Thoughts on TPC Calibration for DUNE

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Dec 14, 2017

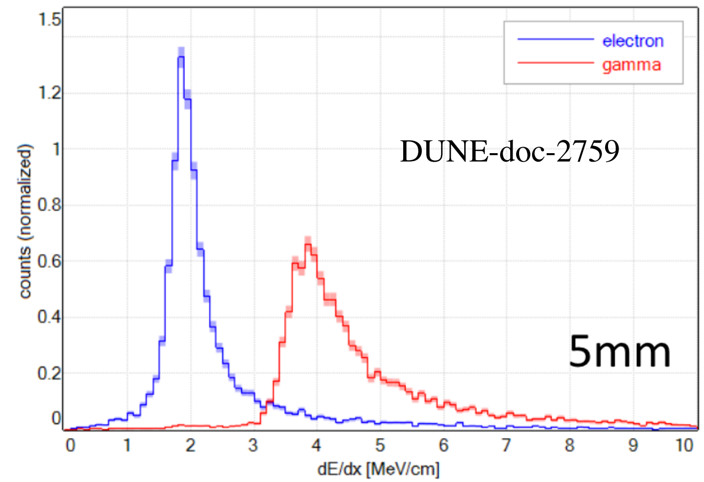
DUNE Calibration TF Meeting

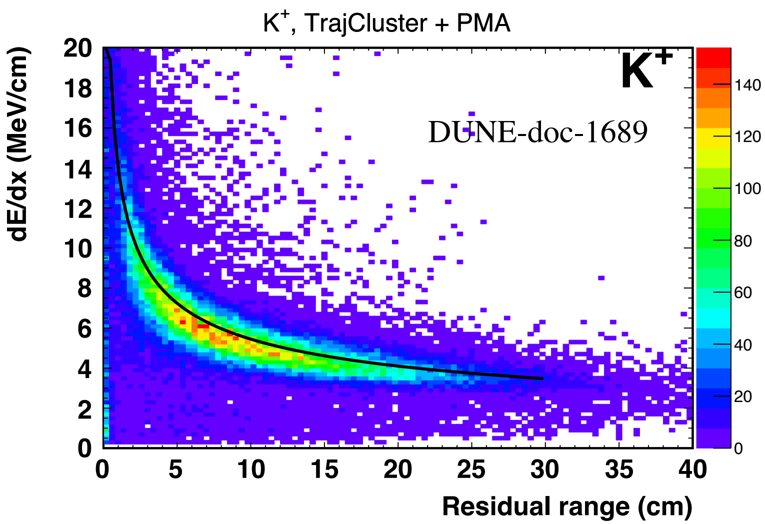
Introduction

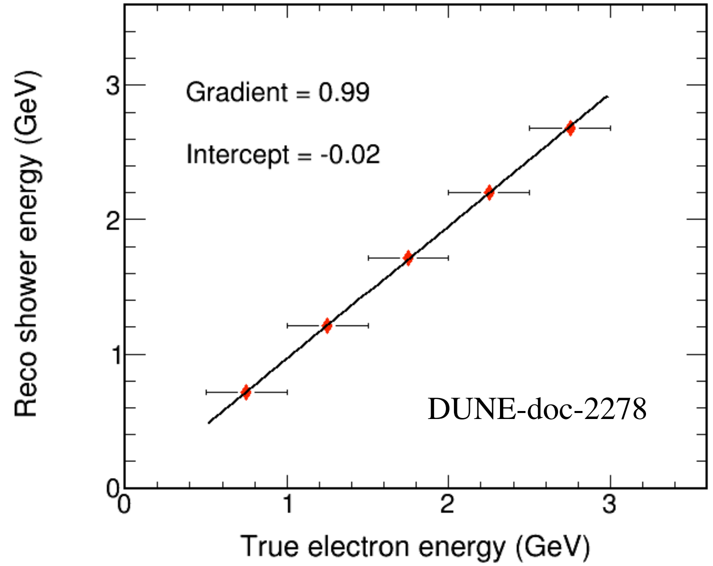
- Some thoughts on TPC calibration
  - Based on my calibration experience on MINOS (thanks to Jeff Hartnell)
  - Also largely based on my work together with Varuna Meddage on MicroBooNE
  - Focus on TPC dE/dx calibration
- Useful data samples
  - Charge injection system
  - Cosmic ray muons
    - 4000 per day per 10 kt module
    - 30 stopping muons per day per 10 kt module
    - Not enough statistics to do calibration per channel or per TPC, should be ok to perform calibration per module
  - Laser system

Physics requirements

- Oscillation analysis
  - Reconstruct dE/dx of the initial segment of the shower for e/γ separation
  - Electron and hadronic energy reconstruction
- Proton decay searches
  - PID based on calorimetry



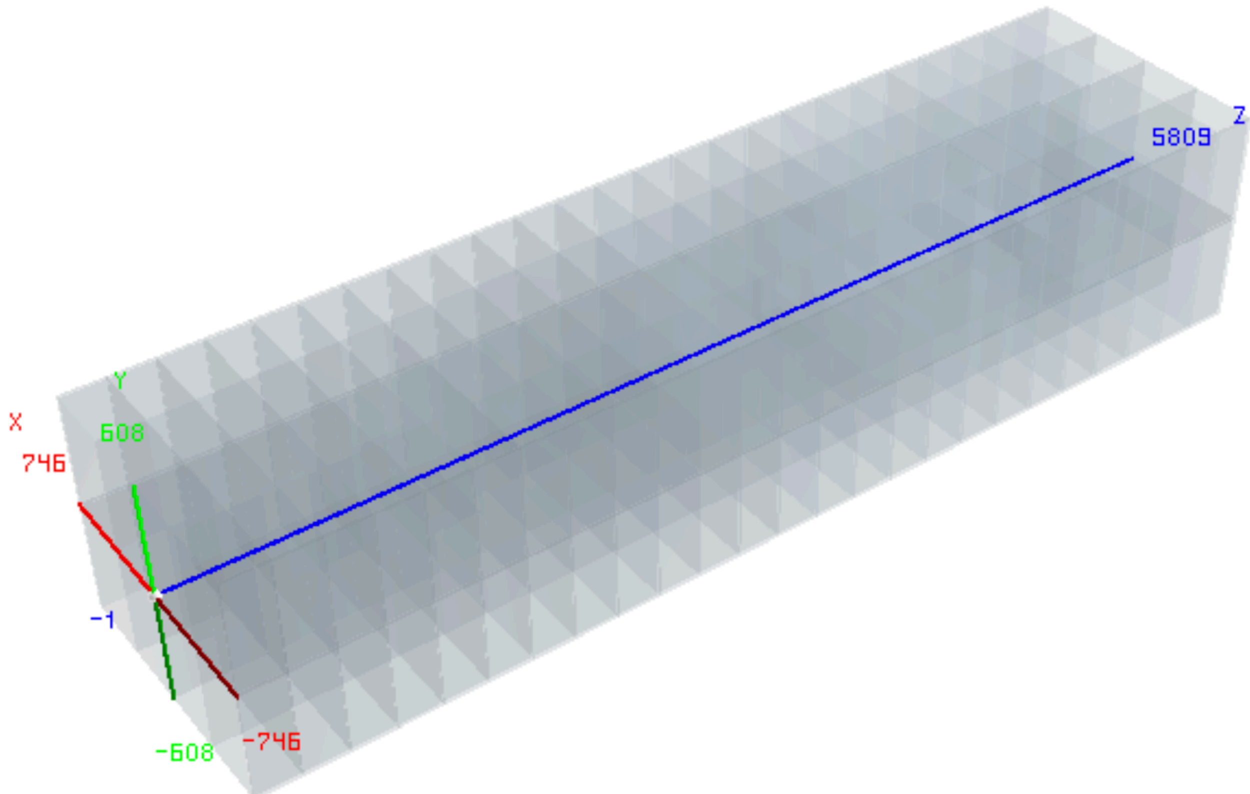




Calibration approach

- Goal: achieve uniform detector response in space and over time and provide reliable energy information for physics analyses
- Two steps
    - Relative calibration
        - Spatial calibration: remove channel-by-channel variation, wire response variation and attenuation caused by impurities
        - Temporal calibration: remove time dependent variations: changes in electron lifetime, drift in electronics gain etc.
    - Absolute calibration
        - Calorimetry constant: convert ADC to the number of electrons
        - Recombination: quenching effects

DUNE FD 10kt module



- x: drift direction
- y: vertical direction (collection wire direction)
- z: beam direction

Channel-by-channel calibration

- Remove gain variations between channels
- Can use charge injection system to measure gain and linearity of each channel
- 1-2% variations based on MicroBooNE experience

Wire response calibration

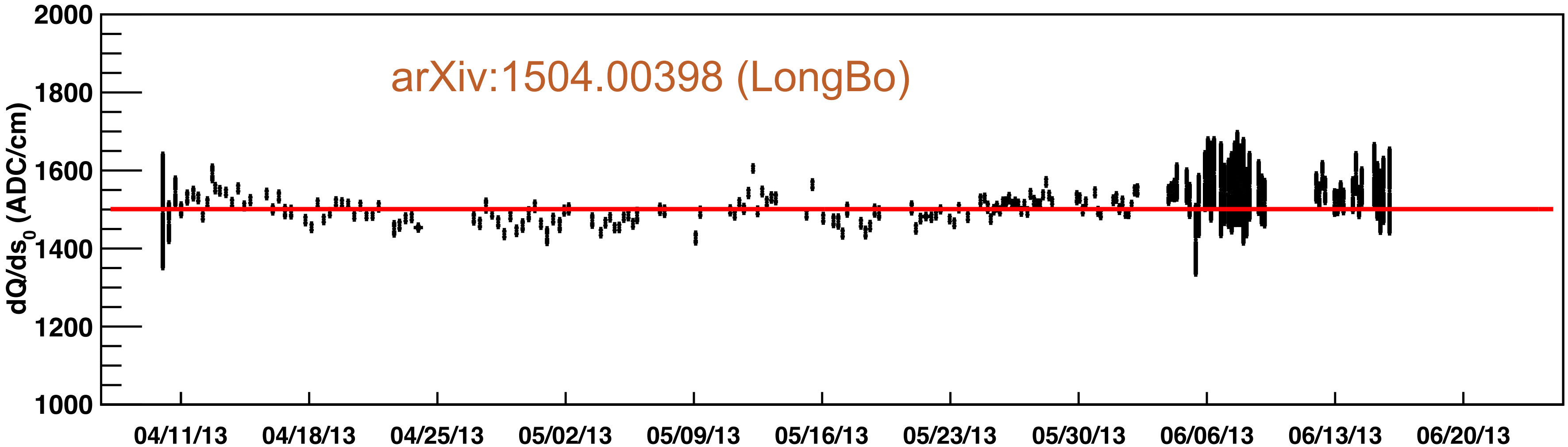
- Non-uniformity in wire response caused by shorted wires or touch wires
- Quite important effect on MicroBooNE: ~20% in some regions
- 2D effect: response changed by wires behind the current plane
- On MicroBooNE we measure and remove this non-uniformity by measuring dQ/dx as a function of y and z using crossing muons
- We do not have enough statistics to carry out this calibration on DUNE using cosmic ray muons.
- It is likely this is not an issue for DUNE or maybe we can design the laser system to scan the TPC to measure the detector response as a function of y and z.

Attenuation calibration

- Aka lifetime correction
- Attenuation along the drift direction caused by impurities in liquid argon
  - Space charge effects are important for surface LArTPCs
- A big effort on MicroBooNE led by Sowjanya:
  - http://microboone.fnal.gov/wp-content/uploads/MICROBOONE-NOTE-1026-PUB.pdf
- Can be measured and corrected for using dQ/dx as a function of x
  - If lifetime is not changing dramatically, we can make this measure once a day
  - Laser system is potentially good for this calibration (arXiv:1304.6961)
  - If there are no variations between TPCs (electric field etc.), we can combine all cosmic ray muons for this calibration

Temporary calibration

- Remove time dependent variations
- After we remove the spatial variations, we can use laser (if the response if well understood) or cosmic ray muons to remove temporary variations

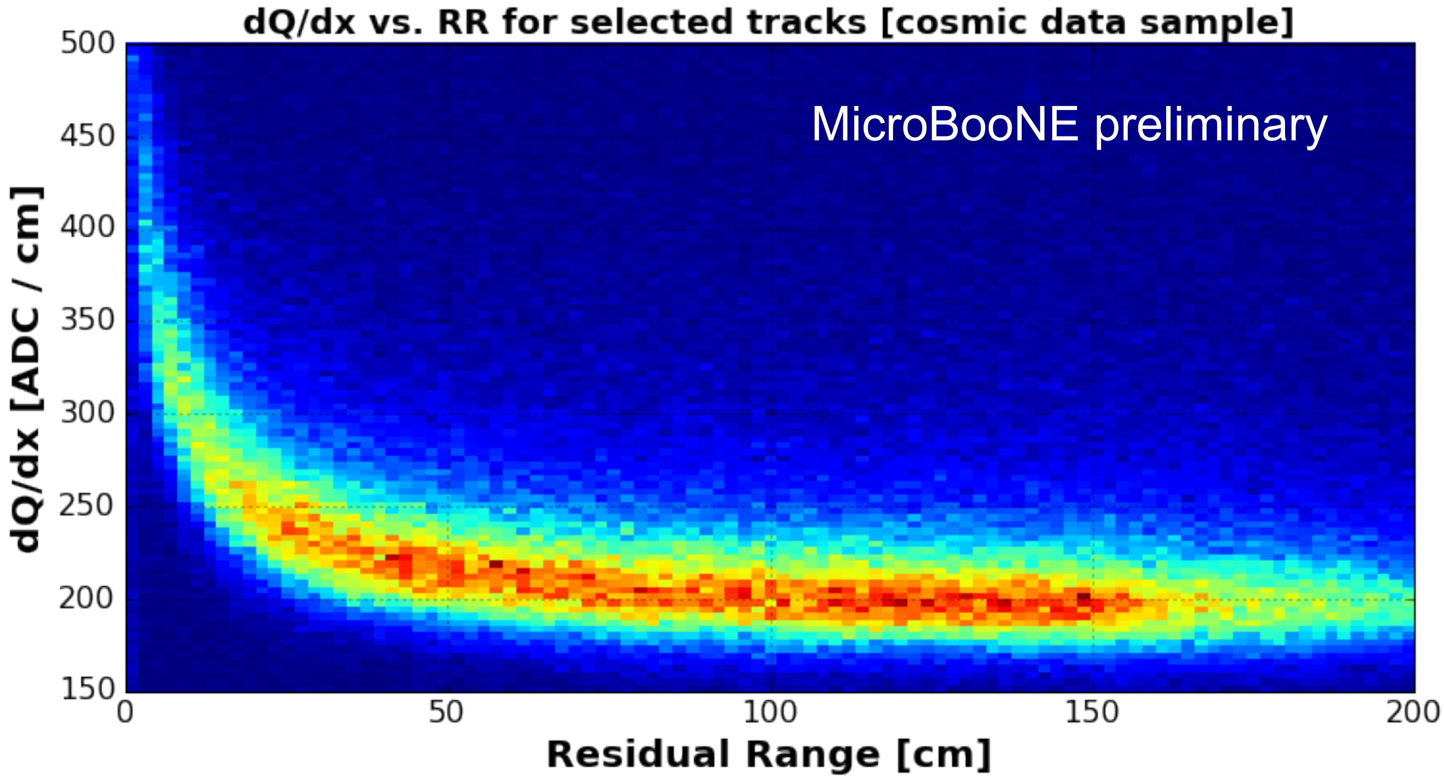


- At this point, the detector response is uniform in space and over time, we can move on to do absolute calibration

Absolute energy calibration

- After we get calibrated dQ/dx, we need to convert it to dE/dx.
- There are two things involved:
  - Calorimetry constants - convert ADC to number of electrons.
  - Recombination effects - measured by ICARUS and ArgoNeuT before
- We can tune the calibration constants (one for each plane) and assume recombination correction is the same as previous measurements so that measured dE/dx matches expectation.
  - Stopping muons are standard handle for this calibration
  - We can combine stopping muons over months to get enough statistics

Stopping muon dQ/dx



- From David Caratelli's thesis

Other issues

- Angular dependence
  - dQ/dx is a function of track angle.
  - Affects proton decay searches more than beam neutrino measurements.
  - Improvements on reconstruction, additional angular dependent corrections
- Calibrate shower energy
  - dE/dx information of shower start is similar to dE/dx reconstruction for tracks
  - To calculate shower energy, we can use an average recombination correction. (ref. DUNE-doc-2278)

Summary

- The goal of dE/dx calibration is to make detector response uniform.
- This can be achieved by using cosmic ray muons and a laser system.