Measurement of the Helicity Difference in $\gamma p \to p\pi^+\pi^-$ with CLAS Spectrometer at Jefferson Laboratory

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on behalf of CLAS collaboration

Florida State University

Conference of HADRON 2009
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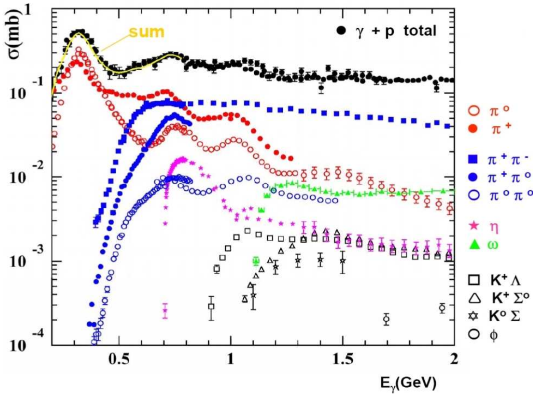
Outline

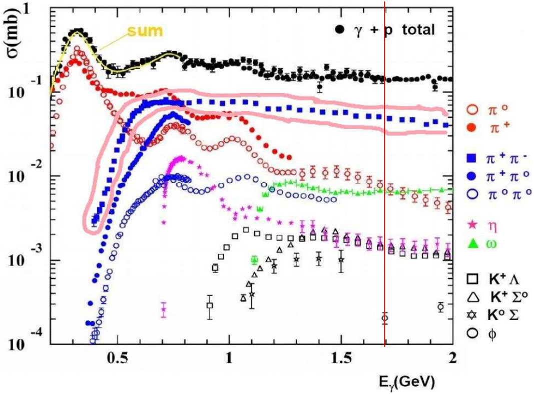
The motivation for the $\pi^+\pi^-$ photoproduction



The cross section of the $\pi^+\pi^-$ photoproduction

dominates above W $\approx$ 1.7GeV

The motivation for the $\pi^+\pi^-$ photoproduction



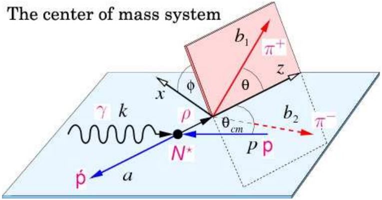
$\gamma p \to p\pi^+\pi^-$

The cross section of the $\pi^+\pi^-$ photoproduction

dominates above W $\approx$ 1.7GeV

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

The 3-particle final state for $\gamma p \rightarrow p\pi^+\pi^-$



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

ex) $\gamma p \rightarrow N^\star \rightarrow$ ṕ $\rho \rightarrow$ ṕ $\pi^+\pi^-$

ϕ^*, θ^*, W, θ_{cm}, and $MM_{\pi^+\pi^-}$

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

(without measuring the polarization of the recoiling nucleon)

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

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

The polarization observable

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

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- 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 $\Rightarrow (\Lambda_x, \Lambda_y, \Lambda_z)$
- $\mathbf{I}^{\odot,s,c}$: The observable arising from use of polarized photons $\Rightarrow \mathbf{I}^\odot, \mathbf{I}^s, \mathbf{I}^c$
- $\vec{\mathbf{P}}$: The polarization observable $\Rightarrow (\mathbf{P_x}, \mathbf{P_y}, \mathbf{P_z})$ $(\mathbf{P}_x^\odot, \mathbf{P}_y^\odot, \mathbf{P}_z^\odot)$ $(\mathbf{P}_x^s, \mathbf{P}_y^s, \mathbf{P}_z^s)$ $(\mathbf{P_x^c}, \mathbf{P_y^c}, \mathbf{P_z^c})$

The polarization observable

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(without measuring the polarization of the recoiling nucleon)

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

The circularly-polarized beam

The longitudinally-polarized target

The polarization observable

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

(without measuring the polarization of the recoiling nucleon)

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

The circularly-polarized beam $\rightarrow \delta_l = 0$

The longitudinally-polarized target

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

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The circularly-polarized beam $\to \delta_l = 0$

The longitudinally-polarized target $\to \Lambda_x = \Lambda_y = 0$

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

The polarization observable

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The circularly-polarized beam $\rightarrow \delta_l = 0$

The longitudinally-polarized target $\rightarrow \Lambda_x = \Lambda_y = 0$

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

The Observable $P_z^{\odot}$

$$P_z^{\odot} = \frac{1}{f \cdot \delta_{\odot} \cdot \Lambda_z} \left\{ \frac{\left(\frac{d\,\sigma(\rightarrow\Rightarrow)}{d\,\Omega} + \frac{d\,\sigma(\leftarrow\Leftarrow)}{d\,\Omega} \right) - \left(\frac{d\,\sigma(\rightarrow\Leftarrow)}{d\,\Omega} + \frac{d\,\sigma(\leftarrow\Rightarrow)}{d\,\Omega} \right)}{\left(\frac{d\,\sigma(\rightarrow\Rightarrow)}{d\,\Omega} + \frac{d\,\sigma(\leftarrow\Leftarrow)}{d\,\Omega} \right) + \left(\frac{d\,\sigma(\rightarrow\Leftarrow)}{d\,\Omega} + \frac{d\,\sigma(\leftarrow\Rightarrow)}{d\,\Omega} \right)} \right\}$$

- f - dilution factor
- $\delta_{\odot}$ - beam polarization
- Λ_z - target polarization
- $\rightarrow$ - the beam polarization direction (It is parallel to the beam)
- $\Rightarrow$ - the target polarization direction (It is parallel to the beam)

The Observable $P_z^{\odot}$

$$P_z^{\odot} = \frac{1}{f \cdot \delta_{\odot} \cdot \Lambda_z} \left\{ \frac{\overbrace{\left(\frac{d\sigma(\rightarrow\Rightarrow)}{d\Omega} + \frac{d\sigma(\leftarrow\Leftarrow)}{d\Omega} \right)}^{\frac{d\sigma_{3/2}}{d\Omega}} - \overbrace{\left(\frac{d\sigma(\rightarrow\Leftarrow)}{d\Omega} + \frac{d\sigma(\leftarrow\Rightarrow)}{d\Omega} \right)}^{\frac{d\sigma_{1/2}}{d\Omega}}}{\underbrace{\left(\frac{d\sigma(\rightarrow\Rightarrow)}{d\Omega} + \frac{d\sigma(\leftarrow\Leftarrow)}{d\Omega} \right)}_{\frac{d\sigma_{3/2}}{d\Omega}} + \underbrace{\left(\frac{d\sigma(\rightarrow\Leftarrow)}{d\Omega} + \frac{d\sigma(\leftarrow\Rightarrow)}{d\Omega} \right)}_{\frac{d\sigma_{1/2}}{d\Omega}}} \right\}$$

- f - dilution factor
- $\delta_{\odot}$ - beam polarization
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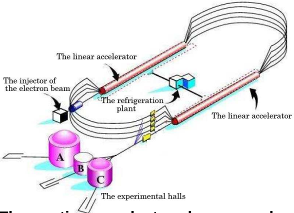
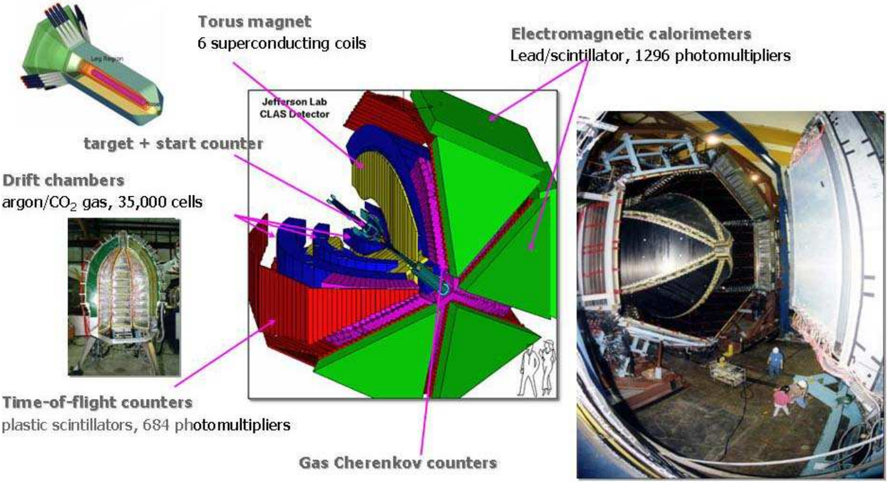
Jefferson Laboratory in Newport News, VA

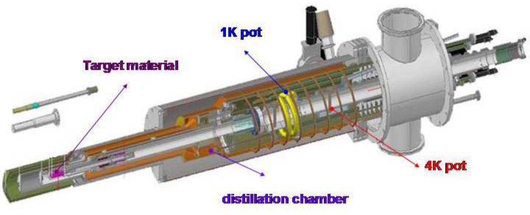


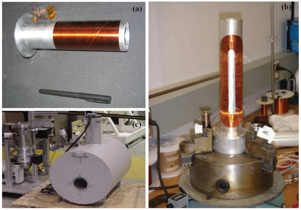
The continuous electron beam accelerator facility (CEBAF) can deliver a continuous electron beam up to 6 GeV.

CEBAF Large Acceptance Spectrometer (CLAS)



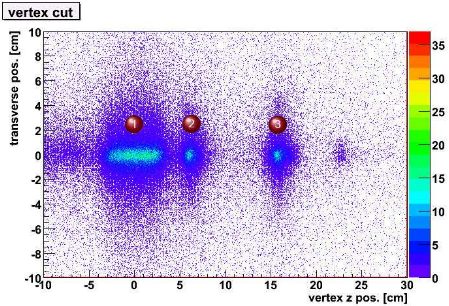
The Frozen-Spin Target (FROST)





The magnets in the FROST experiment

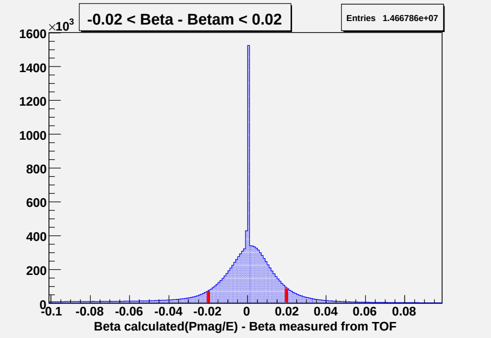
- (a) The longitudinal holding magnet. (About 0.5 T)
- (b) The transversal holding magnet. (Next experiment)
- (c) The polarizing magnet. (5 Tesla solenoid)

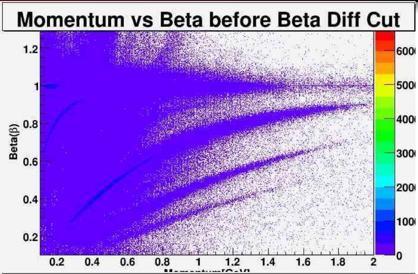


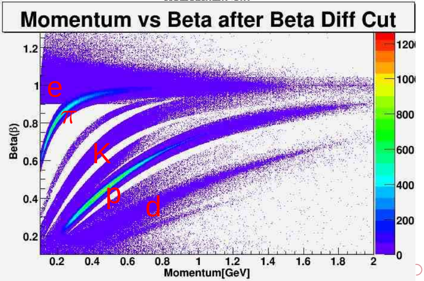
1. Polarized Butanol (C_4H_9OH) (L = 5.0 cm, ϕ = 1.5 cm) $\sim$ 5 g
2. Carbon (^{12}C) (L = 0.15 cm) (6 cm from CLAS center)
3. Polyethylene (CH_2) (L = 0.35 cm) (16 cm from CLAS center)

L: The length and ϕ: The diameter

The particle identification - The beta cut







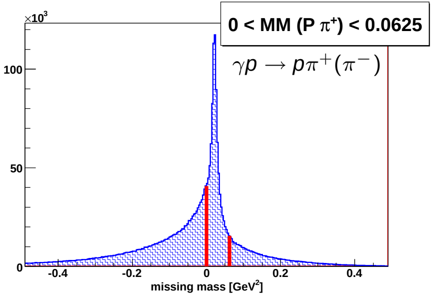
The beta cut =

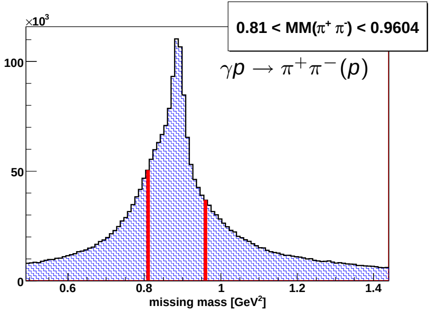
The beta calculated(Pmag/E)

- The beta measured from TOF

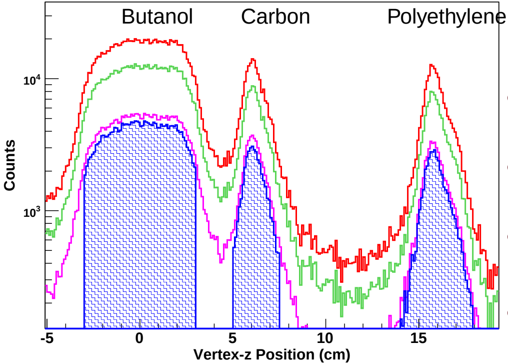
The 4 different topologies of $\gamma p \rightarrow p\pi^+\pi^-$

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





selecting the target



- The red line:

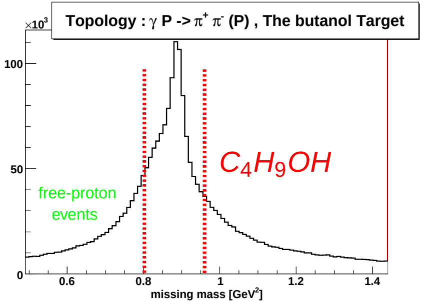
  the raw data
- The green line:

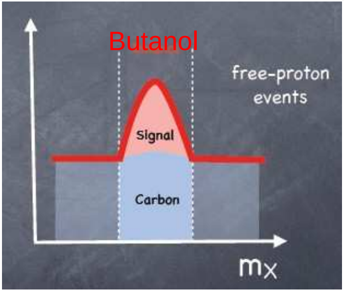
  the data after beta difference cut
- The pink line:

  the data included in $\pi^+ \pi^-$ photoproduction
- The blue part
  - the Z vertex difference cut
  - the three kinds of targets

The target	X and Y axis	Z axis
Butanol	radius 3	[-3.0,3.0]
Carbon		[5,7.5]
Polyethylene		[14,18]

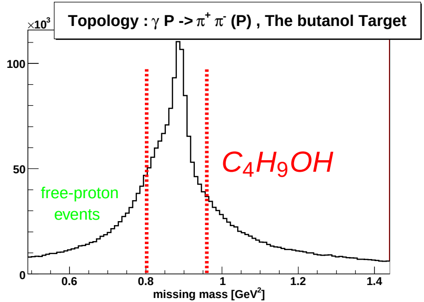
What is the dilution factor?

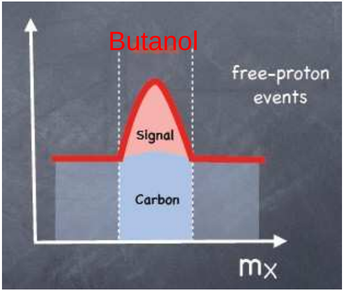




- The hydrogen atoms are polarized longitudinally in FROST experiment
- The butanol (C_4H_9OH) target has the unpolarized atoms like the carbon (C) or the oxygen (O).

What is the dilution factor?

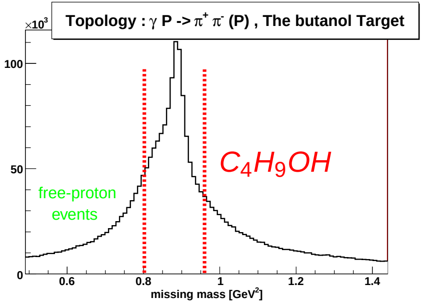


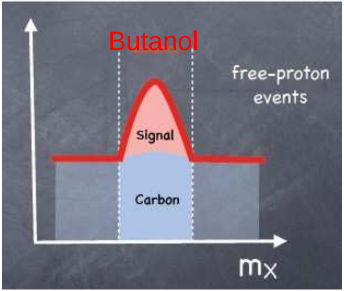


- ◇ The hydrogen atoms are polarized longitudinally in FROST experiment
- ◇ The butanol (C_4H_9OH) target has the unpolarized atoms like the carbon (C) or the oxygen (O).

The dilution factor

What is the dilution factor?

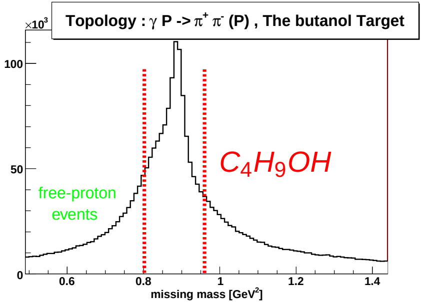


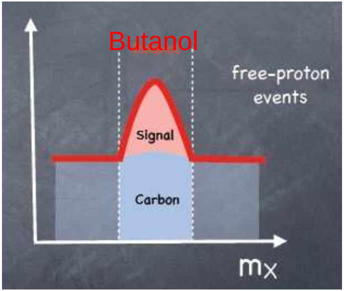


◇ The dilution factor is defined as the ratio between the hydrogen and the full butanol contribution to the cross section

$$\textit{The dilution factor} = \frac{\sigma_H}{\sigma_{C_4H_9OH}}$$

What is the dilution factor?

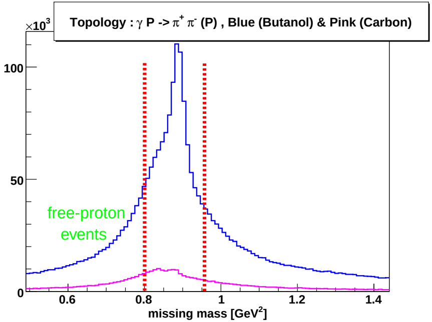


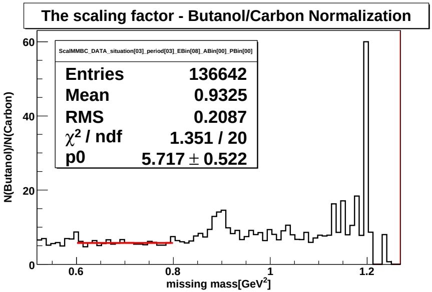


◇ The dilution factor is defined as the ratio between the hydrogen and the full butanol contribution to the cross section

$$\textit{The dilution factor} = \frac{\sigma_H}{\sigma_{C_4H_9OH}} = 1 - \frac{(\textit{The scaling factor})X(N_{carbon})}{N_{butanol}}$$

The missing mass distribution - scaling factor?

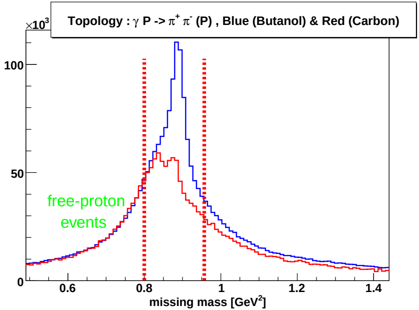


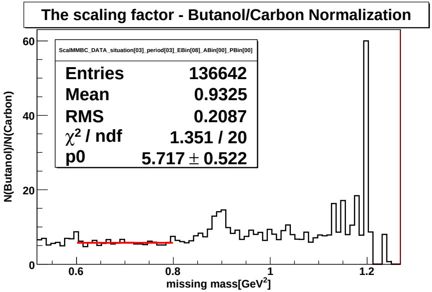


- ◇ The scaling factor normalizes the distribution of the two targets.
- ◇ comparing [0.6,0.8] of the two targets; the butanol and carbon.

$$\textit{The scaling factor} = \frac{\textit{The butanol MM plot (Blue plot)}}{\textit{The carbon MM plot (Pink plot)}}$$

The missing mass distribution - scaling factor?

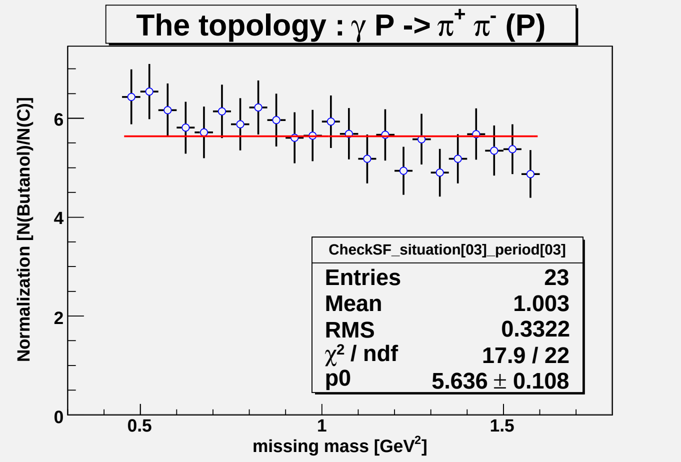




- ◇ (The red plot) = (The pink plot) X (The scaling factor)

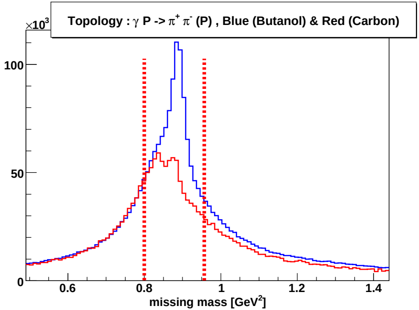
$$\textit{The scaling factor} = \frac{\textit{The butanol MM plot (Blue plot)}}{\textit{The carbon MM plot (Pink plot)}}$$

The scaling factor

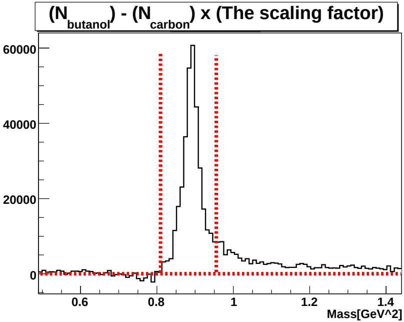


◇ The average scaling factor is 5.636

The missing mass distribution - dilution factor



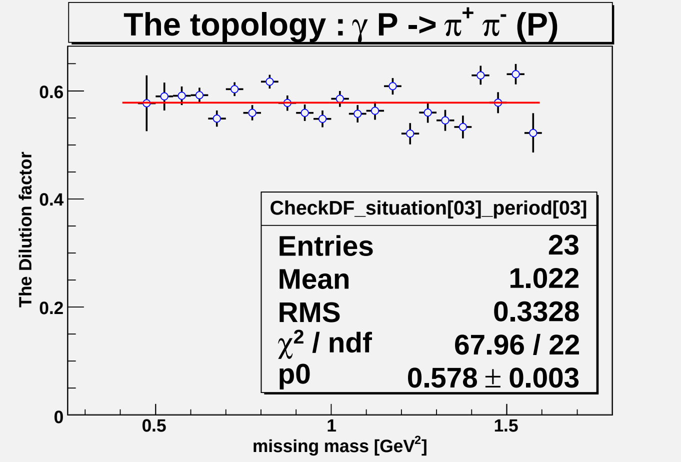
- The blue - ($N_{butanol}$)
- The red - (N_{carbon}) X (The scaling factor))
- The difference = The blue - The red
  ($N_{butanol}$) - (N_{carbon}) X (The scaling factor)



The dilution factor

$$\frac{(N_{butanol}) - (The\ scaling\ factor) X (N_{carbon})}{N_{butanol}}$$

The dilution factor

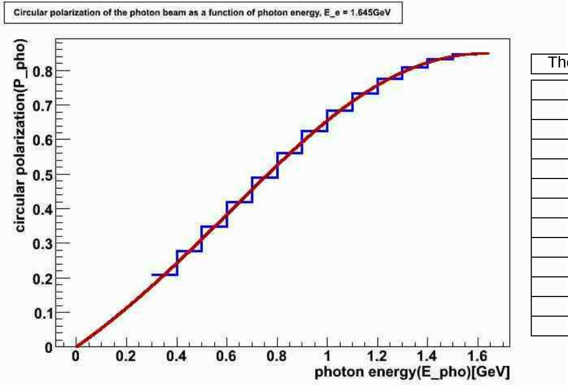


◇ The average dilution factor is 0.578

The beam and target polarization

- target polarization, $\Lambda_z \sim 80\,\%$
- electron beam polarization, $P_e \sim 85\,\%$

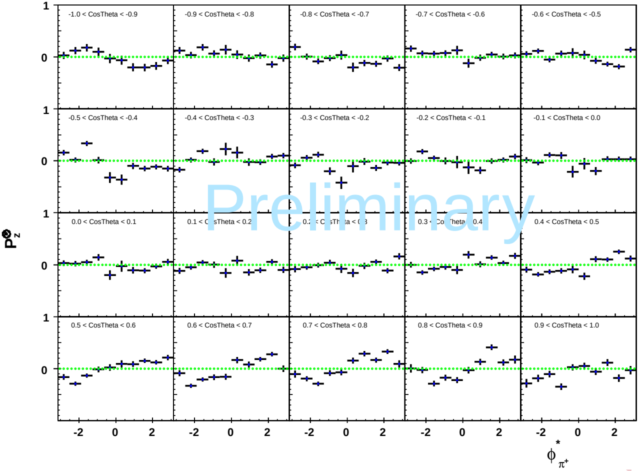
$$P_\gamma = P_e \cdot \frac{(\frac{4}{E_e})\,E_\gamma - (\frac{4}{E_e})^2\,E_\gamma^2}{4 - (\frac{4}{E_e})\,E_\gamma + 3\,(\frac{4}{E_e})^2\,E_\gamma^2}$$

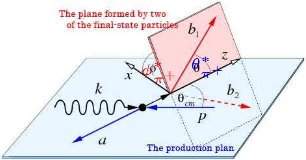


The photon energy [GeV]	The photon polarization
[0.3,0.4]	0.209
[0.4,0.5]	0.277
[0.5,0.6]	0.348
[0.6,0.7]	0.419
[0.7,0.8]	0.490
[0.8,0.9]	0.559
[0.9,1.0]	0.624
[1.0,1.1]	0.683
[1.1,1.2]	0.734
[1.2,1.3]	0.777
[1.3,1.4]	0.810
[1.4,1.5]	0.833
[1.5,1.6]	0.846

The asymmetry plot for $P_z^{\odot}$

The topology $\gamma p \rightarrow \pi^+\pi^-(p)$ (Energy Bin 1100 MeV - 1200 MeV)

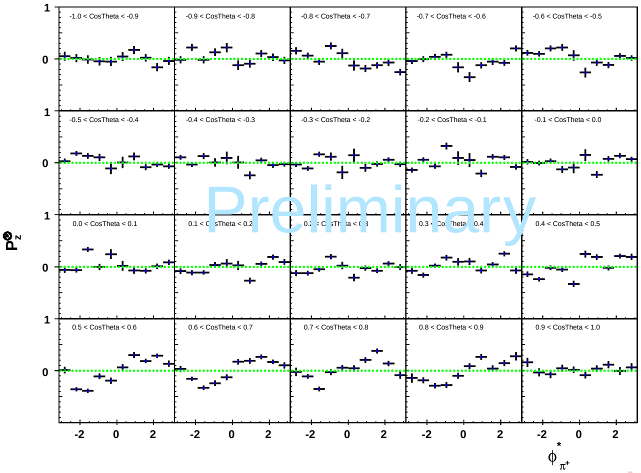


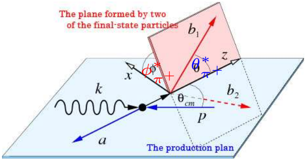


- $\phi^*_{\pi^+}$
  - angle between the production plan and two meson plan, after second boost.
- $\theta^*_{\pi^+}$
  - angle between the production plan and π^+, after the second boost.

The asymmetry plot for $P_z^{\odot}$

The topology $\gamma p \rightarrow \pi^+\pi^-(p)$ (Energy Bin 1200 MeV - 1300 MeV)

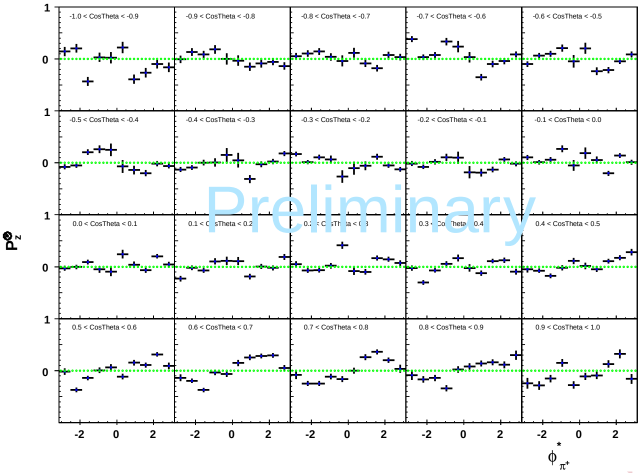


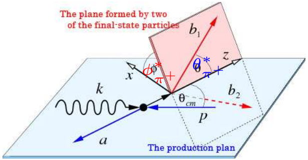


- $\phi^*_{\pi^+}$
  - angle between the production plan and two meson plan, after second boost.
- $\theta^*_{\pi^+}$
  - angle between the production plan and π^+, after the second boost.

The asymmetry plot for $P_z^{\odot}$

The topology $\gamma p \to \pi^+\pi^-(p)$ (Energy Bin 1300 MeV - 1400 MeV)

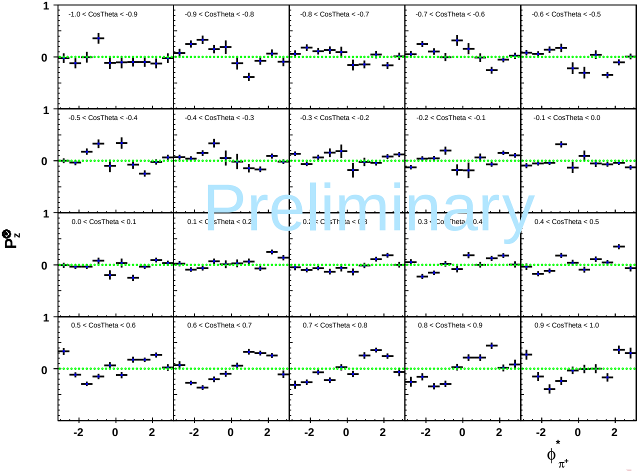


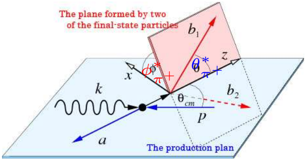


- $\phi^*_{\pi^+}$
  - angle between the production plan and two meson plan, after second boost.
- $\theta^*_{\pi^+}$
  - angle between the production plan and π^+, after the second boost.

The asymmetry plot for $P_z^{\odot}$

The topology $\gamma p \rightarrow \pi^+\pi^-(p)$ (Energy Bin 1400 MeV - 1500 MeV)



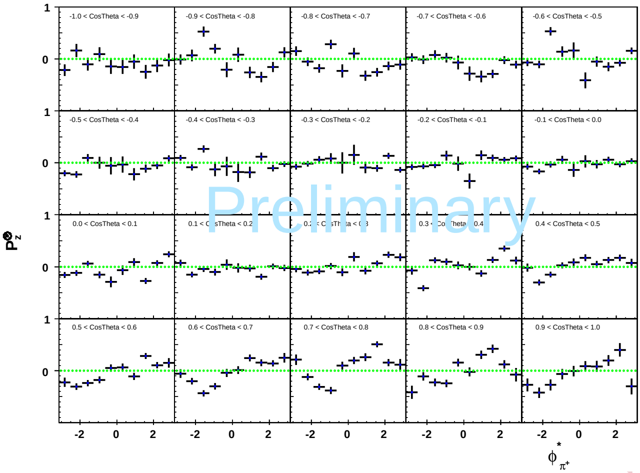


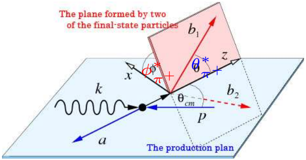
◇ $\phi^*_{\pi^+}$
- angle between the production plan and two meson plan, after second boost.

◇ $\theta^*_{\pi^+}$
- angle between the production plan and π^+, after the second boost.

The asymmetry plot for $P_z^{\odot}$

The topology $\gamma p \rightarrow \pi^+\pi^-(p)$ (Energy Bin 1500 MeV - 1600 MeV)



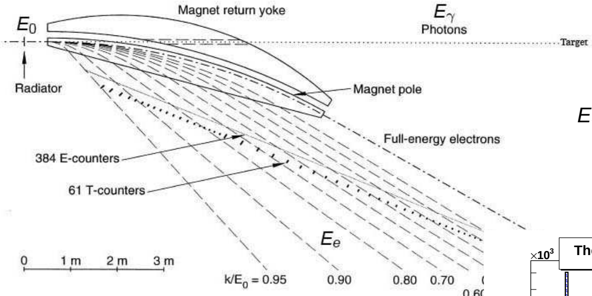


- $\phi^*_{\pi^+}$
  - angle between the production plan and two meson plan, after second boost.
- $\theta^*_{\pi^+}$
  - angle between the production plan and π^+, after the second boost.

Summary

- Preliminary results for $\mathbf{P_z}^{\odot}$ in $\pi^+ \pi^-$ photoproduction
- Studying the dilution factor
  - Butanol/Carbon normalization - The scaling factor
  - Checking the energy dependence of the dilution factor
- Studying the beam and target polarization

The tagging system at CLAS



JLAB Hall B bremsstrahlung photon tagger

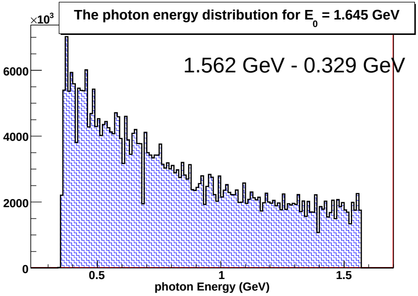
- E_γ = 20-95 % of E_0
- E_γ up to ~5.5 GeV

$$E_\gamma = E_0 - E_e$$

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 FROST DATA summary

g9a run period: Nov. 3, 2007 - Feb. 12, 2008

Data set: 603 Runs, 17,676 files, 35 TBytes

Production Data

Beam current: 15 nA

Torus current: 1920 A

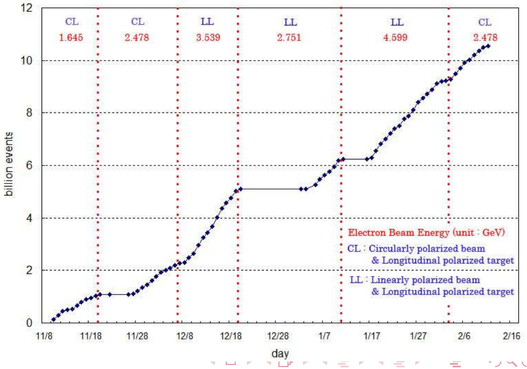
Target:

- Longitudinal polarized target
- Average target polarization ∼ 80 %

Photon beam:

- Circularly and linearly polarized photon beam 0.5 - 2.4 GeV
- Electron beam polarization ∼ 85 %

10.5 Billion events



The FROST DATA summary

g9a run period: Nov. 3, 2007 - Feb. 12, 2008

Data set: 603 Runs, 17,676 files, 35 TBytes

The **longitudinal** polarized target and the **circularly** polarized beam

- Groups of runs with similar conditions

period	Electron Beam Energy	run range	Target Pol.	# files
1	1.645 GeV	55521 - 55536	L+- (<=)	266
2	1.645 GeV	55537 - 55555	L+- (<=)	377
3	1.645 GeV	55556 - 55595	L++ (=>)	806
4	2.478 GeV	55604 - 55625	L-+ (<=)	382
5	2.478 GeV	55630 - 55676	L– (=>)	971
6	2.478 GeV	56164 - 56193	L++ (=>)	681
7	2.478 GeV	56196 - 56233	L+- (<=)	766

The **longitudinal** polarized target and the **linearly** polarized beam

- PARA, PERP, AMO

Electron Beam Energy	run range
3.539 GeV	55678 - 55844
2.751 GeV	55854 - 55938
4.599 GeV	55945 - 56152