24th Rencontres de Blois, 2012

Searching for Dark Matter: The LUX Experiment

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for the LUX Collaboration

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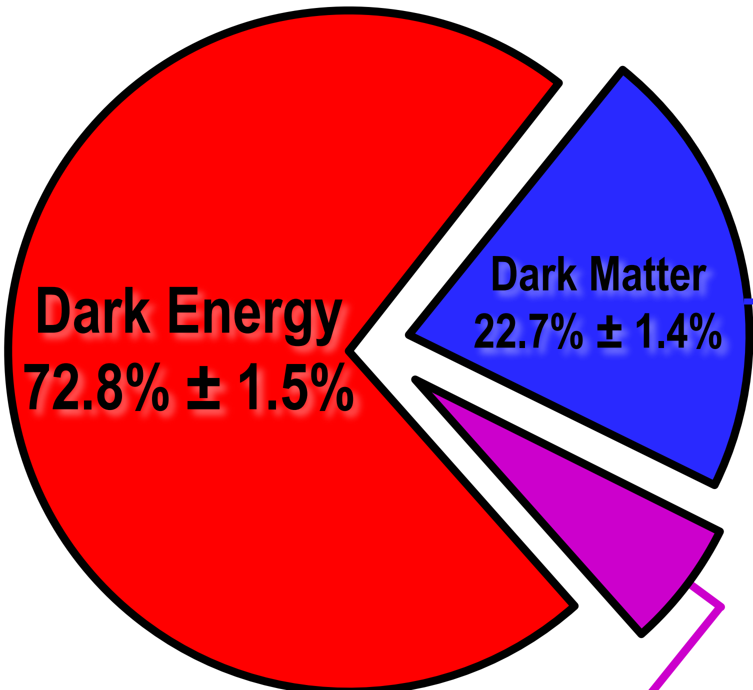
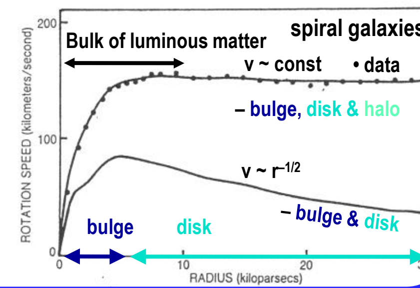
Dark Matter



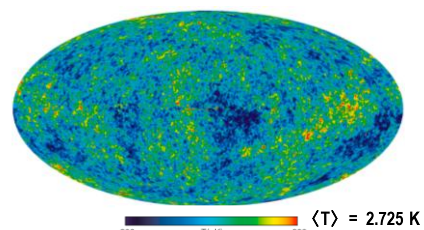
Baryonic Matter
~ 4%

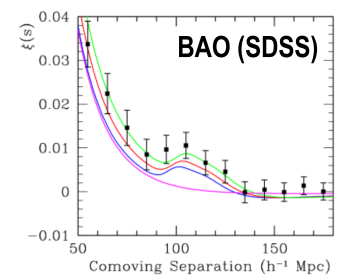
ΛCDM Model

Motion of galaxies and galaxy clusters

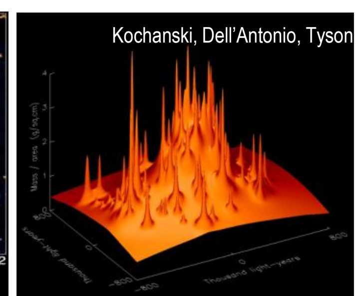


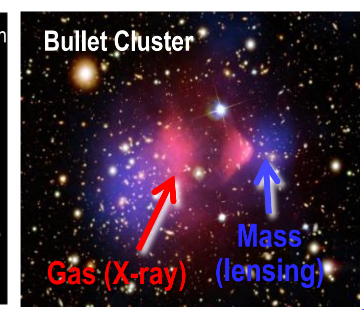
Cosmological Evidence (CMB, BAO, Supernovae…)





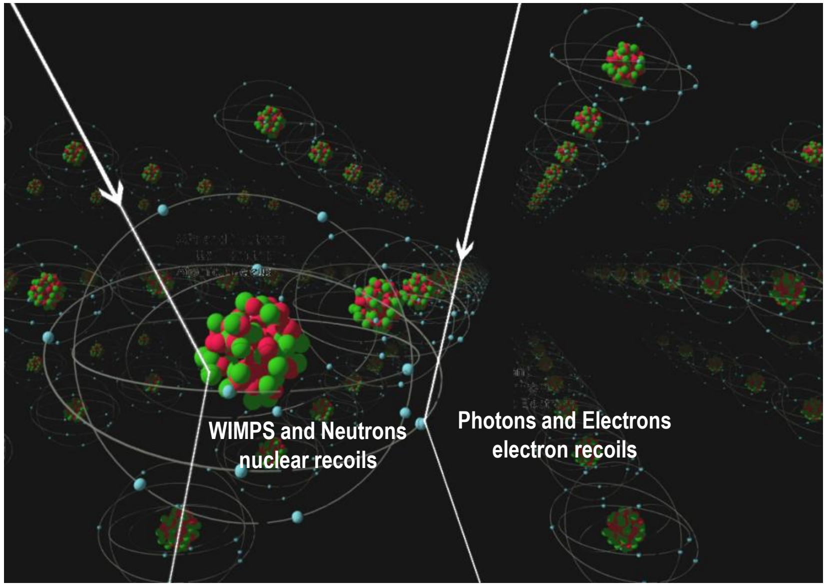
Gravitational Lensing (weak/strong)

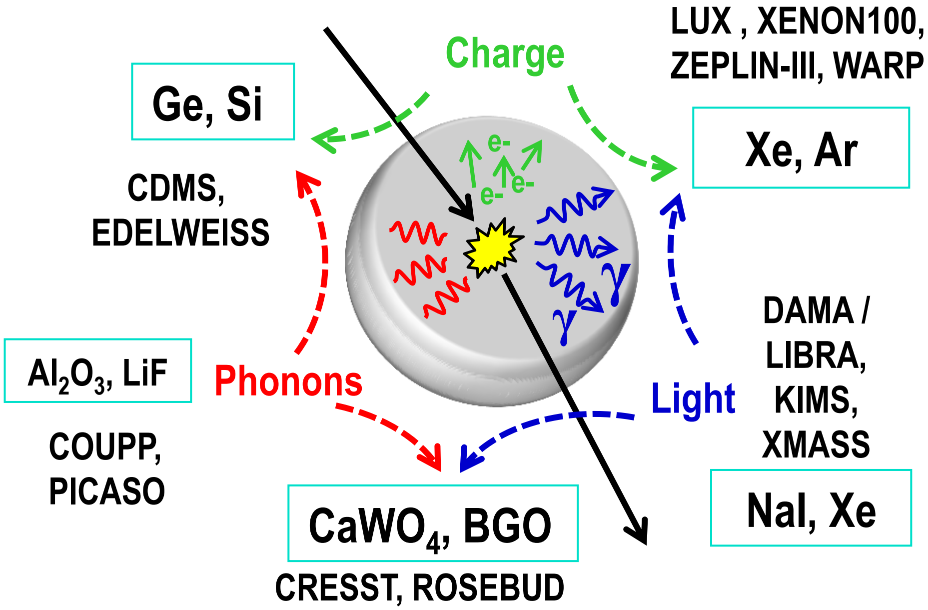




Dark Matter Candidate: WIMPs

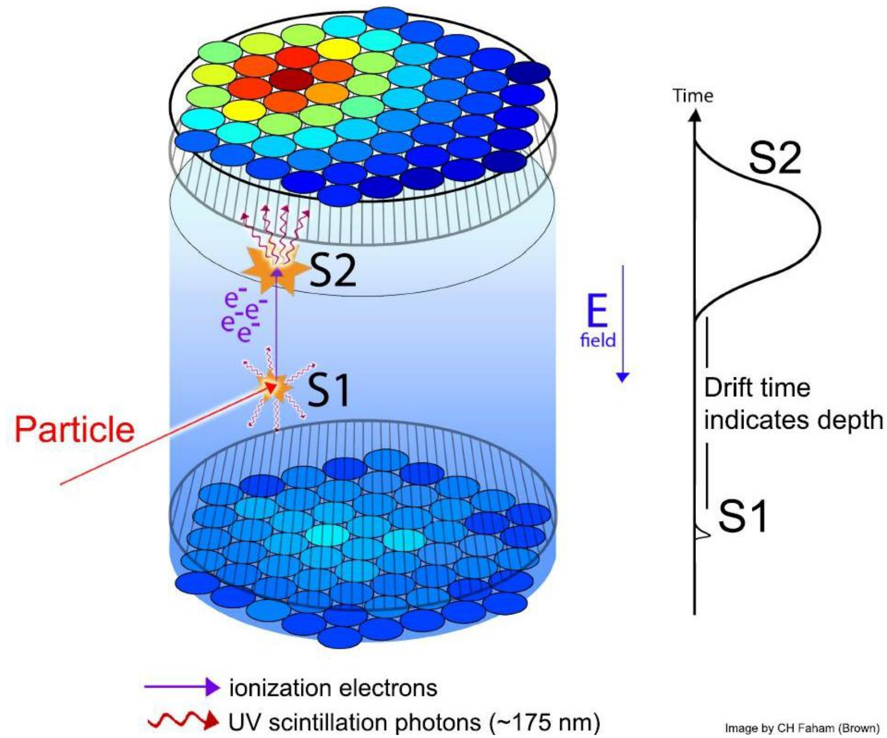
- WIMPs: Stable (or long lived) particles, relics from the Big Bang
  - Supersymmetry independently predicts *weakly interacting massive particles* (e.g. Neutralinos)
  - M_{WIMP}: in the range 10 GeV – 1 TeV
- Direct Detection: WIMPs (like neutrons) scatter elastically off nuclei
  - Photons and electrons scatter off atomic electrons
  - Recoil energy ≈ few keV – tens of keV (require detectors with low threshold)
  - Detectable via light, charge, phonons, or a combination of them



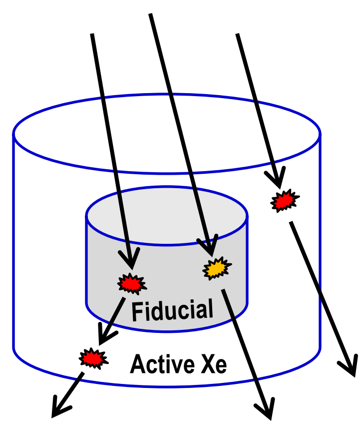


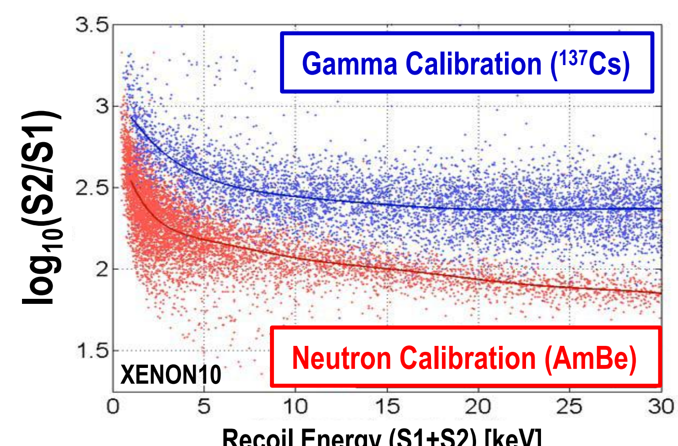
Dual Phase Xe Detector

- **Dual Phase: Gas and Liquid Xe**
  - High density (~3 g/cm^3) and high Z
- **Sensitive to both Scintillation Light (S1) and Charge (S2)**
  - Different yields of light and charge for nuclear recoils (WIMPs, neutrons) and electron recoils (γ, e-)
  - Event-by-event discrimination: charge/light => bands
  - Background rejection: >99.5% (LUX)
  - Nuclear recoil acceptance: 50%



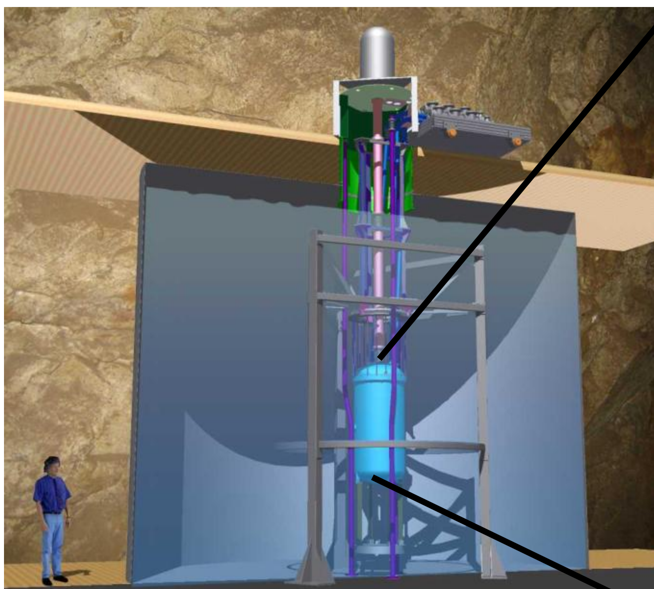
- **Position reconstruction**
  - Z from S2-S1 timing, XY from S2 pattern
  - Self-shielding:
    - Active: veto high-E and multiple scatters
    - Passive: fiducial volume

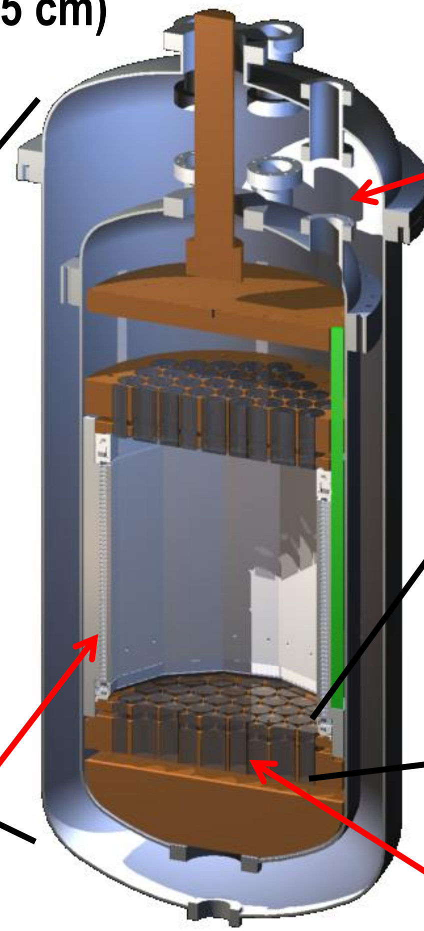


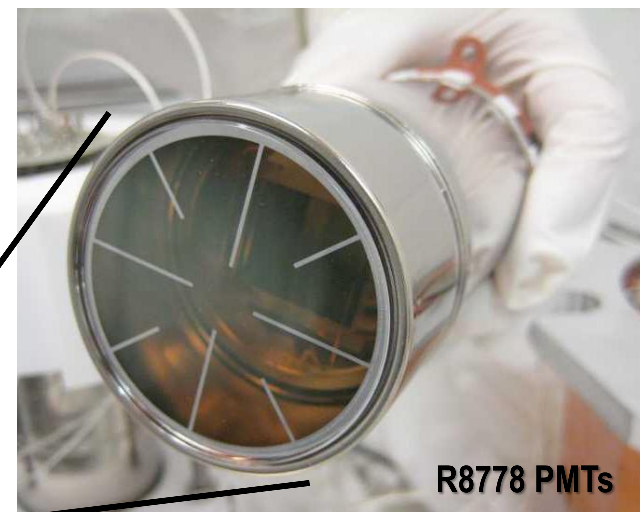


The LUX Detector

- To be deployed in the Sanford Lab at the Homestake Mine (South Dakota, USA)
- 1.5 km deep (4300 m.w.e., μ flux reduced $\times 10^{-7}$ compared to sea level)
- 350kg Liquid Xe Detector (59 cm height, 49 cm diameter)
- 122 PMTs (Hamamatsu R8778, ø = 5 cm)
  61 on top, 61 on bottom
- Low-background Ti Cryostat

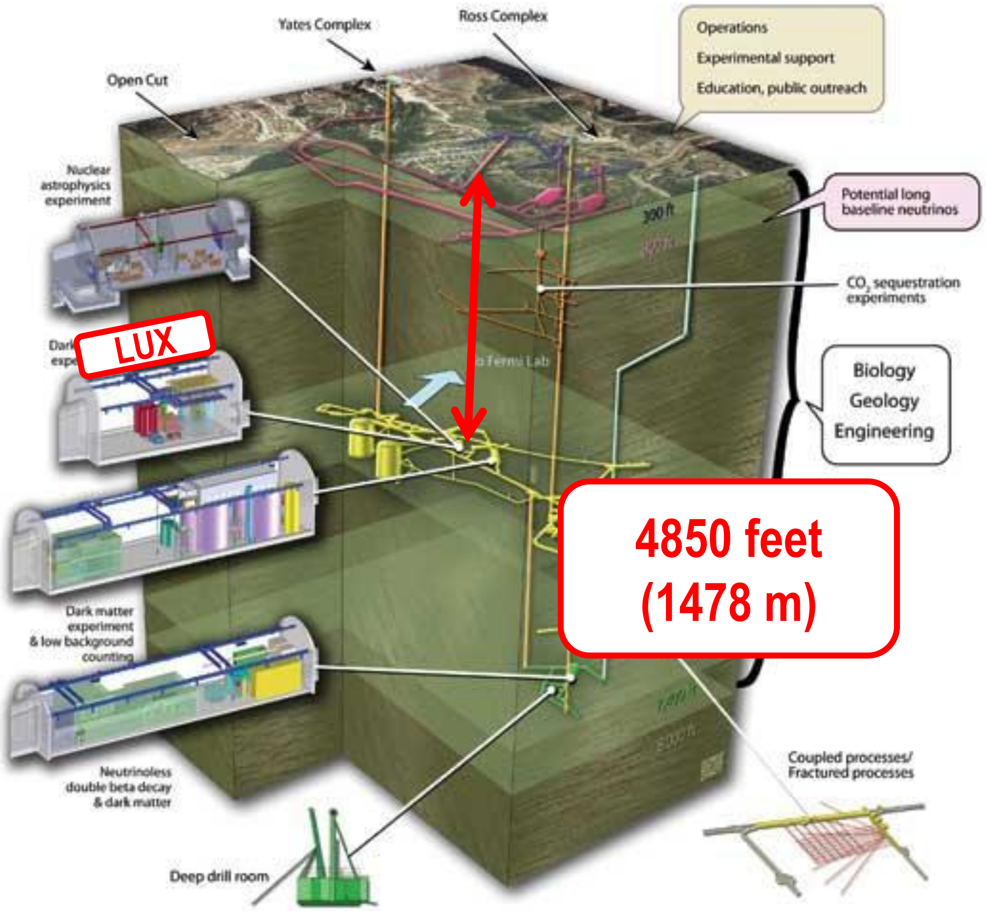


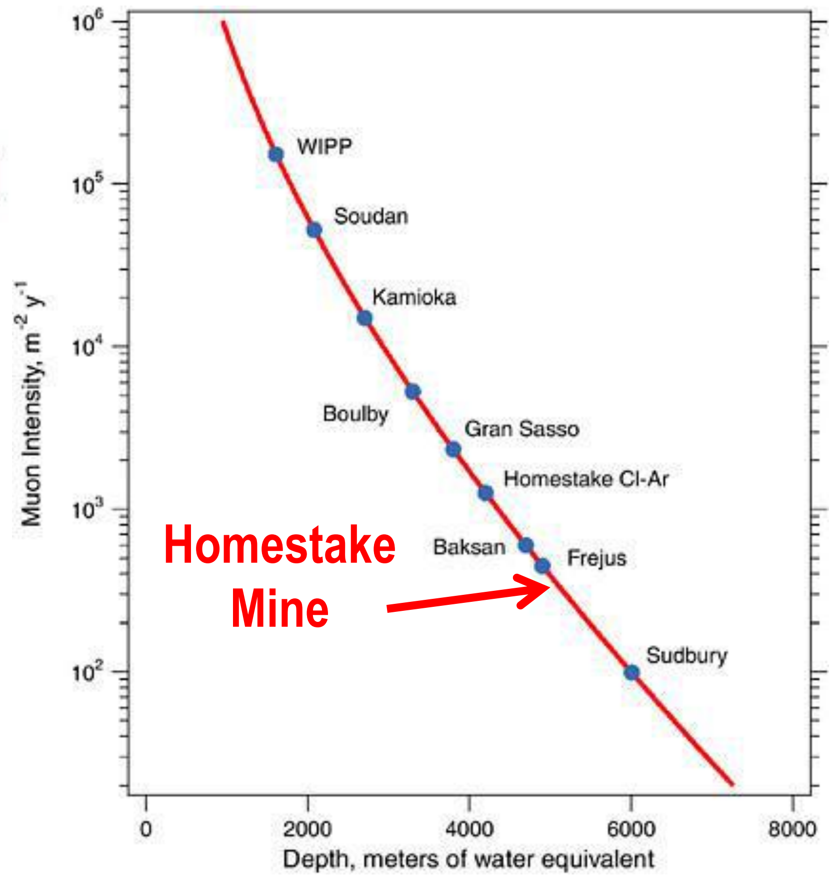




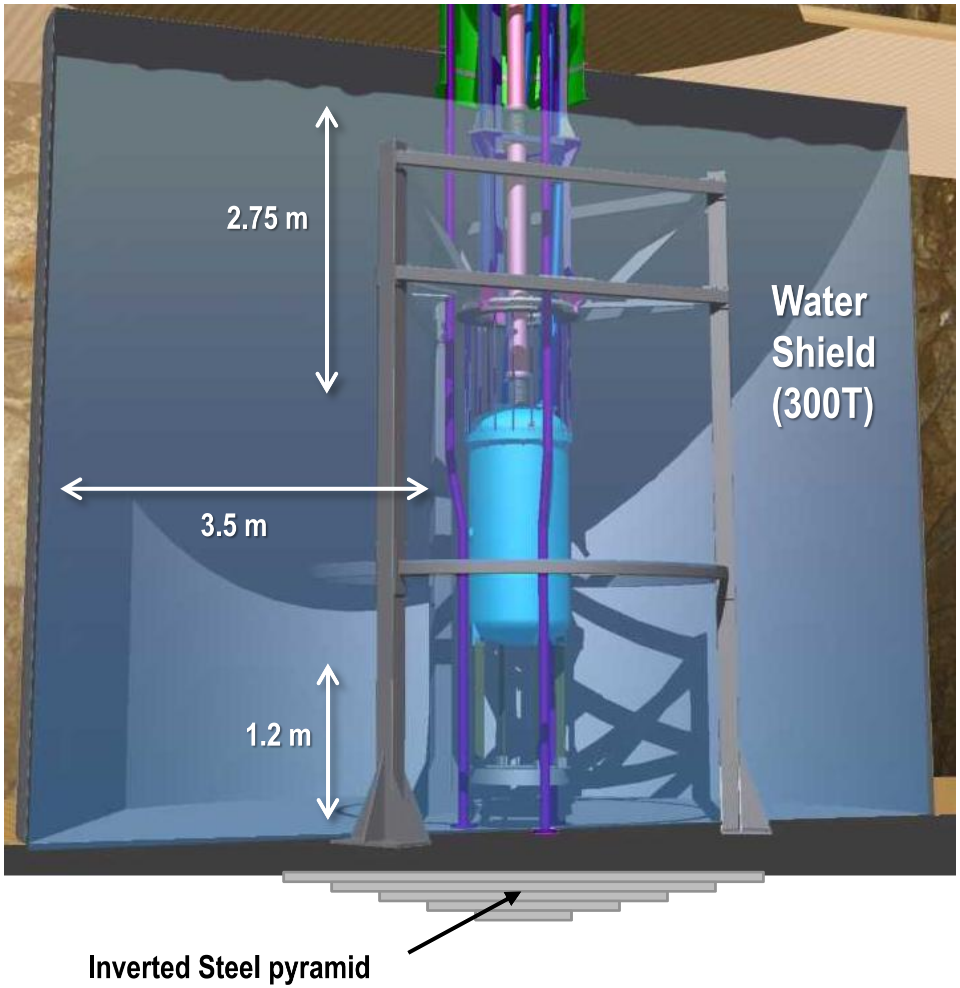
Sanford Lab at Homestake Mine

- To be deployed in the Sanford Underground Research Facility (SURF) at the Homestake Mine (South Dakota, USA)
- 1.5 km deep (4300 m.w.e., μ flux reduced x10^{-7} compared to sea level)

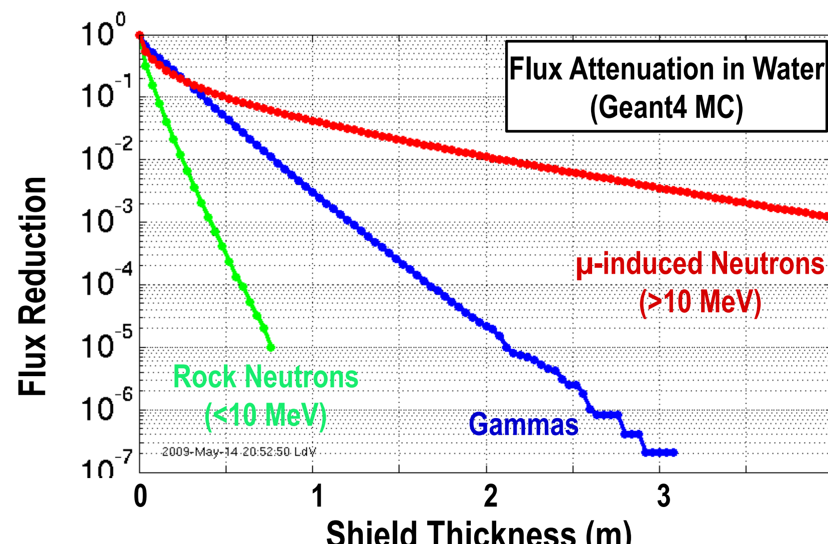




LUX Water Shield



- Water Tank: ø = 8 m, h = 6 m (300 Tonnes)
  - 3.5 m shield thickness on the sides
  - Inverted steel pyramid (20 tons) under tank to increase shielding on top/bottom
  - Muon Veto: 20 PMTs (ø = 10")
- Ultra-low background facility
  - Gamma event rate reduction: 2×10^{-10}
  - High-energy neutrons (> 10 MeV) rate reduction $\sim 10^{-3}$ => < 100 $ndru_r$



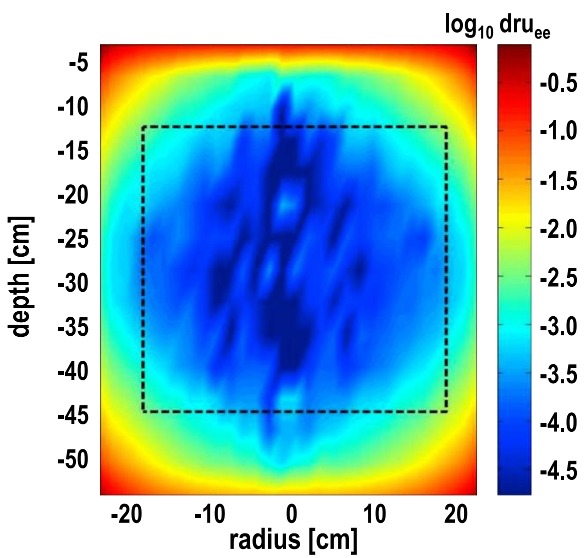
LUX Internals

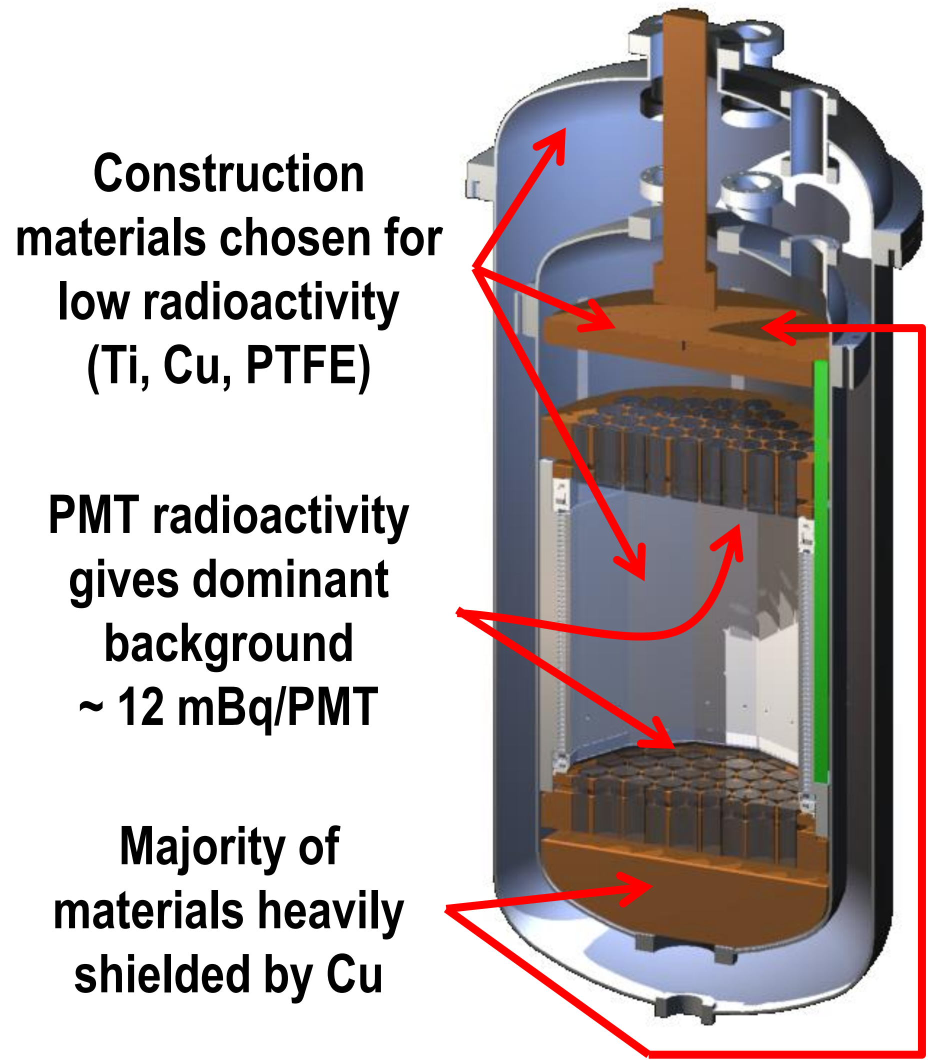
- All detector components are screened for radioactivity at the SOLO counting facilities and by LBNL
  - Internal backgrounds dominate over external (from cavern rock)
- Active region defined by PTFE slabs (high reflectivity for Xe scintillation light)

100 kg fiducial reduces background by 10^{-4}

γ: ~ 400 μdru
n: ~ 500 ndru

dru = events / kg / keV / s

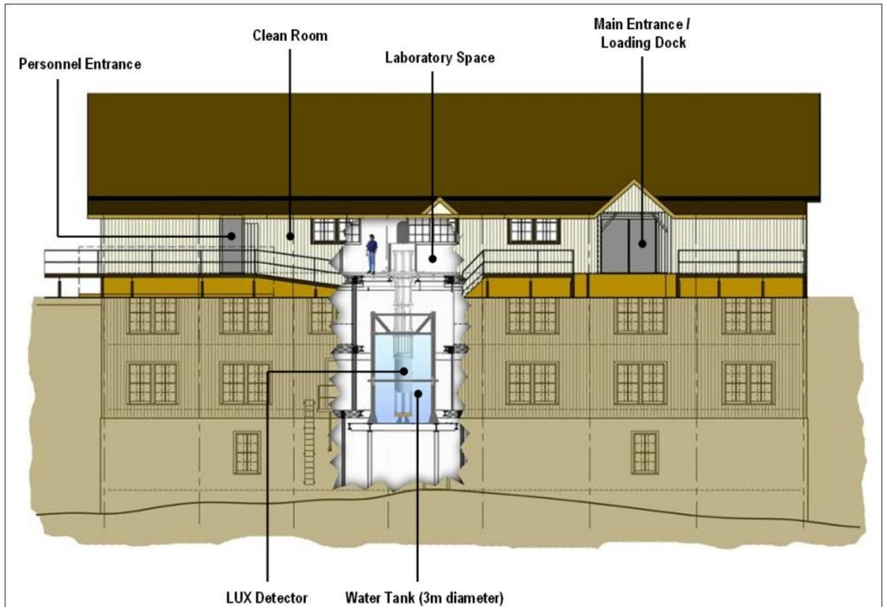


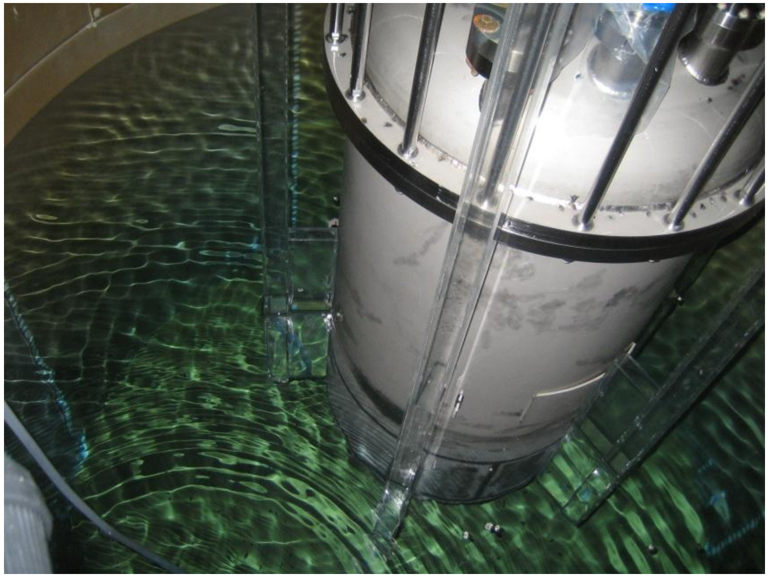


LUX Surface Run (at Homestake)

- Stable cryogenic operation for > 100 days
  - Ended on Feb 2012, detector being moved underground
- First successful use of technologies proposed for tonne-scale detectors:
  - Biggest double phase Xe detector in operation: 350 kg, 122 PMTs
  - Low background Titanium vessel
  - Thermosyphon cooling
  - Full scale deployment in water tank

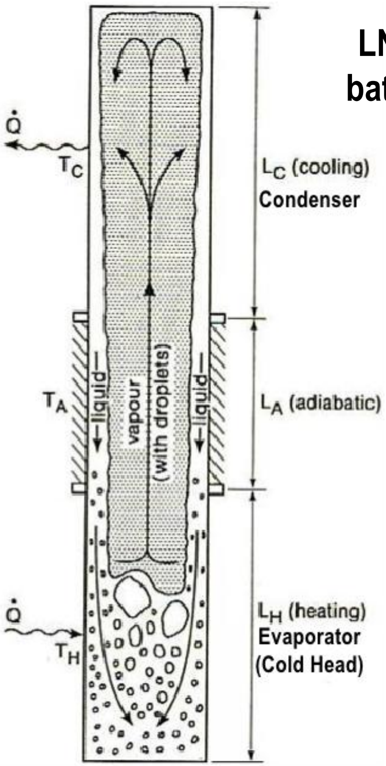




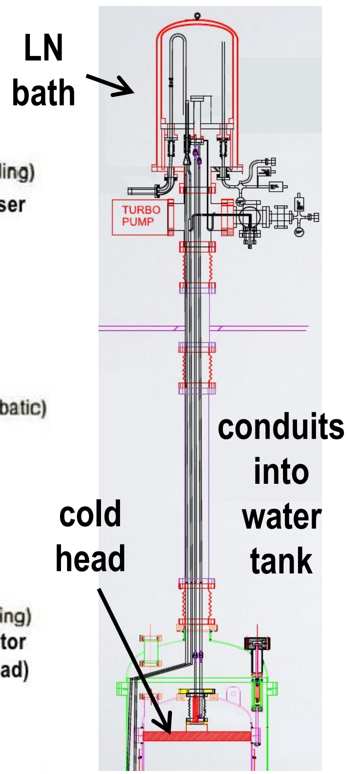


Surface Run – Cooling System

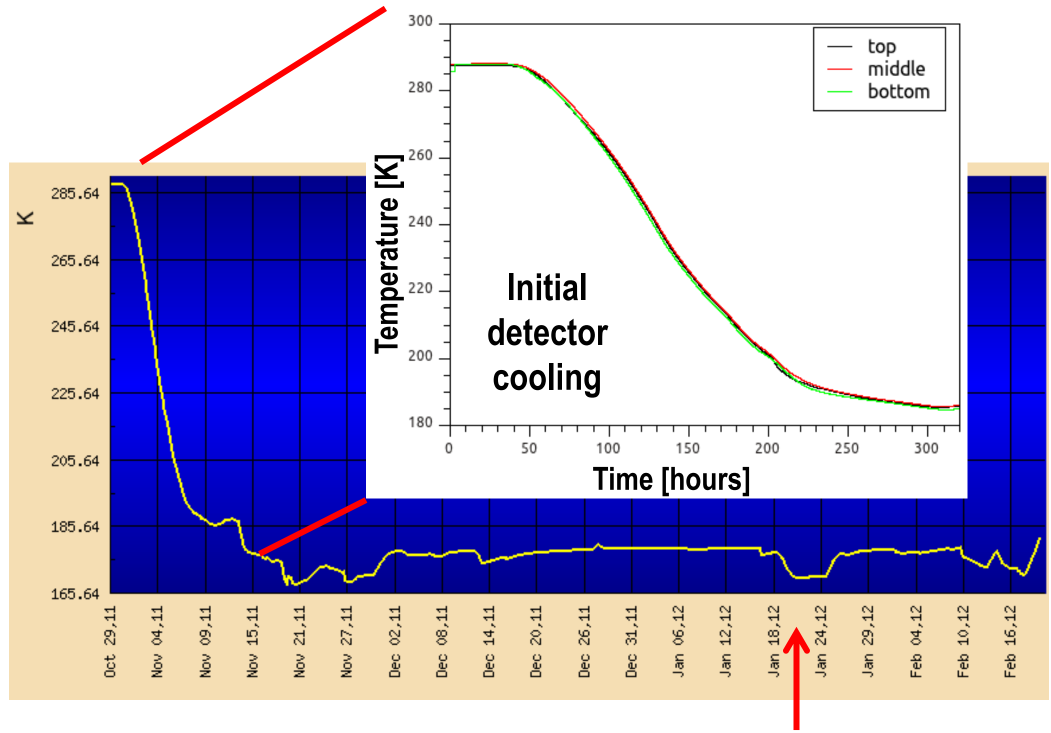
- Thermosyphon: ~kW capacity, multiple cold head deployment;
- High flow plumbing and heat exchanger for rapid circulation through external purifier: 35 liters per minute (300 kg/day)
  - Very low heat load: < 5 W



Thermosyphon principle



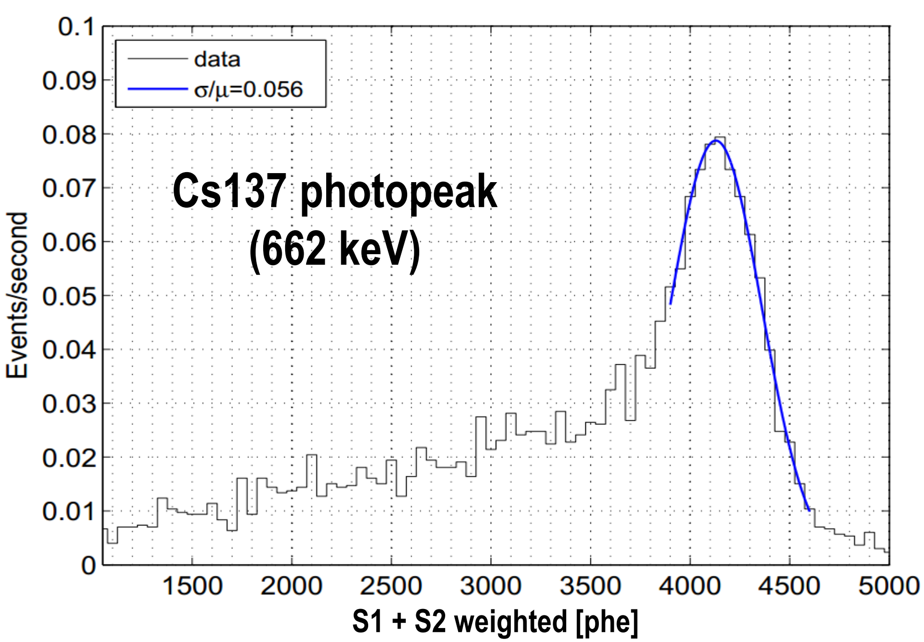
LUX Thermosyphon

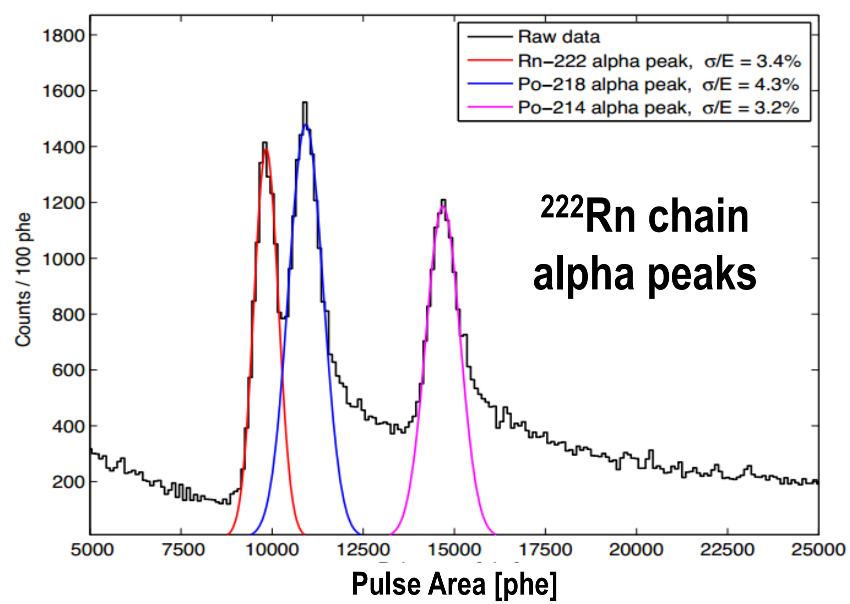


temperature variation <=> circulation change

Surface Run – Signals

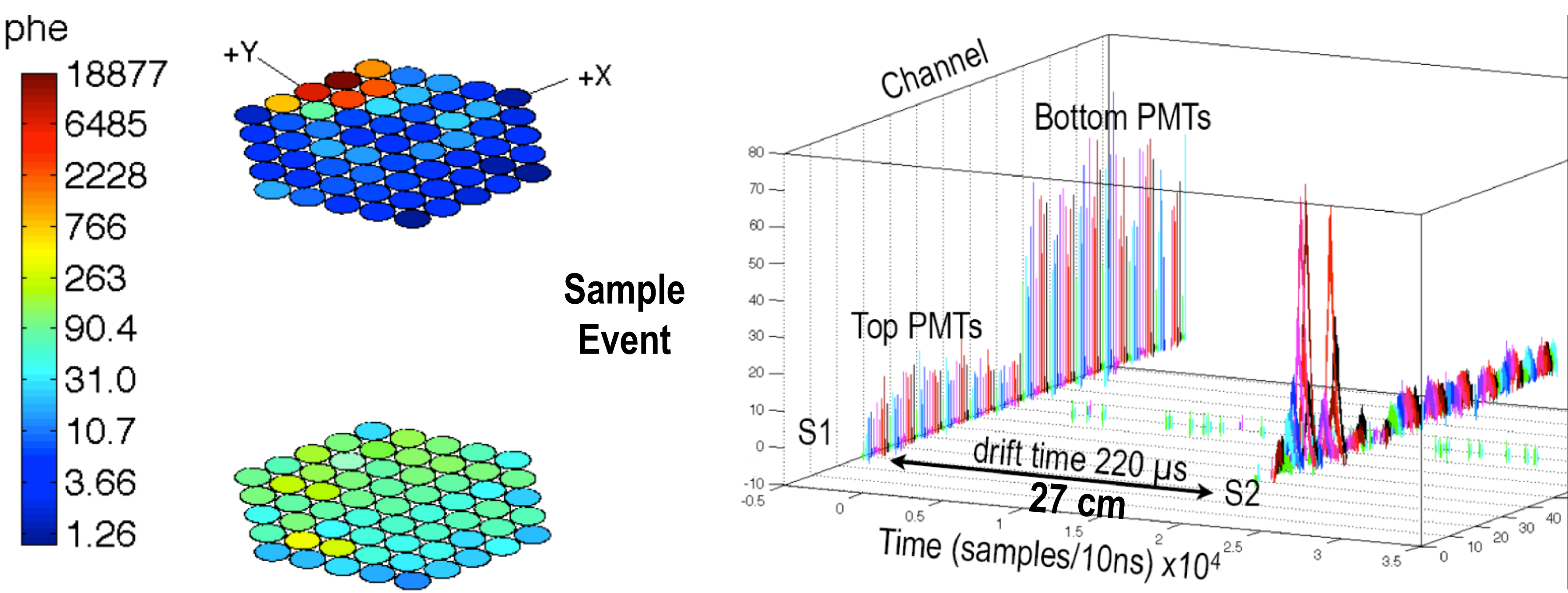
- **Functional trigger, DAQ, analysis chain:**
  - 3 TB of data generated and processed – backgrounds and gamma source calibrations
  - DAQ samples at 100 MHz with 14 bit depth;
  - 122/122 PMTs are working (1 faulty base)
  - PMT operation limited to low gain (1e5 - 5e5) due to overwhelming Muon background at surface (~300 MeV per event => too much light)
  - E resolution: ~ 6% at 662 keV (Cs137), ~ 3% at 5.5 MeV (α's)





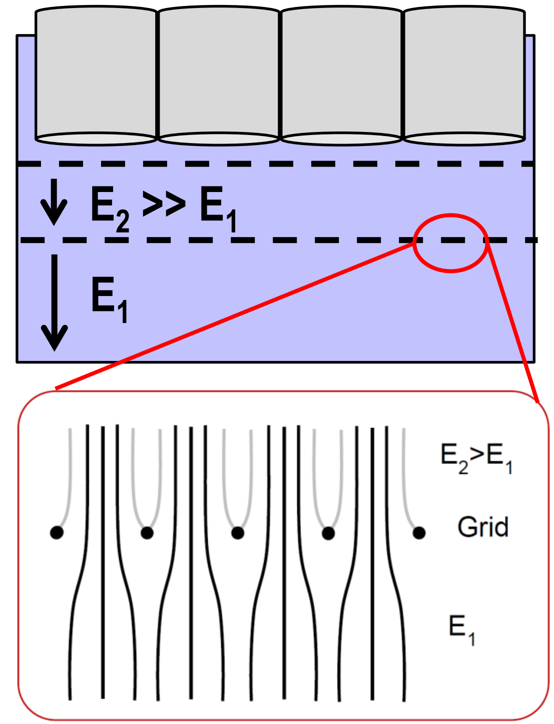
Surface Run – Light and Charge

- Light collection: ~ 8 phe/keV$_{ee}$ in detector center (zero electric field)
  - Comparison with MC simulation: $R_{PTFE} > 95\%$; $\lambda_{abs} > 5$ m
- Xe purity (Electron lifetime) monitored by muon, alpha and gammas signals.
  - Muon tagging system using plastic scintillator panels
  - Alphas from ^{222}Rn injection
- Electron lifetime measured by alphas: > 90 μs (12 cm)
  - Broken internal pipe limited circulation through active region and purification performance
  - Lifetime known to be higher, a limiting pulse threshold effect under study

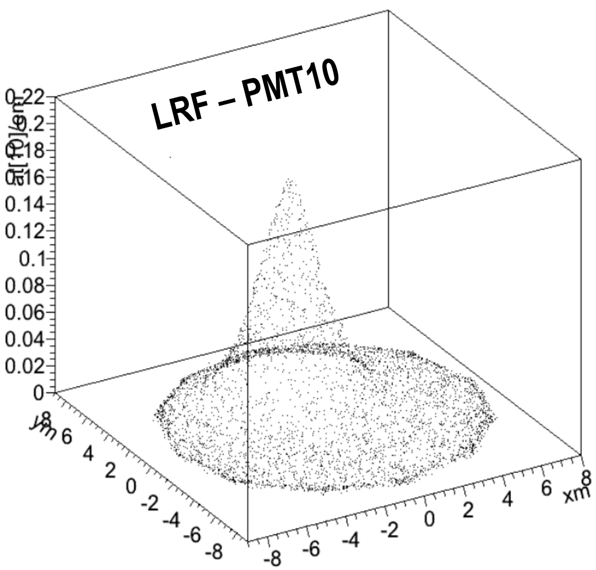


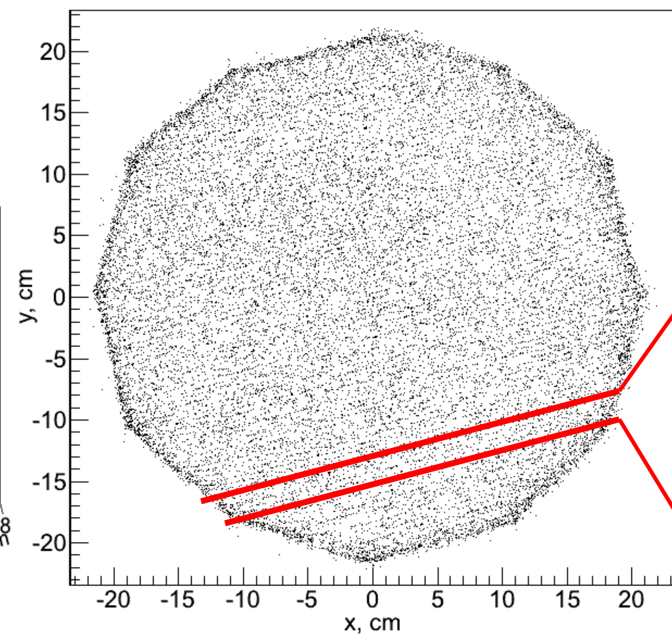
Surface Run – Event Reconstruction

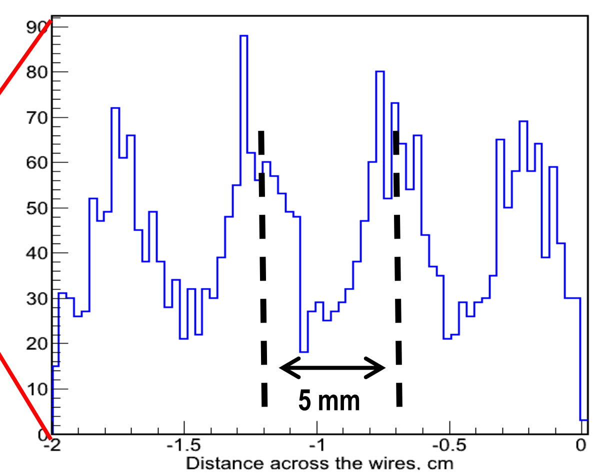
- **Event Reconstruction Software: Mercury**
  - **Light Response Functions (LRFs) are obtained by iteratively fitting the radial distribution of events for each PMT**
  - **Uses χ^2 minimization of S2 hit pattern (relative to LRFs) to reconstruct each event position**
  - **LRFs can be found using background data**



- **Reconstruction of XY from α interactions (E = 5.5 MeV) near anode grid resolves grid wires with 5 mm pitch**

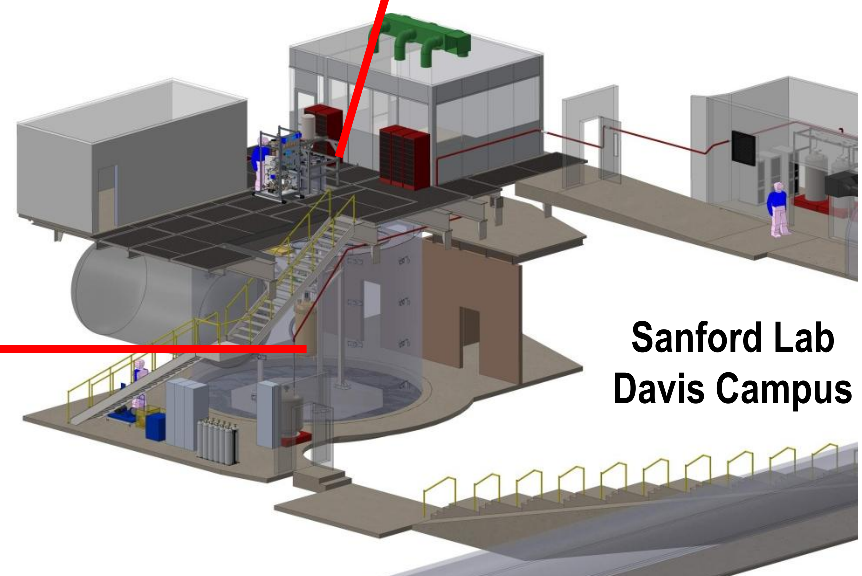




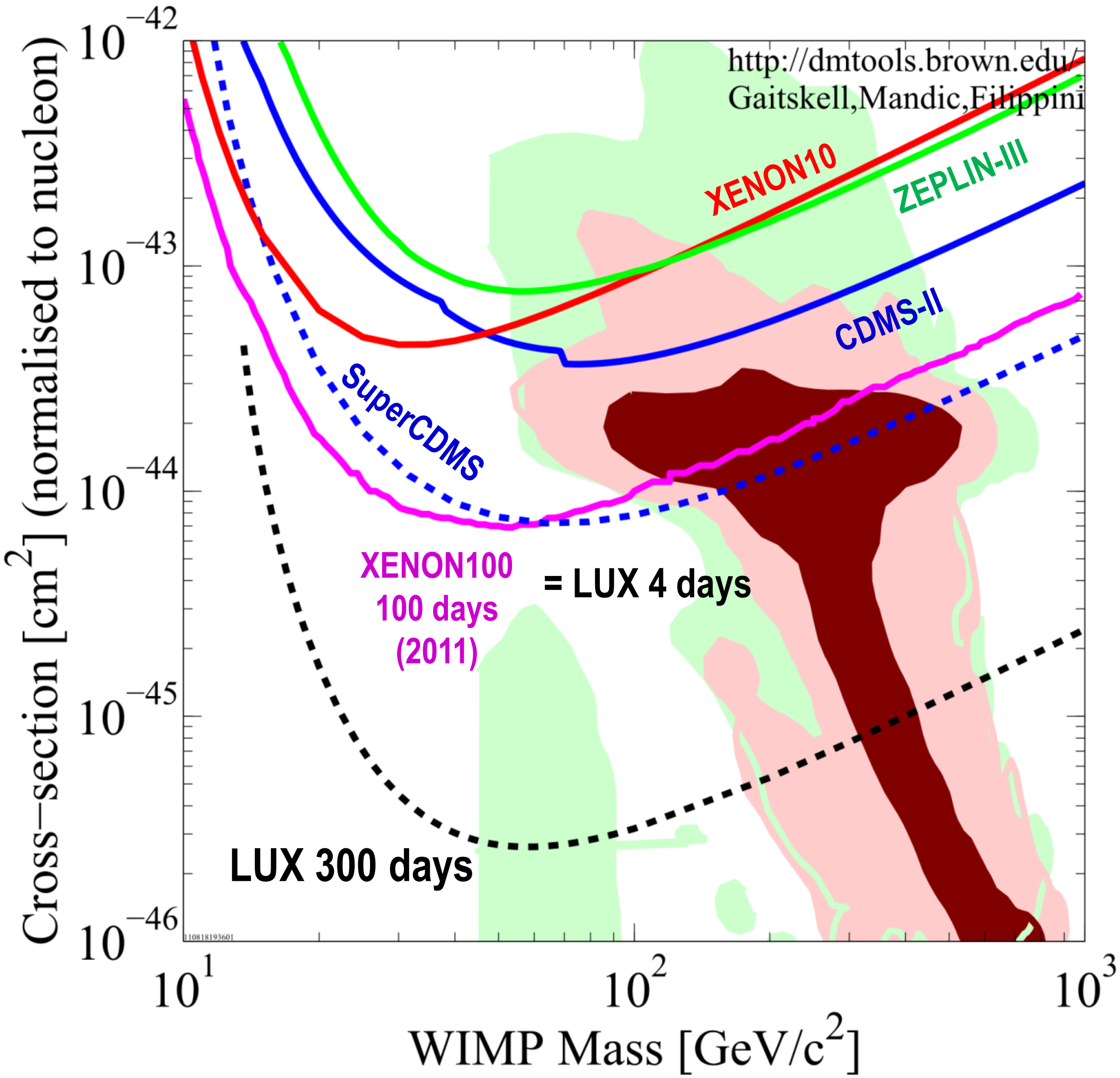


Underground Deployment (Homestake Mine)

- **Underground Science Timeline**
  - Start dismantling at surface March 2012
  - Start installation underground May 21, 2012
  - Finish installation September 2012
  - Finish commissioning November 2012
  - First science data before the end of 2012
  - First result in first quarter of 2013
  - 300 days result by end 2013



Sensitivity Limits



Exclusion curves for WIMP-nucleon cross-sections

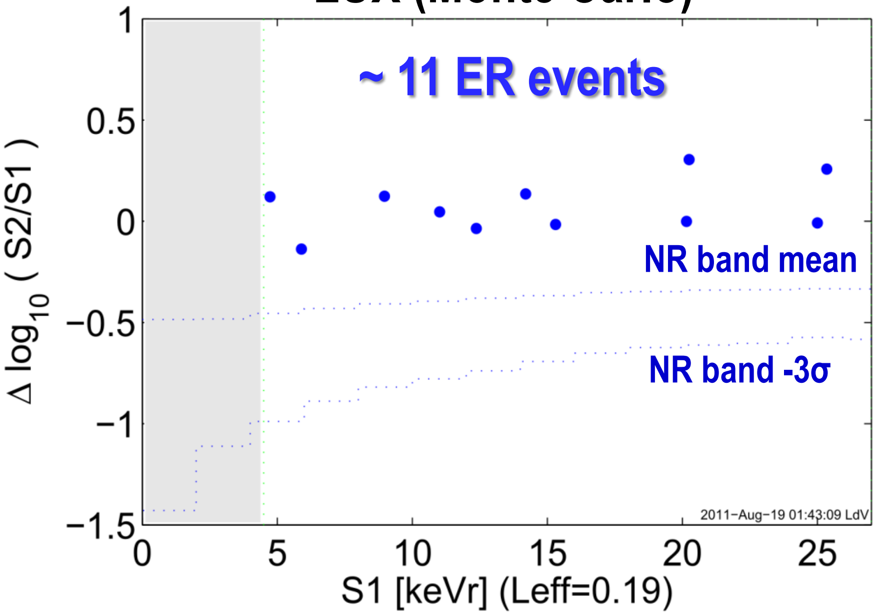
Spin-independent coupling

LUX WIMP Sensitivity

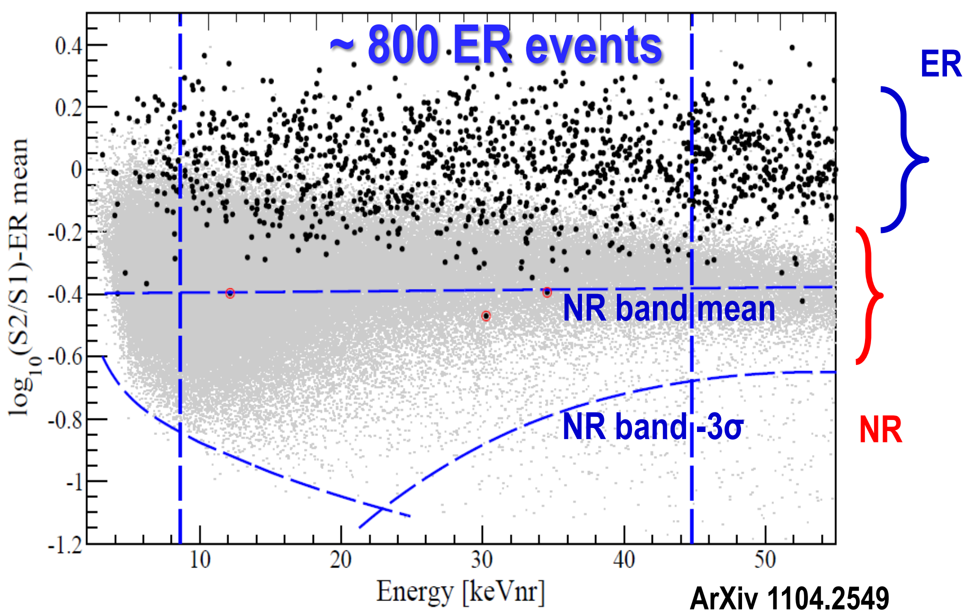
- LUX is designed for very low ER background rate, with strong emphasis on unambiguous discovery of WIMP signal
- Contrast LUX with current best limit (XENON100)
  - 40 kg x 100 day XENON100 exposure => 100 kg fiducial x 40 days in LUX

equivalent kg-days

LUX (Monte Carlo)



XENON100



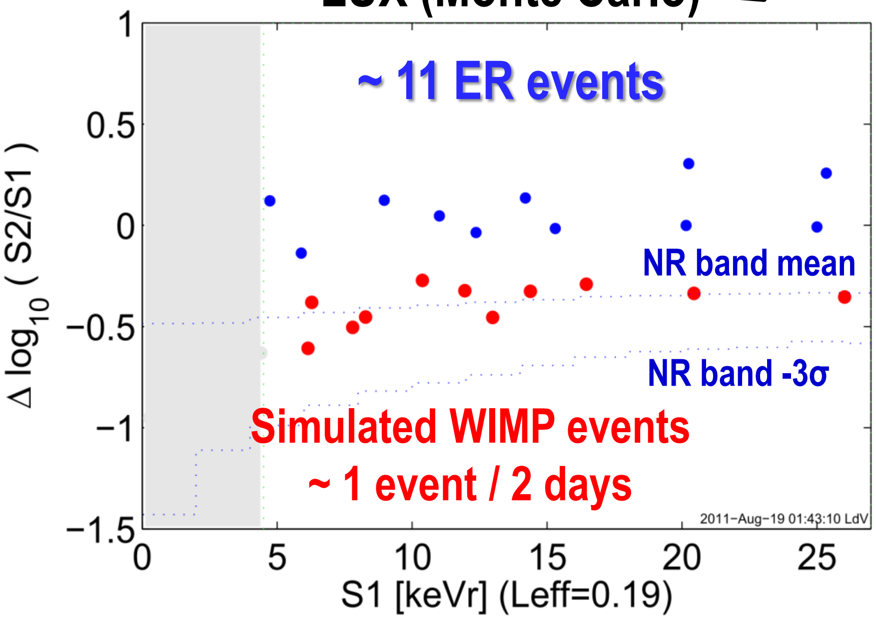
ArXiv 1104.2549

LUX WIMP Sensitivity

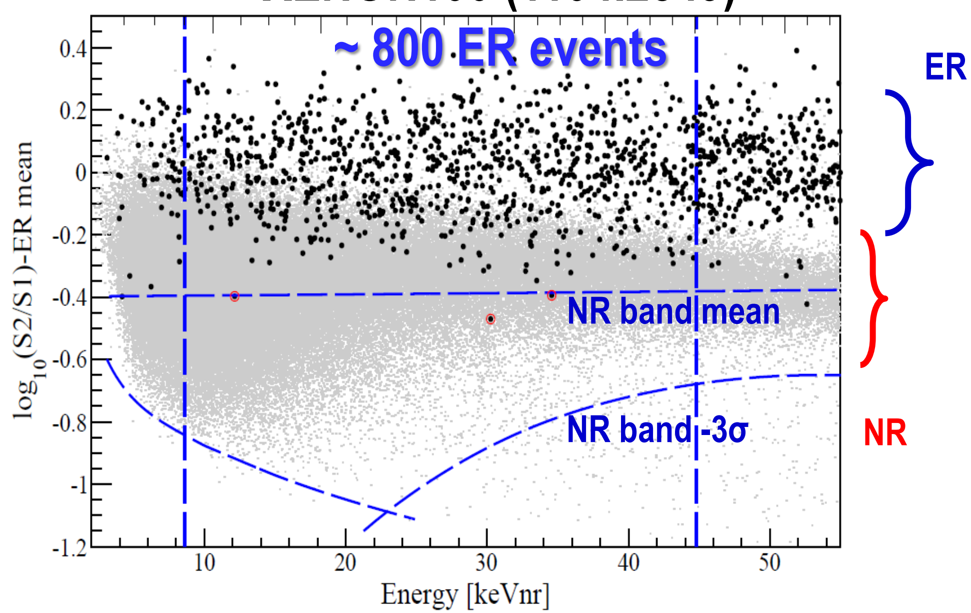
- LUX is designed for very low ER background rate, with strong emphasis on unambiguous discovery of WIMP signal
- Contrast LUX with current best limit (XENON100)
  - 40 kg x 100 day XENON100 exposure => 100 kg fiducial x 40 day in LUX
- What will WIMPs look like in LUX?
  - Best 90% CL Exclusion Limit: $\sigma_{WIMP} = 10^{-44}$ cm^2 at 100 GeV

equivalent kg-days

LUX (Monte Carlo)

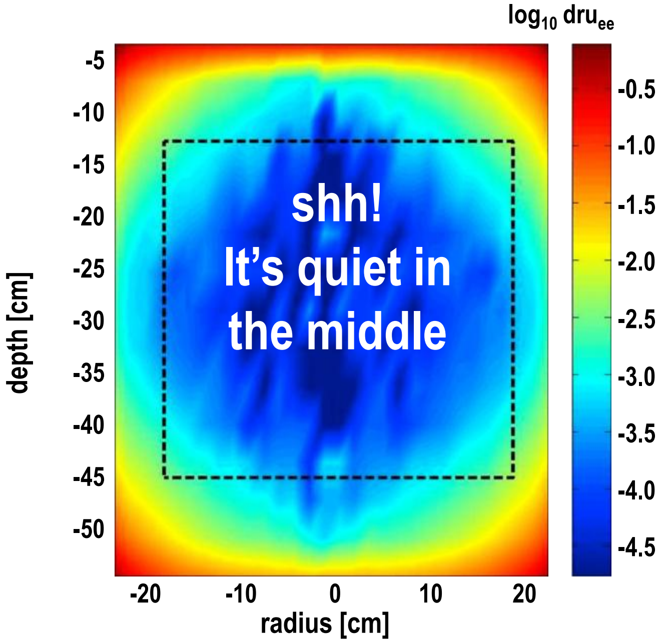


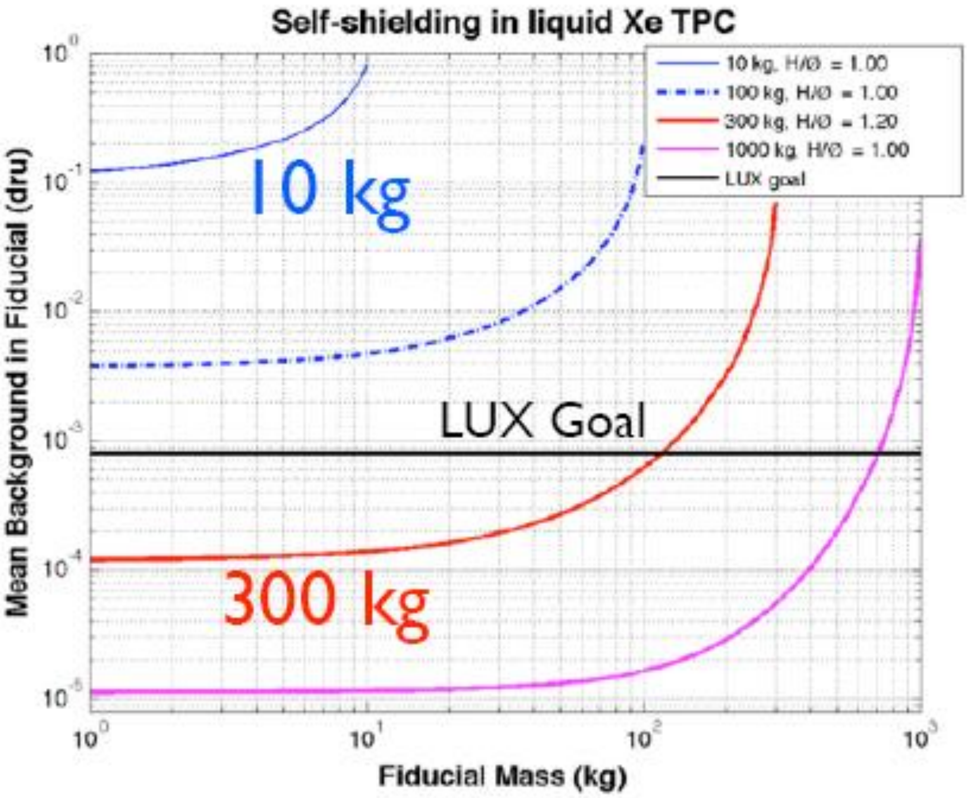
XENON100 (1104.2549)



LUX Backgrounds – Self-shielding

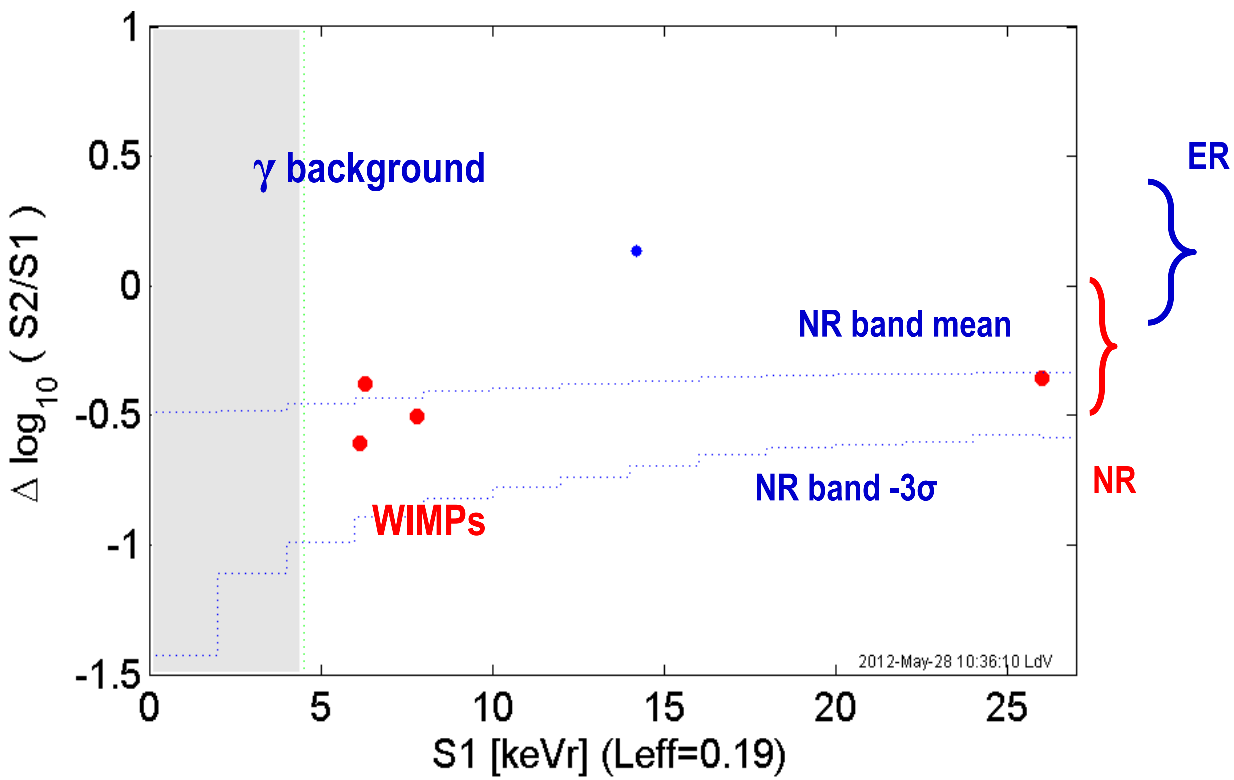
- At LUX's scale, self-shielding allows nearly background-free acquisition by using a reduced fiducial:





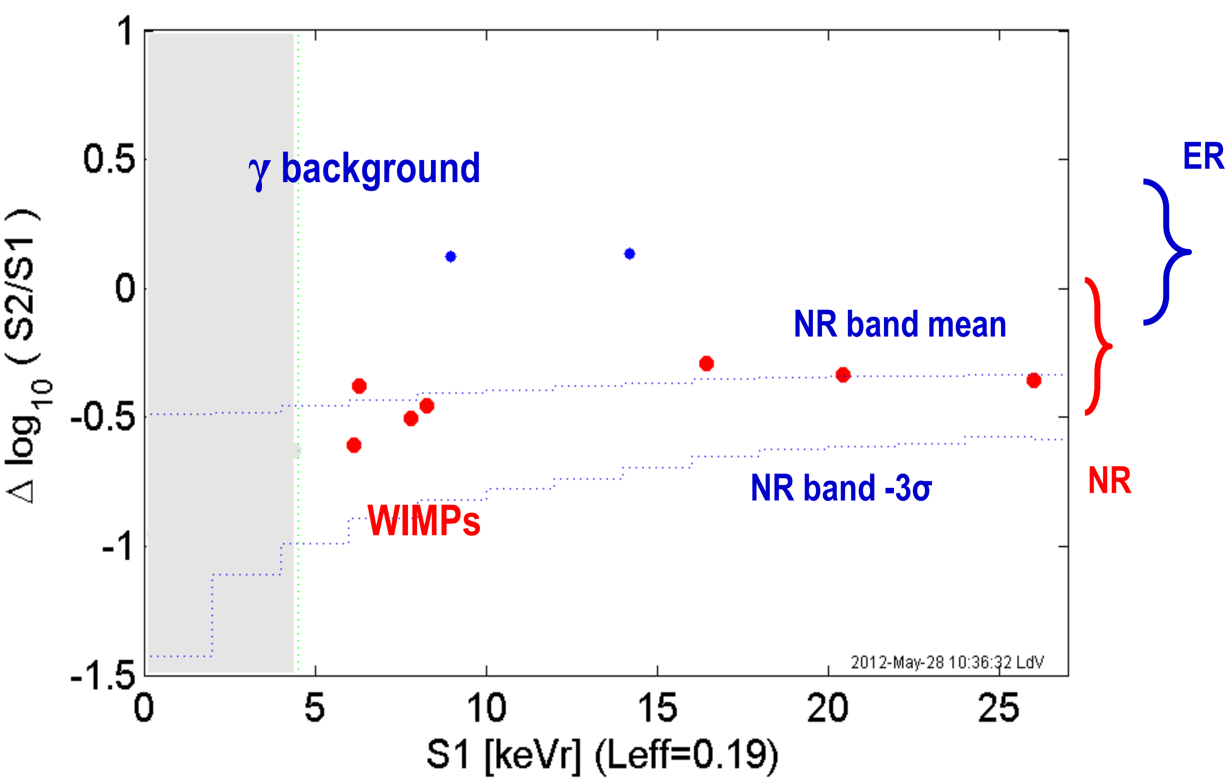
Simulated WIMP signal in LUX

- Example: m_{WIMP} = 100 GeV/c^2 and σ_{WIMP} = 1x10^{-44} cm^2 (sensitivity limit set by XENON100)
- 40 days acquisition, 25 kg fiducial mass
  - 1 single background event, before cuts and discrimination (ER Background ~390 µdru)



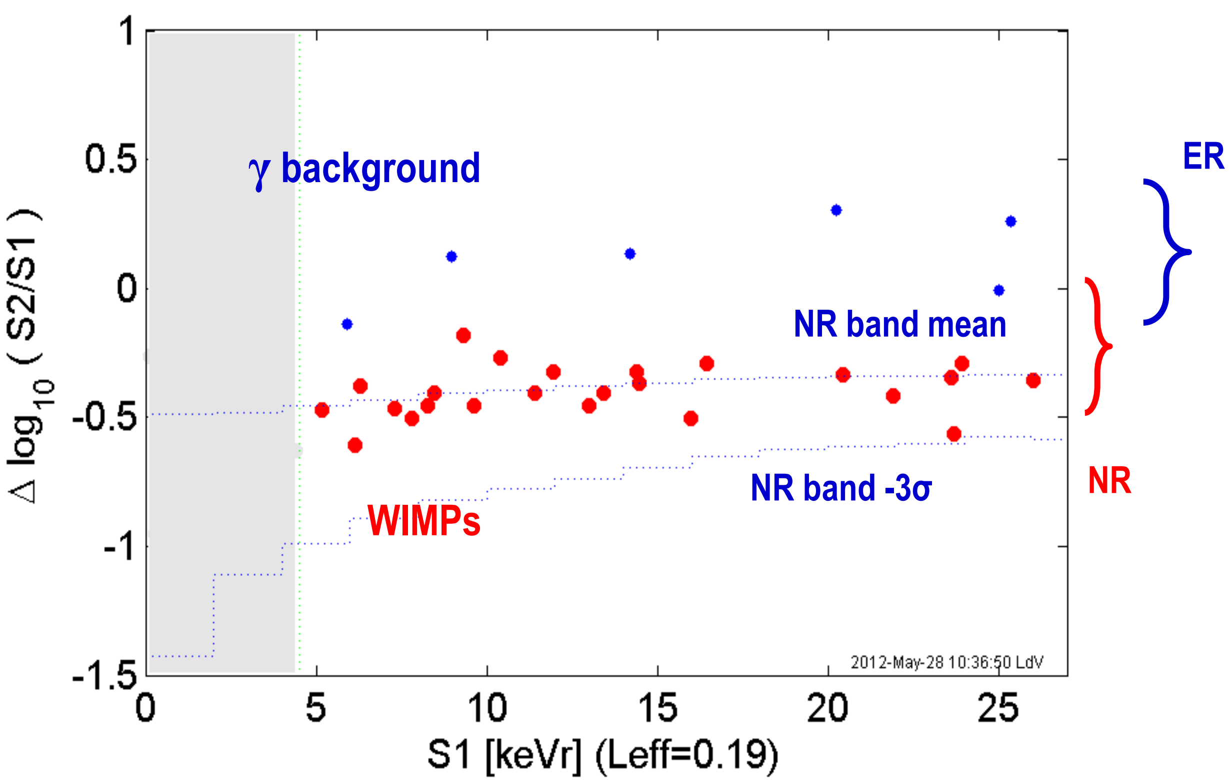
Simulated WIMP signal in LUX

- Example: m_{WIMP} = 100 GeV/c^2 and σ_{WIMP} = 1x10^{-44} cm^2 (sensitivity limit set by XENON100)
- 100 days acquisition, 25 kg fiducial mass
  - Still only a couple of background events; well defined WIMP signal



Simulated WIMP signal in LUX

- Example: m_{WIMP} = 100 GeV/c^2 and σ_{WIMP} = 1×10^{-44} cm^2 (sensitivity limit set by XENON100)
- 300 days acquisition, 25 kg fiducial mass
  - Longer exposure, signal becomes better defined
  - Still only a handful of background events, before cuts and discrimination



The LUX Collaboration

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Peter Sorensen	Staff Physicist
John Bower	Engineer

SD School of Mines

Xinhua Bai	PI, Professor

Collaboration was formed in 2007 and fully funded by DOE and NSF in 2008.

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Markus Horn	Postdoc
Blair Edwards	Postdoc
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Nicole Larsen	Graduate Student
Evan Pease	Graduate Student

Summary

- LUX is the largest double-phase Xe detector in operation
- Surface Run on-site (at Homestake mine) marked successful test of technologies proposed for tonne-scale detectors
  - >100 days cryogenic operation
  - Full deployment inside water shield
- All systems fully tested and characterized
  - Purification 300 kg/day
  - Excellent light collection (8 phe/keV) => low energy threshold
  - All PMTs working
  - DAQ, Trigger and Data Processing Software ready
- Underground deployment this summer, science data by end of 2012
  - Matches and surpasses all existing sensitivity limits within days of science run start (for WIMPs with mass above ~10 GeV)

The End

Thank You