The target asymmetry $\mathbf{P}_z$ in $\gamma\vec{p} \rightarrow p\pi^+\pi^-$ with CLAS spectrometer at the JLab (Ph.D. Student Annual Review)

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Outline

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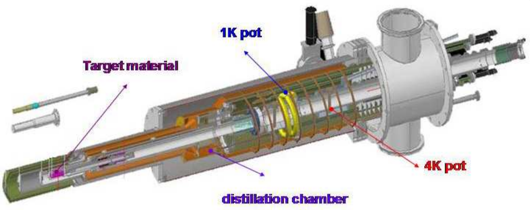
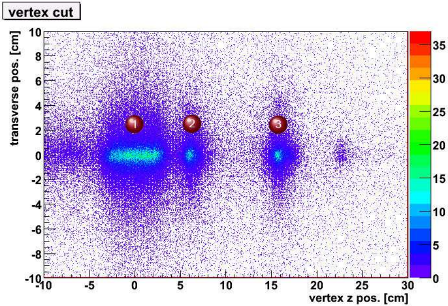
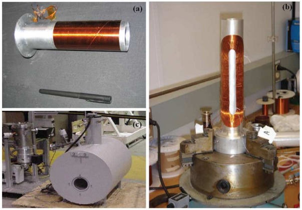
1. The FROzen-Spin Target (FROST)
   - The FROzen-Spin Target (FROST)
   - The FROST-g9a run Period
   - Polarization observables
2. The current status of the analysis
   - Dilution factor
   - Target Polarization
   - Normalization Factor
3. The Preliminary results

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

Production data

Target:

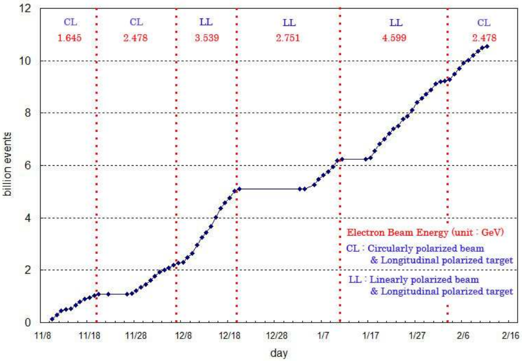
- Longitudinal polarized target
- Average target polarization
  ∼ 82 % (+Pol) and 85 % (-Pol)

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

10.5 Billion events



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)

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

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

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

15 Observables

Polarization observables

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

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

3 Observables

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

$$\mathbf{P_z}(\mathbf{E}_\gamma, \theta^*, \phi^*) = \frac{1}{\mathbf{D}(\mathbf{E}_\gamma, \mathbf{top.}) \cdot \overline{\Lambda}_z} \frac{\left\{ N(\Rightarrow)_{but.} - N(\Leftarrow)_{but.} \right\}}{\left\{ N(\Rightarrow)_{but.} + N(\Leftarrow)_{but.} \right\}}$$

Polarization observable, $\mathbf{P_z}$

$$\mathbf{P_z}(\mathbf{E}_\gamma,\ \theta^*,\ \phi^*) = \frac{1}{\mathbf{D}(\mathbf{E}_\gamma,\mathbf{topology})\cdot\overline{\Lambda}_z}\frac{\left\{N(\Rightarrow)_{but.} - N(\Leftarrow)_{but.}\right\}}{\left\{N(\Rightarrow)_{but.} + N(\Leftarrow)_{but.}\right\}}$$

$$N(\Rightarrow)_{but.} = N(\rightarrow\Rightarrow; E_\gamma,\ \theta^*,\ \phi^*) + N(\leftarrow\Rightarrow; E_\gamma,\ \theta^*,\ \phi^*)$$

$$N(\Leftarrow)_{but.} = \frac{N(\rightarrow\Leftarrow; E_\gamma, \theta^*, \phi^*)}{\mathbf{A}(\Leftarrow)\,/\,\mathbf{A}(\Rightarrow)} + \frac{N(\leftarrow\Leftarrow; E_\gamma, \theta^*, \phi^*)}{\mathbf{A}(\Leftarrow)\,/\,\mathbf{A}(\Rightarrow)}$$

Three important parameters for polarization observable, $\mathbf{P_z}$

- $\mathbf{D}(\mathbf{E}_\gamma,\mathbf{topology})$: Dilution Factor
- $\overline{\Lambda}_z$: The average of the target polarizations
- $\mathbf{A}(\Leftarrow)\,/\,\mathbf{A}(\Rightarrow)$: The normalization factors

- N terms : the number of events for the different polarization configuration
  - $\Rightarrow$ (or $\Leftarrow$) : The target polarization direction is parallel (or antiparallel) to the beam

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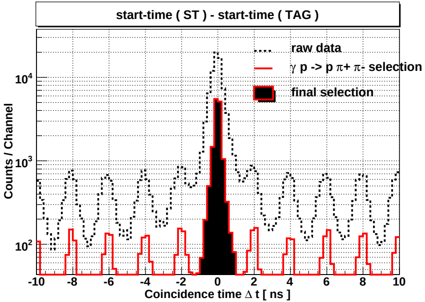
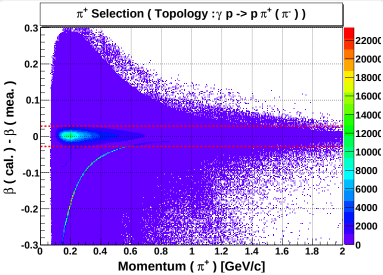
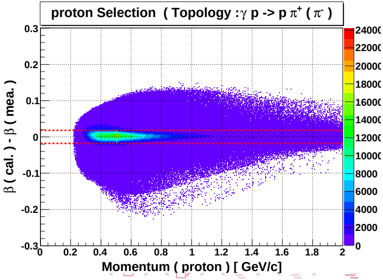
Particle identification ($\vec{\gamma}$, p, π^+, π^-)



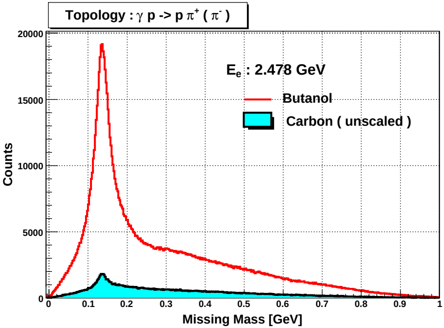


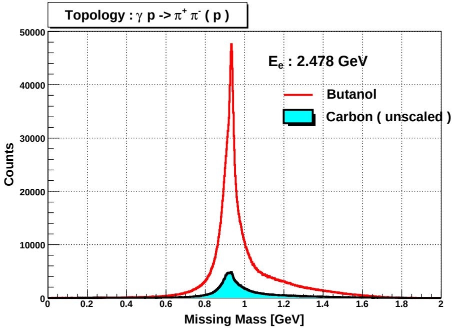


- Coincidence Time : $|\Delta t| < 1.2\ [ns]$
- Particle identification
  - Proton : $|\Delta\beta| < 0.01882$
  - π^+ : $|\Delta\beta| < 0.0285$
  - π^- : $|\Delta\beta| < 0.0264$

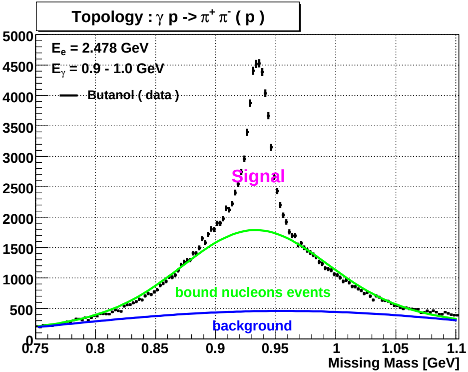
The four different topologies of $\gamma p \rightarrow p\pi^+\pi^-$

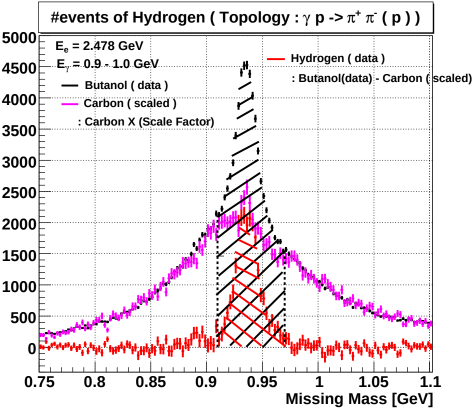
- The topology : $\gamma p \rightarrow p\pi^+(\pi^-)$
- The topology : $\gamma p \rightarrow p\pi^-(\pi^+)$
- The topology : $\gamma p \rightarrow \pi^+\pi^-(p)$
- The topology : $\gamma p \rightarrow p\pi^+\pi^-$





Dilution factor, $\mathbf{D}(\mathbf{E}_\gamma, \textbf{topology})$

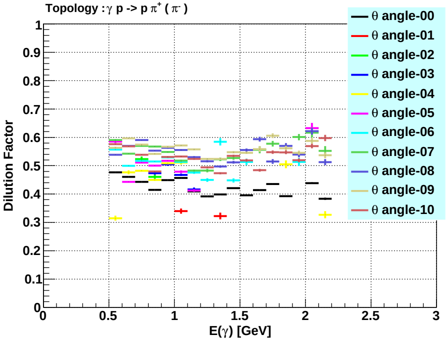


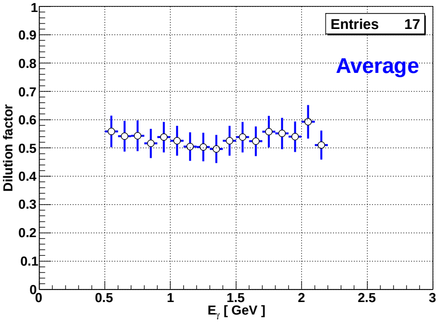


$$\text{Dilution factor} = \frac{\sigma_H}{\sigma_{C_4H_9OH}} = \frac{N_{butanol} - N_{carbon} \cdot S}{N_{butanol}} = \frac{(AREA)\ of\ \mathbf{N_{Hydrogen}}}{(AREA)\ of\ \mathbf{N_{Butanol}}}$$

(S : Scale Factor-> Normalization factor btw butanol and carbon target)

The angle dependence of the dilution factor



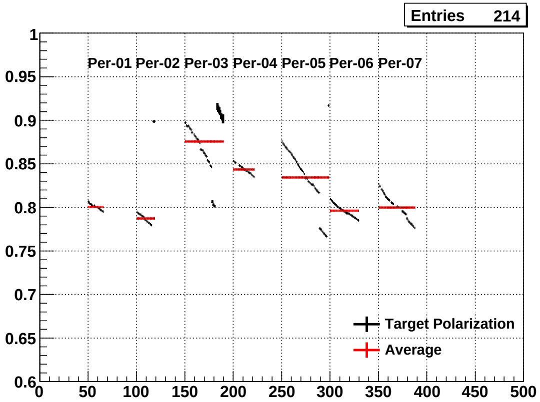


- θ angle-00 : $0 < \theta < 180$
- θ angle-01 : $0 < \theta < 18$
- θ angle-02 : $18 < \theta < 36$ . . .

- Average from θ angle-01 to θ angle-10
- Error : statistic error + systematic error (10 %)

θ angle : The π^+ polar angle in the rest frame of the $\pi^+ \pi^-$ system

Target Polarization, $\overline{\Lambda}_z$



Target Polarization at periods

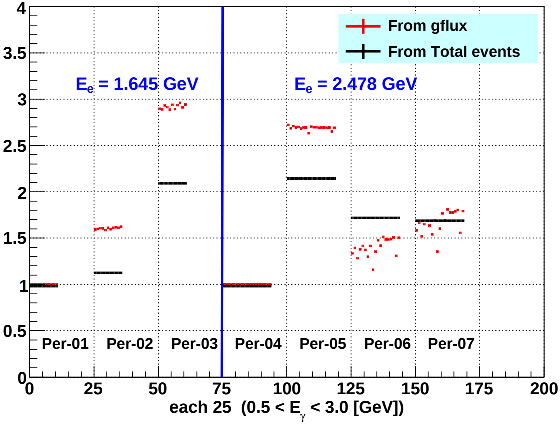
Period 01 : 0.800 ($\Leftarrow$)
Period 02 : 0.787 ($\Leftarrow$)
Period 03 : 0.876 ($\Rightarrow$)
E_e : 1.6 GeV

Period 04 : 0.843 ($\Rightarrow$)
Period 05 : 0.834 ($\Leftarrow$)
Period 06 : 0.796 ($\Rightarrow$)
Period 07 : 0.800 ($\Leftarrow$)
E_e : 2.4 GeV

- Target polarization, $\Rightarrow$ (or $\Leftarrow$) : The direction is parallel (or antiparallel) to the beam
- There are groups of runs with similar conditions in data with circularly polarized beam

  These are defined as periods

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



- ◇ From gflux : use the number of total photons
- ◇ From Total events : use the number of total events

as the normalization factor

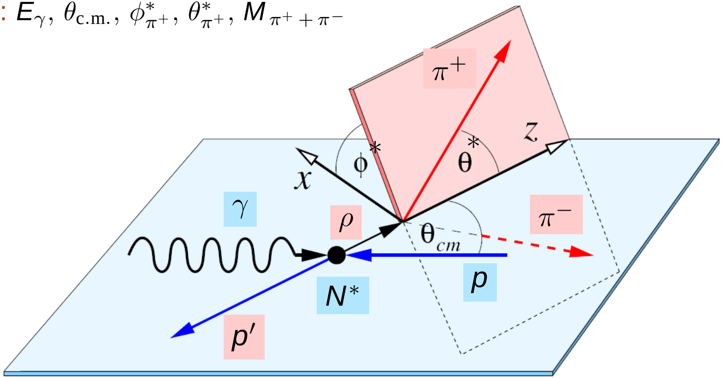
Outline

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

The $\pi^+ \pi^-$ in the final state require 5 independent variables!

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

ex: $E_\gamma,\ \theta_{\rm c.m.},\ \phi^*_{\pi^+},\ \theta^*_{\pi^+},\ M_{\pi^+ + \pi^-}$



Polarization observable, $\mathbf{P_z}$

$$\mathbf{P_z}(\mathbf{E}_\gamma,\ \theta^*,\ \phi^*) = \frac{1}{\mathbf{D}(\mathbf{E}_\gamma,\mathbf{topology}) \cdot \overline{\Lambda}_z} \frac{\left\{ N(\Rightarrow)_{but.} - N(\Leftarrow)_{but.} \right\}}{\left\{ N(\Rightarrow)_{but.} + N(\Leftarrow)_{but.} \right\}}$$

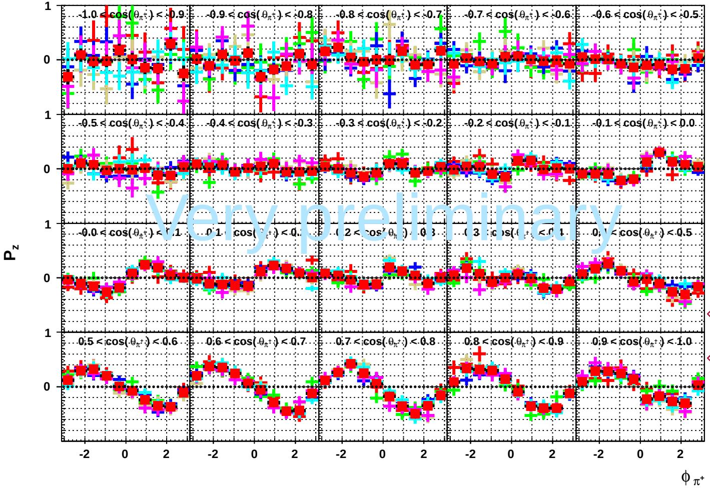
Target Polarization

- $N(\Rightarrow)_{but.}$: Period 3, 4, and 6
- $N(\Leftarrow)_{but.}$: Period 1, 2, 5, and 7

- There are 6 combinations for Polarization observable, $\mathbf{P_z}$
  - $[1,3]$, $[2,3]$, $[4,5]$, $[4,7]$, $[6,5]$, $[6,7]$

Target asymmetry for $\mathbf{P_z}$

E_γ : 700 - 800 MeV



Data used

- Per-13
- Per-23
- Per-67
- Per-45
- Per-47
- Per-65
- All-Ave

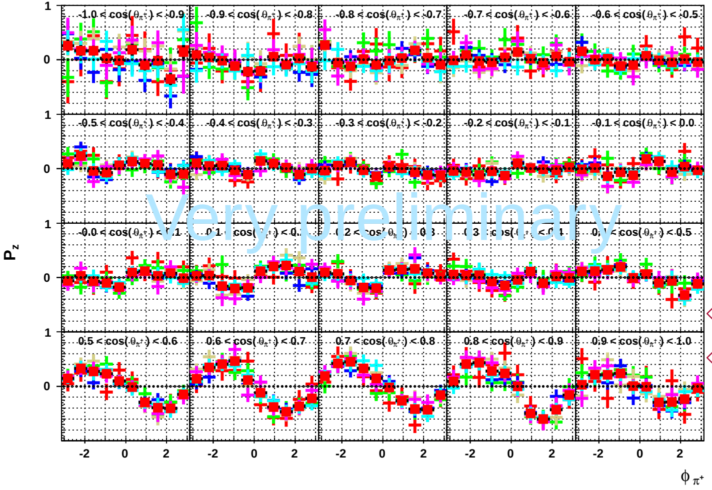
◇ ϕ_{π^+} : the π^+ azimuthal angle

◇ θ_{π^+} : the π^+ polar angle

(in the rest frame of the $\pi^+\pi^-$ system)

Target asymmetry for P_z

E_γ : 800 - 900 MeV



Data used

- Per-13
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- Per-65
- All-Ave

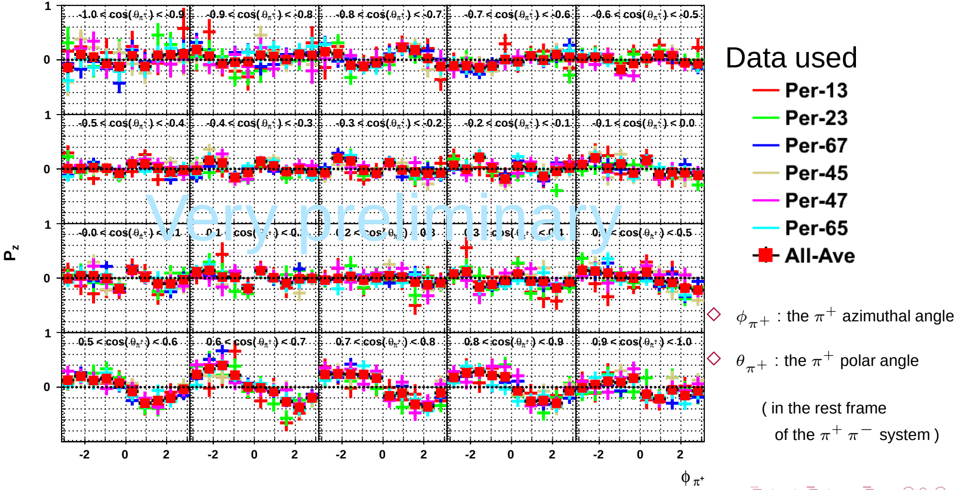
◇ ϕ_{π^+} : the π^+ azimuthal angle

◇ θ_{π^+} : the π^+ polar angle

(in the rest frame
of the $\pi^+ \pi^-$ system)

Target asymmetry for $\mathbf{P_z}$

E_γ : 900 - 1000 MeV



- ϕ_{π^+} : the π^+ azimuthal angle
- θ_{π^+} : the π^+ polar angle

(in the rest frame of the $\pi^+ \pi^-$ system)

Summary

- Polarization observables $\mathbf{P_z}$ made in the different periods have very nice agreement.
- The sinusoidal structure of the asymmetries can be observed.
- The proper normalization factors are not existed now

In future,

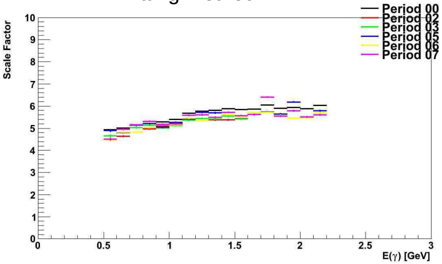
- Results for $\mathbf{I}^{\odot}$ and $\mathbf{P}_z^{\odot}$ in $\pi^+ \pi^-$ photoproduction

The Frozen-Spin Target - Summary of Results

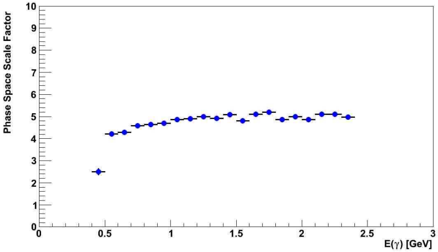
	Expectation	Result
Base temperature:	50 mK	28 mK (w/o beam) 30 mK (w/ beam)
Cooling Power:	10 μW (Frozen) 20 mW (Polarizing)	800 μW @ 50mK 60mW @ 300 mK
Polarization:	80 %	+ 82 % - 85 %
1/e Relaxation Time:	500 hours	2700 hours (+ Pol.) 1600 hours (-Pol.)

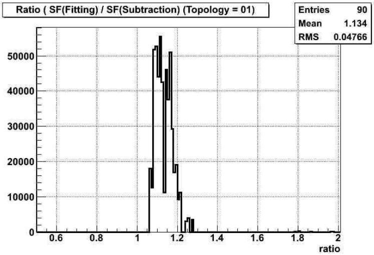
Systematic error in the dilution factor

Fitting method



Subtraction method





- Topology : $\gamma p \rightarrow p \pi^+ \pi^-$
- The ratio of values made by the different methods is about 1.1
- Systematic error : 10 %