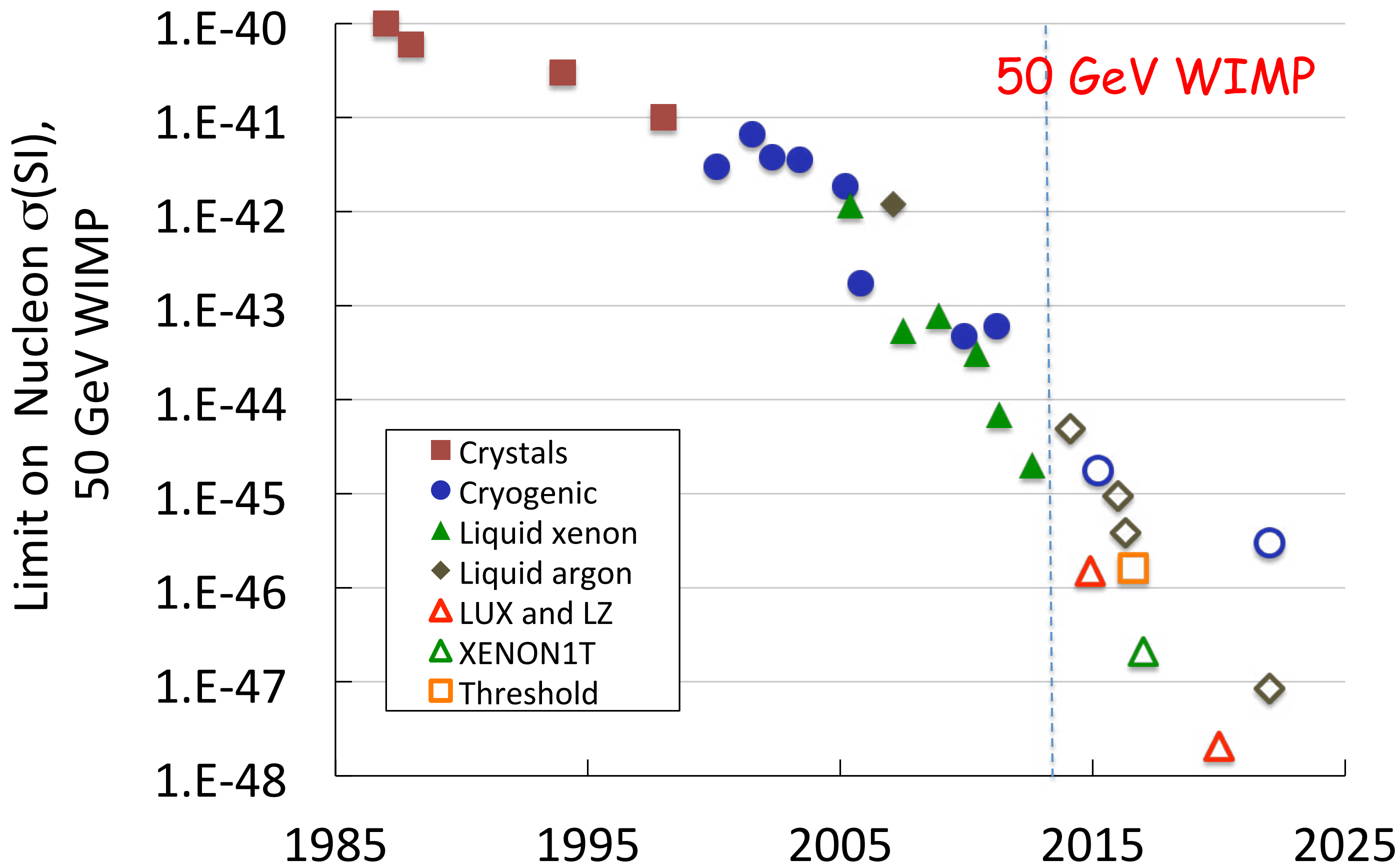
LZ: A 2^{nd} Generation Direct Dark Matter Search Experiment

Mani Tripathi

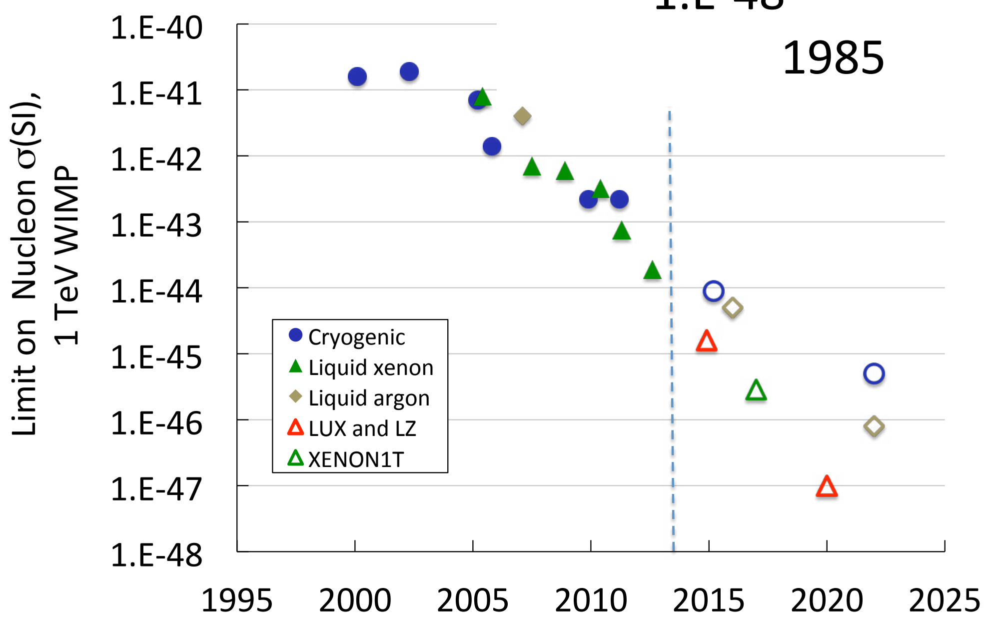
UC, Davis

9/11/13

A compact history of WIMP Searches



1 TeV WIMP



LZ is poised to possibly provide an end-point to this saga … hopefully by discovering WIMPs or, by ruling out most of the theoretical <u>and</u> experimentally accessible landscape.

Plots compiled by Mike Witherell, UCSB

LZ: Evolution of LUX and ZEPLIN

Building on experiences gained in both programs, the proposed new experiment will utilize the LUX infrastructure at the Sanford Underground Research Facility to mount a state-of-the-art detector. Highlighted features include:

- LUX water shield and an added liquid scintillator active veto.
- Instrumented "skin" region of peripheral xenon as another veto system.
- Unprecedented levels of Kr removal from Xe.
- Radon suppression during construction, assembly and operations.
- Photomultipliers with ultra-low natural radioactivity.
- Cryogenics and Xe purification systems made external to the main detector in a unique design.
- Fully digital deadtime-less data acquisition and trigger system.

LZ Collaboration

US Groups

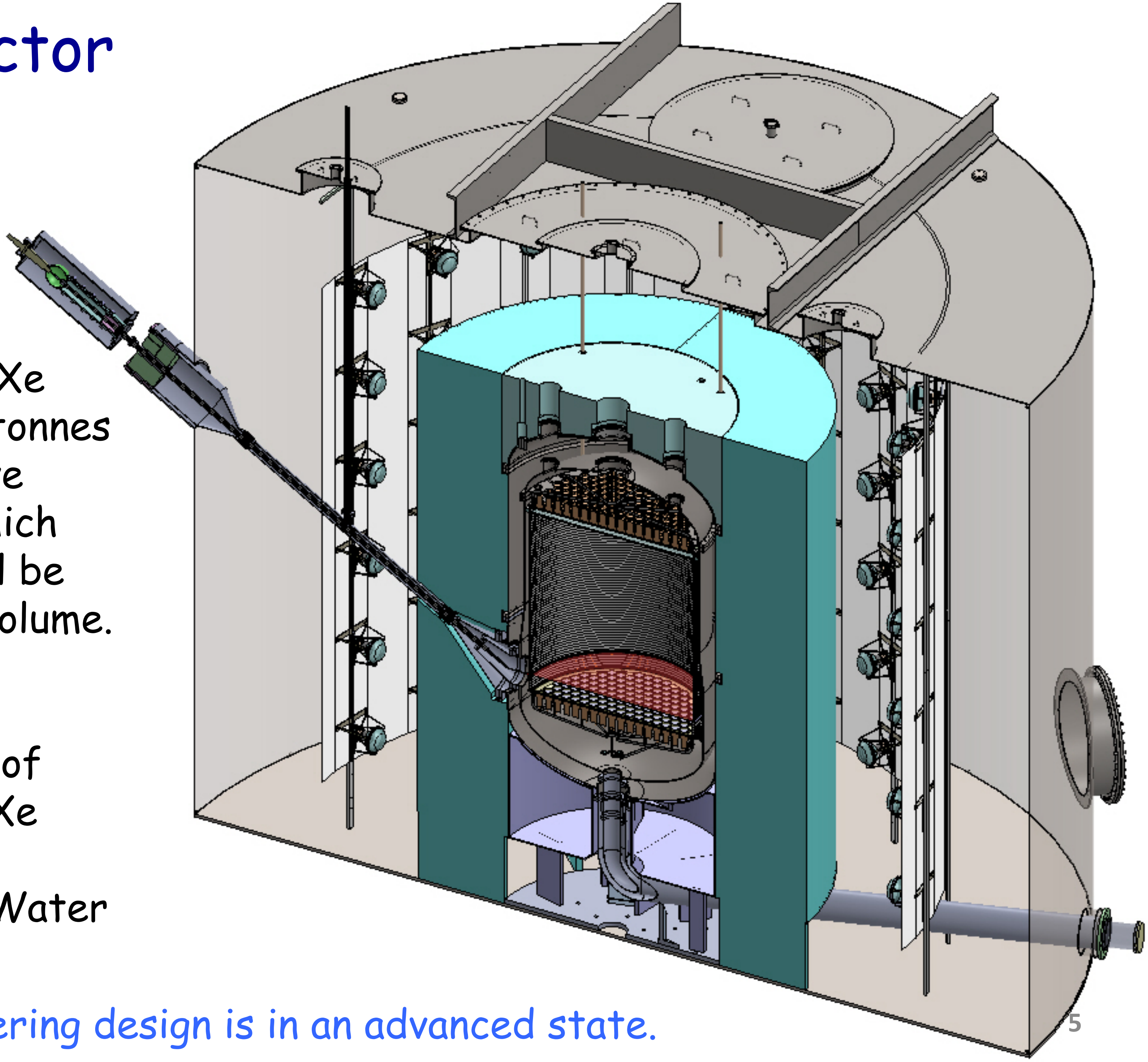
Brookhaven National Laboratory
Brown University
Case Western Reserve University
LBNL/UC, Berkeley
Lawrence Livermore Lab
SLAC
SD School of Mines & Technology
SD Science and Technology Authority
Texas A&M University
University of Alabama
UC, Davis
UC, Santa Barbara
University of Maryland
University of Rochester
University of South Dakota
University of Wisconsin
Washington University
Yale University

European Groups

University College London
University of Oxford
University of Sheffield
Edinburgh University
Imperial College London
LIP-Coimbra
MEPHI, Moscow
STFC Rutherford Appleton Laboratory
STFC Daresbury Laboratory

18 US and 9 European institutions

LZ Detector

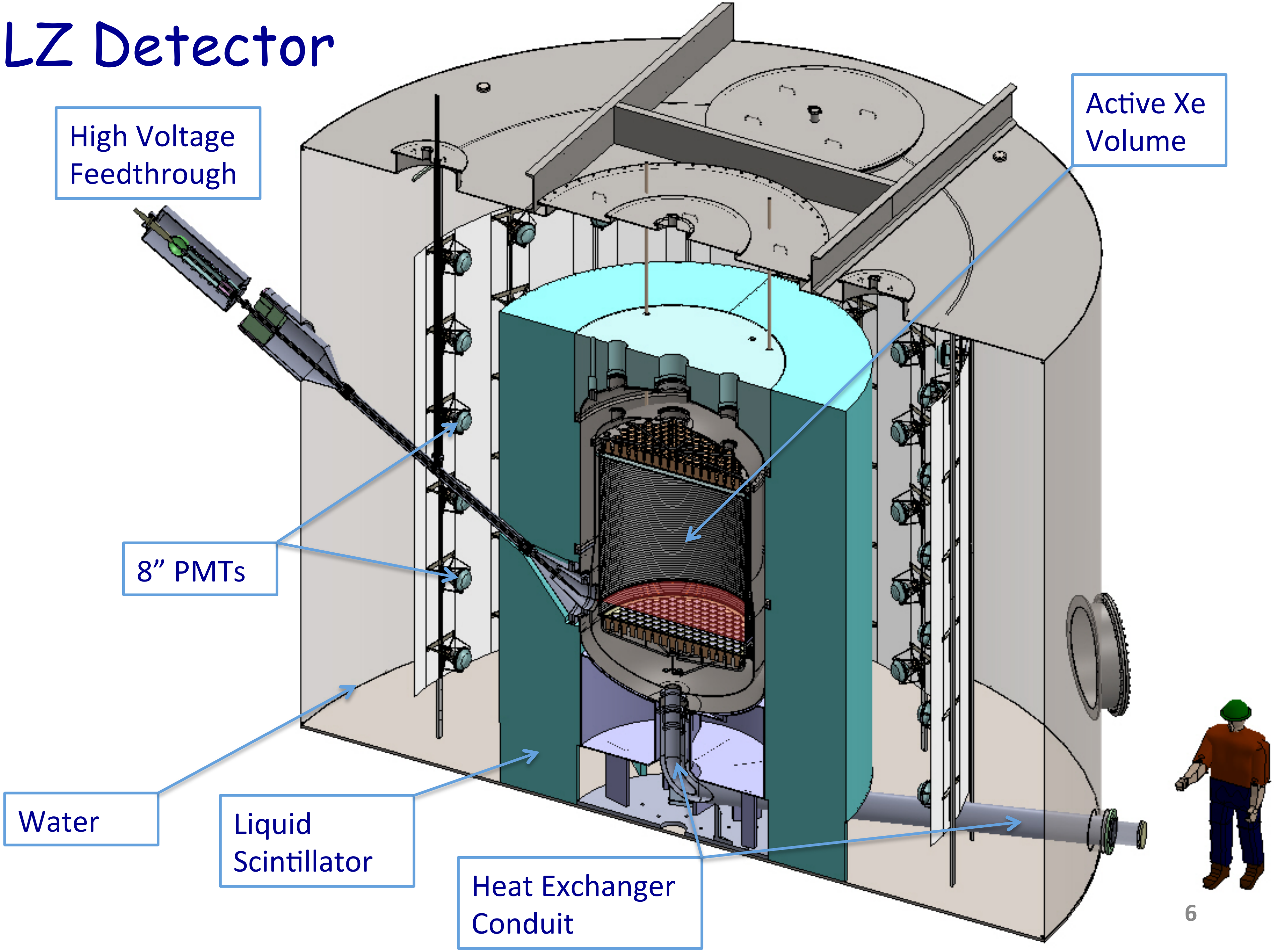


A two-phase Xe TPC with ~7 tonnes of Xe in active volume, of which ~6 tonnes will be the fiducial volume.

Three layers of shield/veto: Xe "skin", Liquid Scintillator, Water tank.

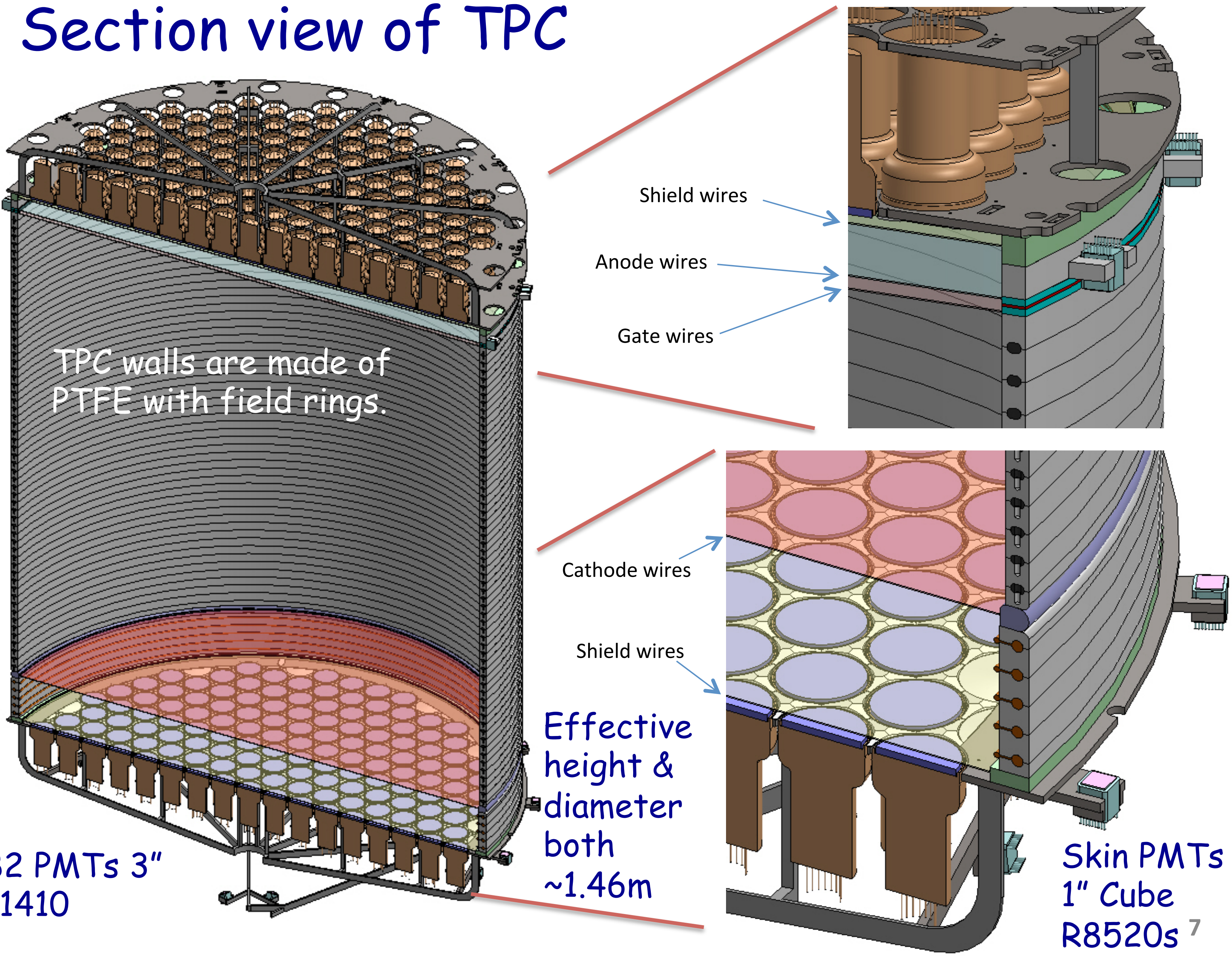
Engineering design is in an advanced state.

LZ Detector



High Voltage Feedthrough
Active Xe Volume
8” PMTs
Water
Liquid Scintillator
Heat Exchanger Conduit

Section view of TPC



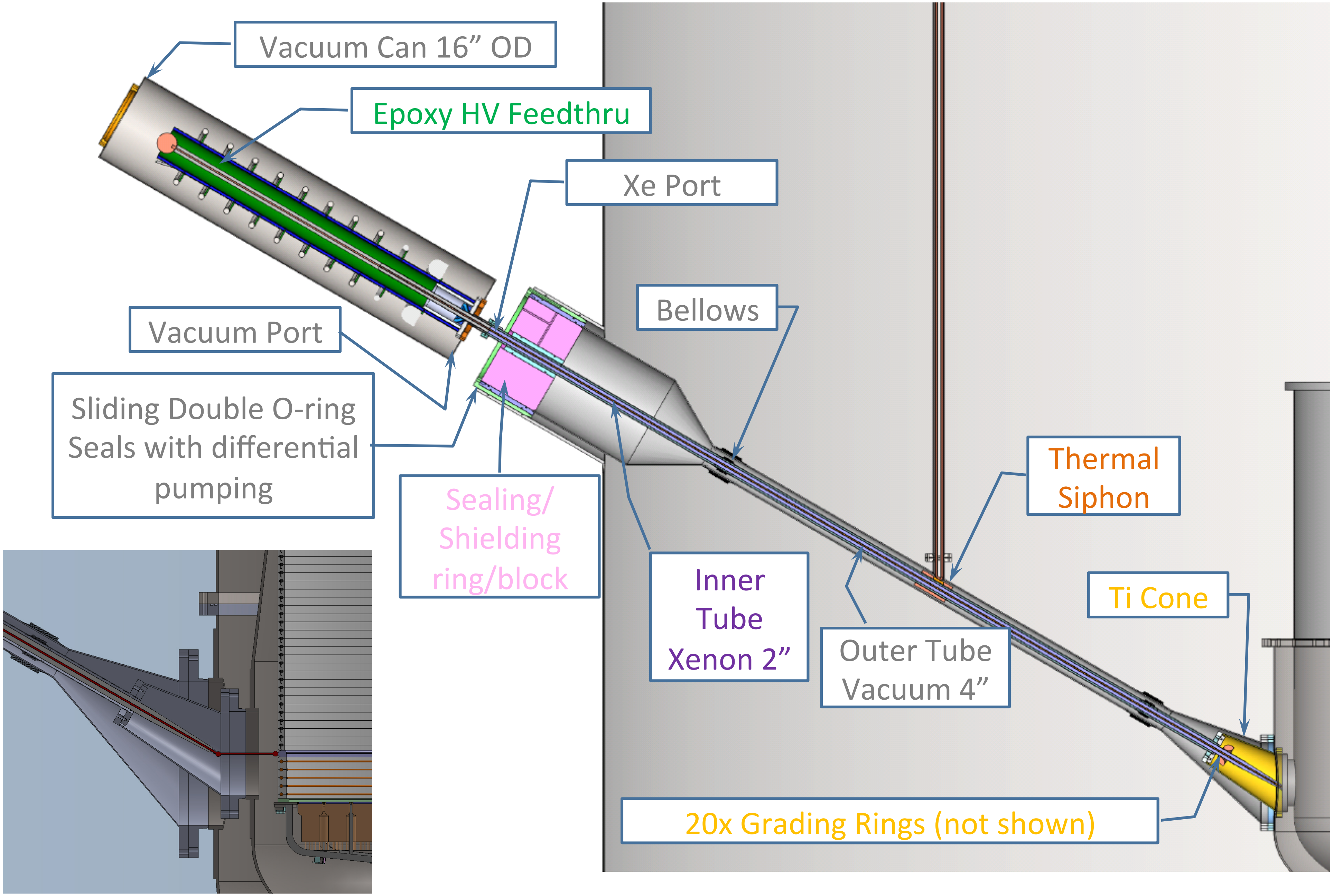
482 PMTs 3″ R11410

Effective height & diameter both ~1.46m

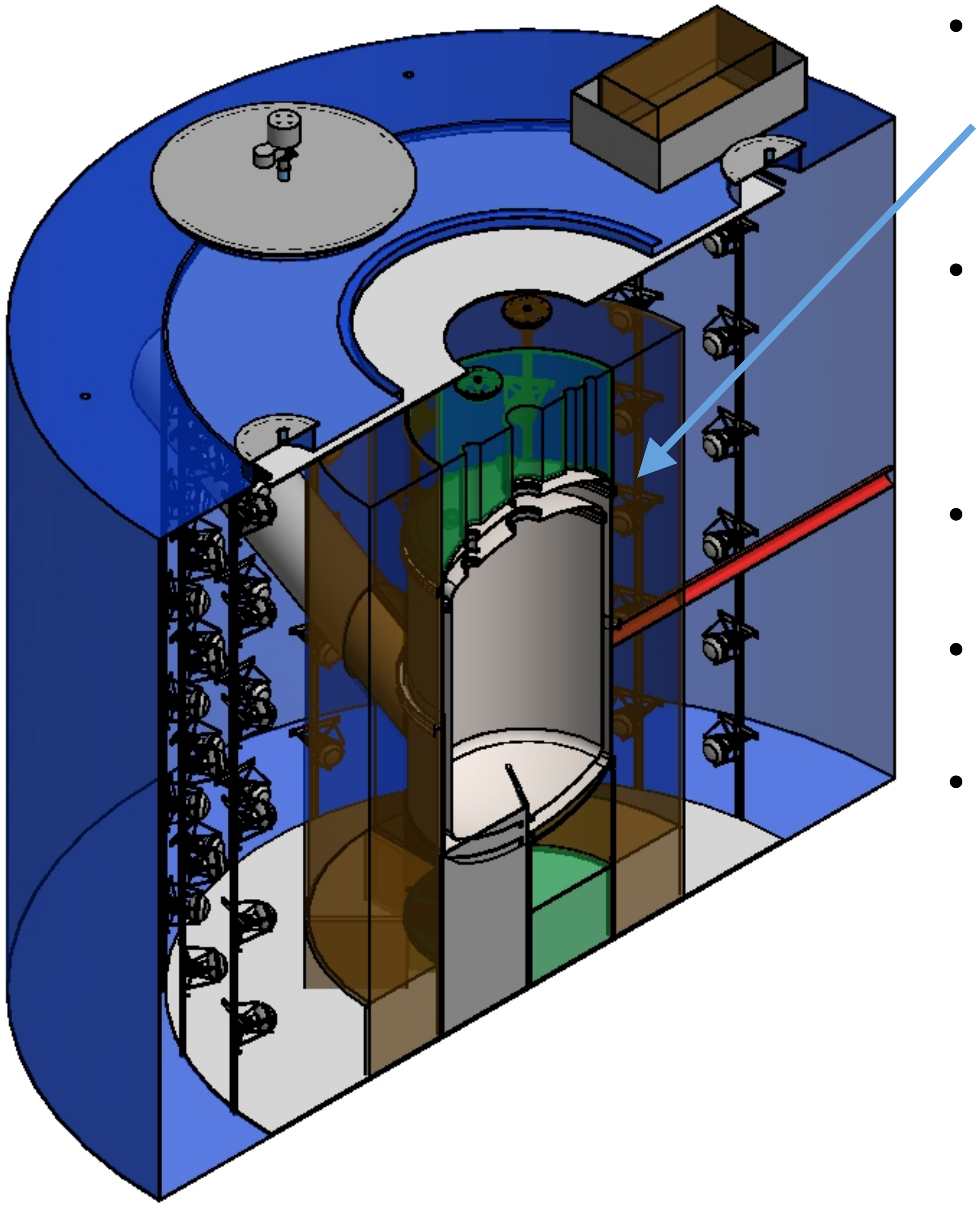
Skin PMTs 1″ Cube R8520s

HV Umbilical Concept

Nominal Operation Voltage ~ 100kV
Design Voltage ~ 200 kV

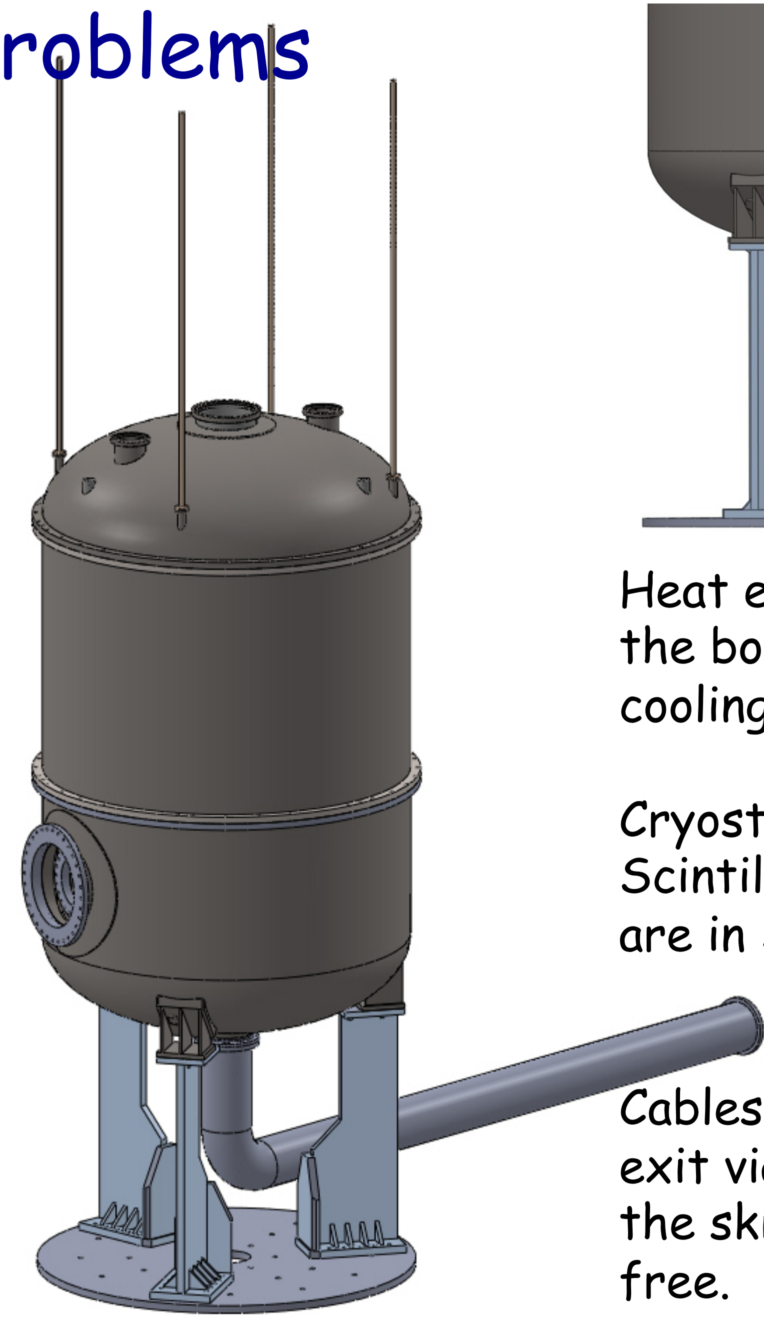


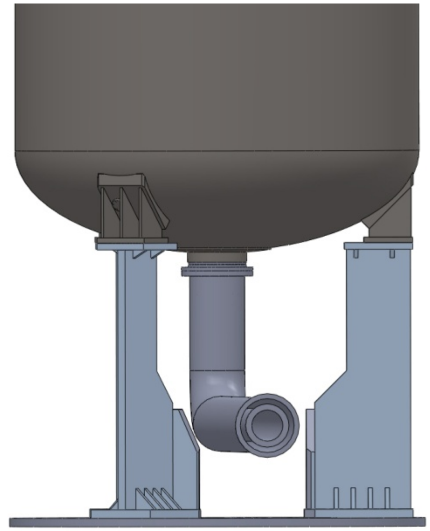
Gamma/neutron veto system



- 9 acrylic tanks surrounding the detector (4 side, 2 top, 3 bottom). 120 8" PMTs.
- Filled with liquid scintillator: Gd loaded (0.2%) LAB (linear alkyl benzene).
- Average thickness ~ 0.75m
- Total LAB Mass: 25 tonnes.
- Enables suppression of neutron-induced nuclear recoil rate to below neutrino expectation for active xenon volume.

Innovative solutions to complex engineering problems

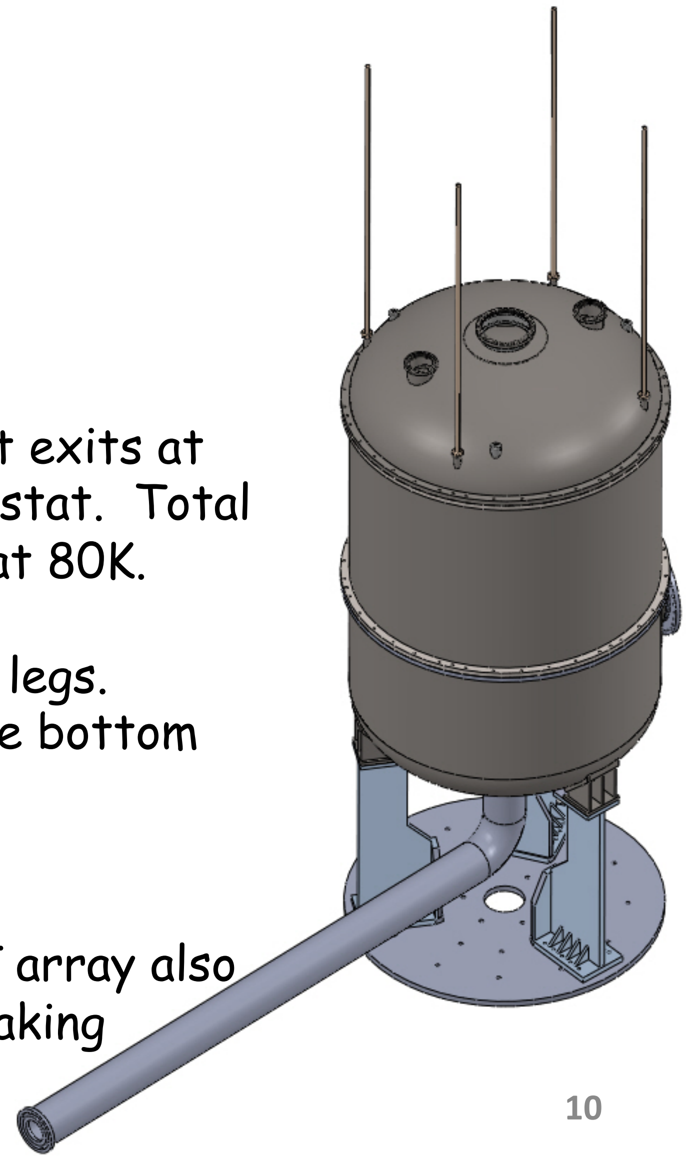




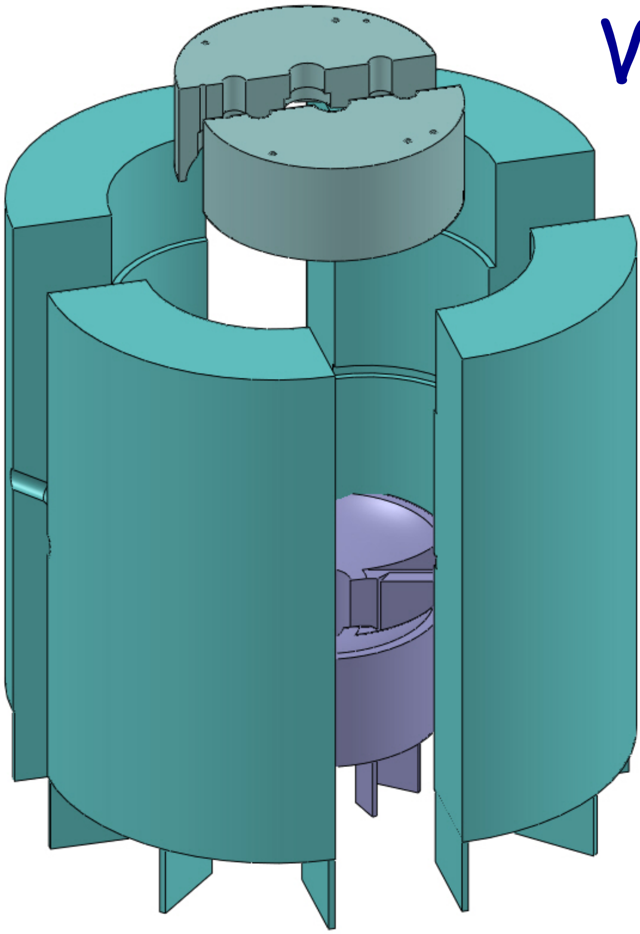
Heat exchanger conduit exits at the bottom of the cryostat. Total cooling power is ~1kW at 80K.

Cryostat support has 3 legs. Scintillator tanks at the bottom are in 3 pieces.

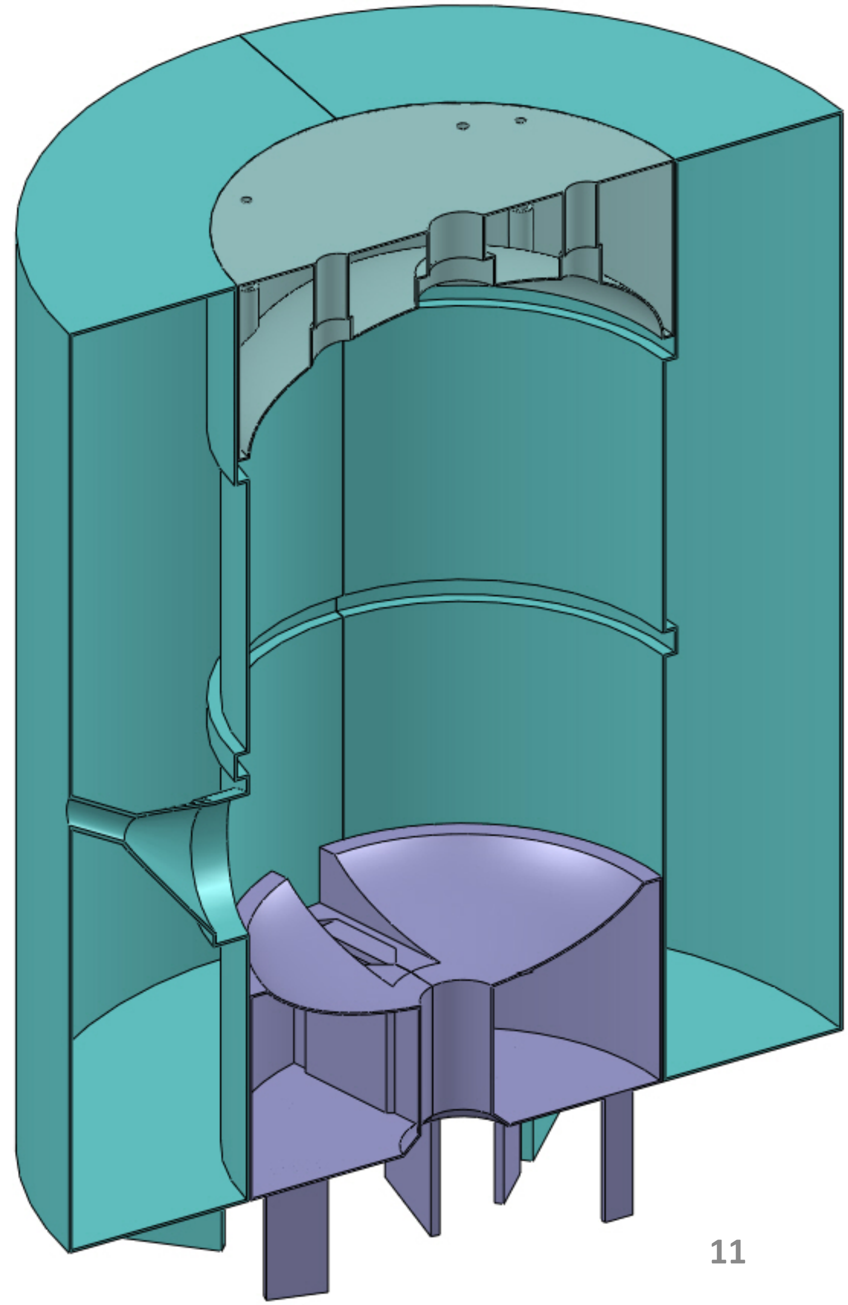
Cables for bottom PMT array also exit via this conduit, making the skin region clutter free.

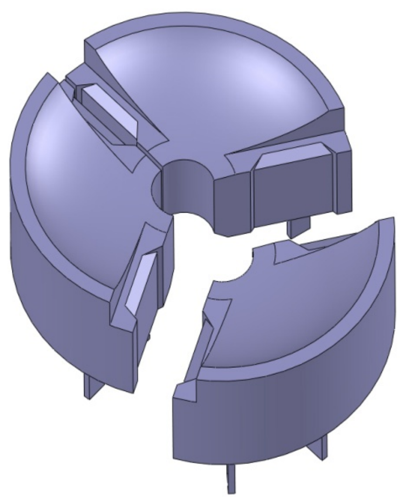


Water/Liquid Scintillator tanks



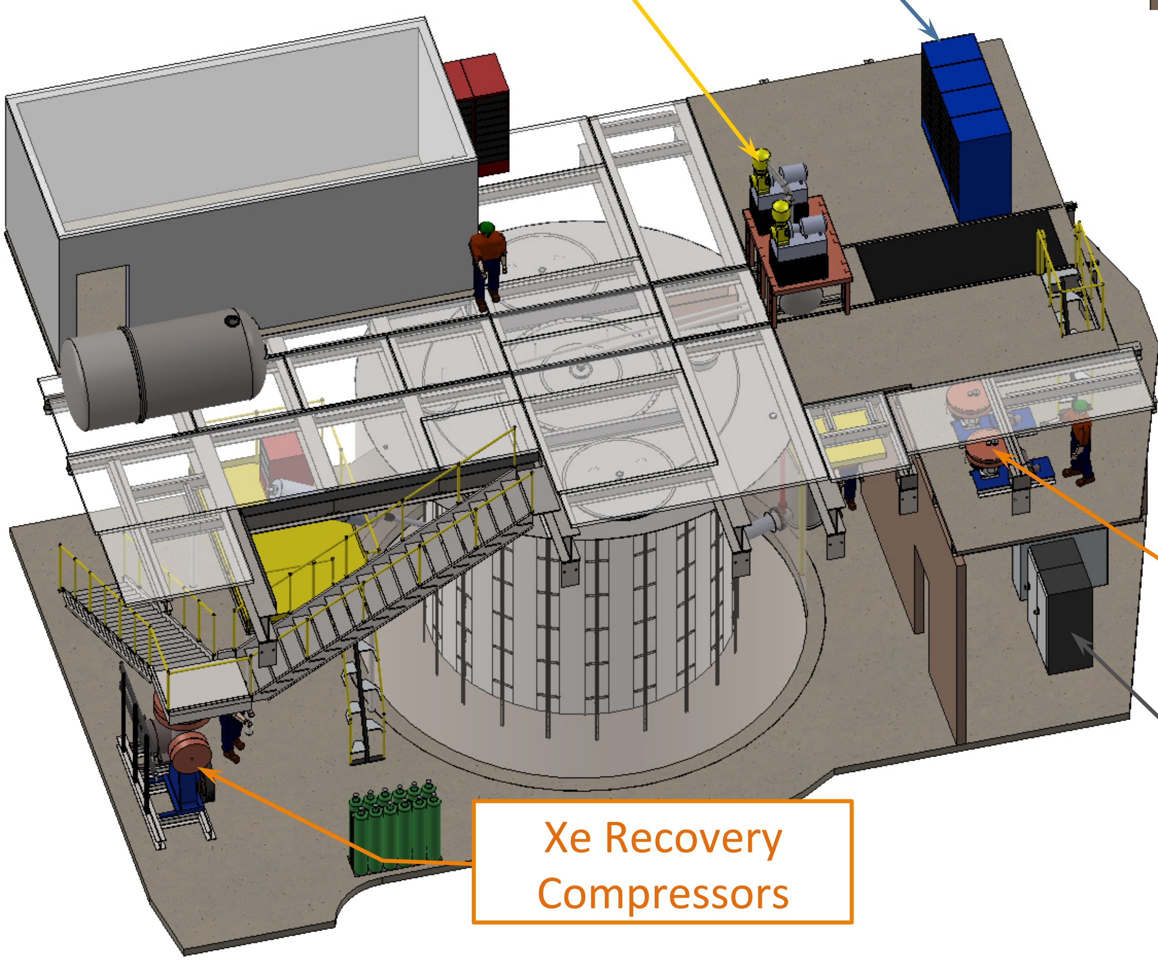
The water tank has a 7.62m diameter, and is 5.92m tall. It supports 228 tonnes of water, which is continuously purified.

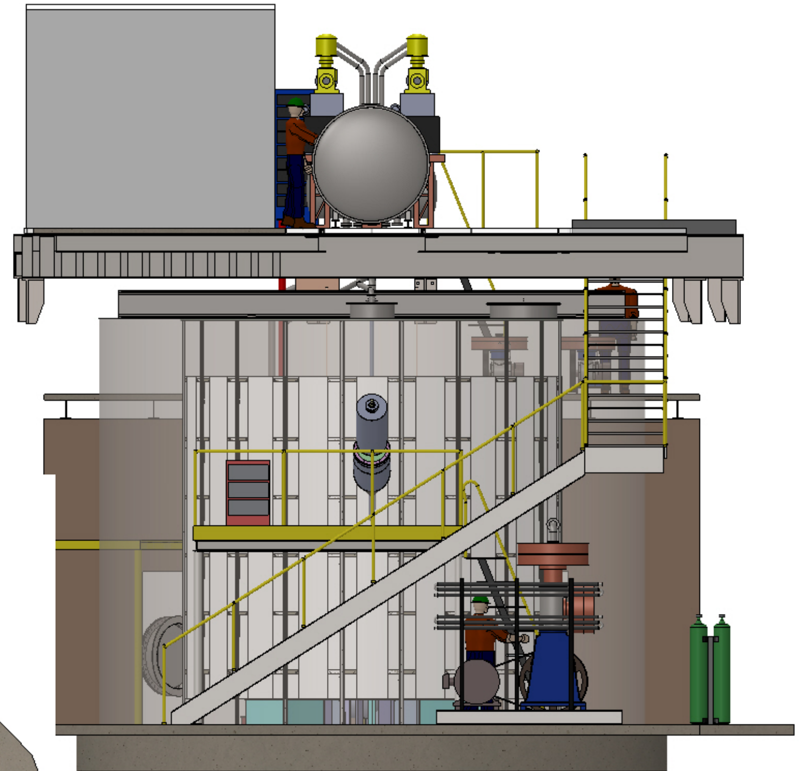




Lower LS tanks split into thirds to fit around the cryostat supports

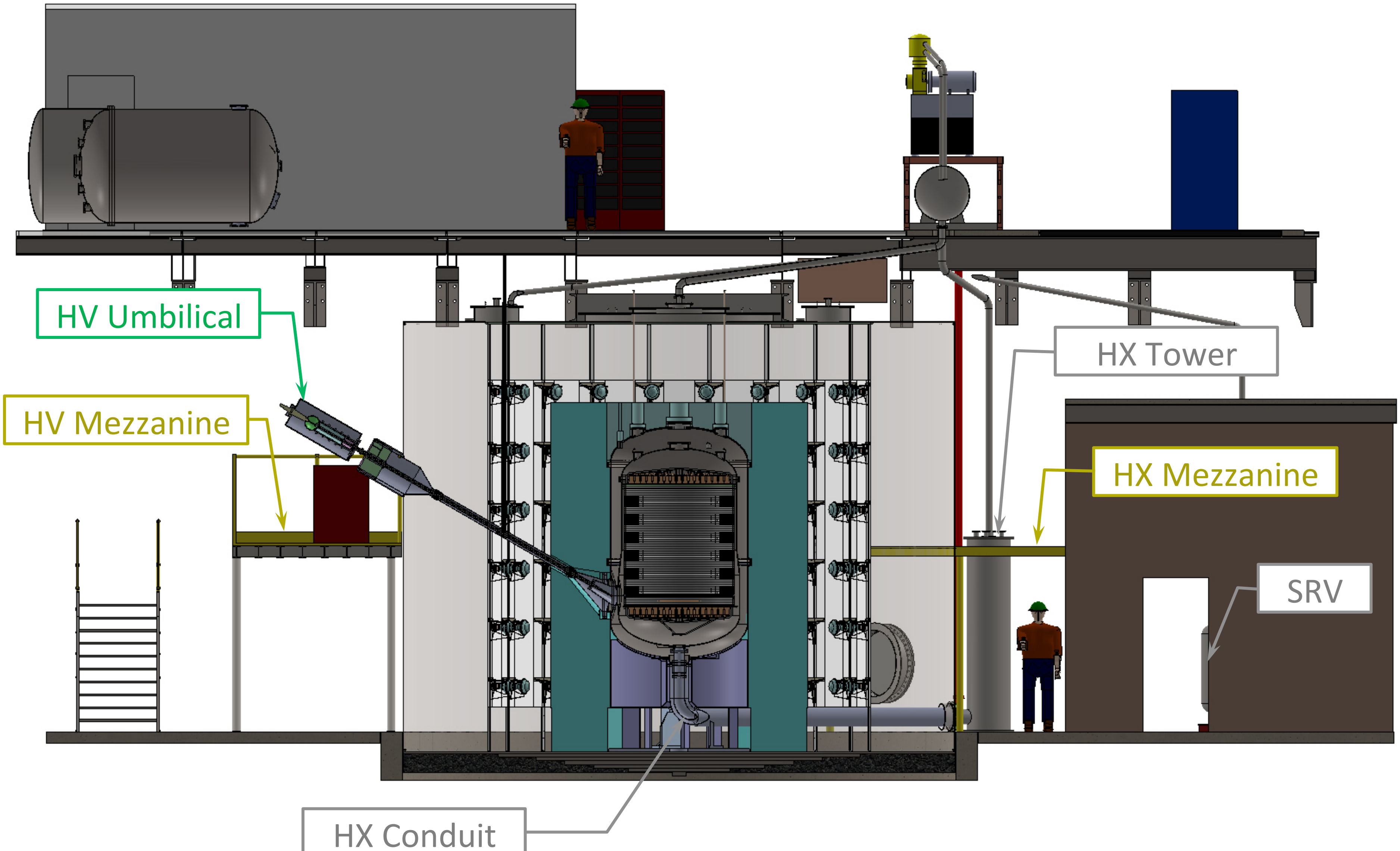
Davis Cavern with LZ detector





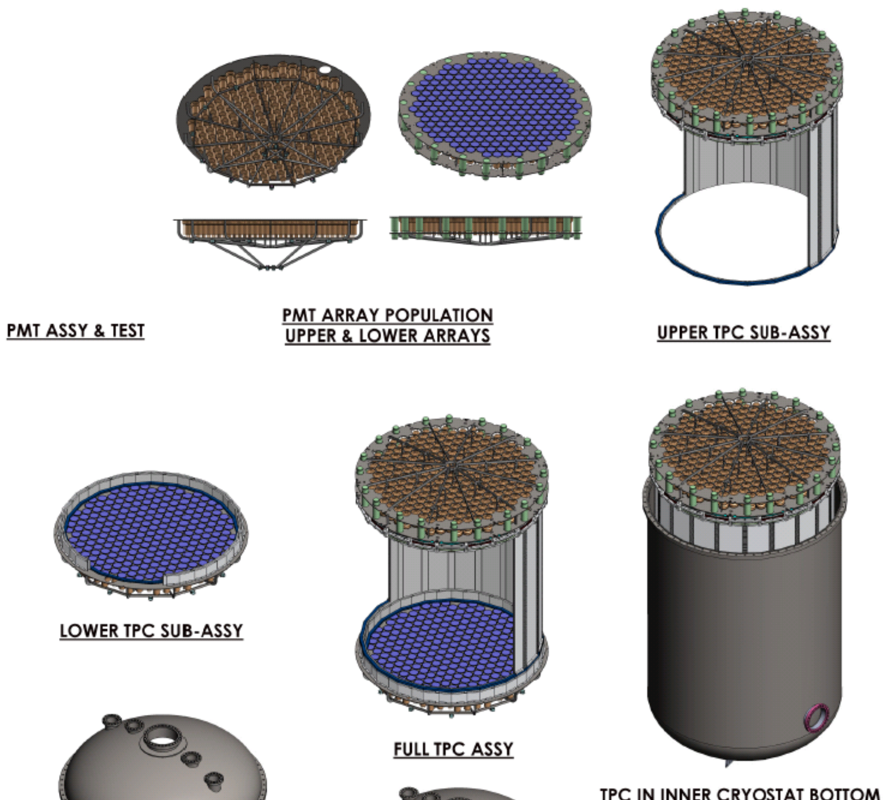
Looking North with water tank transparent

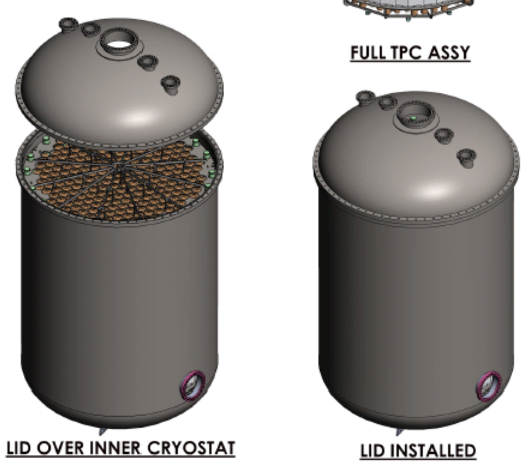
Section view



Installation Sequence

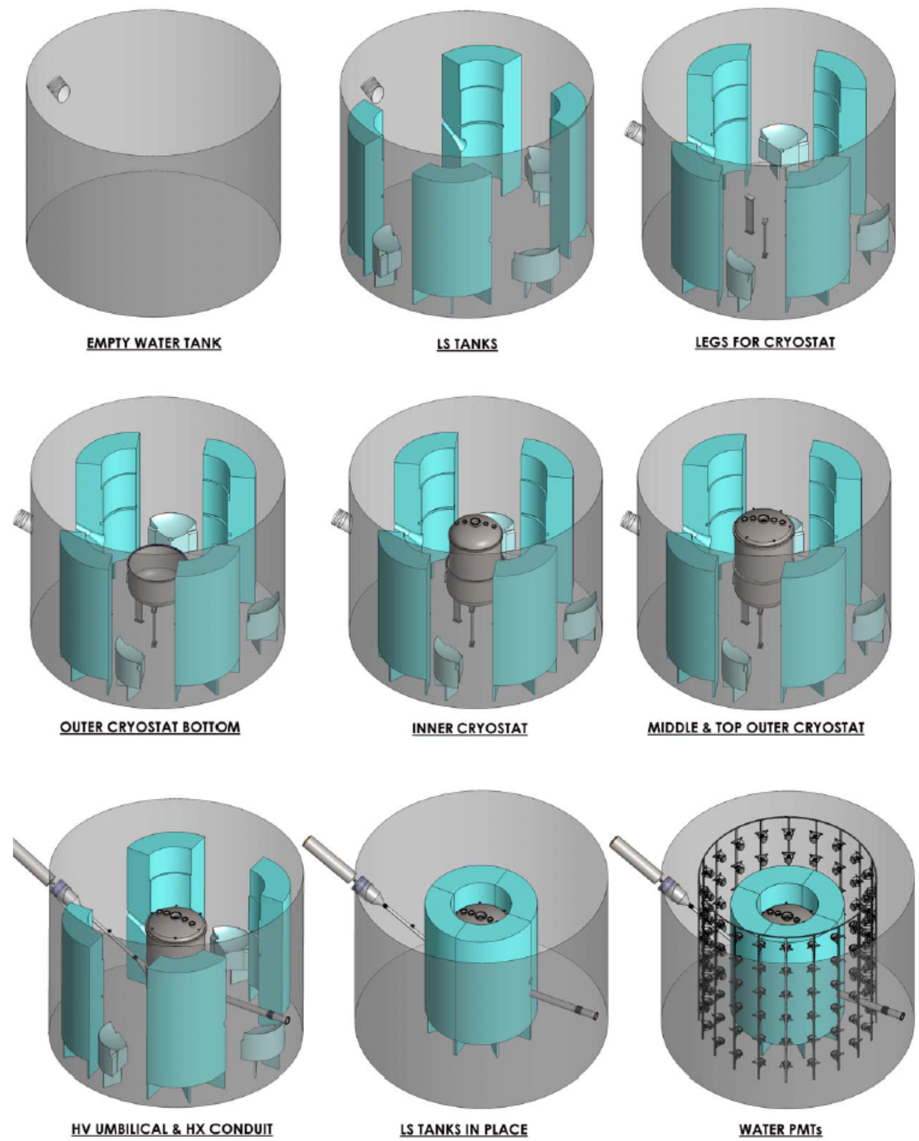
Above Ground Assembly





TPC and inner cryostat are assembled on the surface and installed as a unit.

Underground Assembly



Sensitivity and Physics Reach

LZ has a robust simulation package

Full Geant4 based simulations, pioneered in LUXSim*, have been carried forward to LZ.

[*D. Akerib, et al., NIM A675, 2012]

Microphysics of Xe light and charge yield is being simulated by NEST*. Together with Dahl thesis, it has become something of an industry standard by now and handles the subtleties remarkably well.

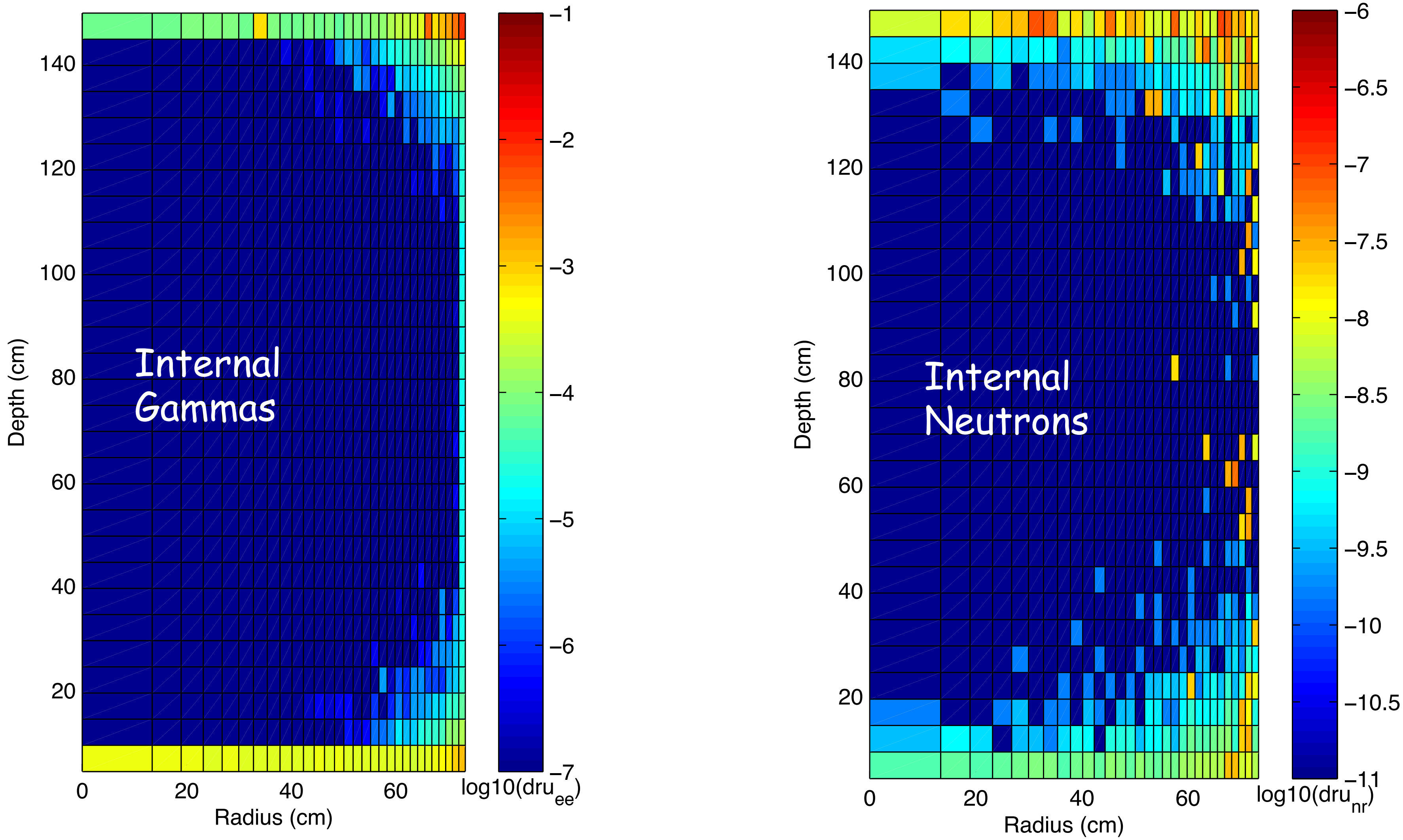
[*M. Szydagis, et al., JINST 6 P10002, 2011]

A complete geometrical description of the LZ detector has been implemented. It is being continually updated as the design evolves.

A detailed simulation of the electronics chain and pulse finding algorithms are being implemented, as per lessons learned from LUX.

We have high confidence in our understanding of the projected performance of this detector.

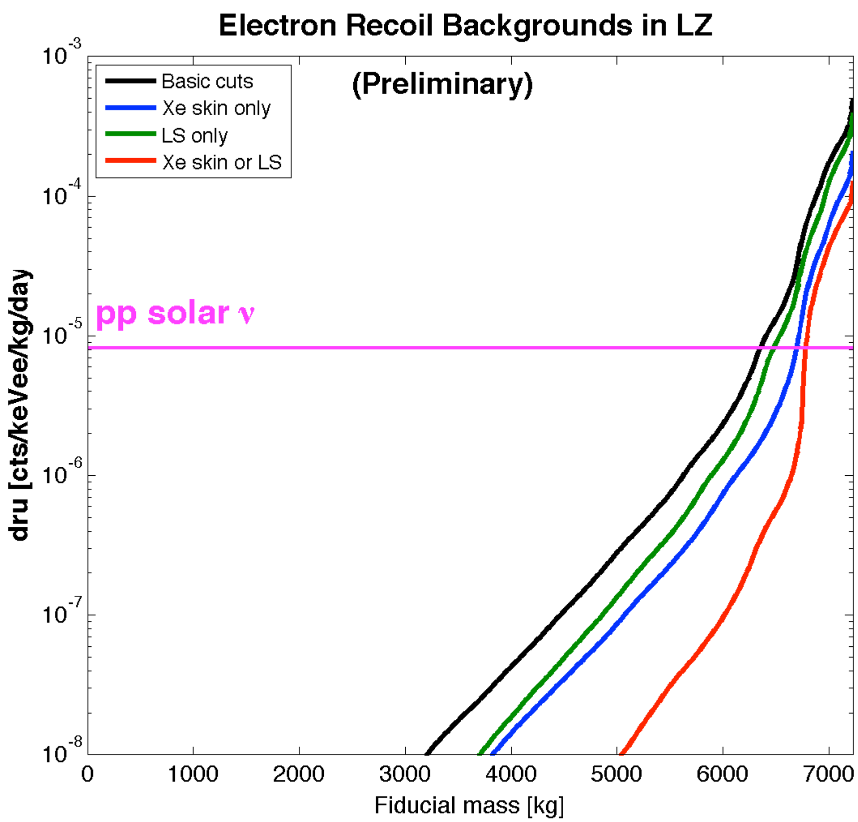
Background Simulations

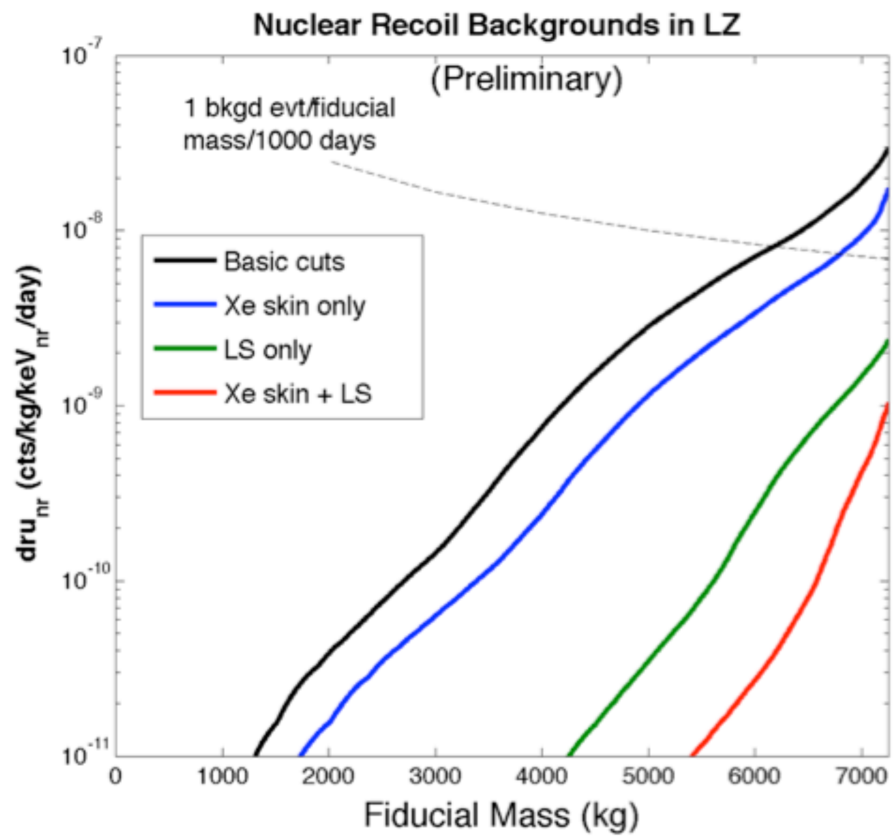


The rate from solar pp neutrinos is expected to be ~ 8×10^{-6} cnts/kg/keVee/day.

Gammas from rock <1/400 PMT rate and Muon-induced neutrons < 1/100 of PMT rate

Fiducial Mass





A fiducial mass of ~6 tonnes (86%) can be achieved.

Backgrounds & Discrimination

- Nuclear recoils due to neutrons from detector structures such as PMTs, Ti cryostat, etc., are sub-dominant to leakage from electron recoils.

- Goal for Krypton: <0.02 ppt. This will represent ~10% of solar pp rate. Best production level obtained by LUX is ~0.2 ppt, which would be equal to pp rate. However, we are confident about achieving purity close to the goal level.

- Goal for Radon in LXe: <0.6 mBq.

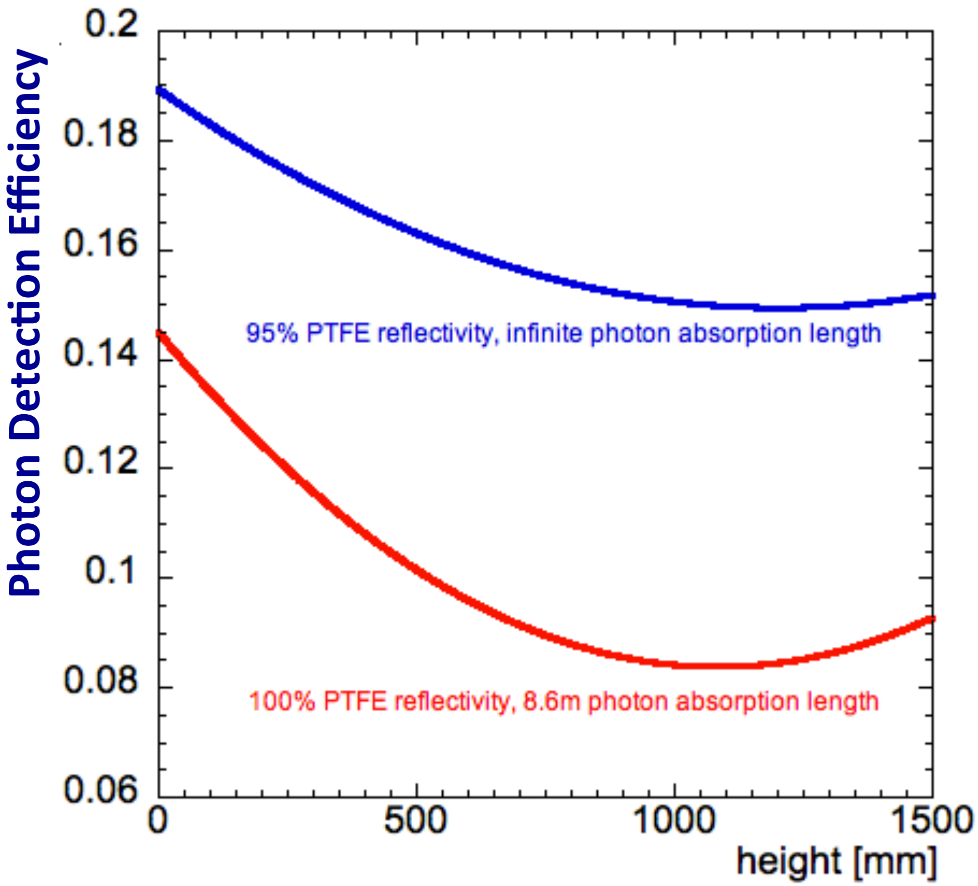
- Discrimination: >99.5% for 4-30 keVnr (99.8% at 1.4 kV/cm)

- Goal for NR Acceptance: 50%

- For a total exposure of 1000 days and 6000 kg fiducial mass:
  pp neutrino leakage events ~1.46
  coherent neutrino scatter NR events ~0.26 (for 50% acceptance)

Photon Detection Efficiency and NR Threshold

Both NR threshold and discrimination power improve with light collection efficiency. LUX has demonstrated 8.4 pe/keV (at 662keV w/ zero field), or PDE ~13%, which is >2x better than XENON100.

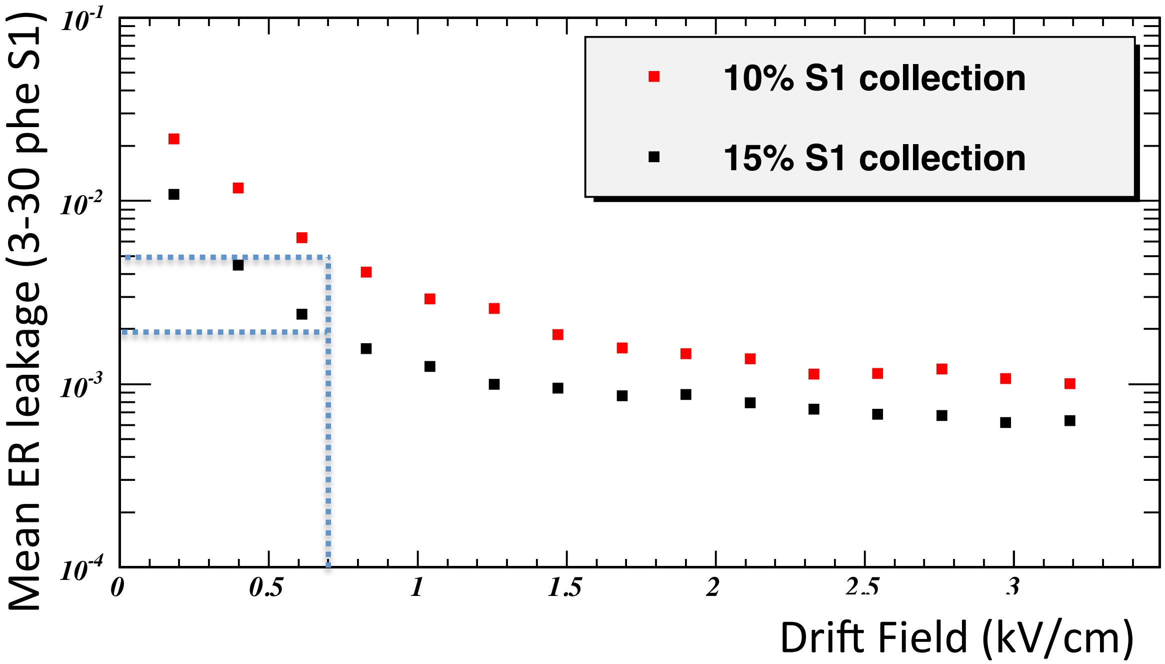


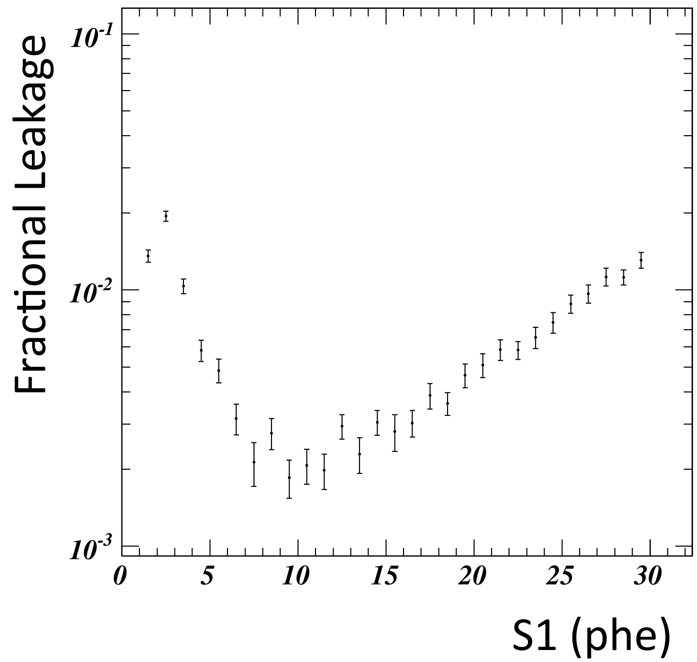
Photon det. eff.	Threshold (keVnr)* Raw S1 4 phe	3 phe	2 phe
0.17	4.9	3.9	2.8
0.16	5.1	4.1	2.9
0.15	5.4	4.3	3.1
0.14	*5.7*	4.5	3.3
0.13	*6.0*	4.8	3.5
0.12	6.4	5.1	3.7
0.11	6.9	5.5	4.0
0.10	7.4	*5.9*	4.3
0.09	8.0	6.4	4.7
0.08	8.7	7.0	5.1
0.07	9.7	7.8	*5.7*
0.06	11	8.7	*6.4*
0.05	12	10	7.4

*NEST-defined scale

Discrimination

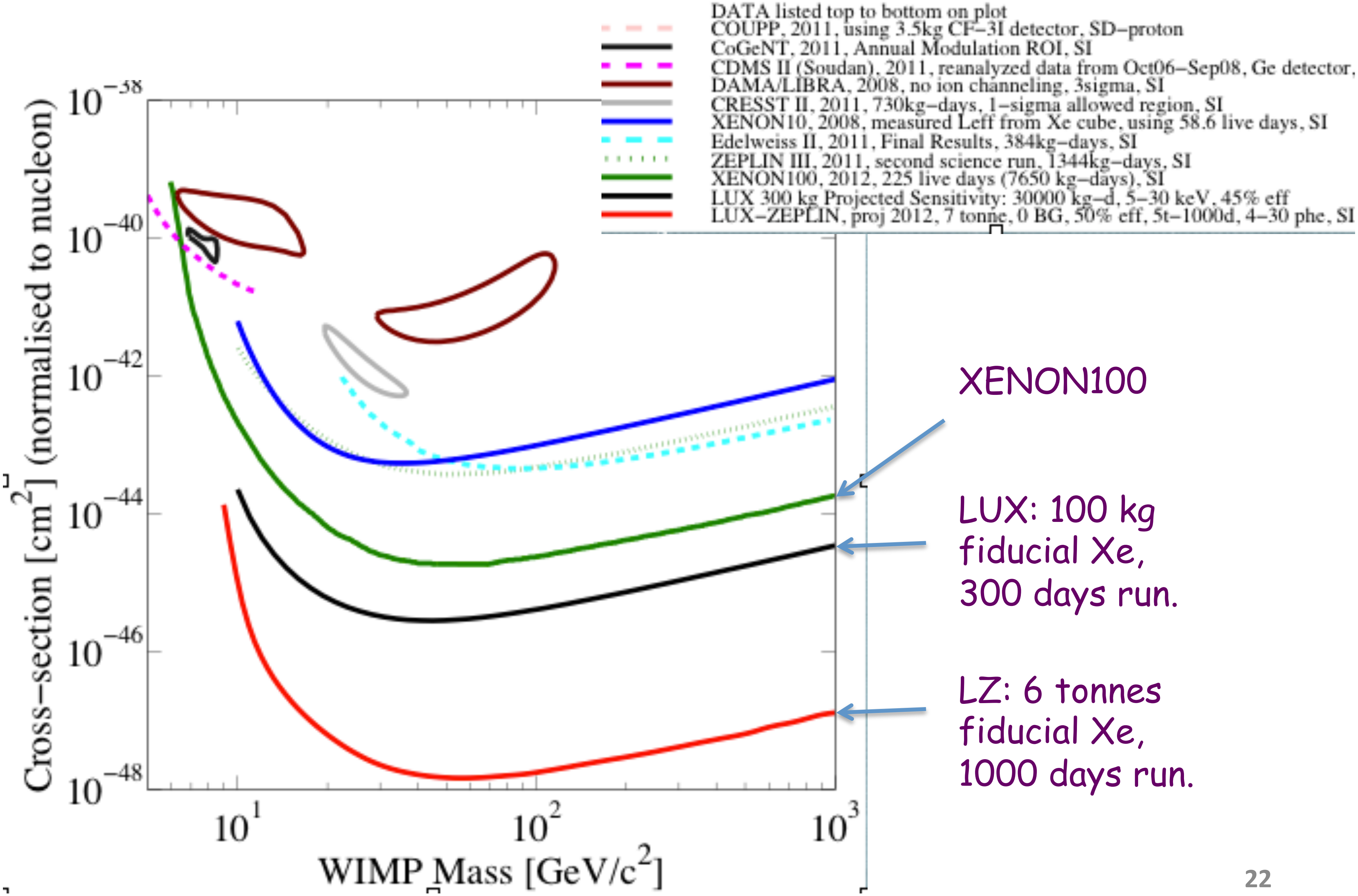
Discrimination power also improves with drift field, especially at low energies. For nominal 700 V/cm, the goal of 99.5% (mean rejection) can be achieved even at 10% light collection efficiency. This improves to 99.8% for 15% light collection. Of course, it improves rapidly with electric field.





The plot on the right shows how rejection power varies with S1. It is plotted for the case of a mean rejection of 99.5% (700 V/cm and 10% light collection).

Reach for WIMP Search



Summary

- LZ holds the promise to be the definitive 2nd generation direct WIMP search experiment.
- An international team of physicists and engineers is in place and working coherently.
- Design concepts are being rapidly translated into full engineering drawings and assembly sequences.
- Progress on various R&D fronts will be reported by 11/26/13 (DOE/NSF deadline).
- Benchmark physics processes are being continually studied and refined.

Thank You

Snowmass Preliminary