Lawrence Livermore National Laboratory

LUX - and other LLNL Office of Science Projects in the Advanced Detectors Group

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Wednesday, February 9, 2011

The Advanced Detectors Group

- Fundamental Physics – Rare Event Detection for Dark Matter and Neutrino Science
  1. **LUX (DOE-OS-HEP)**
  2. **ADMX (DOE-OS-HEP)**
  3. **Double Chooz - and other oscillation studies (LLNL LDRD)**
  4. DUSEL R&D, water detectors for DM and neutrino experiments (DOE-OS-HEP)
  5. DUSEL R&D HPXE for neutrinoless double beta decay (DOE-OS-HEP)

- Applied Physics –Rare Event Detection for Nonproliferation, Arms Control and International Nuclear Security
  - World leader in Applied Antineutrino Physics
  - Active R&D in advanced water, scintillator and noble liquid detectors

A partial list of our academic collaborators:
Brown, Case Western, Texas A&M, U. of Chicago, Columbia, Kansas State U. , MIT, UC Berkeley Yale, U. of Alabama, UC Davis, U. of Maryland, U. of Notre Dame, U. of Tennessee … France, Germany, Japan, Russia

ADG Staff working on DOE-HEP and related projects

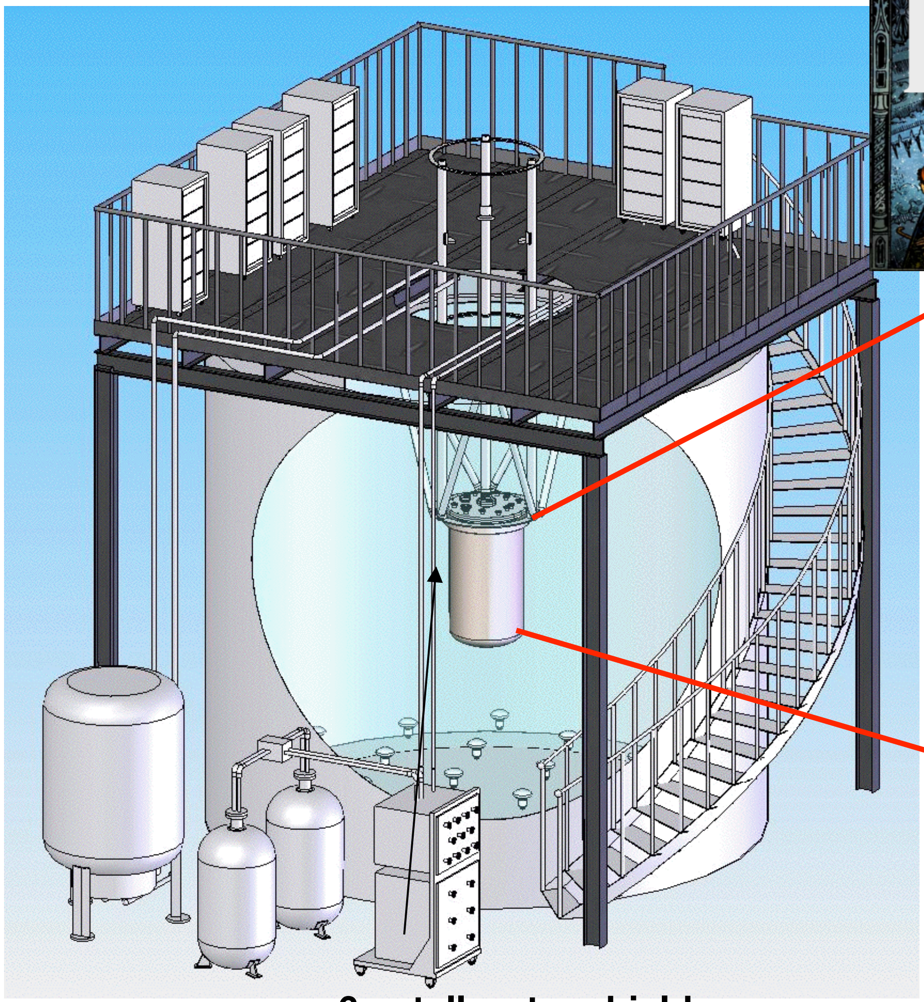
LLNL Physics Team	Physics Ph.D	Experience
A. Bernstein	Columbia	LLNL LUX PI: Founder of LLNL/SNL Applied Antineutrino Physics program
K. Kazkaz	U. Washington	LUX simulations ; coherent scatter detector development
Melinda Sweany (student)	UC Davis	LUX grad student – simulations and modeling
P. Sorensen (PD)	Brown	Key roles in LUX and Xenon-10 experiments
N.Bowden	Harvard	LLNL Double Chooz PI; Applied Antineutrino Phyics
Greg Keefer (PD)	U. Tennesee	Double Chooz and Applied antineutrino physics
Tim Classen (PD)	Davis	Double Chooz and Applied antineutrino physics
S. Dazeley	Adelaide	Water det. DUSEL R&D PI ;inventor, Gd-Cerenkov neutron detector
Serge Ouedraogo (PD)	U. Alabama	DUSEL Water Detector project, IAEA safeguards
M. Heffner	Davis	HPXE DUEL R&D co-I; nTPC PI; fission TPC PI
Joshua Renner (student)	UC Berkeley	HPXE project – simulations
Gianpaolo Carosi	MIT	ADMX expt. , directional neutron detection
Darin Kinion	MIT	ADMX expt. , SQUID development

Most support is from synergistic LDRD or DOE nonproliferation R&D activity not a large 'standing army' dilemma for HEP

Currently funded DOE Office of Science Projects in the ADG

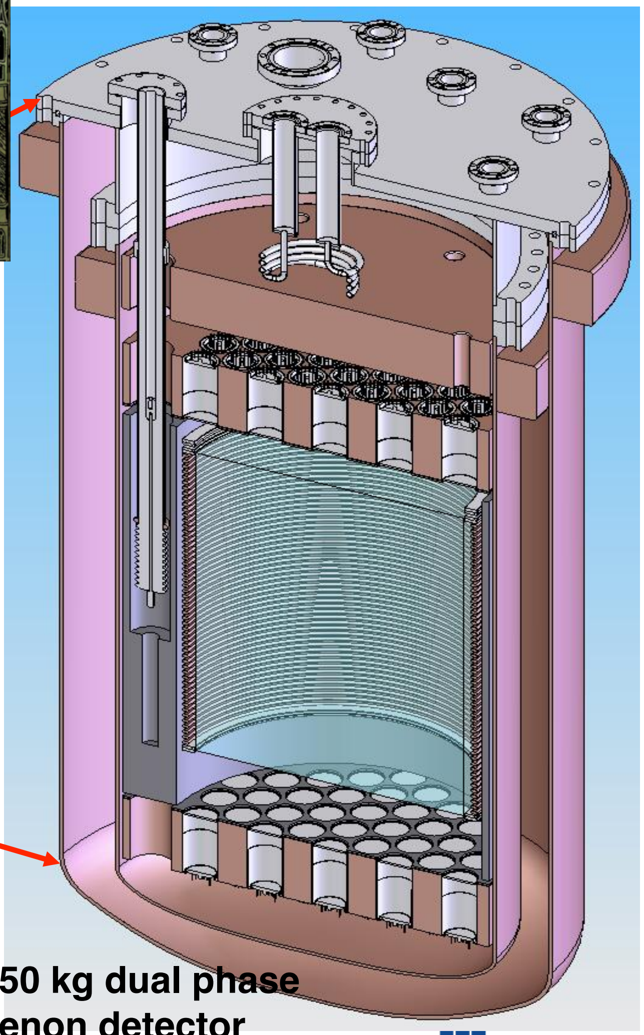
Project Status	Project	Start Date	Duration (years)	Funding status	FY08	FY09	FY10	FY11
Current	ADMX	04/08 (phase I ops)	4	Received	300K	300K	282K	250K
				Remaining	0K	50K	16K	213K
Current	LUX DM	05/08	4	Received	45K	~150K	420K	0(587K proposed)
				Remaining				190K
Current	Xenon TPC DUSEL R&D	06/09	2	Received		99K	150K	0
				Remaining		0K	70K	70K
Completed (new proposal this FY)	Water Detector DUSEL R&D	06/08	2.5	Received	200K	170K	0	0
				Remaining			70K	7K
Proposed	Reactor Anomaly Experiment	FY11	3	SOI forthcoming				

The LUX Dark Matter Experiment at the Sanford Laboratory



6 m tall water shield

Most of LUX
is now in place
at the Sanford
Above-ground
Laboratory
In Lead, S.D.



350 kg dual phase
xenon detector

LLNL participation in the Large Underground Xenon (LUX) Dark Matter Search Experiment

1. LUX Science
   - Detector installation (Sorensen, Bernstein) – OS-HEP
   - Simulations framework (Kazkaz) (LDRD)
   - Simulations group lead (Kazkaz) OS-HEP
   - Water shield simulations (Sweany) OS-HEP
   - Analysis group lead (Sorensen) OS-HEP
   - publications on xenon detector physics (Sorensen) (LDRD)
2. LUX Engineering and Safety - OS-HEP
   - LUX is making use of LLNL's well developed safety and engineering sectors to assist with establishing the safety and functionality of the LUX detection system
   - LLNL closely involved in safety aspects of detector design, in providing input to subsystem leads, and in responding to DOE/NSF/Sanford safety review mandates – cryogenics, gas handling electronics

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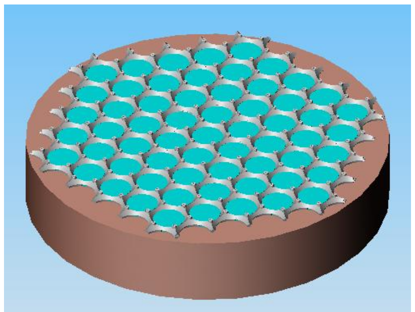
LUX engineering and safety

- Detector mechanical engineering and hardware



Mount design by LLNL Mechanical Tech Dennis Carr

6 enclosed UPS powered electronics racks From LLNL salvage yard house all LUX rack mounted electronics

- Safety engineering and review is critical in this new Laboratory
  - Instituted electrical component review process now used by Sanford lab for all LUX equipment (AHJ process)
  - Developed Sanford-approved online training matrix for all LUX procedures and personnel
  - Major upgrades to electronics and cryogenics schematics by LLNL engineers
  - LLNL pressure safety engineer has confirmed ASME code adherence of the lUX cryogenic and gas handling systems (report now being generated)
  - General experience to date: LLNL matrix and deep bench has allowed flexible and timely response to queries from LUX collaborators and Sanford Lab.

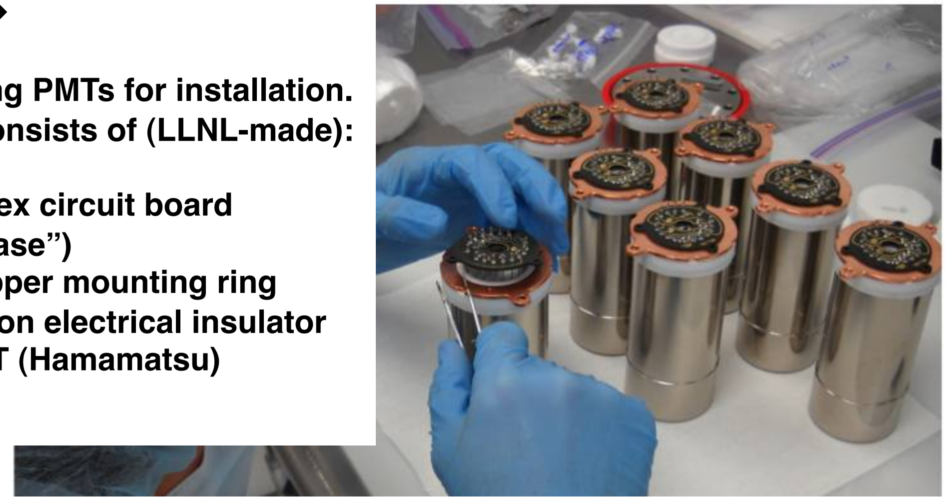
LLNL contributions to LUX construction and deployment at Homestake

(below) Preparing to pull 260 PMT cables through the vacuum conduit…

(right) ➔

Preparing PMTs for installation. Stack consists of (LLNL-made):

(1) Cirlex circuit board ("base")
(2) Copper mounting ring
(3) Teflon electrical insulator
(4) PMT (Hamamatsu)



(above) LLNL custom-designed and built PMT hardware/signal connections:
(a) Teflon "top-hat" insulator and PMT backing plate
(b) Cirlex PMT signal plug (similar for PMT HV)
(c) Mating the cables into the PMT circuit boards

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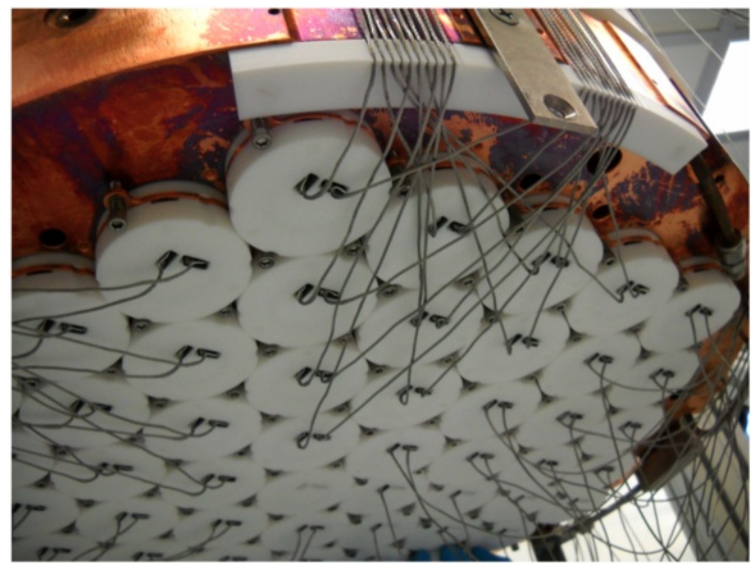
LLNL contributions to LUX construction and deployment at Homestake (II)

(below) PMT cables have been pulled through the vacuum conduit, now on to the task of routing, strain-relieving and

(right) ➔

In addition to PMT and cabling deployment, we lend expertise to multiple on-site construction tasks as needed (right) ➔

PMTs and cables fully installed, connected, strain-relieved and electrical checkouts successful!



Related work, funded by LDRD:
LLNL is expanding the theoretical understanding liquid xenon dark matter detectors

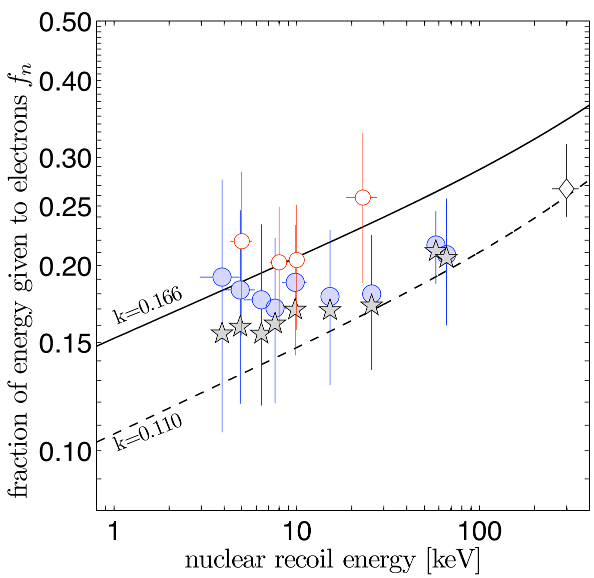
Nuclear recoil energy scale in liquid xenon with application to the direct detection of dark matter

Peter Sorensen[1,*] and Carl Eric Dahl[2]
[1] *Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550, USA*
[2] *Enrico Fermi Institute, KICP and Department of Physics, University of Chicago, Chicago, USA*
(Dated: January 31, 2011)

We show for the first time that the quenching of electronic excitation from nuclear recoils in liquid xenon is well-described by Lindhard theory, if the nuclear recoil energy is reconstructed using the combined (scintillation and ionization) energy scale proposed by Shutt *et al.*. We argue for the adoption of this perspective in favor of the existing preference for reconstructing nuclear recoil energy solely from primary scintillation. We show that signal partitioning into scintillation and ionization is well-described by the Thomas-Imel box model. We discuss the implications for liquid xenon detectors aimed at the direct detection of dark matter.

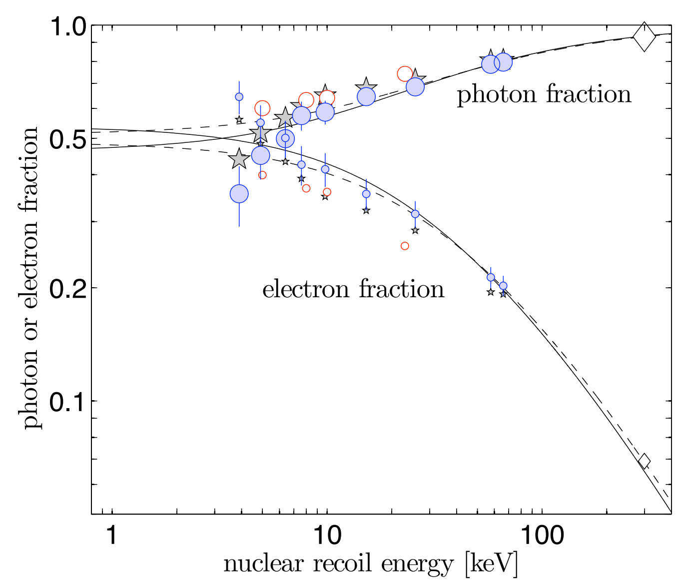
PACS numbers: 95.35.+d, 95.55.Vj, 14.80.Nb, 29.40.-n

(left) accepted to Phys. Rev. D, provides new clarity on nuclear recoil energy scale in liquid xenon, which has recently lead to controversy.

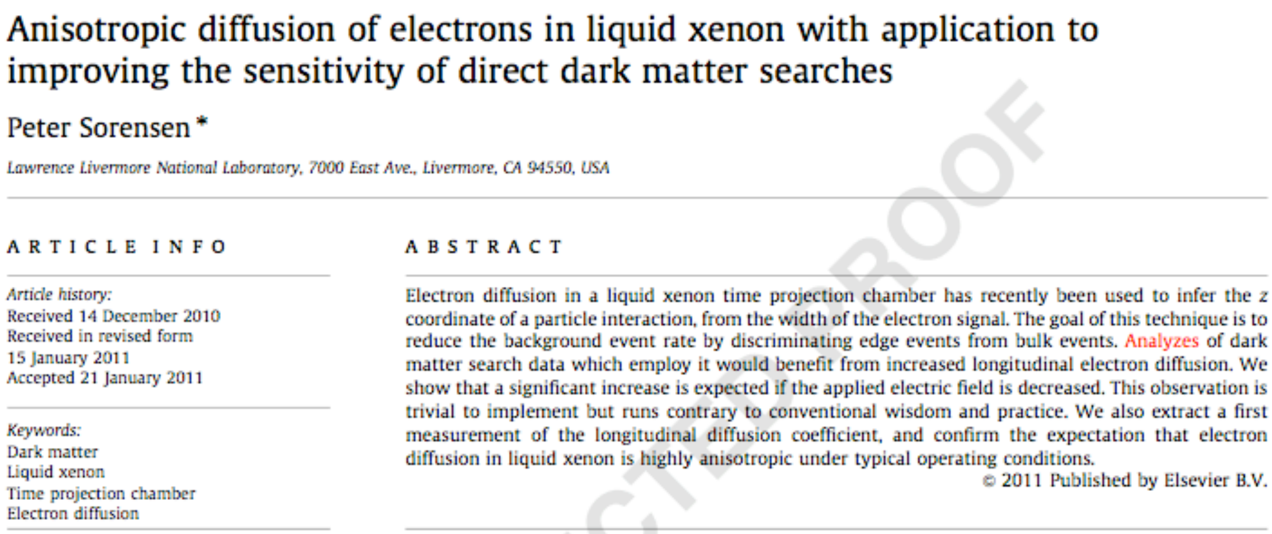


(left) First demonstration that Lindhard theory describes energy loss for nuclear recoils in xenon.

(right) explanation for observed non-proportionality of scintillation (and ionization) signal can be explained by Thomas-Imel recombination model.



LLNL is expanding the theoretical understanding liquid xenon dark matter detectors (II)



Anisotropic diffusion of electrons in liquid xenon with application to improving the sensitivity of direct dark matter searches

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A R T I C L E I N F O

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Keywords:
Dark matter
Liquid xenon
Time projection chamber
Electron diffusion

A B S T R A C T

Electron diffusion in a liquid xenon time projection chamber has recently been used to infer the *z* coordinate of a particle interaction, from the width of the electron signal. The goal of this technique is to reduce the background event rate by discriminating edge events from bulk events. Analyzes of dark matter search data which employ it would benefit from increased longitudinal electron diffusion. We show that a significant increase is expected if the applied electric field is decreased. This observation is trivial to implement but runs contrary to conventional wisdom and practice. We also extract a first measurement of the longitudinal diffusion coefficient, and confirm the expectation that electron diffusion in liquid xenon is highly anisotropic under typical operating conditions.

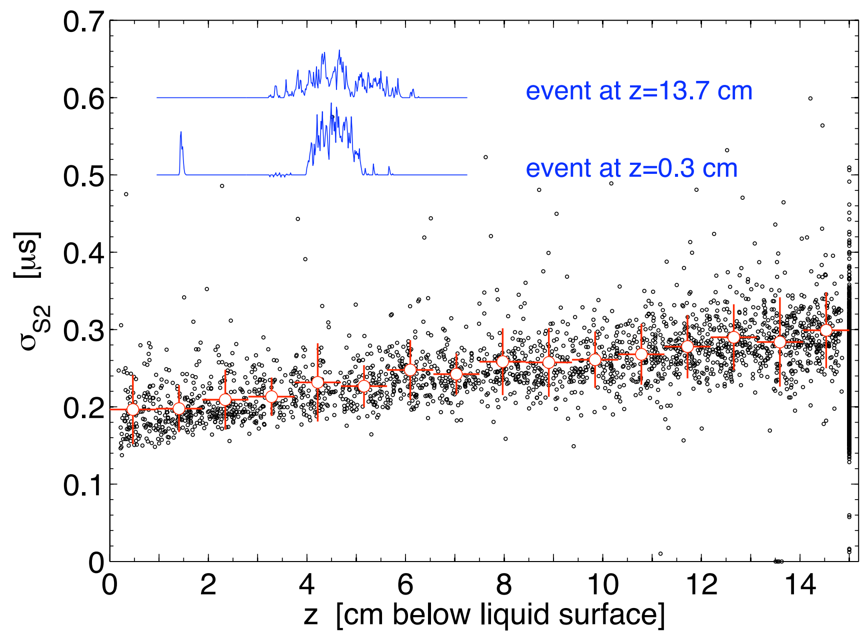
(left) accepted to Nucl. Instr. Meth. A, first measurement of the longitudinal diffusion coefficient of electrons in liquid xenon.

New analysis of XENON10 data nearing completion – using only S2, so with much lower energy threshold than all previous liquid xenon dark matter search results. No hint of light dark matter (as putatively observed by CoGeNT, CRESST and DAMA)

(right)

XENON10 width of S2 pulse increases with drift time through liquid xenon.

Longitudinal diffusion increases with decreasing Ed – this can be used to reconstruct z coordinate solely from the width of the S2 signal.



NOTE: our group is also leading the LUX Analysis Working Group.

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LUXSim A generalized simulation infrastructure for DM/rare event experiments, based on GEANT

- A set of C++ classes that greatly improves reliability
  - OLD GEANT way: geometry, event generation and event recording all done separately
  - The LUXSIM way: only geometry needs defining – particle sourcing and recording is automated
  - Greatly reduces the introduction of bugs and increases reliability
  - Ability to load multiple, simultaneous sources onto detector components

- Now in use with LUX and two LLNL detectors
- Validated E&M interactions down to 3 keV (WIMP-scale energies)
- New U/Th decay chain generators for accurate timing and spatial distribution
- Added spallation neutron generator based on Mei & Hime PRD73 (2006)
- Completed studies of optical photon reflectivity and transport within LUX (metal grids and meshes, PTFE walls), crucial for energy/position reconstruction testing

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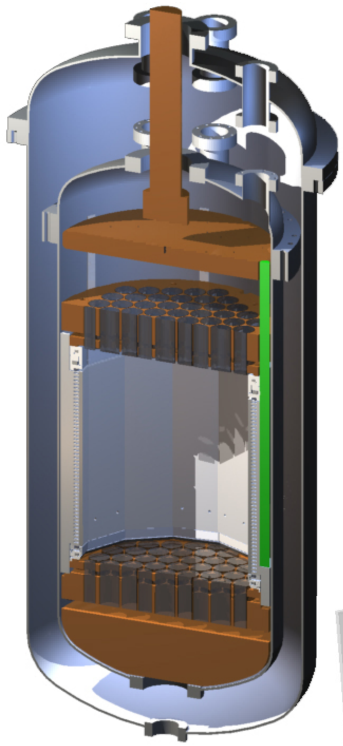
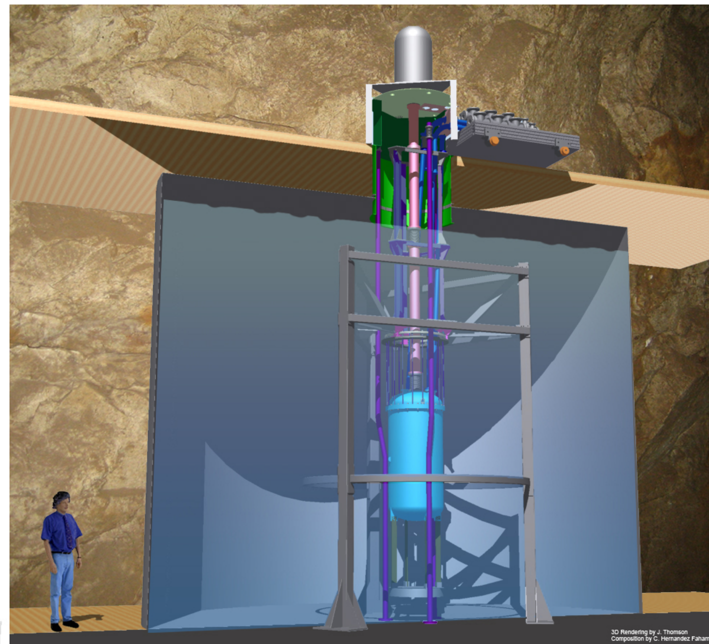
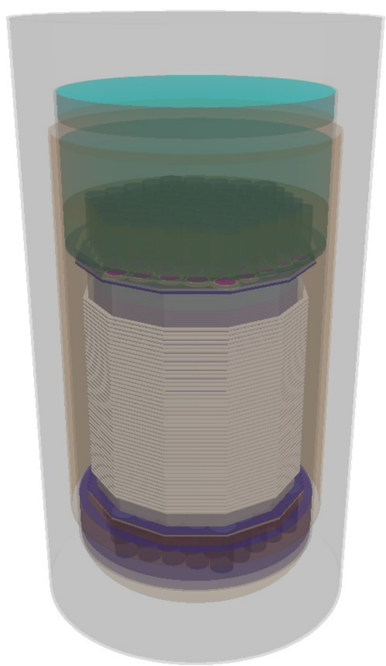
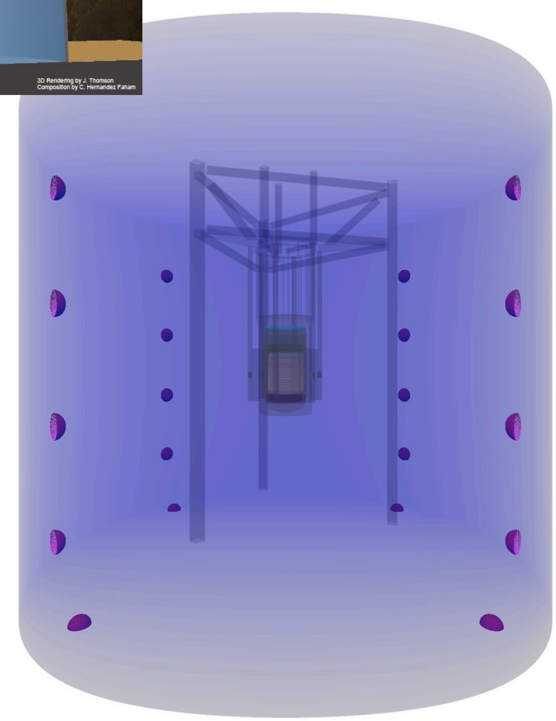
LUXSim Results: LUX1.0 Simulations (PRELIMINARY) – Melinda Sweany and other UC Davis students







Geometries created at LLNL by Melinda Sweany from all available engineering diagrams, vendor records, internal notes, and conversations. The most accurate composite image of the LUX detector internals.



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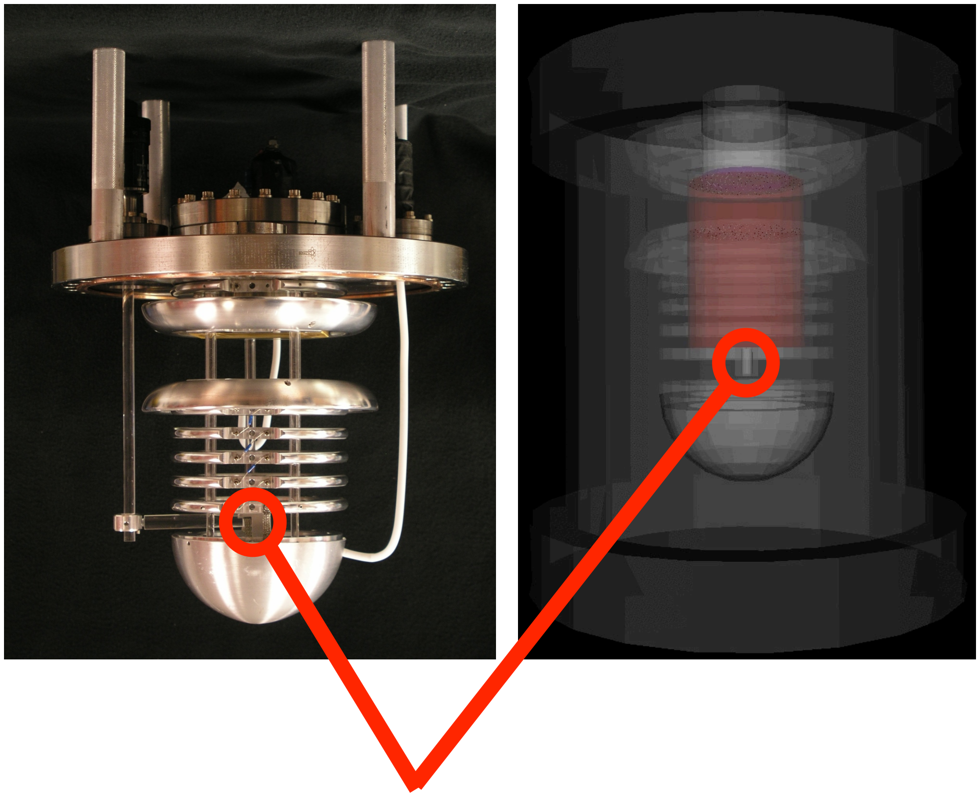
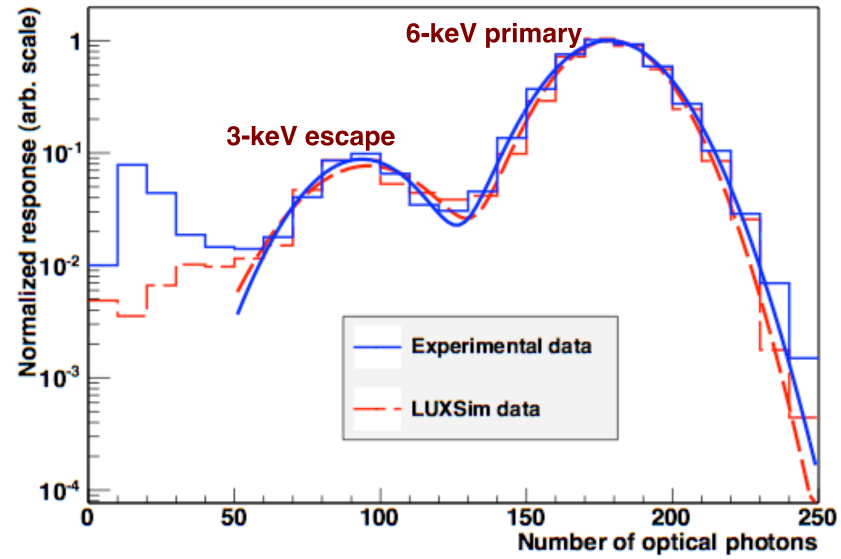
LUXSim Case Study:
LLNL Single-Phase Prototype for secondary scintillation light studies in xenon and argon

Experimental validation with LLNL testbed detector



^{55}Fe source
(6 keV X-ray)



The only free parameter was how many photons were generated per ionization electron per mm of track length 0.54).

Relative peak heights and peak widths are LUXSim predictions. No background events were included in the simulation

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LUXSim - Future Work

- **Put LUXSim to use!**
  - Radioactive background from detector components
  - LUX1.0 calibration source simulations
- **Ongoing development, feature implementation, and bug squashing**
  - Surface sampler from Detwiler *et al.*, *IEEE TNS* 55 (2008).
  - DUSEL-specific generators: (α,n) from rock, cosmic muon/neutron flux from measurements
  - LZ3 / LZ20 geometry
  - Detector response module to convert simulation data to digitized pulses to feed directly into experimental analysis stream
- **Will (hopefully) form the basis of the FAARM unified simulation framework for DUSEL (workshop Feb 25-26)**
  - Provide expertise and assistance to multiple groups at DUSEL as requested
  - Results used to improve performance of LUXSim (Material dependencies? New generators?)
- **Compare LUX0.1 experimental data to simulation results**
  - Provide greater confidence in LUX1.0 and LZ3 / LZ20 predictions and analyses
- **Test LUX analysis algorithms:**
  - Electron vs. ion recoil tagging
  - S1/S2 identification
  - Position reconstruction
  - Energy reconstruction

Conclusions

- LLNL continues to make essential contributions to LUX Science, Engineering and Safety Operations

- LLNL and ADG nonproliferation/nuclear security programs provide staff, infrastructure and tools that directly benefit OS-HEP Rare Event Detection missions in Dark Matter and Neutrino Science - this theme is true for virtually every DOE-OS project at LLNL

- HEP may wish to consider joint science and security development projects in cooperation with nonproliferation sponsors and LLNL