TCS Simulation: Accuracies of Reconstructed Quantities and Beam Generated Backgrounds

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Outline

Setup

- Configuration
- Constituents

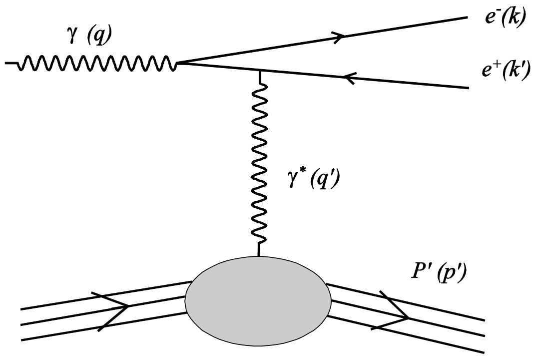
Vertex reconstruction

- Principles
- Results

Beam backgrounds:

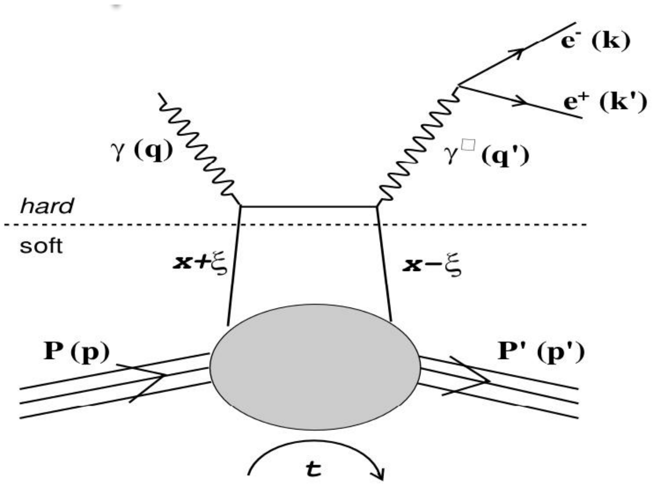
- in the trackers
- in the calorimeters

Physics case & apparatus



BH

⊕



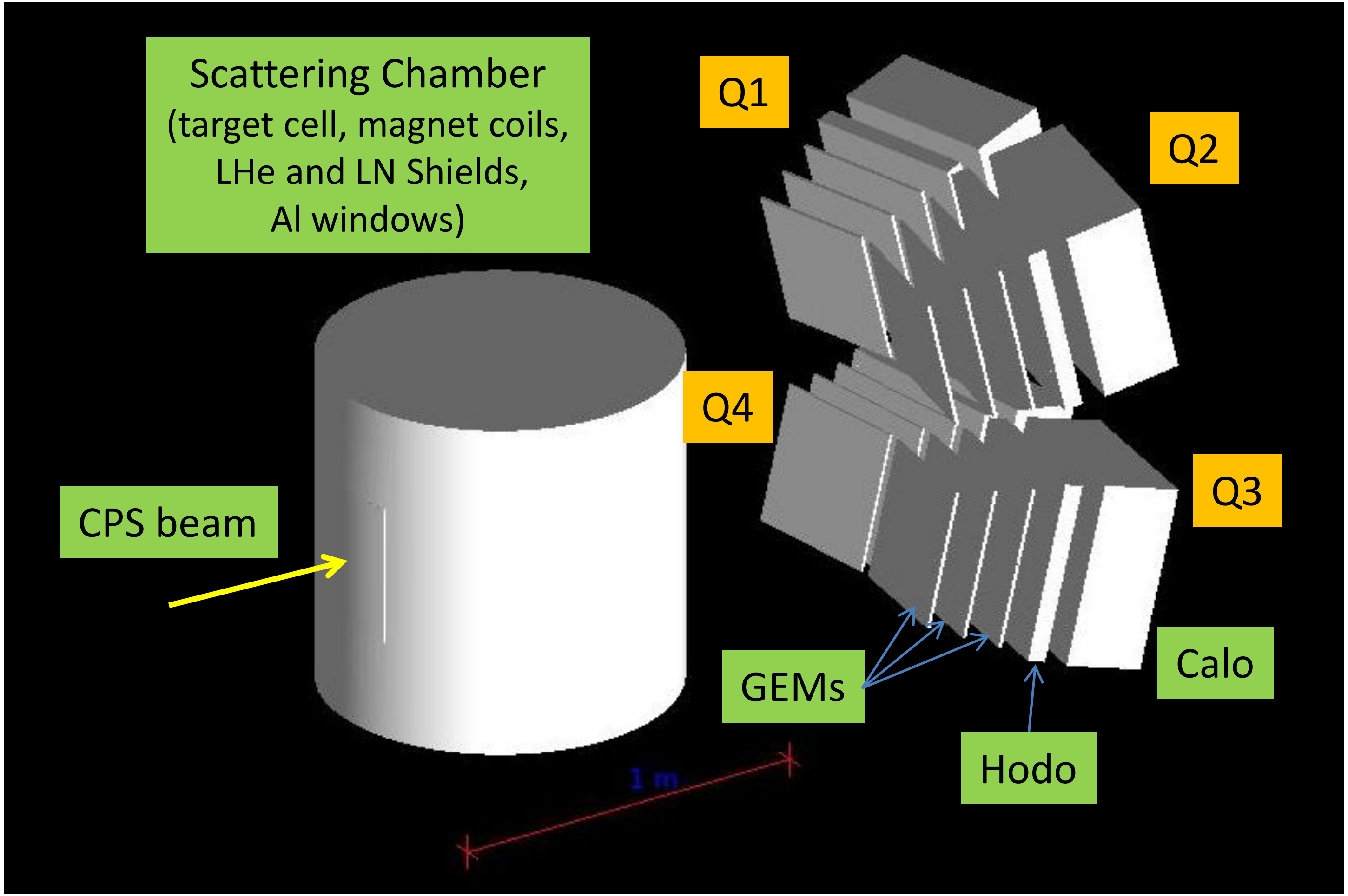
TCS

TCS and BH produce same final states.
TCS comes in interference with BH.
TCS signal << BH signal at JLab energies.
TCS can be measured via BSA and/or TSA.
TCS w/ trans. pol. proton sensitive to GPD Ẽ, hence to OAM.

Needed experimental setup of:

- High energy polarized photon source
- Target with transversely polarized protons
- Counters to detect and identify e-, e+, p.
- Trackers to reconstruct reaction vertex.

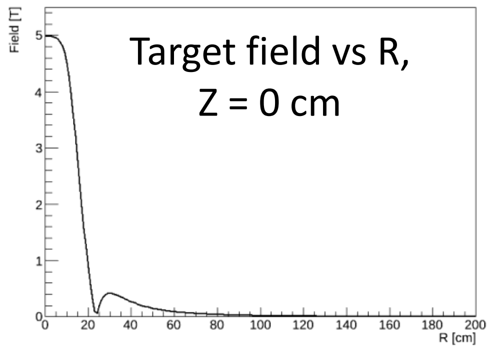
Setup



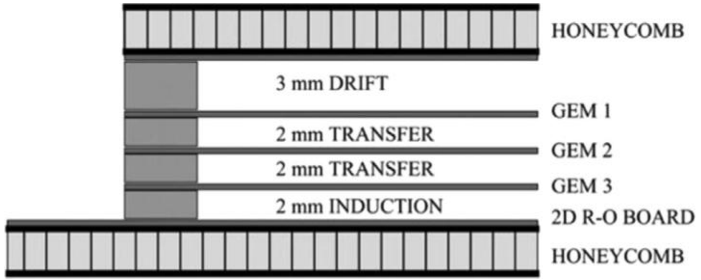
- CPS photon beam
- JLab/UVA NH_3 (g2p) polarized target
- Triple-GEMs for e^+ , e^- , p tracking
- Hodoscopes for p detection/PID
- $PbWO_4$ calorimeters for e^+ , e^- detection/PID

CPS beam
- 2 mm rastered collinear bremsstrahlung photon beam , E_{MAX} = 11 GeV
- Intensity: $1.5x10^{12}$ equivalent γ/s → $2x10^{13}$ γ/s in [10 MeV, 11 GeV] range

Target assembly
- Scattering Chamber with thin Al windows
- 3 cm target cell, with ammonia beds in LHe
- Magnet coils, LHe and LN Shields
- Chamber & magnet rotated 90^{o}
- Magnetic field map, 5T at center



Trackers
- Like COMPASS triple-GEM detectors
  (F.Sauli , NIMA 805 (2016) 2-24)
- Working gas: 70% Ar, 30% CO_2, ρ = 1.7 mg/cm^3
- Hit signal: energy deposition in the DRIFT region



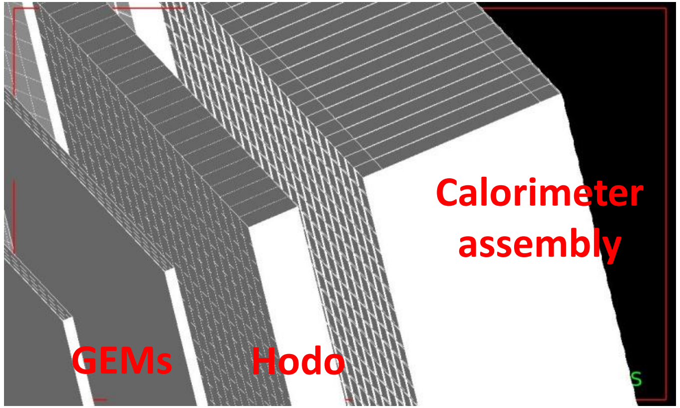
Setup

Hodoscopes

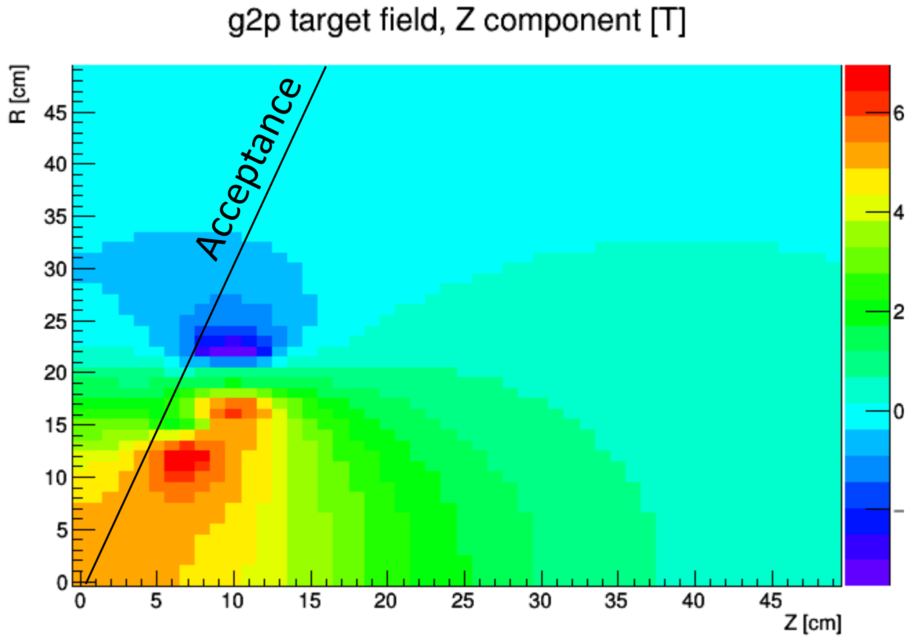
- The concept of proton detection yet to be worked out.
- Currently presented by hodoscopic assembly of 2x2x5 cm^3 plastic blocks, no signal output.

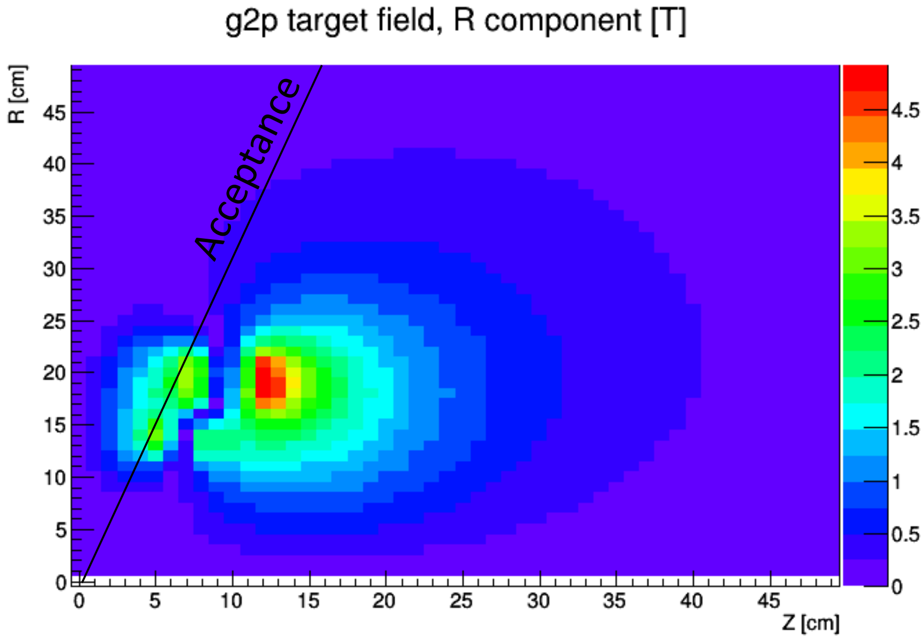
Calorimeters

- NPS modules (2x2x20 cm^3 $PbWO_4$ crystals, WM2000 reflector & Tedlar film, R4125 PMT)
- Carbon composite front and back frames, 2 cm wide, 0.5 mm thick.
- Optical photon tracking.
- Hit signals in photoelectrons.



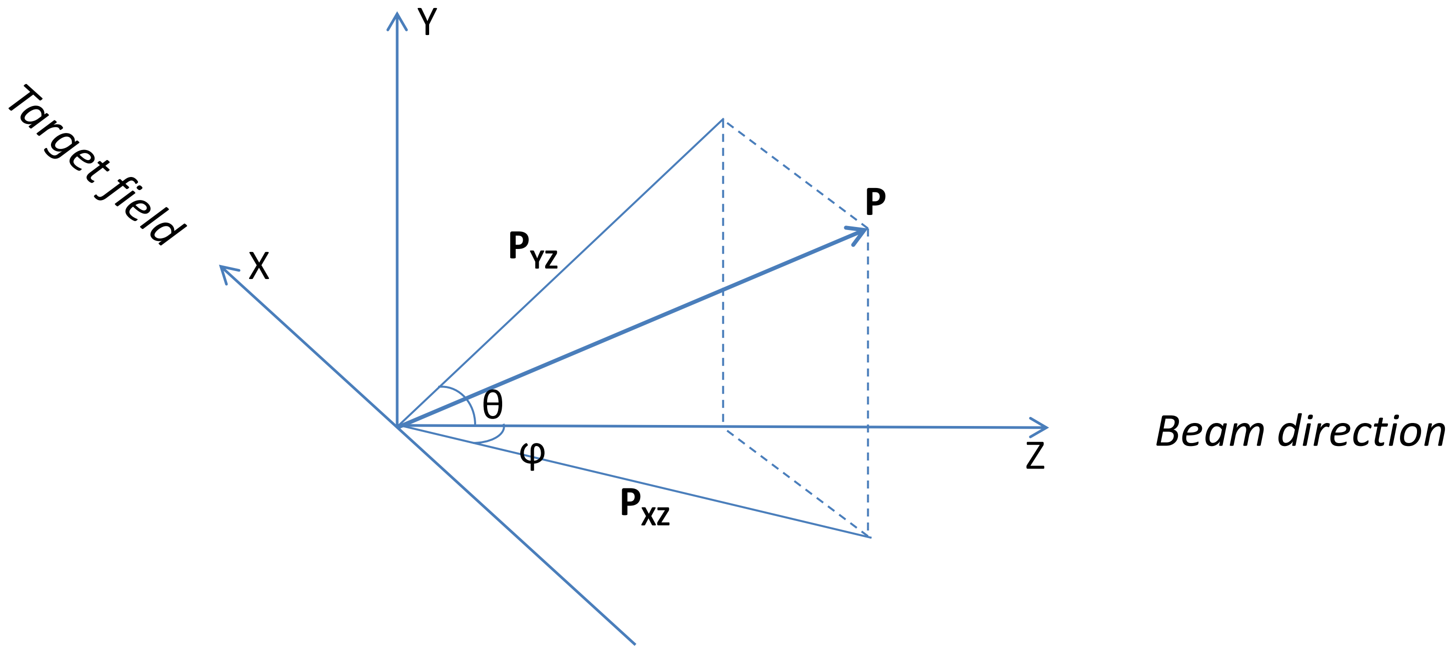
Target's magnetic field components





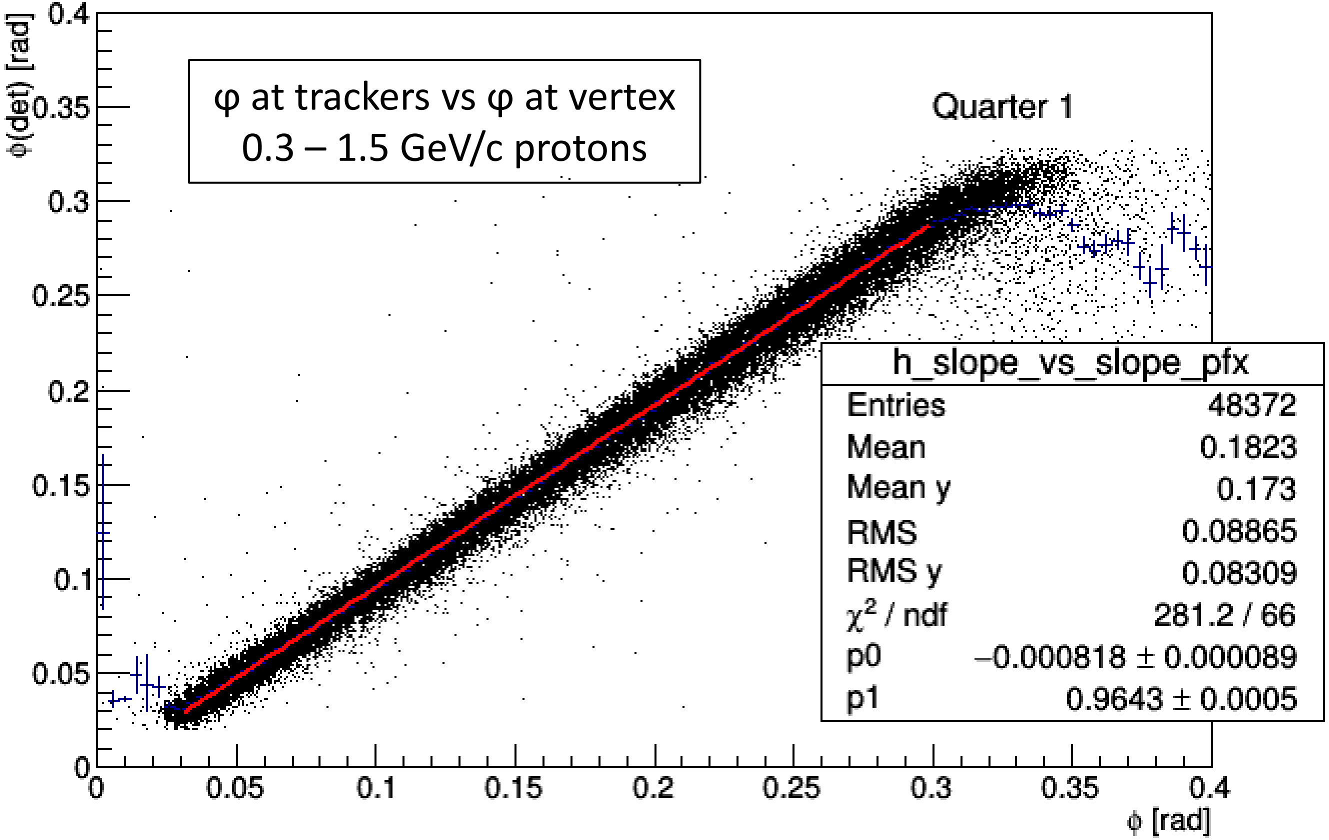
Magnetic field is mostly along target's Z axis, confined within R < 20 cm.
"Irregularities" out of angular acceptance of 90^0 rotated target assembly.

Conventions



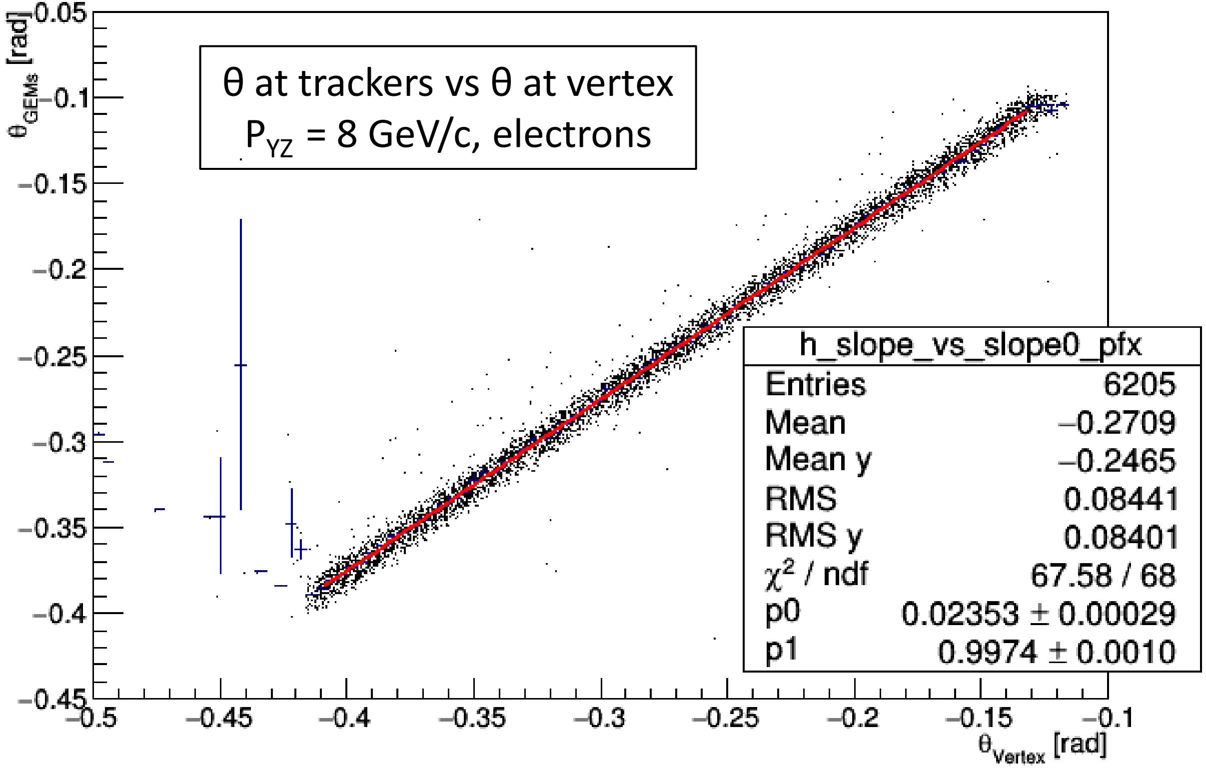
Target field perp. to beam → decompose movement into X direction and in YZ plane.

Proton, φ reconstruction



Almost 1:1 correspondence between φ at vertex and φ at GEMs.

e-, θ linear regression

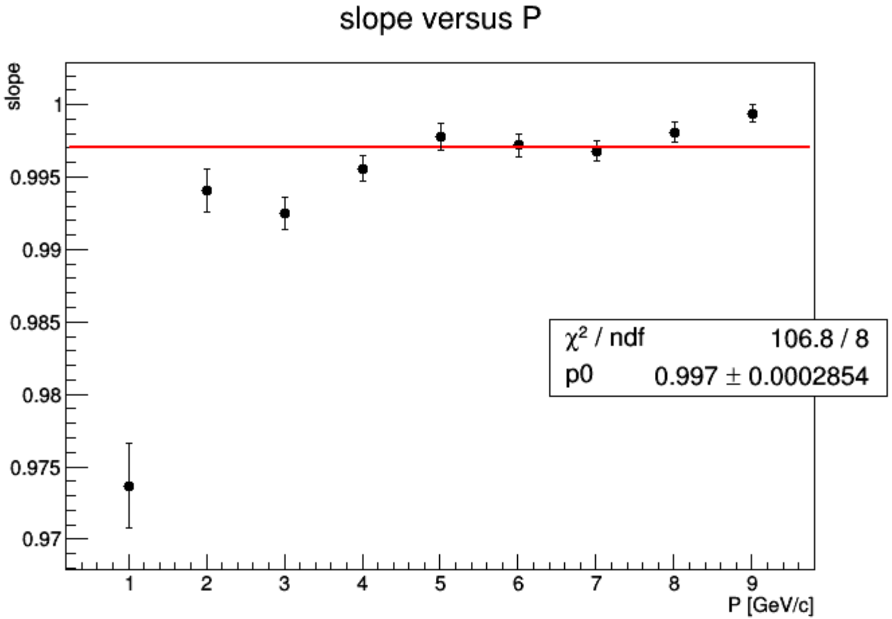


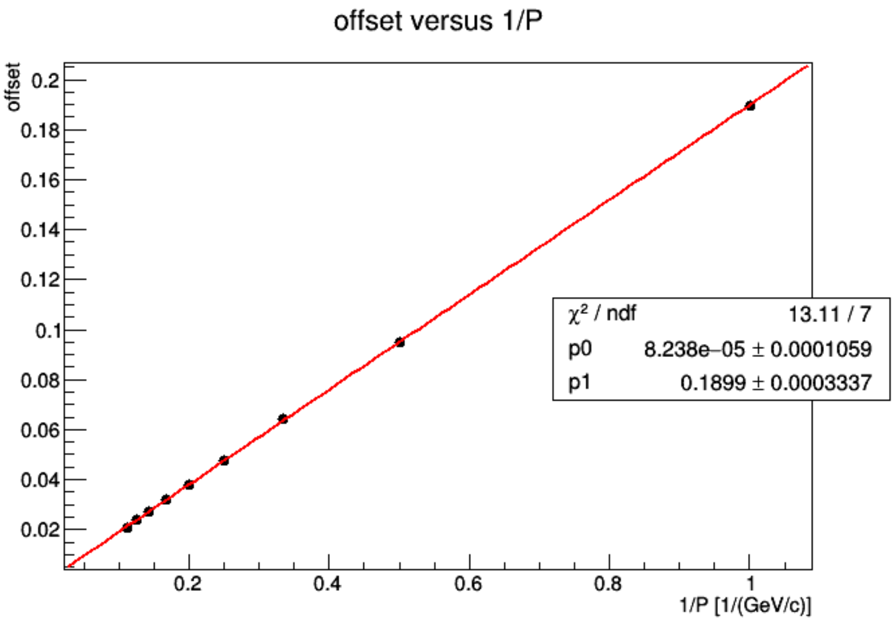
$\Theta = \Theta_0 + 0.3 \cdot \int Bdl/P$

Approximate
$\Theta \sim a \cdot \Theta_0 + b$;
expect
- $a \sim 1$,
- $b \sim 0.21/P$
- for $\int Bdl \sim 0.7$ Tm.

For fixed P_{YZ}, there is linear relation between θ at vertex and θ from GEM trackers.

e-, θ linear regression





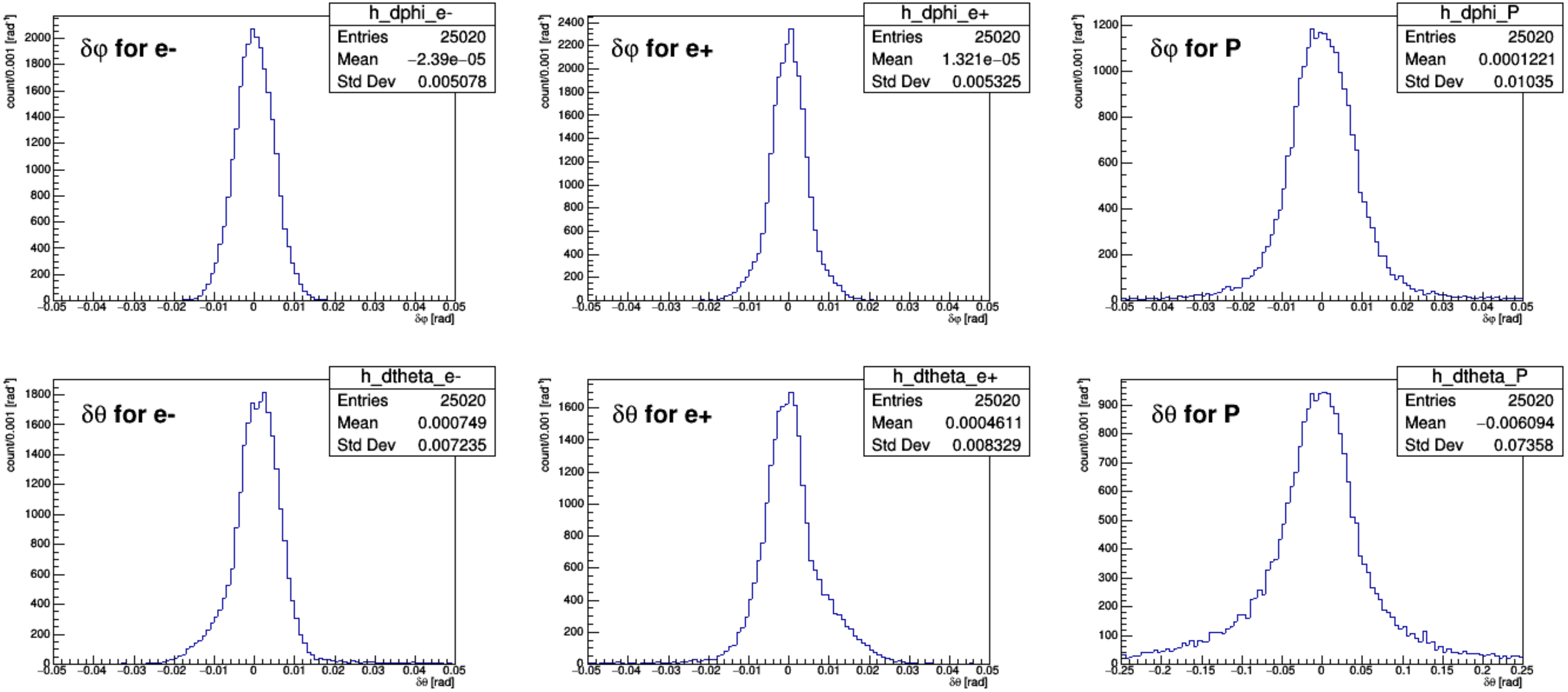
Slope and offset of the θ linear regression versus P_{YZ} and $1/P_{YZ}$ respectively.
Expected slope = 1, offset = $0.21/P_{YZ}$.

Vertex reconstruction, step by step

1) Use TCS events from DEEPGen generator (M.Boer) tracked through the TCS setup (target field + interaction with material)
2) Select events with e-, e+ and p tracks passing through GEMs (request hits in the 1-st layer, and in either or both of 2-nd and 3-rd layers)
3) Sample measured track coordinates in GEMs (assume conservative 100 μm resolution)
4) Sample deposited in the calorimeters energies from e- and e+ tracks (assume PRIMEX/HYCAL resolution)
5) Assign e- and e+ momenta equal to the energy depositions in the calorimeters
6) Determine detected track directions from GEM hits (straight line fit)
7) For e- and e+:
   a) Put φ at vertex equal φ measured at GEMs
   b) Derive θ at vertex from linear regression (for the measured in the calorimeters momenta)
8) Derive γ* 4-momentum equal to sum of lepton momenta
9) For the recoil proton:
   a) Derive φ at vertex from φ measured by GEMs, by linear regression
   b) Put P_X and P_Y at vertex equal to P_X and P_Y of γ* (*co-planarity*)
   c) Derive P_Z at vertex from P_X and φ at vertex
   d) Iterate [(θ measured, P_{YZ}) → θ at vertex → P_Z at vertex] one time

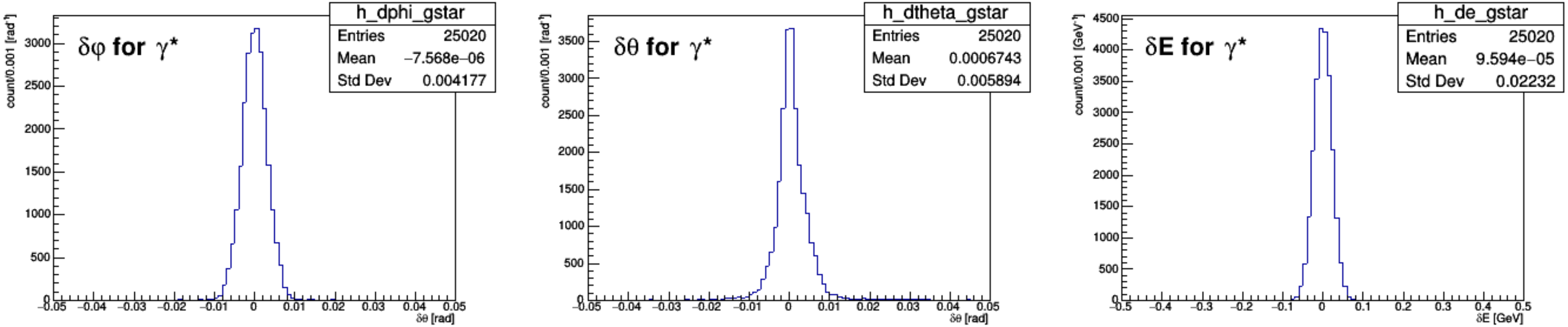
Note: If *E* (or *P*) available from *p* detector → reconstruct *p* similar to *e+*, *e-*, cut on co-planarity to refine events.

Angle reconstruction of TCS events



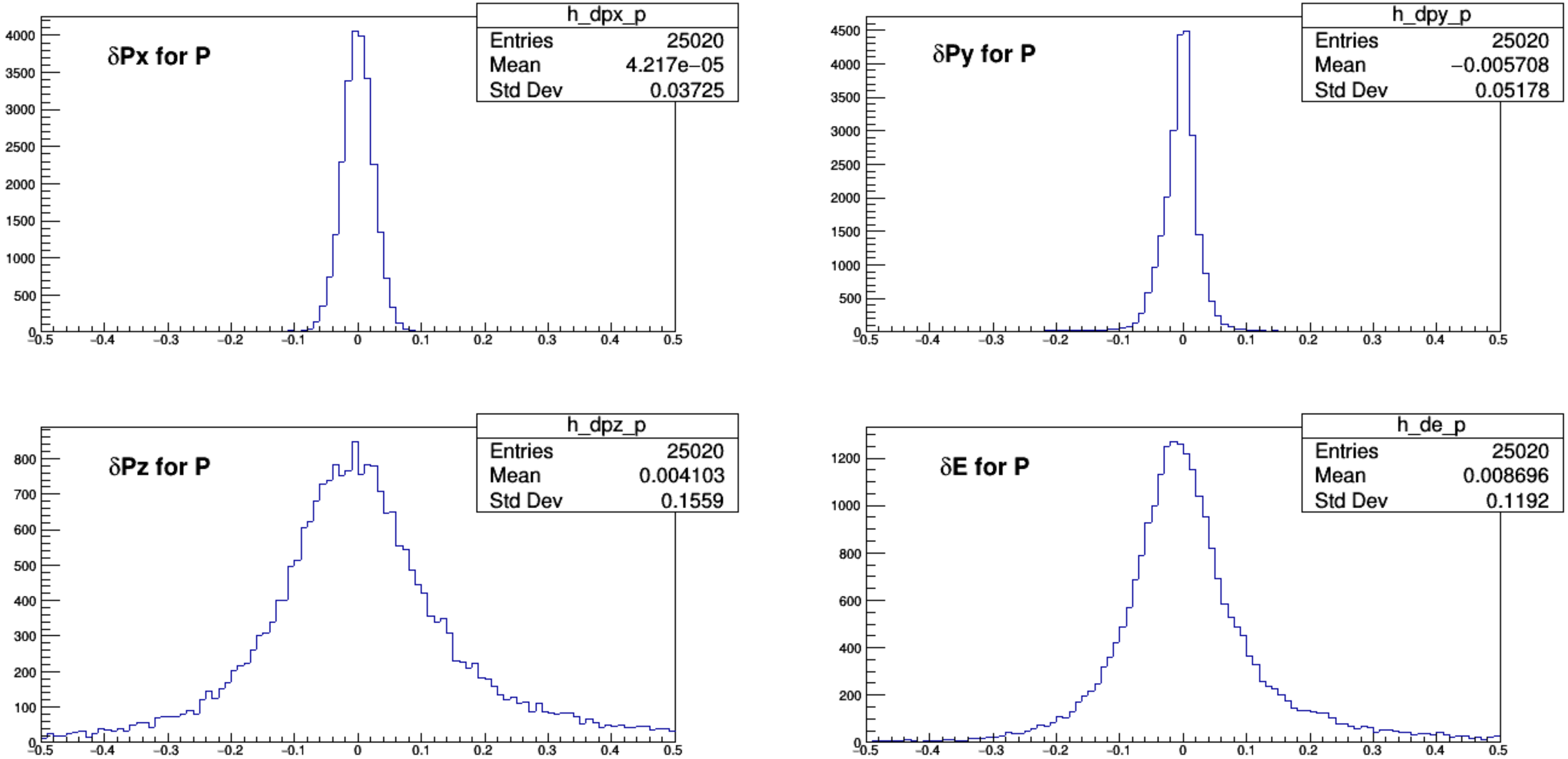
Integrated over E_γ[5 GeV, 11 GeV], Q^2[4 GeV^2, 9 GeV^2], -t [0 GeV^2, 2 GeV^2]

γ* reconstruction



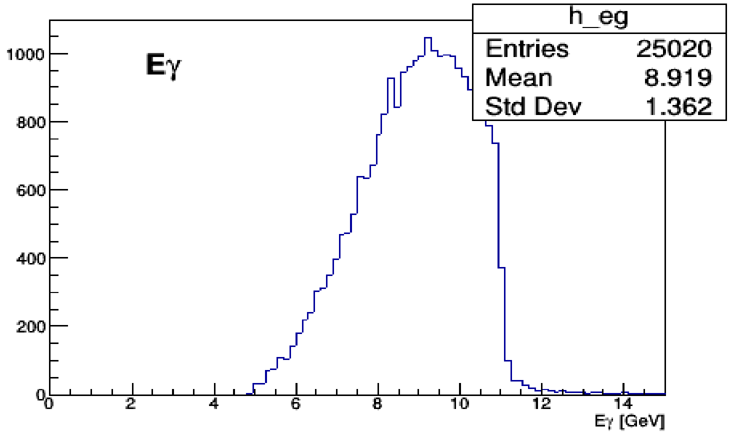
Integrated over E_γ[5 GeV, 11 GeV], Q^2[4 GeV^2, 9 GeV^2], -t [0 GeV^2, 2 GeV^2]

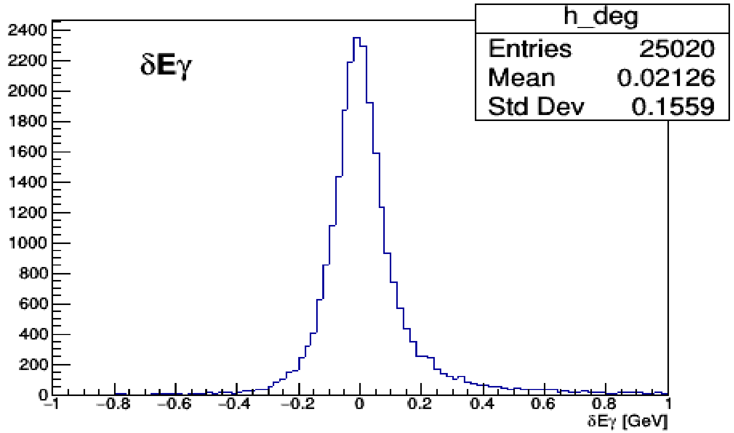
Recoil proton reconstruction

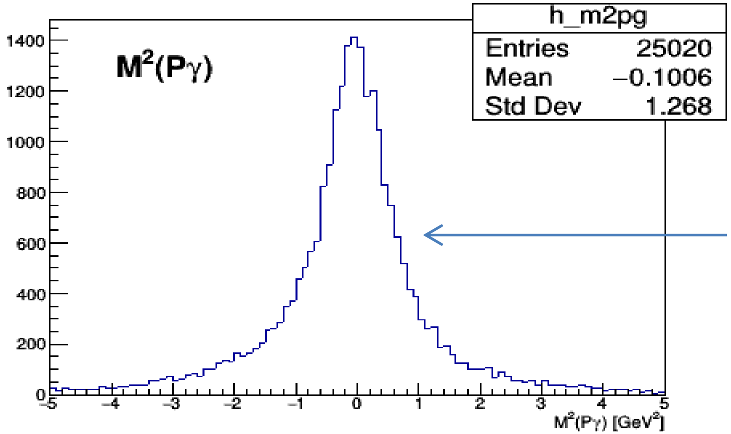


Integrated over E_γ[5 GeV, 11 GeV], Q^2[4 GeV^2, 9 GeV^2], -t [0 GeV^2, 2 GeV^2]

γ incident reconstruction

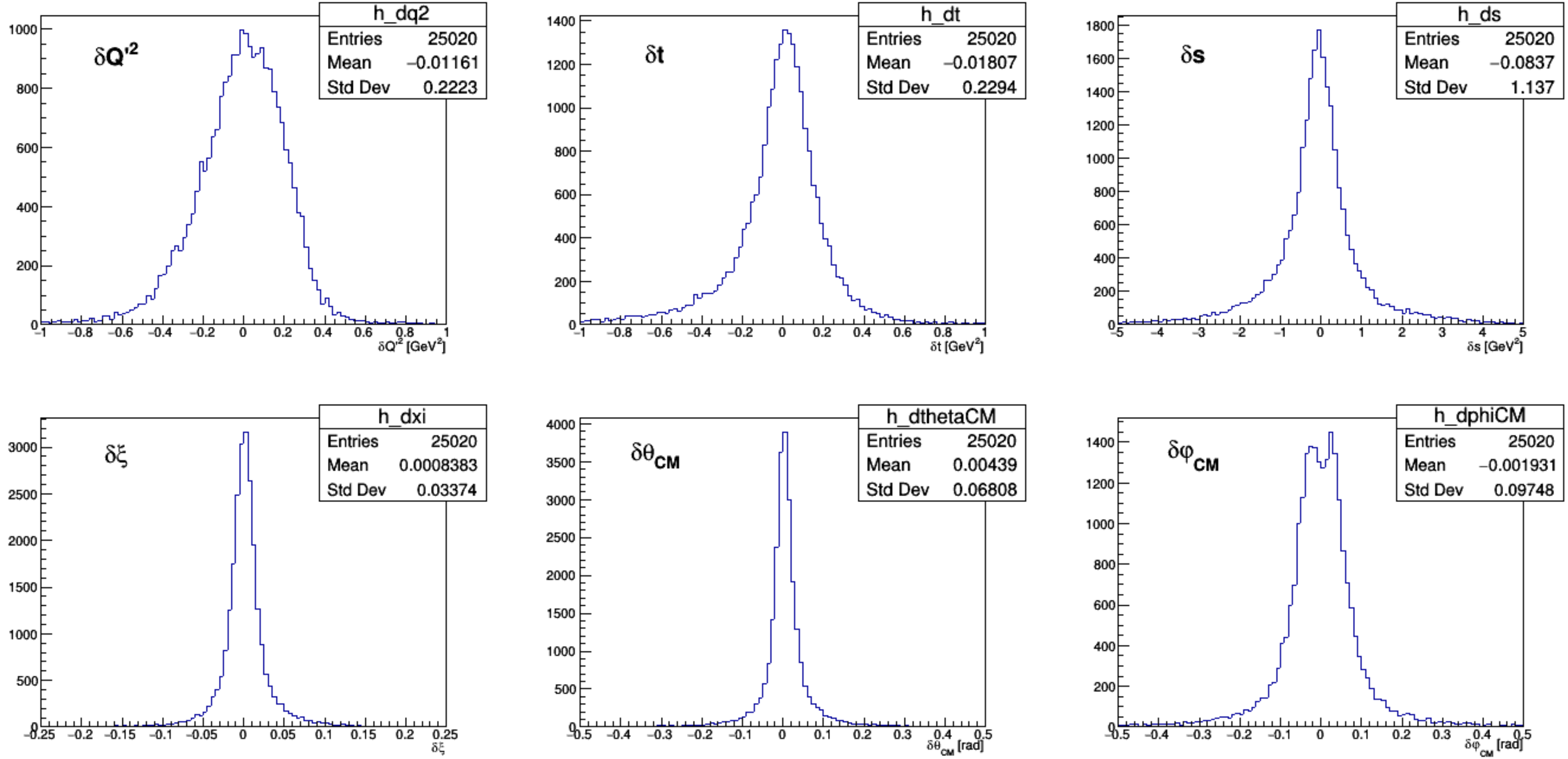






M_X^2 (exclusivity cuts to be applied)

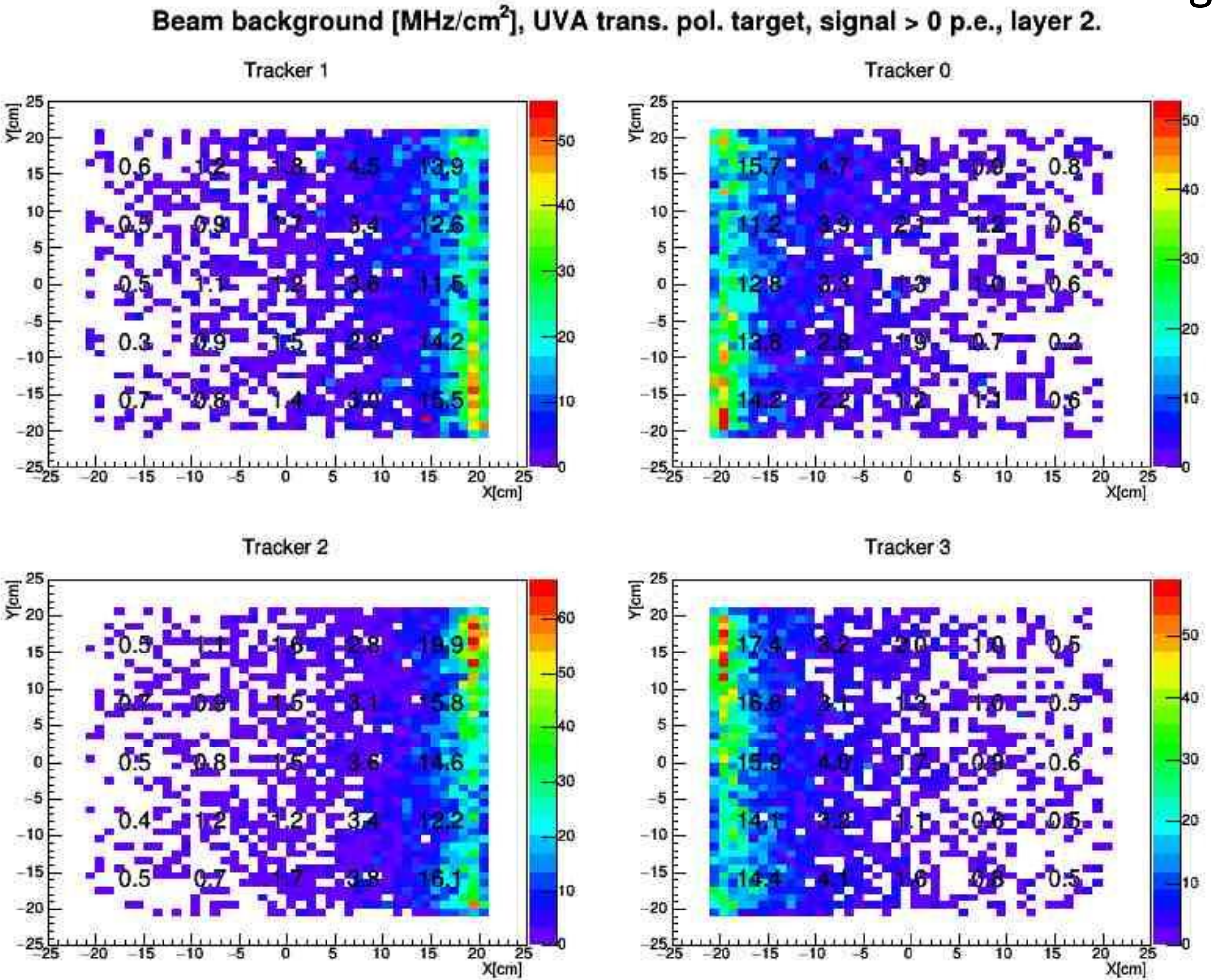
Accuracies of reconstruction of TCS quantities



Conclusion on vertex reconstruction

- The proposed setup allows for a descent γ^* reconstruction at vertex (resolution on angles ~5 mrad, energy resolution ~ 20 MeV).
- Modest accuracies of proton reconstruction can be achieved ($\delta\varphi$ ~ 10 mrad, $\delta\theta$ ~ 75 mrad, δE ~ 120 MeV) without its energy/momentum measurement.
- Missing mass resolution is estimated at $M_X^2 = 1.3$ GeV^2/c^4.
- Accuracies on the reconstructed TCS quantities allow for meaningful binning in data analysis.

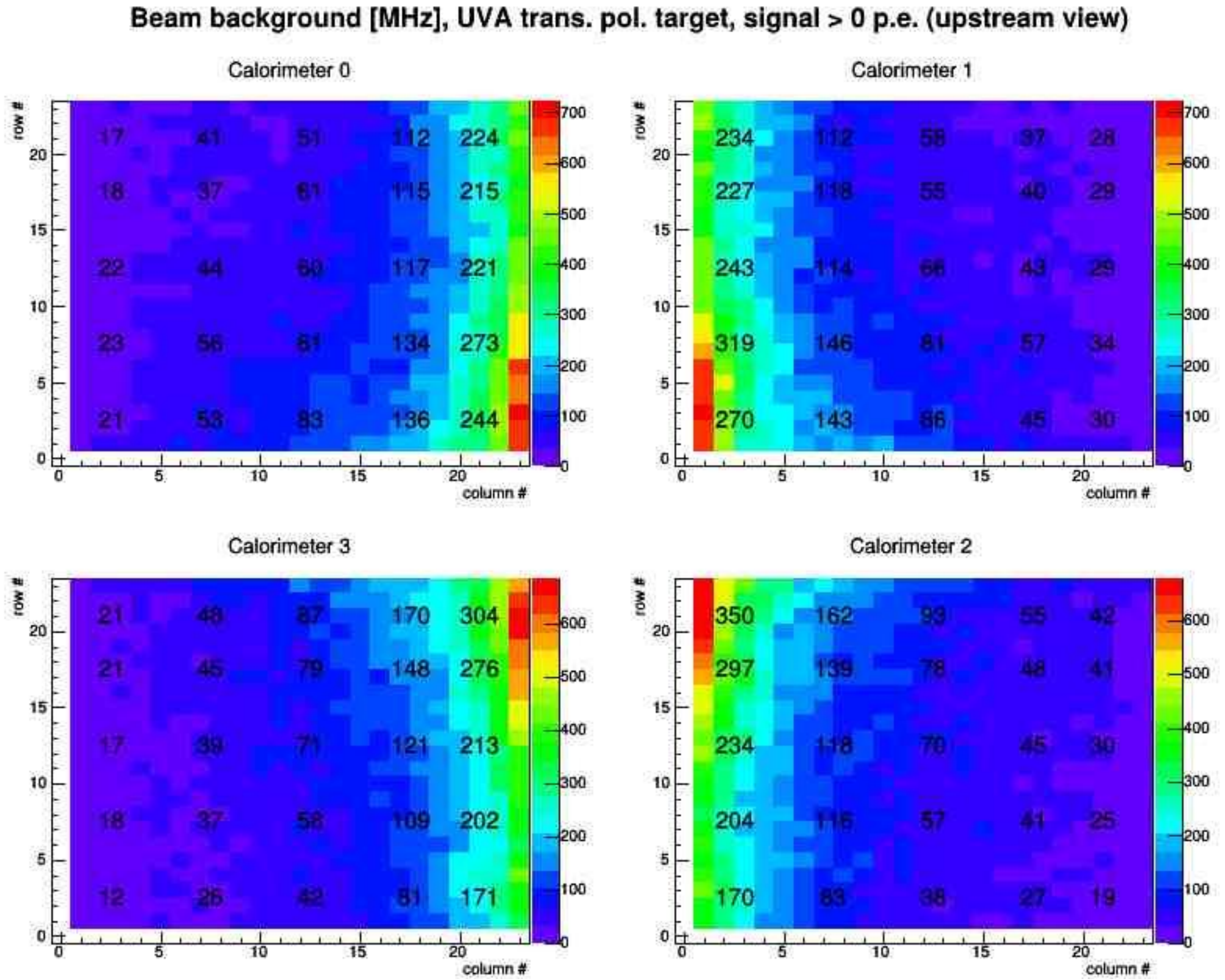
Background rates in GEM Trackers



CPS bremsstrahlung beam , $2x10^{13}$ γ/s in [10 MeV, 11 GeV] range, passing through scattering chamber (no beam pipes).

Rates ~1-2 MHz/cm^2 at centers, **below tolerable >10^6 Hz/mm^2** [PDG].

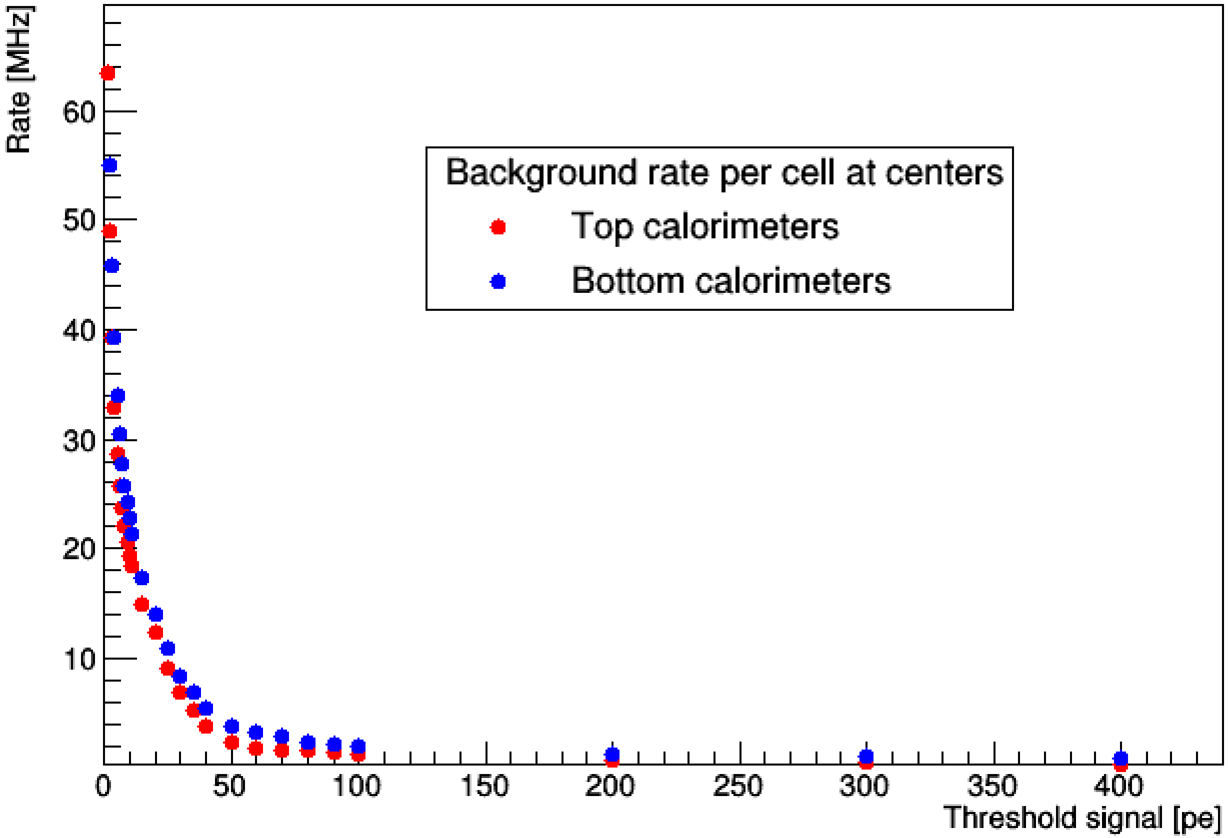
Background rates in calorimeters



For signals 1 p.e. and higher.

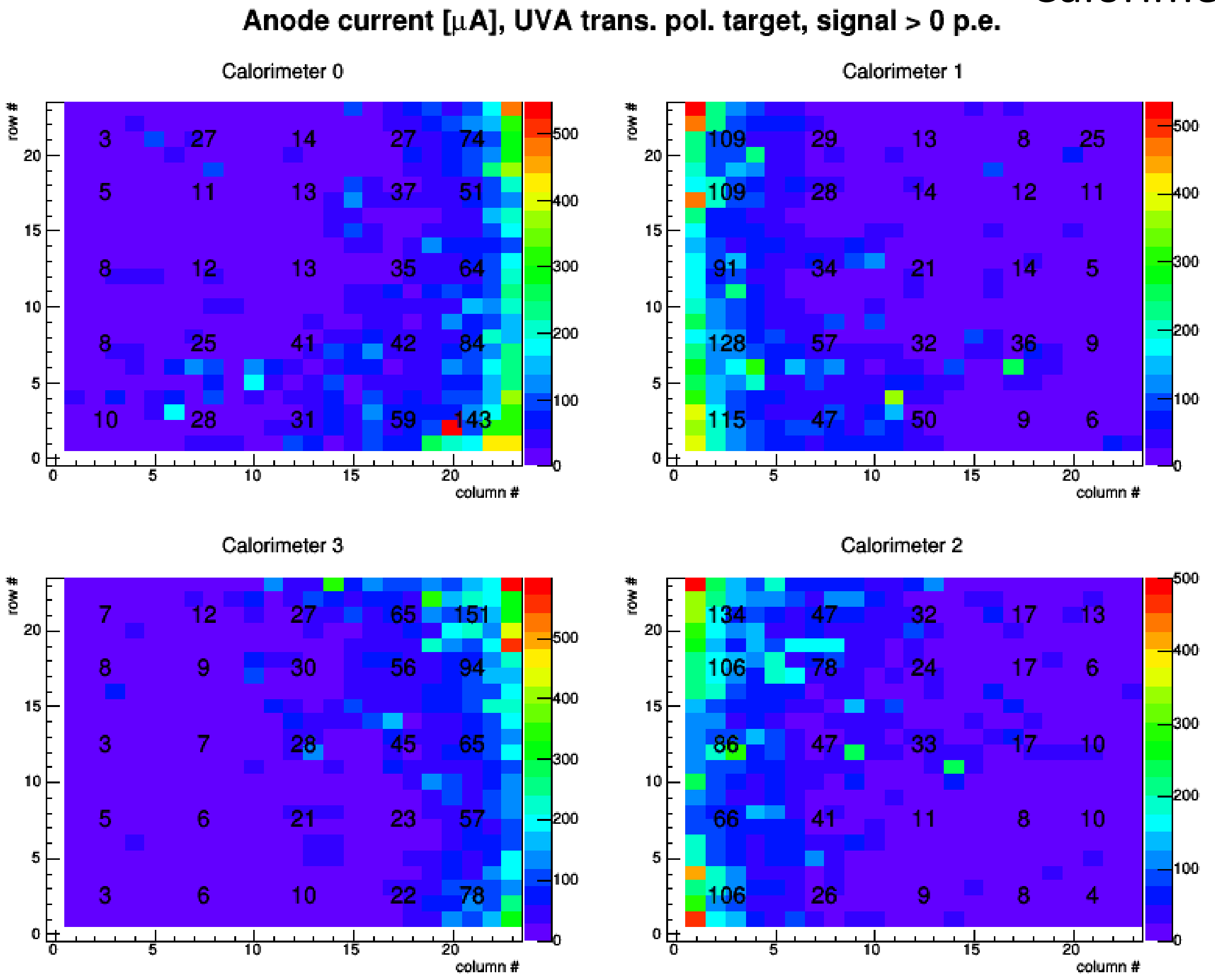
Rates ~60 – 80 MHz at centers.

Background rates in calorimeters



~60% of beam background comes from low amplitude signals < 5 p.e. (E_{Dep} < 1.5 MeV), and ~95% from signals < 50 p.e. (E_{Dep} < 15 MeV). Note: signal from 1 GeV e^- ~ 3500 p.e..

Calorimeters’ PMT anode currents



Modified bases w/ amplifier, 1kV HV, gain ~ 10^5.

Signals 1 p.e. and higher.

I_A ~ 10 – 30 μA at centers.

Compare w/ **Max. I_A= 0.1 mA** for R4125 PMT (Hamamatsu booklet).

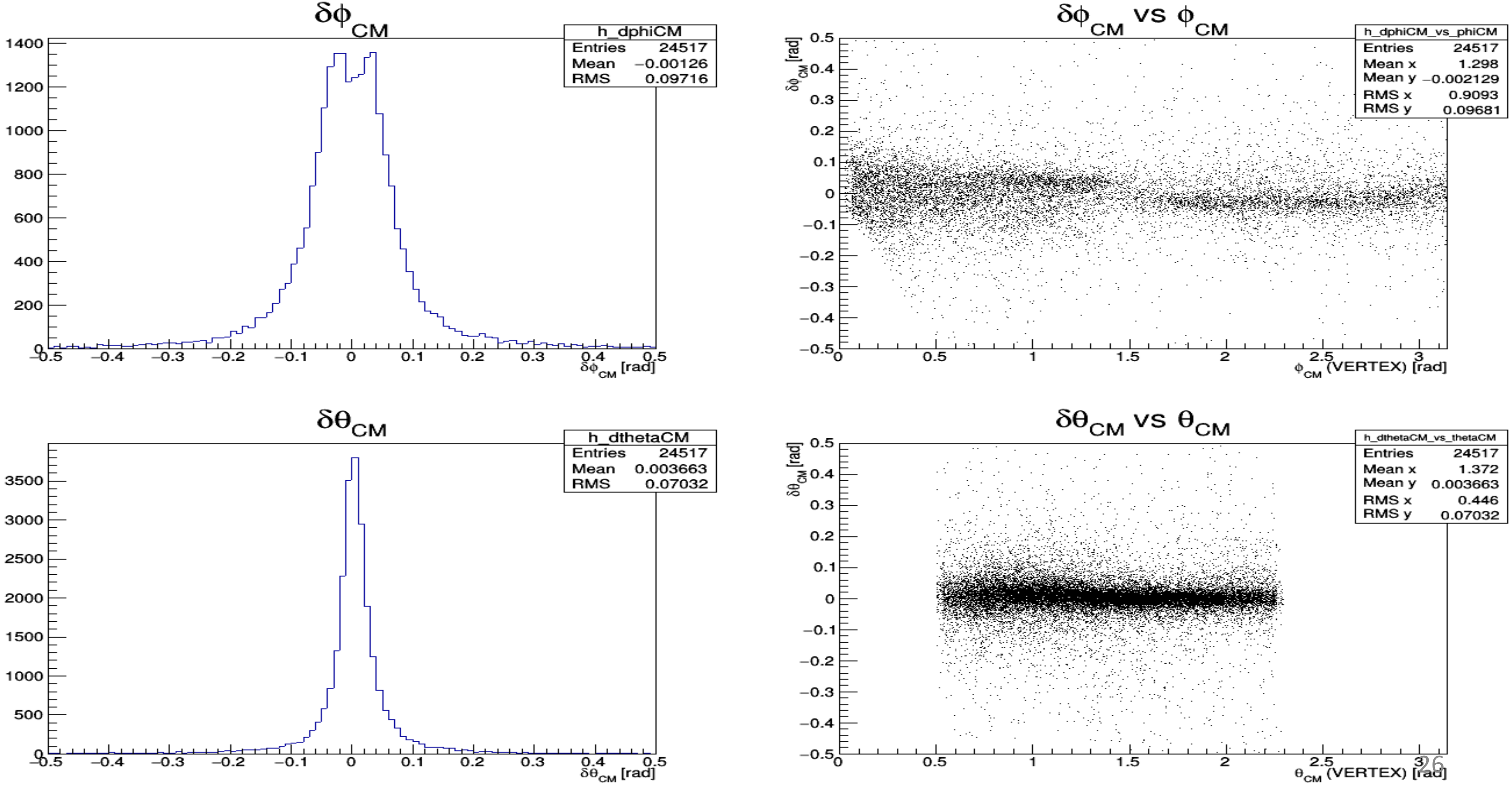
Conclusion on beam backgrounds

- Background rates in the trackers are quite tolerable for GEM operation.
- Background induced anode currents at the centers of calorimeters 10 – 30 μA, tolerable. May cause pedestal shifts.
- Anode currents comparable with Hamamatsu Max. Rating specifications expected in PMTs close to beam pipe. May need to exclude them and reduce acceptance.
- *Note*: beam pipes (and support structures) are not simulated, may affect background rates.

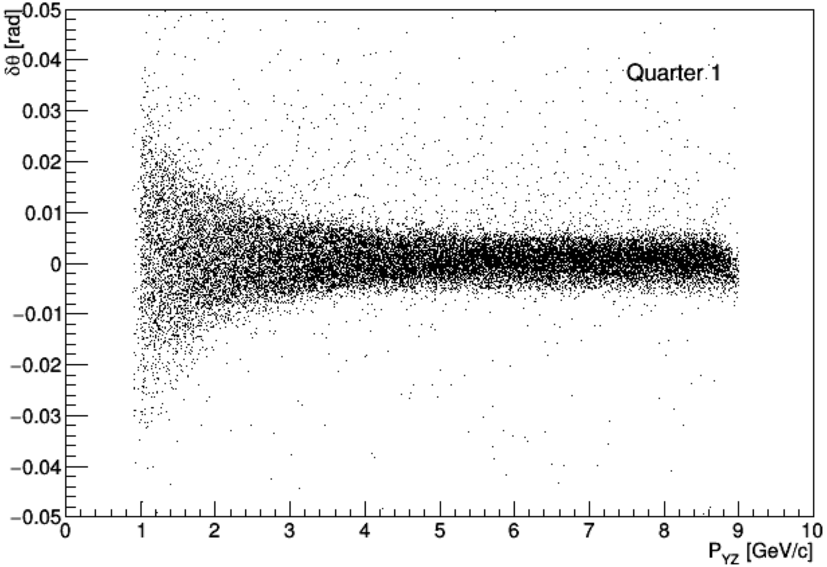
Thank you for your attention!

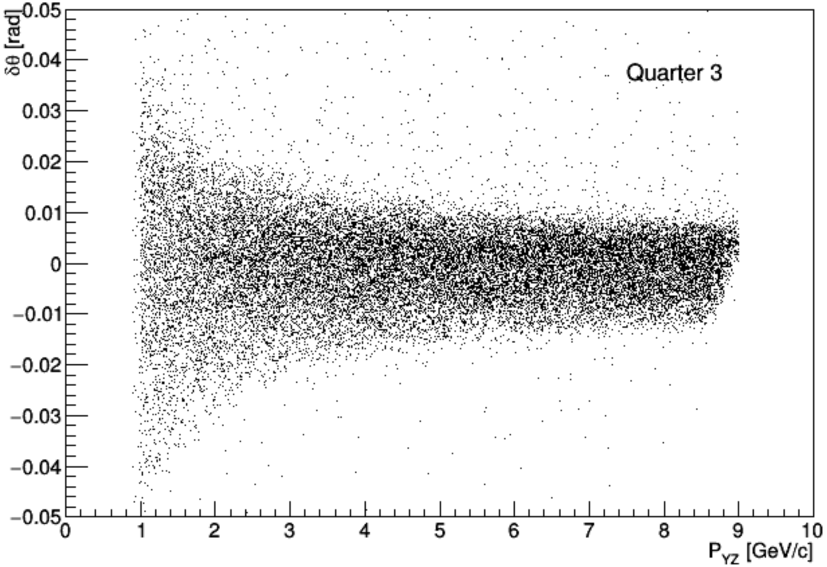
Back up

CM angle reconstruction of TCS events



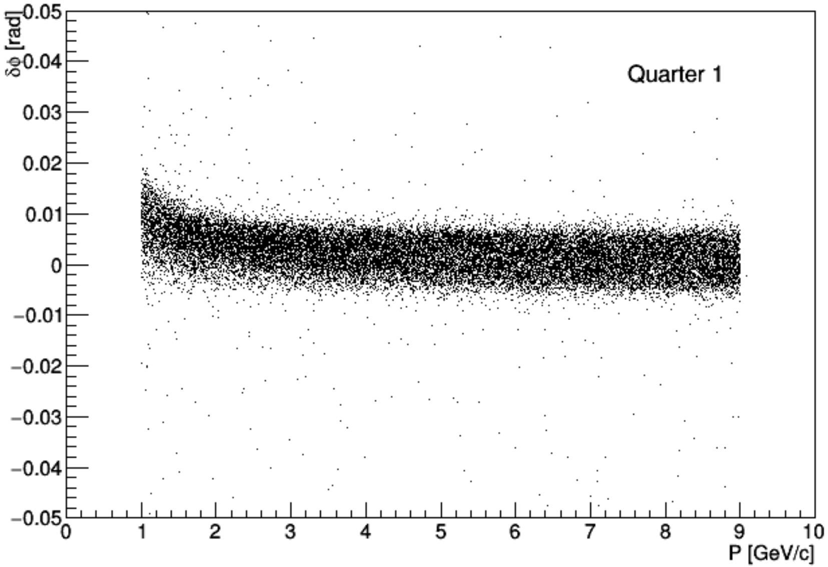
e-, Θ accuracy versus P

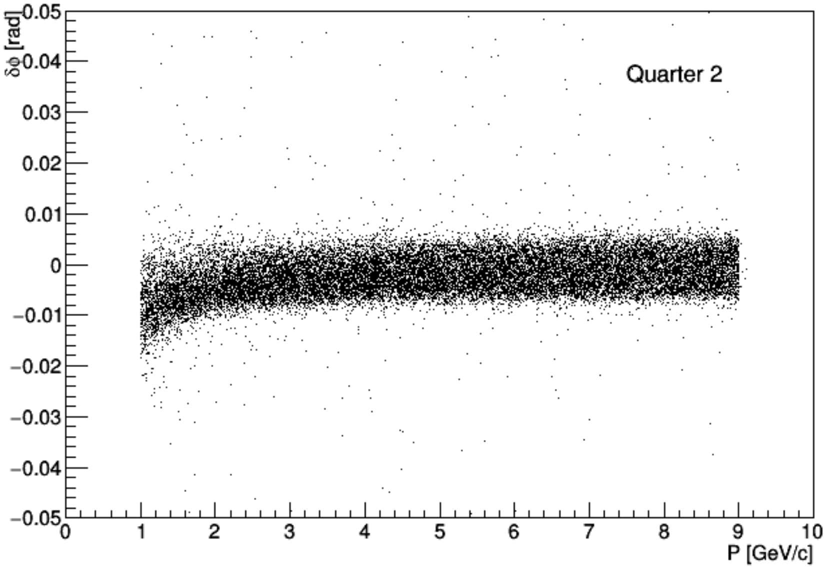




Spread of the reconstructed θ residuals for e- tracks in quarters 1 (above beam) and 3 (below beam).

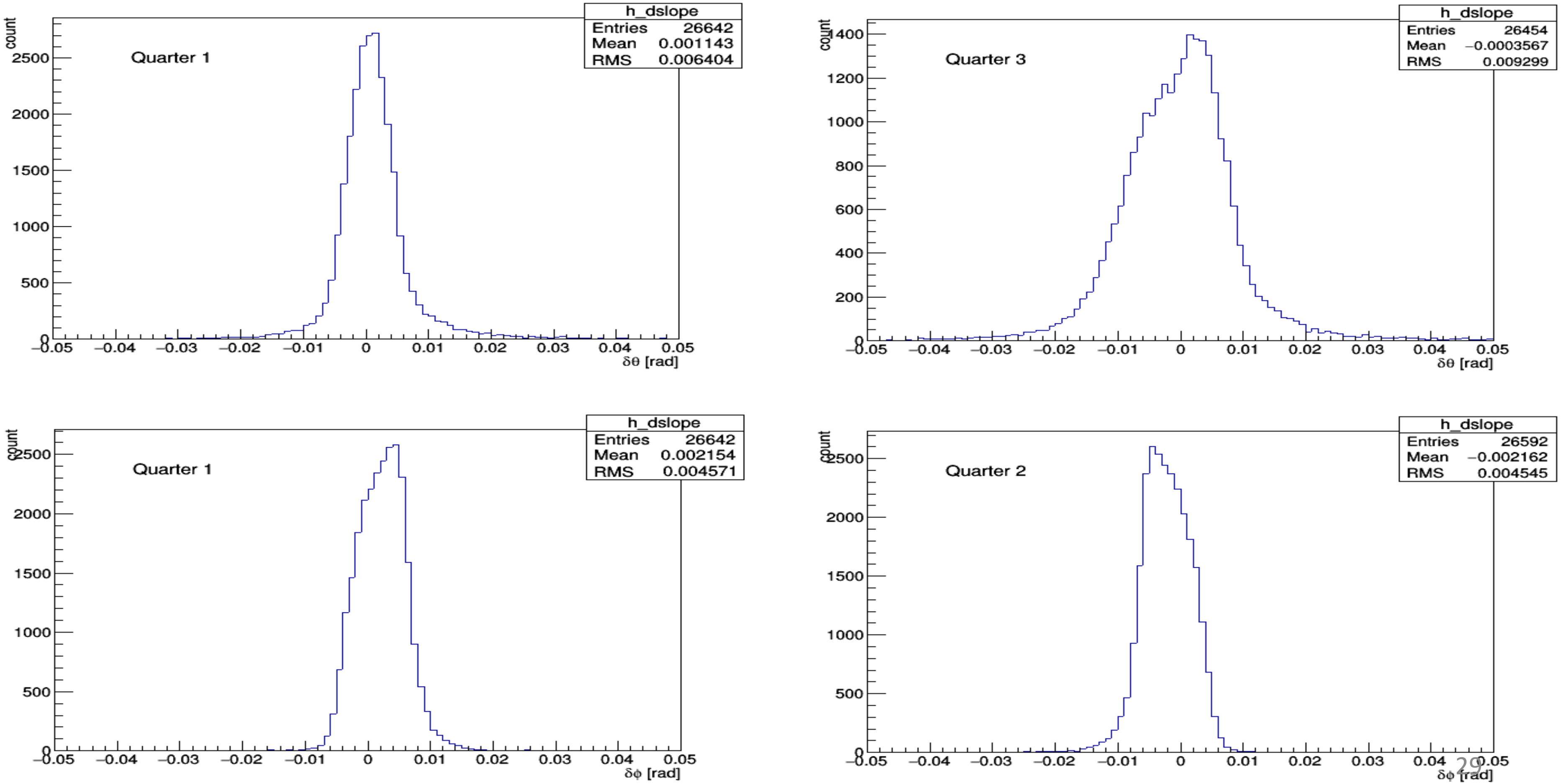
e-, φ accuracy versus P



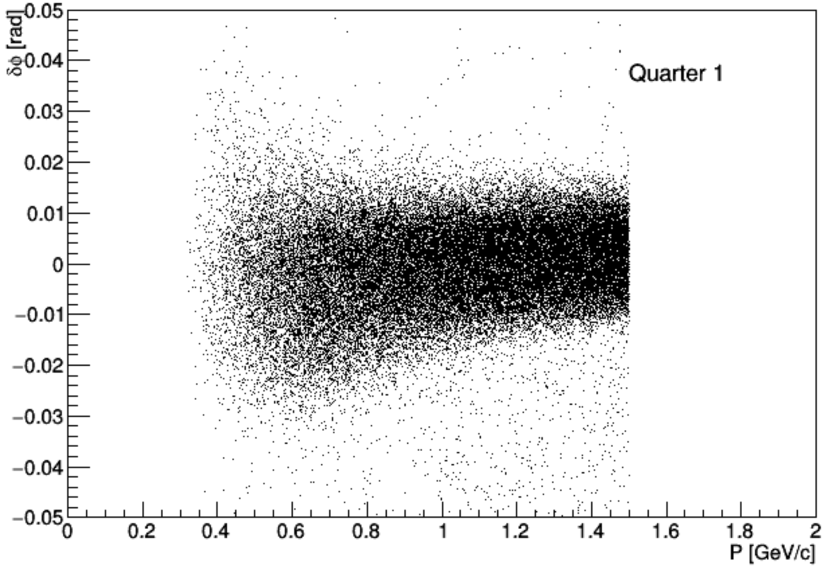


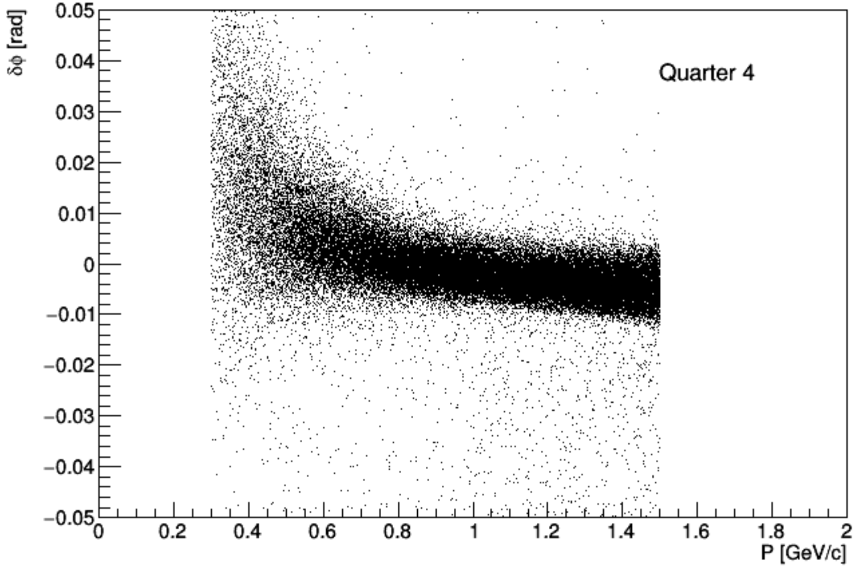
Spread of reconstructed φ residuals for e- tracks in quarters 1 (left of beam) and 2 (right of beam).

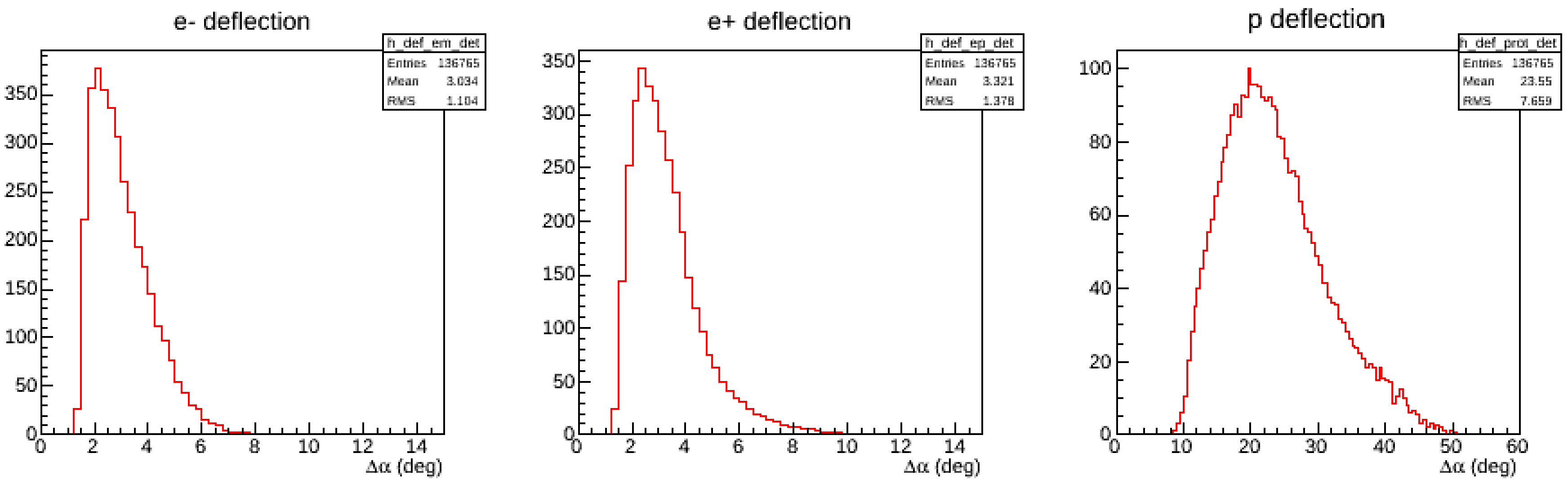
e-, reconstruction of θ and φ



proton, φ accuracy versus P







Deflections of accepted tracks in the target magnetic field (BdL~0.7 Tm) relative to directions at target (from *old* simulations, w/ tracker hodoscopes, w/o GEM trackers).