^{220}Rn Injection Source for DUNE Calibrations

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DUNE CALCI Meeting

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^{220}Rn Source Injection in LAr

- Several hardware calibration options for DUNE FD:
  - Ionization laser system – E field measurements
  - Pulsed neutron source (PNS) – study low-energy electron response
  - Fixed radioactive sources – study low-energy electron response
- Another idea: injection of radioactive sources directly into the LAr – specifically, radon:
  - **^{222}Rn** explored at MicroBooNE (see **here**); useful if avoid LAr filter (copper getter removes ^{222}Rn) but long-lived decay product ^{210}Pb plates out on light detectors (long-term background source)
  - **^{220}Rn** used in LXe dark matter detectors (see **here**) but not yet explored in LAr detectors (to knowledge of M. Mooney)
- Proposal by M. Mooney: investigate ^{220}Rn for DUNE FD and ND-LAr calibrations, with preliminary tests at both the 2x2 ND-LAr prototype and ProtoDUNE II – detailed talk **here**

Making the Case @ DUNE

^{220}RnPo α-decays: measure LAr flow… *maybe*

^{212}Pb β$^-$-decay: low-energy calibration

^{212}BiPo decay: a ton of applications!

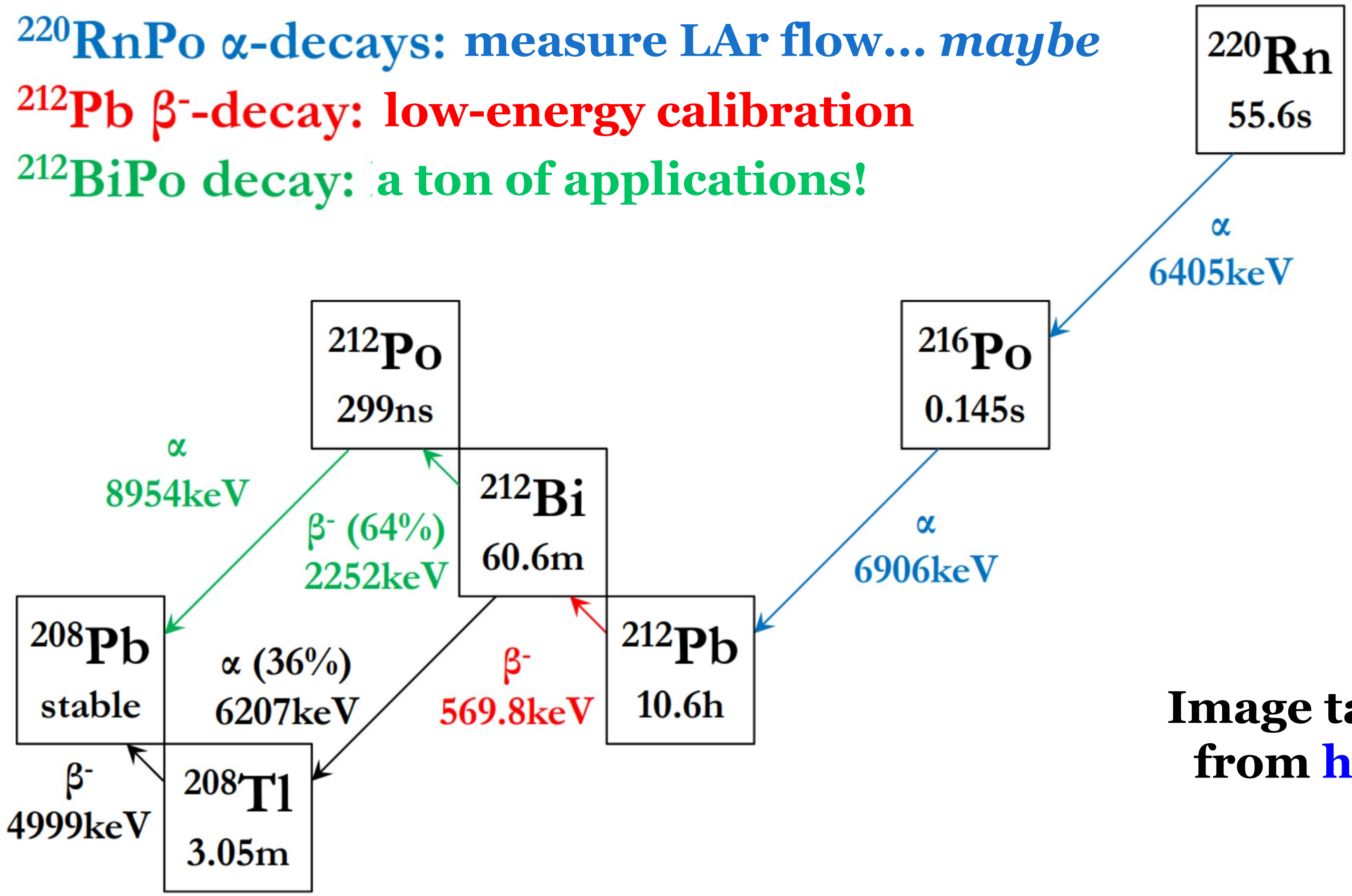


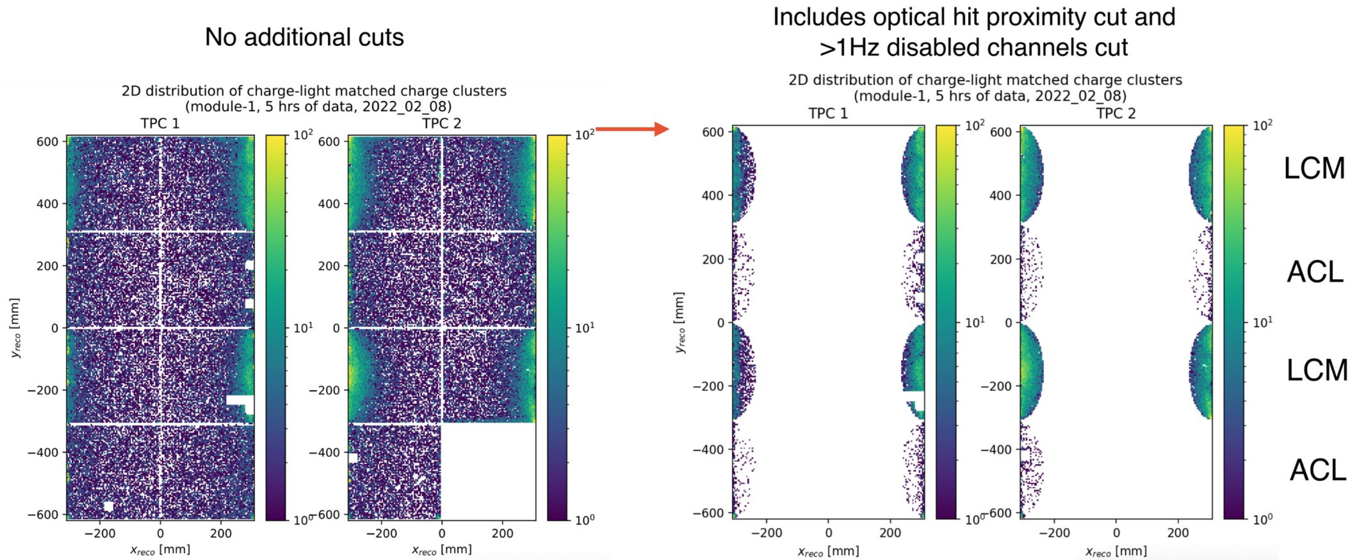
Image taken from here

Calibrations w/ $^{212}Bi \rightarrow {}^{212}Po \rightarrow {}^{208}Pb$

- ^{212}Pb (parent isotope of ^{212}Bi) half-life of 10.6 hours long enough to enable spreading throughout even large LArTPC detectors
  - Convective currents will mix isotope into and throughout active volume
- $^{212}Bi \rightarrow {}^{212}Po$ **beta electron end point of 2.3 MeV** produces charge yield well above charge readout threshold (100-300 keV)
- $^{212}Po \rightarrow {}^{208}Pb$ **alpha energy of 9 MeV** ~300 ns later yields "huge" amount of light for t_0 tag (reconstruct point-like activity **in 3D**)
  - Roughly 350,000 photons produced at single point in detector
- Calibration applications (a sampling, potentially more):
  - **Extract spatial variations in light yield – tune "optical library"**
  - Light detector timing resolution studies (~300 ns between decays)
  - Electron lifetime measurement
  - **Measure electric field** (spatial offsets, recomb. E-field dependence)
  - Mapping LAr flow via migration of decays through detector over time

Charge+Light Matching in 2x2 Modules

Sam Fogarty



- PhD student Sam Fogarty (CSU) leading studies of charge+light matching for "intrinsic" radiologicals within LAr in 2x2 modules
- High-purity selection: > 95% purity w/ proximity cut
- Light detectors: half LCMs (0.6% PDE), half ArCLights (0.2% PDE)
  - Compare to DUNE FD / ProtoDUNE II: **2-3% PDE → should see light from 9 MeV alpha (~350k photons) anywhere in active volume**
  - Trigger threshold artificially high for 2x2 module data-taking, can lower
- More info in Sam's Calibration WG talk (next talk on agenda)

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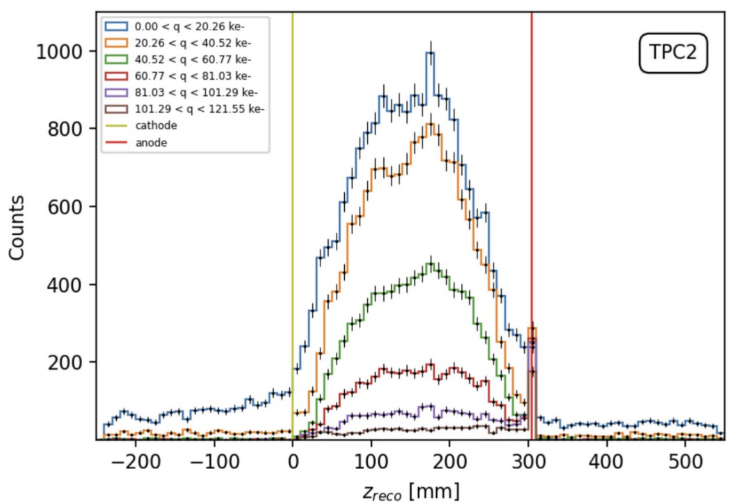

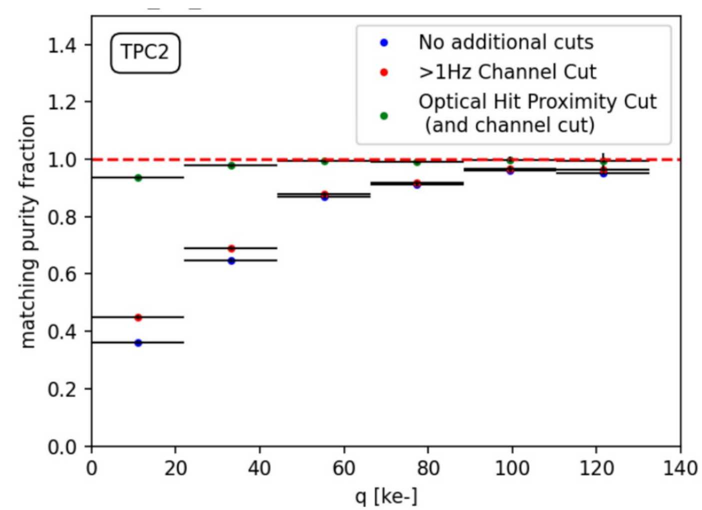

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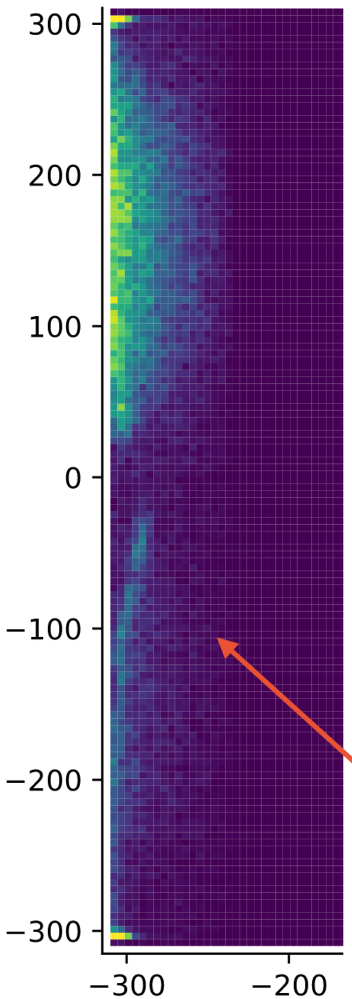
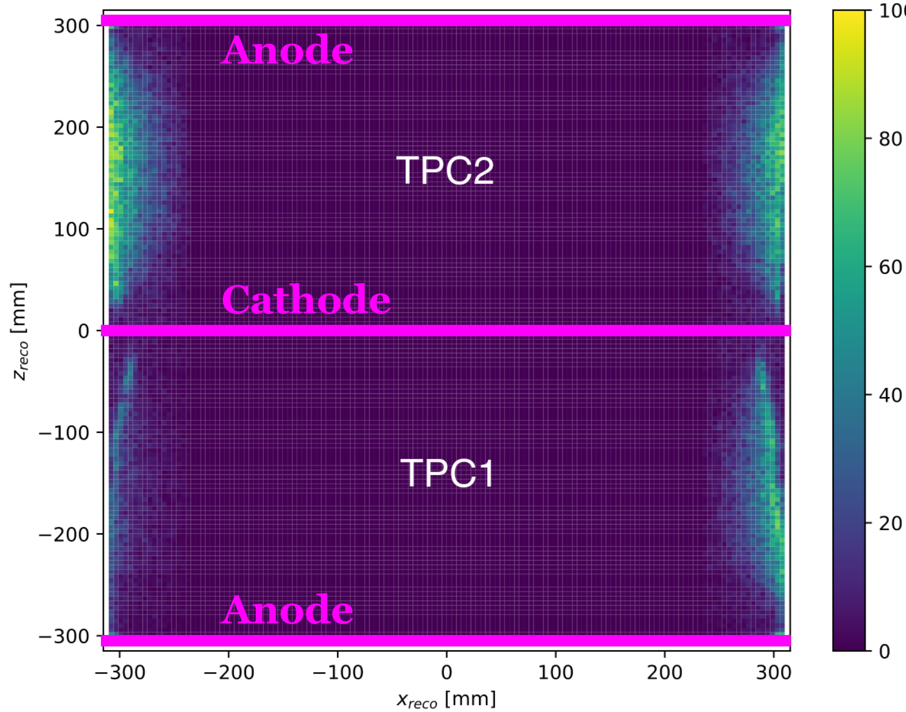
E Field Distortions in 2x2 TPC Module

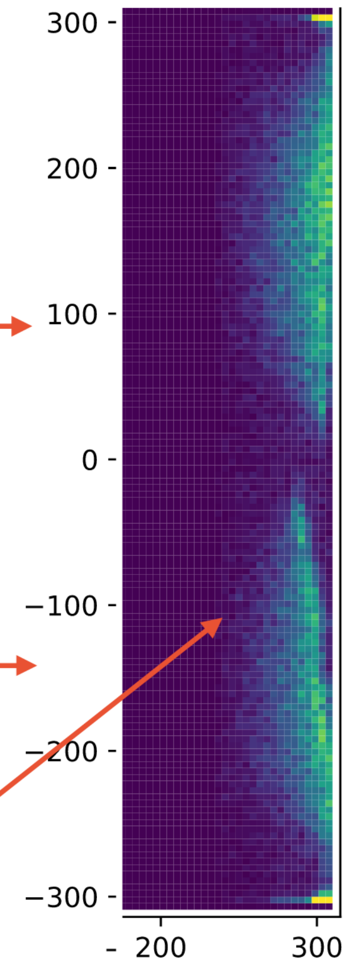
Sam Fogarty

5 hours of data
(on surface @ Bern)

x_{reco} vs z_{reco} - distribution







Indication of E-field distortions in TPC1, caused by non-zero transverse E-field component (~2.2cm offset at y ~ -35 mm)

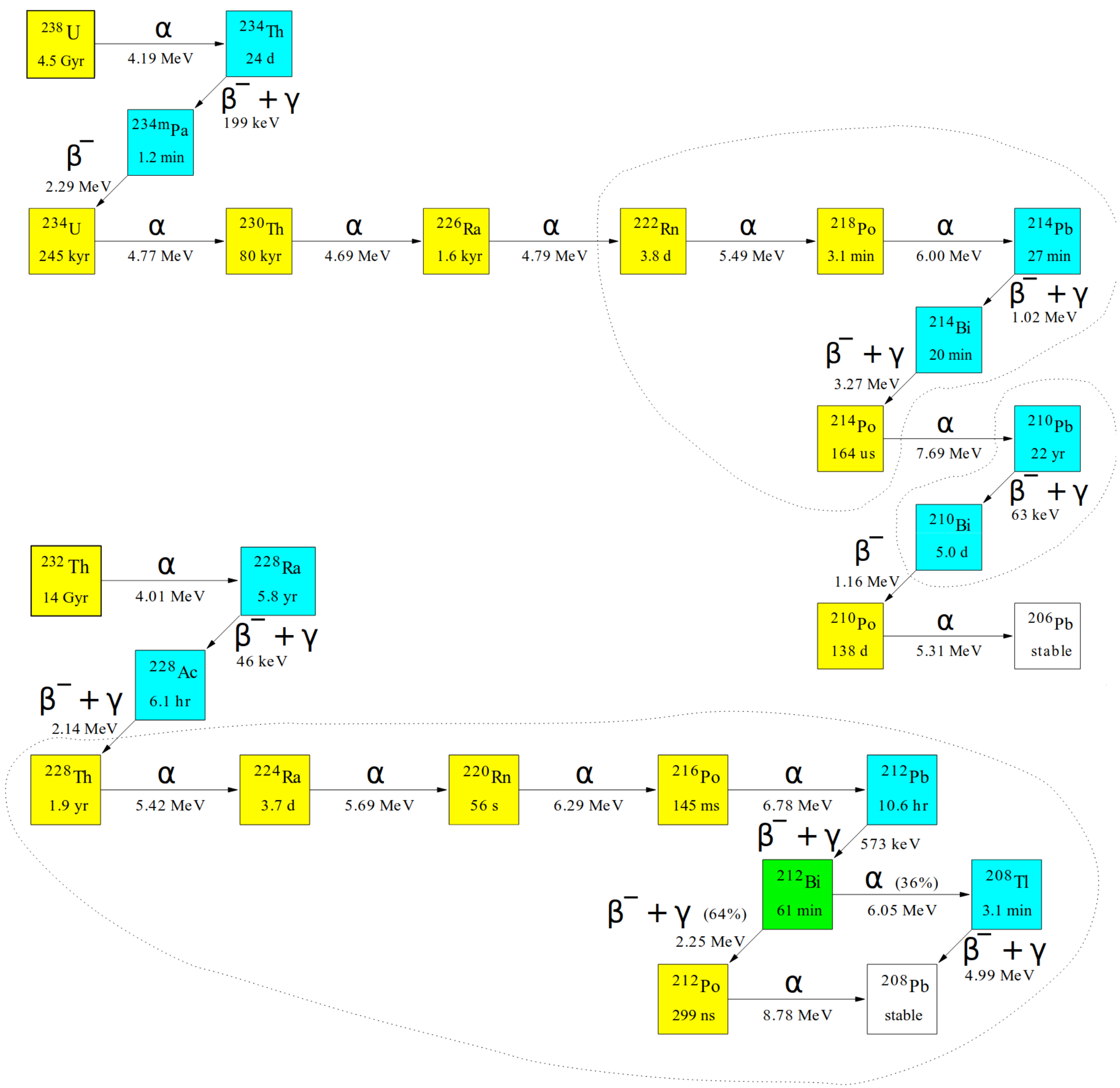
^{220}Rn Injection Plans

- Test w/ ^{220}Rn at CSU R&D LArTPC (cubic foot) to ensure viability
  - Already have ~30 kBq ^{228}Th source, run in December/January
- Follow up with test at ND-LAr 2x2 prototype in early 2024
- Could then carry out test at ProtoDUNE II sometime in 2024
  - Serve as "proof of principle" test for DUNE FD, though tagging light from individual decays will be harder due to large cosmic muon flux
  - Discussing w/ Filippo Resnati; should be straightforward to introduce source after LAr filters via separate gas line (using additional filter for GAr)
- Continue to study potential deployment in DUNE FD
  - DUNE VD FD fluid flow maps from Erik Voirin suggest that ^{220}Rn will spread throughout active volume reasonably well – see backup slides
  - Study capability of tagging light from individual decays given large size of detector (multiple nearby decays → potential combinatorics problem)
  - Check DAQ capabilities to see how to maximize detector duty cycle while source active (e.g. high trigger rate)

Proposed PD II Input Line

BACKUP SLIDES

$^{238}U/^{232}Th$ Decay Chains



Modeling Decay Rate

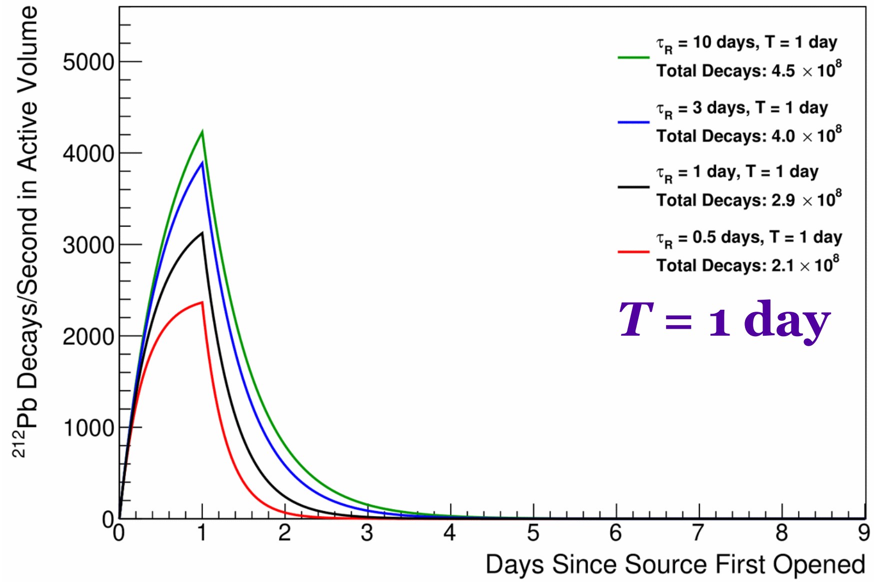
- Assume secular equilibrium for upstream decays in decay chain (^{228}Th → ^{224}Ra → ^{220}Rn) and ^{220}Rn → ^{216}Po → ^{212}Pb instantaneous
- Model amount of ^{212}Pb in total volume, $N(t)$, assuming constant source activity S, ^{212}Pb lifetime τ, LAr recirculation timescale τ_R (included as a "decay" term), and time source "open" T
- Finally, compute ^{212}Pb decay rate in active volume, $D(t)$, assuming uniform distribution of decays throughout detector and active-volume-to-total-volume ratio f

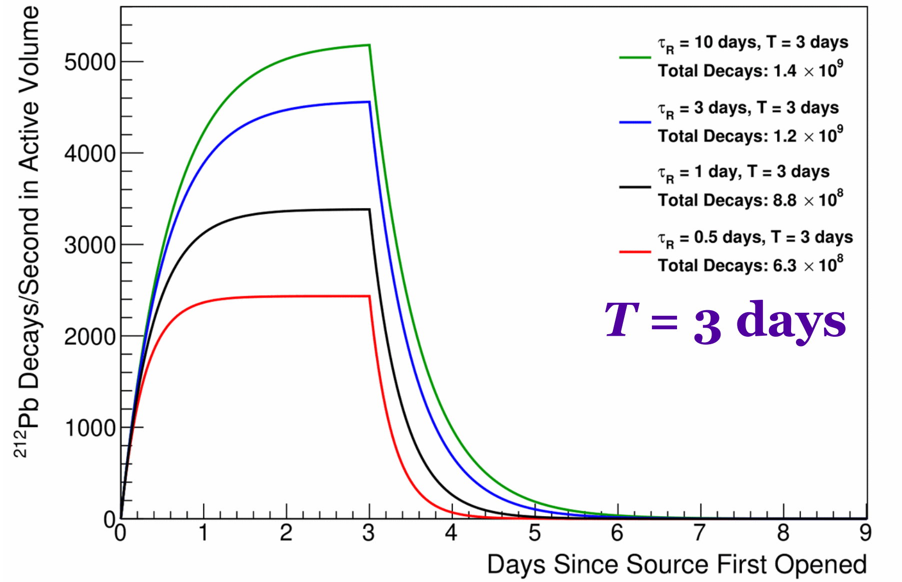
$$\frac{d}{dt}N(t) = S\left(\theta(t) - \theta(t-T)\right) - \lambda N(t) - \lambda_R N(t)$$

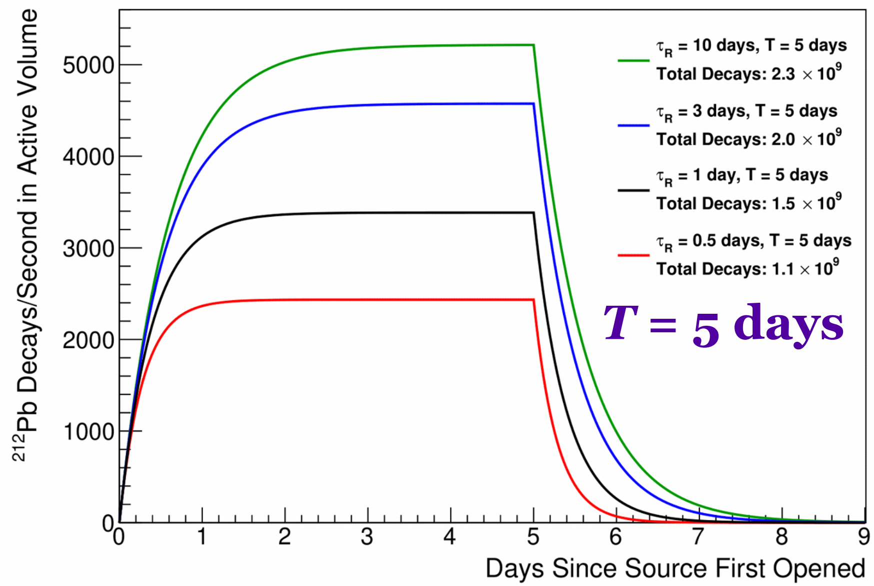
$$N(0) = 0 \qquad \lambda \equiv \frac{1}{\tau} \qquad \lambda_R \equiv \frac{1}{\tau_R}$$

$$D(t) \equiv f\lambda N(t) = fS\frac{\lambda}{\lambda+\lambda_R}\left[\left(1-e^{-(\lambda+\lambda_R)t}\right)\left(\theta(t)-\theta(t-T)\right) + \left(1-e^{-(\lambda+\lambda_R)T}\right)e^{-(\lambda+\lambda_R)(t-T)}\theta(t-T)\right]$$

Results: Decay Rate vs. Time







Assumptions:

S = 18.5 kBq

f = 0.3

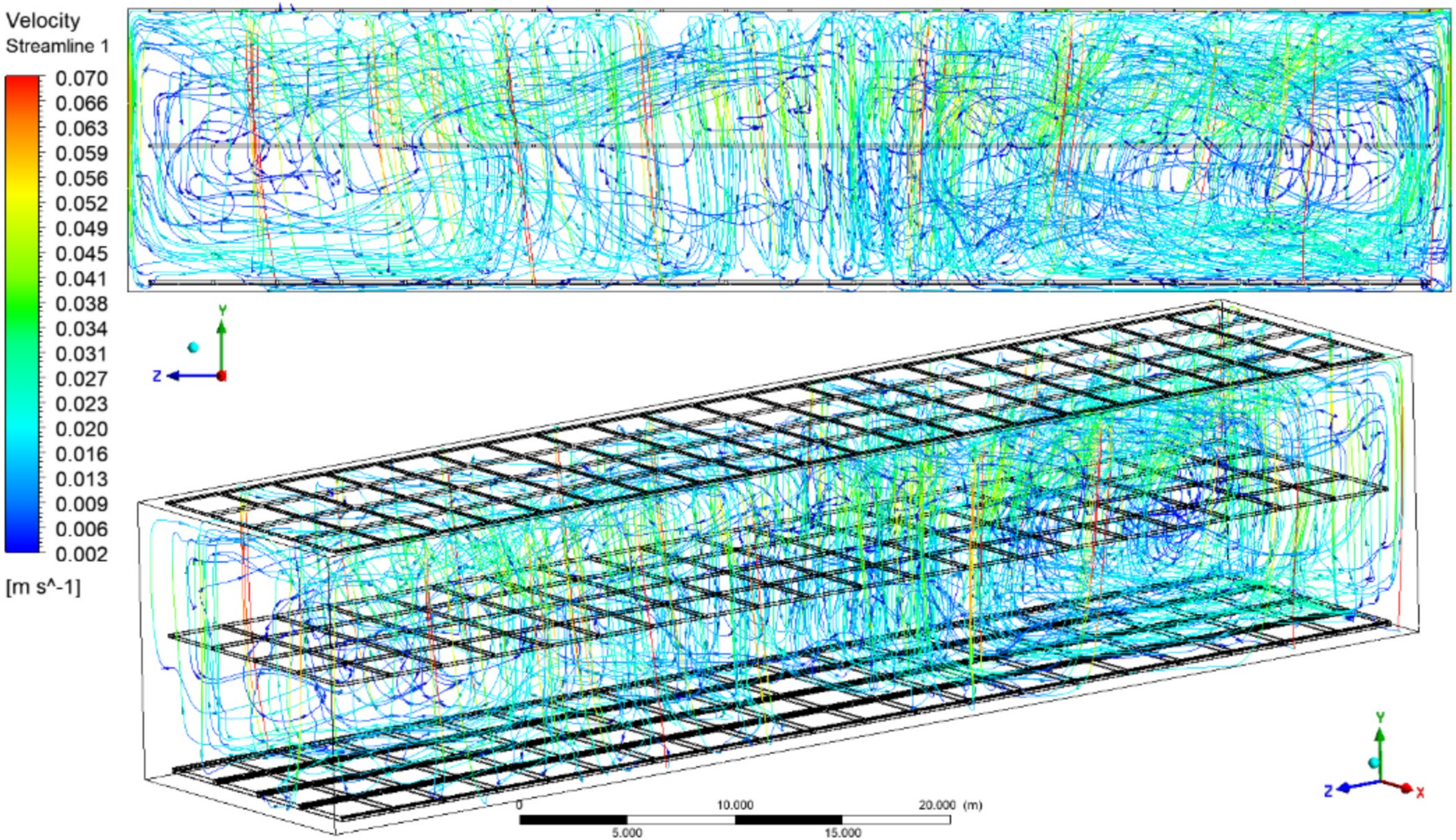
τ = 0.64 days

τ_R: varies (see plots)

T: varies (see plots)

DUNE VD FD CFD Model

Erik Voirin
(see here)



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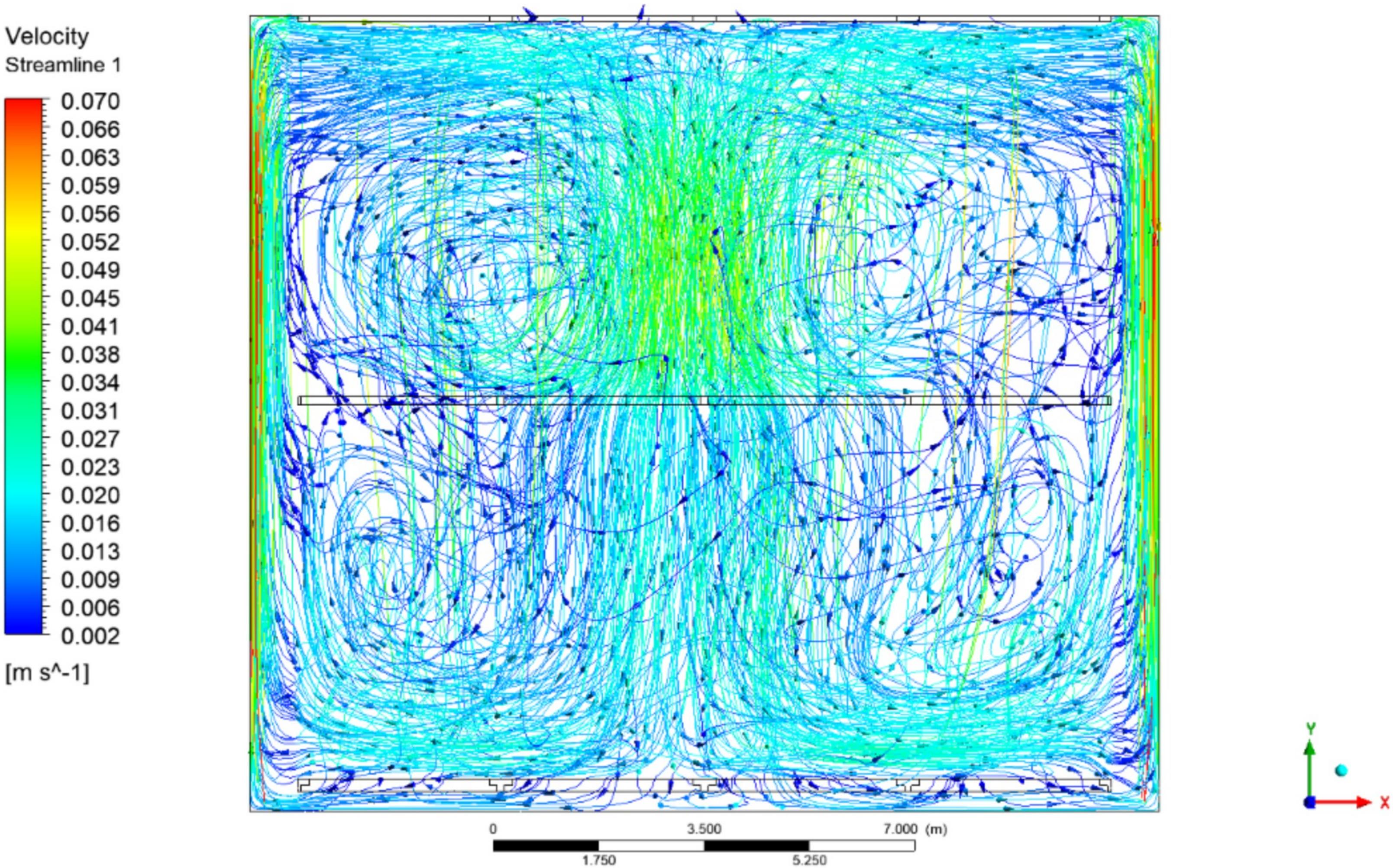
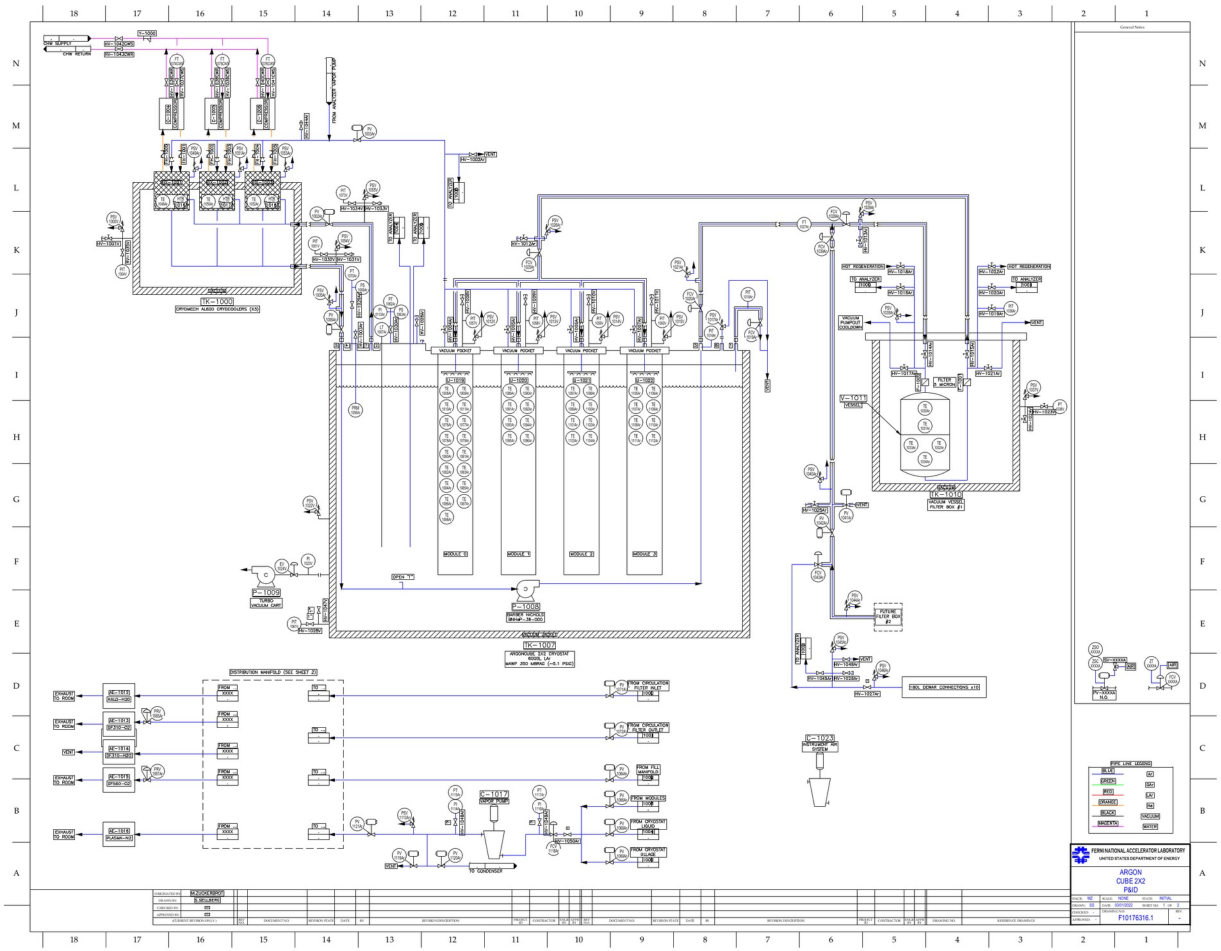


^{220}Rn at ND-LAr 2x2 Prototype

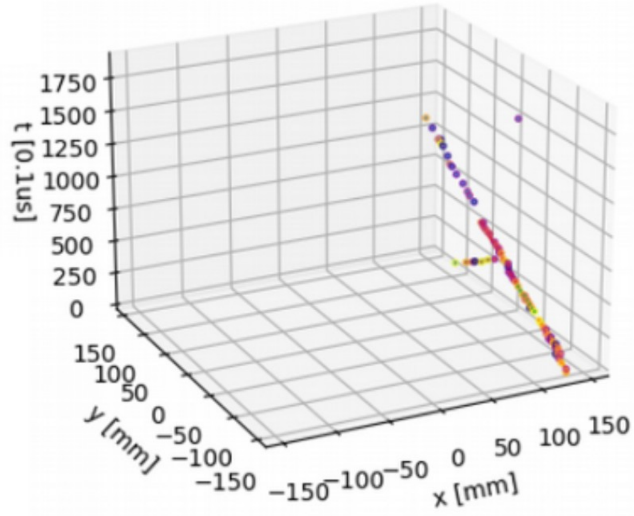


Mike Zuckerbrot:

"Draw a small amount of flow from the gas analyzer tap at the filter outlet, route it into the analyzer valve manifold, and with some valve routing trickery, we can bring it back out of the panel, past your radon source vessel, and into the ¼" dipstick that goes **below liquid level** which would typically be used to sample the cryostat liquid to the analyzers. Downside would be during that process we lose the ability to sample from most system points, but once we are pure and the detector is working, that probably doesn't matter. It would also be possible to install a dedicated ¼" dipstick, we have a couple ½" spare ports available it would fit in. **I don't see any showstoppers or enormous costs with the proposal.**"

CSU SingleCube – 2021 Run

- Successful CSU SingleCube run on Friday, April 16th – complete tracks observed!
  - Max PS setting of 20 kV (E_{drift} = 550 V/cm)
  - 100+ μs electron lifetime w/o LAr recirculation
  - Stable pixel plane trigger rates
- Pursuing cost-effective upgrade to implement LAr recirculation in order to further increase electron lifetime
- *Setup ready to serve as ND-LAr test stand*



CSU SingleCube Tracks