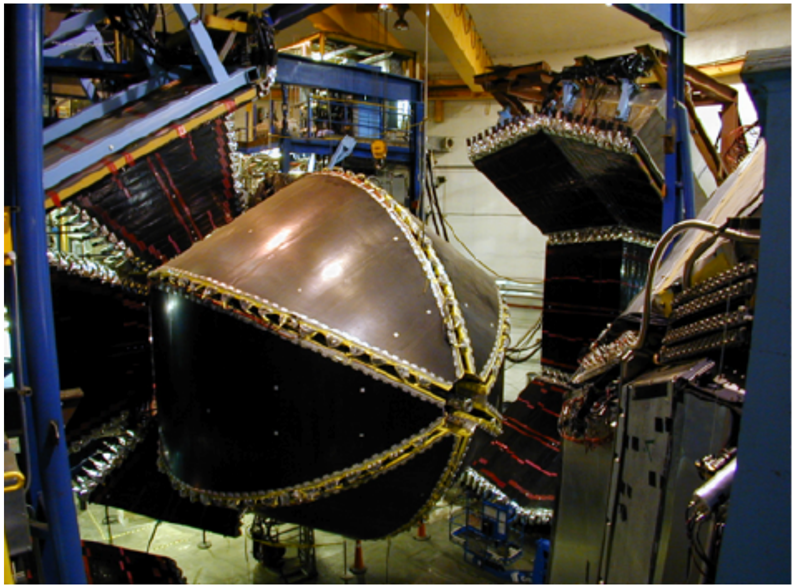
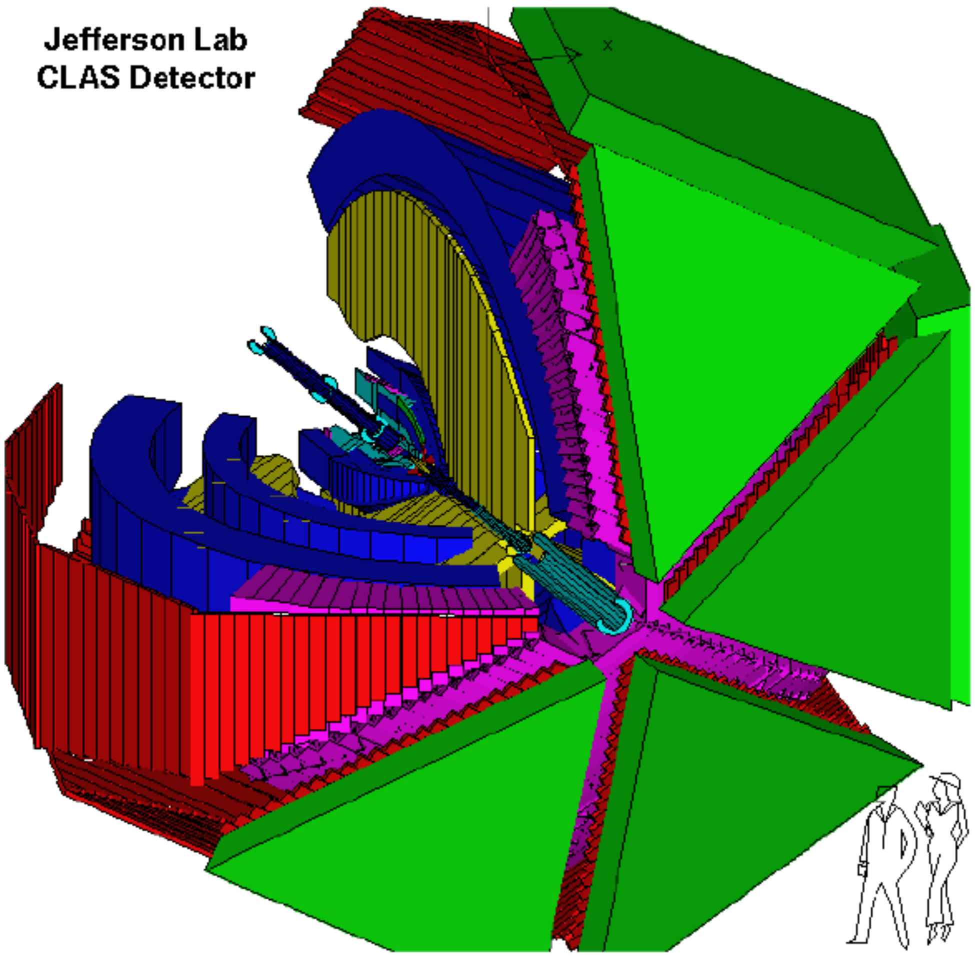
CLAS Results on Meson Spectroscopy

Diane Schott (GW)
On behalf of the CLAS Collaboration and the
Jlab Physics Analysis Center (JPAC)

The CLAS Detector





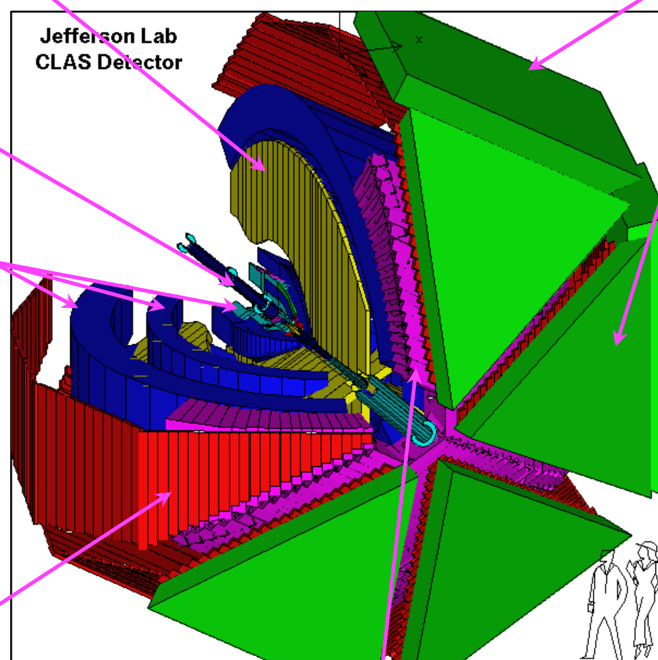
The CLAS Detector

Torus magnet
6 superconducting coils

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

target + start counter

Drift chambers
argon/CO_2 gas, 35,000 cells



Time-of-flight counters
plastic scintillators, 684 photomultipliers

Gas Cherenkov counters
e/π separation, 256 PMTs

Associated Groups

- Jlab Physics Analysis Center
  - Provide theoretical support, codes and guidance to experimental collaborations interested in hadron spectroscopy throughout the world, especially at JLab: Hall B (CLAS & CLAS12) and D (GlueX)
- Light Meson Decay Group, PWA Working Group, Hadron Spectroscopy Center
  - To coordinate collaboration and exchanges

JPAC: motivation

- A complete understanding of the hadron spectrum and discovering new resonances
- For: GlueX, CLAS12, COMPASS, LHCb, BES-III,VEPP, PANDA, ...

JPAC at work

- Close collaboration with experimentalists
- Experimentalist provide events (four-vectors in the detector) and MC acceptance. Both will be publicly available (as DOE requires)
- Theorists provide amplitudes (theorist outside JPAC are welcomed). Codes available to the community
- We (theorists and experimentalists) fit theory corrected by acceptance to the actual data through a likelihood function (four-vectors and particle identification is the input)
- $\Rightarrow$ Physics

Outline

- Recent results
  - Cross-section
    - $\gamma D \rightarrow p\pi^-(p)$
    - $\gamma D \rightarrow K^+\Sigma^*(1385)^-(p)$
    - $\gamma D \rightarrow K^*(892)^0\Lambda(p)$
    - $\gamma p \rightarrow p\omega \rightarrow p\pi^+\pi^-\pi^0$
  - Amplitude Analysis
    - $\omega \rightarrow \pi^+\pi^-\pi^0$
    - $\eta \rightarrow \pi^+\pi^-\pi^0$
    - $\gamma p \rightarrow pK+K-$
  - Dark Photon Search

Quasi-free Cross Section Measurements at CLAS:

$\gamma D \rightarrow p\pi^-(p)$

$\gamma D \rightarrow K^+\Sigma^*(1385)^-(p)$

$\gamma D \rightarrow K^*(892)^0\Lambda(p)$

Paul Mattione, Carnegie Mellon University
for the CLAS Collaboration
supported by the DOE Office of Science

N* Resonance Spectrum (2012)

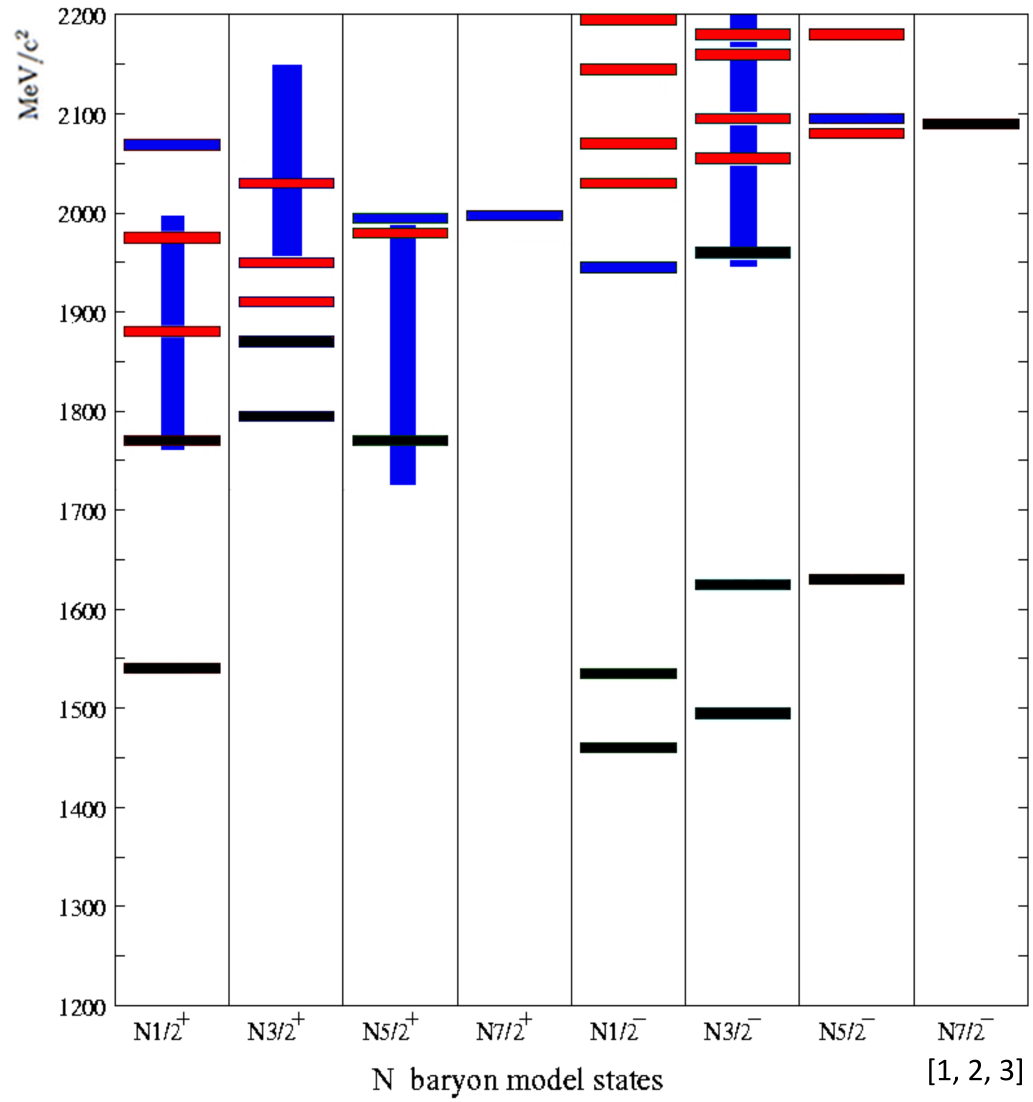
- Predicted N* spectrum (Capstick, Isgur) [1]
  - Quark model
- PDG [3] changes since 2010:
  - 4 new PDG resonances (vertical bars)
  - 2 states upgraded to ***: N(1900)[3/2]$^+$, N(1875)[3/2]$^-$
- Most searches:
  - Proton targets, non-strange channels (e.g. πN)

Legend

Black: “Established” (4*, 3*) [3]

Blue: Inconclusive (2*, 1*) [3]

Red: Unobserved [3]

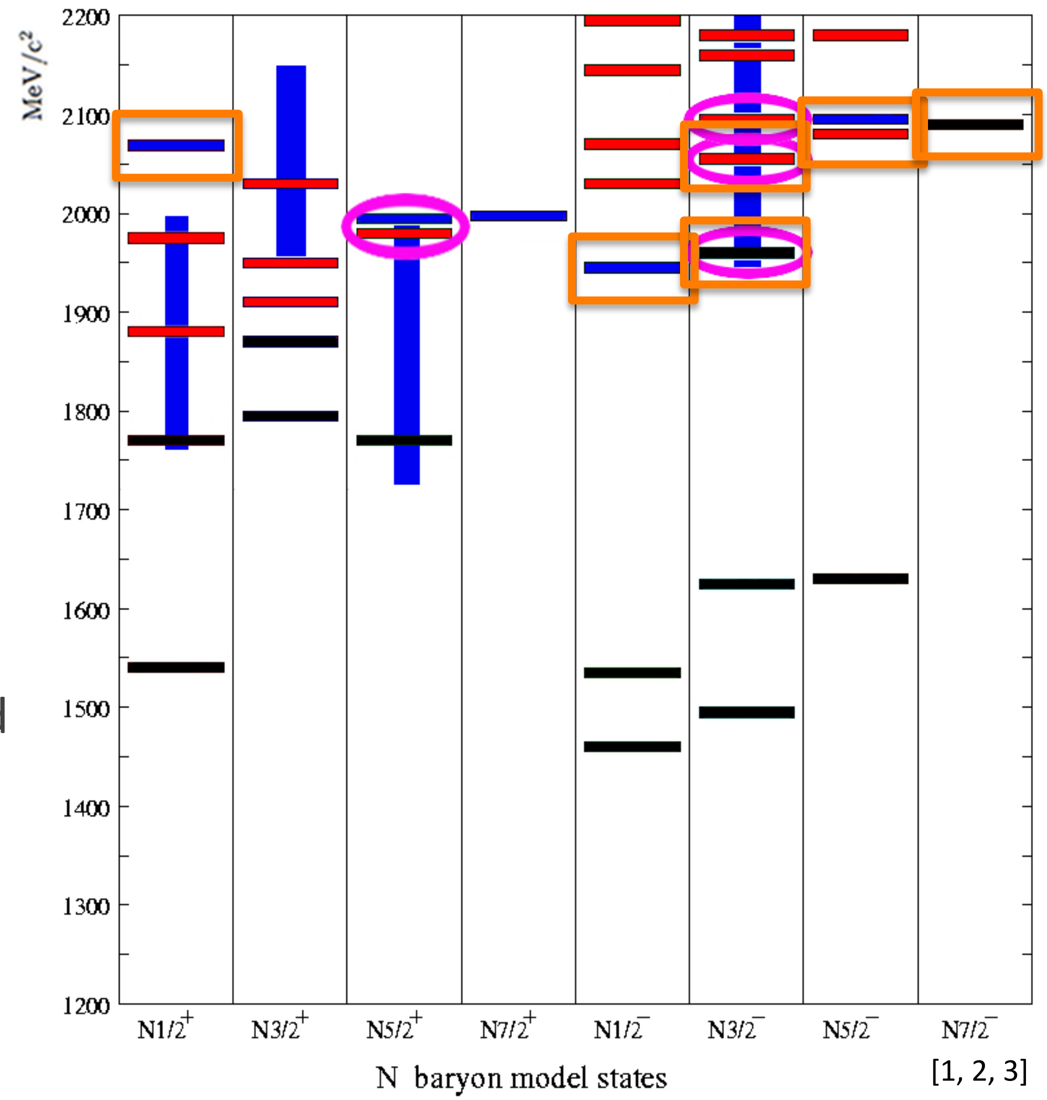


[1, 2, 3]

Searching for N* Resonances

- "Missing" N* resonances [1]
  - Wide, overlapping
  - Correlated quark-pair? [4]
- N* decays: KY, **K*Y**, **KY***
  - Couplings sizable vs. Nπ [3]
  - Sparse γn data vs. γp
    - Amplitudes (isospin)
- No known γn → K*(892)^{0}Λ cross section measurements
- LEPS γn → K$^+$Σ*(1385)$^-$ data limited to low-θ [6]

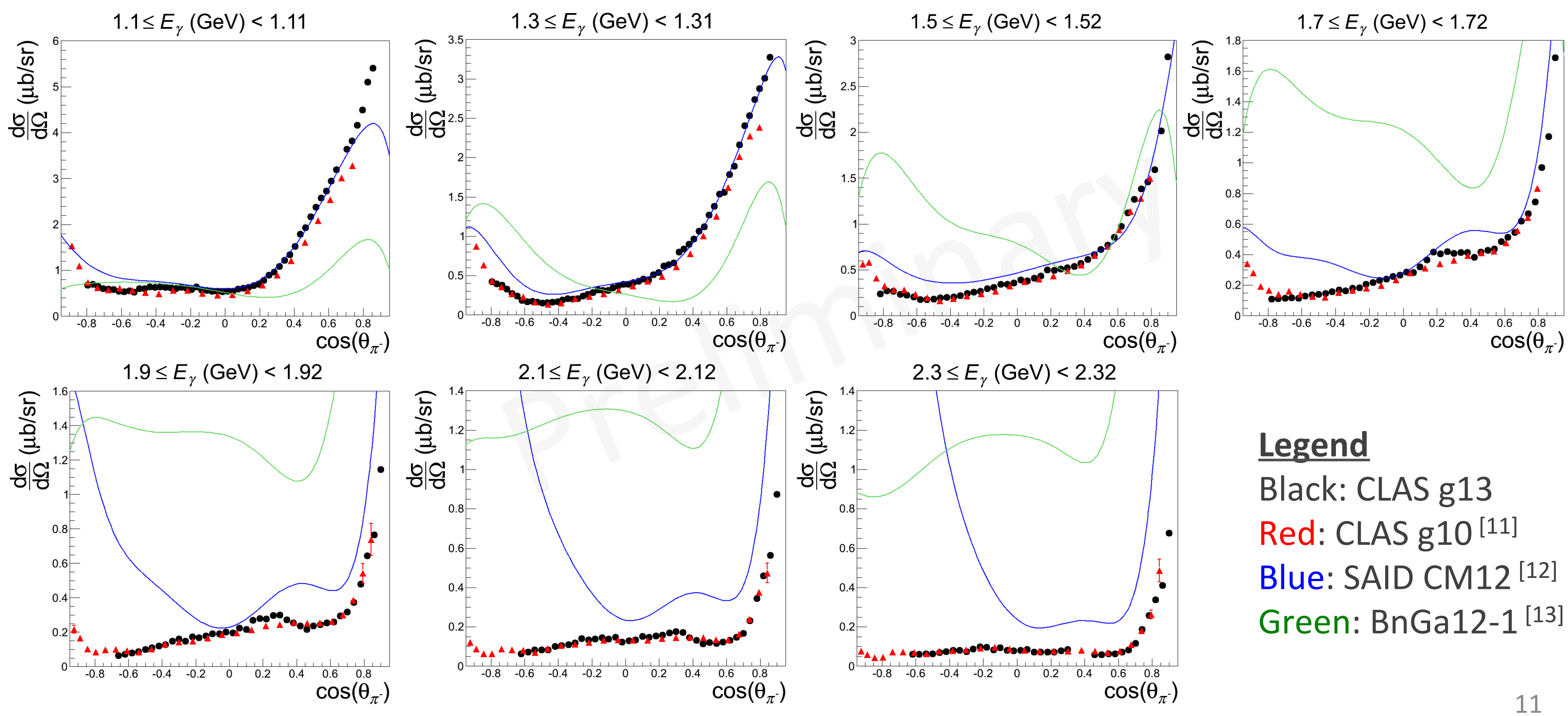
<ins>**Legend**</ins>
Black: "Established" (4*, 3*) [3]
Blue: Inconclusive (2*, 1*) [3]
Red: Unobserved [3]
Orange: γN → K*(892) Λ
Violet: γN → KΣ*(1385) [5]



[1, 2, 3]

$\gamma D \rightarrow p\pi^-(p)$ Cross Section

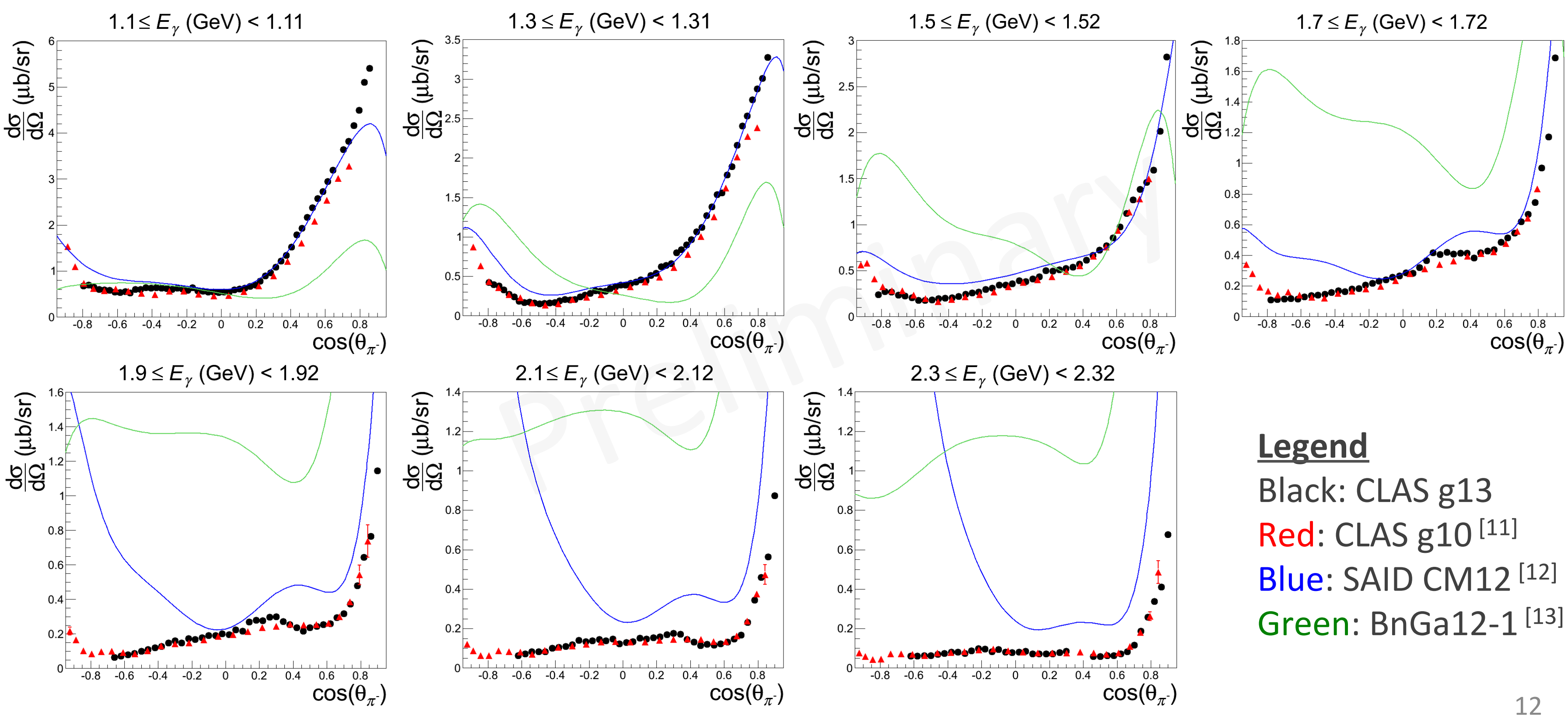
- CLAS g13: Preliminary, high statistics: ~300 million events in ~9000 bins:
  - 10- & 20-MeV-wide bins from $0.56 < E_\gamma$ (GeV) < 2.52
  - Significant increase in statistics: CLAS g10 [11] had ~3000 bins
- Compared to CLAS g10 [11], SAID CM12 [12], BnGa12-1 [13]
  - Statistical uncertainties only (g10 pre-FSI correction)



γD → pπ⁻(p) Cross Section

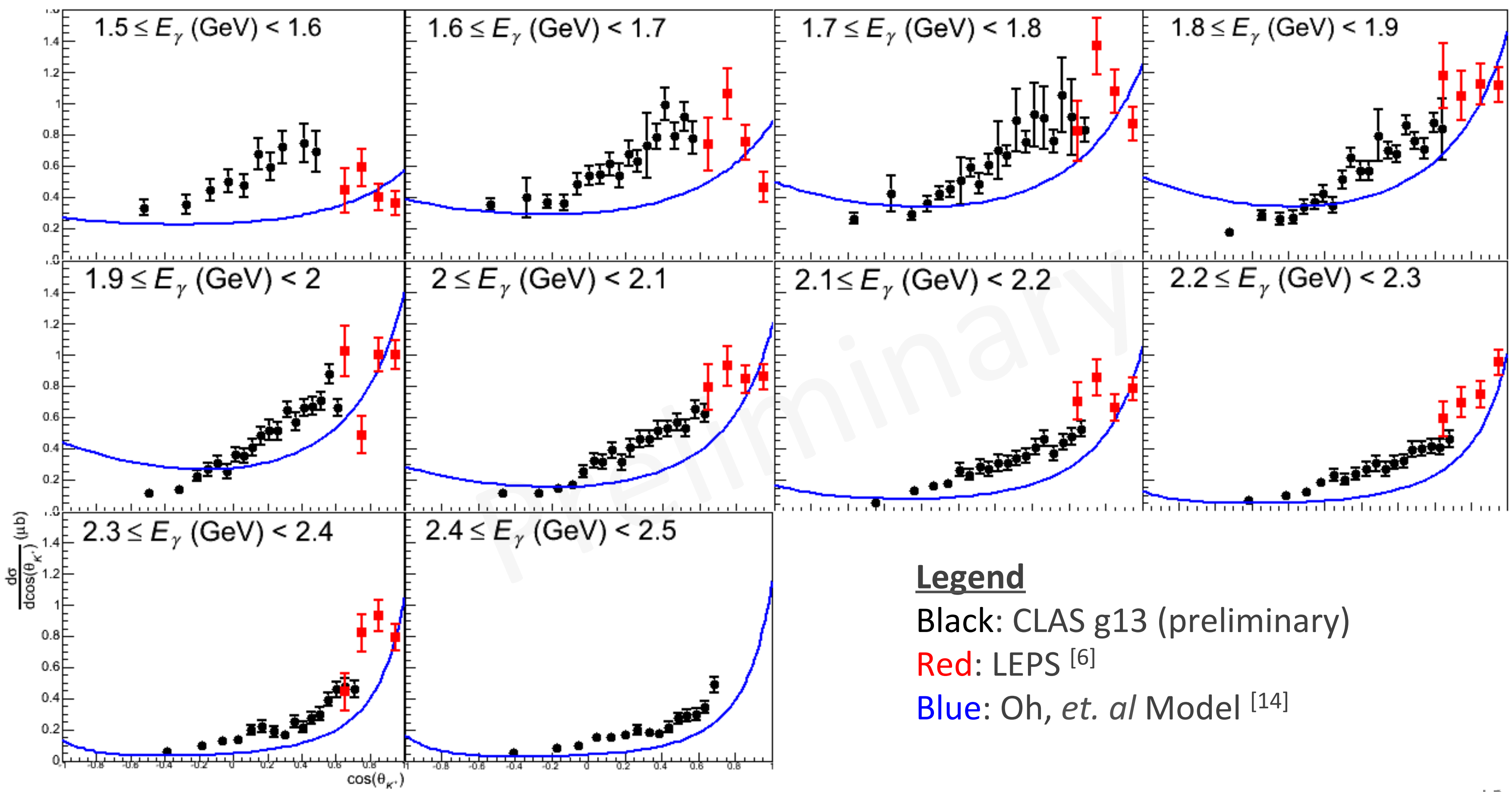
– Overall good matching between g10 & g13, need more acceptance studies

– Data will improve:
  – Understanding of N* couplings to neutron in πN
  – Understanding of rescattering: working with Igor Strakovsky (GWU)



γD → $K^+\Sigma^*(1385)^-$(p) Cross Section

- Data: LEPS [6], Preliminary CLAS g13, Oh *et. al* model [14]:
  - CLAS g13: ~100000 events, no systematic errors, ~ -0.5 < cos(θ) < 0.75
  - Oh, *et. al* model: Effective Lagrangians
    - Dominated by t-channel K^+ and K^{*+}, some N*'s and Δ*'s included



Legend

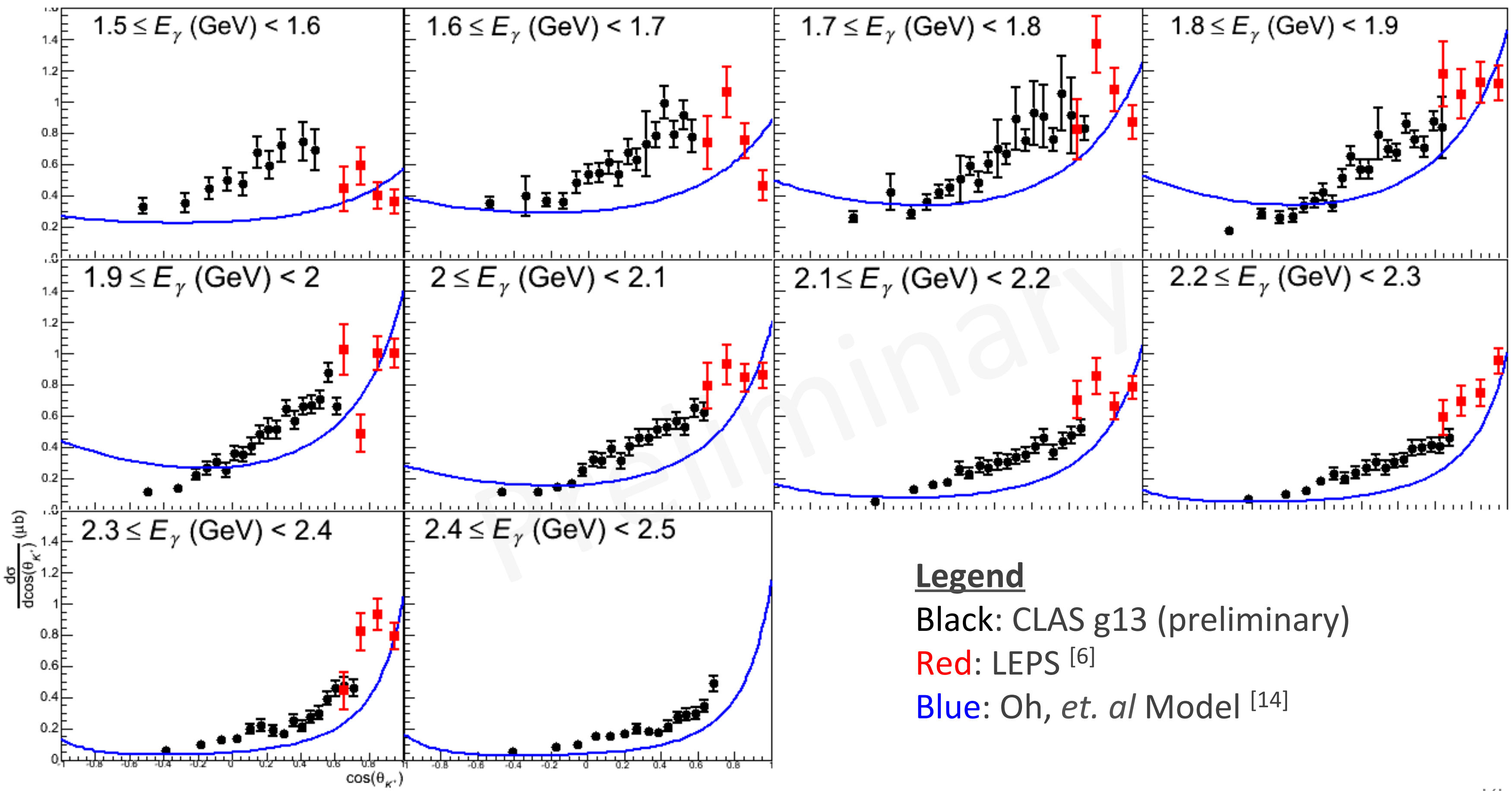
Black: CLAS g13 (preliminary)

Red: LEPS [6]

Blue: Oh, *et. al* Model [14]

γD → $K^+\Sigma^*(1385)^-(p)$ Cross Section

- t-channel dominated
- g13 & LEPS close, model significantly lower
  - Disagreement with prediction: perhaps t-channel modeling



Legend

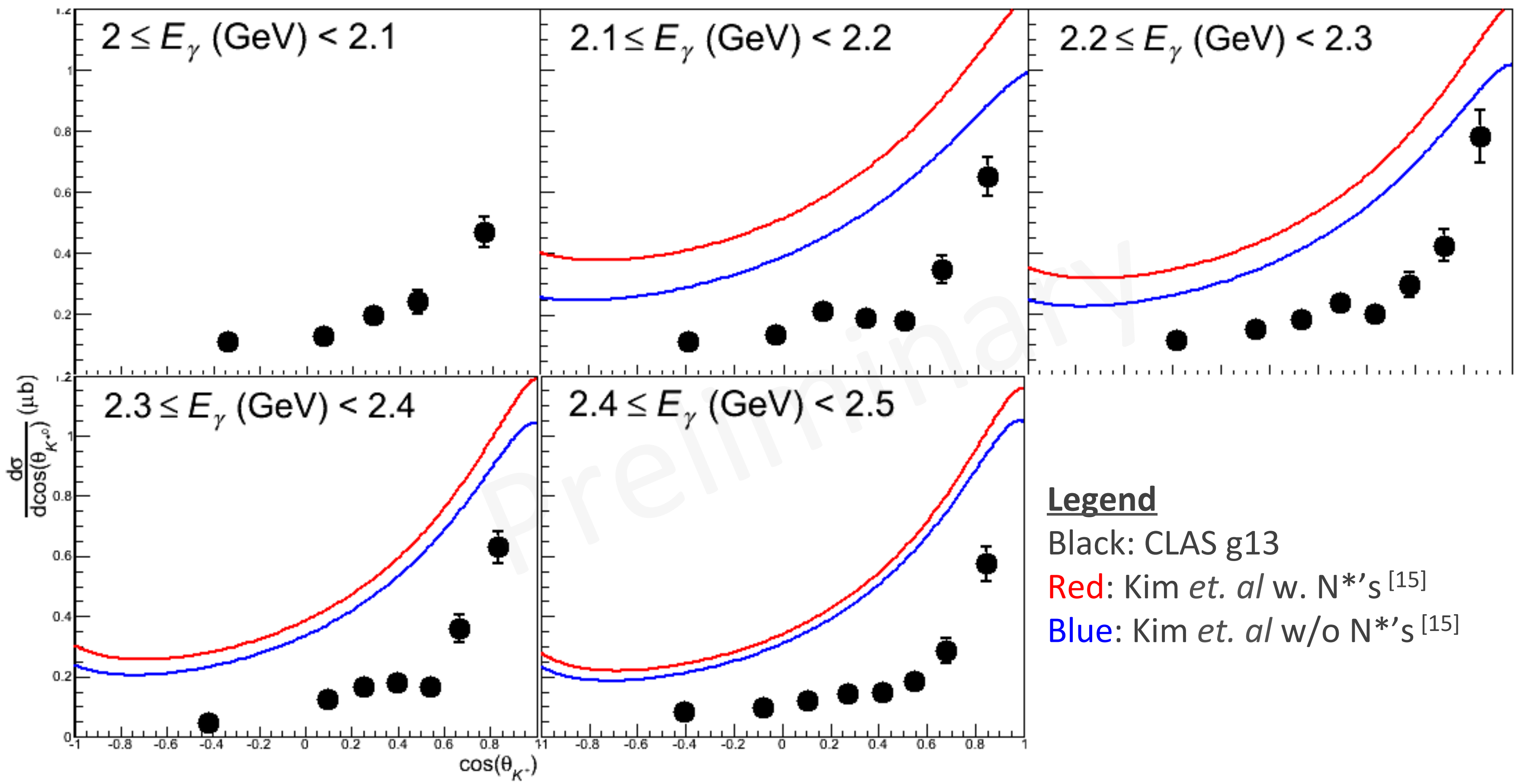
Black: CLAS g13 (preliminary)

Red: LEPS [6]

Blue: Oh, *et. al* Model [14]

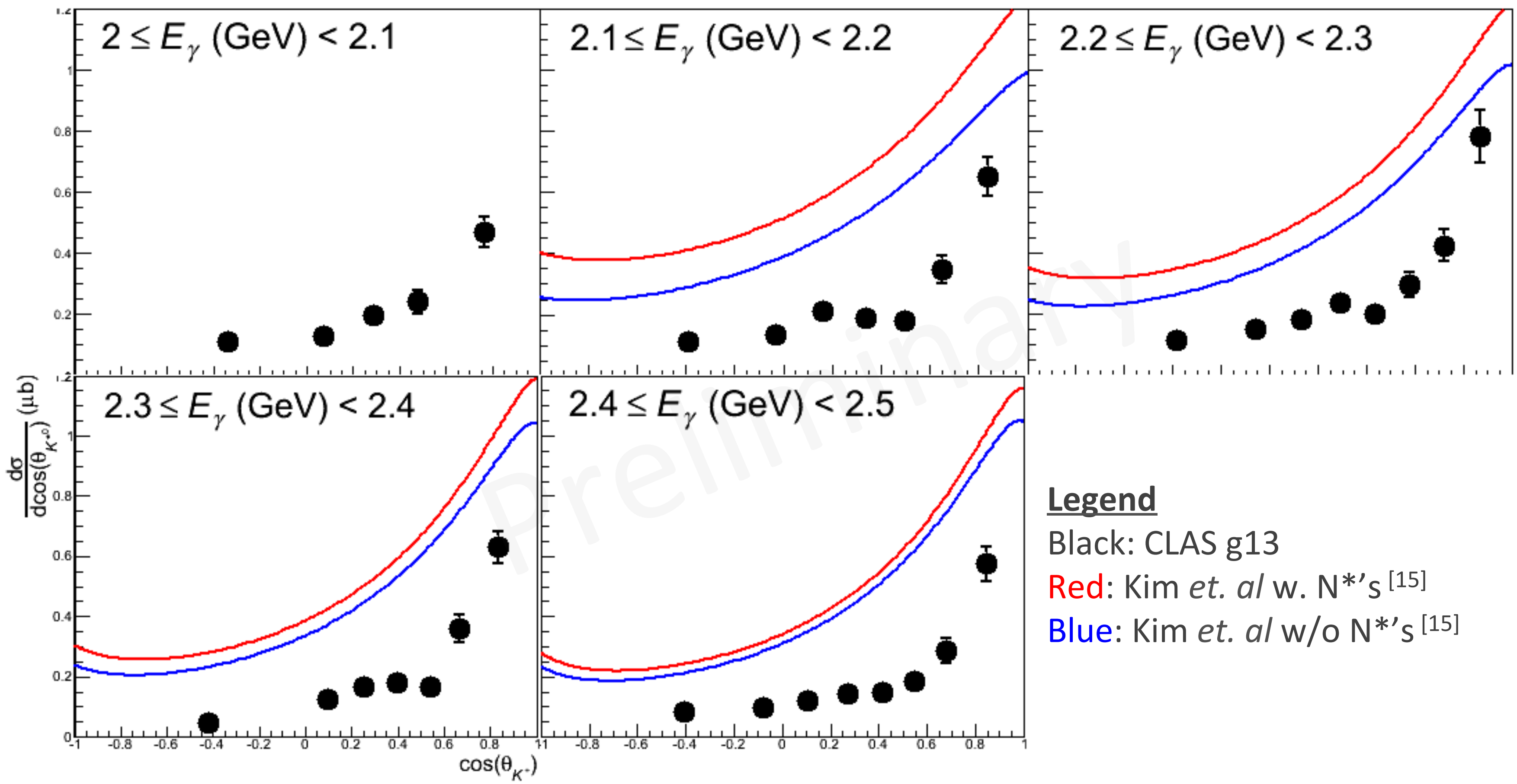
γD → K*(892)^{0}Λ(p) Cross Section

- Data: Preliminary CLAS g13 (~17000 events, no systematic errors)
- S.-H. Kim, *et. al* model [15]: Effective Lagrangians
  - K^0 t-channel exchange dominates, N[3/2-](2080) is dominant N*



γD → K*(892)^{0}Λ(p) Cross Section

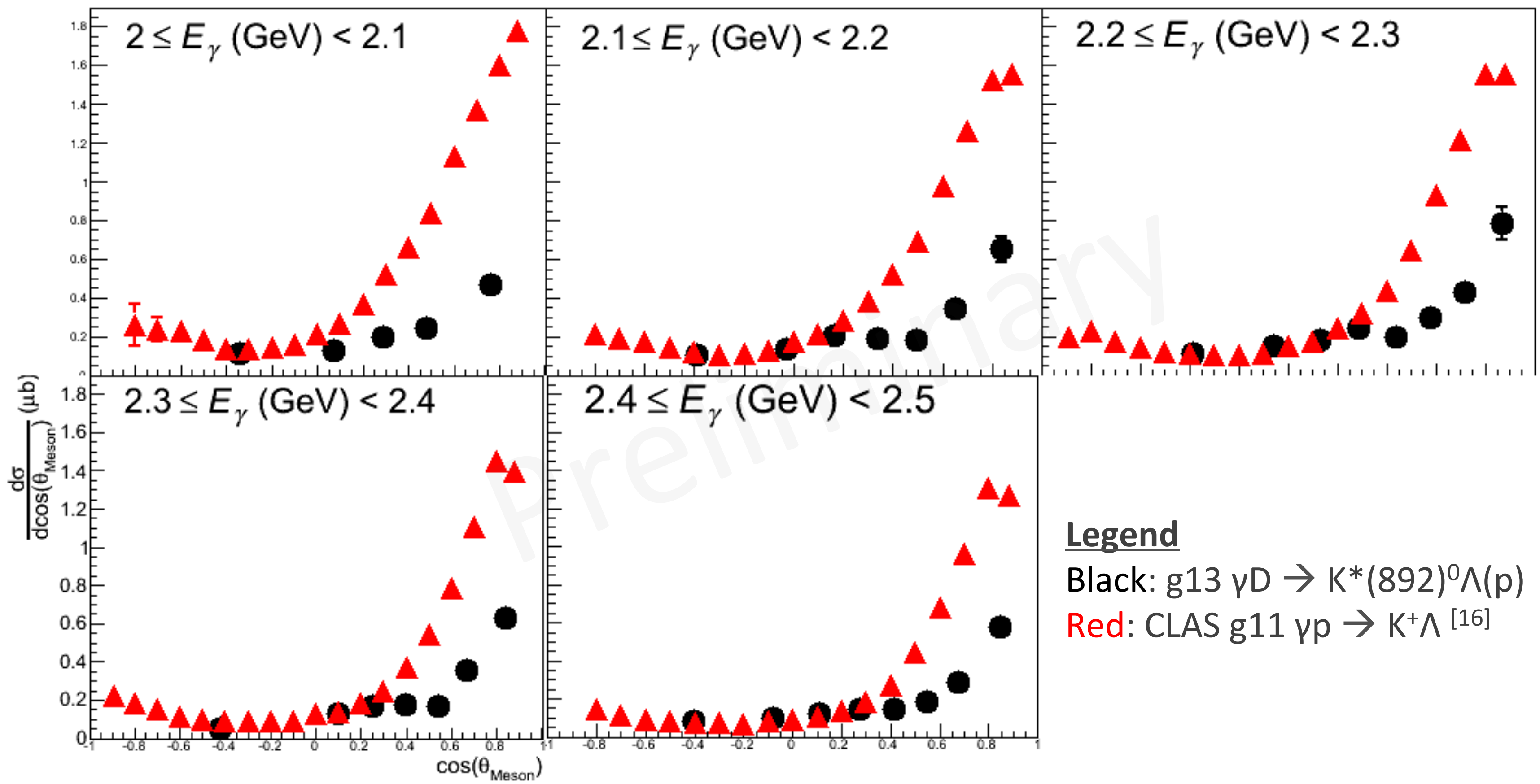
- t-channel dominated
  - Disagreement with prediction: perhaps t-channel modeling
  - Possible small K*(892)^{0}Σ^0 background leakage, need to investigate



$\gamma D \rightarrow K^*(892)^0\Lambda(p)$ vs. $\gamma p \rightarrow K^+\Lambda$

- ~Comparison vs. ground state [16] ($\gamma D \rightarrow K^0\Lambda(p)$ being analyzed):
  - Similar at Mid-θ

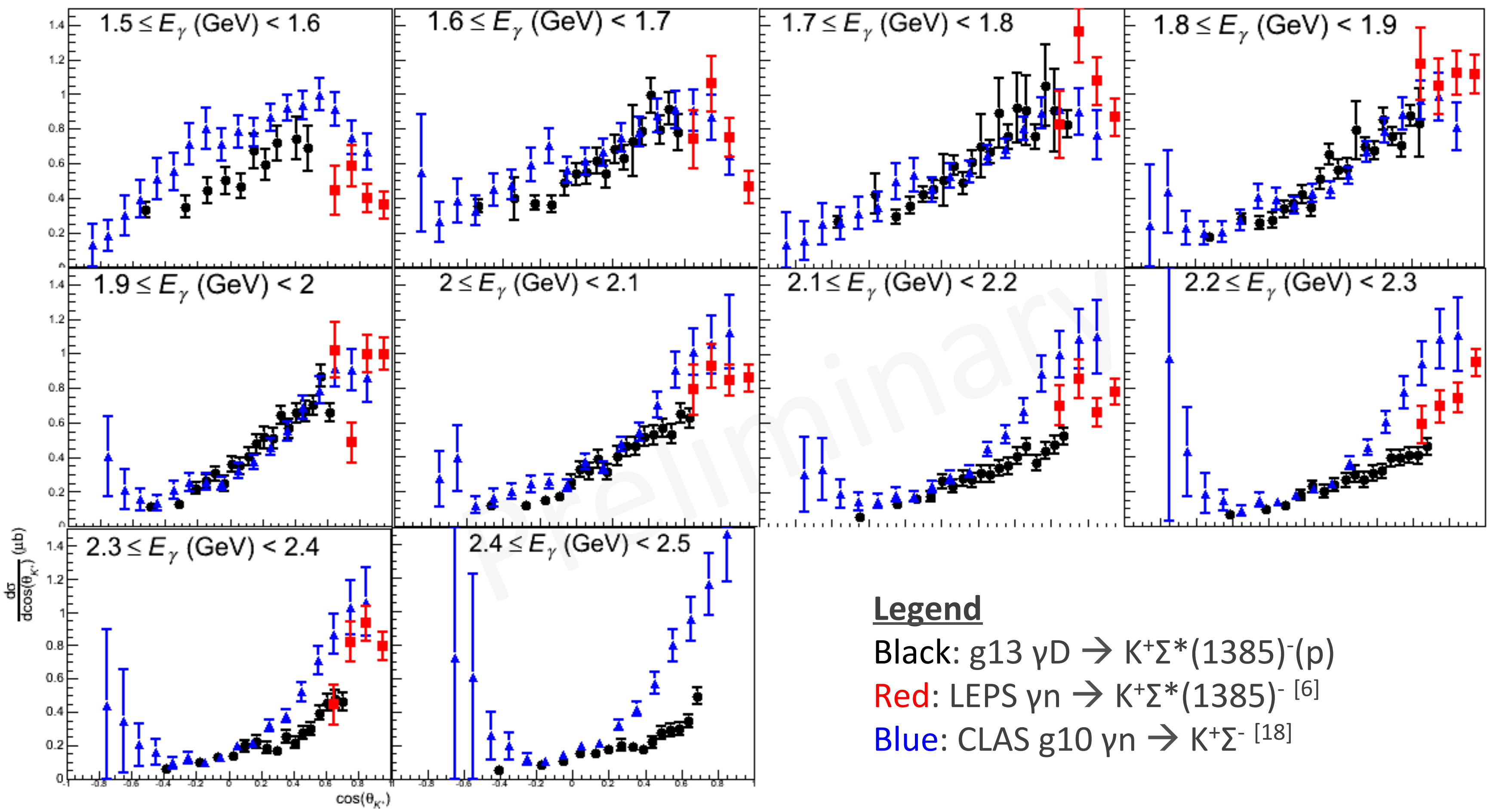
- Rescattering through πN: ~20% effect on KΛ [17]
  - K*Λ sizable vs. KΛ: N* coupled-channels analyses



Legend
Black: g13 $\gamma D \rightarrow K^*(892)^0\Lambda(p)$
Red: CLAS g11 $\gamma p \rightarrow K^+\Lambda$ [16]

γD → $K^+\Sigma^*(1385)^-$(p) vs. γD → $K^+\Sigma^-$(p)

- Scale comparison vs. ground state
  - Similar scale in most regions
  - KΣ*(1385): N* coupled-channels analyses



Legend

Black: g13 γD → $K^+\Sigma^*(1385)^-$(p)

Red: LEPS γn → $K^+\Sigma^*(1385)^-$ [6]

Blue: CLAS g10 γn → $K^+\Sigma^-$ [18]

Summary

- N* spectrum: Strong force and hadronic structure
  - Role of quark correlations: limit N* spectrum
  - Search in KY, K*Y, and KY* channels
- Preliminary quasi-free cross sections:
  - $\gamma D \rightarrow p\pi^-(p)$, $\gamma D \rightarrow K^*(892)^0\Lambda(p)$, & $\gamma D \rightarrow K^+\Sigma^*(1385)^-(p)$
  - N* couplings, greater understanding of interactions
  - High-statistics $\gamma D \rightarrow p\pi^-(p)$ data: study rescattering
  - K*Y & KY* sizable vs. KY: include in coupled-channels analyses
- These results will be published after systematic studies are performed, and will contribute to the search for the N* resonances.

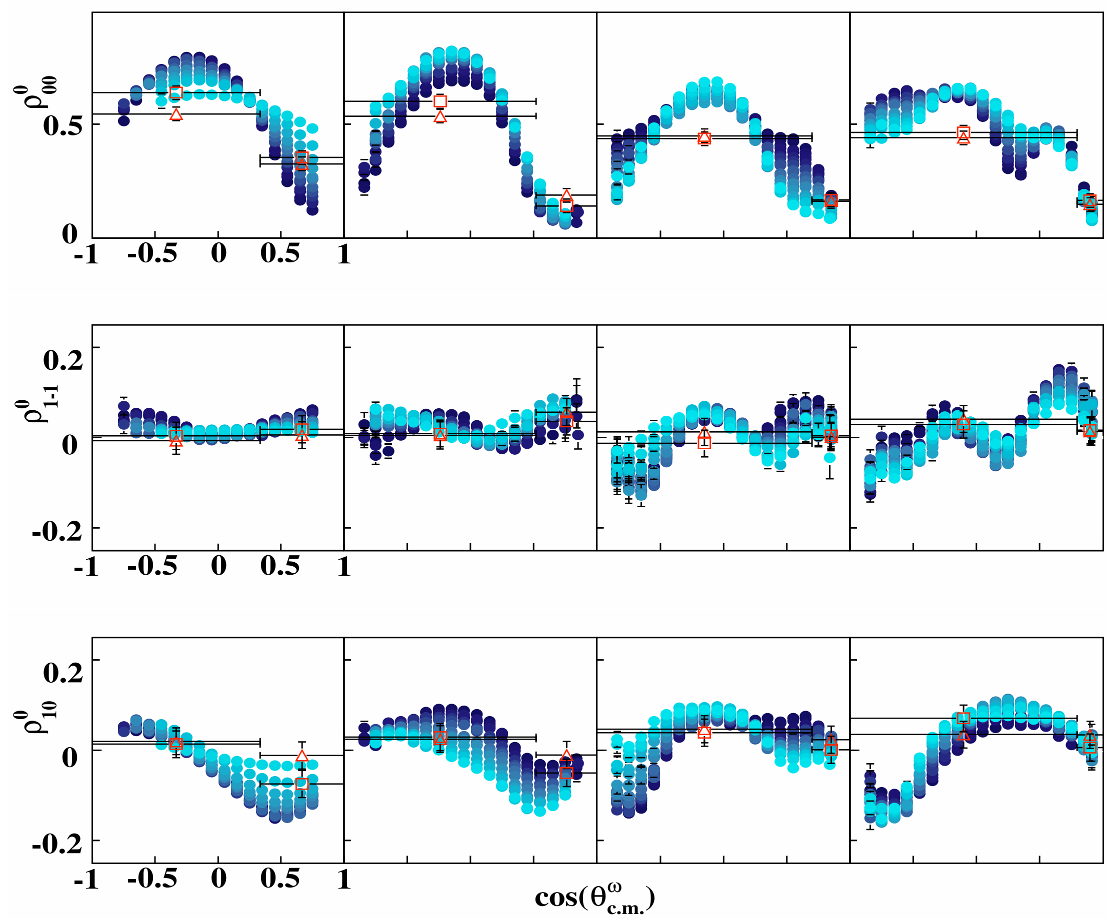
N* states in $\gamma p \rightarrow p\omega \rightarrow p\pi^+\pi^-\pi^0$?

$$\mathcal{I}(\sqrt{s}, \cos\theta^{\phi}_{\mathrm{c.m.}}) \sim \frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\zeta - \sqrt{2}Re\rho^0_{10}\sin 2\zeta\cos\varphi - \rho^0_{1-1}\cos 2\varphi,$$

- Very precise cross sections in W, $\cos\theta_\omega$. From ω decays => SDME ρ^0_{00}, ρ^0_{1-1}, ρ^0_{10}, shown in blue - blue shades.

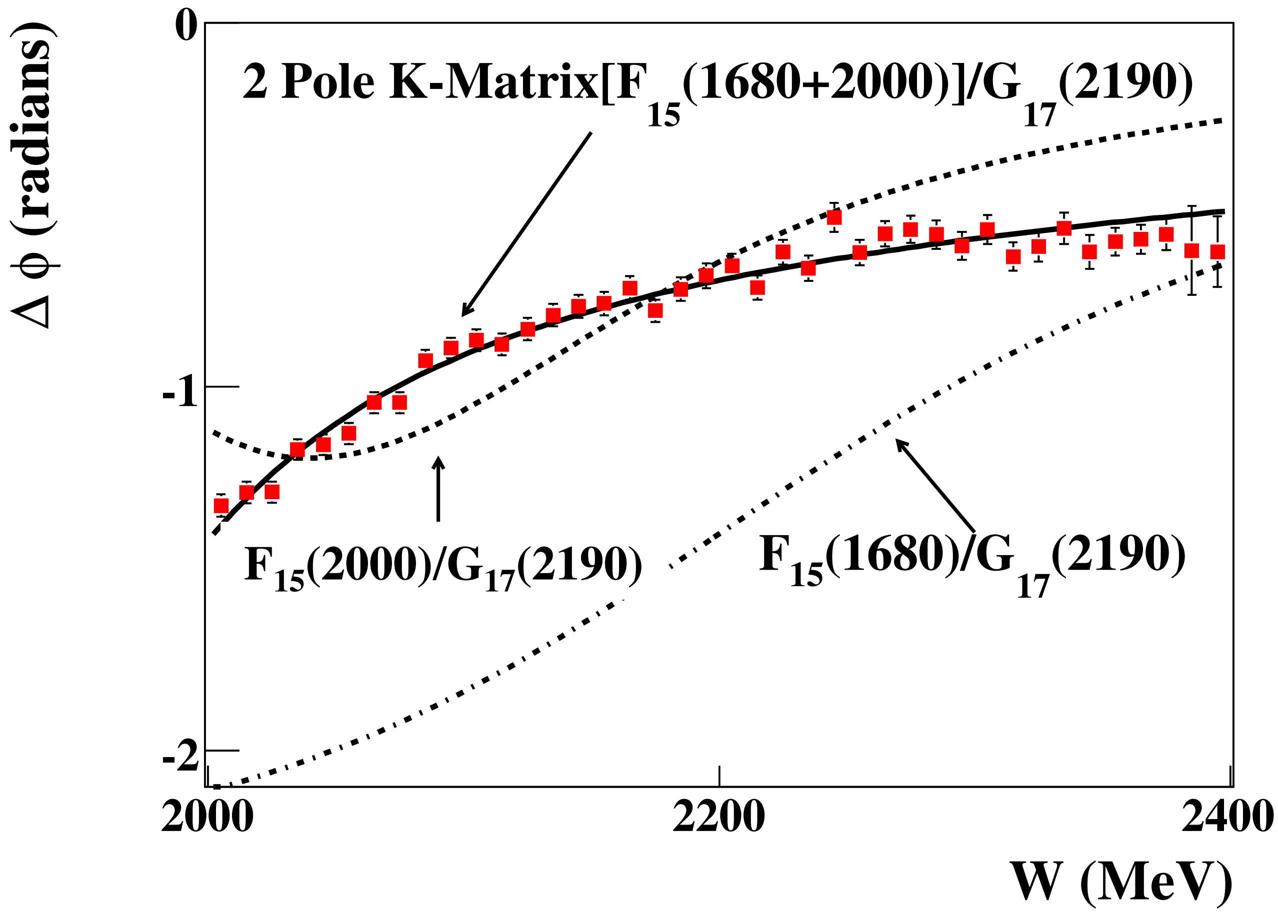
(ω data not yet included in coupled-channel amplitude analyses, in preparation by several groups.)

W=1.7 – 2.4 GeV, ΔW=10 MeV bins



M. Williams, et al. (CLAS), Phys. Rev. C80:065209, 2009

N* states in $\gamma p \rightarrow p\omega \rightarrow p\pi^+\pi^-\pi^0$



M. Williams, et al. (CLAS) , Phys.Rev. C80 (2009) 065208

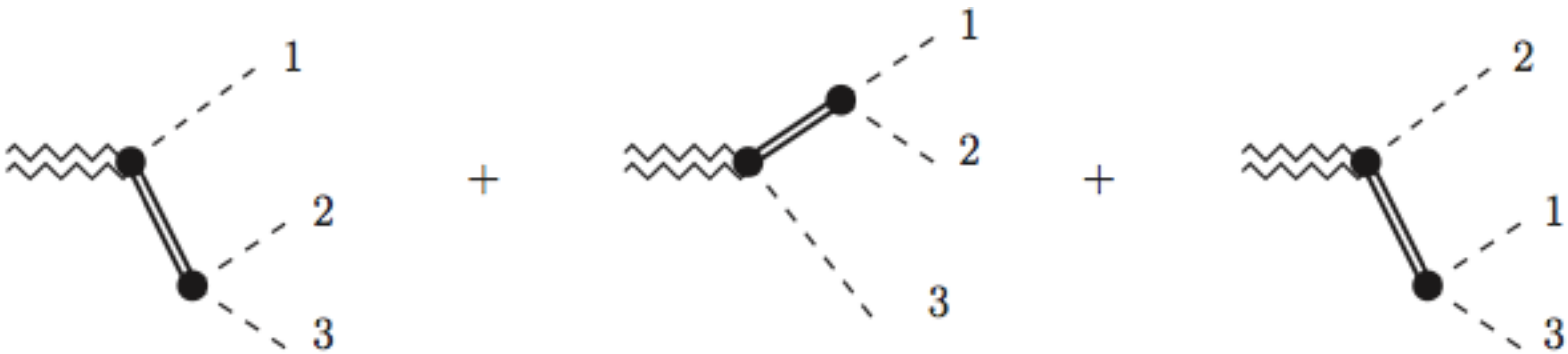
- The data are used as input to a single channel event-based, energy independent partial wave analysis (the first ever for baryons).

- **ω** photoproduction is dominated by the well known **F_{15}(1680) and G_{17}(2190)**, and the "missing" ** **F_{15}(2000)**.

N* states in $\gamma p \rightarrow p\omega \rightarrow p\pi^+\pi^-\pi^0$

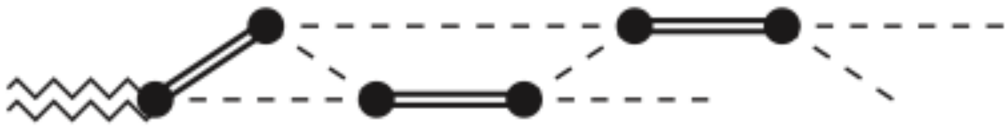
- Using JPAC amplitudes to fit $\omega \rightarrow \pi^+\pi^-\pi^0$
  - Theory: I. Danilkin @JLab, P. Guo @IU
  - Experimental support: A. Celentano @INFN, B. Vernarsky @CMU
- Ongoing collaboration between JPAC and CLAS
  - Initial test channels for 2 & 3 body interaction amplitudes
    - η to 3π, ω to 3π, pK^+K^-

2 Body Amplitudes



- Isobar Approximation
- -> violates unitarity

3 Body Amplitudes

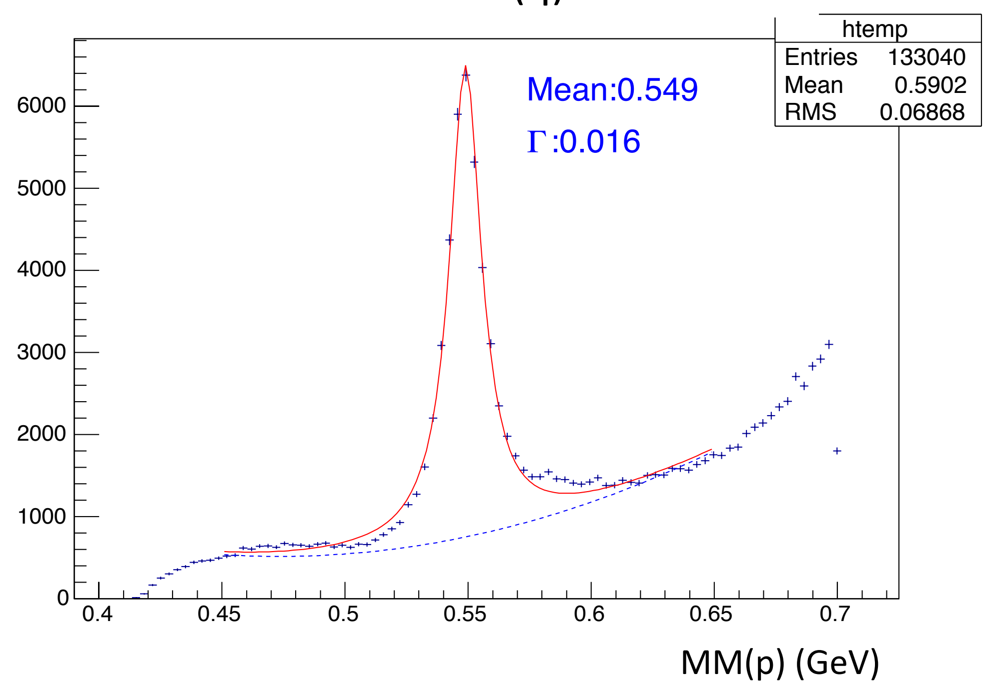


- Including with Isobar Approximation
- Rescattering effects
  - Khuri-Treiman equations
- Amplitudes from dispersive integrals
  - Restoration of unitarity

$\eta \rightarrow \pi^+\pi^-\pi^0$
Dalitz decay analysis

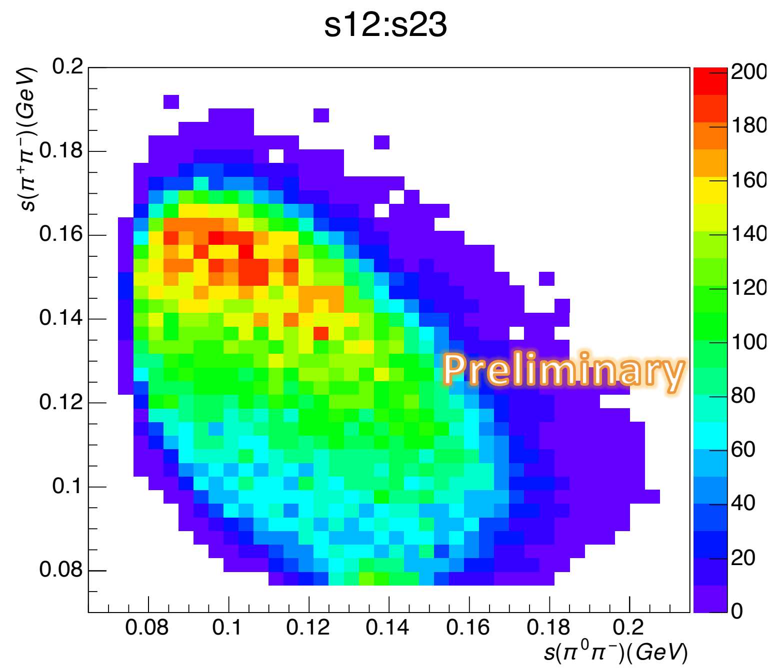
- Theory: P. Guo @IU
- Experimental support: D. Schott @GW, M. Kunkel @ODU, LMD Group

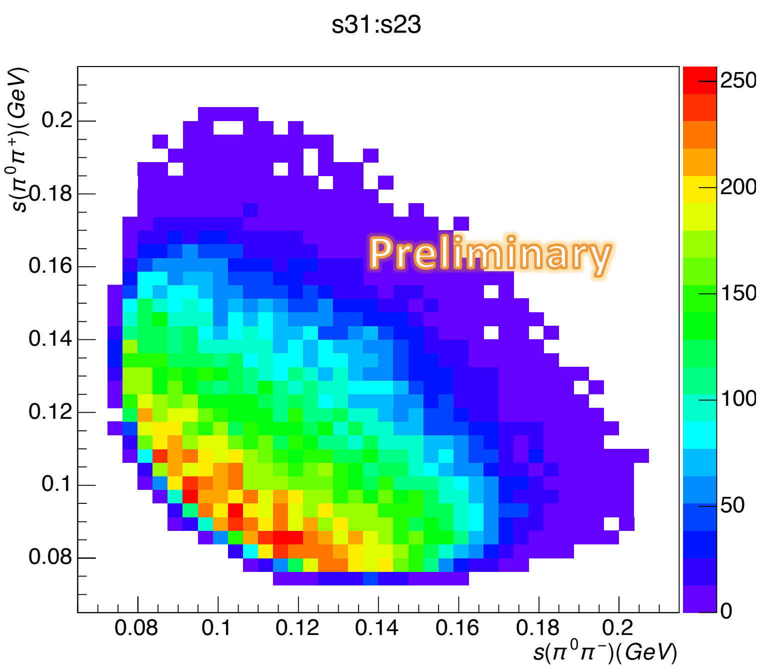
Mass (η)

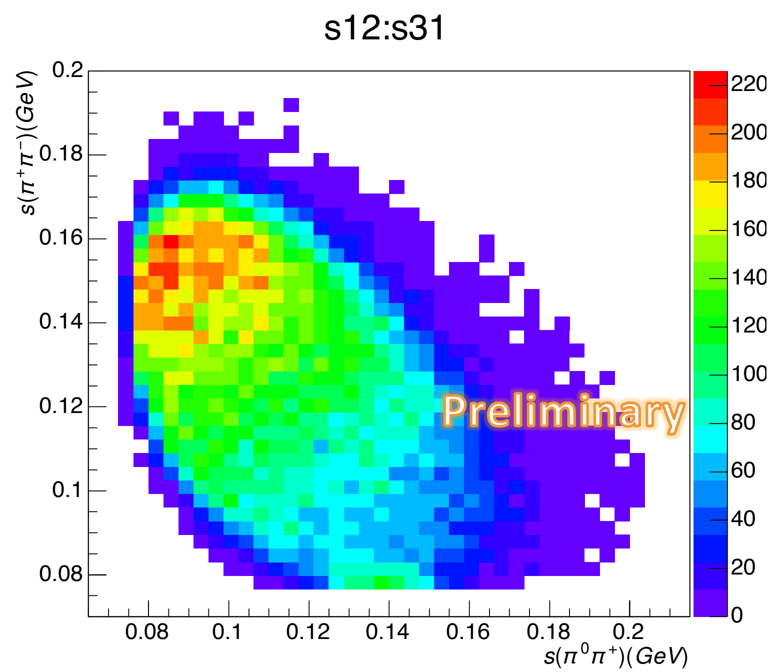


Data

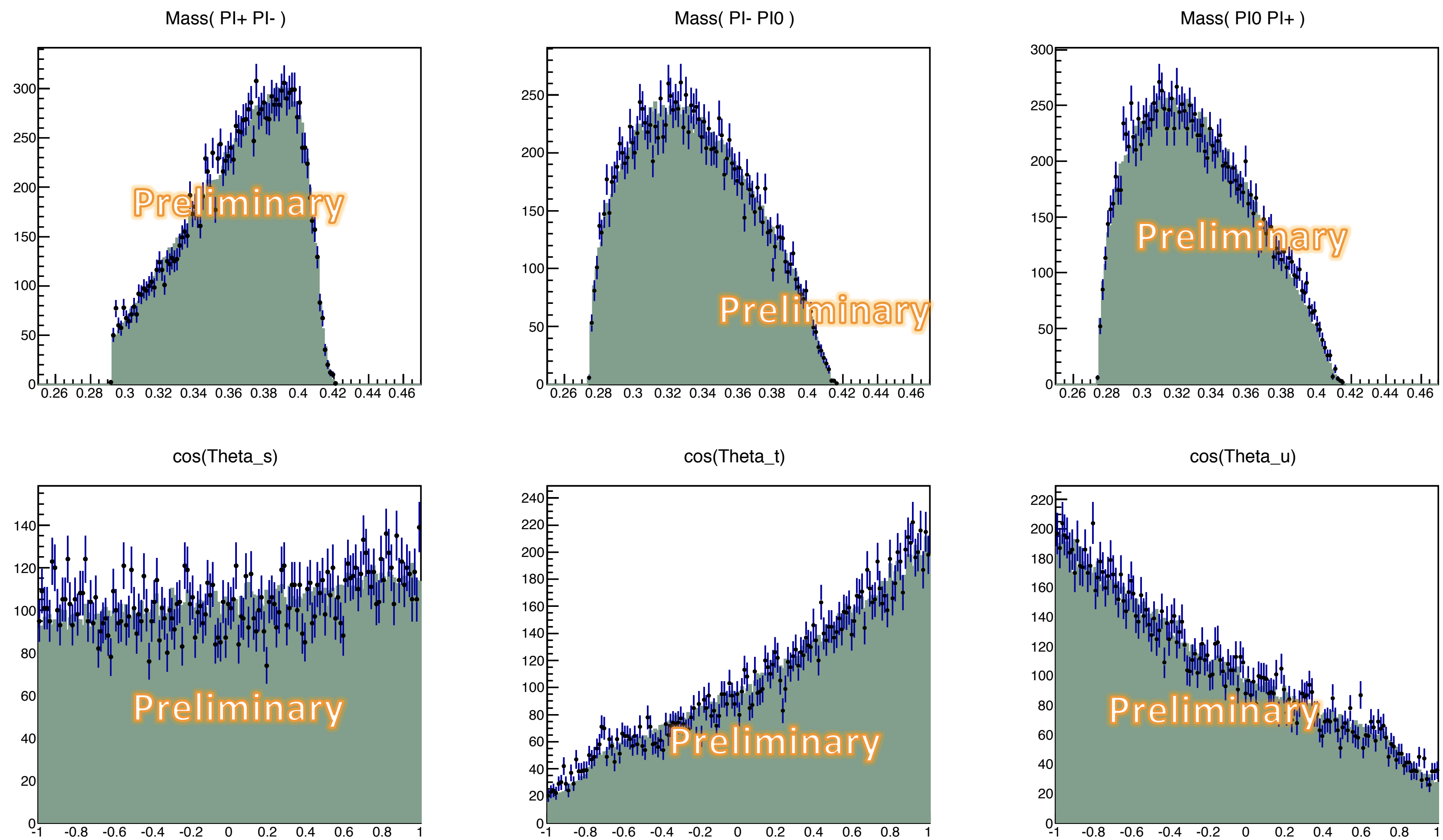
First look:







Initial test fit using:
2-body decay amplitudes



Plans

- Take the results of the 2-body and 3-body fits to estimate the 3-body contribution
    - The 3-body amplitude includes the 2-body, so by comparing the 2 sets of fits, one can extract the 3-body contribution
- Investigate possible background minimization
    - Look at sidebands of the η
    - Event weights
- Analyze g11 data to compare to g12 results

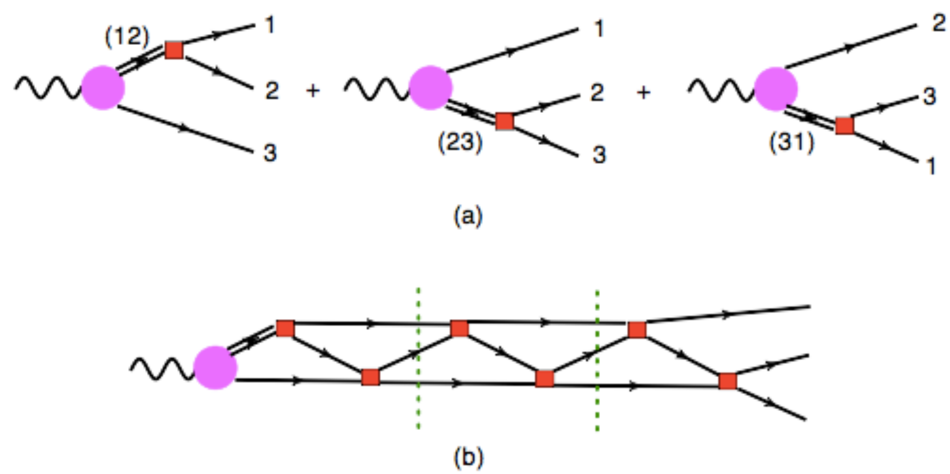
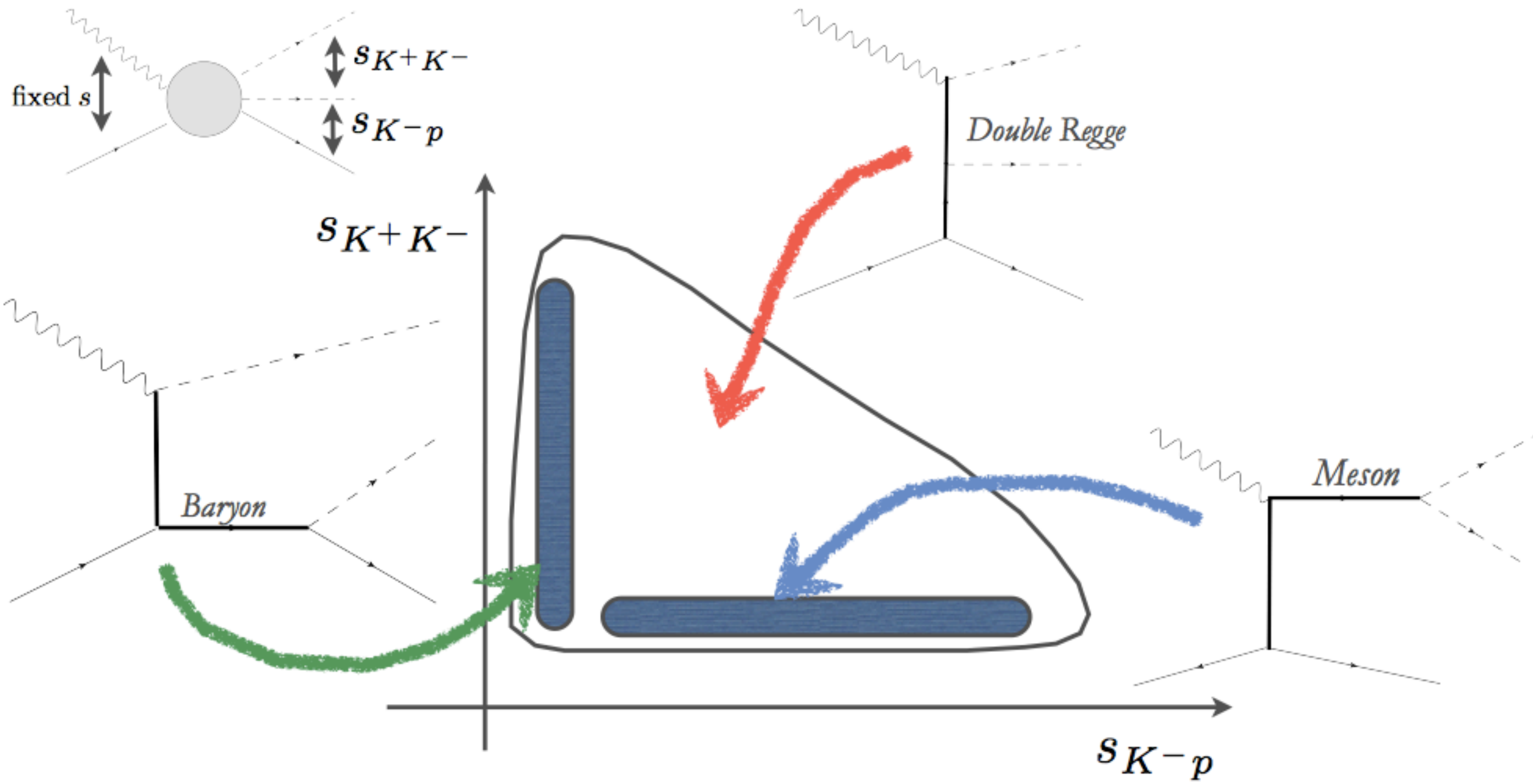


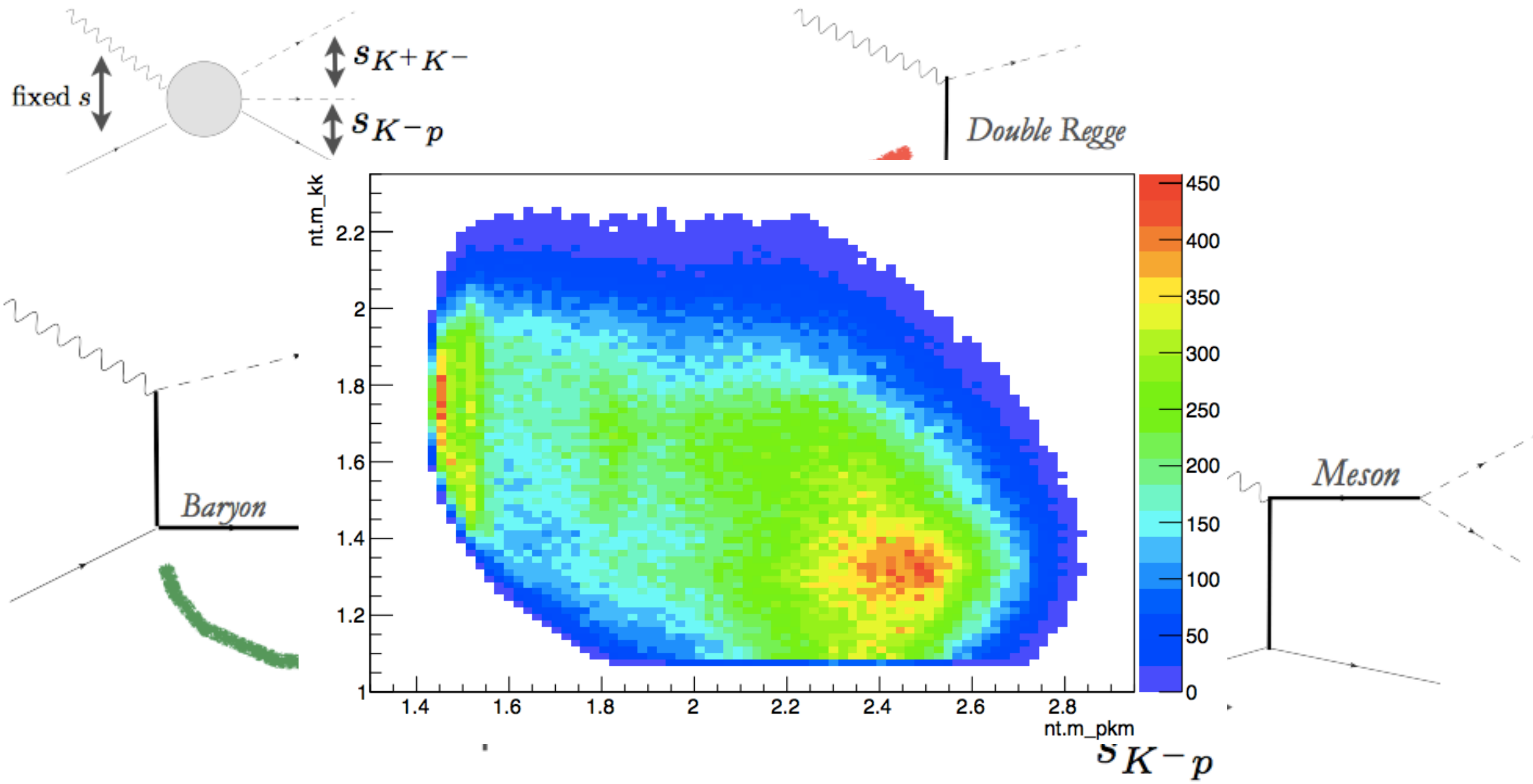
FIG. 2: (a) Naive Isobar model. (b) Three-body rescattering effect.

$\gamma p \rightarrow pK^+K^-$

- Theory: M. Shi @JLab, V. Mathieu @IU, C. Ramirez @JLab, R. Workman @GW, A. Szczepaniak @IU
- Experimental support: D. Schott, PWA Working Group



fixed s
$s_{K^+K^-}$
s_{K^-p}
Double Regge
$s_{K^+K^-}$
Baryon
Meson
s_{K^-p}



fixed s
$s_{K^+K^-}$
s_{K^-p}
Double Regge
Baryon
Meson
nt.m_kk
nt.m_pkm
s_{K^-p}
450
400
350
300
250
200
150
100
50
0

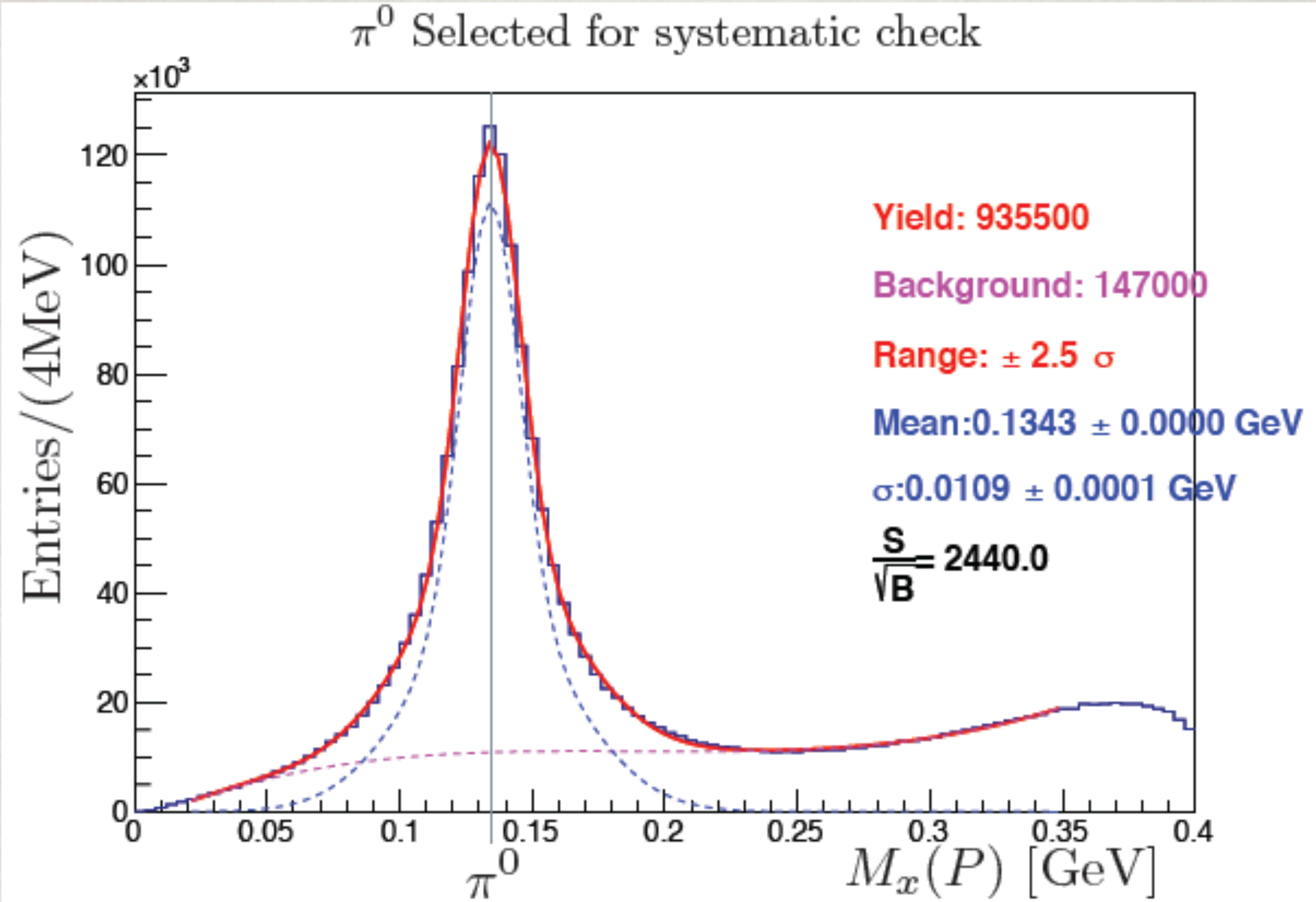
Summary

- Amplitude analysis can be performed in many ways. JPAC is trying a different approach.
- Stay tuned!

Dark Photon Search

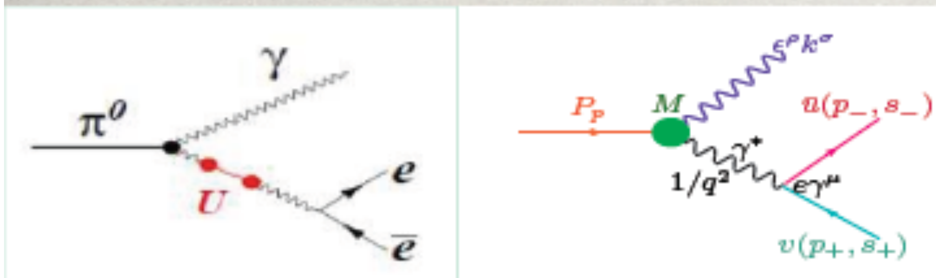
- The following work is done primarily by the ODU group at CLAS:
  - M. Kunkel and M. Amaryan

STATISTICS

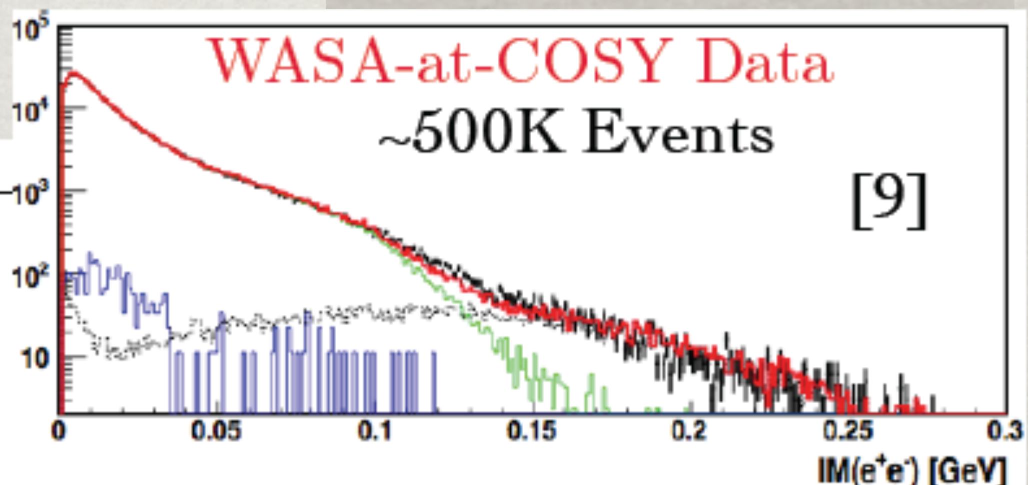


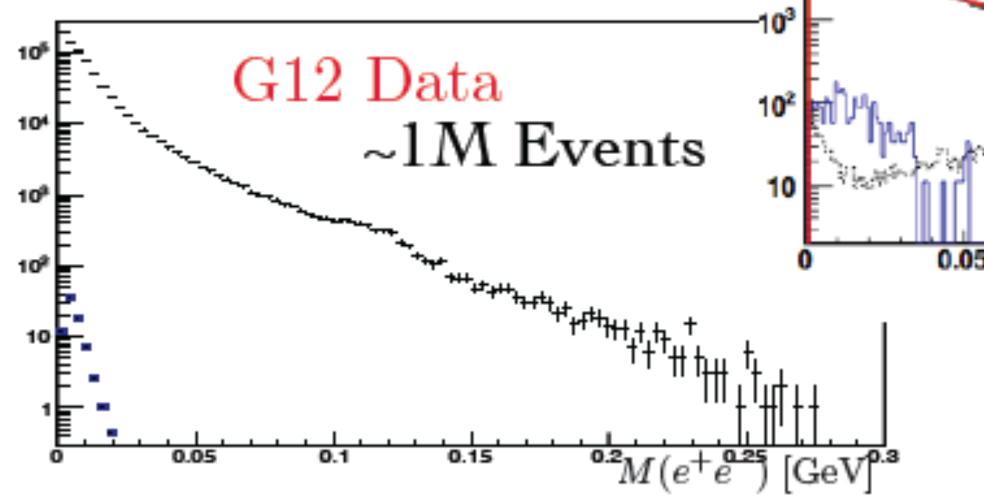
π^0 Selected for systematic check
×10³
Entries/(4MeV)
0
20
40
60
80
100
120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
π^0
$M_x(P)$ [GeV]
Yield: 935500
Background: 147000
Range: ± 2.5 σ
Mean:0.1343 ± 0.0000 GeV
σ:0.0109 ± 0.0001 GeV
$\frac{S}{\sqrt{B}}$= 2440.0

Dark Photon



[9] arXiv:1304.0671v2 [hep-ex]





Entries/(1MeV)

– Data
--- MC sum
--- MC $\pi^0 \rightarrow e^+e^-\gamma$
--- MC conversion
- - - MC $\pi^0 \rightarrow e^+e^-\gamma$ plus false e^+ from π^+

Dark Photon Upper Limits

arXiV: 1304.0671v1

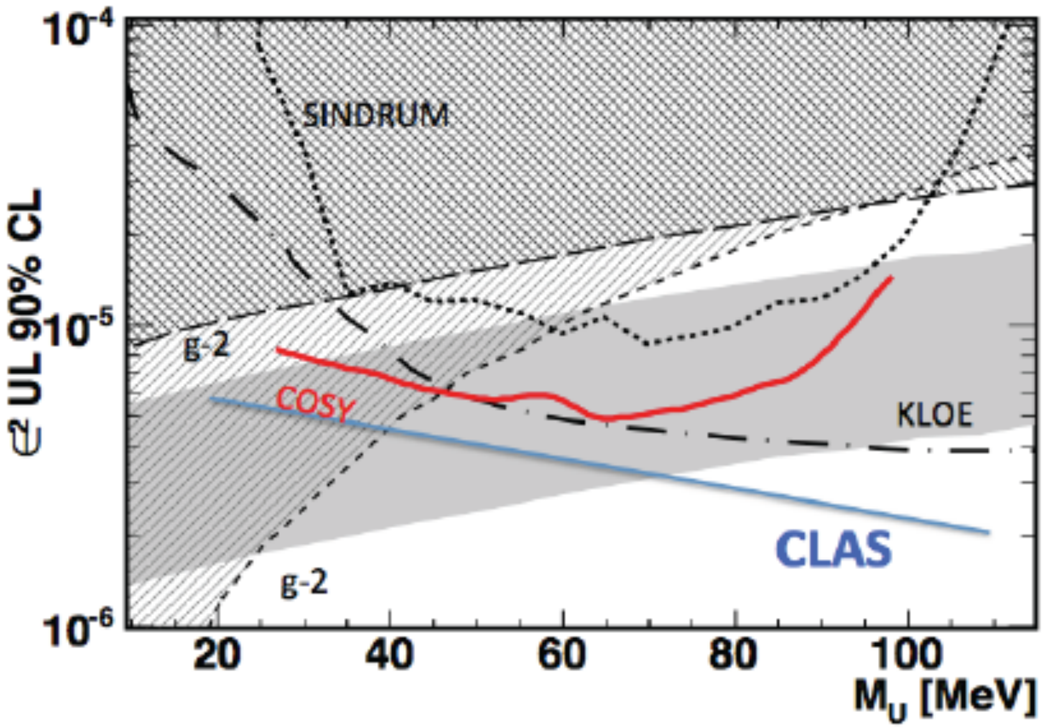


Figure 8: Summary of the 90% CL upper limits for the mixing parameter ϵ^2 from WASA-at-COSY (red solid line) compared to SINDRUM $\pi^0 \to e^+e^-\gamma$ [34] (dotted line) and recent combined KLOE $\phi \to \eta e^+e^-$ [43] (dashed dotted) upper limits. The long respectively short dashed lines (and the corresponding hatched areas) are the upper limits derived from the muon and the electron $g-2$ [29]. In addition the gray area represents the $\pm 2\sigma$ preferred band around the present value of the muon $g-2$.

Summary

- Recent results
  - Cross-section
    - $\gamma D \rightarrow p\pi^-(p)$
    - $\gamma D \rightarrow K^+\Sigma^*(1385)^-(p)$
    - $\gamma D \rightarrow K^*(892)^0\Lambda(p)$
      - Are expecting final results soon
    - $\gamma p \rightarrow p\omega \rightarrow p\pi^+\pi^-\pi^0$
  - Amplitude Analysis
    - $\omega \rightarrow \pi^+\pi^-\pi^0$
    - $\eta \rightarrow \pi^+\pi^-\pi^0$
    - $\gamma p \rightarrow pK^+K^-$
      - Collaboration between JPAC and CLAS is ramping up and will bring results soon
  - Dark Photon Search
    - Search for dark photons possible at CLAS using the high statistics data set.
      - Better limits on parameter space.