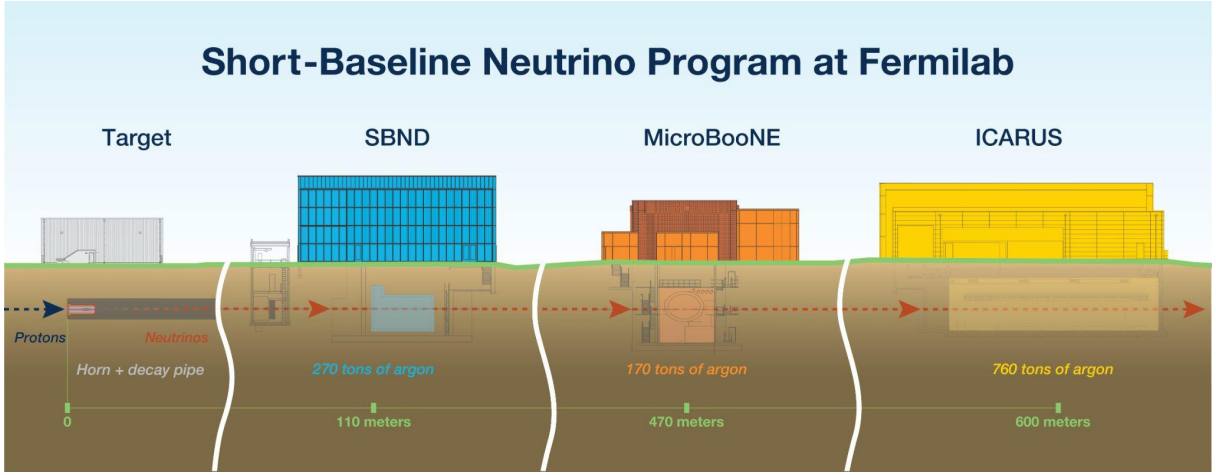
Michel reconstruction in ICARUS

On behalf of ICARUS Collaboration

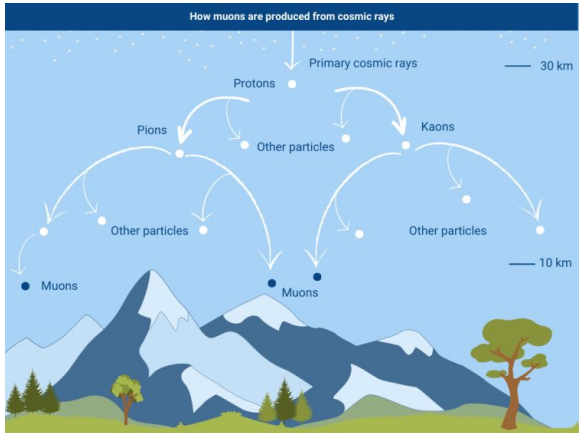
Yeon-jae Jwa, SLAC

SBN program at Fermilab

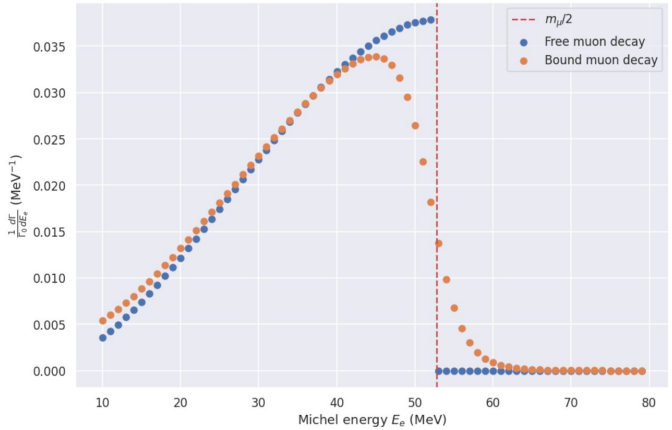


- SBND, MicroBooNE, and ICARUS receive Fermilab's Booster Neutrino Beam (BNB) at different baselines.
- ICARUS, the far detector of SBN program, is the current largest running LArTPC with 600T volume, and it has been taking data since 2022.

Michel Electrons



Cosmic rays crash into the Earth's atmosphere, creating a stream of new particles, among them muons. (Graphic: A. Vlasov/IAEA)

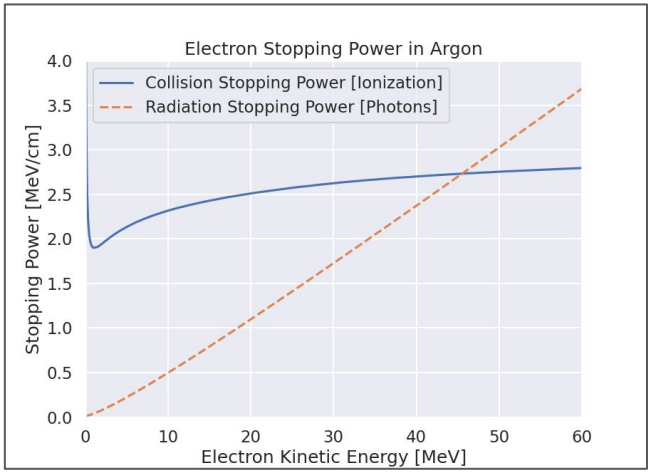


Theoretically calculated Michel energy. (Image credit: Laura Dominé, 2023)

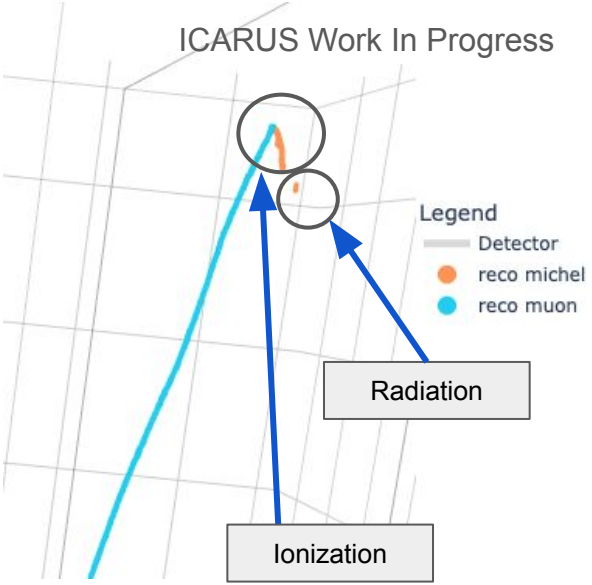
- Michel electrons are produced by the decay-at-rest of cosmic-ray muons.
- Michels have a well understood energy spectrum ranging up to ~50 MeV.
- Michel reconstruction demonstrates the detector’s capability in low-energy electron reconstruction.

Michel electron energy depositions in LAr

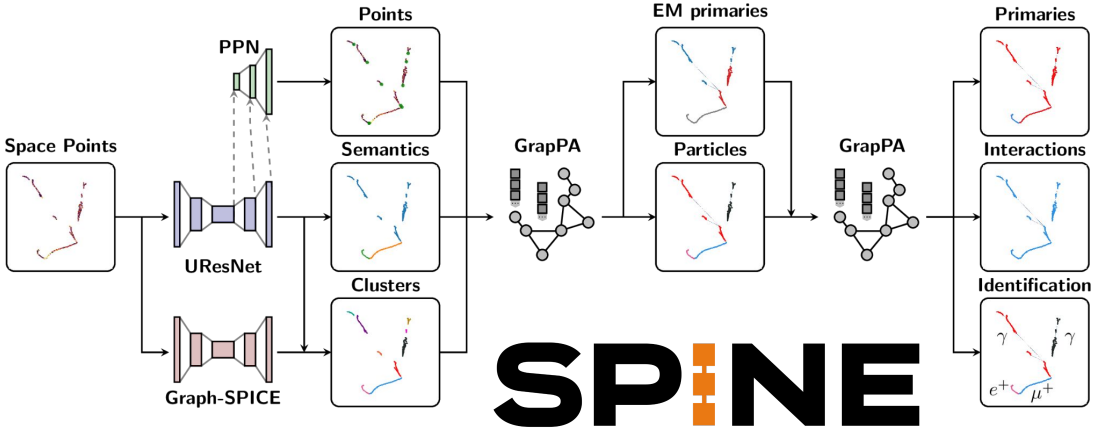
- The energy loss of Michel electrons in liquid argon has two contributing parts; electron ionization and photon radiation.

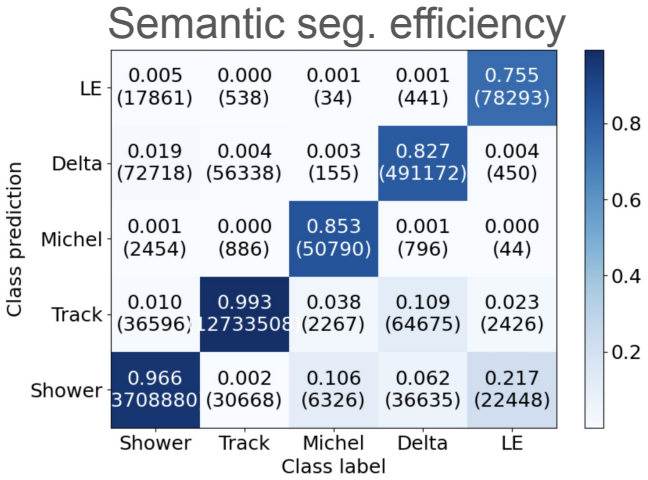


Electron stopping power in Argon from tabulated ESTAR database.



Michel reconstruction using SPINE



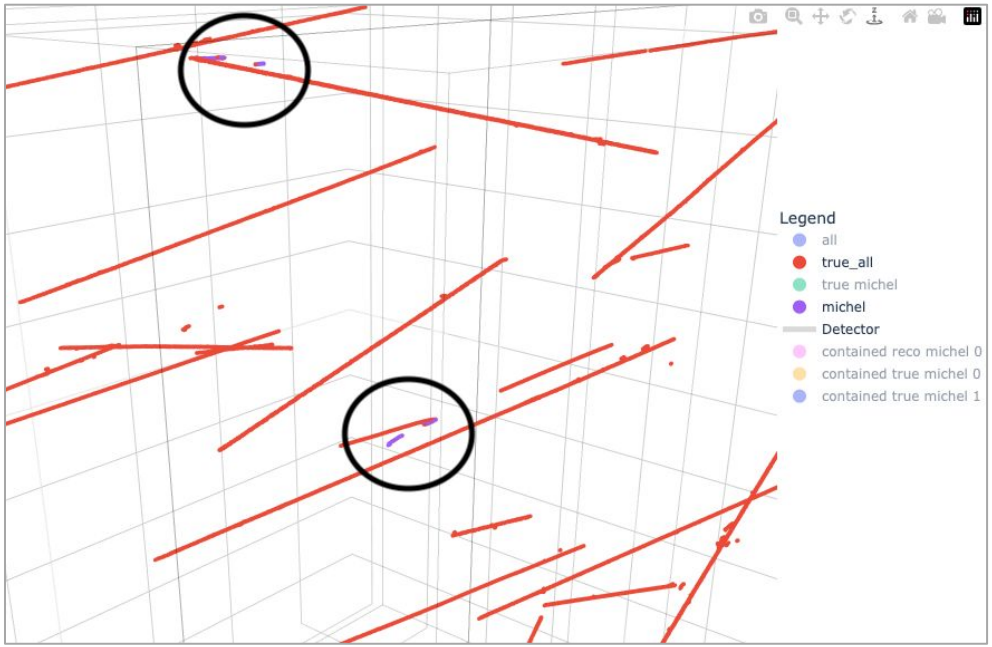


- Voxel semantics: shower-like/track-like/Michel-like/Delta-like/low energy-like
- Reconstructed voxels are further grouped to fragments/particles/interactions
- Find more details on **SPINE** in Francois' talk

End-to-End, Machine-Learning-Based Data Reconstruction Chain for LArTPC detectors	*Francois Drielsma*
HCI J4, ETH Zurich	14:10 - 14:35

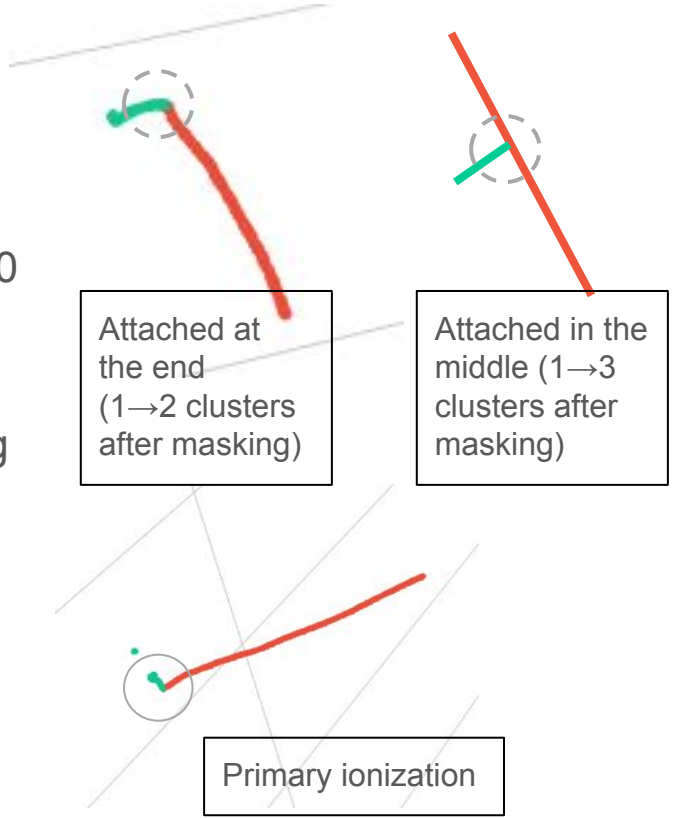
Sample

- Sample used:
  - MC: BNB+Corsika simulation (~21k events)
  - Data: ICARUS Run2 on-beam (~17k events)
- Typically ~3 stopping cosmic muons with Michels per event in ICARUS.
  - Total 60,691 true Michels are found in the MC sample, 56,492 are reconstructed as Michels by SPINE reconstruction.



Michel selection

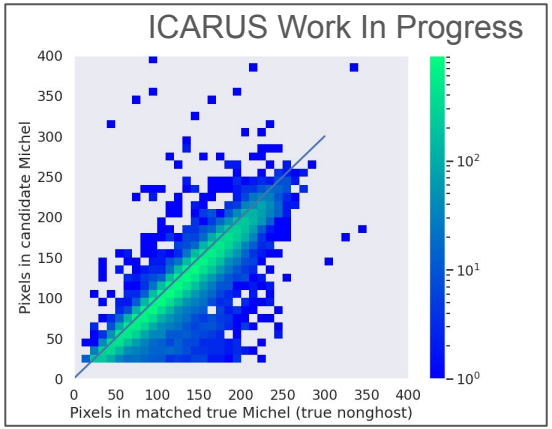
- Candidate Michels are fully contained within a detector module (5 cm margin) and consist of at least 20 reconstructed voxels.
- Candidate Michel and track are closer than 3 cm (10 voxels)
- When 4.5cm (15 voxels) mask is applied on the touching point, the number of clusters after masking is should be larger by 1 or equal than the non-masked to ensure the Michel is attached at the end (see the example on the right.)
- Primary ionization is defined as the closest cluster from the touching point after above selection.



Selection performance

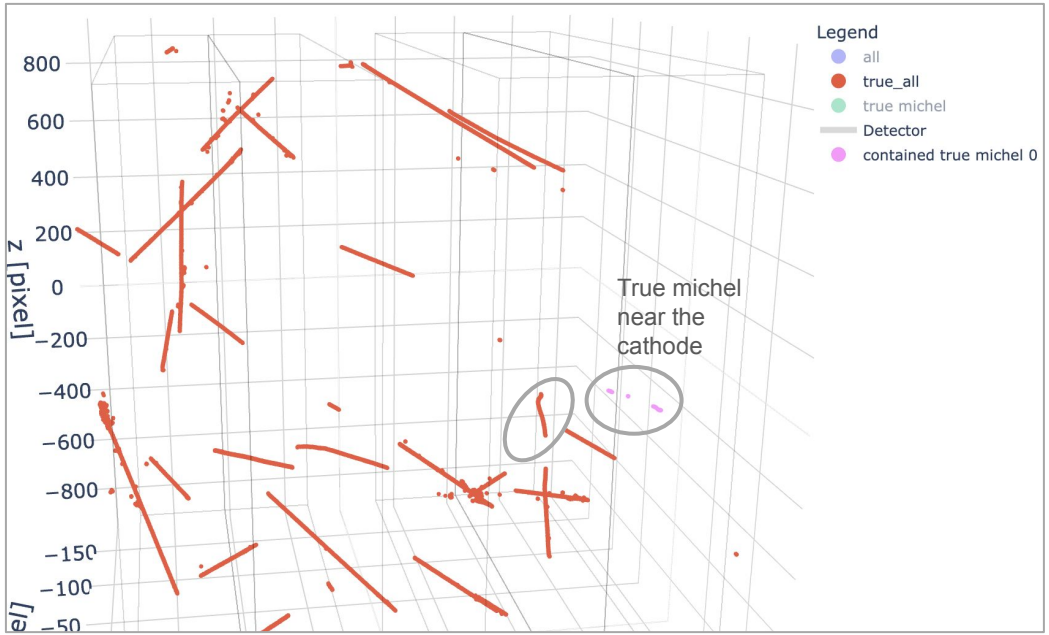
- Candidate Michels selected using the criteria are matched to true michels.
  - One-to-one matching done using intersection-over-union between true and candidate michel voxels
- Selection efficiency: matched michels / true michels
- Selection purity: matched michels / candidate michels

	Efficiency	Purity
No cut	56.1 %	60.3 %
contained	80.72 %	85.23 %
Reco. voxels >= 20	78.83 %	90.87 %
attached at the end	**87.6 %**	**93.9 %**



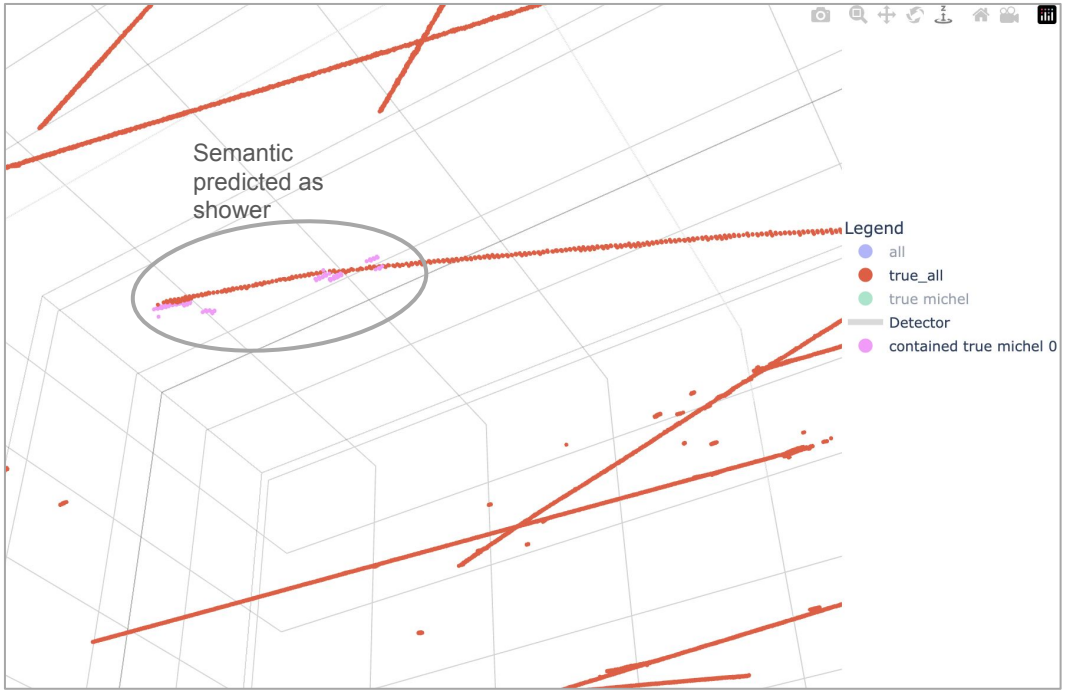
Selection performance - understanding mistakes

- Missed true michels
  - Very small true michels fail in reconstruction
  - **True michel near the cathode boundary**
  - Shower confusion
- Mis-identification
  - Mislabeling
  - Deghosting mistake



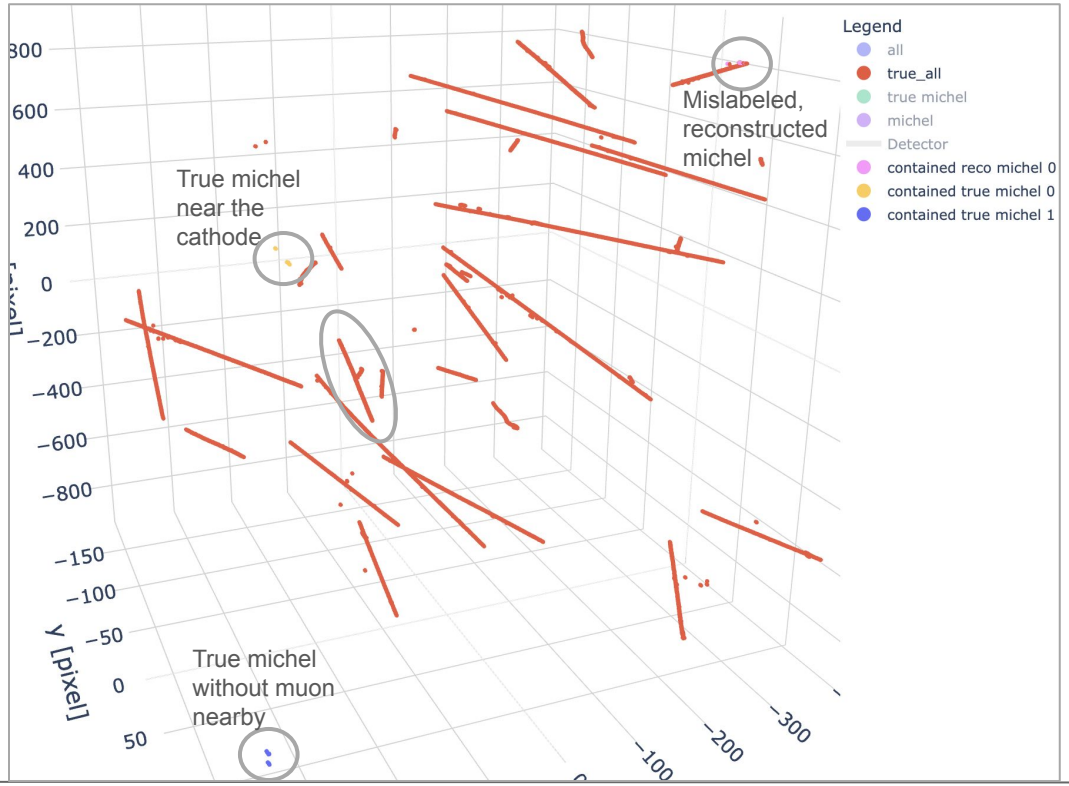
Selection performance - understanding mistakes

- Missed true michels
  - Very small true michels fail in reconstruction
  - True michel near the cathode boundary
  - **Shower confusion**
- Mis-identification
  - Mislabeling
  - Deghosting mistake



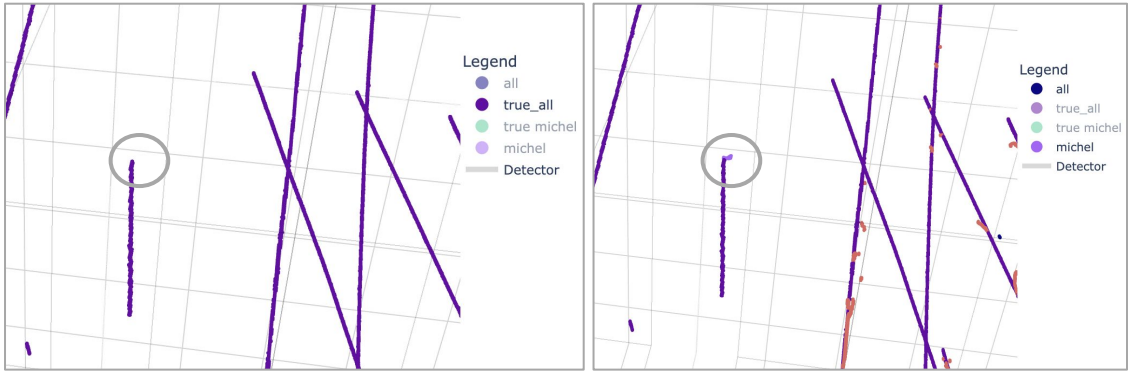
Selection performance - understanding mistakes

- Missed true michels
  - Very small true michels fail in reconstruction
  - **True michel near the cathode boundary**
  - Shower confusion
- Mis-identification
  - **Mislabeling**
  - Deghosting mistake

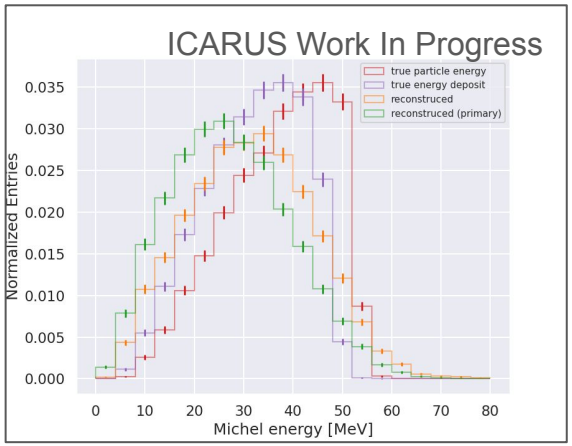


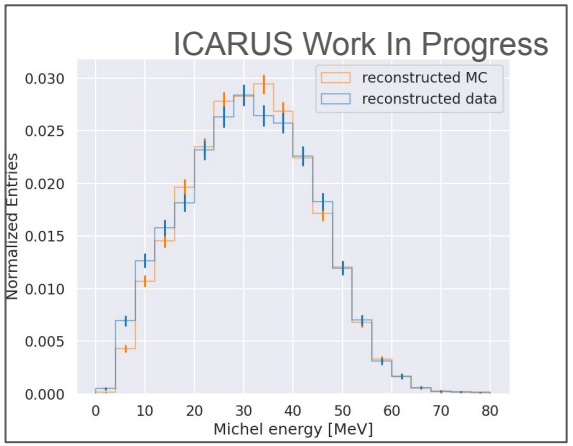
Selection performance - understanding mistakes

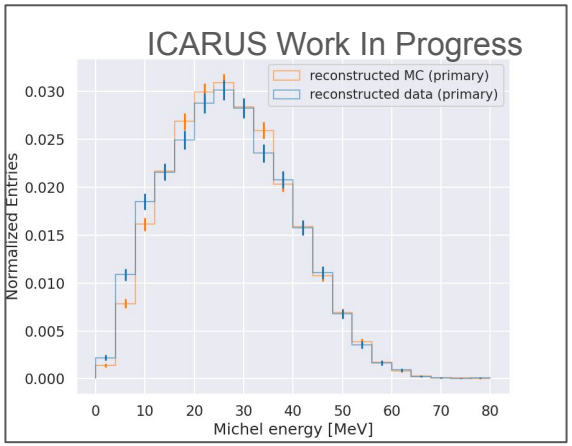
- Missed true michels
  - Very small true michels fail in reconstruction
  - True michel near the cathode boundary
  - Shower confusion
- Mis-identification
  - Mislabeling
  - **Deghosting mistake**



Michel energy reconstruction





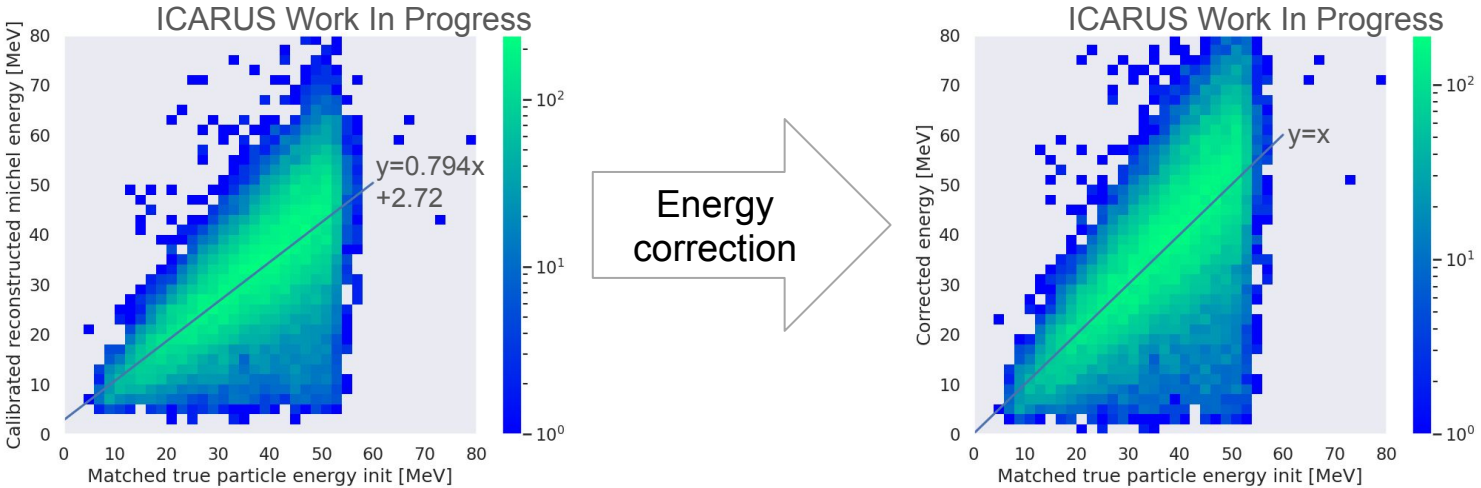


- Michel reconstructed energy is found after applying shower energy calibration on the voxel depoistions.
  - Details on calibration can be found in Dan's talk.

NuMI Electron Neutrino Selection at ICARUS with Machine Learning Reconstruction	*Daniel Carber*
HCI J4, ETH Zurich	16:30 - 16:55

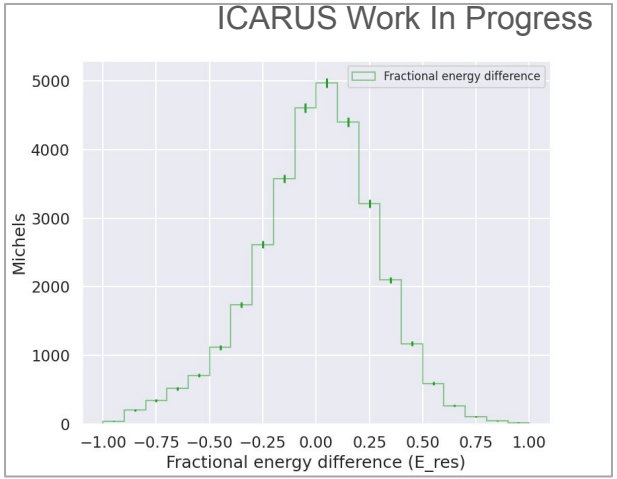
- Data/MC distributions are in good agreement in this first look.

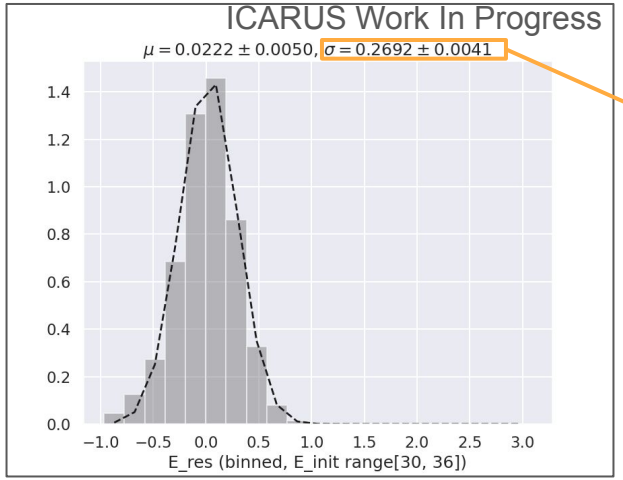
Fractional energy resolution (1)

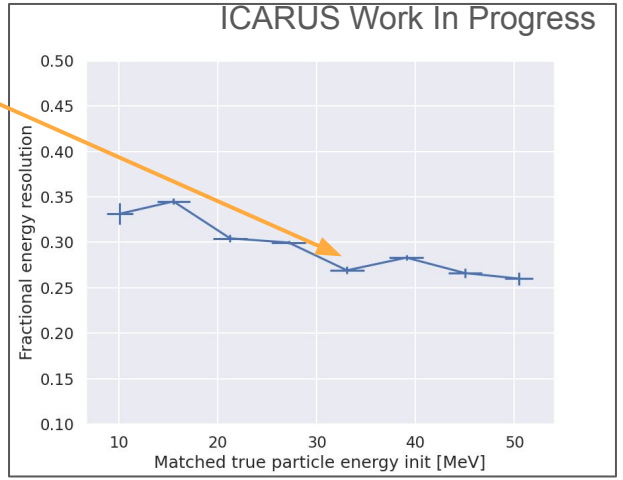


- Fractional energy resolution of true particle initial energy (E_{init}) is obtained from reconstructed Michel energy (E_{reco}).
- E_{corr} is the inferred true particle initial energy from the reconstructed.
  - E_{corr}: $(E_{reco} - \beta)/\alpha$, where α: slope, β: y-intercept from linear fit of (x,y: E_{init}, E_{reco})

Fractional energy resolution (2)

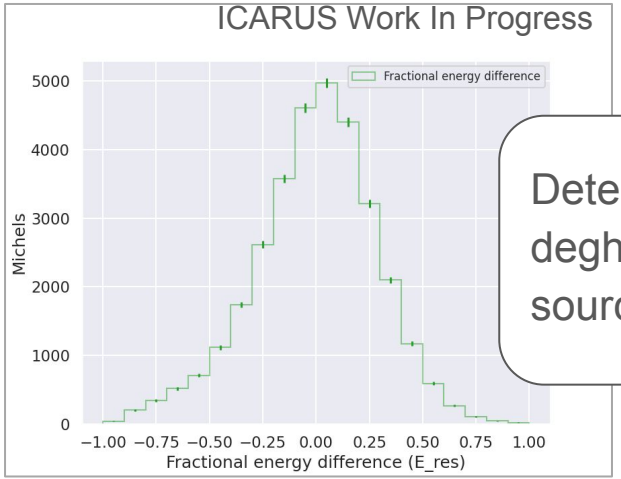


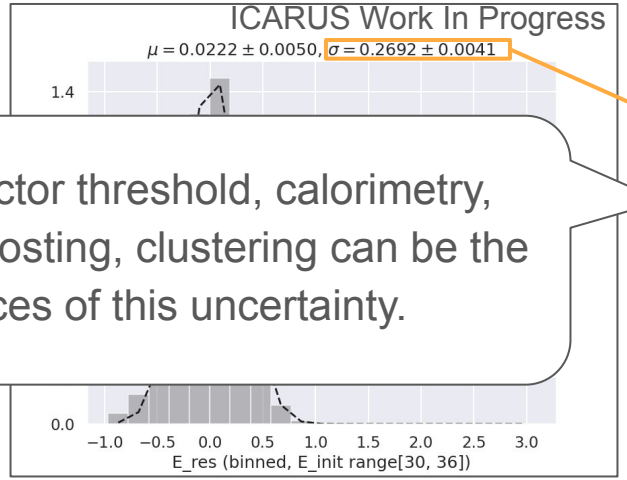




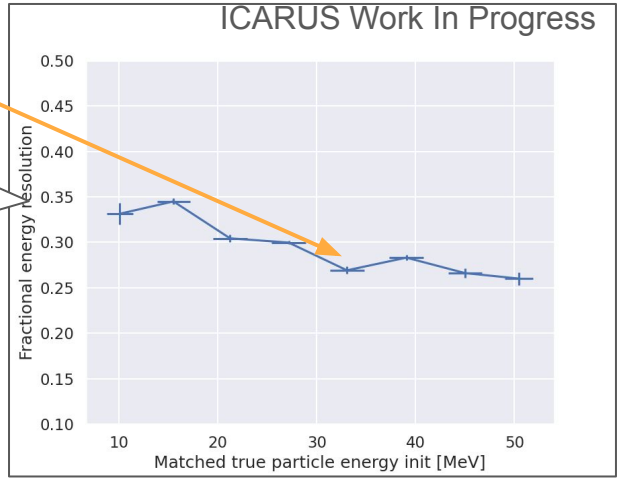
- E_{res}, the fractional error in true energy estimation, is defined as $(E_{corr} - E_{init}) / E_{init}$
- E_{res} is binned by E_{init} and fitted to Gaussian to obtain the width of the spread.
- σ in the gaussian fit estimates the fractional energy resolution in the energy bin.
- Fractional energy resolution is found within 25-35% range, with slightly decreasing trend.

Fractional energy resolution (2)





Detector threshold, calorimetry, deghosting, clustering can be the sources of this uncertainty.



- E_{res}, the fractional error in true energy estimation, is defined as $(E_{corr} - E_{init}) / E_{init}$
- E_{res} is binned by E_{init} and fitted to Gaussian to obtain the width of the spread.
- σ in the gaussian fit estimates the fractional energy resolution in the energy bin.
- Fractional energy resolution is found within 25-35% range, with slightly decreasing trend.

Conclusions

- The initial look on the Michel reconstruction in ICARUS is presented.
  - The selection demonstrated 87.6% efficiency, 93.9% purity.
  - Fractional energy resolution with respect to true Michel energy is shown.
    - Energy resolution is found to be 25%-35% of true particle initial energy.
- There is plenty room for further explorations for this study.
  - The selection can further utilize SPINE reconstruction outputs such as track end point prediction.
  - Performance as a function of energy
  - Michel direction reconstruction can be also studied to demonstrate the reconstruction capability.
  - Investigate the sources of fractional energy uncertainty
  - Systematic uncertainty for the shower energy reconstruction is to be studied.

Conclusions

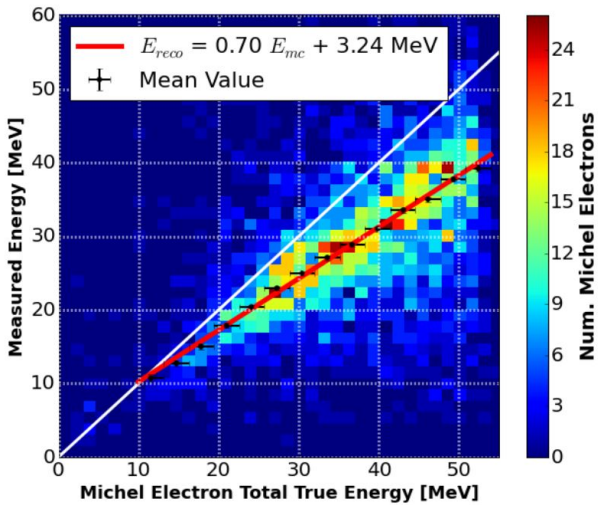
- The initial look on the Michel reconstruction in ICARUS is presented.
  - The selection demonstrated 87.6% efficiency, 93.9% purity.
  - Fractional energy resolution with respect to true Michel energy is shown.
    - Energy resolution is found to be 25%-35% of true particle initial energy.
- There is plenty room for further explorations for this study.
  - The selection can further utilize SPINE reconstruction outputs such as track end point prediction.
  - Performance as a function of energy
  - Michel direction reconstruction can be also studied to demonstrate the reconstruction capability.
  - Investigate the sources of fractional energy uncertainty
  - Systematic uncertainty for the shower energy reconstruction is to be studied.

Thank you for your attention :)

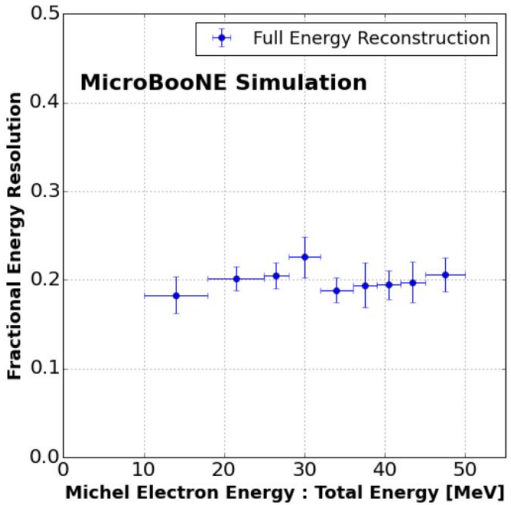
Back up

Michel reconstruction in MicroBooNE

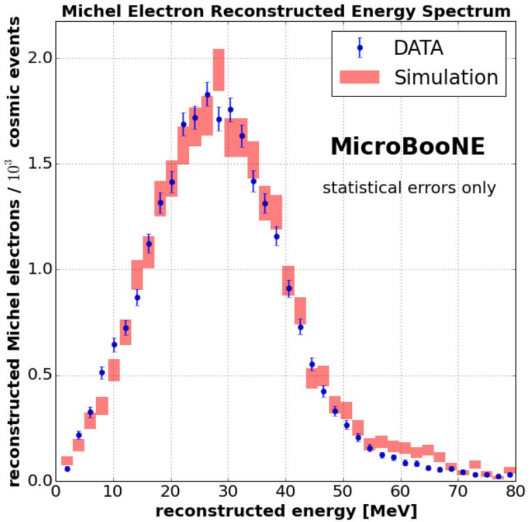
R. Acciarri *et al*, "Michel electron reconstruction using cosmic-ray data from the MicroBooNE LArTPC", 2017, *JINST*, 12 P09014



(a)

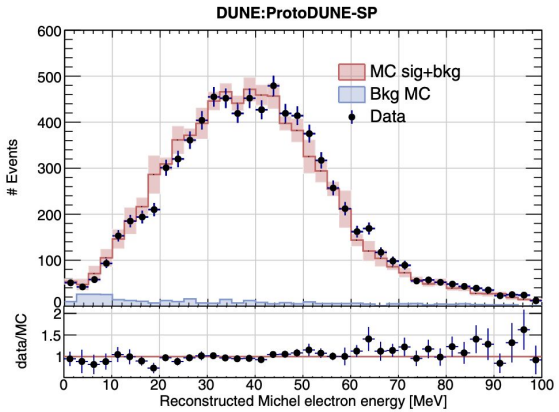


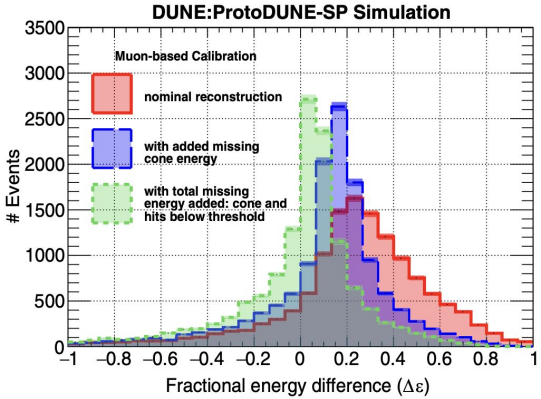
(b)

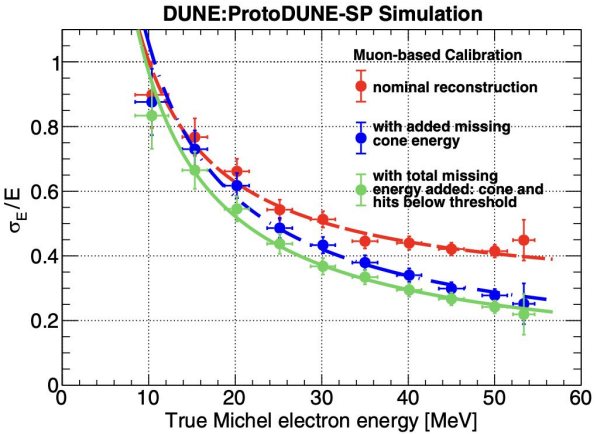


Michel reconstruction in ProtoDUNE

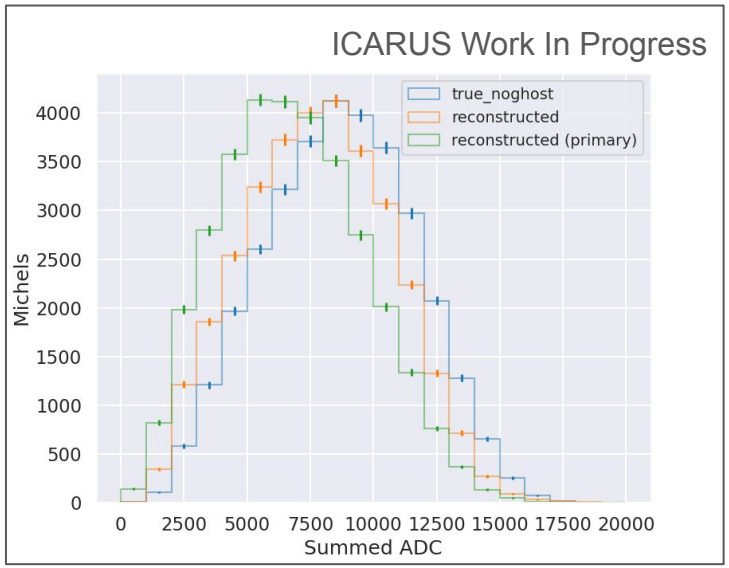
A. Abed Abud *et al.* (DUNE Collaboration), “Identification and reconstruction of low-energy electrons in the ProtoDUNE-SP detector” , Phys. Rev. D **107**, 092012

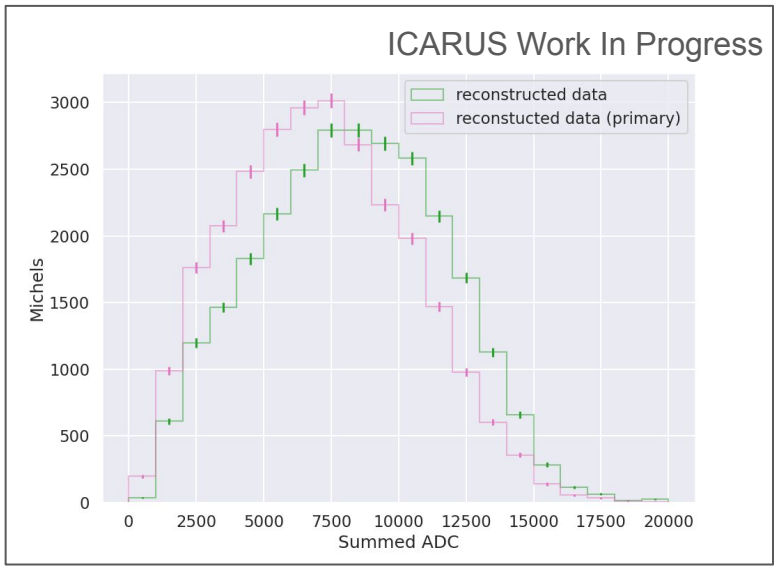






Selection performance: Summed ADC (before shower energy calibration)





Energetic Michel