# Production of $\pi^0\eta$ pairs off nucleons and nuclei

**Vahe Sokhoyan, Sergey Prakhov**

Bonn, 21.03.2017

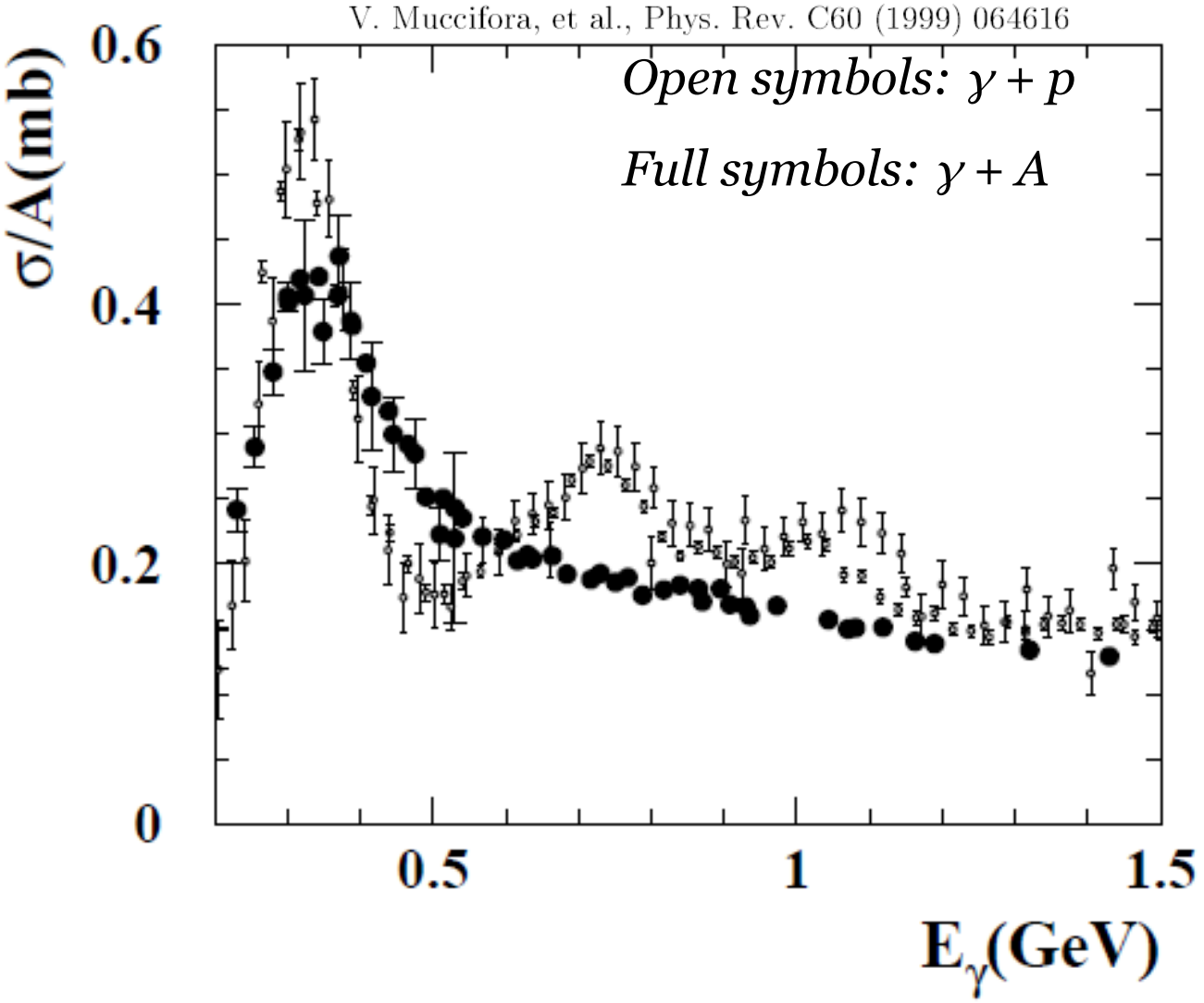

**Supported by the Carl-Zeiss-Stiftung**

# Motivation

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

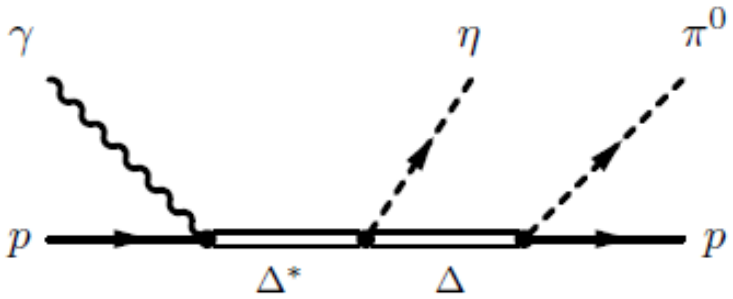
  Pronounced in-medium effect: No bump structure in the photoabsorption cross-section measured for $\gamma + A$

  → not fully explained in a model-independent way

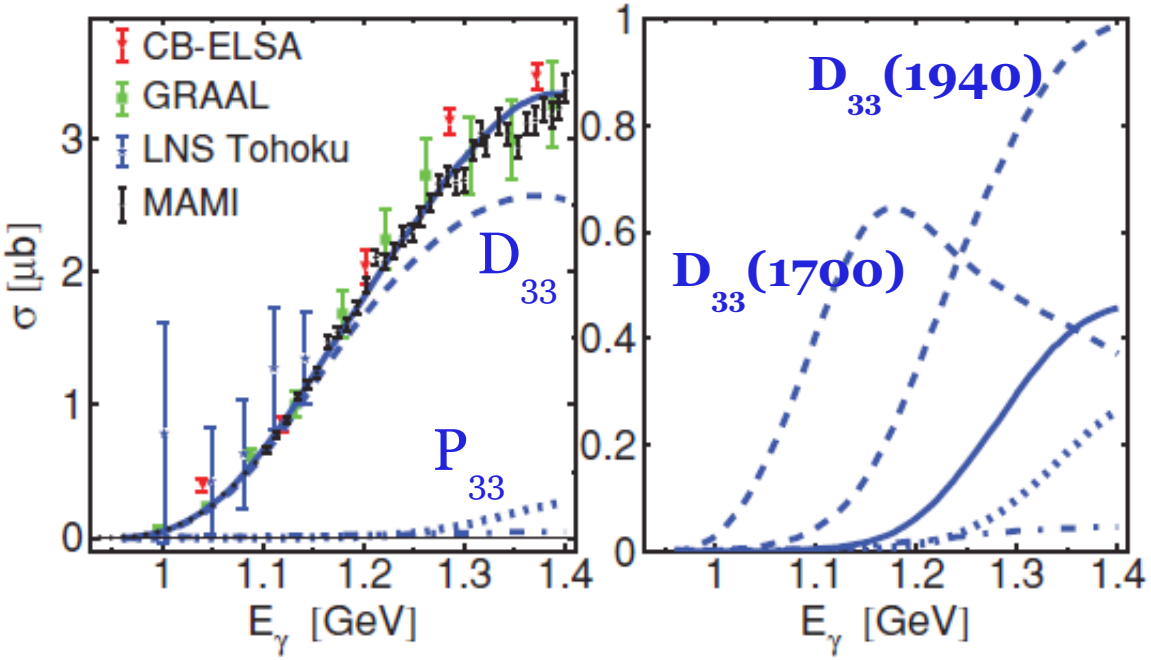


# $\pi^0\eta$ photoproduction (proton target)

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

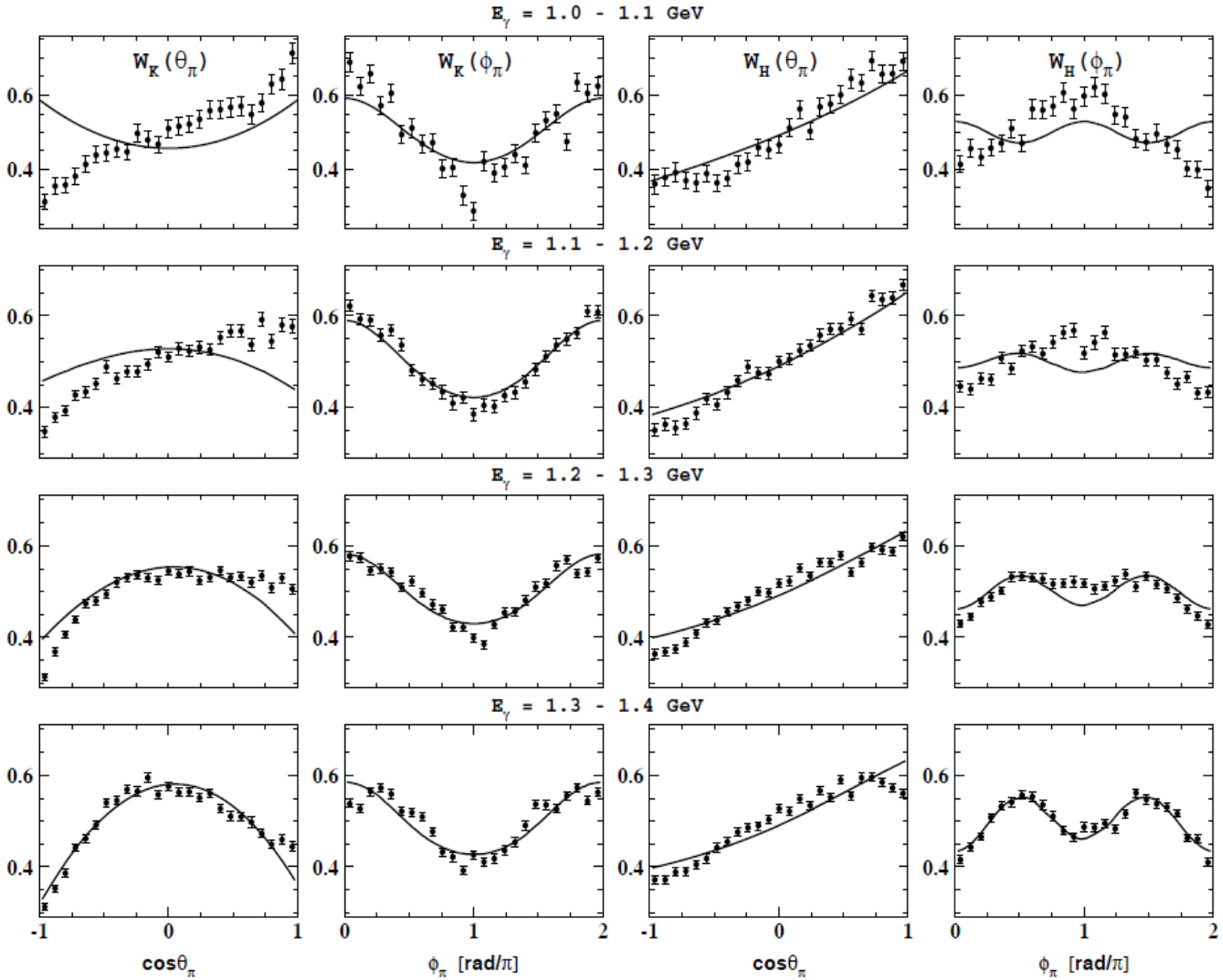



- $D_{33}(1700)$ dominates close to the production threshold




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

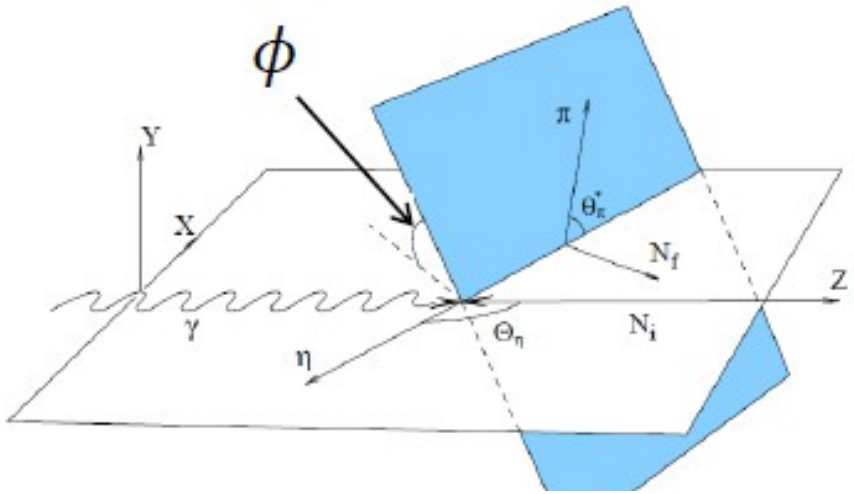
## Double meson final states:
## For a complete experiment, 15 observables are needed!

**W. Roberts and T. Oed, Phys. Rev. C 71, 055201 (2005)**

## Polarized cross-section (only polarized beam):

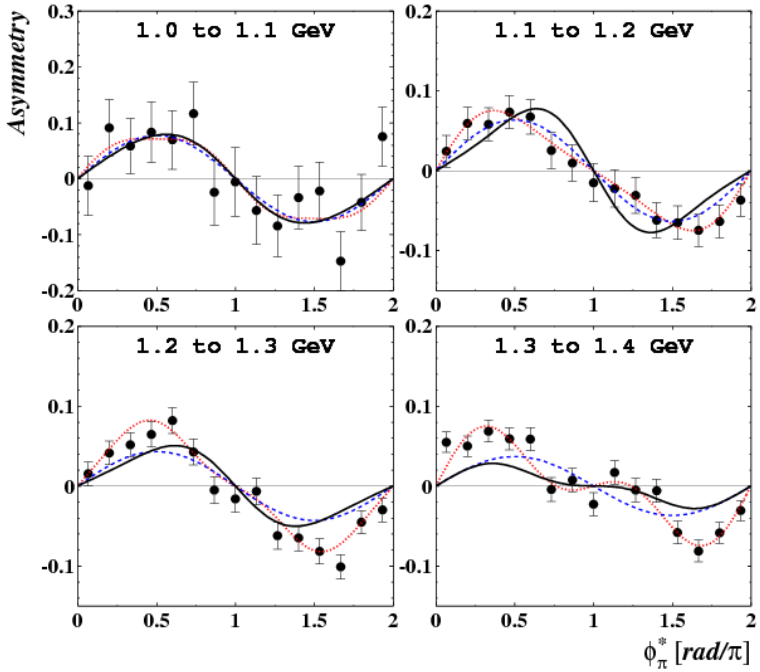
$$\frac{d\sigma}{dx_i} = \left(\frac{d\sigma}{dx_i}\right)_0 (1 + P_\gamma I^\odot + \delta_l (I^c \cos 2\varphi + I^s \sin 2\varphi))$$

*Pγ: degree of circular polarization, $\delta_l$: degree of linear polarization*




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

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




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

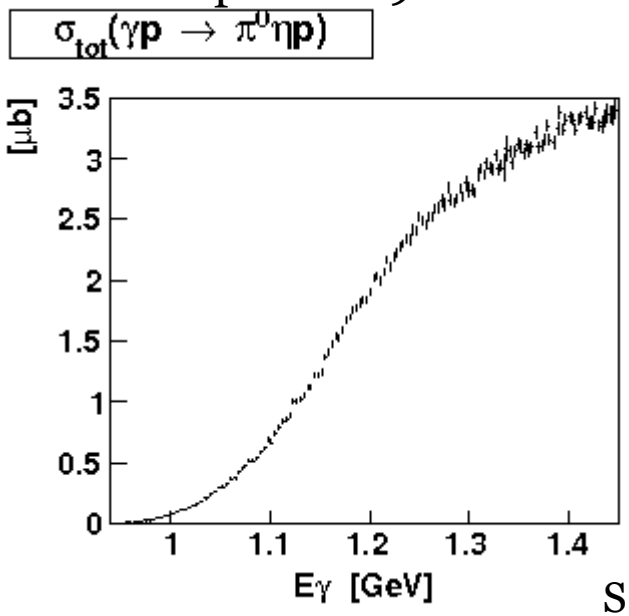
**V. L. Kashevarov, et al., Phys. Lett. B 693, 551 (2010)**

# Reanalysis of the LH2 data

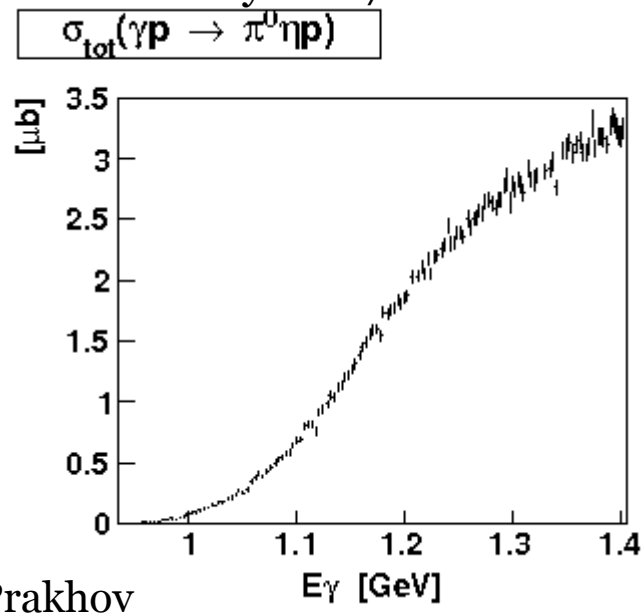
Advantages:

- Improved statistics: More than 1.500.000 events (!) for the unpolarized cross-section and more than 1.000.000 events in the polarized sample
- Kinematic fit applied
- Event-based data (5D) sample obtained
- Finer binning and extension of the energy coverage to the threshold region
- Total cross-section, angular distributions, Dalitz plots and beam helicity asymmetry extracted → input for PWA with a potentially high impact

April 2009 data

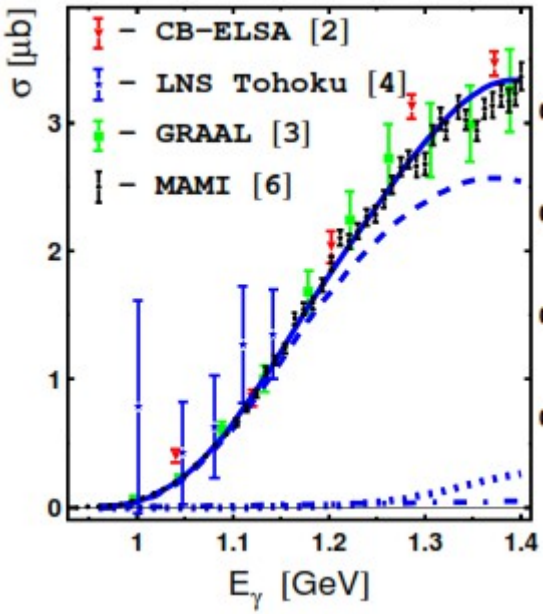



July 2007 data




S. Prakhov

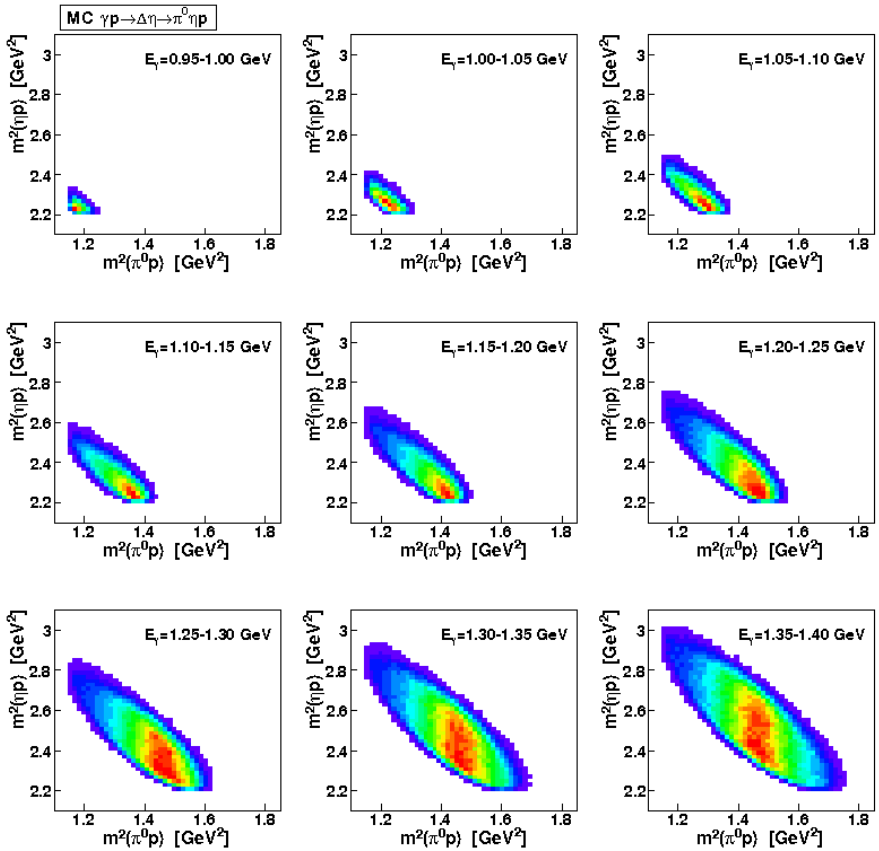
V. L. Kashevarov, A. Fix et al., Eur. Phys., J. A 42, 141 (2009)



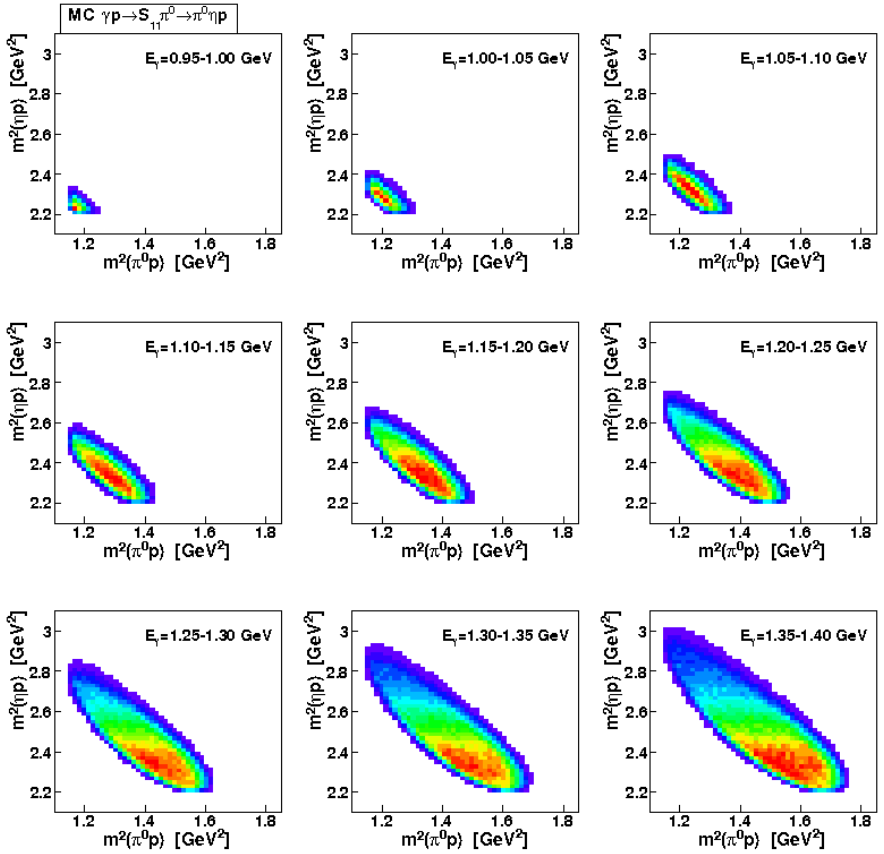
# Reanalysis of the LH2 data, Dalitz plots

## Monte Carlo simulation

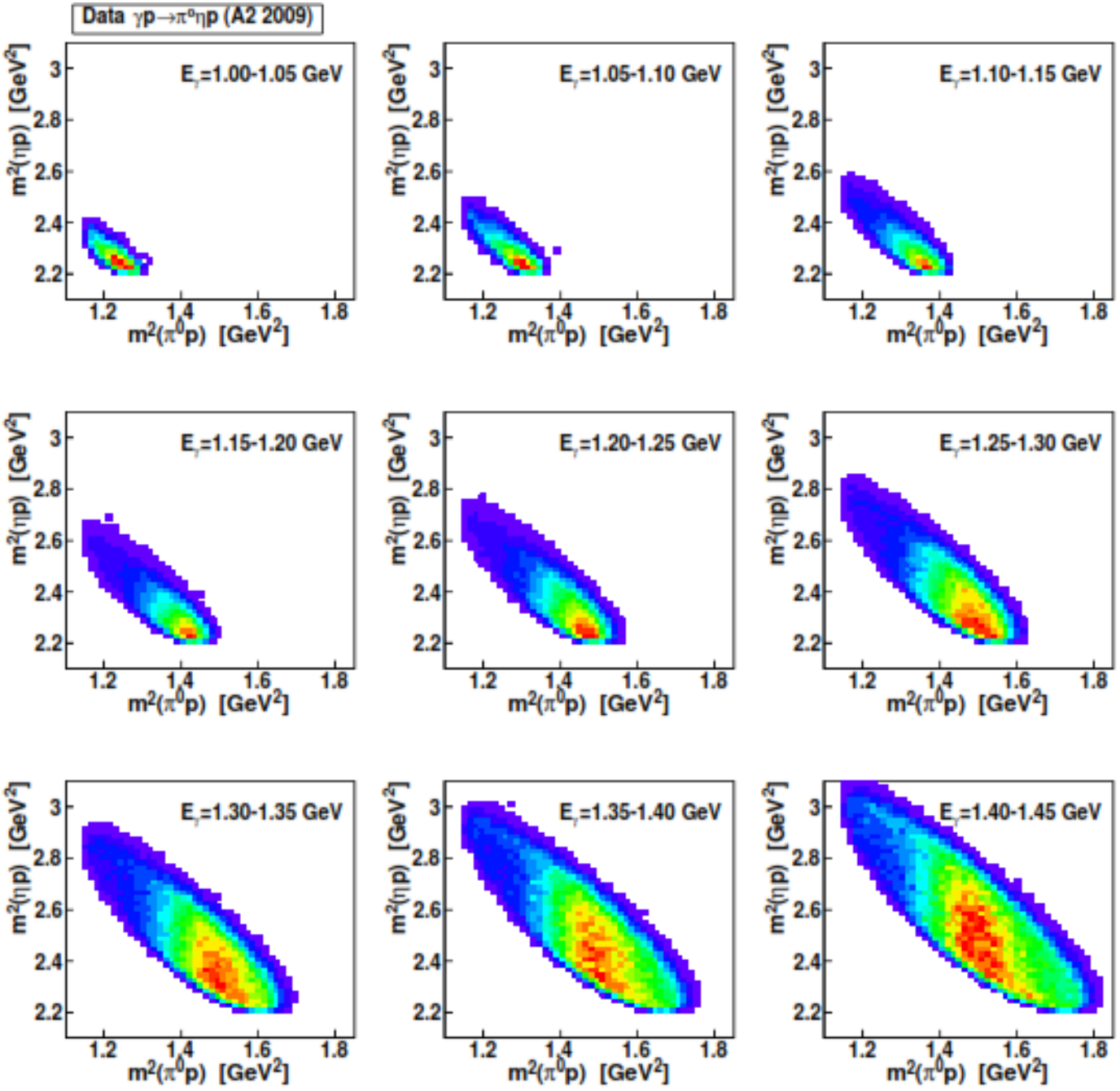
### $\gamma p \to \Delta(1232)\eta \to p\pi^0\eta$




### $\gamma p \to S_{11}(1535)\pi^0 \to p\pi^0\eta$

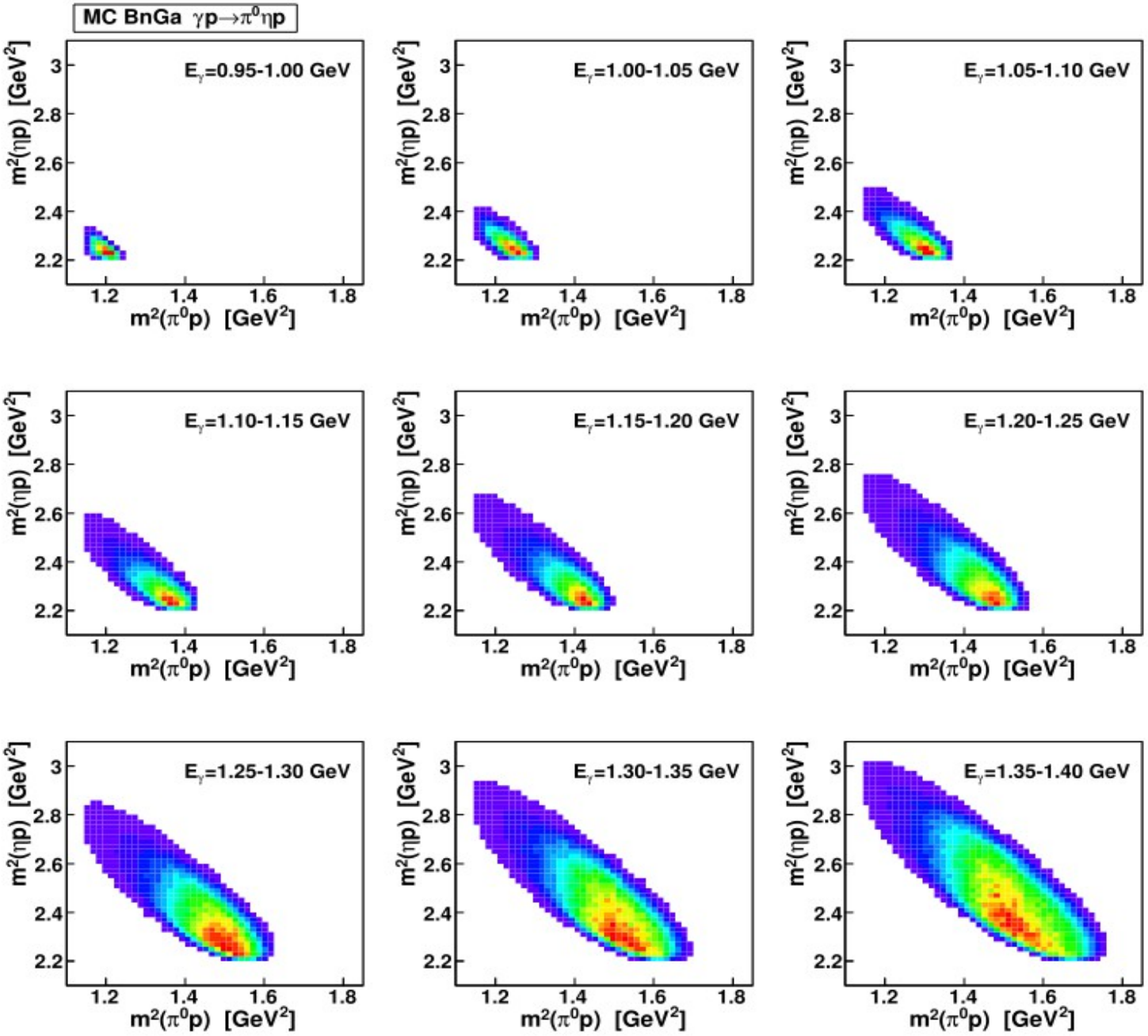


# Reanalysis of the LH2 data, Dalitz plots



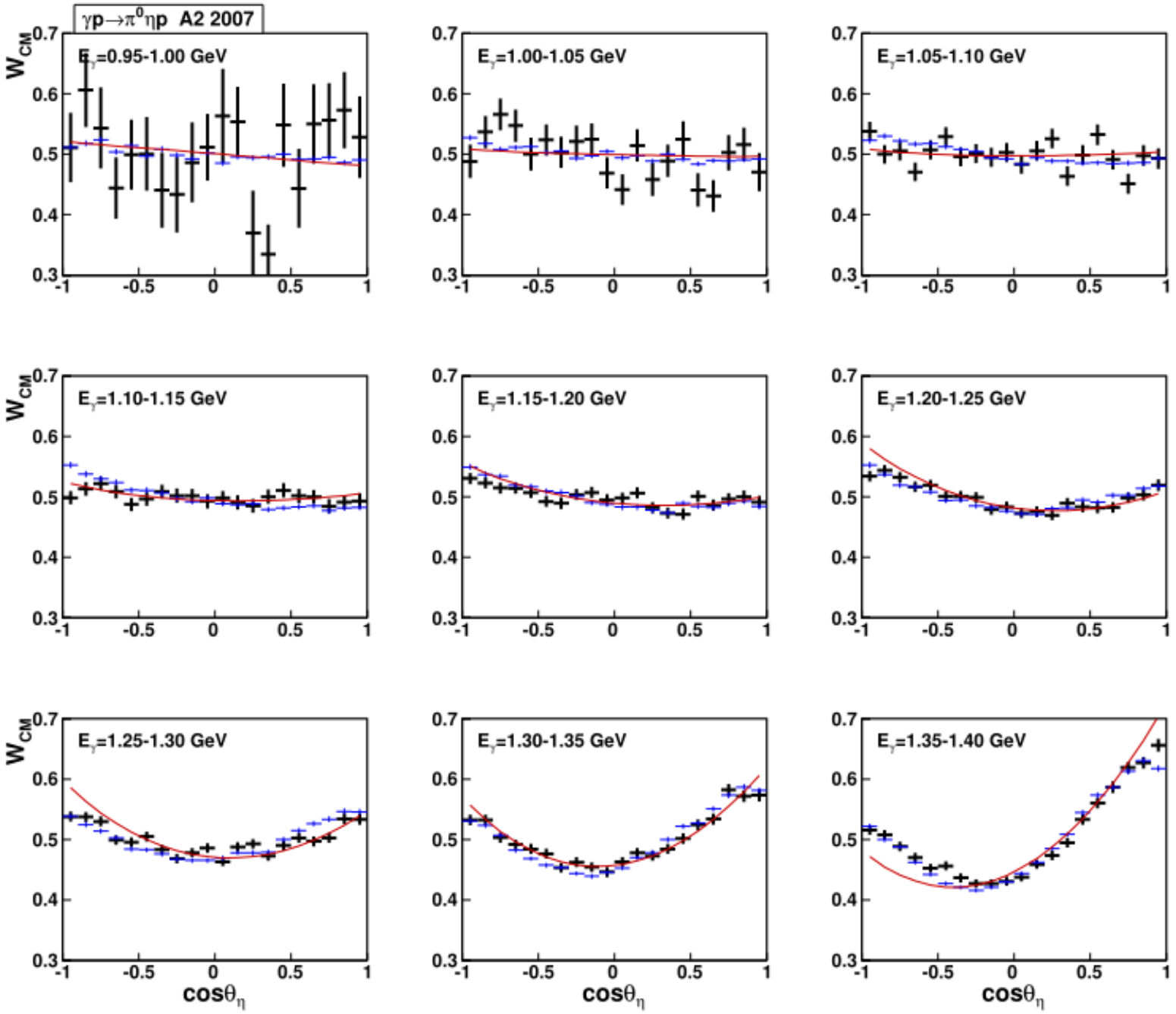

Strong contribution from $\gamma p \rightarrow (D_{33}(1700)) \rightarrow \Delta(1232)\eta \rightarrow p\pi^0\eta$

# BnGa PWA, Dalitz plots



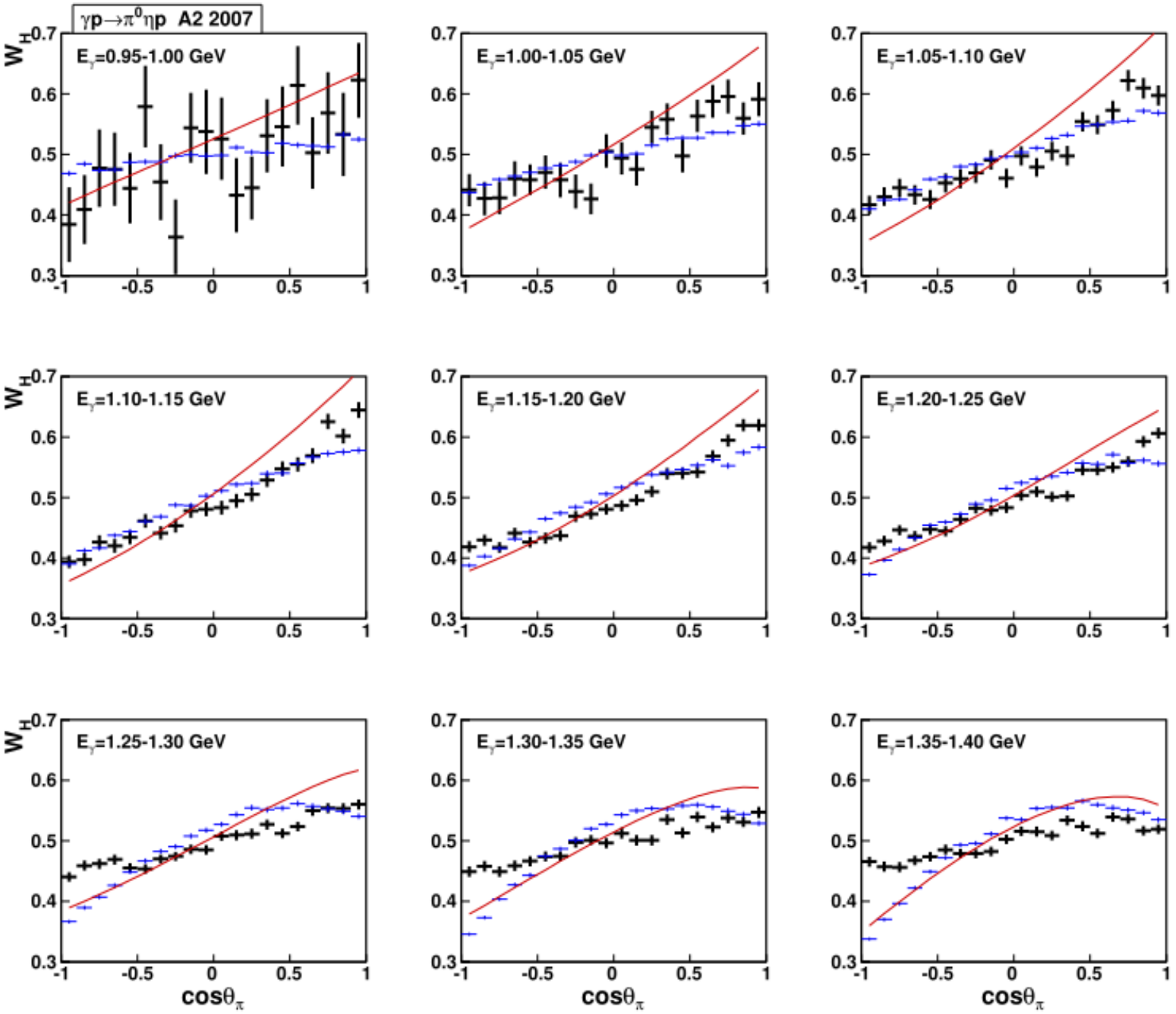

Significant contribution from $\gamma p \rightarrow S_{11}\pi^0 \rightarrow p\pi^0\eta$

# Unpolarized cross-sections




Black: A2 data
Red: A. Fix model
Blue: BnGa PWA (prediction)

# Unpolarized cross-sections

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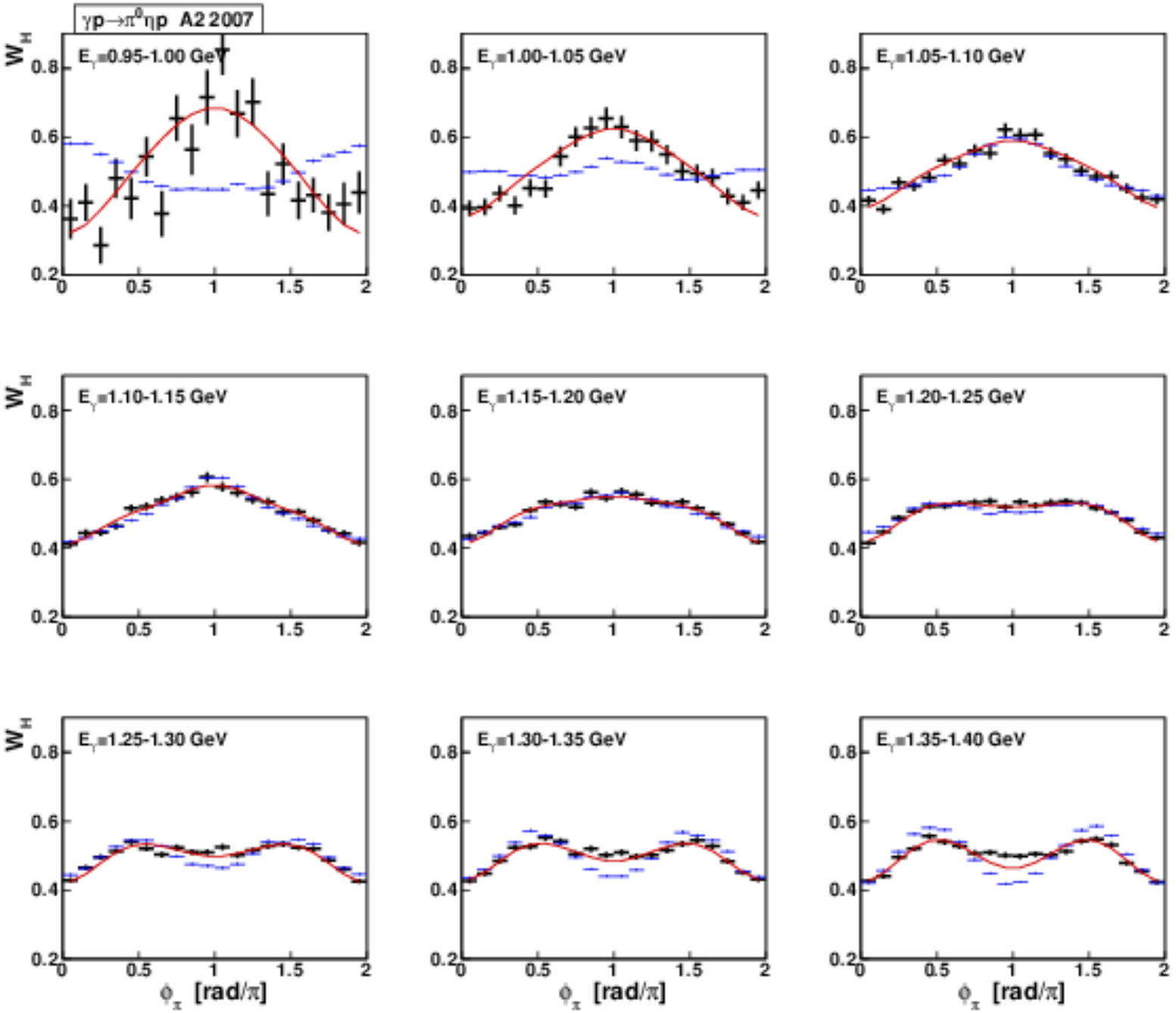
Differences at higher energies!

# Unpolarized cross-sections




Black: A2 data
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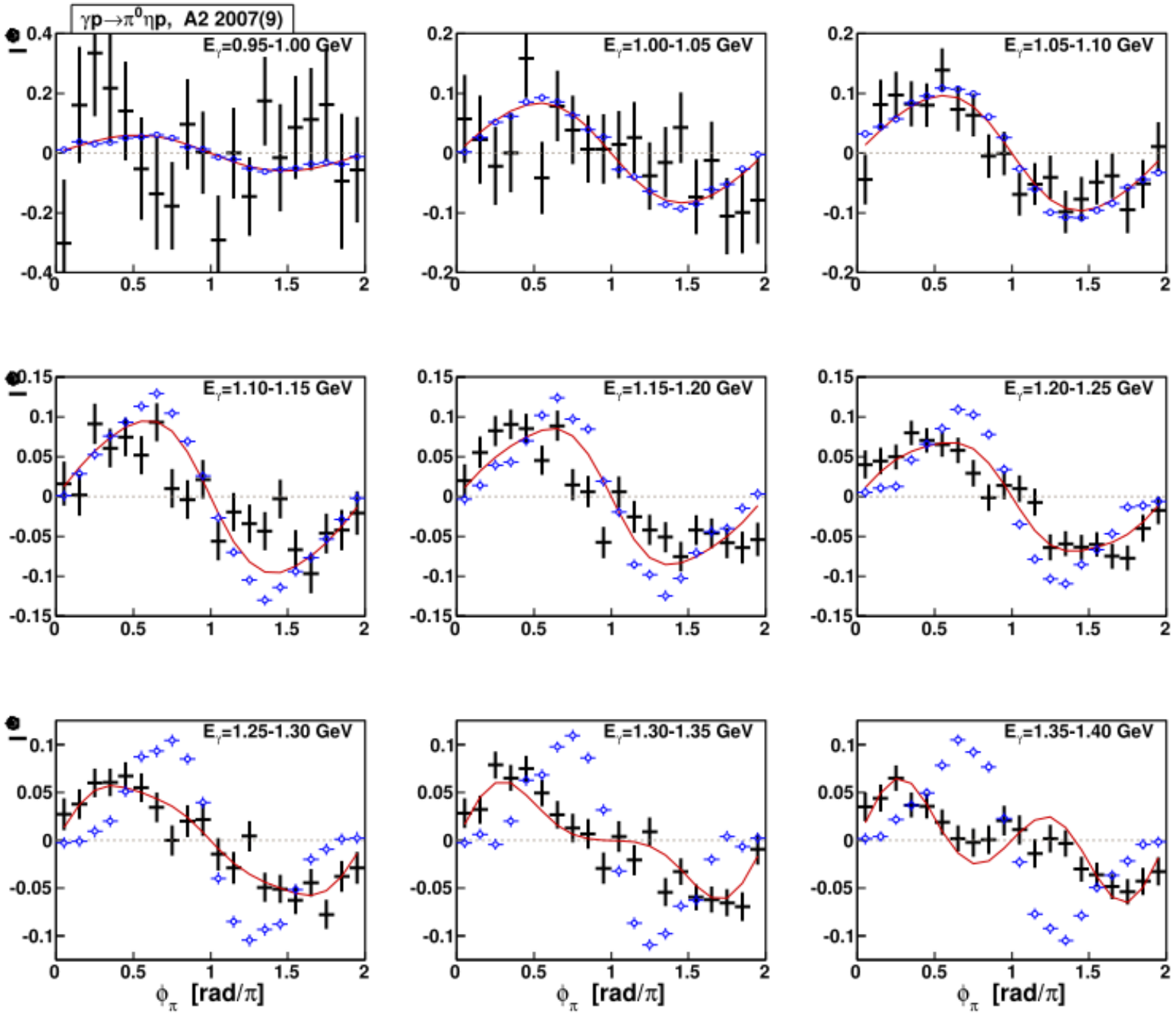
Differences at the threshold and higher energies!

# Beam helicity asymmetry




Black: A2 data
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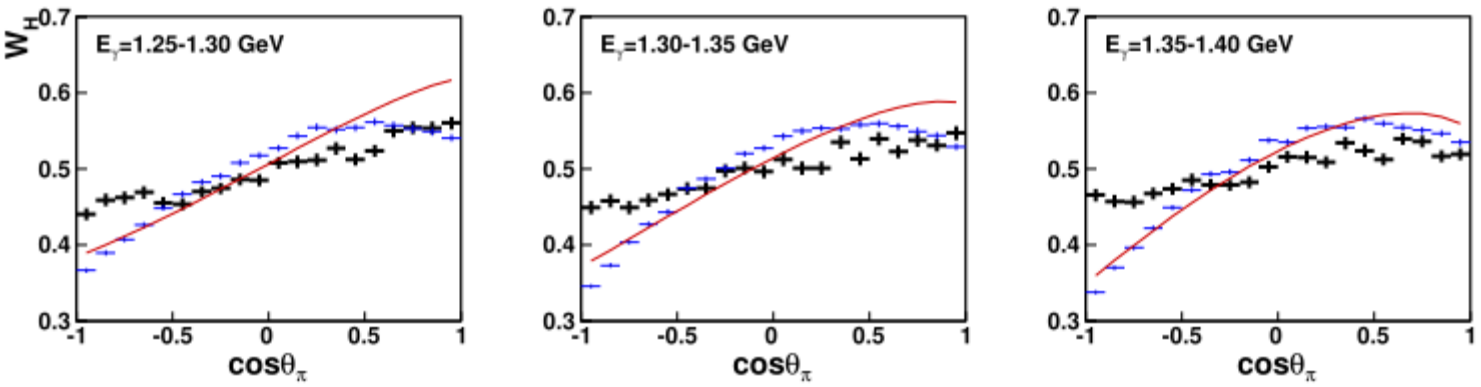
Differences at higher energies!

# Resonance contributions

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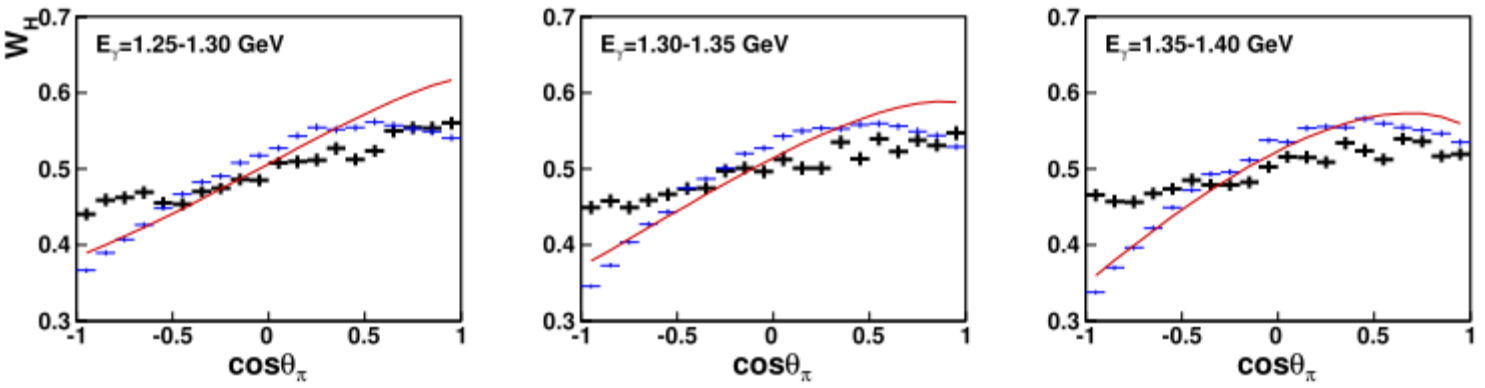
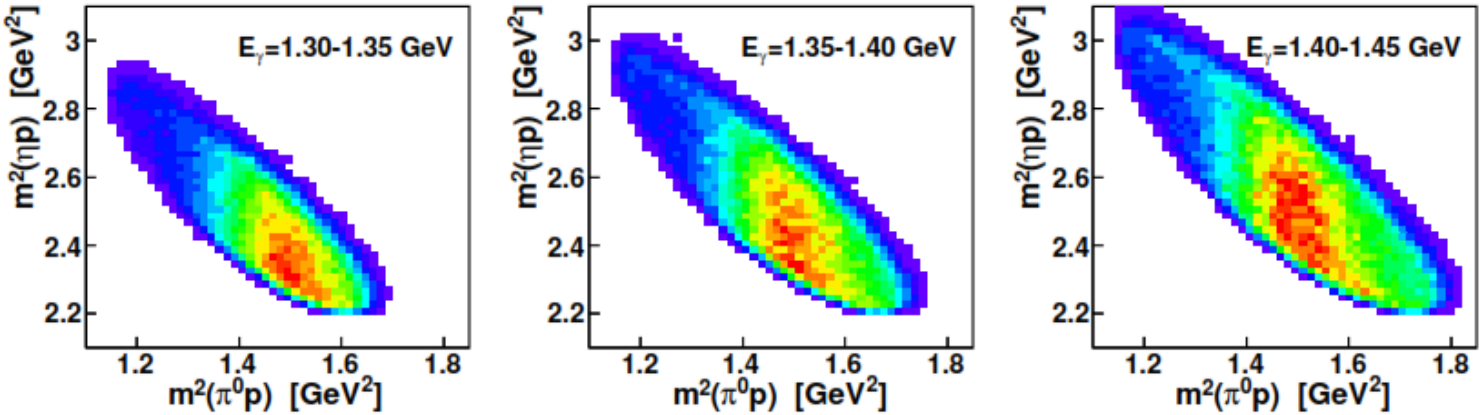
# Resonance contributions




$m^2(\pi^0 p) > 1.31\ GeV^2$ $m^2(\pi^0 p) > 1.32\ GeV^2$ $m^2(\pi^0 p) > 1.34\ GeV^2$

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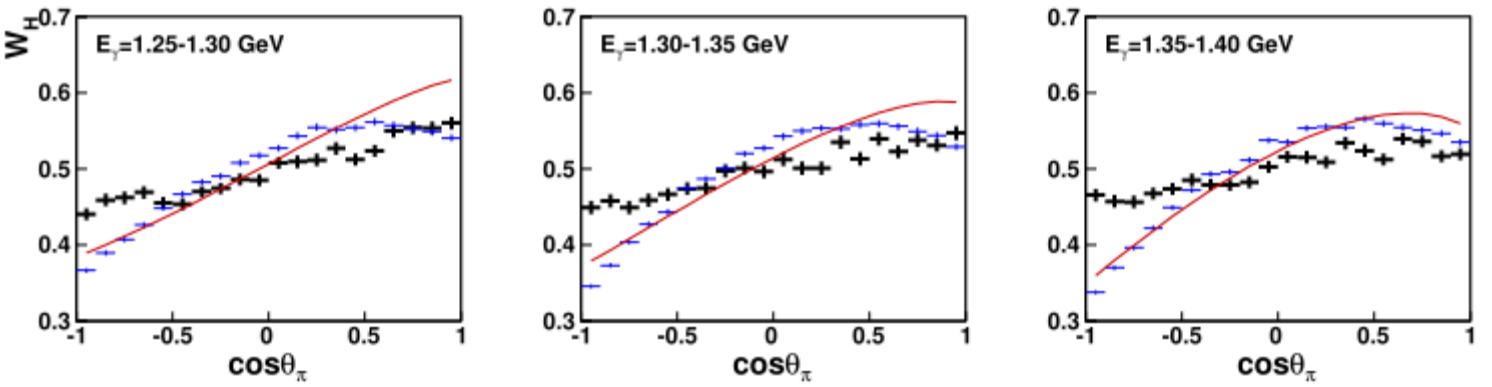
# Resonance contributions

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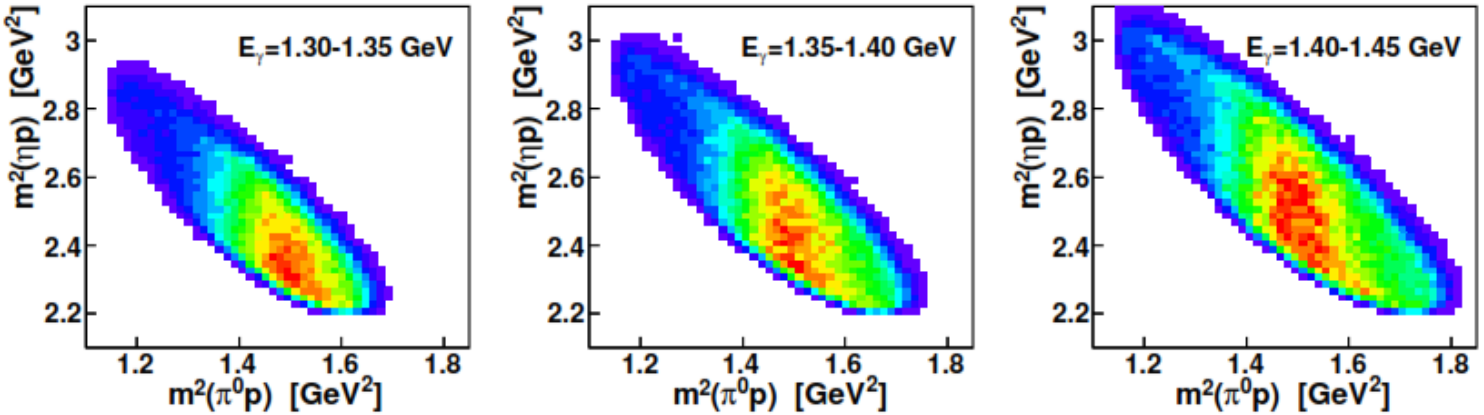
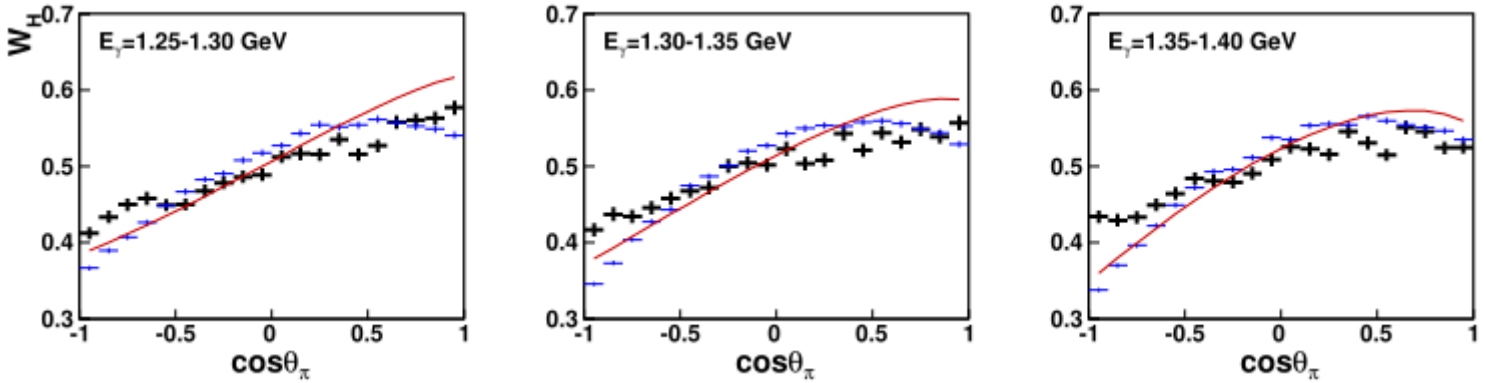
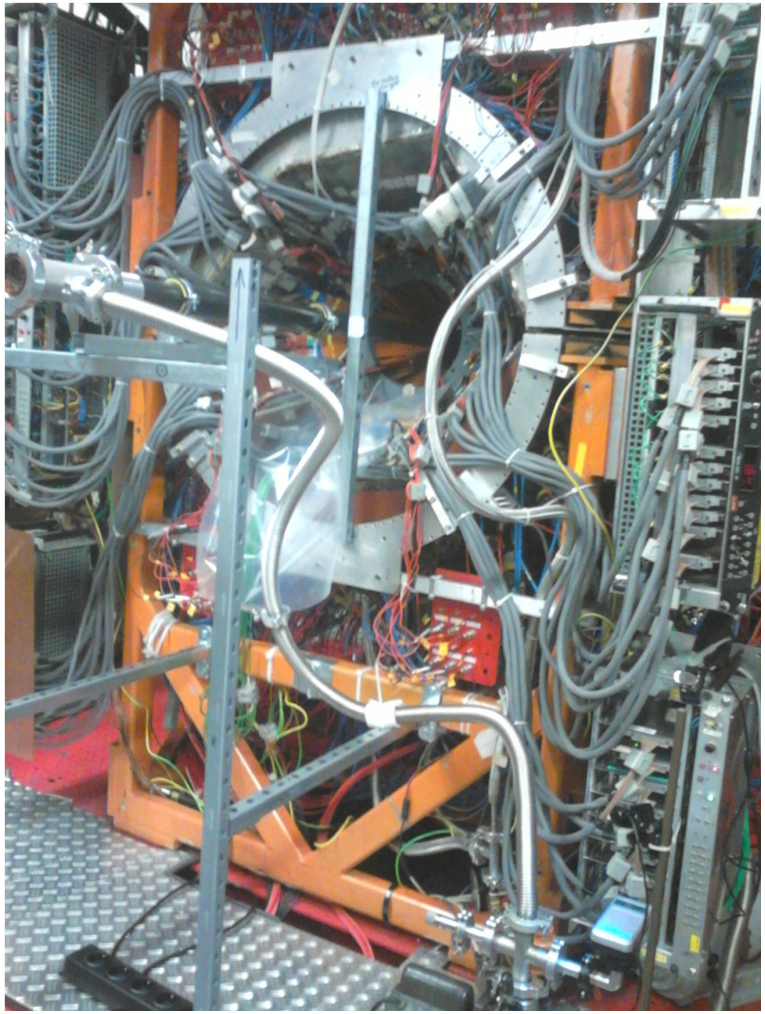


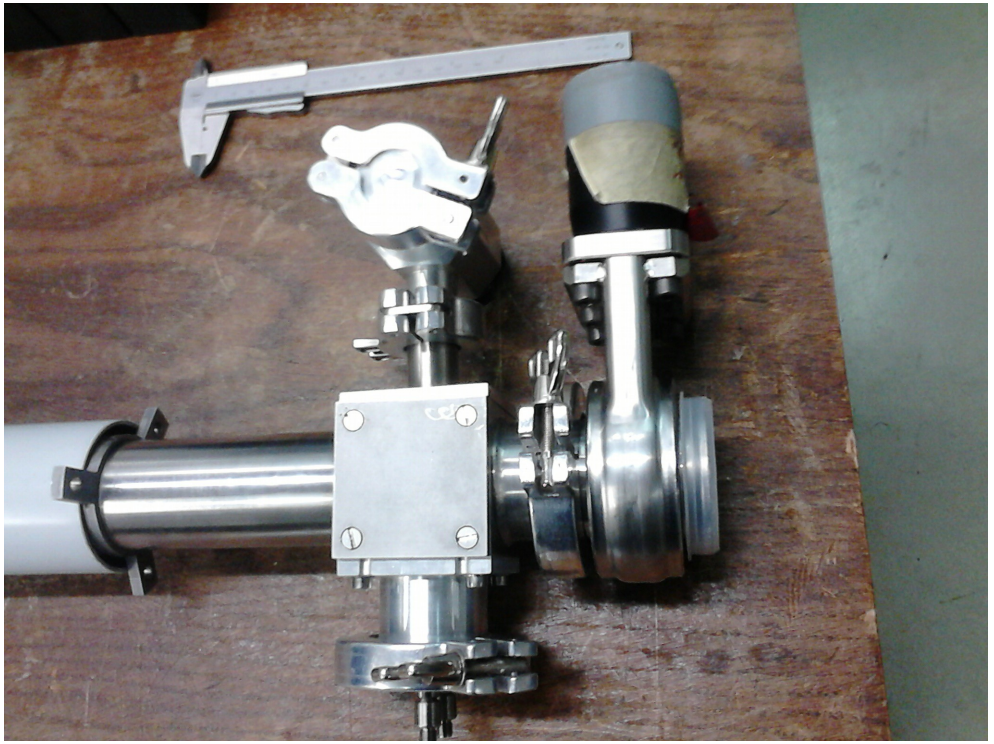



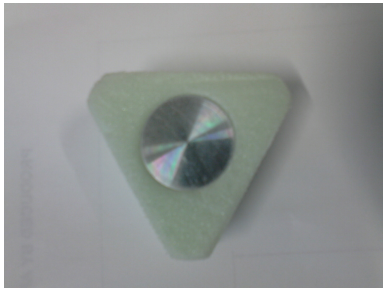

Black: A2 data
Red: A. Fix model
Blue: BnGa PWA (prediction)

# Experimental Setup (solid targets)

- 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







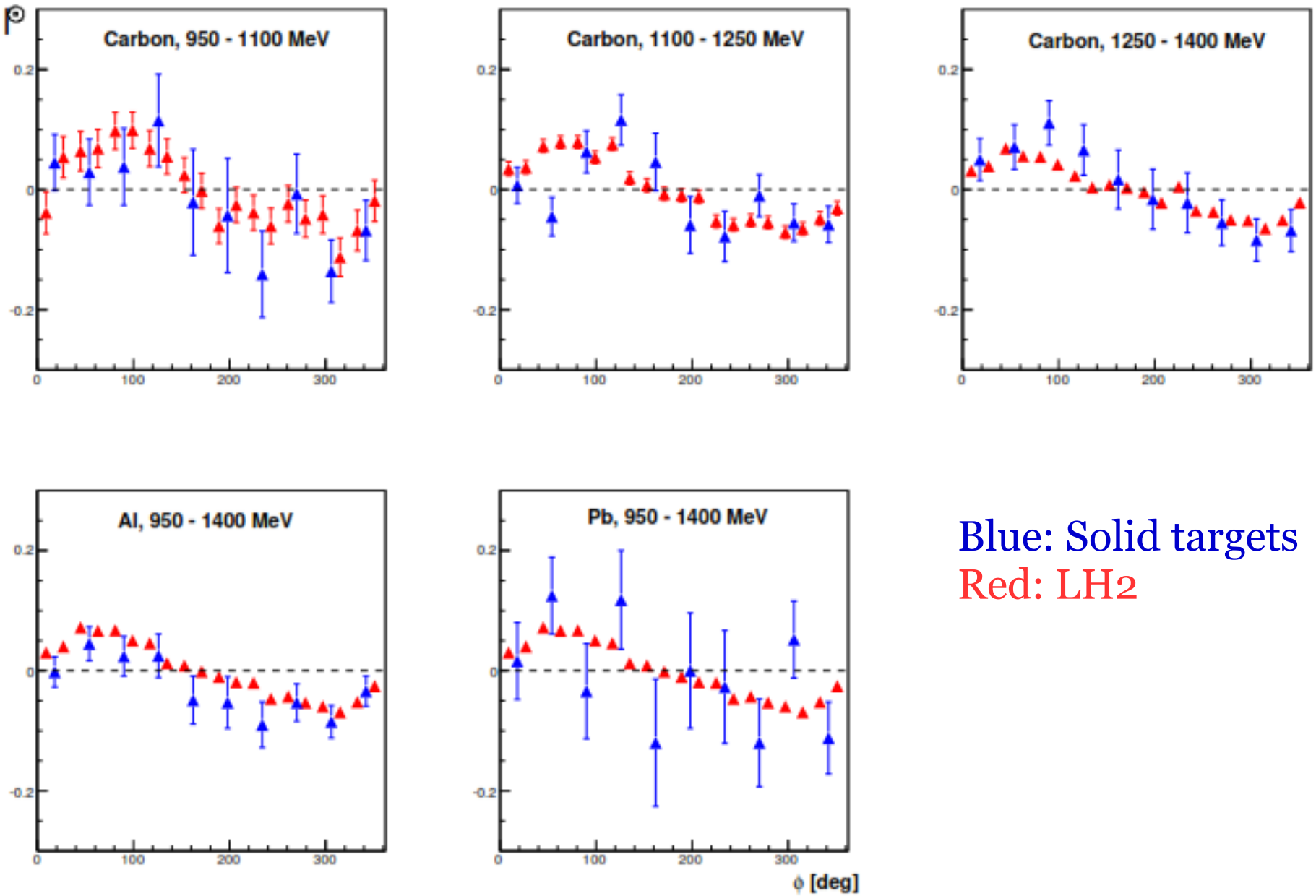
# Run conditions (solid targets)

- Targets C (2 cm), Al (8 mm), Pb (0.5 mm), empty target
- Circularly polarized photons (electron polarization 70-74%)
- Currents: 4.5 nA (C), 7.5 nA (Al), 16.5 nA (Pb)
- Trigger: M2+ and $CB_{Esum}$
- Collimator: 2.5 mm

Analysis:

- Selection of 4, 5 and 6 hits
- Missing mass cut, invariant mass cut, combinatorial analysis
- Empty target contribution negligible
- Carbon (84444 events), Aluminum (65610 events), Lead (17178 events)

# Beam helicity asymmetry (solid targets)




Blue: Solid targets
Red: LH2

Agreement between LH2 and solid target data (particularly for Carbon)
Final State Interaction is practically not affecting the asymmetry signal

# Summary

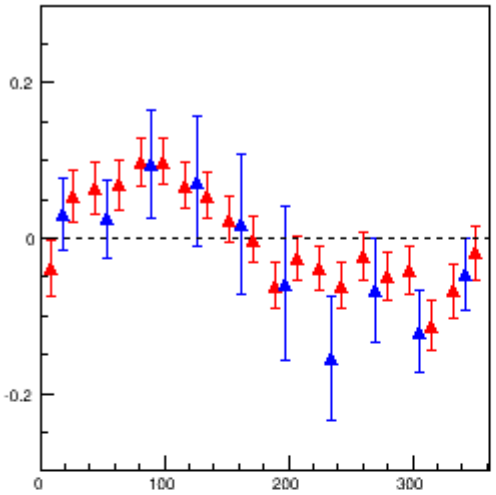
- Reanalysis of the LH2 data finished: Cross-sections, Dalitz plots, beam helicity asymmetry extracted → Highest statistics event-based data set for 950-1450 MeV
- Dominance of $\gamma p \rightarrow (D_{33}(1700)) \rightarrow \Delta(1232)\eta \rightarrow p\pi^0\eta$
- Differences with models in the threshold region and at higher energies → impact for the PWA
- Beam helicity asymmetry extracted for Carbon, Aluminum and Lead targets
- $D_{33}(1700)$ resonance shows very similar signal for free protons and nuclear targets in the beam helicity asymmetry
- Extraction of total and differential cross-sections for solid targets in progress
- Two papers to be published

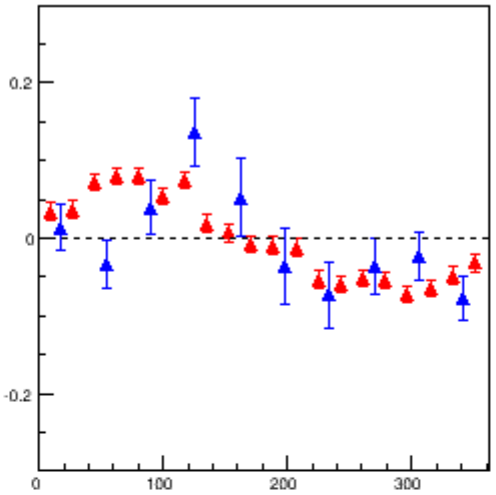
**Thank you for your attention!**

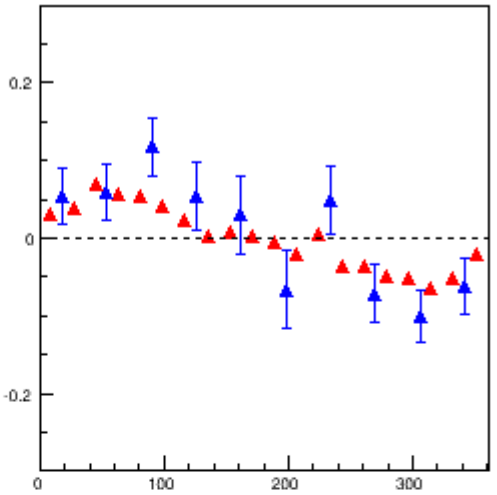
# Backup

# Beam helicity asymmetry (solid targets, MM)

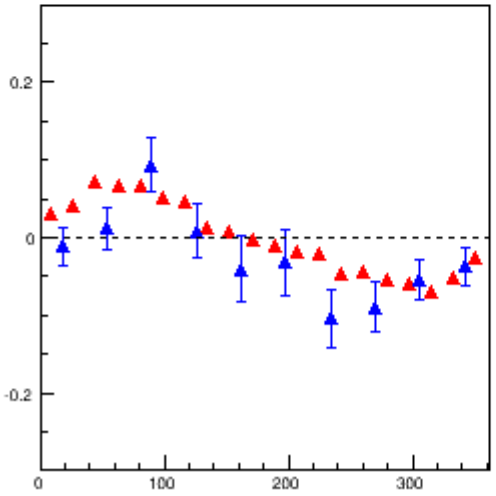
Carbon



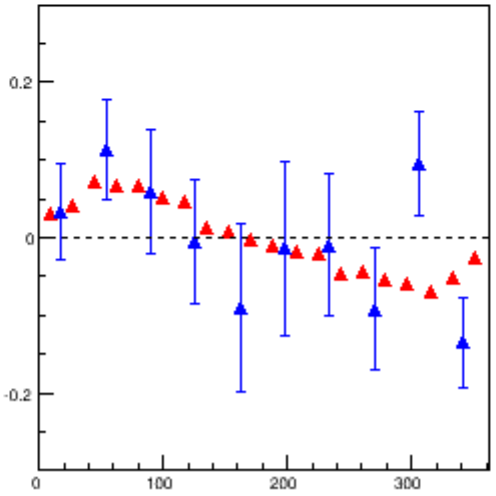




Al



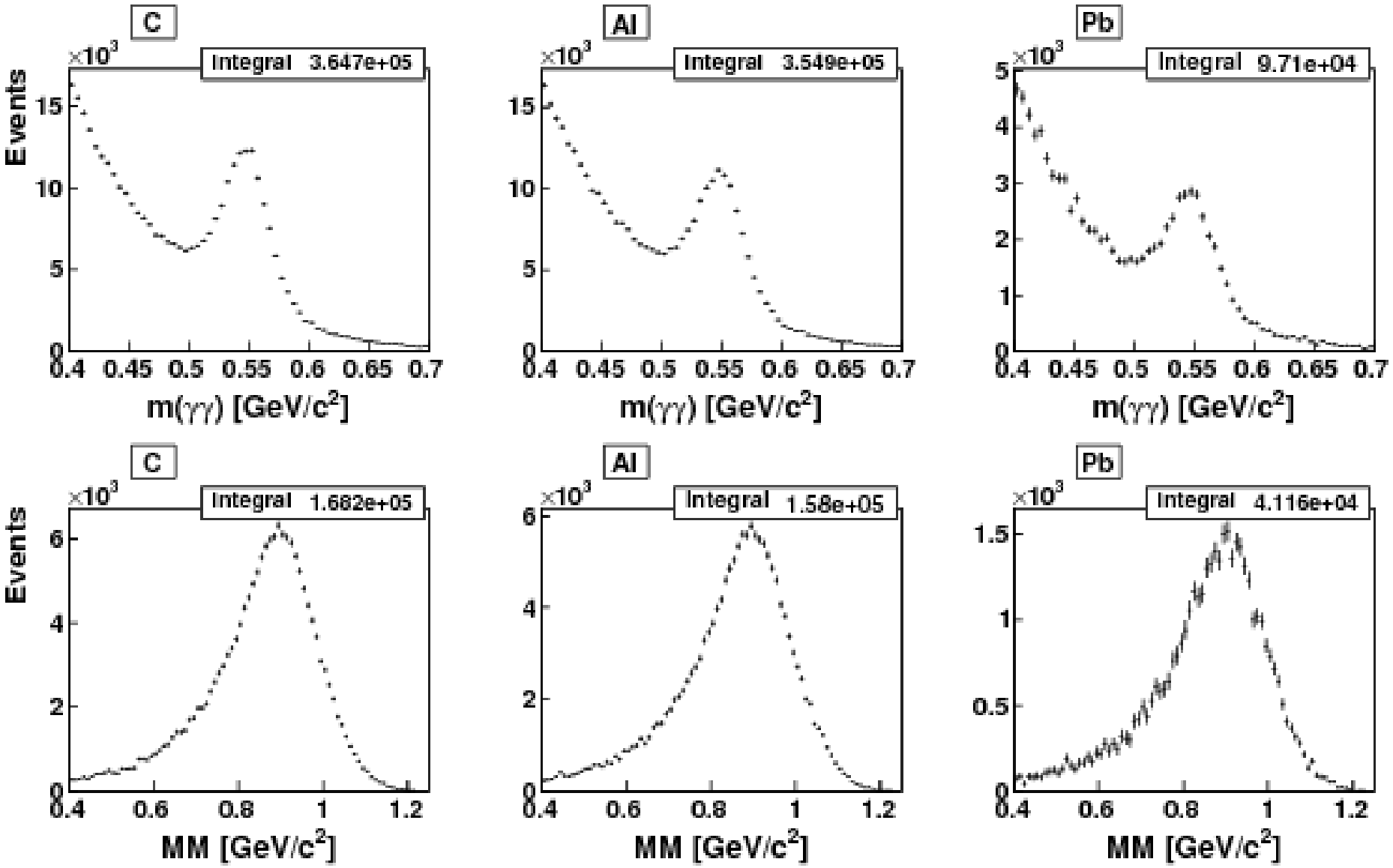

Pb




Blue: Solid targets
Red: LH2

Agreement between LH2 and solid target data (particularly for Carbon)
Final State Interaction is practically not affecting the asymmetry signal

# Invariant and missing mass distributions



# 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 $\gamma$ (+ 1 charged hit or + X hits)
- Invariant mass cut
- Missing mass cut (?)
- Subtraction of random timing background
- Negligible empty target contribution

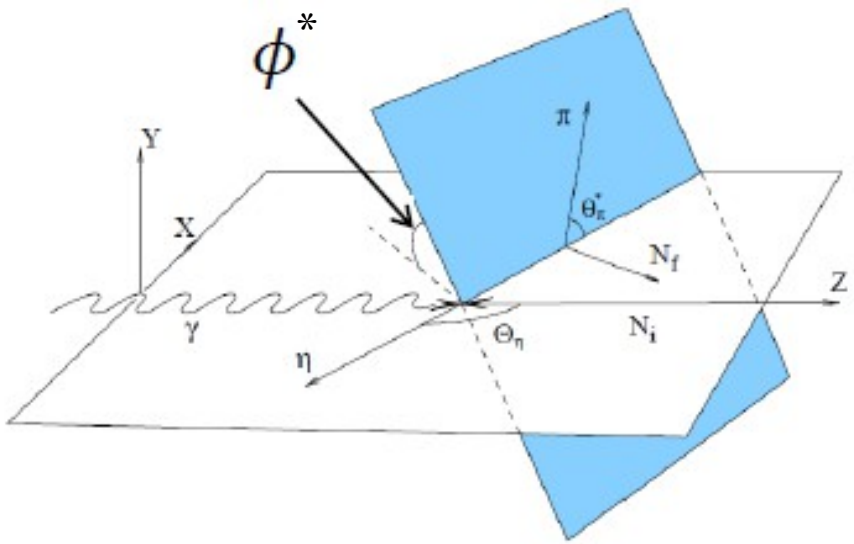
# Run conditions

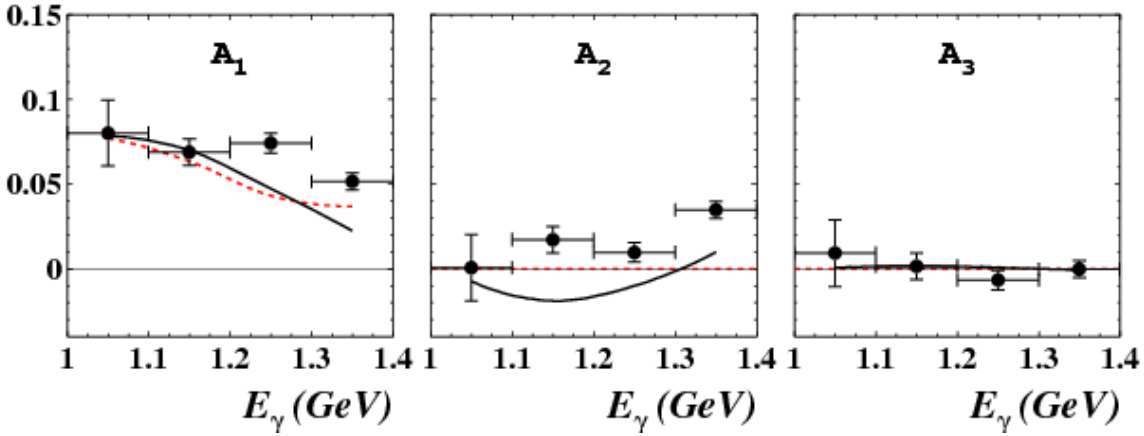
- Targets C (2 cm), Al (8 mm), Pb (0.5 mm), empty target
- $E_{beam}$ = 1557 MeV (+ 8 hours with 883 MeV with the Pb target)
- Circularly polarized photons (electron polarization 70-74%)
- Tagged photon energy $E_\gamma$ > 500 MeV for C and Al, $E_\gamma$ > 780 MeV for Pb
- Currents: 4.5 nA (C), 7.5 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
- Preliminary analysis shows compatible resolution between LH2 (April 2009) and Carbon 2015 data (Sergey Prakhov)

# Beam helicity asymmetry (proton target)




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 $E_\gamma$ < 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

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?