

Michel electrons energy reconstruction in DUNE Prototypes: Simulations and Data



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Neutrinos are neutral leptons which come in three flavors (electronic, muonic, tauic)

- massless in the SM **but** observed oscillations implies neutrinos are massive
- the correct SM extension for neutrino masses and is still an open questions

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flavor-dependent

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$$\nu_\mu \rightarrow \nu_e$$

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mixing matrix ($U_{\alpha i}$)

	1	2	3
e			
μ			
τ			

mixing weights
uncertainties

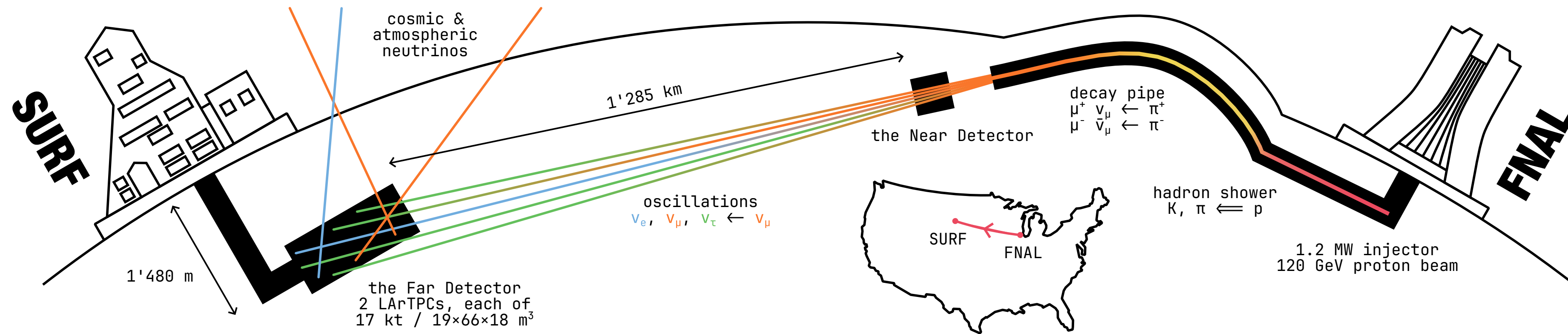
oscillation parameters

$$\theta_{12}, \theta_{23}, \theta_{13}, \delta_{CP}$$

$$\Delta m_{21}^2, \Delta m_{31}^2, \Delta m_{32}^2$$

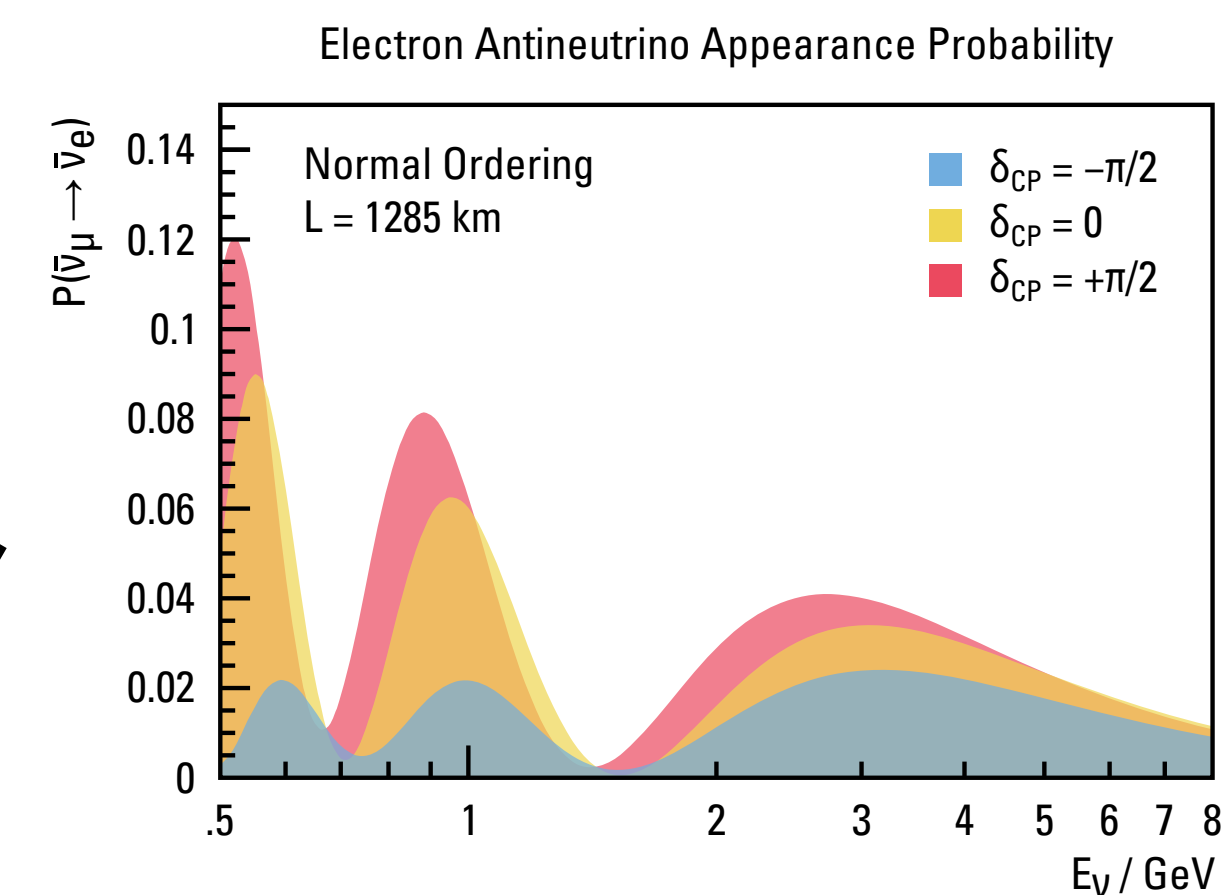
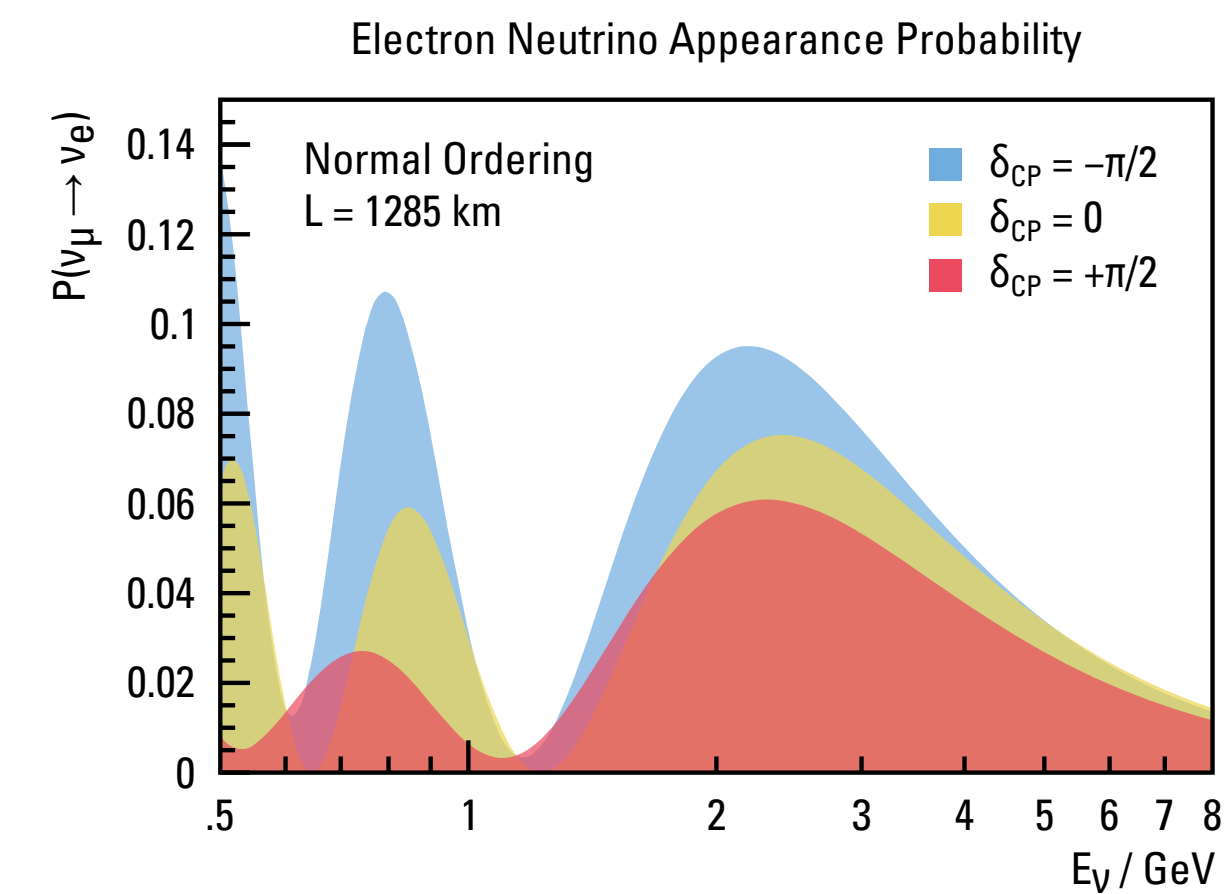
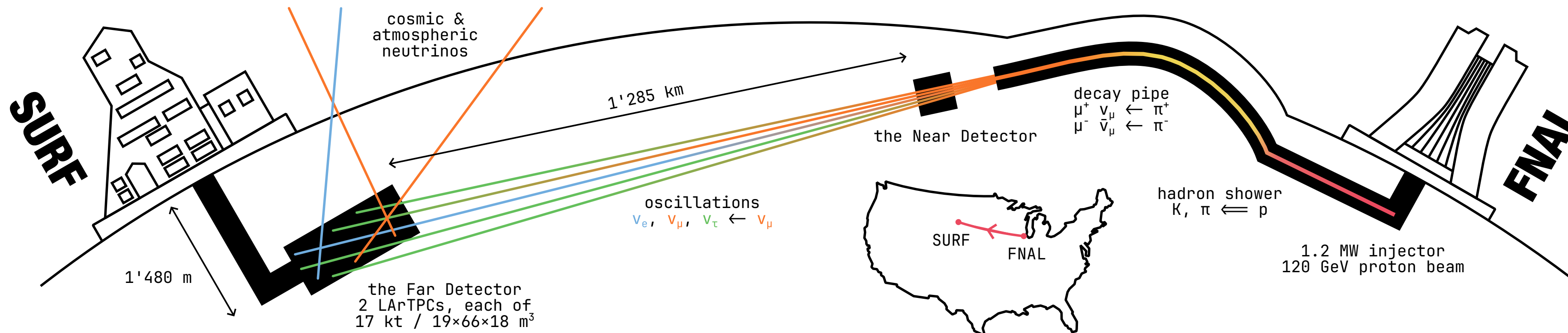
The Deep Underground Neutrino Experiment (DUNE), starting operations *c.* 2030

- Long baseline, beam **neutrino oscillations** experiment



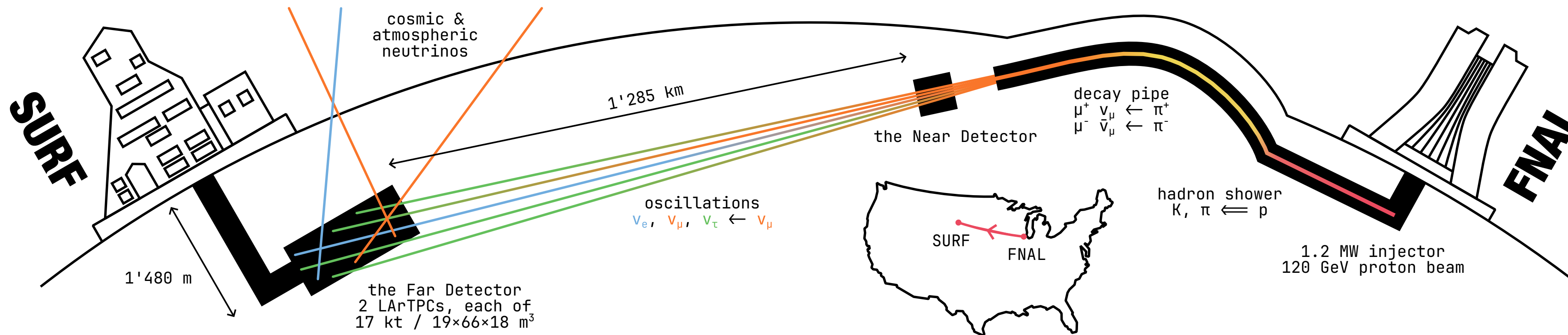
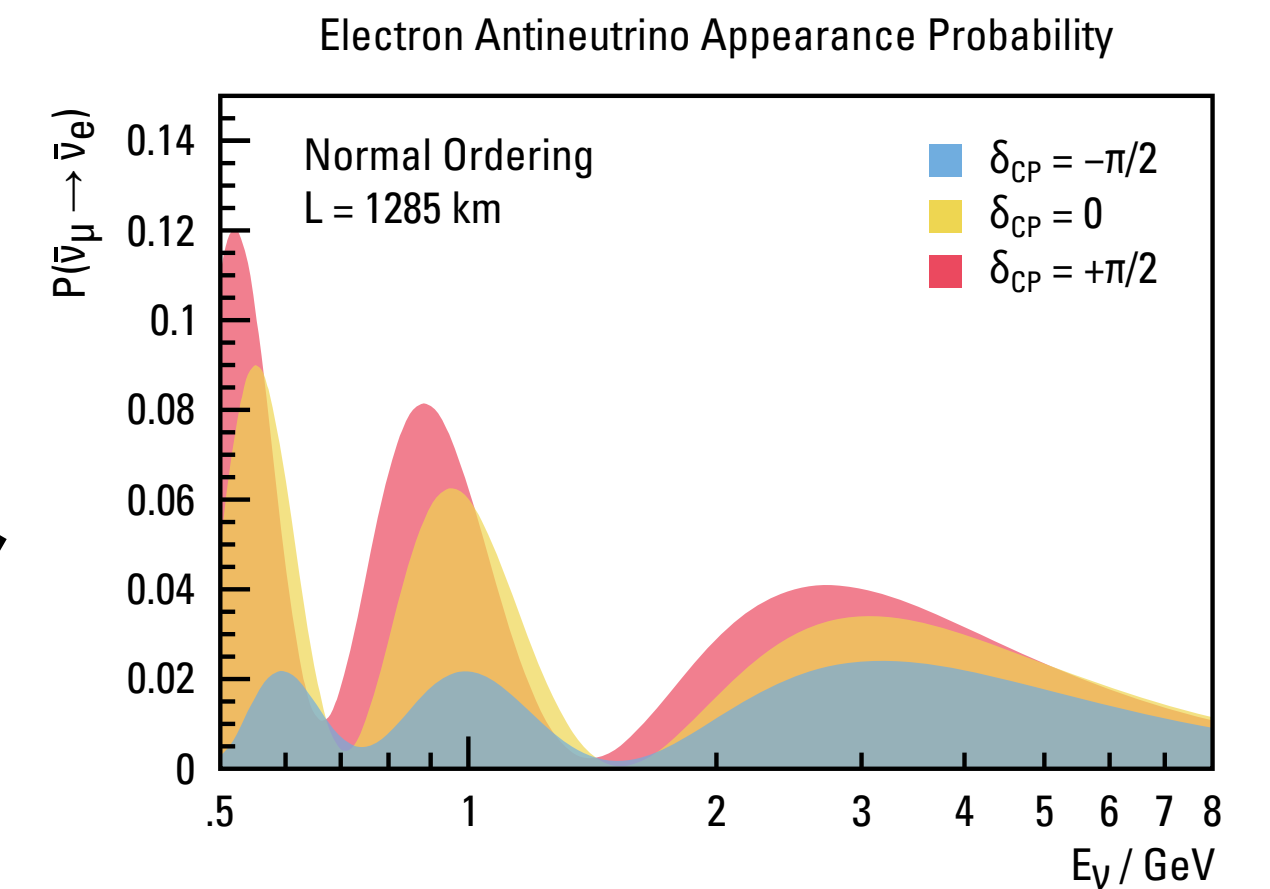
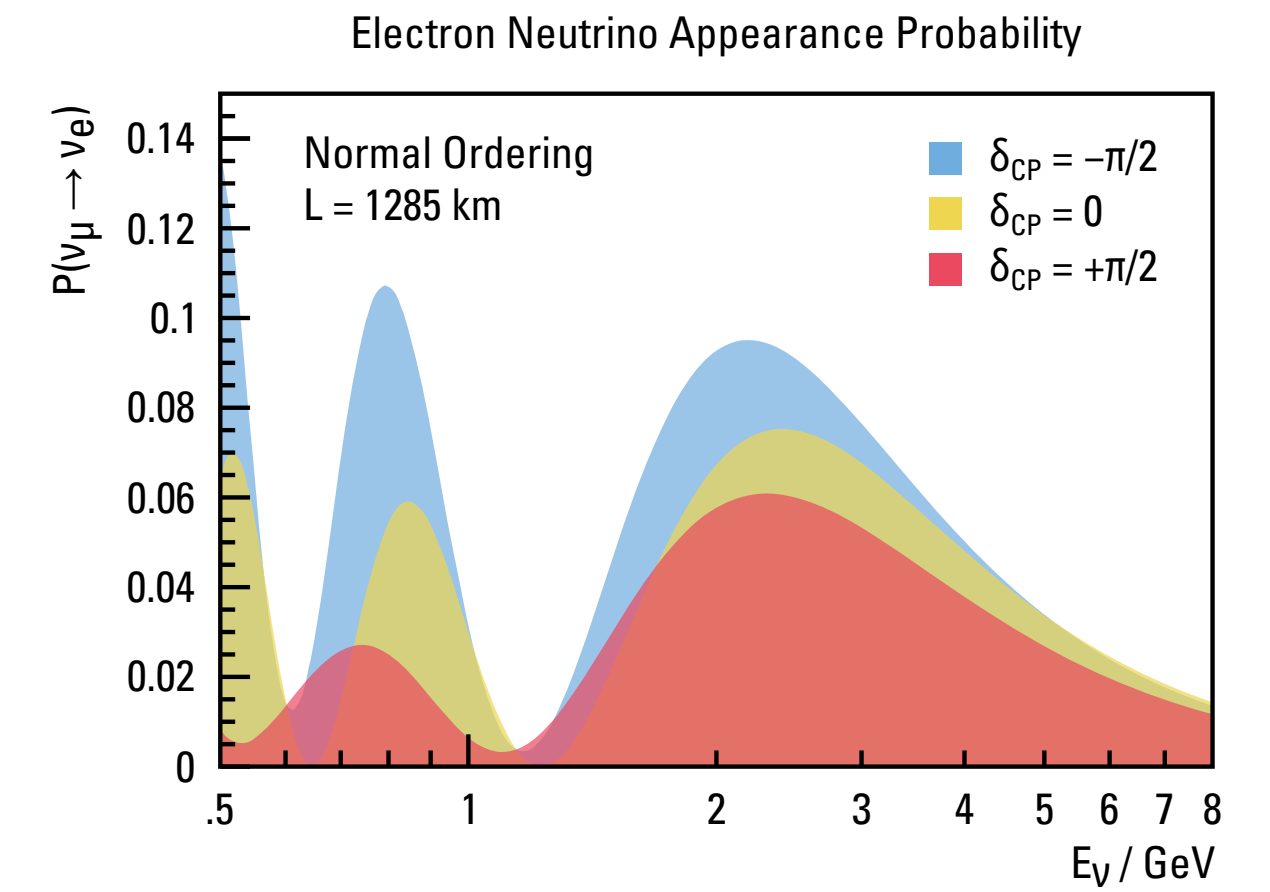
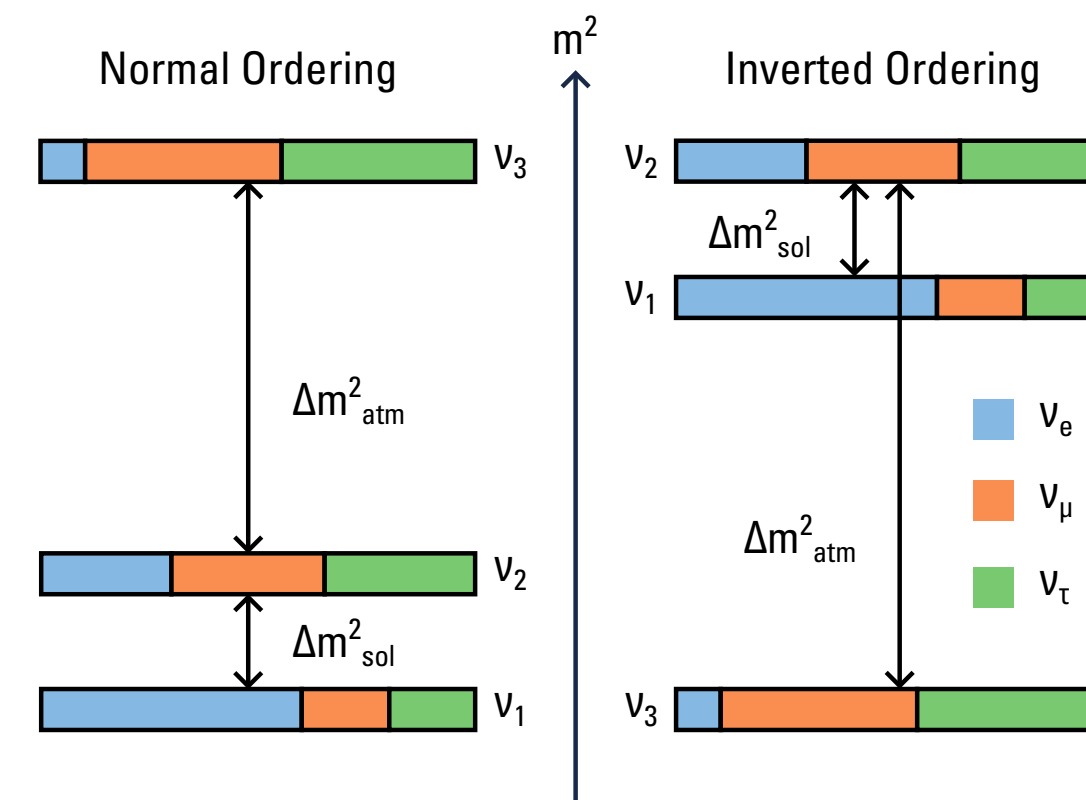
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- Main goals: determine **CP Violation** in leptonic sector



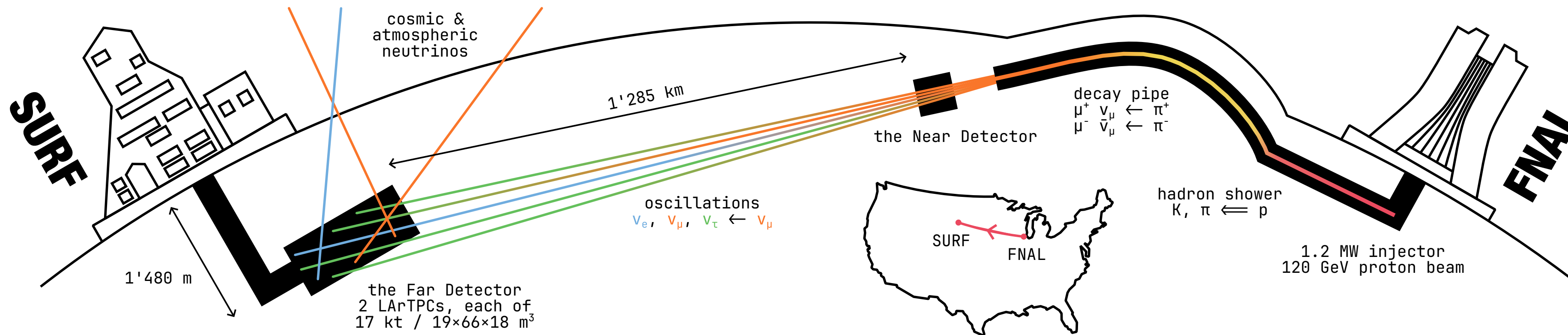
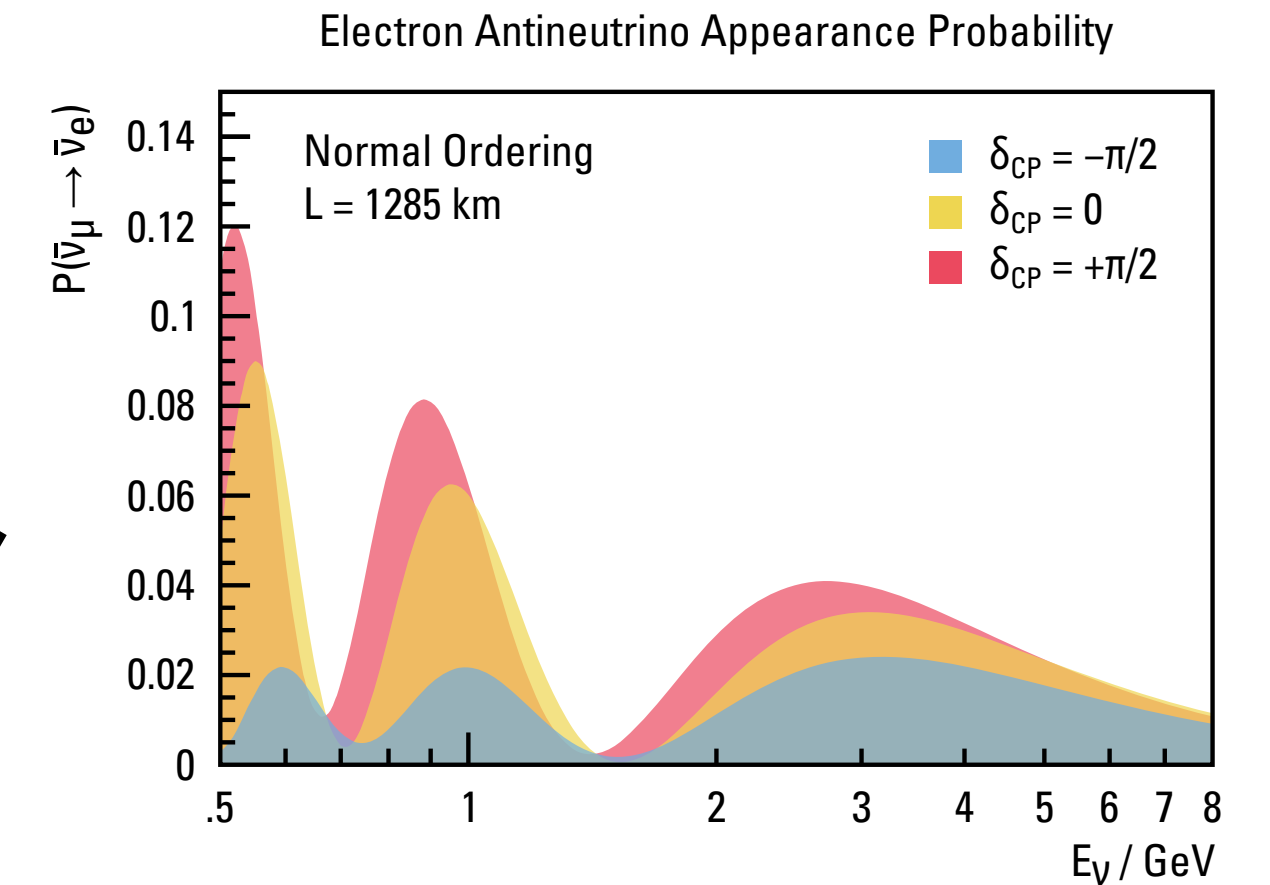
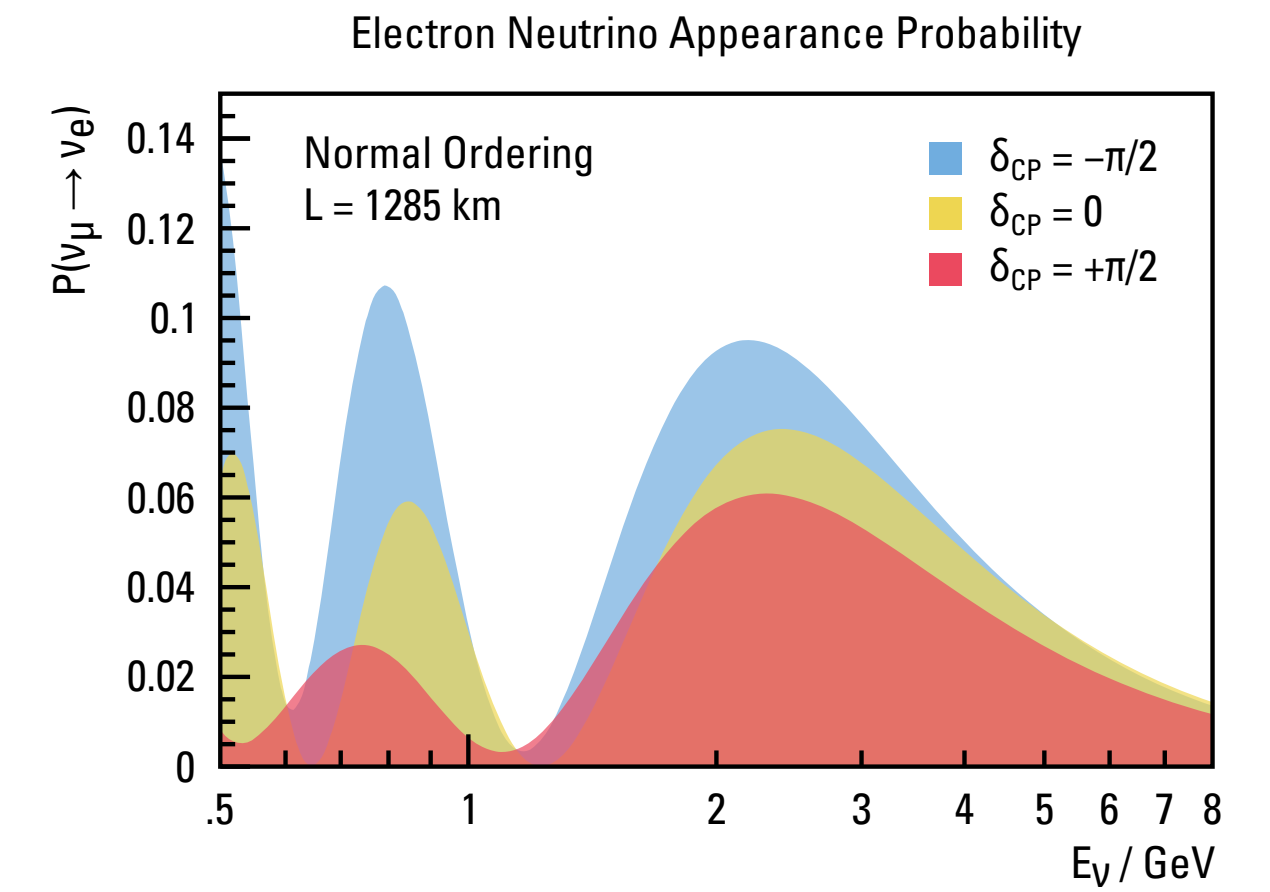
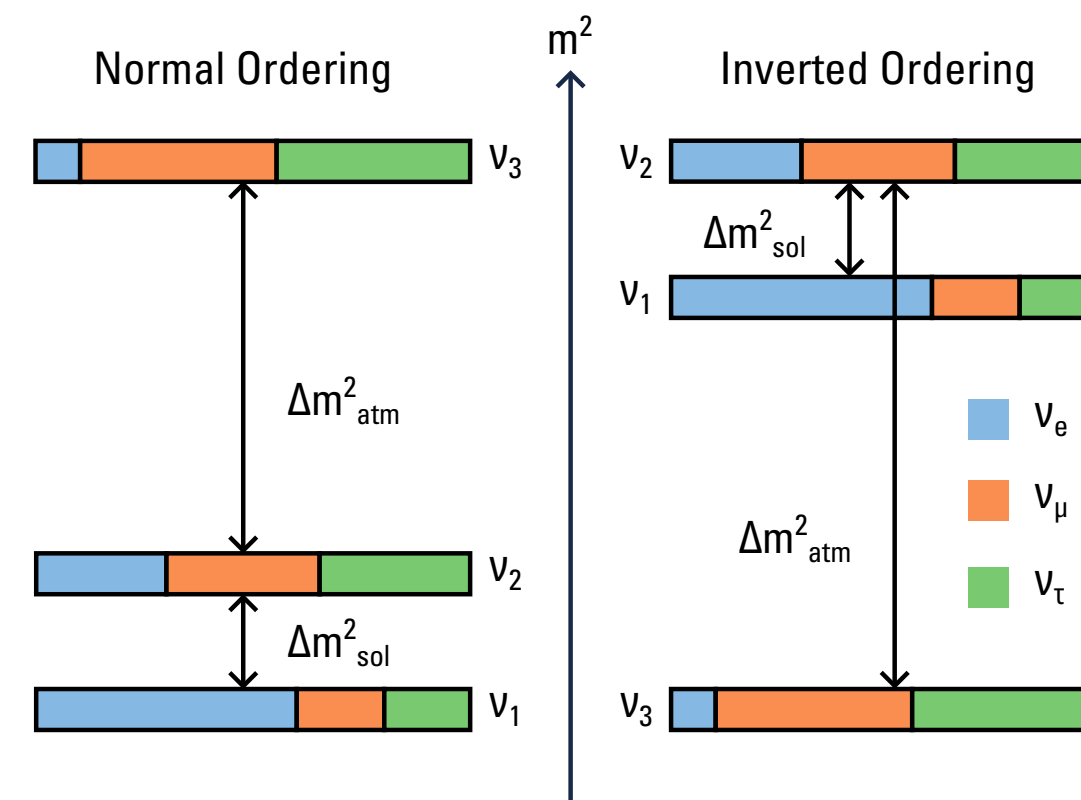
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- Other interests: hypothetical **proton decay**
detection of **supernova neutrinos**

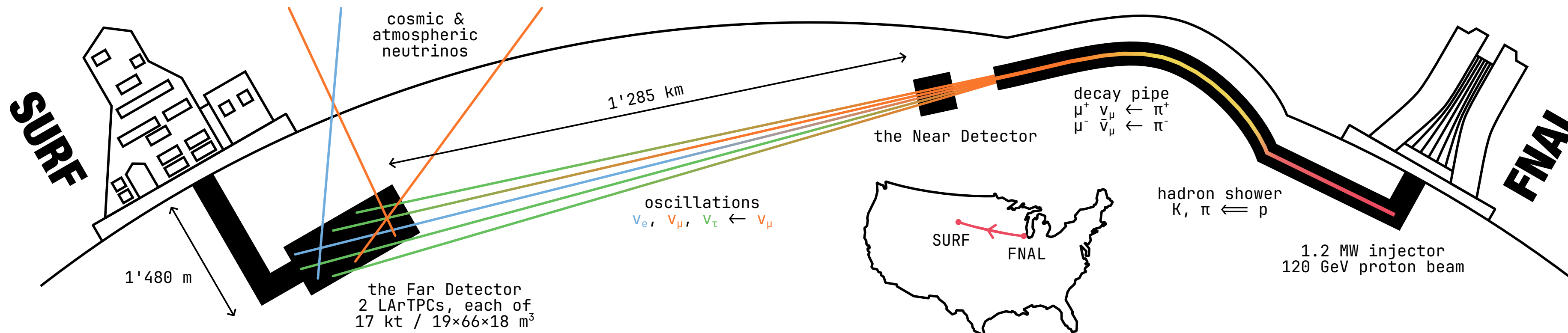
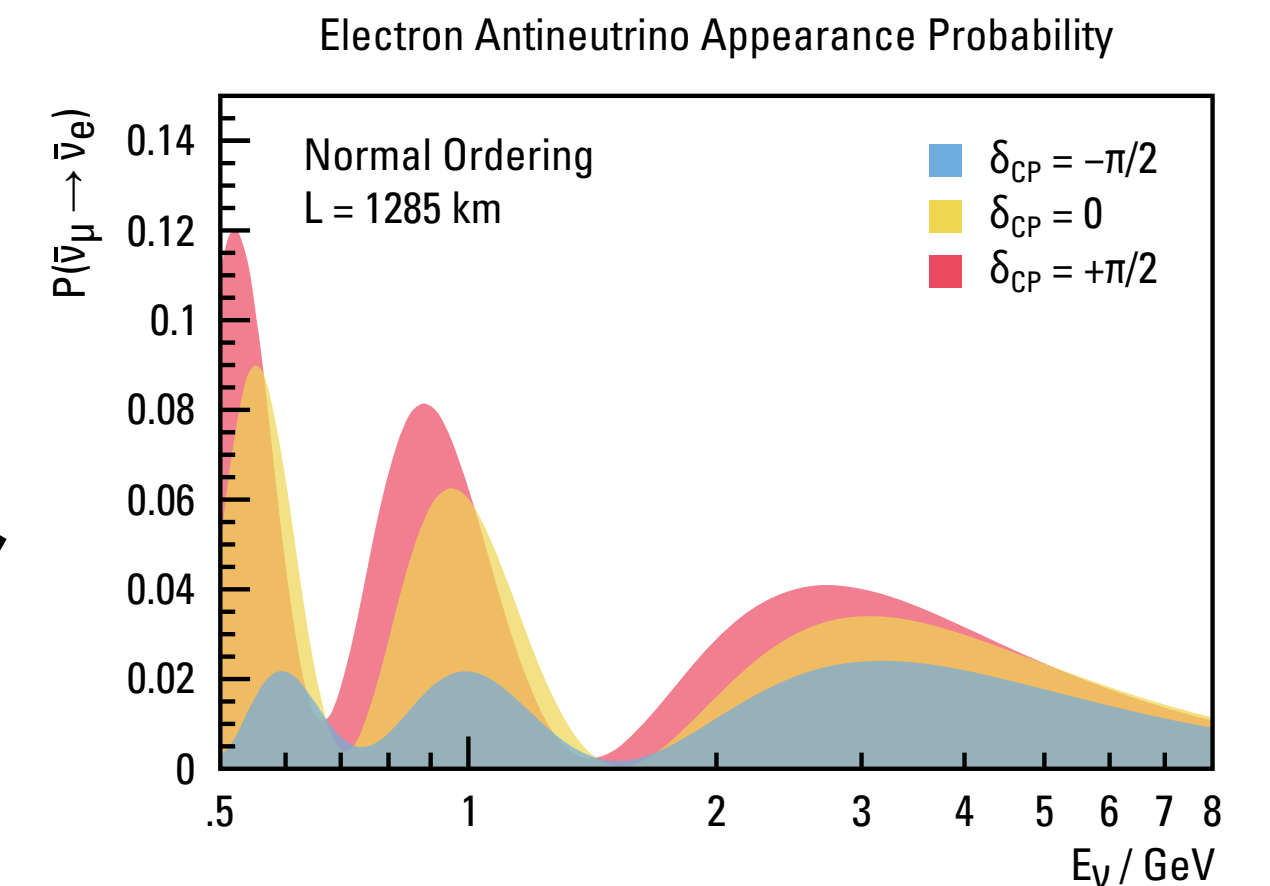
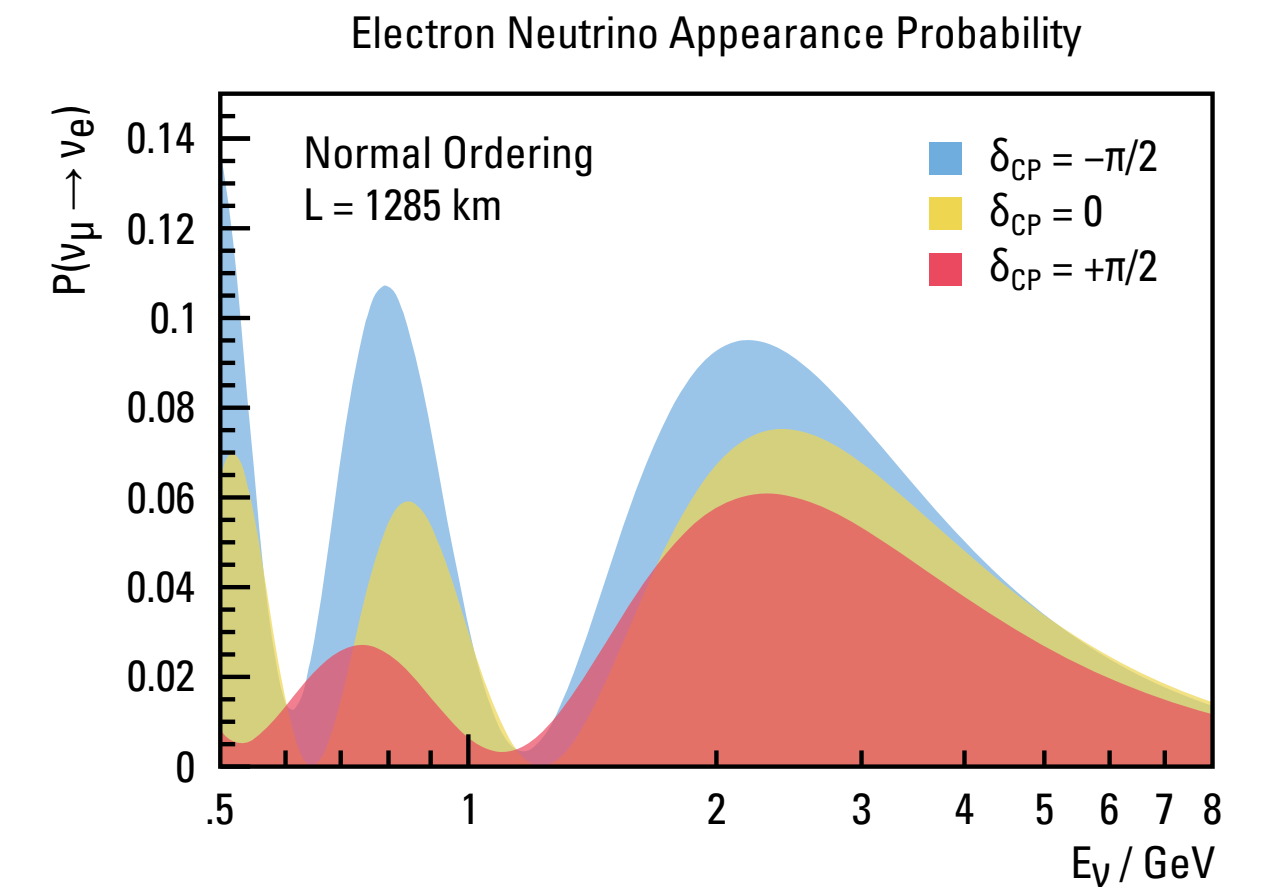
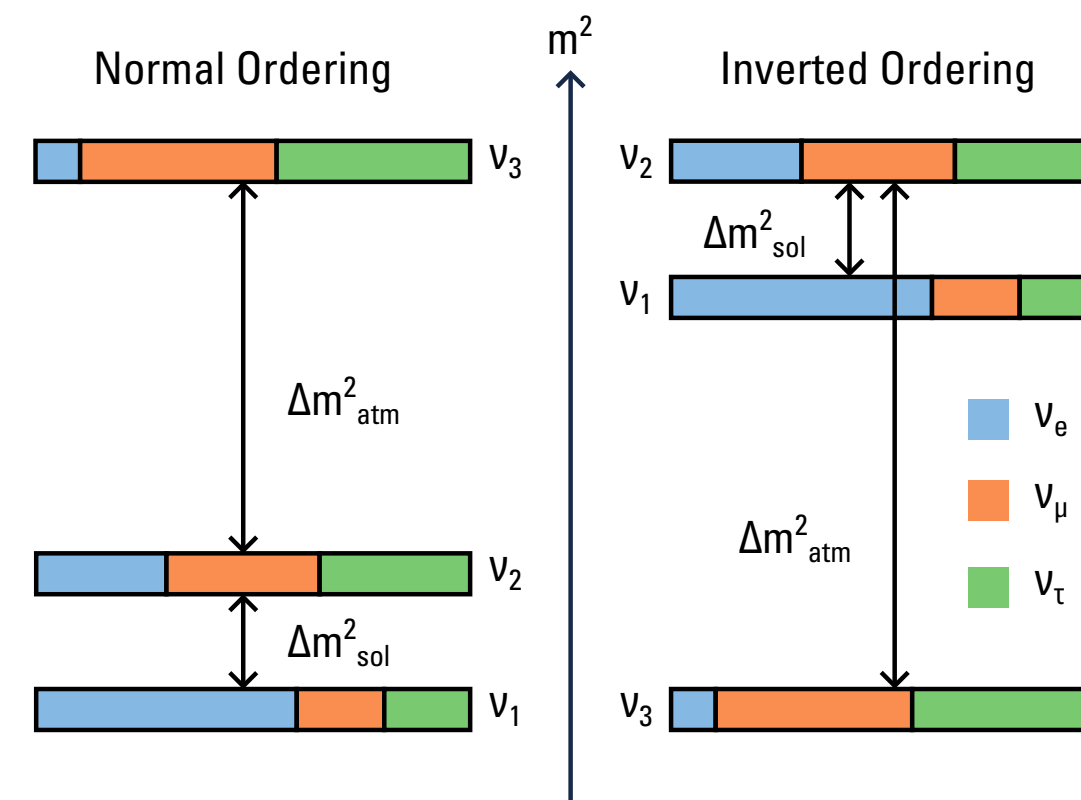


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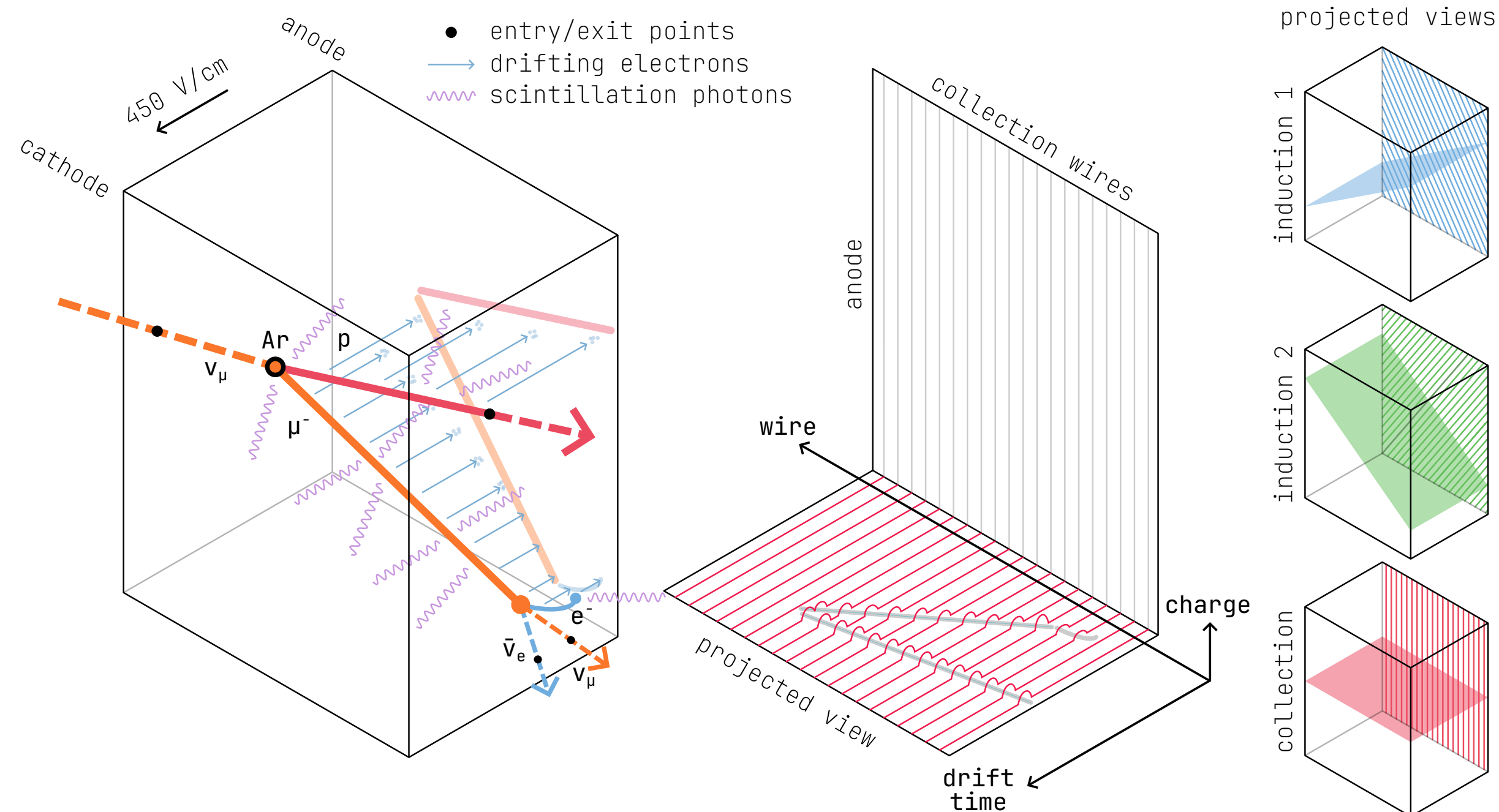
observed **once** (SN 1987A) with **few** events
low energy ~10 MeV



Two far detector prototypes at CERN, ProtoDUNE Horizontal Drift and Vertical Drift

- Time projecting chambers filled with liquid Argon

Time projecting chamber principle



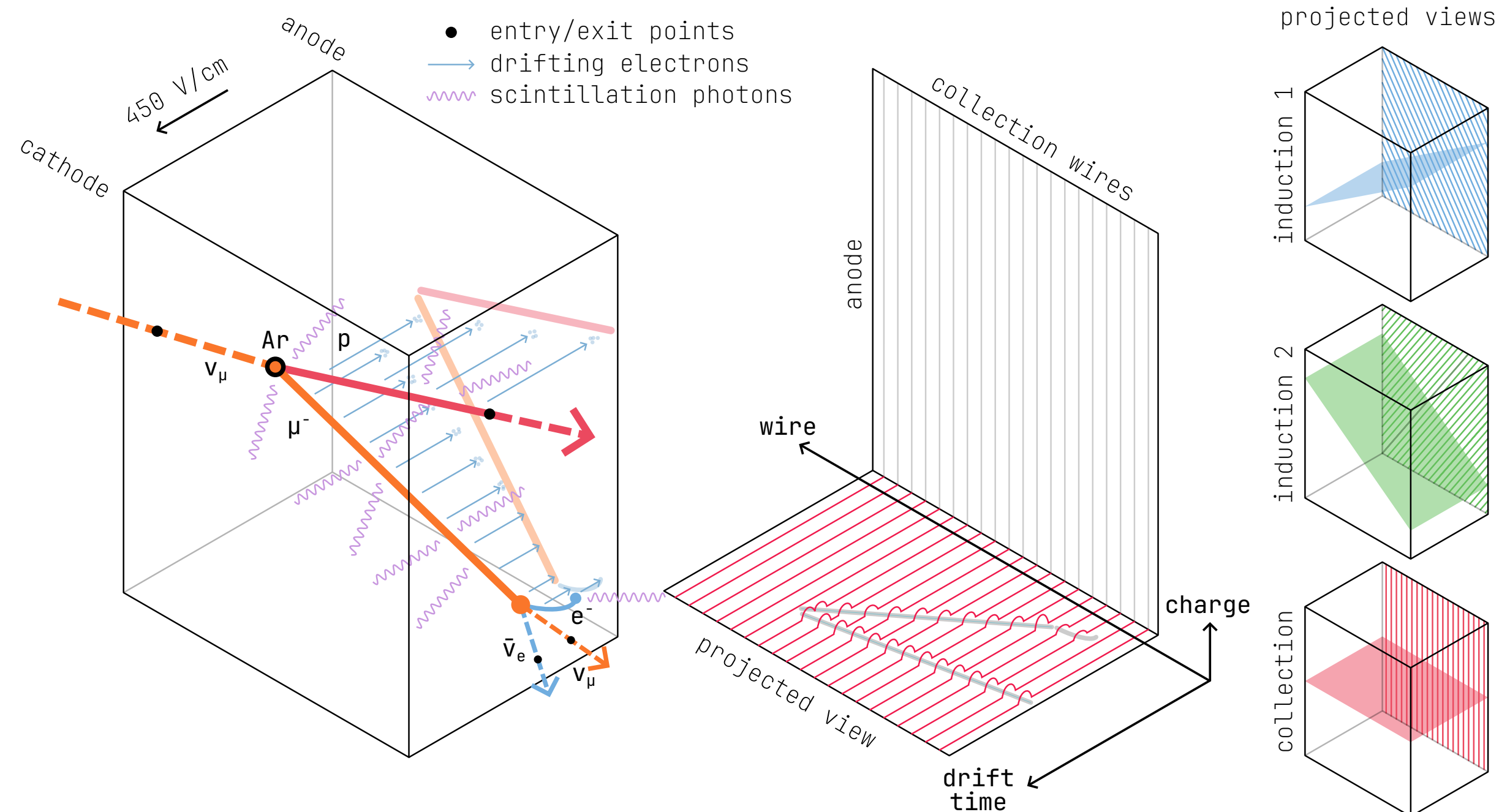
ProtoDUNE Vertical Drift



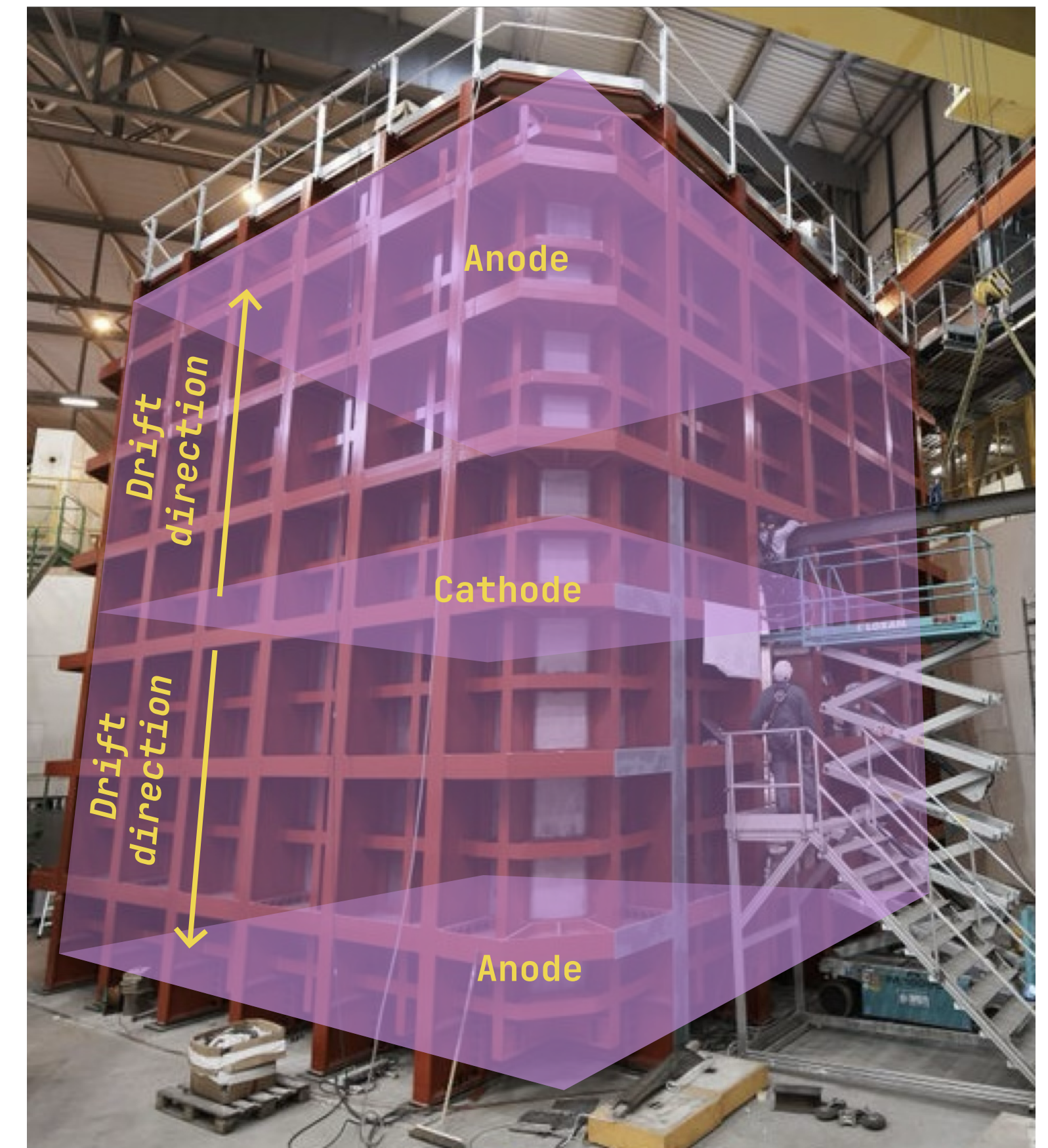
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- Time projecting chambers filled with liquid Argon
- Two 3 m long drift volumes each
- At ground level: cosmics
- Data available

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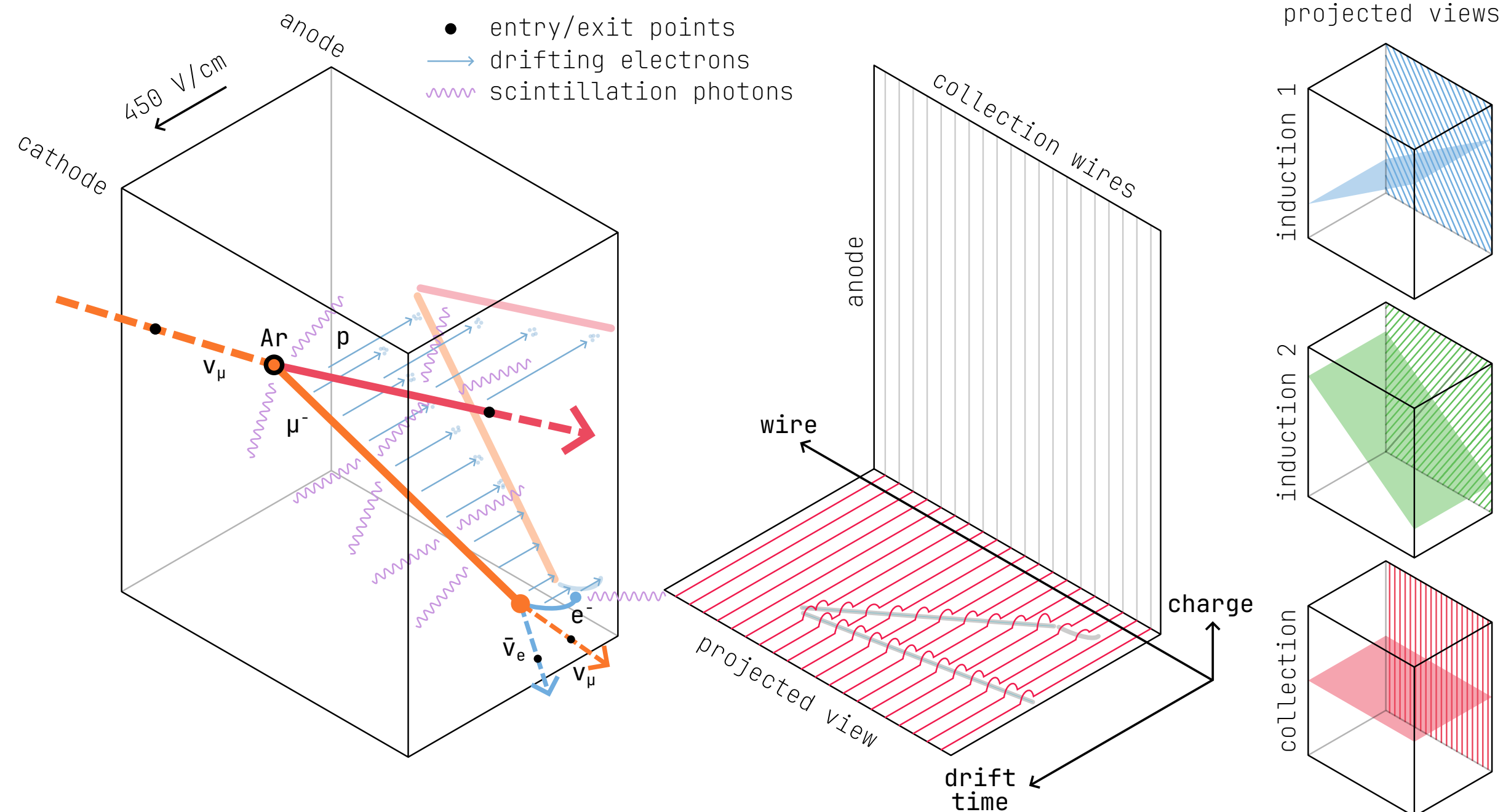
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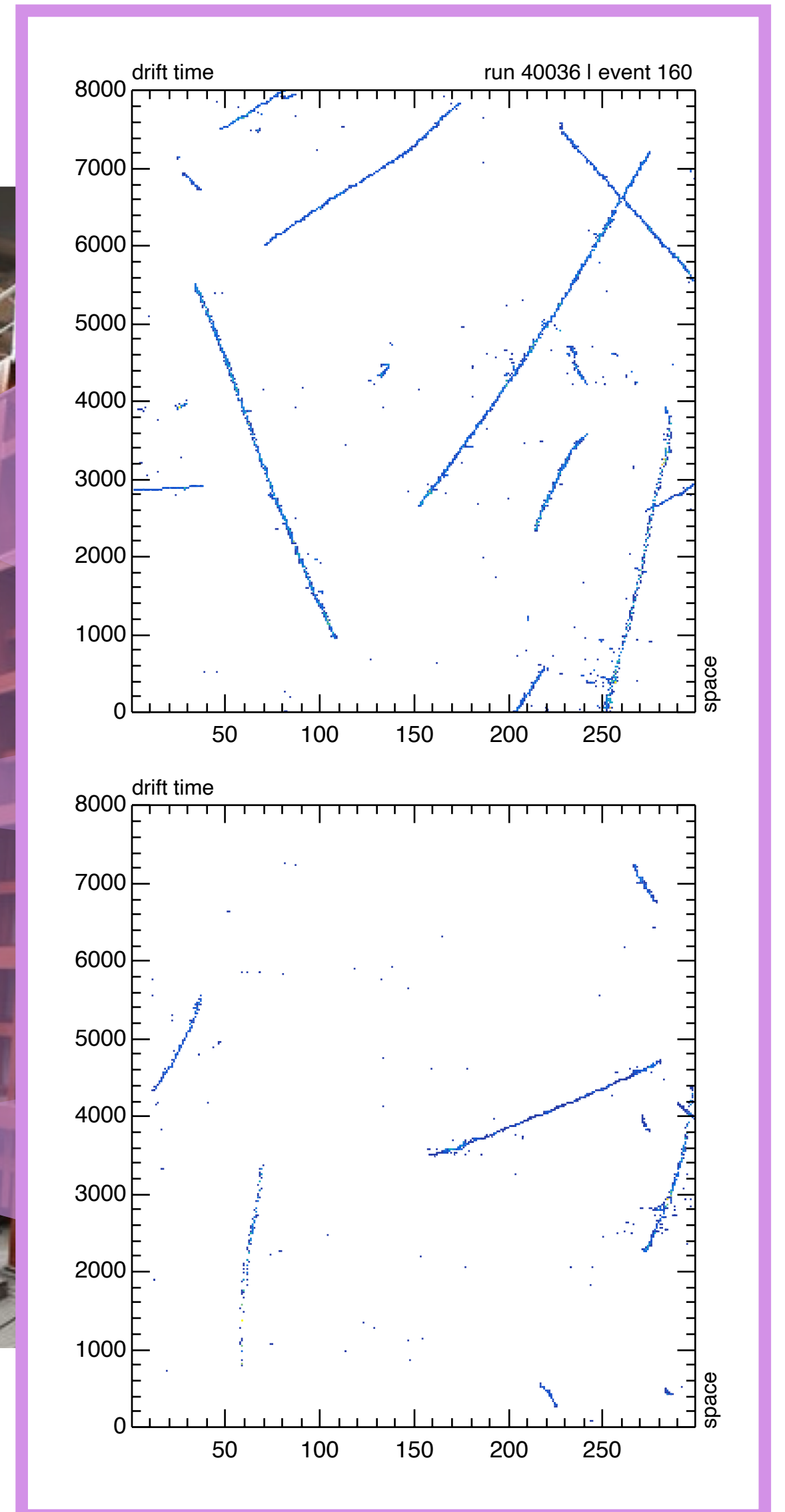
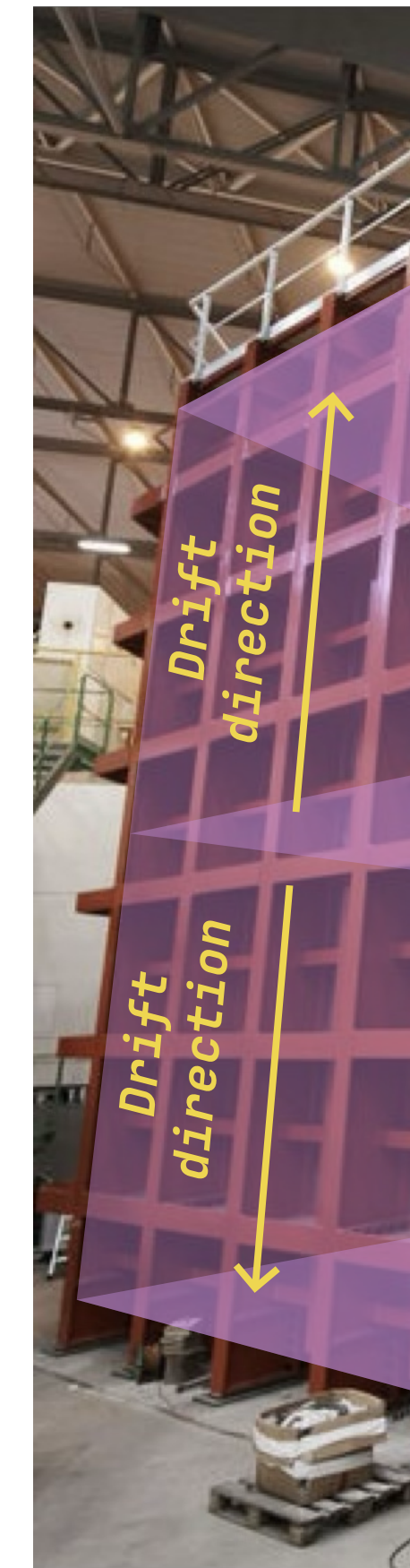
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Typical 1-view event display



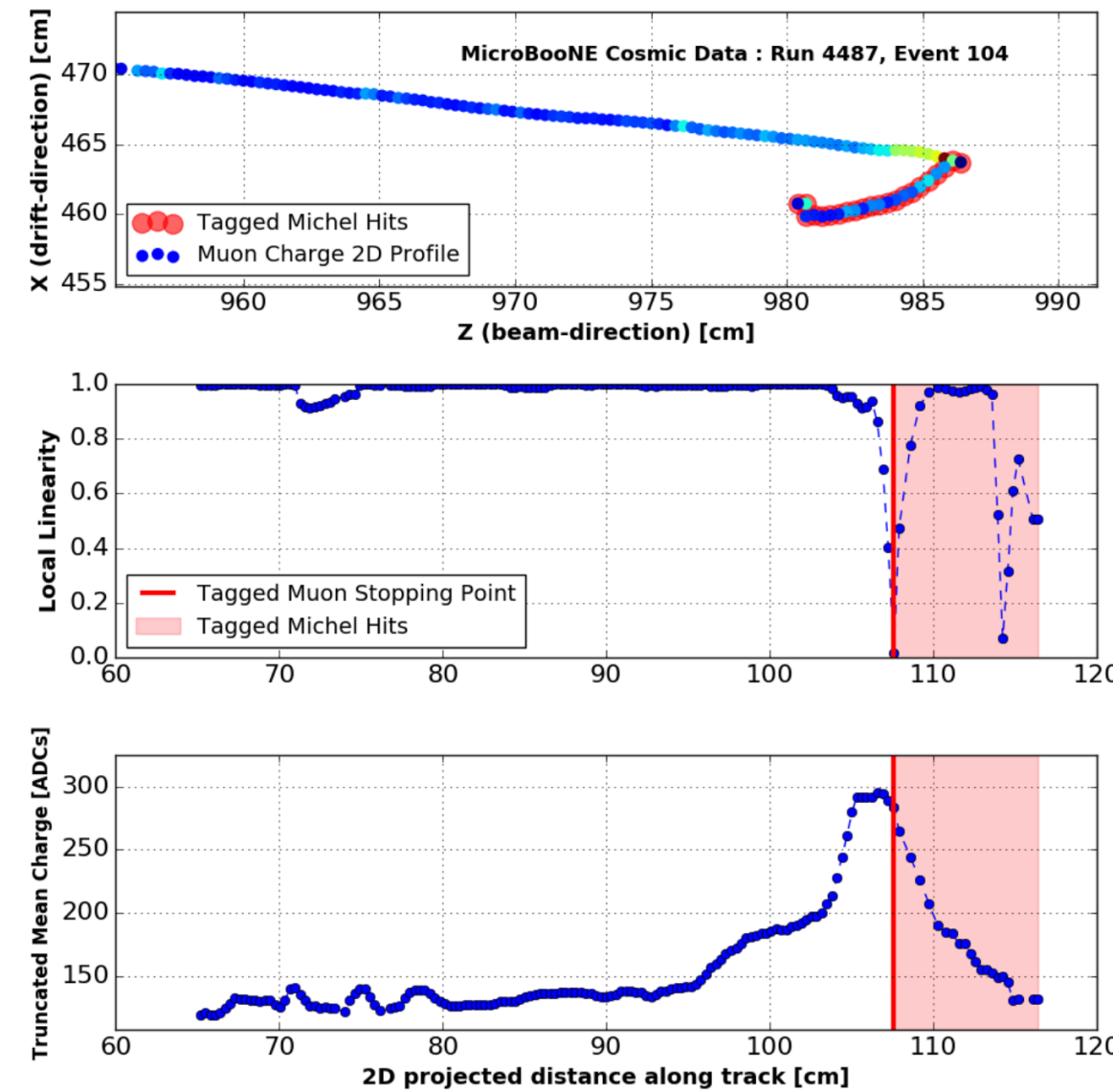
Michel electrons

- $\mu^\pm \rightarrow e^\pm \nu_\mu \nu_e$ with $E_e = 0-50$ MeV
- Abundant in cosmics: ~ 1 /cm²/s
- Ideal for **low-energy calibration**
 - Supernova neutrinos energy range
 - Map of the EM field

Michel electrons

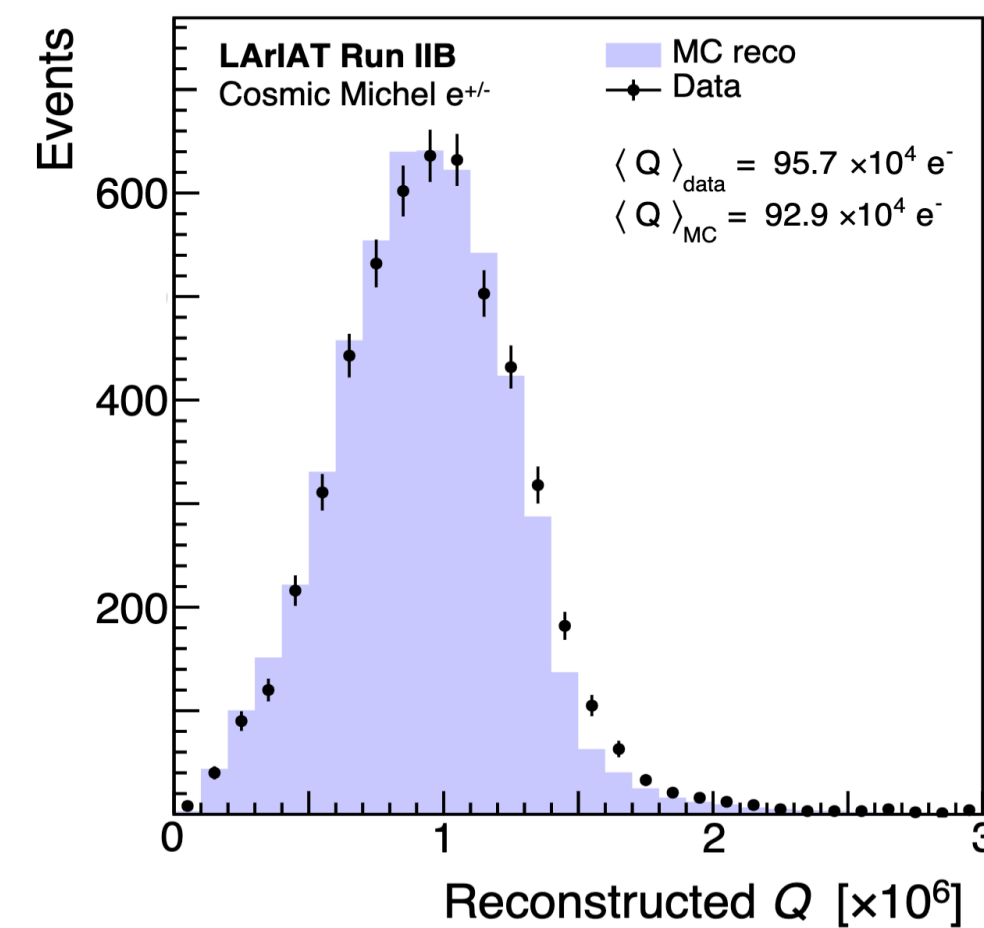
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MicroBooNE



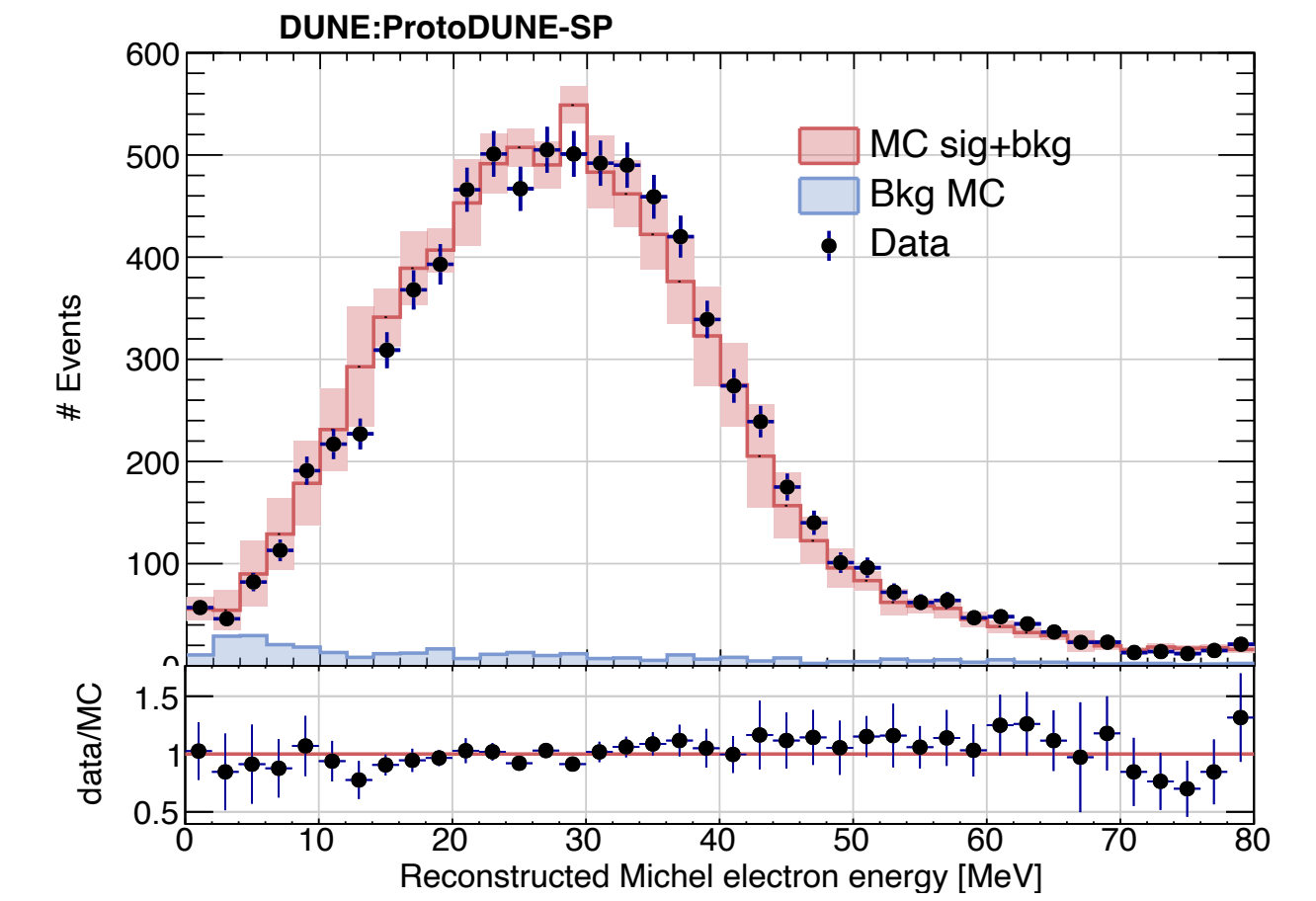
@ MicroBooNE Collaboration / arXiv:1704.02927

LArIAT



@ LArIAT Collaboration / arXiv:1909.07920

ProtoDUNE-SP



@ DUNE Collaboration / arXiv:2211.01166

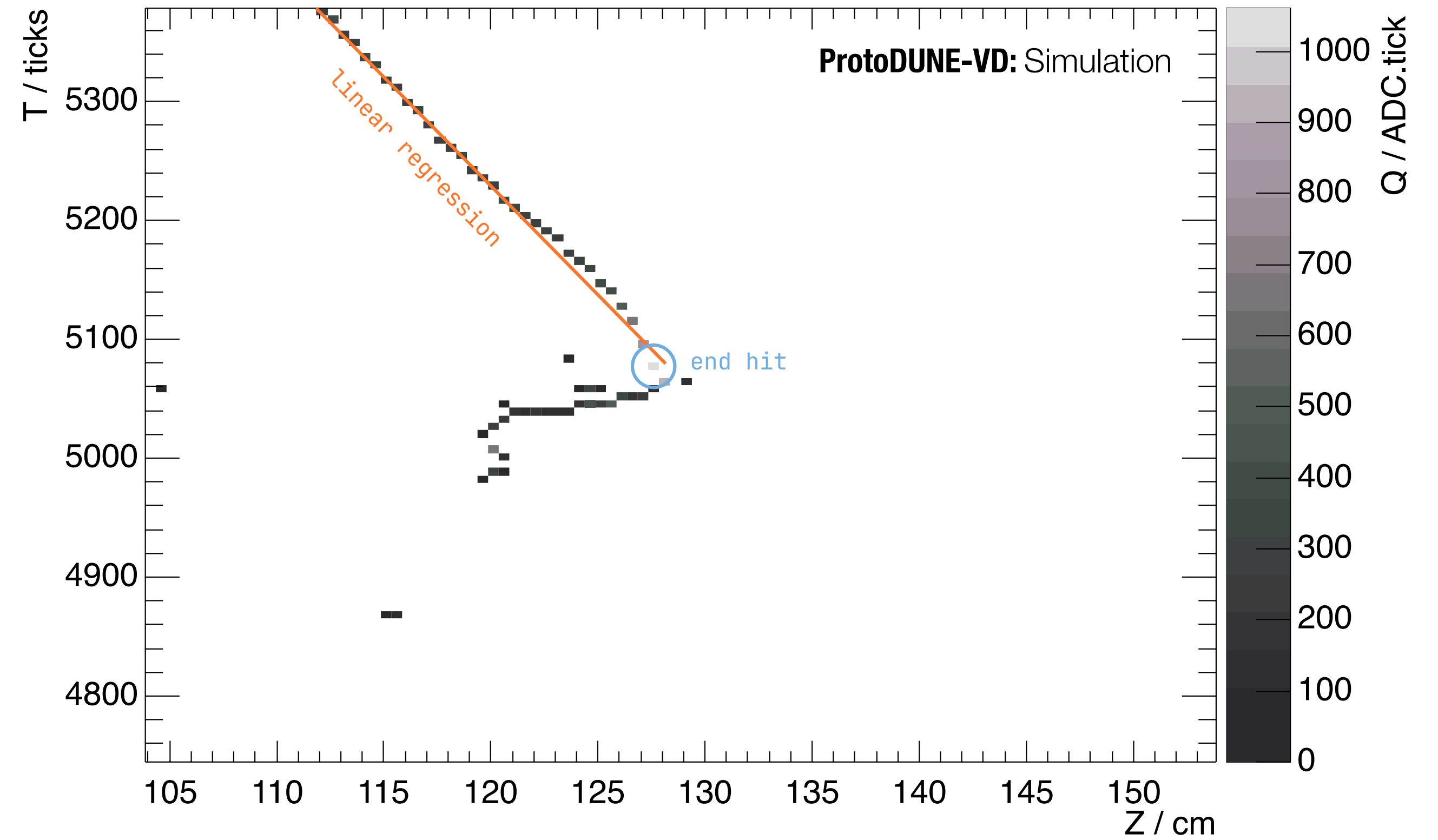
My work in ProtoDUNE-HD and -VD
(LArSoft module based on Pandora)

MichelAnalysis_module.cc

Select well reconstructed **stopping muon** candidates

Using **Pandora track** reconstruction

Michel electron illustration

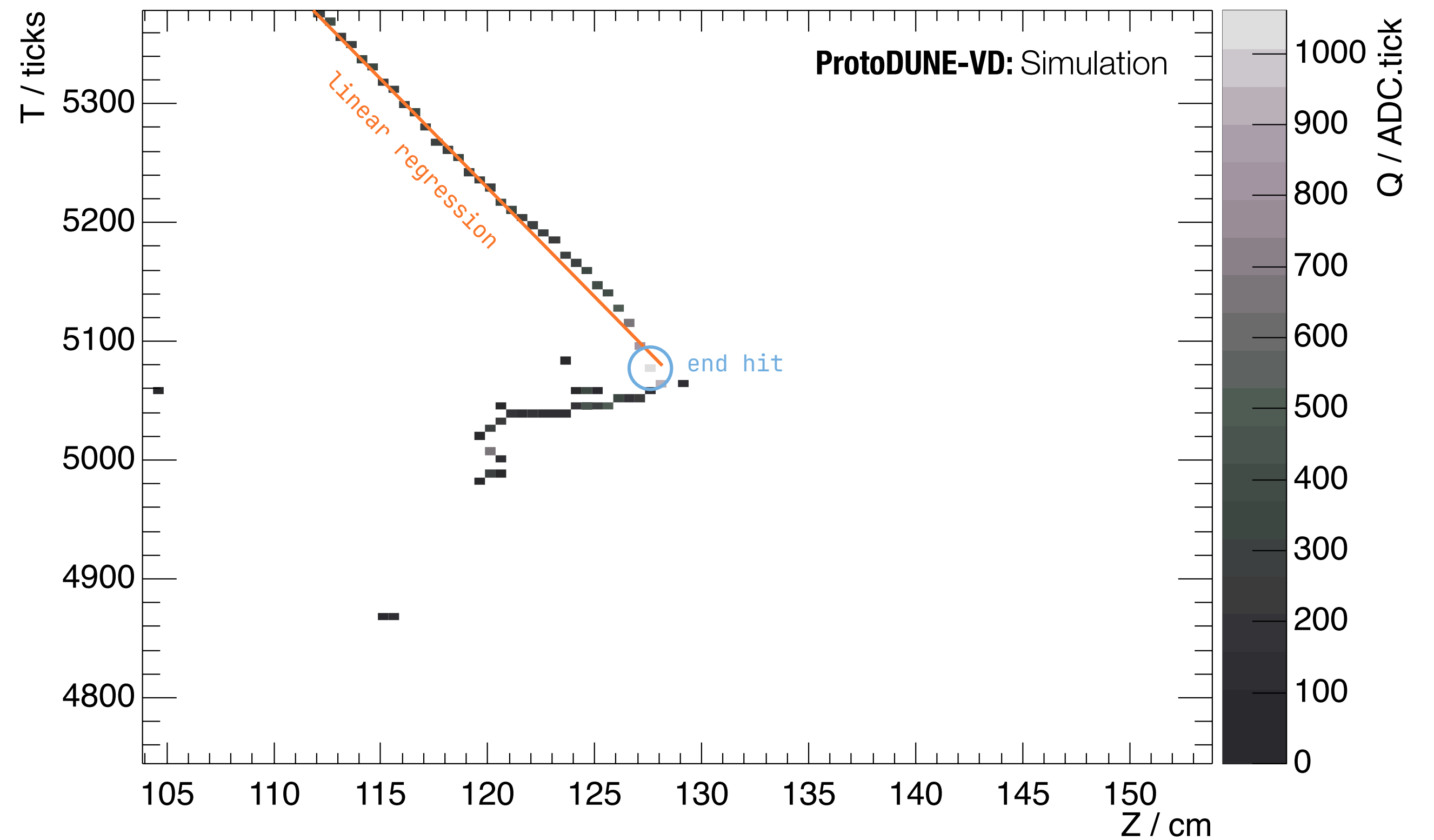


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- **Quality** cuts (length)
- **Cathode** crossing, for X reconstruction
- **Fiducial** cuts, 20 cm margin in X, Y, Z, T

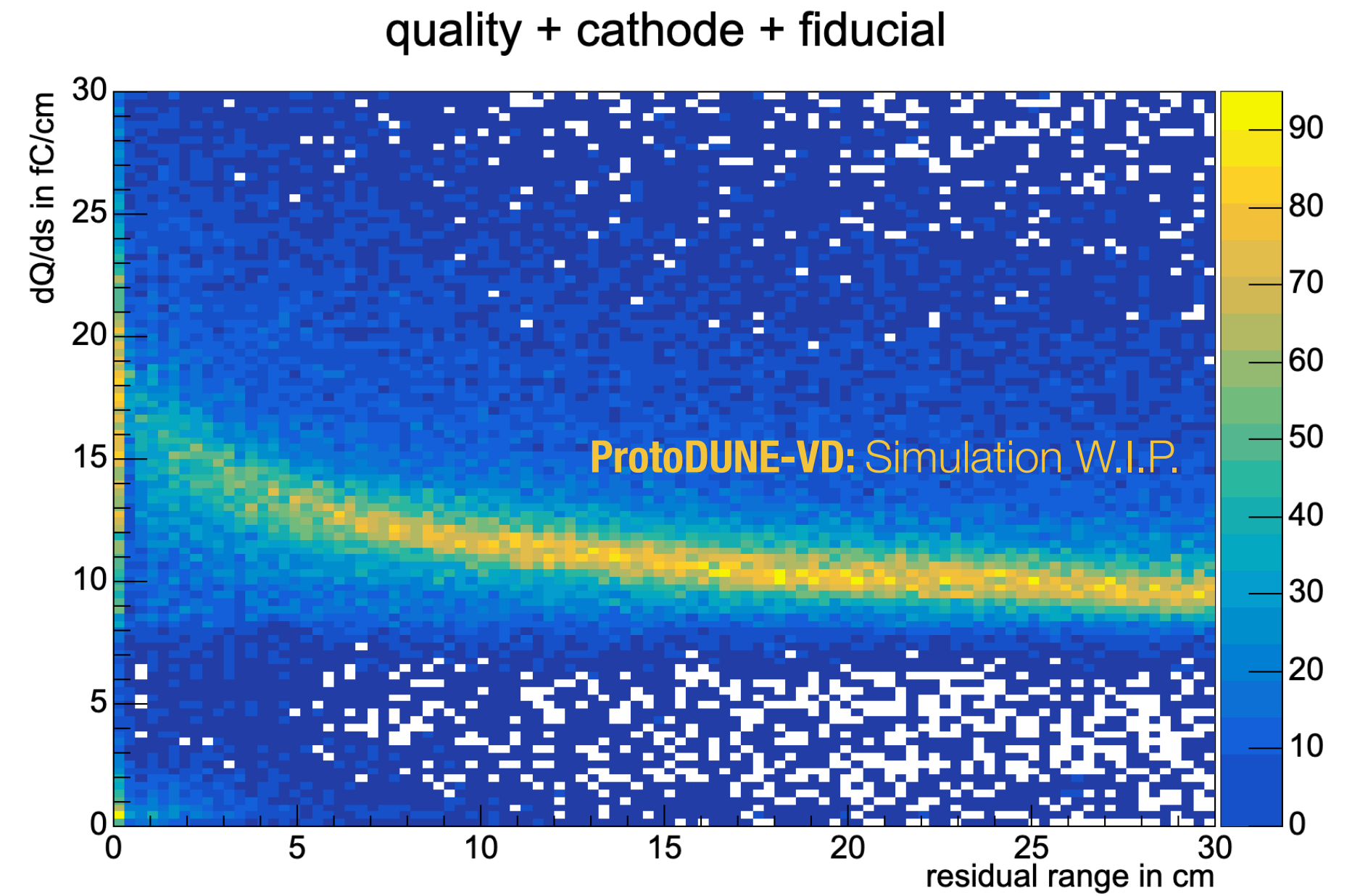
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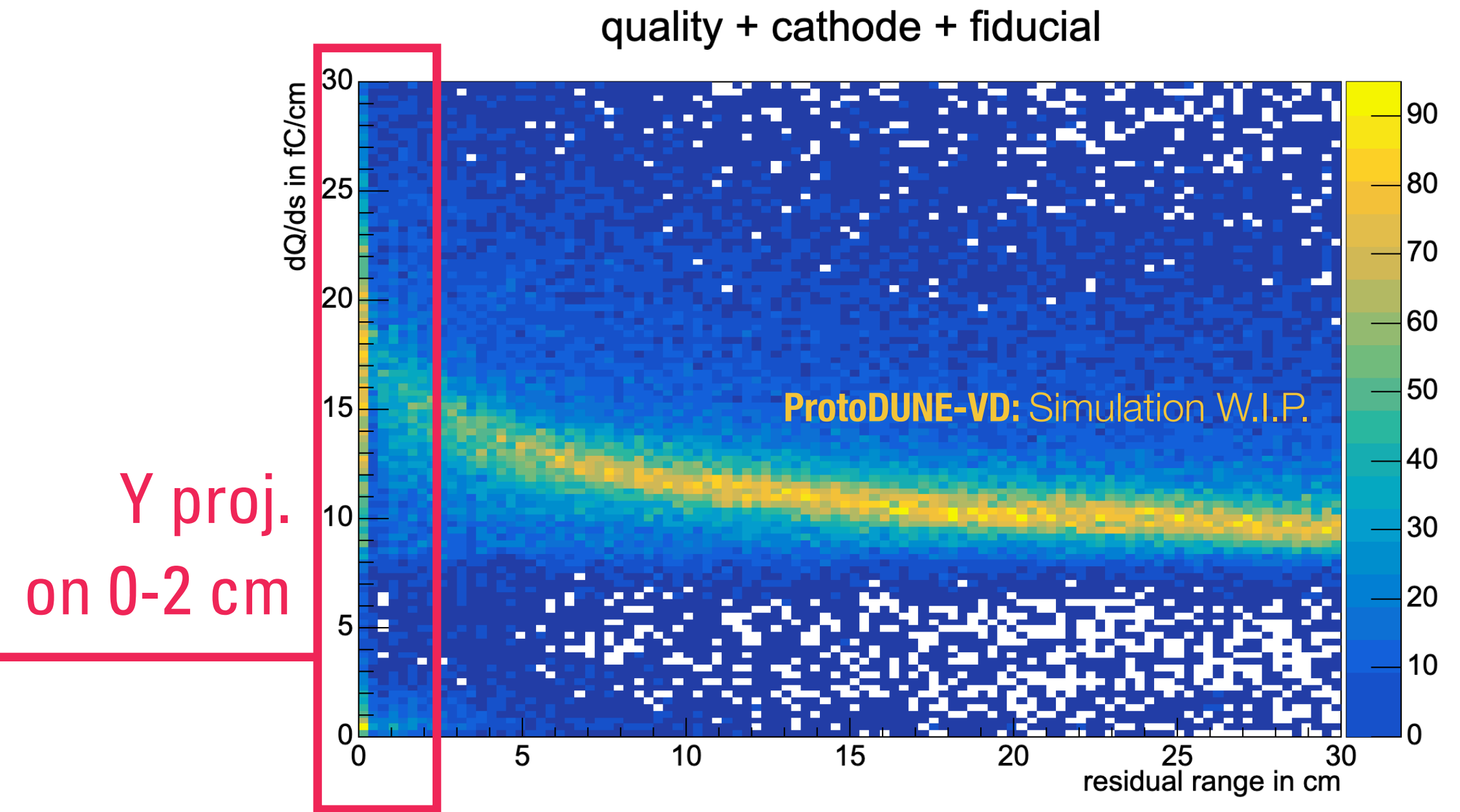
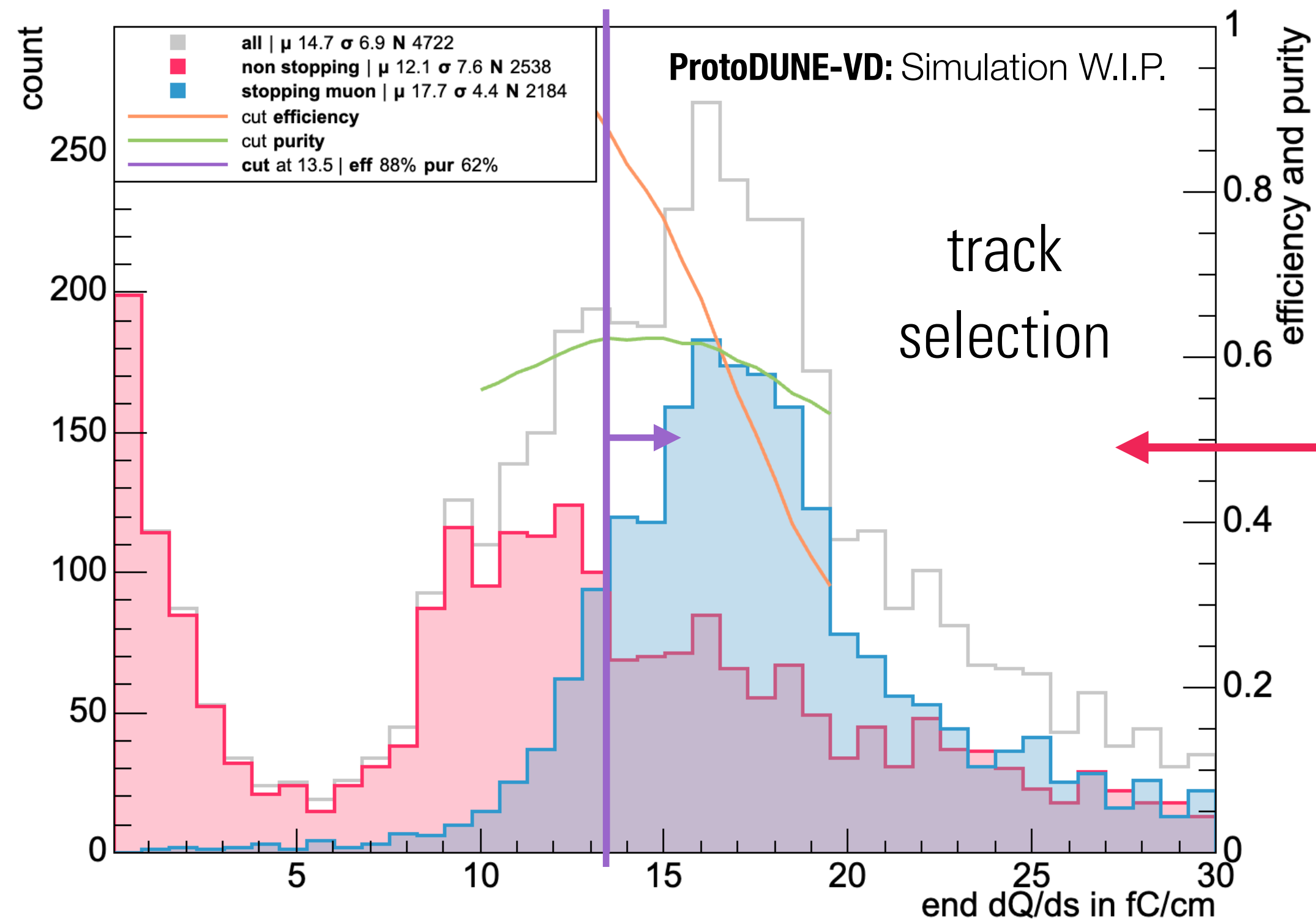


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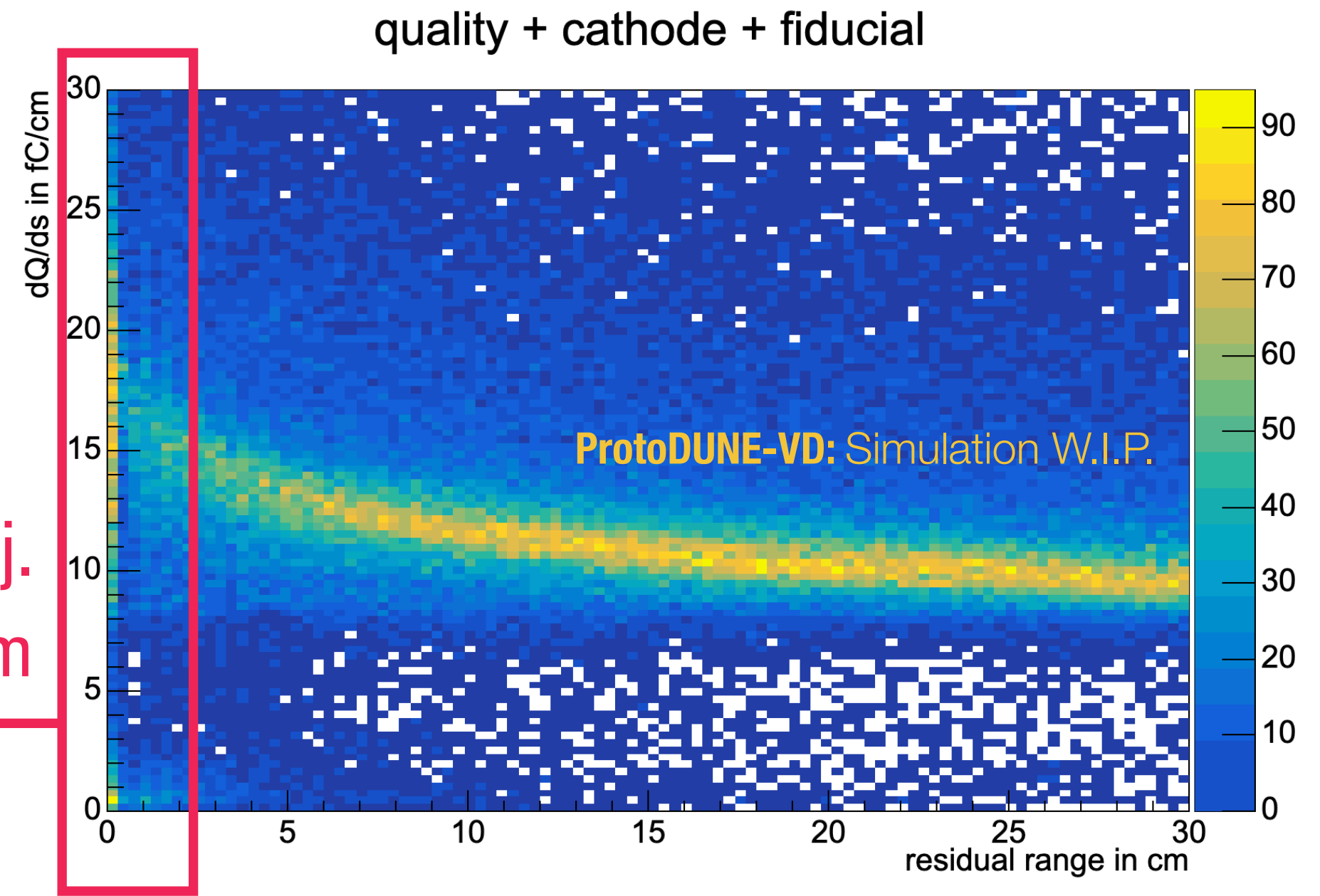
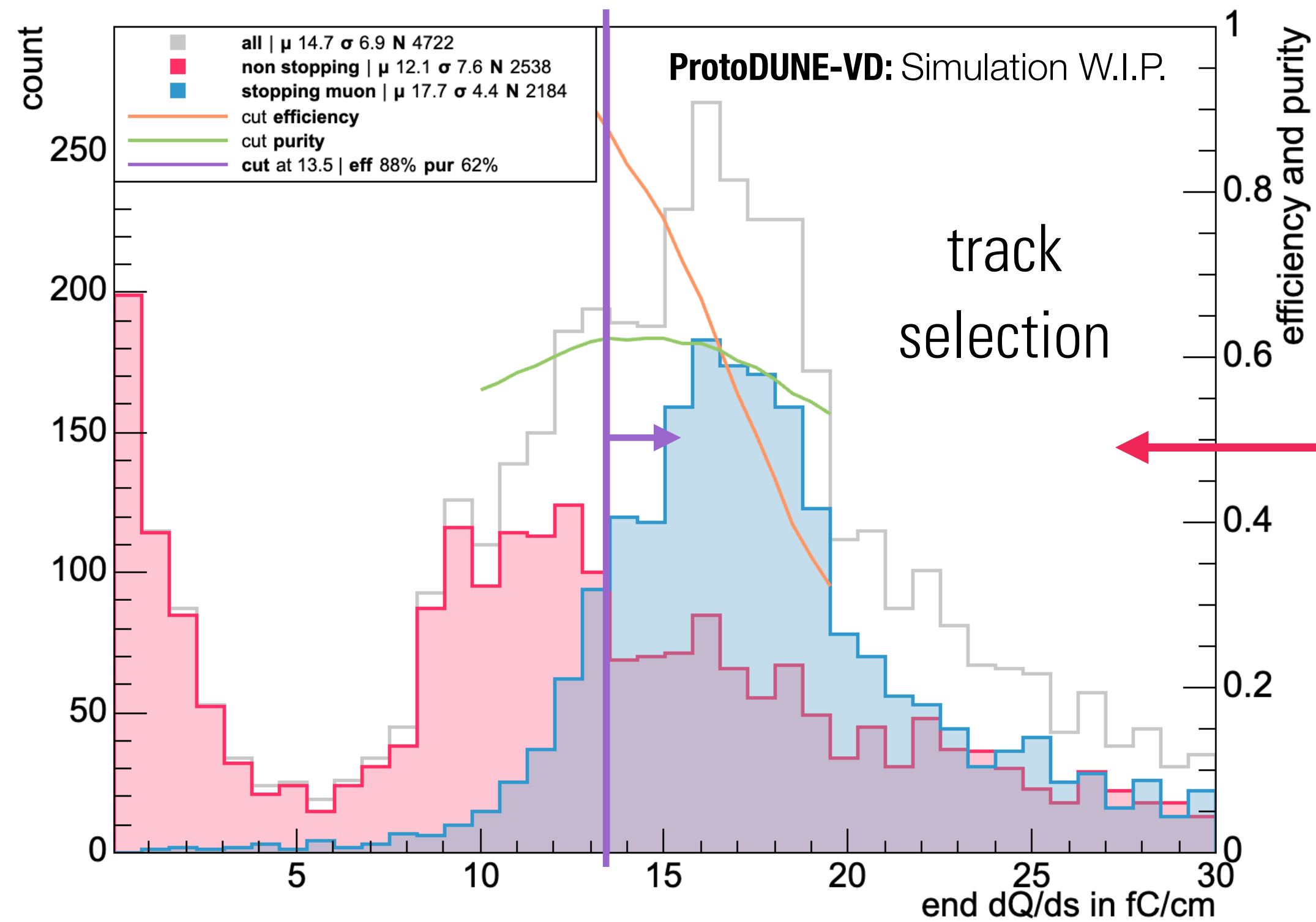


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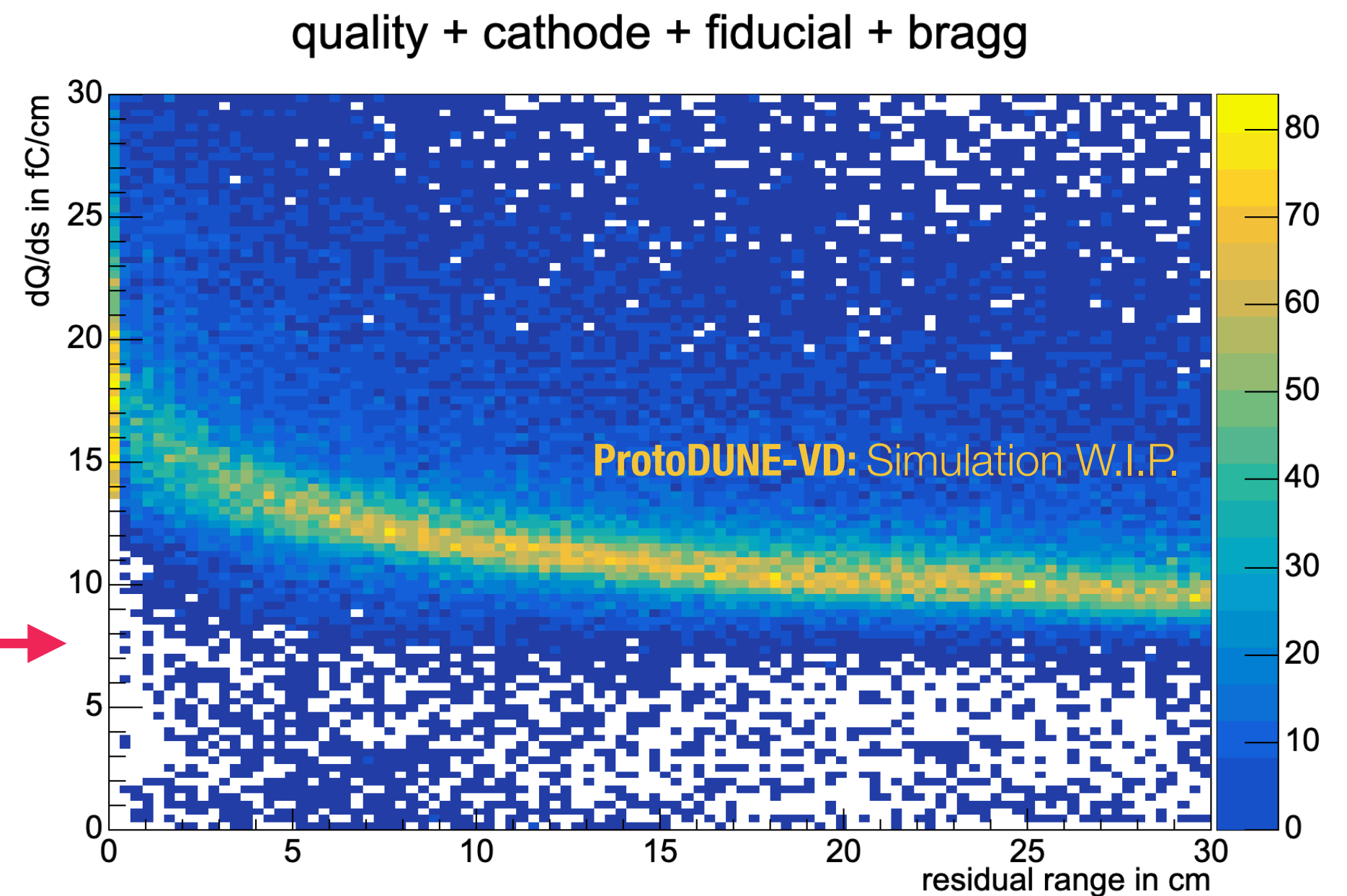
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Y proj.
on 0-2 cm

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

after Bragg cut



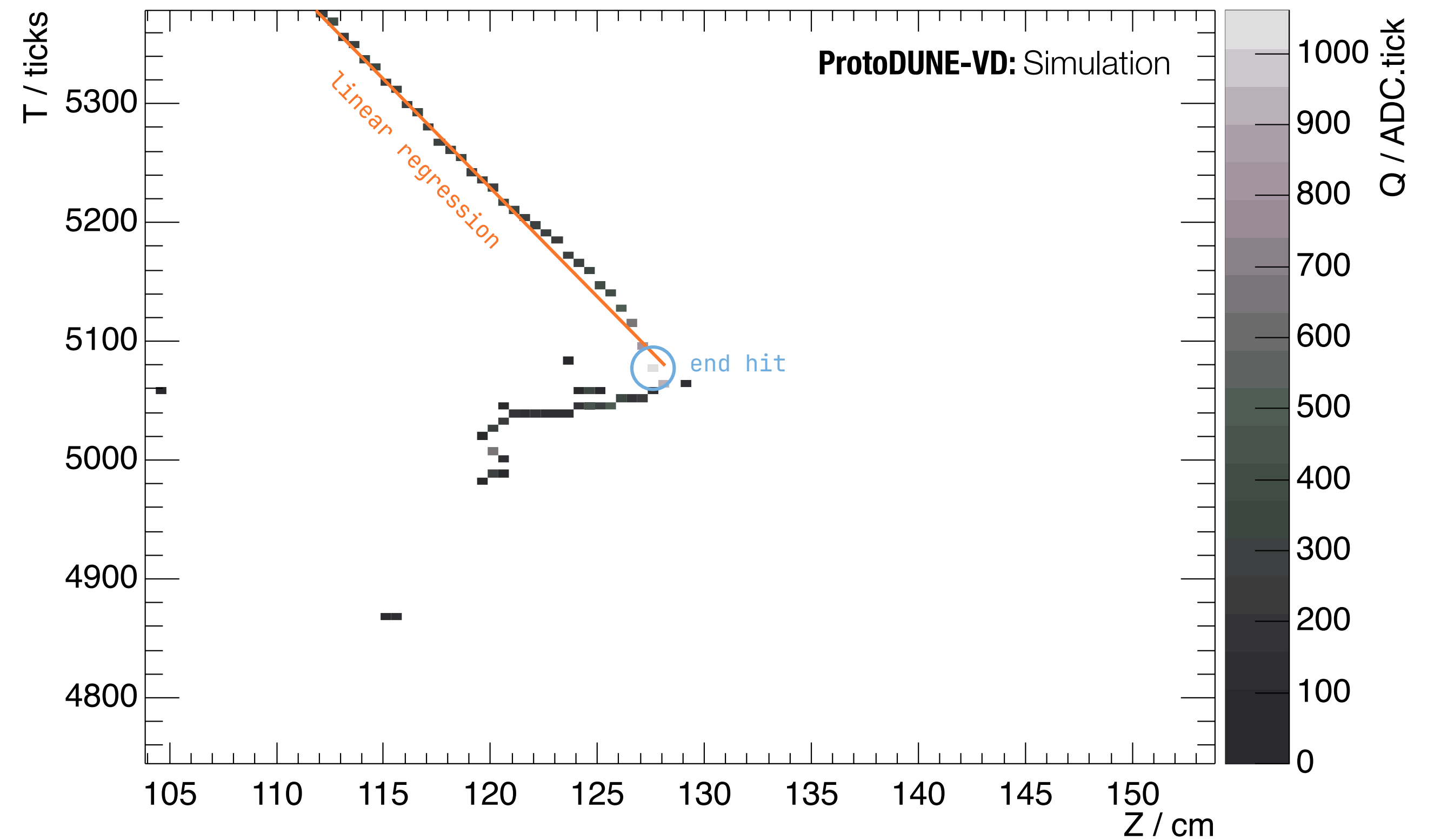
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Using **Pandora track** reconstruction

Michel electron illustration



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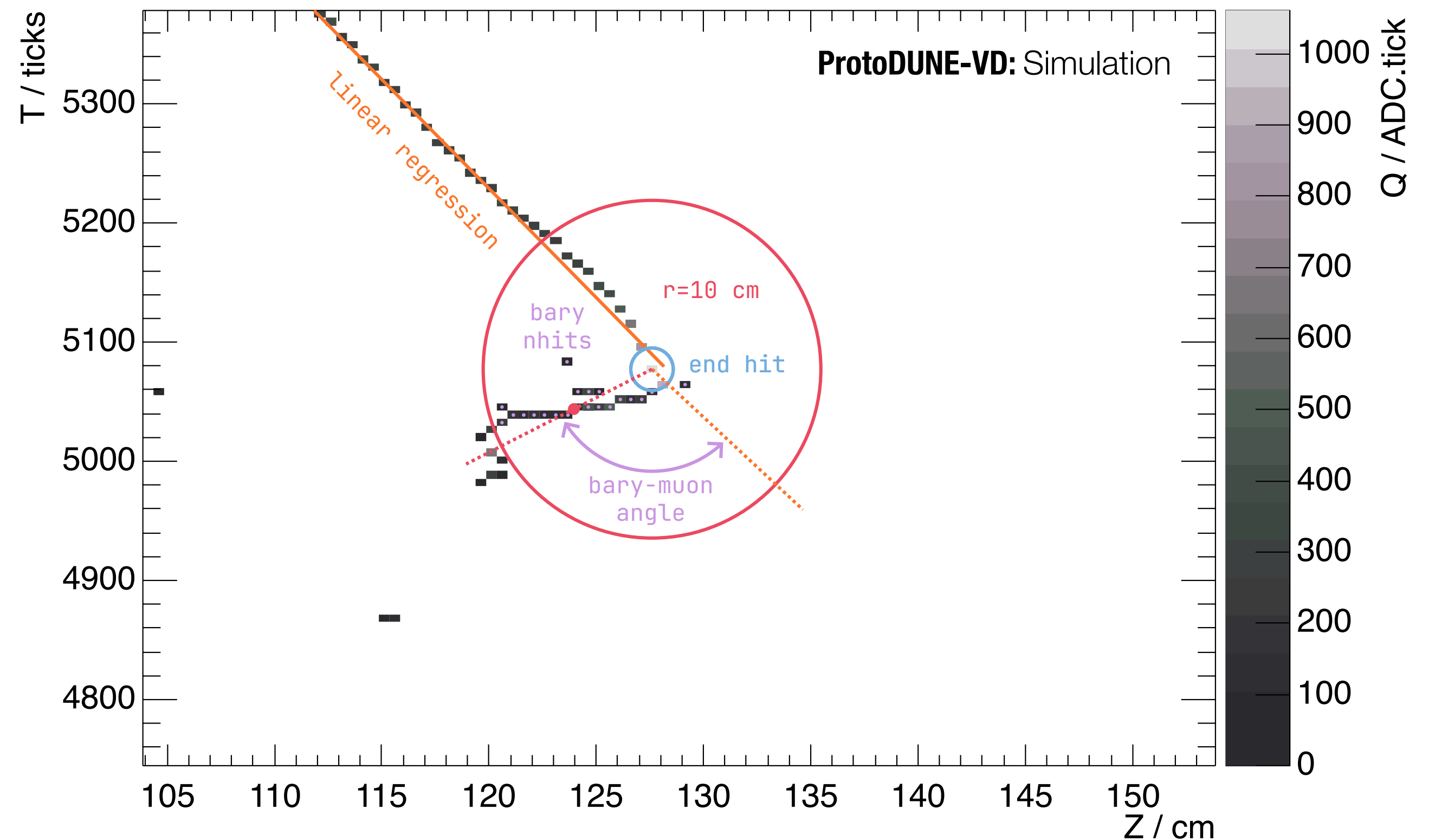
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Select **Michel electron** event candidates

- Topological cuts
 - ▶ no long tracks passing by (prevent contamination)
 - ▶ at least 4 Hits 10 cm around the end point
 - ▶ barycenter-muon angle in 30° - 150°

Using **Pandora track** reconstruction

Michel electron illustration



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ProtoDUNE-VD: Simulation W.I.P.

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

ProtoDUNE-HD: Simulation W.I.P.

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Efficiency: 2.2 %

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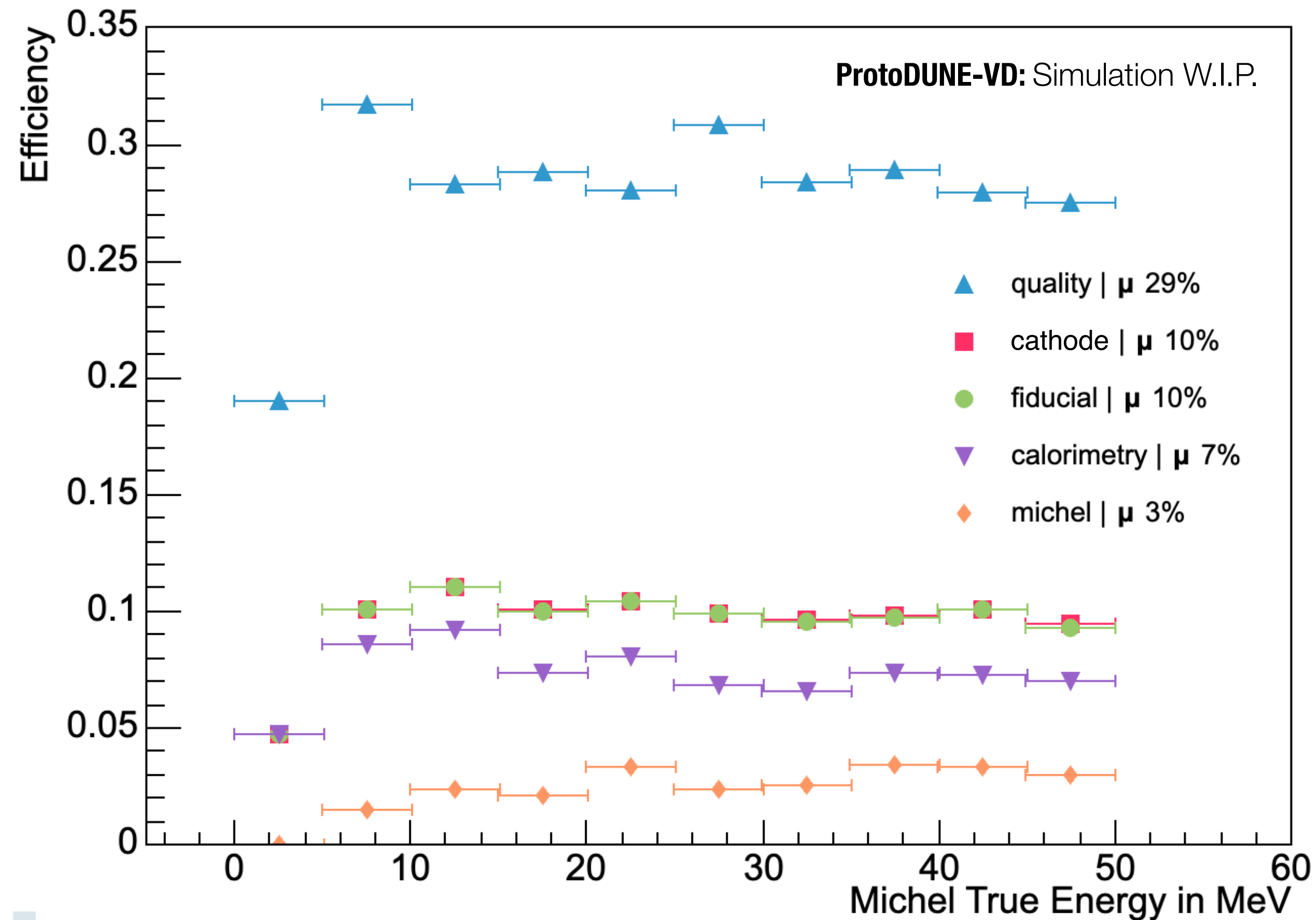
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Selection efficiency bias



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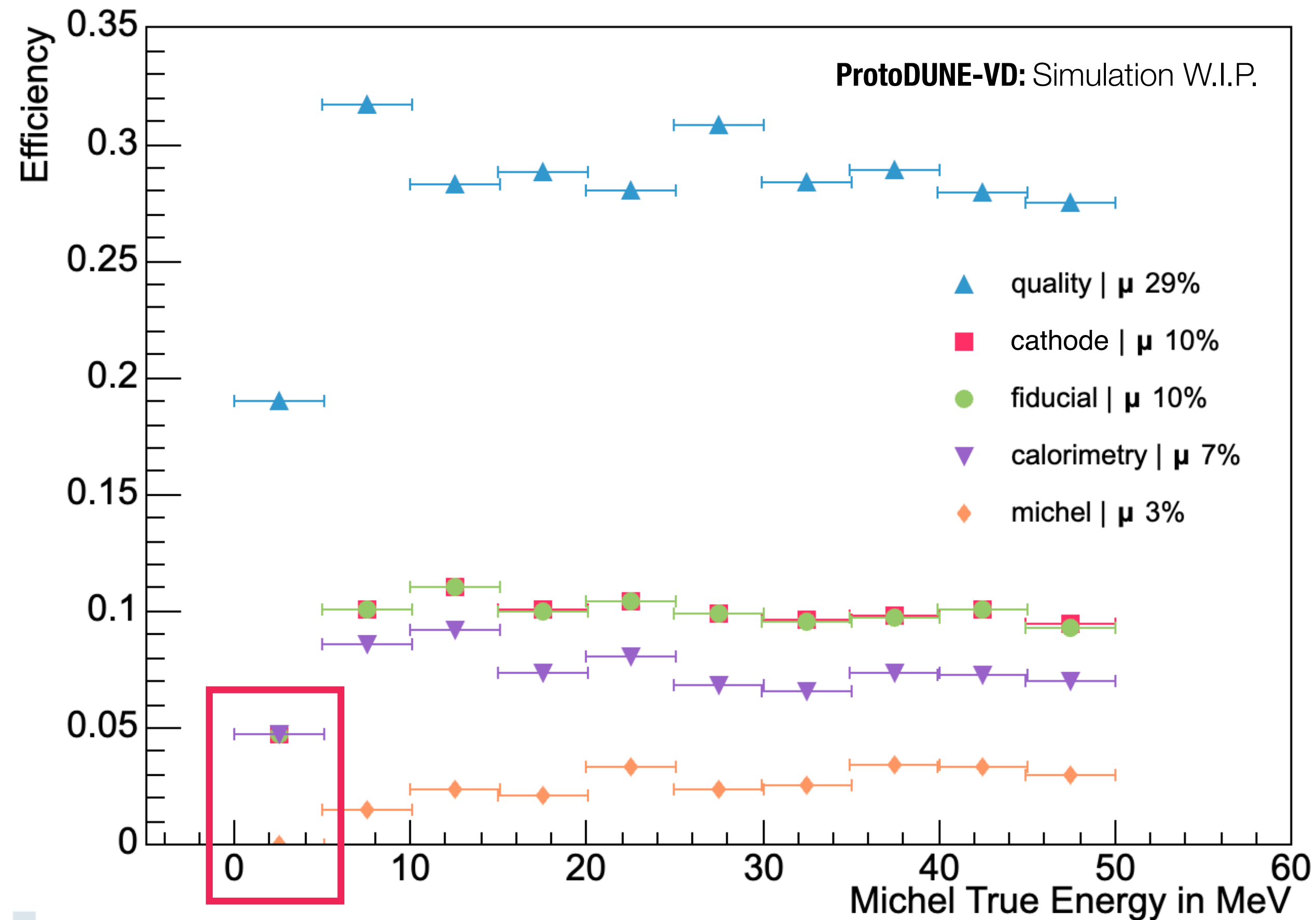
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no reconstructed Michel electrons below 5 MeV

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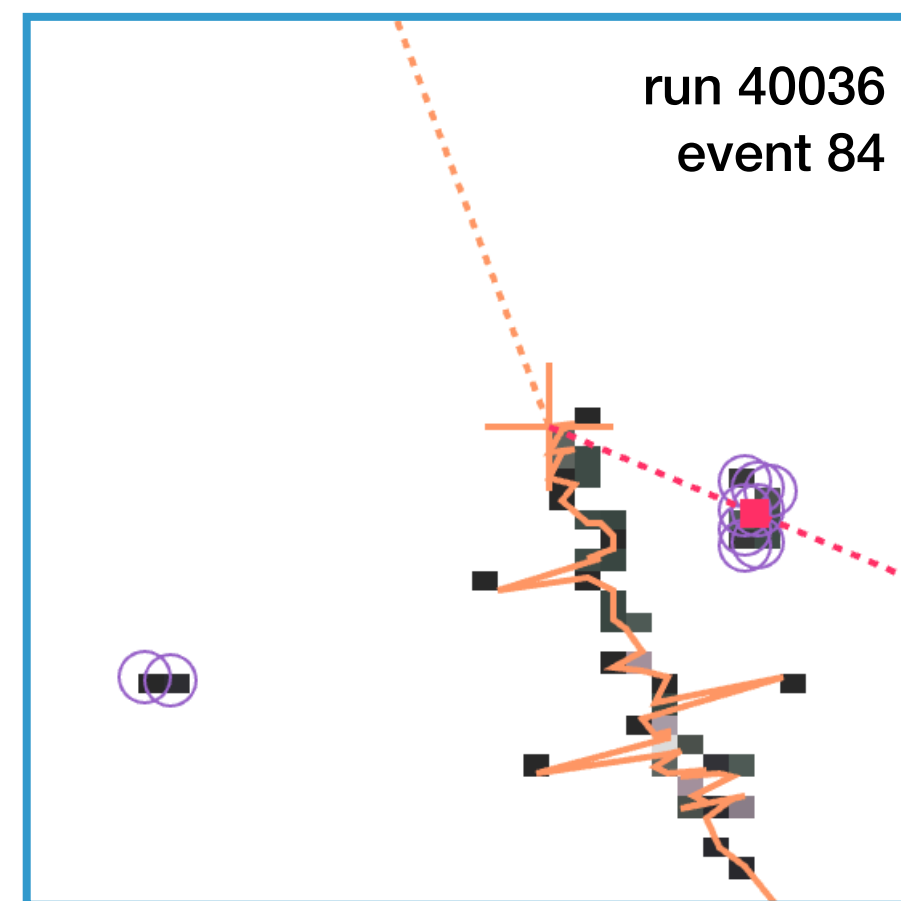
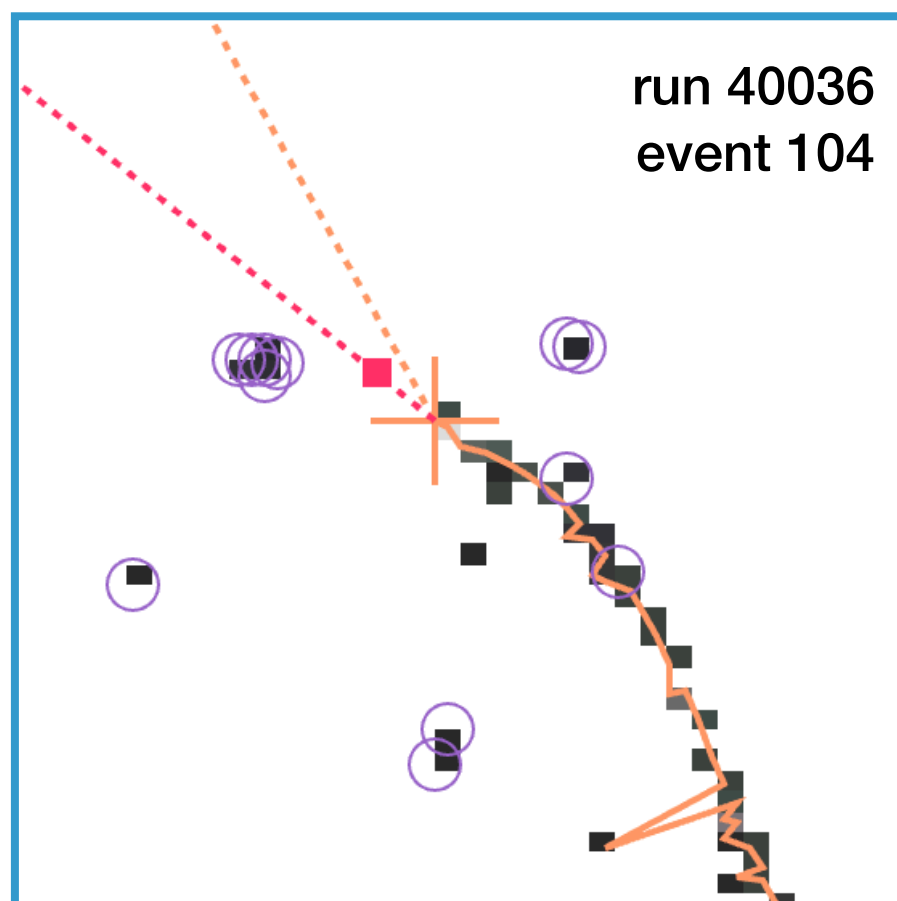
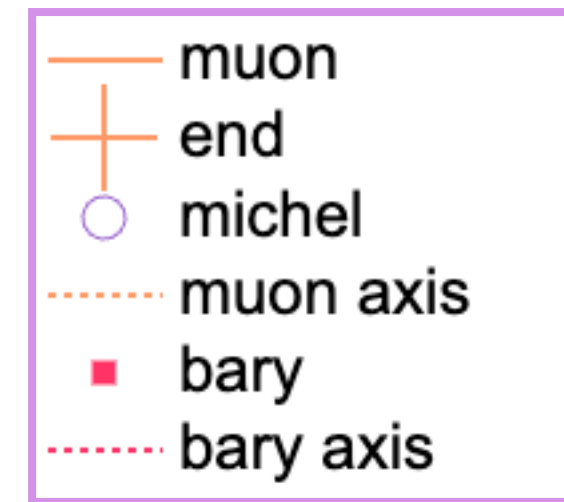
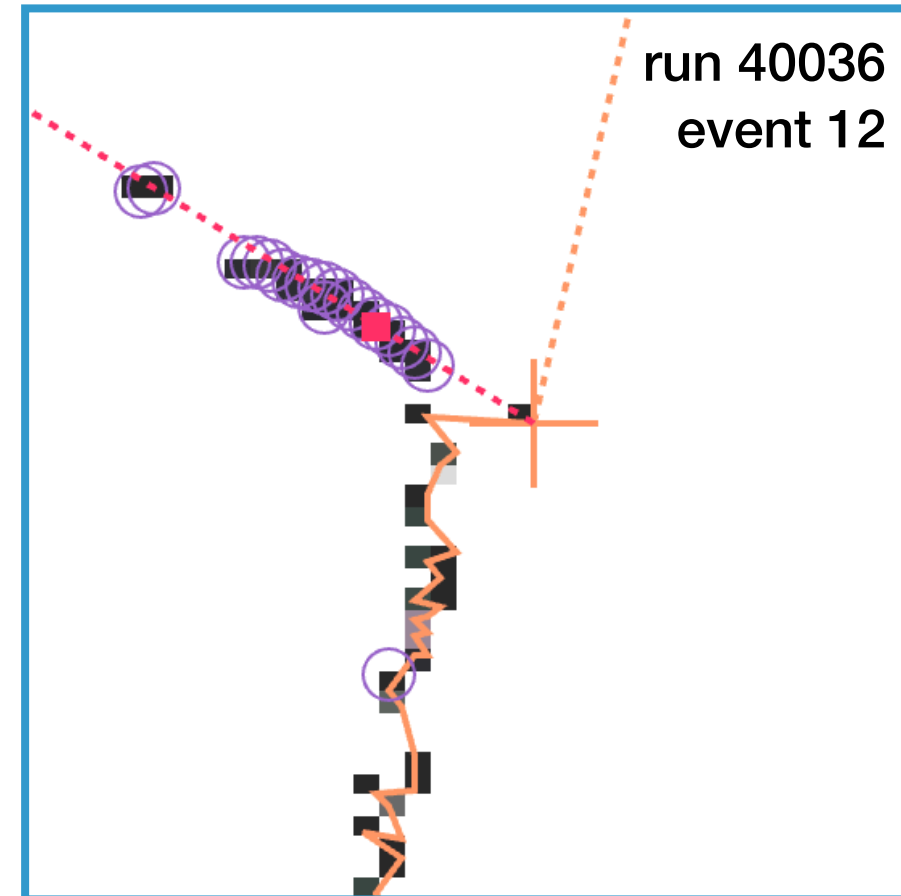
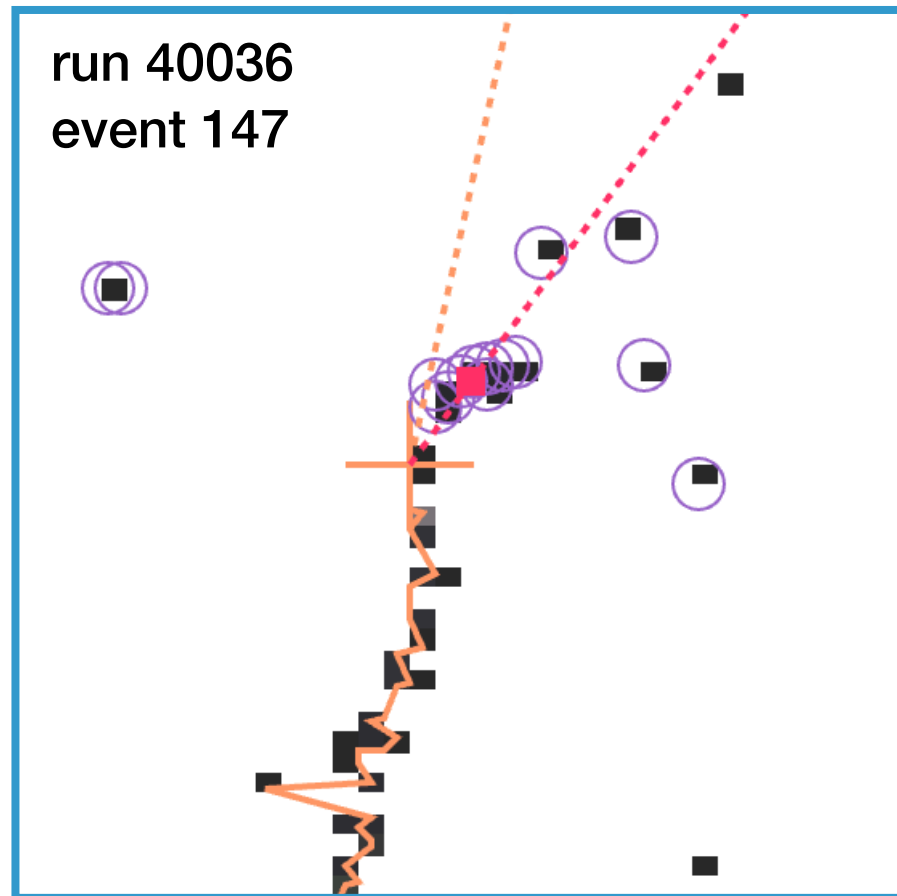
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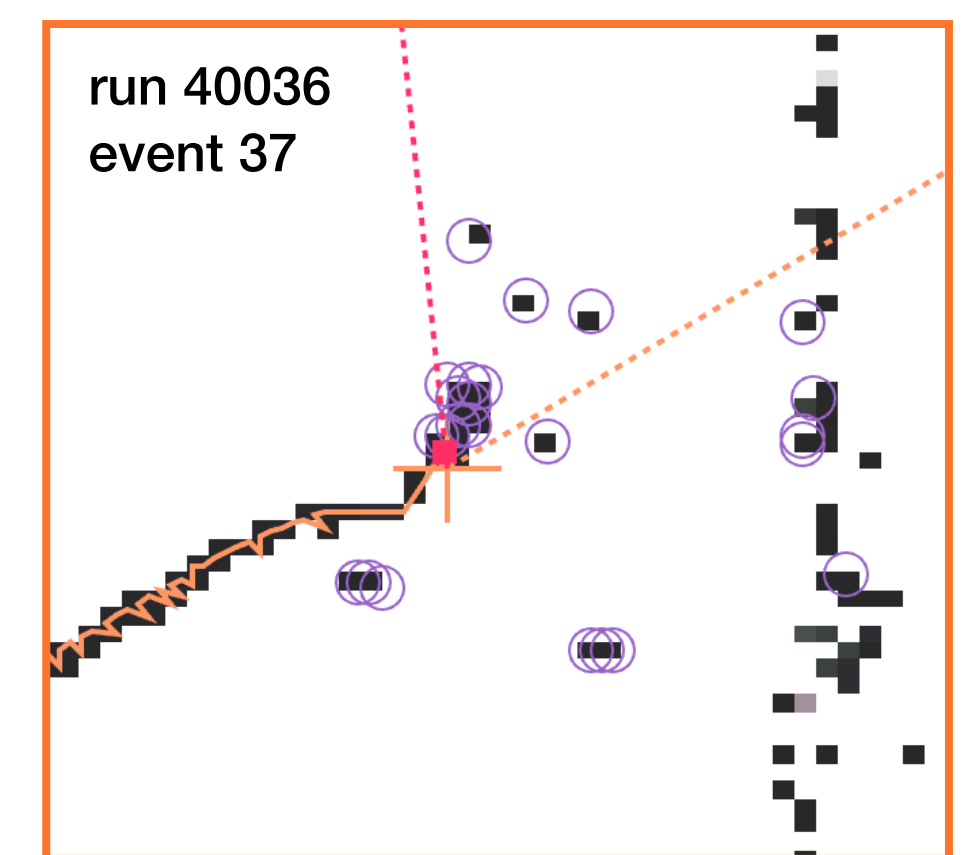
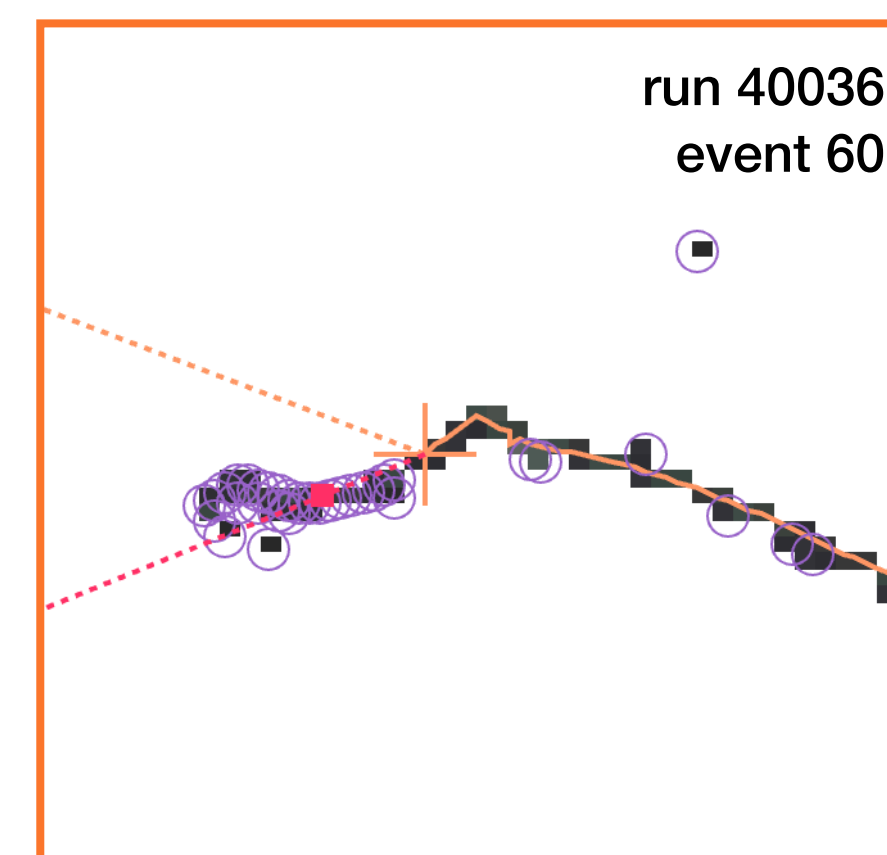
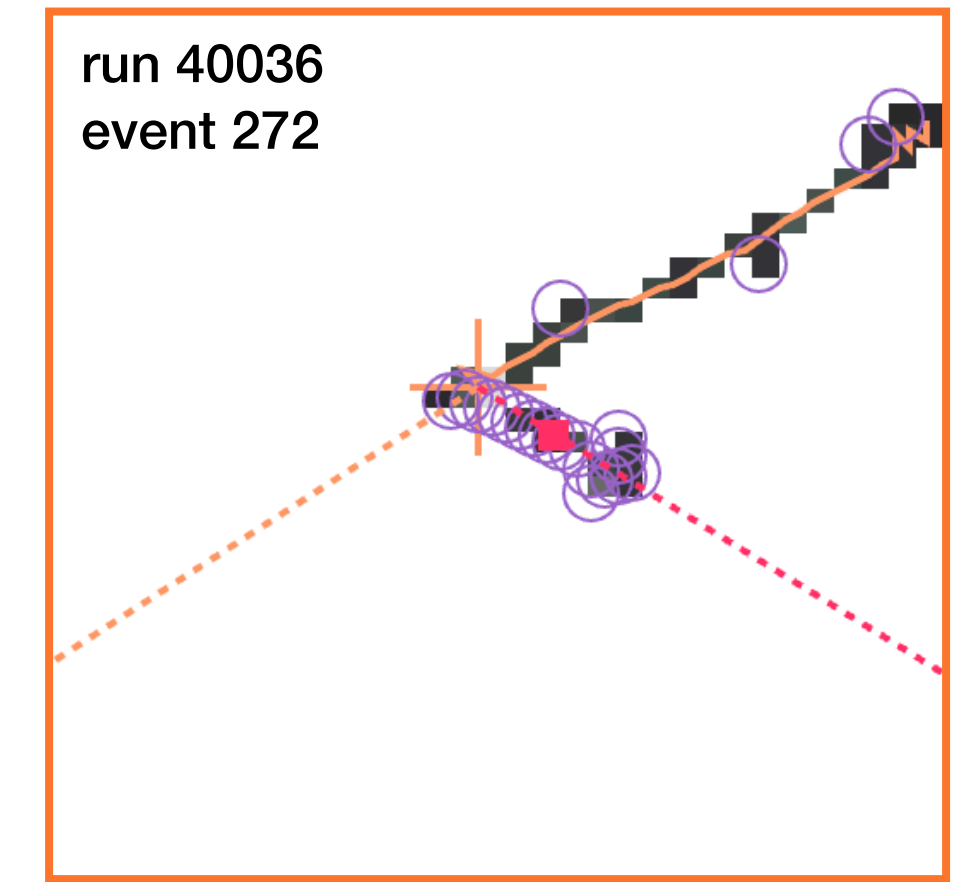
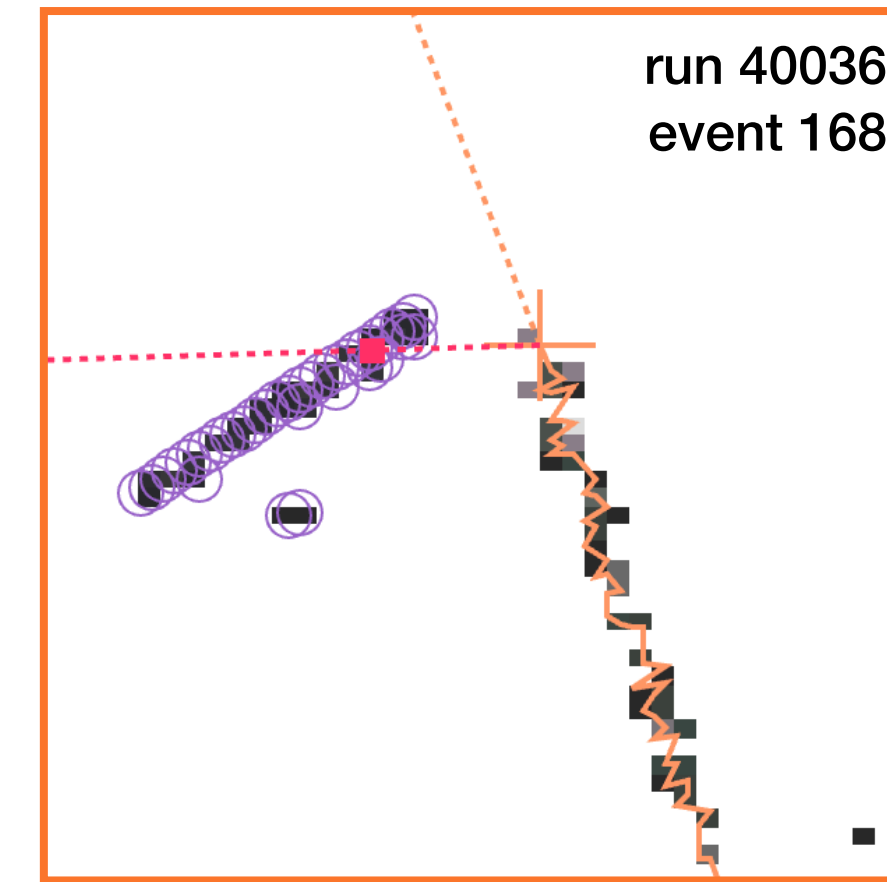
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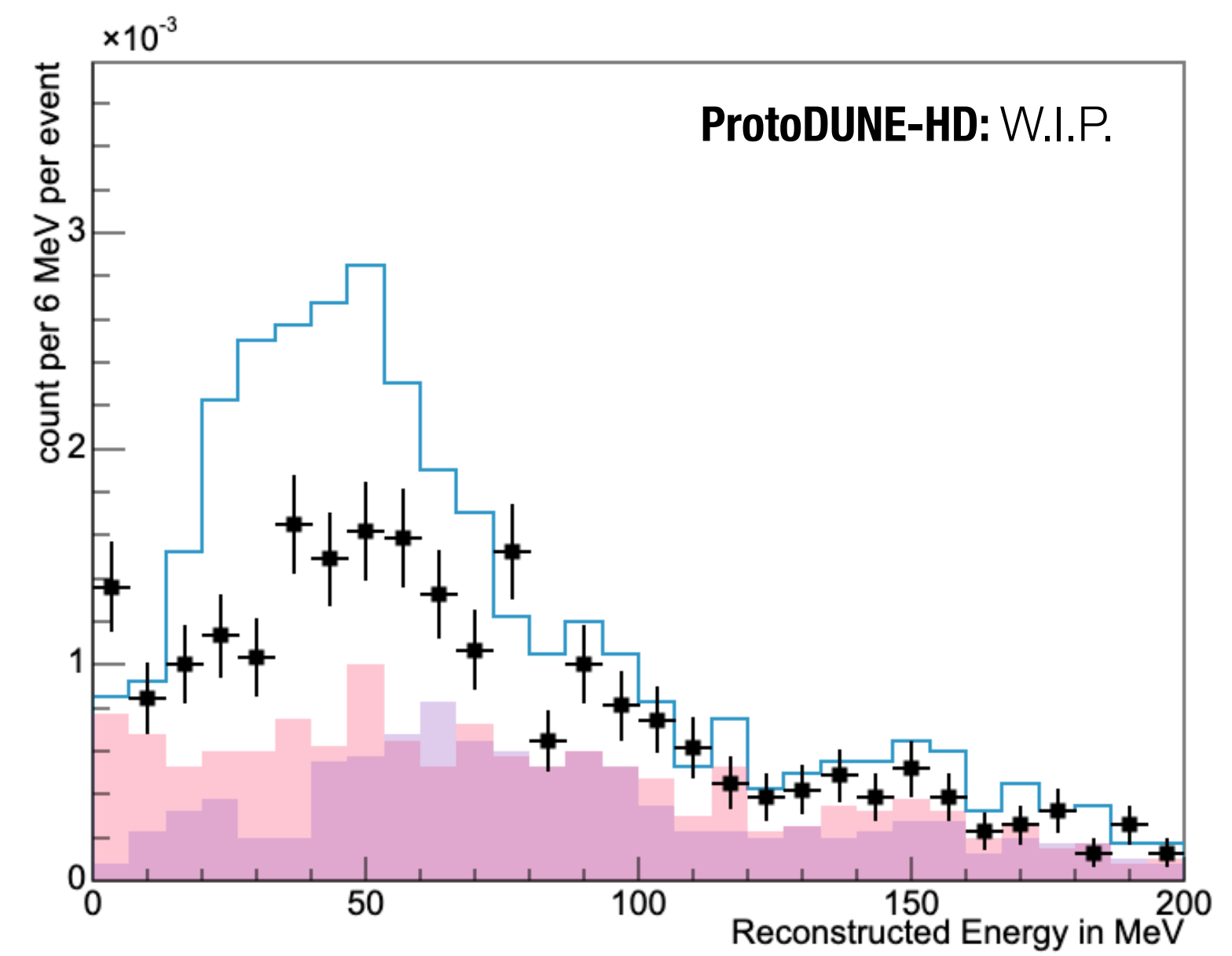
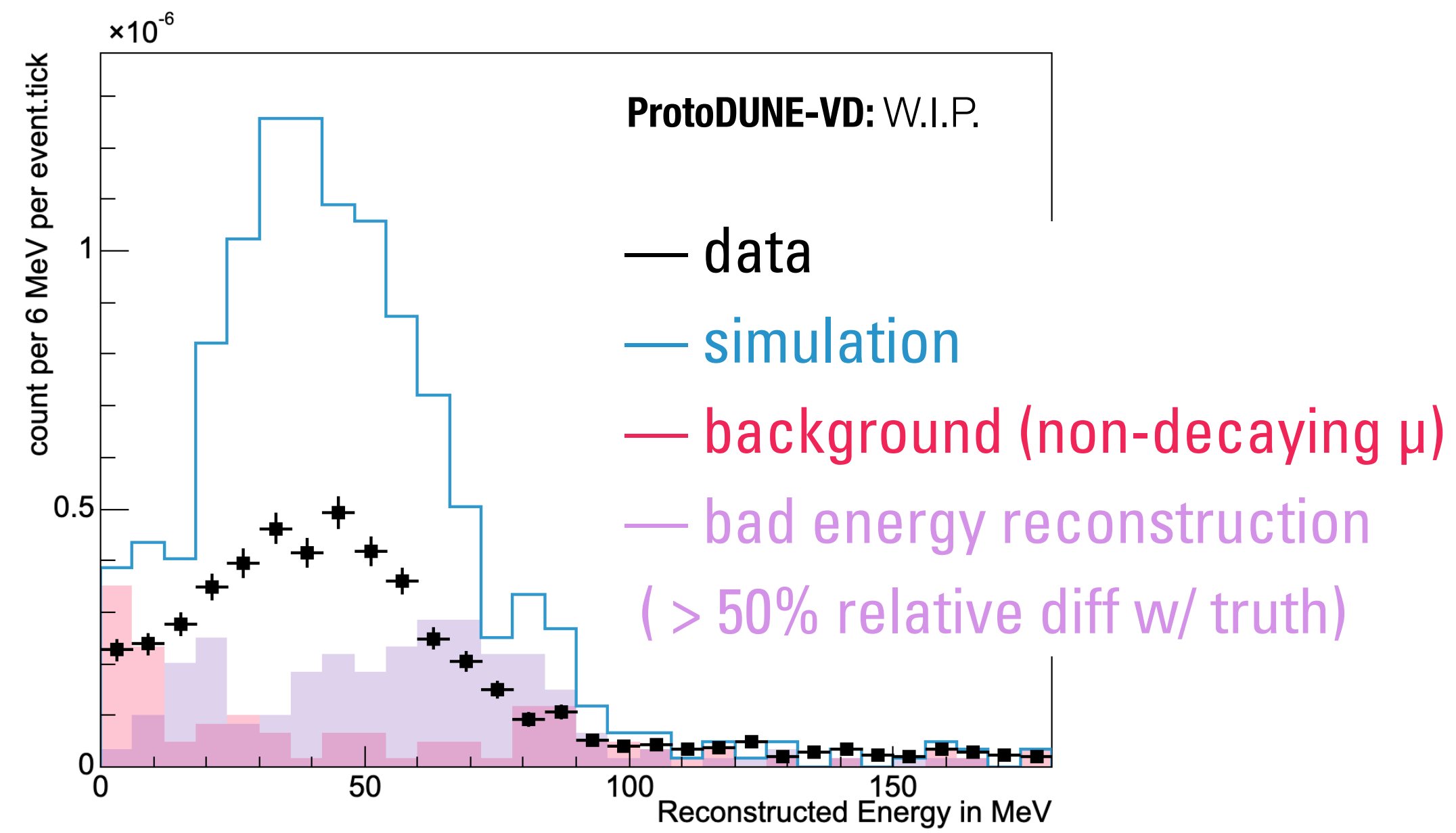
Random reconstructed events passing selections in ProtoDUNE-VD

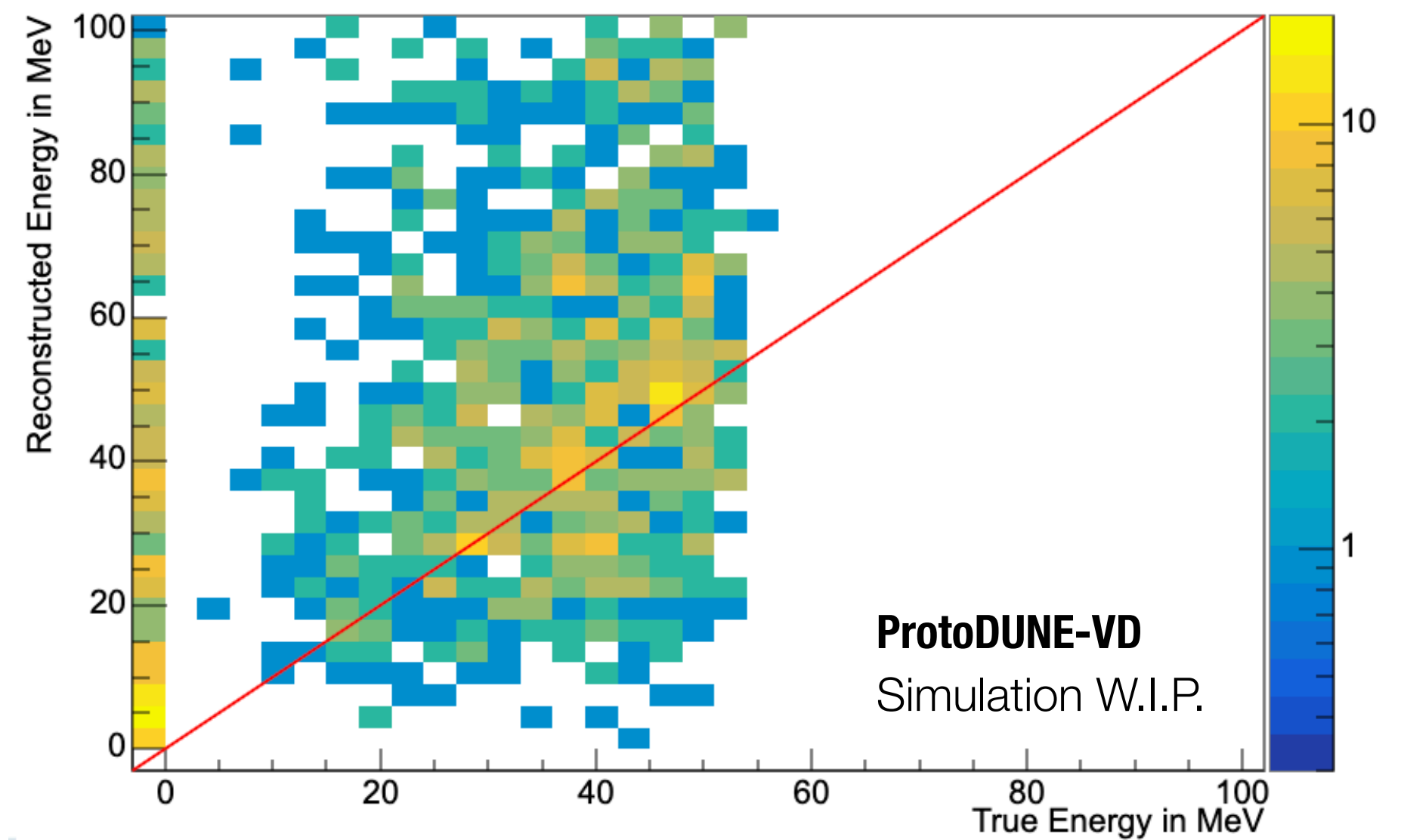
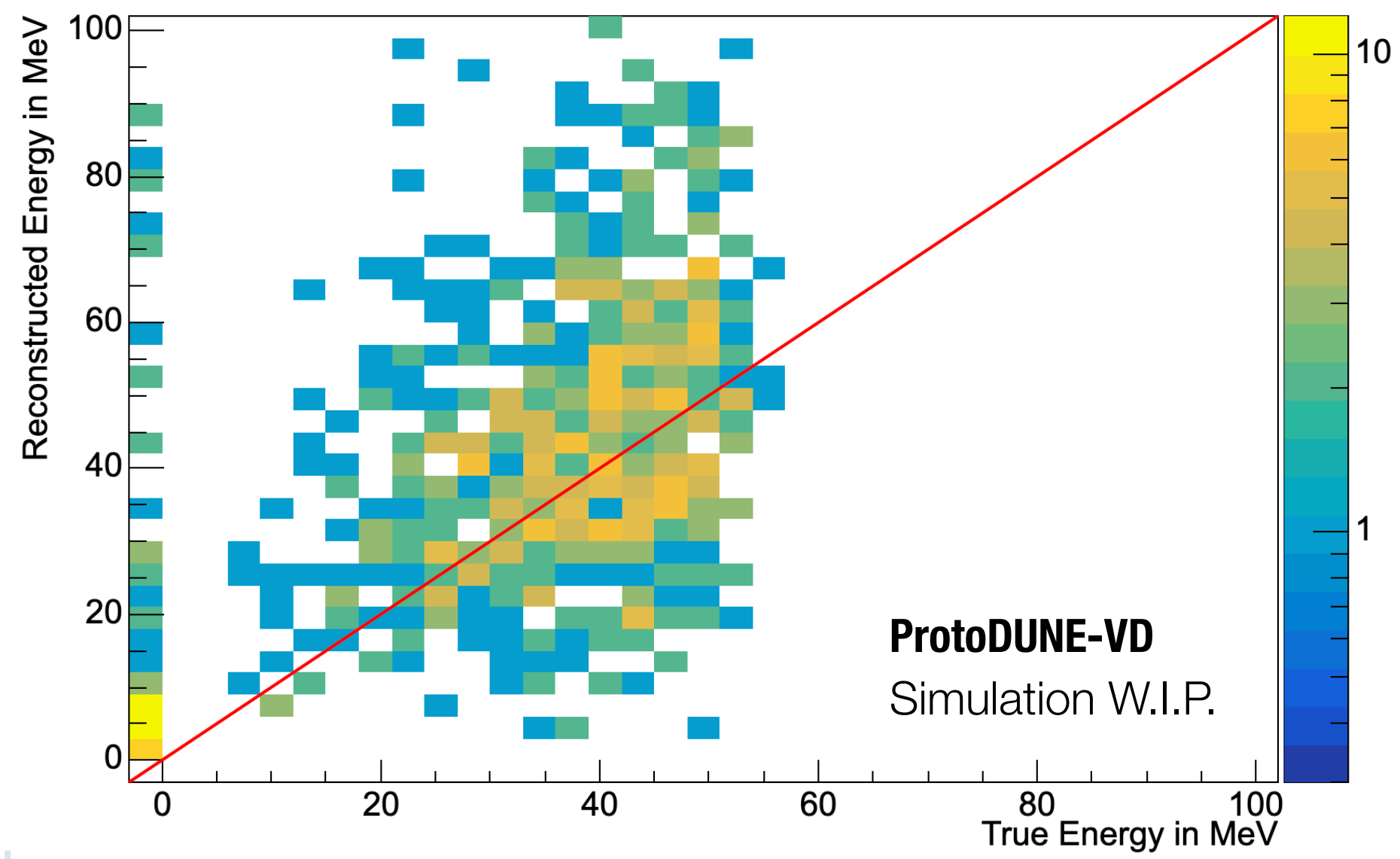
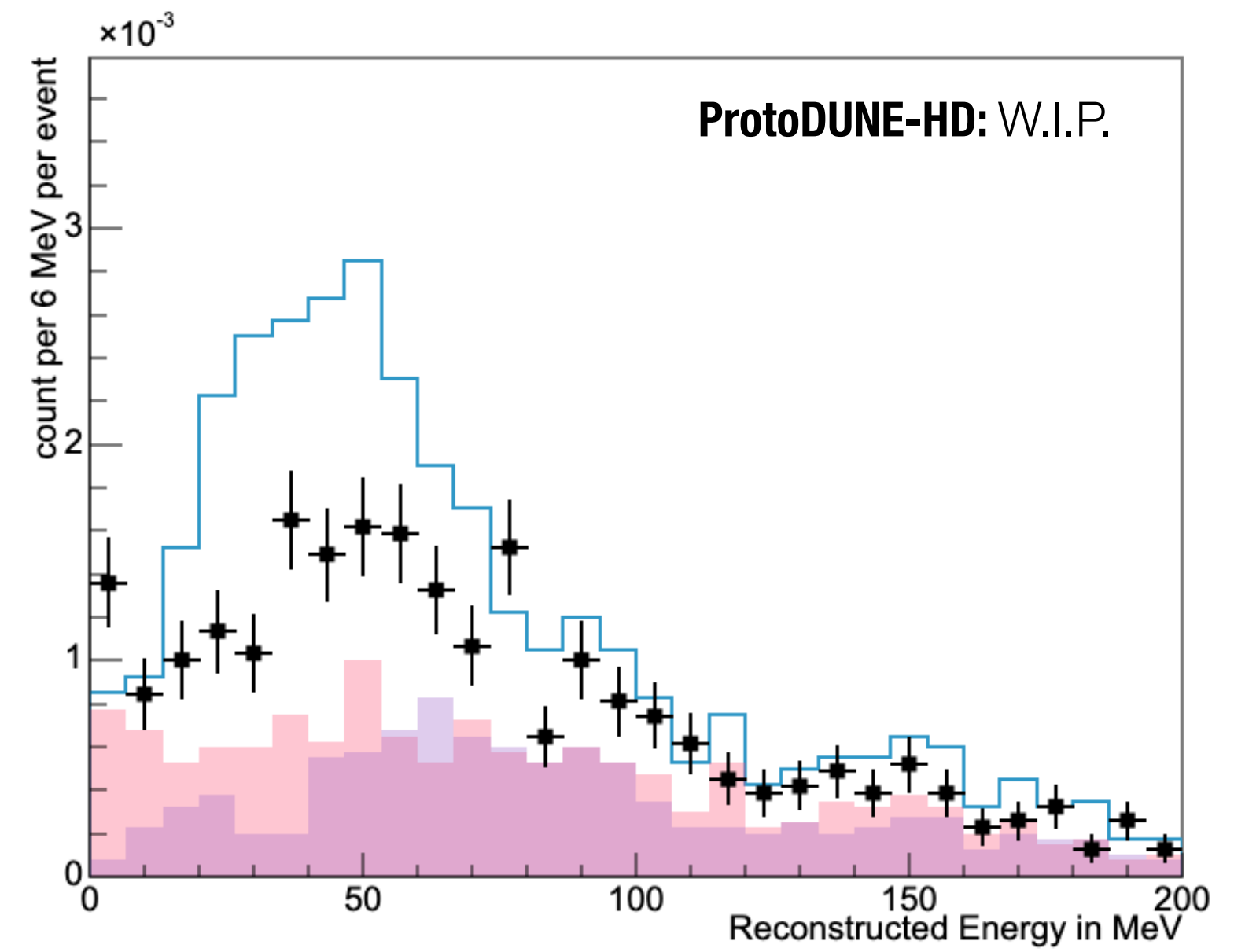
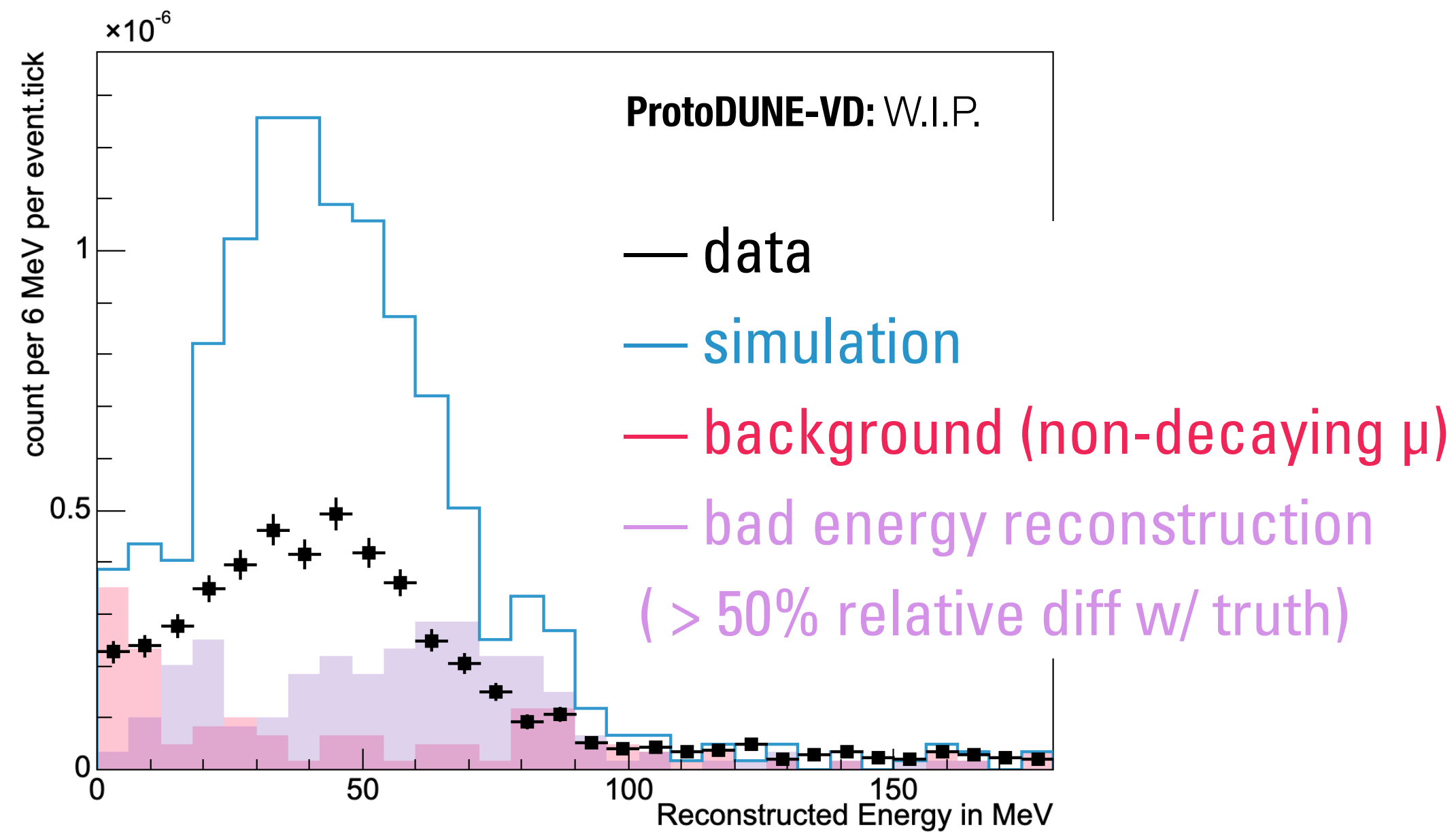
E = 10 - 30 MeV

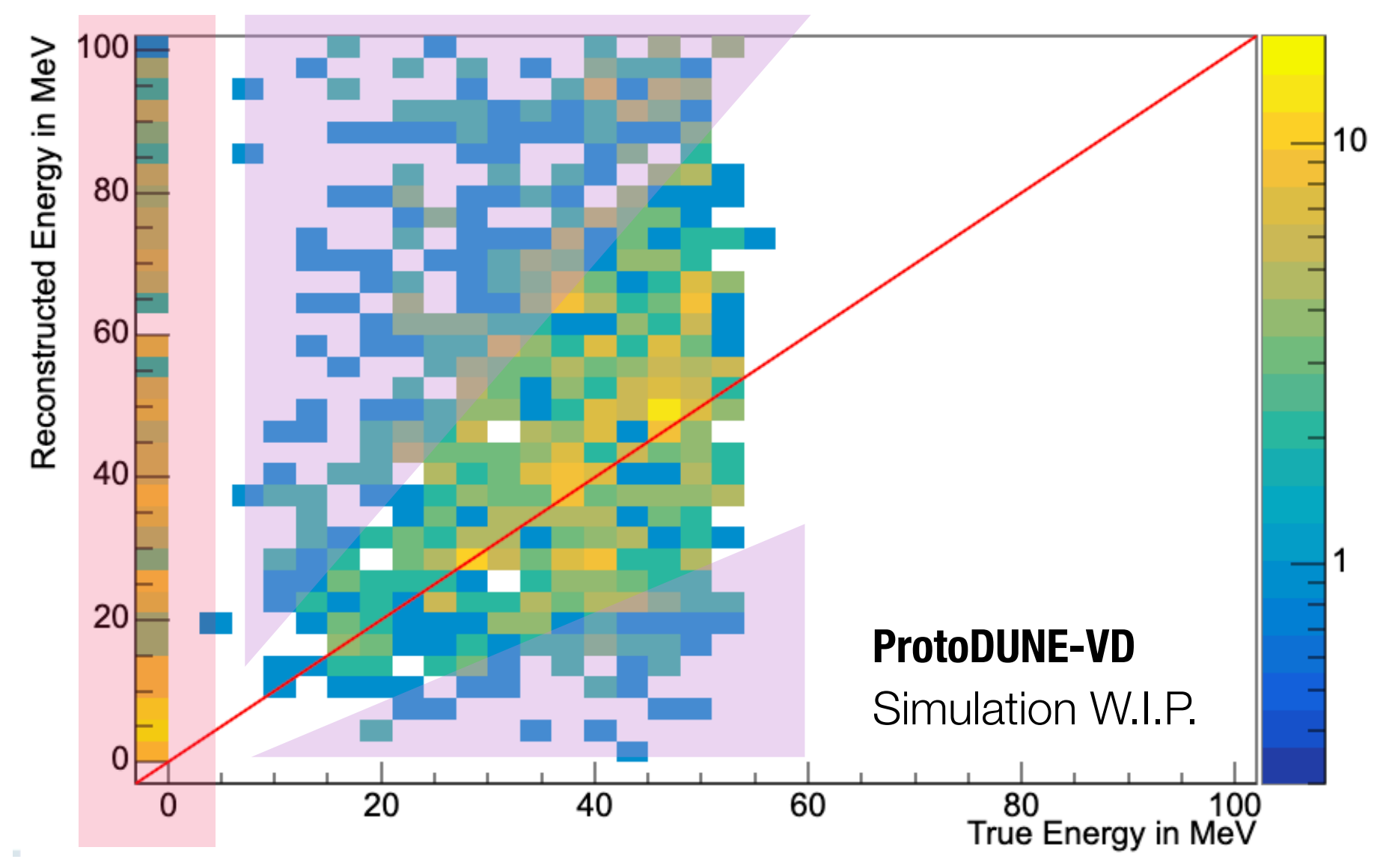
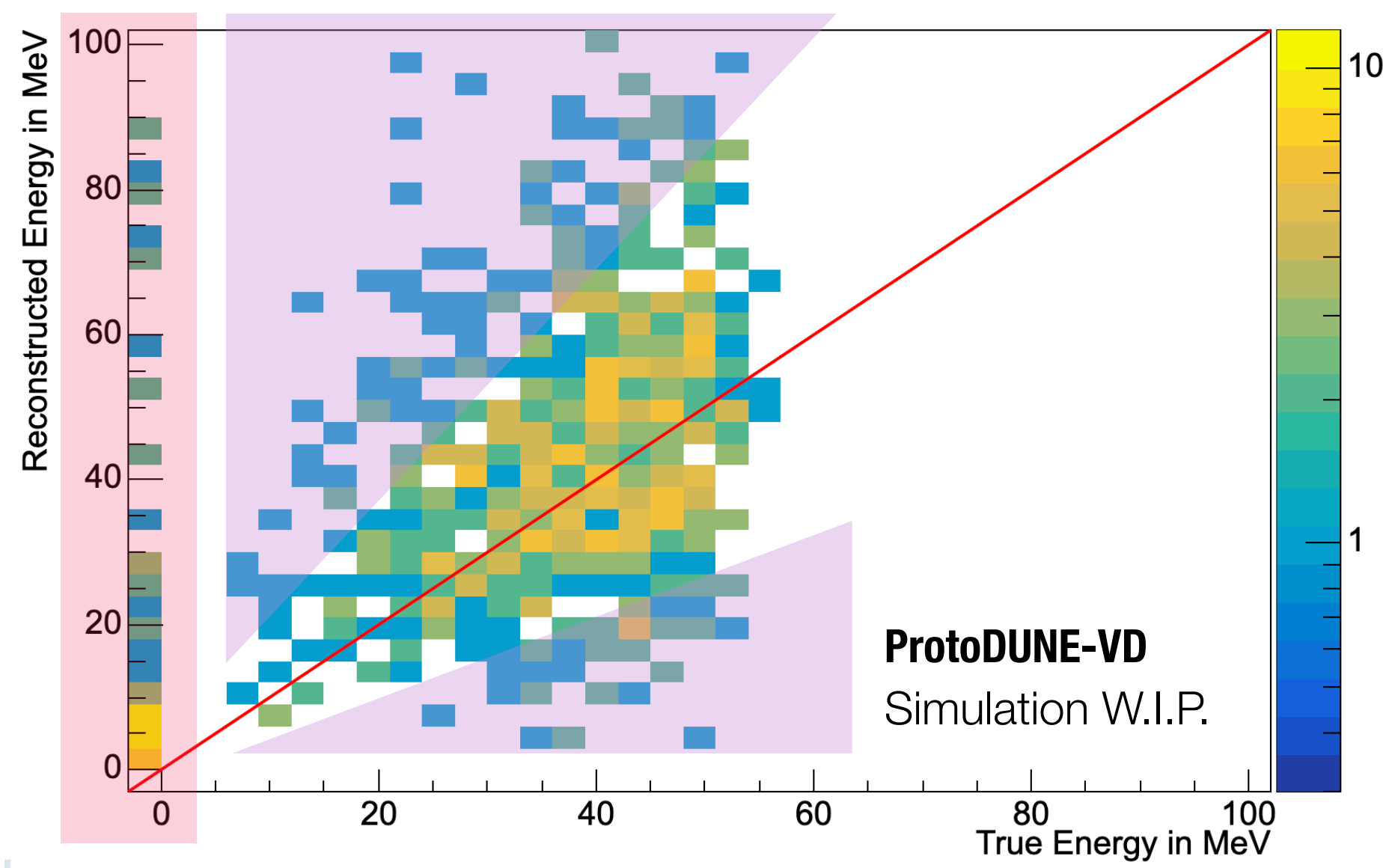
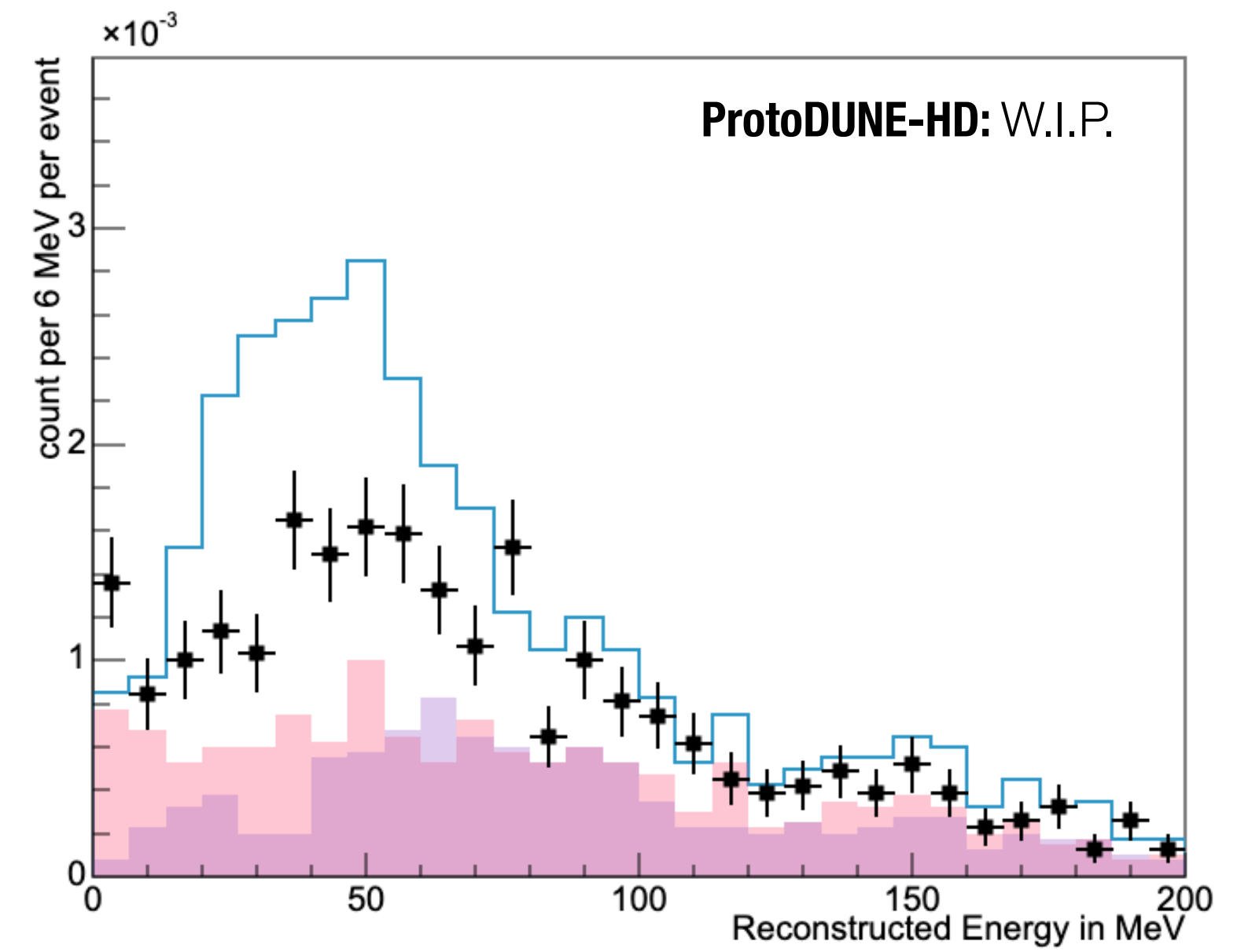
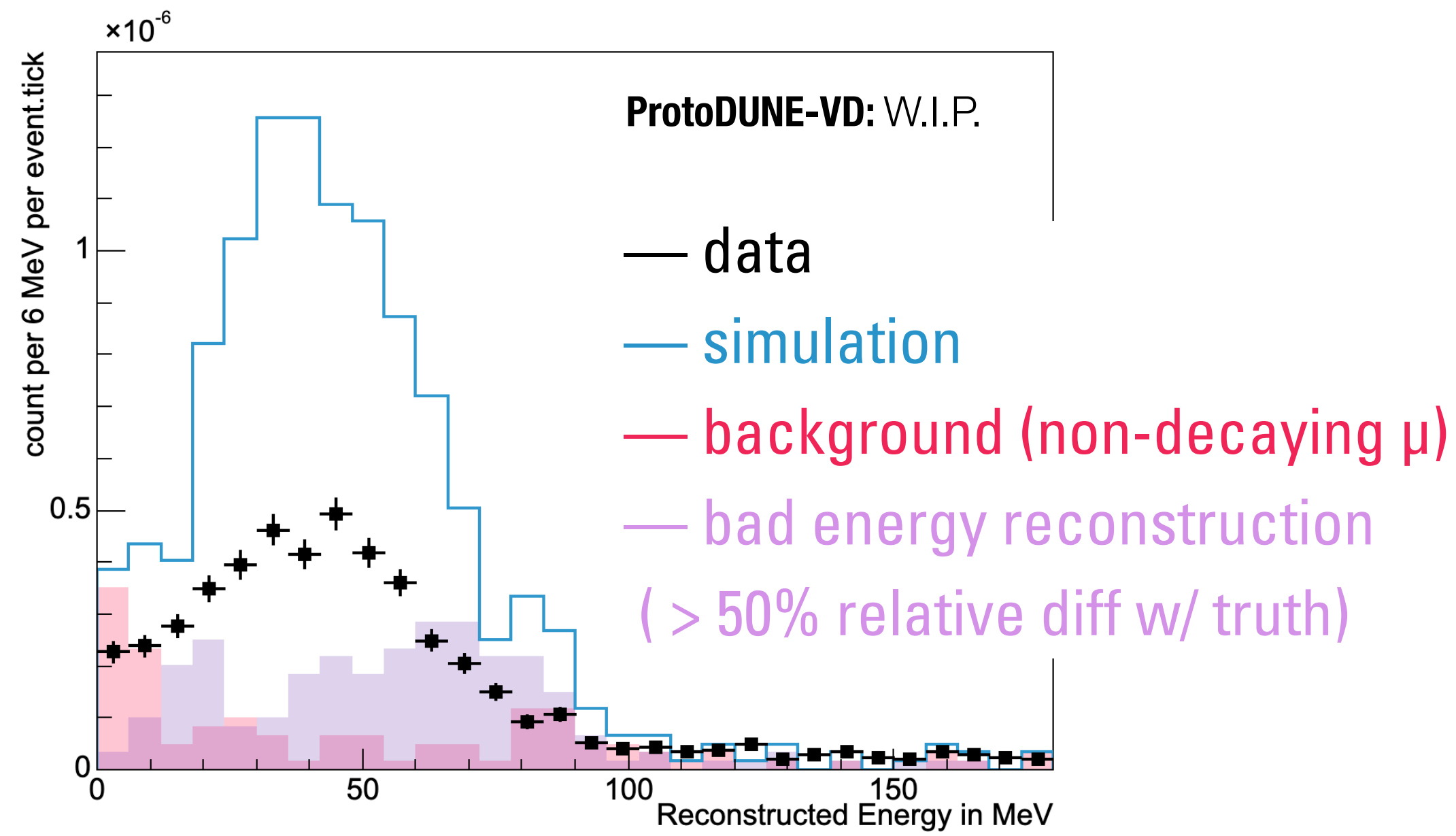


E = 30 - 45 MeV









Key point

- First Michel electron spectra in ProtoDUNE-VD and ProtoDUNE-HD

Perspectives

- Use under-development AI/ML solutions with SPINE (cf. Nived's poster)
- Michel electrons as a probe to DUNE low energy sensitivity and supernovae signal reconstruction capability

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