Modifications of the $D_{33}(1700)$ resonance in the nuclear medium

Vahe Sokhoyan

Nuclear Photoproduction with GlueX
Topical Workshop, April 28 - 29, 2016

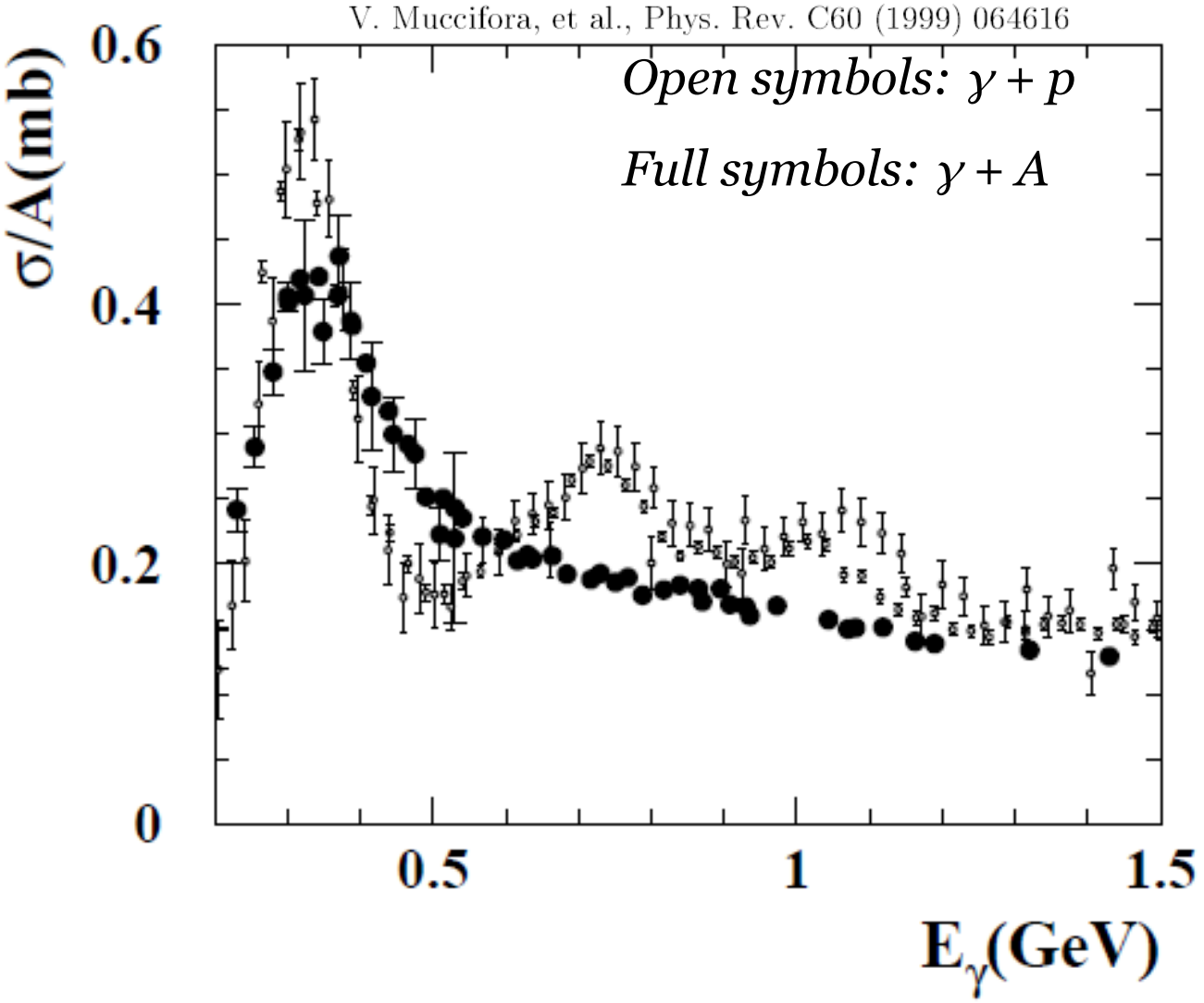
Supported by the Carl-Zeiss-Stiftung

Motivation

- Goal: Search for in-medium modifications of baryon resonances

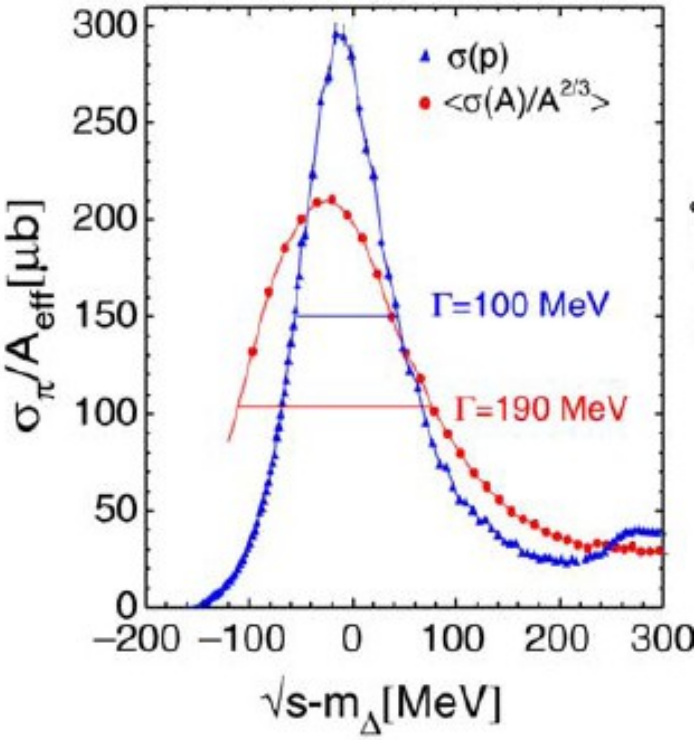
  Pronounced in-medium effect: No bump structure in the photoabsorption cross-section measured for $\gamma + A$

  → not fully explained in a model-independent way



In-medium modifications

- The width for Δ(1232) is changed in the nuclear medium from 100 MeV to ~190 MeV in good agreement with the BUU model (University Gießen) calculations

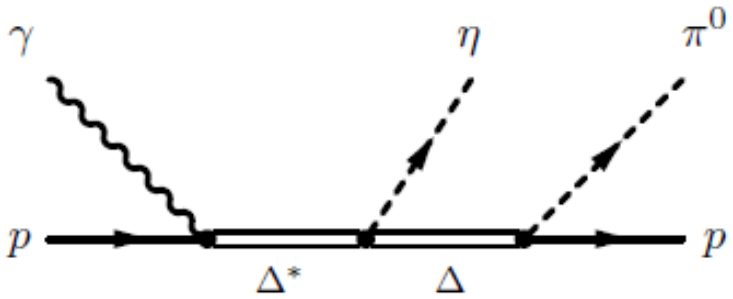


B. Krusche, Progress in Particle and Nuclear Physics 55 (2005) 46–70
M. Post, J. Lehr, U. Mosel, Nuclear Phys. A 741 (2004) 81

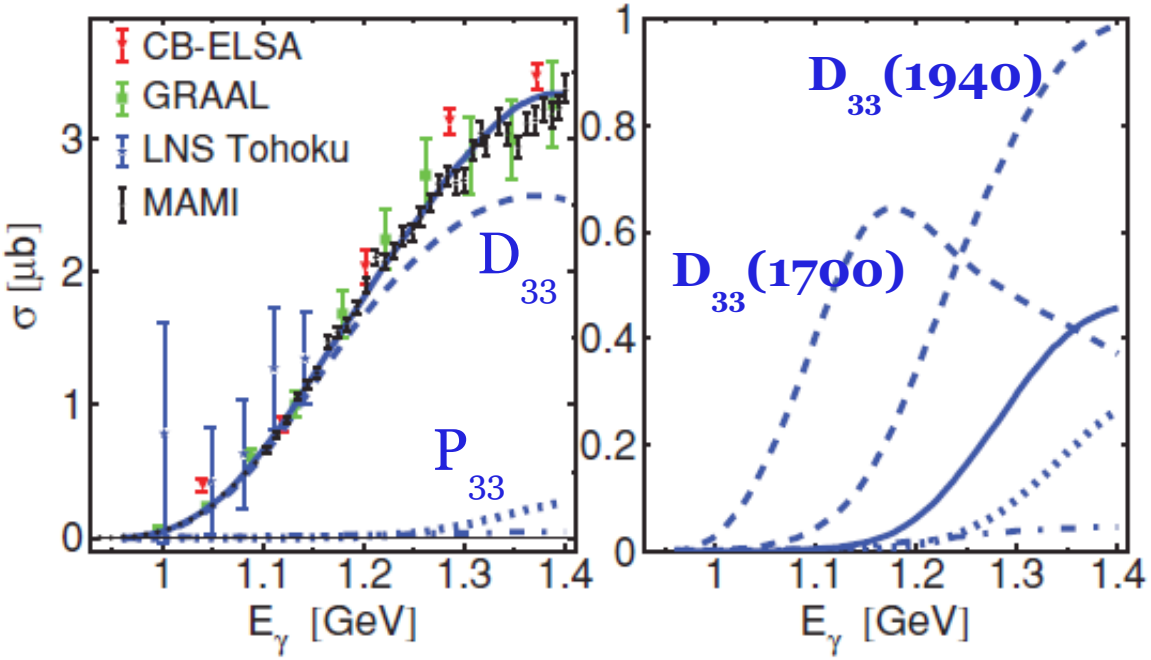
- Second resonance region: No strong experimental indication for significant modifications of $D_{13}(1520)$ or $S_{11}(1535)$

$\pi^0\eta$ photoproduction (proton target)

- The production of $\pi^0\eta$ pairs best suited to study the $D_{33}(1700)$ resonance
- η acts as an isospin filter: Access to $\gamma p \rightarrow D_{33}(1700) \rightarrow \Delta(1232)\eta \rightarrow p\pi^0\eta$

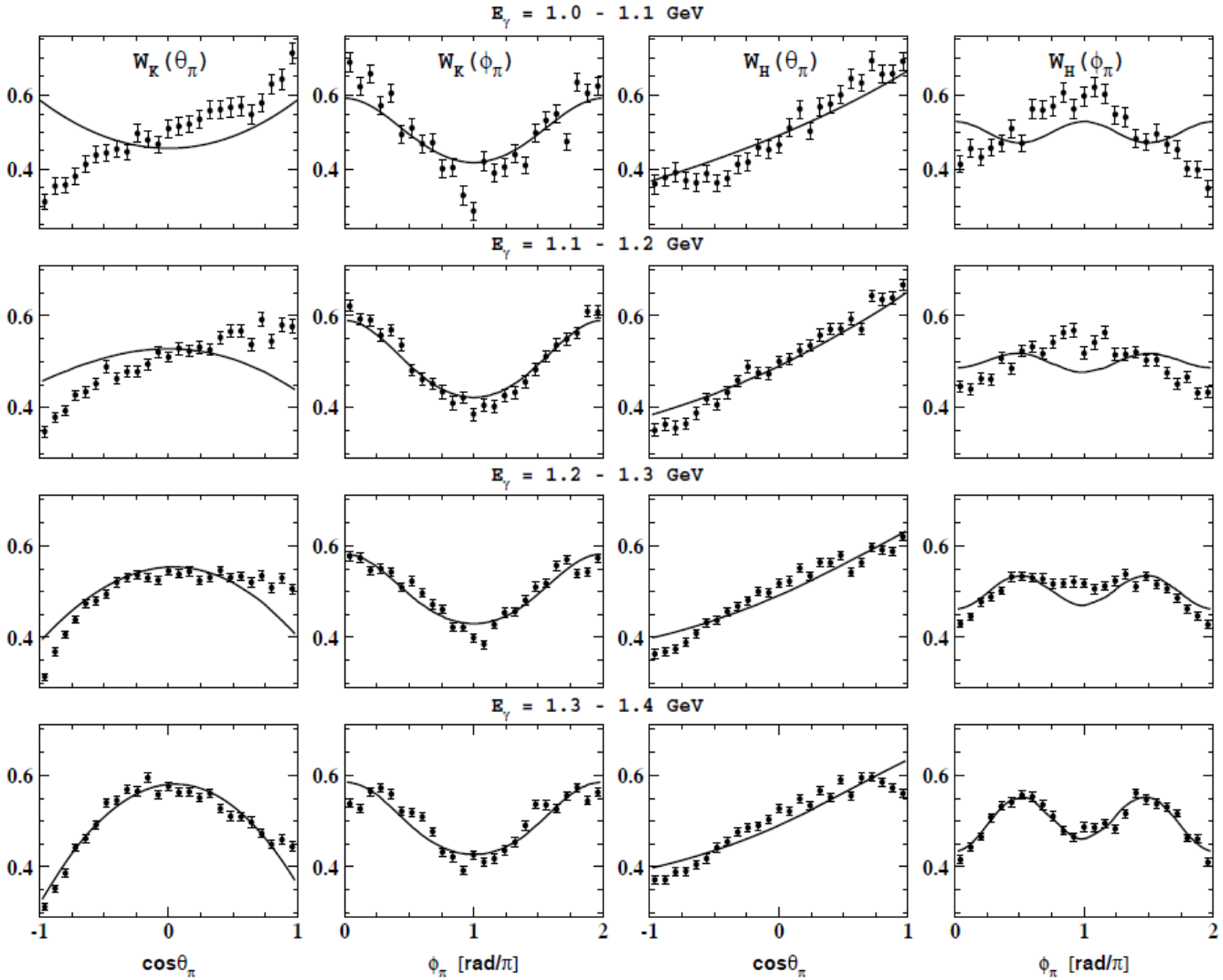


- $D_{33}(1700)$ dominates close to the production threshold



V. L. Kashevarov, A. Fix et al., Eur. Phys., J. A 42, 141 (2009) [A2 Collaboration]

Angular distributions (proton target)



Angular distributions: Reasonable agreement with a model including only the D_{33} amplitude

V. L. Kashevarov, A. Fix et al., Eur. Phys., J. A 42, 141 (2009)
[A2 Collaboration]

Polarization observables

Double meson final states:
For a complete experiment, 15 observables are needed!
W. Roberts and T. Oed, Phys. Rev. C 71, 055201 (2005)

Polarized cross-section (only polarized beam):

$$\frac{d\sigma}{dx_i} = \left(\frac{d\sigma}{dx_i}\right)_0 (1 + P_\gamma\, I^\odot + \delta_l\,(I^c cos\,2\varphi + I^s sin\,2\varphi))$$

Pγ: degree of circular polarization, δ_l: degree of linear polarization

Linear polarization: high sensitivity to resonances

V. S., E. Gutz, V. Crede, H. van Pee, et al., Eur. Phys. J. A51, 2015 *[CBELSA/TAPS Collaboration]*
V. S., E. Gutz, H. van Pee et al., Phys.Lett. B746, 2015 *[CBELSA/TAPS Collaboration]*
E. Gutz, V.S., H. van Pee et al., *Phys. Lett. B687, 2010 [CBELSA/TAPS Collaboration]*
E. Gutz, V. Crede, V.S., H. van Pee et al., *Eur. Phys. J. A50 74, 2014 [CBELSA/TAPS Collaboration]*

- Relatively low polarization at energies ~1 GeV
- Difficulties in extraction of unpolarized cross-sections

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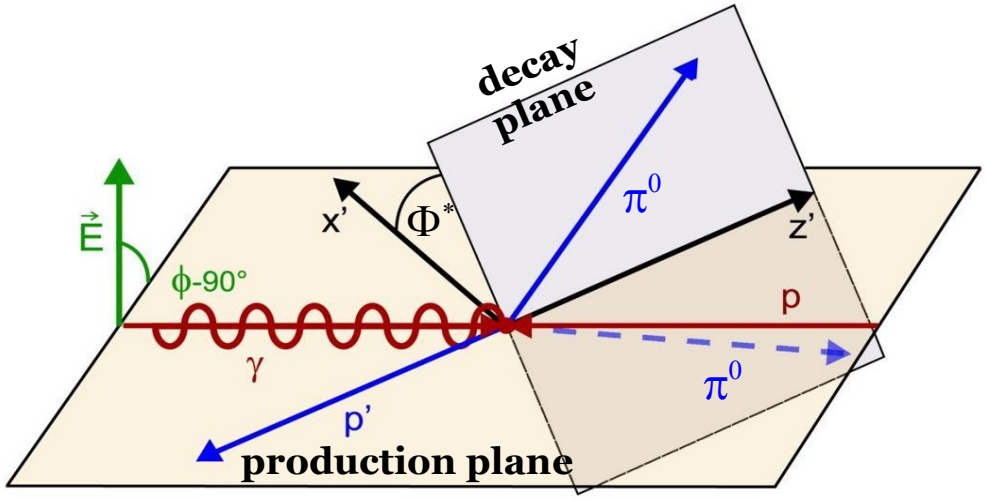
Circular polarization: high sensitivity to $D_{33}(1700)$

V. L. Kashevarov, A.Fix et al., *Phys. Lett. B 693, 551, 2010 [A2 Collaboration]*
High values of polarization achievable at ~1 GeV
No modification of the incoming photon energy spectrum

Measurement of I^s and I^c

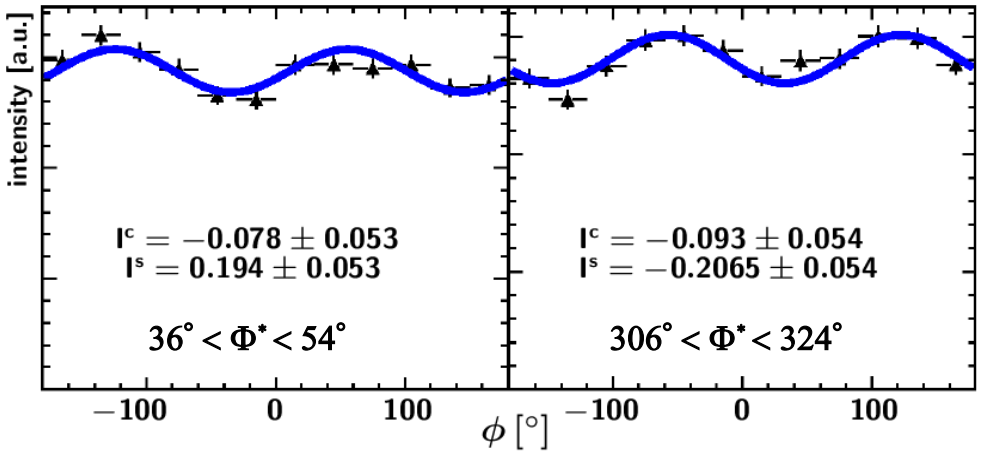
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 + \delta_l[I^s \sin(2\phi) + I^c \cos(2\phi)]\}$$



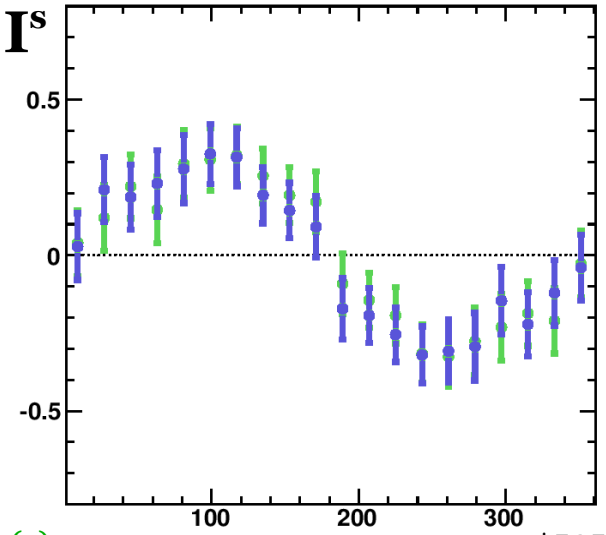
$I^c(\Phi^*) = I^c(2\pi - \Phi^*)$

$I^s(\Phi^*) = -I^s(2\pi - \Phi^*)$

$f(\phi) = A(1+\delta_l(B\sin2\phi + C\cos2\phi))$

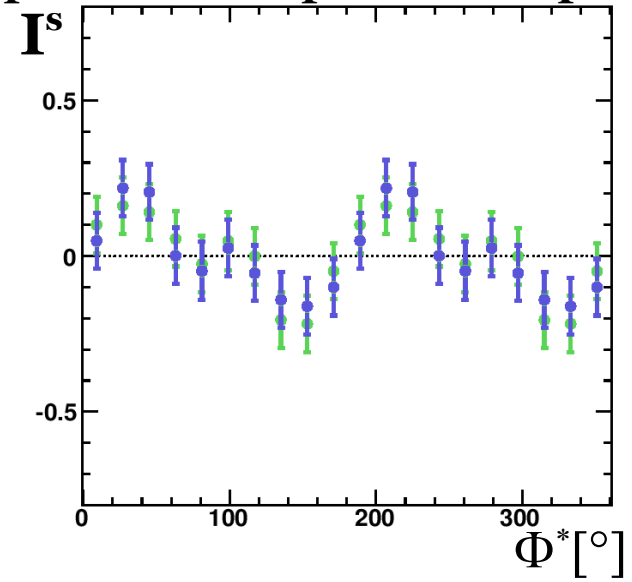


π^o in the production plane

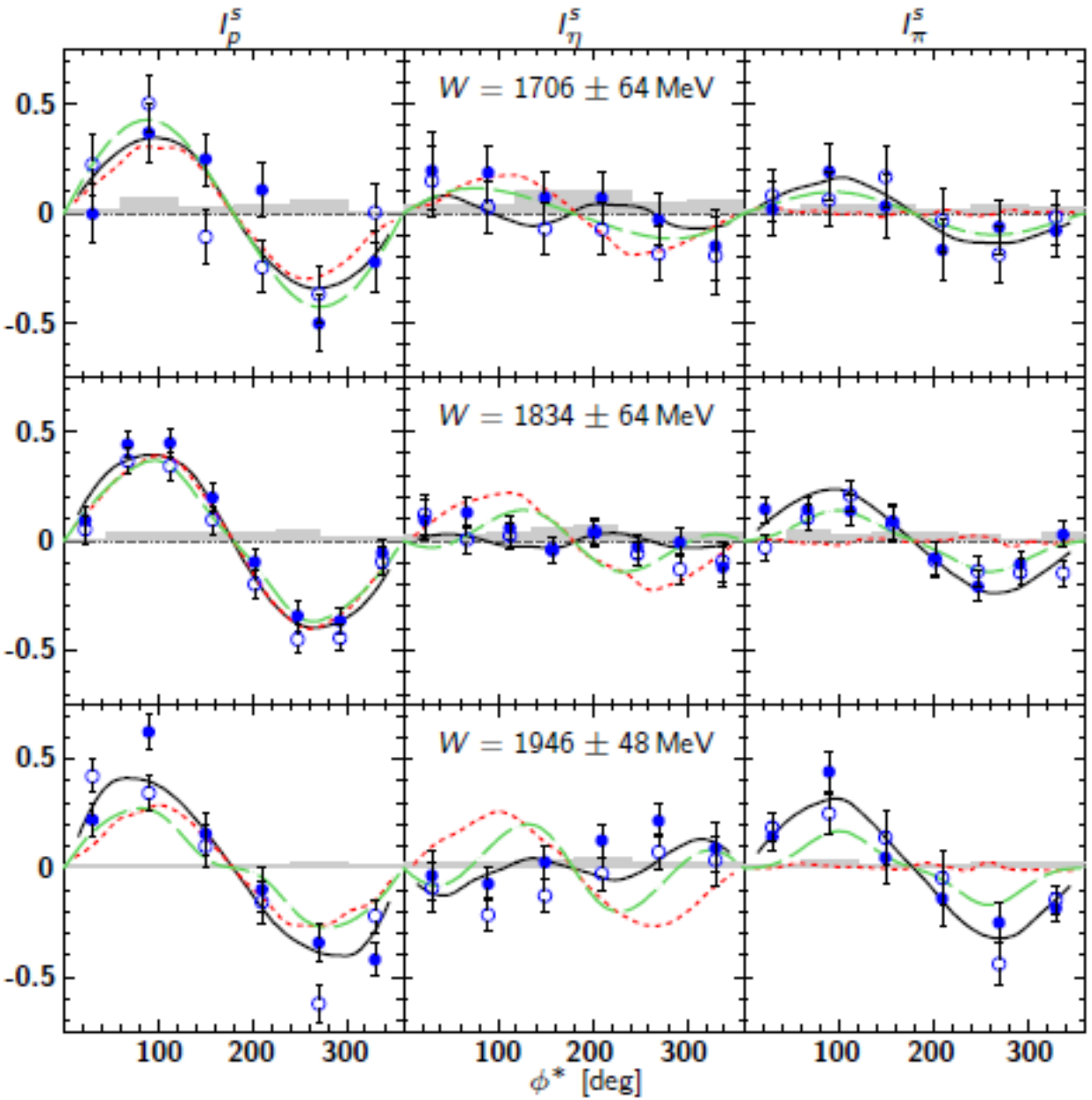


$I^{s(c)}(\Phi^*) = I^{s(c)}(\Phi^* + \pi)$

proton in the production plane



$\pi^0\eta$ photoproduction (CBELSA/TAPS)



Closed symbols:
$I^s(\phi^*)$
Open symbols:
$-I^s(2\pi - \phi^*)$

Bars: Systematic error estimate

Curves:

— BnGa-PWA

— Valencia model
M. Döring, E. Oset, U.-G. Meißner
Eur. Phys. J. A 46 (2010) 315

— Fix isobar model
A. Fix et al., Phys. Rev. C
82 (2010) 035207

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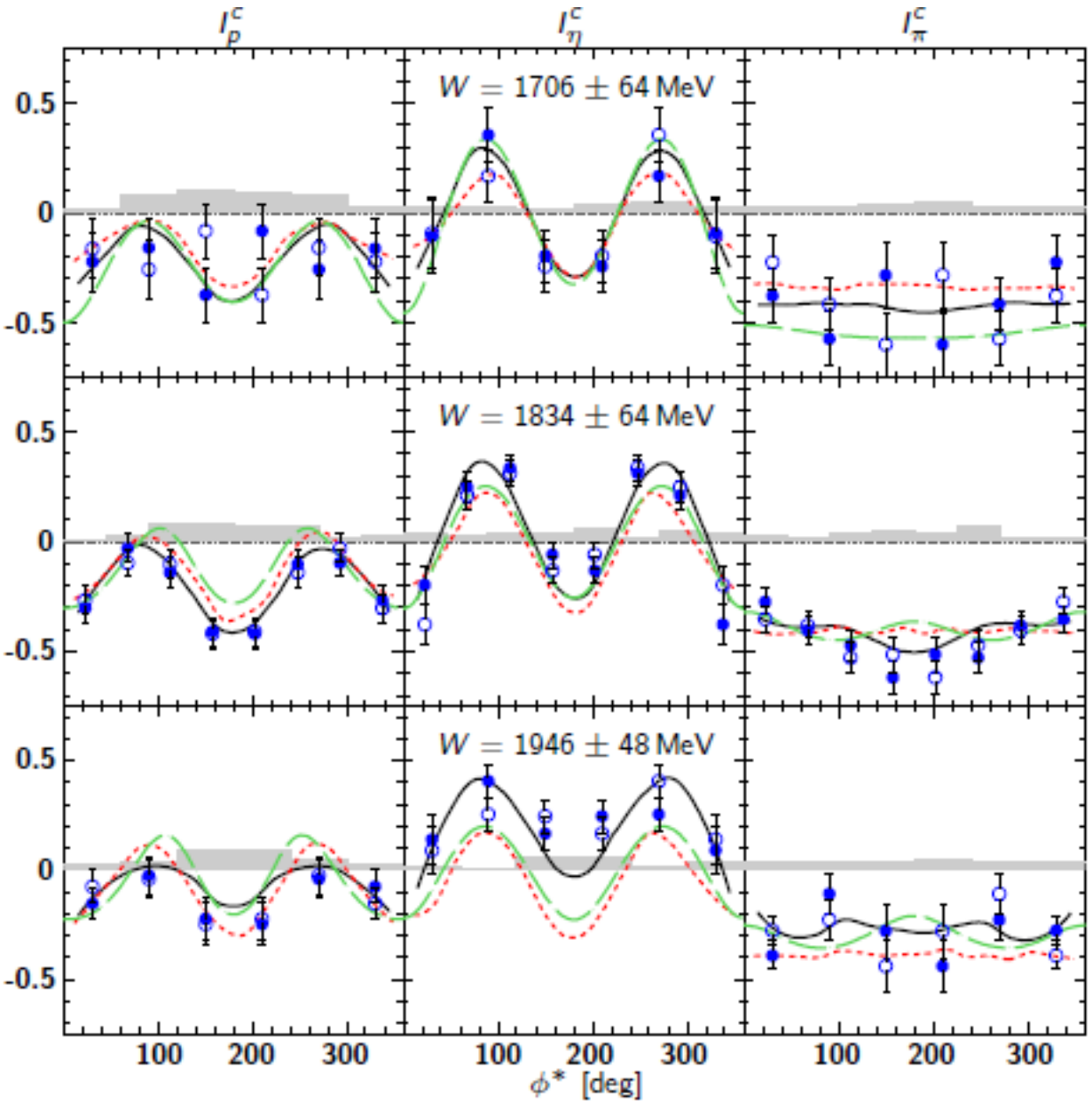

Closed symbols:
$I^c(\phi^*)$
Open symbols:
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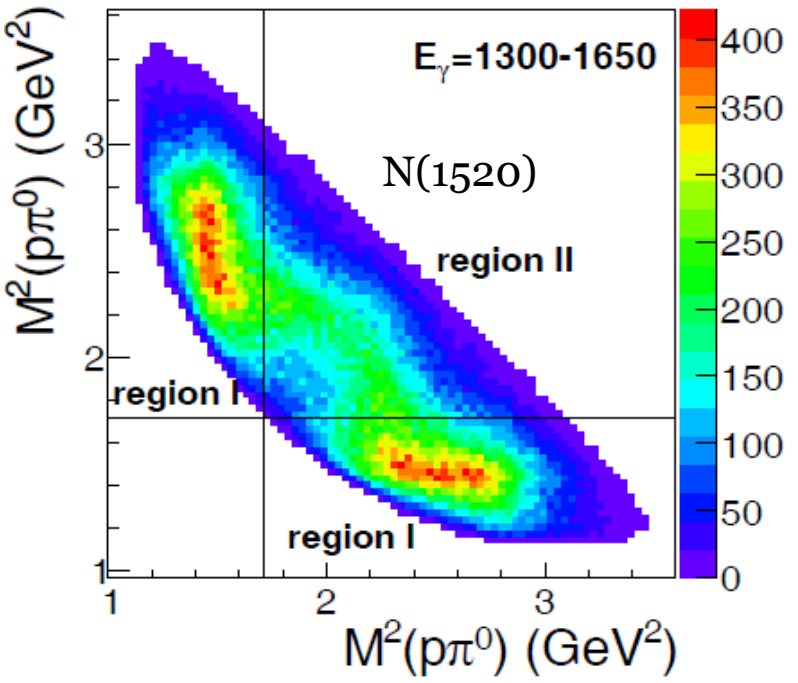
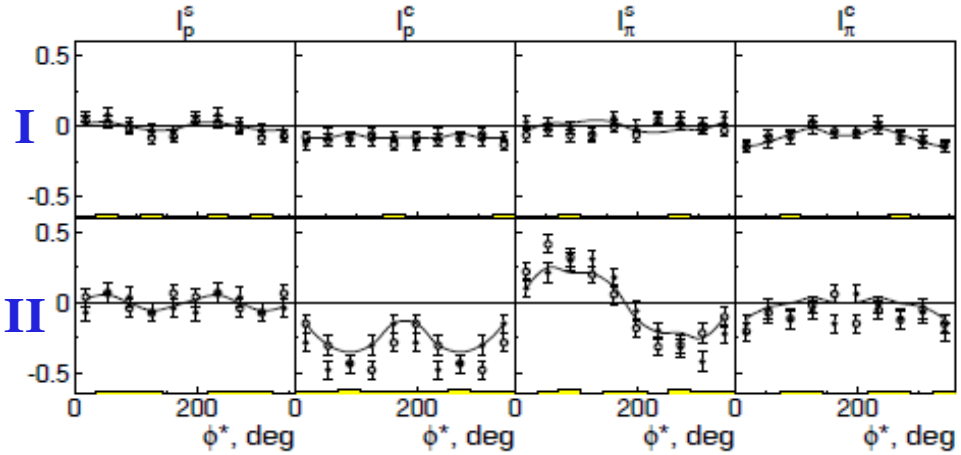
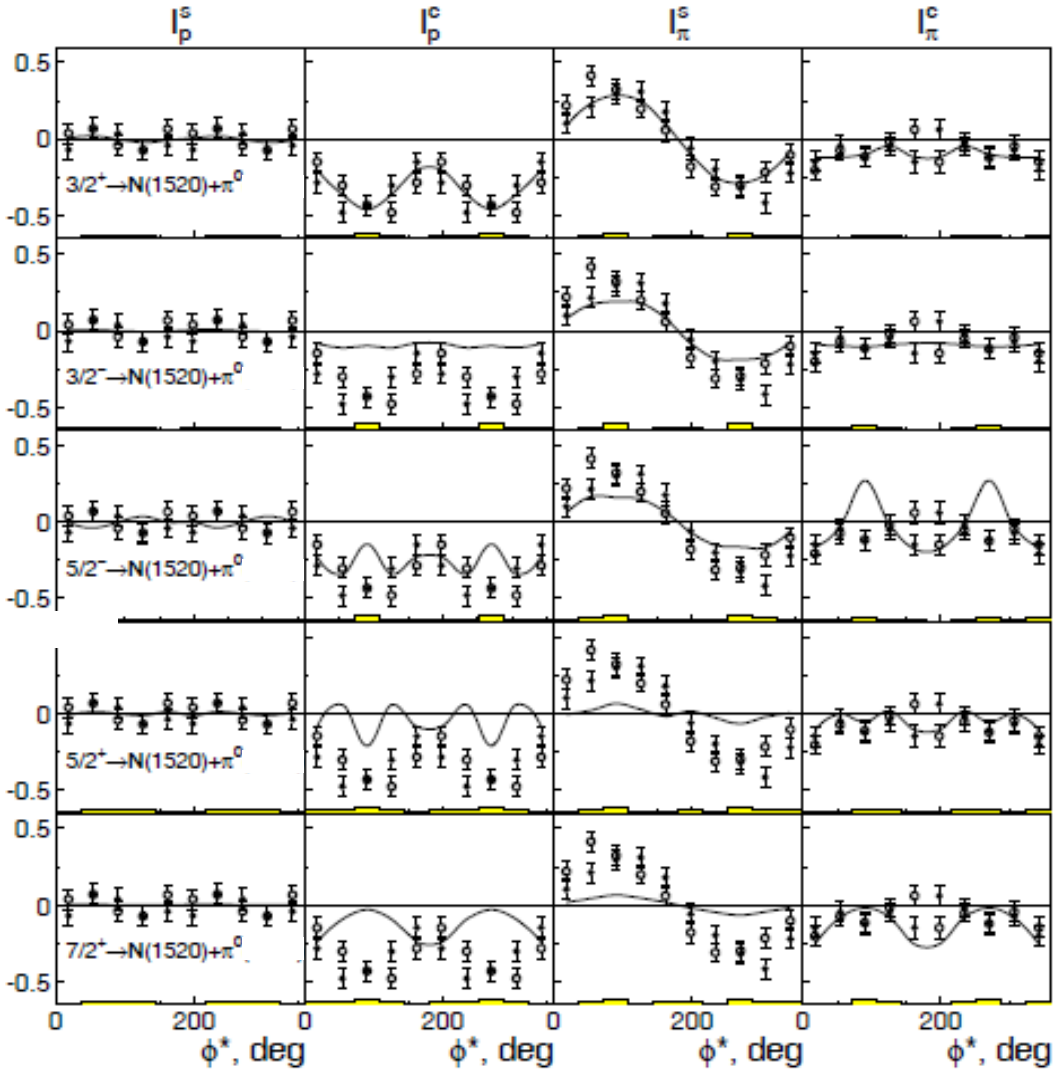
I^s and I^c in $\gamma p \to p\pi^0\pi^0$ and N(1900)3/2$^+$ resonance



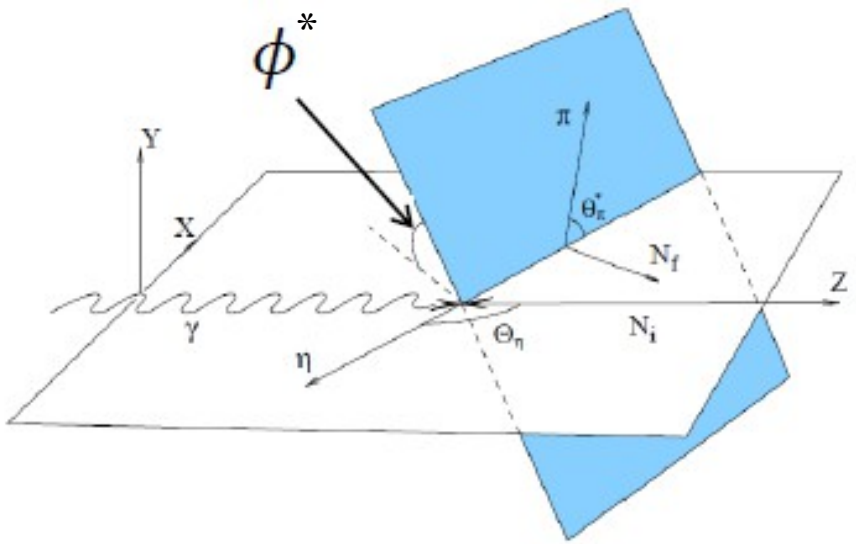


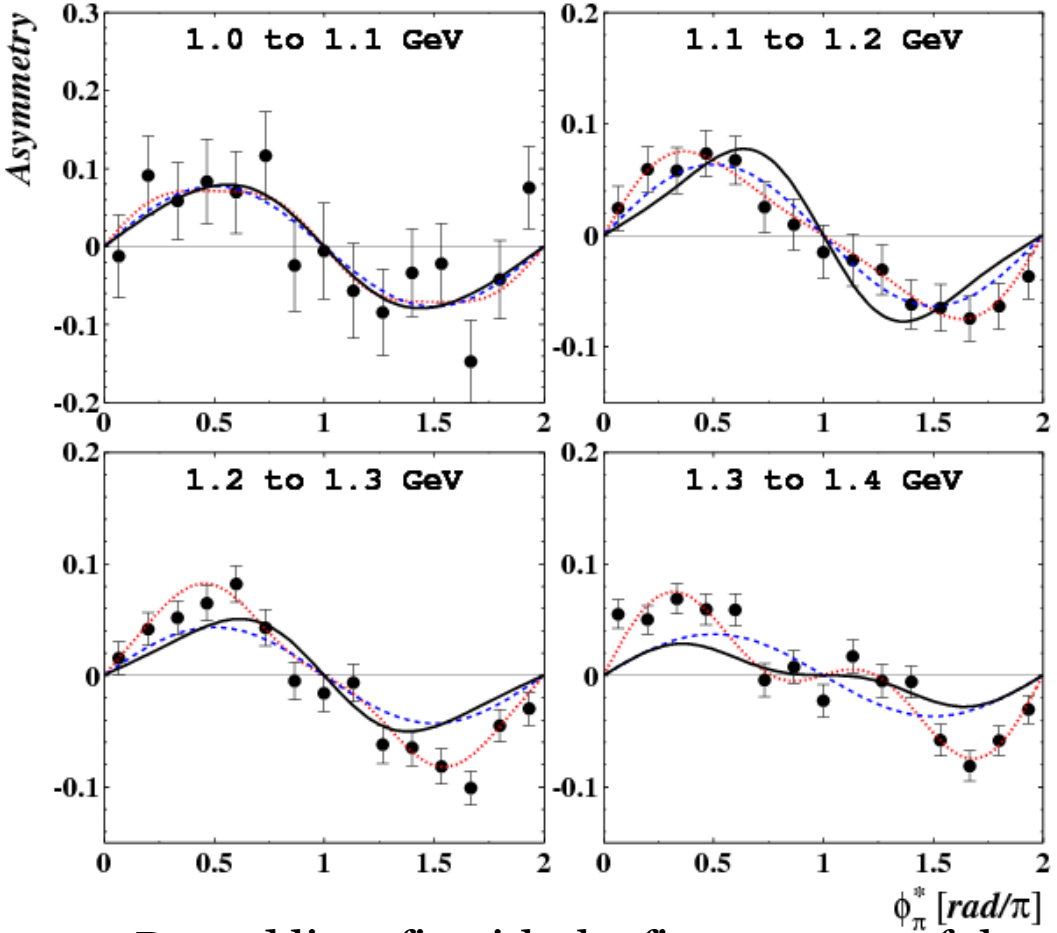


Dominance of the N(1900)3/2$^+$resonance directly seen in the data

V. S., E. Gutz, H. van Pee et al., Phys.Lett. B746 (2015) 127-131

Beam helicity asymmetry (proton target)





Beam helicity asymmetry:

$$W^c(\phi) \sim \sigma^+(\phi) - \sigma^-(\phi)$$

$W^c(\phi)$ can be expanded as:

$$W^c(\phi) = \sum_{n=1}^{n_{max}} A_n \sin n\phi$$

Dotted line: fit with the first 3 terms of the sine expansion (A1, A2, A3)
Solid line: isobar model with 6 resonances
Dashed line: only D33 wave

V. L. Kashevarov, et al., Phys. Lett. B 693, 551 (2010)

[A2 Collaboration]

Both unpolarized and polarized data indicate the dominance of the D_{33} wave at energies $E_\gamma < 1.2$ GeV

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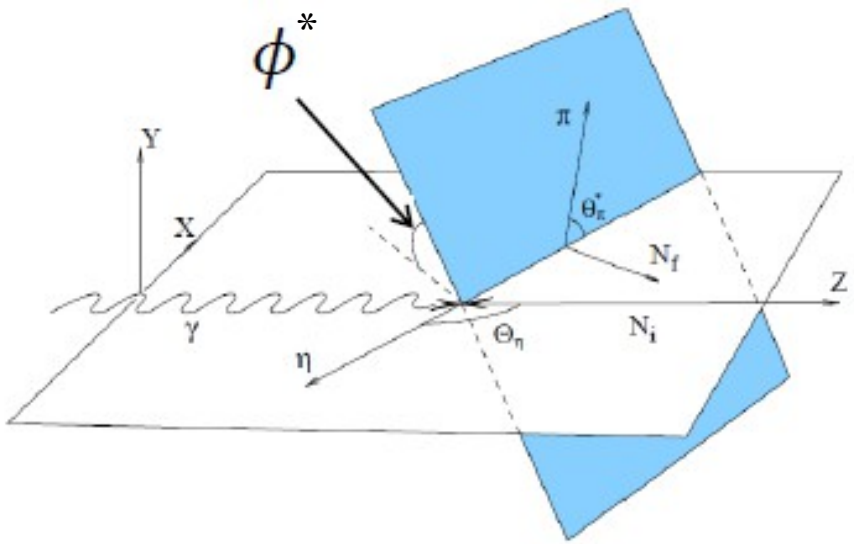

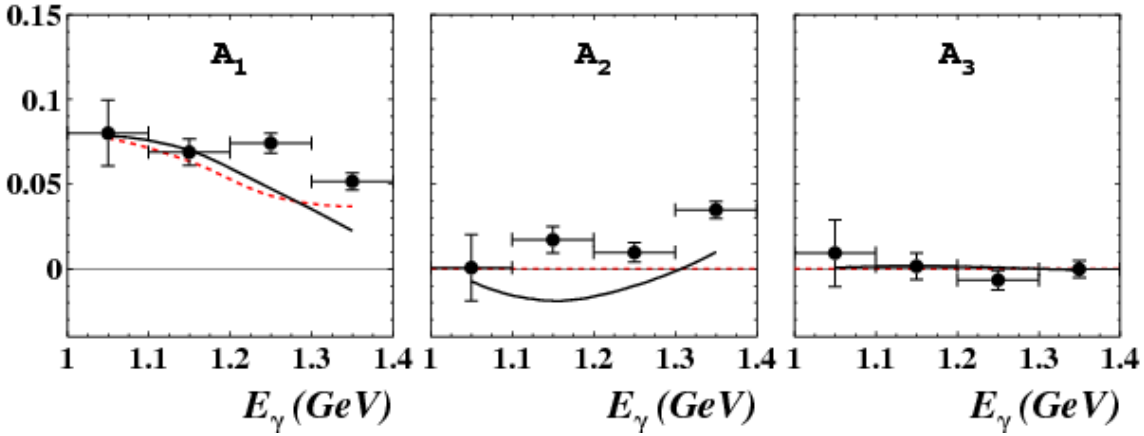

Coefficients of the sine expansion
Solid line : full model prediction
Dashed line: only the *D*33 amplitude.

V. L. Kashevarov, et al., Phys. Lett. B 693, 551 (2010)

$W^c(\phi)$ can be expanded as:

$$W^c(\phi) = \sum_{n=1}^{n_{max}} A_n \sin n\phi$$

A_1 represents purely the contribution of the D_{33} wave

A_2 is sensitive to interference terms

A_3 is negligible

Both unpolarized and polarized data indicate the dominance of the D_{33} wave at energies E_γ < 1.2 GeV

Existing data and next steps

Existing data sets:

- The structure in these observables is reasonably described by the $D_{33}(1700)$ resonance within the isobar model for the proton target at $E_\gamma < 1.2$ GeV (A. Fix, et al.)
- Any changes of these observables beyond FSI will allow access to the in-medium properties of the $D_{33}(1700)$
- Measurements performed by the A2 Collaboration with proton and deuteron targets will be used as a reference

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This program is aiming for:

- Study modifications of the $D_{33}(1700)$ resonance
- Measurement and interpretation of polarization observables for the investigation of in-medium modifications (and unpolarized cross-sections)
- Better understanding of the Final State Interaction (FSI)
- Understanding of the nature of the $D_{33}(1700)$: Is it dynamically generated?

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We are extracting:

- **Differential cross-sections and beam helicity asymmetry close to the $\pi^0\eta$ production threshold with C, Al and Pb targets**

- Data on ^{4}He will be acquired in the near future

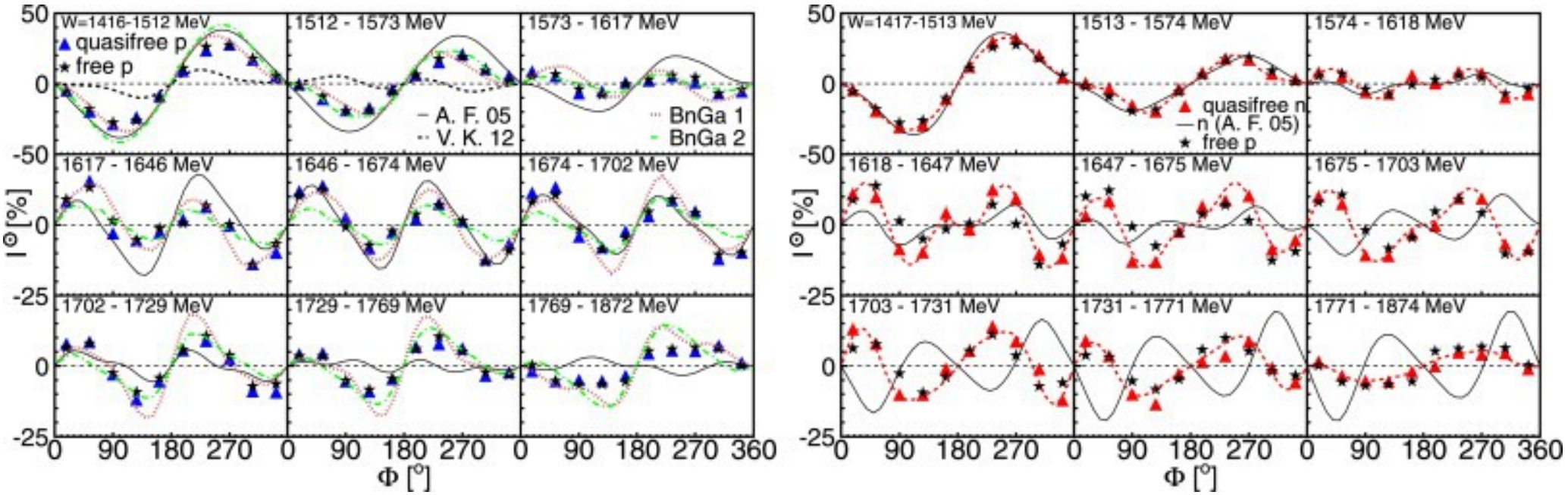
Understanding of the FSI

Experimental method:

- Investigation of the FSI with light nuclei (deuteron, helium isotopes)
- Investigation of the coherent component
- Measurements with different targets
- New asymmetry data can be useful for the understanding of the mechanisms of the FSI
- and:
- Estimates from the model of A. Fix (includes FSI)
- Interested to obtain calculations from the BUU transport model

Understanding of the FSI

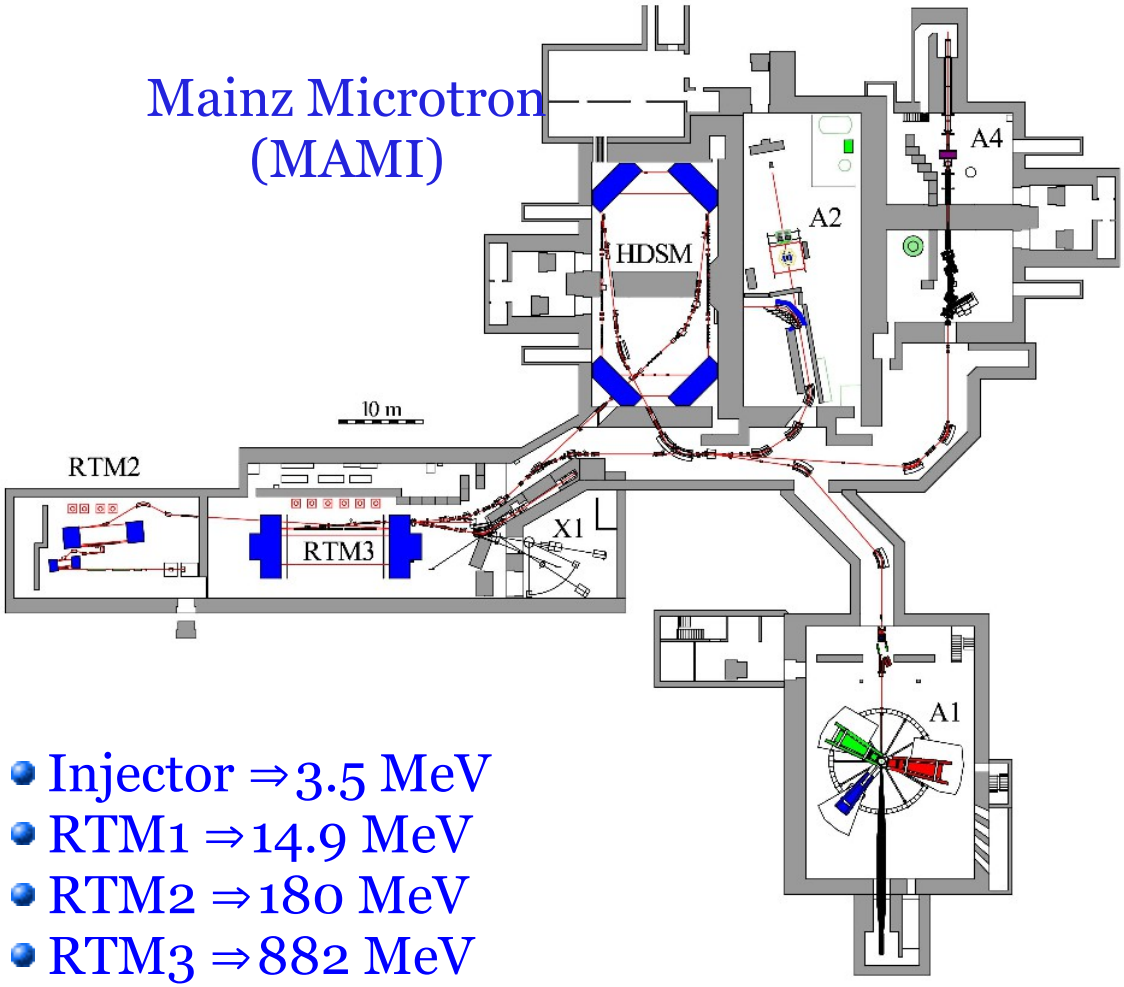
Example: Significant reduction of the total cross-section was observed for the deuteron target in several reactions, indicating strong FSI effects, but e.g. for the production of 2 neutral pions, the beam helicity asymmetry is in excellent agreement for the free proton (hydrogen target) and quasi-free proton (deuteron target) data
(M. Oberle, B. Krusche et al., Phys. Lett. B721 (2013) 237-243 [A2 Collaboration])



Black: free proton, Blue: quasi-free proton. Red: quasi-free neutrons
M. Oberle, B. Krusche et al., Phys.Lett. B721 (2013) 237-243
[A2 Collaboration]

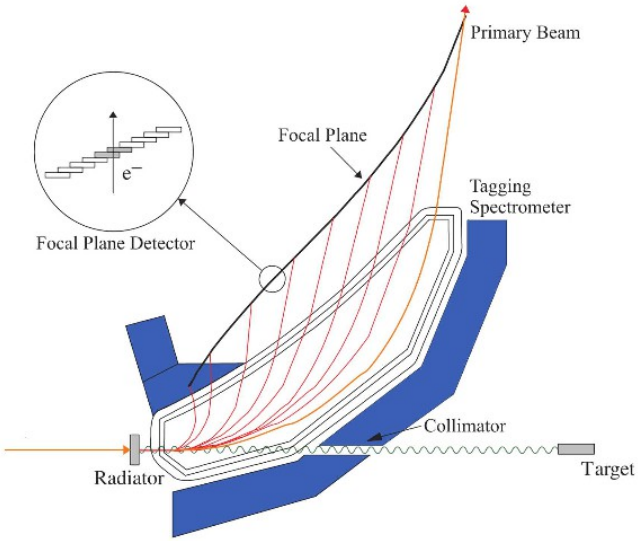
MAMI and Crystal Ball experiment

Mainz Microtron (MAMI)



- Injector ⇒ 3.5 MeV
- RTM1 ⇒ 14.9 MeV
- RTM2 ⇒ 180 MeV
- RTM3 ⇒ 882 MeV
- HDSM ⇒ 1.6 GeV

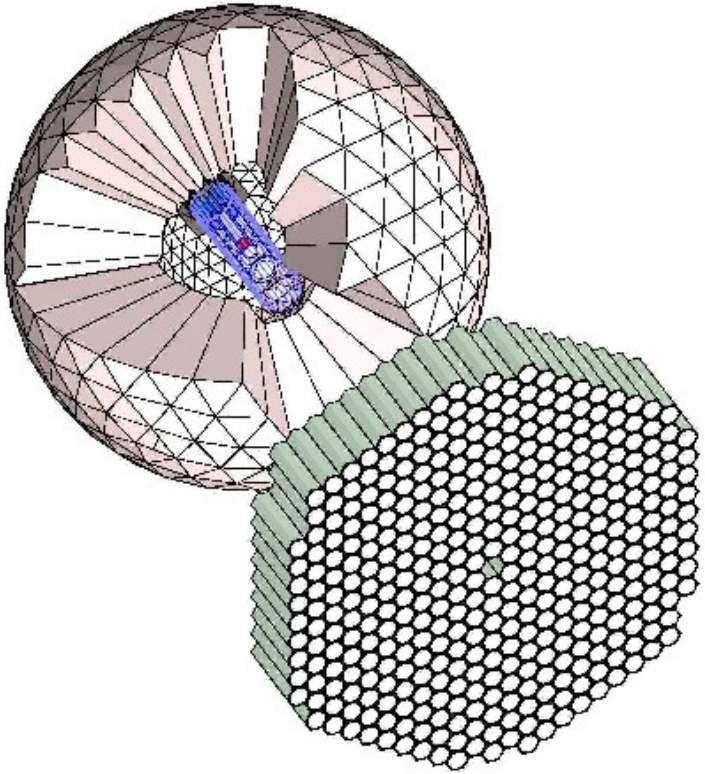
Tagger

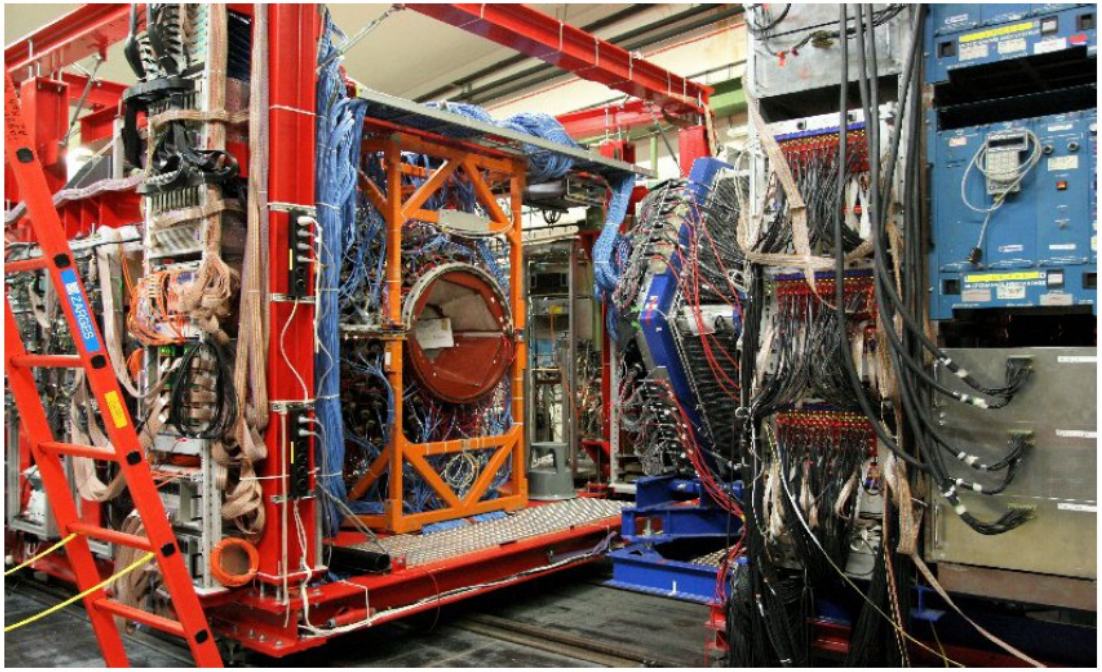


$E_\gamma = E_o - E_{e^-}$

- High-Flux, Tagged, Bremsstrahlung Photon Beam: Unpolarized, Linear, and Circular
- Polarized and Unpolarized Targets

Crystal Ball/TAPS experiment





Crystal Ball:

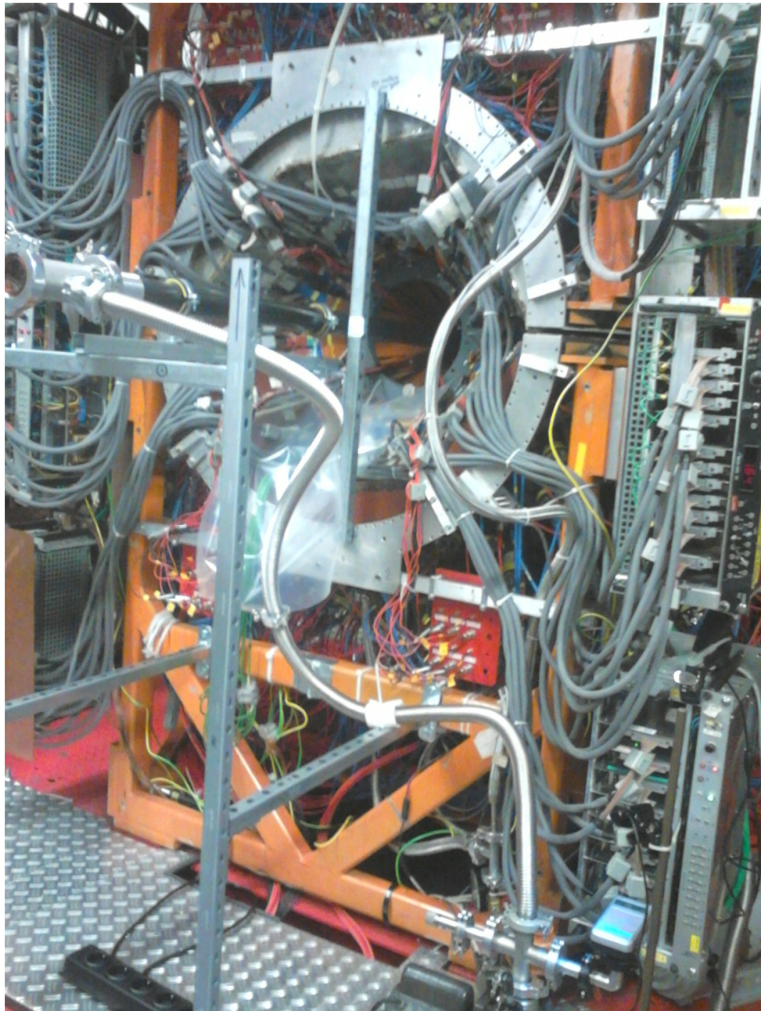
- 672 NaI Crystals
- 24 Particle Identification Detector Paddles
- 2 Multiwire Proportional Chambers

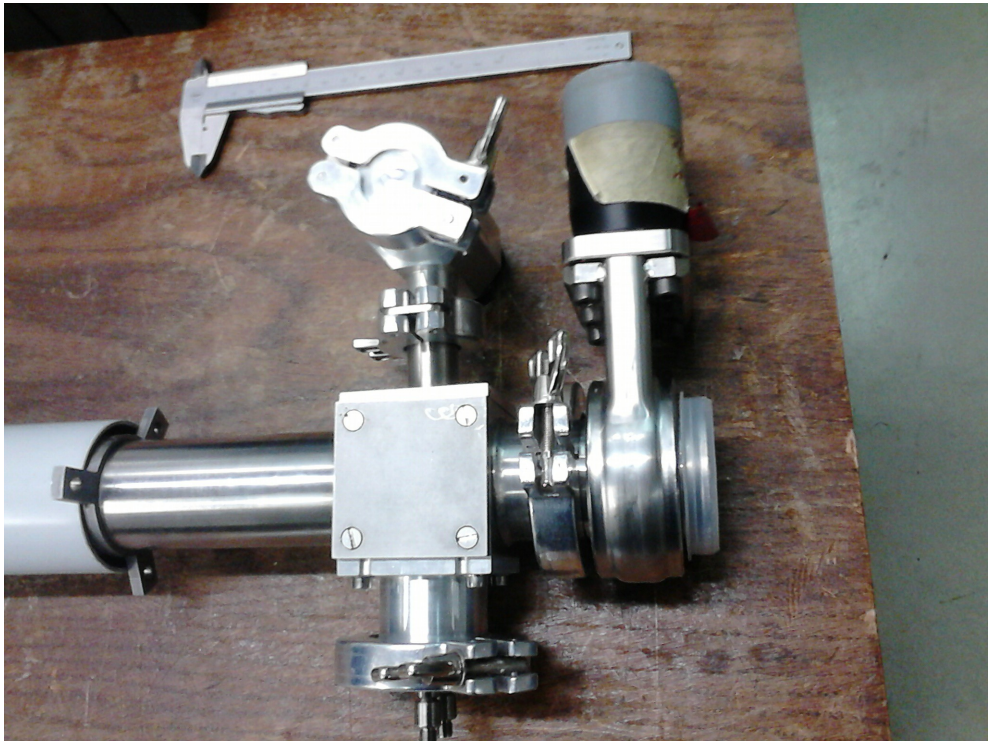
TAPS:

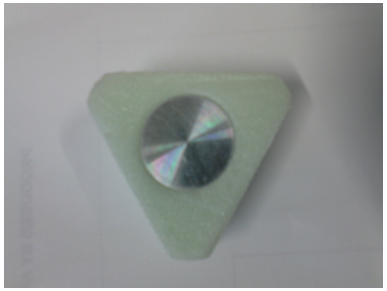
- 366 BaF_2 and 72 $PbWO_4$ Crystals
- 384 Veto Detectors

Experimental Setup

- Carbon pipe for positioning targets in the Crystal Ball
- Targets: C, Al, Pb and other parts such as an inserter prepared
- Empty insert for the cryostat built in the KPH Mechanical and Vacuum Workhops







Run conditions

- Targets C (2 cm), Al (8 mm), Pb (0.5 mm), empty target
- E_{beam} = 1557 MeV (+ 8 hours with 883 MeV with the Pb target)
- Circularly polarized photons (electron polarization 70-74%)
- Tagged photon energy E_γ > 500 MeV for C and Al, E_γ > 780 MeV for Pb
- Currents: 4.5 nA (C), 7.5 nA (Al), 16.5 nA (Pb)
- Collimator: 2.5 mm
- Trigger: M2+ and

  CB_{Esum} > 320 MeV for Al and Pb targets

  CB_{Esum} > 350 MeV for C target

Acquired data

- C target ~90 h with 1557 MeV beam
- Al target ~120 h with 1557 MeV beam
- Pb target ~100 h (1557 MeV beam), ~8 h with 883 MeV beam
- Empty ~20 h with 1557 MeV beam

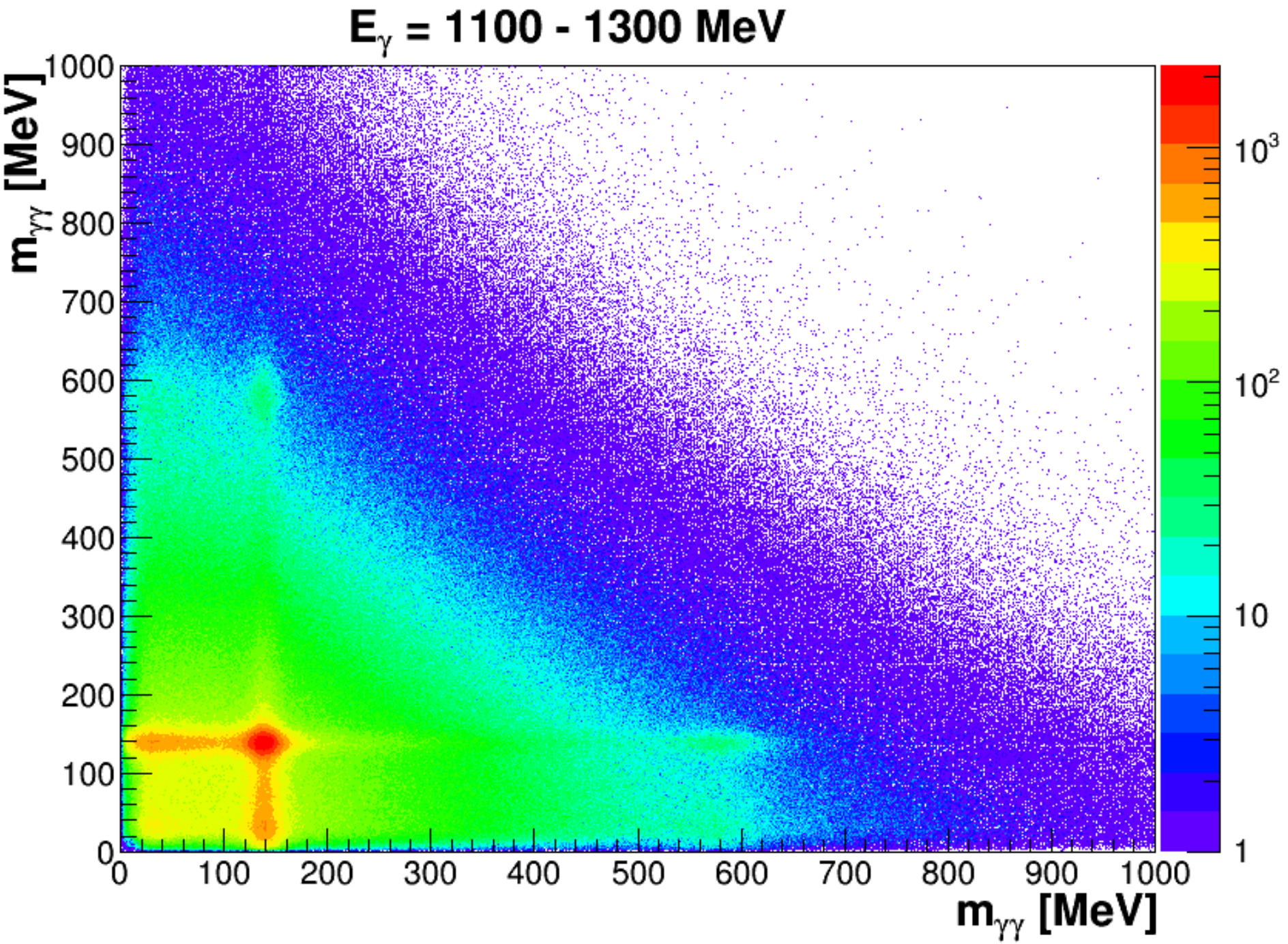
Acquired data

- C target ~90 h with 1557 MeV beam
- Al target ~120 h with 1557 MeV beam
- Pb target ~100 h (1557 MeV beam), ~8 h with 883 MeV beam
- Empty ~20 h with 1557 MeV beam

Preliminary selection of events with $\pi^0\eta$ and $\pi^0\pi^0$ production

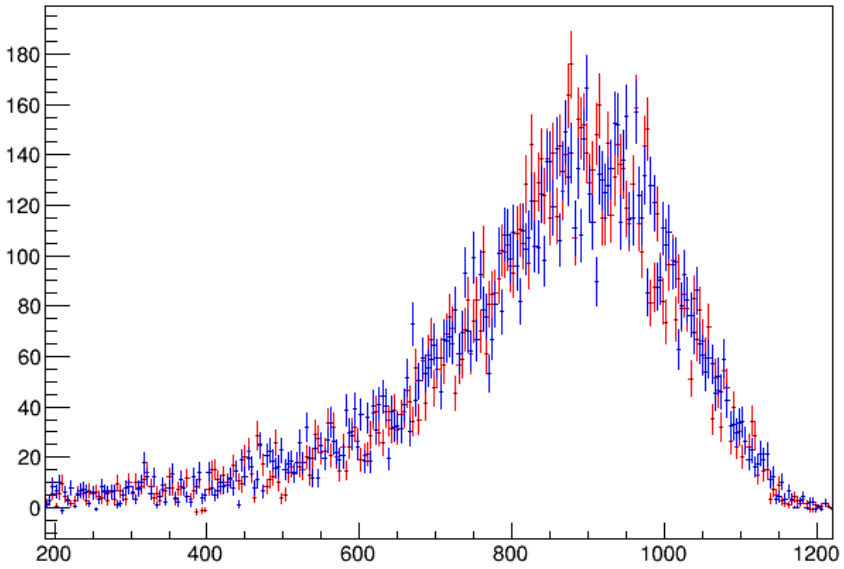
- $E\gamma_{(beam)}$ = 1000 – 1450 MeV
- Selecting events with 4 γ (+ 1 charged hit or + X hits)
- Invariant mass cut
- Missing mass cut (?)
- Subtraction of random timing background
- Negligible empty target contribution

Example Spectra (Carbon target)



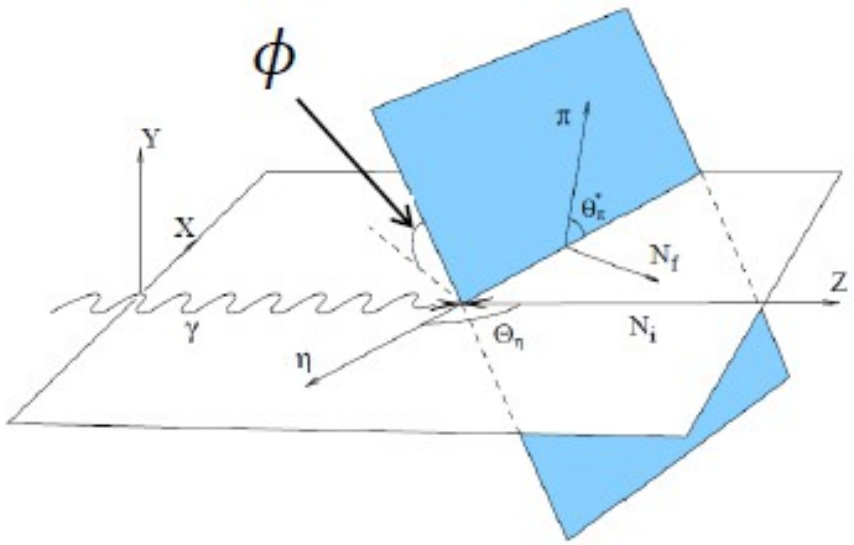
Example Spectra (Aluminium target)

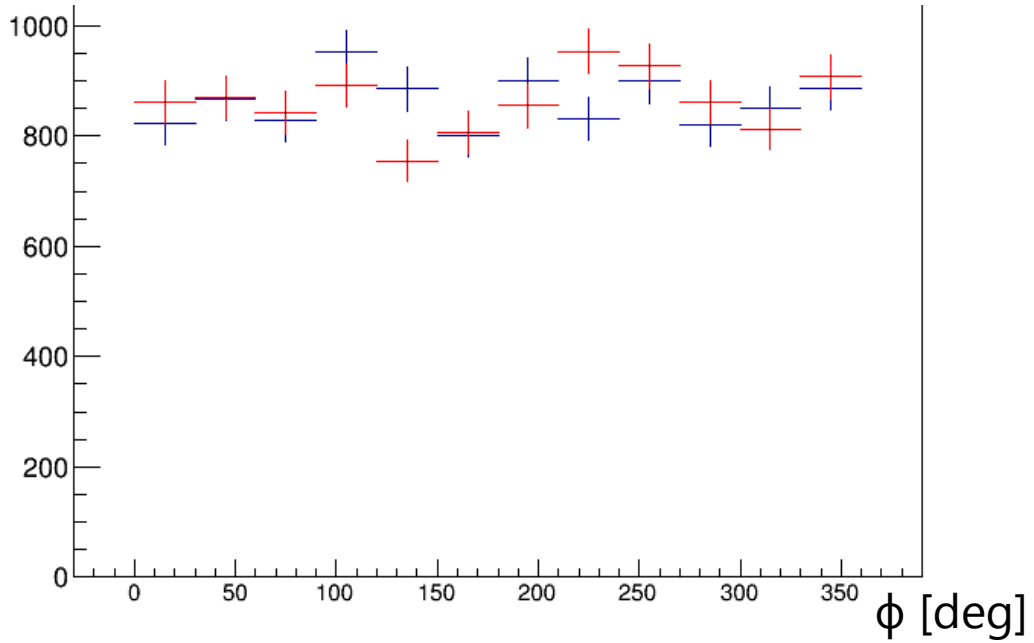
E_γ = 950 – 1450 MeV



Missing Mass [MeV]

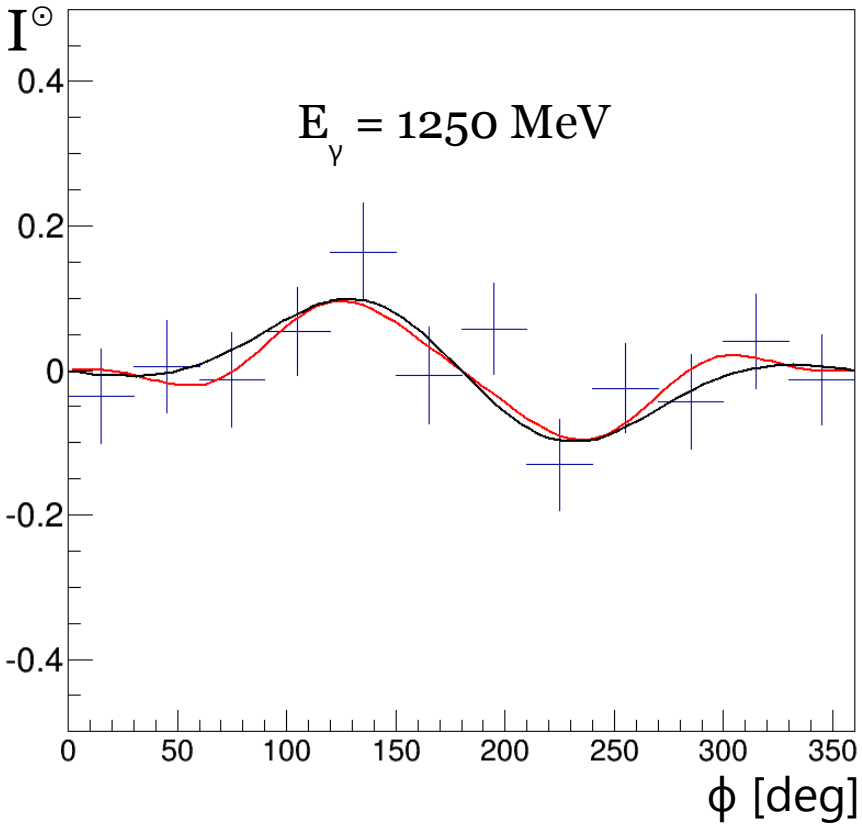
Agreement between “unpolarized” distributions with different helicity

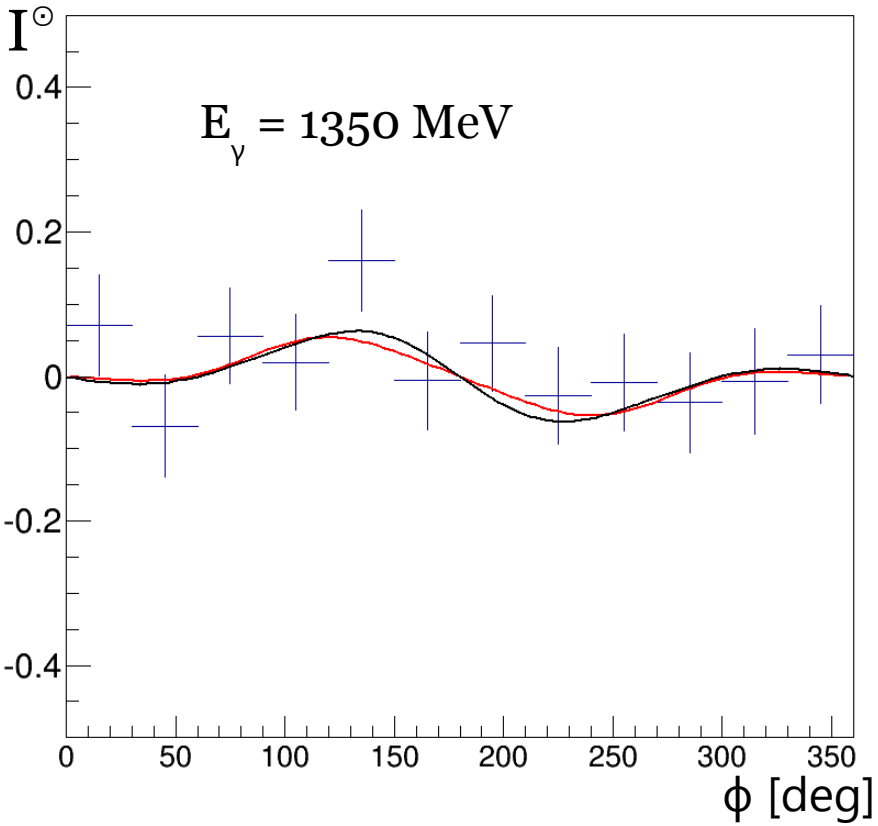




Difference in 3-body kinematics: ϕ dependence seen in the data

Example Spectra (Al target)





- Very preliminary asymmetries seen in the data for ~35% of Aluminium data (4 photons + X) events considered
- Curves: red fit to the data, black calculation within isobar model
- Small asymmetry in energy binning → differential distributions

Outlook: Next steps

- New project aiming for the investigation of the $D_{33}(1700)$ resonance in the nuclear medium
- Differential cross-sections for $\pi^0\eta$ photoproduction and beam helicity asymmetry will be extracted
- Existing data obtained with proton and deuteron targets will be used as a reference
- FSI effects will be investigated in cooperation with theory groups

Available manpower:

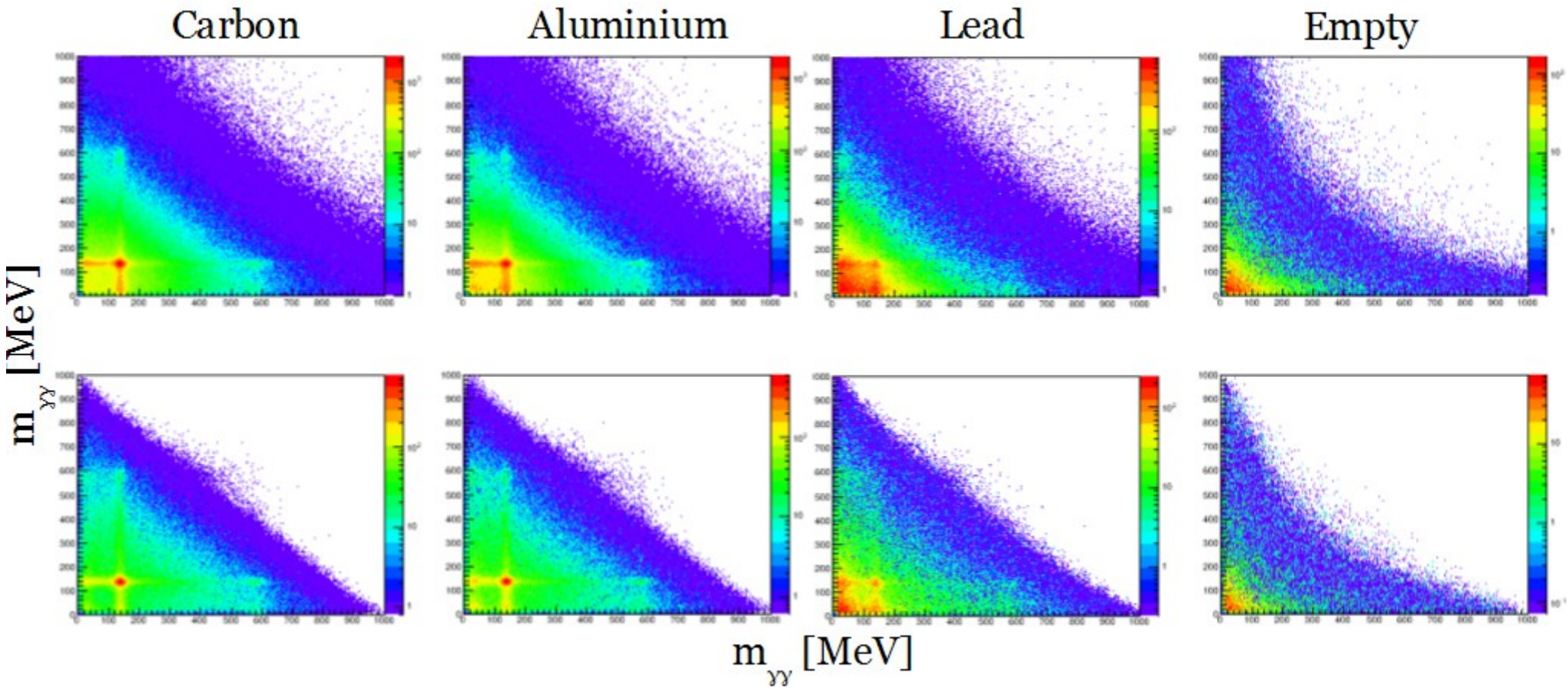
Master and Diploma students

Experienced postdoc, S. Prakhov (UCLA) will contribute to the data analysis

Thank you for your attention!

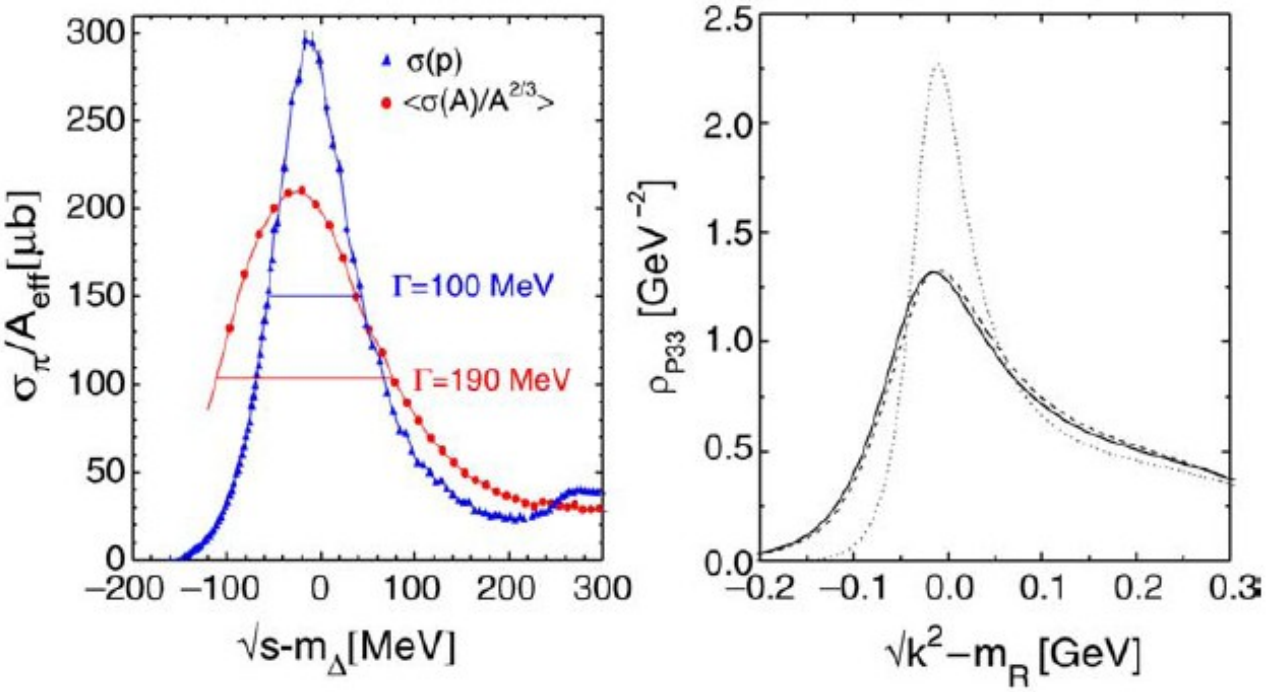
Backup

Example Spectra (Carbon target)



Motivation

- The width for Δ(1232) is changed in the nuclear medium from 100 MeV to ~190 MeV in good agreement with theory (BUU model) calculations



- Second resonance region: No strong experimental indication for significant modifications of $D_{13}(1520)$ or $S_{11}(1535)$