

# Michel electrons energy reconstruction in ProtoDUNE Simulation and Data



Jérémy Quélin Lechevranton  
DUNE France, Apr. 1<sup>st</sup>, 2026



## Michel electrons

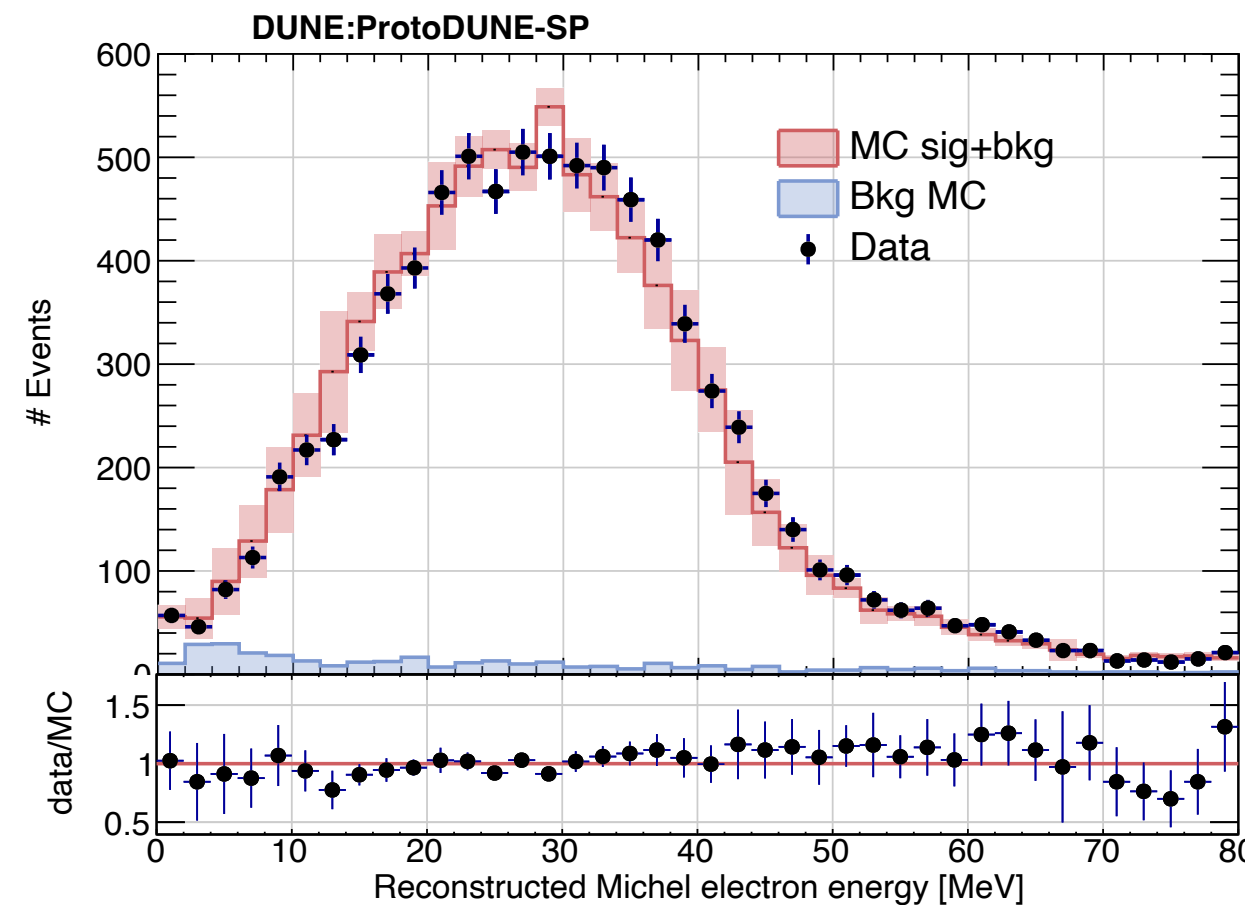
- $\mu^\pm \rightarrow e^\pm \nu_\mu \nu_e$  with  $E_e = 0-50$  MeV
- Abundant in cosmics:  $\sim 1$  /cm<sup>2</sup>/s
- Ideal for low-energy calibration
  - Supernova neutrinos energy range
  - Map of the EM field

LArSoft module available [here](#)

- MichelAnalysis\_module.cc
- released on DUNE/protoduneana.git

## Previous analysis in LArTPC:

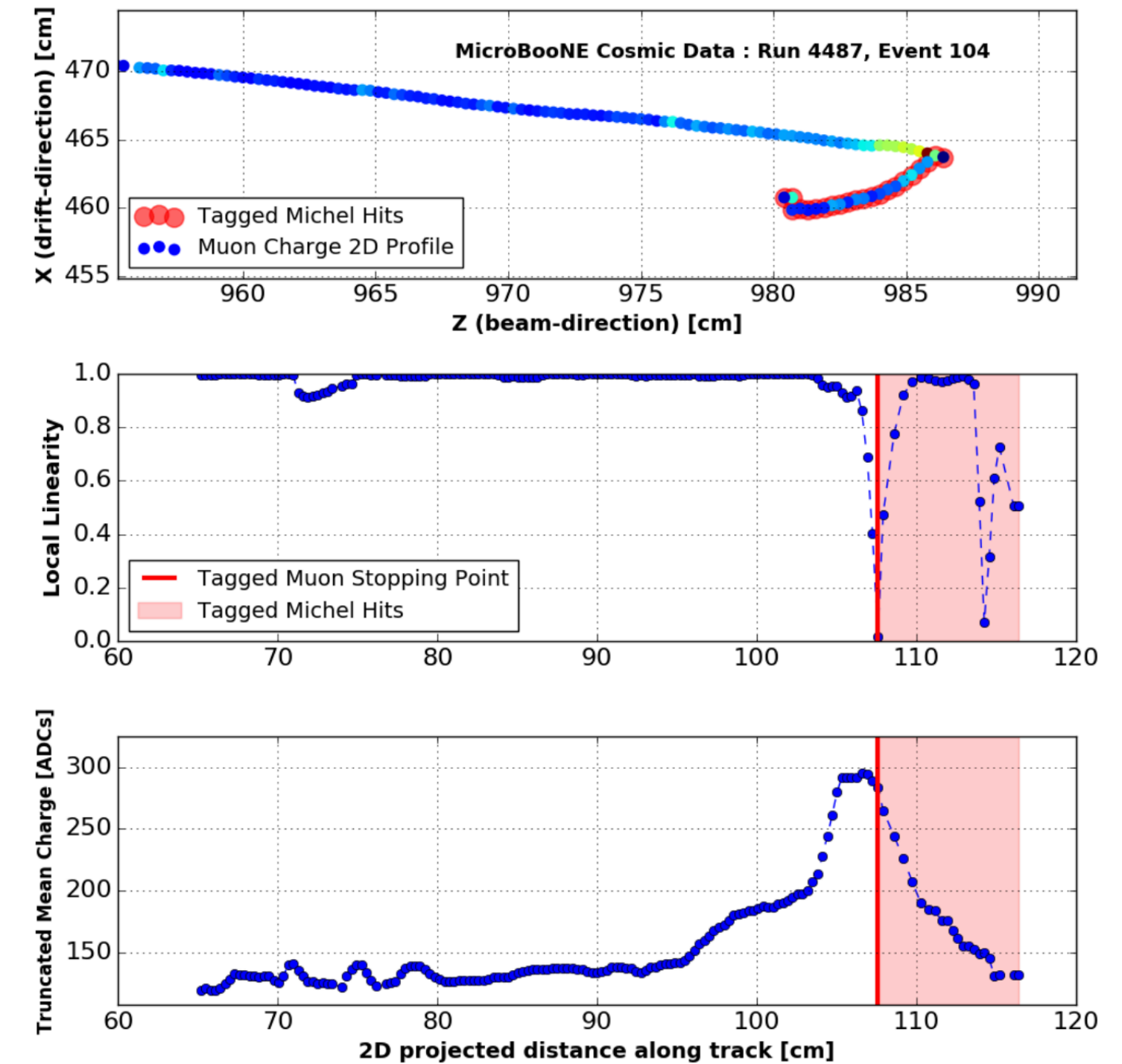
- ProtoDUNE-SP



@ DUNE Collaboration / arXiv:2211.01166

- no available module for HD/VD

- MicroBooNE

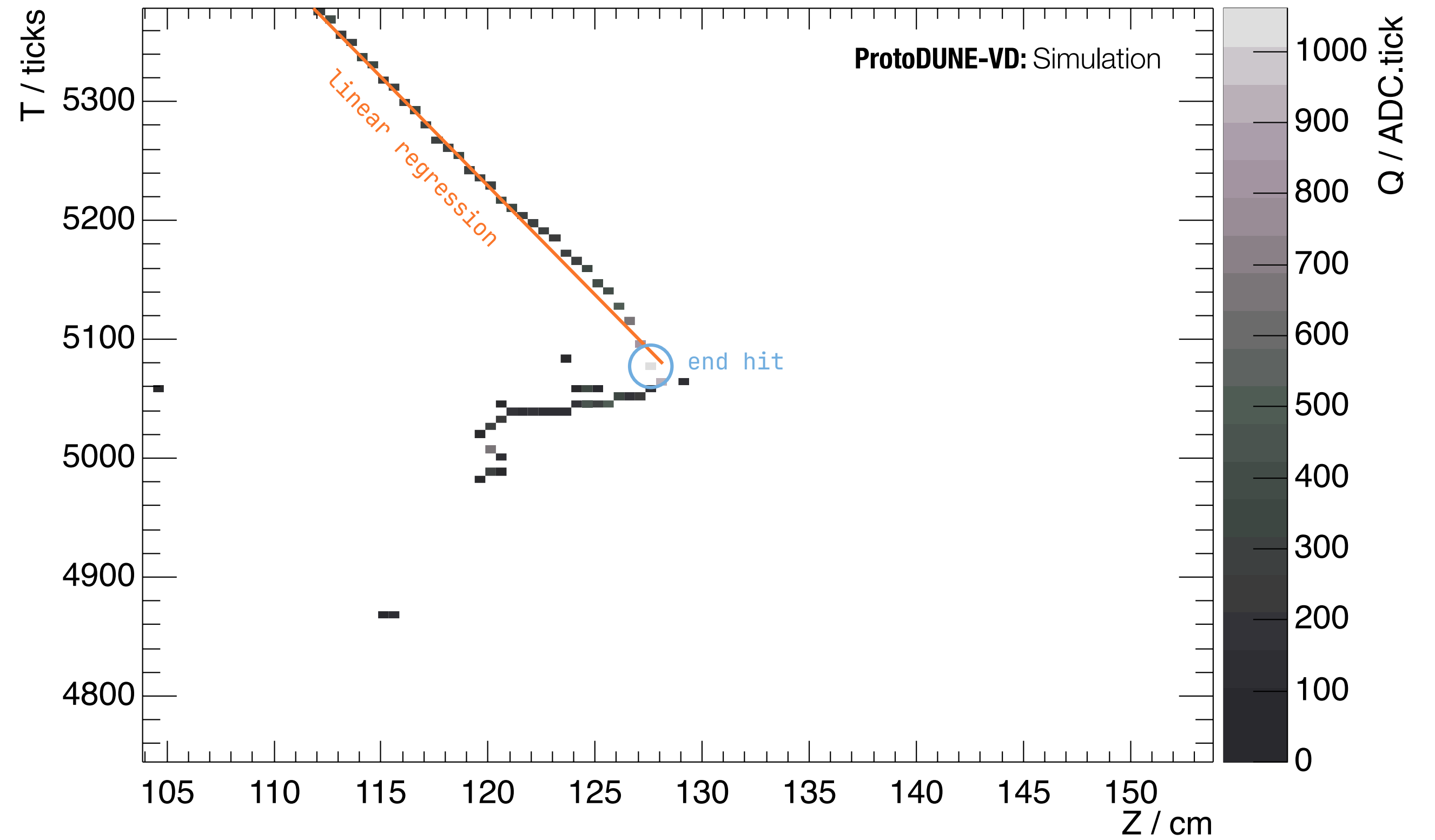


@ MicroBooNE Collaboration / arXiv:1704.02927

Select well reconstructed **stopping muon** candidates

Using **Pandora track** reconstruction

Michel electron illustration

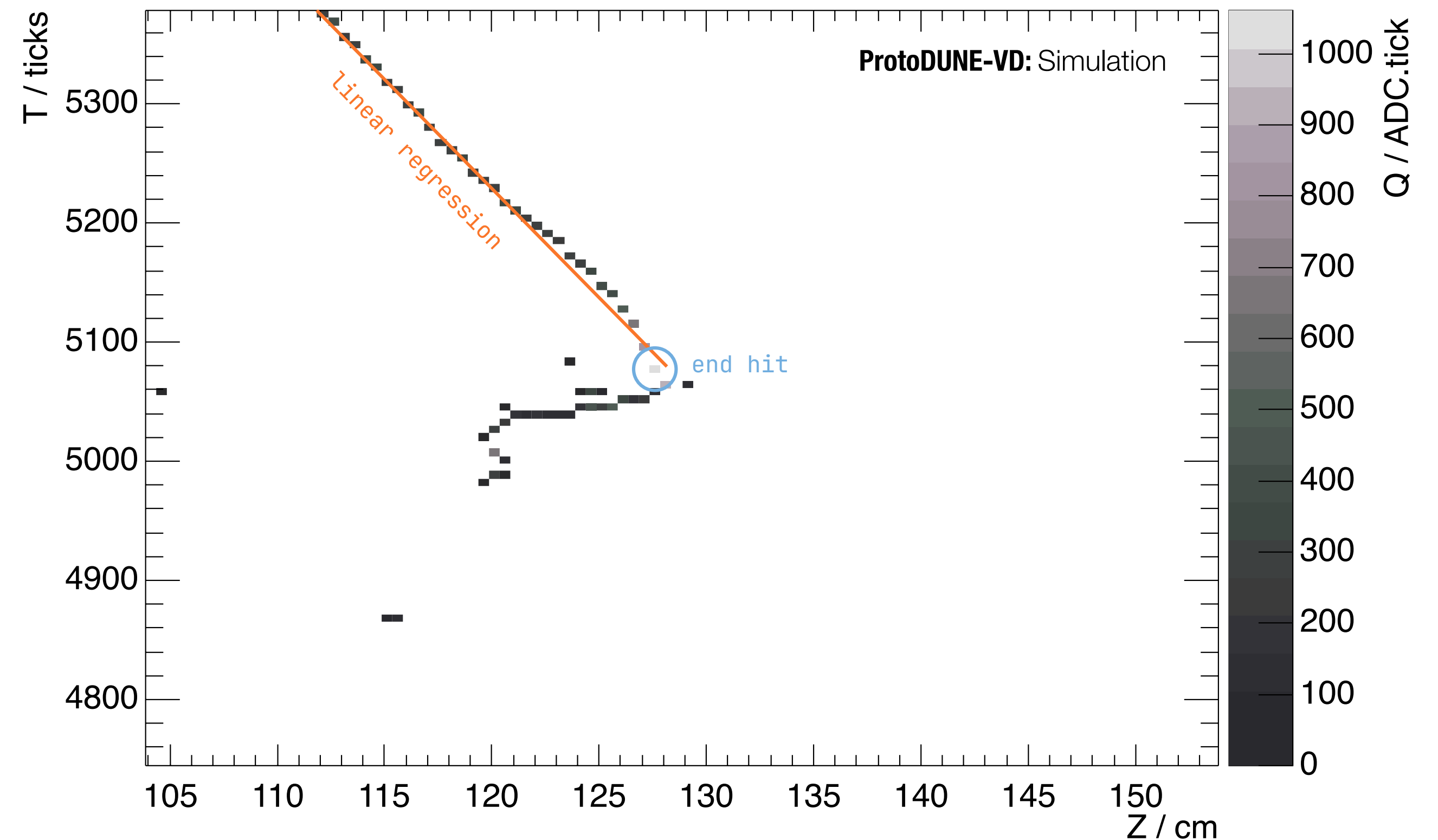


Select well reconstructed **stopping muon** candidates

- **Quality** cuts (length, regression  $r^2$ , jumping tracks)
- **Cathode** crossing, for X reconstruction
  - Michel events only in bottom drift
  - first tests with anode crossing were inconclusive
- **Fiducial** cuts, 20 cm margin in X, Y, Z, T

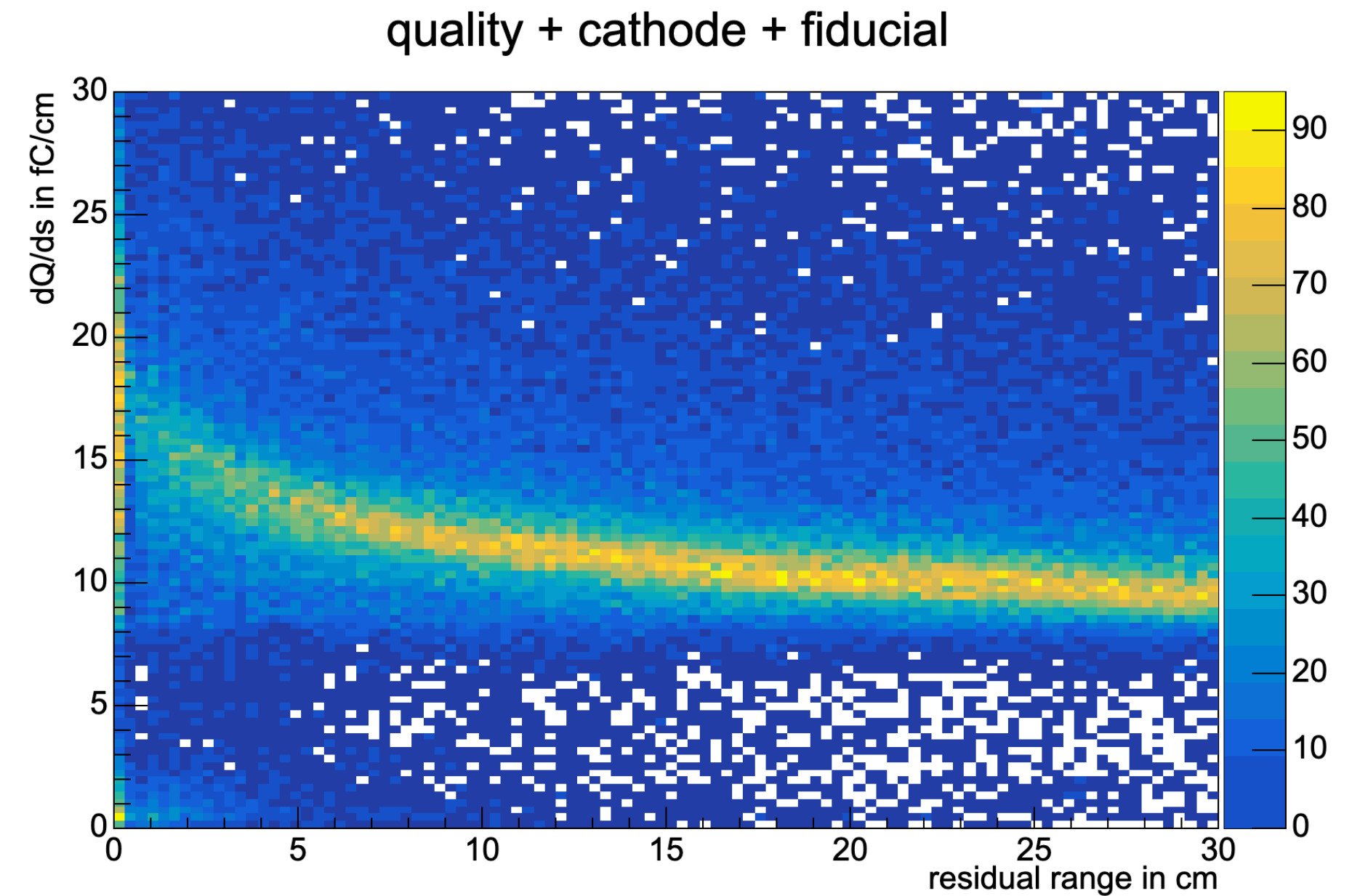
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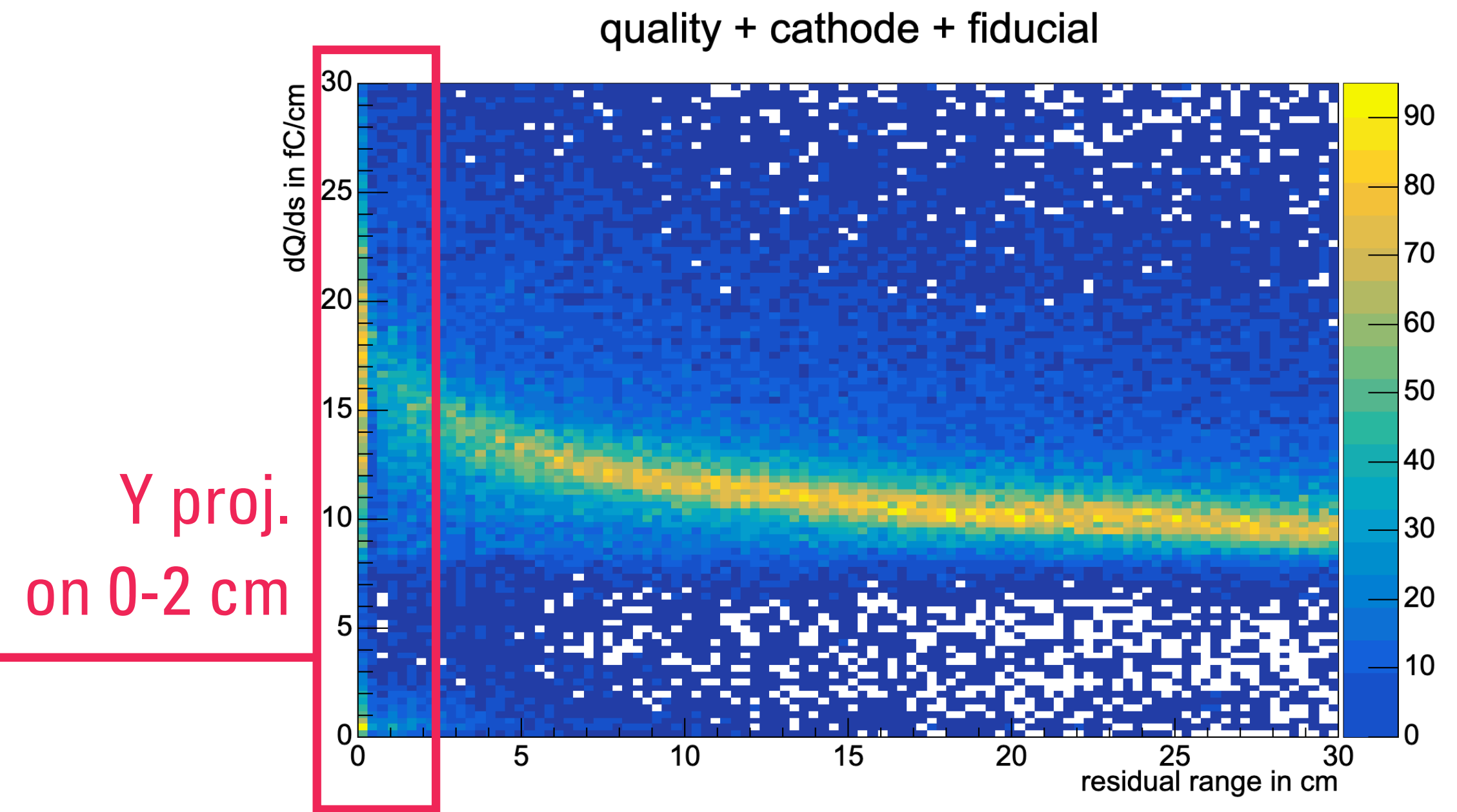
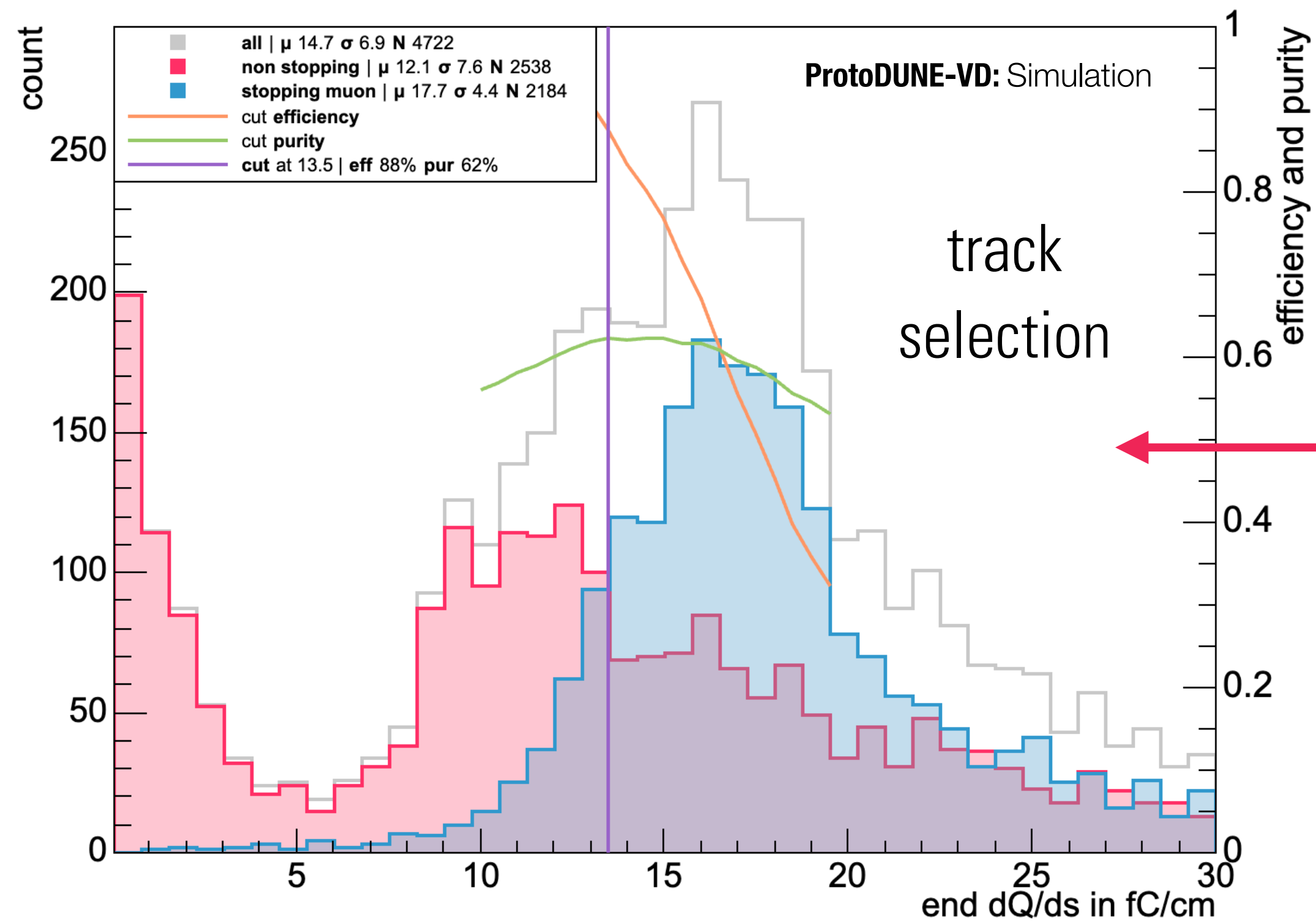


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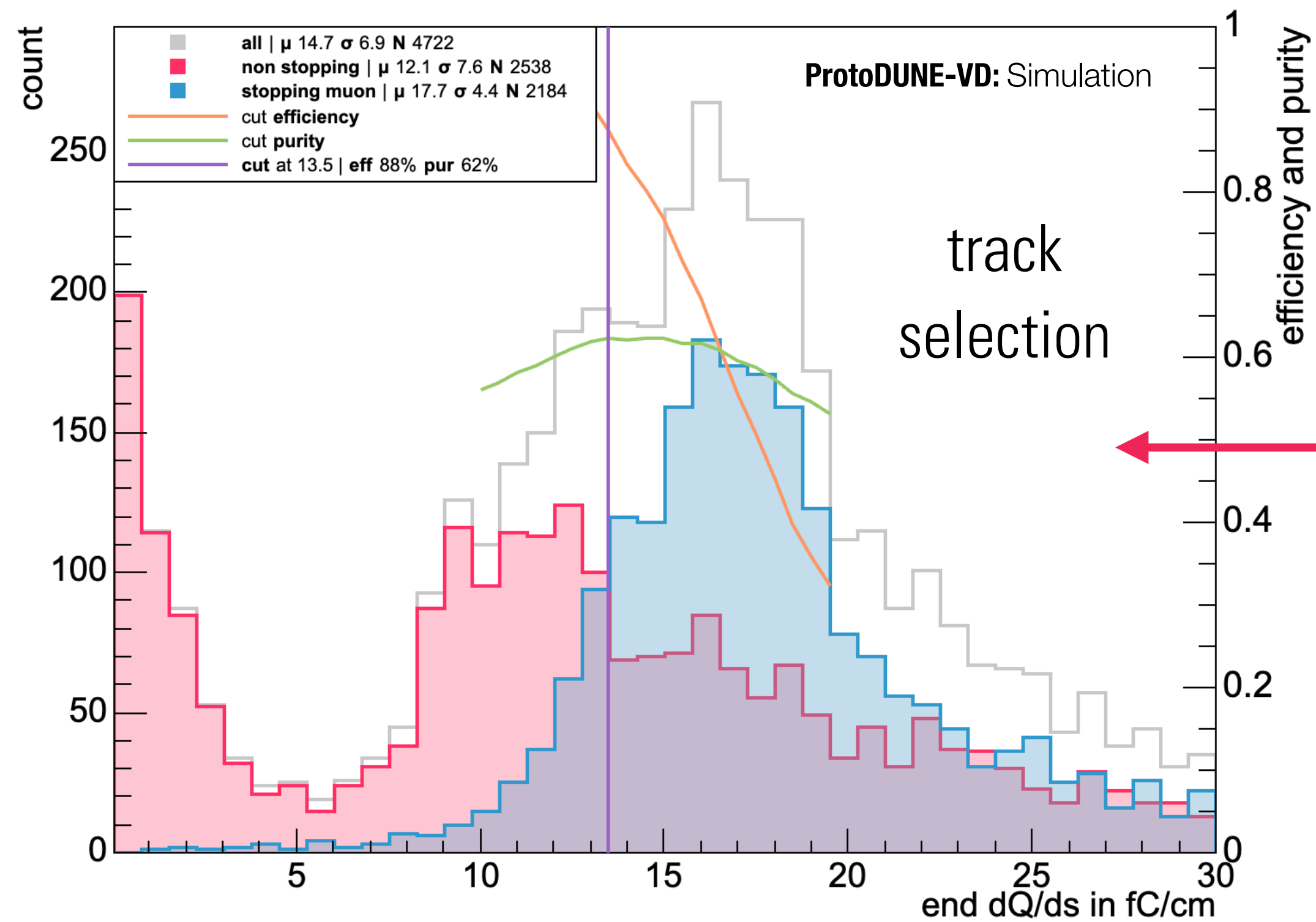


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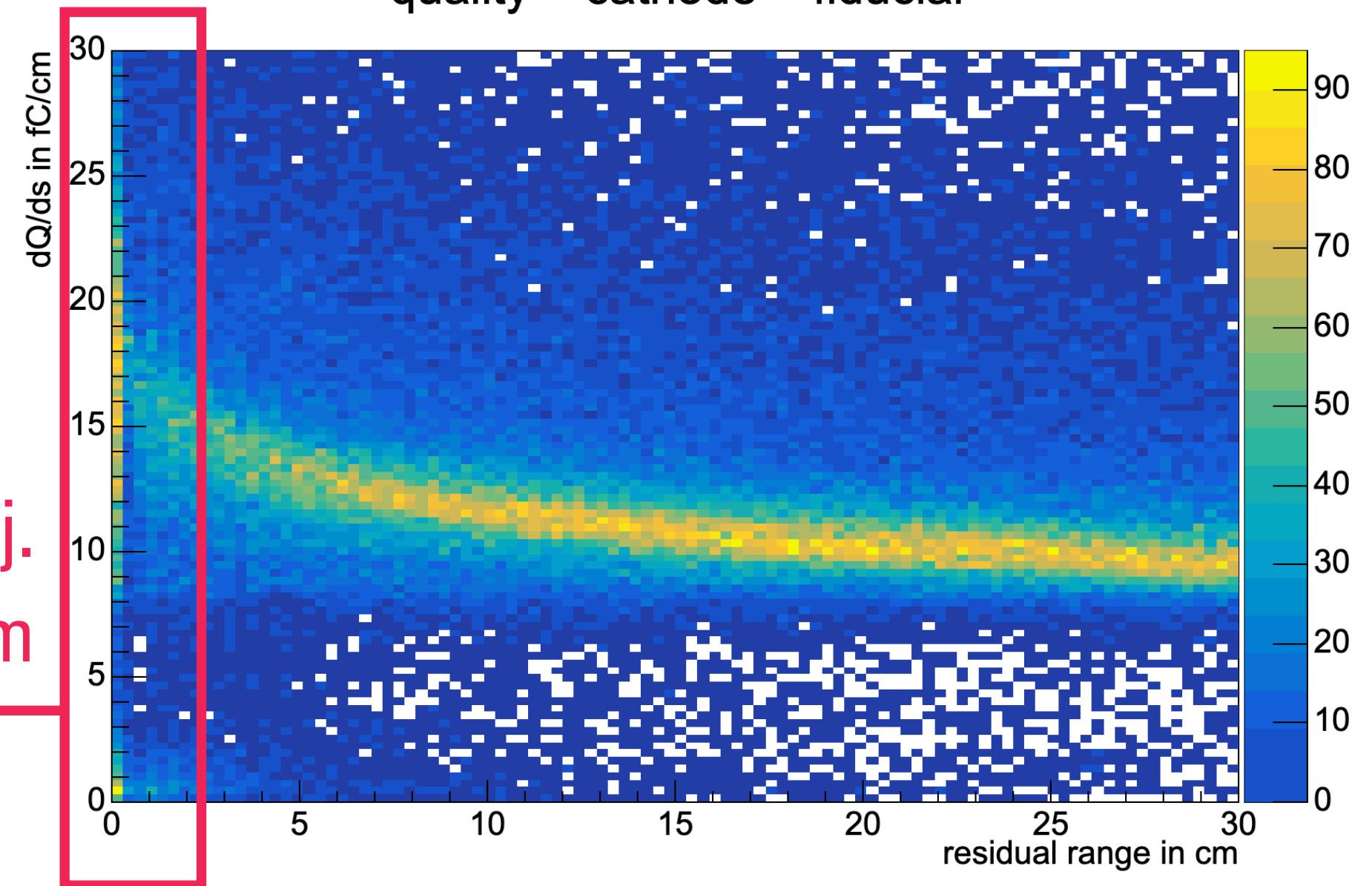
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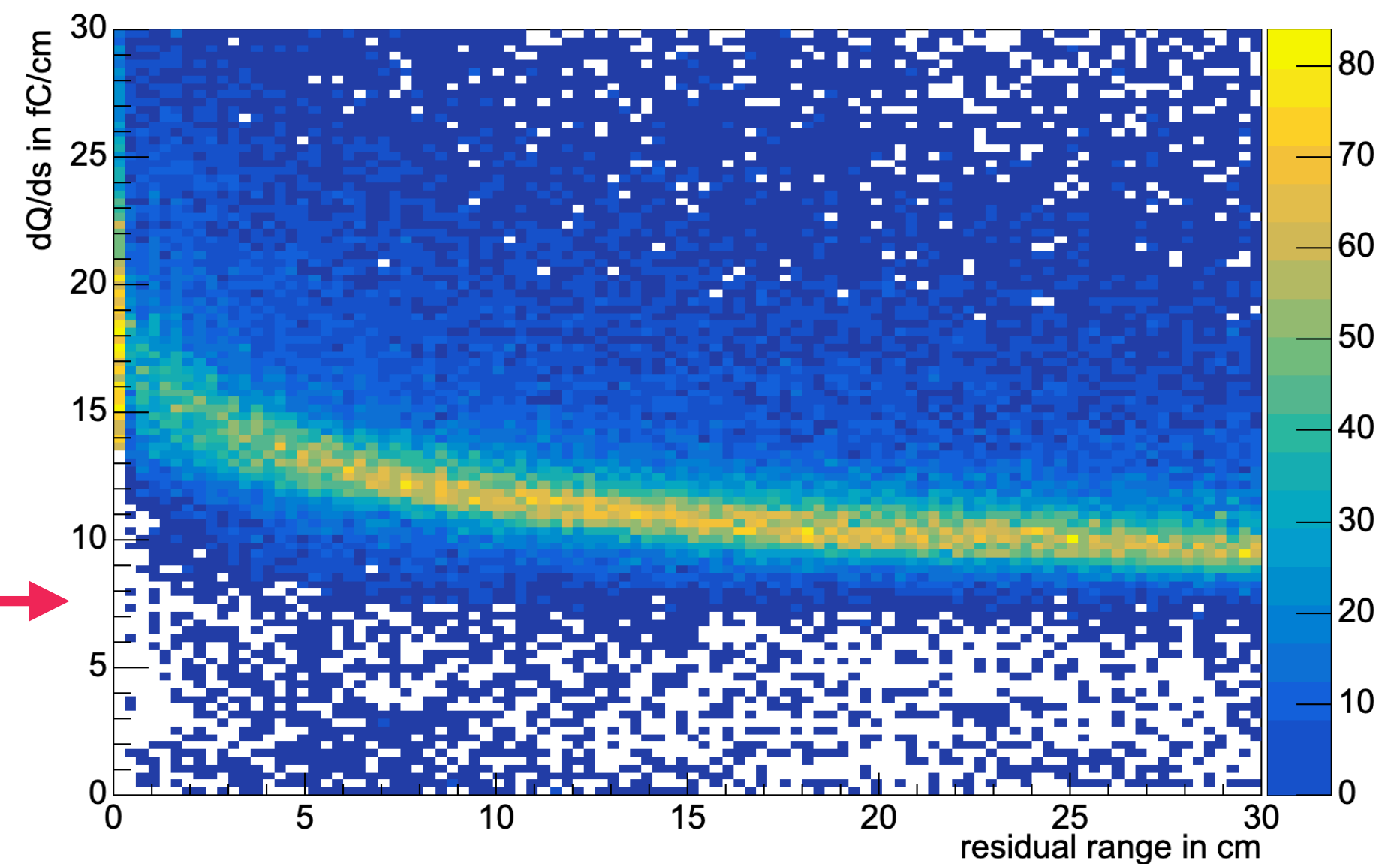
- **Calorimetry**, search for a Bragg peak

after Bragg cut

quality + cathode + fiducial



quality + cathode + fiducial + bragg



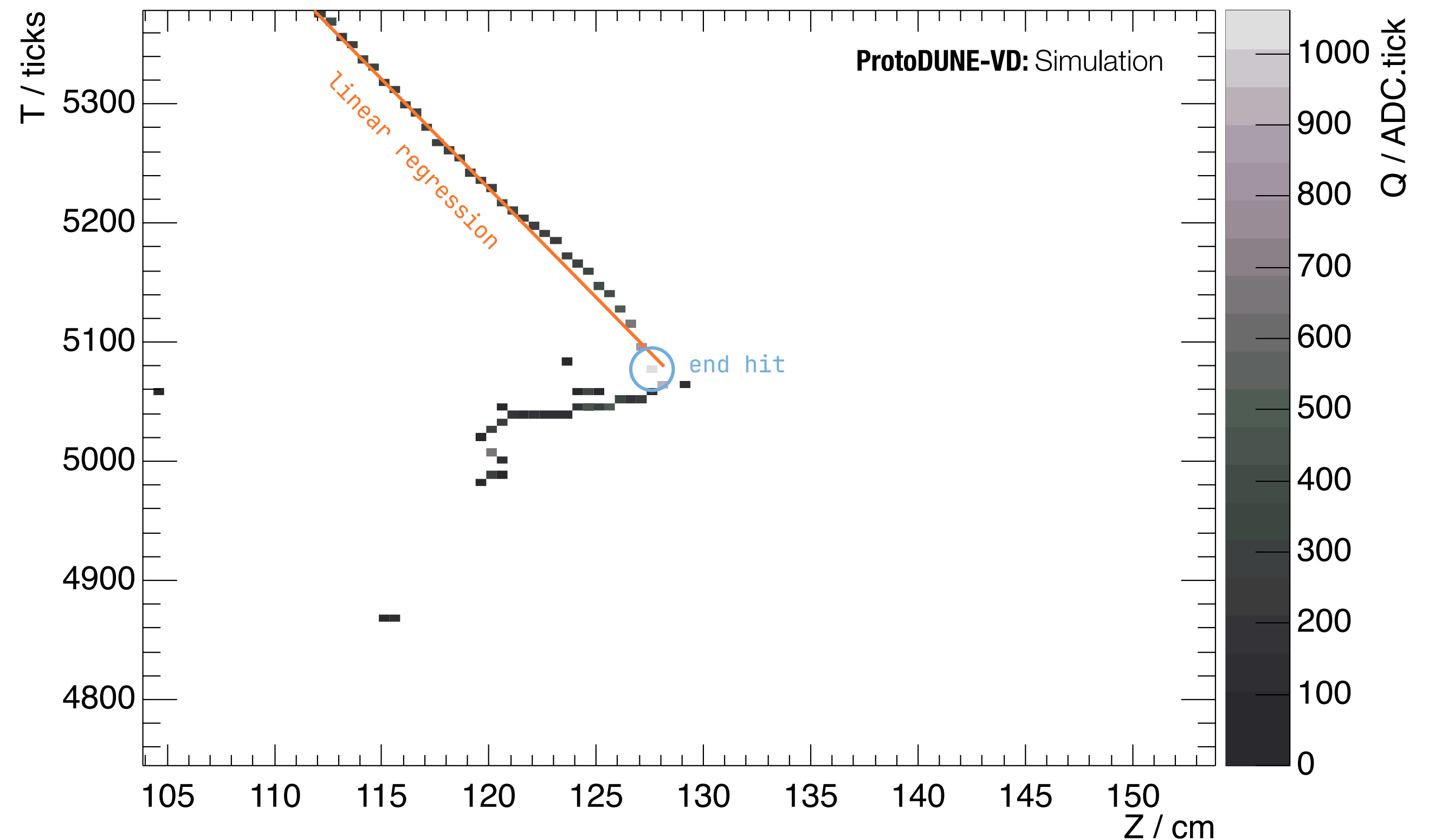
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Select **Michel electron** event candidates

Using **Pandora track** reconstruction

Michel electron illustration



Select well reconstructed stopping muon candidates

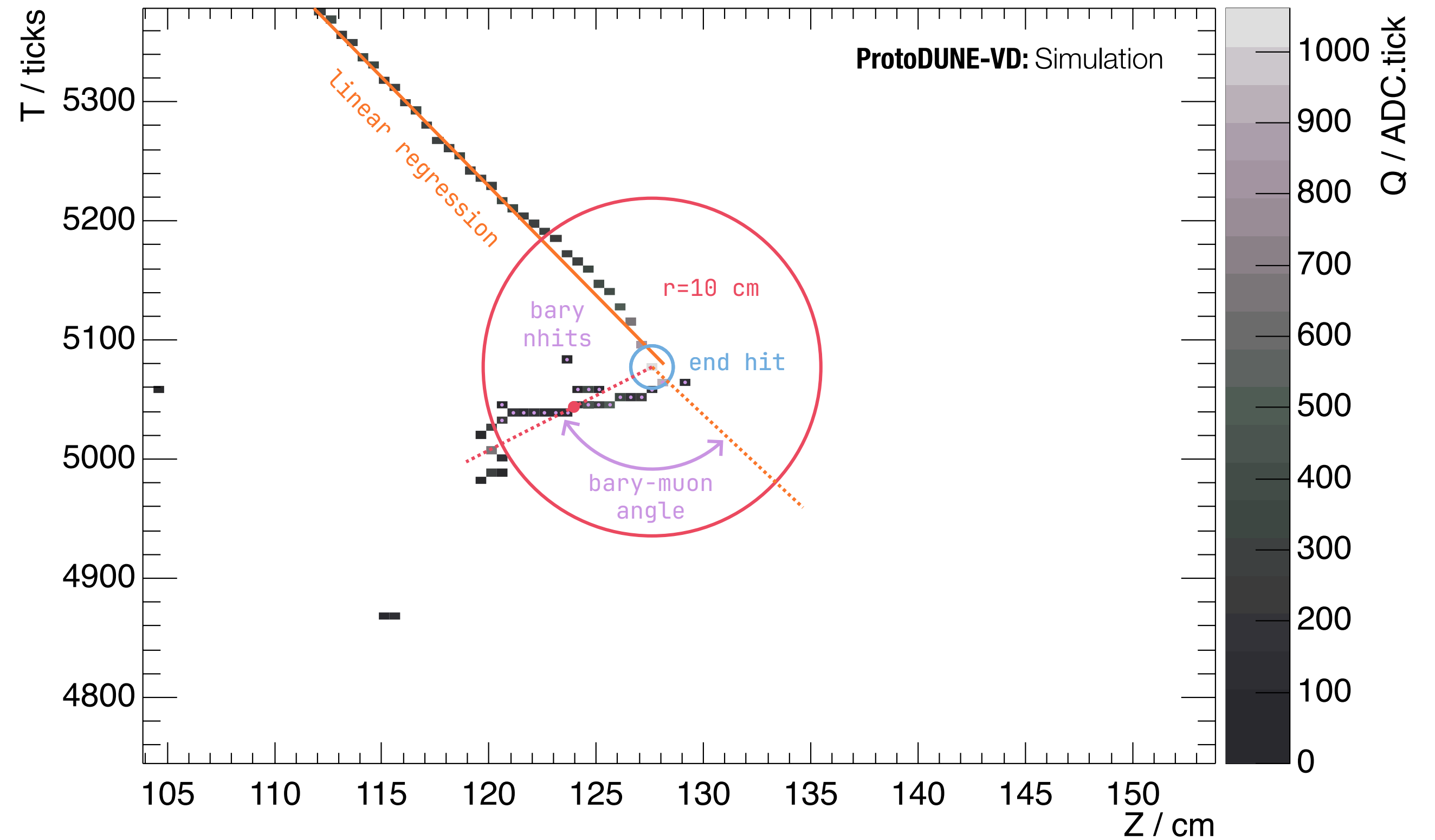
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Select **Michel electron** event candidates

- Topological cuts
  - no long tracks passing by
  - at least 4 Hits 10 cm around the end point
  - barycenter-muon angle in  $30^\circ$ - $150^\circ$

Using **Pandora track** reconstruction

Michel electron illustration



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Cosmics (by Y. Kermaidic, workflow 11250)

**ProtoDUNE-VD:** Simulation

	all tracks	full selection
all tracks	374'342	699
truly stopping muons	30'272	664
truly decaying muons	20'871	611

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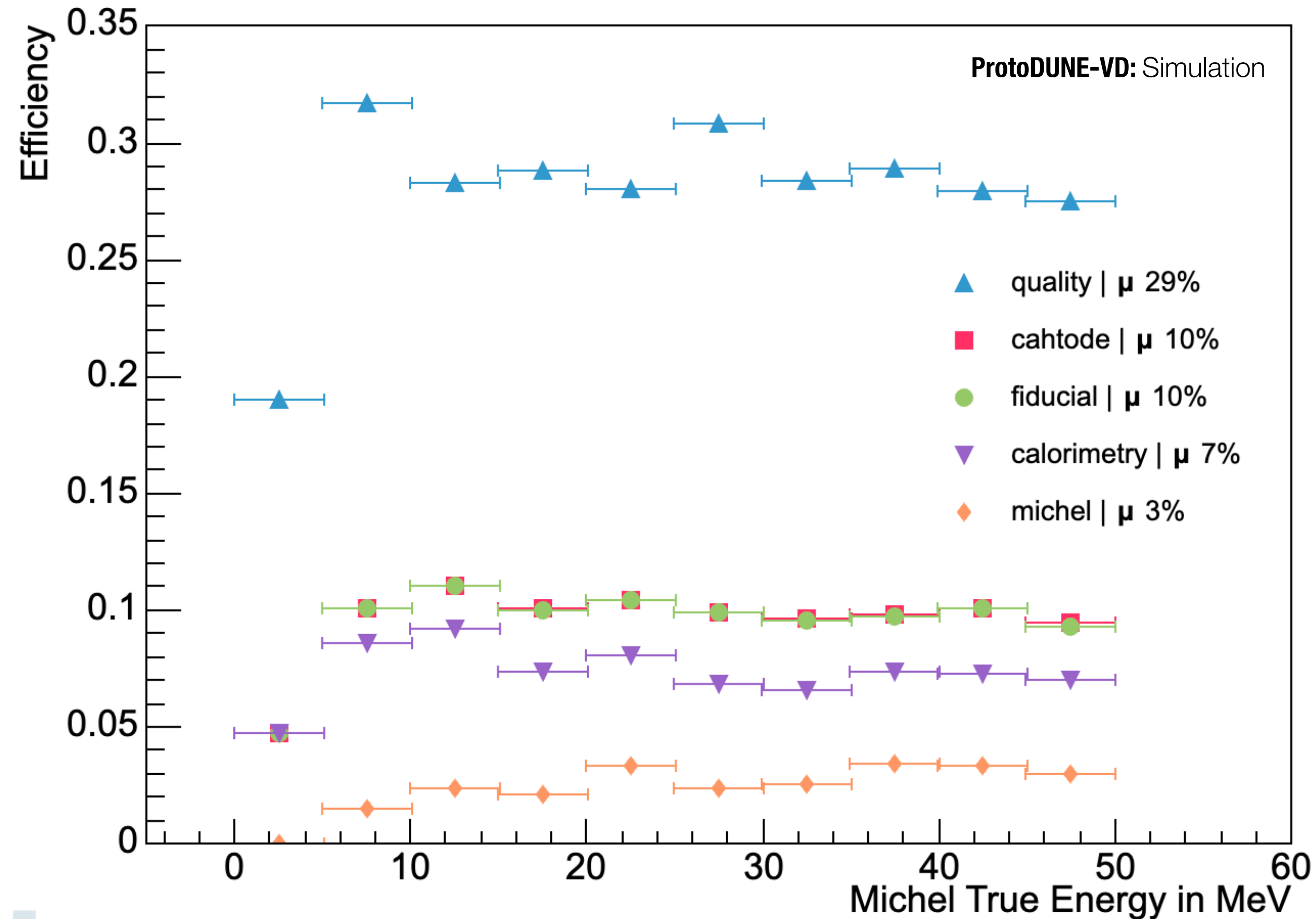
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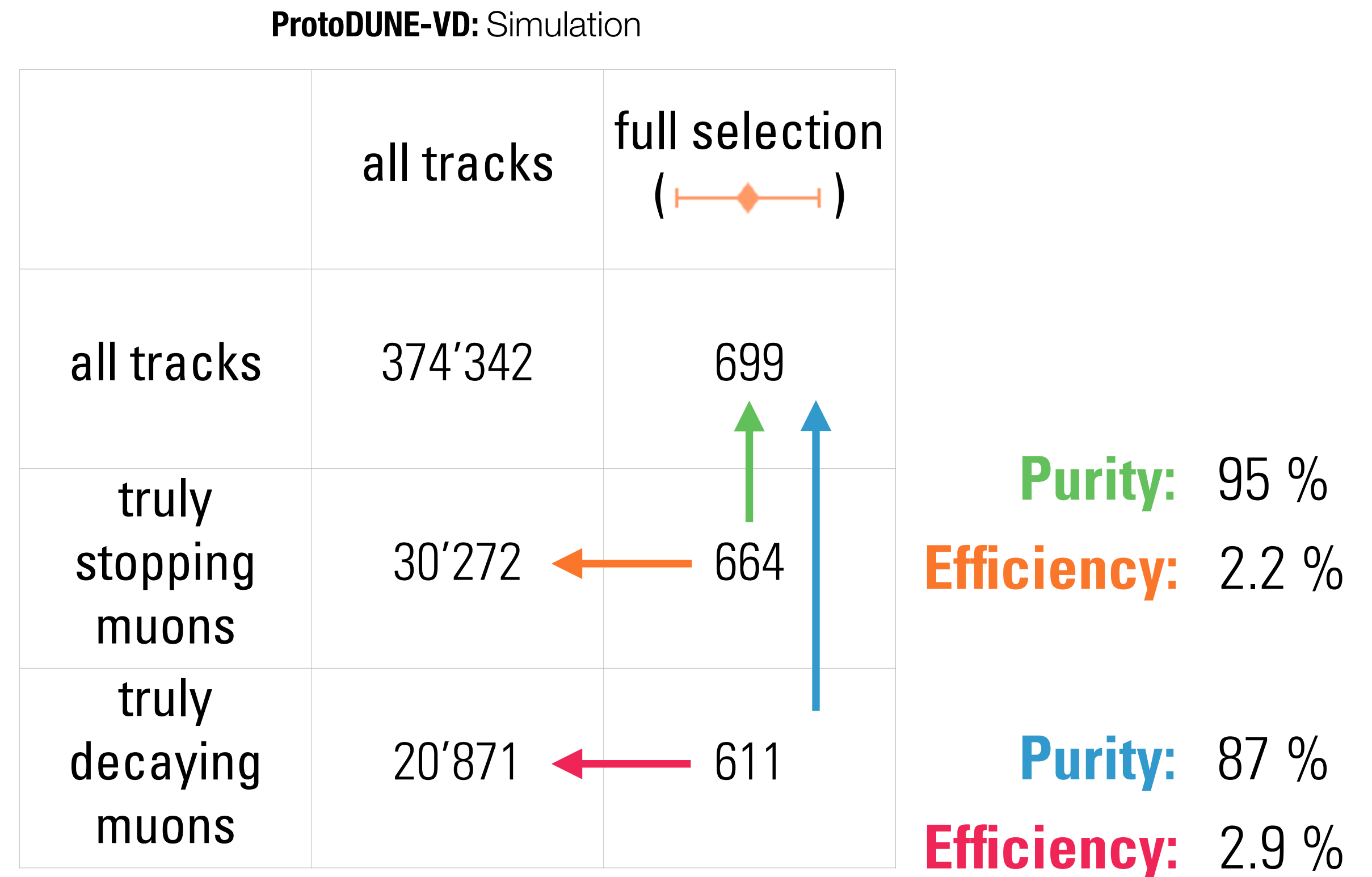
**Purity:** 95 %  
**Efficiency:** 2.2 %

**Purity:** 87 %  
**Efficiency:** 2.9 %

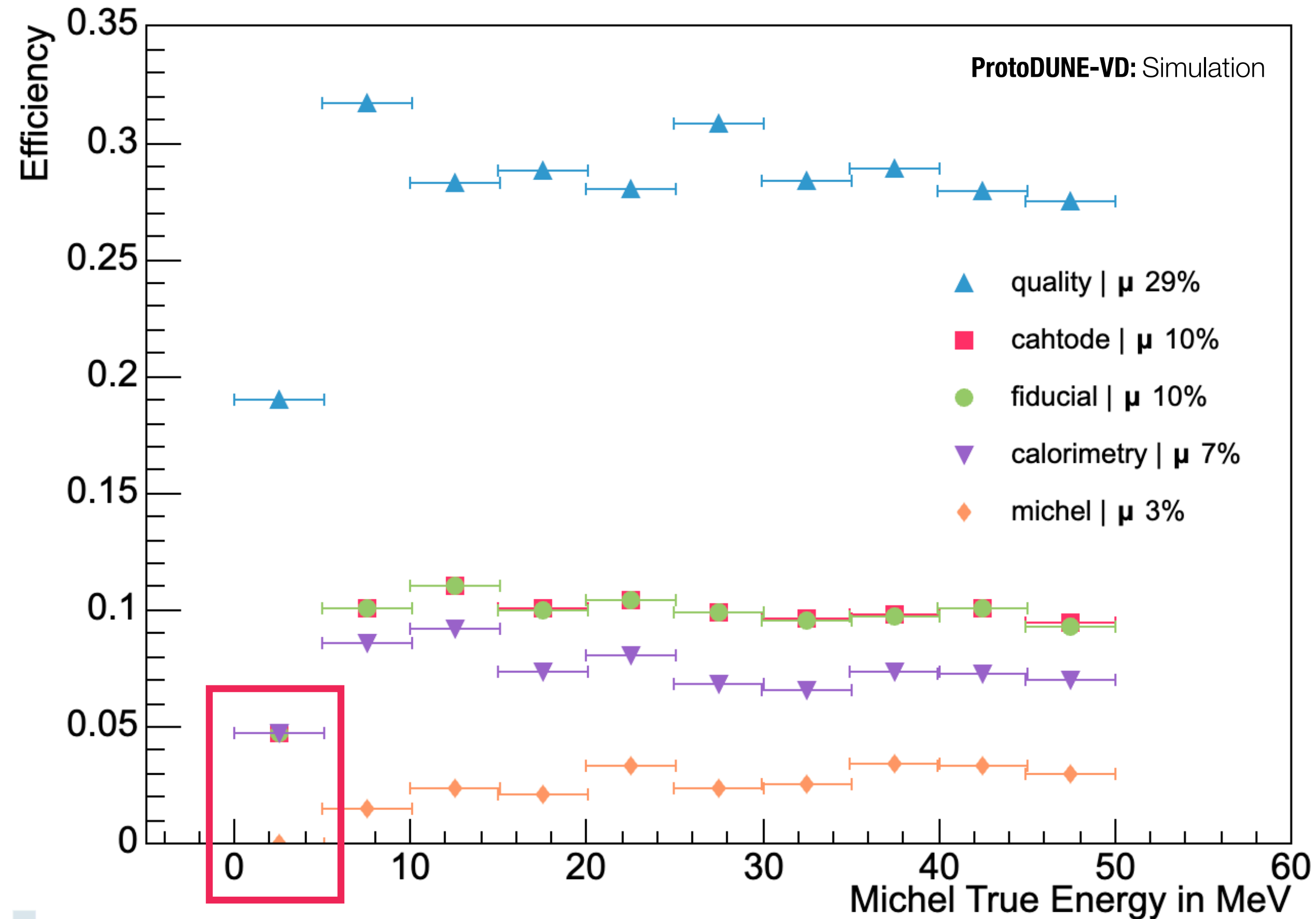
### Selection efficiency bias



### Cosmics (by Y. Kermaidic, workflow 11250)

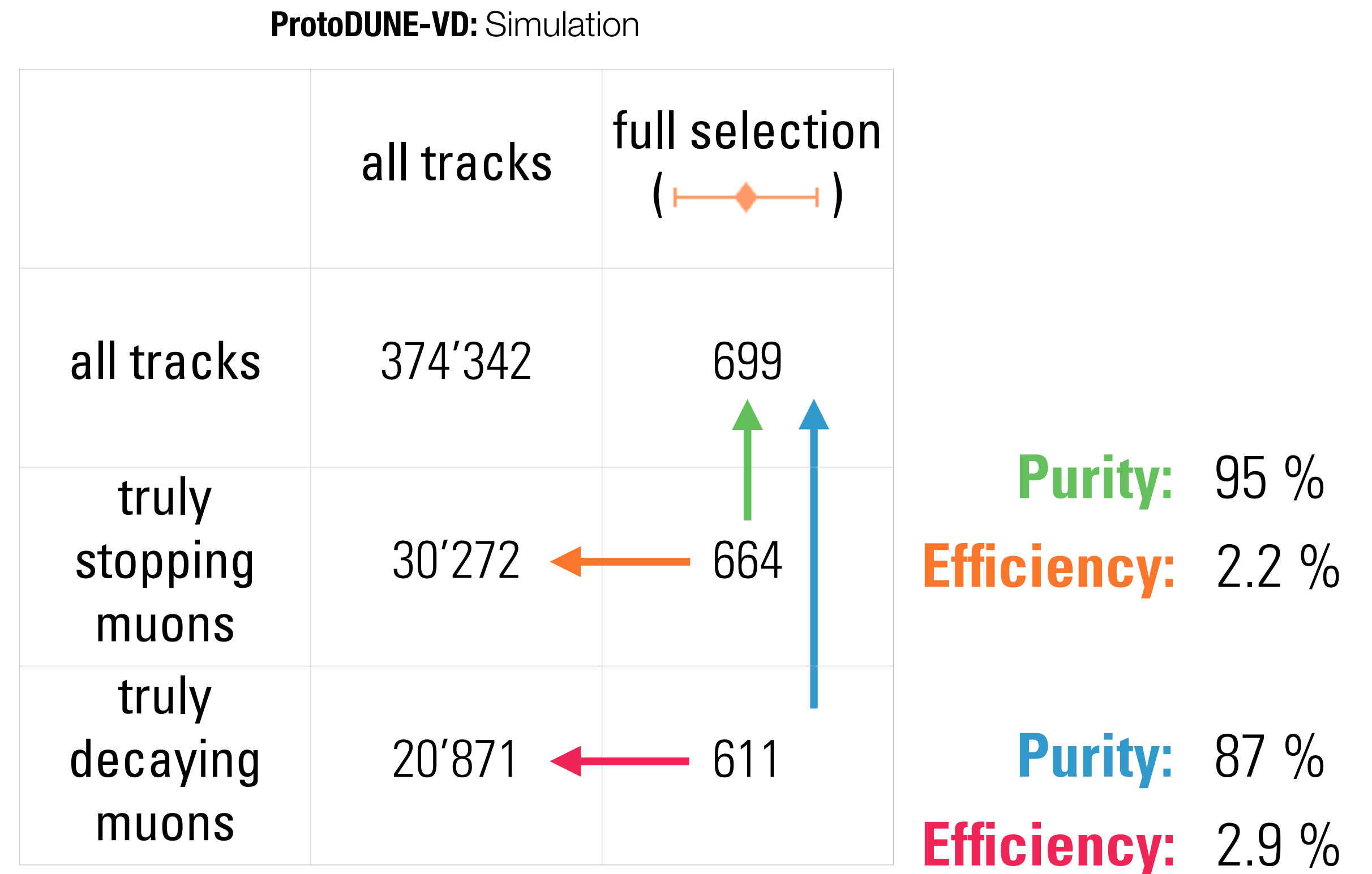


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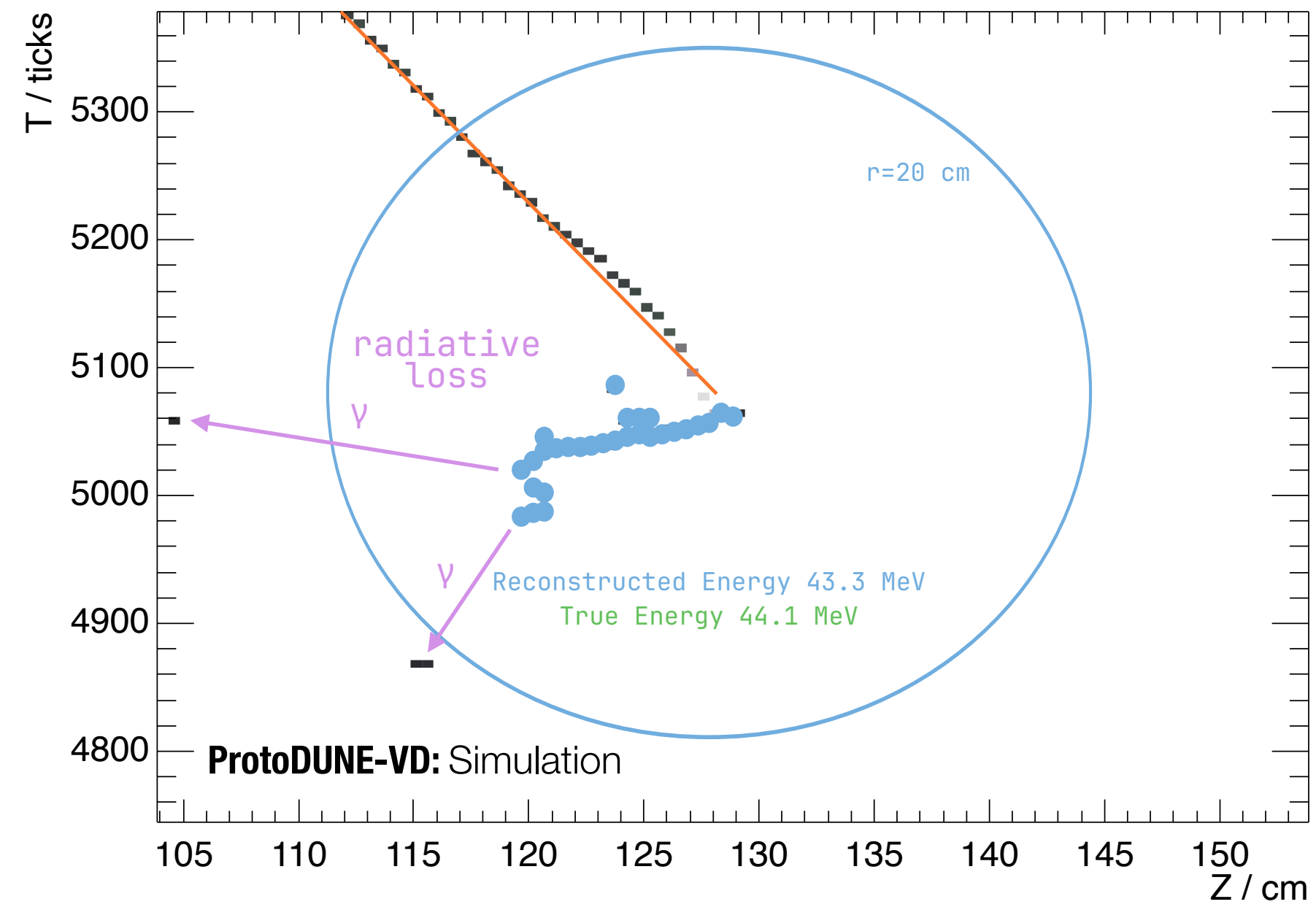


no reconstructed Michel electrons below 5 MeV

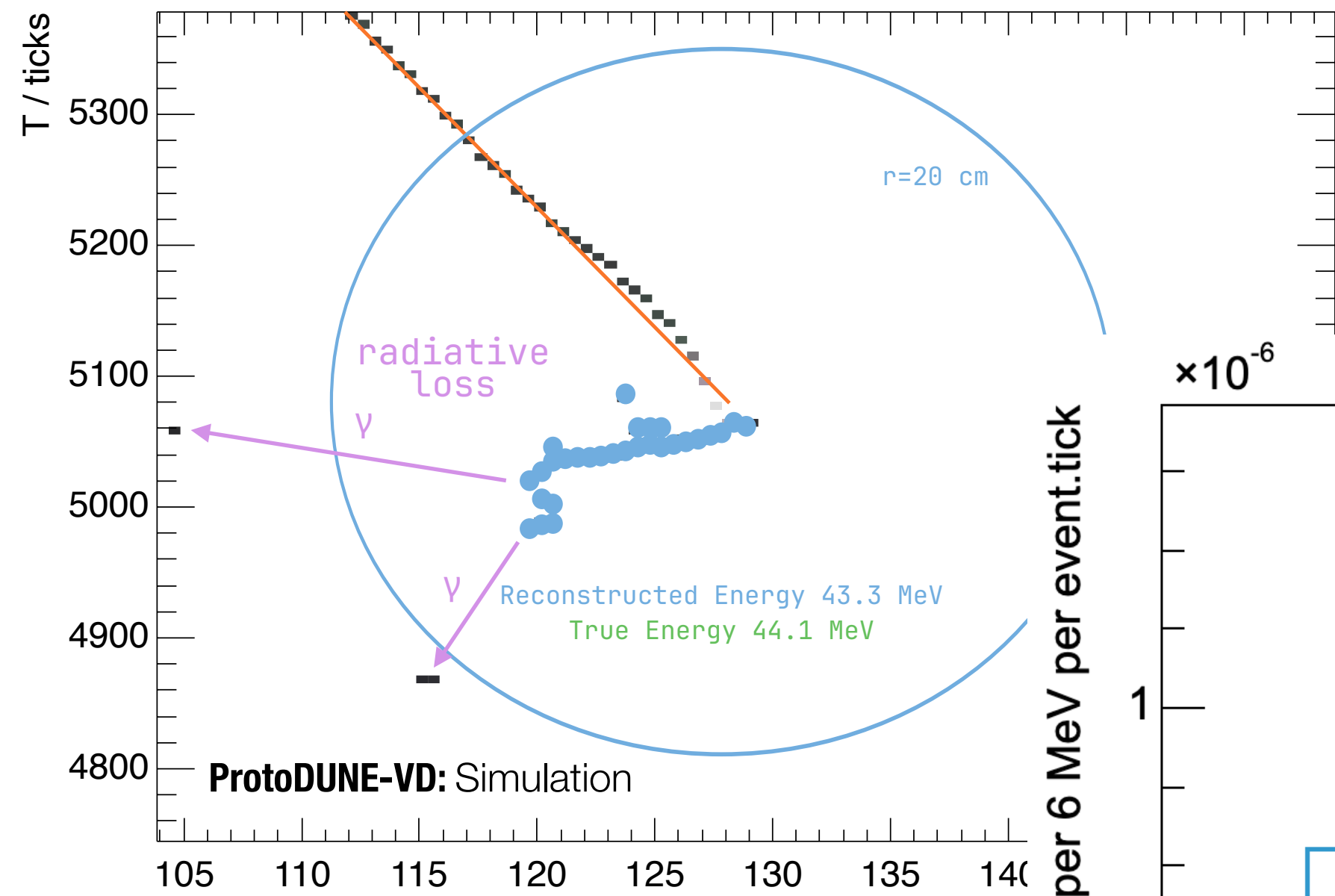
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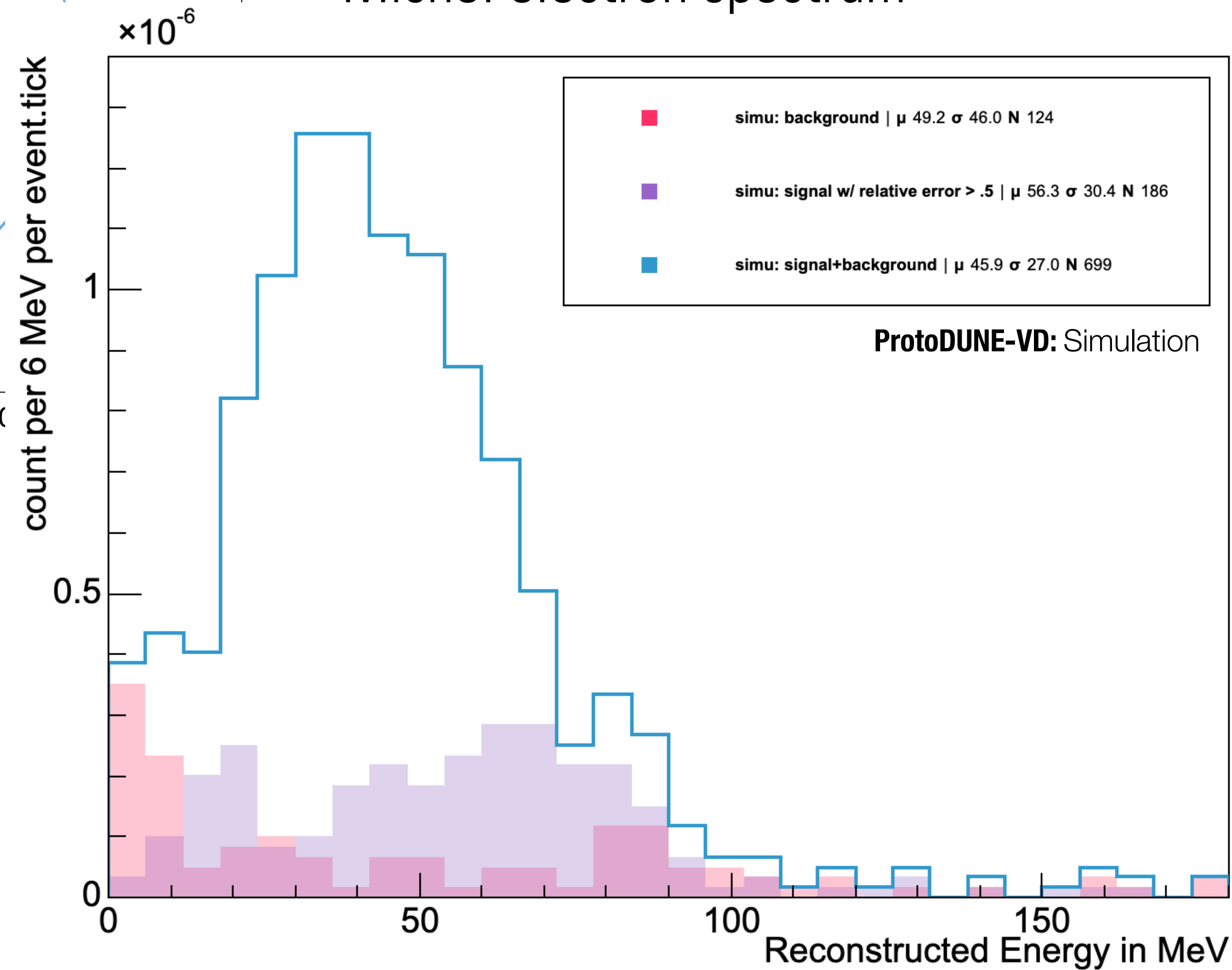
Integrate all charges in a 20 cm radius (excl. long tracks)



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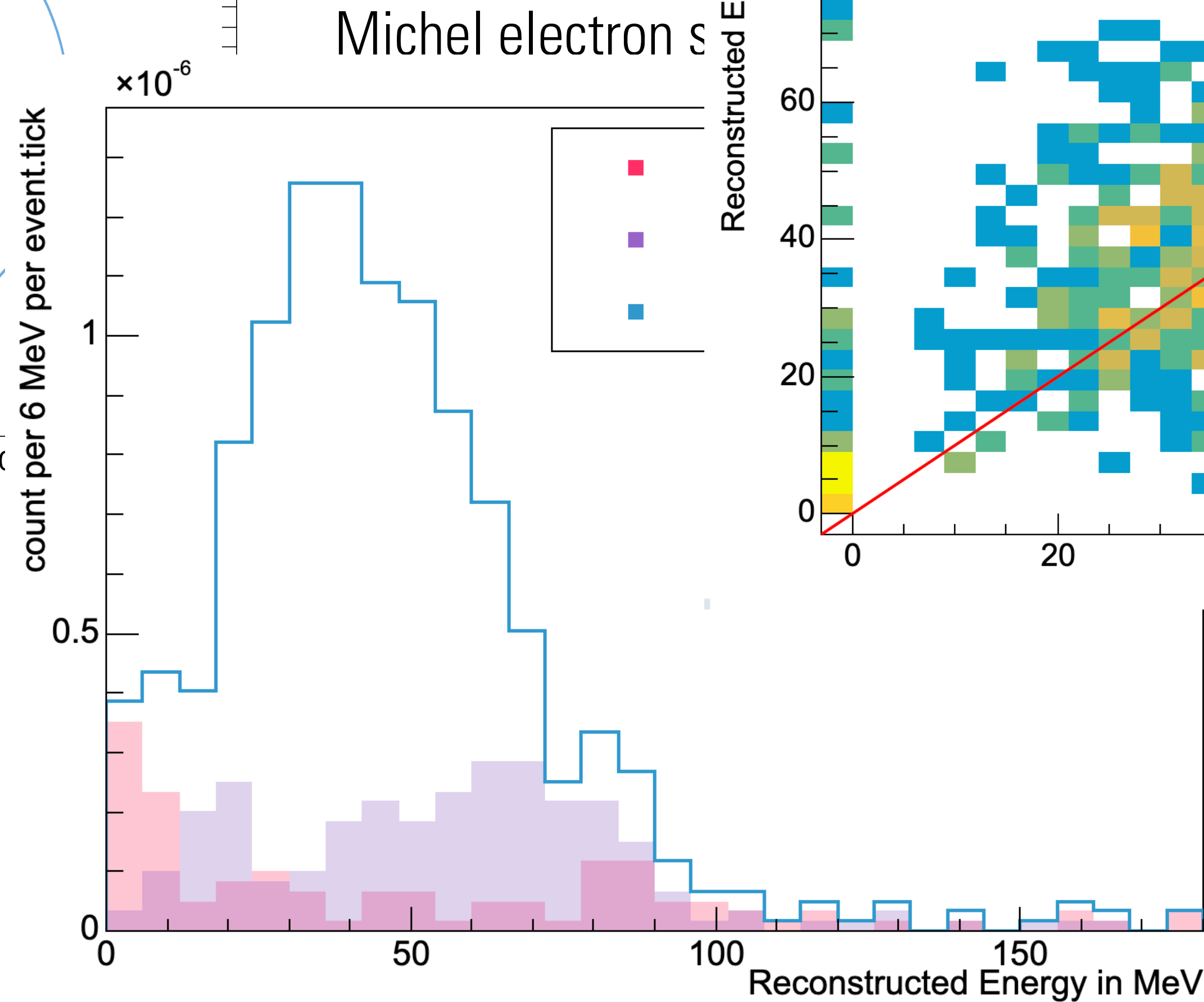
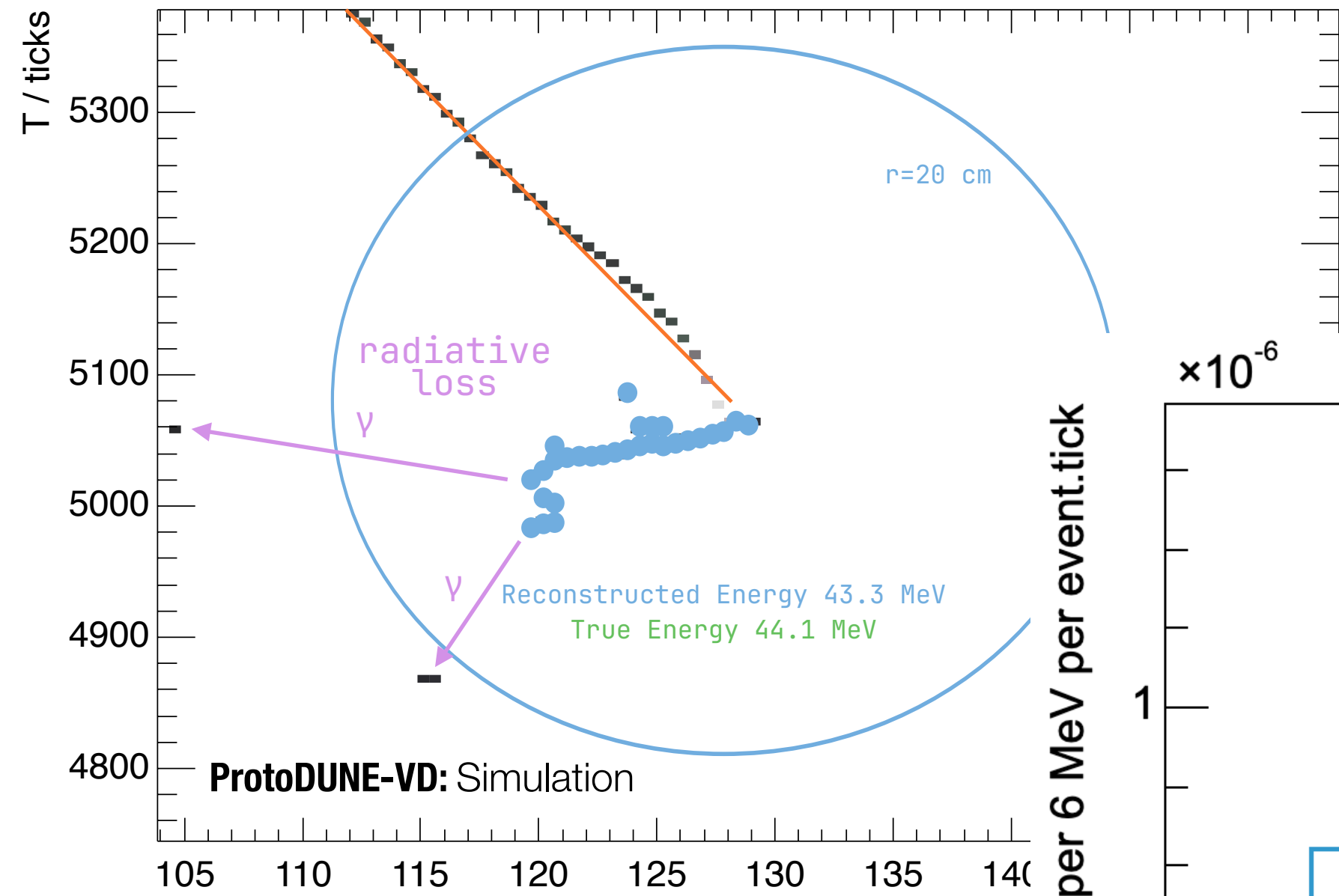
### Michel electron spectrum



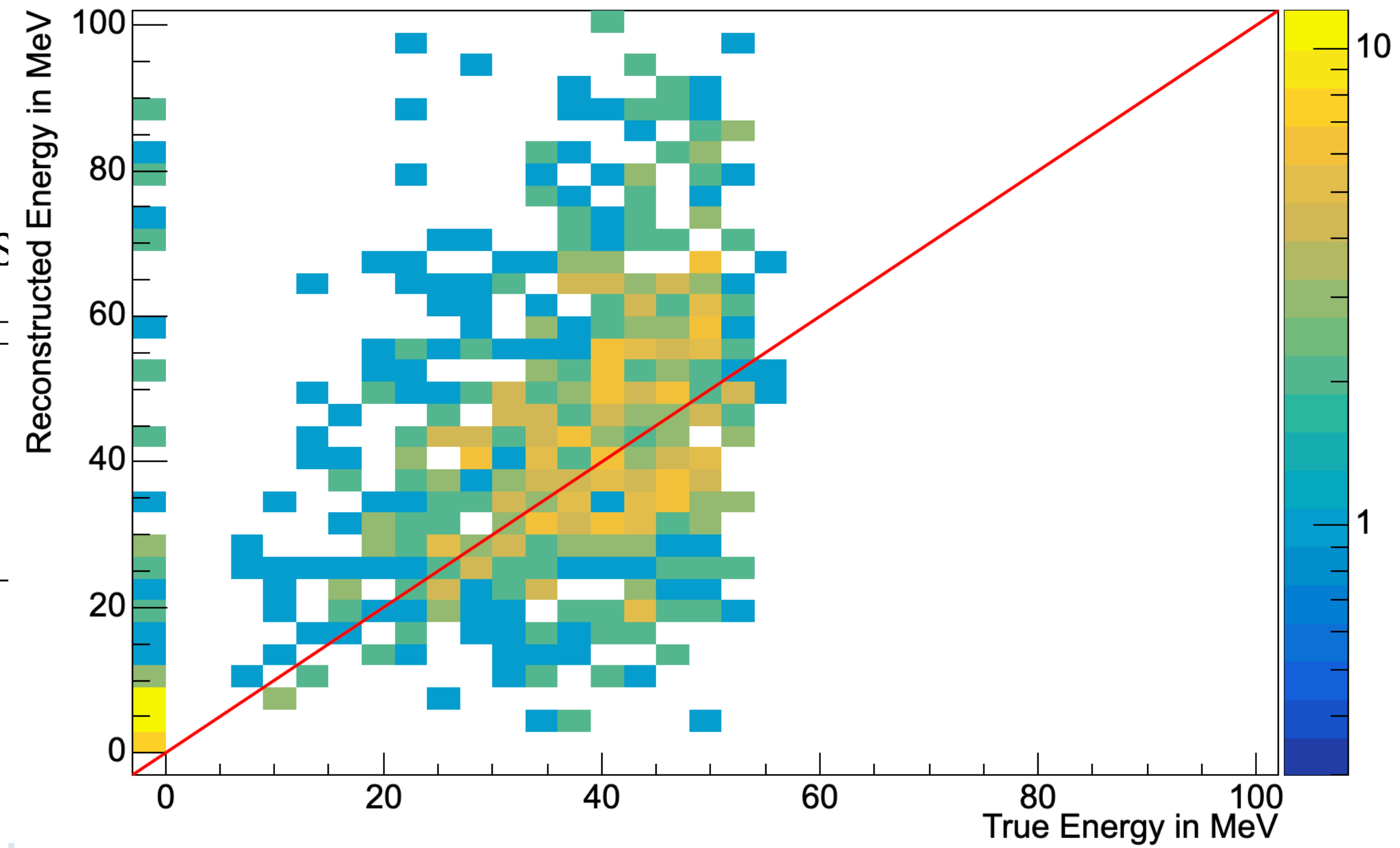
background

ill ener. reco.

Integrate all charges in a 20 cm radius (excl. long tracks)



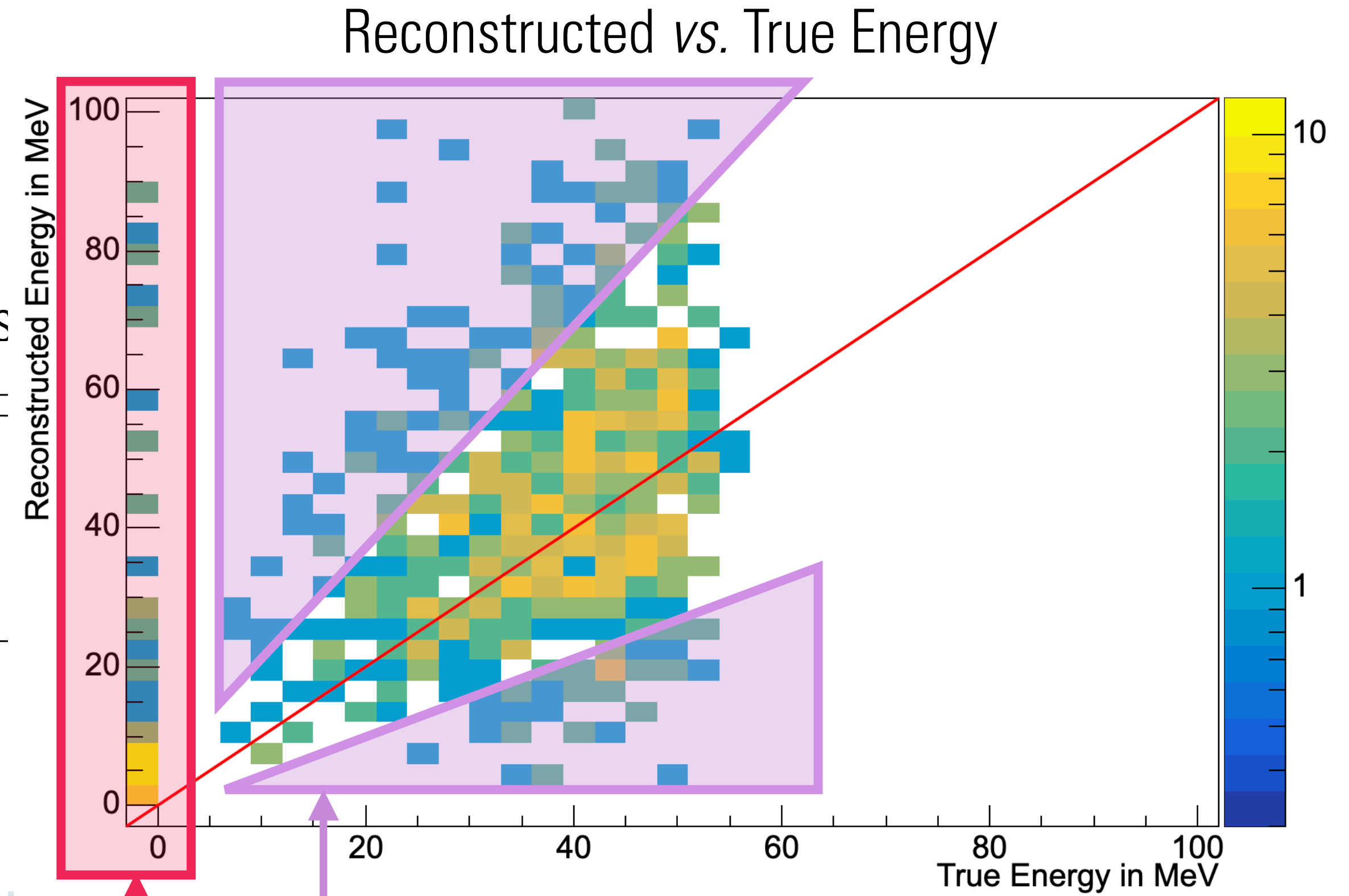
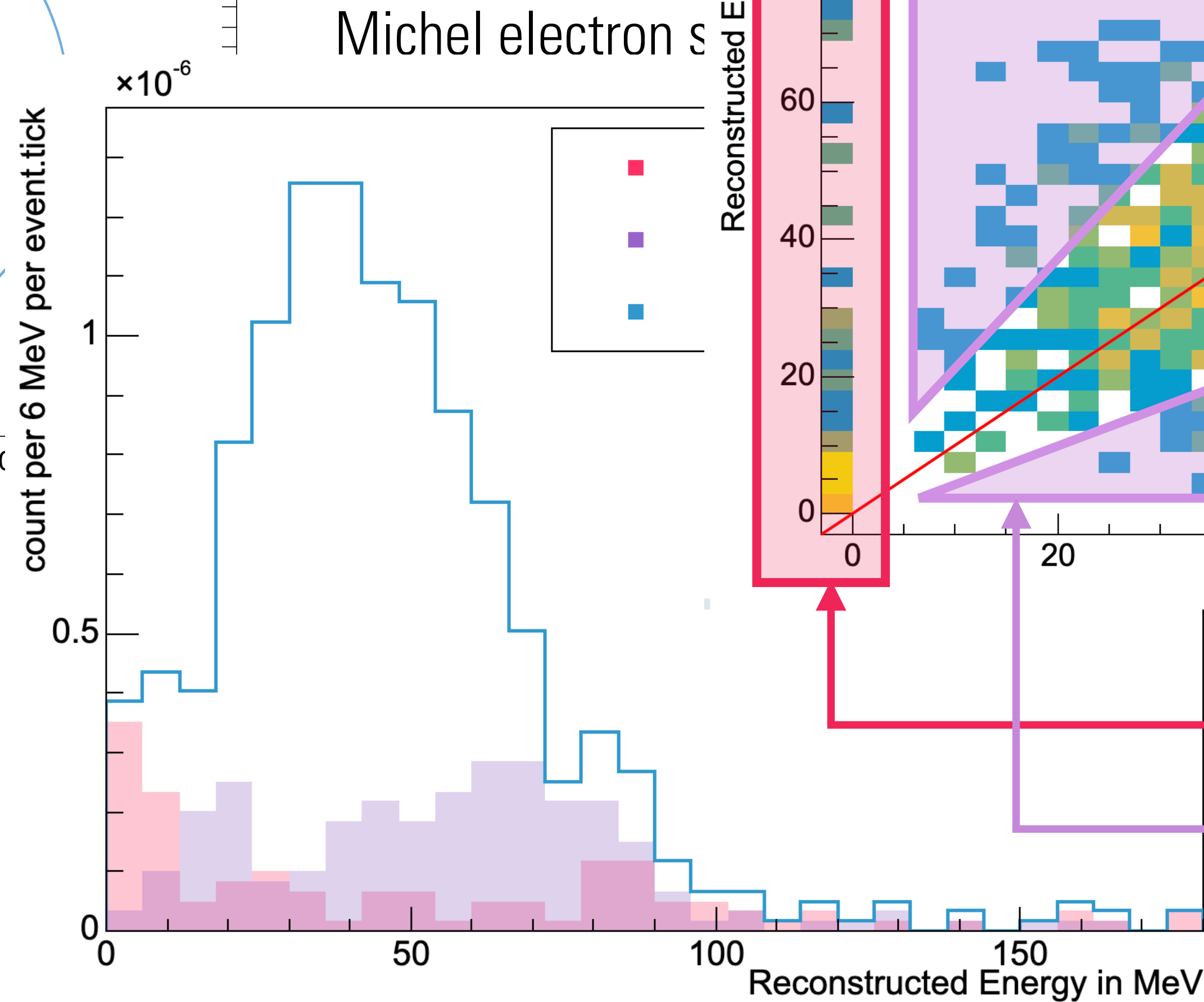
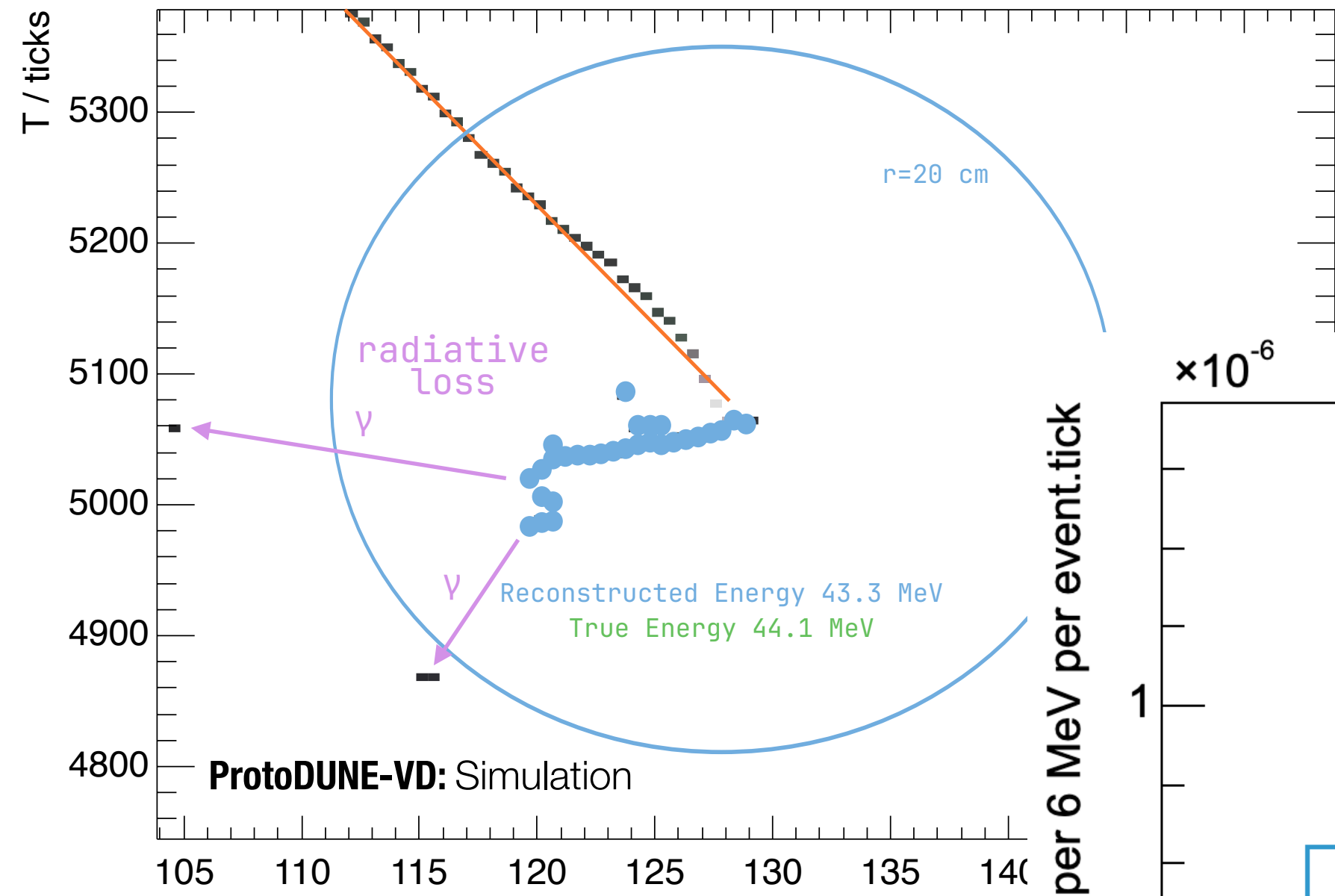
### Reconstructed vs. True Energy



**background**

**ill ener. reco.**

Integrate all charges in a 20 cm radius (excl. long tracks)



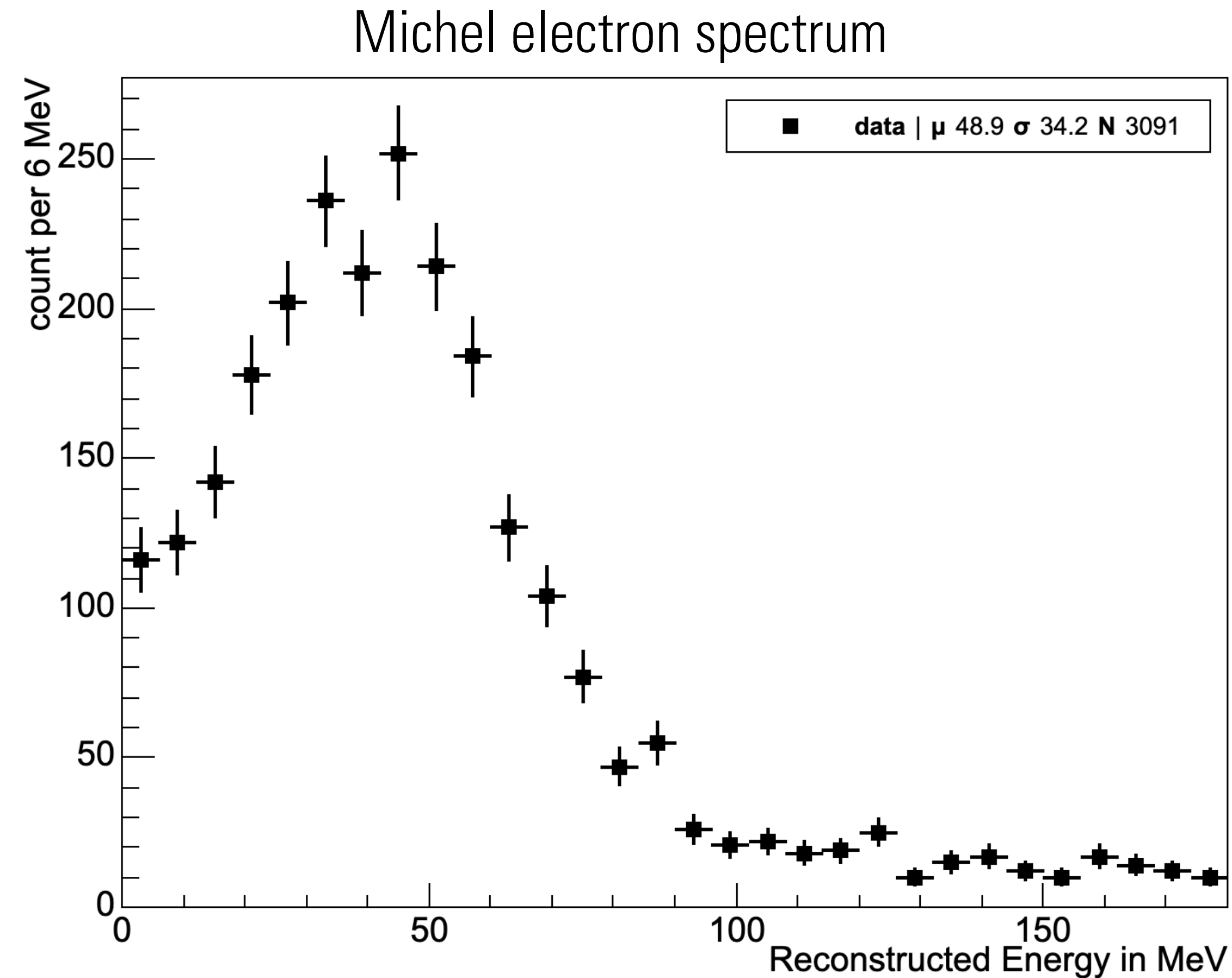
background = first bin

ill ener. reco. = far from diag.

Data:

- Runs: 40'890, 39'933, 40'346
- 51'114 events (of 10'000 ticks)
- 3'518'295 tracks total
- 3'776 michel electron candidates

Calibration with the MIP dQ/ds



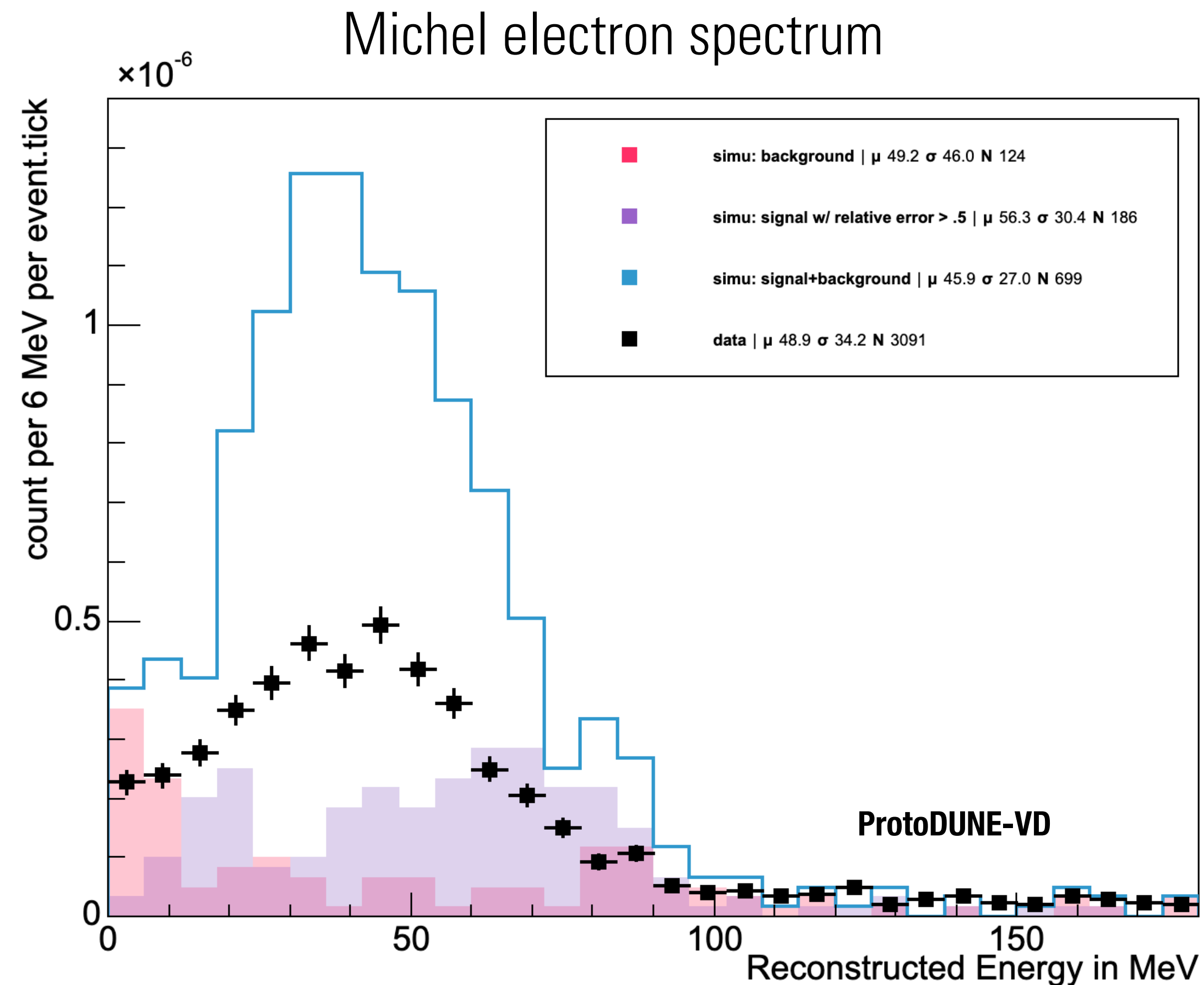
## Simulation:

- Cosmics (by Y. Kermaidic, workflow 11250)
- 9'940 events (of 6'000 ticks)
- 374'342 tracks total
- 835 michel electron candidates

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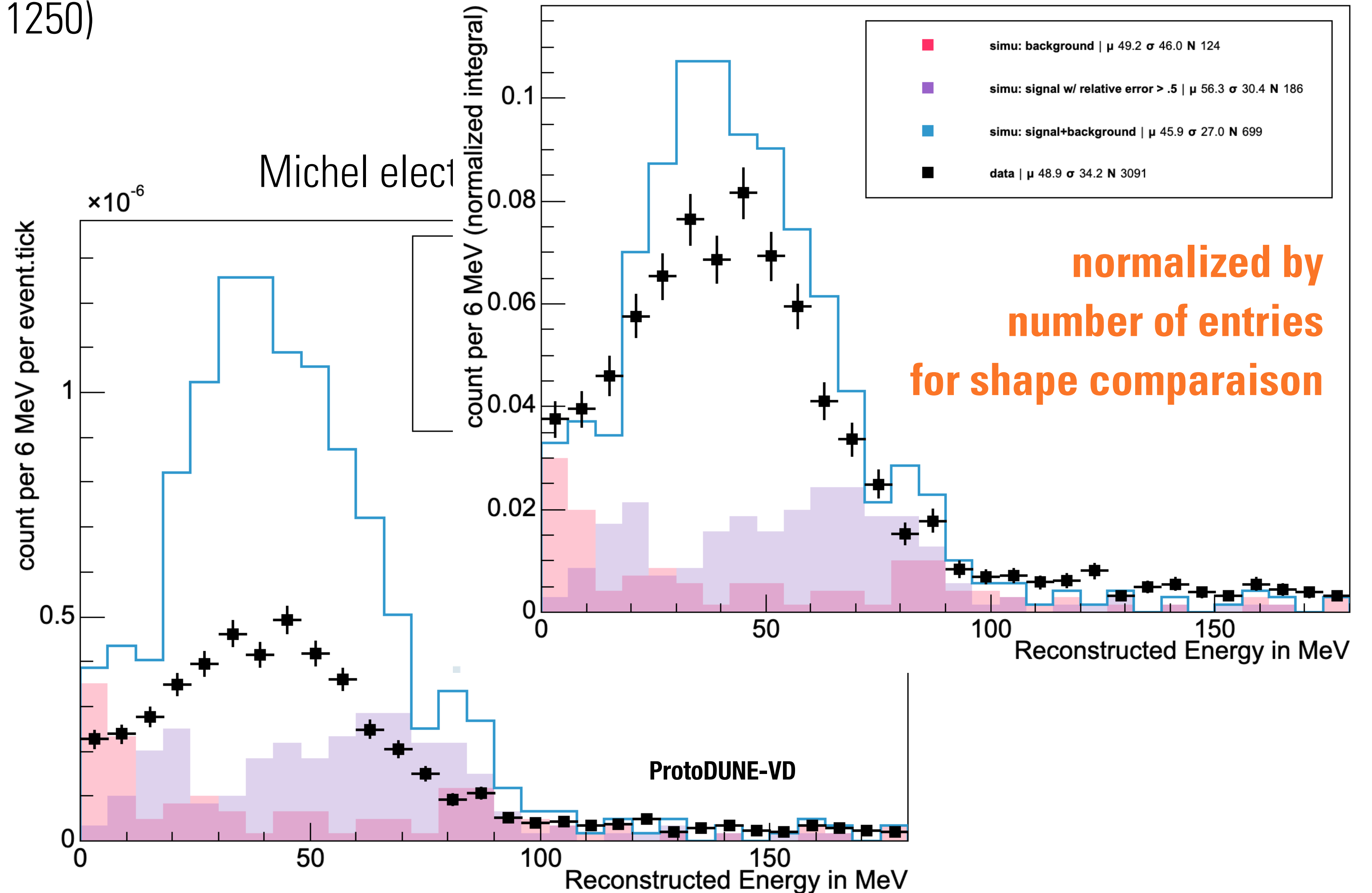
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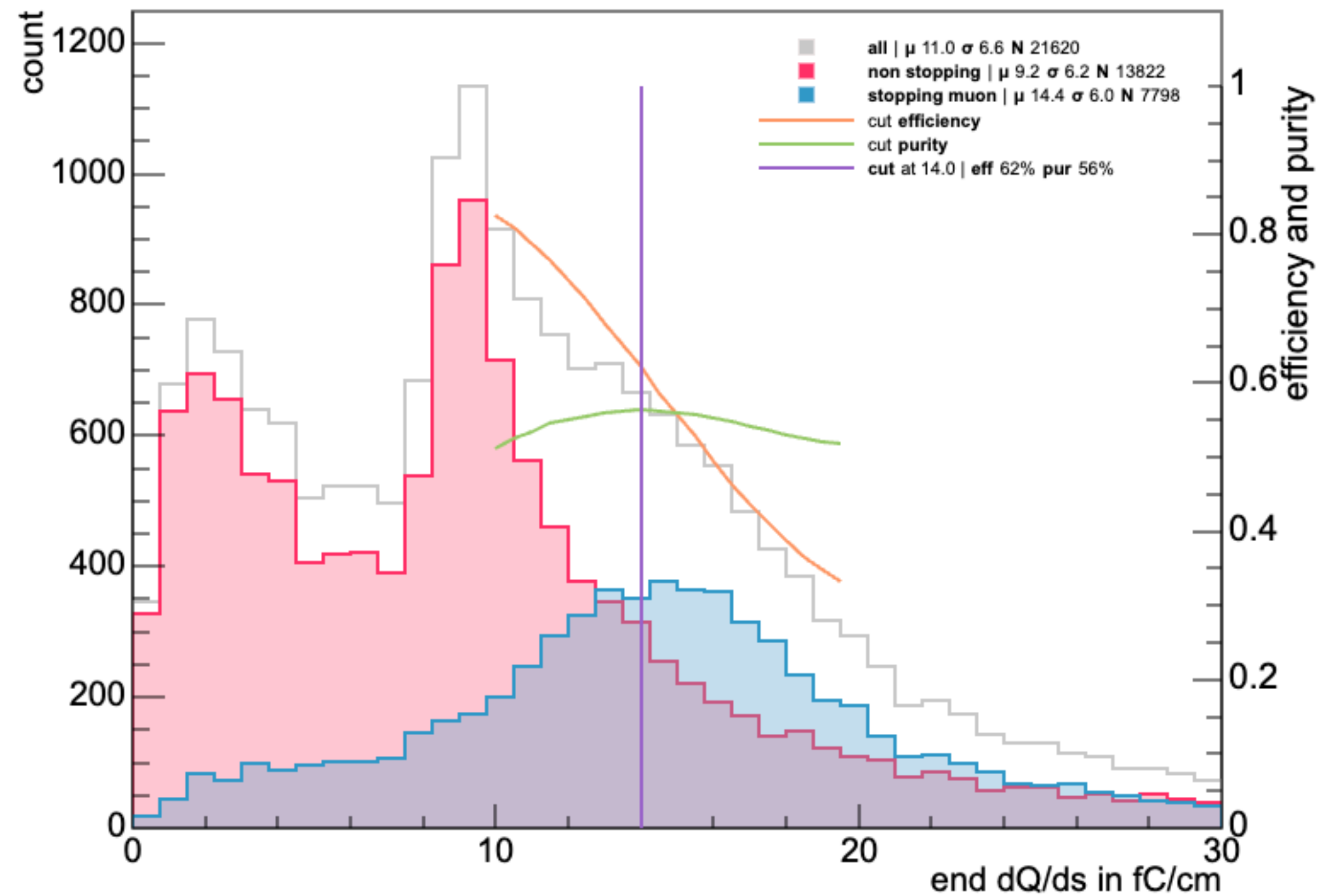
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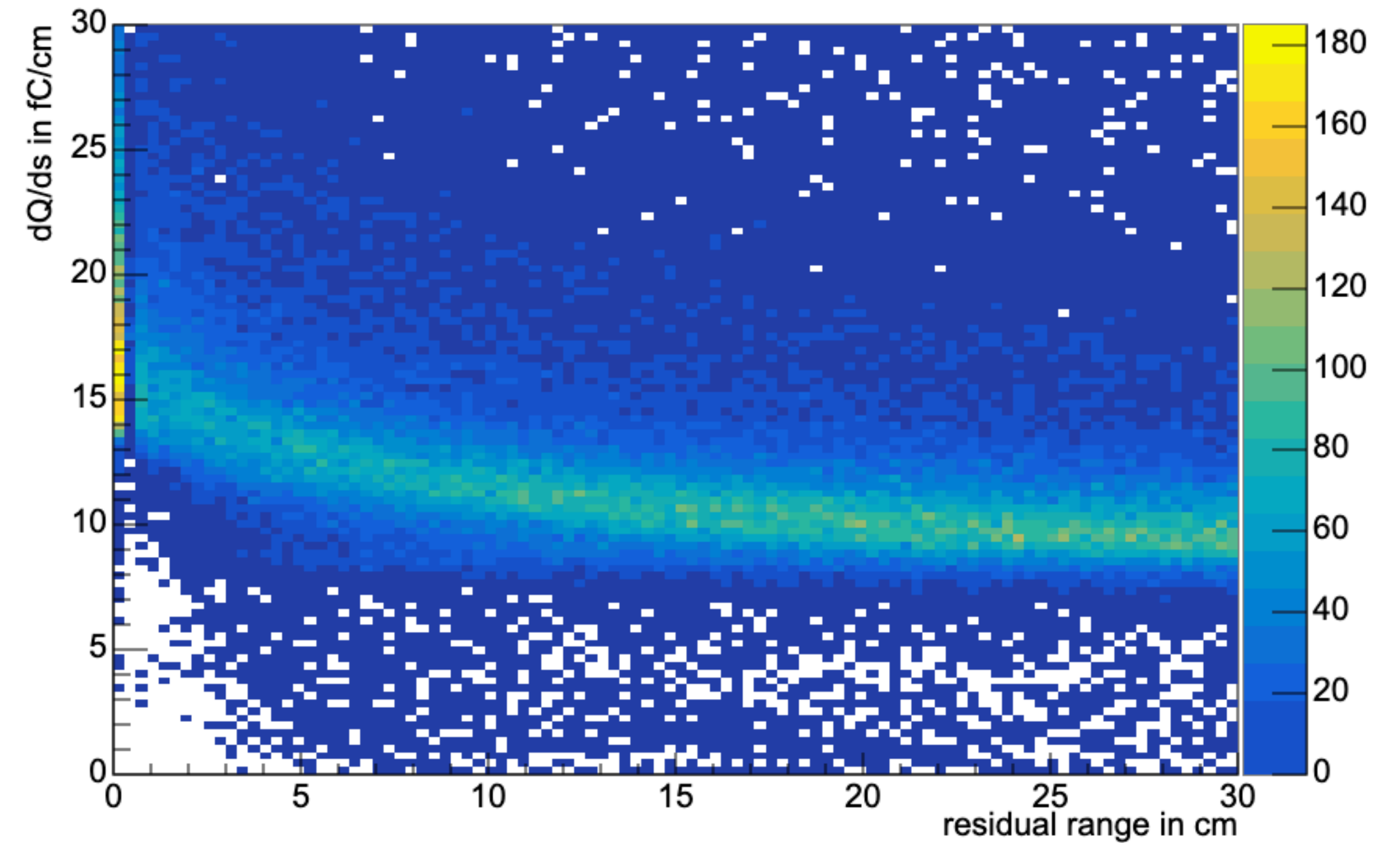


## Analysis on PDHD

- Cosmics (full dataset mc 2025a)
- Different module version (available [here](#))
- Same analysis logic

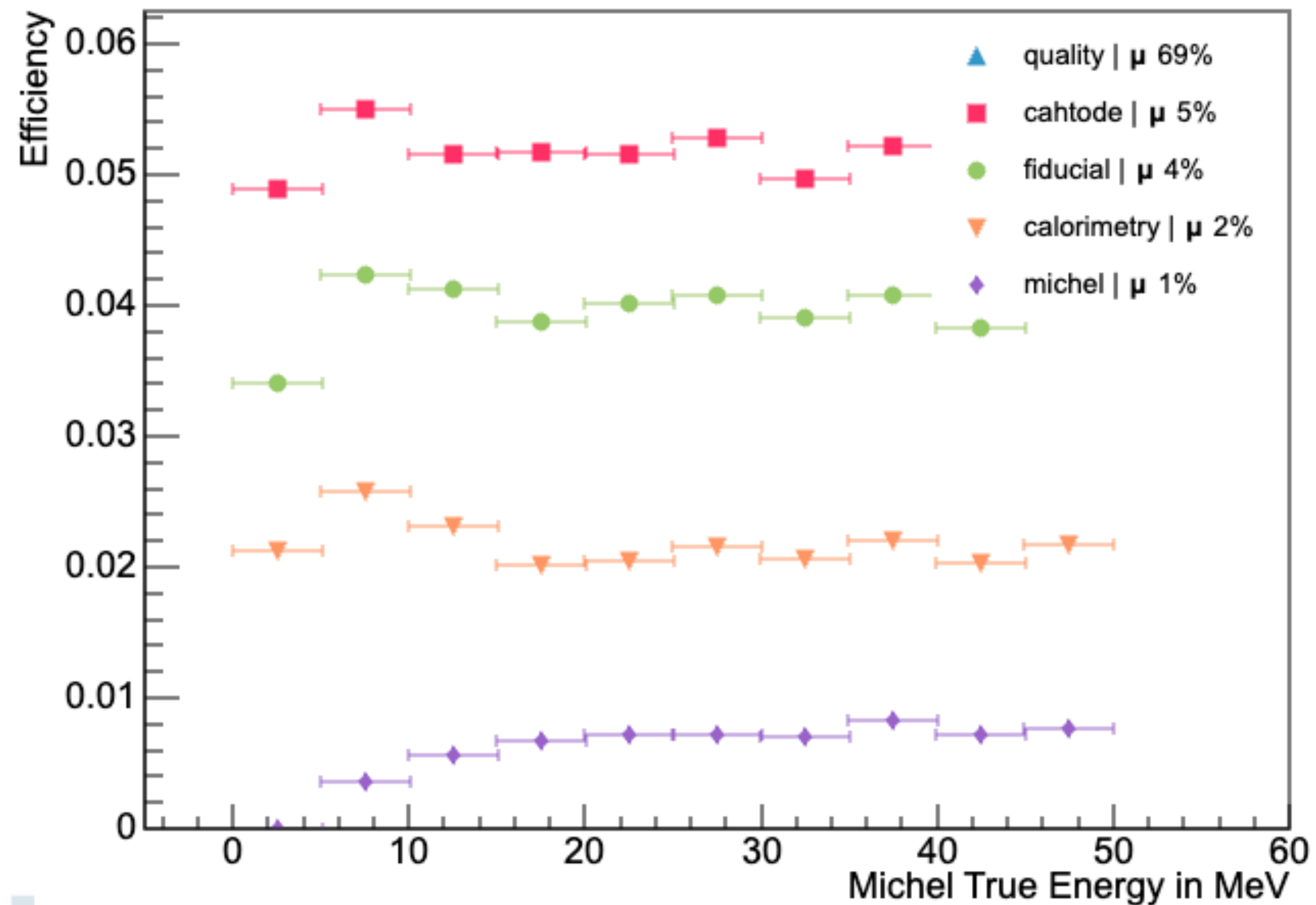


quality + cathode + fiducial + bragg



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ProtoDUNE-HD: Simulation

	all tracks	full selection ( $\mu$ )
all tracks	2'456'769	1'713
truly stopping muons	196'386	1'370
truly decaying muons	131'160	1'184

**Purity:** 80 %  
**Efficiency:** 0.7 %

**Purity:** 69 %  
**Efficiency:** 0.9 %

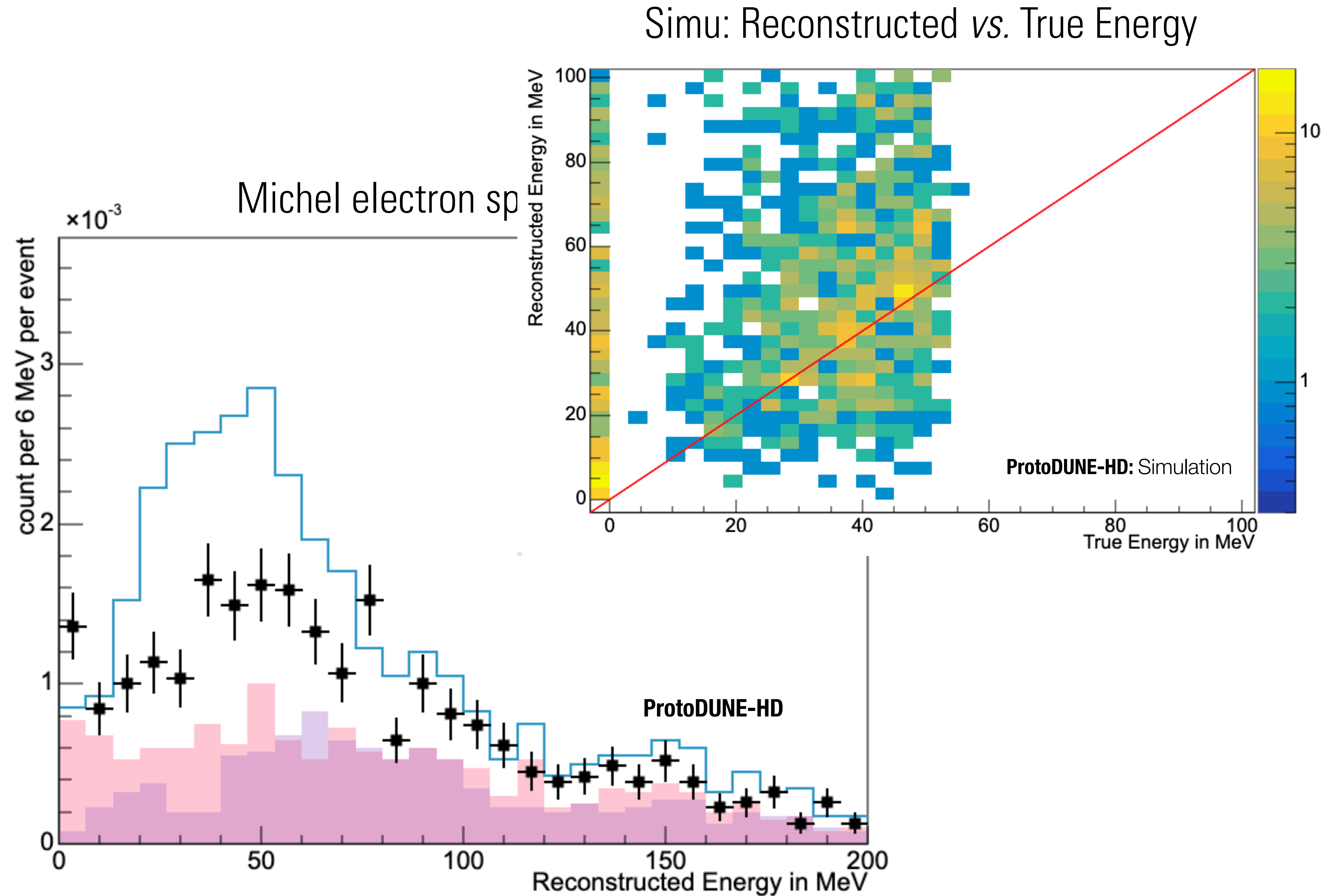
## Simulation:

- Cosmics (full dataset mc 2025a)
- 39'967 events
- 4'082'437 tracks total
- 2'012 michel electron candidates

## Data:

- Run: 28'116
- 30'889 events
- 2'559'212 tracks total
- 938 michel electron candidates

## Calibration with the MIP dQ/ds



## Muon selection

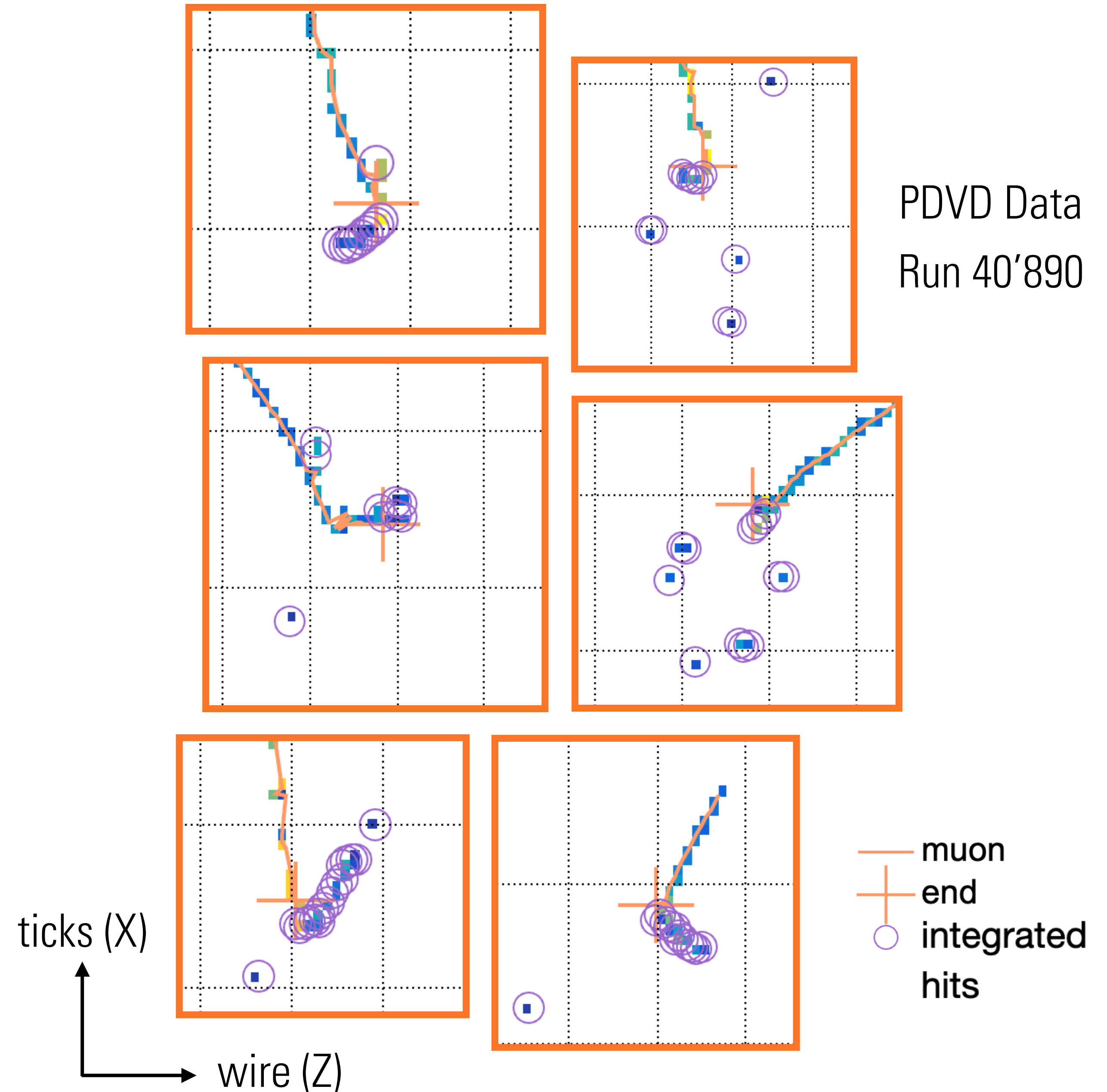
- Working well overall, clear Bragg peak
- Normalization to be better understood

## Michel energy reconstruction

- First spectrum in ProtoDUNE Data
- Waiting for official PDVD Simulations

## Outlook

- Take a look at SPINE reconstruction with expected (much) better efficiency and purity (cf. Nived's presentation)



**Thank you for your attention!**