14pT4-3

COMET実験における CDCの飛跡再構成手法の研究

Study of CDC track reconstruction in the COMET experiment

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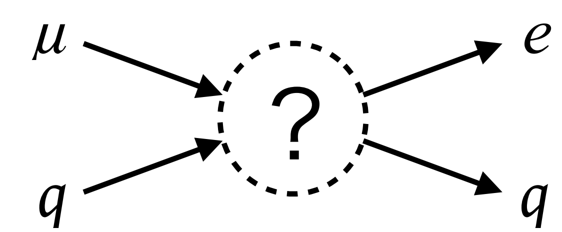
Contents

μ-e conversion & COMET

- **Muon-to-electron conversion:**
  - Neutrinoless coherent transition in nuclear field
  - Violates the Lepton Flavor conservation
  - Search for NEW physics beyond the Standard Model

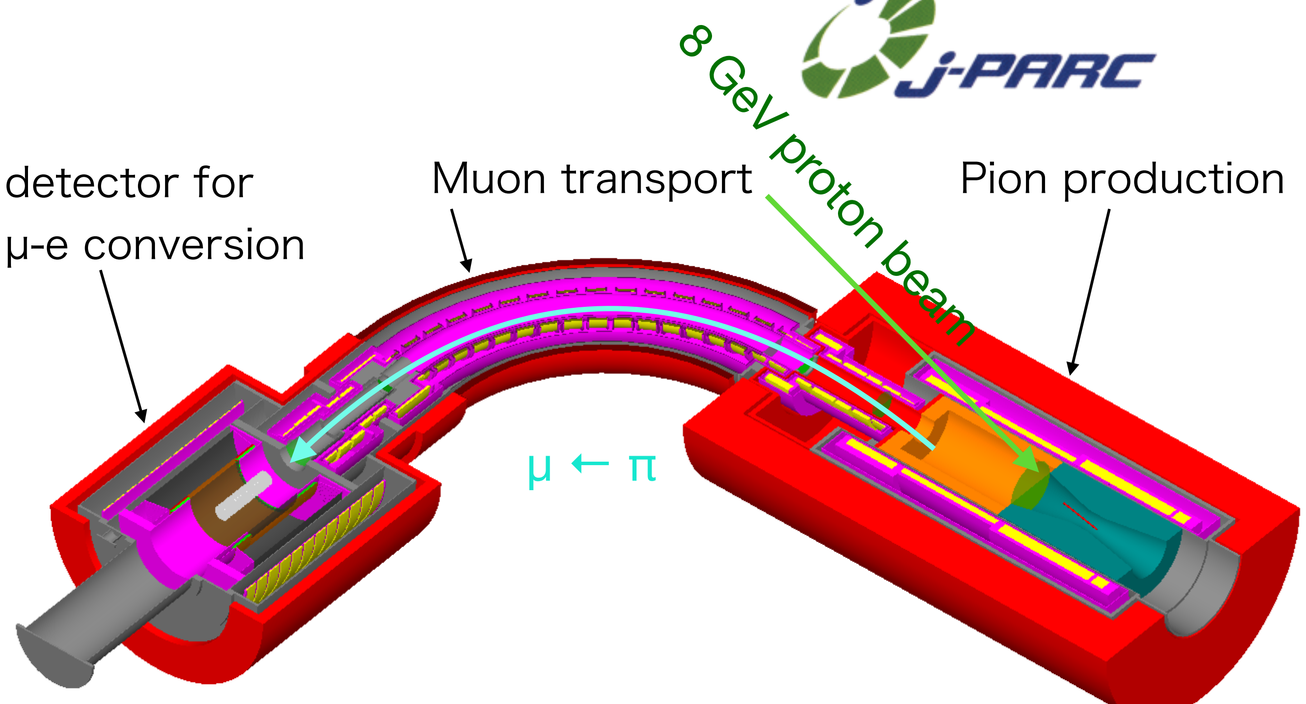
$$\mu^- + N \rightarrow e^- + N$$



- **The COMET experiment:**
  - Explores the μ-e conversion at **J-PARC** with single event sensitivity of
    - Phase-I: **3×10^{-15}** (×100 improvement)
    - Phase-II: **3×10^{-17}** (×10,000 improvement)

COMET Phase-I

Start 2023

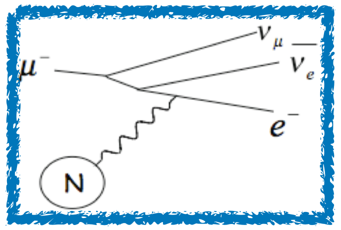


Technical Design Report

PTEP 2020, 033C01

COMET CDC

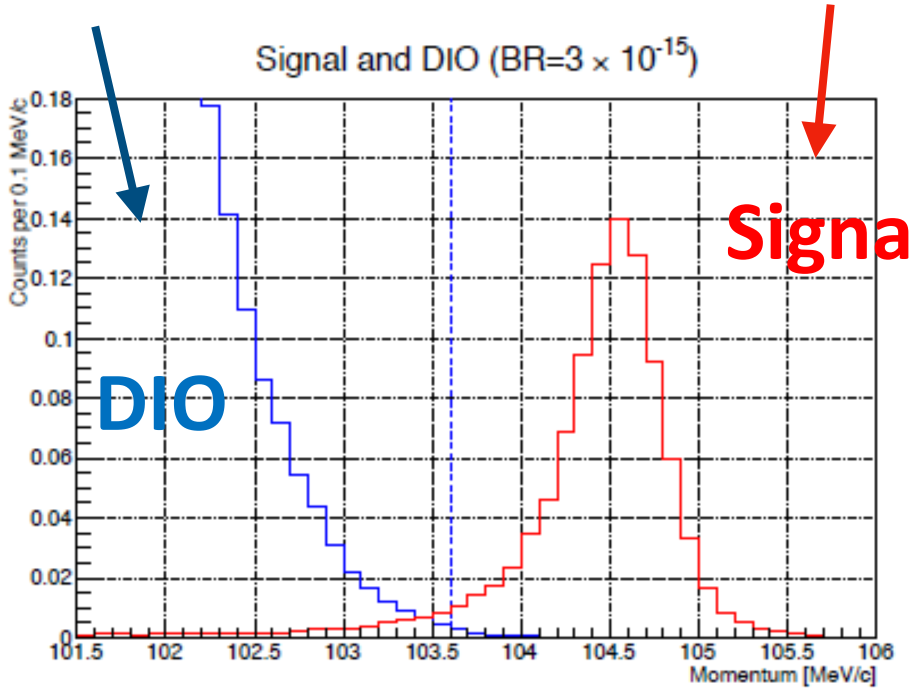
Decay-In-Orbit



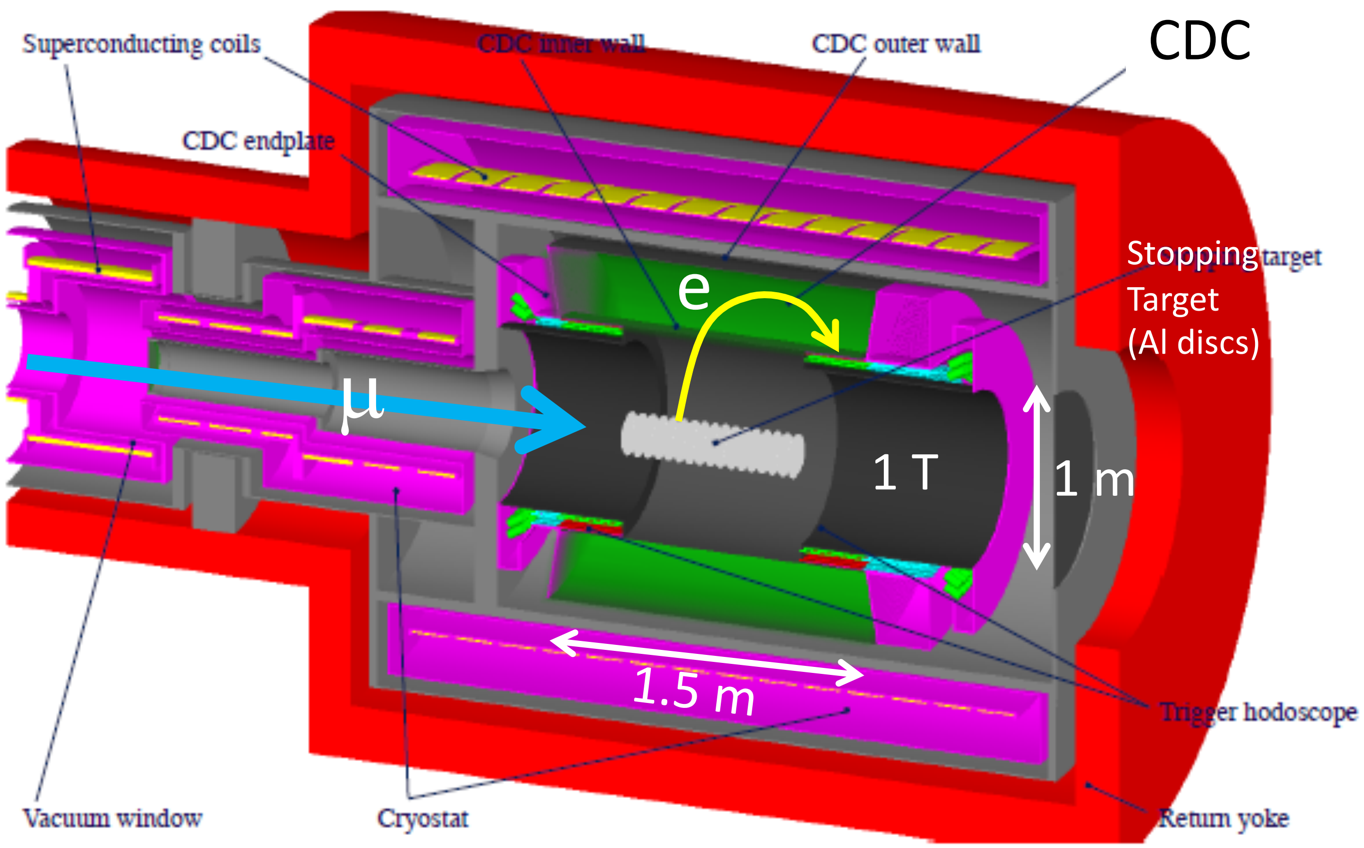
μ-e conversion

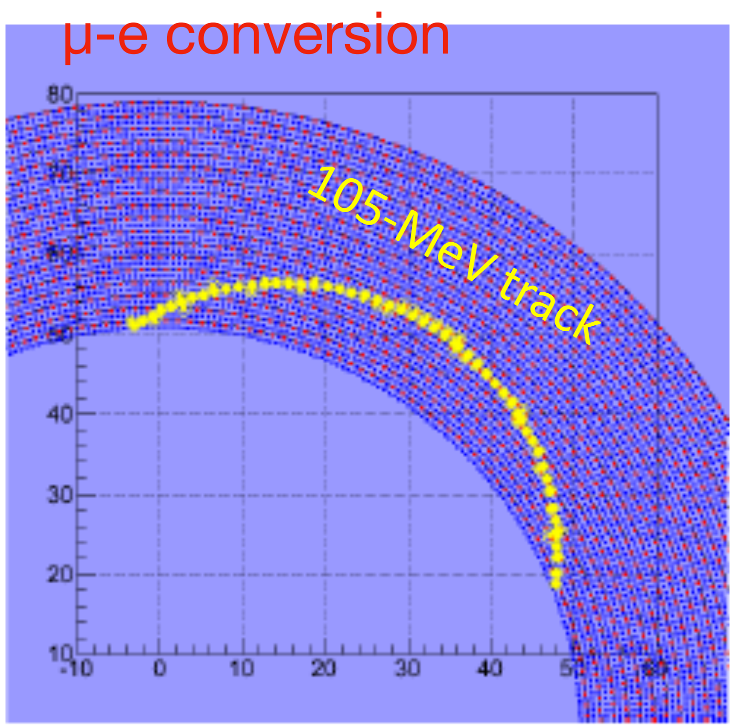
$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

105 MeV/c



Electron momentum [MeV/c]





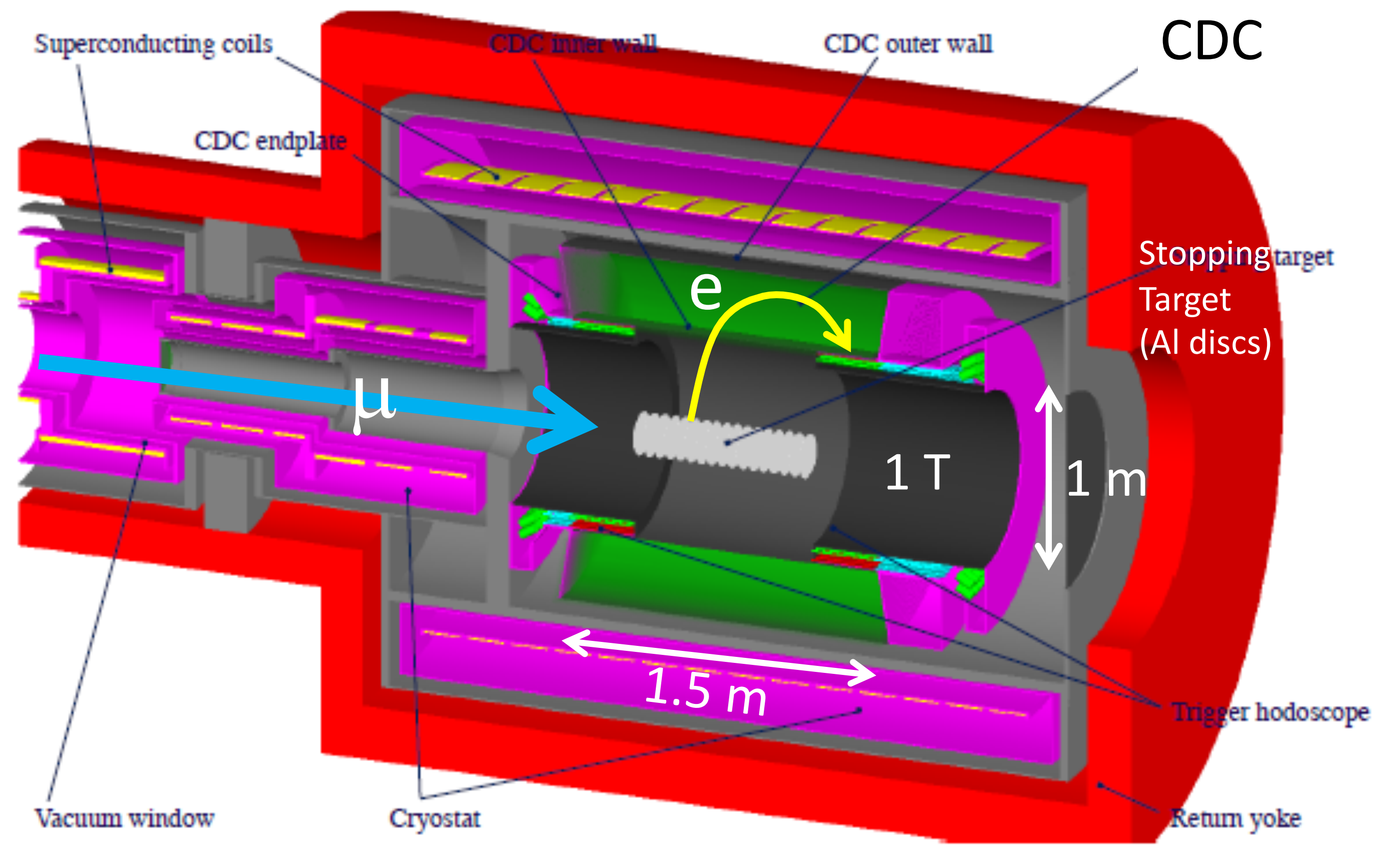
0.2% momentum resolution for 105 MeV/c is required !

200 keV/c

COMET CDC

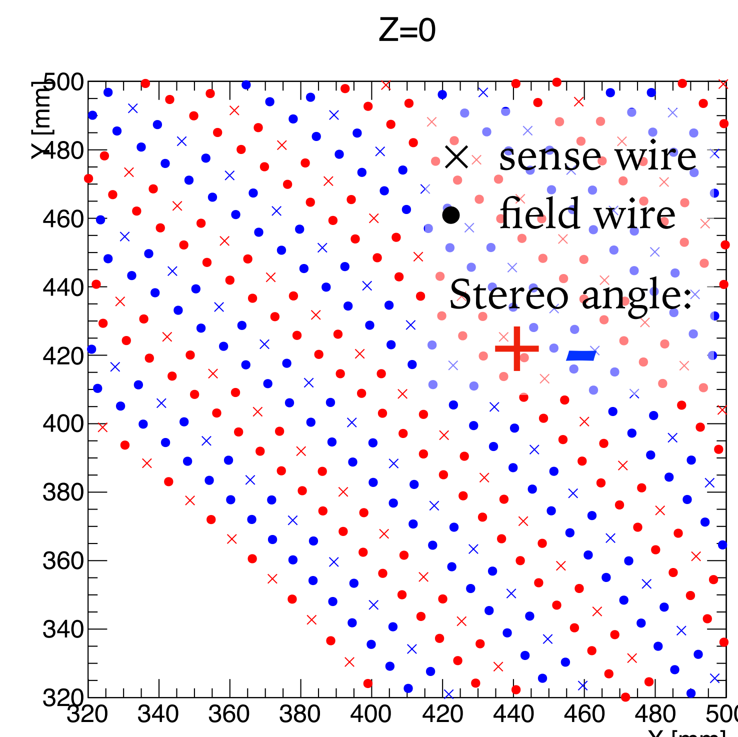
Table 13.1: Main parameters of the CDC.

Inner wall	Length	1495.5 mm
	Radius	496.0~496.5 mm
	Thickness	0.5 mm
Outer wall	Length	1577.3 mm
	Radius	835.0~840.0 mm
	Thickness	5.0 mm
Number of sense layers		20 (including 2 guard layers)
Sense wire	Material	Au plated W
	Diameter	25 μm
	Number of wires	4986
	Tension	50 g
Field wire	Material	Al
	Diameter	126 μm
	Number of wires	14562
	Tension	80 g
Gas	Mixture	He:i-C_4H_{10} (90:10)
	Volume	2084 L



Features

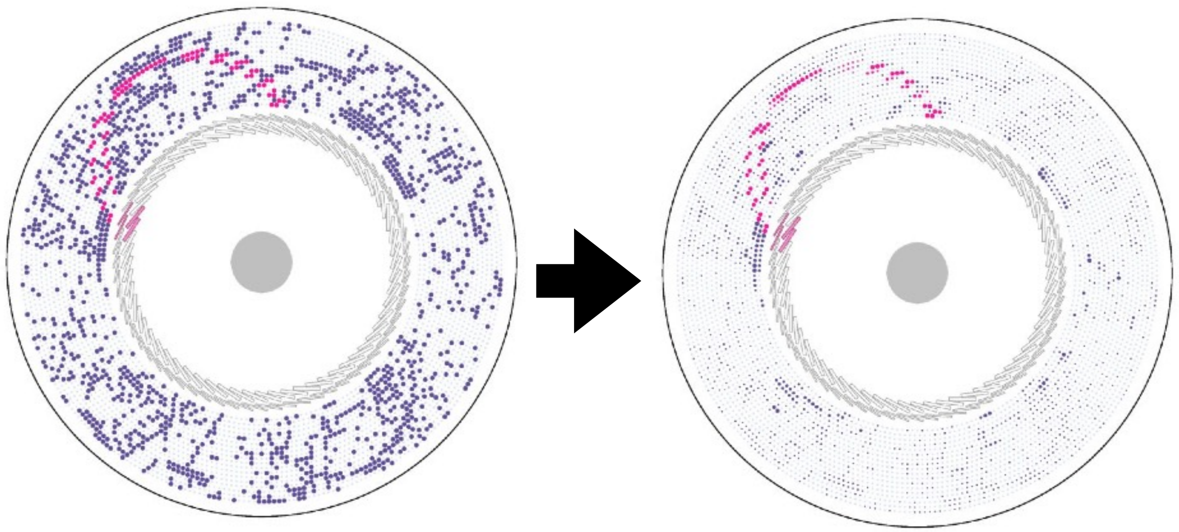
- Low mass gas = He:iC_4H_{10} (90:10) 👈 p resolution
- Alternative all stereo wire, ±4 deg 👈 z resolution
- Large inner bore, ϕ 1 m @ 1 T 👈 suppress DIO hits



20 layers in total

Track Reconstruction

Example of high occupancy case (15%)



① Hit Classification

By using GBDT, 98% of noises are rejected
while keeping 99% of signals.

② Track Finding

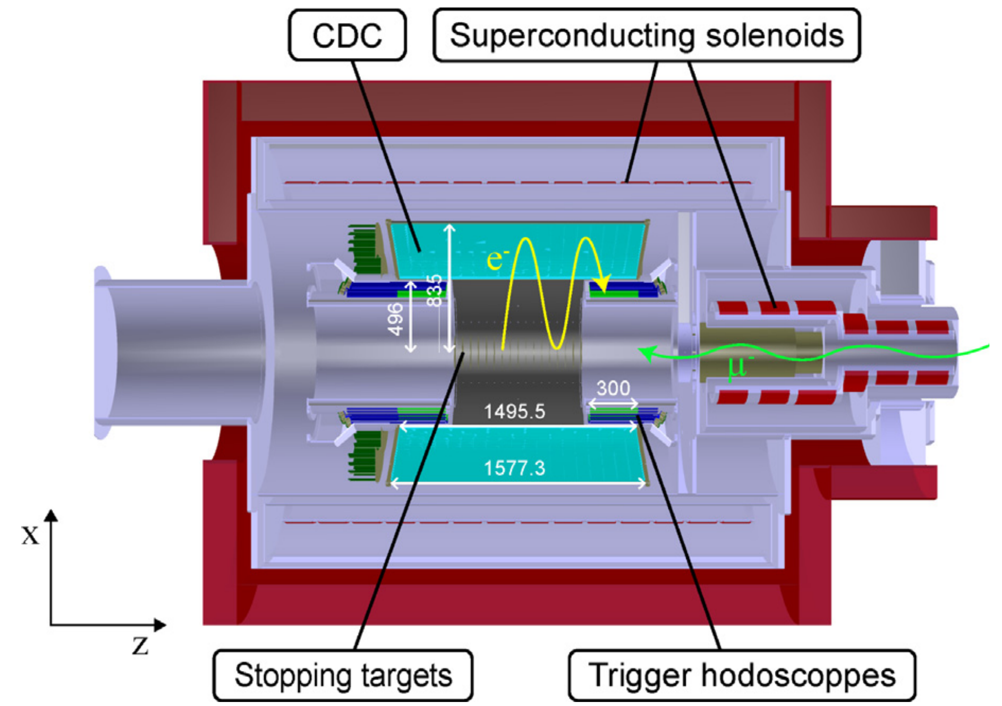
Hough Transformation + α

(Under development)

③ Track Turn Identification

32% of signal events are multiple turn.
Fast classification of turns will be done by GPU or ML.

Yeo et al., CPC 258, 107606 (2021)



④ Track Fitting

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Track Fitting using GENFIT

We implemented GENFIT into the COMET software framework (ICEDUST).

GENFIT

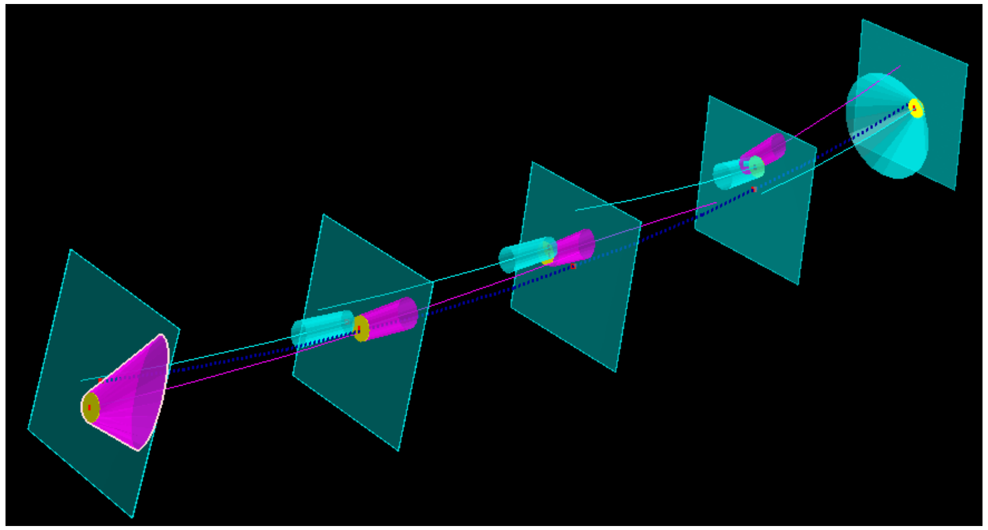
- Generic Track Fitting Framework
- Experiment-independent, modular packages
- Open source C++ code
- Originally developed in PandaROOT at TUM
- Widely used in many experiments, e.g. Belle-II, SHiP, FOPI etc.
- Suitable for low-energy experiments
- Fitter Options:
  - Kalman Filter, Deterministic Annealing Filter etc.

GenFit in GitHub

Hoppner et al. NIM A 620, 518 (2010)

Bilka et al., arXiv:1902.04405

Works well !!



An application of Track Fitting

Track-direction ID method

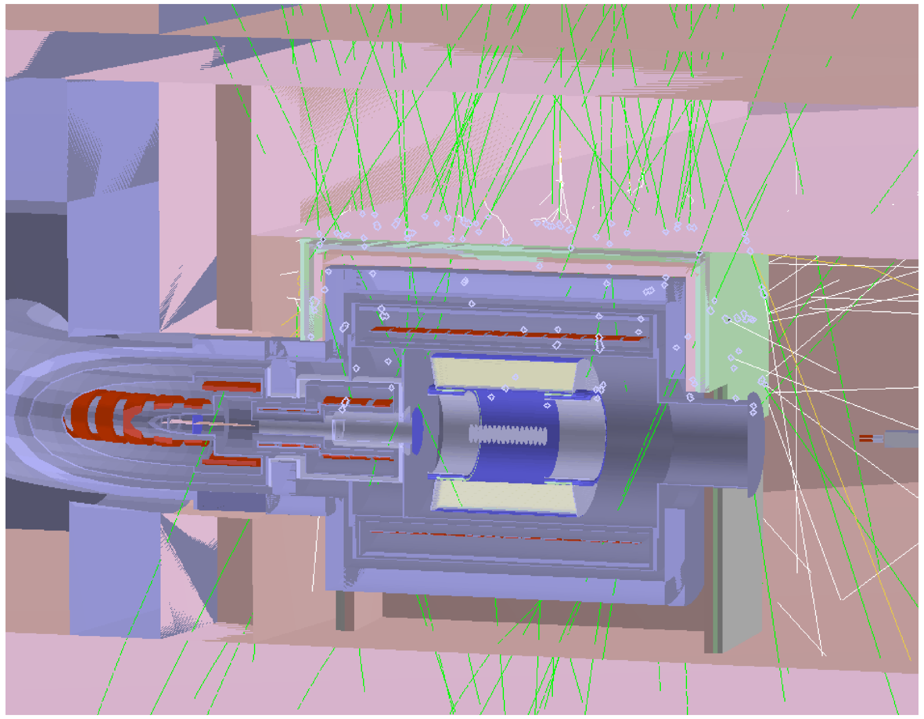
1. Motivation & Idea

Motivation — Cosmic-ray BG

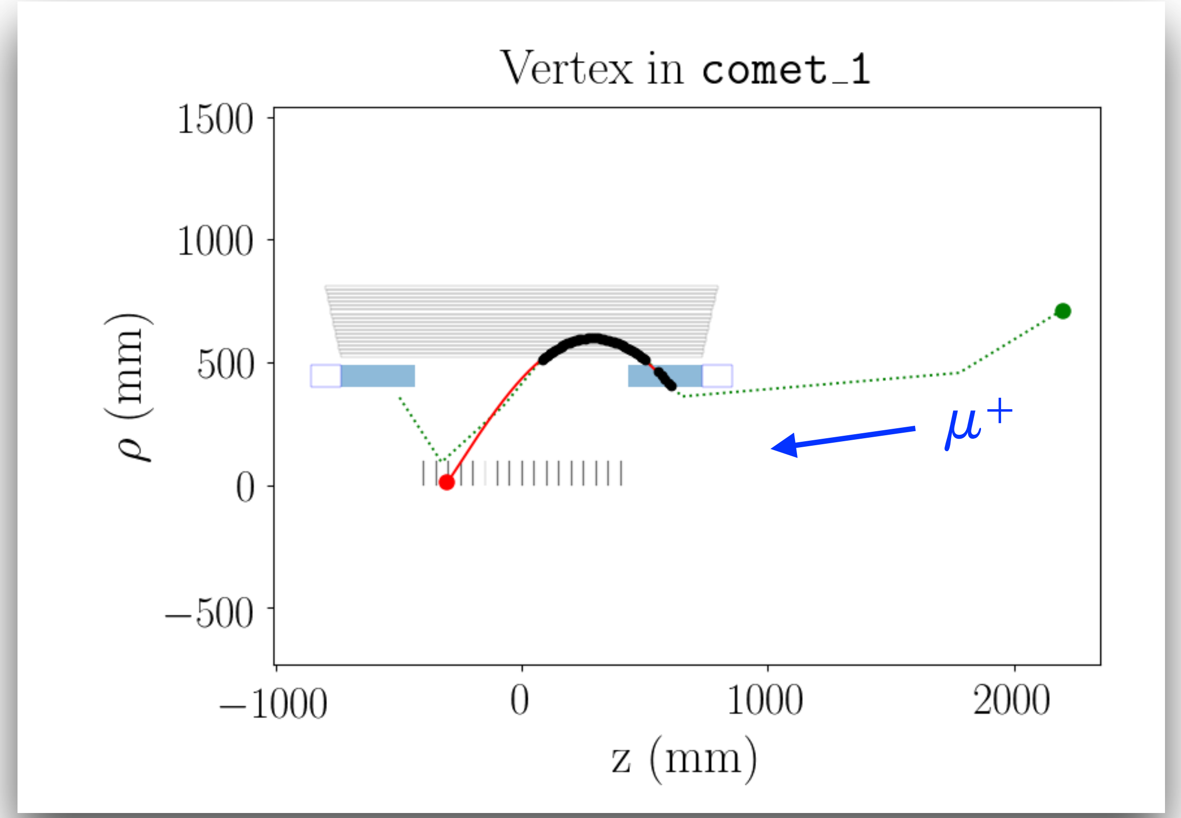
- **Cosmic rays** may create 105-MeV electrons that come into a detector and make trigger.

- Cosmic-ray induced BG is basically eliminated by **veto counter** arrays which cover Detector Solenoid (DS) Magnet.
  - ✓ with 99.99% veto efficiency.

- However, there are uncovered holes through which cosmic rays **may sneak into** DS.



Motivation — Sneaking cosmic-ray BG



Sneaking cosmic μ^+ can be a significant BG.

- does not hit CRV (sneaking from downstream hole of DS),
- scattered by CTH support frame,
- hits CTH and enters CDC from the reverse direction compared to the signal electron track, and
- finally hits stopping target.

In the latest simulation, without any measure, 2.4 ± 0.9 BG events remains.

Notice Why μ^+ (not μ^-)

The trajectory of positive charged particles with reverse track direction looks the same as the signal electron track.

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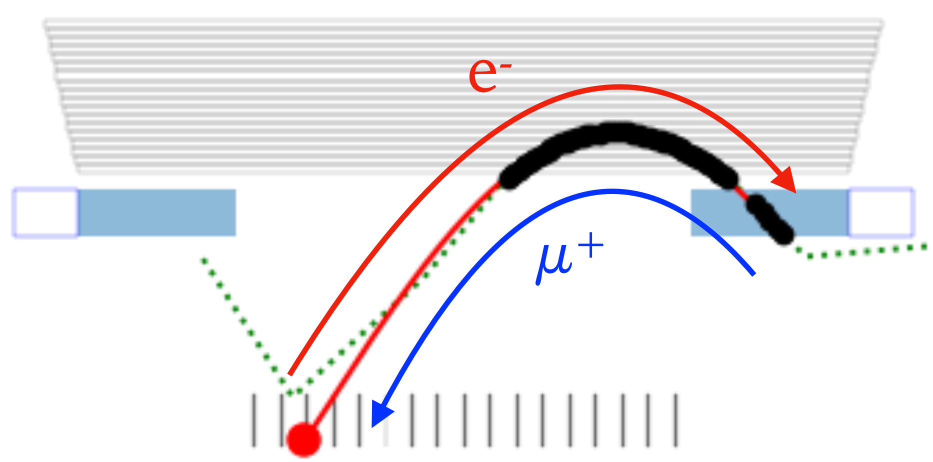
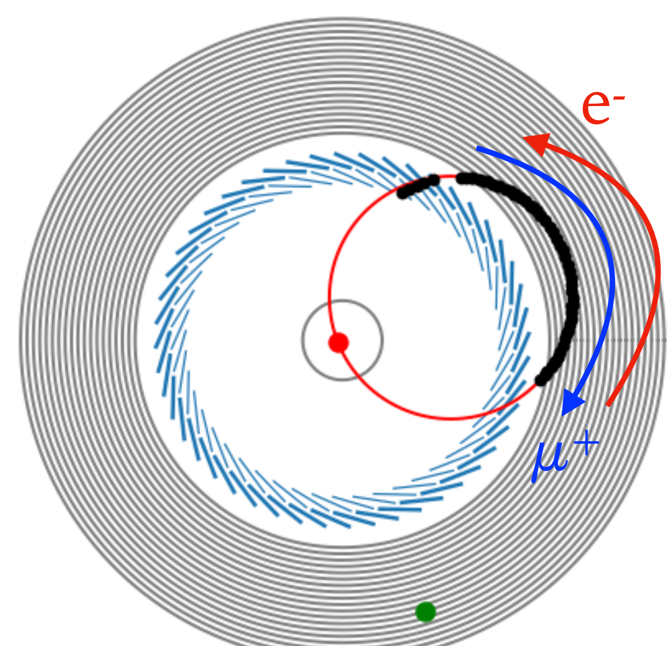
Feature of sneaking μ+ BG

	μ-e Conv. Signal	Sneaking cosmic BG
Particle	e^-	μ^+
Speed β	1	0.7
Track direction	Target → CDC → CTH (Normal)	CTH → CDC → Traget (Reverse)

for 105 MeV/c

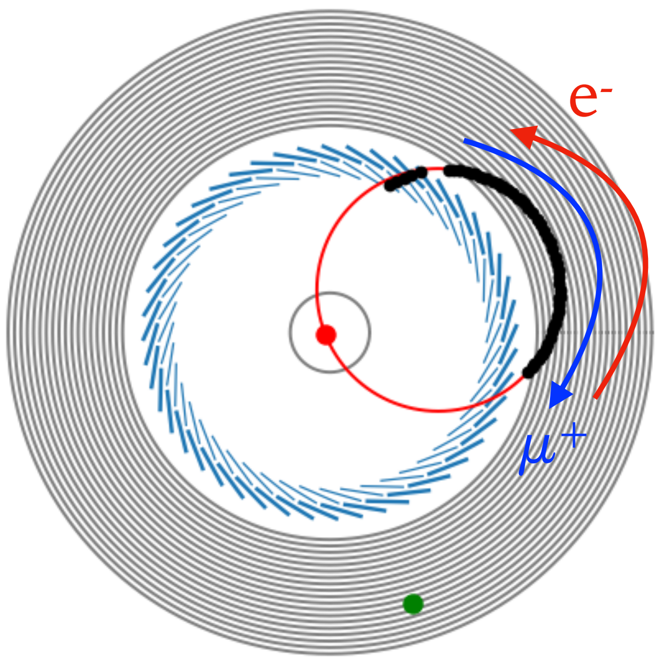




Can we know track direction ?

We normally assume the track direction is from Target to CTH.

A. TOF miscorrection



In order to know correct drift time, time-0 is corrected according to TOF between CTH and each CDC hit.

For signal e^- (β=1), $-4 < \mathrm{TOF} < 0$ ns

For reverse μ^+ (β=0.7), $0 < \mathrm{TOF} < 5.7$ ns

This causes miscorrection of at longest **9.7 ns** for reverse μ^+.

9.7 ns × 25 μm/ns* = **240 μm**

(comparable to spatial resolution of 150 μm)

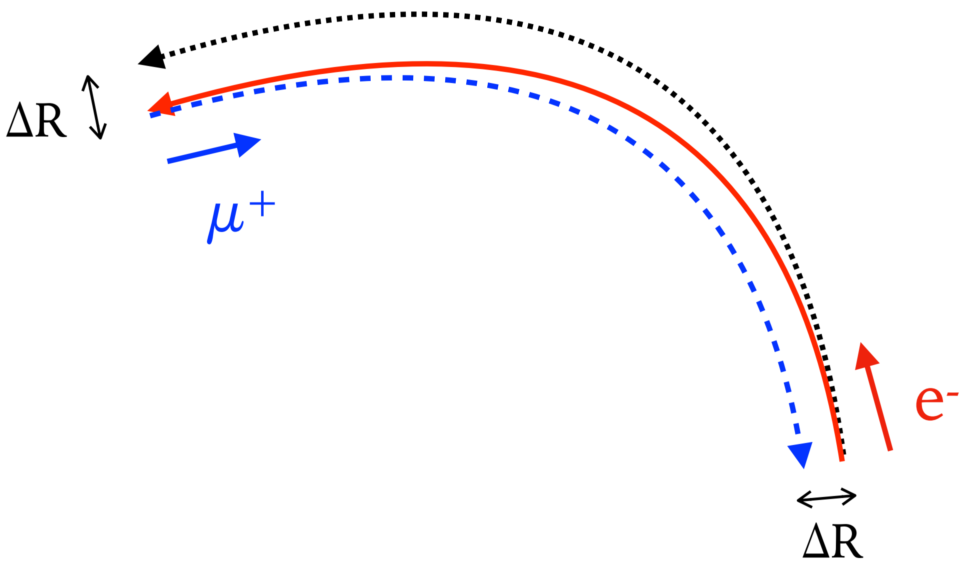
* Drift velocity for He:iC_4H_{10} (90:10) ~ typically 25 μm/ns

Naive idea

This miscorrection will make the difference in χ^2 between normal & reverse direction hypotheses.

Can we know track direction ?

B. Material effect



Energy loss is corrected in Kalman Filter

dE ~ 1.5 keV per cell

ΔE ~ 1.5 keV × 50 cells = 75 keV for track turn

$$\Delta R = \frac{\Delta p}{0.3B} = \frac{75\,\mathrm{keV}}{0.3 \times 1\,\mathrm{T}} = 250\,\mu\mathrm{m}$$ (Rough estimation)

(comparable to spatial resolution of 150 μm)

Energy loss correction also makes miscorrection if the track direction is wrong.
→ worsen χ^2 !

An application of Track Fitting

Track-direction ID method

2. Simulation & Analysis

MC event generation

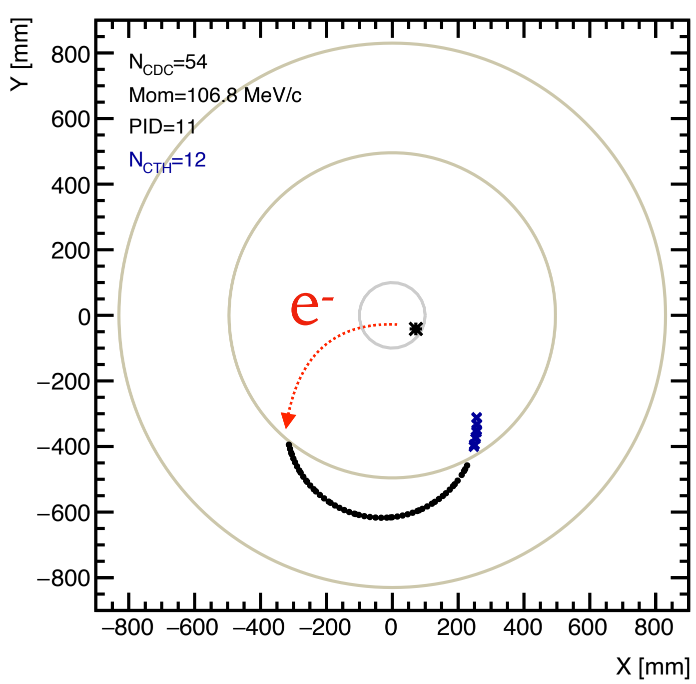
Signal e⁻ MC sample

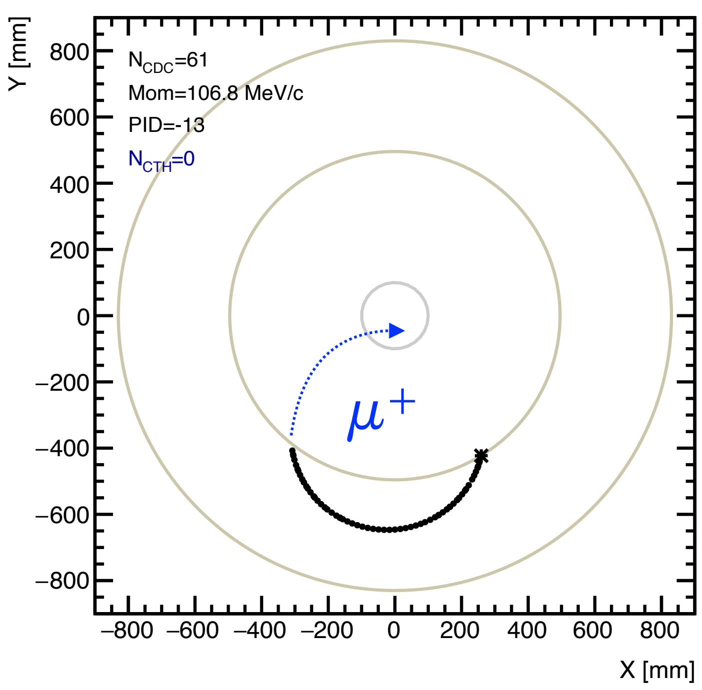
- electron e⁻
- 100—110 MeV/c
- From stopping target disks
- CDC max layer >= 5
- Require CTH hits
- Single turn only
- Spatial resolution: 150 μm

Reversed

Reversed μ⁺ MC sample:

- muon μ⁺
- 100—110 MeV/c
- From CTH to target disks
- CDC max layer >= 5
- Single turn only
- Spatial resolution: 150 μm





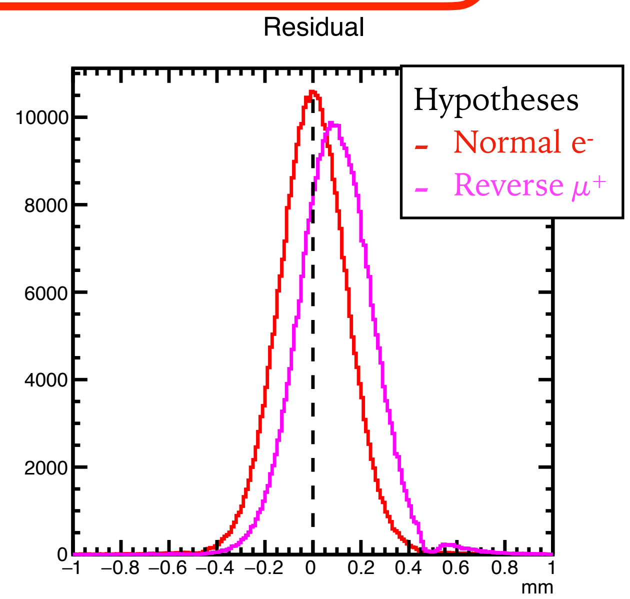
Track Fitting with 2 Hypotheses

Compare 2 hypotheses

Normal-direction e^- vs Reverse-direction μ^+

This induces **miscorrection of TOF**

Signal e^- MC sample



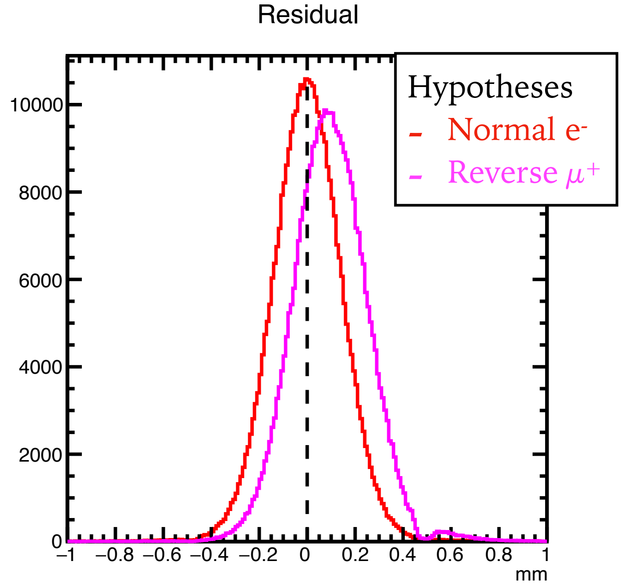
Track Fitting with 2 Hypotheses

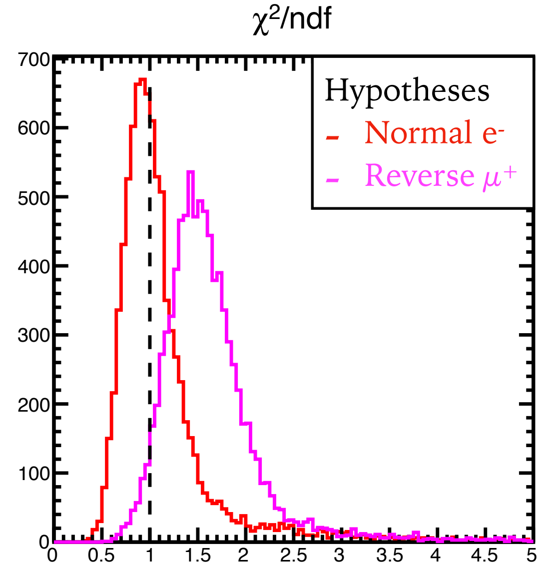
Compare 2 hypotheses

Normal-direction e^- vs Reverse-direction μ^+

This induces **miscorrection of TOF**

Signal e^- MC sample





Difference does exist !

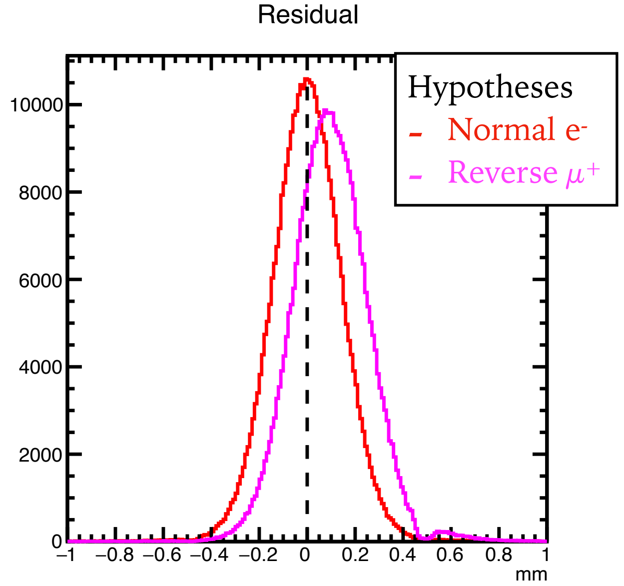
Track Fitting with 2 Hypotheses

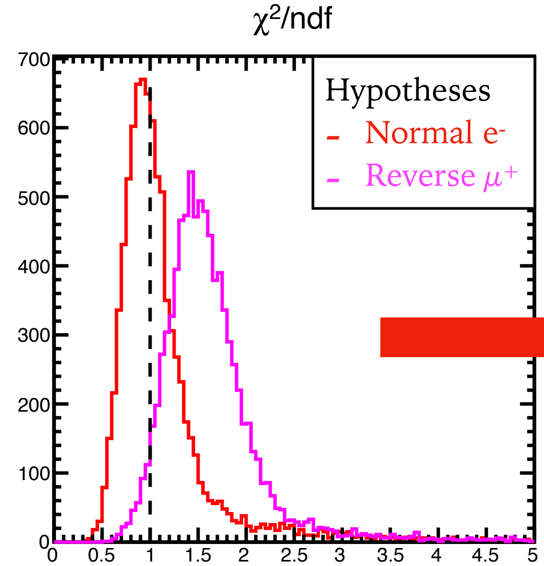
Compare 2 hypotheses

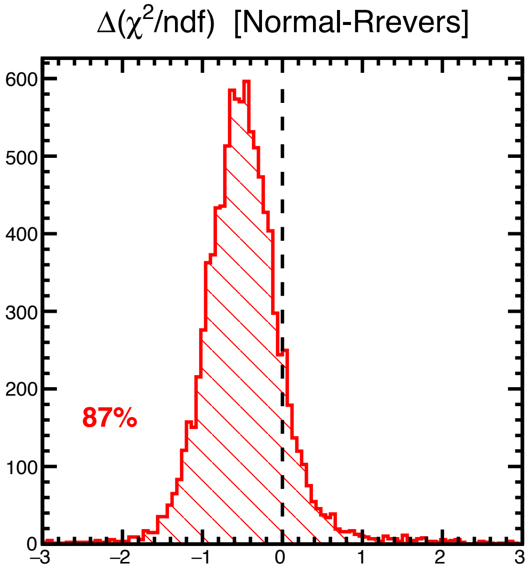
Normal-direction e^- vs Reverse-direction μ^+

This induces **miscorrection of TOF**

Signal e^- MC sample







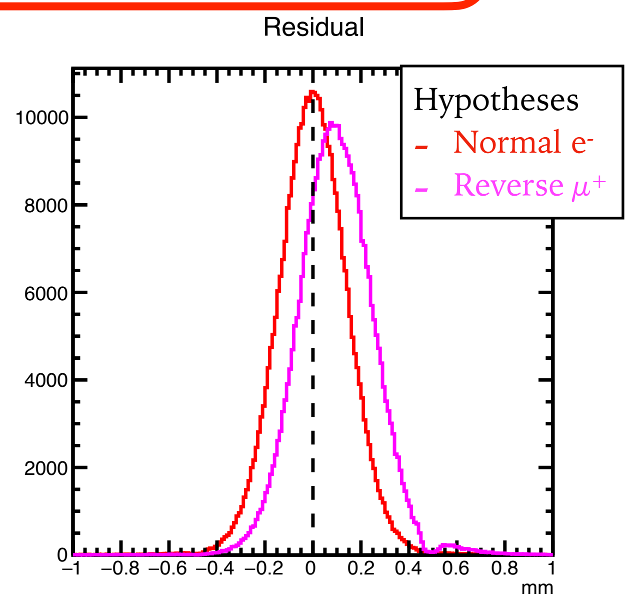
Track Fitting with 2 Hypotheses

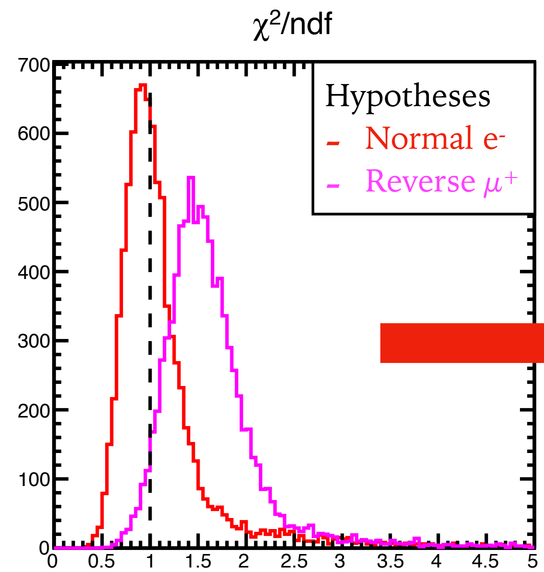
Compare 2 hypotheses

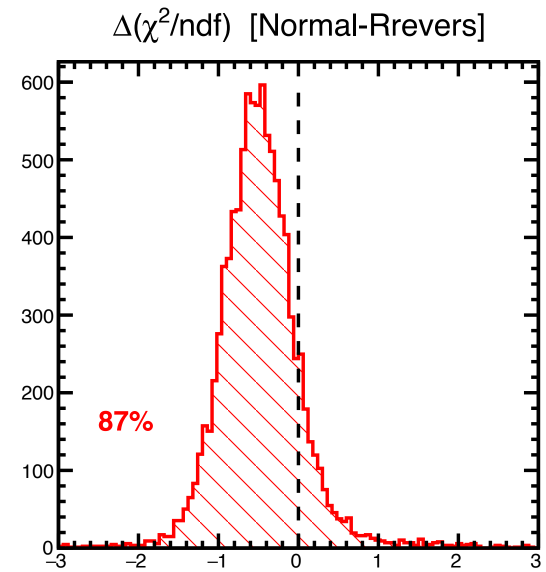
Normal-direction e⁻ vs Reverse-direction μ⁺

This induces **miscorrection of TOF**

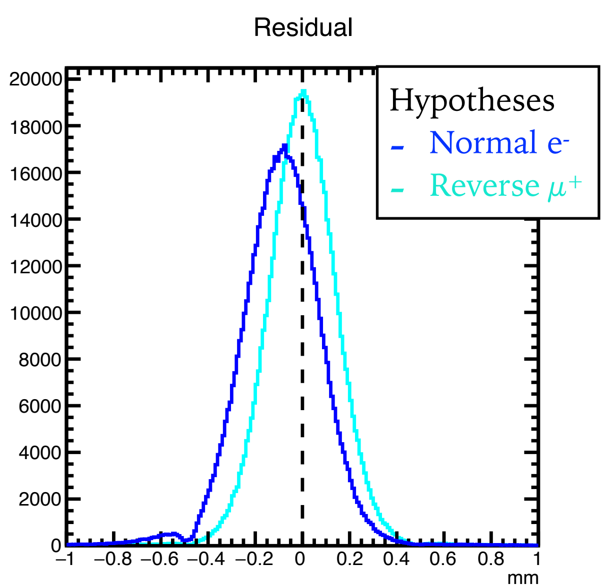
Signal e⁻ MC sample

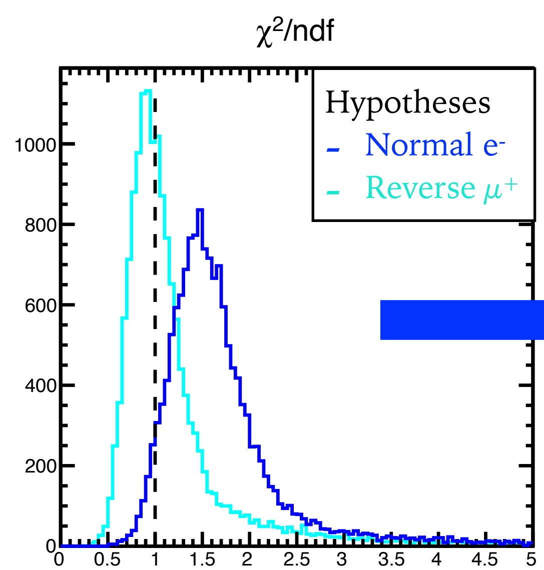


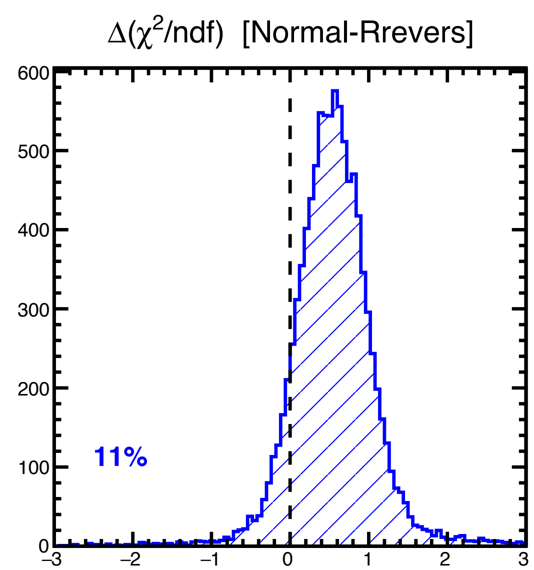




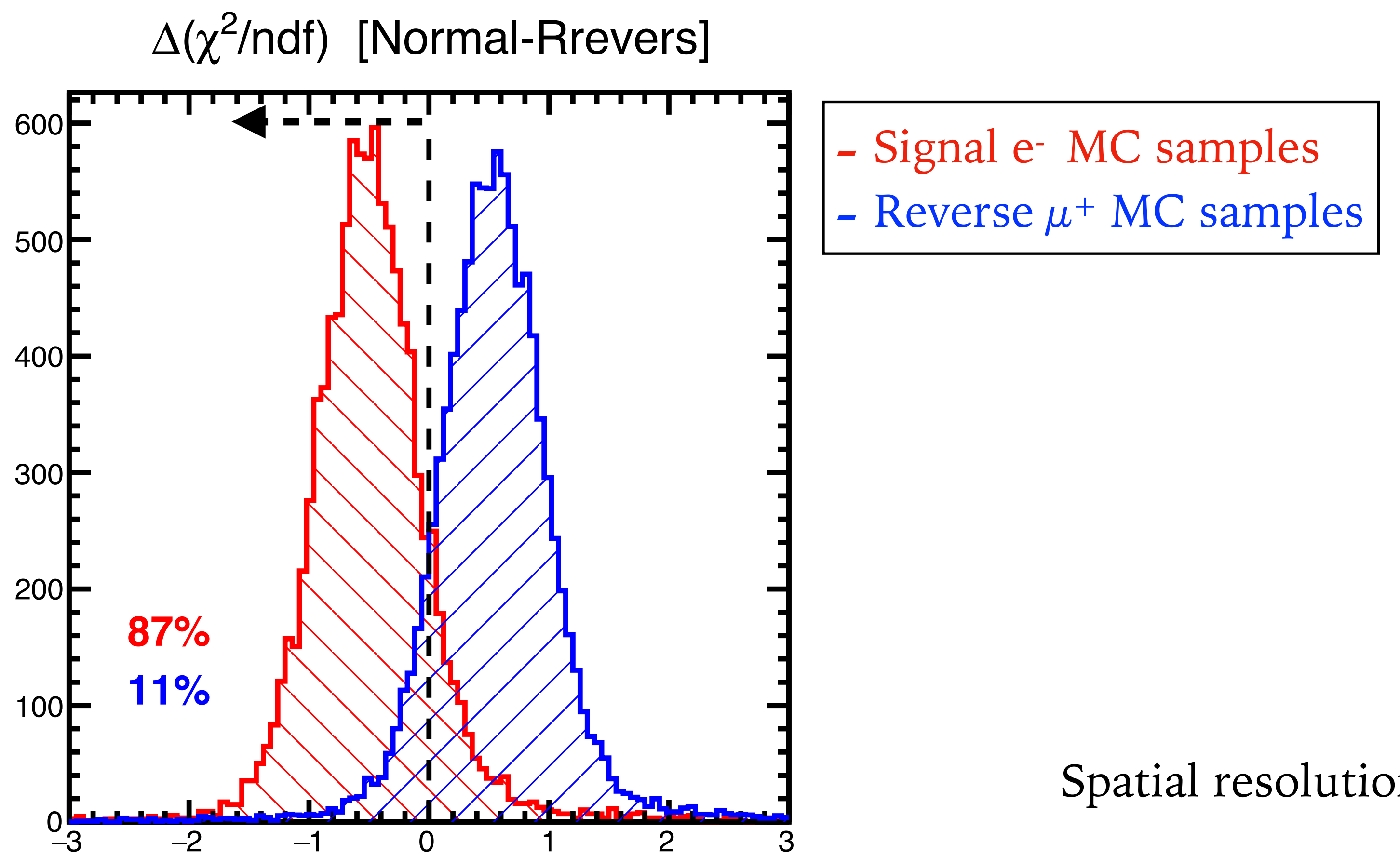
Reversed μ⁺ MC sample







Signal retention & BG rejection



Spatial resolution = 150 μm

If we set threshold as $\Delta(\chi^2/\mathrm{ndf}) < 0$,

87% of signal e^- are retained

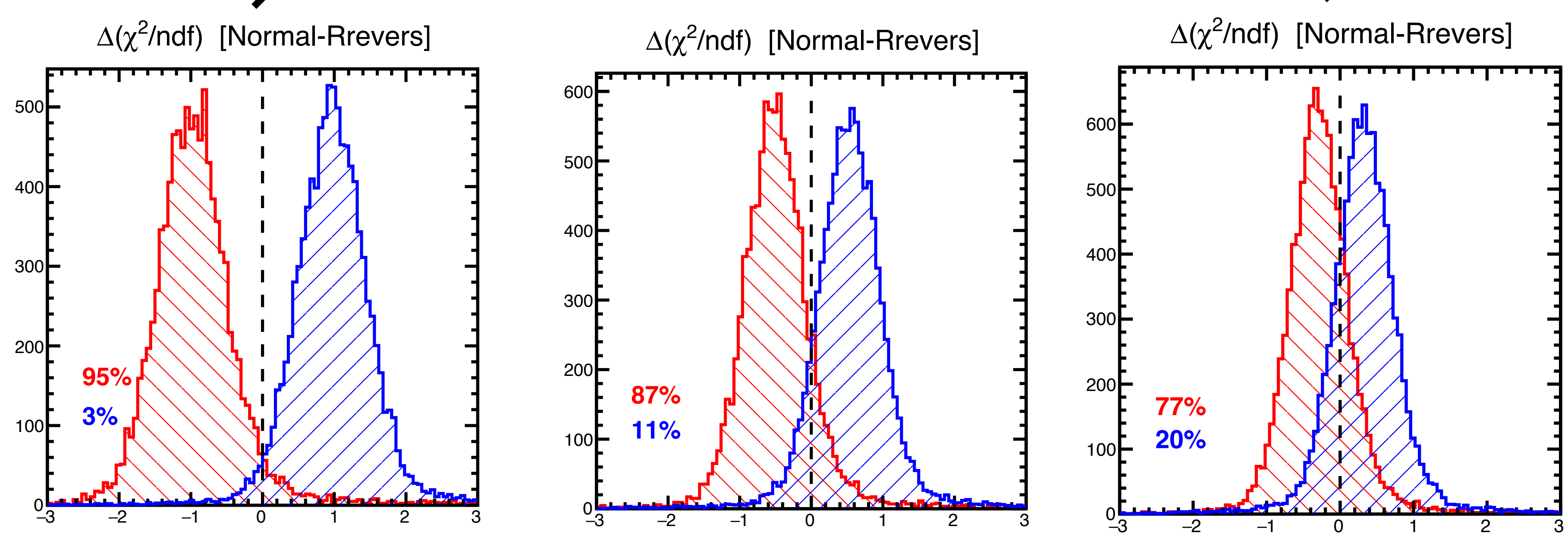
89% of reverse μ^+ are eliminated

BG can be suppressed to **11%**

Dependence of spatial resolution

$\Delta(\chi^2/\mathrm{ndf}) < 0$

Spatial Resolution	100 μm	150 μm	200 μm
Signal Retention (e^-)	95%	87%	77%
Contamination (μ^+)	3%	11%	20%



✓ Rejection power is sensitive to spatial resolution.

We expect **~150 μm** resolution based on a prototype test

Wu et al., NIM A 1015, 165756 (2021)

Reduction of BG events

Spatial Resolution	100 μm	150 μm	200 μm	Without Direction ID method
Signal Retention (e^-)	95%	87%	77%	100%
Contamination (μ^+)	3%	11%	20%	100%
BG events	0.07	0.26	0.48	2.4

Latest Prediction

Assuming 150 μm spatial resolution,

Sneaking cosmic μ^+ BG can be reduced to **0.26** events

Summary

- Track Reconstruction algorithm is being developed.
- As an application of track fitting, **“Track Direction ID”** method was developed
  - to suppress sneaking cosmic μ^+ BG.
  - Demonstrated that reverse μ^+ track can be suppressed to **11%**, with signal e^- track retention efficiency of **87%** (assuming 150 μm spatial resolution).

    ✓ Note reduction power is sensitive to the CDC spatial resolution.
  - → Sneaking μ^+ BG can be reduced from 2.4 to **0.26** events.

[Prospect]

- Room to improve reduction power by using more sophisticated techniques instead of simple comparison of χ^2/ndf.

Backup

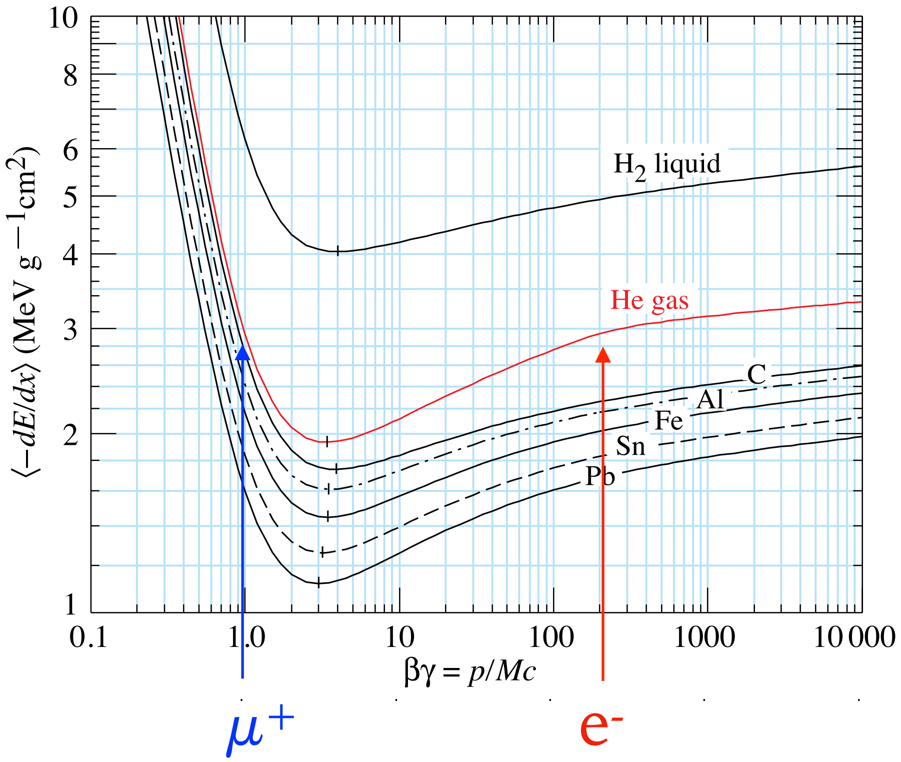
How to discriminate reverse μ+ ?

1. Cherenkov radiation ☹️

μ^+ with $\beta=0.7$ exceeds the Cherenkov threshold of Acrylic (n=1.49), $\beta_{th}=0.67$.
(Perhaps the number of photons may help to some extent.)

2. dE/dx ☹️

Unfortunately dE/dx in He for **e^- ($\beta\gamma=200$)** and **μ^+ ($\beta\gamma=1$)** are almost the same.
→ difficult to separate



from PDG

3. Track direction

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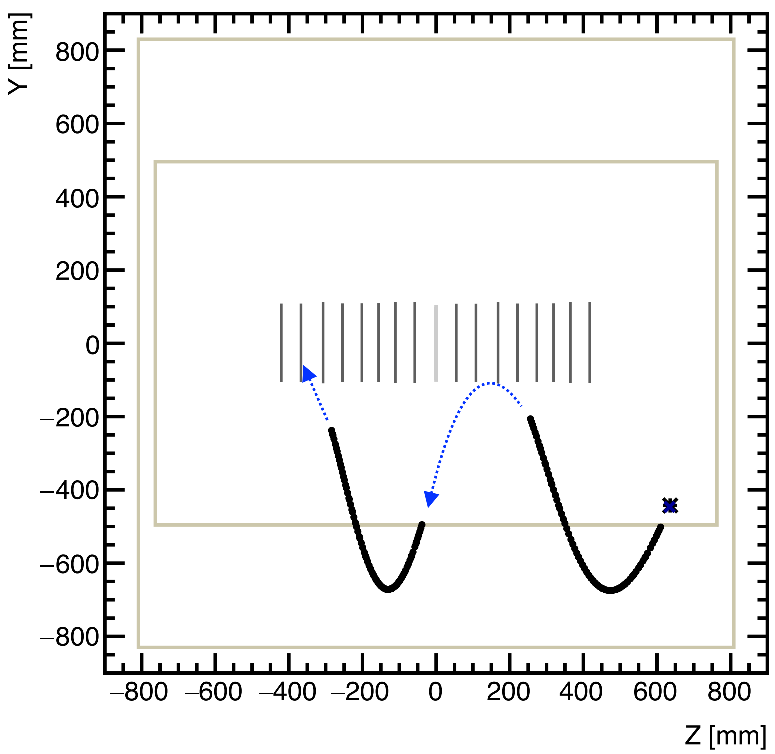
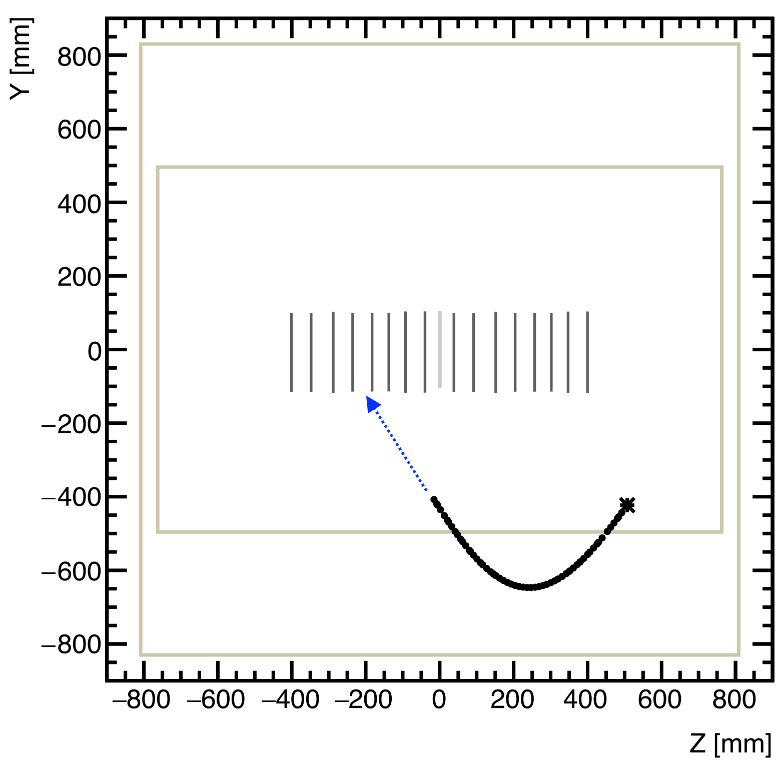
Note for multiple-turn events



If a track has multiple turns,
the direction will be easily identified
by checking momentum attenuation
in-between the turns.



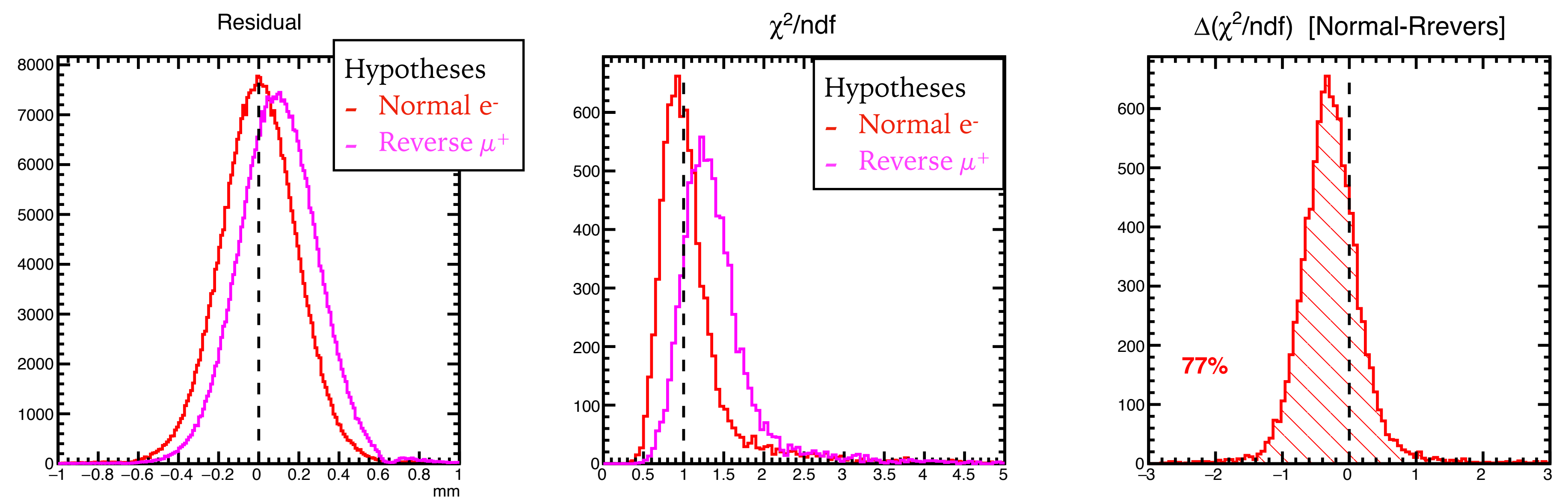
Therefore, we deal with
only single-turn events in this study.

Spatial resolution = 200 μm

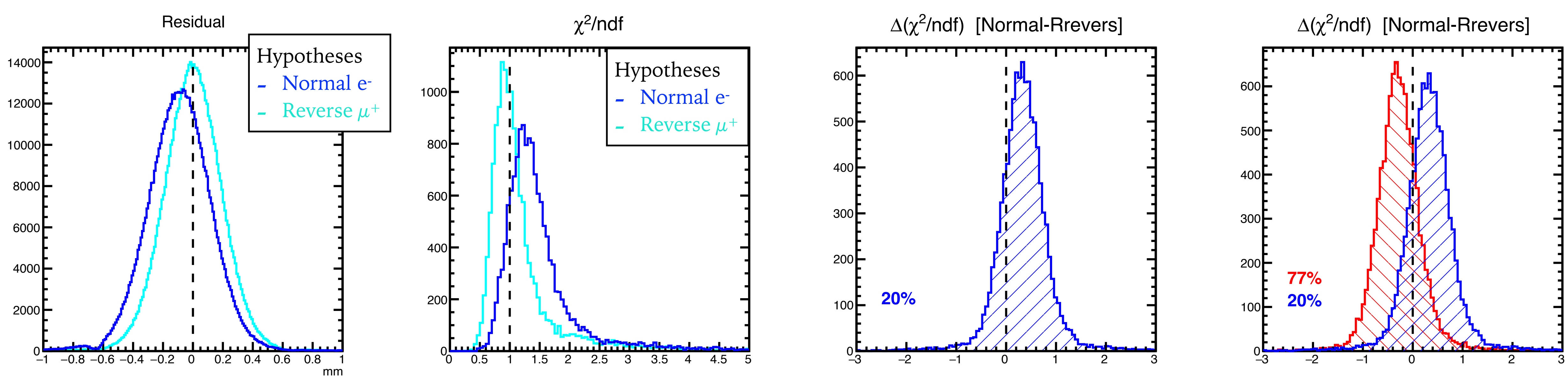
Compare 2 hypotheses

Normal-direction e- vs Reverse-direction μ+

Signal e- MC sample



Reversed μ+ MC sample



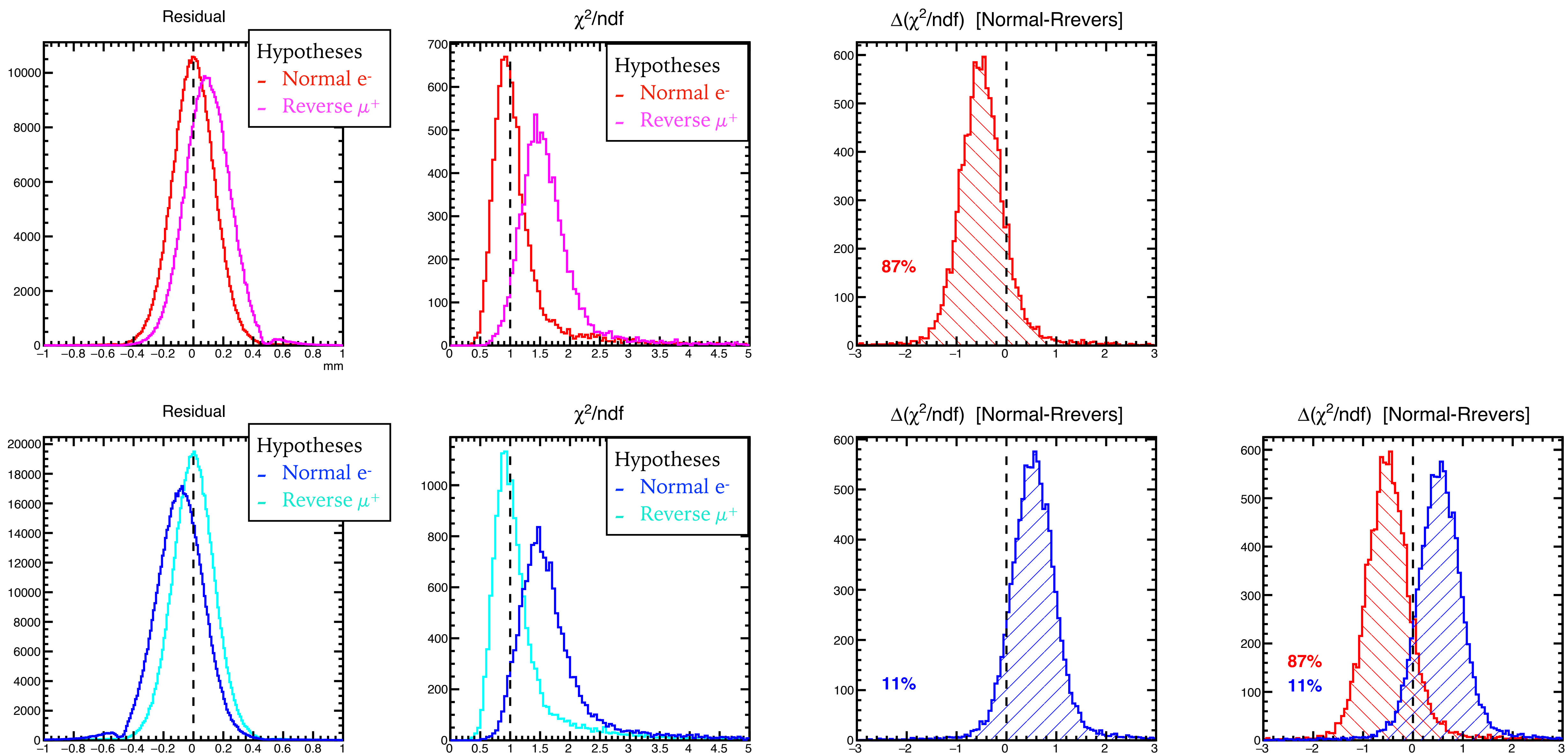
Spatial resolution = 150 µm

Compare 2 hypotheses

Normal-direction e- vs Reverse-direction µ+

Signal e⁻ MC sample

Reversed µ+ MC sample

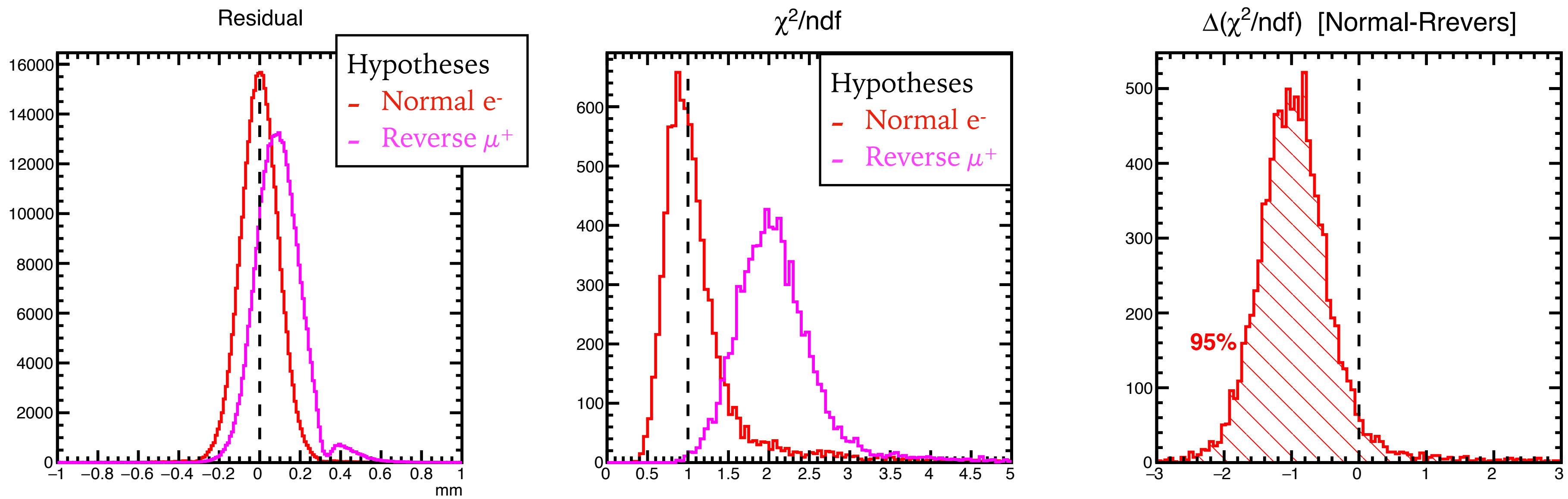


Spatial resolution = 100 µm

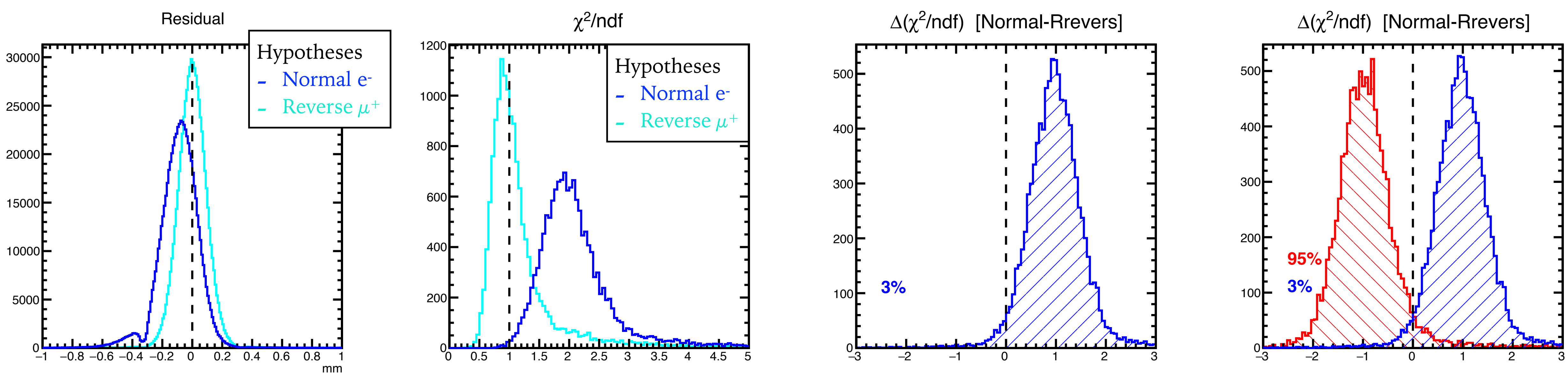
Compare 2 hypotheses

Normal-direction e- vs Reverse-direction µ+

Signal e- MC sample

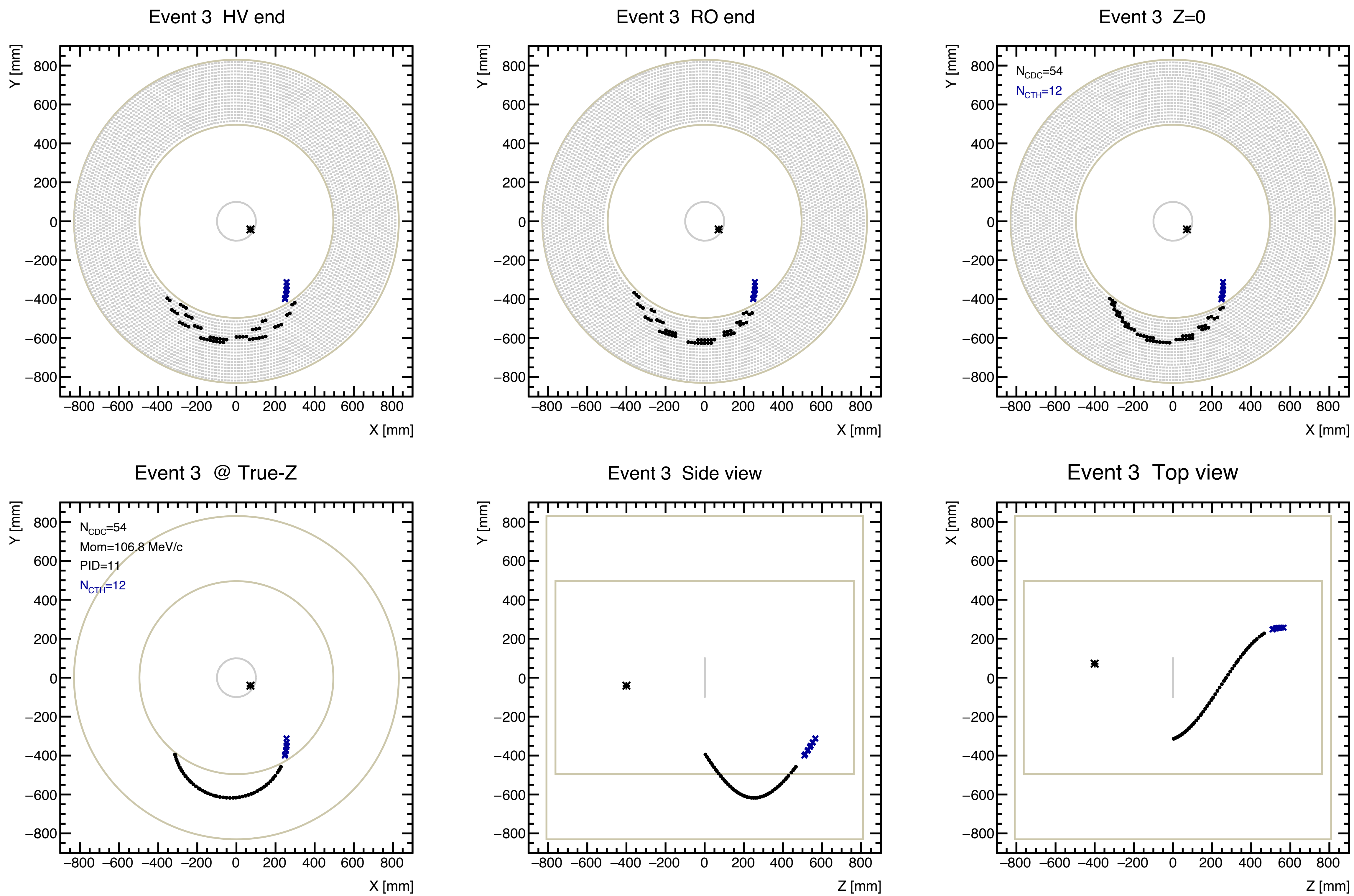


Reversed µ+ MC sample



Event display example

Signal e⁻ MC sample



Momentum resolution

Signal e⁻ MC sample

- electron e⁻
- 100—110 MeV/c
- From center stopping target disk
- CDC max layer >= 5
- Require CTH hits
- Single turn only
- Spatial resolution: 200 μm
- NDF >= 30
- χ^2/ndf < 2