TPC Calibration in the Short Baseline Near Detector

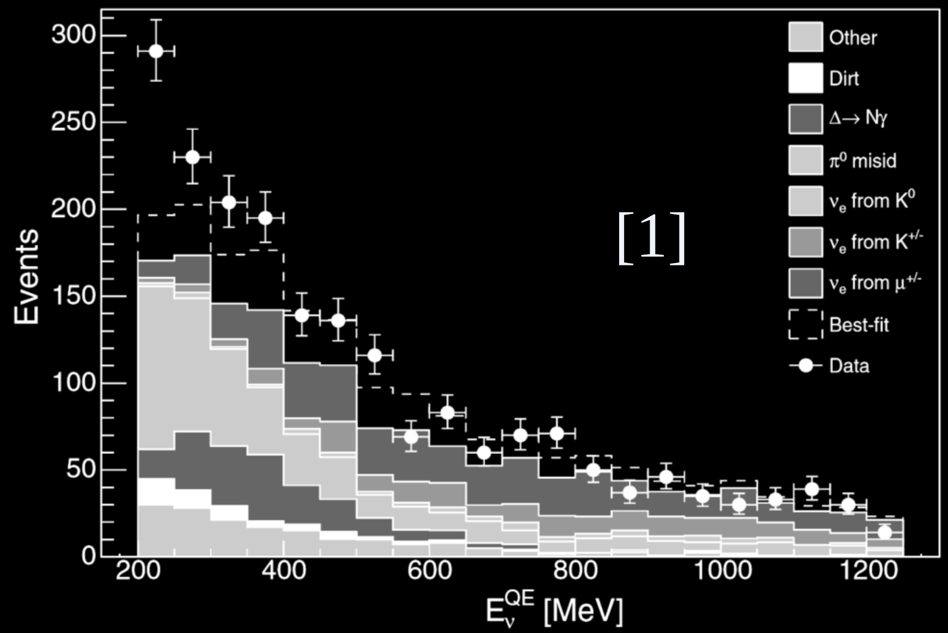
Robert Darby

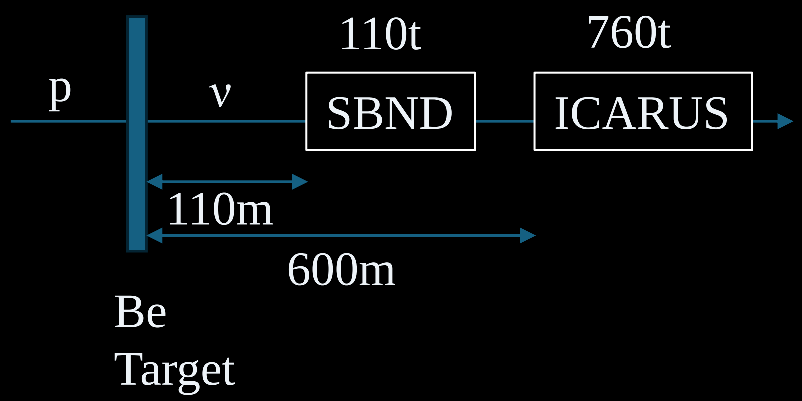
R.Darby@sussex.ac.ukuk

The SBN Program and SBND

Short Baseline Neutrino (SBN) Program

- Comprised of SBND & ICARUS, based at Fermilab
- ICARUS started data-taking in 2022, SBND will begin by summer 2024
- Main physics goal is to **investigate sterile neutrino hypothesis for the Low Energy Excess seen at LSBND/MiniBooNE**





SBND Overview

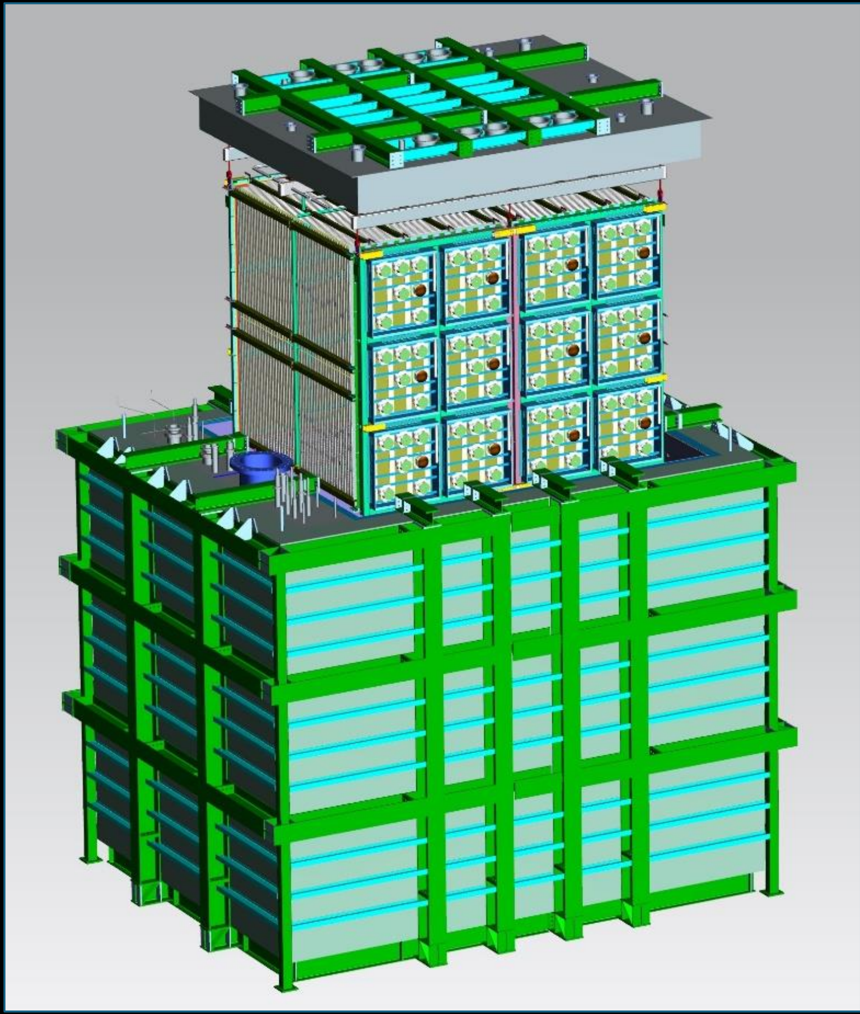
SBND is a Liquid Argon Time Projection Chamber (LArTPC)

Readouts:

- 2 TPCs with 3x2 anode planes (induction = U,V; collection=Y), ~11k total wires
- 120 PMTs + 192 X-ARAPUCAs
- 7 Cosmic Ray Tagger (CRT) planes

To optimise physics performance, precise calibration is neeced

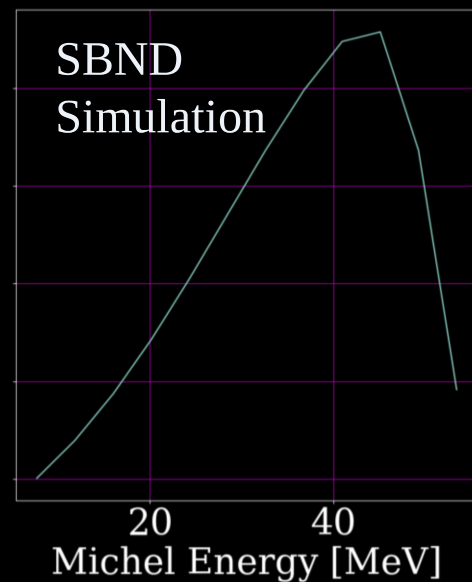
Use standard candles – including **stopping μ**

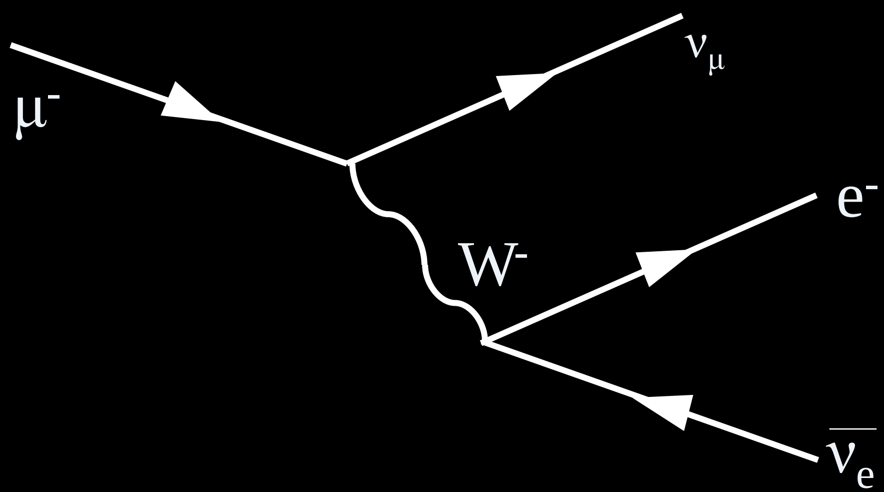


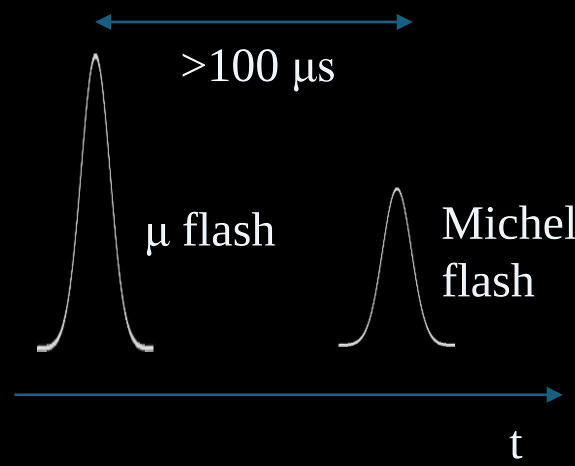
Stopping μ in SBND

Stopping μ Physics

- μ lifetime ~2.2 μs – longer than other interactions
- Michel e^- = e^- from μ decay at rest
- Can identify μ decay point by:
  - Bragg peak
  - Michel flash
  - Track direction change

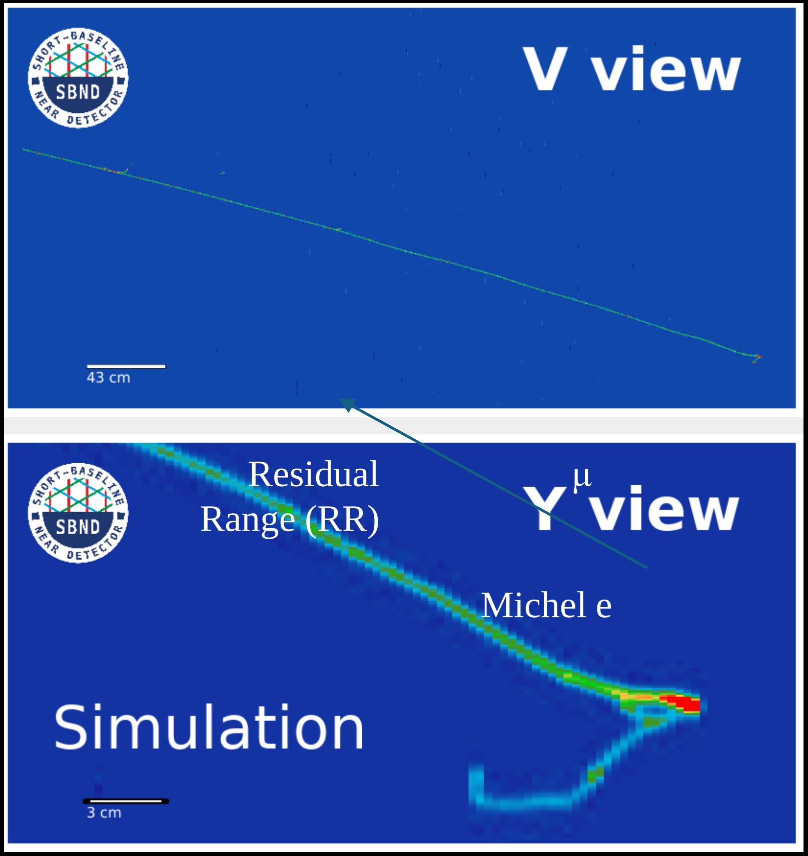






Stopping μ in SBND

- Expect ~800 cosmic rays /s
- Stopping μ + Michel e used in:
  - Energy scale calibration ($C_{calib} = e^{-}/ADC$)
  - Light yield
- μ^{-}/Michels are minimally ionising
- Residual range (RR) = distance from end of track

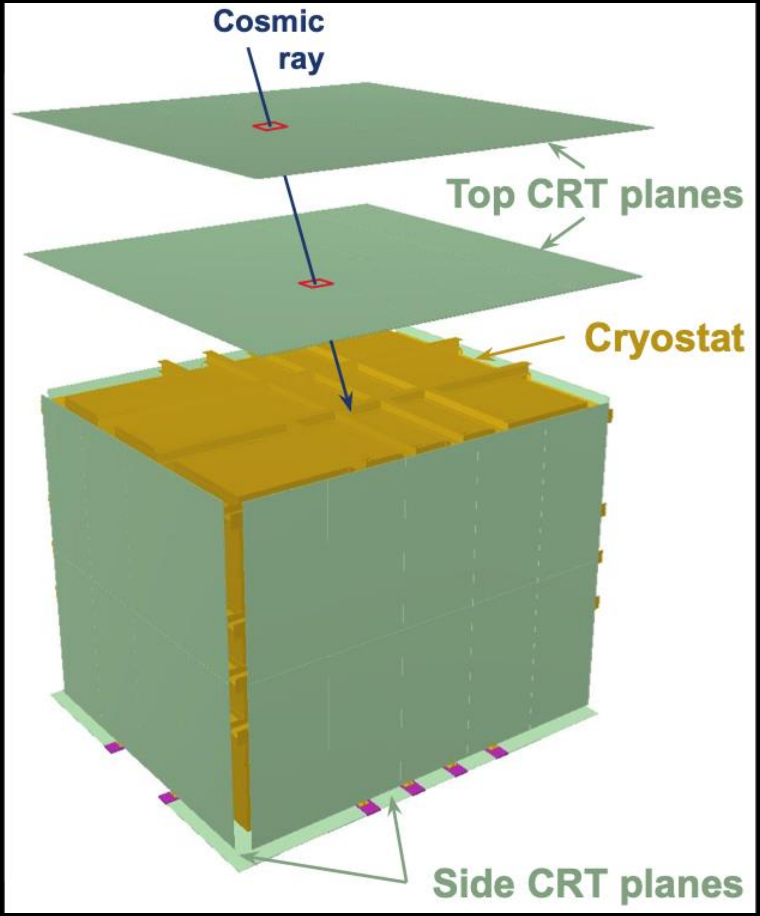


Select stopping μ? Use a trigger

Stopping μ Trigger

Trigger Overview

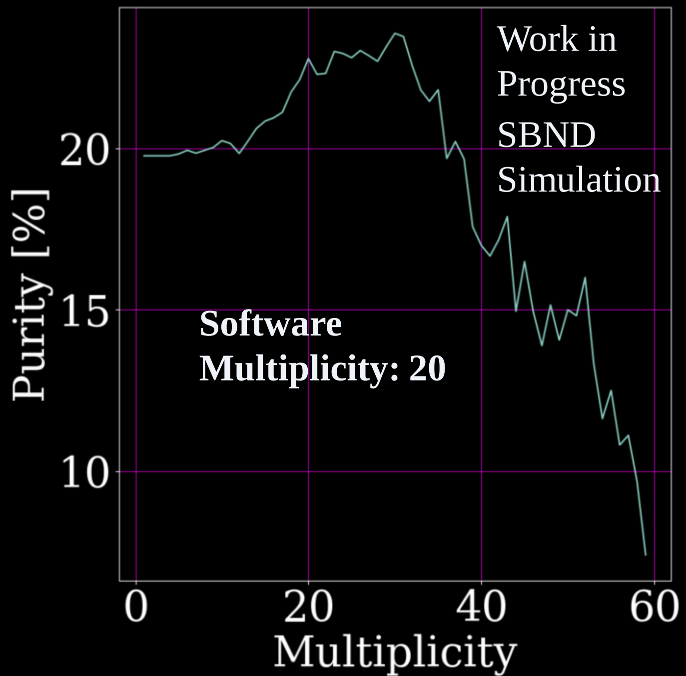
- Stopping trigger has two phases:
  - Detect coincidence (< 100ns) between PMTs and either (bottom CRT plane veto)
    - A single CRT plane
    - Both top planes
  - Detect Michel flash in PMT waveforms >100ns after initial coincidence
    - Add PMT waveforms by ADC and multiplicity
    - Search for single coincident peak ins ummed ADC, multiplicity waveforms



Multiplicity = no. PMTs with time coincident signal over threshold

Multiplicity Thresholds

1270 simulated cosmic ray showers



Drop at multiplicity of 60 PMTs due to higher proportion of stopping μ contained in single TPC (60 PMTs) than crossing μ which enter both

Stopping μ contained in single TPC useful for light yield measurements, so multiplicity < 60 used for hardware

Performance

Stage	N Stopping	N Background	N Total	Purity (%)	Efficiency (%)
Simulation	1175	20069	21244	5.5	100
CRT + PMT Coincidence	752	17609	18361	4.1	64.0
> 50 Multiplicity	678	10512	11190	6.1	57.7
1 ADC + Multiplicity Peak	171	609	780	21.9	14.6
> 30 Multiplicity	121	344	465	26.0	10.3

Purity: 26.0 %

Efficiciency: 10.3 %

Energy Scale Calibration

Energy Scale Calibration

- Energy-scale calibration will help ensure hit calorimetry is accurate – direct impact on cross-section, oscillation measurements.

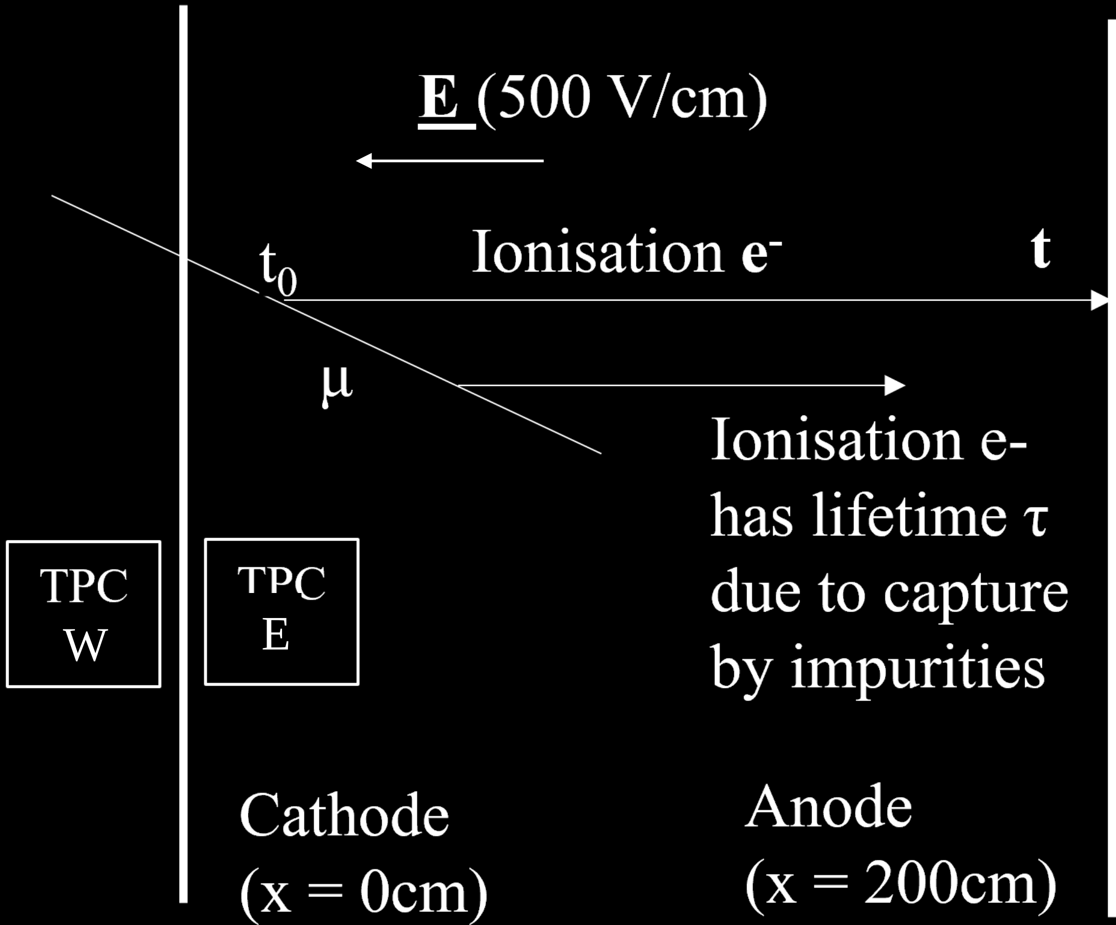
Method:

1. Perform data selection cuts on stopping tracks
2. e^- lifetime corrections – account for e^- absorption by impurities
3. Fit Landau-Gaussian convolution to dQ/dx for RR bins
4. Calculate expected dQ/dx from PDG dE/dx
5. Fit to find C_{calib}

Sample

- 20k simulated and reconstructed cosmic events
- Only select cathode-crossing stopping μ
- μ stop >15cm from detector edge – large track length, induction plane coverage
- Pitch = track angle after recombination. Hits with 0.6 < pitch < 0.8cm used to match literature
- Hits are anisochronous – do not overlap with neighbours in track

Electron Lifetime Correction

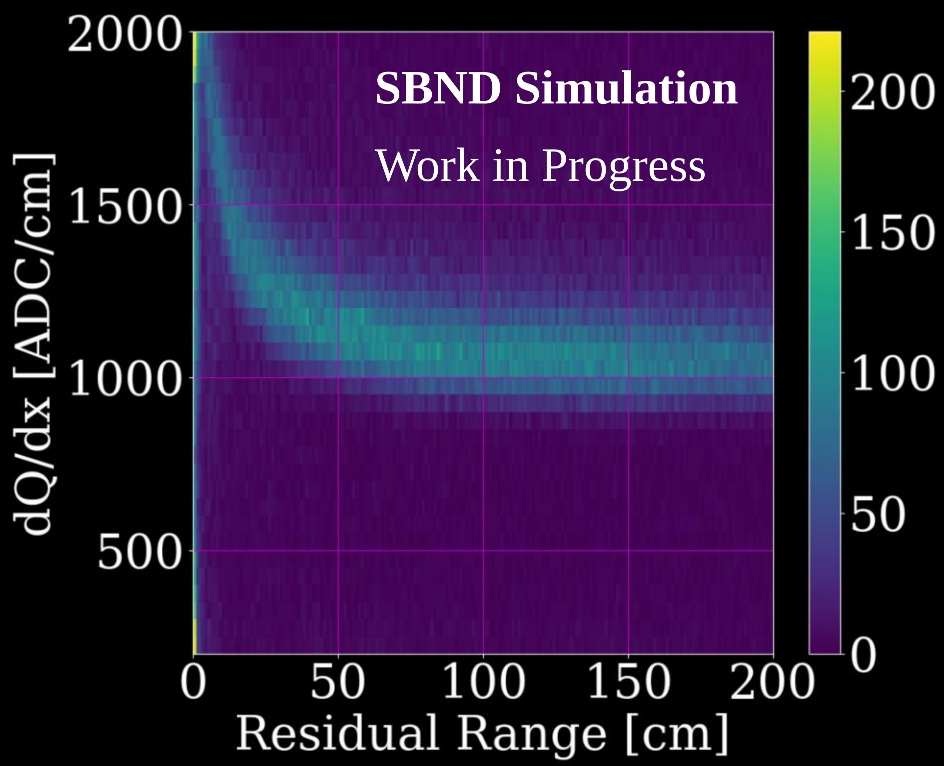


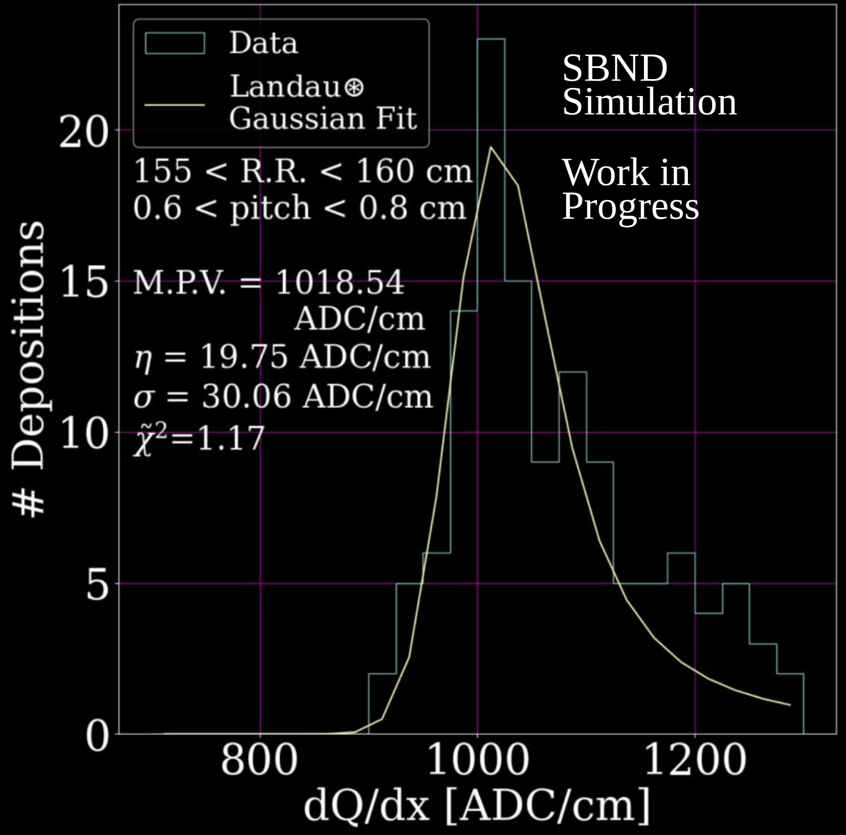
- Lifetime accounts for ionisation e⁻ capture by impurities

$$\frac{dQ}{dx}' = e^{\frac{t_0 - t}{\tau}} \frac{dQ}{dx}$$

MC Data and Lifetime Correction

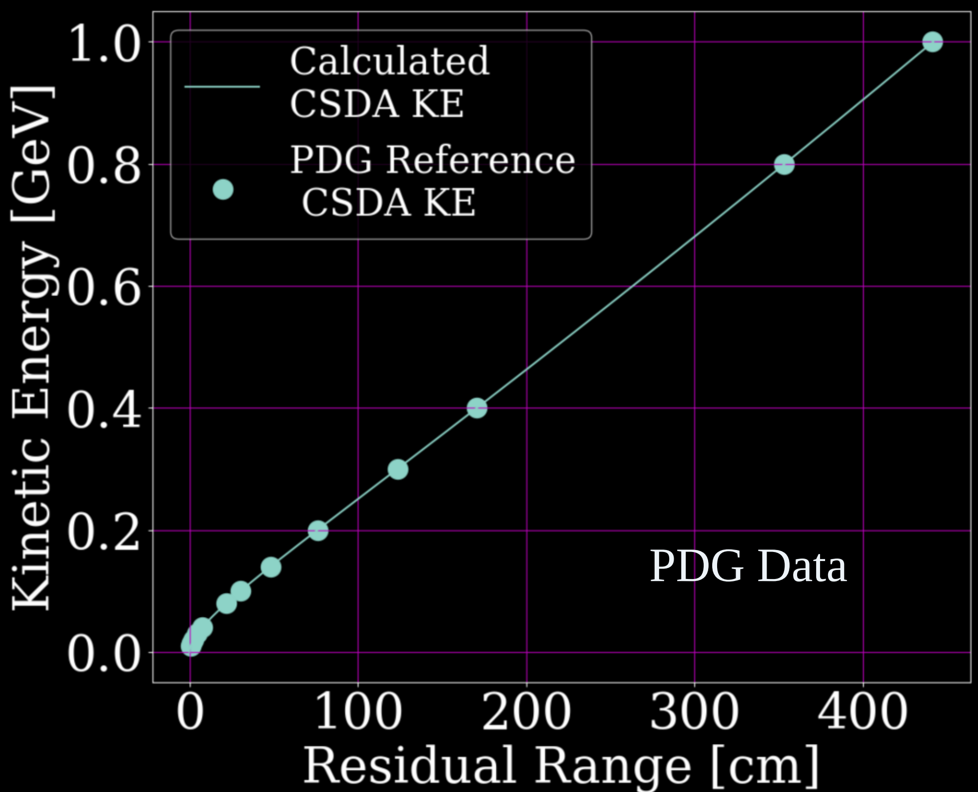
- Apply lifetime corrections then apply Landau-Gaussian fit to Residual Range between120-200cm, 5cm bins

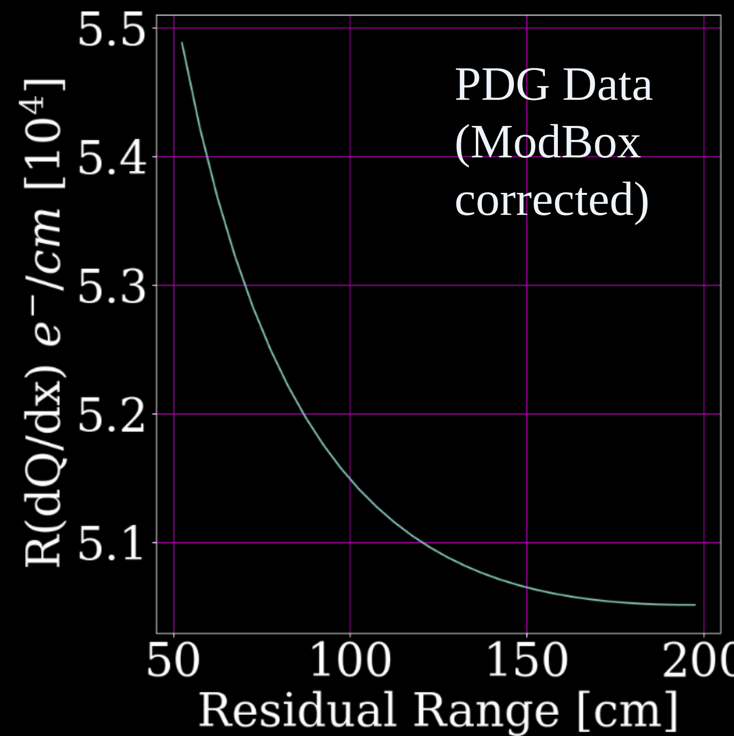




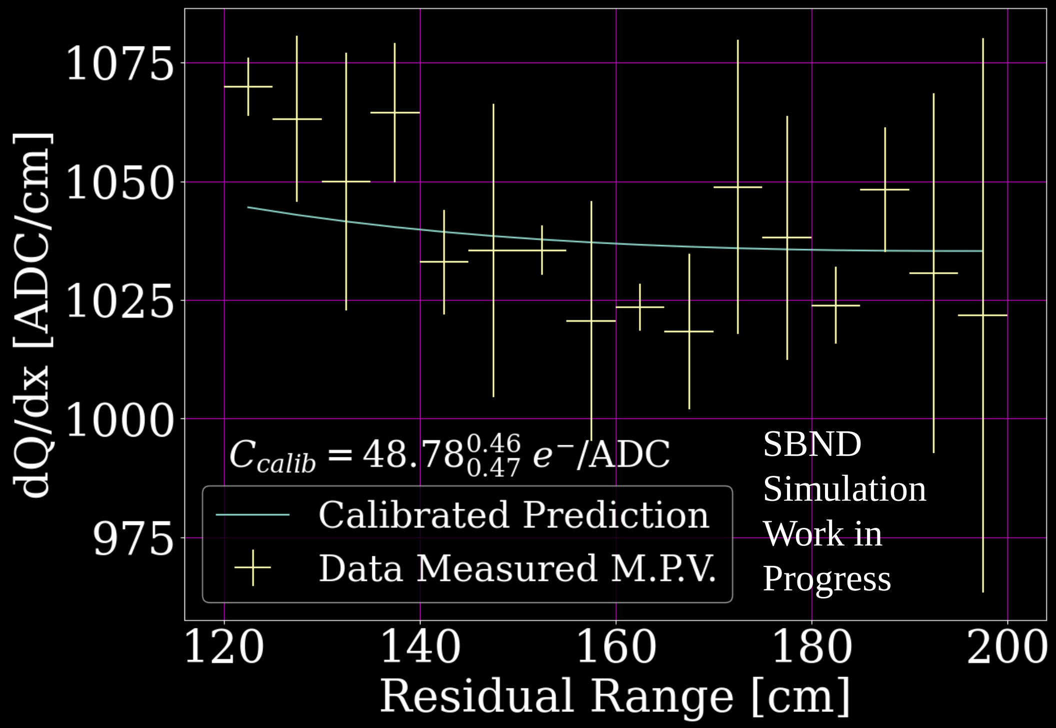
Recombination Corrections

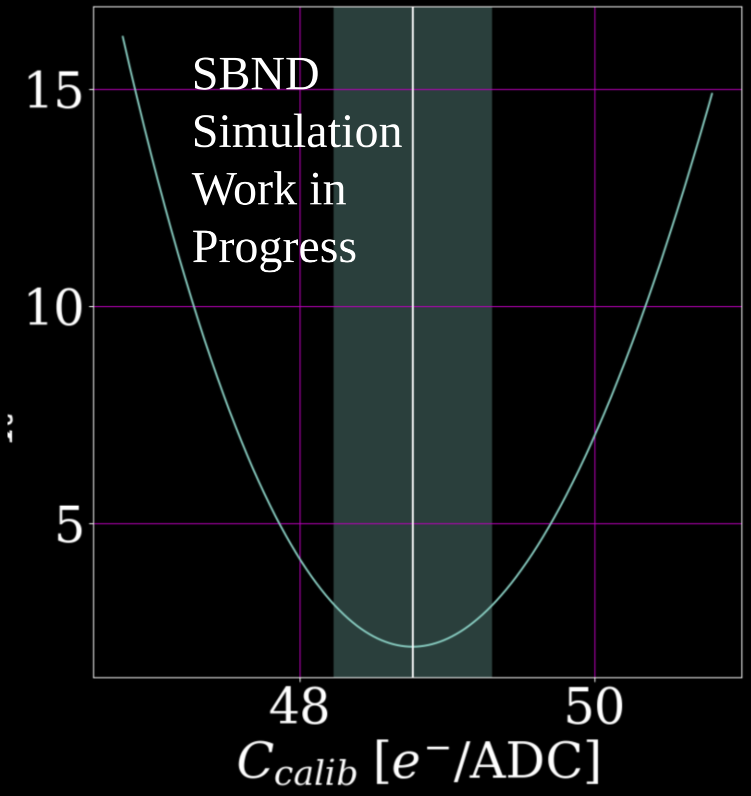
- Using PDG data for muon Residual Range vs KE in LAr [2]
- Recombination correction account for e^- recombining with parent/nearby LAr ion
- Apply ArgoNEUT ModBox recombination corrections [3, 4]





The Fit





C_{calib} = e^{-}/ADC = dQ/dx [exp] / dQ/dx [data MPV]

Expected value = 50 e$_{-}$/ADC – some bias being applied in reconstruction/method.

Summary + Future

- ❑ Stopping Muon Trigger developed
- ❑ Workflow for calculating e^-/ADC gain for SBND prepared

Coming Next…

- ❑ Investigate bias leading to higher than expected C_{calib}
- ❑ Using Data:
  - Select stopping muons and Michel e for light yield calibrations, using Lar late-light absorption by impurities

---

Final Goal:

- ❑ Low-energy Q+L calorimetry module configured with Michel energy spectrum. Used for ν_e CC measurements.

References

[1] Aguilar-Arevalo, A. A., Brown, B. C., Conrad, J. M., Dharmapalan, R., Diaz, A., Djurcic, Z., ... & MiniBooNE Collaboration. (2021). Updated MiniBooNE neutrino oscillation results with increased data and new background studies. *Physical Review D*, *103*(5), 052002.

[2]https://pdg.lbl.gov/2012/AtomicNuclearProperties/MUON_ELOSS_TABLES/muonloss_289.pdf

[3] Acciarri, R., Adams, C., Asaadi, J., Baller, B., Bolton, T., Bromberg, C., ... & Zeller, G. P. (2013). A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC. *Journal of Instrumentation*, *8*(08), P08005.

[4] Doke, T., Masuda, K., & Shibamura, E. (1990). Estimation of absolute photon yields in liquid argon and xenon for relativistic (1 MeV) electrons. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *291*(3), 617-620.