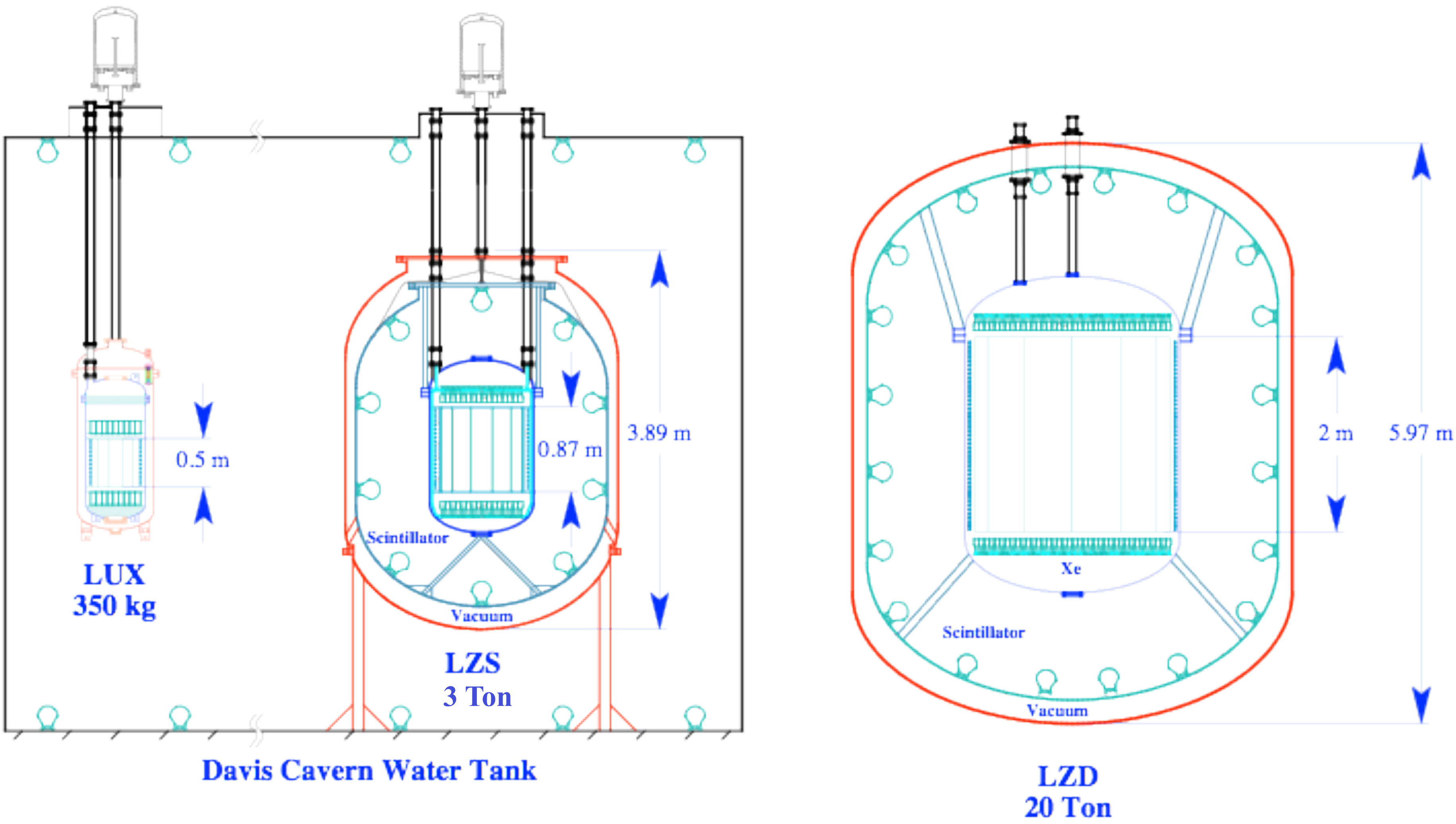
After LUX: The LZ Program

(LUX-ZEPLIN)

The Large Underground Xenon (LUX) dark matter search experiment is currently being deployed at the Sanford Laboratory at Homestake in South Dakota (see Rick Gaistkell's talk), as a precursor to DUSEL. In partnership with more international institutions, we are already thinking about the next (two) experiment(s) that will follow: LZ-S (3 t) and LZ-D (20 t).

The LZ Program at one glance

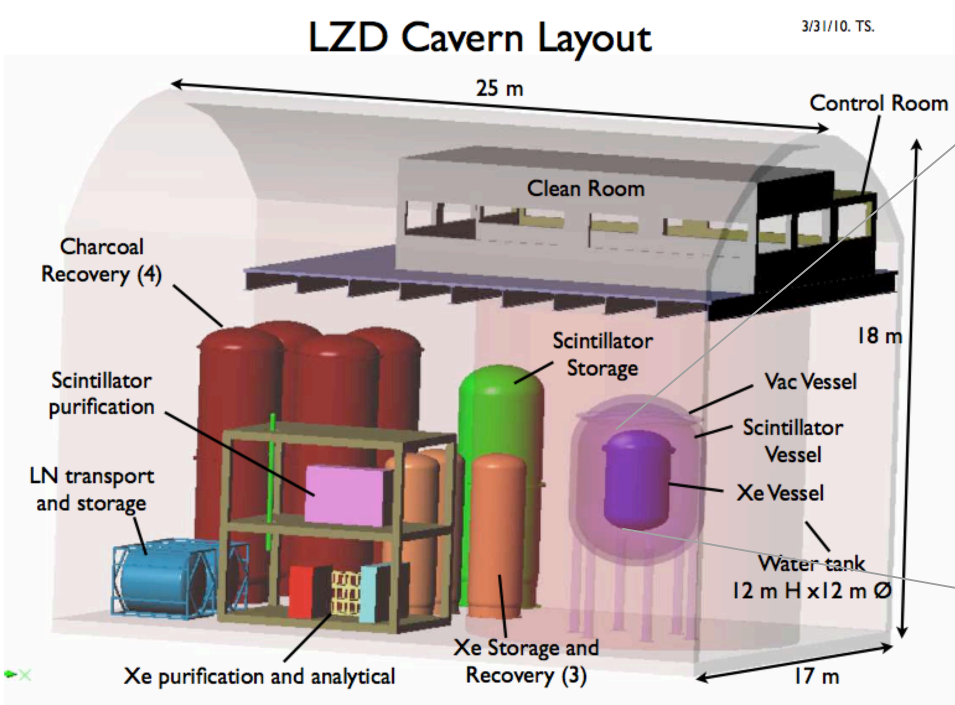


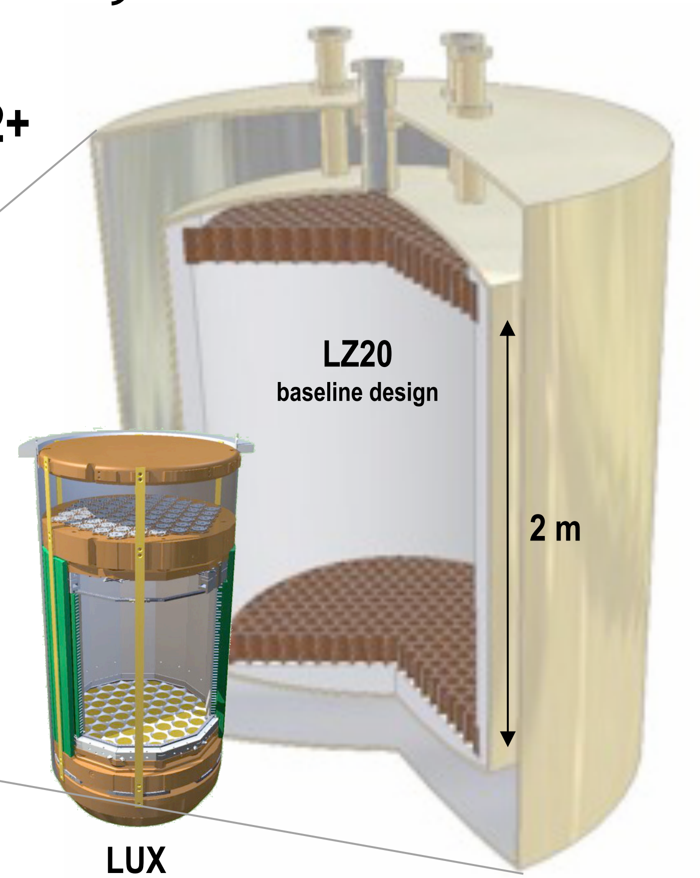
The LZ Program

- LUX (14 US institutions) + New collaborators from Zeplin III and US institutions
  - Imperial College, London
  - STFC Rutherford Appleton Lab
  - STFC Daresbury Laboratory
  - ITEP, Moscow
  - University of Edinburgh
  - Moscow Engineering Physics
  - Institute LIP, Coimbra

  UK and PT groups to join LUX late 2010, subject to local agencies approval

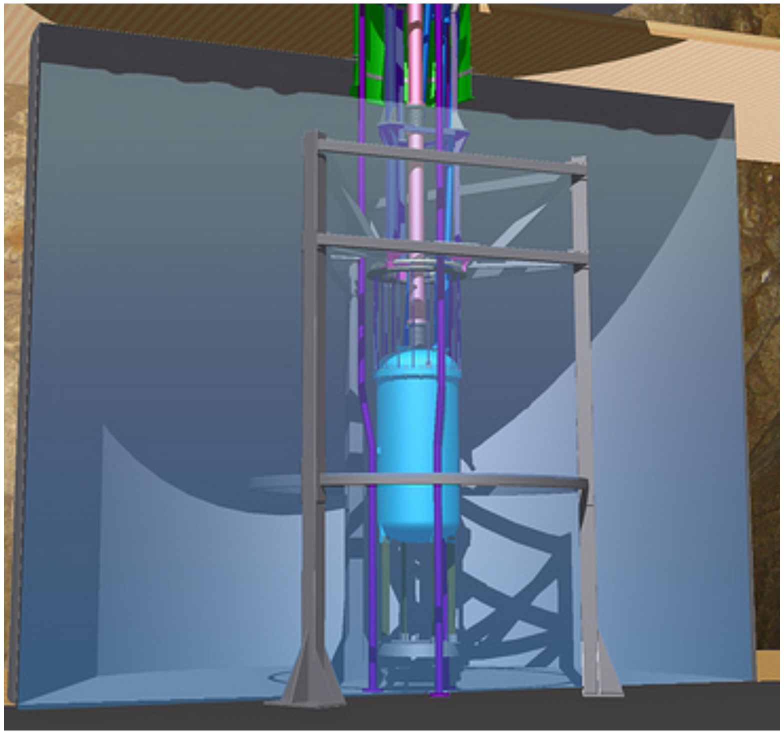
- Two phases: LZ-S (3 t), LZ-D (20 t) from 2012 → 2022+





LUX Innovations for LZ

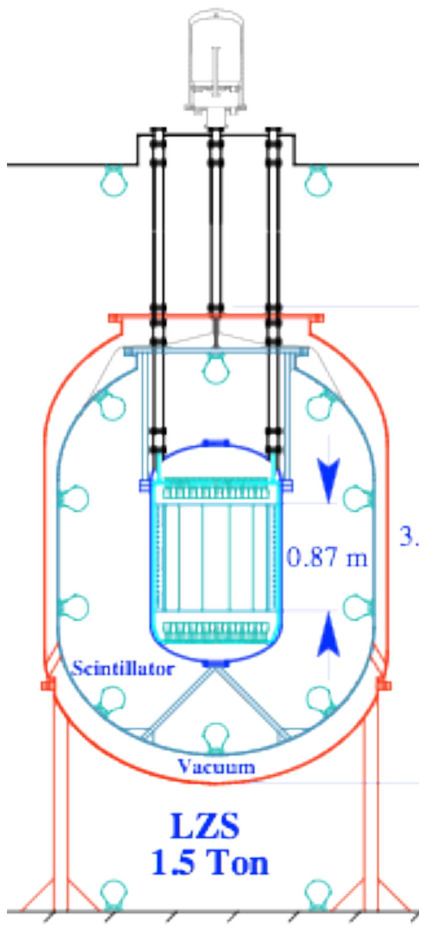
- Davis Cavern Infrastructure, water shield: ready for up to 3 ton instrument
- Heat exchanger, high flow rate Xe purification system
- Remote feedthroughs and cryogenics
- Low-background titanium cryostat
- Scalable internals construction
- Scalable trigger and DAQ (DDC-8)
- ^{83m}Kr, ^{3}H calibration sources
- Automated Control and Emergency Recovery systems
- Safety review process



LZ Program: New Features

- 3" PMTs at ~1 mBq radioactivity level
- Liquid Scintillator shield/veto
- Internal active plastic veto
- Internal imaging system

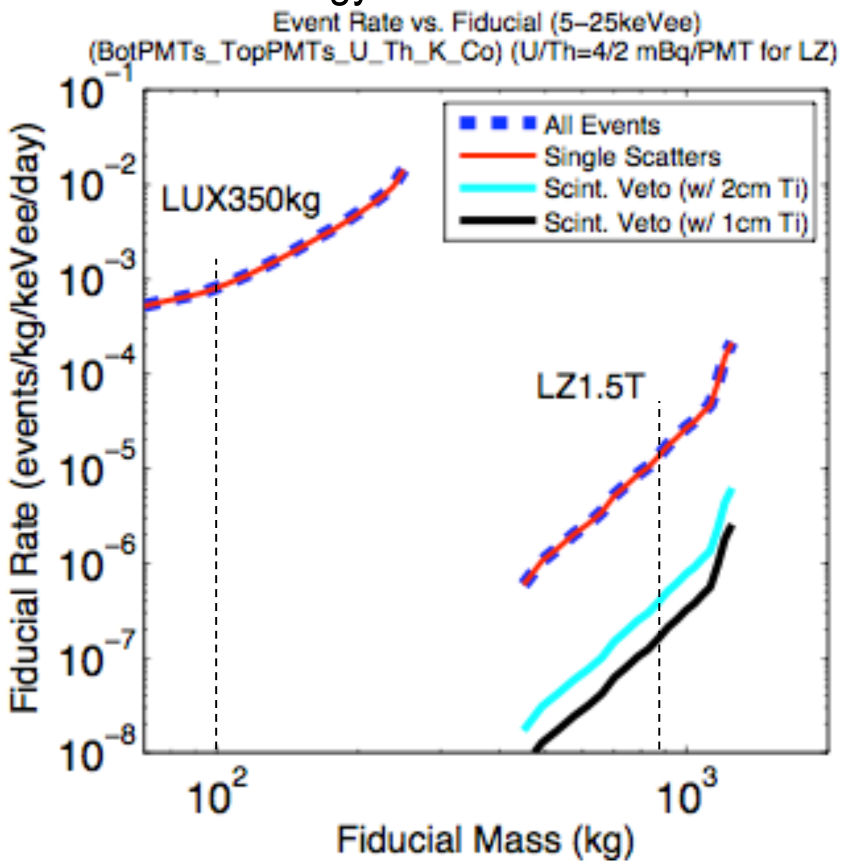
- ...That's it. Progress on sensitivity comes chiefly with:
  - Increasing the Xe mass
  - Scaling up existing LUX technology
  - Xe self-shielding is driving the background rates down dramatically



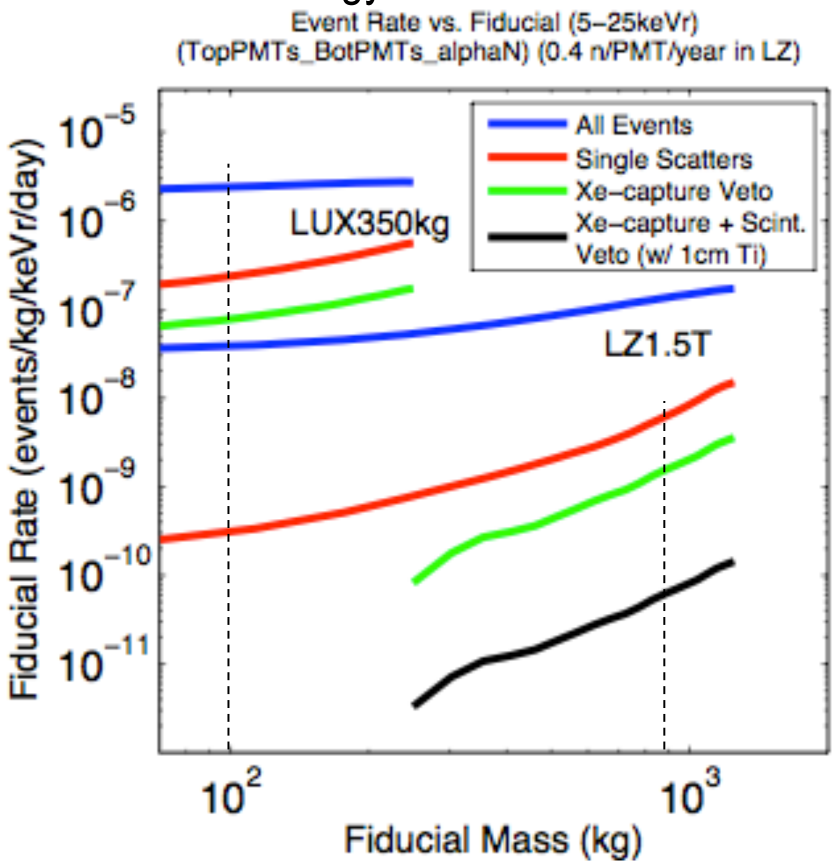
LZ Program: Shielding

- **Simulations results for LZ-S**
  - Power of Xe self-shielding
  - Additional rejection thanks to external scintillator veto
- **LZ-D: Requires a 12m x 12m shield**
  - Dimensions driven by μ-induced high E neutrons
  - All other external backgrounds (γ & n) subdominant

Low Energy Electron Recoil Events



Low Energy Nuclear Recoil Events



LZ Program: Scintillator Shield/Veto

Scintillator housed as close as possible to LXe

- Ti cryostat especially helpful, want ~1 cm thickness.

Cold (175 K) placement immediately outside LXe.

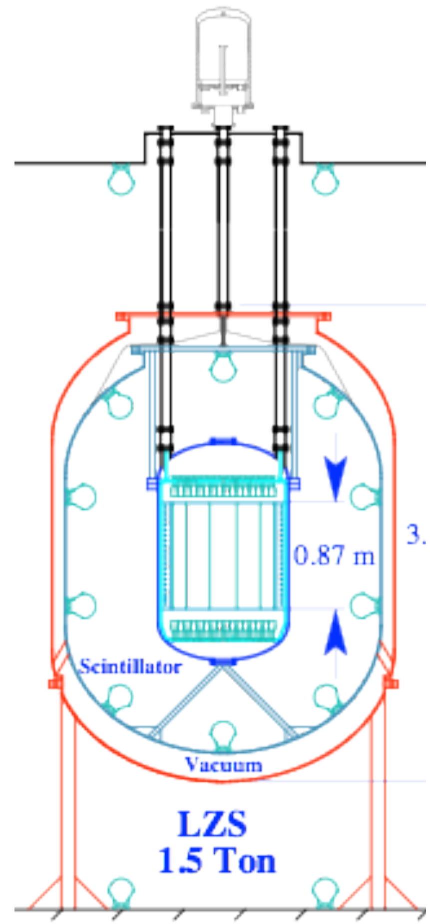
- Highest efficiency.
- Enhances cryo safety.
- Likely choice: iso-hexane + flour. Expect factor 2-3 less light than pseudocumene. Enhanced flammability.

Warm: tradeoff in performance

Program of low temperature scintillator study, combined with MC studies

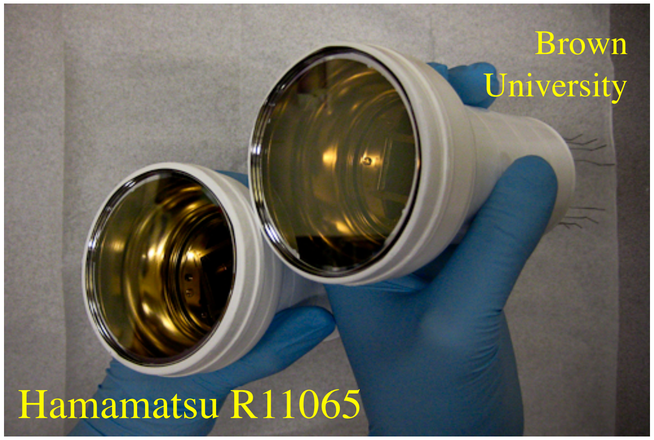
Goal: ≥ 10 reduction of gamma, neutron rates in LXe.

Final decision on scintillator veto option based on performance, safety.

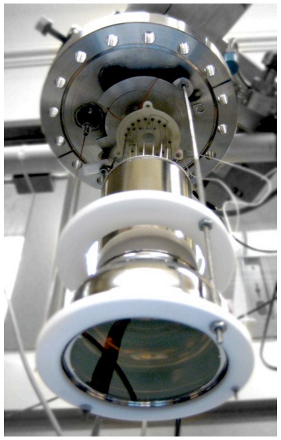


LZ Program: PMTs

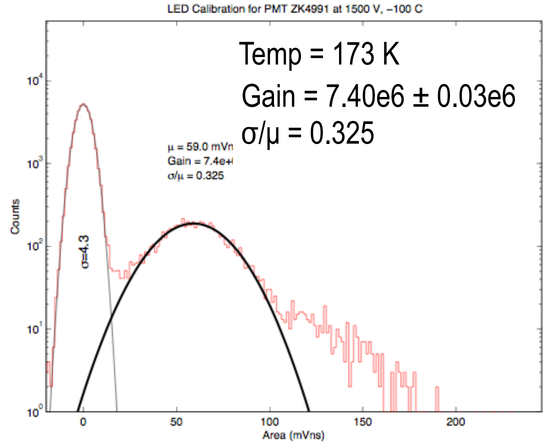
3" Diameter PMT for LXe



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/area further reduced.**
- **In 2009 initially fab of and tested Hamamatsu 3" R11065 in LXe**
  - Tested QE/LXe operation - all PMTs performed identically as R8778
  - Well understood, stable performance.
  - High gains $>5\times10^6$ 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 LZ-D detector
  - Upgraded Hamamatsu Super bialkali photocathodes will also be available to move QE above 40%

Requirement is for 1000 x 3" PMT for LZ-D (Production yields and cost well understood)

LZ Program: Cryogenics

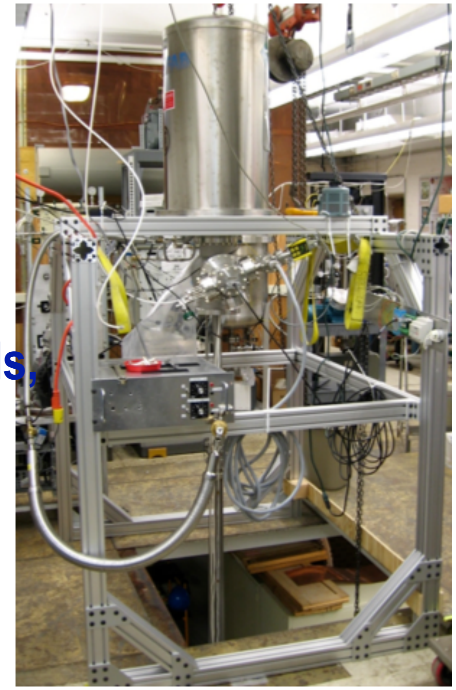
Architecture developed for LUX

- 2 years operational experience on full-size prototype (LUX 0.1).
- ~70 thermometers, 5 P&ID control points.

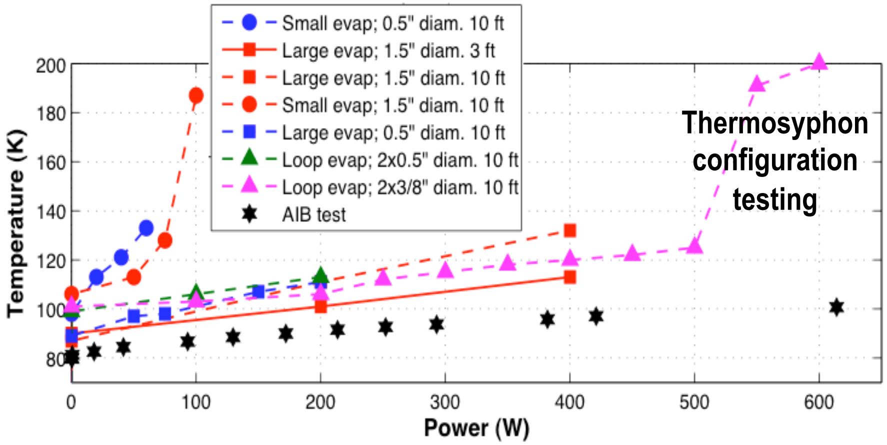
Liquid nitrogen (LN) thermosyphon backbone.

- Extremely high capacity, remotely deployed, multiple cold heads, tunable to low power for fine control.
- Intrinsically safe: passive, insensitive to power loss.

Probable LN generation on site to avoid LN transport.



“Conventional” system for pre-cooling scintillator



LZ Program: Internals

Large area grid prototyping

- Scale will increase for 0.5 m to 2m and maintain acceptable deflection

Low mass field ring development

- Minimize mass for veto

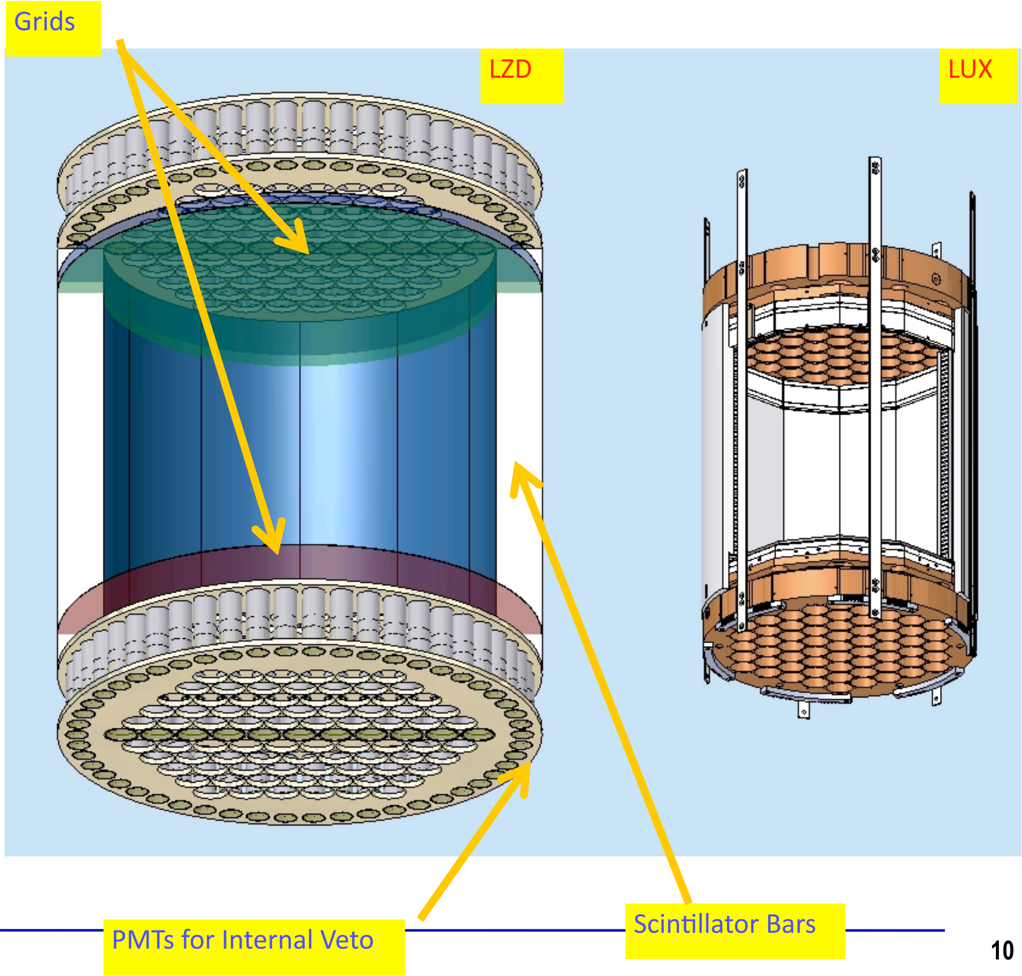
Investigation of active plastic to enhance veto capability

- LXe compatibility
- Maximize light collection

Development of internal imaging system for enhanced monitoring

- Internal fiberscope to view liquid surface and components

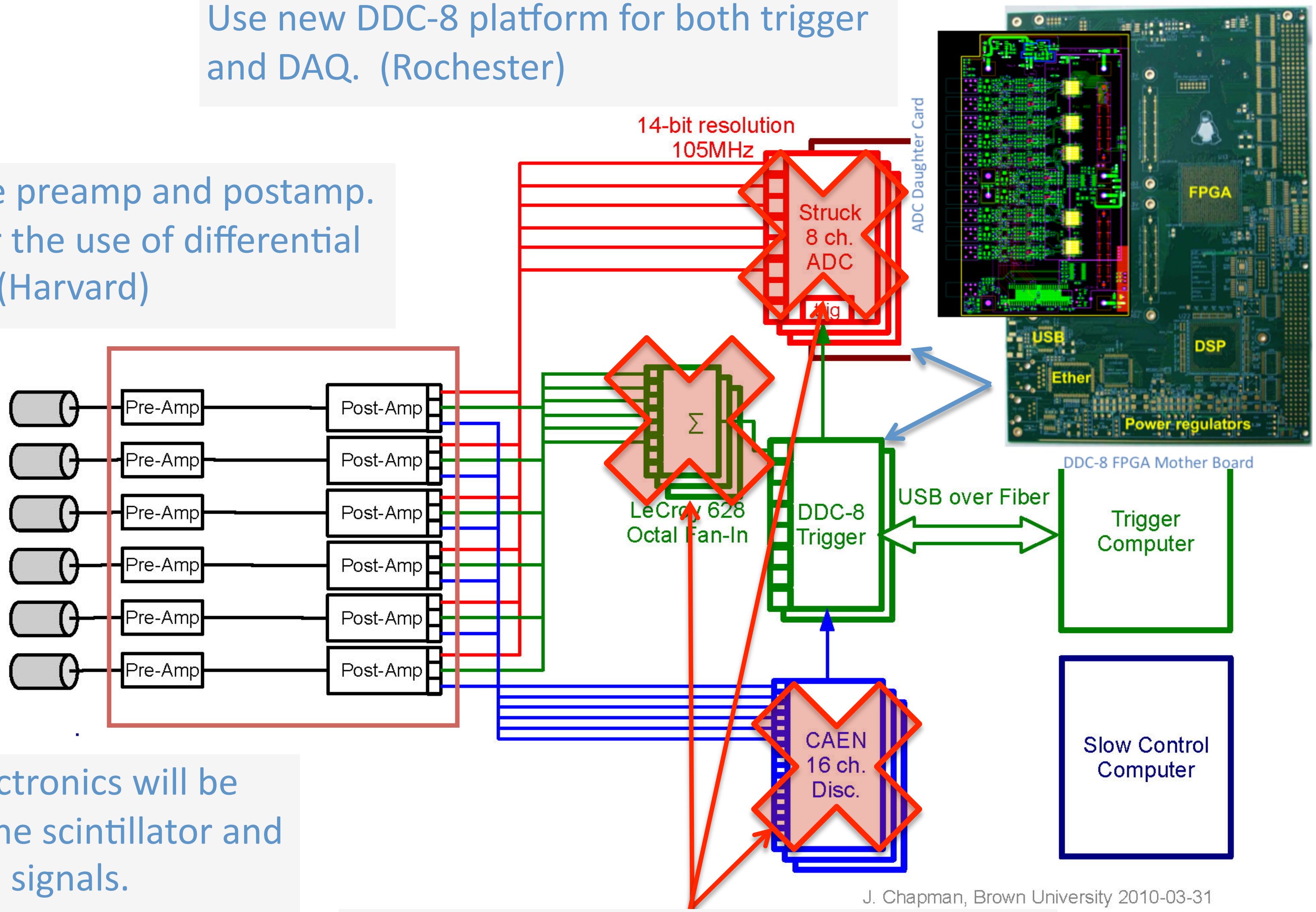
Multi-ton scale will require scale up of TPC components including grids, field rings and insulator supports. Components must also be compatible with external veto.



LZ Program: Electronics S4 development

Use new DDC-8 platform for both trigger and DAQ. (Rochester)

Integrate preamp and postamp. Consider the use of differential signals. (Harvard)



LUX-350 electronics will be reused for the scintillator and water shield signals. (UC Davis)

Eliminate summers and discriminators.
Replace Struck ADCs with DDC-8 digitizers.

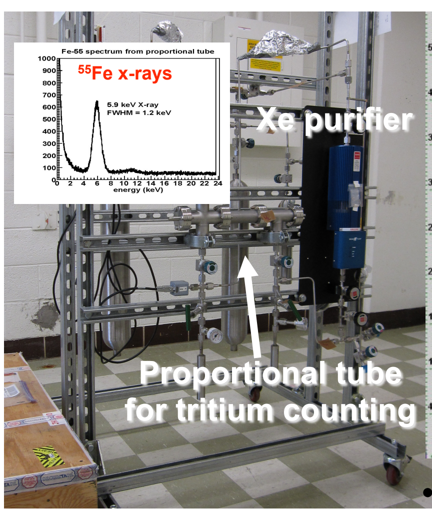
LZ Program: Internal Calibration Sources

Essential to have internal calibration source for large-volume Xe detectors

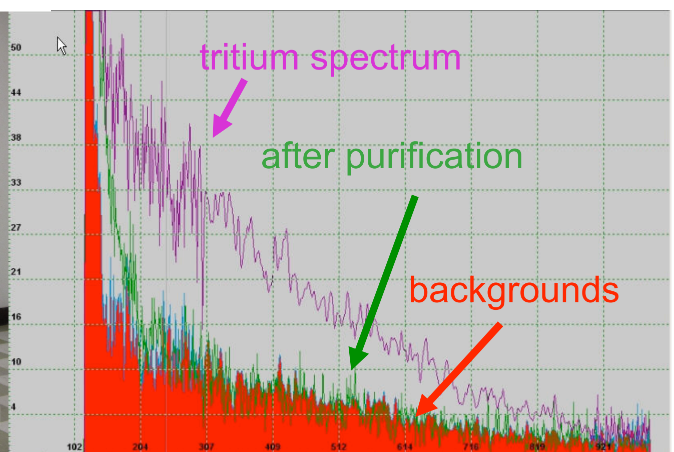
Two methods developed for LUX to be used by LZ:

- **Energy calibration: ^{83m}Kr (Yale)**
- **Electron recoil discrimination: Tritium source (Maryland)**

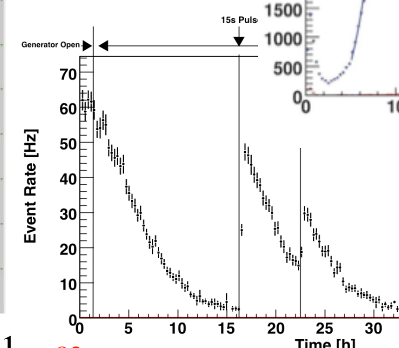
Tritiated methane (CH_3T)



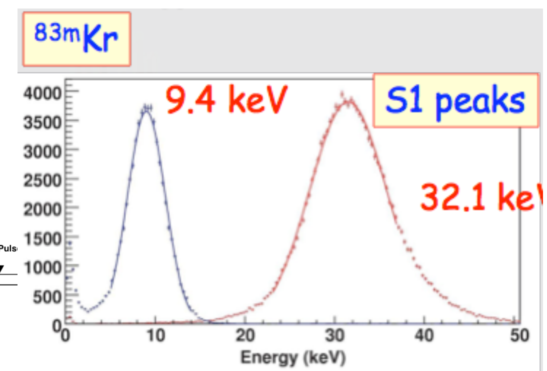
First test of removal from LXe: >90%

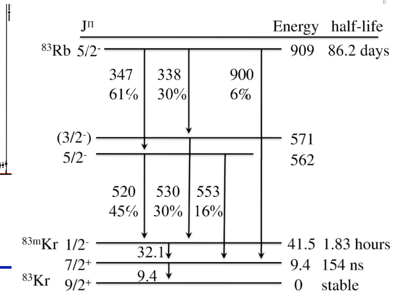


• 99.99% removal from gas (arXiv:1002:2791)

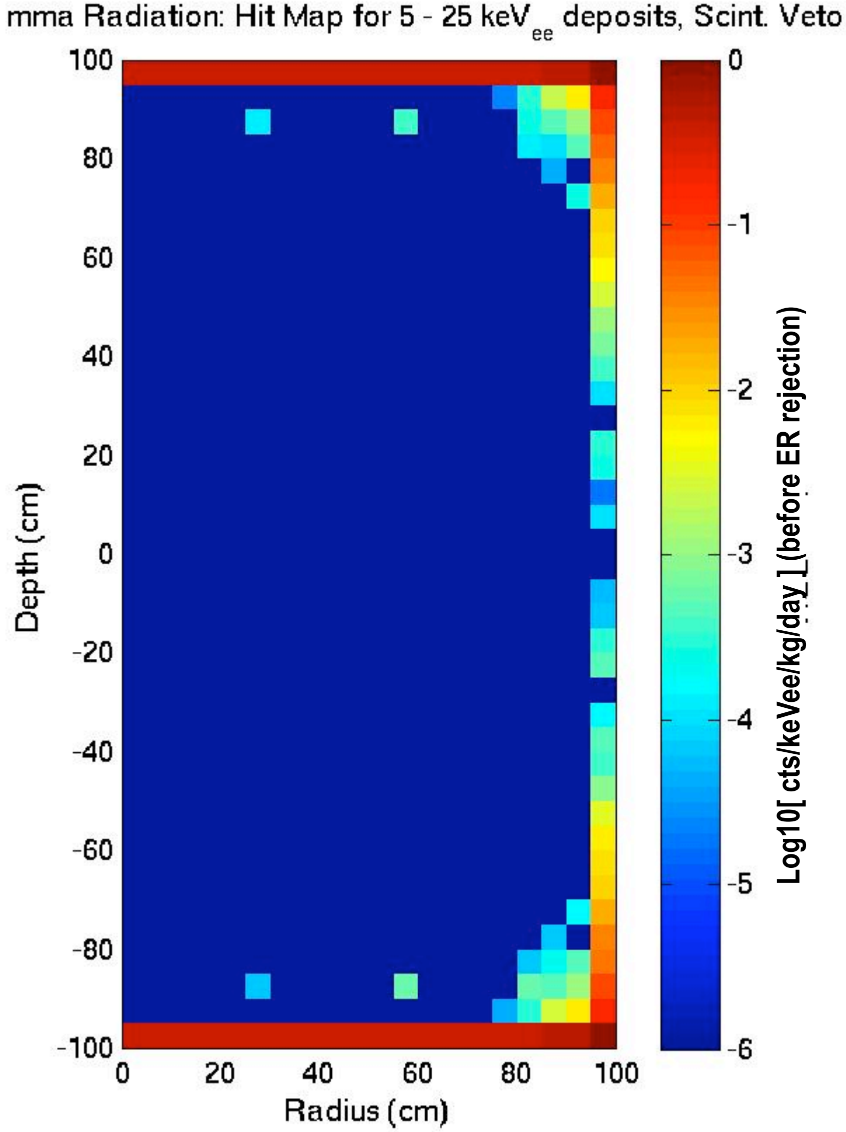


^{83}Kr: 1.8 hr half-life





LZ Program: Example of background MC for LZ-D

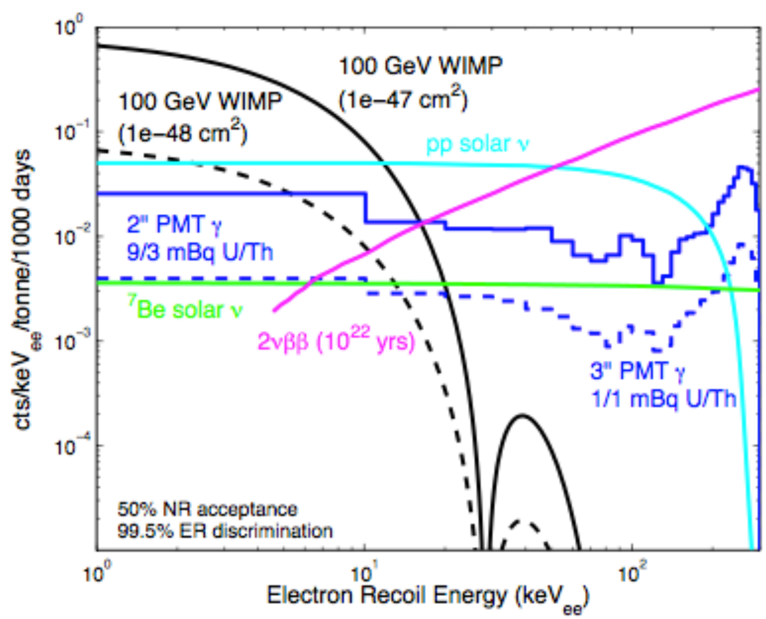


(Left) Self-shielding of gamma events from U/Th/K/Co at edge of detector

e.g. PMTs ~1 mBq

(Below) Energy dependence of ER signals and backgrounds after 99.5% rejection

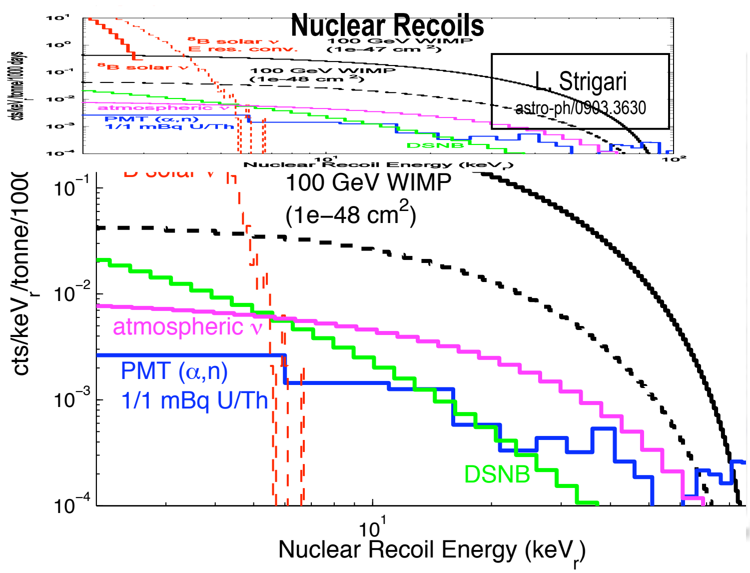
Also shown is WIMP signal for comparison (scaled to keVee)

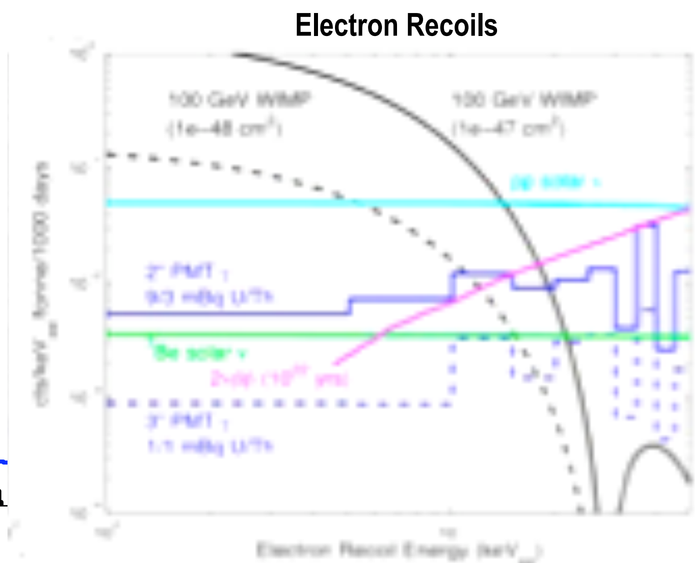


LZ Program: LZ-D, ultimate search?

- 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-D reaches this fundamental limit for direct WIMP searches

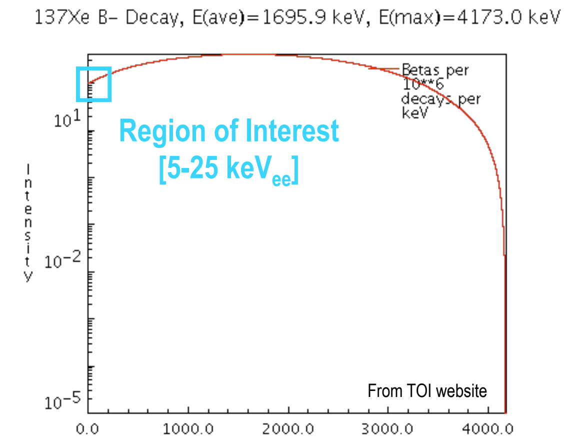
- LZ-D also sensitive to $\beta\beta0\nu$ decay in natural xenon up to lifetimes of ~1.3 10^{26} years !





Cosmogenic Backgrounds for large underground Xenon detectors

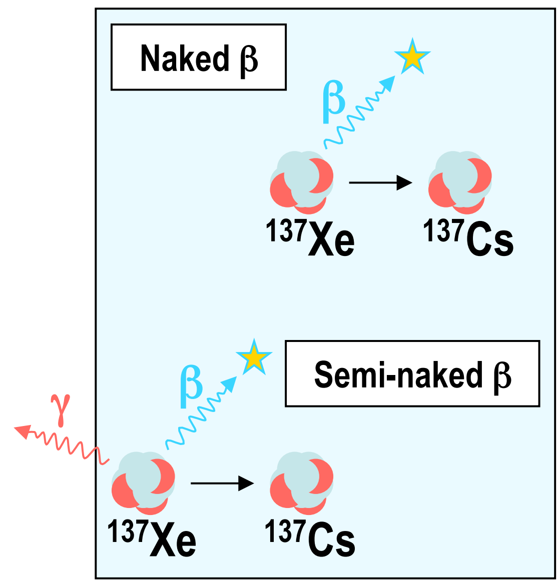
- Unprecedented sensitivity reach means we need to look into previously overlooked cosmogenic backgrounds
  - <u>Reference</u>: p-p solar neutrinos irreducible background **~10^{-5} /keV$_{ee}$/kg/d** (before 99.5% ER rejection)
  - Neutrons from muon spallation
    - in the rock (well known background for years, killed by water shield)
    - in the xenon
  - Negative muon capture → leads to neutron emission + radioactive isotopes in Xe
    - in xenon
    - in water
  - Photonuclear neutron production in the water
  - Fast neutron activation of xenon
  - Thermal neutron capture on xenon
  - More processes currently being checked and studied…



- Activation of the xenon → many isotopes, looked at all significant ones (> 200 !)
  - Searching for "Naked beta" emitters or "semi-naked beta" emitters
    - No coincident radiation (or not detected)
    - Potentially low energy deposition in WIMP search range [5–25 keVee]
    - Statistical chance of leakage into nuclear recoil region (< 0.5%)
  - Example: ^{137}Xe (from neutron activation of natural Xe)
    - 67% BR to naked 4.1 MeV beta
    - 30% BR to 3.7 MeV beta + 450 keV gamma
    - Probability for a 450 keV gamma to "escape" from 10 cm of Xe = 0.3 %
  - Calculated single event rates in [5- 25 keV$_{ee}$]
    - From muon capture on xenon: **~10^{-9} /keV$_{ee}$/kg/d**

      (assuming a muon flux of 5 10^{-9} /cm^2/s)
      (assuming a stopping muon fraction of 0.5 % per 100 g/cm^2 of Xe)
    - From thermal neutron activation of xenon: **~5 10^{-8} /keV$_{ee}$/kg/d**

      (assuming a thermal neutron flux of ~5 10^{-7} /cm^2/s)
    - From fast neutron activation of xenon: **~10^{-7} /keV$_{ee}$/kg/d**
- ALL <u>well below</u> the p-p solar neutrino background rate



Cosmogenic Backgrounds for large underground Xenon detectors

• Neutron production

Neutron Type	Source Volume	Neutron Production	Ratio into LXe
Cosmic Muon Induced Spallation Neutrons	Shielding Water	2.45e-03/s	1.39e-05
	Liquid Scintillator	8.01e-05/s	2.36e-02
	LXe Target	2.07e-04/s	1
Capture Muon Induced MeV Neutrons	Shielding Water	1.20e-03/s	0
	Liquid Scintillator	1.06e-05/s	1.17e-02
	LXe Target	8.07e-03/s	1
Photon-Nucleus Produced $\sim$ 200 keV Neutrons	Shielding Water	1.09e-05/s/ppt	0
	Liquid Scintillator	1.03e-07/s/ppt	2.62e-03

Neutron production rate in different volumes of a 20-tonne Xe detector with a 1-m thick liquid scintillator around the cryostat.

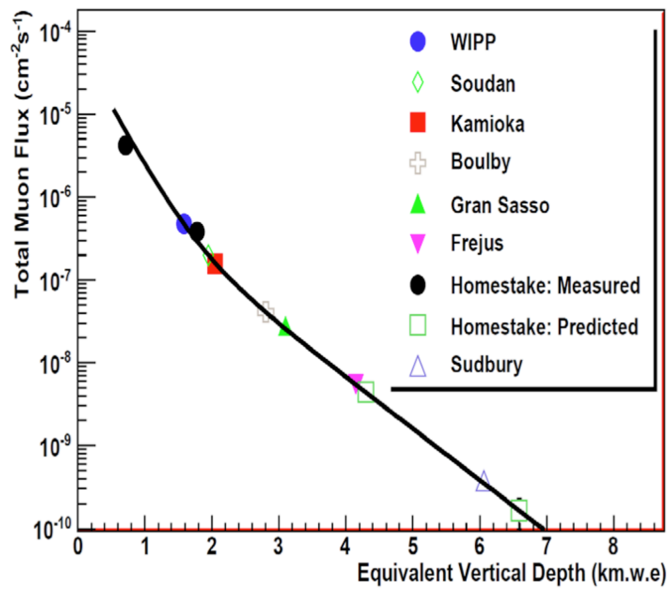
The “Ratio into LXe” represents the fraction of produced neutrons which actually enter the active volume according to preliminary Monte-Carlo. It does not take into account the chance or the multiplicity of interaction.

• Thermal Neutron Flux

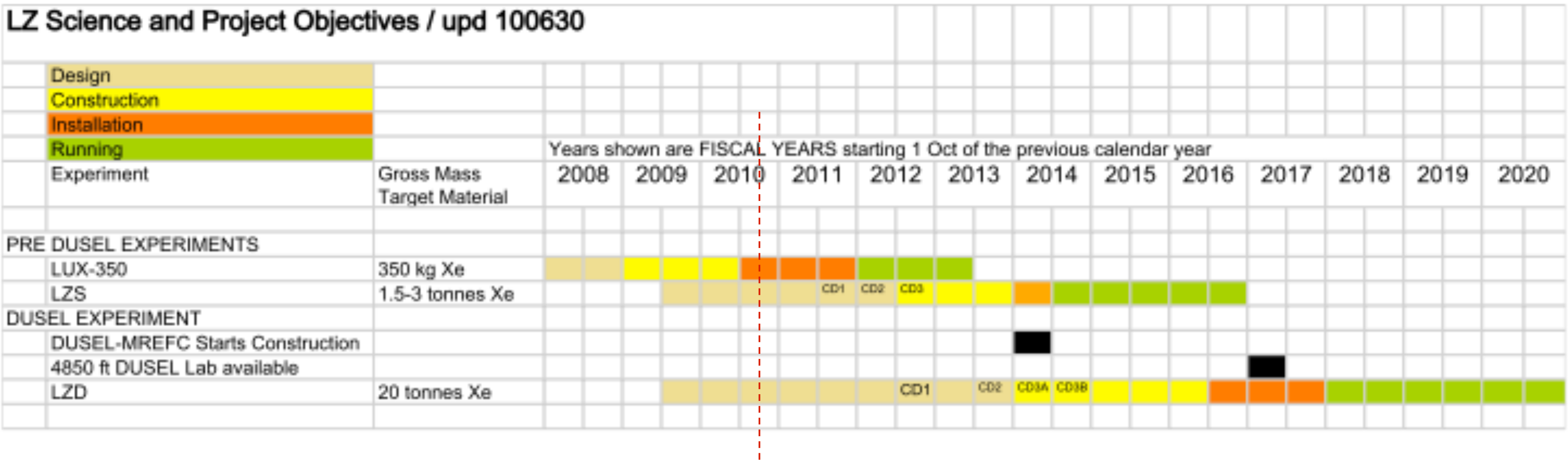
- Thermal neutron flux in detector subject to effects of water shield
- Currently running neutron propagation MC to make sure current estimate (based on flux outside of shield) is not too far off.
- Current safety margin ~10^2

• Muon Flux

- Total flux vs depth relation well-known. Homestake 4850 ft: Φ_μ ~ 5 10^{-9} /cm^2/s
- For Cosmogenic Background: Need stopping muon flux in H_2O, Xe, Liq. Scint
  - Modern references on low-energy muons underground surprisingly sparse
  - In contact with various groups to find or make a measurement
  - However: Would have to be > 10^3 larger than current estimates to be an issue



LZ Program: Time line

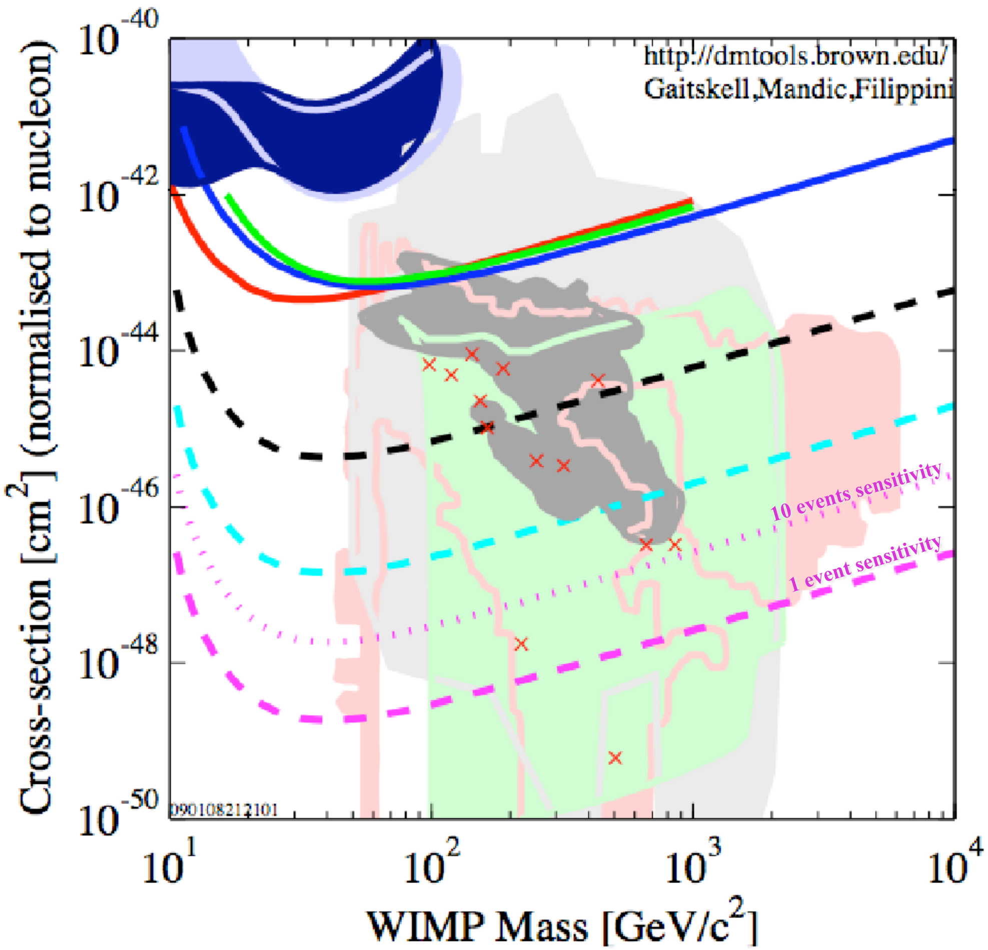


LUX schedule is symbiotic with Sanford development. Science in 2012. Developing engineering and safety protocols.

LZ-S utilizes Davis Complex. Large physics return for cost. Construction retires risks for LZ-D.

Need focus on LZ-S funding and schedule.

LZ Program: SI WIMP Sensitivity



- Projections based on
  - Known background levels
  - Previously obtained e$^-$ attenuation lengths and discrimination factors

LUX (constr: 2009-2011, ops: 2011-2012)
100 kg x 300 days

LZ-S (constr: 2012-2013, ops: 2013-2014)
1,200 kg x 500 days

LZ-D (constr: 2014-2017, ops: 2017-2022)
17,000 kg x 1,000 days

- Fiducial volumes selected to match < 1 NR event in full exposure

Additional Slides

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

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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

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

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Harry Nelson	Professor
Dean White	Engineer
Susanne Kyre	Engineer

SD School of Mines
IceCube

Xinhua Bai	Professor
Mark Hanardt	Undergraduate Student

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ZEPLIN II

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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

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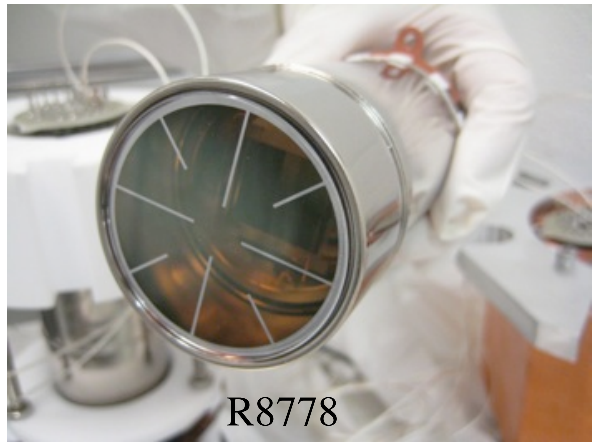
James Nikkel	Research Scientist
Sidney Cahn	Research Scientist
Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Louis Kastens	Graduate Student
Nicole Larsen	Graduate Student

LZ Program: PMTs

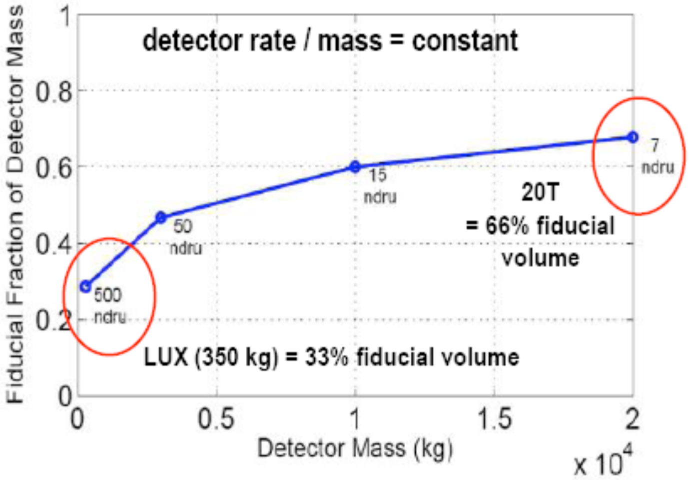


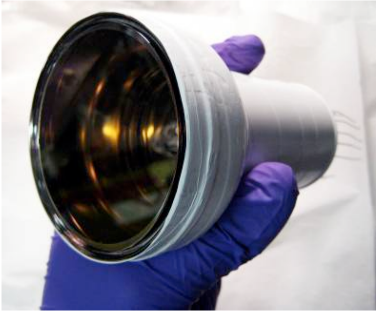
Current LUX 350 Experiment: Using 122 x 2” R8778 Hamamatsu

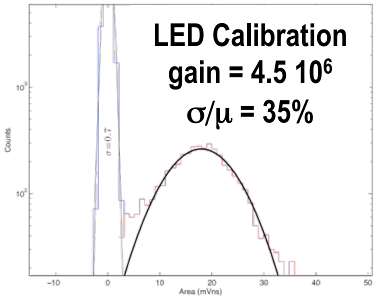
- Production yields high/very stable - long track record with technology
- U/Th 10/2 mBq/PMT
  - There has been tremendous progress in reducing PMT backgrounds
  - The level of radioactivity already achieved in these PMTs would be an acceptable baseline for the LZ-S and LZ-D experiments
- Demonstrated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

LZ Program

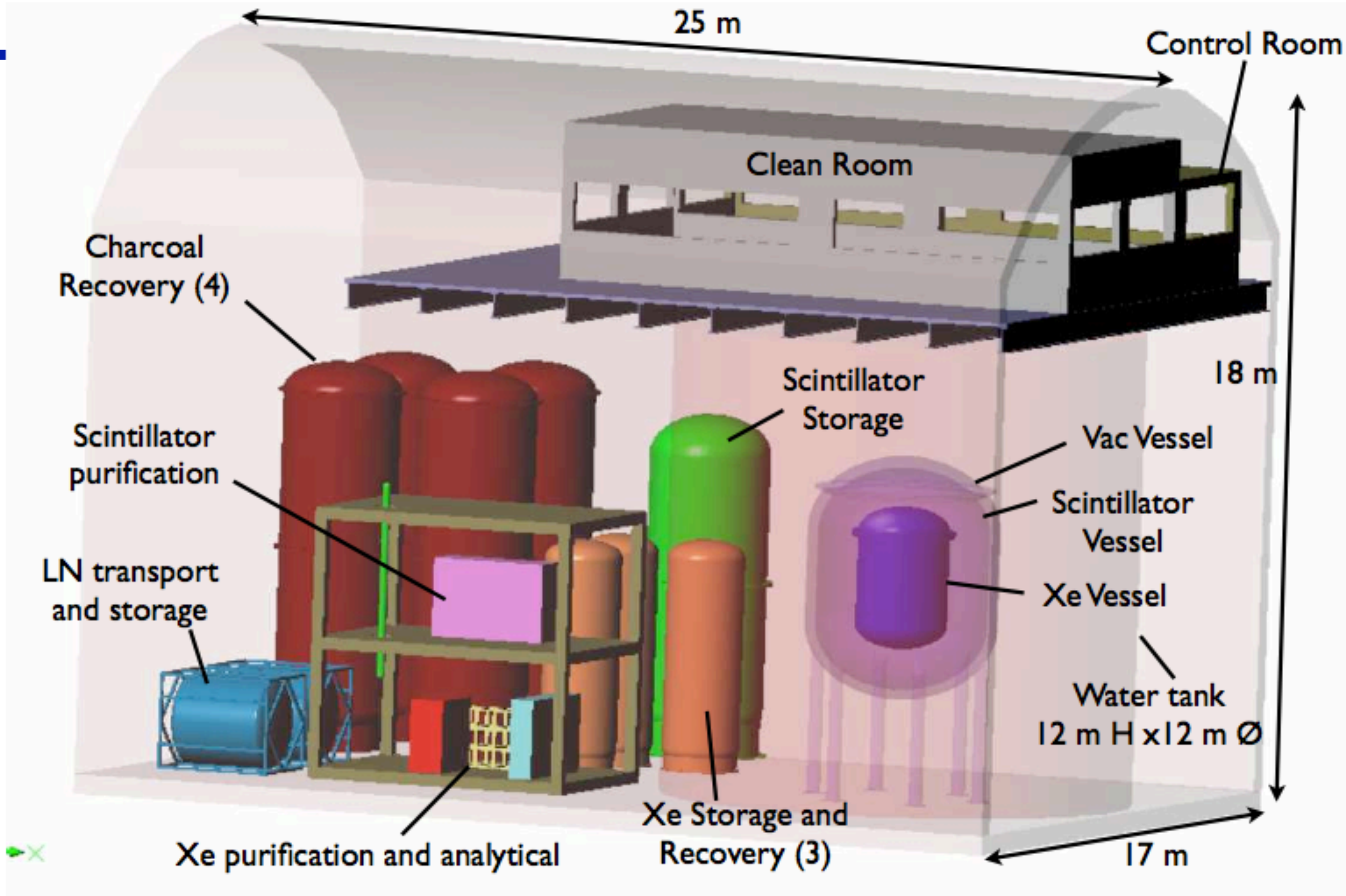
- LZ-S: 3 tonnes detector in Davis water shield (SUSEL)
  - Proposal start: Sept 2009
  - Bigger 3" PMTs already in testing. Goal ~1 mBq/PMT
- LZ-D: 20 tonnes detector, part of ISE for DUSEL
  - « ultimate » direct detection experiment
- Requirements
  - Mechanics, safety: LUX 350kg will demonstrate
  - Light collection: current understanding 20t scale ok
  - Xe purity: LZ-D requires $<10^{-14}$ Kr/Xe, < ~mBq Rn
    - state of art already demonstrated (SNO, Borexino) + Xe much easier to purify
    - work in progress to achieve high reliability
  - Backgrounds
    - Goal: < 2 neutron events / 3,000 tonne.days (before acceptance cut)
    - PMT background already improved by x2 compared to 2" tubes improvement by x10 likely in near future (currently XMASS has < 1 mBq/PMT)
    - Extensive study of cosmogenic backgrounds in progress
      - still subdominant at -4850 ft for 20 tonne scale







Facility requirements: Space



Hall height is now > 18m

LZD layout nominally consistent with baseline cavern

Water tank dimension critical, 12 m is conservative.

Staging must be carefully considered.