Noble Travails: LUX @ Sanford Lab

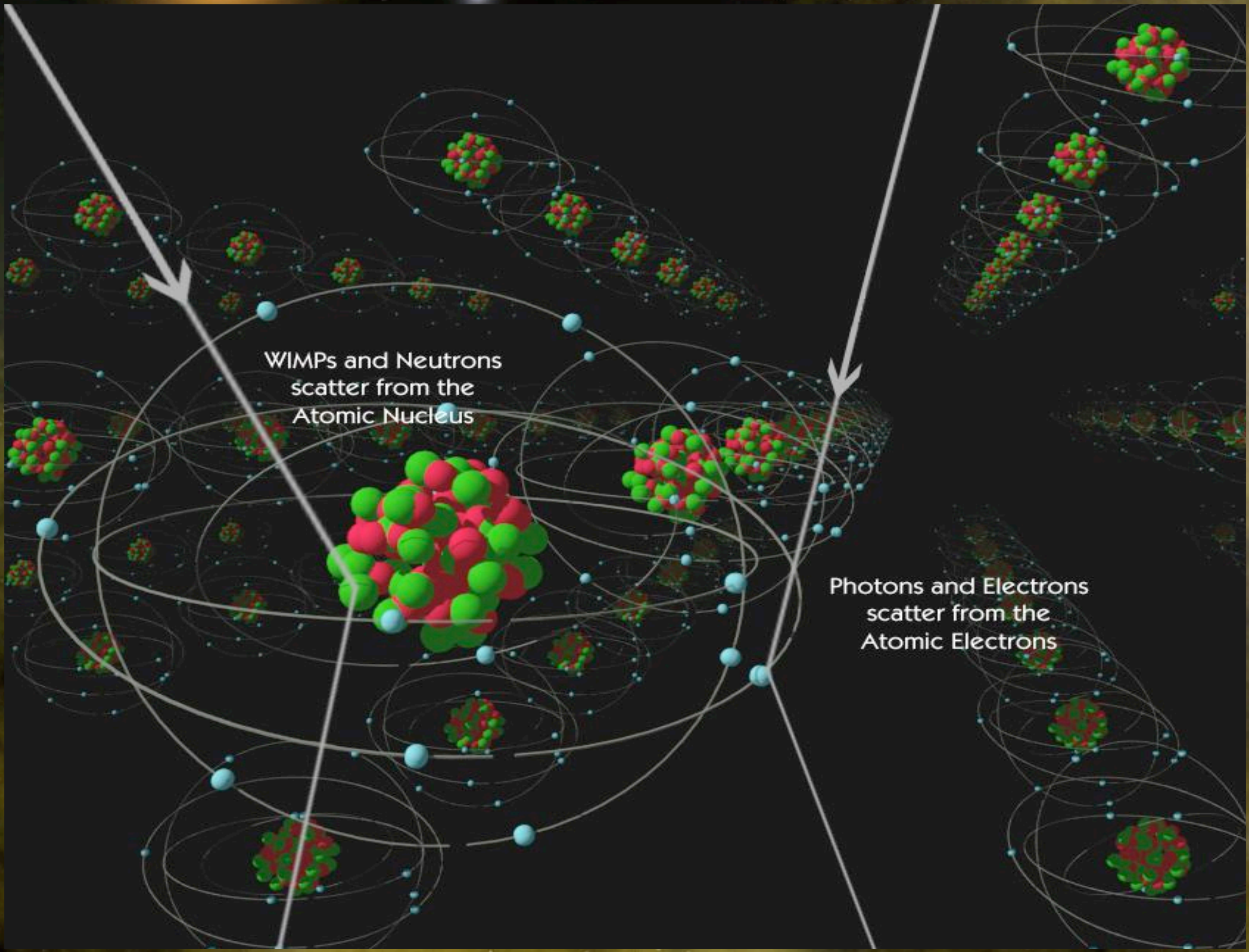
http://luxdarkmatter.org

Rick Gaitskell,
Joint Spokesperson,
LUX Collaboration

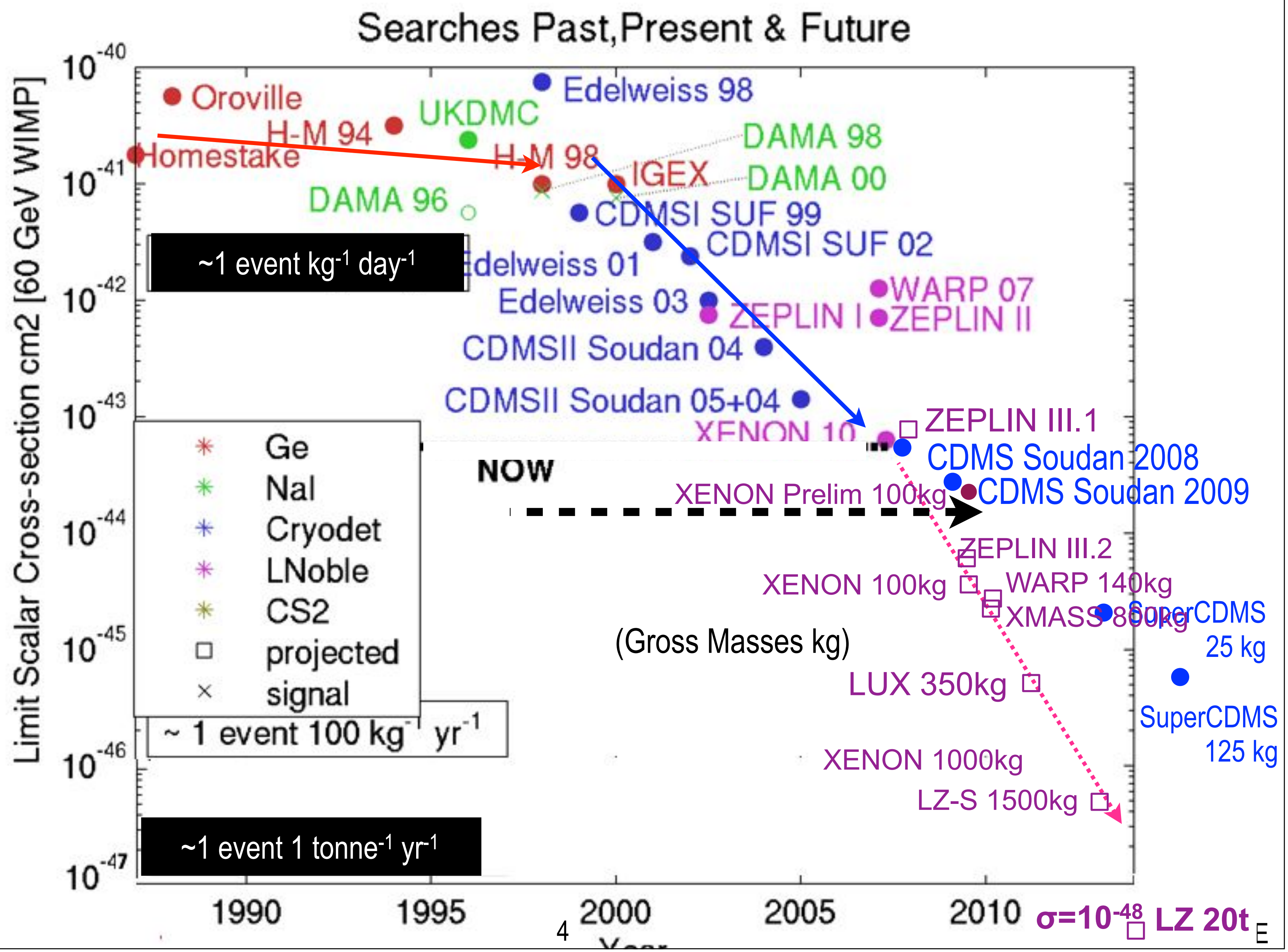
Particle Astrophysics Group, Brown University, Department of Physics (Supported by US DOE HEP)
http://particleastro.brown.edu


atter
LEVEL NO. 27
2341 FEET BELOW THE SURFACE
CDMS II: Winter
@Soudan Minnesota
New Sanford Lab
LUX @Homestake,
South Dakota
PHYSICS ITALIAN
STYLE XENON10
@ Gran Sasso
Sanford
Laboratory

Interaction with Ordinary Matter



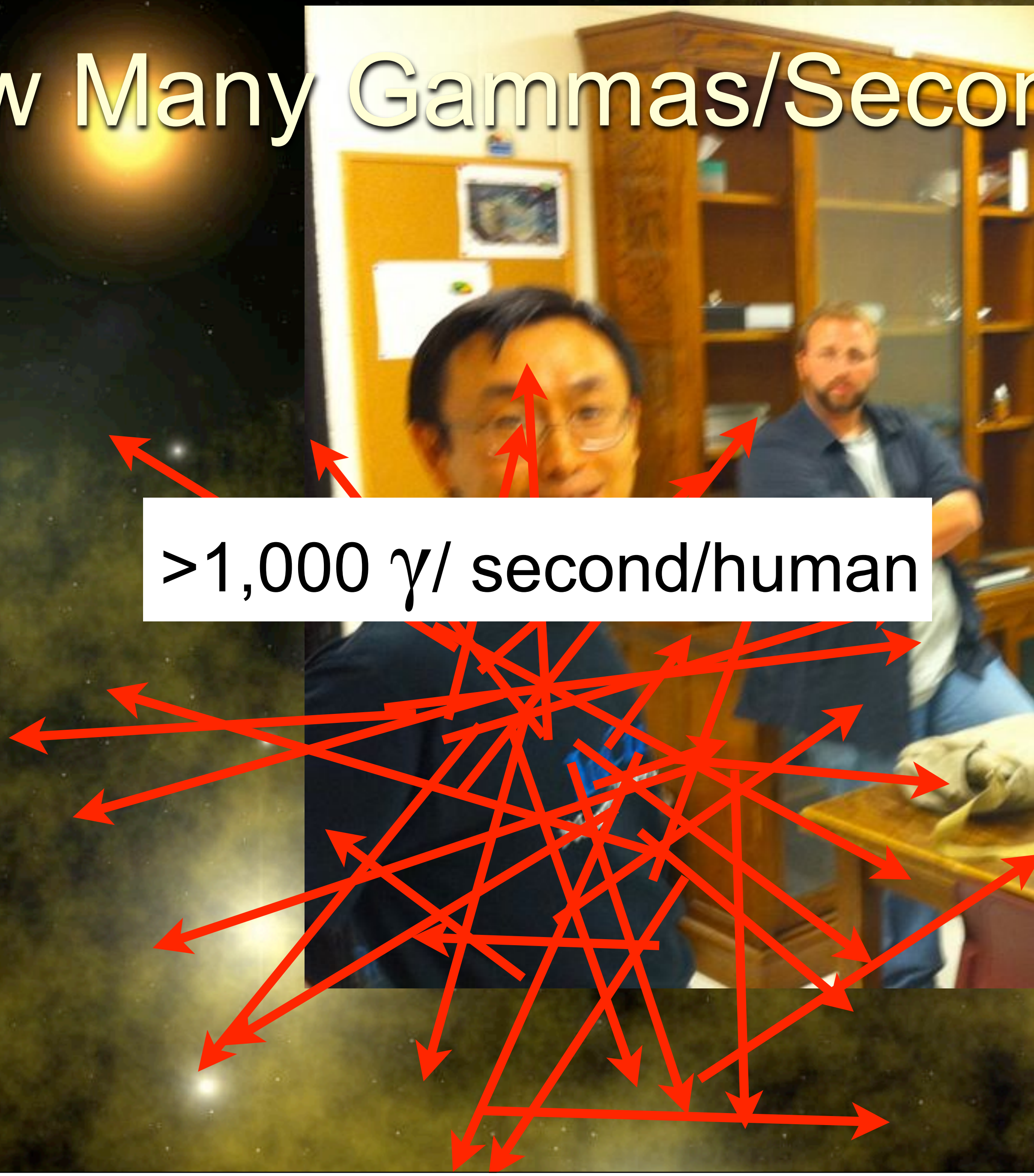
DM Direct Search Progress Over Time (2010)



Radioactive Background Challenges

- Search sensitivity (low energy region <<100 keV)
  - Current Exp Limit < 1 evt/kg/month, ~< $10^{-1.5}$ evt/kg/day
  - Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day
- Activity of typical Human?

How Many Gammas/Second?

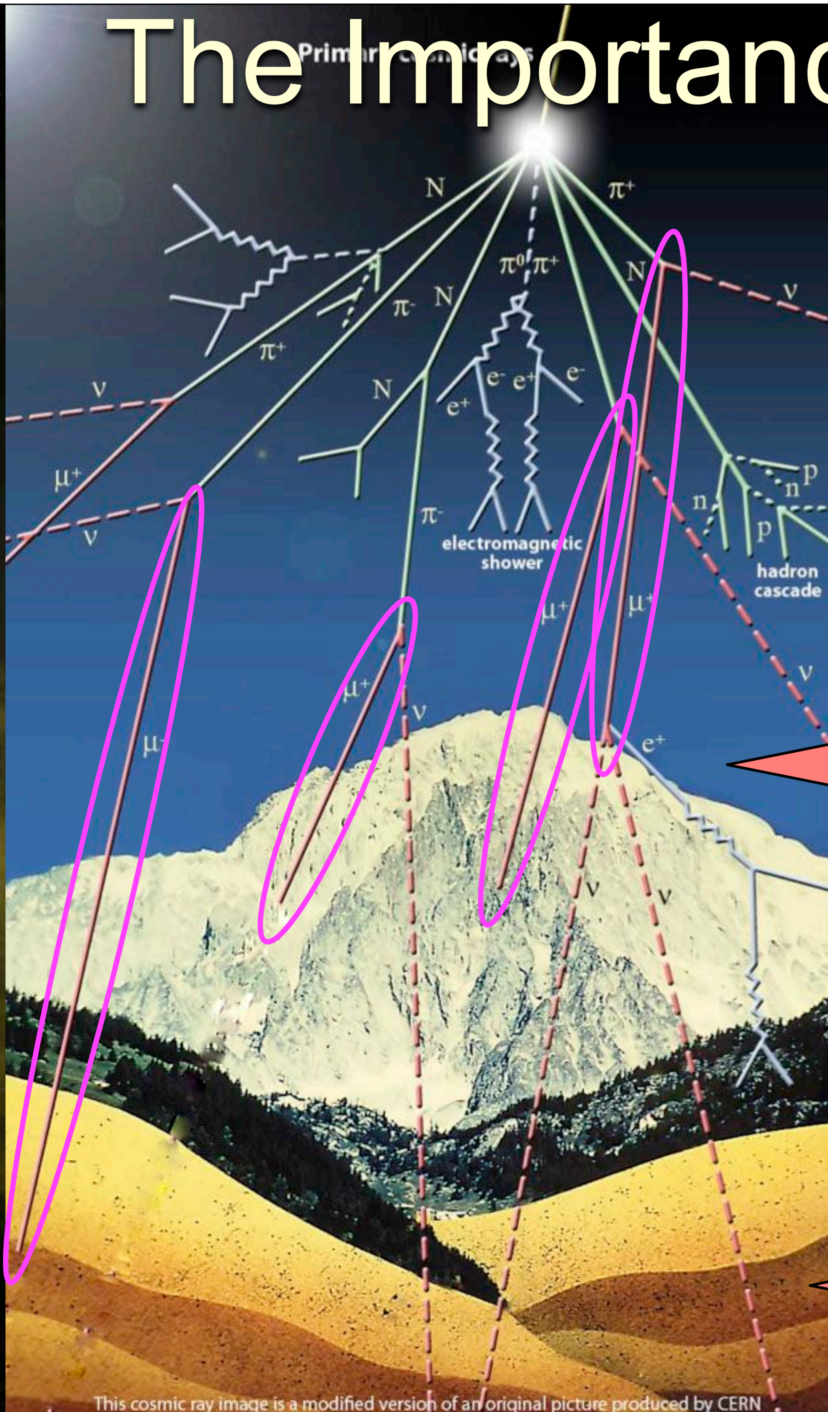


>1,000 γ/ second/human

Background Challenges

- Search sensitivity (low energy region <<100 keV)
  - Current Exp Limit < 1 evt/kg/month, ~< $10^{-1.5}$ evt/kg/day
  - Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day
- Activity of typical Human?
- ~10 kBq (10^4 decays per second, 10^9 decays per day)
- Environmental Gamma Activity
  - Unshielded 10^7 evt/kg/day (all values integrated 0–100 keV)
  - This can be easily reduced to ~10^2 evt/kg/day using 25 cm of Pb
- Main technique to date focuses on nuclear vs electron recoil discrimination
  - This is how CDMS II experiment went from 10^2 -> 10^{-1} evts/kg/day (continue push for >>99.99% rejection)
- Moving below this
  - Reduction in External Gammas: e.g. High Purity Water Shield 4m gives <<1 evt/kg/day
  - Gammas from Internal components - goal intrinsic U/Th contamination toward ppt (10^{-12} g/g) levels
  - Detector Target can exploit self shielding for inner fiducial if intrinsic radiopurity is good
- Environmental Neutron Activity / Cosmic Rays => DEEP
  - (α,n) from rock 0.1 cm^{-2} day^{-1}
  - Since <8 MeV use standard moderators (e.g. polyethylene, or water, 0.1x flux per 10 cm
  - Cosmic Ray Muons generate high energy neutrons 50 MeV - 3 GeV which are tough to moderate
  - Need for depth (DUSEL) - surface muon 1/hand/sec, Homestake 4850 ft 1/hand/month

The Importance of Depth



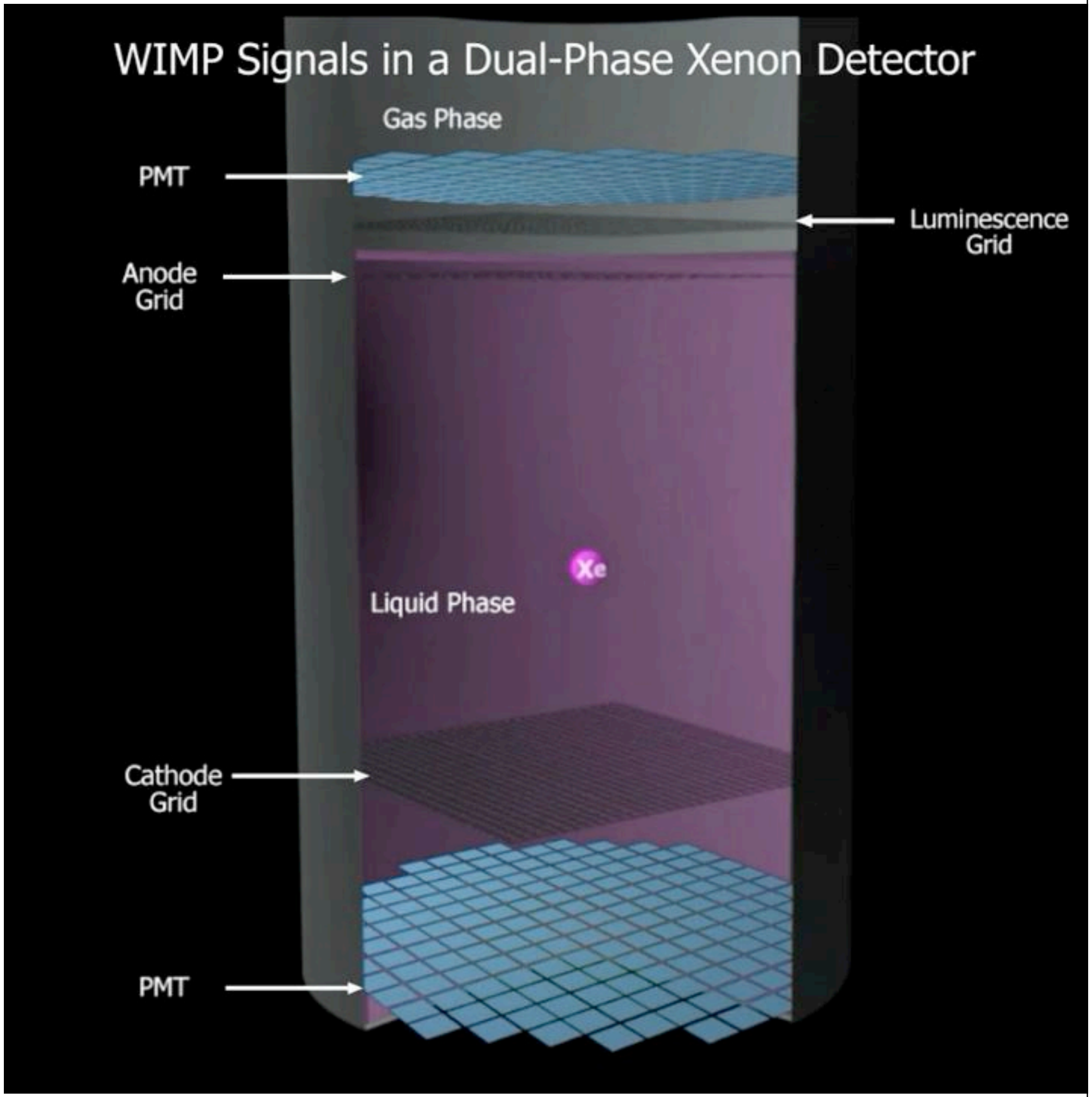
At the earth's surface cosmic ray muons pass through your hand at more than 1 every second

At a depth of 4850 ft underground in Sanford Lab, the rock overburden reduces the flux of cosmic muons through your hand to around 1 per year

Noble Liquid Dual phase Time Projection Chamber

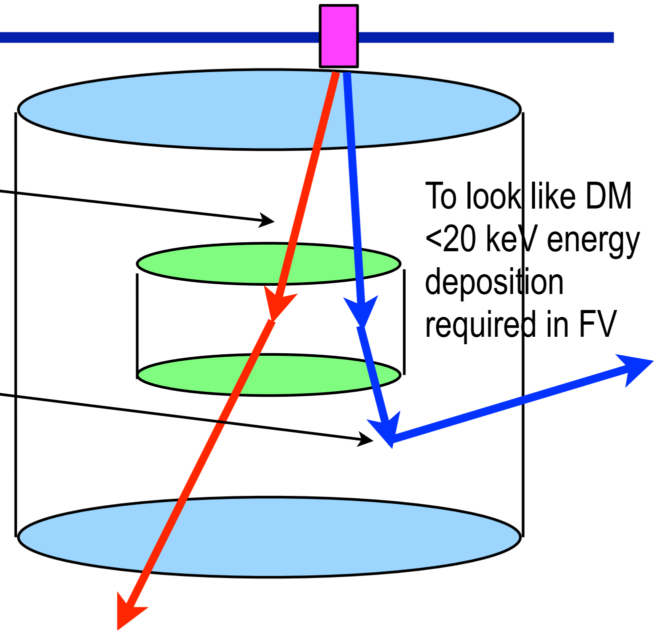
- Can measure single electrons and photons.
- Charge yield reduced for nuclear recoils.
- Good 3D imaging
  - *Eliminating edges crucial.*

- Imminent Results:
  - XENON100 (2010, Gran Sasso Italy)
  - ZEPLIN III (2010, Boulby, New run)
- Construction/Running
  - XENON100 (Gran Sasso)
  - LUX 350 kg (Sanford Lab, SD)
  - WARP 140 (Gran Sasso)
  - XMASS-DM 10 kg (Kamioka)
  - ARDM (Canfranc)
- Single Phase is a distinct technique
  - XMASS 800 kg
  - CLEAN/DEAP 350 kg+3500 kg

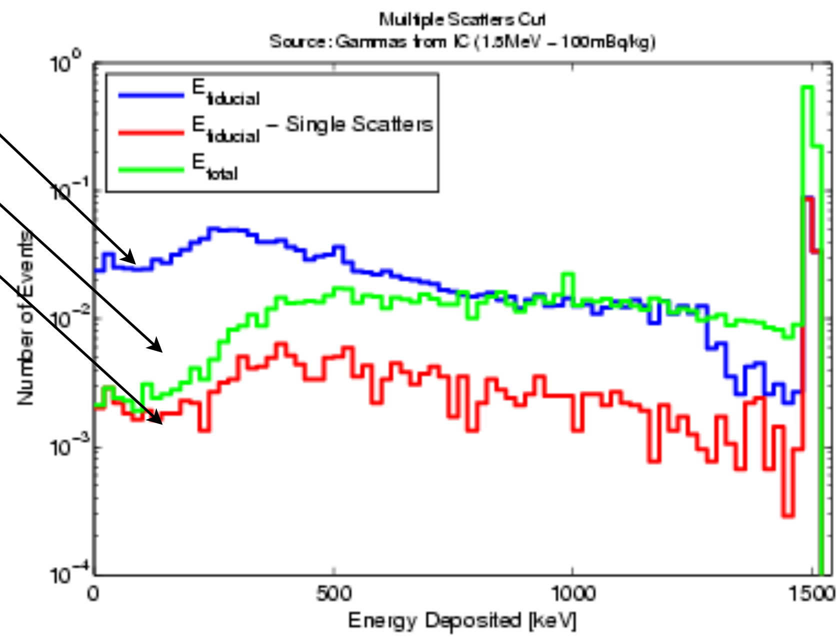


Topology of Gamma Events That Deposit Small Energy in FV

- The rate of ER events in FV is determined by small angle scattering Compton events, that interact once in the FV
  - The rate of above events is suppressed by the tendency for the γ's to scatter a second time. Either on the way in, or way out.
  - The chance of no secondary scatter occurring is more heavily suppressed the more LXe there is
    - The important optimization is to maximize the amount of LXe that lies along a line from the greatest sources of radioactivity (PMTs?) that pass through the FV.

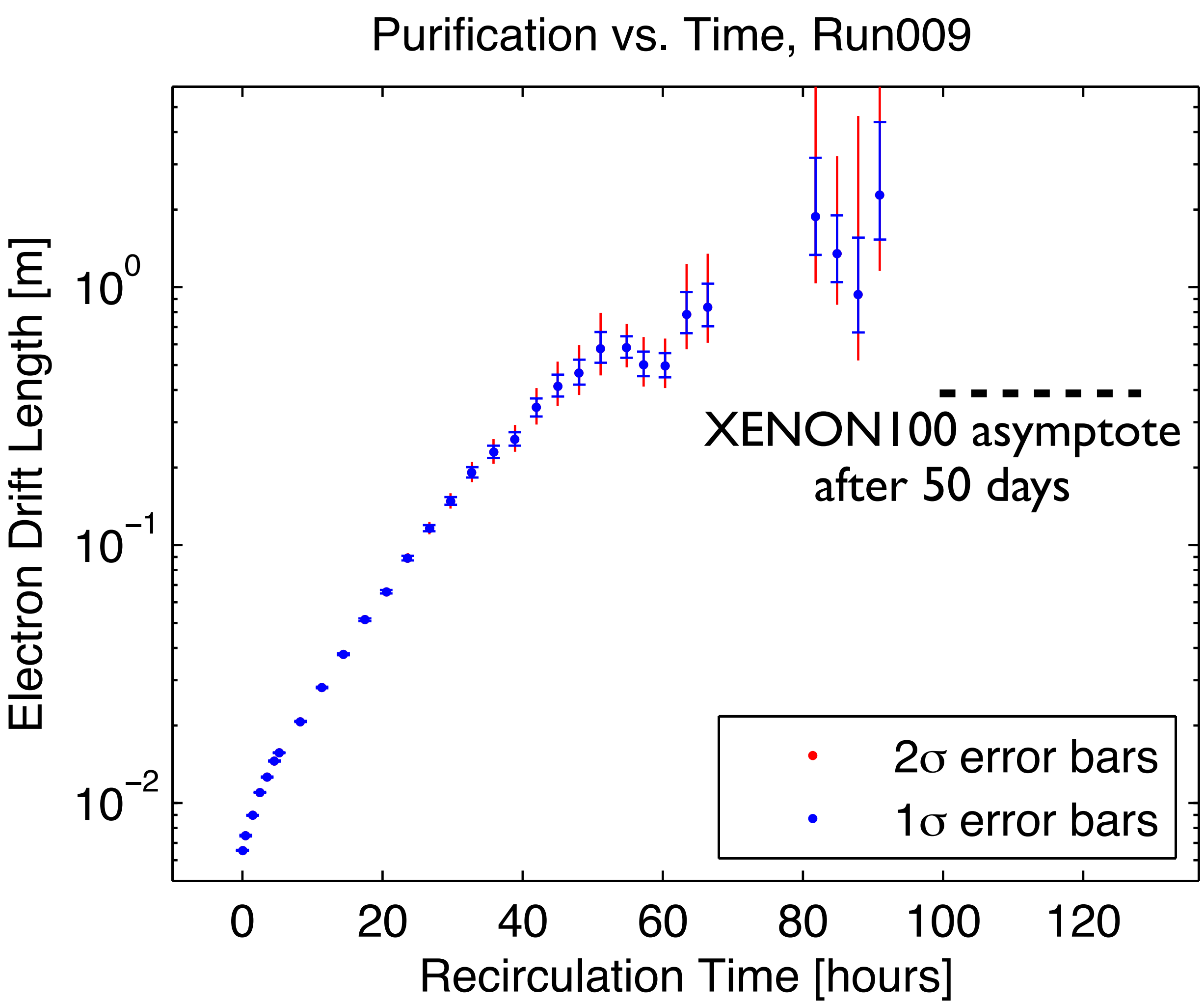


- Example for 1.5 MeV γ from outside LXe volume
  - Energy Spectrum for part of energy deposited in FV
  - Energy spectrum for all energy in detector
  - Additional application of multiple scatters cut has little additional effect on low energy event rate



- Conclusion for Event Suppression
  - xyz resolution of detector is important simply in defining FV. Little additional reduction from locating vertices.
  - (Full xyz hit pattern does assist in bg source identification)

Comparison with LUX 0.1 Purity



0.2 tonnes circulation per day

- ~9 hr time constant for purification

- > 2 m electron drift length achieved (> 1000 us) with 60kg target

- Errors dominated by use of 5 cm test cell drift within large cryostat

The LUX Collaboration

Brown

XENON10, CDMS

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

Case Western

SNO, Borexino, XENON10, CDMS

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

Harvard

BABAR, ATLAS

Masahiro Morii	Professor
Michal Wlasenko	Postdoc

Lawrence Berkeley + UC Berkeley

SNO, KamLAND

Bob Jacobsen	Professor
Jim Siegrist	Professor
Joseph Rasson	Engineer
Mia ihm	Grad Student

Lawrence Livermore

XENON10

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

University of Maryland

EXO

Carter Hall	Professor
Douglas Leonard	Postdoc

Collaboration meeting, Homestake, March 2010

Formed in 2007, fully funded DOE/NSF in 2008

SD School of Mines

IceCube

Xinhua Bai	Professor
Mark Hanardt	Undergraduate Student

Texas A&M

ZEPLIN II

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

UC Davis

Double Chooz, CMS

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

UC Santa Barbara

CDMS

Harry Nelson	Professor
	Graduate Student

University of Rochester

ZEPLIN II

Frank Wolfs	Professor
Udo Shroeder	Professor
Wojtek Skutski	Senior Scientist
Jan Toke	Senior Scientist
Eryk Druszkiewicz	Graduate Student

U. South Dakota

Majorana, CLEAN-DEAP

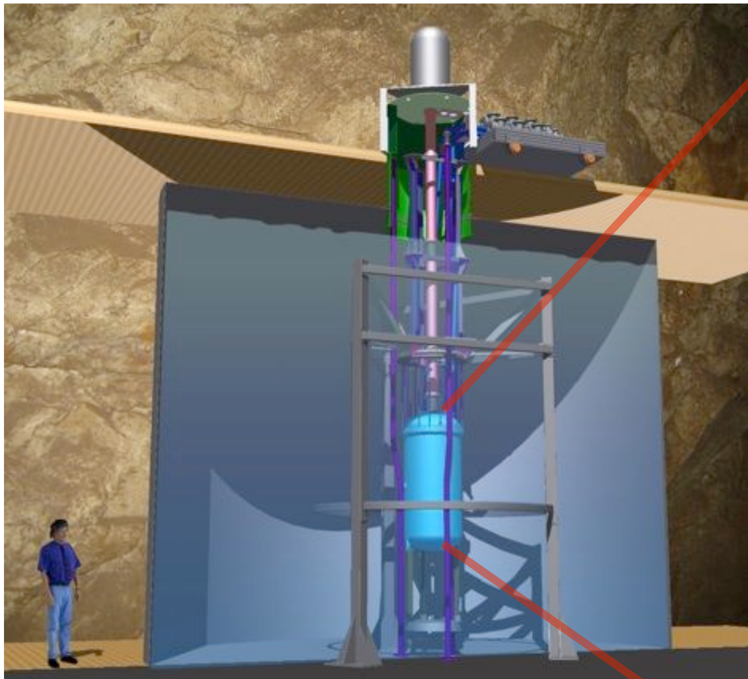
DongMing Mei	Professor
Wengchang Xiang	Postdoc
Chao Zhang	Postdoc
Jason Spaans	Graduate Student
Xiaoyi Yang	Graduate Student

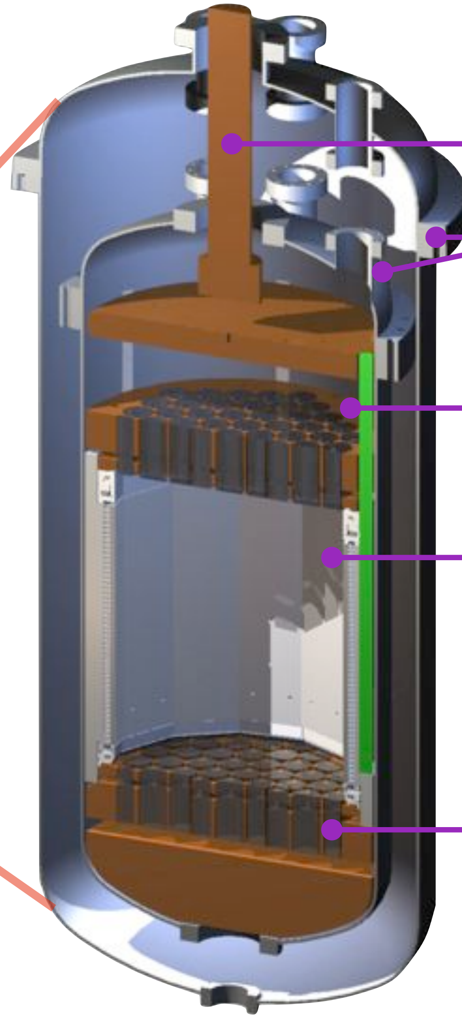
Yale

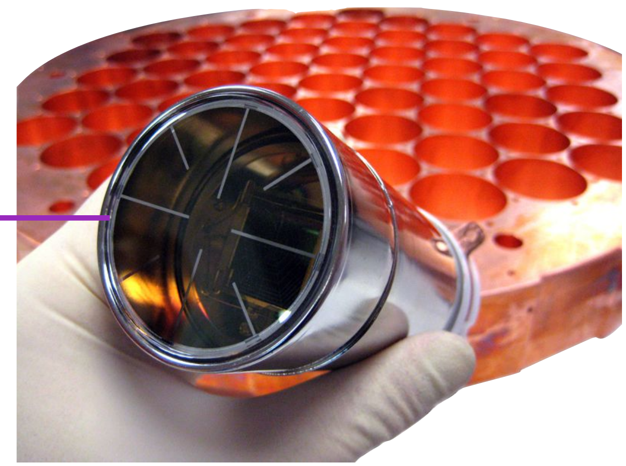
XENON10, CLEAN-DEAP

Daniel McKinsey	Professor
James Nikkel	Research Scientist
Sidney Cahn	Research Scientist
Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Louis Kastens	Graduate Student
Nicole Larsen	Graduate Student

The LUX Experiment







2” Hamamatsu R8778
Photomultiplier Tubes (PMTs)

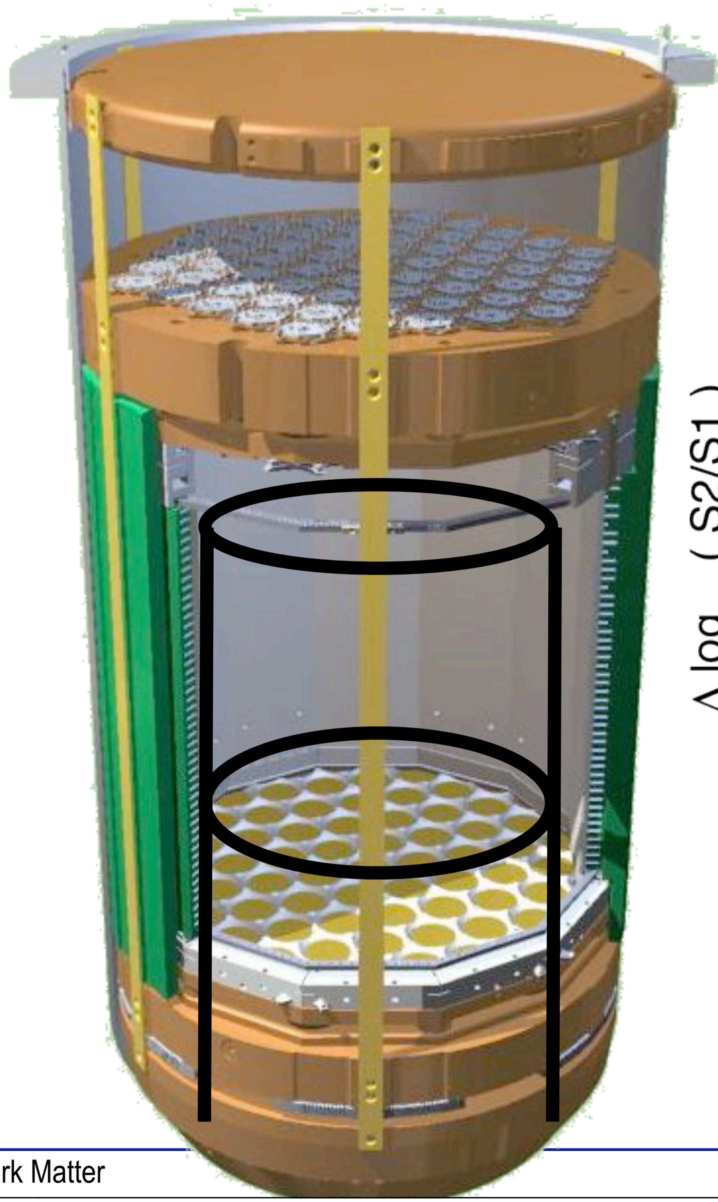
- 350 kg LXe detector
- 122 PMTs (2” round)
- Low-background Ti cryostat
- PTFE reflector cage
- Thermosyphon used for cooling (>1 kW)

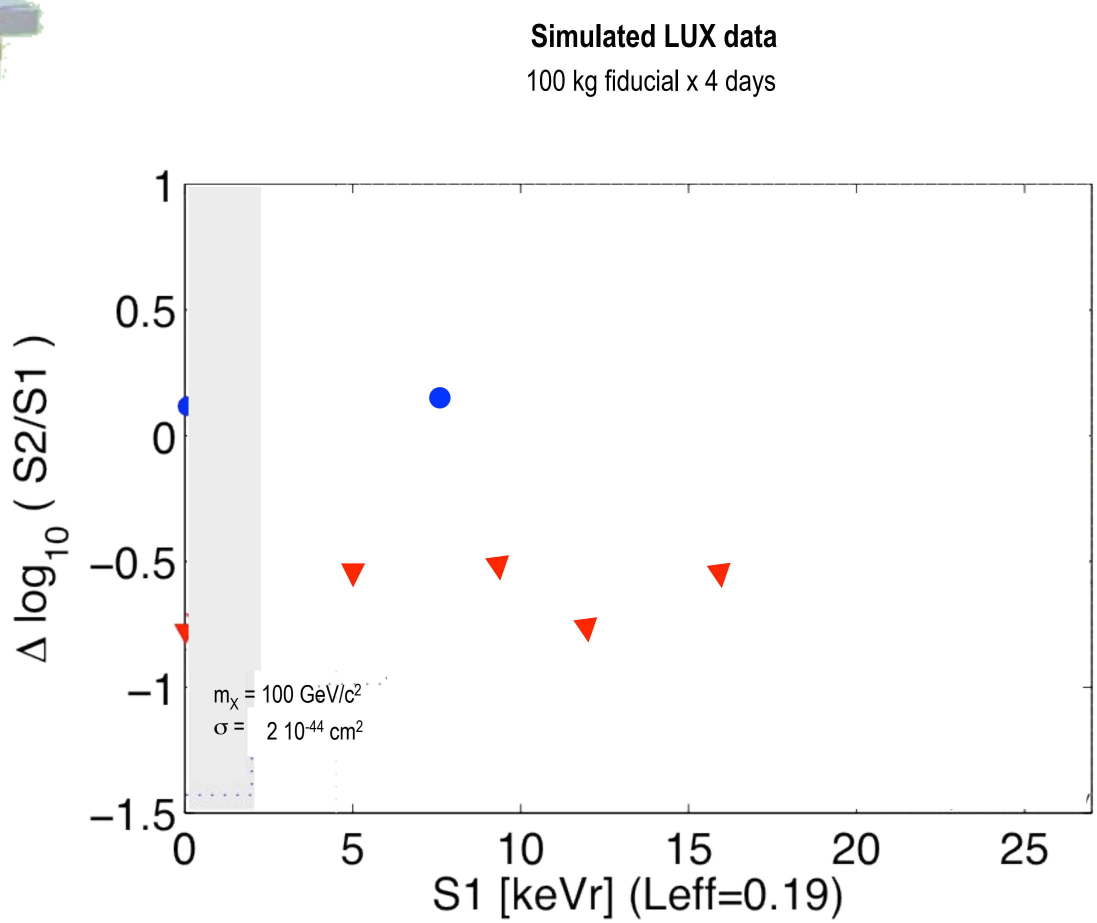
LUX WIMP Sensitivity

In < 2 live days we will surpass sensitivity of all existing results for dark matter direct detection experiments

Focus on discovery ... we must design detectors with high contrast for signal ...

LUX 350 kg / First Few Days of Operation

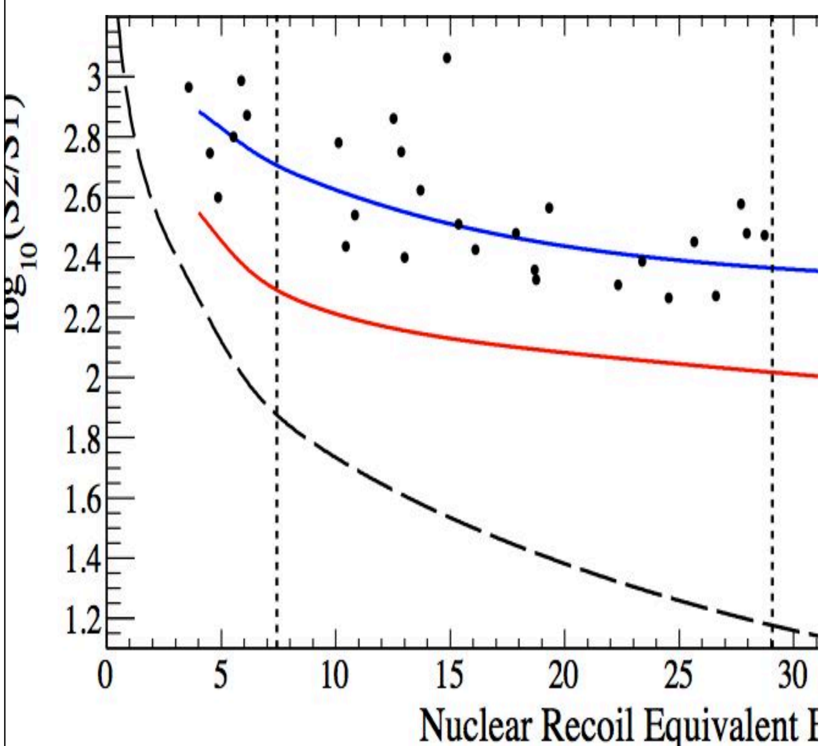


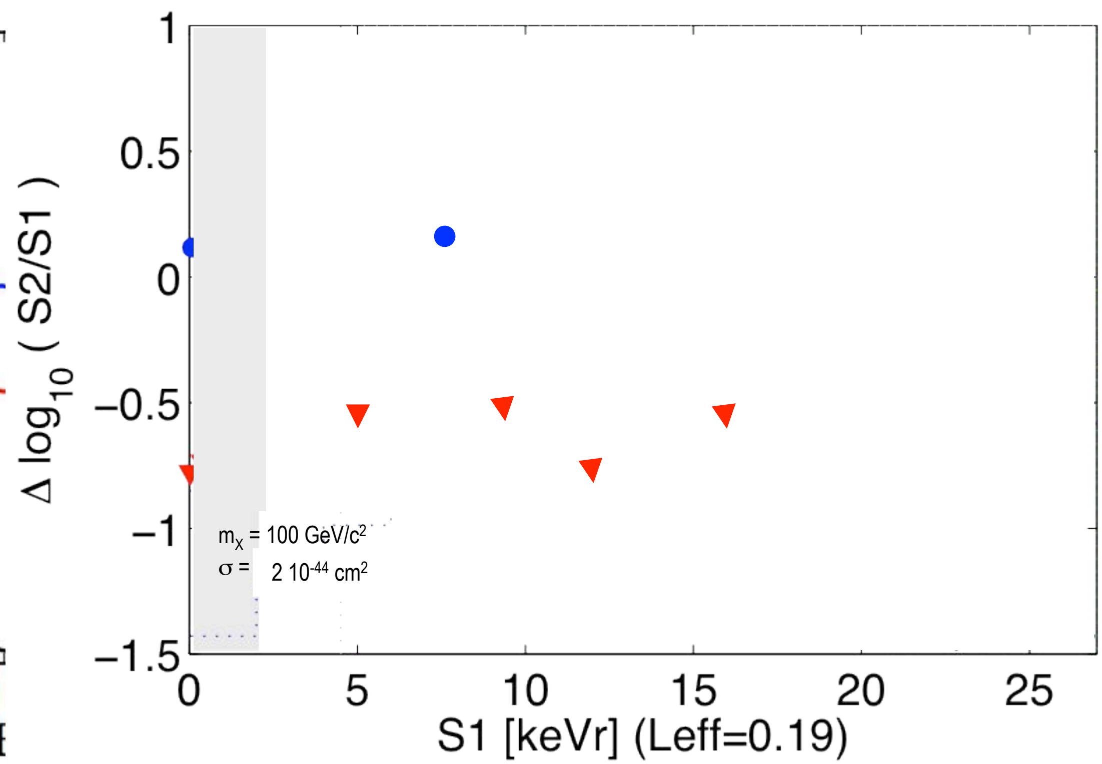


LUX 350 kg / Equiv to XENON100 11 day data

Simulated LUX data

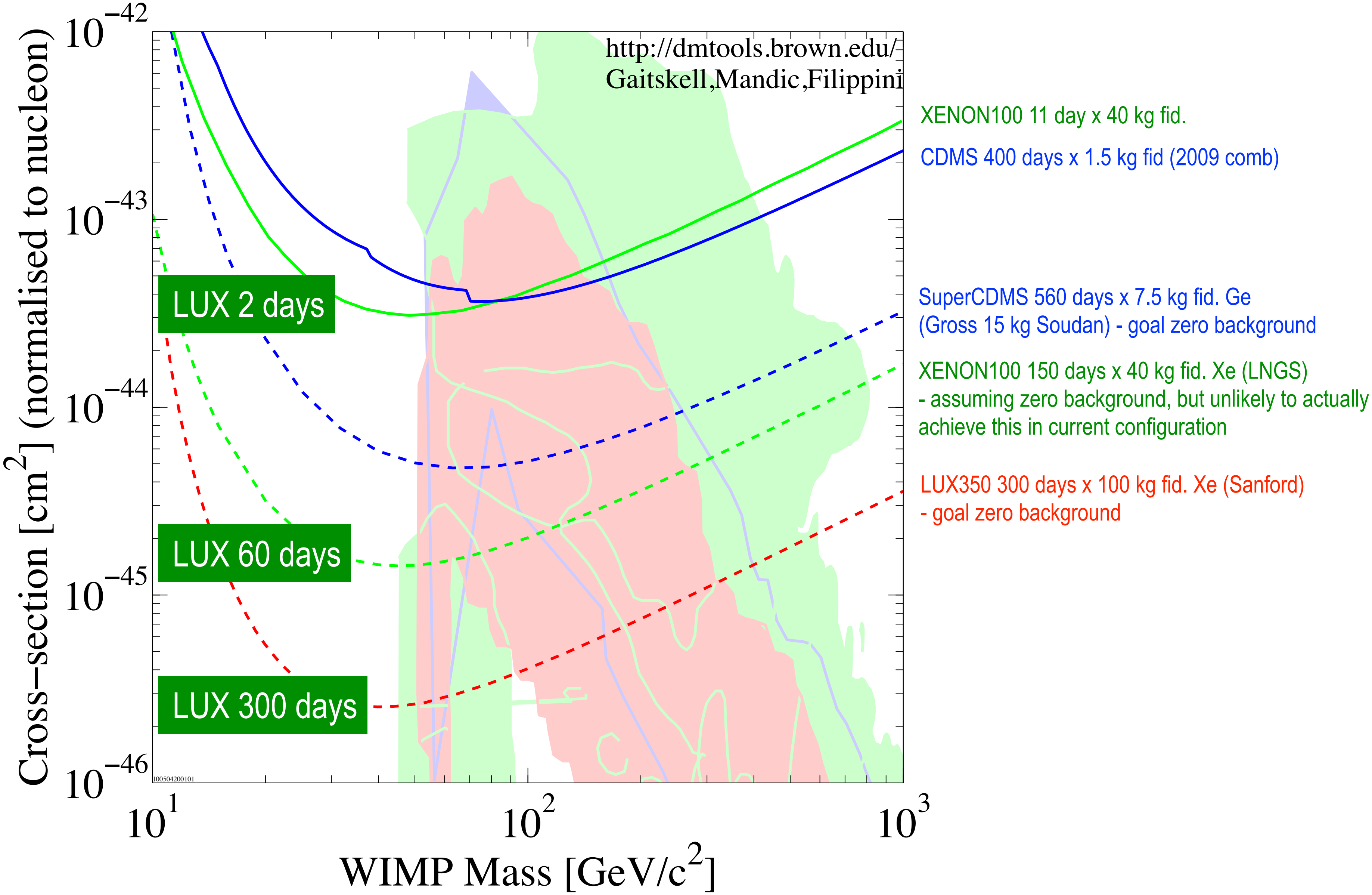
100 kg fiducial x 4 days





- LUX has 1/25th ER event rate, due to increased self-shielding
- WIMP events shown are assuming cross section at current 90% CL exclusion
- Since we will have ~100% acceptance for NR only really require 2 days exposure

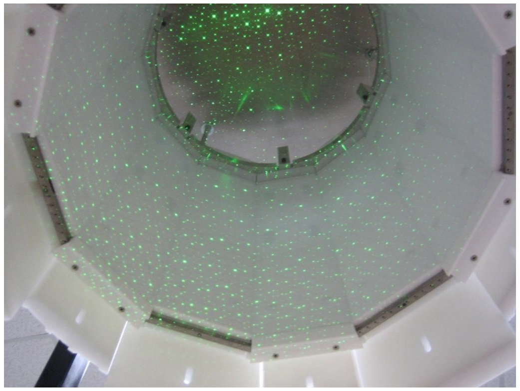
Sensitivity Curves



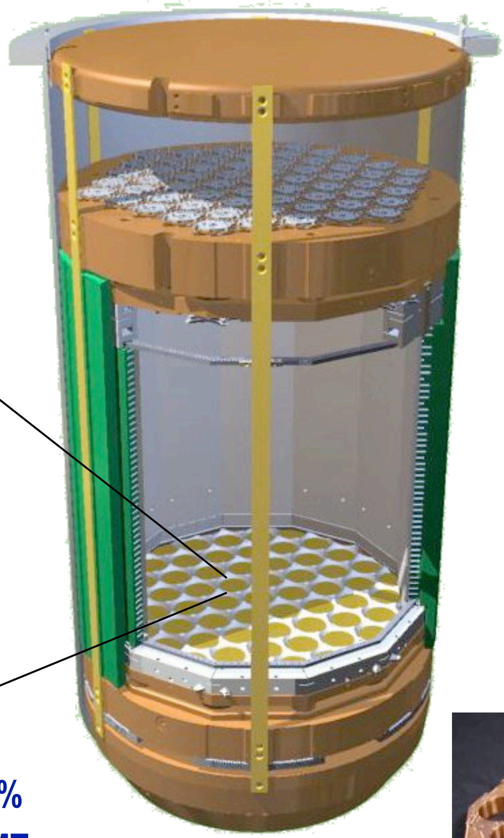
Summary

- The scale of the LUX detector was chosen to maximally exploit self-shielding
  - The mfp for Compton Scattering of gamma's sets the scale for the exponential suppression of external backgrounds
  - We are also implementing techniques that will be require for multi-tonne detectors - Talk by Simon Fiorucci to follow
    - Water tank is a very scalable background shield

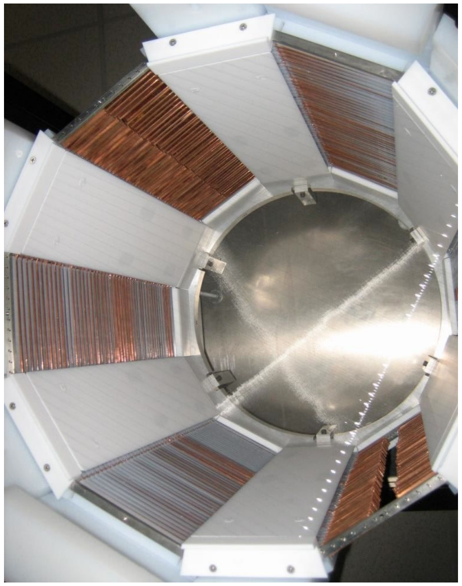
LUX Detector - Internals



- HV Grids in place and tested



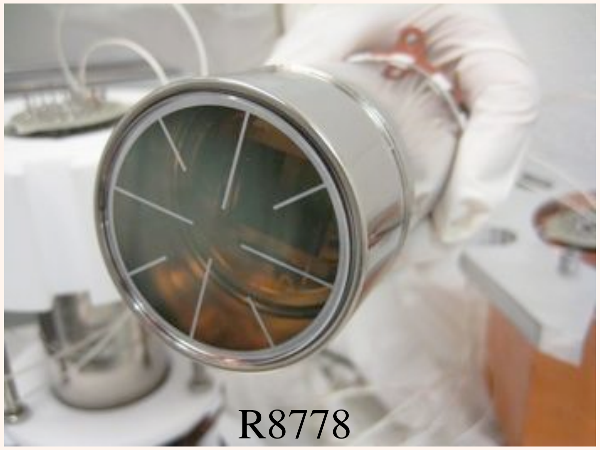
- 122 2" PMT R8778
  - 175 nm, QE > ~30%
  - U/Th ~9/3 mBq/PMT
  - All tested in LUX 0.1 program



- Dodecagonal field cage + PTFE reflector panels

- Copper PMT holding plate

PMTs (LZS and LZD 20 tonne LXe)

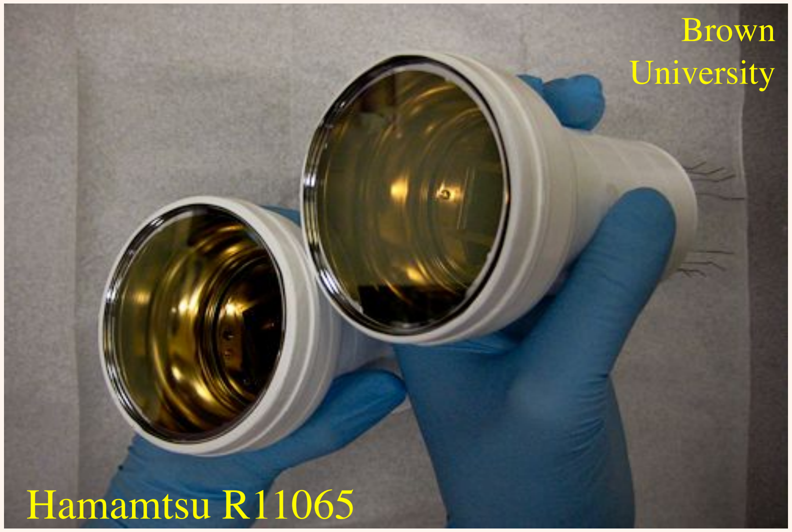


- Current LUX 350 Experiment: Using 122 x 2” R8778 Hamamatsu
  - Production yields high/very stable - long track record with technology
  - U/Th 10/2 mBq/PMT
    - There has been tremendous progress in reducing PMT backgrounds
    - The level of radioactivity already achieved in these PMTs would be an acceptable baseline for the LZS and LZD experiments
  - Demonstrated QE: average=33%, max 39% at 175 nm
    - Permits factor 3 better phe/keV response in LUX than in XENON100

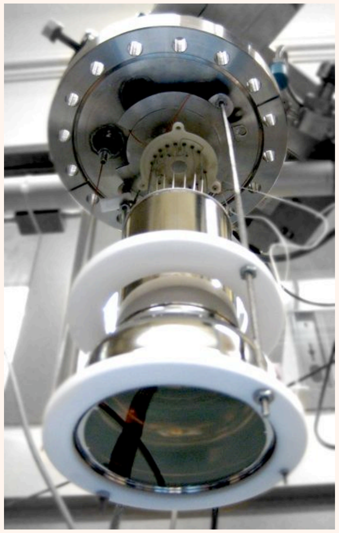
SEE FIORUCCI TALK THIS AFTERNOON

PMTs (LZS and LZD 20 tonne LXe)

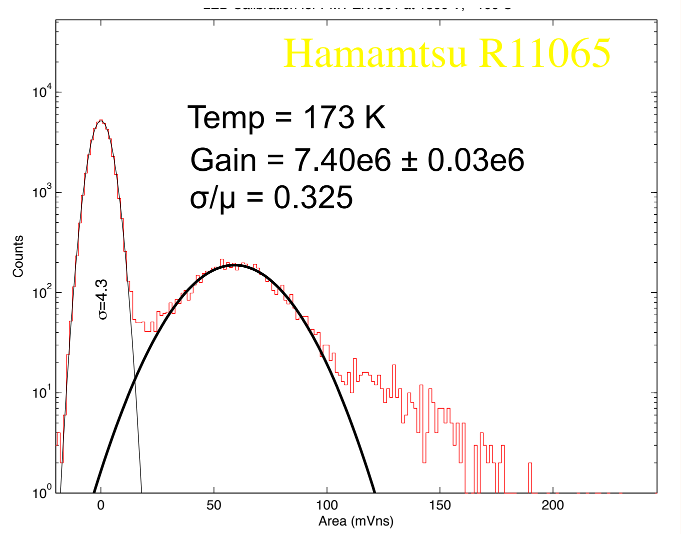
3" Diameter PMT for LXe



3" Testing in LXe



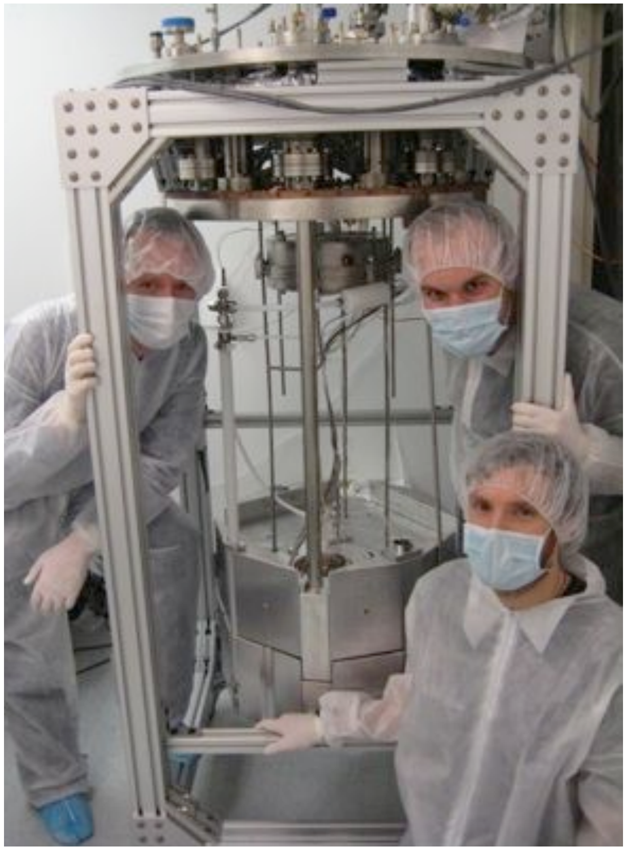
Single phe calibration, -100 C, -1500 V



- Under LZ S4 development program: DUSEL R&D
  - Larger diameter - twice collection area. Radioactivity further reduced.
  - In 2009 initially fab of and tested Hamamatsu 3" R11065 in LXe
    - Tested QE/LXe operation - all PMTs performed identically to those of same as R8778
    - Well understood performance. Stable performance.
    - High gains >5x10^6 mean that no additional amplifiers required. Electronics within cryostat are limited to passive components with very low/well understood radioactive backgrounds
  - Developed new ultra low background 3" PMTs for LXe: R11410mod
    - Background measured U/Th <1/1 mBq/PMT (90% CL) - No U/Th signal seen
    - This comfortably exceeds background requirements for LZD detector
    - Upgraded Hamamatsu Super bialkali photocathodes will also be available to move QE above 40%
- Requirement is for 1000x3" PMT for LZD (20 tonne)

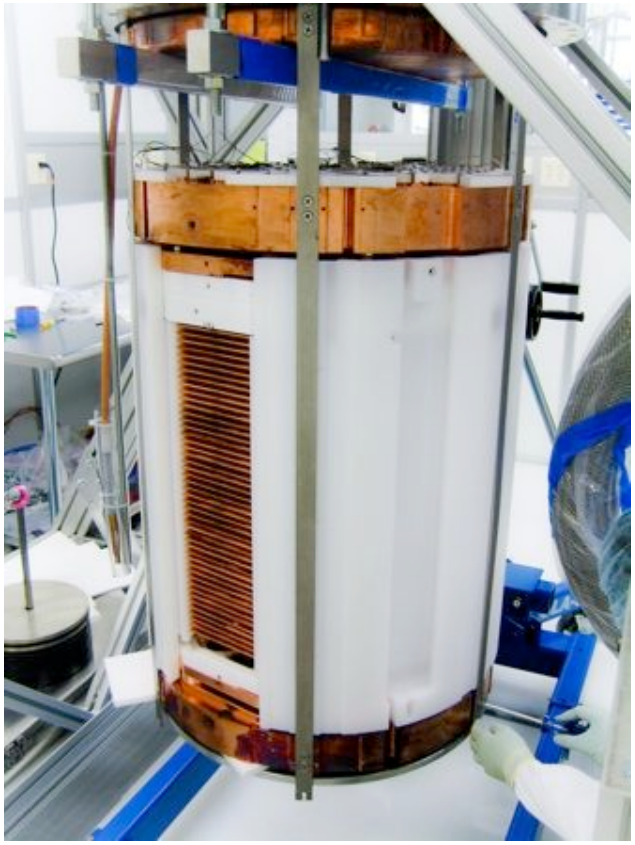
The LUX Program

LUX0.1 - CWRU



2007-2009

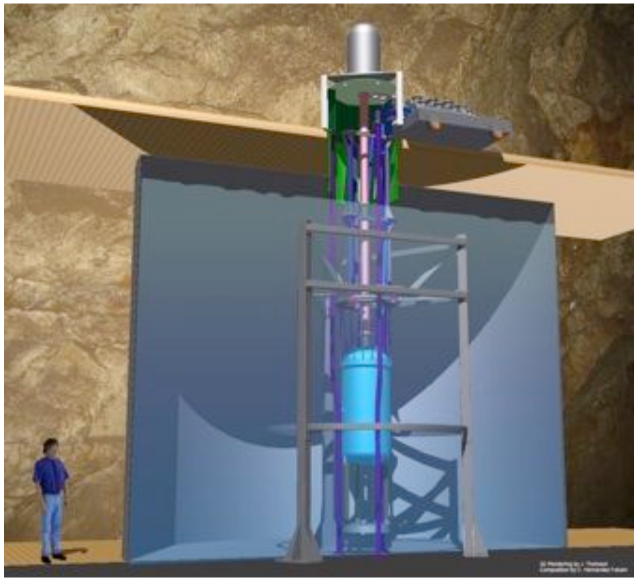
LUX - Surface



2010-2011

Right now

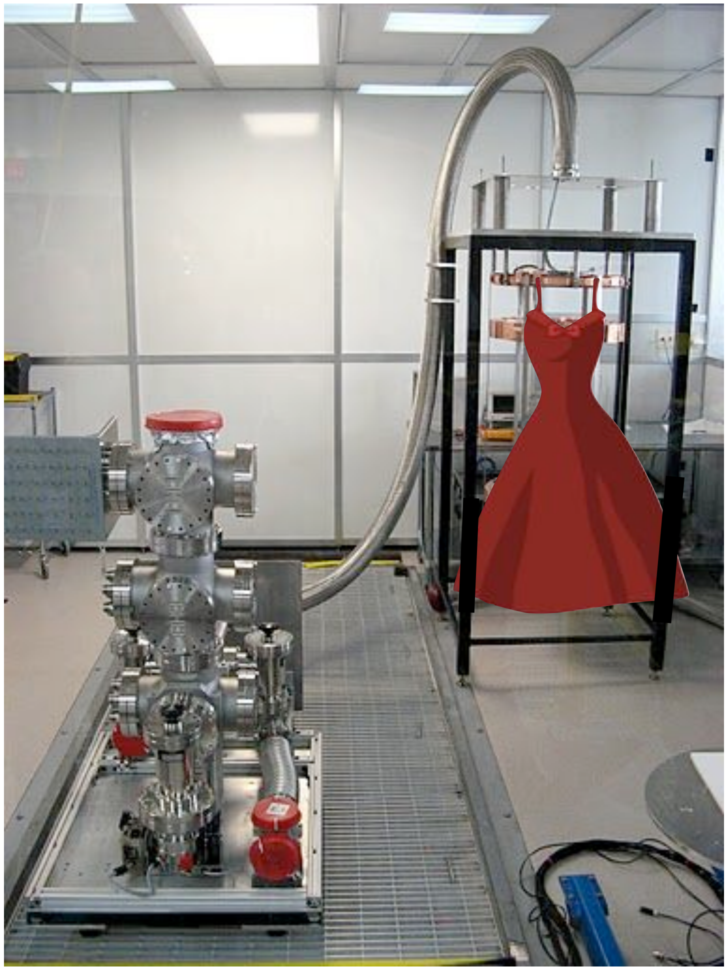
LUX - Underground



2011+

Present: LUX at the Sanford Surface Facility

The dress rehearsal



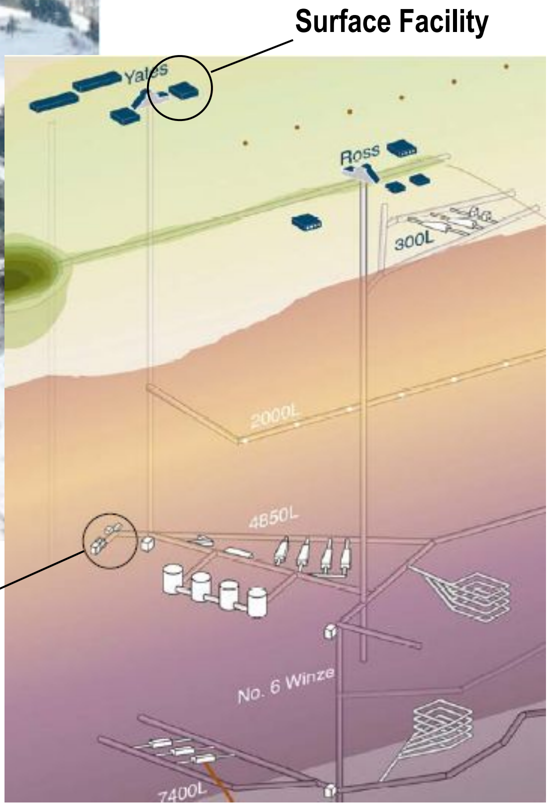
- Full-scale LUX assembly and deployment
- **Duplicate** of the underground layout
  - Smaller water tank (3 m)
  - Cleanroom class 1,000 (will be relocated underground)
- LUX operations since November 2009

LUX Detector Assembly Animation v1.1

LUX Collaboration Drawings: James White, TAMU; Animation: Carlos Faham, Brown University , v1.1

Right now: LUX at the Sanford Surface Facility

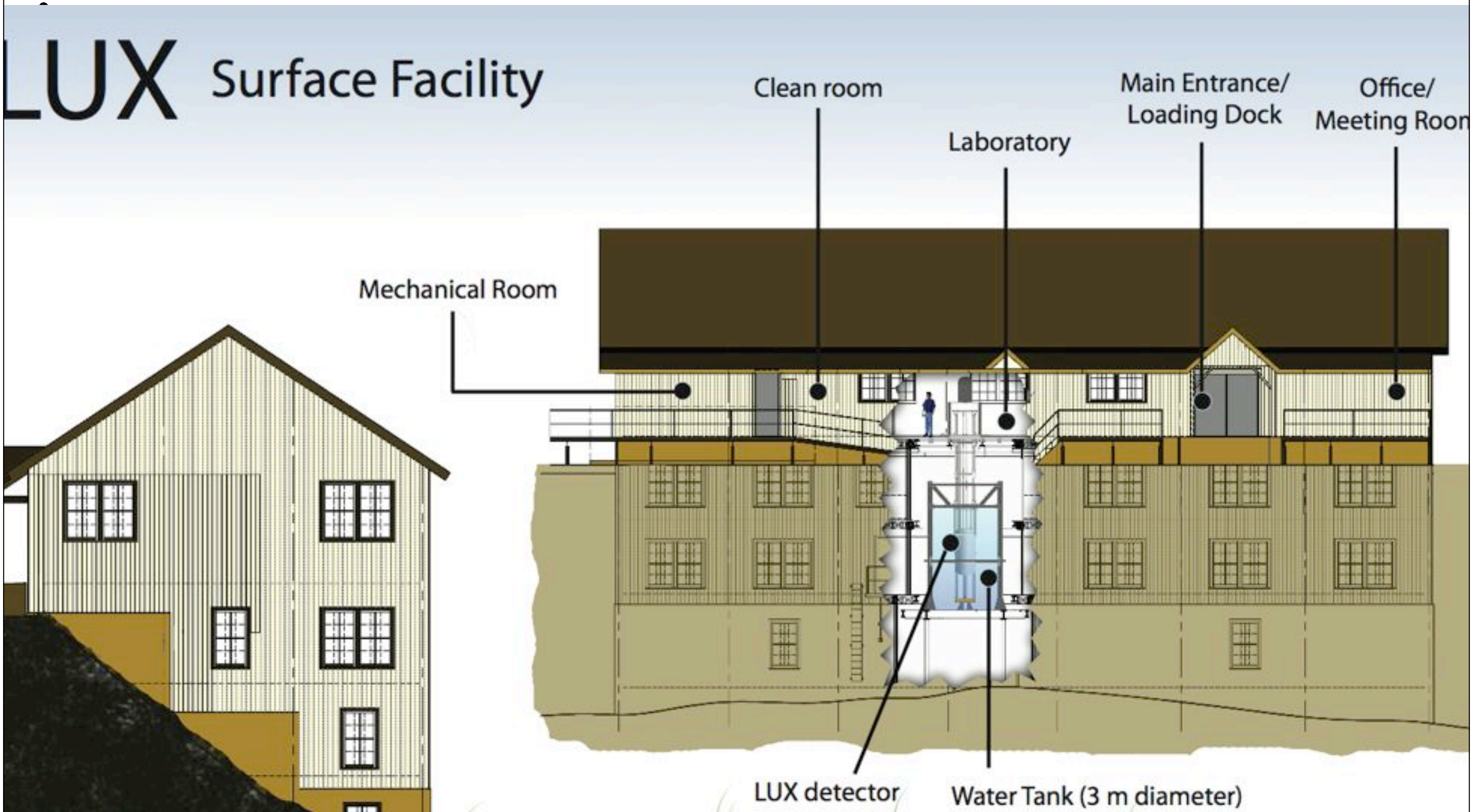
Sanford Lab @ Homestake



- Funded with 70 M$ private donation + 39 M$ from state of SD
- Demonstrator for DUSEL, but already competitive!

LUX Surface Facility @ Sanford Lab

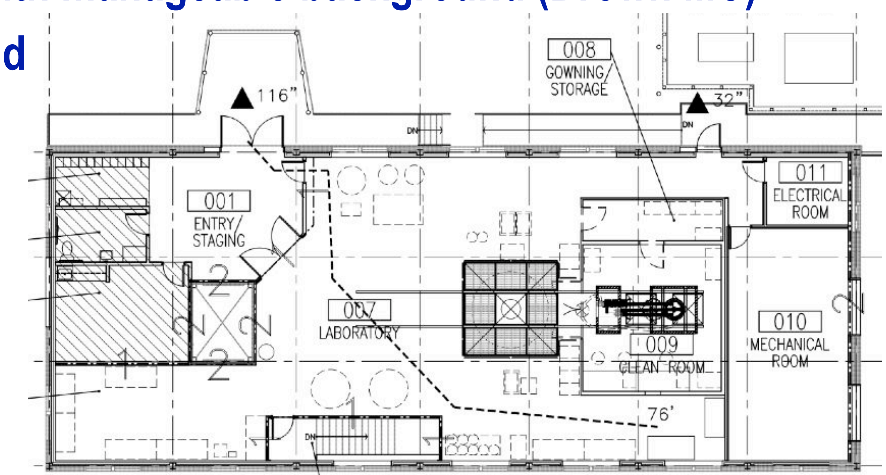
- Fully Operational Since Nov 2009 - Detector Assembly Started (Layout Same as Davis Underground Lab)



Sanford Lab – LUX Surface Facility

- Full-scale test of LUX assembly and deployment
  - 350 kg Xe
  - 122 PMTs
  - Titanium cryostat
  - Full DAQ system

- Refurb supported entirely by SDSTA funds
- Exact duplicate of the underground layout for all major systems
  - Smaller d=3m water tank, permits data taking with manageable background (Brown MC)
  - CL 1k clean room, will be relocated underground



See larger version next slide


High Voltage
OFF


SLA-5

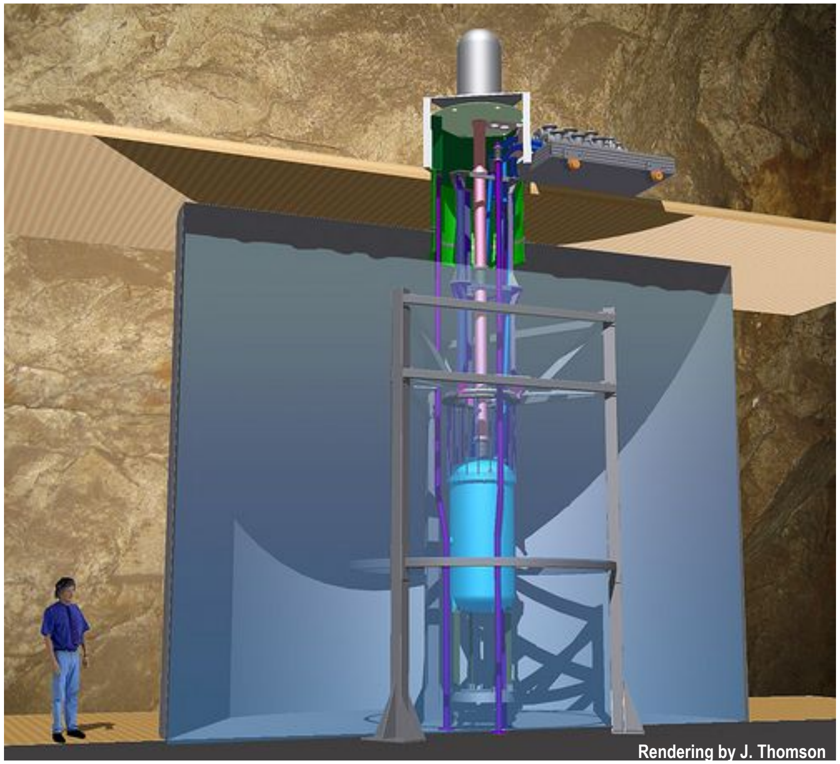

SLA-5

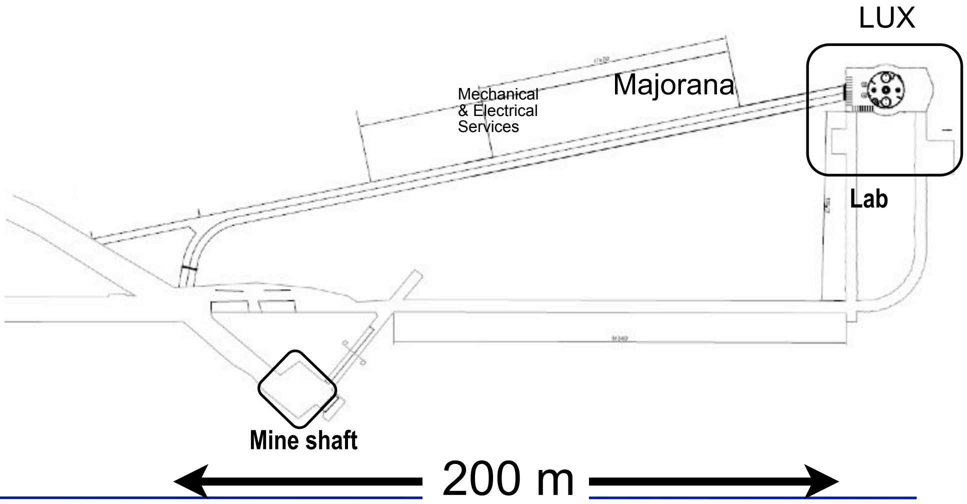
1964 / 2009 “They want to fill the cavern with what ?*?”

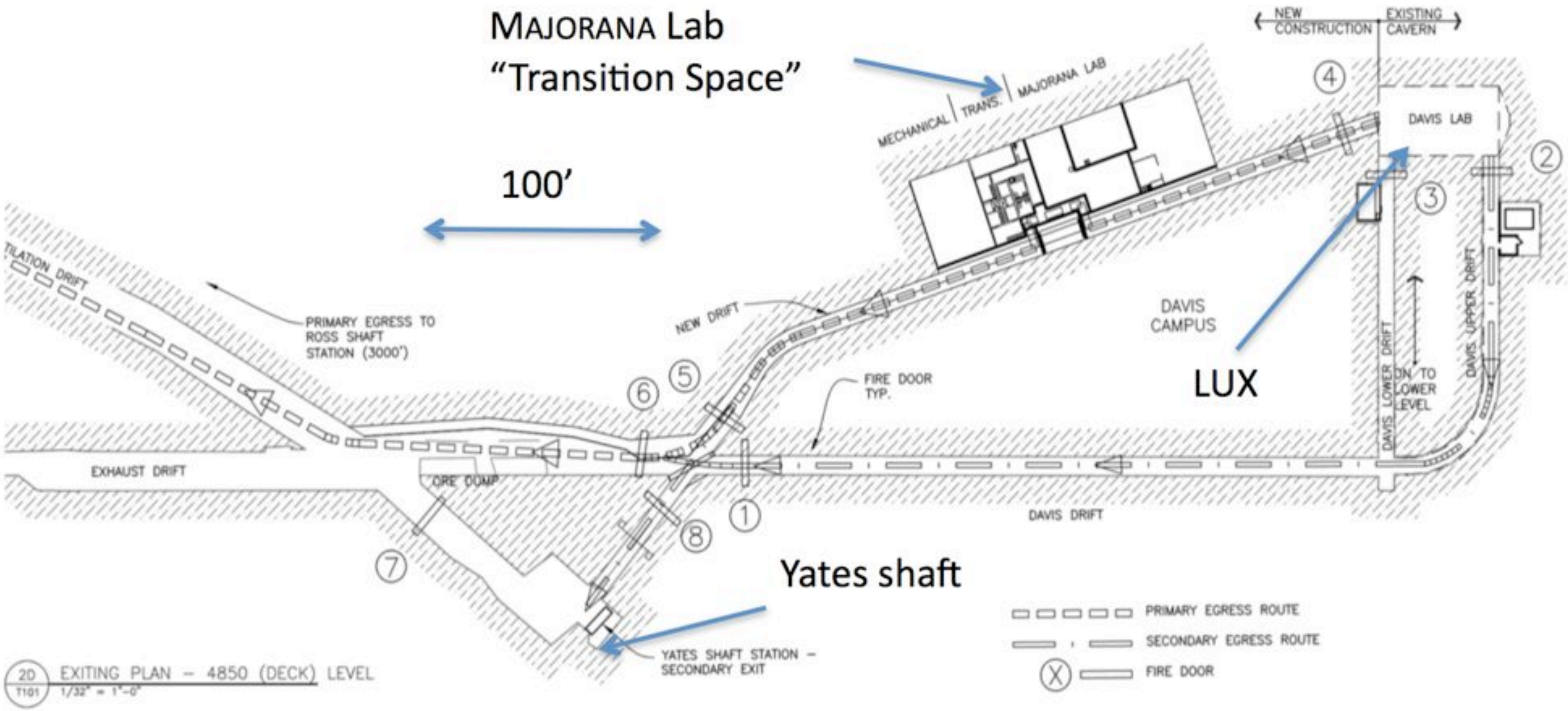
Davis Cavern

LUX 1.0 – Davis Laboratory (4850L)

- Construction/excavation completed
  - Shared access with Majorana facility,
- Two storey, dedicated LUX 55’ x 30’ x 32’ facility, CL 100k
  - Includes CL 1k clean room, control room, counting facility

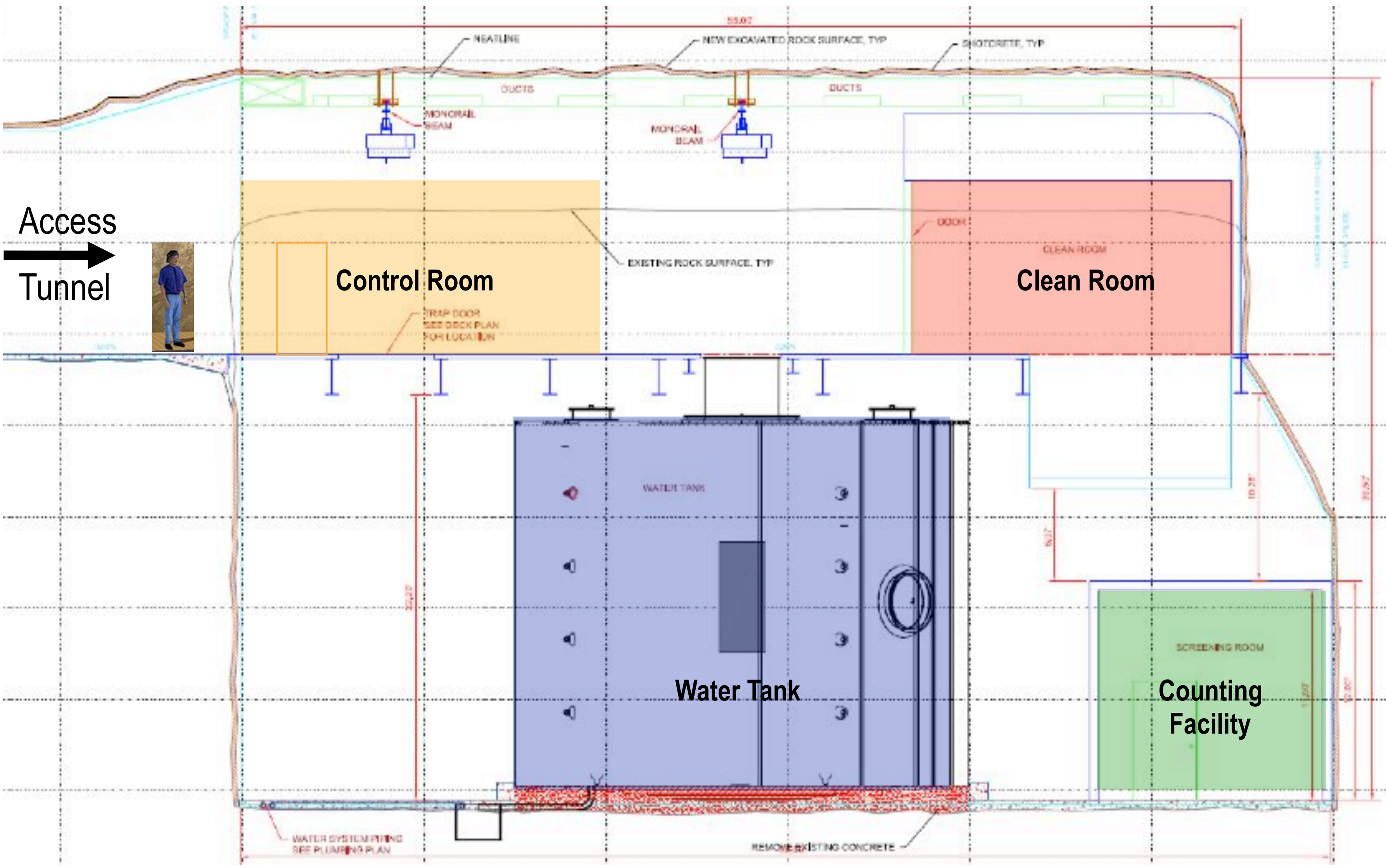




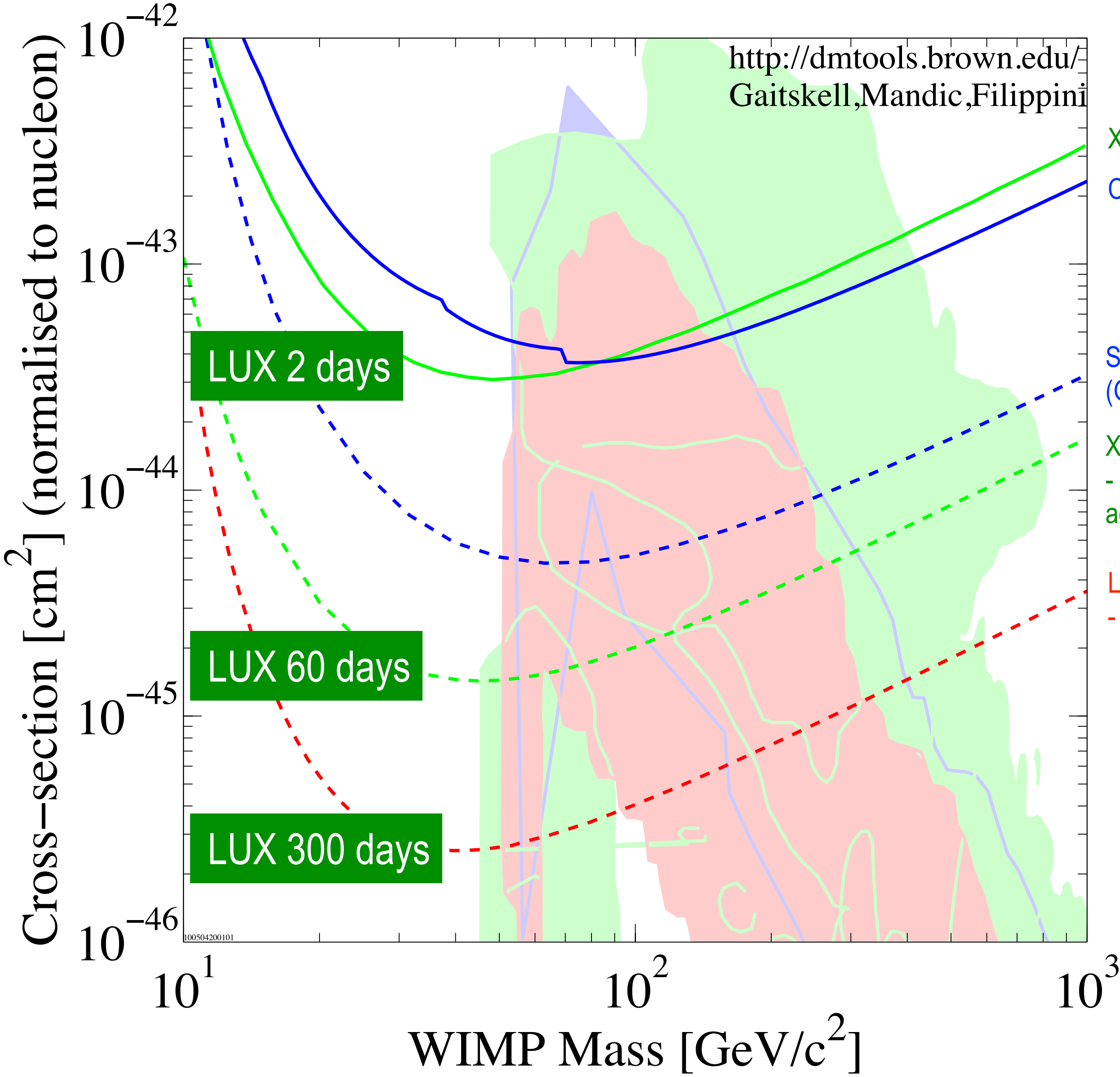


Davis Campus, 4850' level, near Yates shaft

Sanford Lab – Davis Laboratory Layout (Side View)



Sensitivity Curves



XENON100 11 day x 40 kg fid.

CDMS 400 days x 1.5 kg fid (2009 comb)

SuperCDMS 560 days x 7.5 kg fid. Ge
(Gross 15 kg Soudan) - goal zero background

XENON100 150 days x 40 kg fid. Xe (LNGS)
- assuming zero background, but unlikely to actually achieve this in current configuration

LUX350 300 days x 100 kg fid. Xe (Sanford)
- goal zero background

Future LUX-ZEPLIN III (LZ) Program

- New collaborators from Zeplin III and US institutions
  - Imperial College, London
  - STFC Rutherford Appleton Lab
  - ITEP, Moscow
  - Moscow Engineering Physics Institute
  - LIP, Coimbra
  - University of Edimburgh
  - UC Santa Barbara
  - LBNL
- Several phases: 3 tonne at Sanford Lab, SUSEL, 2012-> and 20 tonne at DUSEL from 2014 → 2018+
- DUSEL Program at Homestake 4850L and 7400L