The LZ Dark Matter Experiment

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(for the LZ Collaboration)

COSMO-16, Ann Arbor, Michigan

August 9, 2016

The LZ Collaboration

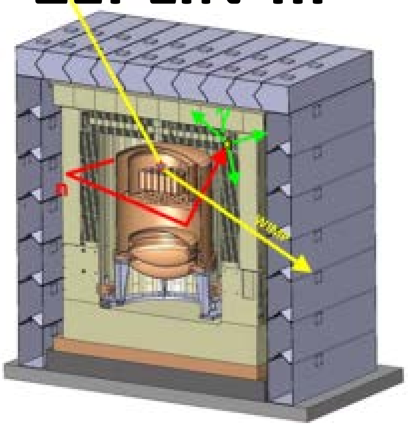
32 institutions
about 200 people
still growing

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
Kavli Institute for Particle Astrophysics & Cosmology
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

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)

LZ = LUX + ZEPLIN

ZEPLIN-III

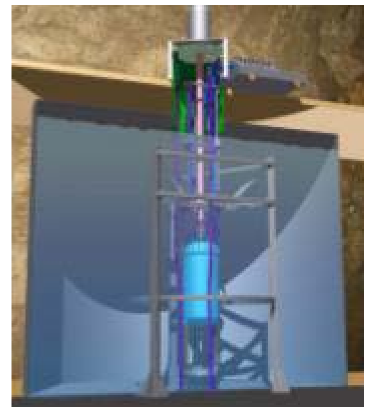


6 kg LXe fid

ZEPLIN pioneered WIMP-search with 2-phase Xe 3.9×10^{-44} cm^2

+

LUX

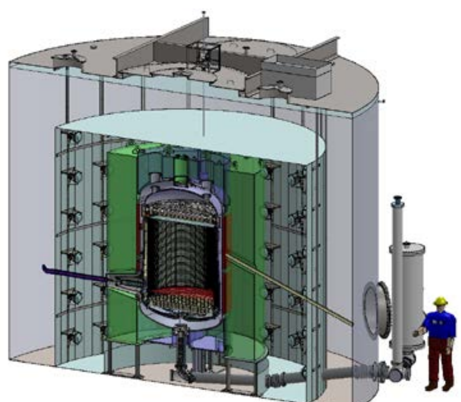


100 kg

current world leader: 2.2×10^{-46} cm^2 at 50 GeV/c^2 and counting

→

LZ



5,600 kg

Scale-up using demonstrated technology and experience for low-risk but aggressive program:

- internal background-free strategy
- some infrastructure inherited from LUX
- **LZ expected sensitivity: 3×10^{-48} cm^2 with 3-yr run**

Sanford Underground Research Facility

Davis Cavern 1480 m
(4200 mwe)
LZ in LUX Water Tank
South Dakota, USA

LZ Here

Scale up ≈ 50 in Fiducial Mass

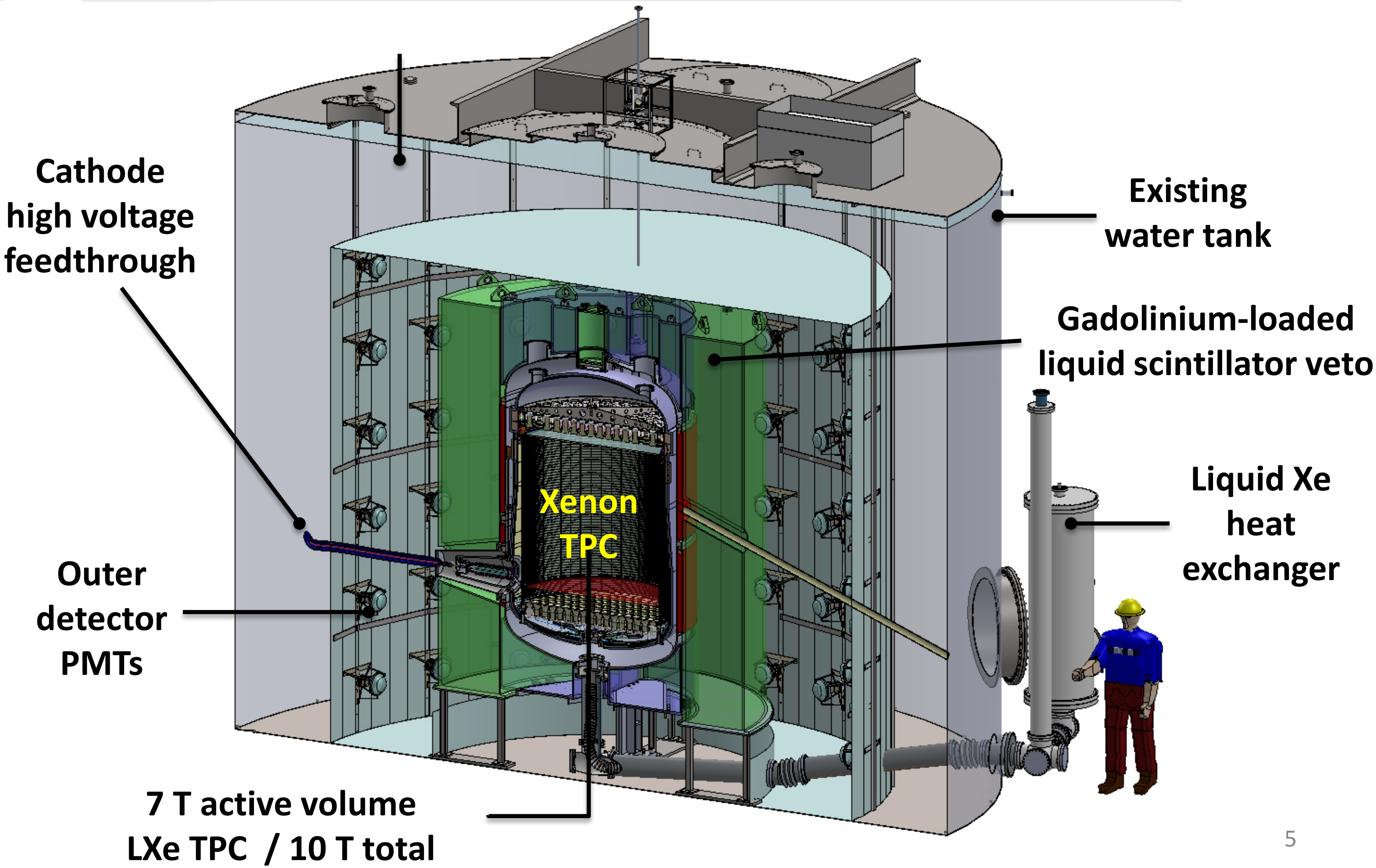
LZ

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

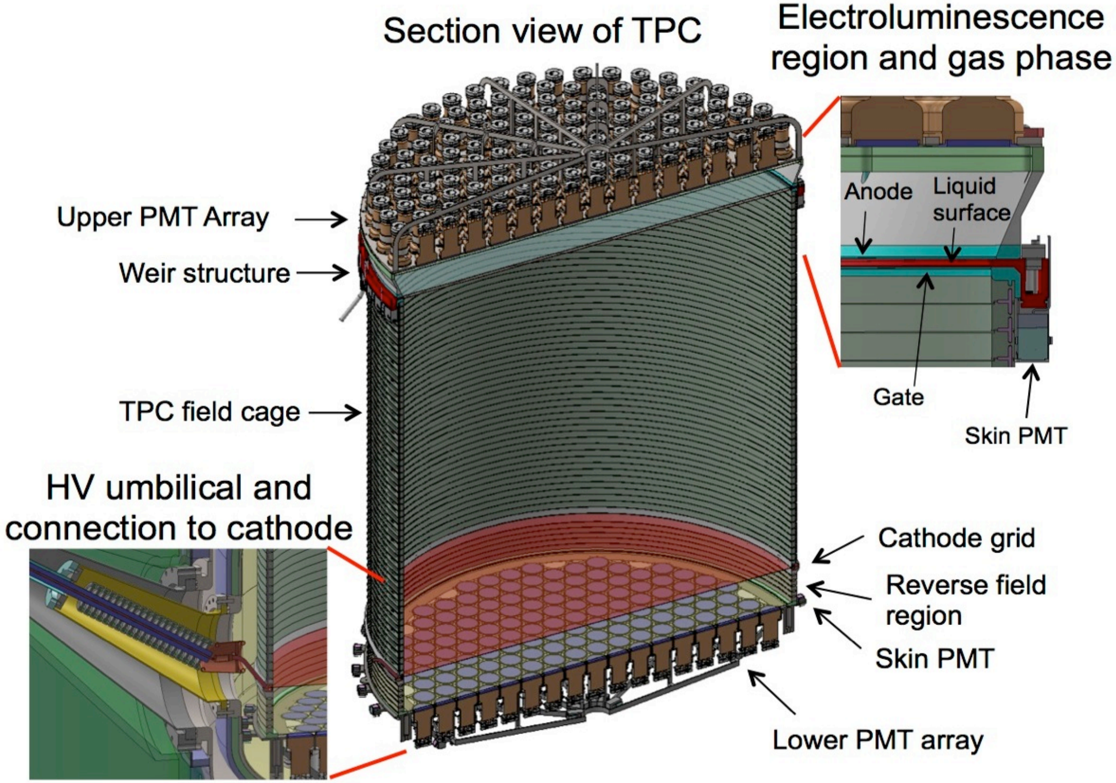
LUX

+ maintain background-free, low-energy response

LZ Detector Overview



Dual-phase liquid xenon TPC



- 7 T active LXe mass, 146 cm diameter, 146 cm length
- 494 PMTs (253 top, 241 bot) 3” R11410 PMTs (activity ~mBq; high QE)
- TPC lined with high-reflectivity PTFE ($R_{PTFE} \geq 95\%$)
- instrumented “Skin” region optically separated from TPC (180 PMT)

Background Reduction: key design points

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

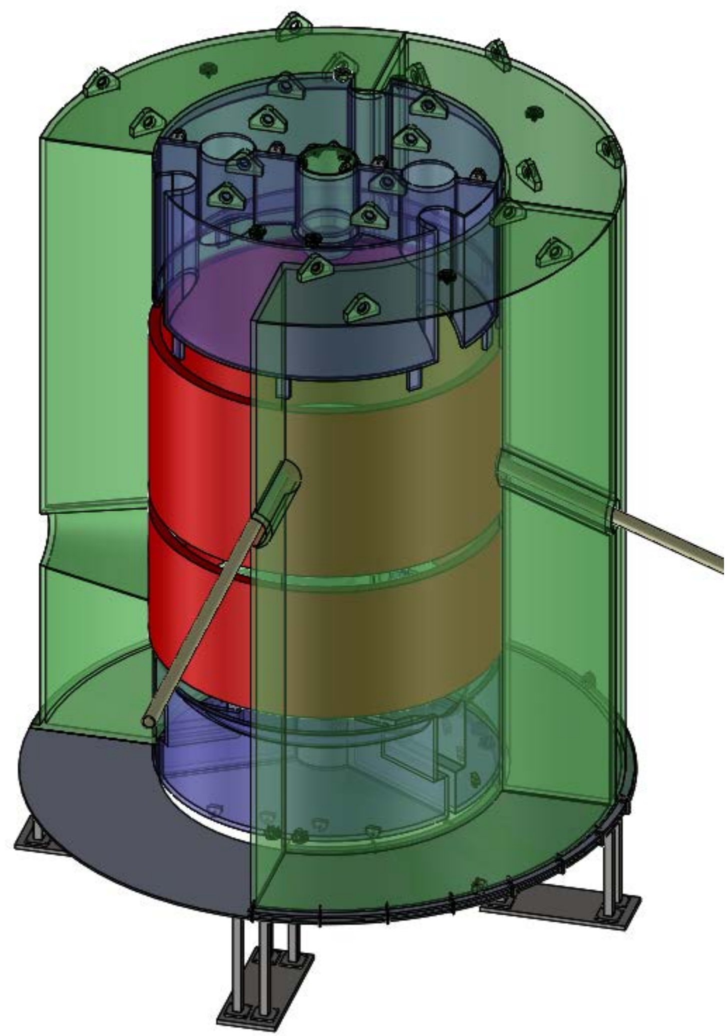
Performance Drivers

	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 keV_{nr} S1 threshold (4.5 keV_{nr} LUX)
- 0.35 kV/cm drift field, 99.5% ER/NR disc.
  (already surpassed in LUX at 0.2 kV/cm)

The Outer Detector (OD)

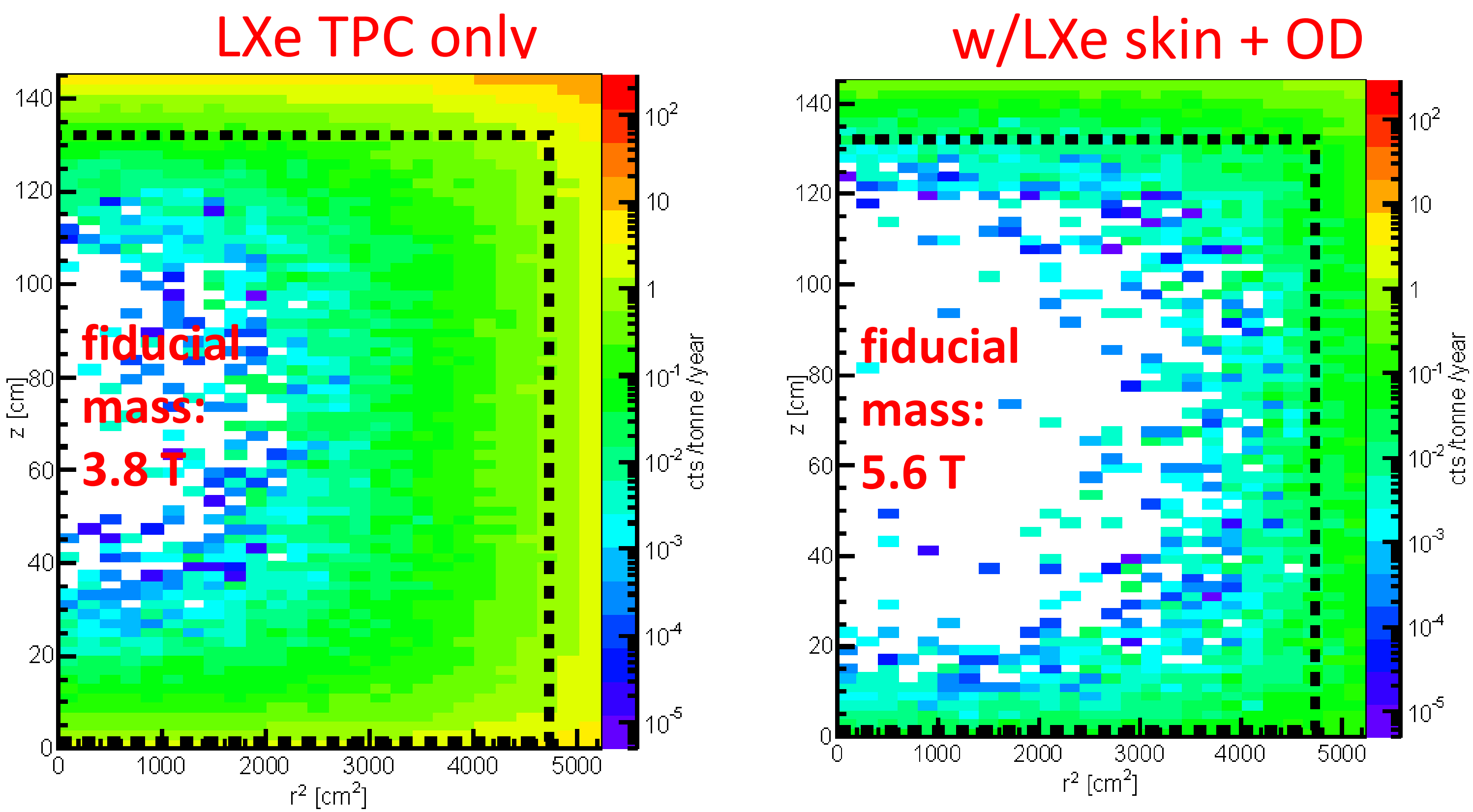
- Essential to utilize most Xe, maximize fiducial volume
- Hermetic measurement of penetrating backgrounds
- Segmented tanks – installation constraints (shaft, water tank)
- 60 cm thick, 21.5 T of Gadolinium-loaded LAB* liquid scintillator, OK underground
- 97% efficiency for neutrons
- Daya Bay legacy, scintillator & tanks (and people)



* Linear AlkylBenzene

Powerful Background Rejection

Simulated single NR scatter in TPC before/after Skin+OD vetoes

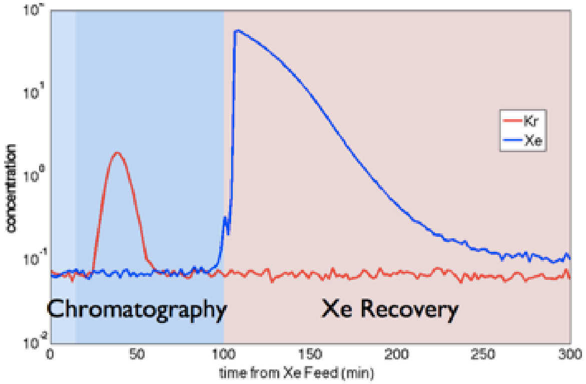


- Increases effective fiducial mass from 3.8 T → 5.6 T
- Internal backgrounds now dominate

Control of Internal Backgrounds

- Rn (and Kr) dominant internal background sources
- Rn:
  - Emanates from most materials
  - 20 mBq requirement, 1 mBq goal
    - Rn removal system at UMich
  - Four measurement systems with ~0.1 mBq sensitivity
  - Main assembly laboratory at SURF will have reduced radon air system
- Kr:
  - Remove ^{85}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

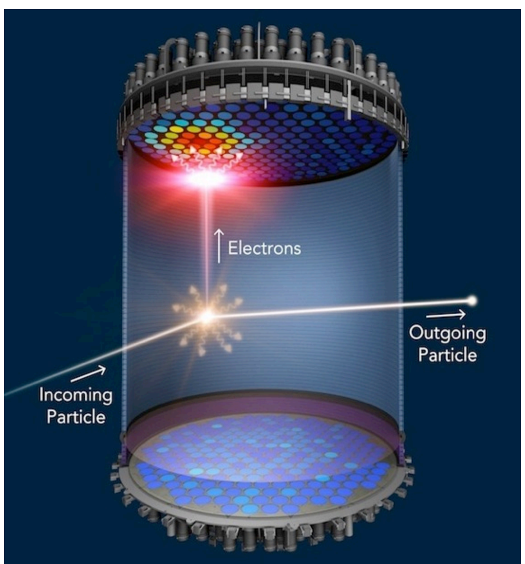
Chromatography from column



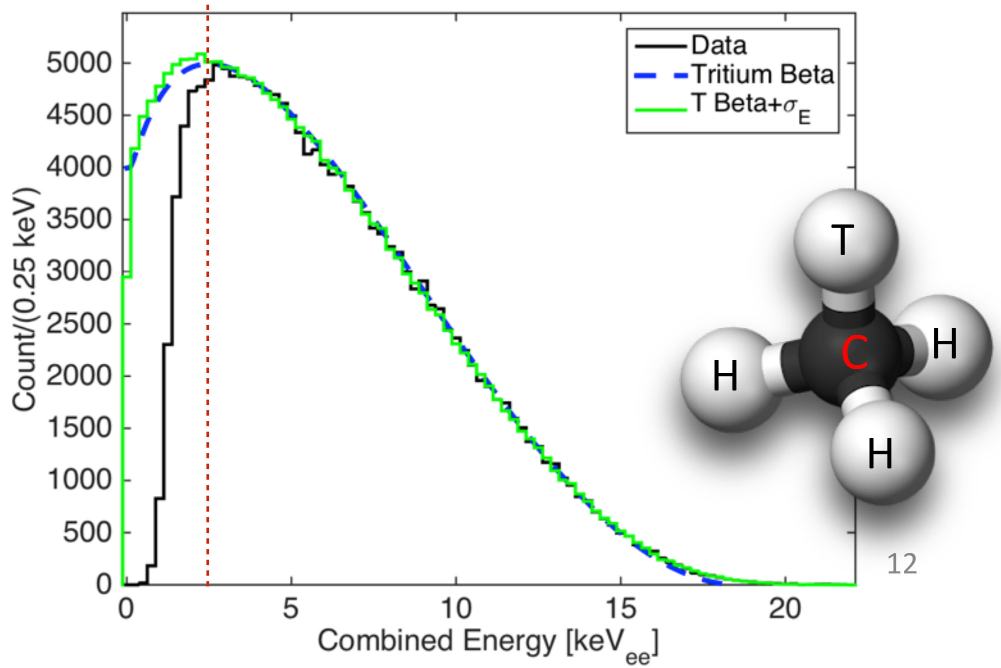
Calibrations

- Expand upon successful LUX program (and other experience)
- DD Neutron Generator (Nuclear Recoils)
- Tritiated Methane (Electron Recoils)
- Movable photon sources e.g. tubes penetrating cryostat
- Additional sources e.g. YBe source for low energy (Nuclear Recoils)

DD neutron calibration



Tritium Beta Spectrum Measured in LUX



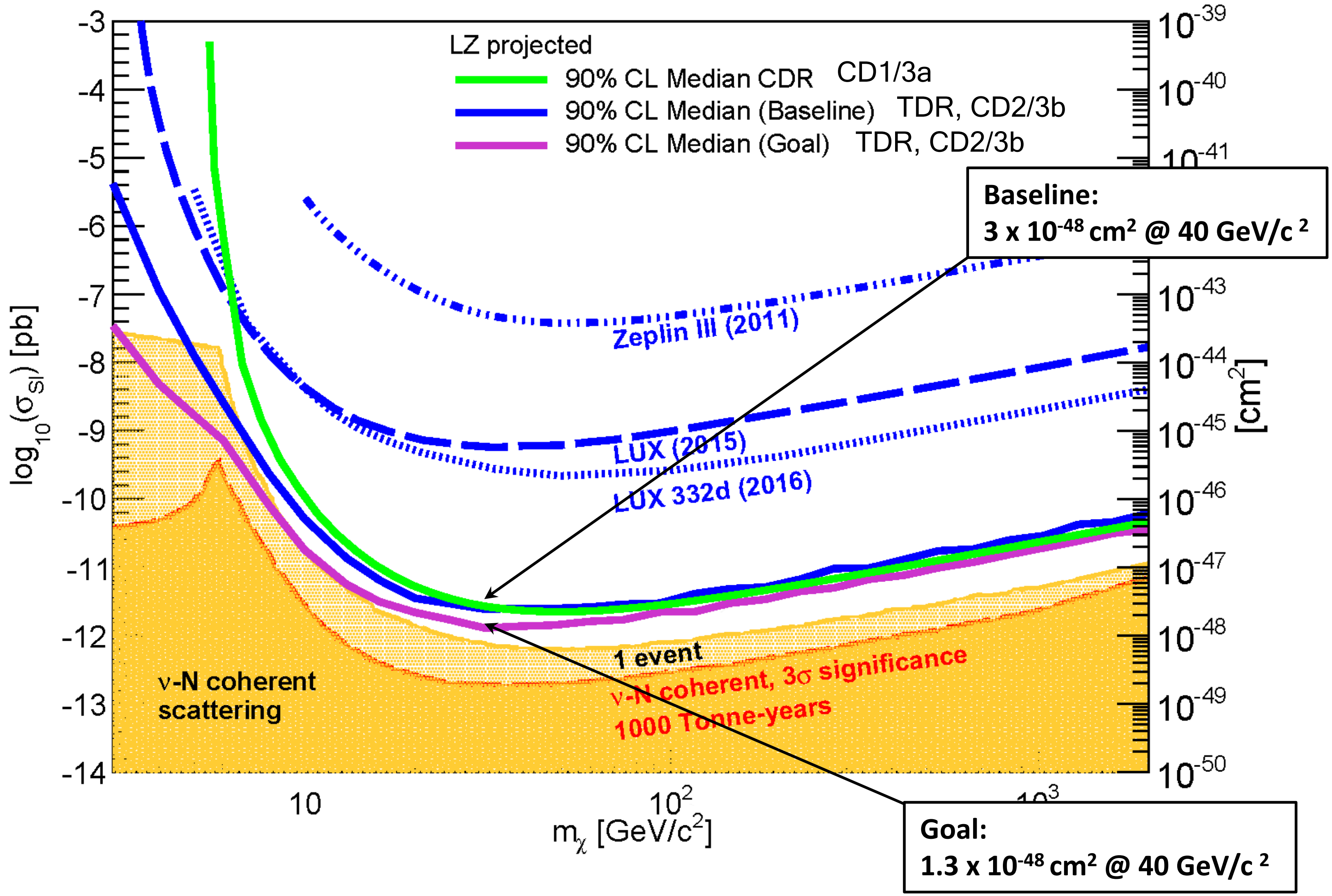
Detector Prototyping

Extensive program of prototype development underway, with three general approaches:

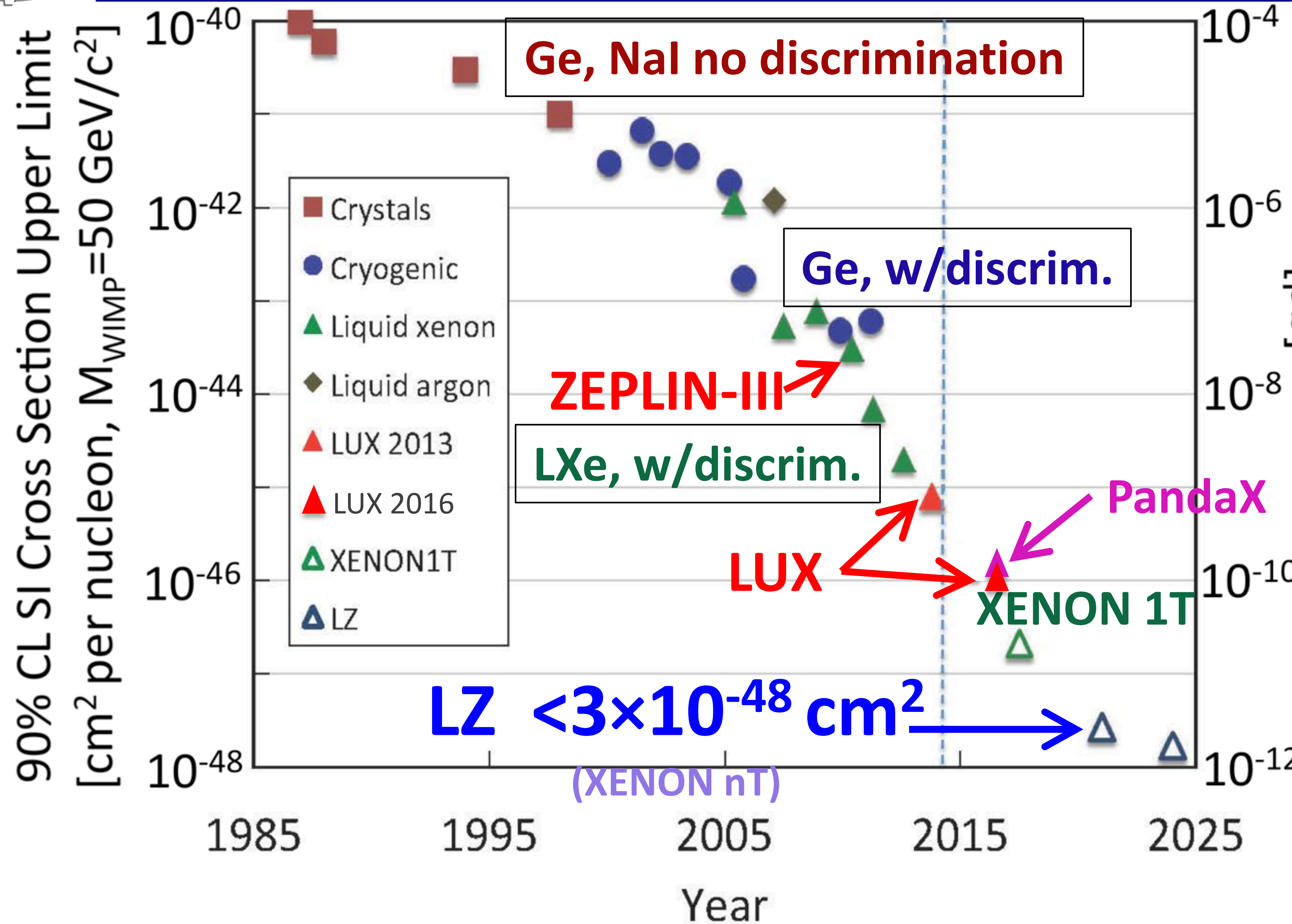
- Testing in liquid argon, primarily of HV elements at LBNL
- Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, UC Berkeley, LBNL, U Michigan, UC Davis, Imperial College, MEPhI, LIP (arXiv:1507.01310, [physics.ins-det], arXiv:1608.01717 [physics.ins-det])
- System test platform at SLAC, Phase I about 100 kg of LXe, TPC prototype testing ongoing (includes field testing of array of custom made sensors)

Projected LZ Sensitivity – Spin Independent

(5.6 T fiducial, 1000 live-days)



Time Evolution



Timeline

Year	Month	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	August	DOE CD-2/3b approval expected
2017	March	LUX removed from underground
	August	Beneficial occupancy surface assembly building
2018	June	Beneficial occupancy for underground installation
2019		Underground installation
2020	April	Start operations
2025+		Planning on 5+ years of operations

Summary

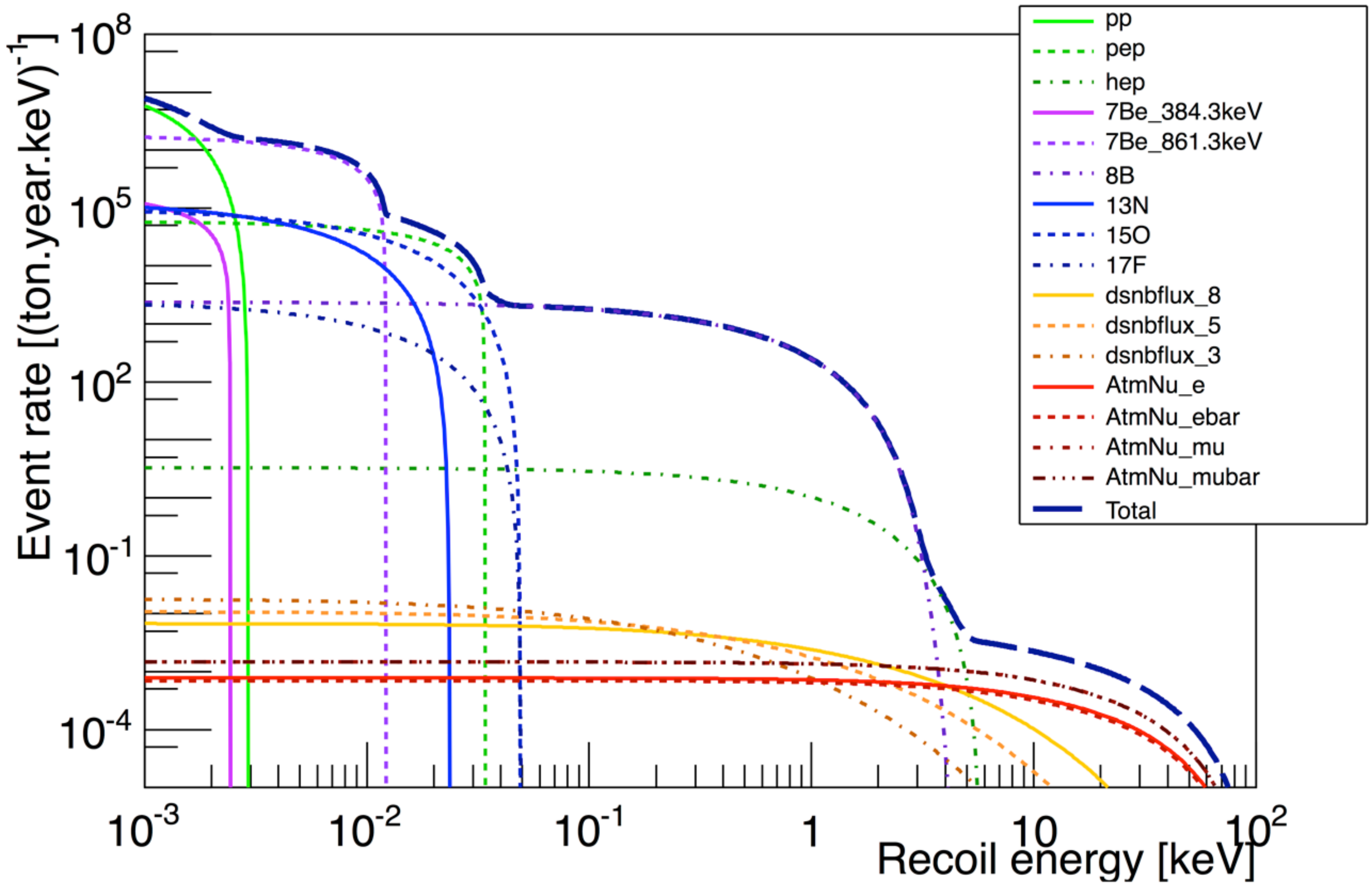
- LZ Project well underway, with procurement of Xe, PMTs and cryostat vessels started
- Extensive prototype program underway
- LZ benefits from the excellent LUX calibration techniques and understanding of background
- Will explore significant fraction of available phase space:
  - WIMP sensitivity 3×10^{-48} cm^2 @ 40 GeV/c^2 and approaching neutrino floor

Extra Slides

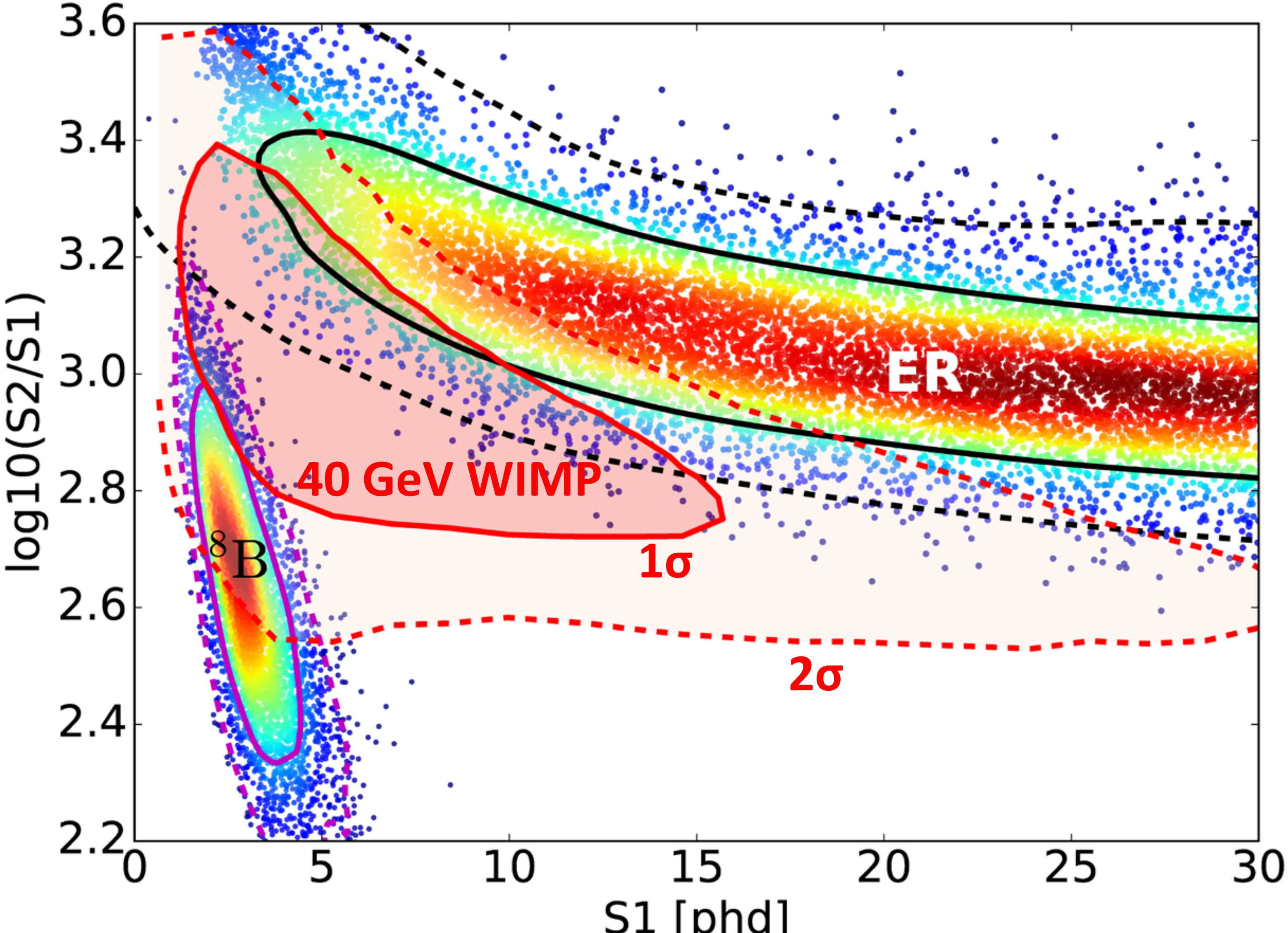
Xe purification and cryogenics

- Gas phase purification through getter: 10 tons/2.5 days
- Trap-enhanced mass spec; sensitivity: ~ppt
- High-efficiency two-phase heat exchange
- LN_2 thermosiphon-based cryogenics: multiple cooling locations

Neutrino Background



WIMP Signal Region



Non-WIMP physics

- Effective Field Theory Interaction Decomposition
- Neutrinoless Double Beta Decay
- Axions/Axion-like-particles, leptophilic DM, fractionally charged particles
- External Neutrino Physics:
    - Solar
    - Supernova
    - Sterile Neutrino

Status and outlook for WIMP detection