Single-Electron Sensitive Liquid Xenon Detectors for Reactor Neutrino Detection

Kaixuan Ni
University of California San Diego

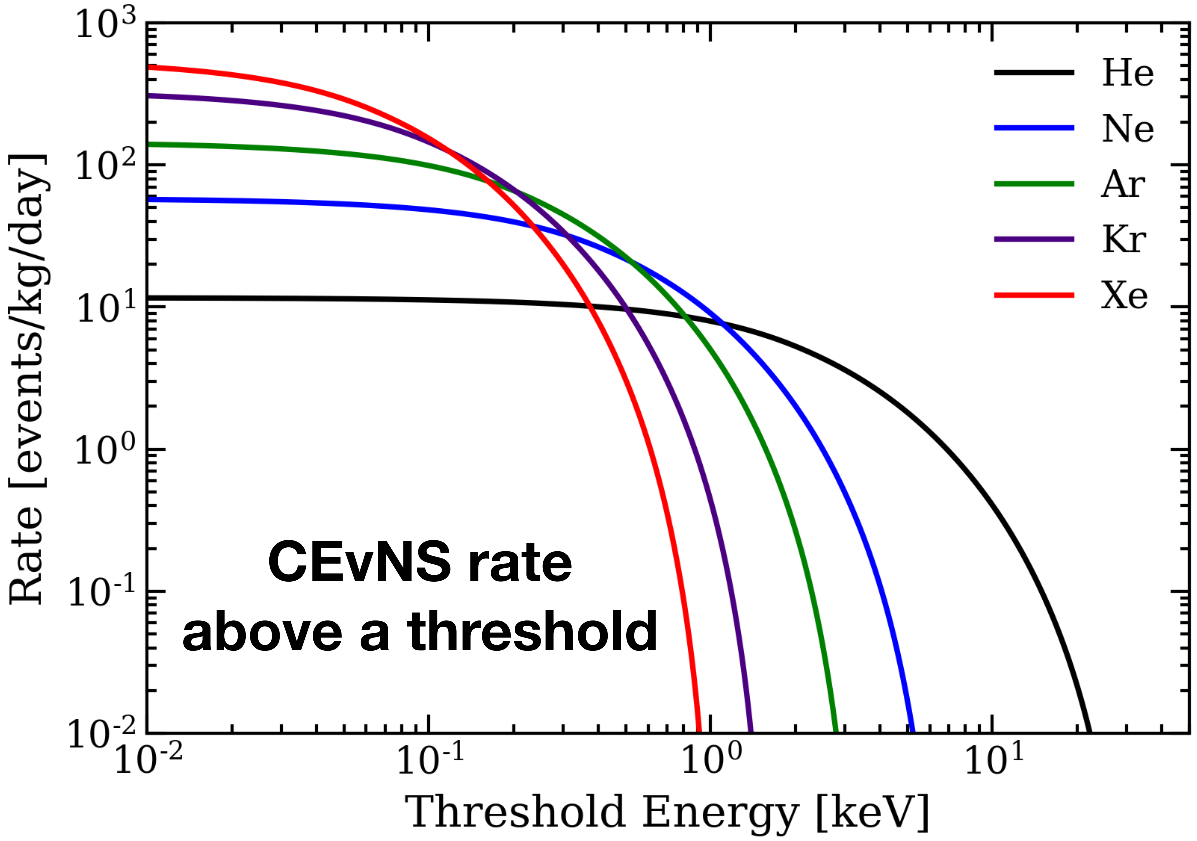
nikx@physics.ucsd.edu

Snowmass-IF-Noble-Element, July 27, 2020

Nuclear reactor is a powerful tool to study neutrinos

- Historically, inverse beta decay (IBD) experiments successfully measured the neutrino oscillation parameters, and "reactor neutrino anomaly" triggers investigation of "sterile neutrinos"
- Reactor neutrino electron scattering experiments were used to search for an anomalous neutrino magnetic moment. (note: recent liquid xenon detector XENON1T provides similar constraints using solar neutrinos)
- Coherent elastic neutrino-nucleus scattering (CEvNS) from reactor neutrinos provide a new channel to investigate non-standard interactions, sterile neutrinos, etc.
- Given the large cross section, CEvNS provides a *compact* detector solution for reactor antineutrino monitoring for nuclear safeguard applications

Noble Elements for Reactor Neutrino Detection



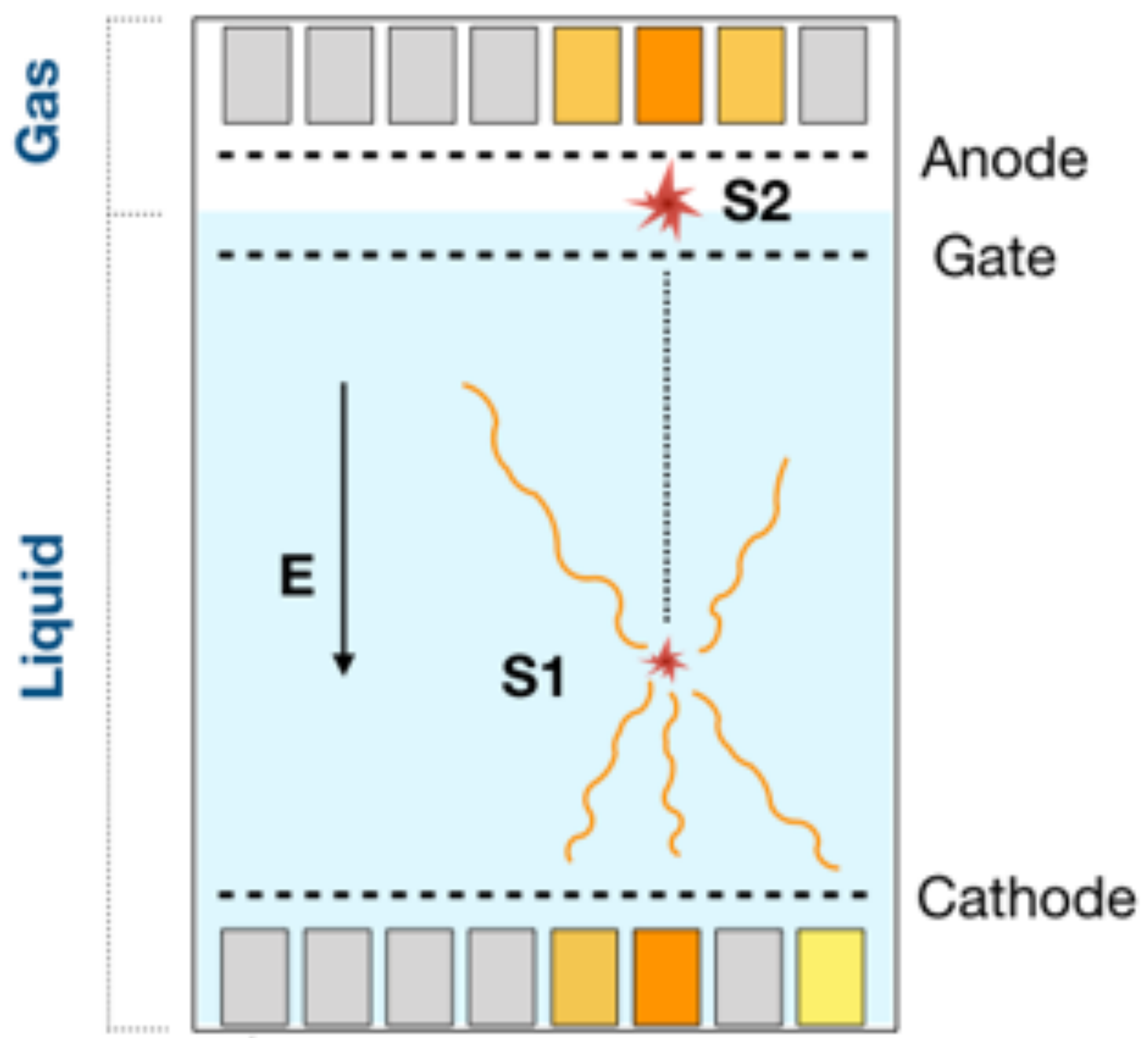
- based on reactor antineutrino spectrum from Mueller et al (1191,2553) and Hayes, Vogel (1605.02047) with 7.6% ^{238}U, 25% ^{235}U, 14.8% ^{241}Pu, 51% ^{239}Pu, normalized to a flux of 6×10^{12} $cm^{-2}s^{-1}$ (~28 m from a 3 GWth reactor)
- ~10 events/kg/day expected at nuclear recoil energy threshold of 0.4~1.0 keV (target dependent)
- A low-cost, compact neutrino detector with 10~100 kg **liquid** target: >100 neutrino events/day
- LXe is a very promising target. LNe and LAr are also promising (require wavelength shift and ^{39}Ar removal)

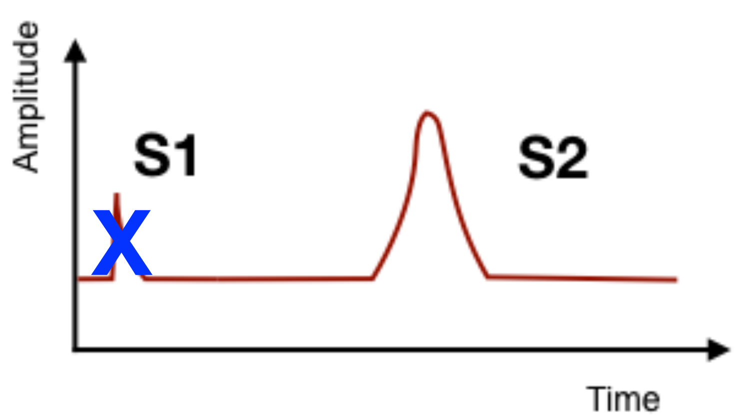
Elements	Liquid Density (kg/liter)	Threshold (keV) to get ~10/kg/day	Scintillation wavelength (nm)	Boiling Point (K)	Intrinsic Radioactivity
LHe	0.1	~1.0	80	4	none
LNe	1.2	~1.0	78	27	none
LAr	1.4	~0.9	127	87	^{39}Ar (1 Bq/kg)
LKr	2.4	~0.5	148	120	^{85}Kr (1 MBq/kg)
LXe	3.0	~0.4	178	169	none

pros cons

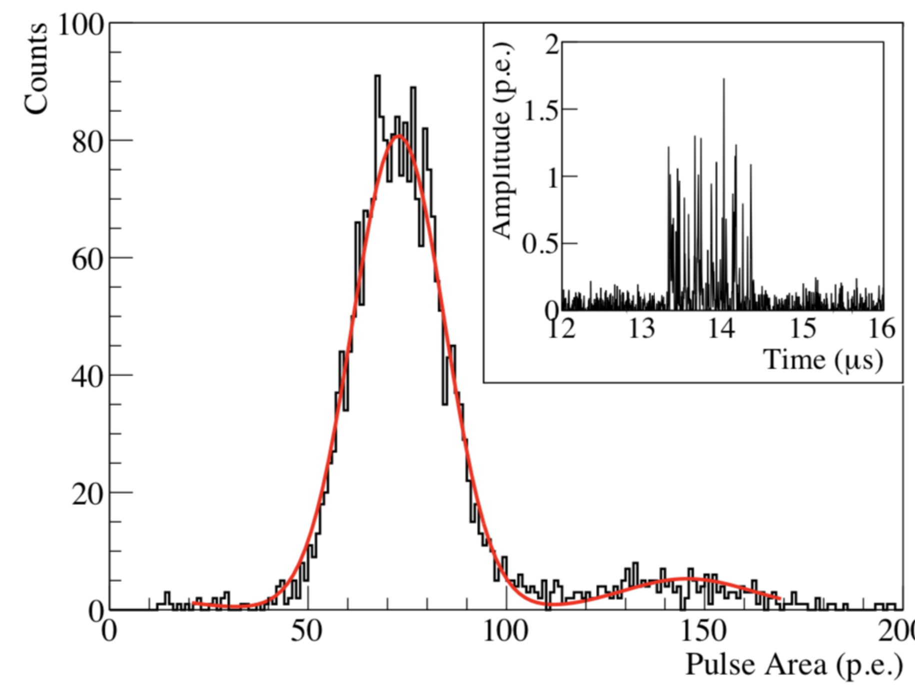
K. Ni (UCSD)

Two-phase Xenon Detector in Electron Counting mode





J. Xu et al., arXiv:1904.02885



Single-electron signals from the XeNeu detector (LLNL)

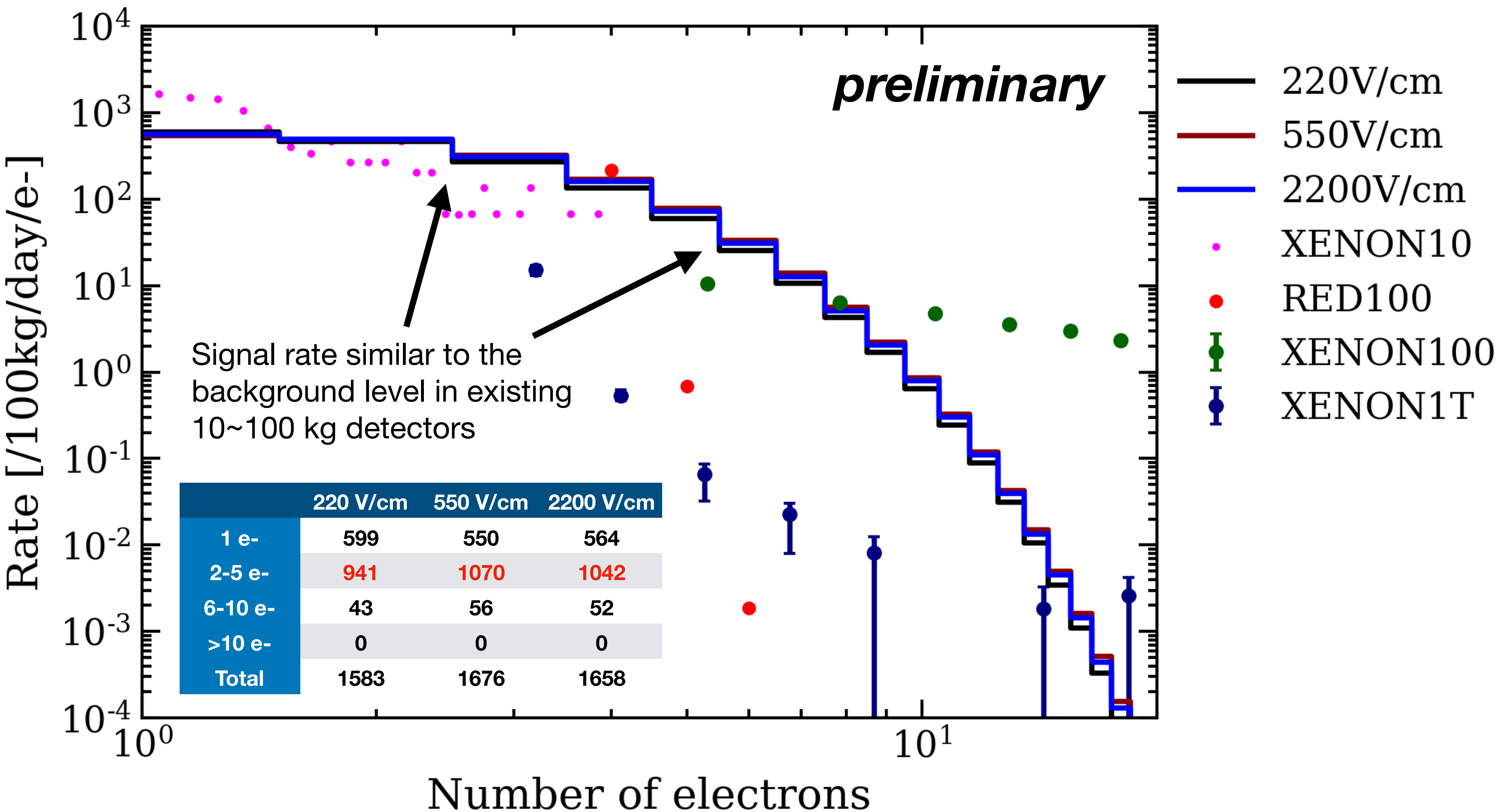
With ionization(S2)-only signal (EC - Electron Counting mode):

- **ER threshold: ~20 eV**
- **NR threshold: ~300 eV**
- **S2-only background:**
  - **No ER/NR discrimination**
  - **Only XY position determined, no Z**
  - **Single-and-few electrons background**

K. Ni (UCSD)

CEvNS event rate in liquid xenon
expected neutrino events vs. measured background

Using the liquid xenon ionization yield from the most recent NEST model, compatible with the latest measurement by Lenardo, Xu et al., 1908.00518

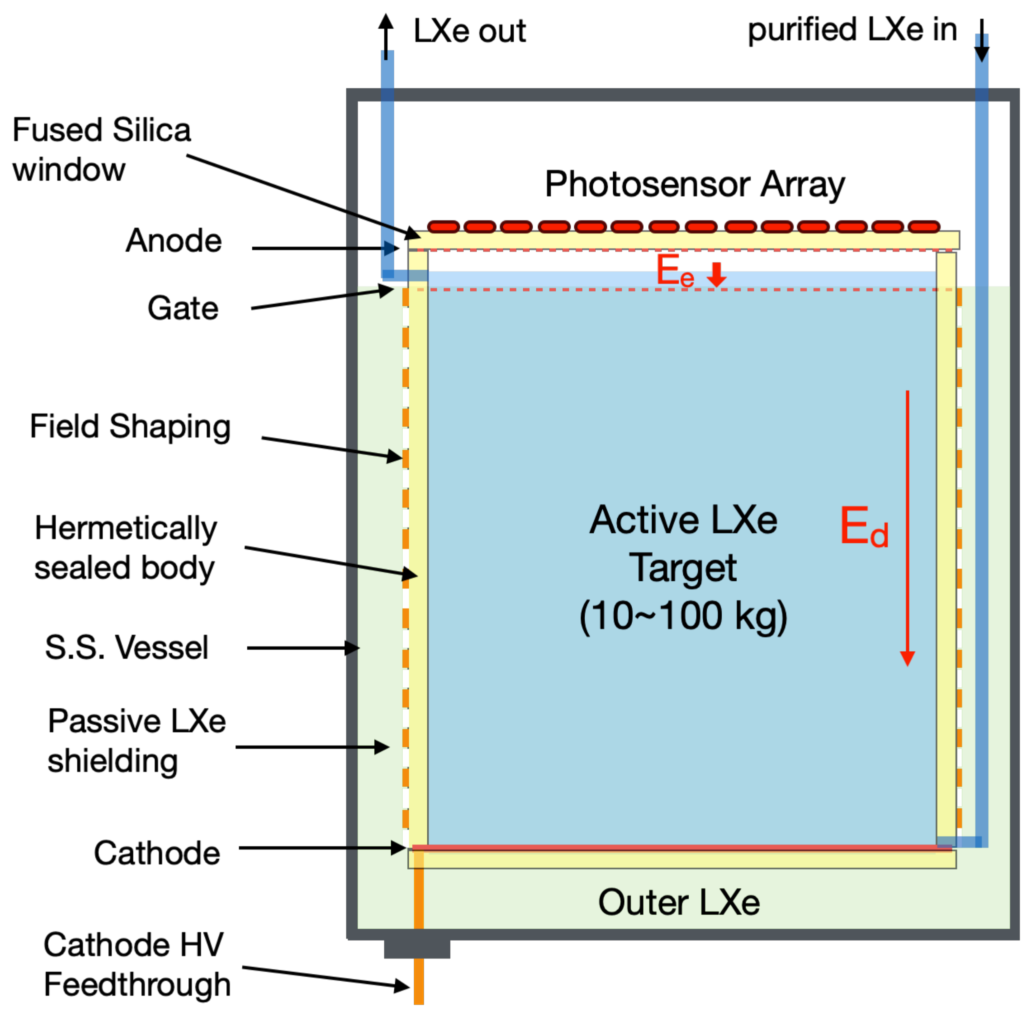


	220 V/cm	550 V/cm	2200 V/cm
1 e-	599	550	564
2-5 e-	941	1070	1042
6-10 e-	43	56	52
>10 e-	0	0	0
Total	1583	1676	1658

K. Ni (UCSD)

NUXE: *neutrino detection with xenon*

Conceptual design of a NUXE detector



Goal: reduce single/few electron background by 1/10~1/100 compared to XENON10/100

- **10~100-kg active LXe target**
  - simple, compact, cost-effective
  - most relevant technology well developed
  - ionization-only: single-electron sensitive
  - **detect >100 neutrinos/day near a reactor**
- **Ultra-pure LXe with Sealed Chamber:**
  - **>10 ms electron lifetime**
  - ○ less outgassing (limit materials touching target)
  - ○ prevent external outgassing entering into the target
  - ○ improve purification efficiency (purified LXe fed directly into the target)
- **Complete electron extraction at liquid surface**:
  - ○ high extraction field: 7~10 kV/cm (in liquid)
  - ○ assisted e- extraction with infrared light
  - ○ extraction field switching
- **Control electron emission from electrodes**: passivation, graphene, gold or platinum coating
- **Surface or shallow underground operation**

➡ **Explore new physics of neutrinos through reactor neutrino detection**

➡ **Application: real-time reactor neutrino monitoring for nuclear safeguards**

➡ **Techniques developed for this detector is applicable to *light dark matter search* (previous talk) and *generation-3 liquid xenon detector* for dark matter and neutrino physics**

K. Ni (UCSD)