FERMILAB-SLIDES-21-005-ND

Detector Performance of the MicroBooNE LArTPC

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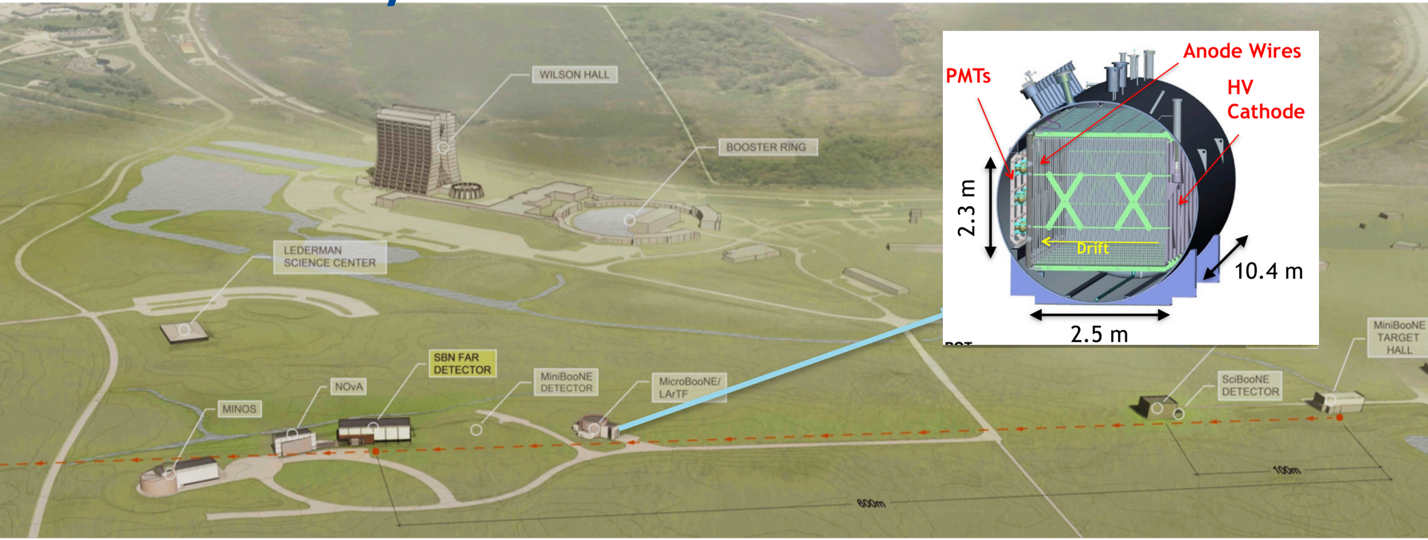
on behalf of the MicroBooNE Collaboration

XIX International Workshop on Neutrino Telescope

24 February 2021

MicroBooNE Physics Goals

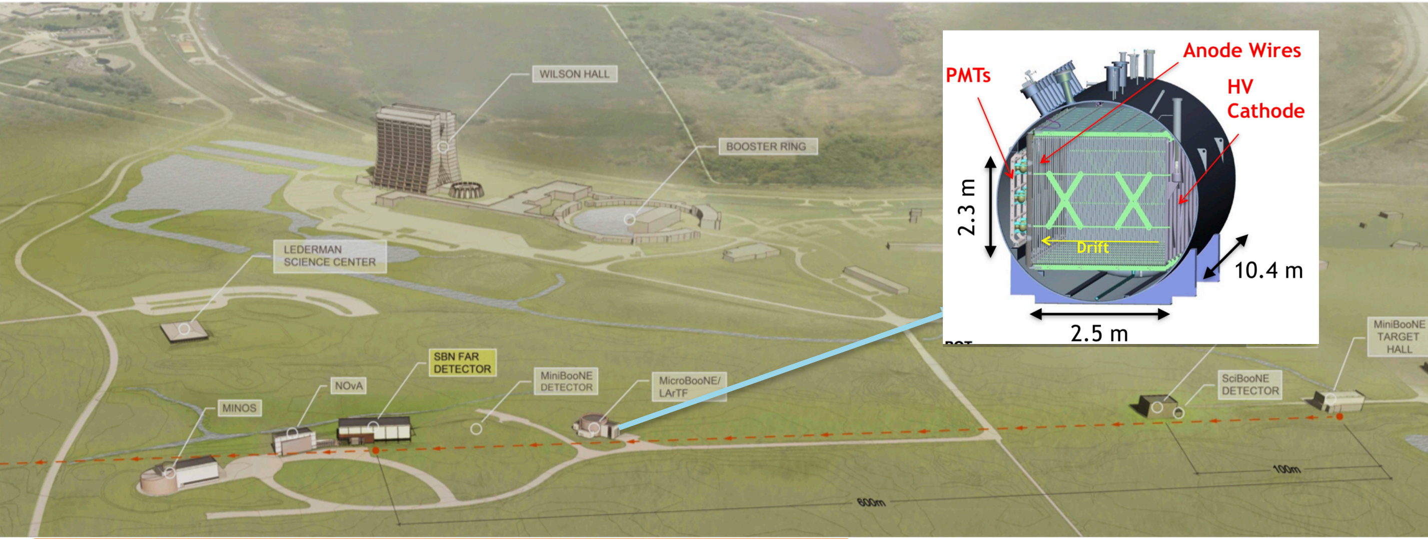


MicroBooNE Physics Goals

- **Study the MiniBooNE Low Energy Excess**
  - Mark Ross-Lonergan, Hanyu Wei, Andrew Mogan
- **Precision Cross Sections Measurements on Argon ~O(1GeV)**
  - Krishan Mistry, Wenqiang Gu, Marina Reggiani Guzzo
- **Beyond Standard Model and Supernovae detection:**
  - Pawel Guzowski

Precise calorimetric and topological reconstruction is crucial to reach these *physics goals!*

MicroBooNE Detector

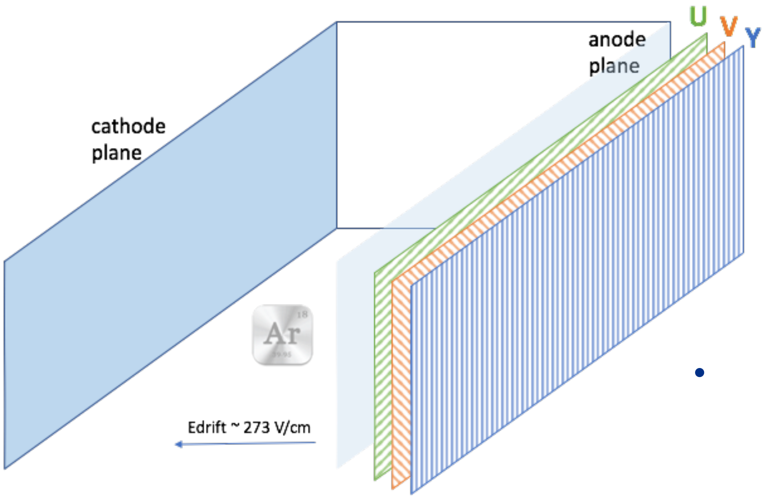


- **First operating detector** in Short Baseline Neutrino Program.
- **Longest running** Liquid Argon Time Projection Chamber (LArTPC) detector.
- Located on surface.
- Collecting cosmic and neutrino data since Fall 2015 with good uptime and purity.
- Provide technical experience in the construction, operation, and analysis of a large LArTPC

Detector Details:

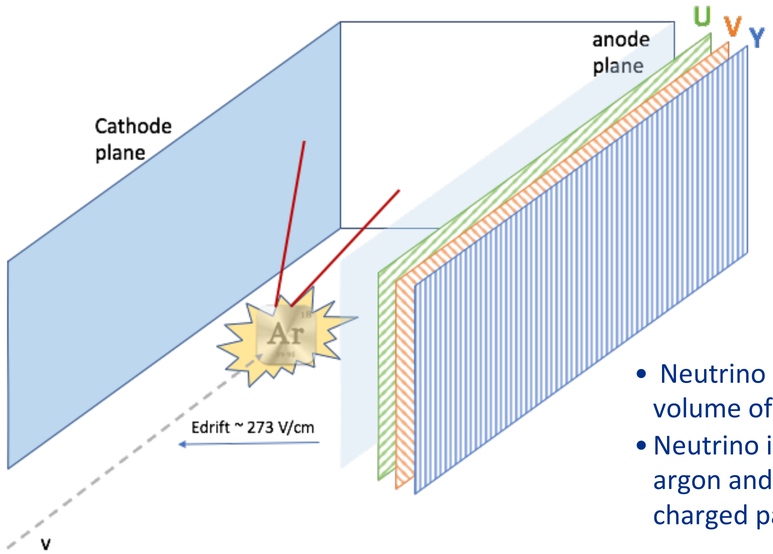
- 85 ton active mass
- 3 Wire Read Out (different orientations)
- Light Detection System
- UV Laser System
- Cosmic Ray Tagger (CRT) System

LArTPC principles



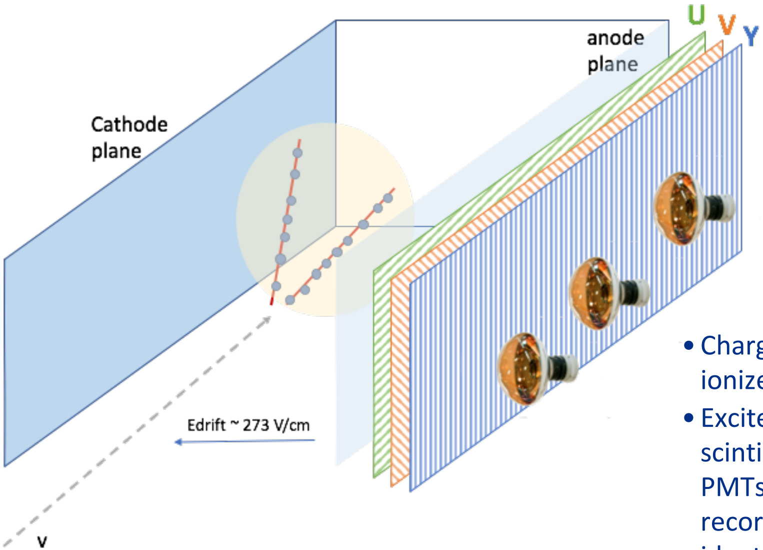
- Start with a large volume of liquid argon and a cathode and and anode

LArTPC principles



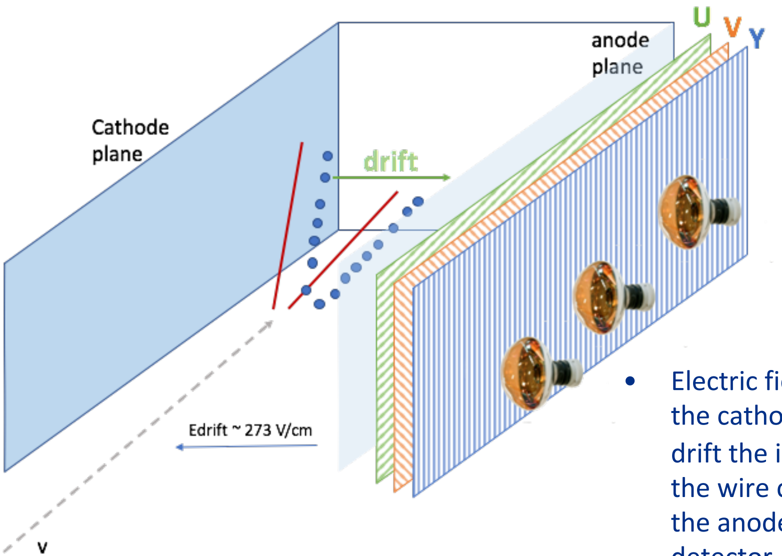
- Neutrino enters the large volume of liquid argon.
- Neutrino interacts with argon and produces charged particles

LArTPC principles



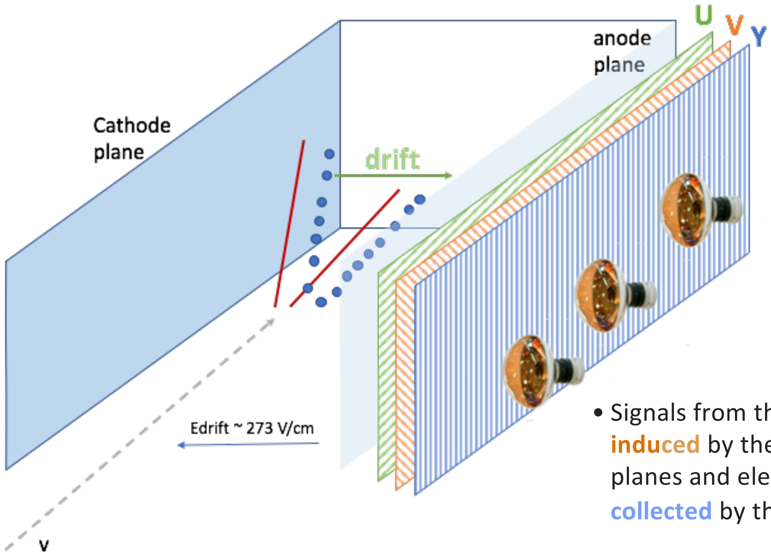
- Charged particle can ionize/excite the argon atoms.
- Excited argons produce scintillation light and arrays of PMTs behind the wire planes recorded the lights and used to identify the time the interaction occurs

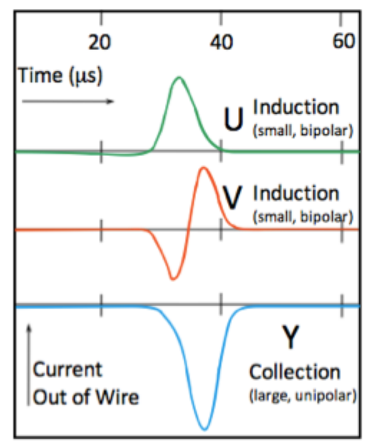
LArTPC principles



- Electric field set up between the cathode and the anode drift the ionized electron to the wire chamber planes on the anode side of the detector.

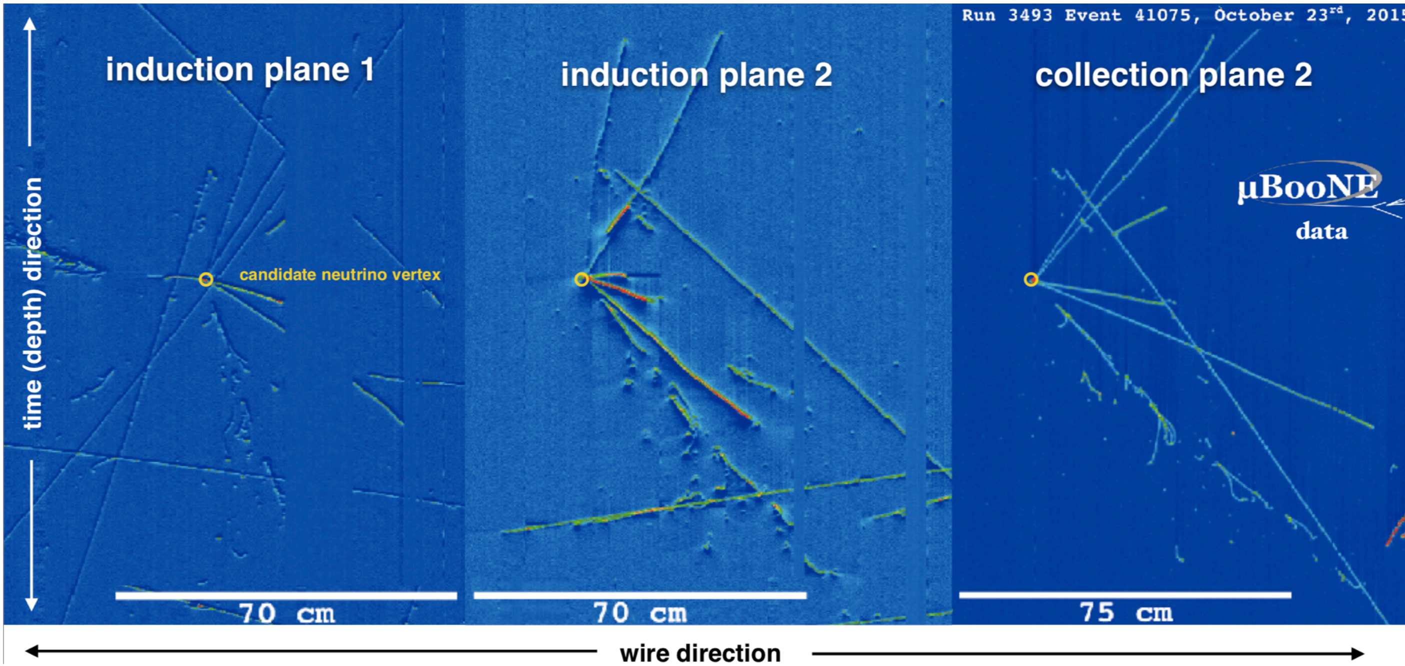
LArTPC principles





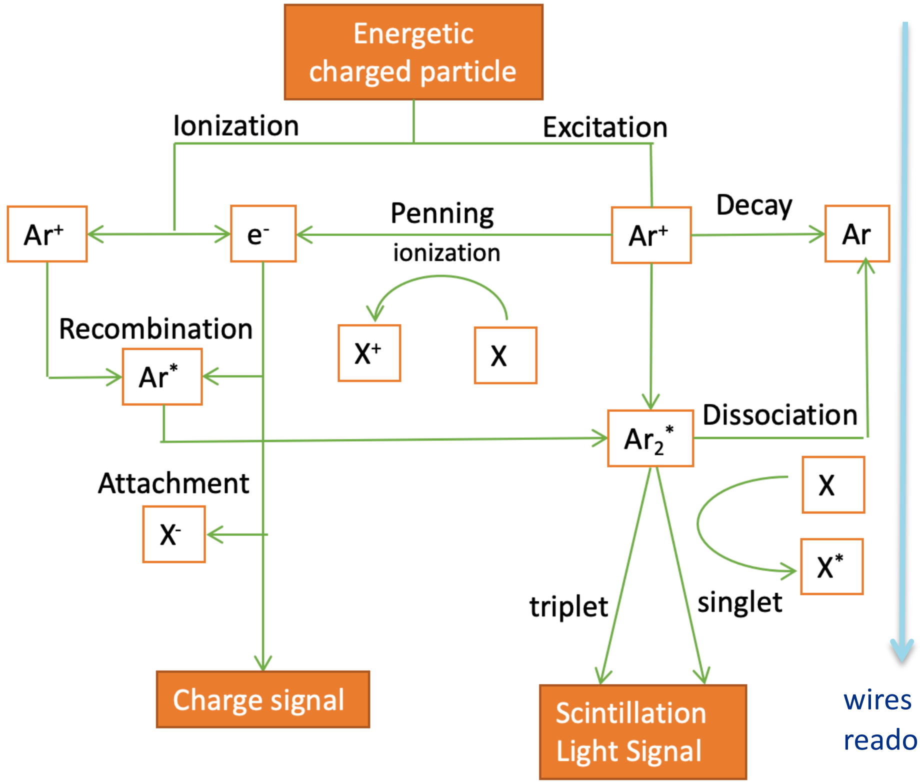
- Signals from the event are **induced** by the first two wire planes and electrons are **collected** by the last plane

Digital "Bubble-chamber"-like images with 3D topology and calorimetry information



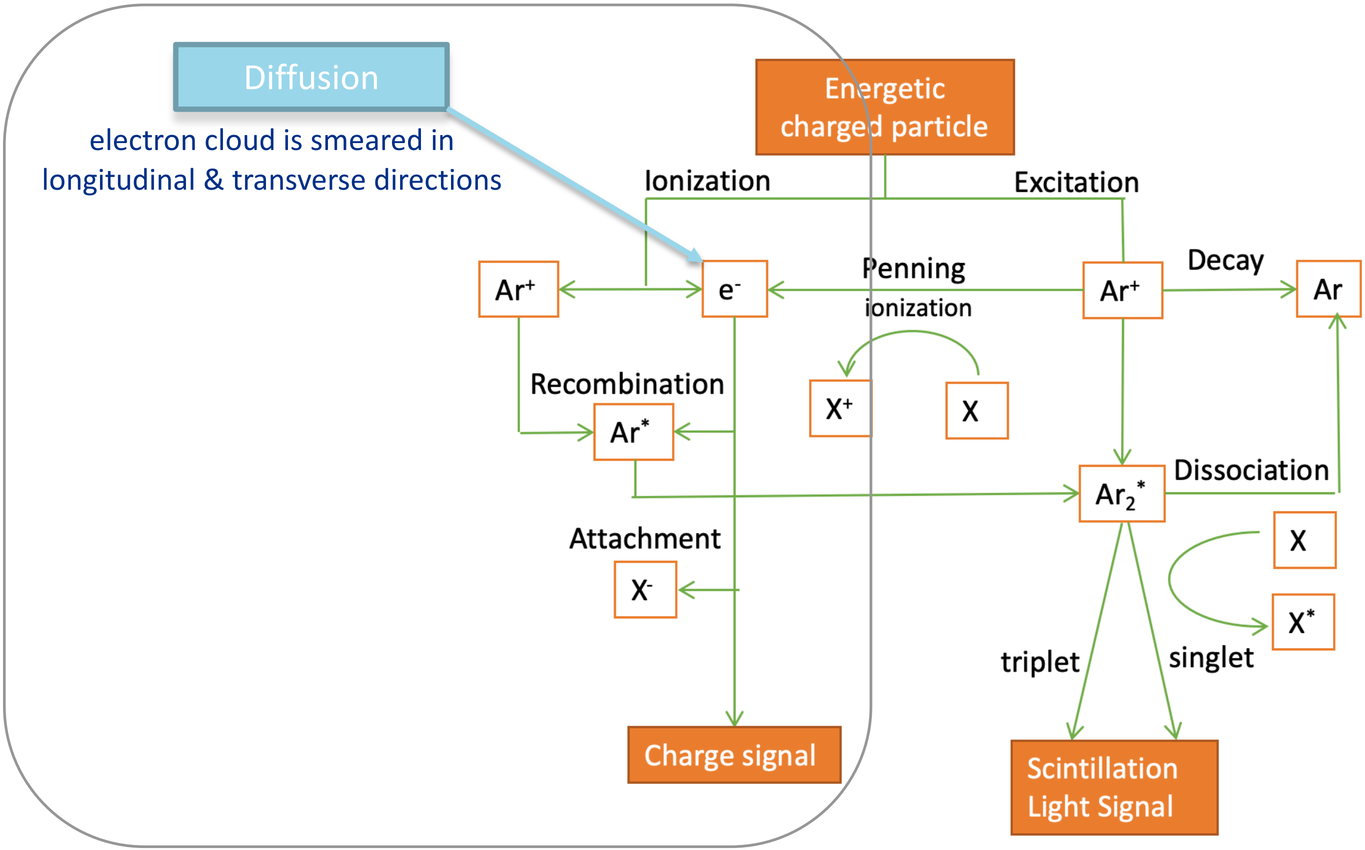
Chosen technology for the DUNE long-baseline ν_e appearance measurement

Understanding Detector Effects

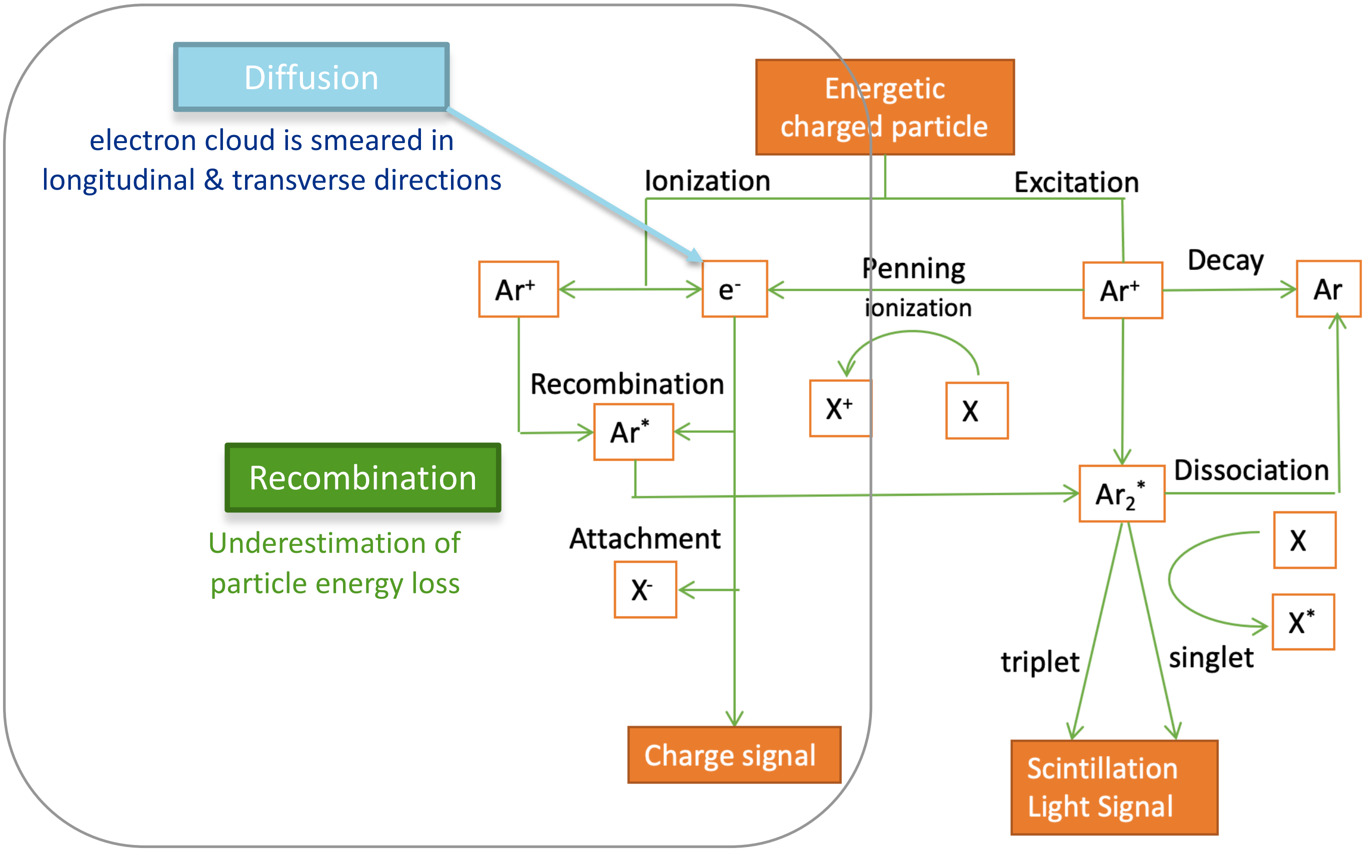


wires
readou

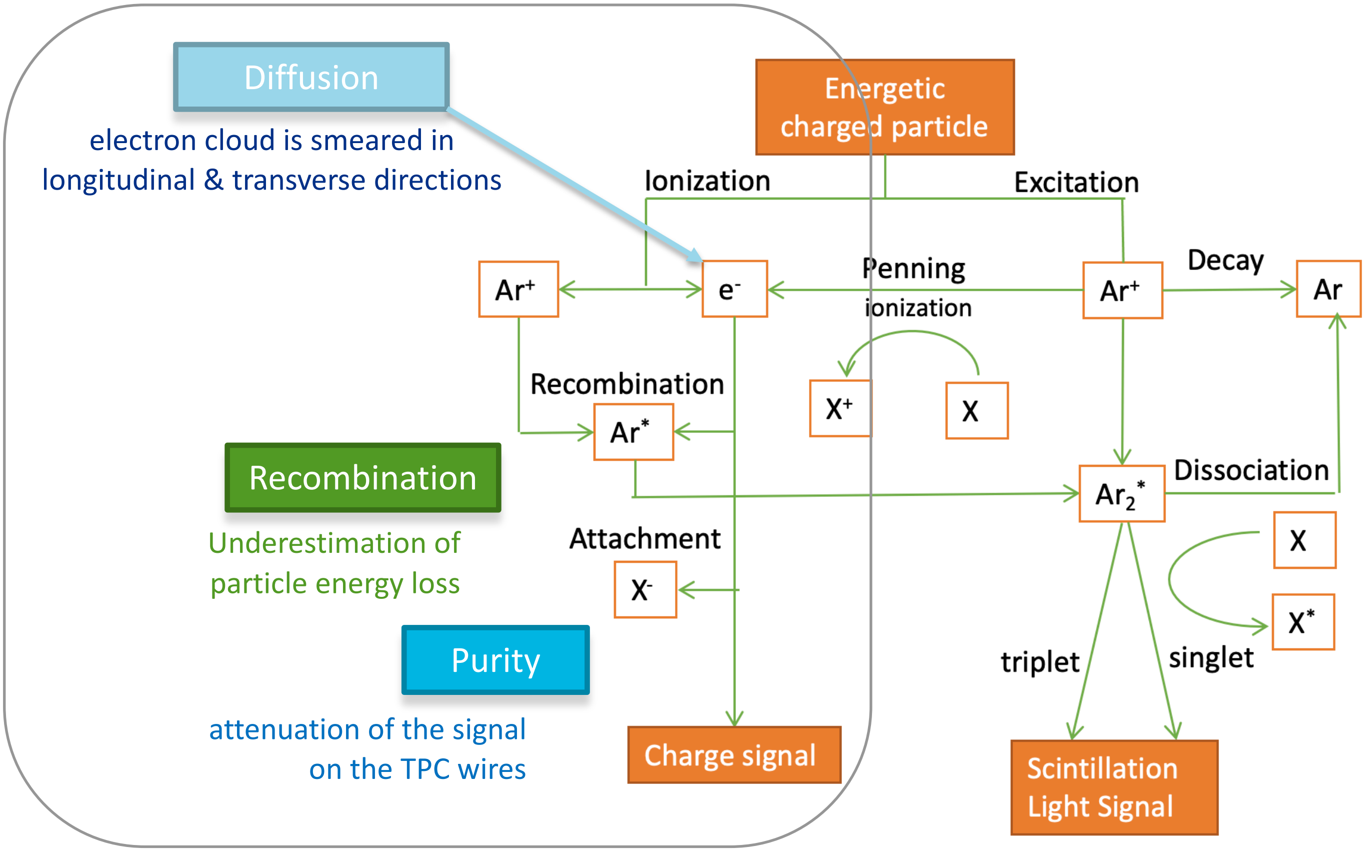
Understanding Detector Effects



Understanding Detector Effects



Understanding Detector Effects



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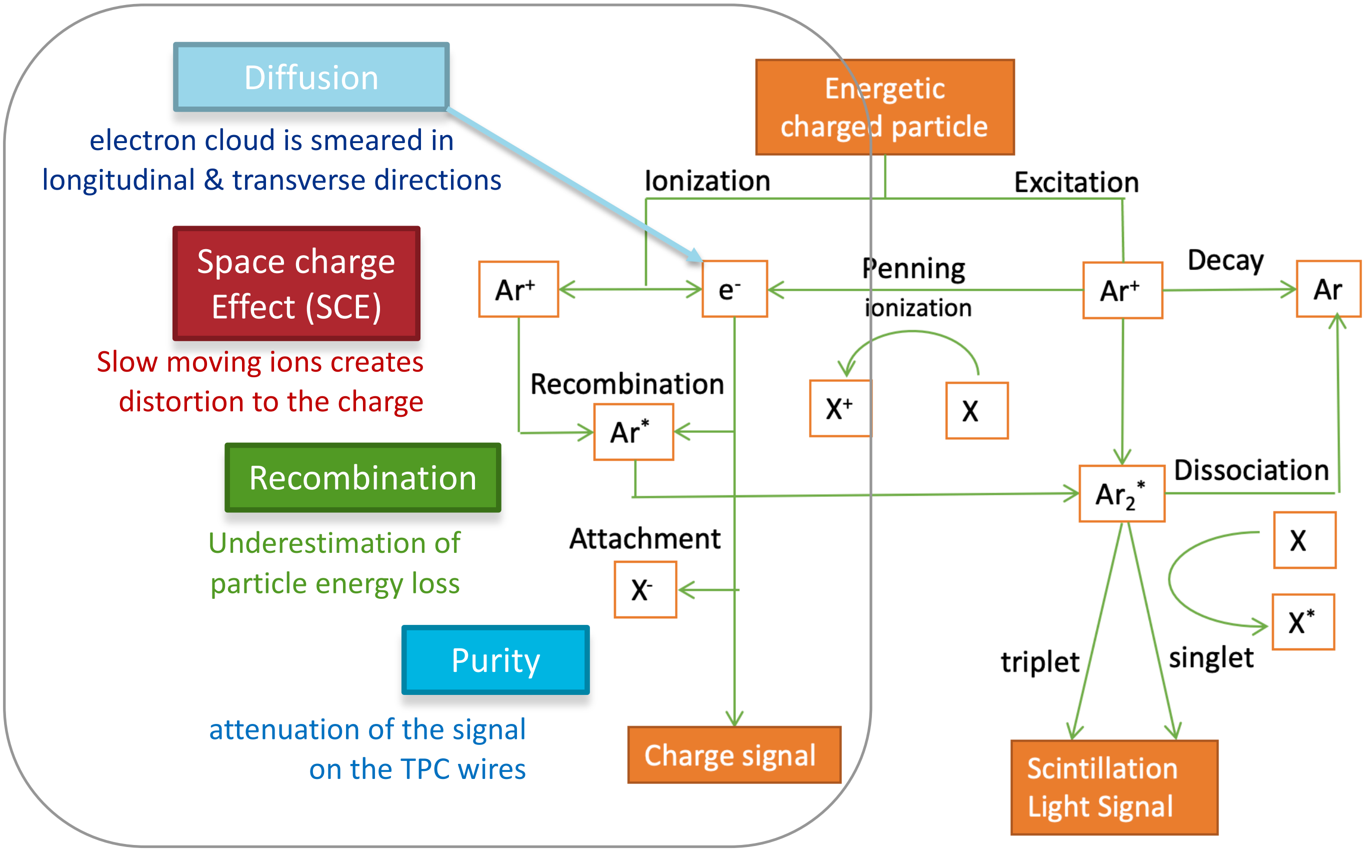
Understanding Detector Effects



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Understanding Detector Effects

Diffusion

electron cloud is smeared in longitudinal & transverse directions

Space charge Effect (SCE)

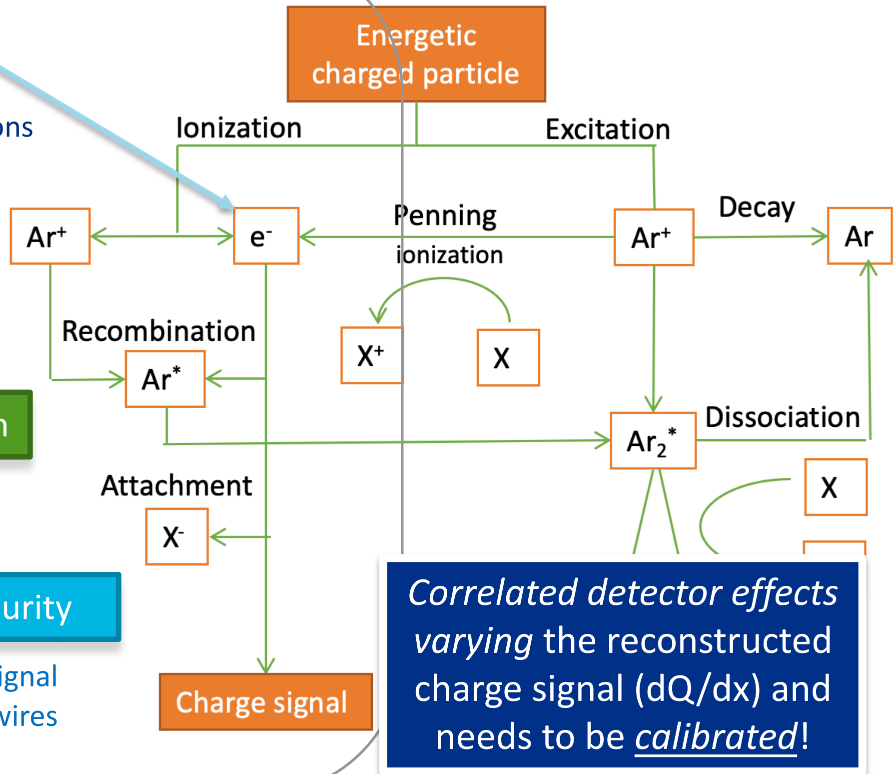
Slow moving ions creates distortion to the charge

Recombination

Underestimation of particle energy loss

Purity

attenuation of the signal on the TPC wires



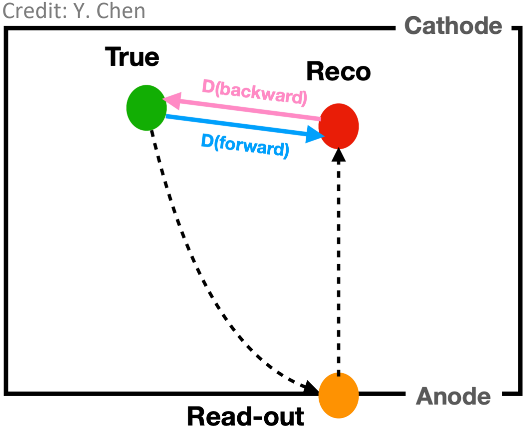
Correlated detector effects varying the reconstructed charge signal (dQ/dx) and needs to be ***calibrated***!

Characterizing Spatial Distortion due to SCE

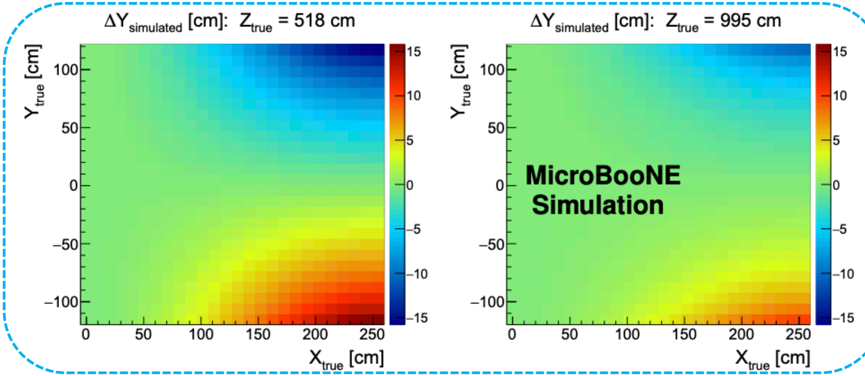
JINST 15, P07010 & P12037 (2020)

- On-surface LArTPC
  - accumulation of Ar^+ produced by cosmic rays, distort the electric field significantly.
  - Spatial distortion of drift electron leads to distorted reconstructed tracks/showers.
- Spatial distortions measured using
  - UV laser tracks
  - cosmic ray muon tracks.

Credit: Y. Chen



Maximal impact of 10-15% distortion around the edges



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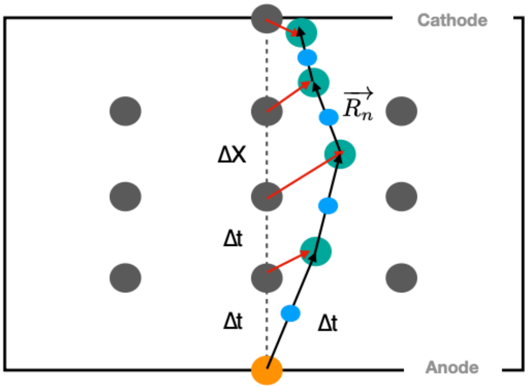
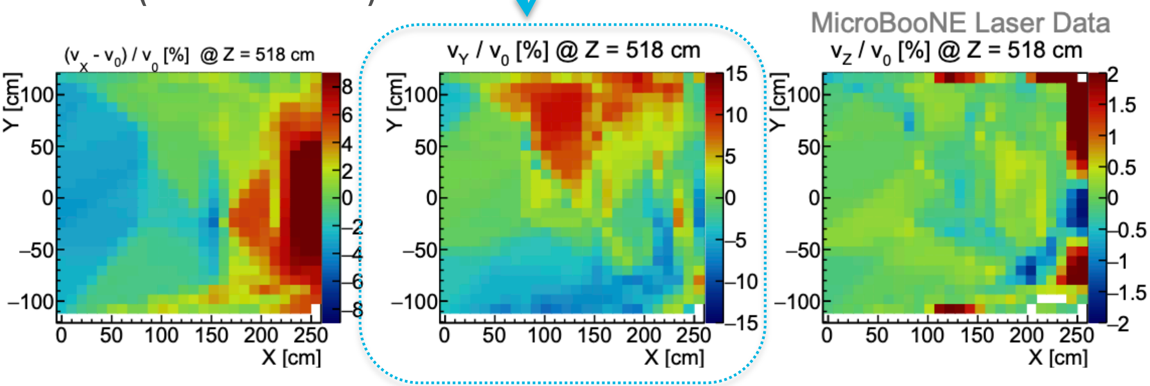
Characterizing Electric Field Distortion due to SCE

JINST 15, P07010 & P12037 (2020)

- Local electron drift velocity is calculated from the spatial distortion map.
- Local electric field magnitude obtained using relationship between the electric field and the drift velocity, which is a function of the liquid argon temperature.
- Distortion is up to ~ **10%** of the nominal E-field (~ 30 V cm^{-1})





JINST 15, P07010 & P12037 (2020)

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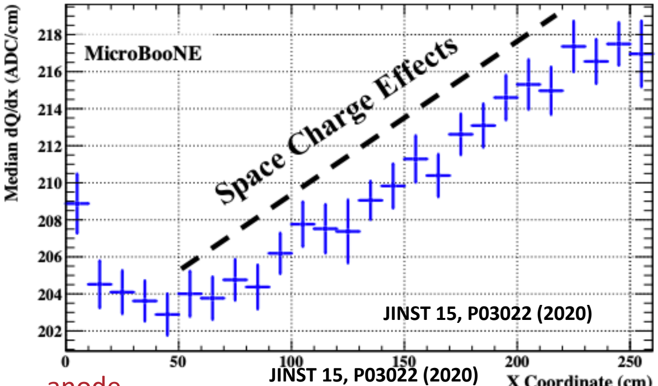
Electron Attenuation and Longitudinal Diffusion

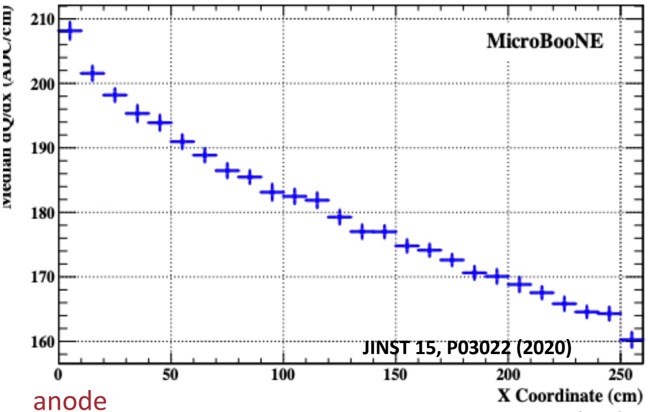
Drift electron lifetime measured using cosmic ray muons crossing anode and cathode.



JINST 15, P03022 (2020)

anode

cathode



anode

cathode

We are including SCE correction in the current drift electron lifetime calibration

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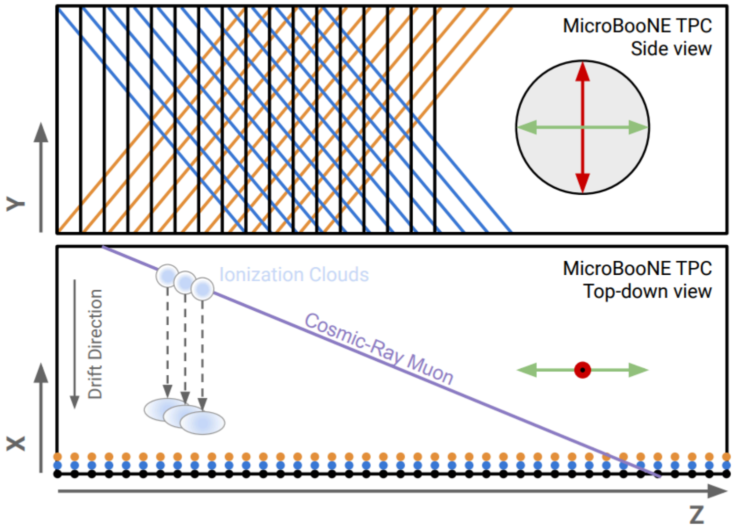
Longitudinal Diffusion

Longitudinal diffusion widens the signal pulses (σ_t) as a function of drift time (t).

Diffusion coefficient (D_L) is extracted from the **t** and $\boldsymbol{\sigma_t}$

Credit: A. Mogan, A. Lister



Only few world data available. MicroBooNE Results are expected to be published soon!

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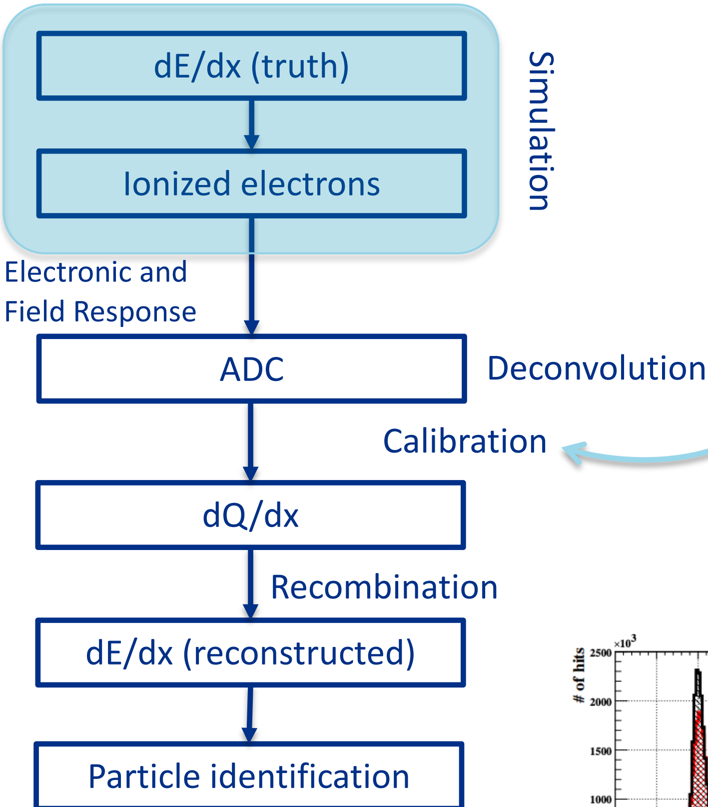
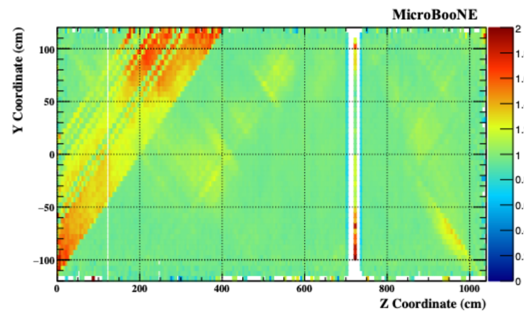
Calibration Technique JINST 15, P03022 (2020)

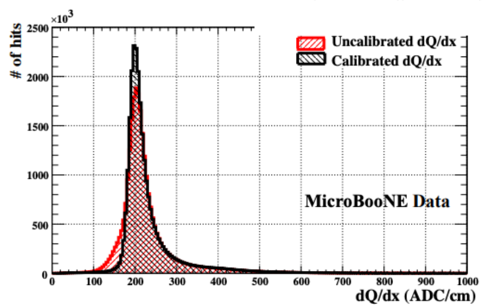


Separate detector nonuniformities into yz plane, x direction, and time, and calibrate them in sequence using Cosmic Ray.

Correcting for:

- space charge, cross-connected TPC channels, and transverse diffusion (y,z)
- Electron attenuation, space charge, and longitudinal diffusion (x)
- Temporal variation (calendar time)





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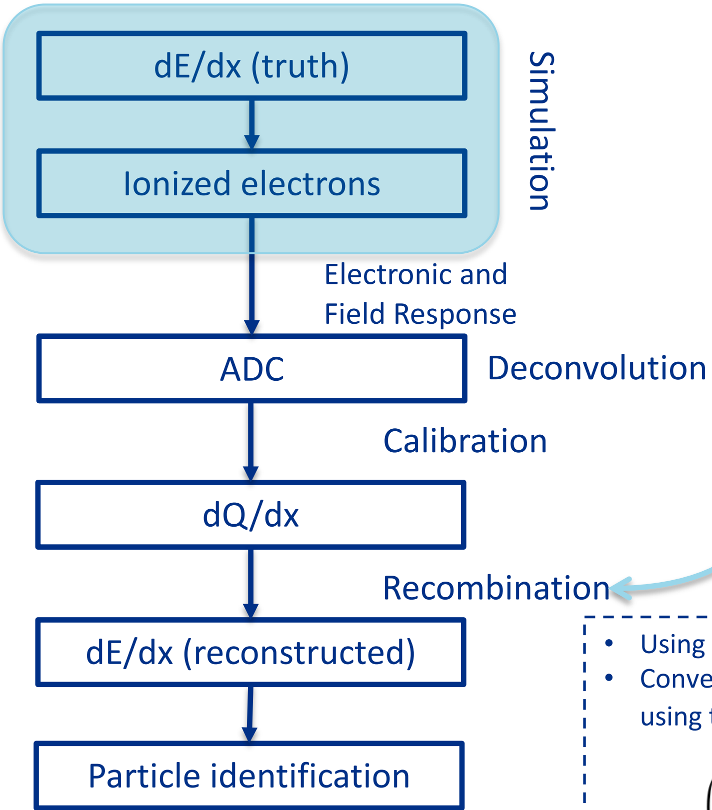
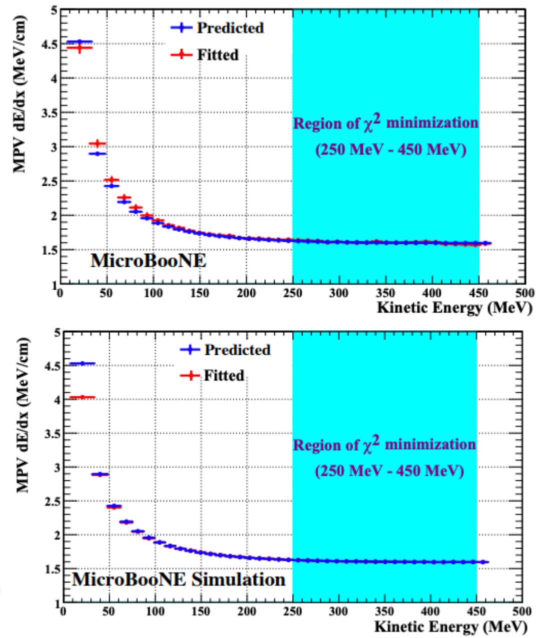
Calibration Technique JINST 15, P03022 (2020)

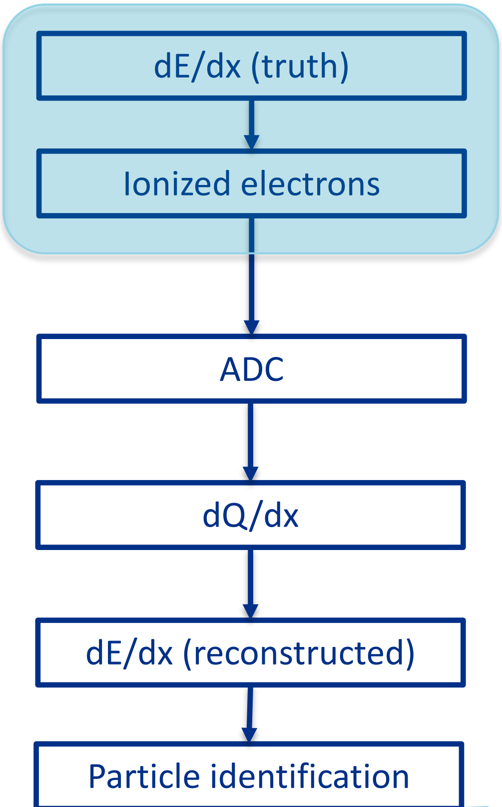




- Using stopping muons.
- Convert the digitized dQ/dx [ADC/cm] to dQ/dx [e/cm] using the **Modified Box Model** and compares data to MC.

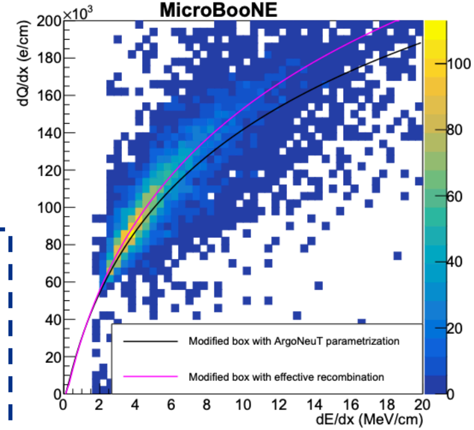
$$\left(\frac{dE}{dx}\right)_{\text{calibrated}} = \frac{\exp\left(\frac{\left(\frac{dQ}{dx}\right)_{\text{calibrated}}}{C_{\text{cal}}}\frac{\beta' W_{\text{ion}}}{\rho\mathscr{E}}\right) - \alpha}{\frac{\beta'}{\rho\mathscr{E}}},$$

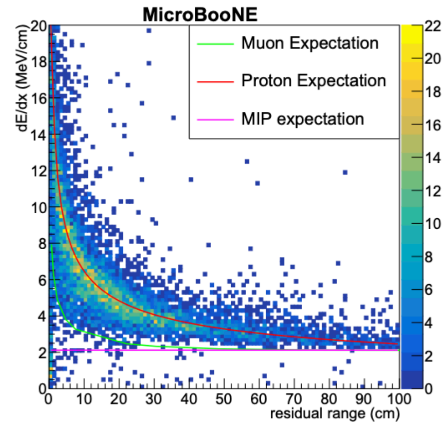
Calibration Technique JINST 15, P03022 (2020)



Pure ν-induced proton sample used to correct for **recombination of electron-ion pairs**. Independent reconstruction of **dE/dx** using a range-based method.

$$\frac{dQ}{dx} = \frac{\ln(\frac{dE}{dx}\frac{\beta'}{\rho\mathscr{E}} + \alpha)}{\frac{\beta'}{\rho\mathscr{E}} W_{\mathrm{ion}}}$$





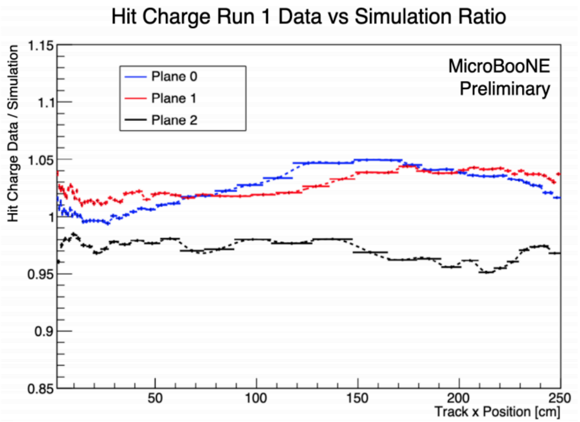
JINST 15, P03022 (2020)

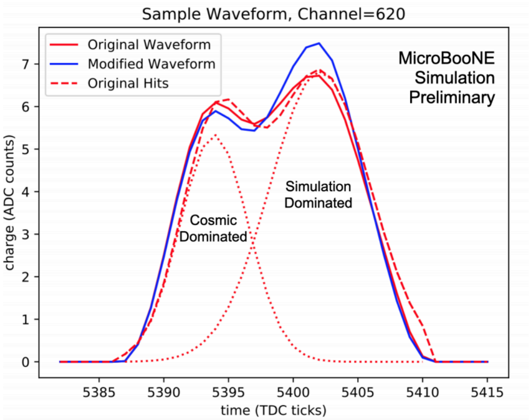
Assessing Detector Systematics

- Various subtle and correlated effects in the detector response model
- Pioneered a novel method to capture waveform-level data/MC differences in response as a function of:
  - position in x, y, and z
  - angular orientation of particle's trajectory, θ_{XZ} and θ_{YZ}

  as a correction and residual detector modeling systematic

Results are expected to be published soon!





MICROBOONE-NOTE-1075-PUB

Summary

- MicroBooNE has been carefully examining LArTPC data **for 5 years** and **publishing detailed detector performance results** to be used by new and upcoming LArTPCs, such as DUNE and SBN program
- MicroBooNE is pioneering in several aspects of the LArTPC performance:
  - Data-driven SCE/E-Field maps **JINST 15, P07010 & P12037 (2020)**
  - Wire field response and signal processing **JINST 13, P07006 & P07007 (2018)**
  - Data-driven method for assessing detector systematics in MicroBooNE
- Developing the first major campaign of calibration for a big LArTPC - **JINST 15, P03022 (2020)**
  - Use of extensive cosmic ray muons for uniformity and response calibration
  - Use of neutrino-induced protons for recombination corrections
  - Use of Data-driven SCE/E-Field maps to correct dQ/dx and dE/dx.
  - Using dedicated calibration studies to better inform simulation

Stay tune for our many upcoming results!

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NSF
FNSNF SWISS NATIONAL SCIENCE FOUNDATION
Science & Technology Facilities Council
THE ROYAL SOCIETY

Thank you!

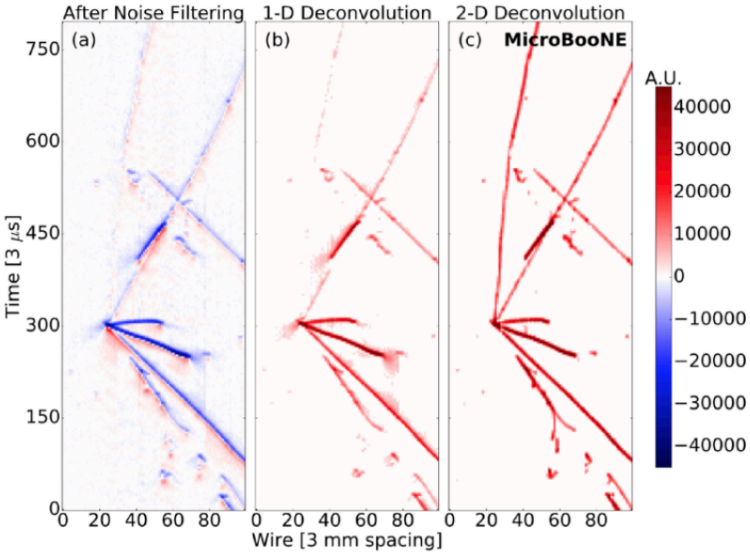
Field and Electronic Response Correction

JINST 13, P07006 & P07007 (2018)

- Pioneered simulation of dynamic-induced current (DIC) in a LArTPC and improves data-Monte Carlo (MC) agreement.
- Developed novel techniques for noise filtering and signal processing
- Full implementation of 2D deconvolution of wire signals improves reconstruction performance and detector calibration.

Time deconvolution

Time & Wire deconvolution



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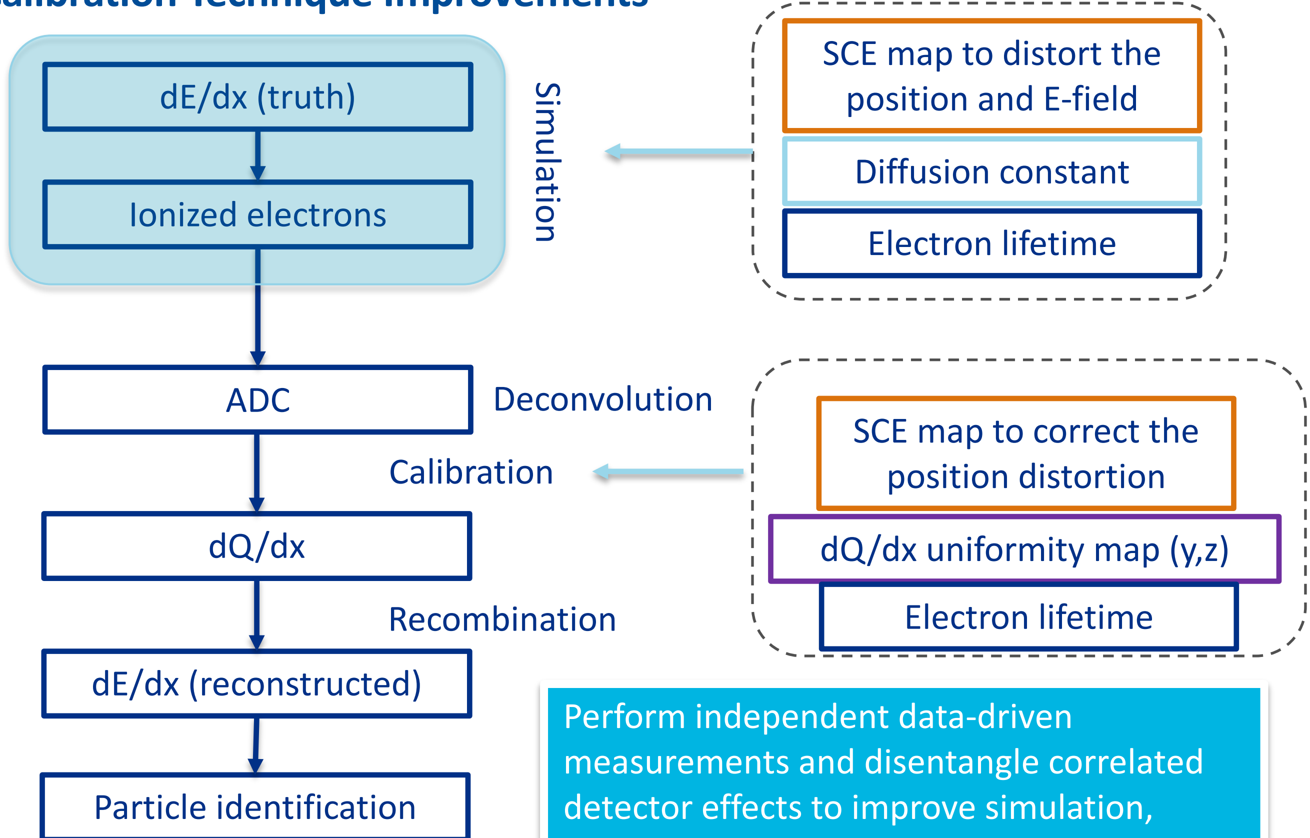
Effective Recombination

	values from ref. [13] [28]	new value
modified box model α	(0.93 ± 0.02)	(0.92 ± 0.02)
modified box model β' (kV/cm)(g/cm^2)/MeV	(0.212 ± 0.002)	(0.184 ± 0.002)
Birks' law A_B	(0.800 ± 0.003)	(0.816 ± 0.012)
Birks' law k (kV/cm)(g/cm^2)/MeV	(0.0486 ± 0.0006)	(0.045 ± 0.001)

Calibration Technique Improvements



Perform independent data-driven measurements and disentangle correlated detector effects to improve simulation, calibration, and systematics uncertainties!