Calibrations of DUNE Far Detector w/ Ar-39

Michael Mooney
Colorado State University

DUNE Calibration Workshop
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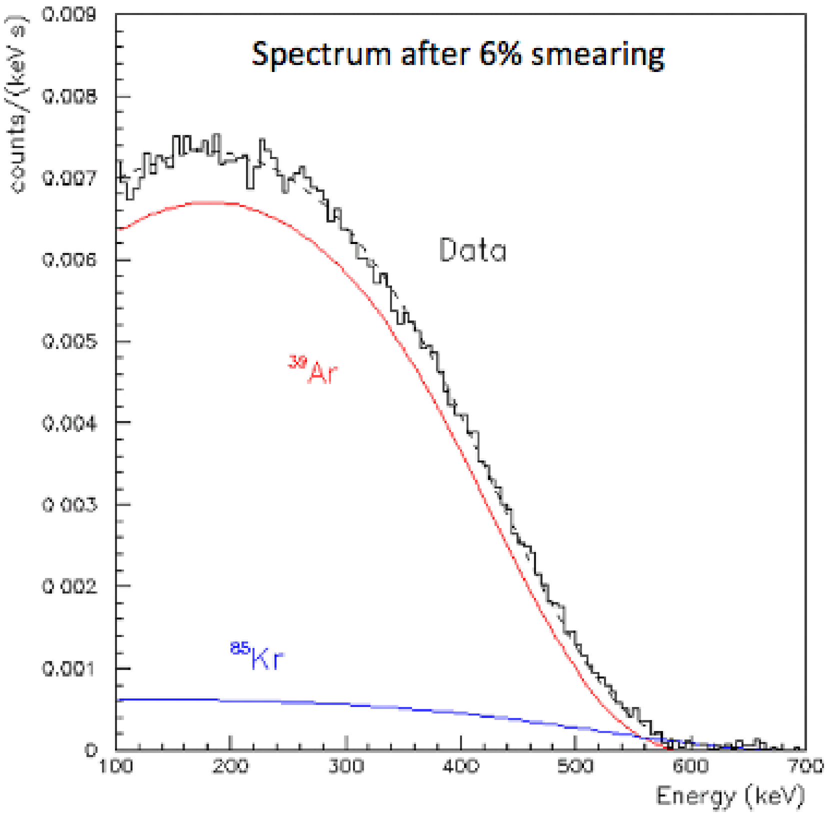
Reality Check

- Many calibrations done at MicroBooNE utilize cosmic rays (e.g. electron lifetime – see backup)
  - MicroBooNE on surface → **4000 cosmics/second**
- Not a reliable option at DUNE FD due to being almost a mile underground
  - DUNE FD: **4000 cosmics/day** (and **20 Michels/day**)
  - … and this is for an entire 10 kt module!
  - Corresponds to 5 cosmics/day/m^3
- Cosmics can still help, but need alternative charge sources for calibrations
- Plenty of **Ar-39 beta decays** at DUNE FD (O(50000) per readout) – good option that should be explored for DUNE, studied first at MicroBooNE/ProtoDUNE

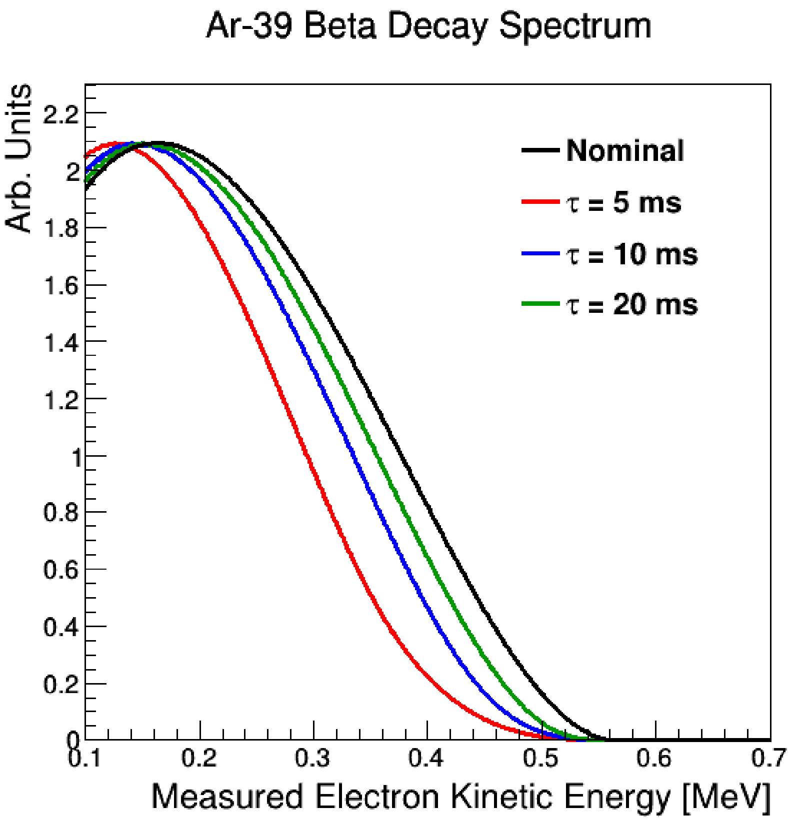
Ar-39 Beta Decays



Benetti et al., "Measurement of the specific activity of Ar-39 in natural argon" (2006).

- Ar-39 beta decay cut-off energy is 565 keV
  - This is **close** to the energy deposited on a single wire by a MIP at MicroBooNE
- Several things smear observed **charge spectrum**, e.g.:
  - Electronics noise
  - Recombination fluctuations
  - Unknown location of Ar-39 decay in drift direction
- <u>For last point</u>: we know decays are **uniform in x**

Ar-39 Beta Decays



Example Use Case:
Fine-Grained Electron Lifetime Measurement

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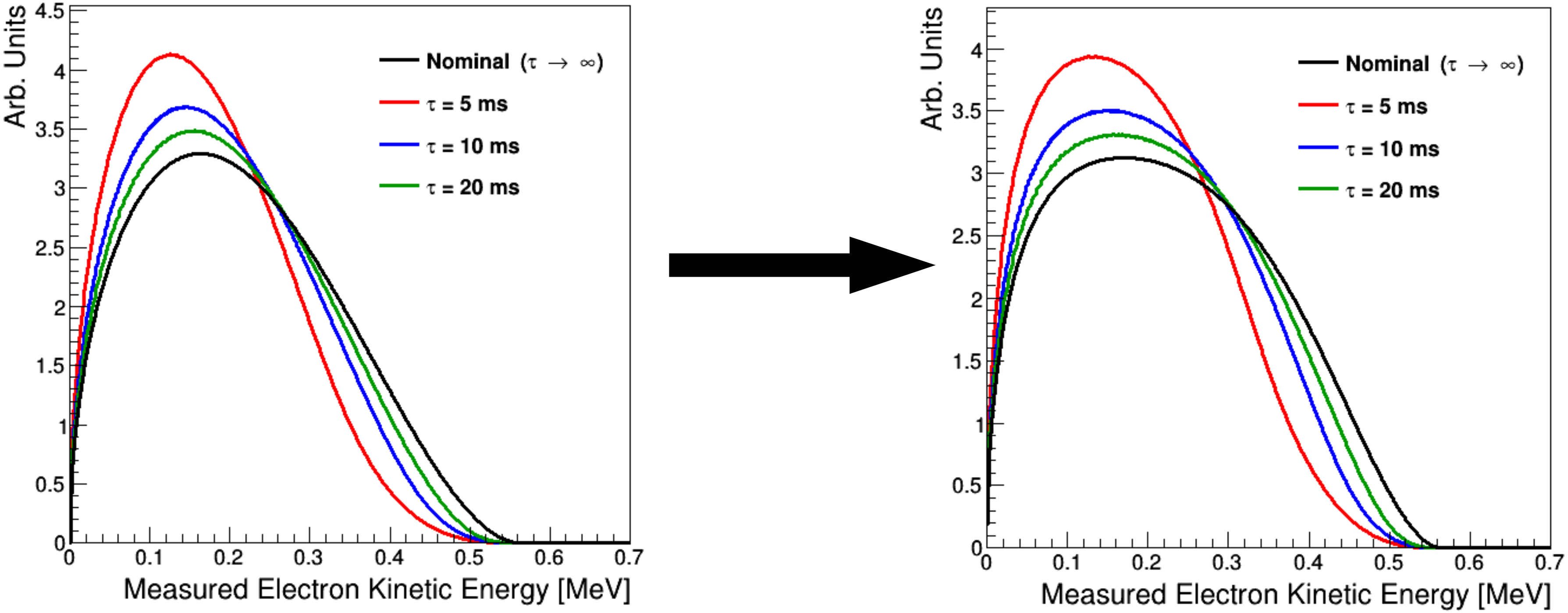
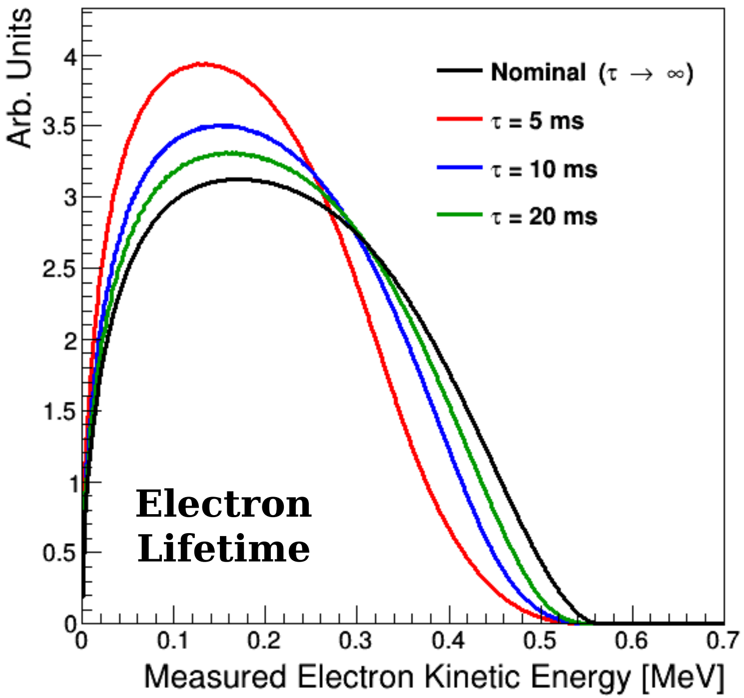
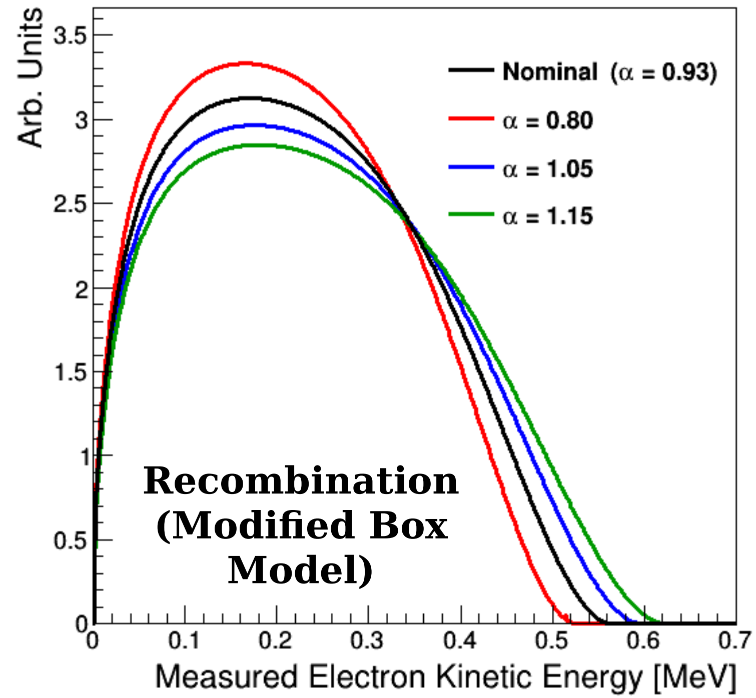
Spectral Shape



- <u>For clarification</u>: previously was showing simple Fermi function for Ar-39 beta decay spectrum
- Have changed to proper shape accounting for first-forbidden unique decay of betas from Ar-39

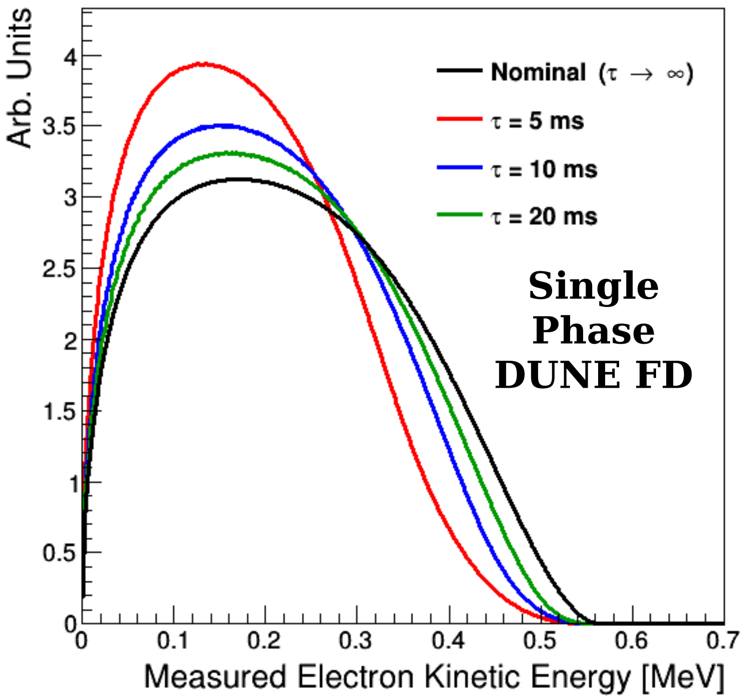
Elec. Lifetime vs. Recomb.

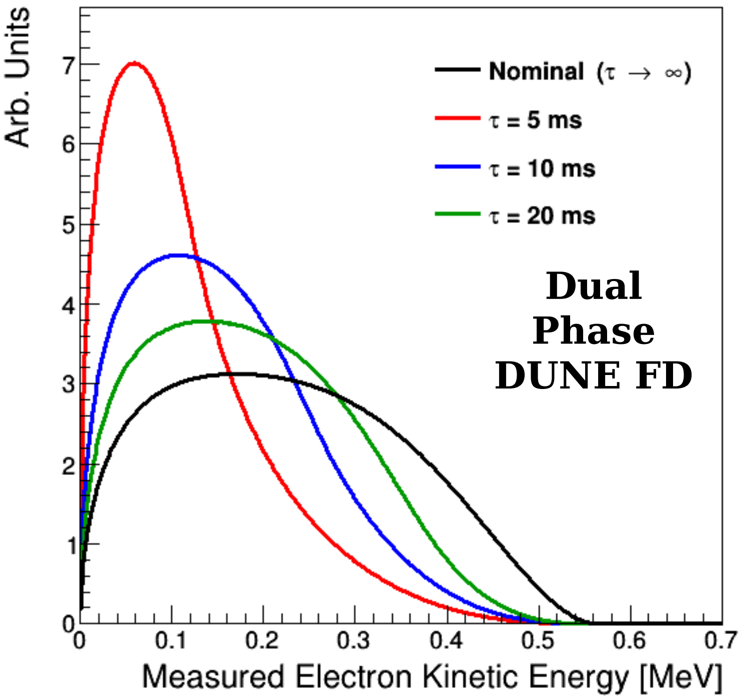




- Electron lifetime and recombination both impact spectrum, but in different ways → largely separable
- Noise also leads to smearing, but this can be measured very precisely with noise data

Single Phase vs. Dual Phase





- Have been showing spectra for lifetimes observed in single phase DUNE FD – also look at dual phase
- Effect is more pronounced in dual phase (longer drift) – measurement should be more precise there

TPC Calibration Items

- Ex-situ (can also be performed in-situ, at least in principle):
  - Diffusion (longitudinal and transverse)
  - Recombination (angular/energy dependence, fluctuations)
  - Wire field response (modulo potential wire-to-wire variations)
- In-situ w/ pulser:
  - Electronics response (gain, shaping time, pole-zero effects, etc.)
  - ADC ASIC calibrations (linearity, other “features” like stuck codes)
- In-situ w/ ionization signals:
  - Electron lifetime (including spatial/temporal variations)
  - Space charge effects and other field effects (e.g. field cage resistor failure)
  - Wire field response wire-to-wire variations
- Do these then study “standard candles” in data (e.g. Michels)

TPC Calib. w/ Ar-39

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- **In-situ w/ ionization signals:**
  - **Electron lifetime (including spatial/temporal variations)**
  - **Space charge effects and other field effects (e.g. field cage resistor failure) → as online monitor of abrupt changes**
  - **Wire field response wire-to-wire variations**
- Do these then study “standard candles” in data (e.g. Michels)

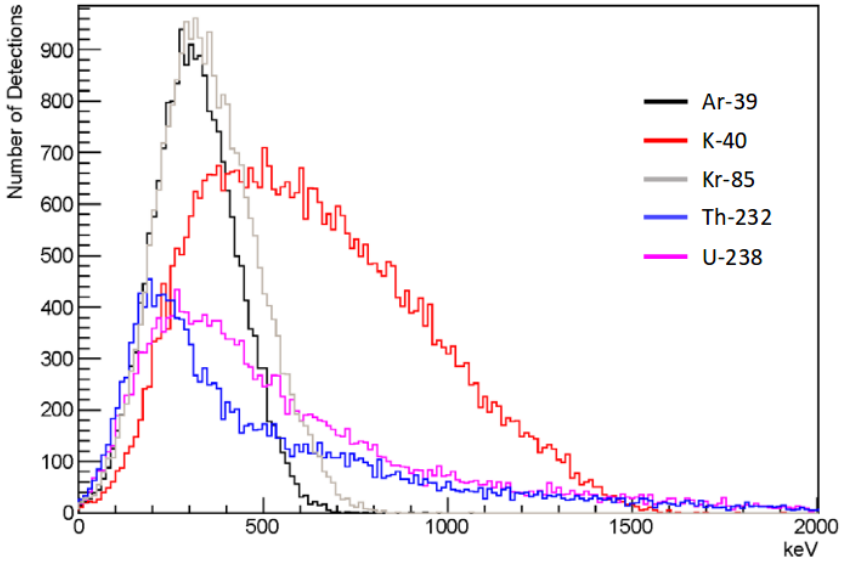
Triggers, Event Rates

- Plenty of Ar-39 beta decays in detector, so just need to take minimum-bias readouts (continuously)
  - External trigger (e.g. pulser) will suffice
- Ar-39 beta decay rate is about 1 Bq/kg
  - 10 kt → O(50k) decays per 5 ms readout (entire module)
- From studies at MicroBooNE (CSU undergraduate Alex Flesher), O(250k) decays can provide high-precision electron lifetime measurement
  - Integrated over entire 10 kt module: O(5) events
  - Every square meter: O(100k) events
  - Every wire pitch: O(2M) events
- Ideally, measure electron lifetime every m^2
  - Wire-to-wire response variations: every wire pitch

Measurement Needs

- How often should we be making electron lifetime measurement?
  - Guess: once a day (currently being done at roughly this rate at MicroBooNE with cosmics)
  - Maybe more/less often, but may not know ahead of DUNE FD operations what necessary rate is
- For O(100k) readouts in one day: **~1 Hz** trigger rate
- This is **a lot of data**, but:
  - Can reduce requirement of spatial precision
  - Can reduce rate of measurement (e.g. every few days)
  - Zero-suppression will help a lot – just need to keep ±1 wire, ±20 time ticks within signal above threshold
    - Collection plane only; induction plane needs more

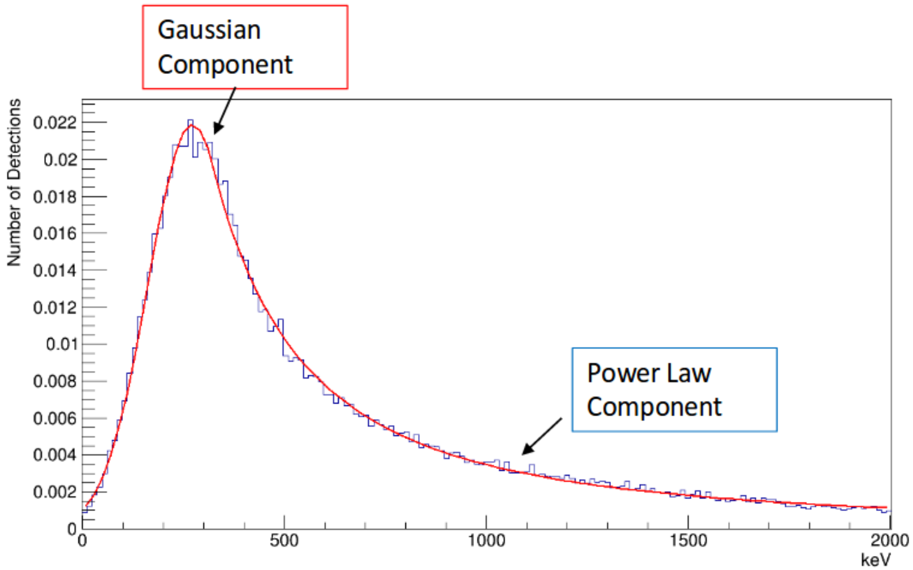
Progress at MicroBooNE



Radiological MC (RadioGen module) run for MicroBooNE

- Things are progressing at MicroBooNE thanks to work by CSU undergraduate Alex Flesher, who is working with Mike
  - Nothing public yet, but **quickly developing effort**
  - Alex will work with new CSU postdoc to produce public result sometime this fall (first: poster in FNAL User's Meeting)
- Also making use of radiological MC (RadioGen module) – thanks to Tom Junk, Juergen Reichenbacher, Jason Stock

Cosmogenic Background



1	Constant	2.18812e-02
2	Mean	2.72060e+02
3	Sigma	1.09478e+02
4	Alpha	-4.82930e-01
5	N	1.70930e+00

From Alex's Recent MicroBooNE Collab. Meeting Talk

- MC cosmogenic background energy spectrum (no radiological sources; only tracks) fits well to the "Crystal Ball" function
- This is helpful for characterizing background contamination related to cosmic tracks

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot \left(B - \frac{x-\bar{x}}{\sigma}\right)^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

where

$$A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

$$B = \frac{n}{|\alpha|} - |\alpha|,$$

$$N = \frac{1}{\sigma(C+D)},$$

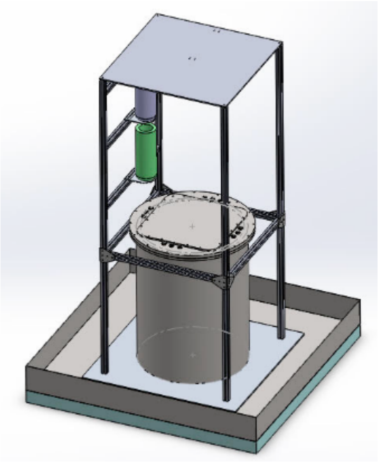
$$C = \frac{n}{|\alpha|} \cdot \frac{1}{n-1} \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

$$D = \sqrt{\frac{\pi}{2}}\left(1 + \operatorname{erf}\left(\frac{|\alpha|}{\sqrt{2}}\right)\right).$$

- ♦ Cosmogenic background (photons, neutrons?) can be mitigated by track proximity "veto" but not eliminated
  - Shape similar to U-238, Th-232 – **complication on surface**

Small Underground TPC

- Lack of knowledge of recombination will complicate use of spectrum for nailing down electron lifetime
  - Need to know both mean recombination and fluctuations in recombination at this energy scale
  - Chatting with experts, conclusion is that we don't know this very well for argon, needs study for precision calibration
- Ahead of DUNE, **measure Ar-39 charge spectrum**
  - At MicroBooNE (ongoing)
  - In separate TPC setup for precision measurement
    - Underground
    - Short drift
    - t_0 tag from light



M. Mooney, D. Warner

Conceptual design for portable cryostat

Discussion

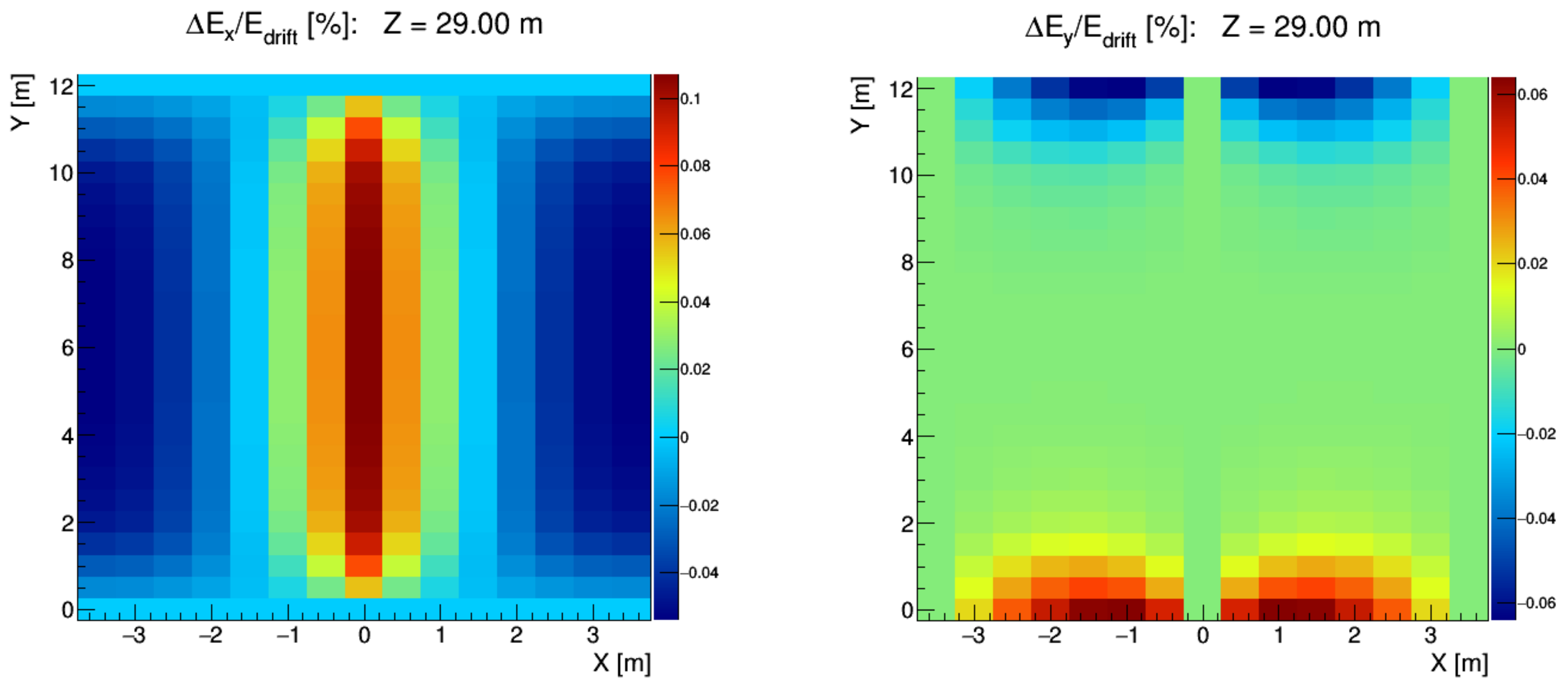
- Uses for Ar-39 beta decays at DUNE FD
  - Fine-grained (time/space) electron lifetime measurement
  - Electric field distortion monitor (from e.g. space charge)
  - Measurement of wire-to-wire field response variations
  - In-situ studies of recombination and diffusion
- Some considerations (mainly for electron lifetime):
  - Probes region closer to anode – can extrapolate, but assumes constant in X; couple with cosmics to get X?
  - Requires precision noise measurement – stable in time?
  - Noise level must not be too high (< 1000 e^- ENC)
  - Saving enough data for induction planes may lead to unreasonable DAQ requirements → measure only in Z?
  - Greatly benefits from precise characterization of Ar-39 beta decay charge spectrum in small underground TPC

BACKUP SLIDES

Ar-39 Data Rates, Etc.

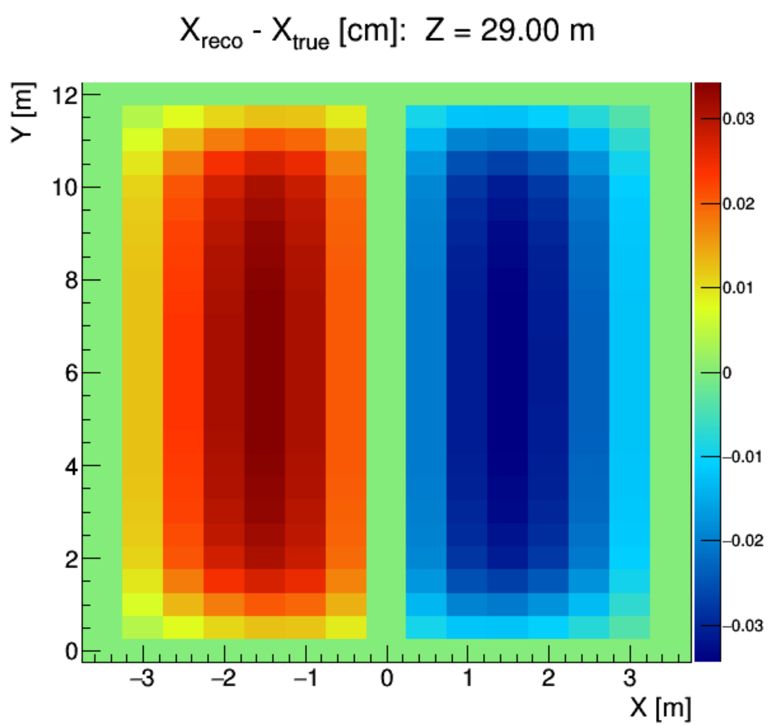
- Working off of previous slide, data rates assuming at 1 Hz trigger rate (entire 10 kt module):
  - Without zero-suppression: 4 GB/s
  - With zero-suppression (if keep all decays): 12 MB/s
  - With zero-suppression (with thresholding): 5 MB/s
- Scale this down as you reduce spatial/temporal granularity of electron lifetime measurement
  - Hard to predict ahead of first operations, numbers here are best guess
  - Limitations of DAQ may restrict measurement
- Note we only need TPC information for measurements, but should take PDS information as well if possible (for PDS calibrations?)

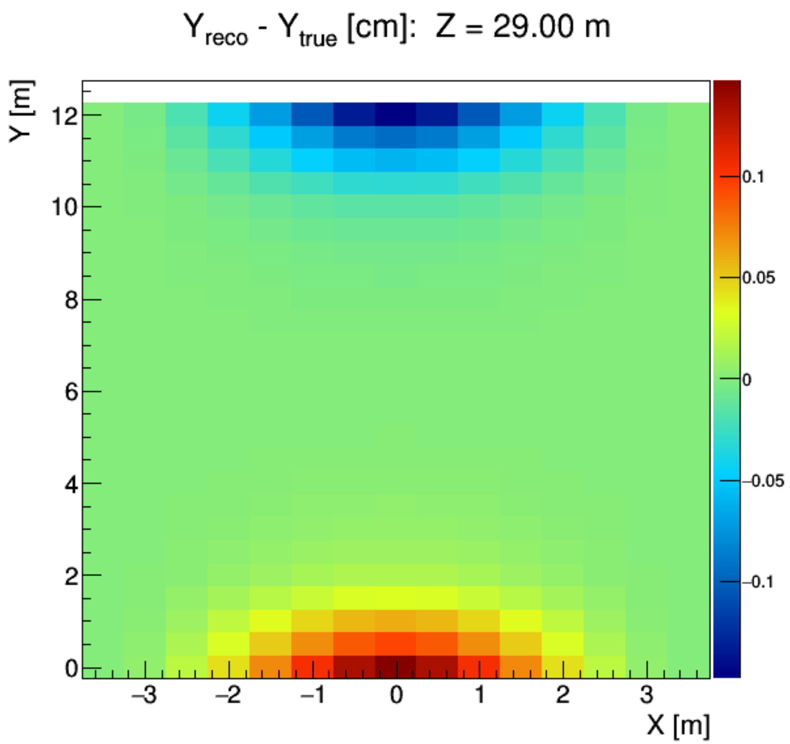
SCE for DUNE SP FD



- DUNE SP FD – looking at one half of central Z slice
    - APA+CPA+APA
- E field distortions on order of **0.1%** – very small!
    - Impact on dQ/dx from recombination **~ 0.03%**

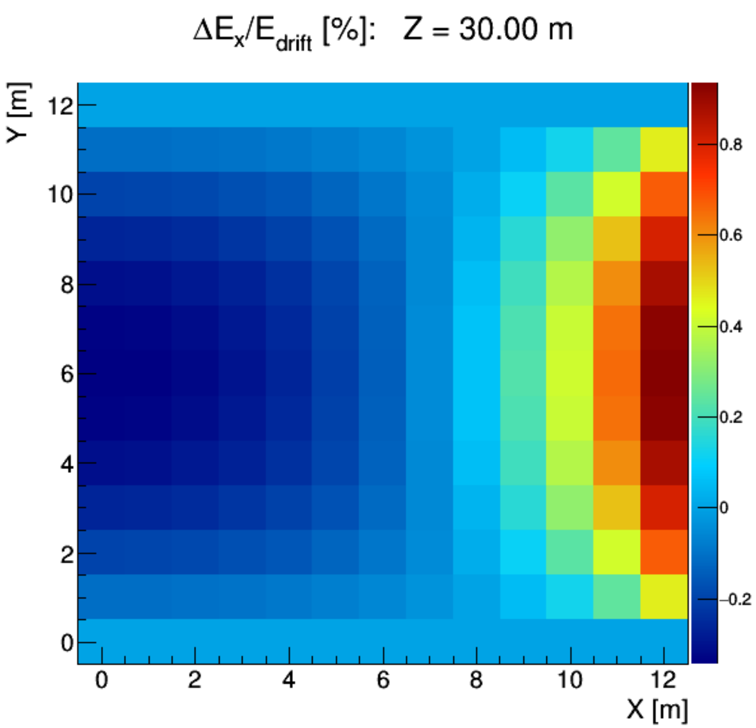
SCE for DUNE SP FD (cont.)

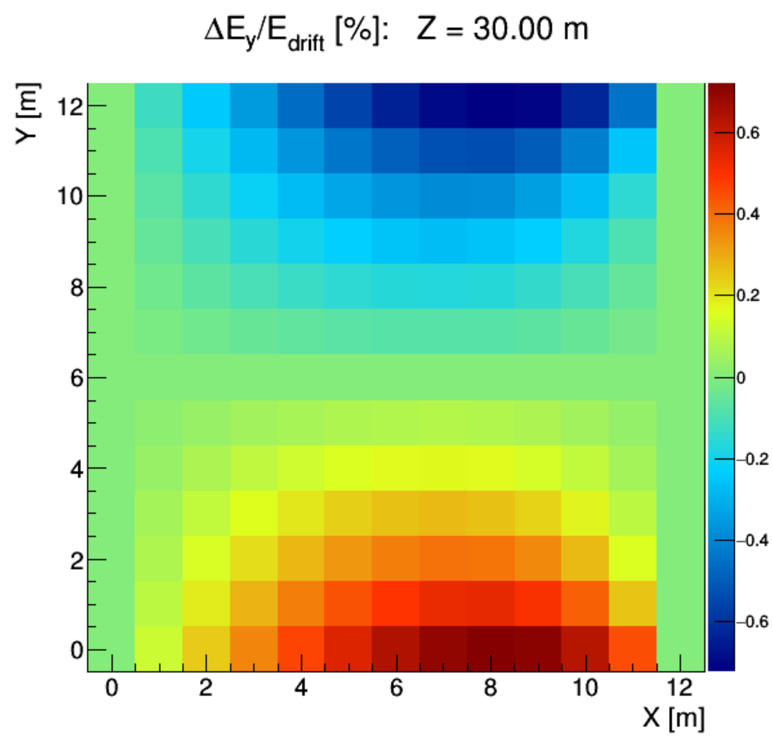




- ♦ DUNE SP FD – looking at one half of central Z slice
  - APA+CPA+APA
- ♦ Spatial distortions on order of **1.0-1.5 mm** – small!
  - Total impact on dQ/dx (including recomb.) **< 0.1%**

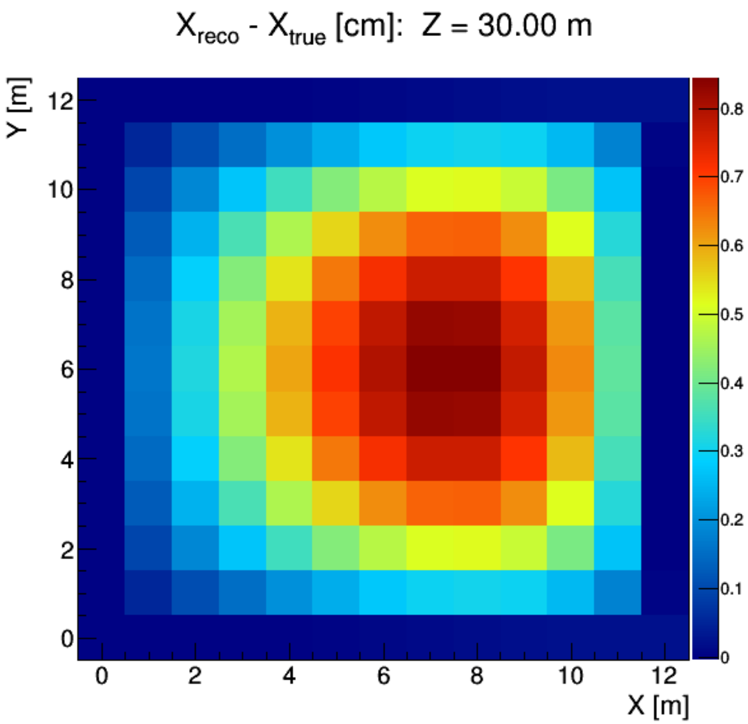
SCE for DUNE DP FD

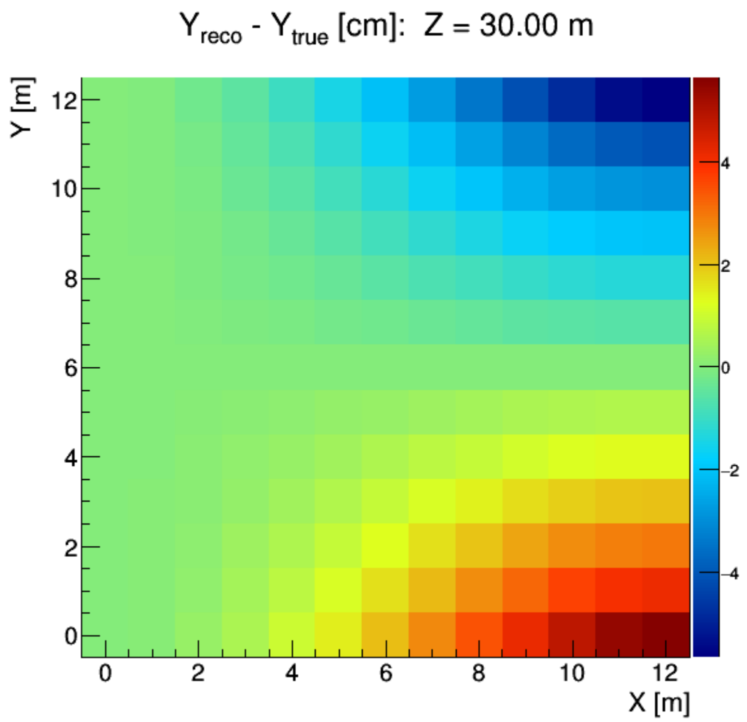




- DUNE DP FD – full detector, central Z slice
  - Ionization **drift is to left** (anode on left, cathode right)
- E field distortions roughly **1%** – larger than for SP
  - Impact on dQ/dx from recombination **~ 0.3%**

SCE for DUNE DP FD (cont.)





- ♦ DUNE DP FD – full detector, central Z slice
  - Ionization **drift is to left** (anode on left, cathode right)
- ♦ Spatial distortions roughly **5 cm** – not negligible!
  - Total impact on dQ/dx (including recomb.) **~ 2-3%**