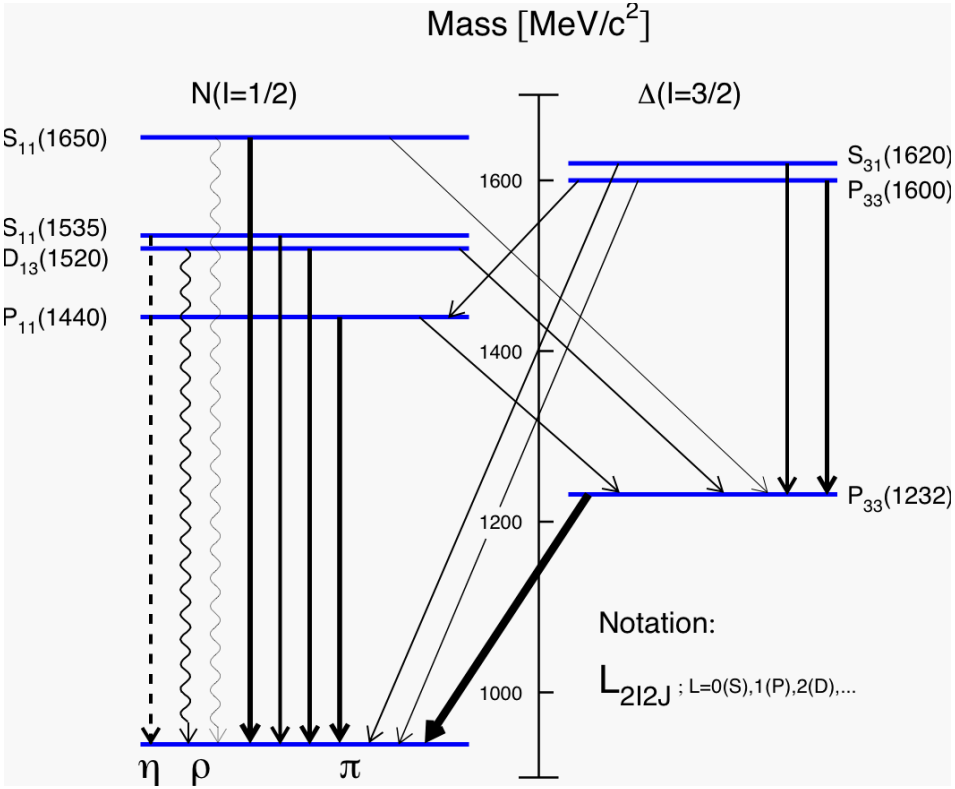
Helicity asymmetry E in $\gamma p \rightarrow \pi^+ n$ with FROST

Steffen Strauch for the CLAS Collaboration
University of South Carolina

The 8th International Workshop on the Physics of Excited Nucleons
NSTAR 2011, Jefferson Lab, Newport News, VA, May 17–20, 2011

Work supported in parts by the U.S. National Science Foundation: NSF PHY-0856010.

Studying the Excited States of the Nucleon

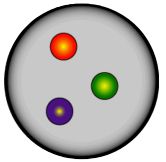


$$\gamma N \rightarrow N\pi, N\pi\pi, N\eta, YK, \ldots$$

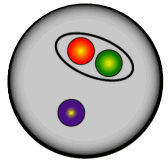
- The location and properties of excited states reflect the dynamics and relevant degrees-of-freedom within the nucleons.

Quark Models

- Symmetric Constituent Quark Models predict overabundance of excited states (**"missing" resonance problem**)



- Quark-Diquark Models predict fewer states



- Quark and Flux-Tube Models predict increased number of states

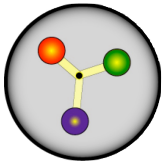
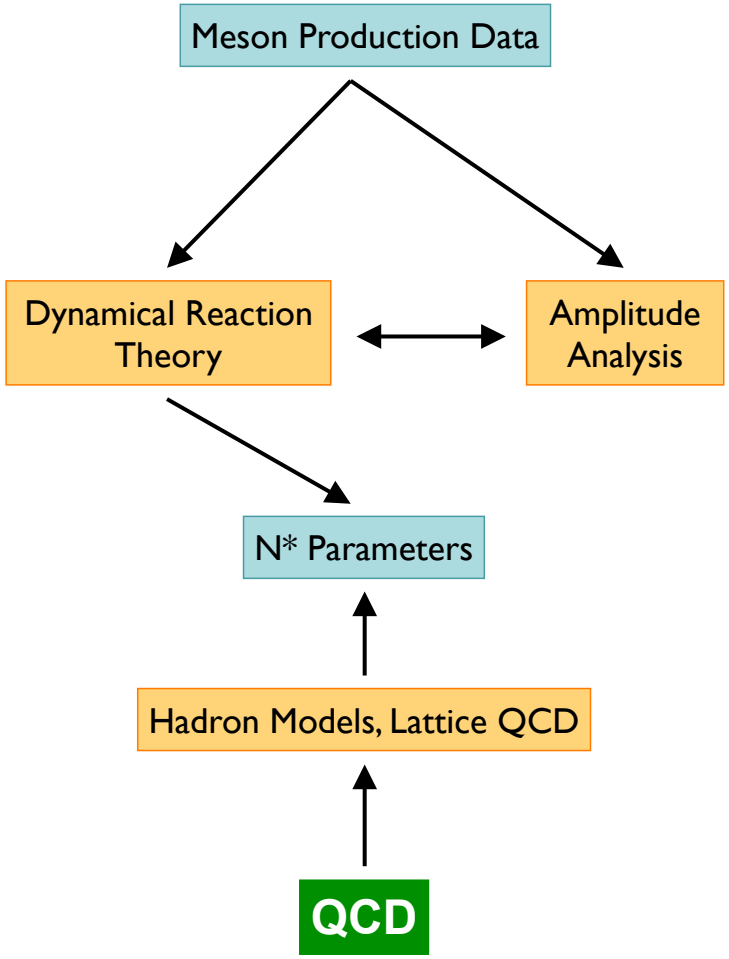


Figure from: B. Krusche and S. Schadmand, Prog. Nucl. Phys. 51, 399 (2003)

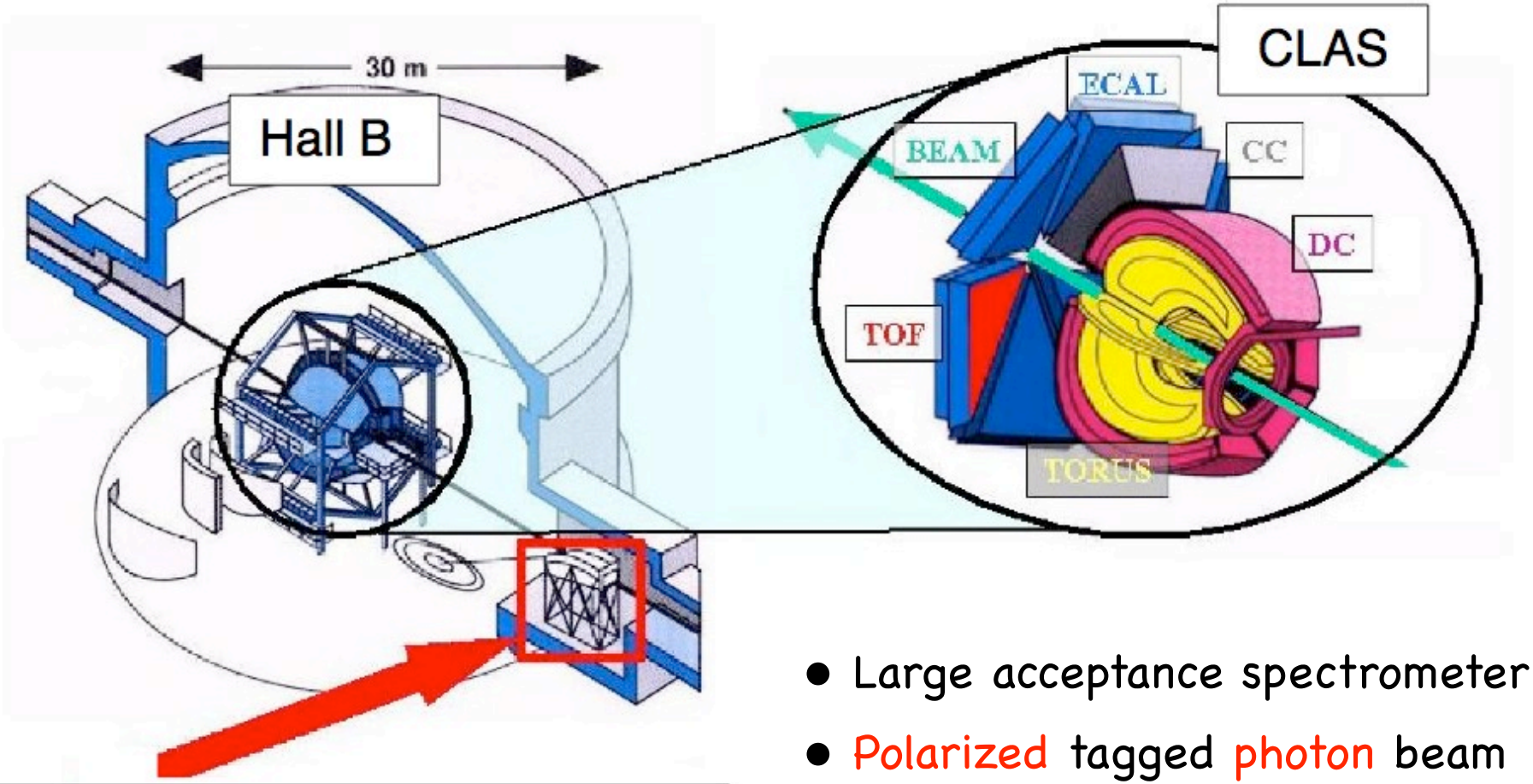
Extraction of Resonance Parameters

- Measurements of eight observables needed to unambiguously determine the four amplitudes of single meson photoproduction:
  - differential cross section: $d\sigma/d\Omega$
  - single polarization observables: P, T, Σ
  - double polarization observables
- CLAS experiments with
  - polarized beam
  - polarized target (FROST, HD-Ice)
  - baryon recoil polarization (weak decay of hyperons)



Excited Baryon Analysis Center at JLab; http://ebac-theory.jlab.org/

The CEBAF Large Acceptance Spectrometer



- Large acceptance spectrometer
- Polarized tagged photon beam
- Polarized target (FROST, HD-Ice)

B. Mecking, et al., Nucl. Instrum. Methods Phys. Res. A **503**, 513 (2003).

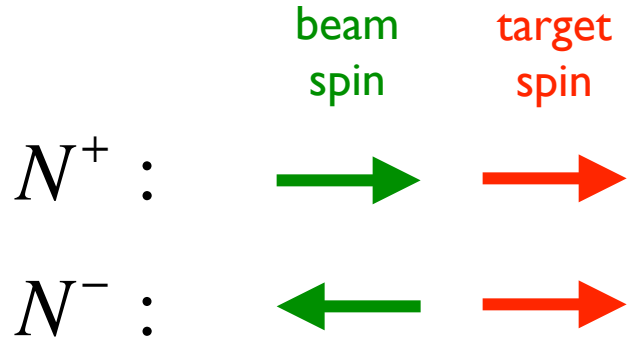
Pion Photoproduction: Observable E

- Circularly polarized beam / longitudinally polarized target

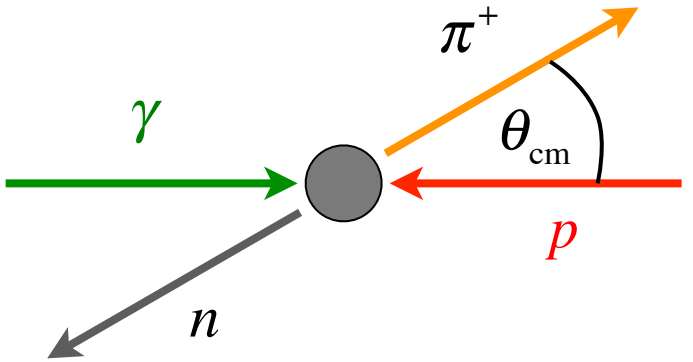
$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{\text{unpol}} \left(1 - P_Z P_\odot E\right)$$

- Estimator for E

$$E = -\frac{1}{hP_Z P_\odot}\frac{N^+ - N^-}{N^+ + N^-}$$

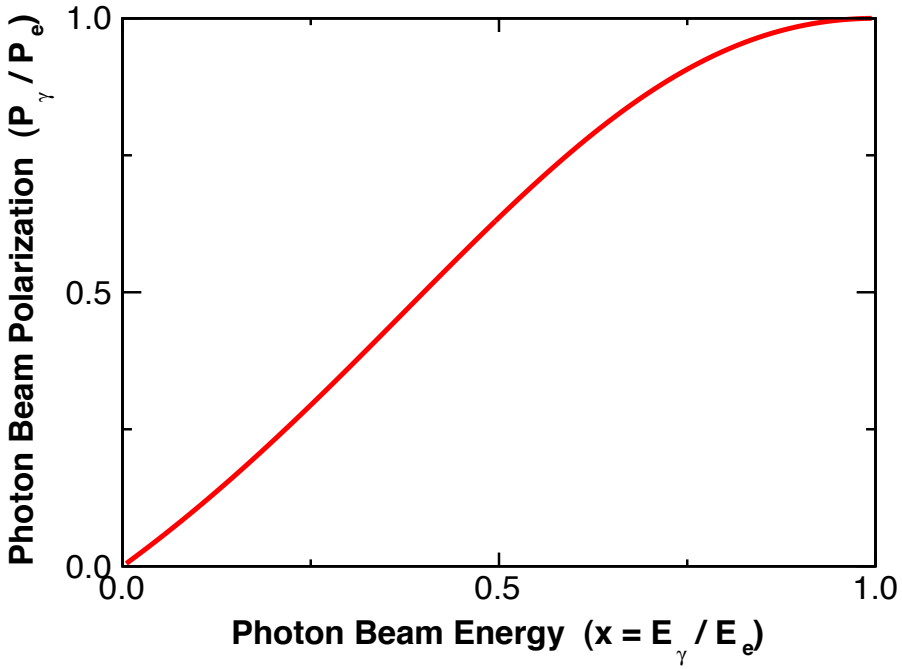


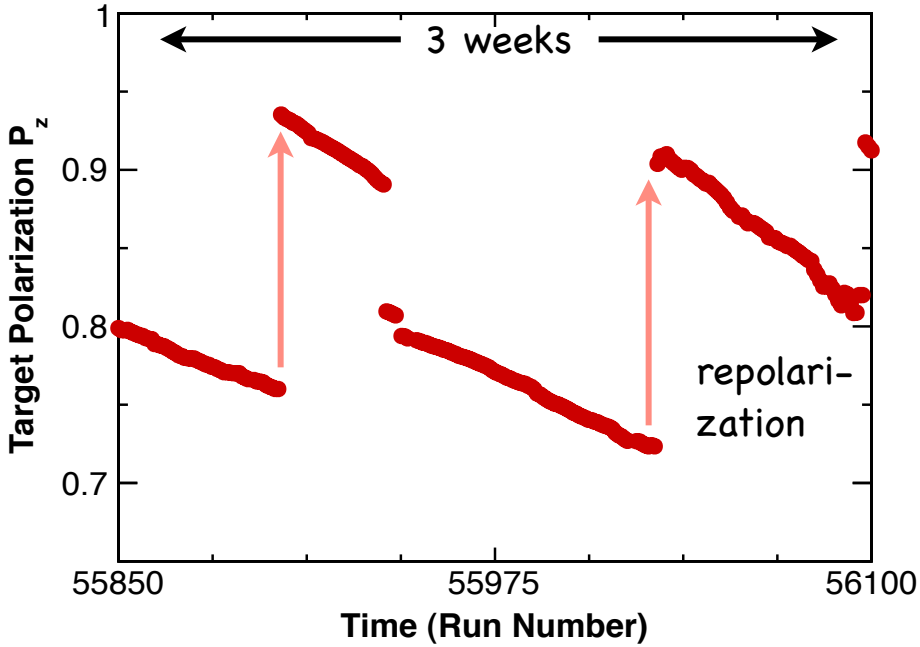
- Data N± from butanol target
- Bound-nucleon background is accounted for by the dilution factor h



I.S. Barker, A. Donnachie, and J.K. Storrow, Nucl. Phys. B75, 347 (1975)

Polarized Beam and Target



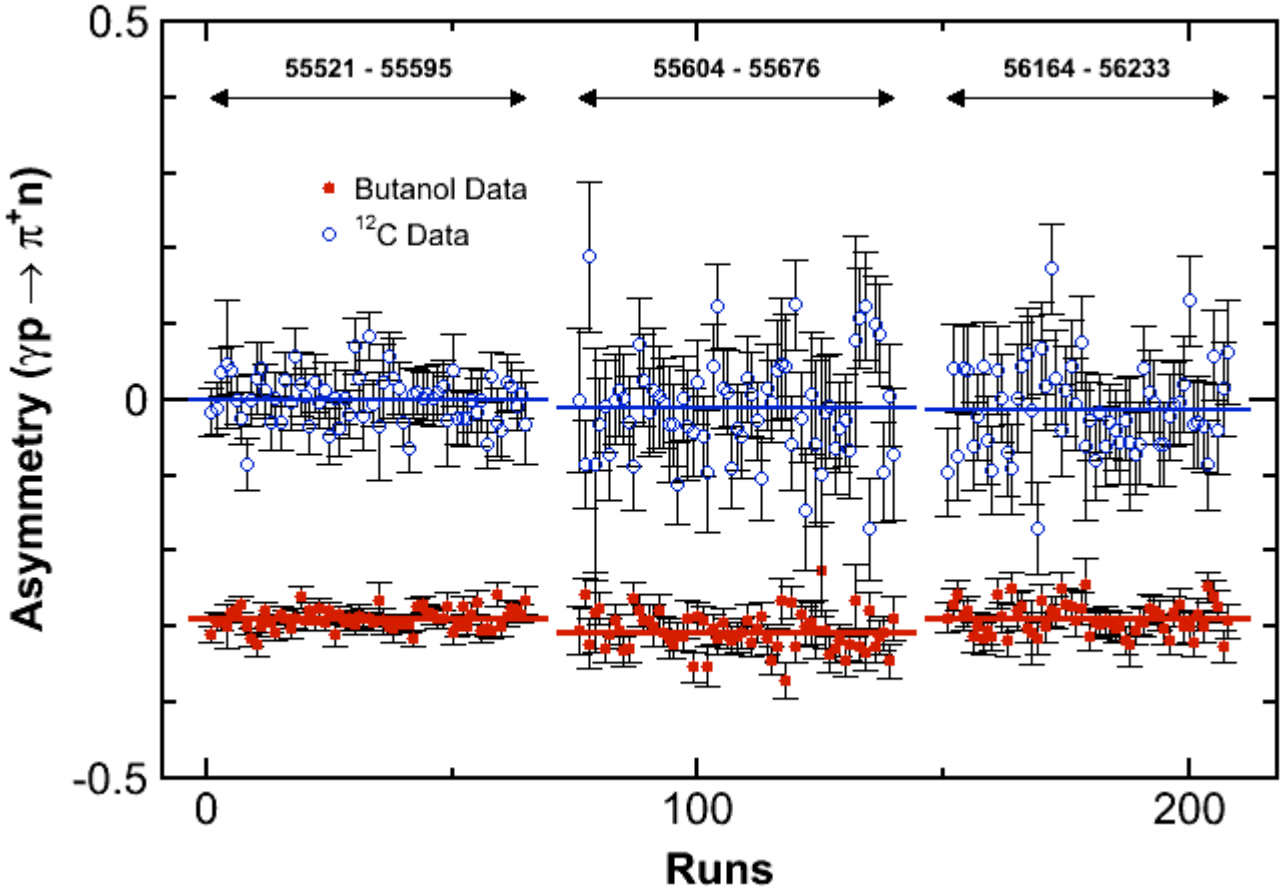


- **Circularly polarized photons**
  - Tagged photon beam
  - E_e = 1.65 GeV, 2.48 GeV
  - Electron beam polarization: $P_e \approx 85\%$
  - Avg. beam charge asy. $\delta N/N < 0.1\%$

- **Longitudinally polarized target**
  - Frozen Spin Butanol (C_4H_9OH) with polarized free protons
  - $P_z \approx 80\%$
  - Target depolarization: τ = 100 days

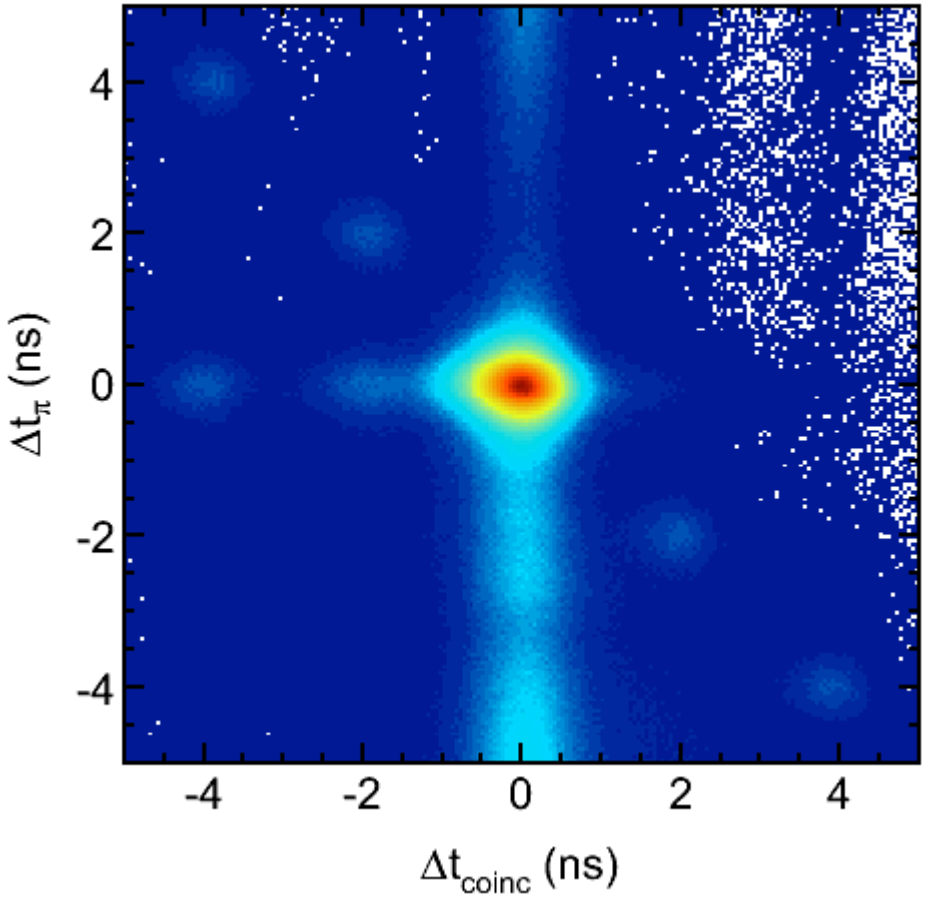
Stability of Beam/Target Polarization

E_e = 1.65 GeV | 1st E_e = 2.48 GeV | 2nd E_e = 2.48 GeV



- Per-run sign of $P_z P_\odot$ is understood
- Asymmetry of butanol data stepwise constant
- Target de- and re-polarizations under control
- Systematic uncertainty of $\sigma(P_z P_\odot) \approx 5\%$.

Particle ID and Coincidence



- Particle identification through time-of-flight measurement

$$\Delta t_\pi = \frac{L}{c}\left[\frac{1}{\beta} - \sqrt{\frac{m_\pi^2}{p^2}+1}\right]$$

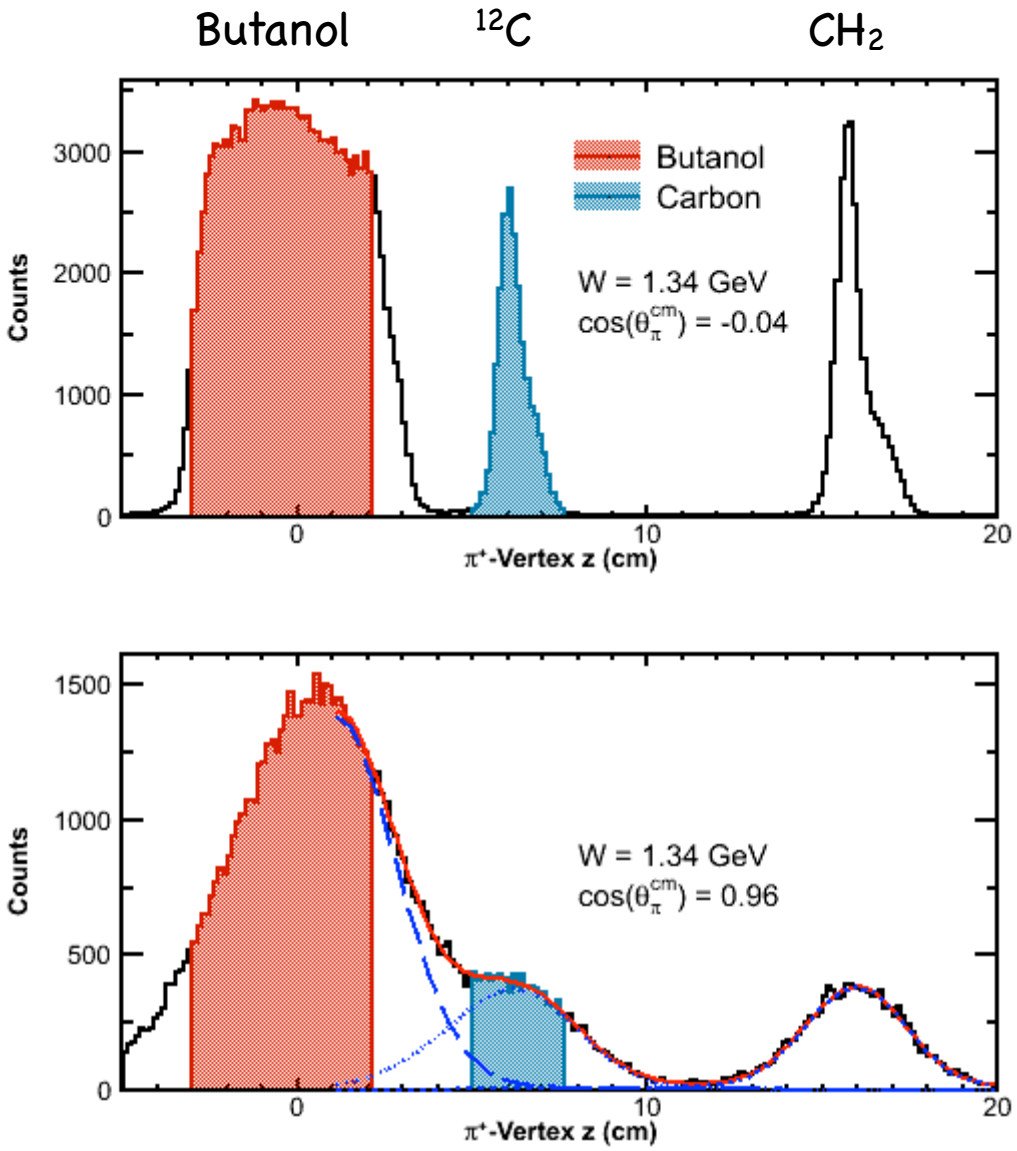
- Tagger - CLAS coincidence

$$\Delta t_{coinc} = t_{vertex}(Tag) - t_{vertex}(CLAS)$$

- Event selection

$$\left|\Delta t_\pi\right| < 1 \text{ ns}$$
$$\left|\Delta t_{coinc}\right| < 1 \text{ ns}$$

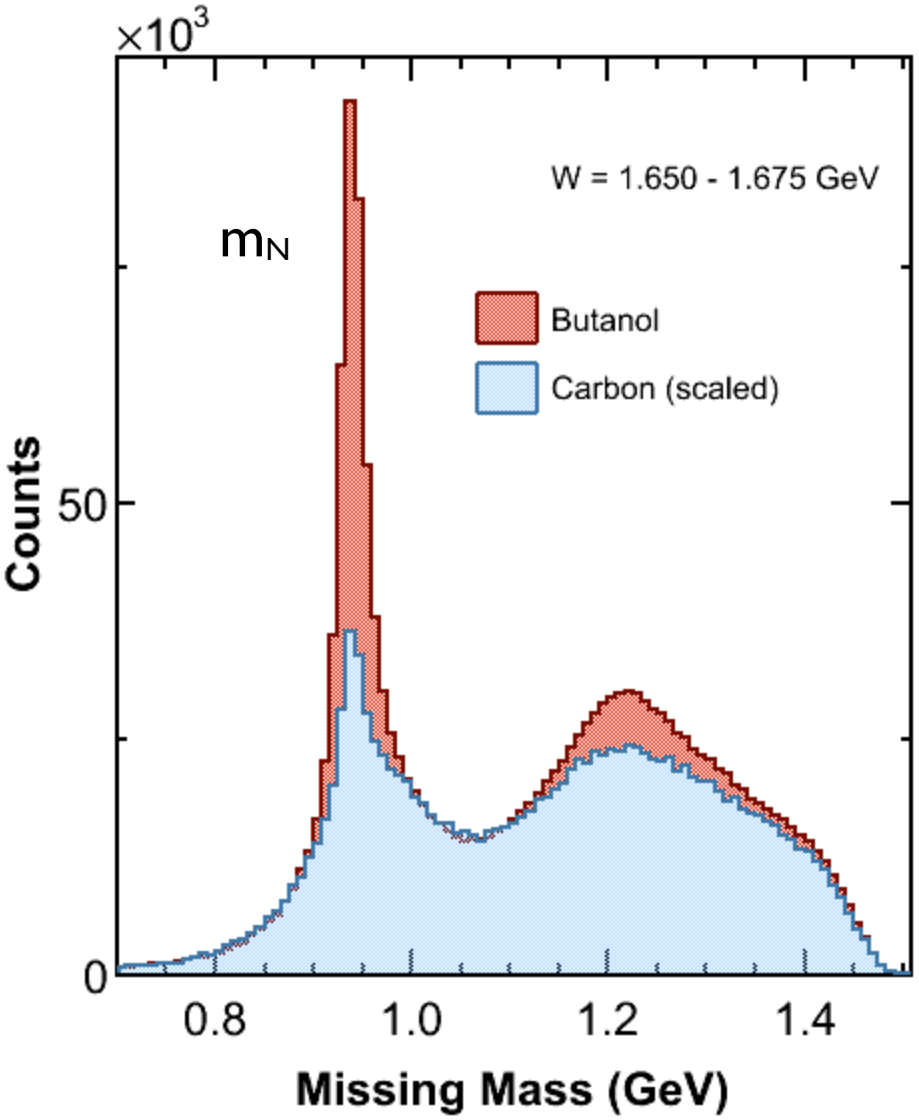
Reconstructed π^+ Vertex



- Frozen Spin **Butanol** (C_4H_9OH) with polarized free protons
- **Carbon target** to determine bound nucleon background
- **Polyethylene** target for systematic studies

- Events from butanol in the carbon-target region at extreme forward angles are taken into account in the dilution-factor calculation.

$\gamma(p,\pi^+)X$ - Missing-Mass Distribution

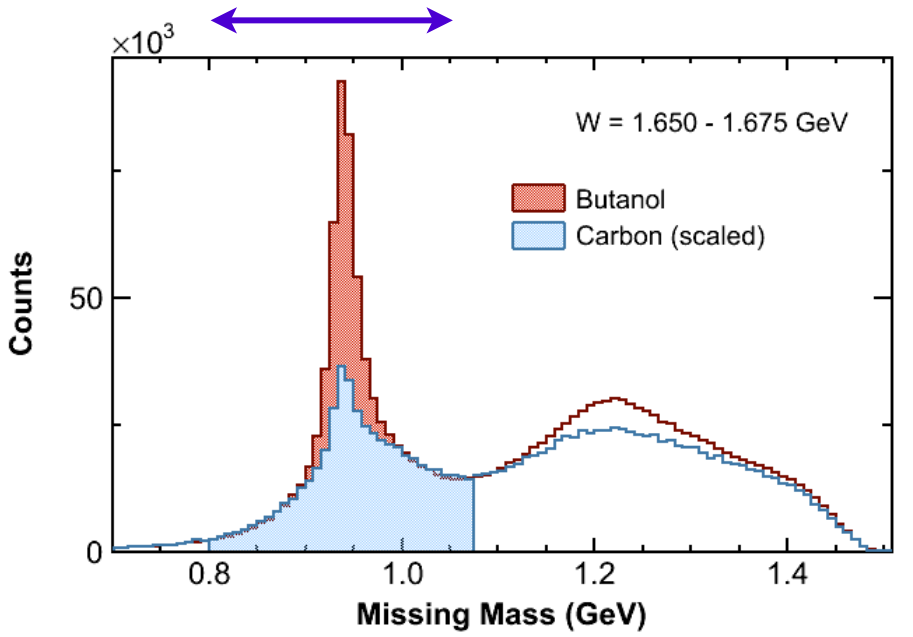


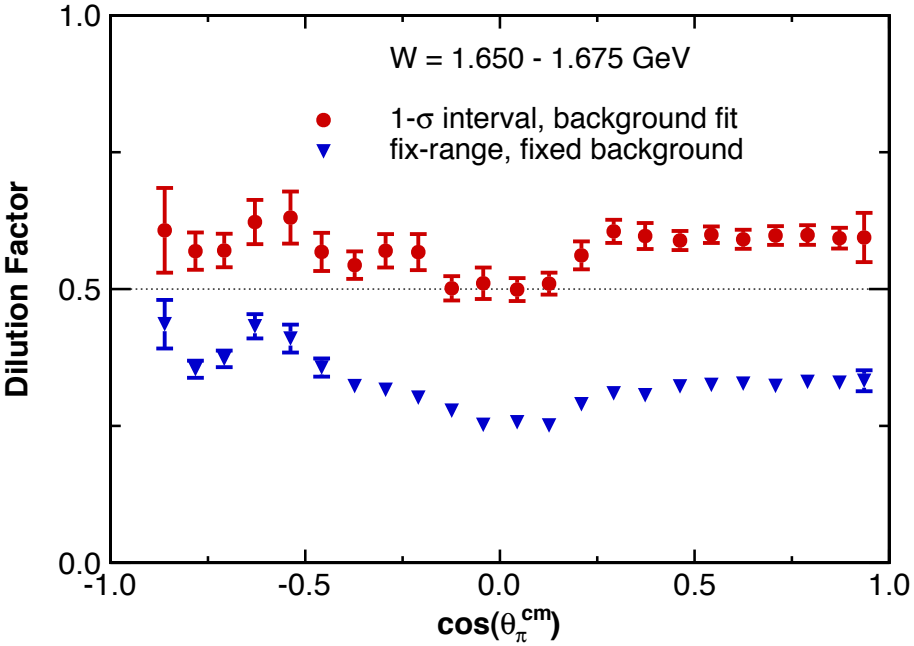
- Identification of reaction channel:

$$m_X \approx m_N$$

- Butanol target: π^+ production off free and bound nucleons
- Background from reactions off bound (unpolarized) nucleons

Dilution Factor





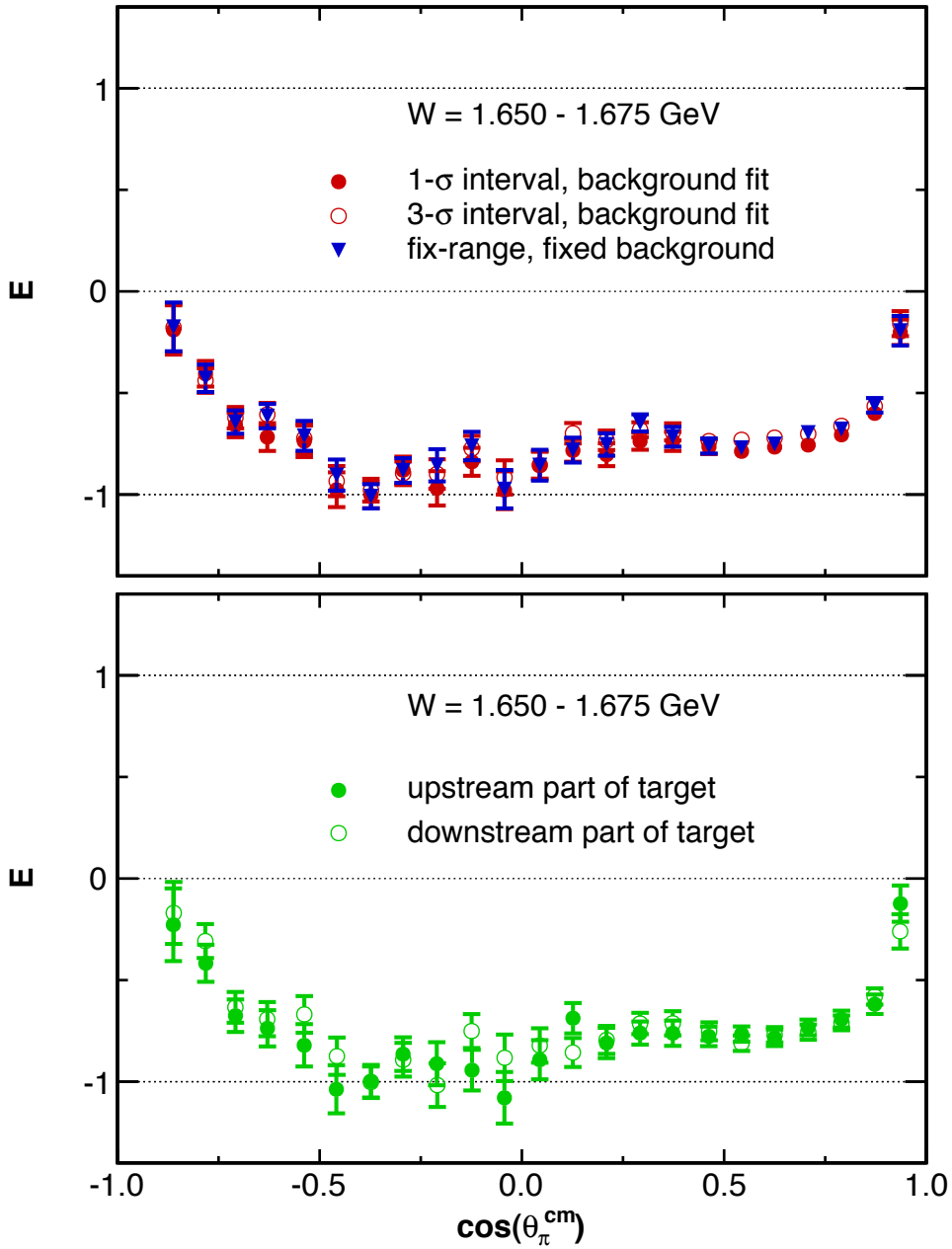
- Quenching of the asymmetry signal

$$A_{\text{exp}} = \frac{N_{\text{free}}}{N_{\text{total}}} A = hA$$

$$\Rightarrow h = \frac{N_{\text{free}}}{N_{\text{total}}} = 1 - \frac{N_{^{12}\text{C}}}{N_{\text{total}}}$$

- For the butanol target (C_4H_9OH) the simple estimate is h ≈ 10/74 ≈ 0.14
- h ≈ 0.5 after event selections
- Figure of merit
- Dilution factor channel dependent

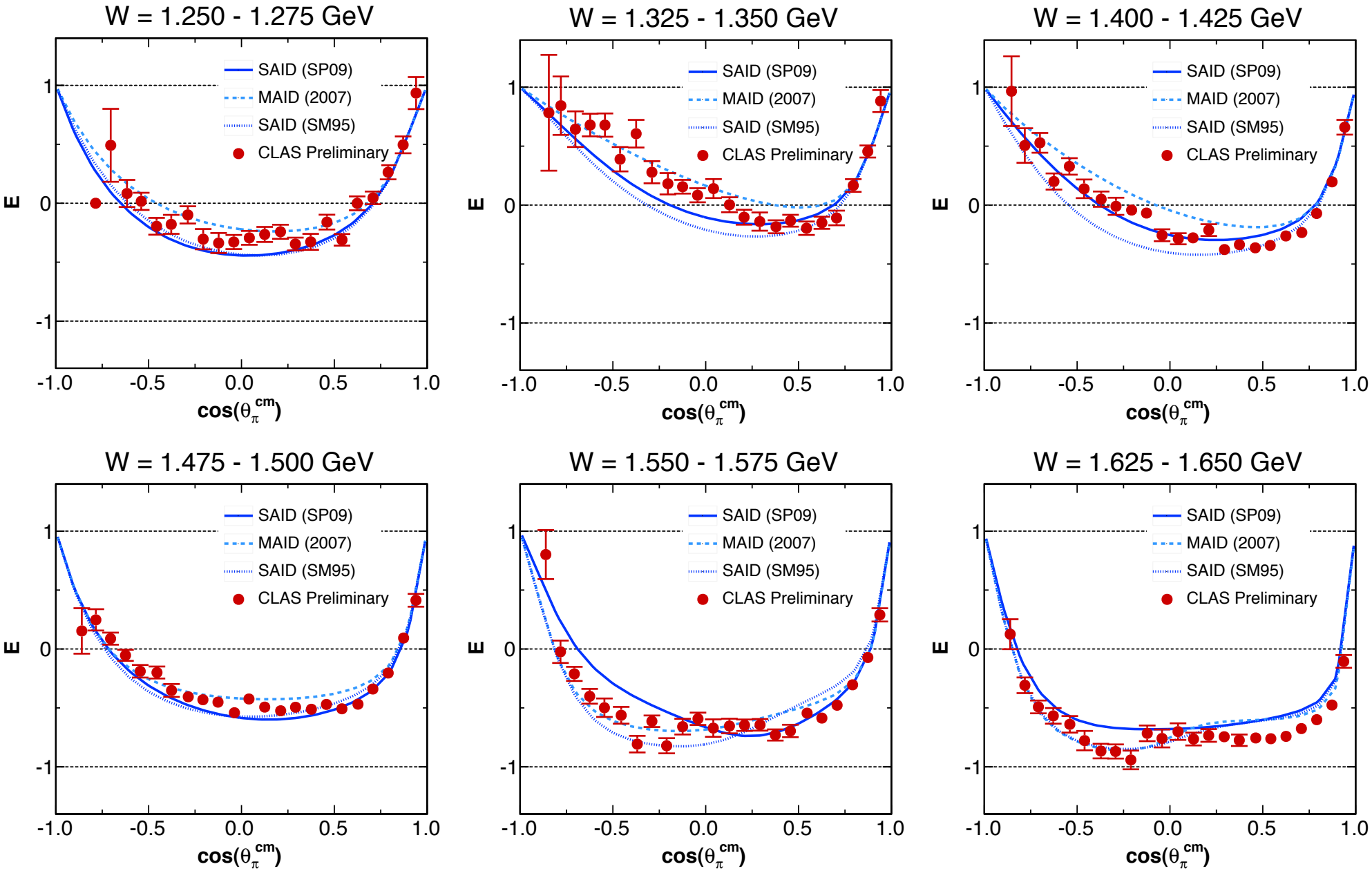
γ(p,π⁺)n - Selected Preliminary Results



$$E = -\frac{1}{hP_Z P_\odot}\frac{N^+ - N^-}{N^+ + N^-}$$

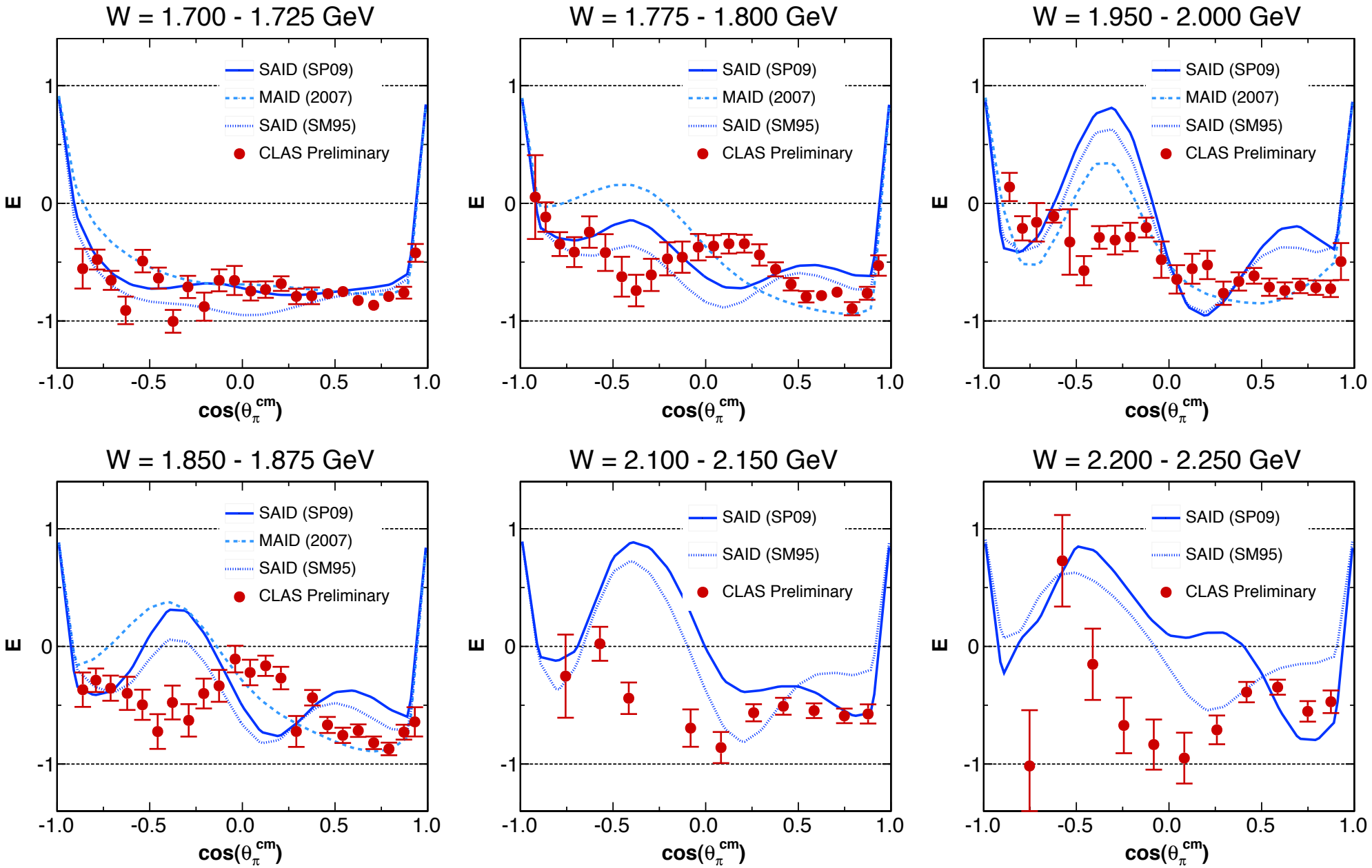
- Analyses with different choices of background determination and event selections give consistent results.
- Analyses of events from different regions of the target give consistent results.

γ(p,π⁺)n - Selected Preliminary Results (1)



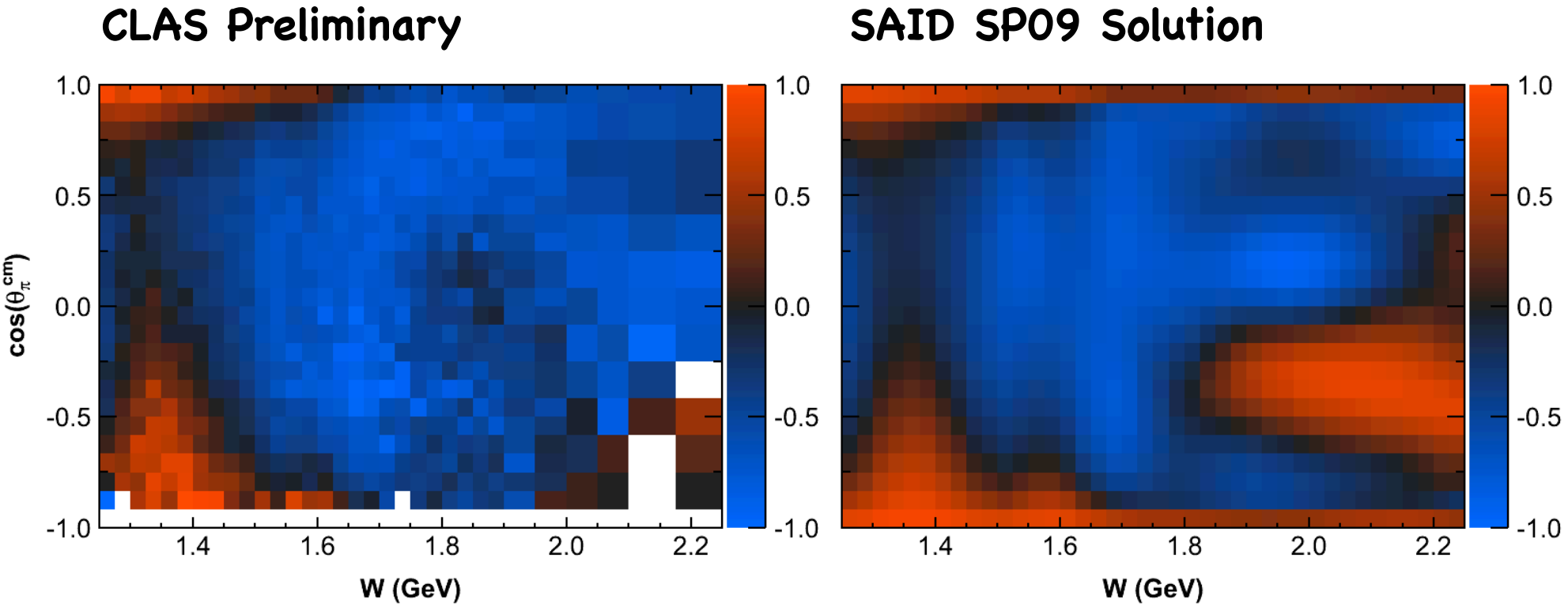
SP09: M. Dugger, et al., Phys. Rev. C **79**, 065206 (2009); **SM95**: R. A. Arndt, I. I. Strakovsky, R. L. Workman, Phys. Rev. C **53**, 430 (1996);
MAID: D. Drechsel, S.S. Kamalov, L. Tiator Nucl. Phys. **A645**, 145 (1999)

γ(p,π⁺)n - Selected Preliminary Results (2)



SP09: M. Dugger, et al., Phys. Rev. C **79**, 065206 (2009); **SM95**: R. A. Arndt, I. I. Strakovsky, R. L. Workman, Phys. Rev. C **53**, 430 (1996);
MAID: D. Drechsel, S.S. Kamalov, L. Tiator Nucl. Phys. **A645**, 145 (1999)

γ(p,π⁺)n – Polarization Observable E



- W < 1.7 GeV: SAID solution describes main features of the preliminary data remarkably well.
- W > 1.7 GeV: Partial-wave analyses currently ambiguous; new data will provide additional constraints and stringent tests.

SP09: M. Dugger, et al., Phys. Rev. C **79**, 065206 (2009)

Summary

- CLAS Frozen-Spin-Target (FROST) Program

$$\gamma p \rightarrow \pi^{+} n$$

- Preliminary results for double-polarization observable E in π^{+} photoproduction

- About 700 data points covering a wide energy and angular range

  $-0.9 < \cos(\theta_{\pi,cm}) < +0.9$

  $1.25\ \text{GeV} < W < 2.25\ \text{GeV}$

  Average uncertainty for E: ±0.08 (statistical) and < 10% (systematics)

- The data will greatly constrain partial-wave analyses and reduce model-dependent uncertainties in the extraction of nucleon resonance properties, providing a new benchmark for comparisons with QCD-inspired models.