Double-spin observables in charged pion photo-production from polarized neutrons in solid HD using the CLAS at Jefferson Lab

@SPIN 2016
Sept. 27, 2016; Champaign, USA

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(On behalf of the g14 Analysis Team
and CLAS collaboration)

1. Experimental conditions and our objective

g14 experiments: Dec. 2011 – May. 2012

* Circularly polarized photon beams: $0.85 < E_\gamma < 2.4$ GeV

$\vec{D}$: 27 days → 4.5 B events (Dpol. ~ + 25 %)

Used for this analysis

Extract E asymmetry from $\gamma + n(p) \rightarrow \pi^- + p\ (p)$

2. Experimental apparatus

Circularly and linearly polarized photon beams

CLAS detectors and electron tagging system

Polarized deuteron target (Solid HD)

3. Independent analyses of this E asymmetry with three methods

(a) Background subtraction (1D-Bsub)
(b) BDT (Boosted Decision Trees) [1] : $K^0\Lambda$ analysis
(c) Kinematical fitting [2]

(a): Background from target cell can be subtracted completely

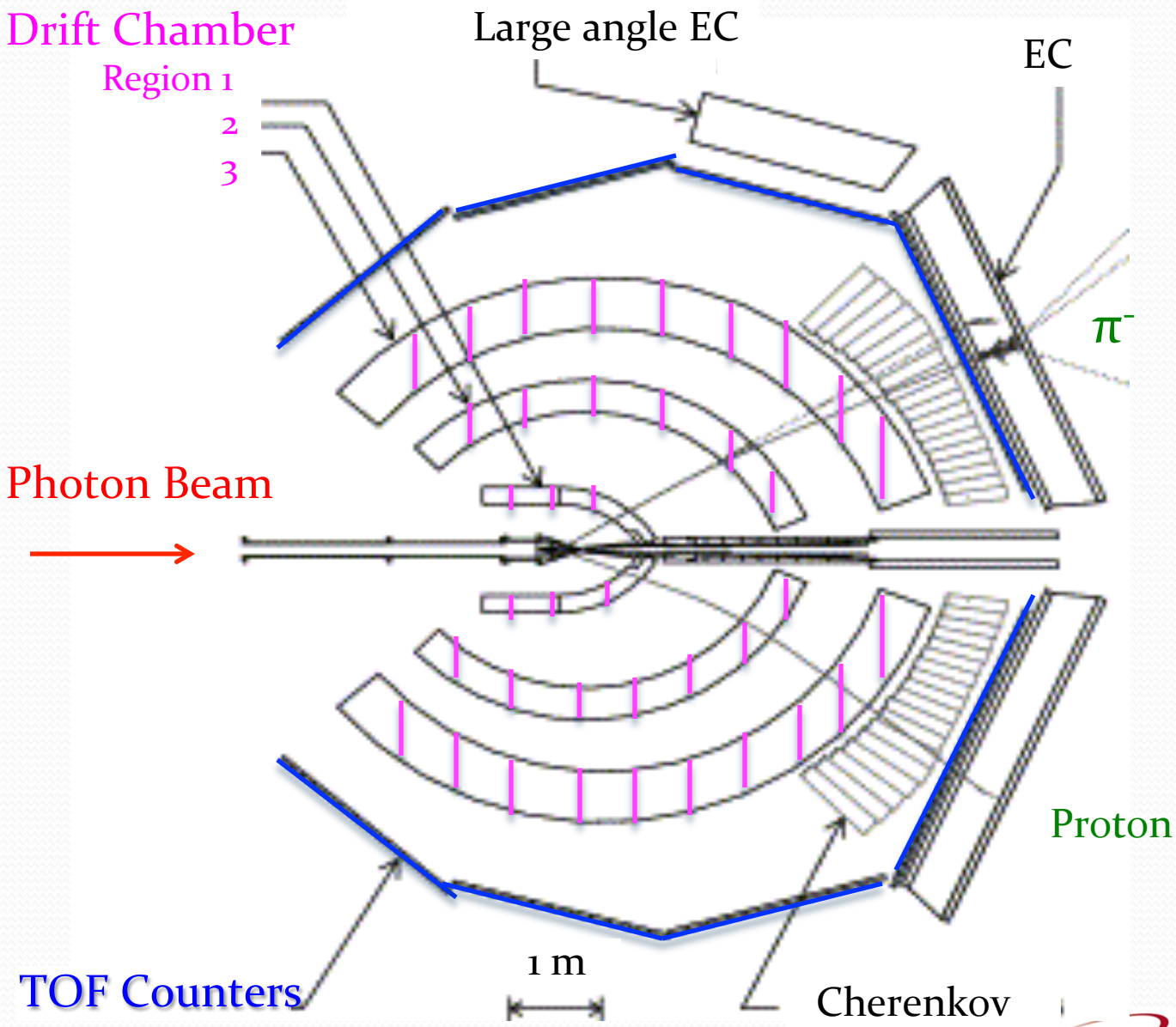
(b) & (c): could be applied to low statistics channels.

Compare and combine the results from three analysis methods

1) from Dao Ho PhD. thesis; "Measurements of the E Polarization Observable for $\gamma d \rightarrow \pi^- p(p_s)$, $\gamma d \rightarrow K_0\Lambda(p_s)$, and $\gamma d \rightarrow \pi^+\pi^- d(0)$ using CLAS g14 data at Jefferson Lab"

2) from Peng Peng PhD thesis; "**Polarization observables for single and double charged pion photo-production with polarized HD target**"

CLAS detector side view (reconstruct and identify π^- & proton)

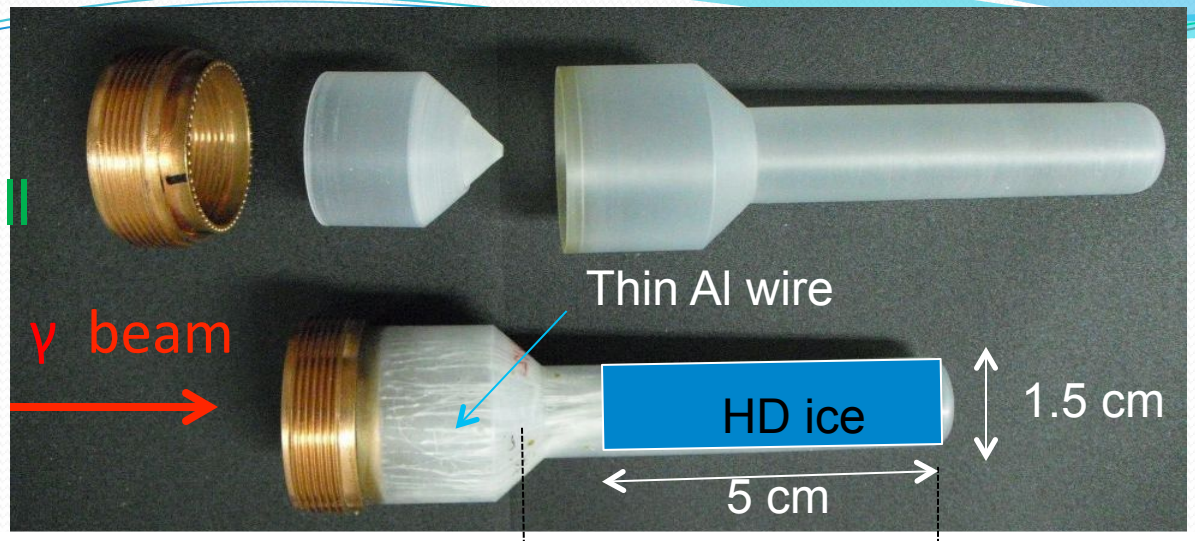


Common corrections for E asymmetry on $\gamma + n(p) \rightarrow \pi^- + p\,(p)$

(a) Energy loss correction
(b) Momentum correction
(c) Tagger photon beam energy correction

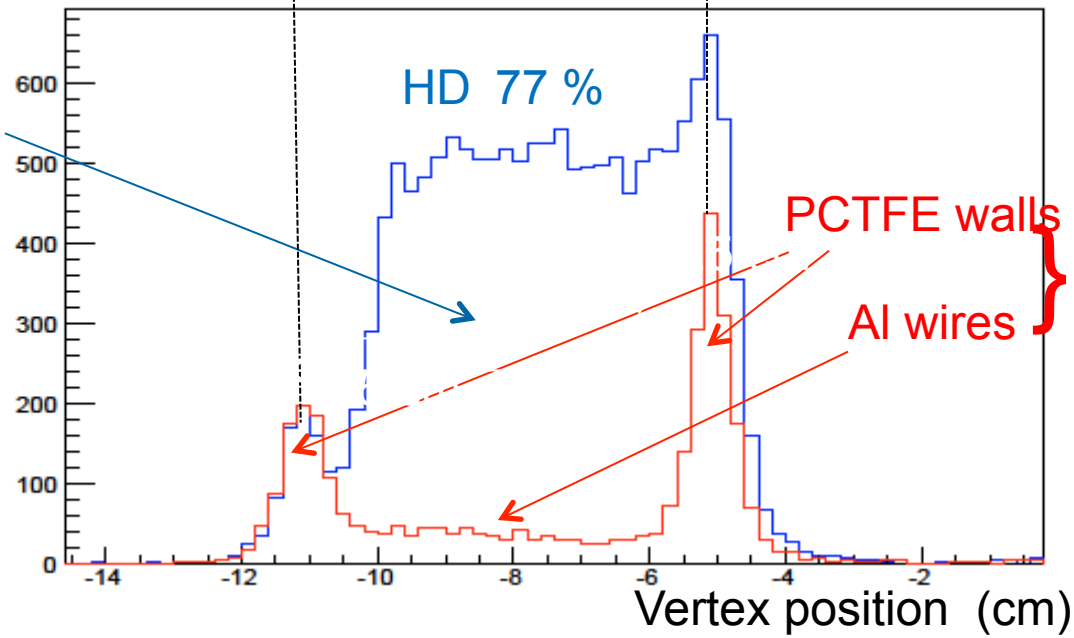
(a) Background subtraction method (No.1)

Target Cell



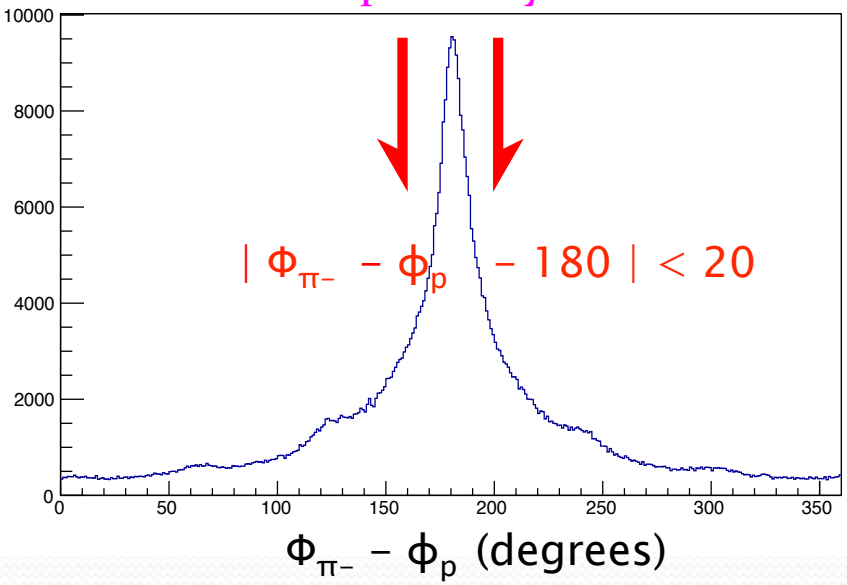
Reconstructed vertex (beam direction) for π^- and proton

HD and target cell



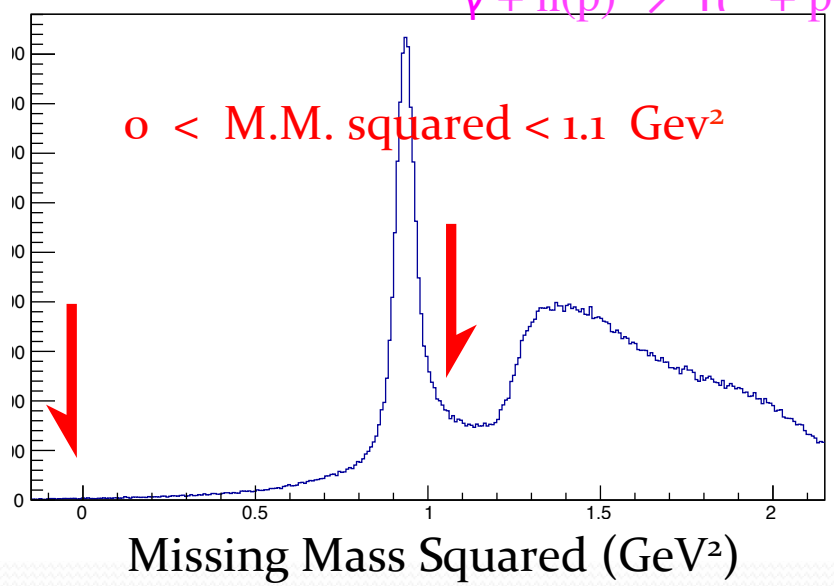
(a) Background subtraction method (No.2); Major cuts

Coplanarity cut

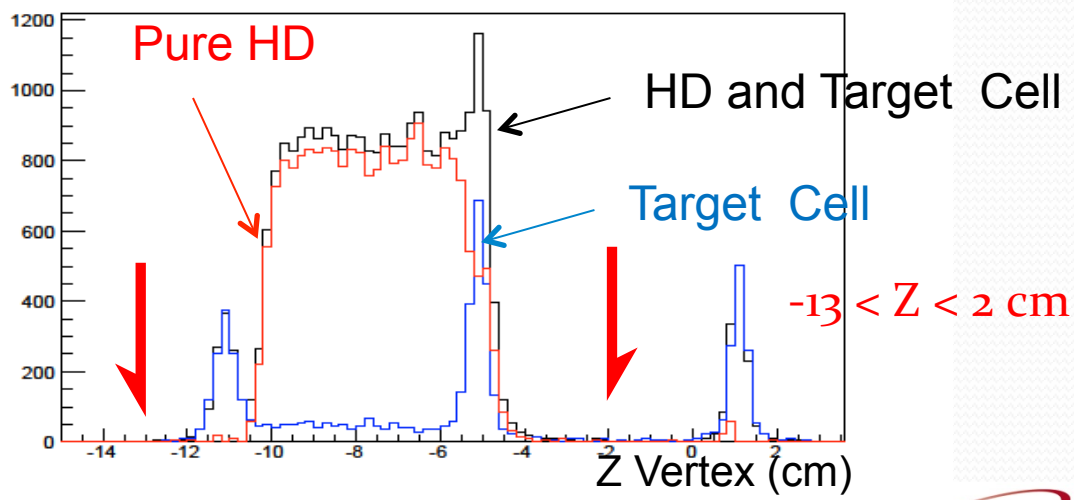


Missing Mass Squared cut

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



Target cell background subtraction & vertex cut



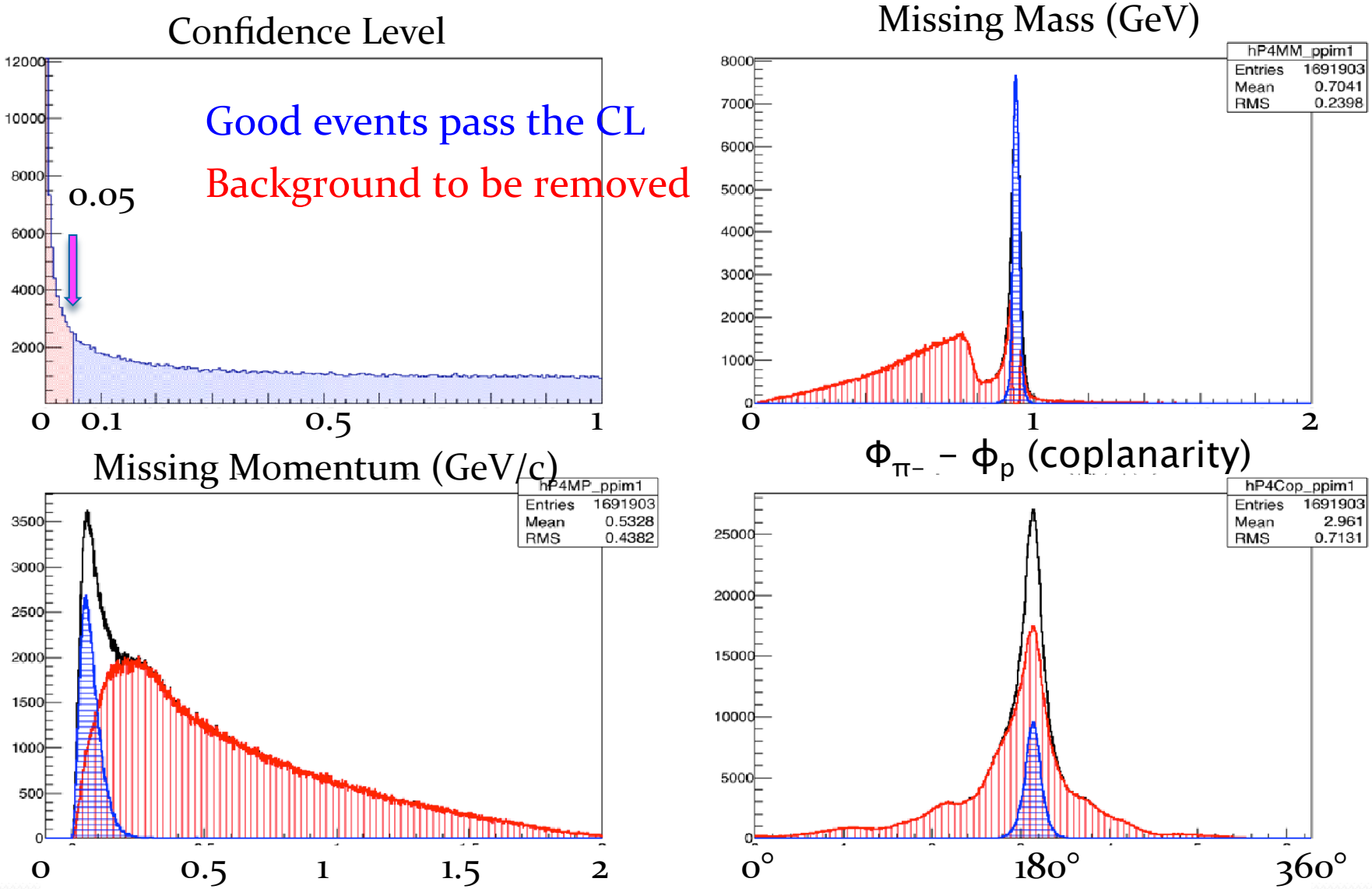
(b) Kinematic fitting method (No.1)

- Apply a hypothesis to the fitter; $\gamma + (n) \rightarrow \pi^- + p$;
- Assume a moving target neutron with unknown Fermi momentum

➡ this method removes the events from

* high-momentum neutrons in the deuteron (automatically)
* Target cell background
* Background from 2 pion productions

(b) Kinematic fitting method (No.2) ; $\gamma + (n) \rightarrow \pi^- + p$



(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.1)

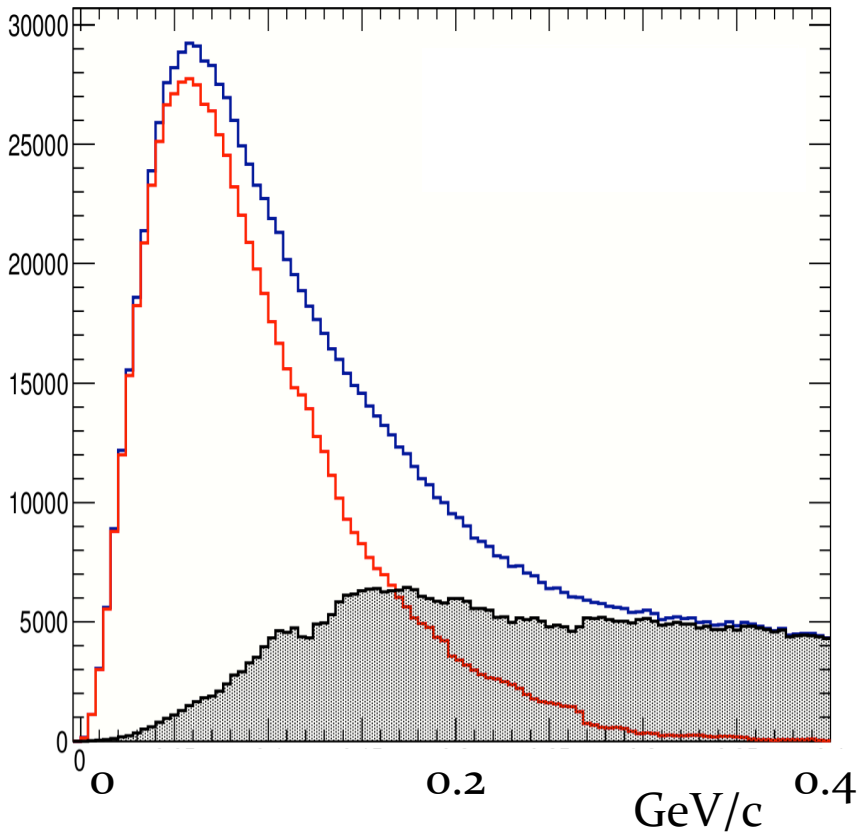
* To reject two backgrounds
  - Target cell
  - Other channels (2 Π productions)

* Train data with
  - signals from Monte Carlo (CLAS geometry and performances)
  - background from target cell data

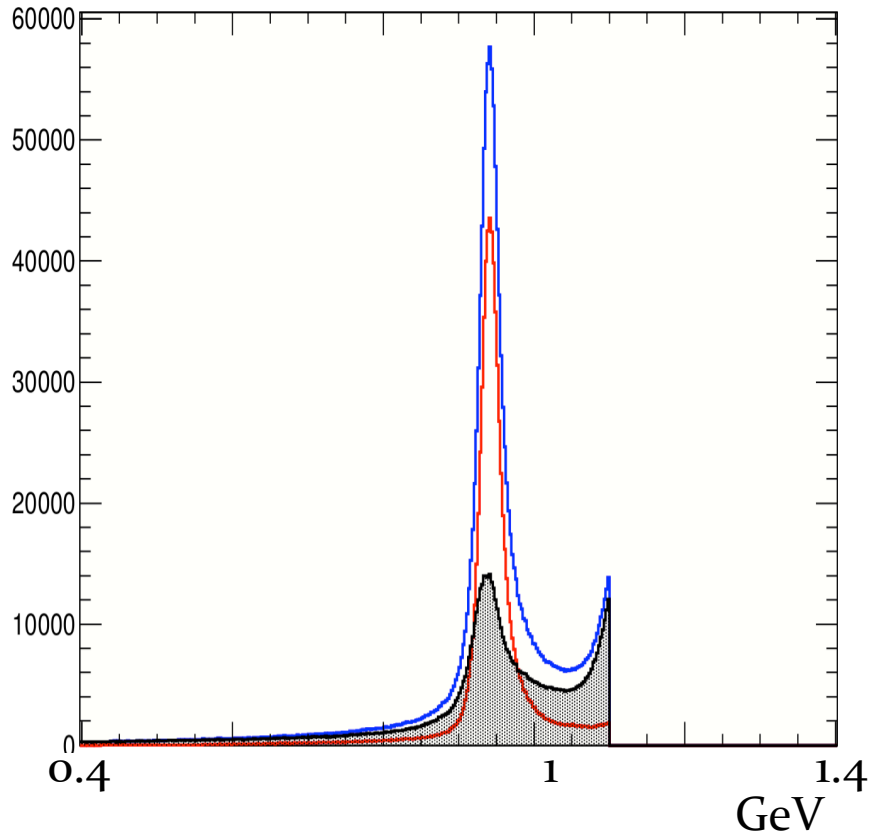
(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.2)

* Before (Blue) and after (Red) BDT applied

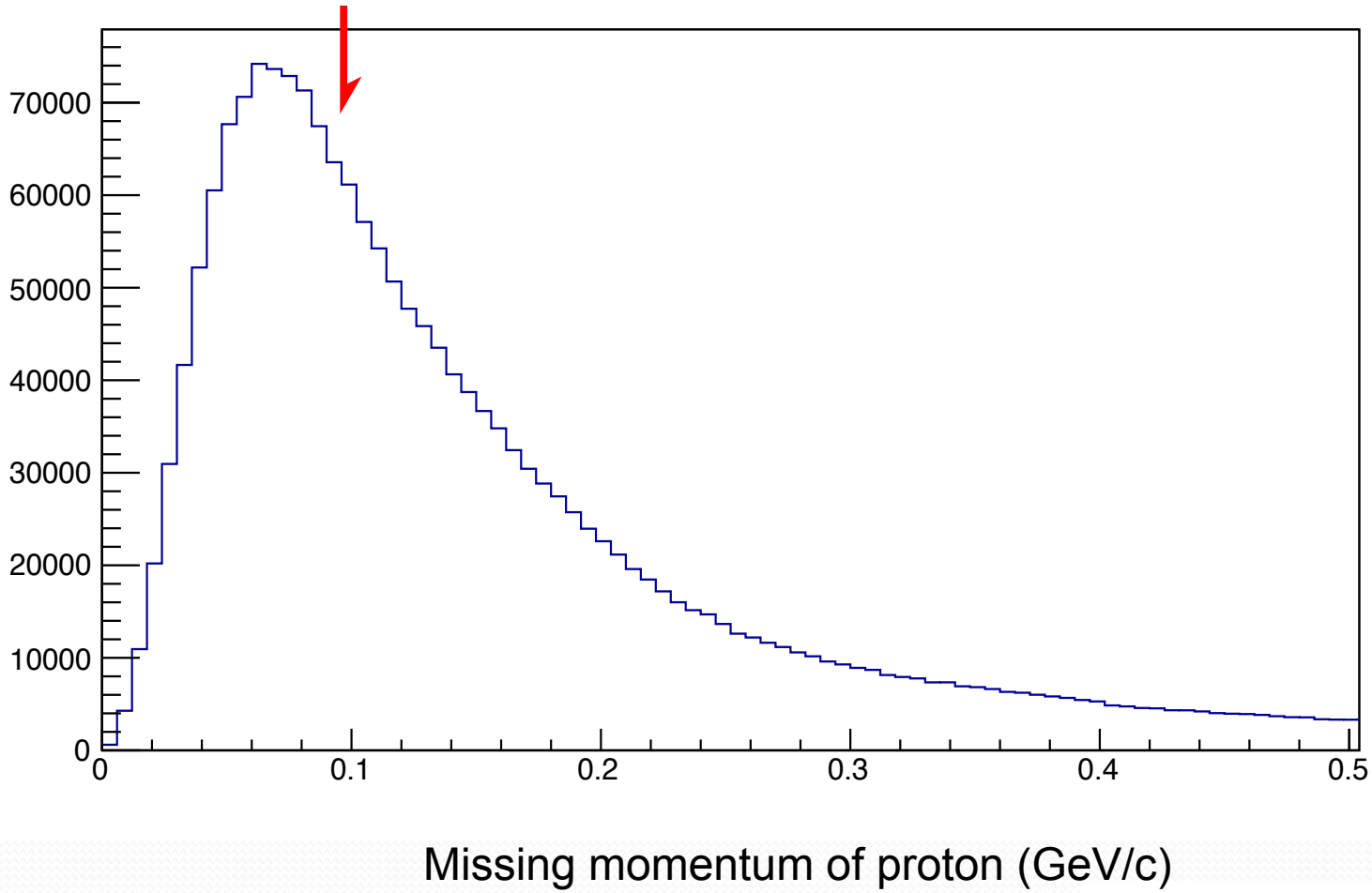
Missing Momentum



Missing Mass

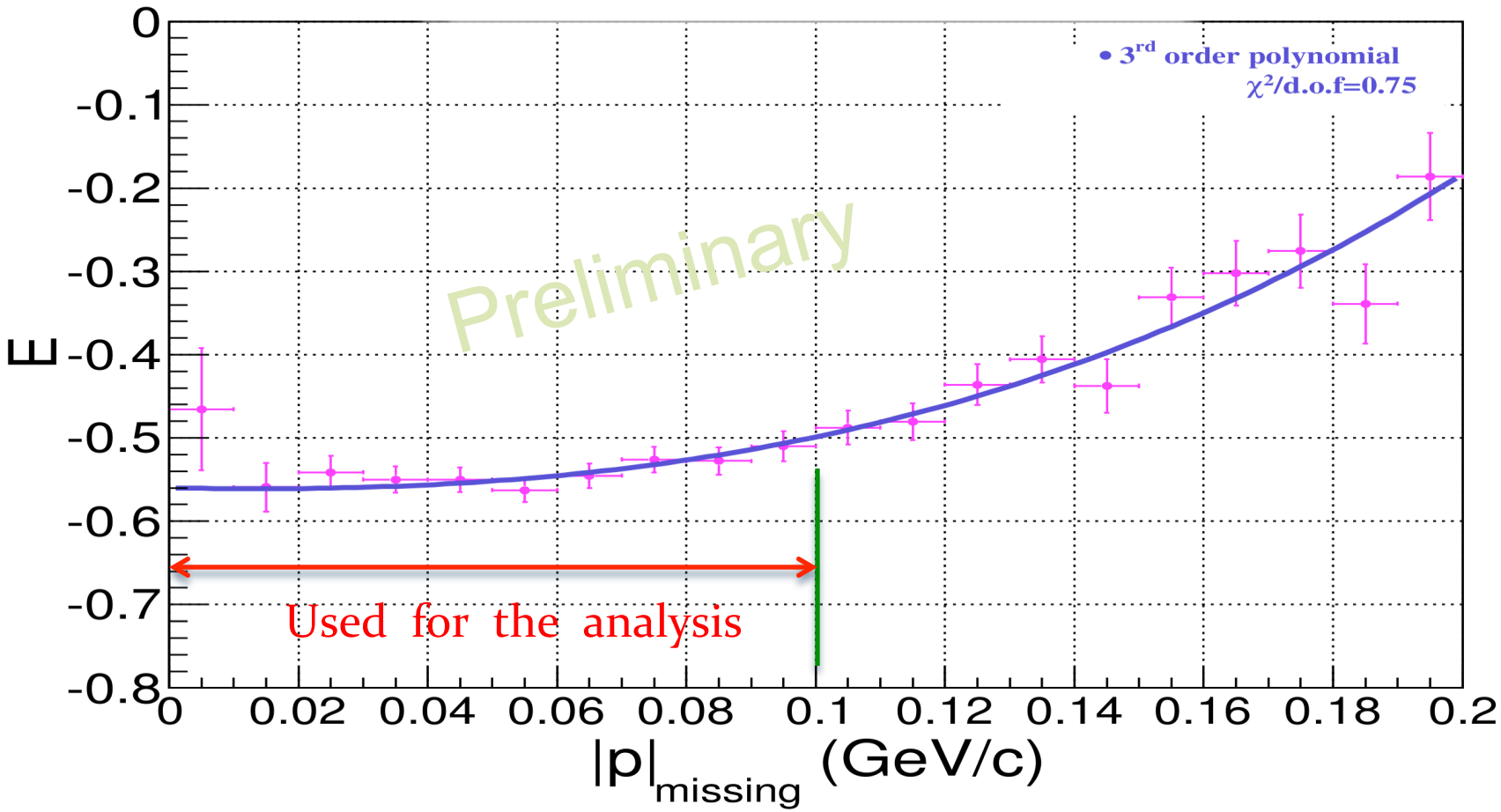


* Common cut for Missing momentum to the three methods

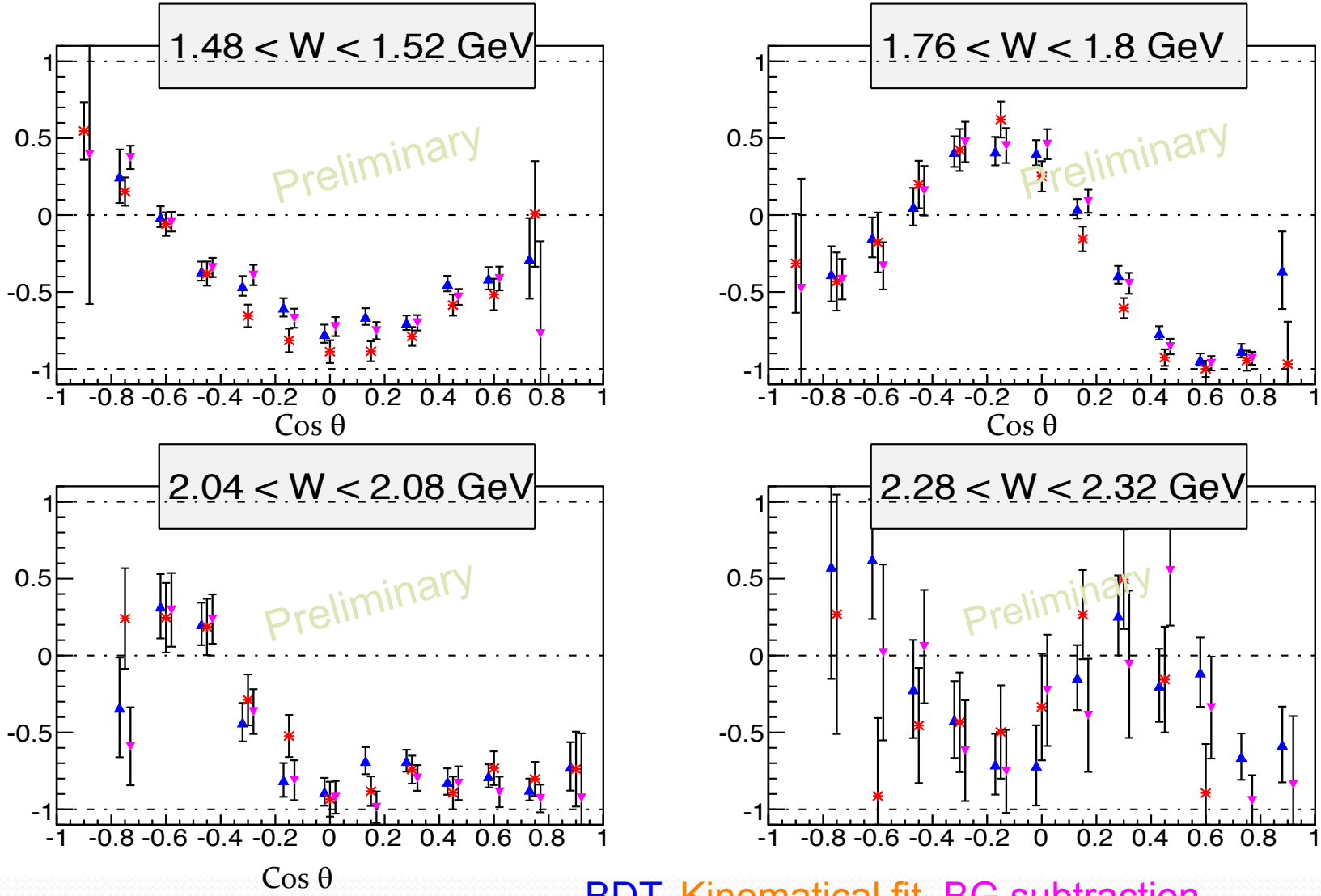


E asymmetry dependence on the missing momentum ranges (all energy and integrated to cos θ_{CM} of π-)

(BDT method)



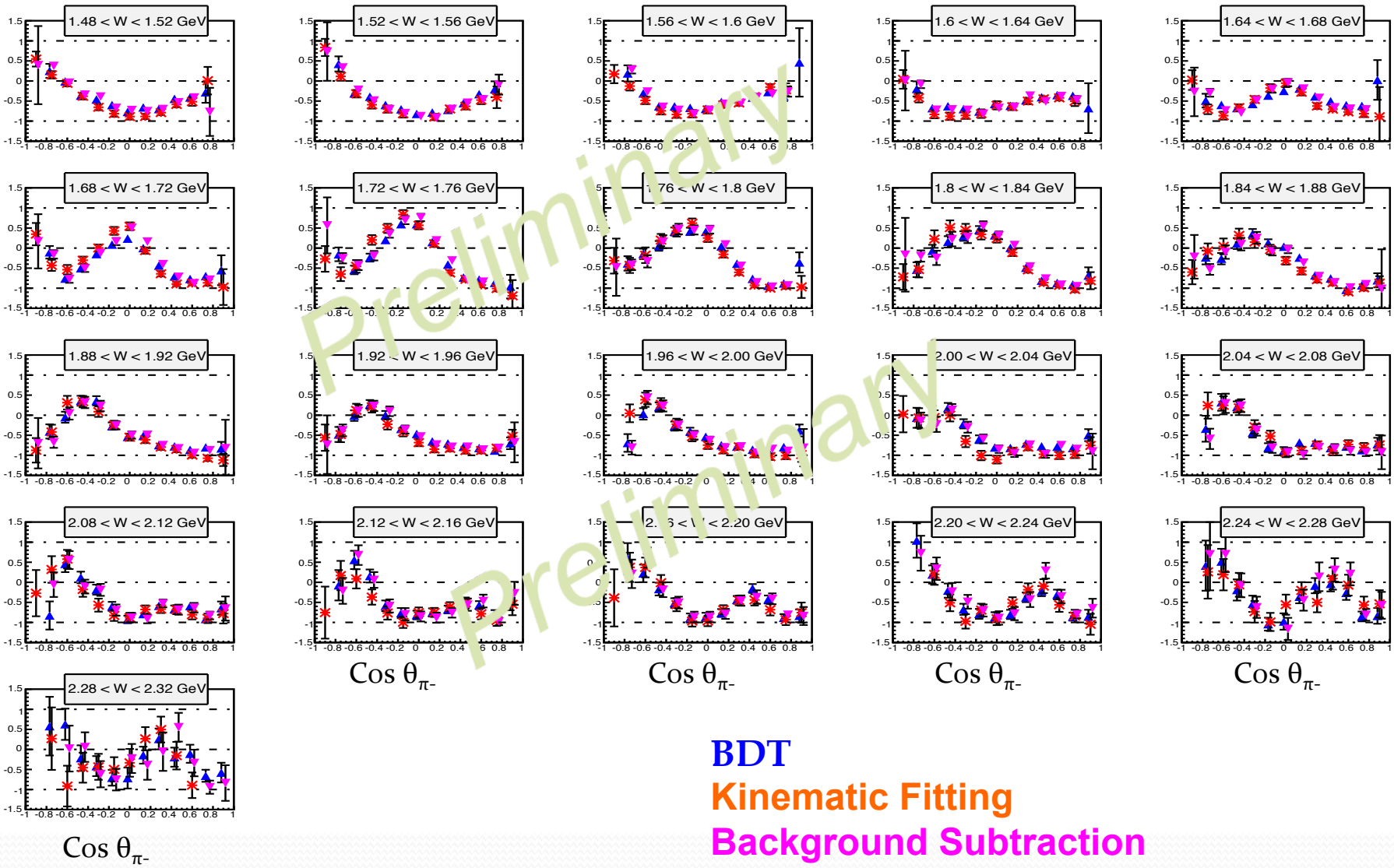
4. Preliminary results; E asymmetries from 3 methods for $\gamma + n(p) \rightarrow \pi^- + p(p)$ ($\cos\theta_{CM}$ of π-)



BDT, Kinematical fit, BG subtraction

E asymmetries for γ+n (p) → π⁻+ p + (p)
Comparisons of three methods

(as a function of Cos θ_{CM})

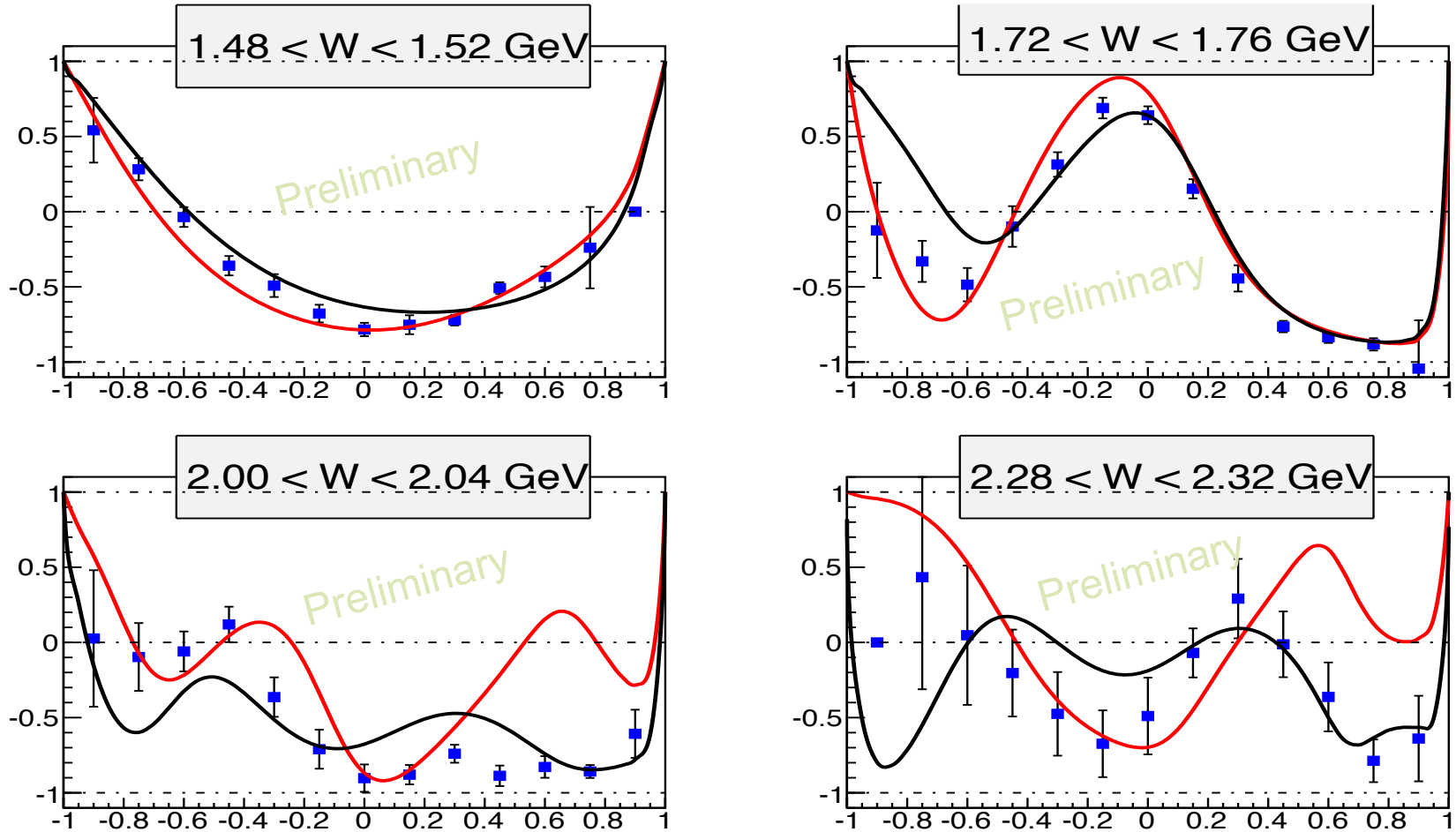


BDT

Kinematic Fitting

Background Subtraction

E asymmetries for combining 3 methods with PWA analysis for $\gamma + n(p) \rightarrow \pi^- + p(p)$ ($\cos\theta_{CM}$ of π-)



Cos θ

Errors: statistical only

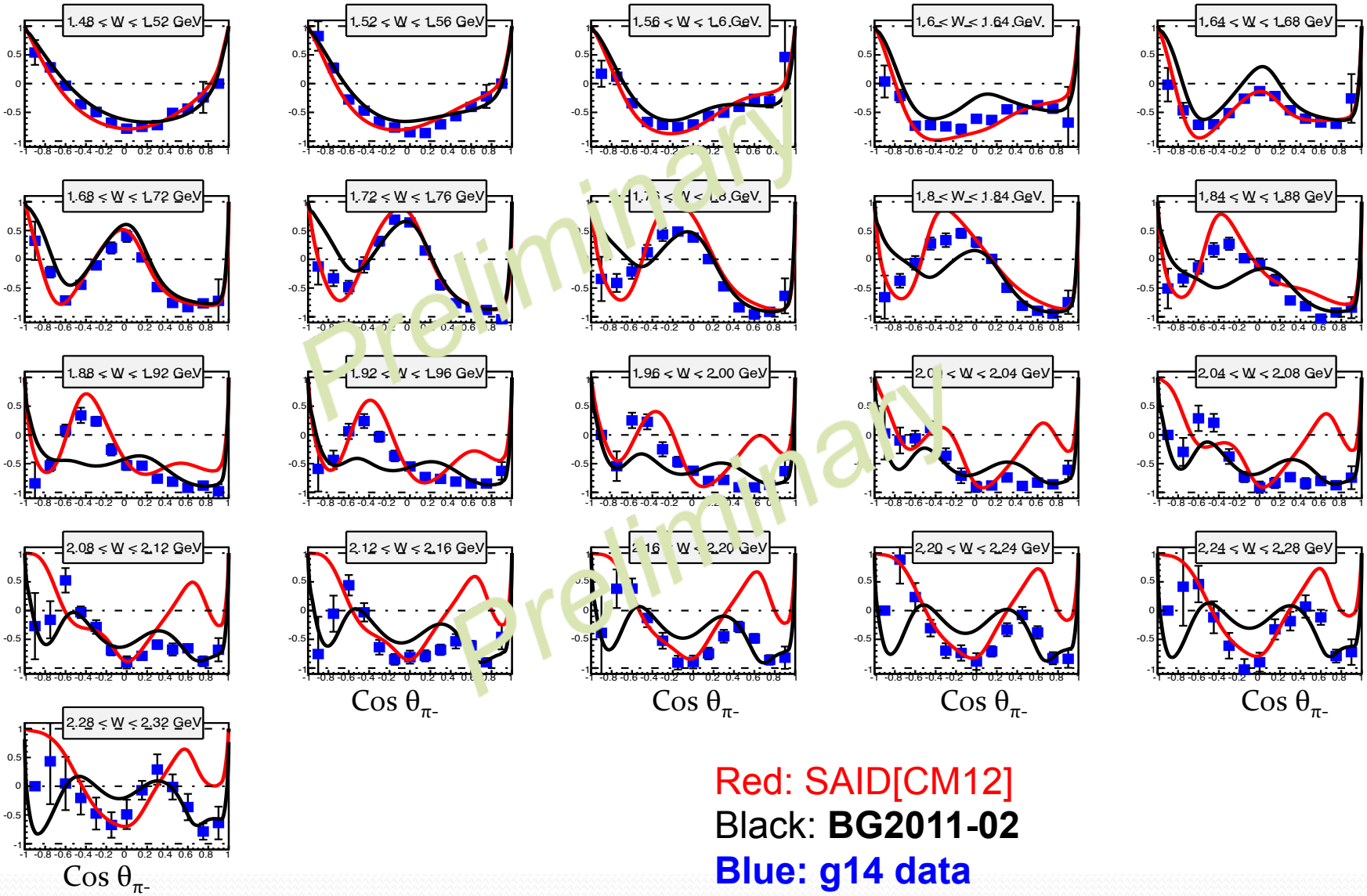
Red: SAID[CM12]

Black: **BG2011-02**

Blue: g14 data

E asymmetries for γ+n (p) → π⁻+ p + (p) (3 methods combined)

All energy bins from this experiment (as a function of Cos θ_{CM})



Red: SAID[CM12]

Black: **BG2011-02**

Blue: g14 data

Combined systematic errors (relative) for the three analysis methods

Contributions to σ_{sys}	σ_{sys}		
	1D-Bsub	kinematic fit	BDT
z-vertex cut / Kel-F suppression:	2.6 %	1.4 %	1.7 %
Confidence level cut / BDT cut:		1.3 %	0.7 %
Missing momentum cut:	1.7 %	2.9 %	1.4 %
PID cut:	1.3 %		
Missing mass cut:	1.4 %		2.6 %
Coplanarity cut:	0.4 %		
Monte Carlo (DC resolution):			0.4 %
Extrapolation to $\lvert p_{missing} \rvert = 0$	2.2 %	2.2 %	2.2 %
σ (cuts)	4.3 %	4.1 %	4.1 %
Photon beam polarization:	3.4 %	3.4 %	3.4 %
Target polarization:	6.0 %	6.0 %	6.0 %
σ (polarization):	6.9 %	6.9 %	6.9 %
σ (total)	8.1 %	8.0 %	8.0 %

5. Summary

a. Completed experiments for pseudoscalar-meson photo-production from longitudinally polarized HD at CLAS for 64 days of circularly and 30 days of linearly polarized photon beams.

b. Preliminary results for E asymmetry for $\gamma + n(p) \rightarrow \pi^- p\ (p)$ were shown. Systematic errors are estimated.

c. Study of Σ and G asymmetries for $\gamma + n(p) \rightarrow \pi^- p\ (p)$ is ongoing

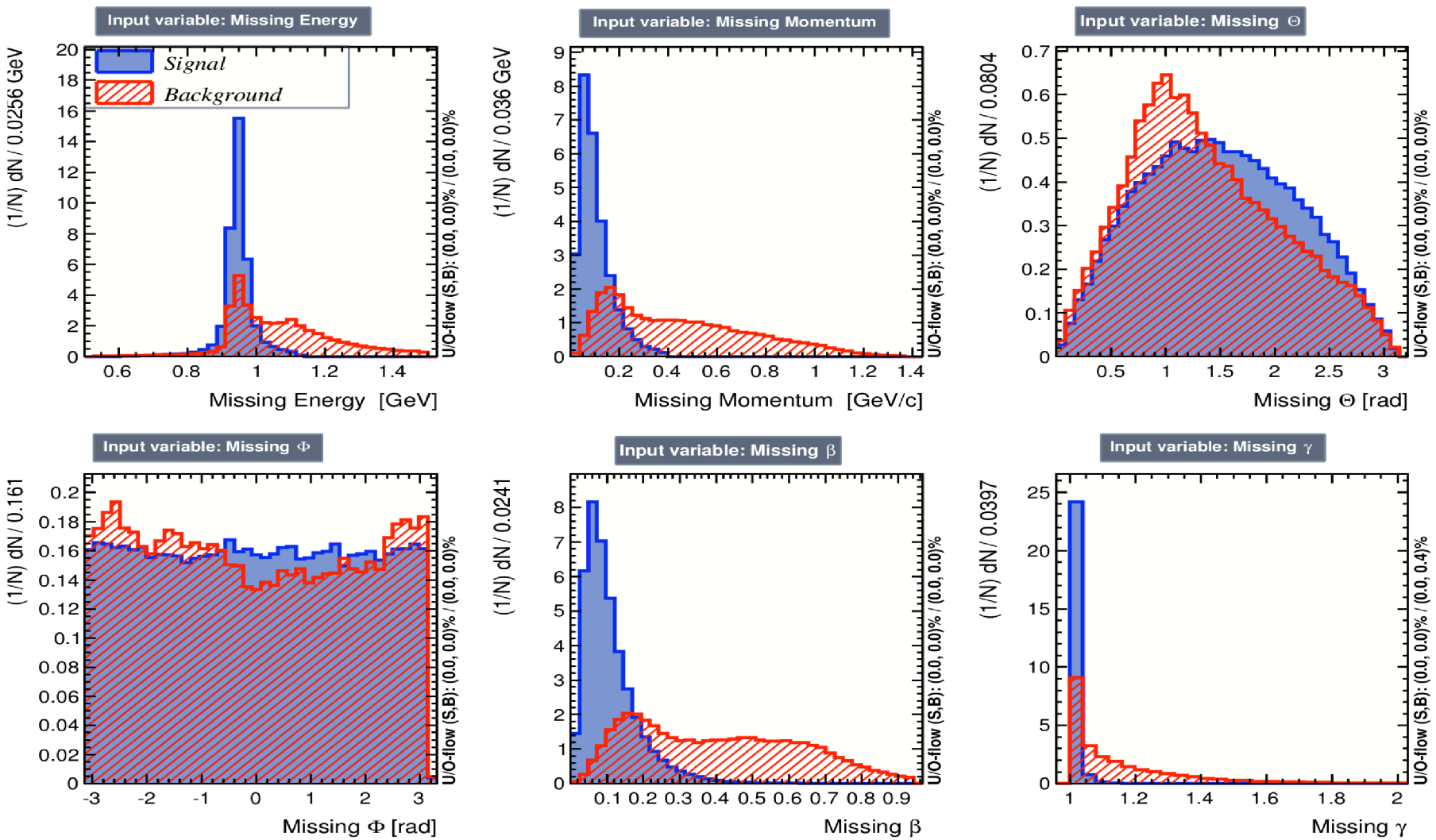
d. Analyses for other channels, like $\gamma + p(n) \rightarrow p\ \pi^+ \pi^-\ (n)$, $\gamma + n(p) \rightarrow n\ \pi^+ \pi^-\ (p)$, $K^0\Lambda$ and $K^+\Sigma^-$ are in progress.

e. For vector meson production, $\gamma + p(n) \rightarrow p\ \rho\ (n)$, analyses are ongoing.

Backup slides

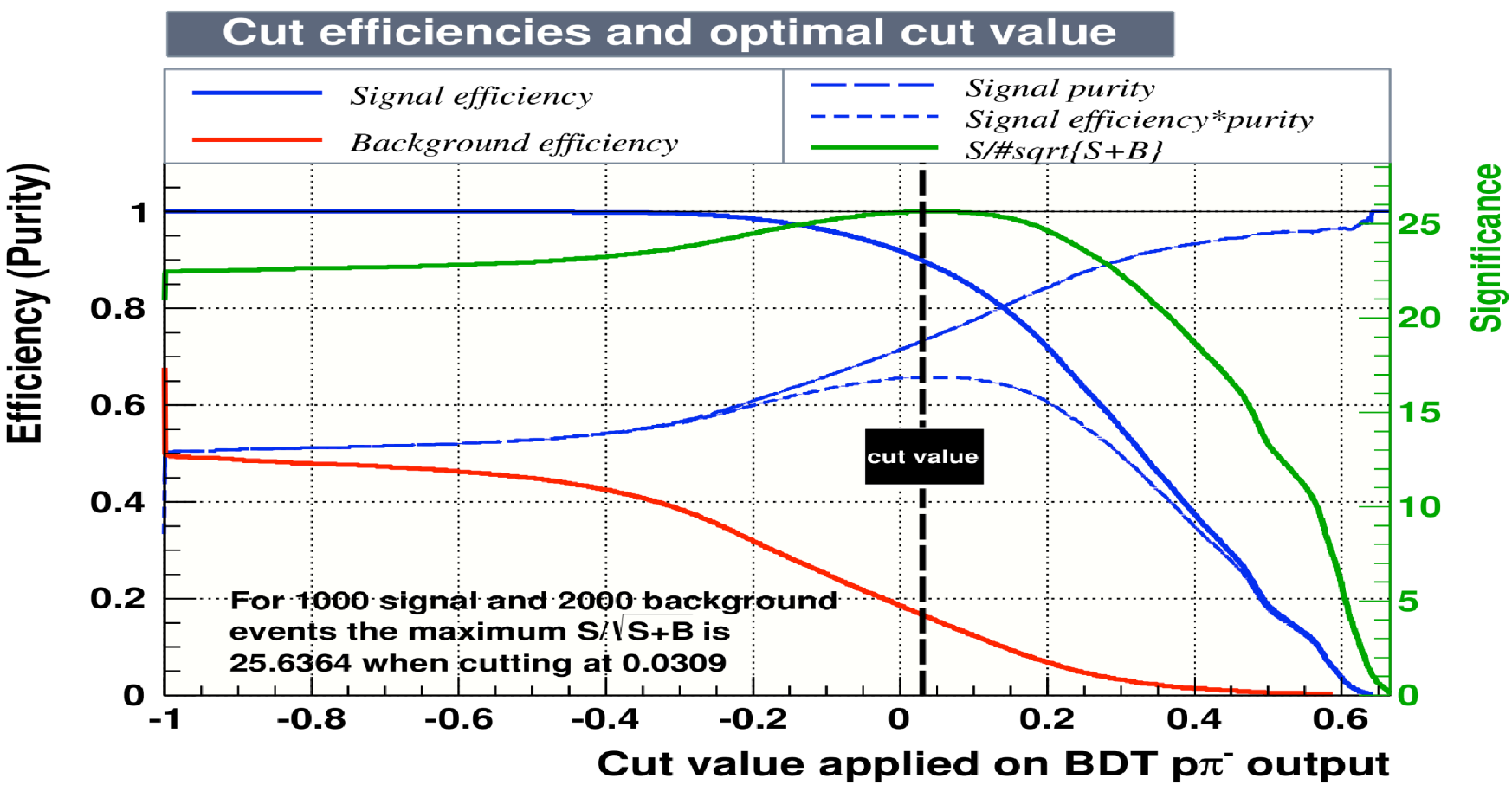
(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.2)

* Build up distinct decision trees in multi dimensional (10 in this case)



(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.3)

* BDT output -> -1 (background) to 1 (Signal)



1. Physics motivation: for missing resonances issue, measure more spin observables for neutron (little known) from HD

Sandorfi –CIPANP'12

Photon beam		Target			Recoil			Target - Recoil								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
$P_L^\gamma \sin(2\phi_\gamma)$		H		G	$O_{x'}$		$O_{z'}$		$C_{z'}$		E		F		$-C_{x'}$	
$P_L^\gamma \cos(2\phi_\gamma)$	$-\Sigma$		$-P$			$-T$		$-L_{z'}$		$T_{z'}$		$-\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^γ		F		$-E$	$C_{x'}$		$C_{z'}$		$-O_{z'}$		G		$-H$		$O_{x'}$	

0

This talk

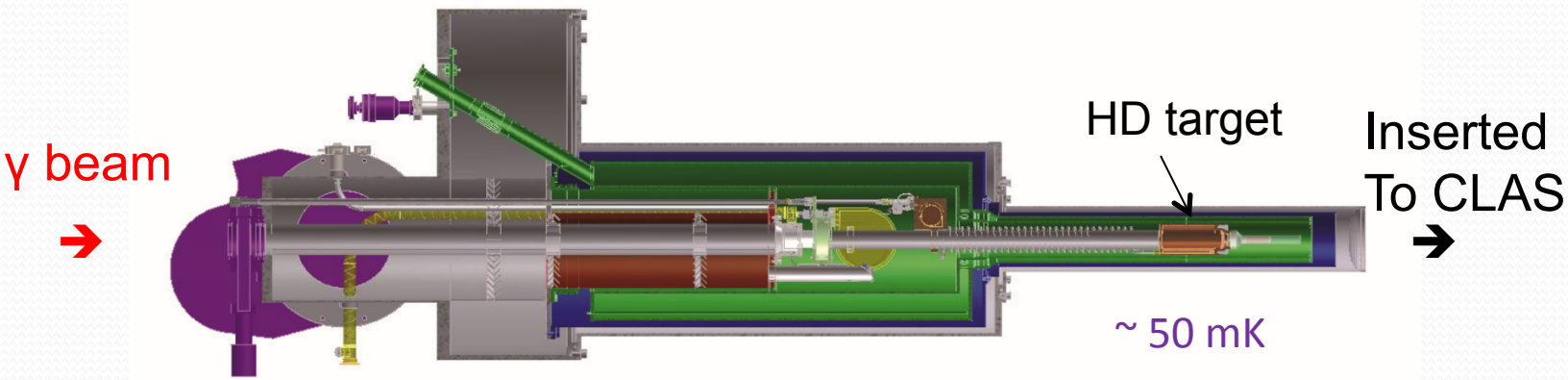
status	CLAS run period	beam	target
complete	g13	$\vec{\gamma}_L$, $\vec{\gamma}_c$	LD_2
complete	g14	$\vec{\gamma}_L$, $\vec{\gamma}_c$	$H\vec{D}$ice

(Longitudinally polarized)

Sandorfi, Hoblit, Kumano, Lee, J.PHYS, G38 (2011)053001

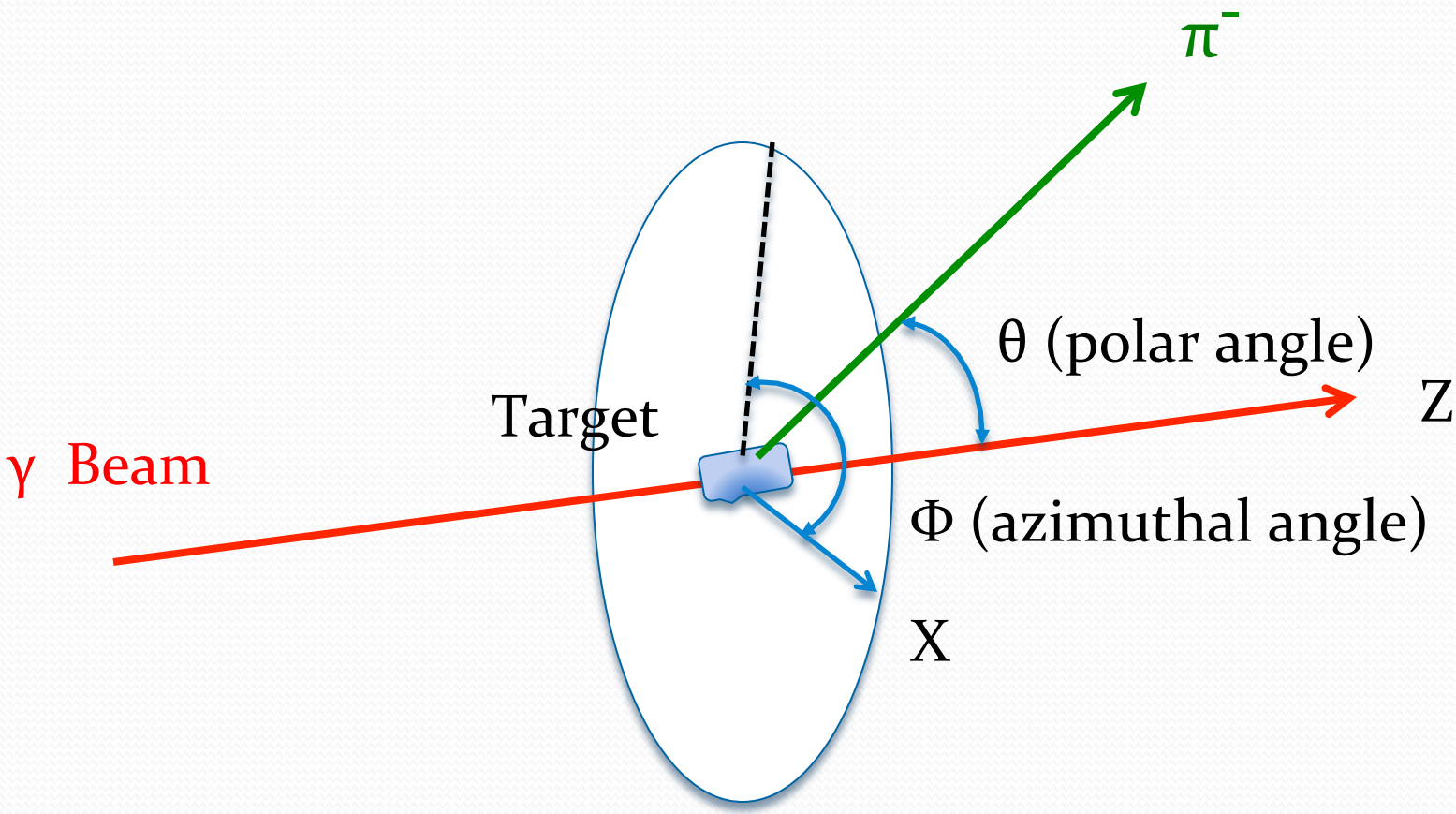
New longitudinally polarized target for this experiment

Frozen Spin Polarized solid HD target
Relaxation time of D > 1 year @ ~ 50 mK and 0.9 Tesla



* Horizontal Dilution Fridge (designed and constructed by HDice group at Jlab)
* 1 Tesla main Solenoid for longitudinal holding field
* Transverse field of 750 Gauss for field rotation (spin flip)
* NMR coil: polarization monitor during the run and spin transfer and H-spin flip, Birdcage coil

Definitions of axes and angles



Pseudoscalar meson reactions and observables measured in this experiment (try Neutron reactions using Deuteron)

reaction	*observable*
$\gamma + n\,(p) \rightarrow \pi^- p\,(p)$	σ_0, Σ, E, G
$\gamma + n\,(p) \rightarrow \pi^+ \pi^- n\,(p)$	σ_0, $I^c\,(\Sigma)$, I^s, I^o, P_z, $P^o_z\,(E)$, $P^s_z\,(G)$, P^c_z
$\gamma + n\,(p) \rightarrow K^0\,\Lambda\,(p)$	σ_0, Σ, E, G $O_{x'}$, $O_{z'}$, $C_{x'}$, $C_{z'}$, P, $T=(-O_{y'})$ $L_{x'}$, $L_{z'}$, $T_{x'}$, $T_{z'}$
$\gamma + n\,(p) \rightarrow K^0\,\Sigma^0\,(p)$	σ_0, Σ, P, E, G
$\gamma + n\,(p) \rightarrow K^+\,\Sigma^-\,(p)$	σ_0, Σ, E, G

From proposal E06-101

3. Experimental conditions and data reduction

g14 experiments: Dec. 2011 – May. 2012

* Circularly polarized photon beams: $0.85 < E_\gamma < 2.4$ GeV

$\overrightarrow{D}$: 27 days → 4.5 B events (Dpol. ~ + 25 %)

Dpol : Preliminary

* Linearly polarized photon beams: $1.6 < E_\gamma < 2.2$ GeV

$\overrightarrow{D}$: 21 days → 2.5 B events (Dpol. ~ + 25 %)

$\overleftarrow{D}$: 9 days → 1.2 B events (Dpol. ~ - 17 %)

(a) Select events; only π^- and Proton detected in CLAS

Particle Identification using $\beta = v/c$ vs P (v: from TOF)