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Mu2e Event Reconstruction: Tuning for Cosmic Events

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New Perspectives 2.0

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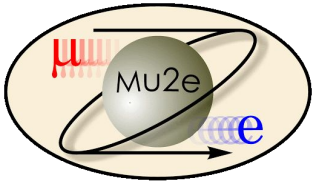
Quick Outline

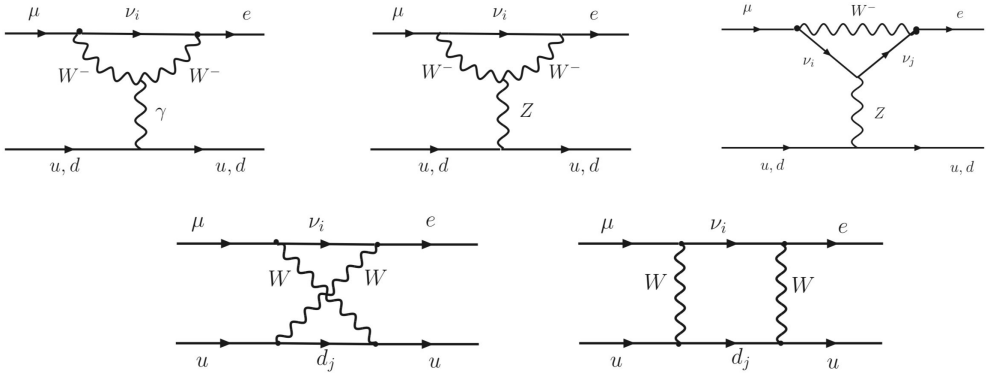


- What is the Mu2e Experiment?
- How does Mu2e detect charged particles?
- What raw measurements are made to reconstruct observables/events?
- What algorithms can be used to reconstruct events?
- How can we tailor reconstruction conditions to improve acceptance of non-signal events?

Charged Lepton Flavor Violation

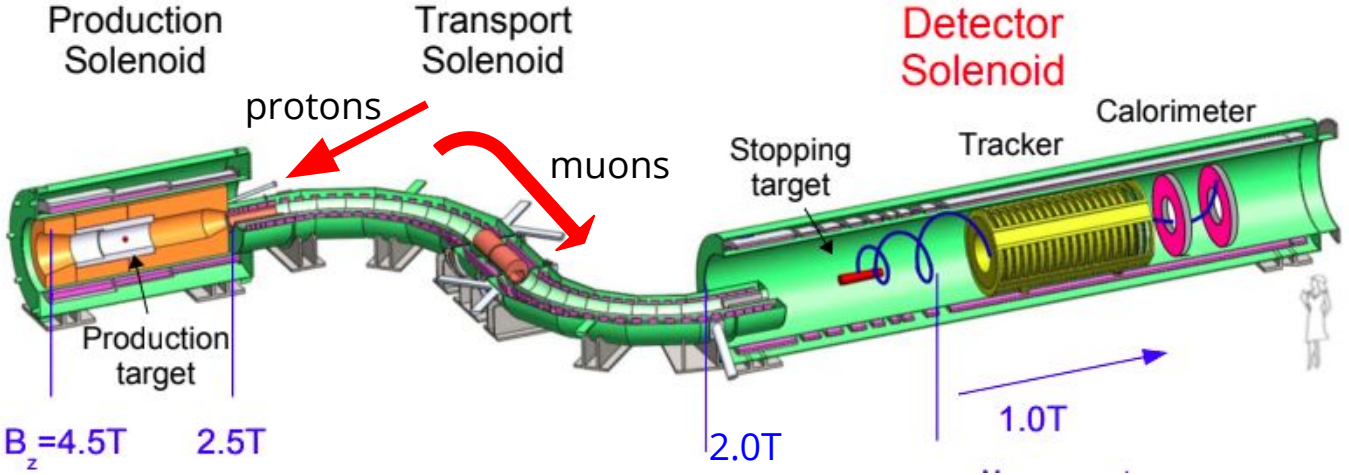
- CLFV is extremely suppressed in the Standard Model
  - SM predictions yield branching ratios of $< 10^{-50}$ for CLFV processes
  - Evidence in favor? Neutrino mixing is LFV!
- Many New Physics models predict boosted rates of CLFV processes
- Any observation of CLFV is clear evidence of new physics!
  - We would never see a rate of 10^{-50} if SM is correct

$\mu^- N \rightarrow e^- N$
(SM)



The Mu2e Experiment at Fermilab

- Looking for the charged-lepton-flavor-violating decay $\mu^- N \rightarrow e^- N$
  - Distinct signal of 105 MeV/c electron - electron energy at muon rest mass
  - Branching ratio according to Standard Model: ~10^{-52}
  - Current limit on decay: ~10^{-13} Mu2e single event sensitivity: 3 x 10^{-17}
- Main detectors: straw tracker, calorimeter

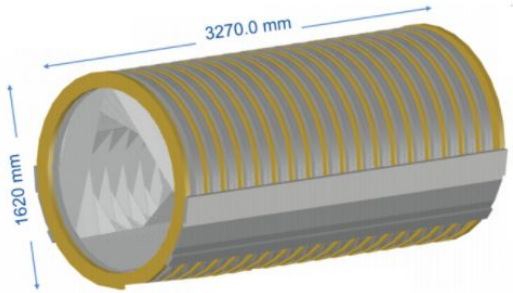


Mu2e Collaboration. Mu2e Technical Design Report (2015).

Main Detectors: Tracker and Calorimeter

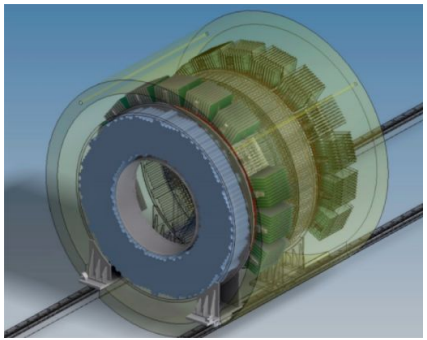
Tracker

- 20,736 Ar/CO_2 filled straws
  - (96 x 6 panels x 36 tracking planes)
- Measures position of charged particles based on ionization of Ar/CO_2 gas
- **Reconstructs charged particle trajectories, momenta -> energy**



Calorimeter

- 1348 Cesium Iodide crystals
  - (674 crystals x 2 disks)
- Measures energy deposition, timing, and position of particles at the far end
- **Measures kinetic energy independently from tracker**



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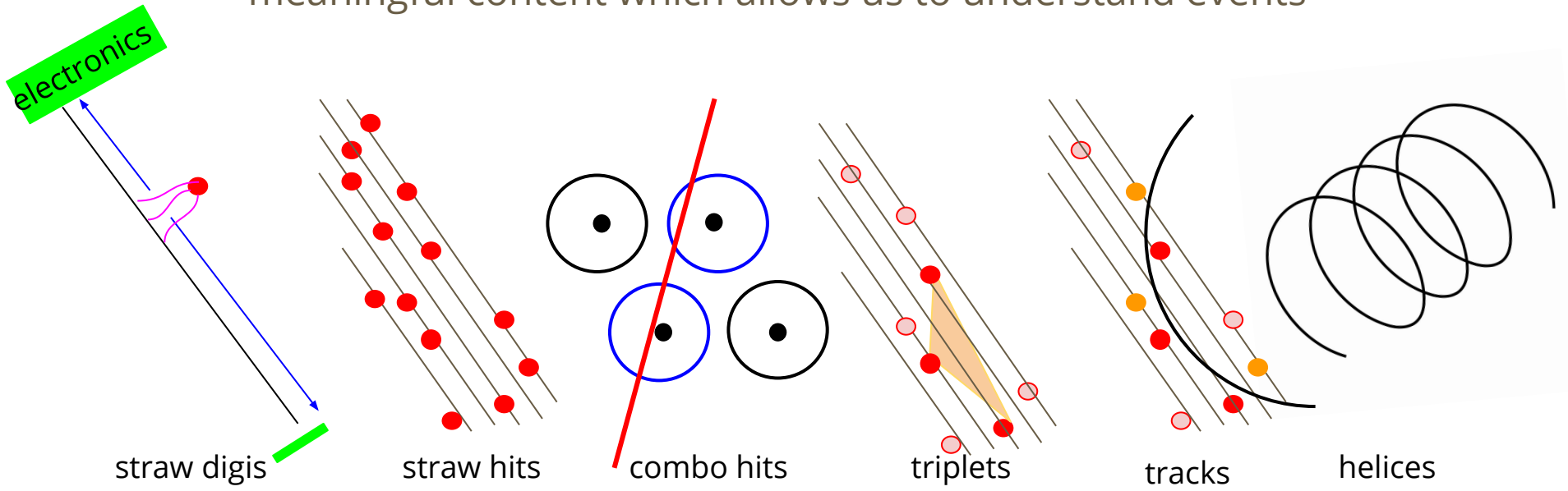
Data Products

particles traveling past wires and impacting crystals

meaningful content which allows us to understand events



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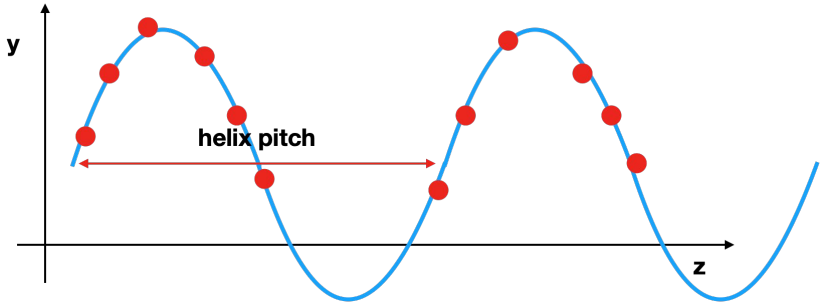
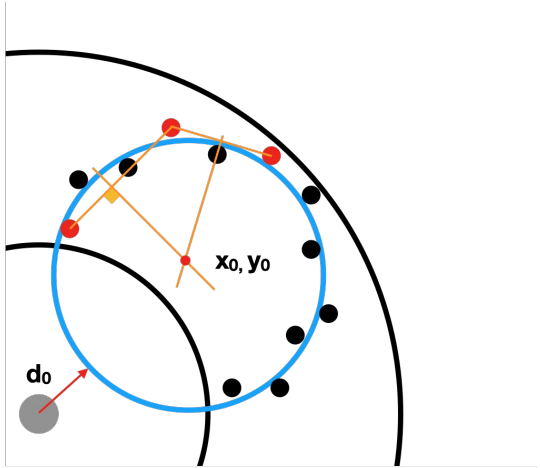
Event Reconstruction Algorithms

TPR (tracker-seeded reco)

- No calorimeter data used at all
- Only uses digis -> helices as described on previous slide



- TPR performs pattern recognition in two stages: the x,y 2D circle helix cross-section and the phi angle, z line of the helix



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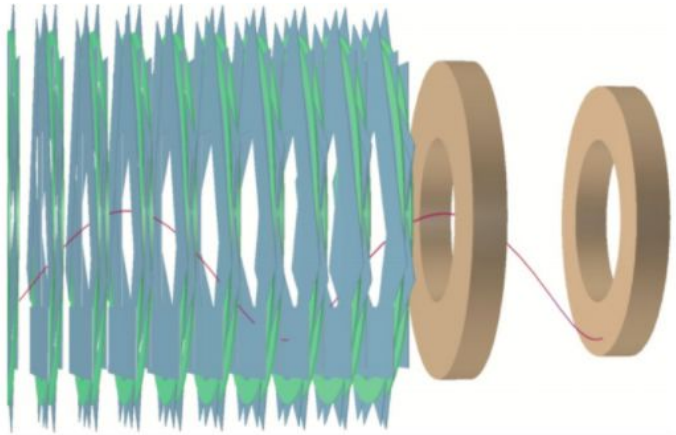
Event Reconstruction Algorithms

CPR (calorimeter-seeded reco)

- Calorimeter data seeds helix search
- Calorimeter clusters must be correlated in time and space with tracker data
- Due to requirement of calormieter cluster, this is a more restricted reconstruction algorithm



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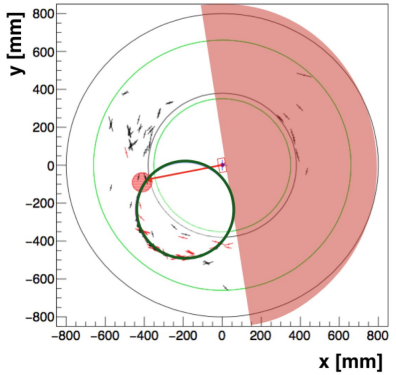
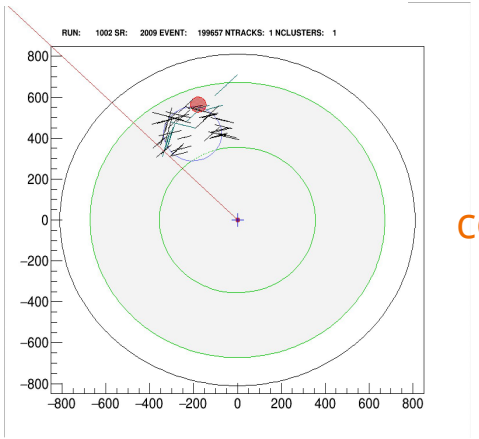
Motivation for Cosmic Ray Investigation

- **Surprising mismatch observed in reconstructed values** when analyzing the same dataset with the CPR and TPR algorithms
  - Different number of events reported by the two algorithms
  - Distributions that varied drastically in shape



CE

- Many events which were picked up by the Cosmic trigger path were **reconstructed by CPR and not by TPR**
  - Can we investigate why these events were not reconstructed by TPR?
  - How can we improve TPR acceptance conditions the accept these events?



cosmic

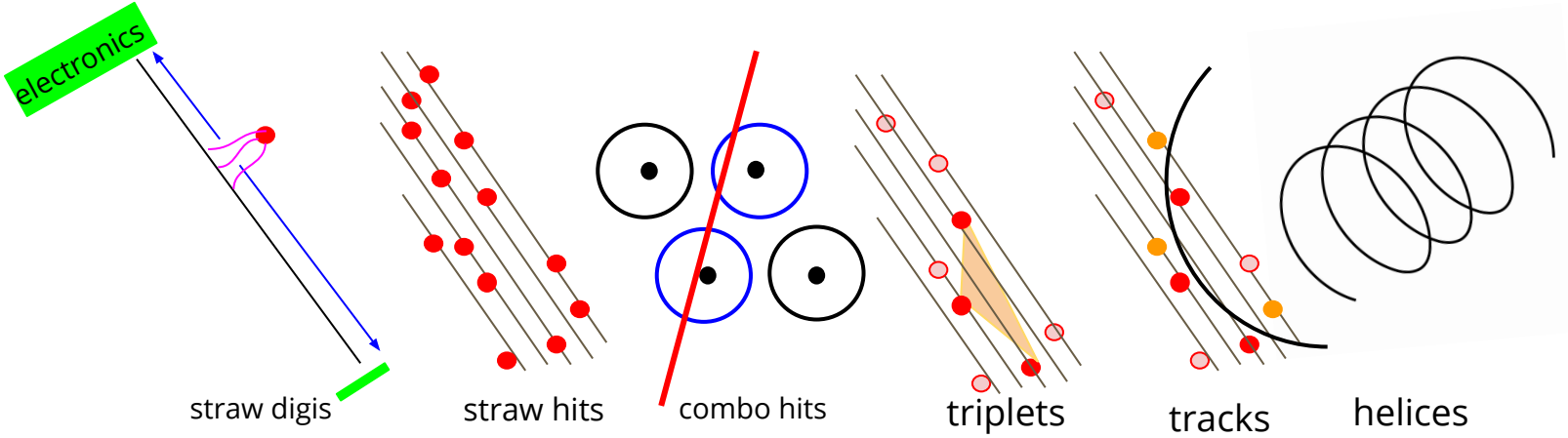
Goals for New Configuration Conditions

- Starting point: investigate the subset of events in a **cosmic ray-induced** dataset which were **reconstructed by CPR and <u>not</u> reconstructed by TPR**

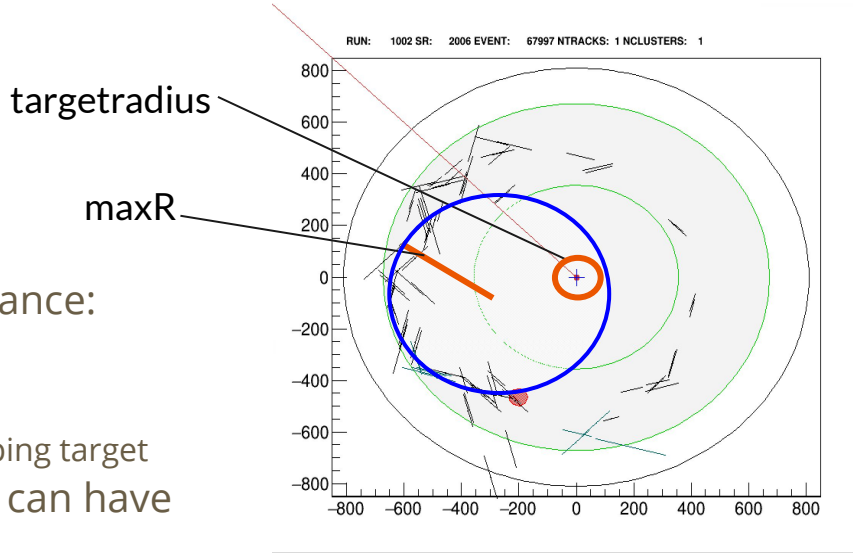
- It will be important for Mu2e to accurately reconstruct cosmic ray events because these events can be **collected any time**, not just when the experiment has beam
  - Use cosmic tracks for **spatial calibration** and measurement of **momentum resolution**
  - Allows for characterization of **cosmic ray backgrounds**
- Ultimately, we would like to accurately reconstruct **<u>all charged particles</u>** passing through the tracker with TPR

What TPR conditions were being violated?

- Upon studying the dataset of events which were reconstructed by CPR but not by TPR, it was clear that these events had **no triplets**
- This gave me a rough starting point of where to begin looking in the code to search for conditions which fail - conditions within triplet grouping
- Conditions which were failing involved restrictions on the radius of the reconstructed 2D helix shape and the side lengths of allowed triplets

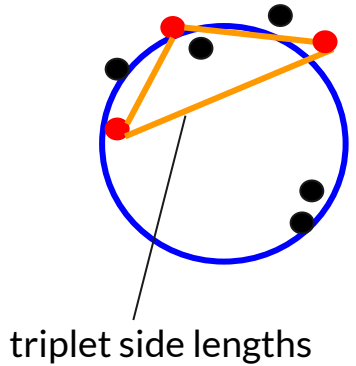


Parameters of Interest



These parameters were altered to increase TPR acceptance:

- targetradius: **radius of stopping target**
  - Remove the requirement that events begin at the stopping target
- maxR: maximum **radius** that **helix cross section** can have
  - Increased to allow any size helix
- maxdist: **upper limit of distance** between two points in a triplet
- mindist: **lower limit of distance** between two points in a triplet



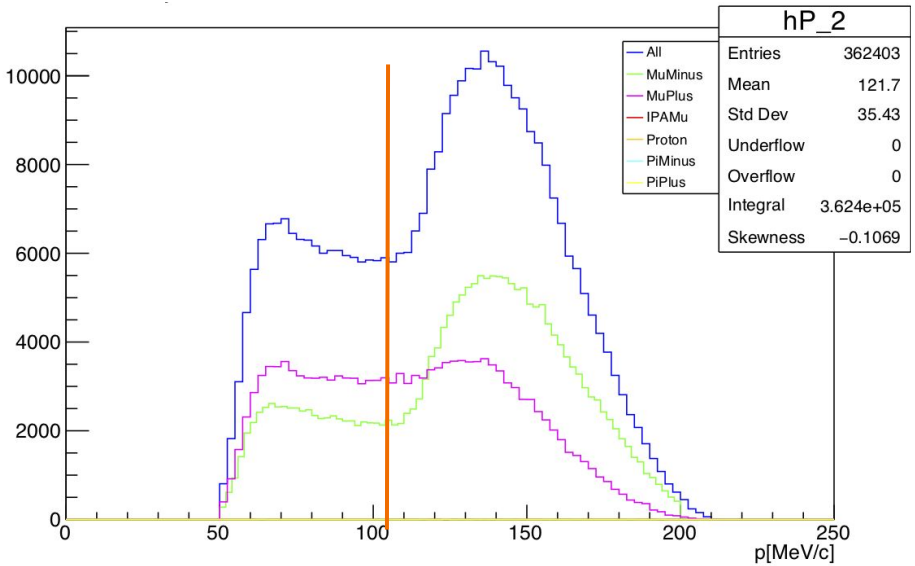
Let's try plotting some reconstructed helix variables!

Plots of CPR and TPR Reconstructed Variables

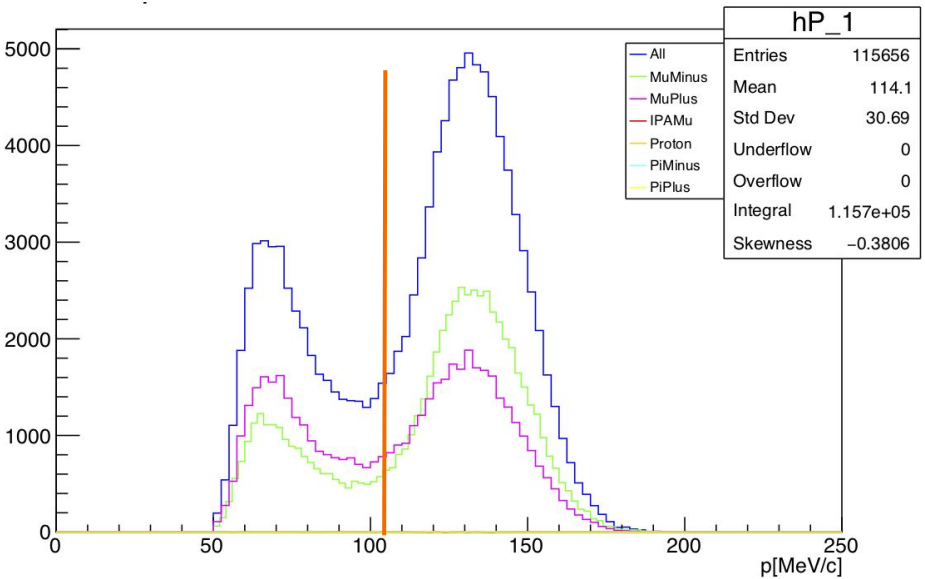
- When I initially looked at the dataset before beginning investigation on violated reconstruction conditions, there were only CPR histograms to see, the TPR histograms were empty

- In the following slides, CPR plots will be on the left and TPR plots will be on the right
  - Green line: particles which originated from parent μ-
  - Magenta line: particles which originated from parent μ+
  - Blue line: total sum of all parent species (green + magenta)

CPR Reconstructed Helix Momentum

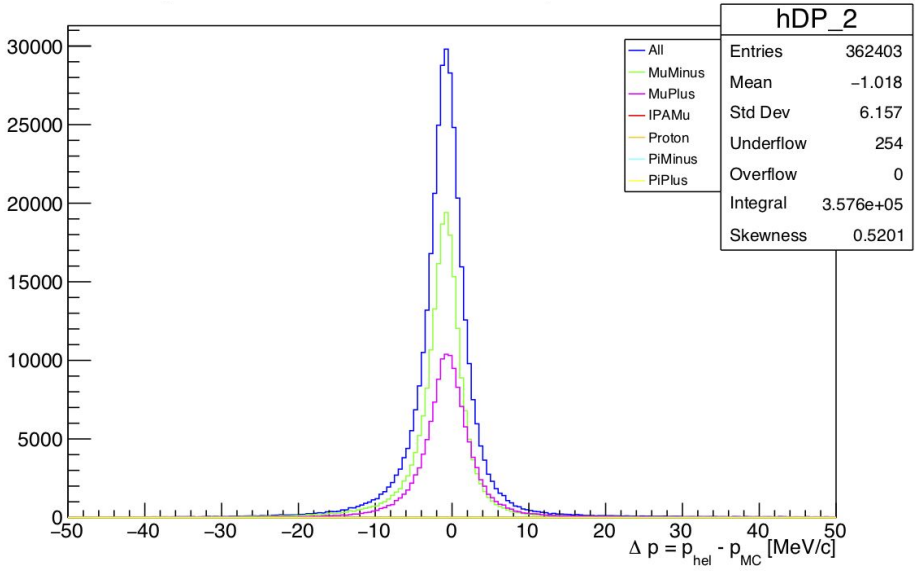


TPR Reconstructed Helix Momentum

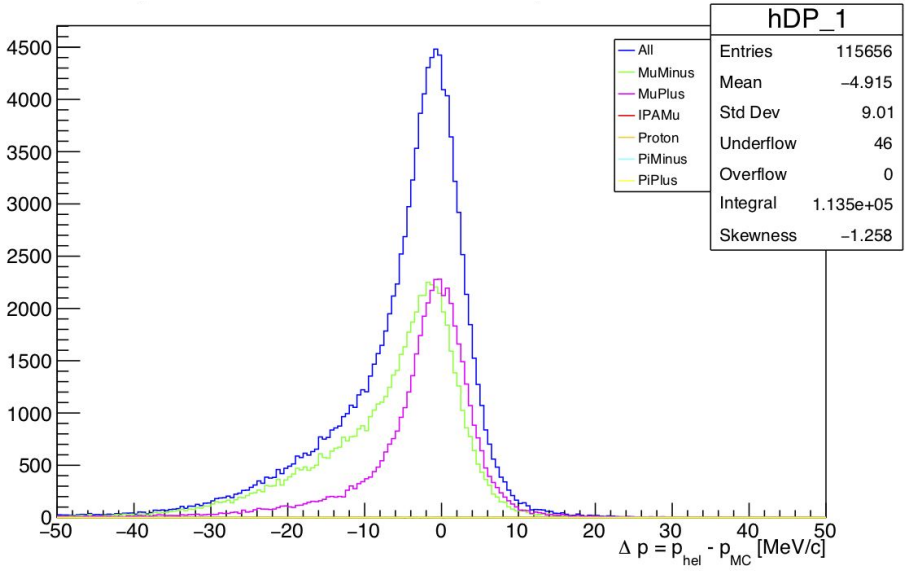


- TPR distribution is missing large chunk of events in the 80-120 MeV/c range and p > 180 MeV/c
- The intermediate gap encompasses our signal region of 105 MeV/c

CPR Momentum Resolution



TPR Momentum Resolution



- Δp = p(reconstructed) - p(MC truth)
- TPR distribution is skewed to the left, indicating consistent misreconstruction to lower momentum than MC truth
- I am still investigating why this exists

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Conclusions and Future Work

- Changing just a few parameters in triplet conditions boosts acceptance of cosmic ray-induced events in the TPR algorithm by ~1/3

CPR	362403 events	100%
TPR after modifications	115656 events	31.9%

- Analyze subset of events to investigate events which are still not reconstructed by TPR
- Plot new variables to get clues on what calculations may be causing very different behaviors in CPR vs TPR
- Take a detailed look into the phi-Z fit of the helix

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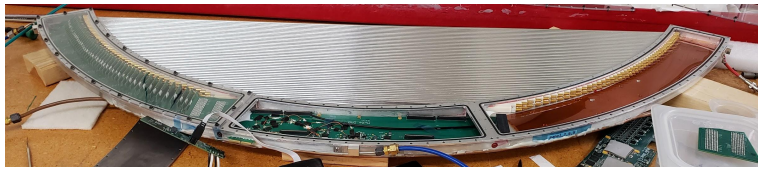
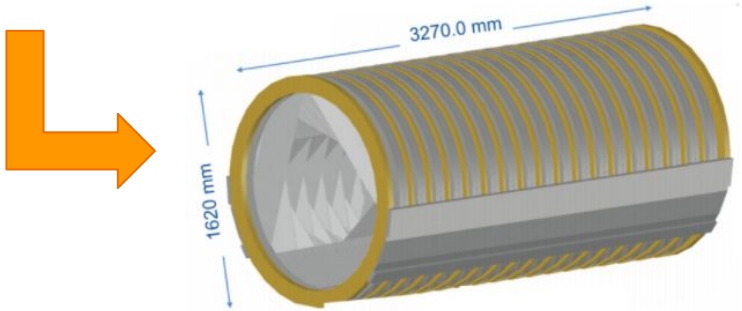
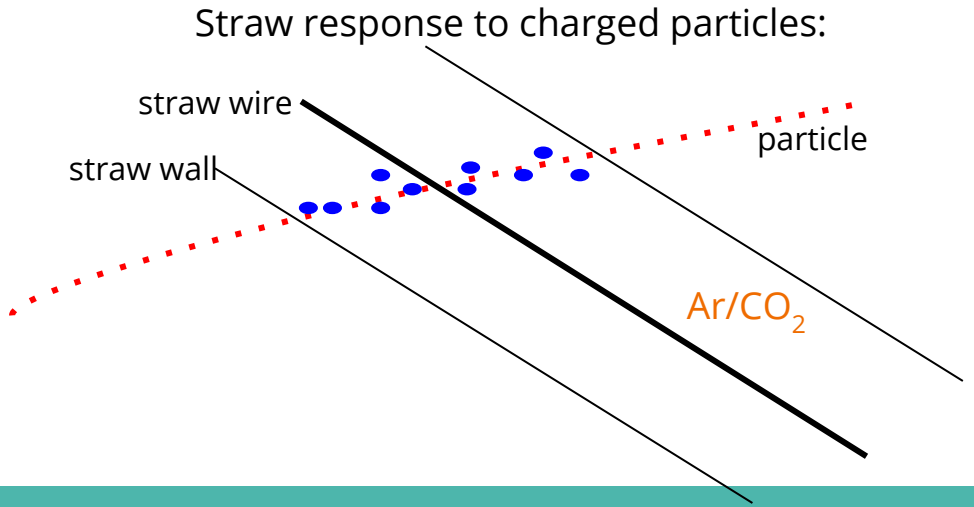
Backup

Straw Tracker

- A lightweight stack of gas-filled straws containing sensitive HV wires which detect charged particles
- 20,736 Ar/CO_2 filled straws (96 x 6 panels x 36 tracking planes)
- Reconstructs charged particle trajectories, momenta -> energy







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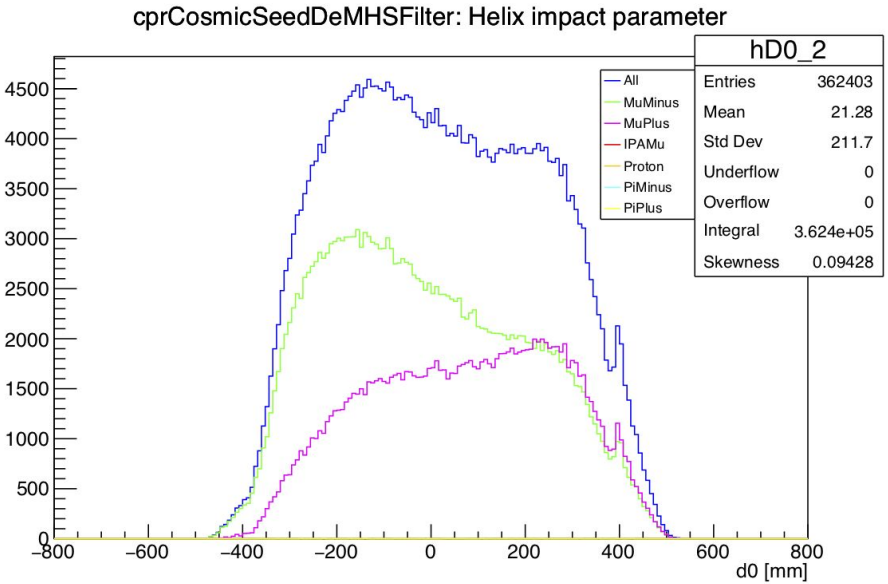
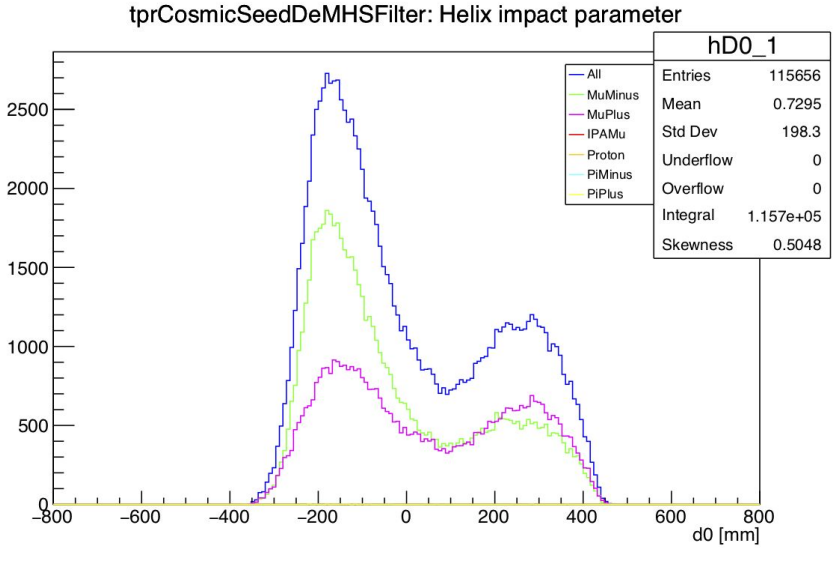
Breakdown of Acceptance

- Let's take the total number of CpR events to be 100% and express the fraction of events picked up after each parameter modification

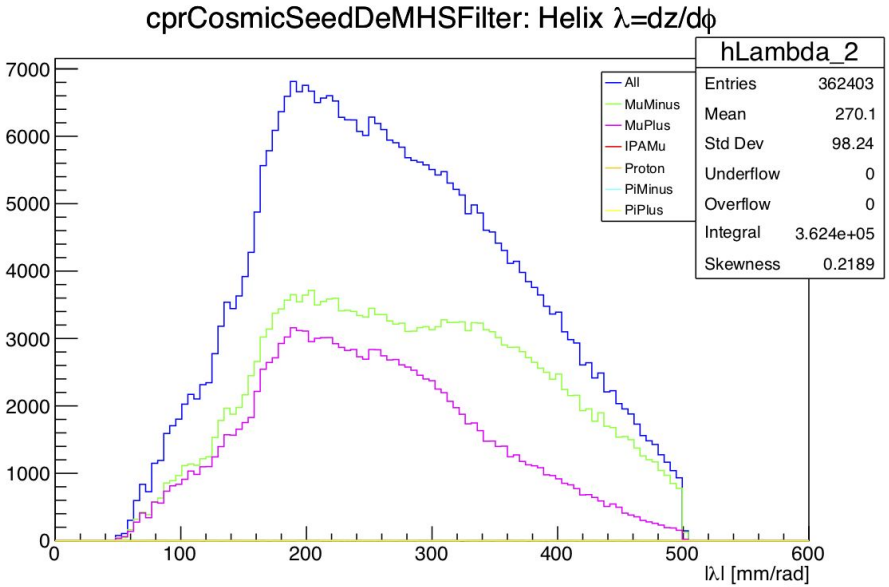
CpR	362403 events	100%
TpR targetradius	31750 events	8.8%
TpR targetradius + maxR	95834 events	26.4%
TpR targetradius + maxR + maxdist	112720 events	31.1%
TpR targetradius + maxR + maxdist + mindist	115656 events	31.9%

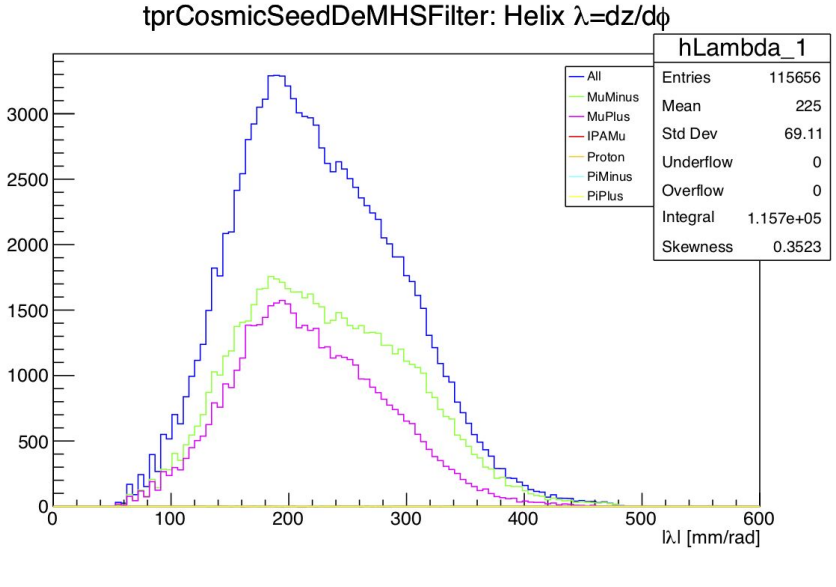




- Left: CPR reconstructed helix impact parameter
- Right: TPR reconstructed helix impact parameter

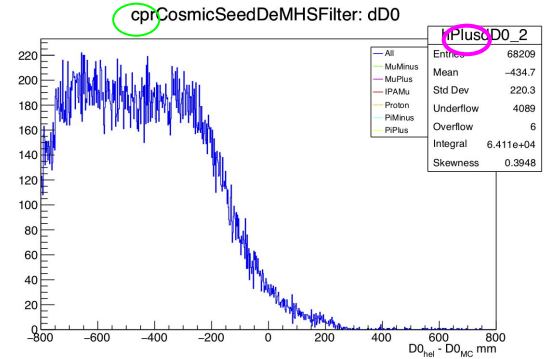
- TPR distribution is very differently shaped, missing large number of events which do not encompass detector center (positive impact parameter) and small tracks which do encompass detector center (small negative impact parameter)

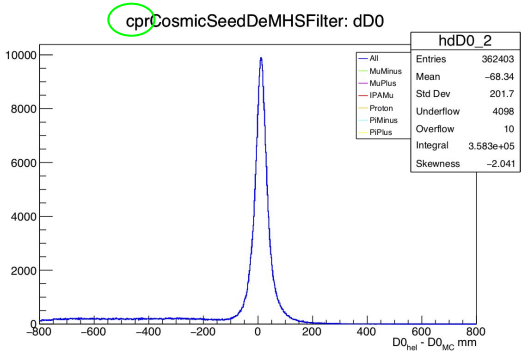


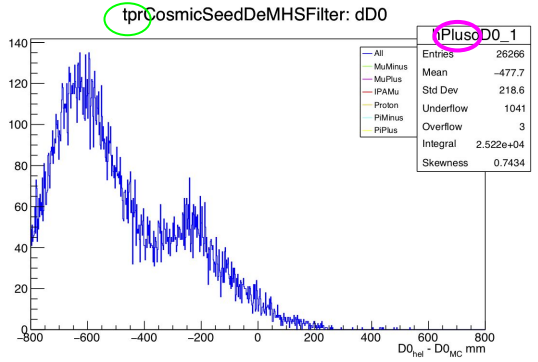


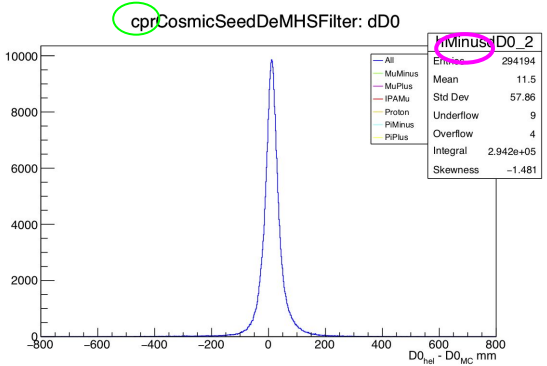
- Left: CpR reconstructed helix lambda
- Right: TpR reconstructed helix lambda

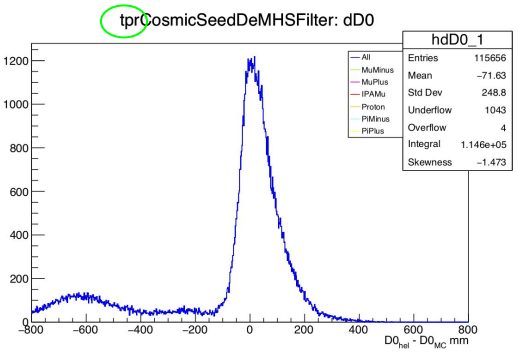
- Lambda = helix pitch / 2π
- It seems that TpR reconstruction misses events at high lambda

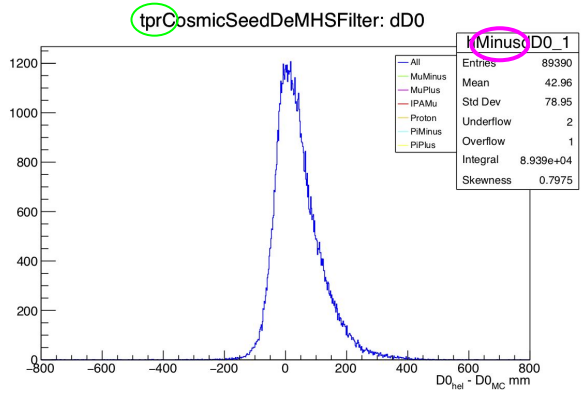












- Helix impact parameter resolution with charge distribution
- Left: CPR, Right: TPR ; Top: Positive end particles, Bottom: Negative end particles
- Positive particles contribute to the long tail on the left side of the dD0 graphs, needs to be studied