Developing Novel Track Trigger Algorithms for the Mu2e Experiment

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The Mu2e Experiment

Mu2e, currently under construction at the Fermi National Accelerator Laboratory with data taking expected to begin in 2026, will search for neutrinoless muon to electron conversion.

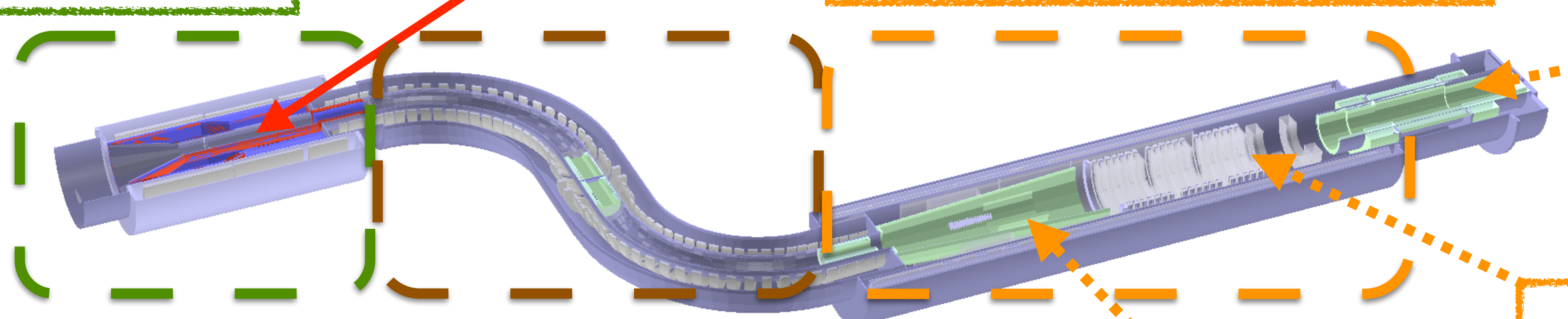
Standard Model w/ small neutrino masses allows CLFV with branching ratio $B \sim 10^{-54}$. Such a branching ratio is experimentally unobservable, but many BSM theories predict CLFV.

The experimental expected sensitivity is $R_{\mu e} = \frac{\Gamma(\mu^- + (A,Z) \rightarrow e^- + (A,Z))}{\Gamma(\mu^- + (A,Z) \rightarrow \text{ capture})} \leq 6 \times 10^{-17}$ @ 90% CL

Production Solenoid
- ➡ 8 GeV proton beam on tungsten target
- ➡ Graded magnetic field for collecting π/μ

Detector Solenoid
- ➡ Capture μ^- on Al target
- ➡ Houses the detector system in 1Tesla B field

Calorimeter
- ➡ 2 disks of **~ 1860 CsI crystals**
- ➡ **σ_t < 500 ps @ 100 MeV**
- ➡ **σ_E/E < 10% @ 100 MeV**



Tracker
- ➡ **~ 22000 straw tubes** filled with Ar/CO_2
- ➡ **$\Delta p/p$ ~ 0.2% @ 100 MeV/c**

Transport Solenoid
- ➡ Select low momentum μ^-
- ➡ Antiproton absorber in the mid-section

Stopping target
- ➡ 34 Al foils; μ lifetime in the Al mesoatom is 864 ns

The Mu2e Trigger System

Trigger Requirements

- The trigger is subject to three requirements:
  1) Trigger on signal candidates at > 90% efficiency w.r.t. offline performance
  2) Trigger rate of < 3 kHz
  3) Make trigger decision in < 5 ms/event
- A lot of data comes in, and it comes in very quickly
  - Meeting these requirements poses a significant experimental challenge
- There is motivation to improve trigger algorithms to measure processes outside of $\mu^- \rightarrow e^-$
  - **$p\bar{p}$** annihilation byproducts to constrain $\bar{p}$ induced backgrounds
    - i.e. μ and π pairs
  - **e^+** around ~ 90 MeV/c to measure $\mu^- \rightarrow e^+$
  - **e^+e^-**conversion pairs from BSM processes

Reconstruction Sequence

Track reconstruction for the Mu2e Experiment is broken down into 4 sequential stages:

1) Hit Reconstruction
   - raw current signals are converted into positional data
   - x, y, z, time, etc. are stored for each straw hit

2) Time Clustering
   - hits close in time to each other are grouped together to create time clusters
   - these time clusters are passed onto the next stage of reconstruction

3) Pattern Recognition (Helix Finding)
   - using hits within time cluster one searches for a helical trajectory
   - hits along helix are grouped together to create helix seed

4) Final Track Fit
   - final track fit with Kalman filter performed on helix seed

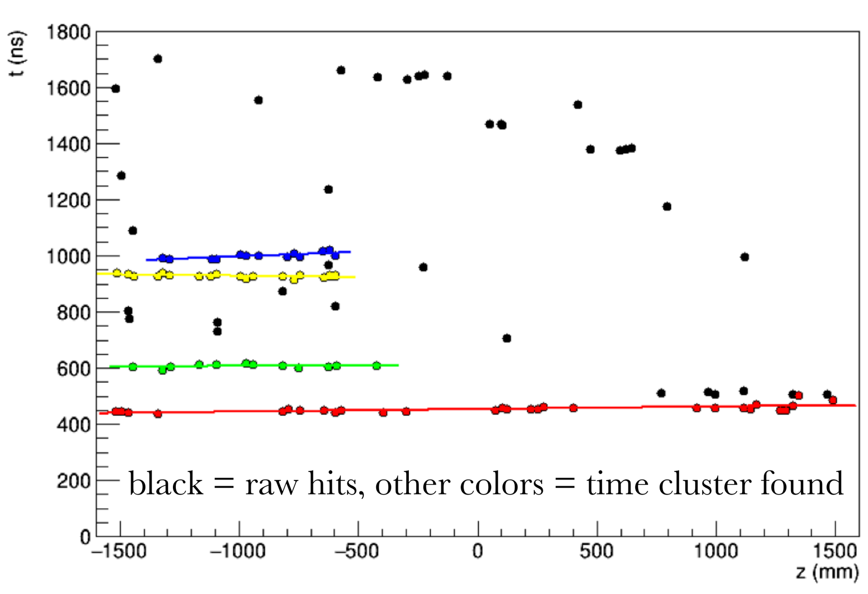
Two conversion electron trigger sequences, **TPR** and **CPR**, are run in parallel. New trigger sequence being developed has been named **APR**.

Reconstruction Shortcomings

- Current time clustering algorithm has some shortcomings:
  - It uses an artificial neural network trained specifically for different types of physics searches
  - Must be run with different configurations for different physics … slows things down, creates messy book-keeping
  - Hit times must be transformed assuming some beta and pitch angle (not physics blind)
- Current helix finding algorithm imposes a few constraints:
  - Min/max radius cut (p_t constraint)
  - Min/max $d\phi/dz$ cut (pitch constraint)
  - One helix per time cluster
- Newer method being worked on addresses these shortcomings
  - It is free of assumptions
  - One configuration for all physics
  - Much looser physics constraints
  - **Addressing these shortcomings allows Mu2e to search for a wider range of physics**

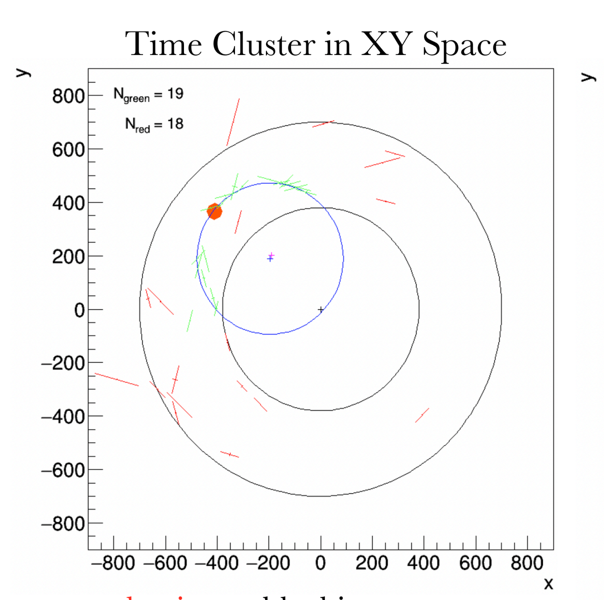
New Track Trigger

TZClusterFinder and AgnosticHelixFinder

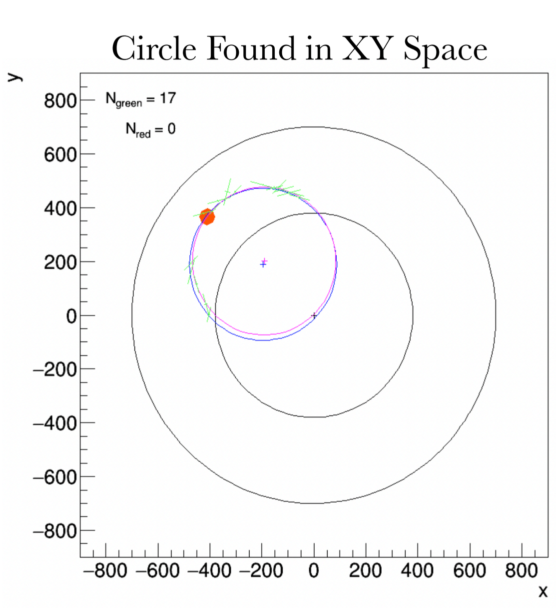


- New time clustering algorithm, **TZClusterFinder**, works by searching for lines in t vs. z space
  - First searches for chunks of hits within some defined dtdz window
  - Then combines chunks within some dt of each other
  - Fits line to combined chunks and recovers hits along said line

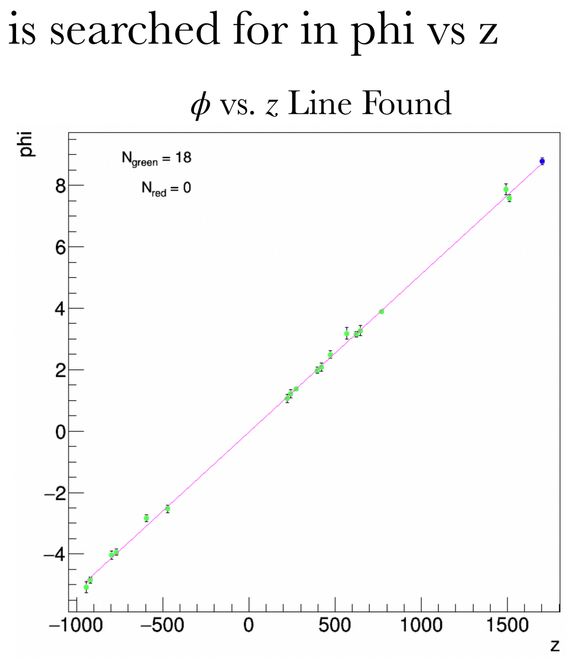
- New pattern recognition algorithm, **AgnosticHelixFinder**, creates many "seed circles" using triplets of straw hits
  - If seed circle has enough consistent hits, then a line is searched for in phi vs z



red points = bkg hits,
green points = CE hits,
red circle = calo cluster,
blue circle = MC truth radius/center



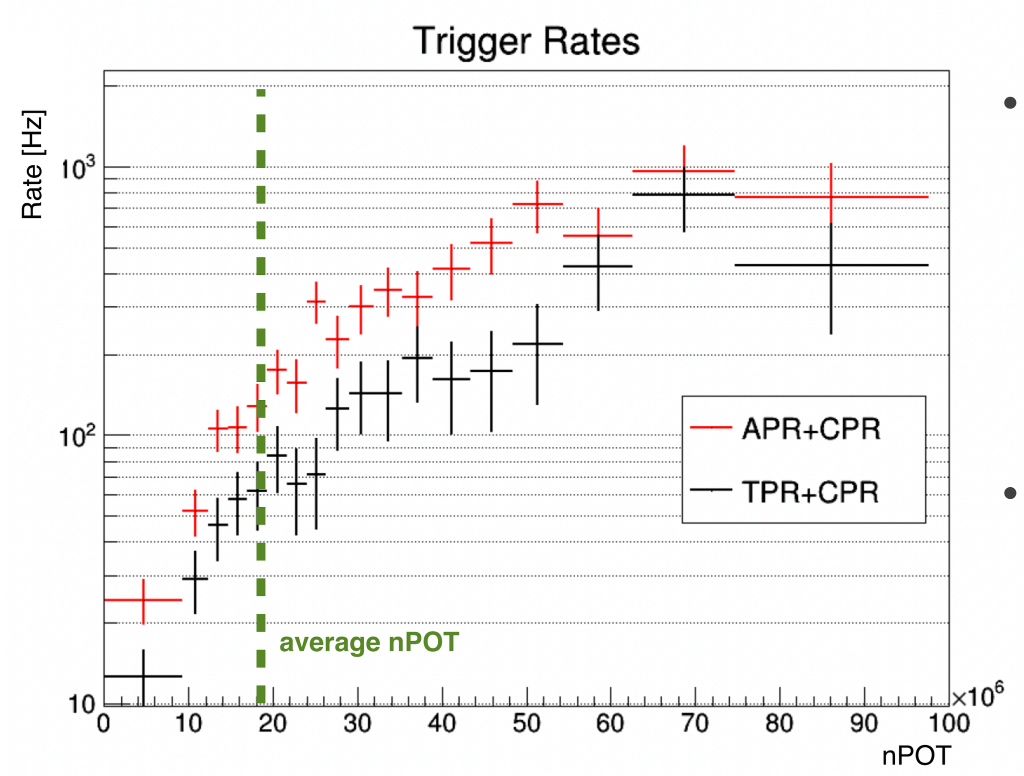
pink circle = helix circle found by algorithm

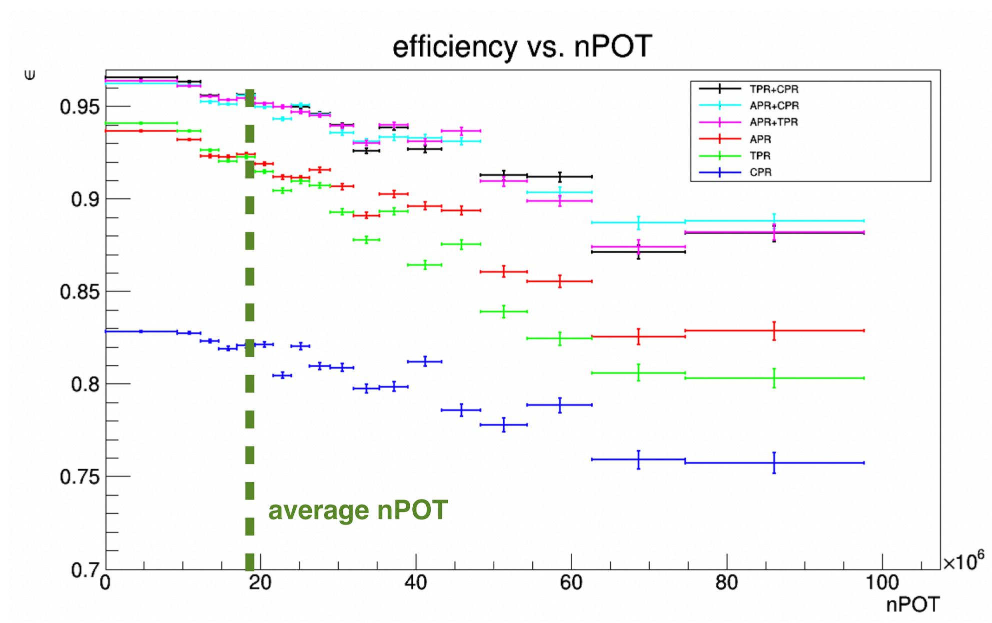


pink line = line found by algorithm, blue point = calo cluster

*events shown come from conversion electron + background dataset

Performance of New Trigger Sequence





- The new algorithm (APR+CPR) is:
  - Significantly faster than the previous version (TPR+CPR)
  - As efficient on conversion electron as previous algorithm, and the expected rate is well within the requirements (a few kHz)
- The new algorithm paves the way for new trigger selection as it can identify topologies that weren't previously reconstructed by TPR+CPR