The beam asymmetry $\mathbf{I}^{\odot}$ in $\vec{\gamma}\vec{p} \to p\pi^+\pi^-$ with the CLAS spectrometer at the JLab (To journey the excited states of nucleon)

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Outline

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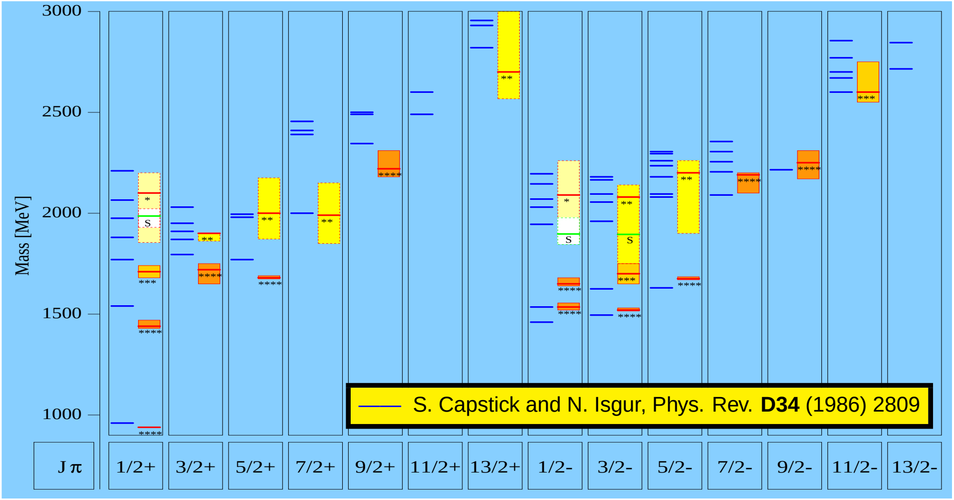
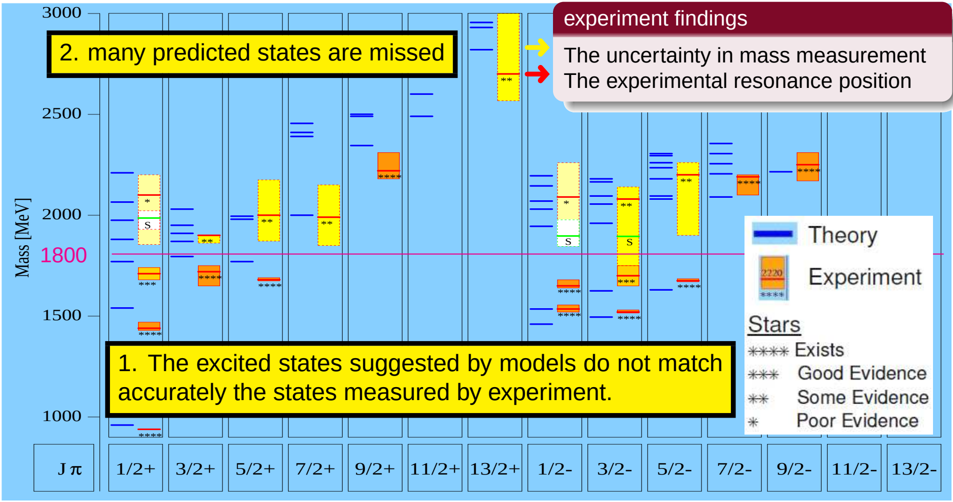
The excited states of the nucleon

Constituent quark models: Gluon-exchange model



The excited states of the nucleon

Constituent quark models: N^* resonances (Isospin $\frac{1}{2}$)



2. many predicted states are missed

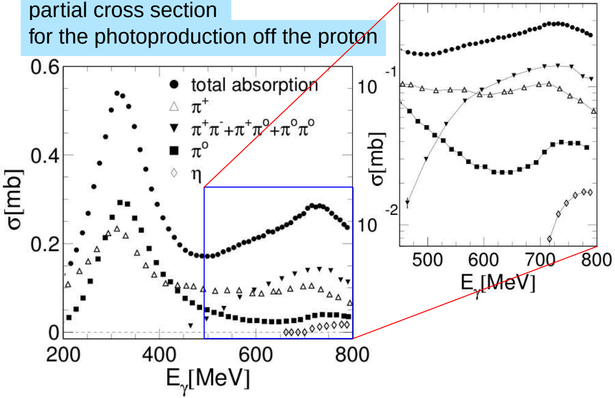
experiment findings

The uncertainty in mass measurement
The experimental resonance position

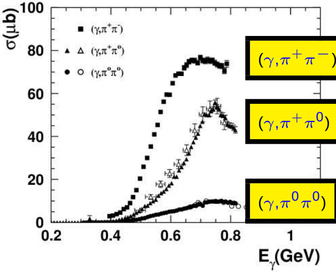
1. The excited states suggested by models do not match accurately the states measured by experiment.

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

partial cross section
for the photoproduction off the proton

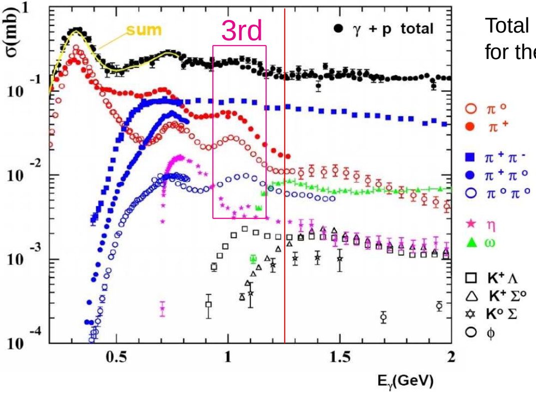


Total cross section
of π π production off the proton

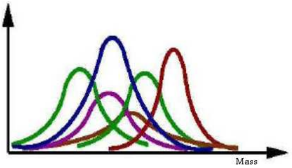


- The total cross section is decomposed into the contributions from the partial channels
- The most intense cross section contribution is from double pion production in the second resonance region
- The $\pi^+\pi^-$ photoproduction occupies the biggest potion of the double pion cross section

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



Total cross section
for the photoproduction off the proton



- The $\pi^+\pi^-$ photoproduction in the third resonance region is the main channel.
- the cross section of the $\pi^+\pi^-$ photoproduction dominates above W $\approx$ 1.8GeV
- The excited states are found as broadly overlapping resonances

$\rightarrow$ The polarization observables can isolate single resonances from other interference terms

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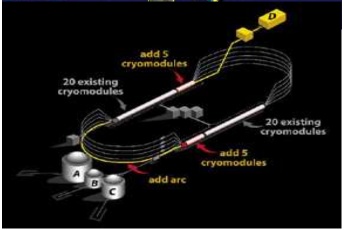
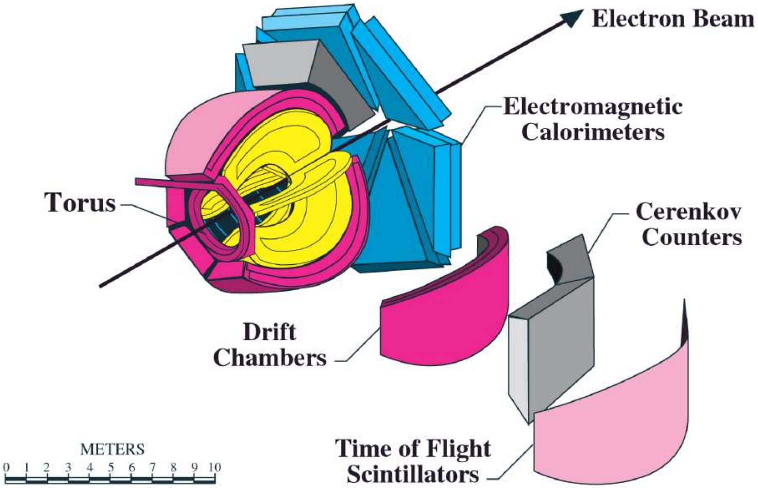
   - CEBAF Large Acceptance Spectrometer (CLAS)
   - The tagging system at CLAS
   - The FROzen-Spin Target (FROST)
3. Data analysis
   - Polarization Observable
   - The Q-factor method
   - Normalization Factor
4. The Preliminary results

Jefferson Laboratory in Newport News, VA



The continuous electron beam accelerator facility (CEBAF) can deliver a continuous electron beam up to 6 GeV.

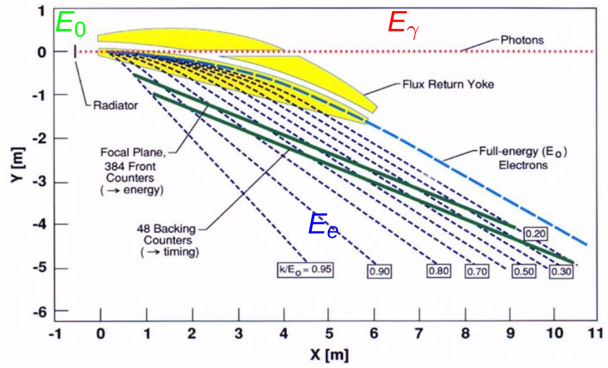
CEBAF Large Acceptance Spectrometer (CLAS)

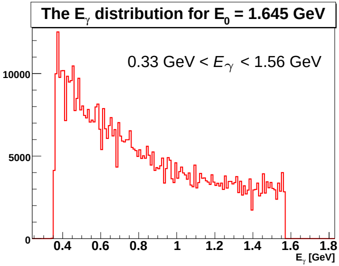


The tagging system at CLAS

JLAB Hall B bremsstrahlung photon tagger

- E_γ = 20-95 % of E_0
- E_γ up to $\sim$5.5 GeV





$$E_\gamma = E_0 - E_e$$

E_γ: The energy of the emitted photon

E_0: The energy of the incident electron

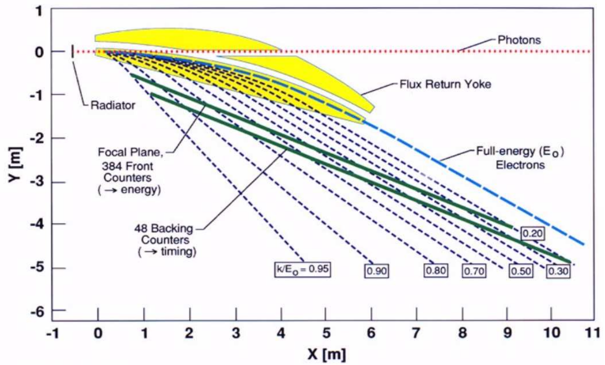
E_e: the energy of the outgoing electron

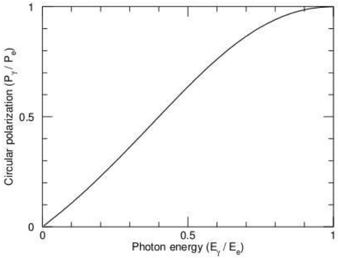
The tagging system at CLAS

JLAB Hall B bremsstrahlung photon tagger

- Circular polarized photon beam

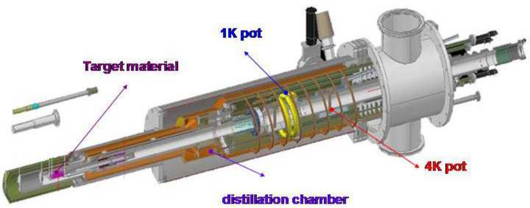
amorphous radiator | longitudinally polarized electron beam



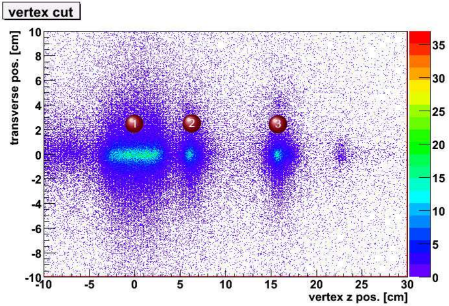


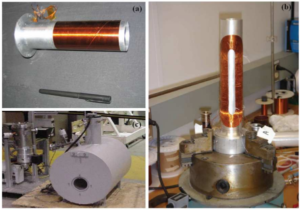
$$\frac{P_\gamma}{P_e} = \frac{4\cdot(\frac{E_\gamma}{E_e}) - (\frac{E_\gamma}{e_\gamma})^2}{4 - 4\cdot(\frac{E_\gamma}{E_e}) + 3\cdot(\frac{E_\gamma}{E_e})^2}$$

The FROzen-Spin Target (FROST)



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





The magnets in the FROST experiment

(a) The longitudinal holding magnet. (About 0.5 T)

(b) The transversal holding magnet. (March 2010 - August 2010)

(c) The polarizing magnet. (5 Tesla solenoid)

1. Polarized Butanol (C_4H_9OH) (L = 5.0 cm, ϕ = 1.5 cm) $\sim$ 5 g
2. Carbon (^{12}C) (L = 0.15 cm) (6 cm from CLAS center)
3. Polyethylene (CH_2) (L = 0.35 cm) (16 cm from CLAS center)

L: The length and ϕ: The diameter

The FROST-g9a run Data

The FROST run period: Nov. 3, 2007 - Feb. 12, 2008

Data set: 35 TBytes

10.5 Billion events

Production data

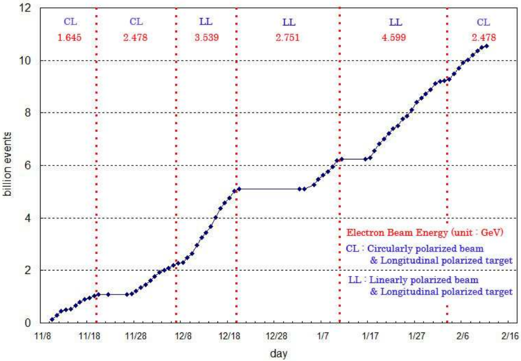
Target:

- Longitudinal polarized target
- Average target polarization
  ∼ 82 % (+Pol) and 85 % (-Pol)

Photon beam:

- Circularly and linearly polarized photon beam
  0.5 - 4.5 GeV
- Electron beam polarization ∼ 85 %

Trigger: - at least one charged particle in CLAS



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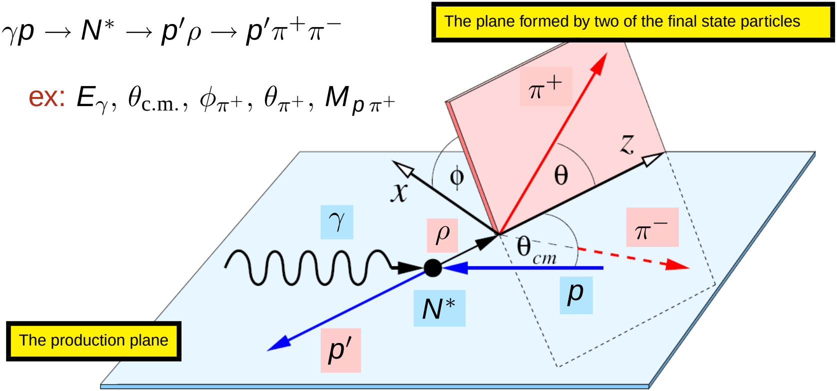
Photoproduction of $\pi^+\pi^-$ off the proton: Kinematics

- The $\pi^+ \pi^-$ photoproduction require 5 independent variables.
- One example channel for the double pion photoproduction :

$$\gamma p \rightarrow N^* \rightarrow p' \rho \rightarrow p' \pi^+ \pi^-$$

ex: $E_\gamma, \theta_{\mathrm{c.m.}}, \phi_{\pi^+}, \theta_{\pi^+}, M_{p\pi^+}$



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

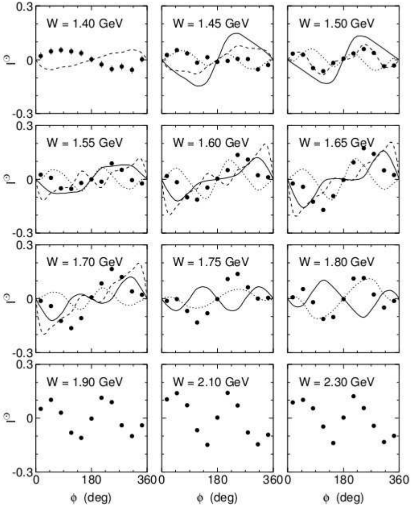
Polarization observables

The data used for this research :

1. The circularly-polarized beam
   $\rightarrow \delta_l = 0$
2. The longitudinally-polarized target
   $\rightarrow \Lambda_x = \Lambda_y = 0$

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

3 Observables



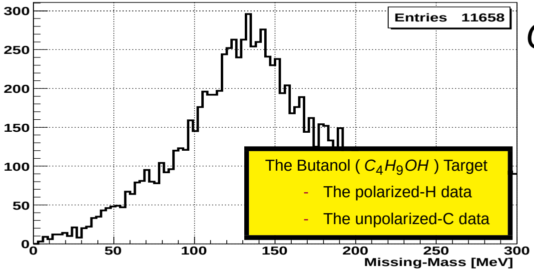
$\mathbf{I}^\odot$ only is published and small and sensitive

- P.R.L. 95, 162003 (2005)

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

$$\mathbf{I}^{\odot}(\mathbf{W},\ \theta^*,\ \phi^*) = \frac{1}{\bar{\delta}_{\odot}(E_\gamma)} \frac{\left\{ N(\rightarrow)_{beam} - N(\leftarrow)_{beam} \right\}}{\left\{ N(\rightarrow)_{beam} + N(\leftarrow)_{beam} \right\}}$$

- ◇ $\bar{\delta}_{\odot}(E_\gamma)$: The average of the beam polarizations
- ◇ $\rightarrow (\leftarrow)$: the direction of the beam polarization is parallel (anti-parallel) to the beam.



$$O_B = \frac{f_H \cdot O_H + f_C \cdot O_C}{f_H + f_C} = \frac{f_H}{f_H + f_C} \cdot O_H + \frac{f_C}{f_H + f_C} \cdot O_C$$

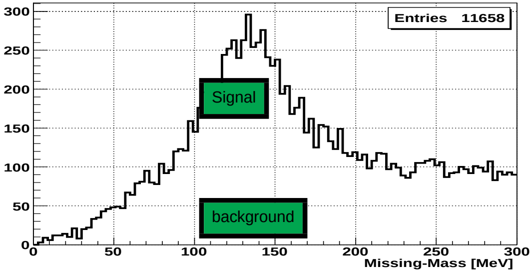
(Dilution Factor)

- O : Polarization Observable
- f_H : the ratio of hydrogen signal to butanol signal

The Q-factor method

- Any cut can not separate a signal from a non-interfering background

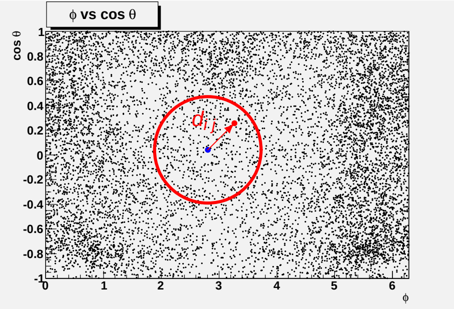
Q-factor method can do it. (supported by Andrew Wilson)



The Q-factor method

- Any cut can not separate a signal from a non-interfering background
- The Q-factor method is used to subtract background
  (developed at CMU, arXiv:0804.3382v1) :
  - The Q-factor is an event-based quality factor.

Step-1. The n_c nearest neighbor events per each event.



Using the kinematic variables, ϕ_{π^+} and θ_{π^+}

1. Find the distance btw any two events, d_{ij}
2. Select the n_c nearest neighbor events

The Q-factor method

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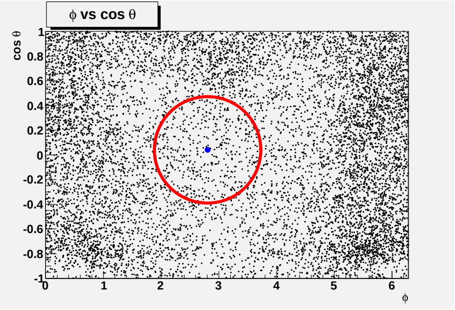
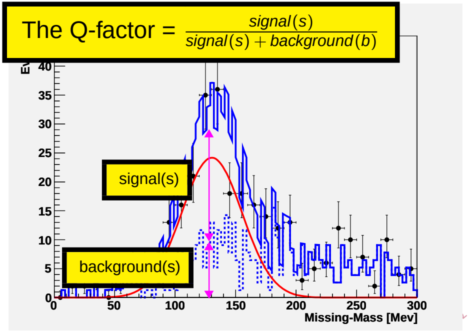
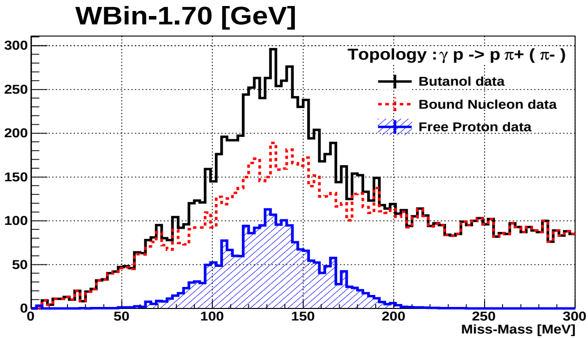


Step-2. The n_c events are fit

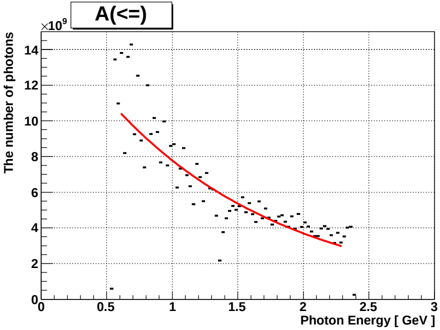


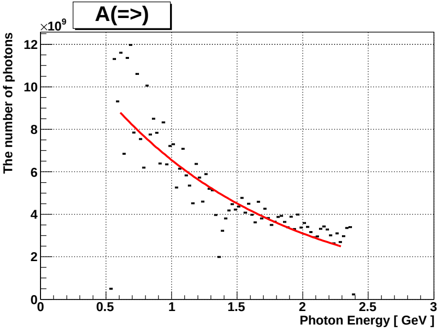
The Q-factor method

- The quasi-free proton data can be extracted from the butanol (C_4H_9OH) data on an event-by-event basis.
  - The Q-factor describes the ratio of hydrogen signal to butanol signal (an event-based dilution factor)
  - The background consists of bound carbon nucleons and other background.



Normalization Factor, $A(\Leftarrow)$ or $A(\Rightarrow)$

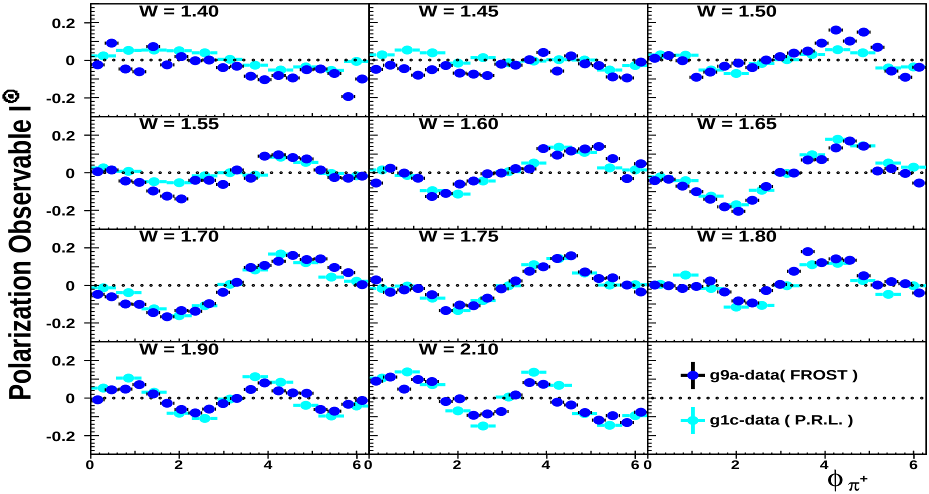




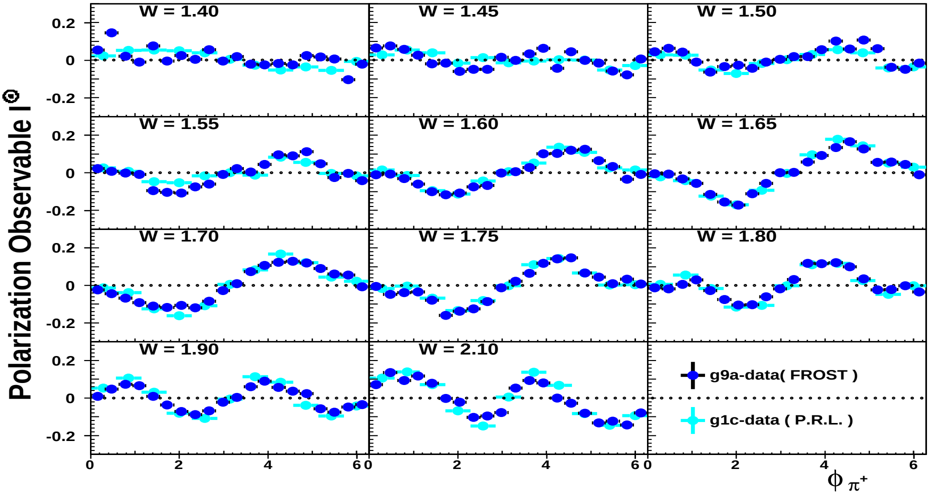
- 25-MeV-wide bins in the range from 0.4875 GeV 2.9875 GeV centers of bins
- Fitting function : par[0] · exp(par[1] · x)

Outline

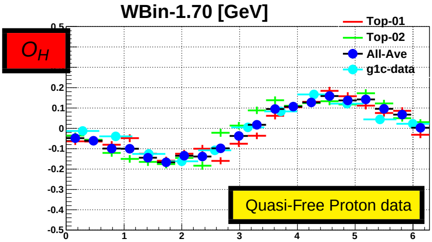
Beam asymmetry for $I^{\odot}$ in quasi-free proton data

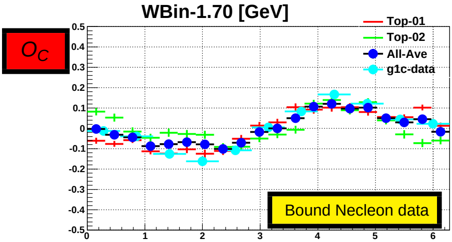


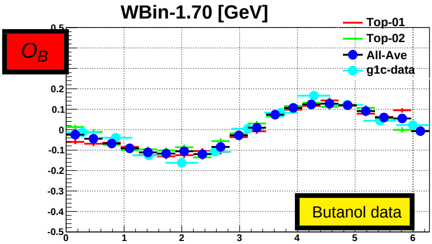
Beam asymmetry for $I^{\odot}$ in butanol data



Observables I$^{\odot}$ in the butanol and hydrogen data







If $O_H = O_C$, (If fermi motion effect is small)

$$O_B = \frac{f_H \cdot O_H + f_C \cdot O_C}{f_H + f_C} = \frac{f_H + f_C}{f_H + f_C} \cdot O_H = O_H$$

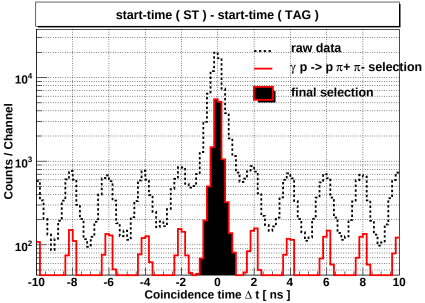
Summary

- Q-factor method can separate the background from the butanol data efficiently.
- Polarization Observable $\mathbf{I}^{\odot}$ made from the FROST and P.R.L. data have very similar shapes.
  - The results of Observable $\mathbf{I}^{\odot}$ would be presented at APS 2012 in Atlanta.
  - The analysis note would be published in JLab.
- Polarization observable $\mathbf{P_z^{\odot}}$ and $\mathbf{P_z^{\odot}}$ would be calculated from Q-factor method.

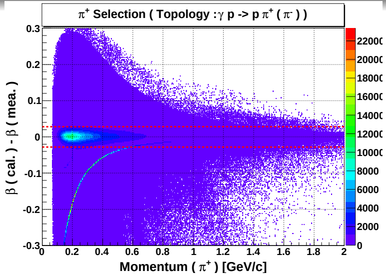
Particle identification for $\gamma p \rightarrow p\pi^+\pi^-$

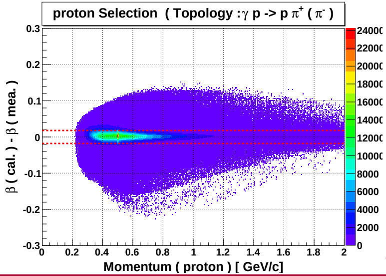
Back Up

Particle identification for $\gamma p \to p\pi^+\pi^-$



- Coincidence Time : $|\Delta t| < 1.2$ $[ns]$
- Particle identification
  - Proton : $|\Delta\beta| < 0.01882$
  - π^+ : $|\Delta\beta| < 0.0285$
  - π^- : $|\Delta\beta| < 0.0264$





The four different topologies of $\gamma p \rightarrow p\pi^+\pi^-$

- The topology : $\gamma p \rightarrow p\pi^+(\pi^-)$
- The topology : $\gamma p \rightarrow p\pi^-(\pi^+)$
- The topology : $\gamma p \rightarrow \pi^+\pi^-(p)$
- The topology : $\gamma p \rightarrow p\pi^+\pi^-$