CFNS MUSE Update

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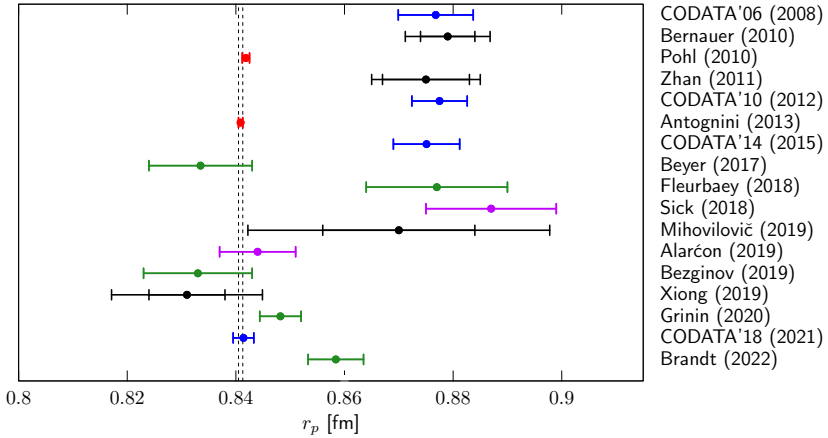
The MUon Scattering Experiment (MUSE)

- 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

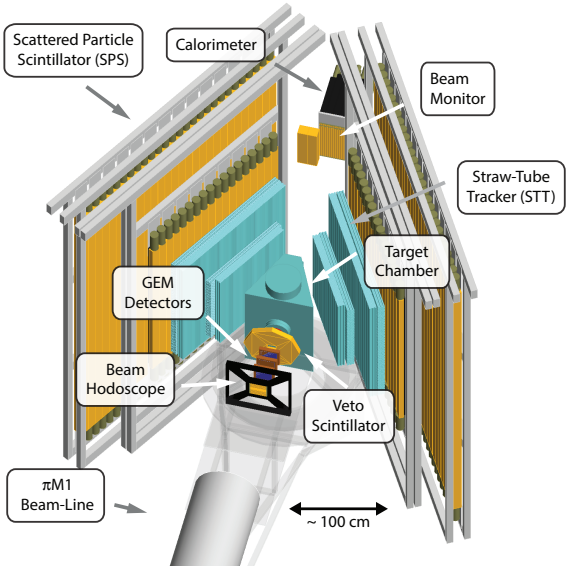


MUSE

- 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

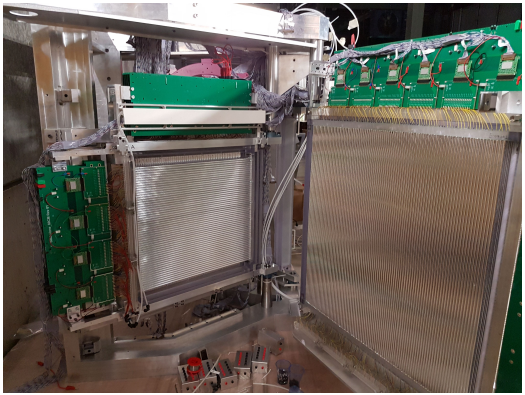
- θ acceptance: $20 - 100^\circ$
- $\pi M1$ Beam Line:
  - p$\in 115, 160, 210$ MeV/c
  - Mixed beam of e, μ, π
  - Both polarities of particles!

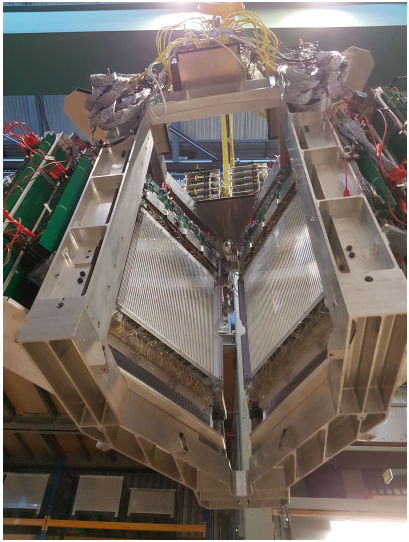


The Straw Tube Trackers (STT)

- Primary scattered particle tracking detector in MUSE
- Mirrored setup:
  - 20 planes of straws (10 horizontal, 10 vertical)
    - Vertical planes: θ
    - Horizontal planes: ϕ
  - Smaller front chamber, larger rear chamber
  - 5.1mm straw radius, 60 and 90 cm long
  - $\sim$ 3000 straws total

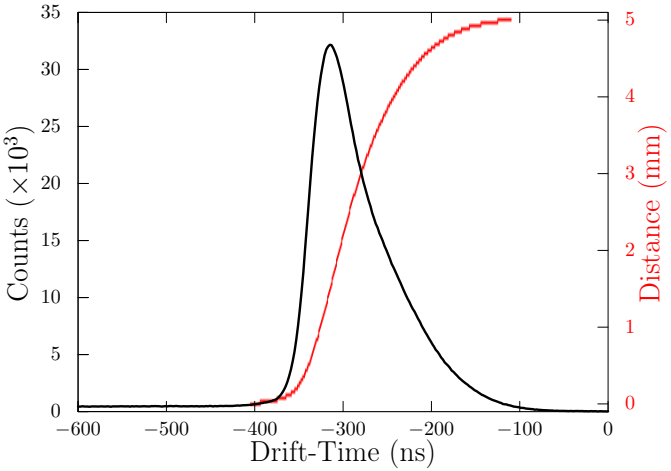
The Straw Tube Trackers (STT)





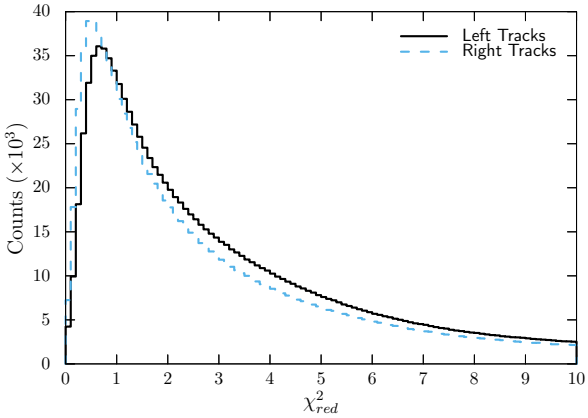
STT Analysis

- Particle ionizes gas → interrupt signal
- Reads out drift time of signal - *not position of hit*

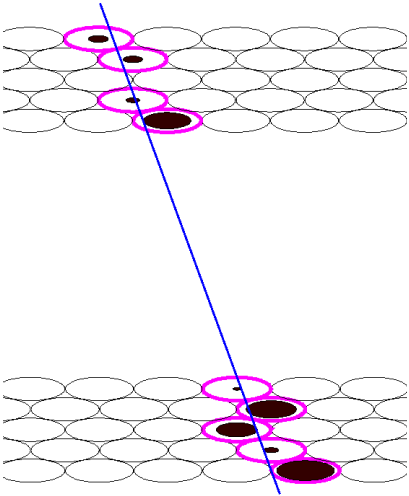


STT Tracking

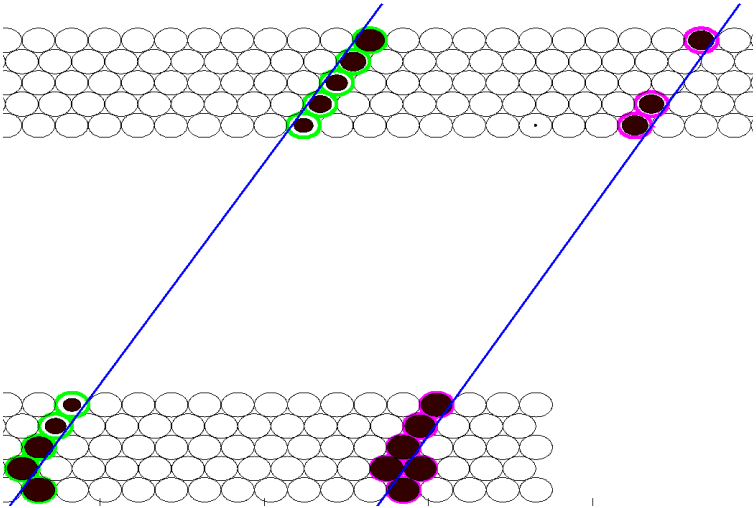
- Process:
  - Filter out noise hits/group tracks together
  - Parametrize track using spherical coordinates $\rightarrow$ 4 free parameters
  - Minimize χ^2 of track to hits (represented by cylinders)



STT Tracking: Sample Events

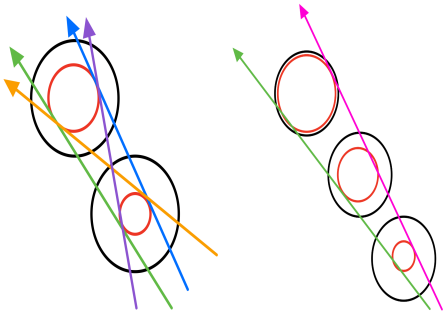


STT Tracking: Sample Events



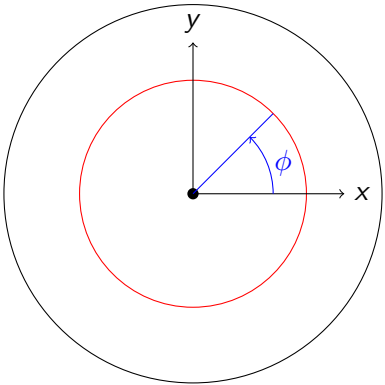
STT Tracking: Difficulties

- Tracking is not straightforward: Left Right Ambiguity
- Makes χ^2 distribution in minimization complex
  - Many local minima for minimizer to get stuck in
- Seeding - minimizer very sensitive to starting guess
  - Tried using OLS to straw centers, using SPS for seeds - all insufficient



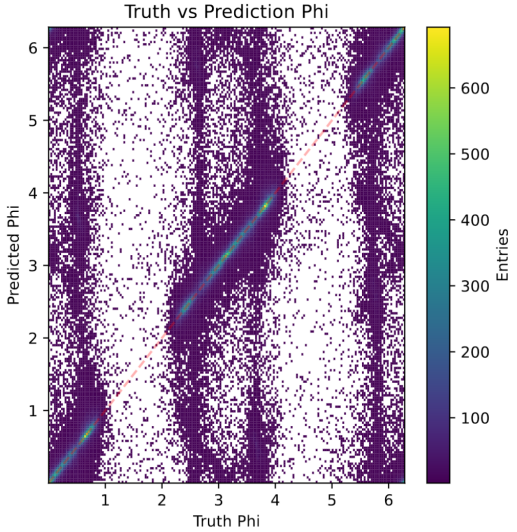
Machine Learning Approach

- Idea: train a neural network to help resolve this ambiguity
- NN to predict ϕ in local straw frame
- Input: hits on set of 5 planes
- Goal: seed minimizer with these predictions, or first pass to refine it



Machine Learning Results

- Still work in progress
- Generating larger dataset as we speak



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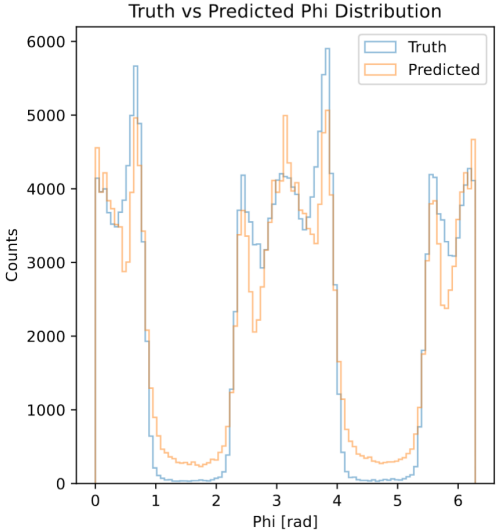

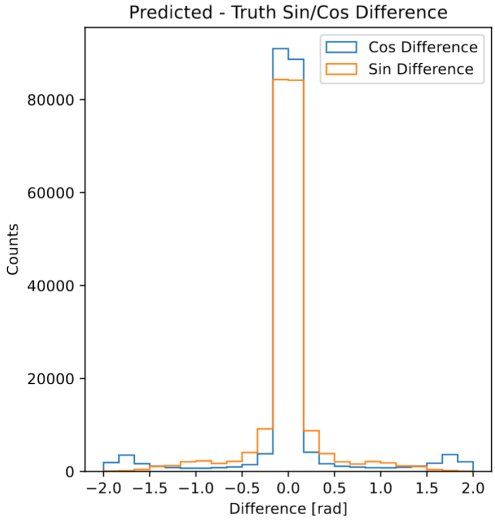

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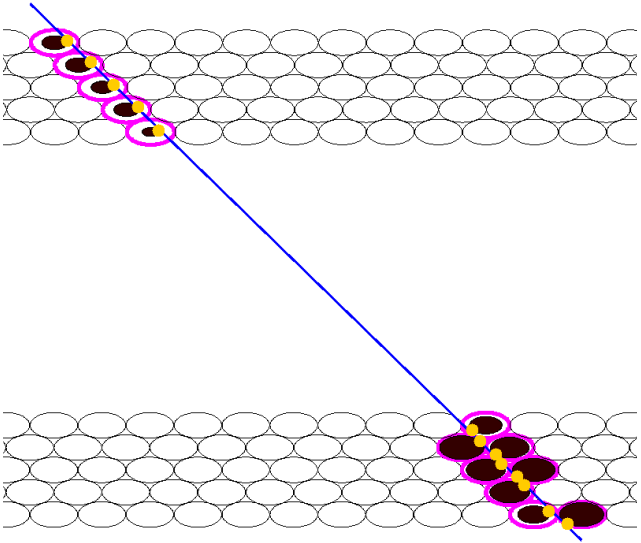
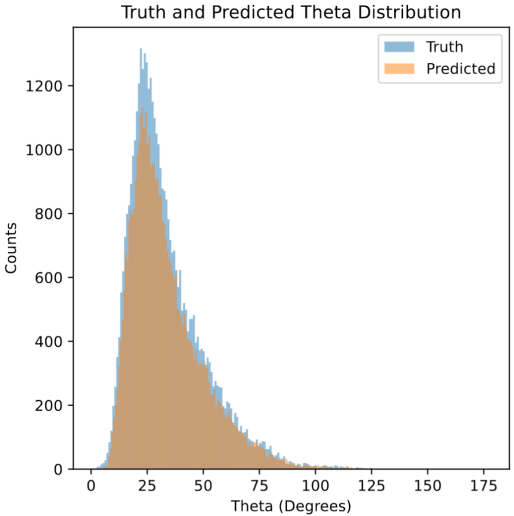
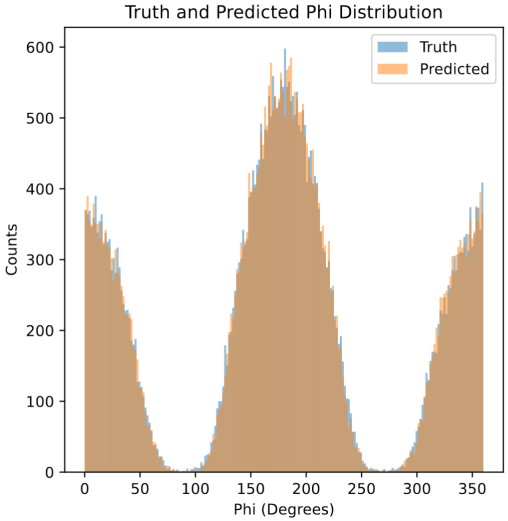


Future ML Work

- Since these predictions are used as a first pass in fitting - still need seed
- Idea: use NN to predict θ, ϕ for *track*
- Promising, very preliminary results
- Next: need NN to predict seed position not just direction
  - Idea: have CNN learn projection to $z = 0$ plane

Future Work


Truth and Predicted Theta Distribution
Truth
Predicted
Counts
Theta (Degrees)
0
200
400
600
800
1000
1200
0
25
50
75
100
125
150
175


Truth and Predicted Phi Distribution
Truth
Predicted
Counts
Phi (Degrees)
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350

Summary

- MUSE will precisely extract r_p via ep and μp scattering
- Precise STT tracking is pivotal to this measurement
- Tracking is improving continuously, but still has ambiguity
- Machine learning may be useful to help address this ambiguity!