Directionality/Micron-Precision

PRD-2 (Develop new modalities for signal detection)

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Relevant LOI's:

"Dual-readout time projection chamber: exploring sub-millimeter pitch for directional dark matter and tau identification in ν_τ CC interactions" (contact: Elena Gramellini <elenag@fnal.gov>)
"Towards directional nuclear recoil detectors: tracking of nuclear recoils in gas Argon TPCs" (contact: David Caratelli <davidc@fnal.gov>)

Instrumentation requirements to achieve physics goals

New dark matter searches breaching the neutrino floor, a full characterization of the CEvNS energy spectrum and the study of ν_τ interactions at high statistics all require the development of new detector technologies.

Common instrumentation requirements are:

- Large target mass to overcome small event cross sections
- O(10-100) μm tracking capabilities
- Prompt processing (order of min max) to collect high statistics for CEvNS and ν_τ events
- Adequate signal-to-noise to measure nuclear recoil (NR) ionization and short tracks
- Smart ROI triggering solutions for viable micron-level readout (avoid extreme # of channels)

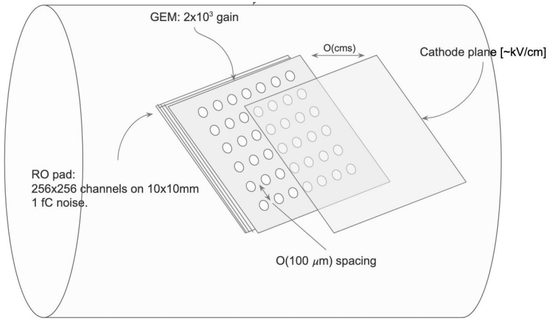
The primary goal of the efforts is to develop detectors capable of tracking O(10-100) μm ionization tracks produced by O(10-100) keV NRs or by the short lived tau lepton.

GArTPC at O(10) atm pressure with optimized new readout technologies could offer an opportunity. Proposed solutions, currently at development early stages:

1. Micron-readout at the anode with GEM technology
2. Dual-Readout TPC based on coarse anode readout (mm pixels, like Q-Pix[1]/LArPix[2]) and localized micron-readout at the cathode (TopMetal or Ion Microscopy)

Significant instrumentation challenges

Schematic of prototype setup in HPGAr environment.



μm sensor pitch w/ o(10s) keV E: realization

- High-granularity GEM sensor → current technology limit in spacing o(100 μm)
- TopMetal CMOS → ~ 87 μm [3], < 15 e− analog noise. Demonstrated e- and ions readout
- Ion spectroscopy → EMCCD camera: ion tracks with μm precision. Need search for optimal chemosensors for positive ions.

μm sensor pitch: scalability

- Instrumenting a large area (ton scale detector): channel counts ~10^6 million μm pixels is unviable.
- Leverage drift velocity difference between electrons and ions for smart ROI trigger on electrons + movable readout of ions at the cathode (demonstrated for barium tagging [4])

Gas properties: Diffusion

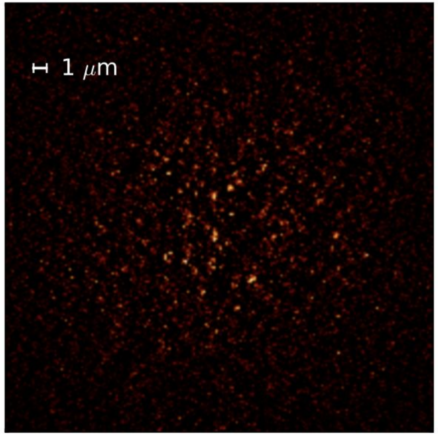
- Limiting diffusion effects through gas doping or via the use of ions as primary carriers (or both)

Viability demonstration

- Efforts are at the early stages: need technology demonstration first, then characterization of tracking resolution capabilities

Collaborators welcome!!

- Want to build a broad effort to enhance micron tracking, common R&D platform would be ideal.



A sample image from the EMCCD showing both near-surface (bright) and deeper (dim) fluorescent molecules.

Relevant physics areas

Solutions for Micron Precision tracking at GArTPC target future neutrino experiments. They could be tested at the SNS facility at ORNL and in the context of DUNE near detector.

The target physics goals are:

- Tracking of o(10-100) MeV Nuclear Recoil:
  → Constrain kinematic of elastic interaction for CEνNS characterization
  → Abate backgrounds for directional low energy Dark Matter

- High statistics ν_τ via τ tracking and neutrino interaction vertex reconstruction.
  → Neutrino Oscillations (Unitarity) and Tau Neutrino Physics

Relevant cross-connections

- (NF10) Neutrino detectors
- (NF6) Neutrino Interactions/Cross-Sections
- (NF3) Beyond the Standard Model
- (CF1) Dark Matter: Particle-like
- (IF07) Electronics/ASICs
- (IF08) Noble Elements
- (IF09) Cross Cutting and Systems Integration