Direct detection of dark sector DM via electron counting in liquid xenon

Peter Sorensen on behalf of the

$U_{A'}(1)$ Collaboration

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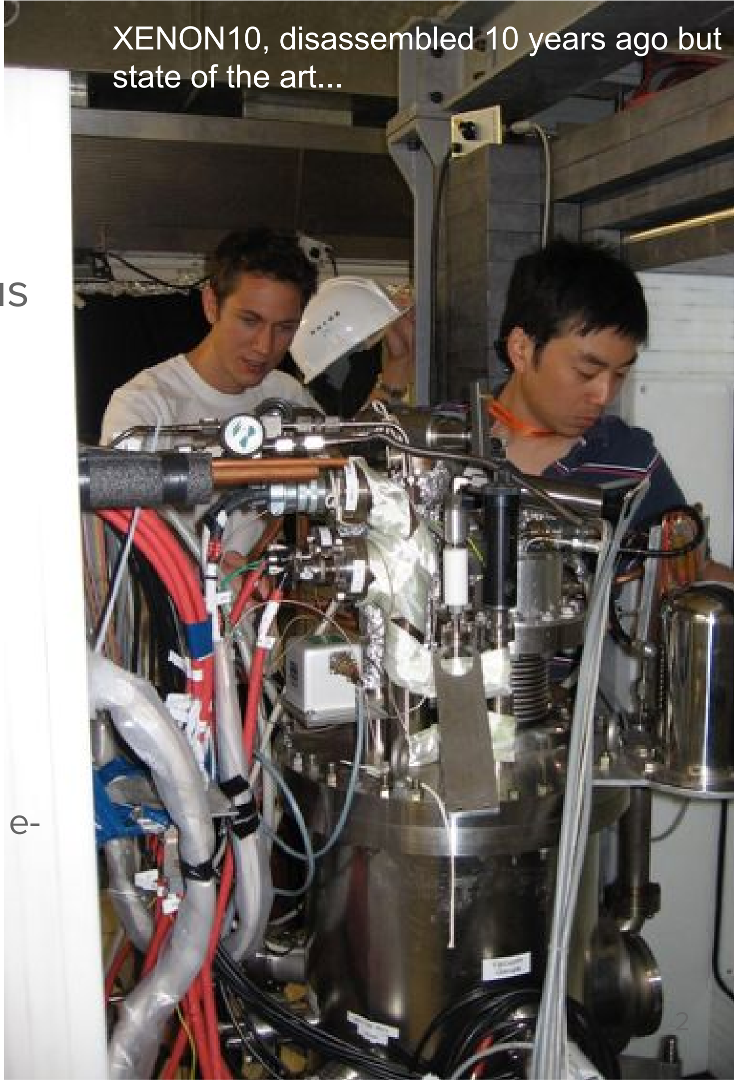
$U_{A'}(1)$ concept

- 10 kg scale liquid xenon TPC with complete focus on S2 signal and mitigation of e- backgrounds
- Without concern for S1 (primary scintillation collection)
  - the design is far simpler
  - and cheaper
  - contains less plastics (easier to achieve purity)
- A 2 kg scale prototype is already built
  - LLNL detector for CENNS
  - Update prototype design for 10 kg active while studying e- background mitigation
- Underground deployment at SURF
  - Small footprint, likely compatible with BLBF space



Target mass versus atomic bandgap

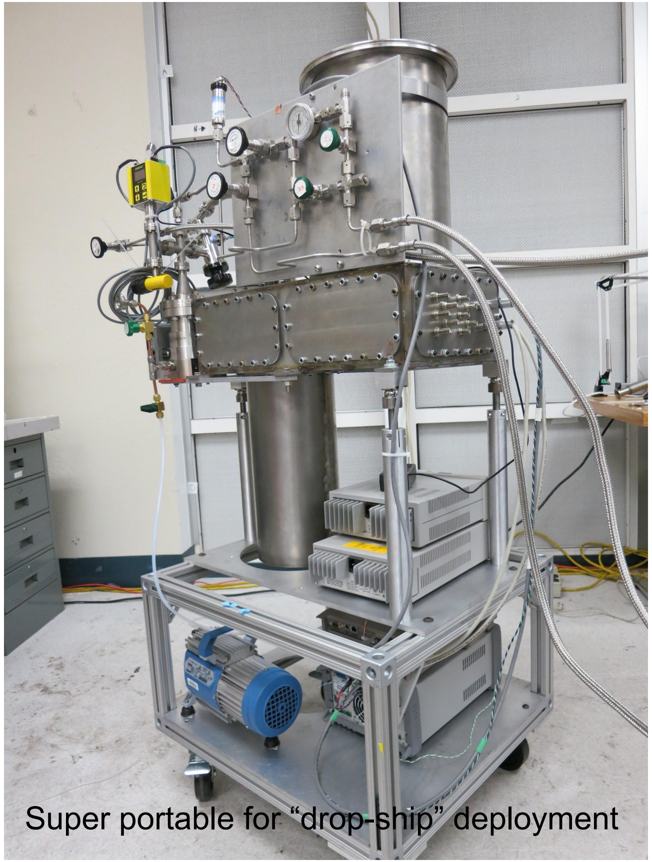
- Xe has a large >9.2 eV band gap, which suppresses the scattering rate
  - Semiconductors have ~1 eV band gap, a distinct advantage, however...
- **Mass is a relentless advantage in direct detection**
- And, tonne-scale liquid xenon TPCs are being deployed and/or built
  - 1000+ kg xenon vs <1 kg for semiconductors
  - It would be great to leverage large, quiet, sensitive targets (e.g. LZ) which are being deployed **anyway** for related purposes
- Even a 10 kg target can search new parameter space in the short term

Sensitivity not guaranteed (unless!)

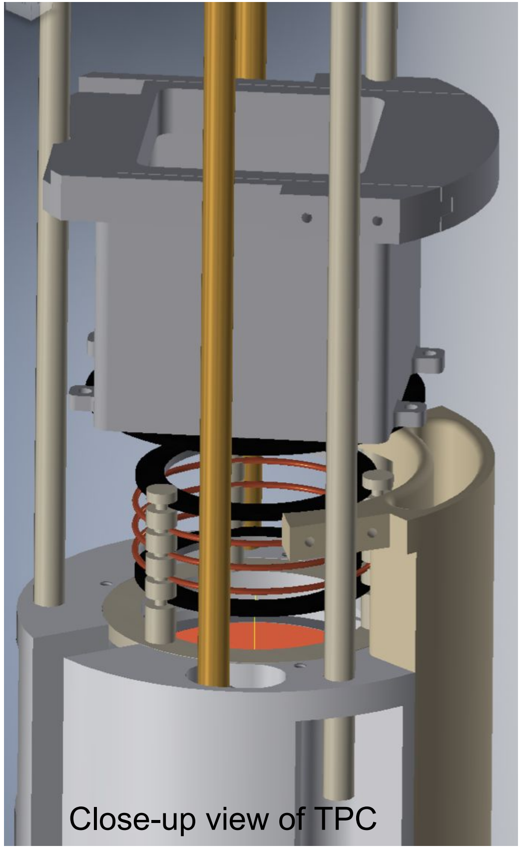
- Ability of LZ/XENON1T to do single electron analyses presently doubtful
  - XENON10: single electron sensitive search but limited by electron train background
  - XENON100: 4-5 electron threshold and still limited by background
  - LUX: in progress...
  - e- backgrounds have been considered a minor irritation to the primary goal of finding WIMPs
  - Efforts to mitigate them have so far been modest
- Mitigation requires a dedicated effort
  - Initial small-scale (surface) efforts underway (LLNL, LBL)
  - **Underground test bed eventually essential due to long lifetime of correlated backgrounds**
- Might as well get a science result in the process!

The $U_{A'}(1)$ experiment

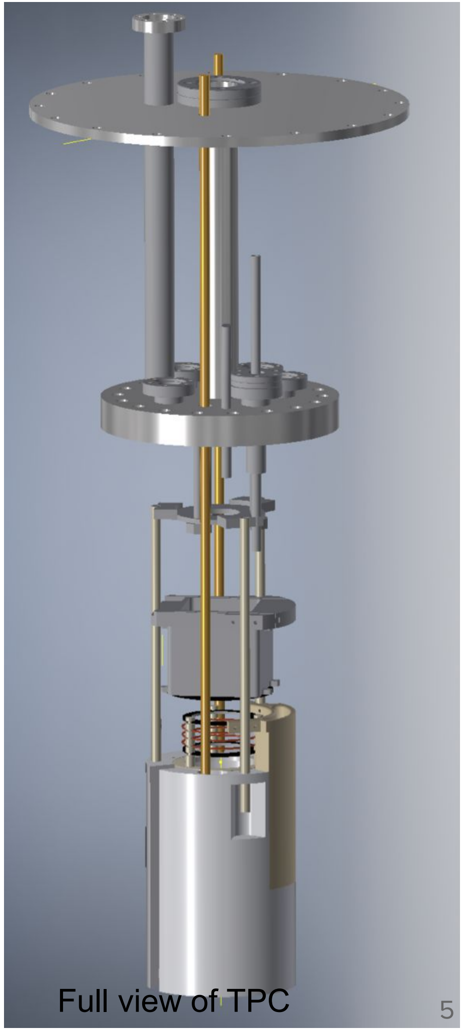
Prototype already built at LLNL



Super portable for “drop-ship” deployment



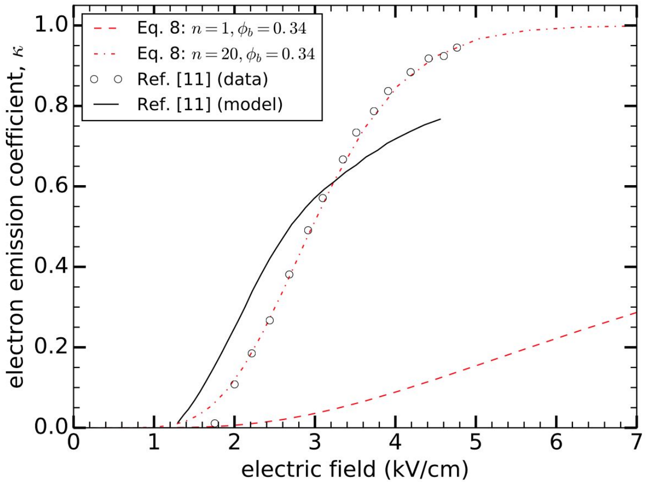
Close-up view of TPC

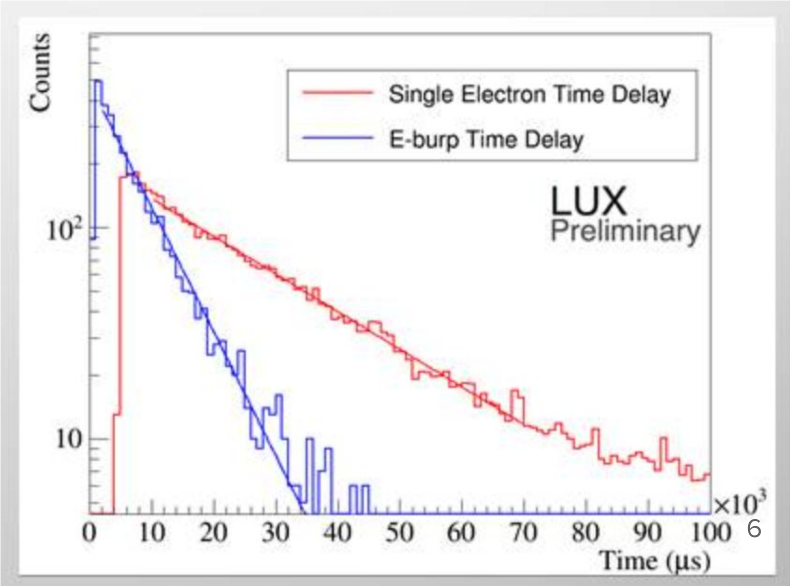


Full view of TPC

Primary R&D is to control e- backgrounds

- LUX studies underway (Jingke Xu, LLNL)
    - e.g. talk at APS 2016 April meeting
    - Two primary classes of electron backgrounds
    - Single e- backgrounds
    - e- clusters
        - events tend to be quite large
        - So less of a concern for few e- counting
- Recent theoretical work on understanding thermal e- trapping (Sorensen, LBL)
    - Predicts trapping lifetime O(10) ms
    - arXiv:1702:04805
- Additional R&D is underway at LBL and LLNL





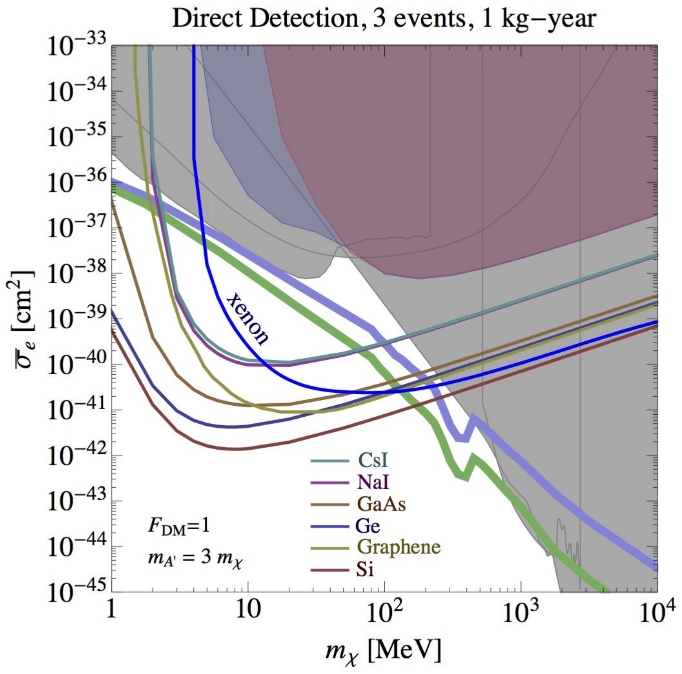
Sources of electron backgrounds

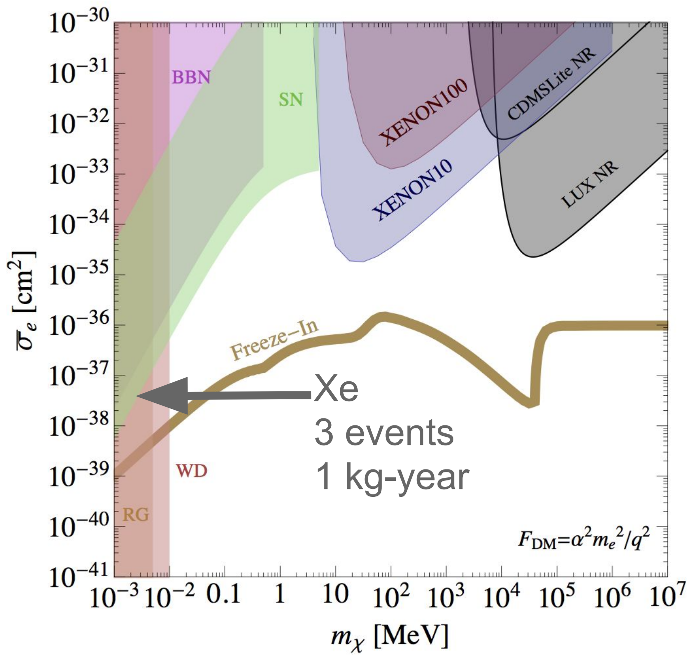
Sources	Mitigations
Trapped electrons at the liquid gas interface	1. larger electron emission field 2. Infrared photons to liberate trapped e- 3. Last resort: HV switching
Spontaneous emission from metal surfaces A. Due to inhomogeneities B. Due to lowered work function resulting from trapped ions	Varies... A. Treatment of metal surfaces B. AC field to de-trap ions

Reach thermal DM production parameter space in <1 year!

The only existing limits on dark sector DM are from liquid xenon targets

Xe
3 events
1 kg-year





plots from Essig et al, cf. arXiv:1703:00910

Timescale and budget

- One year to update design (based on LLNL prototype)
- One year to build and deploy at SURF
- We are talking about a 10 kg scale experiment so these are realistic estimates
- 6 months to commission and verify the success of the background mitigation strategies
- 6 months to obtain first results
- **3 years total project**
    - Of which approx 2 years include R&D
- Estimate $3M project

Summary

- Deploy a small O(10) kg liquid xenon TPC with a focus on electron counting and mitigation of e- backgrounds
  - A cost-effective fishing expedition with a clear target! (cf. Weiner talk, morning plenary)
- Potential for rapid exploration of new dark sector DM parameter space
  - Including freeze-out / freeze-in regions
  - Complementary to beam dump experiments
- Provide essential data on e- backgrounds such that much larger detectors can later also be sensitive to dark sector DM
- Leverage existing infrastructure, expertise and underground facility access within LUX/LZ/community
  - Interested in joining this effort? Contact Adam Bernstein and/or Peter Sorensen

Additional details about mitigations

- larger electron emission field
  - XENON achieved ~5.5 kV/cm
  - Suspect >7 kV/cm needed for substantial reduction of e-train bkgd
- Infrared photons to liberate trapped e-
  - Liquid surface trapping potential is 0.34 eV
  - 940 nm LEDs readily available (1.3 eV photon), trigger on S2
- Last resort: HV switching
  - Divert trapped electrons back to gate electrode
  - Possible in principle, may actually work quite well

Additional detail about dark counts

- From recent paper, arXiv:1702.04805
  - Xe liquid/gas interface presents a 0.34 eV potential barrier for e- dark counts
  - This gives a O(10) ms trapping lifetime

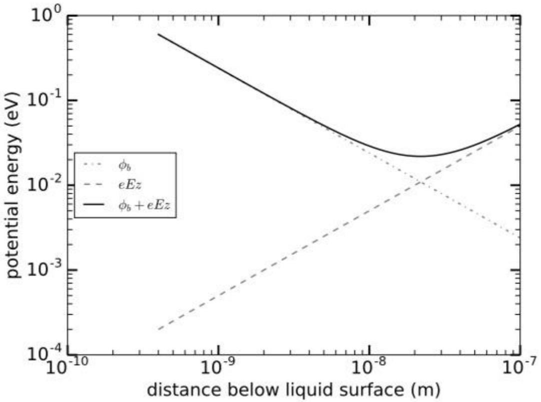


FIG. 2. Potential energy of an electron just below the liquid-gas interface.

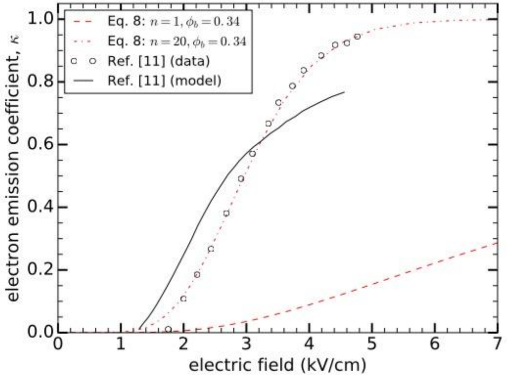


FIG. 1. Absolute efficiency for electron emission from liquid into gas xenon, as a function of the electric field in the liquid phase.

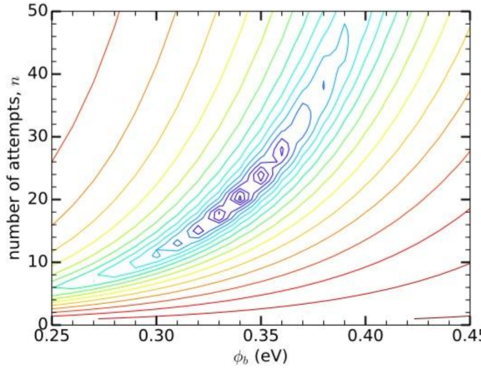
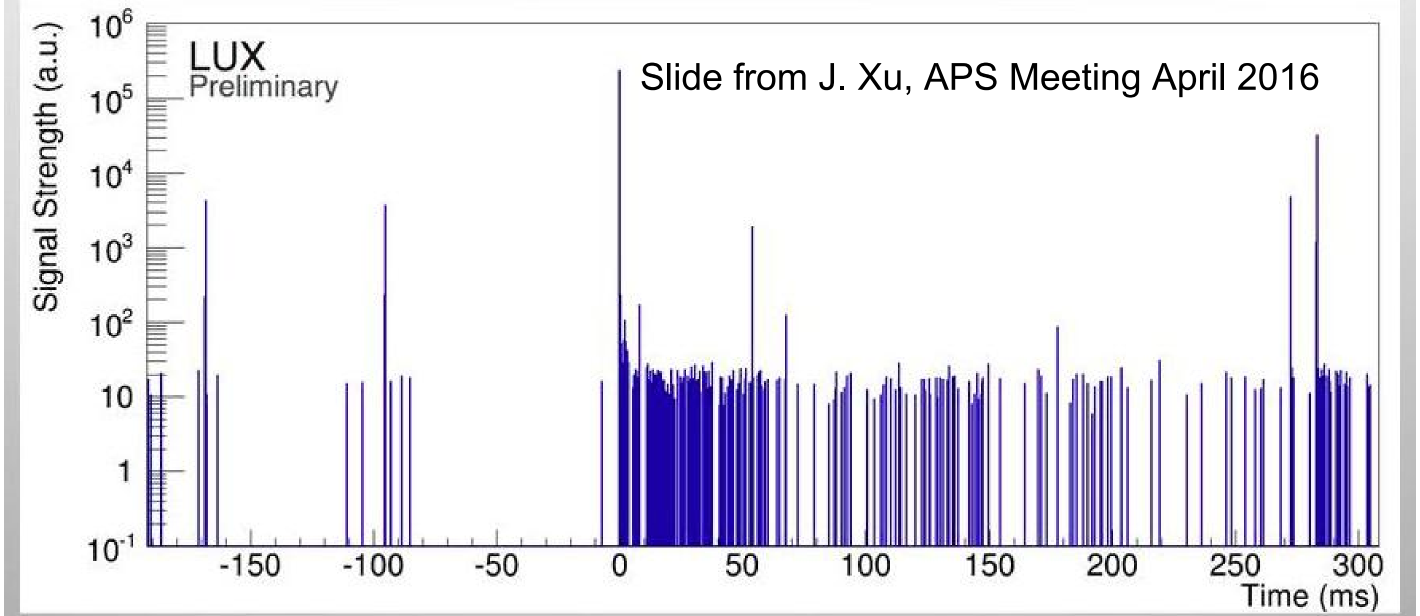


FIG. 4. Contour plot of χ^2 for comparison of the emission model given by Eq. 8 vs the data shown in Fig. 1. Agreement at 2σ is confined to $\phi_b = 0.34 \pm 0.1$ eV.

Additional details about dark counts

A LUX event waveform over 500ms (maximum drift time in LUX: 0.325 ms)



- Temporal event correlations are observed at time scales 1000 times larger than typical LUX event.

Additional plots