Electron attenuation measurement using cosmic ray muons at the MicroBooNE LArTPC

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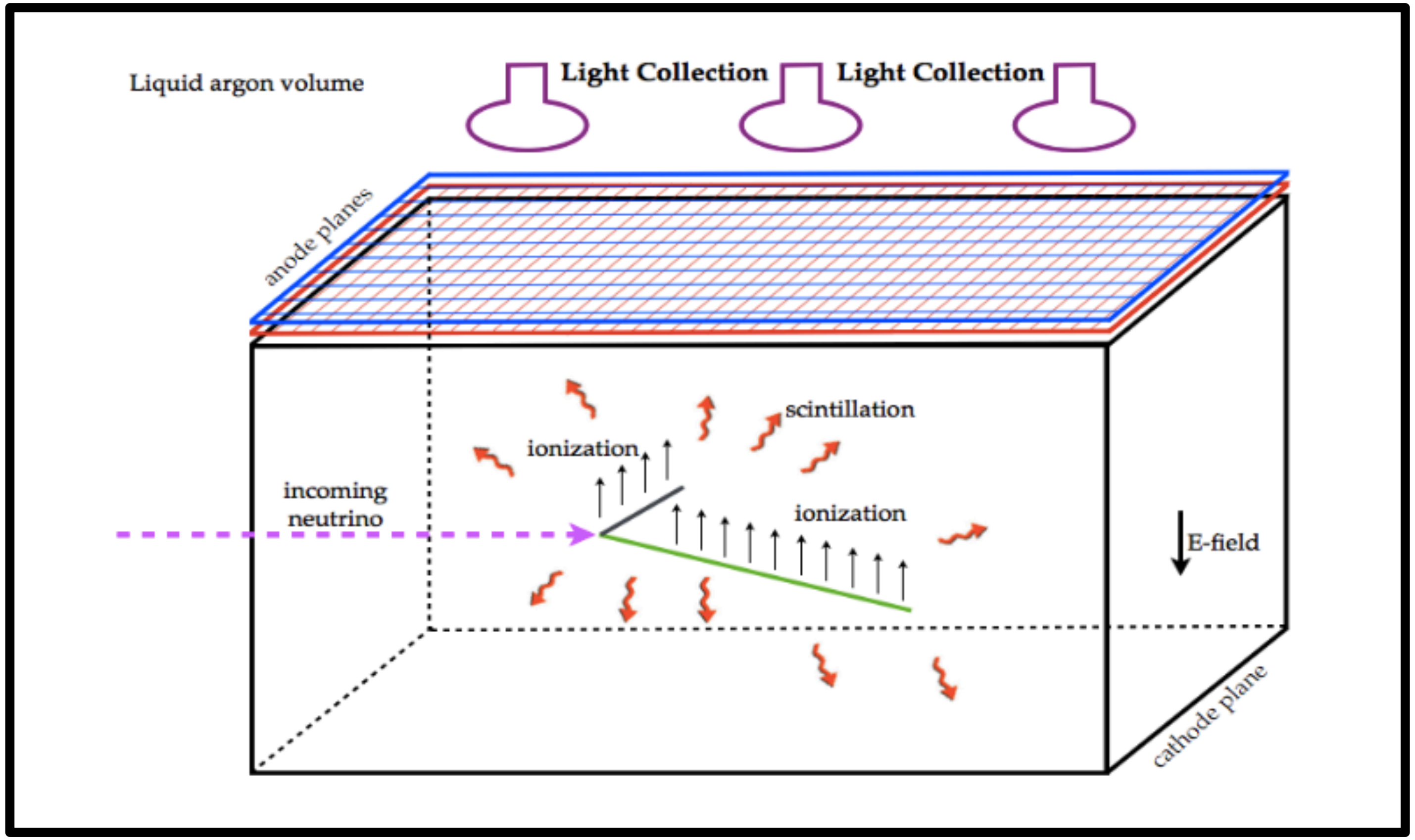
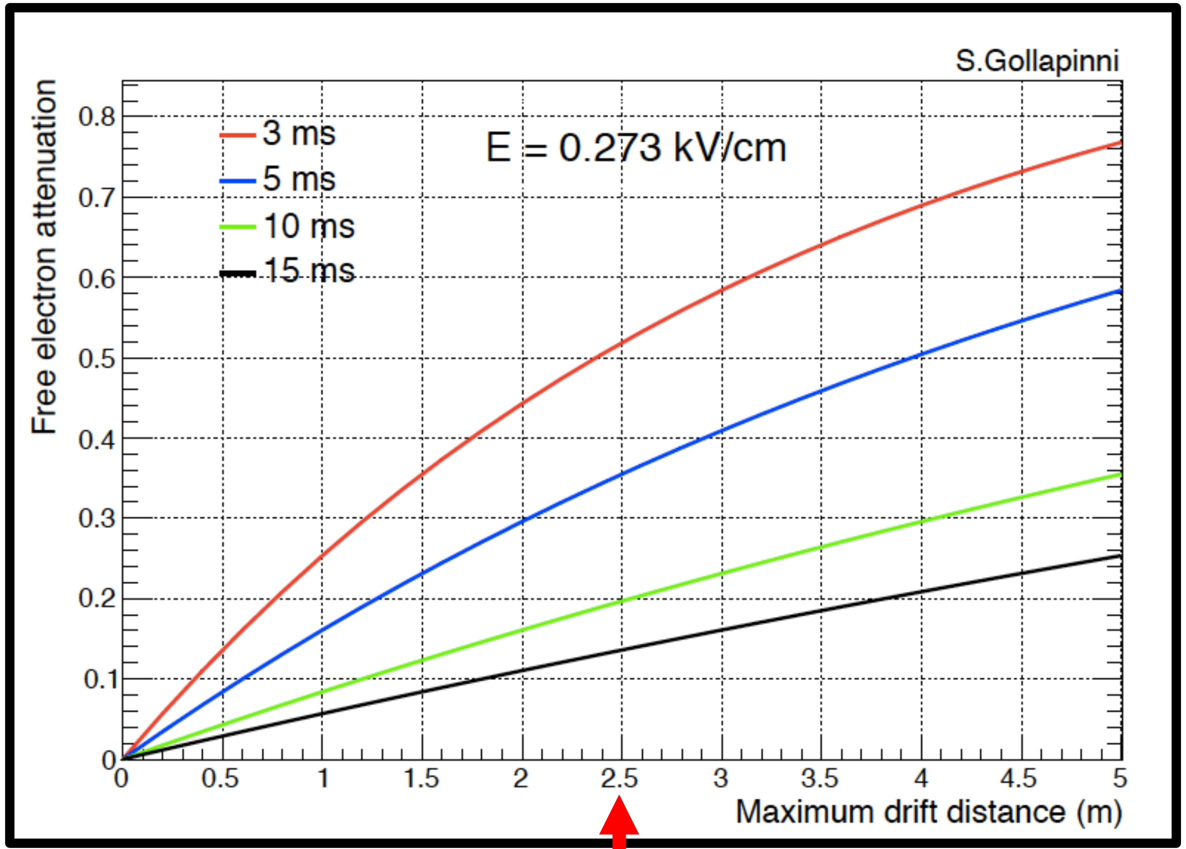
LArTPC Technology



- Stands for **Liquid Argon Time Projection Chamber** technology
- Neutrino interactions with liquid Ar produces secondary charged particles
- Interaction of secondary charged particles with liquid Ar cause both ionization and scintillation light
- Scintillation light is captured by the PMTs while ionization electrons drift to the anode plane under an electric field.
- Information collected by both PMTs and anode plane wires are combined to reconstruct particle tracks and energy

LArTPC technology offers exceptional calorimetric and positional resolution capabilities to study neutrino interactions with Ar

Liquid argon Purity



MicroBooNE drift time is ~ 2 ms

- Electro negative contaminants (O2 and H2O) can capture ionization electrons

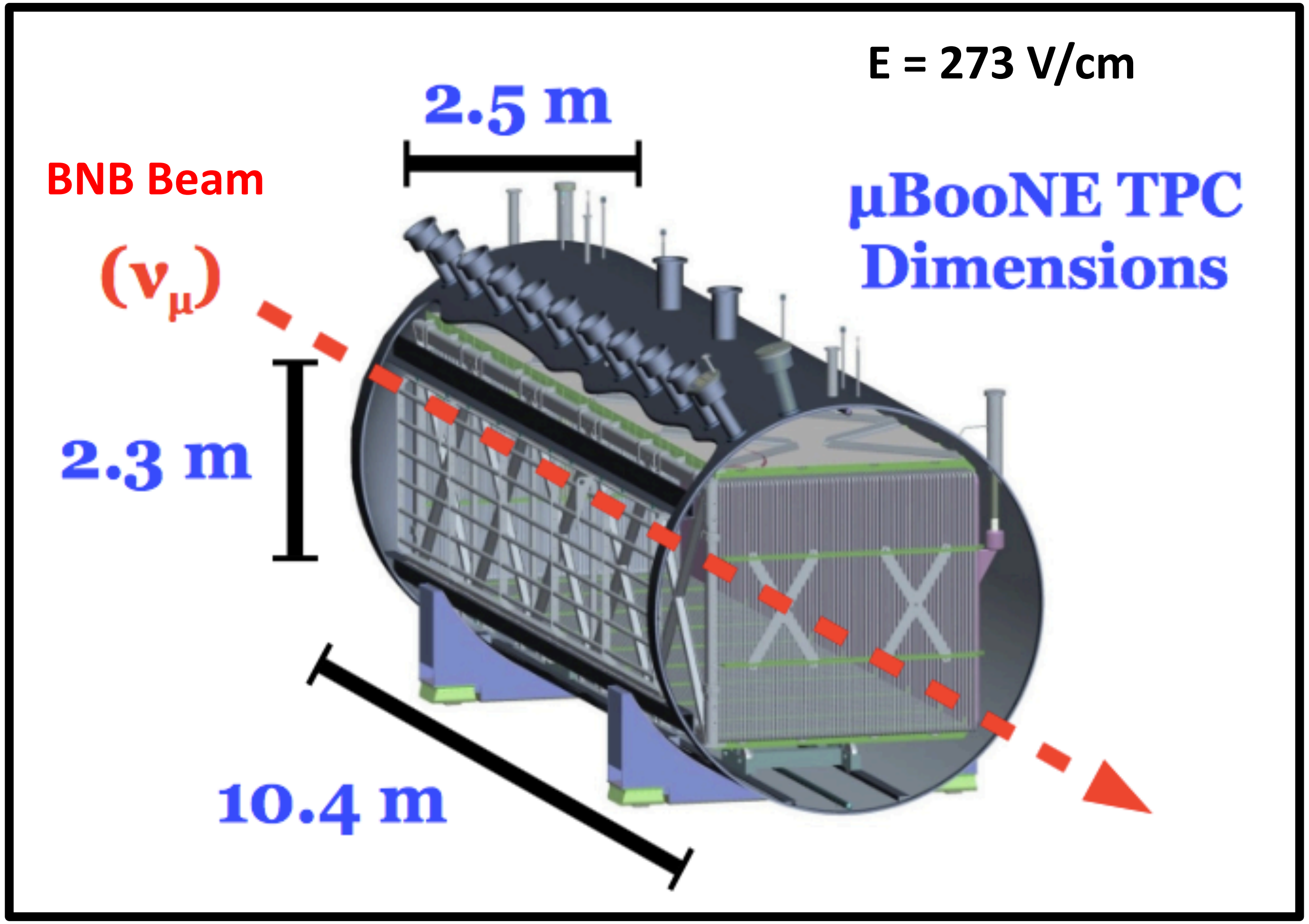
$$\frac{N_e(t_{drift})}{N_e(t_0)} = e^{\left(\frac{-t_{drift}}{\tau}\right)}$$

Electron attenuation

Electron life time

- Electron lifetime is inversely proportional to the level of contaminants (**High electron lifetime -> High Purity**)
- Having a higher electron life time is crucial for the better performance of the detector
- Measuring lifetime is the first step towards energy calibration of the detector and calorimetric reconstruction
- MicroBooNE design goal includes 3 ms lifetime (@ 500 V/cm)
  - Keeping O_2 equivalent contaminants below 100 ppt

MicroBooNE detector

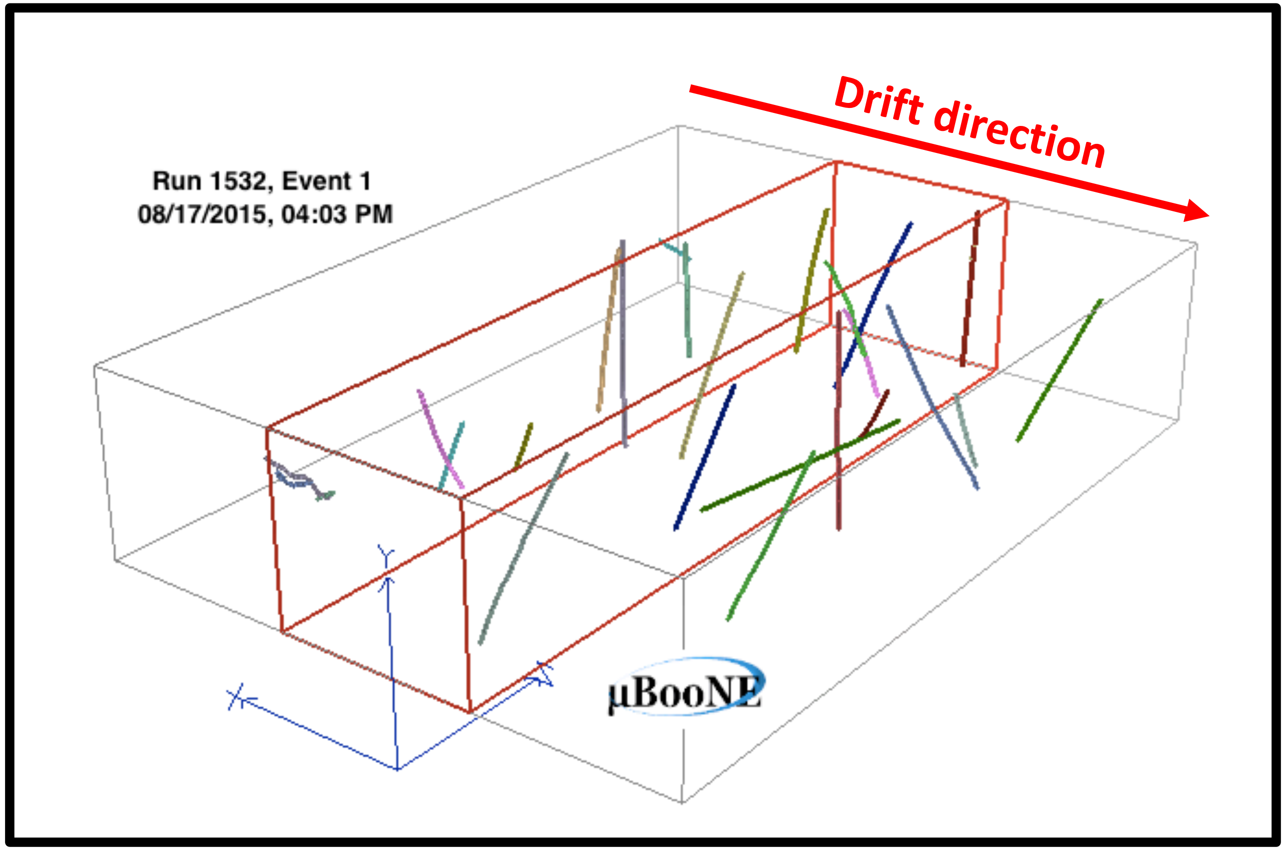


- MicroBooNE is a Liquid Argon Time Projection Chamber (LArTPC) experiment located at Fermilab on the Booster Neutrino Beamline
- Main goals
  - Addressing MiniBooNE low energy excess
  - Neutrino-Argon cross sections
- Collecting data since October 2015
- All the findings and lessons learned will greatly benefit future LArTPC detectors (SBN,DUNE)

MicroBooNE TPC has a active mass of 85 tons of liquid Ar

Measuring Purity in MicroBooNE

- There are 4 ways one can measure the purity
  - Purity monitor : More localized measurement
  - Laser tracks
  - Externally tagged muon tracks
  - TPC crossing cosmic muon tracks : Normal TPC tracks,crossing the whole drift distance



Event display figure of a cosmic muon

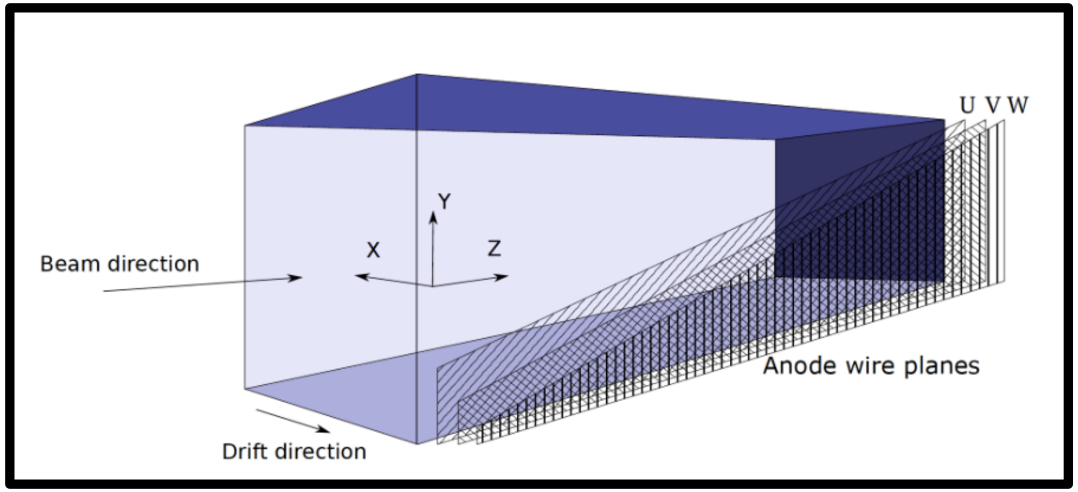
In this talk we are only presenting measurement from TPC crossing cosmic muon tracks

Why TPC crossing muon tracks ?

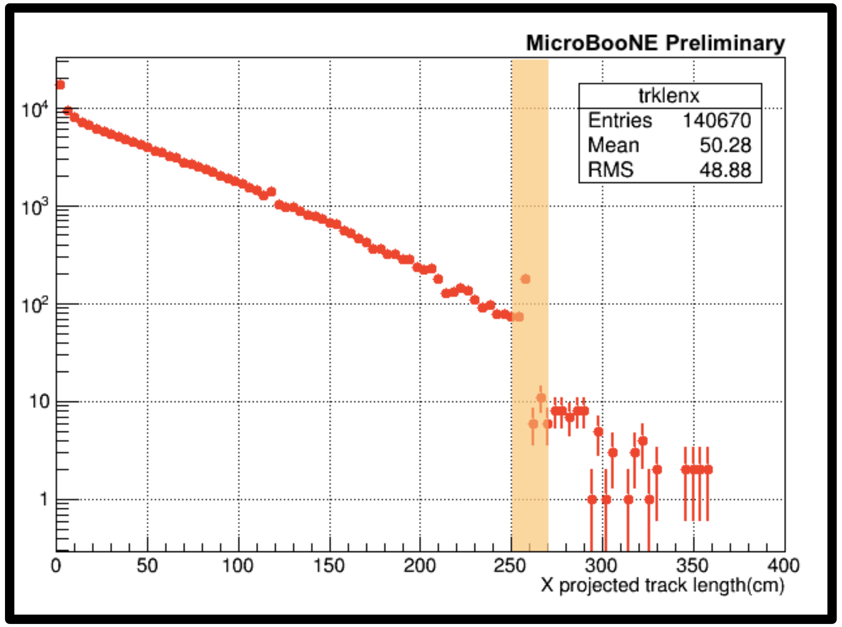
- As MicroBooNE is a surface detector, is an abundant source of cosmic muons
- Start time (t_0) of the track can be accurately determined
  - Cosmic muons can occur at any time in the readout window
  - For TPC crossing muons minimum drift coordinate provides the t_0
- Has a wider angular coverage compared with tracks tagged by external **Muon counter system** (MuCS)
- Crossing tracks uniformly represents the whole drift length
- Uniform distribution of tracks over the TPC helps to find an appropriate life time value while being sensitive to purity variations across the detector

Event Selection

- TPC crossing tracks are isolated
  - **250 cm** < Track length projected in X < **270 cm**
  - In a 5000 event sample, roughly **2%** are crossing tracks
- Angular cuts
  - Get rid of tracks which are either perpendicular or parallel to collection wire plane
- Each track needs to have at least 100 hits in the collection plane (**W**)
- Avoid overlapping shorted channels
  - Some regions of the anode planes, wire responses are modified due to shorted wires



MicroBooNE coordinate system defining different planes



Presence of crossing tracks in data

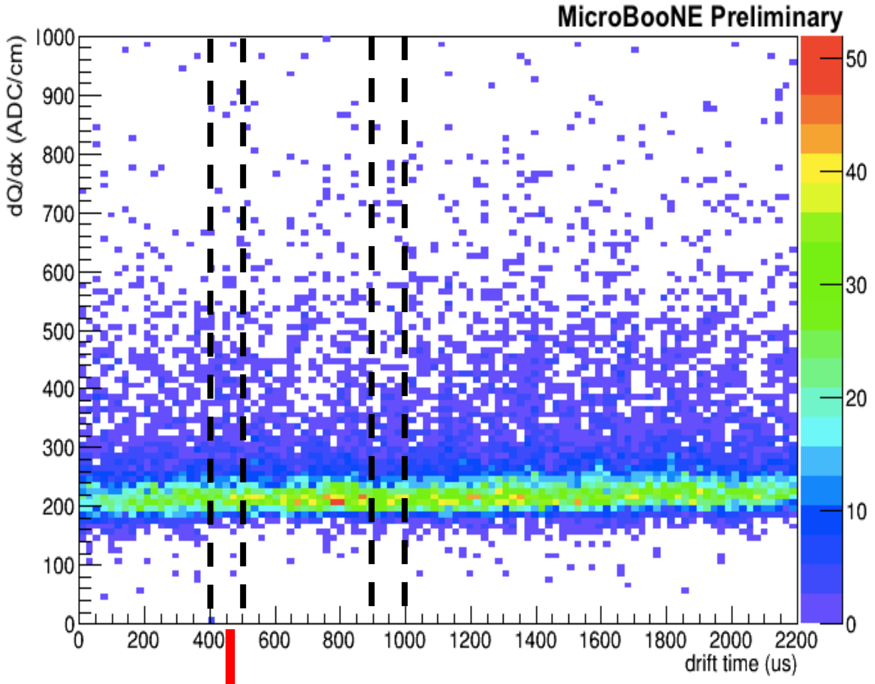
Method

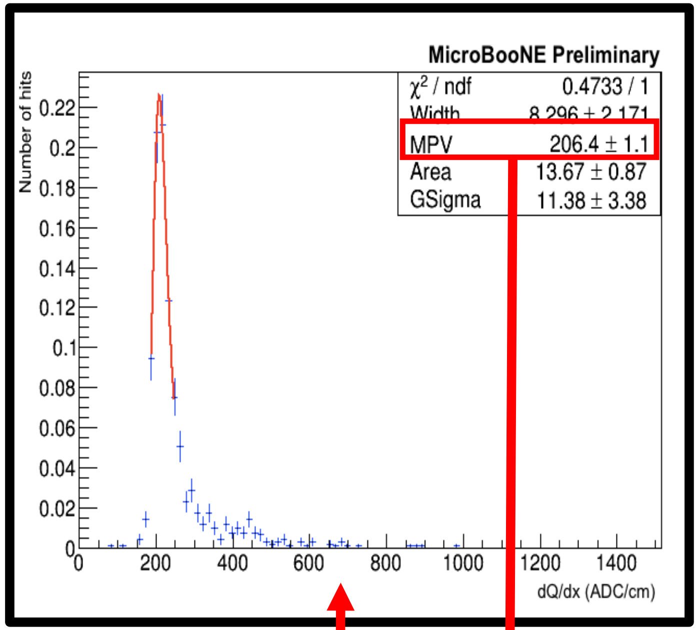
- Divide full drift window (**2200 μs**) into 22 smaller bins (**100 μs**)
  - Fit Landau convolved Gaussian function and get the Most Probable Value (MPV)
- Fit function **f(t)** is fitted to the final distribution to get the charge ratio (Q_A/Q_C)
  - f(t) typically is Exponential, Exponential + Constant or Polynomial of order 2

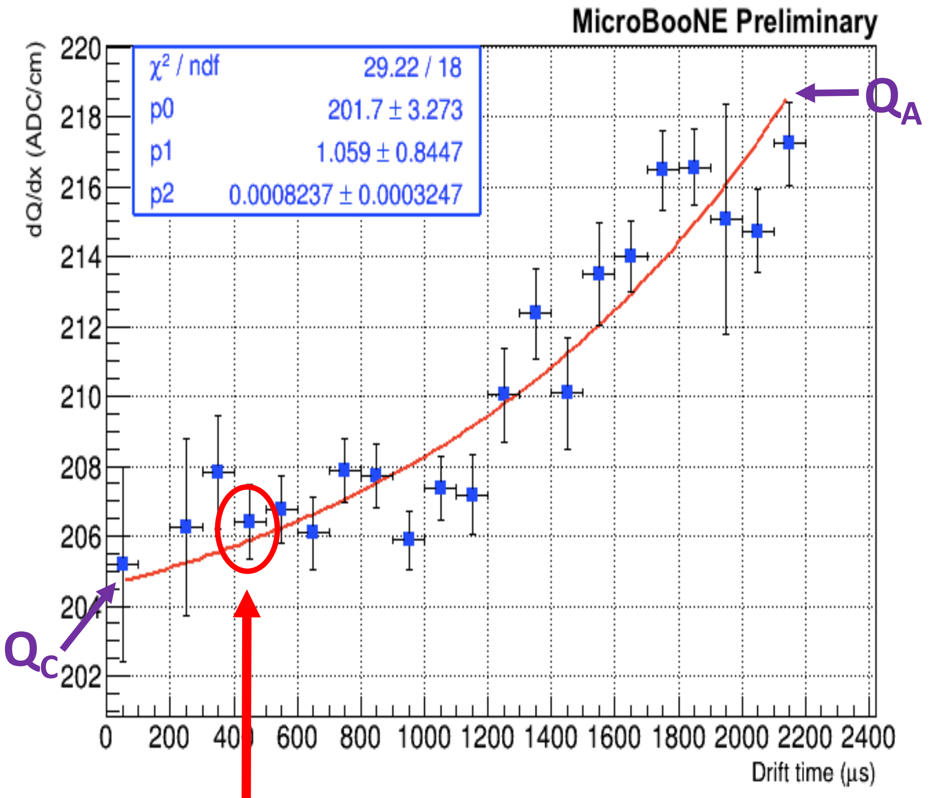
Charge arriving Anode after 2200 μs

$$\frac{Q_A}{Q_C} = \frac{f(t=2200\ \mu s)}{f(t=0\ \mu s)}$$

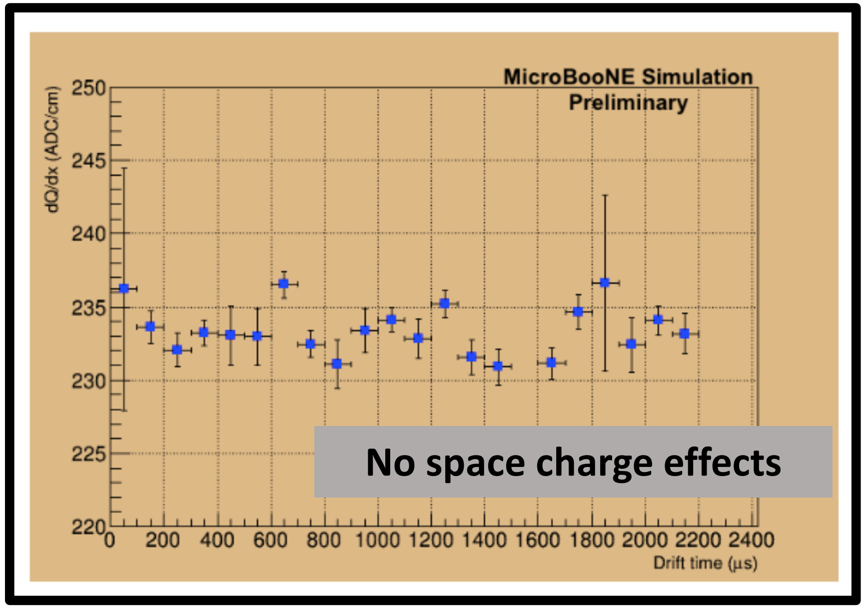
Charge leaving cathode

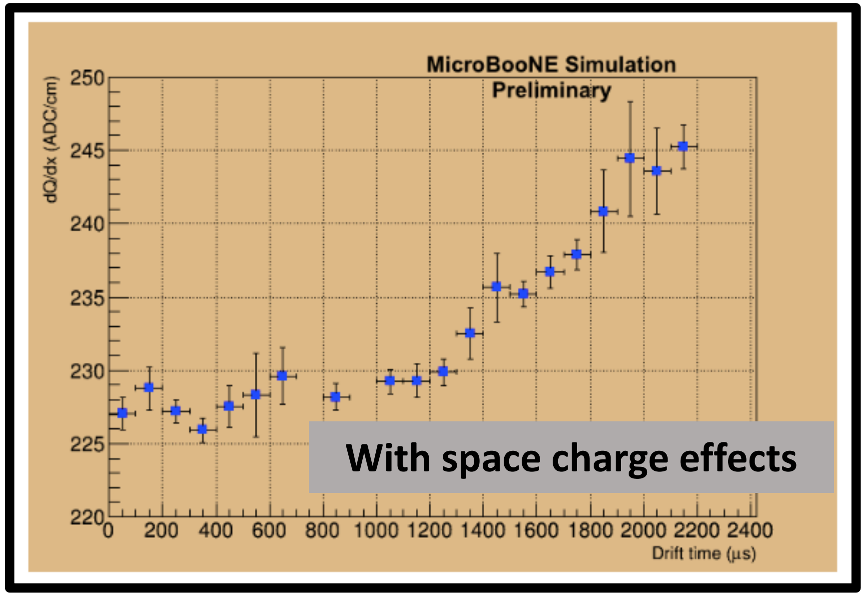






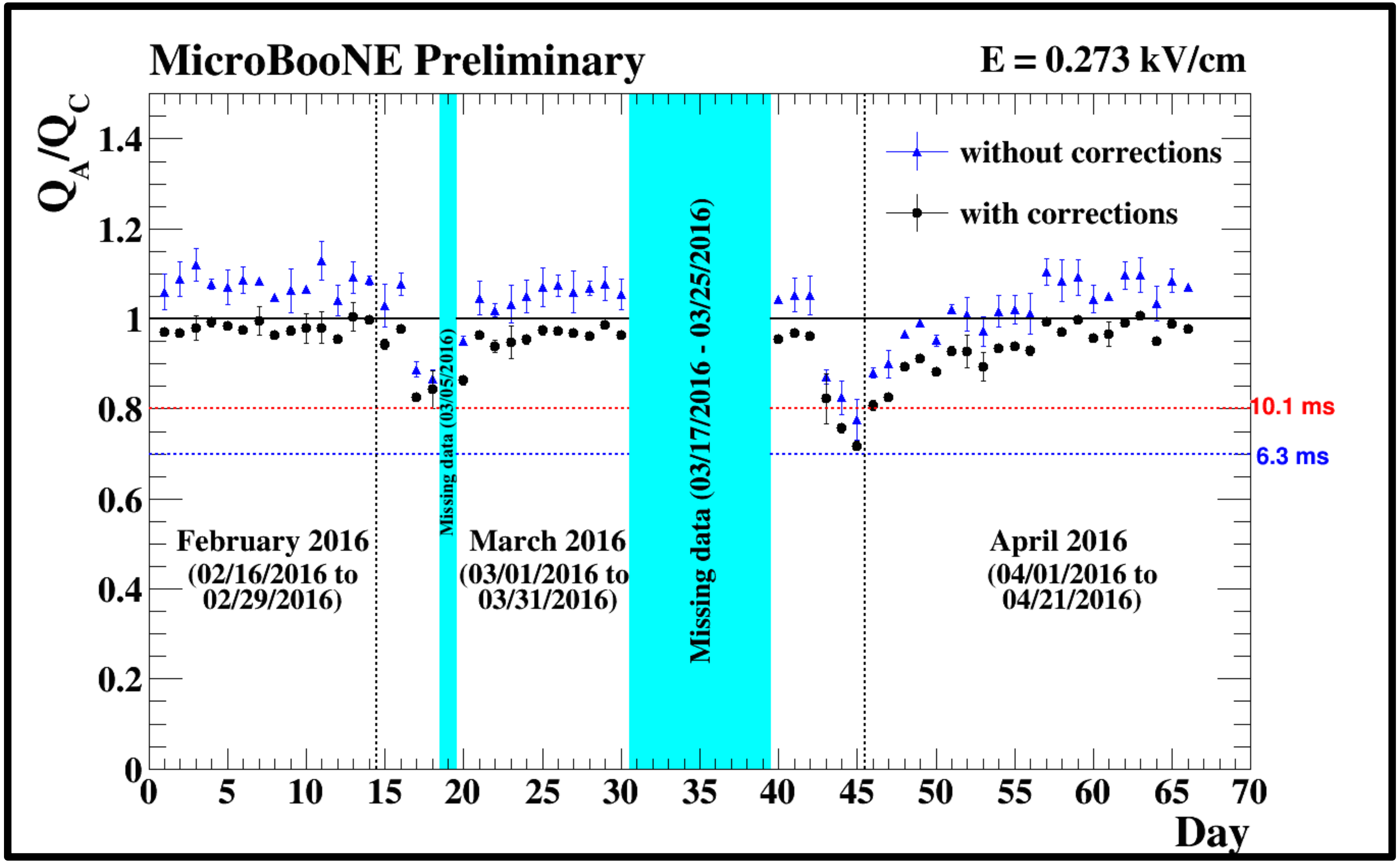
Space charge effects





- Build up of slow moving positive argon ions inside the TPC
- Distorts the **magnitude** of the electric field inside the TPC
  - Impacts electron-ion recombination (suppressed at higher electric fields)
  - At Cathode **12%** increase in the Electric field -> **3.55%** increase in the dQ/dx value
  - At Anode **5%** decrease in the Electric field -> **1.2%** decrease in the dQ/dx value
- Distorts the **directionality** of the electric field inside the TPC
  - Impacts trajectories of ionization electrons
  - Around **5 cm** distortion in drift direction and **12 cm–15 cm** distortions in non-drift directions
  - Can affect the dQ/dx values (Ex : Tracks crossing the wire planes at **45^0** will see about **8%** change in the dQ/dx values)
- Leads to **$Q_A/Q_C > 1$**
  - Expectation is **$Q_A/Q_C < 1$**
  - Introduced a correction for **Space charge effects**

Q_A/Q_C variation after space charge correction



Variation of Q_A/Q_C over time after correcting for space charge effects (statistical errors only)

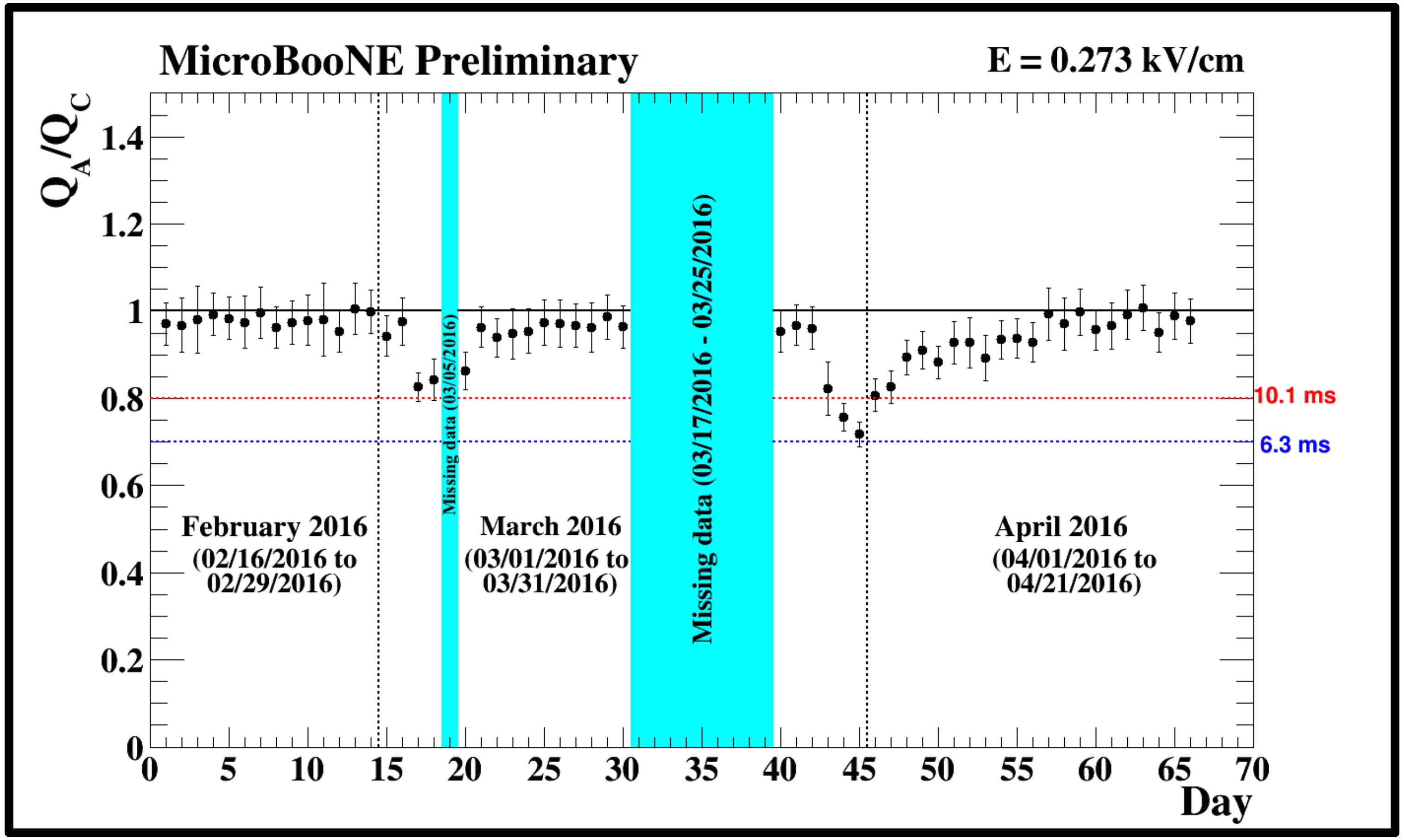
Most of the unexpected Q_A/Q_C behavior goes away with the introduction of space charge correction

Systematics for the analysis

Systematic Name	Method of systematic extracted	Value of the systematic (% of final QA/QC)
Space charge correction	**50%** of the difference of Q_A/Q_C before and after correction	**5.0**
Recombination model	Percentage difference of Q_A/Q_C values for MC samples with default and modified recombination parameters	**1.0**
Diffusion	Percentage difference of Q_A/Q_C values for MC samples with and without diffusion	**2.0**

Final systematic by adding up all systematics in quadrature is 5.5% of final Q_A /Q_C

Results



Variation of Q_A/Q_C over time with all systematic and statistical uncertainties

- Under stable purity conditions (except 2 dips) Q_A/Q_C is very high ranging between **0.88 +/- 0.04** to **1.01 +/- 0.06**
- The lower bound during stable purity conditions corresponds to **18 ms** electron life time and O_2 equivalent contamination **16 ppt**
- The lowest of the Q_A/Q_C value (~**0.72**) in the distribution corresponds to **6.8 ms** electron life time with O_2 equivalent contamination of **44 ppt**

Conclusions

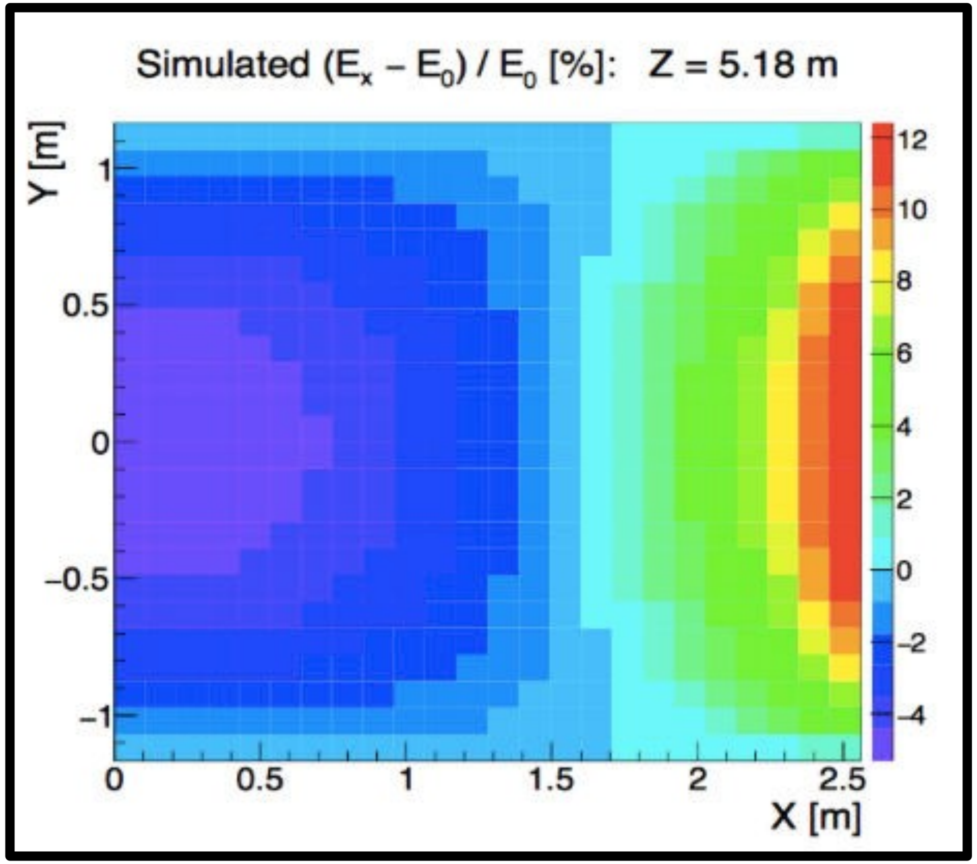
- Made an electron attenuation measurement for MicroBooNE experiment using TPC crossing muon tracks by analyzing 3 months of data (02/16/2016 – 04/21/2016)

- Lowest **Q_A/Q_C** value recorded is **0.88 +/- 0.04** with a corresponding electron lifetime of **18 ms** under stable purity conditions

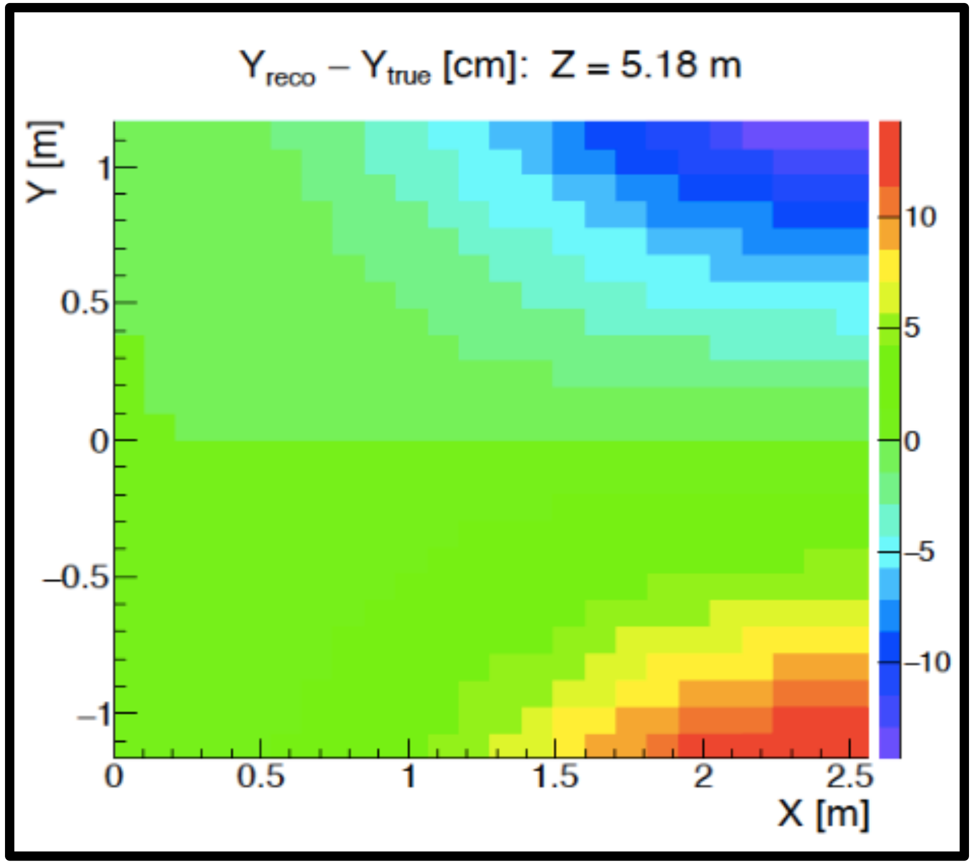
- Measured electron lifetime is better than the initial requirement of **3 ms** (@ 500 V/cm electric field)

Back up Slides

Space Charge Effects



Electric field distortion in central Z region

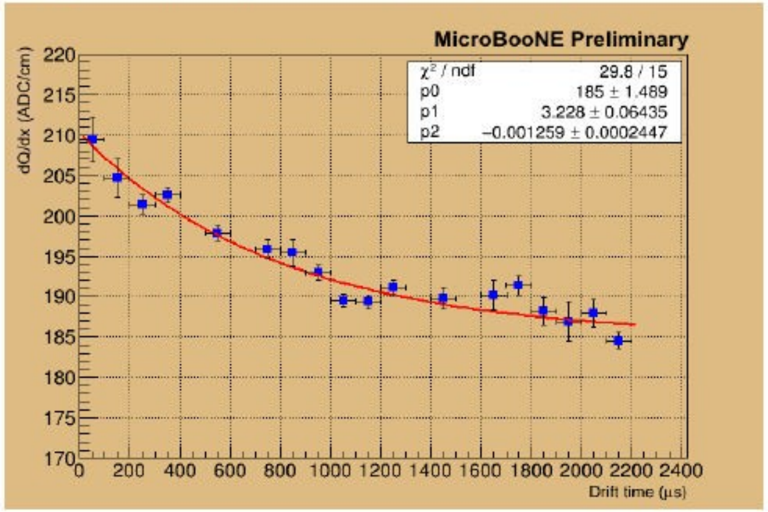


Spatial distortion in central Z region

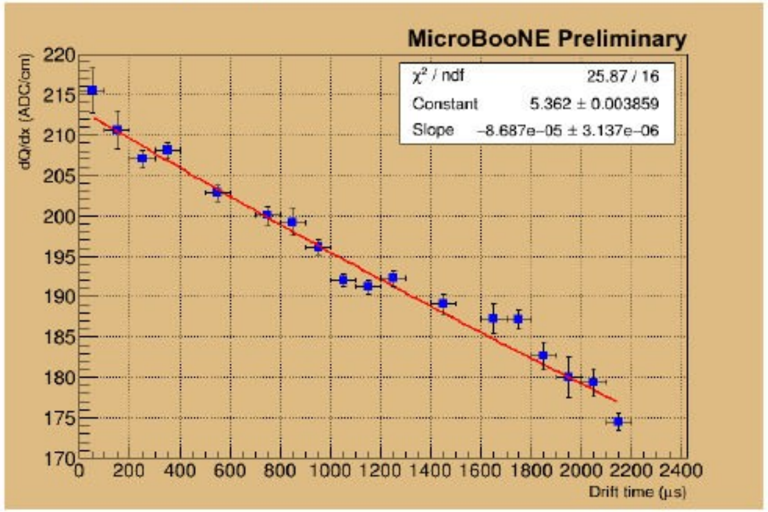
Before and after space charge correction

BEFORE

AFTER



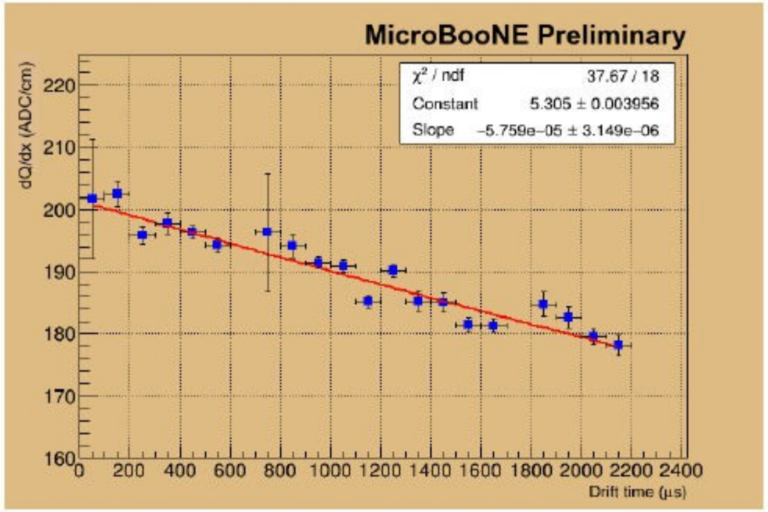
(i) 03/03/2016, day 17 (before)



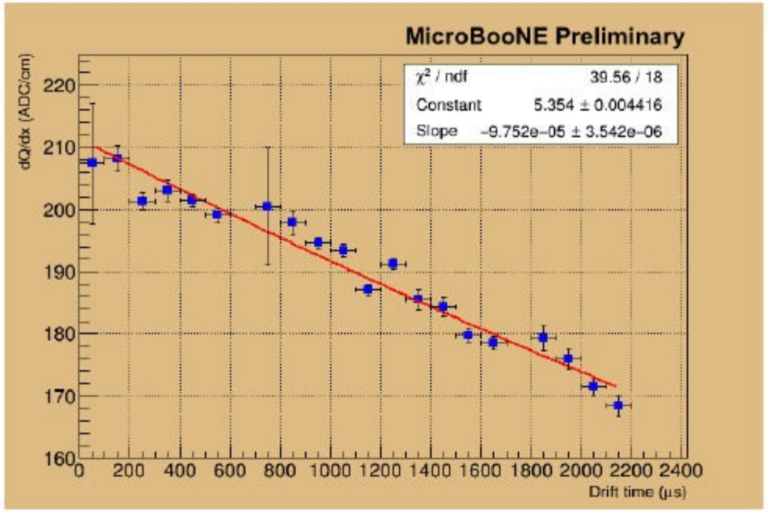
(j) 03/03/2016, day 17 (after)

Low Purity Data

Note: attenuation curve goes to exponential shape for low purity runs after space charge corrections



(k) 04/01/2016, day 36 (before)

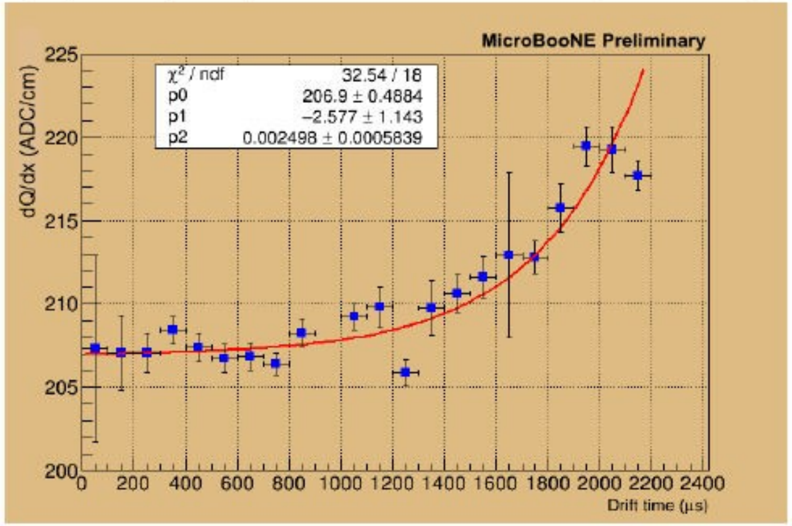


(l) 04/01/2016, day 36 (after)

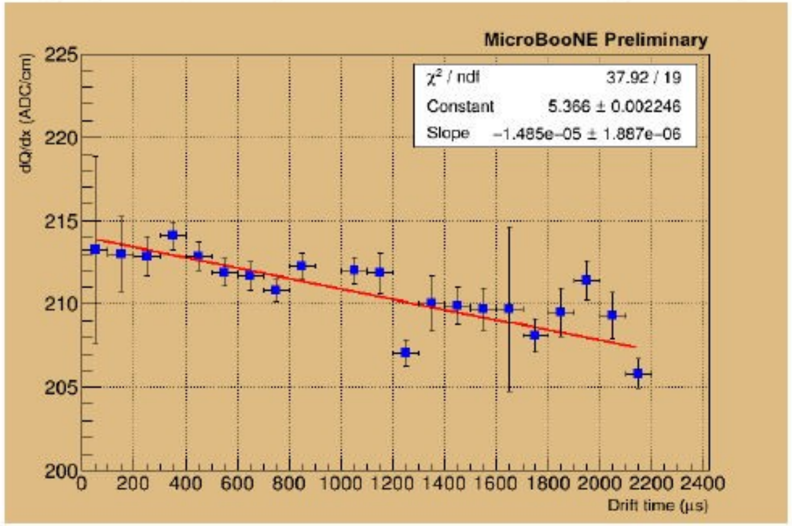
Before and after space charge correction

BEFORE

AFTER



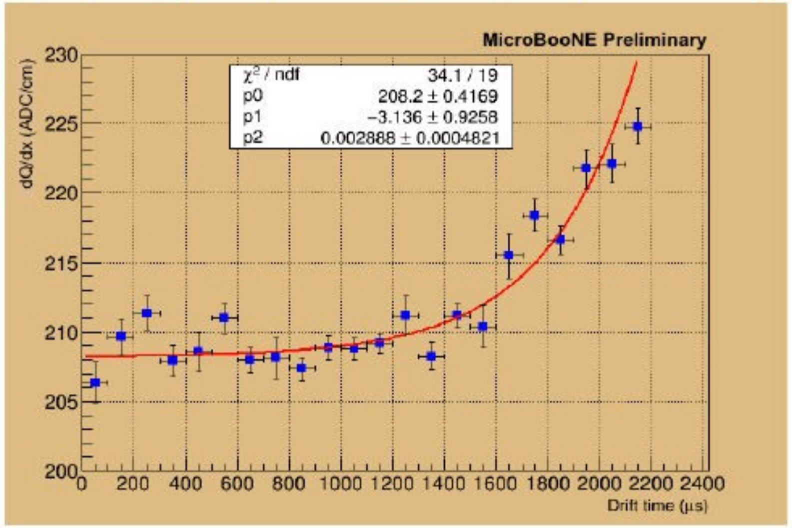
(c) 02/17/2016, day 2(before)

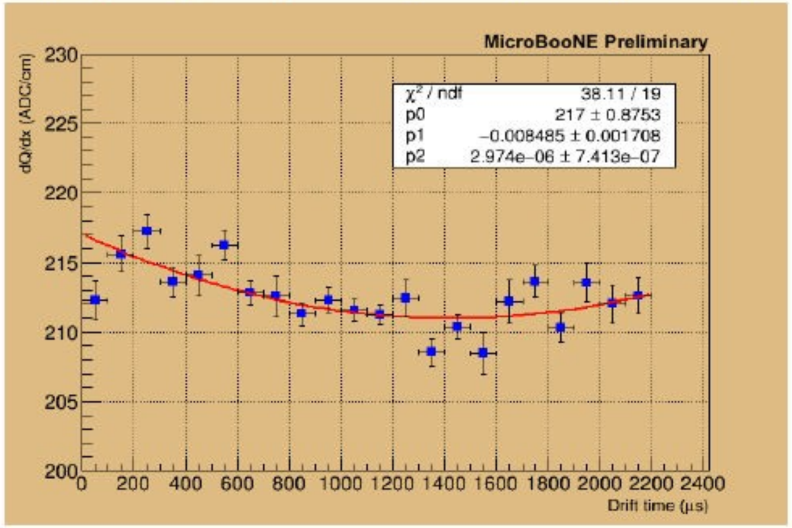


(d) 02/17/2016, day 2 (after)

High Purity Data

Note: attenuation curve shows falling slope after correction





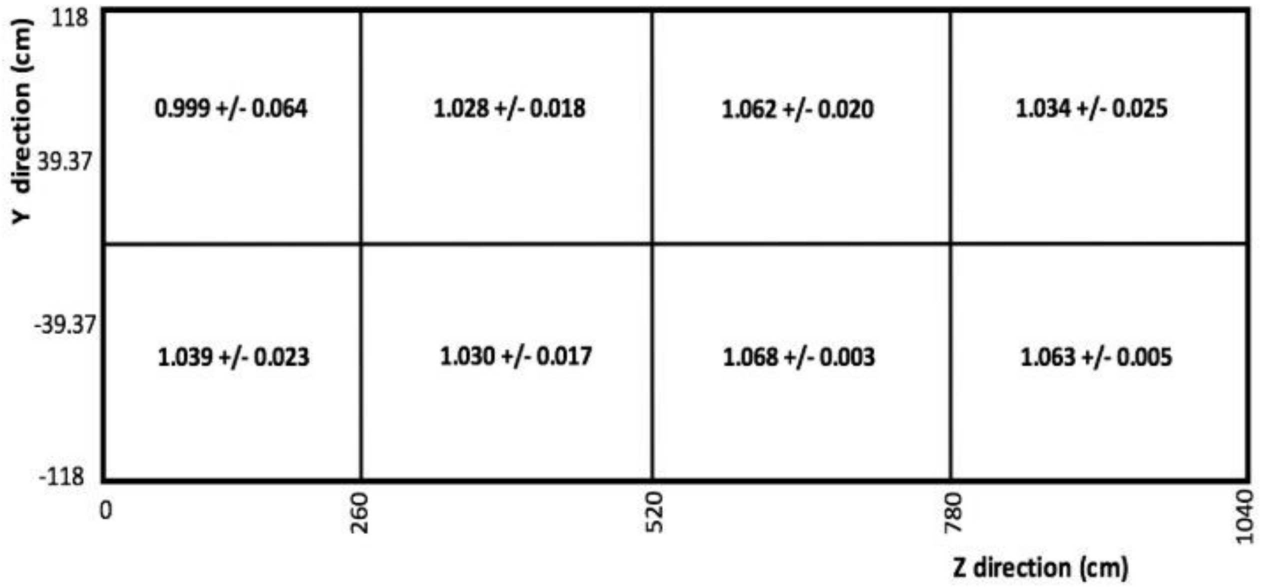
Detector Systematics

Locational dependence of Q_A/Q_C

- Due to the nature of the purification system electro negative contaminants are not distributed uniformly and space charge effects are location dependent

- To see the locational dependence, detector was segmented in to 8 equally sized segments and Q_A/Q_C values are extracted using data for different regions

- Effect is negligible to contribute for systematics



Location dependence of Q_A/Q_C

Detector Systematics

Landau convoluted Gaussian fitting systematic

- Fitting parameters of the Landau distribution are varied
- Observe the effect on final Q_A/Q_C value using data
- Compare with default setting of the parameter
- Negligible effect

Landau convoluted Gaussian fitting systematic

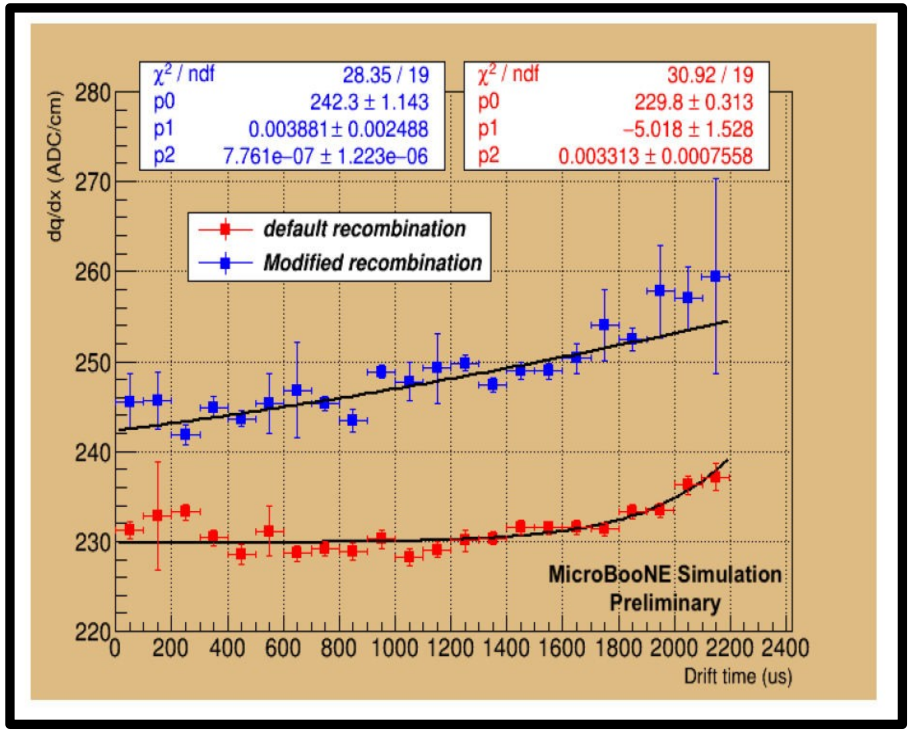
- Dynamic induced charges – Induction of a signal in nearby wires from target wire
- Non uniformity of shaping time of electronics over the detector – varies by 2.5 % over the detector
- Both are considered second order effects

Recombination Systematics

- Liberated electrons get recombined with positive argon ions
- Electric field dependent effect (**high electric field -> low recombination**)
- Modified box model is implemented in simulation stages

$$R_{box} = \frac{\ln\left(\alpha + \frac{\beta_p}{\rho\varepsilon} \cdot \frac{dE}{dx}\right)}{\frac{\beta_p}{\rho\varepsilon} \cdot \frac{dE}{dx}}$$

Recombination constant **Liquid argon density** **Electric field**

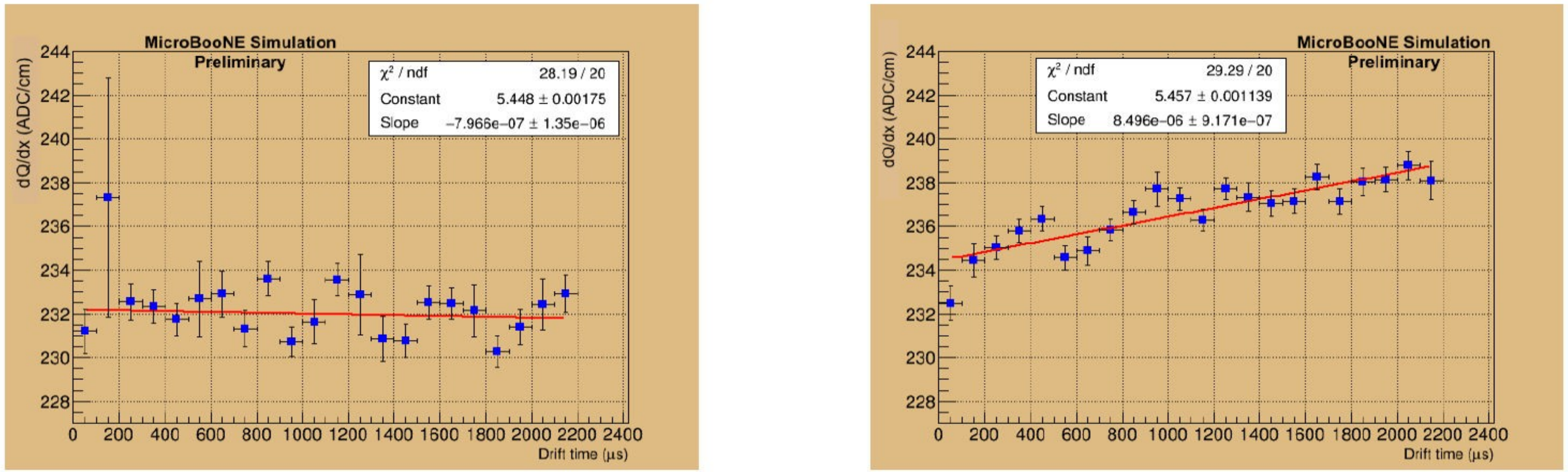


dQ/dx distributions for different recombination configurations

- Values β_p(0.212 +/- 0.002) and α (0.93 +/- 0.02)are coming from the **Argoneut** experiment,operated at **481 V/cm** electric field (JINST Vol. 8, P08005,2013)
- Create two MC samples one having default β_p and α (**Argoneut** values) while in the other sample these values are maximally changed by **0.01** and **0.1** respectively
- Use the final percentage difference of Q_A/Q_C ratios of both samples to calculate the systematic

Diffusion Systematics

- Ionization electron cloud gets smeared out as it drifts to the Anode
- consists of two components
  - Longitudinal diffusion
  - Transverse diffusion
- Create two MC samples one having both diffusion components **OFF** while other having both components **ON**
- Use the final percentage difference of Q_A/Q_C ratios of both samples to calculate the systematic



dQ/dx distributions for different diffusion configuration samples