# Transversely polarized TCS at JLab Hall C using NPS and CPS

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Towards improved hadron femtography
with hard exclusive reactions

Blacksburg, VA, 07/18-22/2022

# Outline

Physics case and motivation

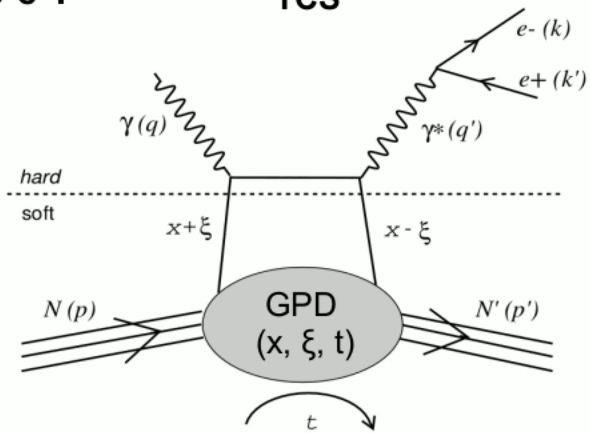
Experimental setup

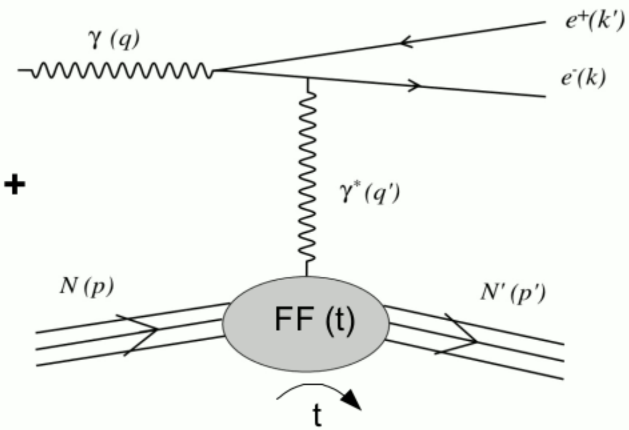
Remarks on analysis

Summary & Outlook

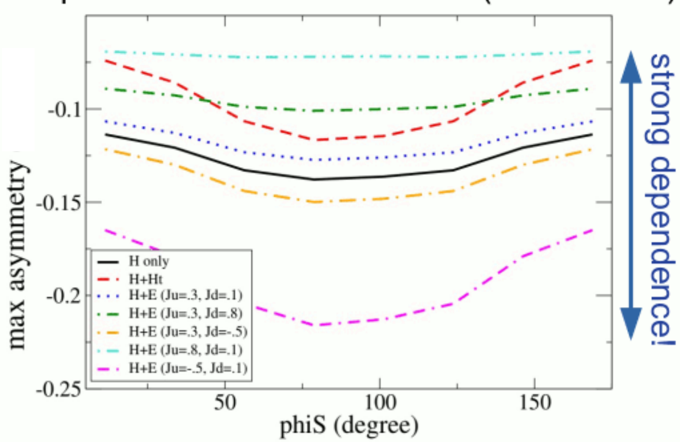
## Physics goals

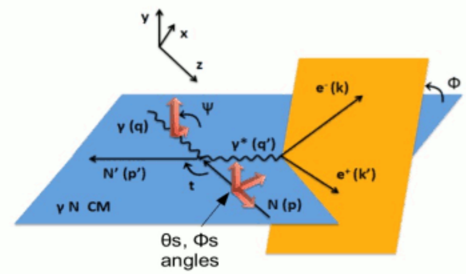
$\gamma P \rightarrow e^+e^- P'$ = **TCS** + **Bethe-Heitler**




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



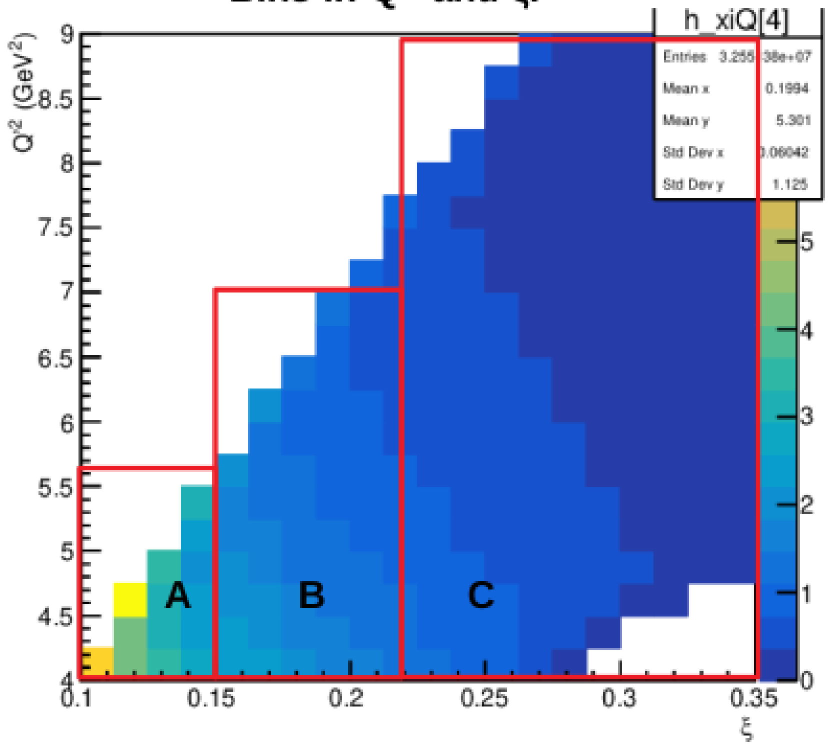

**TSA as a function of φ and $\varphi_S$**

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

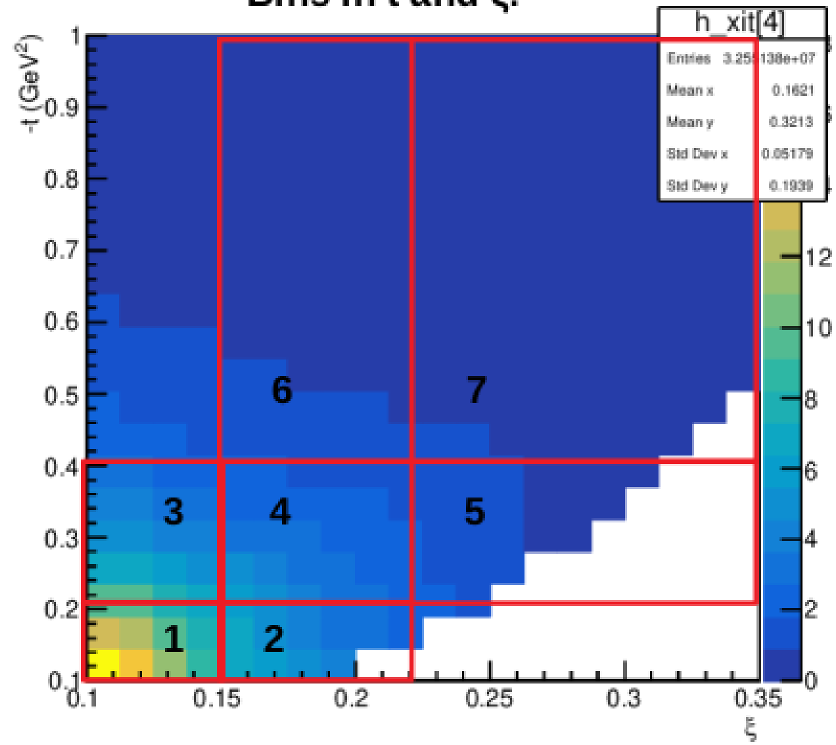
Sensitivity to GPD E (also to H, Ht)

***Courtesy M.Boer***

**Bins in Q'² and ξ:**




**Bins in t and ξ:**

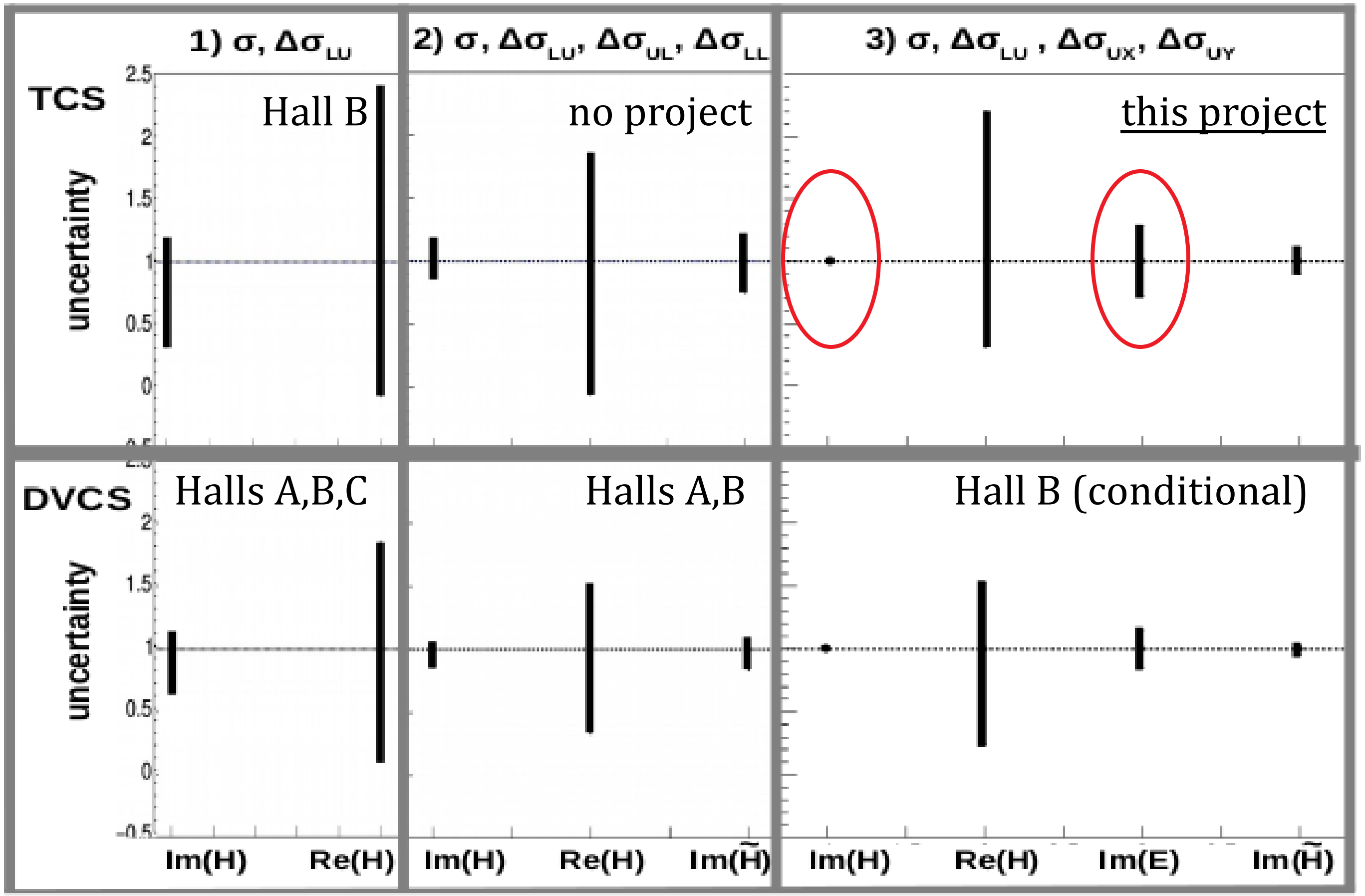



A: $.10 < \xi < .15$ ; $4 < Q'^2 < 5.5$ GeV²
B: $.15 < \xi < .22$ ; $4 < Q'^2 < 7$ GeV²
C: $.22 < \xi < .35$ ; $4 < Q'^2 < 9$ GeV²

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*

# Physics case: Extraction of CFFs from TCS versus DVCS



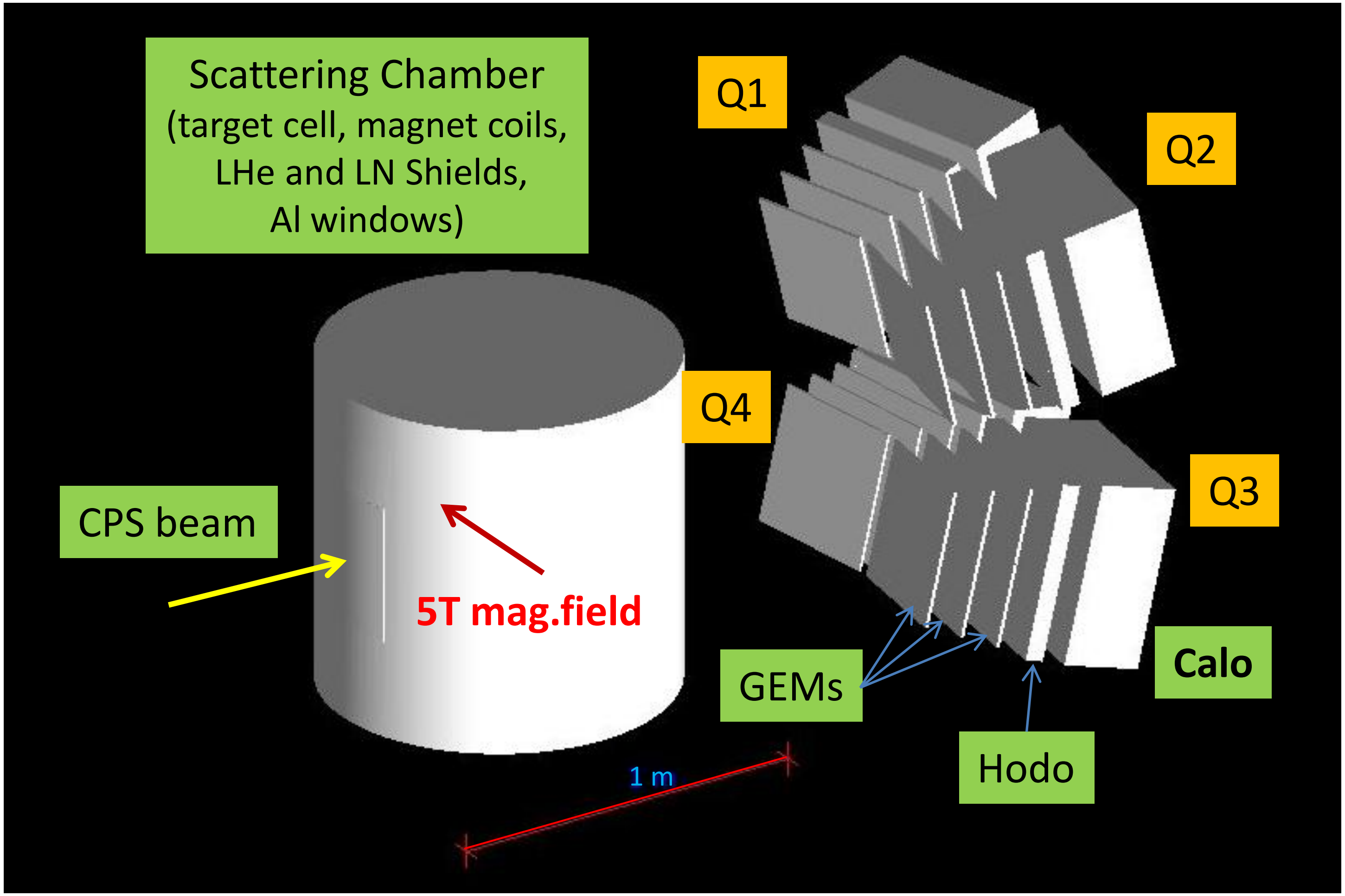

Example estimates of accuracies on the model extraction of CFFs.

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**)

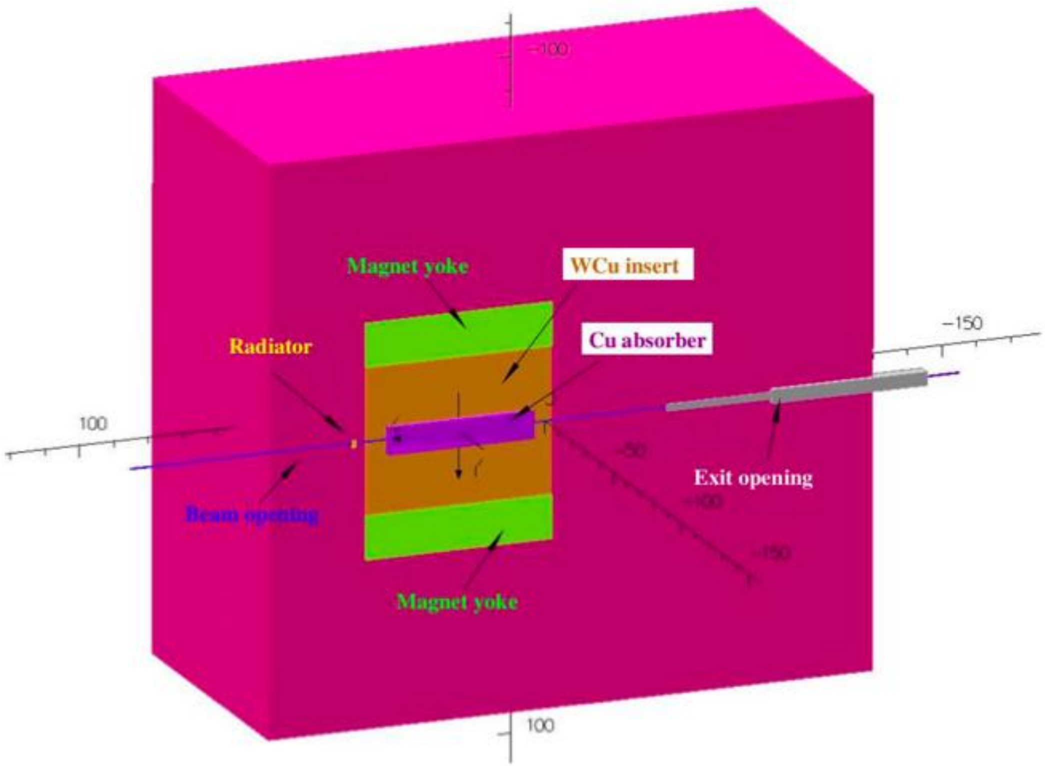
# Experimental apparatus: Setup

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




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

# Experimental apparatus, CPS



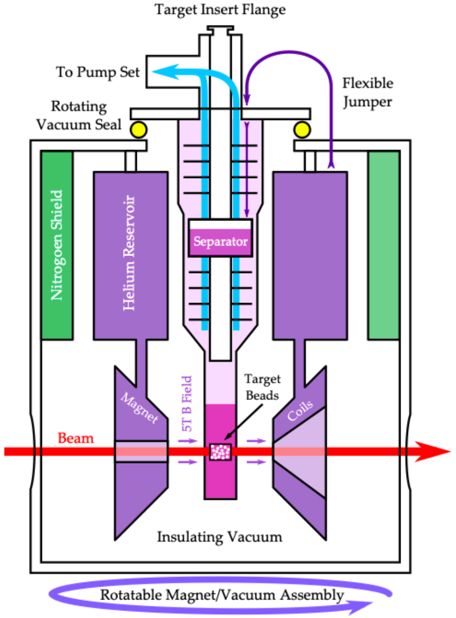

Compact Photon Source under development in Hall C at JLab:

- Combines polarized photon source, collimator and beam dump;
- High intensity directed brem. photon beam (**$1.5\times10^{12}$ 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

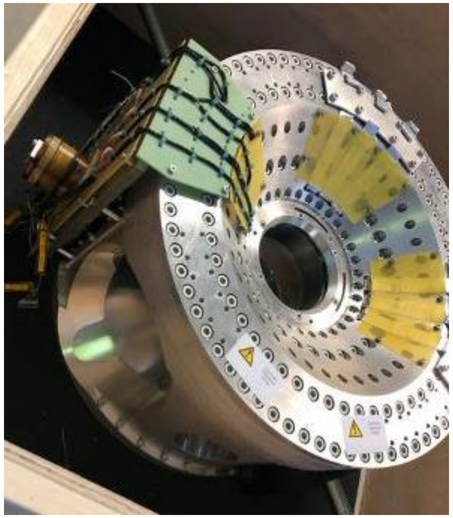
- Target material: **$^{15}NH_3$**, in LHe **at 1°K**.
- Packing fraction 0.6.
- Magnetic field generated by superconducting Helmhotz coils.
- **DNP polarization** by 140 GHz, 20 W RF field.
- Polarization monitored via NMR.
- **Depolarization mitigated** by combined rotation (~1 Hz) around horizontal axis and vertical up/down movement (~10 mm).




*UVA/JLab target*

<u>New polarizing magnet arrived in September 2021!</u>

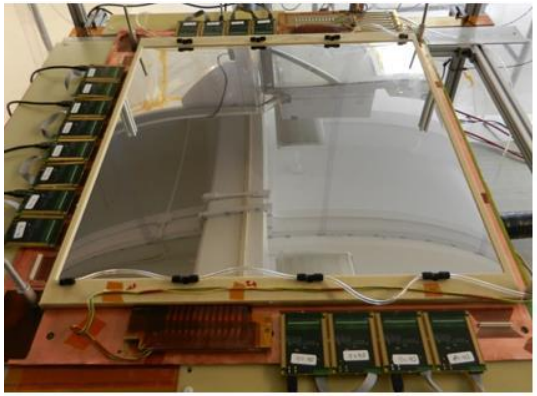
- Drop-in replacement for old Jlab-UVA target
- 5 T magnetic field, 100 ppm uniformity
- **±25° horizontal opening angle** in transverse filed configuration (**increase from ±18°** of JLab-UVA -> increase of TCS acceptance, help with background rates.)



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**:

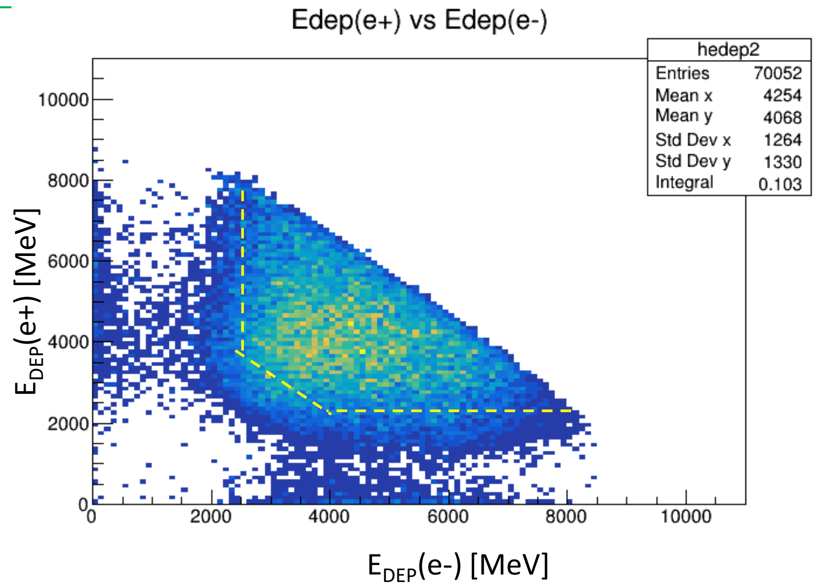
- 2x2x20 cm$^2$ **$PBWO_4$ scin. crystals**, optically isolated
- Modules arranged in a mesh of carbon fiber/μ-metal
- Expected **energy resolution** 2.5%/√E + 1%
- Expected **coordinate resolution** ~3 mm at 1 GeV
- Modules arranged in 4 "fly's eye" assemblies of 23x23 matrix

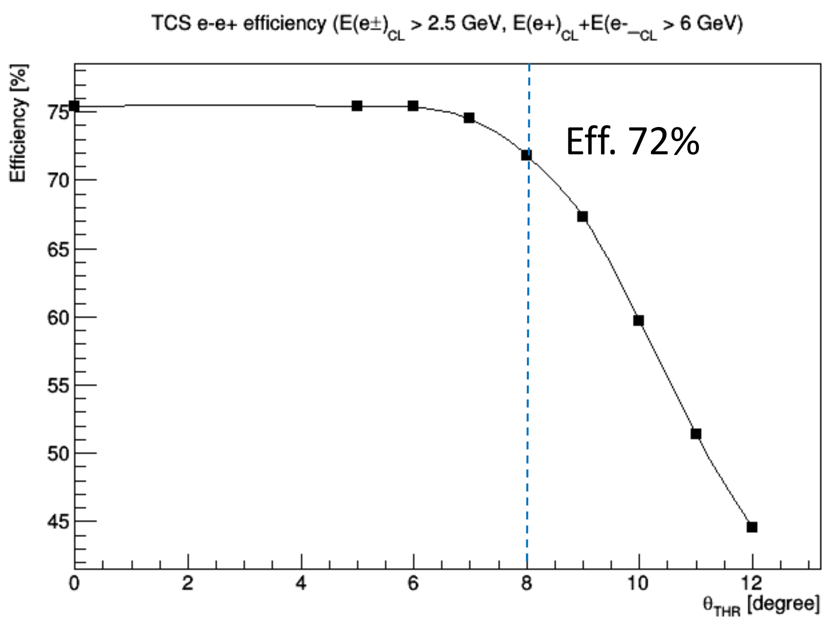
**Total number** of modules needed **2116**.

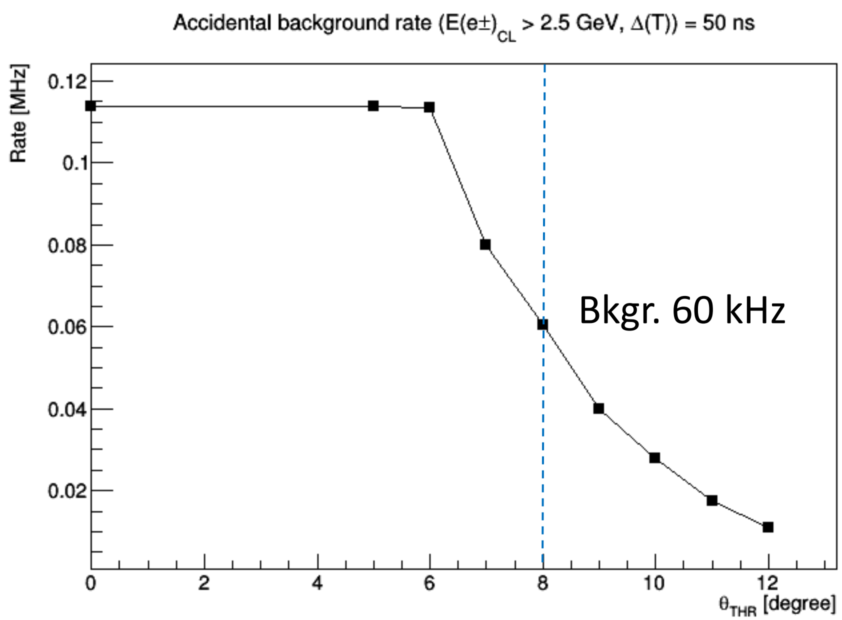
Assembling of NPS calorimeter (June 2022)

# Trigger concept

- Trigger based on **e+ and e- coincident signals** from calorimeters in opposite quarters
- Establish **high 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
- **Background rate under control!**



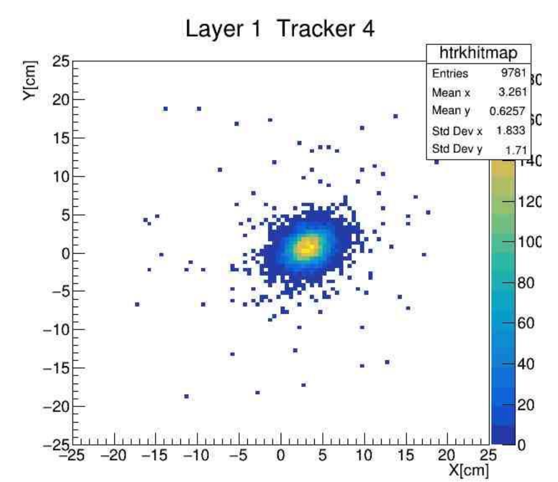



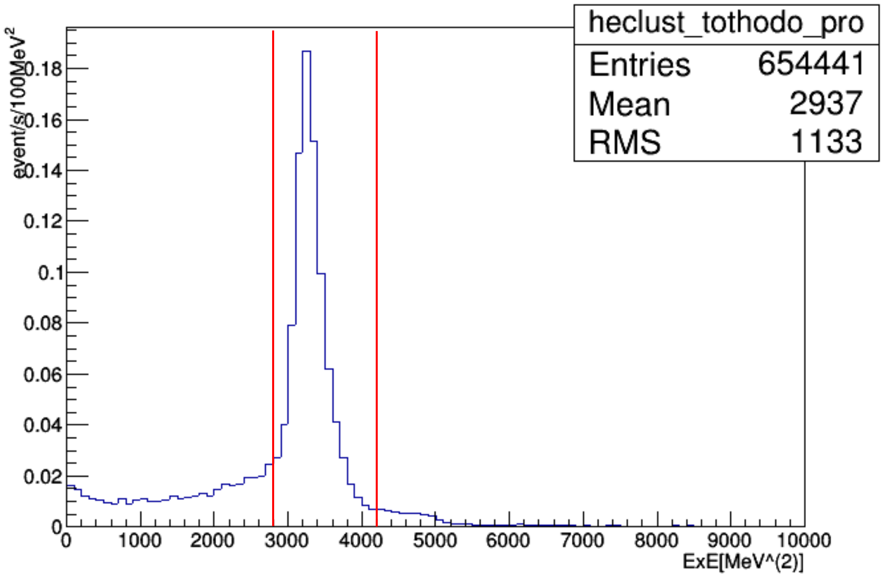

TCS triple coin. detection efficiency and beam background rate vs cut on polar angle Θ.

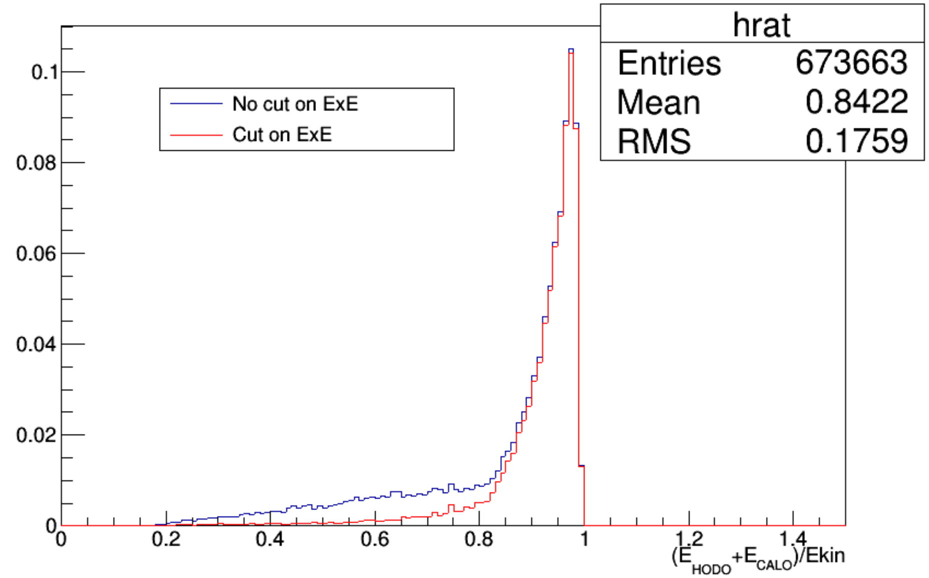
# Recoil proton ID

- Recoil proton detection essential for $-t$
- 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 $ExE = (E_{HODO} + E_{CALO} - 12) \times (E_{HODO} - 7)$



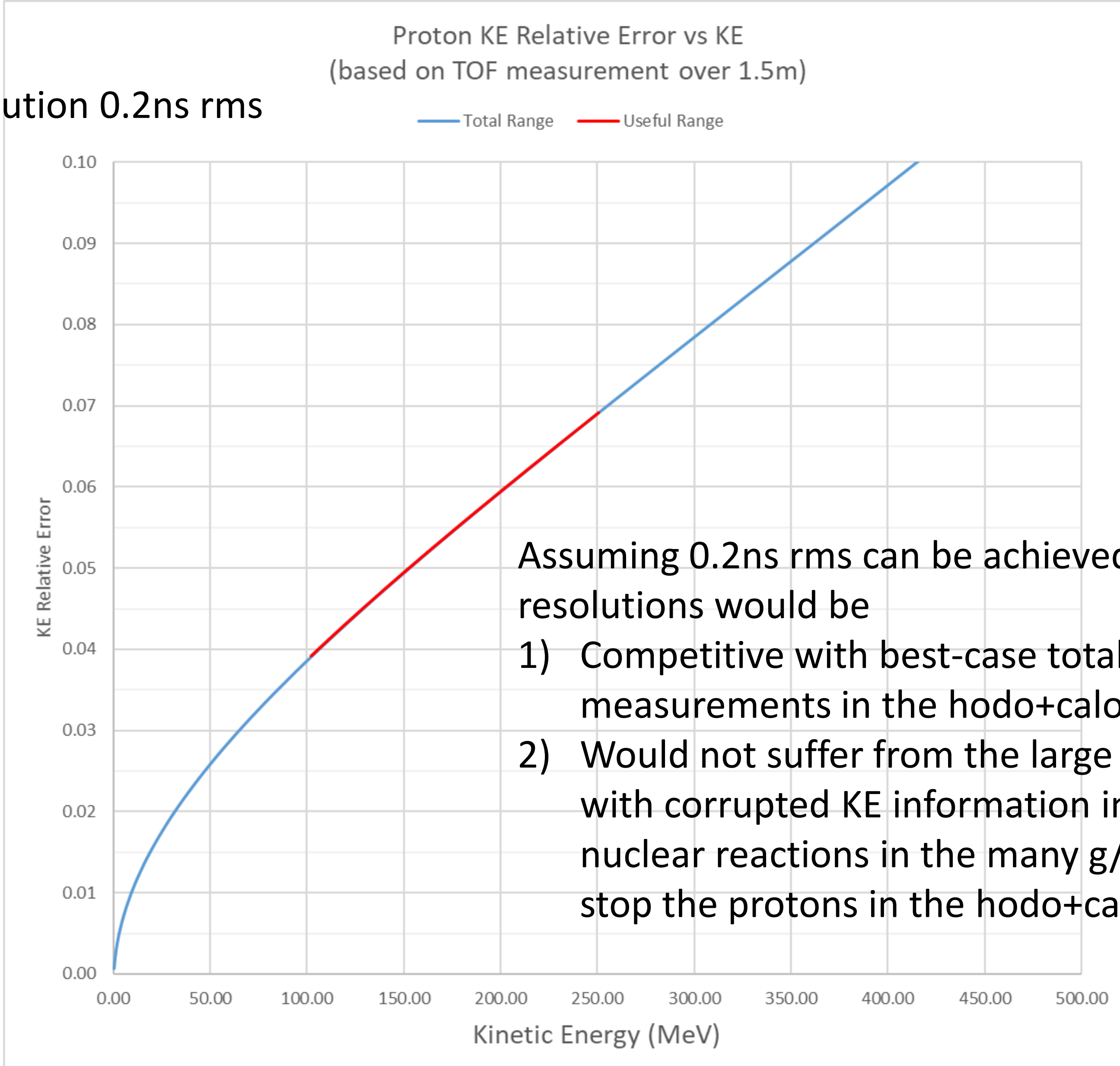

GEM hit pattern from 400 $MeV/c$ protons.



# 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 information due to nuclear reactions in the many g/cm2 needed to stop the protons in the hodo+calorimeter.

*Courtesy D.Mack*

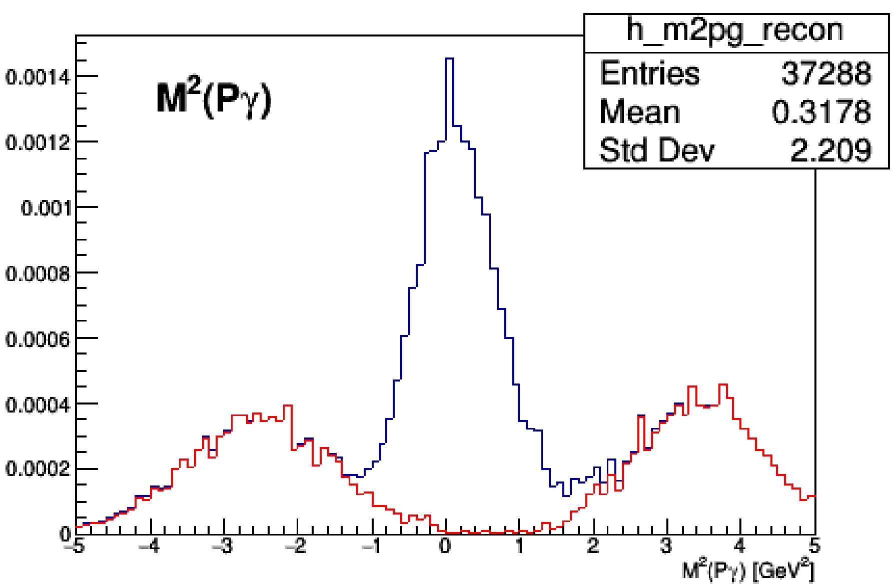
5T target field localized at target cell

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

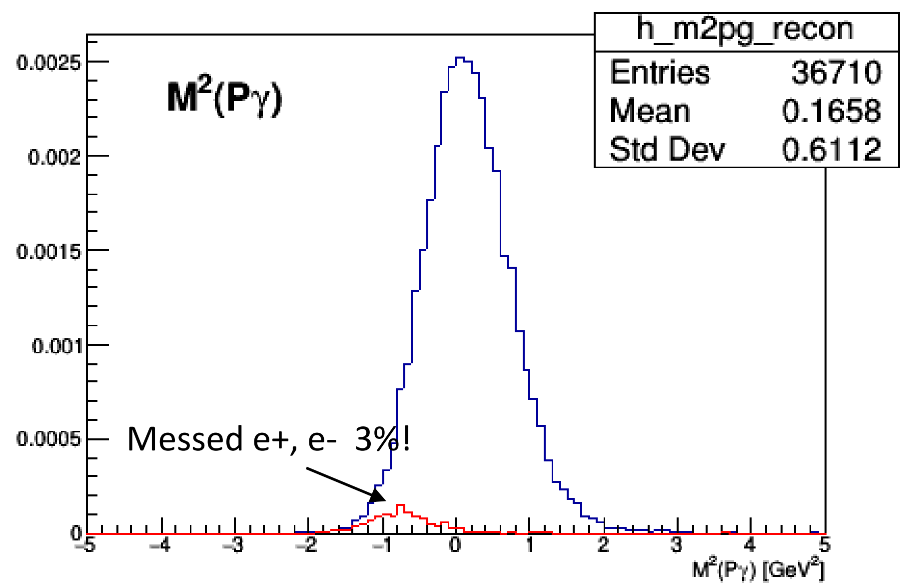
Alternative: use reconstructed incident photon mass:

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

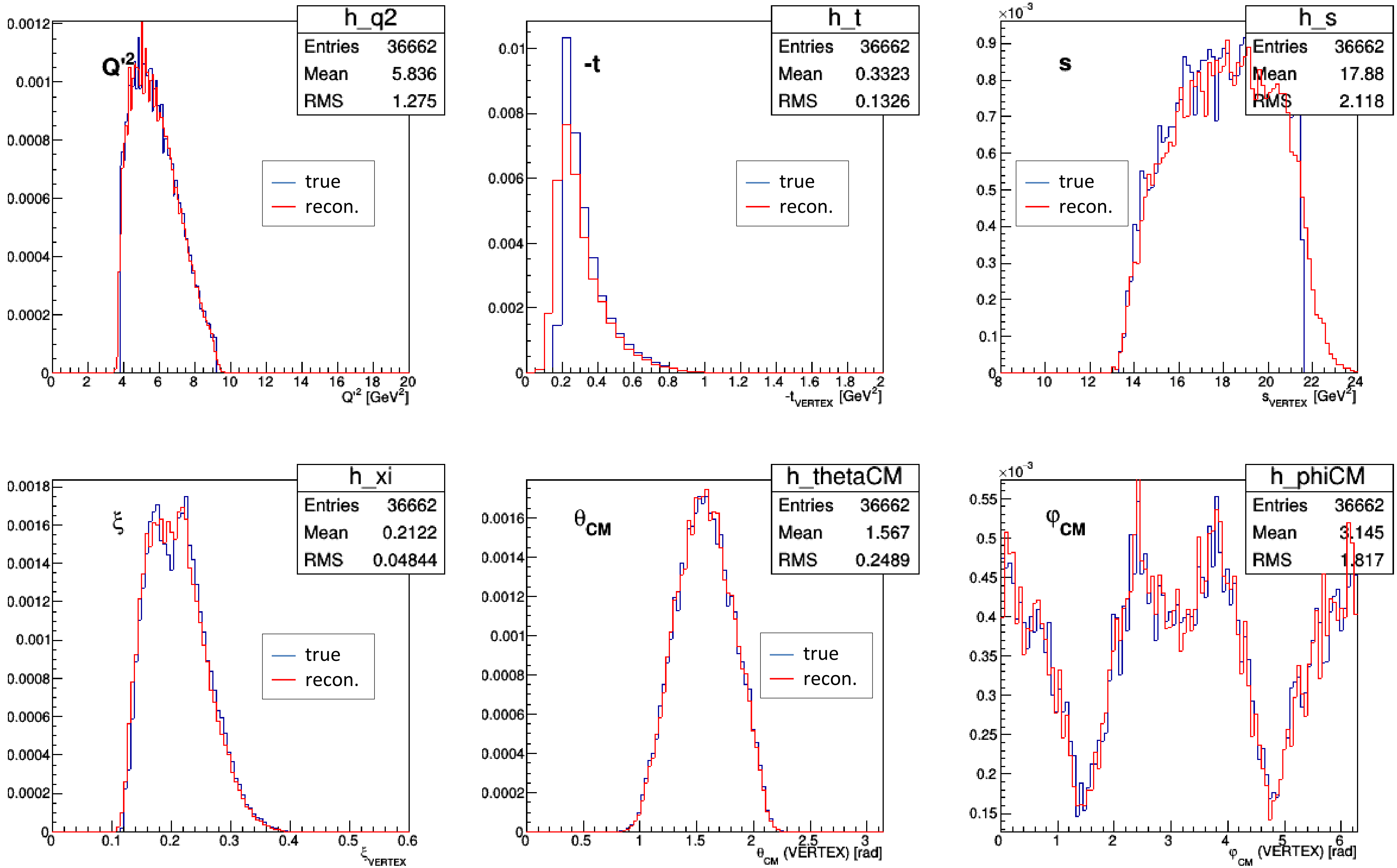
Random lepton charge assignment



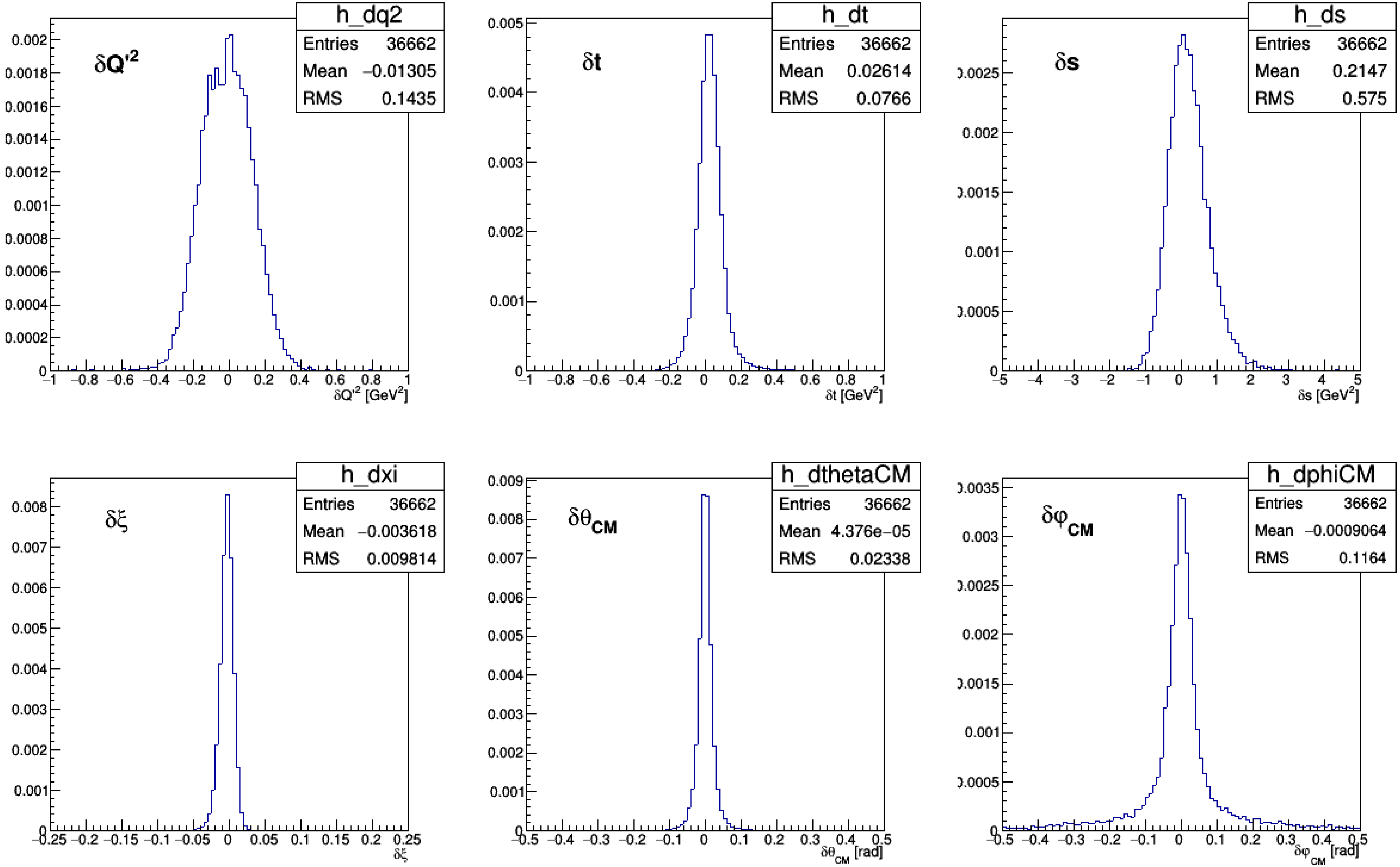

Lepton charges according selection criteria



# Reconstructed versus true quantities



# Residuals of reconstructed quantities




*Resolutions acceptable for analysis.*

# Summary and Outlook

**TSA measurement with transversely oriented target spin is sensitive to Im(E) CFF**, hence to GPD E and OAM of partons.

**Accurate Im(H) CFF** measurement is essential for universality studies.

**Adding data from TCS with transversely oriented target spin** to the data bank from other TCS and DVCS experiments renders an opportunity to **probe the universality of GPDs**, contribute to data set for **GPD global fits**.

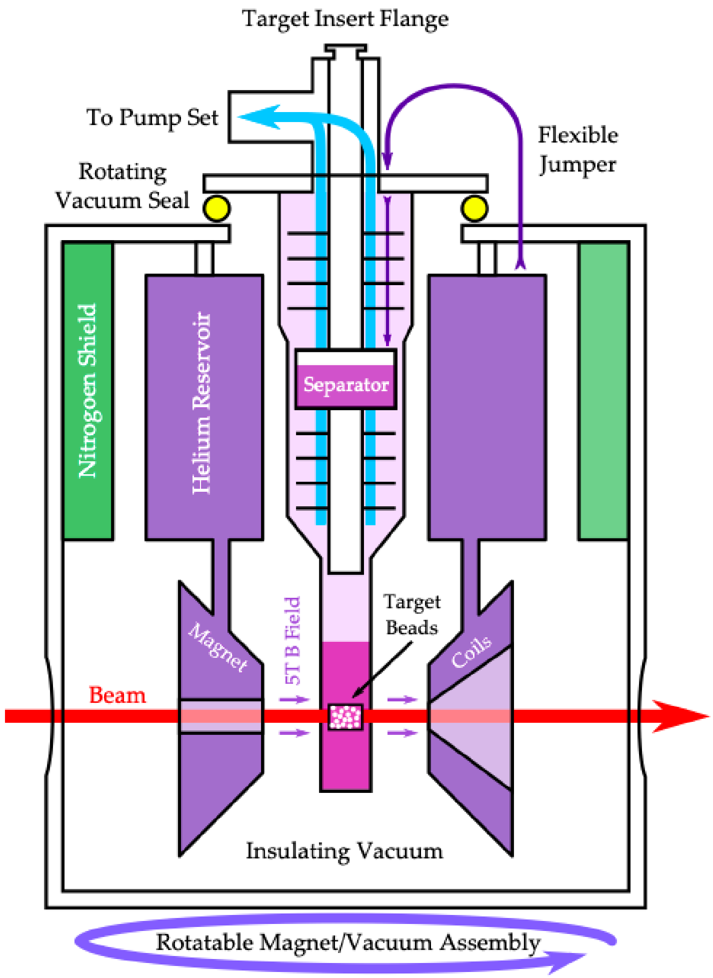
The proposal C-12-18-005 was conditionally approved by PAC 46 and PAC48 with C2 rating, and was deferred by PAC 50 (physics goals endorsed, feasibility of measurement not clear).

More studies needed on the experimental side, with active involvement of experts, also students and postdoc-s.

Thank you for your attention!

# Backup slides

# Experimental apparatus: UVA/JLab polarized target




*UVA target, nominal configuration*

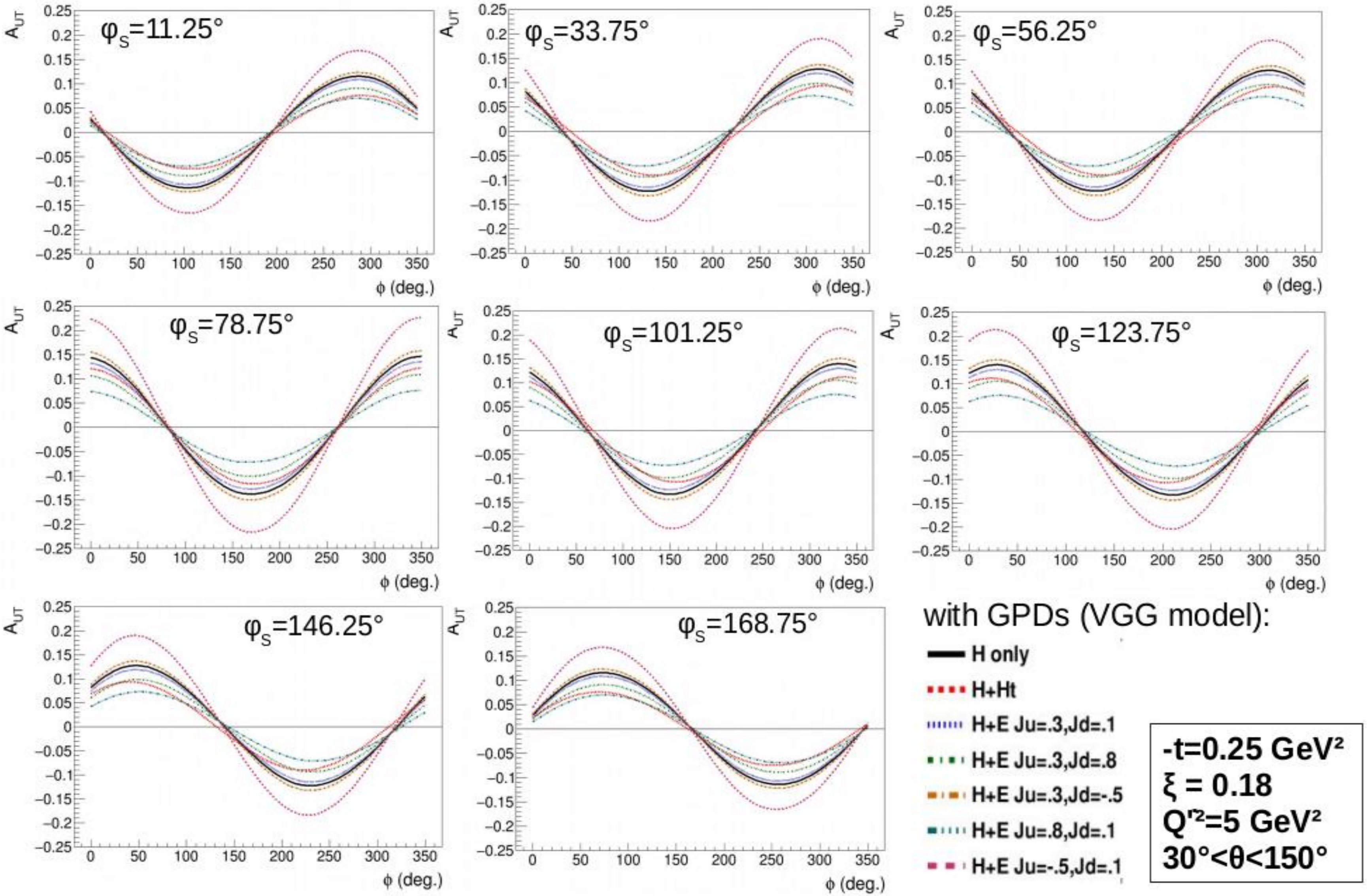
- Target material: $^{15}NH_3$, in LHe at 1°K.
- Packing fraction 0.6.
- 5T (uniform to $10^{-4}$) mag field generated by superconducting Helmhotz coils.
- DNP polarization by 140 GHz, 20 W RF field.
- Polarization monitored via NMR.

**<u>TCS configuration</u>:**

- **Setup rotated by 90°** around vertical axis.
- Sideways magnetic field and polarization.
- Angular acceptance ±17° horizontally, ±21.7° vertically (*±25° horizontally will be available with new magnet*).

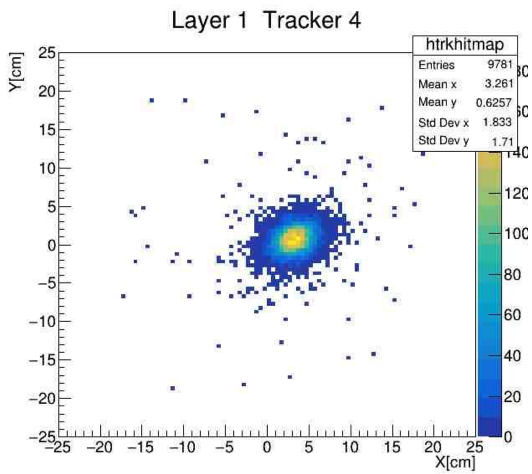
<u>Depolarization mitigated</u> by combined rotation (~1 Hz) around horizontal axis and vertical up/down movement (~10 mm).

# Anticipated results: target asymmetries



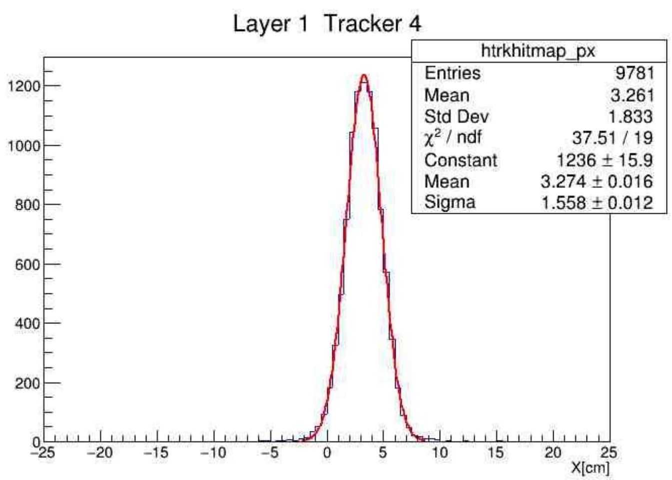

- Shows strong dependence on angular momenta
- 8 bins: fit of 2x2 orthogonal bins (4 independent ones) for CFFs global fits

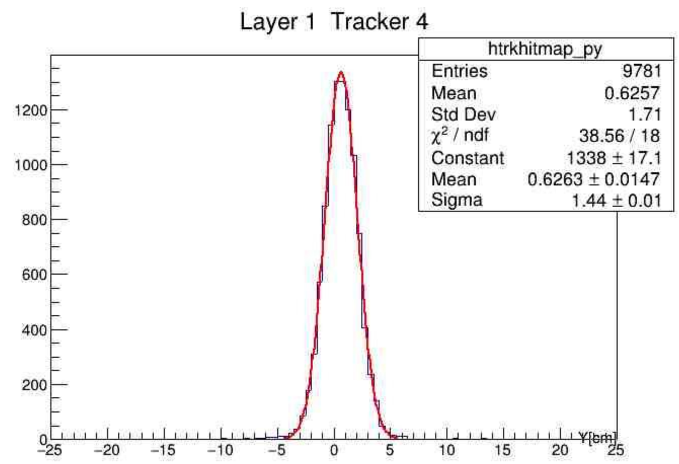
$400\ MeV/c\ (E_{KIN} = 81\ MeV)$ proton passed from target to 1-st layer GEM.




Tracks with $\theta_Y$ = 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:

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

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