δ-rays: A Novel Calibration for DUNE for Low-Energy Astrophysical Neutrinos

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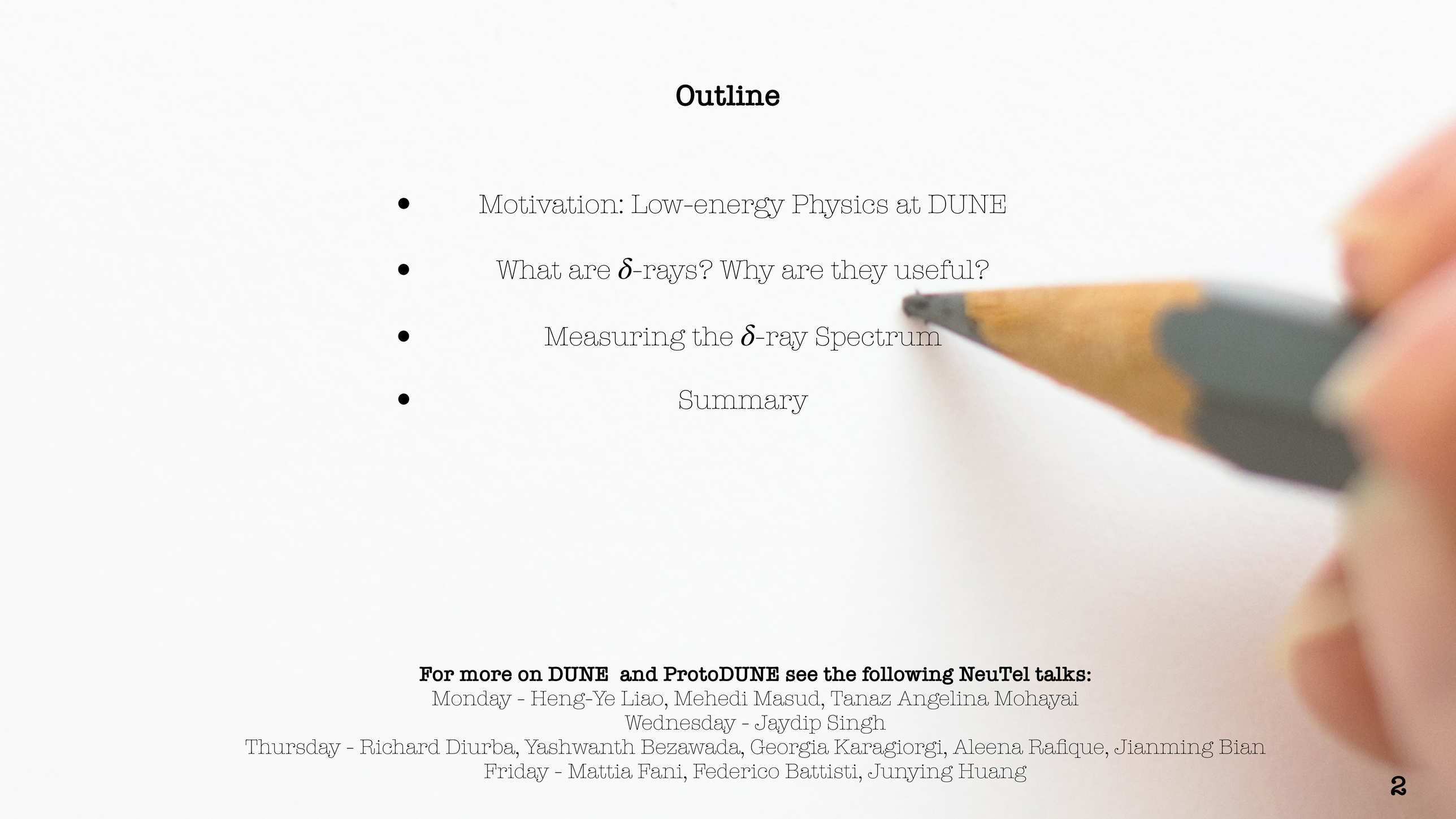
Neutrino Telescopes Workshop

February 22, 2021

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Outline

- Motivation: Low-energy Physics at DUNE
- What are δ-rays? Why are they useful?
- Measuring the δ-ray Spectrum
- Summary



For more on DUNE and ProtoDUNE see the following NeuTel talks:

Monday - Heng-Ye Liao, Mehedi Masud, Tanaz Angelina Mohayai

Wednesday - Jaydip Singh

Thursday - Richard Diurba, Yashwanth Bezawada, Georgia Karagiorgi, Aleena Rafique, Jianming Bian

Friday - Mattia Fani, Federico Battisti, Junying Huang

Low-Energy Physics: Supernovae

- Core-collapse supernovae shed $\sim 99\%$ of their binding energy in the form of ν's in seconds.

- Upon arrival, $< E_\nu > \sim \mathcal{O}\ (10\ \text{MeV})$.

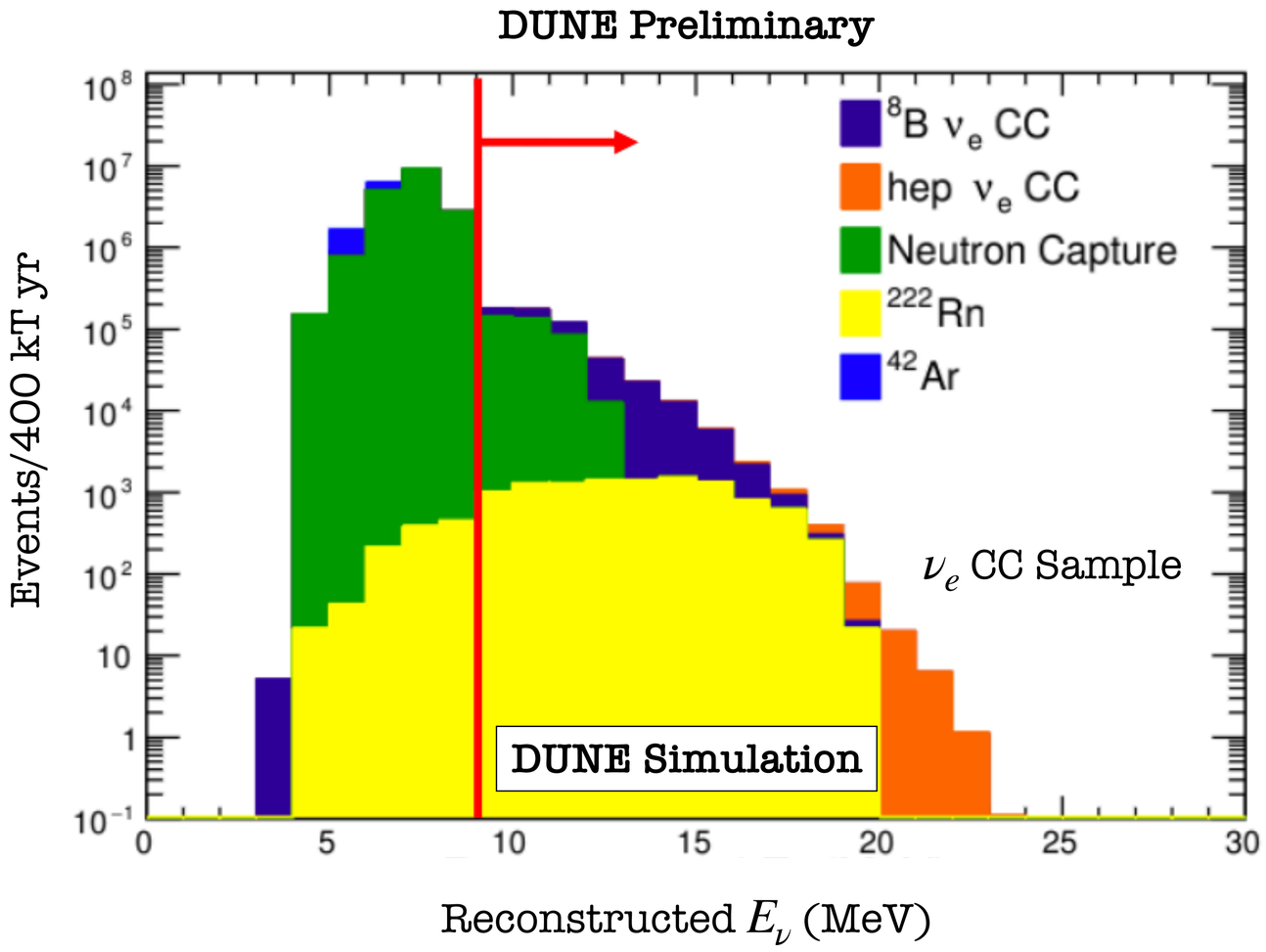
DUNE will see the electrons associated with these ν interactions.

$$(\nu_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}^*)$$

- We must calibrate DUNE's response to electrons of $\sim \mathcal{O}\ (10\ \text{MeV})$ to learn the lessons that these ν's will bring.

Sandbox Studio, Ana Kova (2018)

Low-Energy Physics: Solar

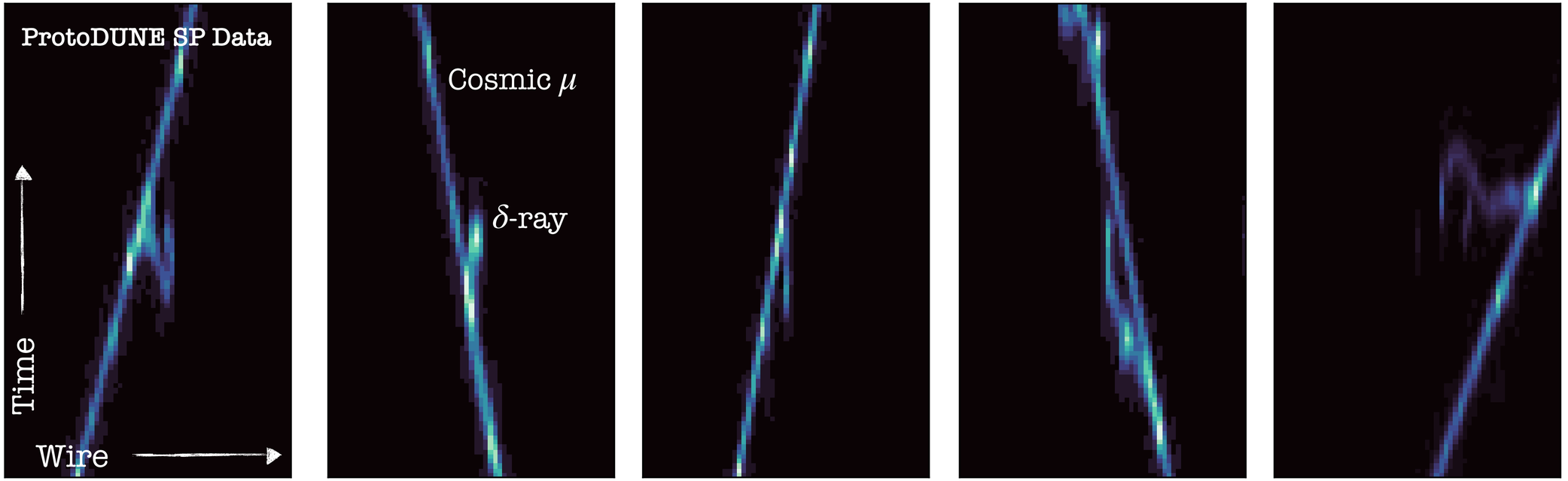


- ν's produced via fusion in the Sun's core are also $\mathcal{O}$ (10 MeV)
- "hep" ν's are yet to be seen (produced from the fusion of a nucleus of Helium and a proton, and emitted at a much lower flux compared to other solar ν's)
- Background dominate below 10 MeV.

"DUNE: Progress and Physics"
Michael Mooney, Neutrino 2020

What are δ-rays?

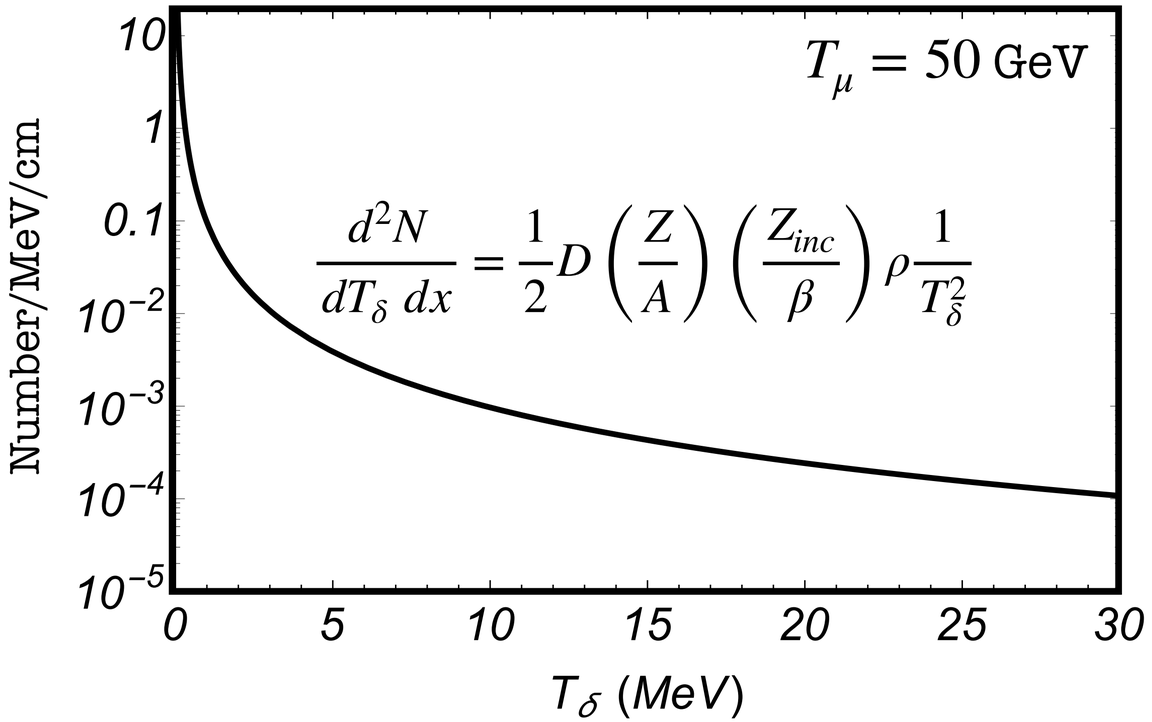
δ-rays at ProtoDUNE SP
Collection Plane Snippets: 50 μs x 30 cm



ProtoDUNE SP is a liquid argon time projection chamber (LArTCP) prototype for DUNE.

Why are δ-rays useful?

Natural calibration sources are scarce underground at DUNE.

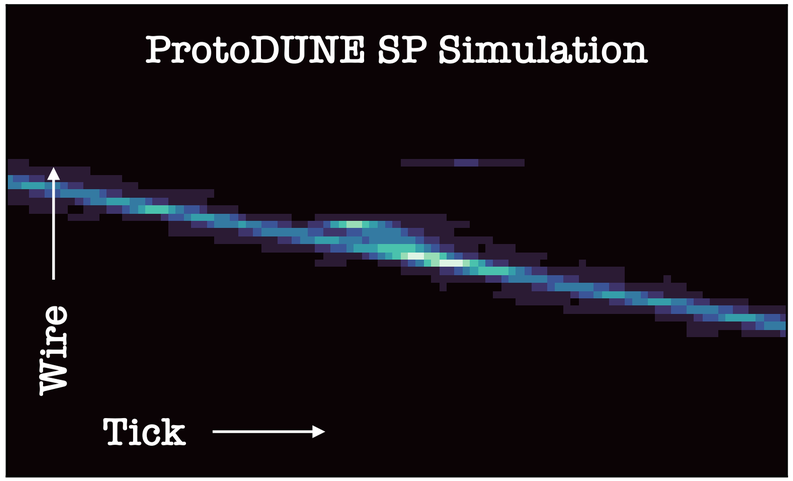


δ Ray Rates
(Assuming 10kT module and 12m tracks)

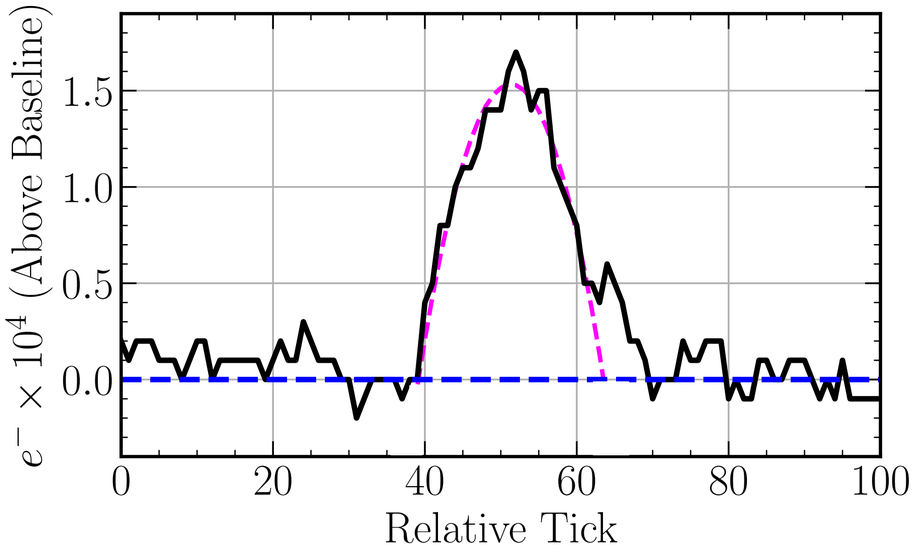
Energy Cutoff	#/track	#/day
> 2 MeV	51	240k
> 5 MeV	22	100k
> 10 MeV	11	52k
> 20 MeV	5.5	26k

We can use the numerous δ-rays at DUNE to calibrate low energy physics.

δ-ray Calorimetry



Collapse Unto Ticks



- In the collapsed space, the muon is a baseline and the δ-ray is a peak.
- Integrate above the baseline and below the peak.

[Sum above the blue line and below the black line between the crossings set by the magenta line (parabolic fit to the peak).]

Scaling Charge to Energy

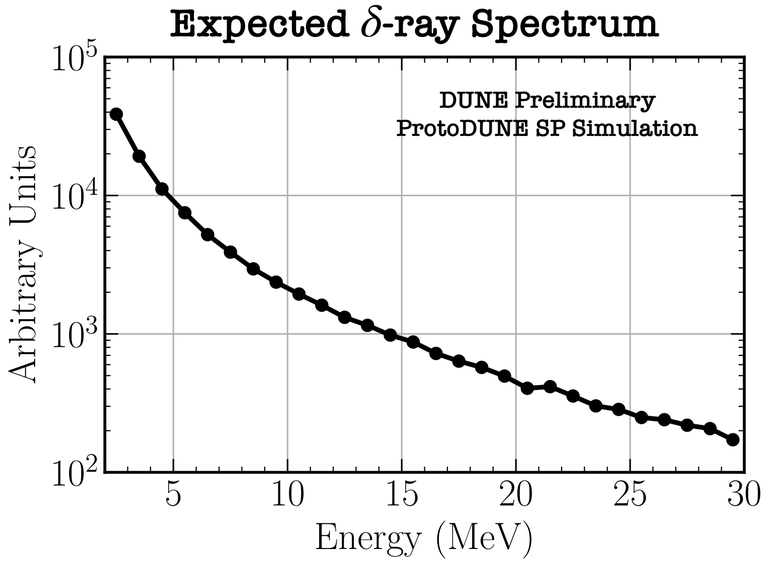
$$E = (\mathcal{Q}/\mathcal{R}) \times W$$

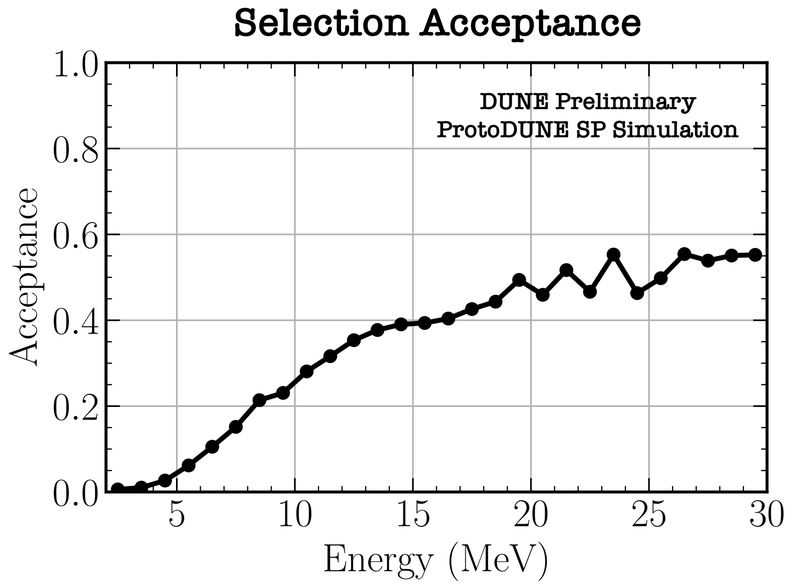
$\mathcal{Q}$ = Measured Charge

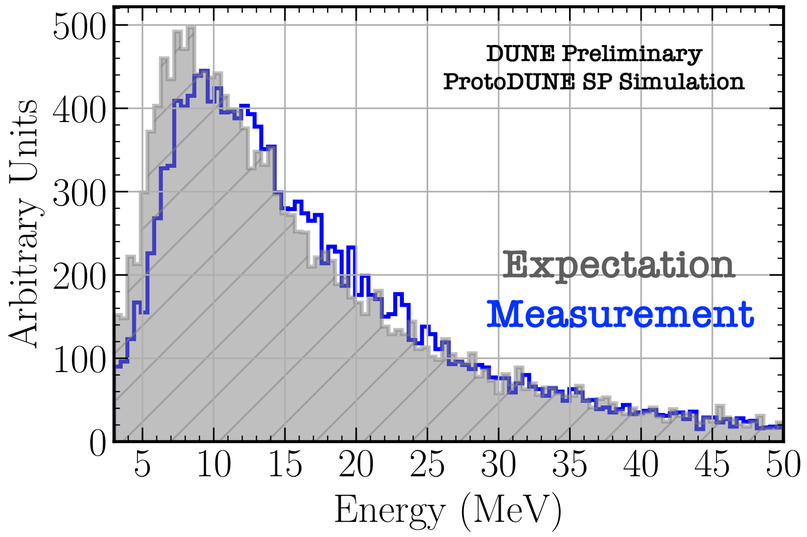
$\mathcal{R}$ = Recombination Factor (set to 0.66)

W = Ionization Work Function for Argon (23.6 eV/e^-)

Measuring the δ-ray Spectrum







- The first attempt at measuring the δ-ray spectrum is promising.
- Working on implementing full calibration.

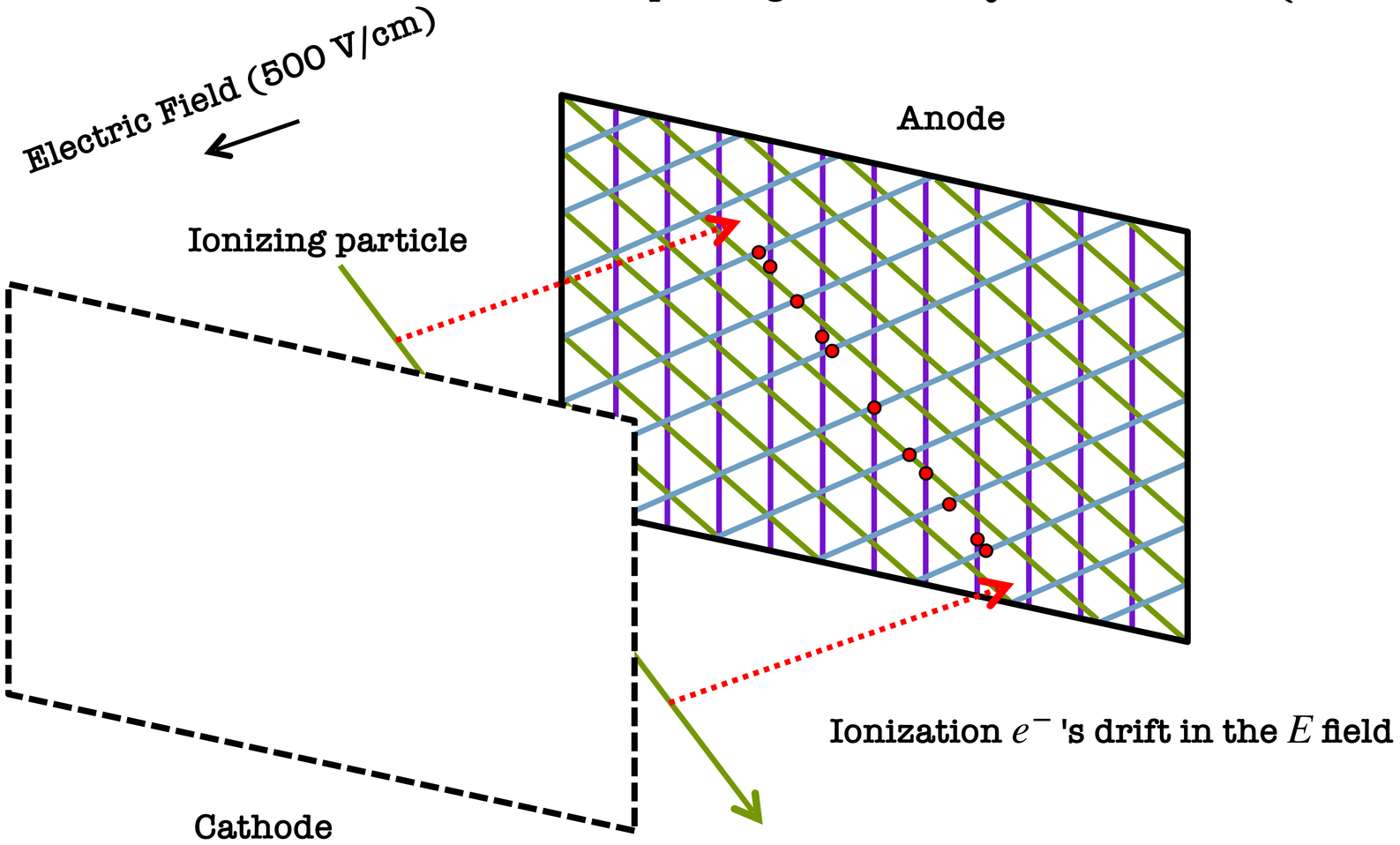
Summary

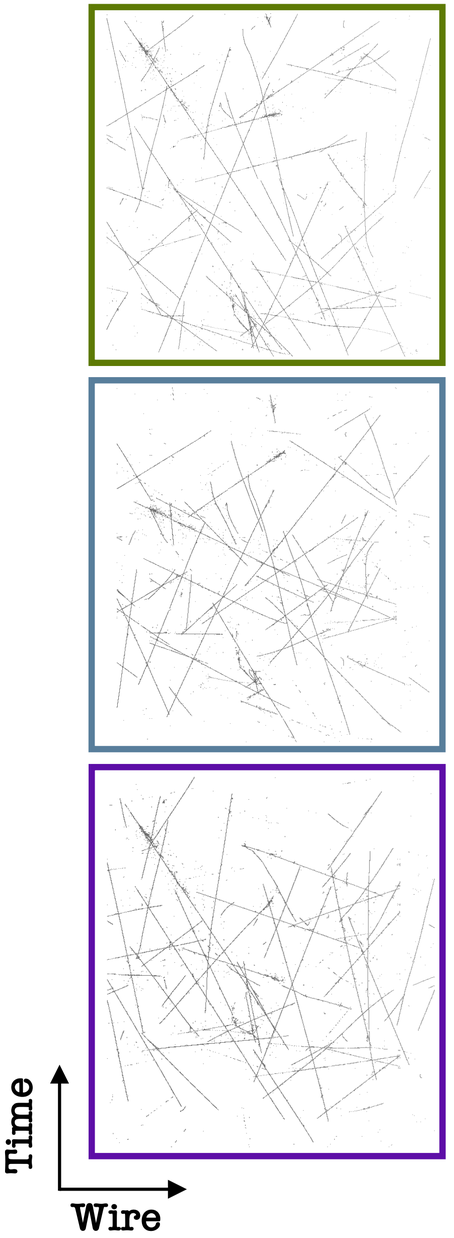
- DUNE will see solar and SN ν's of $< E_\nu > \sim \mathcal{O}$ (10 MeV)
- δ-rays are well understood, will be ubiquitous at DUNE, and have similar energies
- δ-rays are a useful standard candle for low-energy physics

Backup

What's DUNE?

Liquid Argon Time Projection Chamber (LArTPC)





"Neutrino Event Reconstruction in DUNE using Pandora"
Leigh Whitehead, ICHEP Conference 2020

δ-ray Charge Measurement Resolution