Time-like Compton Scattering in Hall C

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For the Hall C TCS collaboration

NPS Collaboration Meeting, 07/17/2024

Outline

TCS with **polarized** target

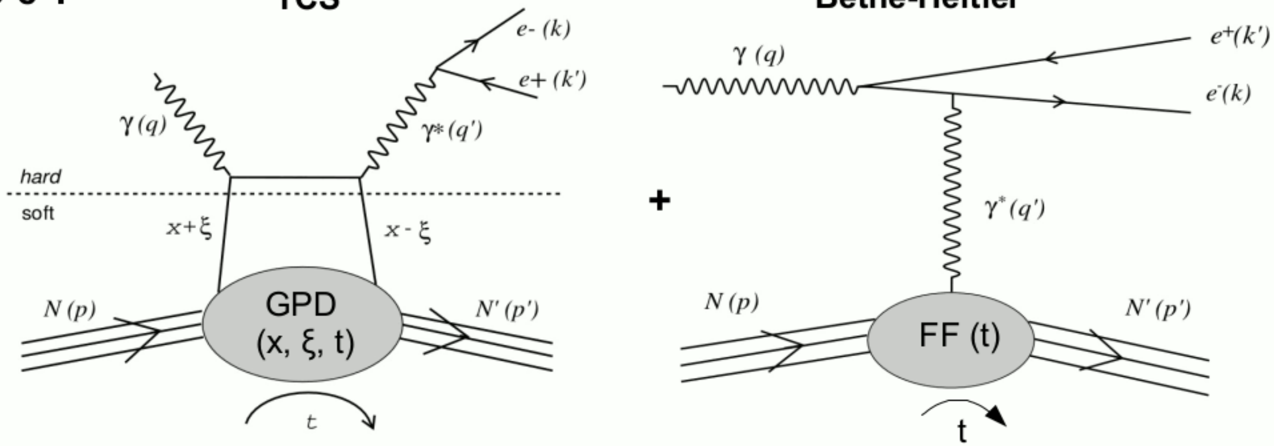
- Physics case and motivation
- Experimental setup
- Simulations
- Status

TCS with **un-polarized** target

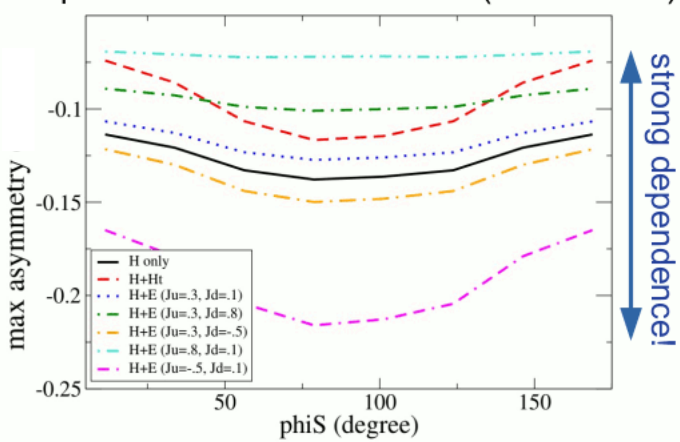
- Physics case and motivation
- Experimental setup
- Simulations
- Status

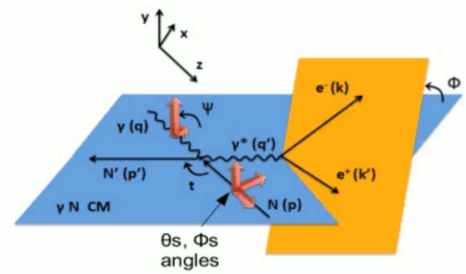
Physics goals

$\gamma P \rightarrow e^+e^- P'$ = **TCS** + **Bethe-Heitler**



Sin(φ) moment of transverse spin asymmetry vs φ_S,
Dependence in GPD E and $J^{u,d}$ (VGG model)





TSA as a function of φ and φ_S

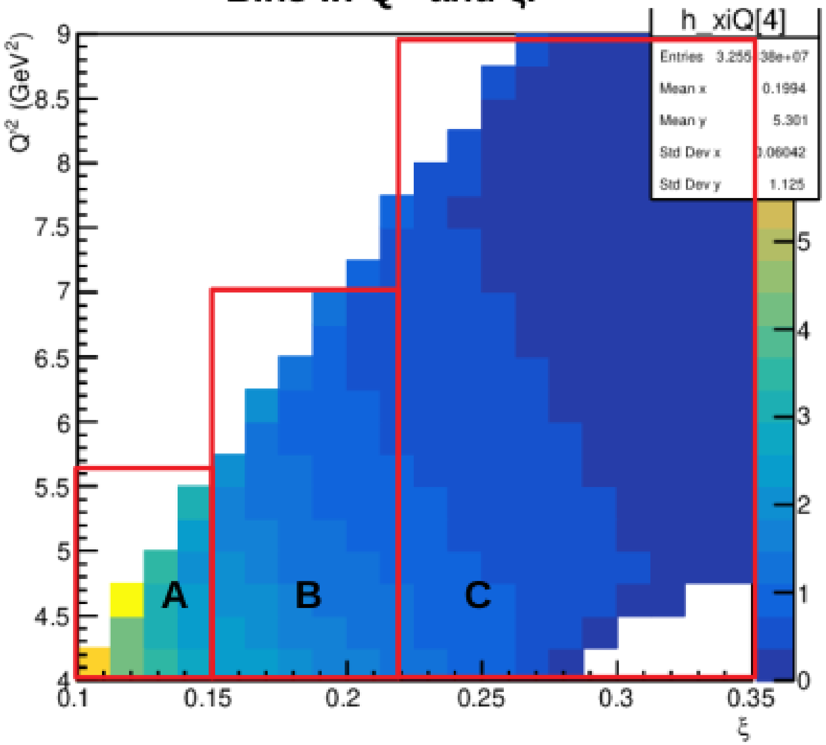
- Sensitive to Im(interference), BH cancels
- Strong dependence in angular momenta,

Sensitivity to GPD E (also to H, Ht)

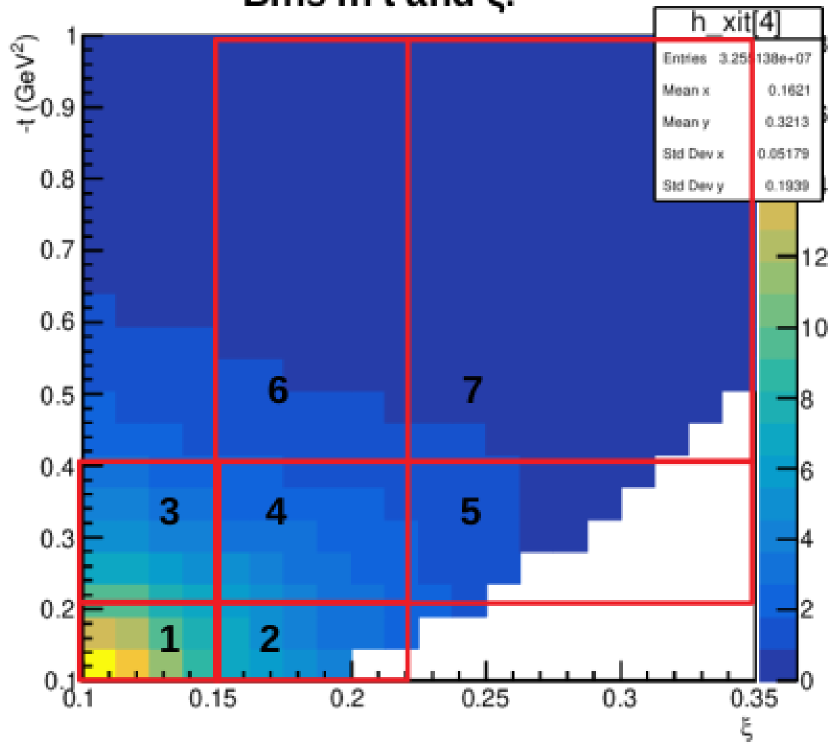
Courtesy M.Boer

TCS w/ polarized target: Kinematic Coverage

Bins in Q'² and ξ:



Bins in t and ξ:

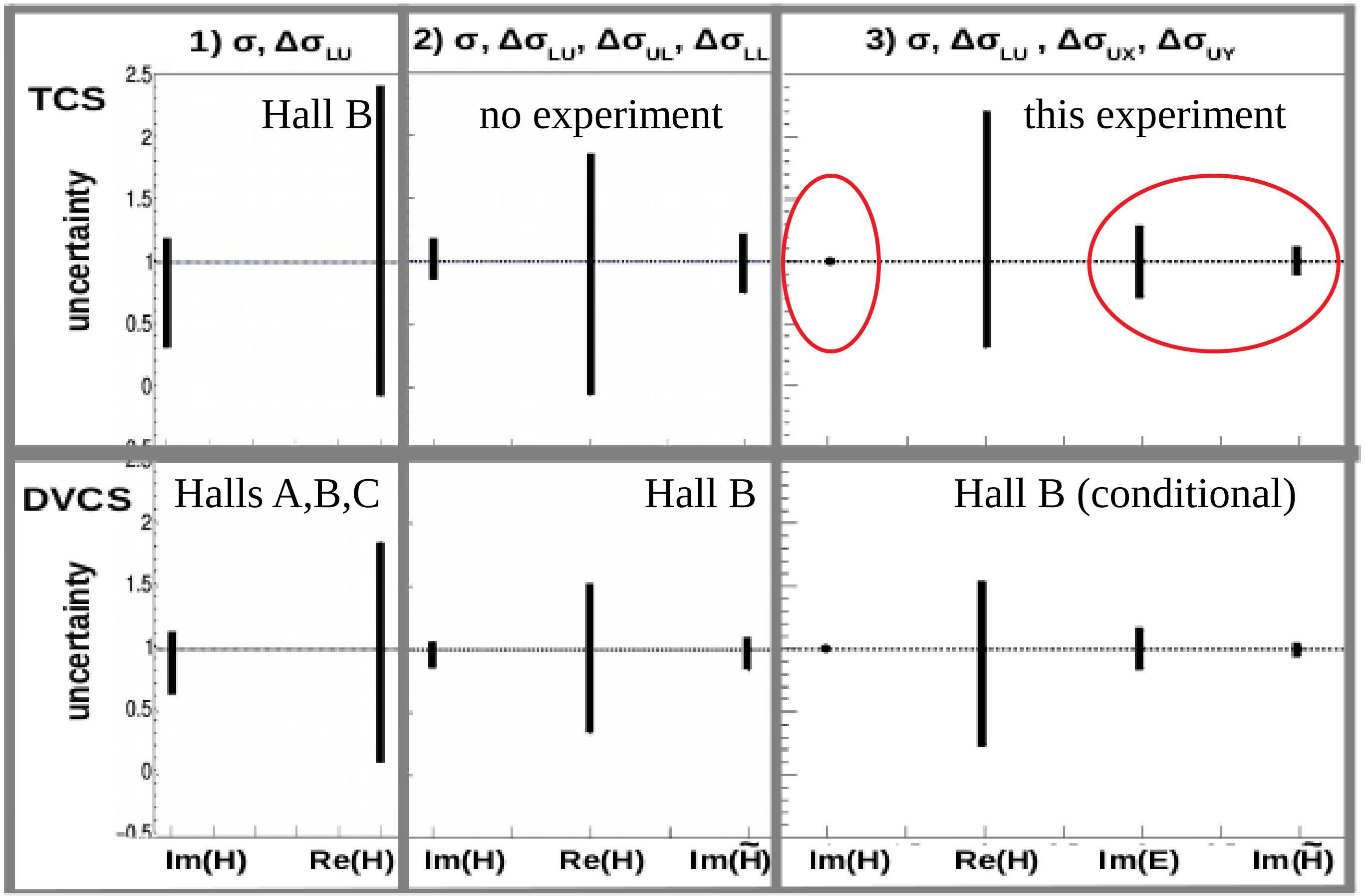


A: .10 < ξ < .15 ; 4 < Q'² < 5.5 GeV²
B: .15 < ξ < .22 ; 4 < Q'² < 7 GeV²
C: .22 < ξ < .35 ; 4 < Q'² < 9 GeV²

1, 2: .1 < -t < .2 GeV²
3, 4, 5: .2 < -t < .35 GeV²
6, 7: .35 < -t < .7 GeV²

Kinematic region out of pion resonance production

TCS w/ polarized target: Extraction of CFFs from TCS versus DVCS



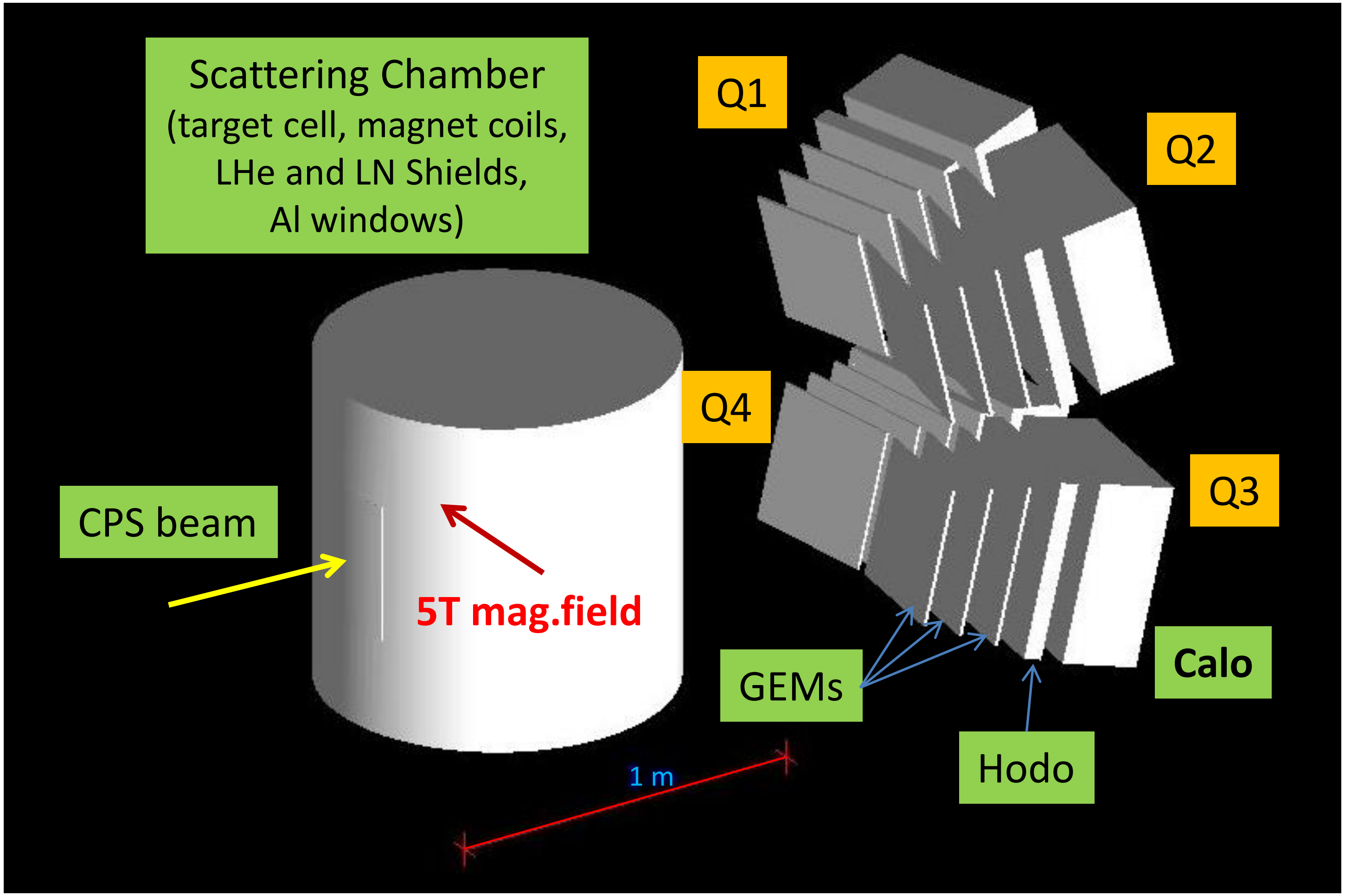
Example estimates of accuracies on the model extraction of CFFs.

TCS with trans. pol. Target:

- Allows for extraction of **Im(E)** (**unique to this proposal**)
- Allows for extraction of **Im(H) to good accuracy** (**universality tests**)

TCS w/ polarized target: Experimental apparatus

$$\gamma + p \rightarrow \gamma^* (e^+ + e^-) + p'$$

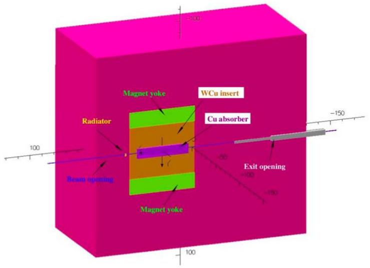


- Detect e^+, e^-, recoil p in coincidence
- CPS bremsstrahlung photon beam
- Jlab-UVA NH_3 target, transversely polarized
- Detectors arranged in 4 quarters, oriented to target
- Multiple GEMs for e^+, e^-, p tracking
- Hodoscopes for recoil proton detection/PID
- $PbWO_4$ calorimeters for e^+, e^-, p detection/PID

TCS w/ polarized target: Experimental apparatus

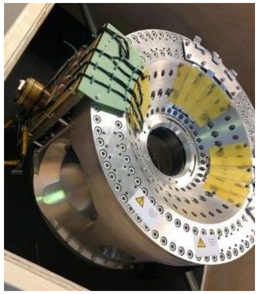
<u>Compact Photon Source (CPS)</u>:

- Combines polarized photon source, collimator and beam dump;
- High intensity photon beam (**1.5×10^{12} γ/s in [5.5 GeV, 11 GeV]** range from 2.5 µA primary e- beam on 10% X_0 Cu radiator , ~1 mm spot size at 2 m from radiator).



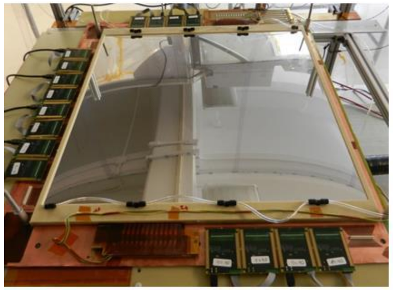
<u>Target</u>:

- Material: ^{15}**NH_3** in LHe at 1°K, packing fraction 0.6.
- Polarization: **5 T** transverse magnetic field; DNP by 140 GHz, 20 W RF field; NMR monitored.
- Acceptance: **±25° horizontally, ±23° vertically.**



<u>GEM trackers:</u>

- Coordinate reconstruction accuracy **~80 µm**
- Background rate tolerance up to **10^6 Hz/mm^2**
- Minimum material thickness along particle pass, big size manufacturing
- Use at Jlab: SBS, SoLID DDVCS, Prad

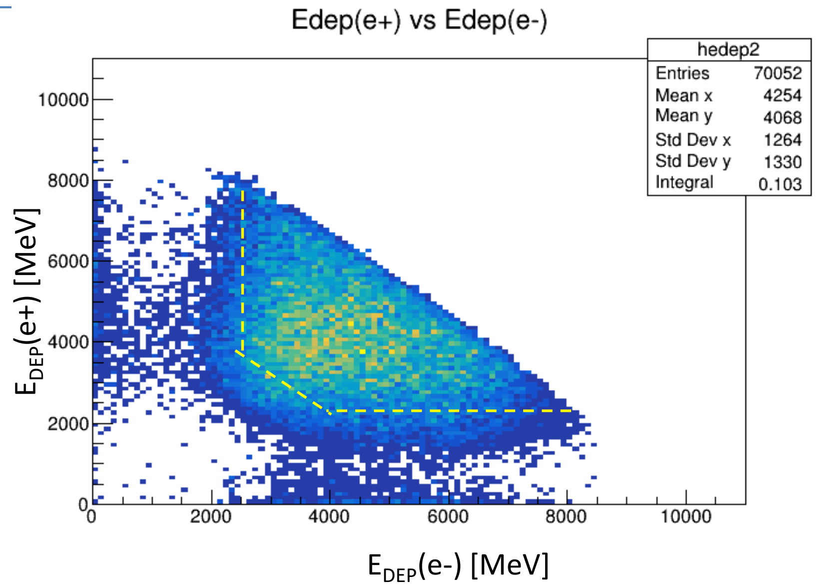


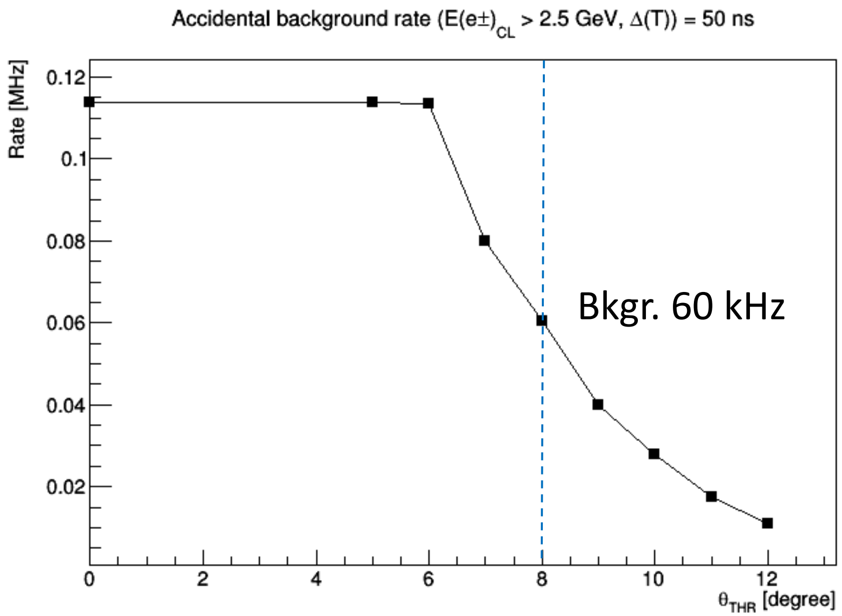
<u>Calorimeters, clones of the NPS calorimeter:</u>

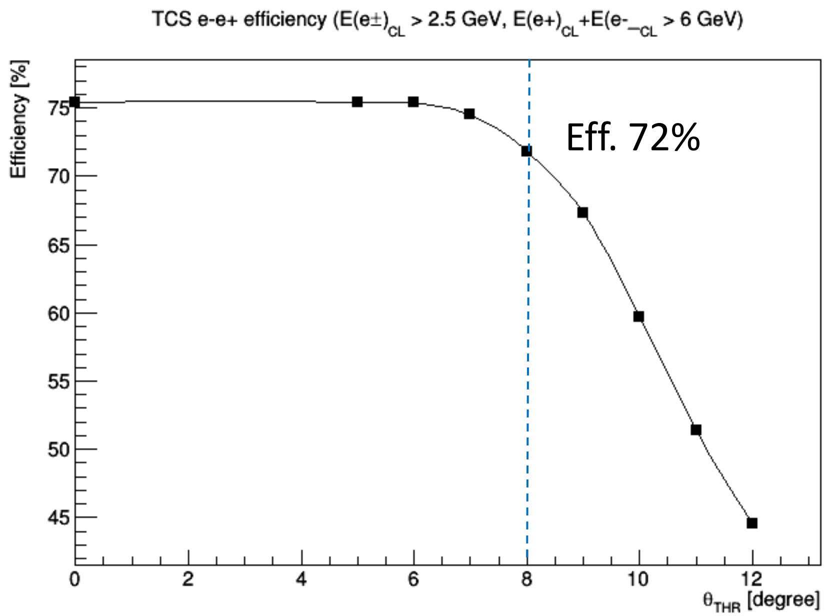
- 2x2x20 cm^2 **$PBWO_4$** scin. crystals, arranged in carbon fiber/µ-metal mesh
- Expected energy resolution **2.5%/√E + 1%**
- Expected coordinate resolution **~3 mm** at 1 GeV
- Modules arranged in 4 assemblies of 23x23 matrix
- Total number of modules **2116**.

TCS w/ polarized target: Trigger concept

- Trigger based on **e+ and e- coincident signals** from calorimeters in opposite quarters
- Establish **thresholds on E_{DEP}(e+), E_{DEP}(e-), E_{DEP}(e+)+E_{DEP}(e-)** to control background
- **Exclude high background** region close to beam pipe

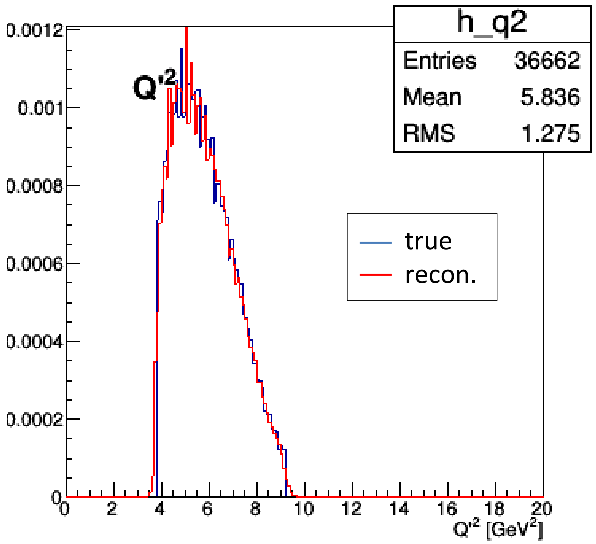


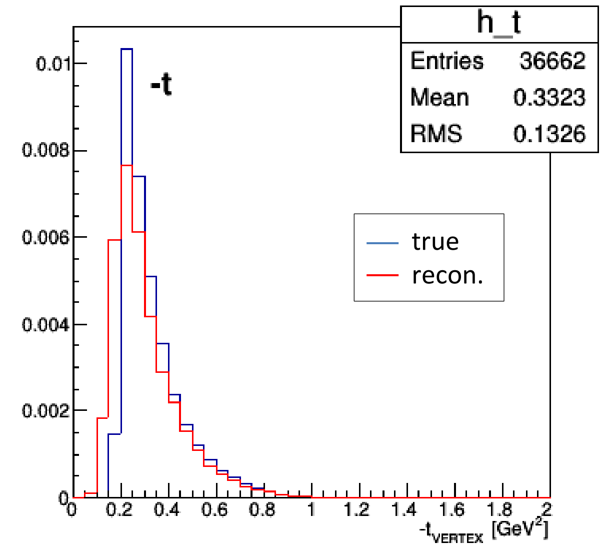


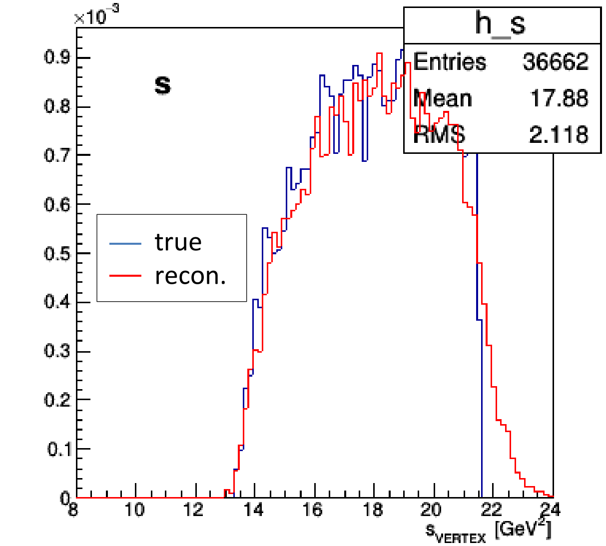


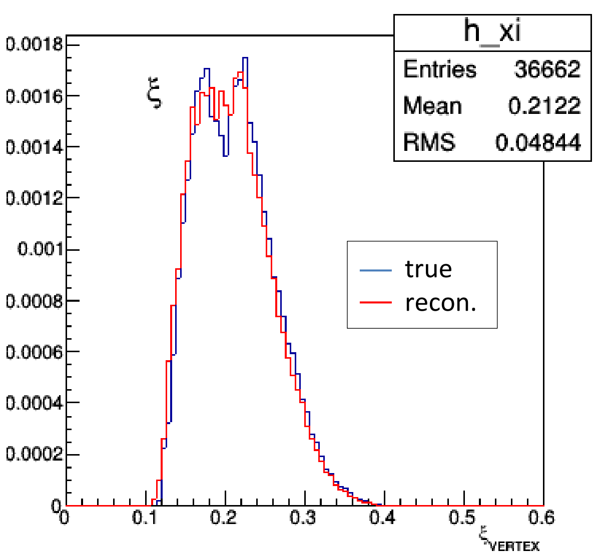
Beam background rate and TCS triple coin. detection efficiency vs cut on polar angle Θ.

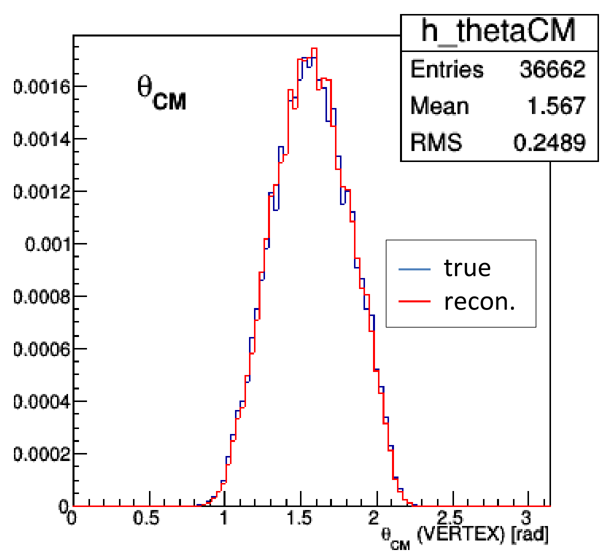
TCS w/ polarized target: Reconstructed versus True Quantities

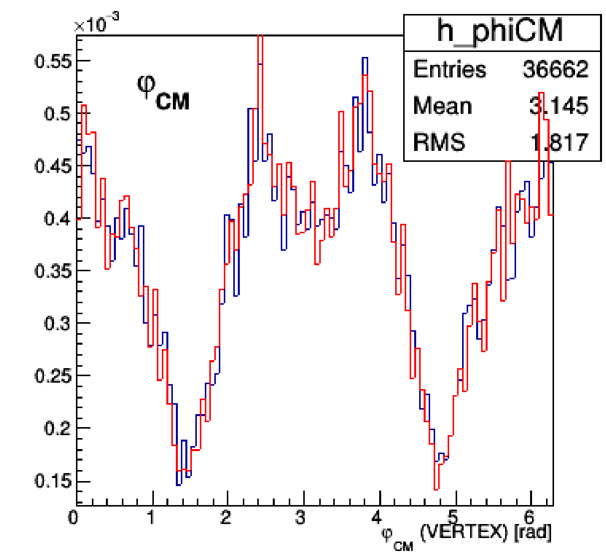












Note: physical and beam backgrounds are not taken into account in the reconstruction.

TCS w/ polarized target: Status

The proposal C-12-18-005 was conditionally approved by PAC 46 and PAC48 with C2 rating, was deferred by PAC 50:

> **Summary:** The PAC acknowledges that the physics case of the proposal is strong and nicely complements the extensive program of GPD-related measurements at JLab. However, given the difficulty of the measurement, the PAC feels that a deeper review of the experimental issues raised above is required, and that the collaboration needs to increase their workforce focusing on the challenging technical issues of this proposal. Given the extent of the additional work needed, the PAC recommends a deferral of this proposal, to enable sufficient time for addressing the technical issues.

The physics program is solid, issues with experimental setup and feasibility of measurements.

Discussed PAC identified issues and pass forward with E.Aschenauer:

- Prioritized tasks (Physics background calculations first)
- Identified pitfalls (Rad. Damage of hodo-s, SiPM sensitivity to neutrons…)
- Discussed possible modifications of detector package (GEM based TRD)
- Identified experts to contact

…

TCS w/ un-polarized target: Physics Case, Motivation

TCS Program

Observables	GPD	Target	Beam	Experiments
Unpol. cross sections vs ϕ	$\Re(H), \Im(H)$	Unpolarized (Lh2)	unpolarized	ClAS12 , SoLID (future), Unpol. TCS in Hall C
Cross sections vs ϕ	$\Im(H), \Im(\tilde{H})$	Unpolarized (Lh2)	Circularly polarized	ClAS12 , SoLID (future), Unpol. TCS in Hall C
Cross sections vs ϕ & ψ	$\Re(H), D - term$	Unpolarized (Lh2)	Linearly polarized	Possible with GlueX
Cross sections vs ϕ	$\Im(\tilde{H})$	Longitudinally polarized target	unpolarized	Possible with CLAS12
Cross section vs ϕ & ϕ_S	$\Im(E), \Im(\tilde{H})$	Transversely polarized target	unpolarized	Pol. TCS in Hall C Work in progress
Double spin asym. vs ϕ	$\Re(CFF)$	log. Polarized	Circularly polarized	Extremely interesting but very difficult
Double spin asym. vs ϕ & ϕ_S	$\Re(CFF)$	trans. Polarized	Circularly polarized	Extremely interesting but very difficult
Double spin asym. vs ϕ & ψ	$\Im(CFFs)$	log. Polarized	Longitudinally polarized	Not useful too complex and not enough info
Double spin asym. vs ϕ_S & ψ	$\Im(CFFs)$	trans. Polarized	Longitudinally polarized	Not useful too complex and not enough info

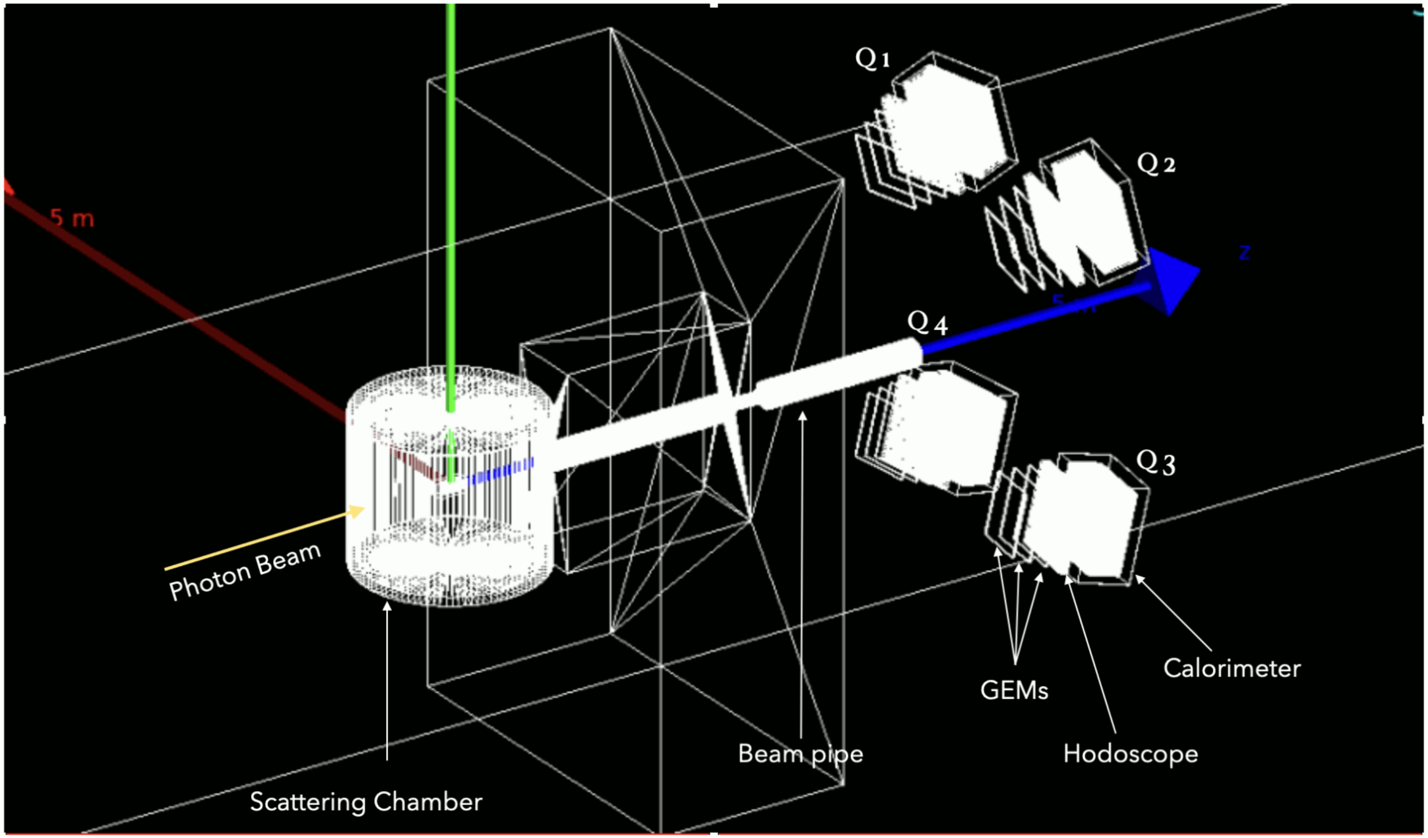
Biswas, D. (VT) TCS @ HaLL C Hall C Winter Collab. Meet. 2024 5

From D.Biswas' presentation on 2024 Winter Hal A/C meeting.

With unpol., circularly pol. γ incident, TCS unpolarized is sensitive to Re(H) and Im(H) GPD-s.

TCS w/ un-polarized target: Experimental apparatus

$$\gamma + p \rightarrow \gamma^* (e^+ + e^-) + p'$$



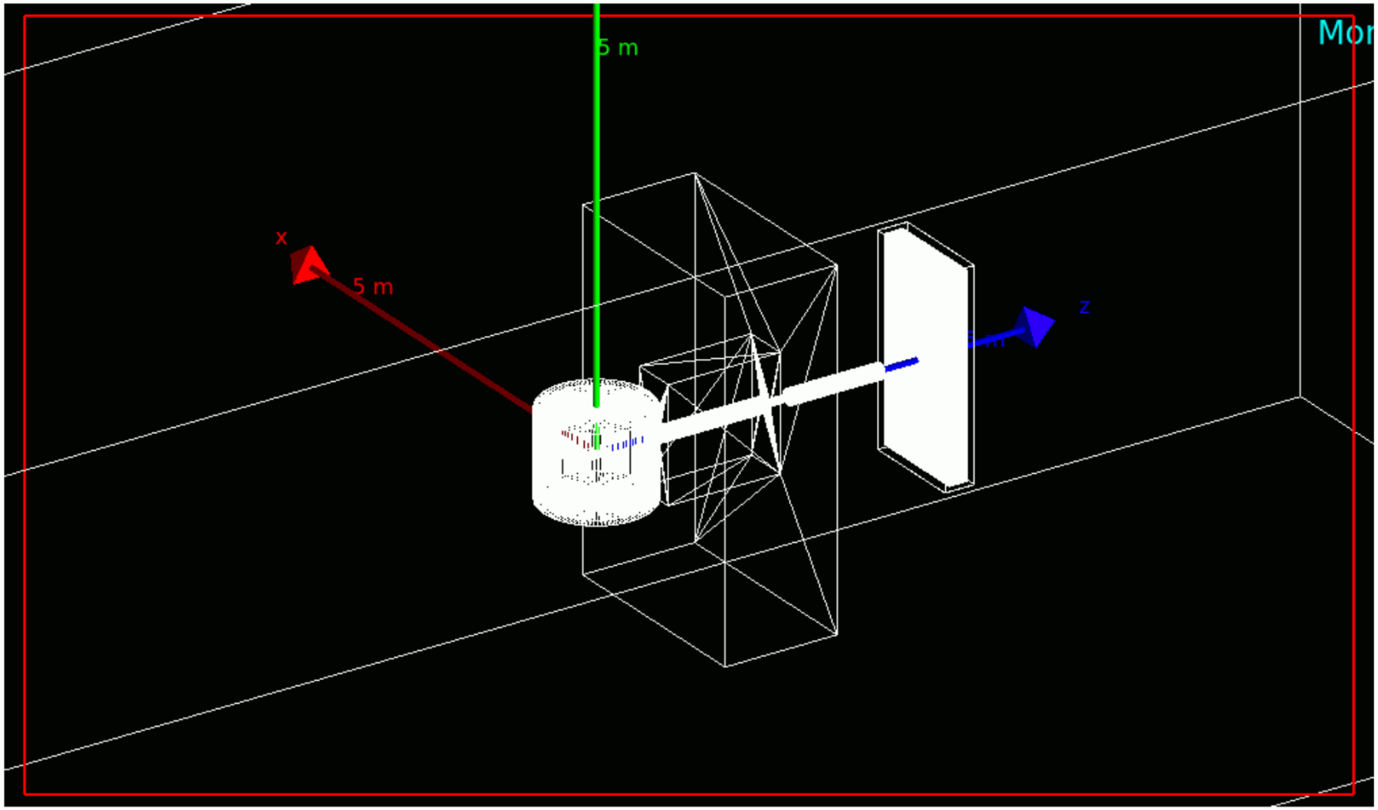
- Detect e^+, e^-, recoil p in coincidence
- **Circularly polarized** CPS brem. photon beam
- Jlab 15 cm **LH2** cryogenic target
- Analyzing ~2Tm **SBS** magnet (31"x48" bore)
- Detectors arranged in 4 quarters
- Multiple GEMs for e^+, e^-, p tracking
- Hodoscopes for recoil proton detection/PID
- $PbWO_4$ calorimeters for e^+, e^-, p detection/PID

TCS w/ un-polarized target: Experimental apparatus

Key differences between polarized and unpolarized setups:

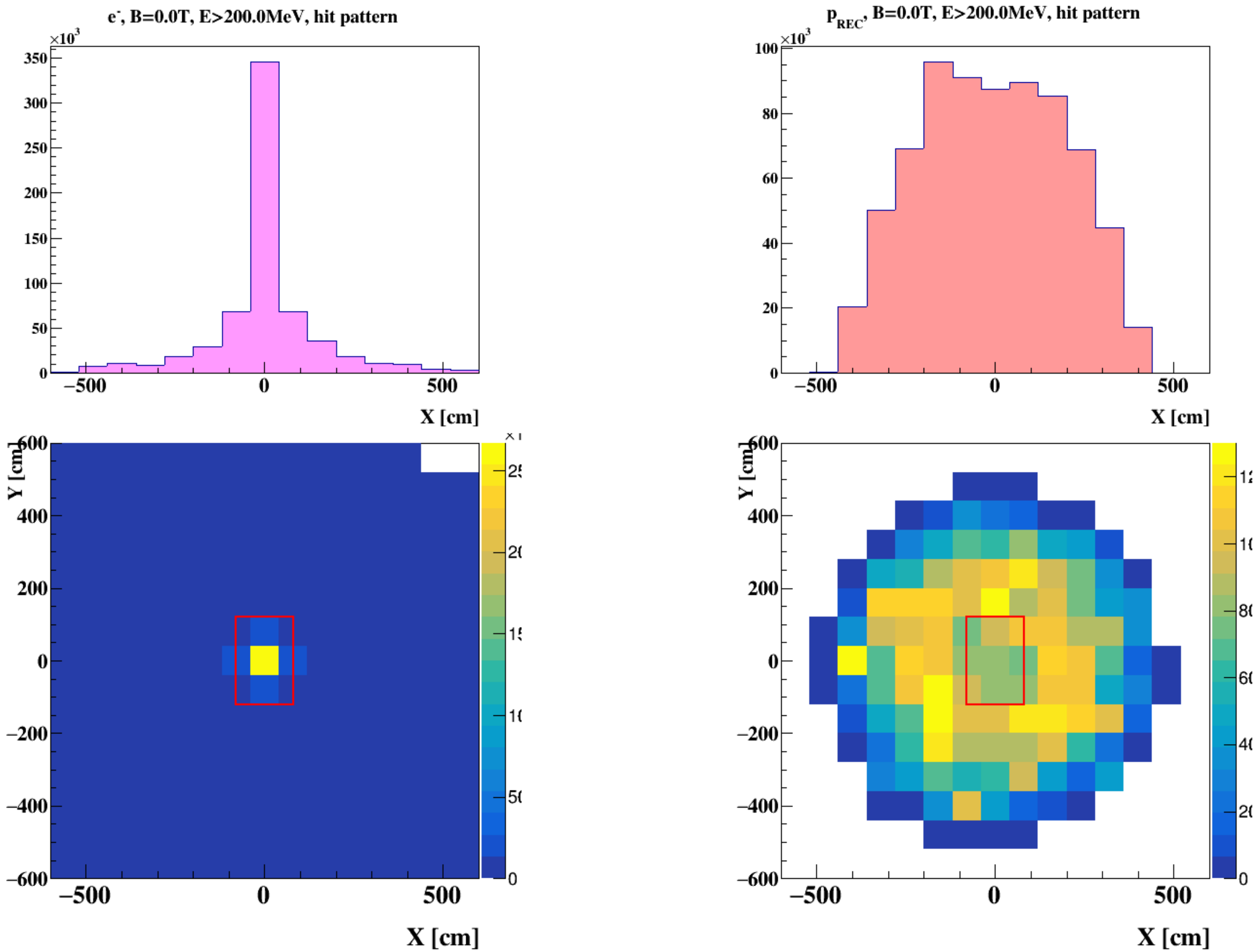
- 15 cm LN2 target versus 3cm NH_3 polarized target, no polarizing magnetic field.
- Analyzing magnet:
  - ~2 Tm field integral
  - 31” wide, 48” high, 48” deep bore
  - Allows separation of e-, e+ tracks at detectors
  - Momenta from tracking useful for PID with calorimeters and hodoscopes
  - Allows vertex reconstruction at target

TCS w/ un-polarized target: Simulations



A setup from Geant4 simulations used for acceptance and optimization studies.

TCS w/ un-polarized target: Simulations



Distributions of TCS e- (left) and recoil proton (right) track coordinates at the face of plane calorimeter. The rectangle encompasses tracks within aperture of the SBS magnet. The SBS magnet is not exited.

Done:

- A Geant 4 code is developed to simulate setup
- TCS events are sampled by the DEEPGen generator
- Responses of detectors to the TCS events are simulated
- Rates of e+e- coincidence and triple coincidence events are estimated for a configuration of setup

To be done:

- Optimize the setup for max. triple coincidence triple rate (magnets' field and position, detector coverage and positions)
- Estimate TCS trigger rates and triple coincidences
- Generate events of principal physics backgrounds and estimate their rates in the setup
- Estimate background rates from beam interaction with matter

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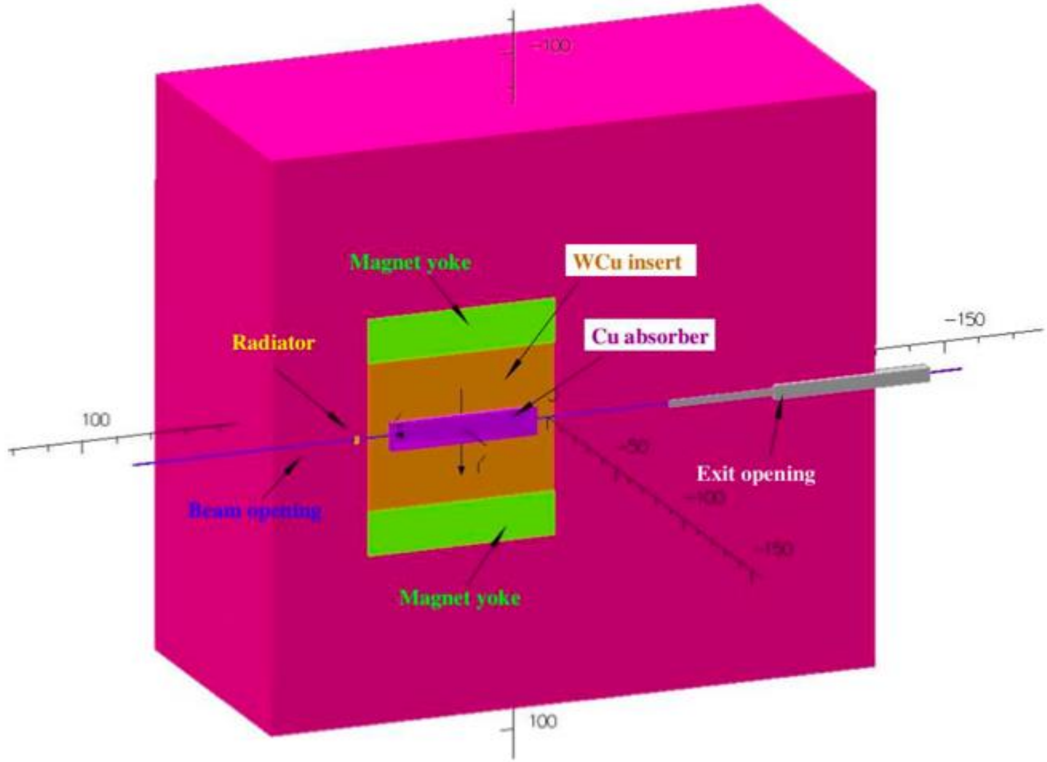
Thank you for your attention!

Backup slides

Experimental apparatus, CPS



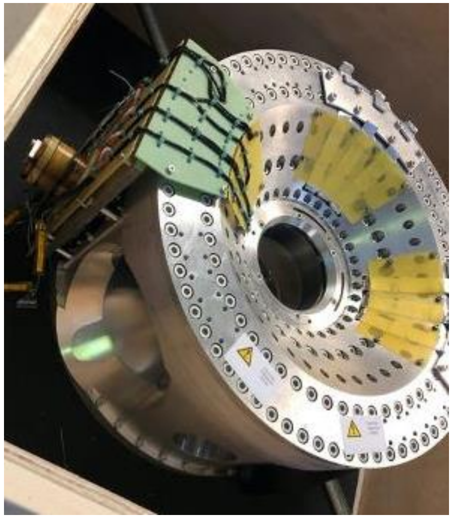
Compact Photon Source under development in Hall C at JLab:

- Combines polarized photon source, collimator and beam dump;
- High intensity directed brem. photon beam (**1.5×10^{12} γ/s in [5.5 GeV, 11 GeV] range** from **2.5 µA primary e- beam** on **10% X_0 Cu radiator** , **~1 mm spot size** at 2 m from radiator);
- 3.2 T warm magnet to bend incoming electrons to local beam dump;
- Highly shielded design (W/Cu alloy) to minimize prompt and residual radiation.

D.Day et al., NIMA 957 (2020) 163429

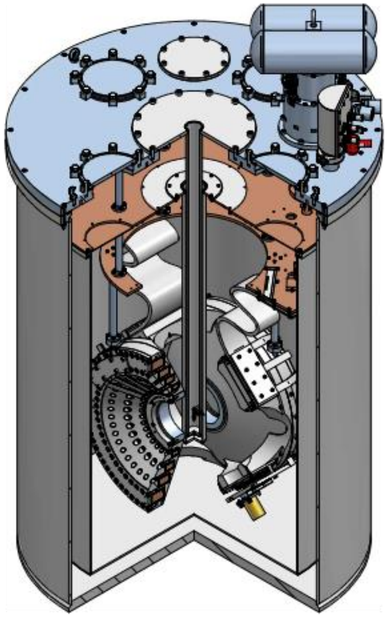
Experimental apparatus: Polarized target

- Target material: ^{15}**NH$_3$**, in LHe **at 1°K**.
- Packing fraction 0.6.
- Magnetic field generated by superconducting Helmhotz coils.
- **DNP polarization** by 140 GHz, 20 W RF field.
- Polarization monitored via NMR.
- **Depolarization mitigated** by combined rotation (~1 Hz) around horizontal axis and vertical up/down movement (~10 mm).



New polarizing magnet arrived in September 2021!

- Drop-in replacement for old Jlab-UVA target
- 5 T magnetic field, 100 ppm uniformity
- **±25° horizontal opening angle** in transverse filed configuration (increase from ±18° --> **increase of TCS acceptance**, help with background rates.)

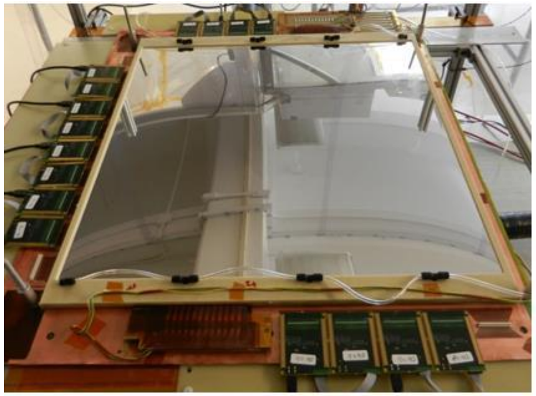


Horizontal field orientation

GEM trackers:

- Coordinate reconstruction accuracy **~80 μm**
- Background rate tolerance up to **10^6 Hz/mm^2**
- Minimum material thickness along particle pass
- Big size manufacturing

Use at Jlab: SBS, SoLID DDVCS, Prad



SBS BT GEM prototype (*K.Gnanvo et al., NIMA 782 (2015) 77-86*)

Hodoscopes:

- To provide dE/dX signal from low momentum recoil protons
- 2x2x5 cm^3 scintillators arranged in "Fly's eye" hodoscopic construction

Calorimeters, **clones of the NPS calorimeter**:

- 2x2x20 cm^2 **$PBWO_4$ scin. crystals**, optically isolated
- Modules arranged in a mesh of carbon fiber/μ-metal
- Expected **energy resolution** 2.5%/√E + 1%
- Expected **coordinate resolution** ~3 mm at 1 GeV
- Modules arranged in 4 "fly's eye" assemblies of 23x23 matrix

Total number of modules needed **2116**.

Assembling of NPS calorimeter (June 2022)

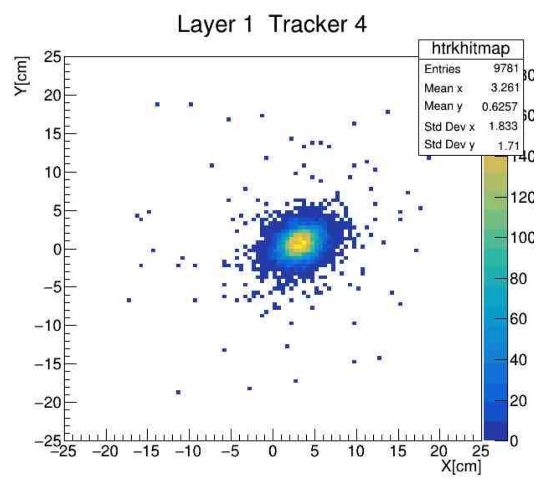
Recoil proton ID

Low energy protons, E_{KIN} from ~30 MeV to 450 MeV

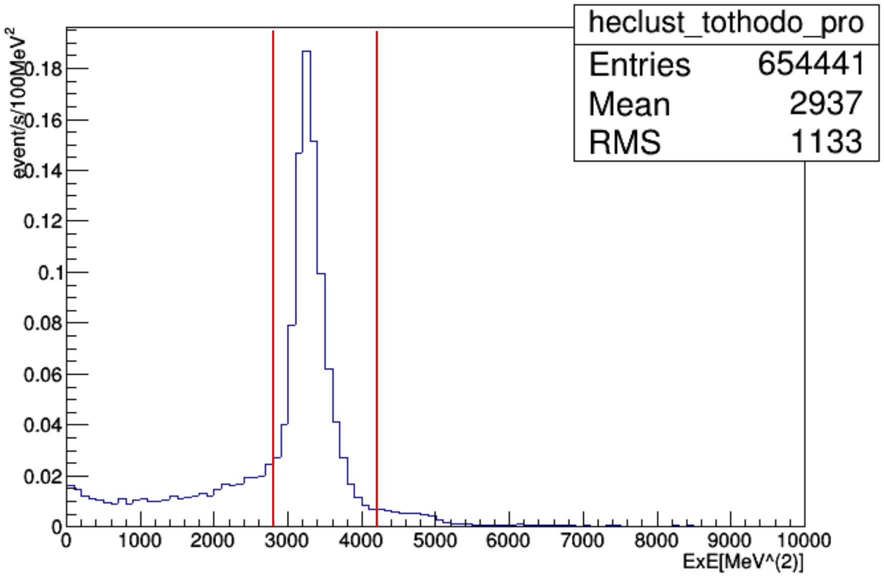
Cuts to select good protons:

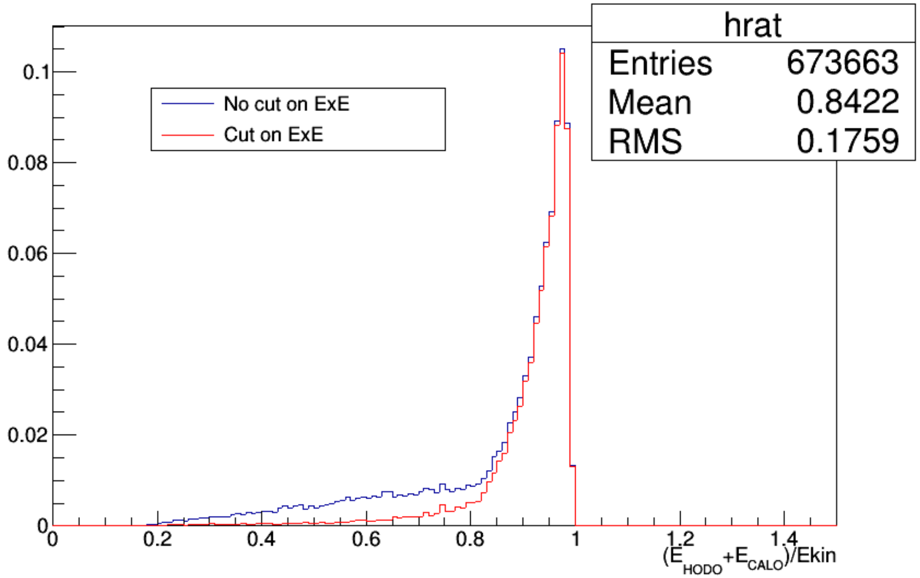
- $E_{HODO} > 15\ MeV$
- $90\ MeV < E_{HODO} + E_{CALO} < 450\ MeV$
- $2800\ MeV^2 < ExE < 4200\ MeV^2$,

$$where\ ExE = (E_{HODO} + E_{CALO} - 12) \times (E_{HODO} - 7)$$



GEM hit pattern from 400 MeV/c protons.





Lepton charge assignment

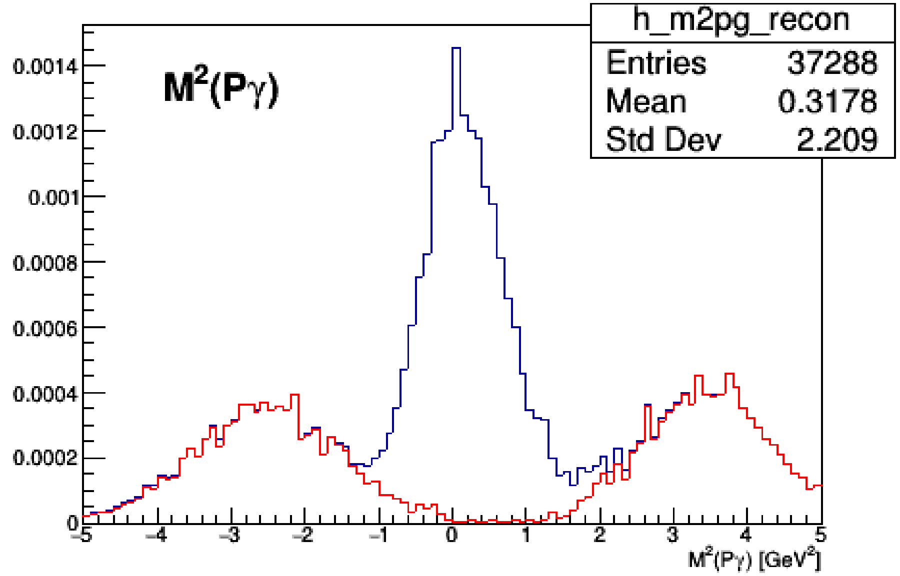
5T target field localized at target cell

Field behind scattering chamber too weak to distinguish pos. and neg. tracks.

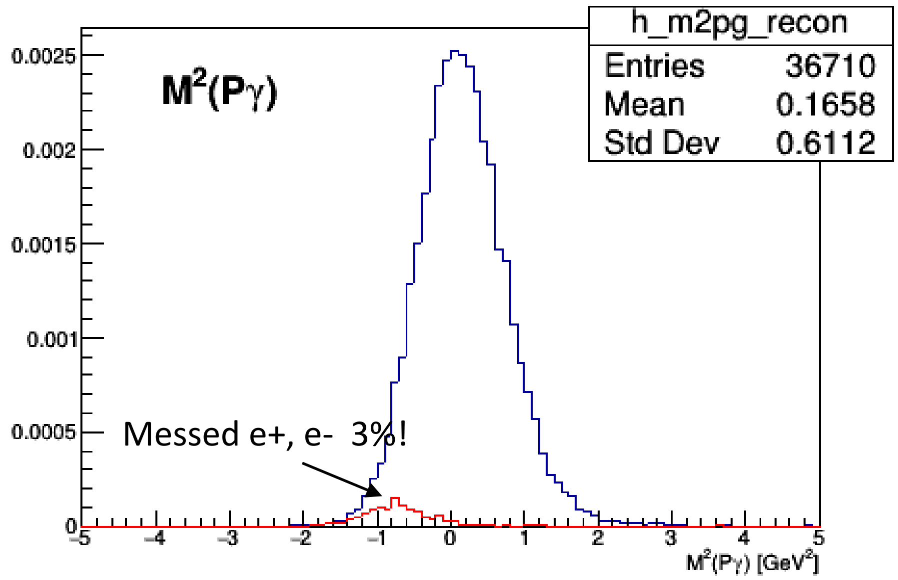
Alternative: use reconstructed incident photon mass:

- Reconstruct recoil proton;
- Reconstruct leptons twice, by assigning (+,-) and (-,+) charges;
- Combine with reconstructed proton to get 2 masses, choose smaller one.

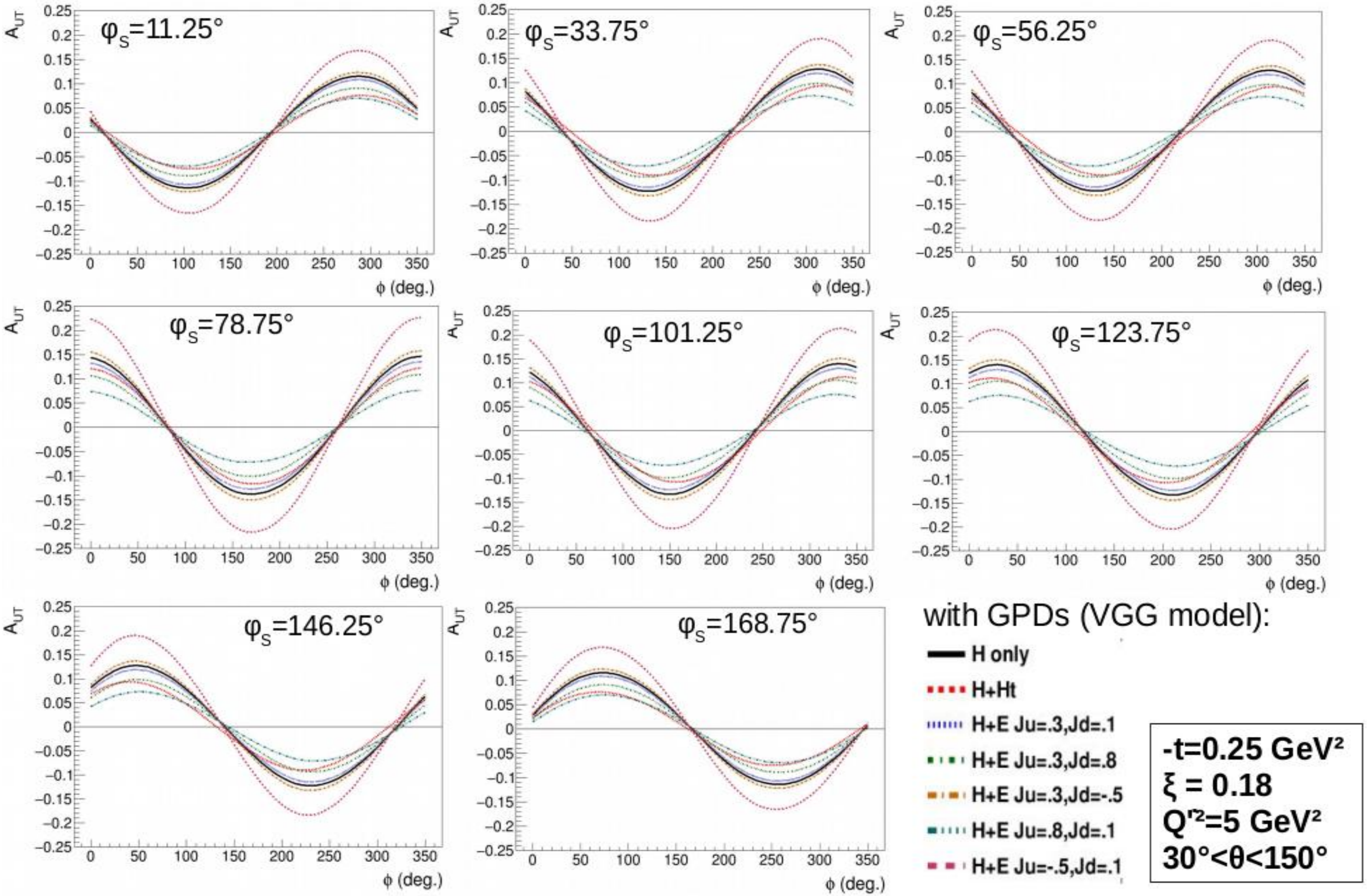
Random lepton charge assignment



Lepton charges according selection criteria

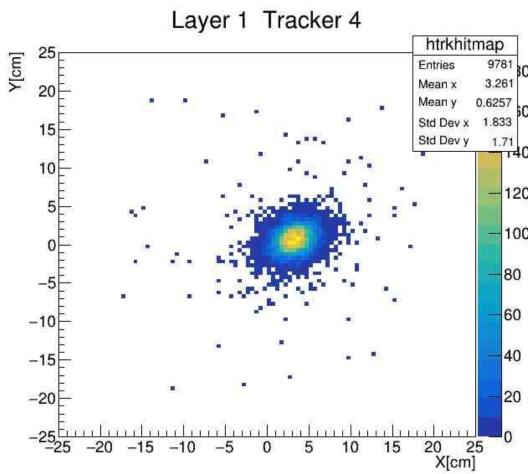


Anticipated results: target asymmetries



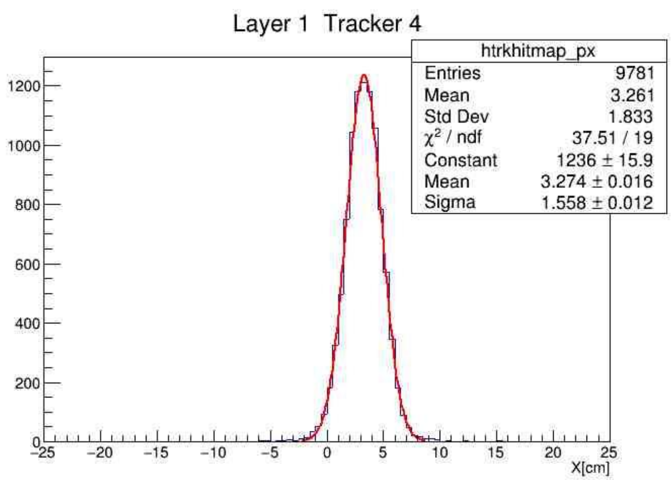
- Shows strong dependence on angular momenta
- 8 bins: fit of 2x2 orthogonal bins (4 independent ones) for CFFs global fits

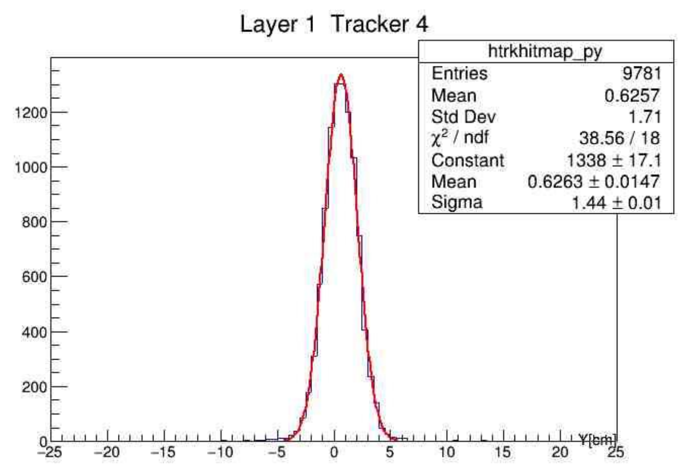
$400\ MeV/c\ (E_{KIN} = 81\ MeV)$ proton passed from target to 1-st layer GEM.



Tracks with θ_Y = 15° at vertex:

- Hit spot size $\sigma \sim 1.5cm$
- Fraction of hits within $R < 4.5cm$ -- 94.5%



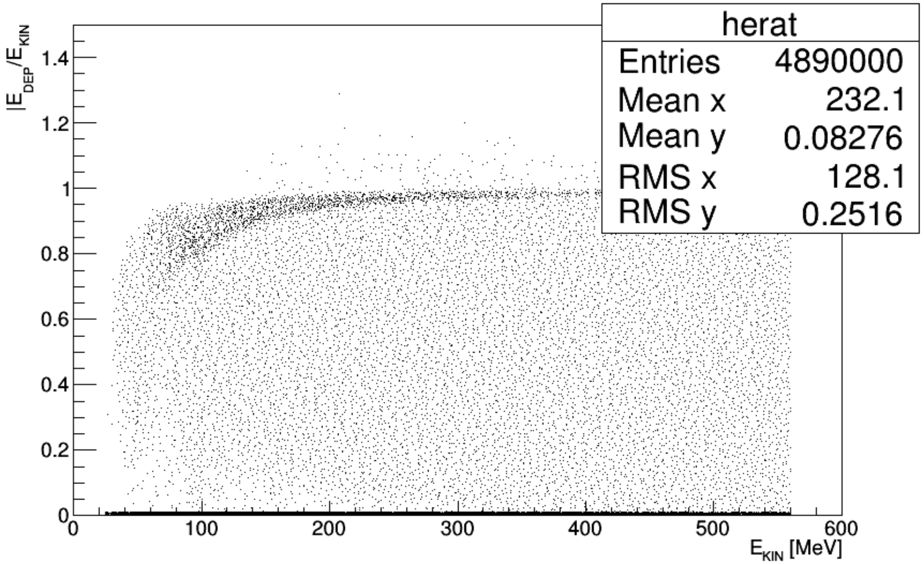


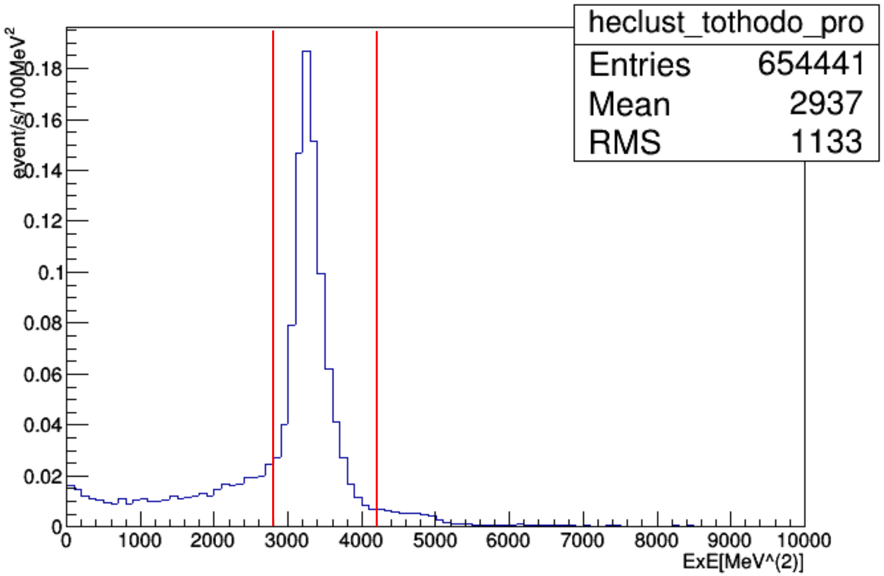
Proton selection

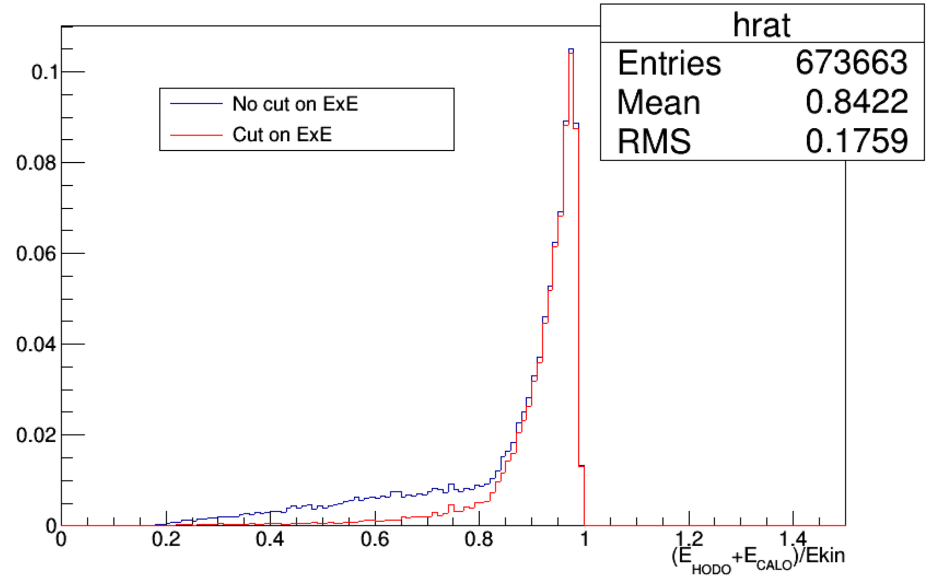
Cuts to select good protons:

- $E_{HODO} > 15\ MeV$
- $90\ MeV < E_{HODO} + E_{CALO} < 450\ MeV$
- $2800\ MeV^2 < ExE < 4200\ MeV^2$,

$$ExE = (E_{HODO} + E_{CALO} - 12) \times (E_{HODO} - 7)$$

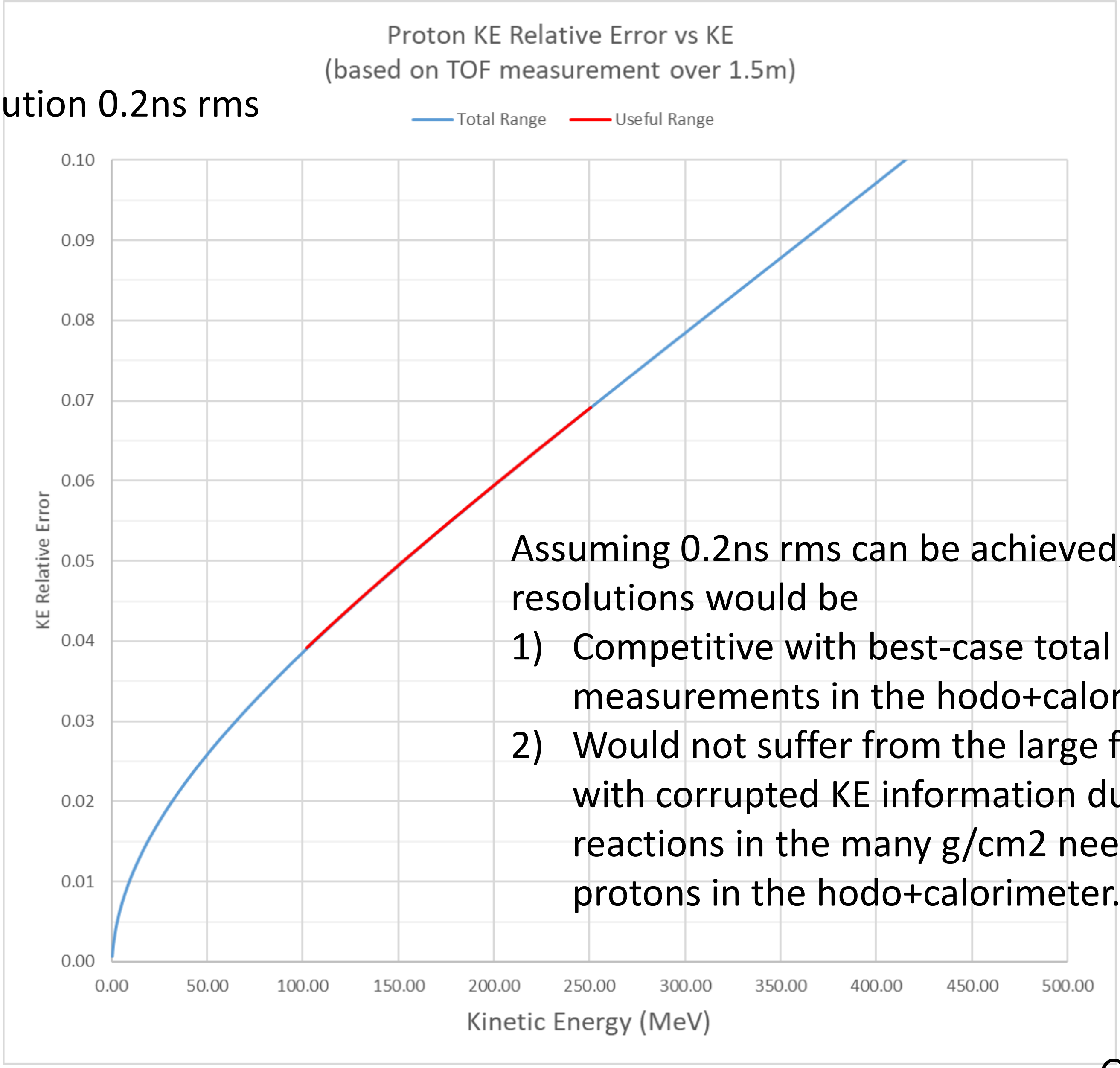






Recoil proton ID

Time resolution 0.2ns rms

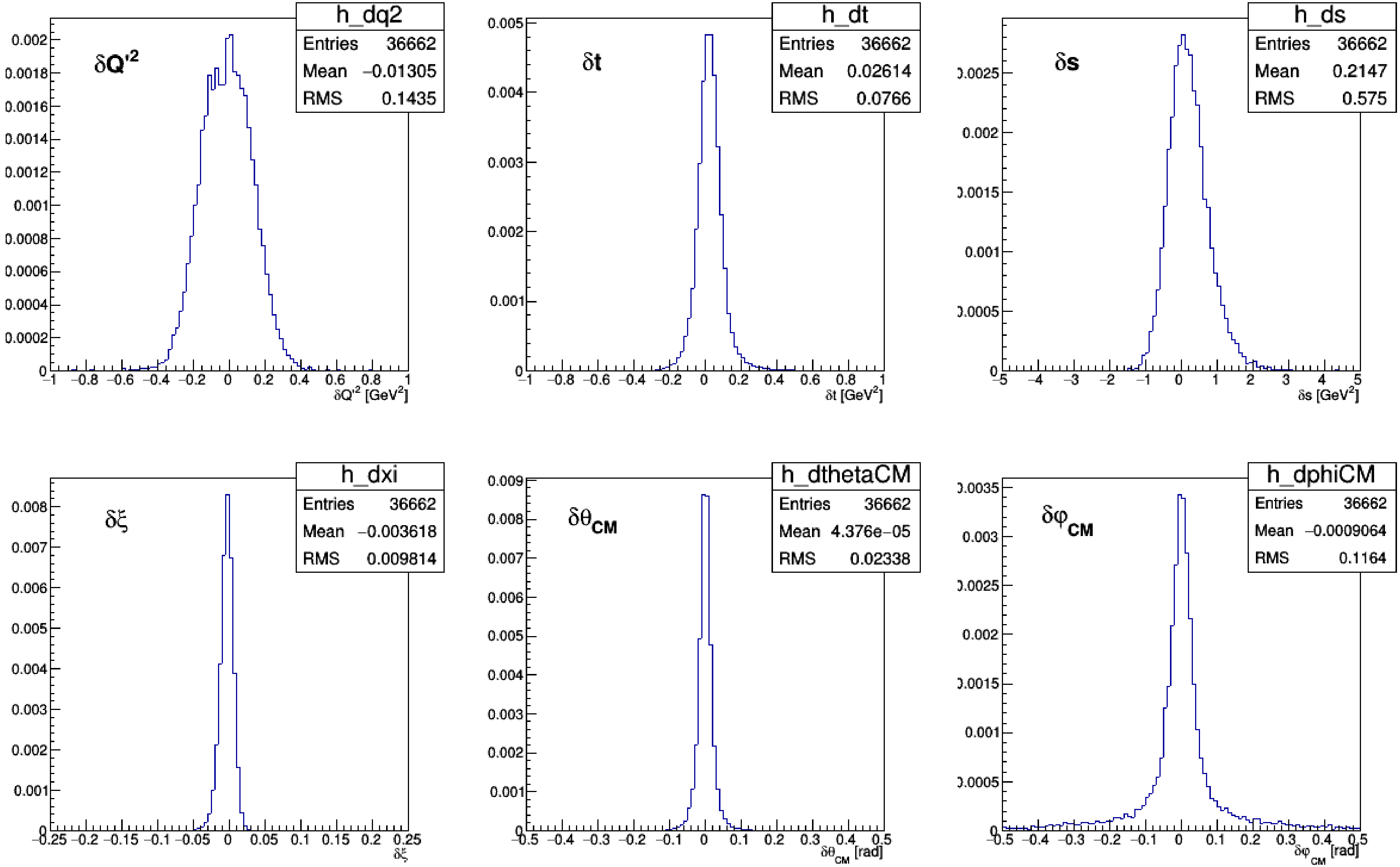


Assuming 0.2ns rms can be achieved, these resolutions would be

1) Competitive with best-case total absorption measurements in the hodo+calorimeter, but
2) Would not suffer from the large fraction of events with corrupted KE information due to nuclear reactions in the many g/cm2 needed to stop the protons in the hodo+calorimeter.

Courtesy D.Mack

Residuals of reconstructed quantities



Resolutions acceptable for analysis.