Measurement of polarization observables in $\vec{\gamma}\vec{p} \rightarrow p\pi^{+}\pi^{-}$ with CLAS spectrometer at JLab

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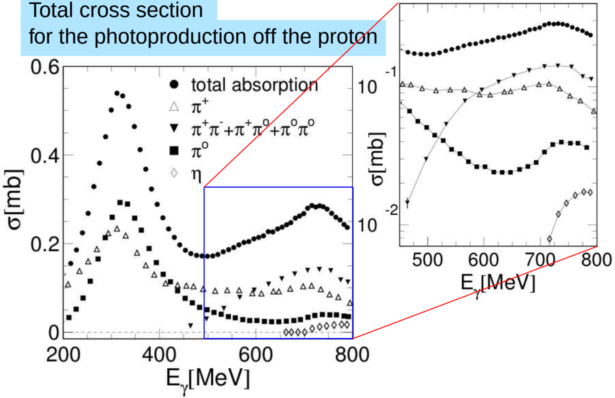
Outline

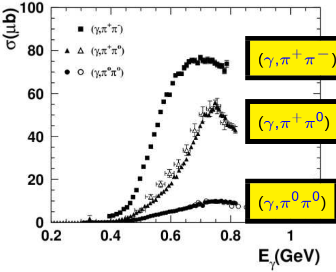
1. Introduction
   - Why is $\pi^+\pi^-$ photoproduction needed
2. FROST Experiment
   - The FROzen-Spin Target (FROST)
3. Data Analysis
   - Polarization Observables
   - Basic event selection
4. The Preliminary Results
   - Polarization Observable $\mathbf{I}^{\odot}$
   - Polarization Observable $\mathbf{P_z}$
   - Polarization Observable $\mathbf{P_z^{\odot}}$

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

Total cross section
for the photoproduction off the proton



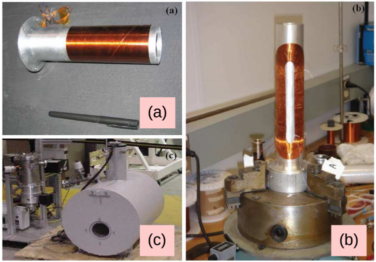
Total cross section
of π π production off the proton



- Search for new baryon states that are predicted by quark models decaying to $\Delta\pi$ and p ρ.
- The most intense 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)



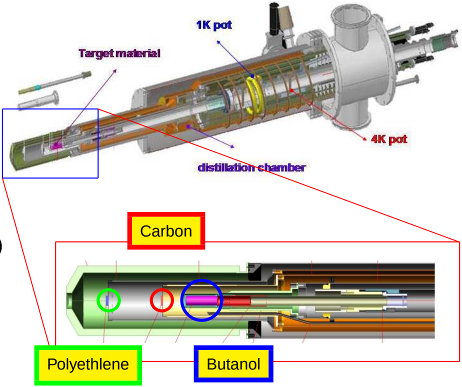
(a) The longitudinal holding magnet. (0.56 T) (g9a : Nov. 2007 - Feb. 2008)

(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)



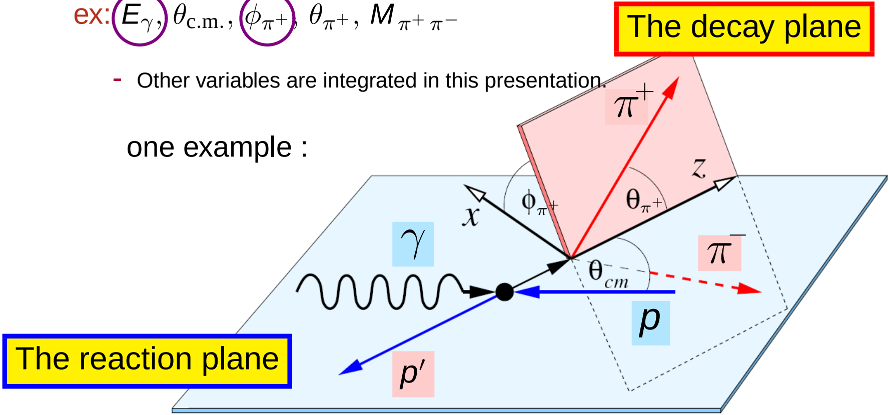
Photoproduction of $\pi^+\pi^-$ off the proton: Kinematics

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

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

- Other variables are integrated in this presentation.

one example :



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

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

(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
- $\delta_{\odot, l}$: 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

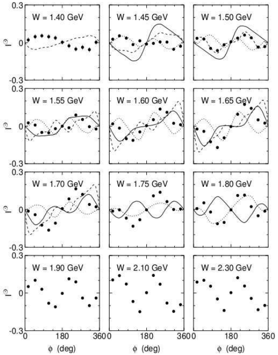
Polarization observables

The data used for this research :

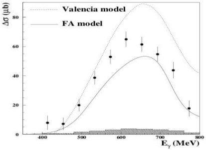
1. circularly-polarized beam
2. longitudinally-polarized target

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

- $\delta_\odot$ and $\vec{\Lambda}_z$: The degree of beam and target polarizaton
- $\mathbf{P}_z^\odot$, $\mathbf{P_z}$, and $\mathbf{I}^\odot$: The polarization observables



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

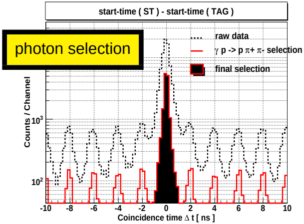


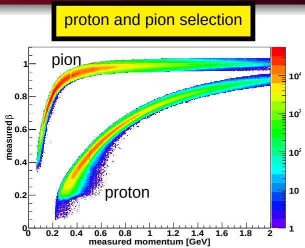
$\mathbf{P}_z^\odot$: Eur.Phys.J. A 34, 11-21 (2007, GDH Collaboration)

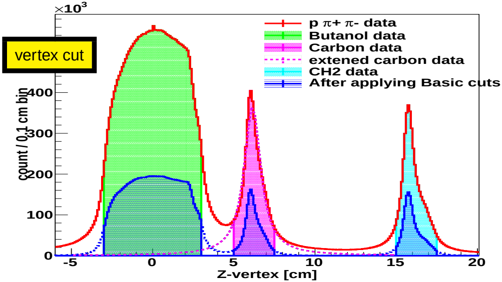
- The helicity-dependent total cross-section difference

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

Basic event selection



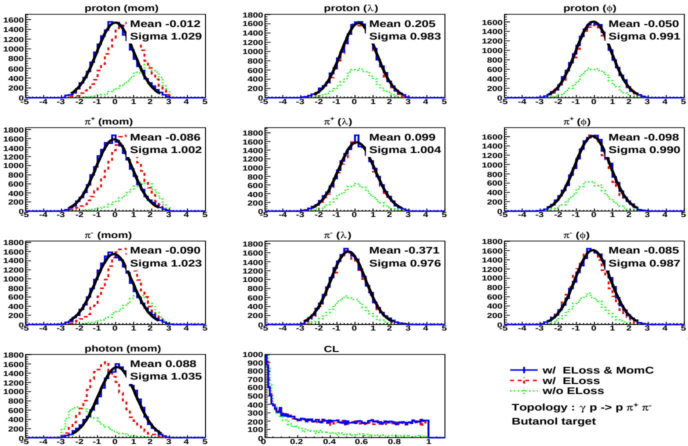




- Basic Cuts
  - photon selection
    : $|\ \Delta t_{TGPB}\ | < 1.2$ ns
  - proton selection
    : $|\ \beta_c\text{-}\beta_m\ | < 0.032$
  - pion selection
    : $|\ \beta_c\text{-}\beta_m\ | < 0.044$
  - vertex cut (Butanol)
    : $|\ Z_{MVRT}\ | < 3$ cm
  - accidental cut
    : ngrf = 1 & tagrid
  - cofidence-level cut
    : CL-cut $>$ 5 %

Basic event selection

- The kinematic fitting



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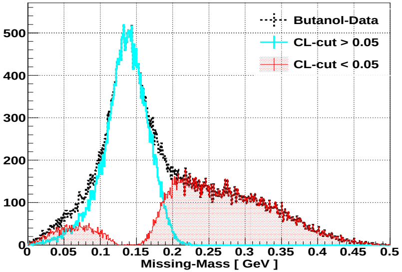
- Corrections
  - Energy-loss correction
  - Photon-beam correction
  - Momentum correction

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
- $\rightarrow (\leftarrow)$: the direction of the beam polarization is parallel (anti-parallel) to the beam.

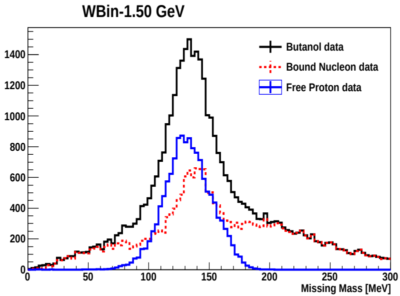


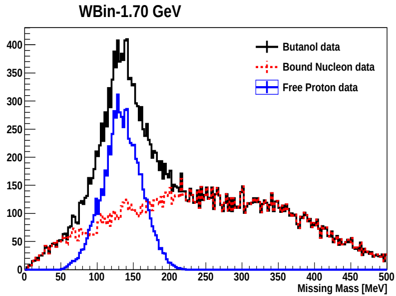
example :

- 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 % Coinfidence Level Cut

Polarization observable $I^{\odot}$ with Q-factor

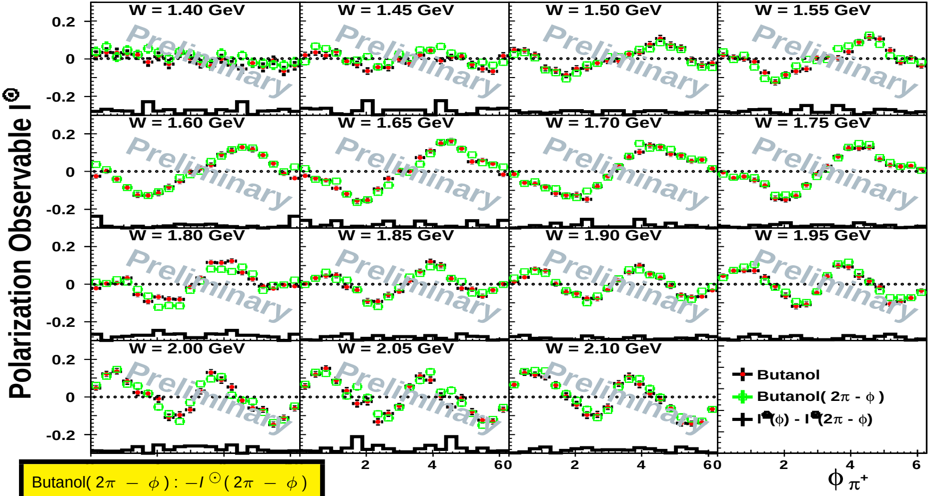
- The Q-factor method is used to subtract background (developed at CMU, arXiv:0804.3382v1) :
  - The Q-factor is an event-based quality factor which describes the ration of hydrogen signal to butanol signal, i.e. an event-based dilution factor.
- From the butanol (C_4H_9OH) data, the free proton data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





Beam-Helicity Asymmetry $I^{\odot}$ with the mirror image

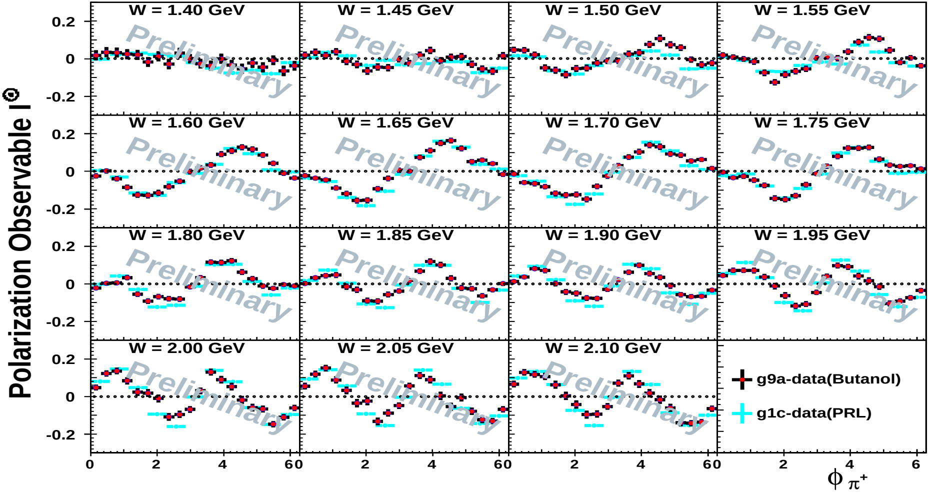
- Kinematic variables $\theta_{\text{c.m.}}, \theta_{\pi^+}, M_{\pi^+\pi^-}$ are integrated over.



Butanol($2\pi - \phi$) : $-I^{\odot}(2\pi - \phi)$

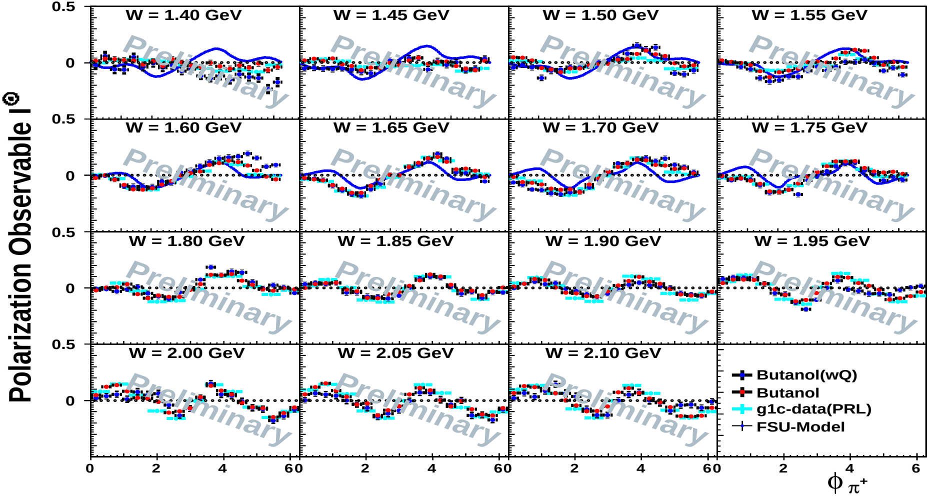
Beam-Helicity Asymmetry $I^{\odot}$ with the published data

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

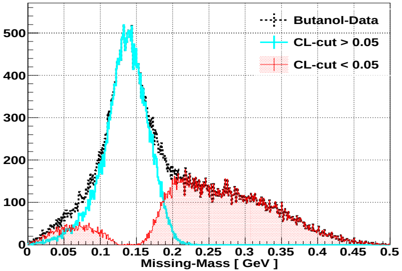


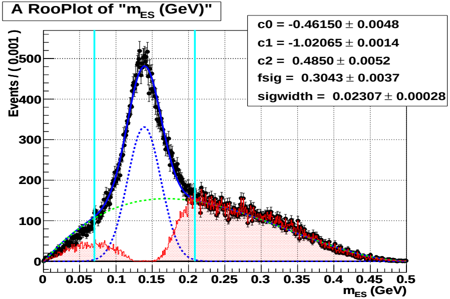
Beam-Helicity Asymmetry $\mathbf{I}^{\odot}$

- FSU-model calculation by Winston Roberts



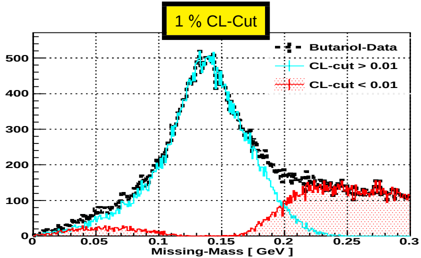
The background effect in Beam-Helicity Asymmetry I ☉

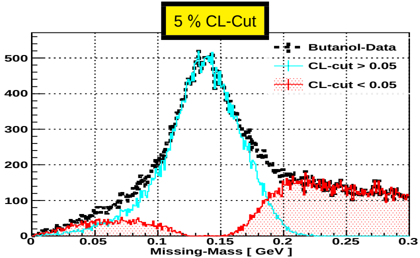


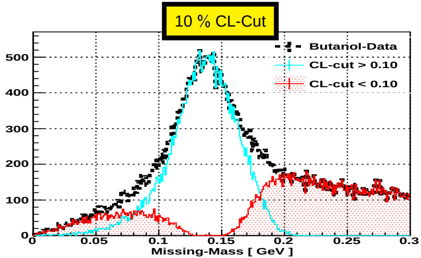


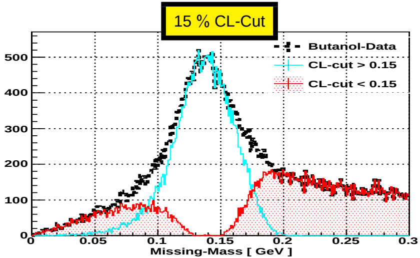
- Butanol data are composed of
  - free-proton data
  - bound-nucleon data & background data
- Fitting function : gaussian + Chebycheby
- g9a dataset is not sensitive to distinguish between the beam asymmetry from free-proton, bound-nucleon and background data.

Missing mass distribution in several CL-cuts.

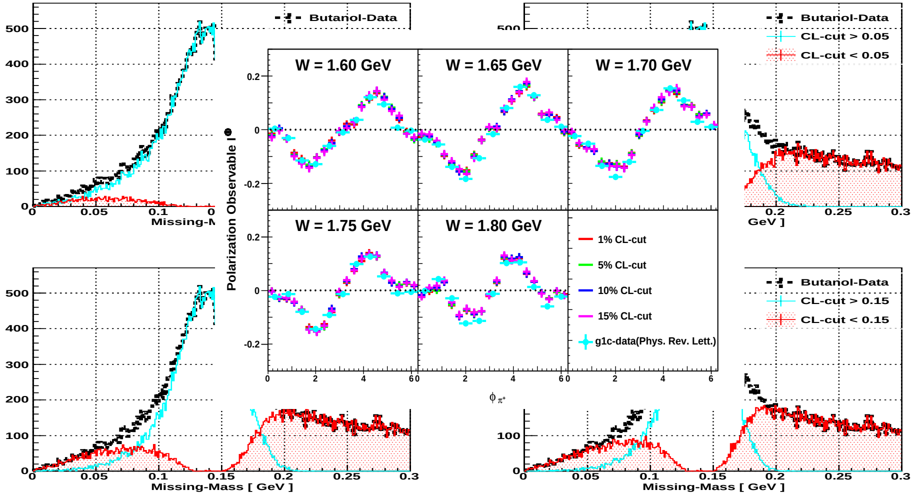






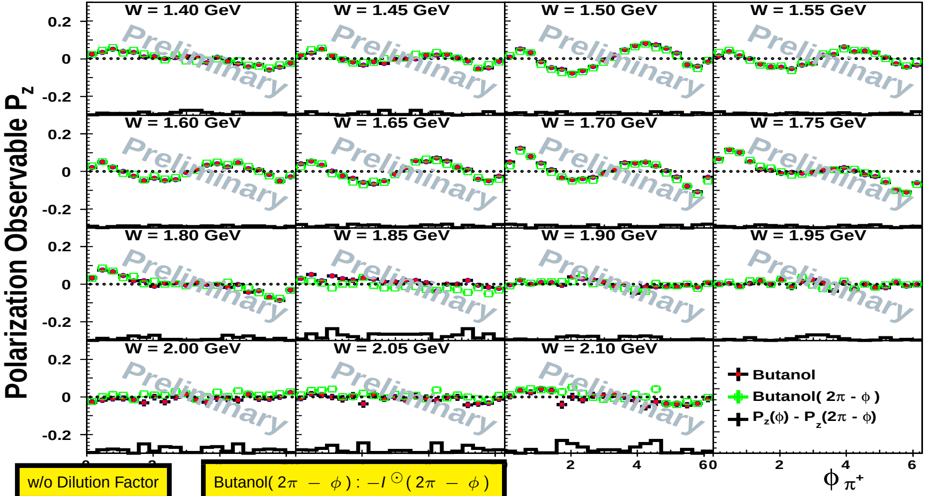


Polarization observable I$^{\odot}$ in several CLcuts.



Target Asymmetry P_z with the mirror image

- Kinematic variables $\theta_{\rm c.m.}$, θ_{π^+}, $M_{\pi^+\pi^-}$ are integrated over.

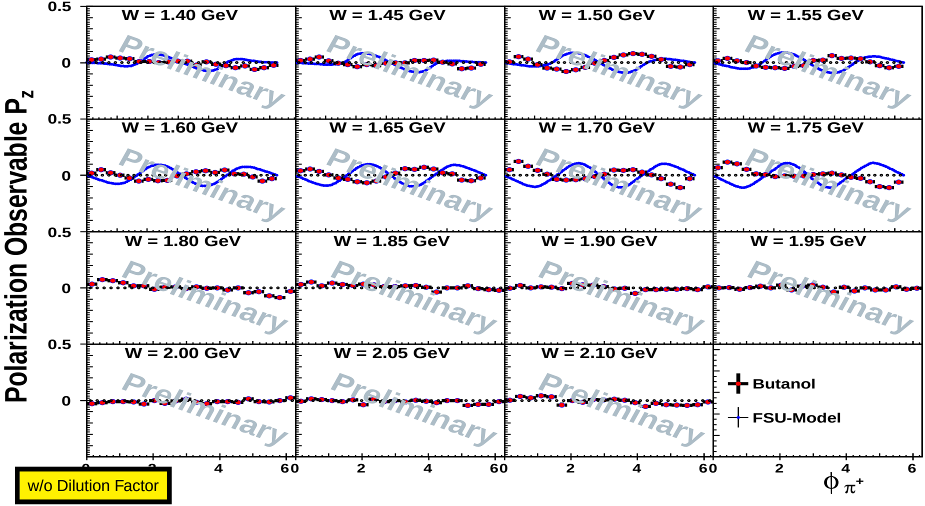


w/o Dilution Factor

Butanol($2\pi - \phi$) : $-I^{\odot}(2\pi - \phi)$

Target Asymmetry P_z

- FSU-model calculation by Winston Roberts



w/o Dilution Factor

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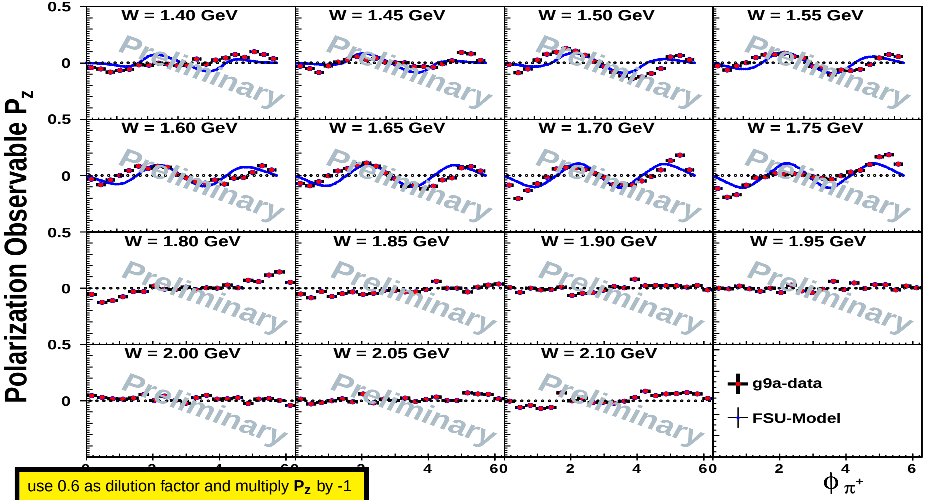
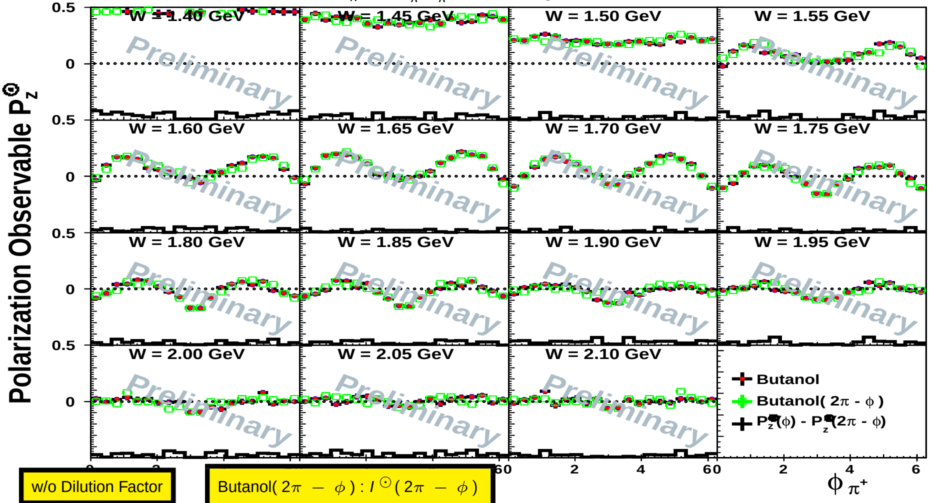


use 0.6 as dilution factor and multiply P_z by -1

Helicity Difference $P_z^{\odot}$ with the mirror image

- Kinematic variables $\theta_{\text{c.m.}}$, θ_{π^+}, $M_{\pi^+\pi^-}$ are integrated over.



w/o Dilution Factor

Butanol$(2\pi - \phi) : I^{\odot}(2\pi - \phi)$

Helicity Difference $P_z^{\odot}$

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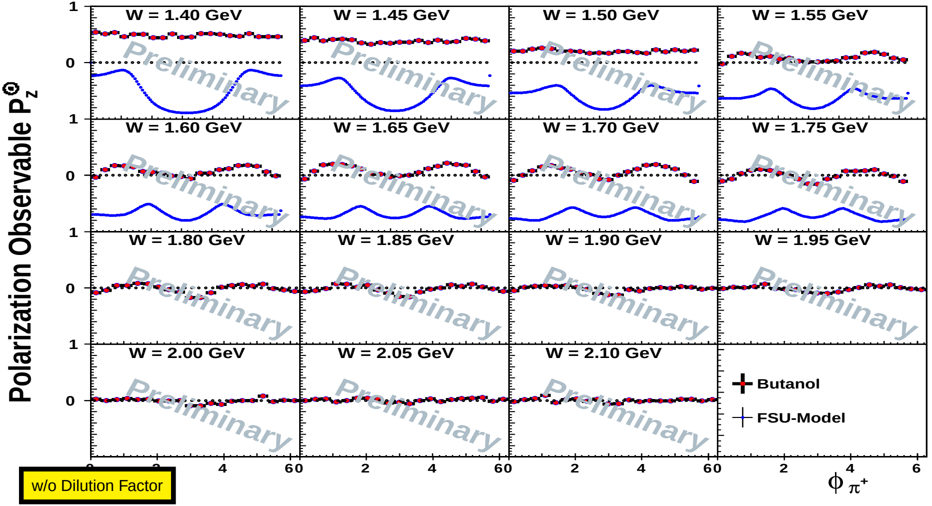

w/o Dilution Factor

Helicity Difference $P_z^{\odot}$

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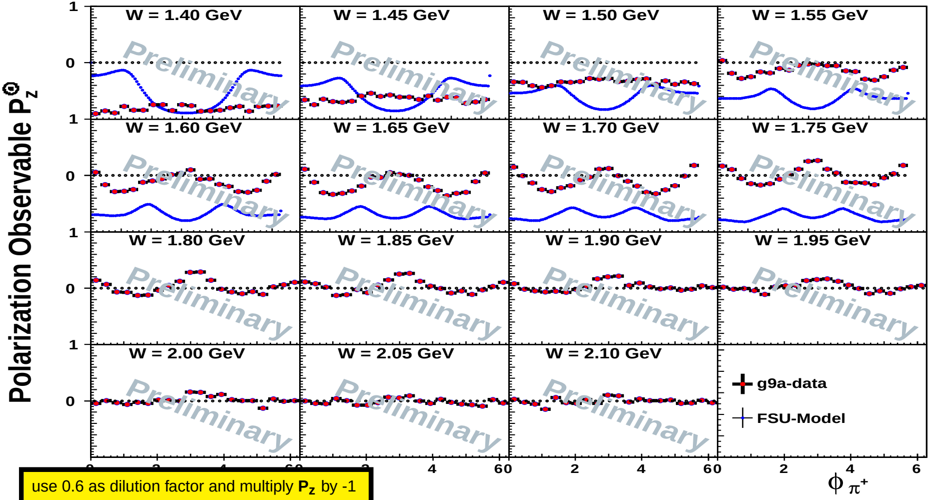
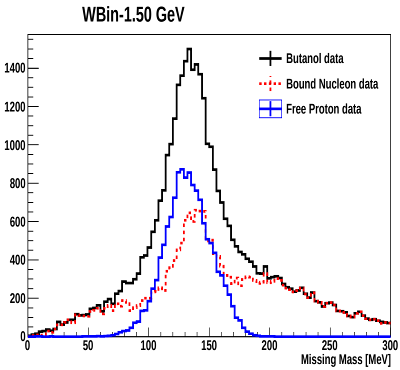
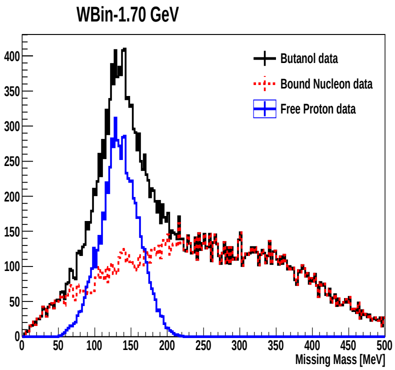


use 0.6 as dilution factor and multiply P_z by -1

What is the next step for Q-factor method

- There is a hydrogen contamination problem in g9a carbon data
- Solution : use g9b carbon data for Q-factor method





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.
  - The proper carbon data need to be used in g9a analysis

I am looking for Postdoc job.