SUSY, Trieste, 2013

Searching for Dark Matter: The LUX Experiment

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for the LUX Collaboration

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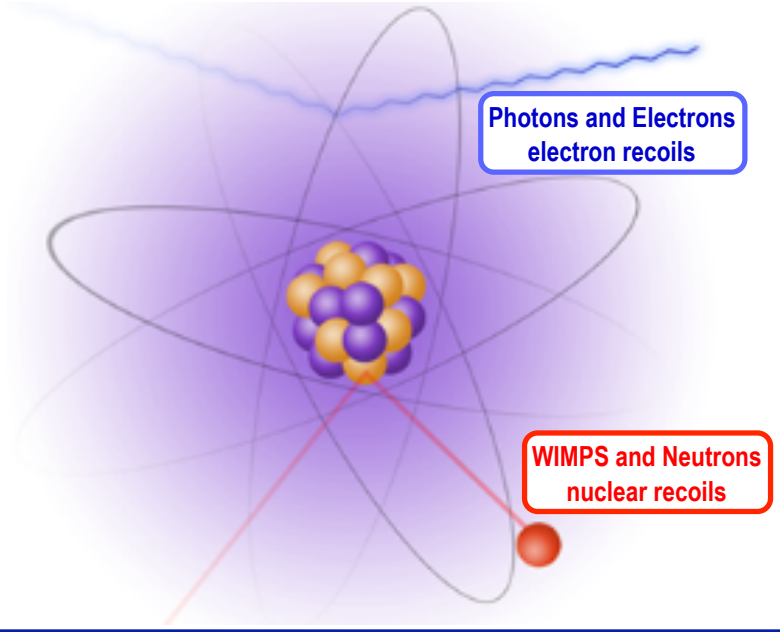
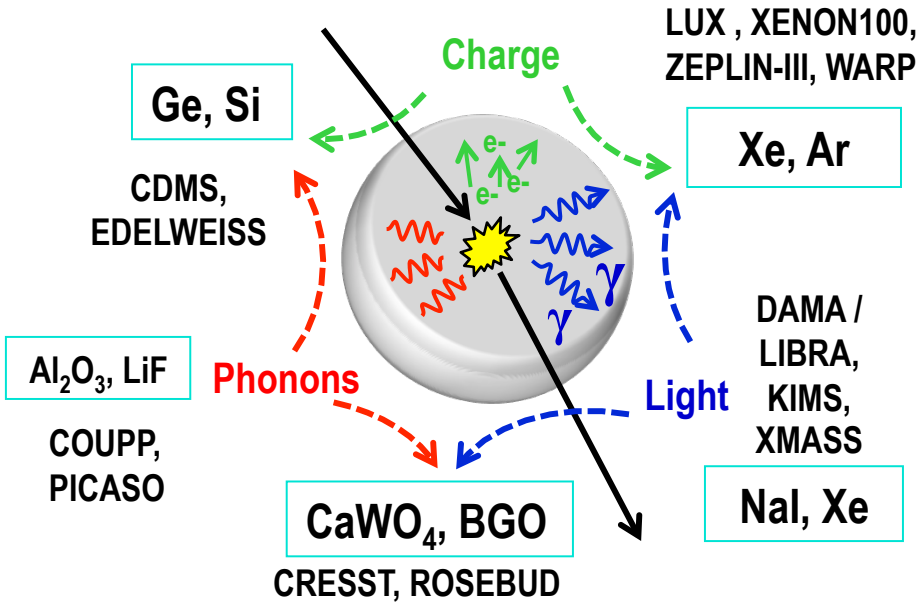
Dark Matter Direct Detection

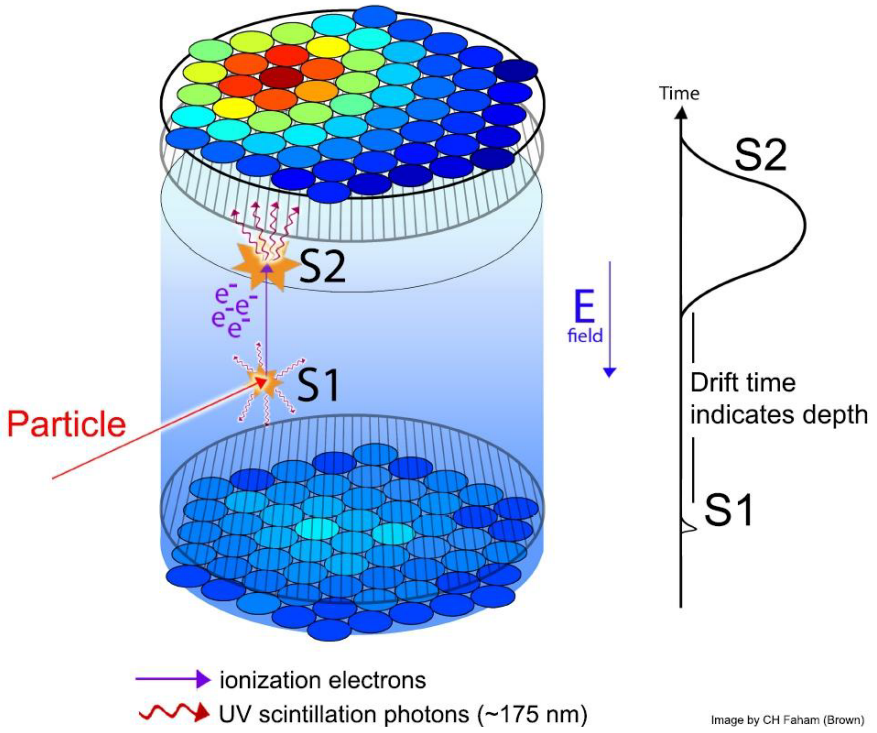
- **Leading Candidatre: WIMPs**
  - Stable (or long lived) particles, relics from the Big Bang, with M_{WIMP} in the range 10 GeV – 1 TeV
  - Supersymmetry independently predicts Weakly Interacting Massive Particles (*LSP*)
- **Direct Detection: WIMPs (like neutrons) scatter elastically off nuclei**
  - Photons and electrons scatter off atomic electrons
  - Nuclear Recoil energy ≈ few keV – tens of keV (require detectors with low threshold)
  - Nuclear Recoils detectable via light, charge, phonons, or a combination of them

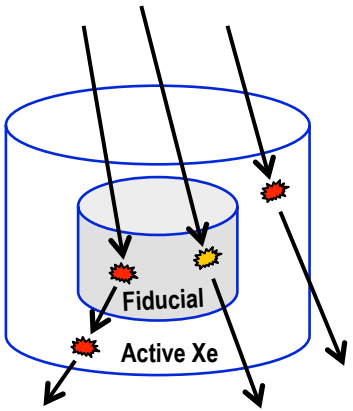


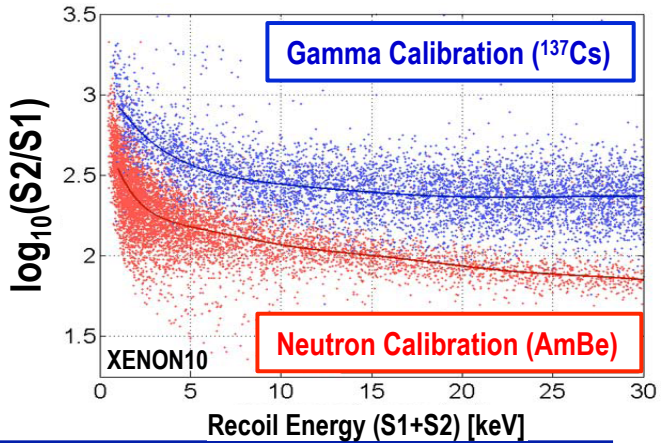


Dual Phase Xe Detector

- **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 Collaboration

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Collaboration Meeting, Sanford Lab, April 2013

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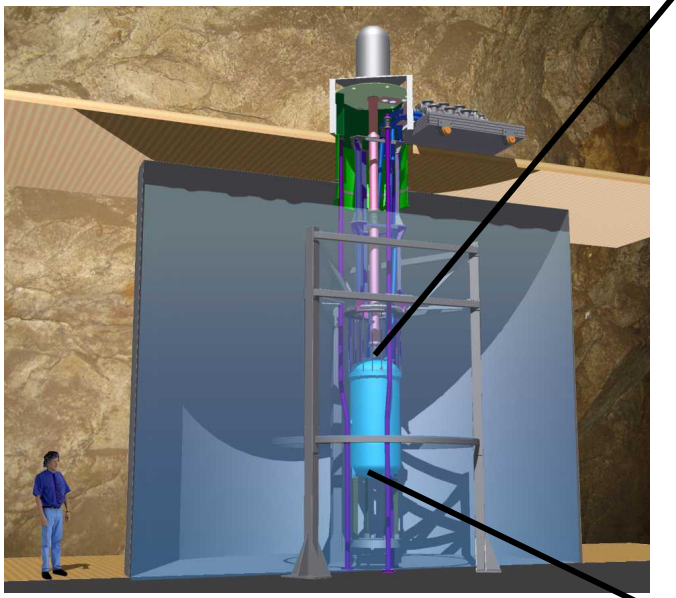
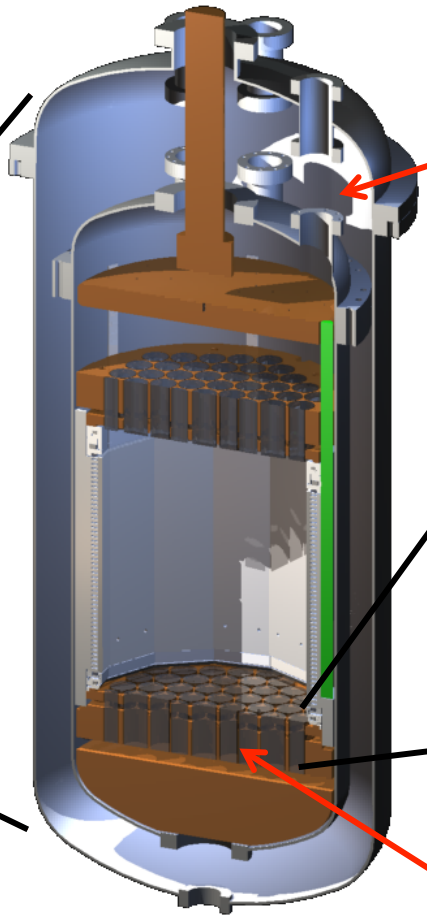
Ariana Hackenburg	Graduate Student
Elizabeth Boulton	Graduate Student

The LUX Detector

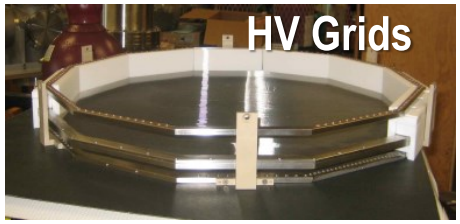
- Large Underground Xenon
- 350kg Liquid Xe Detector (59 cm height, 49 cm diameter)
- 122 PMTs (Hamamatsu R8778, ø = 5 cm)
  61 on top, 61 on bottom
- Low-background Ti Cryostat
- Water tank shielding

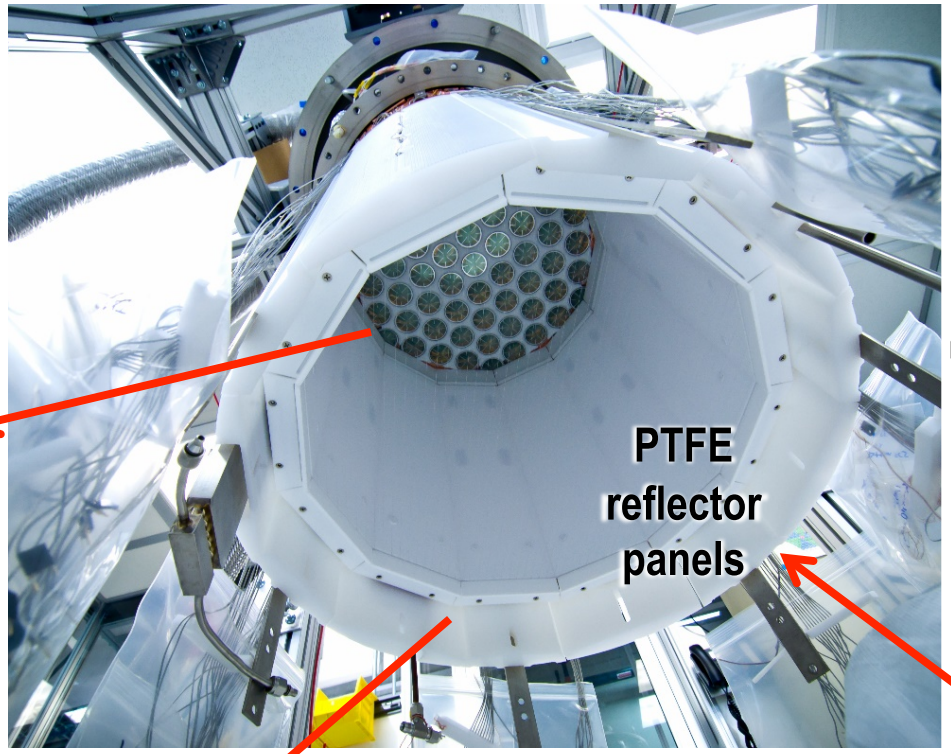
NIM. A 704,
111-126 (2013)
arXiv:1211.3788



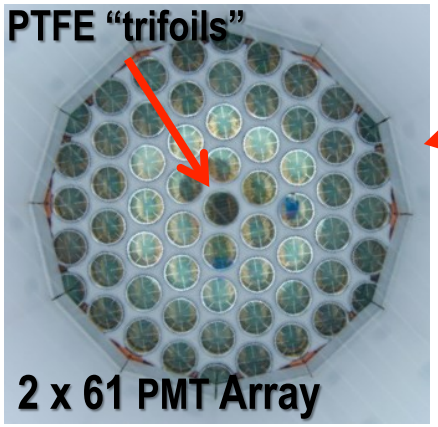


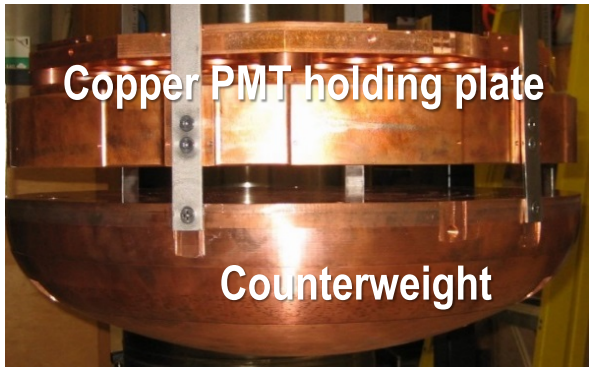
LUX Internals - Pictures

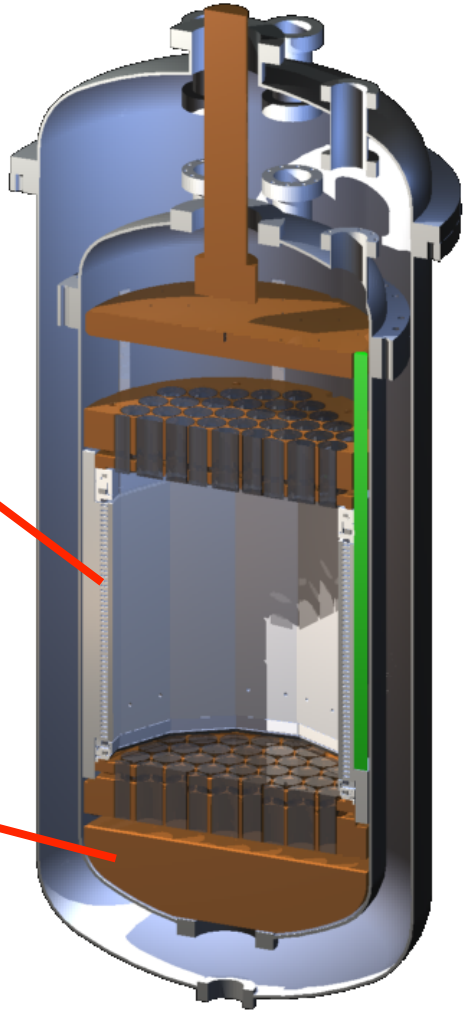




Active region defined by PTFE slabs (high reflectivity for Xe scintillation light)

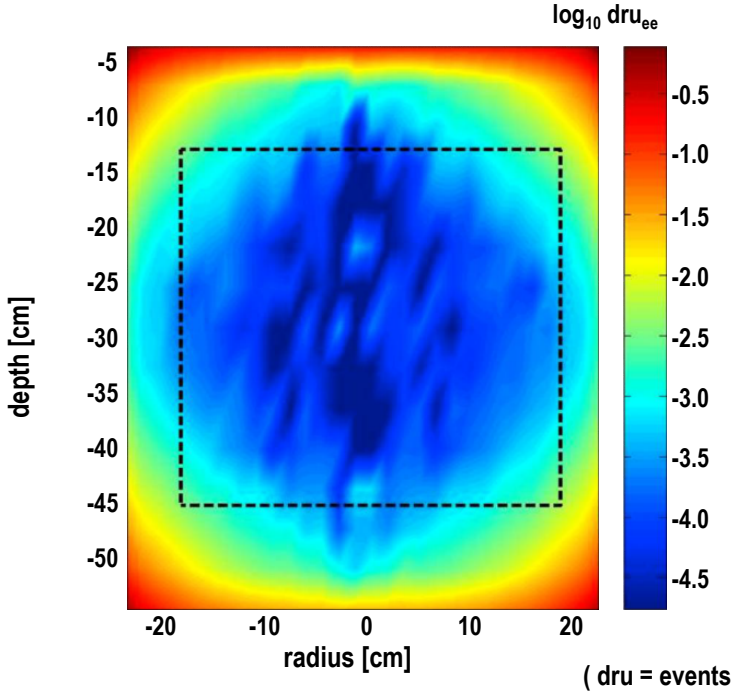






LUX Internals - Backgrounds

- All detector components are screened for radioactivity at the SOLO counting facilities and by LBNL
  - Internal backgrounds dominate over external (from cavern rock)
- 100 kg fiducial reduces background by 10^{-4}
  - γ: ~ 260 μdru (50 ER evts / 300 days)
  - n: ~ 500 ndru (<1 NR evt / 300 days)

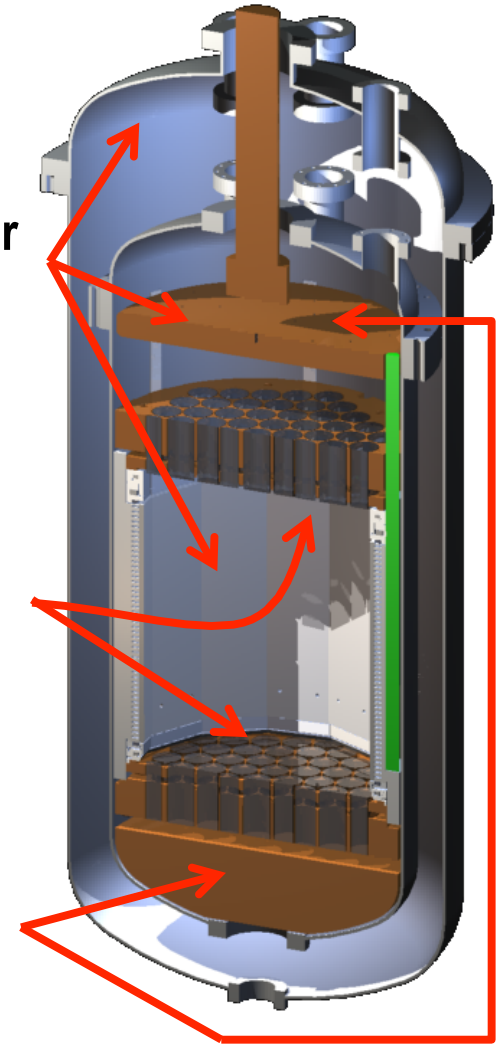


(dru = events / kg / keV / day)

Construction materials chosen for low radioactivity (Ti, Cu, PTFE)

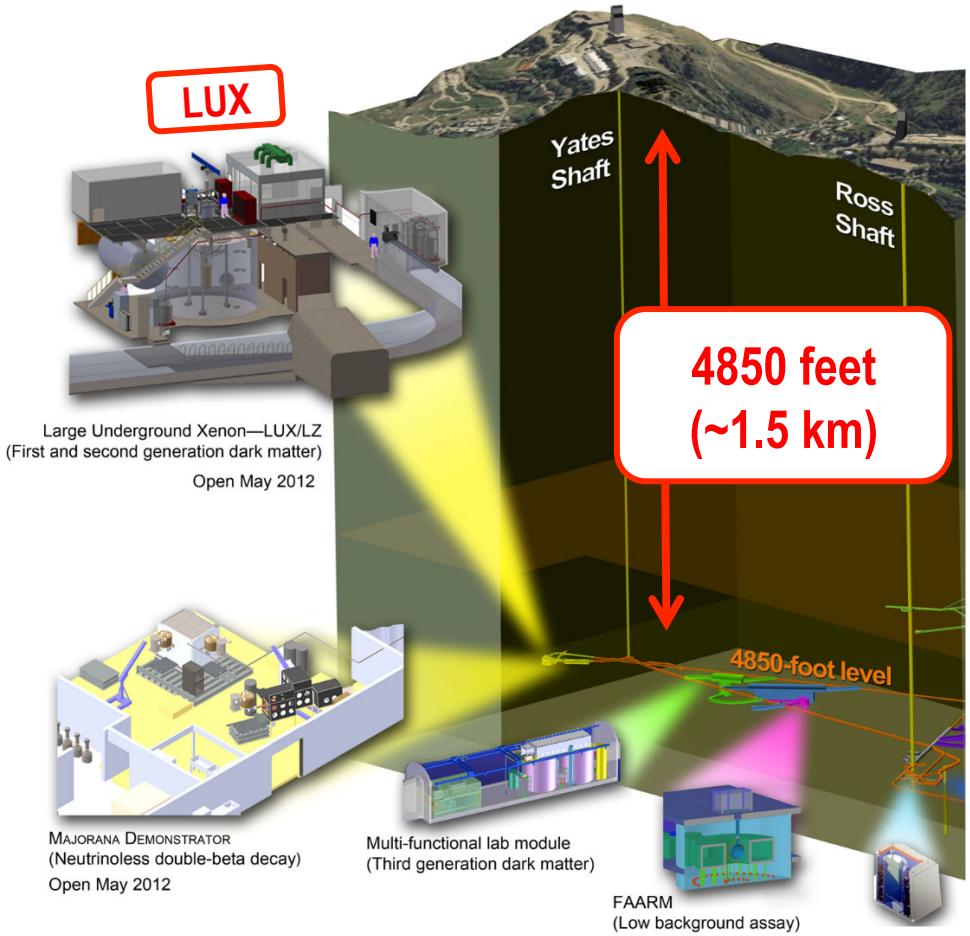
PMT radioactivity gives dominant background ~ 12 mBq/PMT

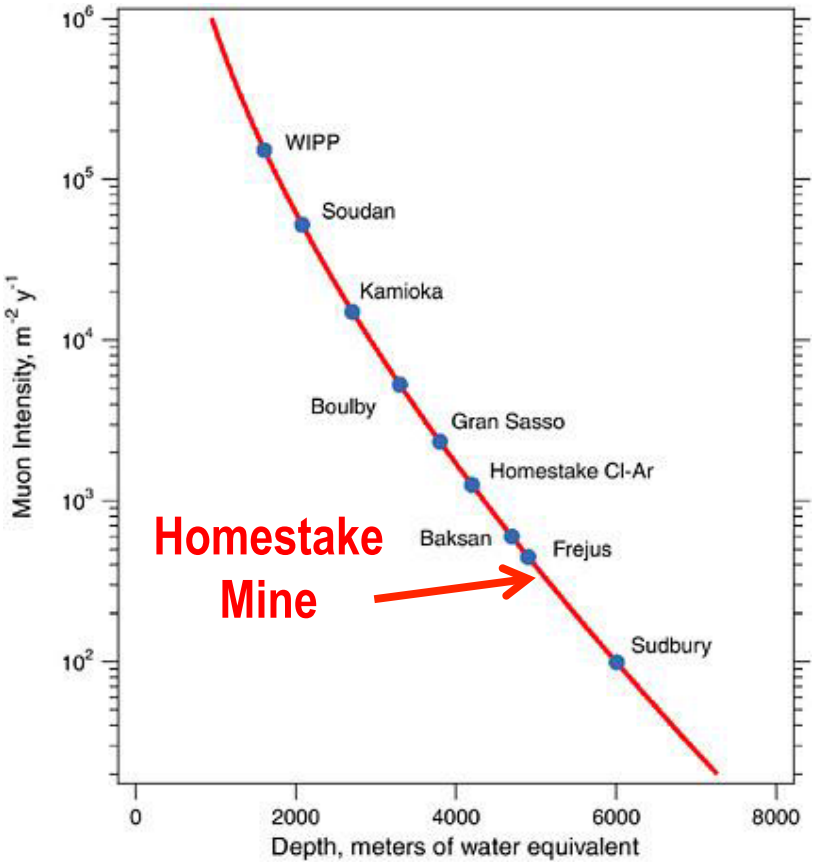
Majority of materials heavily shielded by Cu shields



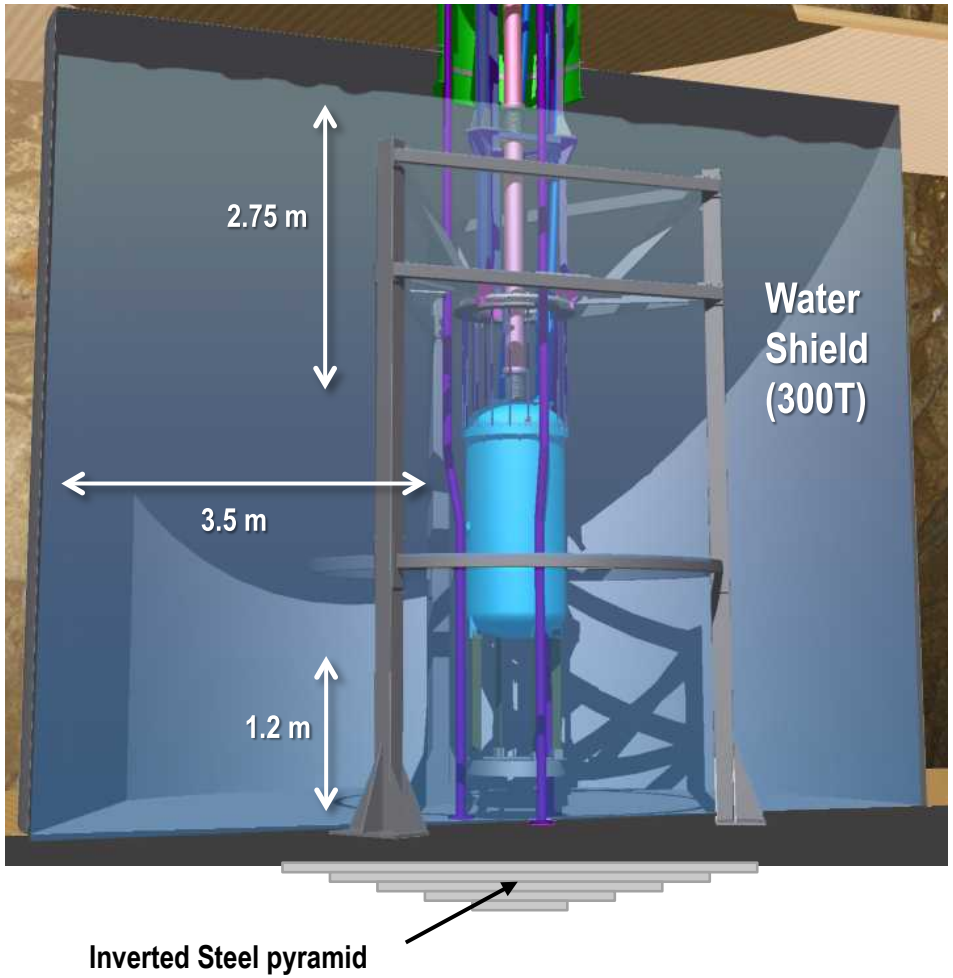
Sanford Lab at Homestake Mine

- Currently 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)

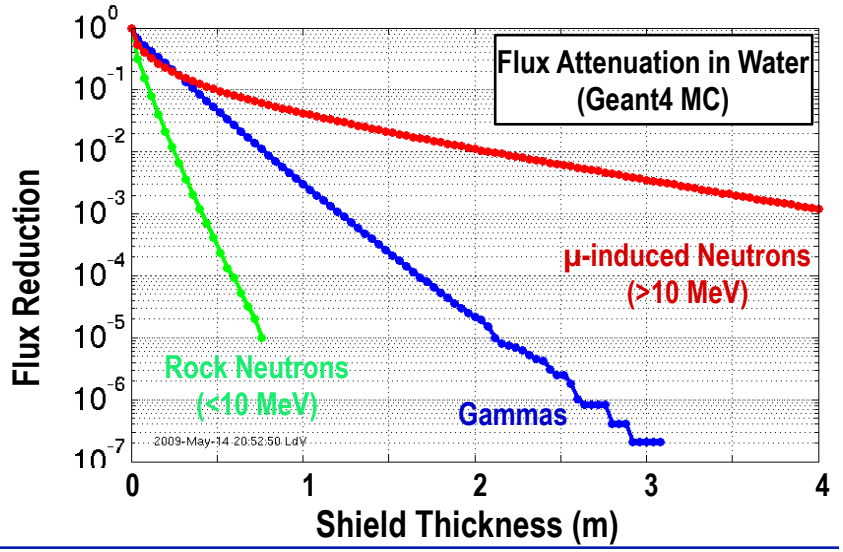




LUX Water Shield

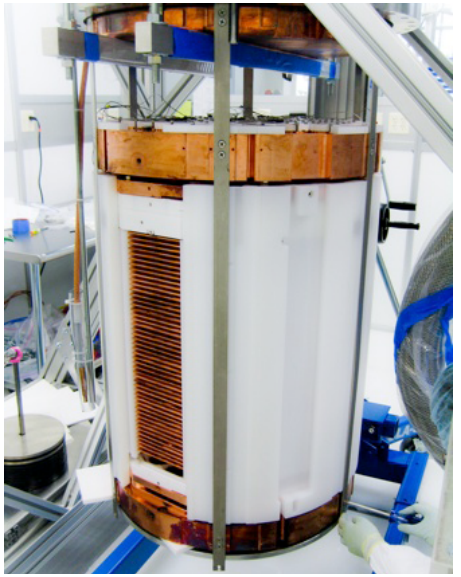


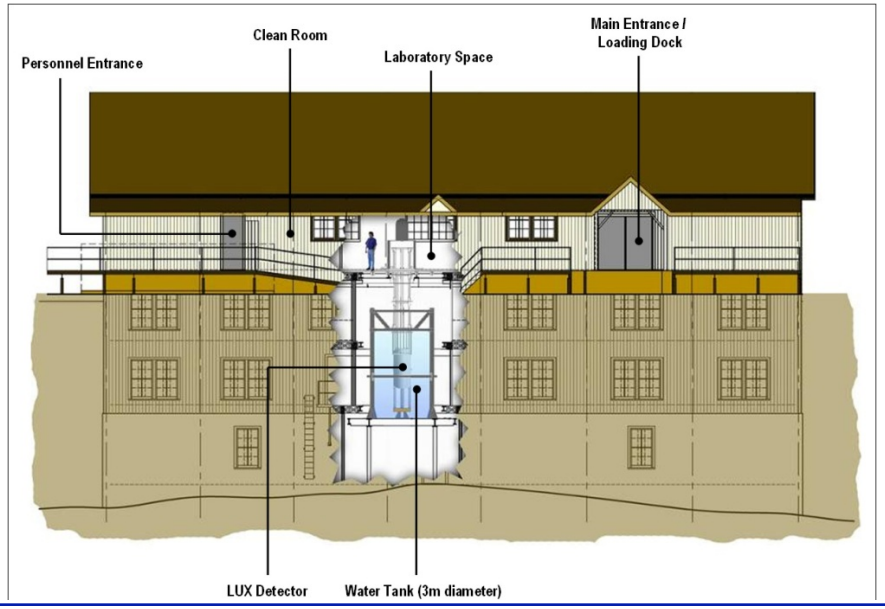
- Water Tank: ø = 8 m, h = 6 m (300 Tonnes)
  - 3.5 m shield thickness on the sides
  - Inverted steel pyramid (20 tons) under tank to increase shielding on top/bottom
  - Muon Veto: 20 PMTs (ø = 10")
- Ultra-low background facility
  - Gamma event rate reduction: 2×10^{-10}
  - High-energy neutrons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

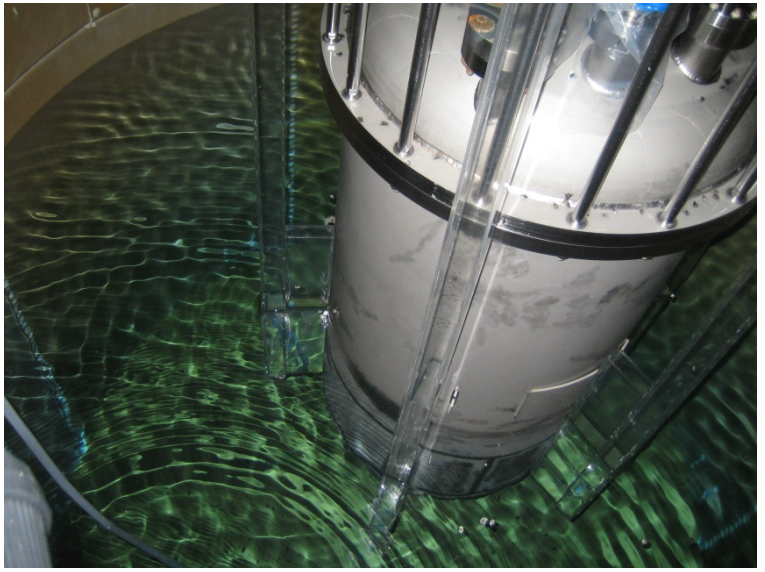


LUX Surface Run (at Homestake)

- Detector Construction and Deployment finished on Sept 2011
- Stable cryogenic operation for > 100 days (Nov 2011 – Feb 2012)
  - Results: arXiv:1210.4569
- First demonstration of technologies proposed for tonne-scale detectors:
  - Biggest double phase Xe detector in operation: 370 kg, 122 PMTs
  - Thermosyphon cooling allows continuous purification of 300 kg/day
  - Full scale deployment in water tank
  - Low background Titanium vessel

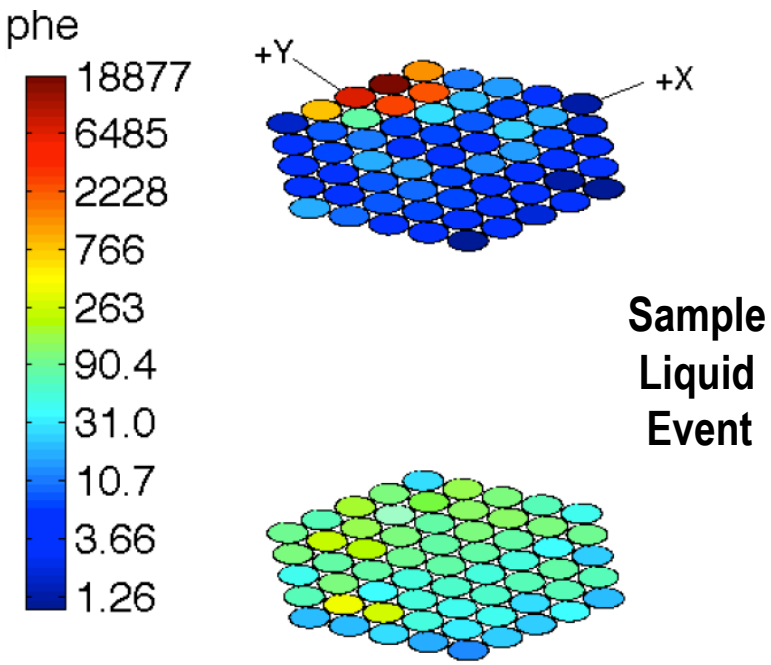




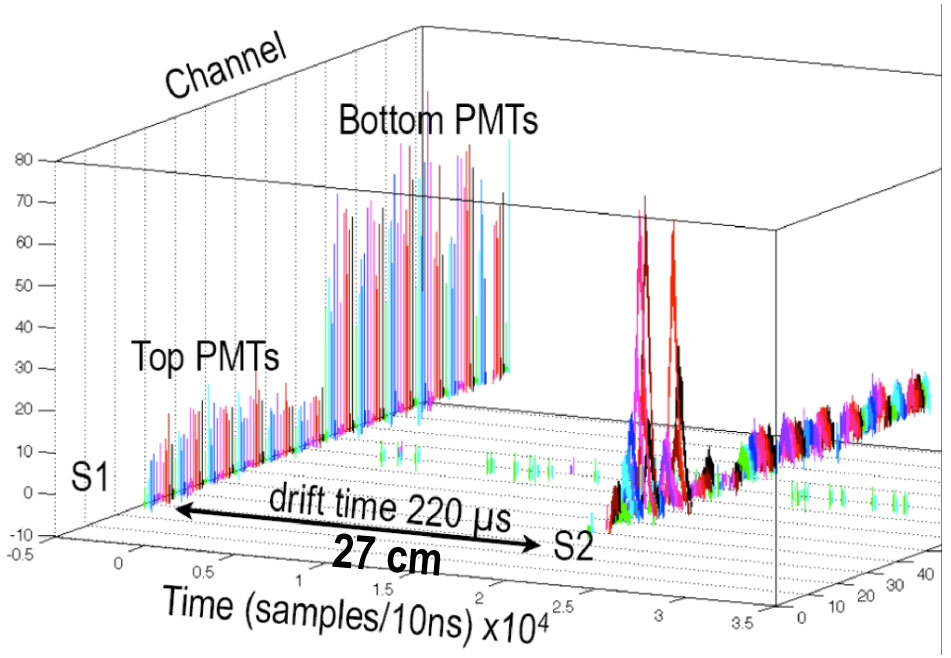


Surface Run – Signals

- **Functional trigger, DAQ, analysis chain:**
  - **Backgrounds and gamma source calibrations**
  - **3 TB of data generated and processed**
  - **122/122 PMTs are working (1 faulty base)**

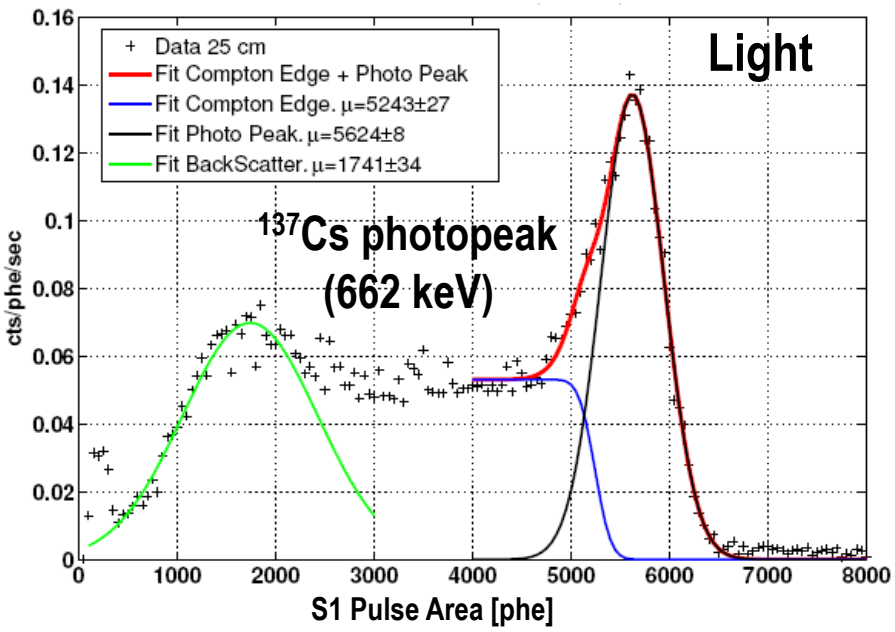


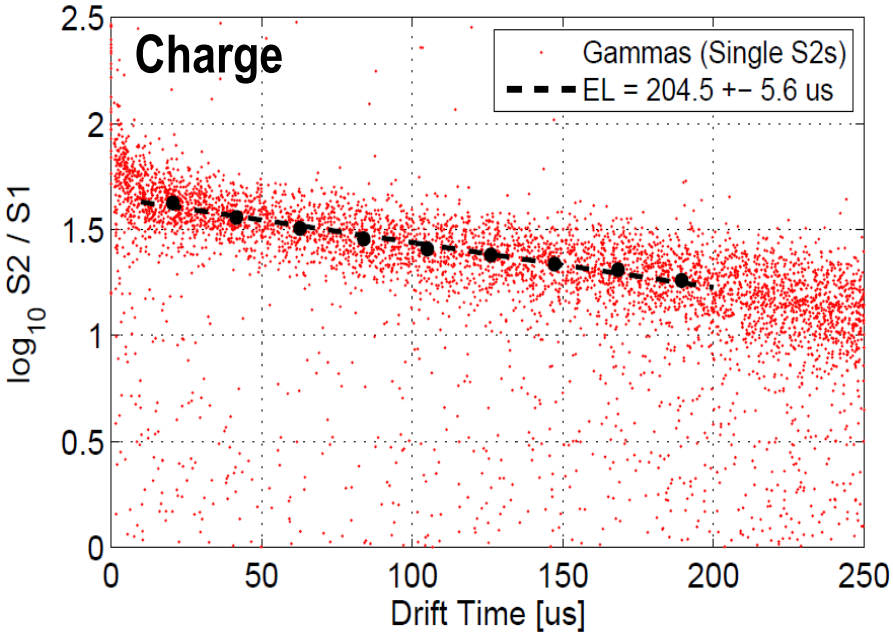
Sample Liquid Event



Surface Run – Light (S1) and Charge (S2)

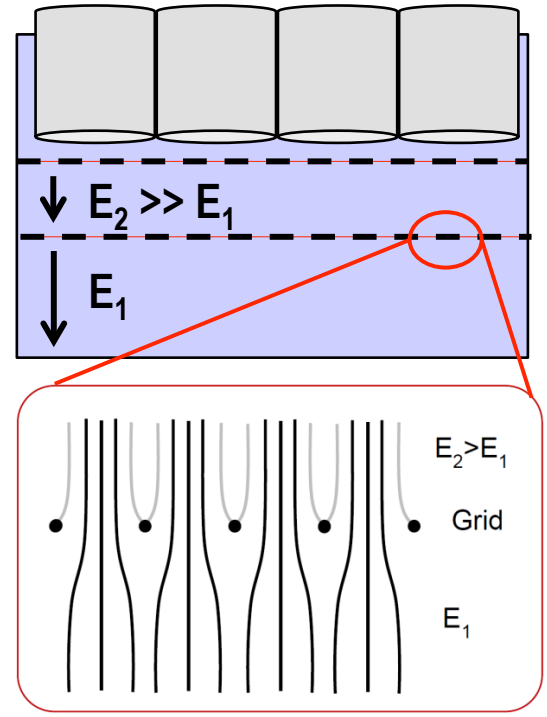
- Light collection efficiency: ~ 8 phe/keV$_{ee}$ in detector center (with Cs137, zero electric field)
  - ~6 phe/keV$_{ee}$ after scaling to 122 keV @ 500 V/cm
  - E resolution: ~ 6% at 662 keV (Cs137), ~ 3% at 5.5 MeV (α's)
  - At low PMT gain! Expected to improve when switching from 5e5 to 4e6
- Charge collection efficiency driven by Xe purity = Electron lifetime = 204 ± 6 μ → 25 cm
  - Monitored by muon, alpha and gammas signals.
    - Muon tagging system using plastic scintillators
    - Alphas from ^{222}Rn injection
  - Broken internal pipe limited circulation through active region and purification performance
    - ≥ 1 m electron drift length for UG Sience Run

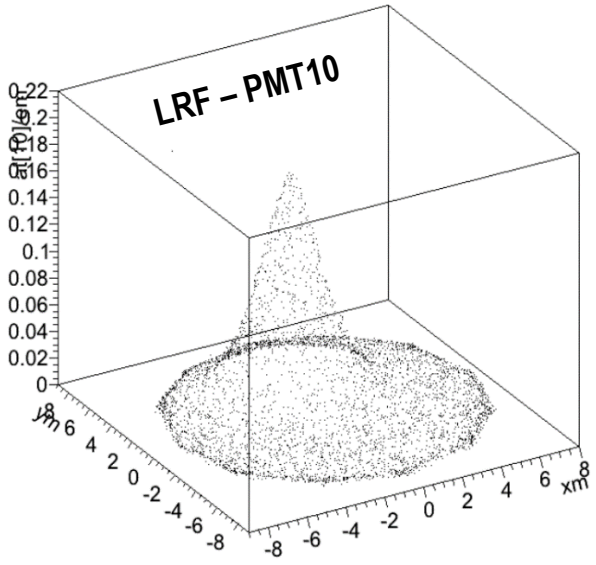


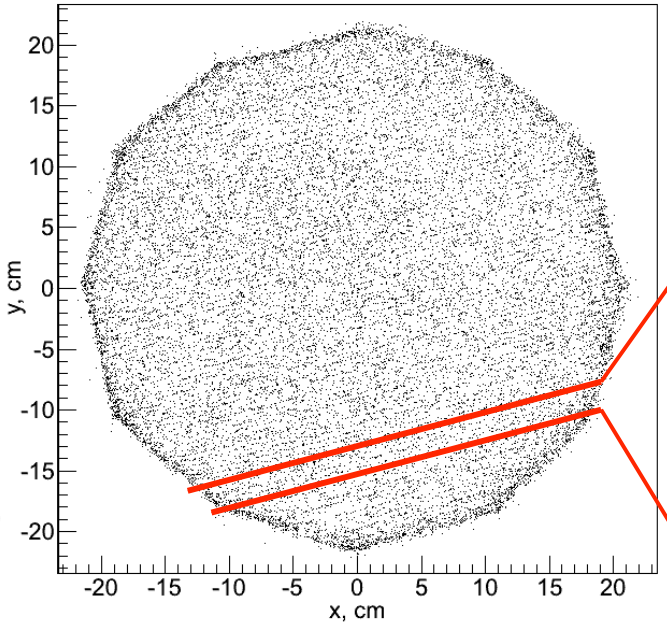


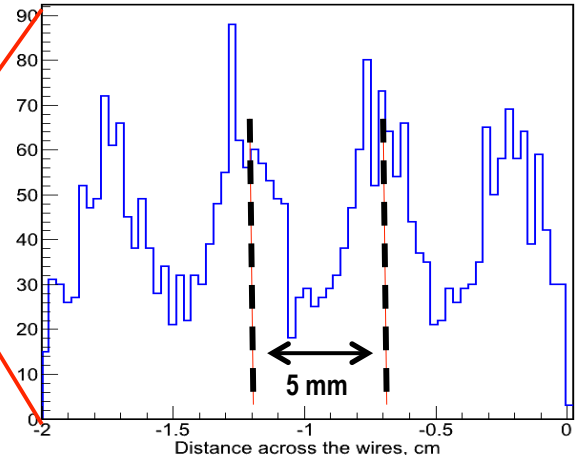
Surface Run – Event Reconstruction

- Position and Amplitude 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
  - Calibrated using real detector data, rather than simulations
- Reconstruction of XY from α interactions (E = 5.5 MeV) near anode grid resolves grid wires with 5 mm pitch





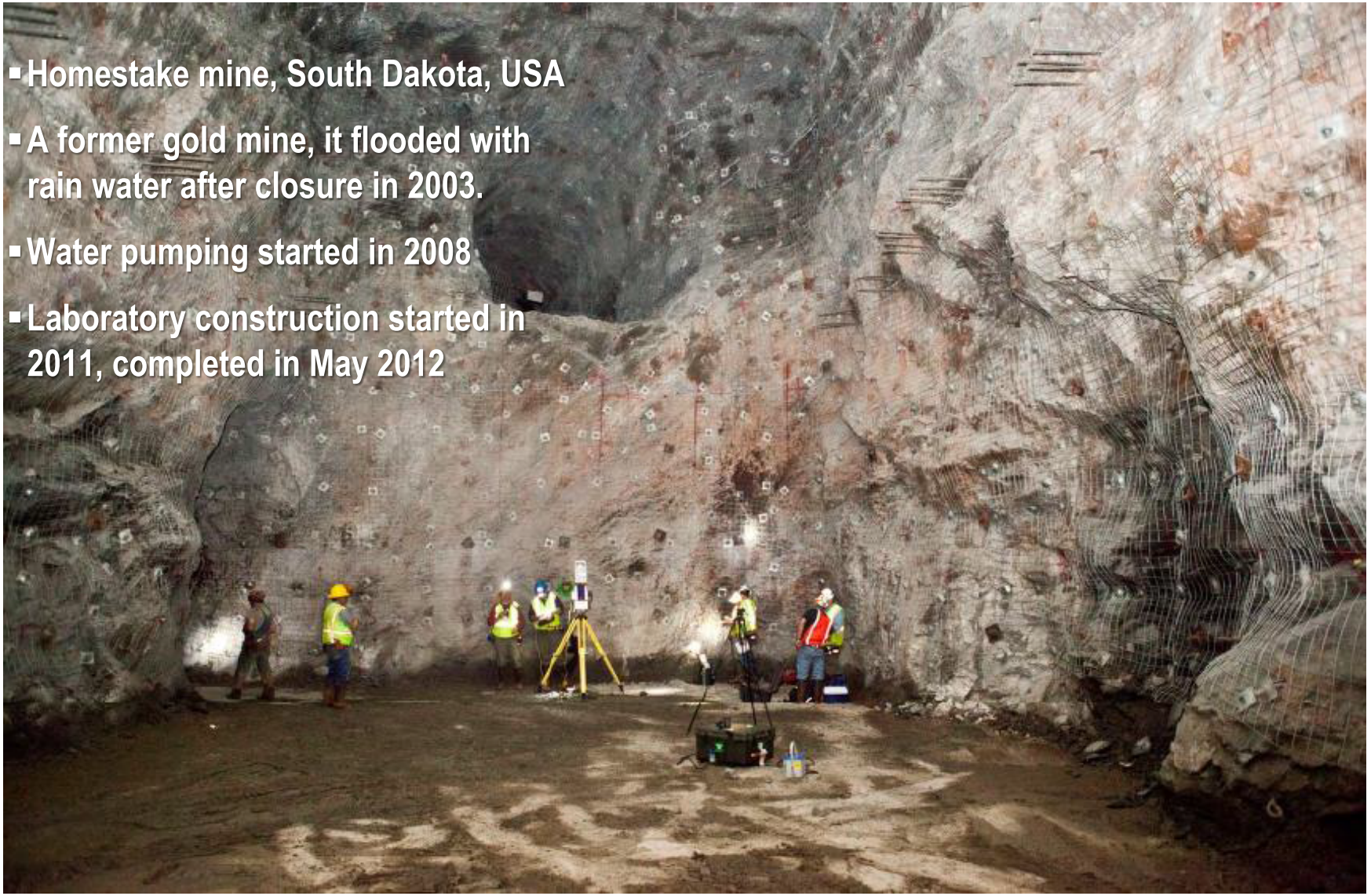




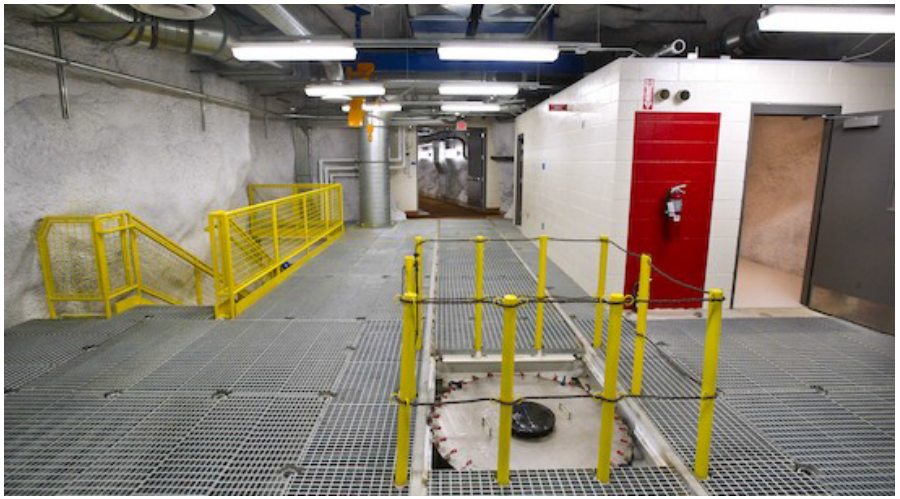
Moving Underground

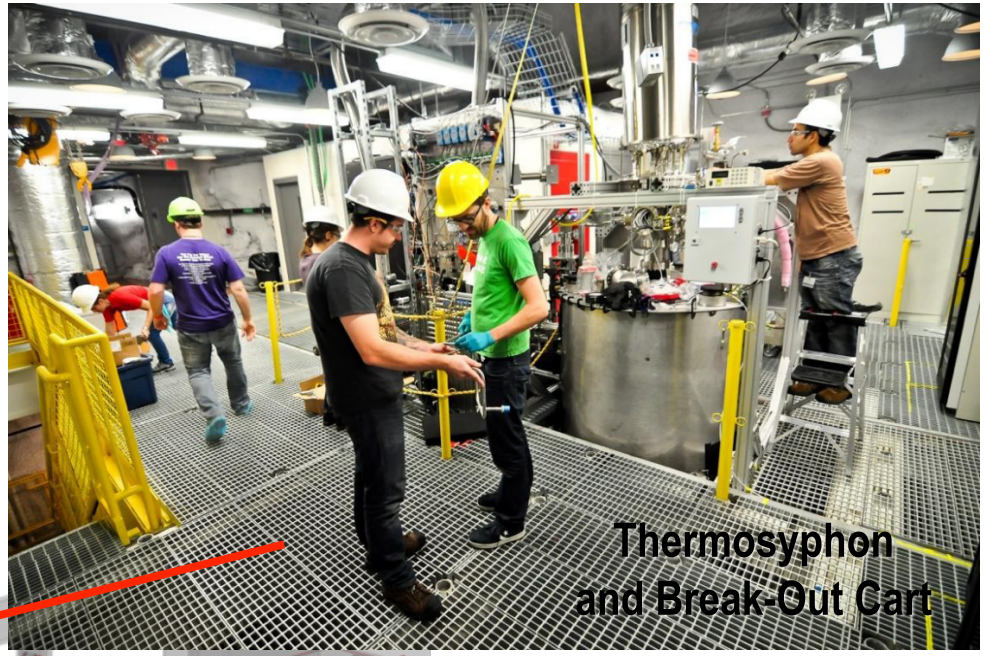
- Detector successfully moved underground on July 11-12, 2012
  - No problems related to move (all components still functional) => no need to open detector underground

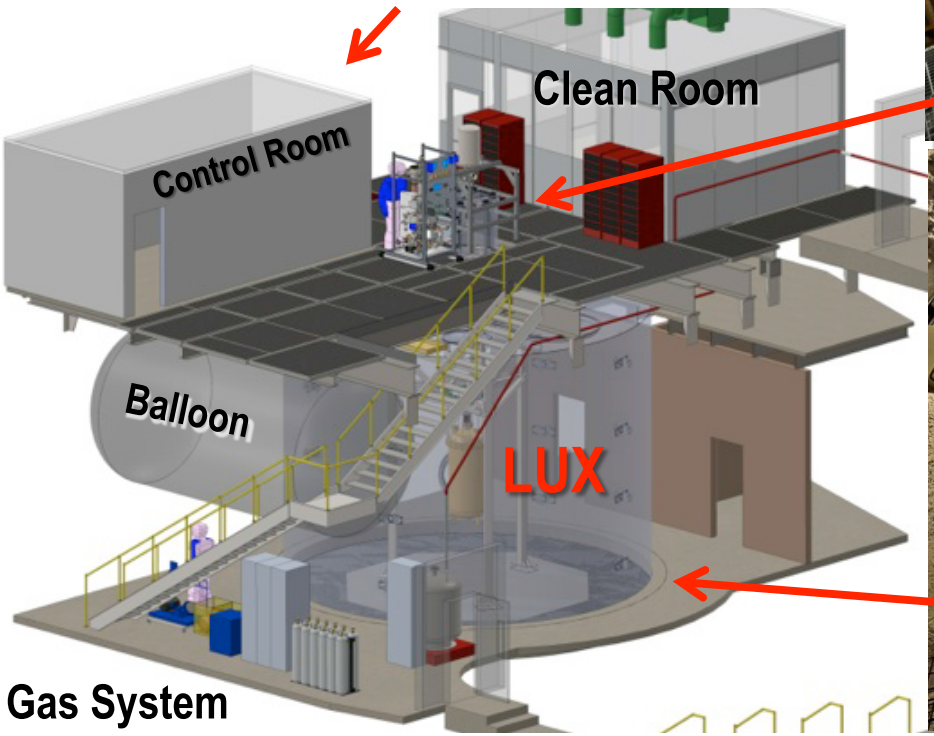
Building an Underground ~~Lair~~ Lab

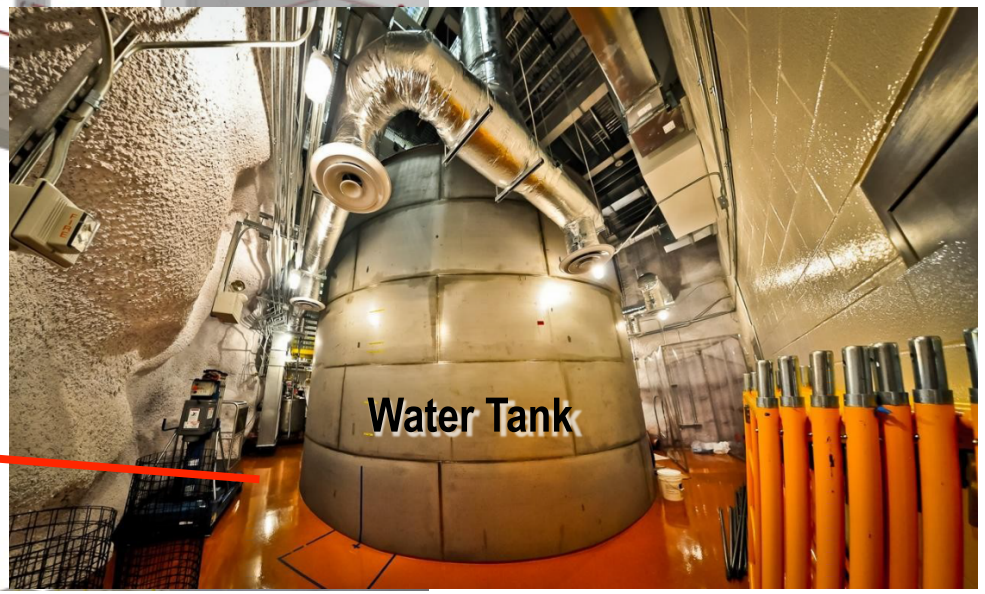


Underground Deployment

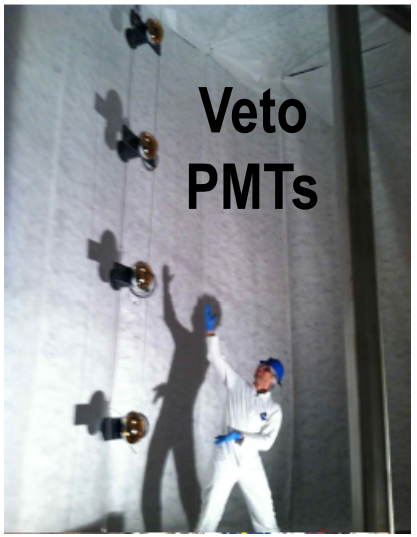






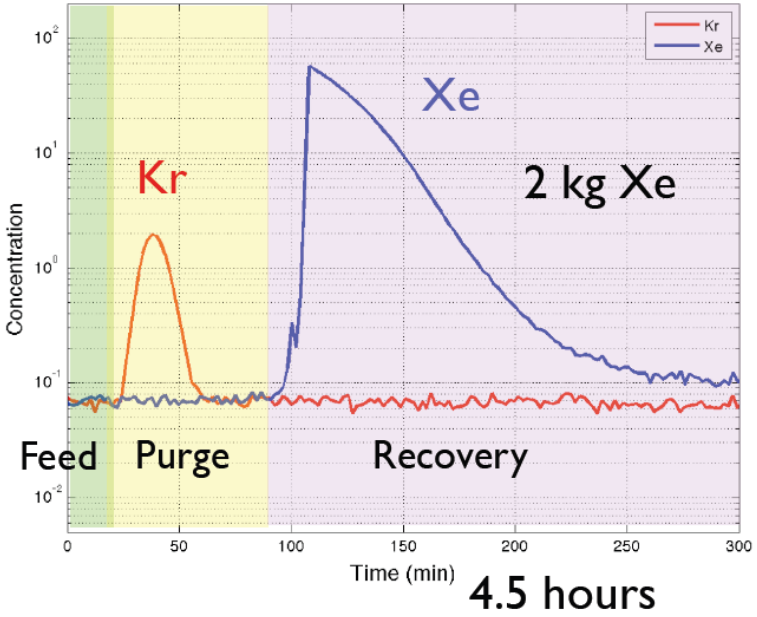


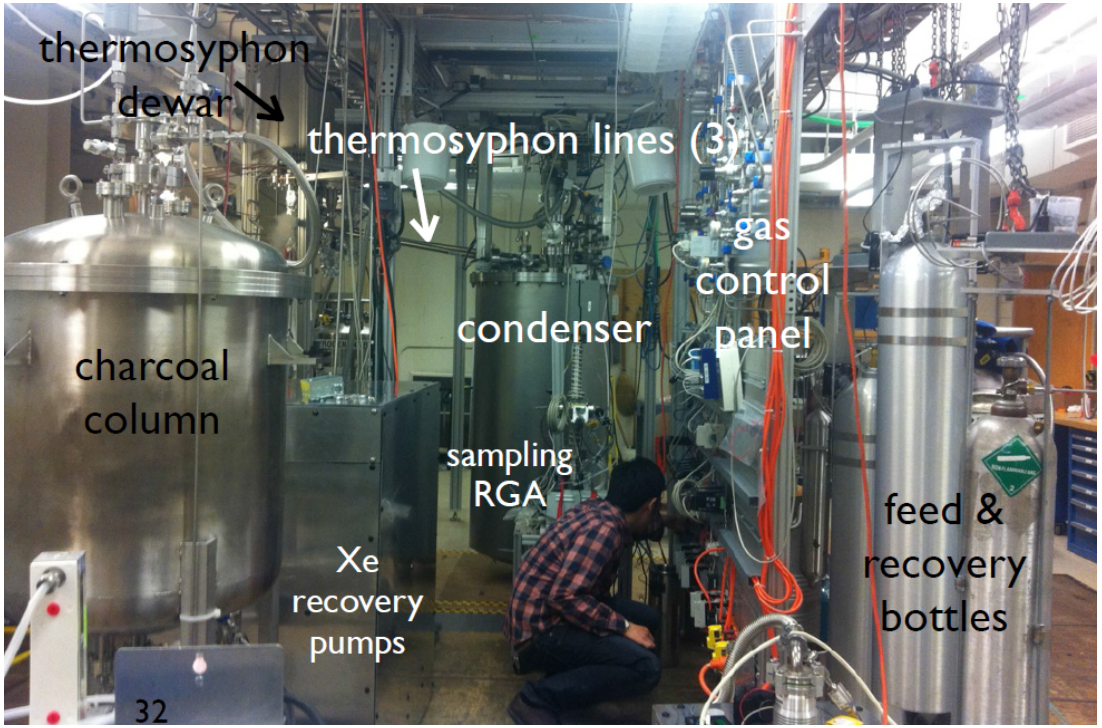
LUX in the Water Tank



Krypton Removal System

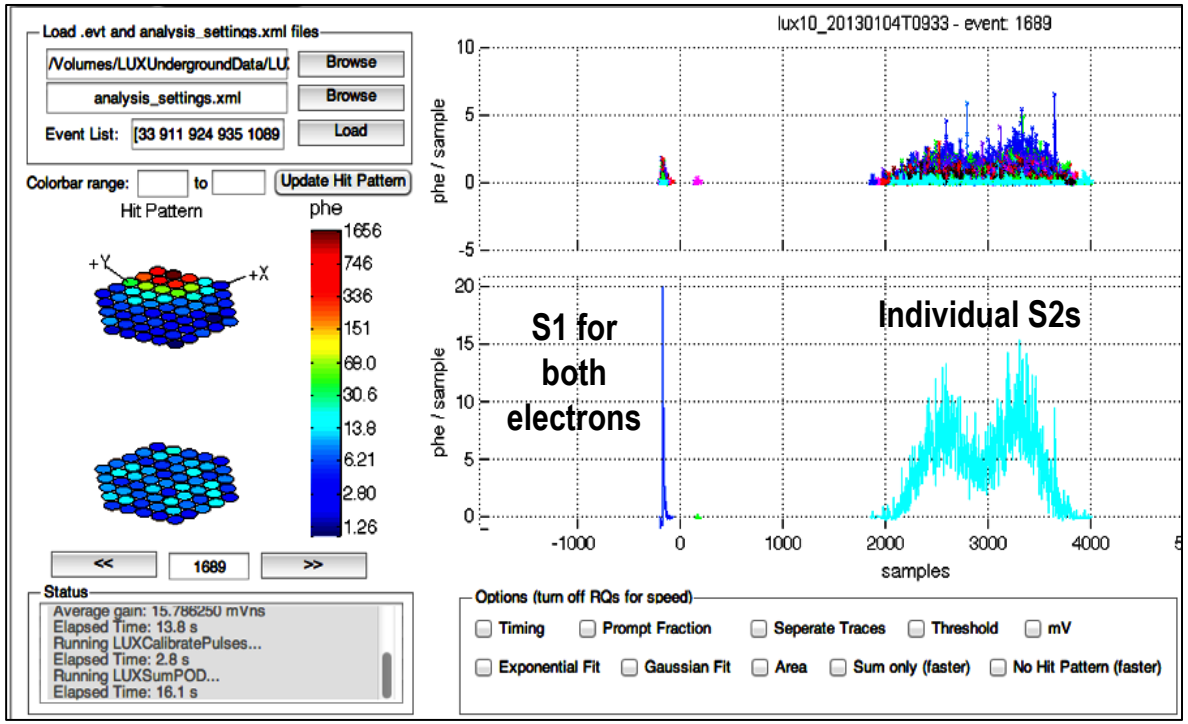
- ^{85}Kr - beta decay – intrinsic background in liquid Xe
  - Research grade Xenon: ~100 ppb Kr => 10^4 - 10^5 reduction needed
- August 2012 - January 2013: Kr removal at Case Western Reserve University
  - Chromatographic separation system
- Kr concentration reduced from 130 ppb to 4 ppt, (factor of 30000)
  - 1 ppt is achievable (useful for next-generation detectors)

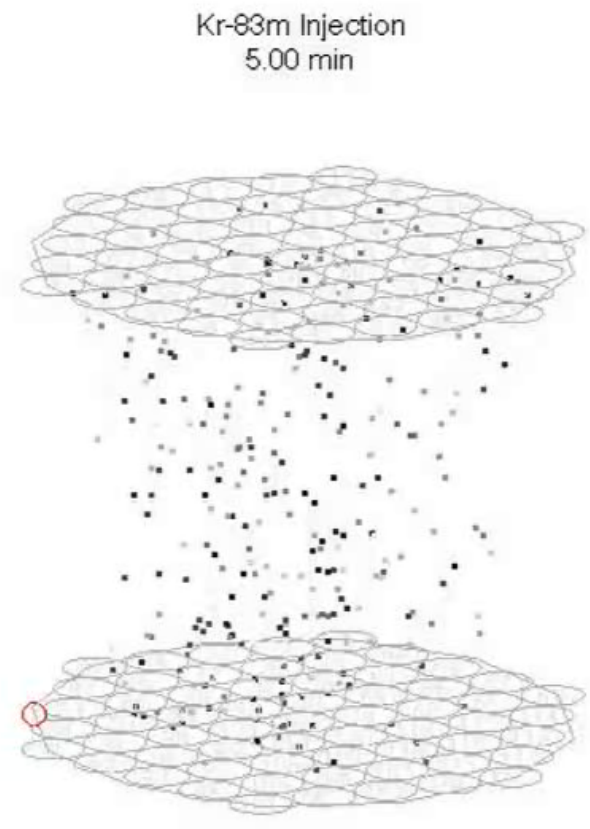




First Underground Data (Xe Gas)

- ^{83m}Kr Calibration in Xe Gas – Jan 2013
  - Injection into Xe gas circulation path
  - 2 internal conversion electrons at 32.1 and 9.4 keV, $\tau_{separation}$ = 154 ns
  - 1.8 hour half-life



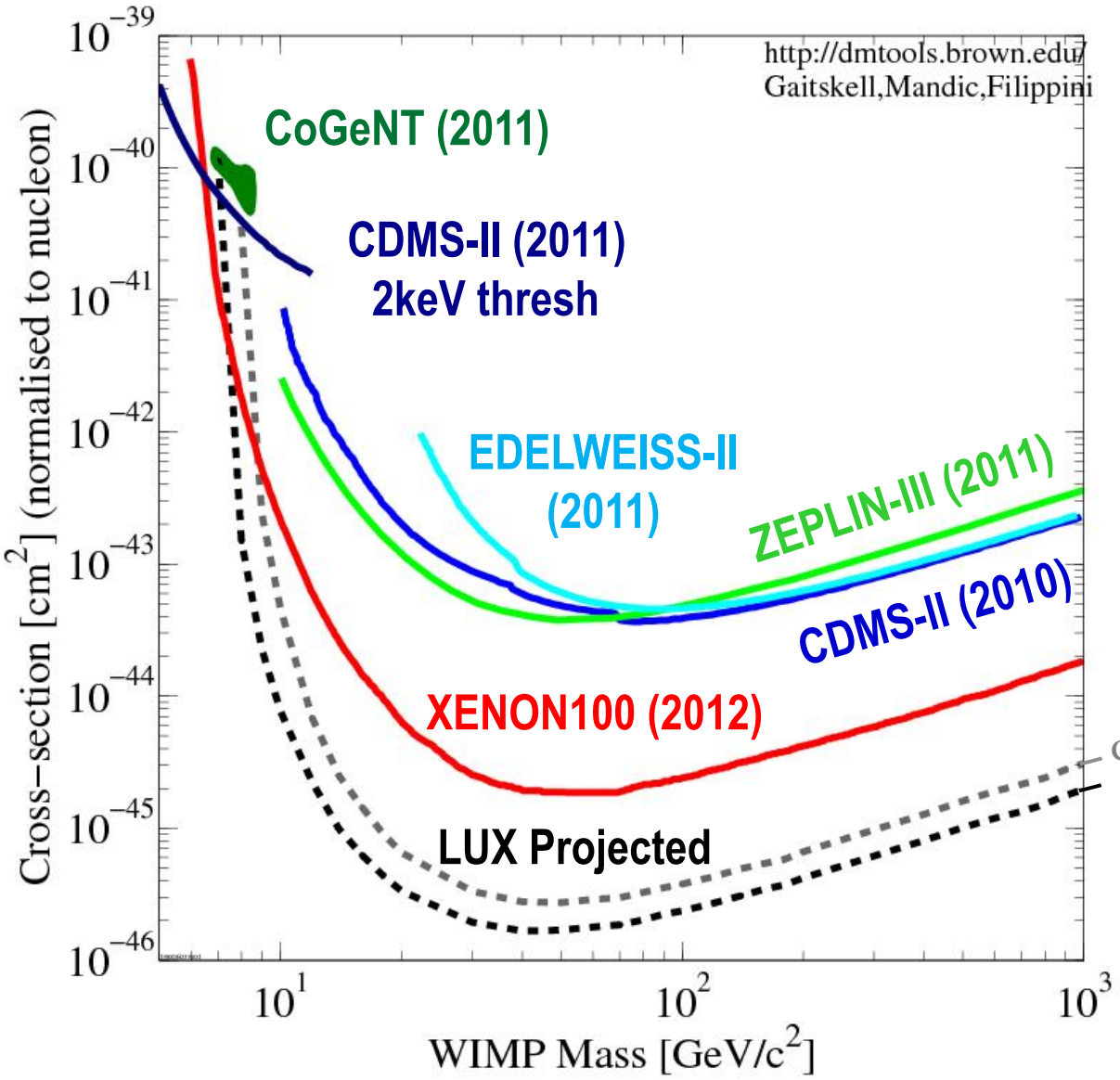


Full XYZ Reconstruction

Science Run

- January 2013: Detector Cooldown
- February 2013: Xe fill and condensation (350 kg in 3 days)
- March 2013: Xe purification started
- Currently:
  - Data Taking, ER and NR Calibrations, Analysis ongoing
  - Electron drift of > 100 cm achieved
    - Compare to detector active region height of 50 cm
- Goal for 2013: Intermediary Result by end of the year
  - ~ 60 live-days of WIMP Search
  - Improve current best limit by 2x or 3x (depending on the background)
- Science goal: 300 live days
  - Plus a few weeks of calibration data
  - Result to be released in 2015

Sensitivity Limits



Exclusion curves for WIMP-nucleon cross-sections

Spin-independent coupling

LUX
30,000 kg-days

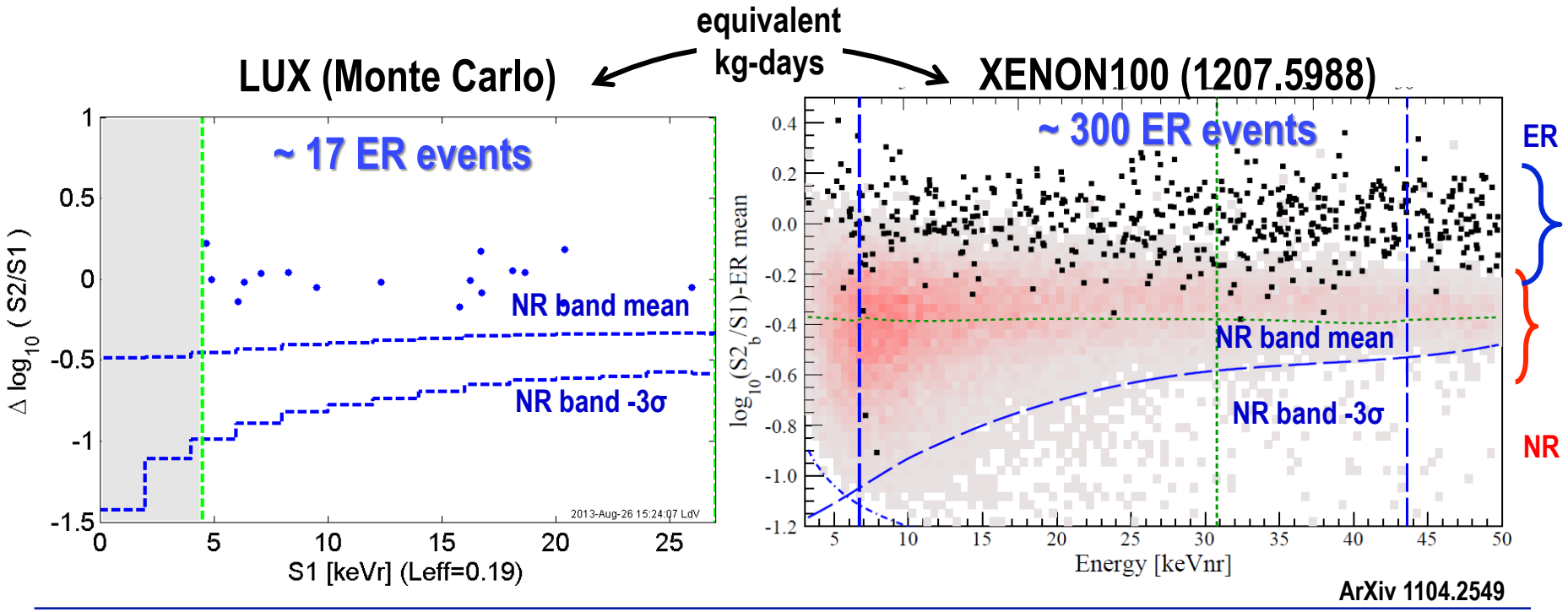
Conservative 15% effective light collection

Optimistic 20% effective light collection

2 x 10^{-46} cm^2 for a WIMP mass of 40 GeV/c^2

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)
  - 34 kg x 225 day XENON100 exposure => 100 kg fiducial x 76 days in LUX



LUX WIMP Sensitivity

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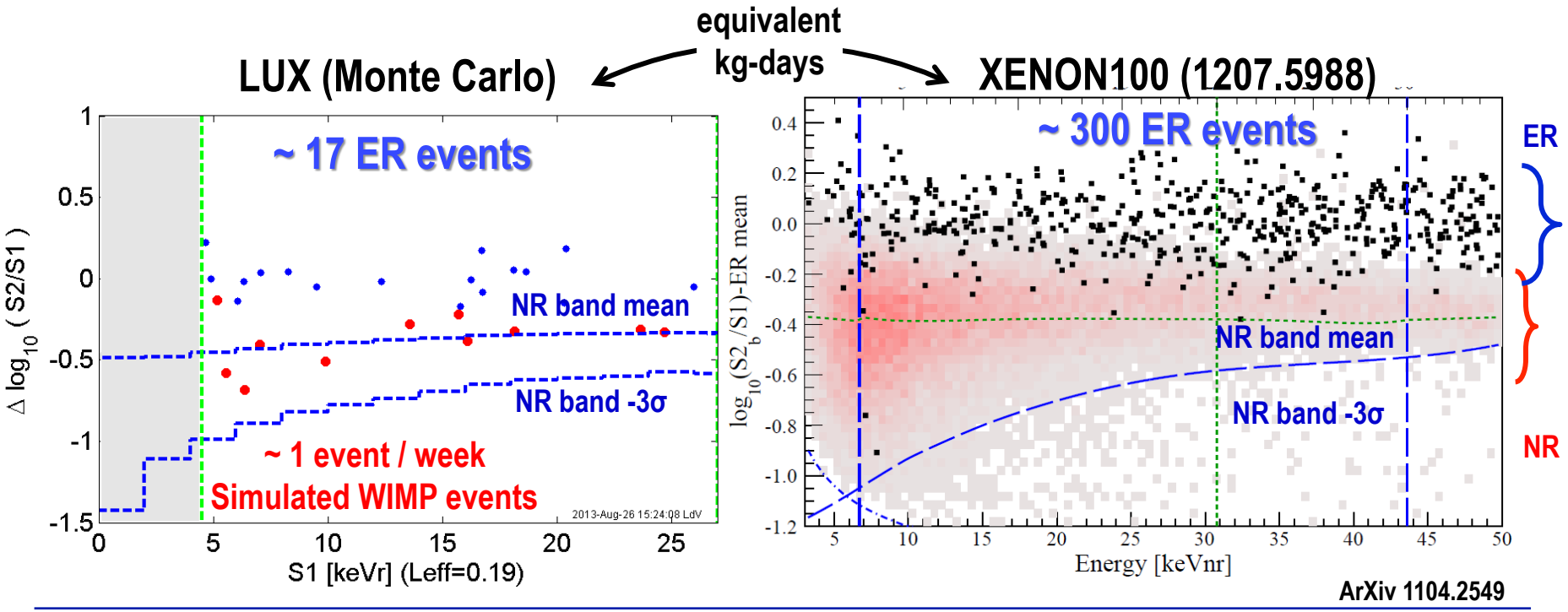
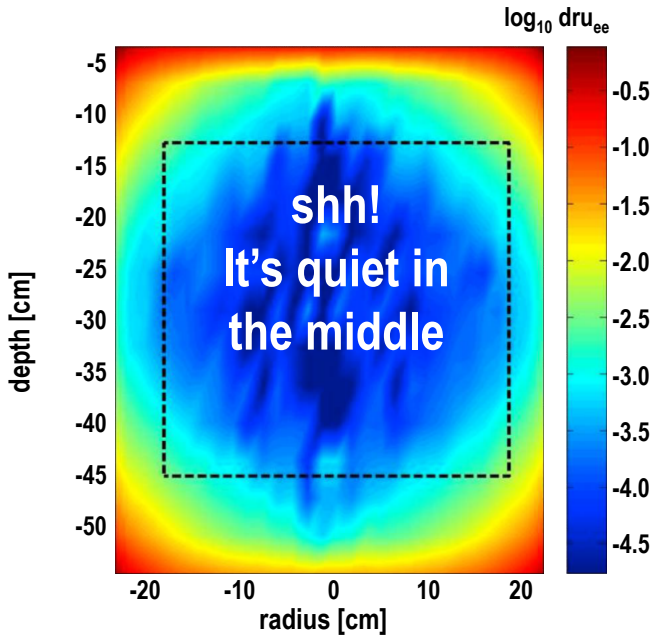
- Contrast LUX with current best limit (XENON100)
  - 34 kg x 225 day XENON100 exposure => 100 kg fiducial x 76 days in LUX
- What will WIMPs look like in LUX?
  - Best 90% CL Exclusion Limit: $\sigma_{WIMP} = 3 \times 10^{-45}$ cm^2 at 100 GeV (XENON100, 1207.5988)

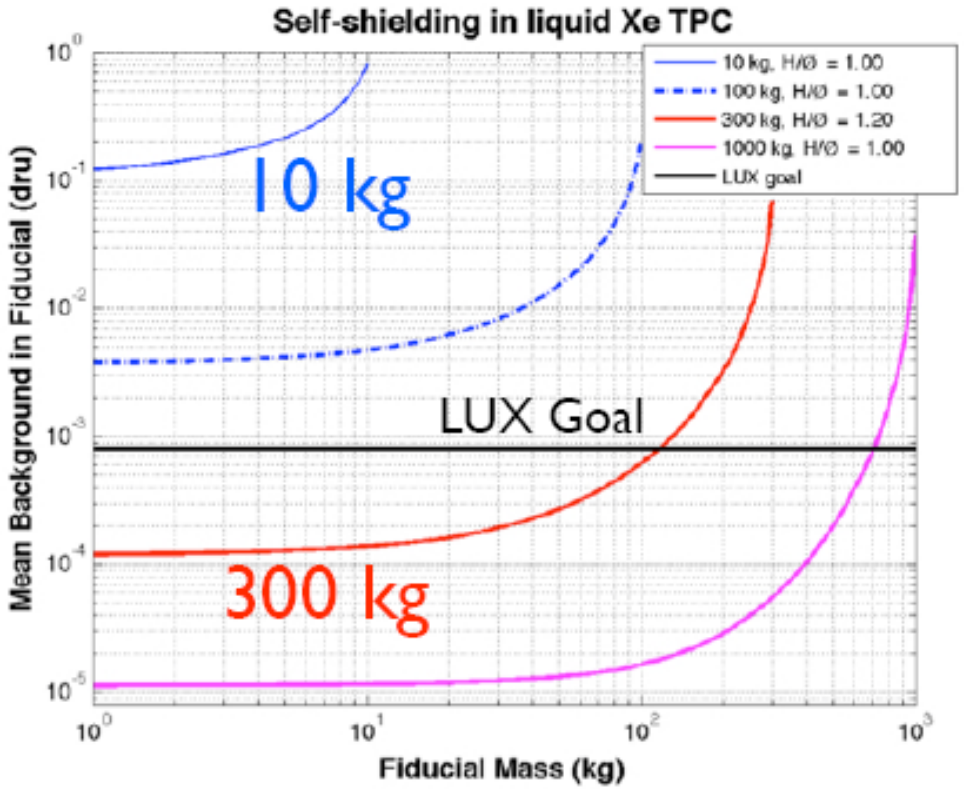


ArXiv 1104.2549

LUX Backgrounds – Self-shielding

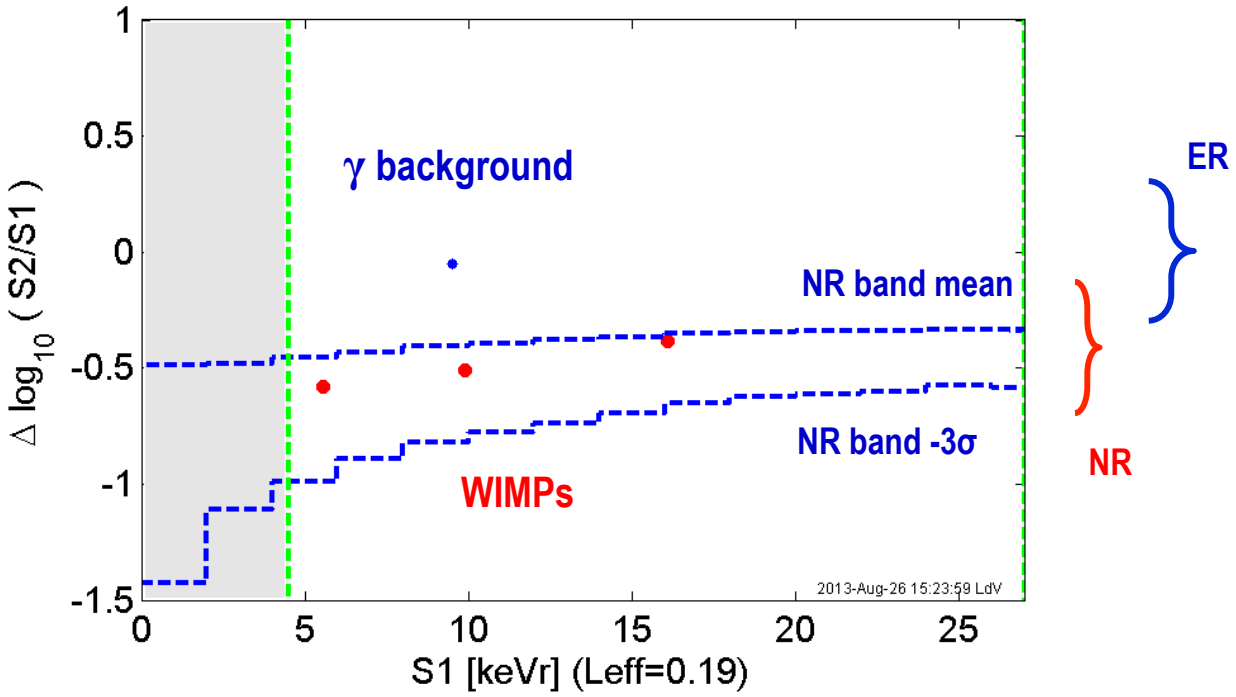
- At LUX's scale, self-shielding allows nearly background-free acquisition by using a reduced fiducial volume:





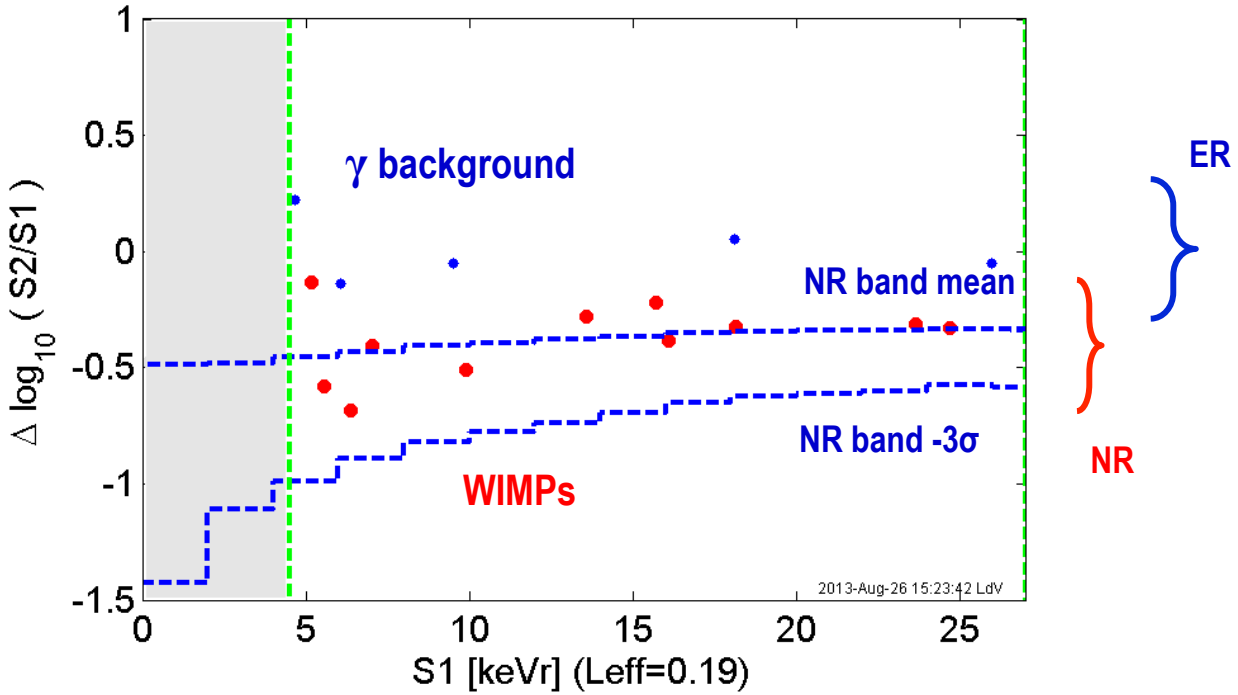
Simulated WIMP signal in LUX

- Example: m_{WIMP} = 100 GeV/c^2 and σ_{WIMP} = 3x10^{-45} cm^2 (sensitivity limit set by XENON100)
- 76 days acquisition, 25 kg fiducial mass
  - 1 single background event, before cuts and discrimination (ER Background ~260 μdru)



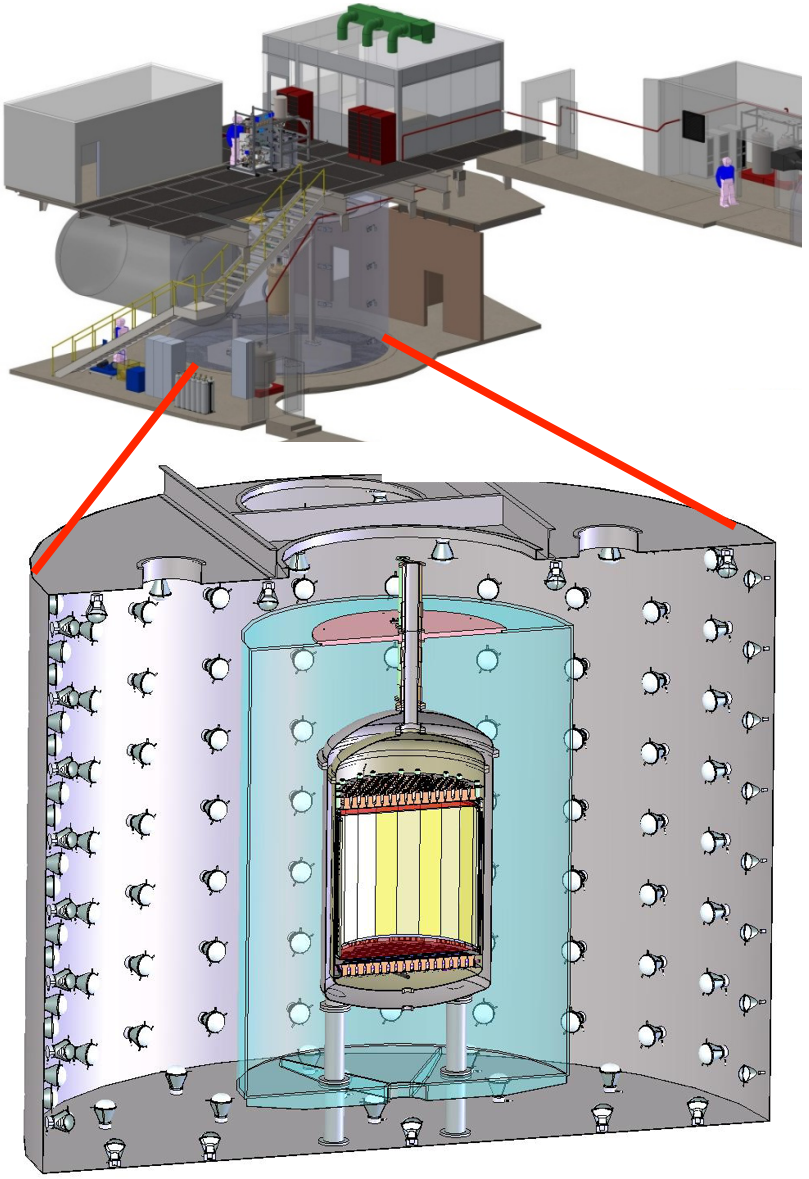
Simulated WIMP signal in LUX

- Example: m_{WIMP} = 100 GeV/c^2 and σ_{WIMP} = 3x10^{-45} 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



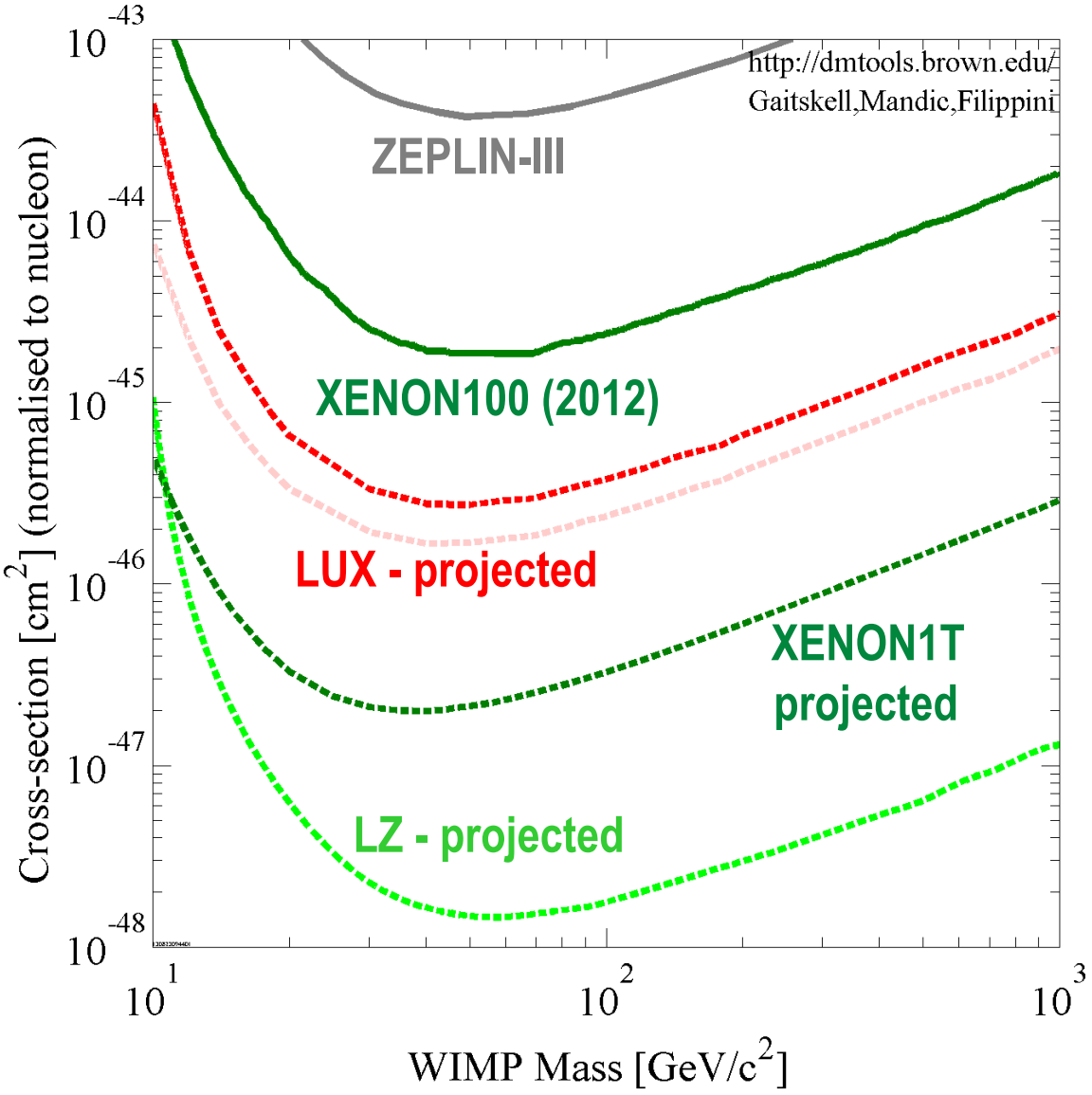
LZ Program - Overview

- Born from the joining of LUX and ZEPLIN
  - Construction: 2015 - 2016
  - Operation: 2016 - 2019 (...?)
- New features compared to LUX
  - Xe mass 7 T, 5 T fiducial
  - ~500 3” PMTs (@ 1 mBq level)
  - Liquid scintillator veto
- Increased sensitivity will come from
  - Xe mass increase
  - Xe self-shielding reduces backgrounds dramatically



LZ Sensitivity

- Liquid Xenon detectors are very powerful tools in the direct search for dark matter!

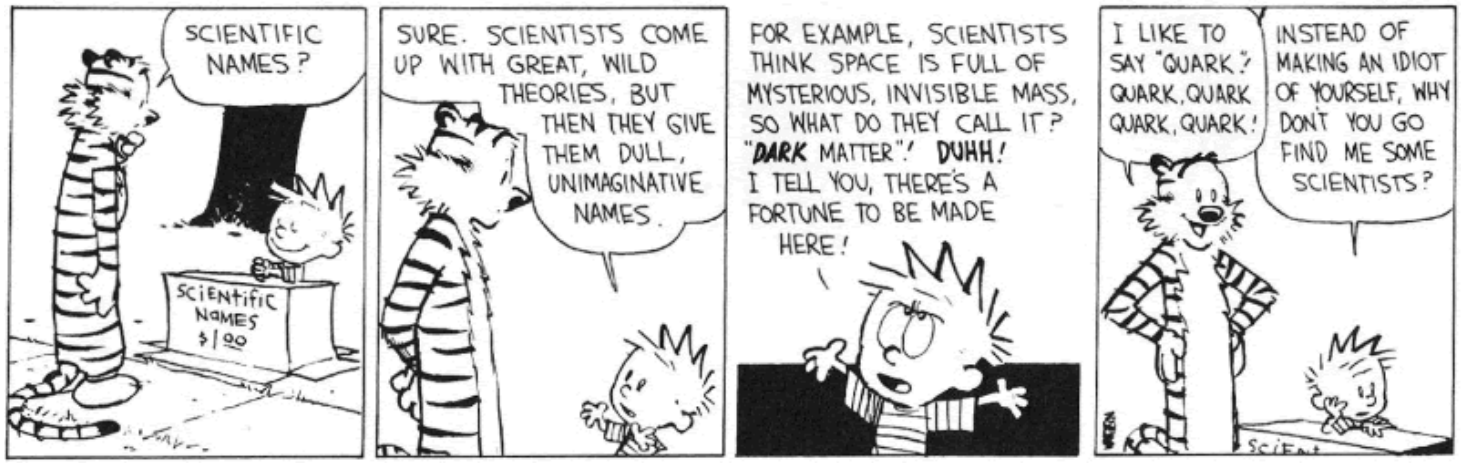


Summary

- 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
- Preliminary Science Result by the end of 2013
  - Matches and surpasses all existing sensitivity limits (for WIMPs with mass above ~10 GeV)

Thank you !

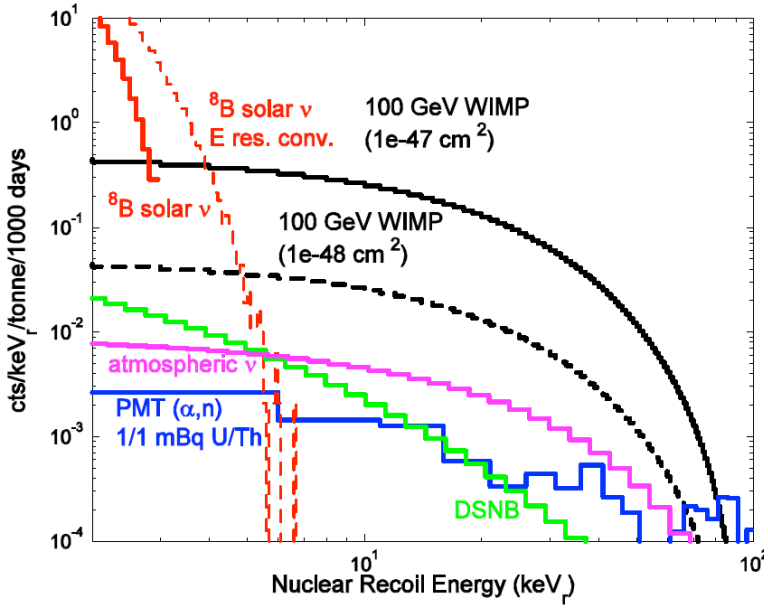
The End

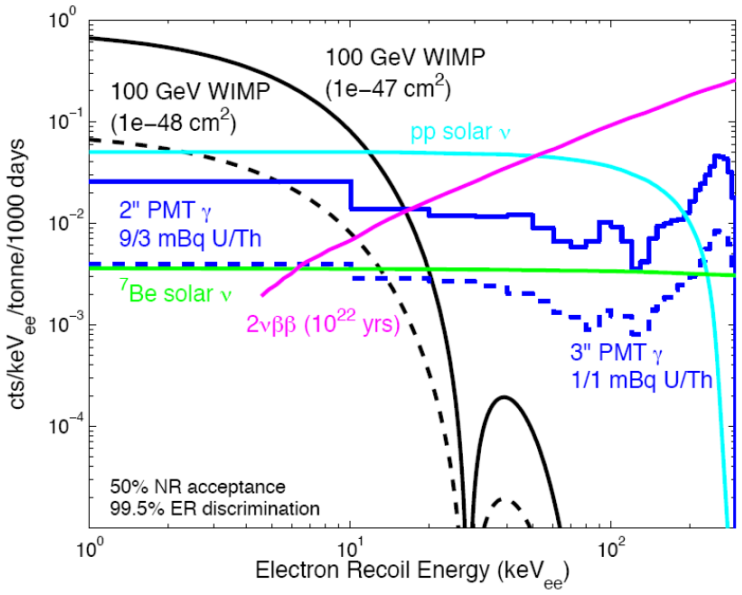

SCIENTIFIC NAMES?
SCIENTIFIC NAMES $1.00
SURE. SCIENTISTS COME UP WITH GREAT, WILD THEORIES, BUT THEN THEY GIVE THEM DULL, UNIMAGINATIVE NAMES.
FOR EXAMPLE, SCIENTISTS THINK SPACE IS FULL OF MYSTERIOUS, INVISIBLE MASS, SO WHAT DO THEY CALL IT? "DARK MATTER"! DUHH! I TELL YOU, THERE'S A FORTUNE TO BE MADE HERE!
I LIKE TO SAY "QUARK." QUARK, QUARK QUARK, QUARK!
INSTEAD OF MAKING AN IDIOT OF YOURSELF, WHY DON'T YOU GO FIND ME SOME SCIENTISTS?

Backup Slides

LZ: The Ultimate DM Detector

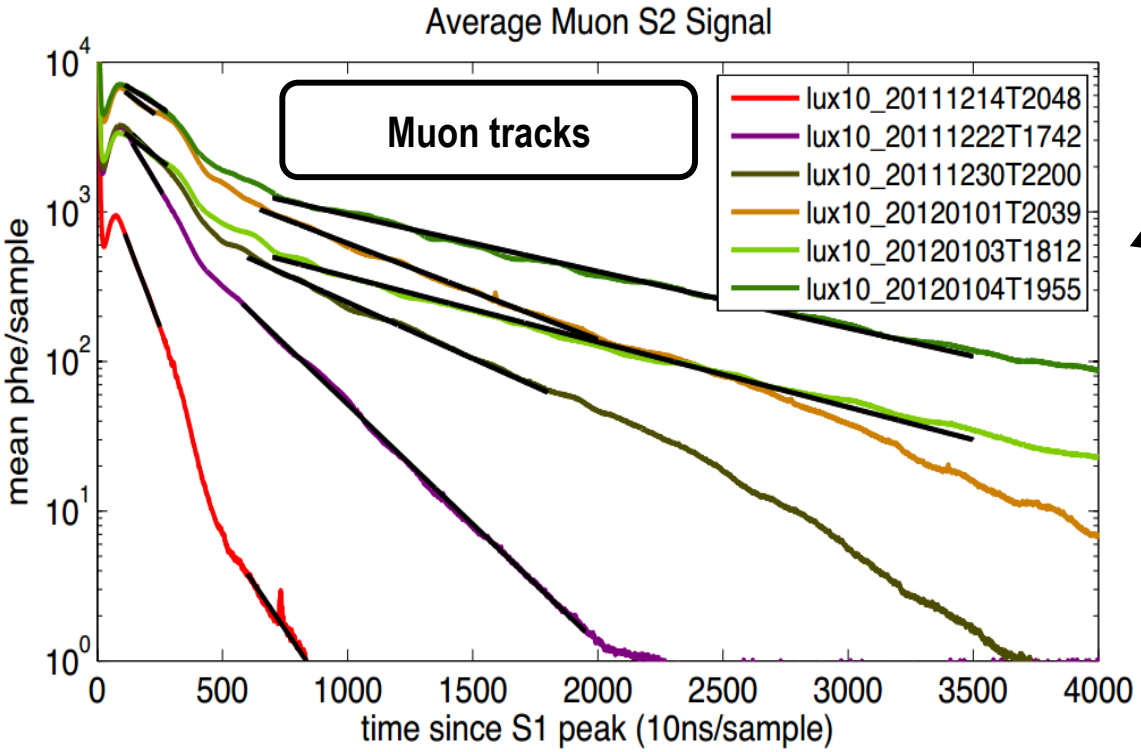
- Electron Recoil signal limited by p-p solar neutrinos
  - Subdominant with current background rejection
- Nuclear Recoil background: coherent neutrino scattering
  - ^{8}B solar neutrinos
  - Atmospheric neutrinos
  - Diffuse cosmic supernova background
- LZ reaches this fundamental limit for direct WIMP searches

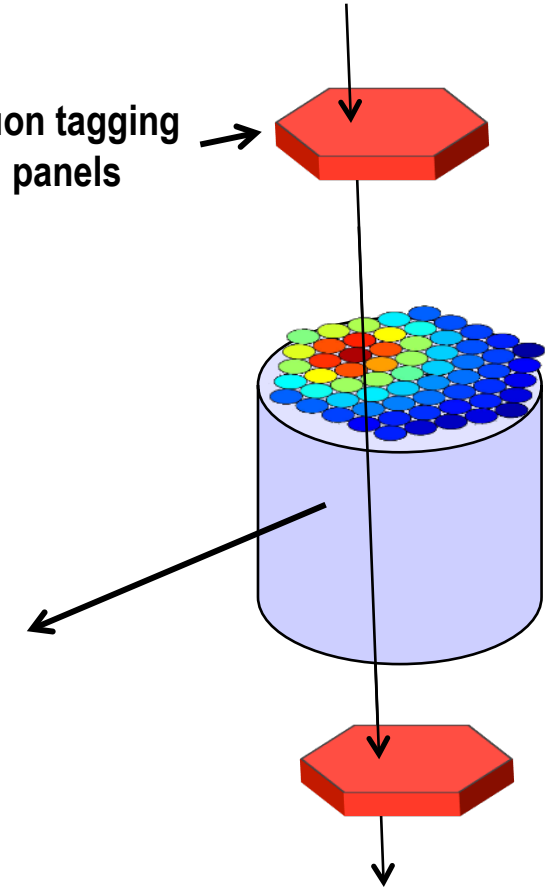




Surface Run – Light and Charge

- Electron lifetime (Xe purity) monitored by muon, alpha and gammas signals.
  - Muon tagging system using plastic scintillator panels





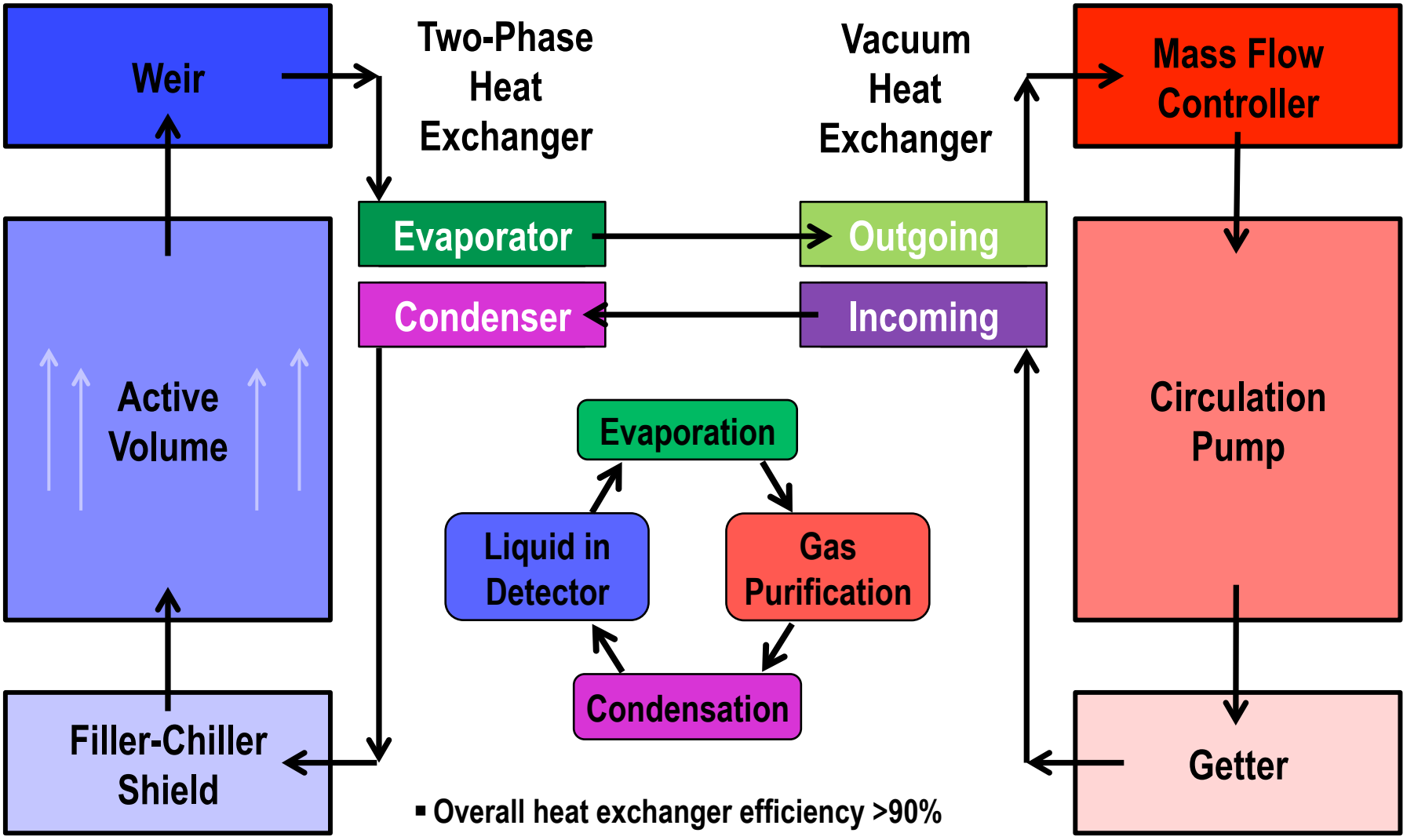
LUX Group at LIP-Coimbra

- 1 P.I. + 5 Post-Docs
- Sub-systems Responsibilities
  - Data Processing and Analysis
    - Analysis Coordinator for the LUX Experiment
    - Position Reconstruction Software (Mercury, arXiv:1112.1481)
  - LUX Background Simulations
  - LN System: design, deployment and operation
  - Slow Control and Automated Controlled Recovery System (ACRS)
  - Automated Source Delivery System
  - Muon-tagging system during Surface Run
  - PMT Response Characterization (at LIP-Coimbra)
  - PTFE Reflectivity Measurements (at LIP-Coimbra)
- On-site Detector Operations
  - Detector construction, deployment and operation at the Sanford Lab
  - Year-long onsite coverage by LIP-Coimbra personnel
    - One of us is always there!
  - Shift Managers and Detector Operations Managers

Liquid Xe Experiments

- ZEPLIN I
- ZEPLIN II
- XENON 10
- ZEPLIN III
- XENON 100
- LUX
- X-MASS
- XENON 1T
- PANDA-X
- LZ

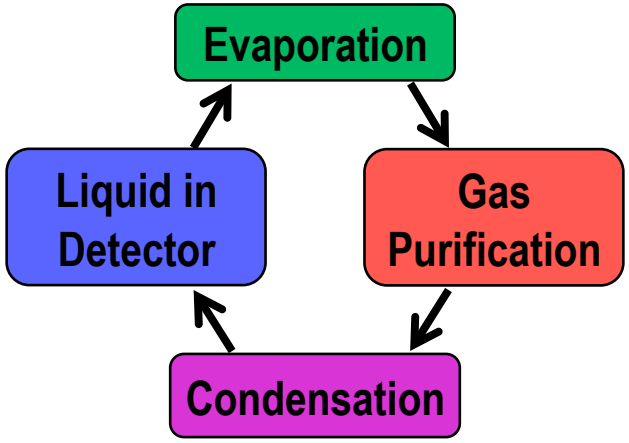
Circulation Path

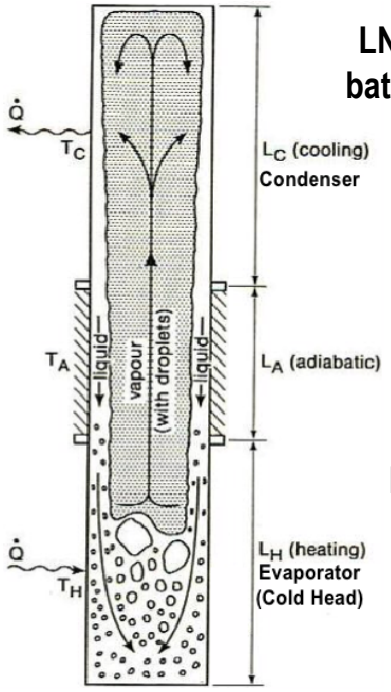


- Overall heat exchanger efficiency >90%
- Heat load is < 25W at typical 200 kg/day circulation rate

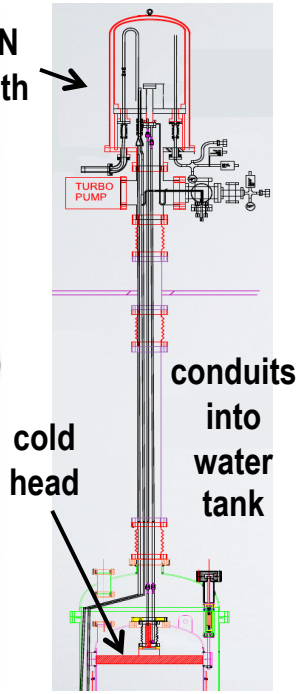
Surface Run – Thermosyphon Cooling System

- Thermosyphon: ~kW capacity, multiple cold head deployment;
- Demonstrated cooling of entire detector mass: ~800 kg in <2 weeks
- High flow plumbing and heat exchanger for rapid circulation through external purifier: 35 liters per minute (300 kg/day)

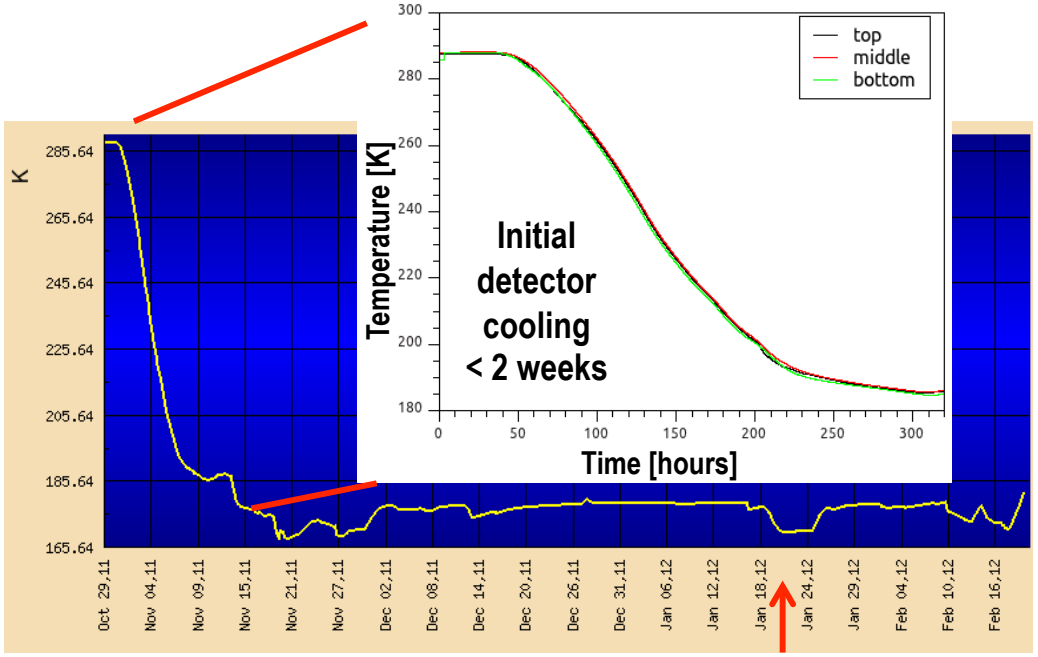




Thermosyphon principle



LUX Thermosyphon



temperature variation <=> circulation change

Rn Injection

- 150 Bq of ^{222}Rn were injected in the system to trace the complex Xe circulation path by looking at the evolution of the large alpha signals over time
- This rate guaranteed that alpha signals would still be available for calibrations at the end of the surface run, while still keeping ^{210}Pb backgrounds subdominant