Recent results from the CBELSA/TAPS experiment at ELSA

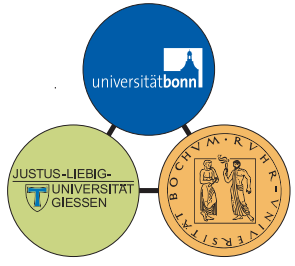
Annika Thiel

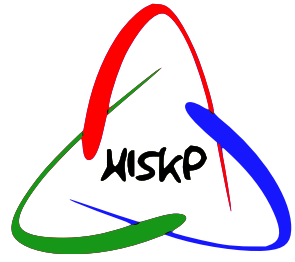
for the CBELSA/TAPS collaboration

HISKP, University of Bonn, Germany

10th International Workshop on the Physics of Excited Nucleons
NSTAR 2015

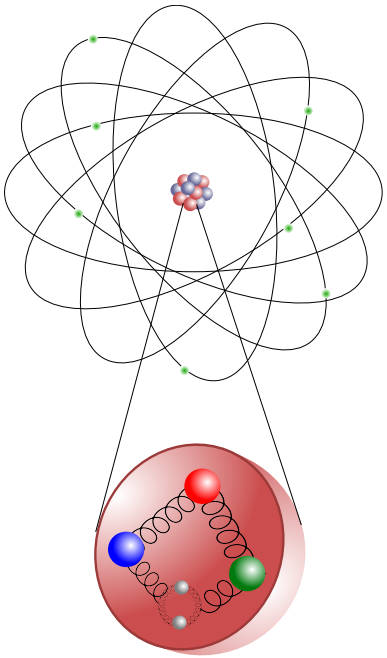
05/25/2015





Structure of Matter: Spectroscopy

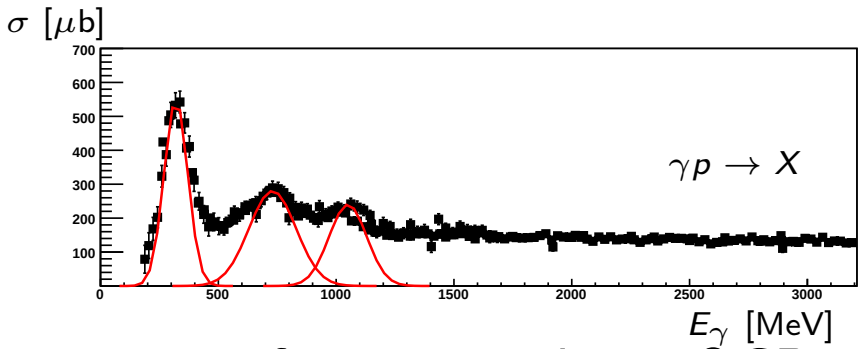
Spectroscopy of atoms



excitation spectrum

→ information about QED

Spectroscopy of hadrons



→ information about QCD

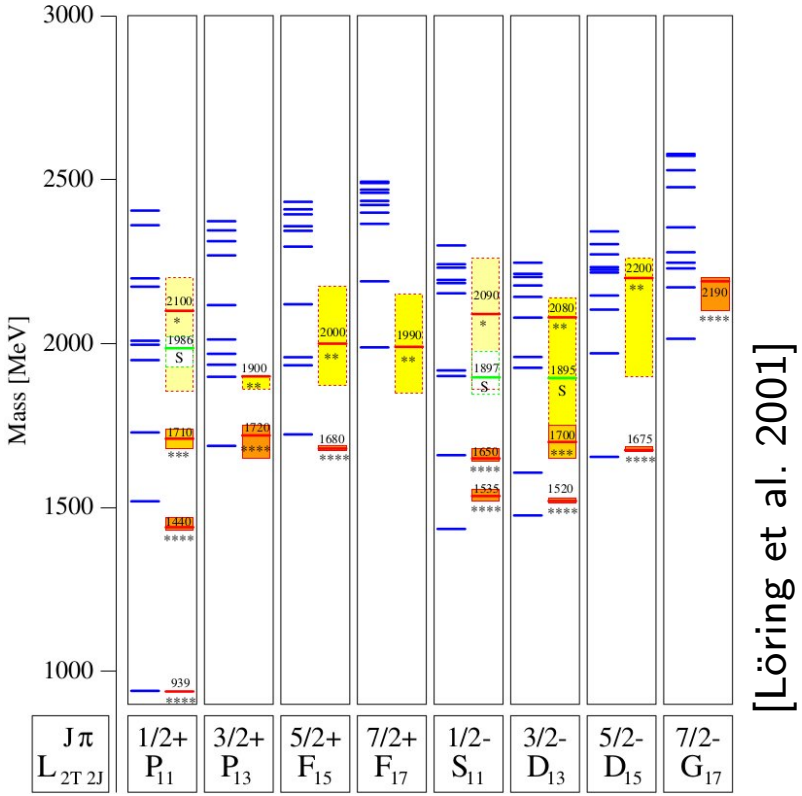
Spectroscopy of Hadrons

Excitation spectrum gives information about the dynamics inside the nucleon (quarks and gluons)

→ Baryon excitation spectrum needs to be understood

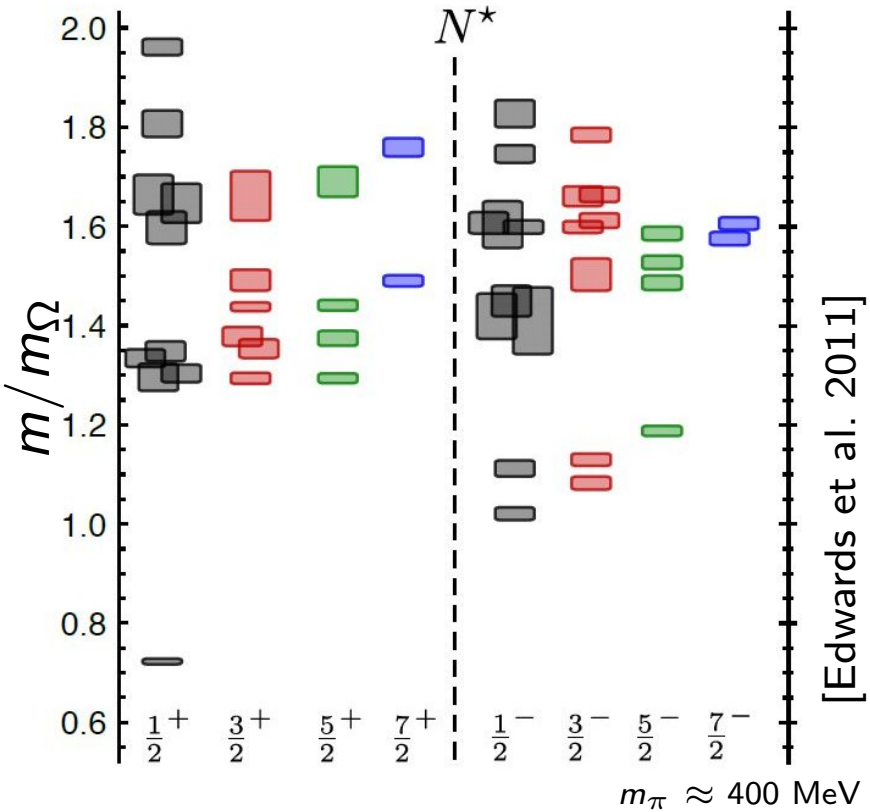
Theoretical Predictions

Quark models



[Löring et al. 2001]

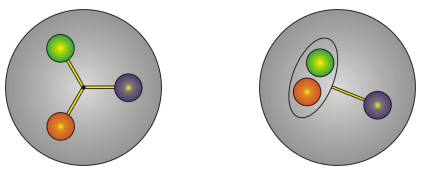
Lattice QCD calculations



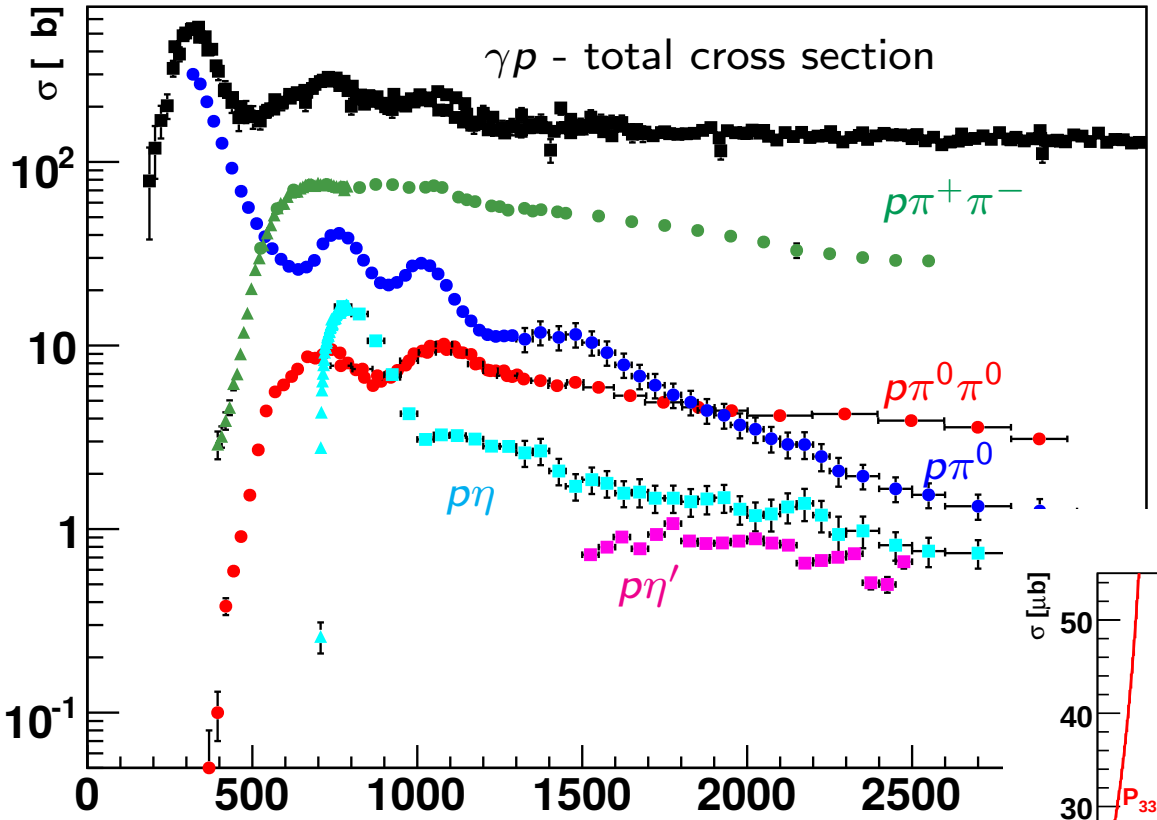
[Edwards et al. 2011]

Calculations predict more resonances than have been measured ("missing resonances")

→ What are the relevant degrees of freedom?

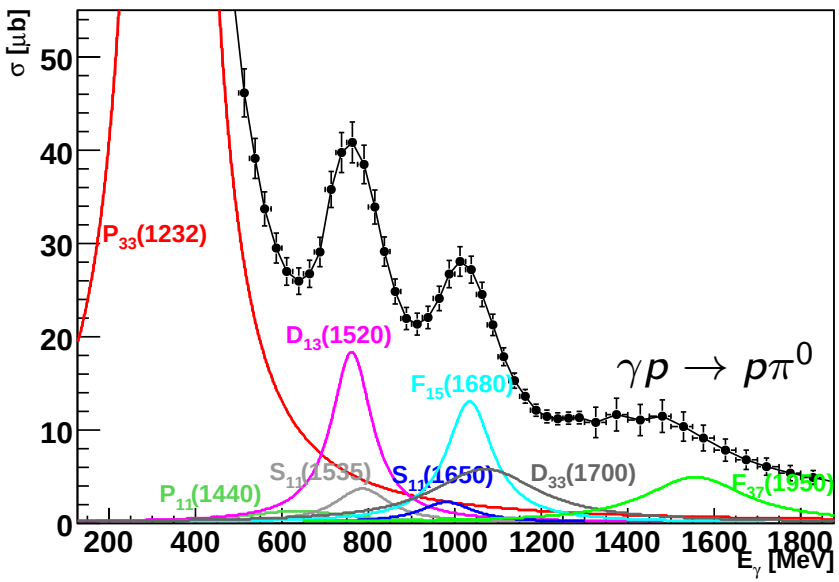


Resonances



Partial wave analysis needed to disentangle the resonances.

Resonances overlap strongly with different strengths and widths
$\rightarrow$ Weak resonance contributions difficult to measure

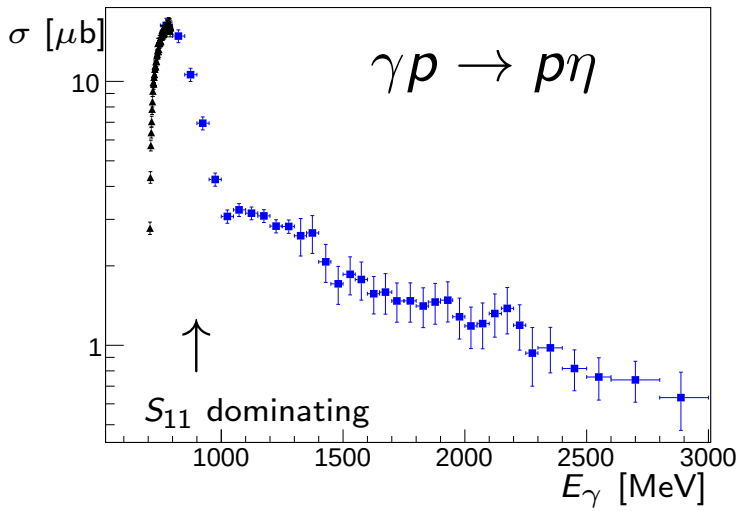


Cross Section

Total cross section:

Sum of different partial waves

$$\sigma_{tot} \sim |A_{1/2}(S_{11})|^2 + |A_{1/2}(P_{13})|^2 + |A_{3/2}(P_{13})|^2 + \cdots$$



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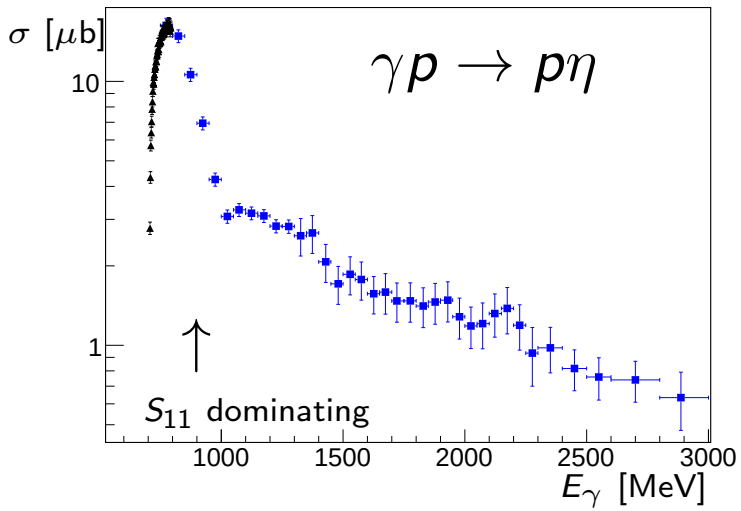
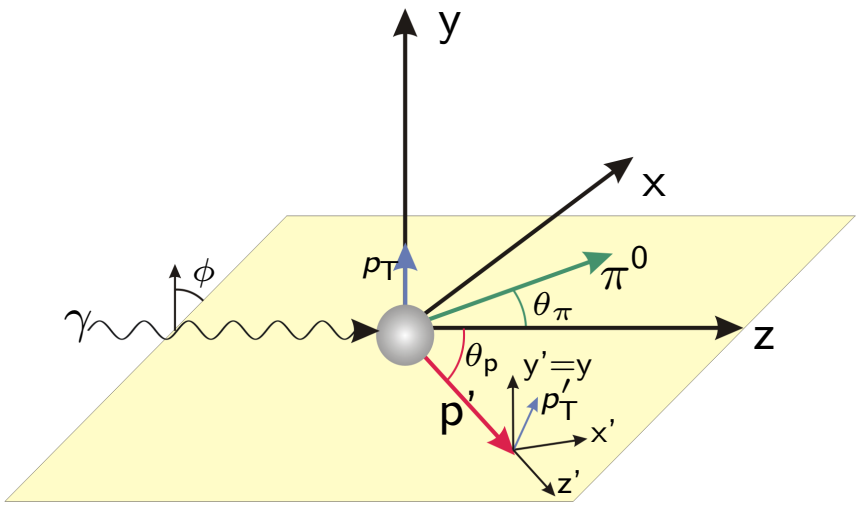


Polarization observables sensitive to interference terms:

$$\Sigma \sim A_{1/2}(S_{11}) \cdot A_{1/2}(P_{11}) + \cdots$$

Measurement of polarization observables necessary for a unique solution of the partial wave analysis and to identify small resonance contributions.

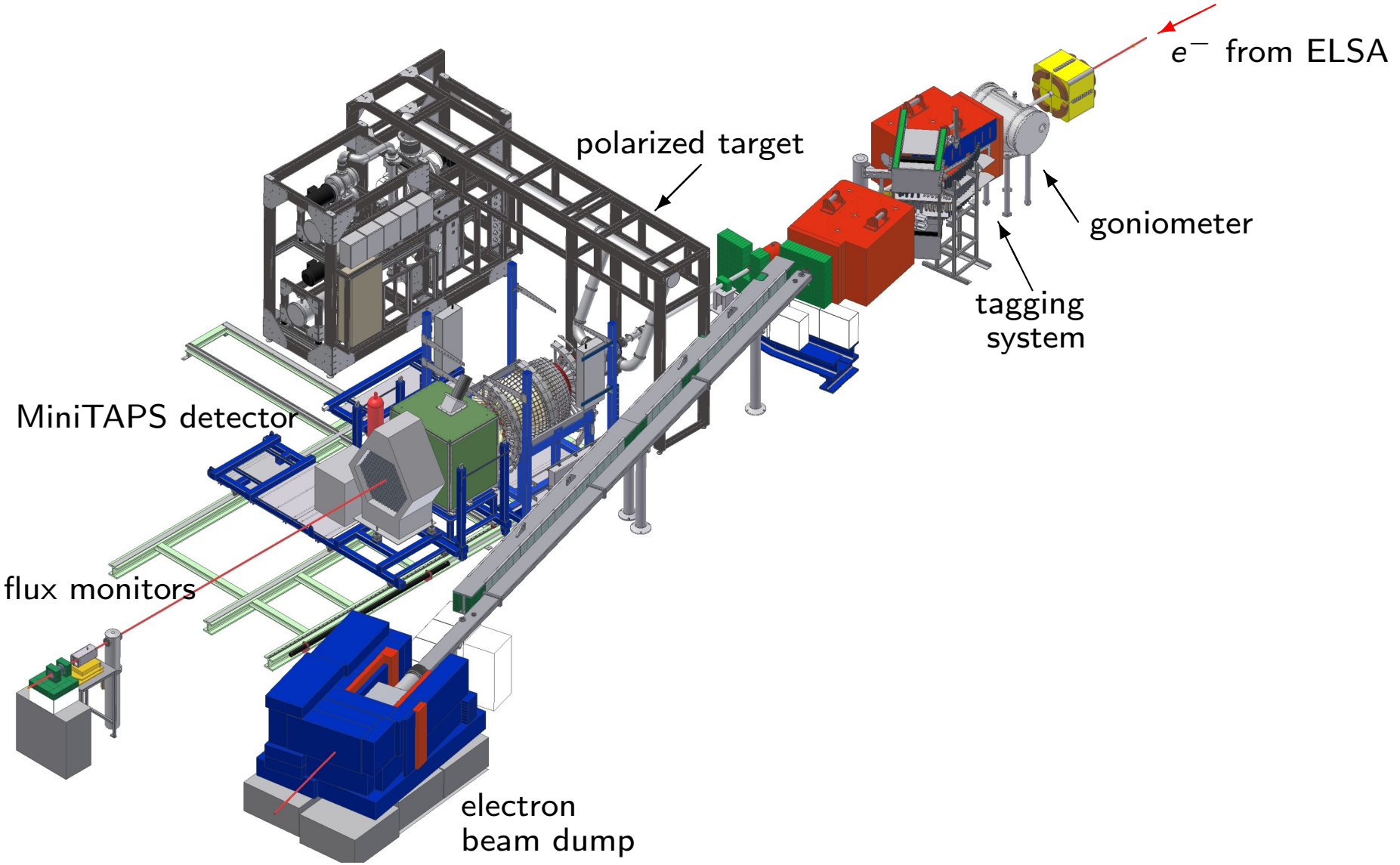
Polarization Observables



Polarization Observables in photoproduction of pseudoscalar mesons:

		Target			Recoil			Target+Recoil			
		–	–	–	x'	y'	z'	x'	x'	z'	z'
Photon		x	y	z	–	–	–	x	z	x	z
unpolarized	σ	–	T	–	–	P	–	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linearly polarized	Σ	H	-P	-G	$O_{x'}$	-T	$O_{z'}$	–	–	–	–
circularly polarized	–	F	–	-E	$-C_{x'}$	–	$-C_{z'}$	–	–	–	–

The Setup of the CBELSA/TAPS Experiment



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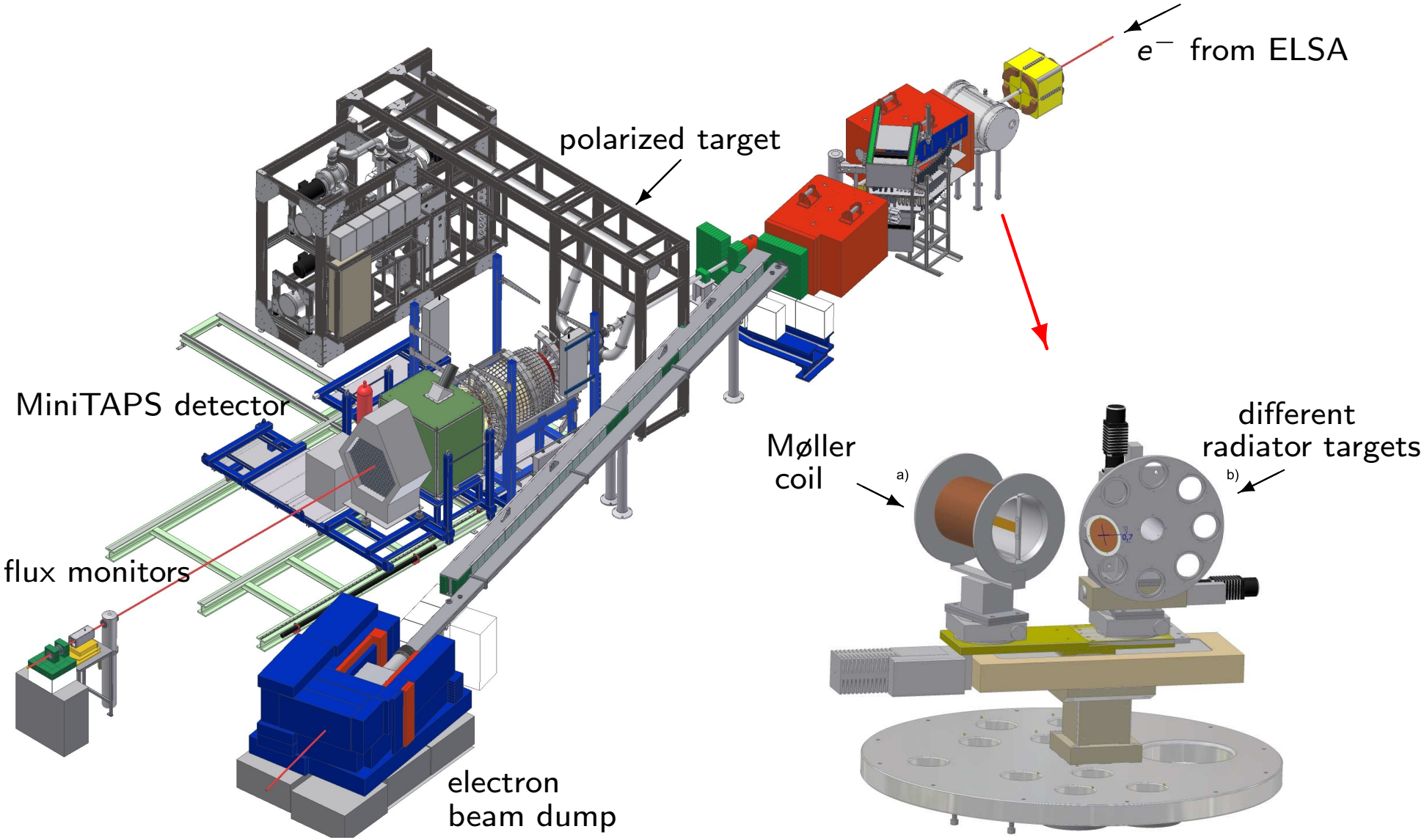

$\rightarrow$ circularly and linearly polarized photons

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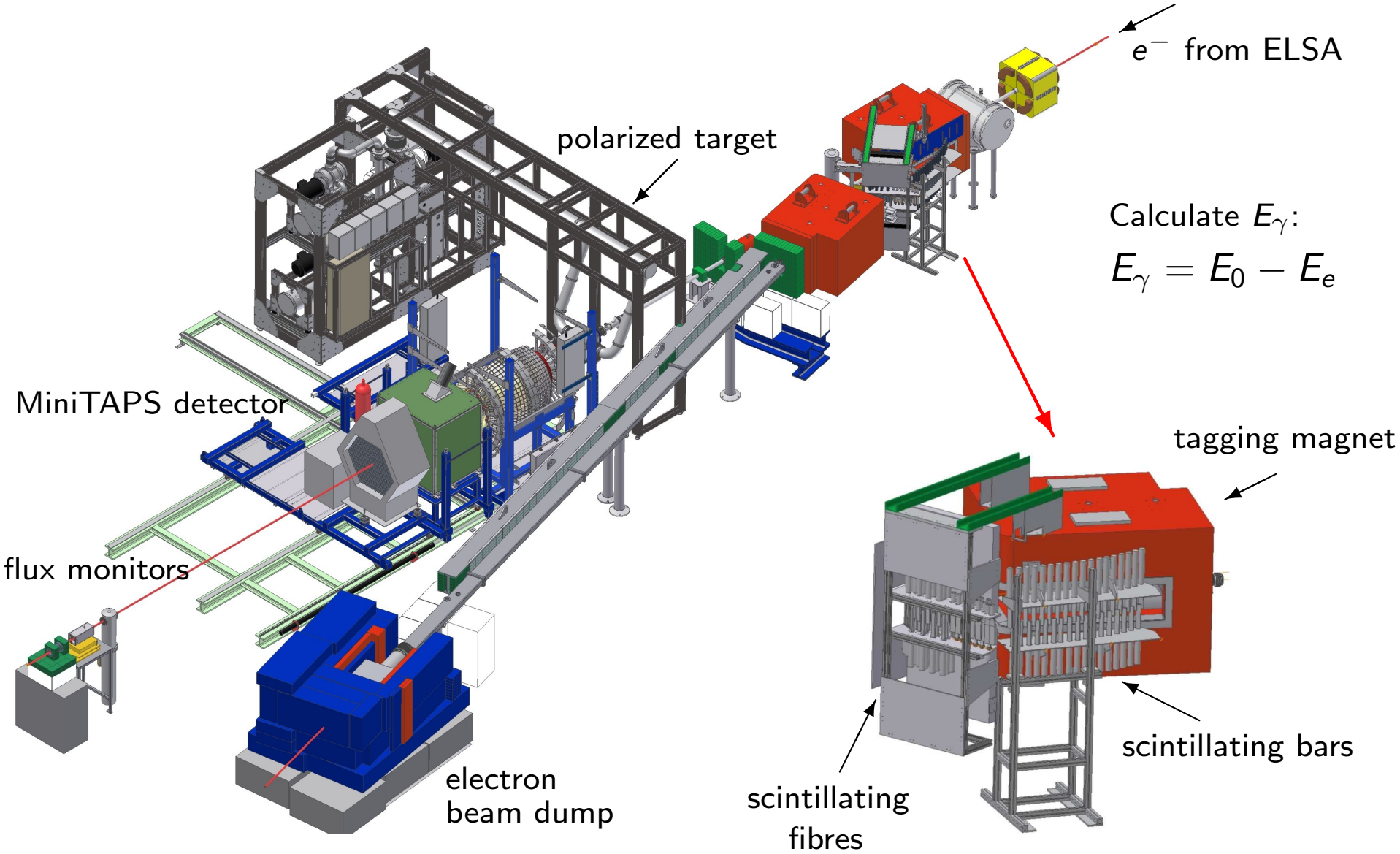

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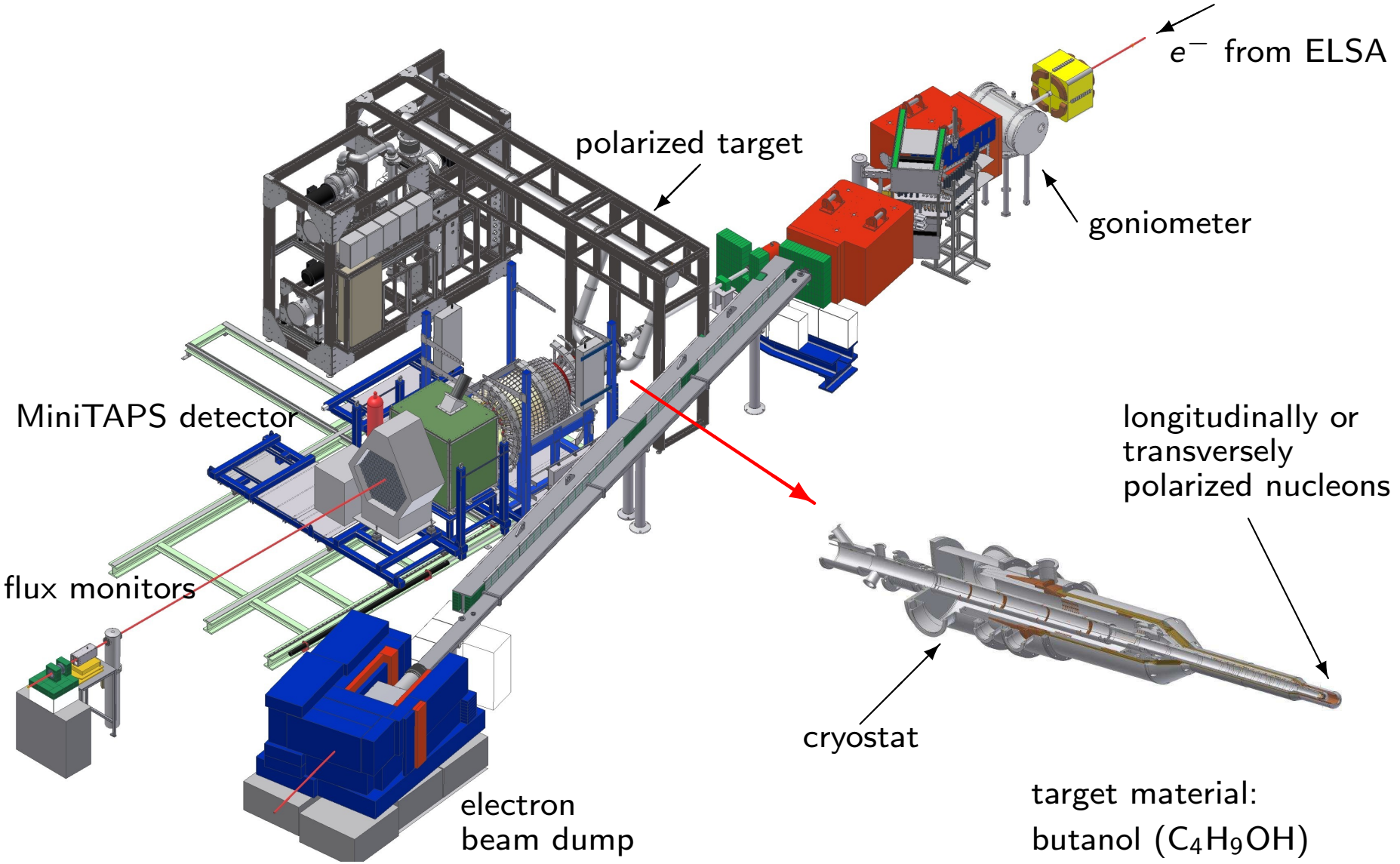
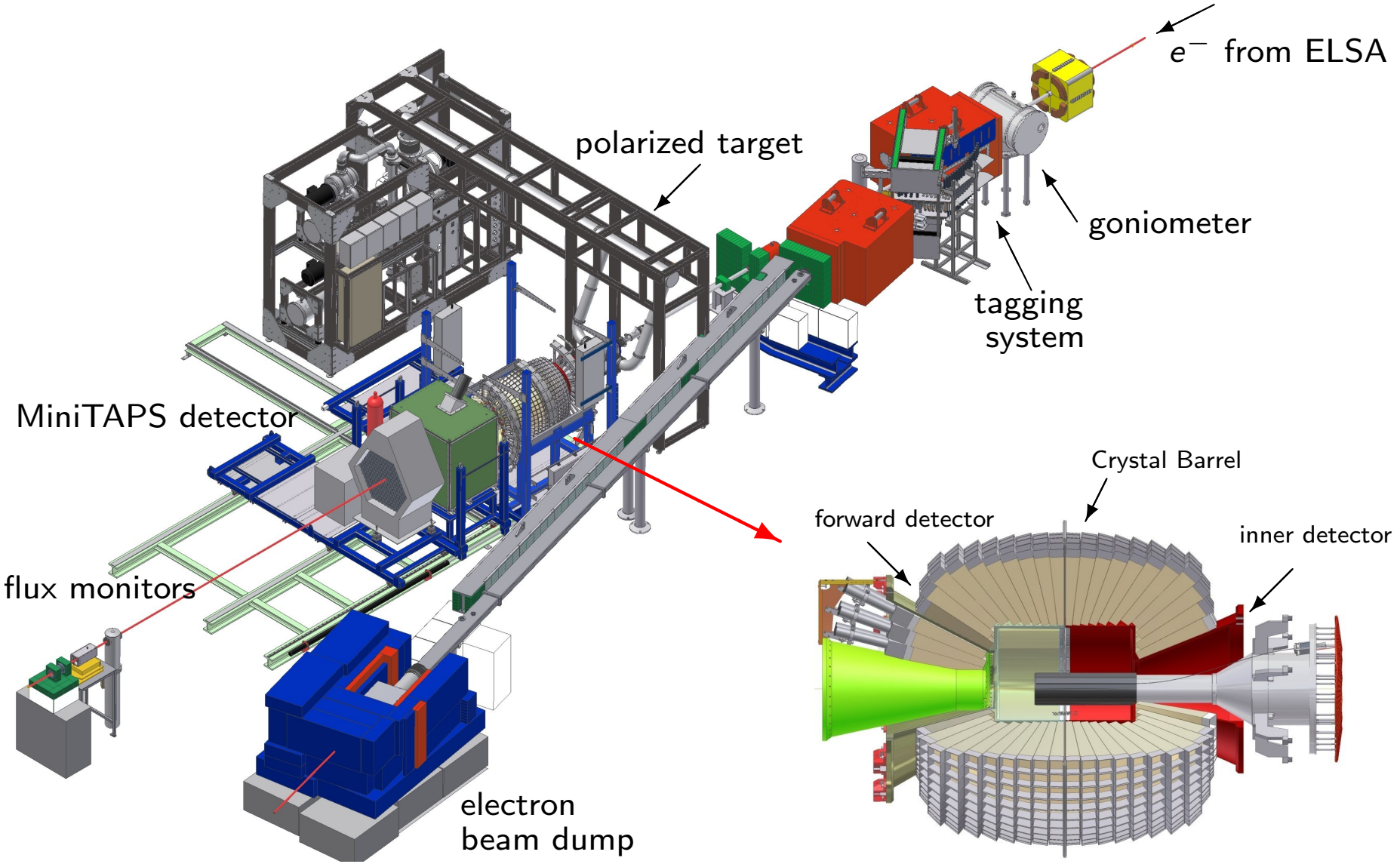
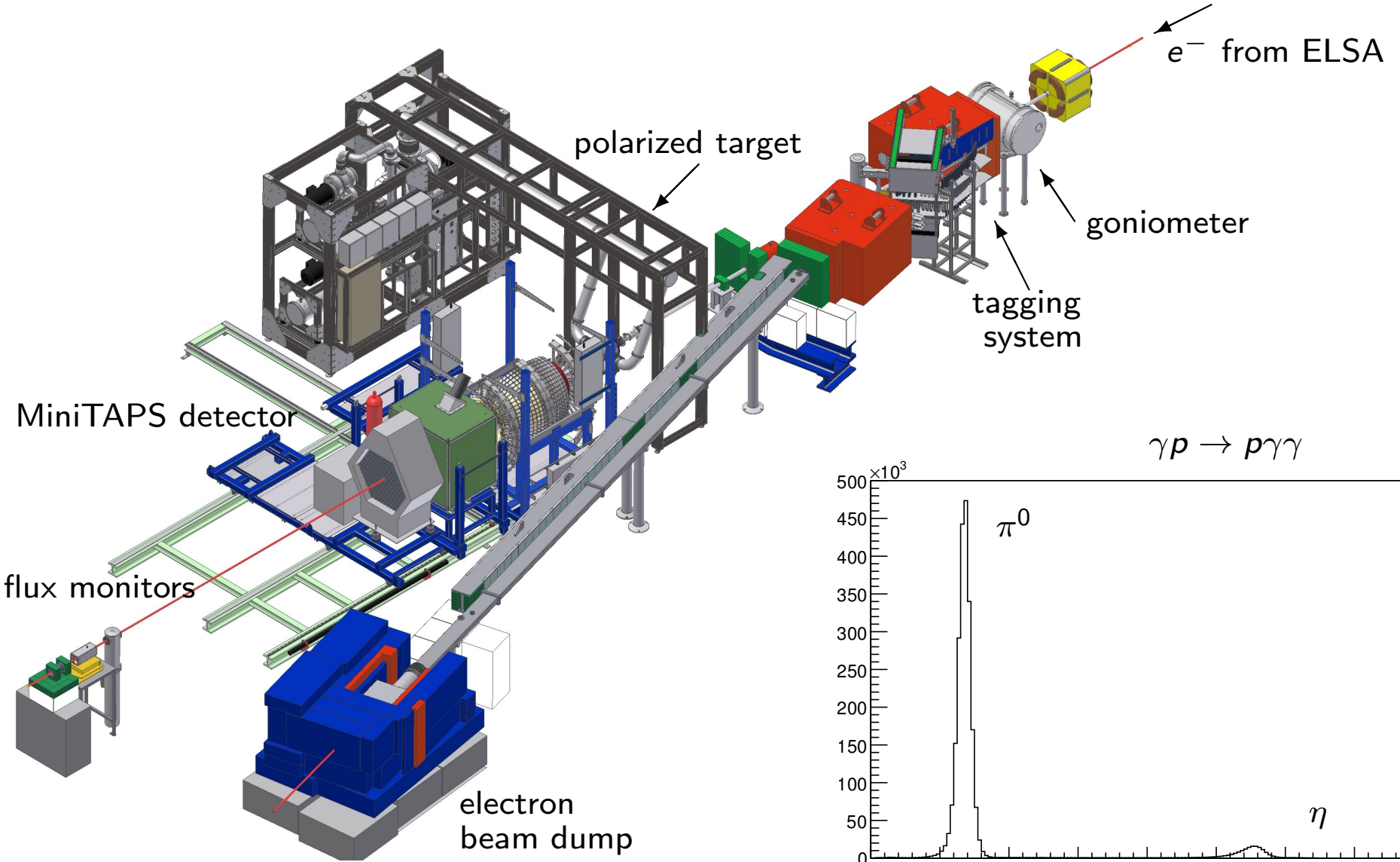


The Setup of the CBELSA/TAPS Experiment



$\rightarrow$ nearly full 4π angular coverage

The Setup of the CBELSA/TAPS Experiment



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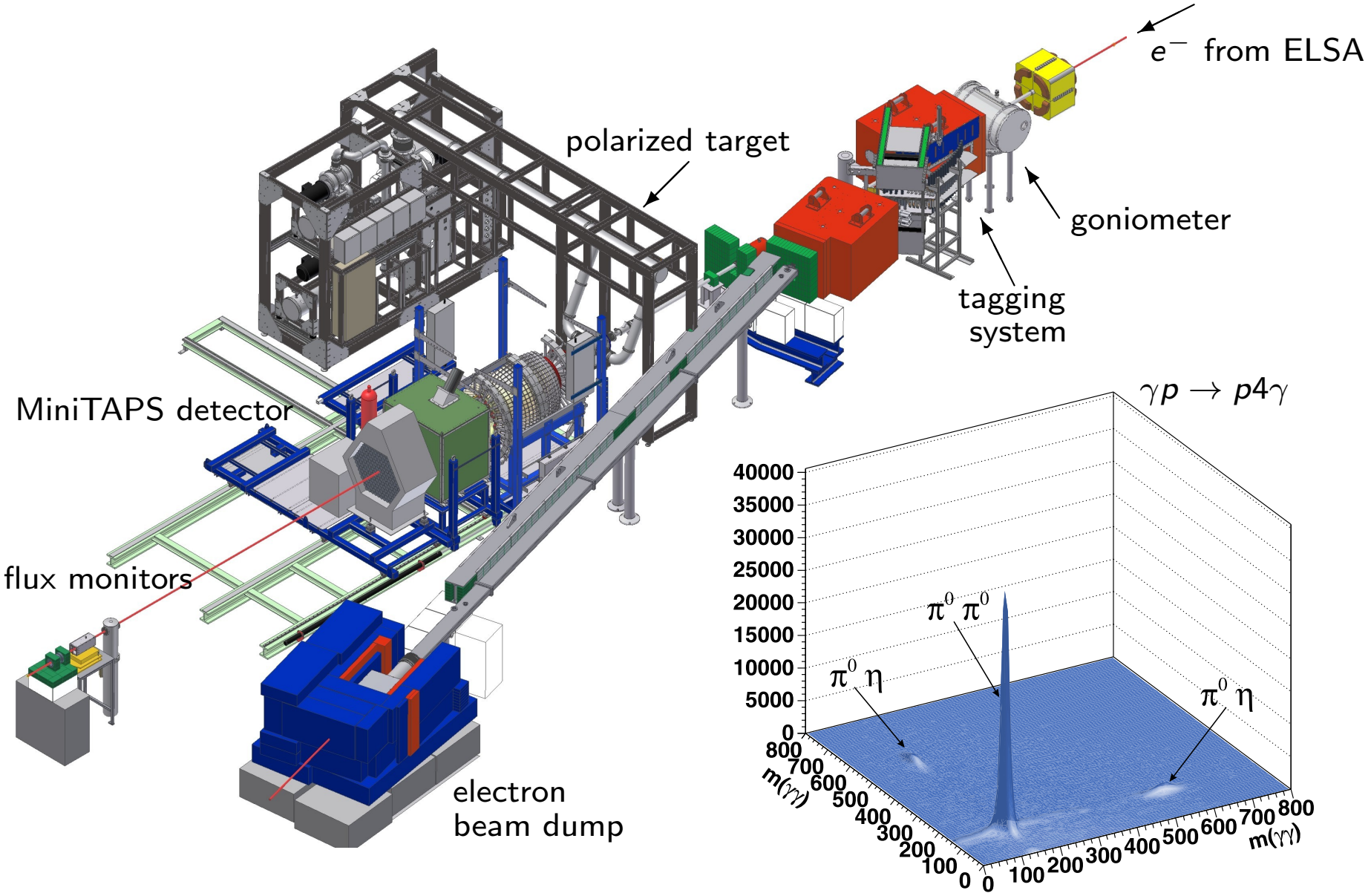
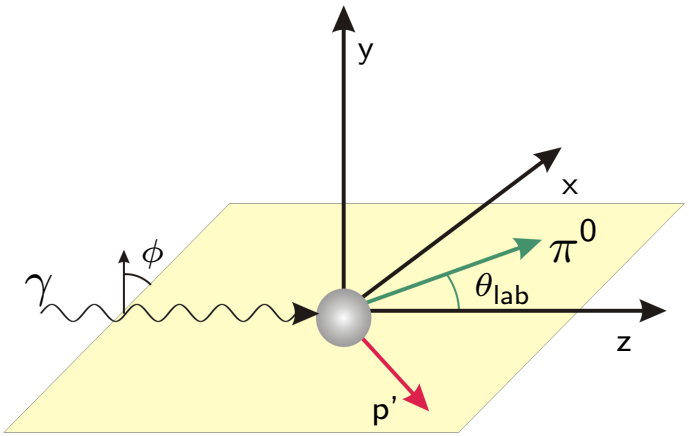


Cross Section with Beam und Target Polarization



$$\begin{aligned}\frac{d\sigma}{d\Omega}(\theta,\phi) &= \frac{d\sigma}{d\Omega}(\theta)\cdot\Big[1 - p_\gamma^{lin}\Sigma\cos(2\phi)\\ &+ p_x(-p_\gamma^{lin}H\sin(2\phi) + p_\gamma^{circ}F)\\ &- p_y(-T + p_\gamma^{lin}P\cos(2\phi))\\ &- p_z(-p_\gamma^{lin}G\sin(2\phi) + p_\gamma^{circ}E)\Big]\end{aligned}$$

Photon Polarization		Target Polarization x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

π^0-photoproduction:

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

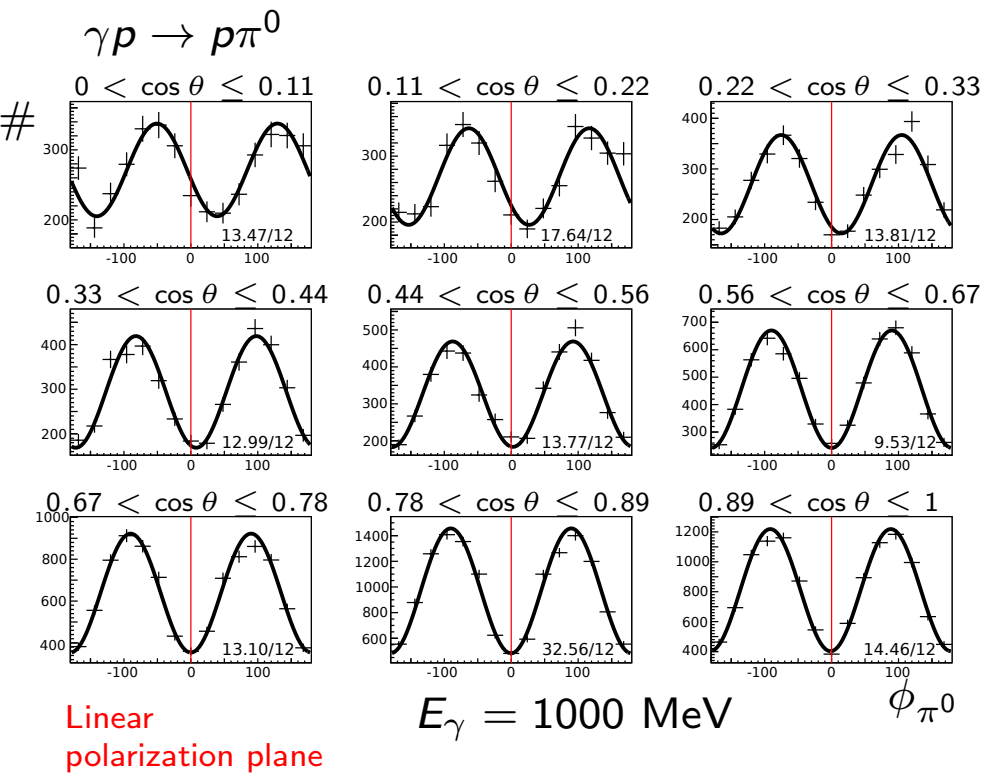
η-photoproduction:

publication in preparation

ϕ-Distribution of the Mesons

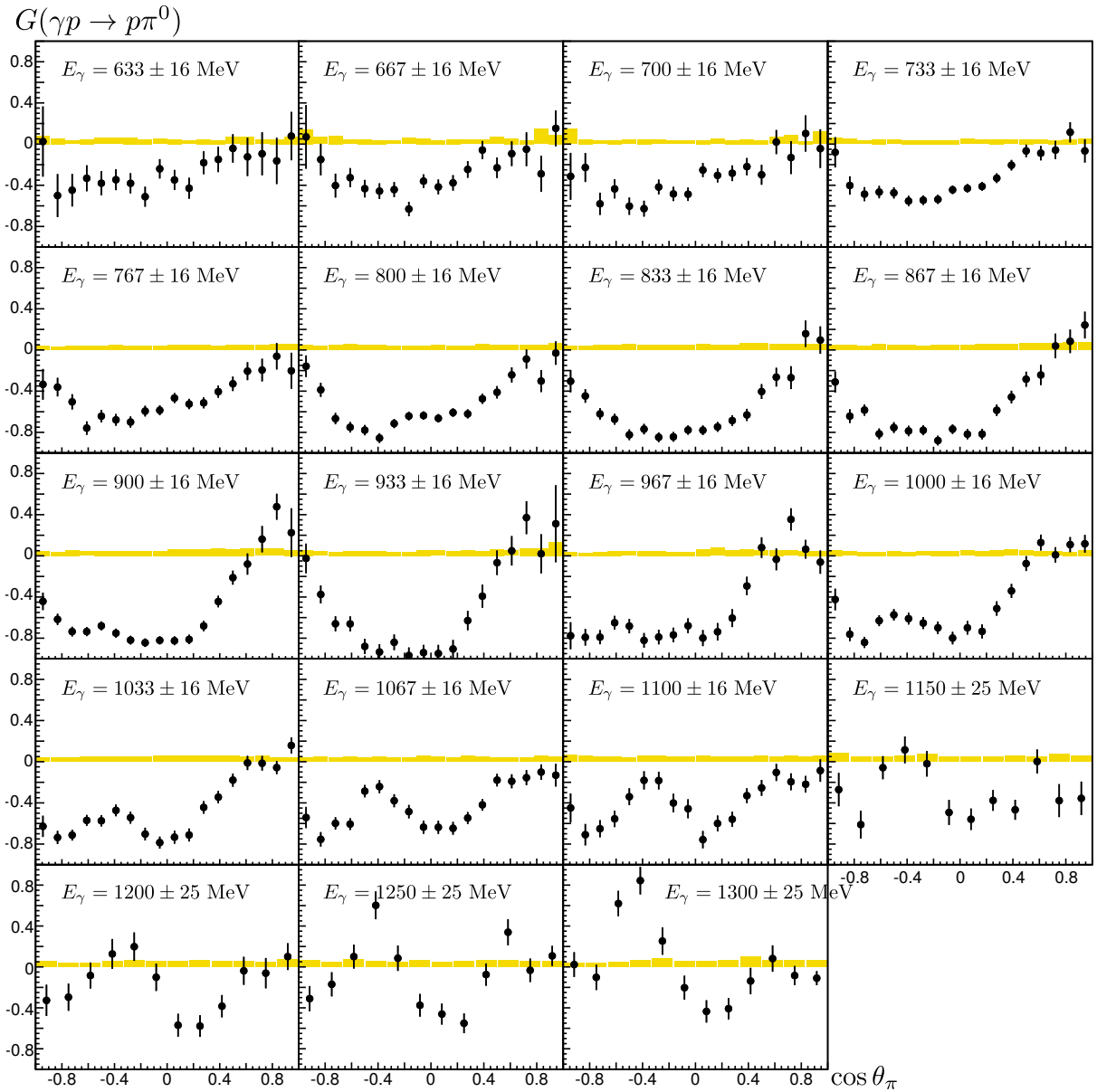
Cross section with longitudinally polarized target and linearly polarized photons:

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \left[1 - p_\gamma^{lin} \Sigma \cos(2\phi) + p_z p_\gamma^{lin} G \sin(2\phi)\right]$$



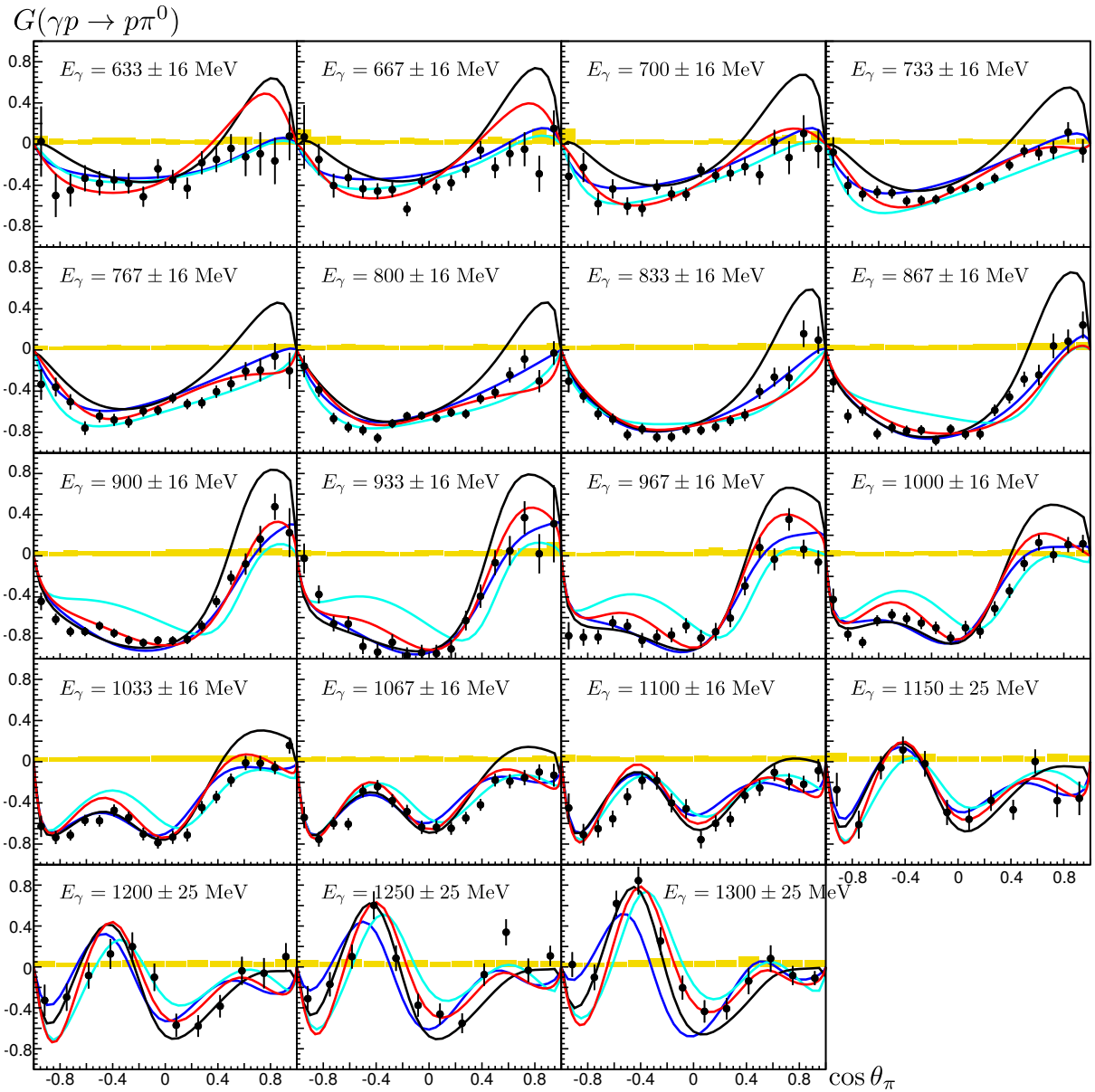
- Influence of polarization observables directy visible
- Symmetric around linear polarization plane
  $\to \Sigma$ dominating
- Deviation from symmetry
  $\to$ influence of double polarization observable G

$\gamma p \to p\pi^0$: Double Polarization Observable G



First measurement of the observable over large energy range with a wide angular coverage

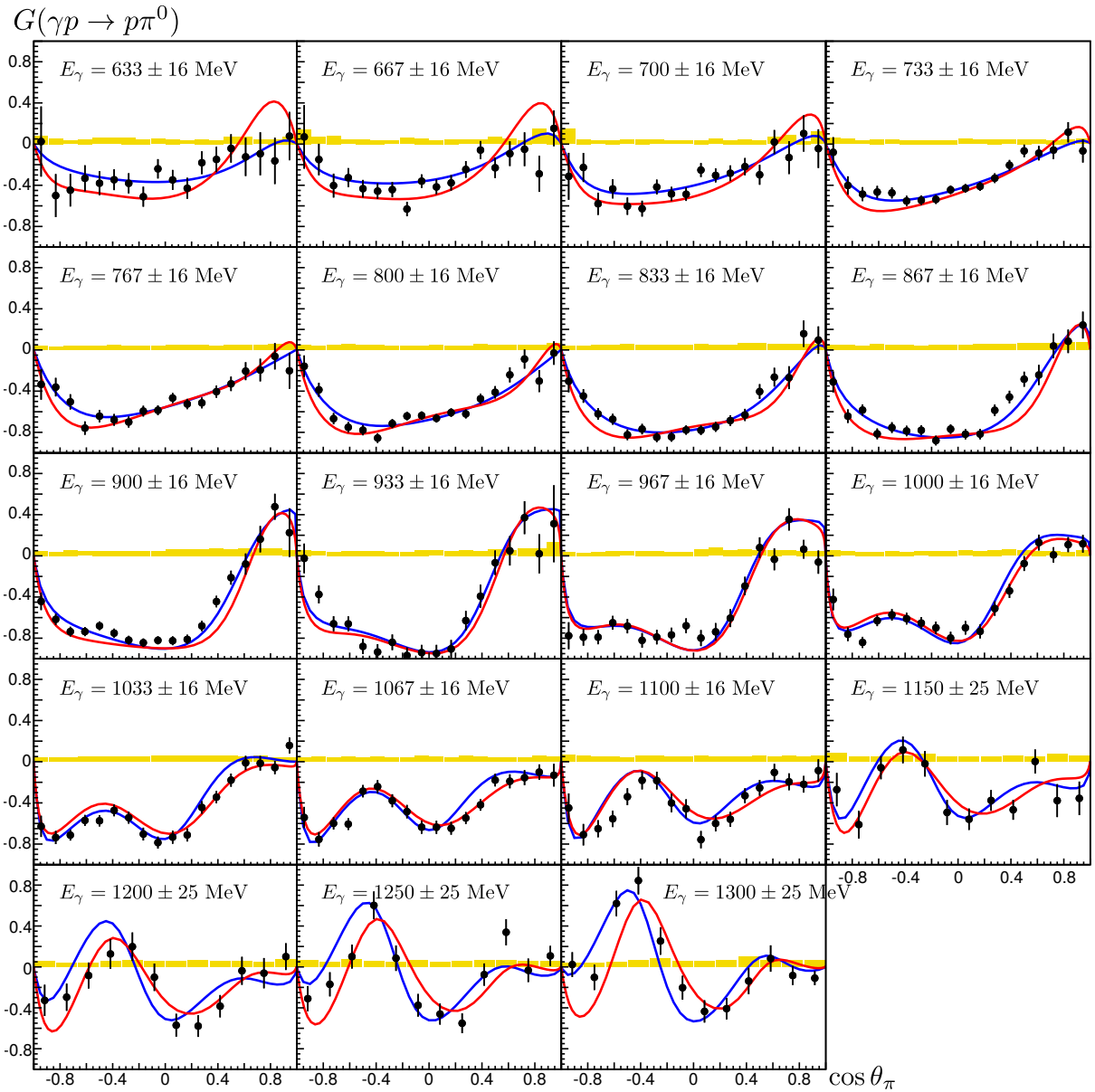
$\gamma p \to p\pi^0$: Double Polarization Observable G



Predictions to the data:

BnGa11-02
SAID (CM12)
MAID07
BnJu13-1

$\gamma p \to p\pi^0$: Double Polarization Observable G

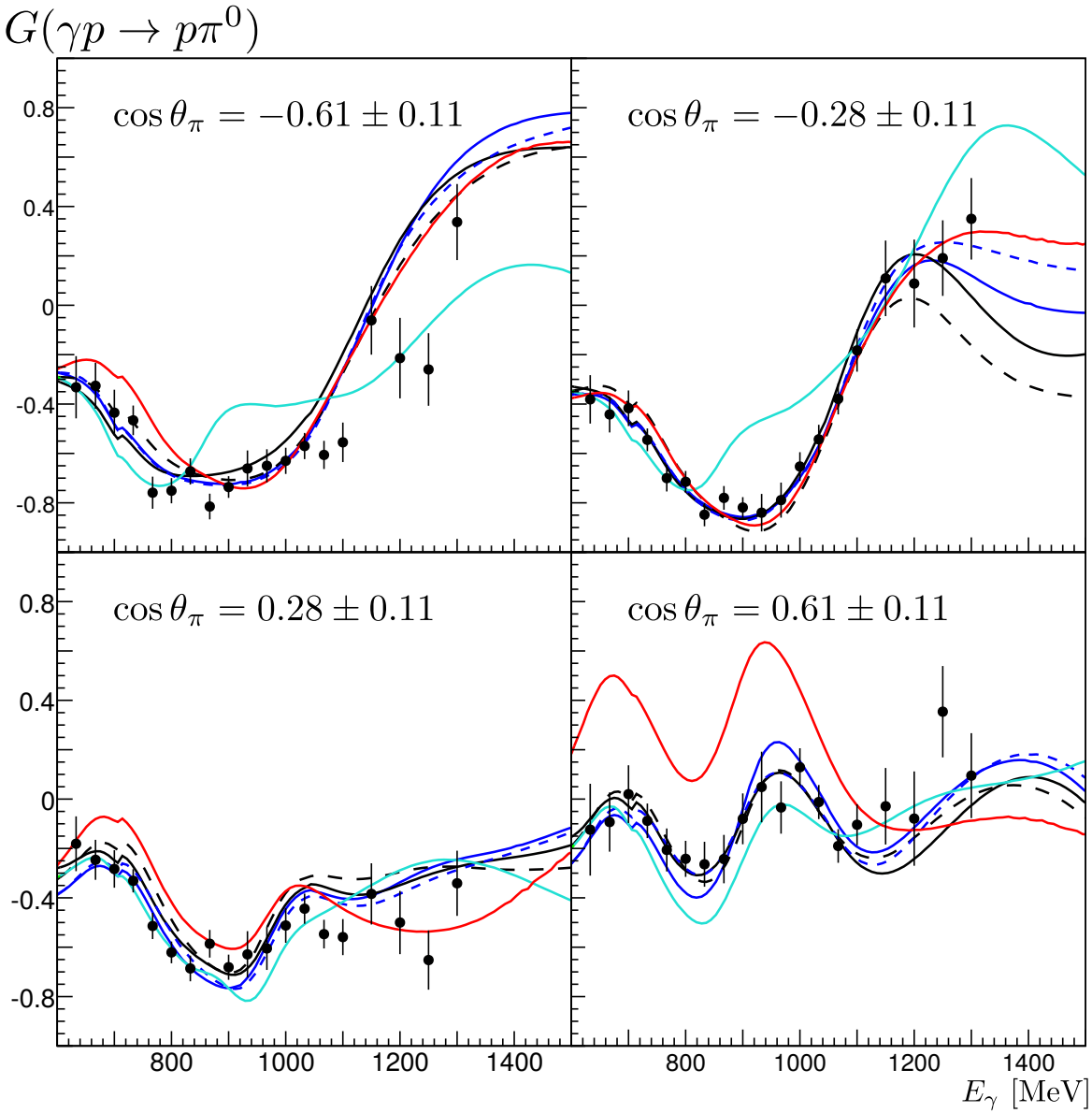


Fits to the data:

BnGa14-02
BnJu15-B

See talks by
A. Sarantsev and
D. Rönchen

$\gamma p \to p\pi^0$: Double Polarization Observable G



PWA Models:

MAID07

BnGa11

BnGa14

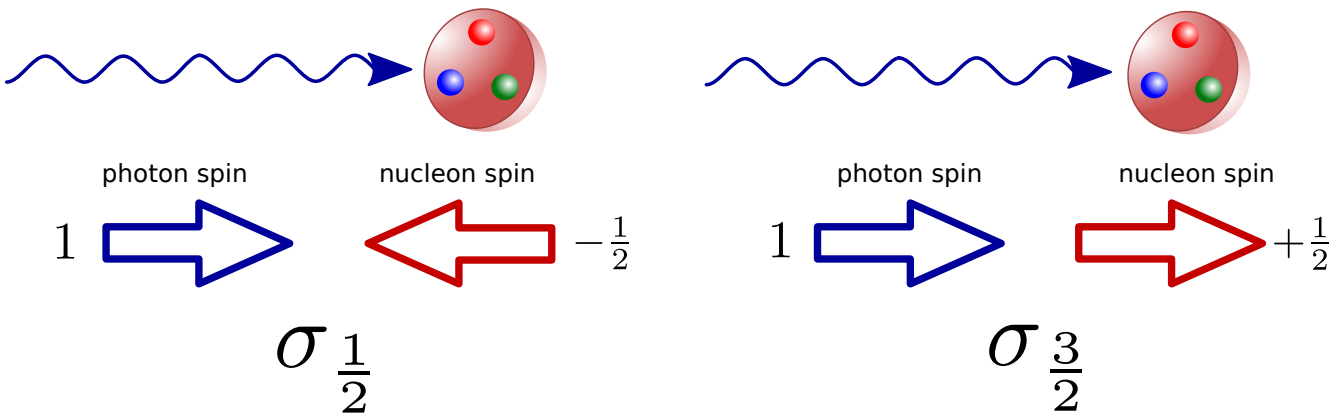
SAID (CM12)

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

A.Thiel et al. to be submitted to EPJA

The Double Polarization Observable E

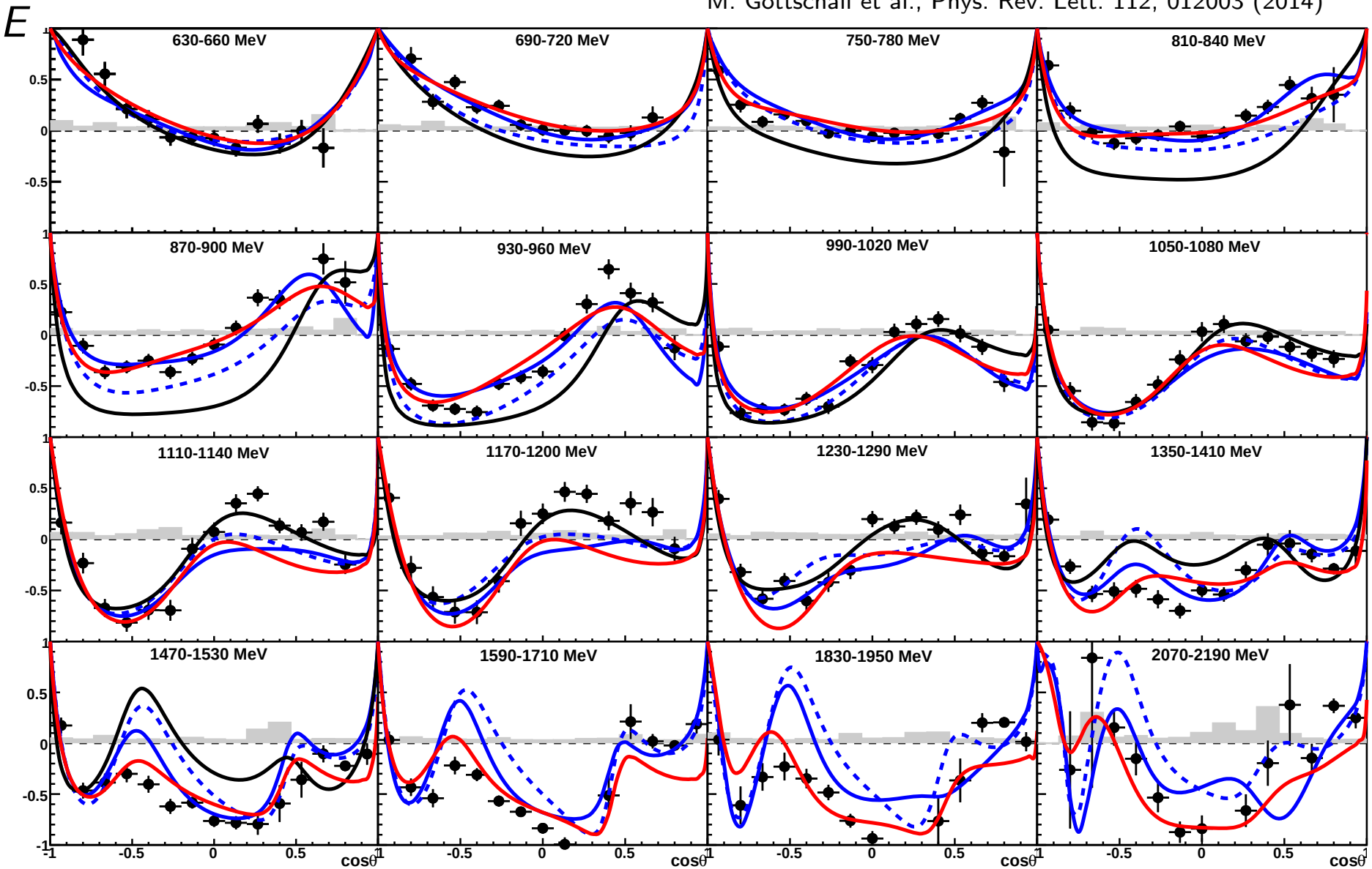
- Circularly polarized photons on a longitudinally polarized target
- Observable is a helicity asymmetry
- Two spin configurations possible:



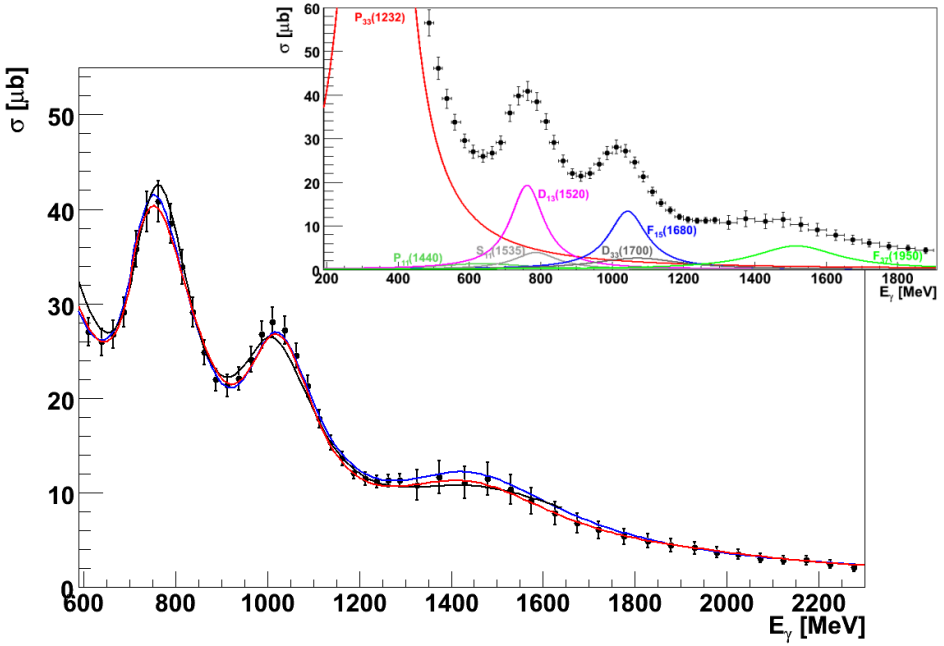
$$E(\theta, E_\gamma) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

$\gamma p \to p\pi^0$: Double Polarization Observable E

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



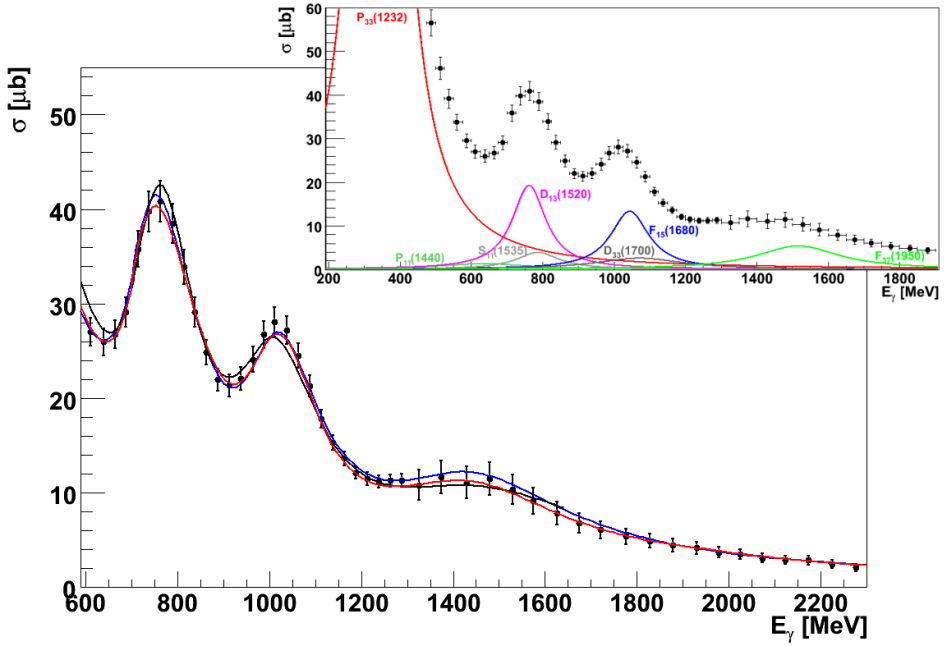
$\gamma p \to p\pi^0$: $\sigma_{1/2}$ vs. $\sigma_{3/2}$



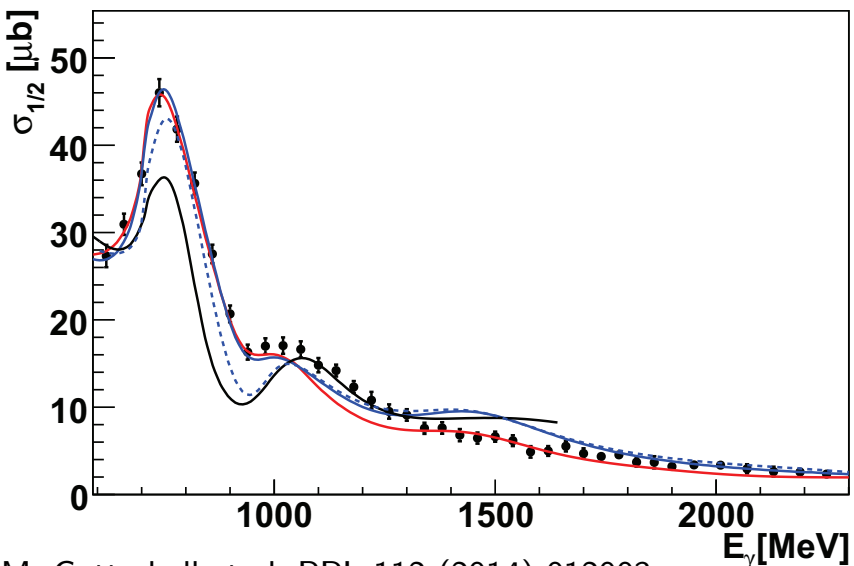
- Different models show good description of the cross section
- Spin dependent cross section can be extracted:
  $\sigma^{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$

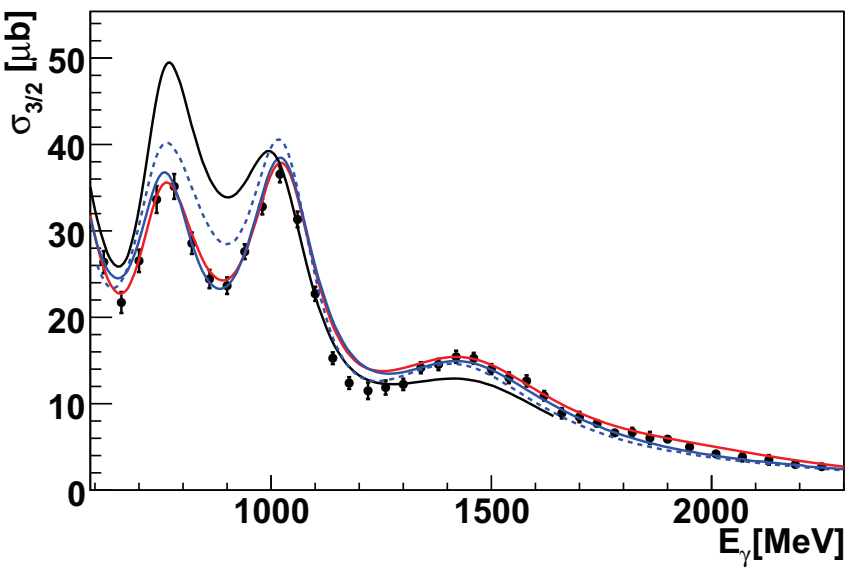
M. Gottschall et al. PRL 112 (2014) 012003

$\gamma p \to p\pi^0$: $\sigma_{1/2}$ vs. $\sigma_{3/2}$



- Different models show good description of the cross section
- Spin dependent cross section can be extracted:
  $\sigma^{1/2(3/2)} = \sigma_0 \cdot (1 \pm E)$
- Large differences occur in $\sigma^{1/2}$ and $\sigma^{3/2}$ cross sections

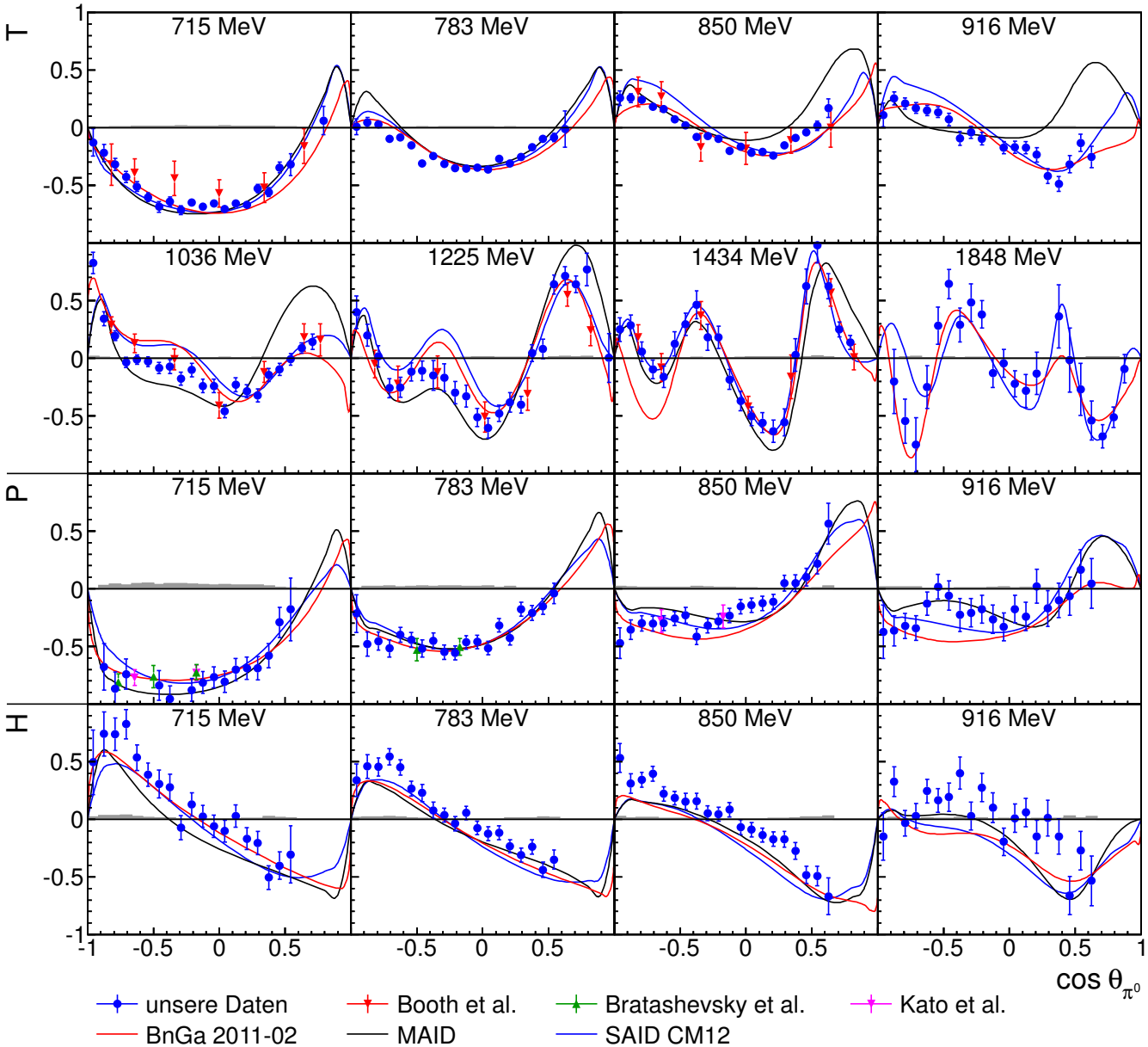




— MAID
– – SAID SN11
— SAID CM12
— BnGa11-02

M. Gottschall et al. PRL 112 (2014) 012003

$\gamma p \to p\pi^0$: Polarization Observables T, P and H



Transversly polarized target lead to several new observables

High quality data set with large angular coverage and wide energy range

Only selected bins shown here

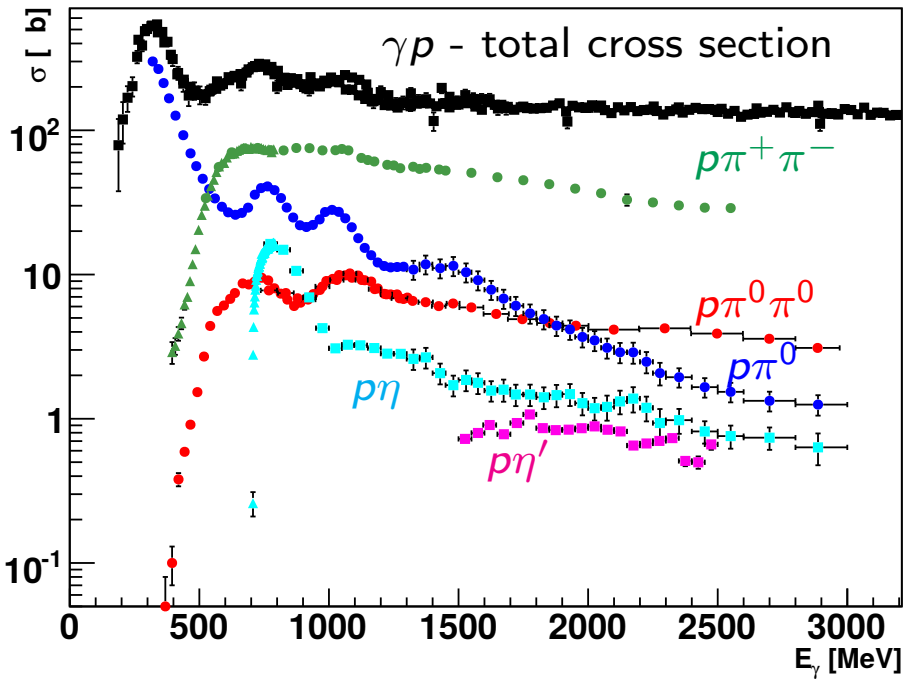
J. Hartmann et al.
PRL 113 (2014) 062001

Extraction of observables for different final states

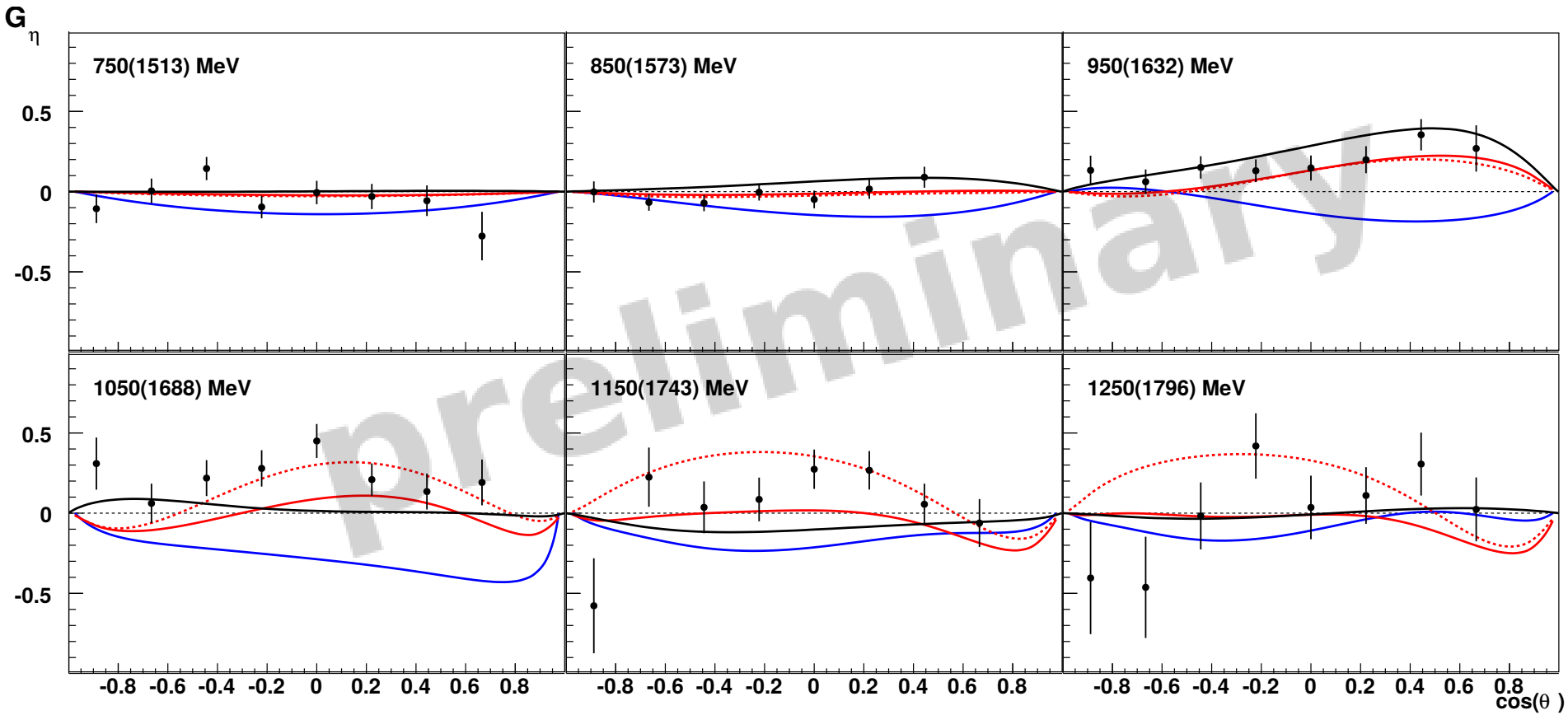
- Photoproduction off neutrons necessary for isospin separation

see talks by M. Dieterle and D. Werthmüller

- Many final states in photoproduction possible, important to measure them
- η and η' photoproduction can work as isospin filters, only resonances with $T = 1/2$ can contribute



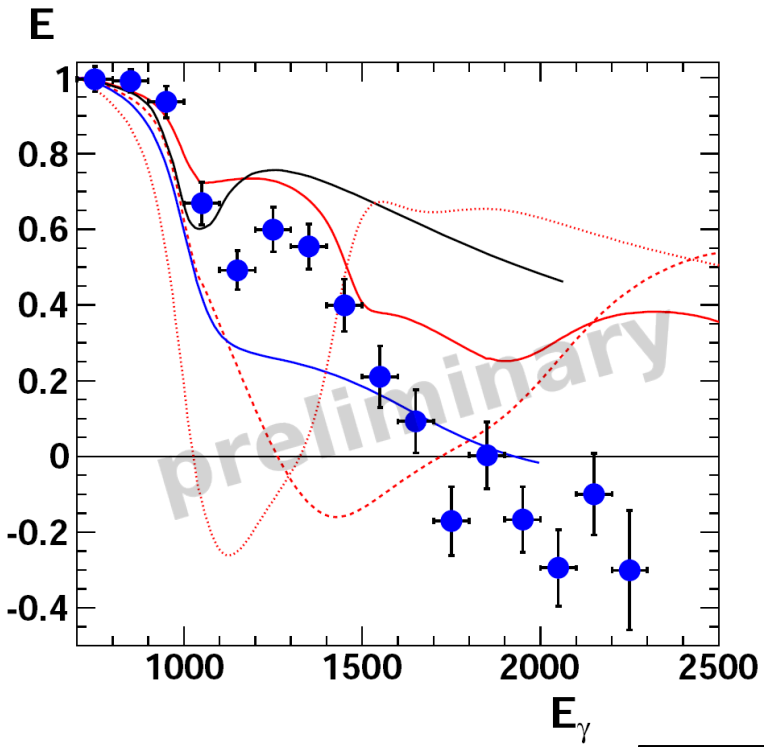
$\gamma p \to p\eta$: Polarization Observable G



— BnGa14-02 –– BnGa14-01 — ηMAID — SAID (GE09)

Additional data now taken by the Crystal Ball experiment in Mainz

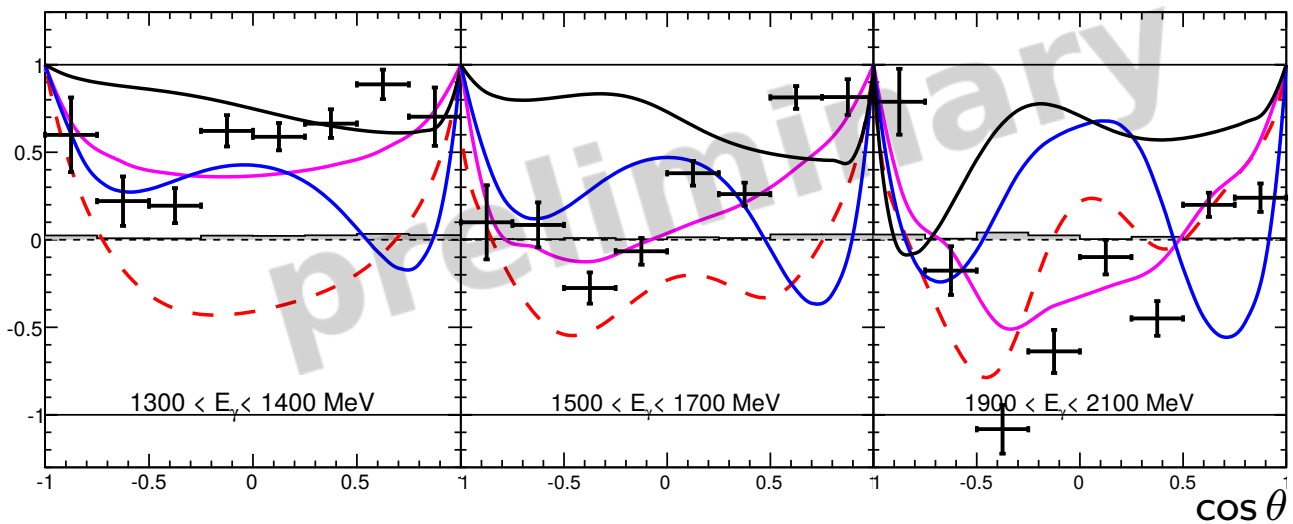
$\gamma p \to p\eta$: Double Polarization Observable E



$$E(\theta, E_\gamma) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

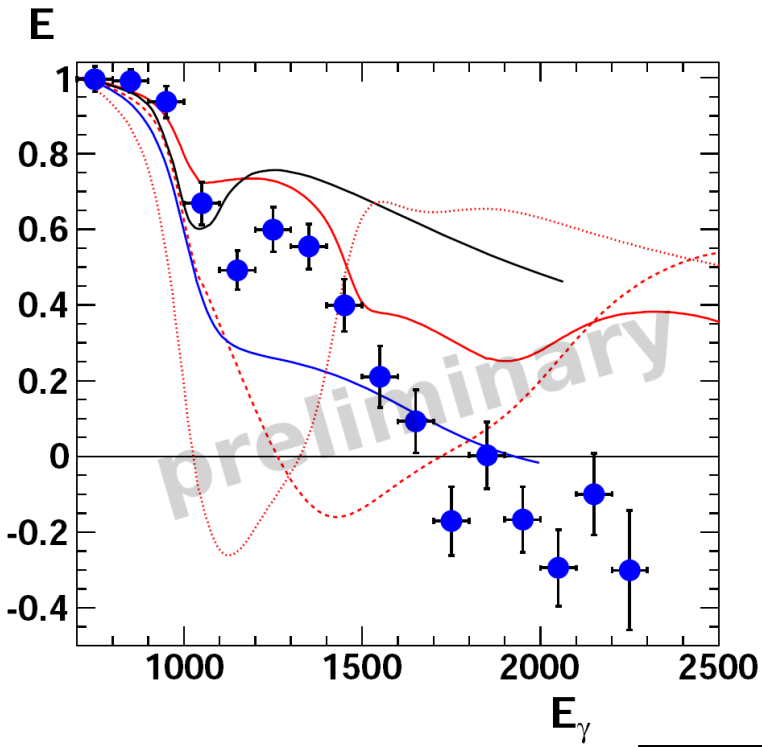
- At threshold: E close to 1 due to $S_{11}(1535)$ dominating
- At higher energies: large discrepancies in the predictions

— BnGa 2011-02
– – BnGa 2011-01
· · · BnGa-PWA (w/o P11 (1710))
— MAID
— SAID (GE09)
— BnGa14



J. Müller,
publication in preparation

$\gamma p \to p\eta$: Double Polarization Observable E



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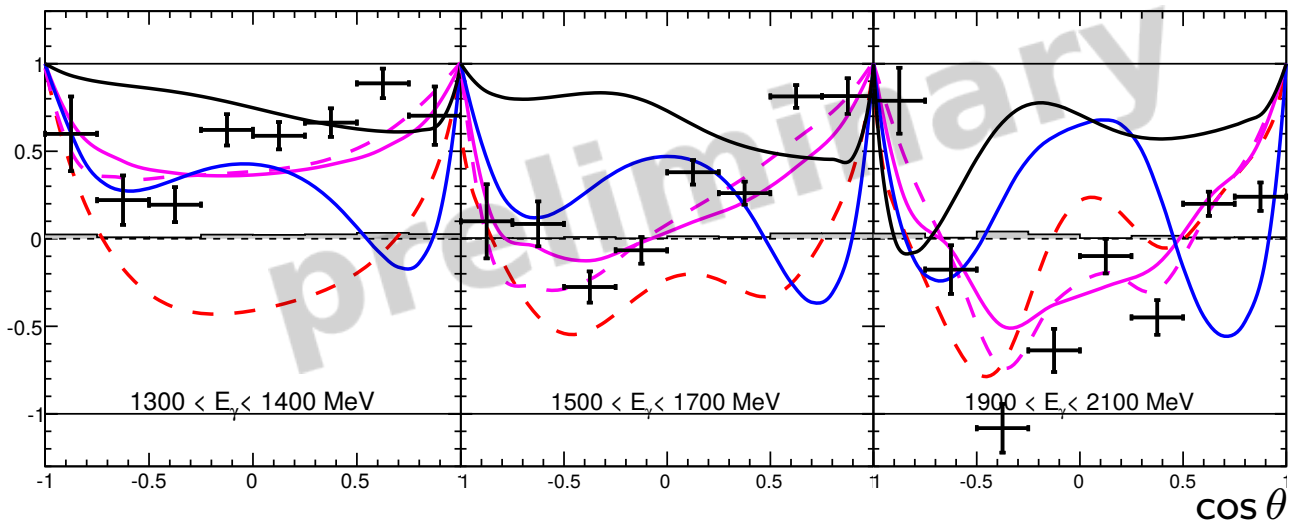
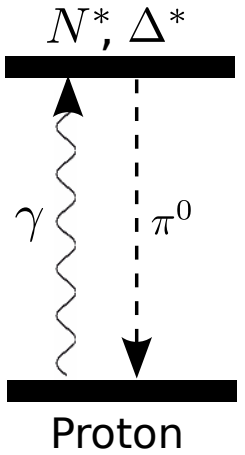
— BnGa 2011-02
– – BnGa 2011-01
· · · BnGa-PWA (w/o P11 (1710))
— MAID
— SAID (GE09)
— BnGa14
– – BnGa14 with additional resonance



J. Müller,
publication in preparation

Observables in Multi-Meson Final States

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



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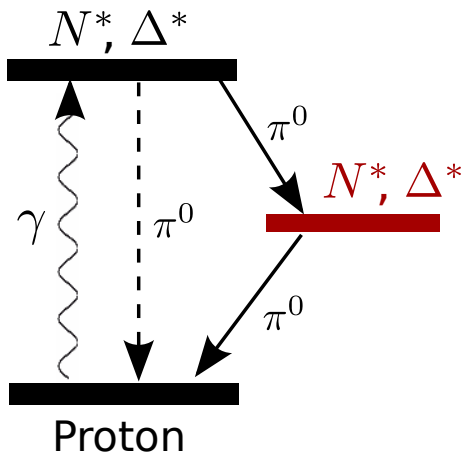

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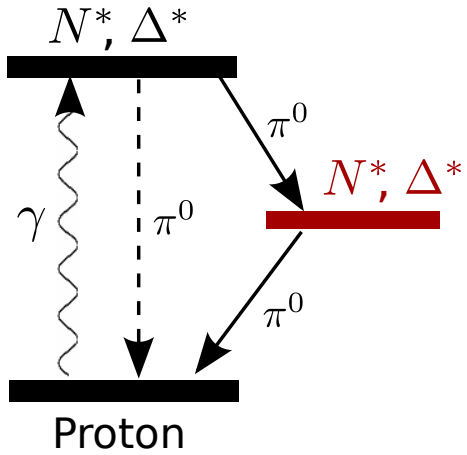
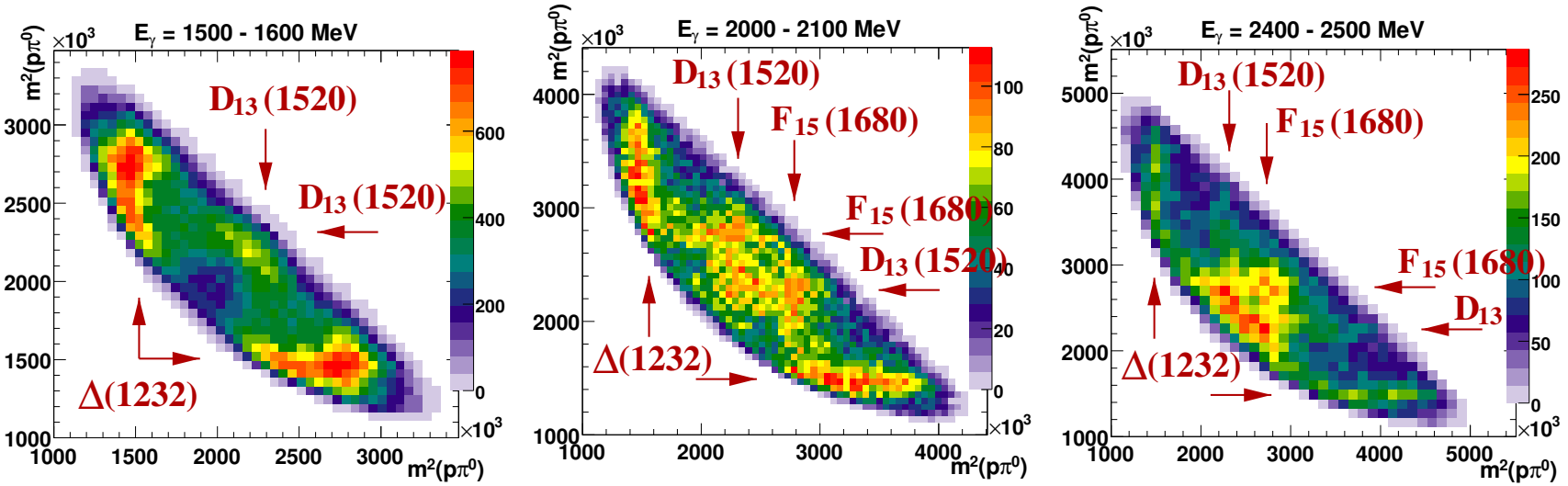
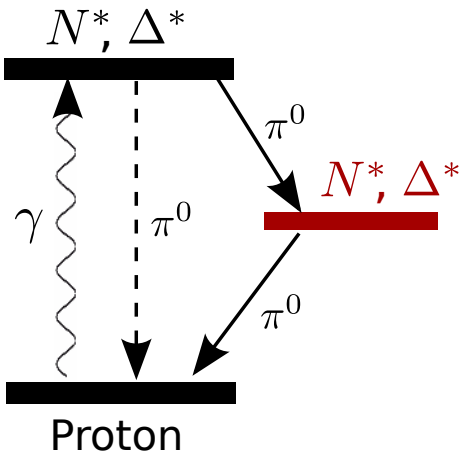




V. Sokhoyan

$\gamma p \to p\pi^0\pi^0$: New Interpretation of the Cascade Decays



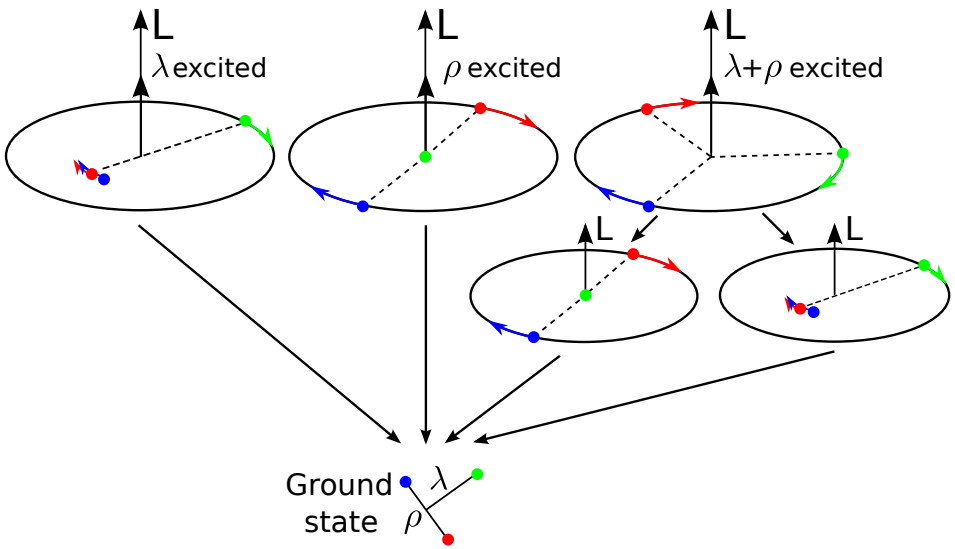
Two quartets of baryon resonances (N^* and Δ^*) observed in the fourth resonance region

Branching ratio measurements show:
N^* decay more often in orbitally excited intermediate states than Δ^*

Both oscillators λ and ρ excited?

Cascade decay needed to de-excite both oscillators
$\to$ direct decay into $N\pi$ reduced.

$\rightsquigarrow$ Contradiction to a quark-diquark view of the nucleon?

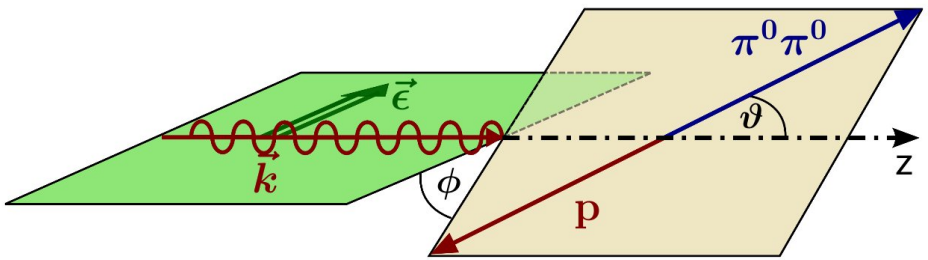


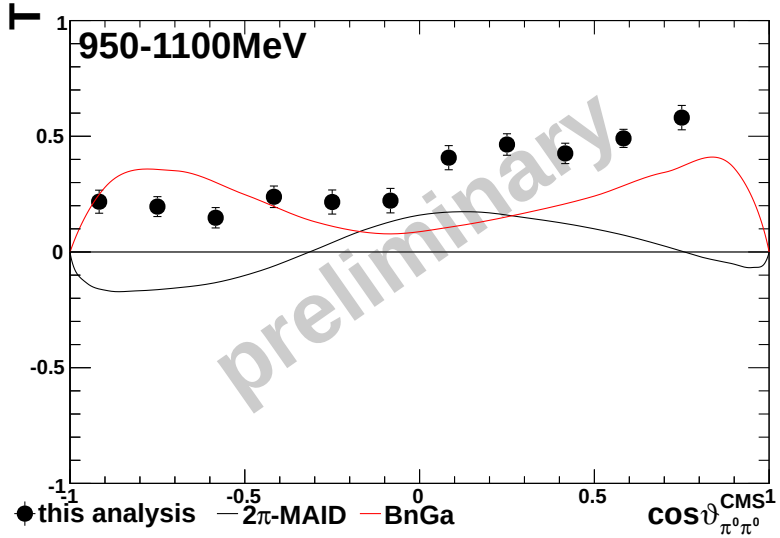
A. Thiel et al., Phys. Rev. Lett. 114, 091803

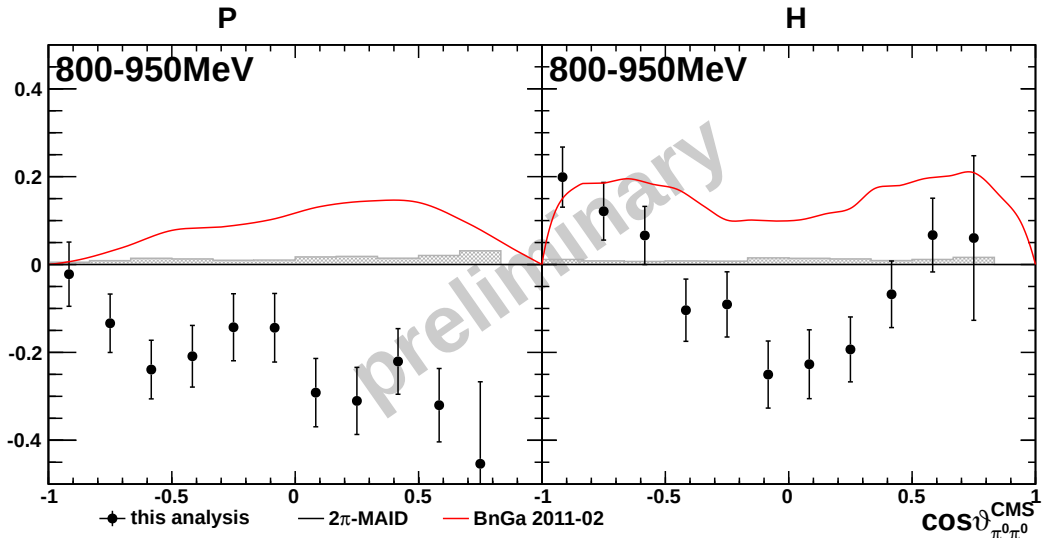
$\gamma p \to p\pi^0\pi^0$: Polarization Observables T, P, H

T. Seifen, Ph. Mahlberg

Here:
only results shown in quasi two-body kinematics

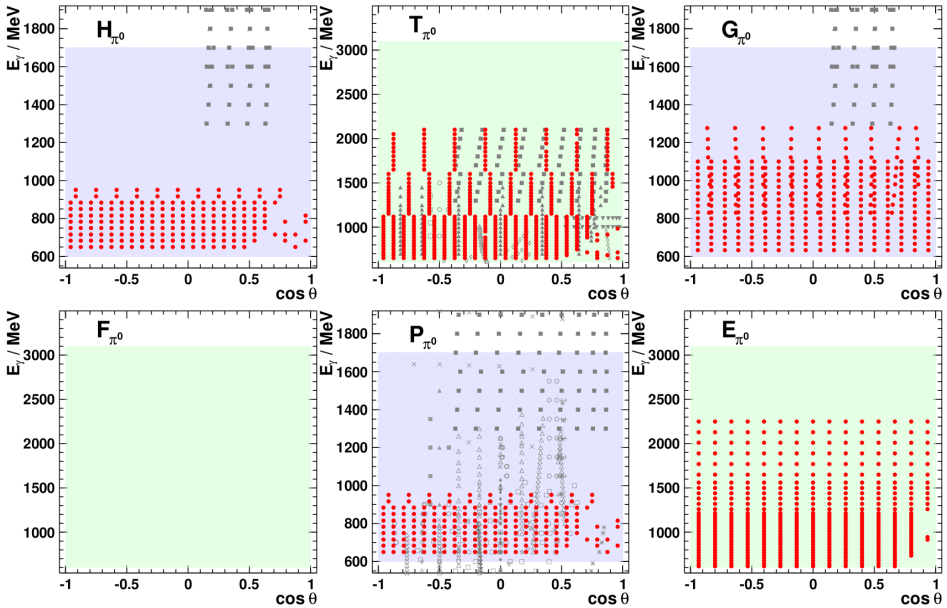






For further details see talk by Ph. Mahlberg

Measured Datasets in π^0 Photoproduction

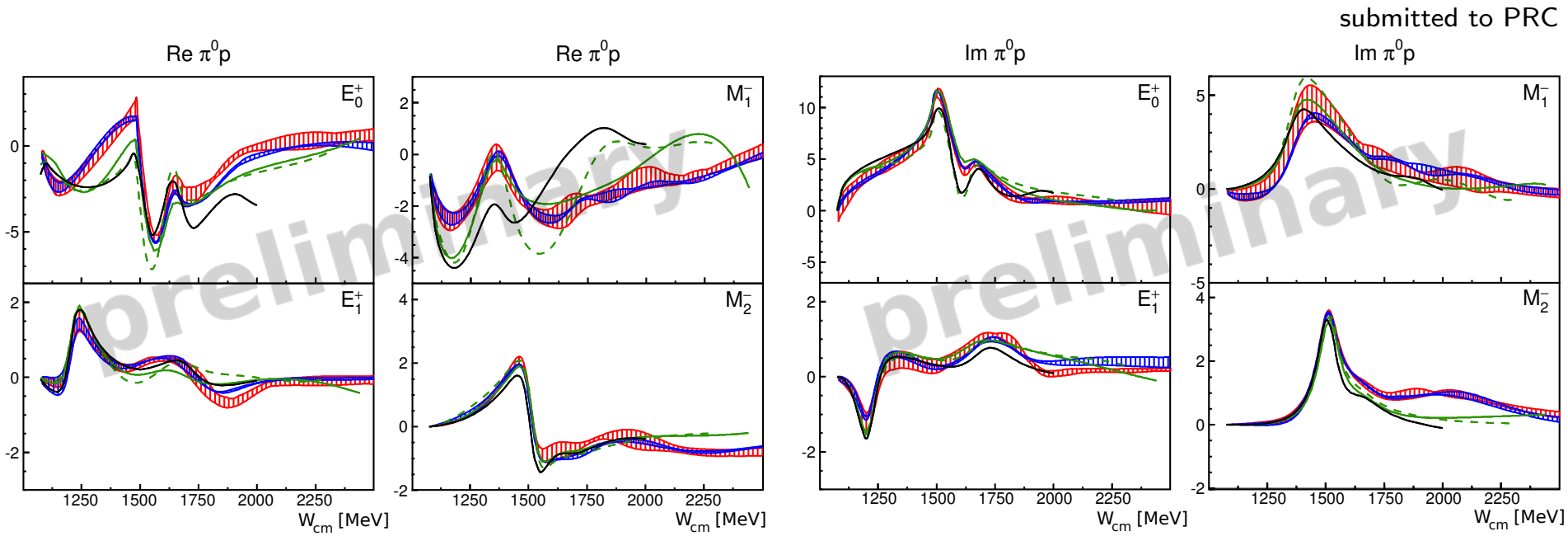


Photon Polarization		Target Pol. x	y	z
unpolarized	σ	–	T	–
linearly polarized	Σ	H	P	G
circularly polarized	–	F	–	E

- Nearly full dataset available now for π^0 photoproduction

$\rightarrow$ New datapoints fitted by the BnGa PWA

New Fit from BnGa



MAID, SAID CM12 (solid) SN11 (dashed), BnGa, BnGa with double pol. obs.

- Still large differences in the different PW analyses visible
- By using additional observables, the fit error bands get smaller

→ Including more polarization observables will converge all analyses to the same solution

Comparison between PDG values and BnGa results

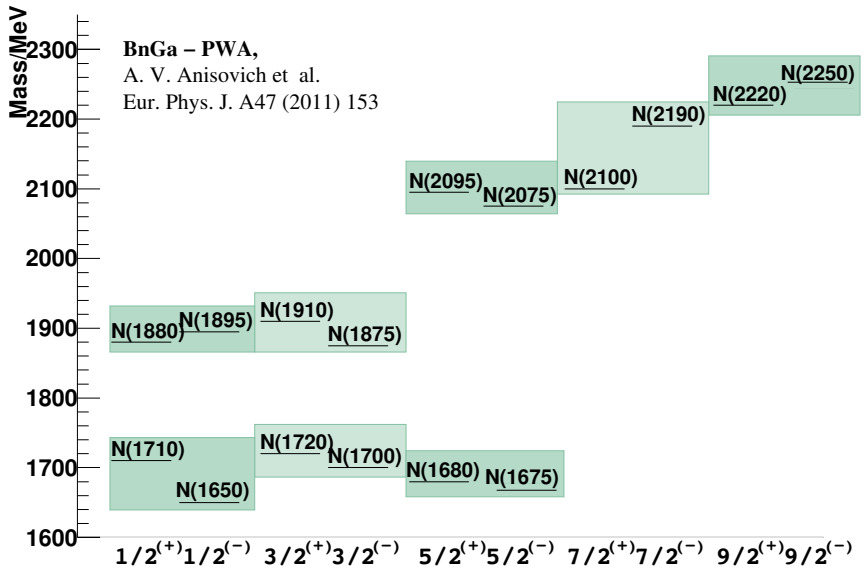
- Until 2010: almost only results from pion nucleon scattering used in the PDG, only few pion photoproduction data used
- BnGa group included photoproduction data with different final states from several experiments
- Now: new values from the BnGa fits are entering the PDG

	PDG 2010	BnGa-PWA	PDG 2012	GWU'06
N(1860)5/2$^+$		*	**	
N(1875)3/2$^-$		***	***	
N(1880)1/2$^+$		**	**	
N(1895)1/2$^-$		**	**	
N(1900)3/2$^+$	**	***	***	**no evidence**
N(2060)5/2$^-$		***	**	
N(2150)3/2$^-$		**	**	
Δ(1940)3/2$^-$	*	*	**	**no evidence**

$\rightarrow$ Same effect with the double polarization data?

Still Many Open Questions...

- Parity doublets occuring at high energies. Do they exist for all high mass states?
  They are not predicted by the current lattice QCD calculations nor by constituent quark models.



- Still many missing resonances. Why haven't we found them yet?

- Is it possible to do a complete experiment? How many observables and which precision is needed?

Conclusion

- Reactions like $\gamma p \to p\pi^0$, $p\eta$, $p\eta'$, $p\pi^0\pi^0$ have been measured with polarized photons and protons with the CBELSA/TAPS experiment

- Different single and double polarization observables have been successfully extracted over a wide energy range

  (see talks by F. Afzal and Ph. Mahlberg)

- Data for the observables Σ, G, E, T, P and H has been published for π^0 photoproduction, other channels will follow soon

Outlook

- Crystal Barrel detector is currently upgarded for a higher detection efficiency for photoproduction off the neutron
- Several other experiments (CLAS, Crystal Ball/MAMI, BGO-OD) will help to create a comprehensive database of polarization observables in different reactions
- New polarization data will help to understand the resonance spectrum and will provide an experimental basis for comparison with constituent quark models, lattice QCD or other methods

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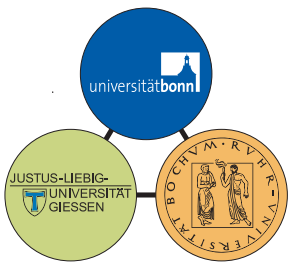
Thank you
for your attention.



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