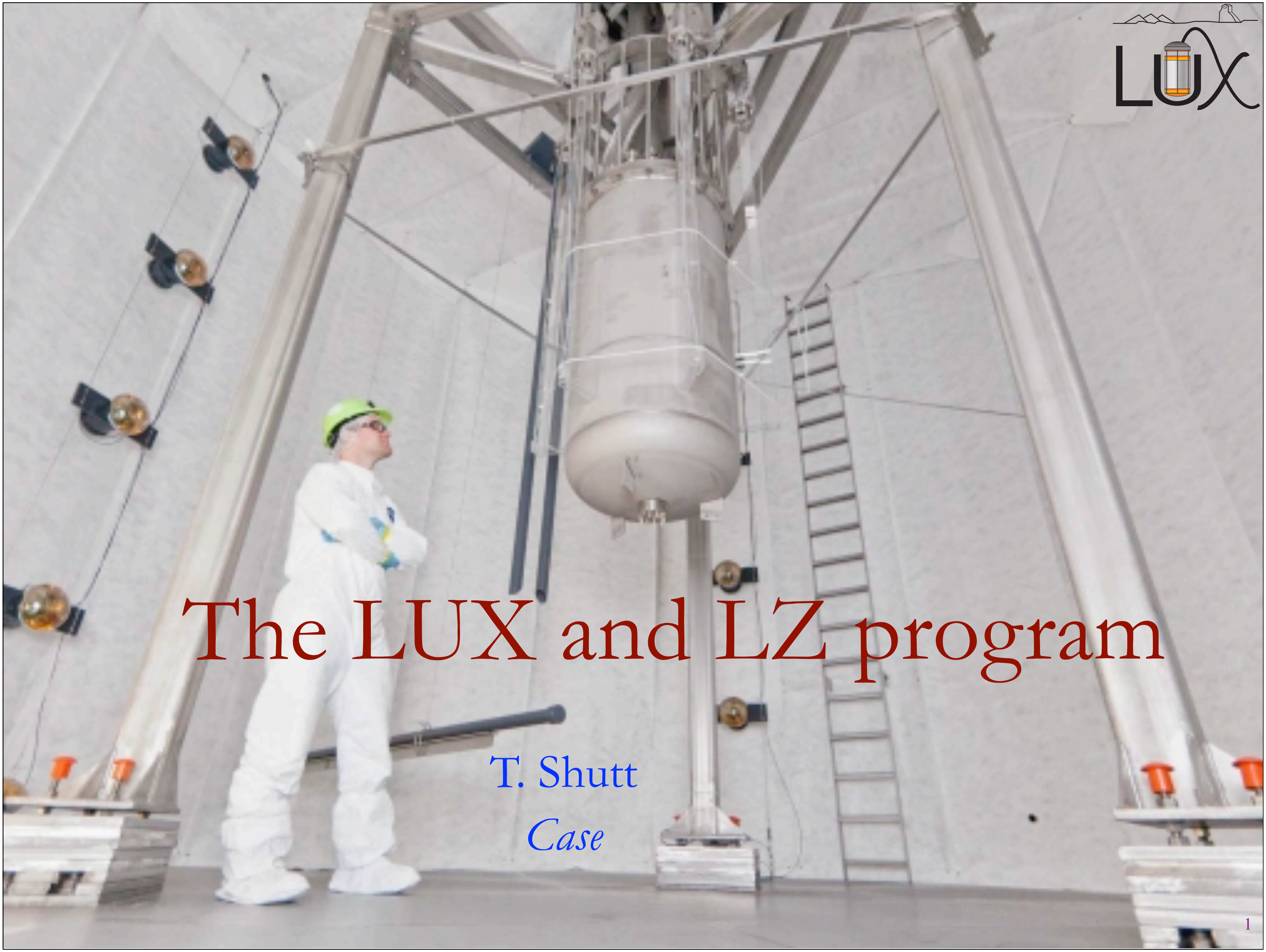

The LUX and LZ program

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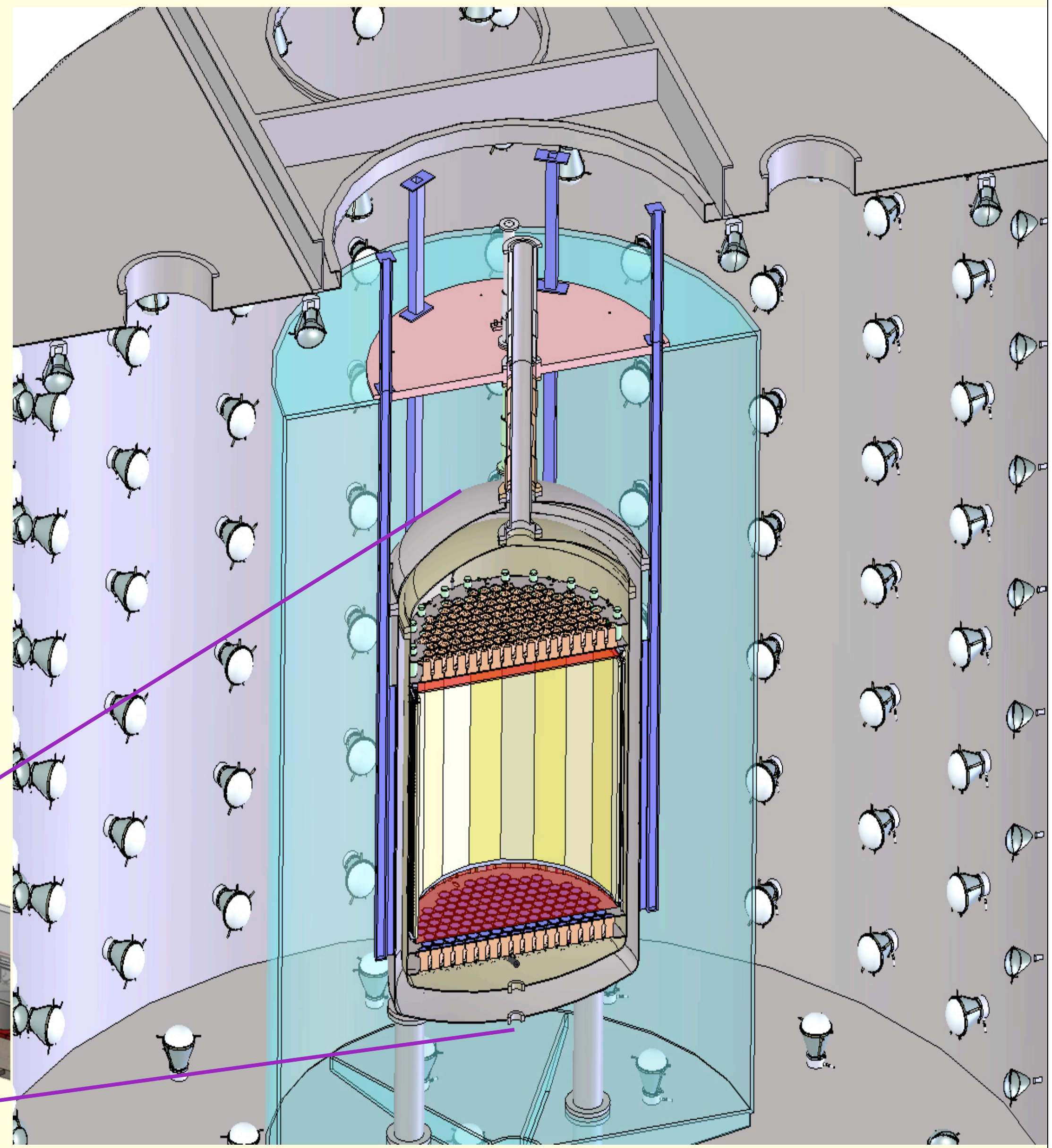
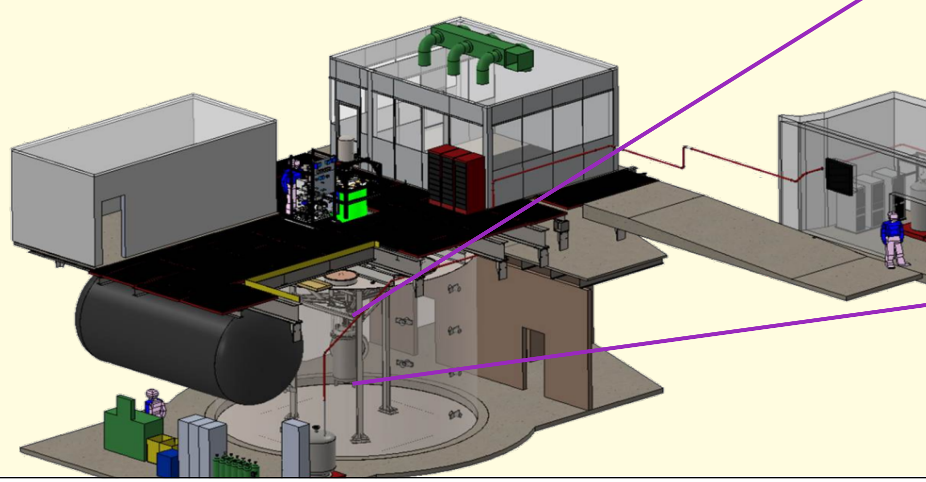
Case


Black Hills of South Dakota

LZ Overview

- LUX + ZEPLIN collaborations
- 20-fold scale-up from LUX
- Two-component veto system
  – 0.75 m thick Gd-loaded LAB scintillator shield (c.f.: Daya Bay)
  – Instrumented Xe "skin"
  – Effective for neutrons and gammas
- Fits in existing Davis Campus water shield, and complex
- SDSTA commitment to procure Xe.





LUX background expectations

- Expected LUX backgrounds

	LUX active	LUX fiducial	
Gamma	1.0	4e-4	cnts/kg/keVer/day
Beta	2.0E-04	2.0E-04	cnts/kg/keVer/day
Alpha	20	7	mHz
Radiogenic Neutrons	11E-6	1.6E-6	cnts/kg/keVnr/day
Cosmogenic Neutrons	0.2E-6	0.1E-6	cnts/kg/keVnr/day

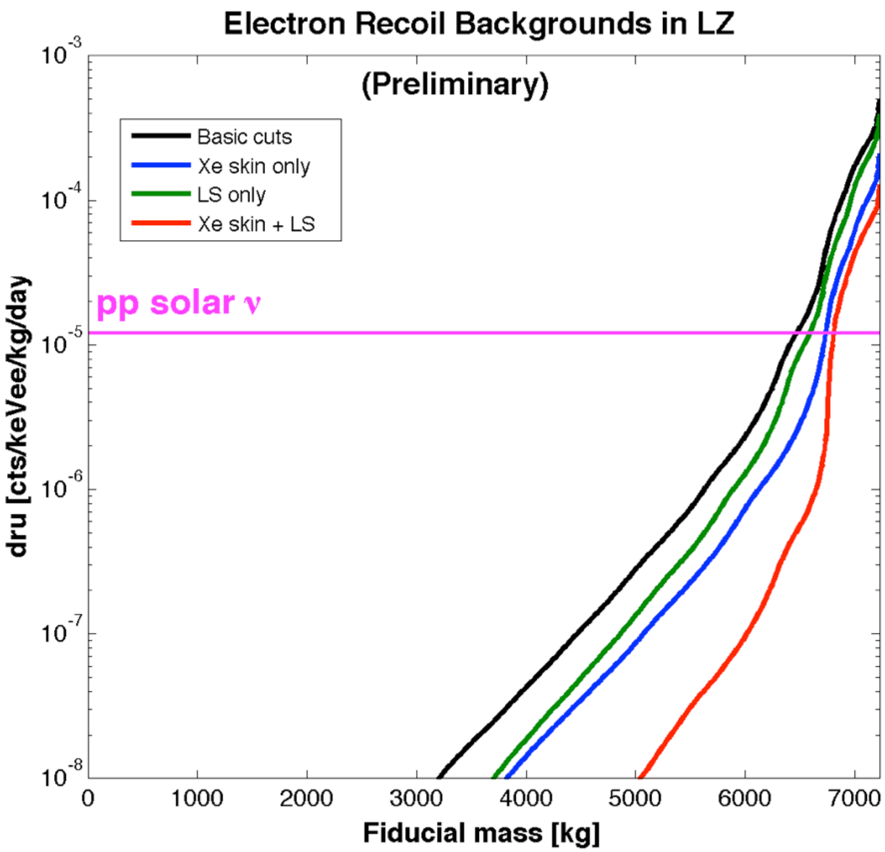
- Dominant Electron and Nuclear recoil backgrounds in WIMP range come from (R8778) PMTs

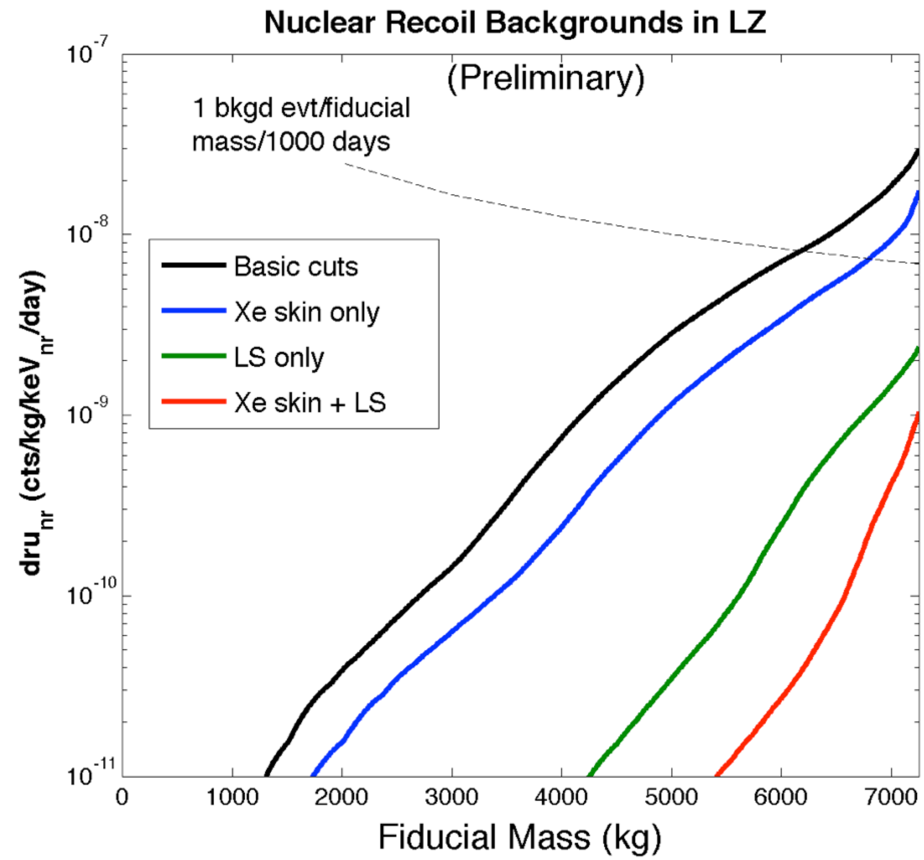
- LUX fiducial mass: 100 kg (~33% of fully active mass).
  - Assumes 99.5 % ER/NR discrimination, and above backgrounds
  - For short initial run, larger 200 kg mass possible

Backgrounds - Future

- Dominant backgrounds in LZ
  - Electron recoil: Solar pp neutrinos, at 1.2E-5 cnts/kg/keVee/day
  - Nuclear recoils: neutrons from PMTs, and Ti (at current limits).
    - Sub-dominant to non-discriminated electron recoils
  - Sufficiently low for search
- Important backgrounds in LZ
  - Krypton goal: 0.03 ppt, or 10% of solar pp neutrinos
    - Best production value: <0.2 ppt (from sampling), is tolerable
  - In LXe radon goal: 0.6 mBq (^{214}Pb) in full active volume, somewhat lower than most current values
    - Compare: ~μBq in Borexino, SNO
  - These (preliminary) targets render electron recoils from radioactivity sub-dominant to pp neutrinos
- G3 phase (beyond LZ)
  - Radioactive backgrounds need no further improvement beyond LZ.

LZ Backgrounds

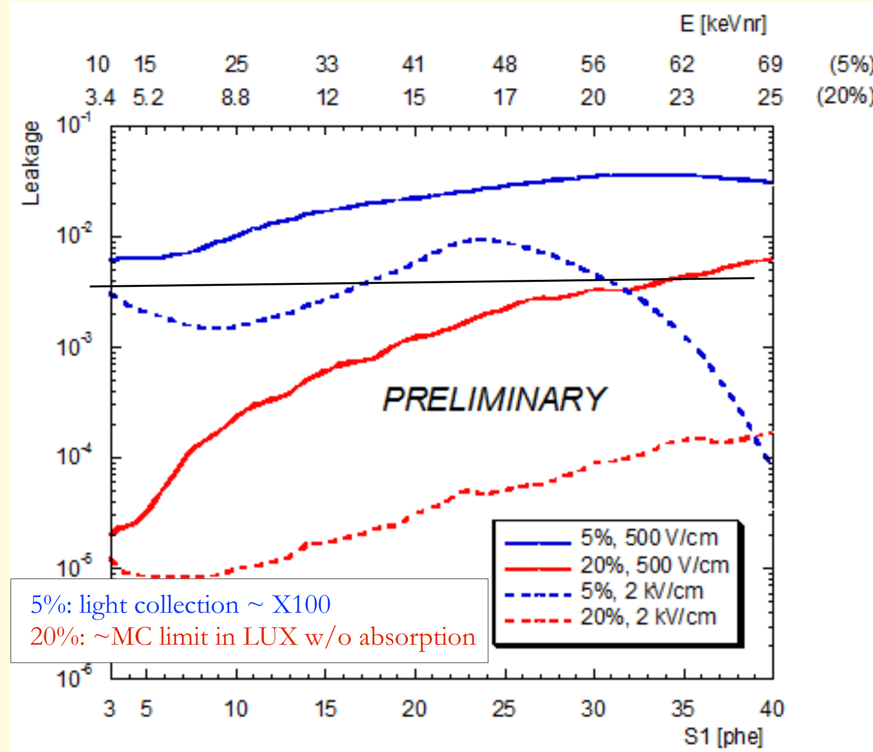




- Fiducial mass >6 tons, approaching 90% fiducial.

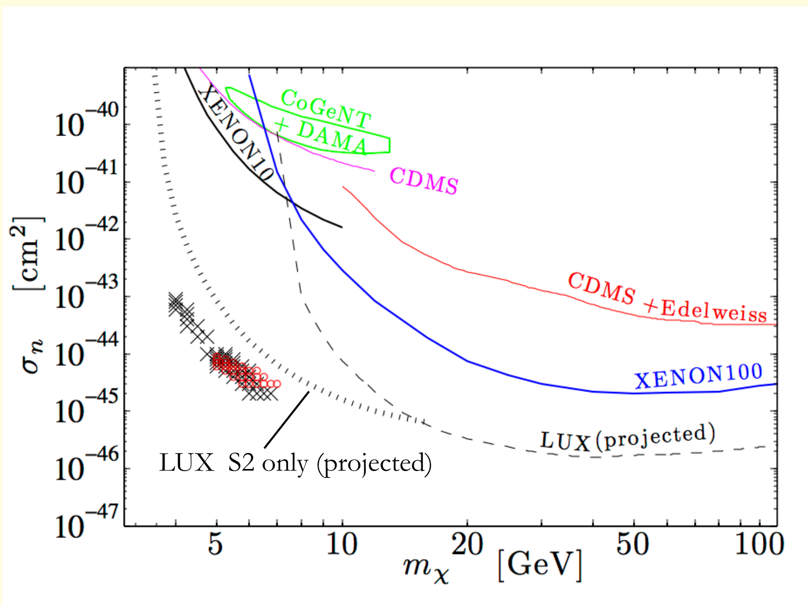
Discrimination

- Electron recoil discrimination in this technology is well established
  - Measured discrimination: ZEPLIN III, XENON10, XENON100
  - Monte Carlo tool (NEST) to predict behavior vs field and light collection, based on underlying physics model and band measurements (Dahl)
  - Ongoing calibrations of low energy nuclear (and electron) recoils
- Key features:
  - Discrimination better at higher fields.
  - Discrimination improves with light collection, especially at lowest energies
- Design value - 99.5%, 5-25 keVnr
  - LUX: >2x light yield over XENON100
  - ZEPLIN III: 99.99% at 3.9 kV/cm field.
  - LZ baseline: 500 V/cm, ~XENON100.
- G3 phase (20-50 tons) beyond LZ
  - Requires ≥ 99.95%
  - Combination of field and light could push towards 99.99%



Threshold, acceptance

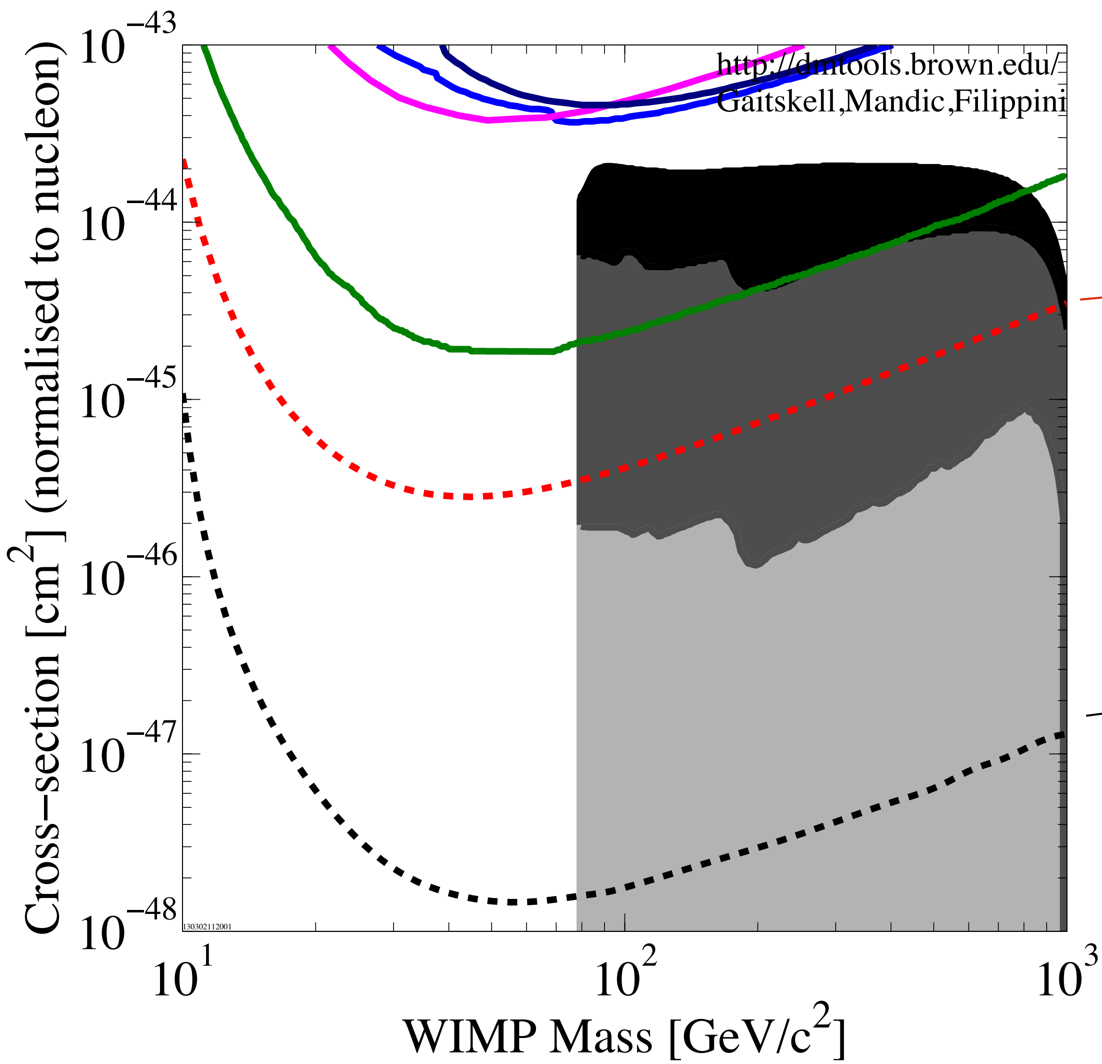
- Our nominal energy window is 3-30 pe in S1, or roughly 4 - 25 keVnr.
  - Benefit from 8.4 pe/keV$_{662keV_ZF}$ light yield in LUX
  - (Using conservative assumptions for
- Nominal 50% nuclear recoil acceptance.
  - Will likely evolve to energy dependent acceptance
- S2 only analysis: A promising new technique.
  - Rate of single and multiple electrons requires further study
  - Need to calibrate nuclear recoil response in this low energy range



Assumptions:

- 5 electron / 1.4 keV threshold
- Model of depth from S2 pulse shape
- Flat ER background to zero energy

Projected sensitivities



LUX: 300 kg fully active Xe, 370 kg total.
Operations underway, through 2015

LZ: 7.2 tons fully active Xe, 8+ tons total.
Start 2017.
(Zero background limit shown)

G3 scale experiment. 20+ tons, reaching coherent neutrino background, if discrimination reaches ≥ ~ 99.95%. Possibly as array of detectors.

Experimental Challenges

- Development work to scale from LUX to LZ is focussed on the following areas
  - Drift field and cathode high voltage.
    - Baseline goal: 75 kV on cathode, 500 V/cm drift field (equivalent to XENON100)
    - Drift Fields > 4kV/cm have been stably demonstrated: ZEPLIN III, Case, Yale prototypes
    - LUX feedthrough technology tested to 100 kV.
  - Must assure high light reflectivity for PTFE
  - Kr removal. Need 10x better than current demonstration of 10^6 separation to < ~0.2 ppt.
  - LXe Purification (for charge and light collection). Need to scale demonstrated heat exchange and gas purification technology
  - Rn emanation. Need robust screening program. Goal is 0.6 mBq, lower than current results, but much less stringent than Borexino, SNO.
  - Rn plateout control. Existing techniques adequate.

Further answers to questions

- (4) Discrimination
  - Values at 100 keVnr. Since Xe has little sensitivity at high energy, the discrimination has not well characterized there. We S2/S1 will be significantly higher at 100 keVnr (except for very low values of drift field), and pulse shape discrimination also provides an important extra amount of discrimination.
  - In existing data sets, there is a tail of low S2/S1 events at high energies that are roughly consistent with MC predictions of pathological event topologies in which S1 light from scattering outside the TPC leaks into active volume, hence suppressing S2/S1. In existing data sets this effect appears mostly at high energy (>~30keVr). We expect the fully instrumented LXe skin planned for LZ to sharply reduce the number of such pathological event topologies.
  - At low energy, any such tails are already present in the demonstrated discrimination performance to date: 99.99% in ZEPLIN III at 3.9 kV/cm drift field, 99.5% in XENON10, and 99.75% in XENON100 (with reduced acceptance). To the limit of current statistics, the width of the log(S2/S1) band is gaussian, but much higher statistics data would be useful. It very difficult to obtain in-situ results with gamma rays because of self-shielding. We plan within the LUX and LZ to measure it in situ with tritium, and also in a test detector.
  - Neutrons, cosmogenic and radiogenic. These are tagged by both multiple scattering, and by measuring the electro-magnetic shower following neutron capture. This latter effect is powerful in the central detector alone, but sharply enhanced by the combination of Xe skin and outer scintillator.

Further answers to questions

- (8) Annual modulation
  - Any search for annular modulation requires the largest number of events possible, and in that sense the very large mass and sensitivity of LZ is ideally suited for modulation searches.
  - That being said, current best limits for standard spin independent scattering from XENON100 place an upper limit on the event rate in LZ such that the possible modulation will be essentially too weak to be robustly measured for standard WIMP scenarios. Less sensitive experiments have even less ability to measure modulation.
    - If current limits are not taken as a constraint, then there is no significant impediment to an annual modulation search in the nuclear recoil channel.
  - LZ will also have the lowest background electron recoil signal at low energy of any detector. Thus it will be very well suited to a search for an annual modulation in the electron recoil channel, with very low threshold: roughly ~ 1 keVee for the full S1/S2 signal, and presumably near 100 eV for S2 only signal.

Further answers to questions

- (9) Unique ability to distinguish a WIMIP
  - An important unique capability is the ability to search in S2 only mode. As discussed above, this promises to extend the sensitivity to very low WIMP mass, but this capability remains to be fully explored and exploited.
  - The fully imaging capability of a TPC is unique in the dark matter field, and very powerfully rejects external backgrounds.
  - We anticipate that the dominant background in LZ to be a very well known astrophysical signal.
  - The combination of the external liquid scintillator and LXe skin provides an extra handle to both remove and fully measure external backgrounds. We currently project 93% vetoing for gammas and 96% veto rate for neutrons.
- (9) Other targets/isotopes
  - The LUX / LZ design is currently only suitable for a liquid Xe target, though of course Xe and Ar two phase TPCs have strong common features.
  - As an upgrade, isotopic separation allows both spin/non-spin, enhanced double beta decay sensitivity, and high precision pp solar neutrino measurement.
  - A large Xe dual phase TPC can support a strong program of non dark-matter physics. Of particular note are, neutrinoless double beta decay for ^{136}Xe, and measurement of both coherent scattering of ^{8}B neutrinos, and elastic scattering of pp solar neutrinos, neither of which has to date been measured.

Questions

- (9) Sensitivity to non-standard interactions.
  - We have very broad sensitivity to any low rate, non standard signal, due to the following attributes of the technology
    - Lowest ER background of any experiment, with very low S2 only threshold (~30 eV)
    - Lowest NR background of any experiment, also with low threshold.
    - Imaging detector.

- (10) WIMP properties and astrophysical parameters
  - The ability of both a single Xe experiment, and Xe targets in comparison with other targets have been extensively discussed in the literature
  - Perhaps the most important requirement for any such measurement is the need for high statistics. The very large mass and sensitivity of LZ is ideal for this.