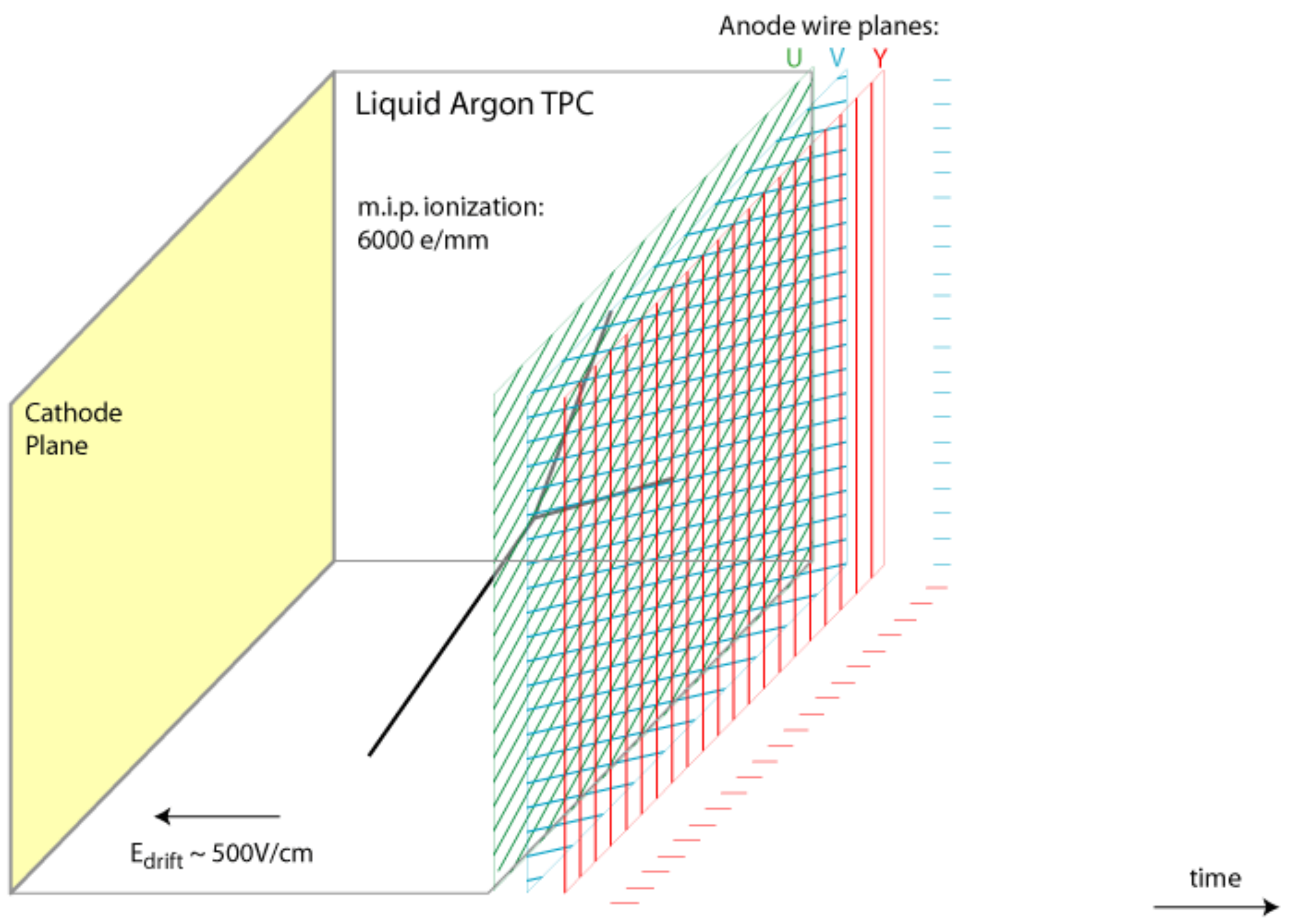
SN ν in LArTPCs — Challenges and Opportunities

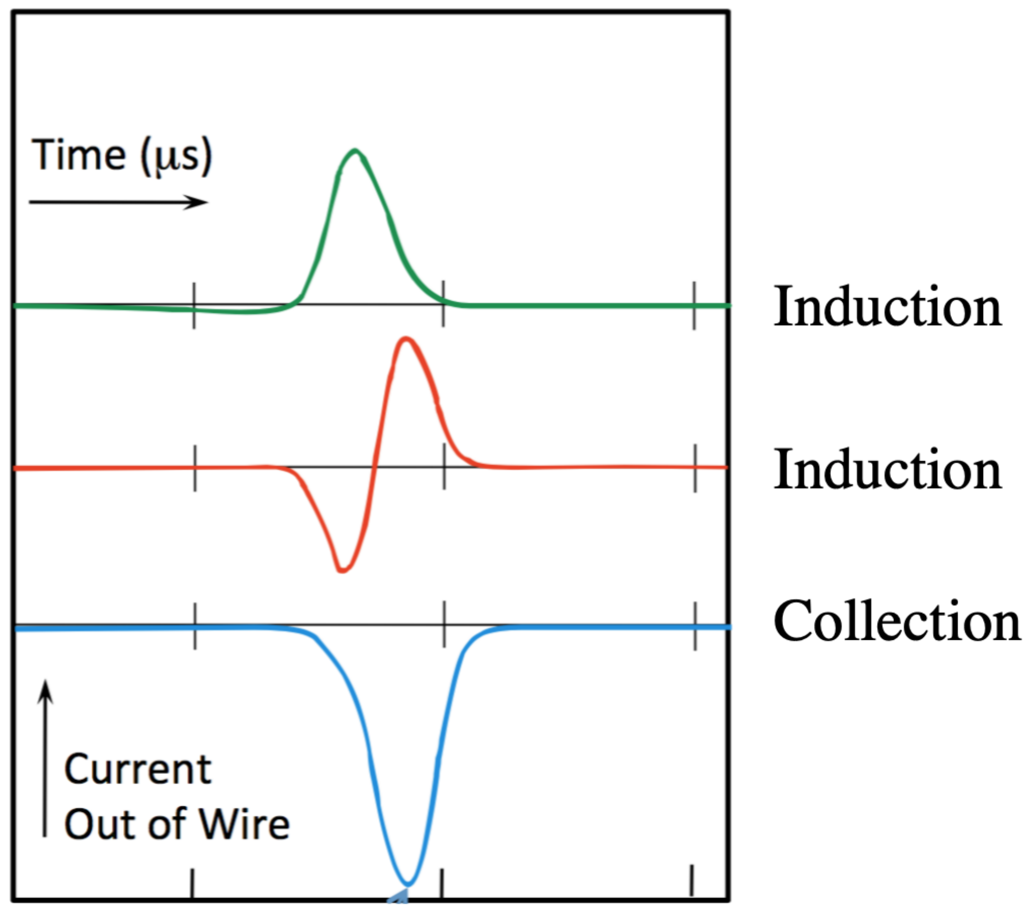
ICEBERG AI-Neutrino Meeting (03/01/2023)

Avinay Bhat

Figures taken from my thesis: https://inspirehep.net/literature/1936297

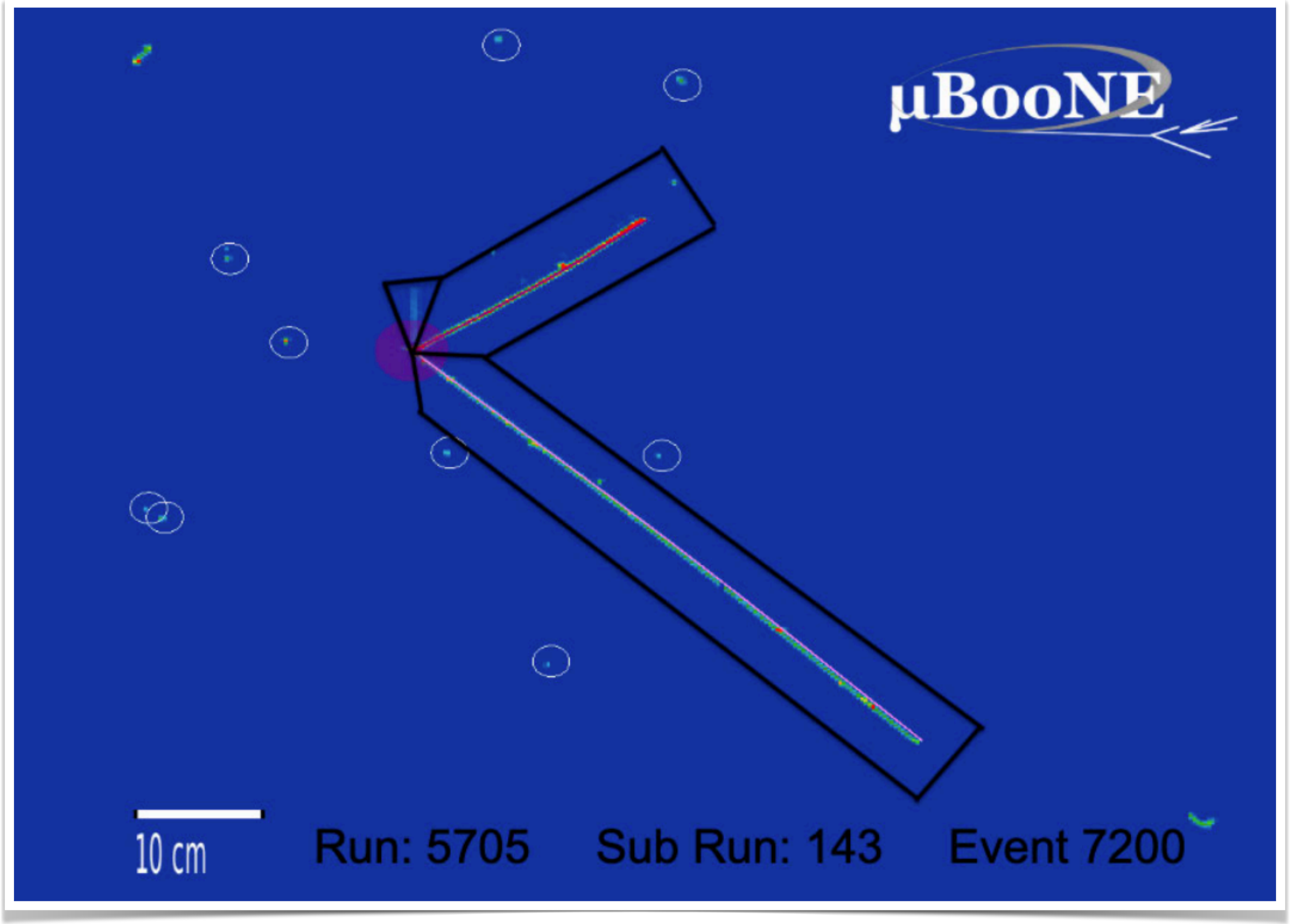
LArTPCs at Work





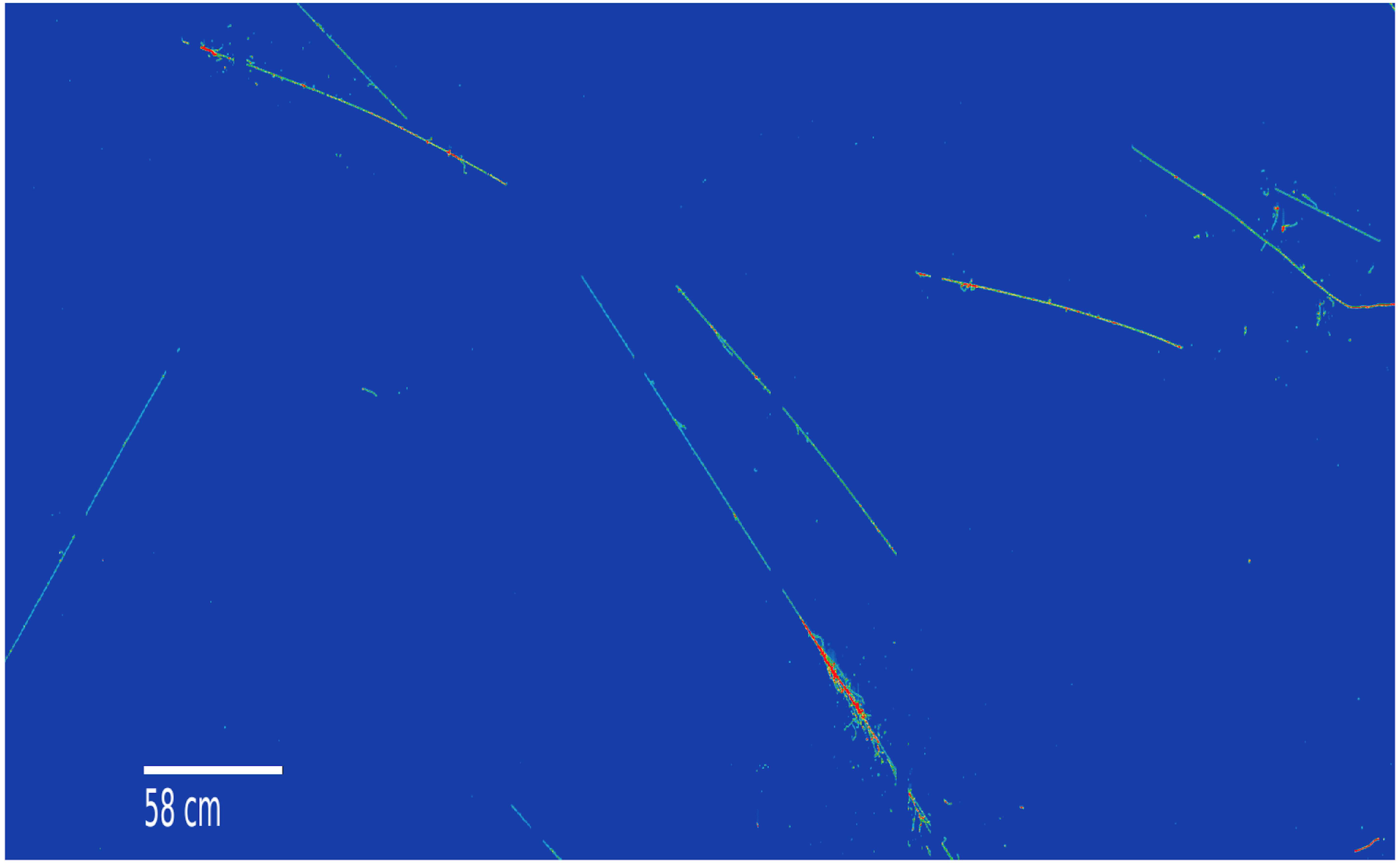
- Passing charged particles ionize argon
- Electric field drifts electrons to wire chamber planes
- Induction/Collection planes image charge, record dE/dx
- Scintillation light in LAr

Beam Neutrino Interactions ~GeV scale



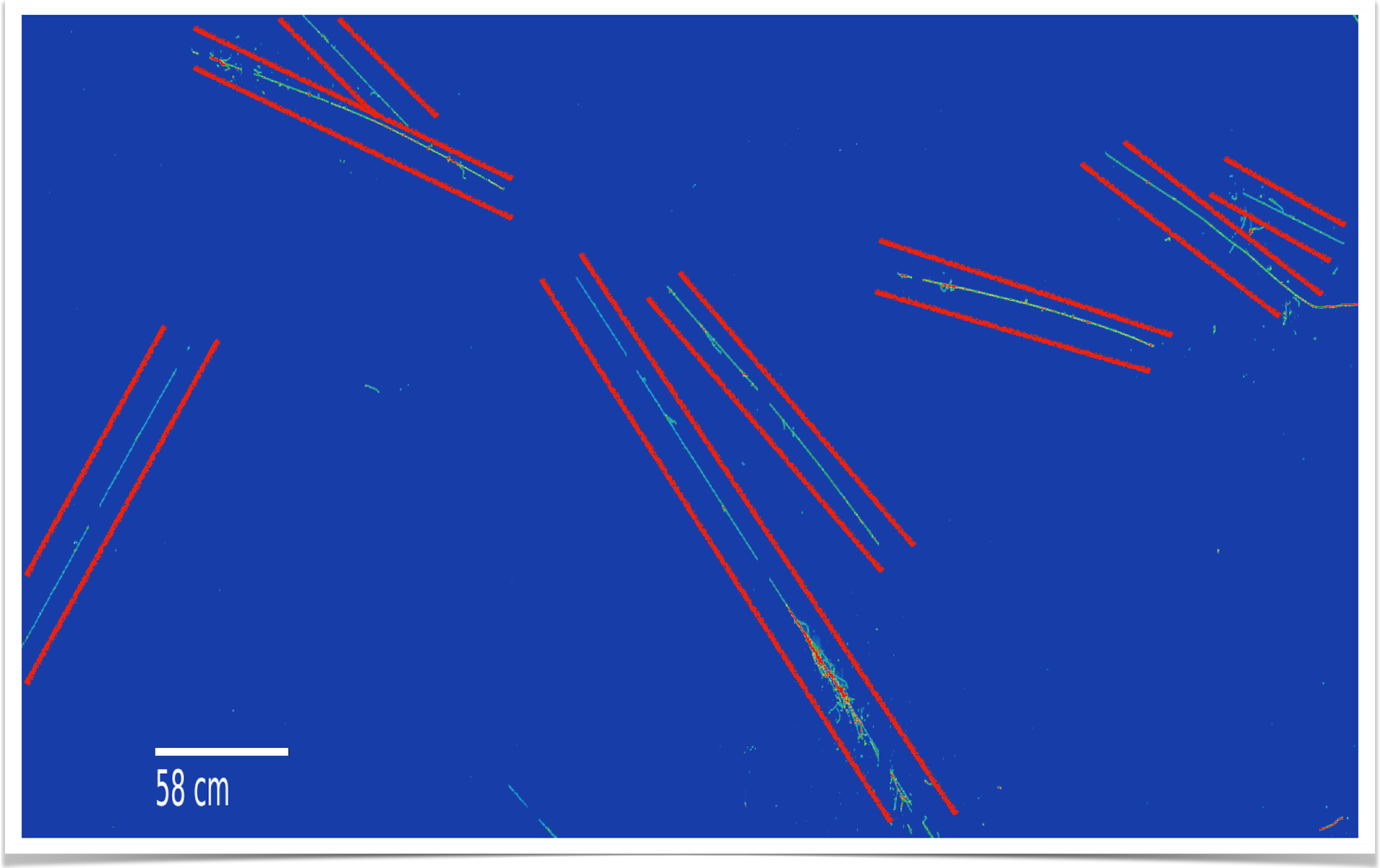
- Well defined tracks and showers corresponding to final state particles from a neutrino interaction.
- Gammas from neutrino interactions such as photons from nuclear de-excitation and from neutron scatter.

Supernova Neutrino Interactions ~ MeV Scale



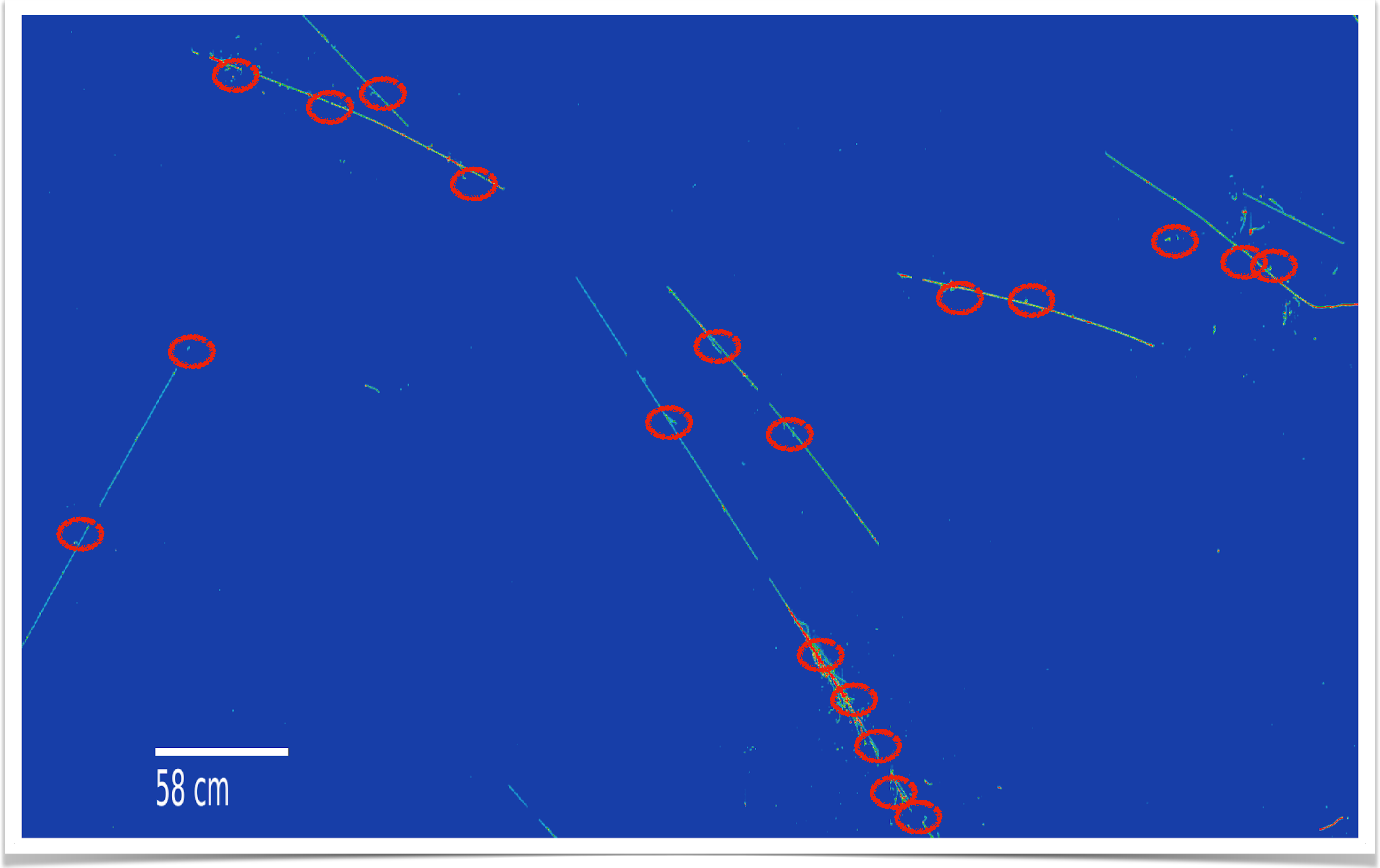
- In this event display, we have:

Supernova Neutrino Interactions ~ MeV Scale



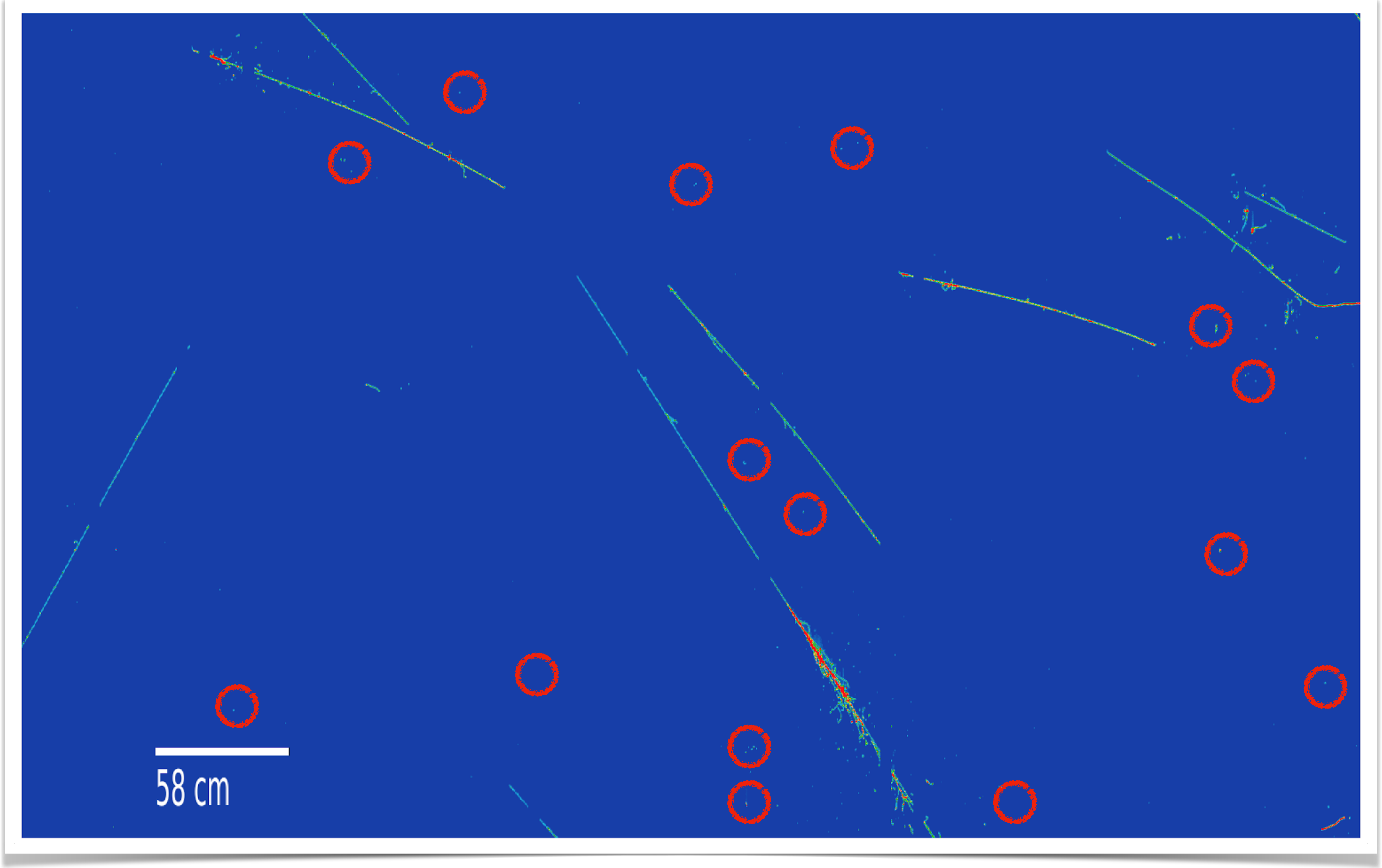
- In this event display, we have:
  - Long Cosmic Muons

Supernova Neutrino Interactions ~ MeV Scale



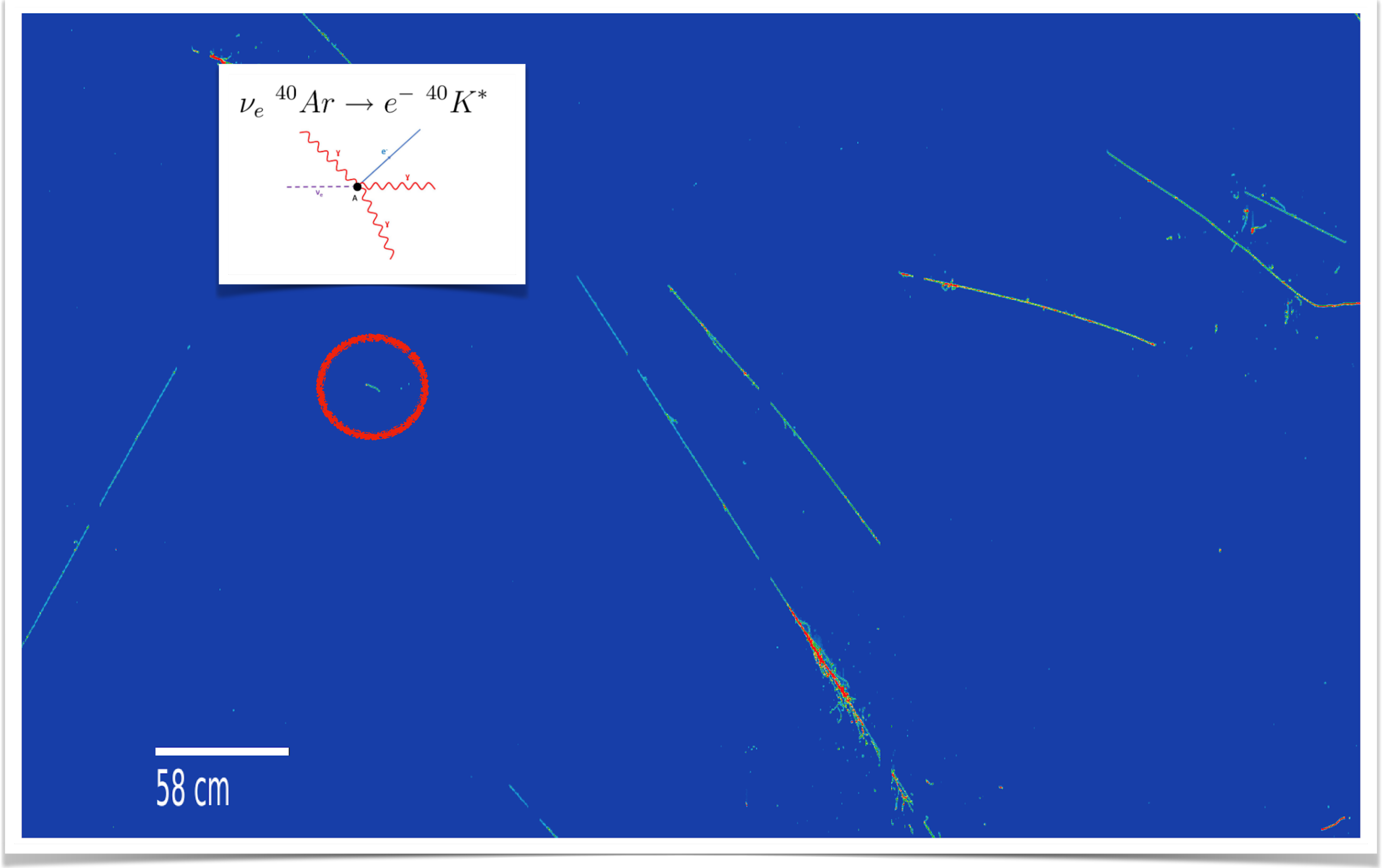
- In this event display, we have:
  - Long Cosmic Muons
  - Deltas and Bremsstrahlung from cosmic muons

Supernova Neutrino Interactions ~ MeV Scale



- In this event display, we have:
  - Long Cosmic Muons
  - Deltas and Bremsstrahlung from cosmic muons
  - Electronics noise, ^{39}Ar and neutron scatter from spallation.

Supernova Neutrino Interactions ~ MeV Scale

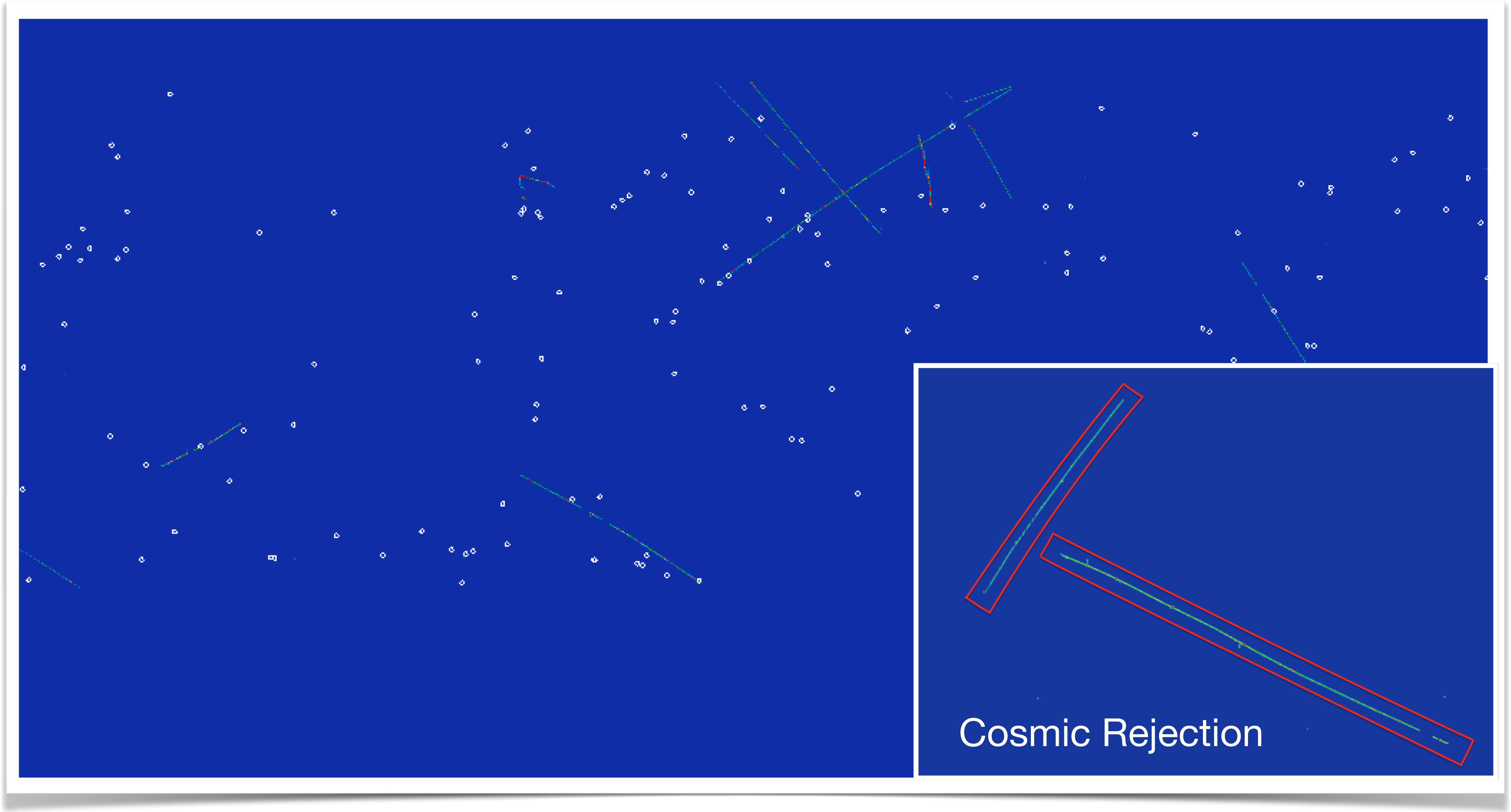


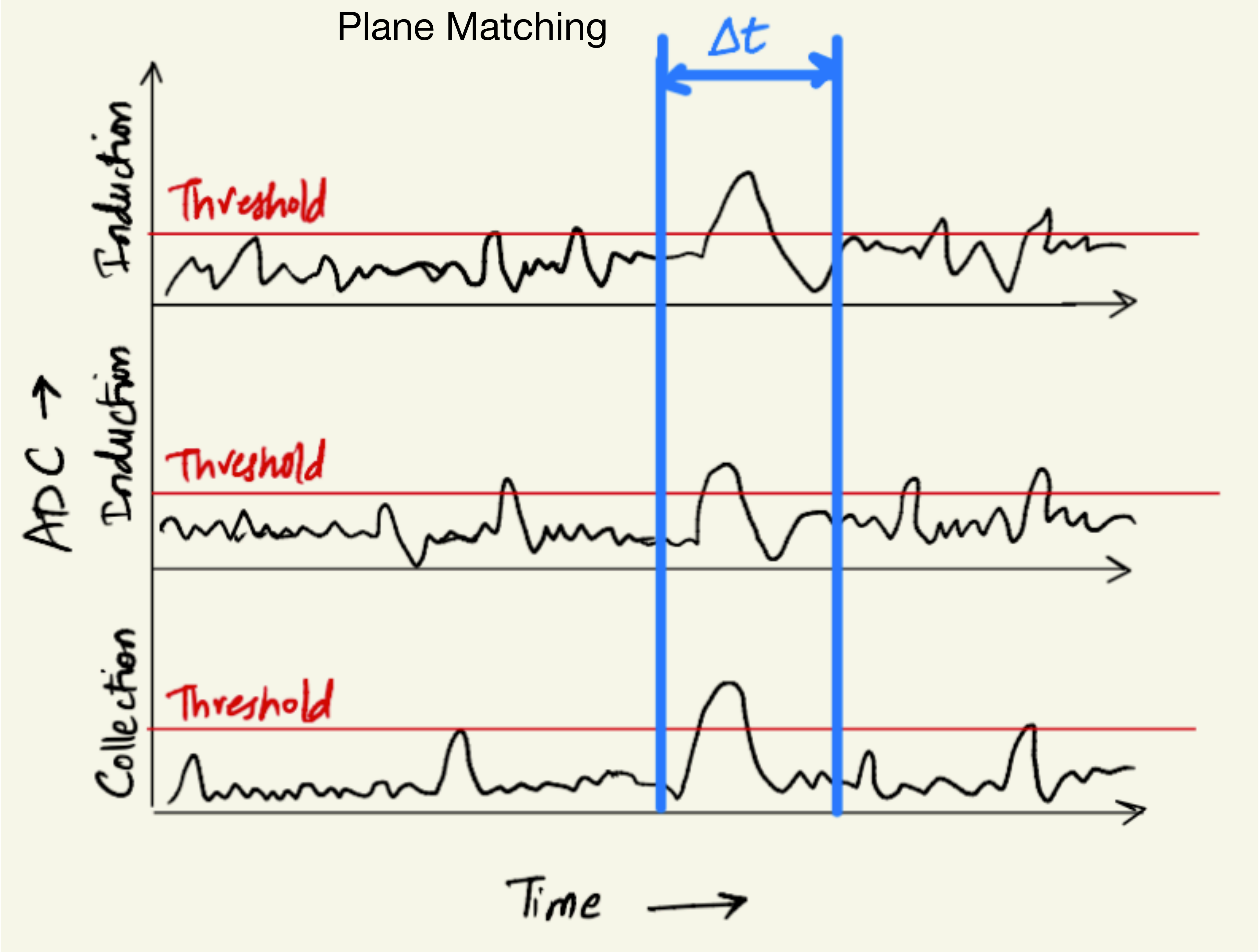
Simulated using MARLEY

- Supernova Neutrino final states fall in the 10s of MeV energy range.

- Lots of challenges:
    1. Charge deposition is mostly point like.
    2. Light Collection System not sensitive enough, for t0 tagging.
    3. Need special reconstruction tools.
    4. Completely inundated with background.
    5. Need powerful discrimination tools for signal/background as well as between different backgrounds:
        - Electronics noise
        - Deltas and Compton scatters from Cosmic muons
        - Ar39 beta decays
        - Neutrons from spallation and neutrino interactions.
        - Photons from nuclear de-excitation.

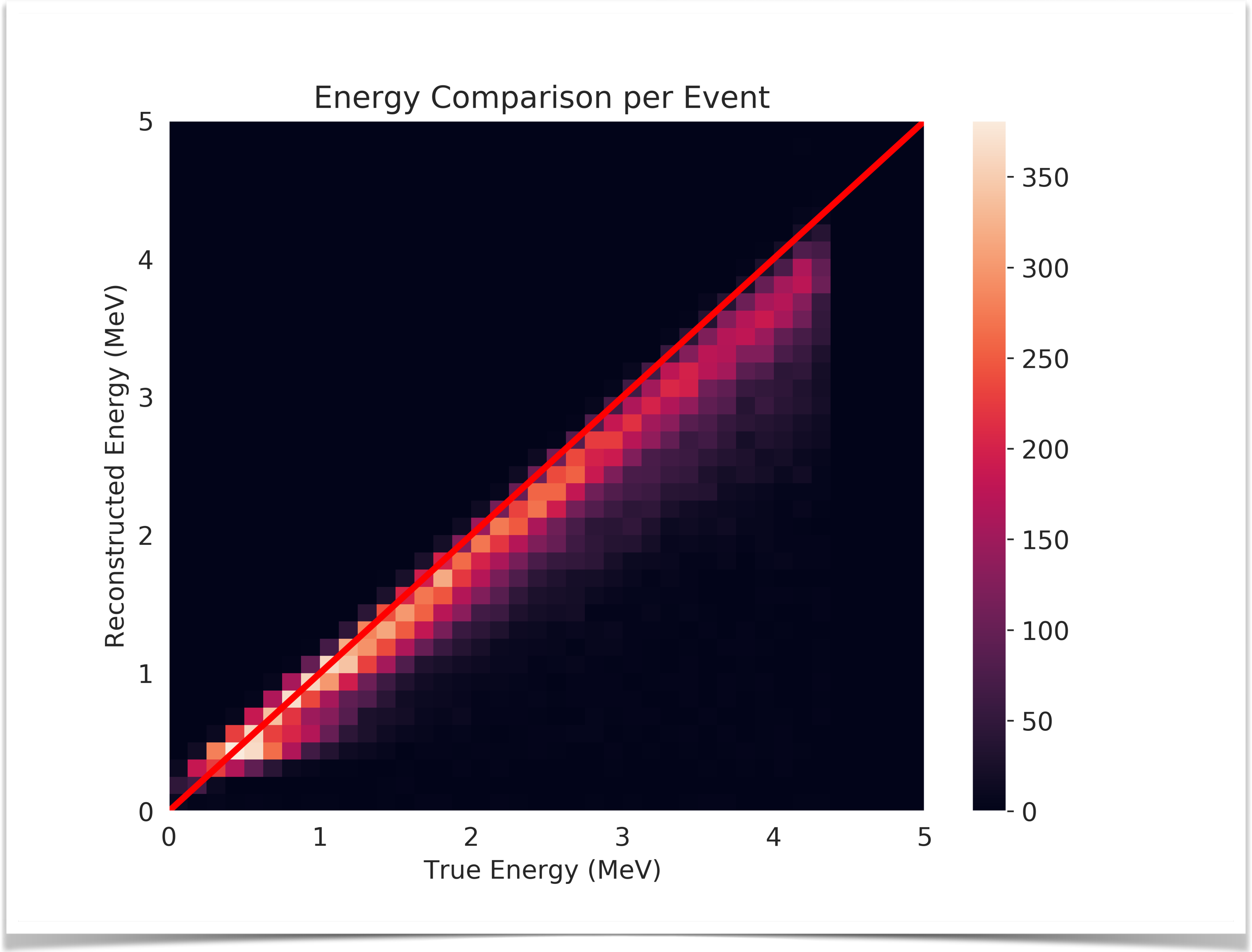
MeV Scale Physics on MicroBooNE

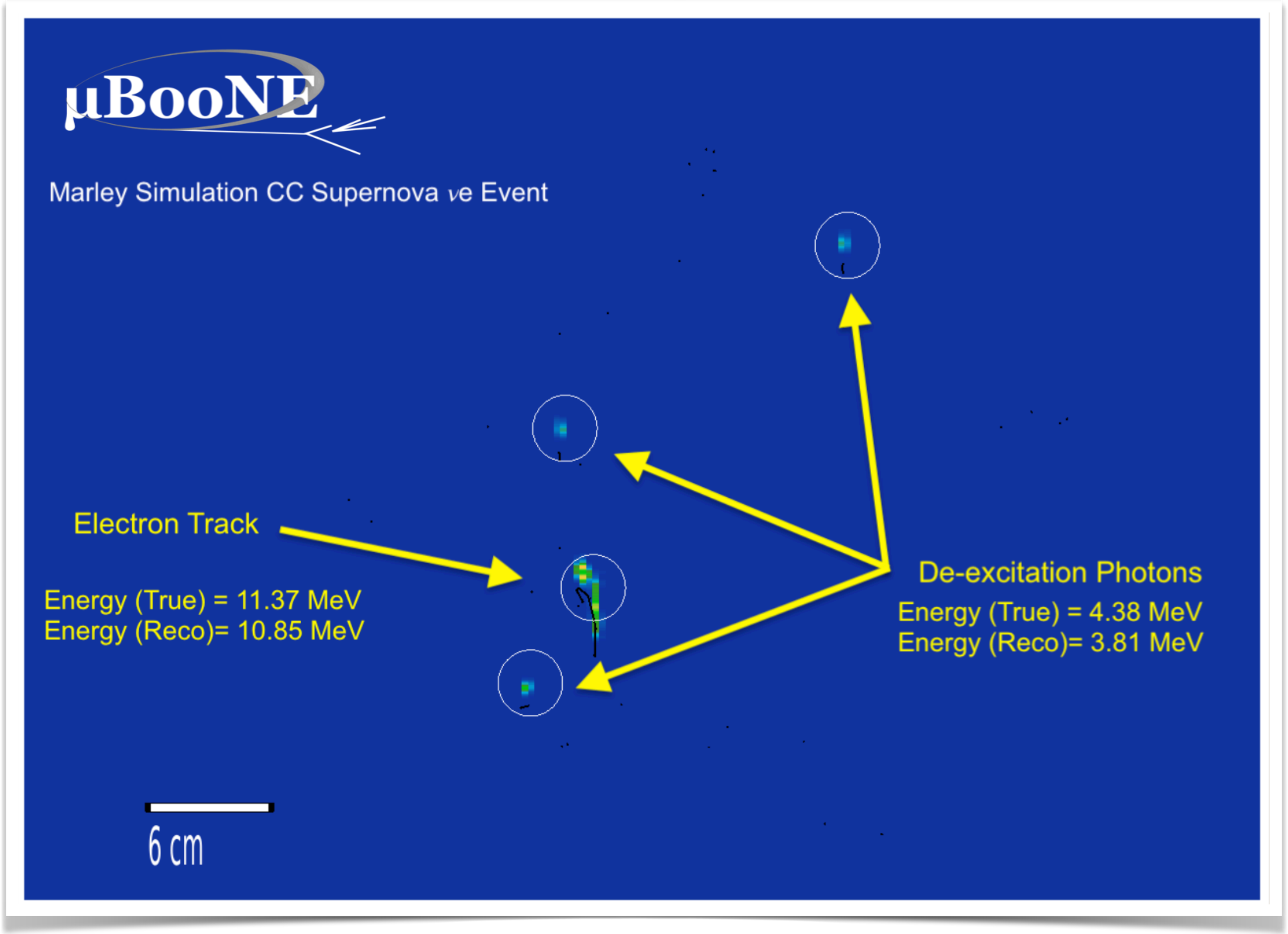




- Threshold lowering enabled access to low energy depositions.
- Plane matching allowed considerable discrimination between noise and background.
- Can’t yet discriminate between Ar-39 v/s spallation from cosmological neutrons.
- Would like to drop the threshold as low as possible and still retain discriminating power.

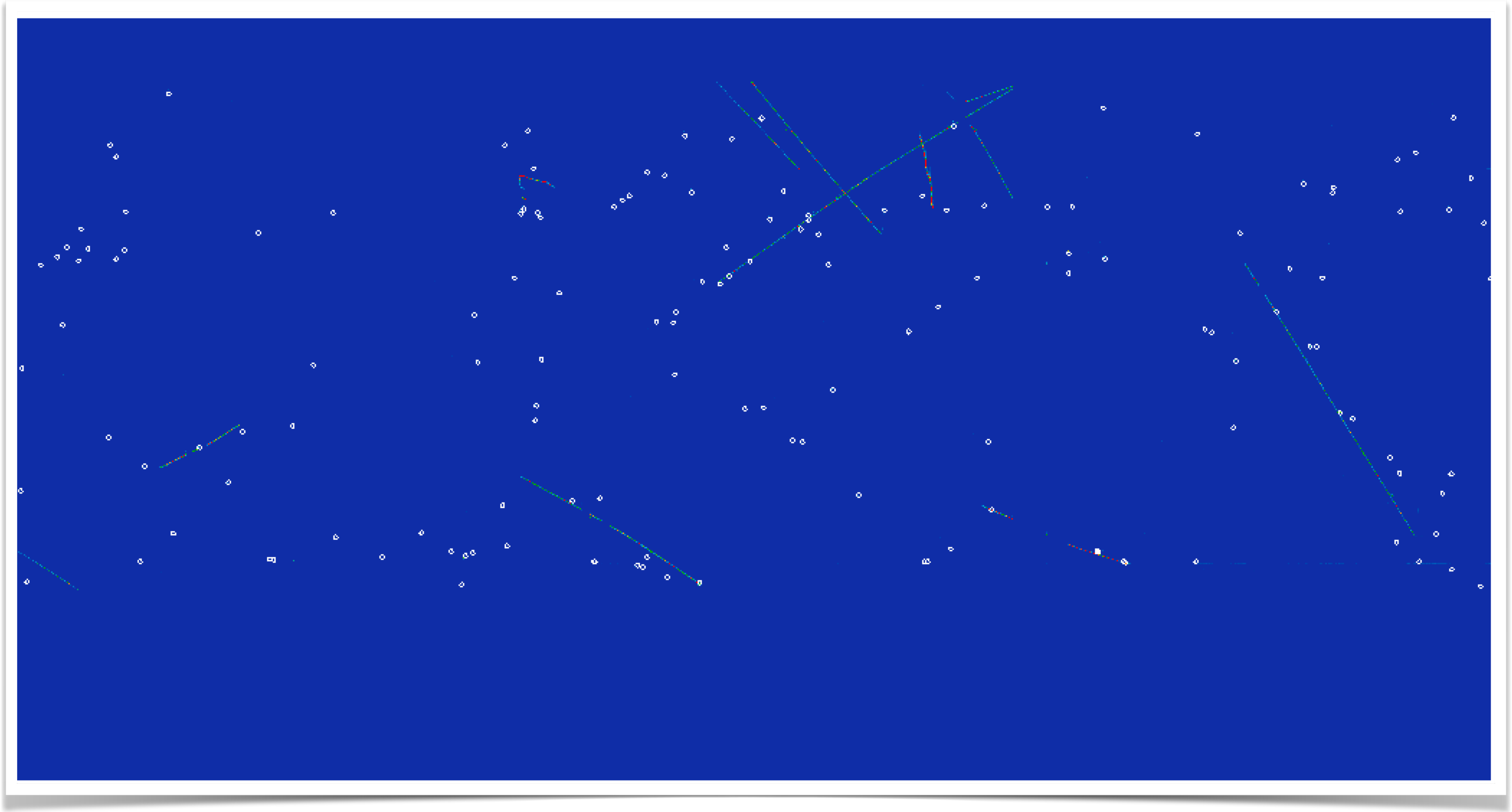
MeV Scale Physics on MicroBooNE





- Developed tools to reconstruct the position and energy of MeV scale de-excitation photons and neutron scatter photons.
- Extended to partial reconstruction of CC SN ν_e events.

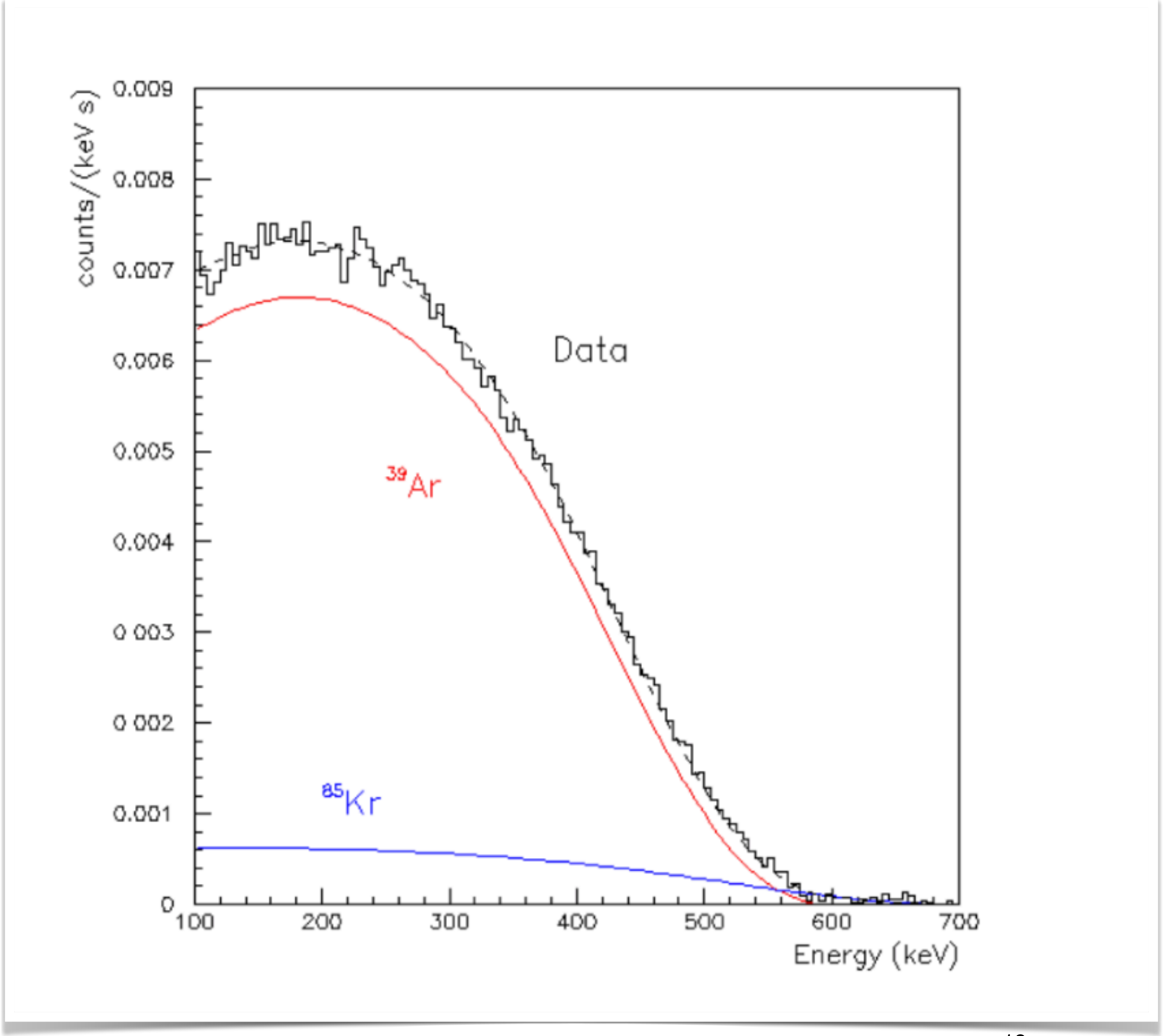
MeV Scale Physics—^{39}Ar



MicroBooNE Event Readout

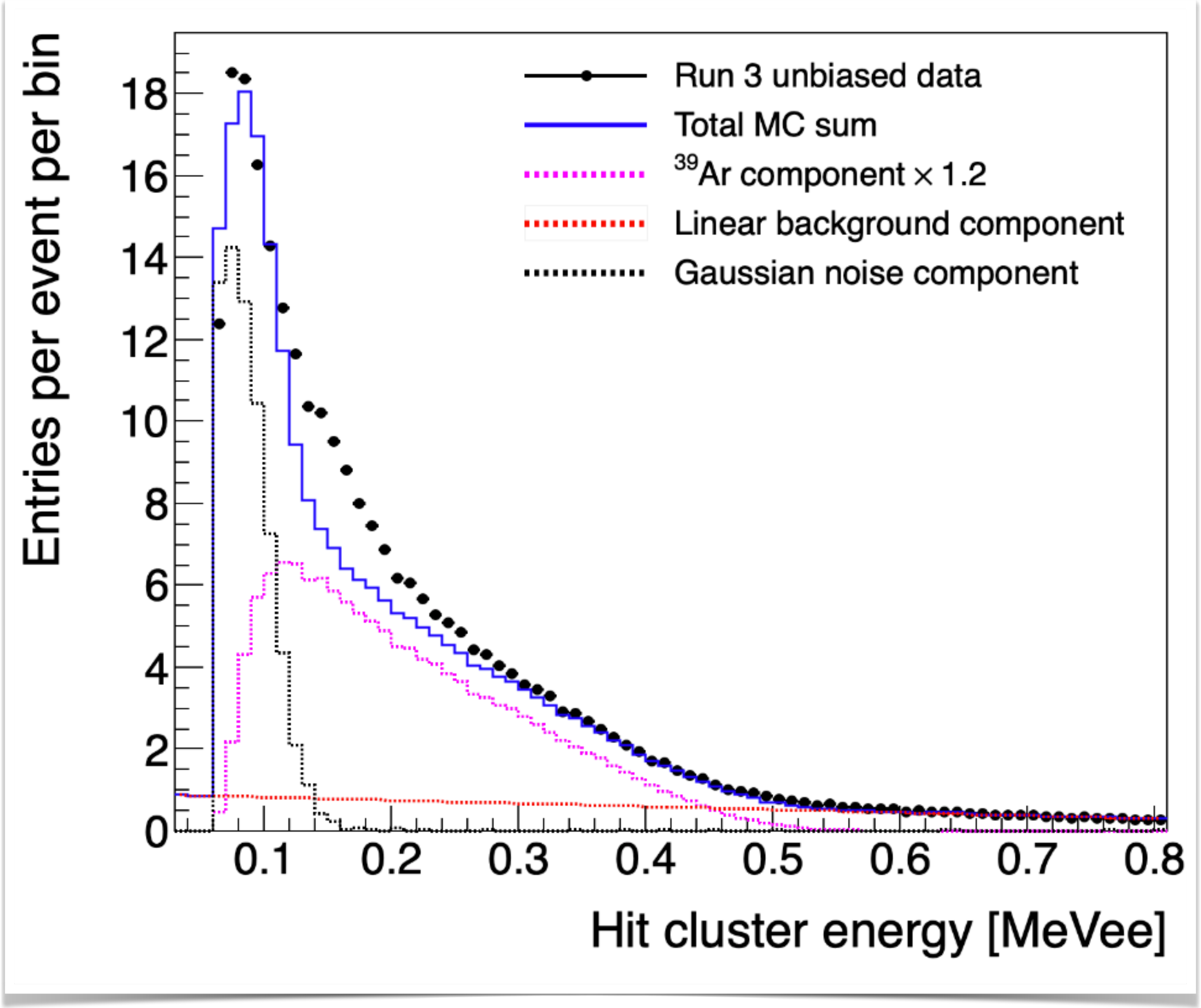
- ^{39}Ar decay is frequently observed in LArTPC
- Expect 1 Bq/kg
- ~400 per MicroBooNE readout event

MeV Scale Physics — ^{39}Ar



- ^{39}Ar decay is frequently observed in LArTPC
- Expect 1 Bq/kg
- ~400 per MicroBooNE readout event
- ^{39}Ar beta decay energy spectrum is well known
- Decay events should have a uniform distribution across the detector in drift direction

^{39}Ar as a calibration mechanism



- The primary detector response parameters of interest are the electron lifetime and recombination factor.
- One can use the reconstructed ^{39}Ar energy spectrum to measure these two quantities simultaneously.
- Measuring wire-to-wire response variations and monitoring electric field distortions, as well as diffusion.
- Simple point-like topology of ^{39}Ar beta decays makes it easier to perform these measurements as opposed to cosmic tracks.
- Important implications for DUNE

Where can AI help?

- Need powerful discrimination at every level to enable real time detection of SN neutrinos:
    1. Between noise and real physics depositions (background)
    2. Between Compton scatter photons from ^{39}Ar betas v/s neutrons from cosmic primaries.
    3. Finally between SN neutrinos and all of the above.

- Perhaps start with one level at a time using PINNs and progressively move on to the next?
    - How can we discriminate deltas and Brem from cosmic muons? Use a distance veto?
    - Utilize plane matching in addition to discrimination using ROI.
    - Utilize ^{39}Ar beta decay spectrum end point to establish a cut off for energy. Also use the spectrum for validation.
    - Compare the rate for classified ^{39}Ar with the known rate of 1Bq/kg.
    - Utilize the ratio of charge/size for these low energy blips to do PID.
    - Test how stable the CNN is with noise and gain variation.

- For level 3, may be can prioritize SN elastic scattering events, since they are the most important for DUNE alert.

Where can we start?

- Understanding the backgrounds and effectively mitigating them is crucial for the success of this project.

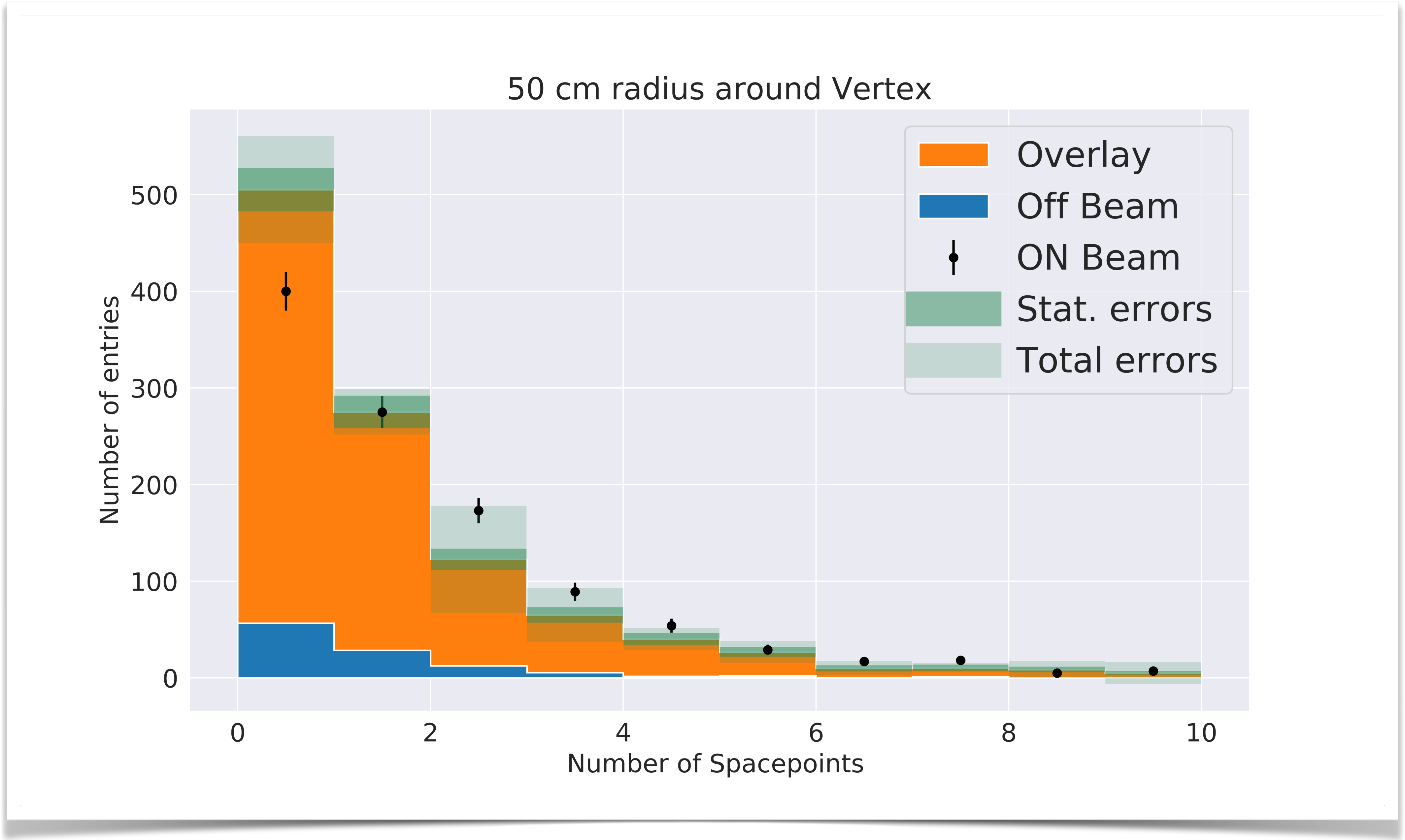
- We always start with what we know— simulation.
    1. Electronics noise within ICEBERG.
    2. Preliminary simulation: Using particle gun: electrons, gammas or neutrons. Won't be able to generate the right spectrum.
    3. Advanced simulation: Using Decay0 to simulate ^{39}Ar betas and CORSIKA to simulate cosmic muons and associated neutrons.
    4. Simulate SN ν using MARLEY. Can only simulate CC interactions.

- Validation of background classification with ICEBERG data.

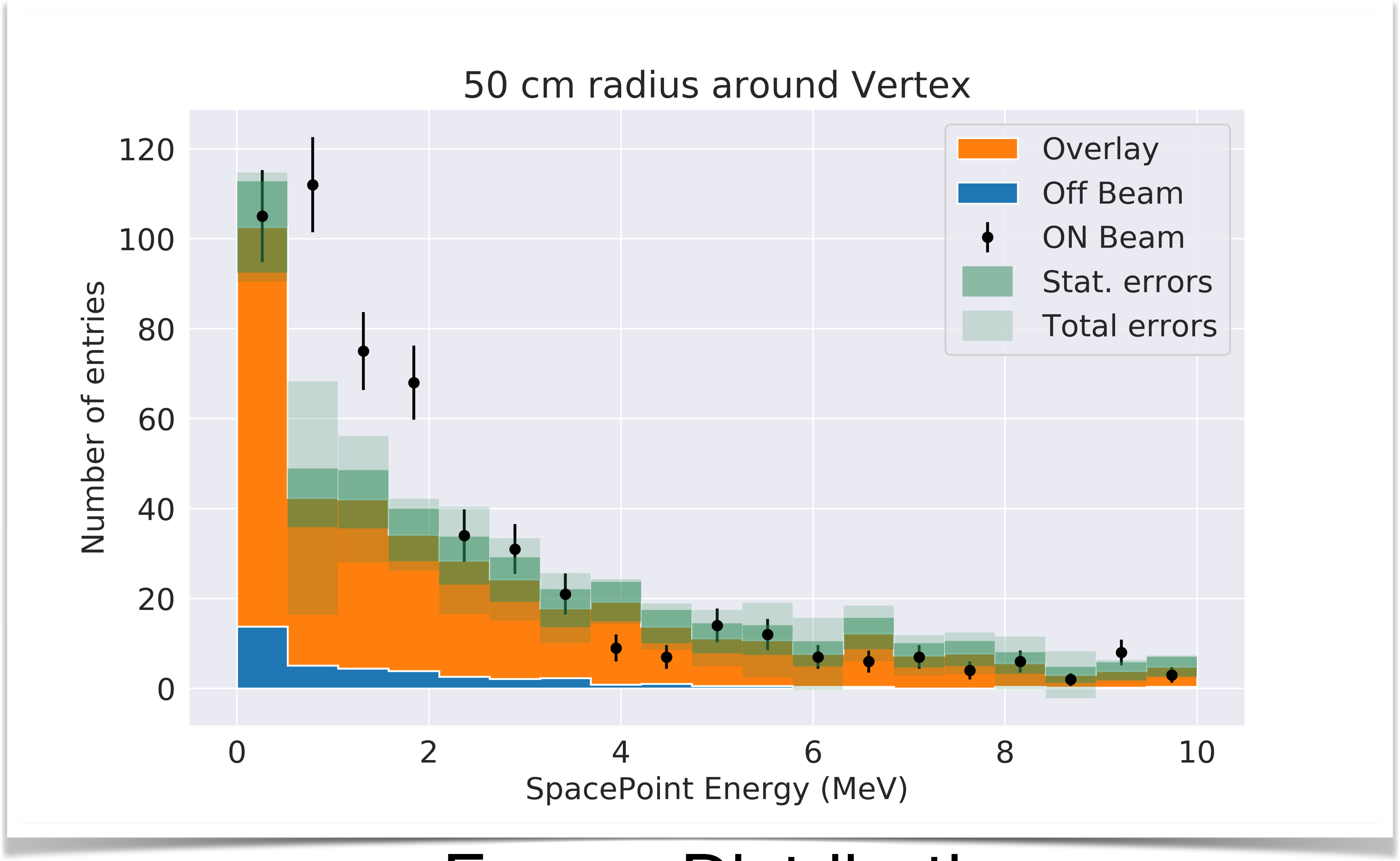
- Utilize publicly available datasets from MicroBooNE for further testing or validation: https://microboone.fnal.gov/documents-publications/public-datasets/

BackUp Slides

MeV Scale Physics— Nuclear de-excitation



Spatial Distribution

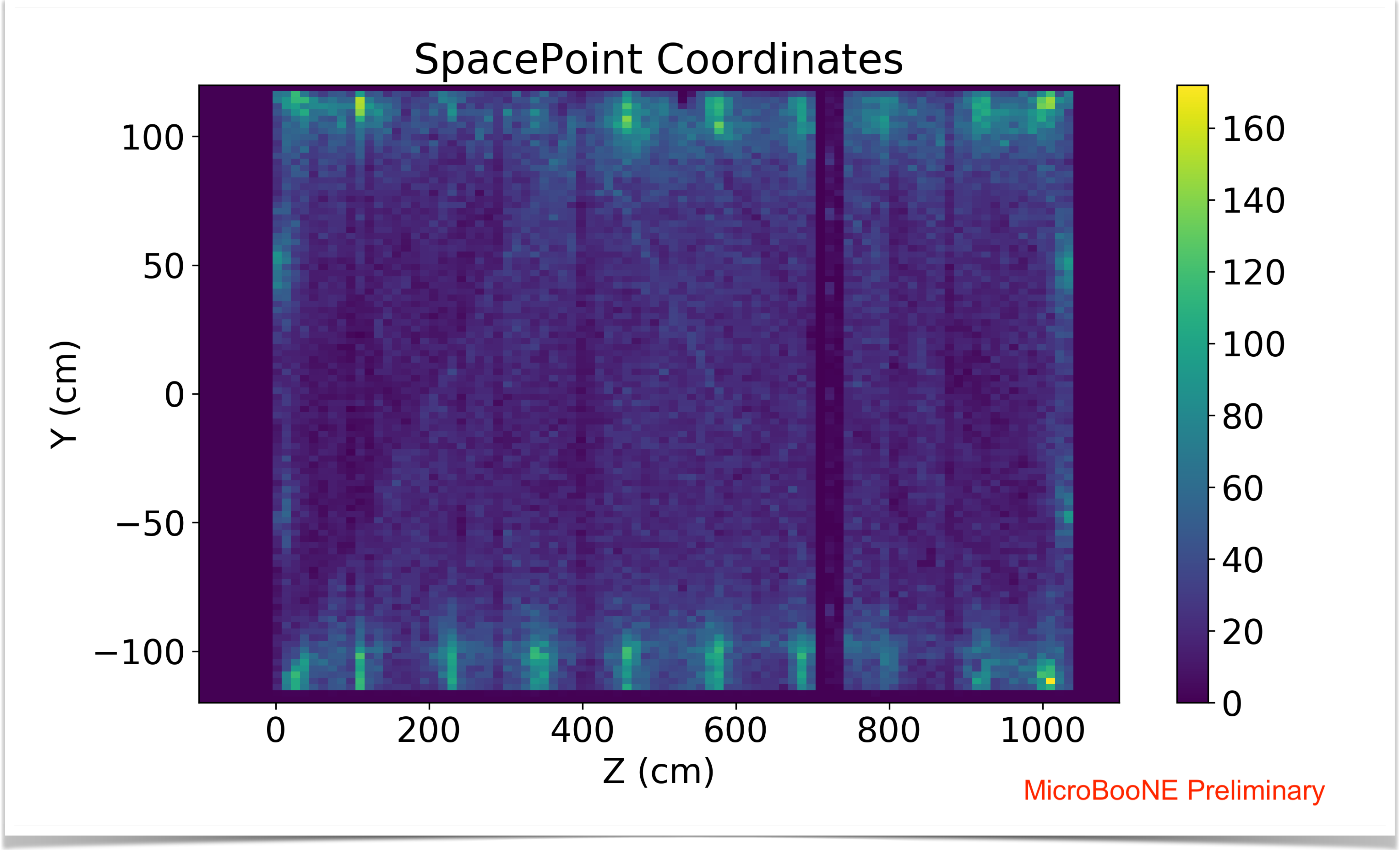


Energy Distribution

- Excess of data over simulation around the neutrino vertex. This is because GENIE v3.0.4 doesn’t simulate de-excitation photons from neutrino interactions.

- GENIE v3.2 simulates these for the first time but no direct validation against data.

MeV Scale Physics— Radiological Activity



- Hot spots in the spatial distribution of MeV scale activity within the MicroBooNE TPC.
- Attributed to the presence of G10 material in the support ribs of the detector.
- Working with Bryce L and Diego at IIT to simulate, reconstruct and compare the energy spectrum of gammas from ^{208}Tl, ^{40}K etc.