Michel electrons

Tagging and Reconstruction

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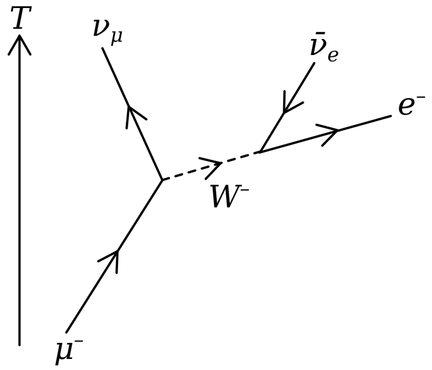
Michel electrons

A **Michel electron** is an electron produced when a muon decays at rest

Michel-electron in DUNE for:

1. Nu/nubar separation in nu-mu CC through μ **charge tagging**
   - **focus on Michel-e tagging efficiency**
2. Low-energy calibration and directionality ⇒ **Jérémy**
   - **focus on Michel-e reconstruction**



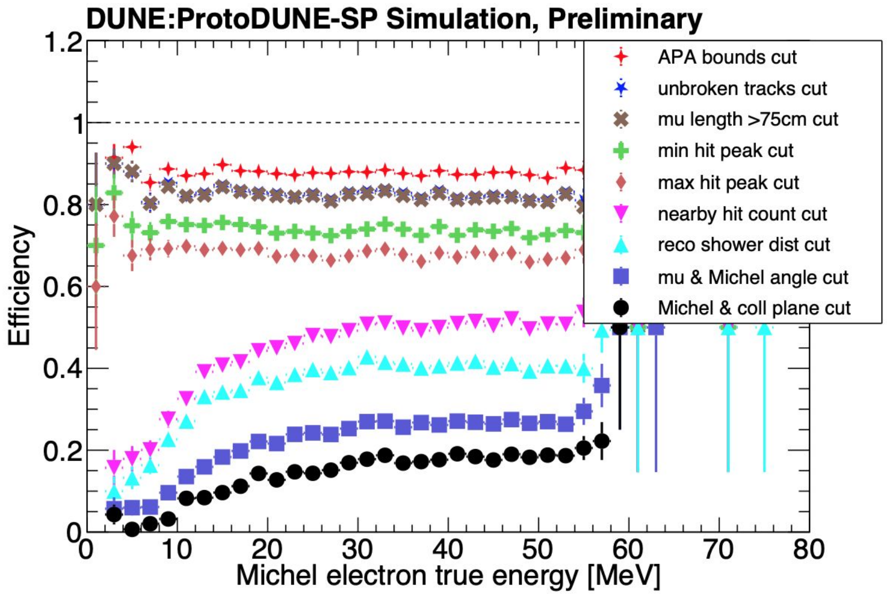
To validate the simulation and to develop selection and reconstruction algorithms:

- Use **ProtoDUNE data** in comparison with MC

Previous work on ProtoDUNE-SP

Previous studies on Michel-e by Aleena for ProtoDUNE-SP paper
arXiv:2211:01166 + TechNote

⇒ efficiency for tagging Michel electrons is very low!



Muon track selection in ProtoDUNE:

1. T0-tagged tracks.
2. Tracks starting from point close to or beyond one or more of the detector boundaries.
3. Muon tracks end inside Fiducial Volume. ($-309 < x < +309$, $80 < y < 557$, $80 < z < 610$)
4. Remove tracks that cross the cathode.

Michel-e hits selection:

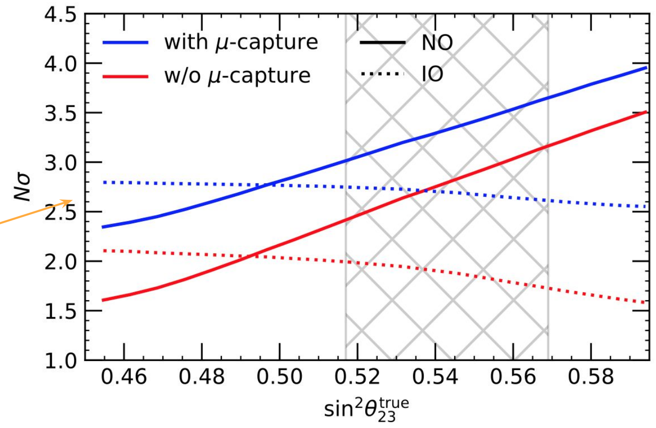
1. Tracks that end around **APA bounds**
2. Unbroken tracks
3. Cosmic muon track **length > 75 cm**
4. Tracks with hit peak **time > 200 ticks** (1 tick = 500 ns)
5. Tracks with hit peak **time < 5800 ticks**
6. Tracks having **5 < nearby hits < 40** around the end point
7. Tracks having closest reconstructed **shower distance < 10 cm**
8. Angle between candidate muon and Michel electron **< 130°**
9. Angle between the detector collection plane and the straight line to Michel candidate **> 10° & < 170°**

Charge tagging in atmospheric neutrinos

Sudy in paper: arXiv:1905.03589:

- If it is possible to distinguish **ν/ν̅** for atmospheric neutrinos,   DUNE could significantly improve the sensitivity to **mass ordering**.

For *Normal Ordering*, sensitivity of mass ordering ~ **3.5σ** after 7 years of exposure.



Charge Tagging:

- It’s not possible to do **charge discrimination** with LArTPC (no magnetic field)
- One way to discriminate **Muon charge** is to distinguish **capture events** from **decay events** (with Michel-e)
  - μ^+ always decays in e^+
  - μ^- can decay to e^- (~ 28%) or be captured on Argon nuclei (~72%)
- We can identify μ decays by tagging of Michel-e

In the paper they assume 100% efficiency for tagging Michel electrons (as in ICARUS and LArIAT)

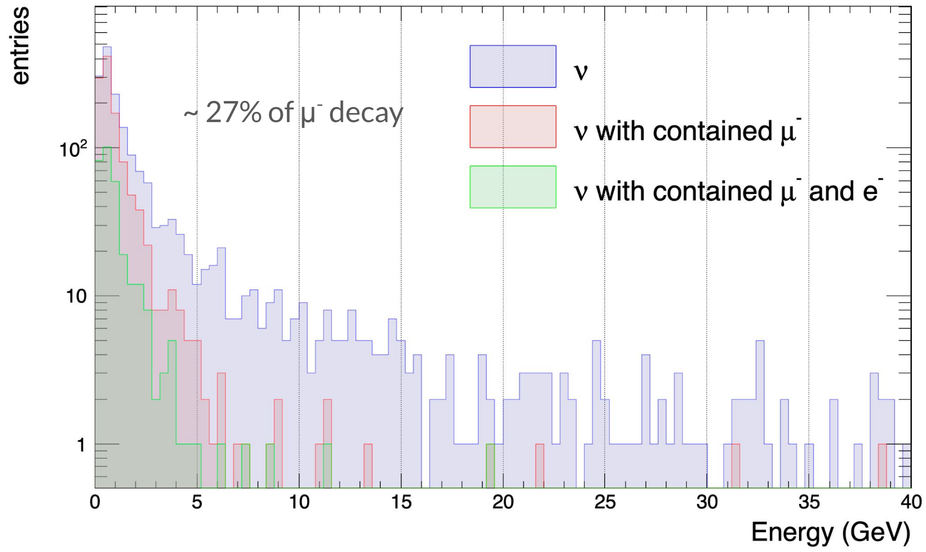
We need to figure out how to maximize efficiency to approach at least 70% (minimum requirement)

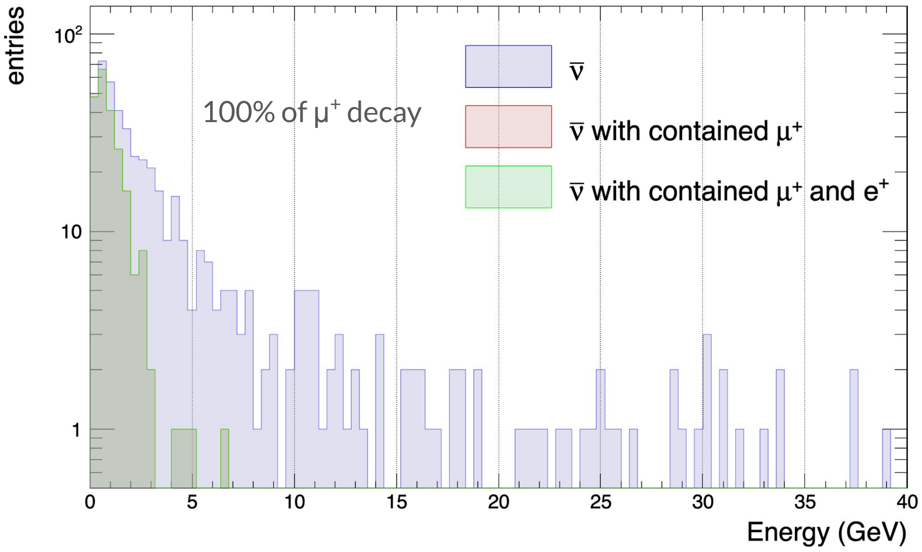
Sanity checks on atmospheric MC samples

True energy distribution of neutrino:

- Two different distribution: $\mathbf{\nu_\mu}$ **- cc** events (μ^-) and $\mathbf{\bar{\nu}_\mu}$ **- cc** (μ^+) events
- First: consider only fully contained muons from neutrino interaction
- Second: events where the muons decays to Michel electrons

⇒ Event fractions and energy spectra are consistent with expectations

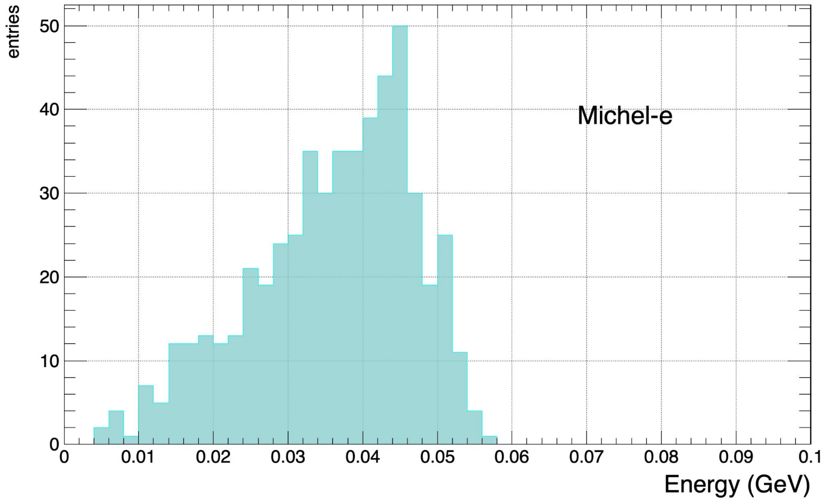


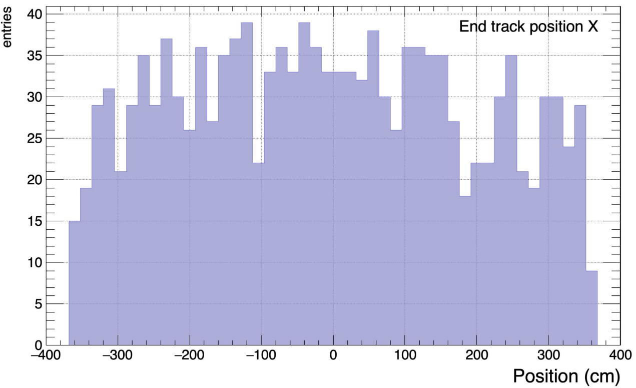


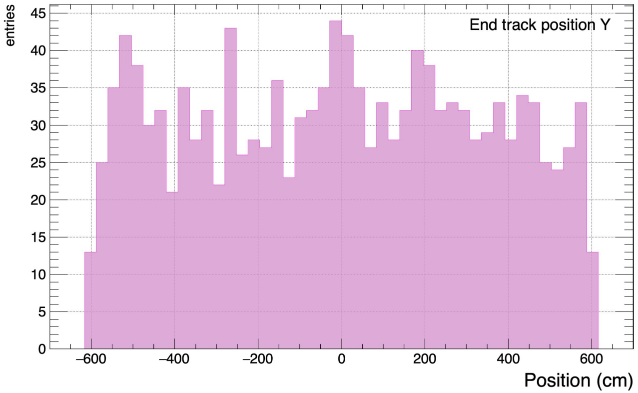
Sanity checks on atmospheric MC samples

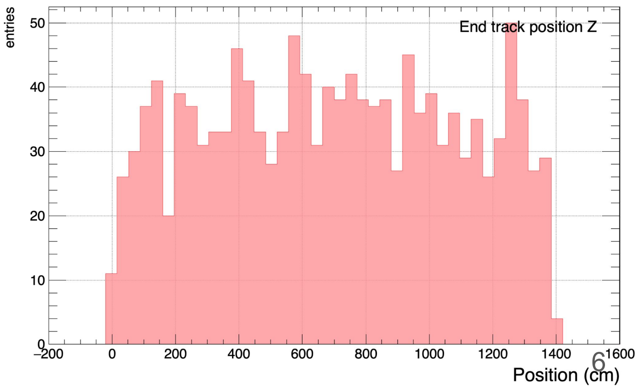
Other checks from the simulation:

- **True Energy** distribution of Michel-e
- Distribution of **End Position** of muon tracks



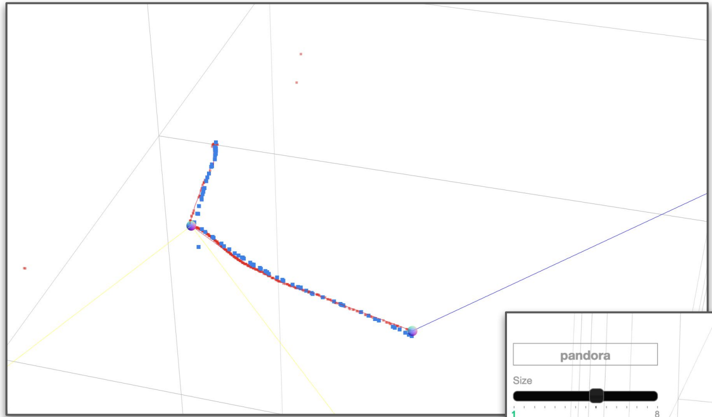


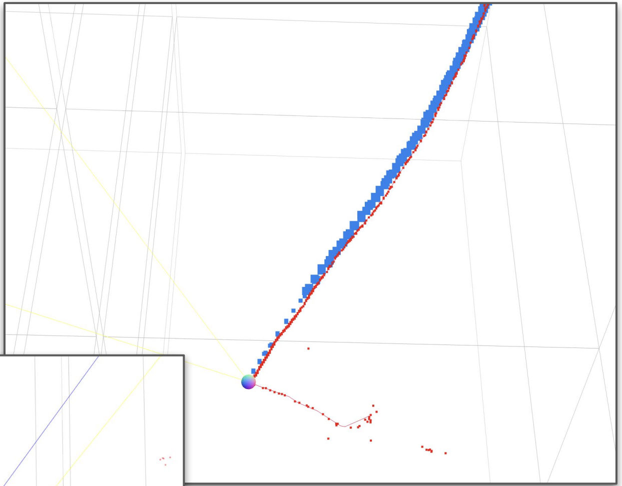




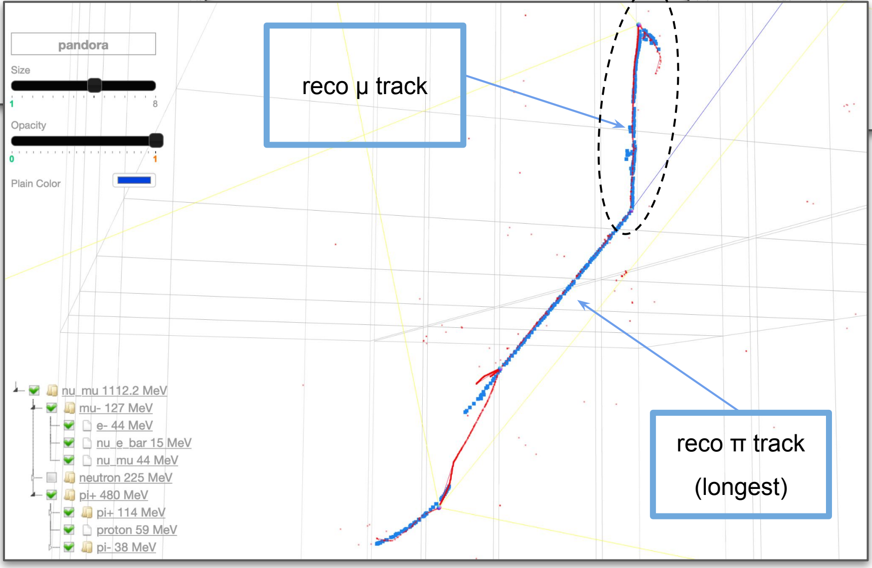
Event displays examples

Electron track **well reconstructed**:





Example of bad muon track reconstruction

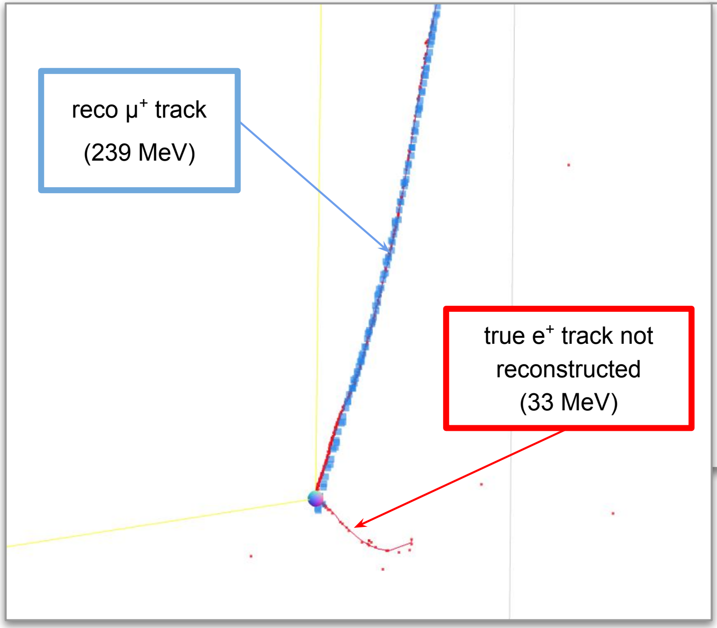


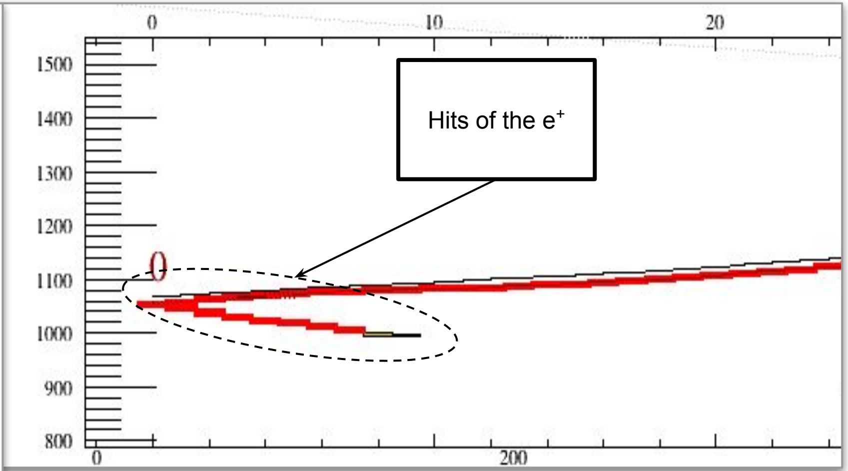
I selected reco **μ** searching for longest track

Longest track is muon ~90%

Event displays examples

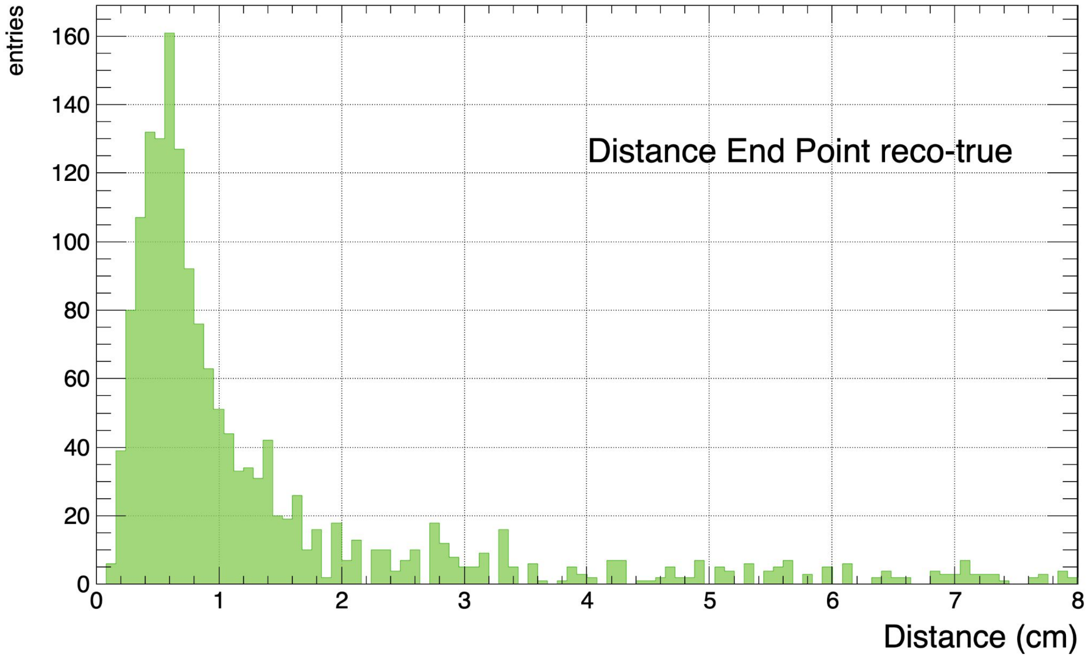
Sometimes **Pandora** cannot reconstruct the electron as a track or shower:





To select the Michel-e , we must also get the **unassociated hits** close to the muon track endpoint
⇒ algorithm under development

Preliminary selection



Distance between

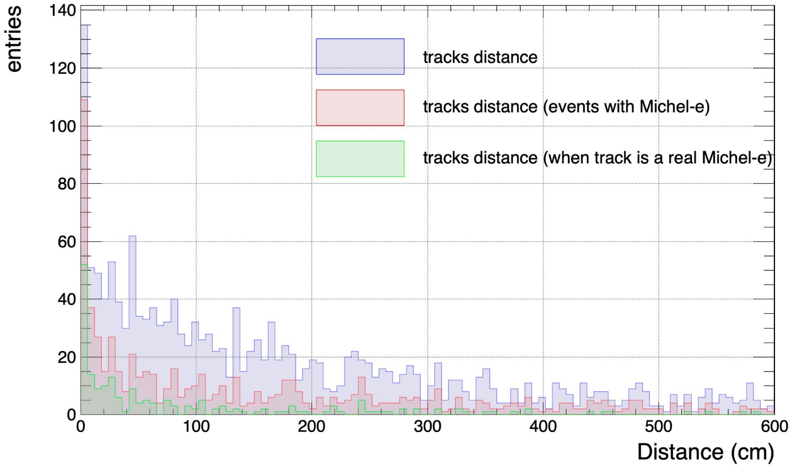
Reco and True track End Point

of muons targeted as longest track.

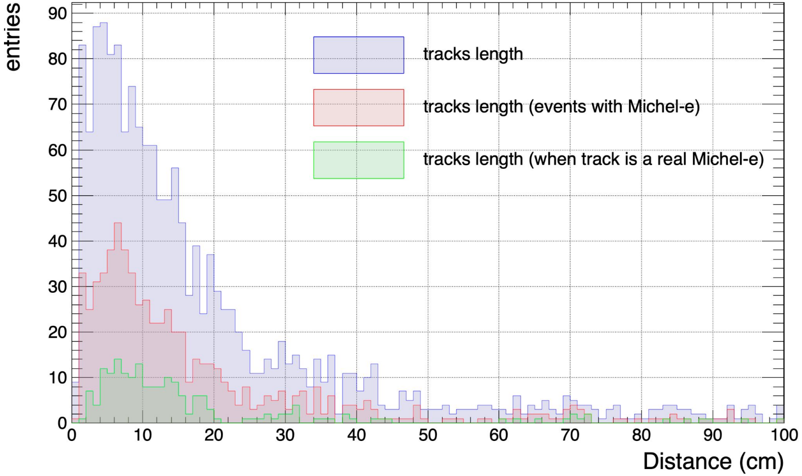
Preliminary studies for Michel-e selection

Distance between:

- ➔ Reco track End Point of muon
- ➔ Reco track Start Point of other tracks



Length of all tracks that are not the longest one (muon)



In principle, the **green distribution** represents the true electrons reconstructed tracks

⇒ Why do these tracks have a very distant start point and are very long ?

[problem in truth association?]

Next steps

1. Optimise efficiency of Michel-e tagging on atmospheric neutrino MC
   a. Optimise selection for well reconstructed muon tracks
   b. Use reconstructed PFParticles when available
   c. Use unassociated Hits
2. Validate MC studies by comparing efficiency on **data and MC** using **ProtoDUNE-VD**
3. Study the possibility to improve Michel-e tagging algorithm using both **charge** and **light**.

Michel Electrons Analysis: low energy calibration

DUNE France Analysis Workshop
June 5th 2024

Jérémy QUÉLIN LECHEVRANTON

DUNE

IJCLab Irène Joliot-Curie

Motivations

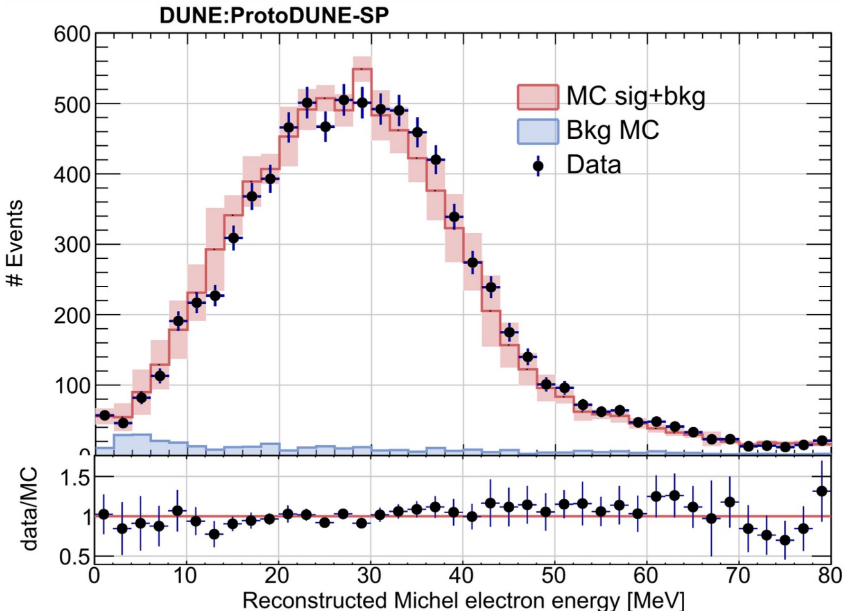
Low-energy (tens of MeV) response

- Calibration of low-energy electrons
- Supernova neutrinos
- Electric field topology
  - Space charge effect (SCE)
  - Side effects

Modus Operandi

Michel e^- from cosmics in PD-HD/VD

A. Rafique's analysis:



Energy spectrum reconstruction

- High-purity sample
- Influence of position
- Efficacity dependence with energy

Event Selection

Candidate muon selection

- Dying inside the detector
- Passing through the anode (for `t0`-tagging)

Event Selection

Michel electron selection

- Hit number (enough for energy reconstruction)
- Relation to muon
  - Sharp angle between two tracks
  - Bragg peak (muon's dE/dx inflection)
- Convolutional Neural Network (trained on PDSP)

First Try – Simulation

Selection procedure

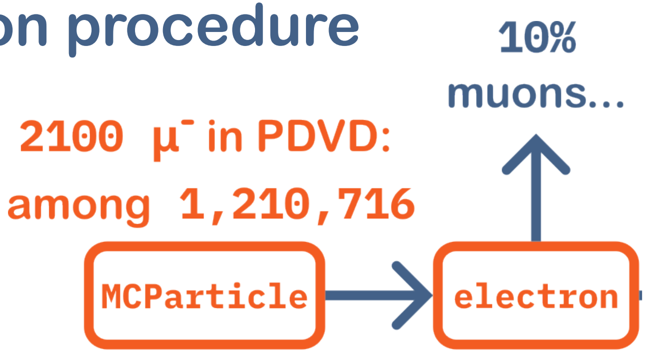
2100 μ^- in PDVD:

among 1,210,716

MCParticle

First Try – Simulation

Selection procedure



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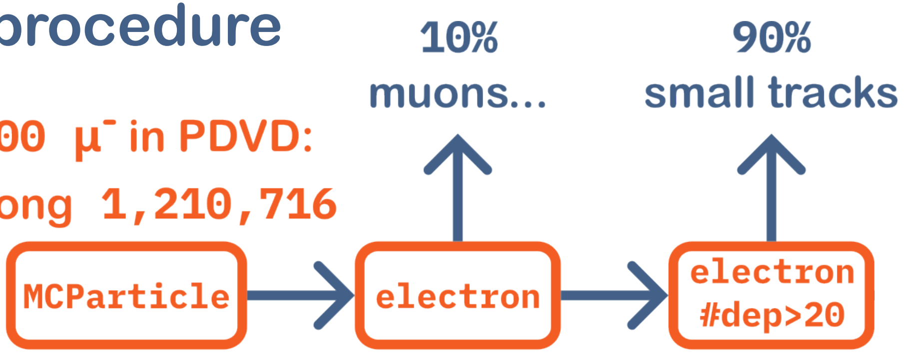

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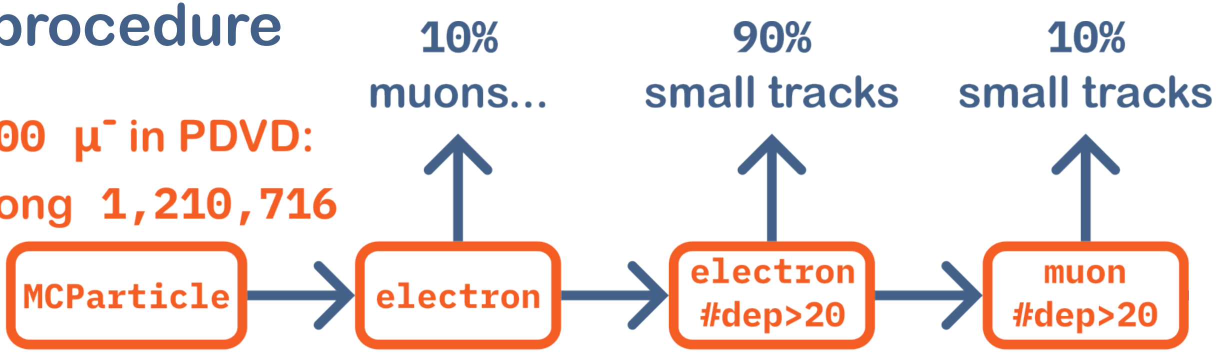

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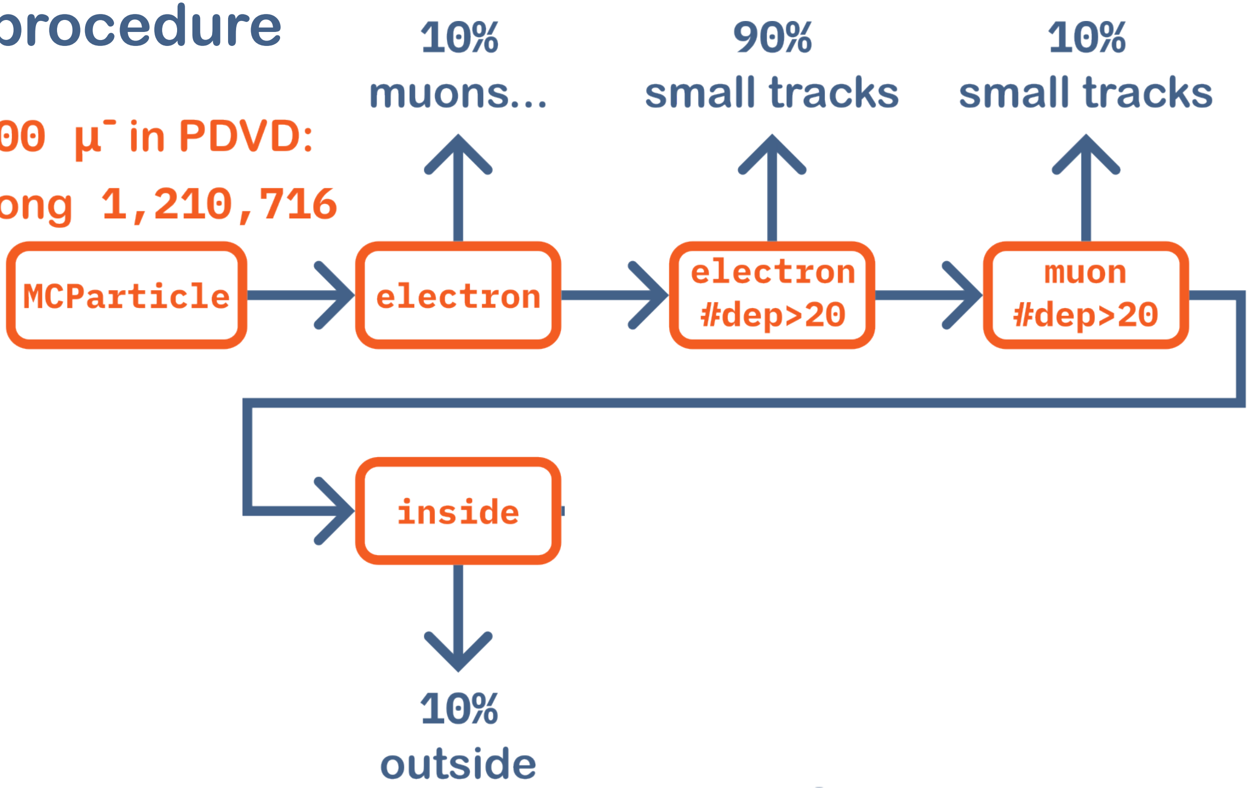

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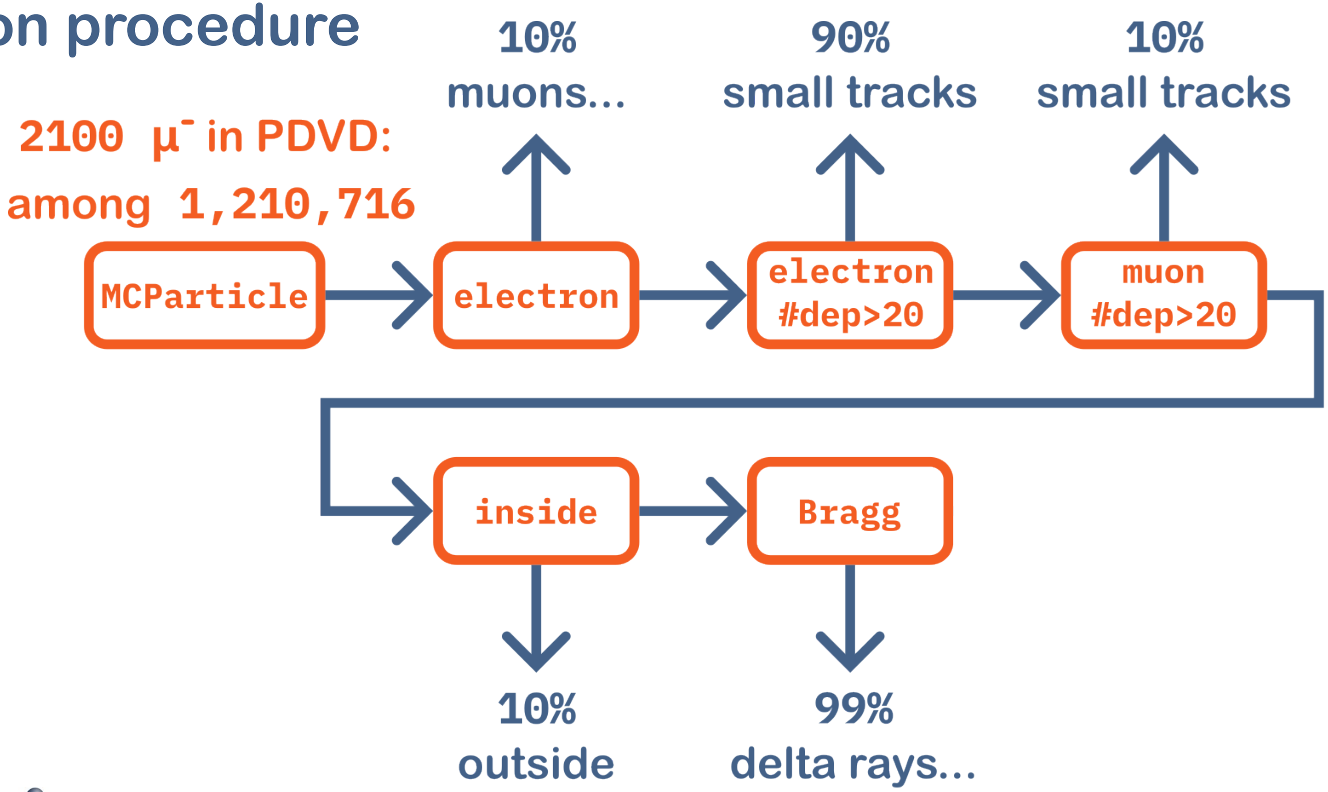
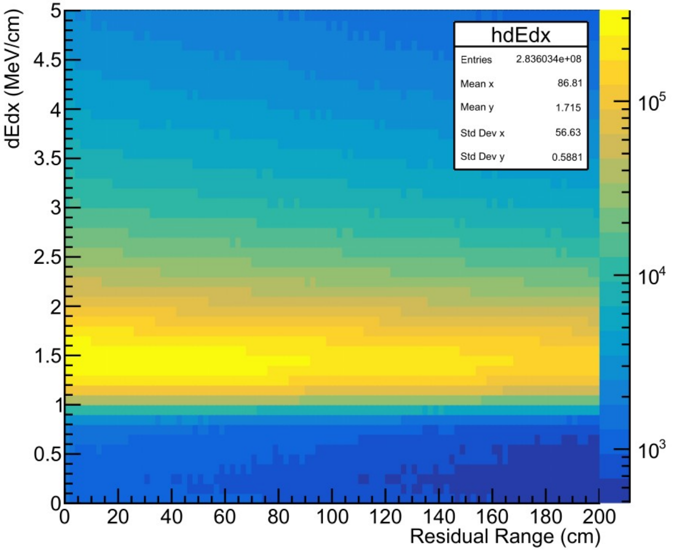
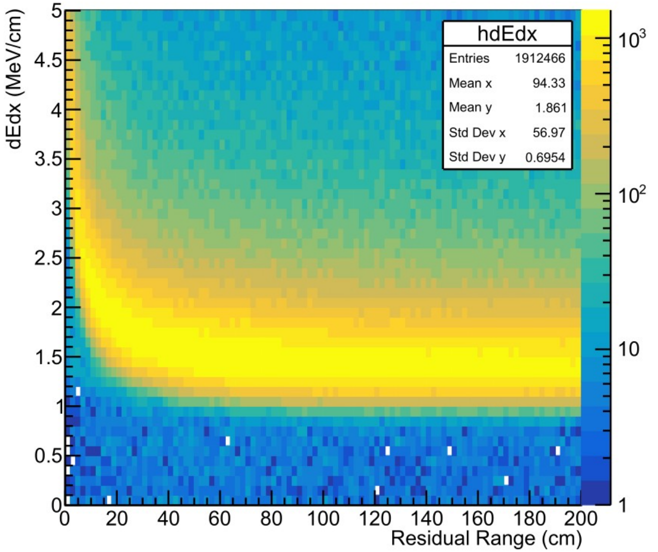


~40k candidates



~200 candidates



lasts deposits average
> 3.5 MeV/cm

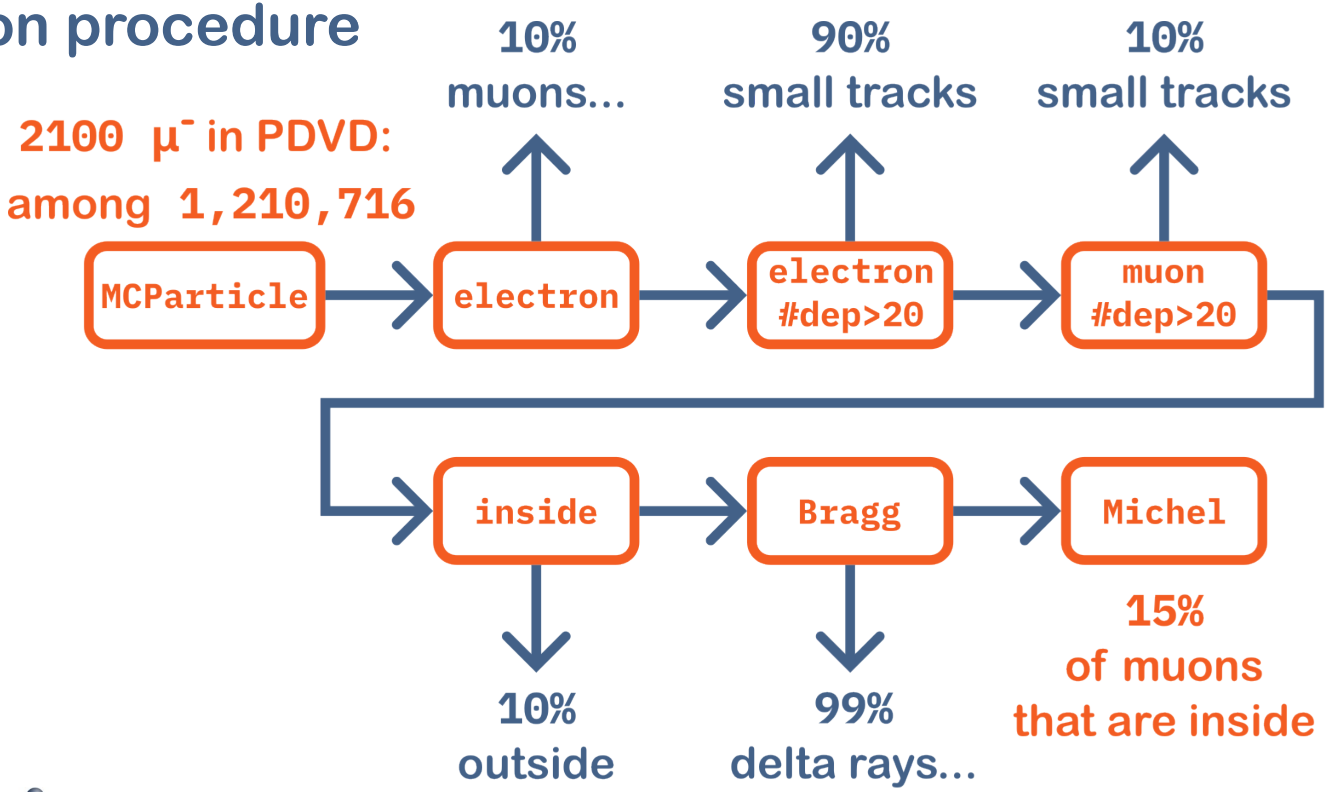
inside → Bragg

10% outside

99% delta rays...

First Try – Simulation

Selection procedure



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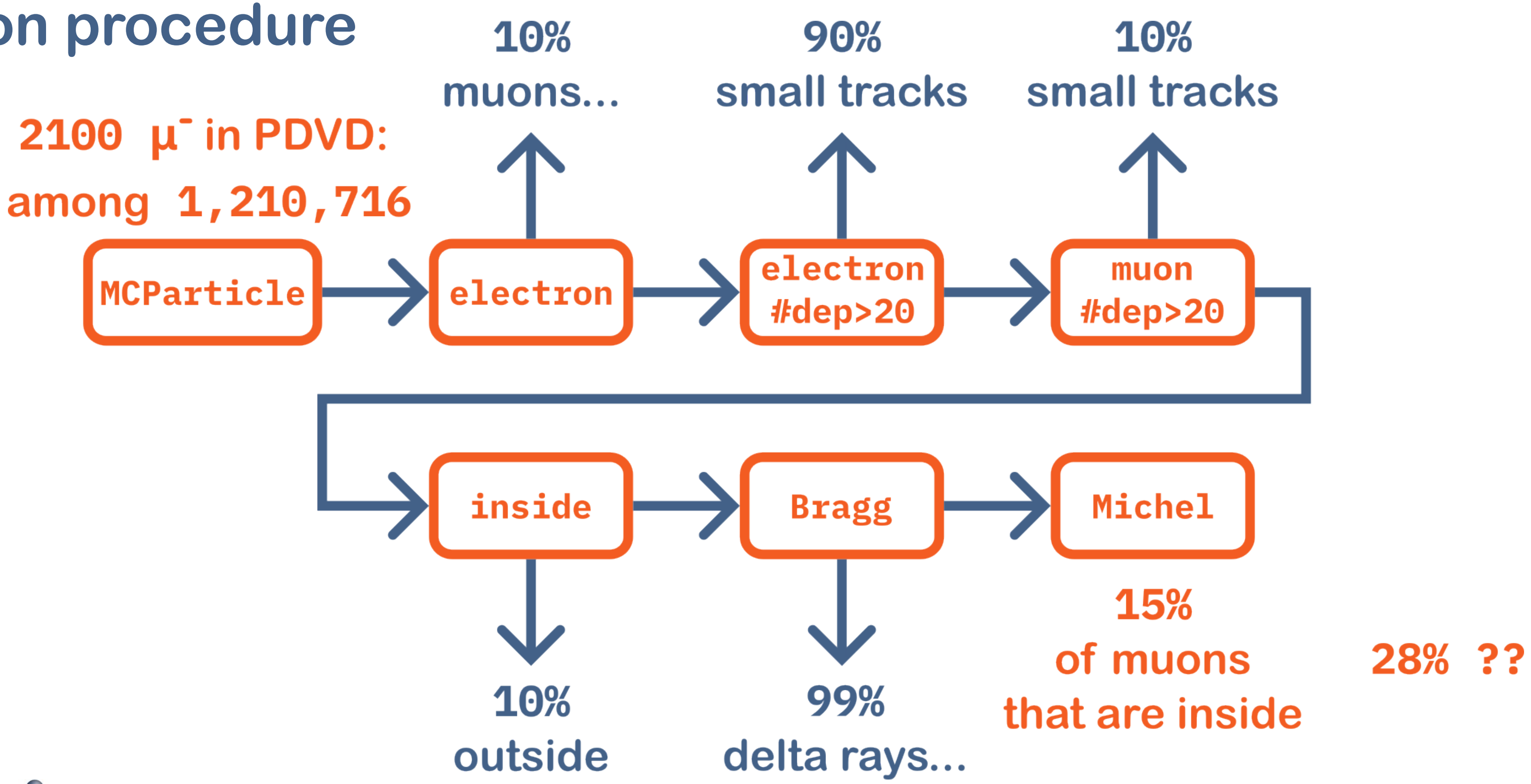

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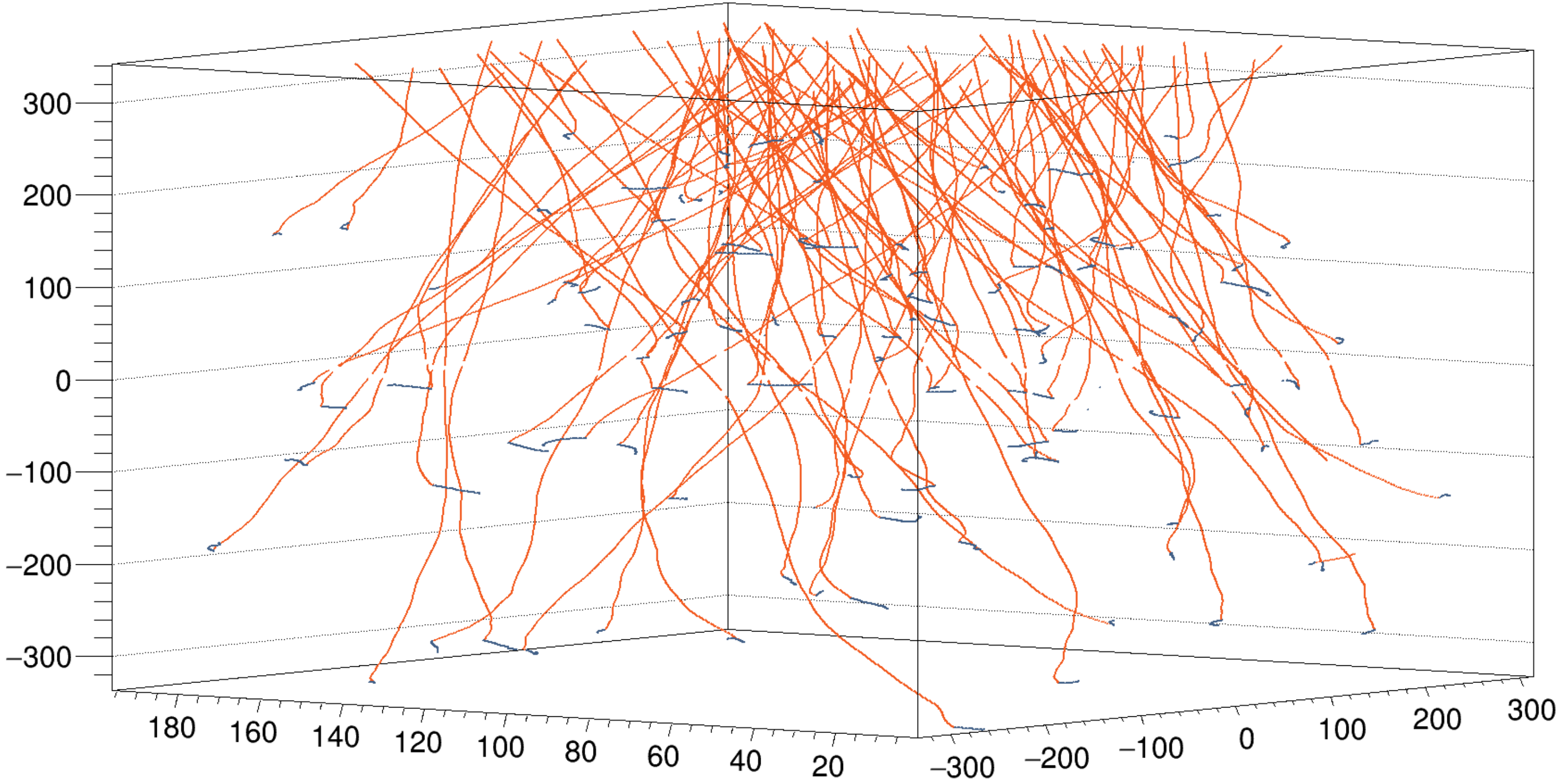
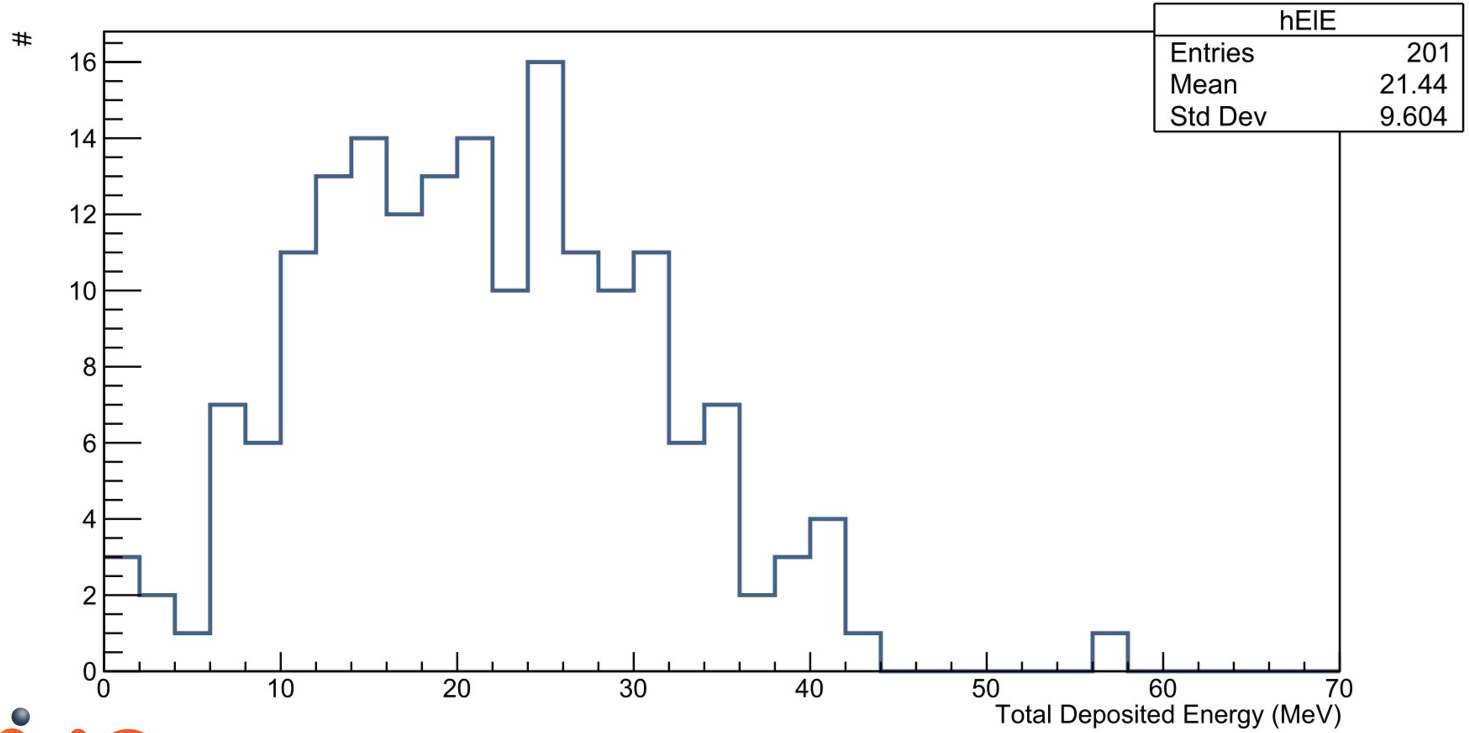


First Try – Simulation

Michel electron energy spectrum (sum of deposits)



Towards Reconstruction

Limitations

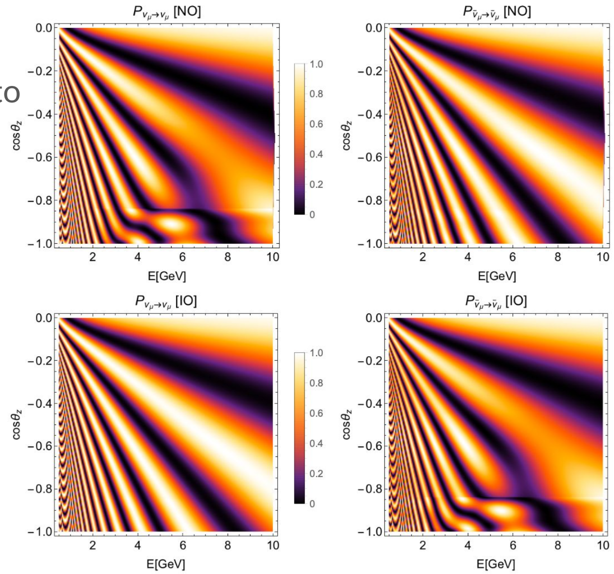
- No access to pdg / mother
  - muons = long tracks
  - michel = after dying muon

Reconstruction objects

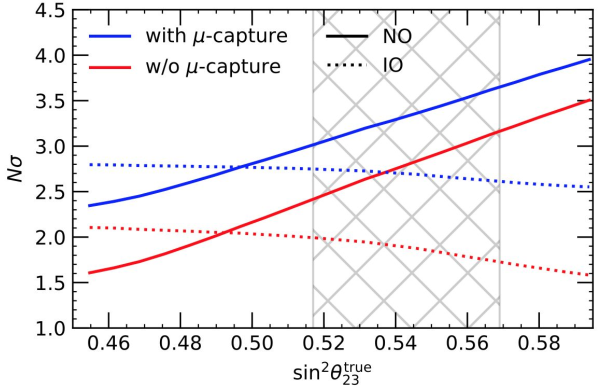
- `Calorimetry`?
- `Cluster`?
  - what `dx` for `dE/dx`?
  - width
  - distance
- `Hits`?
  - what `dx` for `dE/dx`?

Backup

Little review of this paper: [arXiv:1905.03589]



- Study of impact on **mass ordering** sensitivity in the case where it is possible to distinguish $\boldsymbol{\nu/\bar{\nu}}$ for atmospheric neutrinos.
- Resonance at (3-8) GeV for vertical up-going $\nu_\mu/\bar{\nu}_\mu$ ($-1 < \cos\theta_z < -0.8$):
  - for **neutrino** in *Normal Ordering*
  - for **antineutrino** in *Inverted Ordering*
- Results:
  - using neutrino/antineutrino discrimination, DUNE could significantly improve the sensitivity to **mass ordering** with atmospheric neutrinos.



For *NO*, sensitivity of mass ordering ~ **3.5σ** after 7 years of exposure.

Usually difficult, but with **LArTPC** it is possible (even without a magnetic field) via:

1. **Muon charge tagging** via capture vs decay (with Michel-e)
   - Efficiency of μ^- capture on Argon nuclei is $\varepsilon^{cap} \simeq 72\%$
   - Need to recognize Michel-e (or positrons) from μ^- (μ^+) decays
     - Recognizing Michel-e means finding **decay events** with high efficiency
     - We can distinguish **decay events** from **capture events** (composed only of μ^-)
2. Low energy proton tagging
   - For low-multiplicity events, protons occur preferentially in neutrino interactions
3. Inelasticity distribution
   - In antineutrino CC interactions, a high-energy lepton is preferred

The paper (arXiv:1905.03589) focuses on **1.** and assumes 100% efficiency for tagging Michel electrons (as in ICARUS and LArIAT)