8th International Conference on Quarks and Nuclear Physics
November 13-17, 2018, Tsukuba, Japan

Spin observables, Σ and G in charged pion photo-production from polarized neutrons in solid HD at Jefferson Lab

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on behalf of the g14 analysis team and the CLAS collaboration

1. Motivations

- Missing resonance issue

- Why neutron data are important ?

$$A_{\gamma p \to \pi^+ n} = \sqrt{2}\,[\,A_p^{(I=1/2)} - 1/3\ A^{(I=3/2)}\,]$$

$$A_{\gamma n \to \pi^- p} = \sqrt{2}\,[\,A_n^{(I=1/2)} + 1/3\ A^{(I=3/2)}\,]$$

$A^{(I=3/2)}$ can be determined from p or n data alone.

$A^{(I=1/2)}$ needs both of p and n data !

Neutron data are sparse !

2. Experimental conditions & apparatus

g14 experiments: Dec. 2011 – May. 2012

* Linearly polarized photon beams: $1.1 < E_\gamma < 5.3$ GeV

$\vec{D}$: 19 days → 2.9 B events (Dpol. ~ + 25 %)

$\overleftarrow{D}$: 9 days → 1.3 B events (Dpol. ~ - 16 %)

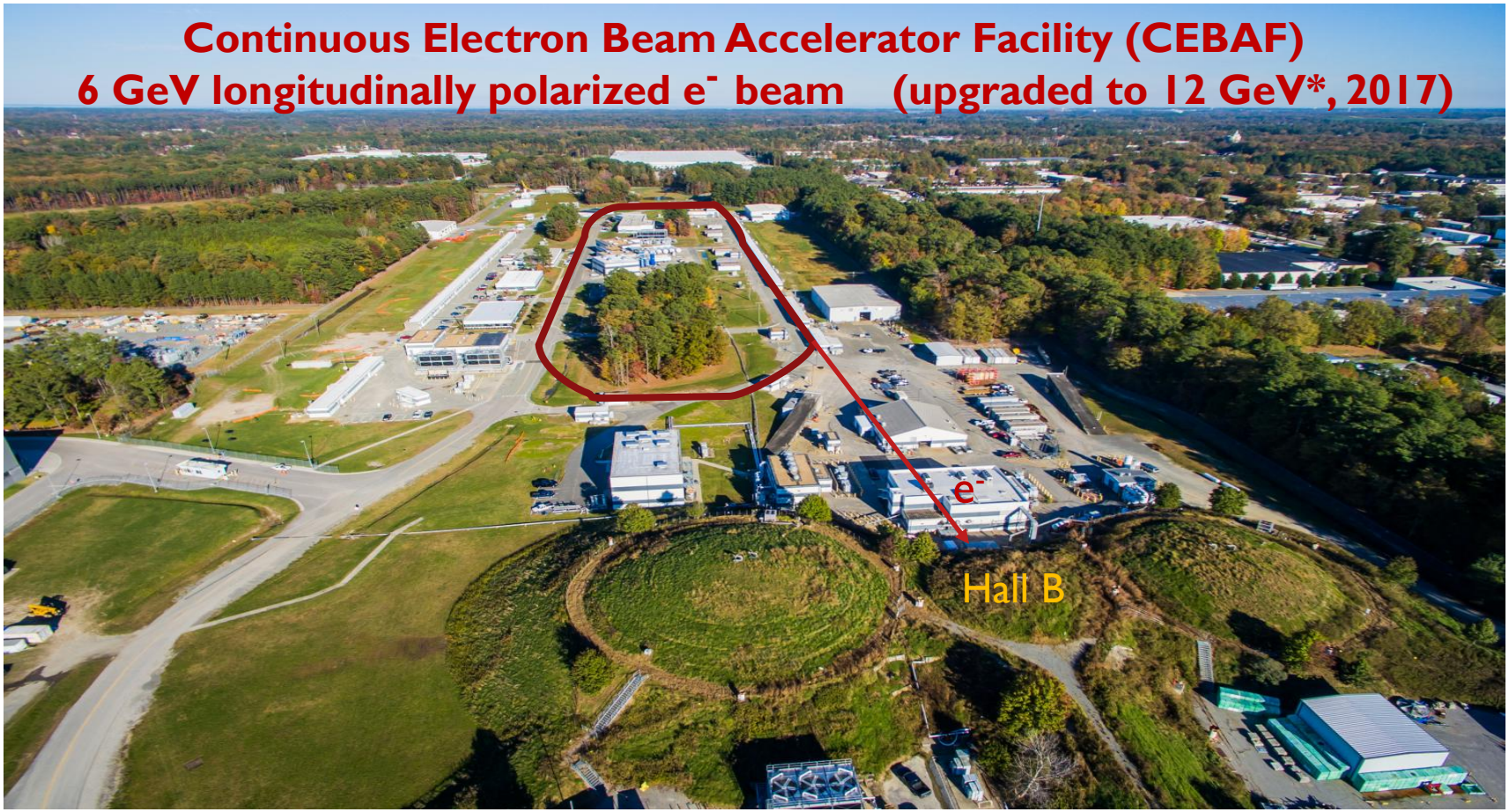
Used for this analysis

Extract **Σ** and **G** asymmetries from $\gamma + n(p) \rightarrow \pi^- + p\ (p)$

intending to use D as a neutron target

Thomas Jefferson National Accelerator Facility

jeffersonlab.jpg 1,500×1,000 pixels 10/16/18, 5:11 PM



https://3c1703fe8d.site.internapcdn.net/newman/gfx/news/hires/2015/jeffersonlab.jpg Page 1 of 1

Located in State of Virginia, USA

* "Jefferson Lab 12 GeV program" by Robert McKeon (Sat. 10 AM)

Experimental apparatus

· Linearly and Circularly polarized photon beams

· CLAS detectors (CEBAF Large Acceptance Spectrometer)

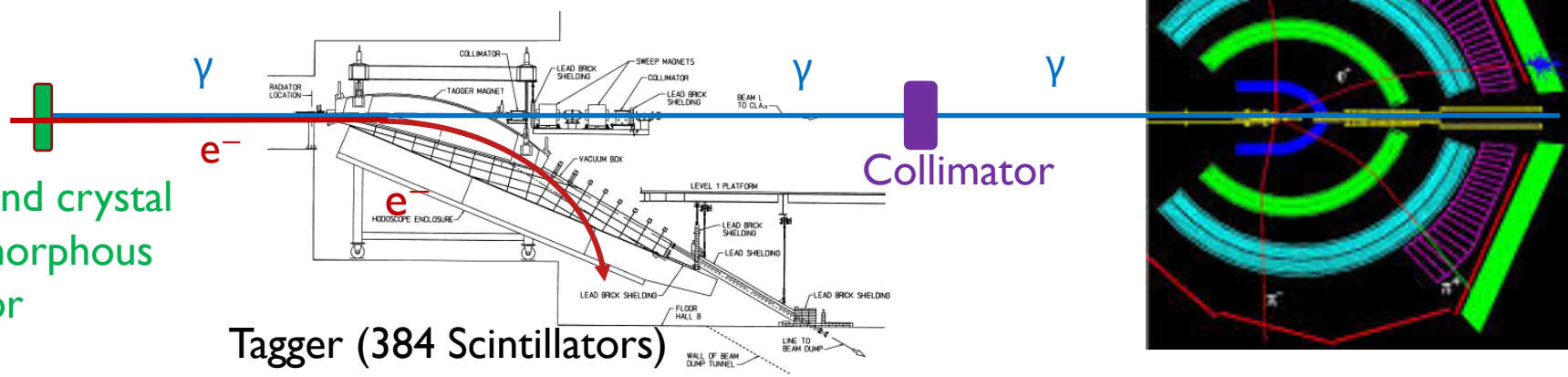
· Longitudinally Polarized Deuteron target (Solid HD) used as a neutron target

E asymmetry from $\gamma\, \mathbf{n} \rightarrow \pi^- \mathbf{p}$ reaction with circularly polarized photon beams from this experiment have been published at **P.R.L, 118, 242002 (2017)**

Linearly polarized photon beams

Coherent bremsstrahlung photon beam line

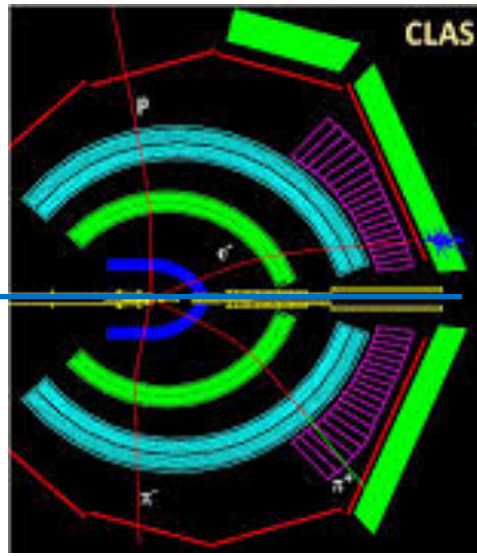
$E\gamma = E_0 - Ee^-$



Diamond crystal or Amorphous radiator

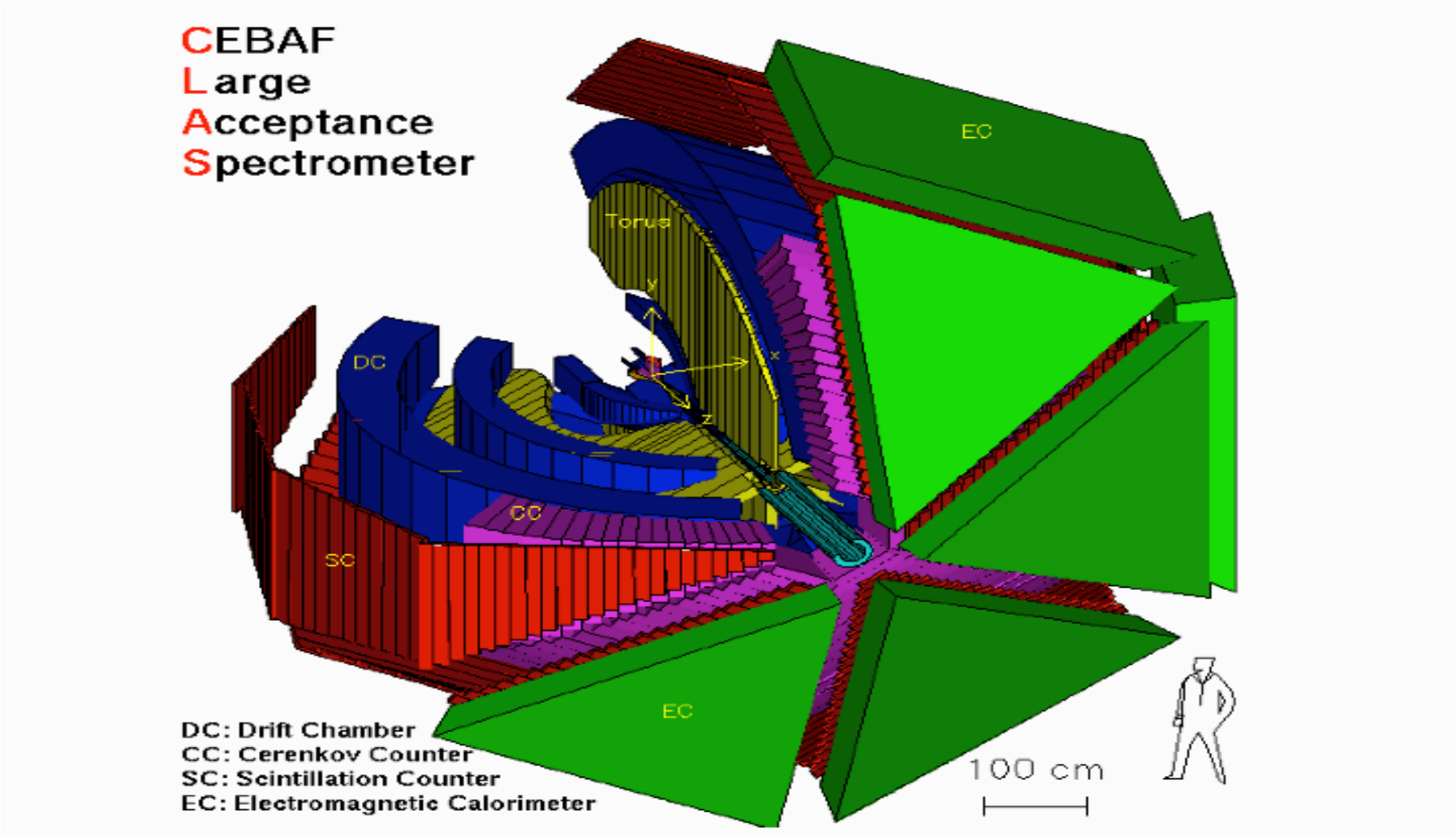
Tagger (384 Scintillators)

Collimator

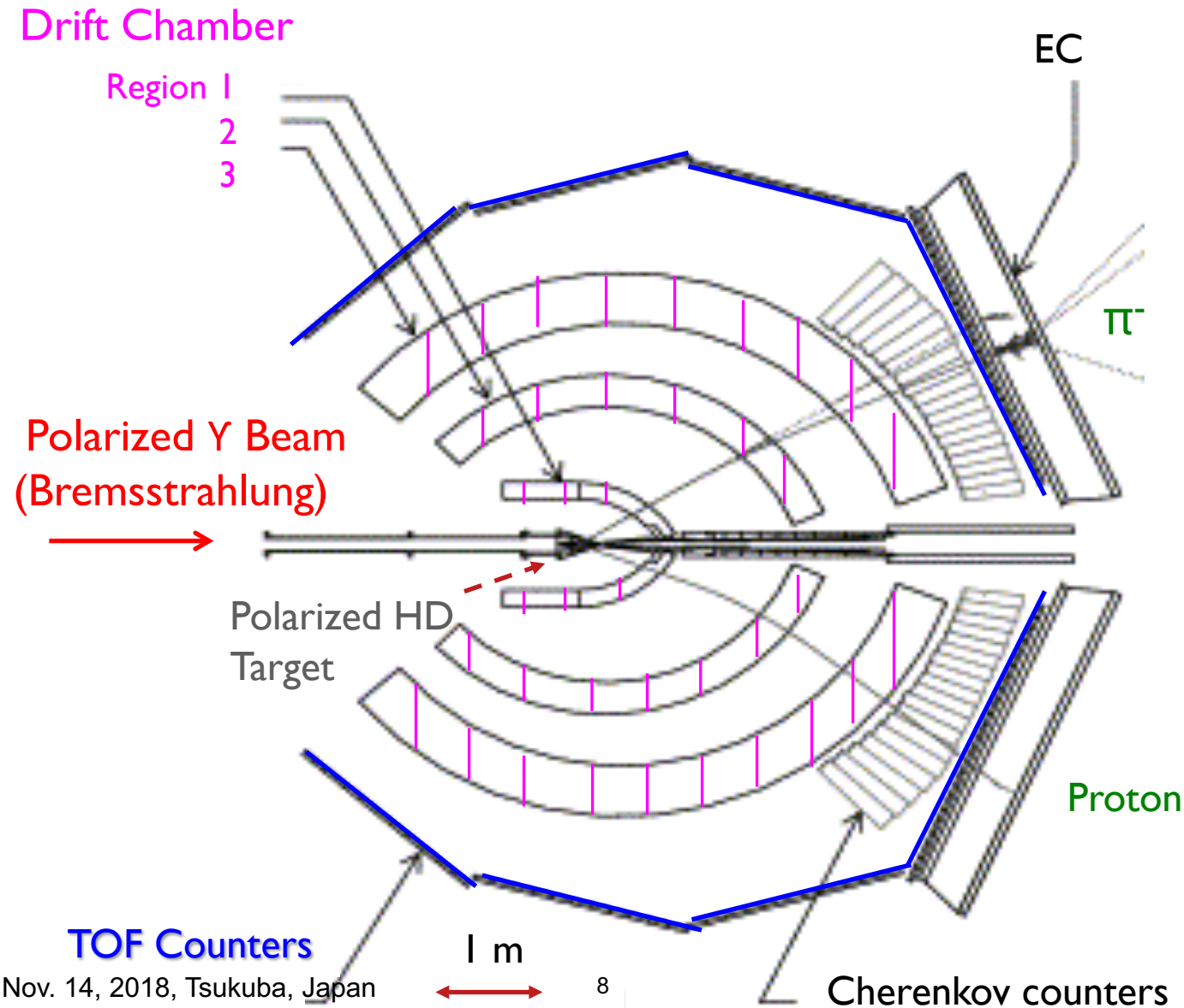


CLAS detectors

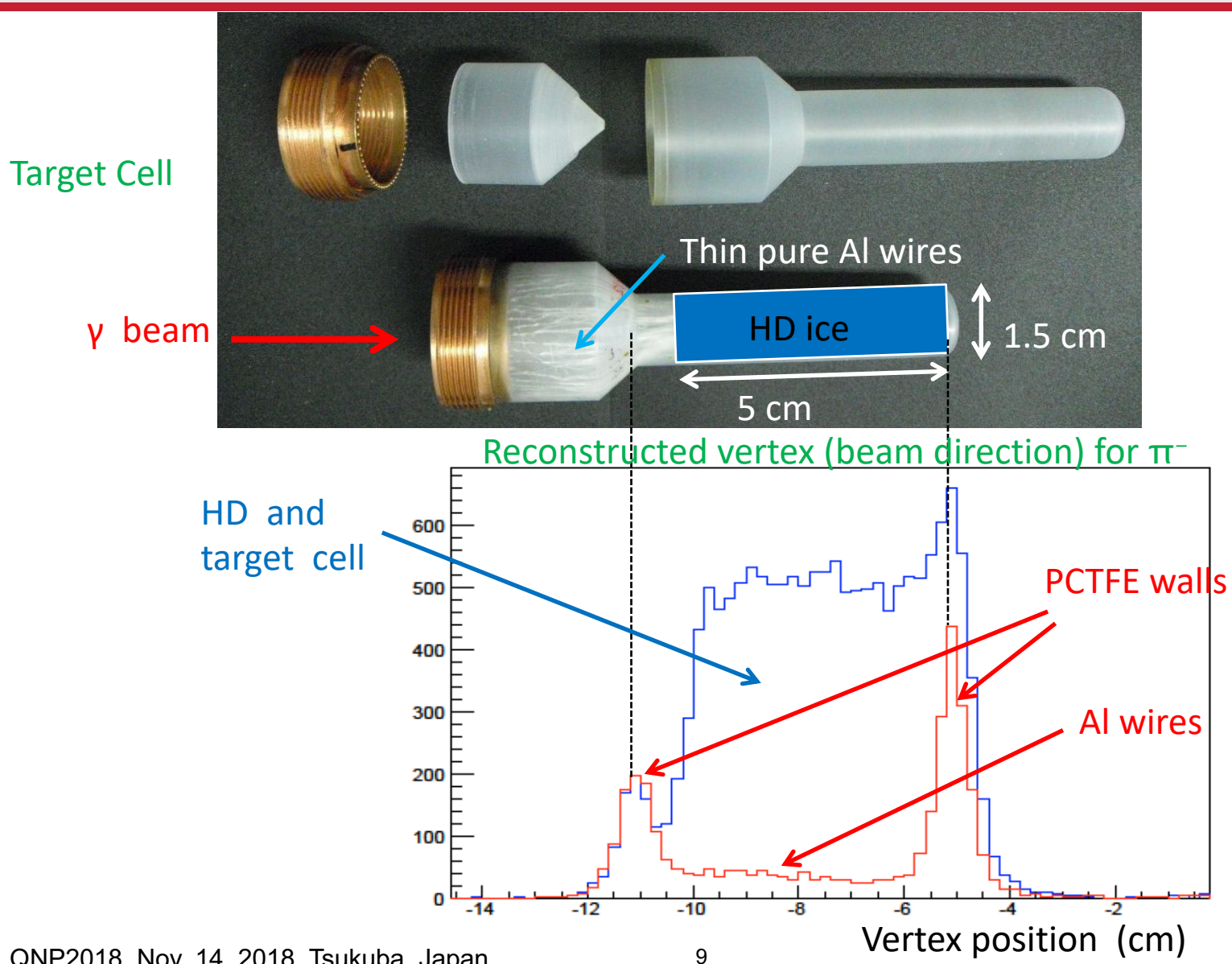
CLAS (CEBAF Large Acceptance Spectrometer)



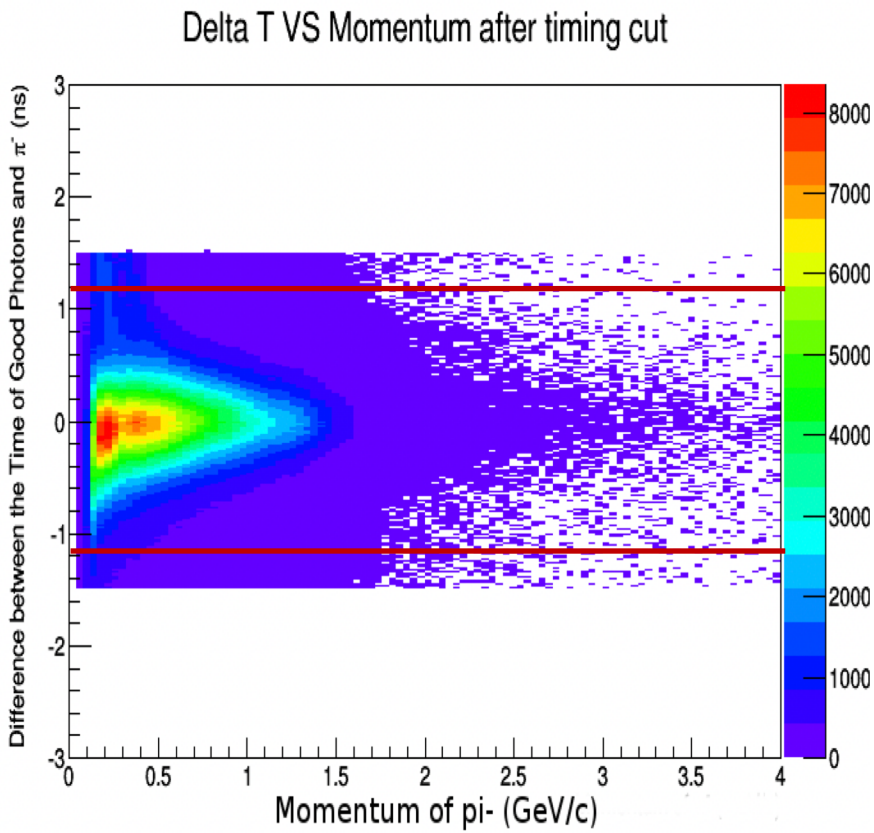
CLAS side view (reconstruct and identify π^- & proton)

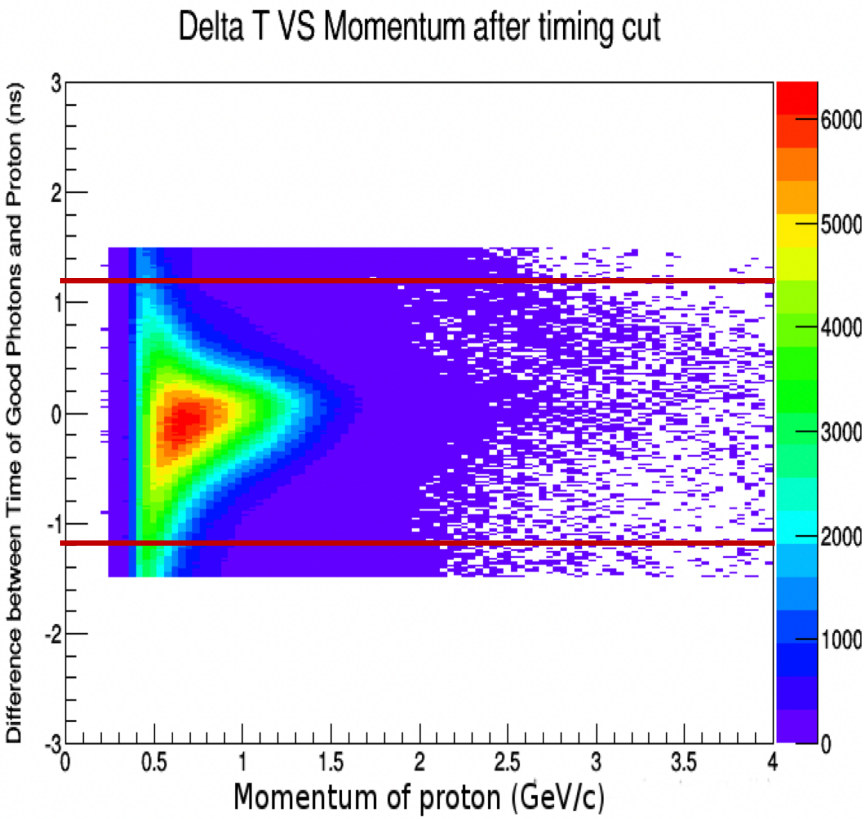


Longitudinally polarized HDice target and background



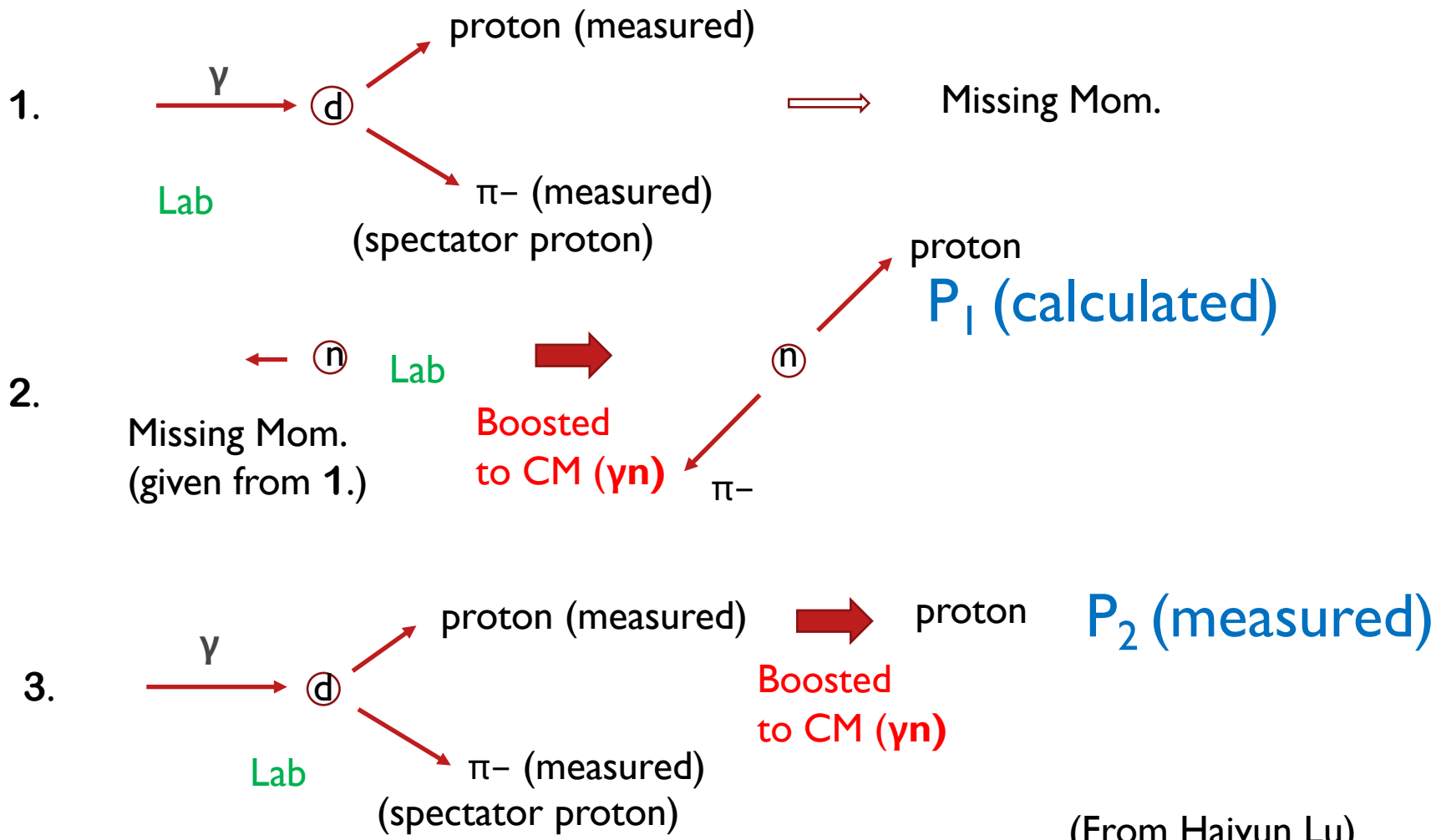
3. Analysis CUTS: Timing cuts for π^- and proton





(From Haiyun Lu)

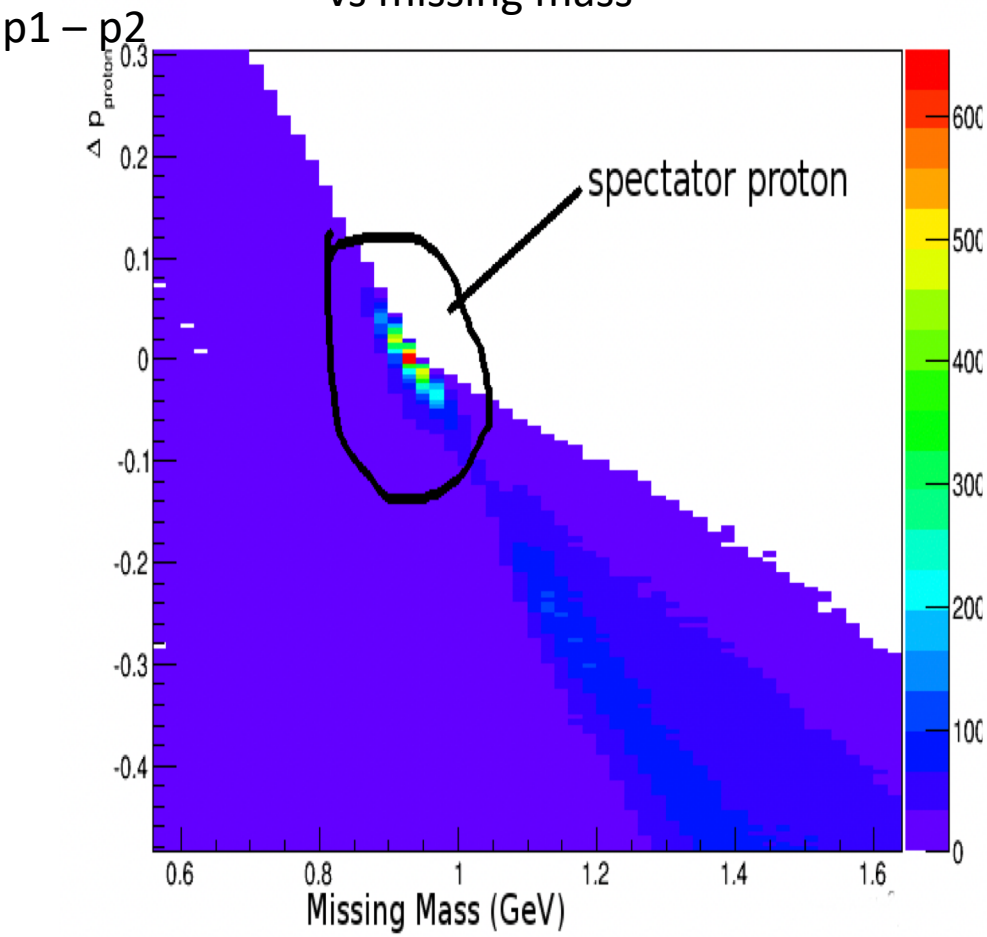
Event Selection for γ n (p) → π⁻ p (p) (No.1)



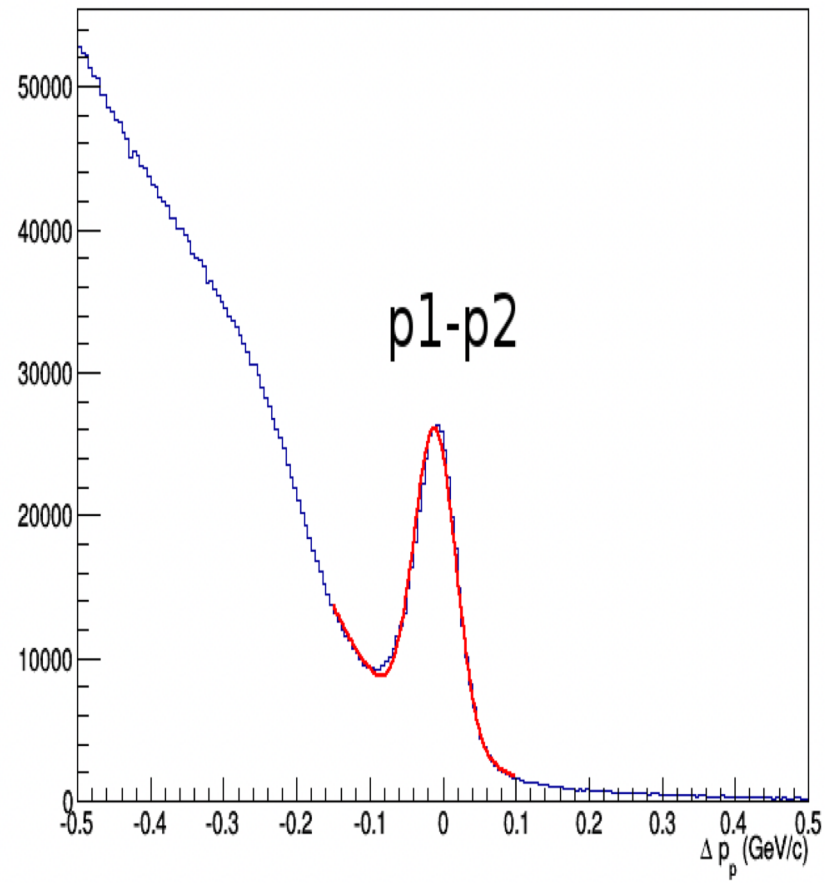
(From Haiyun Lu)

Event selection for γ n (p) → π⁻ p (p) (No.2)

Difference of momentum: (p1 – p2) vs missing mass



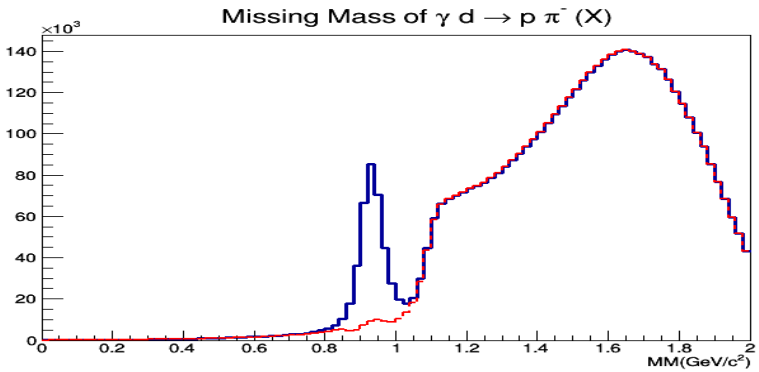
Events are selected within 3σ of the momentum difference peak



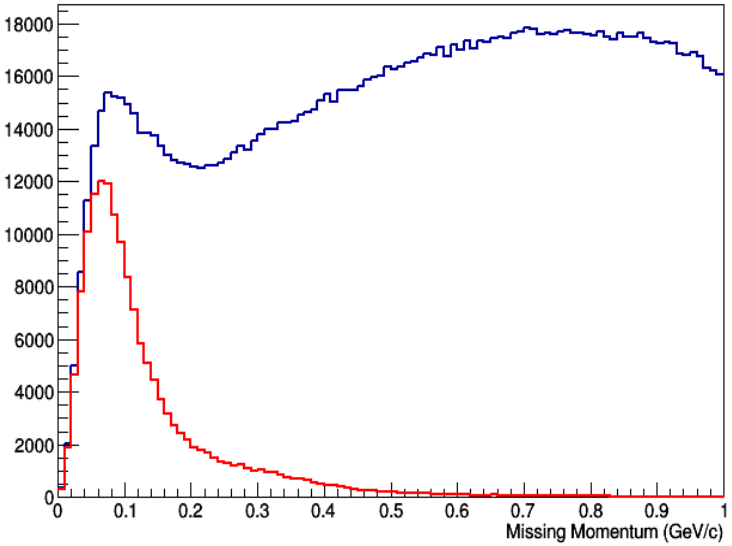
(From Haiyun Lu)

CUTS (results of the selection (previous pages))

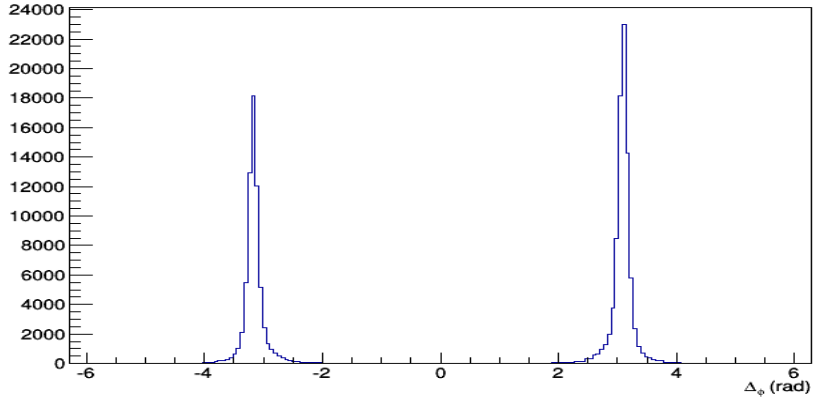
Missing mass before selection and cut away



Missing momentum before and after selection



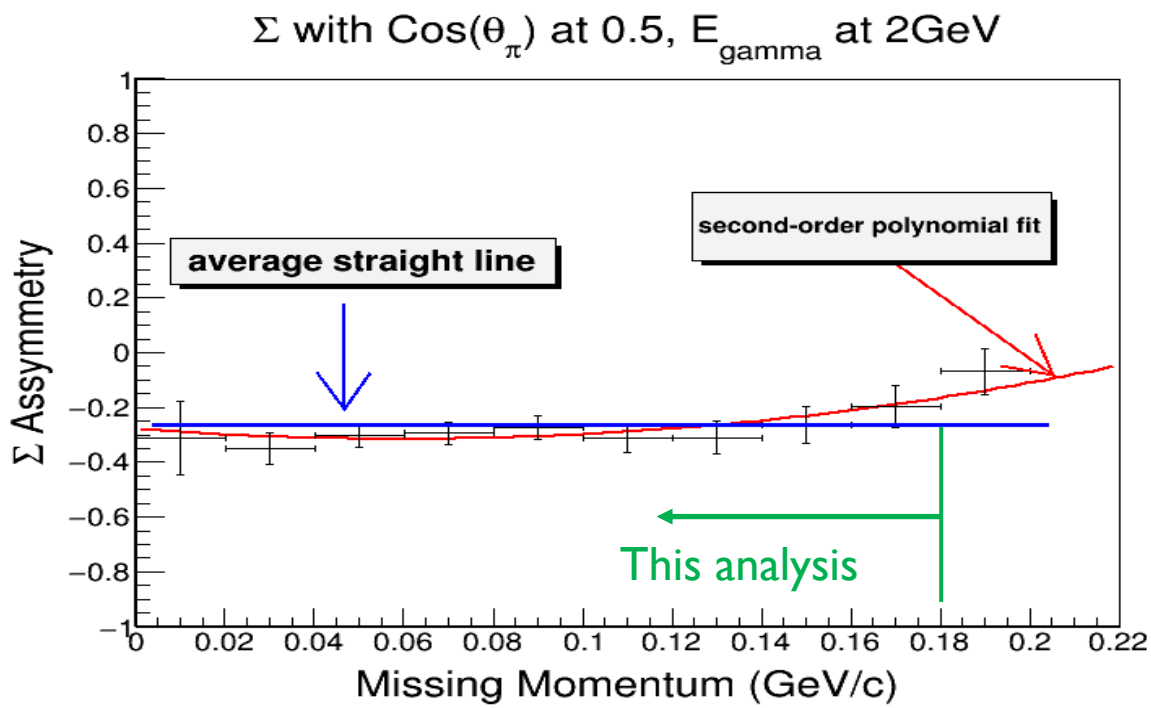
ϕ difference between *p* and π-



(From Haiyun Lu)

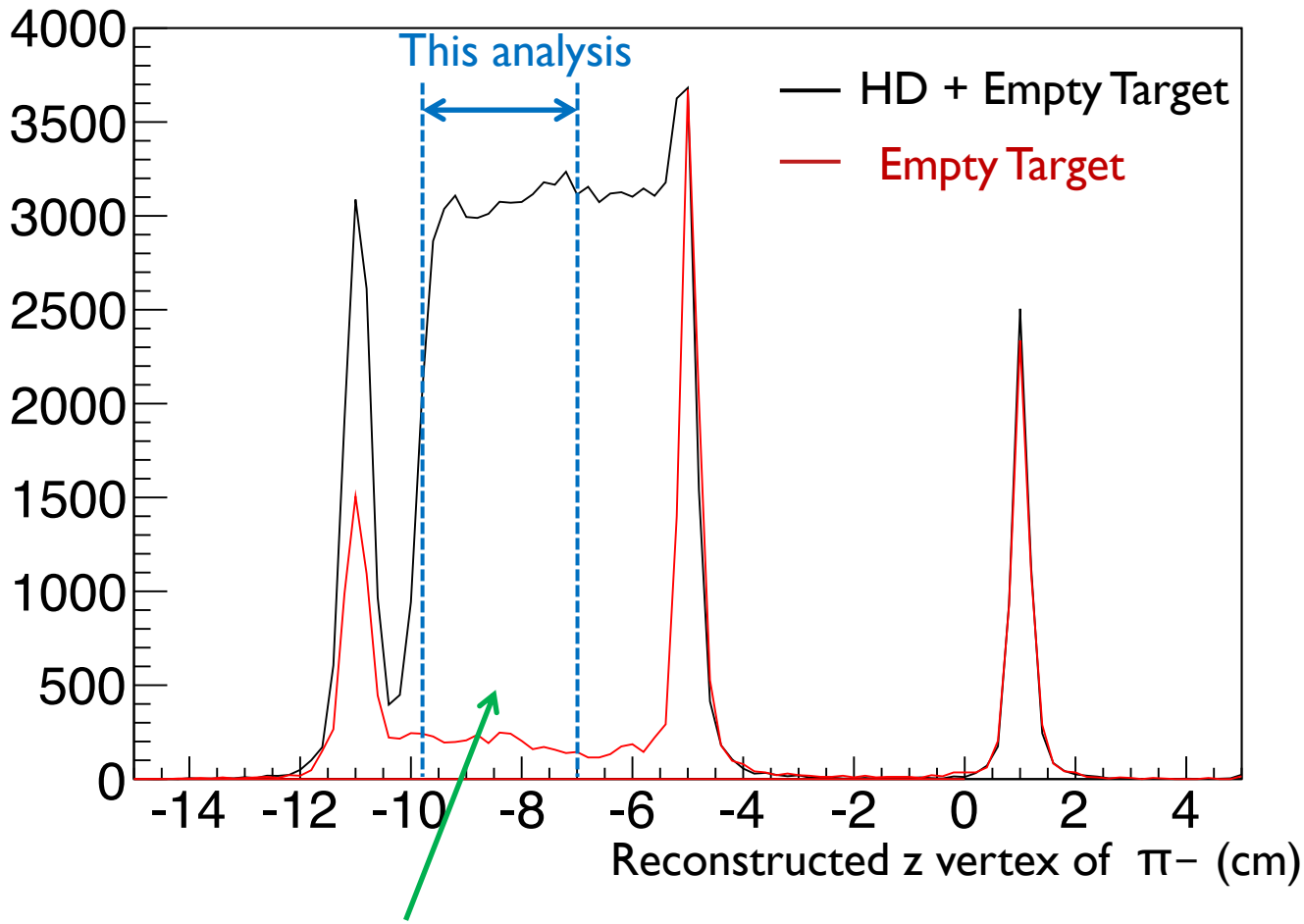
CUTS: Missing momentum cut

Σ with different missing momentum
straight line: the average
curve, second-order polynomial: fit result
used to study systematics



(From Haiyun Lu)

CUTS: Reconstructed vertex cut and dilution factor

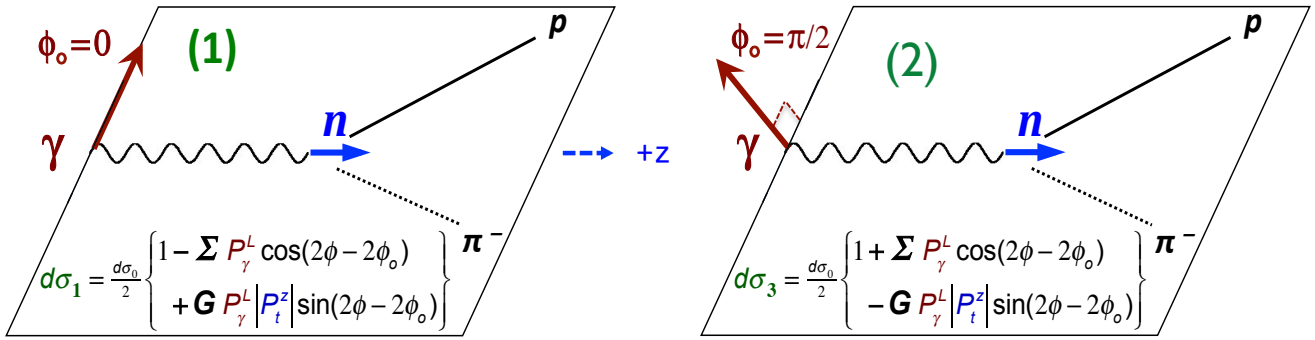


Dilution factor: 1.066 obtained from empty target and HD ratio

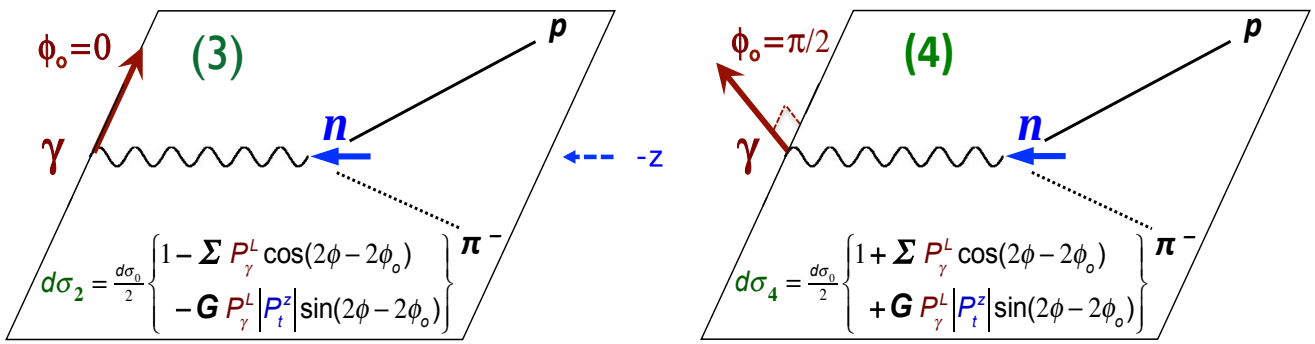
4. Results

Four configurations of beam and target polarizations

Four Experimental Beam-Target Configurations



PARA, +Target PERP, +Target



PARA, – Target PERP, – Target

(Thanks to Andy Sandorfi)

Extract Σ asymmetry

$$N_{\parallel}^{+}(\phi) = a(\phi)\, F_{\parallel}^{+}\ \{\, 1 - P_{\parallel}^{+}\, \Sigma \cos[2(\phi - \phi_0)] + P_{+z}\, P_{\parallel}^{+}\, G \sin[2(\phi - \phi_0)] \,\} \quad (1)\ \text{PARA, + Target}$$

$$N_{\perp}^{+}(\phi) = a(\phi)\, F_{\perp}^{+}\ \{\, 1 + P_{\perp}^{+}\, \Sigma \cos[2(\phi - \phi_0)] - P_{+z}\, P_{\perp}^{+}\, G \sin[2(\phi - \phi_0)] \,\} \quad (2)\ \text{PERP, + Target}$$

$$N_{\parallel}^{-}(\phi) = a(\phi)\, F_{\parallel}^{-}\ \{\, 1 - P_{\parallel}^{-}\, \Sigma \cos[2(\phi - \phi_0)] - P_{-z}\, P_{\parallel}^{-}\, G \sin[2(\phi - \phi_0)] \,\} \quad (3)\ \text{PARA, -Target}$$

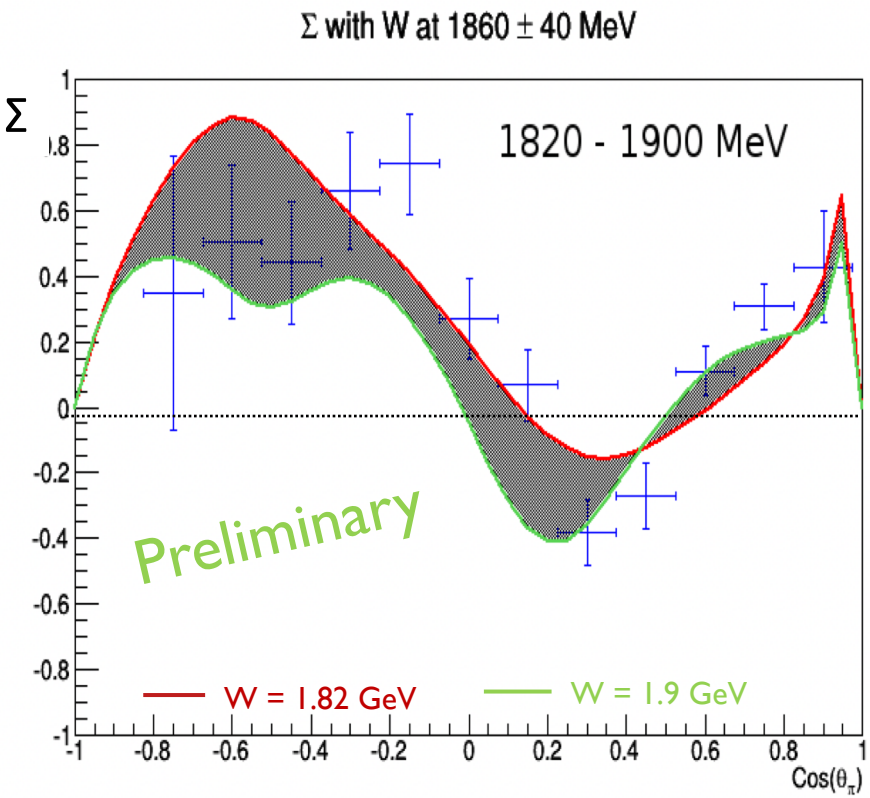
$$N_{\perp}^{-}(\phi) = a(\phi)\, F_{\perp}^{-}\ \{\, 1 + P_{\perp}^{-}\, \Sigma \cos[2(\phi - \phi_0)] + P_{-z}\, P_{\perp}^{-}\, G \sin[2(\phi - \phi_0)] \,\} \quad (4)\ \text{PERP, - Target}$$

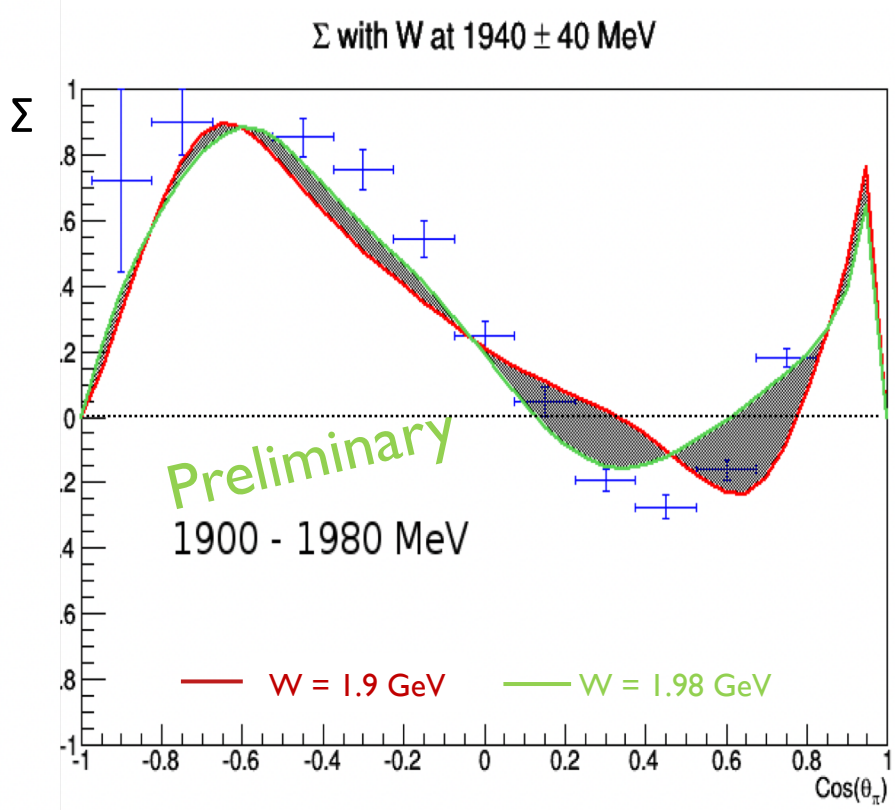
F: flux, $a(\phi)$: acceptance, $P_{\perp}^{+}$: Linear Pol., P_{+z} : target D pol.

$$\frac{(1)/F_{\parallel}^{+} + (3)/F_{\parallel}^{-} - (2)/F_{\perp}^{+} - (4)/F_{\perp}^{-}}{(1)/F_{\parallel}^{+} + (3)/F_{\parallel}^{-} + (2)/F_{\perp}^{+} + (4)/F_{\perp}^{-}} = \frac{-4 \times a(\phi) \times P_{beam} \times \Sigma \times \cos[2(\phi - \phi_0)]}{4 \times a(\phi)}$$

Fit with a parameter of Σ $(\phi_0 = 0)$: $f = -P_{beam} \bullet \Sigma \bullet \cos(2\phi)$

Results: Σ asymmetries vs cos θ $_{\pi-}$ (No.1)





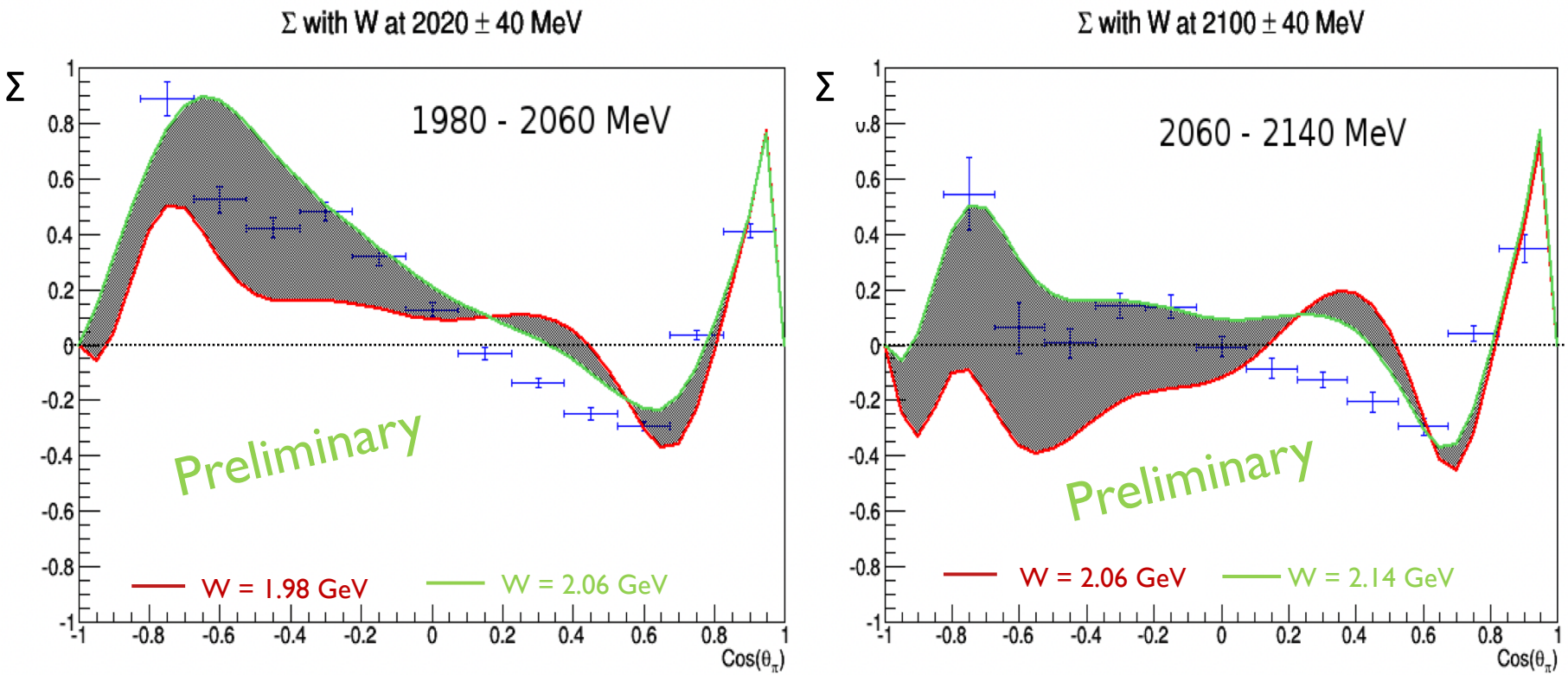
Shaded areas: SAID model* predictions from fits to all published data together with E (g14) and Σ (g13) asymmetries

g14: this experiment, g13 used liquid D_2 target (previous talk)

* SAID [TS21]

(From Haiyun Lu)

Σ asymmetries vs cos θ $_{\pi-}$ (No.2)



Shaded areas: SAID model* predictions from fits to all published data together with E (g14) and Σ (g13) asymmetries

* SAID [TS21]

(From Haiyun Lu)

Extract G asymmetry

$$N_{\parallel}^{+}(\phi) = a(\phi)\, F_{\parallel}^{+} \{ 1 - P_{\parallel}^{+} \Sigma \cos[2(\phi - \phi_0)] + P_{+z} P_{\parallel}^{+} G \sin[2(\phi - \phi_0)] \} \quad (1)$$ PARA, + Target

$$N_{\perp}^{+}(\phi) = a(\phi)\, F_{\perp}^{+} \{ 1 + P_{\perp}^{+} \Sigma \cos[2(\phi - \phi_0)] - P_{+z} P_{\perp}^{+} G \sin[2(\phi - \phi_0)] \} \quad (2)$$ PERP, + Target

$$N_{\parallel}^{-}(\phi) = a(\phi)\, F_{\parallel}^{-} \{ 1 - P_{\parallel}^{-} \Sigma \cos[2(\phi - \phi_0)] - P_{-z} P_{\parallel}^{-} G \sin[2(\phi - \phi_0)] \} \quad (3)$$ PARA, -Target

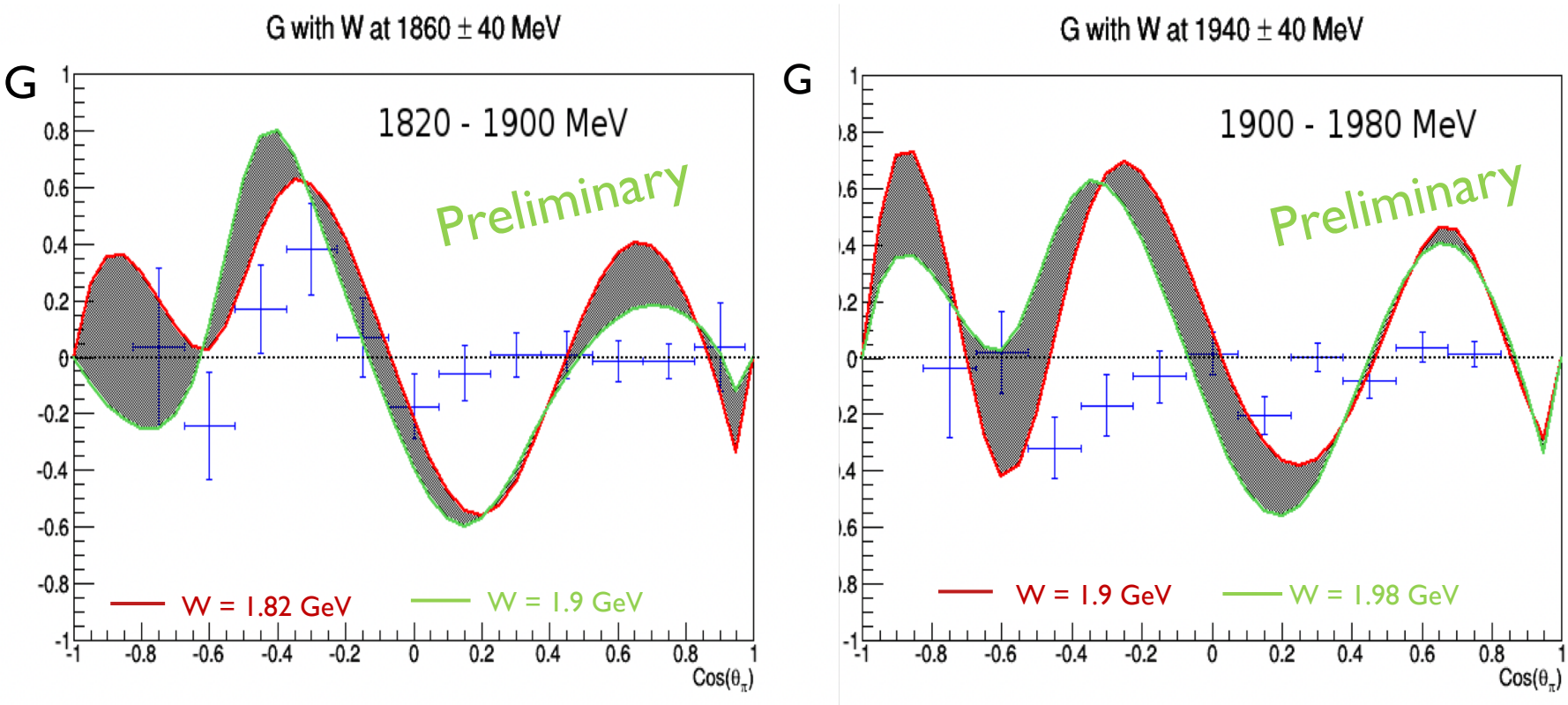
$$N_{\perp}^{-}(\phi) = a(\phi)\, F_{\perp}^{-} \{ 1 + P_{\perp}^{-} \Sigma \cos[2(\phi - \phi_0)] + P_{-z} P_{\perp}^{-} G \sin[2(\phi - \phi_0)] \} \quad (4)$$ PERP, - Target

F: flux, $a(\phi)$: acceptance, $P_{\perp}^{+}$: Linear Pol., P_{+z} : target D pol.

$$\frac{(1)/F_{\parallel}^{+} - (3)/F_{\parallel}^{-} - (2)/F_{\perp}^{+} + (4)/F_{\perp}^{-}}{(1)/F_{\parallel}^{+} + (3)/F_{\parallel}^{-} + (2)/F_{\perp}^{+} + (4)/F_{\perp}^{-}} = \frac{2 \times a(\phi) \times (P_{+z} + P_{-z}) \times P_{beam}\, G \sin[2(\phi - \phi_0)]}{4 \times a(\phi)}$$

Fit with parameter of G $(\phi_0 = 0)$: $f = 0.5 \bullet (P_{+z} + P_{-z}) \bullet P_{beam} \bullet G \sin(2\phi)$

G asymmetries vs cos θ $_{\pi-}$ (No.1)

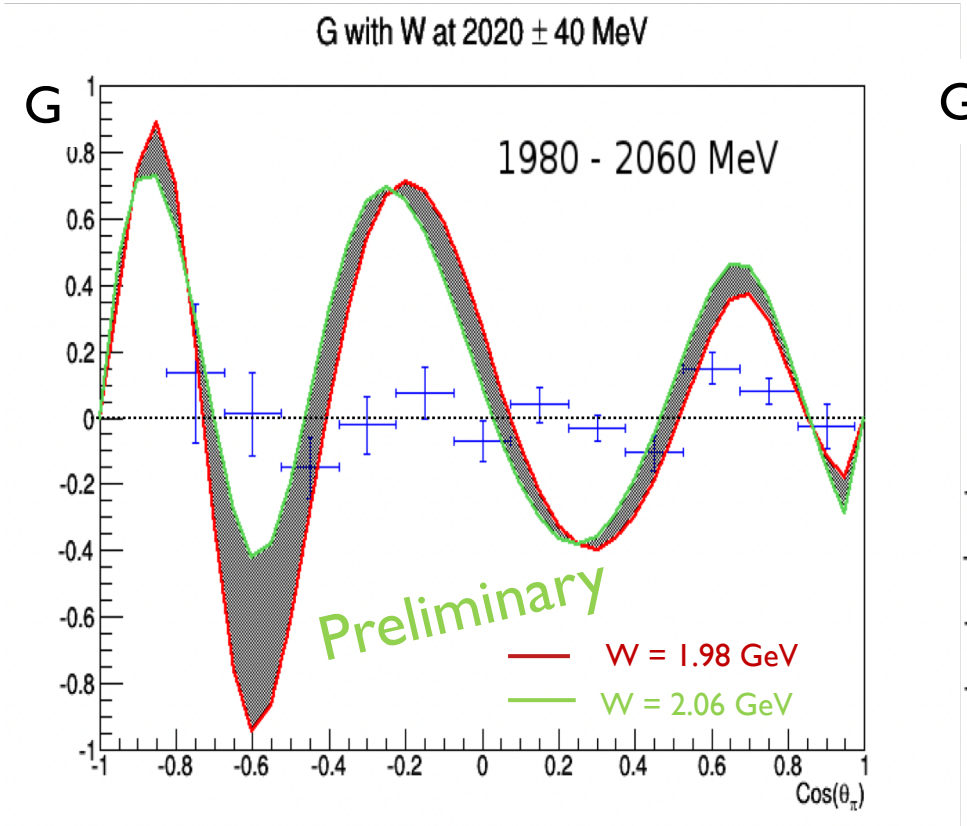


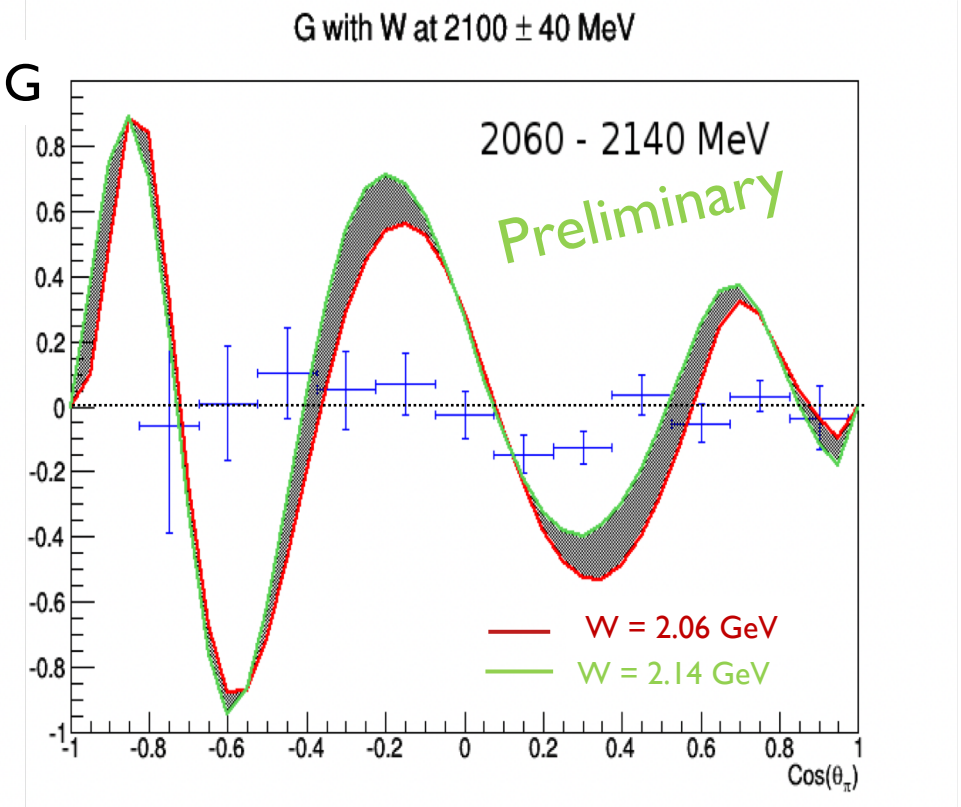
Shaded areas: SAID model* predictions from fits to all published data together with E (g14) and Σ (g13) asymmetries

* SAID [TS21]

(From Haiyun Lu)

G asymmetries vs cos θ $_{\pi-}$ (No.2)





Shaded areas: SAID model* predictions from fits to all published data together with E (g14) and Σ (g13) asymmetries

* SAID [TS21]

(From Haiyun Lu)

5. Status of present analysis

- Analysis with final W instead of initial W bins

$$W_{init} = \sqrt{m_n{}^2 + 2 \bullet m_n \bullet E_\gamma}$$

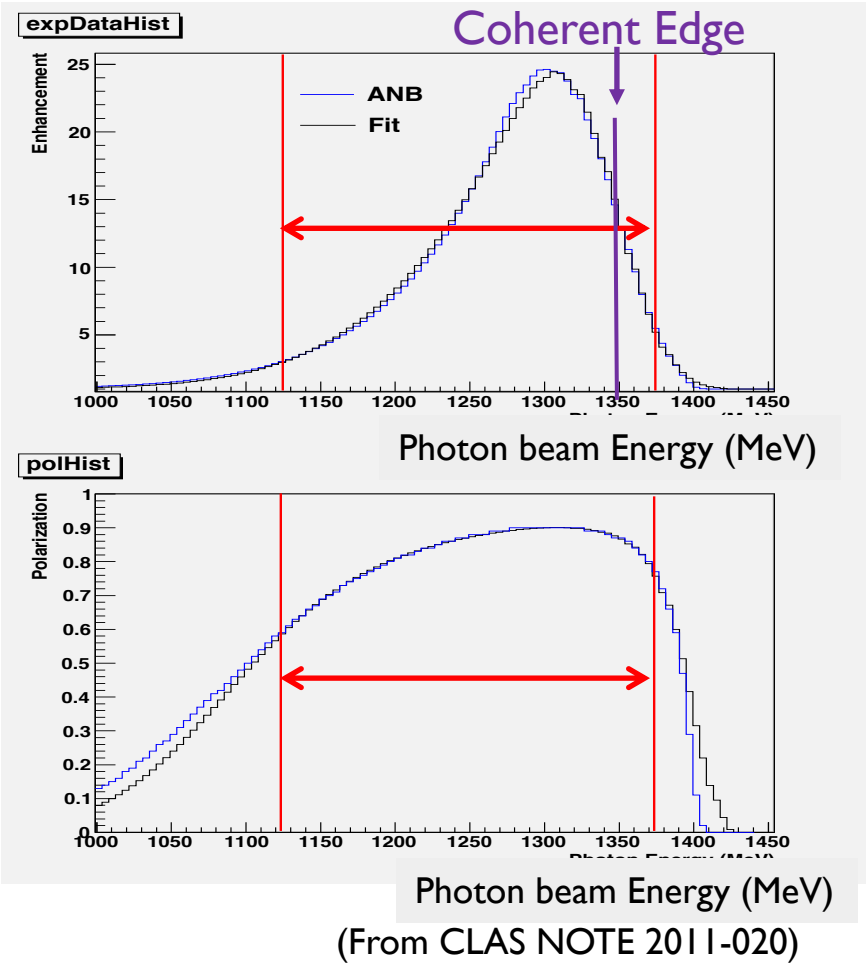
W_{fin}: invariant mass of π^- and proton

- Systematic error estimations

- Corrections or cuts for linearly polarized beams

Extraction of linear polarization

Calculate beam pol. with coherent bremsstrahlung theory



(From CLAS NOTE 2011-020)

ANalytic Bremsstrahlung (ANB) calculation from the Tübingen Group adapting Hall B beam parameters

Fit to the enhancement dist. from Hall B data

These two agree well within photon energy range (250 MeV) shown by the arrows (down to ~200 MeV from the Coherent Edge)

Summary

Performed experiments with linearly polarized photon beams and linearly polarized deuteron targets and obtained preliminary results for **Σ** and G asymmetries

PWA analysis based on the most recent SAID does not describe the G asymmetries extracted from $\gamma\, \mathbf{n} \rightarrow \pi^- \mathbf{p}$ reaction for the first time.
These results give more information to the new PWA analysis.

Further detailed analyses are on going for these asymmetries.