IF-08 PRD-1
“Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity”

Low-Threshold TPCs

based on the LoIs:

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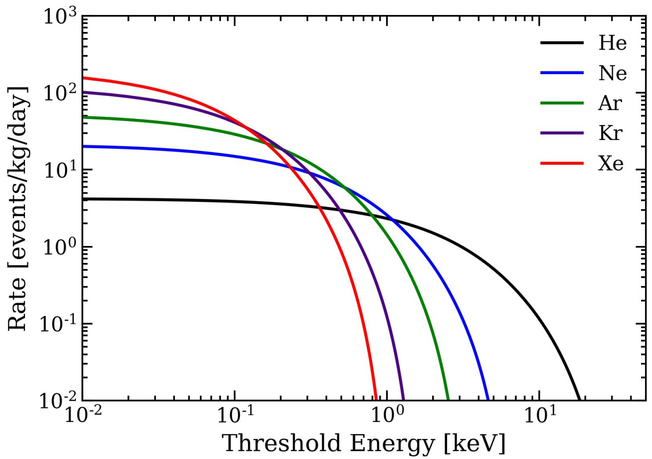
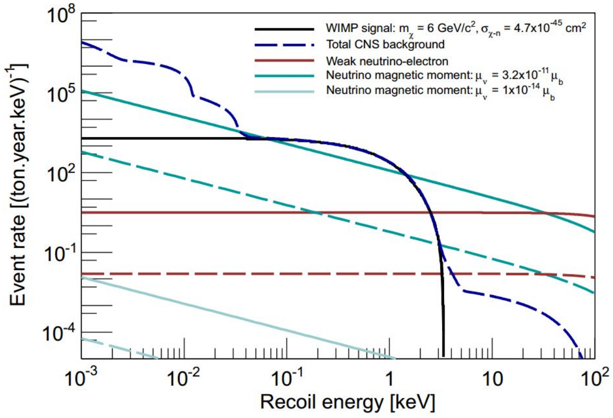
Instrumentation requirements to achieve physics goals

- Noble liquid TPCs for electron-counting (S2-only) analyses
  - LXe, LAr, LNe?
  - LAr+Xe, other dopants
- Low energy thresholds, targeting scale of target's ionization energy: O(10 eVee)
- Low backgrounds:
  - < 1 events/kg/day with 0.5-keVnr threshold for reactor neutrinos
  - O(10^3 events/keV_{nr}/ton/year) for ^8B solar neutrinos
- High-granularity and Single-PE sensitive photosensors to detect S2 light
- Stable high voltage and electrodes system
- High liquid purity



Integrated rate above threshold with $6x10^{12}$ neutrino/cm^2/s (25 m from 3 GWth reactor)



PRD 89, 023524 (2014) - Neutrino backgrounds in LXe

Significant instrumentation challenges

- Low-energy backgrounds
  - Spurious electron backgrounds (chemical impurities, photo-ionization, charge build-up)
    - Not well-understood→R&D needed to characterize SEs
    - Chemical impurities→Improved purification, including in situ liquid-phase purification
    - Charge build-up→Optimize electric field to reduce charge accumulation at liquid surface
  - Electronic recoils (no electronic/nuclear recoil discrimination)
    - Internal β emitters like ^{3}H, ^{39}Ar, ^{85}Kr, $^{220,222}Rn$ decay chains → improved isotope purification
    - γ-emitters in detector components → radiopure photosensor development
    - Cosmogenic nuclides →better understand cosmogenic activation rates
- Lowering thresholds
  - Uncertainties in low-energy electronic and nuclear recoil charge yields → ex situ calibration
    - Observations of the Migdal effect are also helpful to support its use in low-mass DM analyses
  - Electric field optimization→ex situ calibration at variable fields
  - Doping (low-ionization energy dopants for higher charge yields, low-A targets for higher-energy nuclear recoils)
    - Need high purity and stability→R&D to develop high-purity doping and mixing techniques
    - Study effects on TPC response→ex situ calibration with doping

Relevant physics areas

- Low-mass dark matter with 1 MeV–10 GeV masses through recoil channels
  - Dark matter with nuclear and electronic couplings
- Light dark matter with 10 eV–1 keV masses through absorption channels
  - Axion-like particles and hidden photons
- Measurements of CEvNS from artificial neutrino sources (Reactors)
  - Sterile neutrino searches with short baselines
  - Non-standard neutrino interactions and new boson mediators
  - Neutrino magnetic moment
  - Neutron distribution in nucleus (input to nuclear equations of state)
  - Weak mixing angle
- Measurements of CEvNS from natural neutrino sources
  - Supernova neutrinos
  - Solar neutrino measurements (mostly ^{8}B neutrinos)

Relevant cross-connections (e.g., other topical groups, other white papers)

- CF01 WP2: “The landscape of low threshold detection in the next decade”
- CF01 WP3: “Calibrations and Backgrounds for Direct Detection”
- NF white paper on CEvNS measurements

Further reading (e.g., reference for existing TDR, reference paper, etc.)

- J. Billard et al., Implication of neutrino backgrounds on the reach of next generation dark matter direct detection experiments, https://arxiv.org/abs/1307.5458
- R. Essig et al., New Constraints and Prospects for sub-GeV Dark Matter Scattering off Electrons in Xenon, https://arxiv.org/abs/1703.00910
- DarkSide Collaboration, Low-Mass Dark Matter Search with the DarkSide-50 Experiment, https://arxiv.org/abs/1802.06994
- XENON Collaboration, Light Dark Matter Search with Ionization Signals in XENON1T, https://arxiv.org/abs/1907.11485
- RED-100 Collaboration, First ground-level laboratory test of the two-phase xenon emission detector RED-100, 1910.06190
- A. Bernstein et al., LBECA: A Low Background Electron Counting Apparatus for Sub-GeV Dark Matter Detection, https://arxiv.org/abs/2001.09311
- LUX Collaboration, Investigation of background electron emission in the LUX detector, https://arxiv.org/abs/2004.07791
- Y.T. Wei et al., Prospects of detecting the reactor neutrino-Ar coherent elastic scattering with a low threshold dual-phase argon time projection chamber at Taishan, https://arxiv.org/abs/2012.00966
- K. Ni et al. Sensitivity of a Liquid Xenon Detector to Neutrino–Nucleus Coherent Scattering and Neutrino Magnetic Moment from Reactor Neutrinos, *Universe* 2021, *7*(3), 54; https://doi.org/10.3390/universe7030054
- S Al Kharusi et al., SNEWS 2.0: a next-generation supernova early warning system for multi-messenger astronomy, *New J. Phys.* 2021, 23, 031201; https://iopscience.iop.org/article/10.1088/1367-2630/abde33