Large Underground Xenon Dark Matter Search

Matthew Szydagis, University of California, Davis,
on behalf of the LUX collaboration

The LUX Collaboration

Brown

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

Case Western

Thomas Shutt	PI, Professor
Dan Akerib	PI, Professor
Mike Dragowsky	Research Associate Professor
Carmen Carmona	Postdoc
Ken Clark	Postdoc
Tom Coffey	Postdoc
Karen Gibson	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student
Kati Pech	Graduate Student

Harvard

Masahiro Morii	PI, Professor
Michal Wlasenko	Postdoc
John Oliver	Electronics Engineer

Lawrence Berkeley + UC Berkeley

Bob Jacobsen	Professor
Jim Siegrist	Professor
Bill Edwards	Engineer
Joseph Rasson	Engineer
Mia ihm	Graduate Student

Lawrence Livermore

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

University of Maryland

Carter Hall	PI, Professor
Douglas Leonard	Postdoc

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

UC Santa Barbara

Harry Nelson	PI, Professor
Dean White	Engineer
Susanne Kyre	Engineer

LIP Coimbra

Isabel Lopes	PI, Professor
Jose Pinto da Cunha	Assistant Professor
Vladimir Solovov	Senior Researcher
Luiz de Viveiros	Postdoc
Alexander Lindote	Postdoc
Francisco Neves	Postdoc
Claudio Silva	Postdoc

SD School of Mines

Xinhua Bai	PI, Professor, Physics Group Leader
Mark Hanardt	Graduate Student

Texas A&M

James White	PI, Professor
Robert Webb	Professor
Rachel Mannino	Graduate Student
Tyana Stiegler	Graduate Student
Clement Sofka	Graduate Student

UC Davis

Mani Tripathi	PI, Professor
Robert Svoboda	Professor
Richard Lander	Professor
Britt Hollbrook	Senior Engineer
John Thomson	Senior Machinist
Matthew Szydagis	Postdoc
Jeremy Mock	Graduate Student
Melinda Sweany	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student
Sergey Uvarov	Graduate Student

The most recent collaboration meeting was held in Lead, SD in March 2011.

University of Rochester

Frank Wolfs	PI, Professor
Wojtek Skutski	Senior Scientist
Eryk Druszkiewicz	Graduate Student
Mongkol Moongweluwan	Graduate Student

U. South Dakota

Dongming Mei	PI, Professor
Wengchang Xiang	Postdoc
Chao Zhang	Postdoc
Oleg Perevozchikov	Postdoc

Yale

Daniel McKinsey	PI, Professor
Peter Parker	Professor
James Nikkel	Research Scientist
Sidney Cahn	Lecturer/Research Scientist
Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Blair Edwards	Postdoc
Louis Kastens	Graduate Student
Nicole Larsen	Graduate Student

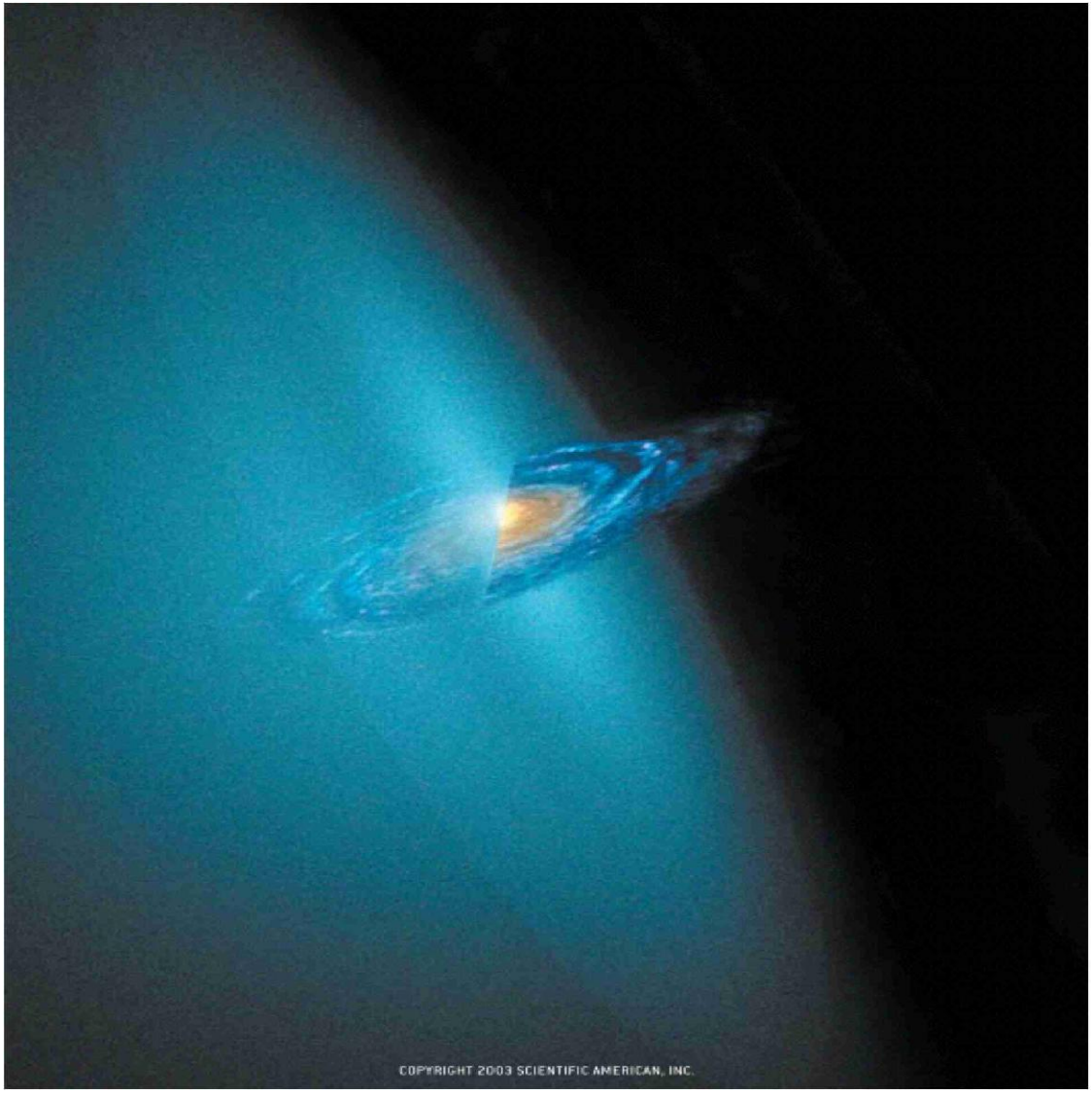
Direct detection of WIMP dark matter

ρ ~ 300 proton masses per liter of space.

If M_{WIMP} = 100 GeV, then 3 WIMPs/L.

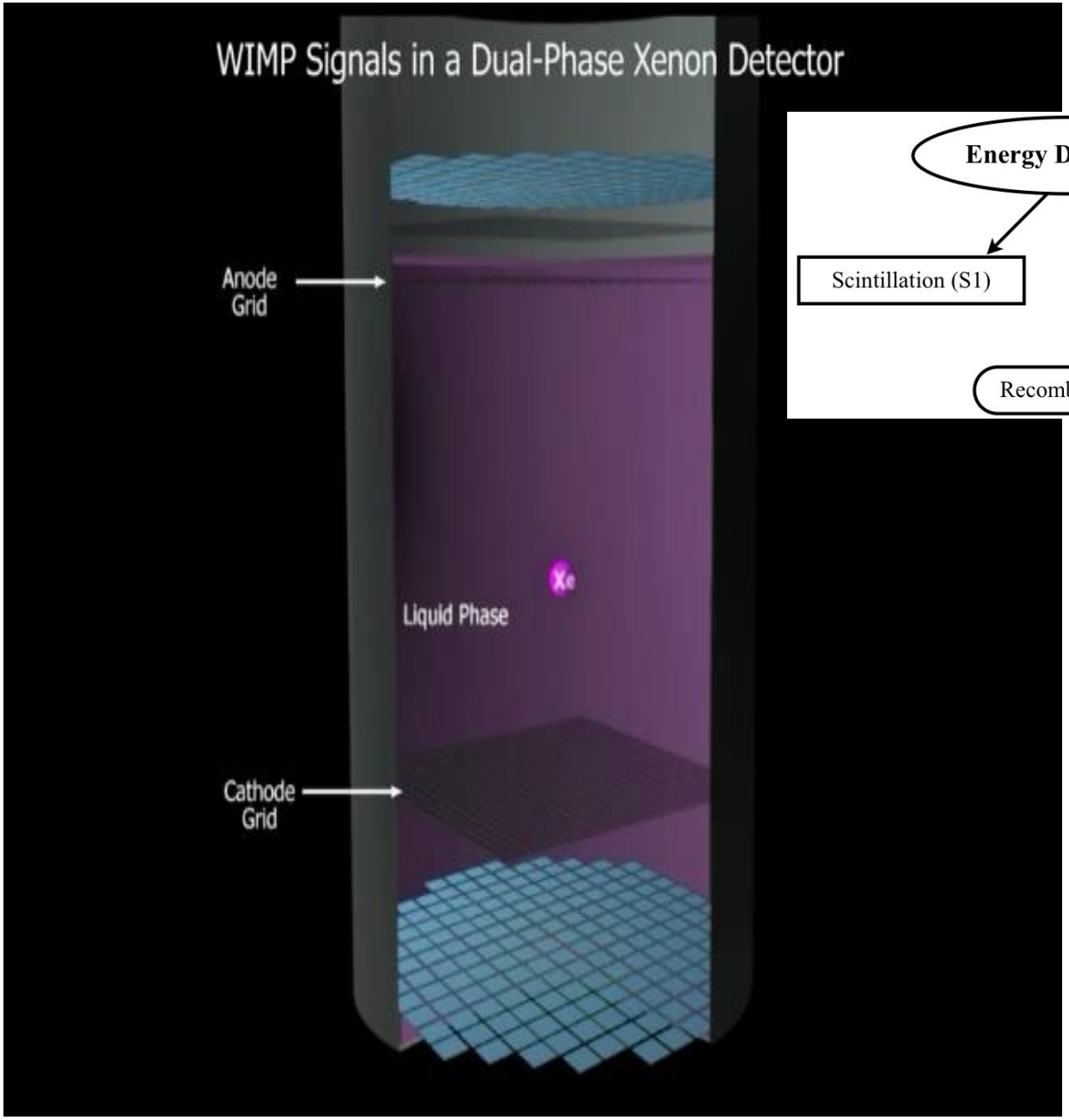
Typical orbital velocity ~ 230 km/s, or 0.1% speed of light.

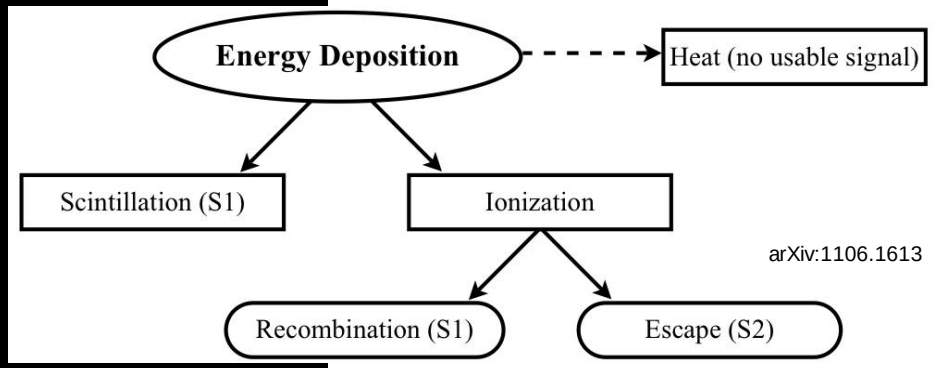
Coherent scalar interactions: σ proportional to A^2.



Rate < 1 event / kg / 100 days, or much, much lower

The Physics of Noble Element Scintillation

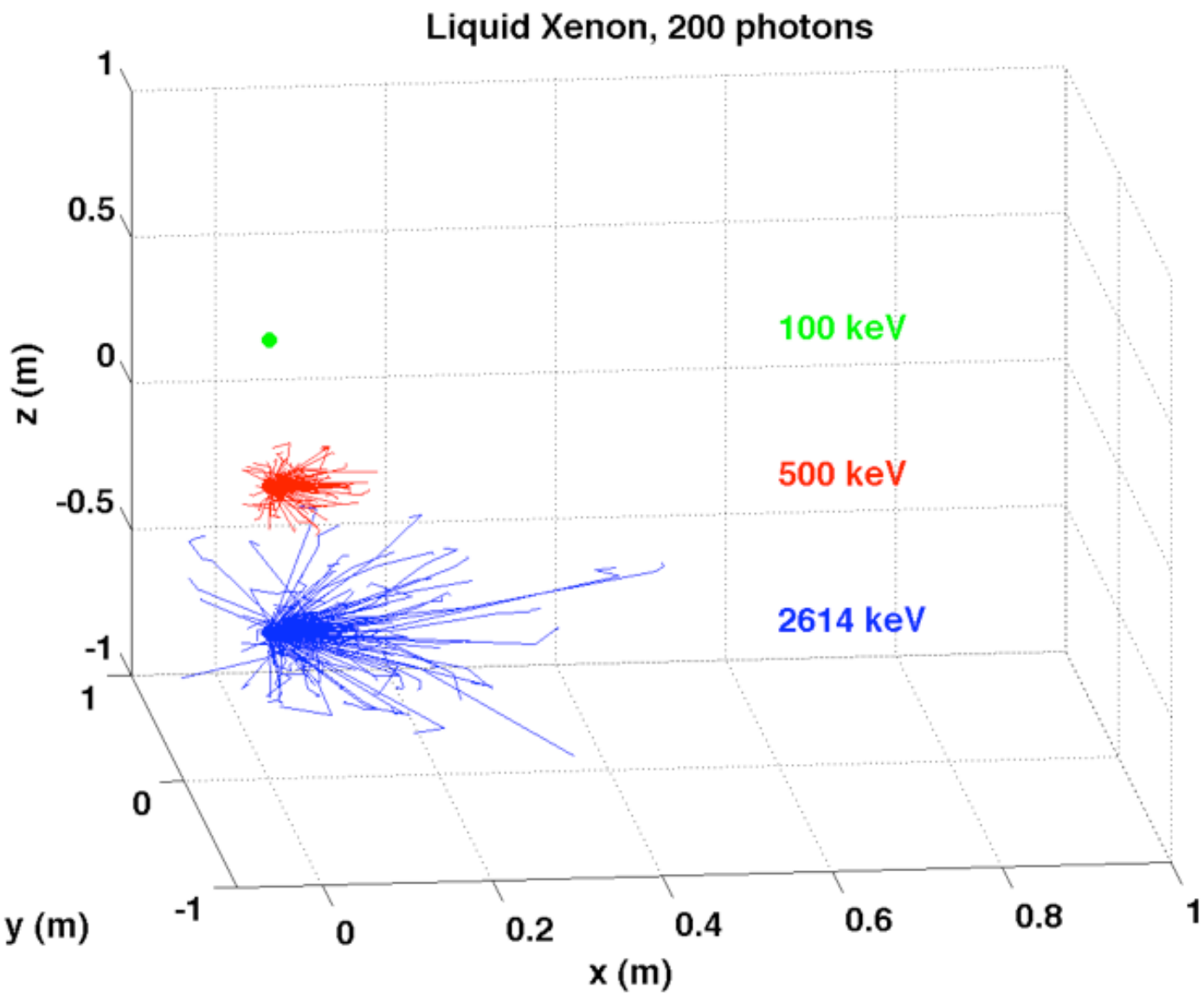




arXiv:1106.1613

- Energy usually deposited in 2 channels
  - Excitation => scintillation in liquid (S1)
  - Ionization => more scintillation in liquid (e-'s recombine) or in the gas (S2)
- Energy lost to heat for nuclear recoils. Makes signal smaller, but makes it different.

Self-shielding of LXe, a dense liquid, is extremely powerful



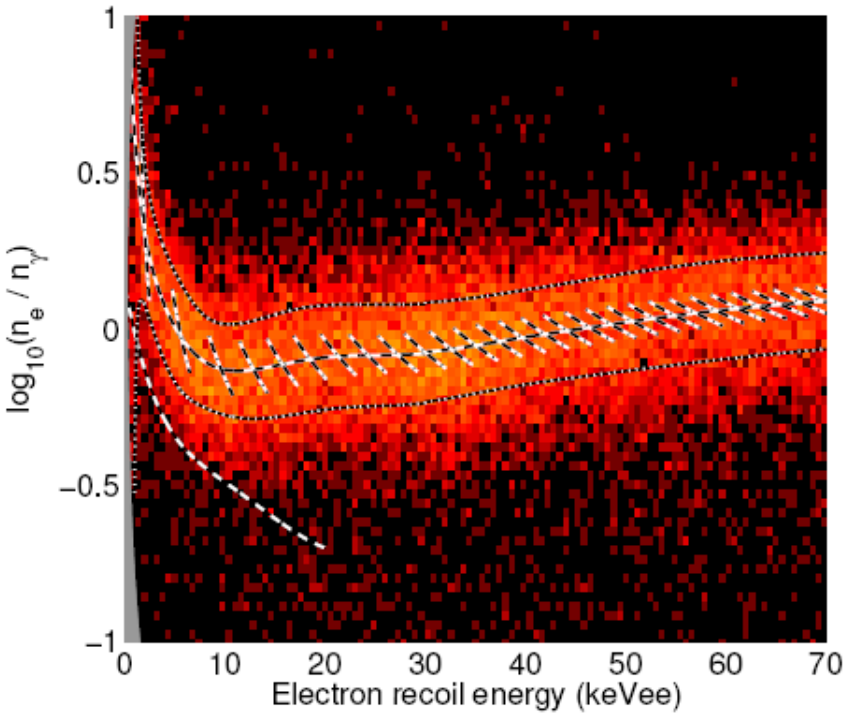
hard for a gamma or a neutron to cross the full volume without scattering more than once

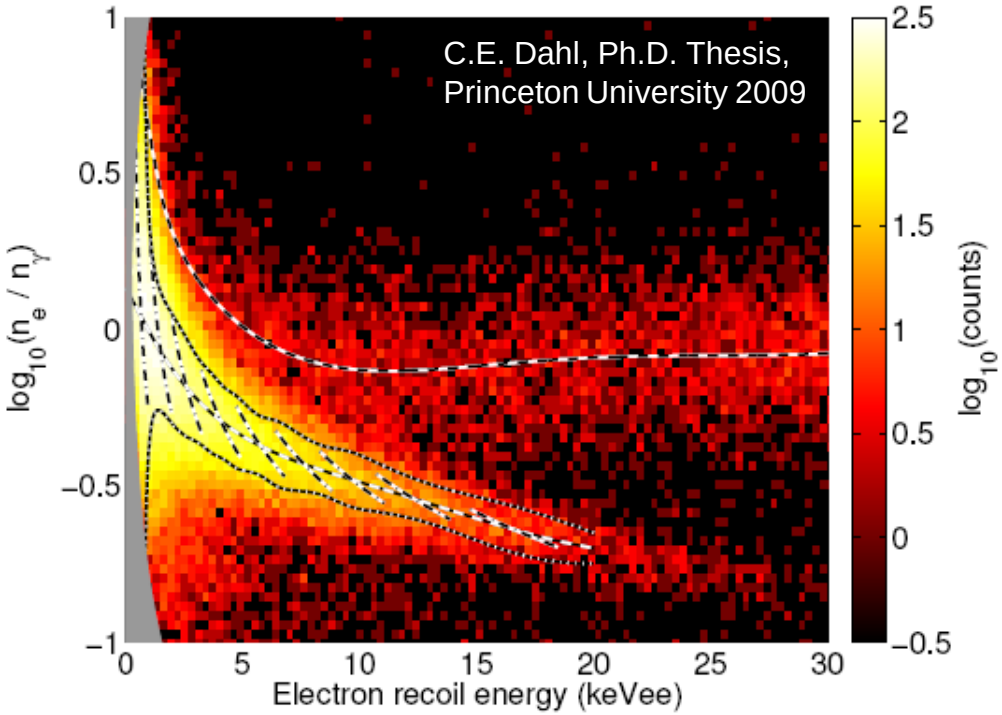
low-energy gammas that can mimic a WIMP should not even make it to the fiducial volume

external neutrons and gammas have to face water shield first anyway…

Fiducial volume cut rejects most backgrounds

Electron Recoils vs. Nuclear Recoils

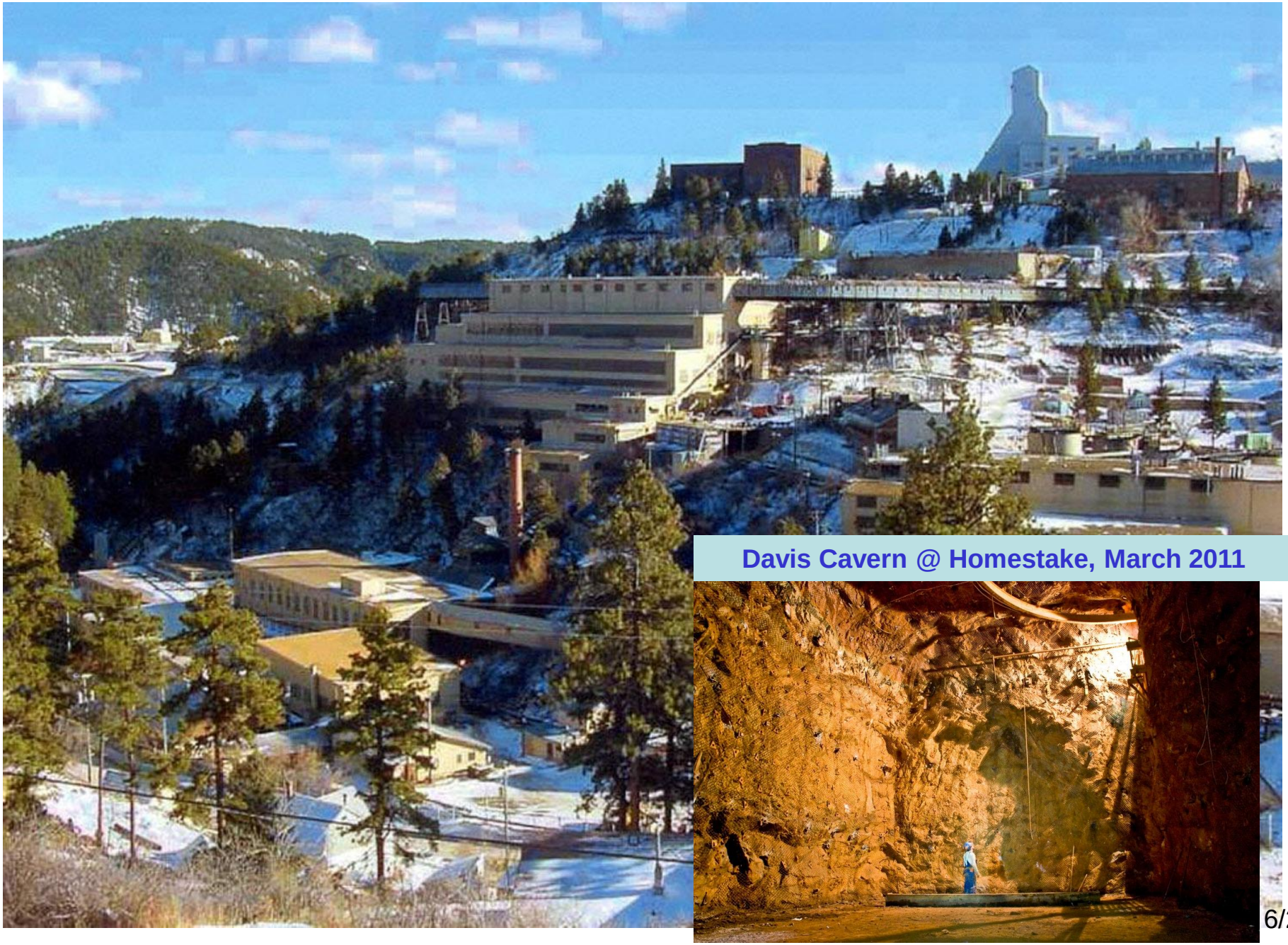




Ionization-to-scintillation ratio allows discrimination between common radioactivity and WIMP events.
Background rejection factor of 99.5%.
Well-established technology and methodology (XENON10/100, Xed, LUX0.1, ZEPLIN-III, others).

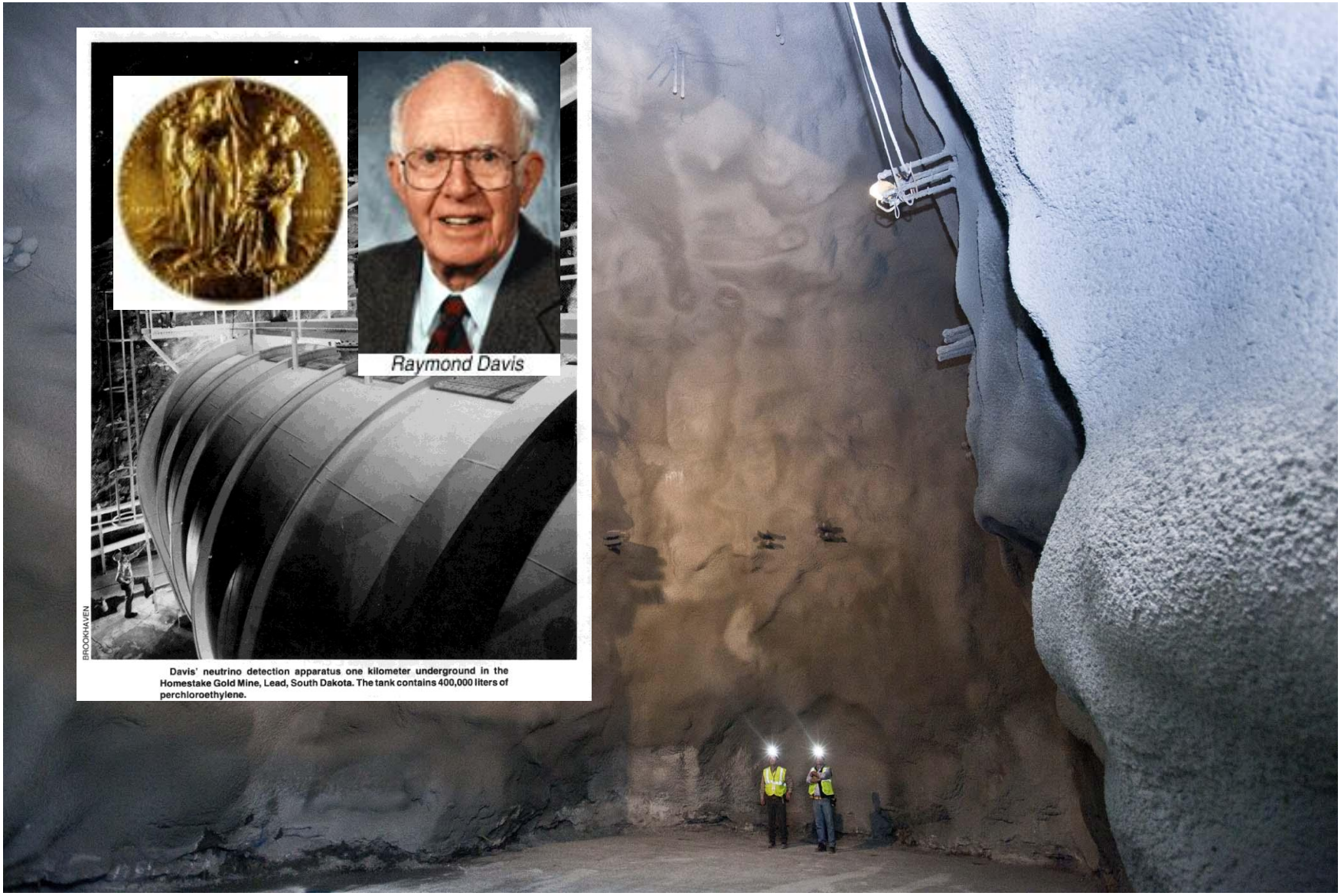
The WIMP Hunters' Hut in the Hills

Homestake (Lead, SD) — once an Au mine



Davis Cavern @ Homestake, March 2011

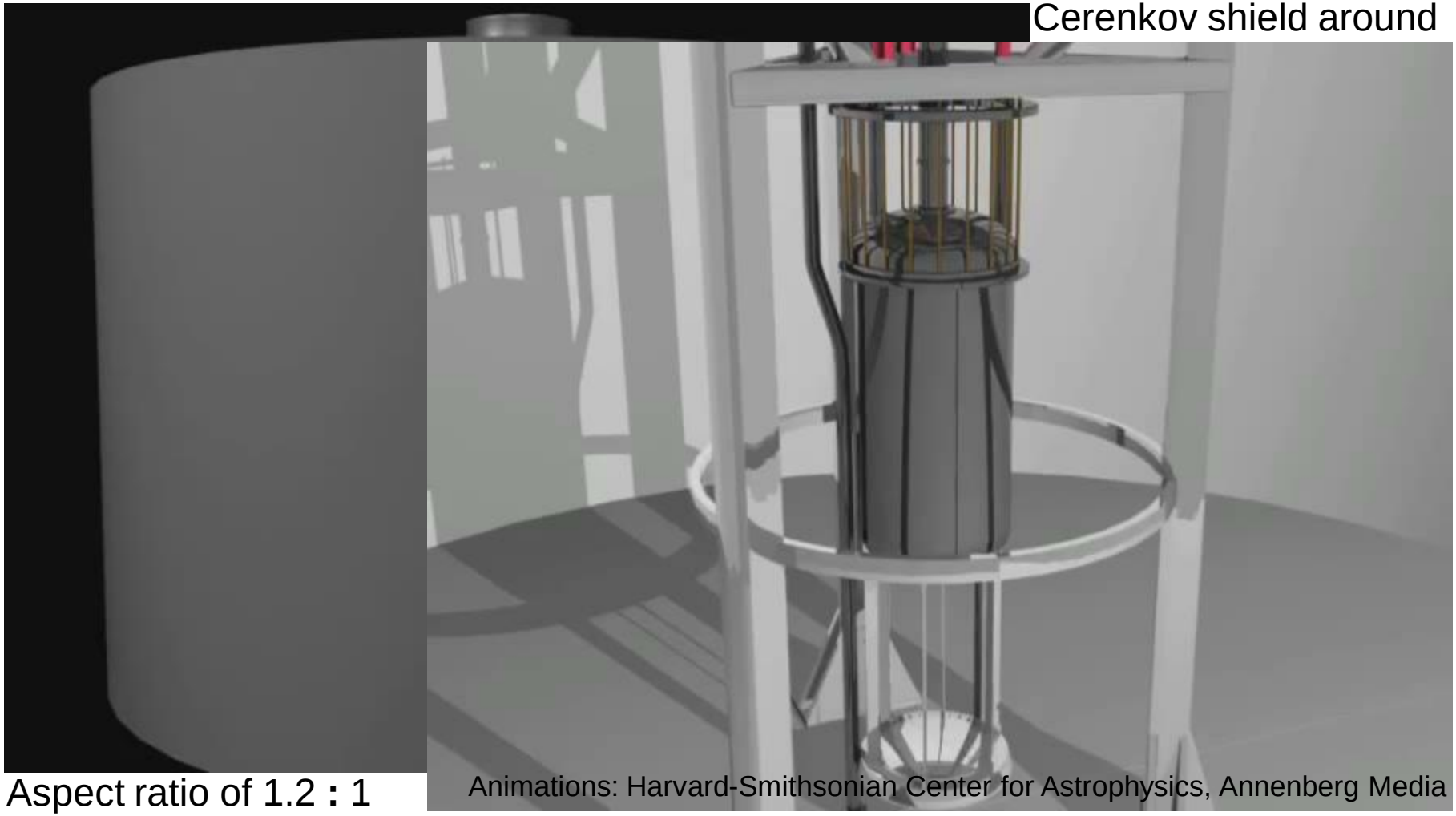
Davis Cavern @ Homestake, March 2011
(Former Home of the Homestake Solar Neutrino Experiment)



Davis' neutrino detection apparatus one kilometer underground in the Homestake Gold Mine, Lead, South Dakota. The tank contains 400,000 liters of perchloroethylene.

LUX Detector - Overview

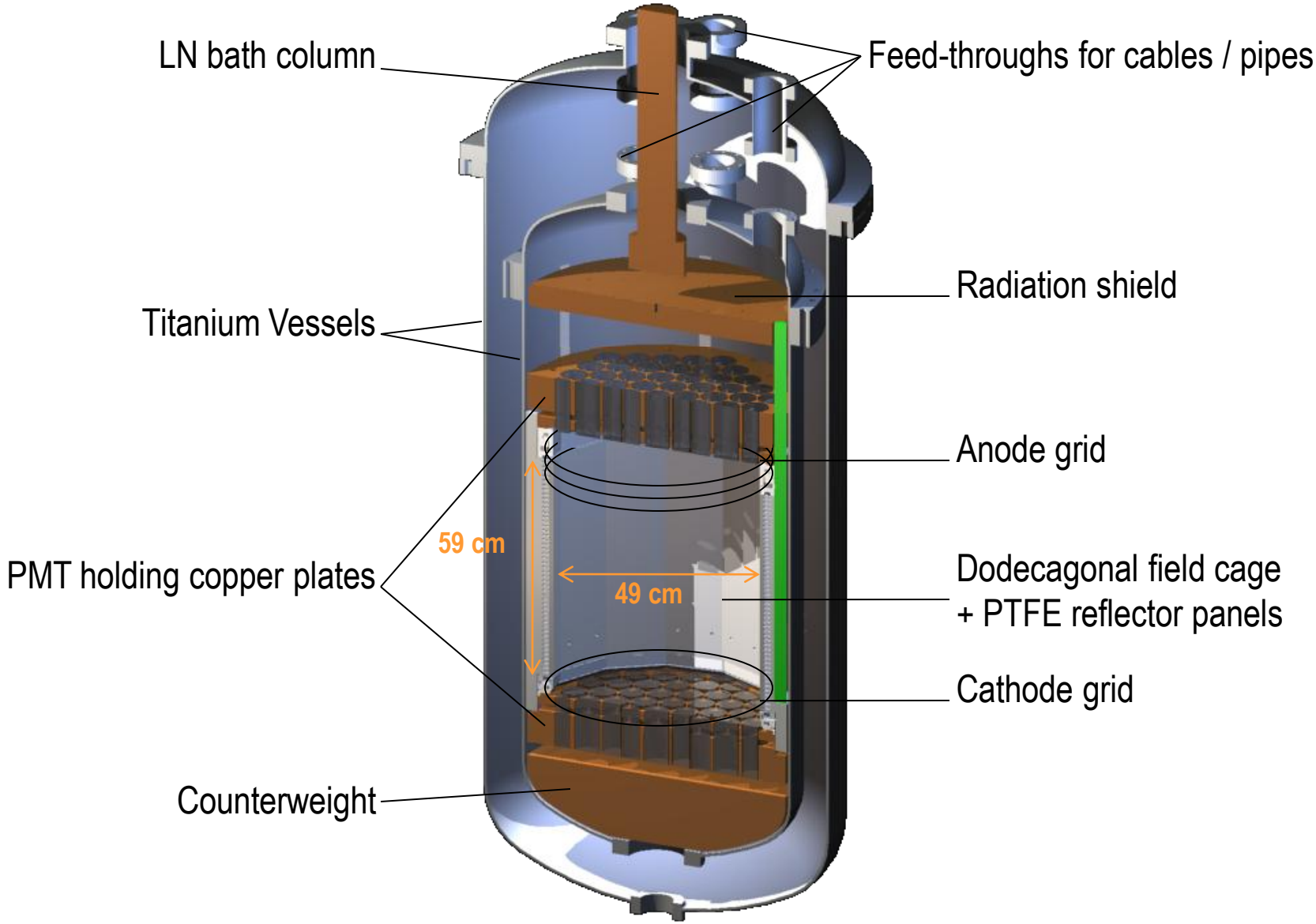
6 m diameter H_2O Cerenkov shield around



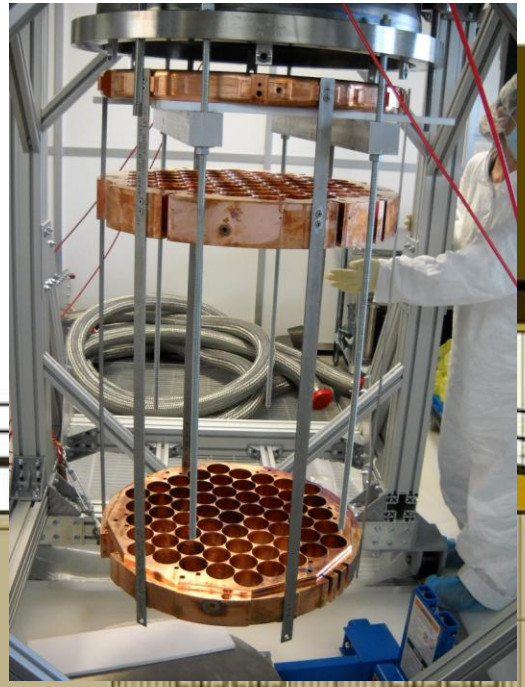
Aspect ratio of 1.2 : 1

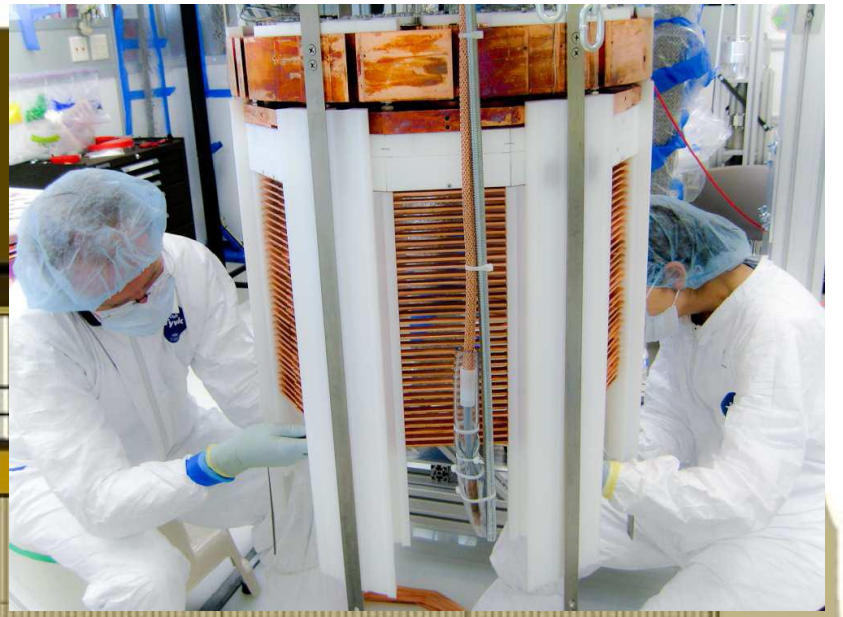
Dual-Phase Liquid Xenon Time Projection Chamber (TPC), 350 kg in total mass
O(1) kV/cm drift field in liquid, and O(10) kV/cm field in the gas stage for S2 production
122 Hamamatsu R8778 PMTs are divided equally between top and bottom
3-D imaging via TPC technique defines ~100 kg fiducial mass, self-shielding used

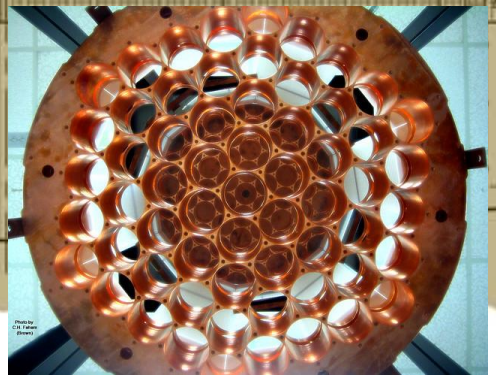
LUX Detector - Overview



LUX – Surface Facility @ Homestake







Test deployment of LUX in the Surface Facility Water Tank – April 2011

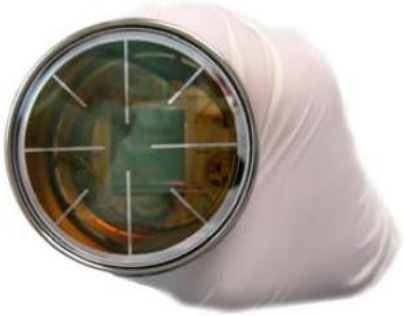
Putting it all together on the surface first…

Recent progress: **LUX cryostat successfully cooled to liquid xenon temperature – May 2011**.

PMTs and Signals

Photomultiplier Tubes (PMTs)

- Hamamatsu R8778 (2” diameter)
- Gain of 3.3 x10^6 (DM search mode)
- Average QE of 33% at room temperature and 178 nm wavelength
- Very low in background

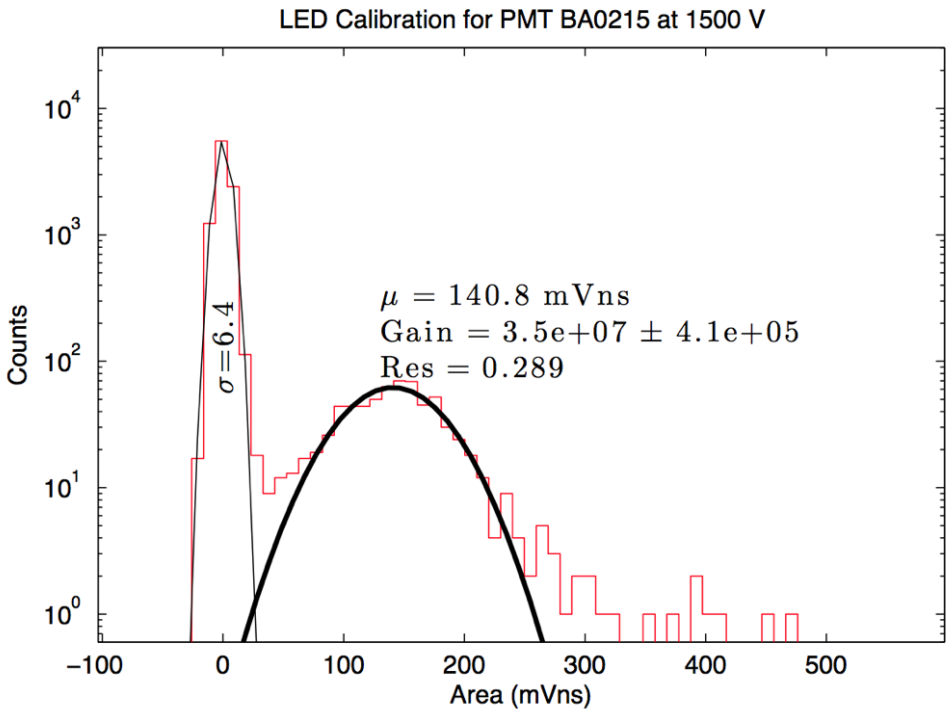


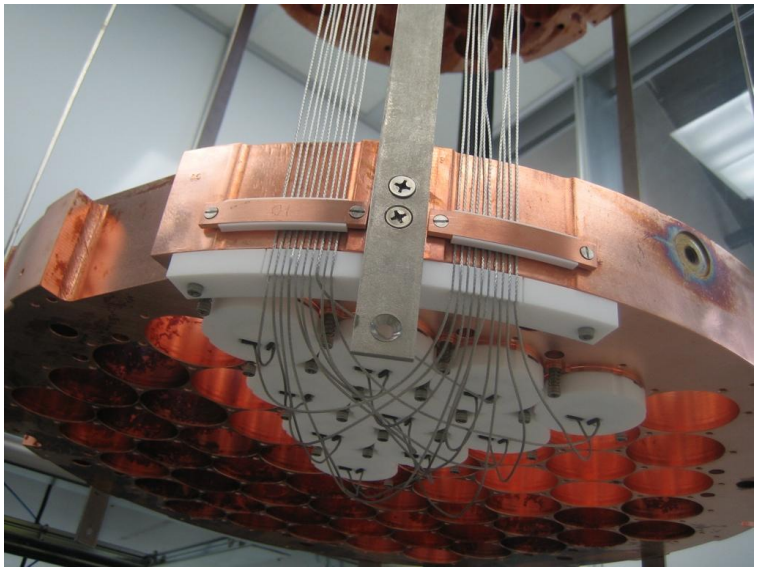
C.H. Faham

10 mBq

^{238}U, ^{232}Th, ^{40}K, ^{60}Co

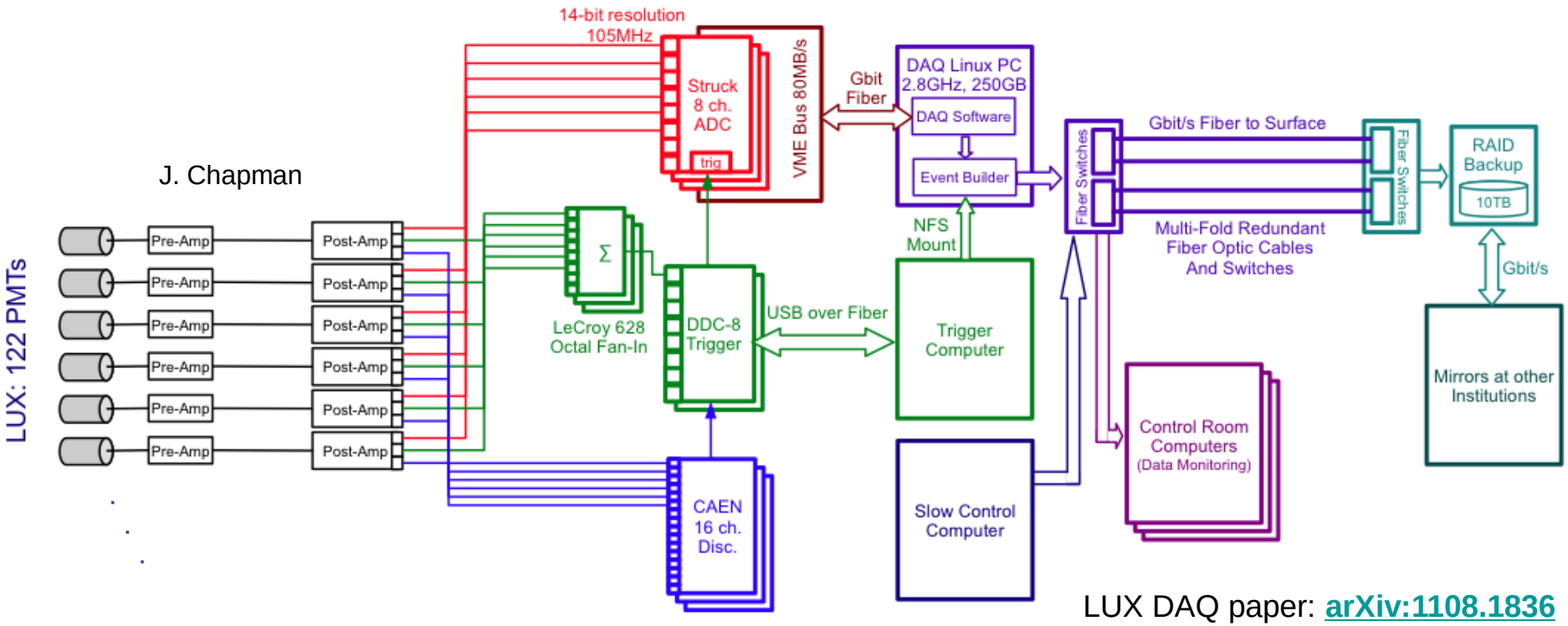
LUX PMT background paper in preparation





Data Acquisition System Schematic

J. Chapman

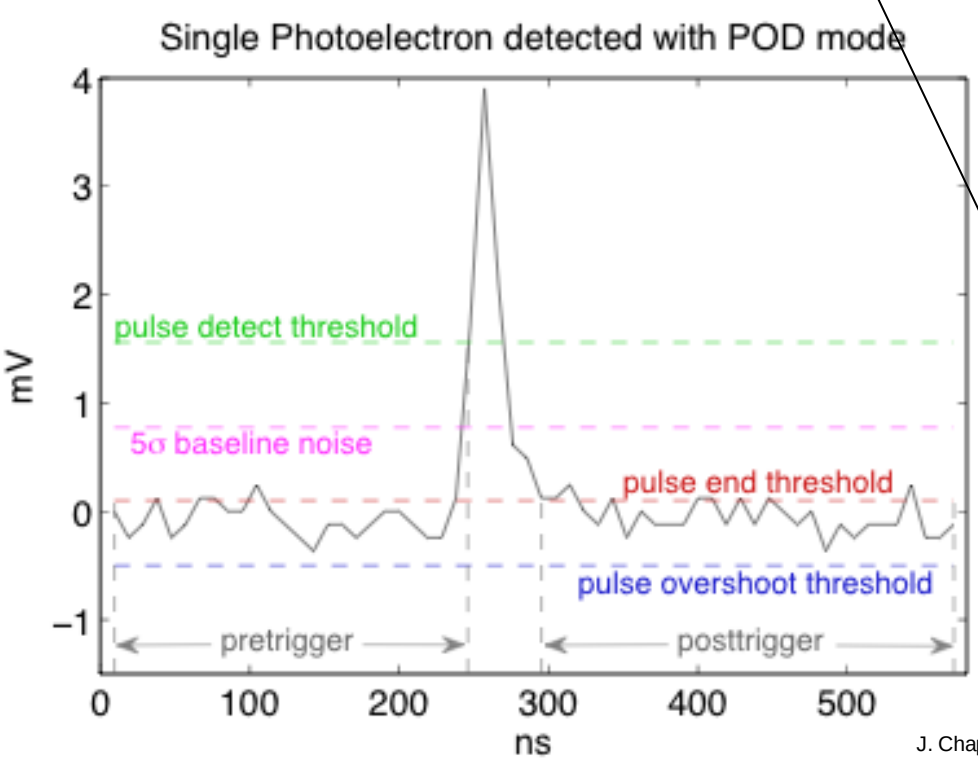


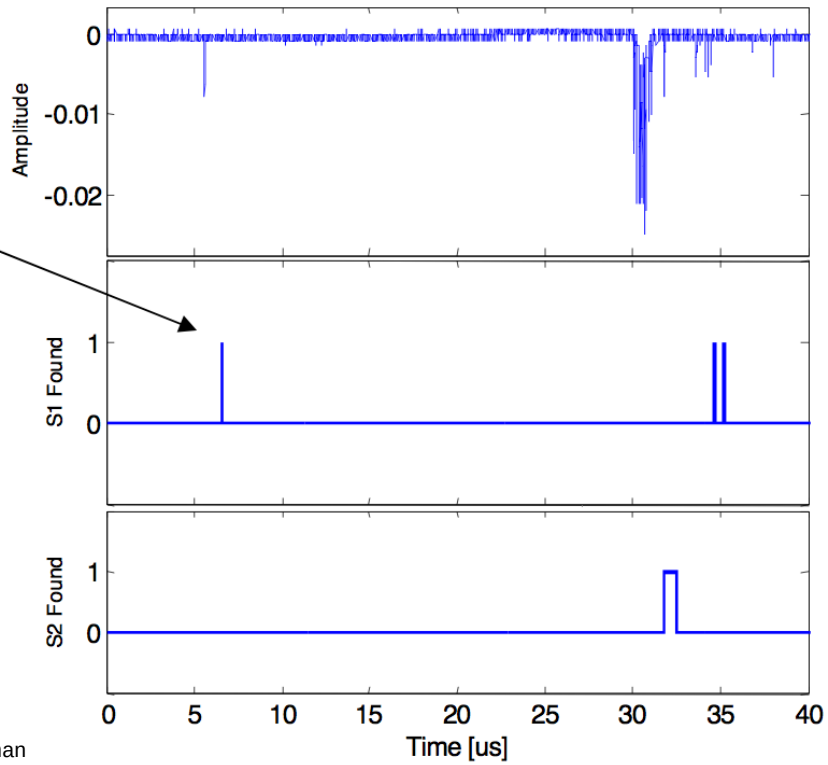
LUX DAQ paper: arXiv:1108.1836

- *Custom-built* analog electronics and custom-built digital trigger
- Can identify S1 and S2 pulses in real time, trigger on S1, S2, or S1+S2 for events
- Specially shaped signals for the digitizer, digital trigger, and analog trigger
- 1.5 kHz acquisition rate w/o dead time => dark matter calibrations w/ zero dead time
- 99.99% zero suppression, and can trigger by position and by energy
- 95% of single photoelectrons constitute >5σ upward fluctuation in baseline noise
- 120 keV_{ee} dynamic range with dark matter search gains

Pulse Only Digitization (POD) Mode and DDC-8 Trigger System

- 24 pretrigger samples and 31 posttrigger samples recorded
- Rolling average of baseline recorded with each pulse (16, 32, 64, or 128 samples)
- 2 double-hagenauer filters (S1 and S2) and robust threshold logic

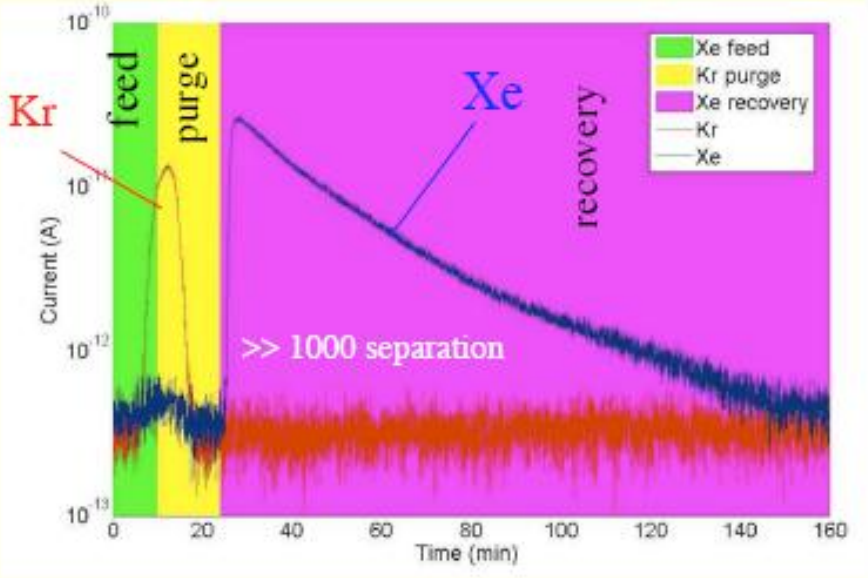




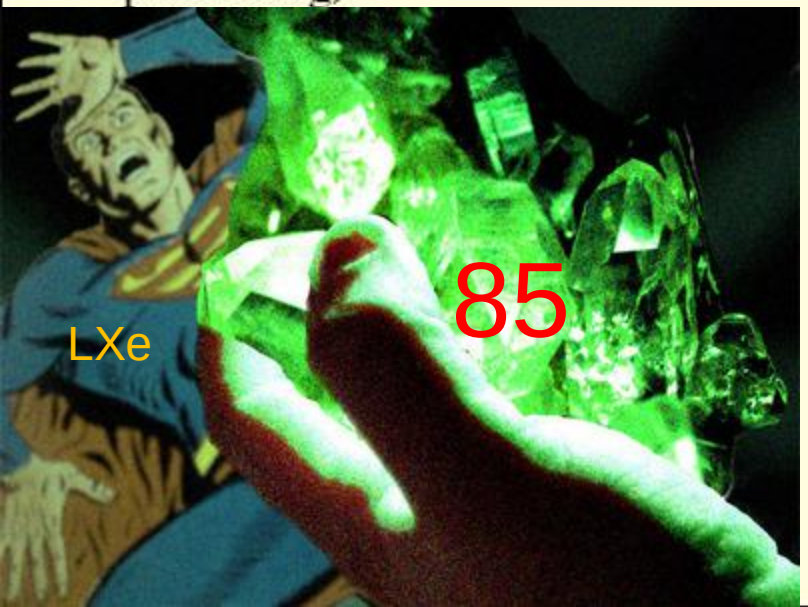
J. Chapman

Kr Removal

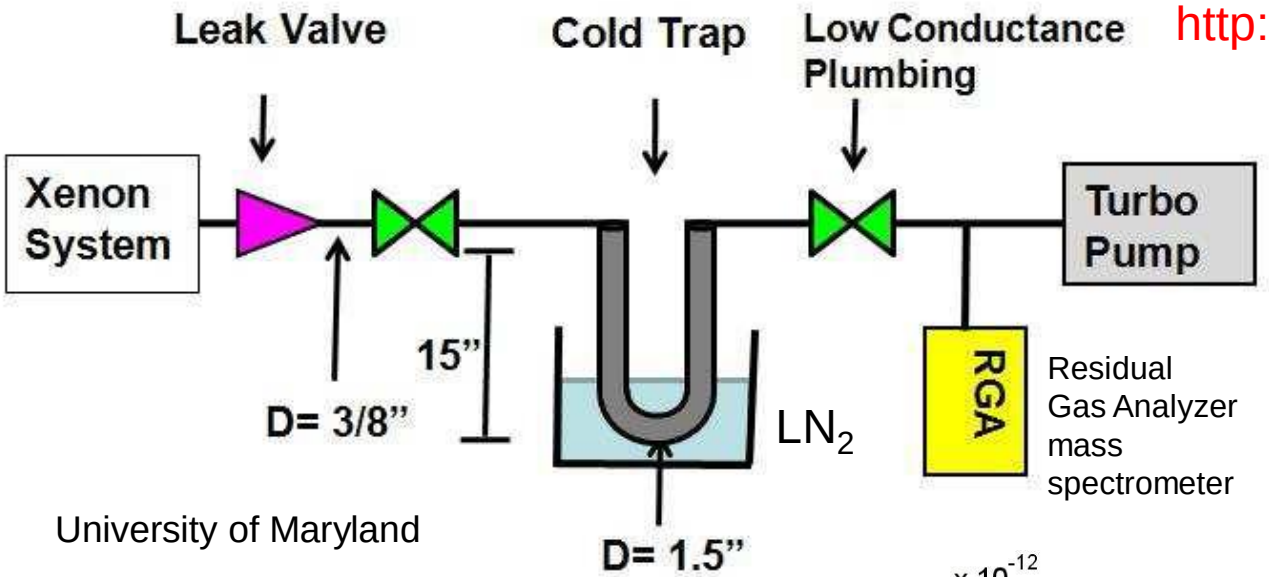
- ^{85}Kr - beta decay
  - Separate commercial Xe/Kr (ppb-ppm g/g)
  - Goals (LUX): 10 ppt
  - Chromatographic system developed for XENON10: < 2 ppt demonstrated at 2 kg/day production
- LUX system
  - 60 kg charcoal column, ~20x pumping speed
  - Vacuum Xe recovery ~ 8kg/day (2 month processing)



Case Western Reserve University



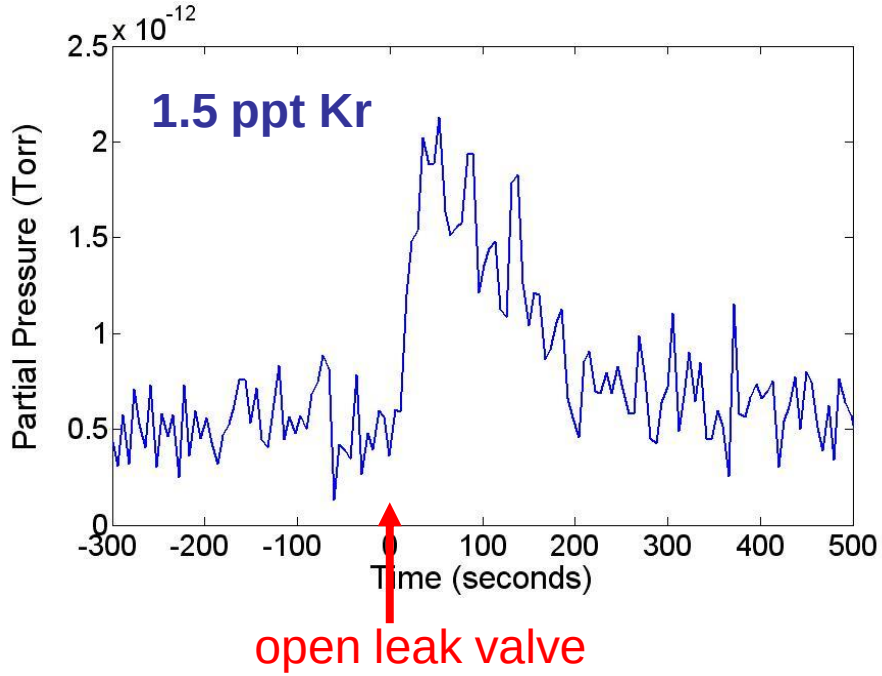
New analytic technique to detect krypton at the part-per-trillion level



http://arxiv.org/abs/1103.2714v3

GOAL: O(10) ppt ^{85}Kr
- Leads to an event rate of O(0.1) events in the 2-10 keV$_{ee}$ regime after 10^4 kg-days and 99.5% rejection of e^- recoils

University of Maryland

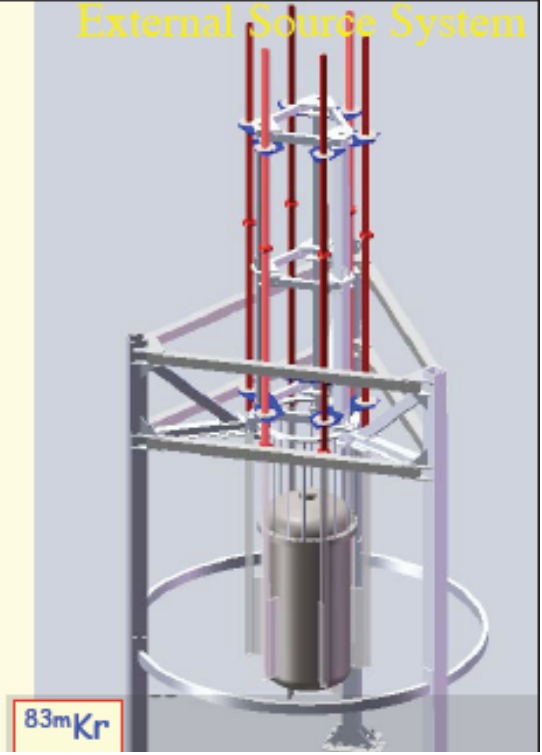


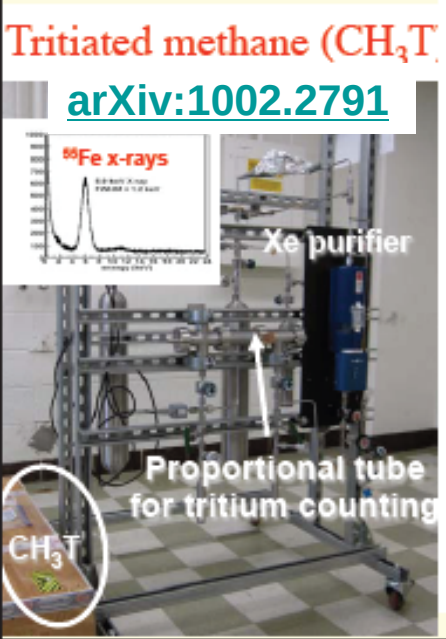
Calibrations

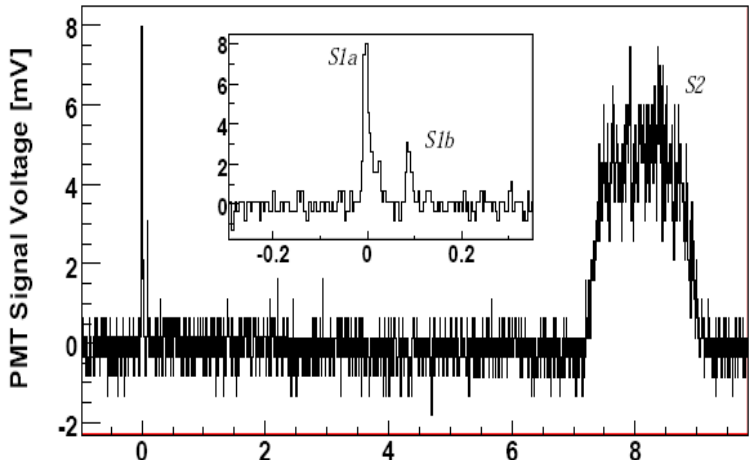
- External gamma/neutron sources: insertion into water tank
- Two internal sources: only way to obtain low energy calibrations in detector center.
  - ^{83}Kr: energy calibration (Yale)
  - Tritium source: electron recoil discrimination (Maryland)

^{137}Cs
^{208}Tl
Am/Be
^{252}Cf

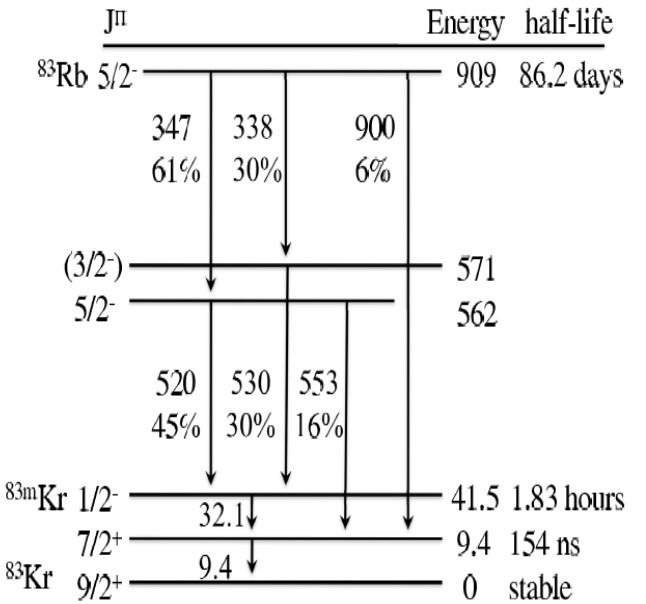
source strengths chosen such that there in no pileup (200 Hz is max)





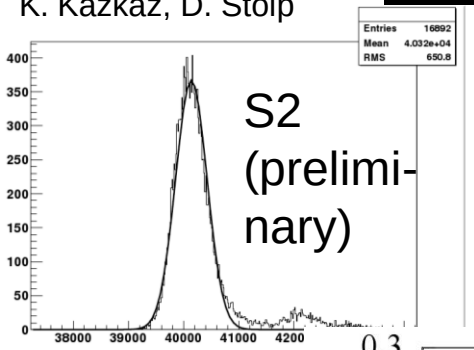


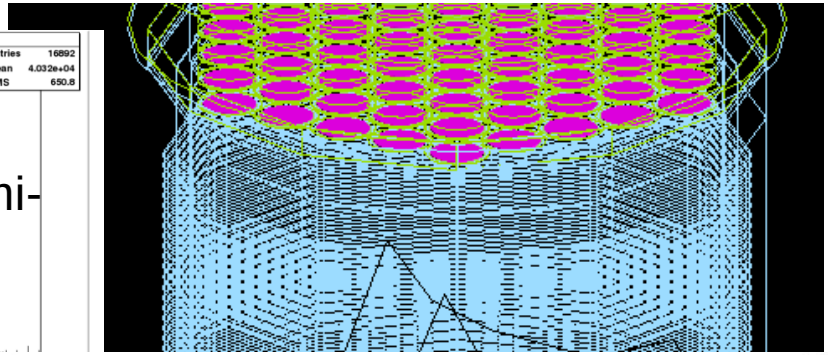
L.W. Kastens et al., *A ^{83}Kr^{m} source for use in low-background liquid xenon time projection chambers*, 2010 JINST 5 P05006



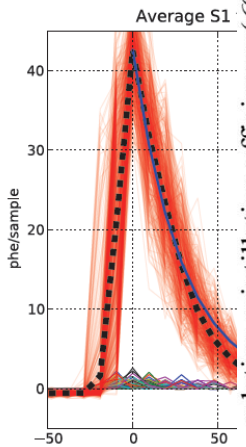
Simulations

K. Kazkaz, D. Stolp

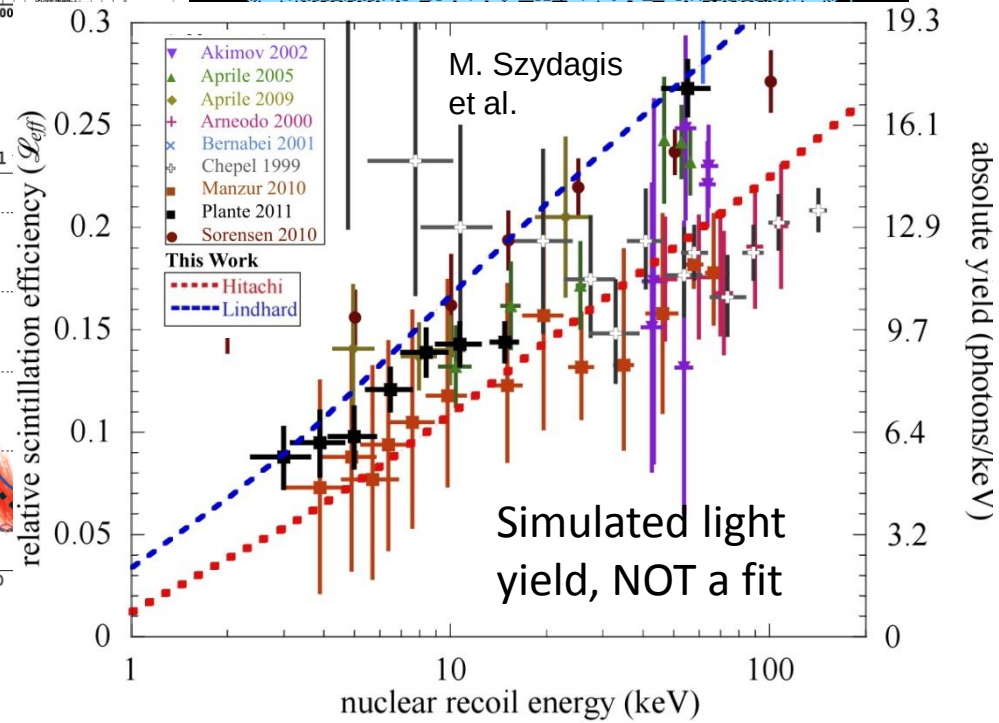




M. Woods



S1

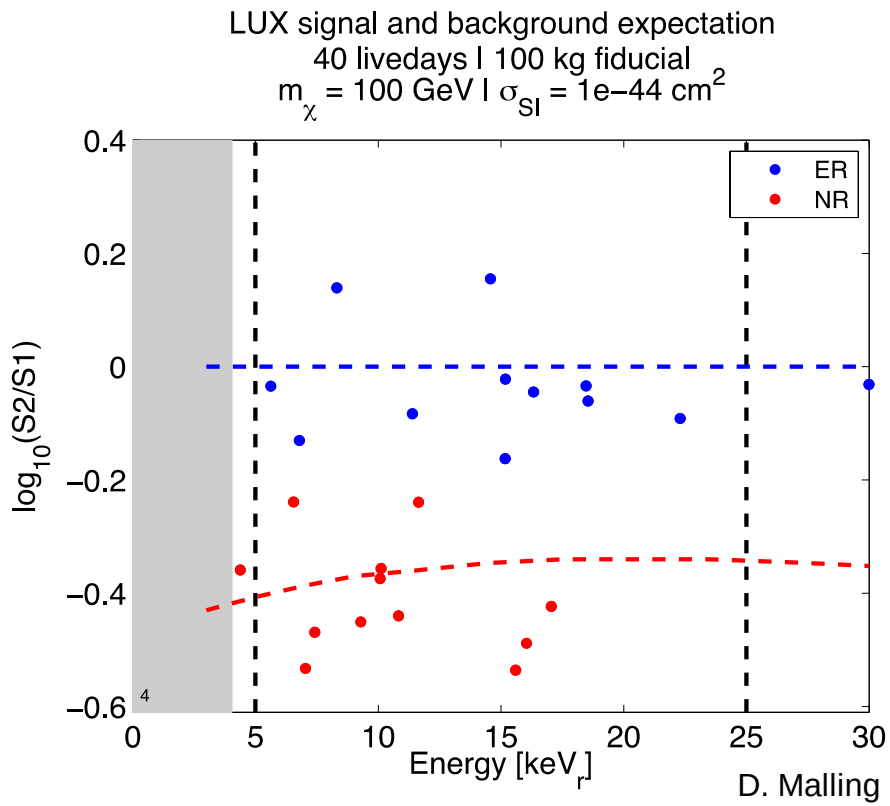


- Very thorough and flexible Geant4 simulation of the geometry: LUXSim
  - For understanding the light collection efficiency for the PMTs
  - For helping know the physics reach
  - Component-centric approach in Geant
  - Includes the small background contributions from all the components: decay chain generator
  - 3-D visualization with OpenGL: shoot particles
- Results in minutes or hours at most with 10^5 - 10^6 photons, analysis fast

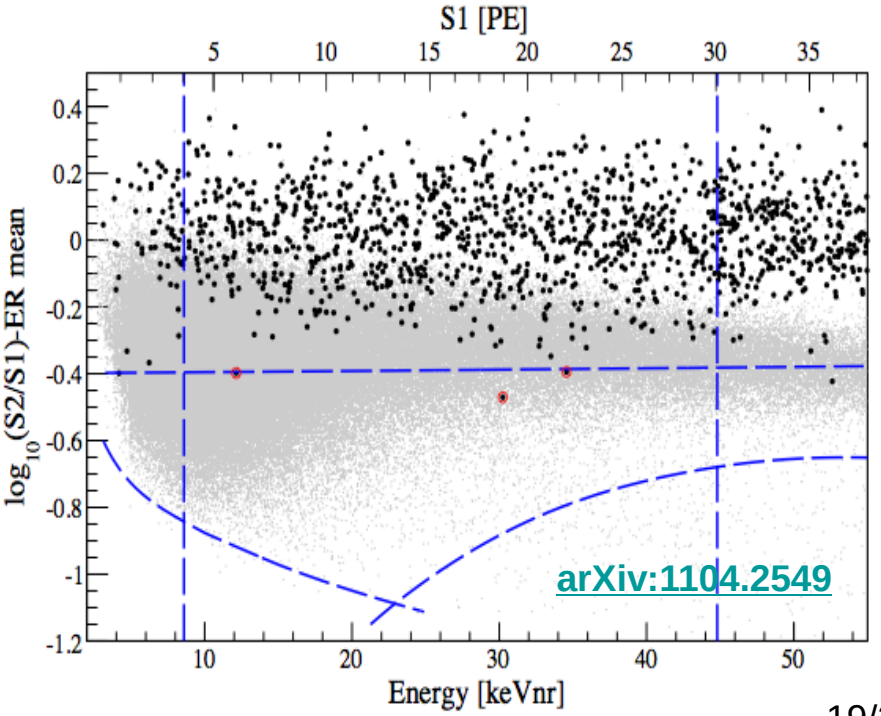
-LUXSim paper in preparation
-decay chain generator paper: **arXiv:1104.2834**
-NEST (Monte Carlo) scintillation physics: **arXiv:1106.1613**, submitted to JINST; C.E. Dahl, Ph.D. Thesis, 2009

LUX Monte Carlo of the First 40 days

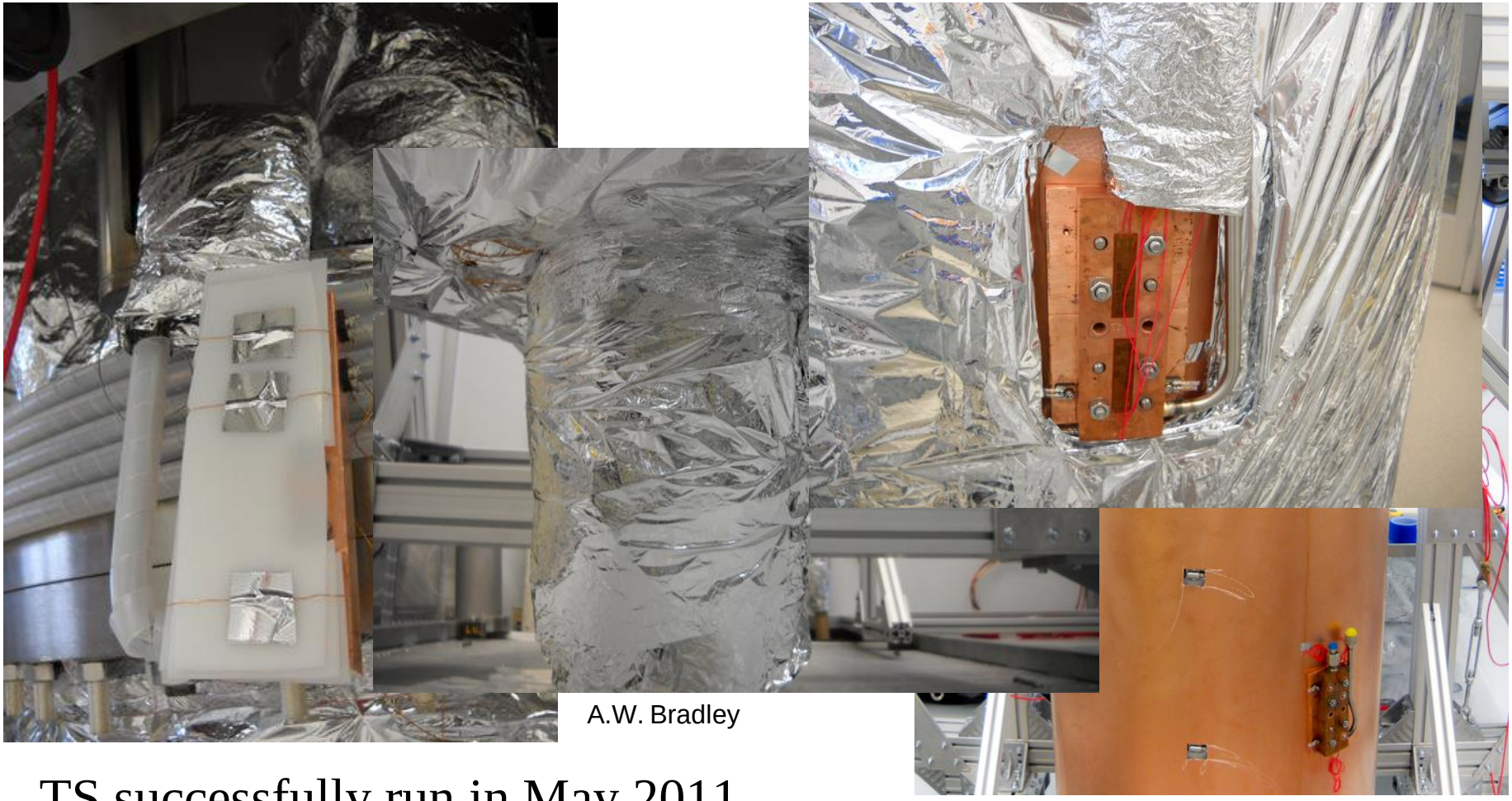
- Red Points: WIMP events after only 40 days assuming a WIMP model for mass 100 GeV at current best 90% CL exclusion sensitivity
- Blue Points: Total # of single scatter electron recoil events (before any cuts) after 40 days of running
- LUX – strong emphasis on WIMP discovery / Plan to run LUX for 300 days



XENON100 4,000 kg-days for comparison.
Note much higher electron recoil rate



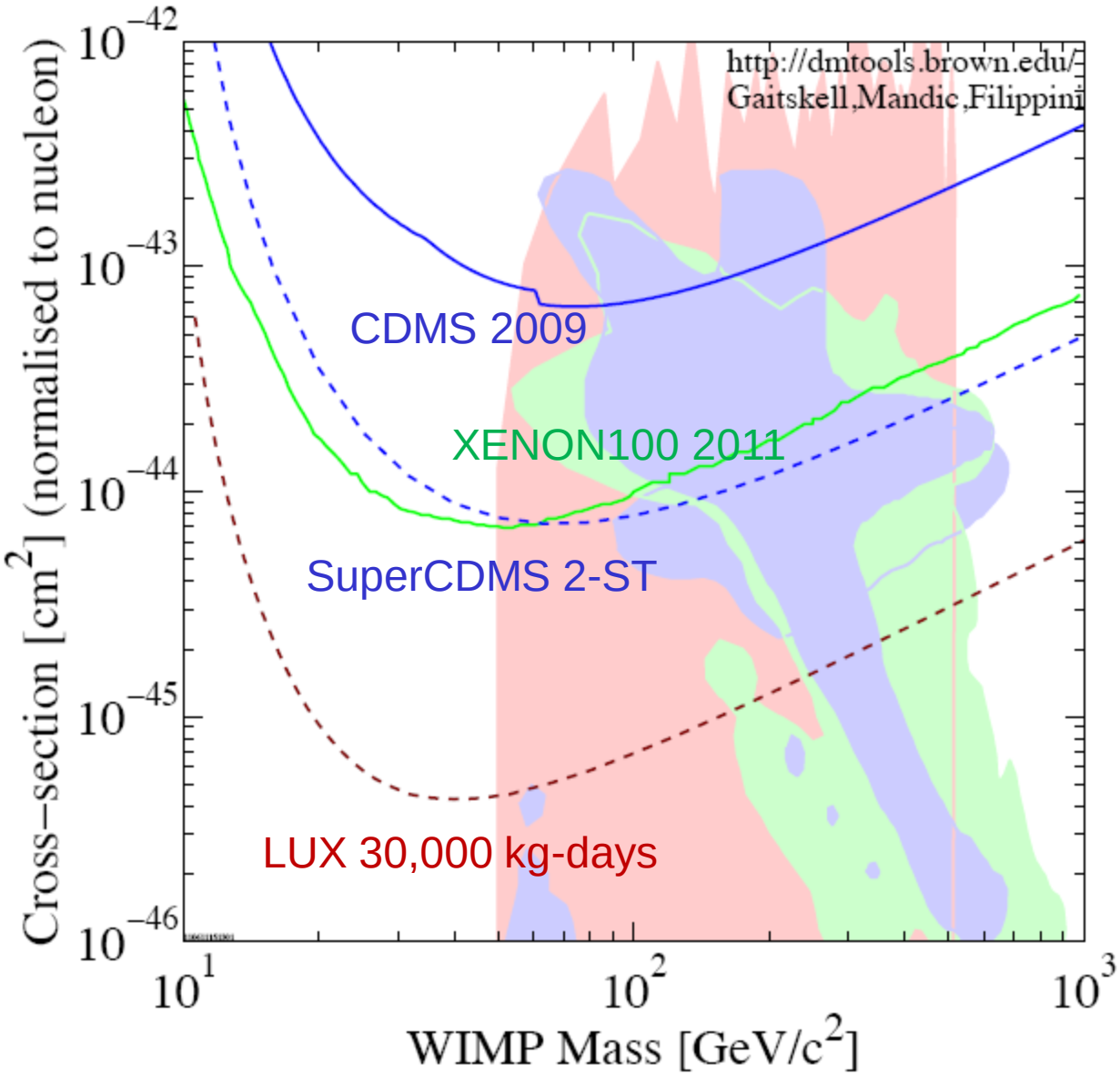
Cryogenics: Thermosyphon Cooling System



A.W. Bradley

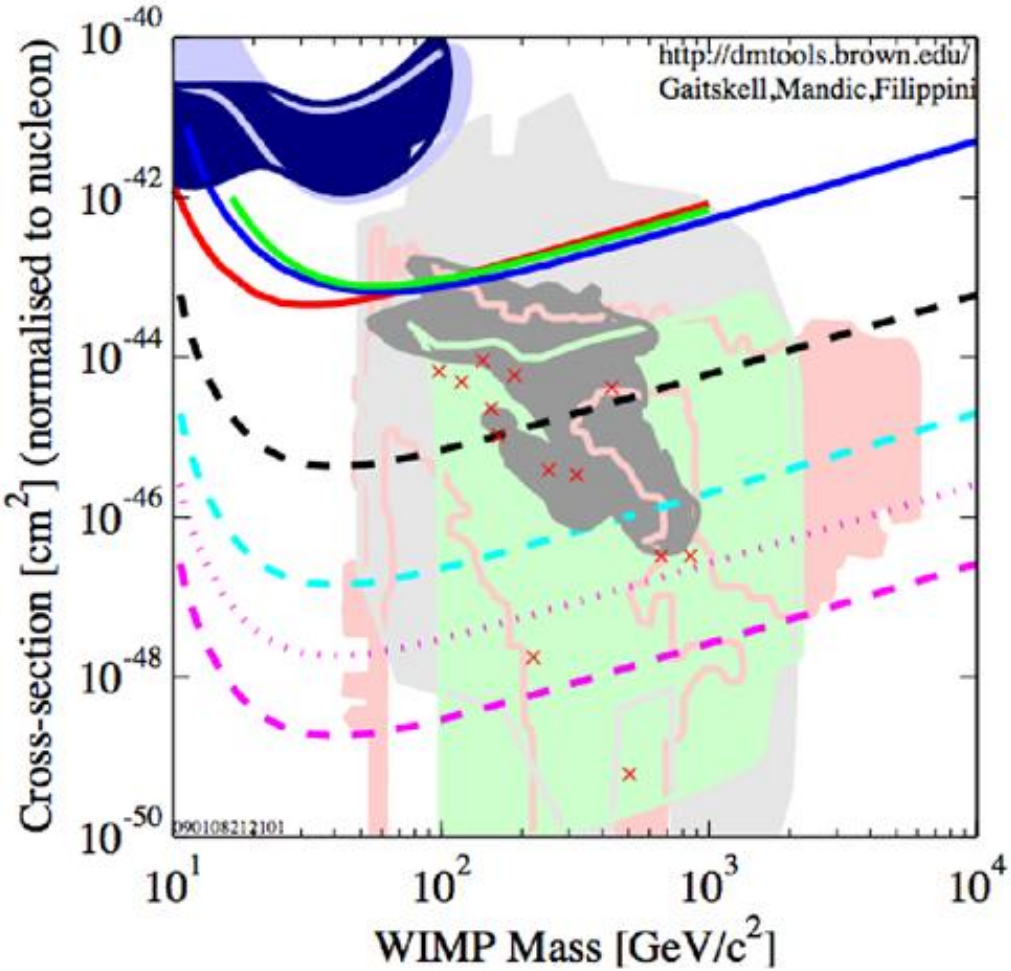
- TS successfully run in May 2011.
- Max cooling rate is 1 K/hr.
- Held target temperature (175-185 K) for days with 50 W PID heaters.
- Heat exchange system more than 95% efficient.

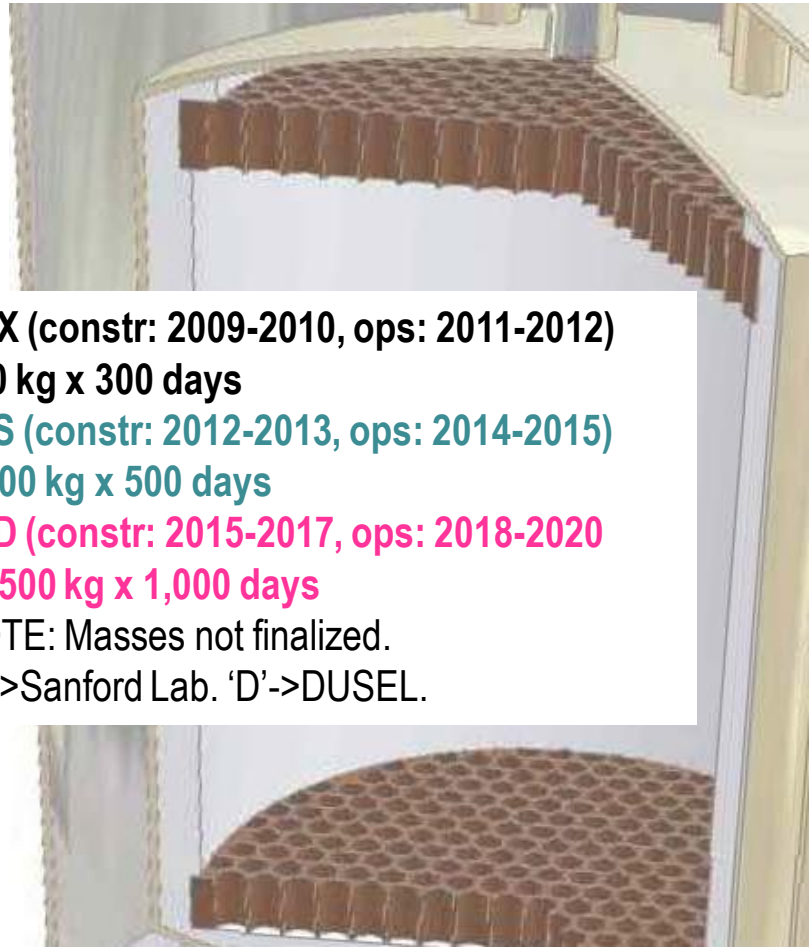
LUX dark matter sensitivity



Status: LUX is <u>now</u> being tested on the surface at Homestake.
Moving underground in December of 2011.

Evolution over Time





LUX (constr: 2009-2010, ops: 2011-2012)
100 kg x 300 days
LZS (constr: 2012-2013, ops: 2014-2015)
1,500 kg x 500 days
LZD (constr: 2015-2017, ops: 2018-2020
13,500 kg x 1,000 days
NOTE: Masses not finalized.
'S'->Sanford Lab. 'D'->DUSEL.

- Projections based on
  - Known background levels
  - Previously obtained electron attenuation lengths
  - Previous discrimination factors
- Careful fiducial volume selection
  - <1 nuclear recoil event during planned exposure (total)

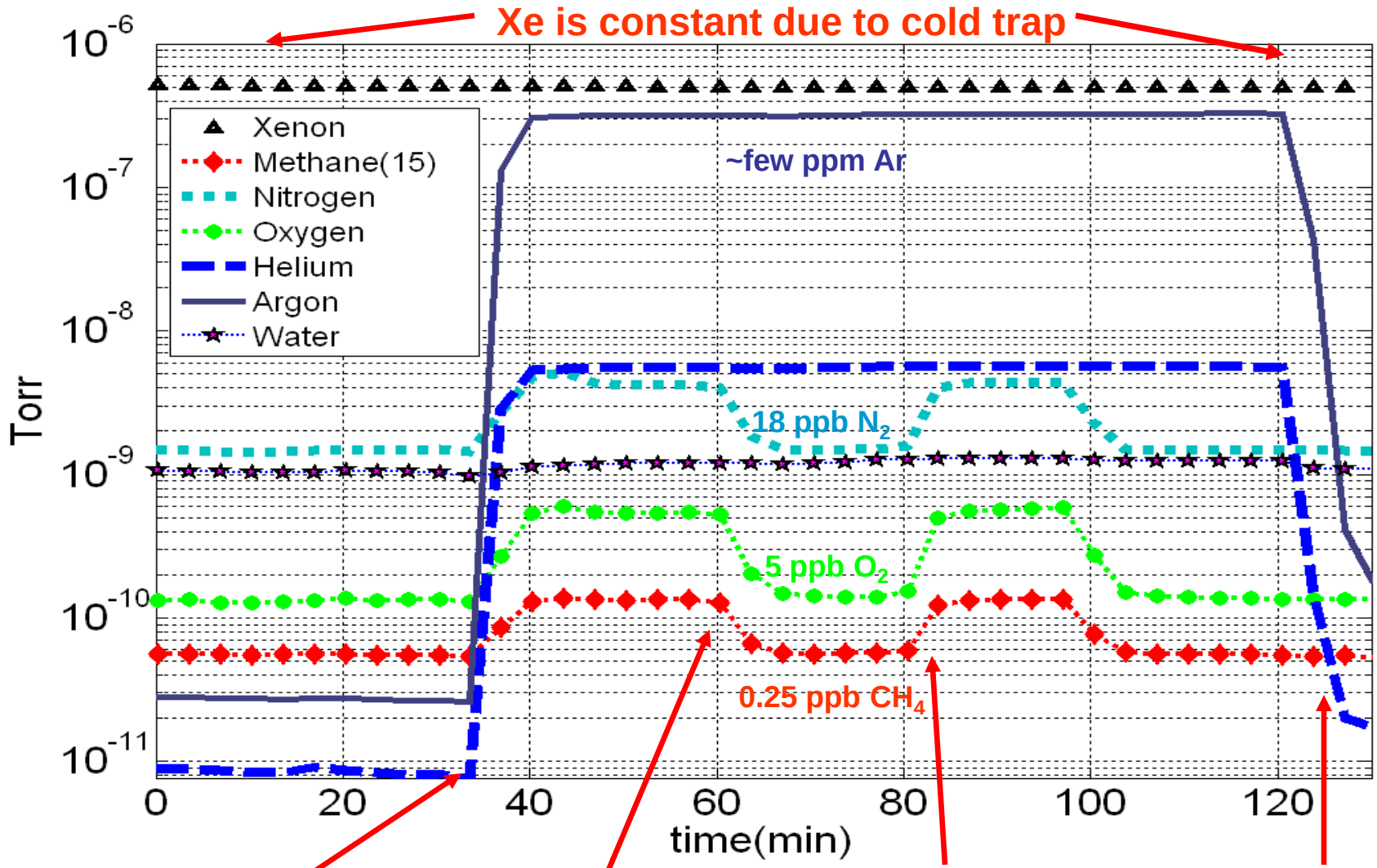
A Brief Summary

- Two signals: discrimination between nuclear, electron recoils when looking at ratio of S2 to S1
- Self-shielding of Xe helps you even more
- Powerful and flexible LUX DAQ
- Proven ^{85}Kr removal and measurement systems
- Thorough calibration with different sources inside and out
- Robust Monte Carlo simulation of geometry and physics
- Proven cryogenic system
- Incredible discovery potential
- Undergoing testing on surface right now, with the underground deployment around the corner

Extra Slides

Can also detect electronegative impurities at a less than 1 ppb level

arXiv:1002.2742



open leak valve, bypass gas purifier

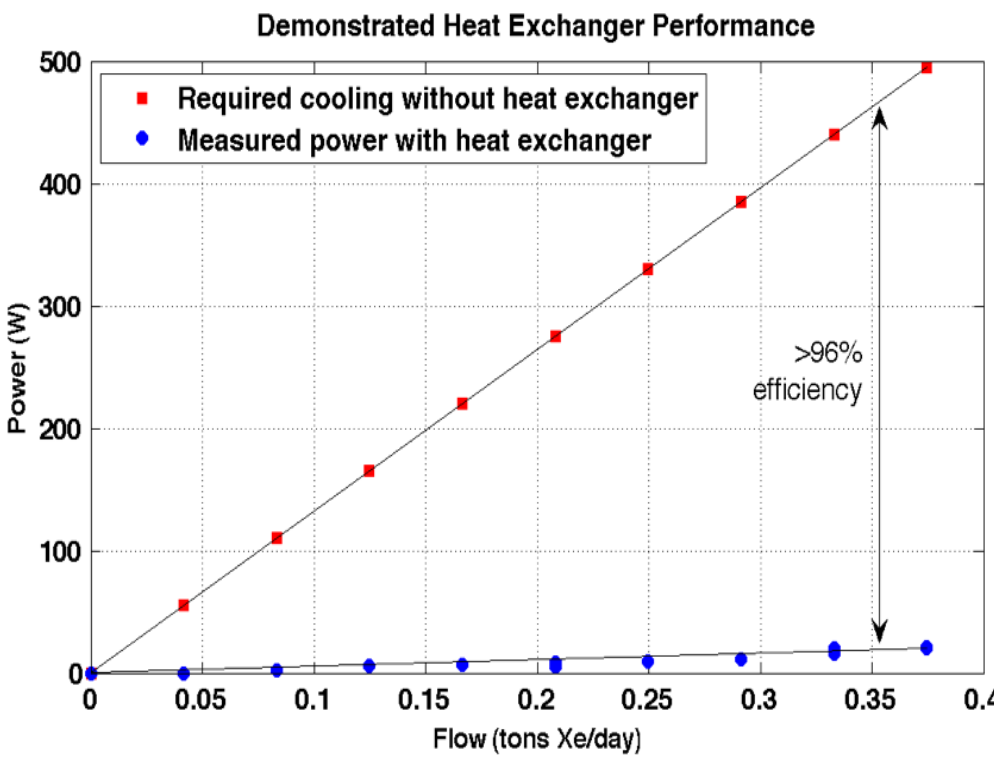
flow through gas purifier

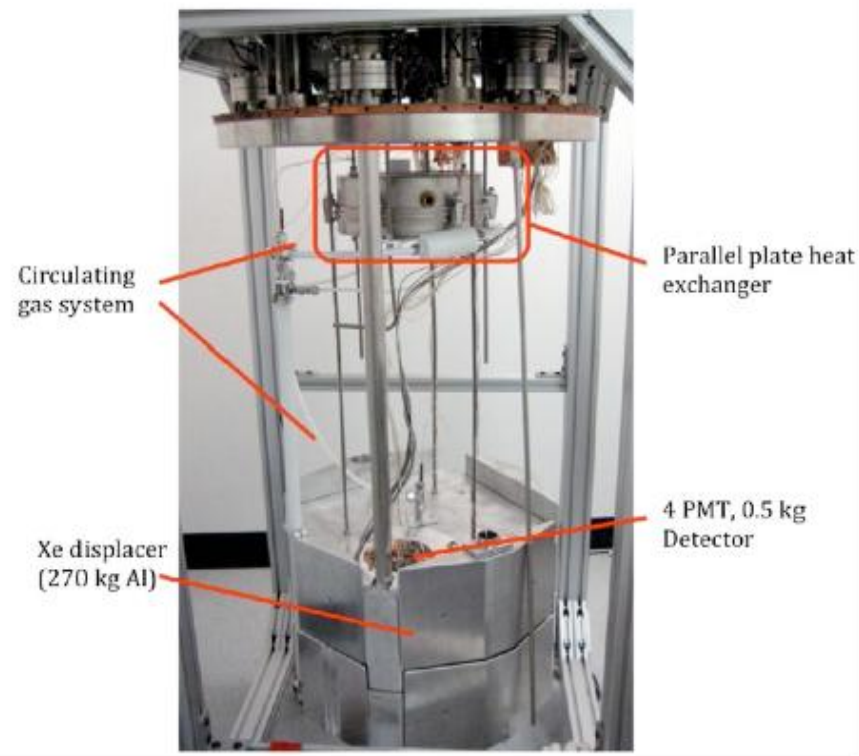
bypass gas purifier

close leak valve to measure backgrounds

Heat Exchanger Operates >96% Efficient

Demonstrated - 18 W required to circulate 0.4 tons of Xe a day
Evaporate Liquid > Gas / Purification -> Re-condense Liquid





LUX 0.1