University of Sheffield

Using Stopping Cosmic Muons for Calibrations at DUNE

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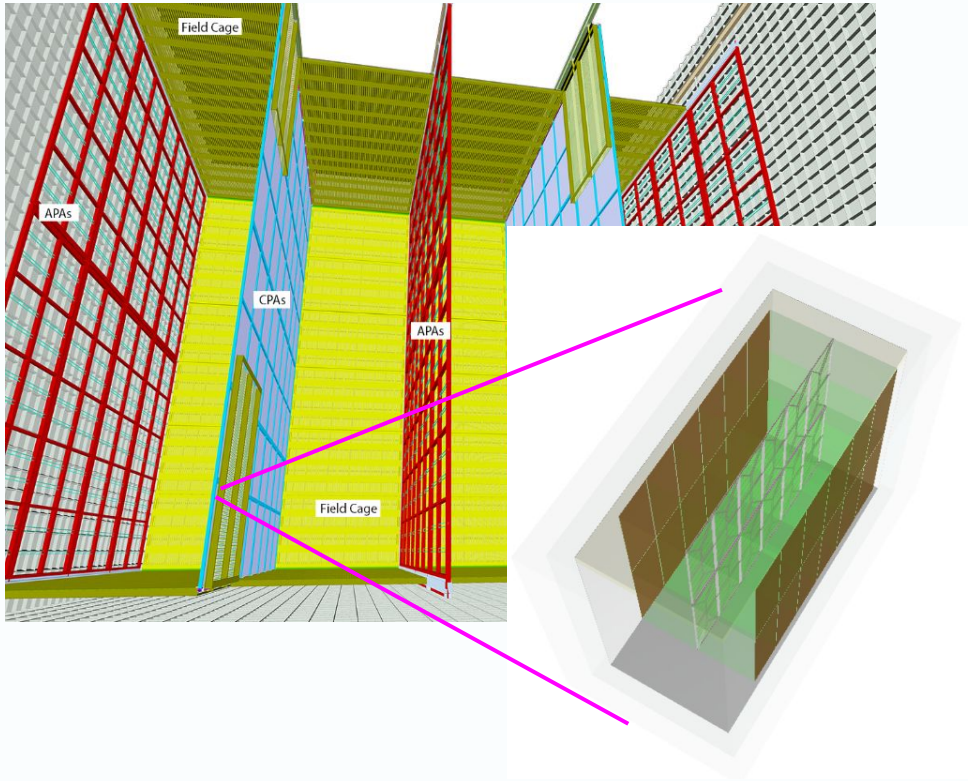
Introduction

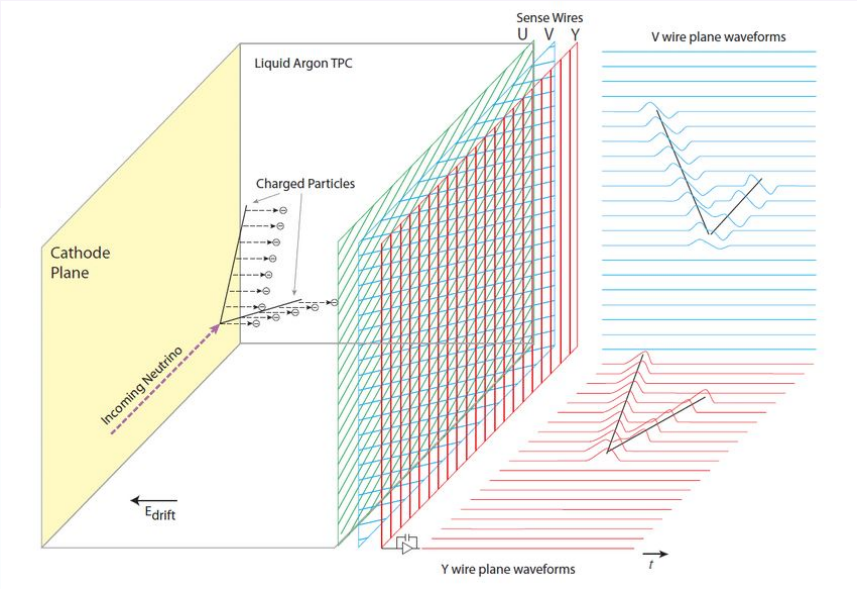
- The **Deep Underground Neutrino Experiment** is an upcoming experiment based at Fermilab
- The Near Detector will be based at Fermilab, with the Far Detector (FD) sitting **1300 km away** in South Dakota
- The full simulation is very **time consuming and complex**, so a **subset** of the detector was used here (~8%)
- The detection system used is a **Liquid Argon Time Projection Chamber** (LArTPC)

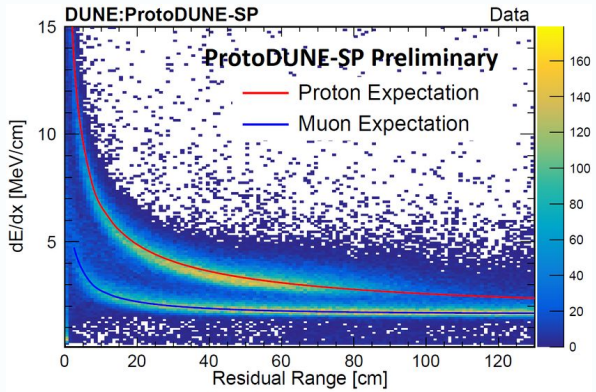


Pictures sourced from Experiment Simulation Configurations Used in DUNE CDR

Hardware and Motivation

- The aim of this calibration is to move **from dQ/dx** (charge per unit length) **to dE/dx** (energy per unit length) which can be used in particle identification
- It is being done using stopping muons as they have a **known energy deposition**, showing a clear Bragg Peak
- This is being done now with simulation as it allows for the **estimation of the required runtime** needed for adequate calibration, as well as to assess any issues such as **non uniformity**





https://www.frontiersin.org/journals/artificial-intelligence/articles/10.3389/frai.2022.855184/full https://pos.sissa.it/390/732/pdf

True Signal Definition and Selection Assessment

A track must…

- Be a true **muon**
- Must have been **directly** simulated
- Have a **true end point** within the TPC active volume

purity = selected signal / selected total

efficiency = selected signal / true signal

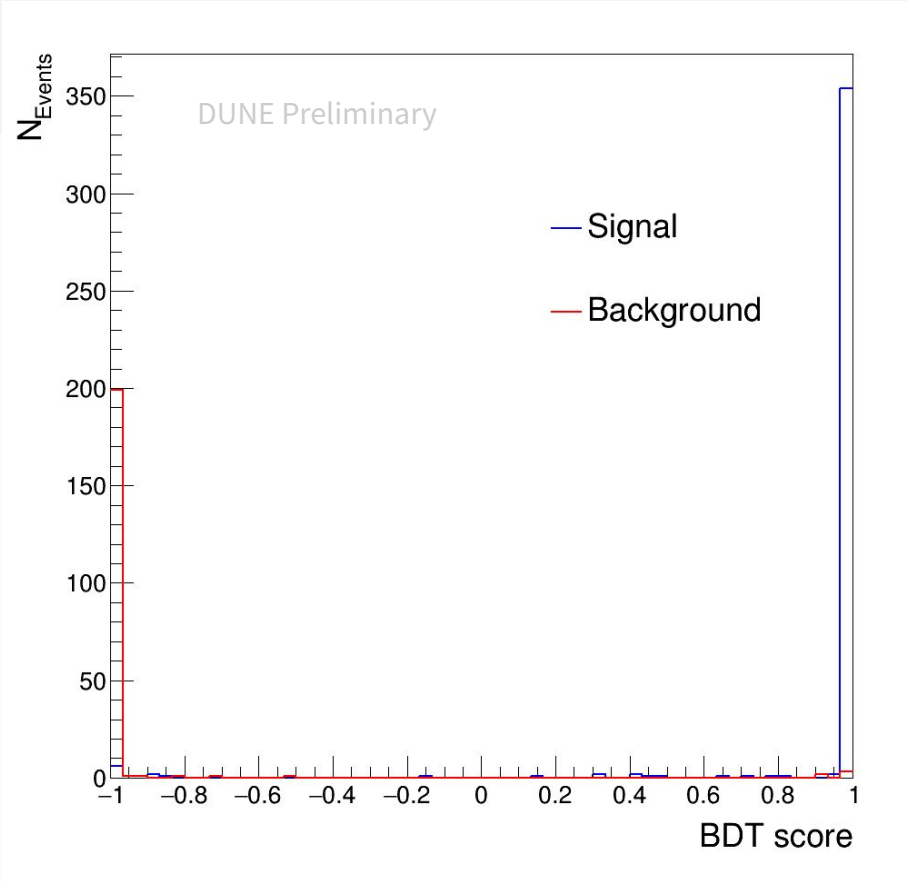
Sample Selection

Ten **preliminary cuts** are made in:
- track position
- track properties
- event composition

A **BDT** was then trained to act as a final cut.

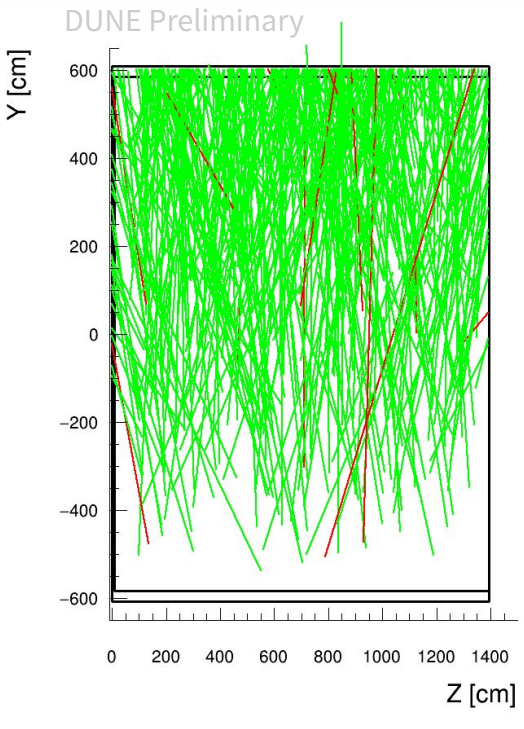
purity = 98.2%
efficiency = 71.4%
good signal tracks = 479

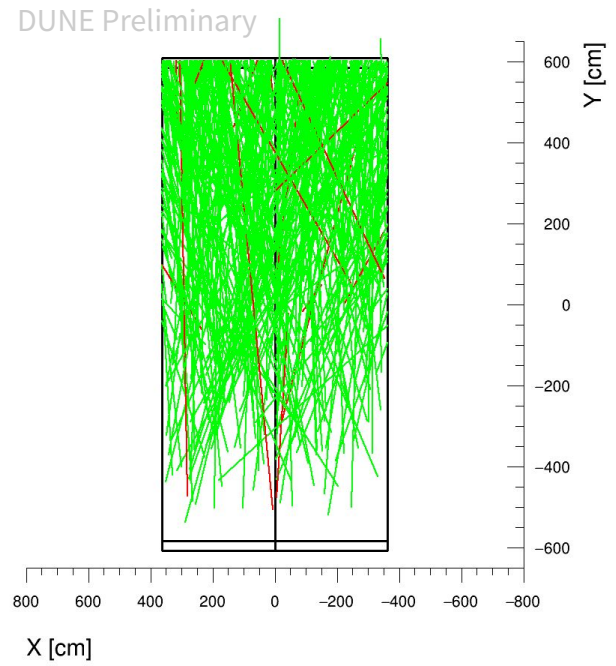
Over about 70 simulated days

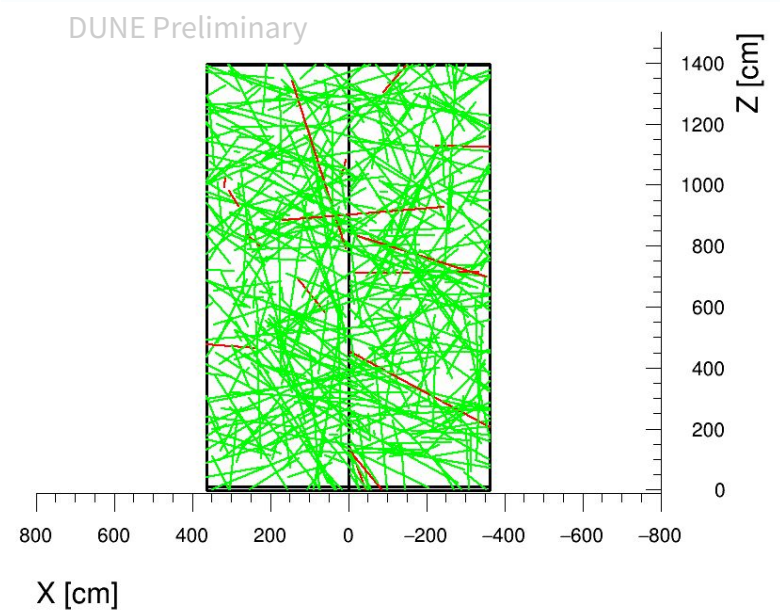


How well does this selection work visually?

X = Drift Direction
Y = Vertical
Z = Beam Direction







Calibration: Two Potential Methods

Modified Box Model (MBM)

Absolute Energy Scale (AE)

Track Selection

Divide track into 5 cm **bins in residual range**

Calculate a dE/dx value with a chosen C_{cal} value and the MBM **then fit** a plot of the dE/dx vs entries to find the MPV values in each residual range bin

Plot reco dQ/dx in each residual range bin and fit to find an **MPV value**

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

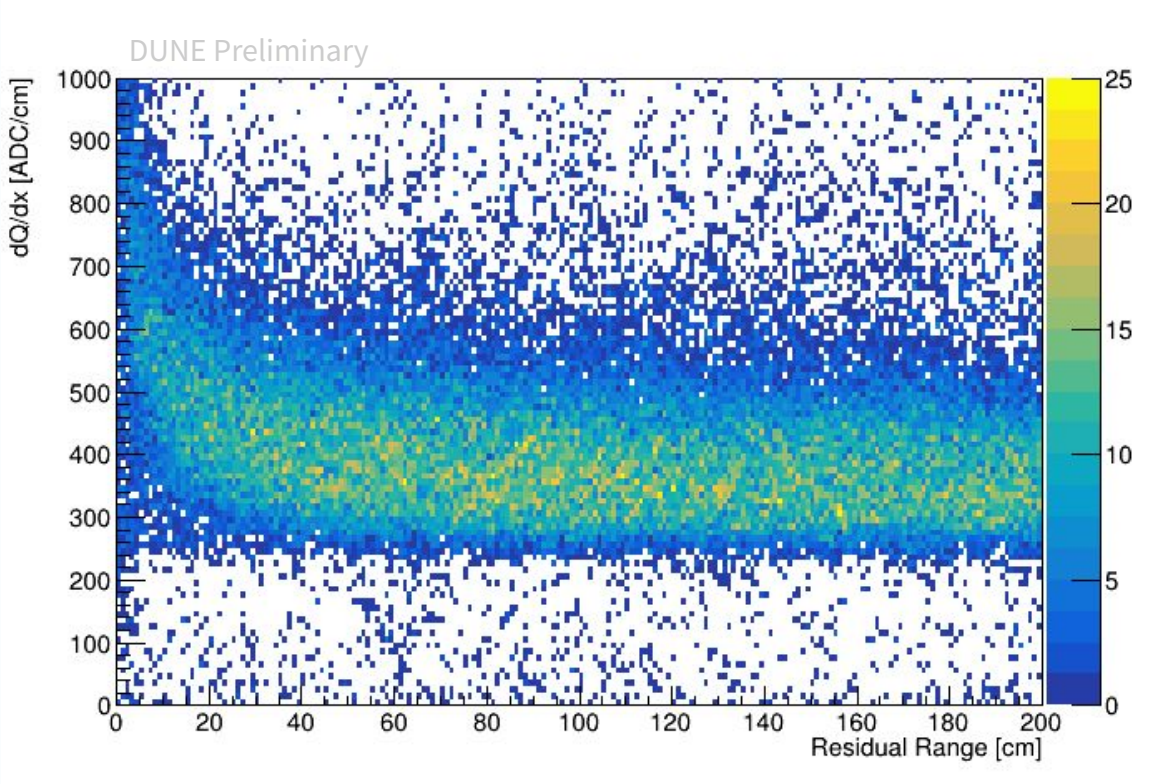
Calculate a **theoretical dE/dx value** in each bin of residual range

$$A + B(1/r) + C(r)$$

Compare χ^2 distributions to find the best C_{cal} value (lowest χ^2 sum across bins)

Plot a ratio of theoretical dE/dx to reco dQ/dx **and fit** to find a conversion equation

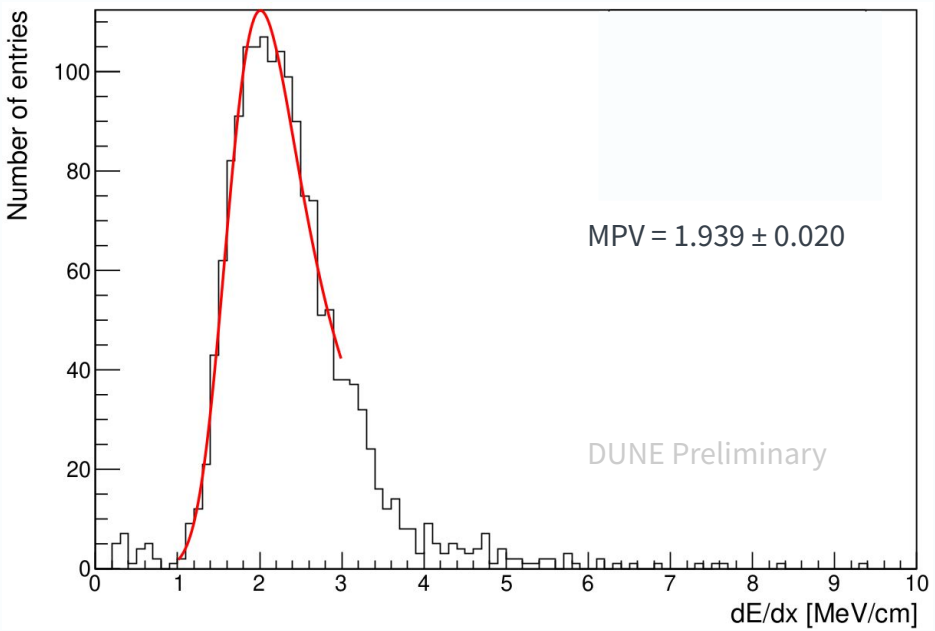
Residual Range vs dQ/dx (Reconstructed Selected Events)



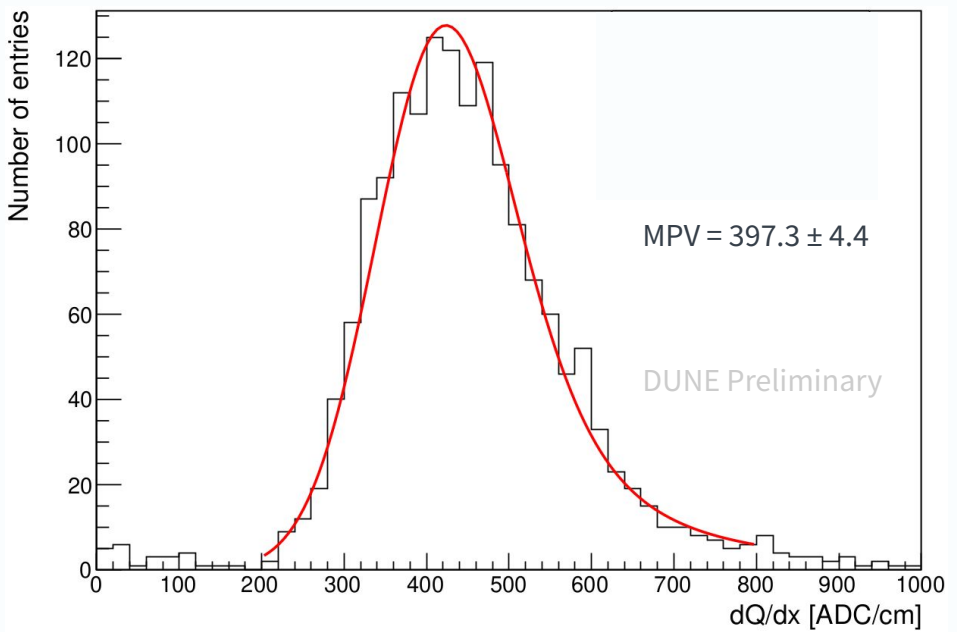
Recombination reduces the Bragg Peak

Fit for Most Probable Value

Modified Box Model



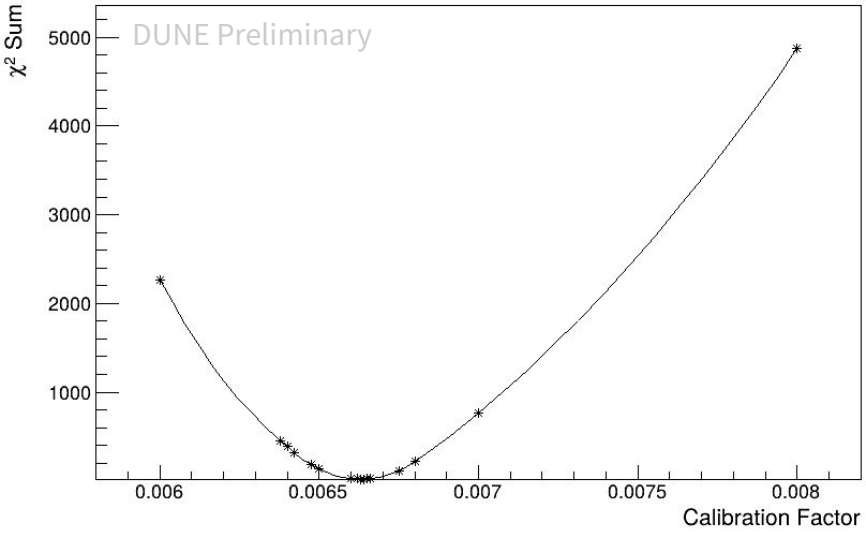
Absolute Energy Scale

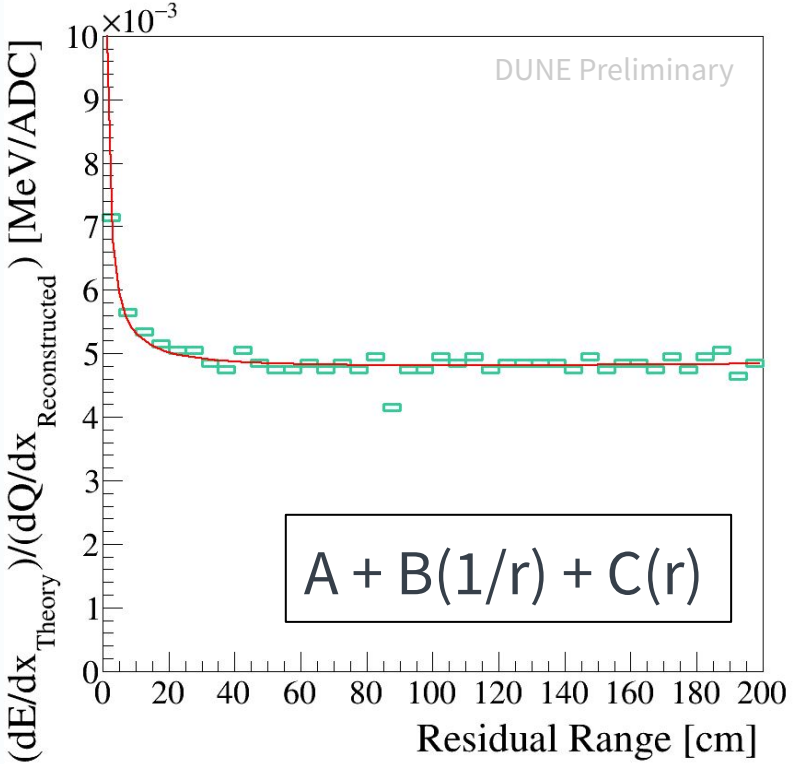


Find the best Ccal/Fit values

Absolute Energy Scale

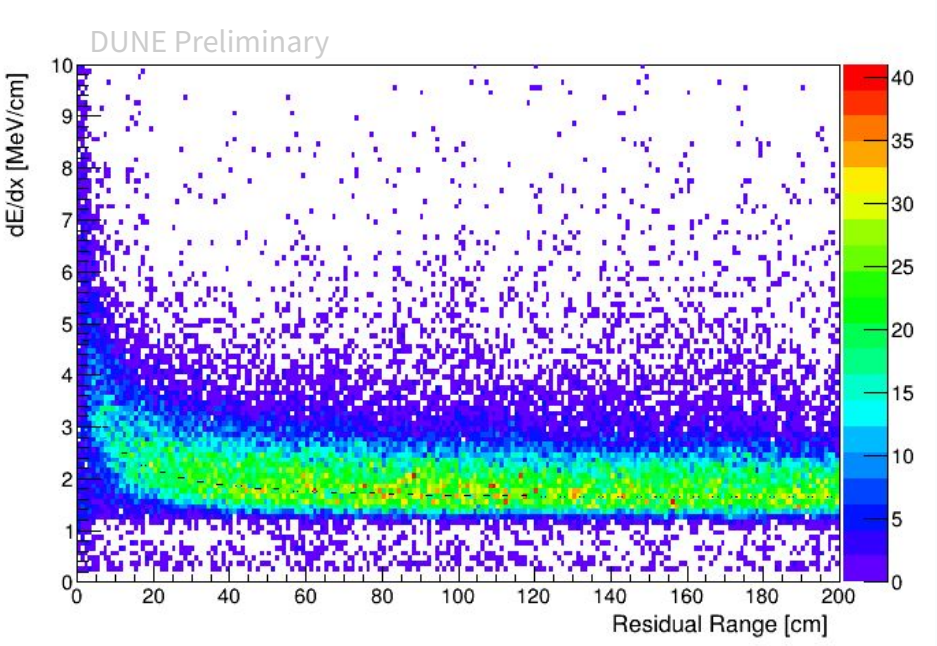
Modified Box Model



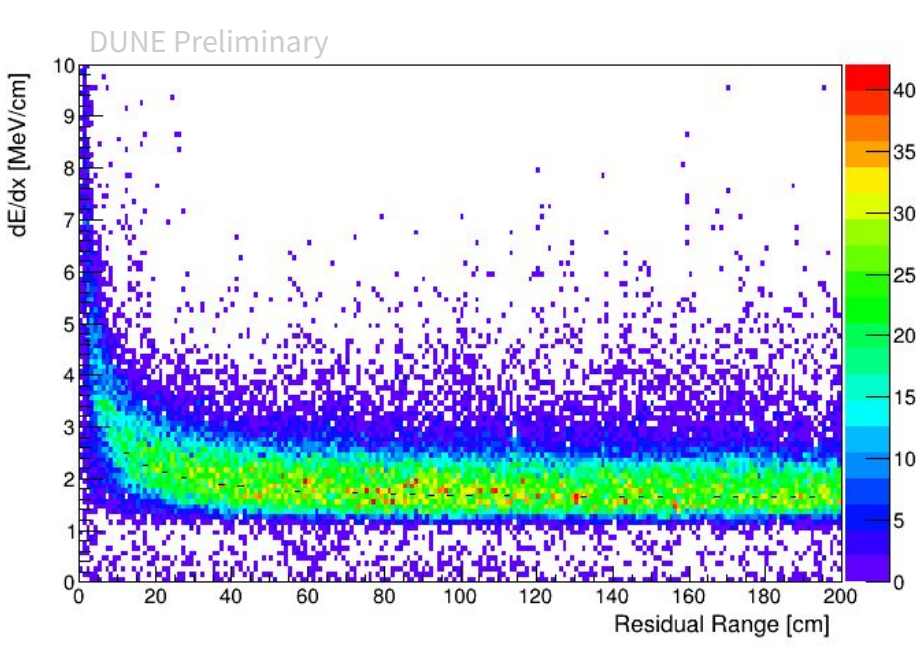


Plot dE/dx against Residual Range

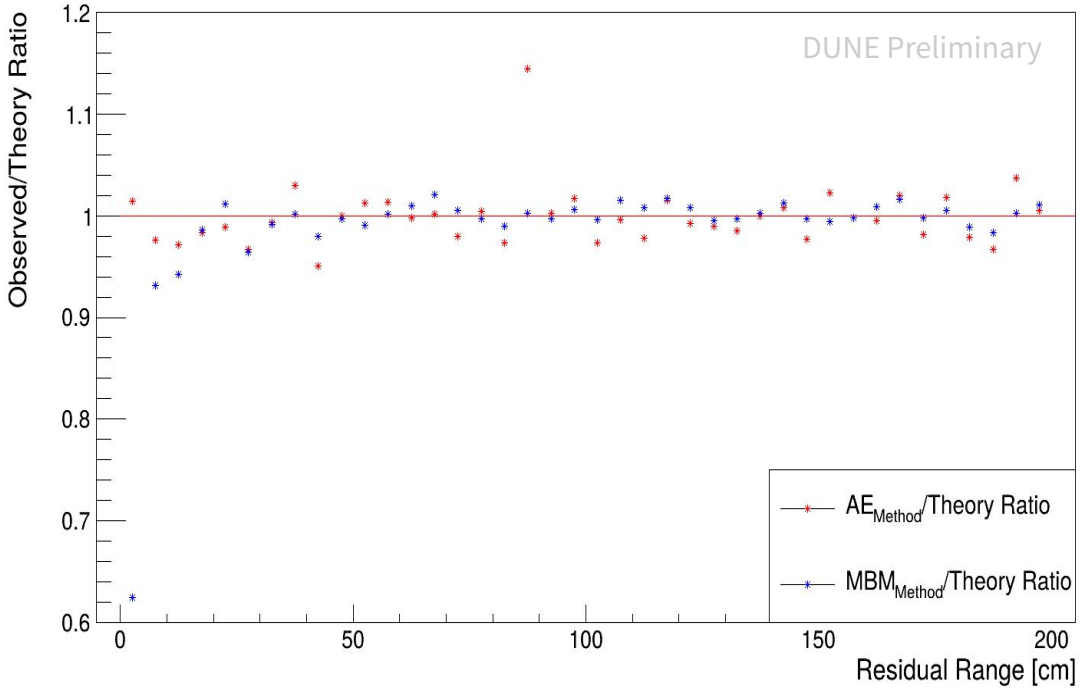
Modified Box Model



Absolute Energy Scale



dE/dx Ratio: Absolute Energy/MBM



- The MPV values found by the two methods are in general **very similar**
- Both are also **close to the theoretical values**, with less than about a 3% average difference seen

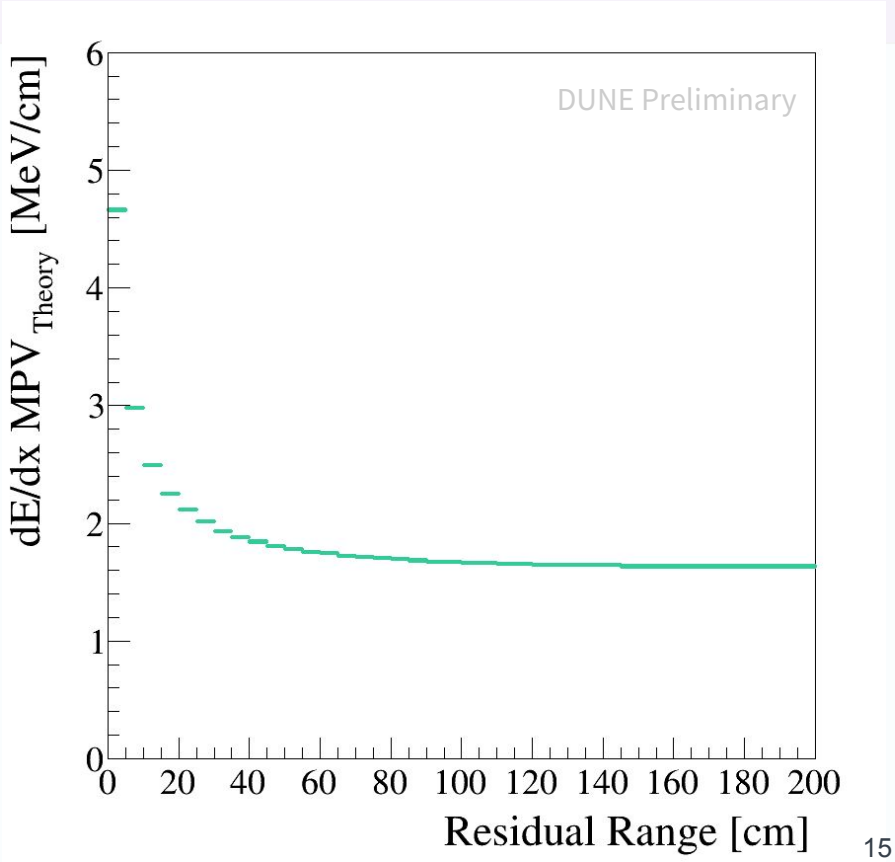
Conclusions

- A stopping muon **selection** of over 98% purity has been successfully developed for a smaller version of the DUNE Far Detector
- Both the standard “Modified Box Model” dQ/dx to dE/dx calibration method and the novel “Absolute Energy” method have been **assessed and compared**
- Everything is now ready to test on a **full scale Far Detector geometry** simulation

Backup

Calculate Theoretical Values

- Use **Landau-Vavilov** theory to make the calculation
- To make this possible, the **inter-hit distance is assumed to be stable**, and the **kinetic energy** for each bin of residual range is **calculated** from the standard dataset seen in PDG



Pitch of Reconstructed Selected Events