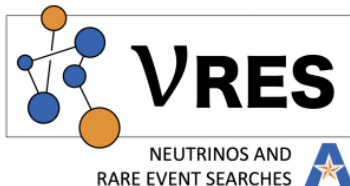
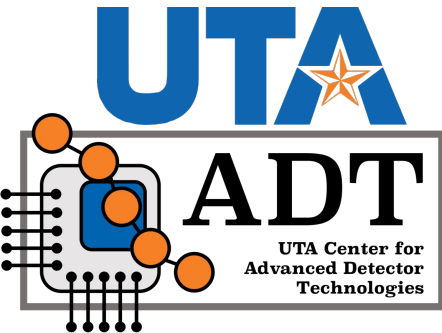
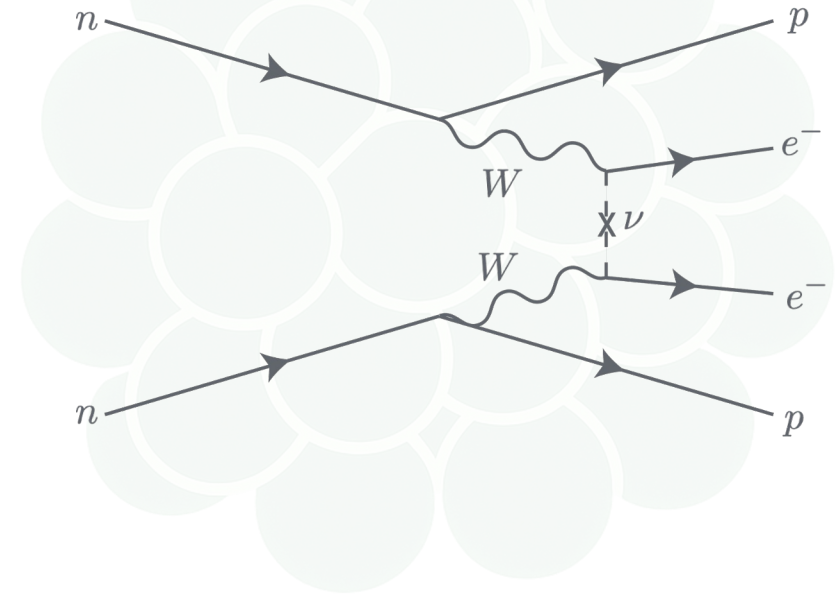


Ton-scale Xenon Gas TPC for $0\nu\beta\beta$ Search at Atmospheric Pressure

Krishan Mistry, David Nygren, Yuan Mei

Second Workshop on Neutrinoless double beta decay search in Xe - next-generation experiment

Paper just dropped on the arXiv!
[arXiv:2609.07378](https://arxiv.org/abs/2609.07378)

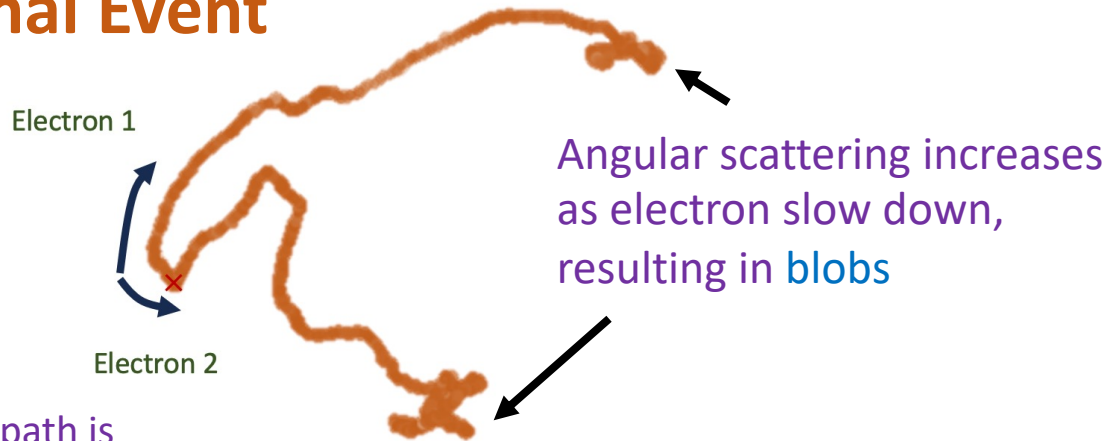


September 2026

krishan.mistry@uta.edu

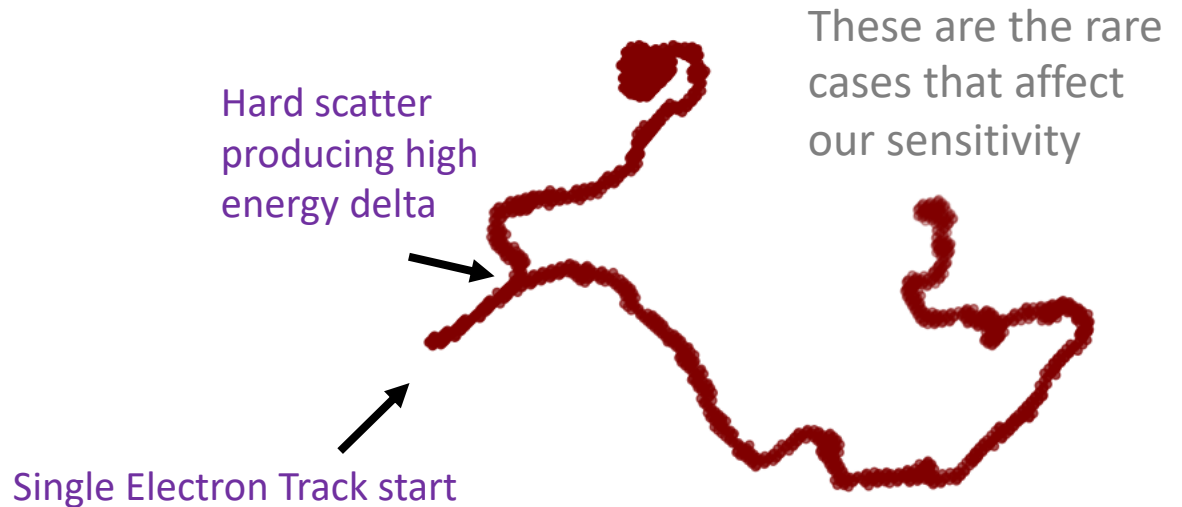
Gas TPC Event Topology

Signal Event



Electron path is straighter when they have the most energy

Background Event



Track Clarity

- Optimize for the best track clarity:

- Diffusion ($\sigma^2_{\max}$) scales as $\rho^{-4/3}$
- Track length (l) scales as $1/\rho$

$$\left. \begin{array}{l} \rightarrow \text{Diffusion } (\sigma^2_{\max}) \text{ scales as } \rho^{-4/3} \\ \rightarrow \text{Track length } (l) \text{ scales as } 1/\rho \end{array} \right\} \text{FOM} = l^2 / \sigma^2_{\max} \sim \rho^{-2/3}$$

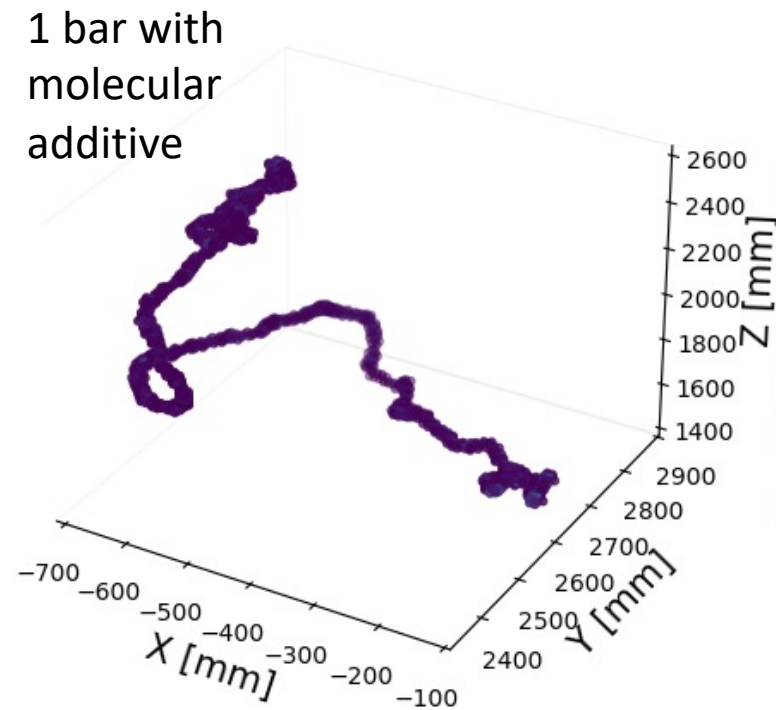
~ factor of 6 better clarity 1 vs 15 bar

1. Turn down pressure all way to 1 bar “Atmospheric TPC”

Tracks are big ~ 2-3 m!

2. Add molecular gas additive CO_2 for strong reduction in diffusion

- Factor of 10 reduction in diffusion with respect to pure xenon!



Benefits of Choice

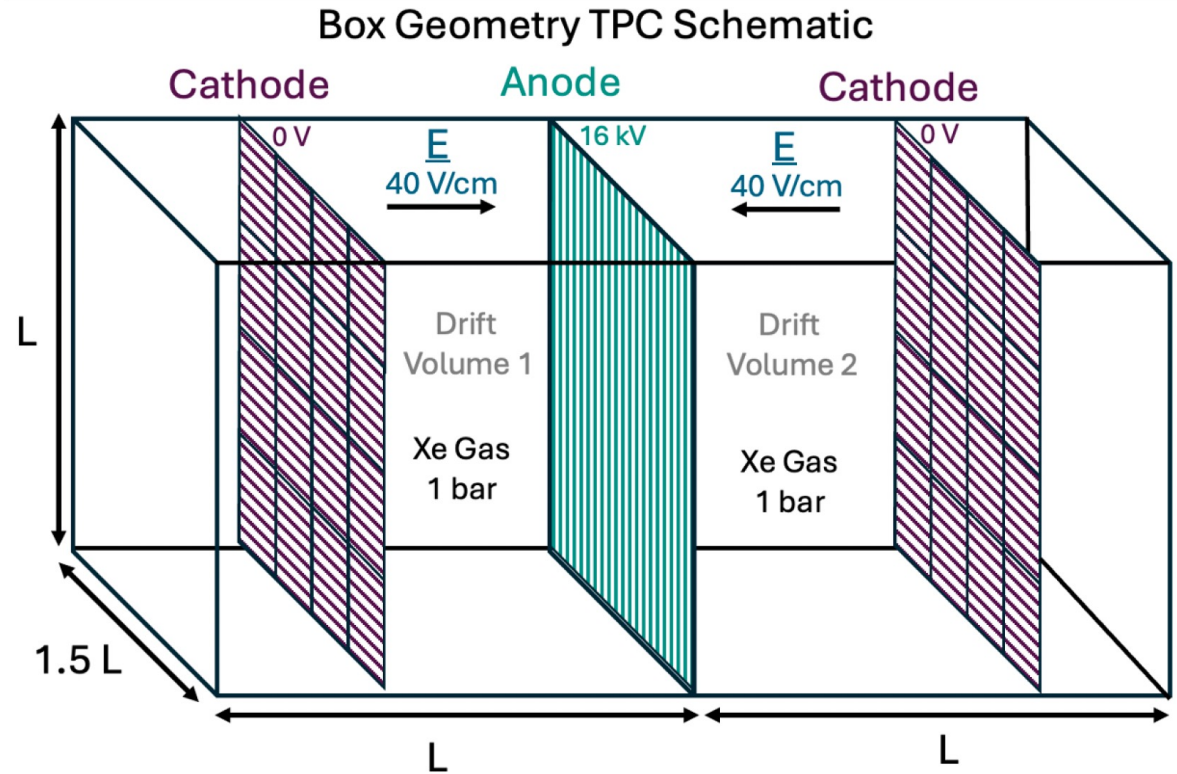
1. Mechanical containment at 1 bar is low-cost and simple to fabricate underground
 - No need for high pressure vessel/cryogenics
2. HV requirements are only 16 kV with potential difference of only 20 V for each 0.5 cm step in the field cage
 - No need for a complicated field cage design
3. Greater transparency to γ -rays partly compensates for larger surface area
4. Electron attachment will be much smaller than at higher pressures

Impacts of Choice

1. No S1 or electroluminescence due to quenching of the scintillation signals
 - Different amplification process needed for energy measurement
2. Cannot get z position from S1
 - Particularly important for removal of radon backgrounds and calibration
3. Detector is large - 4-6 m in size
 - More surface area, more copper shielding, more intrinsic background, and lower containment efficiency (affects signal + background)

Detector Concept (1 ton module)

- Multi wire proportional chamber style anode readout
 - Proportional Avalanche gain
 - Minimal materials inside detector walls
- Shield with 12 cm thick commercial copper and water shield



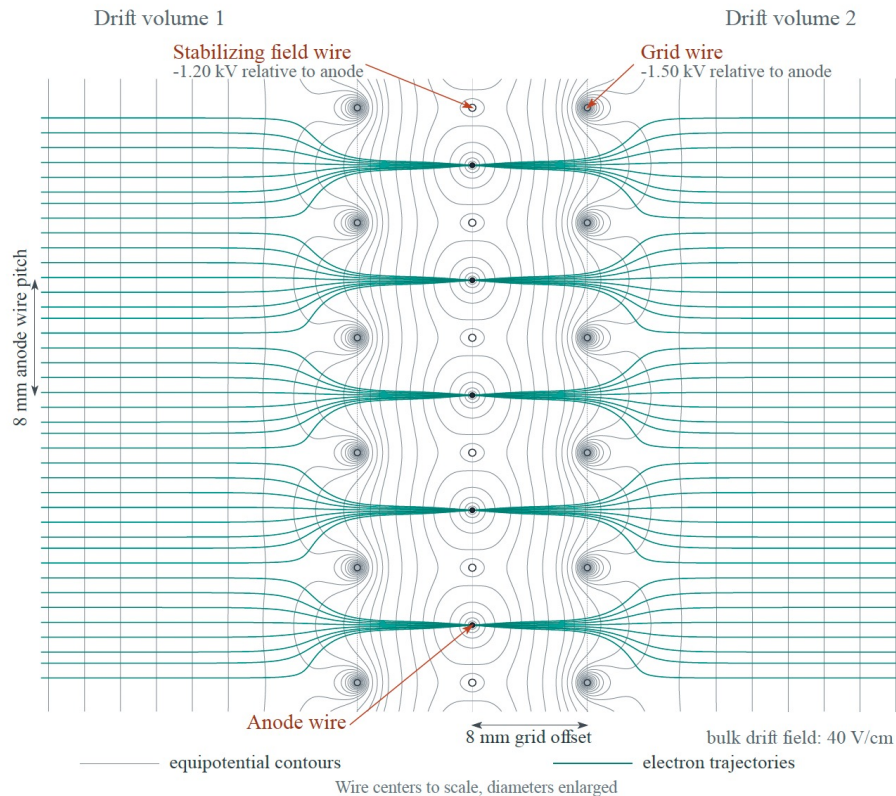
Cathode gives y, t measurement with the secondary ion avalanche signal

Anode wires give x, t measurement

Stitch together 2D projections to make 3D tracks (similar to LArTPCs)

Anode (x, t): Energy Measurement with Proportional Avalanche Gain in Xe-CO₂

Anode Region

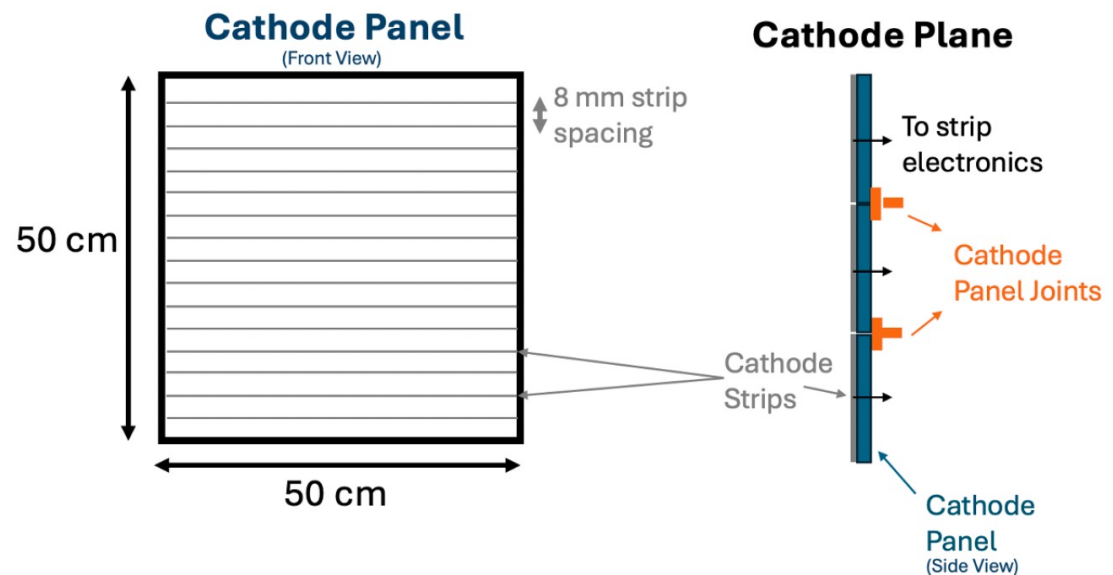


Array of vertically hanging wires, 8 mm spacing. Anode signal dominated by signal induced by the ions

- A key R&D path to be demonstrated is: can we get 1% FWHM energy resolution with proportional avalanche?
- **Optimistic case:** ¹⁰⁹Cd x-ray extrapolation from 22 keV → 0.75% FWHM resolution
- **Practical case:** Gotthard TPC experiment resolution achieved 5% FWHM resolution extrapolated to 2.5 MeV (they achieved their goal)
 - Seems likely we need to measure induced signals on all electrodes and carefully control other factors

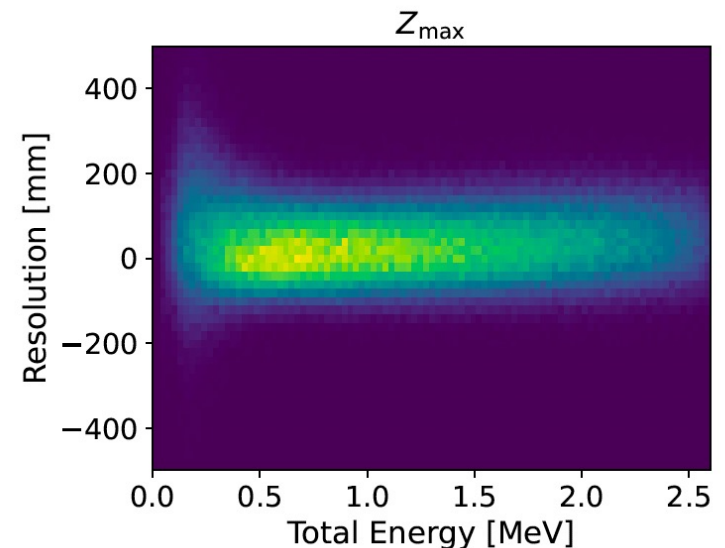
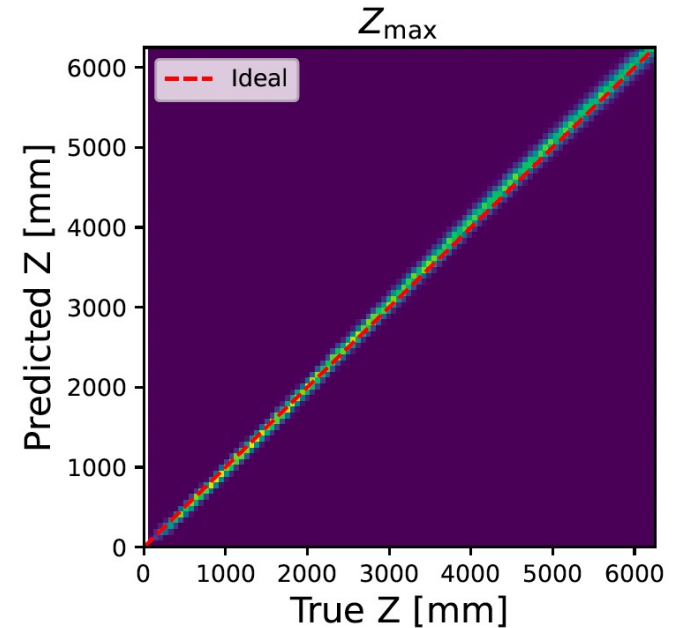
Cathode (y, t): Secondary Ion Measurement

- Ions from the avalanche drift mainly to cathode
 - Secondary signal is used to extract the (y, t) information
- Cathode arranged into panels with readout strips perpendicular to the anode plane
- Possibility of using scintillating plastic to tag charged particles crossing or occurring on surface



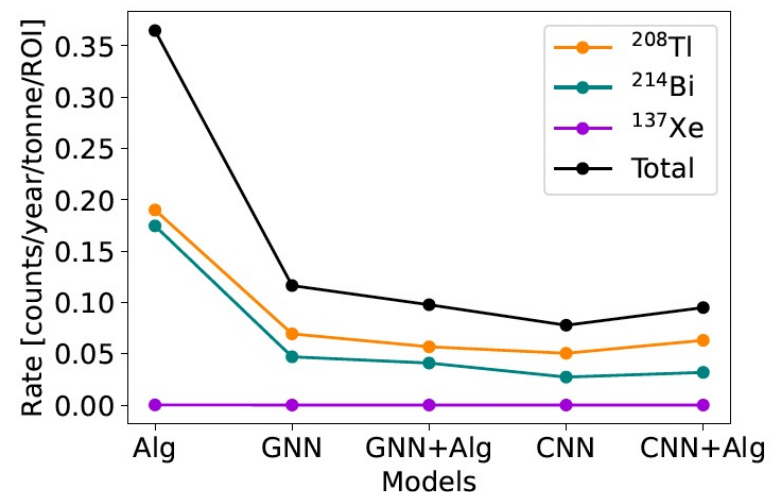
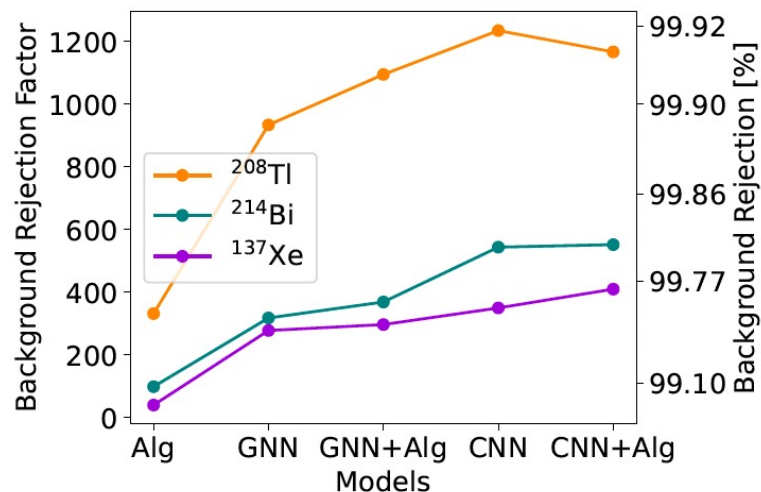
Placement of z-position with no S1

- Placement possible using diffusion of events
 - Larger z results in larger diffusion
- Sparse 3D Convolutional Neural Network to predict z position
 - $z_{\max}$ RMS is 8.5 cm all energies
 - Reduces to 7.5 cm for tracks with energy greater than 1 MeV
 - Further progress seems likely
- Primary ion readout is another option, but this is hard!



ML Analysis Performance (ROI)

- ML can utilize the detailed track topology
- Compare simple analysis [[JINST 21 P04035](#)] to various ML selections (CNN and GNN)
- Despite the lower containment efficiency ($\sim 50\%$), we can get an extra factor 3-4 with ML to get towards 0.1 counts/ton/year



Demonstrator Experiment

- Demonstrator should hold about 100 kg xenon (10% scale)
 - Site location at SNOLAB/Canfranc/SURF/Boulby
- Essential Goals
 1. 1.5% FWHM energy resolution at MeV energy
 2. Head to tail classification at >95.5% background rejection
 3. 3D reconstruction using anode and cathode plane signals
 4. Demonstration that space charge effects and ionic clustering do not affect the placement in y
 5. Operation stability using xenon + molecular additive mixture
 6. Performance must be sufficient to justify ton-scale experiment

Perspectives and Summary

- An audacious but surprisingly plausible concept!
- The background target of 0.1 counts/ton/yr is feasible with machine learning and the detailed tracks
- R&D needed to prove we can reach the desired energy resolution at MeV energies
- A 100 kg scale demonstrator will be required to justify a tonne-scale module
- Further exploration and development seems justified

Extras

Energy Resolution

- All factors that, if left uncorrected, degrade the energy resolution must be clearly understood and kept under control to a high level
- Due to the diffusion of the electron clouds, ion signals generated can be spread around the wire surface
 - Causes some ions to be collected onto the grid electrodes introducing fluctuations that degrade the resolution
 - Need to measure the signal on these electrodes in addition to the anode wires

Energy Resolution

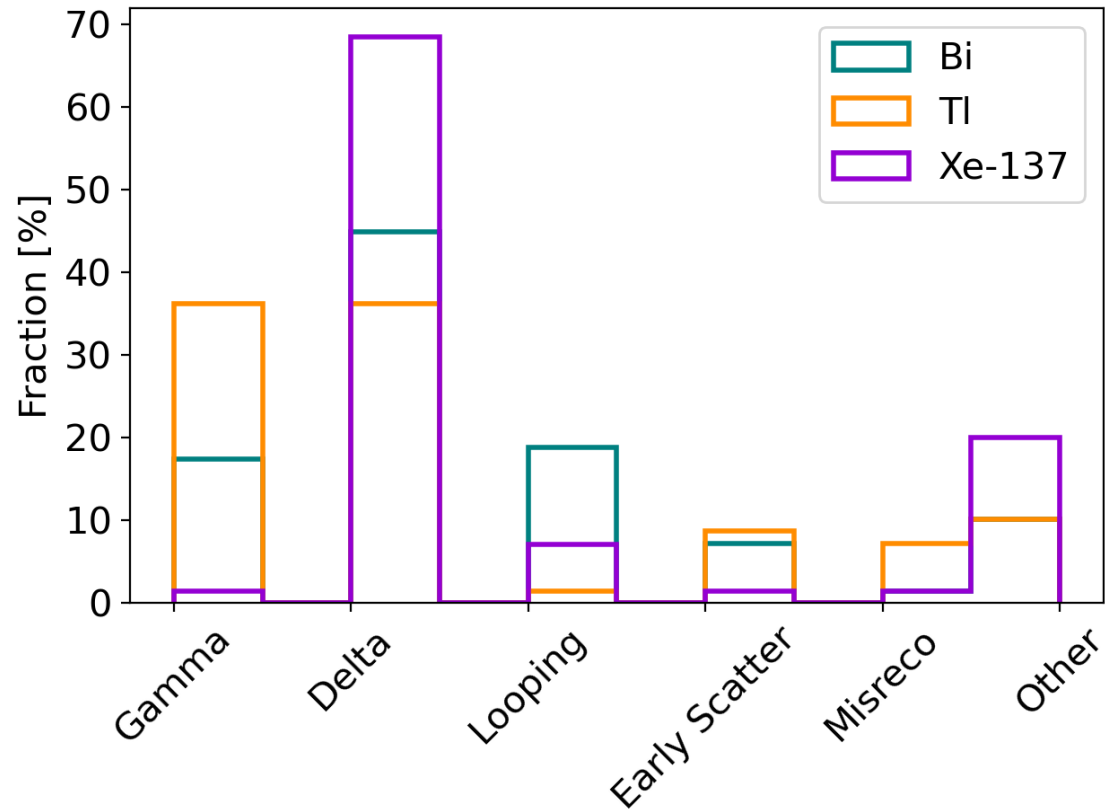
We also identify six other factors which can degrade the energy resolution

1. Geometrical/Mechanical imprecisions of the wires
2. Anode wire uniformity
3. Imperfect electric fields
4. Gas flow and pressure variations along with attachment
5. Channel gain variations
6. Inadequate capture of $1/\text{time}$ signal current by electronics

Background Topologies

Plot shows the reason for background being selected. E.g. gamma means a gamma ray re-interacted near track start producing a second blob

- Largest backgrounds are from deltas and gamma interactions near the track beginning
- ^{137}Xe have the lowest background rejection power and highest delta population



Fractions from hand scan of 70 selected events

Gas System

- May use a similar system to the ALICE Transition Radiation Detector
 - ALICE Operated with Xe-CO₂, 85-15 ratio at 1 bar
 - We will likely operate close to 95-99% Xe
- Commissioning with a flush of pure argon or argon plus CO₂ until oxygen and water levels are low
- Xenon recovery can be done via cryogenic capture which can also remove the slow build up of nitrogen
- Use of hot getters will require the removal of molecular additives

Tracking Algorithm with GNN

- Implement a tracking algorithm to walk along track
 - Construct primary, delta rays, track start/end, and gamma/x-ray deposits
- Also extract the angular information of the track which can be provided as an additional handle to identify blobs and topology

