Present and Future of Baryons with the CBELSA/TAPS experiment at ELSA

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for the CBELSA/TAPS collaboration

NSTAR 2026 , Sevilla, September 7th – 11th 2026

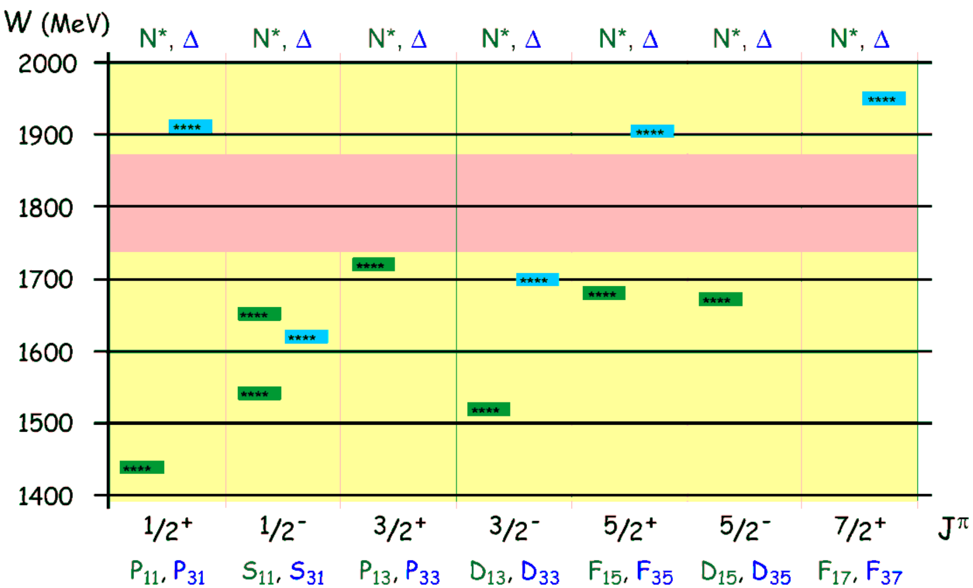
- Introduction
- Impact of the new polarization data
- Problem with a unique PWA solution
- Future plans of the CBELSA/TAPS experiment
- Summary

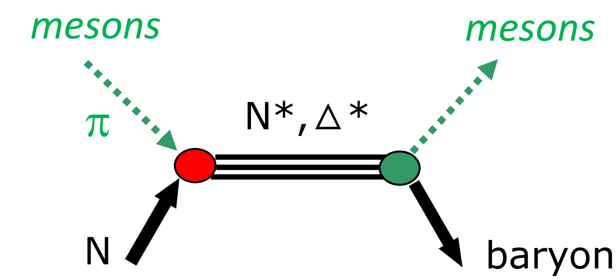
Introduction

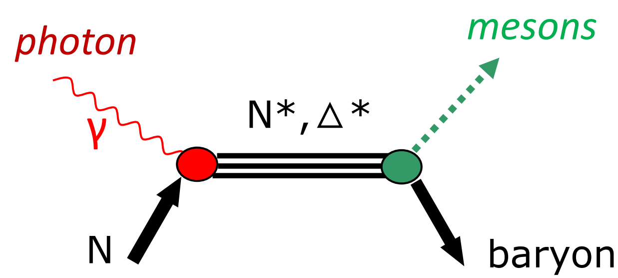
Experiments at ELSA: focus on baryon spectroscopy, meson photoproduction

Excitation spectra: information about interaction and dynamics between constituents

Nucleon Excitation Spectrum







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

only 7 N* and 5 Δ* well established in the mass region 1400 MeV < W < 2000 MeV

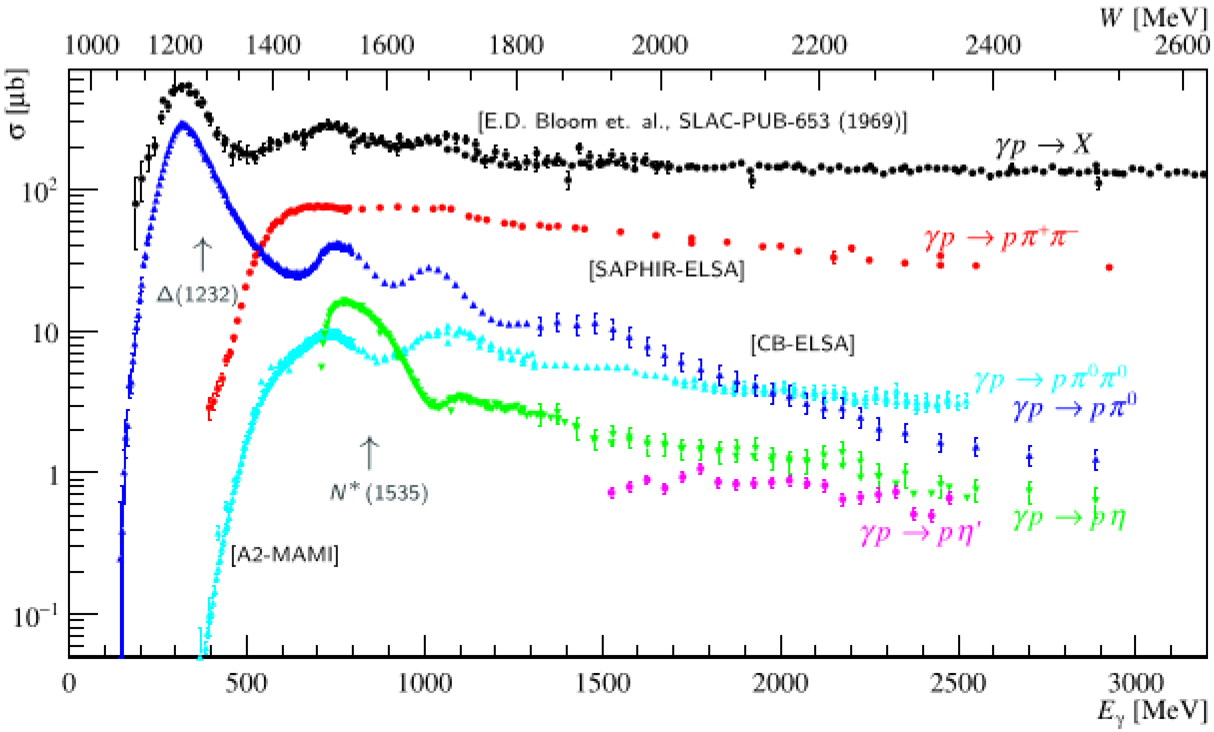
- Energy pattern for the dominant states
  - Constituent Quark Models
  - Dynamic Models , Lattice QCD
- Various nucleon models predict many more states
  - weak coupling to πN final state
  - incomplete data base

V. Mokeev D. Carman C. Morningstar

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



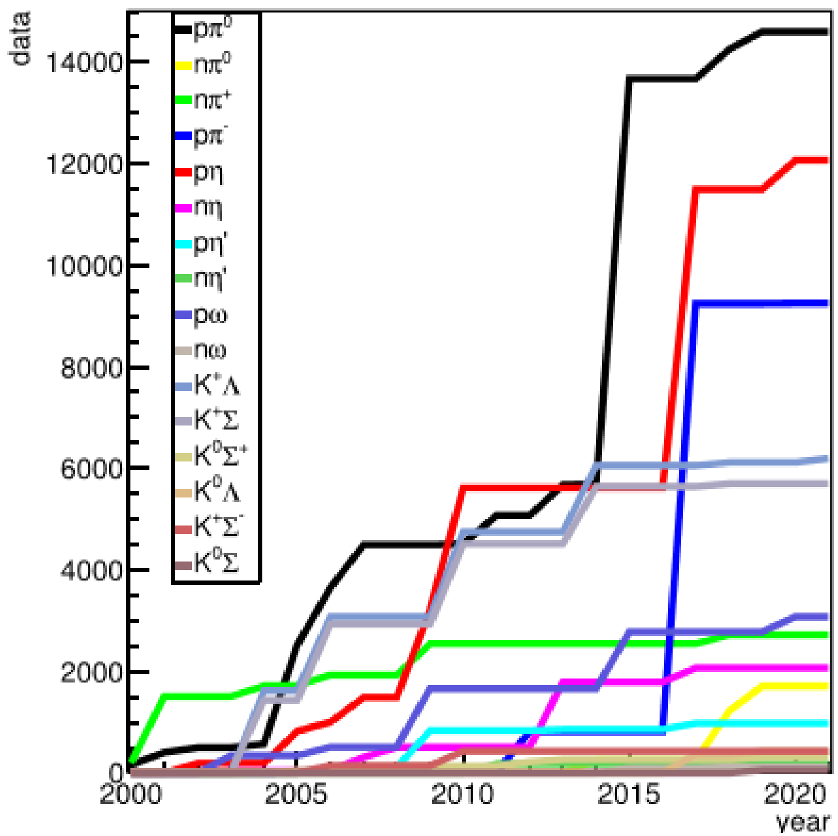
A. Thiel, F. Afzal, Y. Wunderlich Prog. Part. Nuc. Phys. 125 (2022) 103649

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

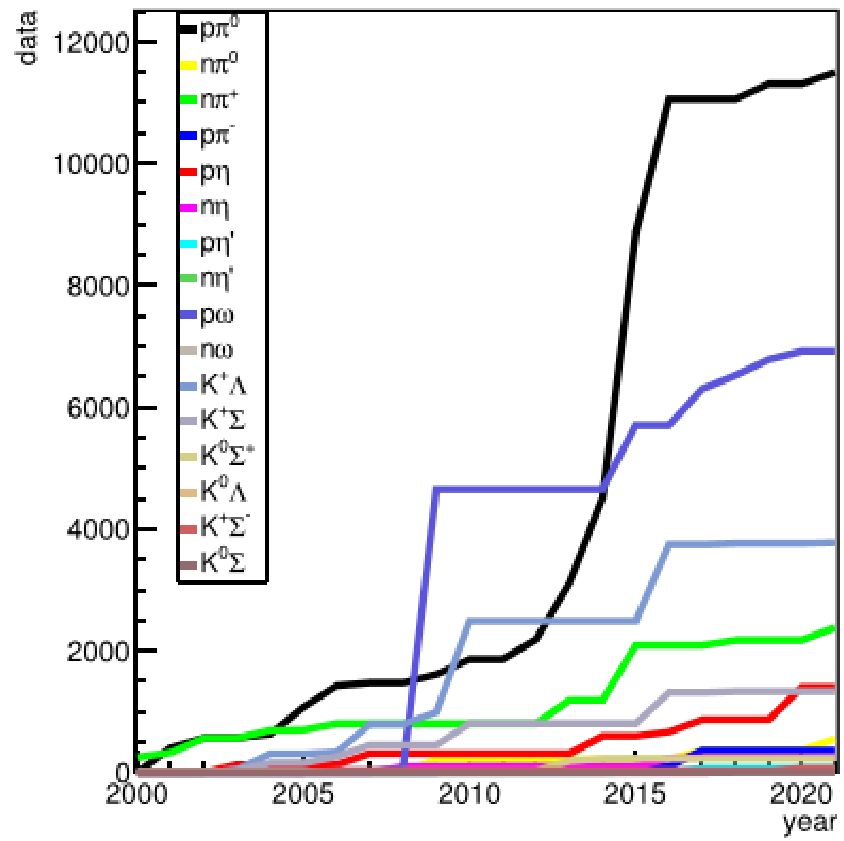
Introduction

- **Status 2022: Data Base**

Unpolarized cross section



Polarization observables



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Introduction

- **Status 2022: Light Baryon Resonances**

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

final states

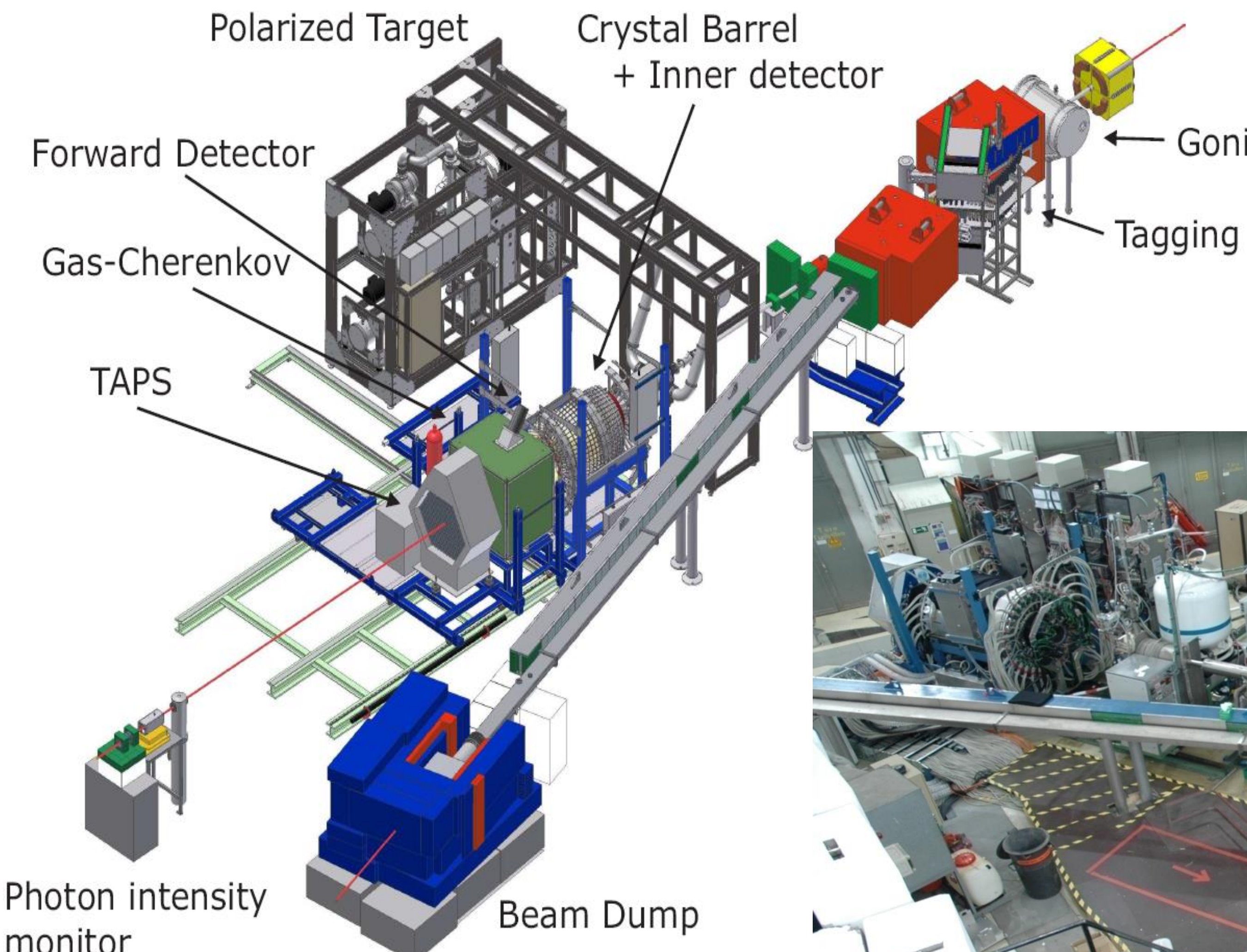
Particle	J^P	overall	PWA	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****											
$N(1440)$	$1/2^+$	****	○ $\diamond_g$ ★ ▷	****	****	****	***	-			-		
$N(1520)$	$3/2^-$	****	○ ◇ ★ ▷	****	****	****	**	****			- - - -		
$N(1535)$	$1/2^-$	****	○ ◇ ★ ▷	****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

- 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

CBELSA/TAPS Experiment

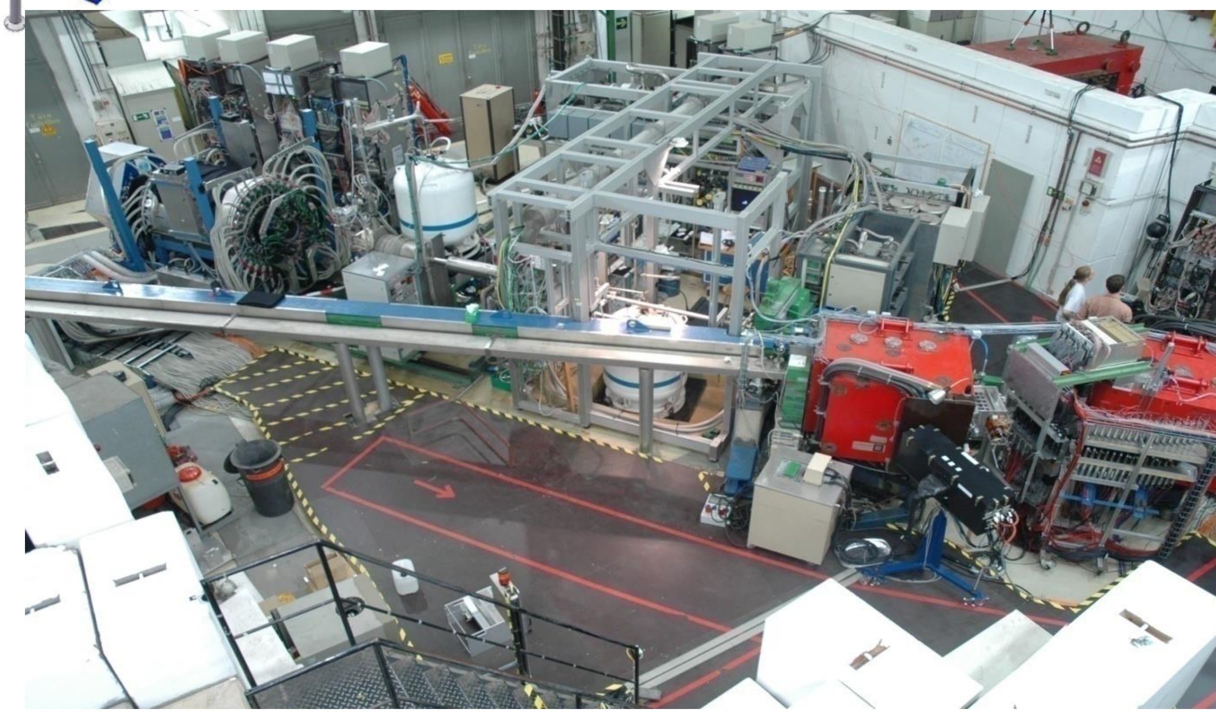


Important:

Polarized beam from ELSA

Polarized targets

4π detector setup



Polarized Photons at ELSA

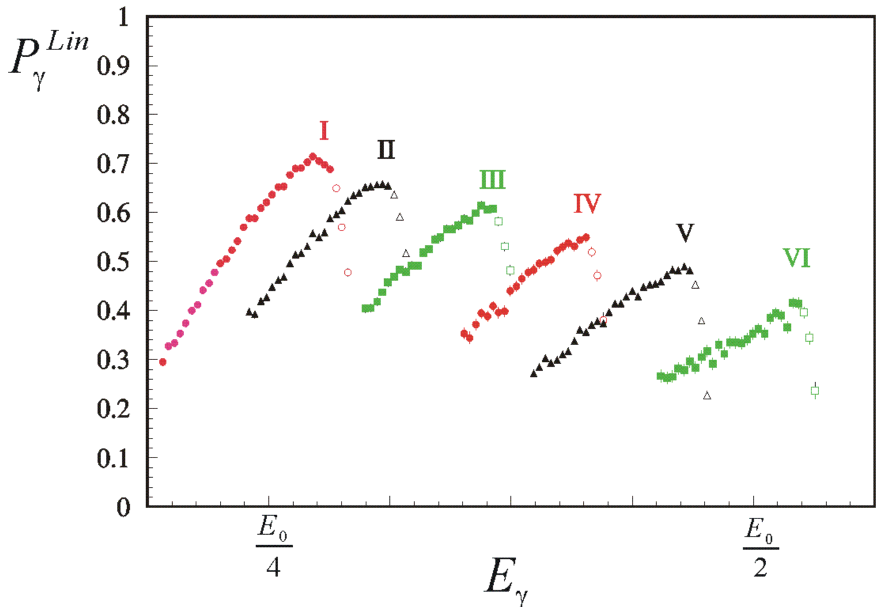
<u>Linearly polarized photons:</u>

- coherent bremsstrahlung
- diamond radiator

<u>Circularly polarized photons:</u>

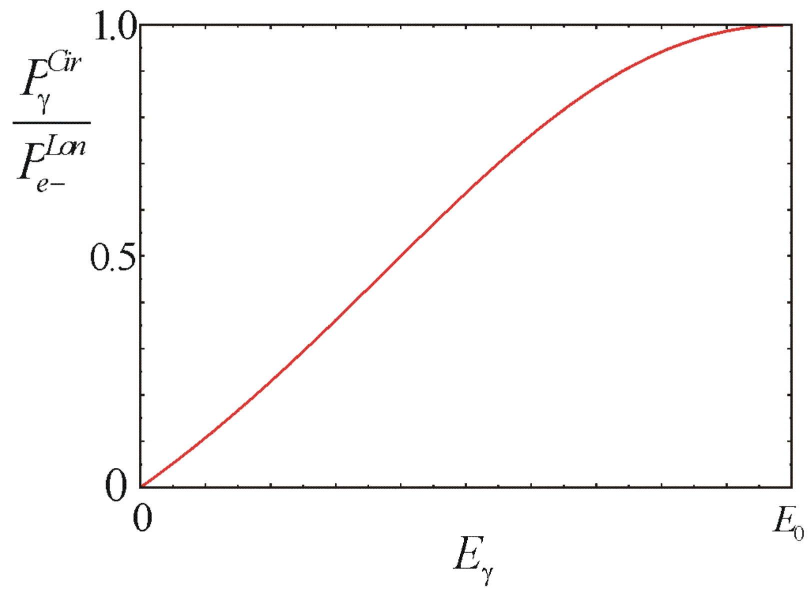
- longitudinally polarized electrons
- helicity transfer to photon

Linearly polarized photons



high polarization at low photon energies

Circularly polarized photons



high polarization at high photon energies

Important new development: use of elliptically polarized photons at MAMI, JLab and ELSA
Longitudinally polarized electrons on a diamond radiator
F. Afzal et al., Phys. Rev. Lett. 132 (2024)12, 121902

Problem with a Unique PWA Solution

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

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

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

  additional constraints:

  (a) s- and p- wave approximation truncated PWA

  (b) Fermi- Watson theorem

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

  same I, J in the final state

  → same scattering phase δ_{IJ}

  two observables sufficient for "complete data base"

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

  beam asymmetry : Σ

- above $\pi\pi$- threshold
  - Fermi- Watson theorem not valid any more
  - More observable needed to get a unique partial wave solution
  - Different final states are important -> coupled PWA are essential

Problem with a Unique PWA Solution

Total cross section:

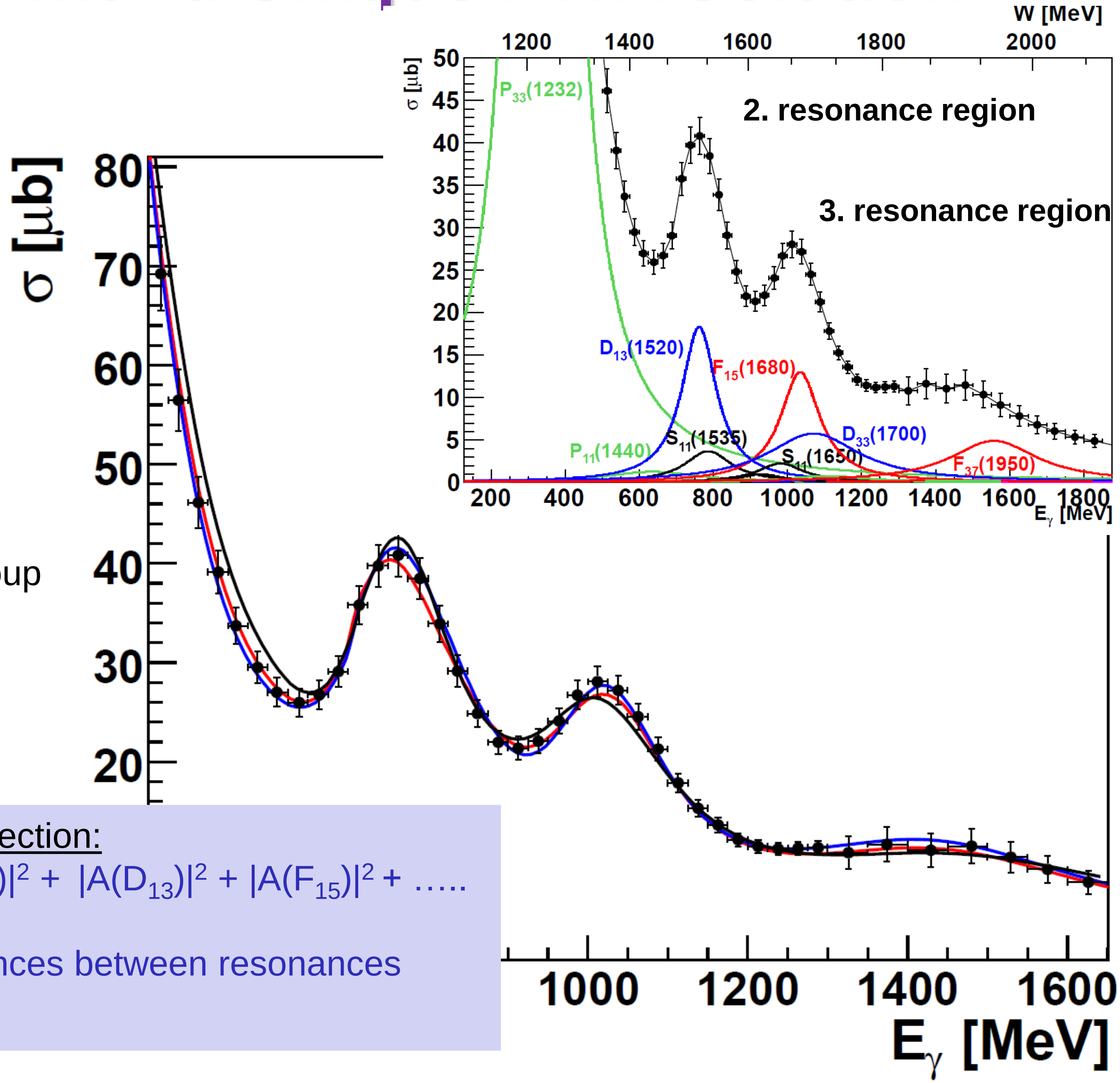
$$\gamma + p \rightarrow p + \pi^0$$

Partial wave analysis:

BnGa — Bonn-Gatchina group

SAID — Washington group

MAID — Mainz group



Total cross section:

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

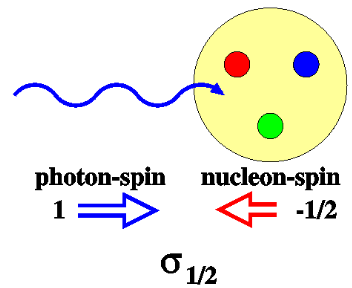
no interferences between resonances

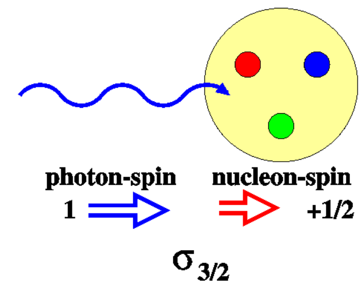
Helicity Dependent Cross Section for $p\pi^0$

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

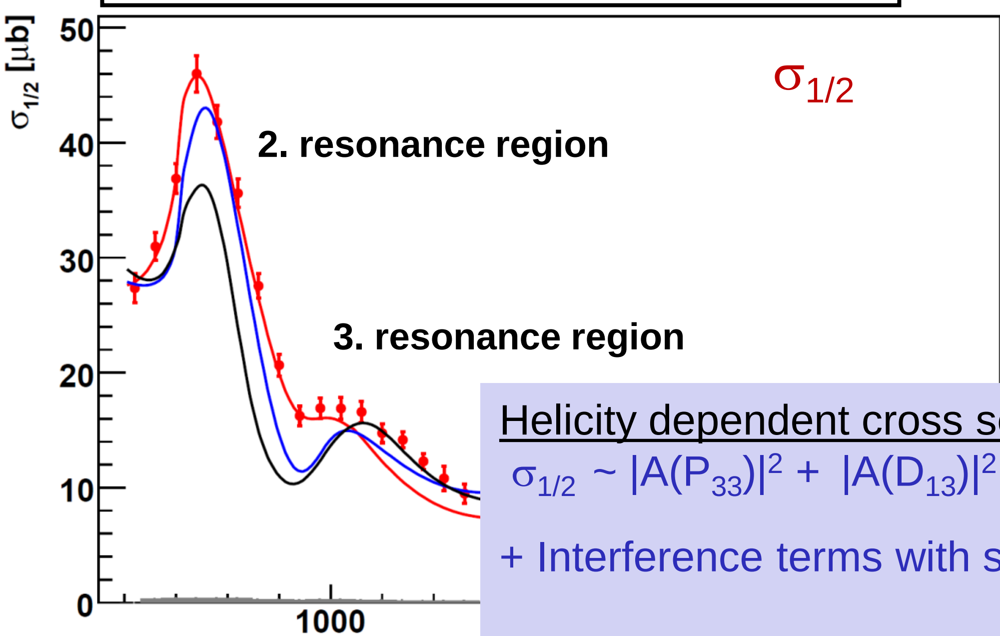
circularly polarized photons

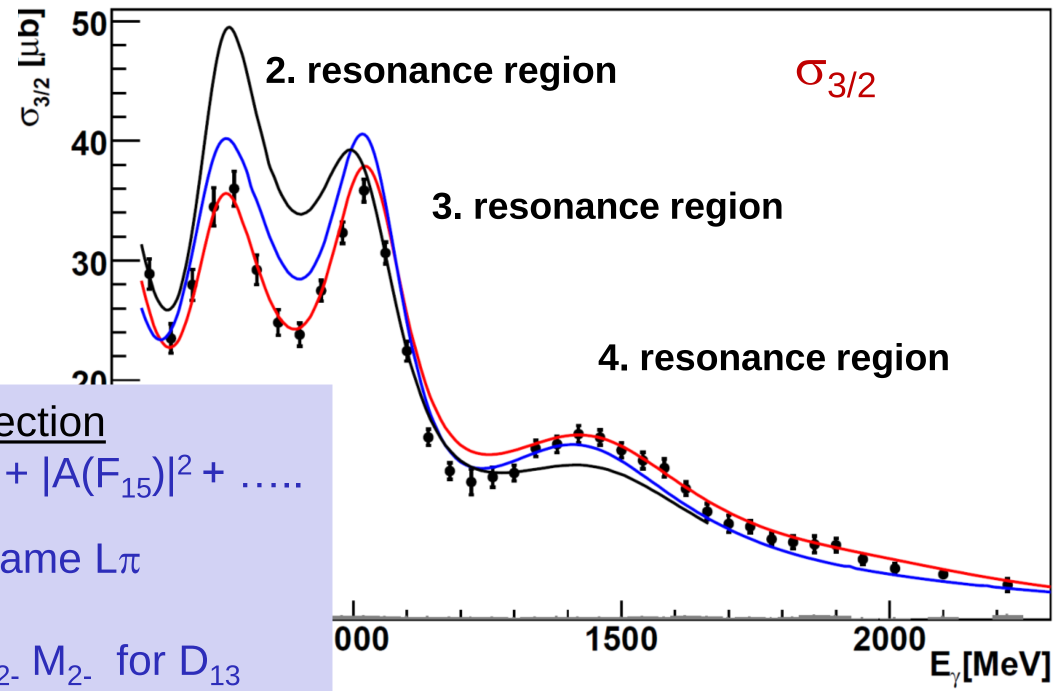
longitudinally polarized proton





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





<u>Helicity dependent cross section</u>

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

+ Interference terms with same $L\pi$

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

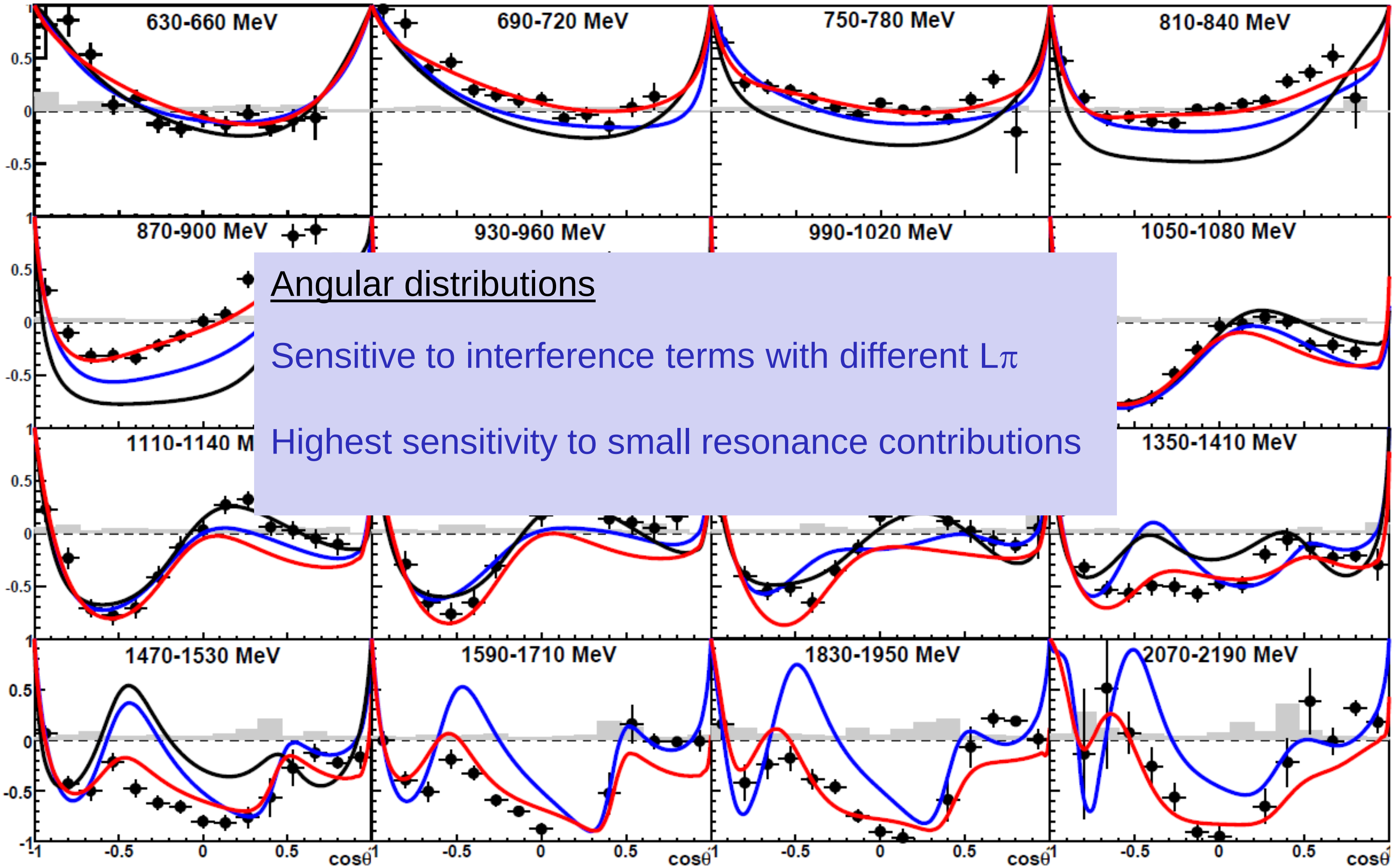
<u>Partial wave analysis predictions :</u> — BnGa — SAID — MAID

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

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

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

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



<u>Angular distributions</u>

Sensitive to interference terms with different L_π

Highest sensitivity to small resonance contributions

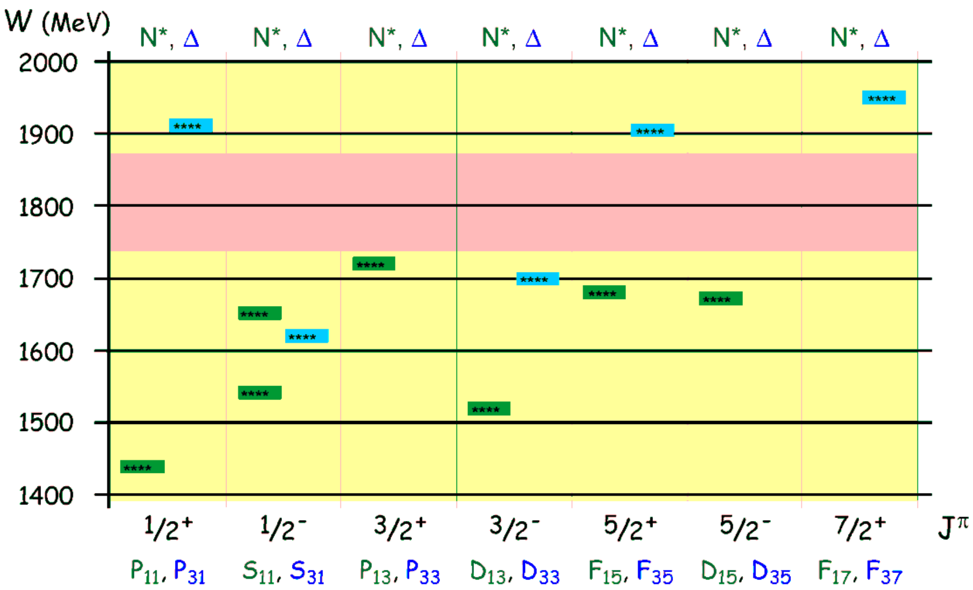
<u>Partial wave analysis prediction:</u>

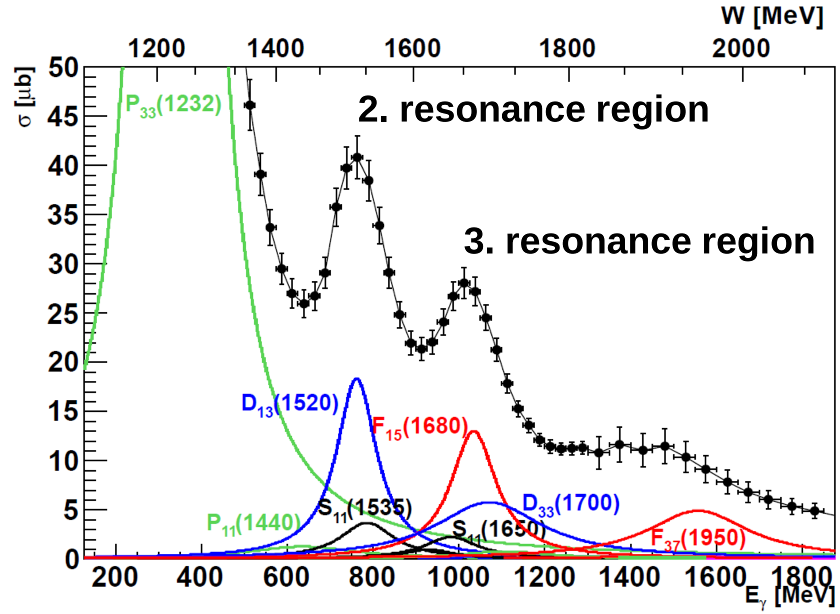
BnGa

SAID

MAID

Impact of the new polarization data





Which L_{max} is seen in the new polarization data ? –> Search for missing resonances

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

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

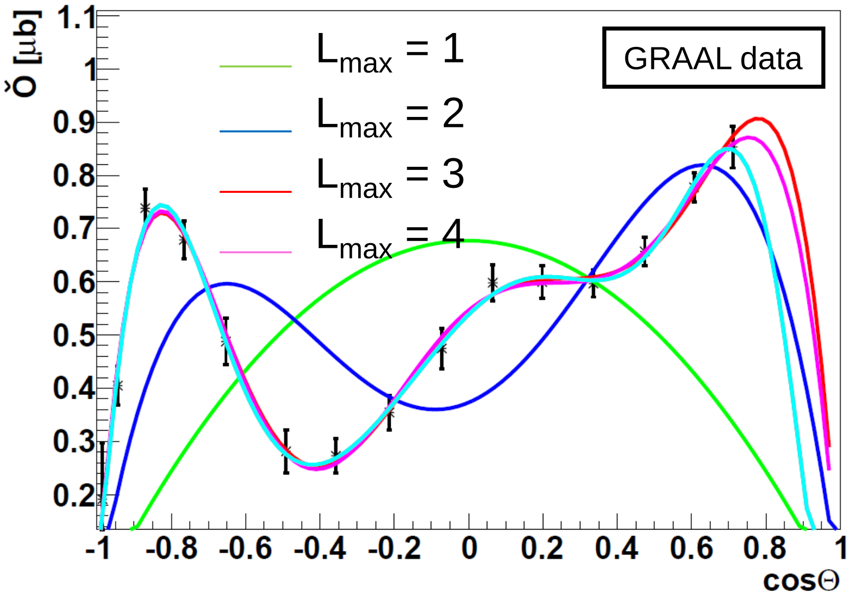
$L_{max} = 2$, D-wave , resonances in D-wave: $D_{13}(1520)$, $D_{15}(1680)$, $D_{33}(1700)$, $D_{35}(?)$,

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

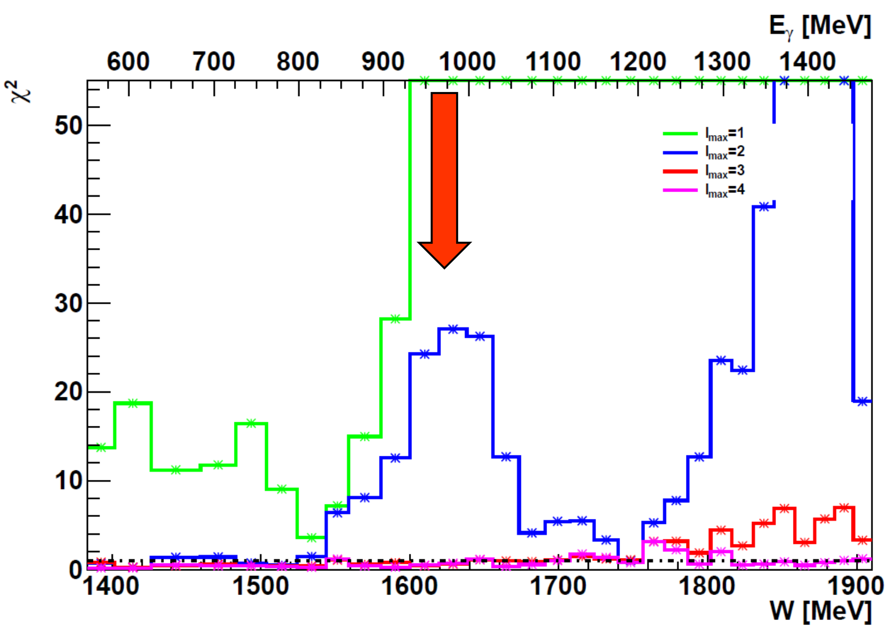
$L_{max} = 4$, G-wave , resonances in G-wave: $G_{17}(?)$, $G_{19}(?)$, $G_{37}(?)$, $G_{39}(?)$

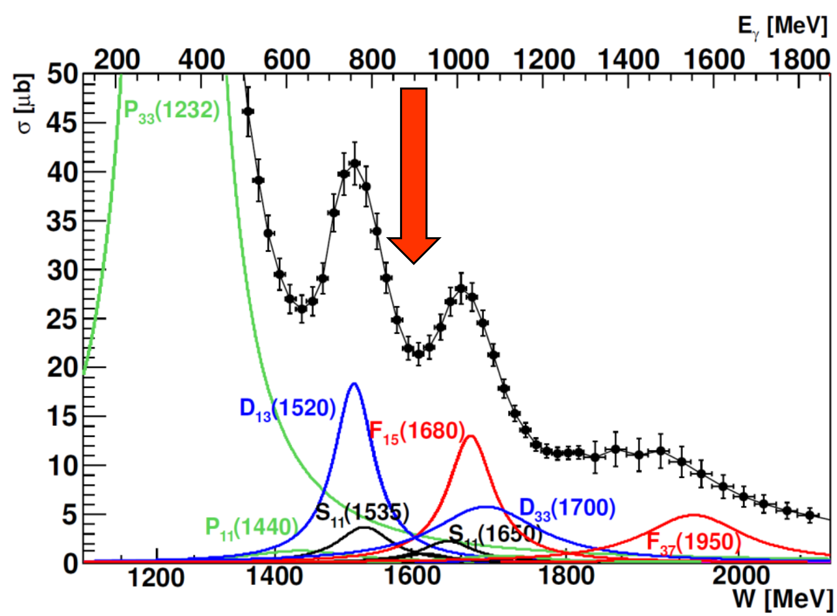
L_{max} Interpretation of Σ- Asymmetry in $p\pi^0$

W=1620 MeV

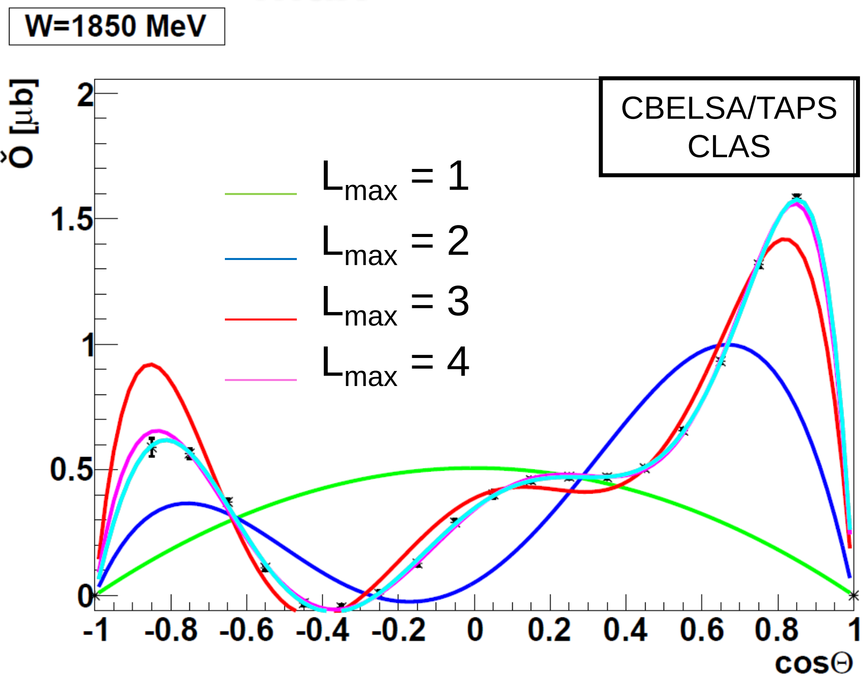


$$\Sigma = \sum_{k=0}^{2L_{max}} (a_L(W))_k \cdot P_k^0(\cos\theta)$$



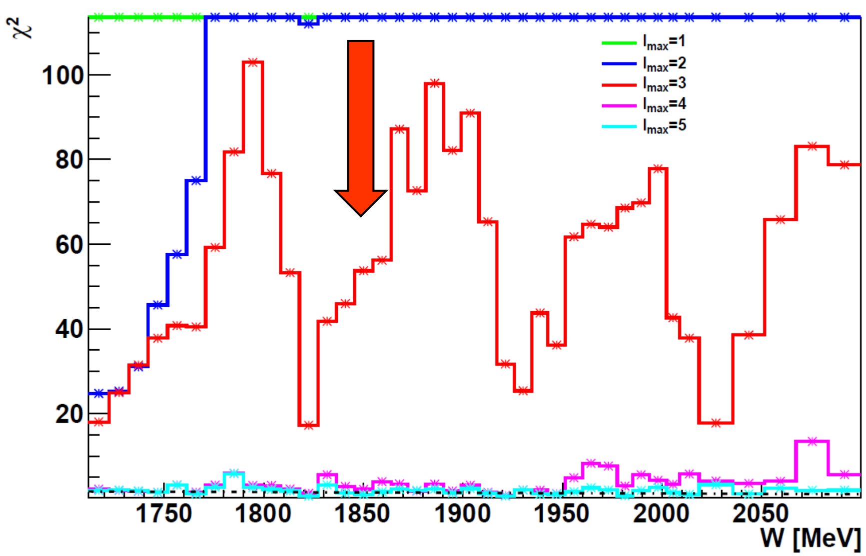


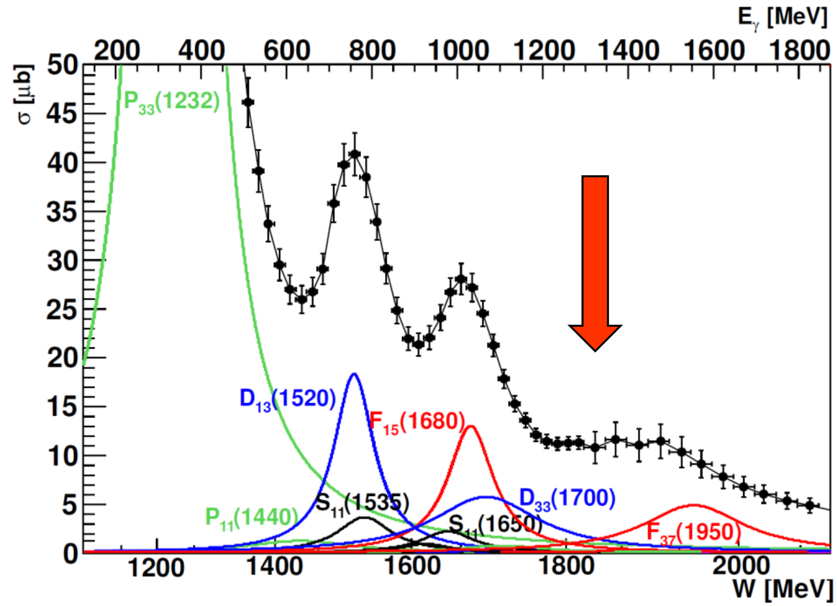
L_{max} Interpretation of Σ- Asymmetry in $p\pi^0$



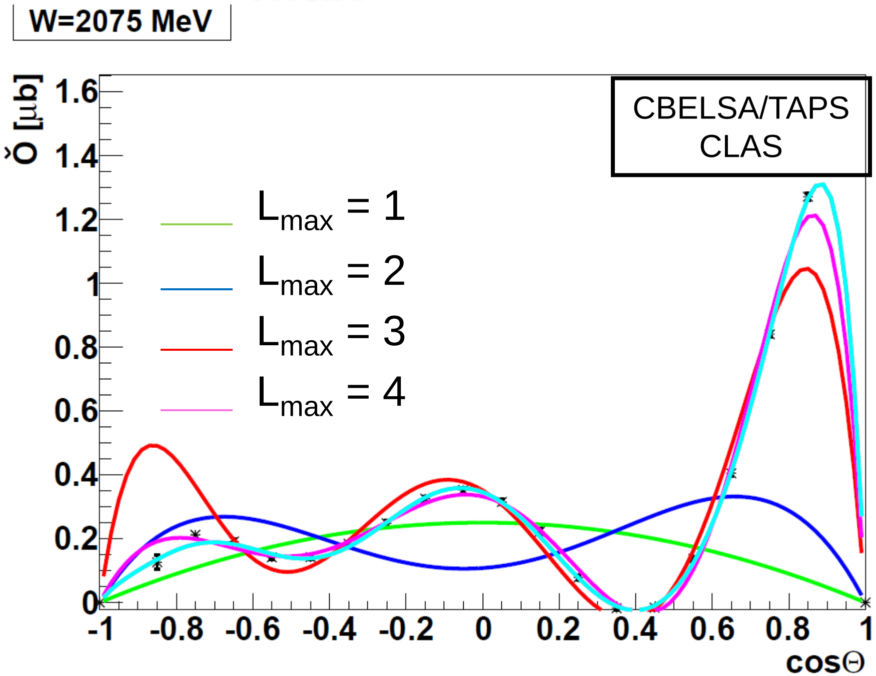
- Significant L = 3 signal seen above W = 1500 MeV
- Below L ≤ 2 seems to be sufficient
- L = 4 signal above W = 1700 MeV

High precision data for **Σ** from
CBELSA/TAPS
CLAS





L_{max} Interpretation of Σ- Asymmetry in $p\pi^0$



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- Below W =1500 MeV
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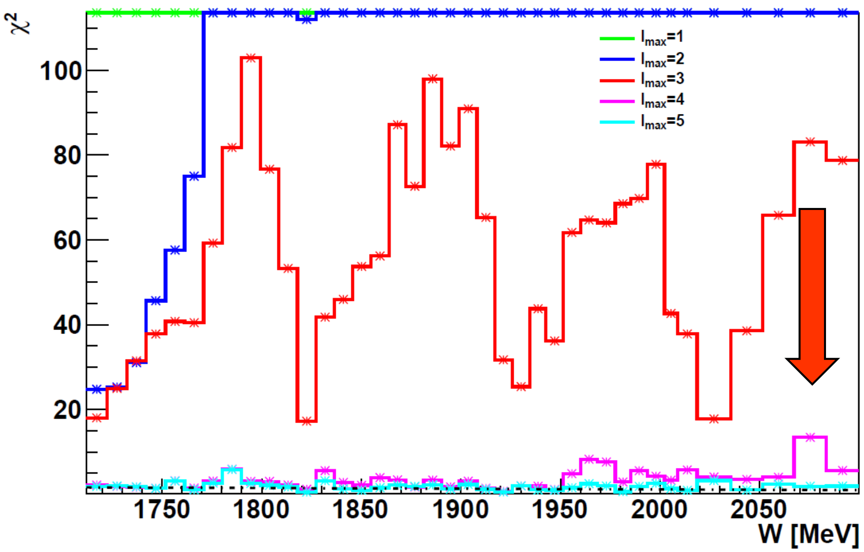
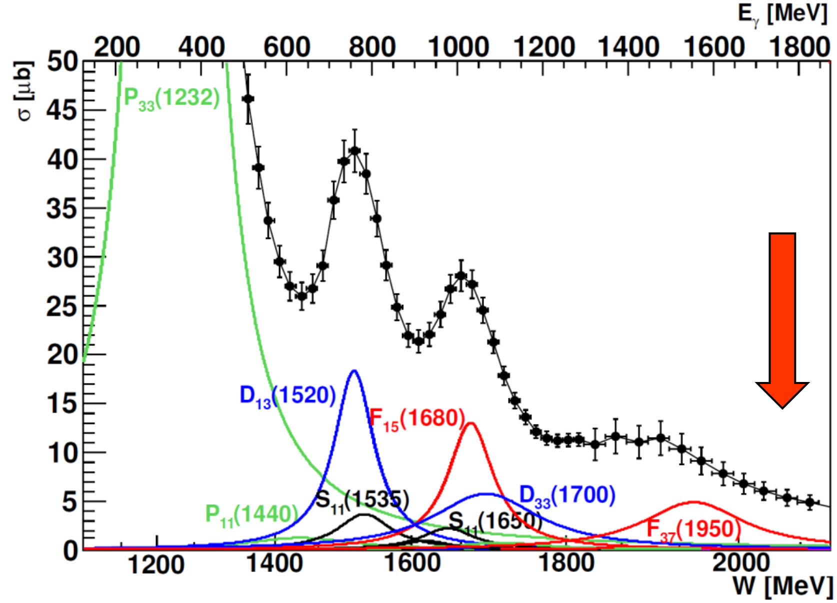
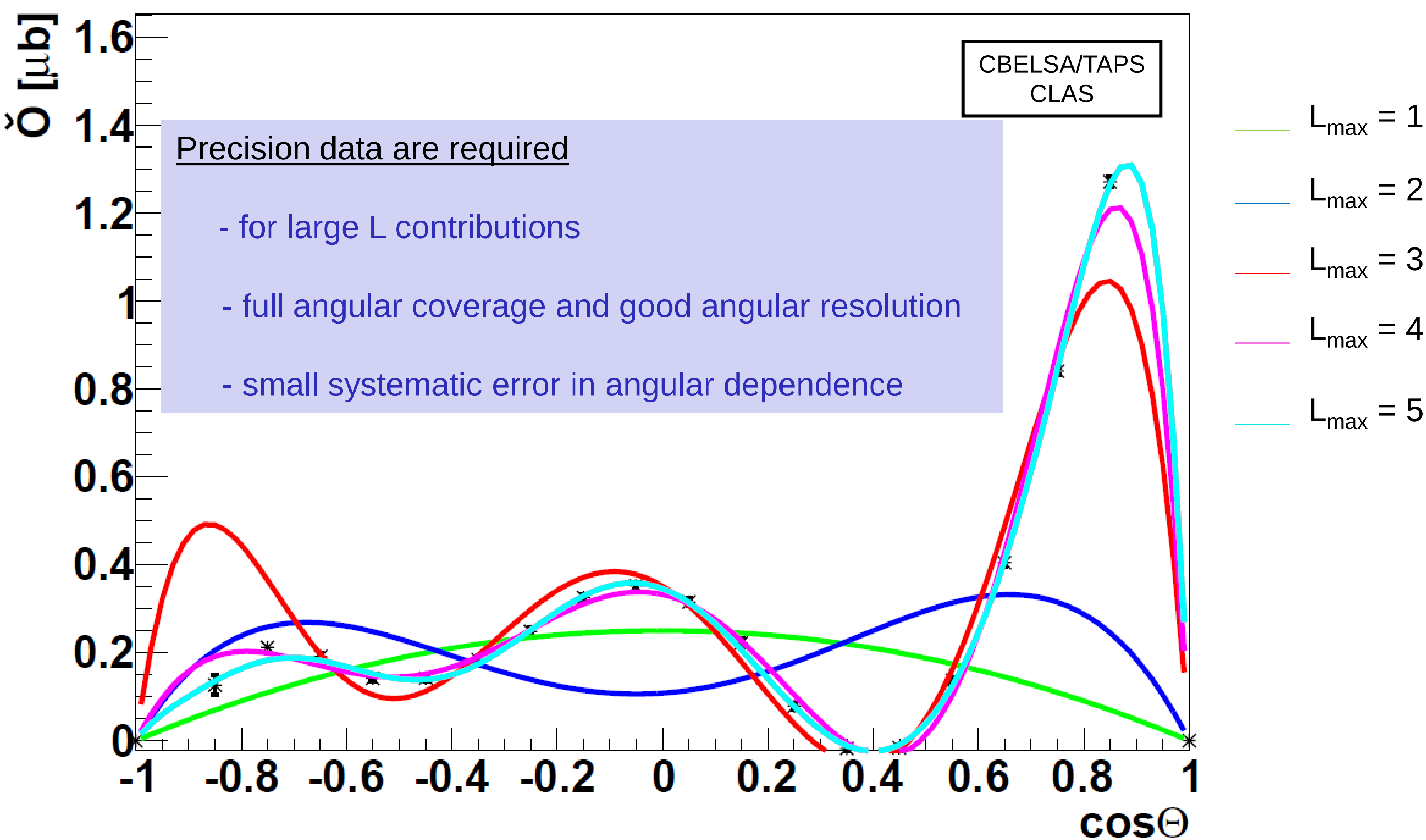
High precision data for Σ from
CBELSA/TAPS
CLAS



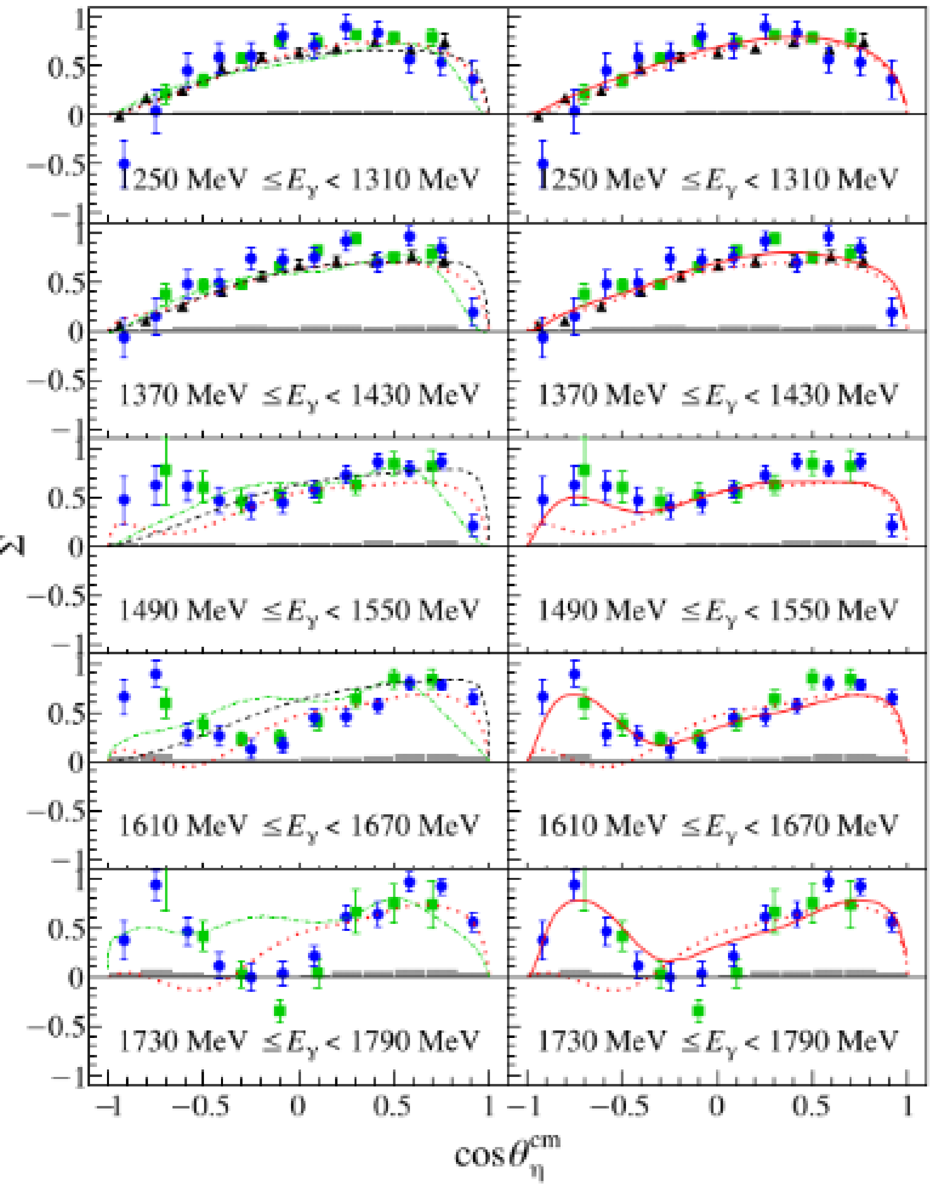


L_{max} Interpretation of Σ- Asymmetry in $p\pi^0$

W=2075 MeV



L_{max} Interpretation of Σ- Asymmetry in pη

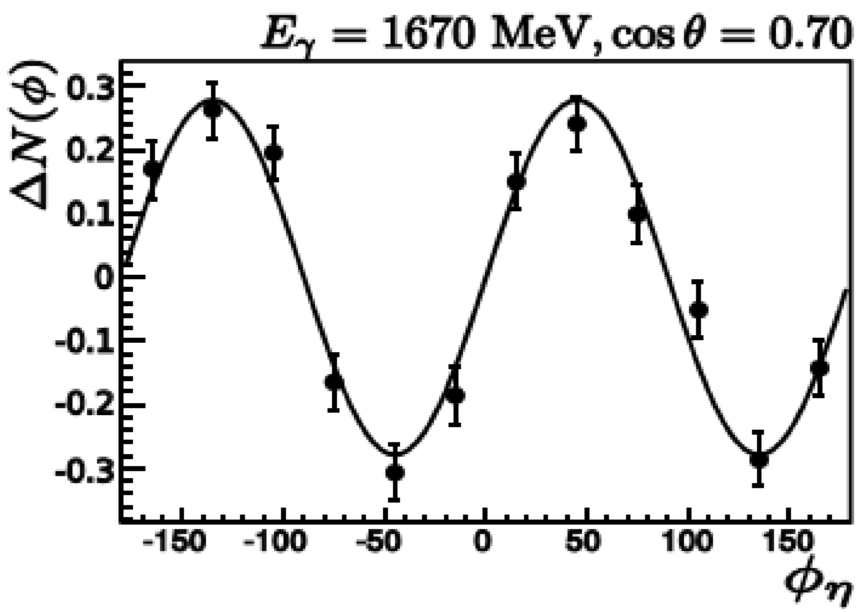


[F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)]

- 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)

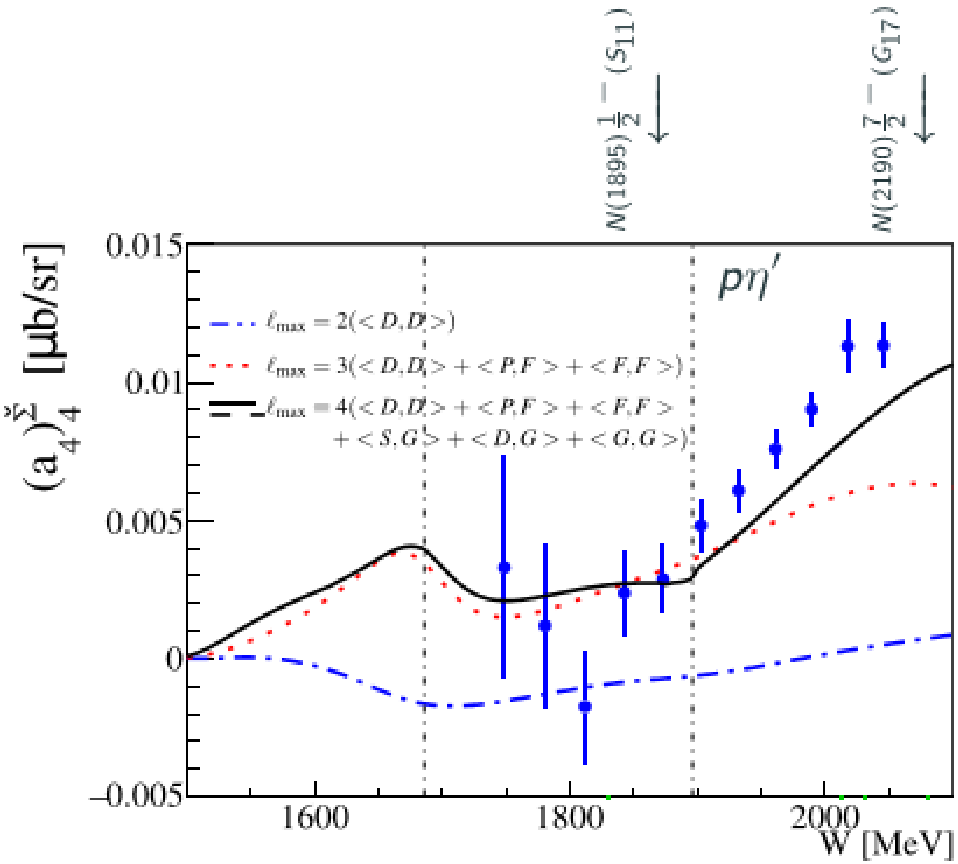
BnGa-2014-02 JüBo-2015-FitB ηMAID
BnGa-2019

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



L_{max} Interpretation of Σ- Asymmetry in pη

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



Compare extracted fit coefficient to BnGa-2019 solution

$$(a_5)_4^{\check{\Sigma}} = \langle D, D\rangle$$
$$+\langle P, F\rangle + \langle F, F\rangle$$
$$+\langle \boldsymbol{S}, \boldsymbol{G}\rangle + \langle D, G\rangle + \langle G, G\rangle$$

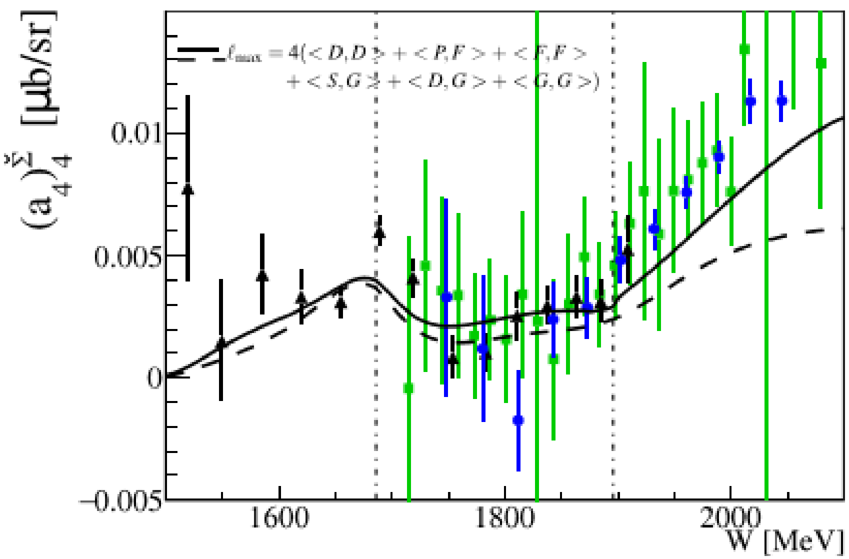
F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

$p\eta'$ 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 in pη

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



▲ 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

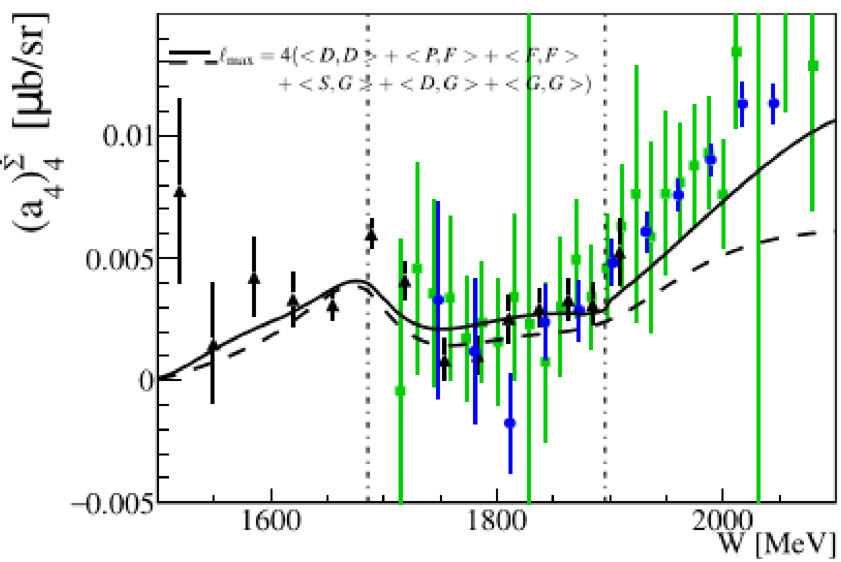
F. Afzal et al., Phys. Rev. Lett. 125, 152002 (2020)

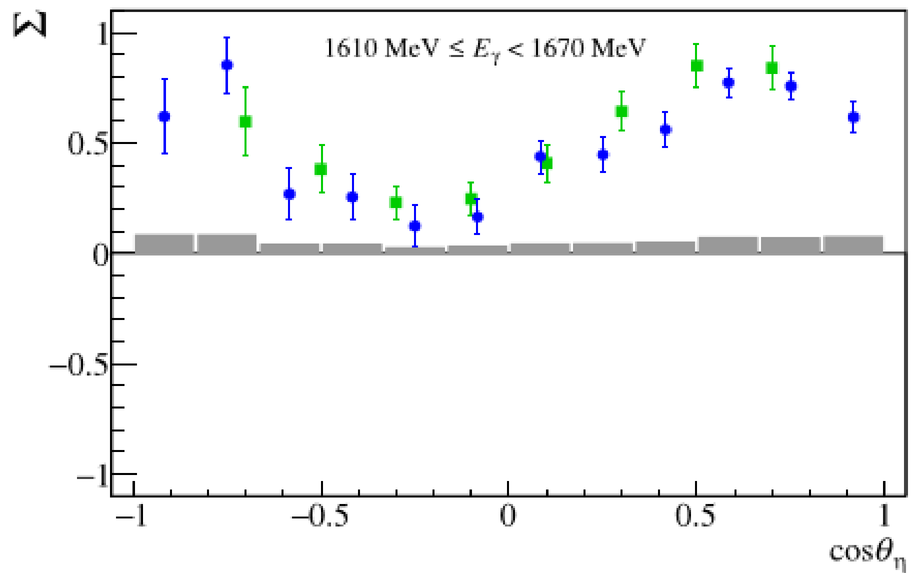
Full angular coverage is very important for $< S, G >$ interference

L_{max} Interpretation of Σ- Asymmetry in pη

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

GRAAL
CLAS
CBELSA/TAPS

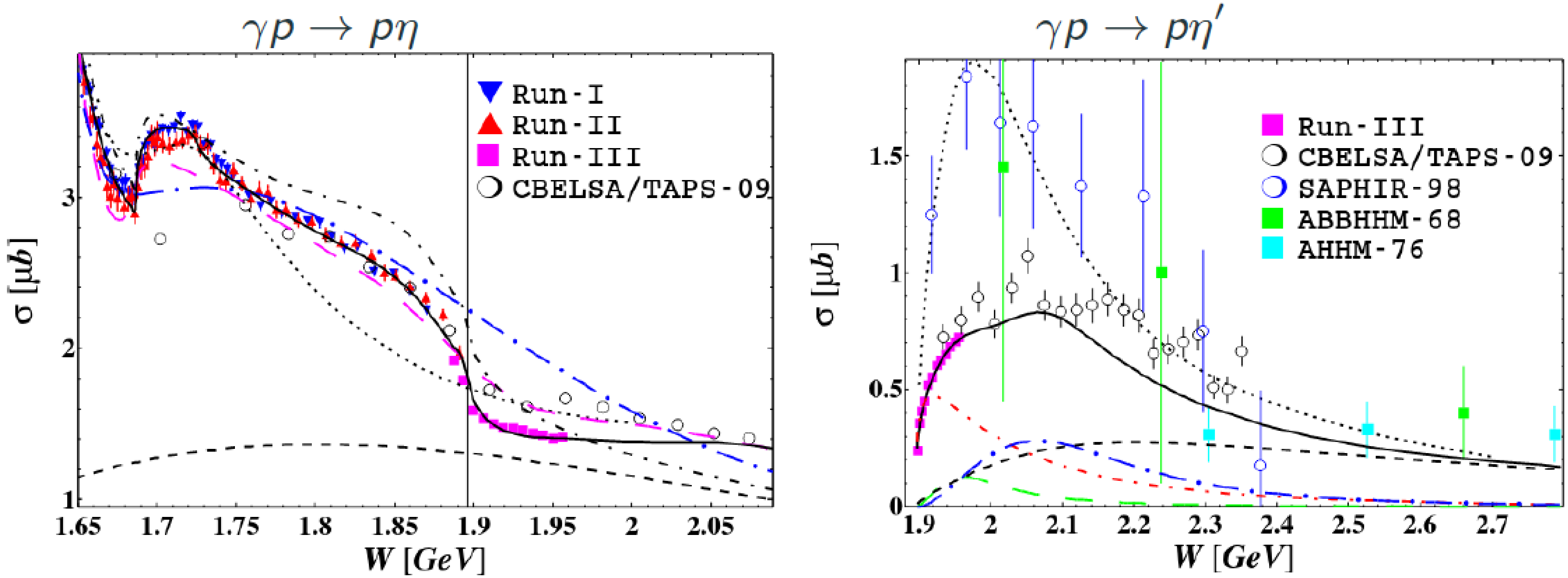




Full angular coverage is very important for $< S, G >$ interference

Third s-wave resonance N(1895)½

Precise MAMI data for pη and pη'



V.L. Kashevarov et al., Phys. Rev. Lett. 118, 21 (2017), p. 212001

- key role for description: 3 $S-$wave resonances: $N(1535)\frac{1}{2}^-$, $N(1650)\frac{1}{2}^-$ and $N(1895)\frac{1}{2}^-$
- strong $p\eta'$ cusp observed in $p\eta$ cross section
- $N(1895)\frac{1}{2}^-$ needed for description of $p\eta'$ cusp and fast rise of $p\eta'$ cross section

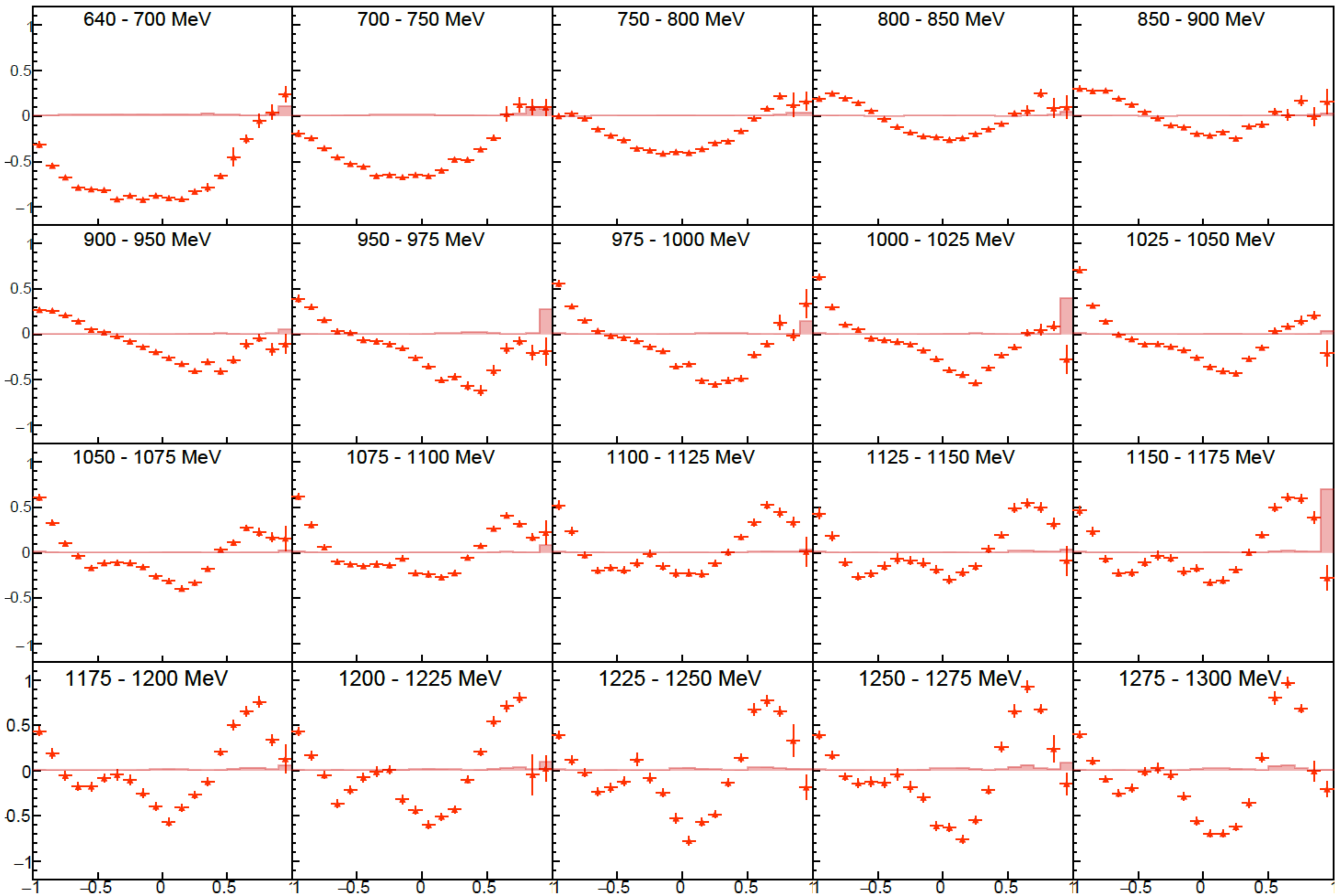
Impact of the polarization data

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

- Precise photoproduction data has entered PDG:
  $\rightarrow$ Evidence for new baryons and decay modes, e.g. MAMI and CBELSA/TAPS data confirm $N(1895)\frac{1}{2}^-$
  MAMI: V.L. Kashevarov et al., PRL 118, 21, 212001 (2017)
  CBELSA/TAPS: F. Afzal et al., PRL 125, 152002 (2020)
  $\rightarrow$ Rules out a naive quark-diquark model
- Multi-meson final states, neutron data may be key to finding new states

New precise target asymmetry data in $p\pi^0$

CBELSA/TAPS: S. Ciupka, PhD Thesis (2026), final data, to be published



New precise target asymmetry data in $p\pi^0$

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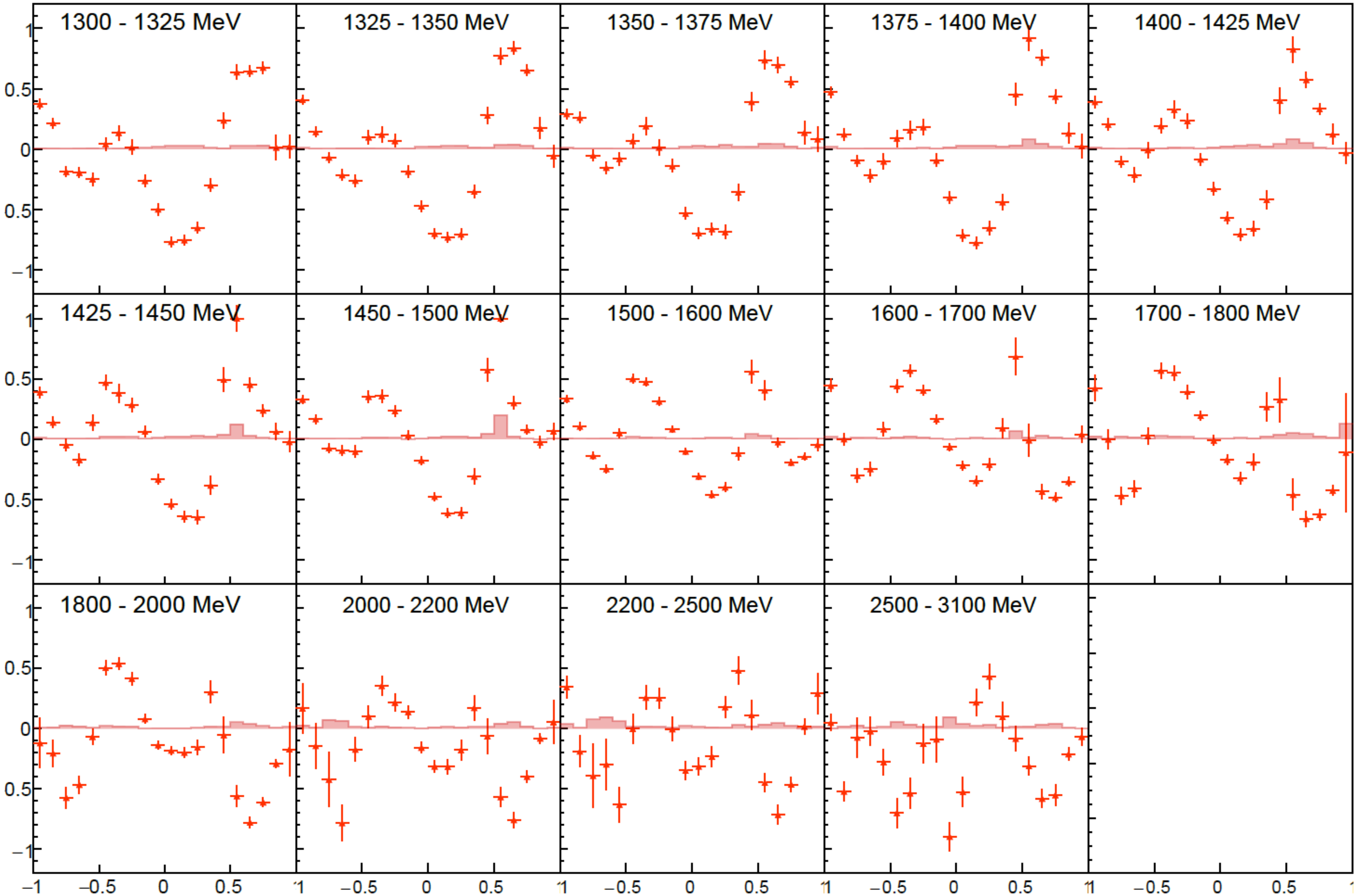

New precise target asymmetry data in $p\pi^0$

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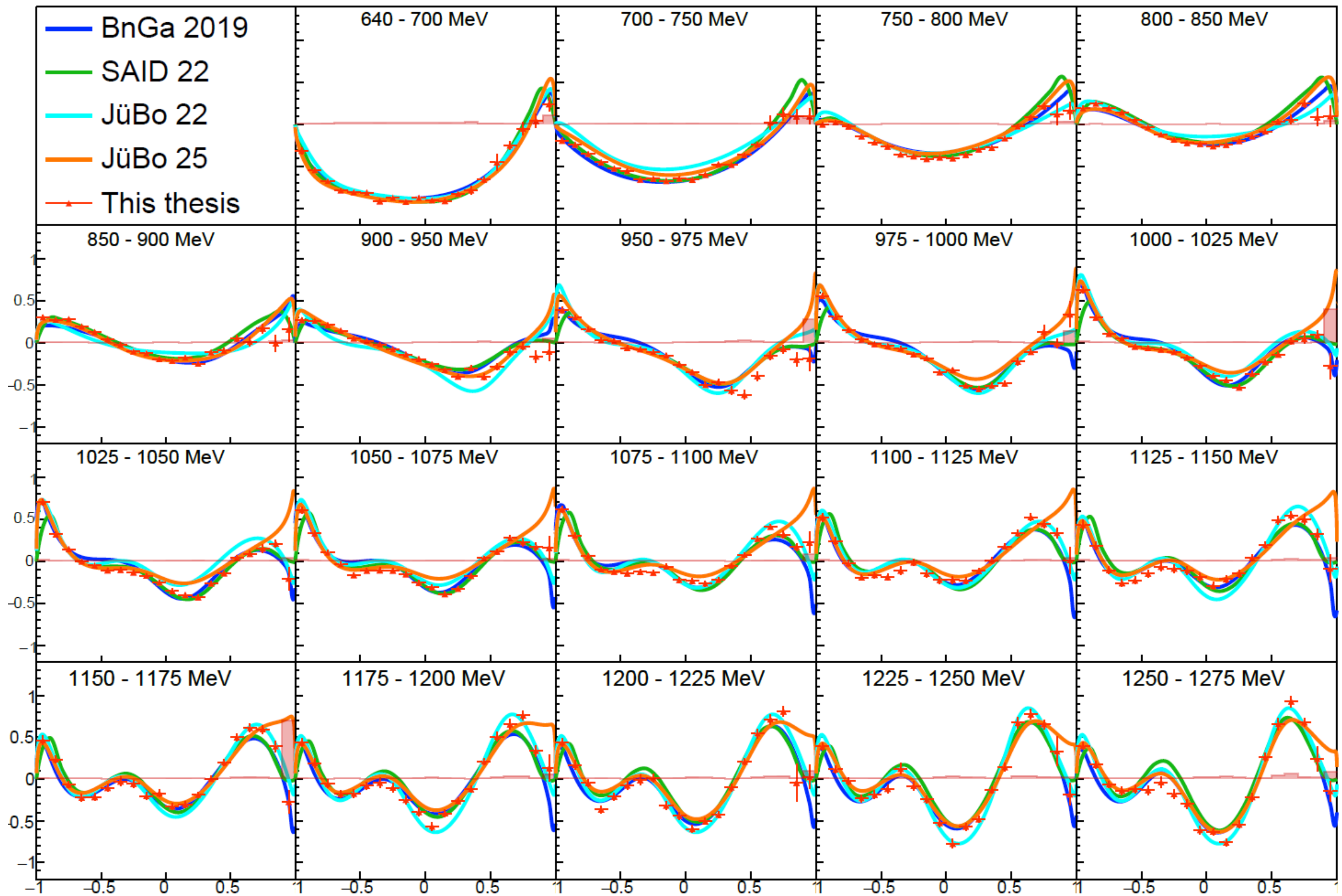
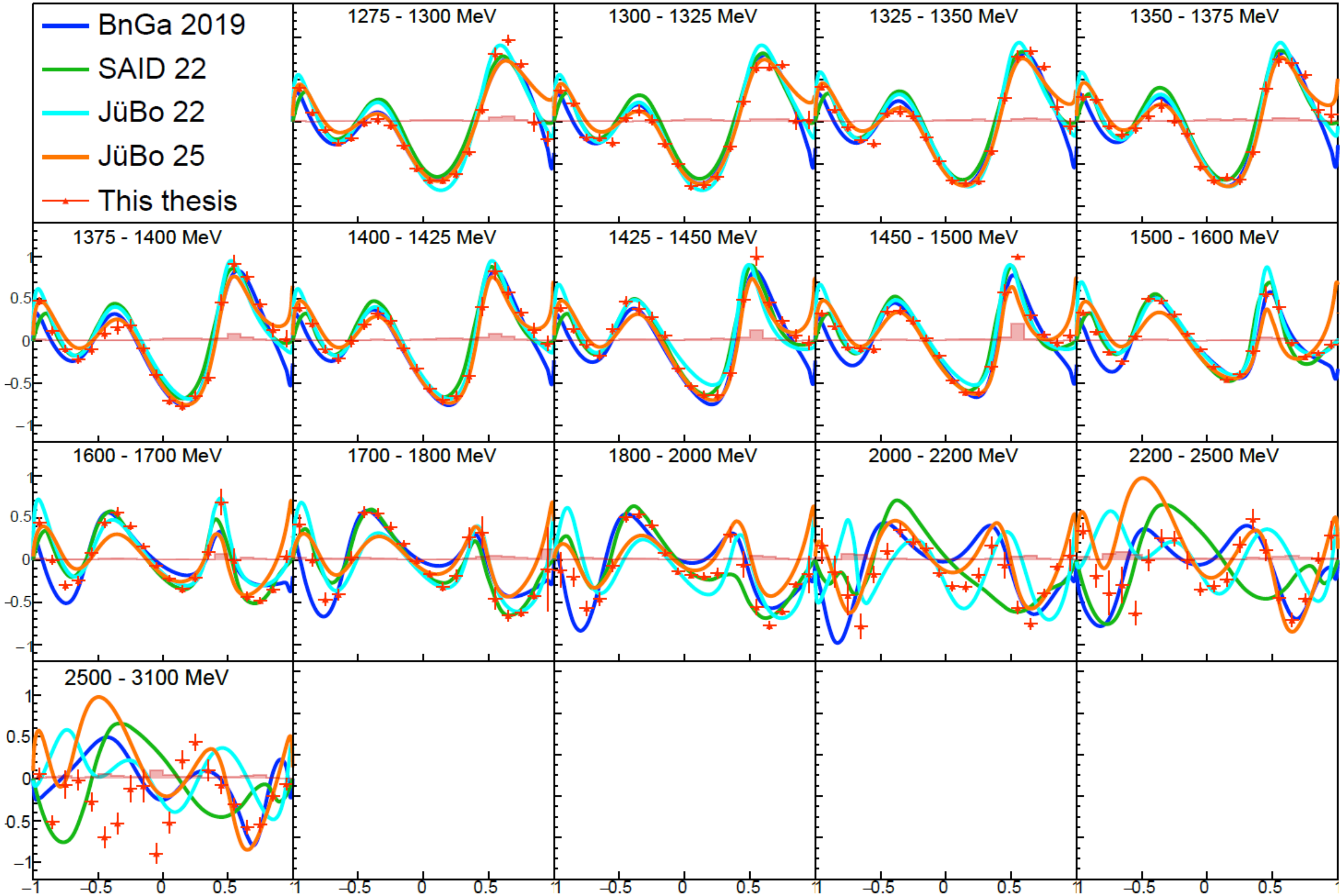


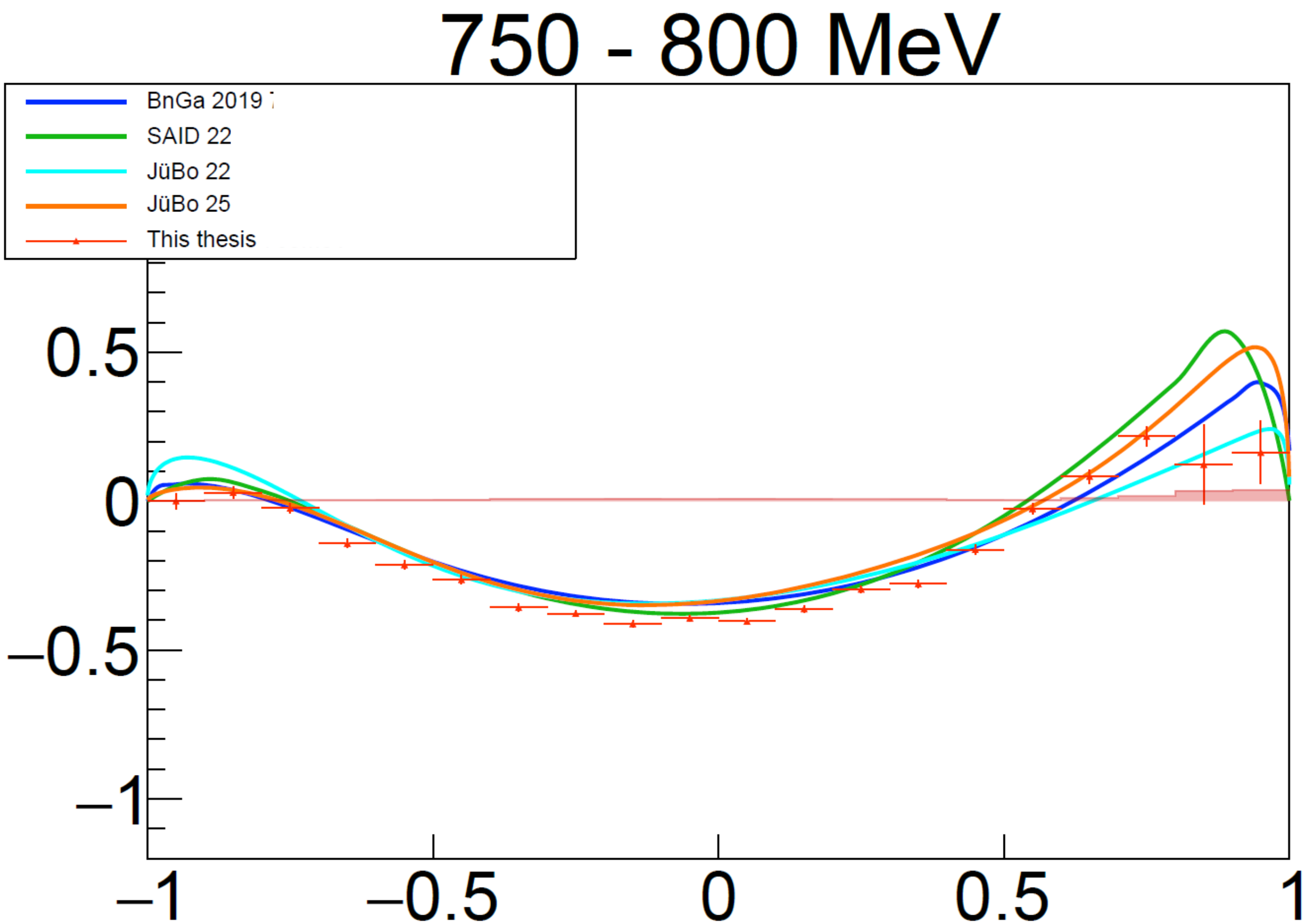
New precise target asymmetry data in $p\pi^0$

S. Ciupka, PhD Thesis (2026), final data, to be published



New precise target asymmetry data in $p\pi^0$

CBELSA/TAPS: S. Ciupka, PhD Thesis (2026), final data, to be published



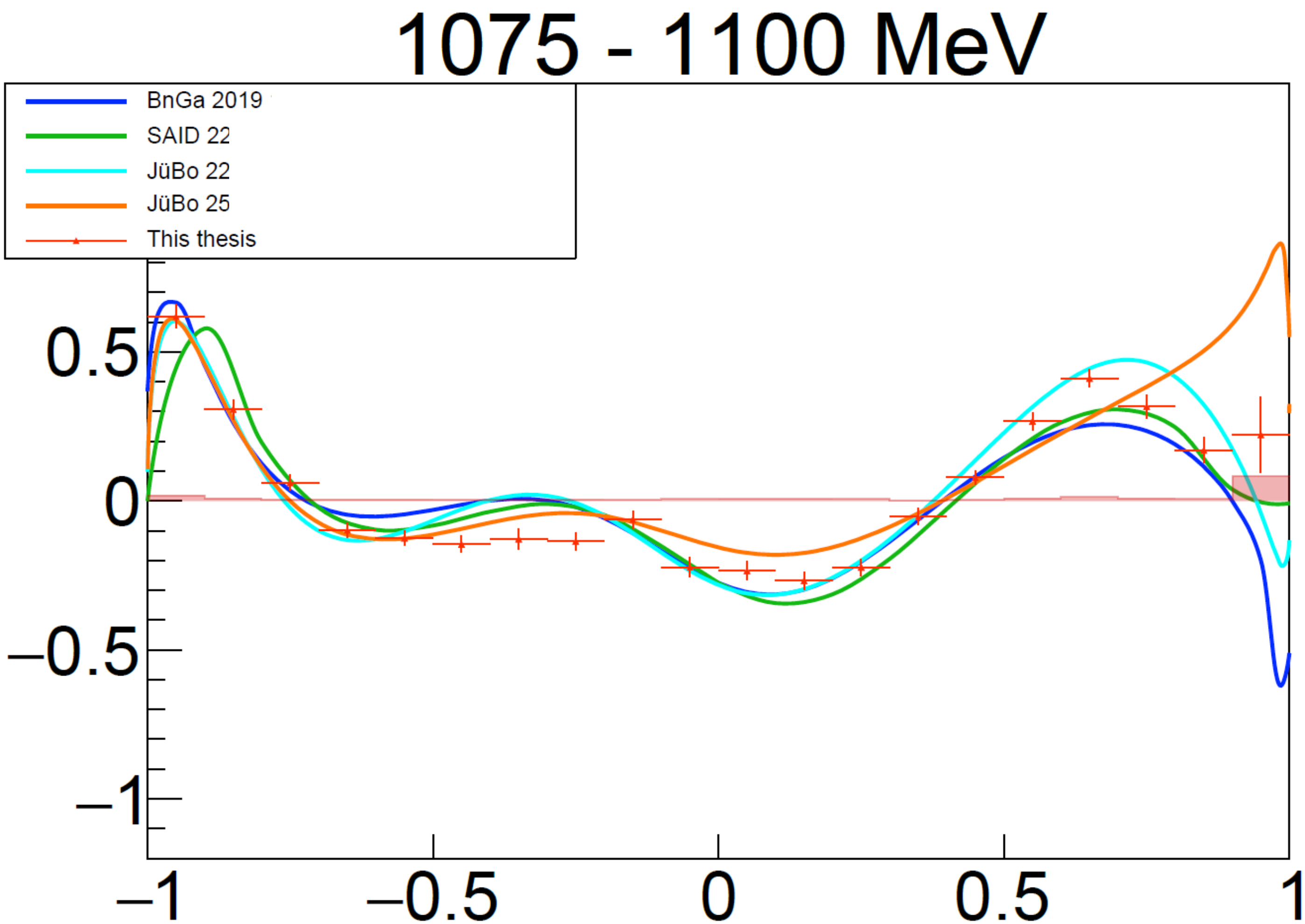
Existing data on T constrain the PWA solutions

CBELSA/TAPS
J. Hartmann et al., 2017

CLAS
H. Jiang et al., 2025

New precise target asymmetry data in $p\pi^0$

CBELSA/TAPS: S. Ciupka, PhD Thesis (2026), final data, to be published

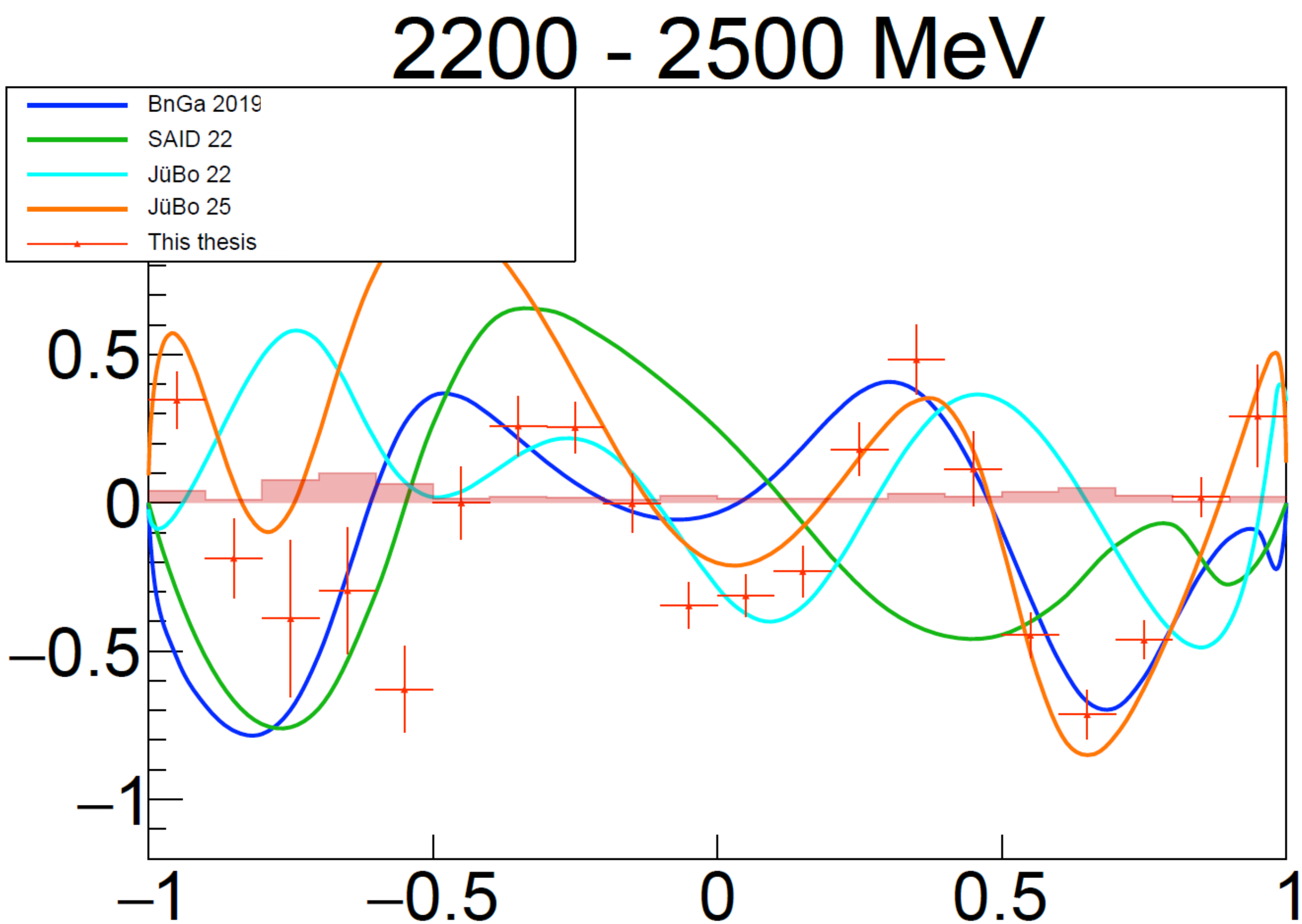


Medium energy range

Extreme forward and
Backward angle ?

New precise target asymmetry data in $p\pi^0$

CBELSA/TAPS: S. Ciupka, PhD Thesis (2026), final data, to be published

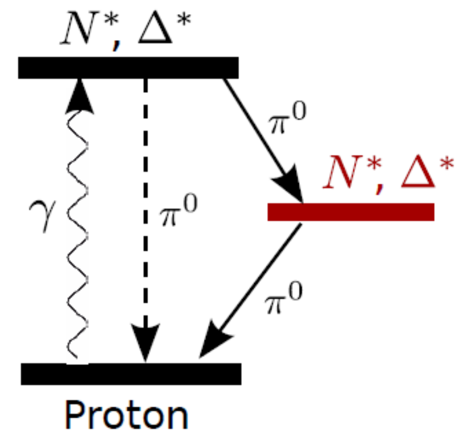


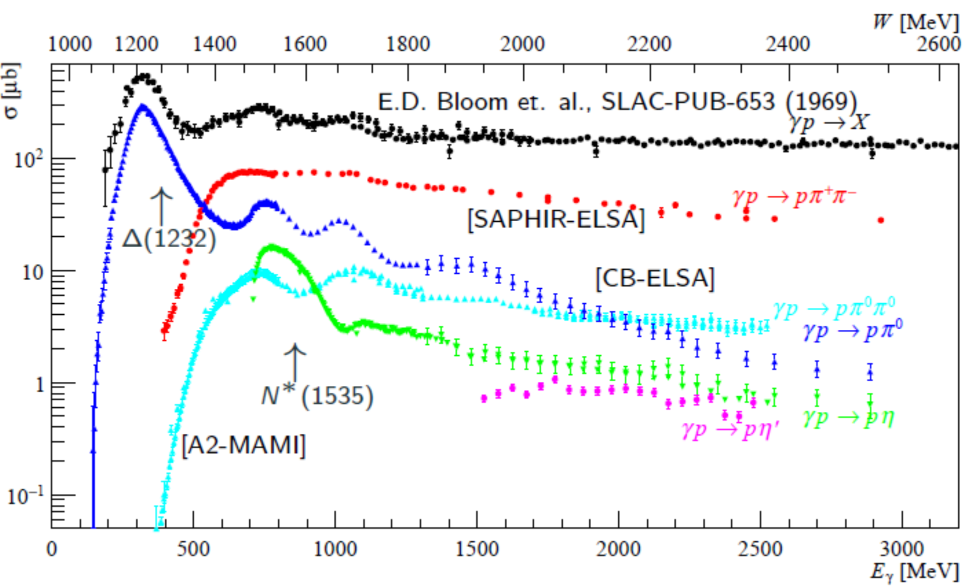
High energy region

Prediction of PWAs in discrepancy with new data

Importance of cascade decays in N $\pi\pi$

- Multi-meson final states like $p\pi^0\pi^0$ are preferred at higher energies
- Less background amplitudes than $p\pi^+\pi^-$ but cannot discriminate between N^*/Δ^*
- Access to sequential decays

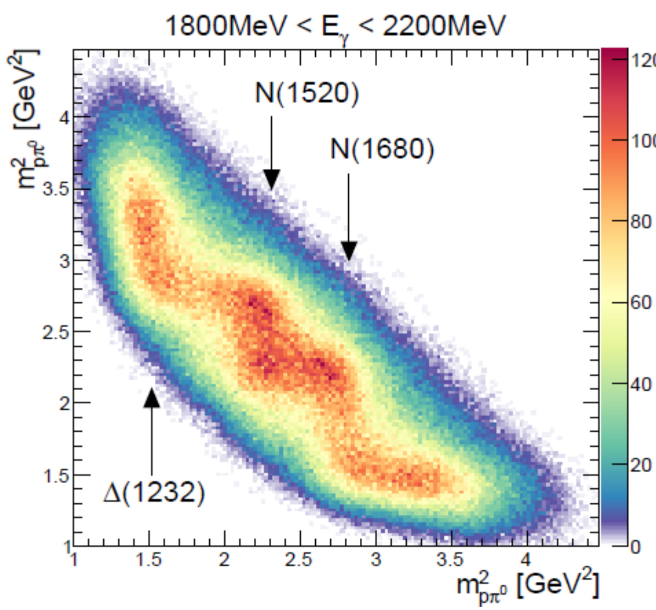




Neutron data in $\pi^0\pi^0$ and $\pi^0\eta$

N. Reinertz, PhD Thesis, will finish in 2027

Talk: L. Reschke



Proton data in $\pi^0\pi^0$ and $\pi^0\eta$

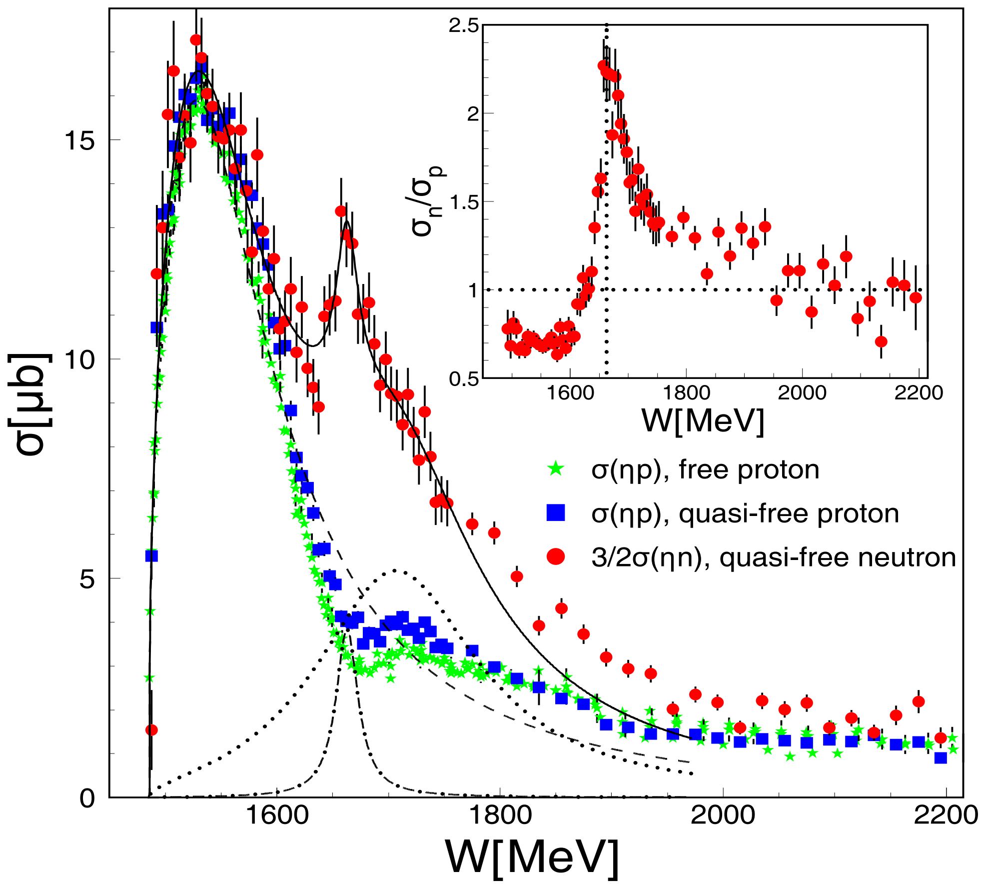
T. Seifen, et al., Eur. Phys. J. A.61 (2025) 7, 173

N. Stausberg, PhD Thesis (2025), final data, to be published

Spectroscopy off the Neutron

- Nucleon resonances (Isospin I =1/2) couple differently to Neutron and Proton

$$\gamma + n \rightarrow n + \eta$$

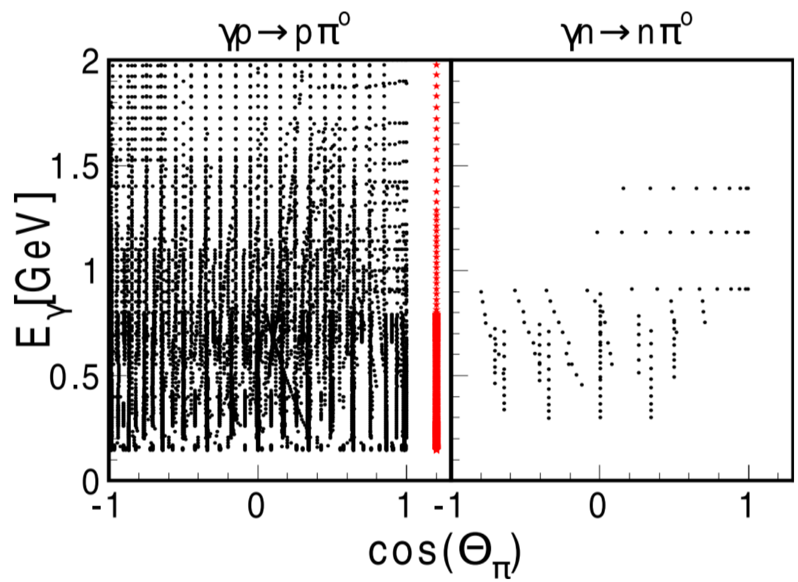


CBELSA/TAPS, *I. Jaegle, PRL 100 (2008), 252002*

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

$$\mathcal{M}_{l\pm}^{(\gamma p \to p\pi^0)} = \mathcal{M}_{p,l}^{1/2} + \frac{2}{3}\mathcal{M}_l^{3/2}$$

$$\mathcal{M}_{l\pm}^{(\gamma n \to n\pi^0)} = -\mathcal{M}_{n,l}^{1/2} + \frac{2}{3}\mathcal{M}_l^{3/2}$$

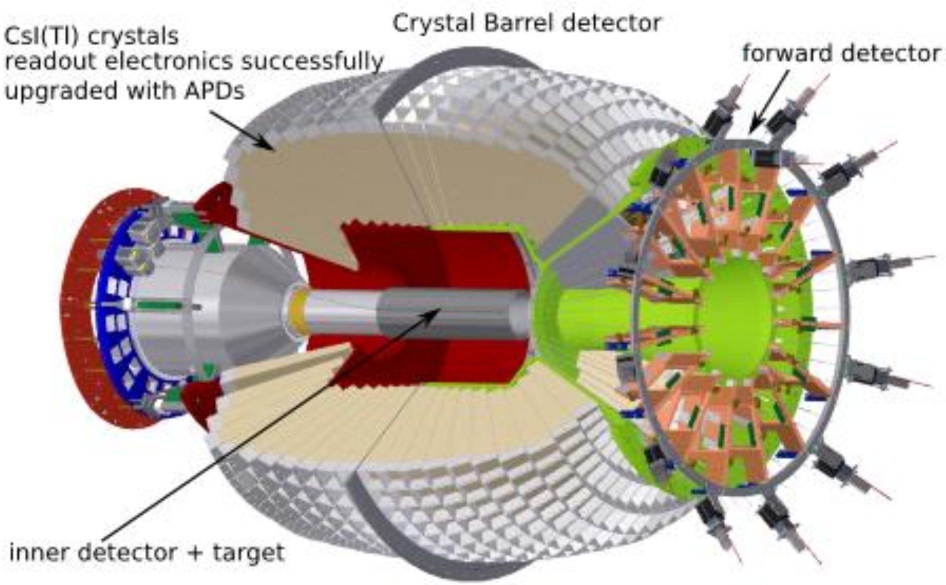


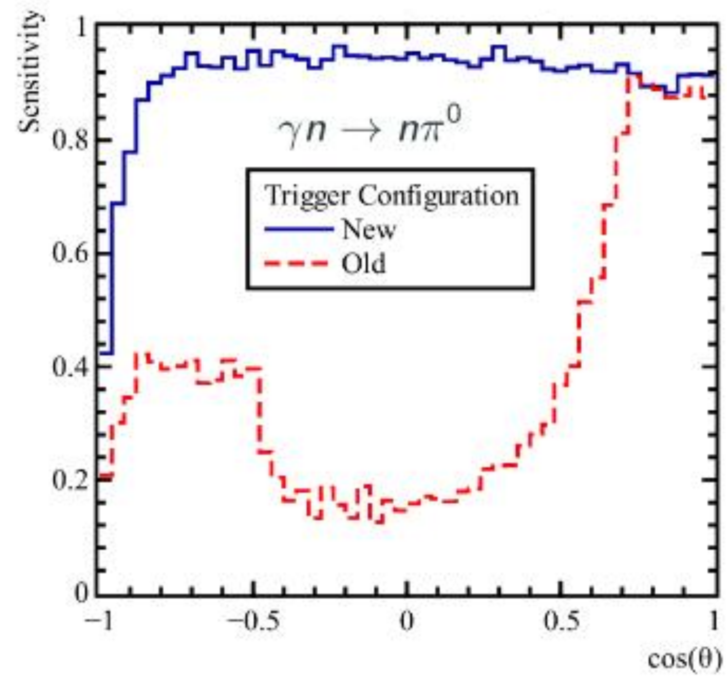
- CBELSA/TAPS experiment has been upgraded for measurements on the neutron

Upgrade of the CBELSA/TAPS-Experiment

- Each CsI(Tl) crystal readout with 2 APDs instead of PIN photodiodes
- Crystal Barrel $\theta > 12^{\circ}$ included in first level trigger
- high trigger acceptance for complete neutral final states

C. Honisch et al., arXiv:2212.12364





Since NSTAR 2022 :

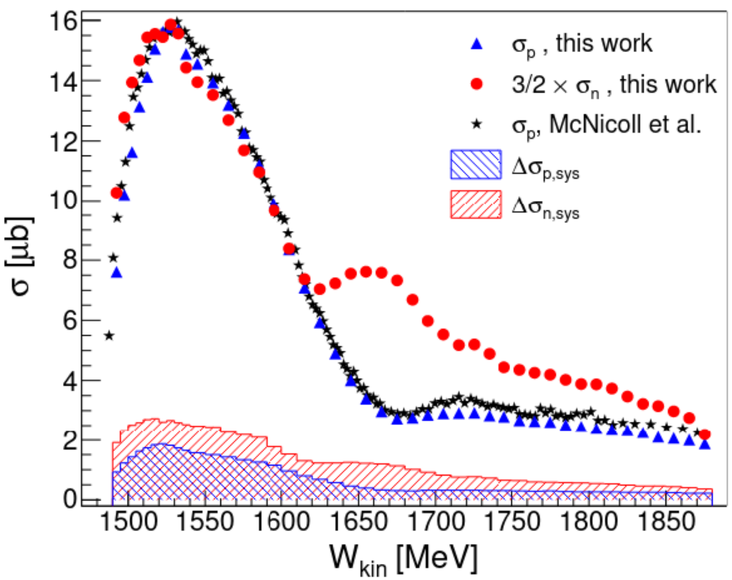
New data on T, P, H off the proton for different final states

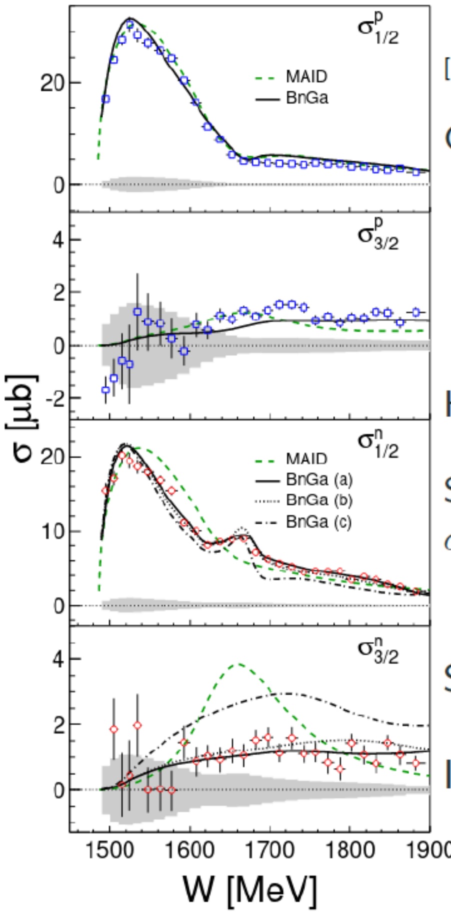
New data on T, P, H off the neutron for different final states

Measurements off Neutron: narrow peak in nη

narrow peak observed in $\gamma n \to n\eta$
at $W = (1670 \pm 5)$ MeV with $\Gamma = 30$ MeV

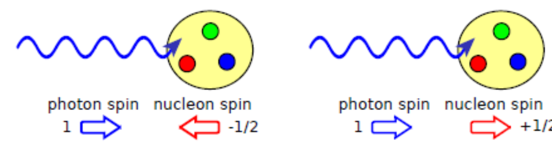
[D. Werthmüller et al., Phys.Rev. C90 (2014) no.1, 015205]





[L. Witthauer et al., Phys. Rev. Lett. 117, no. 13, 132502 (2016)]

Circularly pol. photons & long. pol. target



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

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

Spin dependent cross sections
$\sigma_{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$

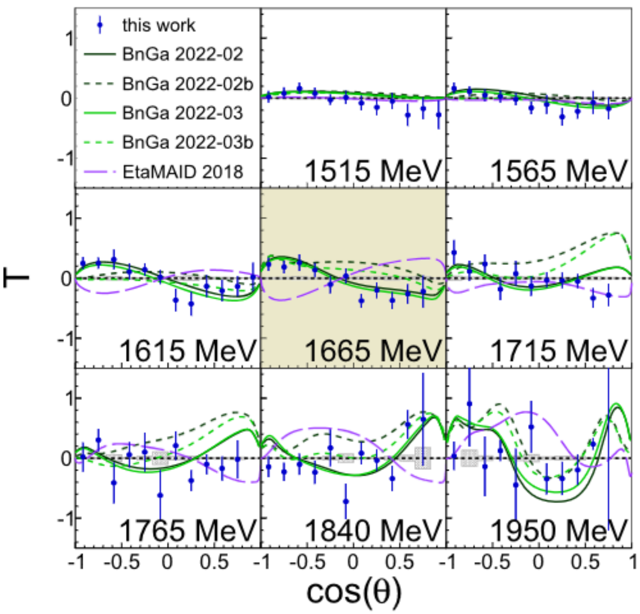
Structure only present in $\sigma^n_{1/2}$!

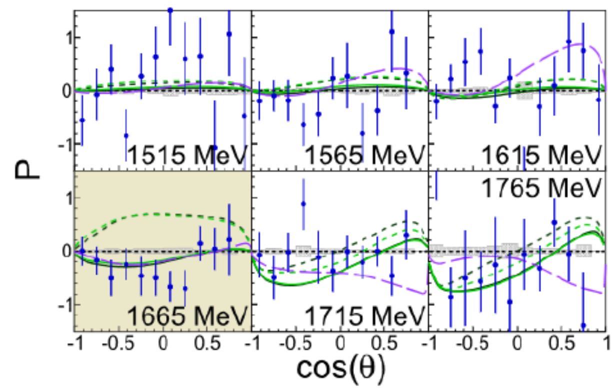
Intrinsic resonance/ interference effects?

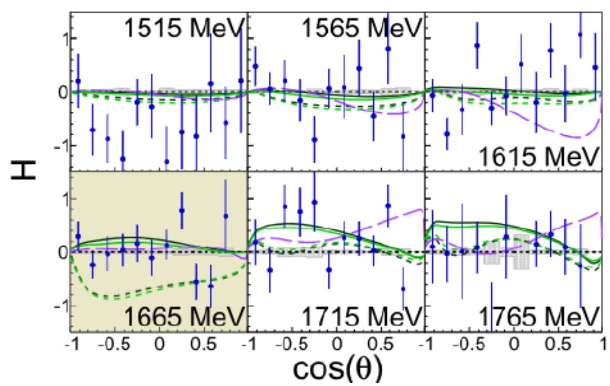
Measurements off Neutron: narrow peak in nη

- More data taken for T, P, H with coherent edges at 1300 MeV, 1600 MeV
- Ongoing analyses of different final states ($N\pi^0$, $N\eta$, $N\eta'$, $N\omega$, $N\pi^0\pi^0$, $N\pi^0\eta$...) and PWA of the data

$\gamma d \to \eta n(p)$







— BnGa 2022-02, — BnGa 2022-03:
interference effect:
$S_{11}(1535)\frac{1}{2}^-$ and $S_{11}(1650)\frac{1}{2}^-$

- - - BnGa 2022-02 b, - - - BnGa 2022-03 b:
new narrow resonance
in P_{11}-wave: $P_{11}(1680)\frac{1}{2}^+$

- - - EtaMAID 2018: interference effect:
$S_{11}(1535)\frac{1}{2}^-$ and $P_{11}(1710)\frac{1}{2}^+$

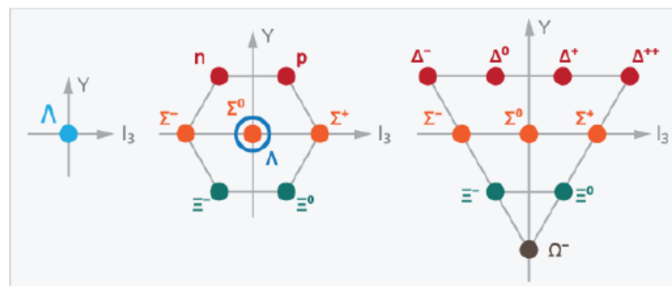
$\rightarrow$ data favors $S - S$ wave interference

N. Jerman et al. Eur. Phys. J. A 59 (2023) 10, 232

Baryon Spectroscopy Future at ELSA

- **"...the field is starved for data" (PDG'2024)** Established resonances remain the same for 40 years!
- Not even all states of the first excitation band known!
- What is the nature of the states? Multi-quark states? Molecules? 2-pole structures (e.g. $\Lambda(1405)$)?

$\frac{1}{2}^+$	$\frac{1}{2}^-$	$\frac{3}{2}^+$	$\frac{3}{2}^-$	$\frac{5}{2}^+$	$\frac{5}{2}^-$	$\frac{7}{2}^+$	$\frac{7}{2}^-$	$\frac{9}{2}^+$	$\frac{9}{2}^-$	$\frac{11}{2}^+$	$\frac{11}{2}^-$	$\frac{13}{2}^+$	$\frac{13}{2}^-$	$\frac{15}{2}^+$
N	N(1535)	N(1720)	N(1520)	N(1680)	N(1675)	N(1990)	N(2190)	N(2220)	N(2250)		N(2600)	N(2700)		
N(1440)	N(1650)	N'(1720)	N(1700)	N(1860)	N(2060)									
N(1710)	N(1895)	N(1900)	N(1875)	N(2000)	N(2570)									
N(1880)		N(2040)	N(2120)											
N(2100)														
N(2300)														
Δ(1750)	Δ(1620)	Δ(1232)	Δ(1700)	Δ(1905)	Δ(1930)	Δ(1950)	Δ(2200)	Δ(2300)	Δ(2400)	Δ(2420)			Δ(2750)	Δ(2950)
Δ(1910)	Δ(1900)	Δ(1600)	Δ(1940)	Δ(2000)	Δ(2350)	Δ(2390)								
	Δ(2150)	Δ(1920)												
Λ(1116)	Λ(1380)	Λ(1890)	Λ(1520)	Λ(1820)	Λ(1830)	Λ(2085)	Λ(2100)	Λ(2350)						
Λ(1600)	Λ(1405)	Λ(2070)	Λ(1690)	Λ(2110)	Λ(2080)									
Λ(1710)	Λ(1670)		Λ(2050)											
Λ(1810)	Λ(1800)		Λ(2325)											
	Λ(2000)													
Σ(1189)	Σ(1620)	Σ(1385)	Σ(1580)	Σ(1915)	Σ(1775)	Σ(2030)	Σ(2100)							
Σ(1660)	Σ(1750)	Σ(1780)	Σ(1670)	Σ(2070)										
Σ(1880)	Σ(1900)	Σ(1940)	Σ(1910)											
	Σ(2110)	Σ(2080)	Σ(2010)											
		Σ(2230)												
Ξ(1315)		Ξ(1530)	Ξ(1820)											
		Ω(1672)												



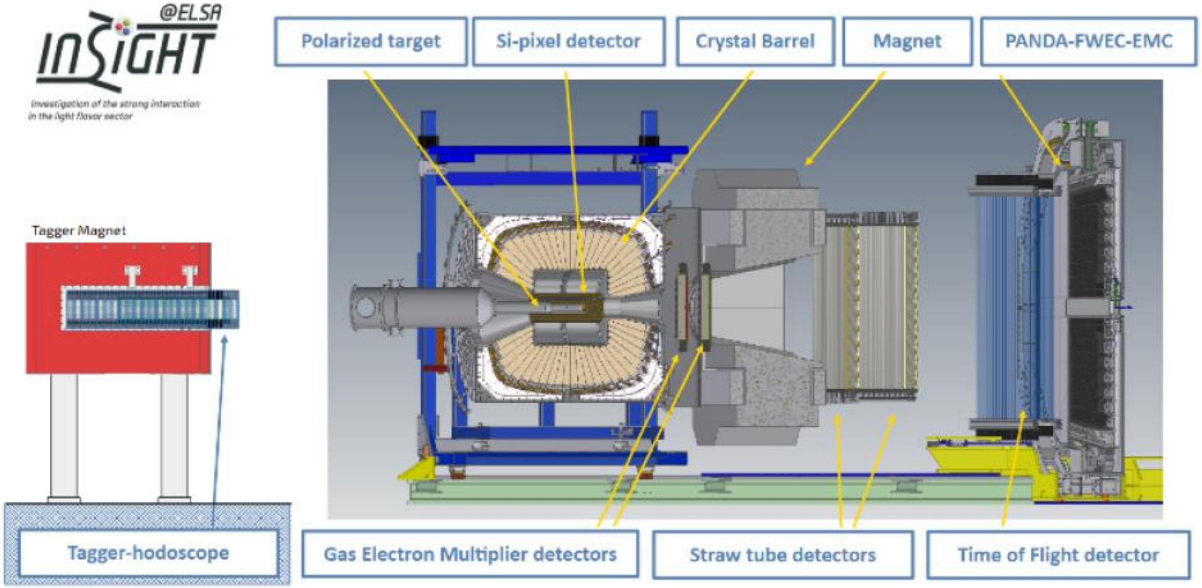
V. Burkert, G. Eichmann, E. Klempt, arXiv:2506.16482 [hep-ph]

$\rightarrow$Important to study spectrum and properties of Λ^*, Σ^* e.g.: $\gamma p \rightarrow K^+\Lambda^* \rightarrow K^+\Sigma^0\pi^0, \Sigma^0 \rightarrow \Lambda\gamma, \Lambda \rightarrow p\pi^-$

Major Upgrade of CBELSA/TAPS-Experiment

- A new experiment as integral part of the new Cluster of Excellence "**Color meets Flavor**"
  → **IN**vestigation of the **S**trong **I**nteraction in the li**GHT** flavor sector (**INSIGHT**)

Talk on Thursday: U. Thoma



Over almost the entire **4π-solid angle**:

High resolution photon measurements
Precise charged particle detection

Arrival of the PANDA-FWEC in Bonn:

at the FTD

<u>Funding:</u>
- Major detector upgrade
- ELSA infrastructure
- a new Professor position in accelerator physics

Summary

- Precise polarization data from ELSA, JLab and MAMI
  - 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 PWA solutions
  - new states have been found, for example $N(1895)^{1/2^-}$

Baryon Spectroscopy Future at ELSA

- In the high W-mass region $p\,\eta$, $p\,\eta'$, $\mathbf{N}\,\pi\pi$ and $K^+\,\Lambda$, $K^+\,\Sigma^0$ will be important
  - the necessary precision in the data is still missing
- Major upgrade of CBELSA/TAPS experiment
  - new INSIGHT experiment

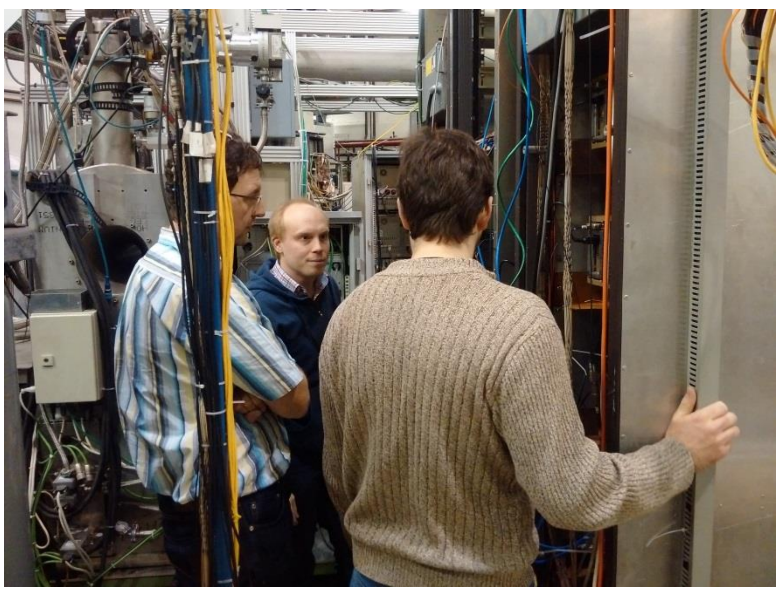
Talk: U. Thoma

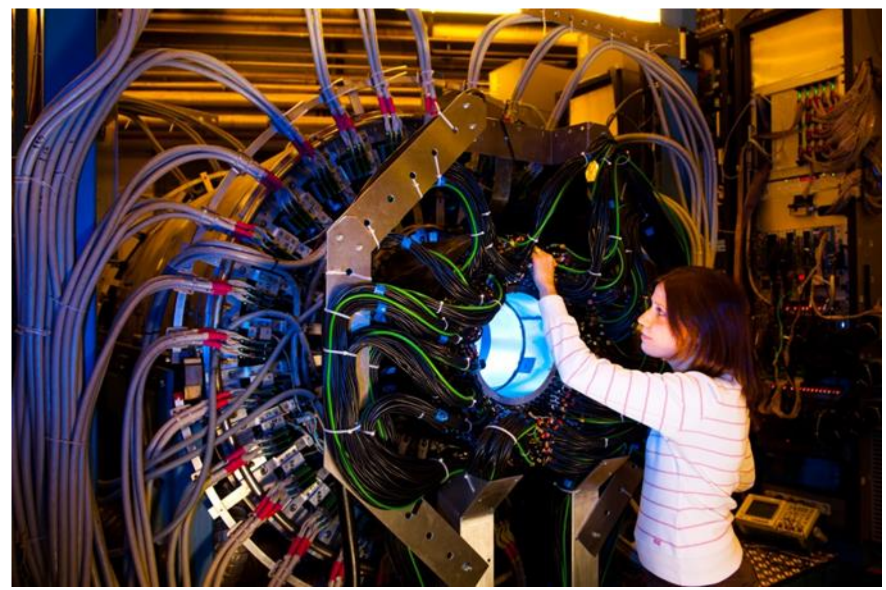
Talk:N. Kolanus

Talk:T. Jude

Talk: L. Reschke

Thank you for your attention





Mainz-Dubna Polarized Target at ELSA

- Mainz-Dubna polarized target :

- $^3He^4He$ Dilution refrigerator (Mainz, JINR Dubna) based on Bonn Frozen spin target design
- Frozen spin target (25 mK at 0.6 T)
- Transverse holding coil (saddle coil at 1.2 K)
- Since 2010 in operation with the Crystal Ball at MAMI, since 2017 in Bonn

Great Thanks to Mainz !

- Operated and maintained by Bonn, Bochum, Dubna and Mainz polarized target groups (H. Dutz, G. Reichertz, Y. Usov and A. Thomas)

- Common effort of the Bonn, Bochum, Dubna and Mainz polarized target groups

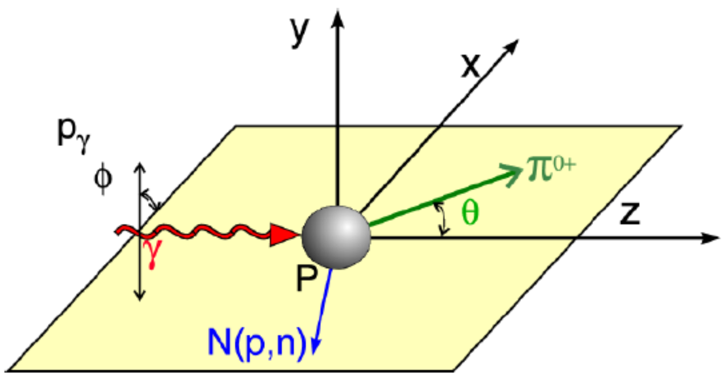
- New second $^3He^4He$ Dilution refrigerator at Bonn finished and under tests
- Corona and the Ukrainian war delayed the final tests

Beam-Target Polarization Observables

photoproduction of pseudoscalar mesons with polarized beam and target :

- all three single polarization observables Σ, P , T and cross section σ
- 4 double polarization observables G , E , F and H

can be measured



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

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \Big[1 - P_\gamma^{\text{lin}}\, \Sigma(\theta)\cos(2\phi)$$

$$\phi) + P_\gamma^{\text{circ}}\, F(\theta)\Big)$$

$$\phi) - T(\theta)\Big)$$

$$\phi) + P_\gamma^{\text{circ}}\, E(\theta)\Big)\Big]$$

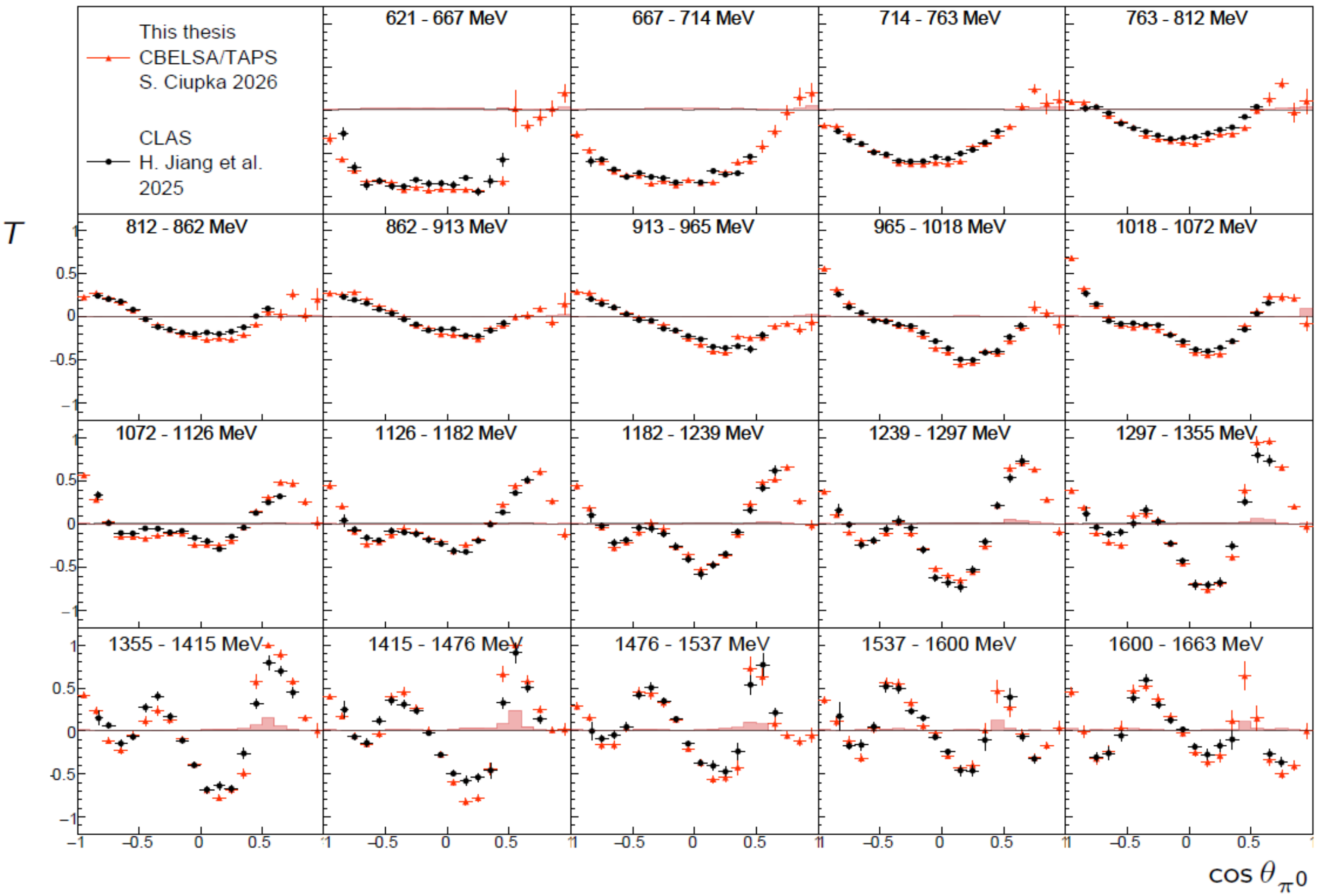
<u>ELSA- Experiments:</u>

Data on all three single pol. observables Σ, P , T and diff. cross section σ

and on four double polarization observables G , E and H and (F)

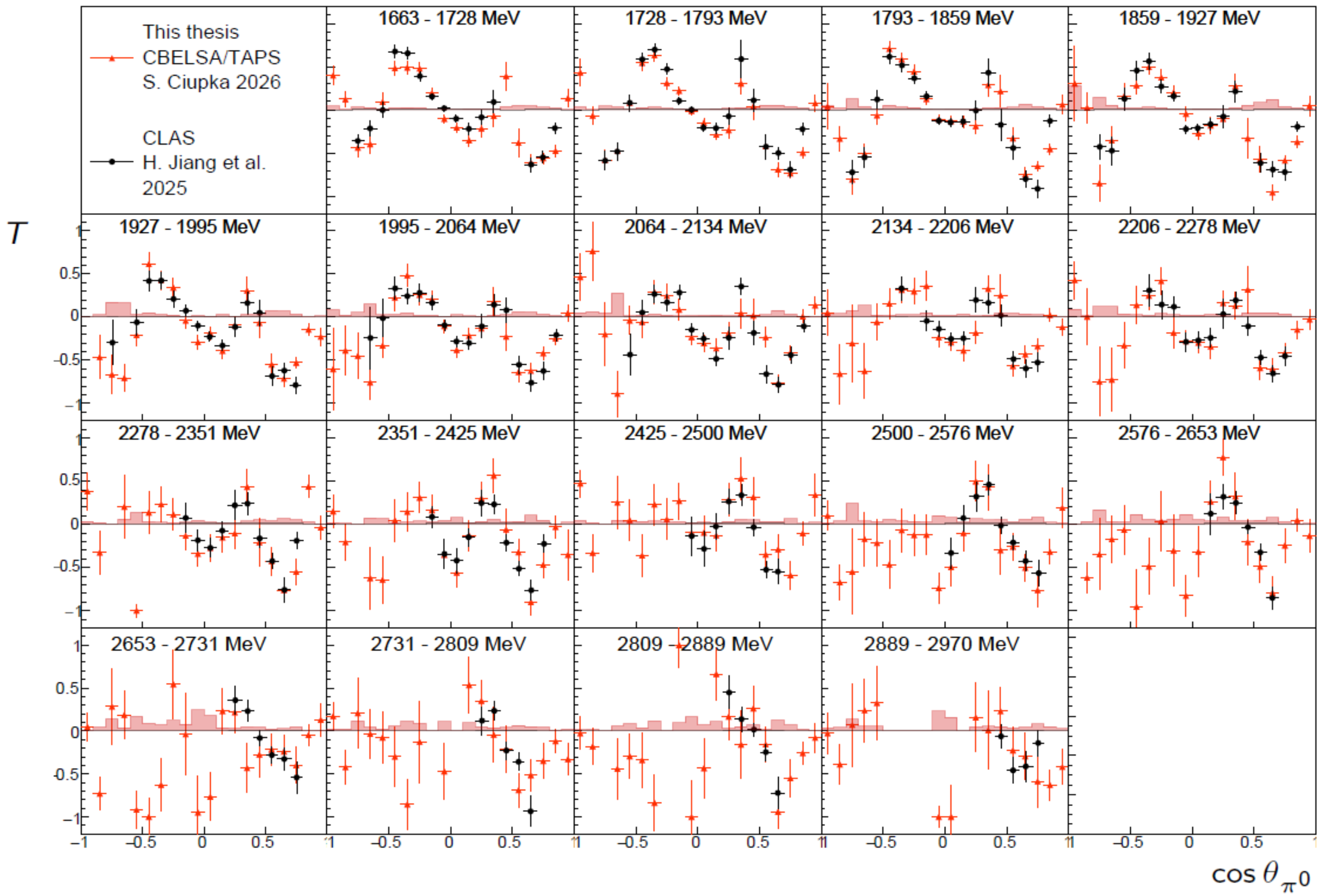
for $\vec{\gamma}\ \vec{p} \rightarrow p\,\pi^0$ and $p\,\eta$, $p\,\eta'$, $p\omega$, $p\pi^0\pi^0$, $p\pi^0\eta$, $K^0\Sigma^+$, ...

Comparison with CLAS - Low energies



	Photon polarization	Target polarization		
		X	Y	Z(beam)
unpolarized	σ	-	T	-
linear	-Σ	H	(-P)	-G
circular	-	F	-	-E

Comparison with CLAS - High energies



	Photon polarization	Target polarization X	Y	Z(beam)
unpolarized	σ	-	T	-
linear	-Σ	H	(-P)	-G
circular	-	F	-	-E