GEM Tracking in MUSE

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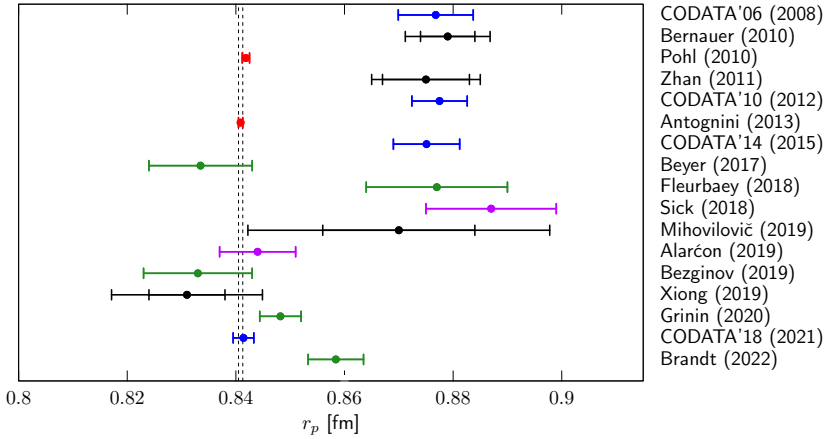
The MUon Scattering Experiment (MUSE)

- 2010: CREMA extract r_p through muonic hydrogen spectroscopy
  - $\sim 7.9\sigma$ from average ep scattering value at time
- Birth of Proton Radius Puzzle

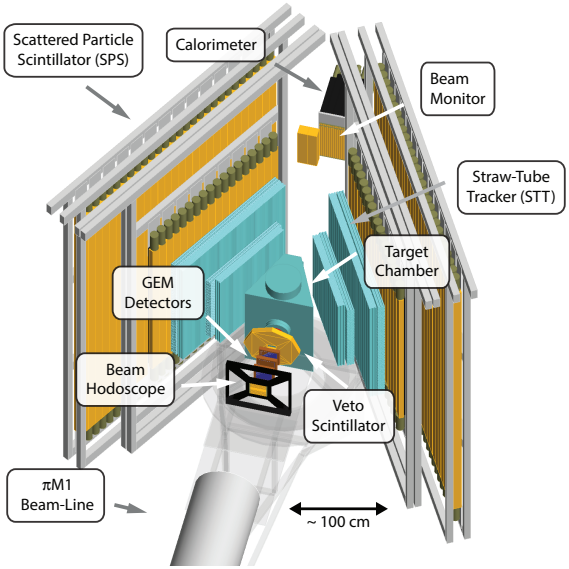


MUSE

- The MUon Scattering Experiment (MUSE) was directly inspired by the proton radius puzzle
- Goals:
  - Precision measurement of r_p via ep and μp scattering
  - Precision study of TPE in ep and μp scattering
  - Direct test of lepton universality
- Housed at the πM1 beamline at the Paul Scherrer Institute

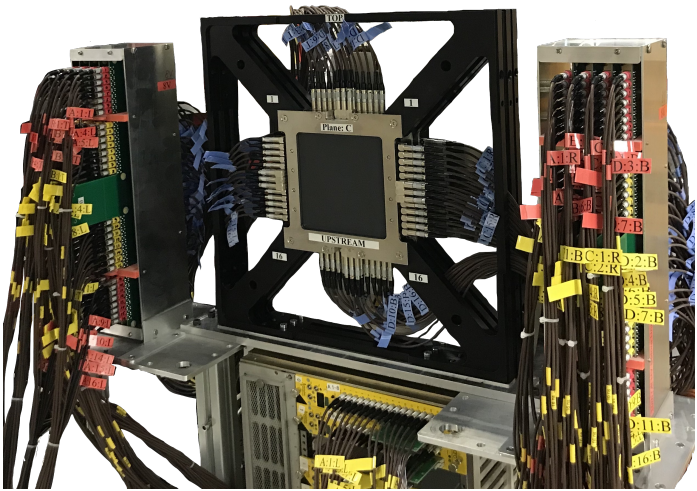
Experimental Setup

- θ acceptance: $20 - 100^{\circ}$
- $\pi M1$ Beam Line:
  - p$\in 115, 160, 210$ MeV/c
  - Mixed beam of e, μ, π
  - Both polarities of particles!

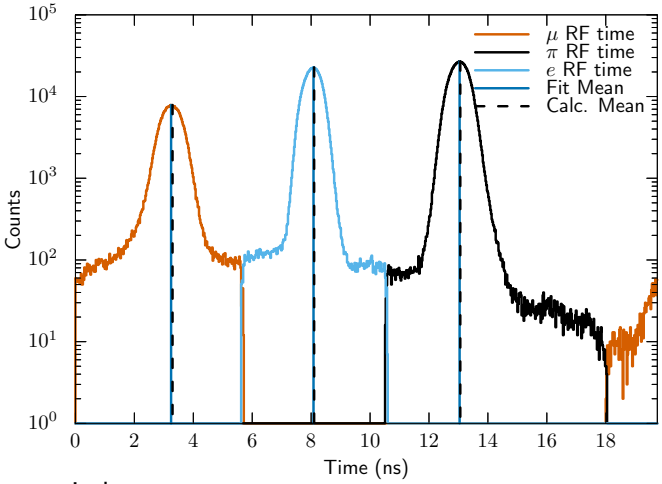


Beam Hodoscope (BH)

- 2 planes of plastic scintillator paddles
- BHC: horizontal paddles, BHD: vertical paddles
- Provide incoming particle timing and pid
- Incoming particle trigger
- BHC widths: 4 and 8 mm
- BHD width: 8 mm



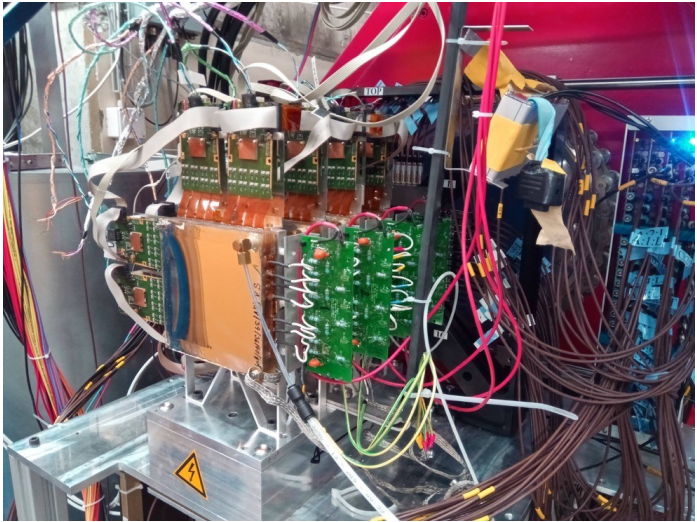
RF Spectrum



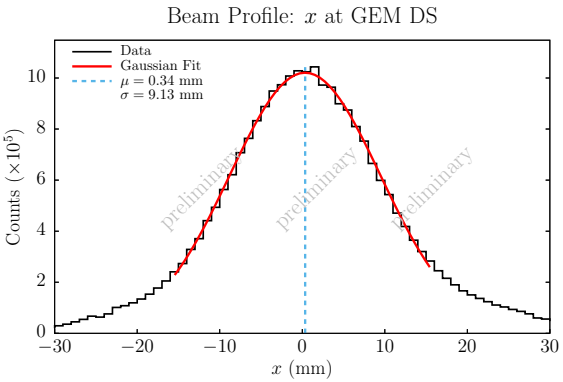
- RF has 19.75 ns period
- $v_e \sim c$ for MUSE momenta $\rightarrow$ fix peak at 8 ns

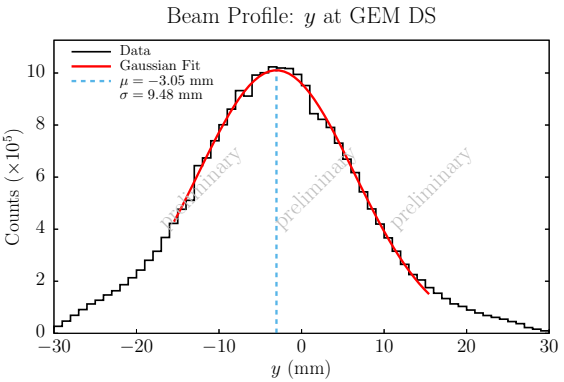
Gas Electron Multipliers (GEMs)

- Incoming particle tracking for MUSE
- Ar/CO_2 (70/30) gas mixture
- Four 100x100 mm^2 GEMs
- Readout in x and y

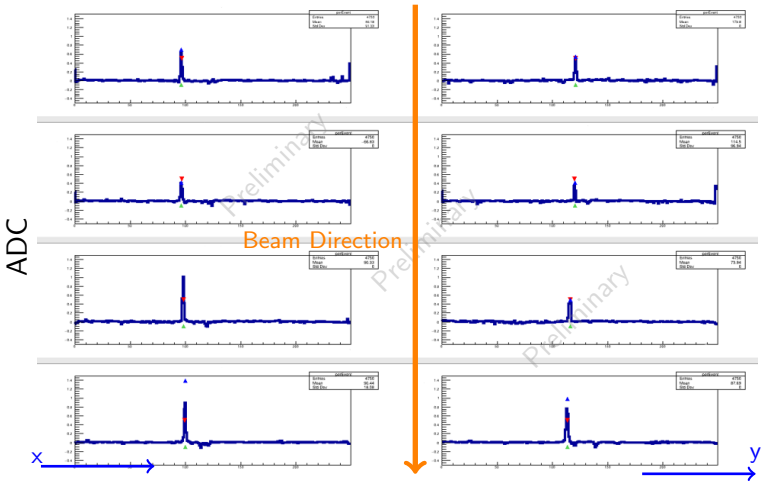


Beam Profile





GEM Clustering



- Find peaks in ADC spectra in GEM x and y
- Fit clusters with line!

GEM Tracking: Approach

- Given sets of all x, y 1D clusters in event:
  1. Attempt to naively fit all clusters in event to a line (next slide)
  2. If χ^2_{red} meets cut: keep track! Else...
  3. Take all 1D combinations of x and y clusters that...
     - Contains at least 3 of 4 GEMs
     - Has at MOST 1 x and 1 y cluster per GEM
     - Has no "outliers" based on preliminary fit (fit first 2 points in candidate to OLS: check distance to other points)
     - Is not a subtrack of a larger track
  4. Fit all combinations to line (next slide)
  5. Select best tracks based on:
     - χ^2_{red}
     - Correlations to BH hits
     - Maximize number of clusters used
     - (x, y) cluster pairs are unique per track

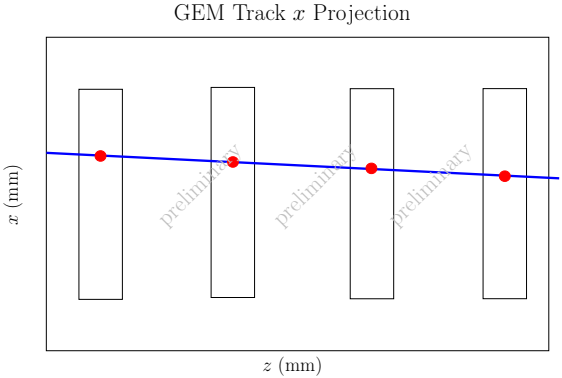
GEM Tracking: Fitting

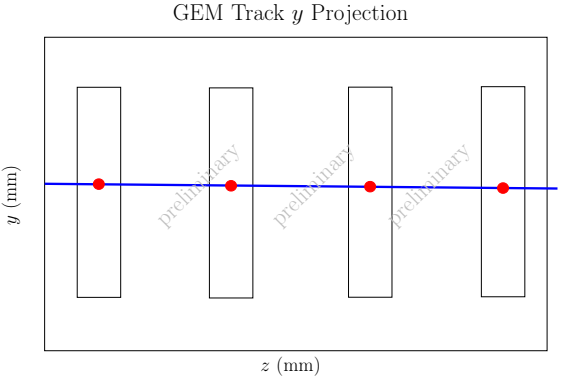
- Parametrize track in spherical coordinates: 4 free parameters!

$$\vec{r} = (r_{pos}, \theta_{pos}, \phi_{pos}) + t \times (1., \theta_{dir}, \phi_{dir})$$

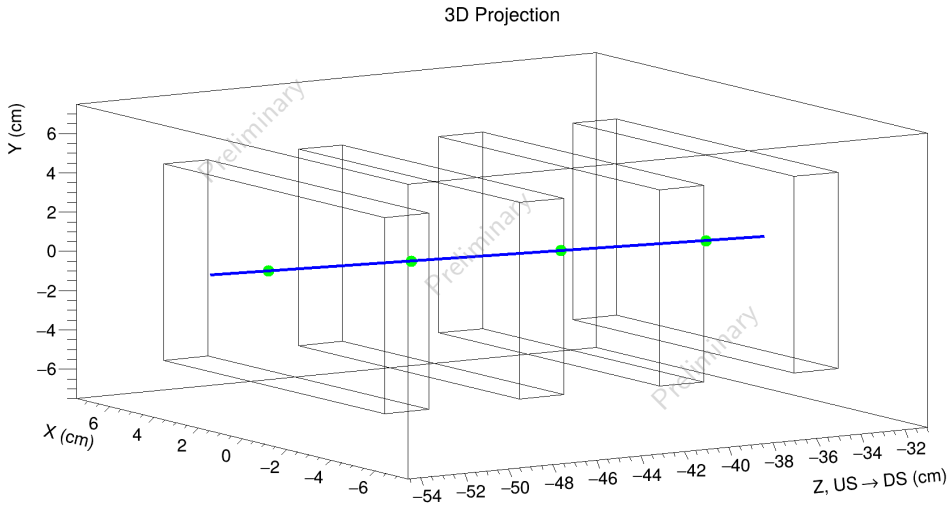
- r_{pos}, seed: OLS to clusters!
- Uses Levenberg-Marquardt algorithm from CMinPack
- Project track to local frame of each GEM plane $\rightarrow$ take x, y residuals here

Single GEM Track: 1D





Single GEM Track: 3D



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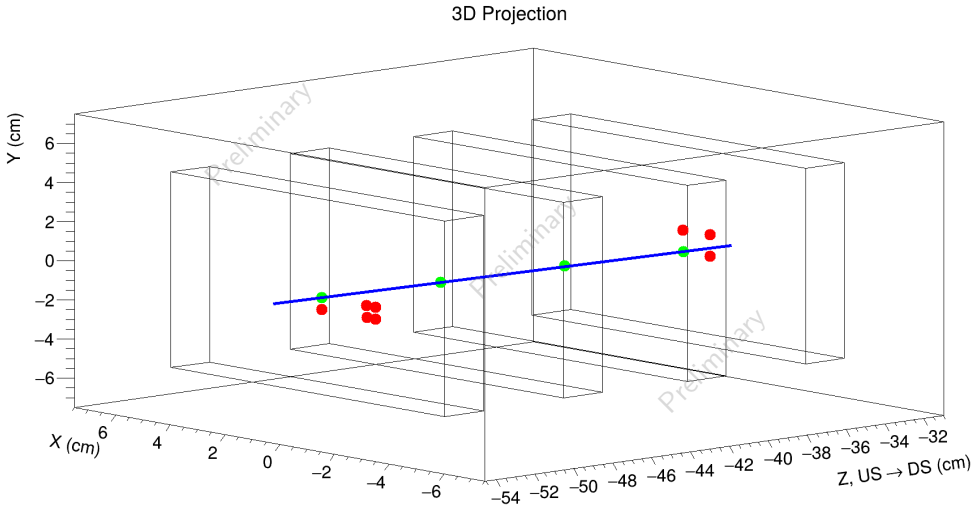
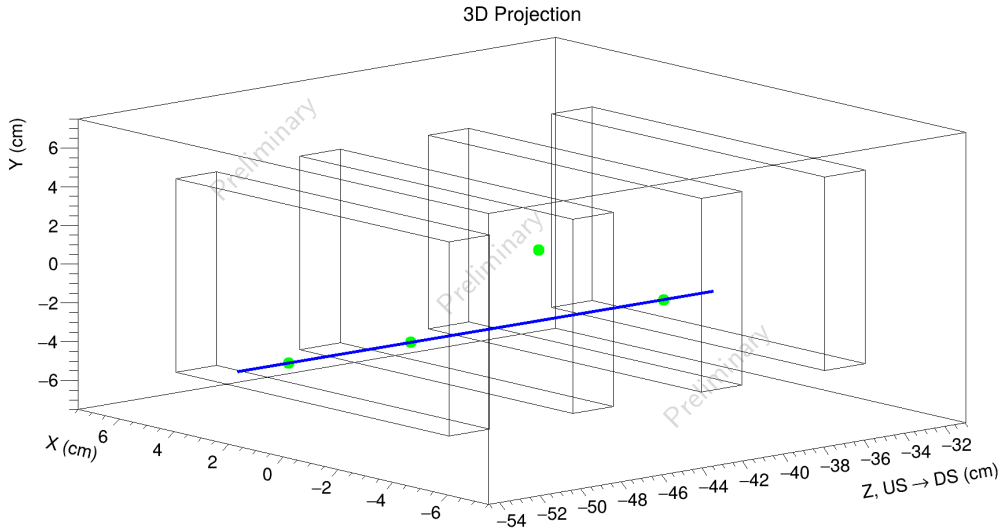
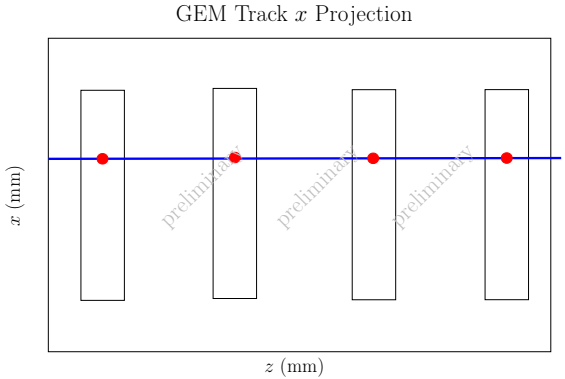
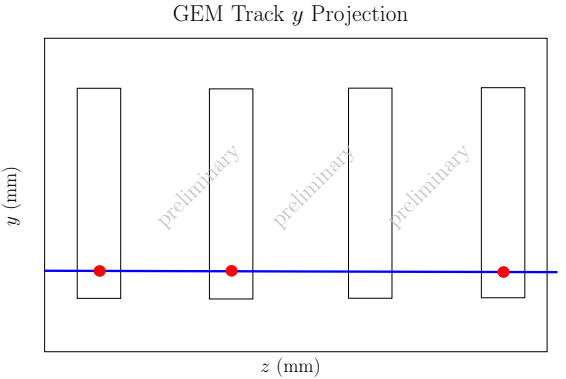


3D Track Example: Missing y Cluster

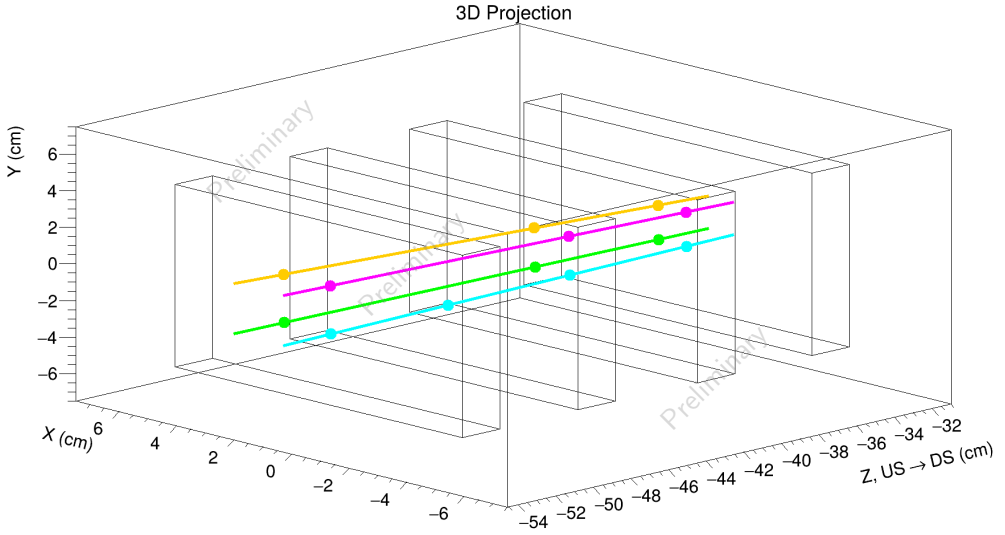


1D Track Examples: Missing y Cluster

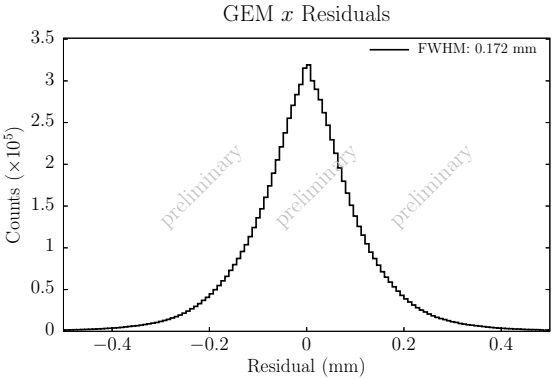


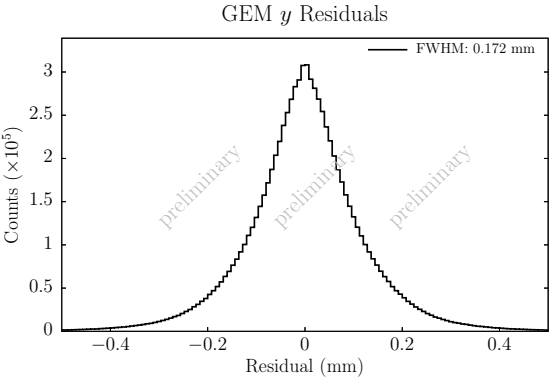


Multiple Tracks



Residuals


GEM x Residuals
FWHM: 0.172 mm
Counts ($\times 10^5$)
Residual (mm)
preliminary
preliminary
preliminary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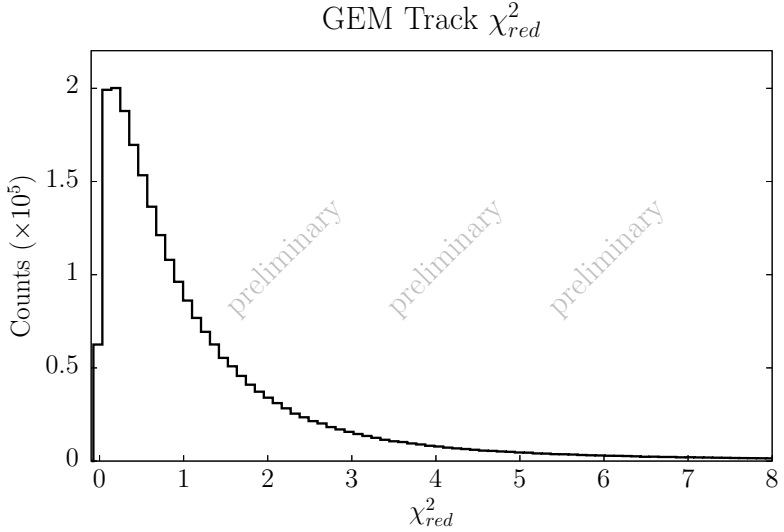
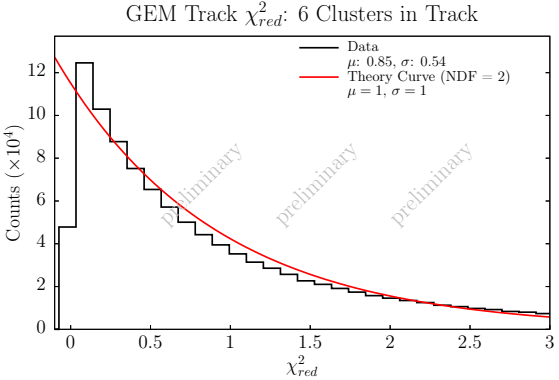
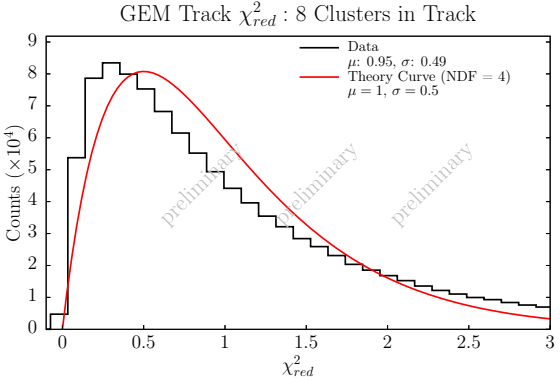
Reduced Chi Square Distribution

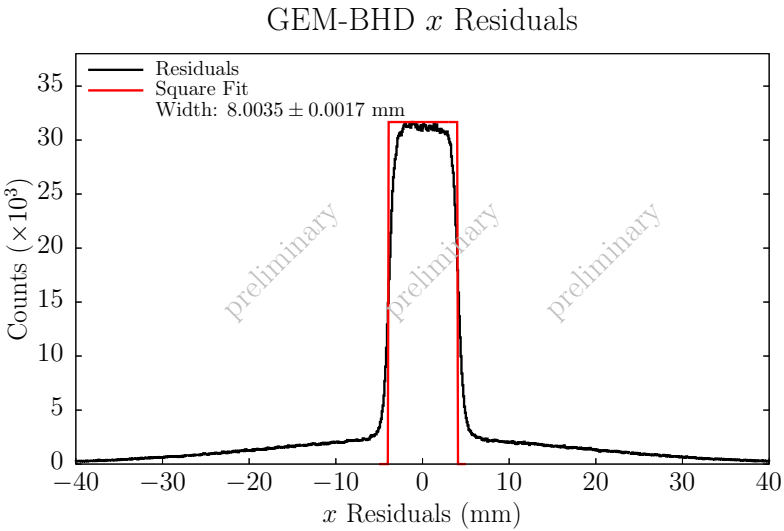


Reduced Chi Square Distributions

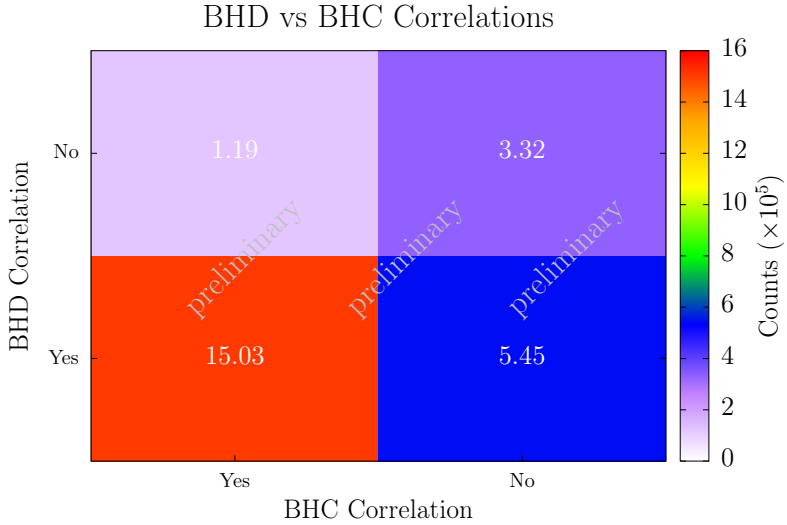




BHD Residuals



BH Correlations



Summary

- πM1 secondary beamline has profile - incoming particle tracking needed
- This is accomplished through our GEMs
- Single and multi tracking with noise filtering successfully implemented
- Residuals and χ^2_{red} distributions indicate good tracking performance, with further improvements to come