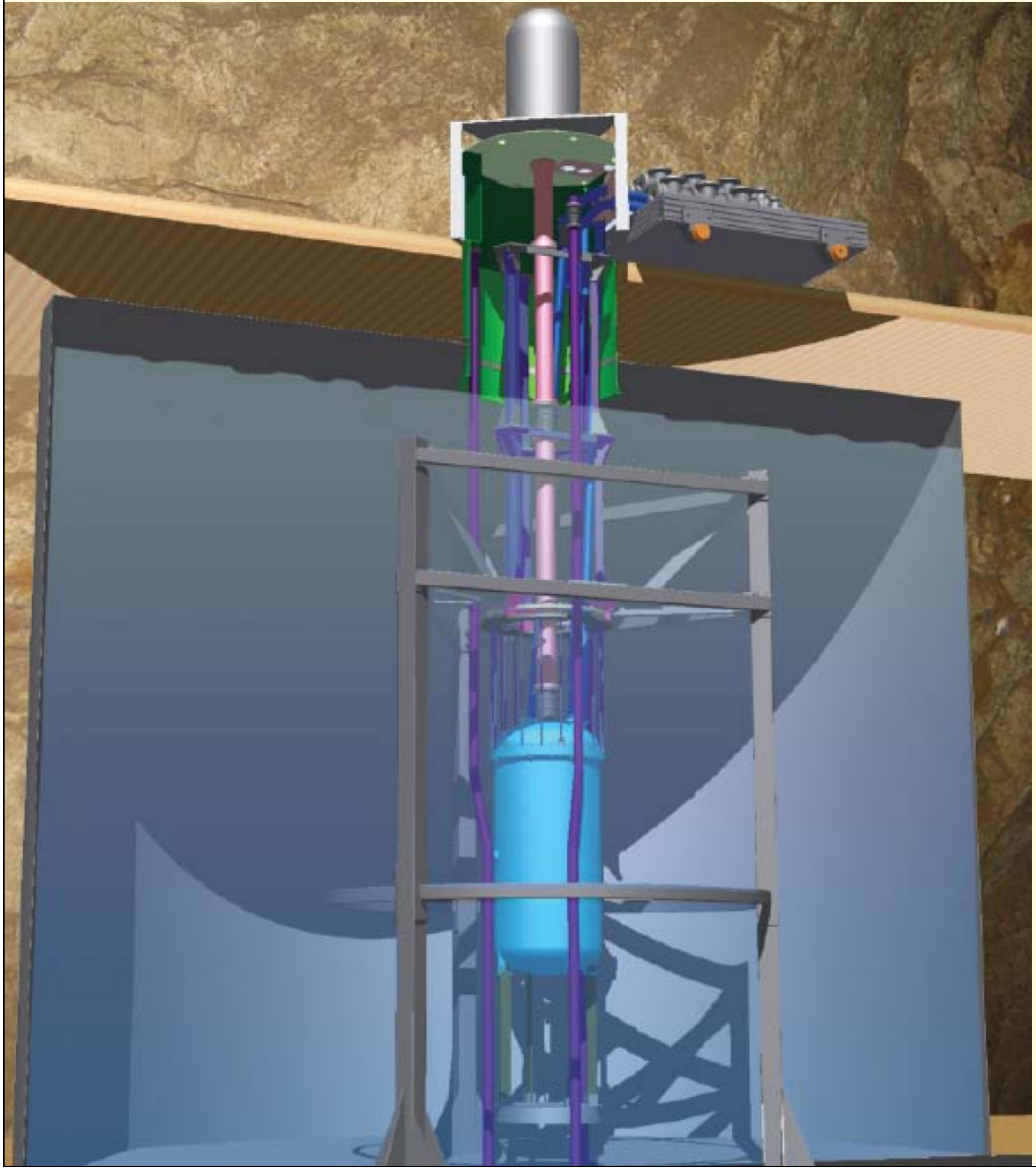
LUX.
Some thoughts on large detectors.
Comments on Xe microphysics.

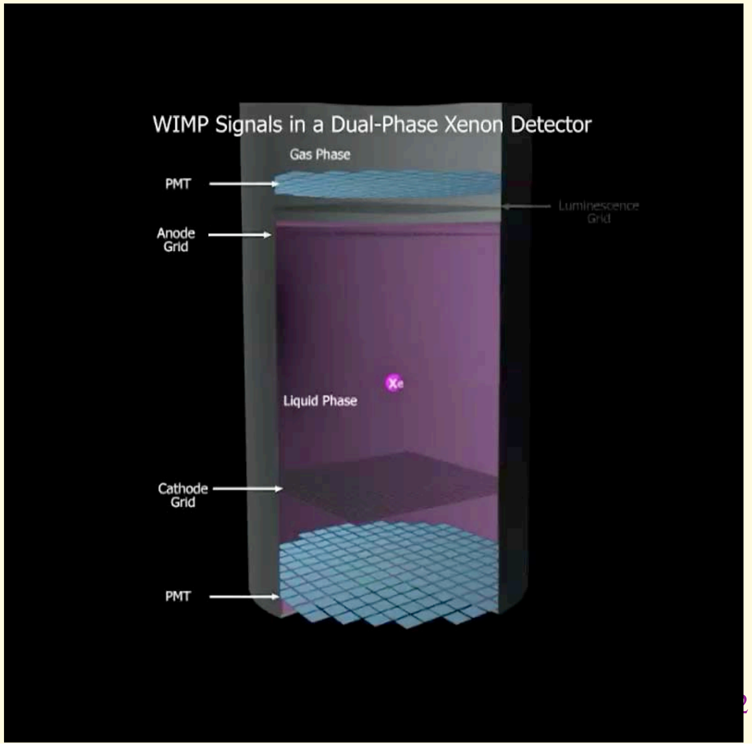
Tom Shutt

Case Western Reserve University

LUX



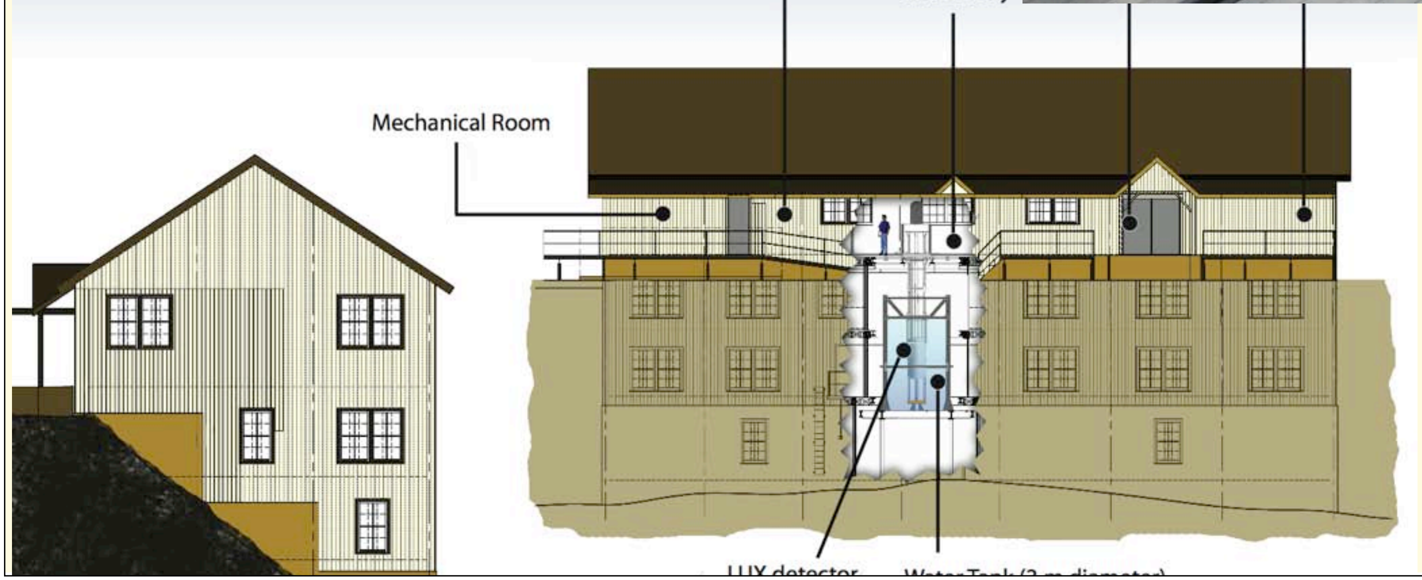
- 300 kg Xe, expected 100 kg fiducial
- At Sanford lab, Homestake SD.
- First water-shielded large dark matter detector



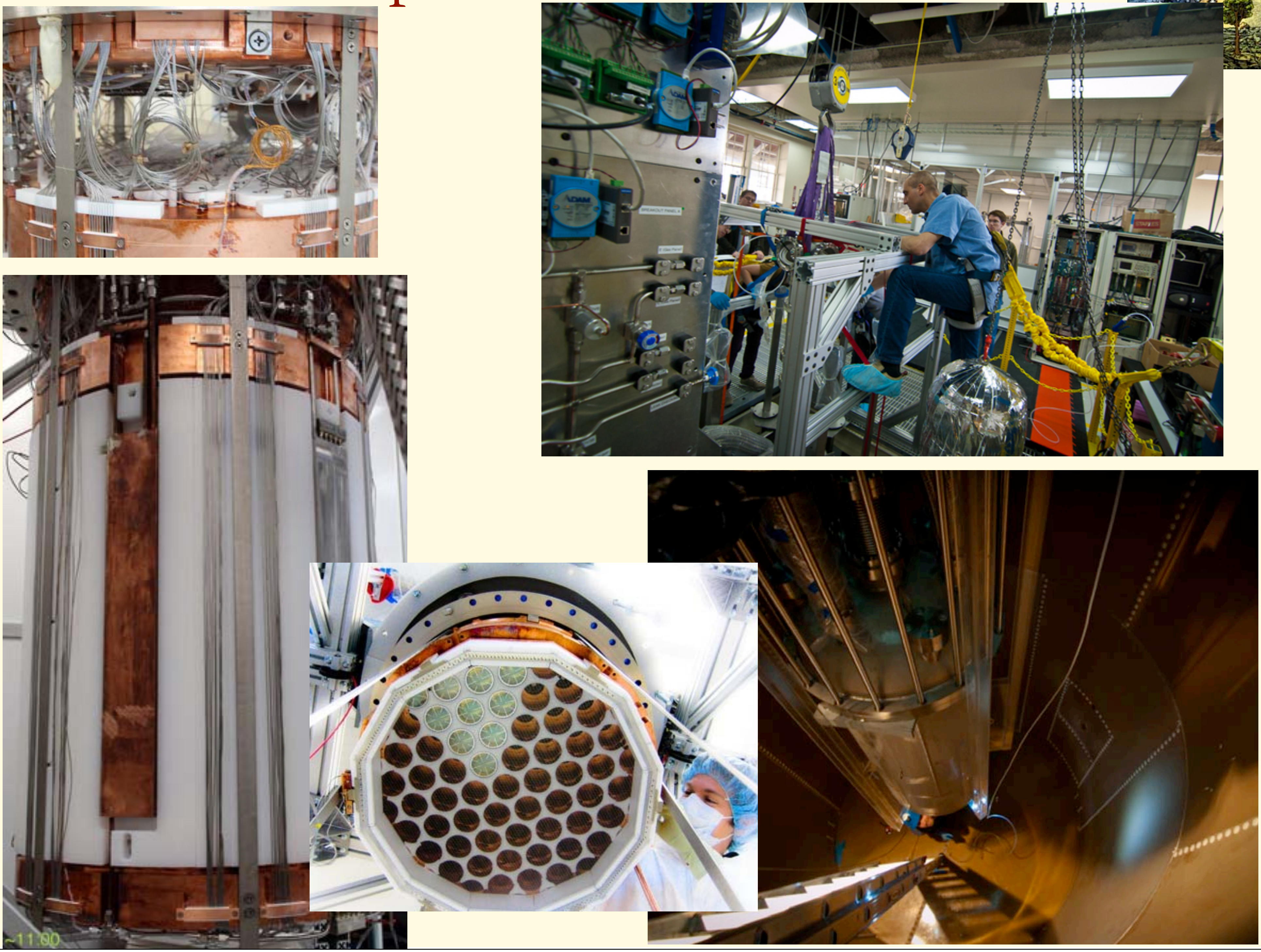
Surface Facility at Sanford Lab

- Old Warehouse
- Occupancy starting Dec 09
- LUX has been:
  - Assembling detector
  - Helping create Sanford Lab

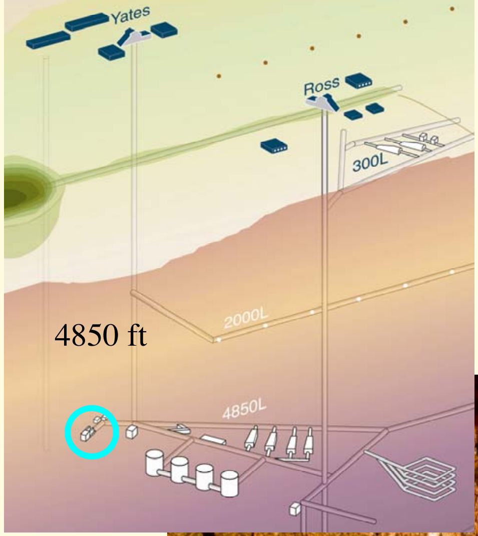
Precision cleaned cryostat returns - July 19, 2010



Surface Operations

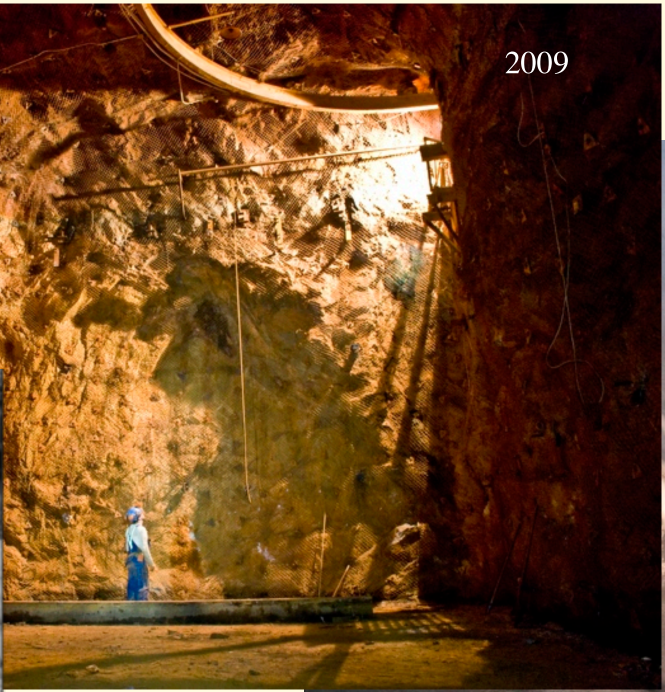


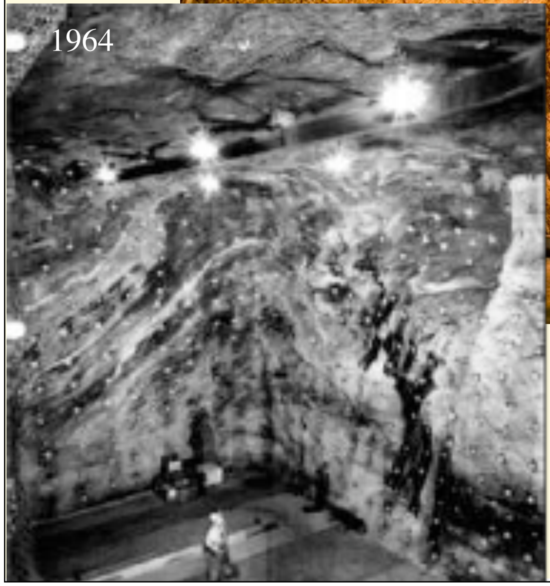
Davis Campus @ SURF




Nov 2011


Nov 2011


2009

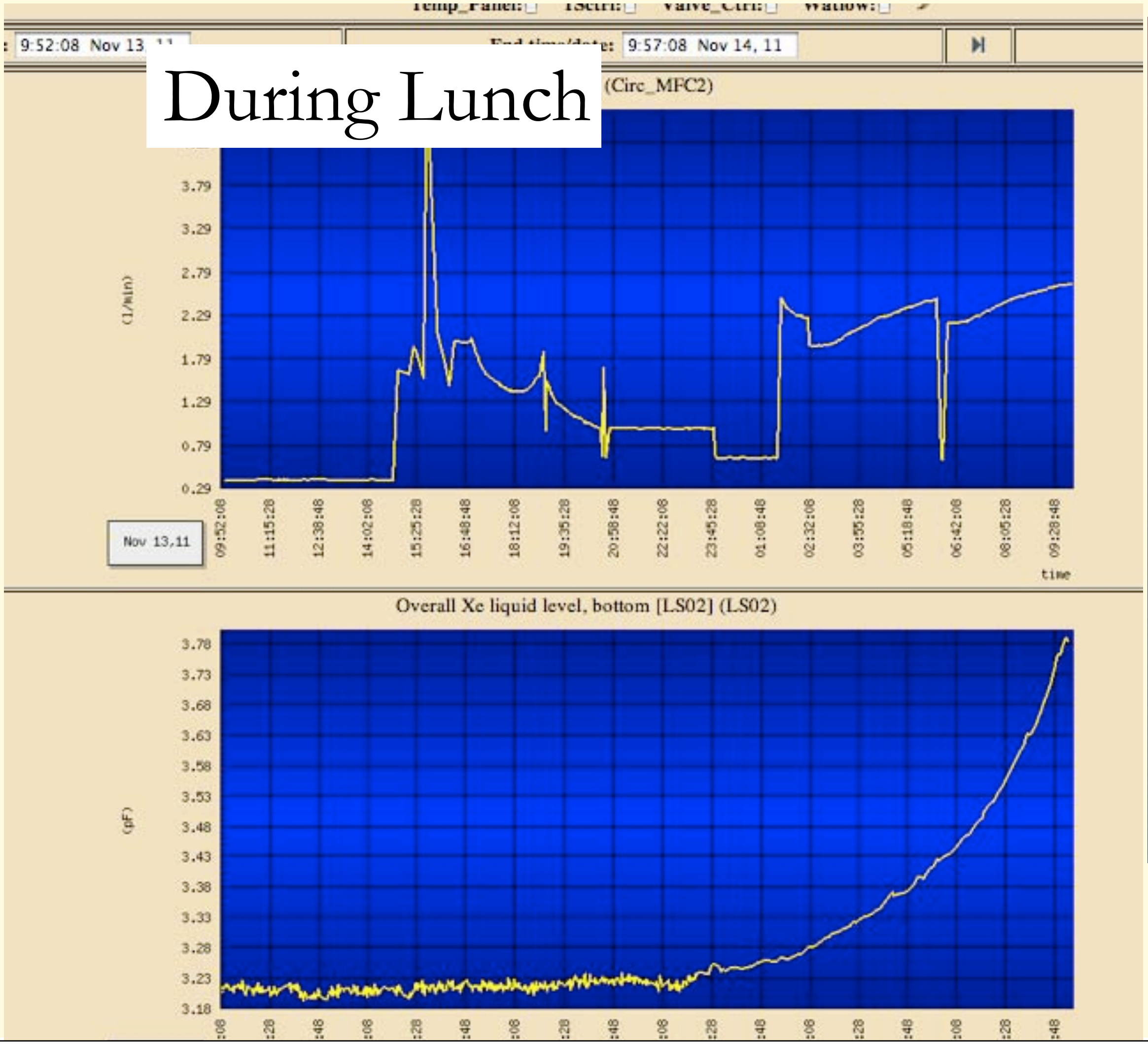

1964

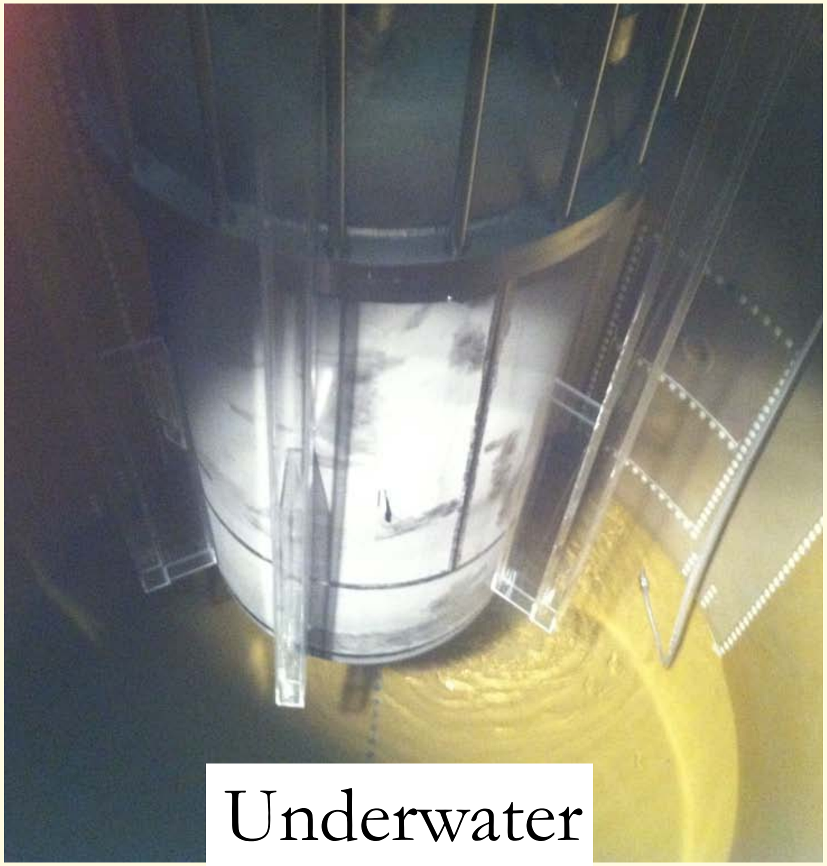

$8.1M outfitting contract - March 2011.

April 2011

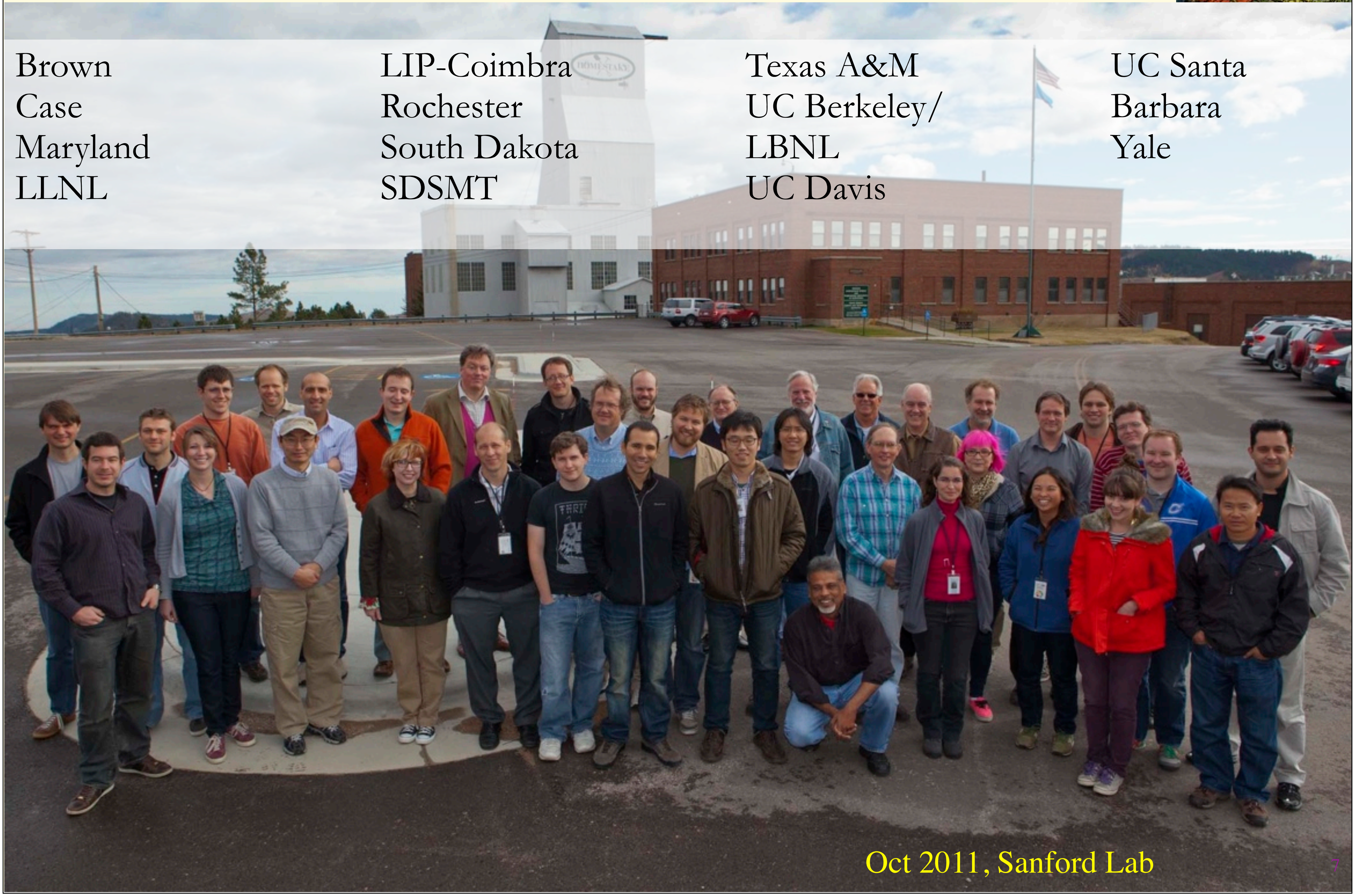
LUX Status

- Cryogenic run - May 2011
- Full run now underway
- Davis Cavern: Beneficial occupancy March 2012
- Full running: Fall 2012


During Lunch


Underwater

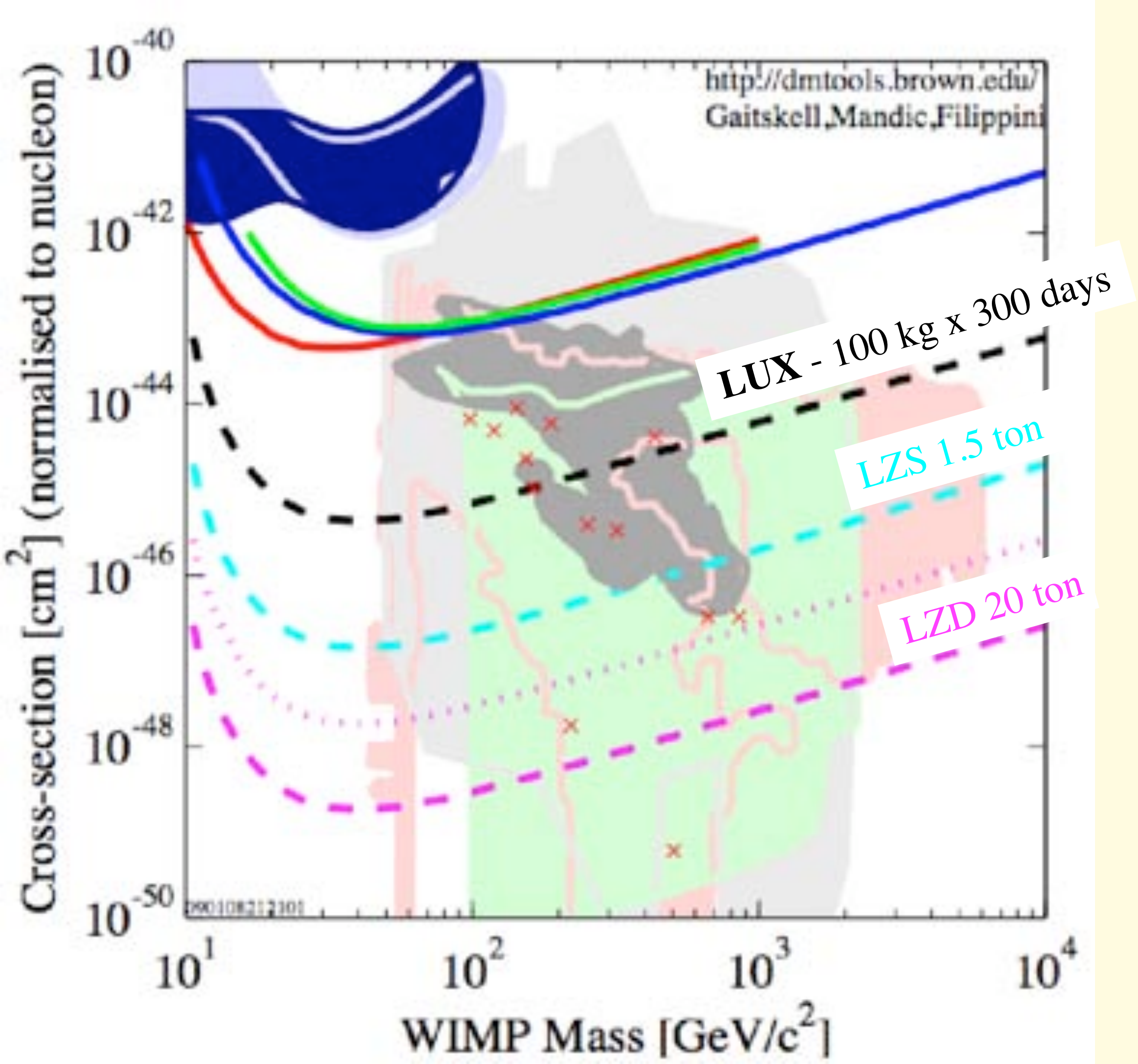
LUX Collaboration



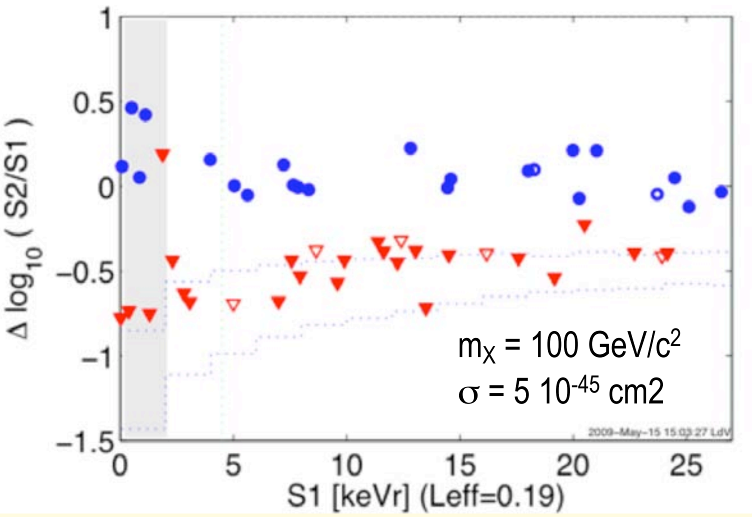
Brown
Case
Maryland
LLNL
LIP-Coimbra
Rochester
South Dakota
SDSMT
Texas A&M
UC Berkeley/LBNL
UC Davis
UC Santa Barbara
Yale

Oct 2011, Sanford Lab

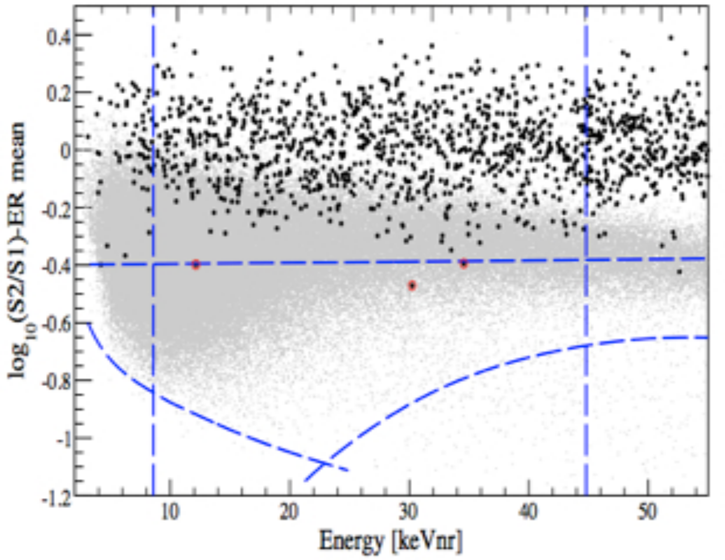
Projected Reach of LUX



Simulated LUX data
(100 kg fiducial, 100 days)



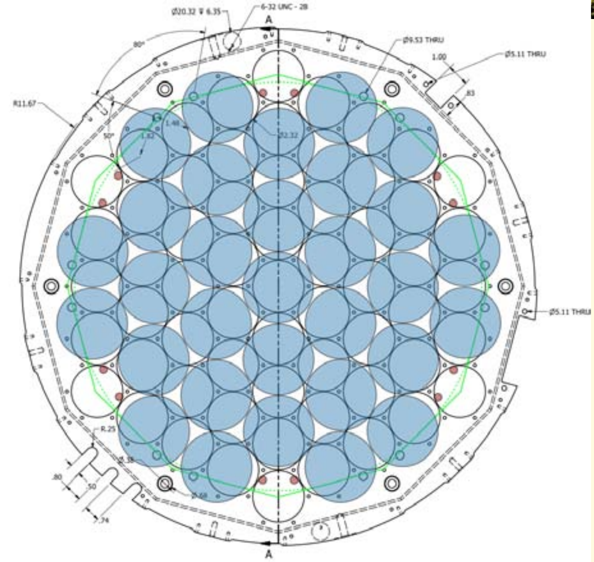
XENON100
(40 kg fiducial, 100 days) - ~800 ER event



- No expected background in 100 kg x 300 days
- “Beneficial occupancy” underground - March 2012
- Full running - Fall 2012

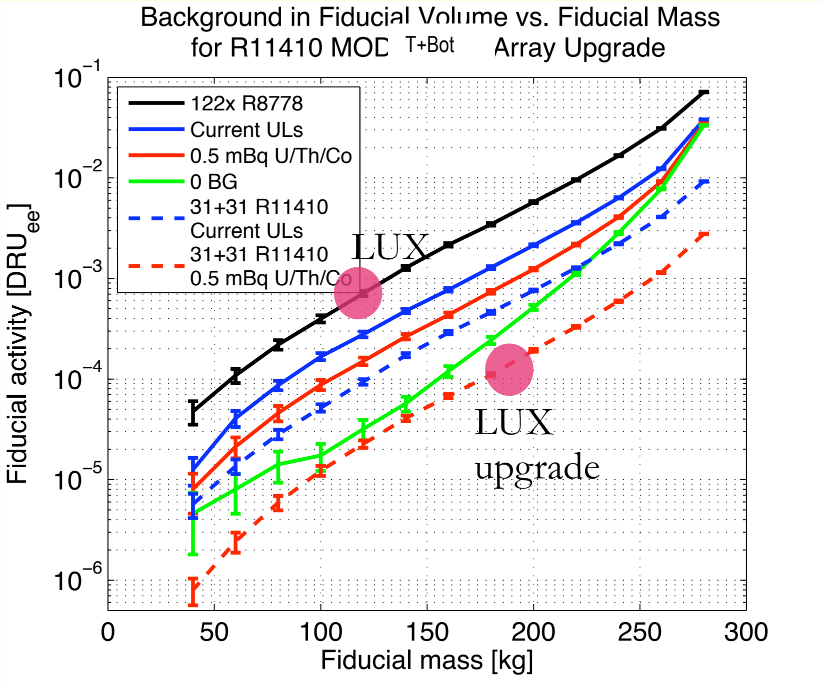
LUX Upgrade

- Replace old PMTs with new
  - Requires only new array holders, detector reassembly
  - BG well below measured limits: total background reduced by 40



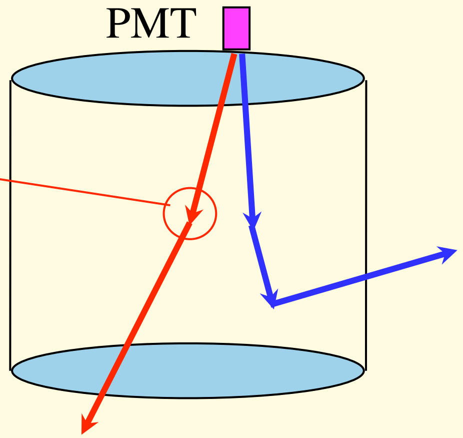
PMT	^{238}U [mBq/ PMT]	^{232}Th [mBq/ PMT]	^{40}K [mBq/ PMT]	^{60}Co [mBq/ PMT]
R8778	9.5±0.6	2.7±0.3	66±2	2.6±0.1
R11410 MOD	<0.4	<0.3	<8.3	2.0±0.2

- Much cleaner potential nuclear recoil signal
- Increase in fiducial mass
- Target - 2013



Some thoughts on scaling up this technology

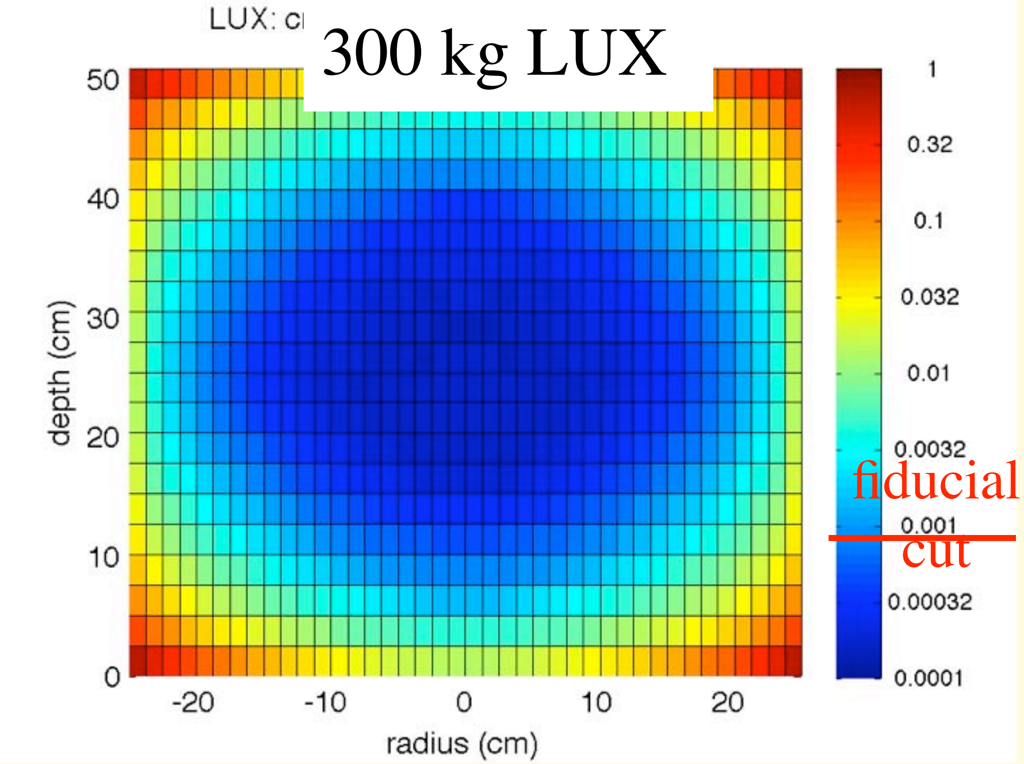
Self-shielding in liquid xenon

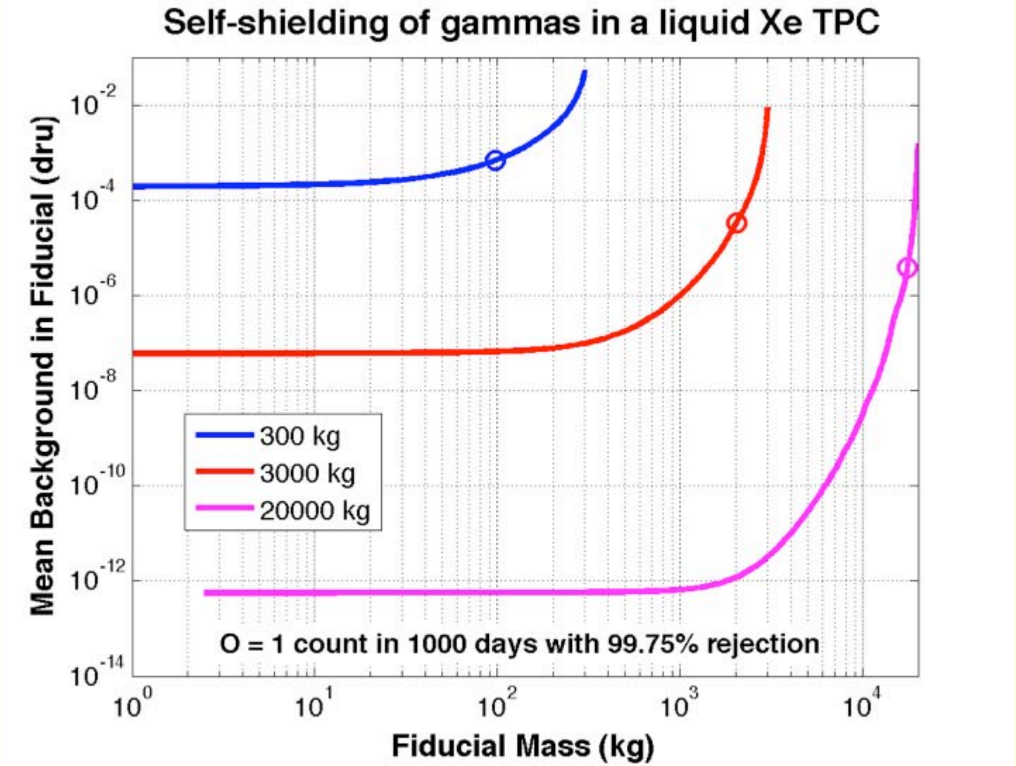


Single, low-energy
Compton scatter

$$P(L) \cong \frac{L}{\lambda} e^{-\frac{L}{\lambda}}$$

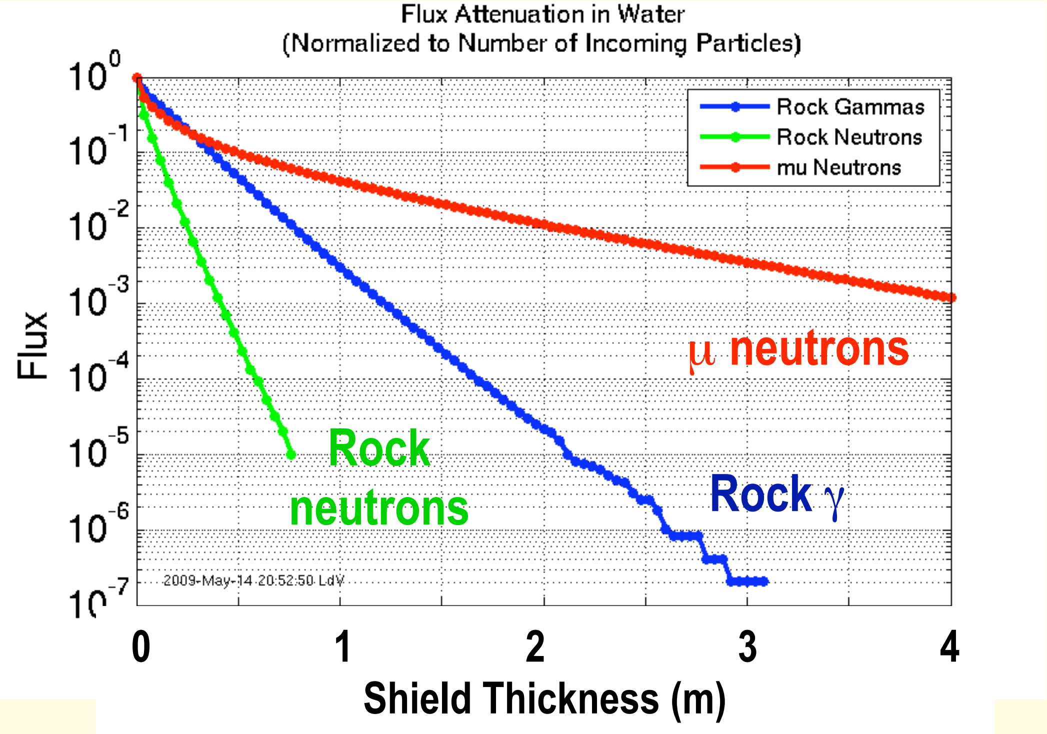
Effective for detectors large compared to ~10 cm gamma penetration distance: few 100 kg and up.





Shielding

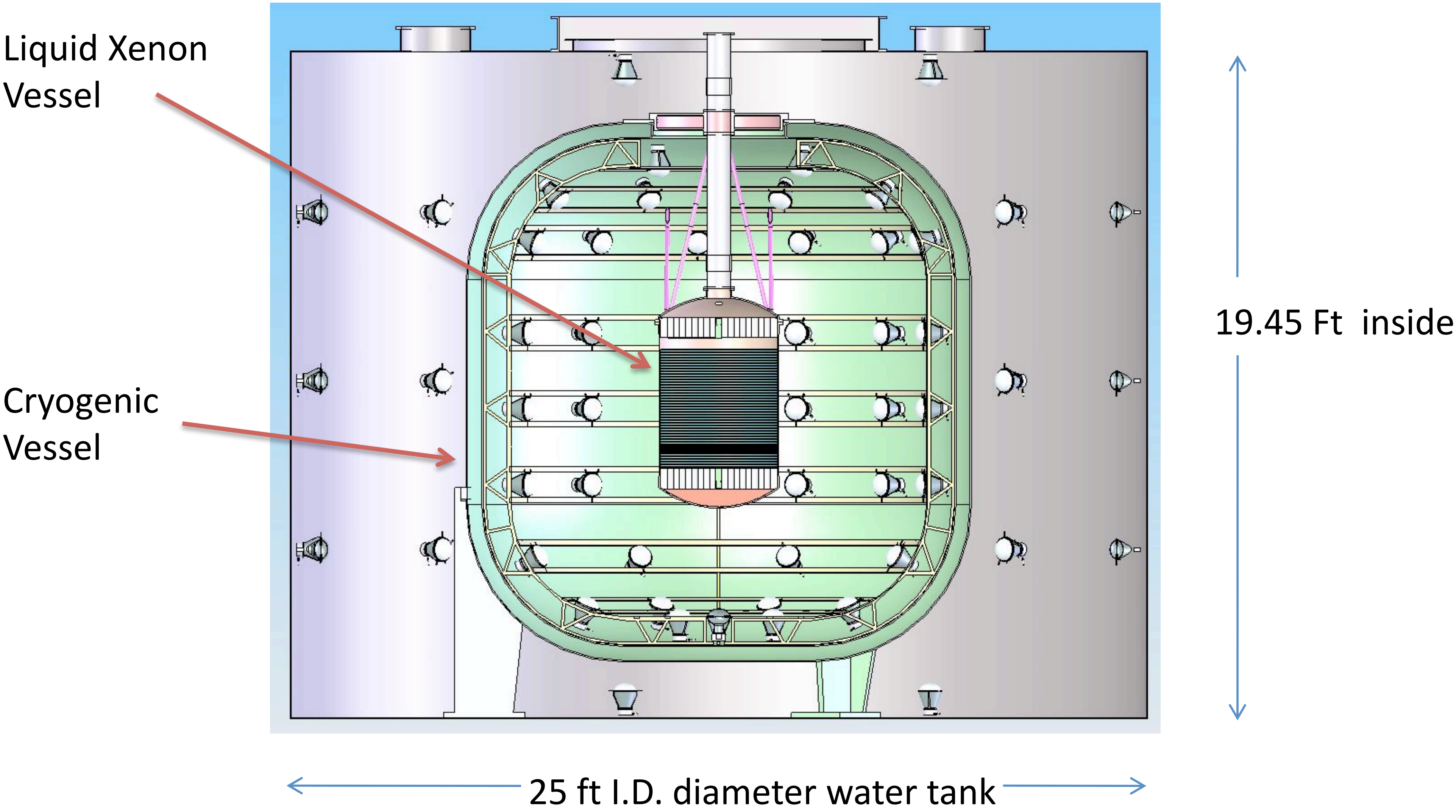
- 4 m water shield + 4850 ft depth adequate up to at least 20 ton scale.
- Liquid scintillator shield. Effective for
  - Internal neutrons
  - Internal gammas
  - External, high-energy neutrons
- Titanium cryostat material
  - Significant new construction material for low background experiments
  - No measured contamination at limits of Oroville capability (< ~0.2 mBq/kg)
  - Enables active shield



175K scintillator shield

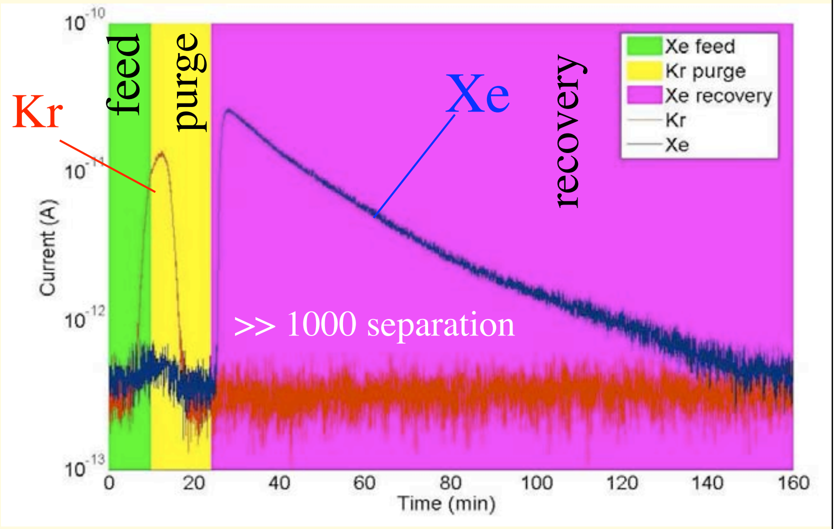
ISOHexane scintillator, housed immediately outside LXe, at LXe temperature. Goal: > 10-fold gamma veto + highly efficient neutron veto

UCSB/LBNL

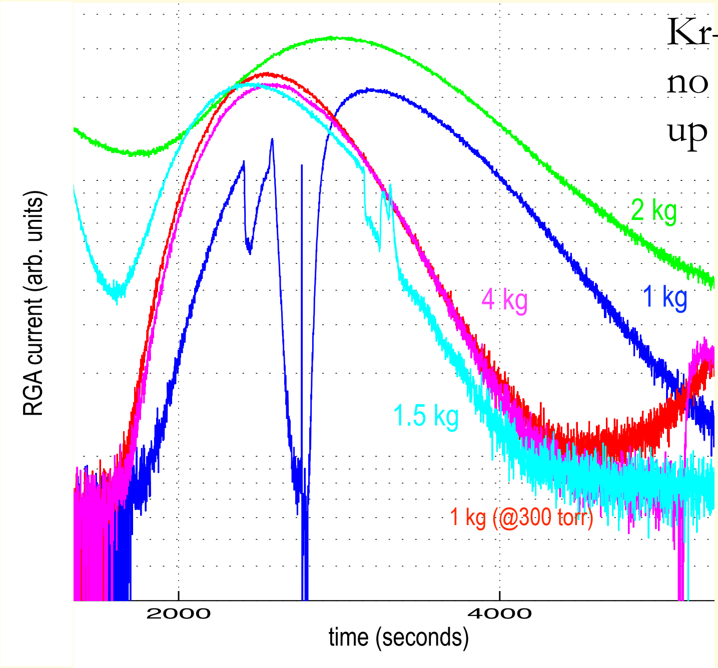


Kr Removal

- ^{85}Kr - beta decay
  - Need Kr/Xe: 10 ppt, LZS 0.5 ppt, LZD 0.05 ppt
  - Commercial Xe/Kr ~ few ppb
  - Chromatographic system: < 2 ppt @ 2 kg/day production
- Scaling up current system
  - 60 kg charcoal column
  - Vacuum phase “recovery” stage
  - High capacity Xe condenser



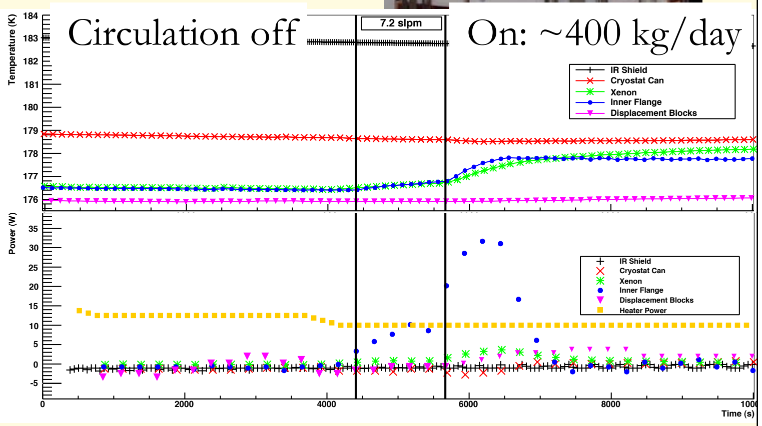
>> 1000 separation



Kr-Xe cocktail:
no noticeable saturation
up to 4 kg Xe per cycle

Xe purification and analysis

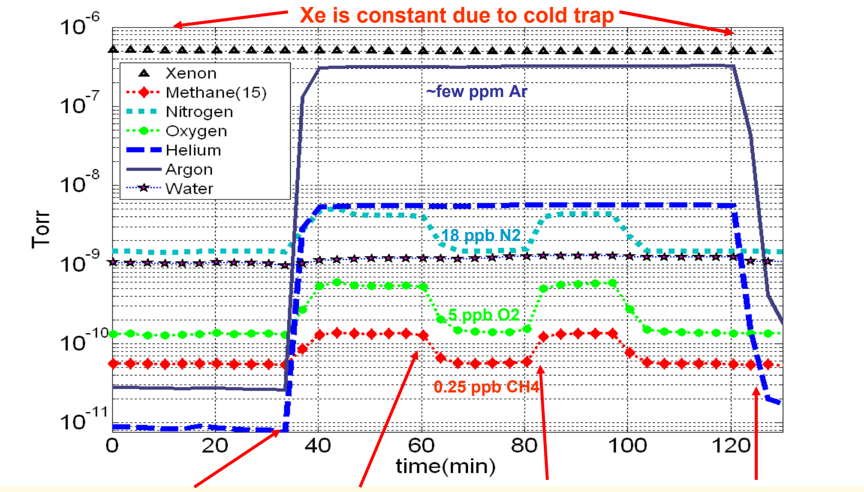
- Gas phase getter purification - standard
- Very high efficiency two-phase heat exchanger
  - Removes large thermal penalty to recondense
- In ~60 kg prototype, obtained purity in few days
- Cold-trap enhanced mass spectrometry: first sensitivity to required impurity levels



Data from coldtrap/RGA

arXiv: 1002:2742

Sensitivity : 0.1 ppb O2
1.0 ppb N2
0.06 ppb CH4

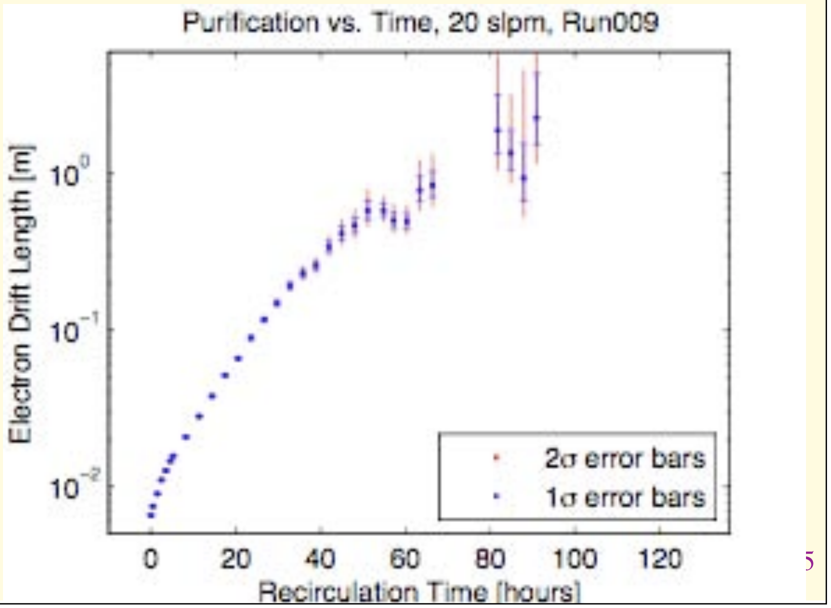


open leak valve, bypass gas purifier

flow through gas purifier

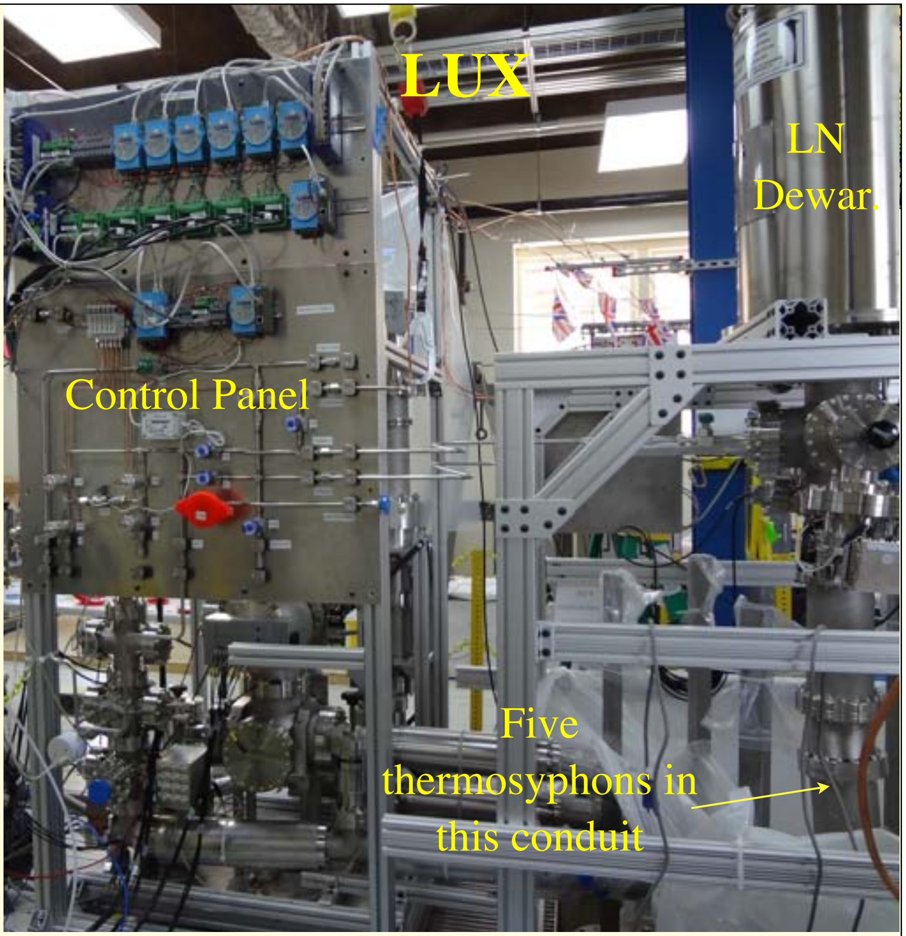
bypass gas purifier

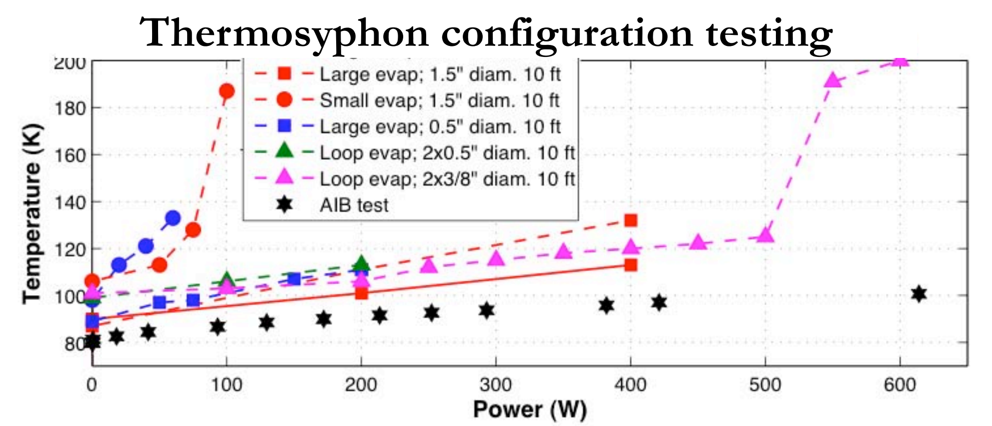
close leak valve to measure backgrounds

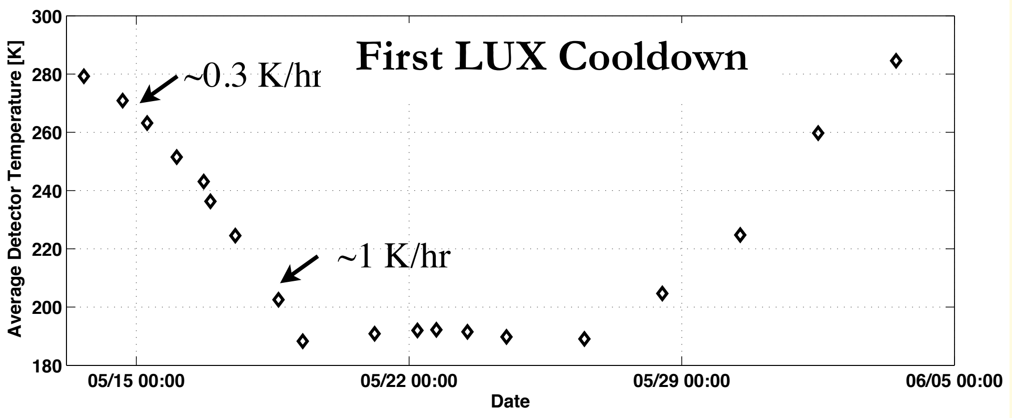


Thermosyphon Cryogenics

- Uniquely suitable for very large scale.
  - Extremely high capacity: equivalent to ~1 m Ø Cu bar.
  - Remote deployment of multiple cold heads.
  - Tunable to low power for fine control.
- Intrinsically safe against power failure
- Cryogenics + Xe systems vetted by lab safety.

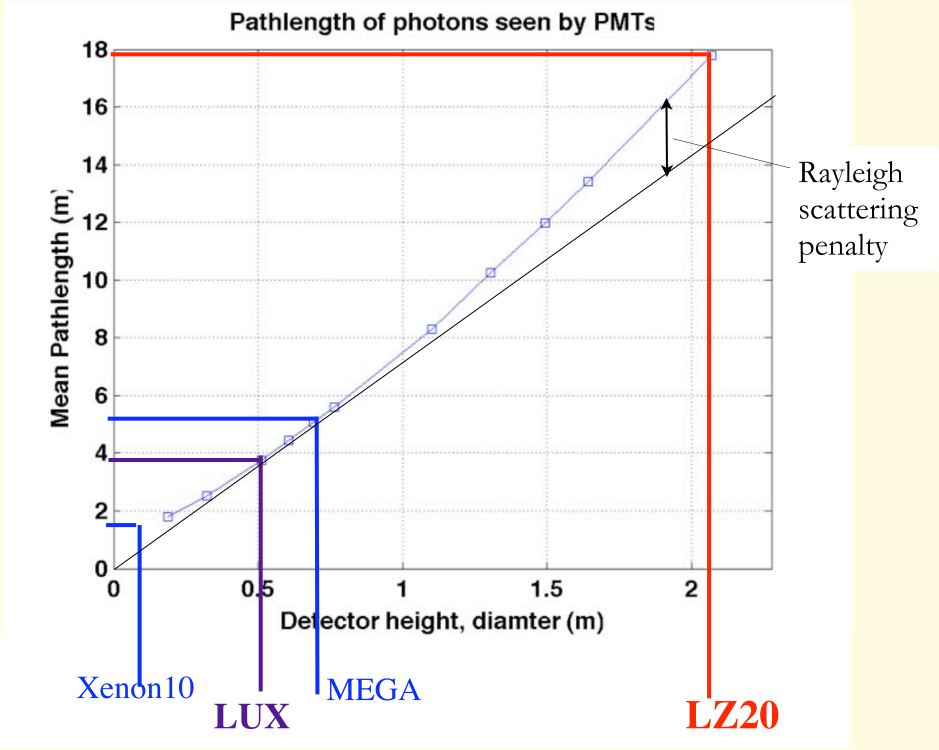




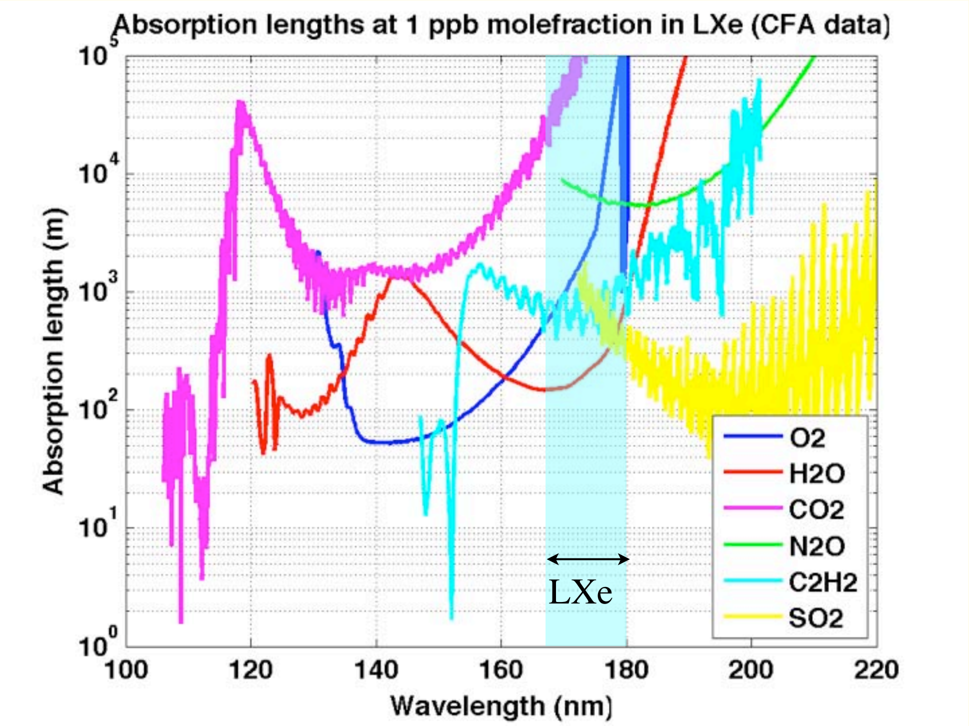


Light collection at the multi-ton scale

- Rayleigh scattering: not yet a problem
- PTFE walls: extraordinarily reflective at 175 nm (7eV)
  - $r \sim 98\%$ or greater: “mirrored box”
- Purity should be achievable - comparable to requirements for charge drift
- With $r \sim 98\%$, should get 2-3 x light of X10, X100: directly lowers threshold

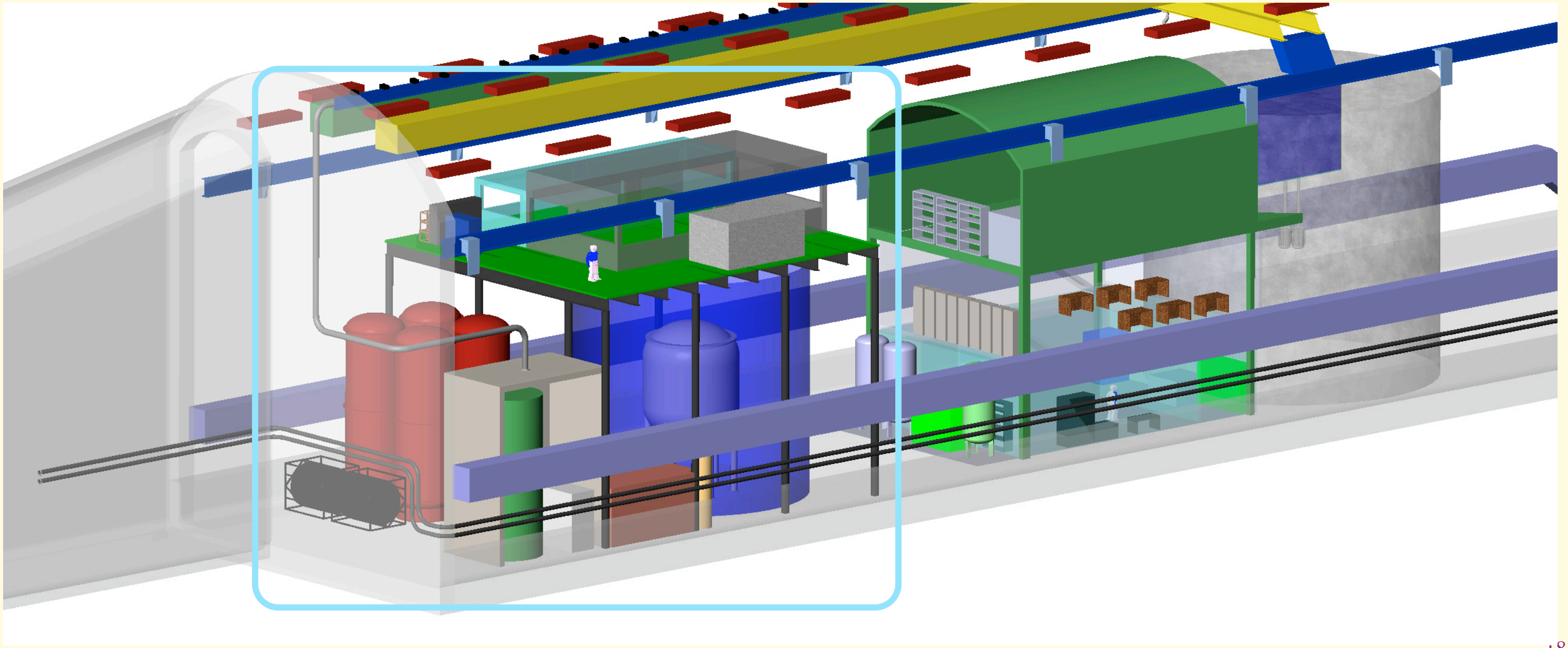


0.1 ppb: 1 km => 2% loss



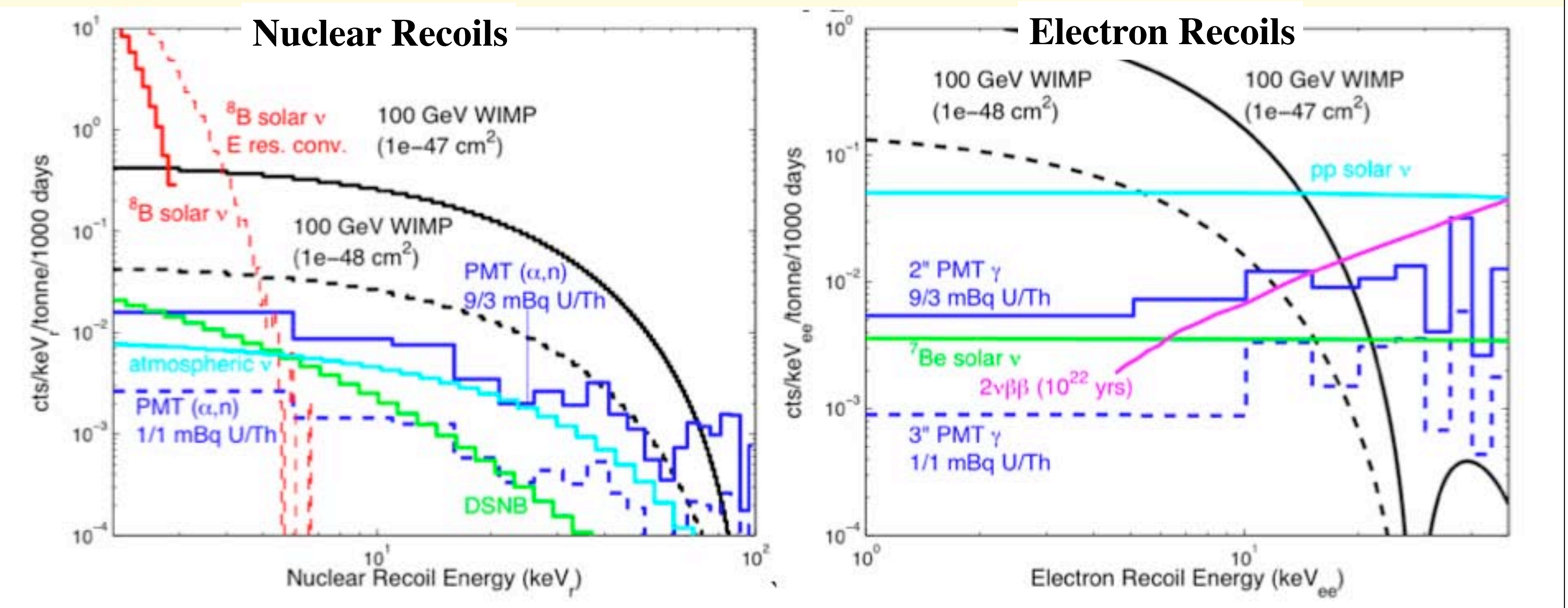
LZD

- 20 ton scale-up of LZS
- Sited at 4850 ft Homestake single lab module, or expanded SNOLab.



20 Tons hits fundamental neutrino limit

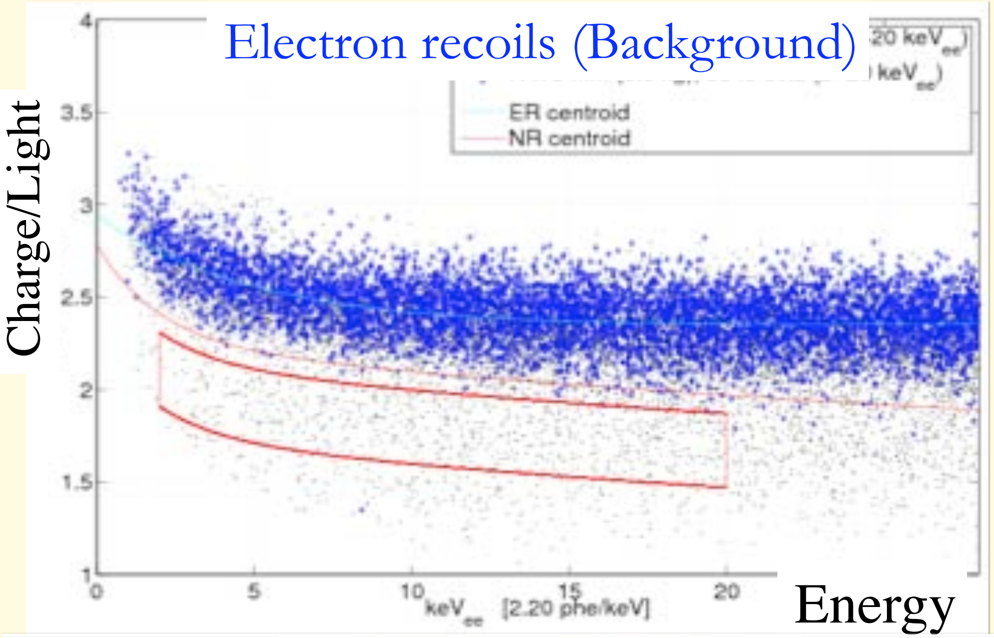
- LZD at 20 tons: 10^{-48} cm^2 WIMP sensitivity
- Atmospheric and diffuse supernova neutrinos set irreducible background just beyond this
- WIMP/supernova ratio independent of target

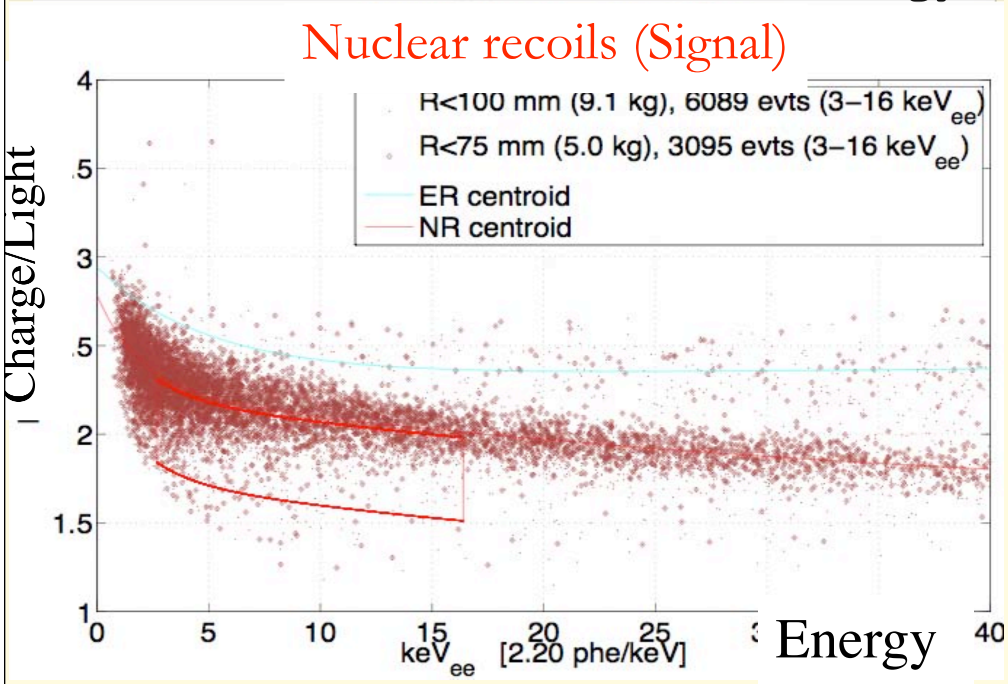


Proven materials backgrounds; 99.5% discrimination; < 1 background n.r. event;

Some comments on Xe microphysics, as it affects dark matter detection

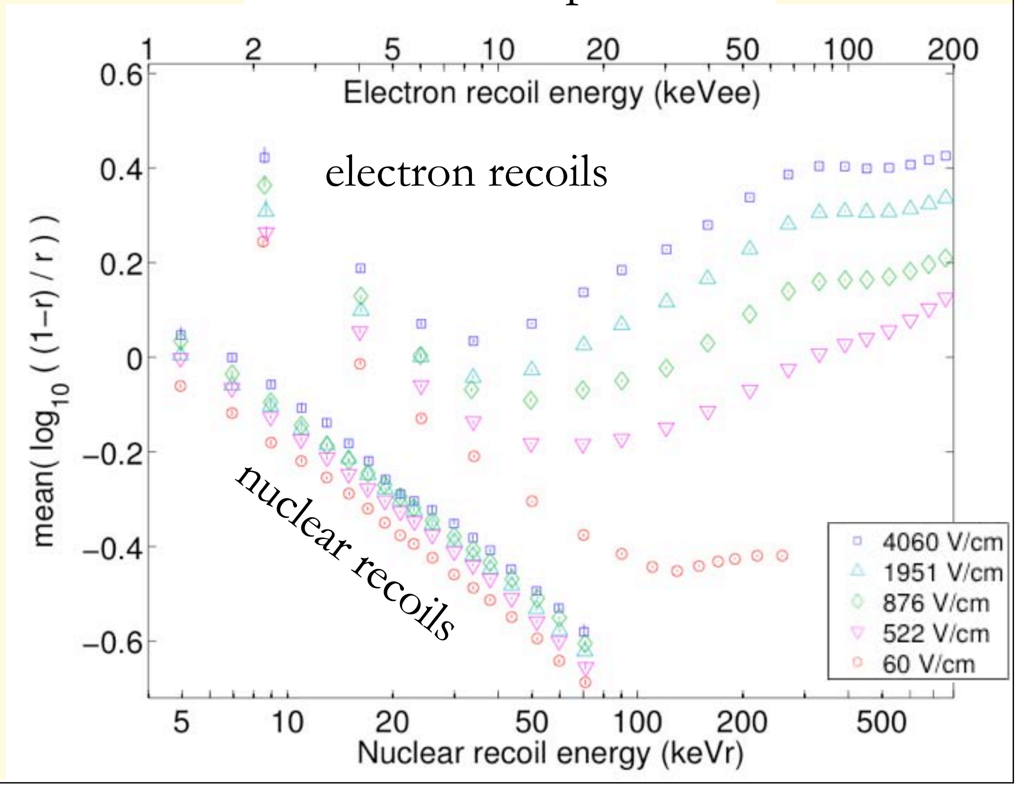
Xe microphysics





- What determines band widths?
- What determines band positions?
- What is the best measure of energy?
- Why does discrimination improve at low energy?

Drift Field Dependence



Energy partitioning

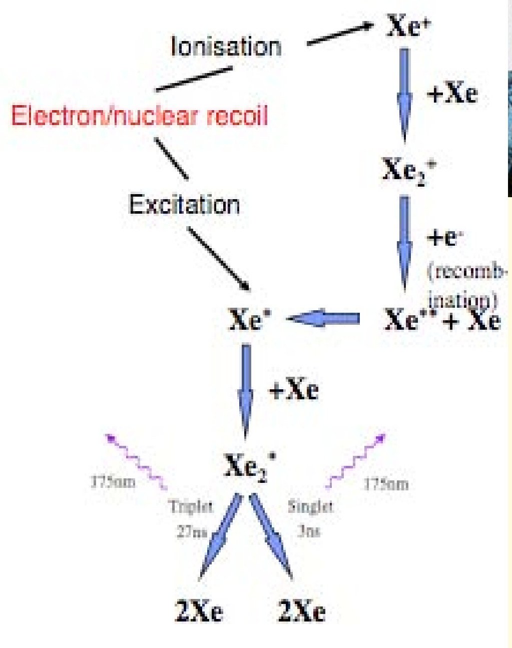
- Excitations:
  - Ionization (N_i)
  - Recombined ions (r) -> photons
  - Excited atoms (N_{ex}) -> photons
    - Doke: predicts 6%
- New formalism:

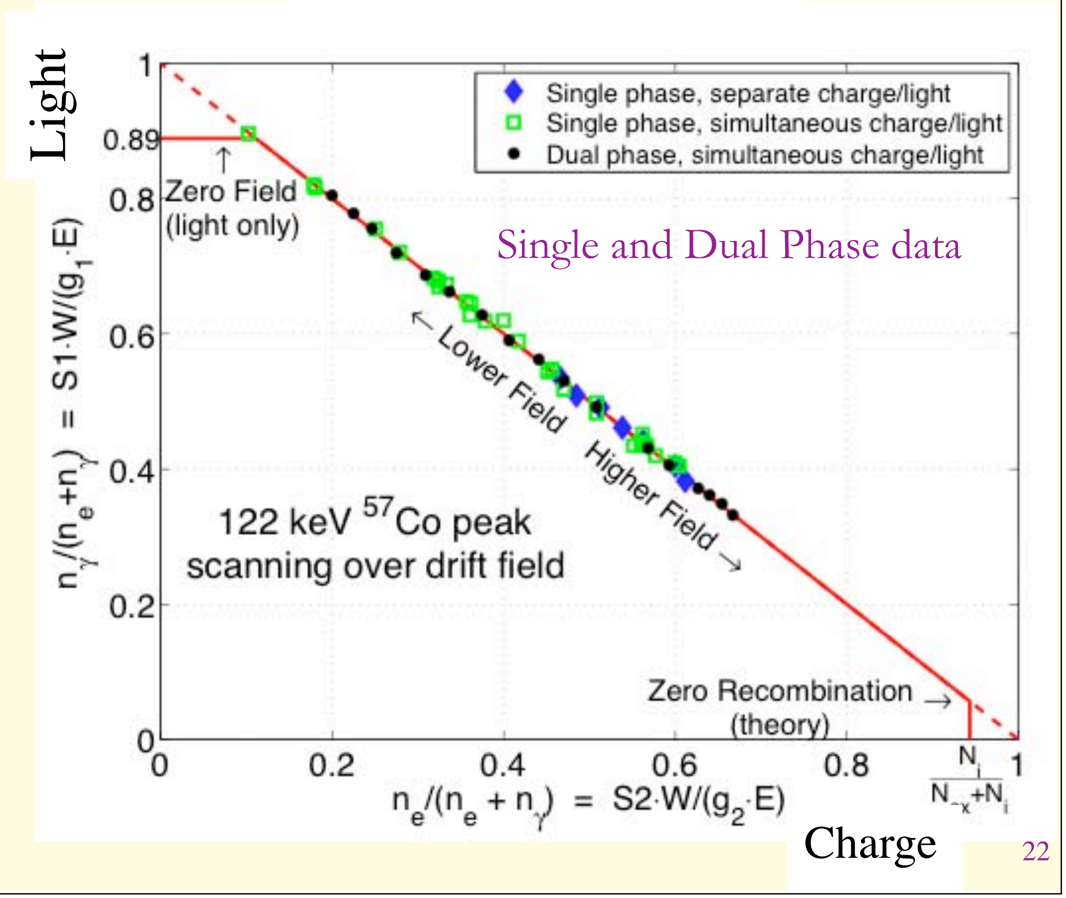
$$n_e = (1 - r) \cdot N_i$$

$$n_\gamma = (\frac{a}{b}\frac{N_{ex}}{N_i} + r) \cdot N_i$$

$$E = (n_e + n_\gamma) \cdot W$$

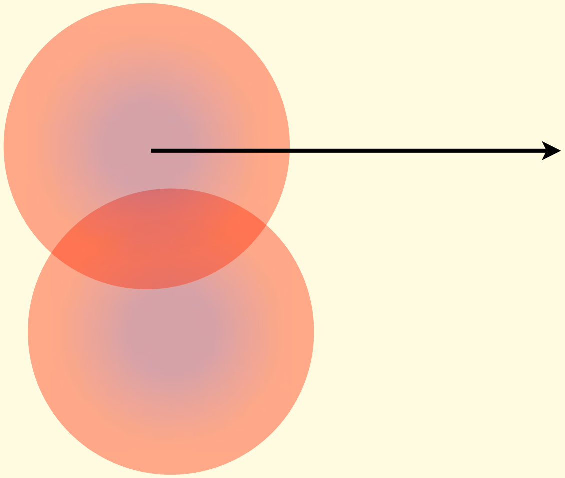
- We find W=13.7±0.2.
- Nuclear recoils have additional factor: Lindhard

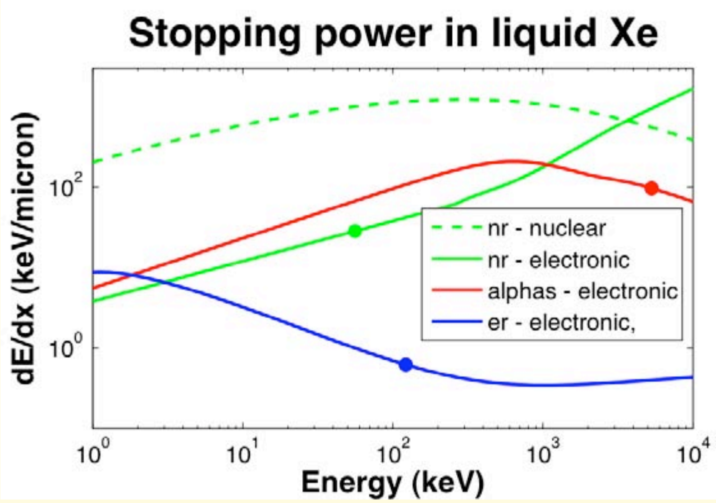




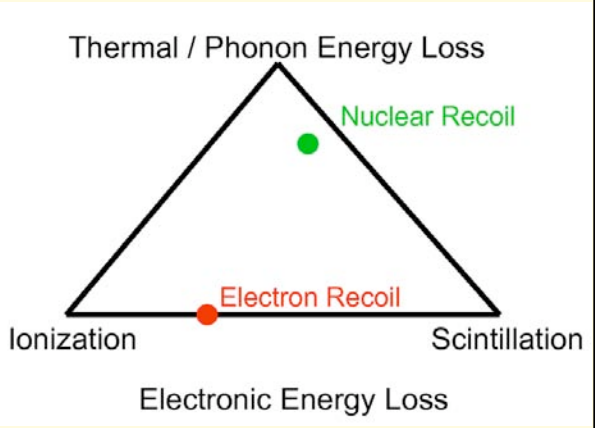
Nuclear recoils: Lindhard

- keV nuclear recoils move slower than electrons in atoms (v_{Fermi}).
- Adiabatic interaction. Electronic excitation due to overlap of shells.

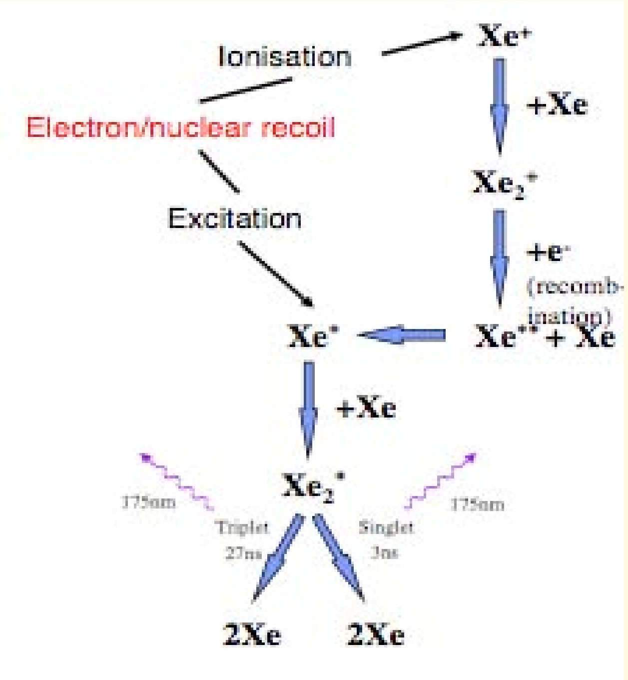


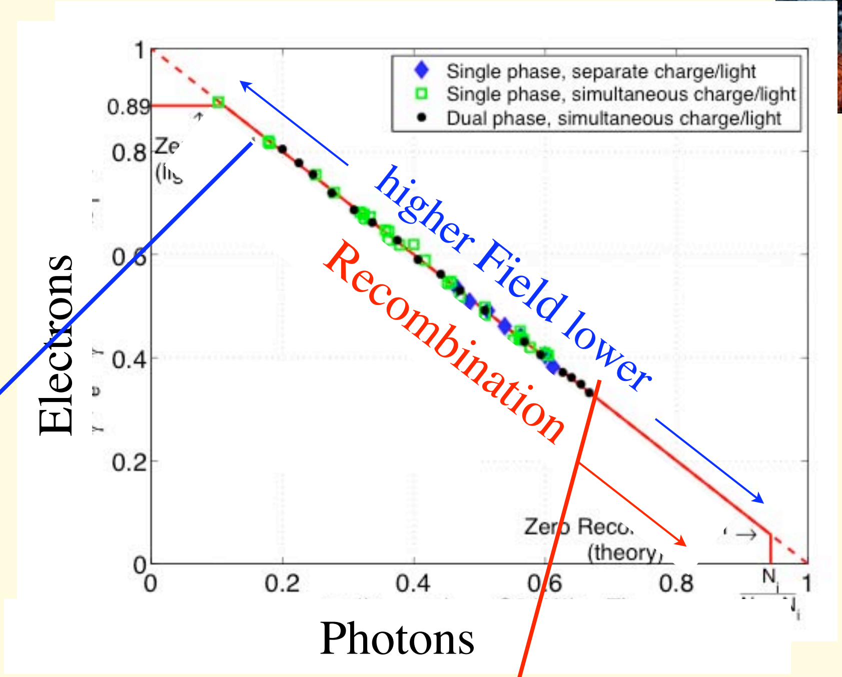


- Equal masses: significant energy “lost” to recoils.
  - (Essentially absent for electron recoils).
- Result: less “electronic excitation” than for electron recoils.
- Described by Lindhard (Copenhagen school, 1960’s)
  - J. Lindhard *et al.*, Mat. Fys. Medd. Dan. Vid. Selsk., vol. 33, no. 10, 1963.



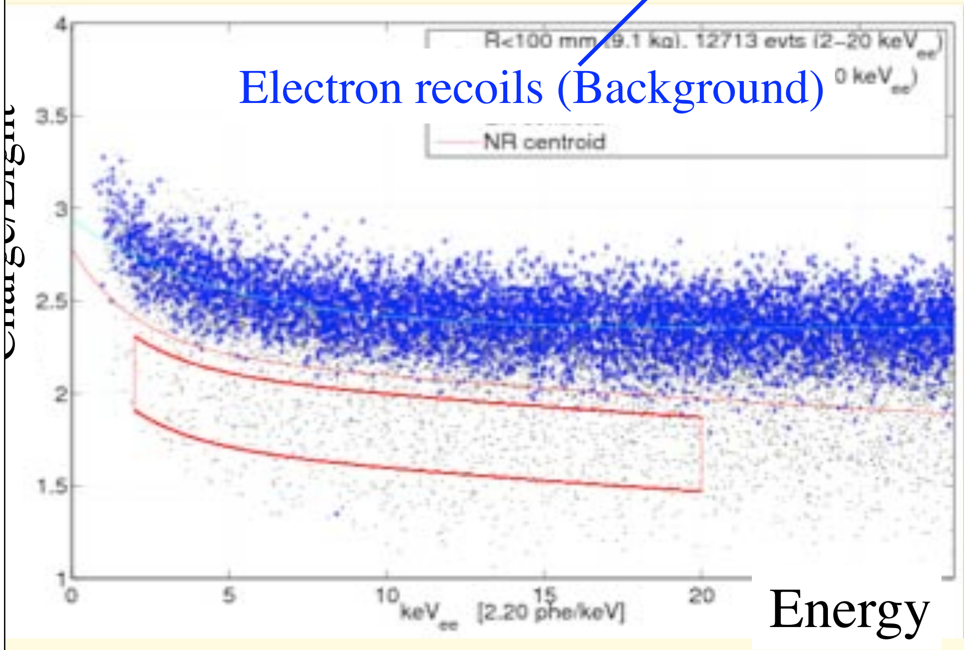
Recombination - based discrimination



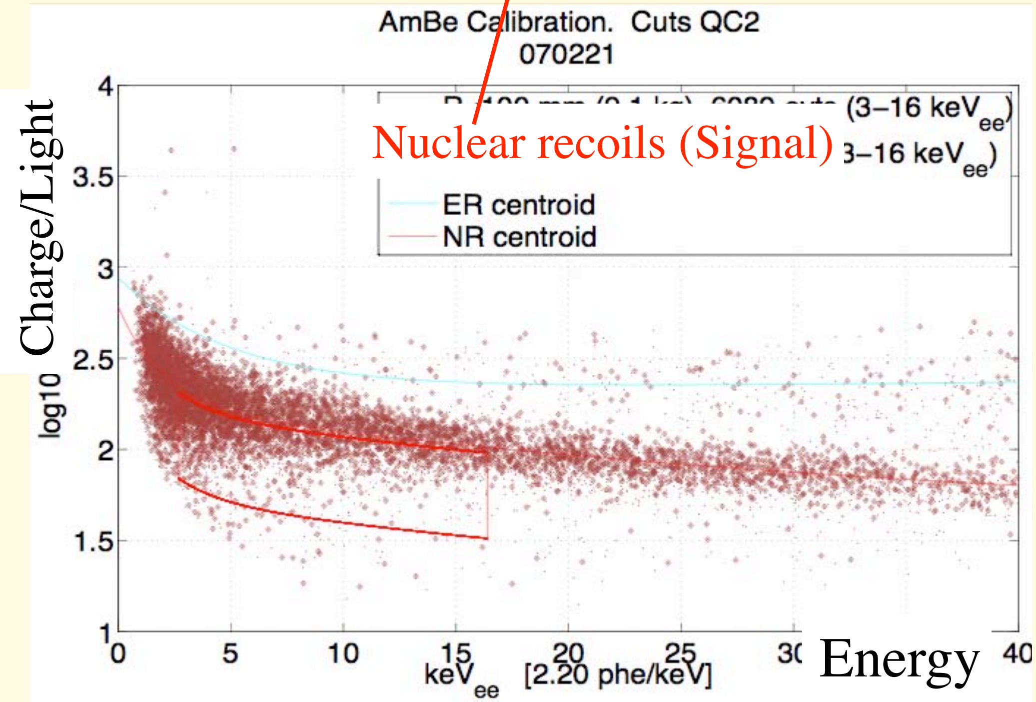


higher Field lower

Recombination



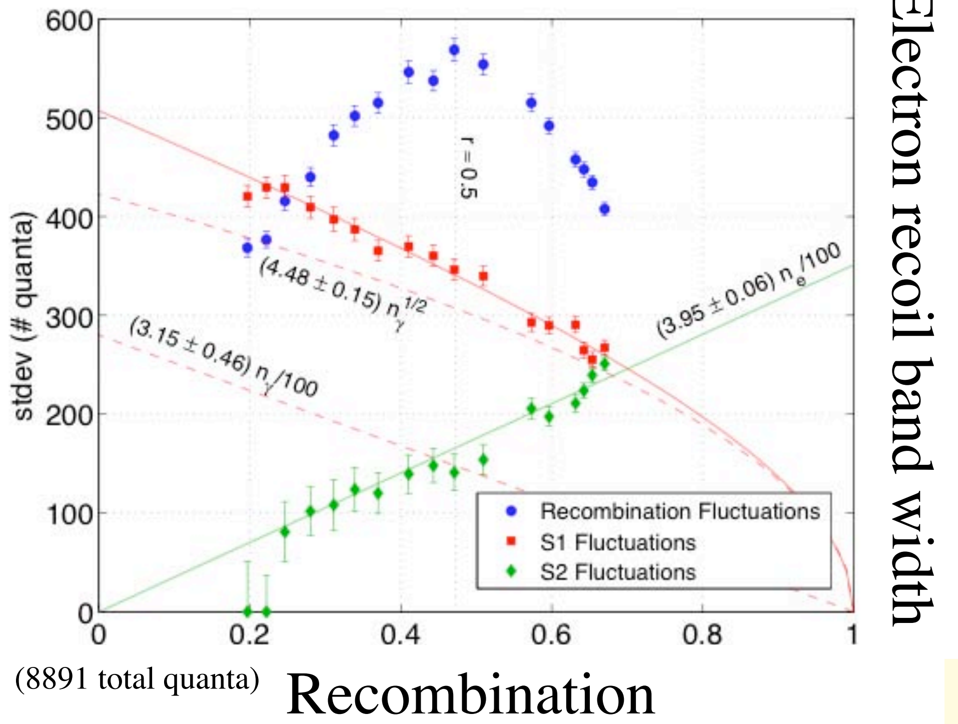
Electron recoils (Background)



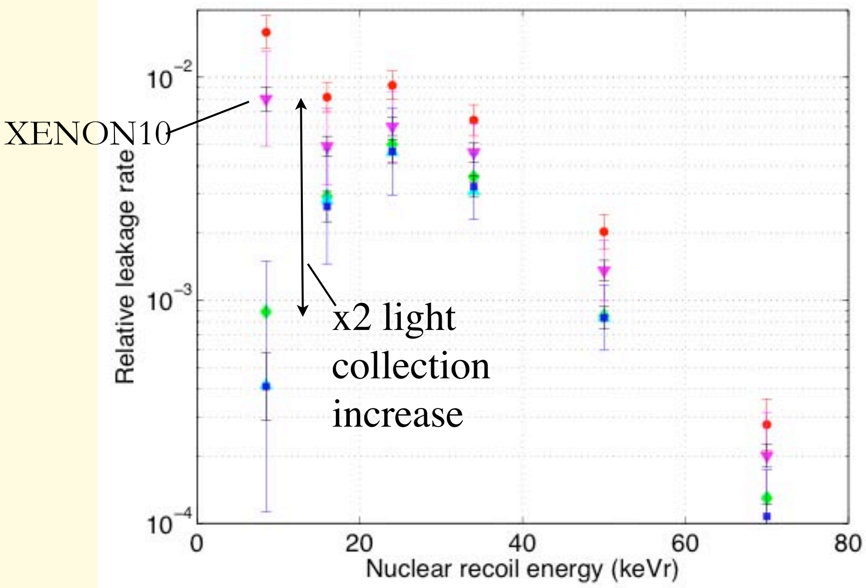
Nuclear recoils (Signal)

Understanding Discrimination

Electron Recoils At 122 keV

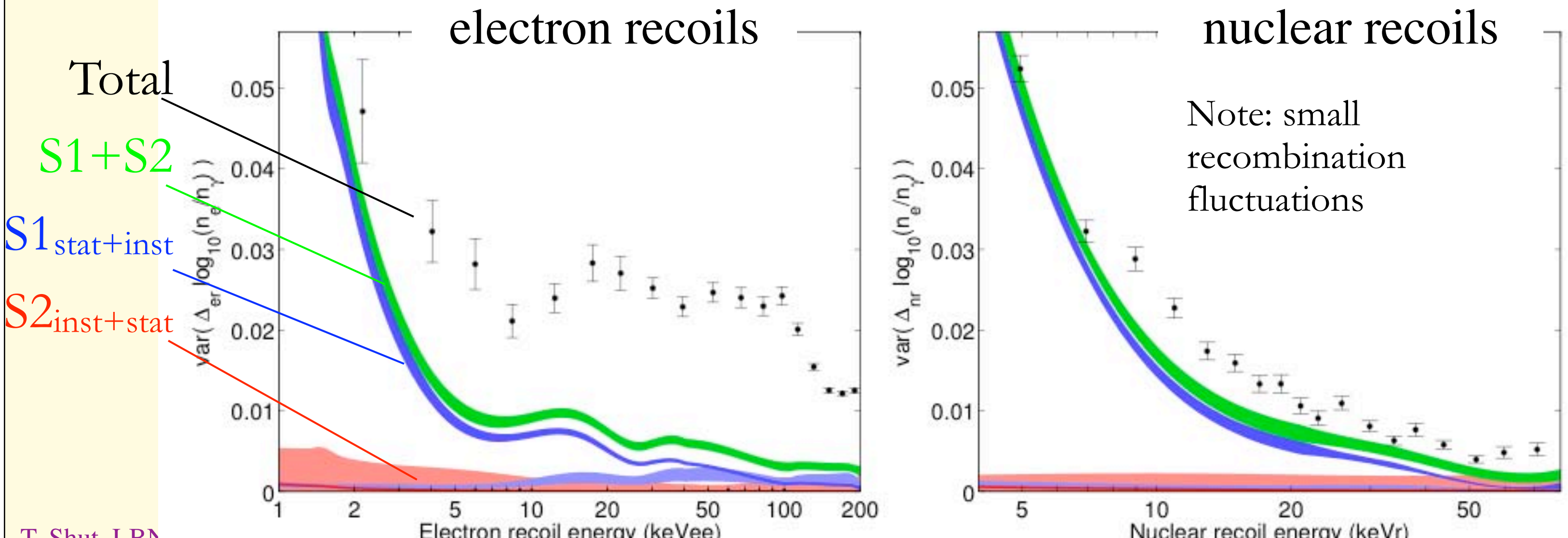


Predicted Discrimiantion



x2 light collection increase

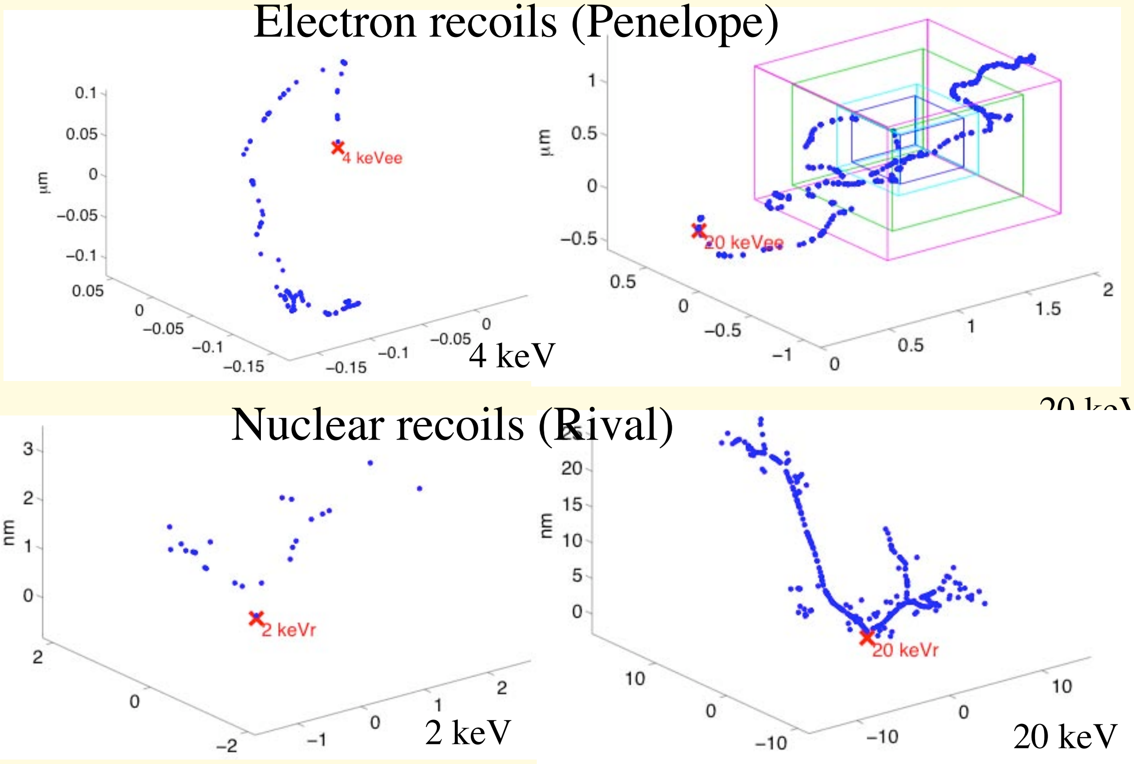
Energy Dependence



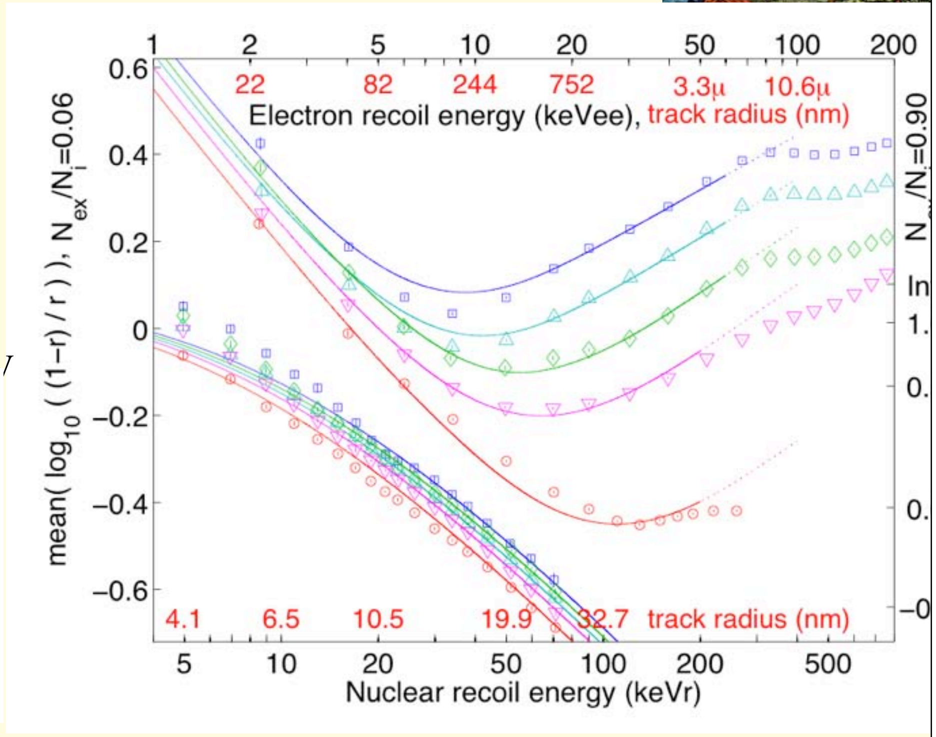
Note: small recombination fluctuations

T. Shut, LBN

Recombination Modeling (Dahl, 2009)


Electron recoils (Penelope)

Nuclear recoils (Rival)



- Long-standing puzzles: shapes of e.r. and n.r. bands, field independence of n.r. and low-energy e.r. bands
- Nuclear recoils have *same recombination* as electron recoils.
  - Discrimination based on enhanced direction-excitation light for nuclear recoils
- Qualitative (but not yet quantitative) understanding of recombination fluctuations

Concluding comments

- Two phase Xe is very powerful technology
  - Large signal
  - Low intrinsic backgrounds
  - Multiple method of background rejection (discrimination, self-shielding, active shielding)

- Low energy potential is high
  - Discrimination good near threshold
  - Factor of 2-3 better light collection might be achievable
  - S2 only data should extend to below ~keV
  - Calibration remains a challenge

- We should try to reach the neutrino limit