GEM Detectors for Muon Scattering Experiment

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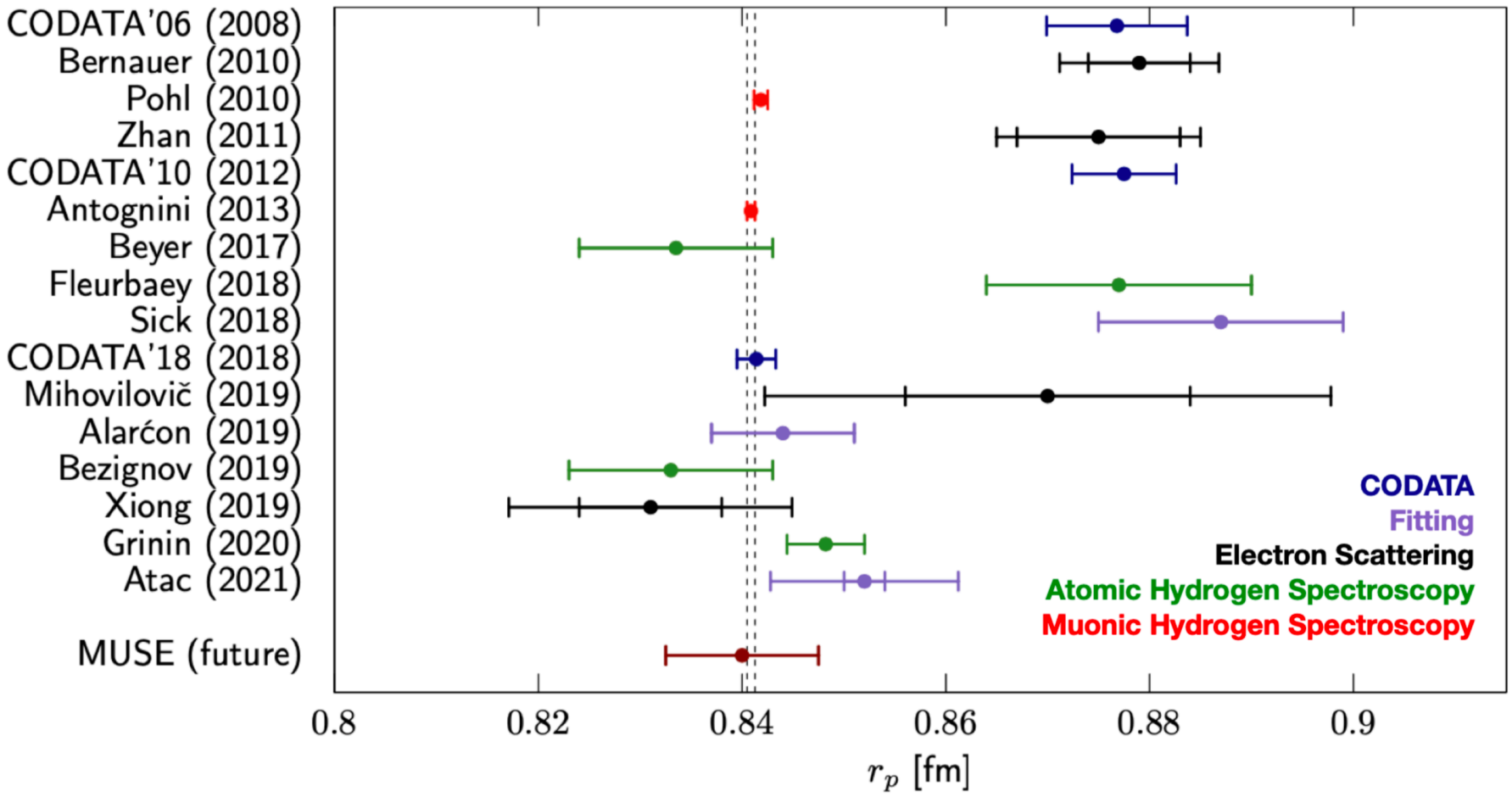
Proton Radius Puzzle

- Proton Radius Puzzle arose from the discrepancy between electronic hydrogen and Muonic hydrogen measurements
- Recent data points to a smaller radius but there are questions about radiative corrections and lack of understanding about earlier results



Plot: courtesy by J. Bernauer

Motivation for μp scattering

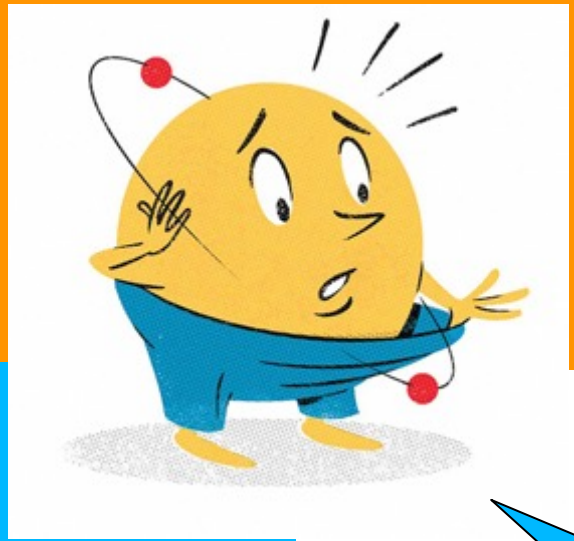
Spectroscopy

Electronic hydrogen

0.877 ± 0.0077

Muonic hydrogen

0.841 ± 0.00039



Electron scattering

0.875 ± 0.0060

Scattering

Muon scattering

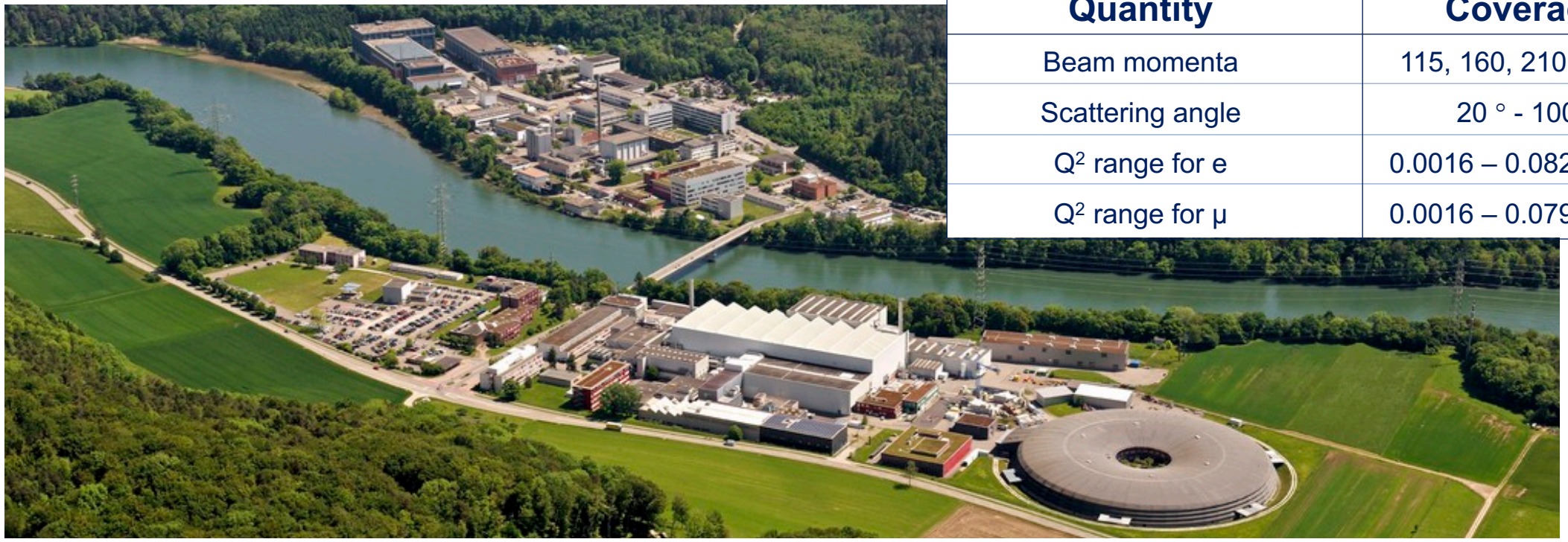
???

Muon Scattering Experiment

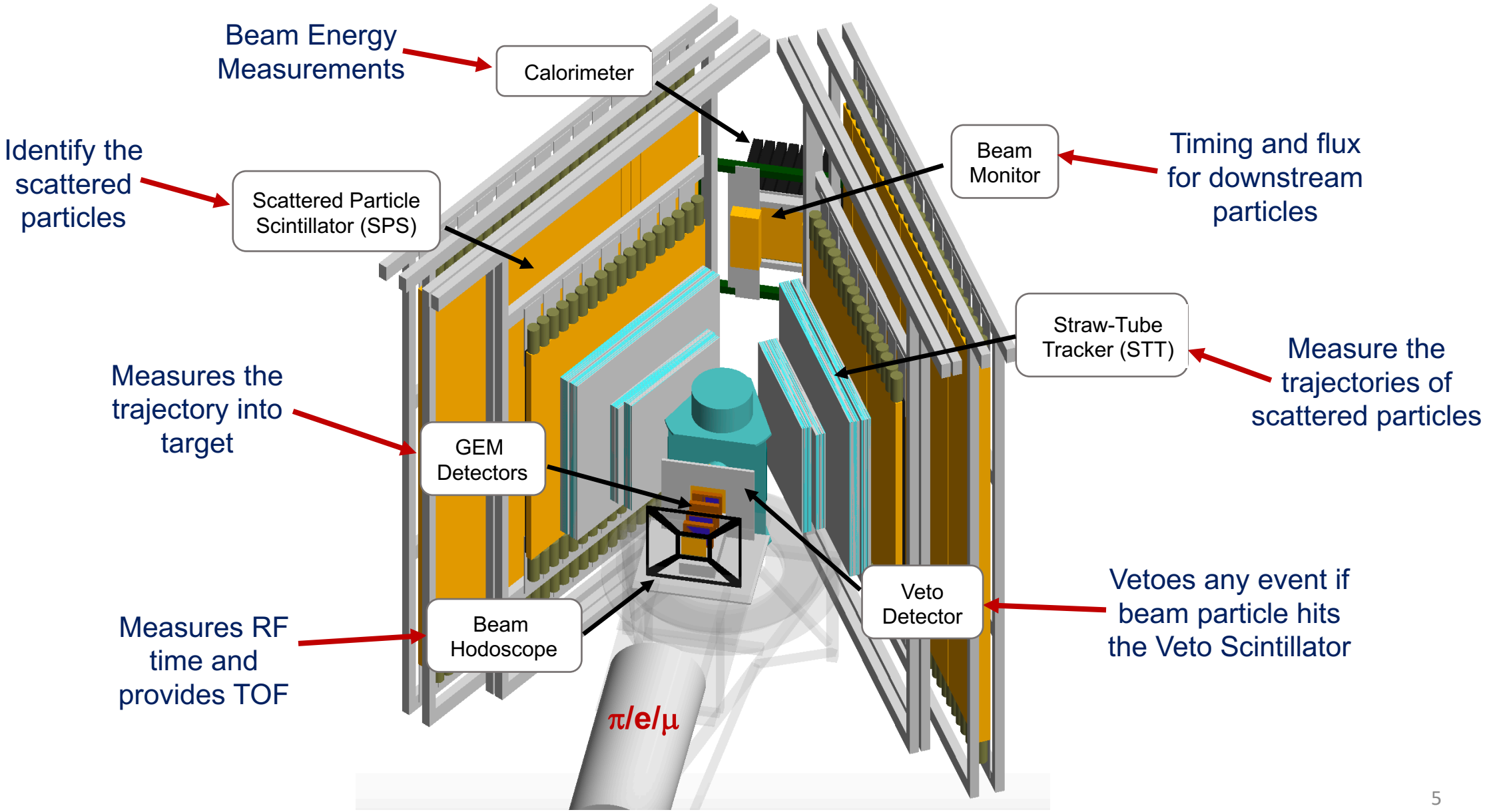
- Located at Paul Scherrer Institut in Villigen, Switzerland
- Secondary beam of ≈ 2 – 15 % μ's, 10 – 98 % e's, 0 – 80% π's

- Simultaneous measurement of elastic electron and muon scattering on the proton
  - test lepton universality
- Measuring with both beam polarities **(e+/π+/μ+) or (e-/π-/μ-)**
  - two photon exchange
- Determine cross section, form factors, and extract precise radius

Quantity	Coverage
Beam momenta	115, 160, 210 MeV/c
Scattering angle	20 ° - 100 °
Q^2 range for e	0.0016 – 0.0820 GeV^2
Q^2 range for μ	0.0016 – 0.0799 GeV^2

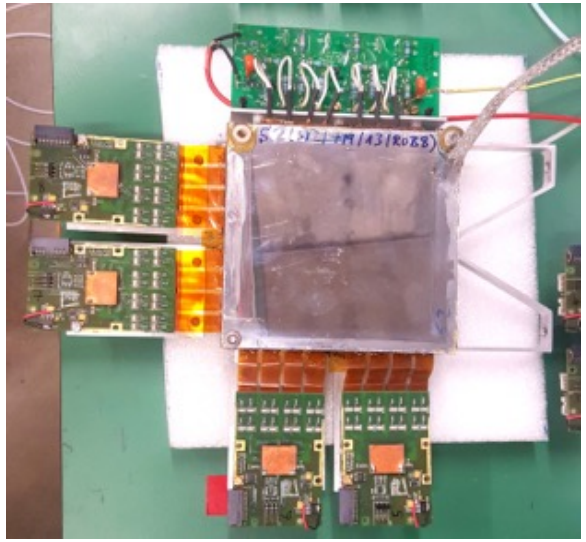


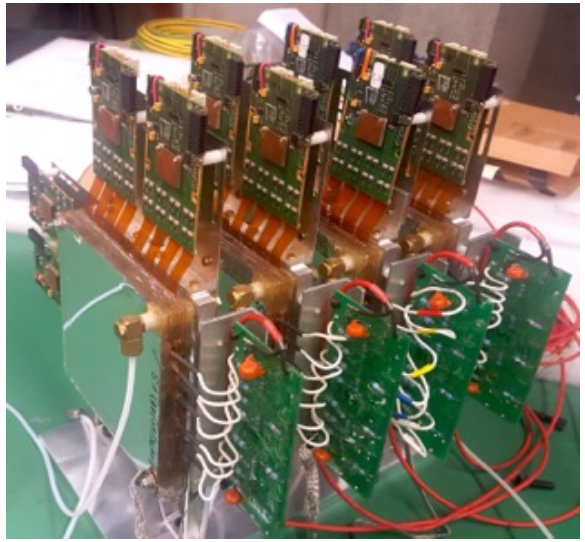
Experimental Set-up at PSI

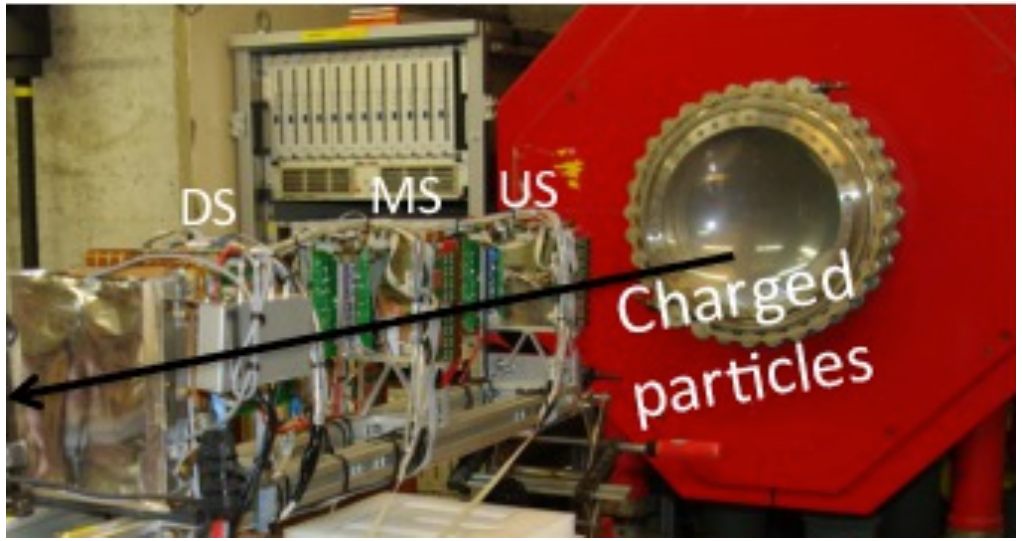


GEMs for MUSE

- Built at Hampton University for OLYMPUS experiment
- 10 x 10 cm^2 triple layer GEM detectors
- 2-D readout plane consist of copper strips
- Supplied $ArCO_2$ gas mixture (70:30 ratio)
- Each GEM with four APV-25 fronted chips to read analog signals from the readout strips
- Total of 1500 readout channels (250 per axis and 500 per element) for 3 GEMs



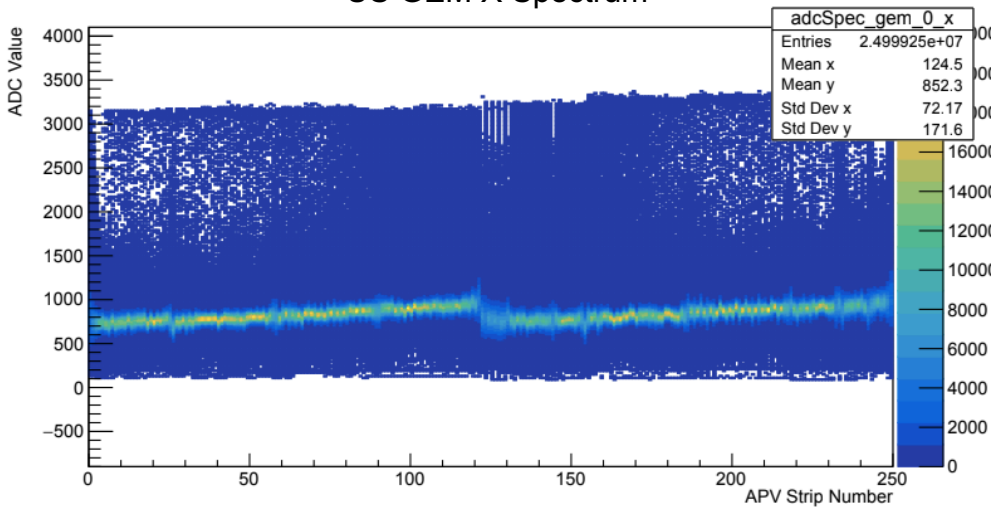




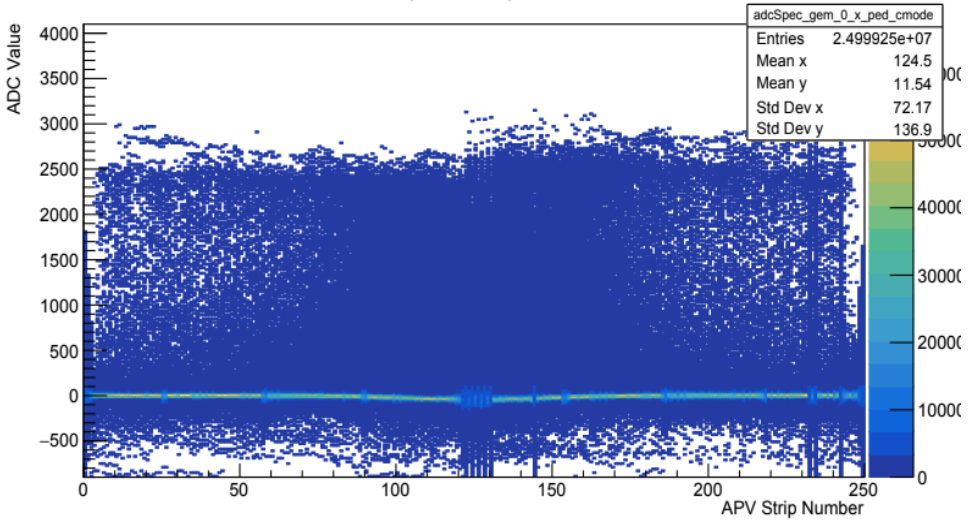
From Raw Data to Noise Subtracted Data

- The analog signals are digitized by Analog Digital Converter (ADC).
- ADC records the integration of the analog signals over time for the total charge registered by a strip.

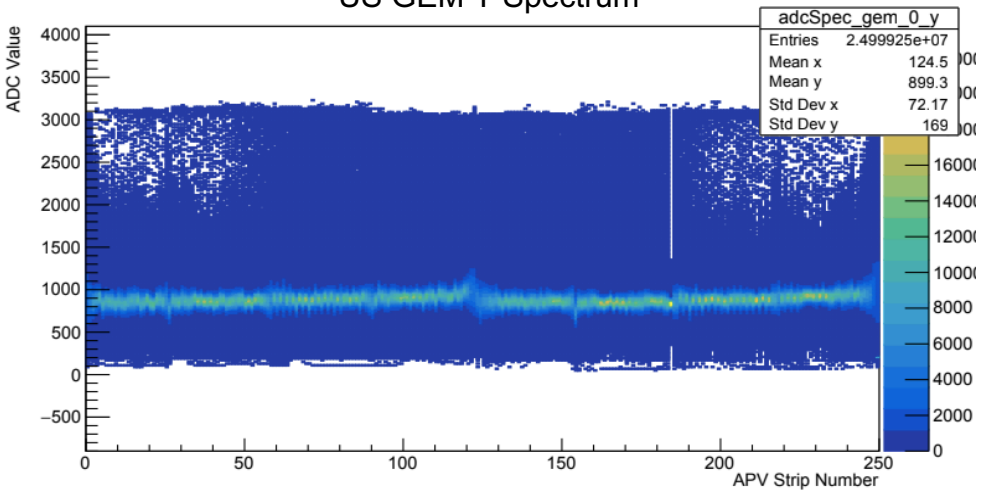
US GEM X Spectrum



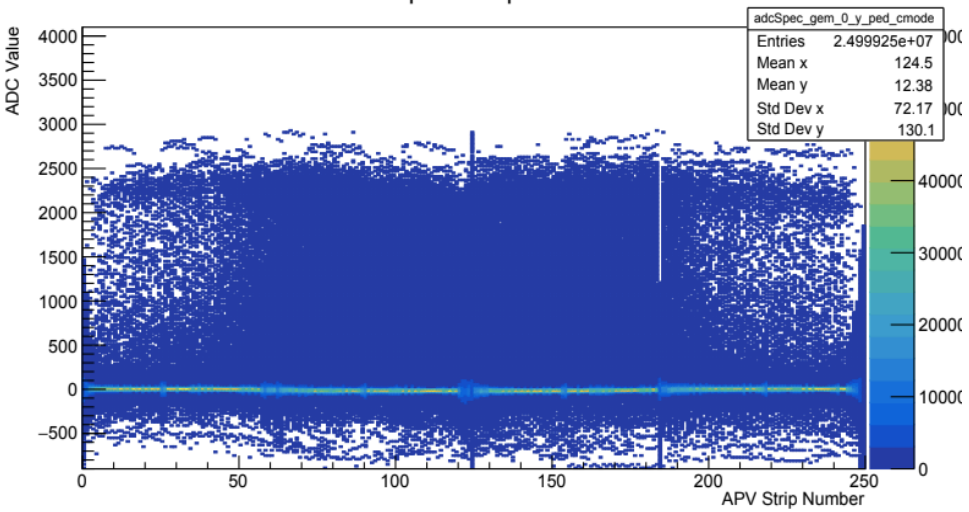
US GEM X Spectrum After Ped and Cmode



US GEM Y Spectrum

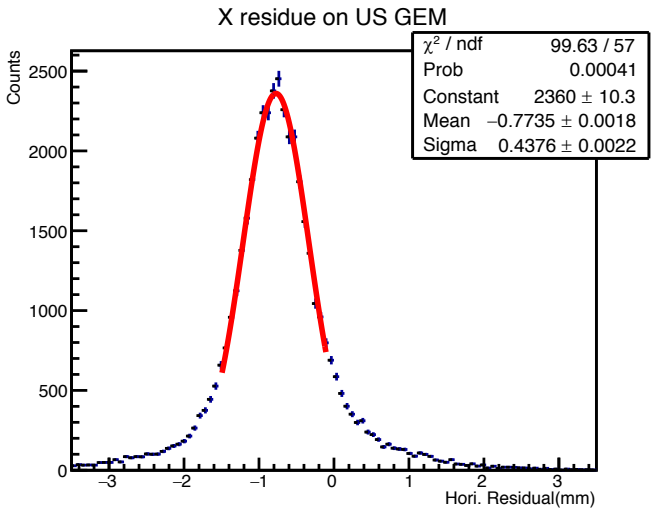


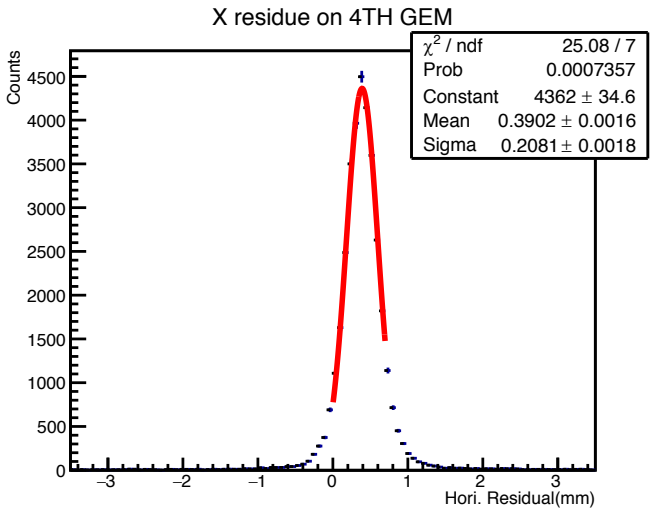
US GEM Y Spectrum After Ped and Cmode

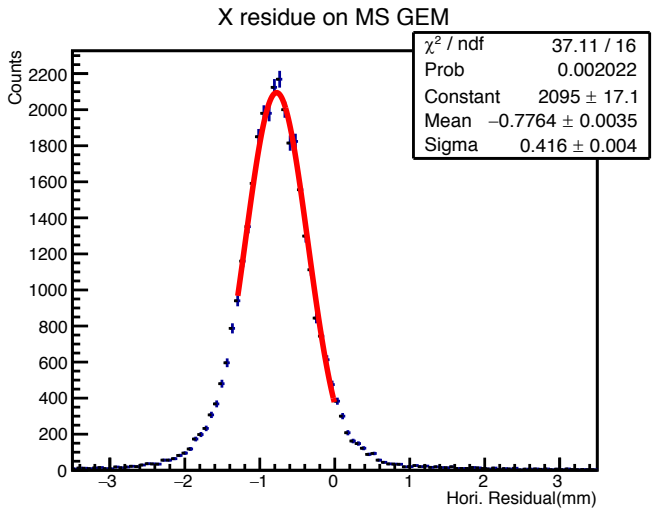


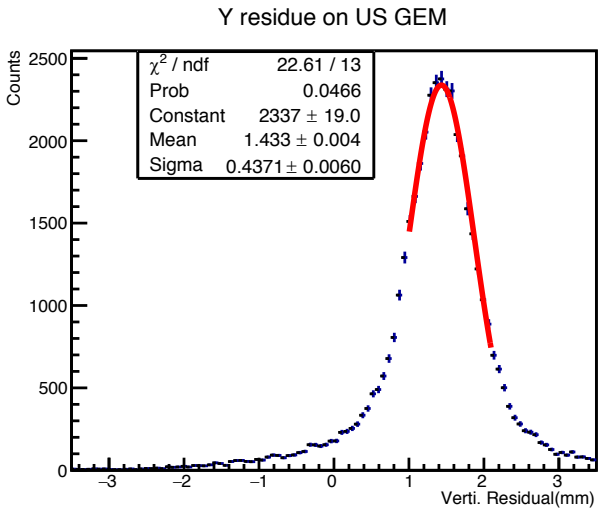
Track Residual

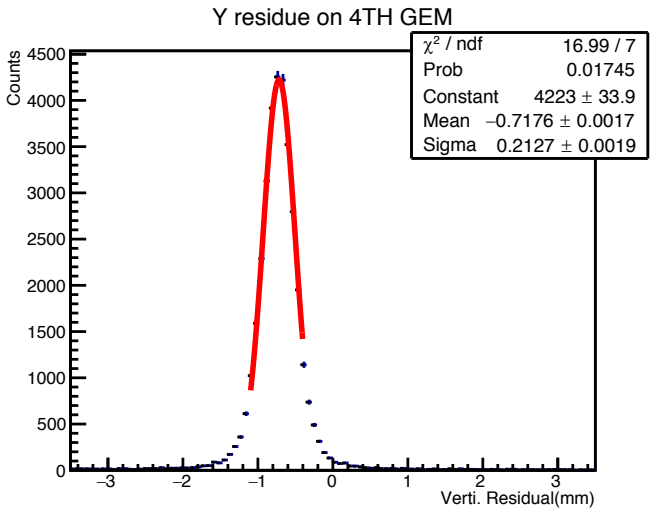
- Tracks are determined by the cluster candidates on 2 GEMs and projected on 3rd GEM
- Compare track and hit at the 3rd GEM for track residuals

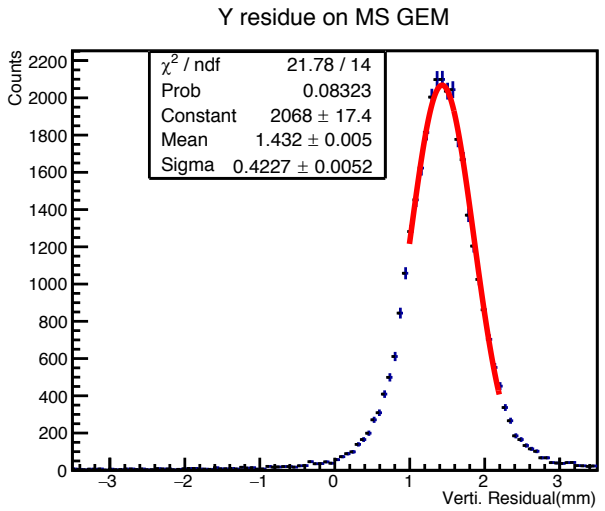






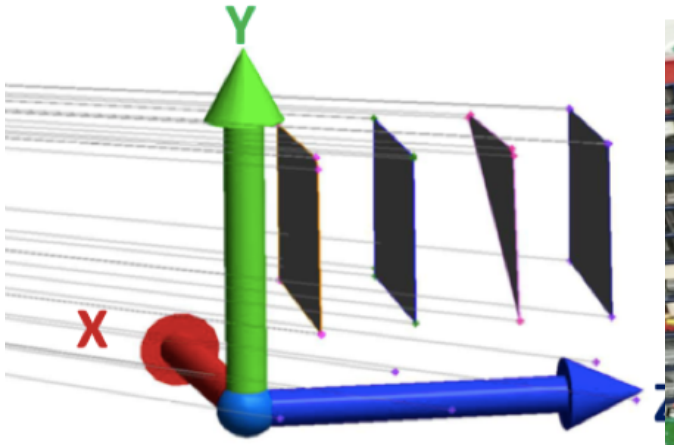


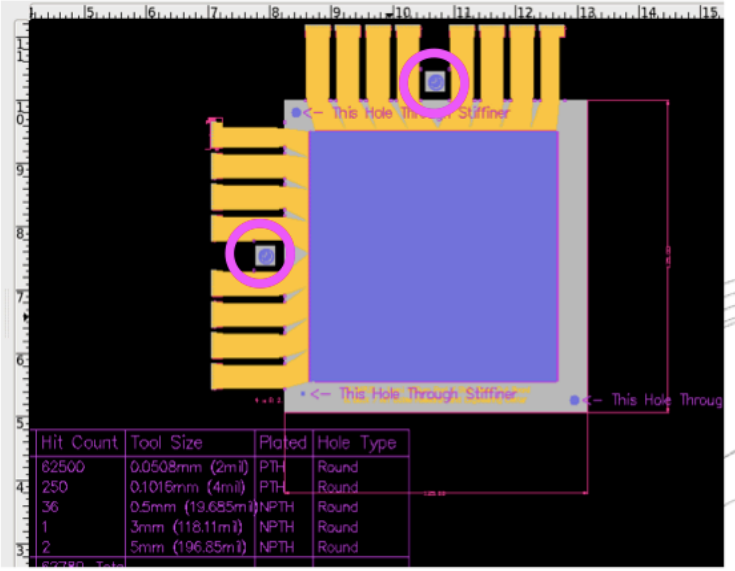


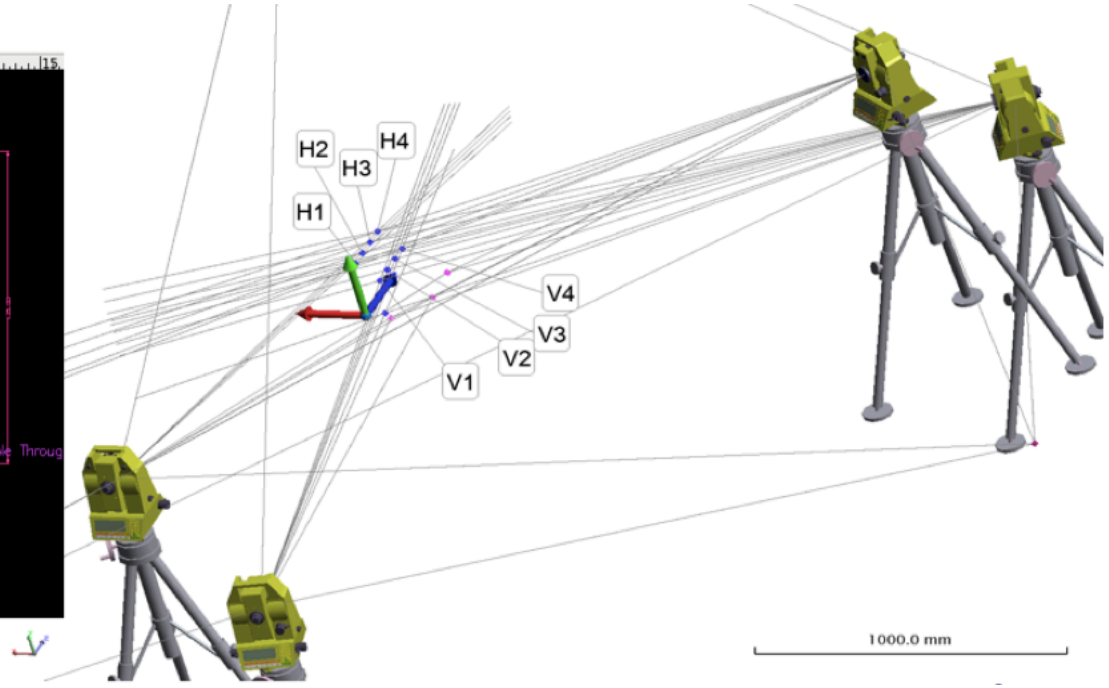


GEMs Alignment Survey

- Three types of data evaluated in the same room coordinate frame:
  1. Horizontal and vertical offsets of the cross hairs
  2. 3D locations of cross hairs
  3. Various points on the readout layer of each GEM

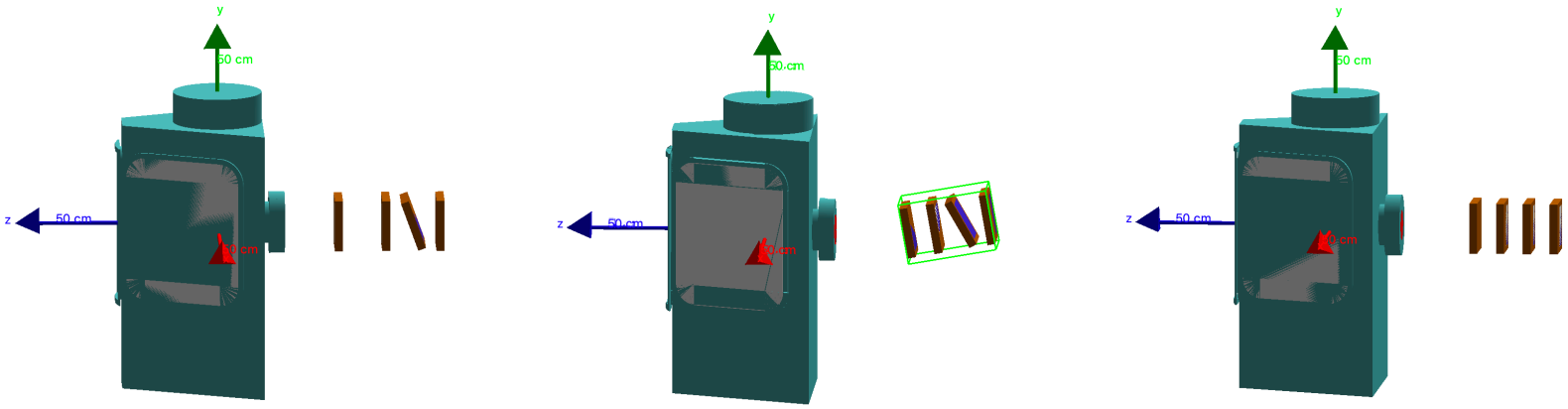




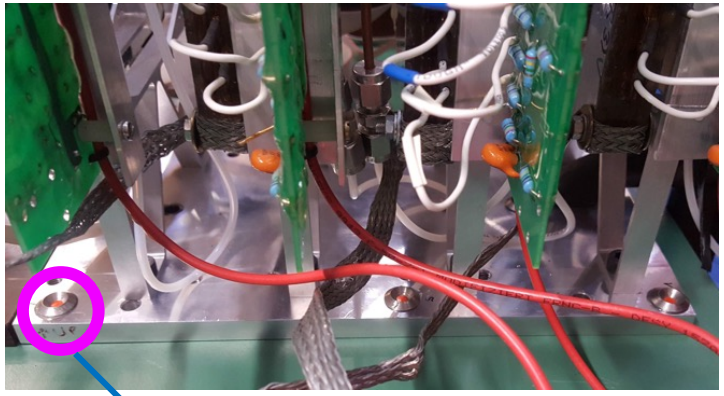


Alignment Strategy

- Translation to move the origin of the local GEM frame to the origin of the surveyed telescope frame
- A set of 3 rotations about X, Y, and Z axes
- Each GEM plane is actively rotated and shifted to transform from the local frame to telescope frame
- The survey of the base plate reflectors in the MUSE frame can be used to obtain the alignment of the telescope frame in the MUSE frame

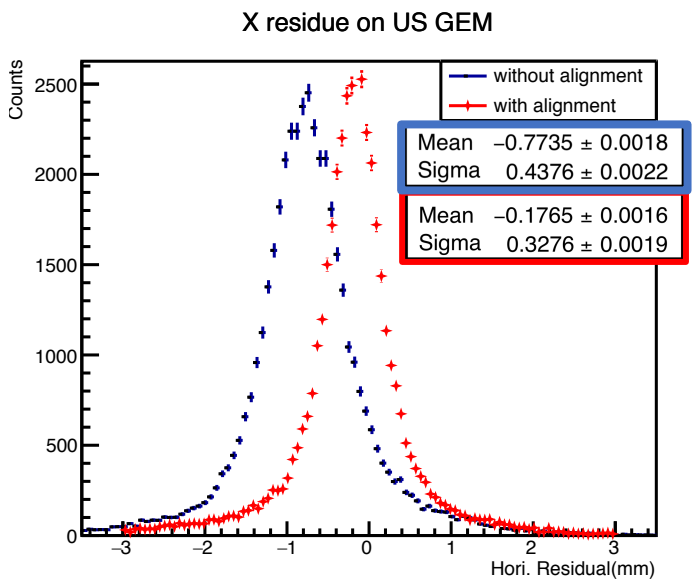


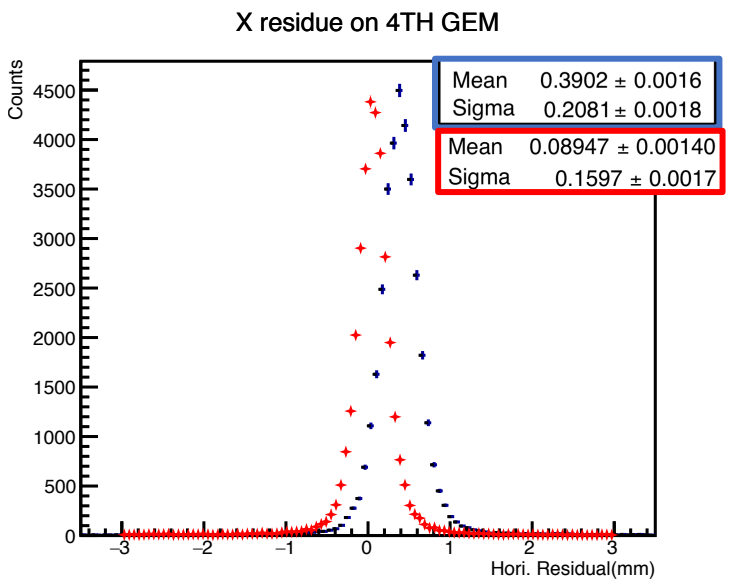
Local frame → ***Telescope frame*** → ***MUSE frame***

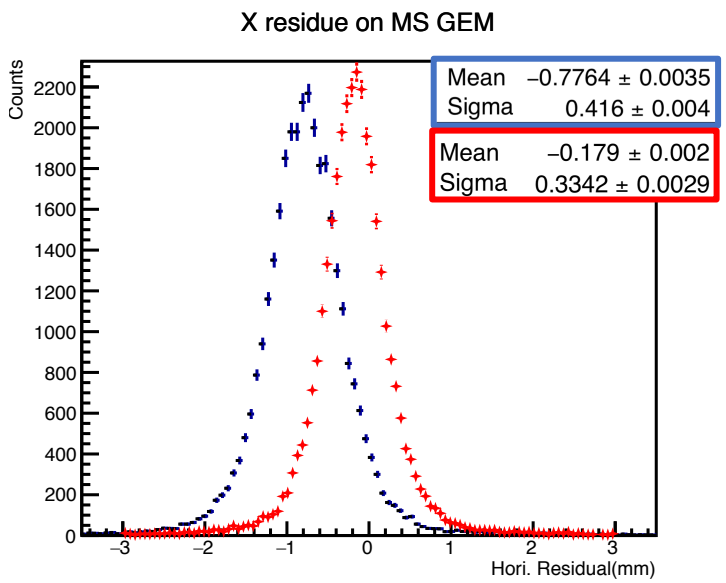


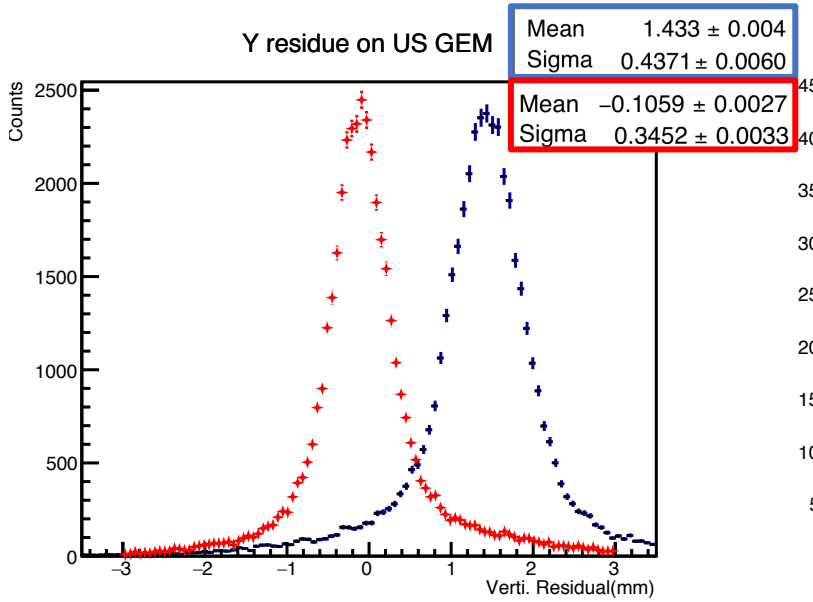
Base plate reflectors

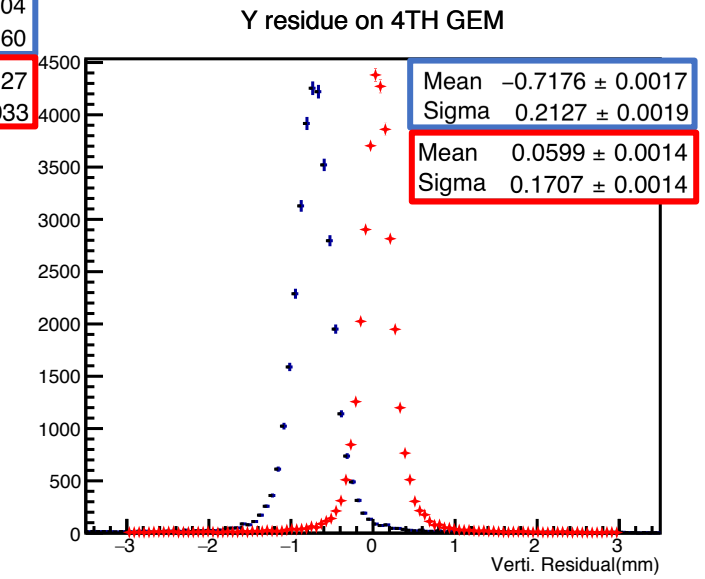
Comparing Track Residuals

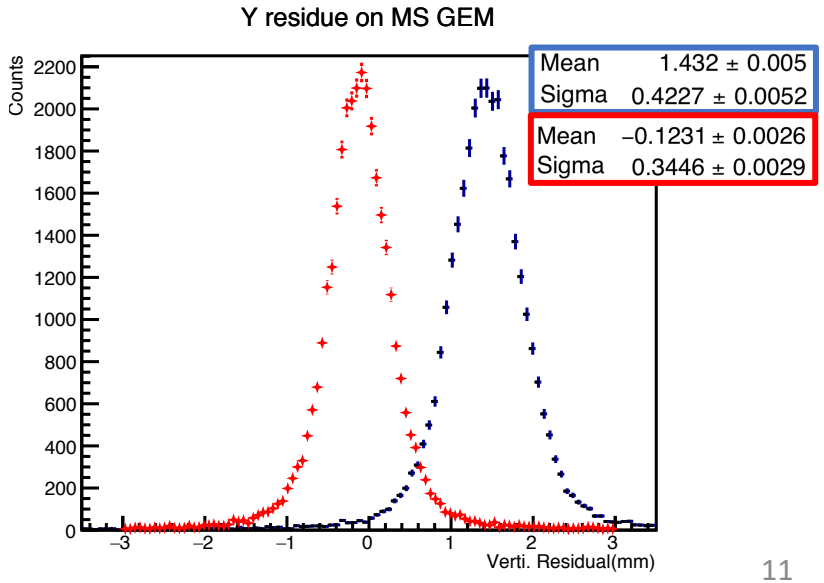








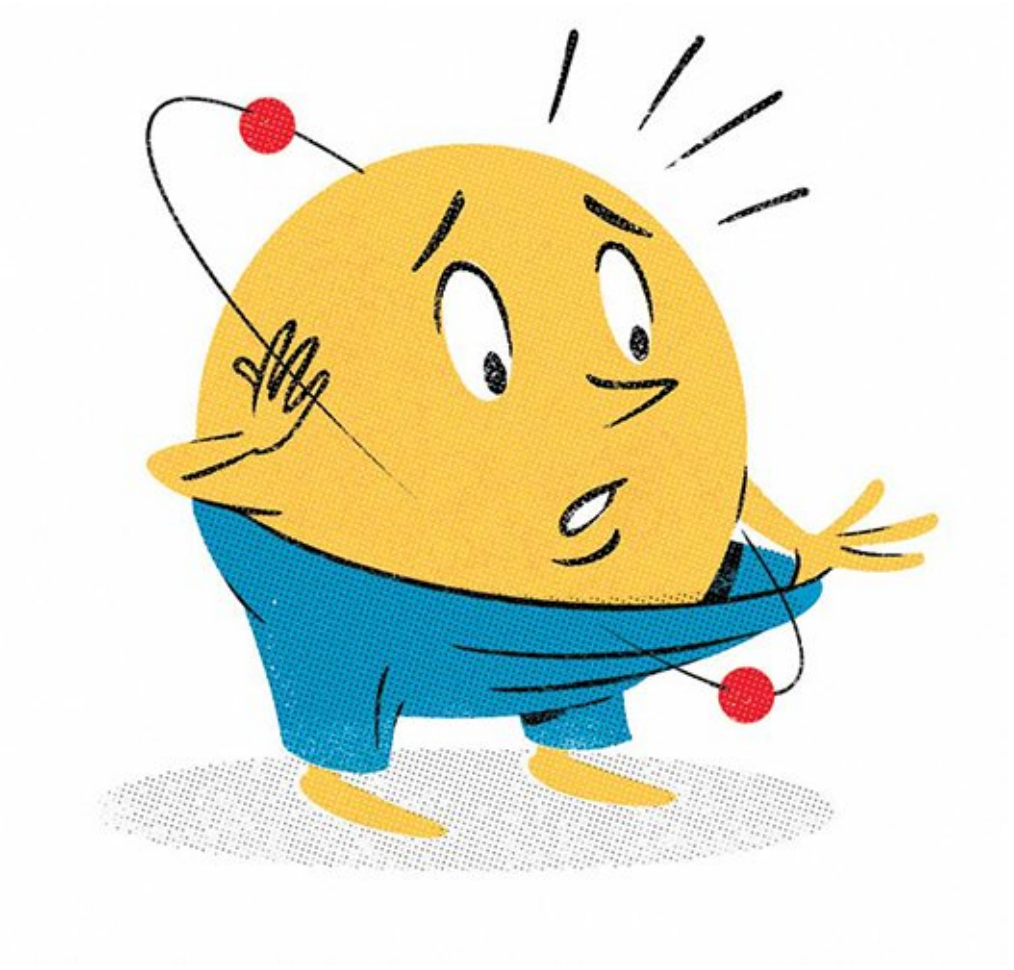




Summary

- MUSE:
  - Fall 2021: completed detector commissioning and took production scattering data
  - 2022 – 2023: more production data taking is planned

- GEMs:
  - Improve data quality by noise suppression (hot/dead channels and cross talk)
  - Multi-sample analysis for clusters for high intensity operation
  - Track based refined alignment of all GEM elements
  - Efficiency test before and after alignment



Questions?