Measurement of the Polarization Observables I^s and I^c for $\vec{\gamma} p \to p\, \pi^+ \pi^-$ using the CLAS Spectrometer

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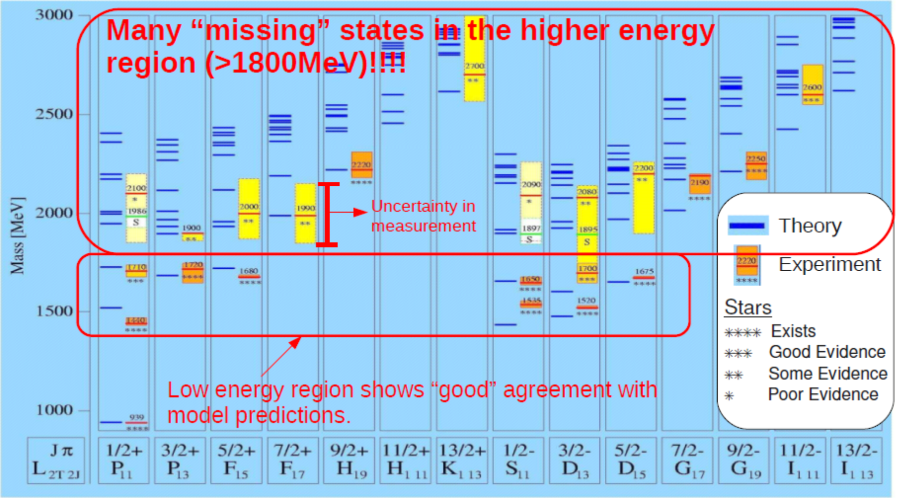
May 19, 2011

Outline

1. Introduction/Motivation
   - Missing Resonances
   - Why so many?
   - Polarization Observables
2. Experiment
   - Jefferson Lab
   - The Hall B CLAS Detector
   - Photon Beam
3. Data Analysis
   - Kinematic Fitting and Kinematics
   - Extraction Method
   - Preliminary Measurements

Constituent Quark Models: Missing Resonances

N* Resonances (I = 1/2)



Why so many missing resonances?

Possible answers and reasons...

- Most of what is found in the PDG handbooks has come from πN and KN scattering $\rightarrow \gamma$N.
- Analyses involved a single meson final state (i.e. $K^+\Lambda$, $K^+\Sigma^0$, Nπ, Nη).
  - Analyze a double-meson final state $\rightarrow$ has the largest cross section.
  - Sequential decay to final ground state particles: ex. $\gamma p \rightarrow N^* \rightarrow \Delta^{++}\pi^- \rightarrow p\,\pi^+\pi^-$.
  - Particle mass widths expected to be $\approx$150 MeV $\rightarrow$ too big for a two-body (single meson) final state.
- Possible quark-diquark structure of the baryon $\rightarrow$ fewer degrees of freedom $\rightarrow$ fewer excited states
- Refinement of the CQMs.

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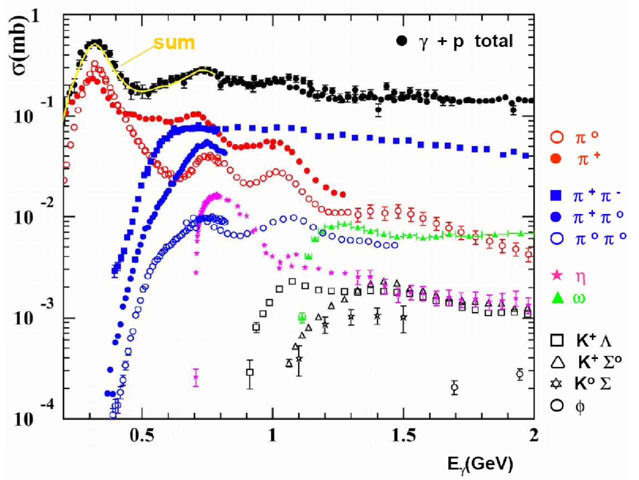

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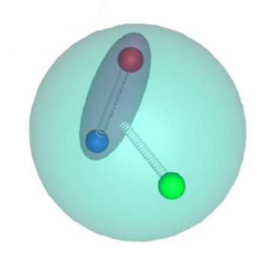

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Polarization Observables: Double Meson Final State

- For a final state with two mesons, there are a total of 15 observables!

Goal: To measure quantities called Polarization Observables which are highly sensitive to resonance production and can be predicted according to model calculations.

Definitions

- I_0 = unpolarized reaction rate
- $\vec{\Lambda}_i$ = direction and degree of polarization of the target
- $\delta_{l,\odot}$ = degree and orientation of photon beam polarization
- $\vec{P}$ = observable arising from the use of a polarized target
- $\mathrm{I}^{\odot,s,c}$ = observables arising from the use of polarized photons
- β = orientation of polarization w.r.t. a final state particle ($\beta = \phi_{lab} + \phi_{polarization}$)

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$$I = I_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_\odot (\mathbf{I}^\odot + \vec{\Lambda}_i \cdot \vec{\mathbf{P}^\odot}) + \delta_l [\sin(2\beta) (\mathbf{I}^\mathbf{s} + \vec{\Lambda}_i \cdot \vec{\mathbf{P}^\mathbf{s}}) + \cos(2\beta) (\mathbf{I}^\mathbf{c} + \vec{\Lambda}_i \cdot \vec{\mathbf{P}^\mathbf{c}})] \}$$

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Reducing the final state equation

- Applying the run conditions of g8b simplifies the final state equation and reduces the number of observables.
- Linearly polarized photon beam incident on an unpolarized LH_2 target. ($\overrightarrow{\Lambda_i} = 0$, $\delta_\odot = 0$)

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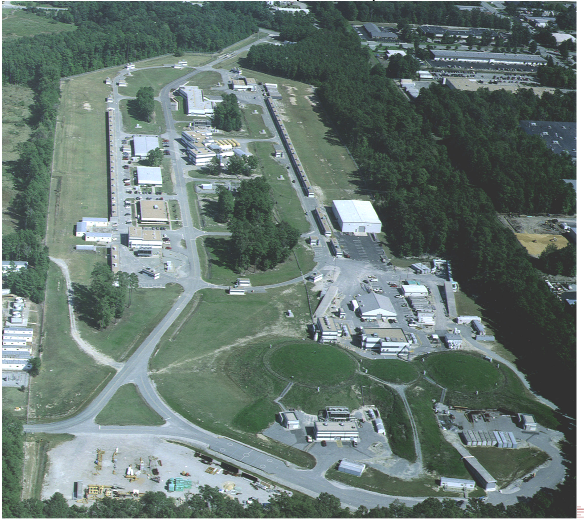
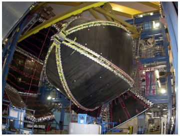
- I^s
- I^c (Σ in the single-meson final state equation)
- Measuring both for $\vec{\gamma} p \to p \, \pi^+ \pi^-$

The Facility

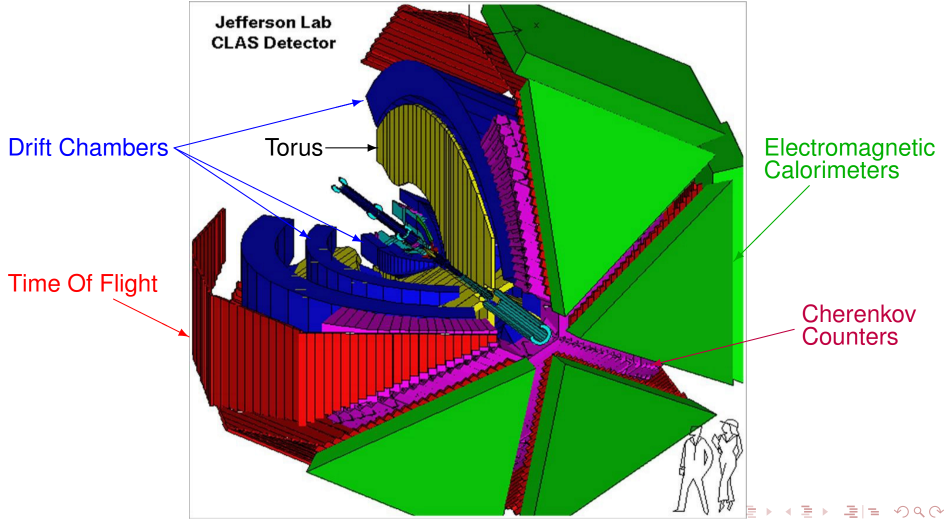
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY (JLAB)





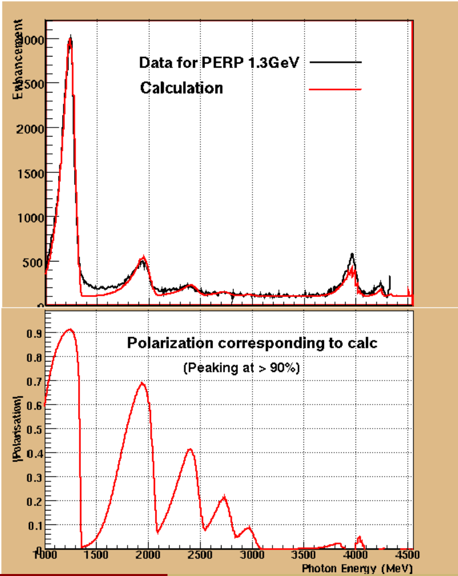
The Hall B CLAS Detector

CEBAF Large Acceptance Spectrometer



Photon Beam

- Hall B can produce a beam of tagged and polarized photons via bremsstrahlung.
- Can tag photons with energies ranging from $(0.2)E_0$ to $(0.95)E_0$.
- Linearly polarized beam:
  - unpolarized electron beam + oriented diamond radiator
  - Can obtain 90% polarization

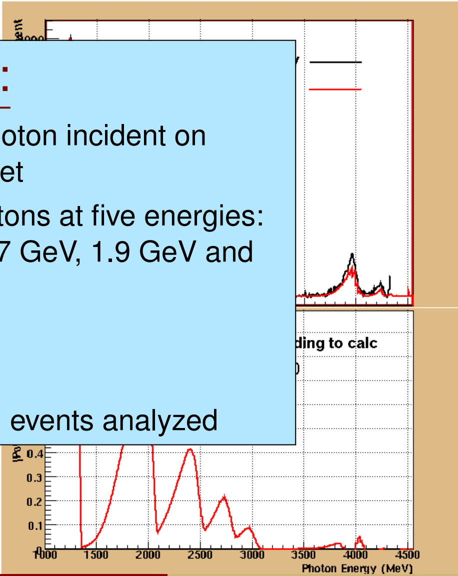


Photon Beam

- Hall B ... tagge... via br...
- Can t... rangi...
- Linea...
  -
  - ... polarization

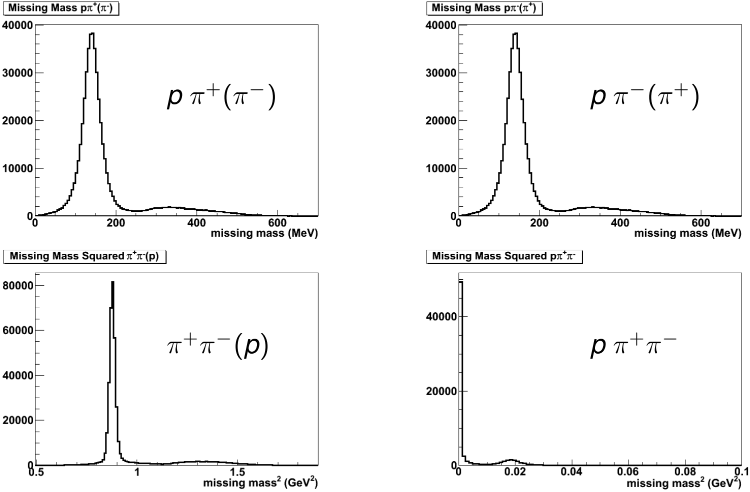
g8b:

- Linearly polarized photon incident on unpolarized LH_2 target
- Highly polarized photons at five energies: 1.3 GeV, 1.5 GeV, 1.7 GeV, 1.9 GeV and 2.1 GeV.
- 30 TB of data
- 10.7 billion events
- 38.34 million $p\,\pi^+\pi^-$ events analyzed



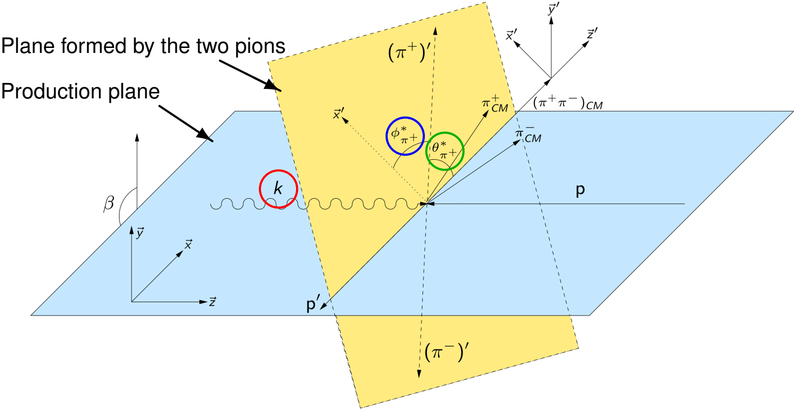
Analysis of $\vec{\gamma}p \to p\,\pi^+\pi^-$

- While $\vec{\gamma}p \to p\,\pi^+\pi^-$ is studied, a total of four topologies are kinematically fitted.



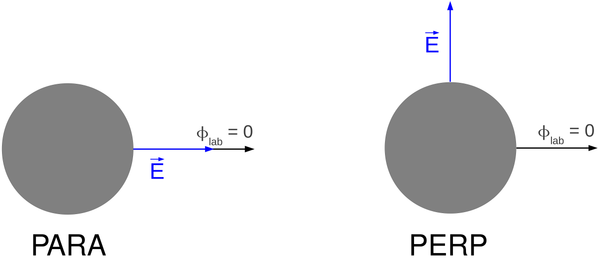
Kinematics

- The analysis of the (double-meson) $\vec{\gamma}p \rightarrow p\,\pi^+\pi^-$ channel requires the use of 5 independent kinematic variables: ($m_{p\pi}$ or $m_{\pi\pi}$), $\cos\theta_p^{CM}$, k, $\cos\theta^*_{\pi^+}$, $\phi^*_{\pi^+}$.



Extracting I^s and I^c: ϕ-distributions

- Three types of (photon) polarization settings were used:
  - Parallel (PARA)
  - Perpendicular (PERP)
  - Amorphous (AMO)



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  - Parallel (PARA)
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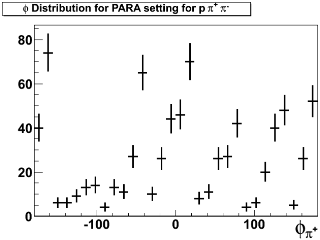
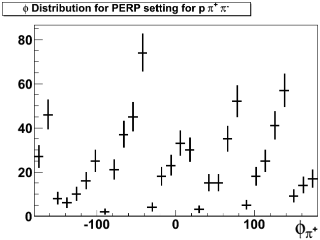
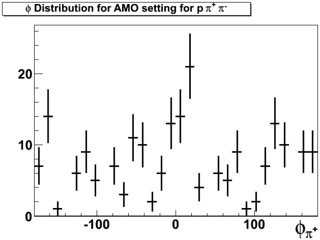
- The polarization of the photon beam breaks the usual ϕ symmetry.
- Events are plotted as a function of lab angle ϕ_{π^+} for each polarization setting.







Extracting I^s and I^c

- Uses the asymmetry between PARA and PERP.
- Asymmetry between PARA and PERP is formed for matching bin combinations.
- Fit to:

$$A(k,\cos\theta^*_{\pi^+},\phi^*_{\pi^+}) = \frac{PARA - PERP}{PARA + PERP} = \frac{I_{PARA} - I_{PERP}}{I_{PARA} + I_{PERP}}$$

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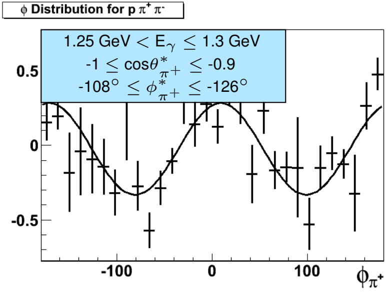

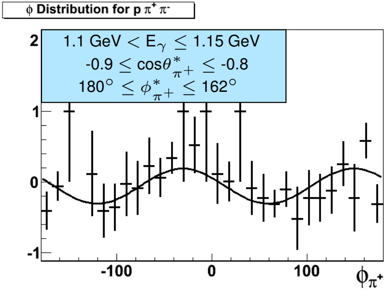

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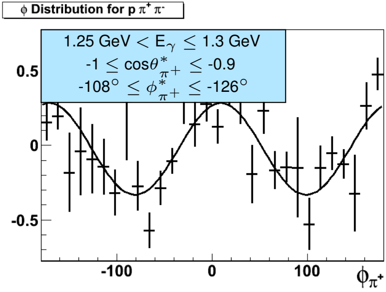
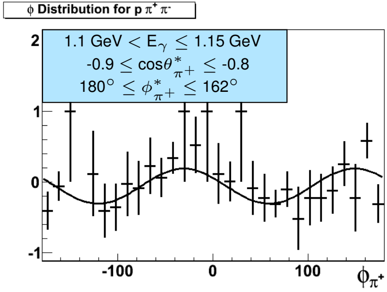
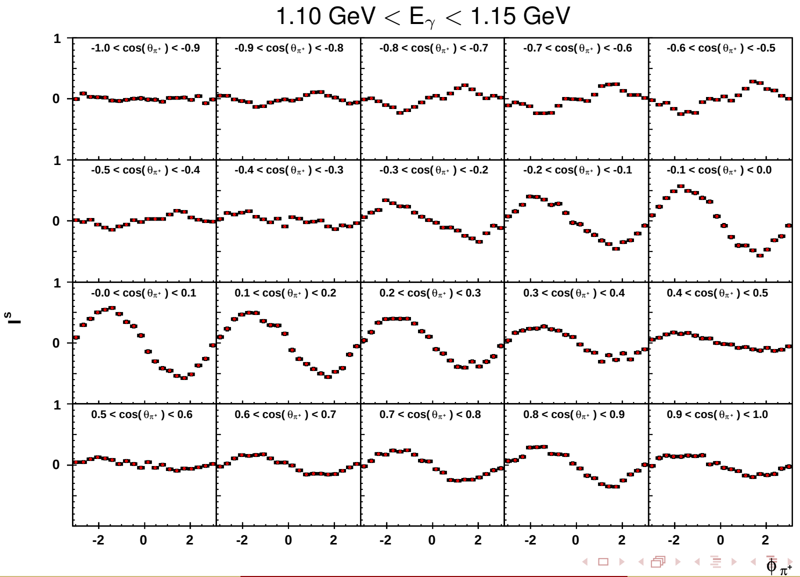




Preliminary Measurement: I^s v $\phi^*_{\pi^+}$



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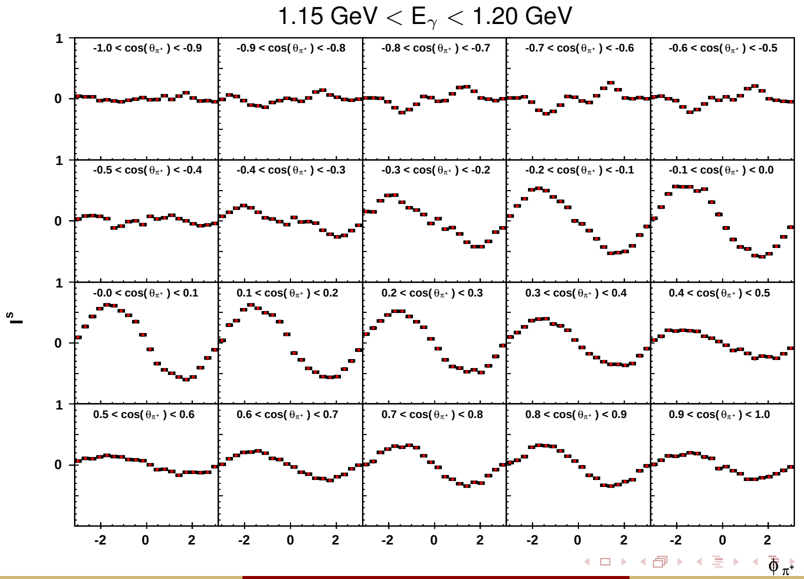

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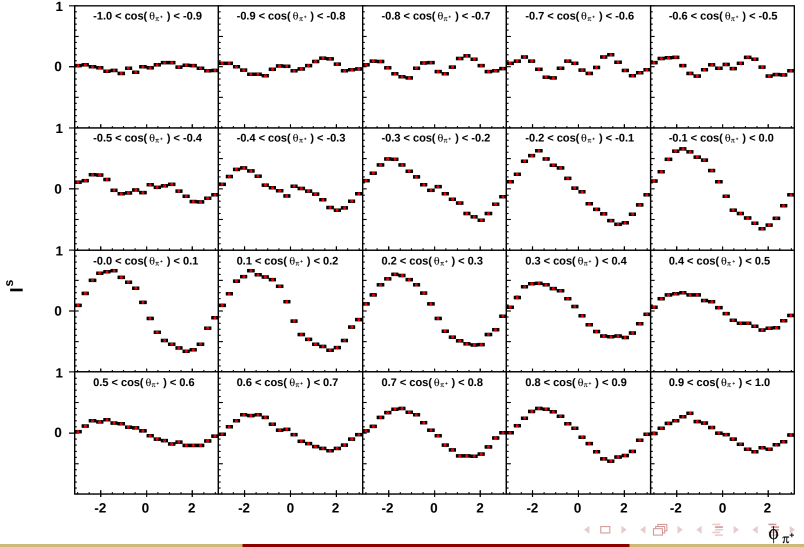
$1.20 \text{ GeV} < E_\gamma < 1.25 \text{ GeV}$



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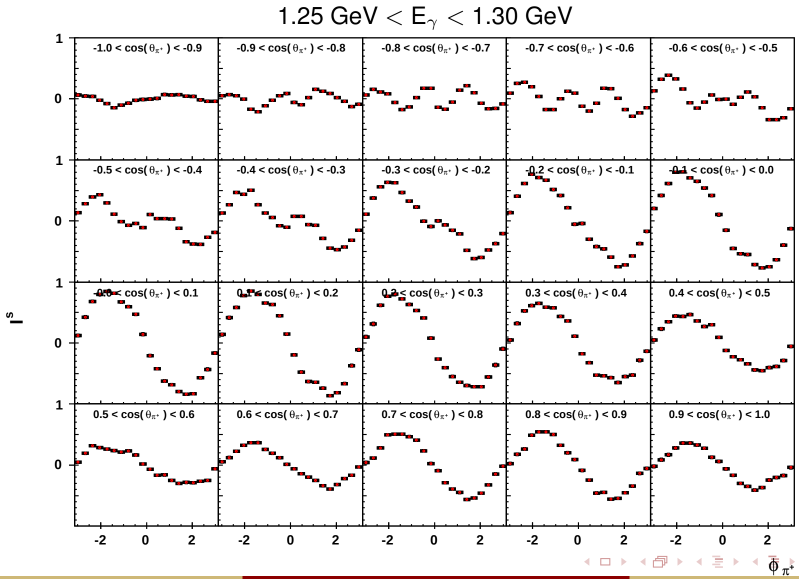

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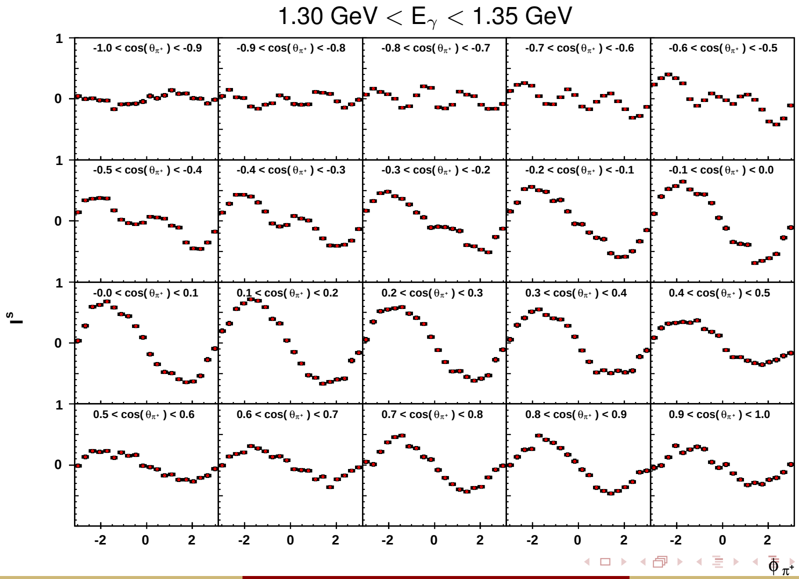

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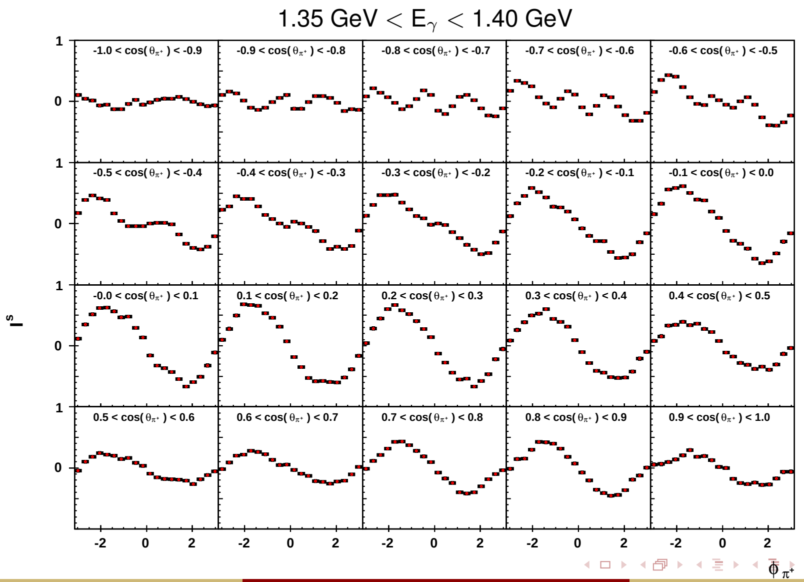

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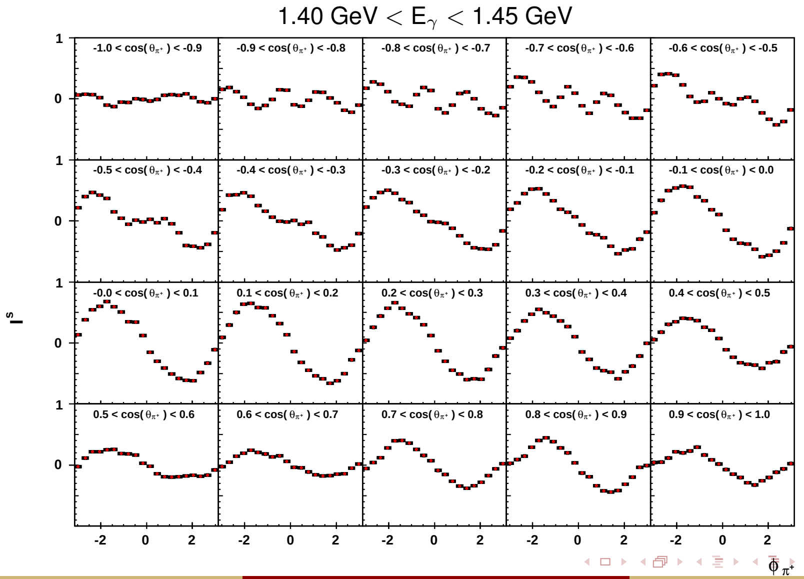

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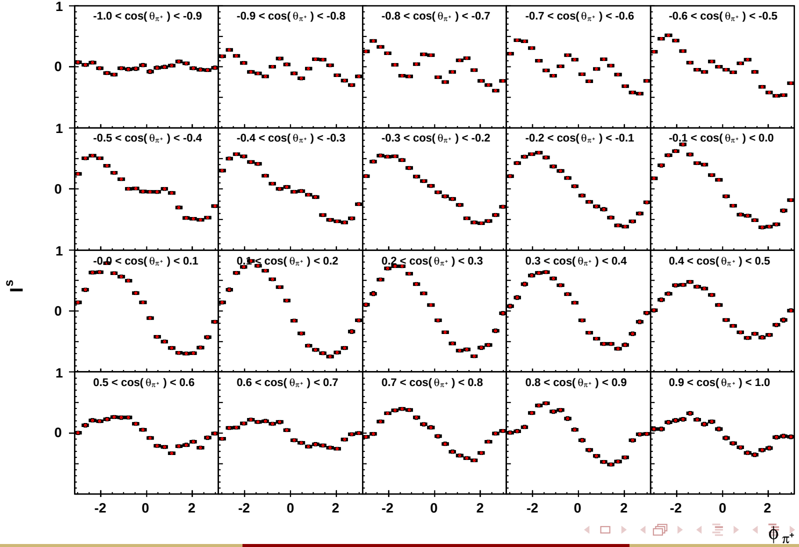
$1.45\ \mathrm{GeV} < E_\gamma < 1.50\ \mathrm{GeV}$



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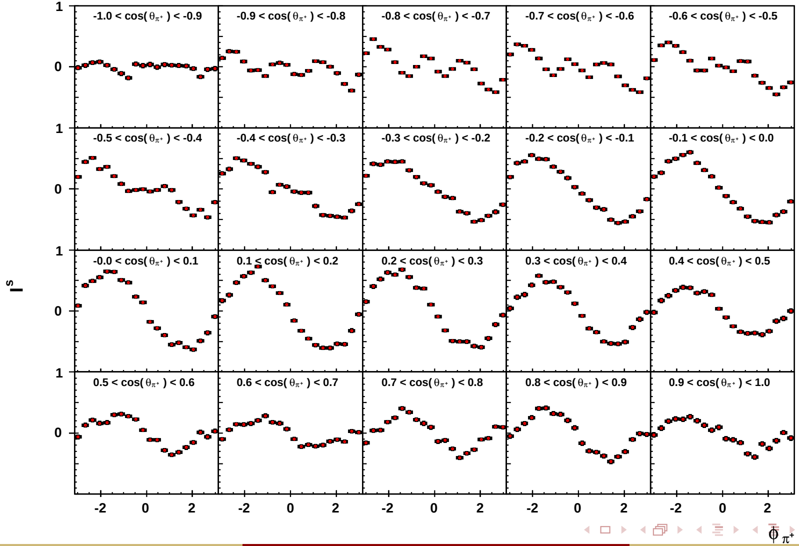

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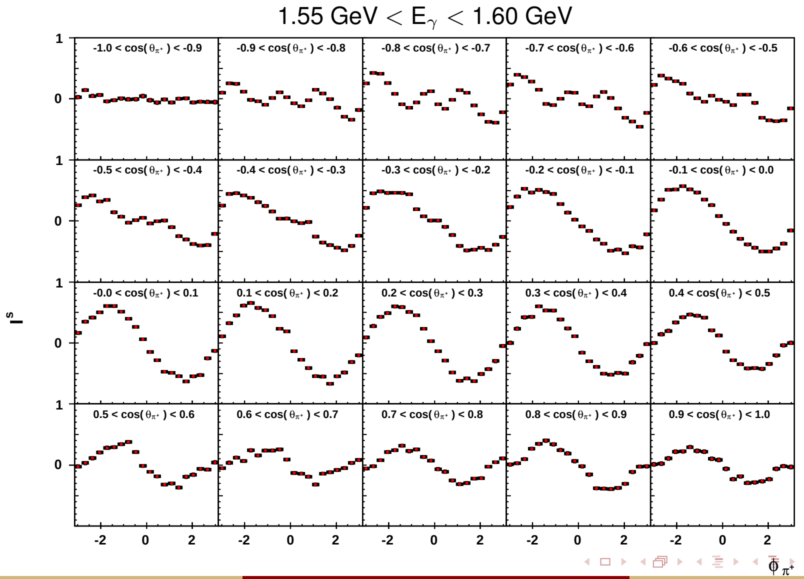

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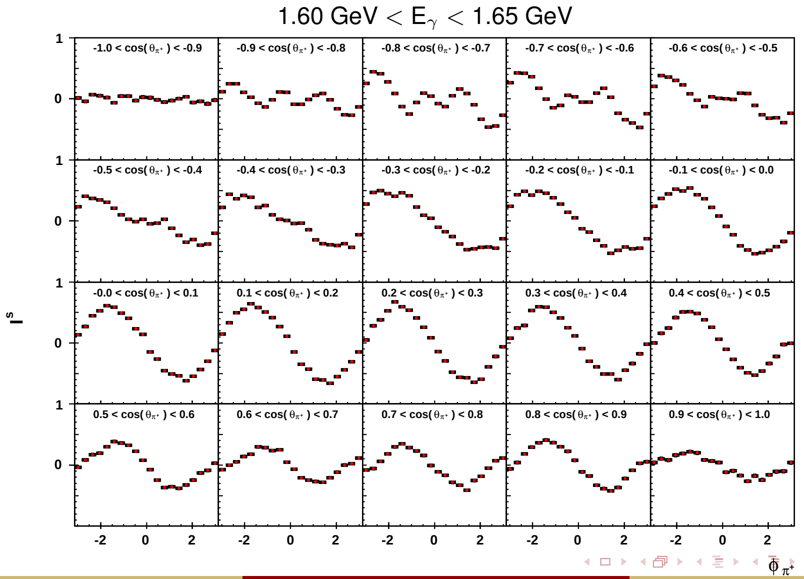

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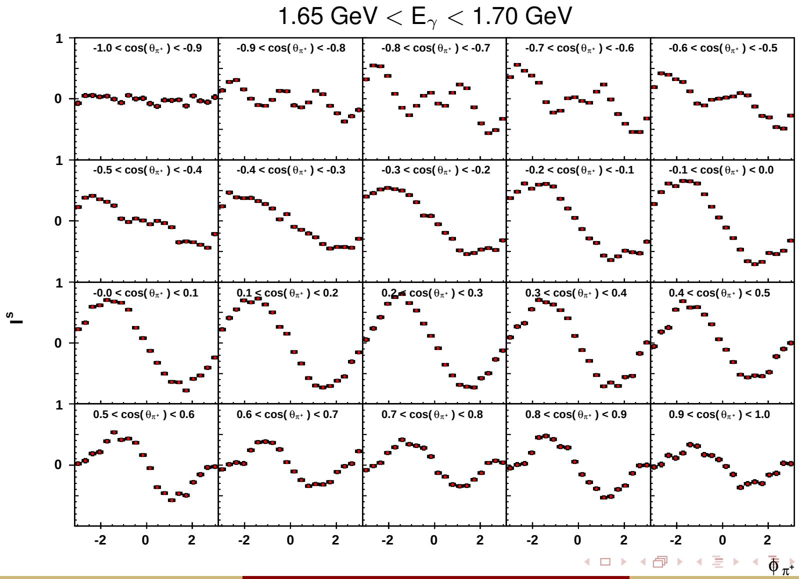
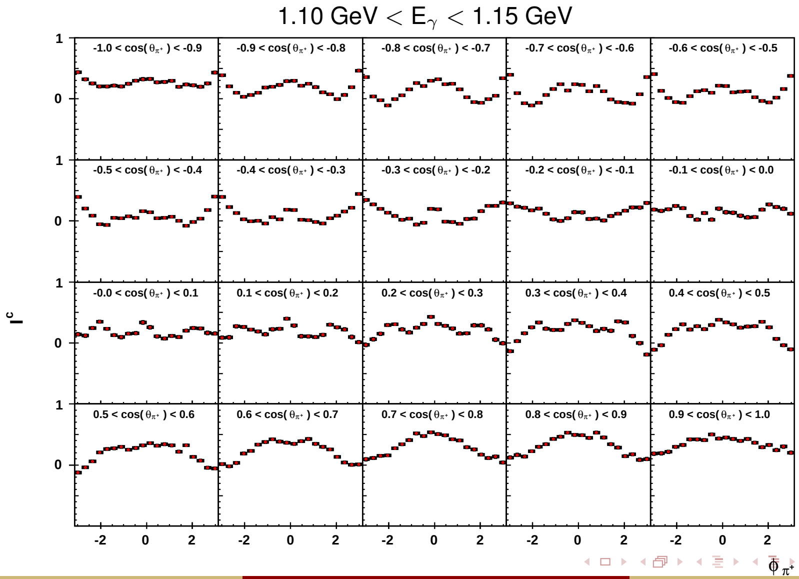


Preliminary Measurement: I^c v $\phi^*_{\pi^+}$



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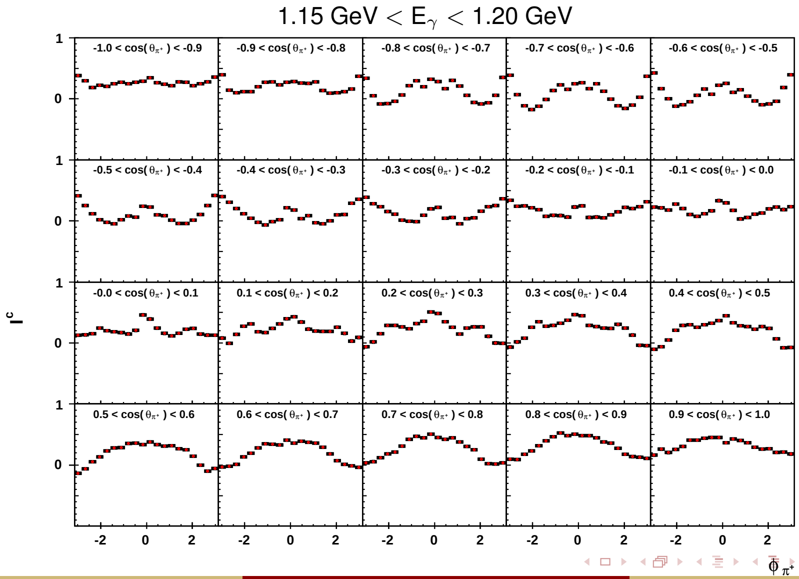

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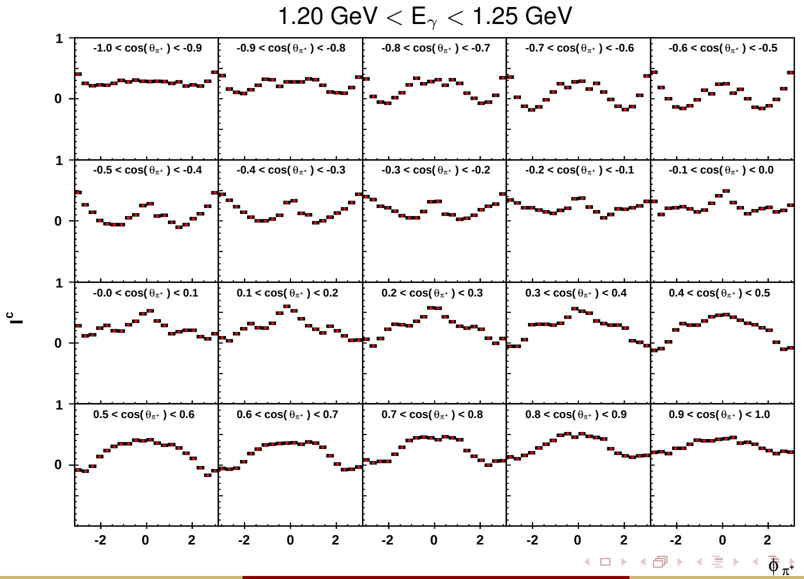

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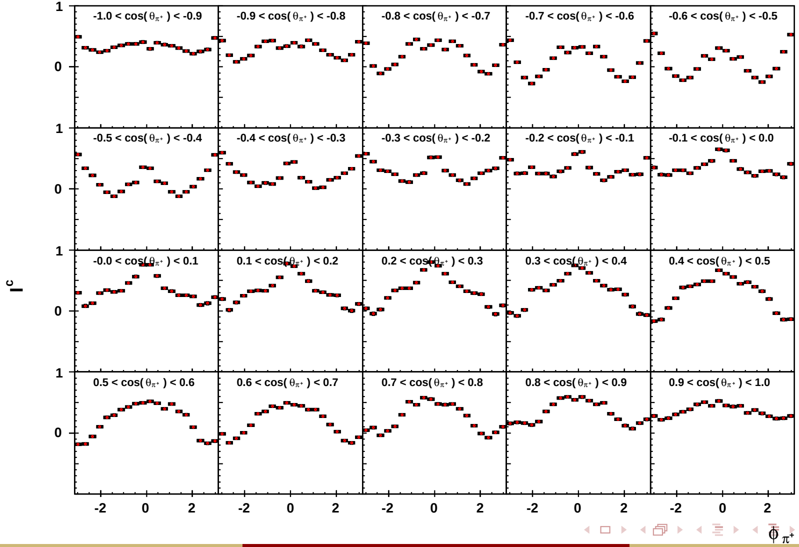

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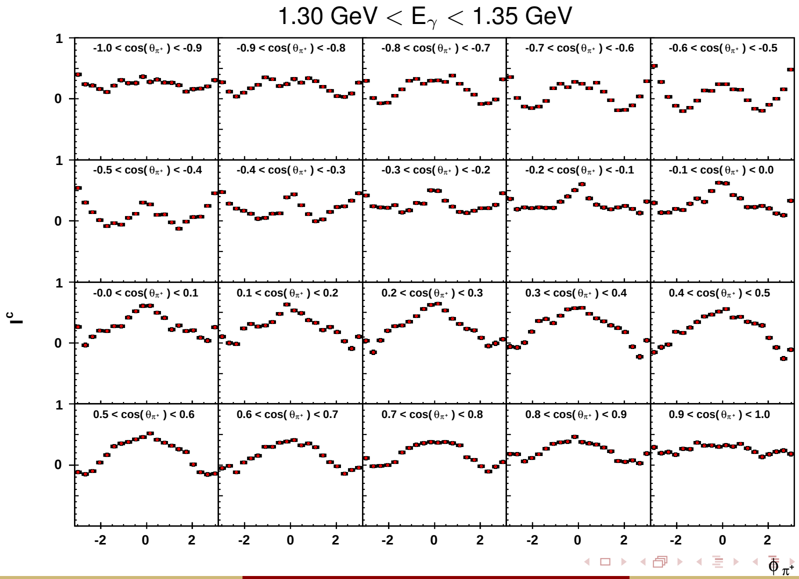

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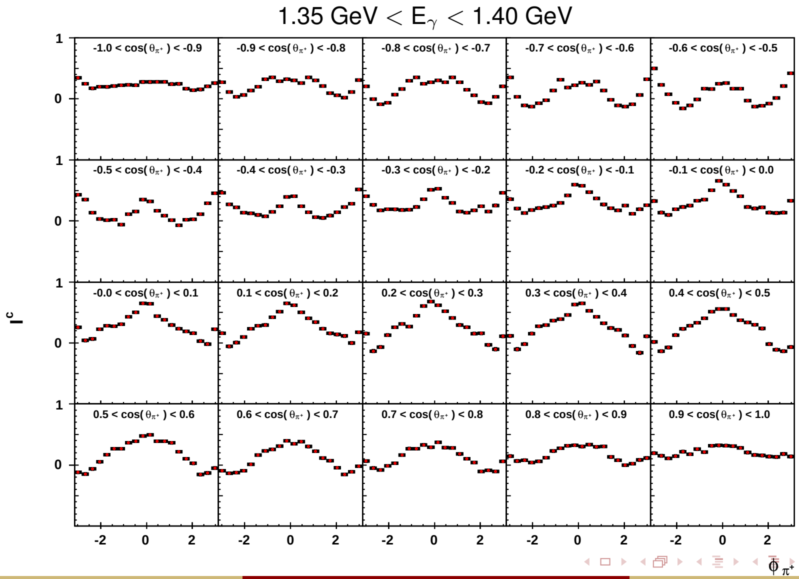

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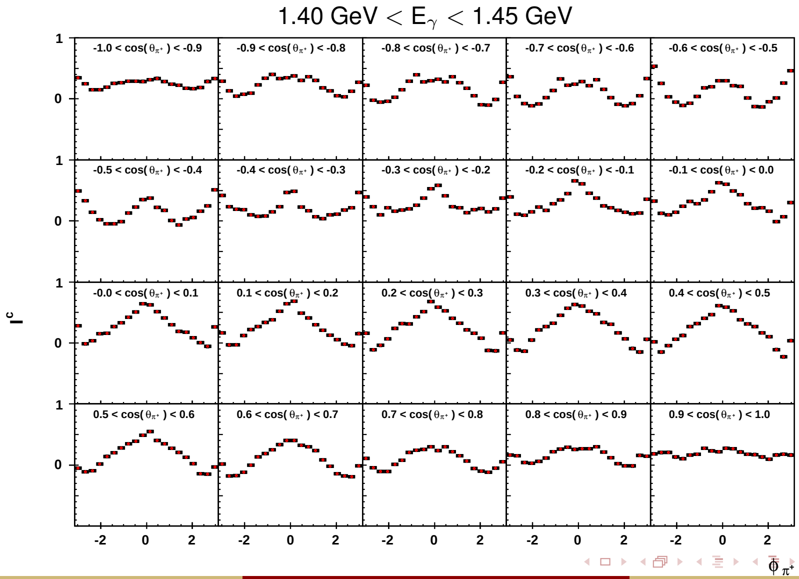

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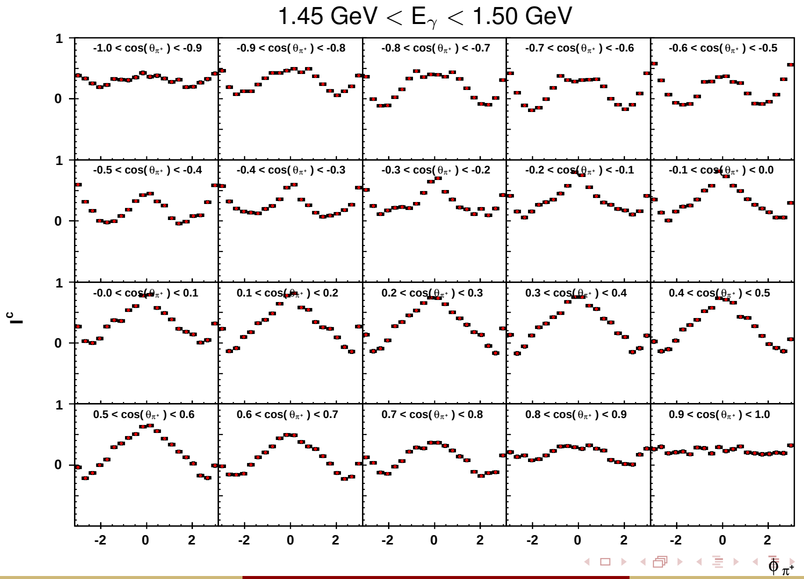

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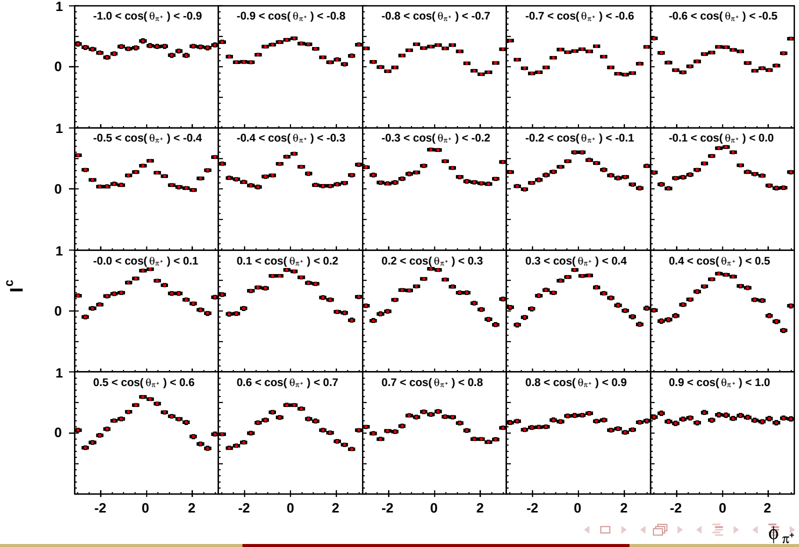

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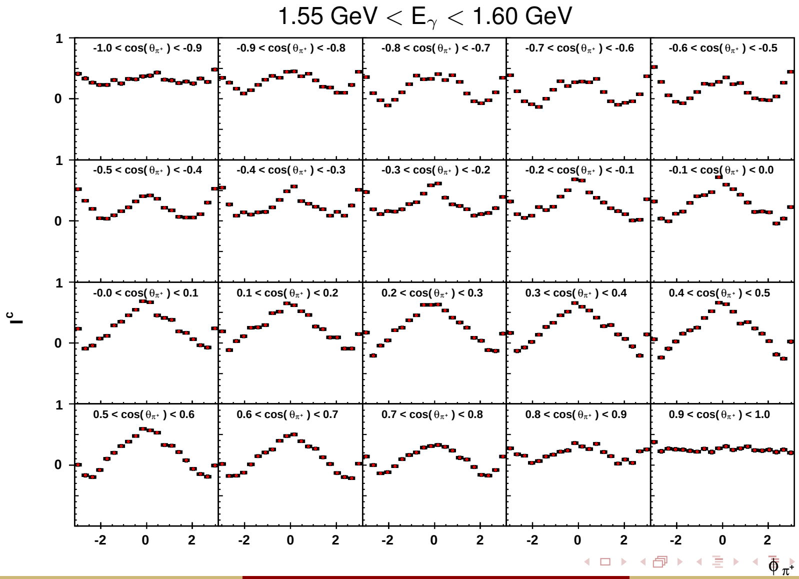

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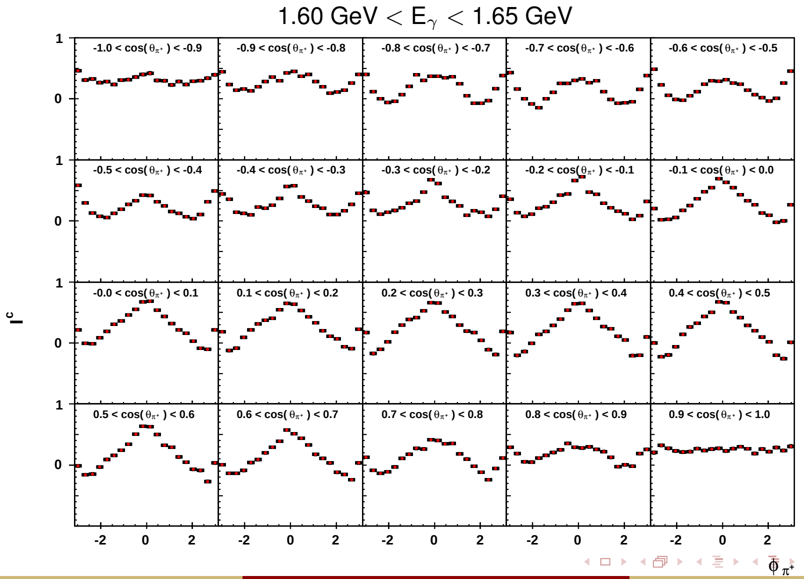
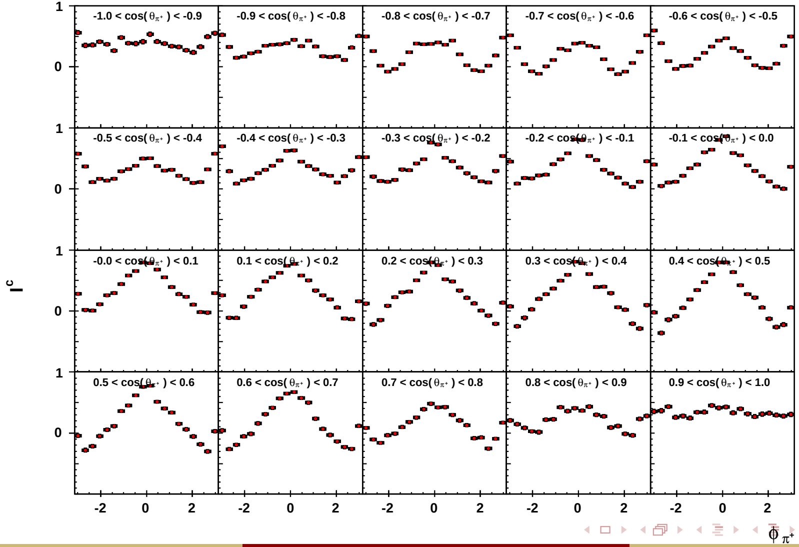


Preliminary Measurement: I^c v $\phi^*_{\pi^+}$

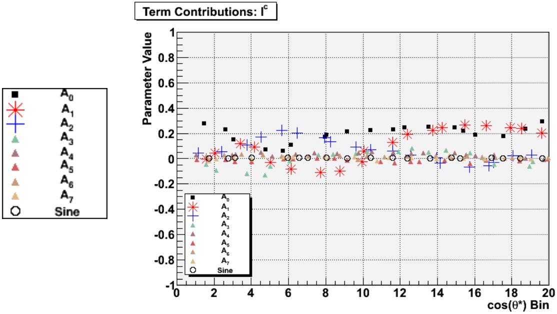
$1.65 \text{ GeV} < E_\gamma < 1.70 \text{ GeV}$



Examination of the behavior of I^s and I^c: I^c

- The behavior of the measured observables is predicted to be either even (I^c) or odd (I^s) as a function of ϕ^*.
- To check the behavior, measurements were fit with expansions of sine and cosine for each $\cos\theta^*_{\pi^+}$ bin.
- Contributions from the different terms were examined.

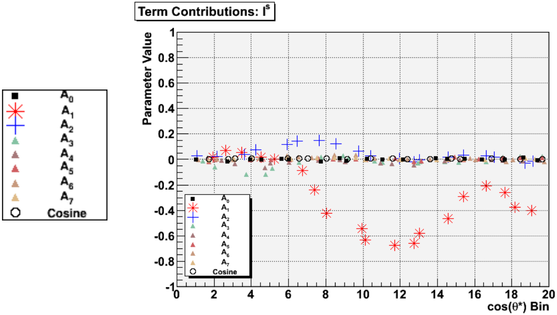
$$f(\phi^*) = A_0 + A_1 cos(\phi^*) + A_2 cos(2\phi^*) + A_3 cos(3\phi^*) + A_4 cos(4\phi^*) + A_5 cos(5\phi^*) + A_6 cos(6\phi^*) + A_7 cos(7\phi^*) + A_8 sin(\phi^*)$$



Examination of the behavior of I^s and I^c: I^s

- The behavior of the measured observables is predicted to be either even (I^c) or odd (I^s) as a function of ϕ^*.
- To check the behavior, measurements were fit with expansions of sine and cosine for each cos$\theta^*_{\pi^+}$ bin.
- Contributions from the different terms were examined.

$$f(\phi^*) = A_0 + A_1 sin(\phi^*) + A_2 sin(2\phi^*) + A_3 sin(3\phi^*) + A_4 sin(4\phi^*) + A_5 sin(5\phi^*) + A_6 sin(6\phi^*) + A_7 sin(7\phi^*) + A_8 cos(\phi^*)$$



Summary

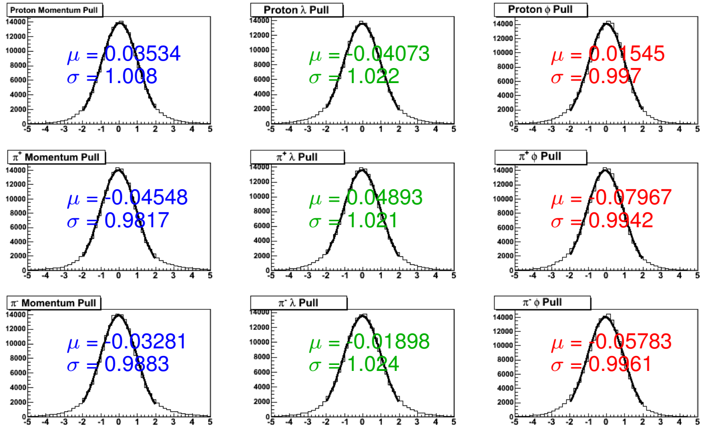
- Polarization Observables are highly sensitive to resonance production.
- By measuring these observables, we can garner more information about the excited baryon spectrum.
- Measured for $\vec{\gamma}p \to p\,\pi^+\pi^-$:
  - I^s and I^c
  - First measurements for a two-charged-pion final state.
- These observable measurements as well as future measurements will aid in the refinement of CQMs as well as aid in future PWA analyses regarding the N* spectrum.
- Outlook: The FROST experiment will provide access to all 15 observables for a double-meson final state.

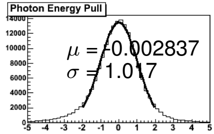
END

Momentum and Photon energy Corrections

- Momentum Corrections:
  - Kinematic fitter is highly sensitive to systematic effects $\rightarrow$ good tool for determining momentum corrections.
  - Corrections are needed to account for variations in torus $\vec{B}$ field and misalignments of Drift Chambers.
  - Determined by examining momentum pull distributions for the proton for $\vec{\gamma}p \rightarrow p\,\pi^+\pi^-$ fits/events.
- Tagger Sag
  - Occurs due to a physical sagging of the support structure for Tagger Hodoscope.
  - Affects the determination of photon energy.
  - Requires energy-dependent correction
    $\rightarrow$ M. Dugger, C. Hanretty, CLAS-Note 2009-030

Check the pull distributions





$\vec{\gamma} p \to p\, \pi^+ \pi^-$

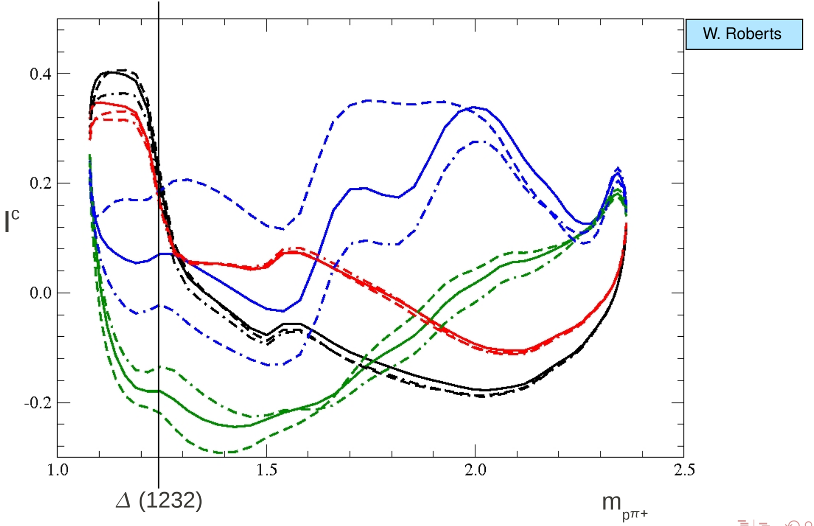
(Run #048326)

p

λ

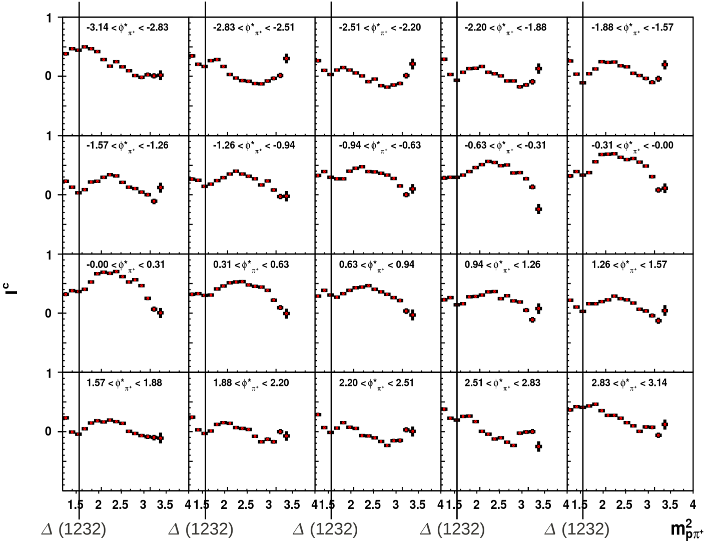
ϕ

Preliminary Measurement: I^c v $m^2_{p\pi^+}$

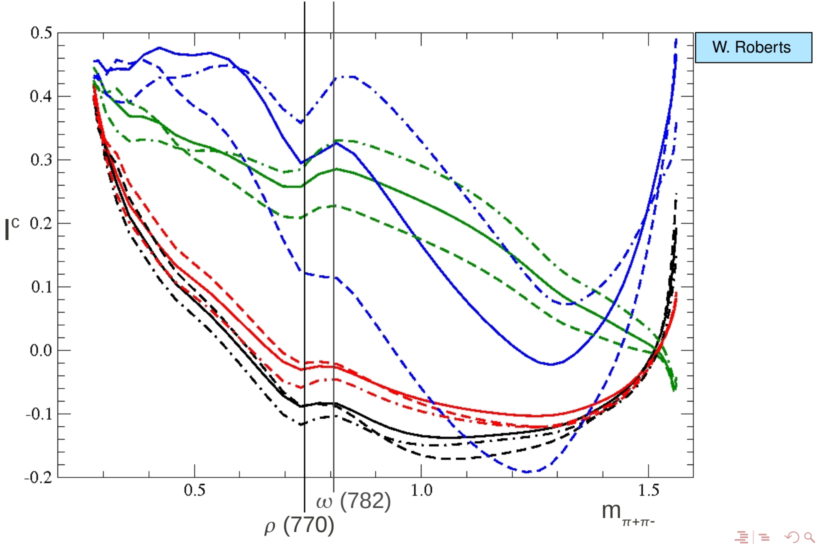


Preliminary Measurement: I^c v $m^2_{p\pi^+}$

1.65 GeV $< E_\gamma <$ 1.70 GeV



Preliminary Measurement: I^c v $m^2_{\pi^+\pi^-}$



Preliminary Measurement: I^c v $m^2_{\pi^+\pi^-}$