonances in F-wave: $F_{15}(1680)$, $F_{17}(?)$, $F_{35}(?)$, $F_{37}(1950)$

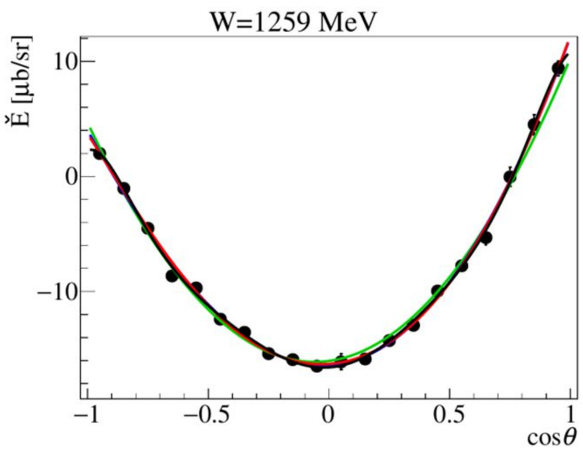
$L_{max} = 4$, G-wave , resonances in G-wave: $G_{17}(?)$, $G_{19}(?)$, $G_{37}(?)$, $G_{39}(?)$

Dominant partial waves for E

$$\check{E}(W,\cos\theta) = E(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=0}^{2L_{max}+1} (a_L(W))_k \cdot P_k^0(\cos\theta)$$

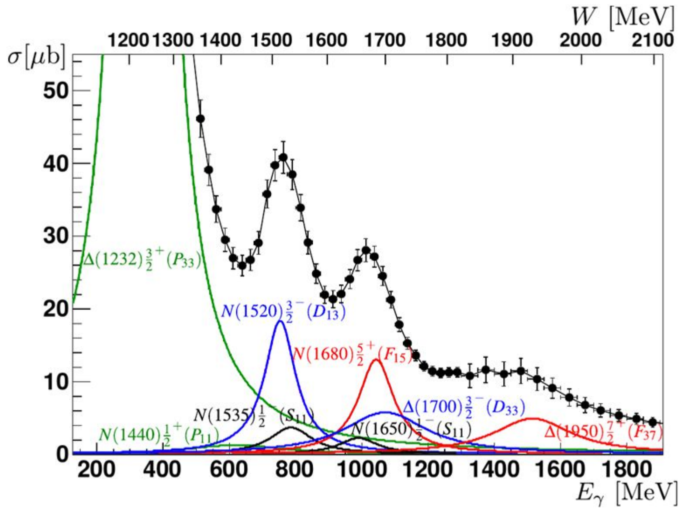


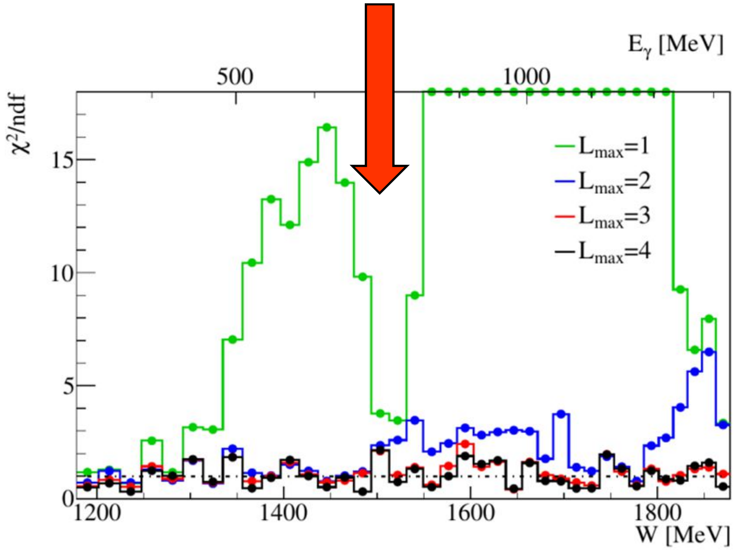


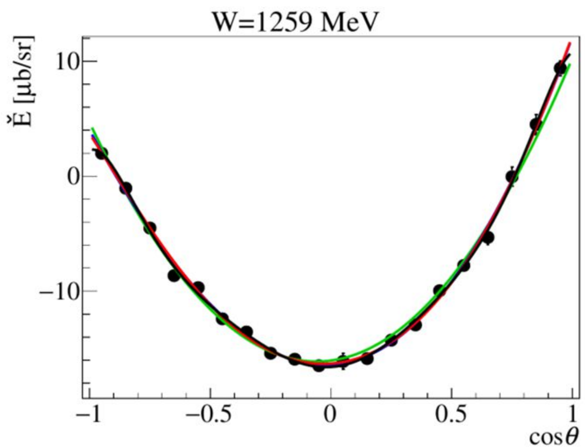


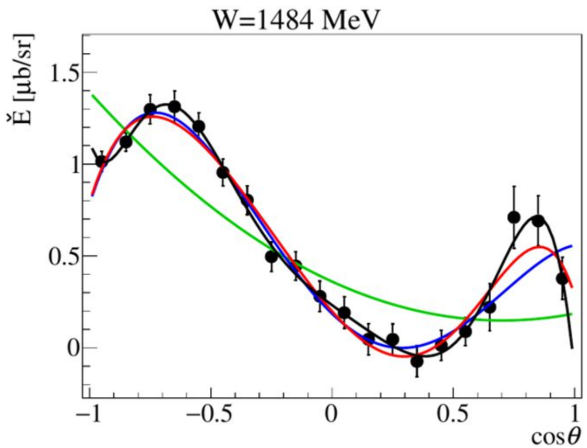
Dominant partial waves for E

$$\check{E}(W, \cos\theta) = E(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=0}^{2L_{max}+1} (a_L(W))_k \cdot P_k^0(\cos\theta)$$



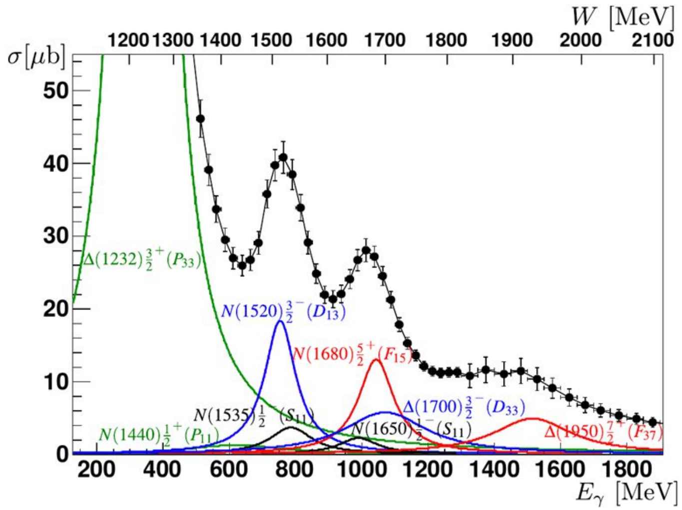


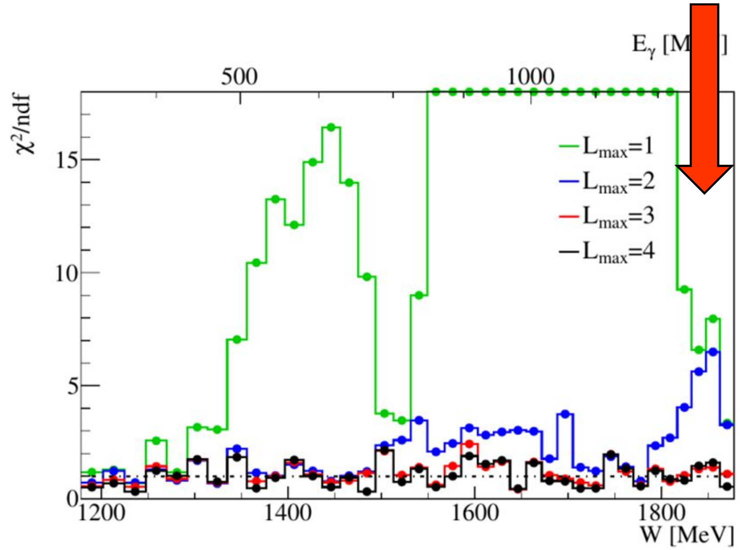


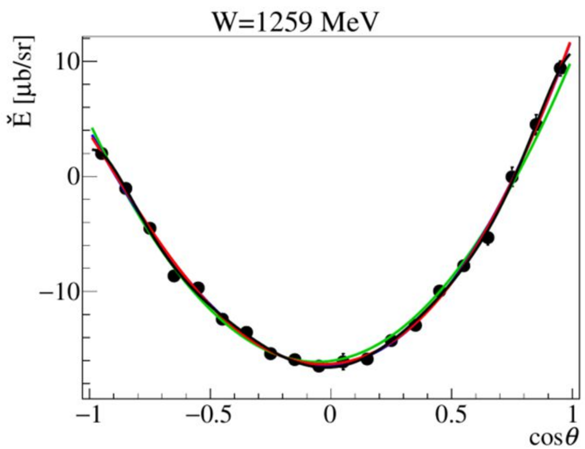


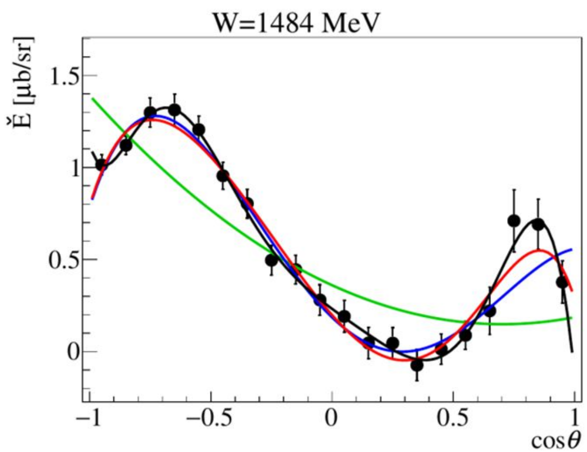
Dominant partial waves for E

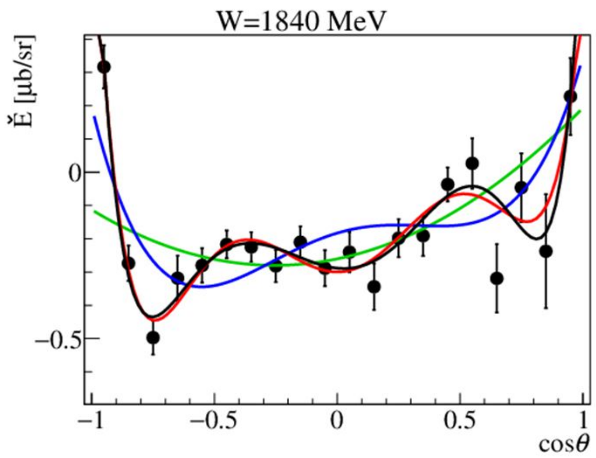
$$\check{E}(W,\cos\theta) = E(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=0}^{2L_{max}+1}(a_L(W))_k\cdot P_k^0(\cos\theta)$$











Dominant partial waves for E

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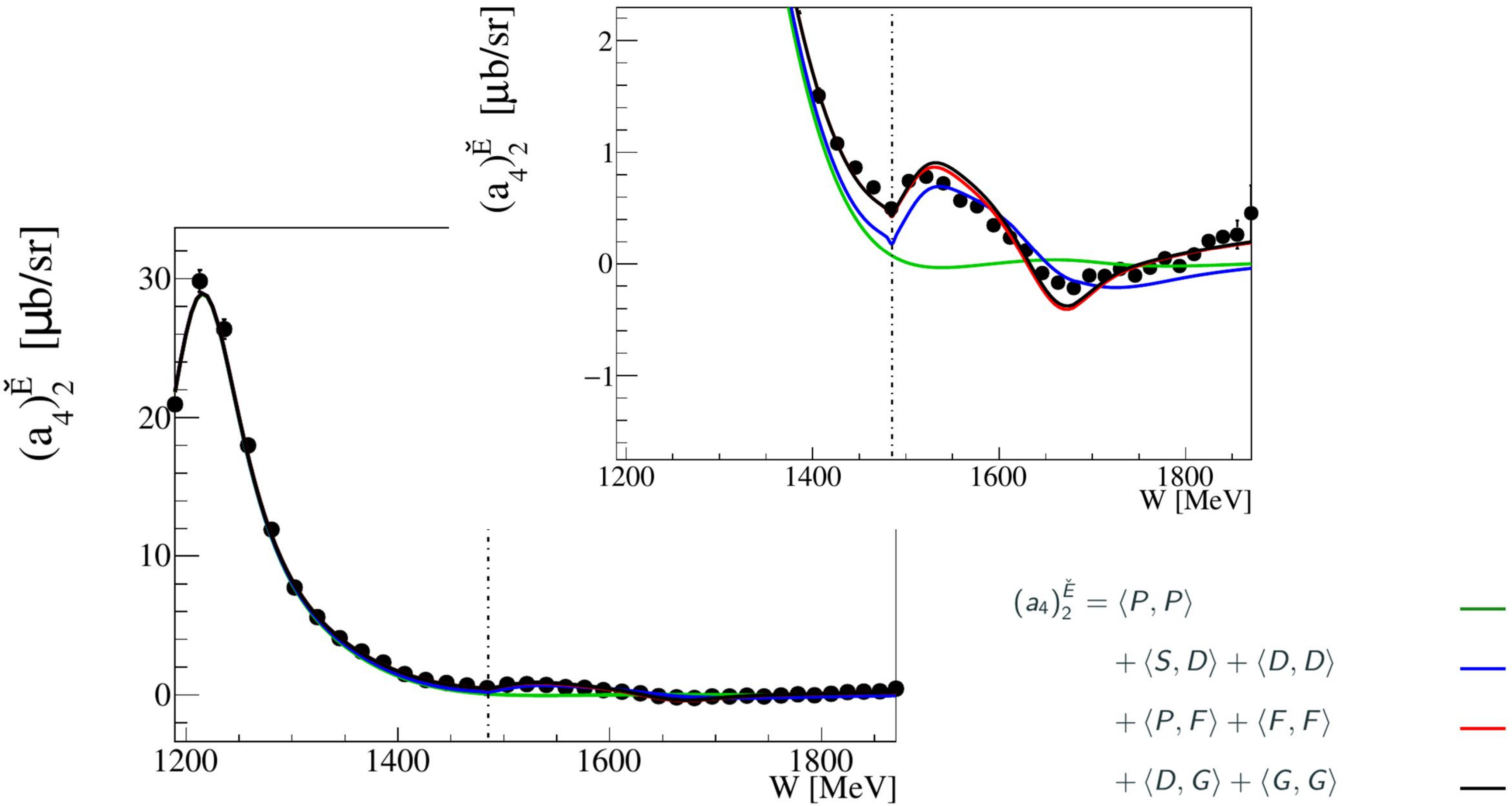
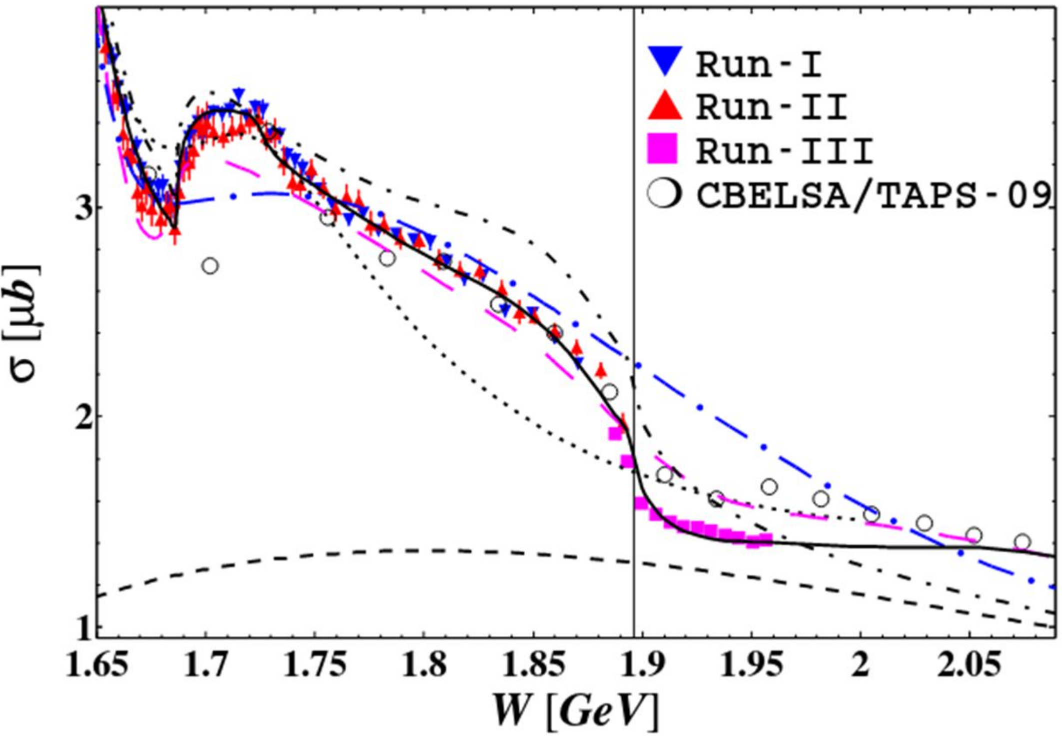
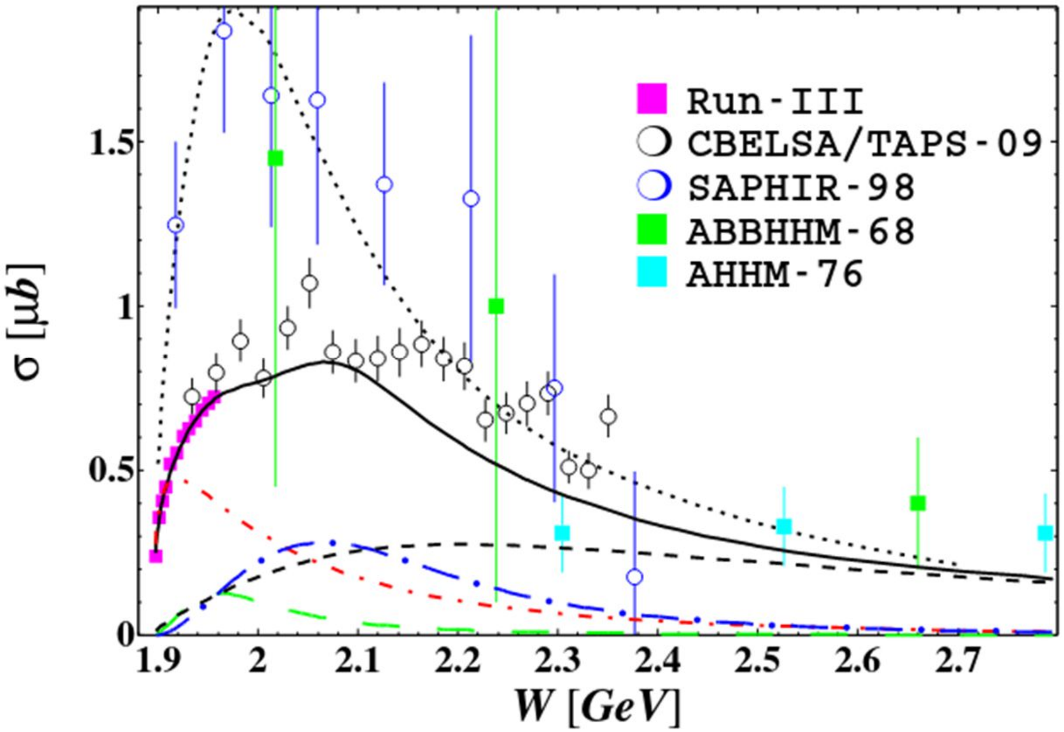


Measurements off protons ($\gamma p \rightarrow p\eta$)

MAMI measurements of pη total cross sections

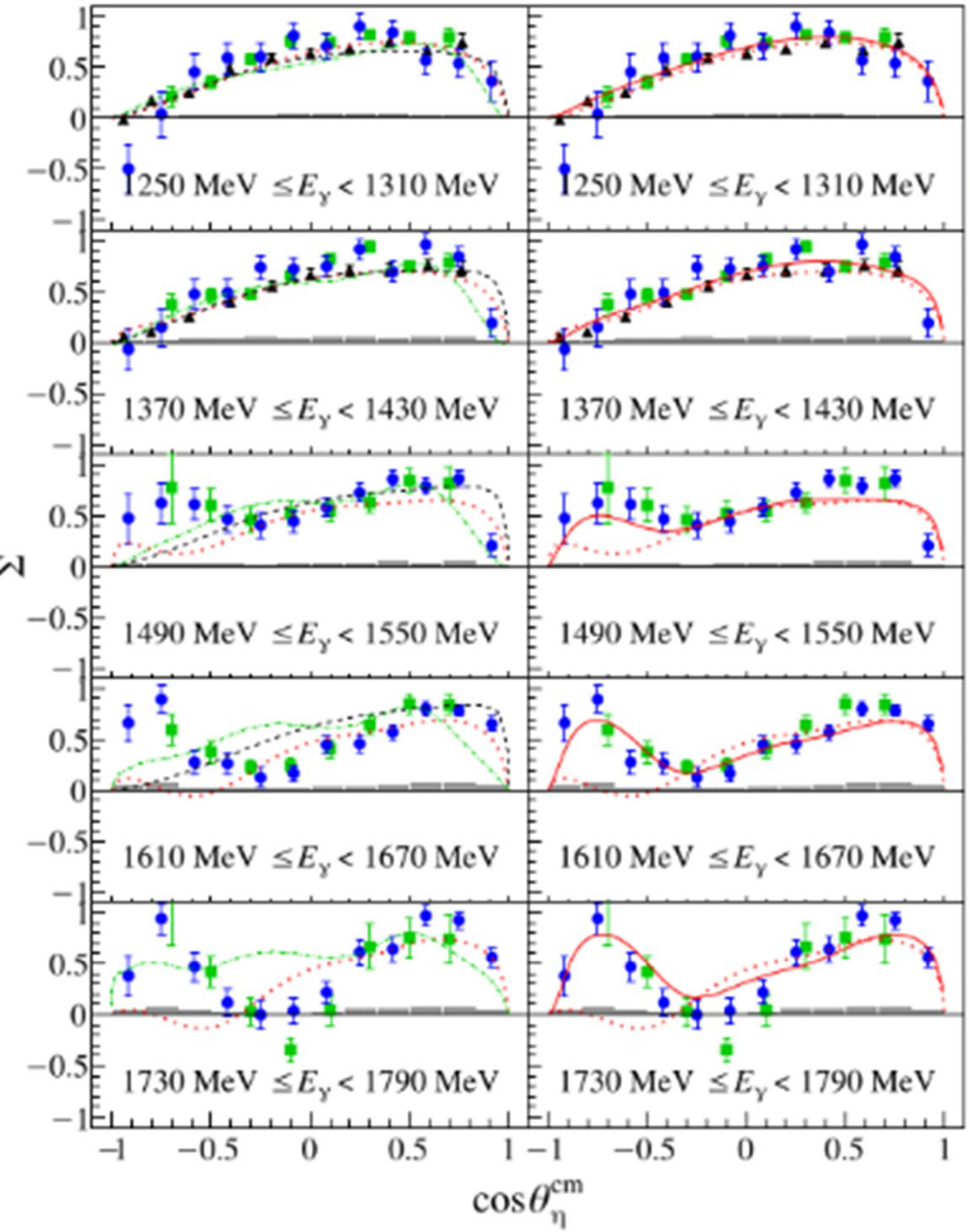




MAMI: V. Kashevarov et al., PRL 118, 21 (2017) 212001

- Key role for description: 3 S-wave resonances, N(1535), N(1650) and N(1895)
- Strong pη' cusp observed in pη total cross section
- N(1895) needed for description of pη' cusp and fast rise of pη' total cross section

ELSA measurement of Σ- Asymmetry in pη



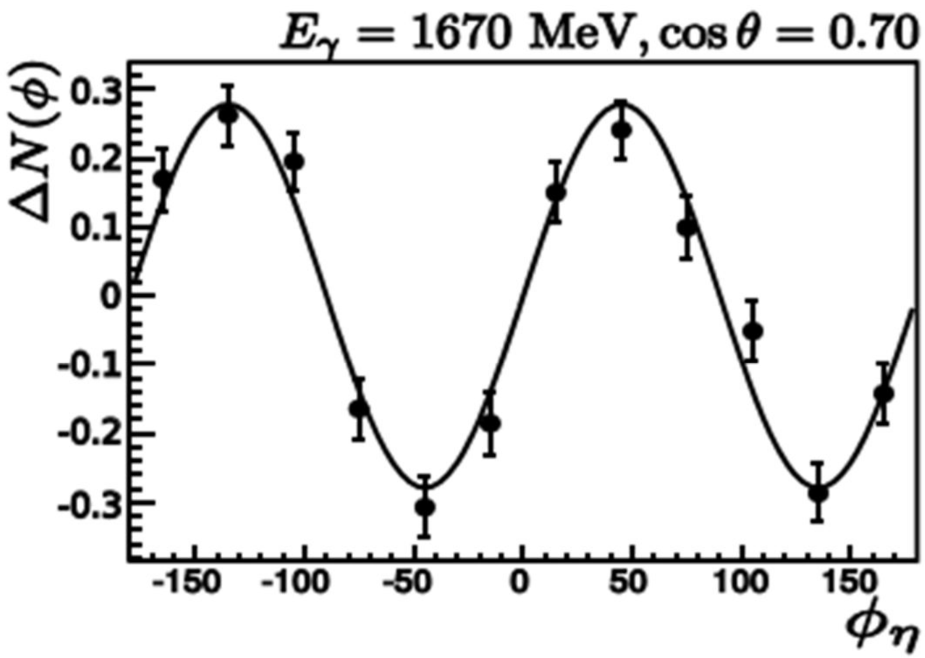
[F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)]

- CBELSA/TAPS data (F. Afzal et al.)
- GRAAL data (O. Bartalini et al., Eur. Phys. J. A33 (2007) 169)
- CLAS data (P. Collins et al., Phys. Lett. B 771 (2017) 213-221)

BnGa-2014-02 | JüBo-2015-FitB | ηMAID

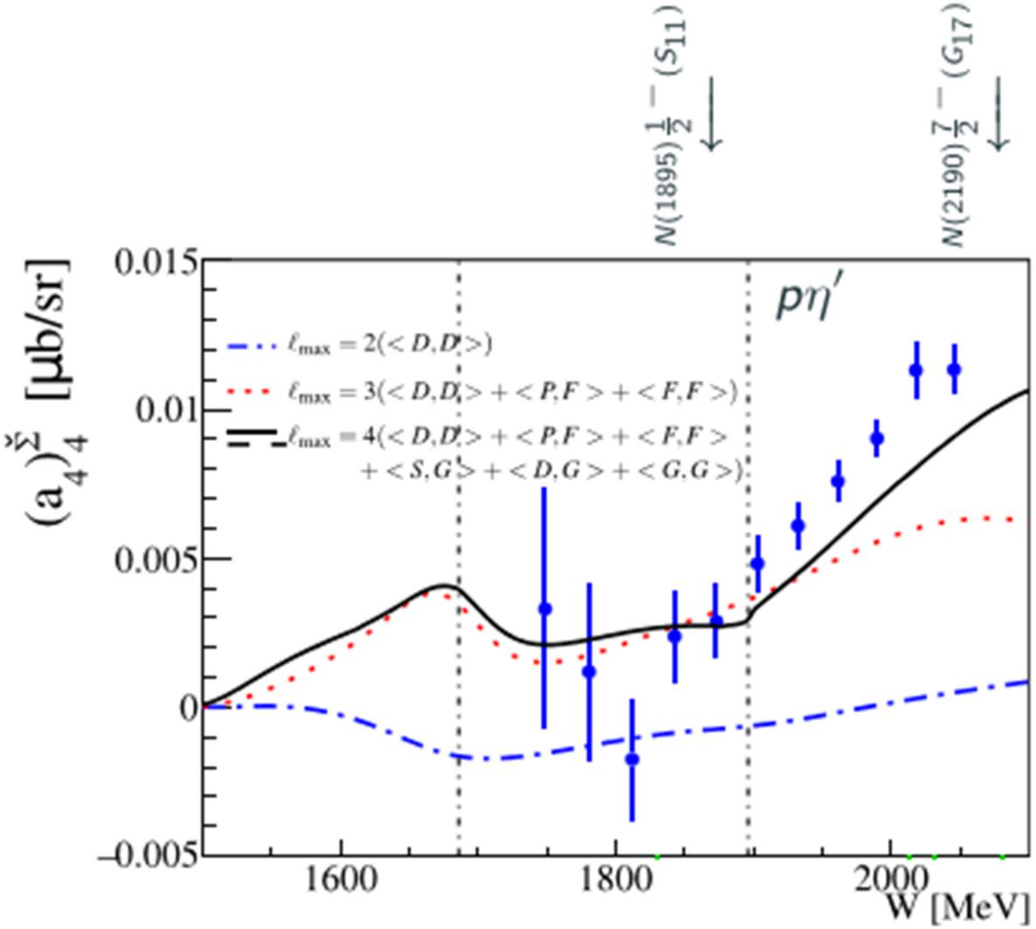
BnGa-2019

$$\Delta N = \frac{N_{-45^\circ} - N_{+45^\circ}}{N_{-45^\circ} + N_{+45^\circ}} = p_\gamma^{lin} \Sigma \sin(2\phi)$$



L_{max} Interpretation of Σ- Asymmetry

$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot\frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$



Compare extracted fit coefficient to BnGa-2019 solution

$$(a_5)_4^{\check{\Sigma}} = \langle D, D\rangle$$

$$+\langle P, F\rangle + \langle F, F\rangle$$

$$+\langle \boldsymbol{S}, \boldsymbol{G}\rangle + \langle D, G\rangle + \langle G, G\rangle$$

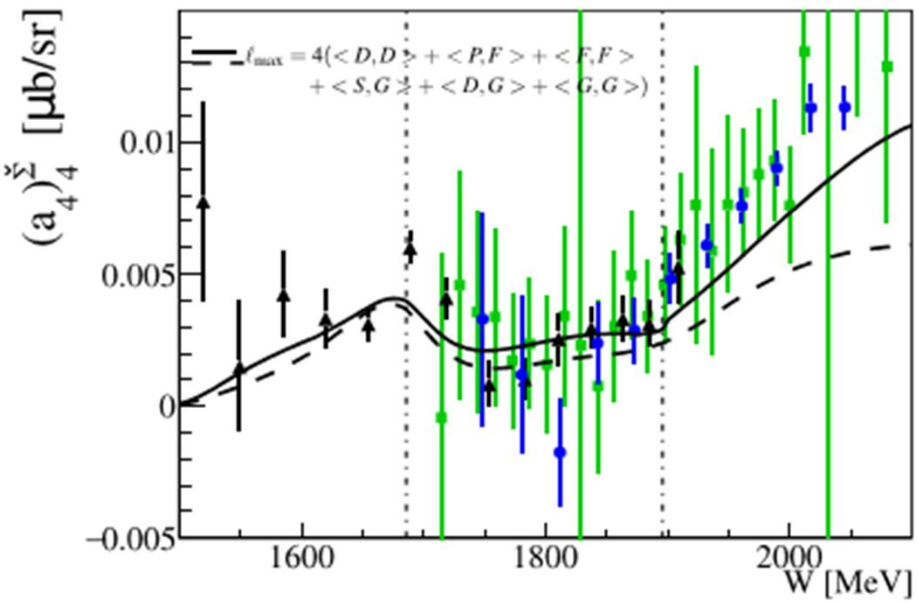
F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

$p\eta'$ channel needs to be included in PWA to describe data

Evidence for $N(1895)\frac{1}{2}^-(S_{11})$ resonance due to strong $p\eta'$ cusp in $p\eta$ S wave

L_{max} Interpretation of Σ- Asymmetry

$$\check{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$



▲ GRAAL data (O. Bartalini et al., Eur. Phys. J. A33 (2007) 169)

• P. Collins et al., Phys. Lett. B 771 (2017) 213-221 (CLAS)

—— BnGa-2019

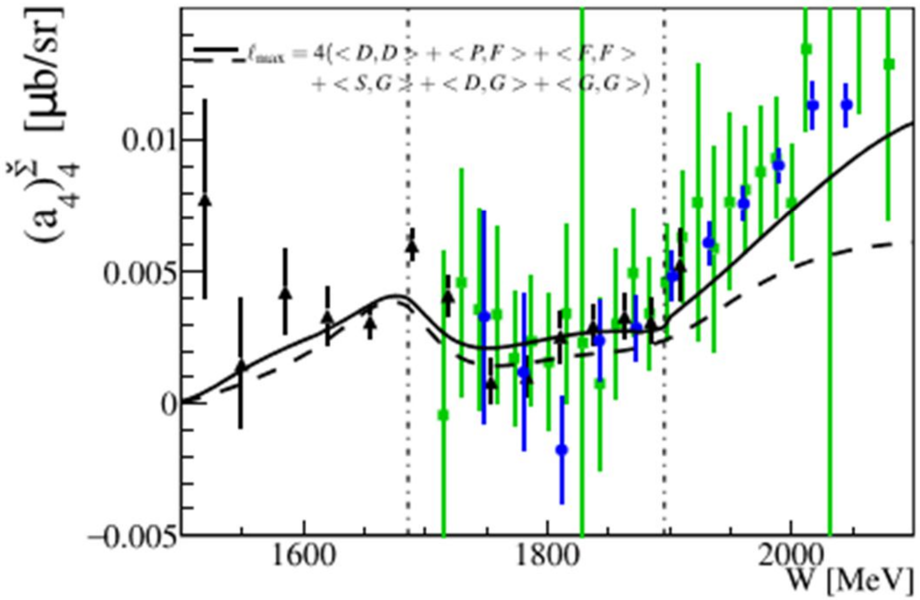
...... BnGa-2014-02

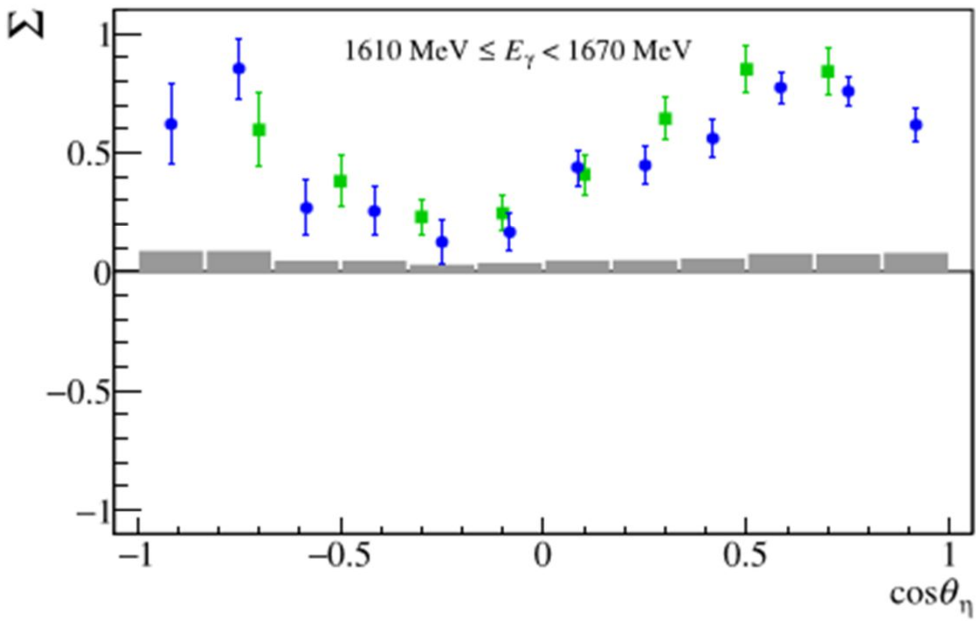
F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

Full angular coverage is very important for $< S, G >$ interference

L_{max} Interpretation of Σ- Asymmetry

$$\check{\Sigma}(W,\cos\theta) = \Sigma(W,\cos\theta)\cdot \frac{d\sigma}{d\Omega}(W,\cos\theta) = \sum_{k=2}^{2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

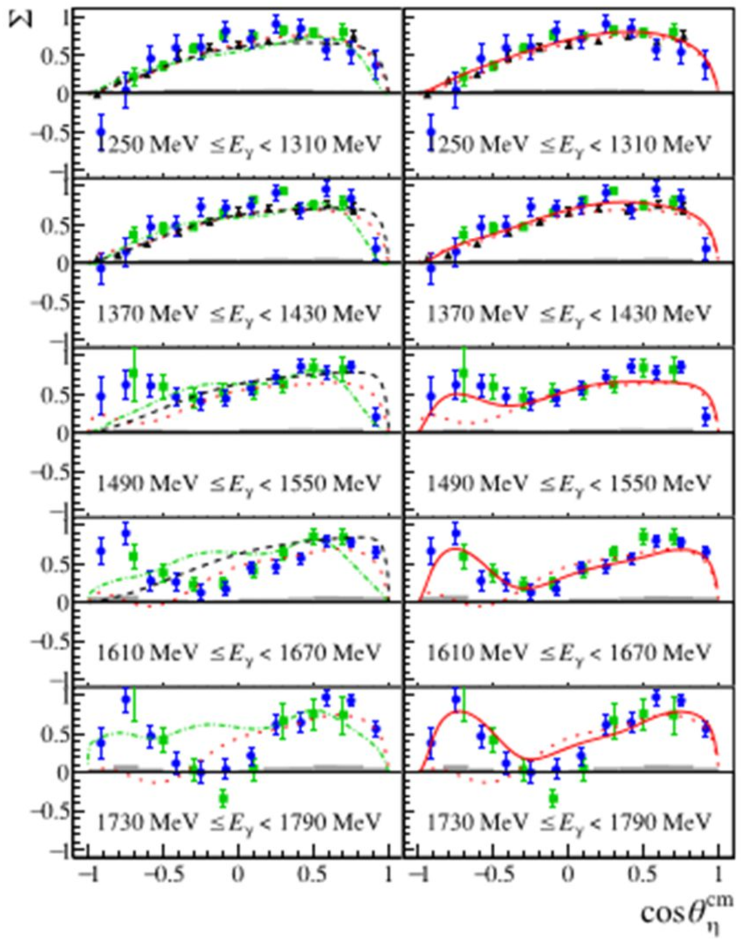


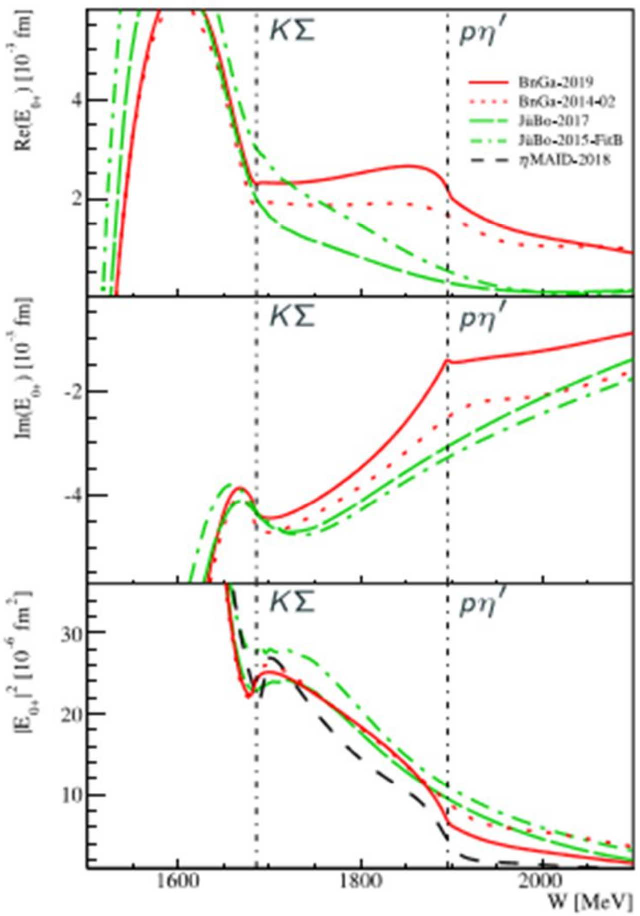


3 (2007) 169)
. (CLAS)

Full angular coverage is very important for $< S, G >$ interference

L_{max} Interpretation of Σ- Asymmetry



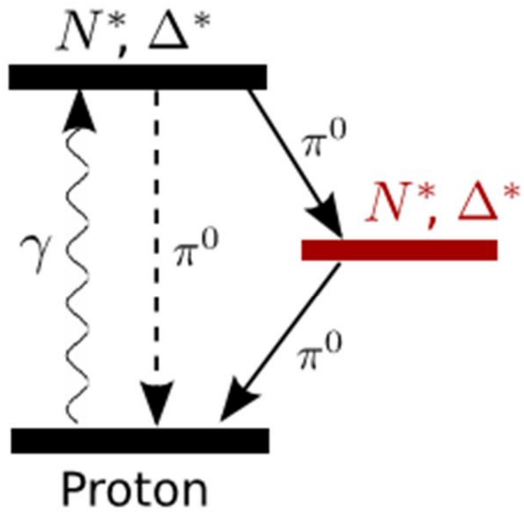


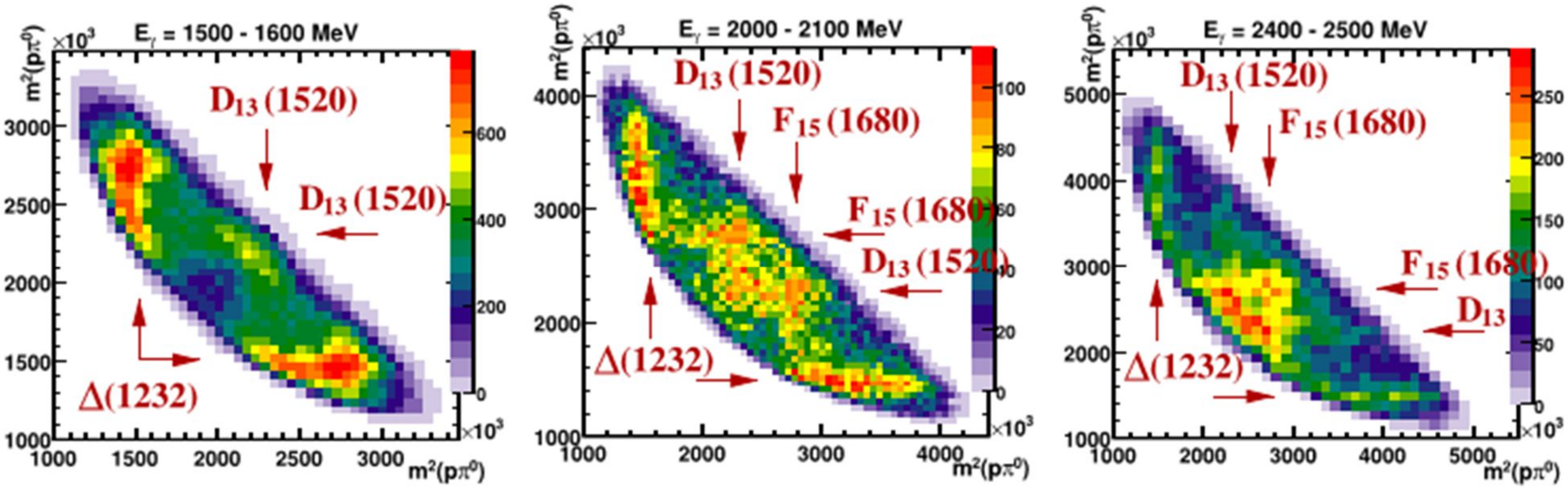
- PWA predictions (BnGa, JüBo, ηMAID) can not describe backward peak in data!
- New fits of BnGa and ηMAID have included the $p\eta'$ cusp in the S wave
- However, JüBo does not!

F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

Observables in Multi-Meson Final States

- Multi-meson final states like $\gamma p \rightarrow p\pi^0\pi^0$ or $\pi^0\eta$ preferred at higher energies
- Probes the high mass region, where the missing resonances occur
- Can help to observe cascading decays





[V. Sokhoyan et al., Eur.Phys.J. A51 (2015) no.8, 95]

Talk: T. Seifen (ELSA), Talk: A. Filippo (CLAS),

Measurements off neutrons

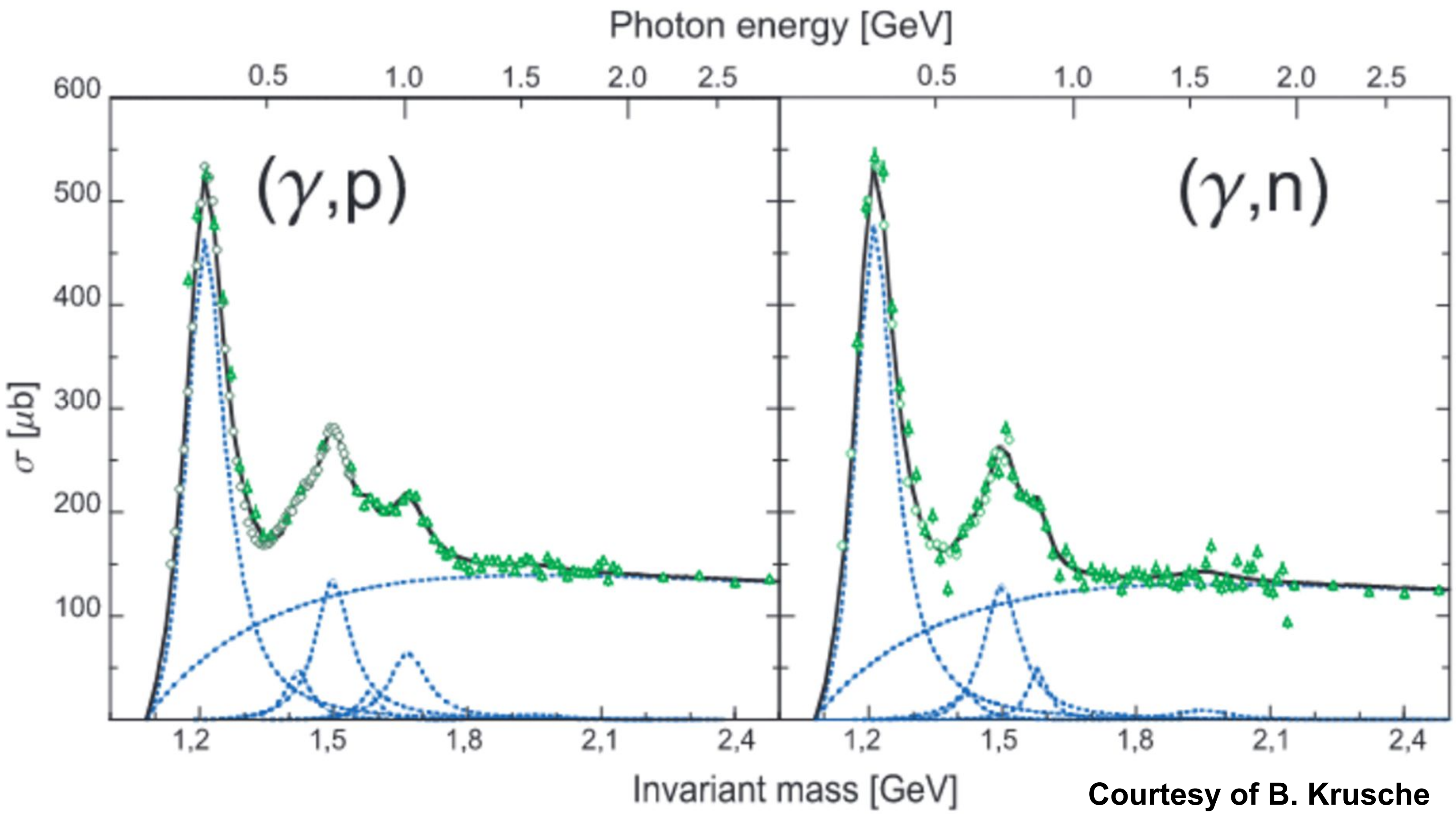
Spectroscopy off neutrons

Motivation

- Electromagnetic spectrum is isospin dependent
- Measurements off neutrons are essential for Isospin separation
- Different resonance contributions

Experimentally complicated to measure

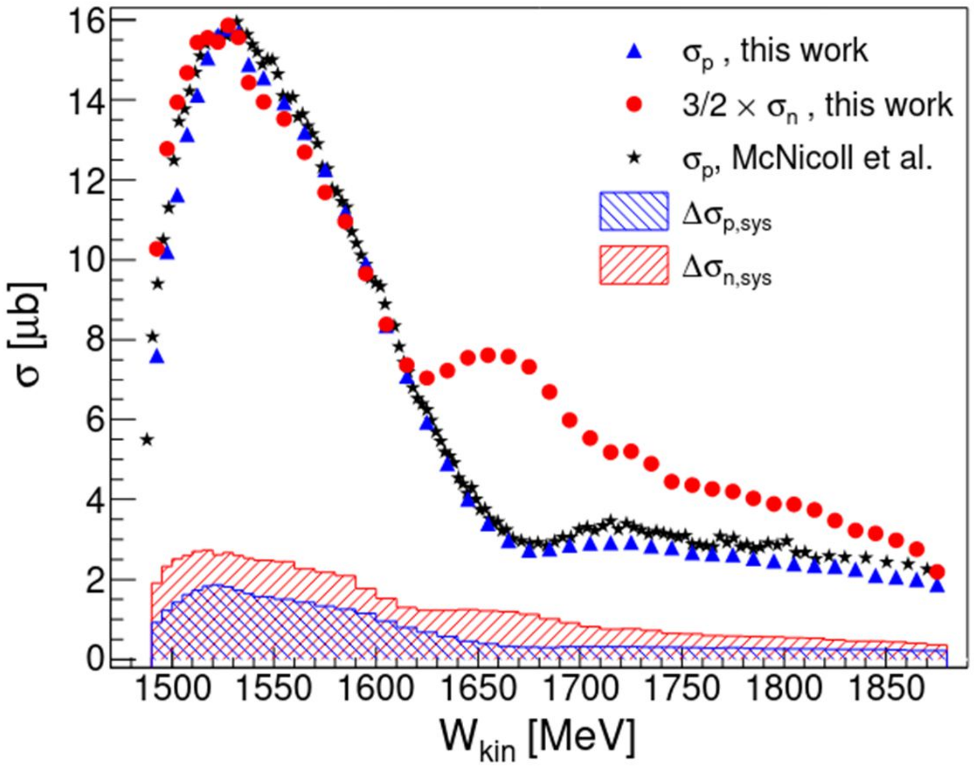
- No free neutron target, deuterium, helium, …
- Nuclear Fermi motion and FSI make Interpretation of results difficult
- Low detection efficiency for neutrons



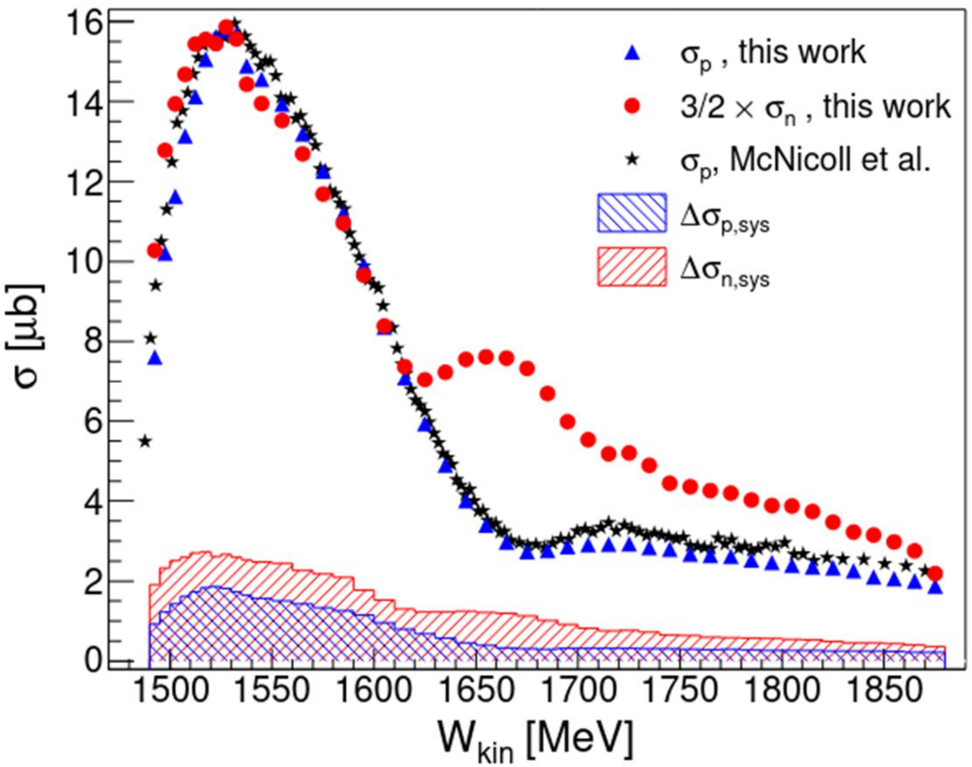
Courtesy of B. Krusche

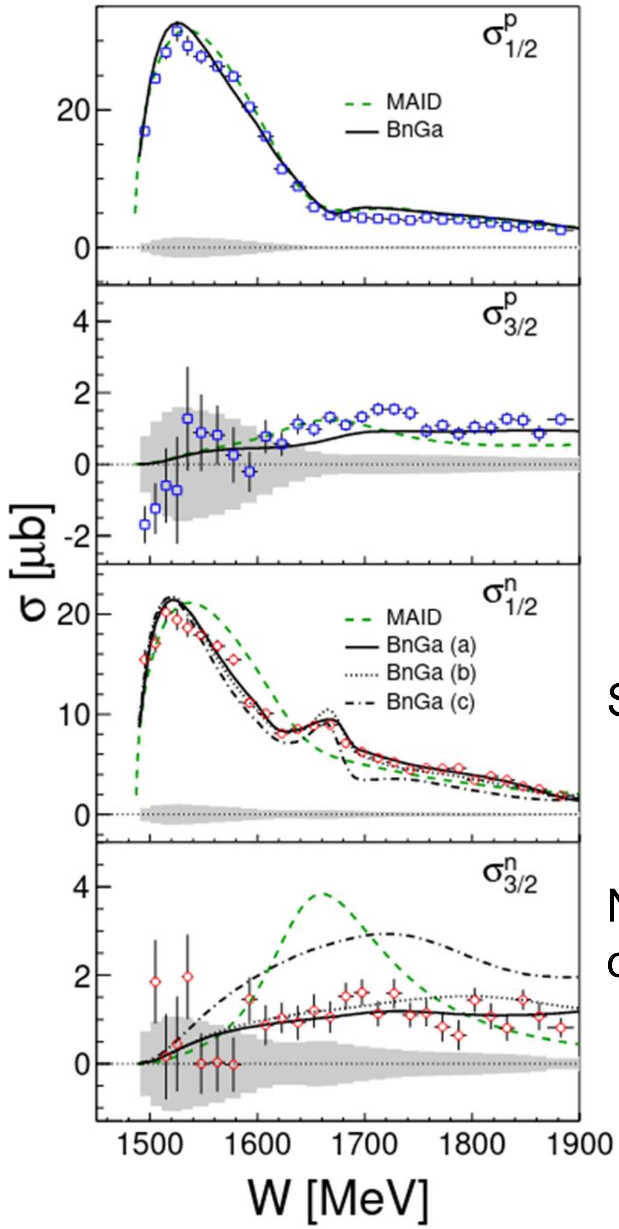
$\gamma n \rightarrow n\eta$: Narrow structure in σ and E

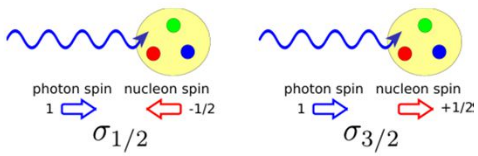
- Narrow peak observed in total cross section σ
  in **γn** –> **nη** at W(1670 +- 5 MeV) with L = 30 MeV



$\gamma n \to n\eta$: Narrow structure in σ and E





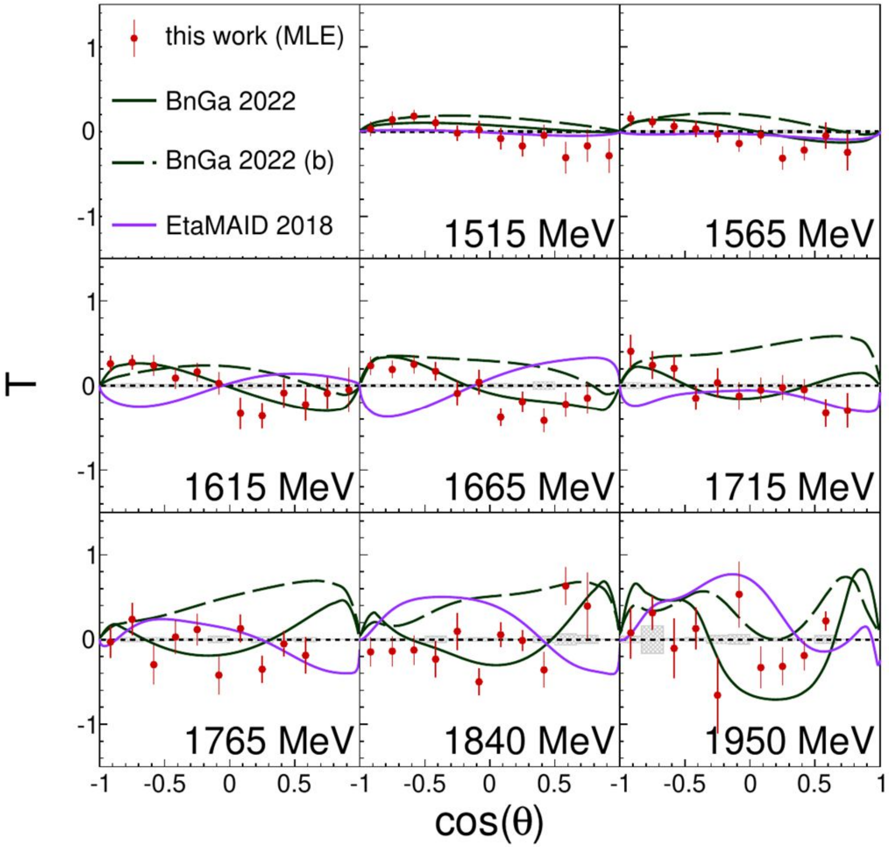


Structure seen only in $\sigma_{1/2}$ in $\gamma n \to n\eta$

New nucleon resonance or interference effect ?

γn –> nη : Preliminary ELSA data

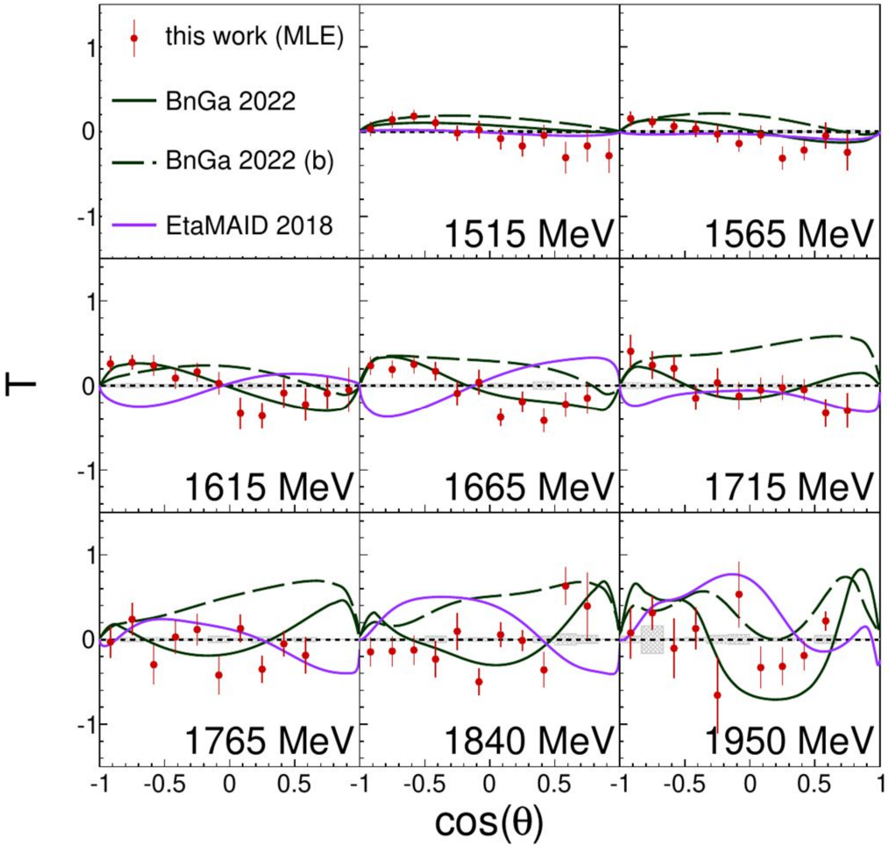
- More data taken for T, P, H with coherent edges at 1300MeV and 1600 MeV
- Ongoing analysis of different final states

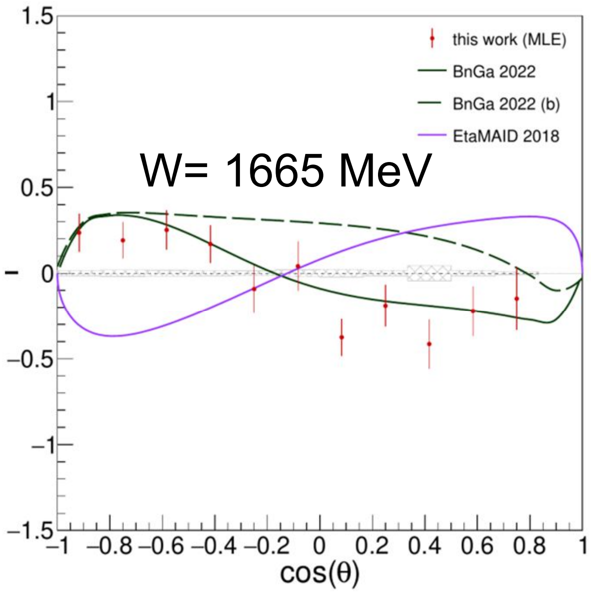


Preliminary work : N. Jermann, B. Krusche

$\gamma n \to n\eta$: Preliminary

- More data taken for T, P, H with coherent edges at 1300MeV and 1600 MeV
- Ongoing analysis of different final states





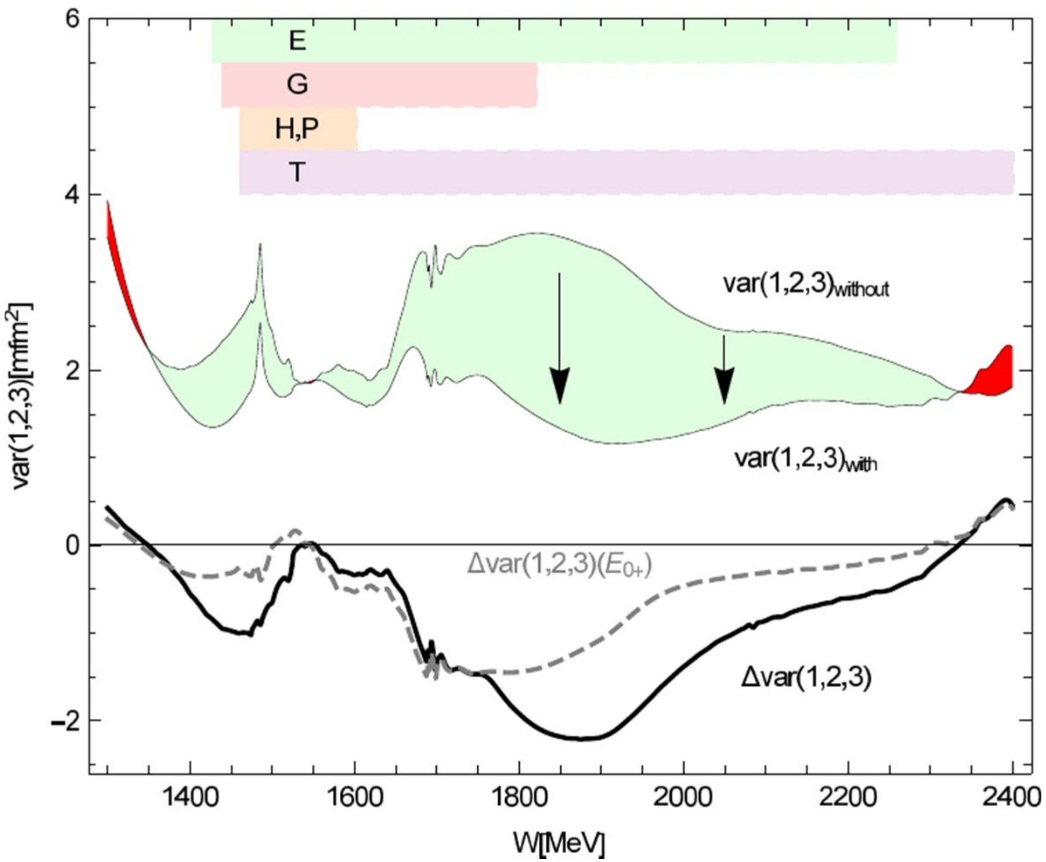
- BnGa 2022 interference effect of $S_{11}(1535)$ and $S_{11}(1650)$
- BnGa 2022 (b) new resonance in P_{11} wave at $P_{11}(1680)$
- EtaMAID 2018 interference effect $S_{11}(1535)$ and $P_{11}(1710)$

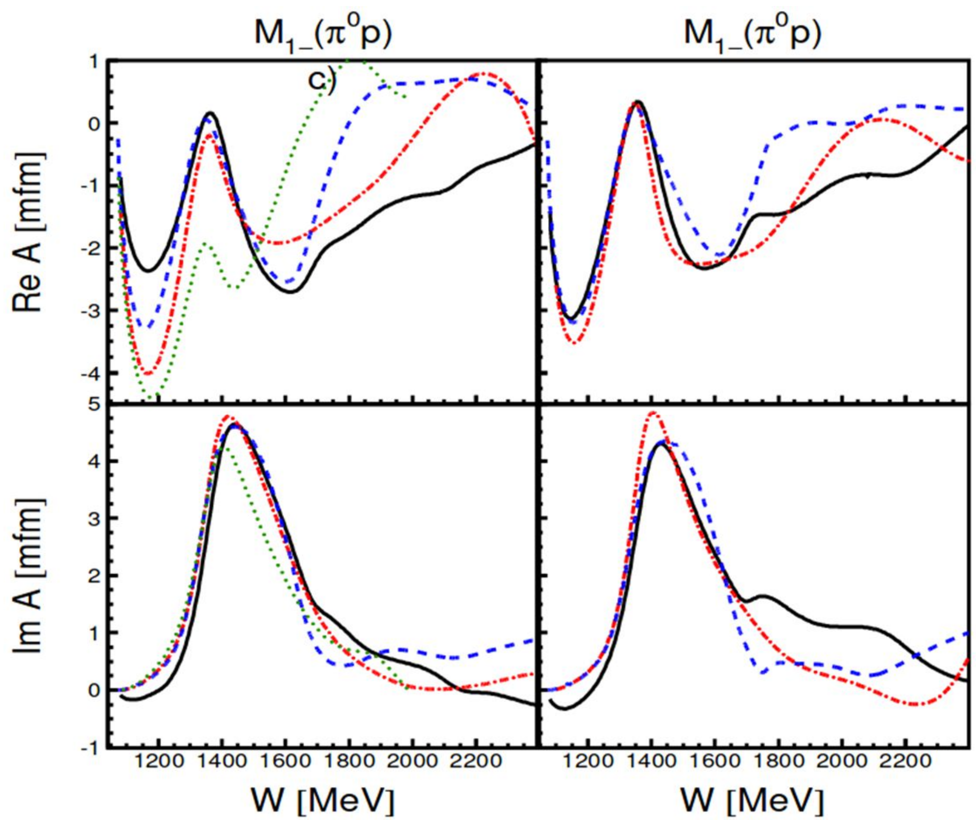
Preliminary work : N. Jermann, B. Krusche

Impact of the new data

$\gamma p \to p\pi^0$: Impact of the new data

- The variance of all three PWAs (BnGa, JüBo and SAID) summed up over all Multipoles up to L=4
- Variance between the PWAs decreases
- Example S-wave and P11- wave





Anisovich, Döring EPJA 52 (2016) no 9, 264

Impact of the new data

- **Status 2022: Light Baryon Resonances**

Particle	J^P	overall	PWA	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****											
$N(1440)$	$1/2^+$	****	○ ◇$_g$ ★ ▷	****	****	****	***	-			-		
$N(1520)$	$3/2^-$	****	○ ◇ ★ ▷	****	****	****	**	****			- - - -		
$N(1535)$	$1/2^-$	****	○ ◇ ★ ▷	****	****	***	*	****			- -		
$N(1650)$	$1/2^-$	****	○ ◇ ★ ▷	****	****	***	*	****	*- -	- -	- -		
$N(1675)$	$5/2^-$	****	○ ◇ ★ ▷	****	****	****	***	*	*	*	-		
$N(1680)$	$5/2^+$	****	○ ◇ ★ ▷	****	****	****	***	*	*	*	- - - -		
$N(1700)$	$3/2^-$	***	○ ▷	**	***	***	*	*	- -	-	-		
$N(1710)$	$1/2^+$	****	○ ◇ ▷	****	****	*-		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	○ ◇ ★ ▷	****	****	***	*	*	****	*	*-	*	
$N(1860)$	$5/2^+$	**	▷	*	**		*	*					
$N(1875)$	$3/2^-$	***	○ ▷	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	○ ▷	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	○ ▷	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	○ ◇ ▷	****	**	**	*	*	**	**	-	*	**
$N(1990)$	$7/2^+$	**	○ ◇ ▷	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	○ ★	**	*-	**	*	*	-	-	- -	*	
$N(2040)$	$3/2^+$	*	▷		*								
$N(2060)$	$5/2^-$	***	○ ◇$_g$ ▷	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	○ ▷	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	○ ▷	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	○ ◇ ★ ▷	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	○ ◇ ★	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	○ ◇ ★ ▷	**	****			*	*	*			
$N(2300)$	$1/2^+$	**			**								
$N(2570)$	$5/2^-$	**			**								
$N(2600)$	$11/2^-$	***	★		***								
$N(2700)$	$13/2^+$	**			**								

- Until 2010: only results from πN-scattering used in the PDG
- PWA groups: BnGa, JüBo. SAID, MAID include photoproduction data
- Now: new values from the fits are entering the PDG

F. Afzal, A. Thiel, Y. Wunderlich Prog. Part. Nuc. Phys. 125 (2022) 103649

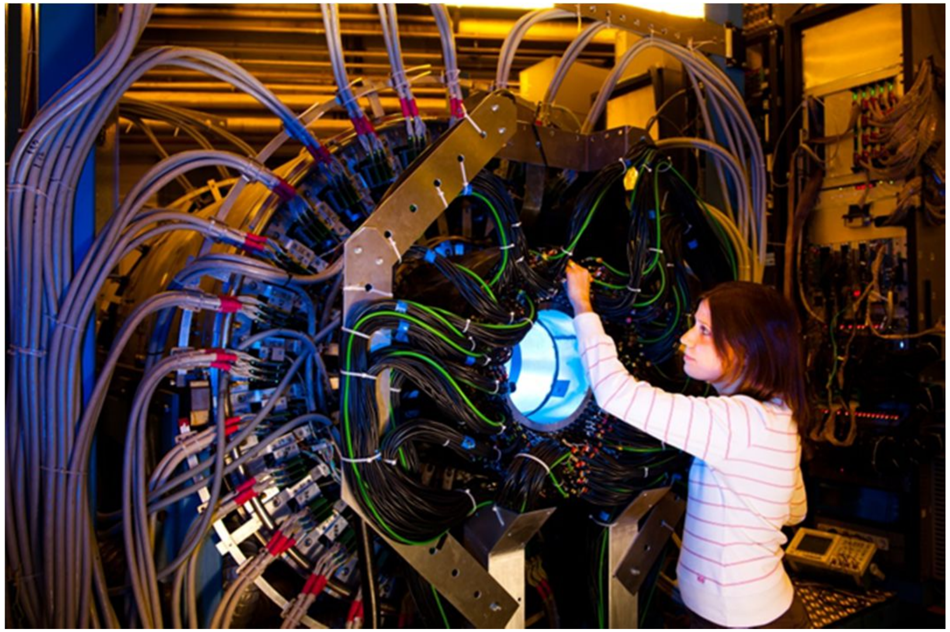
Summary

- Precise data from ELSA, Jlab, MAMI and Spring8
  - polarization data are essential to get unique PWA- solution
  - full angular coverage and precision is important to find high spin states
  - different final states are important, coupled channel analysis
- Impact of the new polarization data
  - the new polarization data constrain the possible multipole solutions
  - new states have been found

Baryon Spectroscopy Future

- In the high W-mass region the final states $p\,\eta$, $p\,\eta'$ and $K^+\,\Lambda$, $K^+\,\Sigma^0$ will be important
  - the necessary precision in the data is still missing
- Polarization data on the Neutron are necessary
  - CBELSA/TAPS experiment has been upgraded and neutron measurements have started

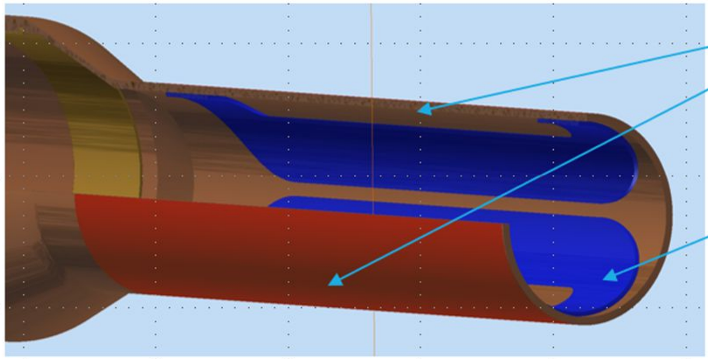
Thank you for your attention



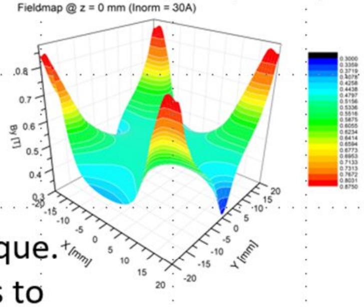
Status of JRA10:CryPTA
Task1 PT UBO

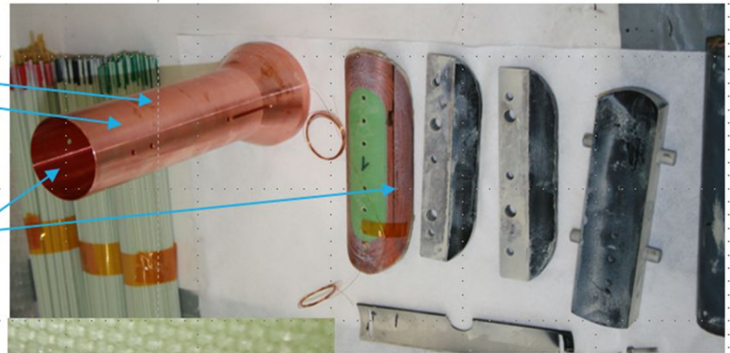
Research Objectives Task1: combined holding magnet system

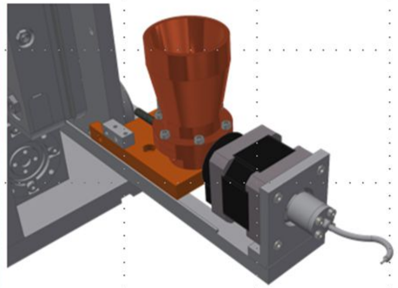
Combined longitudinal and transverse holding coil for the new dilution refrigerator for a variable polarization direction in plane (Milestone MS64)



- Cu-support (cooling)
- Longitudinal field: solenoid (outside)
  - → 4 layers á N590
  - → I_{max} ~ 32 A
  - → B_{max} ~ 0.52 T
- Transverse field: race track like dipole (inside)
  - → 2 x N525
  - → I_{max} ~ 30 A
  - → B_{max} ~ 0.50 T

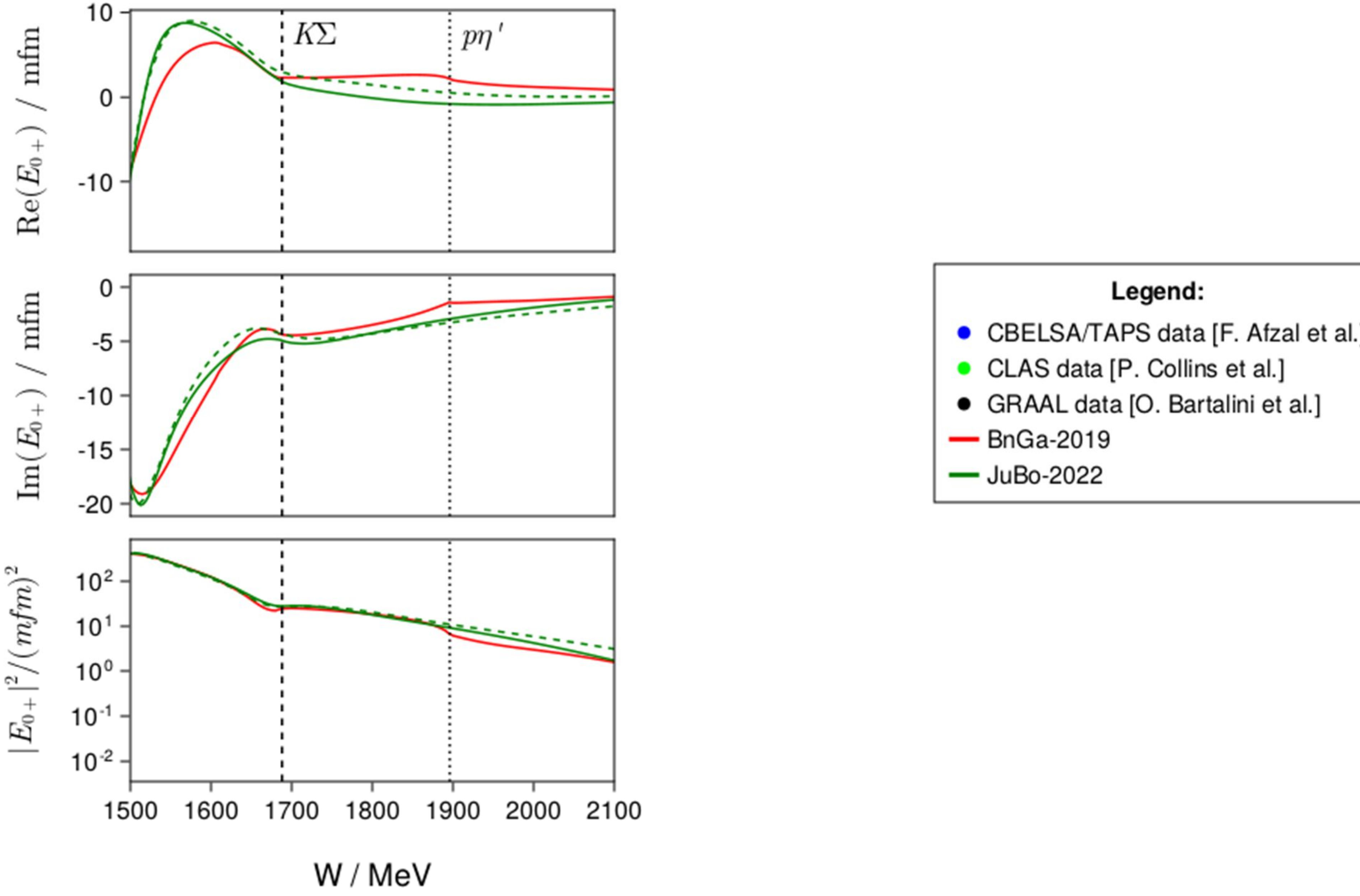




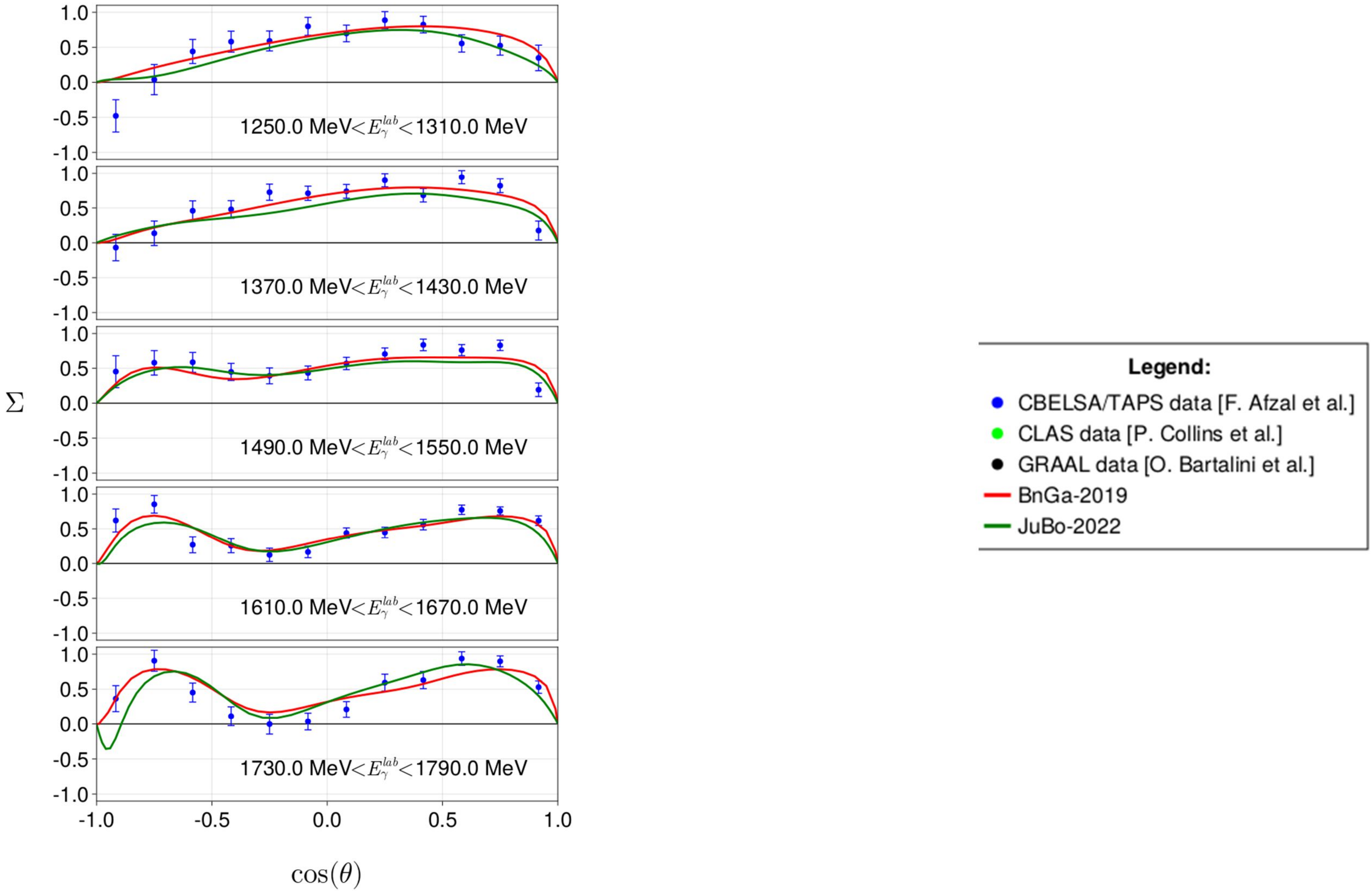


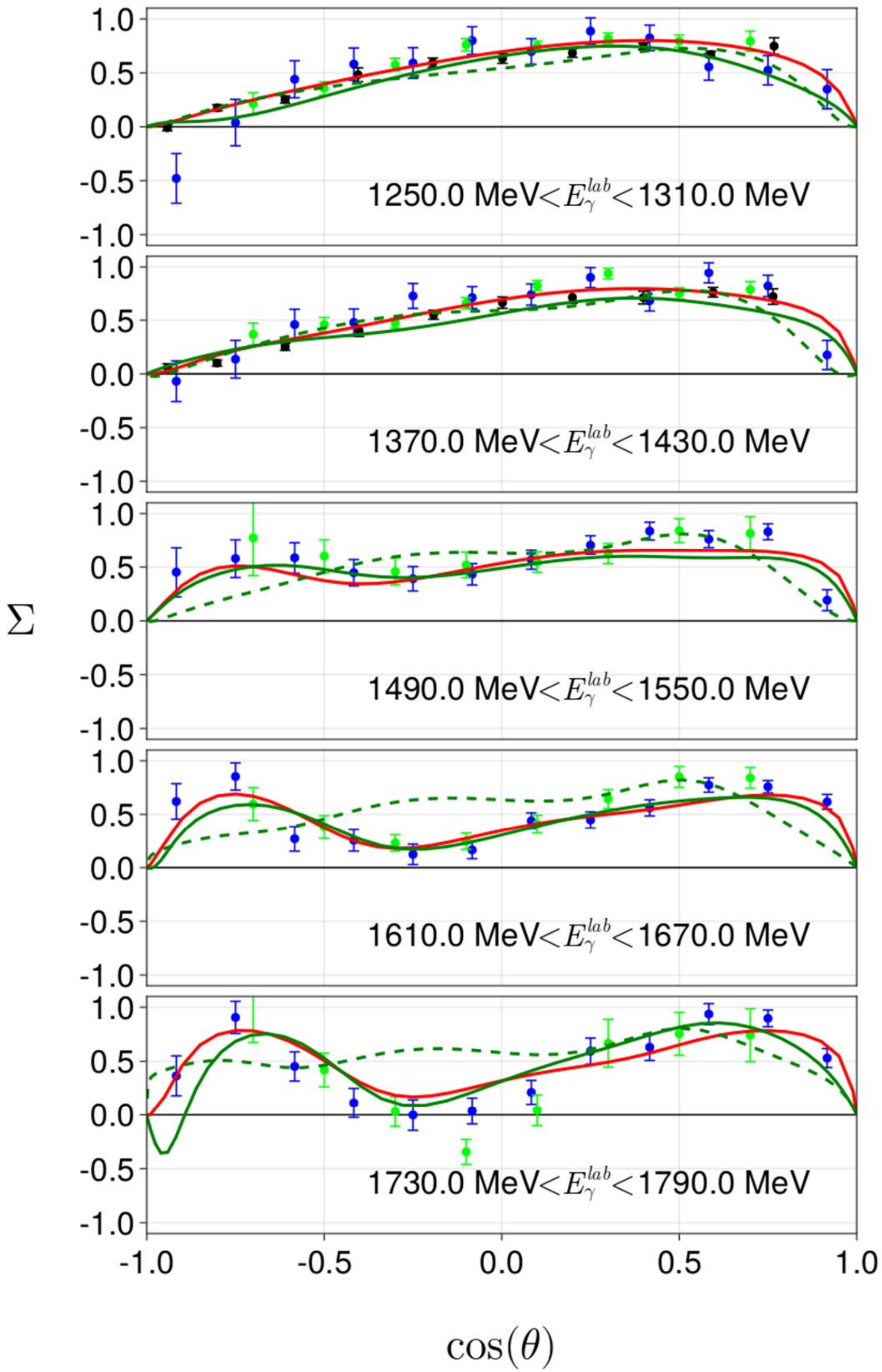
- ➢ Precision wet winding of a solenoid is a well established technique.
- ➢ Wet winding of race tracks with thin superconducting wires has to be improved to guaranty high performance at minimum thickness
- ➢ Problem: inhomogeneous glue distribution within the coil package
- ➢ New wire feeding device is under construction

Courtesy of H. Dutz



Re(E_{0+}) / mfm
Im(E_{0+}) / mfm
$|E_{0+}|^2/(mfm)^2$
$K\Sigma$
$p\eta'$
10
0
-10
-5
-15
-20
10^2
10^1
10^0
10^{-1}
10^{-2}
1500
1600
1700
1800
1900
2000
2100
W / MeV
Legend:
CBELSA/TAPS data [F. Afzal et al.
CLAS data [P. Collins et al.]
GRAAL data [O. Bartalini et al.]
BnGa-2019
JuBo-2022


1250.0 MeV<E_γ^{lab}<1310.0 MeV
1370.0 MeV<E_γ^{lab}<1430.0 MeV
1490.0 MeV<E_γ^{lab}<1550.0 MeV
1610.0 MeV<E_γ^{lab}<1670.0 MeV
1730.0 MeV<E_γ^{lab}<1790.0 MeV
Σ
$\cos(\theta)$
Legend:
CBELSA/TAPS data [F. Afzal et al.]
CLAS data [P. Collins et al.]
GRAAL data [O. Bartalini et al.]
BnGa-2019
JuBo-2022


1250.0 MeV< E_γ^{lab} <1310.0 MeV
1370.0 MeV< E_γ^{lab} <1430.0 MeV
1490.0 MeV< E_γ^{lab} <1550.0 MeV
1610.0 MeV< E_γ^{lab} <1670.0 MeV
1730.0 MeV< E_γ^{lab} <1790.0 MeV
Σ
cos(θ)