Helicity asymmetry measurements for π^0 photoproduction with FROST

Hideko Iwamoto

CLAS Collaboration

The George Washington University

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Outline

1. Motivation

   Study the nucleon resonances and nucleon structure

2. FROST Experiment

   Polarize both beam and target

3. Data Analysis

   Event selection for γ p → π^0 p

4. Results

   Comparison with theoretical models

5. Conclusion

Nucleon Resonance

Mass, width, coupling constants... are not well known

Breit-Wigner (conventional) masses and overall status of N and Δ
- estimation by Particle Data Group (Review of particle physics 2010)

Particle	$L_{2I,\,2J}$	*BW mass*	*BW width*	*decay* $\rightarrow N\pi$	*status*
$N(1440)$	P_{11}	1440	300	$0.55-0.75$	****
$N(1520)$	D_{13}	1520	115	$0.55-0.65$	****
$N(1535)$	S_{11}	1535	150	$0.35-0.55$	****
$N(1650)$	S_{11}	1655	165	$0.60-0.95$	****
$N(1675)$	D_{15}	1675	150	$0.35-0.45$	****
$N(1700)$	D_{13}	1700	100	$0.05-0.15$	***
$N(1710)$	P_{11}	1710	100	$0.10-0.20$	***
$N(1720)$	P_{13}	1720	200	$0.10-0.20$	****
$N(1900)$	P_{13}	1900			**
$N(2080)$	D_{13}	2080			**
$N(2090)$	S_{11}	2090			*
$\Delta(1232)$	P_{33}	1232	118	1.00	****
$\Delta(1600)$	P_{33}	1600	350	$0.10-0.25$	***
$\Delta(1620)$	S_{31}	1630	145	$0.20-0.30$	****
$\Delta(1700)$	D_{33}	1700	300	$0.10-0.20$	****
$\Delta(1750)$	P_{31}	1750			*
$\Delta(1900)$	S_{31}	1900	200	$0.10-0.30$	**

**** Existence is certain

*** Existence ranges from very likely to certain.

** Evidence of existence is only fair.

* Evidence of existence is poor.

FROST (FROzen Spin Target)

Double polarization experiments are important.
Study of excited nucleon states (N* and Δ*)

Photon	Target				Recoil			Target + Recoil			
	$-$	$-$	$-$	$-$	x'	y'	z'	x'	x'	z'	z'
	$-$	x	y	z	$-$	$-$	$-$	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	-$L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	(-P)	$-G$	$O_{x'}$	(-T)	$O_{z'}$	(-$L_{z'}$)	($T_{z'}$)	(-$L_{x'}$)	(-$T_{x'}$)
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

For observable E
(case of circularly polarized beam and longitudinally polarized target)

$$\frac{(d\sigma_E)}{(d\sigma_0)} = 1 - P_z P_c E$$

Experiment for observable E

FROST experiment   Nov.3, 2007 ~ Feb. 12, 2008

Photon beam

- Circularly polarized using linearly polarized electron beam
- E_γ = 0.4 ~ 2.4 GeV (electron beam 1.645 & 2.478 GeV)

Target

- Butanol (C_4H_9OH)
- P_T = 78 ~ 92% of polarization of free proton

Production

Circularly polarized beam

1.645 GeV	1.1 Billion triggers
2.478 GeV	2.3 Billion triggers

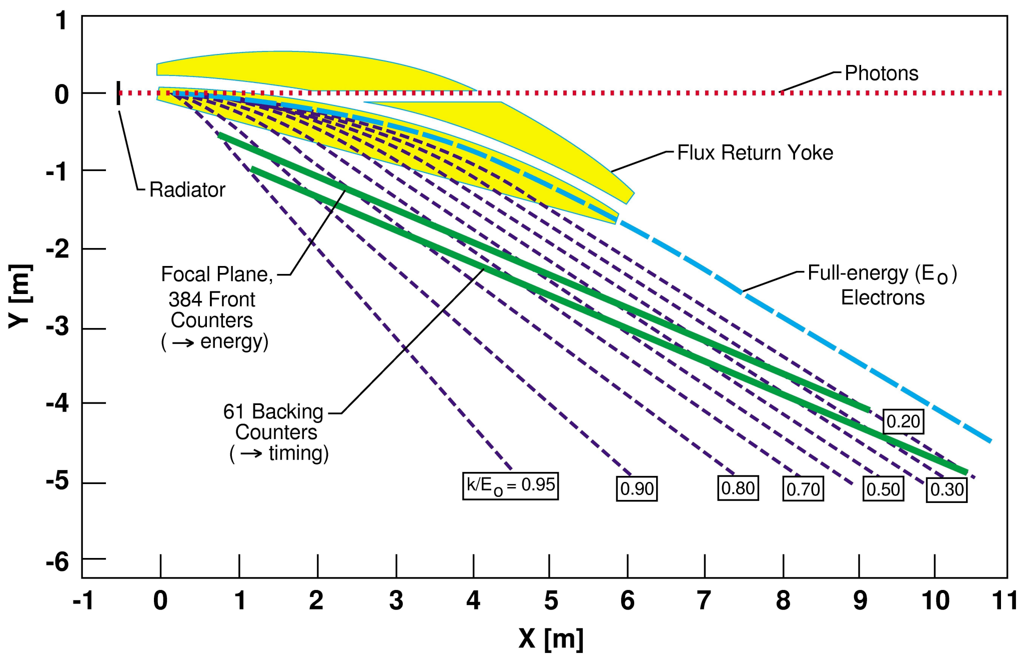
trigger: at least one charged particle in CLAS

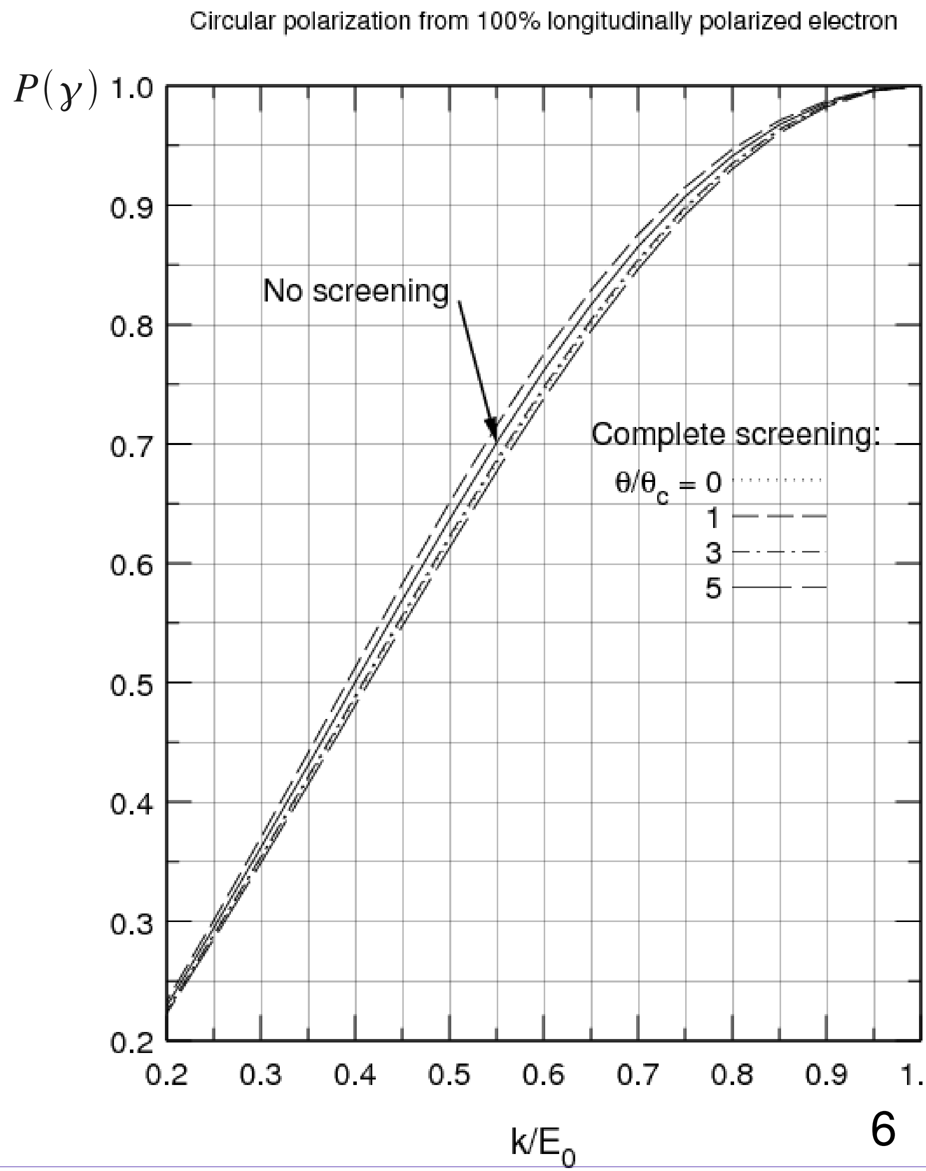
Circularly polarized photon beam

Bremsstrahlung using linearly polarized electron beam

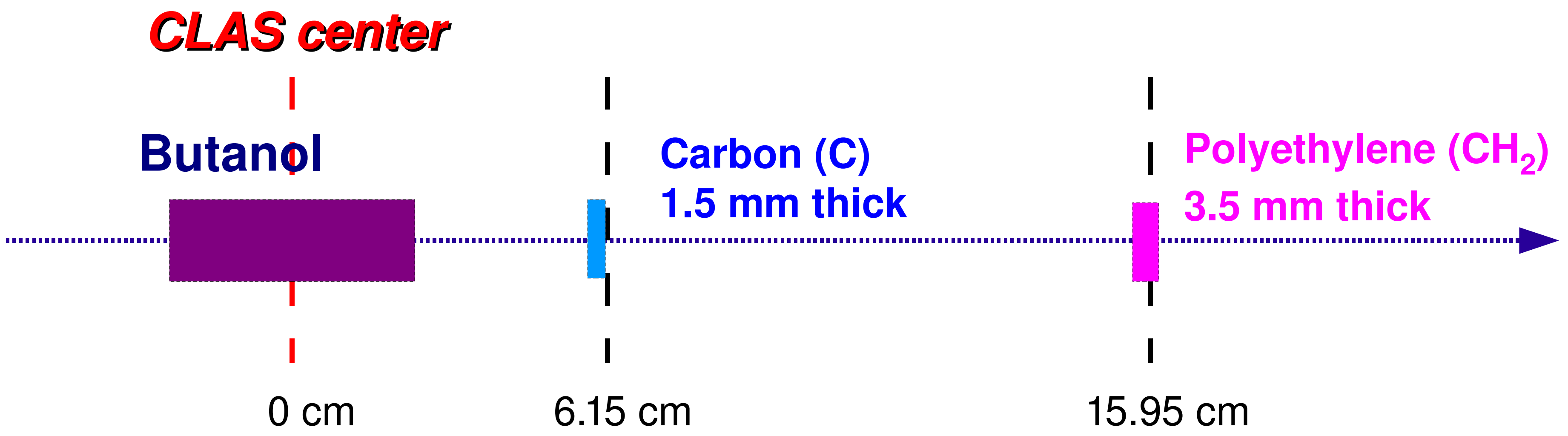
$$P(\gamma) = P(e)\,\frac{4x - x^2}{4 - 4x + 3x^2}$$

$$x = \frac{k}{\epsilon_1} = \frac{(photon\ energy)}{(incident\ electron\ energy)}$$





Targets



Butanol (C_4H_9OH)

Dynamic Nuclear Polarization (DNP) technique

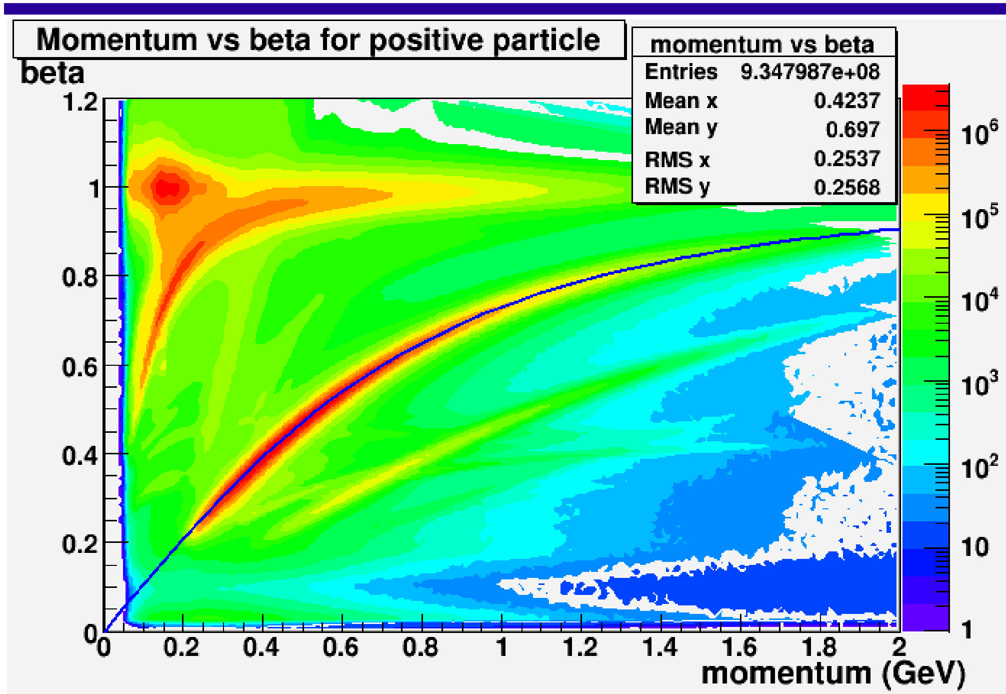
Length 52.8 mm / diameter 15 mm

Holding mode (0.5 T, 28 ~ 30 mK)

Relaxation time ~ 2,000 hours

Polarization 78 % ~ 92 %

Event selection and particle ID for $\gamma p \to \pi^0 p$



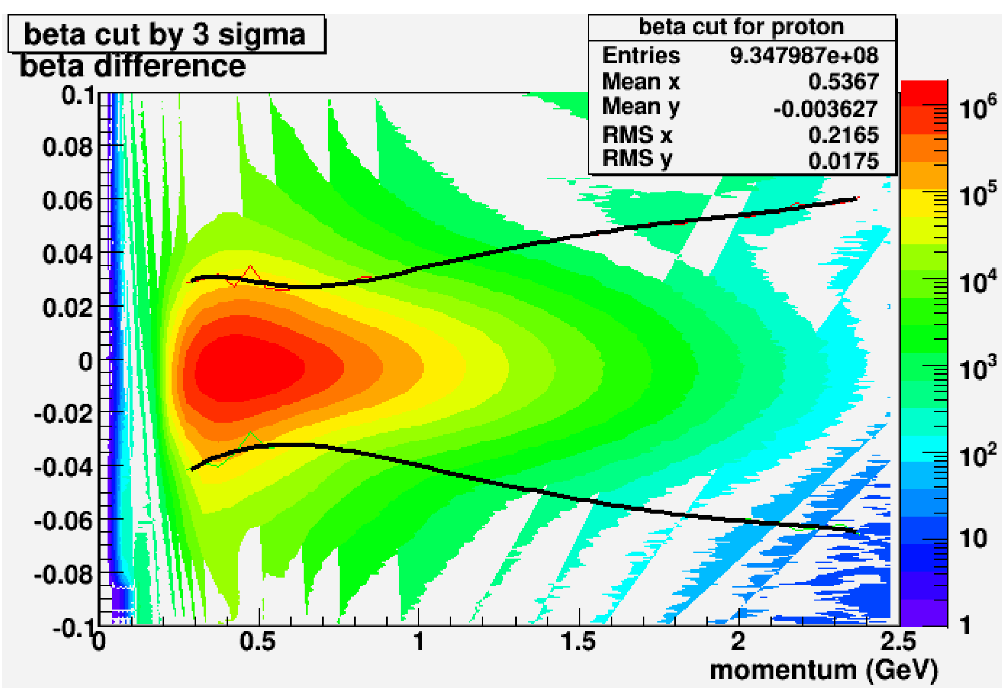
Event selection

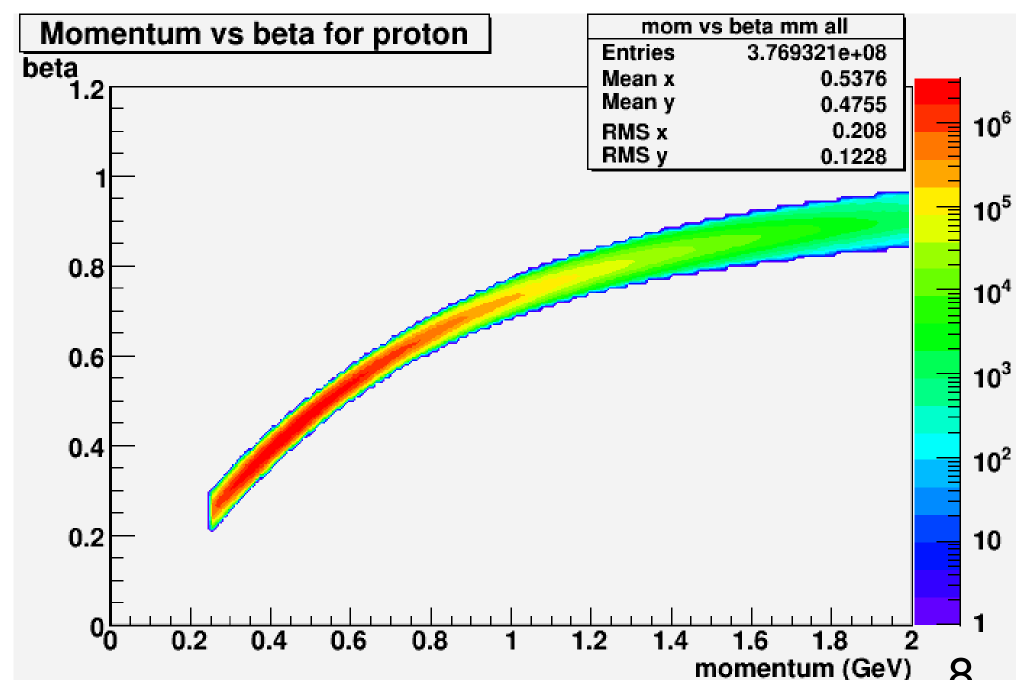
(1) Drift chamber track
(2) Start counter hit
(3) TOF counter hit
(4) One positive particle

Particle ID $\beta_{mean} \pm 3\sigma$

$$\Delta\beta = \beta_m - \beta_c = \beta_m - \sqrt{\left(\frac{p^2}{(m_P^2 + p^2)}\right)}$$

Use missing mass technique





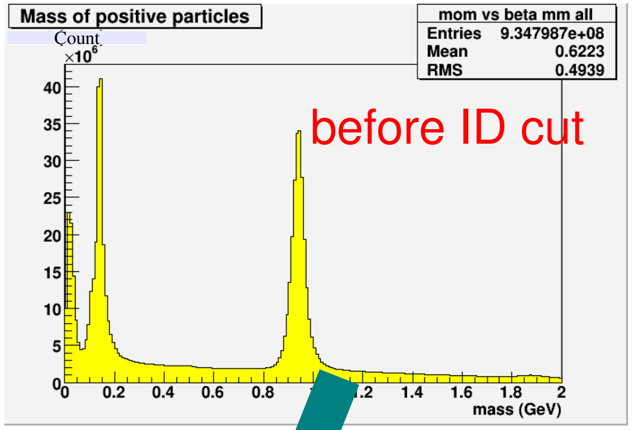
Identify incident photon

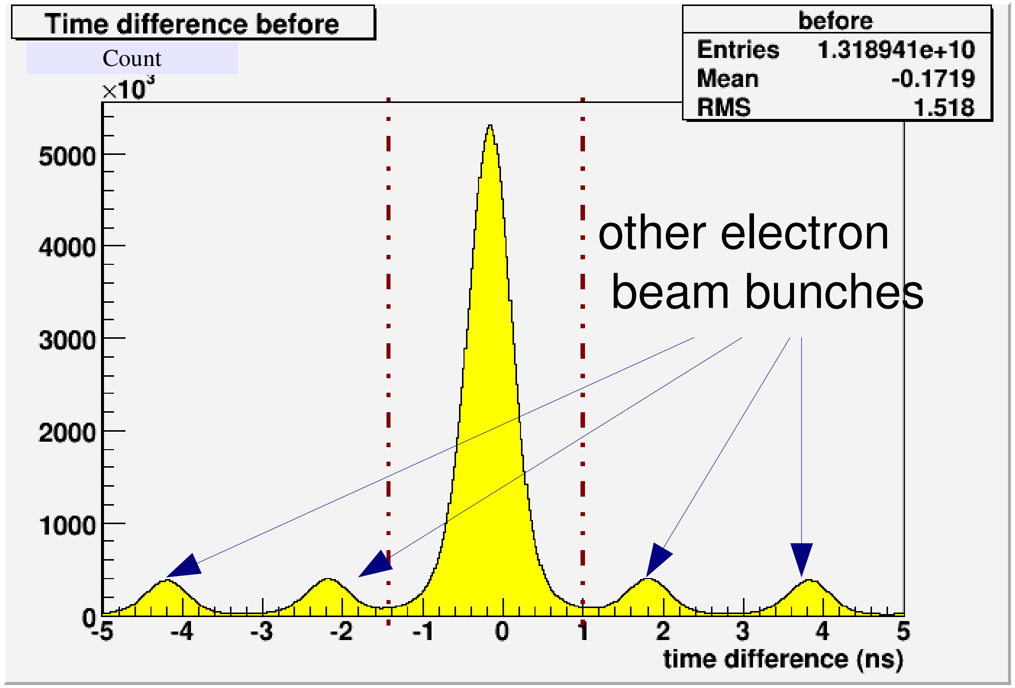
Time difference cut

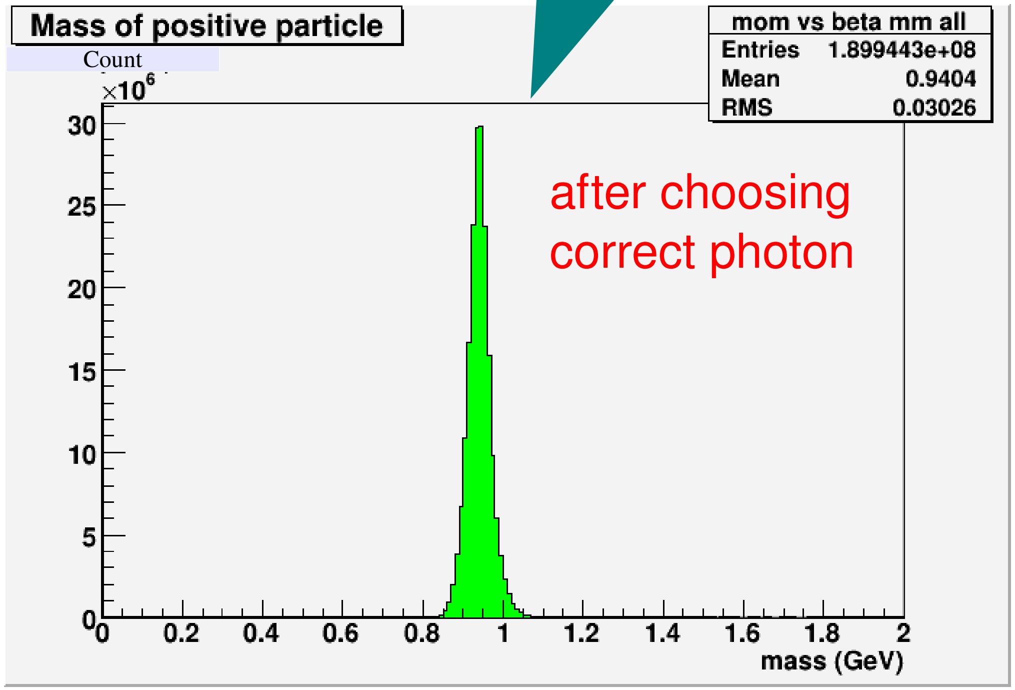
$$\Delta t = t_2 - t_1$$

t_1: vertex time of proton

t_2: vertex time of photon



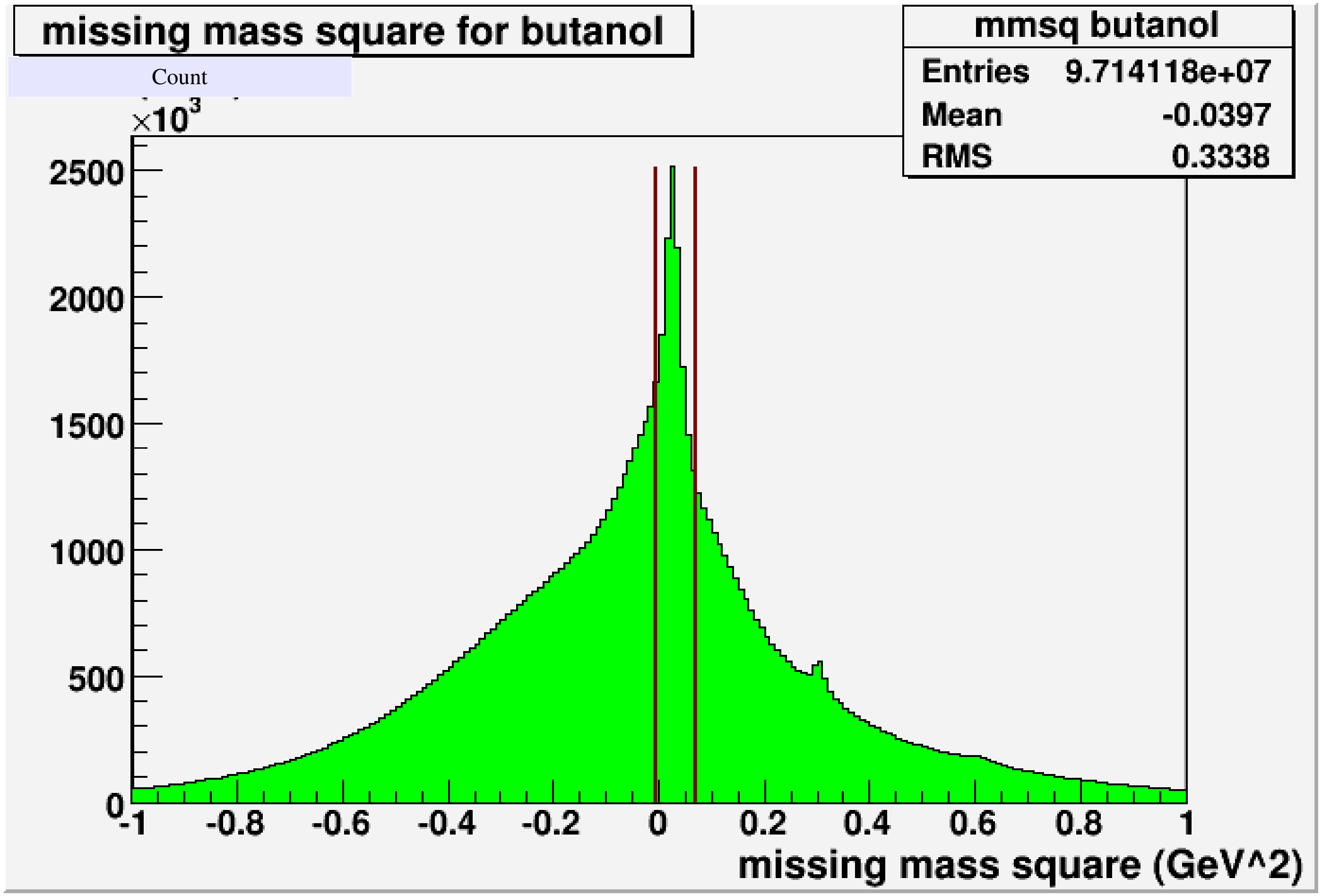




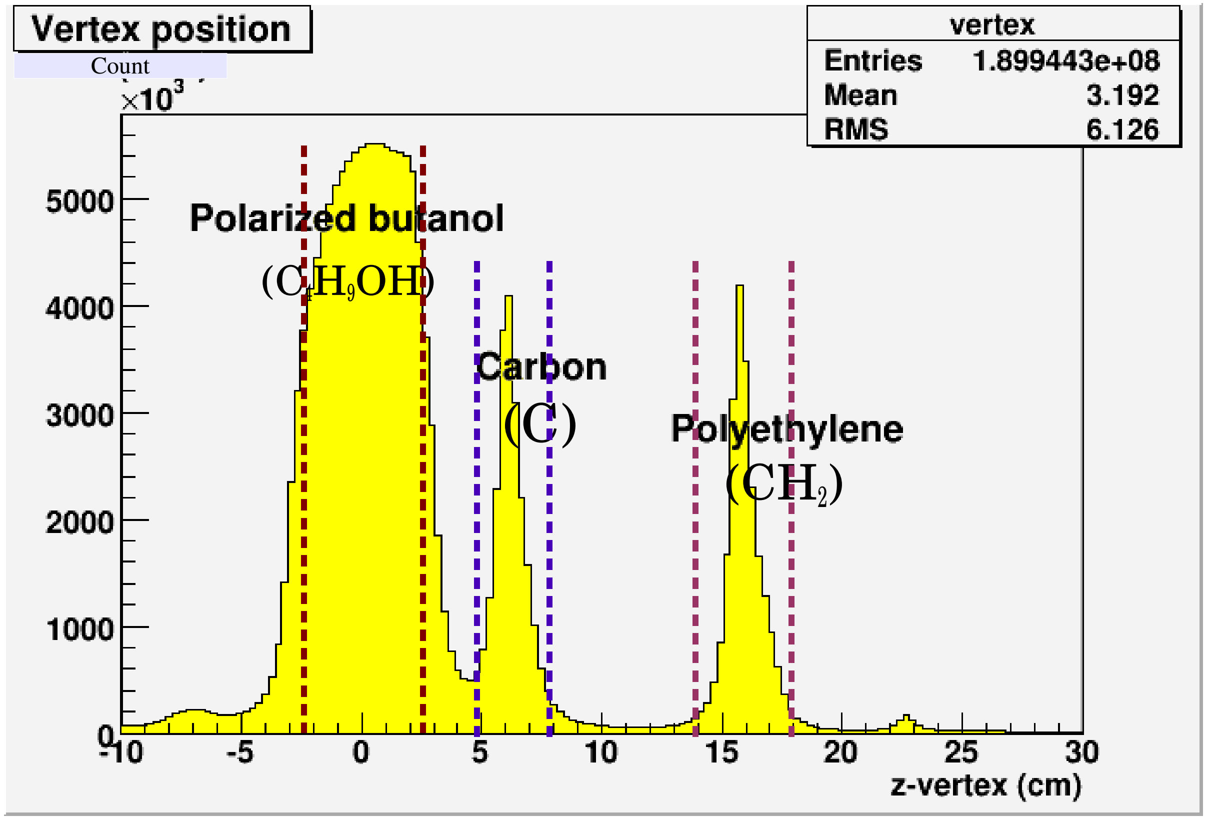
Missing-mass-squared cut

Missing-mass-squared cut depends on the kinematical bin

Cut by mean values $\pm 3\ \sigma$



Target selection



Thickness of targets

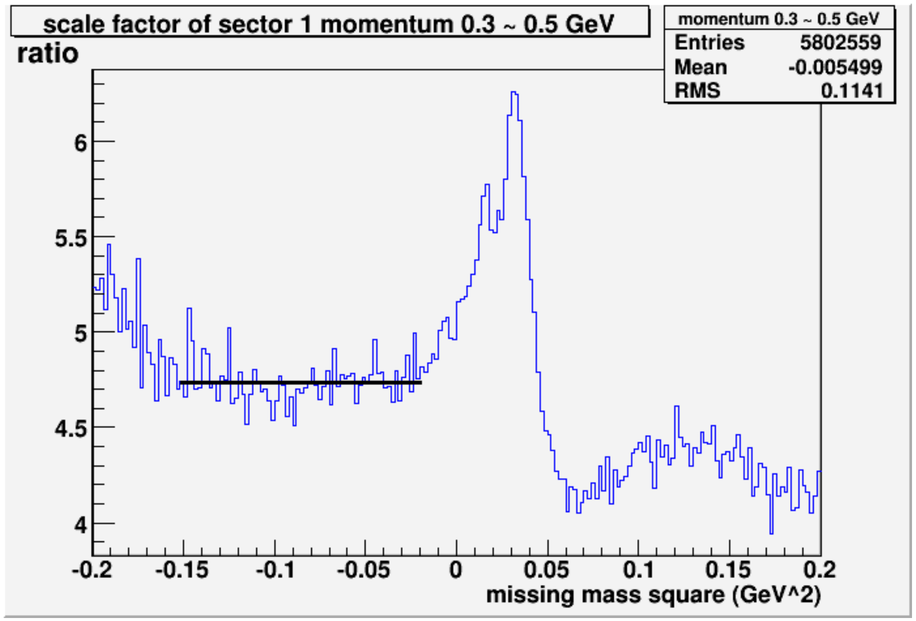
Butanol	52.8 mm
Carbon	1.5 mm
Polyethylene	3.5 mm

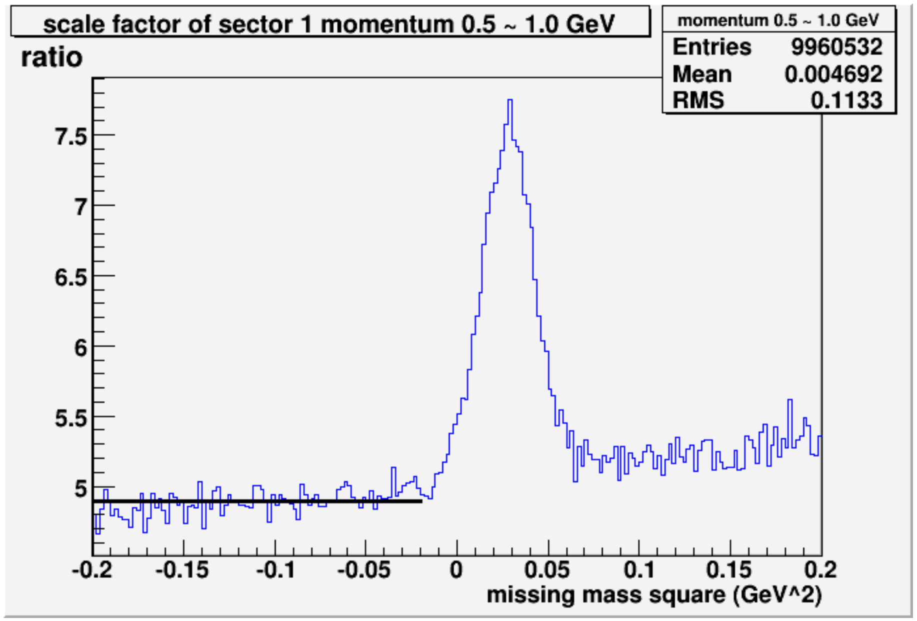
Vertex cut

Butanol	- 2.75 cm < z-vertex < + 2.75 cm
Carbon	+ 5.00 cm < z-vertex < + 8.00 cm
Polyethylene	+14.0 cm < z-vertex < +18.0 cm

Scale factor

Assume the bound nucleon reaction in the butanol target
is similar to that in carbon target

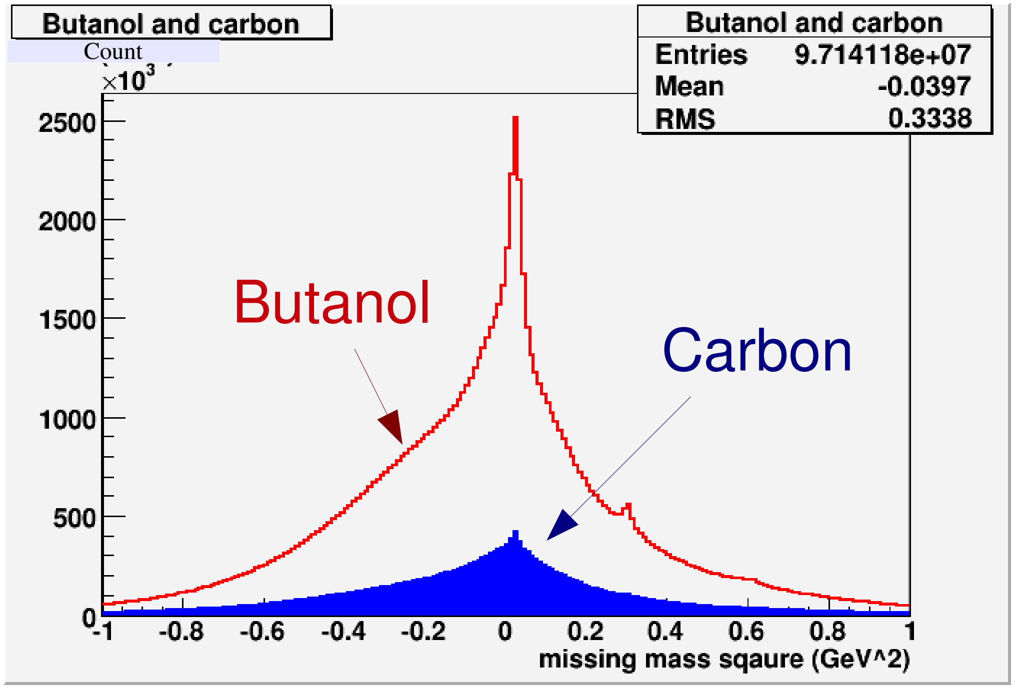


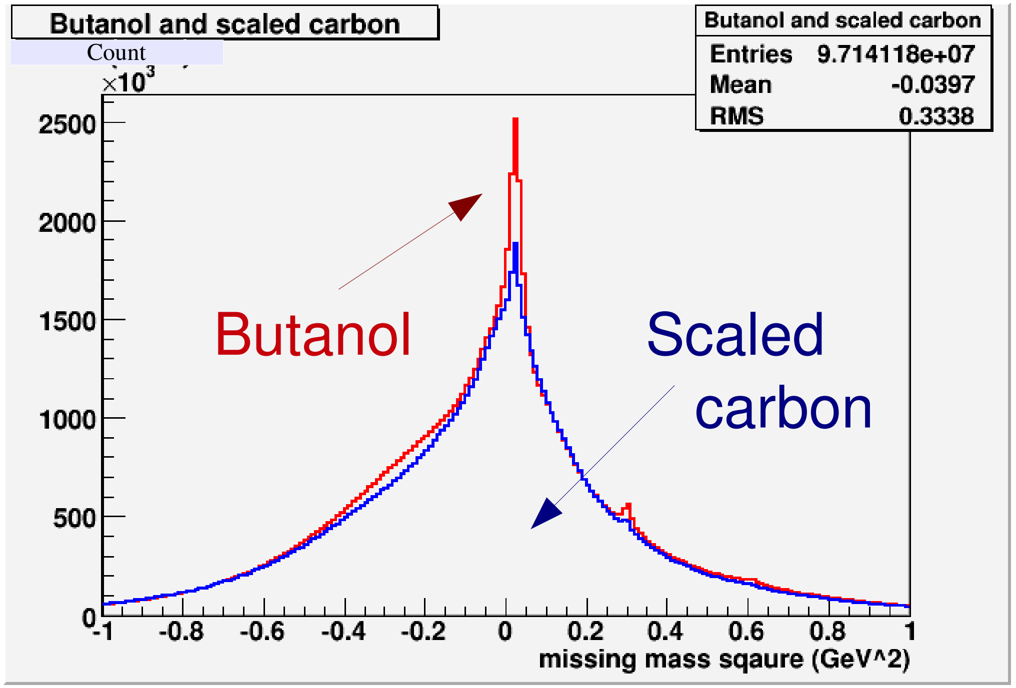


Negative missing mass square part → only bound nucleon reaction
Bound nucleon has Fermi motion

Bump and slope in the negative missing mass square region
→ determine region between -0.2 ~ 0.0 GeV^2

Dilution factor for $\gamma p \rightarrow \pi^0 p$





Use scale factor to multiply carbon events

Cut the missing mass square

by sector and by proton momentum

$$\text{Dilution factor} = \frac{\textbf{Free proton}}{\textbf{Free proton} + \textbf{Bound nucleon}}$$

Dilution factor depends on proton momentum

Uncertainties

Statistical uncertainties $\rightarrow$ Use propagation equation

$$\sigma_E^2 = \left[\left(\frac{\sigma_{D_f}}{D_f}\right)^2 + \left(\frac{\sigma_{P_\gamma}}{P_\gamma}\right)^2 + \left(\frac{\sigma_{P_T}}{P_T}\right)^2 \right] \times E^2 + \frac{(4 N_{1/2} N_{3/2})}{\left[N_{tot}^3 (D_f P_\gamma P_T)^2 \right]}$$

Systematic uncertainties

Electron beam conditions	
Energy of beam	$\approx$ 0.1 %
Beam polarization	$\approx$ 2 %
Beam charge asymmetry	6×10^{-2} %
Target polarization	1.6×10^{-1} %
Fiducial cut	2.5 %
Missing mass square cut	9.6 %
Scale and dilution factor	13 ~ 18 %

Helicity asymmetry E for $\gamma p \rightarrow \pi^0 p$ $\cos\theta^{cm}_{\pi^0}$, $\Delta E_\gamma = 50\,MeV$

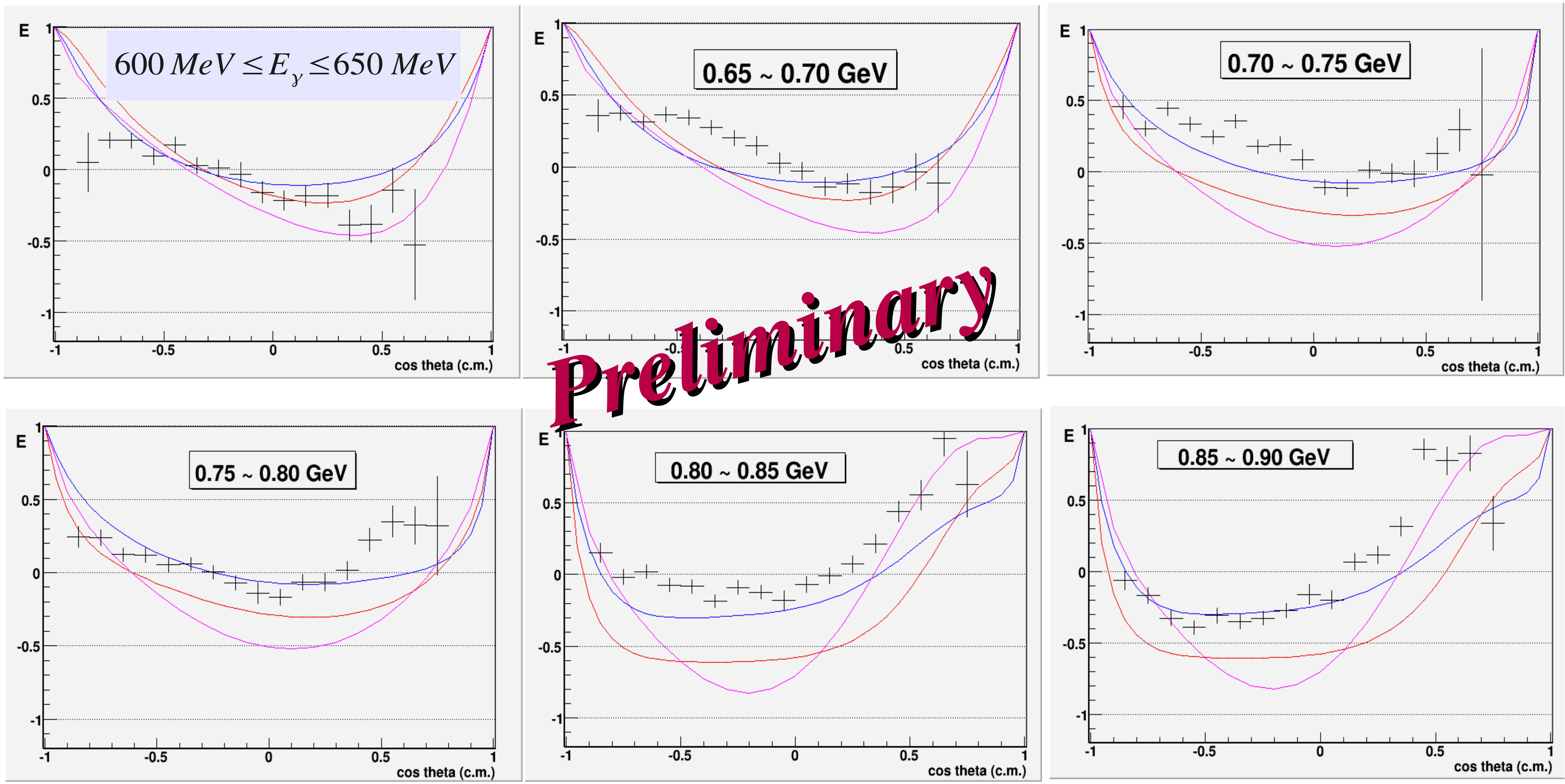
$$E = \frac{1}{D_f P_T P_\gamma}\frac{N_{3/2} - N_{1/2}}{N_{1/2} + N_{3/2}}$$

CLAS	black
SAID2009	blue
MAID2007	red
EBAC	magenta

D_f : max ~ 0.35

P_T 0.78 ~ 0.92

Pe 0.79 ~ 0.87



Only statistical uncertainty of asymmetry is shown

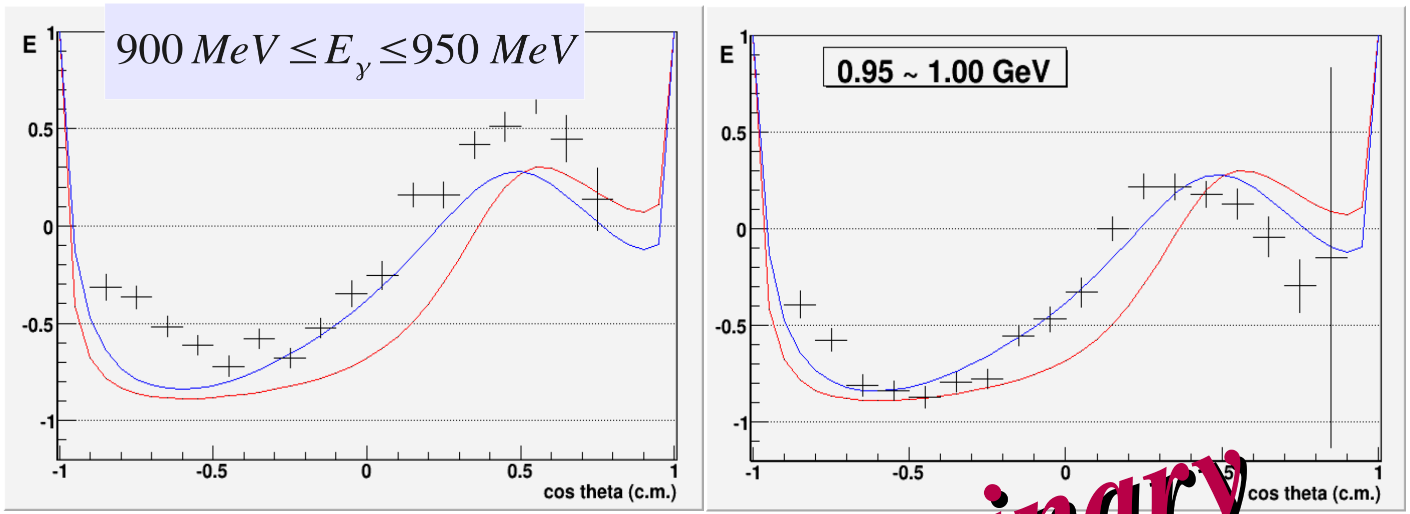
Helicity Asymmetry (2)

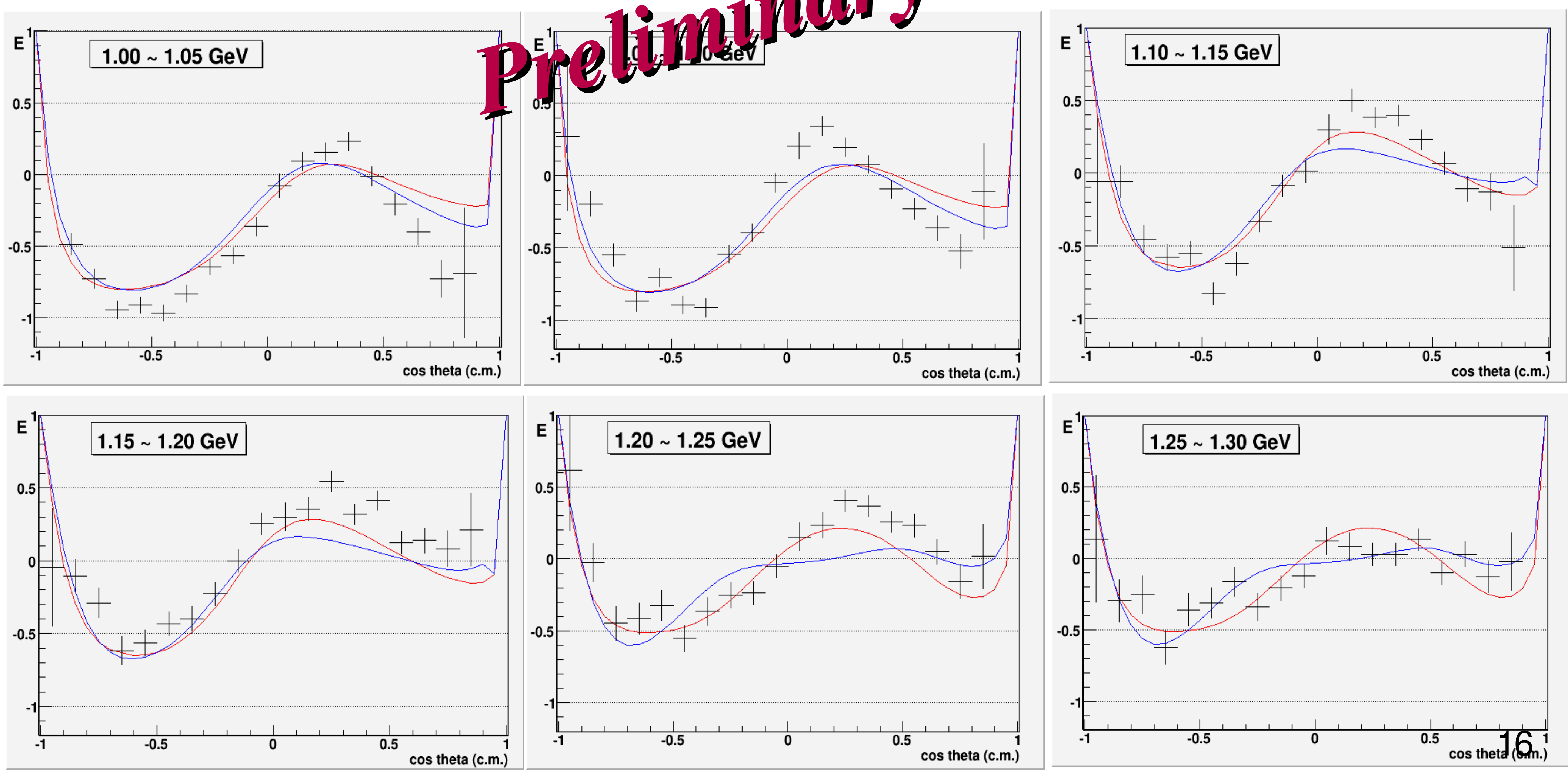
$\cos\theta^{cm}_{\pi^0},\ \Delta E_\gamma = 50\ MeV$

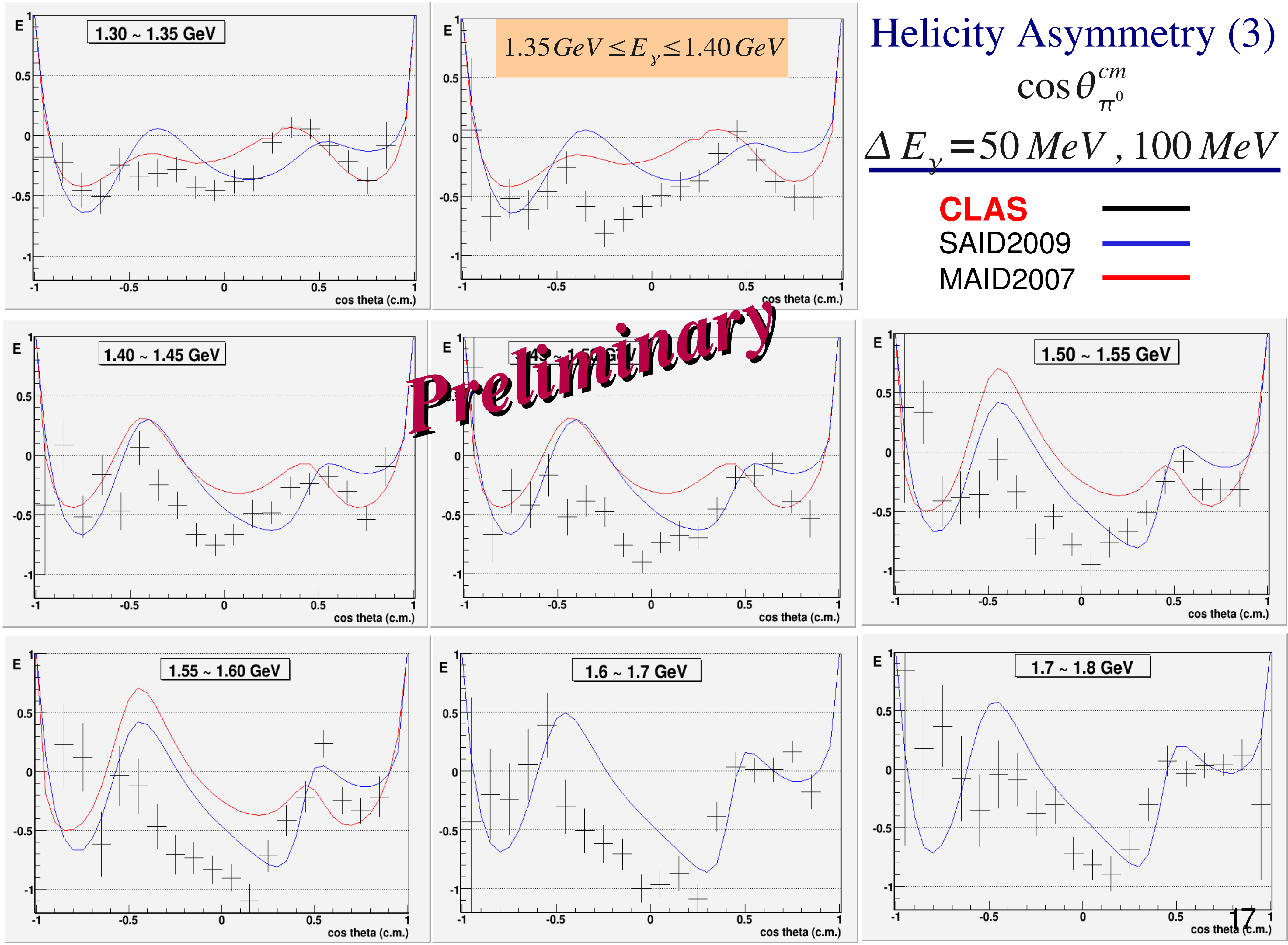
CLAS

SAID2009

MAID2007

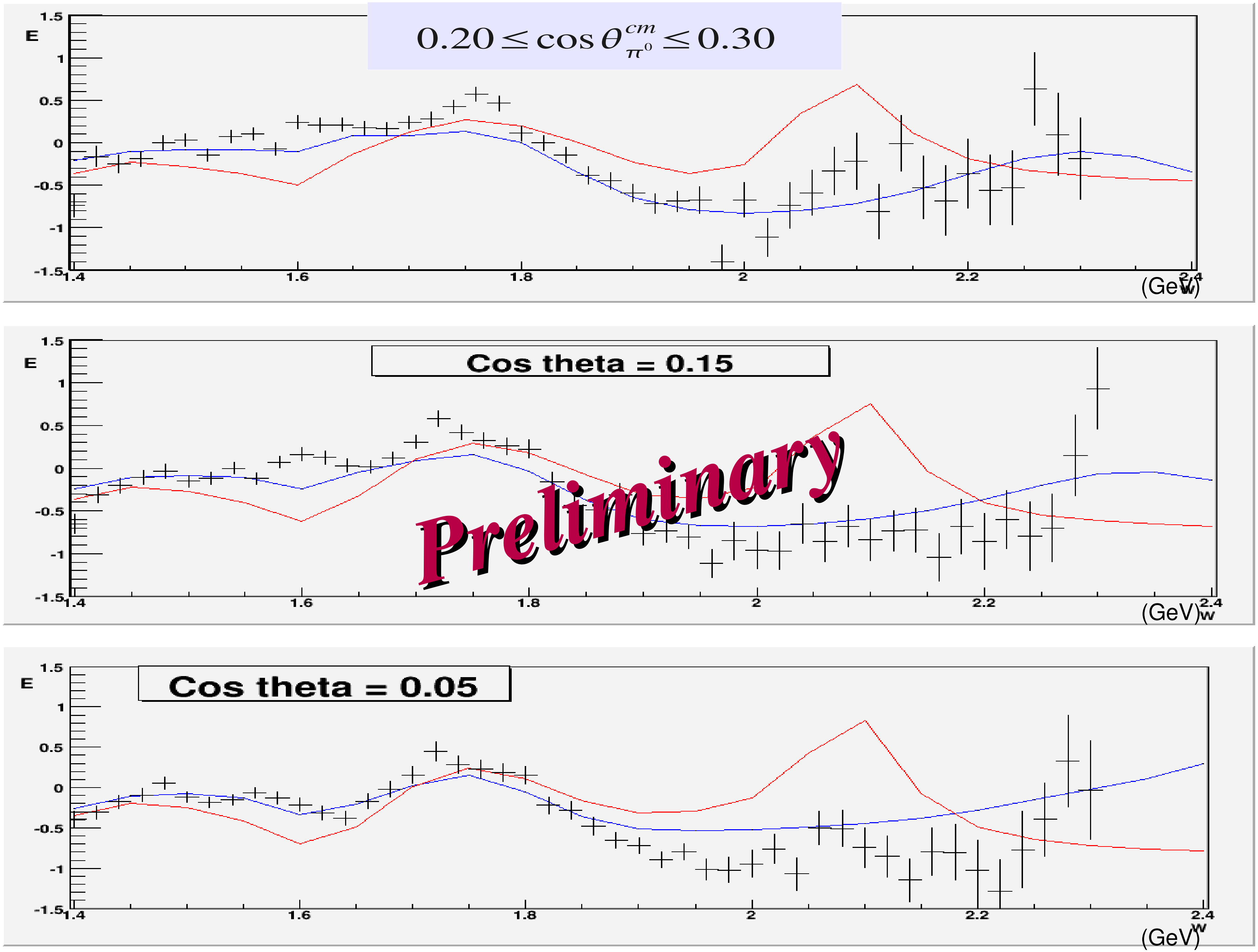





Helicity Asymmetry (3)
$\cos\theta_{\pi^0}^{cm}$
$\Delta E_\gamma = 50\,MeV, 100\,MeV$
CLAS
SAID2009
MAID2007
$1.35\,GeV \le E_\gamma \le 1.40\,GeV$
1.30 ~ 1.35 GeV
1.40 ~ 1.45 GeV
1.50 ~ 1.55 GeV
1.55 ~ 1.60 GeV
1.6 ~ 1.7 GeV
1.7 ~ 1.8 GeV
Preliminary
E
cos theta (c.m.)

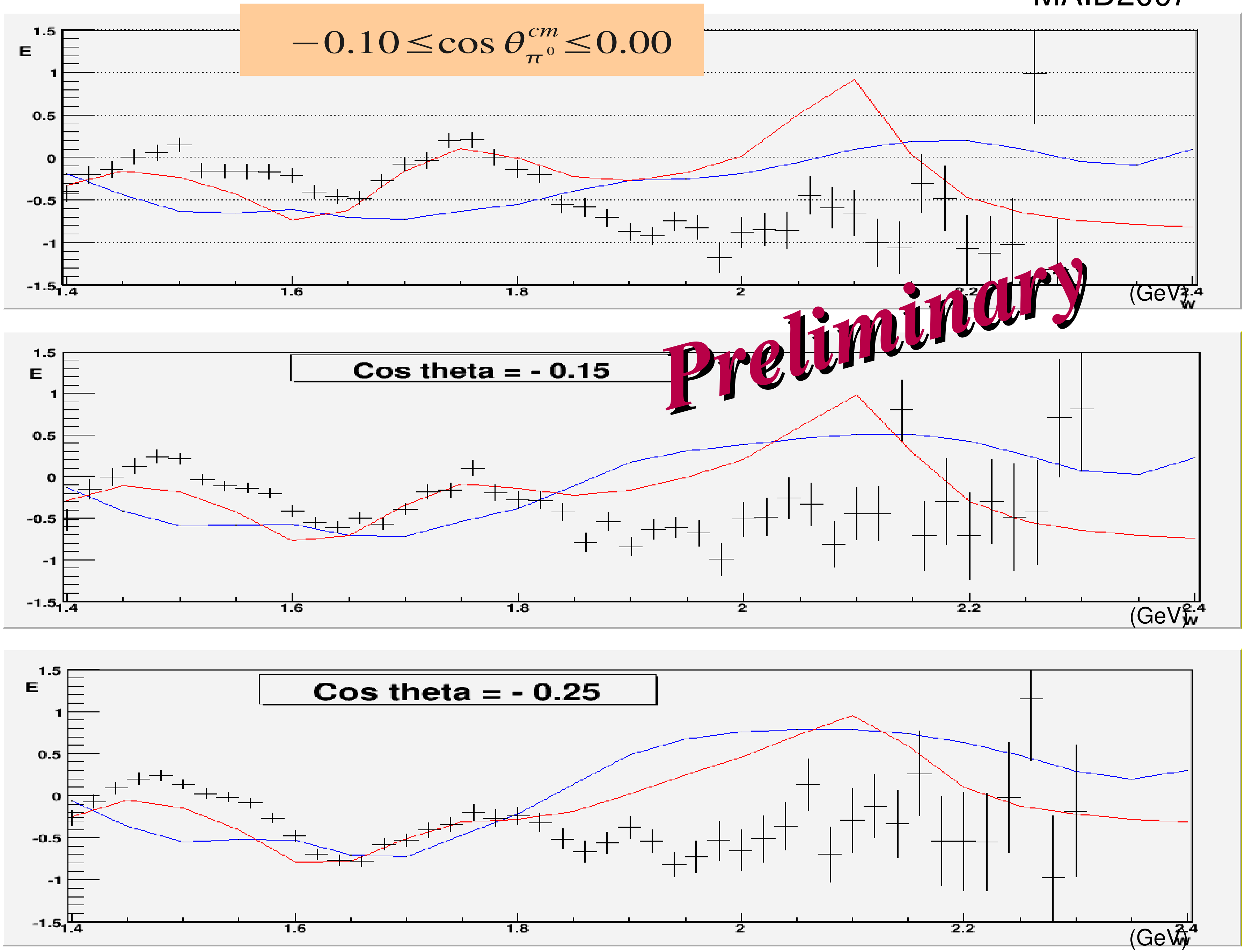
Helicity asymmetry E (4) $W\,,\Delta\cos\theta_{\pi^0}^{cm}=0.1$

CLAS
SAID2009
MAID2007



Helicity asymmetry E (5) $W, \Delta\cos\theta^{cm}_{\pi^0} = 0.1$

CLAS
SAID2009
MAID2007



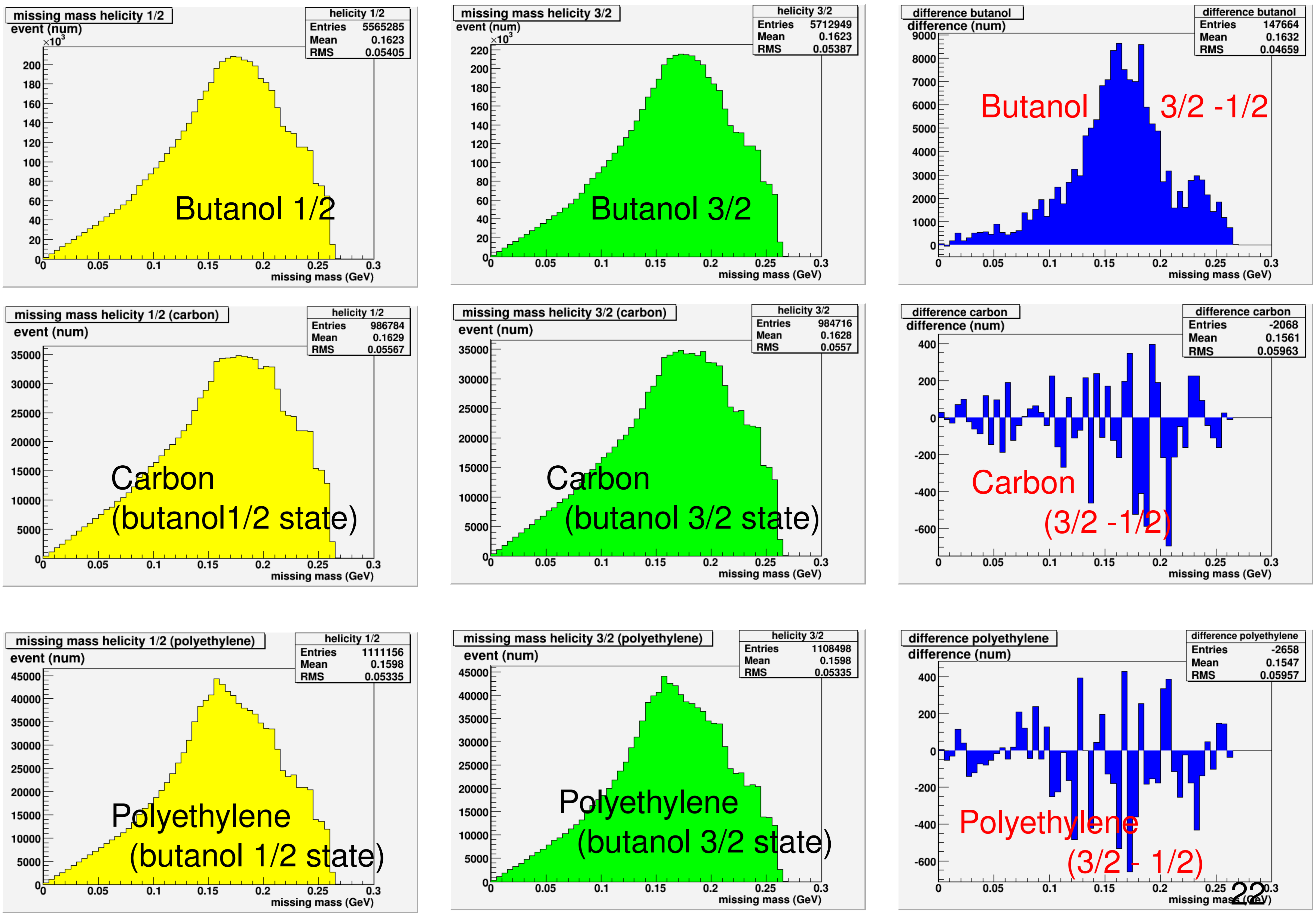
Summary/Conclusion

- The helicity asymmetry E is measured for single π^0 photoproduction with FROST for E_γ = 0.5 – 2.4 GeV.

- At lower E_γ (< 1.35 GeV), the model predictions describe the data (cos θ_{cm}- dependence) well.
- At higher E_γ (> 1.35 GeV), there are some deviation between model calculations and the data (cos θ_{cm}- dependence).
- Significant deviation is observed at the backward π^0 scattering angle, $-0.50 \leq \cos\theta_{cm} \leq 0.0$ and all W values.
- Some deviation is also observed at the backward π^0 scattering angle, $-0.80 \leq \cos\theta_{cm} \leq -0.50$ and 1.4 GeV $\leq$ W $\leq$ 1.7 GeV.
- The new results help constrain the parameters of the models, such as coupling constants and weight of partial waves.

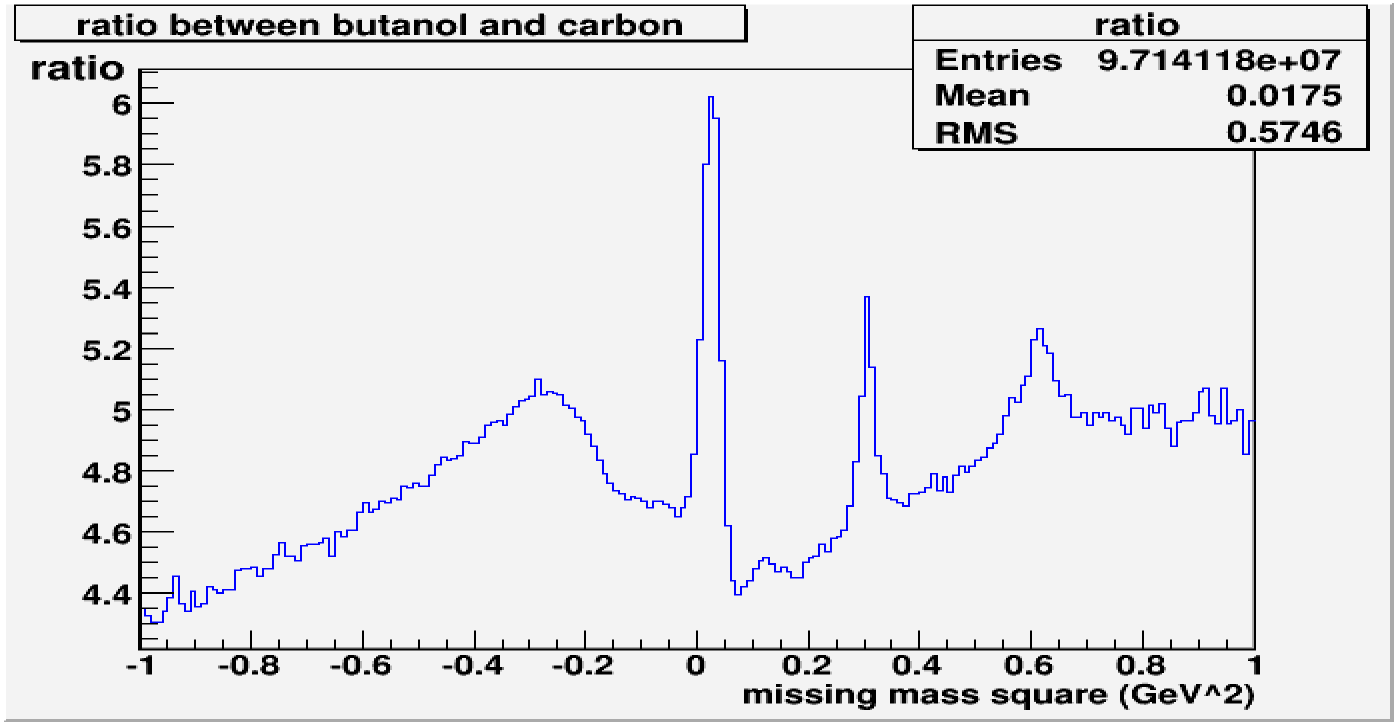
Back up

Target selection (2) - helicity states -



Scale factor (1)

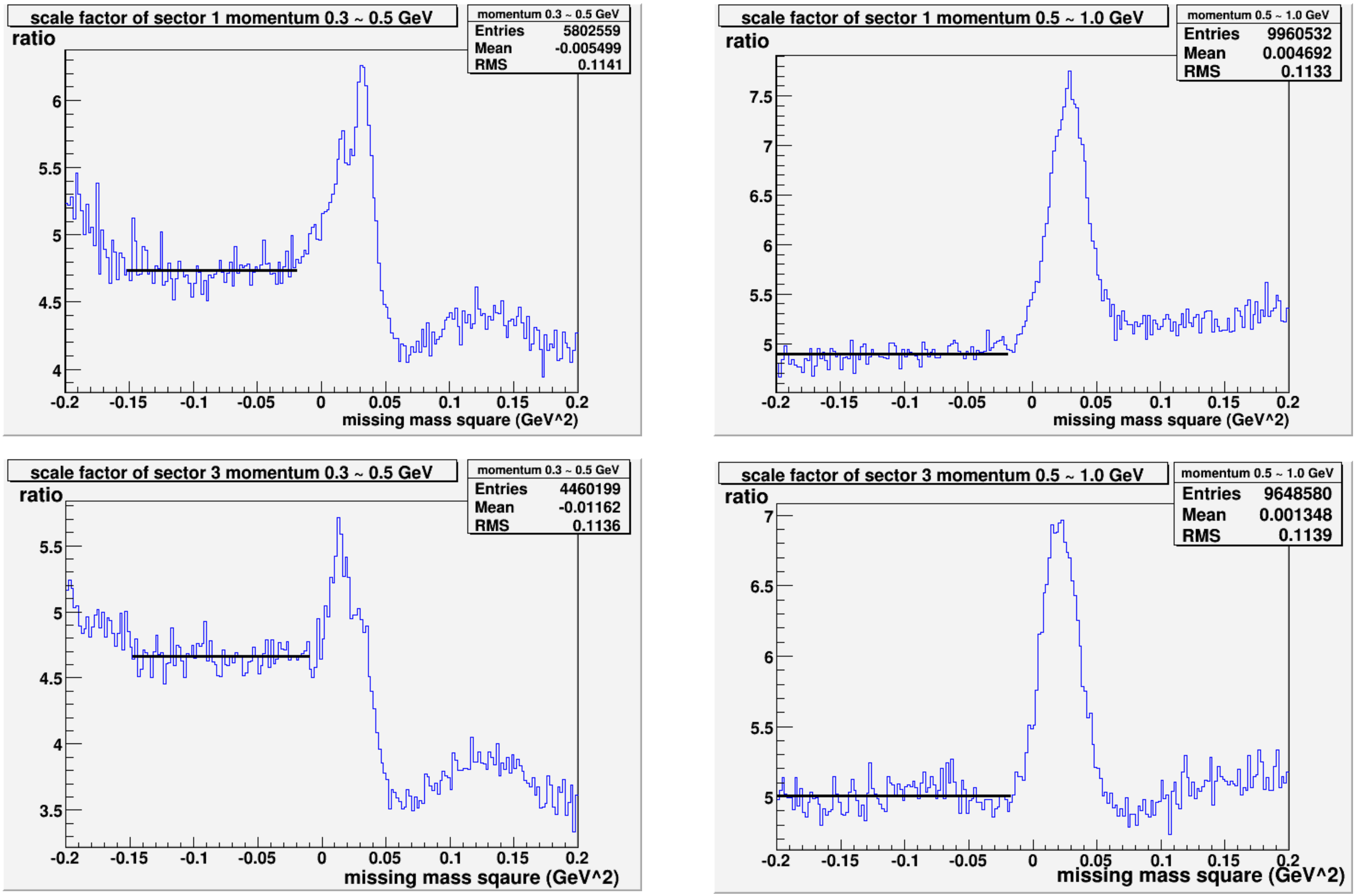
Assume the bound nucleon reaction in the butanol target is quite similar to that in carbon target



Negative missing mass square part → only bound nucleon reaction
Bound nucleon has Fermi motion

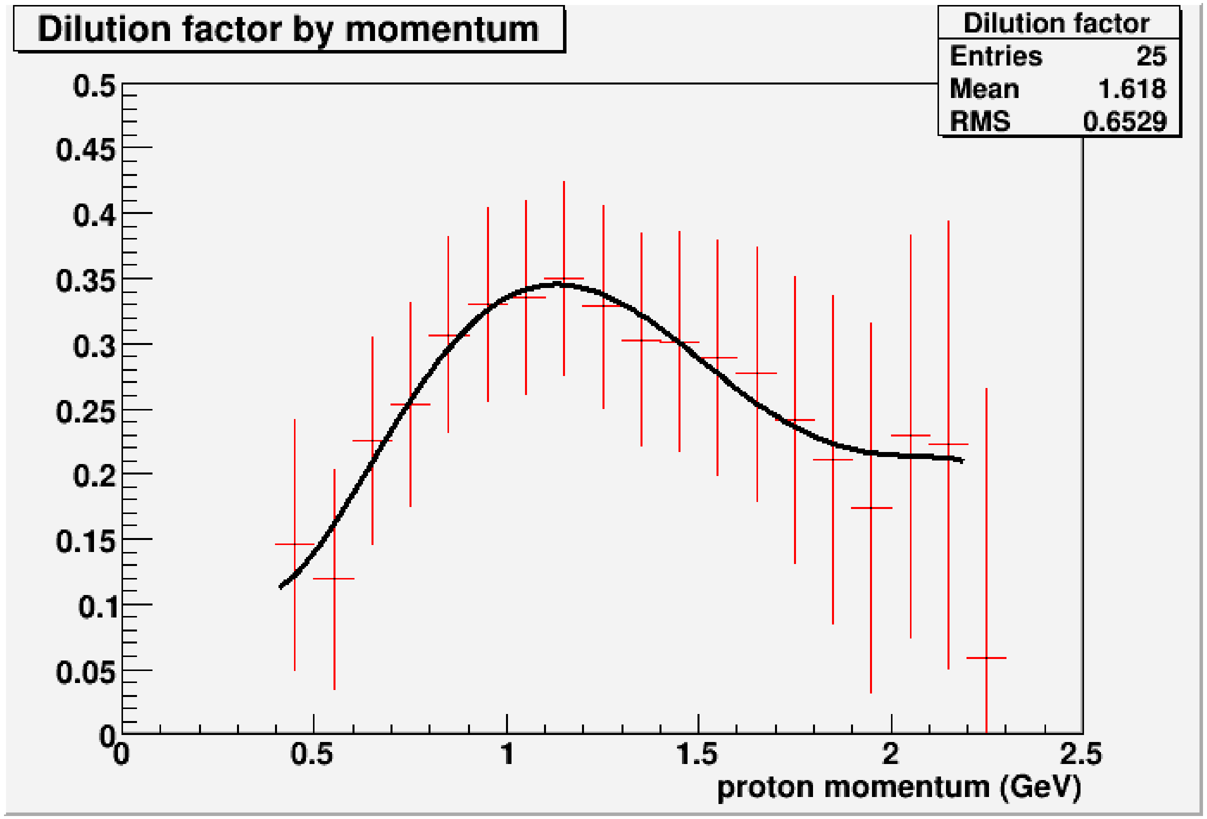
Bump and slope in the negative missing mass square region
→ determine region between -0.2 ~ 0.0 GeV^2

Scale factor (2)



Dilution factor for $\gamma p \rightarrow \pi^0 p$ (2)

$$\text{Dilution factor} = \frac{\text{Free proton reaction}}{\text{Total nucleon reaction}} = 1 - \frac{\text{Scaled carbon}}{\text{Butanol}}$$



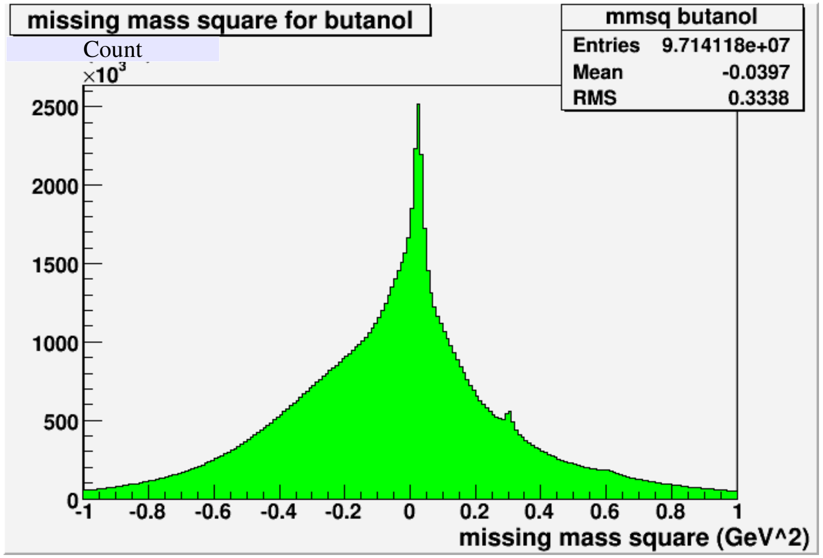
Dilution factor depends on proton momentum
→ fifth-order polynomial

Missing-mass-squared cut

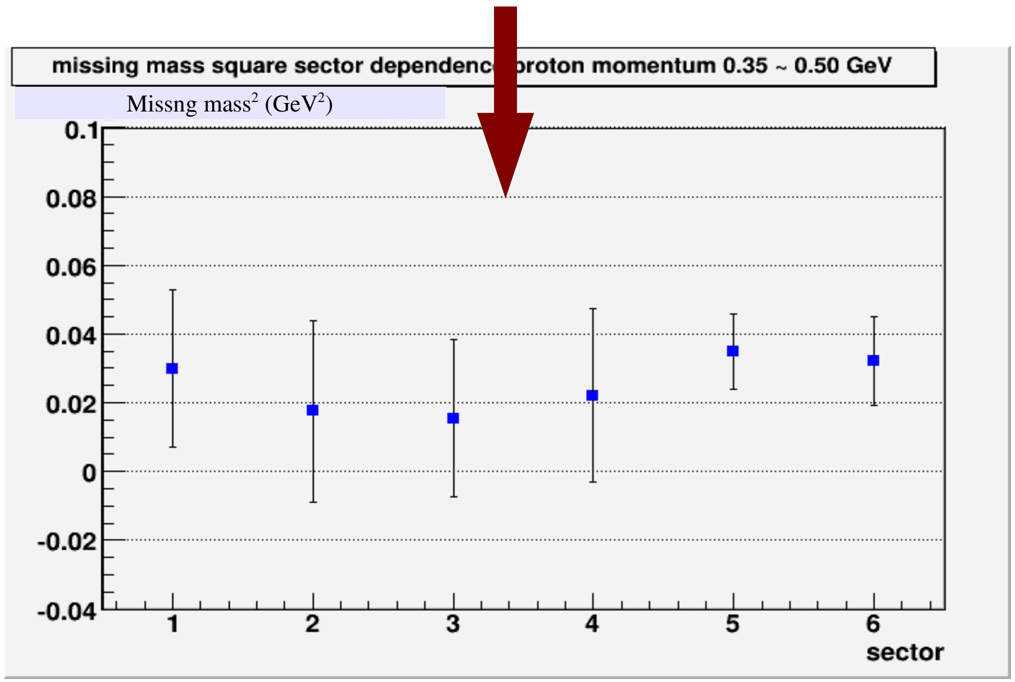
Missing-mass-squared cut depends on the sector and the proton momentum

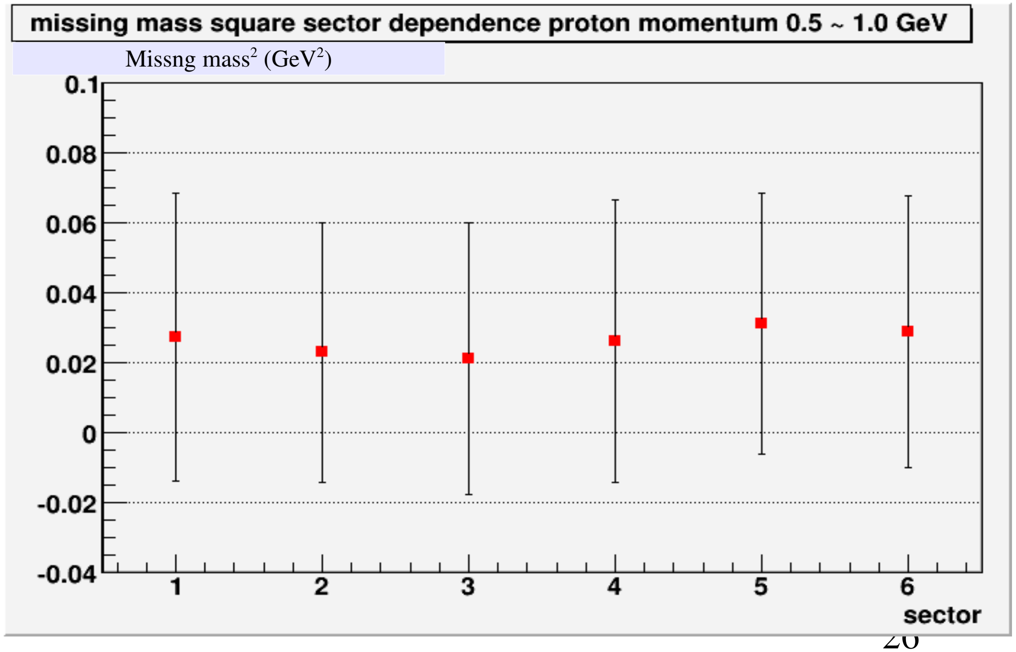
Mean values $\pm$ 3 σ

Low-momentum protons are more sector-dependent

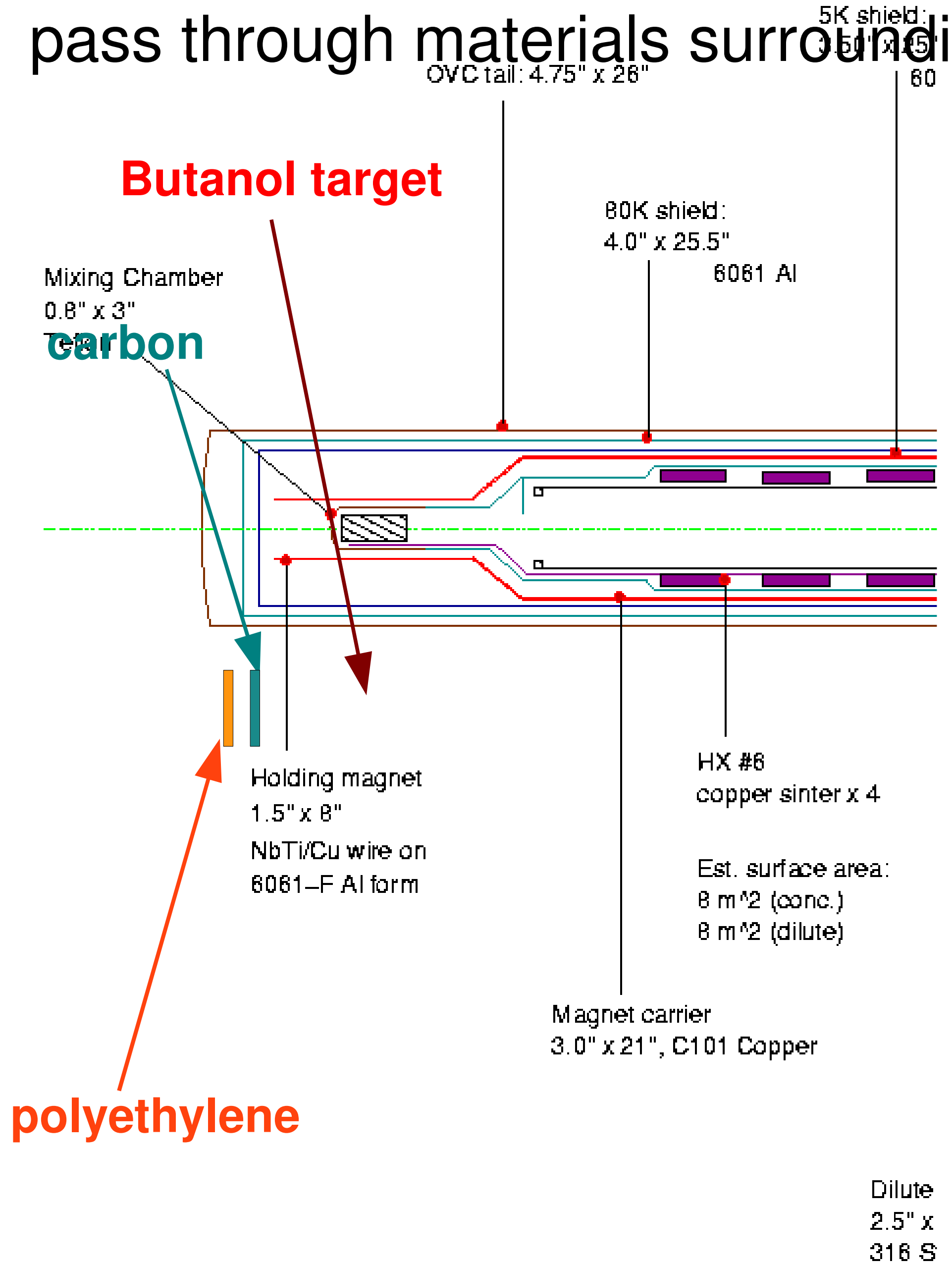


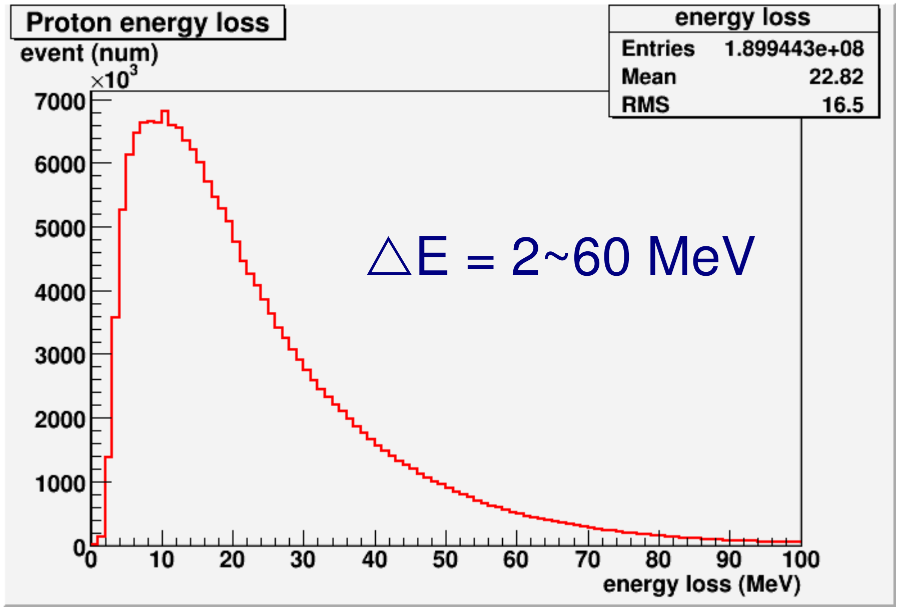
* sector: proton is detected





Protons, especially low-momentum protons, lose energy when they pass through materials surrounding the target.

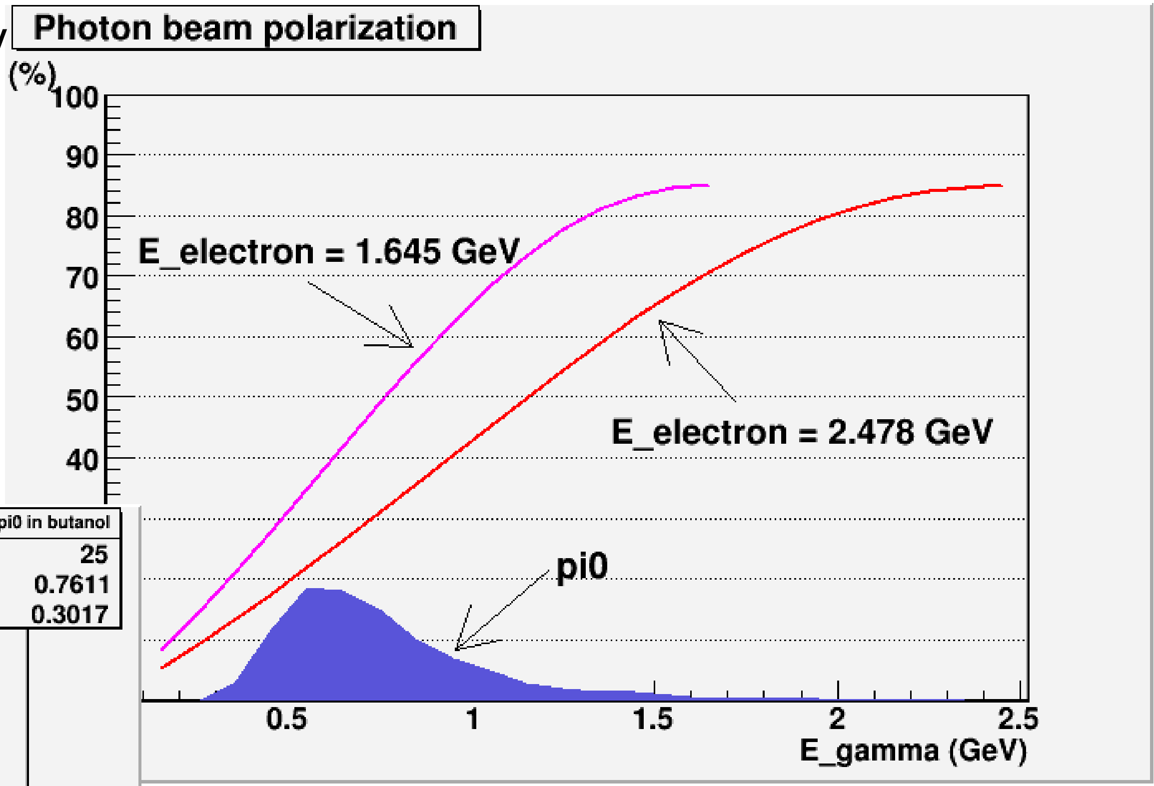


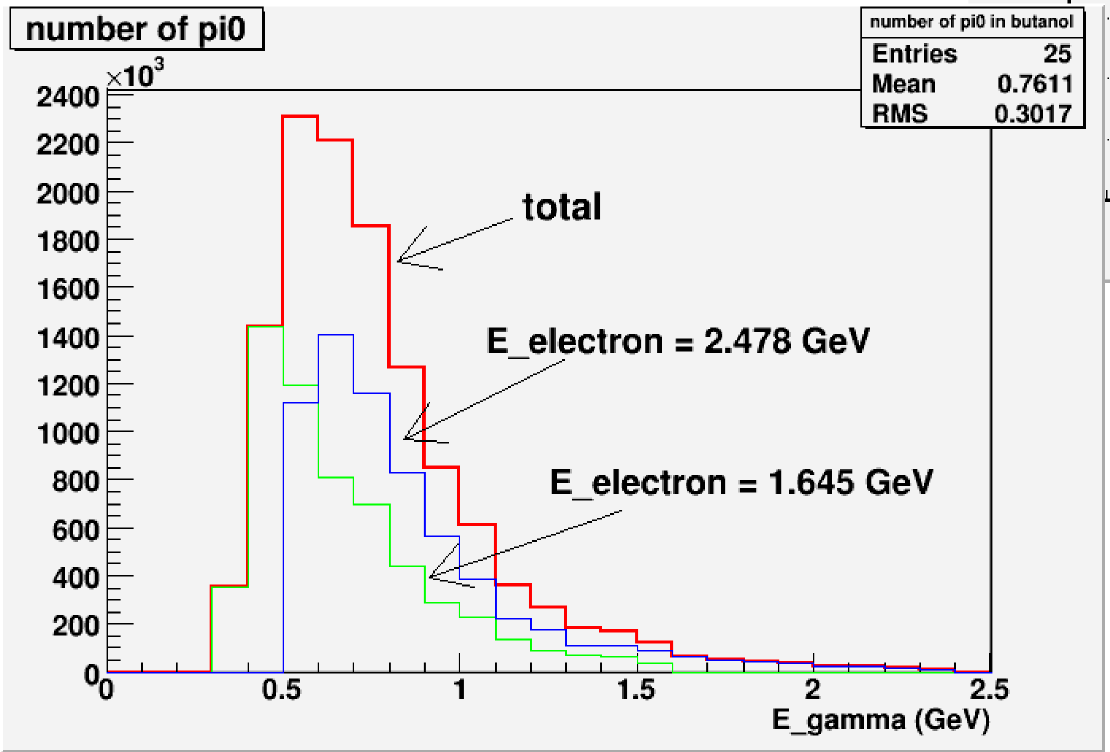


Number of events and polarization

- Helicity state of electron beam changes at rate of 30 Hz
- 7 periods have different direction of target polarization

Period	run number	Beam energy
1	55521 ~ 55536	1.645 GeV
2	55537 ~ 55555	
3	55556 ~ 55595	
4	55604 ~ 55625	2.478 GeV
5	55630 ~ 55678	
6	56164 ~ 56193	
7	56196 ~ 56233	





For majority of events,
photon beam polarization is 15 ~ 65 %.

Fiducial Cuts

Remove events that protons are found in inefficient or inactive region of CLAS (places surrounding the coils of the torus magnet and outside the detectors)

The number of events is reduced to 96.3 %