The LUX-ZEPLIN Dark Matter Experiment

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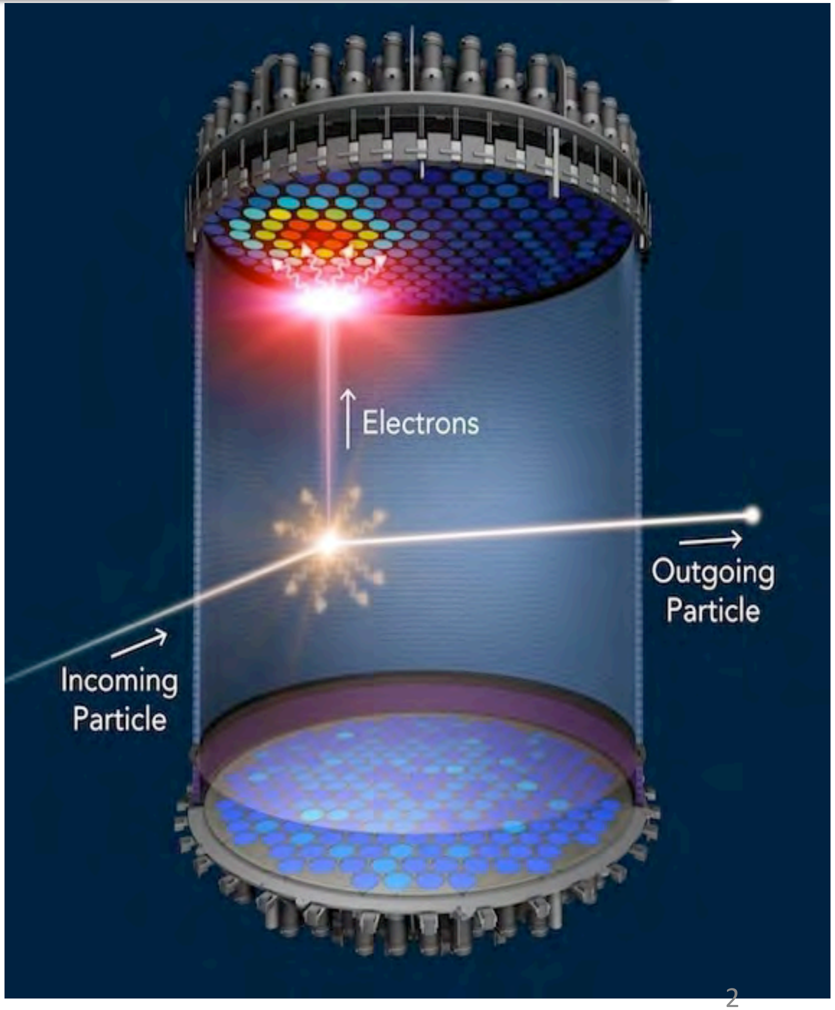
LZ = LUX + ZEPLIN

LIP Coimbra (Portugal)
Center for Underground Physics (Korea)
MEPhI (Russia)
Edinburgh University (UK)
University of Liverpool (UK)
Imperial College London (UK)
University College London (UK)
University of Oxford (UK)
STFC Rutherford Appleton Laboratories (UK)
University of Sheffield (UK)

University of Alabama
University at Albany SUNY
Berkeley Lab (LBNL)
University of California, Berkeley
Brookhaven National Laboratory
Brown University
University of California, Davis
Fermi National Accelerator Laboratory
Lawrence Livermore National Laboratory
University of Maryland
University of Michigan
Northwestern University
University of Rochester
University of California, Santa Barbara
University of South Dakota
South Dakota School of Mines & Technology
South Dakota Science and Technology Authority
SLAC National Accelerator Laboratory
Texas A&M
Washington University
University of Wisconsin

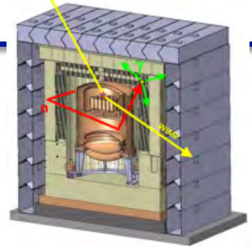
LZ: a Two-Phase Xenon TPC

- High purity xenon target
- Electron-recoil backgrounds distinguished by ratio charge(S2)/light ratio(S1)
- 3D imaging (essential to reject background): Z position from S1 – S2 timing; X-Y positions from light pattern



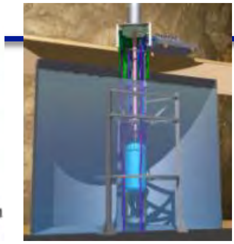
ZEPLIN → LUX → LZ

ZEPLIN-III



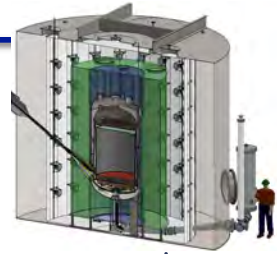
6 kg LXe fid

LUX



100 kg

LZ



5600 kg

LZ built on LUX & ZEPLIN programmes

- **Route to detection & study: a progressive programme**
  - **ZEPLIN** pioneered two-phase Xe for WIMP searches (3.9×10^{-8} pb/n)
  - **LUX** is present world leader in sensitivity (6×10^{-10} pb/n (0.6 zb) at 33 GeV/c^2 and ongoing)
  - **LZ expected sensitivity: <3×10^{-12} pb/n @ 40 GeV/c^2 with 3-year run**
- **Experimental approach: a low risk but aggressive programme**
  - Internal background-free strategy
  - Two-phase Xe technology: high readiness level
  - Some infrastructure inherited from LUX

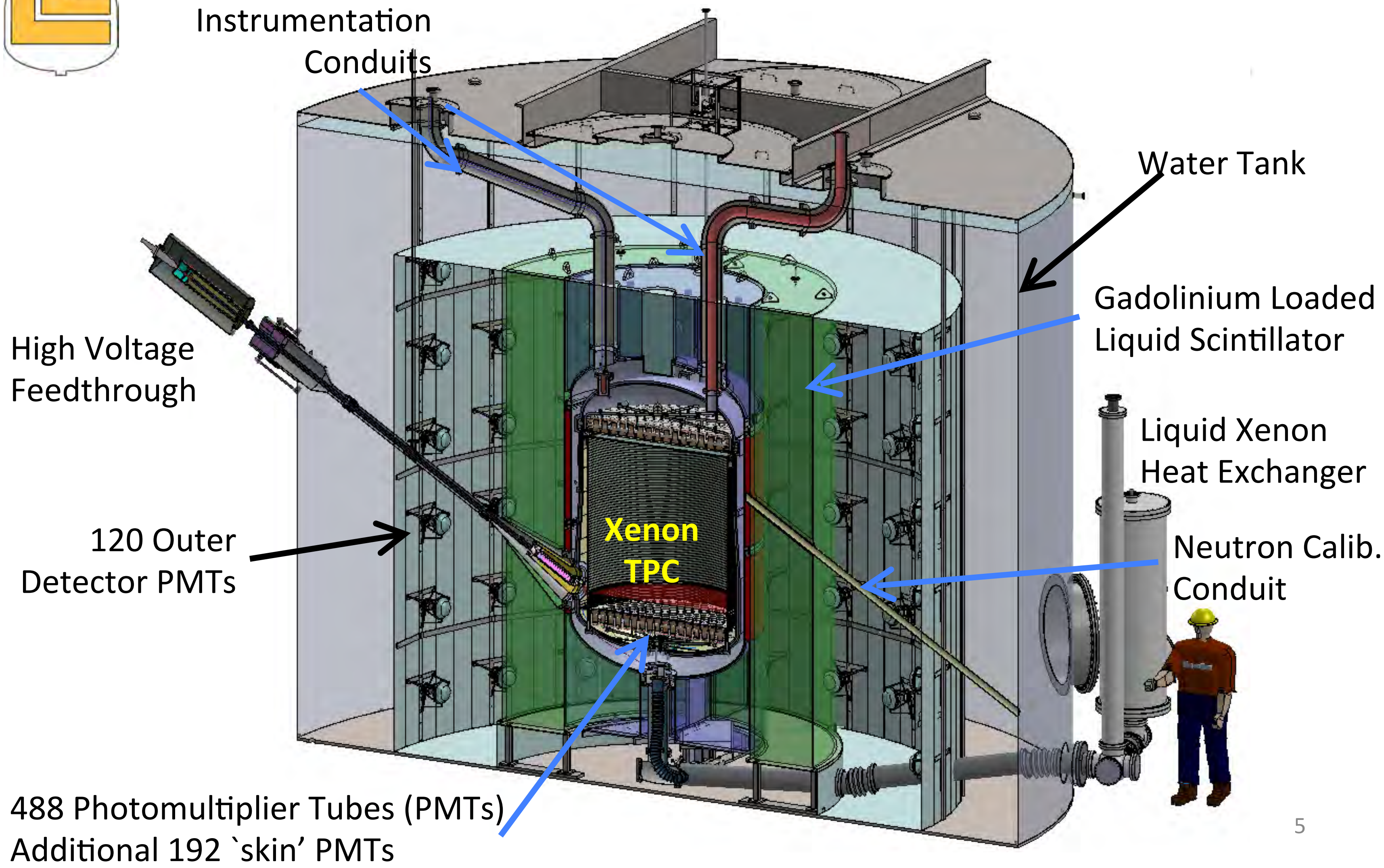
Scale up ≈ 50 in fiducial mass

LZ

Total mass – 10 T
WIMP Active Mass – 7 T
WIMP Fiducial Mass – 5.6 T

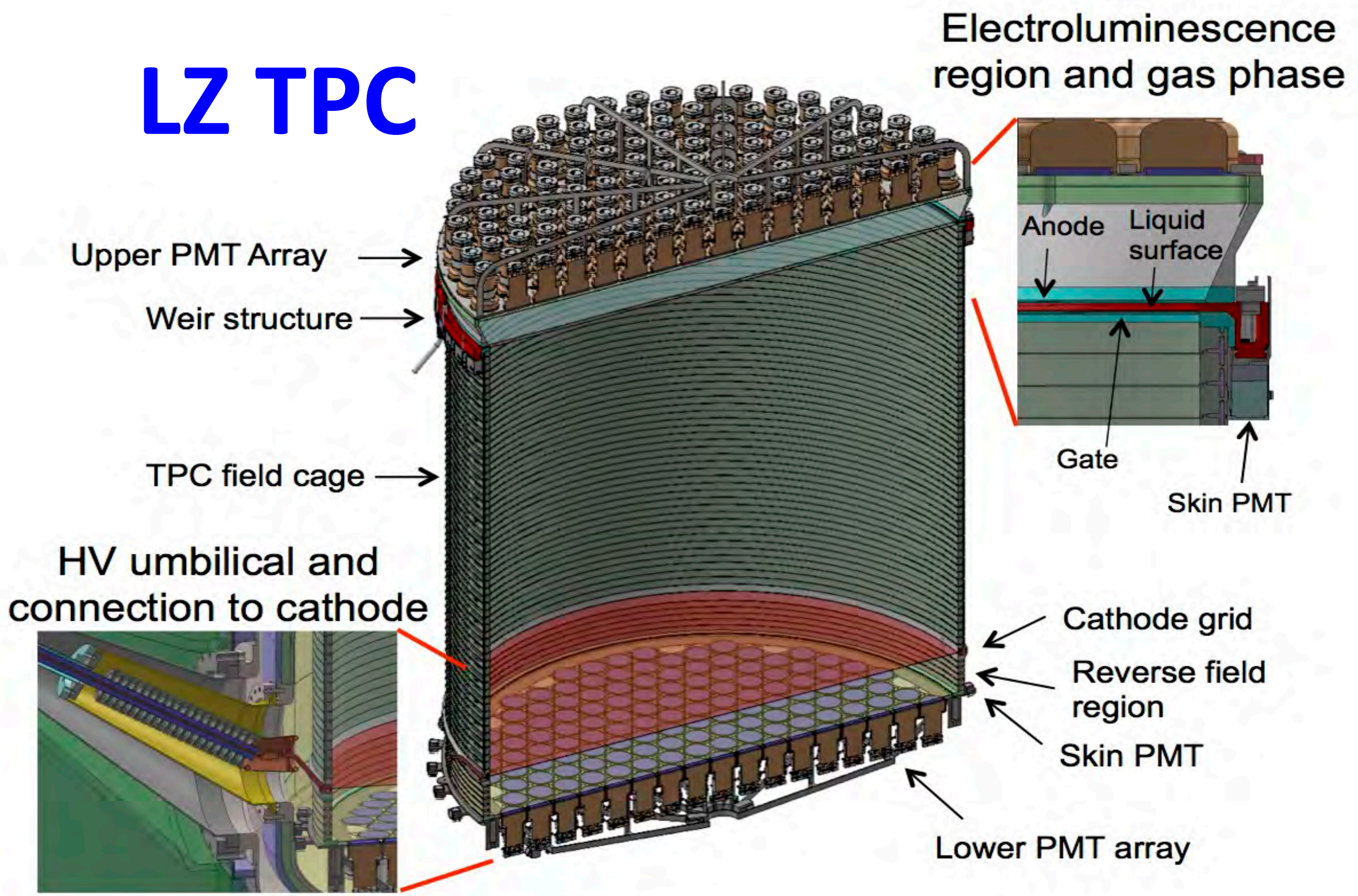
LUX

LZ Overview



Instrumentation
Conduits
Water Tank
Gadolinium Loaded
Liquid Scintillator
High Voltage
Feedthrough
Liquid Xenon
Heat Exchanger
Xenon
TPC
120 Outer
Detector PMTs
Neutron Calib.
Conduit
488 Photomultiplier Tubes (PMTs)
Additional 192 `skin' PMTs

LZ TPC



- 7 tonne active LXe mass; 1.5 m diameter/length
- 247 (top) and 241 (bottom) 3” ϕ PMTs (radioactivity ~mBq; high QE)
- Highly reflective PTFE field cage ($R_{PTFE} \geq$ 95%)

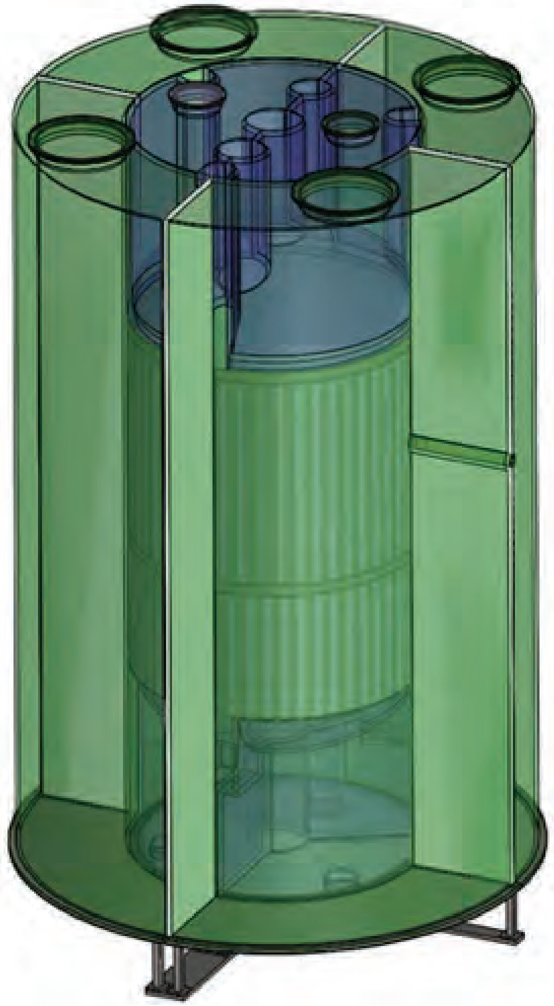
Performance drivers

	Requirement / Baseline	Goal
Cathode HV	50 kV	100 kV
Light collection	7.5%	12%
e^- lifetime (μs)	850	2800
N-fold trigger coincidence	3	2
^{222}Rn	20 mBq	1 mBq

- 5.8 keVr S1 threshold (4.5 keVr LUX)
- 0.7 kV/cm drift field, 99.5% ER/NR disc. (already surpassed in LUX at 0.2 kV/cm)

Outer Detector

- Essential to utilize most Xe, maximize fiducial volume
- Segmented tanks (installation constraints)
- Gd-loaded liquid scintillator, LAB; 60 cm; 21.5 tons
- 97% efficiency for neutrons

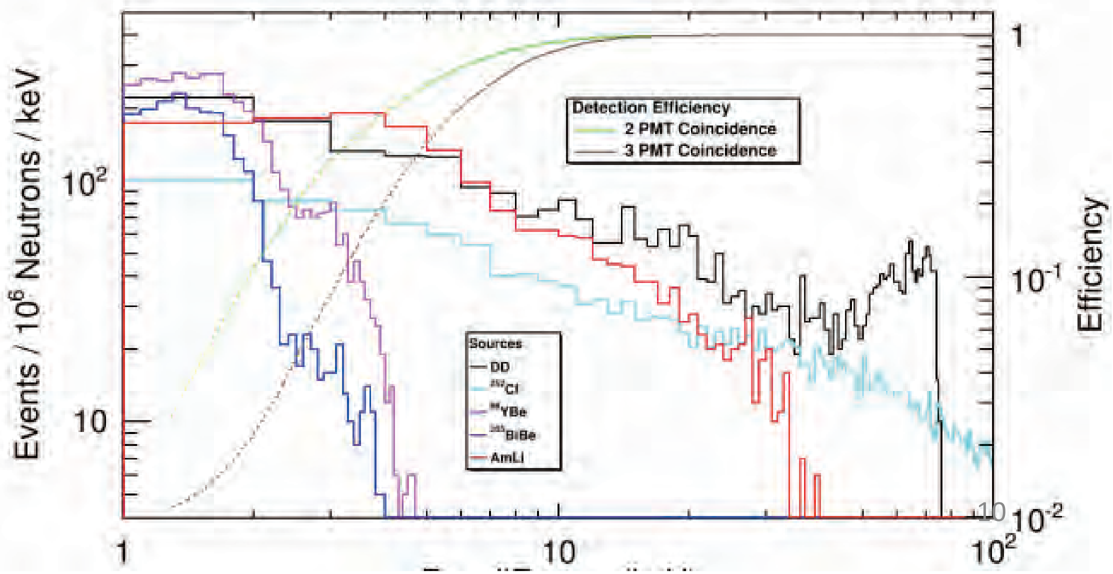


Detector Prototyping

- ✦ Extensive program of prototype development underway
- ✦ Approach:
  - ☐ Testing in liquid argon, primarily of HV elements at LBNL
  - ☐ Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, UC Berkeley, LBNL, U Michigan, UC Davis, Imperial College, MEPhI, LIP
  - ☐ System test platform at SLAC, Phase I about 100 kg of LXe, TPC prototype testing ongoing

Calibrations

- Expand upon successful LUX program
- Spatial response, temporal variation
  - ^{83m}Kr, ^{131m}Xe
- Outer LXe and Gd-scintillator
  - ^{220}Rn, movable gamma ray sources
- Electron and Nuclear recoils
  - Tritium
  - Variety of high and low energy neutron sources

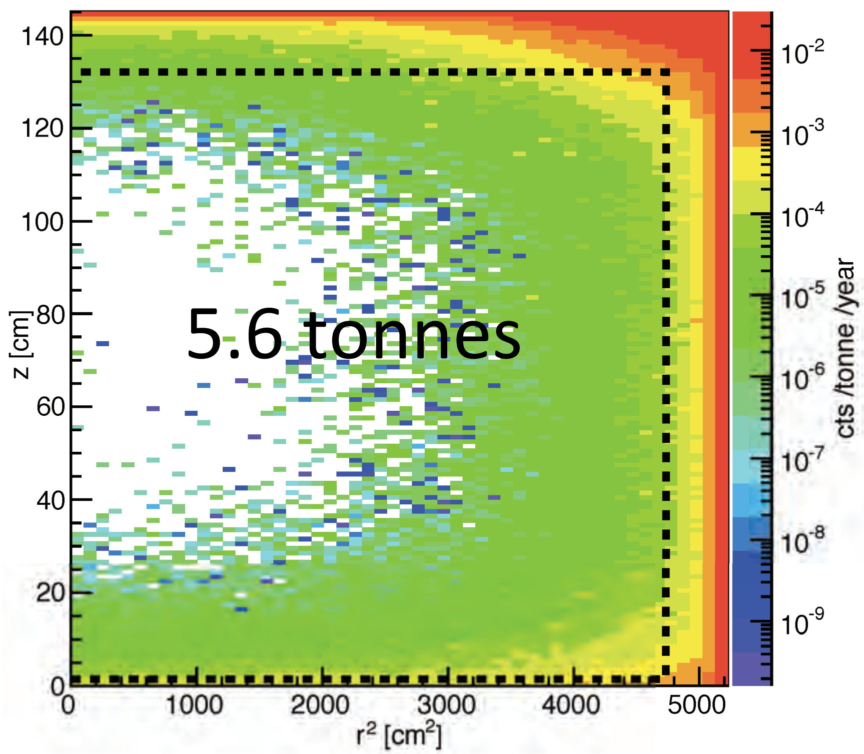


Background Reduction: key design points

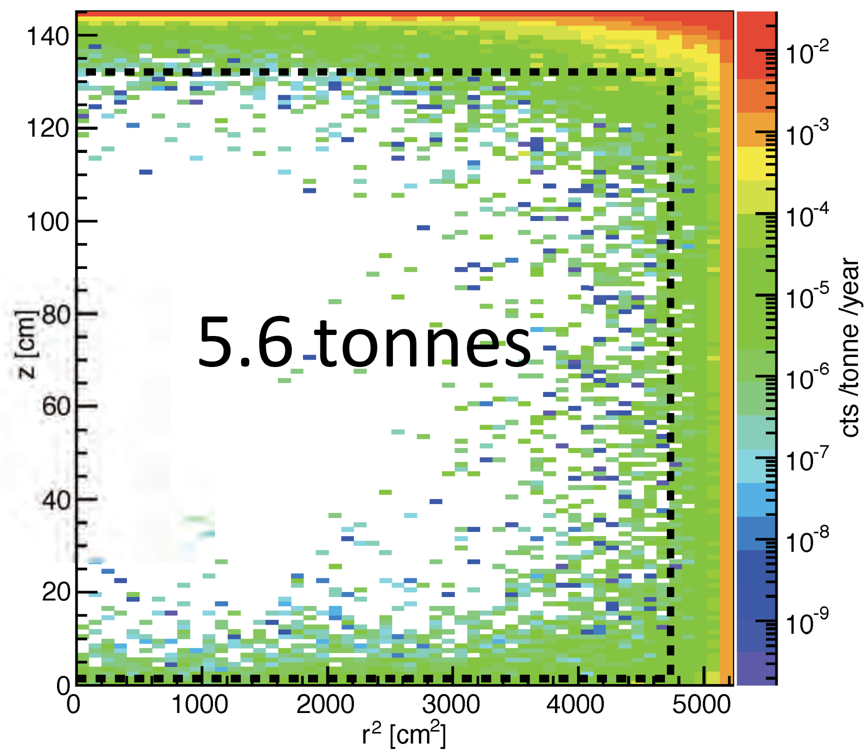
- Photomultipliers of ultra-low natural radioactivity
- Low background titanium cryostact
- Instrumented “skin” region of peripheral xenon as another veto system
- LUX water shield and an added liquid scintillator active veto
- Radon suppression during construction, assembly and operations
- Umprecedented levels of Kr removal from Xe

Background

Single NR scatter in TPC



Vetoed by Gd-LS and Skin

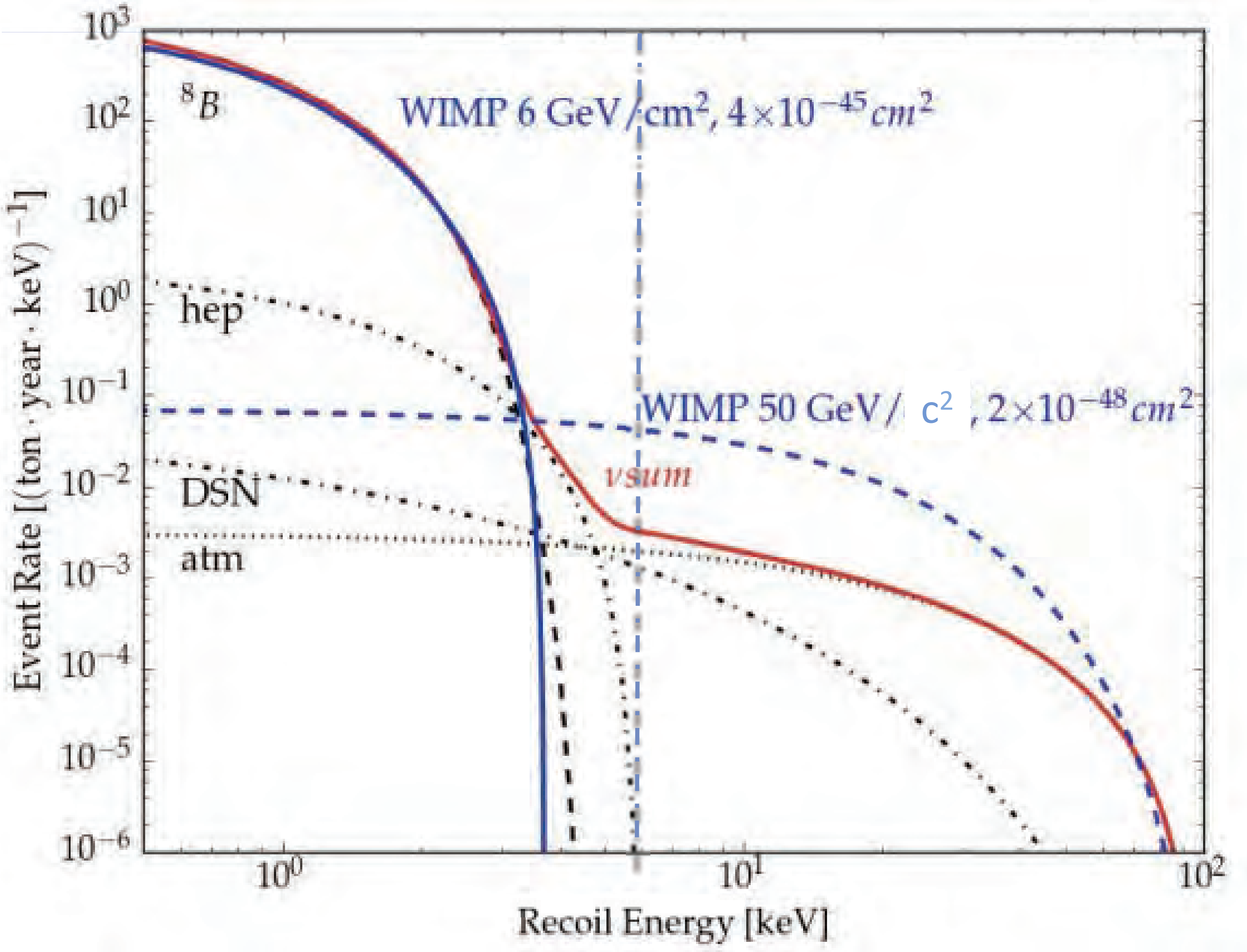


NR background plus ER leakage from sources external to the LXe (6 - 30 keVnr acceptance; 50% NR acceptance and 99.5% ER discrimination);

Expected backgrounds for 5.6 T fiducial - 1,000 days

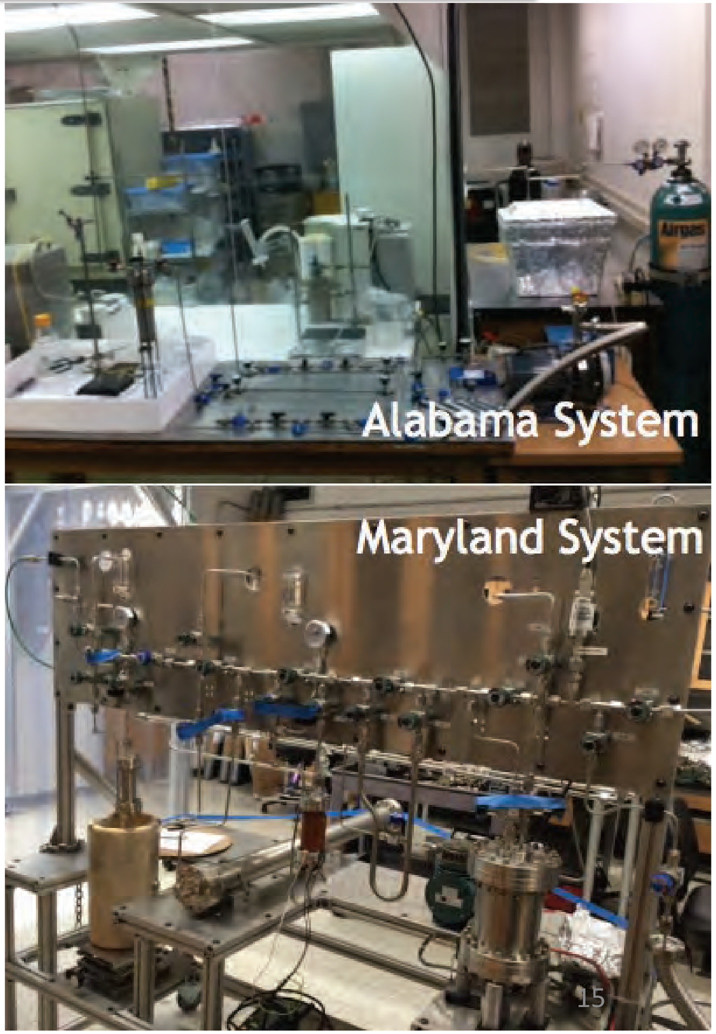
Item	Mass (kg)	U (mBq/kg)	Th (mBq/kg)	Co-60 (mBq/kg)	K-40 (mBq/kg)	n/yr	ER (cts)	NR (cts)
R11410 PMTs	90.8	71.6	3.2	2.8	15.4	80.8	1.84	0.012
R11410 bases	2.6	546	31.7	2.3	82.6	44.3	0.37	0.004
Cryostat Vessels	2406	1.6	0.3	0.1	0.6	123.7	0.55	0.011
Other components							7.16	0.045
Total components							**9.92**	**0.072**
Dispersed radionuclides (Rn, Kr, Ar)							870	
Laboratory and cosmogenics							33	0.12
Surface contamination							0.2	0.37
Xe-136 2νßß							67	
Neutrinos (ν-e, ν-A)							255	0.72
Total events							**1230**	**1.28**
WIMP backgr events (99.5% ER discrimination, 50% NR acceptance)							**6.17**	**0.64**
Total ER+NR background events							**6.81**	

Neutrino NR contribution



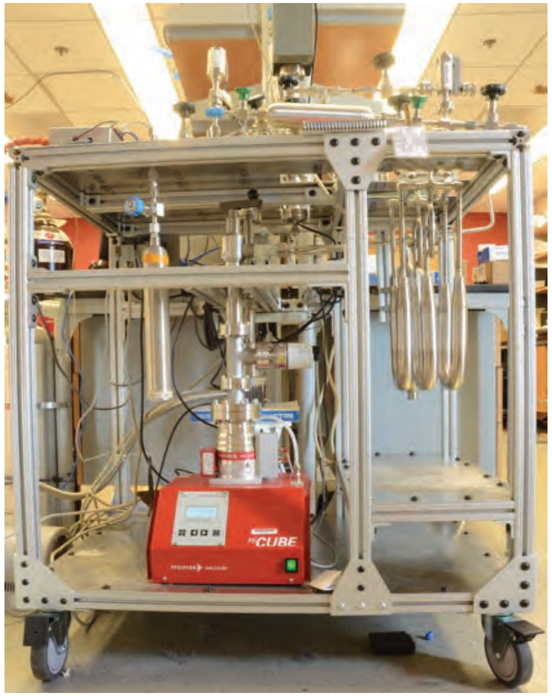
Rn emanation

- Rn (and Kr) – dominante internal radioactive background
- Emanates from most materials
- 20 mBq requirement, 1 mBq goal
- Four separate measurement systems, ~0.1 mBq sensitivity
- Main assembly laboratory at SURF will have reduced radon air system



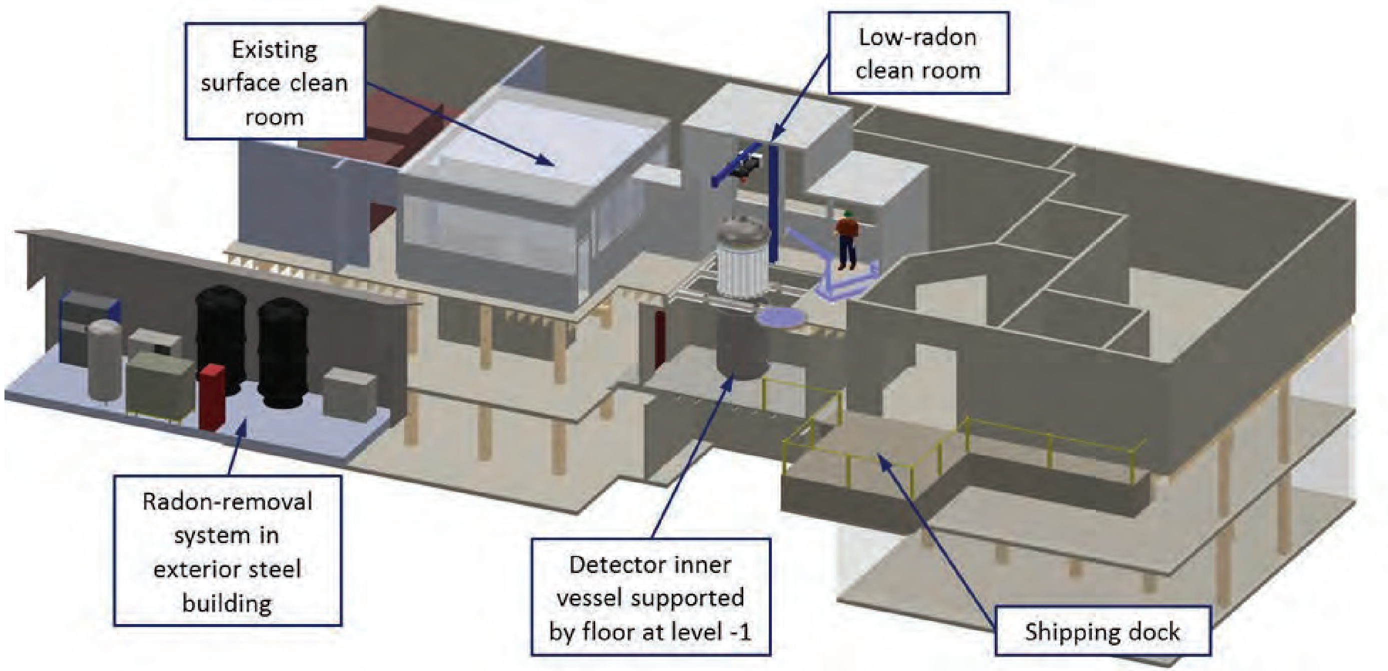
^{85}Kr removal

- Remove Kr to <15 ppq (10^{-15} g/g) using gas chromatography (best LUX batch 200 ppq)
- Setting up to process 200 kg/day at SLAC
- Have a sampling program to instantly assay the removal at SLAC and continuously assay in situ



LZ Underground at SURF

- Years of experience at SURF from LUX
- Dedicated onsite infrastructure improvements for LZ. Design started, construction planned.

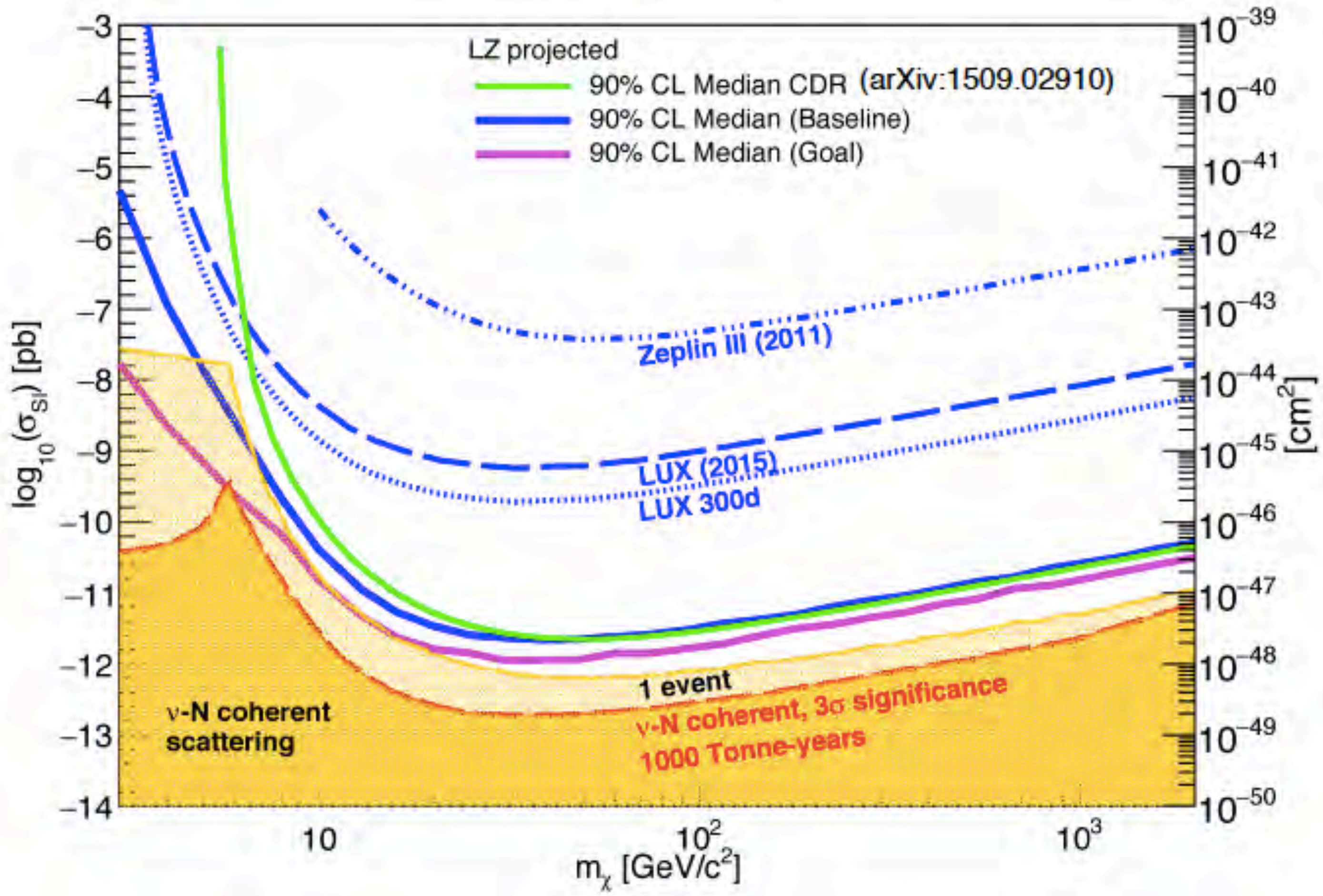


LZ Timeline

Year	Month/Q	Activity
2012	March	LZ (LUX-ZEPLIN) collaboration formed
2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK Conceptual Design Report arXiv:1509.02910
2016	April	**DOE CD-2/3b review passed**
2017	Q2	Begin preparations for surface assembly @ SURF
2019	Q1	Begin underground installation
2020	Q4	Commissioning start

Projected Sensitivity – Spin Independent

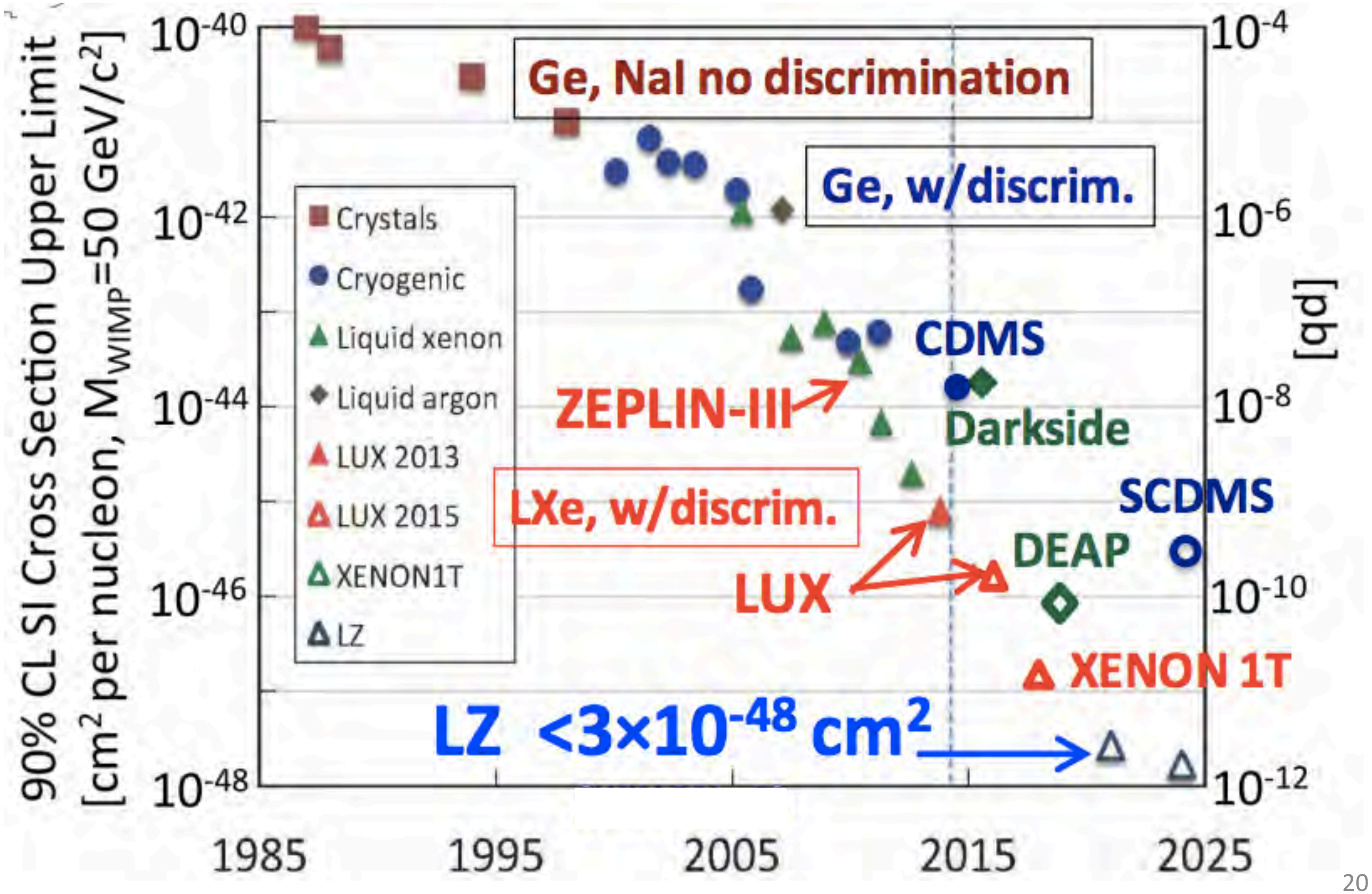
(LZ 5.6 Tonnes, 1000 live days)



Baseline
$\sigma_{SI} = 2.2 \times 10^{-48}$ cm²
B-8 = 7
ATM ν = 0.4

Goal
$\sigma_{SI} = 1.2 \times 10^{-48}$ cm²
B-8 = 220
ATM ν = 3

Time Evolution



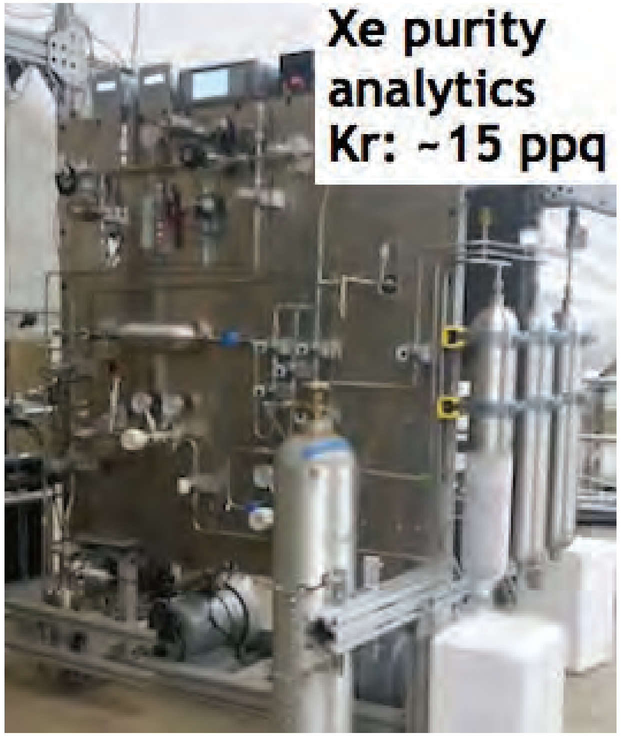
Summary

- LXe is a pre-eminent target for high mass WIMP search
- Two-phase Xe detector technology is very mature and reliable
- LZ leverages LUX innovations in calibrations, cryogenics and ^{85}Kr removal
- High fiducial volume fraction (~80%) due to outer detector and low background from internal materials
- Robust prototyping and test program to optimize detector performance
- Material screening programme well underway
- Limit < 3×10^{-48} cm^2 @ 40 GeV/c^2 in 1000 live-days

Extra Slides

Xe purification and cryogenics

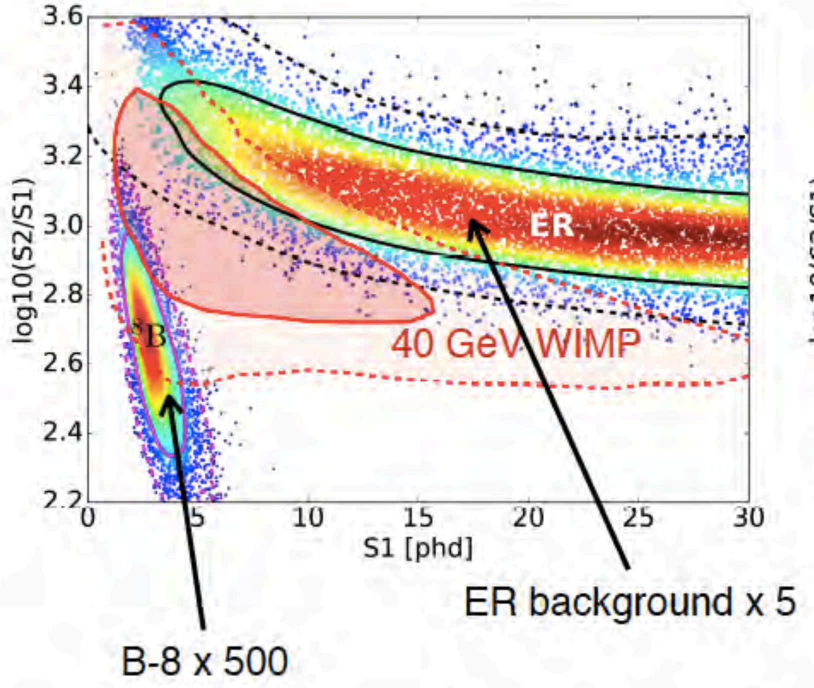
- Gas phase purification through getter- 10 tons/2.5 days
- Trap-enhanced mass spec; sensitivity ~ppt
- High efficiency two-phase heat exchange
- LN thermosyphon-based cryogenics – multiple cooling locations.



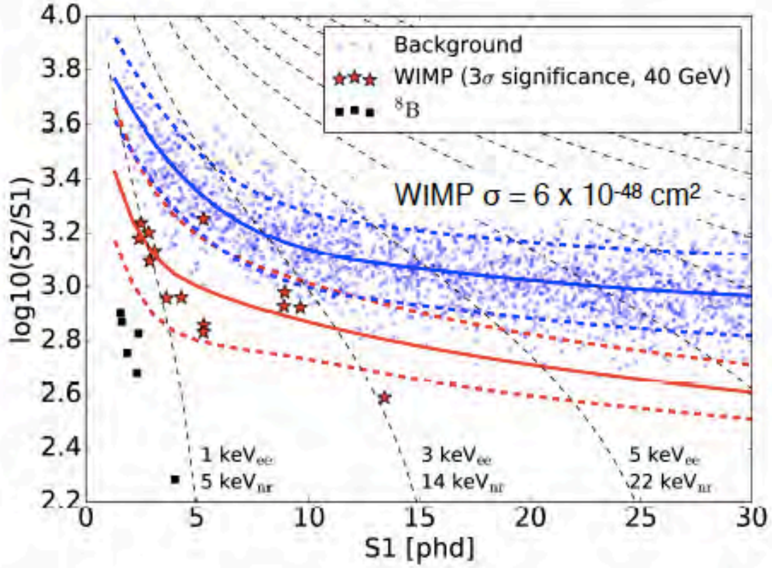
Signal and background

Advanced analysis procedure PDFs for PLR

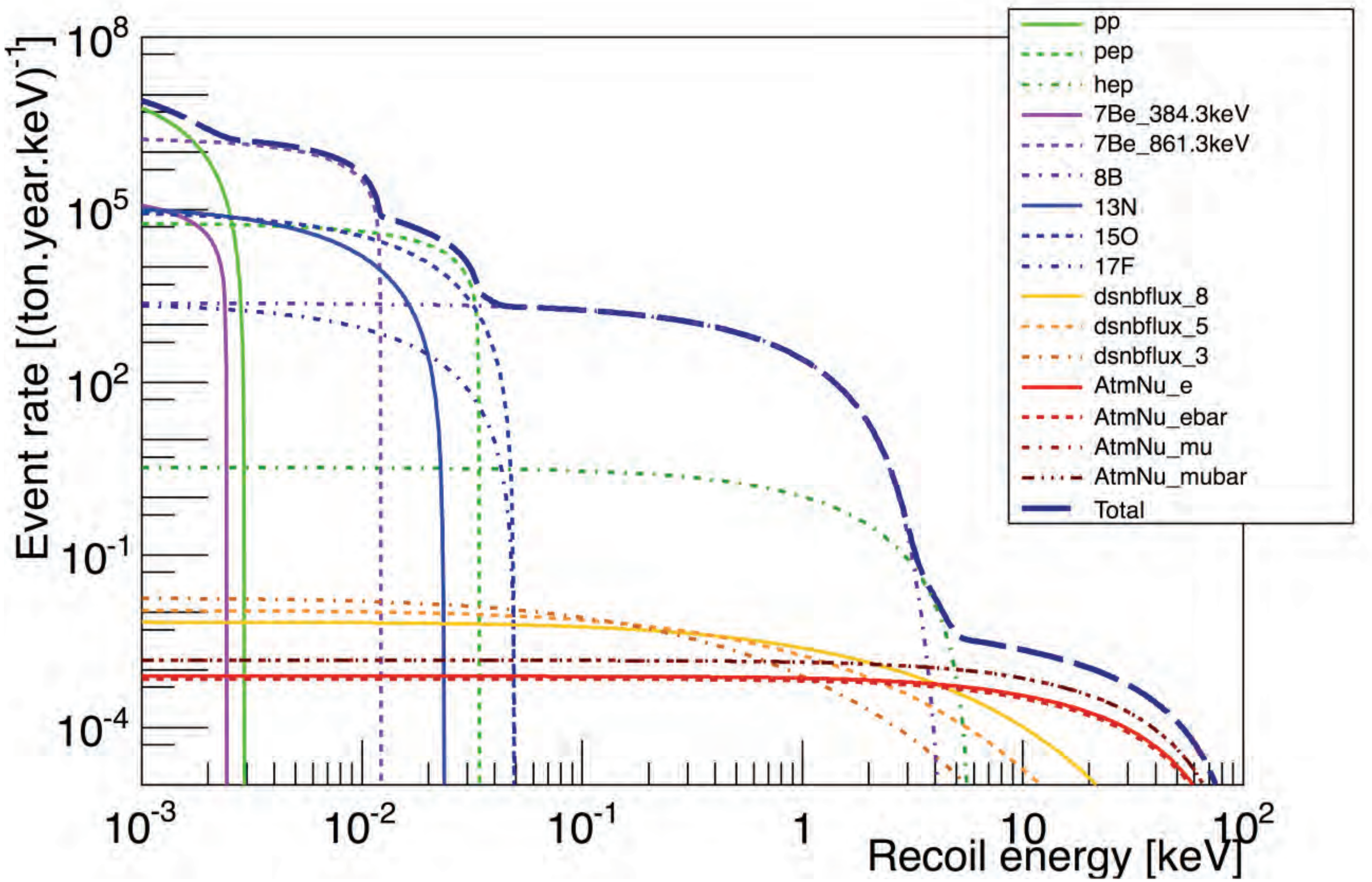
Signal and background models distributions



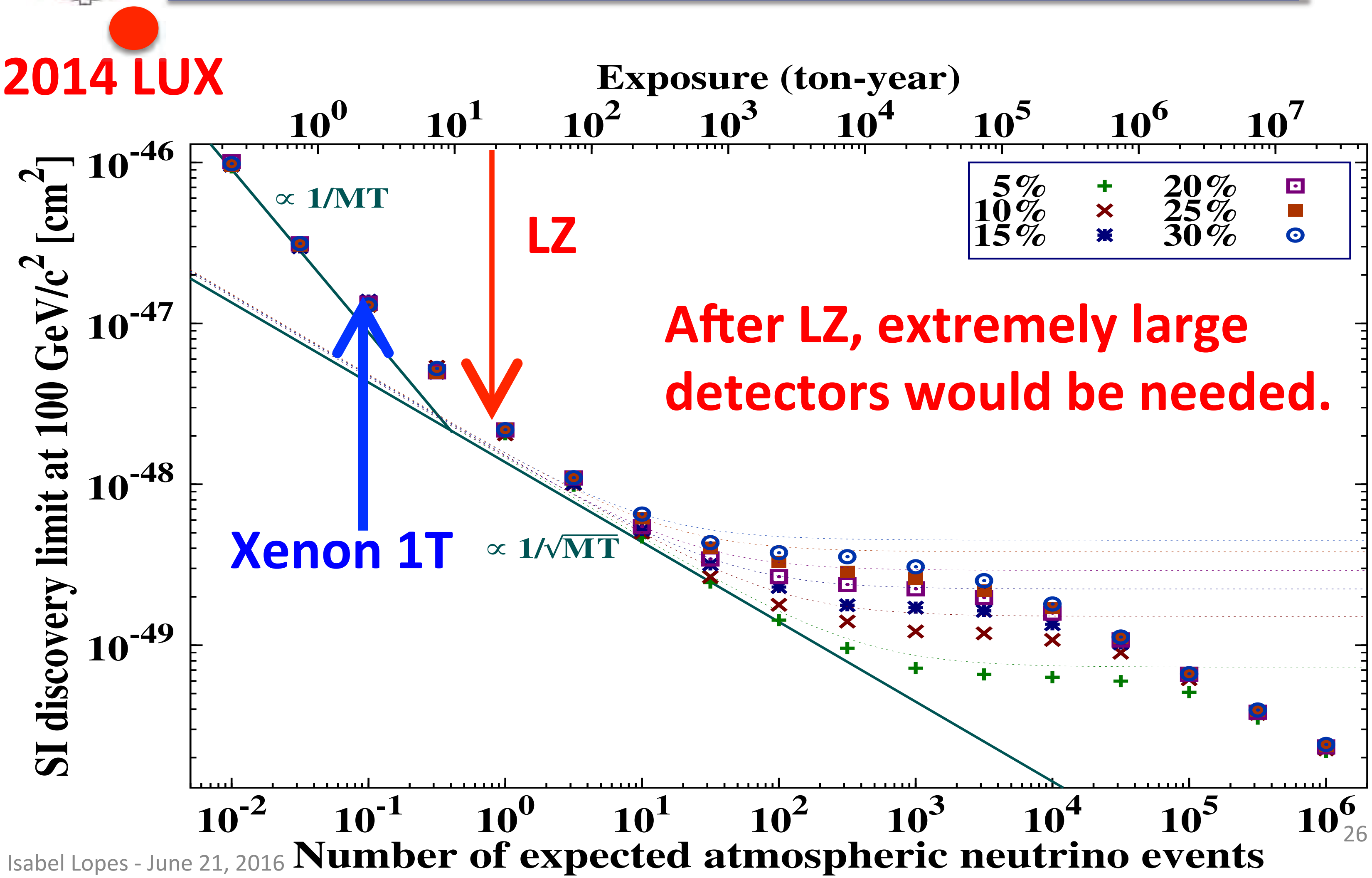
Simulated LZ experiment (1000 days, 5.6 tonnes fiducial)



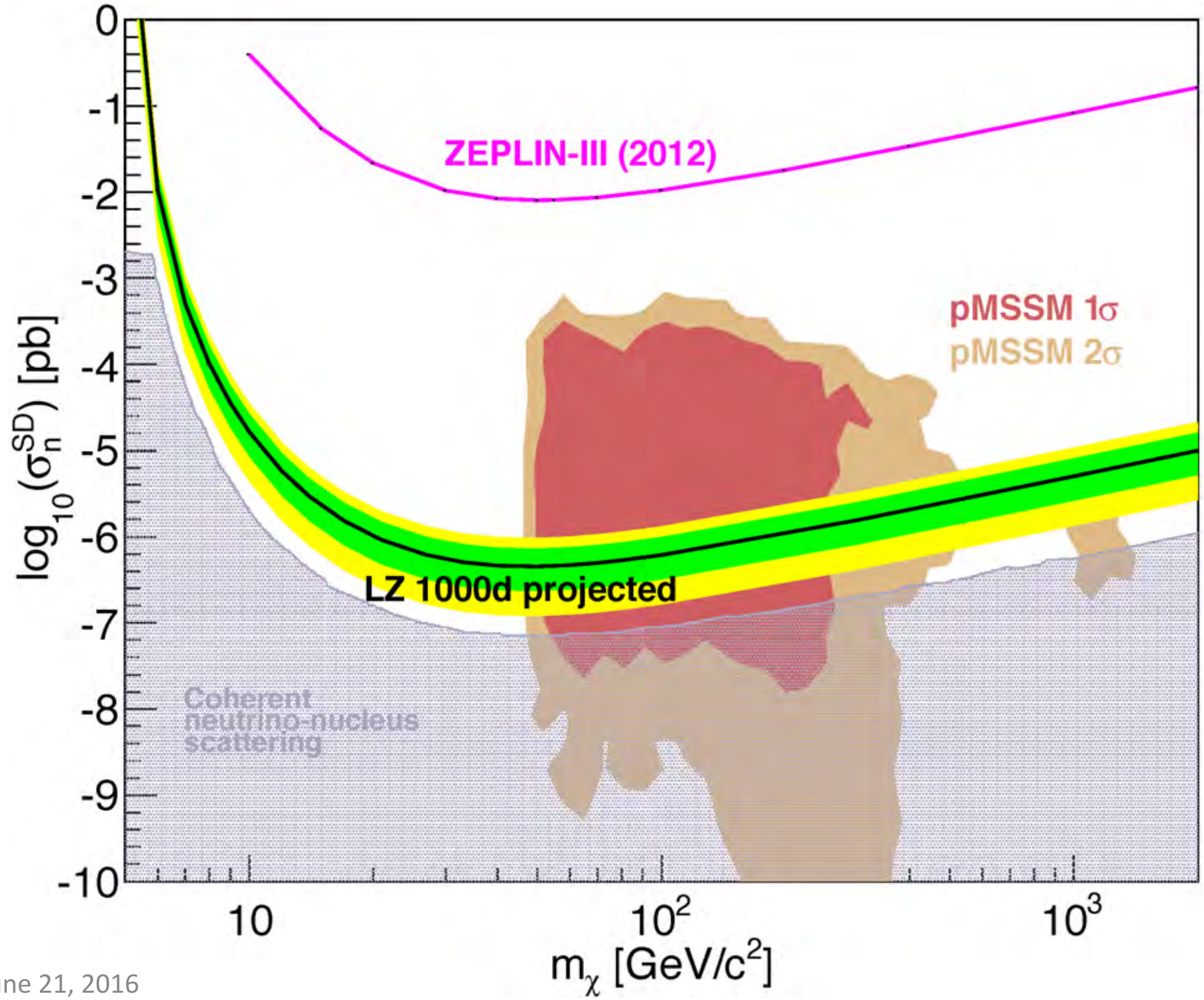
Backgrounds: neutrino contribution



LZ – At the neutrino `knee' arXiv:1408.3581



Spin Dependent Neutron



Spin Dependent Proton