Calibration of the ProtoDUNE-SP detector using cosmic muons

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ProtoDUNE sim/reco Meeting

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Overview

- ProtoDUNE-SP data charge and energy calibration
  - Corrections for space charge effects (SCE) and electron lifetime corrections
- Analysis follows calibration technique developed by Ajib Paudel and Tingjun Yang using Ajib's calibration code
- Examined $\frac{dQ}{dx}$ distribution with and without lifetime corrections
- Determined calibration constants ($\frac{dE}{dx}$) for ProtoDUNE-SP data (run 5759, 5770, and 5841)

Calibration code by Ajib Paudel:
https://wiki.dunescience.org/wiki/DQdx_and_dEdx_calibration_instructions

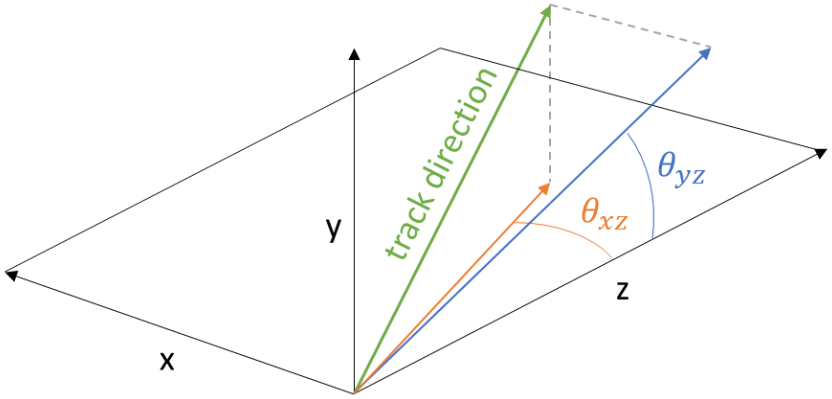
Detector Calibration Corrections

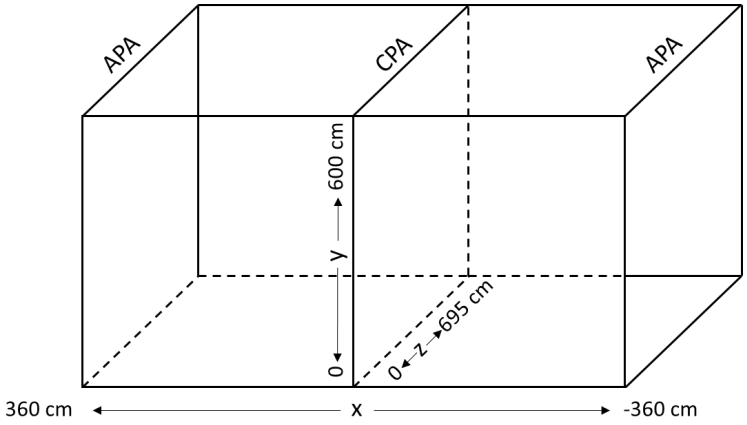
- Space Charge Effects
  - Electric field distortion due to ions
  - Distortion alters particle reconstruction
  - Space charge effects removed based on electric field map measured from cosmic muons
- Electron Lifetime Corrections
  - Ionized electrons captured by impurities (H_2O and O_2) and Ar^{2+}
  - Corrections make detector response ($\frac{dQ}{dx}$) uniform
  - Measured electron lifetime from purity monitor data and recorded in the ProtoDUNE-SP calibration database

ProtoDUNE-SP Calibration Database:
https://wiki.dunescience.org/wiki/ProtoDUNE-SP_Calibration_Database

Crossing Muon Selection

- Track must pass through cathode plane array
- Track must start and end 10 cm from anodes, 50 cm from top or bottom, or 50 cm from sides
- Plane 2:
  - Remove tracks with 60° < $|\theta_{xz}|$ < 120° **or** $|\theta_{xz}|$ < 10° **or** 80° < $|\theta_{yz}|$ < 100°
- Plane 1:
  - If x position is between -360 and 0 cm, remove tracks with $|\theta_{xz}|$ < 130° **or** 80° < $|\theta_{yz}|$ < 100°
  - If x position is between 0 and 360 cm, remove tracks with $|\theta_{xz}|$ > 40° **or** 80° < $|\theta_{yz}|$ < 100°
- Plane 0:
  - If x position is between -360 and 0 cm, remove tracks with $|\theta_{xz}|$ > 40° **or** 80° < $|\theta_{yz}|$ < 100°
  - If x position is between 0 and 360 cm, remove tracks with $|\theta_{xz}|$ < 130° **or** 80° < $|\theta_{yz}|$ < 100°

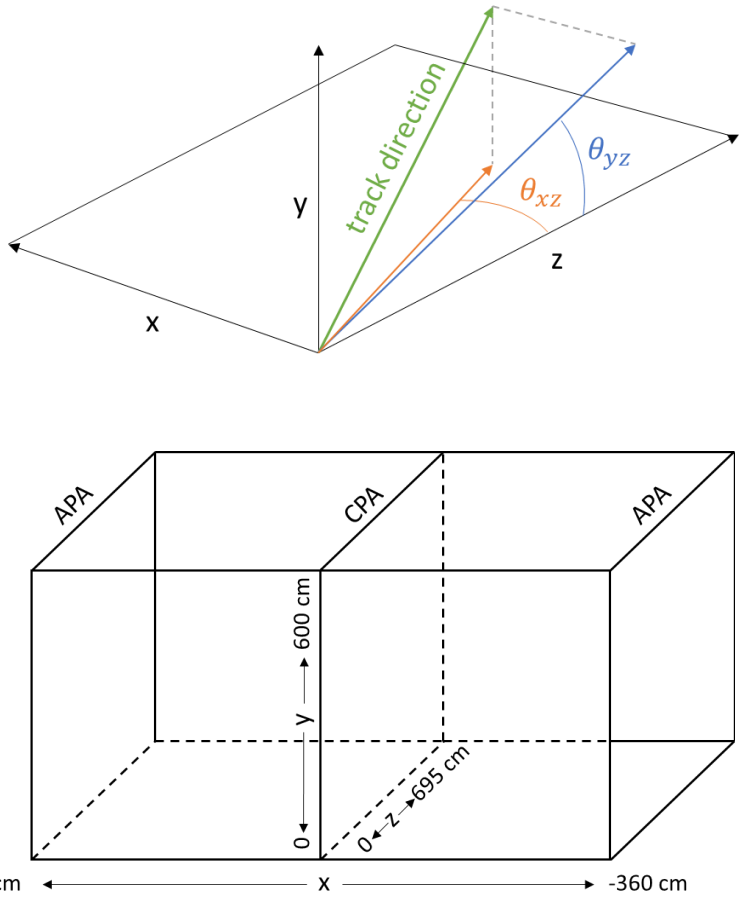




Figures showing geometry of ProtoDUNE-SP detector and definitions of θ_{xz} and θ_{yz}

Stopping Muon Selection

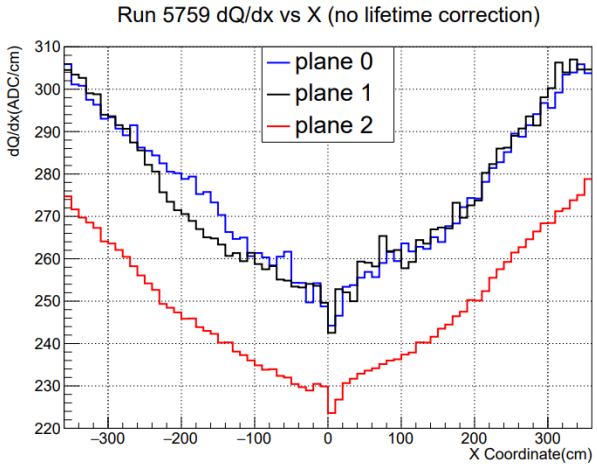
- Angles: removed 65° < $|\Theta_{xz}|$ < 115° **and** 70° < $|\Theta_{yz}|$ < 110°
- Early/late hits: removed tracks with peak time < 250 ticks and peak time > 5900 ticks
- Track length: removed tracks with length < 100 cm or > 700 cm
- Position: removed tracks with start or end z coordinate between 226 and 236 cm **or** z coordinate between 456 and 472 cm

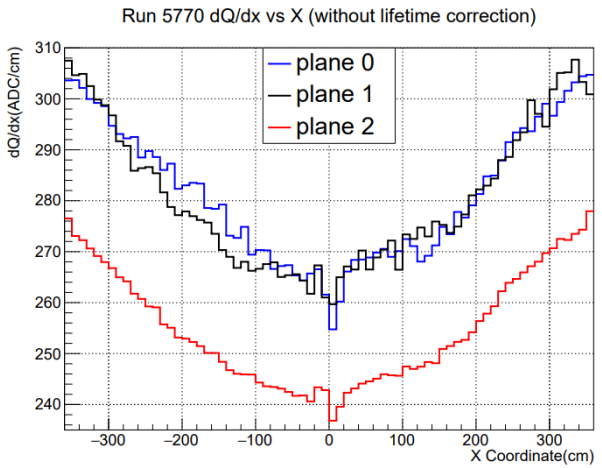


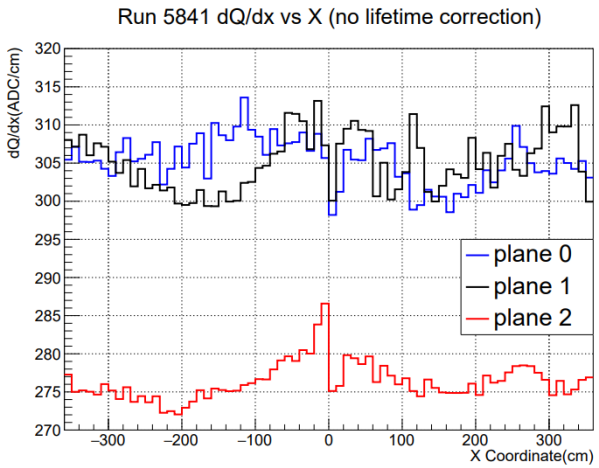
Figures showing geometry of ProtoDUNE-SP detector and definitions of θ_{xz} and θ_{yz}

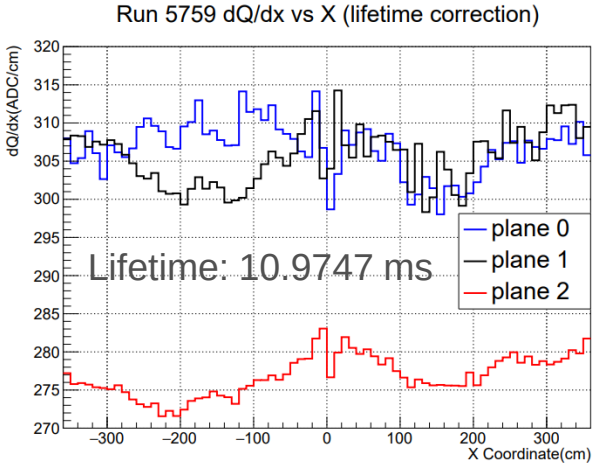
Angular cuts and early/late hits changed from Ajib's code to match selection from https://indico.fnal.gov/event/23989/contributions/74784/attachments/46641/56015/APS_April_meeting_2020.pdf

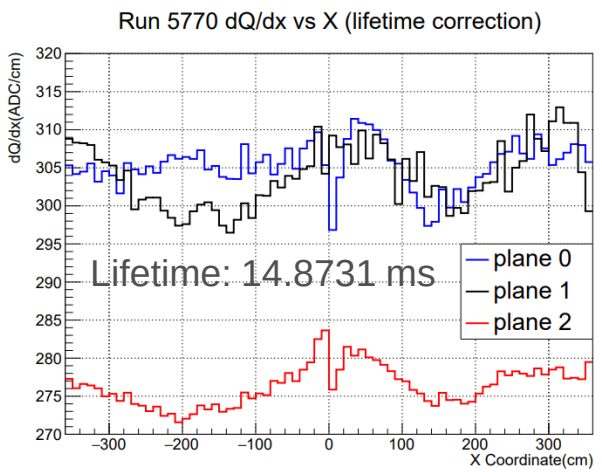
Charge Calibration

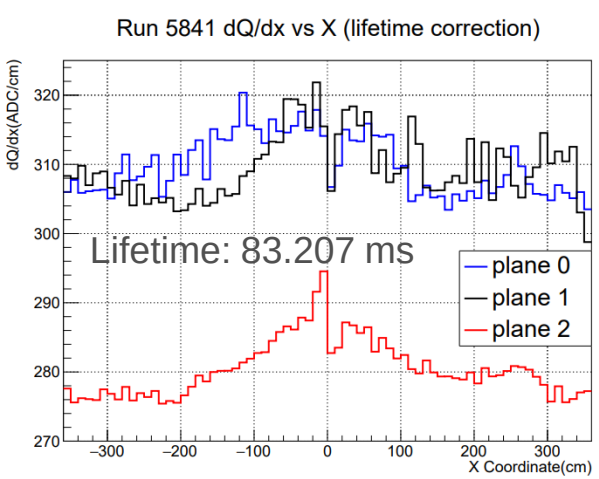












Figures of $\frac{dQ}{dx}$ as a function of x without lifetime correction (top row) and with lifetime correction (bottom row) for runs 5759 (left), 5770 (middle), and 5841 (right)

Calibration Constants

Modified Box Model:

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

where,

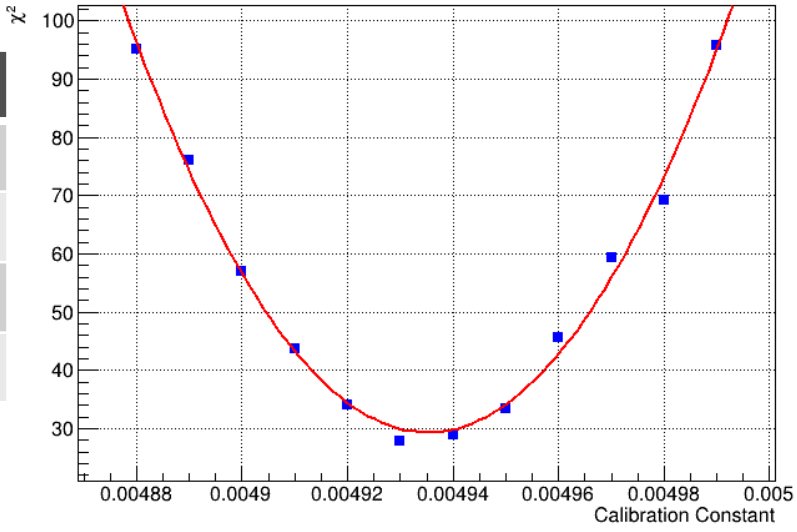
C_{cal} = Calibration constant used to convert ADC values to number of electrons,
W_{ion} = 23.6 x 10^{-6} MeV/electron (the work function of argon),
$\mathscr{E}$ = ProtoDUNE-SP E field based on the space charge maps,
ρ = 1.38 g/cm^3 (liquid argon density at a pressure of 124.106 kPa),
β' = 0.212 (kV/cm)(g/cm^2)/MeV, and
α = 0.93.

Minimum calibration constant (10^{-3} ADC/electron)			
Plane	Run 5759	Run 5770	Run 5841
0	5.414±0.0064	5.375±0.0061	5.516±0.0064
1	5.387±0.0065	5.345±0.0061	5.517±0.0063
2	4.935±0.0068	4.884±0.0053	5.033±0.0076

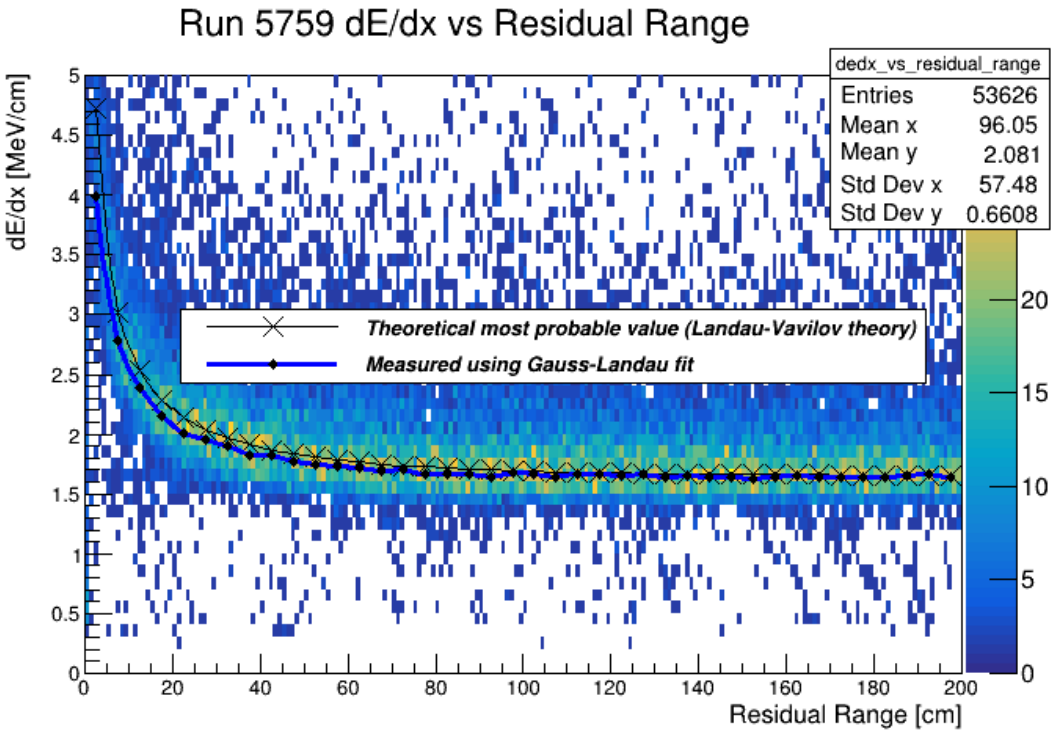
Uncertainty of C_{cal} is given by $\Delta\chi^2 = \chi^2 - \chi^2_{Min} = 1$
arxiv 1907.11736

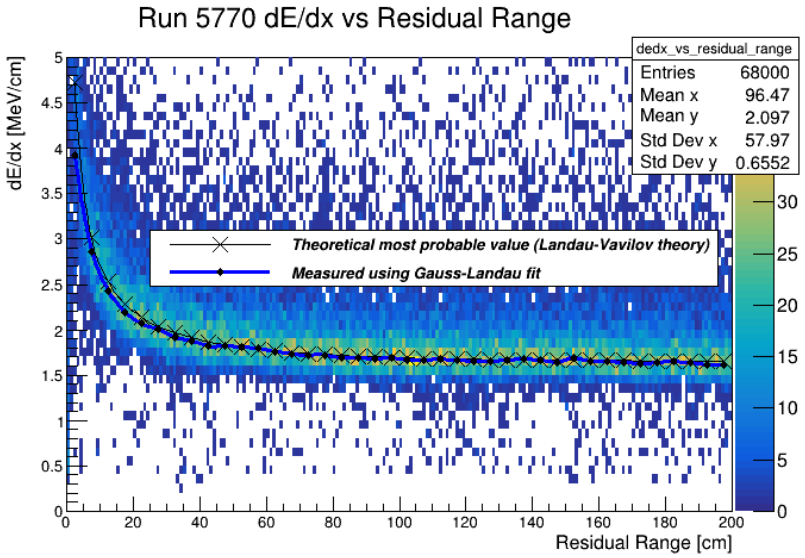
$\frac{dE}{dx}$ values are fit using the Modified Box Model function from the calibrated $\frac{dQ}{dx}$ values from the MIP region of the stopping muon. A quadratic fit is applied to find minimum χ^2 for each plane.

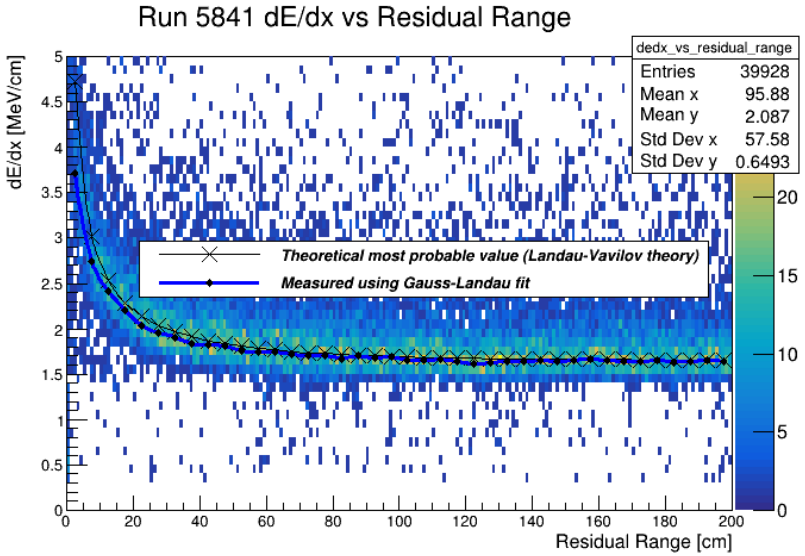
χ^2 as a function of Calibration Constant
Plane 2 of Run 5759



Absolute Energy Calibration







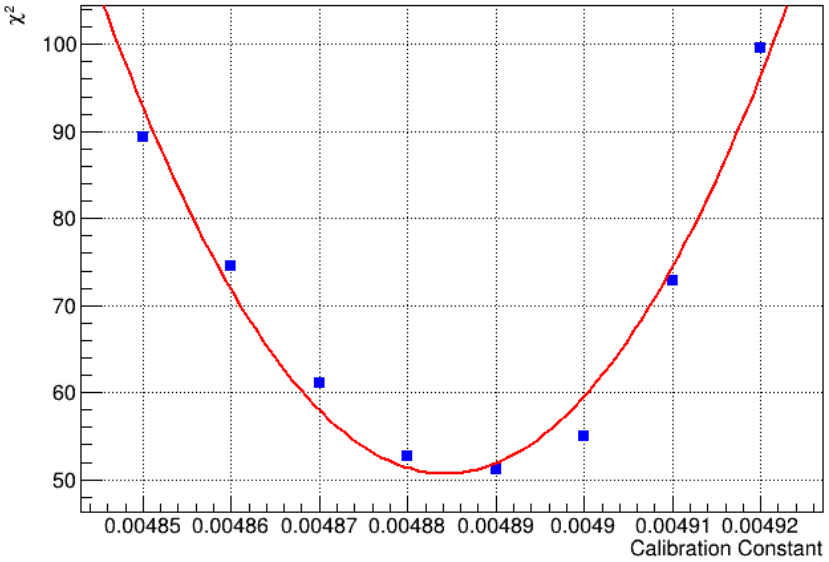
Figures of $\frac{dE}{dx}$ as a function of residual range of stopping muons as predicted by Landau-Vavilov theory from collection planes. *Left:* run 5759, *top:* run 5770, *bottom:* run 5841

Summary

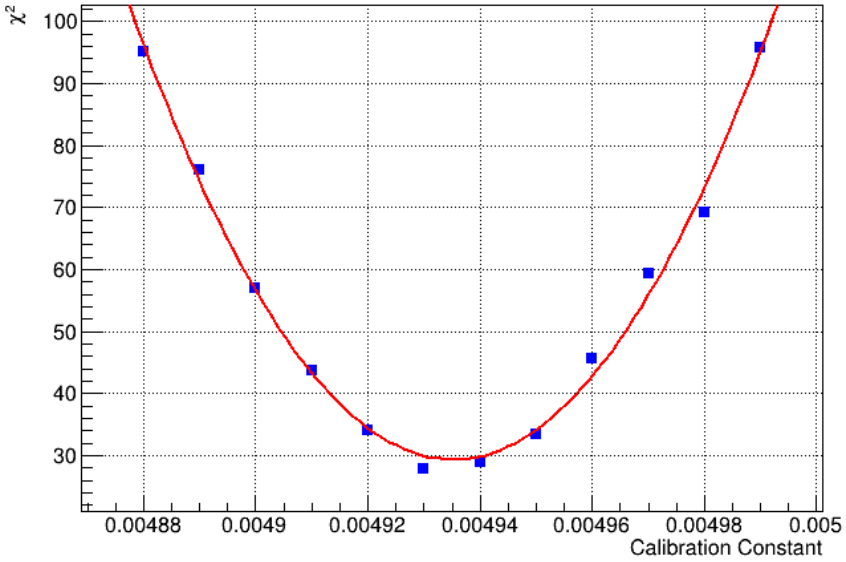
- Applied lifetime corrections
  - $\frac{dQ}{dx}$ distribution is relatively flat after correction
- Determined calibration constants
  - Constants for runs 5759 and 5770 are consistent with each other
- Absolute energy calibration
  - Theoretical $\frac{dE}{dx}$ vs residual range fits well with data

Backup

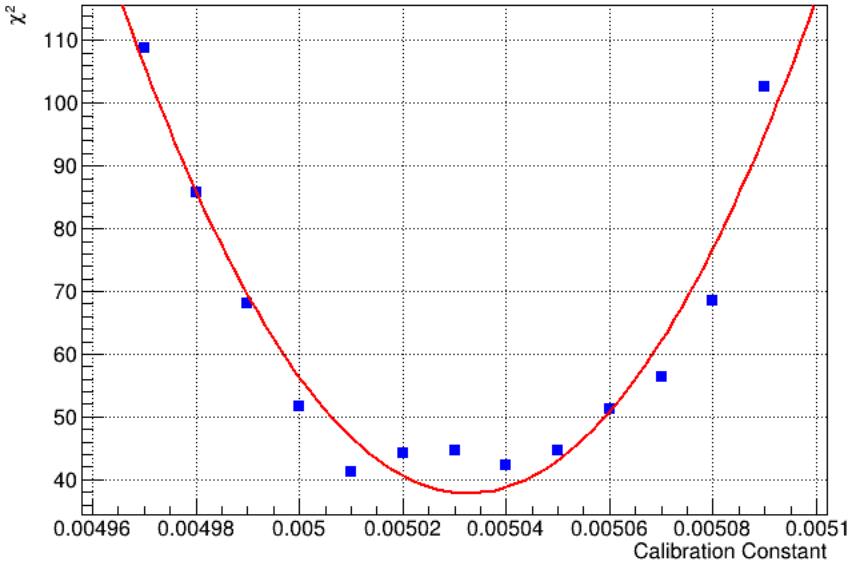
Run 5770



Run 5759



Run 5841



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