CLAS: Double-Pion Beam Asymmetry

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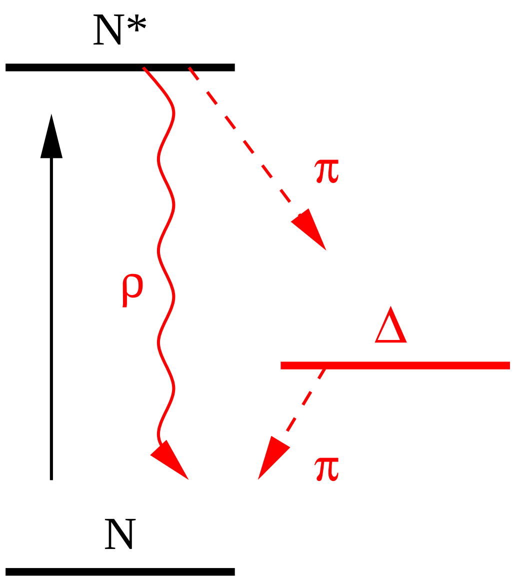
Beam-Helicity Asymmetry in $\pi\pi N$

- Motivation of the experiment
  - Why study double-pion production?
  - Why measuring polarization observables?
- Results of the CLAS $\vec{\gamma}p \rightarrow \pi^+\pi^-p$ measurement
- Discussion
  - Sensitivity of the asymmetry to underlying dynamics
  - Study of background mechanisms
  - Study sequential decay of resonances
- Beyond the beam-helicity asymmetry

Double-Pion Photoproduction: $\gamma N \longrightarrow N\pi\pi$

- Dominant nucleon-resonance decay channels above 1.6 GeV



$$N^* \longrightarrow \rho N \longrightarrow \pi\pi N$$

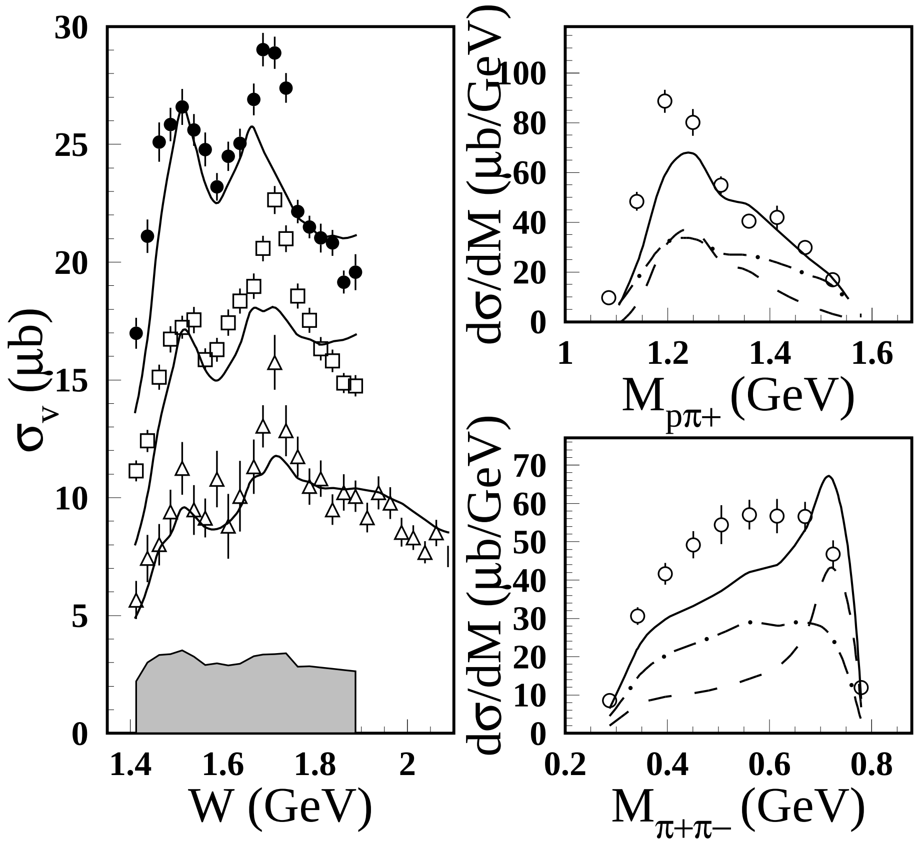
$$N^* \longrightarrow \pi\Delta \longrightarrow \pi\pi N$$

with $\pi\pi N$ final states

- Many “missing” states are predicted to couple strongly to the $\pi\pi N$ channels

Particle Data Group Review, S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).
S. Capstick and W. Roberts, Phys. Rev. D **49**, 4570 (1994)

CLAS Measurement of $ep \rightarrow e'\pi^+\pi^-p$



0.5 GeV^2/c$^2 < Q^2 < 1.5$ GeV^2/c^2

- Comparison of data and phenomenological predictions using available information on N^* and Δ states shows discrepancy.
- Better description: sizeable change of $P_{13}(1720)$ properties or introducing new baryon state.

Figure from M. Ripani *et al.*, Phys. Rev. Lett. **91**, 022002 (2003)

Polarization Observables for Two-Pion Production off the Nucleon

- Eight transversity amplitudes for the $\gamma N \to \pi\pi N$
- Unpolarized cross section

$$I_0 = \sum_{i=1,4} |b_i^+|^2 + \sum_{i=1,4} |b_i^-|^2$$

- Polarization observables allow extraction of more information, including phases.
- Photon polarization asymmetry $I^{\odot}$

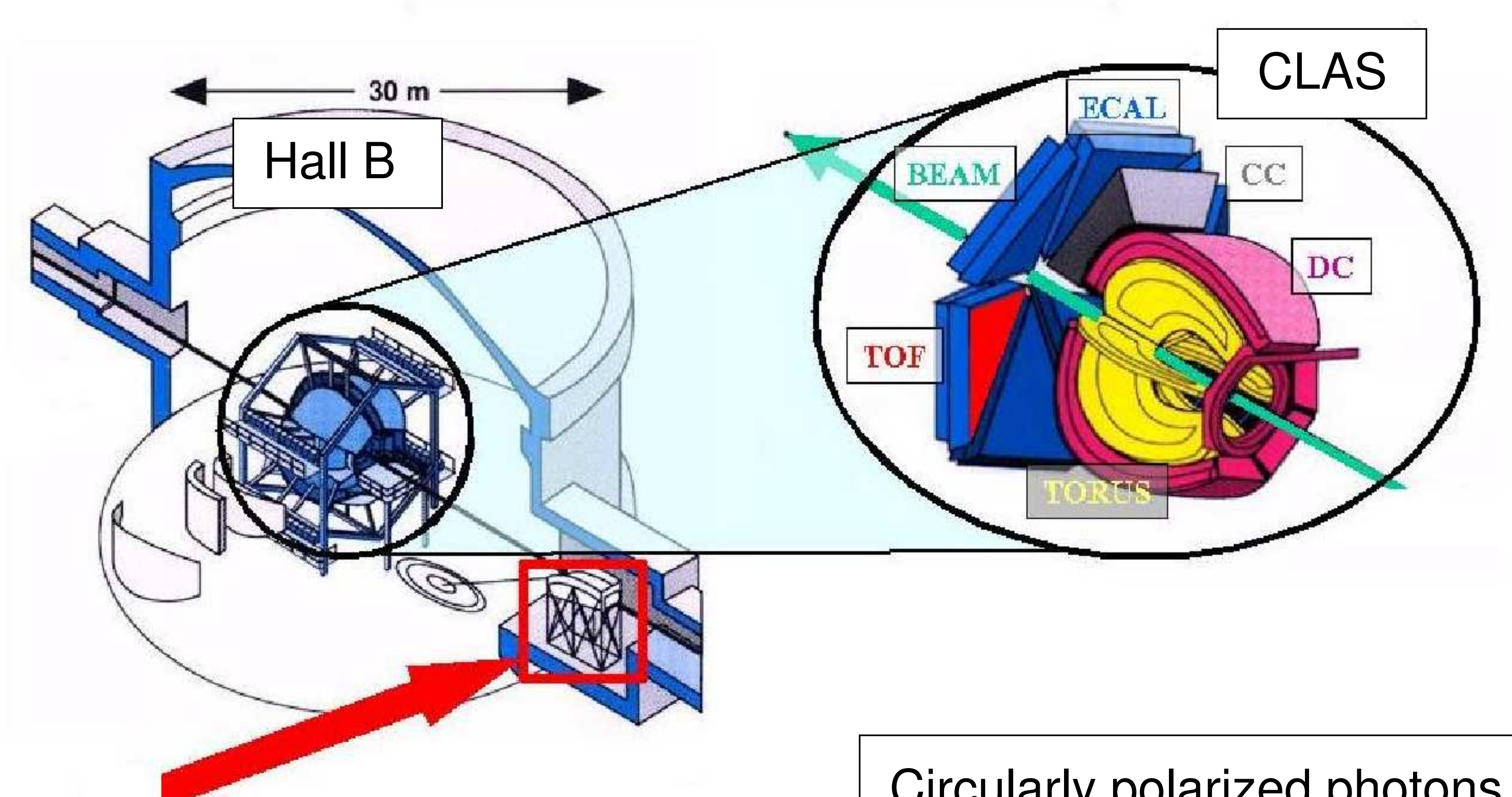
$$I_0 I^{\odot} = \sum_{i=1,4} |b_i^+|^2 - \sum_{i=1,4} |b_i^-|^2$$

- Complete set require additional single-, double- and triple-polarization observables

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

The CLAS $\vec{\gamma} p \to \pi^+ \pi^- p$ Experiment

Jefferson Lab Hall B



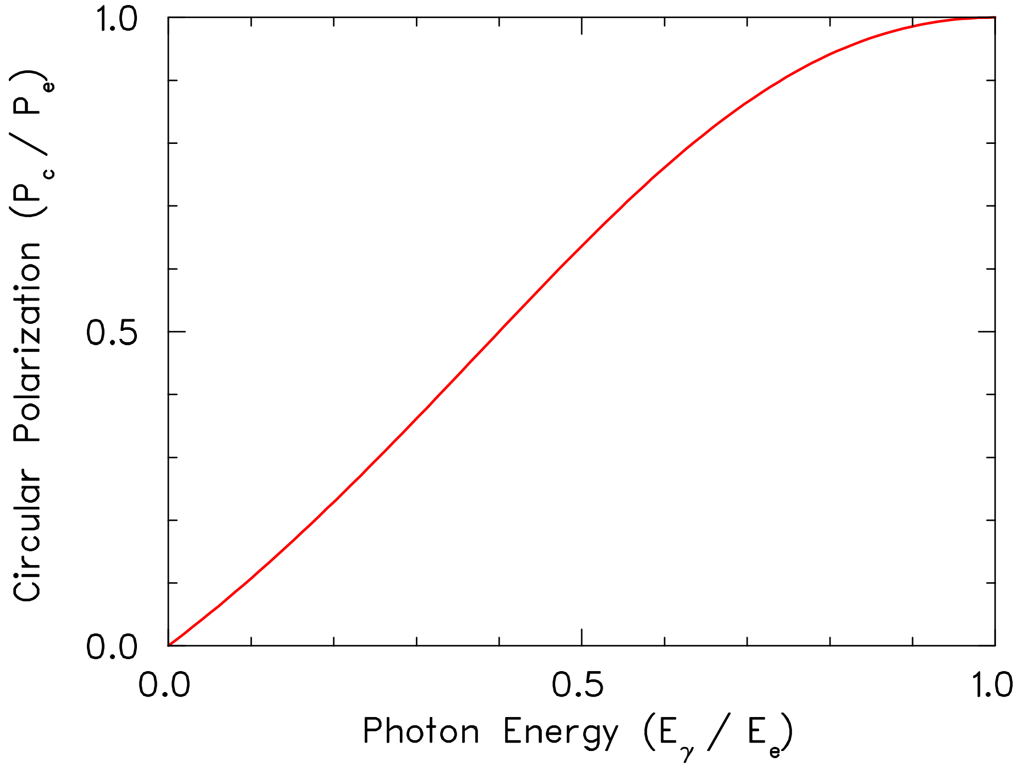
Photon tagger (20%–95% of E_0)

Circularly polarized photons
Unpolarized hydrogen target

S. Strauch *et al.* (CLAS Collaboration), Phys. Rev. Lett. **95**, 162003 (2005)

Photon-Beam Polarization

- Circularly polarized bremsstrahlung ($E_\gamma = 0.5 - 2.3$ GeV) from longitudinally polarized electrons ($P_e \approx 0.67$)



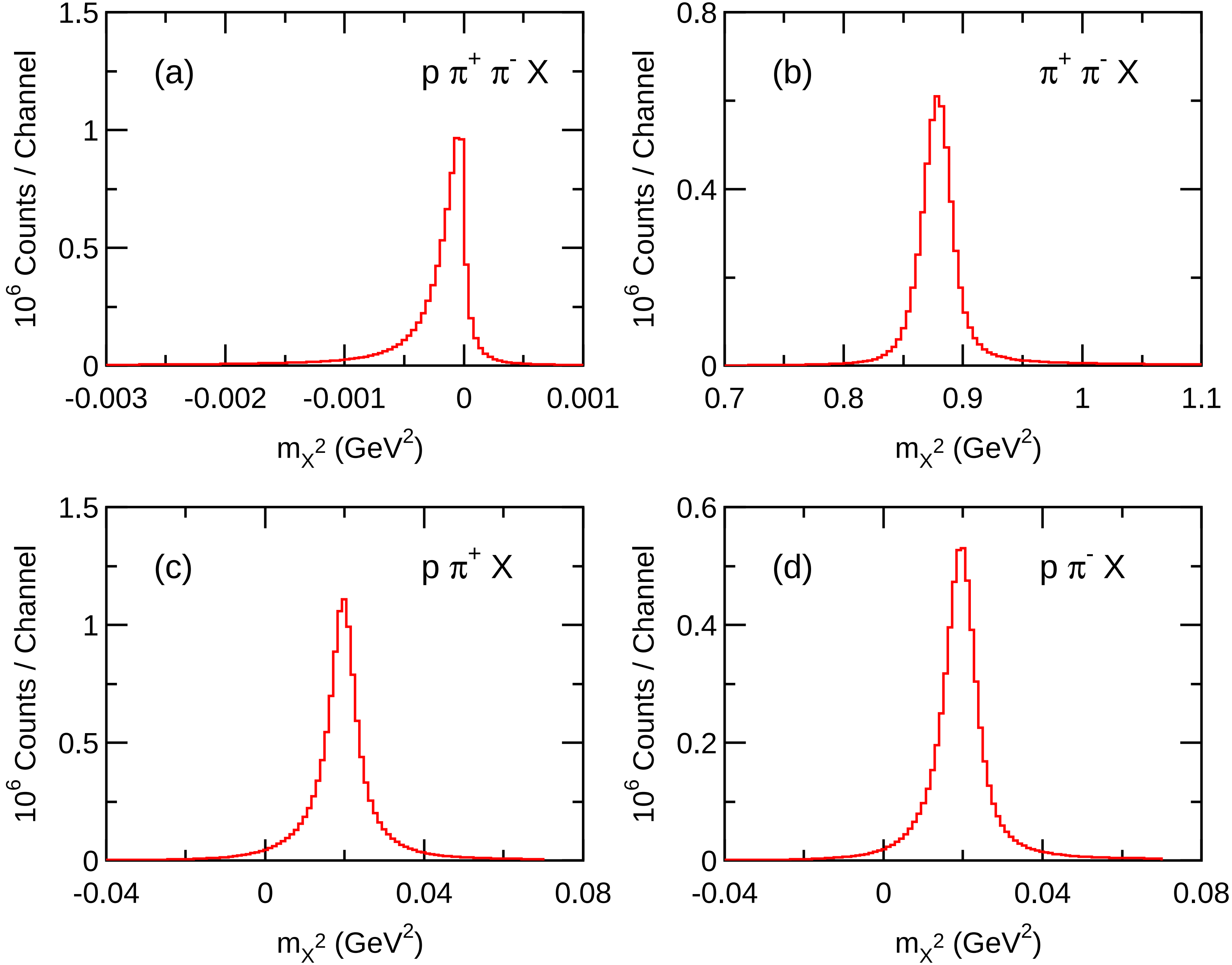
Systematic uncertainty from beam polarization: 3%

- no target polarization, no recoil polarization

H. Olsen and L.C. Maximon, Phys. Rev. **114**, 887 (1959)

$\pi^+\pi^-p$ — Channel Identification

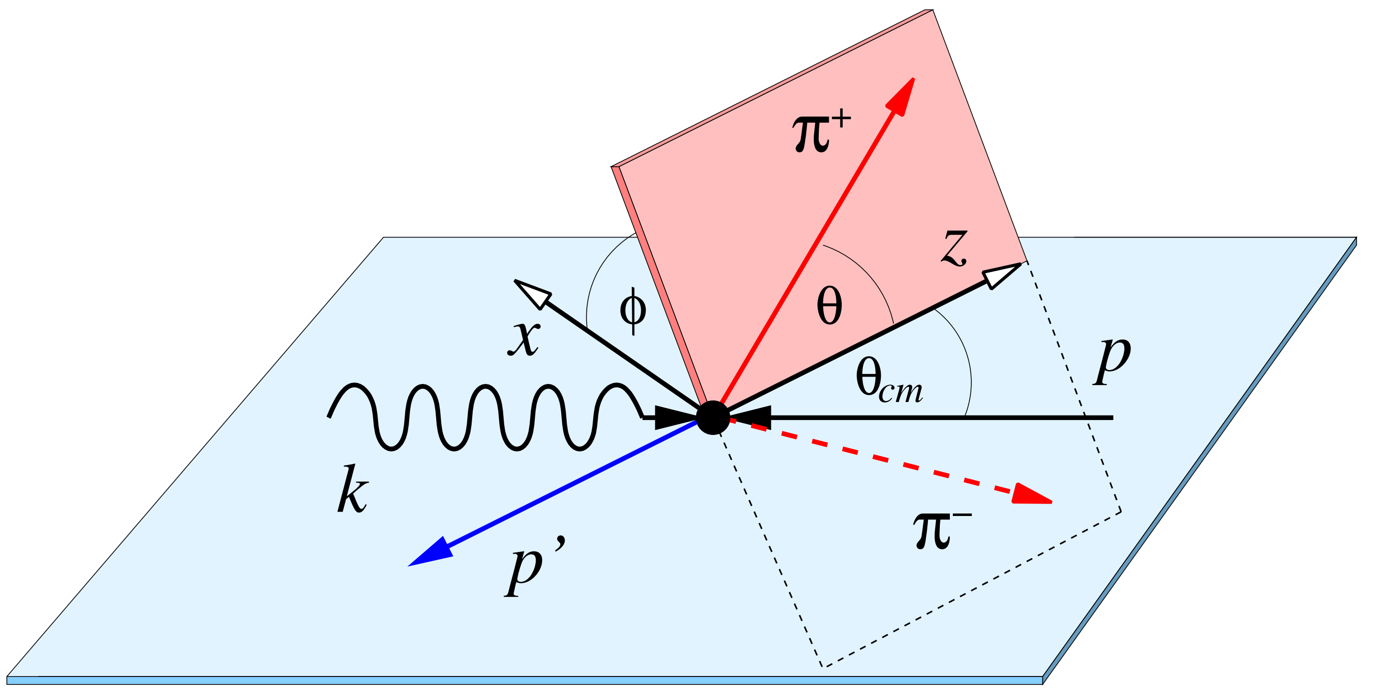
Missing-Mass Technique



Experimental Beam-Helicity Asymmetries

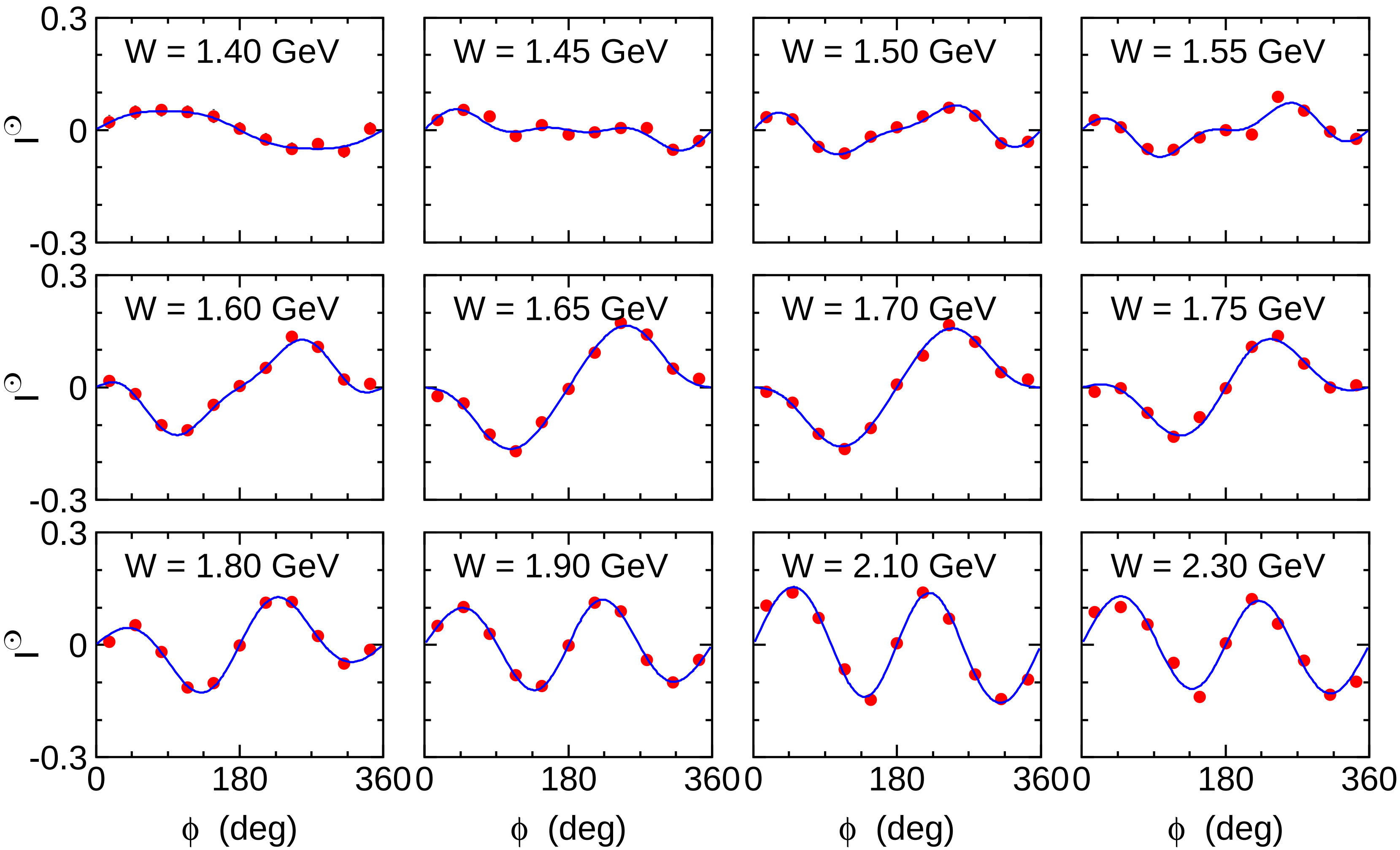
- Asymmetry and Fourier Decomposition

$$I^{\odot}(\phi) = \frac{1}{P_{\odot}} \frac{N(\lambda=+) - N(\lambda=-)}{N(\lambda=+) + N(\lambda=-)} \approx \sum a_k \sin k\phi$$



- 3×10^7 events with $W = 1.35$ to 2.35 GeV

Beam-Helicity Asymmetries



- $I^{\odot}$ observable is odd under ϕ transformation (parity conservation)

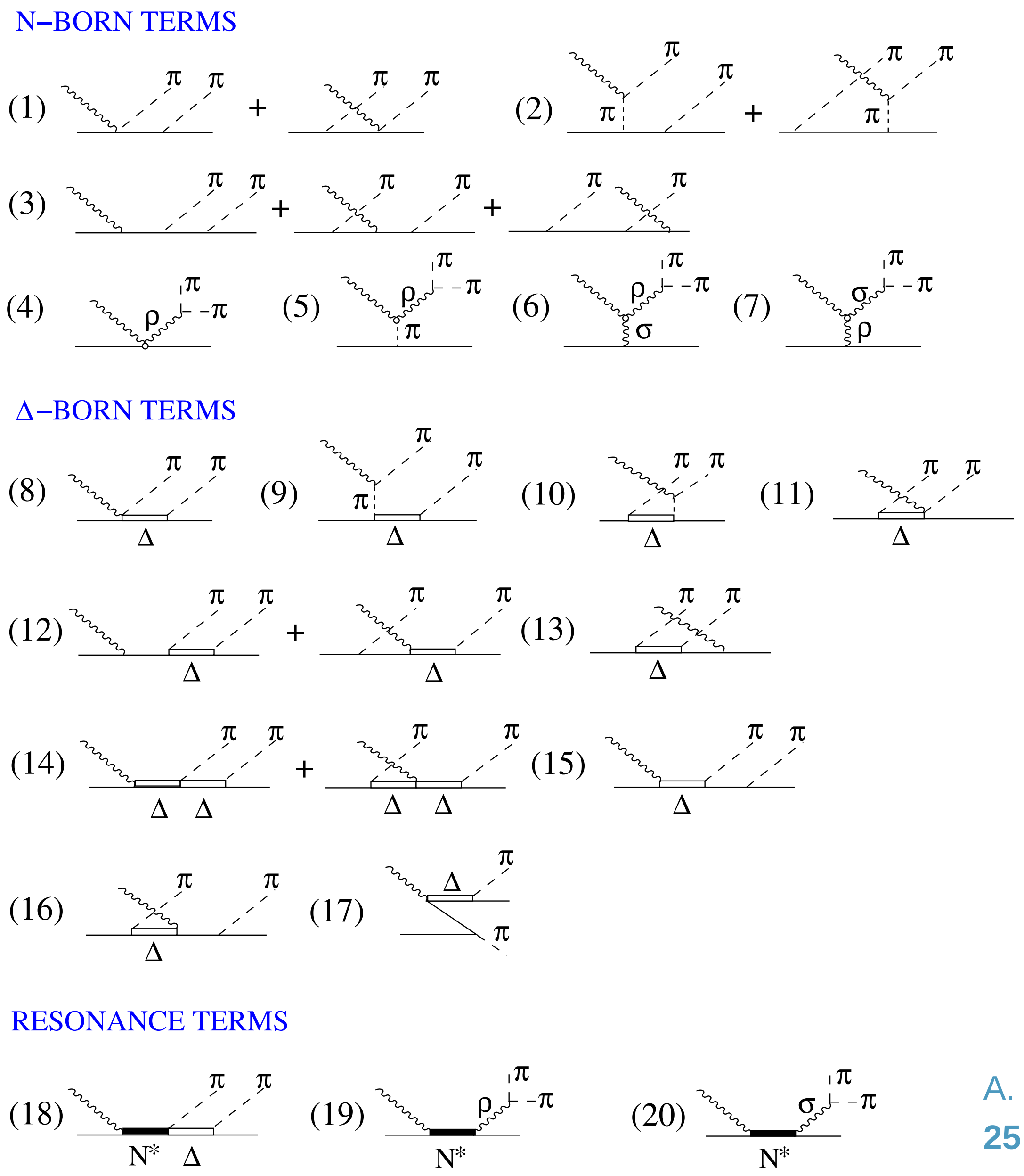
$$I^{\odot}(\phi) = -I^{\odot}(2\pi - \phi), \quad I^{\odot}(0) = I^{\odot}(\pi) = 0$$

Phenomenological Models

- Groups:
  W. Roberts and T. Oed, V. Mokeev, L. Roca, A. Fix and H. Arenhövel
- Models constructed according to the same scheme — effective Lagrangian densities
- Parameters for resonant and background mechanisms taken from experiments or treated as free parameters
- Differences
  - Wide variations in the corresponding coupling constants allowed by the Particle-Data Group listing
  - Treatment of the background, which appears to be very complicated in the effective Lagrangian approach for double-pion photoproduction

W. Roberts and T. Oed, Phys. Rev. C **71**, 055201 (2005); V.I. Mokeev *et al.*, Yad. Fiz. **64**, 1368 (2001); [Phys. At. Nucl. **64**, 1292 (2001)]; L. Roca, Nucl. Phys. A **748**, 192 (2005); A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

$\pi\pi N$ Model of Fix and Arenhövel



- Effective Lagrangian approach with Born and resonance diagrams at the tree level

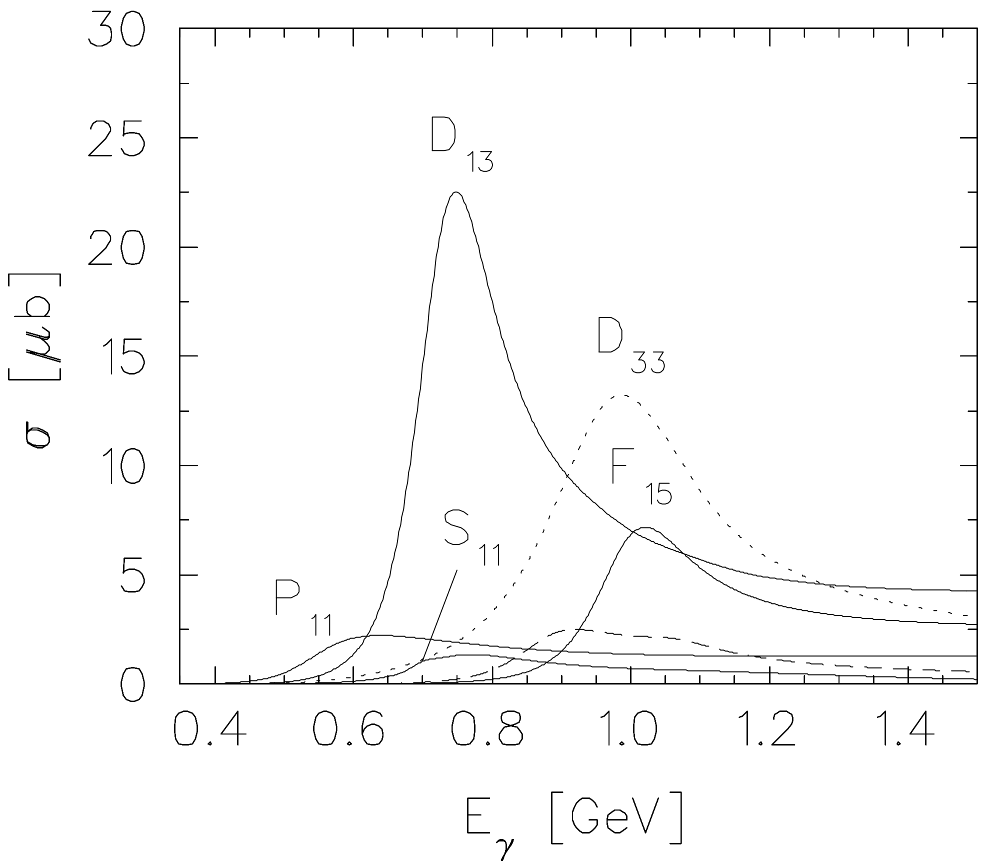
- The model includes the nucleon, $\Delta(1232)$, $N(1440)$, $N(1520)$, $N(1535)$, $N(1680)$, $\Delta(1700)$, and Mesons: σ, ρ

- Event-by-event calculations available

A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

Resonance Contributions

- Contributions to the $\gamma p \longrightarrow p\pi^+\pi^-$ total cross section

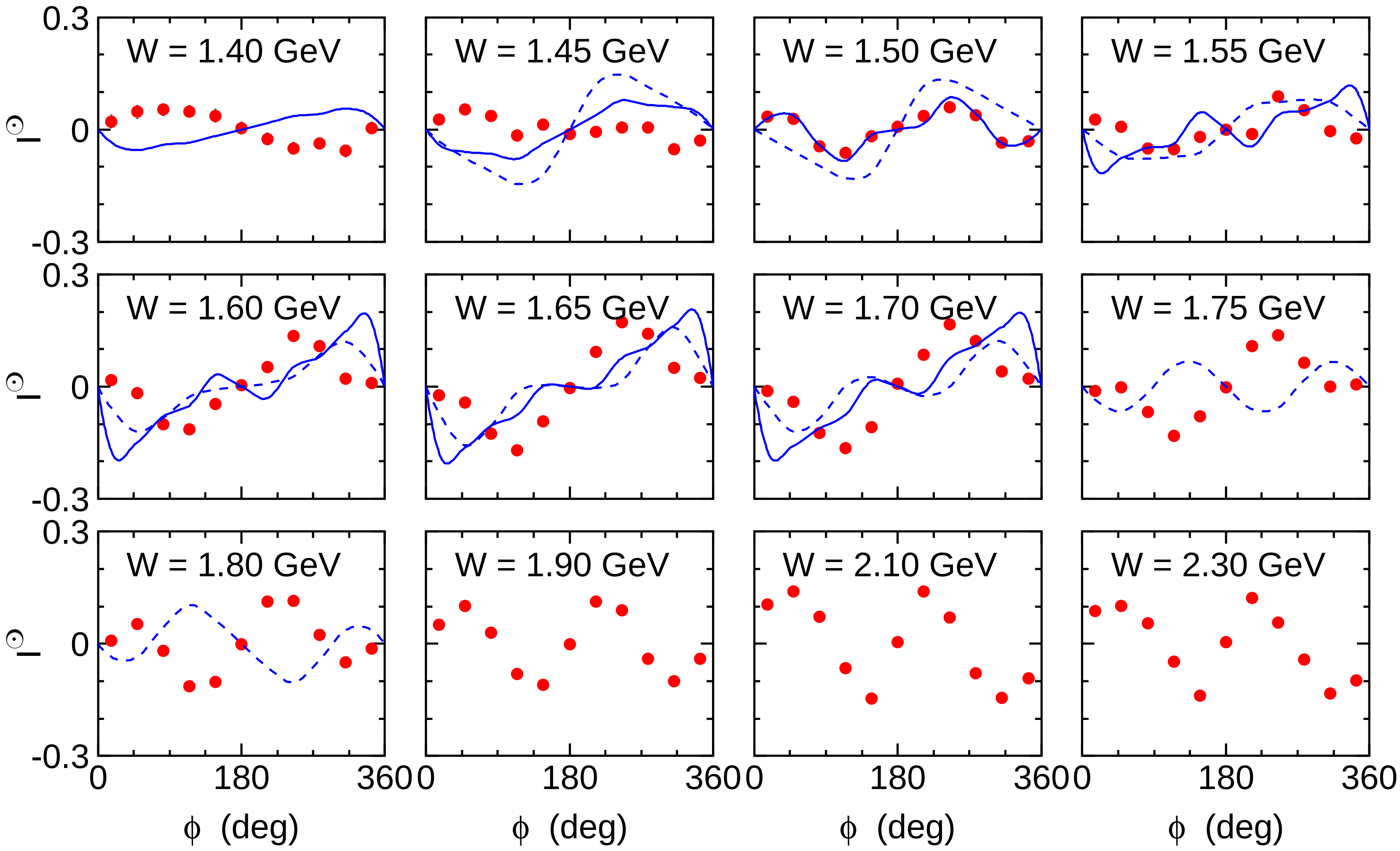


- Strongest contribution from $D_{13}(1520)$

A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

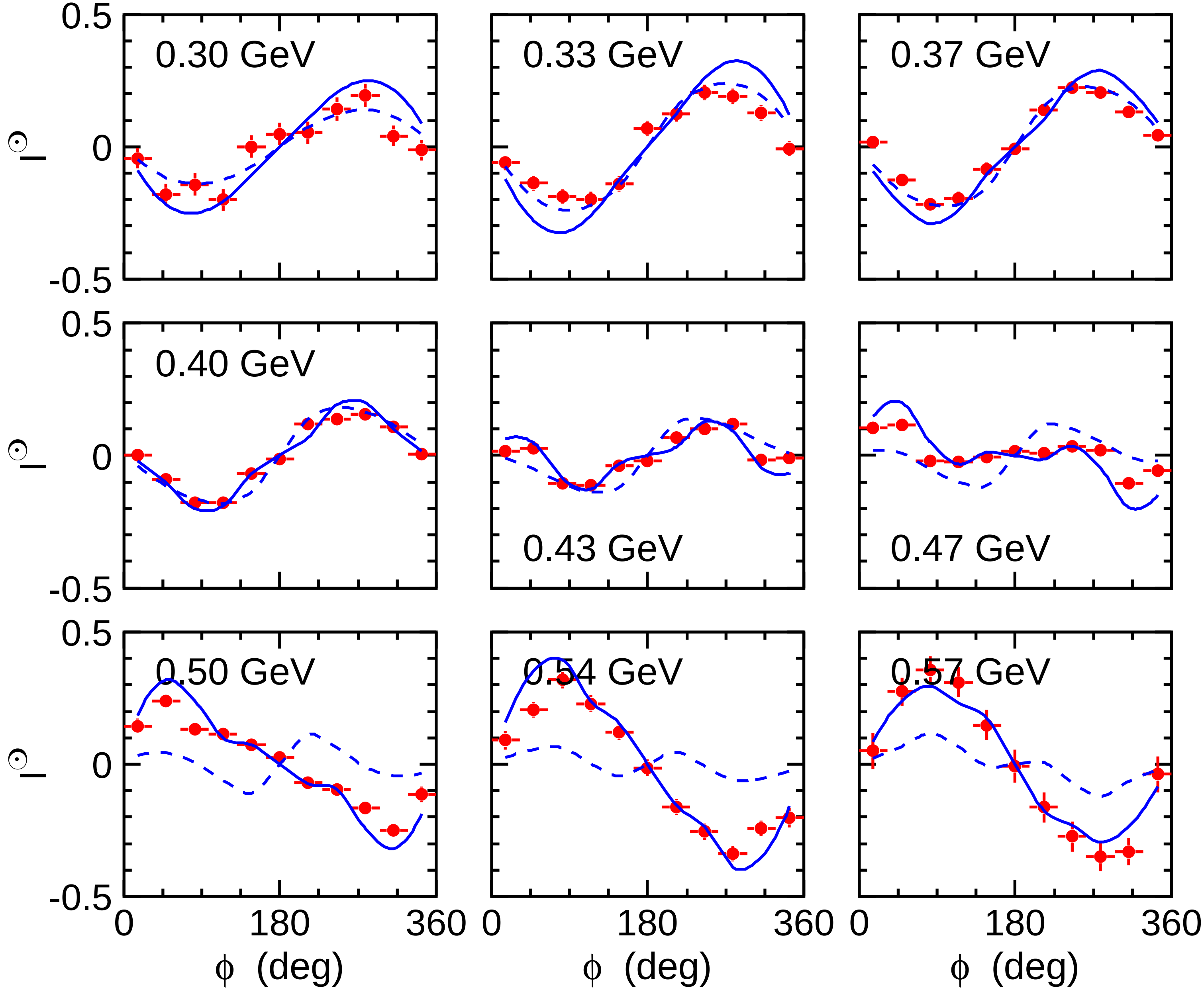
Beam-Helicity Asymmetries

Calculations from Mokeev (dashed) and Fix (solid)

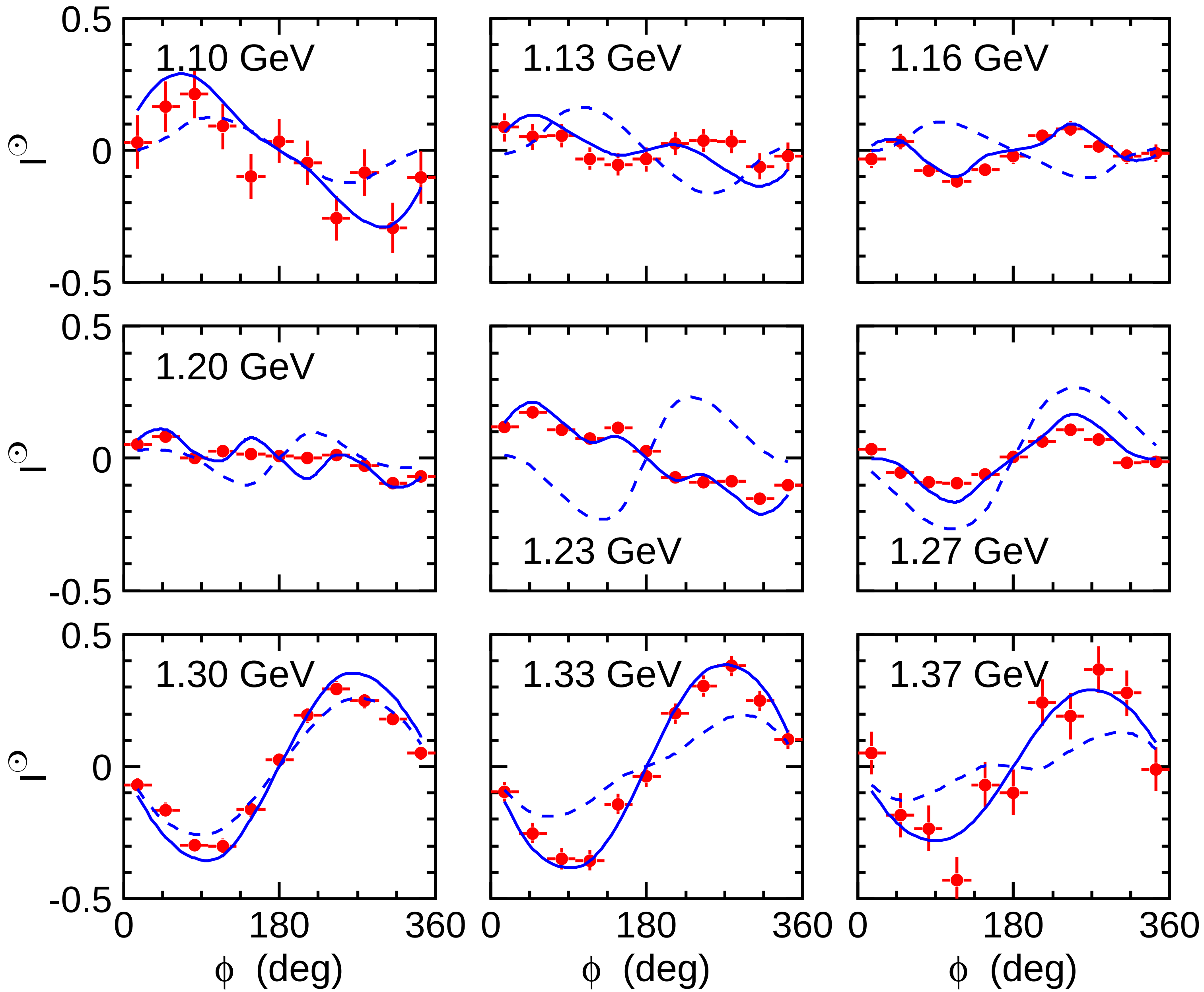


- Model predictions agree remarkably well for certain conditions, for other conditions they are much worse and out of phase entirely.

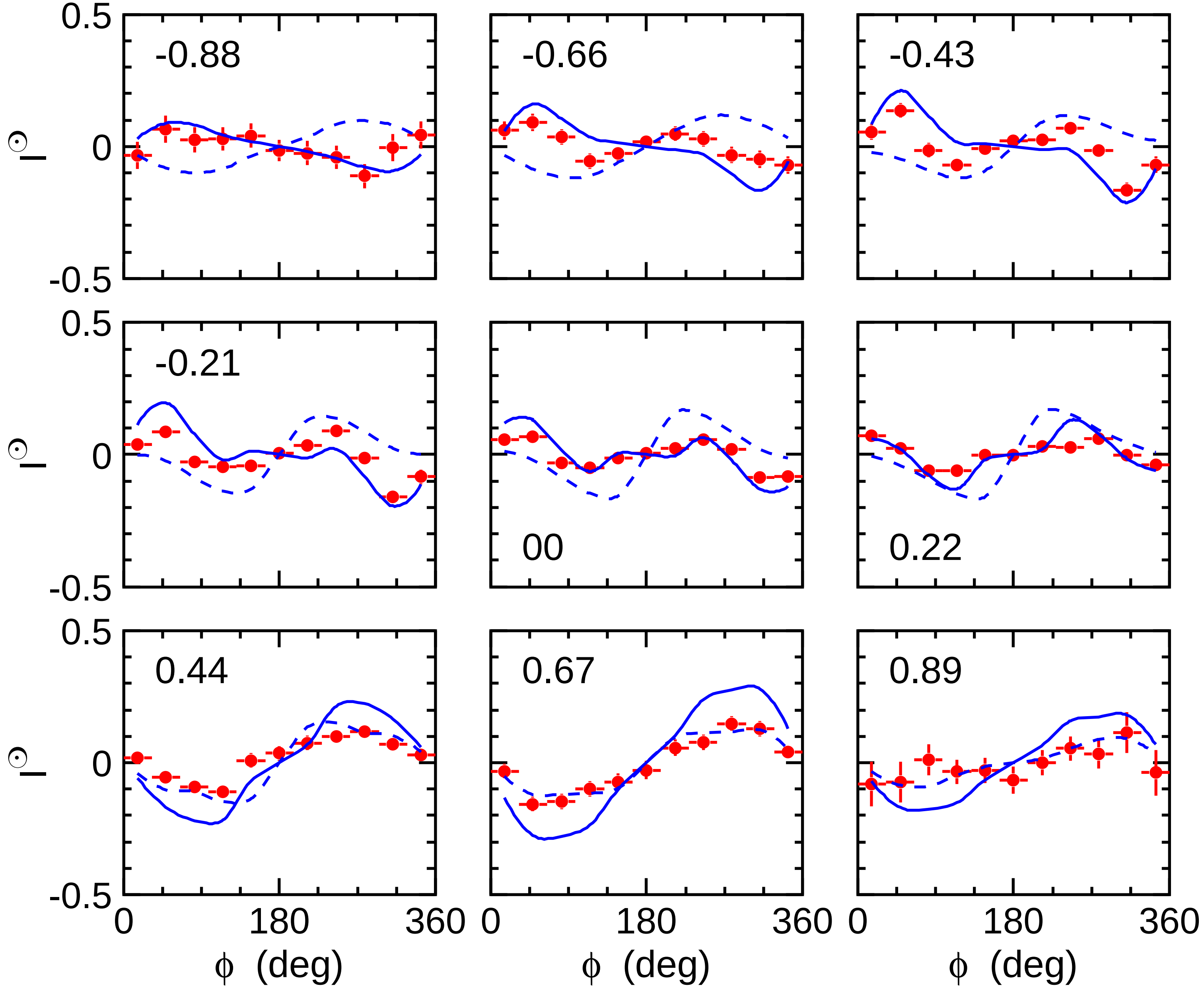
$M(\pi^+\pi^-)$ Distribution at $W = 1.5$ GeV



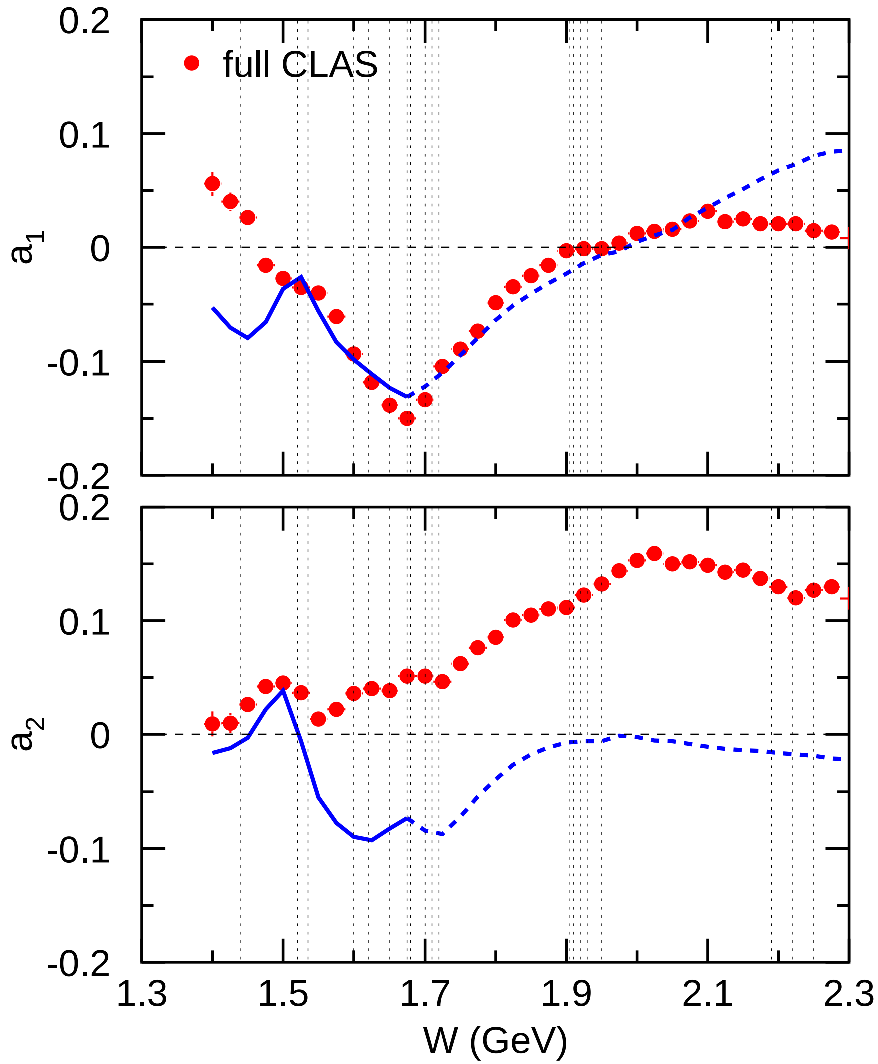
$M(p\pi^+)$ Distribution at $W = 1.5$ GeV



$\cos(\theta_{\mathrm{cm}})$ Distribution at $W = 1.5$ GeV

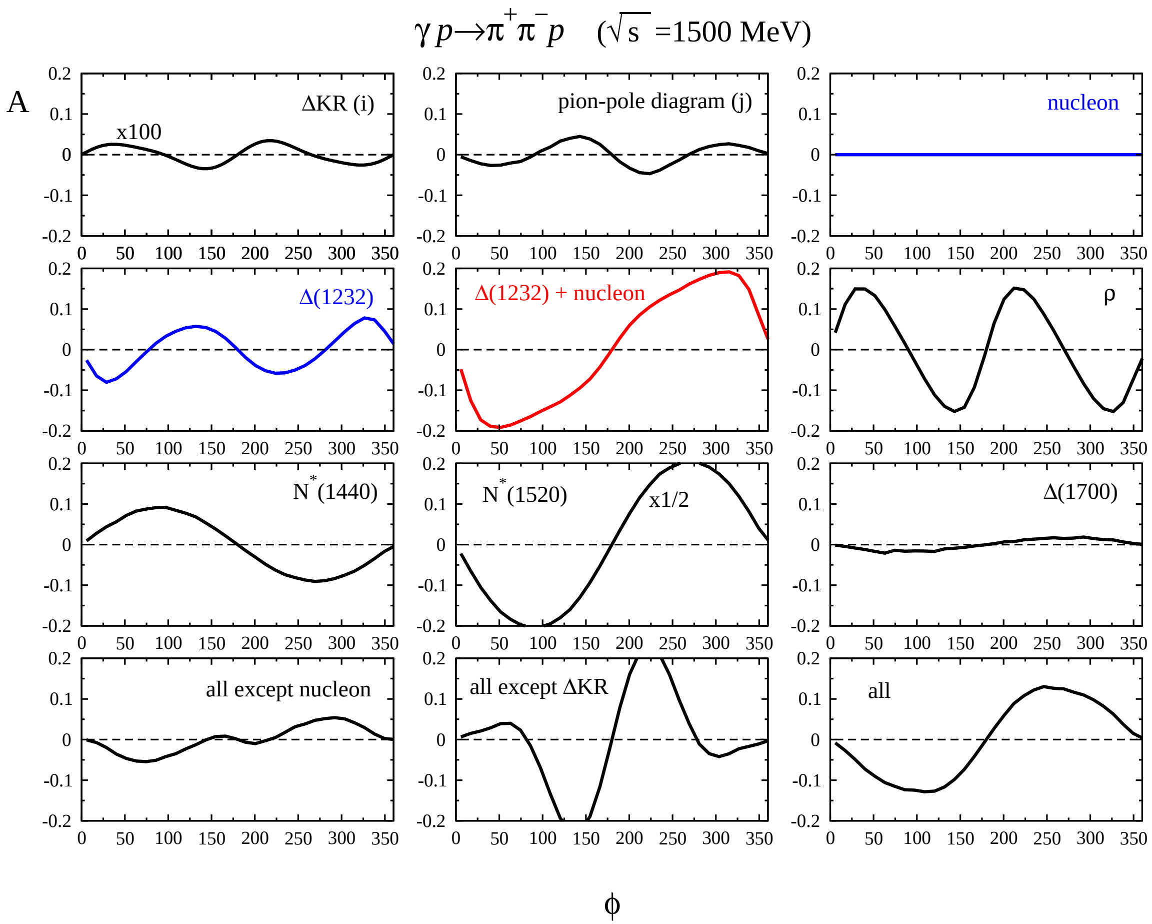


Fourier Coefficients of Angular Distributions



- $I^{\odot} = \sum a_k \sin(k\Phi)$
- Model of Fix and Arenhövel
  - Model valid up to $W = 1.7$ GeV
  - Excellent agreement at $W = 1.5$ GeV
  - Generally good agreement for a_1
  - Problems: a_1 at low values of W, and a_2

Crucial Role of Interferences

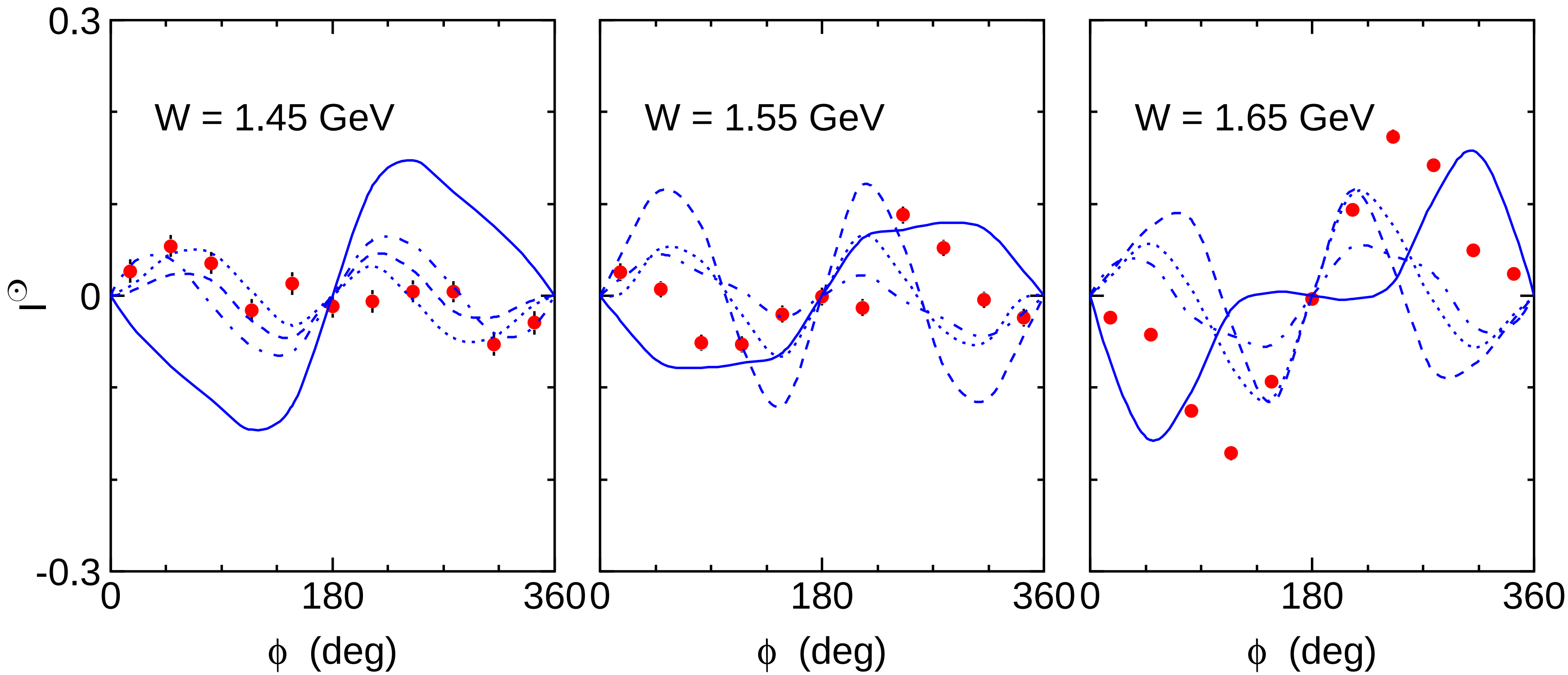


- Calculations by Roca (Valencia model)
- Tree-level mechanisms
- $\Delta(1232)$, $N^*(1440)$, $N^*(1520)$, $\Delta(1700)$
- no free parameters

- Example: intermediate-nucleon mechanisms and $\Delta(1232)$ mechanisms, and interference of both.

L. Roca, Nucl. Phys. A **748**, 192 (2005)

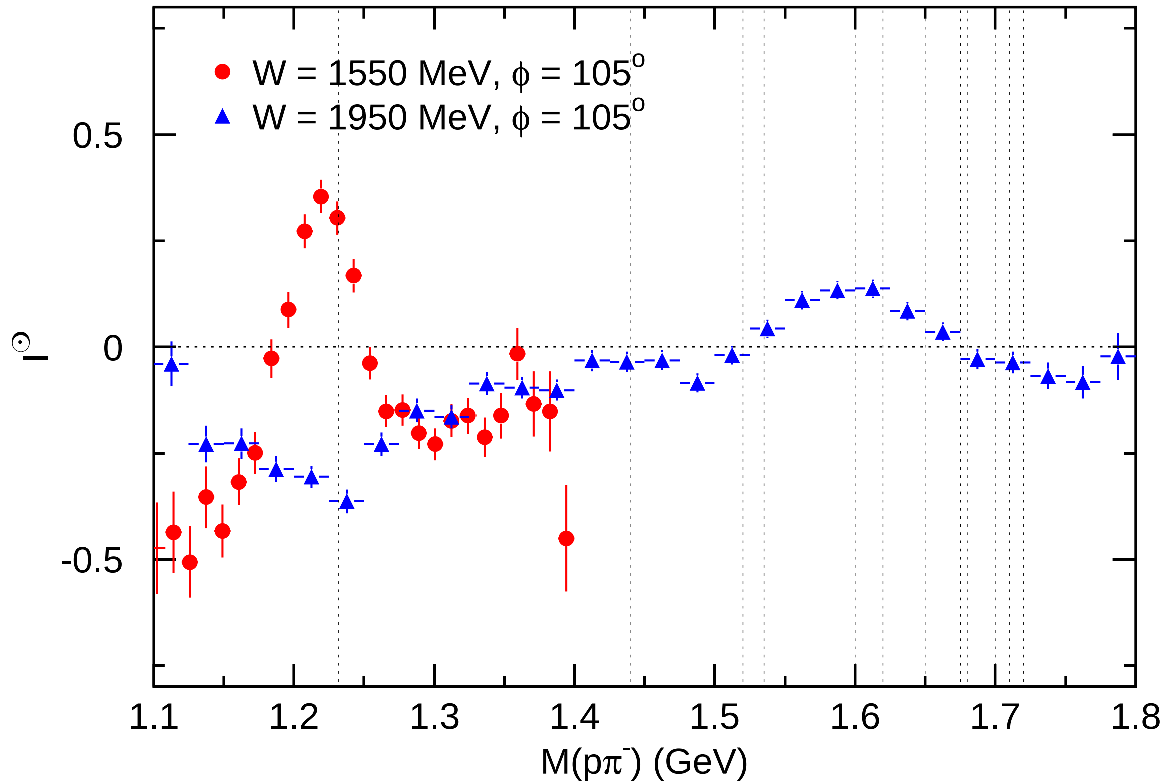
Relative Phases Among $\pi\pi N$ Mechanisms

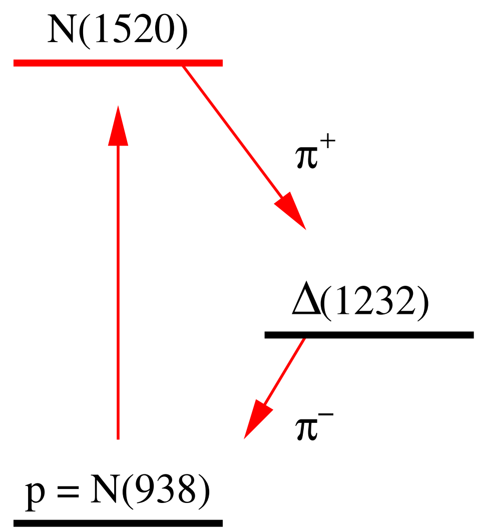


- Example: calculations with relative phases of $0°$, $90°$, $180°$, and $270°$ between the background- and $\pi\Delta$-subchannel amplitudes
- Great potential to improve description

V. Mokeev, private communication

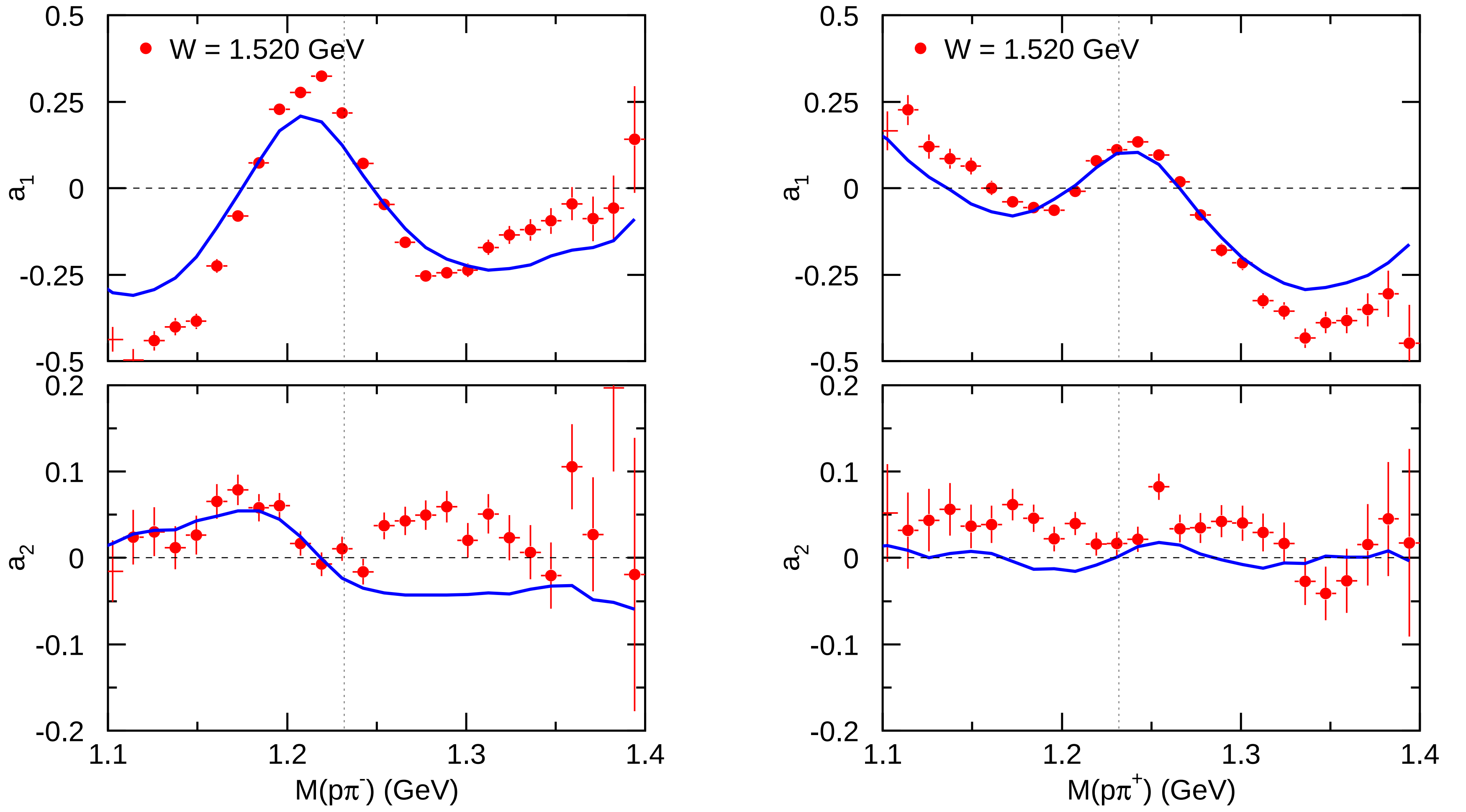
Excitation and Decay of Proton Resonances





- Helicity asymmetries allow detailed study of the $\gamma N \longrightarrow N\pi\pi$ reaction (*e.g.*, sequential decay)

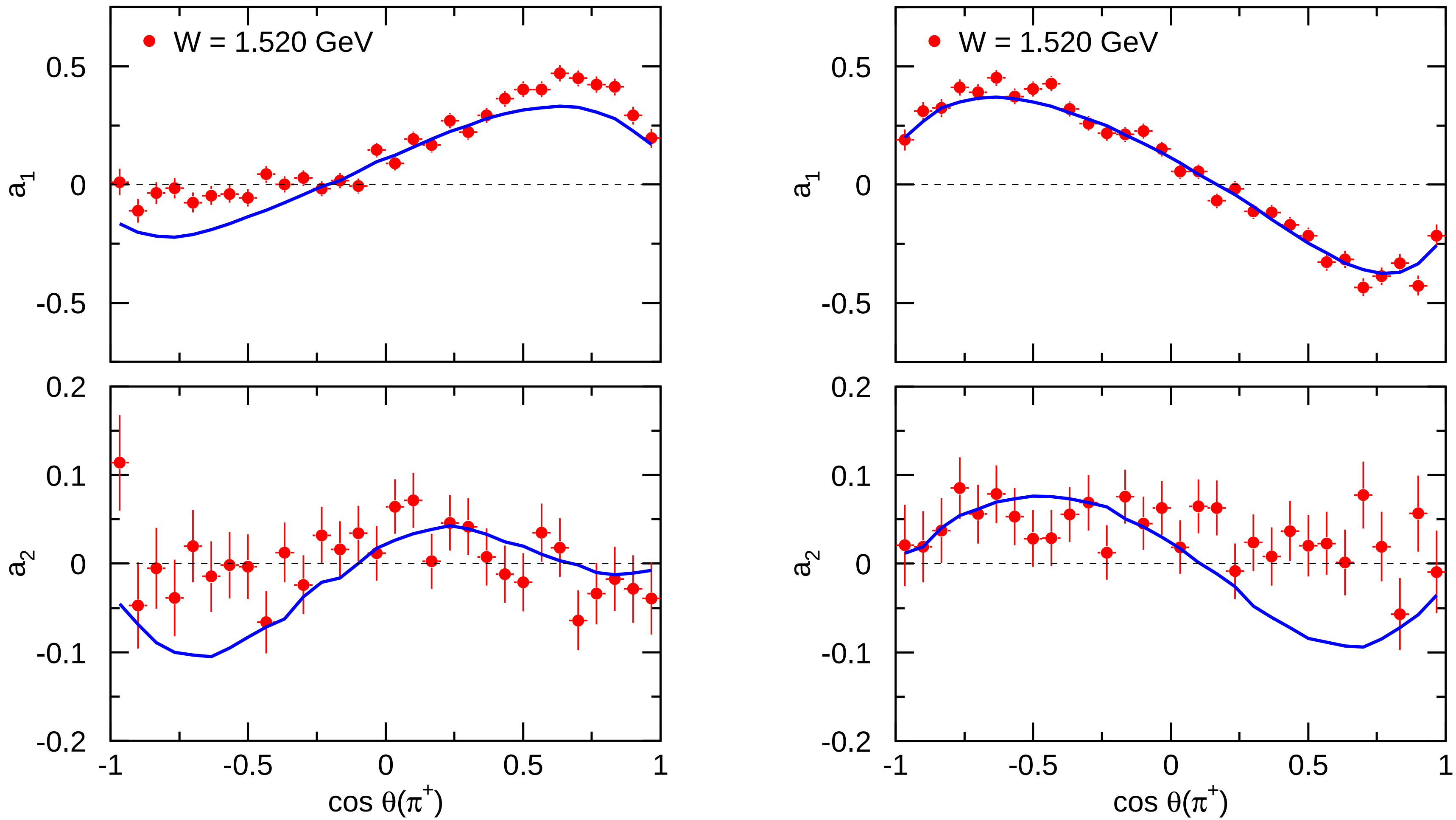
Intermediate $\Delta(1232)$ Resonance



- $N(1520) \rightarrow \pi^+\Delta^0 \rightarrow p\pi\pi$
- $N(1520) \rightarrow \pi^-\Delta^{++} \rightarrow p\pi\pi$

A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

Intermediate $\Delta(1232)$ Resonance



- $M(\pi^- p) \approx m_\Delta \pm 30$ MeV
- $N(1520) \to \pi^+ \Delta^0 \to p\pi\pi$

- $M(\pi^+ p) \approx m_\Delta \pm 30$ MeV
- $N(1520) \to \pi^- \Delta^{++} \to p\pi\pi$

A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

The $\pi^0\pi^0 p$ Channel

- Most background terms excluded in the $\pi^0\pi^0$ channel

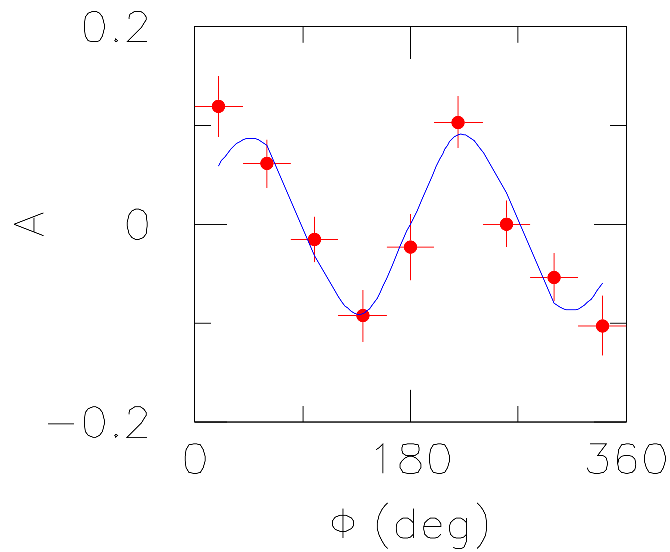
- Two identical particles in the final state

$$A(\phi) = A(\phi + \pi)$$
$$A(\phi) = a_2 \sin 2\phi + \ldots$$

- Illustration: preliminary CLAS data γ^3He$\rightarrow ppn$ for $P_n > 250$ MeV/c

T. Ukwatta, private communication

Preliminary



- Planned measurement of $\gamma p \rightarrow \pi^0\pi^0 p$ at Mainz and Bonn

$\vec{\gamma}\vec{p} \longrightarrow \pi\pi\vec{N}$ Reaction Rate

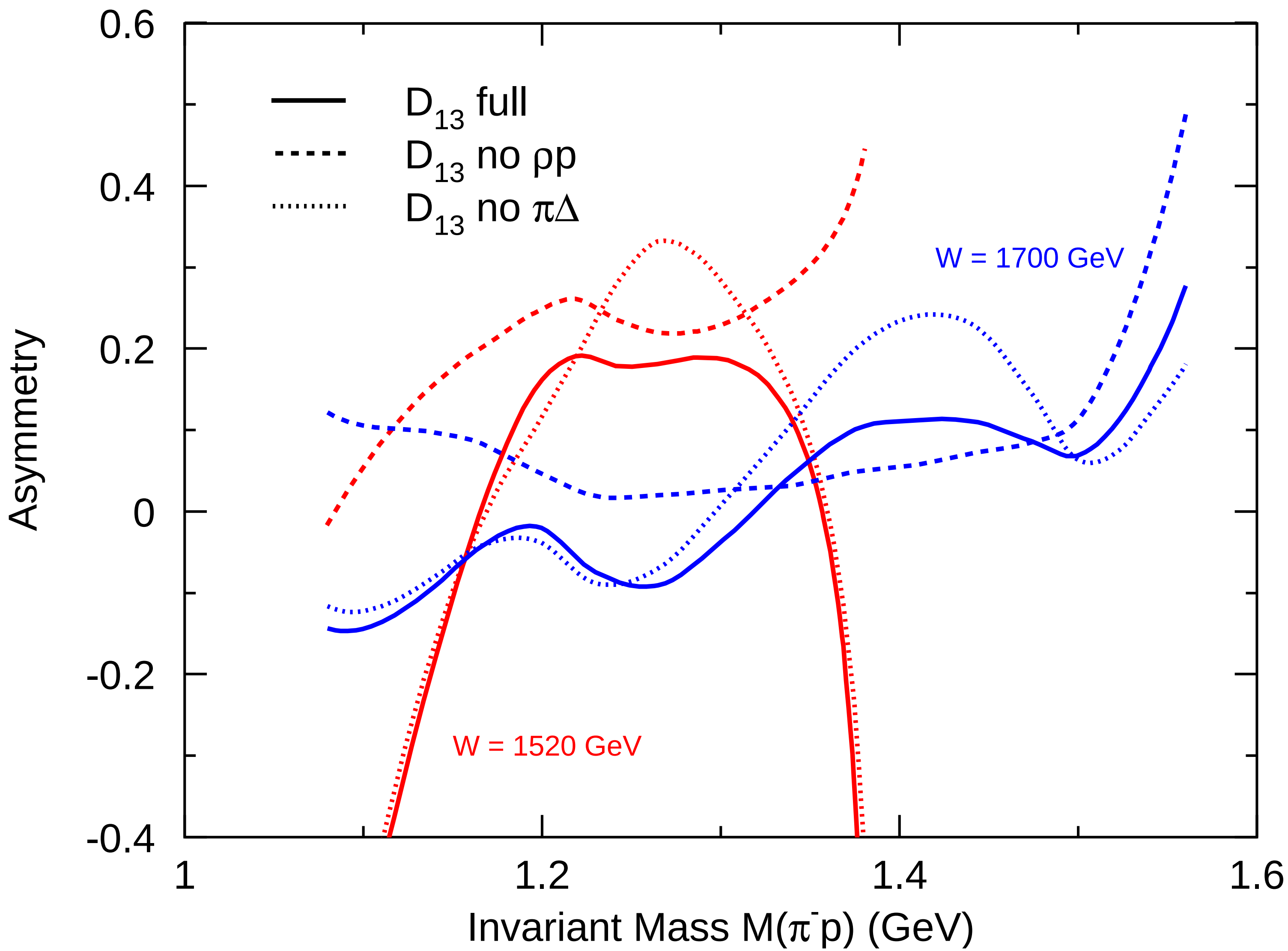
$$
\begin{aligned}
\rho_f I \;=\; & I_0 \Big\{ \Big(1 + \vec{\Lambda}_i \cdot \vec{P} + \vec{\sigma} \cdot \vec{P}' + \Lambda_i^{\alpha} \sigma^{\beta'} \mathcal{O}_{\alpha\beta'} \Big) \\
& + \delta_{\odot} \Big(I^{\odot} + \vec{\Lambda}_i \cdot \vec{P}^{\odot} + \vec{\sigma} \cdot \vec{P}^{\odot\prime} + \Lambda_i^{\alpha} \sigma^{\beta'} \mathcal{O}^{\odot}_{\alpha\beta'} \Big) \\
& + \delta_{\ell} \Big[\sin 2\beta \Big(I^{s} + \vec{\Lambda}_i \cdot \vec{P}^{s} + \vec{\sigma} \cdot \vec{P}^{s\prime} + \Lambda_i^{\alpha} \sigma^{\beta'} \mathcal{O}^{s}_{\alpha\beta'} \Big) \\
& + \cos 2\beta \Big(I^{c} + \vec{\Lambda}_i \cdot \vec{P}^{c} + \vec{\sigma} \cdot \vec{P}^{c\prime} + \Lambda_i^{\alpha} \sigma^{\beta'} \mathcal{O}^{c}_{\alpha\beta'} \Big) \Big] \Big\}
\end{aligned}
$$

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

- Known: I_0, $P_z^{\odot}$ ($\sigma_{3/2} - \sigma_{1/2}$, GDH sum rule); new from CLAS: $I^{\odot}$
- Polarized beam-target experiments with frozen-spin target at CLAS will make available: $P_x^{\odot}$, $P_y^{\odot}$, $P_z^{\odot}$, I^s, P_x^s, P_y^s, P_z^s, I^c, P_x^c, P_y^c, P_z^c

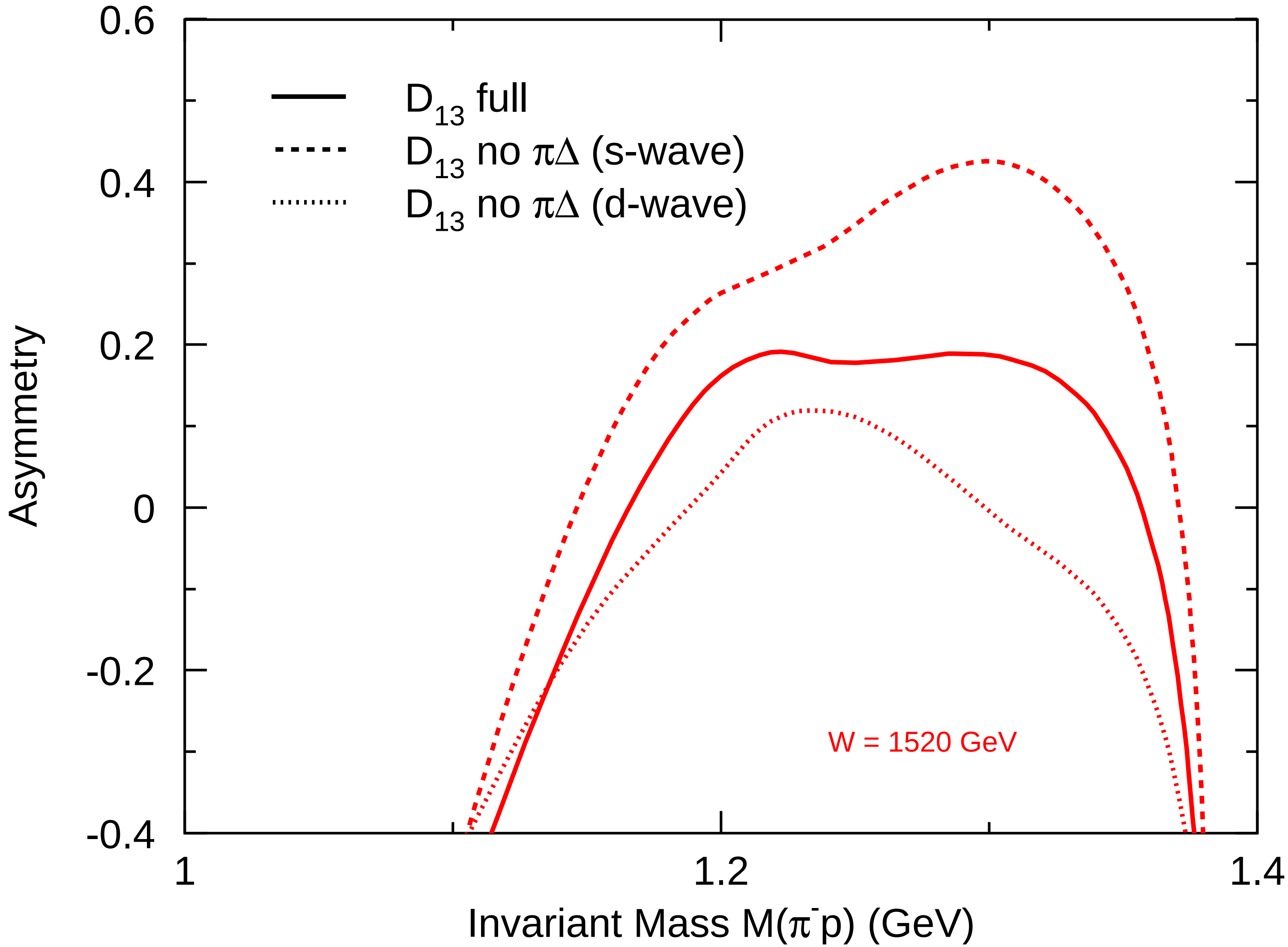
Jefferson Lab proposal to PAC 29, V. Credé*, M. Bellis, S. Strauch, spokespeople

Beam-Target Asymmetry $P_z^{\odot}$



A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

Beam-Target Asymmetry $P_z^{\odot}$



A. Fix and H. Arenhövel, Eur. Phys. J. A **25**, 115 (2005)

Summary

- First measurement of the beam-helicity asymmetry in the $\vec{\gamma} p \rightarrow p \pi^+ \pi^-$ reaction
  - Beam-helicity asymmetry sensitive to details of the reaction mechanisms
  - Models currently do not provide an adequate description for the behavior of this new observable
- Extraction of N* photocoupling and resonance parameters in combined analysis of cross-section and polarization data
  - Interpretation within phenomenological models
  - Constraining partial-wave analyses
- New beam-target polarization experiments (FROST at CLAS)