LZ Dark Matter Experiment

@ Sanford Lab / DUSEL

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LLNL

on behalf of

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Co Spokesperson, LUX Collaboration
US Spokesperson, LZ (LUX ZEPLIN) Collaboration

http://luxdarkmatter.org

Evolution

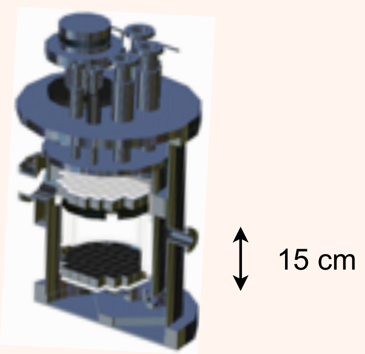
XENON10
22 kg
Fid. 5.4 kg

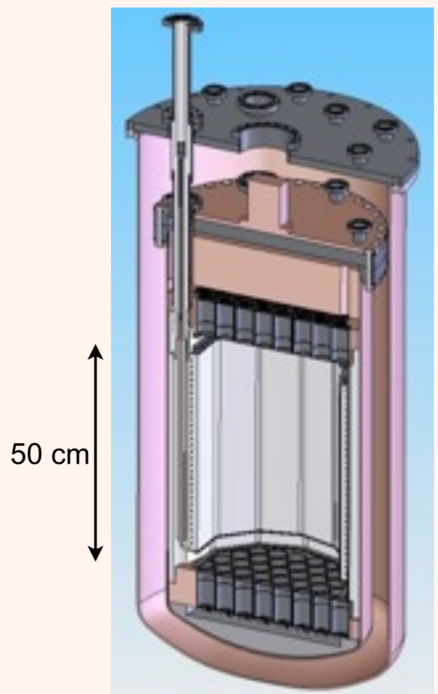
(NOT SHOWN)
XENON100
170 kg
Fid. 40 kg

LUX
350 kg
Fid. 100 kg
x100 sens.

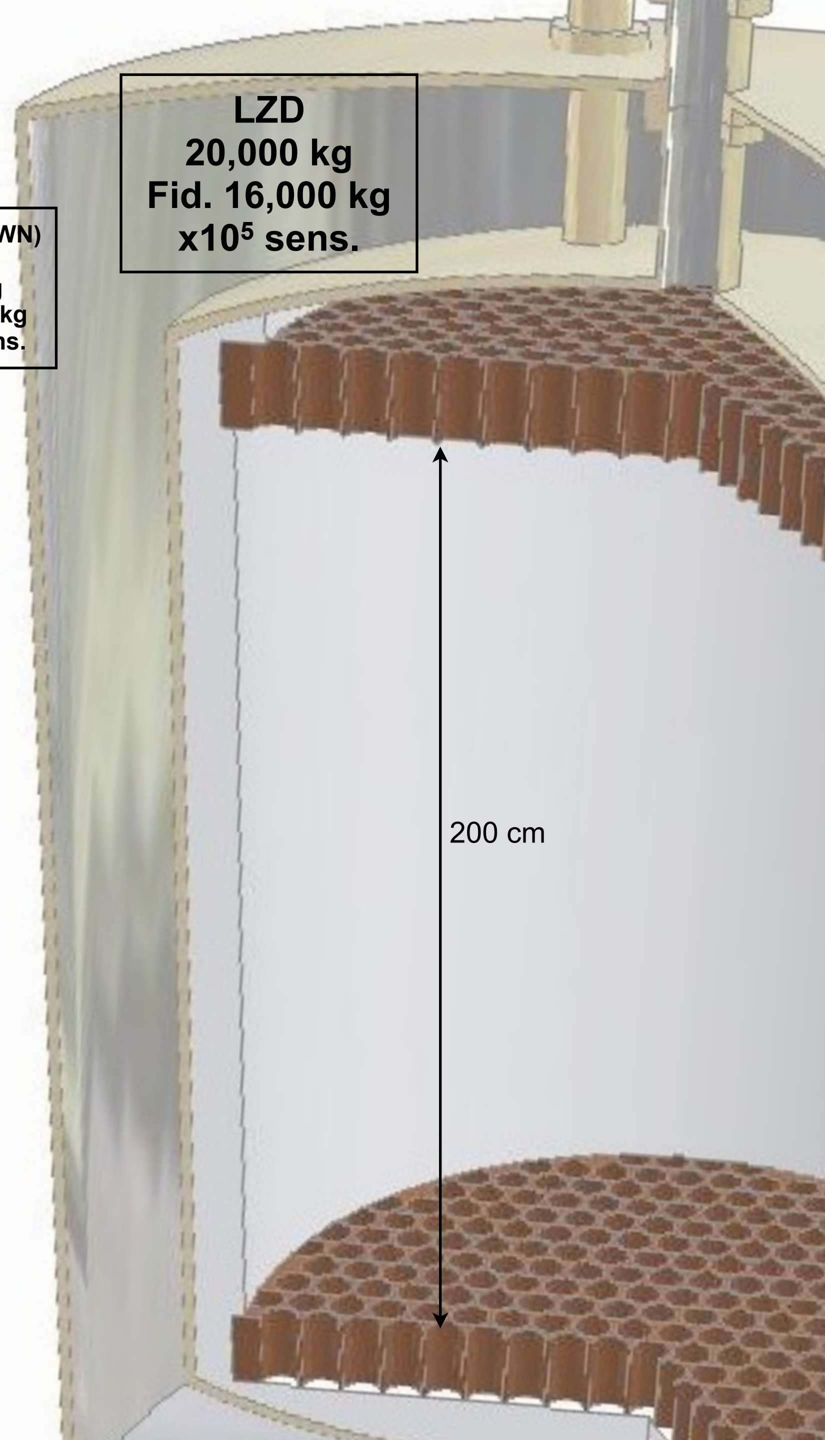
(NOT SHOWN)
LZS
1500 kg
Fid. 1200 kg
x1000 sens.

LZD
20,000 kg
Fid. 16,000 kg
$x10^5$ sens.



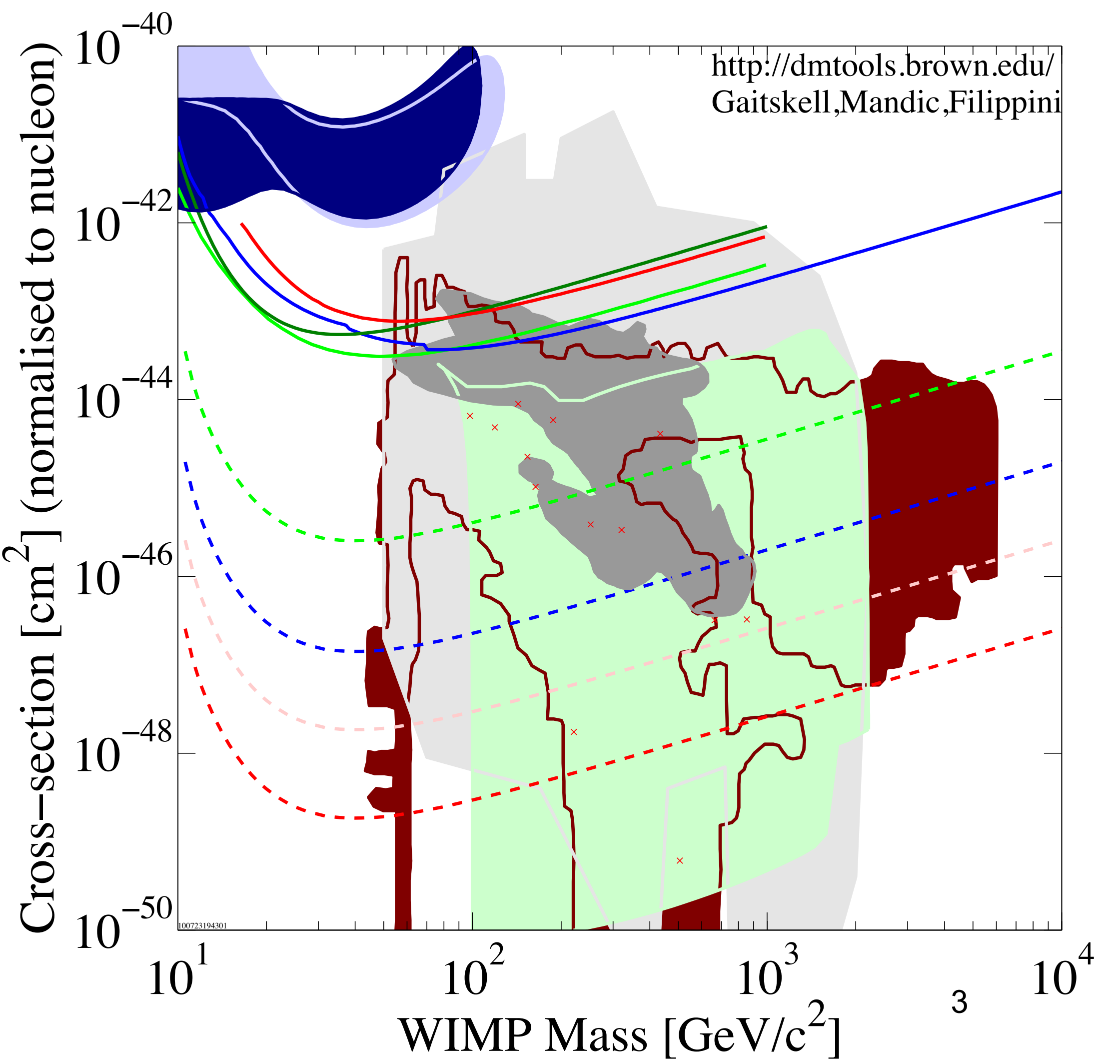


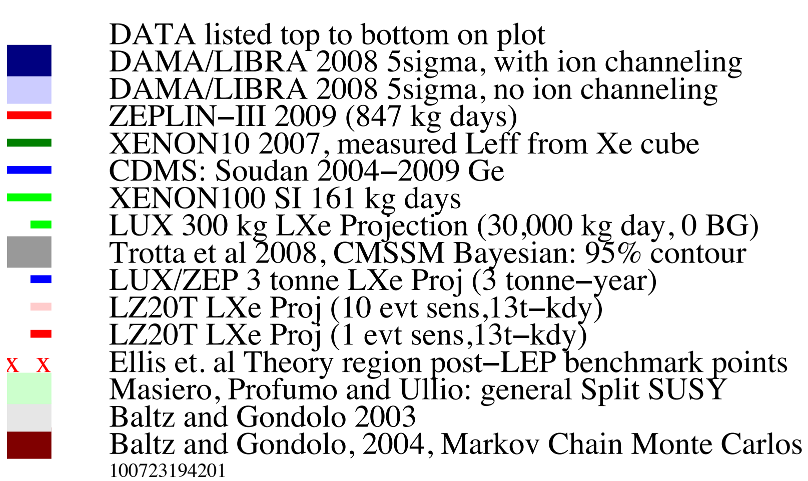
(see talk by T Shutt)



Dark matter sensitivity of LZ

(of course, the point is not exclusion, but **detection)**

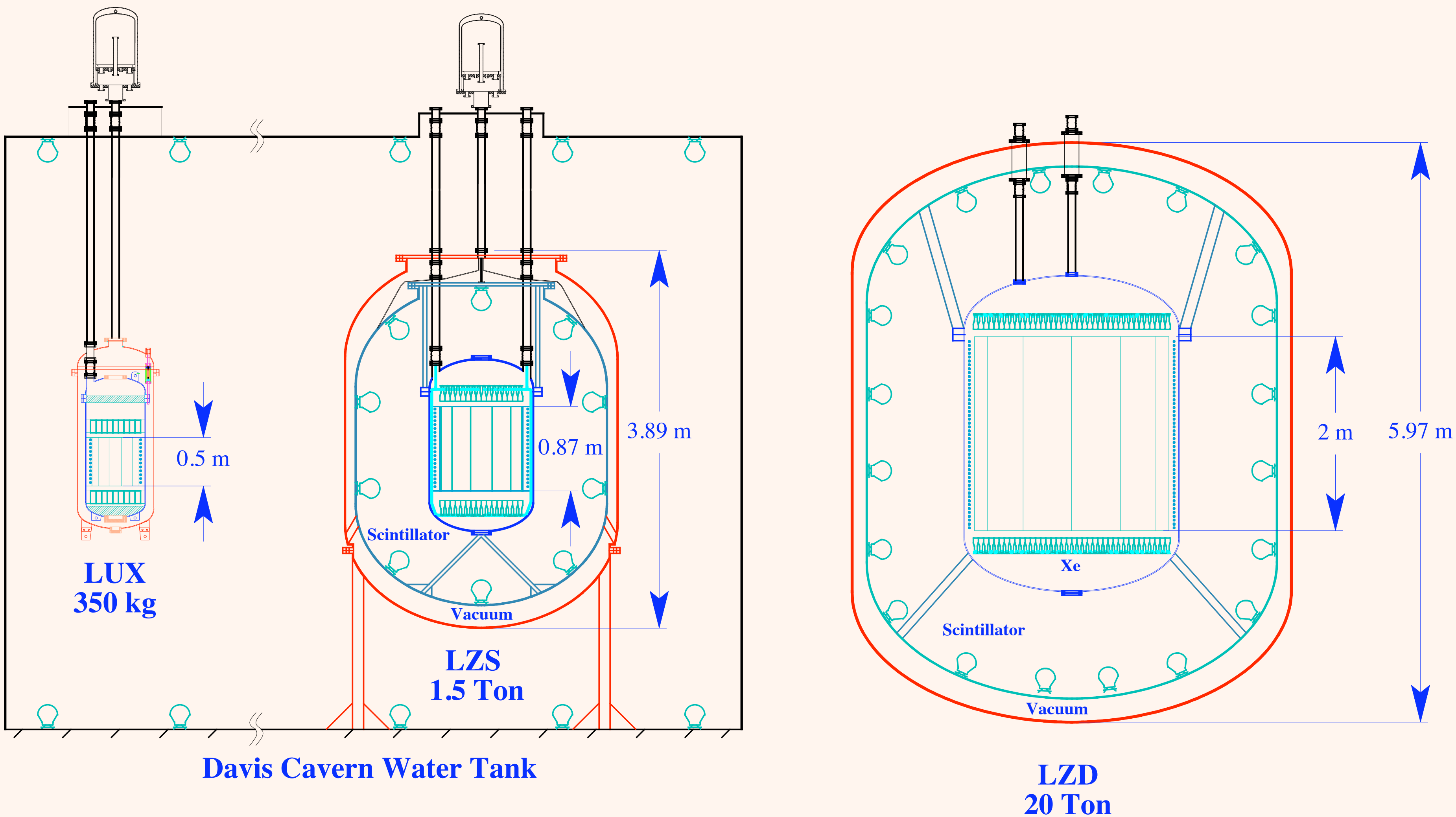




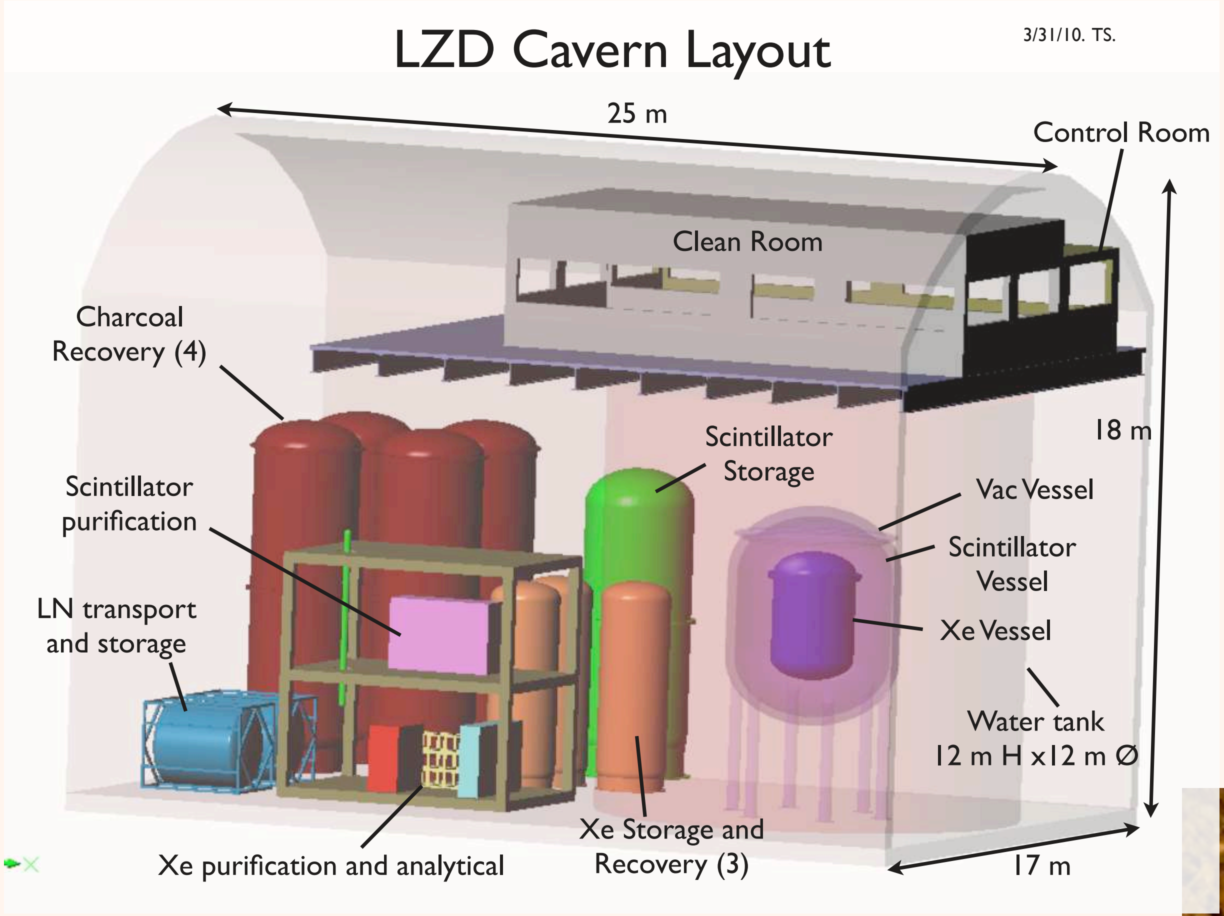
- Projections based on
  - Known background levels
  - Previously obtained e$^-$ attenuation lengths and discrimination factors
- Fiducial volumes selected to match < 1 NR event in full exposure

LUX => LZSanford => LZDusel

- LUX -> LZD is x4 linear increase (similar to CTF -> Borexino scaling)
- also features active scintillator anti-coincidence veto



Installation



- LZD layout nominally consistent with baseline cavern
- Water tank dimension critical, 12 m is conservative.
- Staging must be carefully considered.

The LUX Collaboration

Brown
XENON10, CDMS

Richard Gaitskell	PI, Professor
Simon Fiorucci	Postdoc
Monica Pangilinan	Postdoc
Luiz de Viveiros	Graduate Student
Jeremy Chapman	Graduate Student
Carlos Hernandez Faham	Graduate Student
David Malling	Graduate Student
James Verbus	Graduate Student

Case Western
SNO, Borexino, XENON10, CDMS

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Carmen Carmona	Postdoc
Ken Clark	Postdoc
Karen Gibson	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student

Harvard
BABAR, ATLAS

Masahiro Morii	Professor
Michal Wlasenko	Postdoc

Lawrence Berkeley + UC Berkeley
SNO, KamLAND

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Jim Siegrist	Professor
Joseph Rasson	Engineer
Mia ihm	Grad Student

Lawrence Livermore
XENON10

Adam Bernstein	PI, Leader of Adv. Detectors Group
Dennis Carr	Senior Engineer
Kareem Kazkaz	Staff Physicist
Peter Sorensen	Postdoc

University of Maryland
EXO

Carter Hall	Professor
Douglas Leonard	Postdoc

SD School of Mines
IceCube

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ZEPLIN II

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Robert Webb	Professor
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Tyana Stiegler	Graduate Student
Clement Sofka	Graduate Student

UC Davis
Double Chooz, CMS

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Robert Svoboda	Professor
Richard Lander	Professor
Britt Hollbrook	Senior Engineer
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Matthew Szydagis	Postdoc
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Melinda Sweany	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student

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ZEPLIN II

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U. South Dakota
Majorana, CLEAN-DEAP

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Chao Zhang	Postdoc
Jason Spaans	Graduate Student
Xiaoyi Yang	Graduate Student

Yale
XENON10, CLEAN-DEAP

Daniel McKinsey	Professor
James Nikkel	Research Scientist
Sidney Cahn	Research Scientist
Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Louis Kastens	Graduate Student
Nicole Larsen	Graduate Student

Globalization

LZ Collaboration: 14 USA + 7 International Institutions

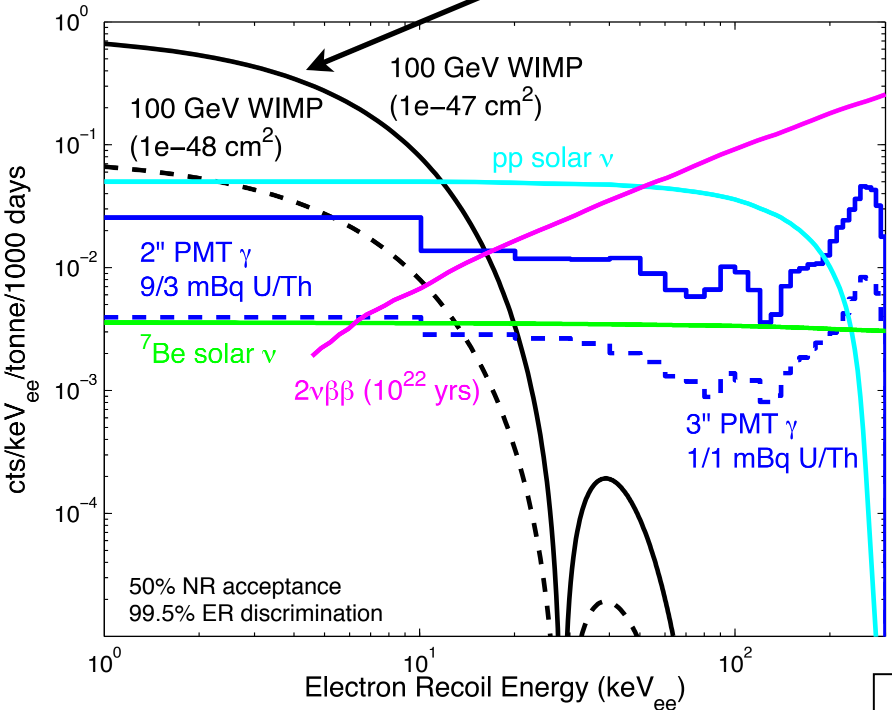
- LUX Collaboration plus...
  - UC Santa Barbara (also shortly to become LUX member)
- ZEPLIN III Collaboration
  - Imperial College London, UK
  - Institute of Theoretical and Experimental Physics (ITEP), Russia
  - LIP-Coimbra, Portugal
  - STFC - Rutherford Appleton Laboratory, UK
  - University of Edinburgh, UK
- Moscow State Engineering Physics Institute (MEPhI), Russia
- STFC - Daresbury Laboratory, UK
- significant low background construction and operational experience in depth across the collaboration
  - Neutrino and DBD
  - CDMS I, II, XENON10 (4 of the 5 active US Groups are in LUX)

Dark Matter Signals + Backgrounds

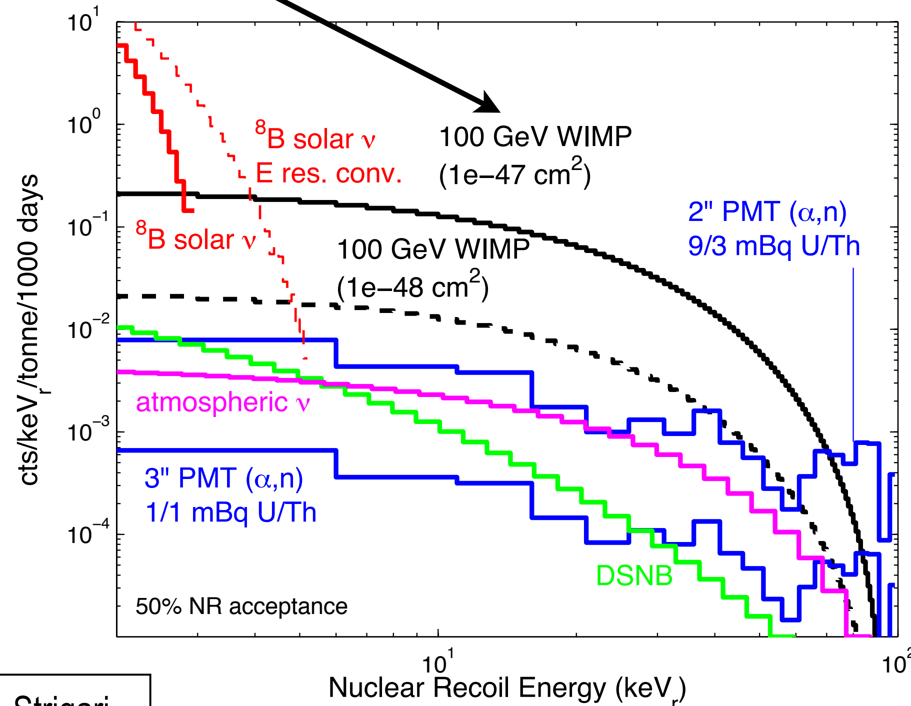
- Projections for 20 tonnes / 13.3 tonnes fiducial
- ER/NR Discrimination in LXe better than 99.5% especially at low energies

10^4 below current sensitivity

Low Energy Electron Recoil Events



Low Energy Nuclear Recoil Events



see L. Strigari
arxiv:0903.3630

Cosmogenic Backgrounds

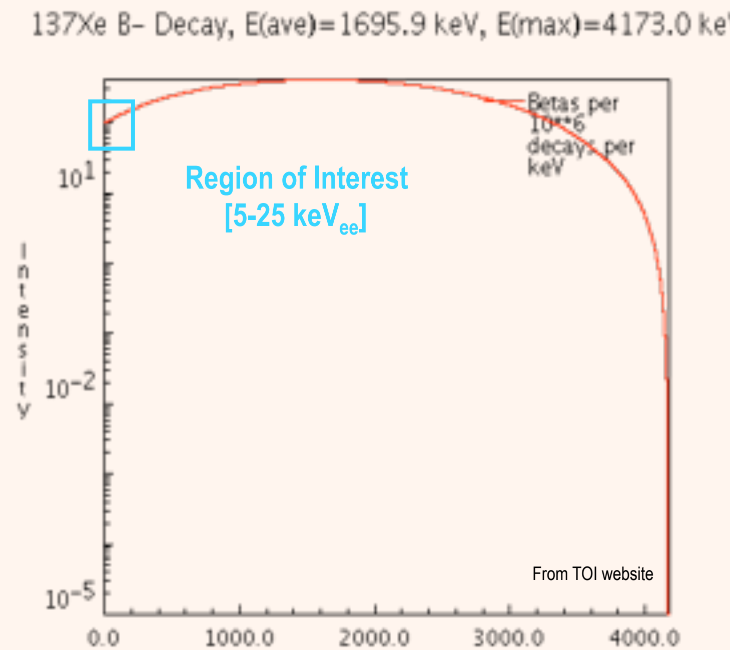
- Unprecedented sensitivity reach means we need to look into previously overlooked cosmogenic backgrounds
  - Reference: p-p solar neutrinos irreducible background **~10^{-5} /keV$_{ee}$/kg/d** (before 99.5% ER rejection)
  - Neutrons from muon spallation
    - in the rock (well known background for years, killed by water shield)
    - in the xenon
  - Negative muon capture → neutron emission + Radioactive isotopes in Xe / H_2O
  - Photonuclear neutron production in the water
  - Fast neutron activation of xenon
  - Thermal neutron capture on xenon

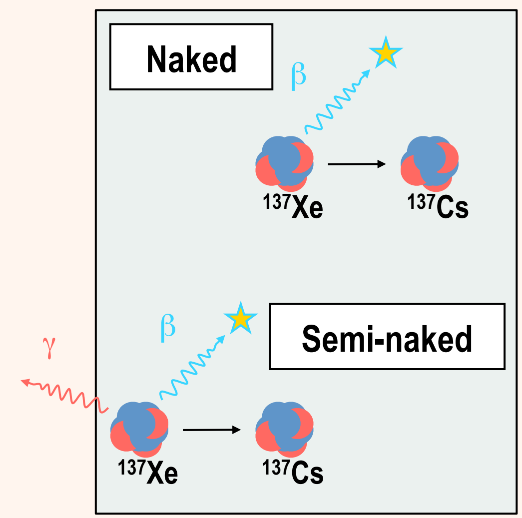
- Activation of the xenon → many isotopes, looked at all significant ones (> 200 !)
  - Searching for “Naked beta” emitters or “semi-naked beta” emitters
    - No coincident radiation (or not detected)
    - Potentially low energy deposition in WIMP search range [5–25 keVee]
    - Statistical chance of leakage into nuclear recoil region (< 0.5%)
  - Example: ^{137}Xe (from neutron activation of natural Xe)
    - 67% BR to naked 4.1 MeV beta
    - 30% BR to 3.7 MeV beta + 450 keV gamma
    - Probability for a 450 keV gamma to “escape” from 10 cm of Xe = 0.3 %
  - Calculated single event rates in [5- 25 keV$_{ee}$]
    - From muon capture on xenon: **~10^{-9} /keV$_{ee}$/kg/d**

      (assuming a muon flux of 5 10^{-9} /cm^2/s)
      (assuming a stopping muon fraction of 0.5 % per 100 g/cm^2 of Xe)
    - From thermal neutron activation of xenon: **~5 10^{-8} /keV$_{ee}$/kg/d**

      (assuming a thermal neutron flux of ~5 10^{-7} /cm^2/s)
    - From fast neutron activation of xenon: **~10^{-7} /keV$_{ee}$/kg/d**

- ALL well below the p-p solar neutrino background rate



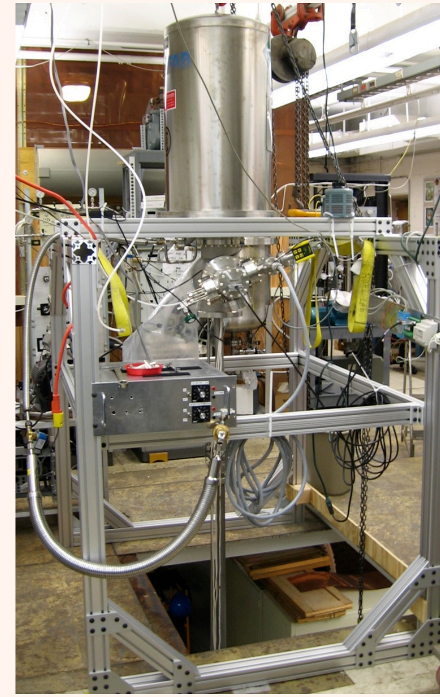


Technical Details

The following few slides will highlight several critical-path R&D efforts that will lead from

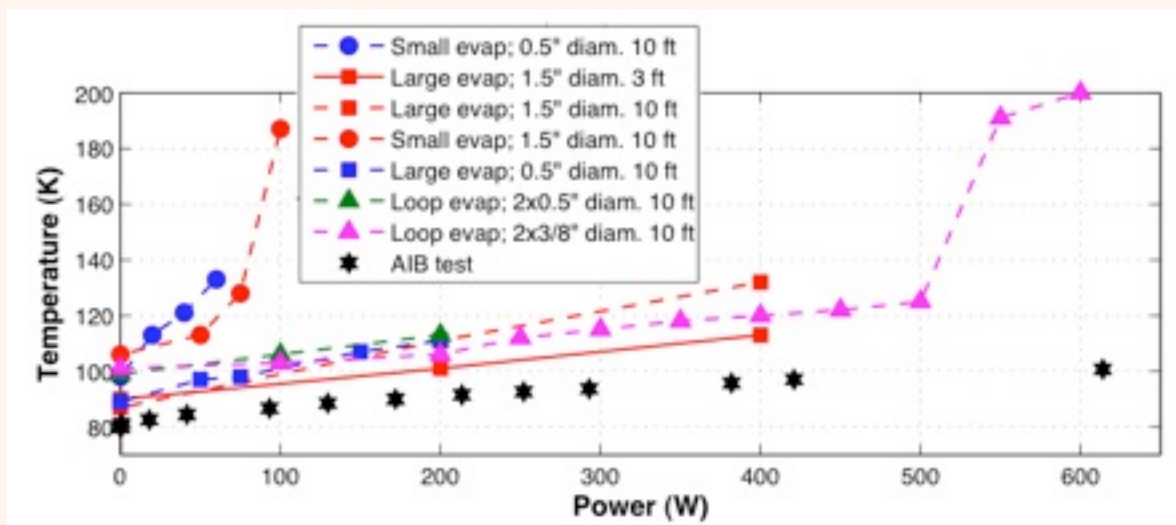
LUX => LZD

Cryogenics



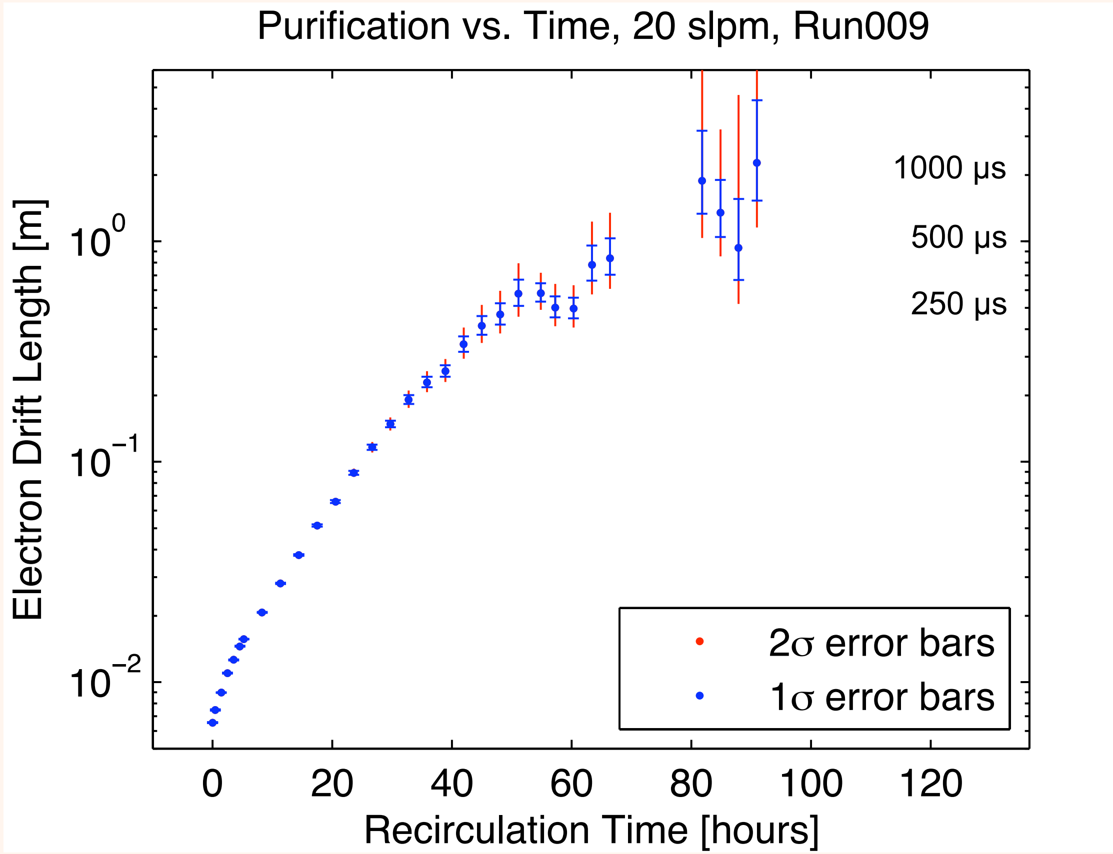
- Architecture developed for LUX
  - 2 years operational experience on full-size prototype (LUX 0.1).
  - 70 thermometers, 5 P&ID control points.
- Liquid nitrogen (LN) thermosyphon backbone.
  - Extremely high capacity, remotely deployed, multiple cold heads, tunable to low power for fine control.
  - Intrinsically safe: passive, insensitive to power loss.
- Probable LN generation on site to avoid LN transport.
- "Conventional" system for pre-cooling scintillator.

Thermosyphon configuration testing



Purification

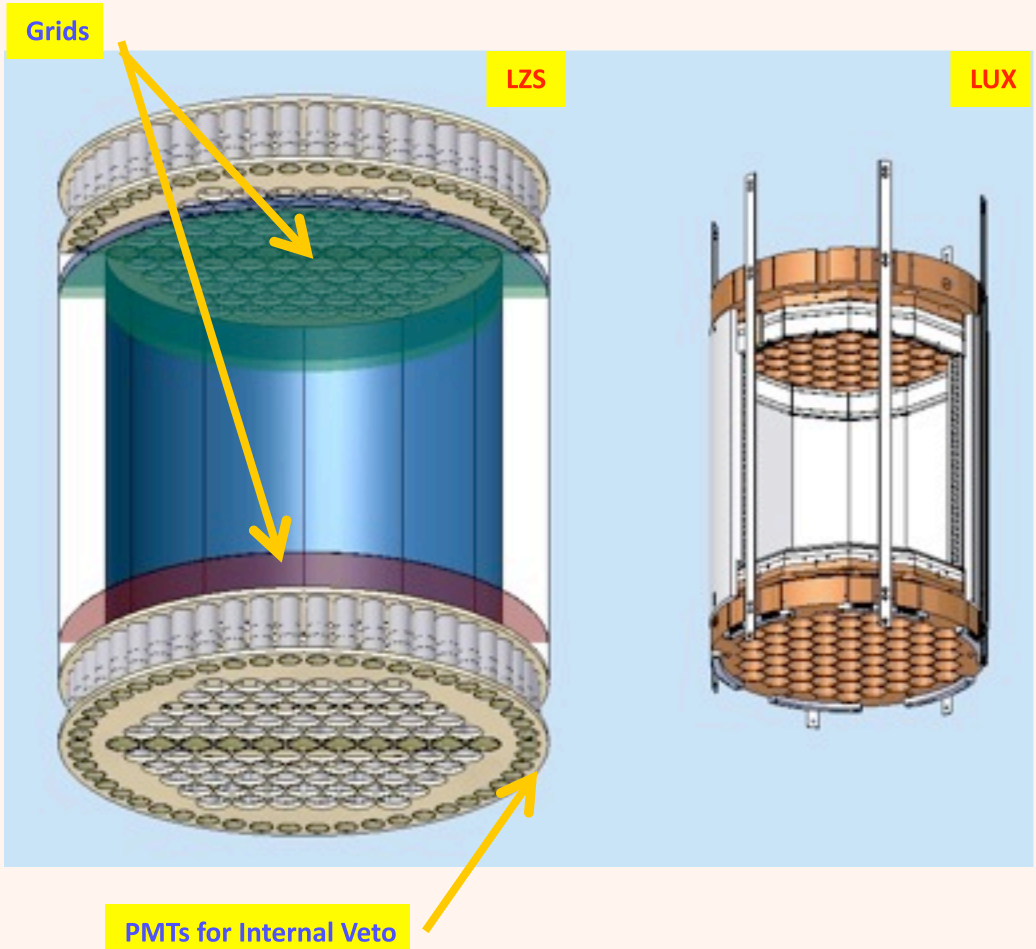
- Purification of Xe for charge and light collection is key challenge.
  - Current (pre-LUX) state of the art: circulate ~30 kg/day Xe through gas-phase getter. Achieve purity after month(s).
- Scalable heat exchanger system:
  - >96% efficient at 0.4 tons/day
  - Unprecedented ~2 day purification - 60 kg Xe
  - Scale to tonnes+/day?



Internal Design Developments

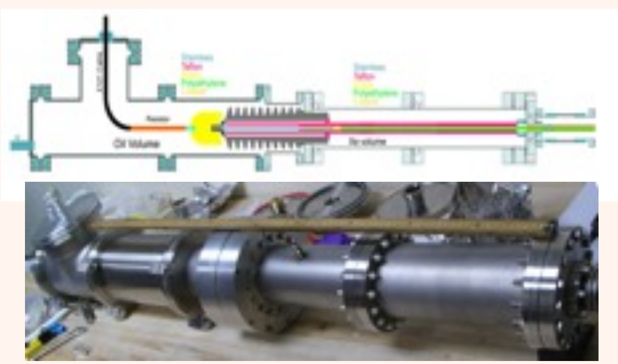
Multi-ton scale will require scale up of TPC components including grids, field rings and insulator supports.

- Large area grid prototyping: scale increase for 0.5 m to 2m and must maintain acceptable deflection
- Low mass field ring development
- Maximize light collection
- Development of internal imaging system for enhanced monitoring



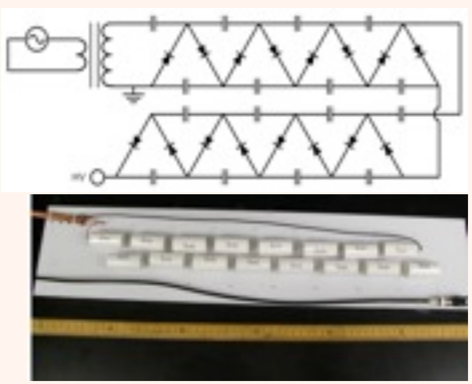
Cathode high voltage

- Core high voltage challenge for experiment. Need to avoid corona discharge in gas
- Feedthrough development
  - -30 KV demonstrated for LUX experiment, working towards -100 KV.
  - **Compare: XENON10 at -13 KV and XENON100 at -16 KV.**
  - Platform developed for continuing program for LZ.
- Discrimination appears to improve mildly with increased field.



FIRST FEEDTHROUGH DESIGN
Commercial ceramic + polyethylene cable. PTFE insulation on exposed metal. Achieved sustained -30 KV. Surface conduction above this.

SECOND FEEDTHROUGH DESIGN
Large metal sphere at feedthrough termination to poly cable. Currently under test.

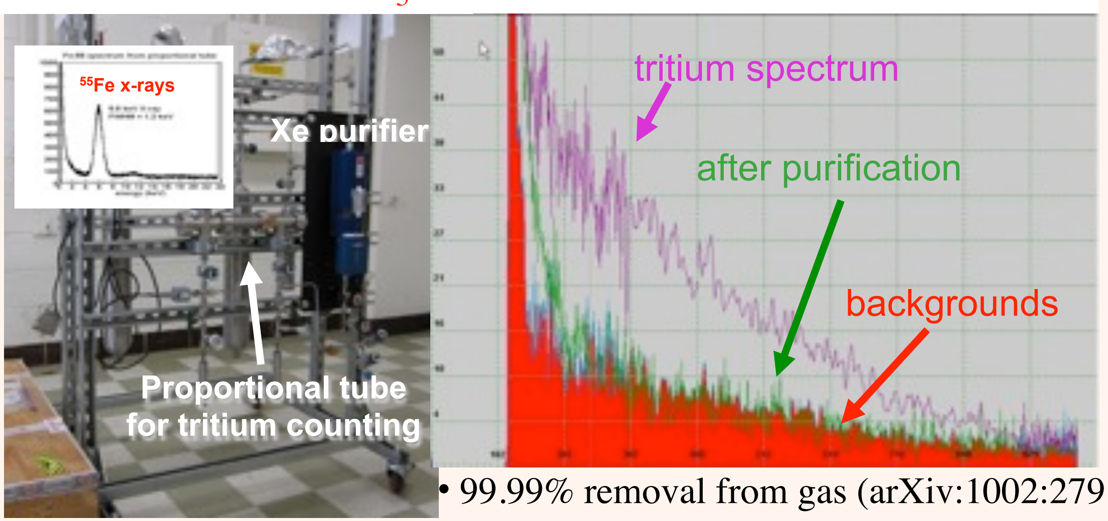


Cockcroft-Walton
Initial 8 stage test, 10 KV from 60 Hz, 1500 VAC. Future tests are planned at higher voltages, and in LXe. Capacitor: polypropylene is low background, but large.

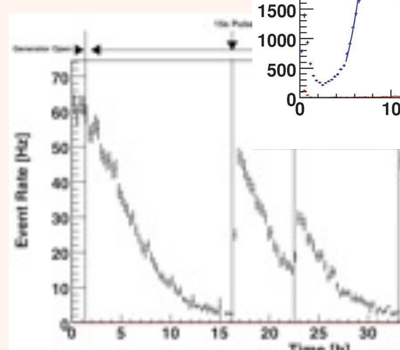
Internal Calibration Sources

- Essential to have internal calibration source for large-volume Xe detectors
- Two methods developed for LUX to be used by LZ:
  - Energy calibration: ^{83}Kr arxiv:0905.1766 , arxiv:0908.0616 (UZH)
  - Electron recoil discrimination: Tritium source

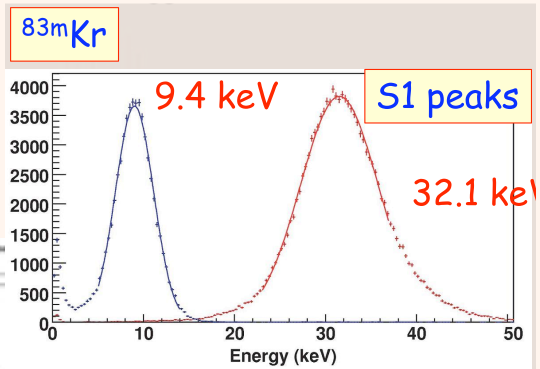
Tritiated methane (CH_3T) First test of removal from LXe: >90%

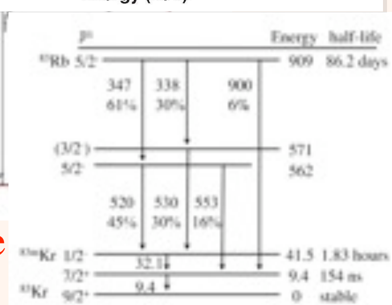


• 99.99% removal from gas (arXiv:1002:2791)



^{83}Kr: 1.8 hr half-life



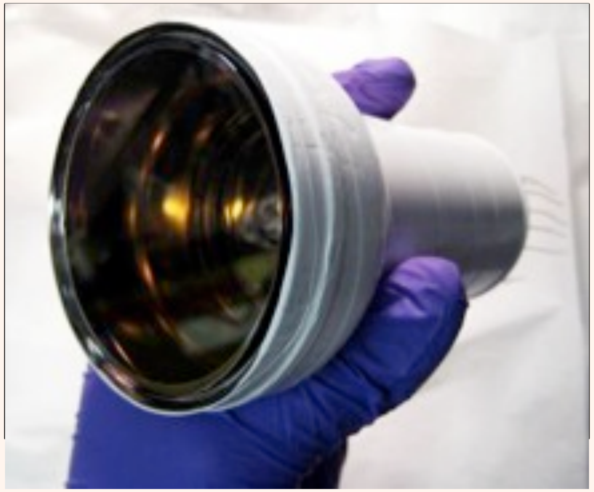


PMTs

LUX

Hamamatsu R8778

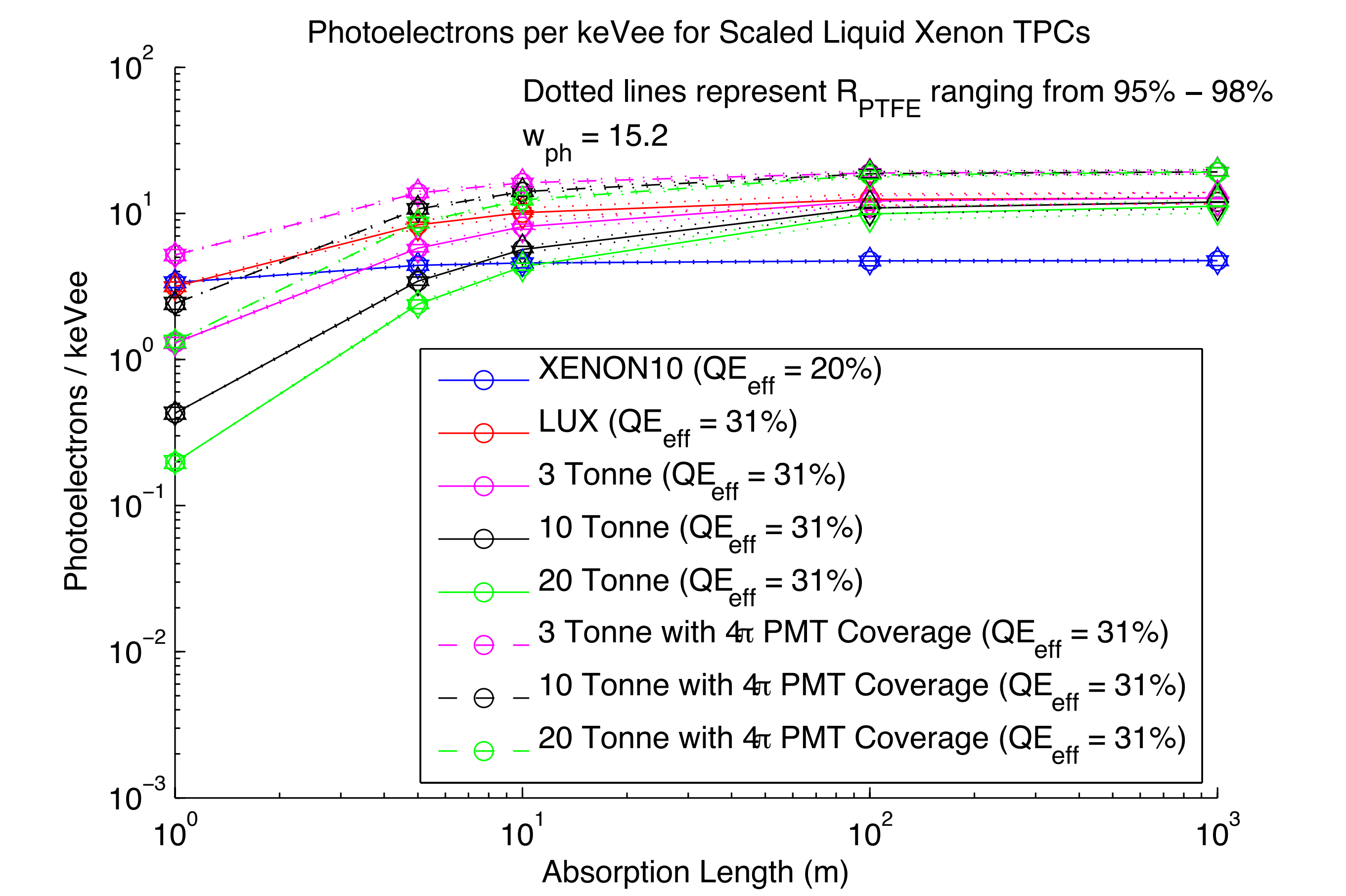
LZS / LZD



Hamamatsu R11065

- LUX: 2” R8778
  - U/Th at 10/2 mBq/PMT (would be acceptable baseline for LZ)
  - QE: average=33%, max 39%
- LZS / LZD: 3” R11065 in LXe
  - Tested QE/LXe operation - same as R8778
  - Developing new ultra low background 3” PMTs for LXe
  - Background achieved U/Th at 1/1 mBq/PMT

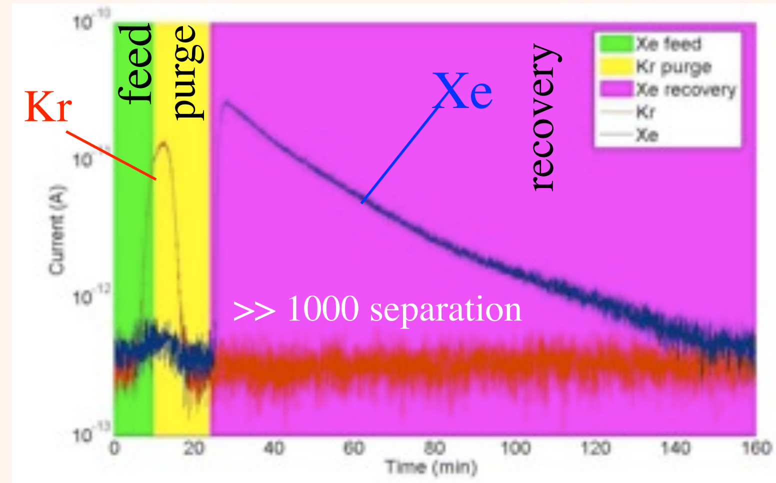
Light collection

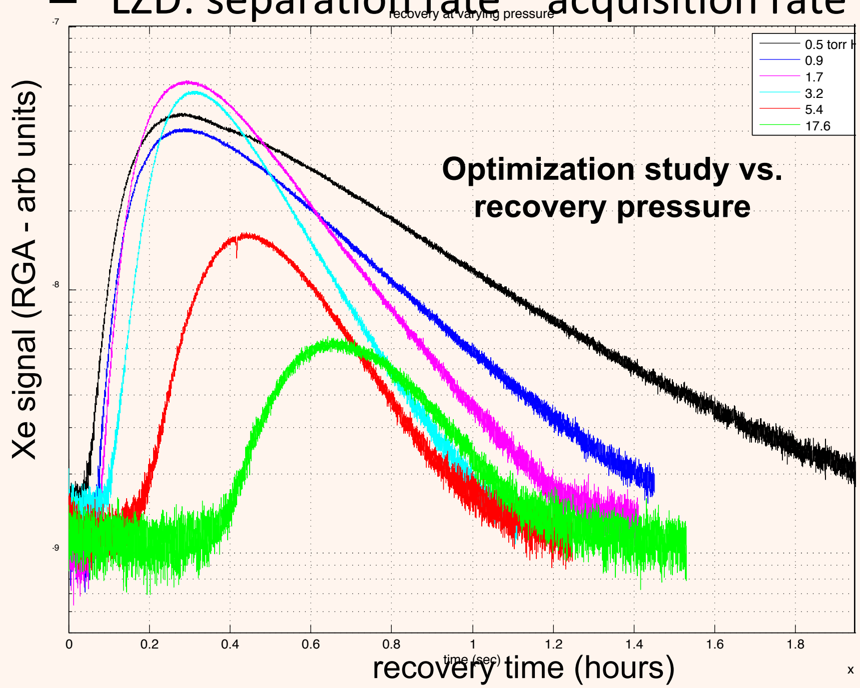


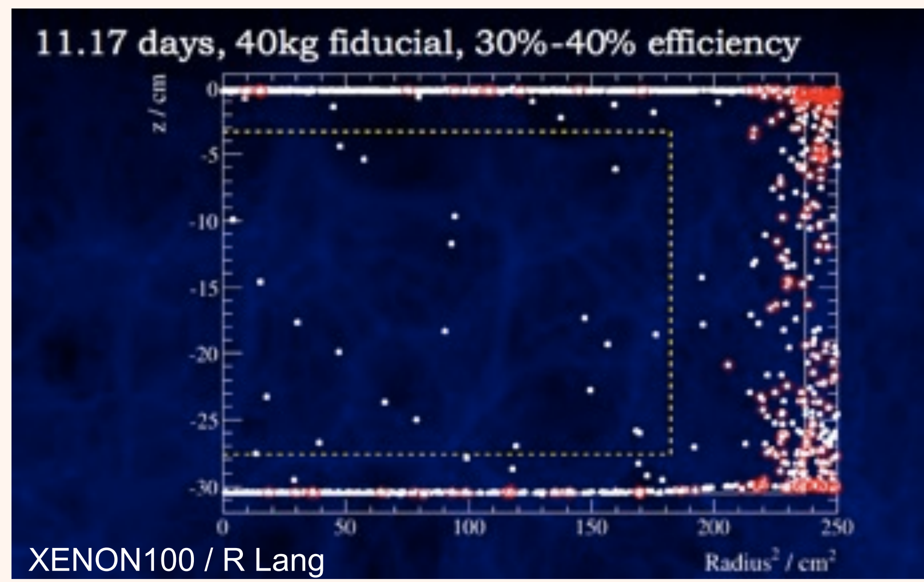
- Enhancements in PMT QE further separates the XENON10 collection efficiency from the larger detectors
- For any likely liquid Xe absorption length, large Xe detectors promise to outperform XENON10 in light collection efficiency as much as 3x (without 4π PMT coverage) or 6x (with 4π PMT coverage)

Kr Removal

- ^{85}Kr - beta decay
  - separate commercial Xe/Kr (typ. ppb to ppm g/g)
  - Goals: LUX 10 ppt, LZS 0.5 ppt, LZD 0.05 ppt
  - Chromatographic system - upper limit 2 ppt demonstrated for 2 kg/day
- Scaling up current system
  - 60 kg charcoal column, x20 pumping speed
  - optimize Xe recovery (presently 8kg/day)
  - LUX: 2 month processing time
  - LZD: separation rate ~ acquisition rate







Summary

- LZ is building a large, well integrated collaboration for G3 experiment. Currently 14 US + 7 Intl.
- LUX => LZS => LZD
- Unprecedented sensitivity; will nature (dark matter m,σ) cooperate?