The LUX-ZEPLIN Dark Matter Experiment

Alden Fan

for the LZ collaboration

Stanford/KIPAC/SLAC

TAUP 2019

Toyama, Japan

9 September 2019

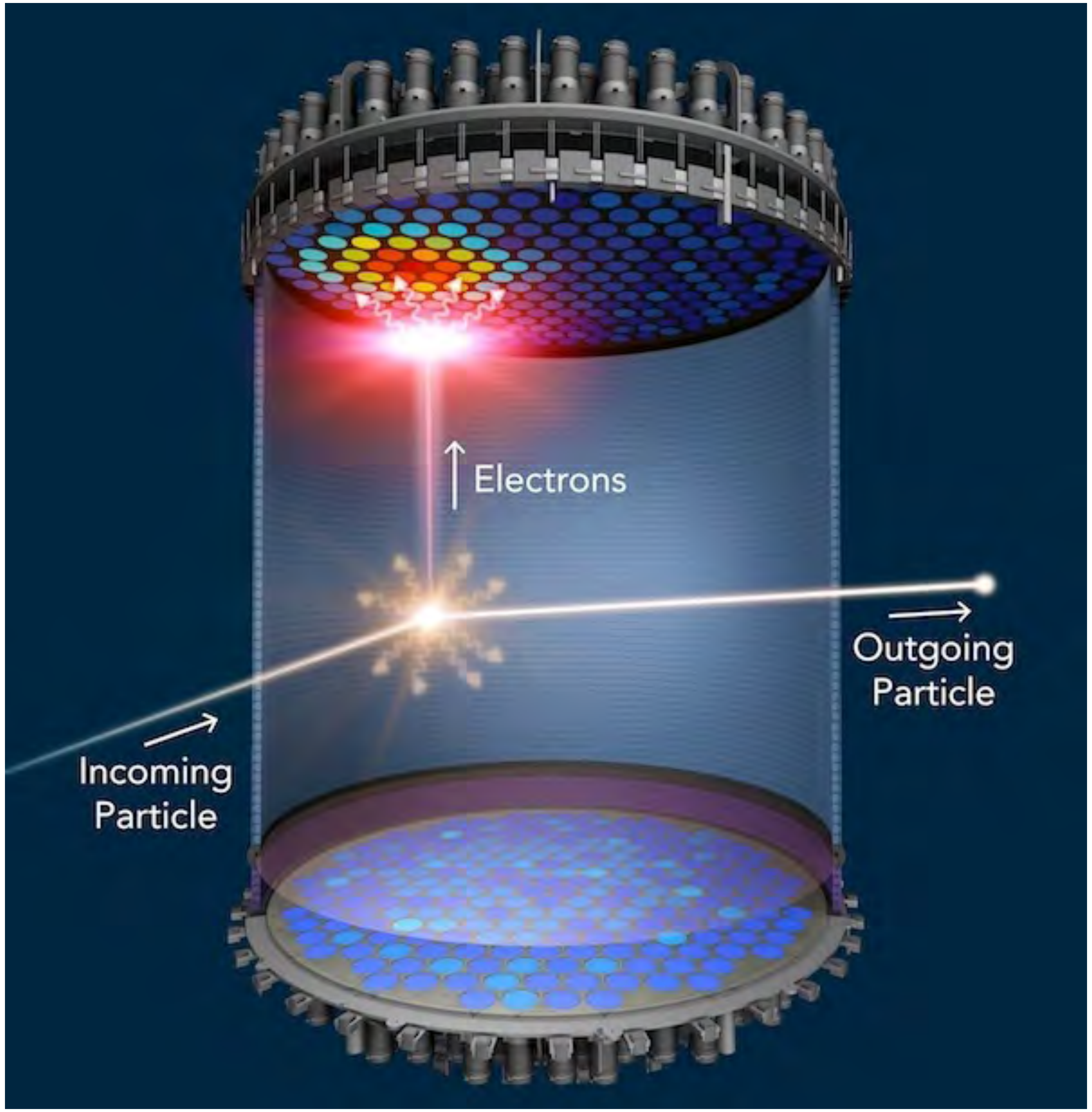
LZ collaboration

36 institutions, ~250 scientists, engineers, technicians

IBS-CUP (Korea)
LIP Coimbra (Portugal)
MEPhI (Russia)
Imperial College London (UK)
Royal Holloway University of London (UK)
STFC Rutherford Appleton Lab (UK)
University College London (UK)
University of Bristol (UK)
University of Edinburgh (UK)
University of Liverpool (UK)
University of Oxford (UK)
University of Sheffield (UK)
Black Hill State University (US)
Brandeis University (US)
Brookhaven National Lab (US)
Brown University (US)
Fermi National Accelerator Lab (US)
Lawrence Berkeley National Lab (US)
Lawrence Livermore National Lab (US)
Northwestern University (US)
Pennsylvania State University (US)
SLAC National Accelerator Lab (US)
South Dakota School of Mines and Technology (US)
South Dakota Science and Technology Authority (US)
Texas A&M University (US)
University at Albany (US)
University of Alabama (US)
University of California, Berkeley (US)
University of California, Davis (US)
University of California, Santa Barbara (US)
University of Maryland (US)
University of Massachusetts (US)
University of Michigan (US)
University of Rochester (US)
University of South Dakota (US)
University of Wisconsin – Madison (US)

Dual-phase liquid xenon TPC

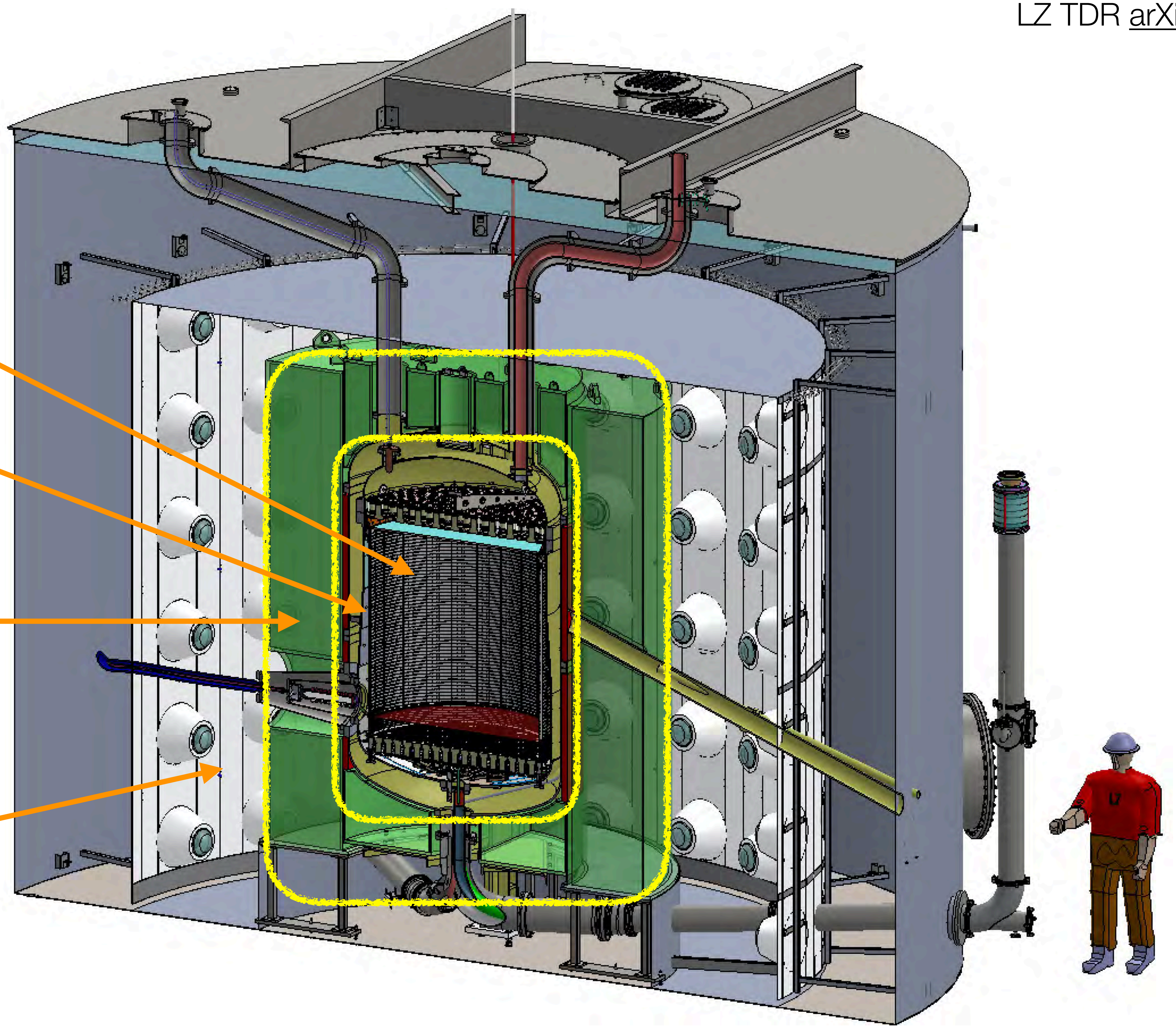
- Looking for very low-energy nuclear recoils from WIMP dark matter
- Particle scattering on Xe produces prompt scintillation (S1) and ionization electrons
- Electrons drift up into gas phase to produce electroluminescence S2
- Full 3D reconstruction from S1-S2 time delay (z) and hit pattern (xy)
- S2/S1 ratio for discrimination between electron recoils (ERs) and nuclear recoils (NR)



LUX-ZEPLIN

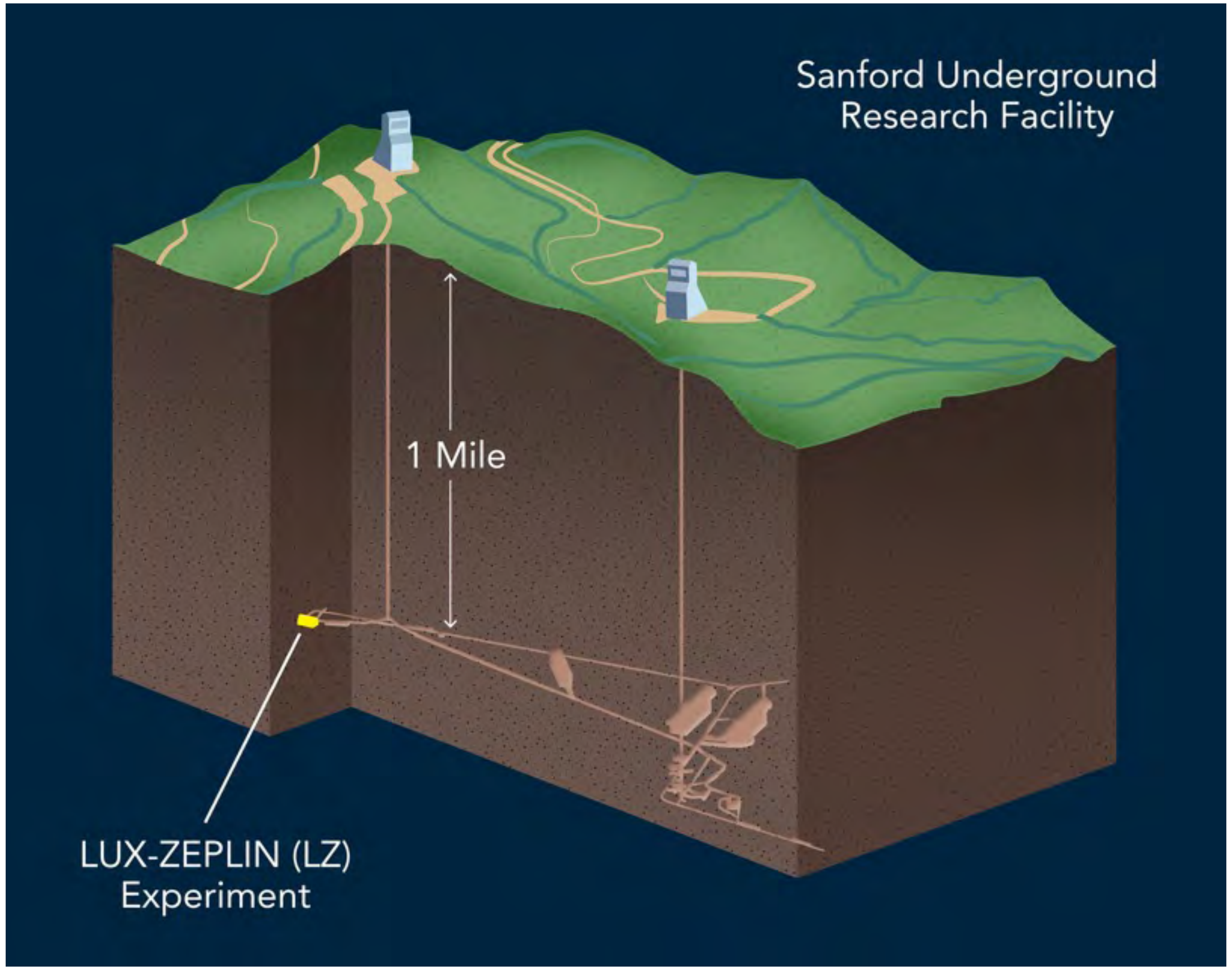
LZ TDR arXiv:1703.09144

Nested detectors



Sanford Underground Research Facility

- Located in Lead, SD (USA) in the Black Hills
- LZ located at the 4850 level (~1.5 km underground)
- 4300 m.w.e. overburden
- Muon flux reduced by O(10^7)



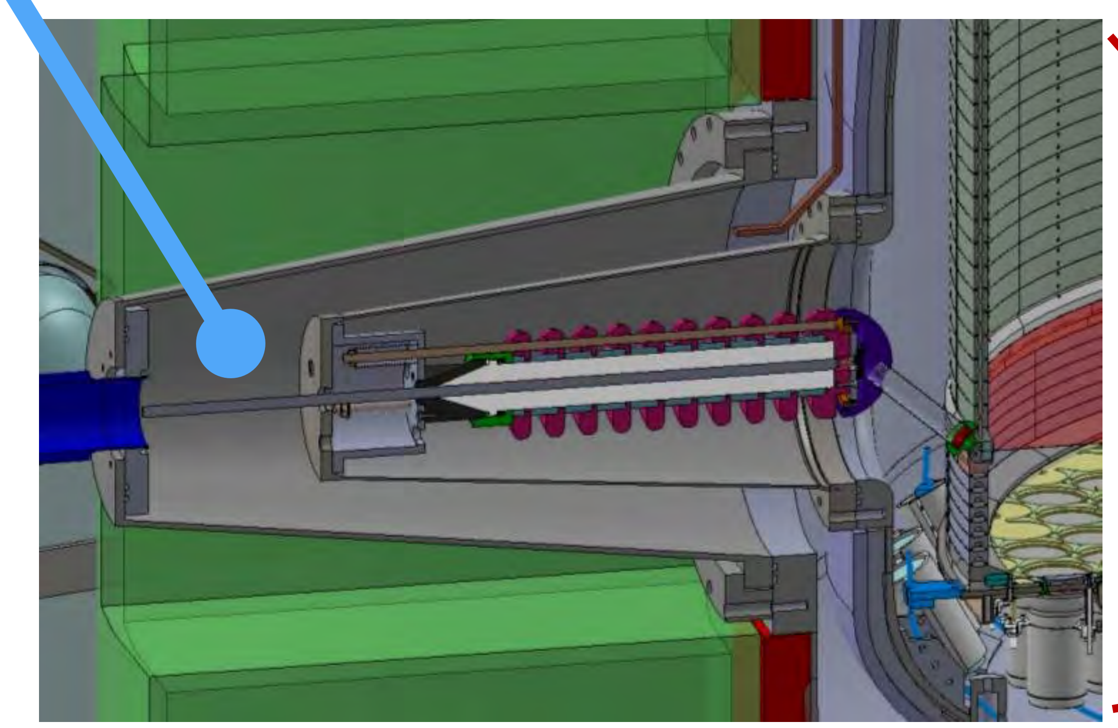
Xenon TPC

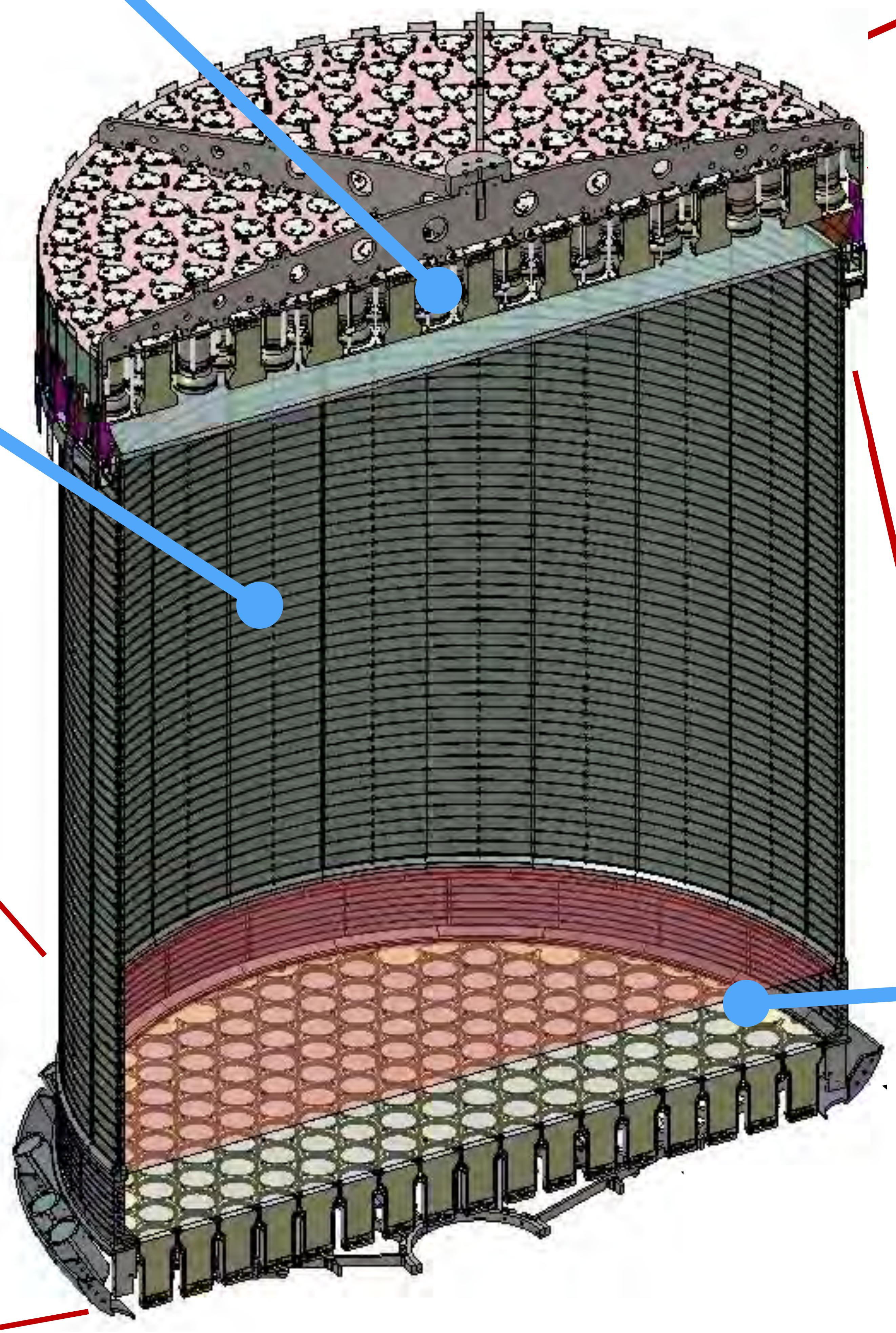
494 PMTs

7 tonne active LXe
5.6 tonne fiducial
(1.5 m diameter x 1.5 m height)

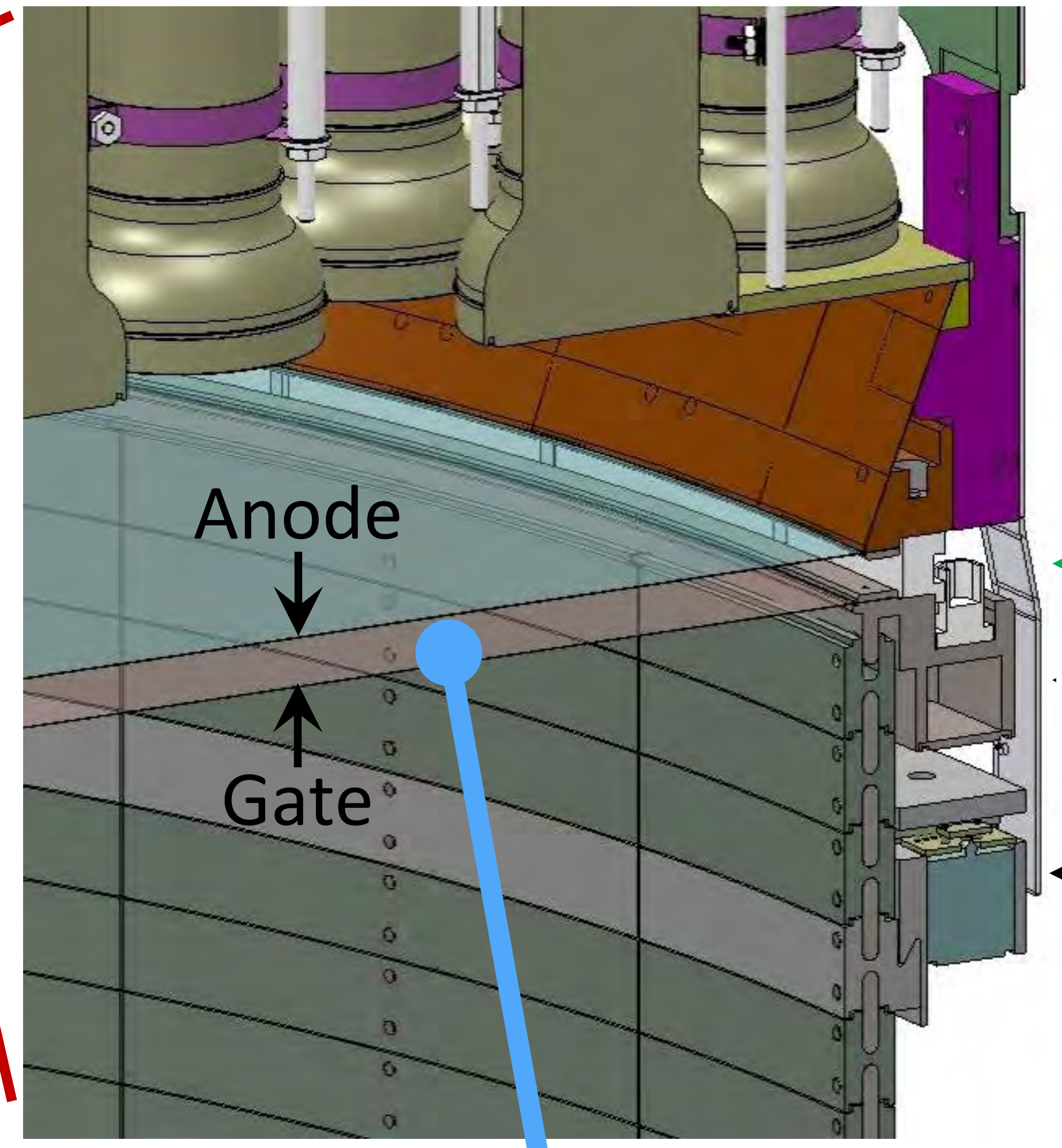
50 kV cathode HV

HV CONNECTION TO CATHODE





GAS PHASE AND
ELECTROLUMINESCENCE REGION



4x grid electrodes

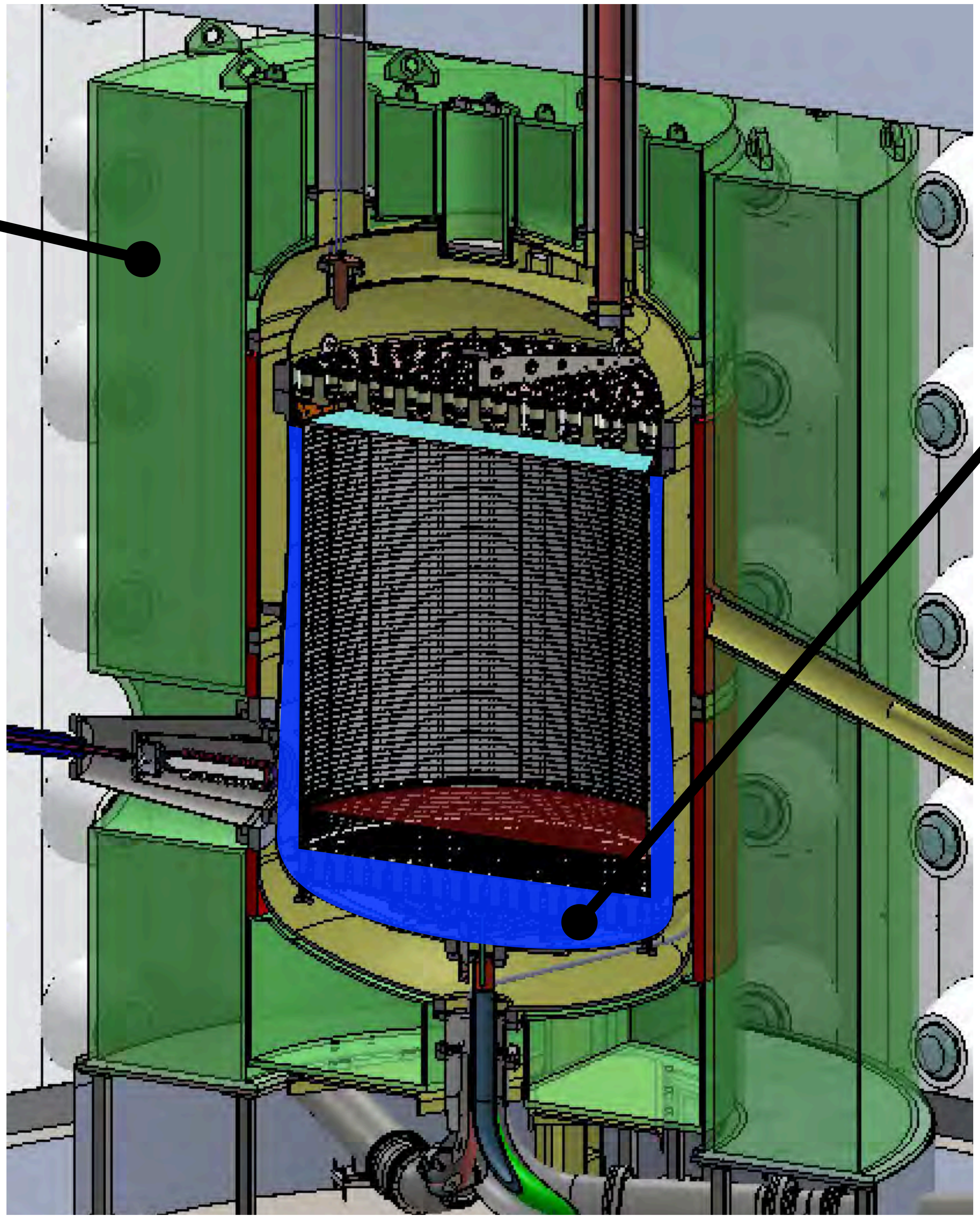
Gas Xe circulation @ 500 slpm
(turnover full mass in 2.5 days)

Outer Detector and Skin Region

The OD

- 17 tonnes Gd-loaded liquid scintillator in acrylic vessels
- 120 8” PMTs mounted in the water tank
- Anti-coincidence detector for γ-rays and neutrons
- Observe ~8.5 MeV γ-rays from thermal neutron capture
- Draw on experience from Daya Bay

See talk by B. Penning
“The LZ Outer Detector”
DM16 Thu afternoon



The Skin

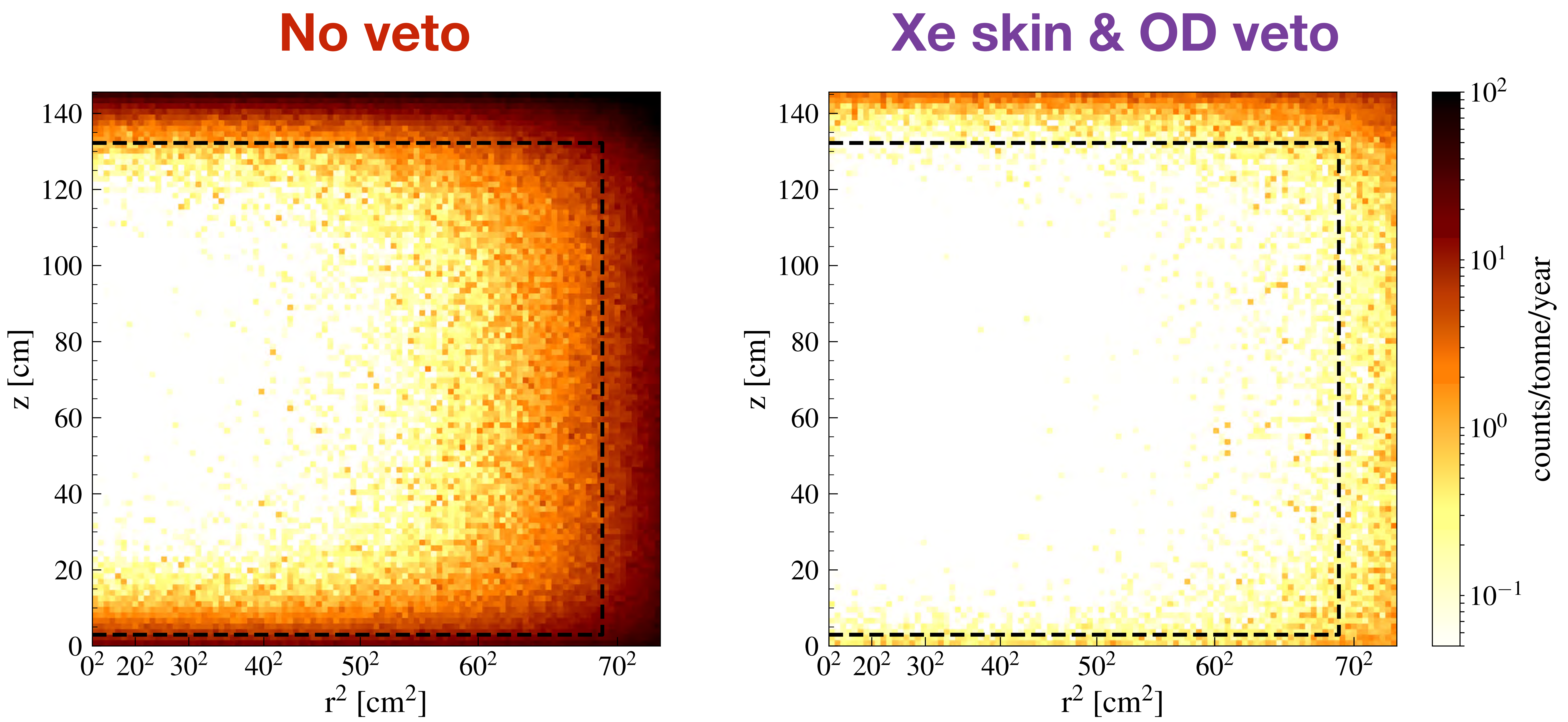
- 2 tonnes of LXe surrounding the TPC
- 1” and 2” PMTs at the top and bottom of the skin region
- Lined with PTFE to maximize light collection efficiency
- Anti-coincidence detector for γ-rays

- **Tag individual neutrons and γ-rays**
- **Characterize BGs in situ**

→Enables discovery potential

Background suppression

Combined veto system allows to define a fiducial volume at 80% of active volume.



	No veto	Xe skin & OD veto
Expected BG NR cts / 1000 days in 5.6t FV in 6-30 keV_{nr}:	**10.43**	**1.03**
NR BG equivalent fiducial volume:	**3.2**	**5.6**

Background sources and mitigation

- **Detector materials**
  - Radio-assay campaign with gamma-screening, ICPMS, NAA
- **Rn emanation**
  - Four Rn emanation screening sites
  - Target Rn activity: 2 μBq/kg
- **Rn daughters and dust on surfaces**
  - TPC assembly in Rn-reduced cleanroom
  - Dust <500 ng/cm^3 on all LXe wetted surfaces
  - Rn-daughter plate-out on TPC walls <0.5 mBq/m^2
- **Xenon contaminants — ^{85}Kr, ^{39}Ar**
  - Charcoal chromatography @ SLAC
- **Cosmogenics and externals**
  - 4300 m.w.e. underground at Sanford Underground Research Facility in Lead, SD
  - Instrumented Xe skin region
  - Gd-LS outer detector
  - High purity water shield

Many sources of BG
Many methods for BG mitigation

See talk by A. Kamaha
"Material Assay and Cleanliness for the LUX-ZEPLIN Experiment"
DM4 Mon afternoon

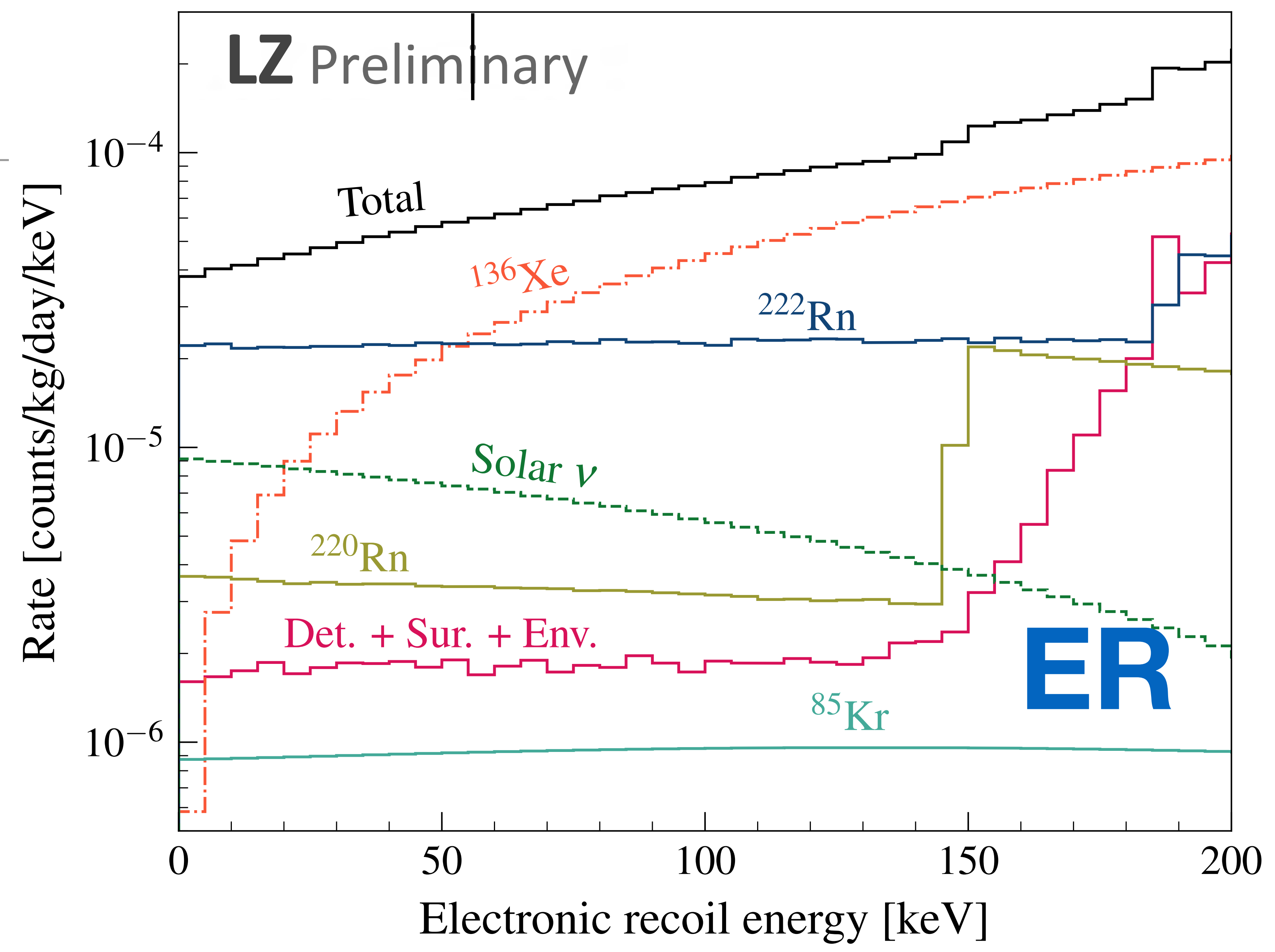
Expected backgrounds

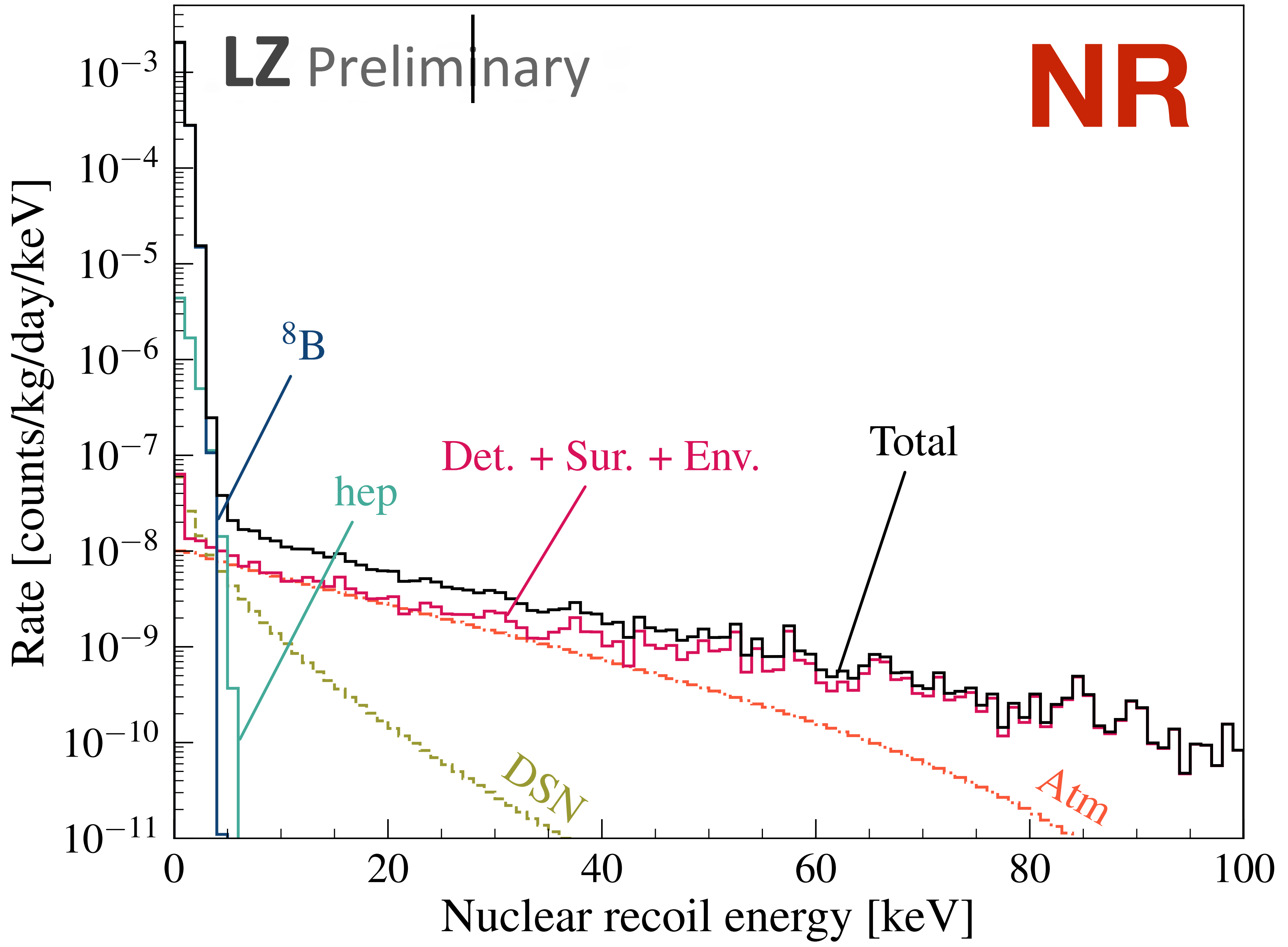
5.6 tonne fiducial volume, 1000 live-days
1.5-6.5 keV_{ee} (6-30 keV_{nr})
single scatters, anti-coincidence with vetoes

Background Source	ER [cts]	NR [cts]
Detector components	9	0.07
Dispersed Radionuclides — Rn, Kr, Ar	819	—
Laboratory and Cosmogenics	5	0.06
Surface Contamination and Dust	40	0.39
Physics Backgrounds — 2β decay, neutrinos*	322	0.51
Total	**1195**	**1.03**
After 99.5% ER discrimination, 50% NR efficiency	**5.97**	**0.51**

* not including ^{8}B and hep

D.S. Akerib et al (LZ collaboration) 2018 arXiv:1802.06039





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See talk by A. Cottle
"Backgrounds and Simulations for the LUX-ZEPLIN Experiment"
DM4 Mon afternoon

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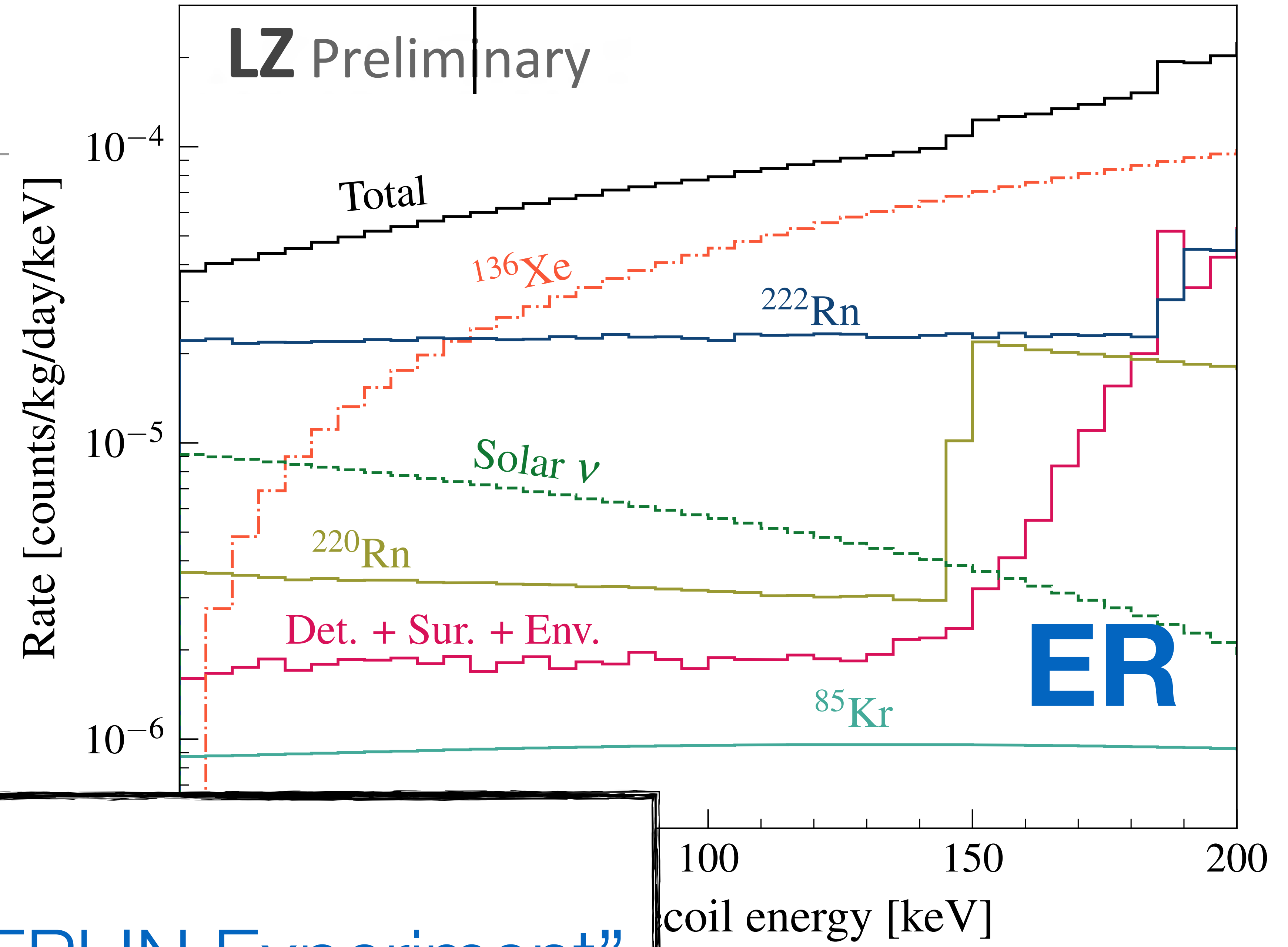
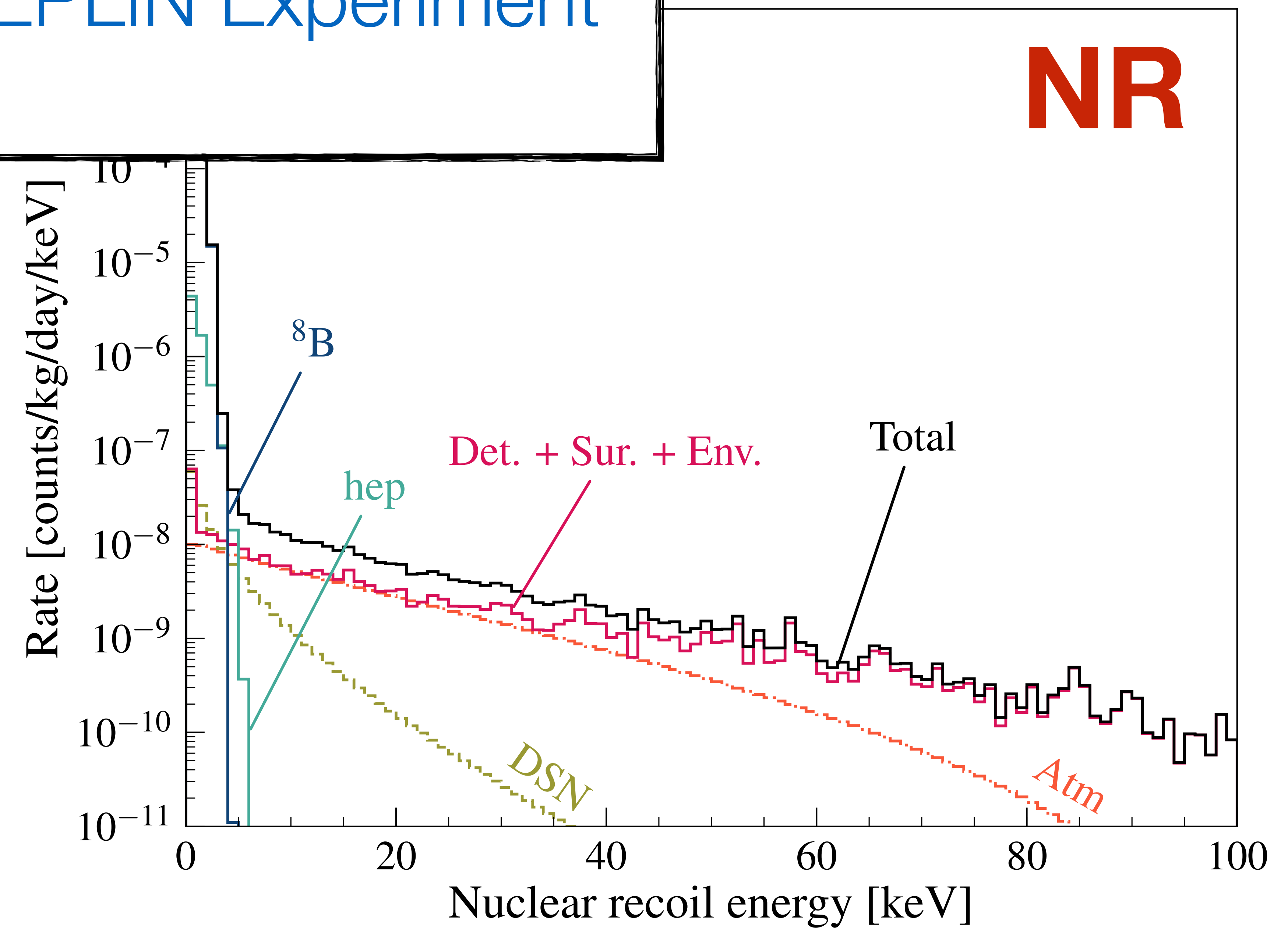
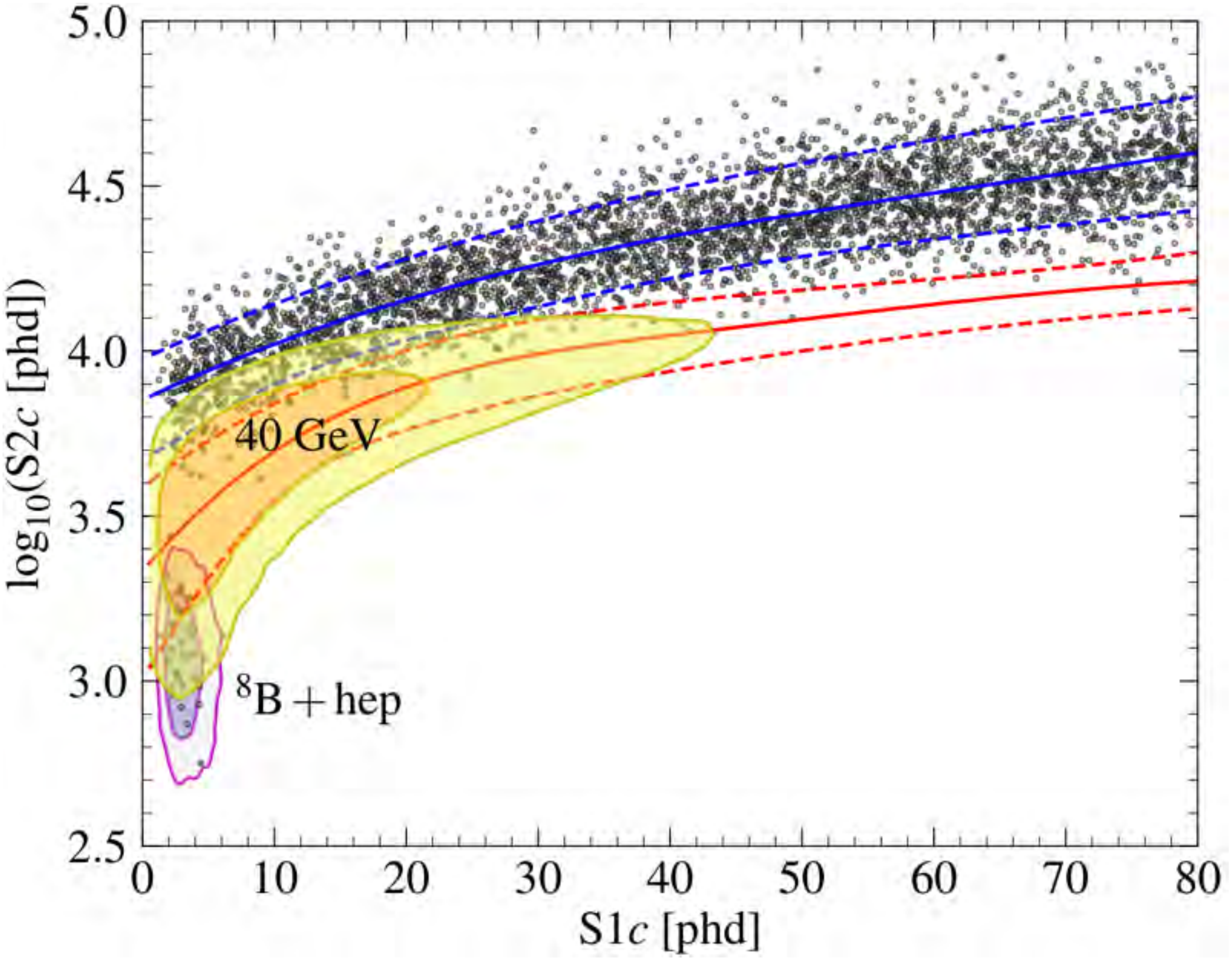
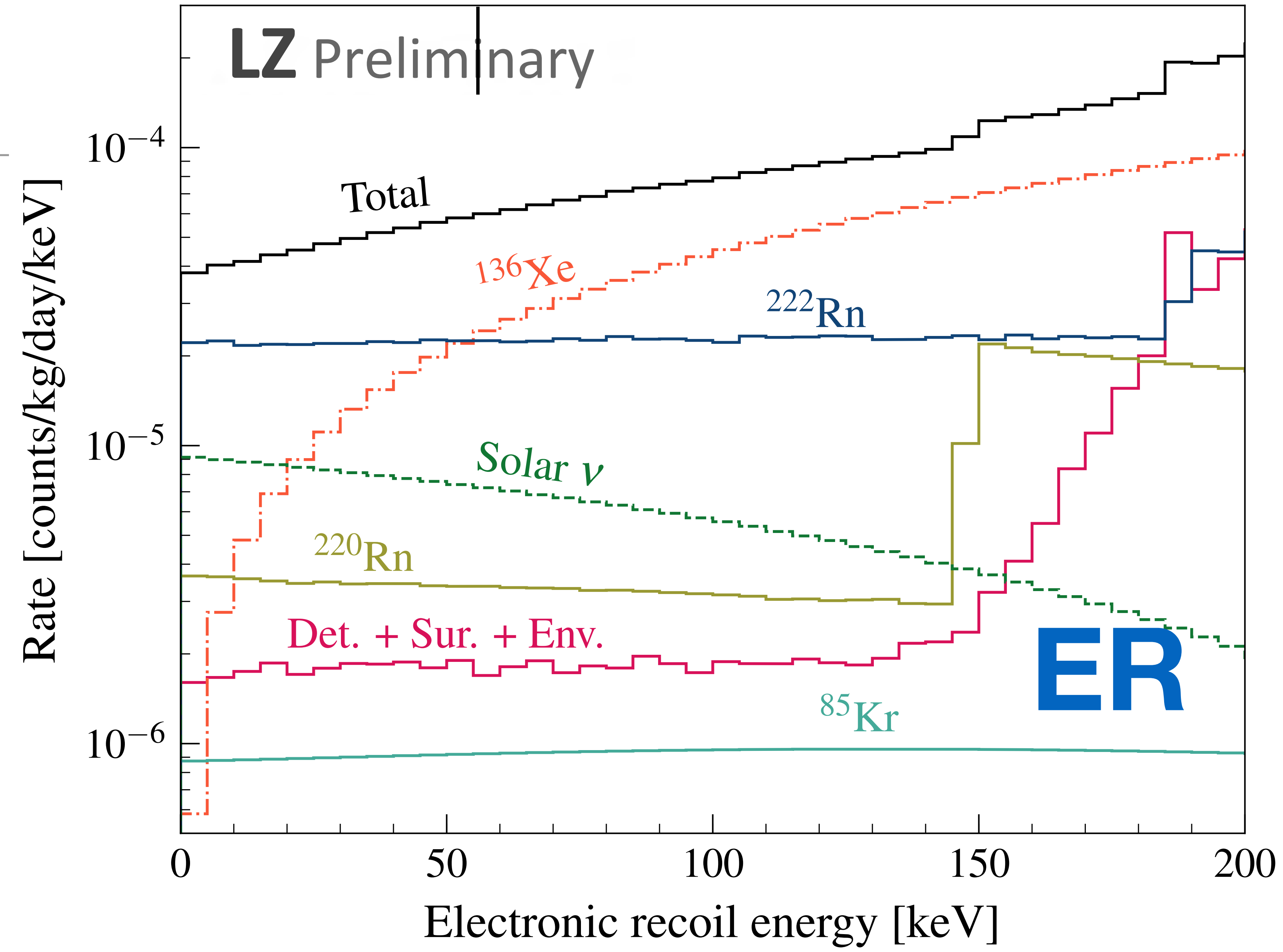


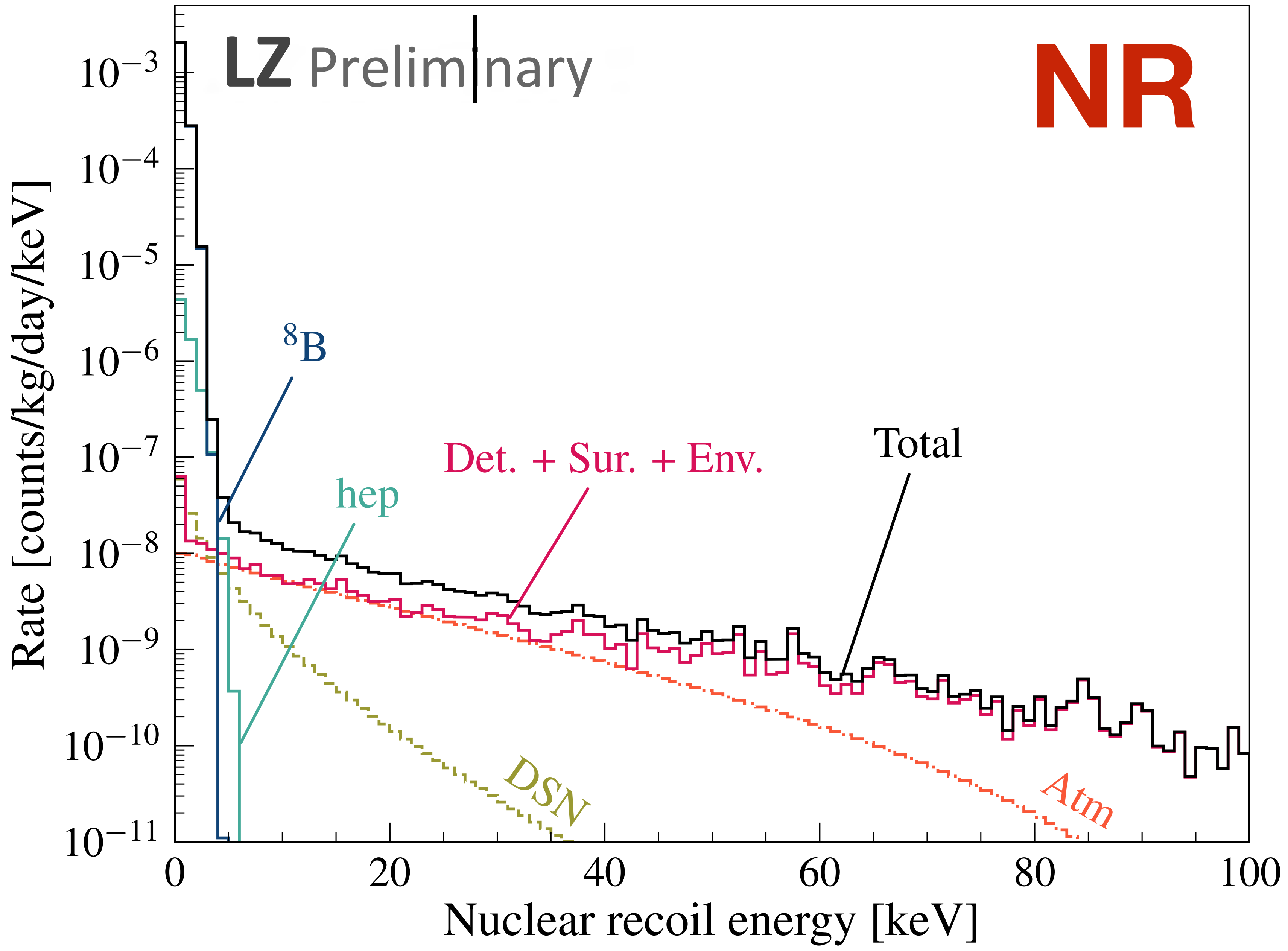


Expected backgrounds

Simulation of a 1000 day run of LZ







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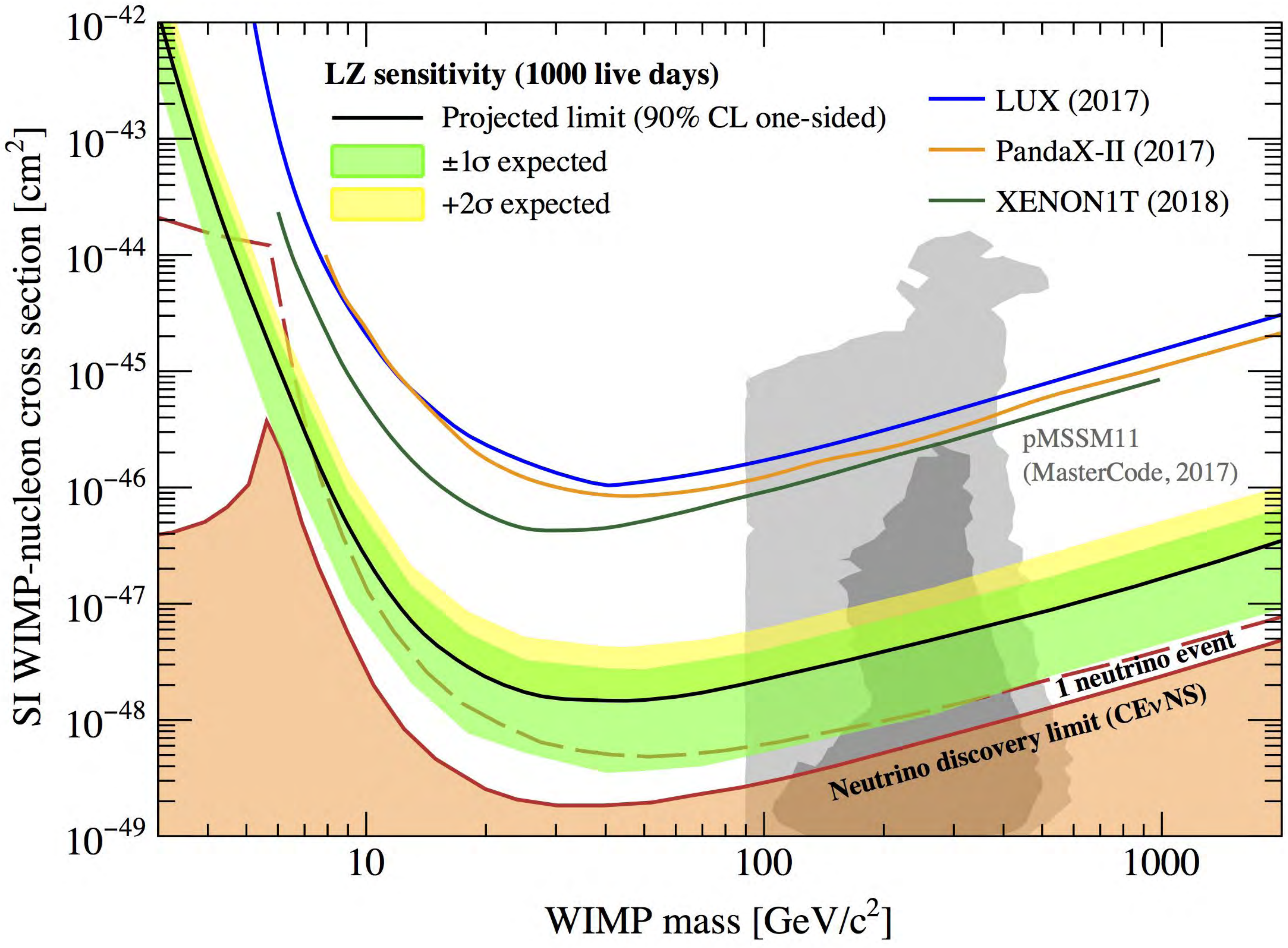
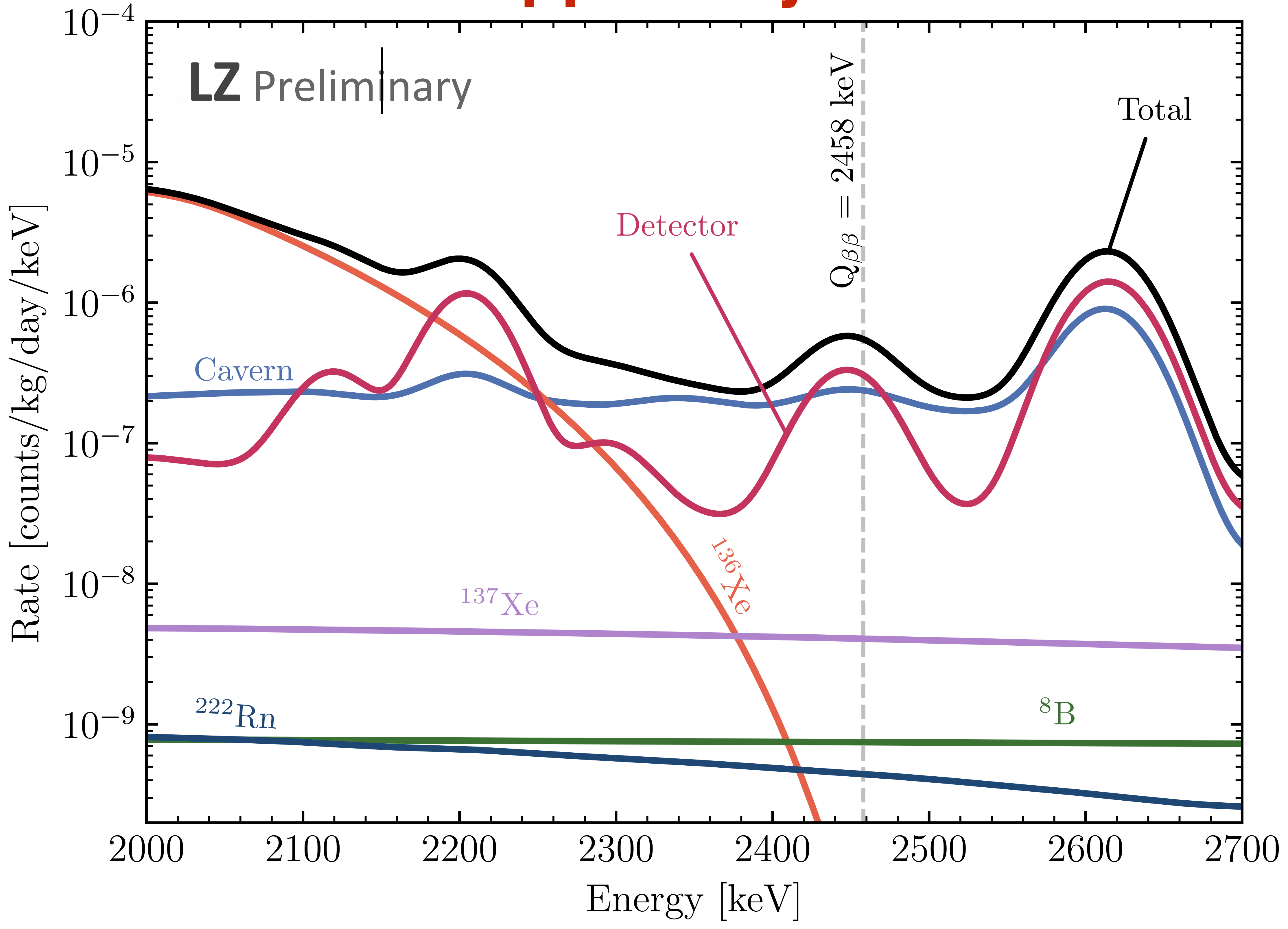
Projected sensitivity



90% CL minimum of 1.6 x 10^{-48} cm^2 at 40 GeV/c^2

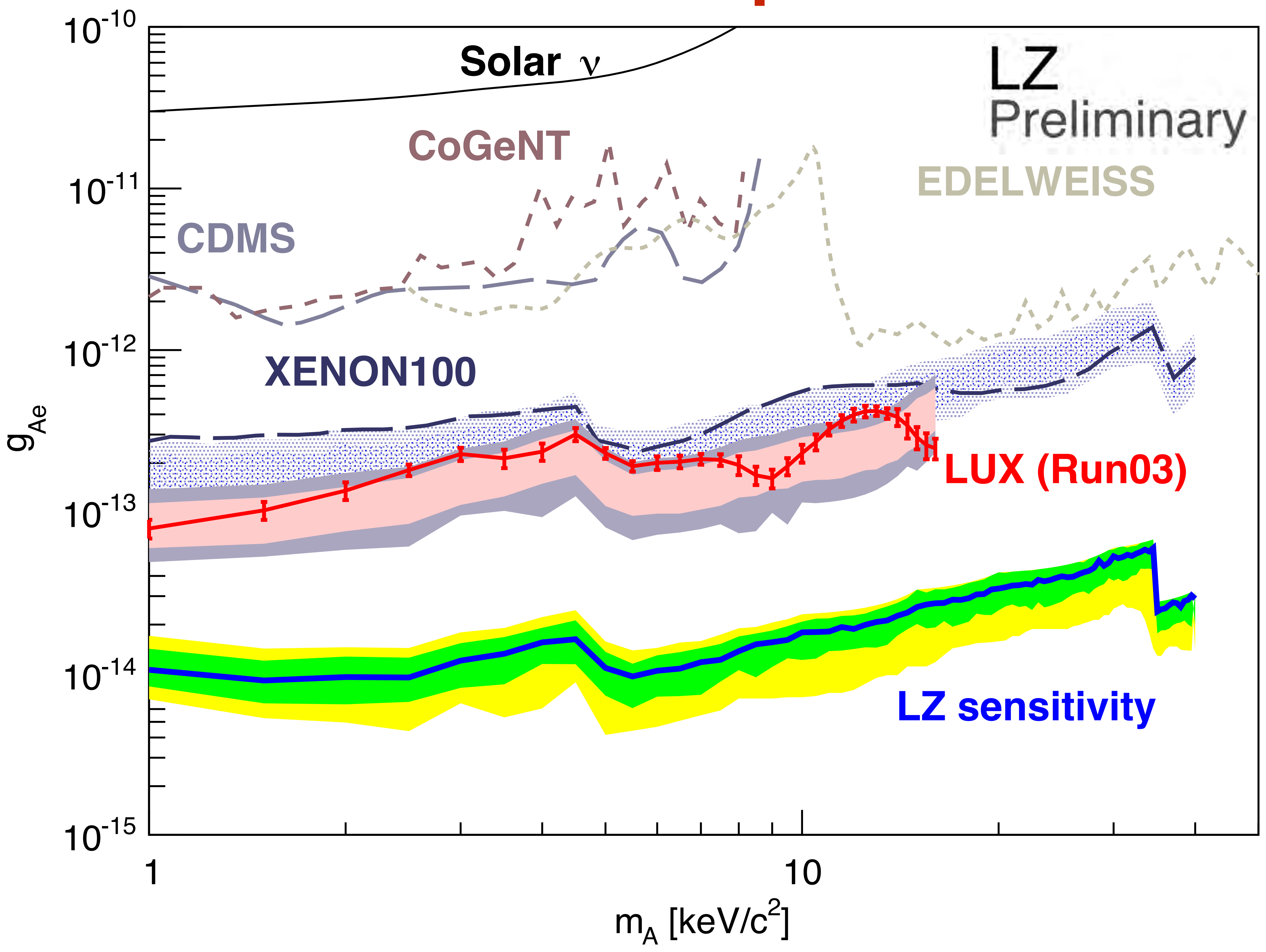
Physics sensitivity beyond WIMPs

0νββ decay



^{136}Xe Q value at 2458 keV
Nominal 1% energy resolution at Q value
$T_{1/2}$ (90% C.L.) > 1 x 10^{26} years in 1000 live days, inner 1 tonne fiducial mass

Axion-like particles

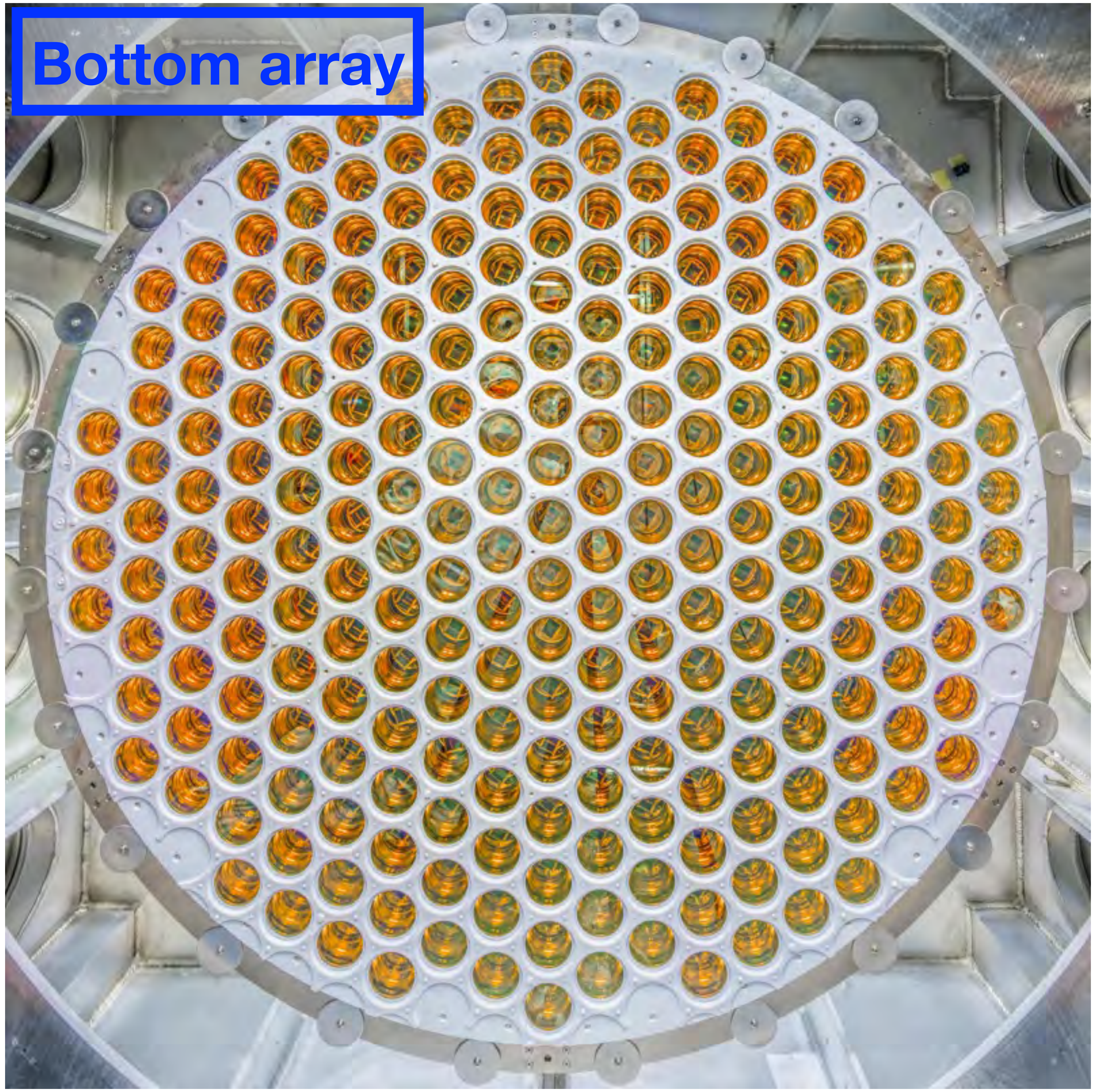


Expected sensitivity for 1000 live-days, 5.6 tonne fiducial mass

Recent Highlights from Construction

TPC: PMT arrays

253 (top) + 241 (bottom)
3” Hamamatsu R11410-22 PMTs



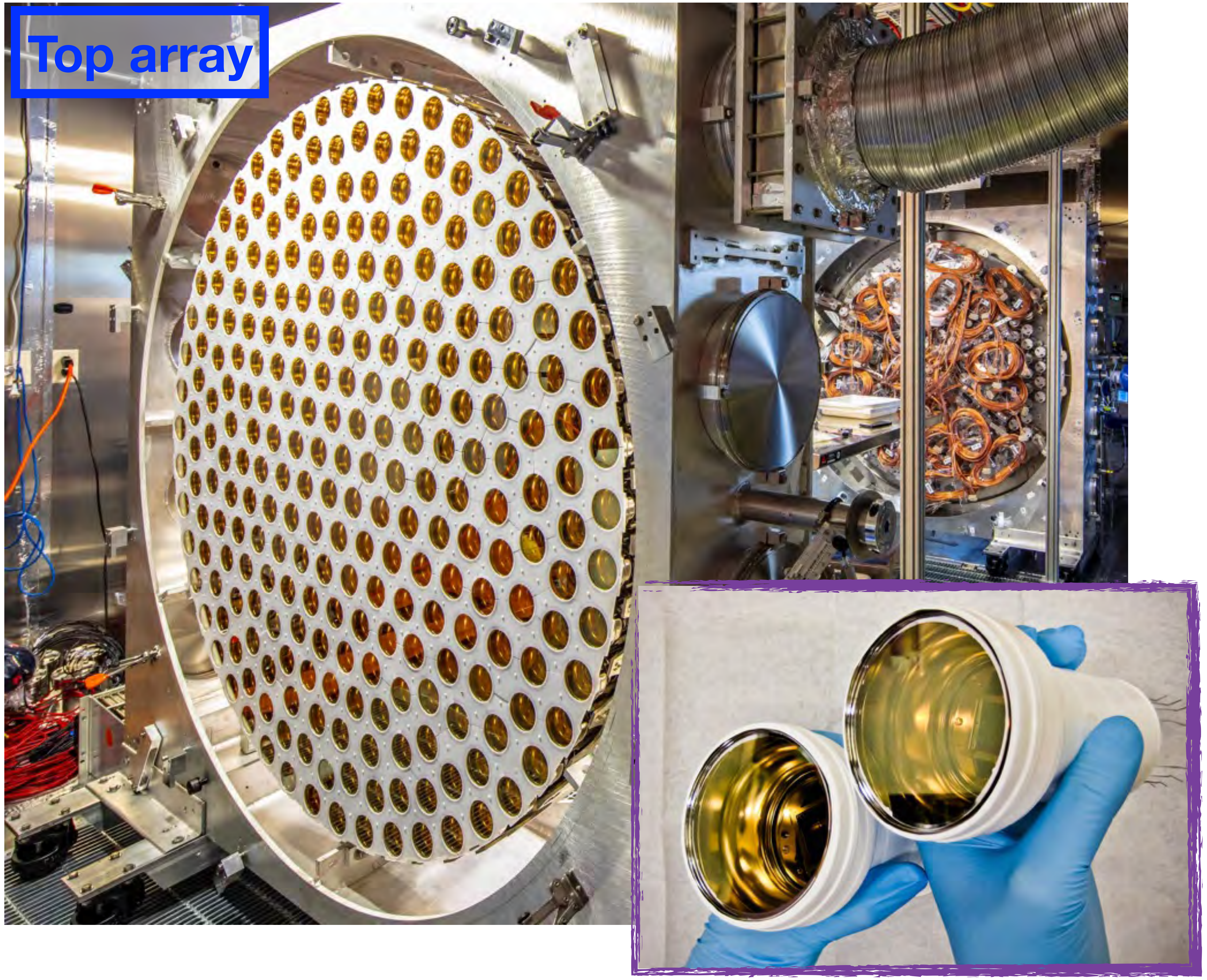
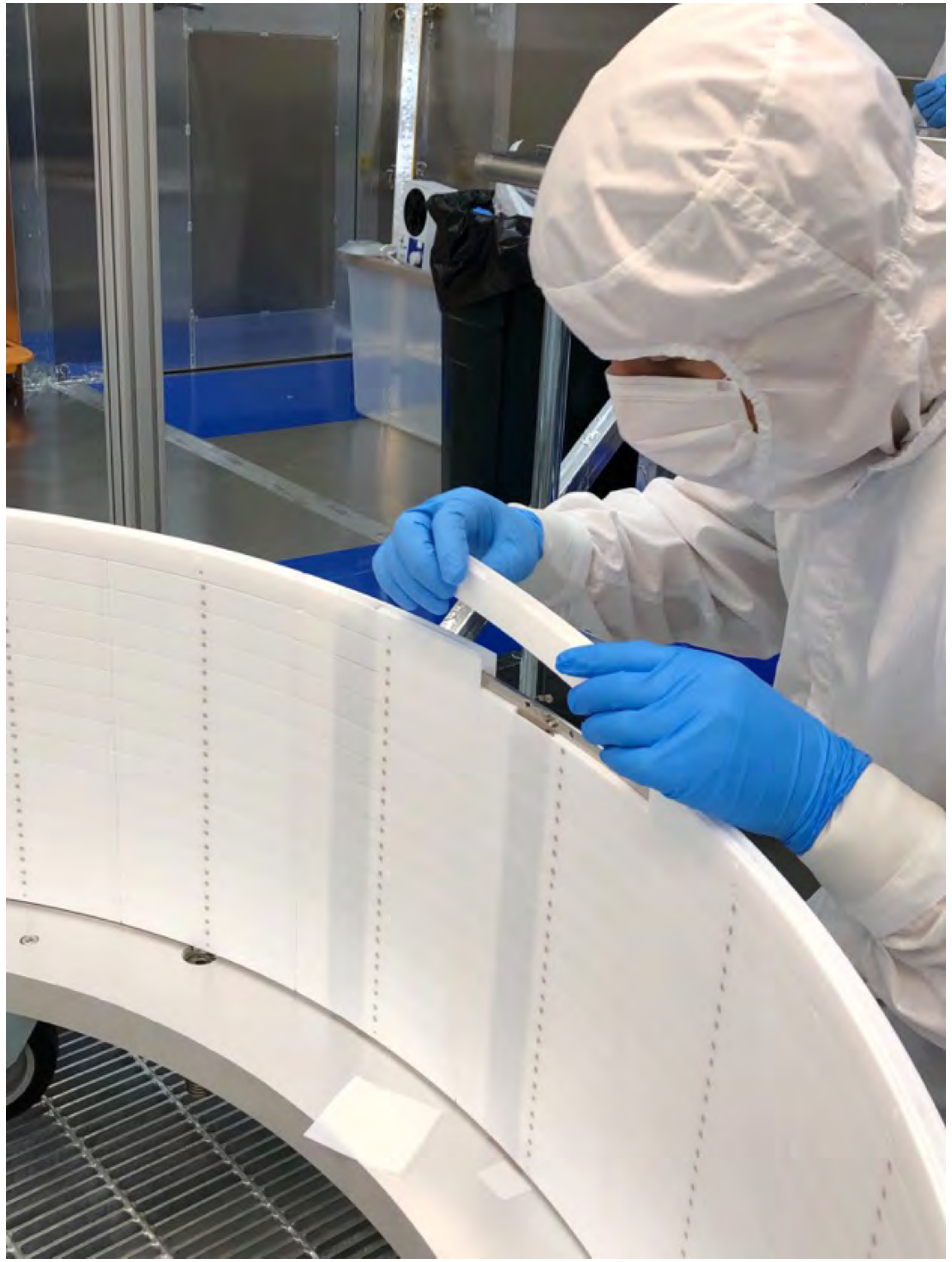


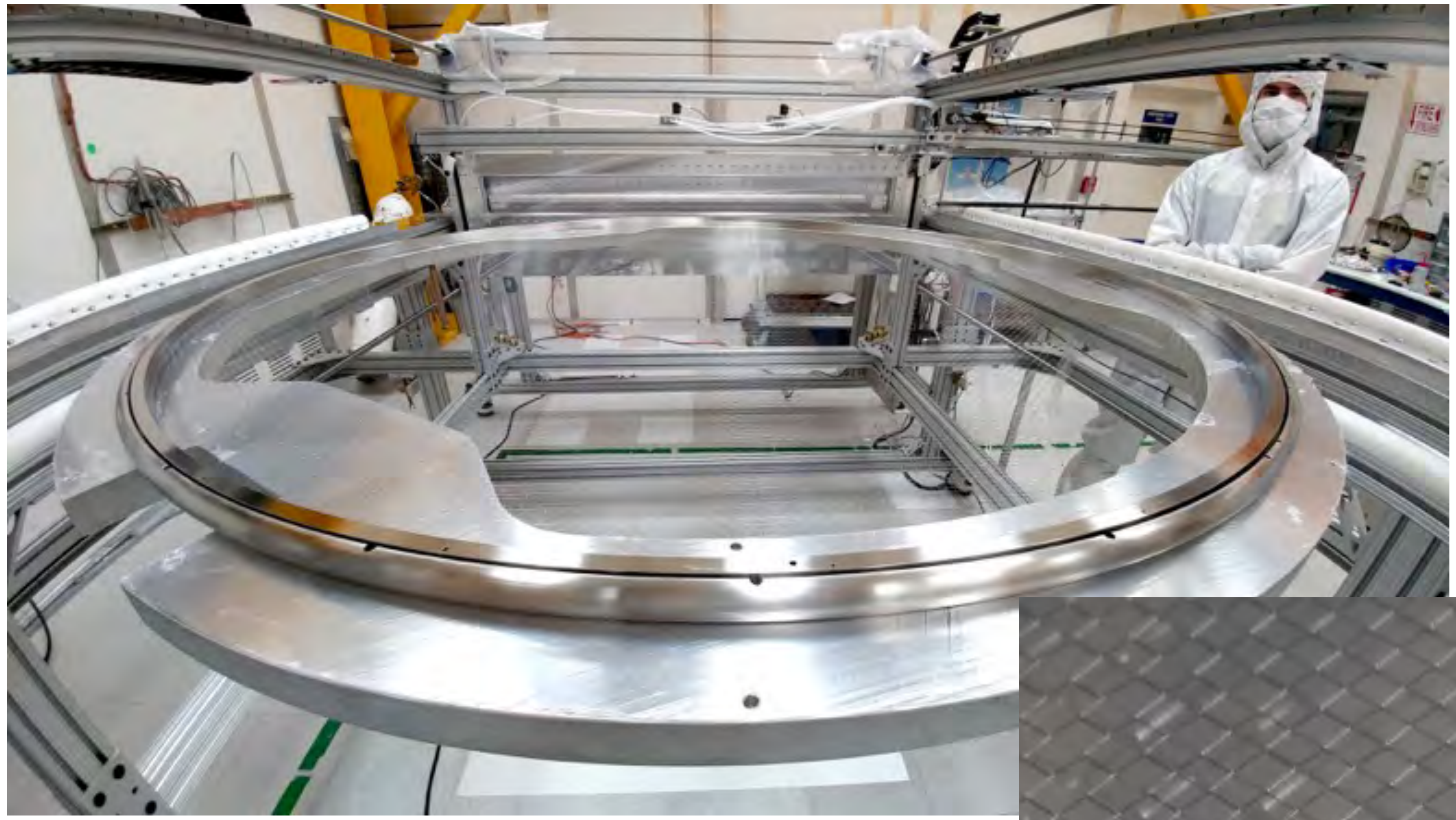
Photo credit: Matt Kapust, SDSTA

TPC: Field cage



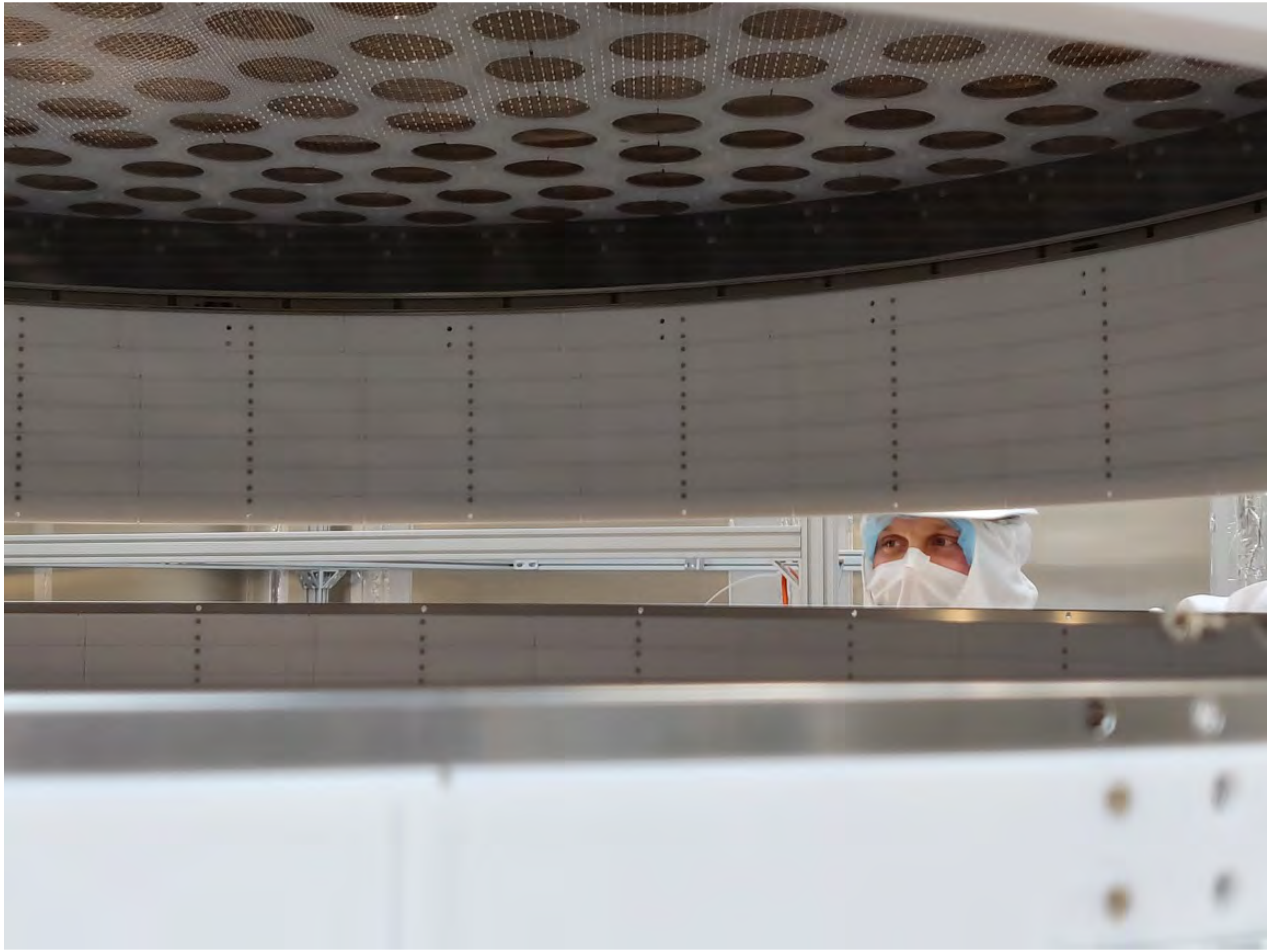
TPC: grids

- Semi-automated loom for weaving SS wire meshes
- Gate grid treated to reduce electron emission rate



See talk by K. Stifter
“Development and performance of high voltage electrodes for the LZ experiment”
DM16 Thu afternoon

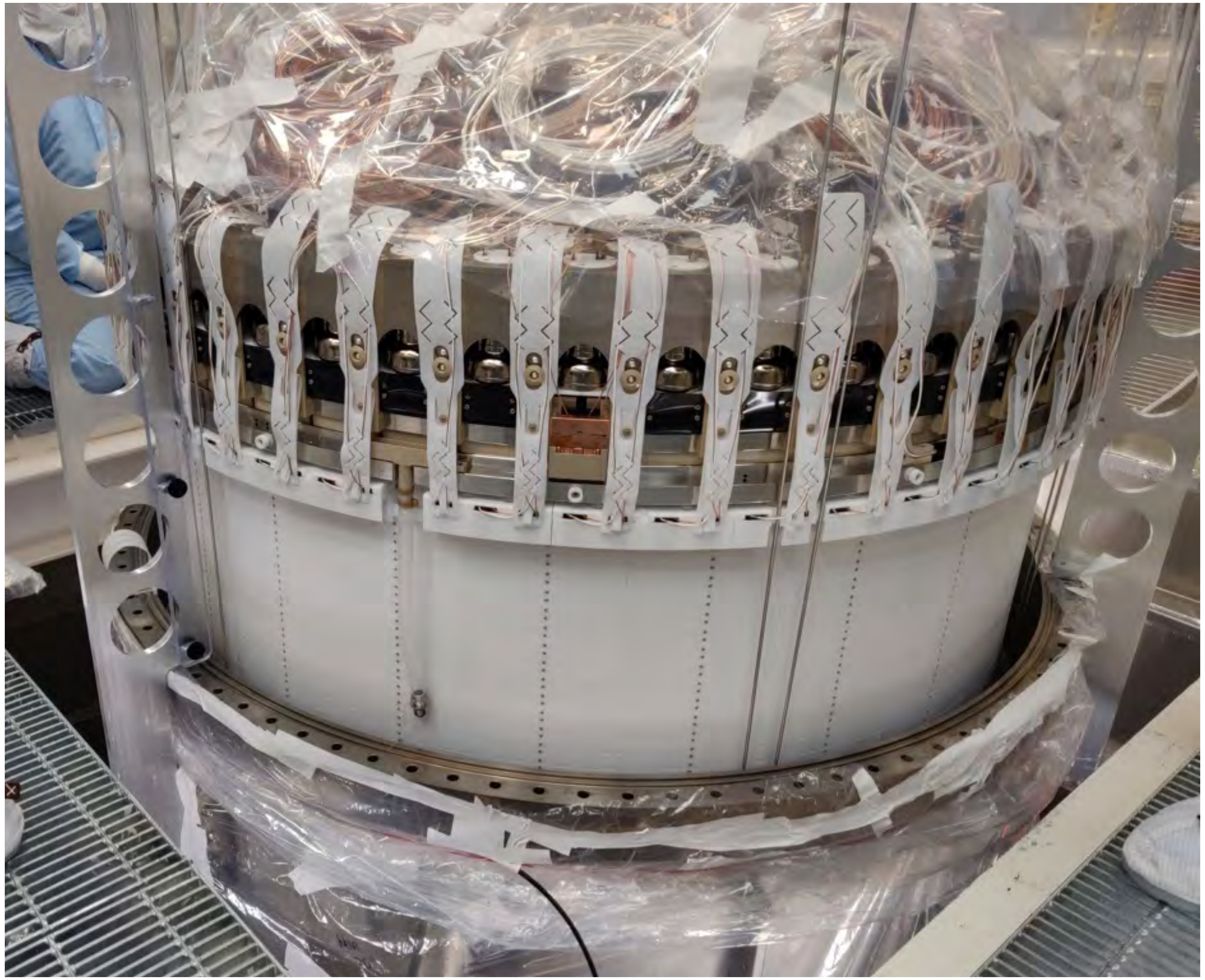
TPC integration



Full TPC

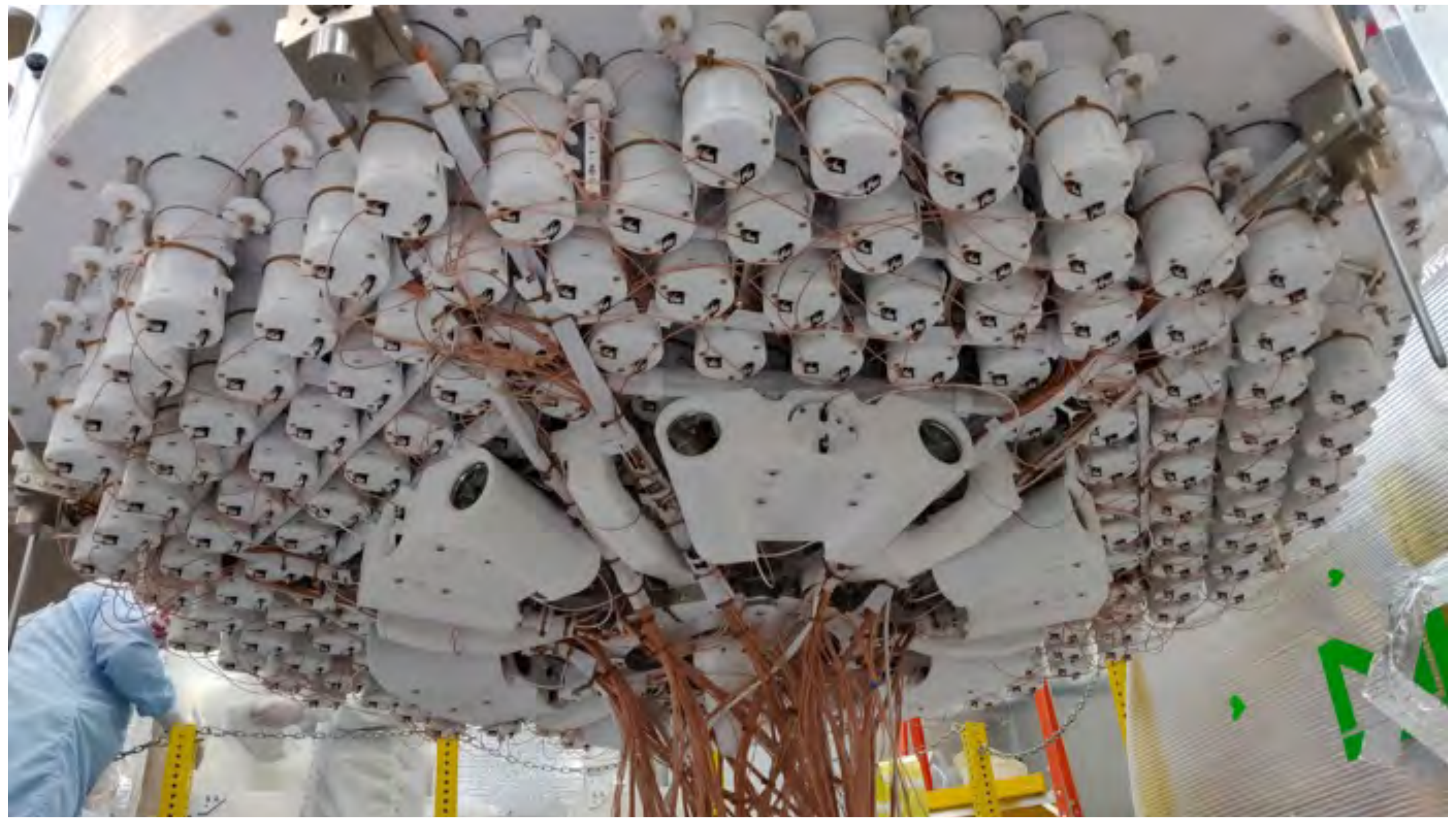
Photo credit: Matt Kapust, SDSTA

Insertion into inner cryostat vessel



Skin detector

Bottom side skin



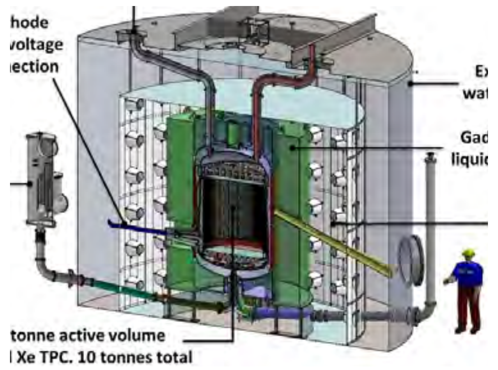
Bottom dome skin

Top skin

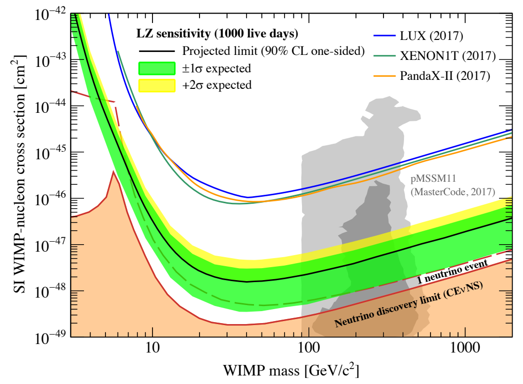
Timeline

CDR
Sep 2015

TDR
Mar 2017



WIMP sensitivity paper
Feb 2018



First science
2021

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021

Titanium paper
Feb 2017

TPC
assembled
Aug 2019

TPC moves
underground

LXe filling
2020

Summary

- LZ is at an advanced stage of assembly
  - The LZ Xe TPC has been assembled at SURF and inserted into its inner cryostat vessel. Transport to underground expected within weeks.
  - All other systems progressing well
- Start of operations in 2020
- First physics in 2021, probing new WIMP parameter space
- Sensitivity to other physics, including $0\nu\beta\beta$, ^{8}B solar neutrinos, and solar axions

Backup

Titanium cryostat

Xe procurement and Kr removal

- 10 tonnes of Xe in hand
- Charcoal chromatography to separate Kr from Xe.
- Demonstration of 0.06 ppt in R&D at SLAC
- Commissioning runs of production system in progress

Outer detector scintillator

Acrylic vessels being staged underground in water tank