Measurement of beam and target polarization observables in $\vec{\gamma}\vec{p} \rightarrow p\pi^+\pi^-$ using the CLAS spectrometer at Jefferson Lab.

Sungkyun Park
on the behalf of CLAS Collaboration

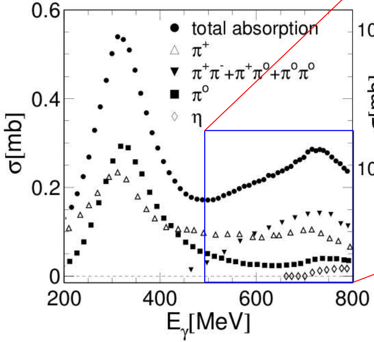
Florida State University

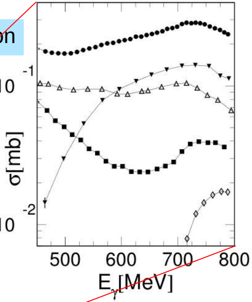
May 27, 2013

Outline

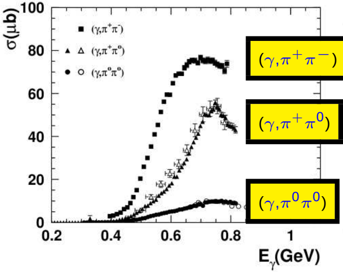
Why is $\pi^+\pi^-$ photoproduction needed ?

Total cross section
for the photoproduction off the proton





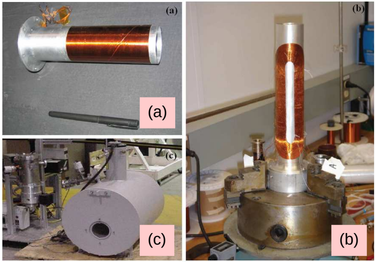
Total cross section
of π π production off the proton



- Search for new baryon states that are predicted by quark models to decay strongly to $\Delta\pi$ and p ρ.
- The most biggest cross section contribution is from double pion production, especially (γ, π^+ π^-), in the second resonance region
- Polarization observables are important in the resonance extraction from data.

The Frozen-Spin Target (FroST)

1 High magnetic field (5 T)



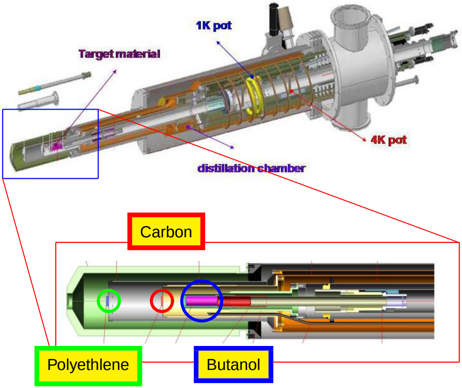
(a) The longitudinal holding magnet. (0.56 T)
(g9a : Nov. 2007 - Feb. 2008)
- ◇ Average target polarization
  ∼ 82 % (+Pol) and 85 % (-Pol)

(b) The transversal holding magnet. (0.50 T)
(g9b : March 2010 - August 2010)

(c) The polarizing magnet. (5 T)

2 Low temperature

28 mK (w/o beam) and 30mK (w/ beam)

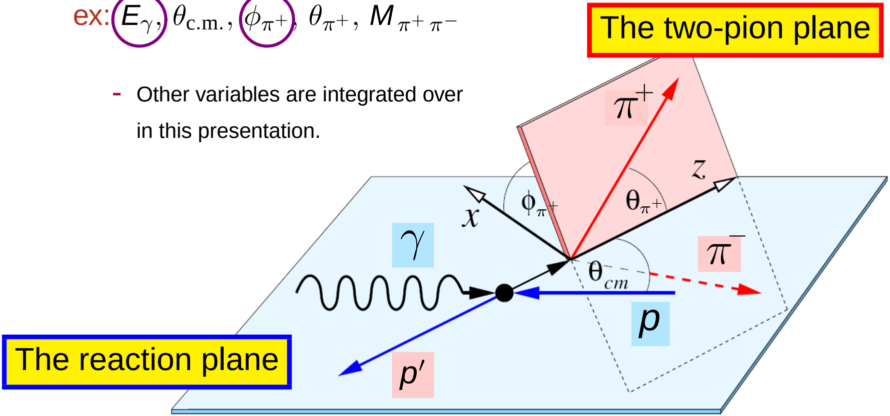


Photoproduction of $\pi^+\pi^-$ off the proton: Kinematics

- The $\pi^+ \pi^-$ photoproduction requires 5 independent variables.

ex: E_γ, $\theta_{\text{c.m.}}$, ϕ_{π^+}, θ_{π^+}, $M_{\pi^+\pi^-}$

- Other variables are integrated over in this presentation.



The differential cross section for $\gamma p \to p\pi^+\pi^-$

The differential cross section for $\gamma p \to p\pi^+\pi^-$

(without measuring the polarization of the recoiling nucleon)

$$\frac{d\sigma}{dx_i} = \sigma_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_{\odot} (\mathbf{I}^{\odot} + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^{\odot})$$

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

- σ_0: The unpolarized cross section
- β: The angle between the direction of polarization and the x-axis
- x_i: The kinematic variables
- $\delta_{\odot, l}$: The degree of polarizaton of the photon beam $\Rightarrow \delta_{\odot}$, and δ_l
- $\vec{\Lambda}_i$: The polarization of the initial nucleon $\Rightarrow (\Lambda_x, \Lambda_y, \Lambda_z)$
- $\mathbf{I}^{\odot, \mathbf{s}, \mathbf{c}}$: The observable arising from use of polarized photons $\Rightarrow \mathbf{I}^{\odot}, \mathbf{I}^{\mathbf{s}}, \mathbf{I}^{\mathbf{c}}$
- $\vec{\mathbf{P}}$: The polarization observable $\Rightarrow (\mathbf{P_x}, \mathbf{P_y}, \mathbf{P_z})$ $(\mathbf{P}_x^{\odot}, \mathbf{P}_y^{\odot}, \mathbf{P}_z^{\odot})$ $(\mathbf{P}_x^{s}, \mathbf{P}_y^{s}, \mathbf{P}_z^{s})$ $(\mathbf{P_x^c}, \mathbf{P_y^c}, \mathbf{P_z^c})$

15 Observables

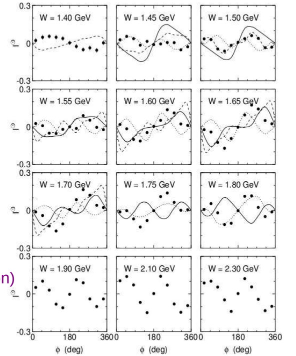
Previous measurements

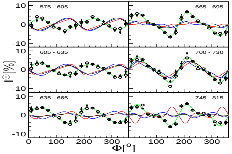
The data used for this analysis :

1. circularly-polarized beam
2. longitudinally-polarized target

$$\frac{d\sigma}{d x_i} = \sigma_0 \{ (1 + \Lambda_z \cdot \mathbf{P_z}) + \delta_\odot (\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P}_z^\odot)\}$$

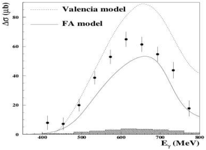
$\mathbf{I}^\odot$: Phys.Rev.Lett. 95, 162003 (2005, CLAS Collaboration)





$\mathbf{I}^\odot$: Phys.Rev.Lett. 103, 052002

(2009, Crystal Ball at MAMI, TAPS, and A2 Collaboration)



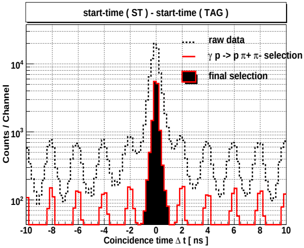
$\mathbf{P}_z^\odot$: Eur.Phys.J. A 34, 11-21 (2007, GDH Collaboration)

- The helicity-dependent total cross-section difference

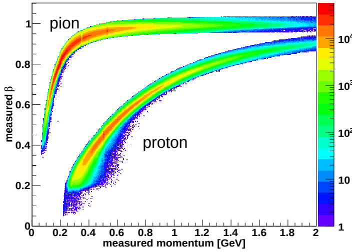
  $\Delta\sigma = (\sigma_{3/2} - \sigma_{1/2})$

Basic event selection

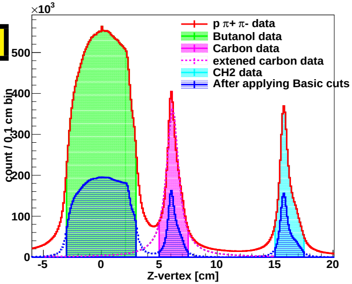
photon selection



proton and pion selection



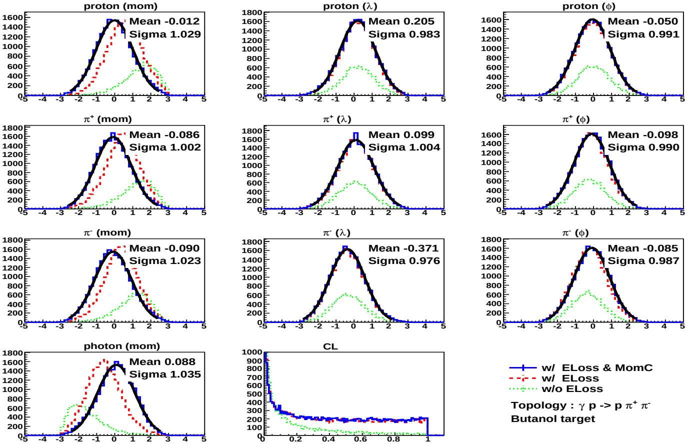
vertex cut



- Basic Cuts
  - photon selection
    : $|\Delta t| < 1.2$ ns
  - proton selection
    : $|\Delta\beta| < 0.032$
  - pion selection
    : $|\Delta\beta| < 0.044$
  - vertex cut (Butanol)
    : $|Zvertex| < 3$ cm
  - accidental cut
    : one photon selection
  - cofidence-level cut
    : CL-cut > 5 %

Basic event selection

The kinematic fitting



Basic Cuts

- photon selection
  : $|\Delta t| < 1.2$ ns
- proton selection
  : $|\Delta\beta| < 0.032$
- pion selection
  : $|\Delta\beta| < 0.044$
- vertex cut (Butanol)
  : $|Zvertex| < 3$ cm
- accidental cut
  : one photon selection
- cofidence-level cut
  : CL-cut > 5 %

Corrections

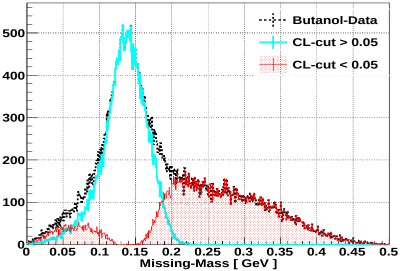
- Energy-loss correction
- Photon-energy correction
- Momentum correction

Polarization observable $\mathbf{I}^{\odot}$

Polarization observable $\mathbf{I}^{\odot}$

$$\mathbf{I}^{\odot}(\mathbf{W},\ \phi_{\pi^+}) = \frac{1}{\bar{\delta}_{\odot}(\mathbf{W})} \frac{\left\{ N(\rightarrow; \mathbf{W}, \phi_{\pi^+})_{beam} - N(\leftarrow; \mathbf{W}, \phi_{\pi^+})_{beam} \right\}}{\left\{ N(\rightarrow; \mathbf{W}, \phi_{\pi^+})_{beam} + N(\leftarrow; \mathbf{W}, \phi_{\pi^+})_{beam} \right\}}$$

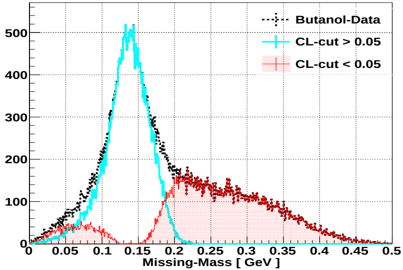
- $\bar{\delta}_{\odot}(\mathbf{W})$: The average degree of the photon beam polarizations
- $\rightarrow (\leftarrow)$: the direction of the beam polarization is parallel (anti-parallel) to the beam.
- Beam-helicity asymmetry for the unpolarized target and circularly-polarized photon beam

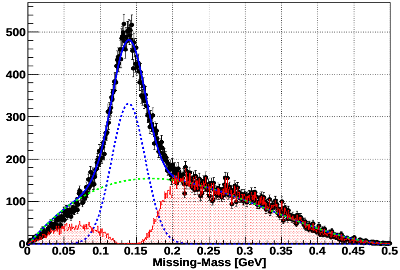


example :

- Topology : $\gamma p \rightarrow p\pi^+(\pi^-)$
- W : 1.60 GeV
- $\theta_{\mathrm{c.m.}},\ \phi_{\pi^+},\ \theta_{\pi^+},\ M_{\pi^+\pi^-}$ are integrated over.
- Using the 5 % Confidence Level Cut
  - There are still an effect of background events

The background effect in Beam-Helicity Asymmetry I



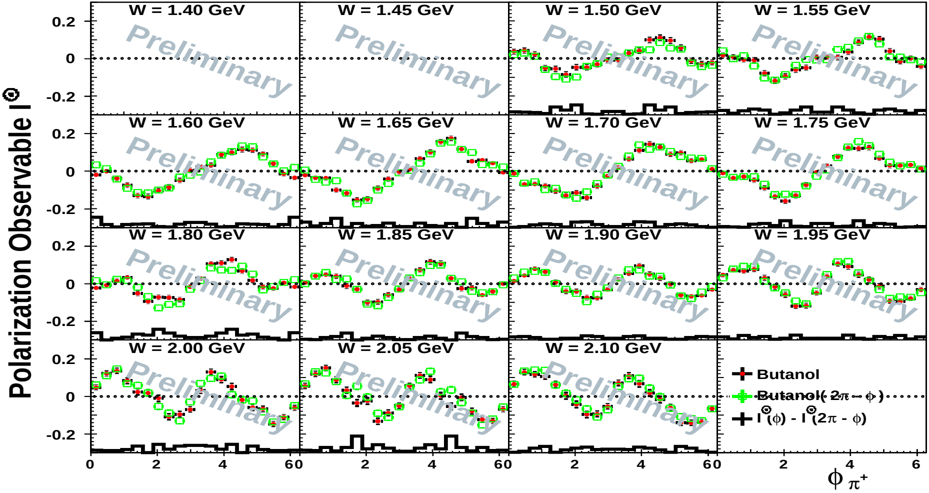


- Fitting function : gaussian + chebyshev pol.

- Butanol data are composed of
  - free-proton data
  - bound-nucleon data & background data
- After applying CL-cut, there are still bound-nucleon and background events.
- These bound-nucleon and background events have a small influence on the beam asymmetry.

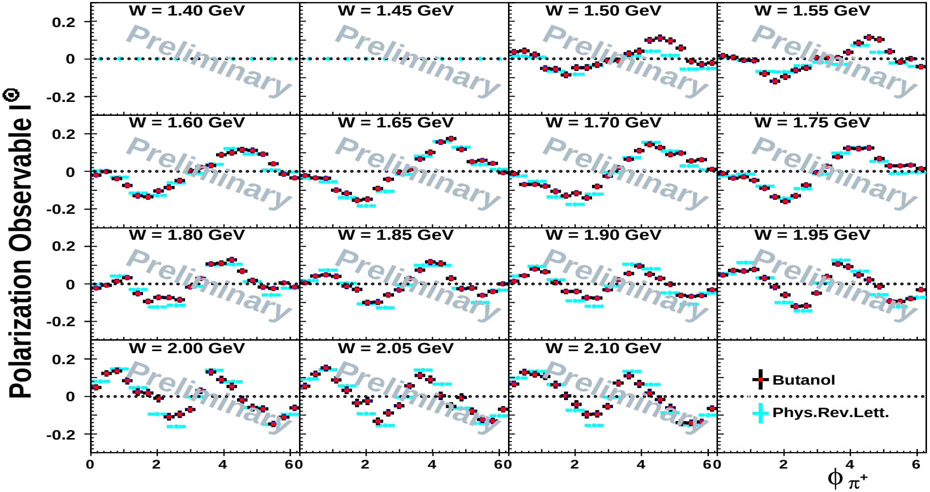
Check the symmetry of polarization observable $I^{\odot}$

- Kinematic variables $\theta_{\mathrm{c.m.}}, \theta_{\pi^+}, M_{\pi^+\pi^-}$ are integrated over.
- Butanol($2\pi - \phi$) : $-I^{\odot}(2\pi - \phi)$



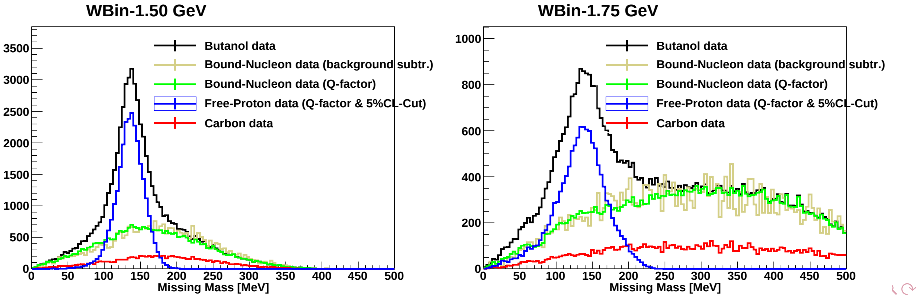
Beam-Helicity Asymmetry $I^{\odot}$ with the published data

- $I^{\odot}$: Phys.Rev.Lett. 95, 162003 (2005, CLAS Collaboration)



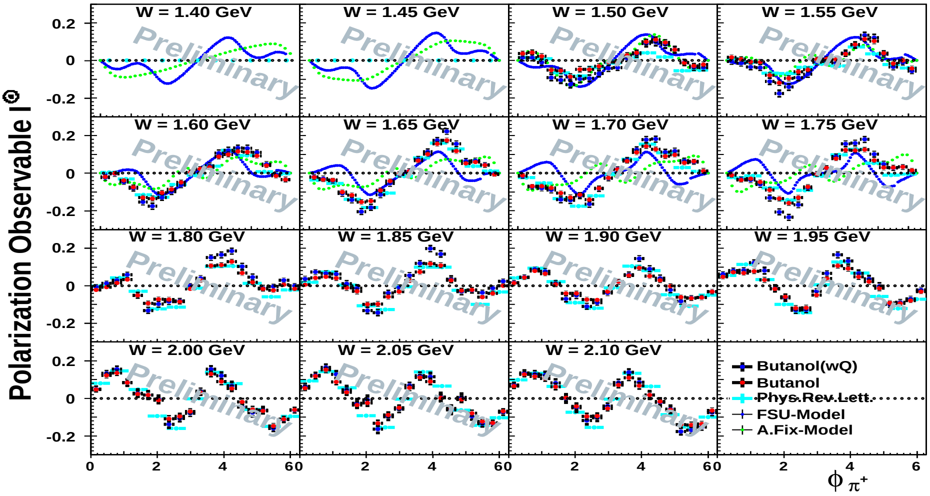
Q-factor method

- The Q-factor method is used to subtract background (developed at CMU, arXiv:0804.3382v1) :
  - The Q-factor is an event-based quality factor which describes the ratio of hydrogen signal to butanol signal, i.e. an event-based dilution factor.
- From the butanol (C_4H_9OH) data, the free proton data is extracted on an event-by-event basis. No overall dilution factor is necessary.
- A comparison between an event-based method and the method for overall background subtraction



Beam-Helicity Asymmetry $I^{\odot}$ with models

- FSU-model calculated by Winston Roberts
- A.Fix-model calculated by Alexander Fix (Eur. Phys. J. A 25, 115-135, 2005)

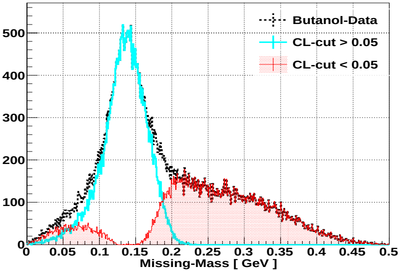


Polarization observable $\mathbf{P_z}$

Polarization observable P_z

$$\mathbf{P_z}(\mathbf{W},\ \phi_{\pi^+}) = \frac{1}{\overline{\Lambda}_z(\mathbf{W})} \frac{\left\{ N(\Rightarrow; \mathbf{W}, \phi_{\pi^+})_{target} - N(\Leftarrow; \mathbf{W}, \phi_{\pi^+})_{target} \right\}}{\left\{ N(\Rightarrow; \mathbf{W}, \phi_{\pi^+})_{target} + N(\Leftarrow; \mathbf{W}, \phi_{\pi^+})_{target} \right\}}$$

- $\overline{\Lambda}_z(\mathbf{W})$: The average of the degree of the target polarizations
- $\Rightarrow$ ($\Leftarrow$) : the direction of the target polarization is parallel (anti-parallel) to the beam.
- Target asymmetry for the linearly-polarized target and unpolarized photon beam

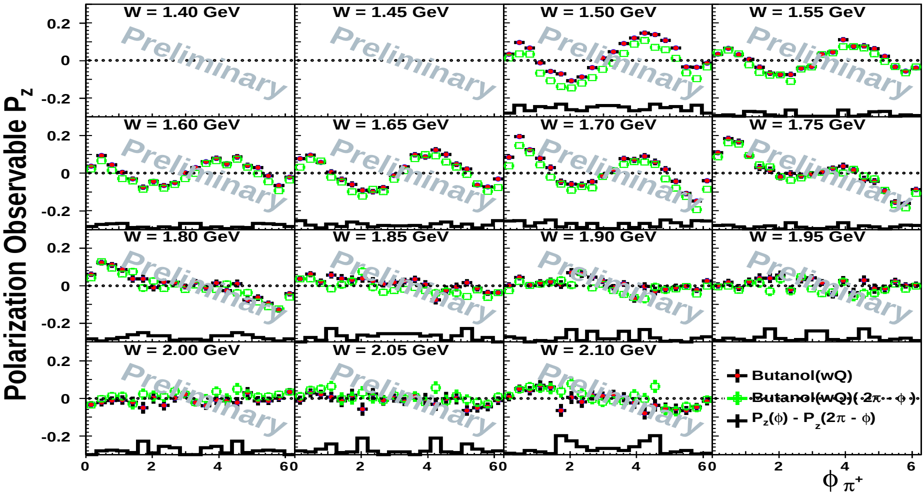


example :

- Topology : $\gamma p \rightarrow p\pi^+(\pi^-)$
- W : 1.60 GeV
- $\theta_{\mathrm{c.m.}}$, ϕ_{π^+}, θ_{π^+}, $M_{\pi^+\pi^-}$ are integrated over.
- Using the 5 % Confidence Level Cut & Q-factor method

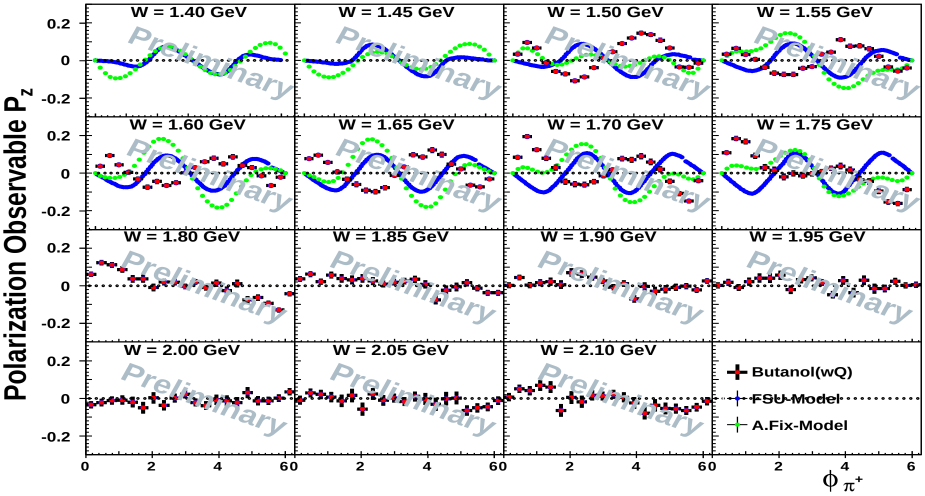
Check the symmetry of polarization observable P_z

- Kinematic variables $\theta_{\mathrm{c.m.}}, \theta_{\pi^+}, M_{\pi^+\pi^-}$ are integrated over.
- Butanol(wQ)($2\pi - \phi$) : $-P_z(2\pi - \phi)$



Target Asymmetry P_z with models

- FSU-model calculated by Winston Roberts
- A.Fix-model calculated by Alexander Fix (Eur. Phys. J. A 25, 115-135, 2005)

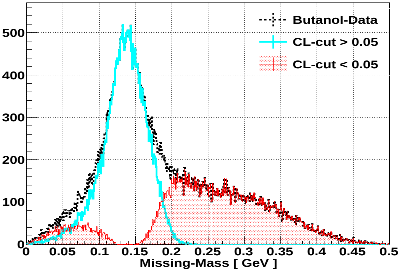


Polarization observable $\mathbf{P_z^{\odot}}$

Polarization observable $P_z^{\odot}$

$$P_z^{\odot}(\mathbf{W},\ \phi_{\pi^+}) = \frac{1}{\overline{\Lambda}_z(\mathbf{W})\cdot\overline{\delta}_{\odot}} \frac{\left\{N(\mathbf{W},\phi_{\pi^+})_{3/2} - N(\mathbf{W},\phi_{\pi^+})_{1/2}\right\}}{\left\{N(\mathbf{W},\phi_{\pi^+})_{3/2} + N(\mathbf{W},\phi_{\pi^+})_{1/2}\right\}}$$

- $\overline{\Lambda}_z(\mathbf{W})$: The average of the degree of the target polarizations
- $\overline{\delta}_{\odot}(\mathbf{W})$: The average of the degree of the photon beam polarizations
- Helicity Difference for the linearly-polarized target and circularly-polarized photon beam

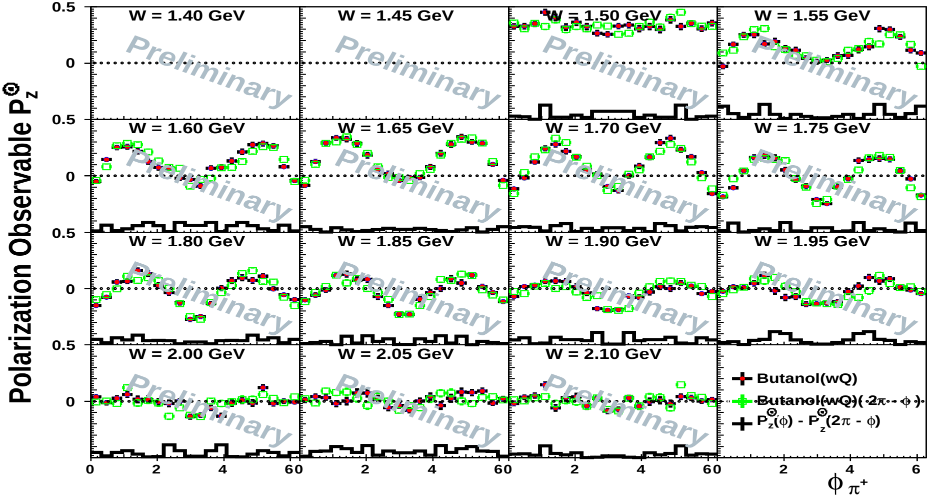


example :

- Topology : $\gamma p \rightarrow p\pi^+(\pi^-)$
- W : 1.60 GeV
- $\theta_{\rm c.m.}$, ϕ_{π^+}, θ_{π^+}, $M_{\pi^+\pi^-}$ are integrated over.
- **Using the 5 % Confidence Level Cut & Q-factor method**

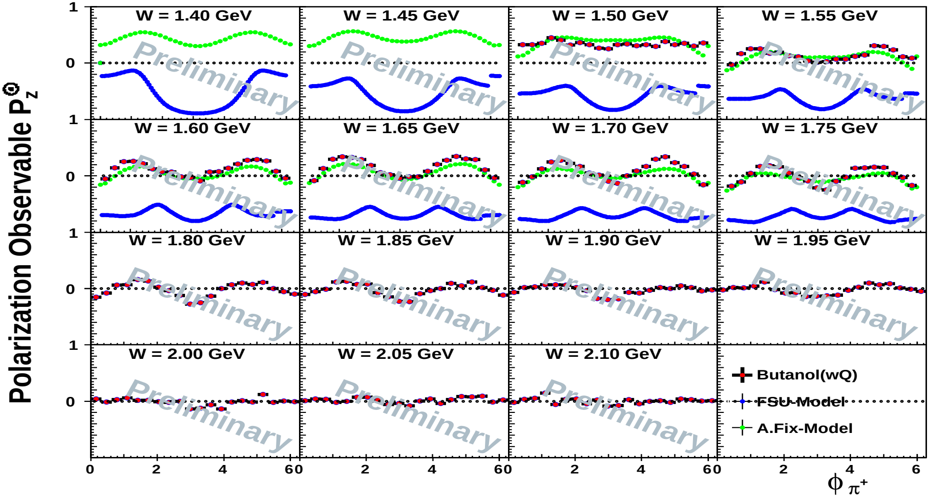
Check the symmetry of polarization observable $P_z^{\odot}$

- Kinematic variables $\theta_{\text{c.m.}}$, θ_{π^+}, $M_{\pi^+\pi^-}$ are integrated over.
- Butanol(wQ)($2\pi - \phi$) : $P_z^{\odot}(2\pi - \phi)$



Helicity Difference $P_z^{\odot}$

- FSU-model calculated by Winston Roberts
- A.Fix-model calculated by Alexander Fix (Eur. Phys. J. A 25, 115-135, 2005)



Summary

◇ Polarization Observable $\mathbf{I}^{\odot}$ using the FROST data is in good agreement with the previously published CLAS data.

- The CLAS-analysis note for Observable $\mathbf{I}^{\odot}$ will be prepared (95 %)
- The systematic errors used for Observable $\mathbf{I}^{\odot}$

Contribution	$\Delta I^{\odot}$	$\Delta I^{\odot}/I^{\odot}$
Circular polarization of photon beam		< 1.8 %
Target polarization		< 4.33 %
Electron beam-charge asymmetry	< 0.004	

◇ Polarization Observables $\mathbf{P_z}$ and $\mathbf{P_z^{\odot}}$ will be first-time measurements for double-pion photoproduction.

◇ The event-based dilution factor can separate the background from the butanol data efficiently.

Back up

Polarization observable $\mathbf{I}^{\odot}$

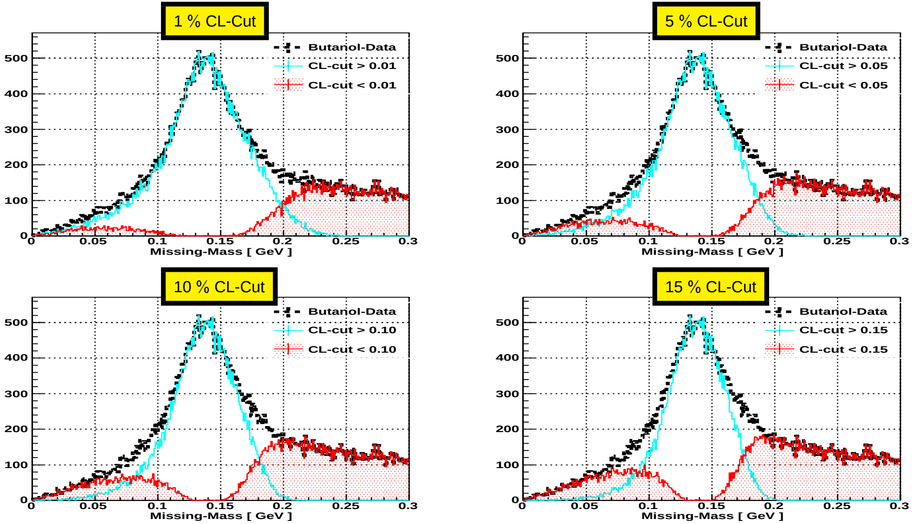
$$\mathbf{I}^{\odot}(\mathbf{W},\ \phi_{\pi^+}) = \frac{1}{\bar{\delta}_{\odot}(\mathbf{W})} \frac{\left\{ N(\rightarrow; \mathbf{W}, \phi_{\pi^+})_{beam} - N(\leftarrow; \mathbf{W}, \phi_{\pi^+})_{beam} \right\}}{\left\{ N(\rightarrow; \mathbf{W}, \phi_{\pi^+})_{beam} + N(\leftarrow; \mathbf{W}, \phi_{\pi^+})_{beam} \right\}}$$

- $\bar{\delta}_{\odot}(\mathbf{W})$: The average of the degree of the photon beam polarizations
- Λ_z : The degree of the target polarizations
- F : The photon flux (Normalization factor between periods)
- $\rightarrow$ ($\leftarrow$) : the direction of the beam polarization is parallel (anti-parallel) to the beam.
- $\Rightarrow$ ($\Leftarrow$) : the direction of the target polarization is parallel (anti-parallel) to the beam.
- Using the dataset with the unpolarized target and circularly-polarized beam

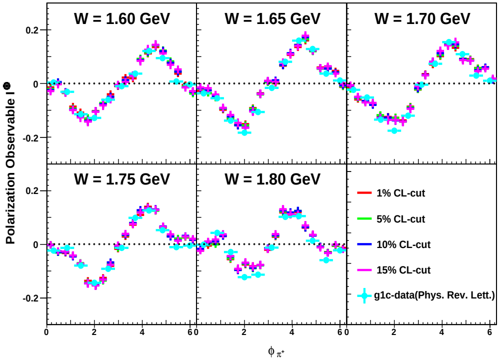
$$N(\rightarrow;\ \mathbf{W},\ \phi_{\pi^+})_{beam} = \frac{N(\rightarrow\Rightarrow; \mathbf{W}, \phi_{\pi^+})_{butanol}}{\Lambda_z(\Rightarrow)\cdot F(\Rightarrow)} + \frac{N(\rightarrow\Leftarrow; \mathbf{W}, \phi_{\pi^+})_{butanol}}{\Lambda_z(\Leftarrow)\cdot F(\Leftarrow)}$$

$$N(\leftarrow;\ \mathbf{W},\ \phi_{\pi^+})_{beam} = \frac{N(\leftarrow\Rightarrow; \mathbf{W}, \phi_{\pi^+})_{butanol}}{\Lambda_z(\Rightarrow)\cdot F(\Rightarrow)} + \frac{N(\leftarrow\Leftarrow; \mathbf{W}, \phi_{\pi^+})_{butanol}}{\Lambda_z(\Leftarrow)\cdot F(\Leftarrow)}$$

Missing mass distribution in several CL-cuts.



The background effect in Beam-Helicity Asymmetry $I^{\odot}$



- The different CL-cuts have the different background effect. However, they have the similar values in the observable $I^{\odot}$.
- g9a dataset is not sensitive to distinguish between the beam asymmetry from free-proton, bound-nucleon and background data.