Michel Electron Reconstruction Using a Novel Deep-Learning-Based Multi-Level Event Reconstruction in ICARUS

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NATIONAL ACCELERATOR LABORATORY

1. Muon Decay-at-rest and Michel Electrons

- Michel electrons, produced by the decay-at-rest of cosmic-ray muons, have a well understood energy spectrum ranging up to ~50 MeV.
- Michel reconstruction demonstrates the detector's capability in low-energy electron reconstruction.

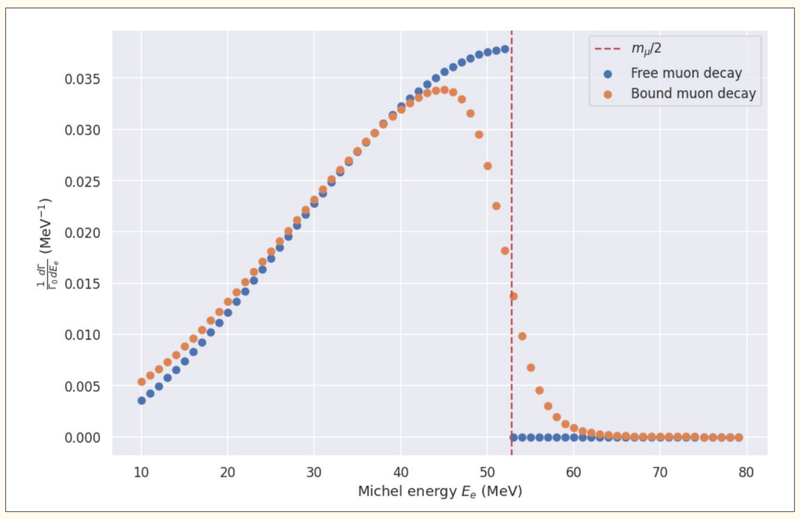


Figure 1. Theoretically calculated Michel energy. Soure: [1].

2. Michel electrons in ICARUS Liquid Argon Time Projection Chamber

- ICARUS is 600T Liquid Argon Time Projection Chamber (LArTPC) situated on the Fermilab beamline, receives abundant cosmic-ray muons.
- The energy loss of Michel electrons in argon has two contributing parts; electron ionization and photon radiation.

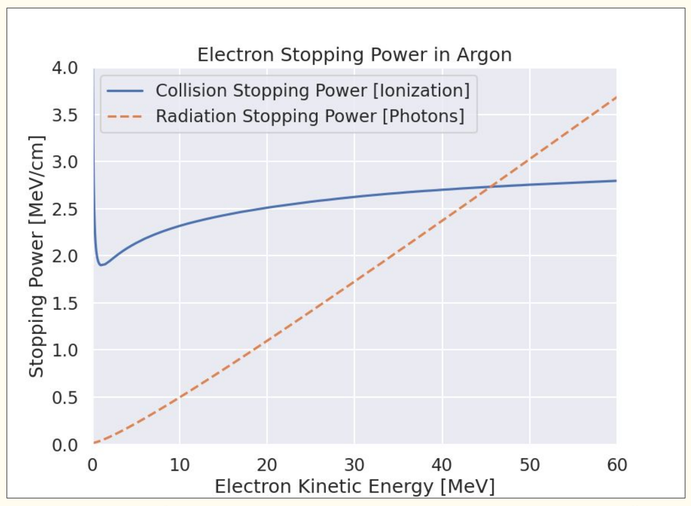
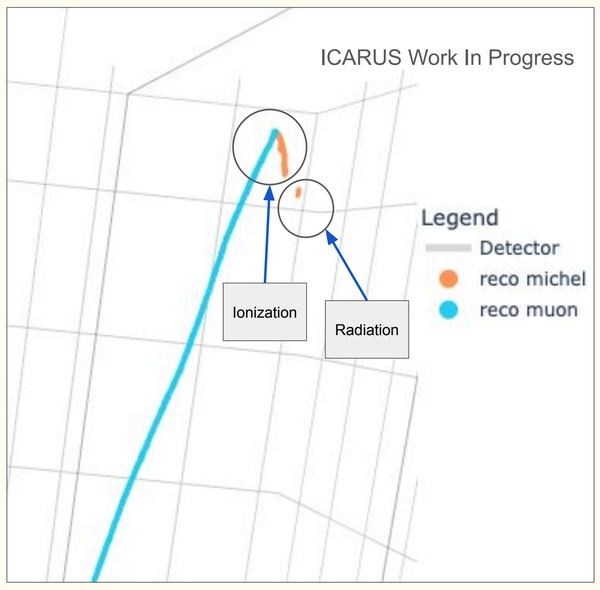


Figure 2. Electron stopping power in Argon from tabulated ESTAR database.



3. Deep-Learning based event reconstruction

- **SPINE**: framework developed for LArTPC 3D reconstruction.
- Voxels are classified as: shower-like/track-like/Michel-like/Delta-like/low energy-like using semantic segmentation.
- Reconstructed voxels are further grouped to fragments/particles/interactions.

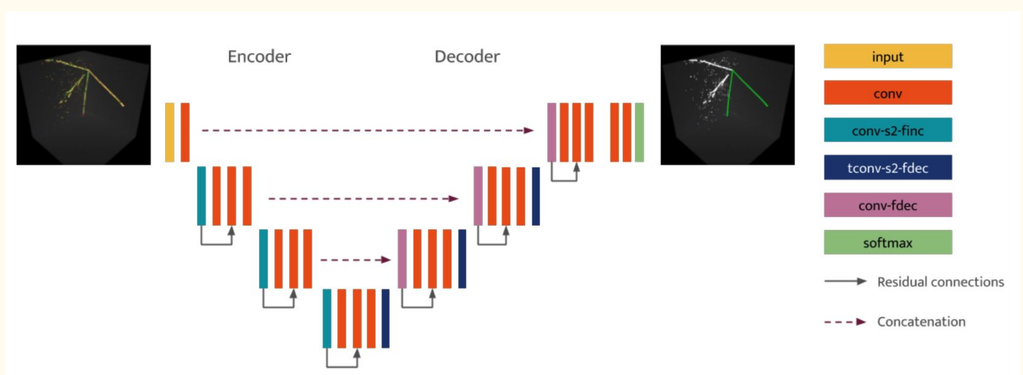


Figure 3. U-net network structure for voxel reconstruction. Source: [2].

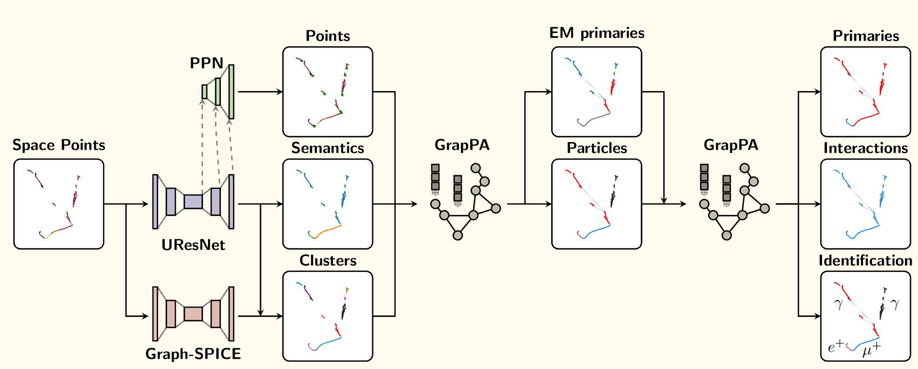


Figure 4. Full reconstruction chain in **SPINE**. Source: [3]

See poster #280 for more details on **SPINE.**
See poster #108, #156 #280, for more analyses using **SPINE**.

SPINE

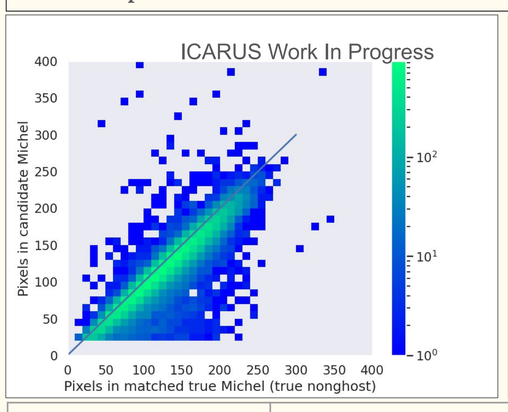
4. Michel electron selection in ICARUS

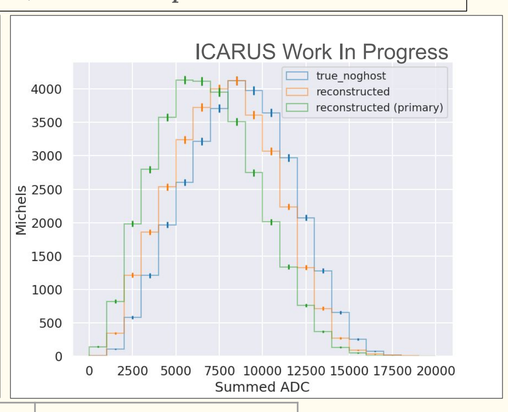
Candidate Michel is

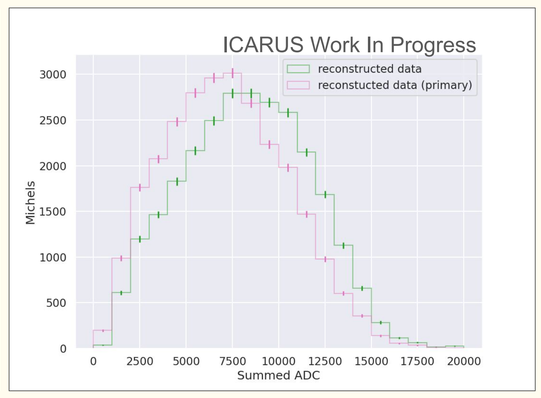
- Within 3 cm distance to a track
- Attached at the end of the track
- At least 20 reconstructed voxels

Candidate Michels are matched to true Michels.
Primary ionization is defined after the selection by finding the closest cluster to the parent muon (using DBScan.)

MC sample: BNB+Corsika simulation, Data sample: on-beam Run2





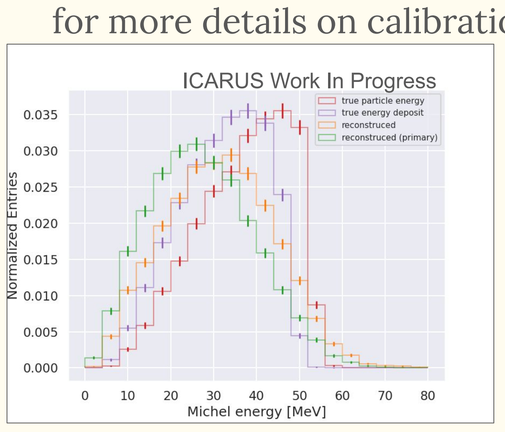


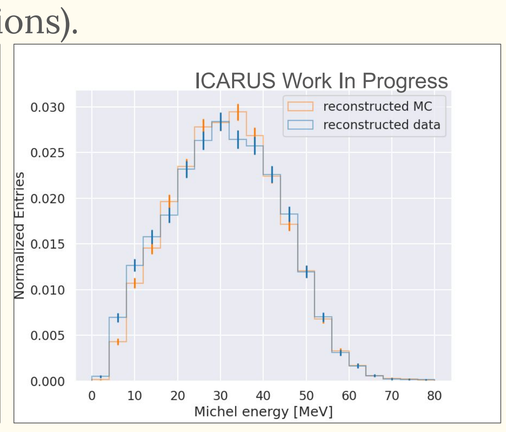
	True Michels	Candidate Michels
Attached to muon	37042	34582
Matched	32460	32460

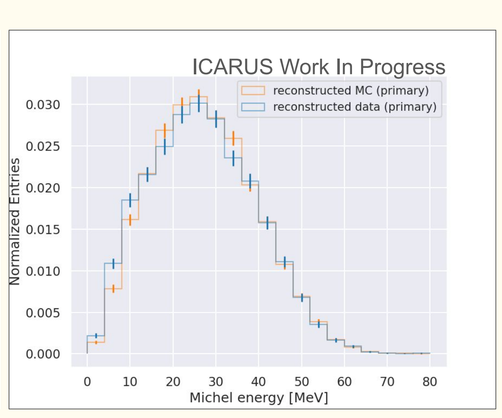
Selection efficiency/purity: 87.63 %/93.86 %

5. Michel energy reconstruction

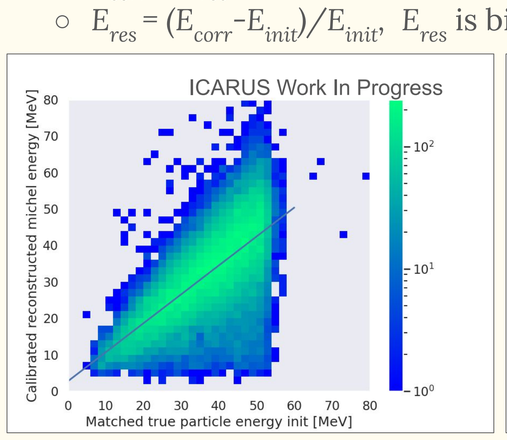
- Summed ADC is translated to energy [MeV] after applying calibrations. (See poster #156 for more details on calibrations).

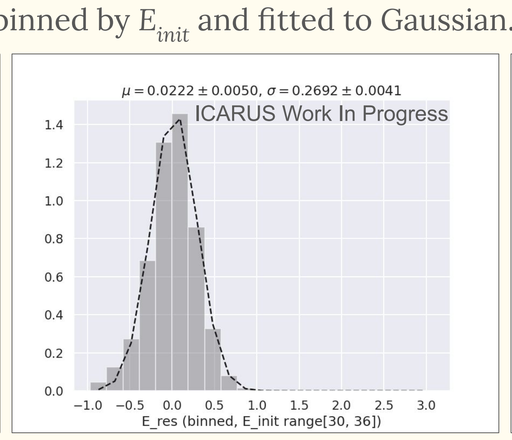


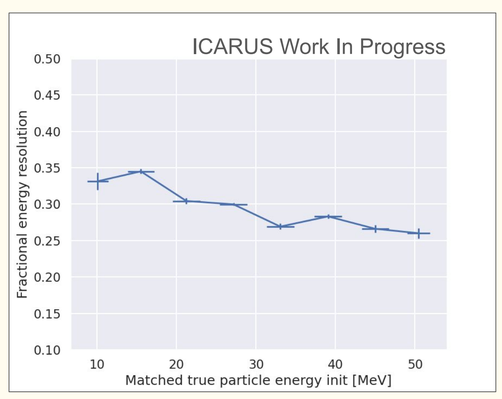




- Fractional energy resolution
  - $E_{corr} = (E_{rec} - \beta)/\alpha$, where α: slope, β: y-intercept from linear fit of (x,y: E_{true}, E_{reco}).
  - $E_{res} = (E_{corr} - E_{init})/E_{init}$, E_{res} is binned by E_{init} and fitted to Gaussian.







6. References

[1] Laura Dominé. (2023), "*Deep Learning based LArTPC Event Reconstruction and Nonmagnetic Muon Sign Determination in the ICARUS Detector*", [Doctoral dissertation, Stanford University.], https://searchworks.stanford.edu/view/14656199

[2] Laura Dominé, Kazu Terao, "*Scalable deep convolutional neural networks for sparse, locally dense liquid argon time projection chamber data*", Phys. Rev. D (2020), 102, 1, 012005

[3] SPINE github repository, https://github.com/DeepLearnPhysics/spine

7. Acknowledgement

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