Noble Element Detectors WG3

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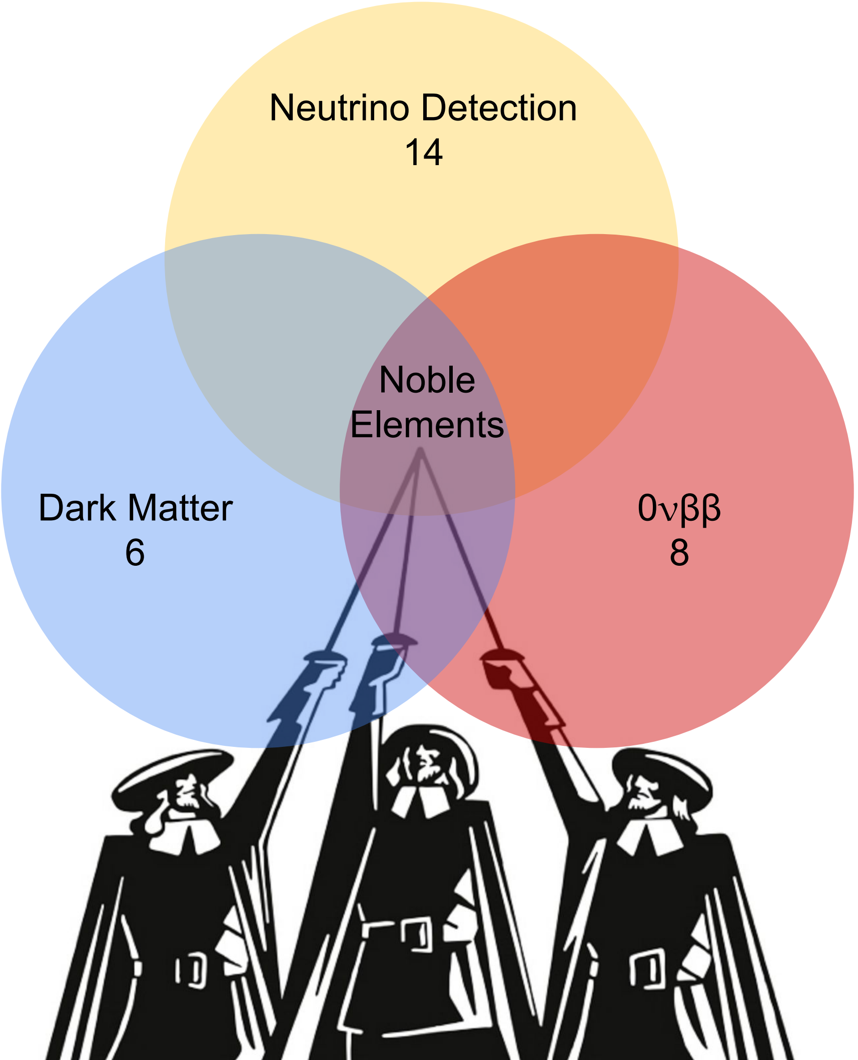
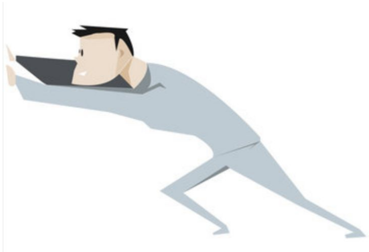
28 Contributions



Neutrino Detection [MeV - 10 GeV]

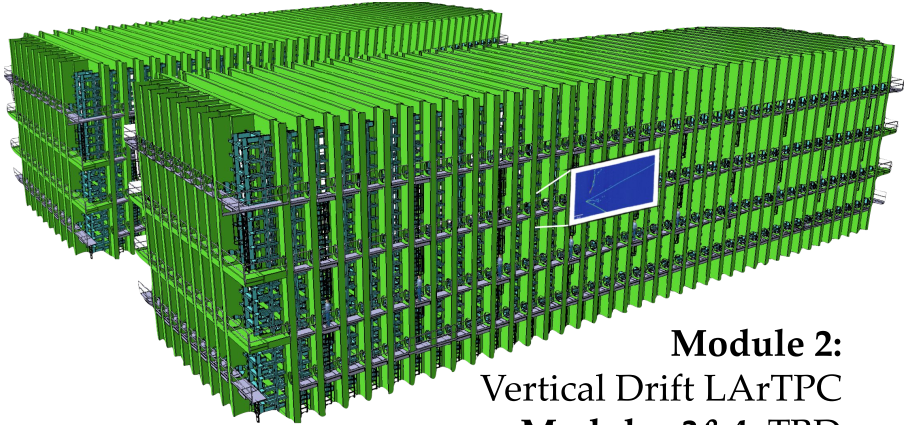


Multi-purpose & Multi-(K)Ton LArTPC neutrino detectors

DUNE

Long Baseline Neutrino Oscillation, Supernovae, BSM rare events
(potentially Solar Neutrinos)

Module 1: “Classic” 10 kTon LArTPC



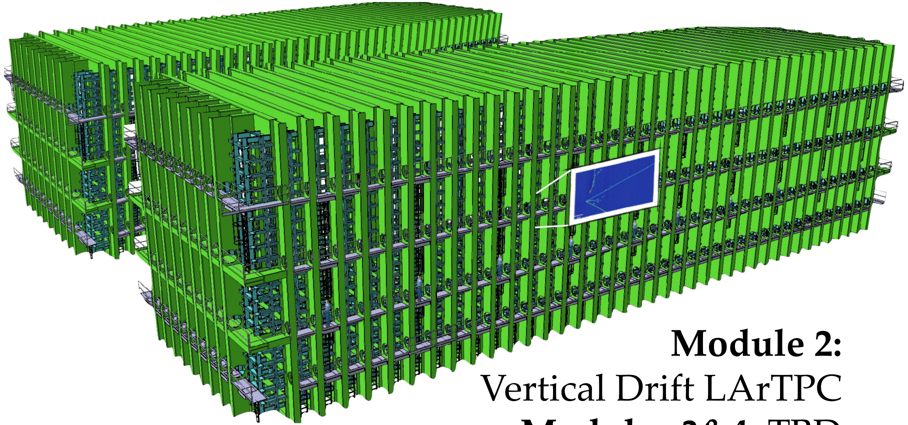
Module 2:
Vertical Drift LArTPC
Modules 3&4: TBD

Multi-purpose & Multi-(K)Ton LArTPC neutrino detectors

- Modeling the electric field is fundamental.

In A Hybrid 3D/2D Field Response Calculation for Liquid Argon Detectors with PCB Based Anode [Sergey Martynenko], the field response is calculated via a Finite Difference Method for the technology of DUNE's Module 2.

Module 1: "Classic" 10 kTon LArTPC



Module 2: Vertical Drift LArTPC
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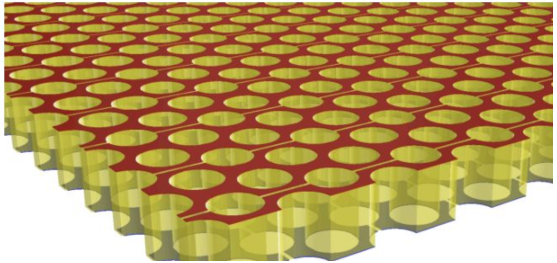
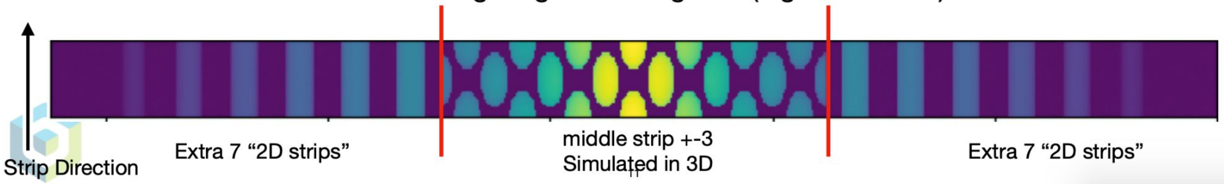


Within 5% agreement with CERN 50-L prototype detector



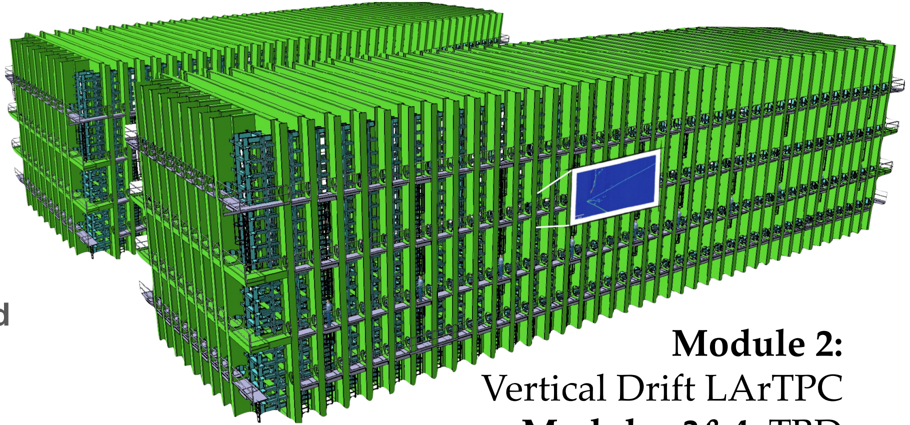
Multi-purpose & Multi-(K)Ton LArTPC neutrino detectors

- Modeling the electric field is fundamental.
- Collecting LAr scintillation light is a key handle.

For PCB Based anode (Module 2) light collection system (X-Arapuca) is mounted on the cathode, operating at HV surface.

Signal over fiber and power over fiber transmission: a new concept for the PDS in DUNE VD [Dante Totani] **demonstrated comparable Signal/Noise ratio between Signal over Fiber and traditional Signal over Copper → wide range of applicability.** To scale demo about to start.

Module 1: "Classic" 10 kTon LArTPC



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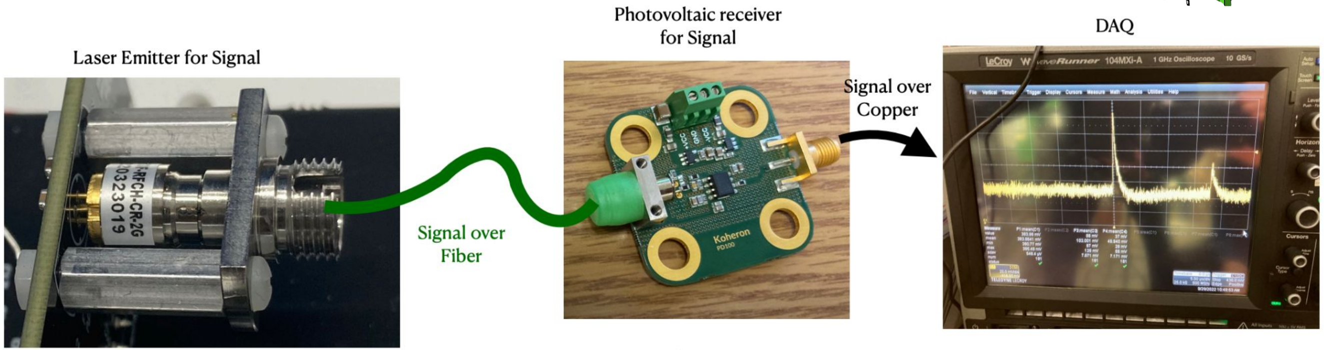


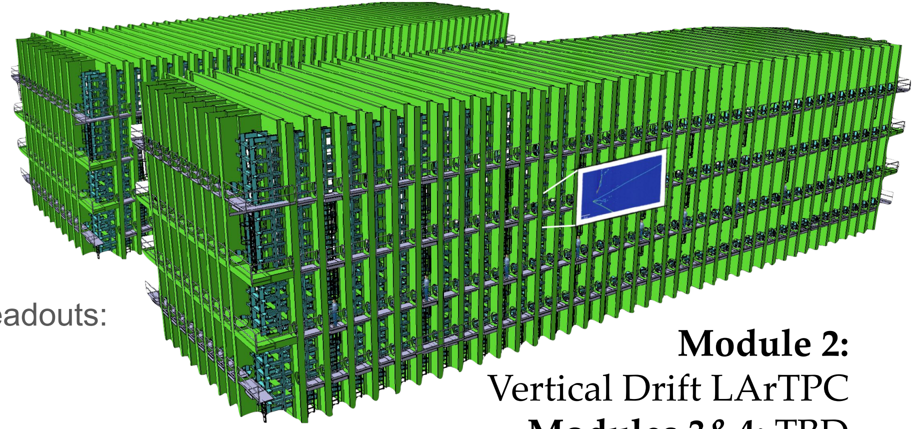
Multi-purpose & Multi-(K)Ton LArTPC neutrino detectors

- Modeling the electric field is fundamental.
- Collecting LAr scintillation light is a key handle.
- Enhancing capabilities:

LAr Doping R&D for Low Energy Sensitive LArTPCs [Fernanda Psihas]: the idea of improving the energy resolution via light to charge conversion will be tested at the TINYTPC program @ FERMILAB

Abating reconstruction ambiguities via pixelated charge readouts: LArPix & Q-Pix

Module 1: "Classic" 10 kTon LArTPC



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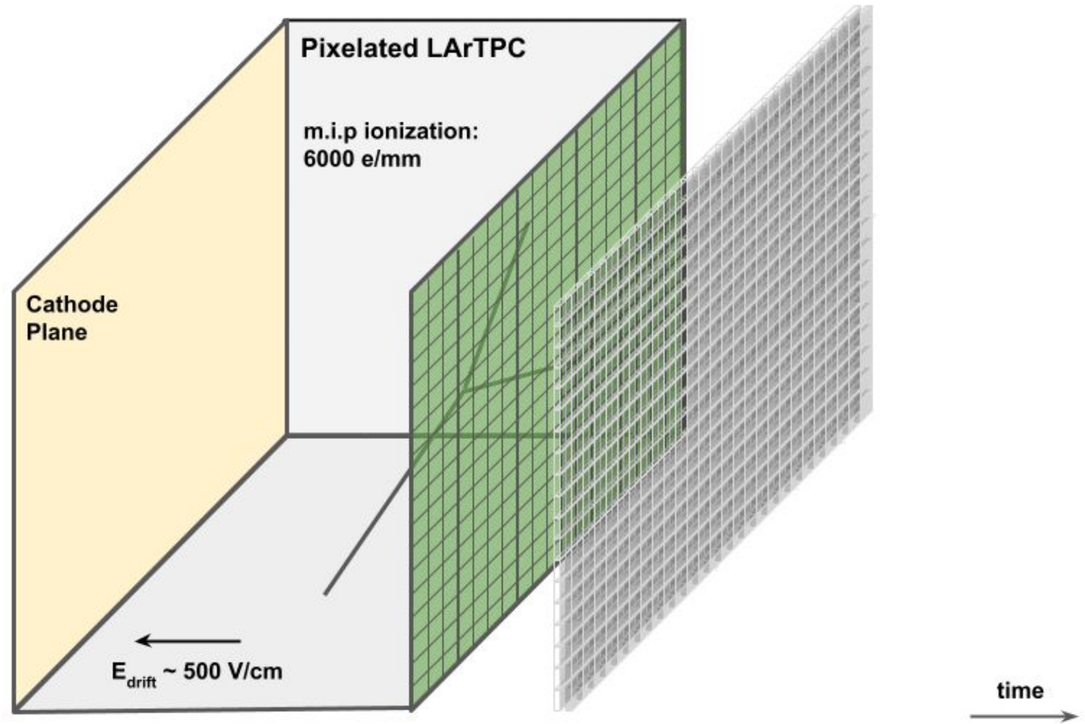
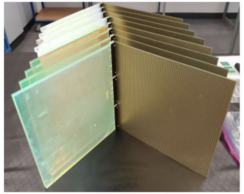
Multi-purpose & Multi-(K)Ton LArTPC neutrino detectors: pixel readouts



Multi-purpose & Multi-(K)Ton LArTPC neutrino detectors: pixel readouts

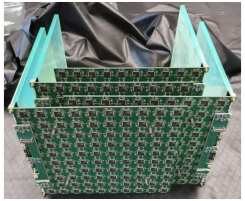
LArPix and LightPix: highly-scalable, cryogenic readout electronics [Brooke Russell]

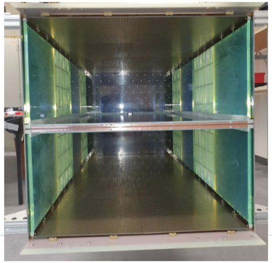
Successful operation of 3 O(100k) channel systems:
>100M cosmic ray events recorded
Quick-turn industry fabrication at competitive cost.
Analogous readout for SiPMs arrays to be deployed soon.



Single pixel tile & light module assemblies

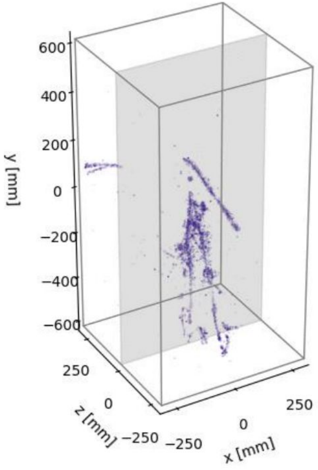
One anode, fully-assembled





Two anodes installed inside field cage

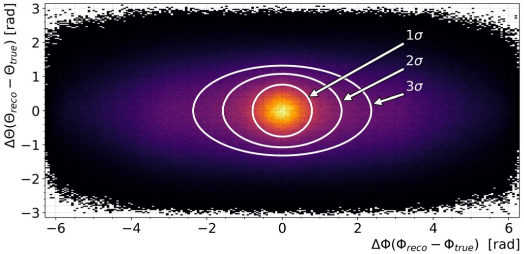
LArPix Cosmic Data



Q-Pix: Charge Readout Design and Prototyping [Jonathan Asaadi]

Charge readout scheme based on the electronic principle of least action. First architecture & CIR design completed: prototype campaign starting Jan 2023.

Physics impact studies show equivalent or better results as "traditional DUNE" with the added benefit of intrinsic 3D readout, significantly lower data rates, continuous untriggered readout.
E.g. 100% SN detection efficiency w/ 4 v_e interactions + directionality



Ar-TPCs operation & development require measurement of the Ar properties

Impacts of Diffusion on High-Level Physics [Adam Lister]: longitudinal & transverse diffusion can subtly bias calibrations at the few-% level. **Measurements of transverse diffusion are critical in current LArTPC!**

Capabilities of the SBND Trigger [Michelle Stancari]

SBND: ~5000 neutrino interactions per day. Unique challenges:

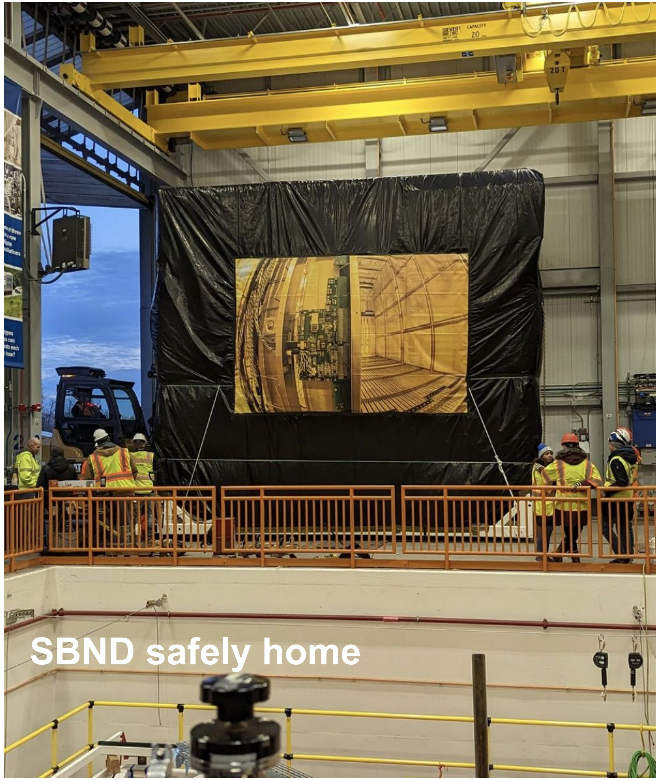
- Potential neutrino pile-up
- Sheer data volume ~100 MB/event

Implementing a “collider-inspired” trigger scheme (L1-L2) for a rough and fast classifications of the events.

Current capabilities:

- Identify (and trash) “empty” beam spills
- Auxiliary detectors (CRT) based triggers for commissioning and calibration.

In development: LArTPC based triggers based on pattern recognition on primitives.



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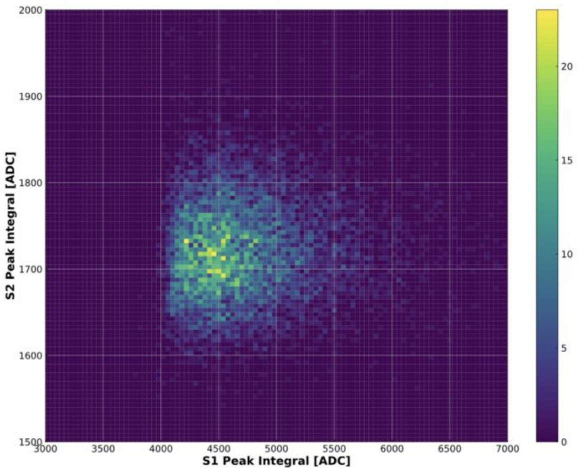
[Measurement of electron in-liquid amplification in pure argon [Wei Mu]]



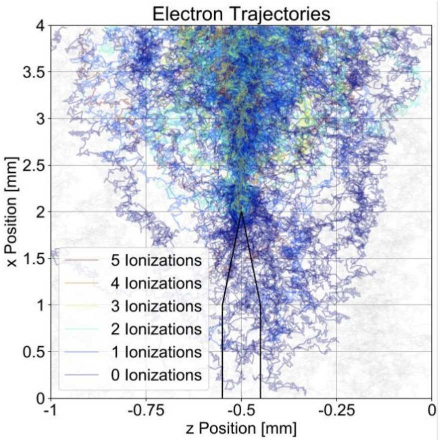
Discrepancy between measurement & extrapolation from GAr

Amplification threshold
Proportional scintillation: ~1.8 vs ~0.6 MV/cm
Electron avalanches: >2.0 vs ~2.5 MV/cm

A measurement of S1 vs S2 in Ar was also performed

[The TRANSLATE (simulation models the TRANSport in Liquid Argon of near-Thermal Electrons) simulation package and the LArCADe Project [David Caratelli]]

Liquid Argon Charge Amplification Devices. Charge amplification in liquid using "tips" to produce high E. Simulate transport for electrons in the LArCADE energy region of interest, reasonable agreement with Swarm parameters in literature.



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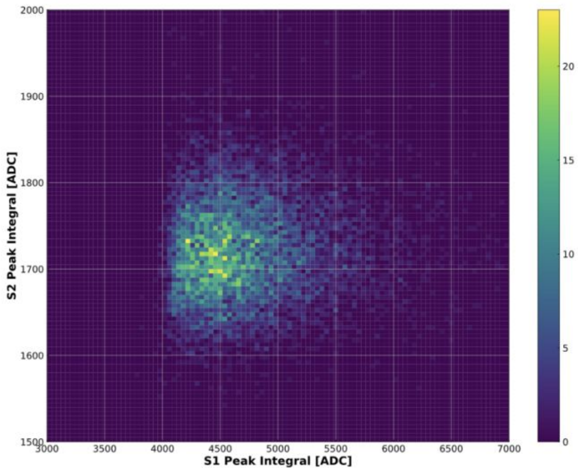

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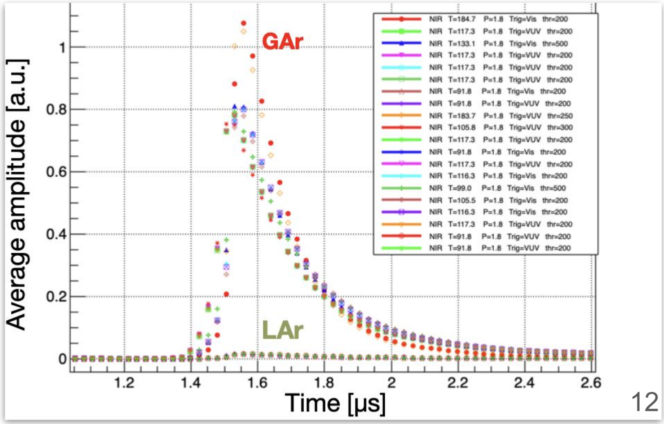
Non-VUV luminescence of liquid and gaseous argon [Alexander Kish] showed:

- in LAr: detection of VUV + visible
- in cold GAr (90–130K): reduction of the fast VUV component, significant signal in the near-infrared.
- in warm GAr (90–130K) the VUV fast component increases.

Near-infrared data in cold GAr and LAr



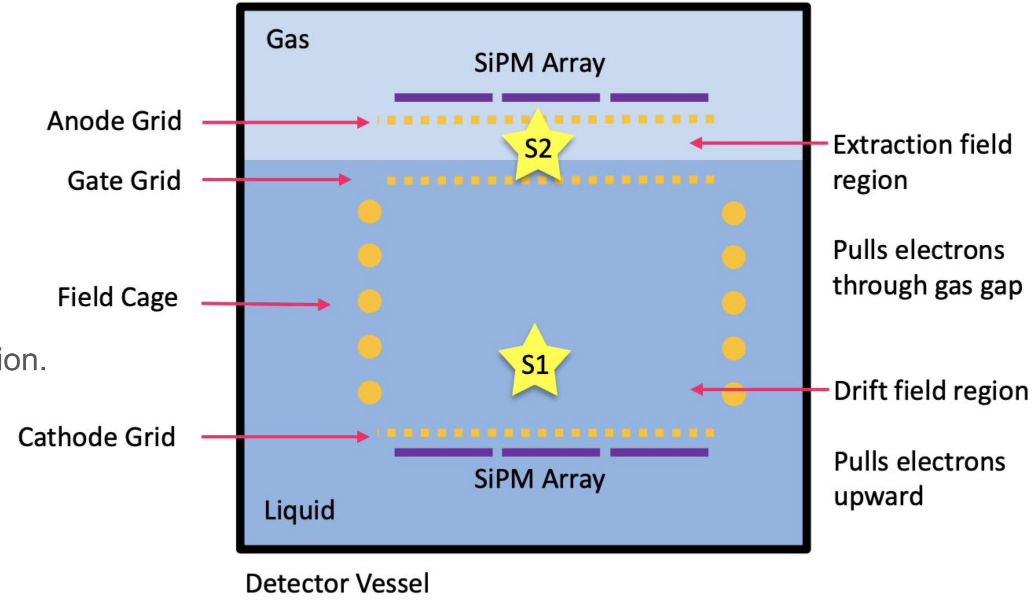
Xenon-Doped Argon Mixtures for Dual Phase TPCs

Combining Ar-Xe can offer opportunity:
WIMP, CEvNS, Supernovae

Challenge: the environment for Xe-Doping in both Liquid and gas.

- Xe and Ar don't mix at low temperature.
- Xe tend to go into the liquid, not in the gas.
- Wicking Separation Mechanism

Leads to Xe freezing & non-uniformity of Xe concentration.



[Controlling the Stability of Xenon-Doped Argon Mixtures [Ethan Bernard]]
[Capacitive Monitoring of Xenon Concentration in a Xenon-Doped Argon Detector [James Kingston]].

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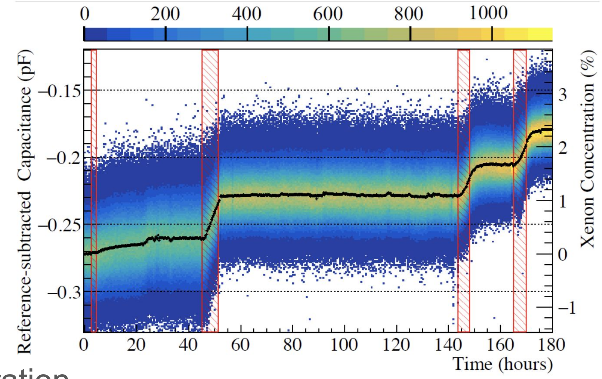
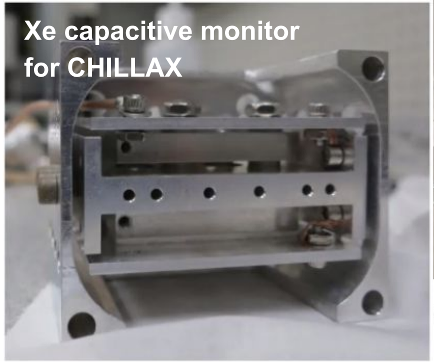


CHILLAX: A liter-scale dual phase xenon-doped argon TPC obtained predictable stable xenon doping of argon liquid and gas.

Monitor Xe concentration by measuring the change in capacitance of xenon-doped argon dielectric medium: linearly dependent on Xe concentration.



CHILLAX detector

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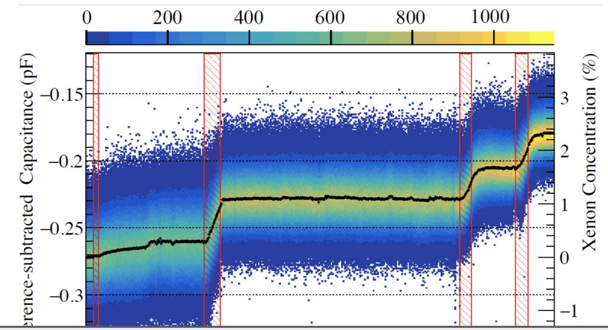
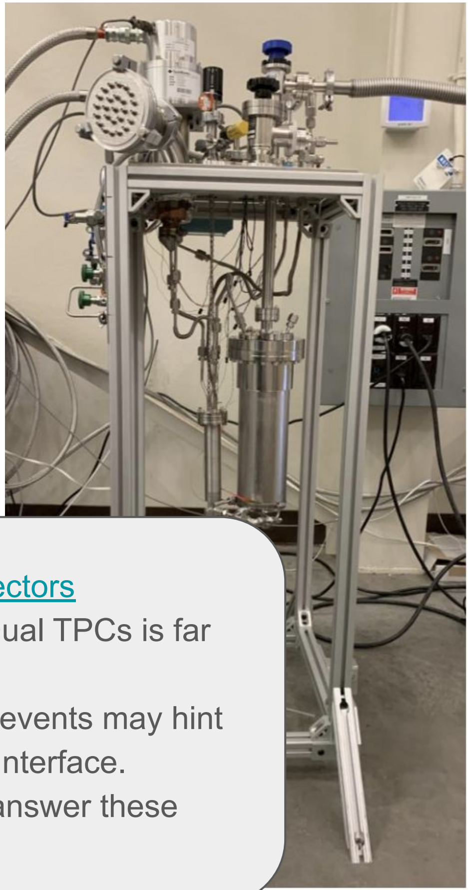


[What surfaces in the operation of noble liquid dual-phase detectors](#)
[Sergey Pereverzev] The microphysics of noble elements in Dual TPCs is far from trivial, especially at the liquid/gas interface.
Unexplained 'bursts' of charge emission after certain types of events may hint to interesting physics in the charges trapped at the liquid/gas interface.
Synergy with condensed matter physics should be sought to answer these detector physics important questions.

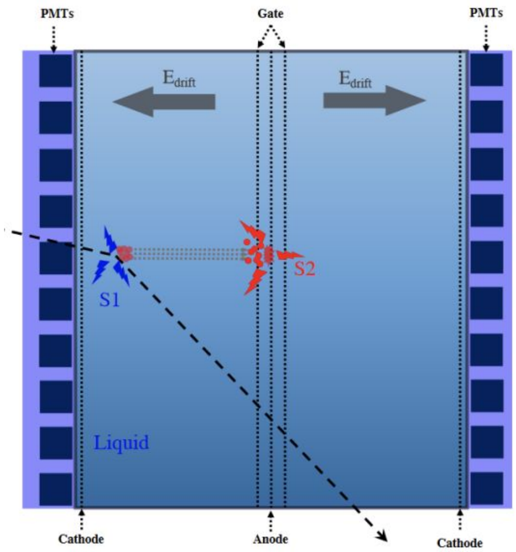


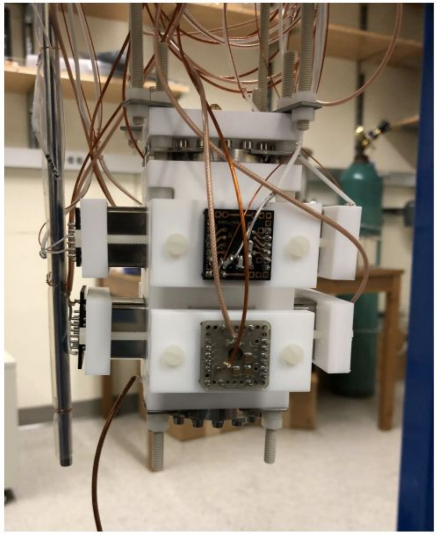
CHILLAX detector

Controlling the Stability of Xenon-Doped Argon Mixtures [Ethan Bernard]
Capacitive Monitoring of Xenon Concentration in a Xenon-Doped Argon Detector [James Kingston].

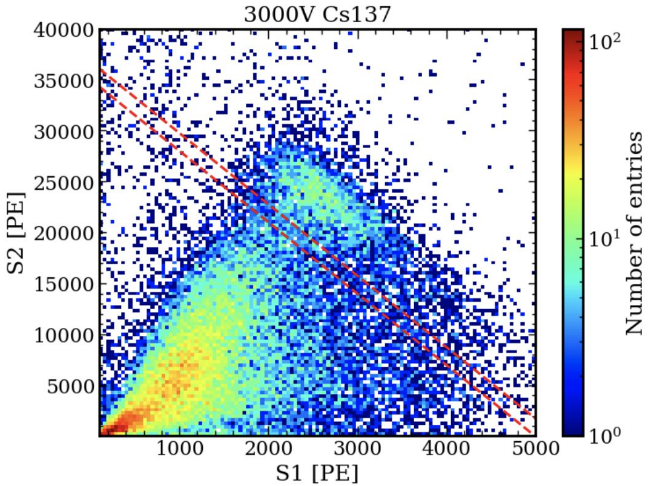
Detecting CEvNS at nuclear reactors: pure $\bar{\nu}_e$ source w/ high flux

Development of a Single Phase Liquid Xenon Detector for Reactor Antineutrino Detection [Jianyang Qi] circumvent a background in double phase due electrons trapped at the liquid/gas surface.





Cs137 & Tritium calibration data from first prototype, field simulation & model for liquid phase electroluminescence
→ working towards scaling up the technology.



Dark Matter

Dual Phase TPCs for Dark Matter Detection

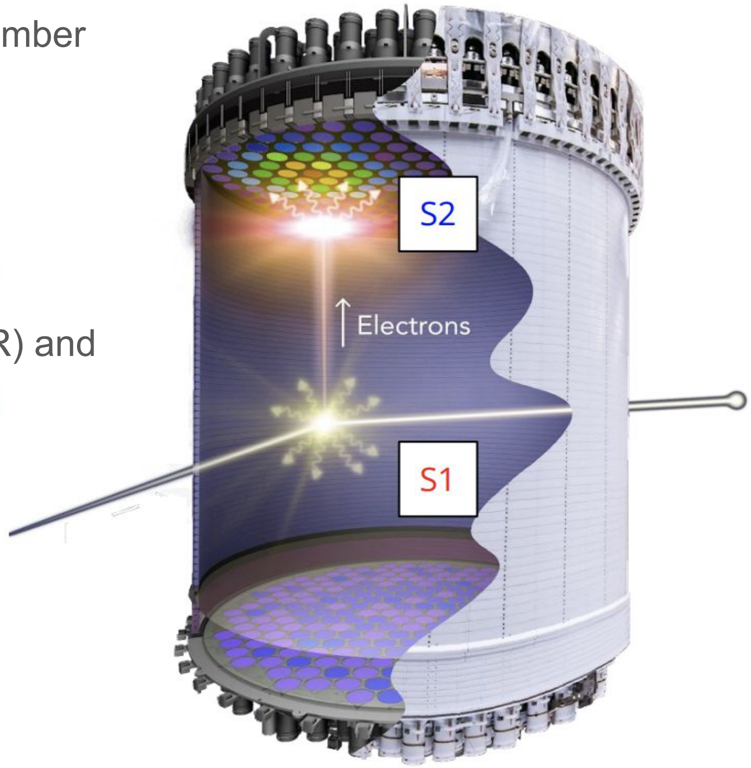
Experiments use liquid-gas dual-phase noble time projection chamber (TPC) to search for Dark Matter

- PID from ratio of scintillation (S1) to electroluminescence (S2)

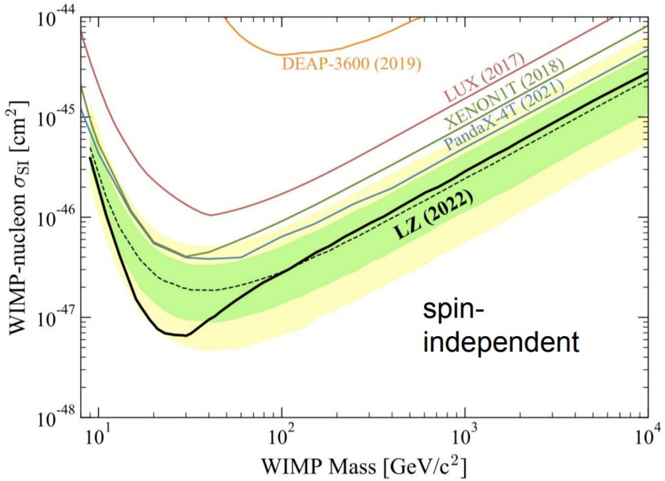
- Calibrate expected signal response of electron recoils (ER) and nuclear recoils (NR) using sources of known energy:
  - ER → gammas, betas
  - NR → neutrons

Name of the game:

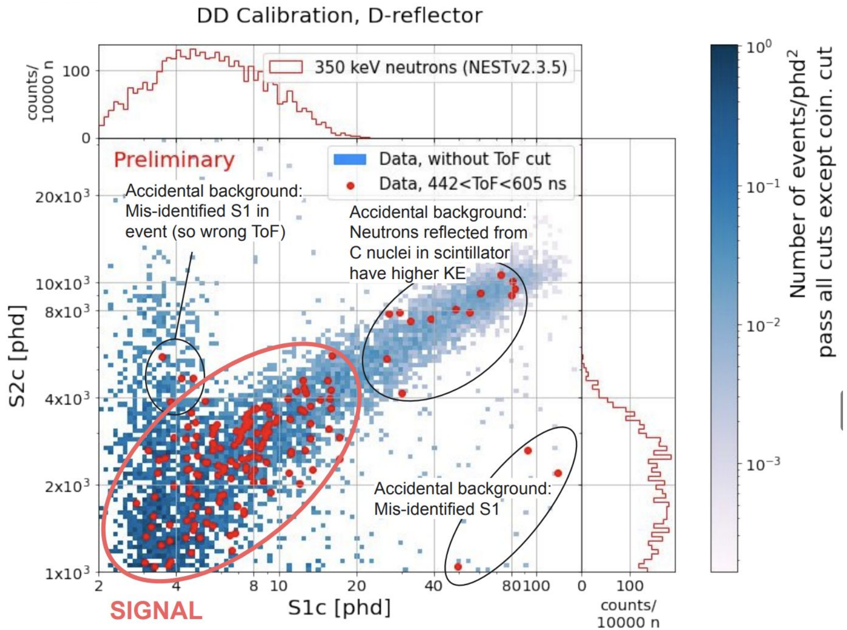
- Incredibly good calibration
- Radiological pure



Dual Phase TPCs for Dark Matter Detection: Xenon



LZ is online and taking high-quality physics data: with 60 live-days
LZ is the most sensitive dark matter detector for NR.



Calibration of the detector is fundamental for sensitivity:

- Monoenergetic DD-Neutron source (NR)
  3 modes: 2.45MeV, ~350keV, 10-200keV
- Robust simulation package to model scintillation light & charge yields: NEST

[LZ Electron Recoil Calibrations and NEST-Based Simulations [Matthew Szydagis]]
[Application of a DD-Neutron Source for Low-Energy Nuclear Recoil Calibrations in the LZ Experiment [Austin Vaitkus]]

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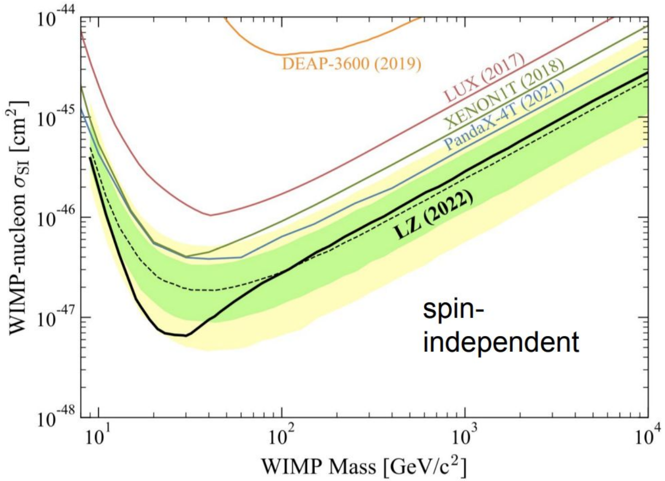

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Additional higher energy calibrations (>100 keV) would help reduce uncertainties associated with event reconstruction.

[Calibrating the scintillation and ionization responses of xenon recoils for high-energy dark matter searches [Teal Pershing]]: independent measurement of light/charge yields for nuclear recoils up to 426 keV.

→ Field-dependent yields measured up to 306 keV
→ Field-averaged yields reported at 379 keV and 426 keV

Light/charge yield measurement to be incorporated in NEST

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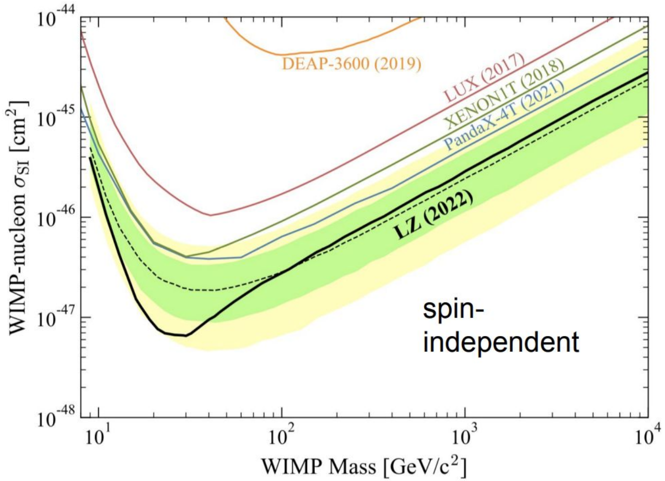

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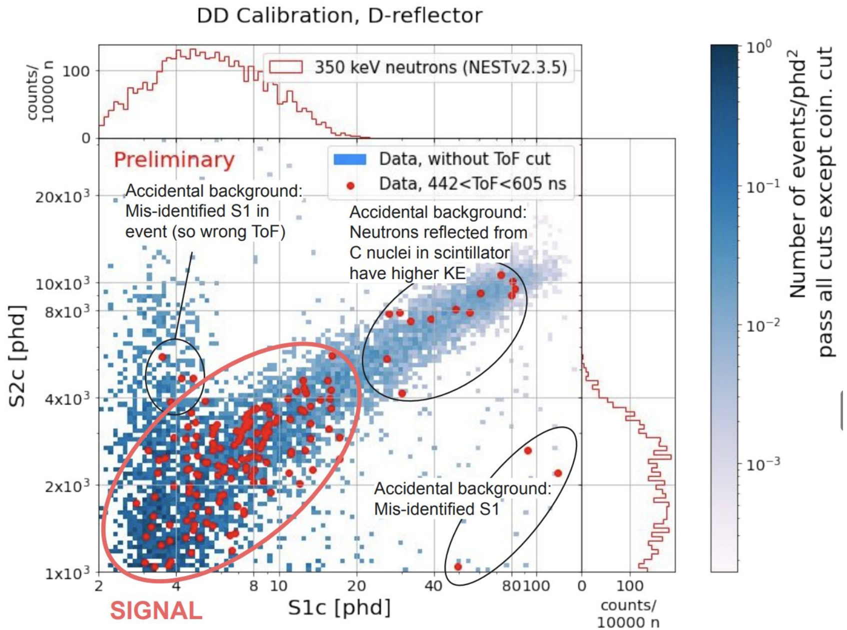

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LZ is far from over: more fine tuning & more data…

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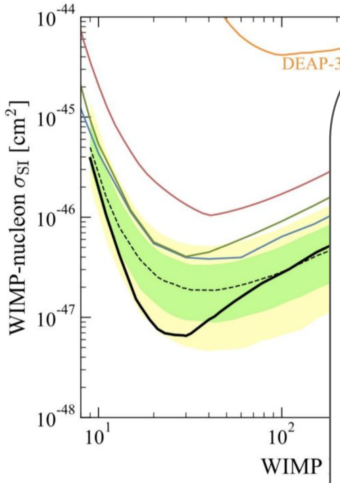
Dual Phase TPCs for Dark Matter Detection: Xenon



Calibration of the detecto

- Monoenergetic D

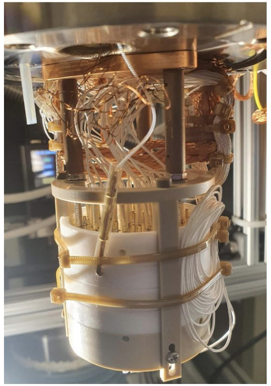
3 modes: 2.45M

- Robust simulatio

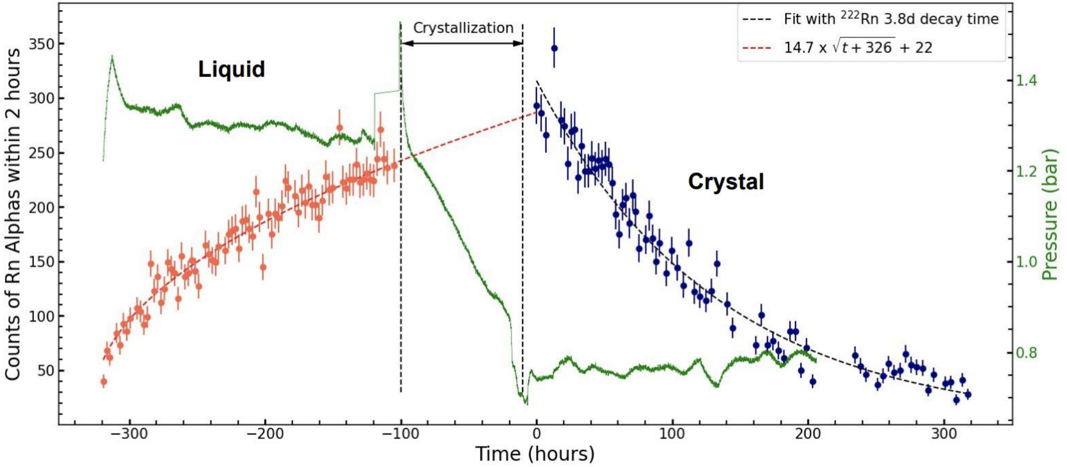
LZ is far from over: more fin

[CrystaLiZe: A Solid Future for LZ [Hao Chen]]

Scope: abating Radon bkg (primary background) by freezing the Xenon.
Working crystal/vapor duale phase TPC w/ solid Xe showing Rd is significantly reduced.



TPC



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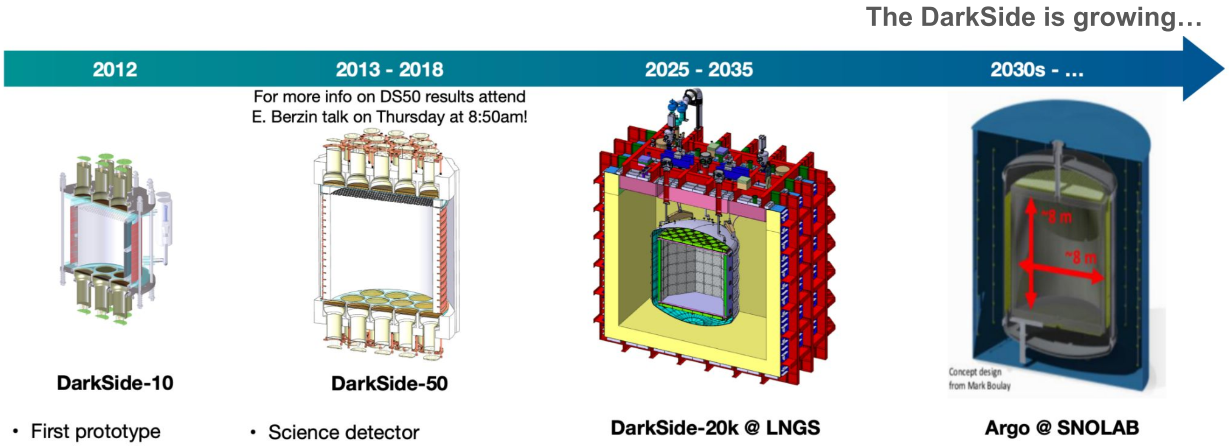
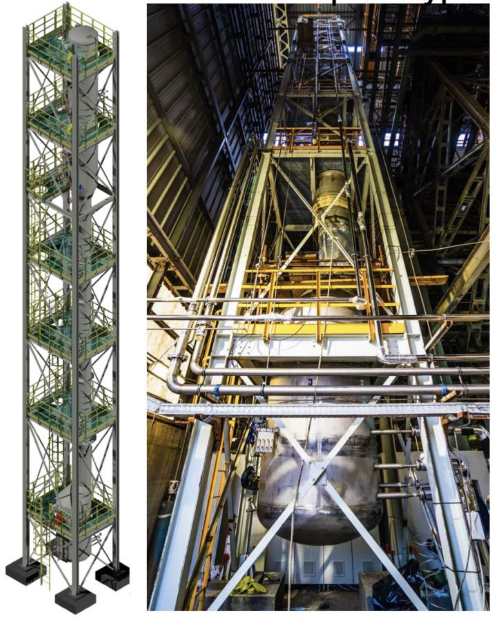
Dual Phase TPCs for Dark Matter Detection: Argon



Drawing and picture of ARIA distillation column prototype



Status and perspectives of the DarkSide experimental program [Claudio Savarese]

WIMP DM search: nuclear recoils (NR), Electron Recoils (ER) are background

Pulse shape discrimination of Ar scintillation light is used to discriminated between electron and nuclear recoil.

Ar39 is a problem because the pileup can be significant at high masses.

→ solution: underground Ar

Delayed Electron Emission in DarkSide-50 [Elizabeth Berzin] Investigate the spurious electron (SE) low energy background in DarkSide-50.

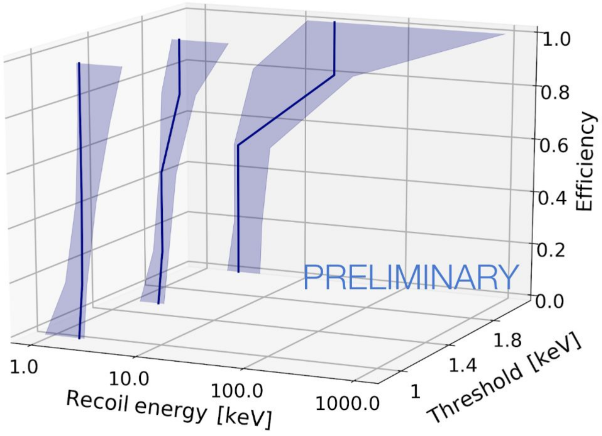
Metastable Media for Dark Matter Detection (and more)

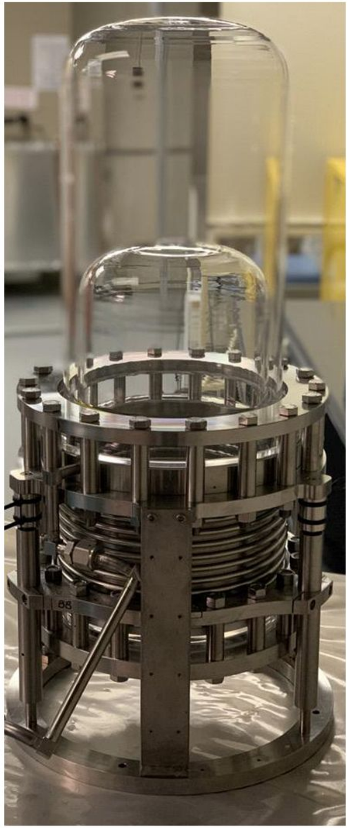
Bubble chambers maintain target fluid (LAr+LXe or LXe) in a superheated state:

- High efficiency low NR threshold: Goal of 100eV recoil threshold (!)
- Scintillating Bubble Chamber collaboration demonstrated extreme insensitivity to ER backgrounds (nucleation to β/γ).

3 experimental handles: scintillation, acoustic, nucleation.
SBC is now commissioning/constructing two LAr bubble chambers, at Fermilab and SNOLab.
[Scintillating Bubble Chambers for Rare Event Searches [Ben Broerman]]

Neutron data taken at a 30g Xe chamber confirmed sensitivity to energies just above the seitz thresholds (few keV region) [Nucleation efficiency of a liquid Xenon bubble chamber [Daniel Durnford]]





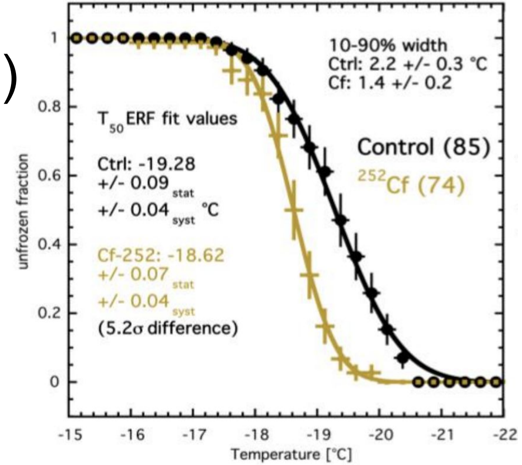
Metastable Media for Dark Matter Detection (and more)

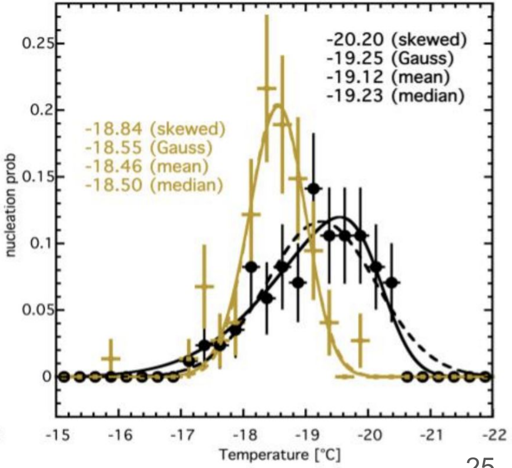
Medium: supercooled water (metastable)
-20 C, 1 atm, liquid.

Clear demonstration of neutron nucleation freezes water
Less clear understanding of gamma nucleation.

Water purity extremely important
Potential for powerful sensitivity in few-GeV regime.

[The Snowball Chamber: Supercooled Water for Dark Matter, Neutrinos, and General Particle Detection [Matthew Szydagis]]



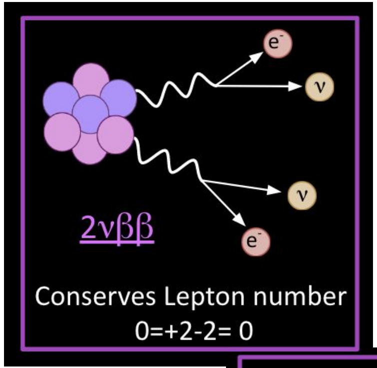


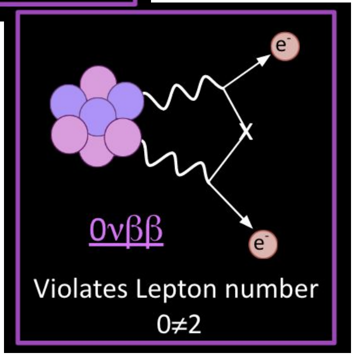
Neutrinoless Double Beta Decay

Xe for neutrinoless double beta decay

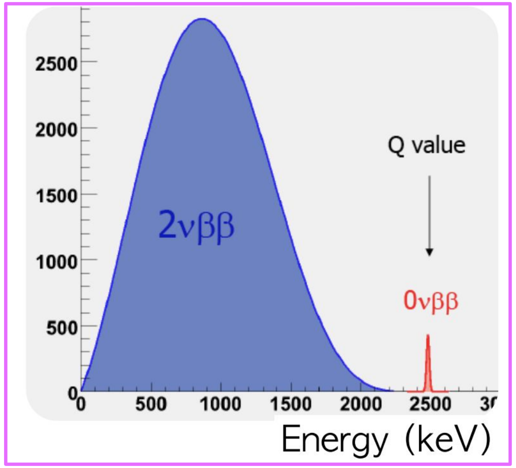
Given the rarity of the event, all 0νββ detectors are bound to 4 fundamental parameters:

→ A nucleus able to undergo this process (Xe!!!)
→ A large volume
→ Extremely low or nonexistent backgrounds
→ Great energy resolution





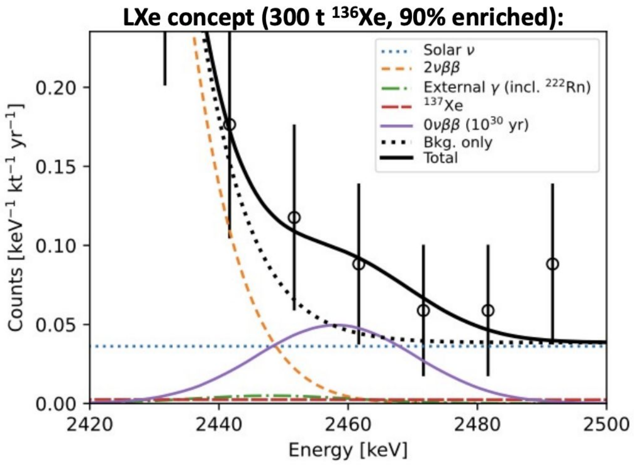
Liquid and High Pressure Gas Xe time projection chambers provide an extremely sensitive, technology for search for 0νββ:
both the source (136Xe) and detector for the decay.

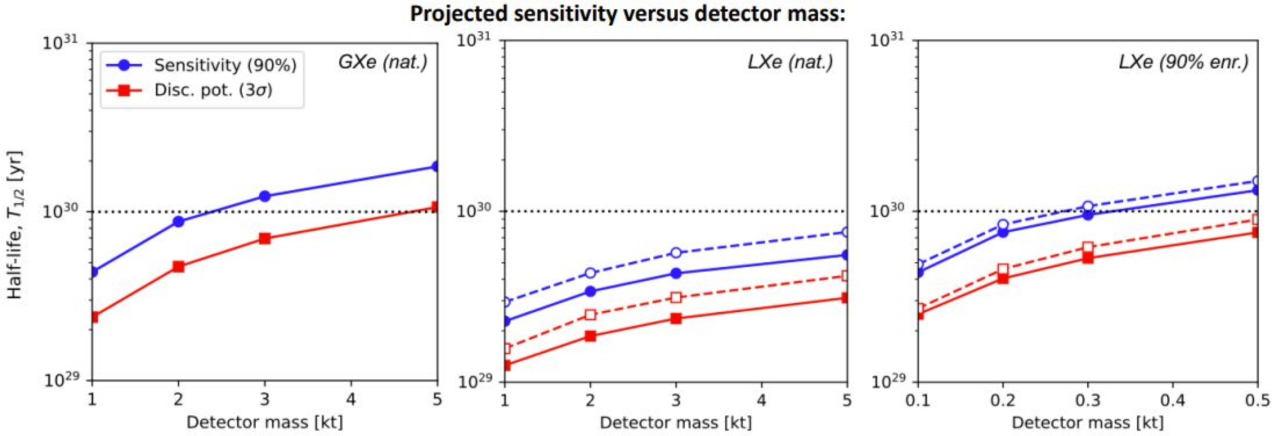


Xe for neutrinoless double beta decay: Next Gen

In terms of large volumes, reaching half-life sensitivity of 10^{30} yr would allow sensitivity to the vast majority of remaining parameter space in the normal hierarchy, but kton-scale would be needed. Direct air capture (DAC) could be both more efficient and substantially expand supply of Xe.

[Kiloton-scale Xenon detectors for neutrinoless double beta decay [David Moore]]

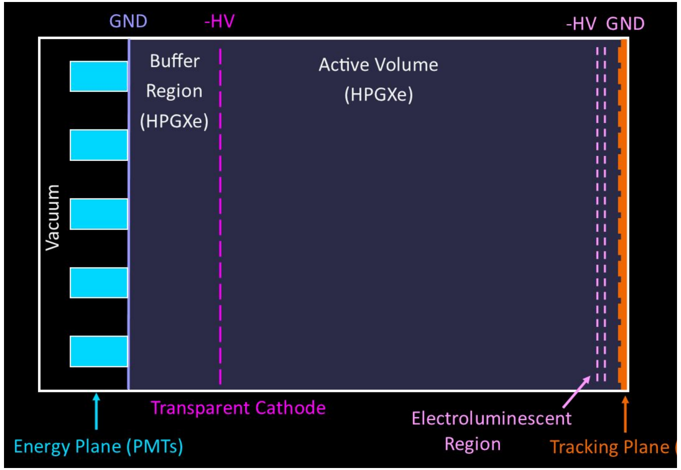




To ensure stability of detector performance, the photon detector system are tested for high VUV exposure.

Successful example for nEXO: [Stability of HPK VUV4 SiPMs following a large dose of VUV radiation [Lucas Darroch]]

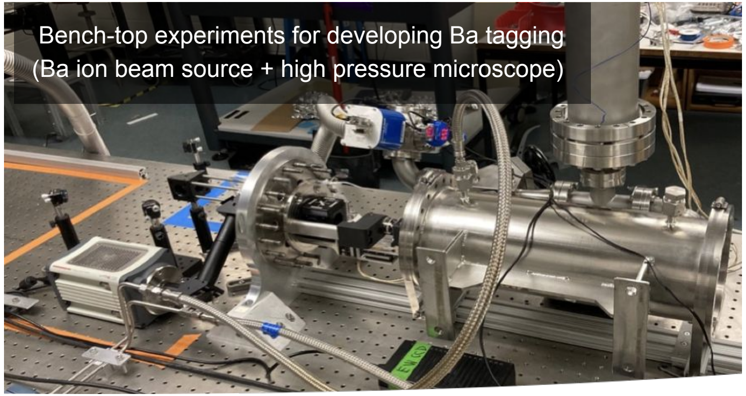
Xe for neutrinoless double beta decay: HPGXe

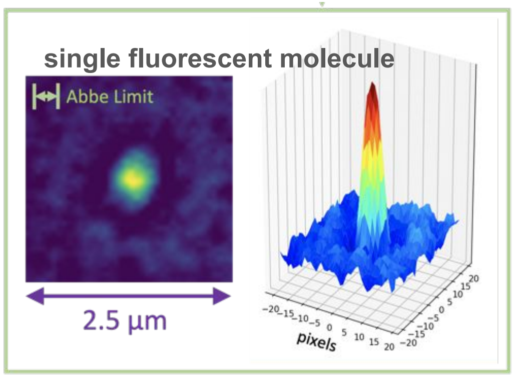


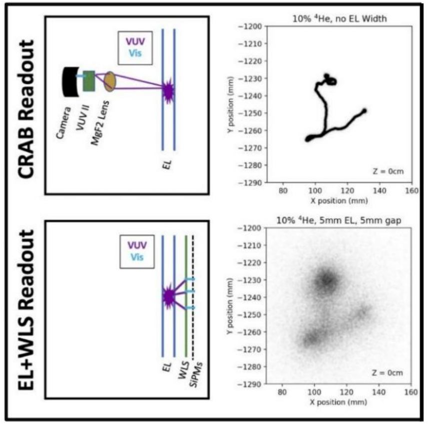
Latest developments of the NEXT R&D Program:

- CRAB-0 (Xe Gas TPC + fast camera with UV Image Intensifier) successfully demonstrated that directly imaging scintillation light is possible with UV sensitive imaging Intensifier in High Pressure Xenon.

- The first viable prototype to identify the Ba ion via single molecule fluorescent imaging has been built.







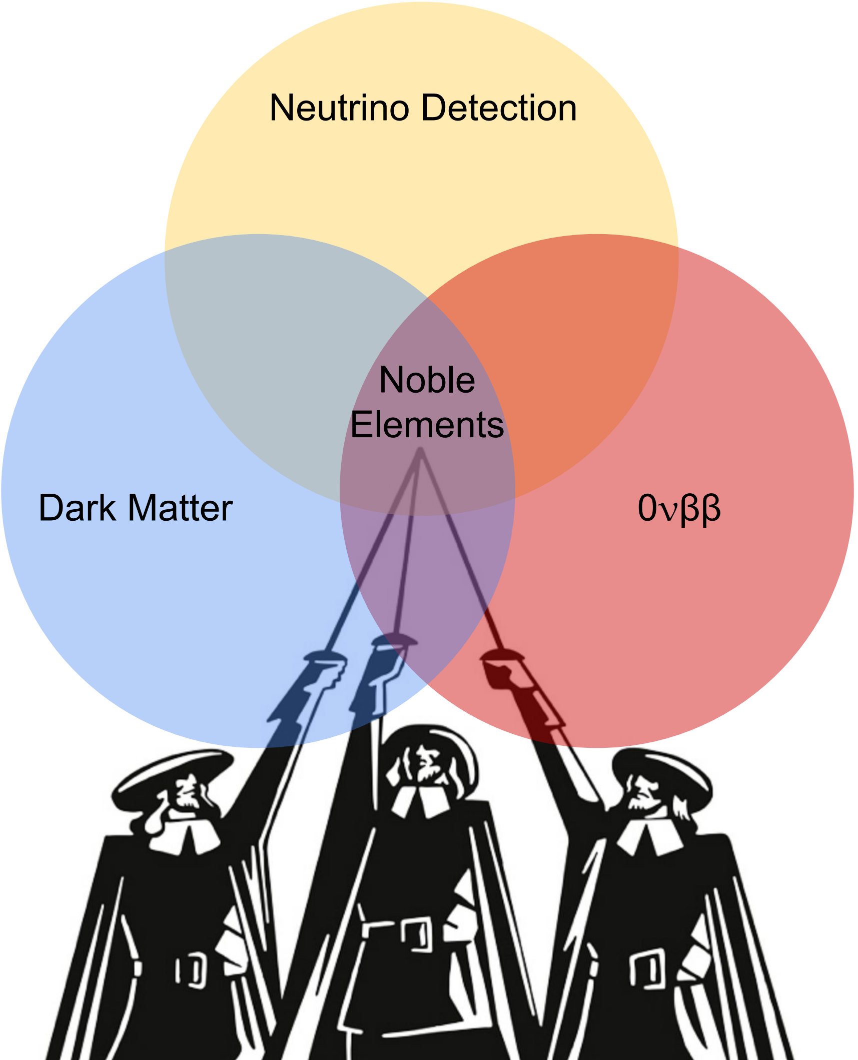
[Camera Readout and Barium Tagging (CRAB) for Neutrinoless Double Beta Decays [Leslie Rogers]],

[CRAB0 Detector [İlker Parmaksiz]] [Development of a Ba Tagging Sensor for NEXT 0νββ Searches [Karen Navarro]]

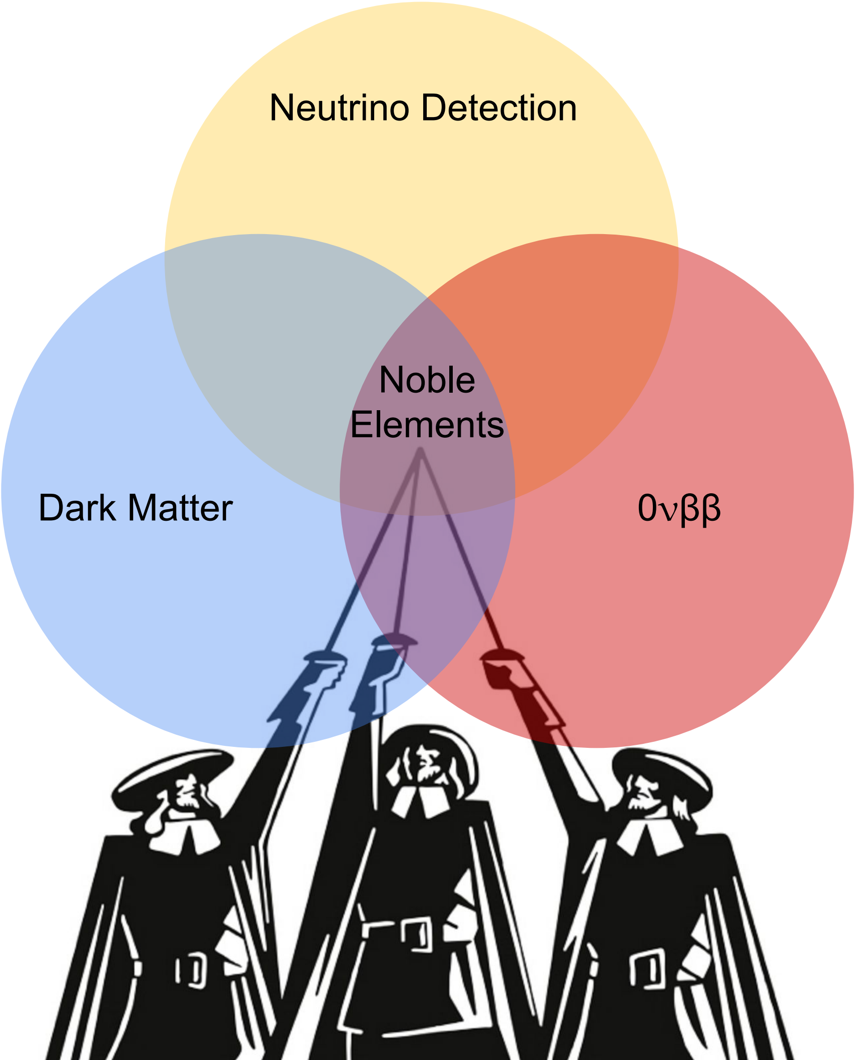
Conclusions

Very active R&D community for noble element detectors: incredibly versatile media.

Generation of new ideas at intersection of the physics topics!



Thanks!


Neutrino Detection
Noble Elements
Dark Matter
$0\nu\beta\beta$