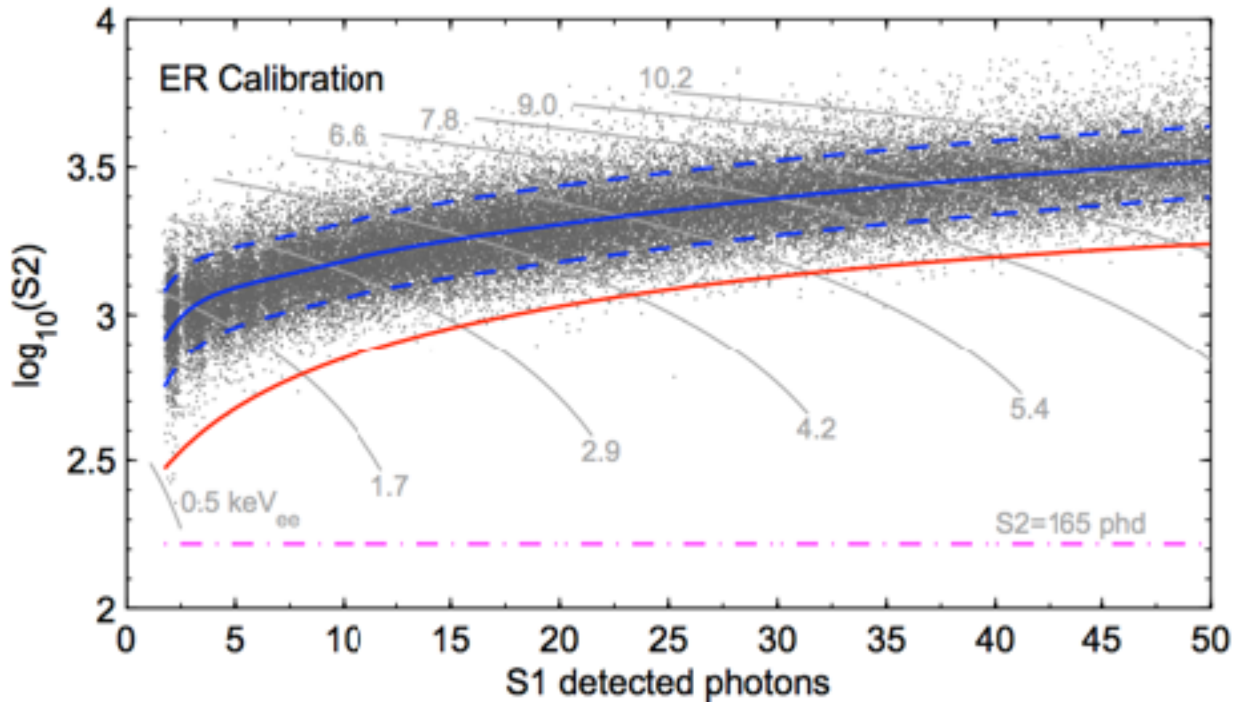
Status of the LZ Dark Matter Experiment

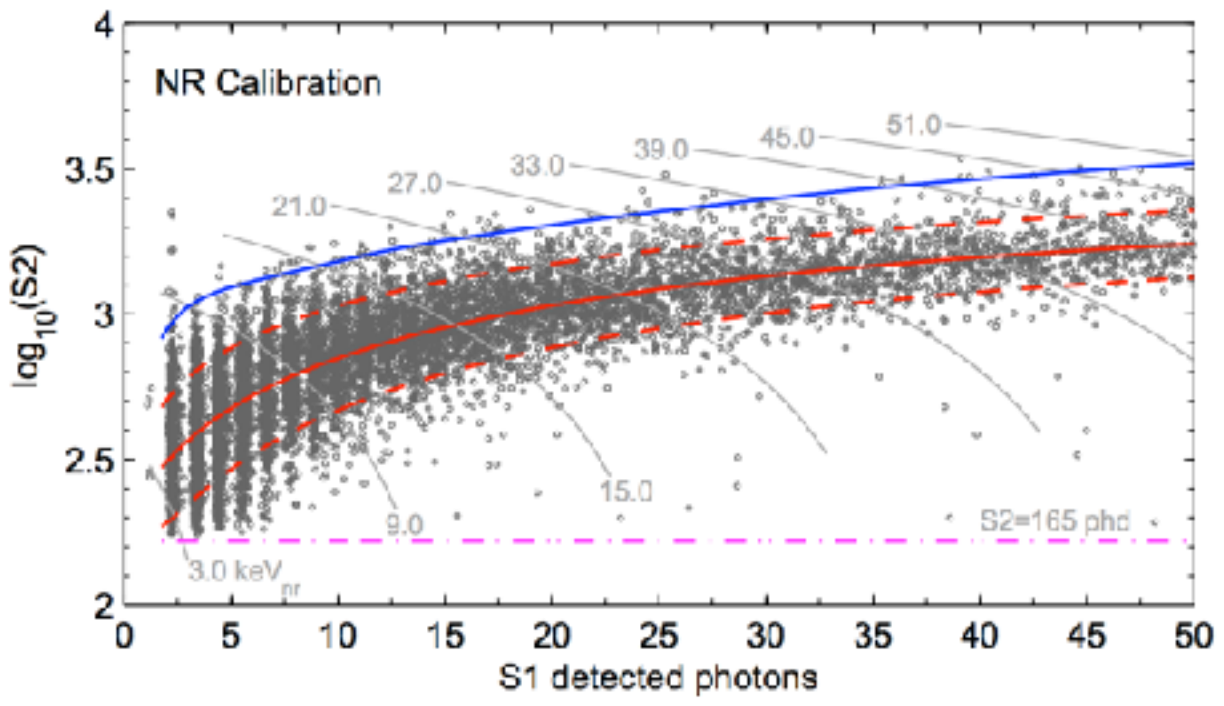
Dr. Sally Shaw - sally@physics.ucsb.edu

DMUK 2022

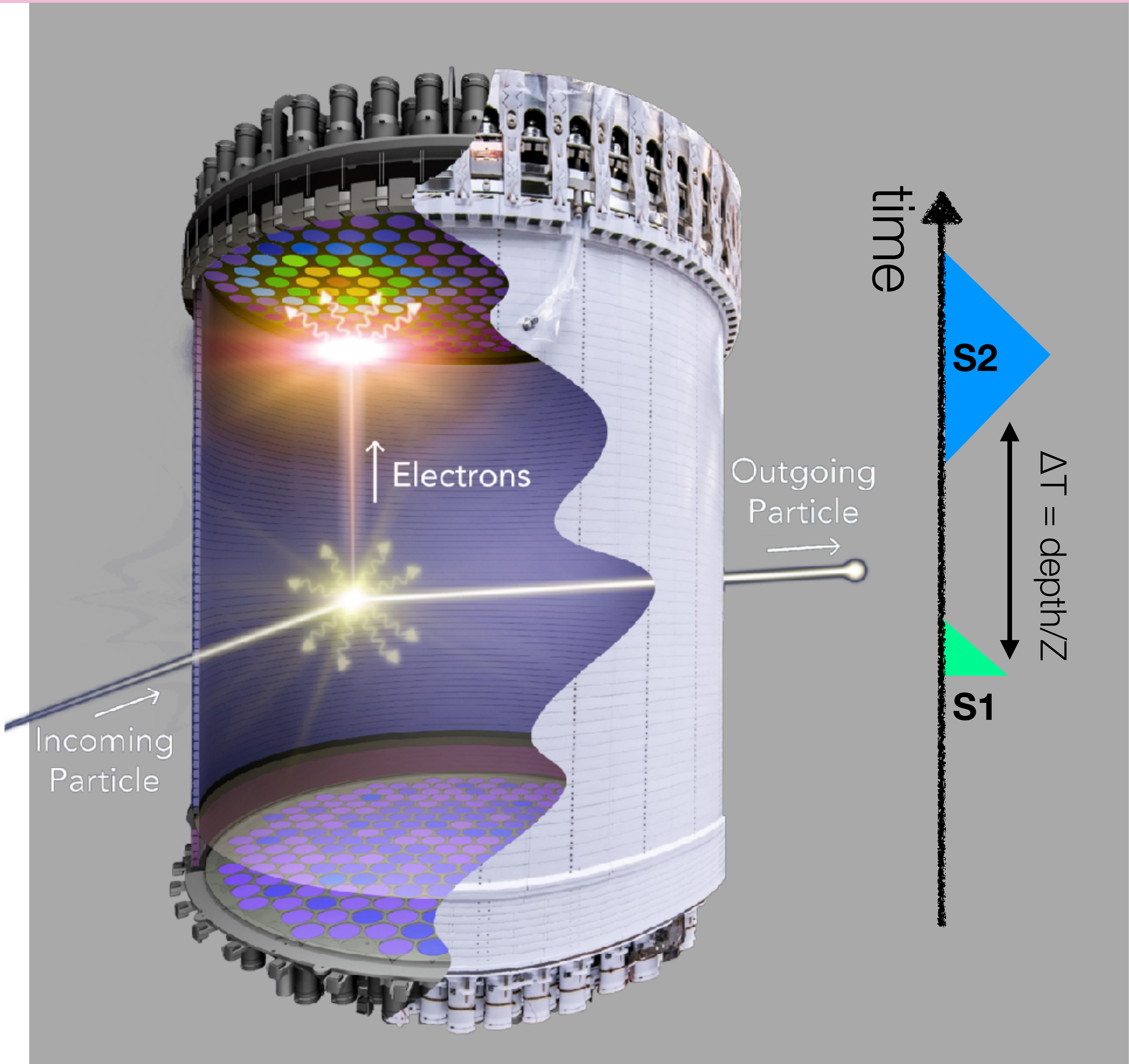
Direct Detection with Dual-Phase LXe TPCs

- Primary signal is **nuclear recoil** of a xenon atom. Most backgrounds are electron recoils.
- Two signals: scintillation (S1) in LXe and ionisation (S2) in GXe
  - ER/NR **discrimination** from ratio of S1 and S2 signals





  - 3D position reconstruction - XY from PMT array, Z from Δt between S1 and S2



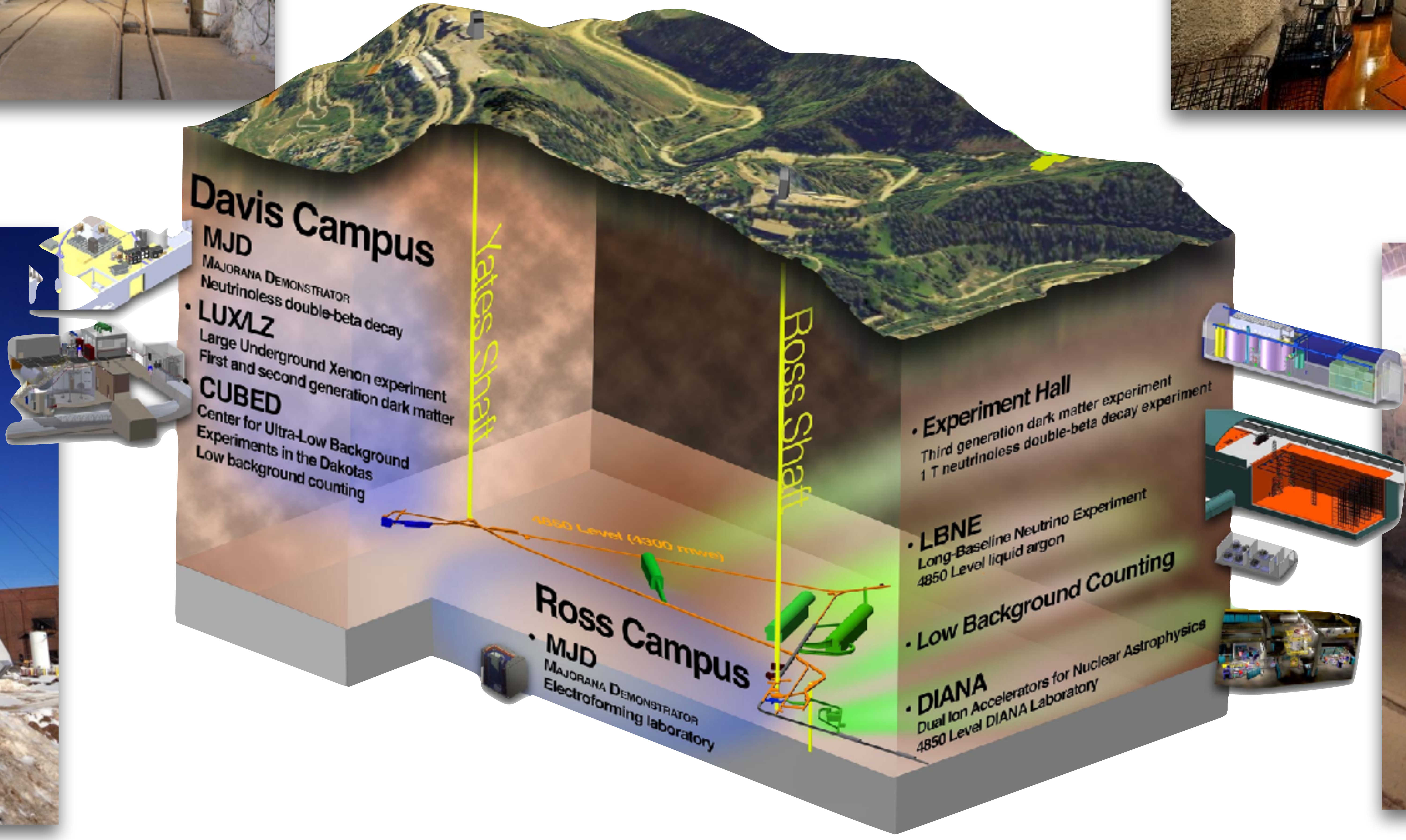
The LZ Collaboration

35 institutions across the US, UK, Portugal and South Korea

250 scientists, engineers, and technicians

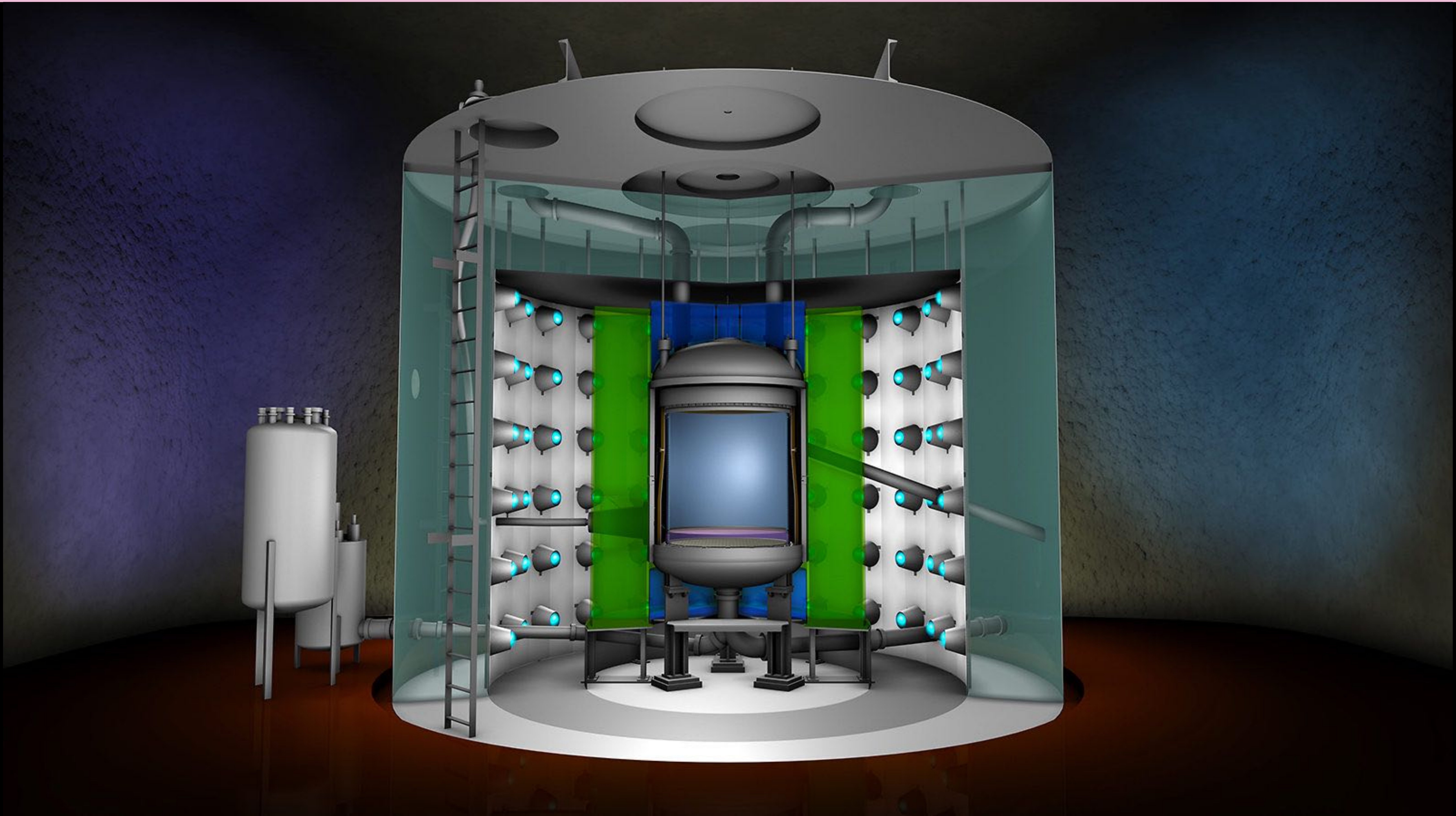
The Sanford Underground Research Facility

Sanford
Underground Research Facility

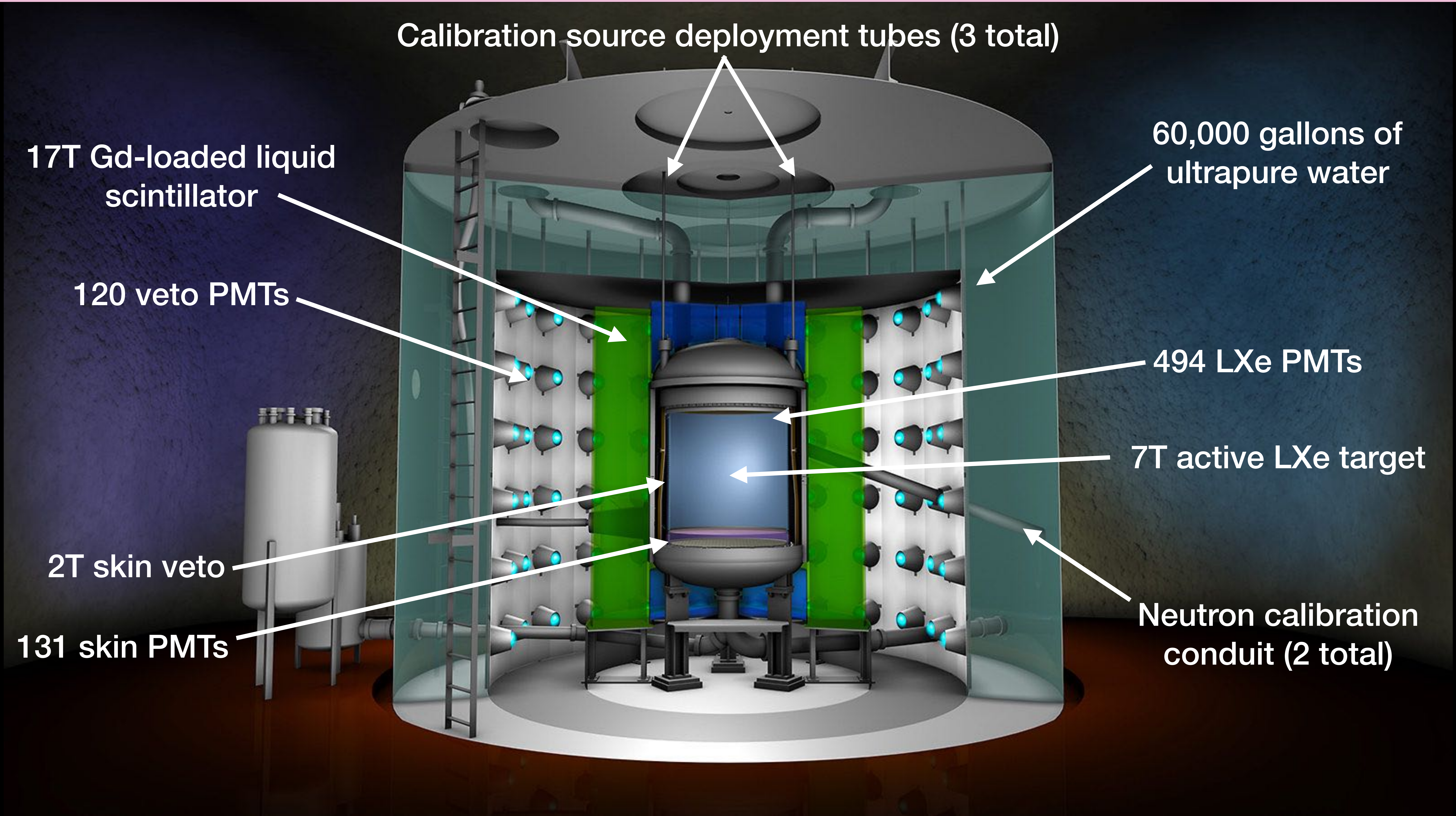


The LZ Detector

The LZ Detector



The LZ Detector



LZ Scale Up

LUX Outer Cryostat

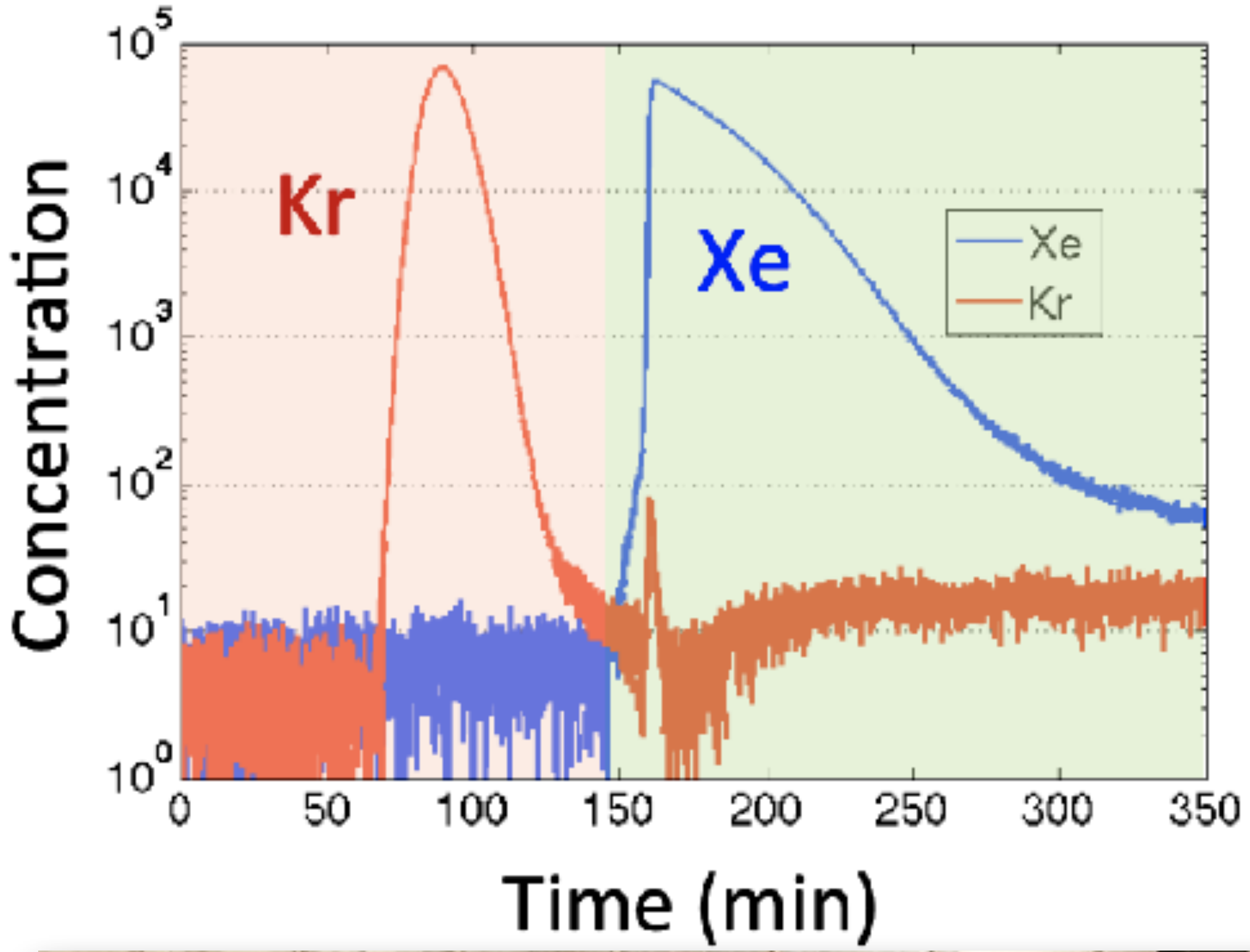
LZ Outer Cryostat

LZ Acrylic Vessel

Xenon

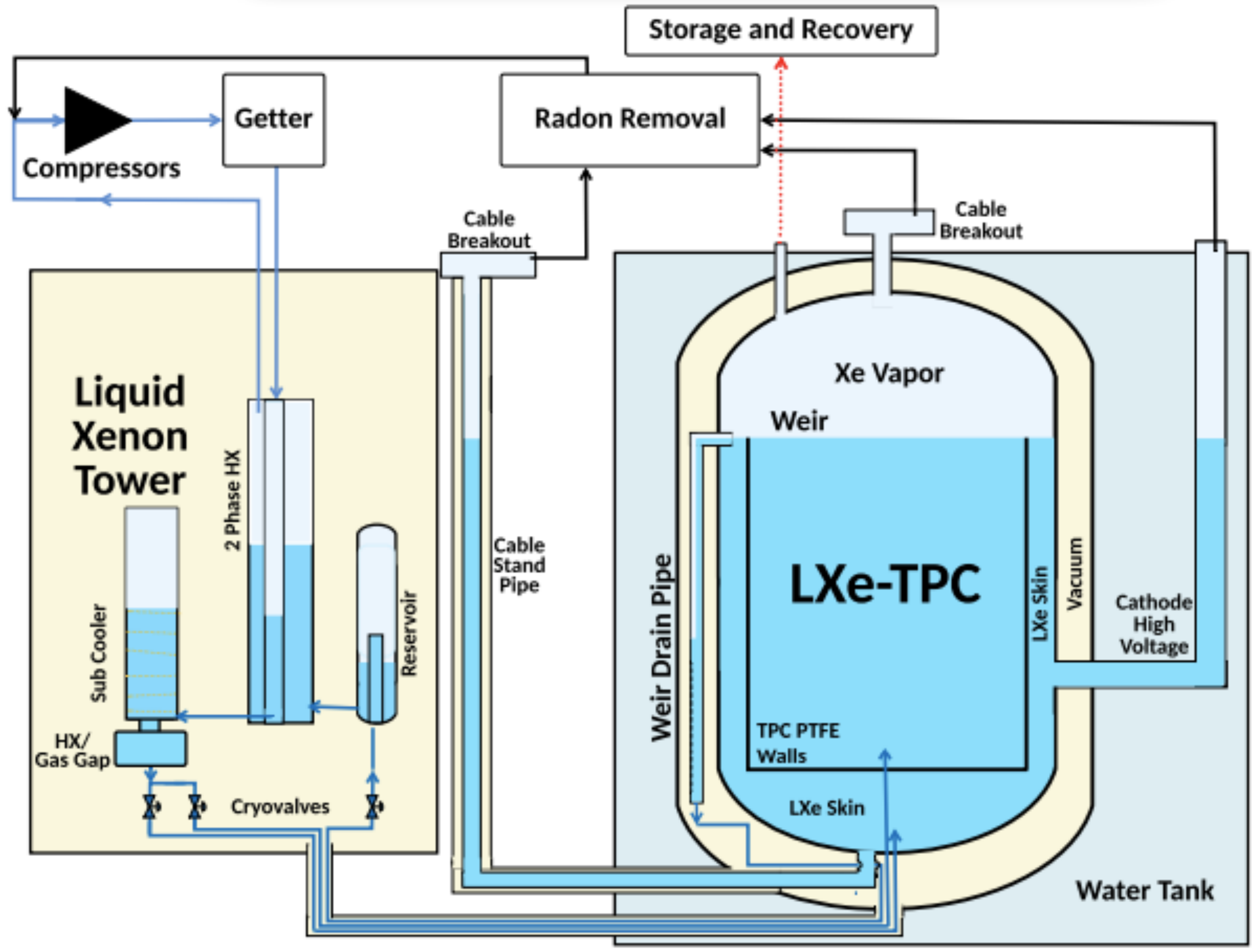
10T total Xenon, undergoes:

- Krypton removal at SLAC
  - **Gas charcoal chromatography**
  - Goal: 0.1 ppt $^{nat}Kr/Xe$
  - Achieved: 0.11 ppq
- Online purification of GXe
  - **Hot zirconium getter** removes electronegative impurities
  - Full 10T purified every 2.4 days
- Radon removal
  - Inline radon removal system uses **activated carbon trap**, 10x reduction of radon in 1 pass
- Electron lifetime
  - Goal: 1 ms
  - Achieved >5 ms



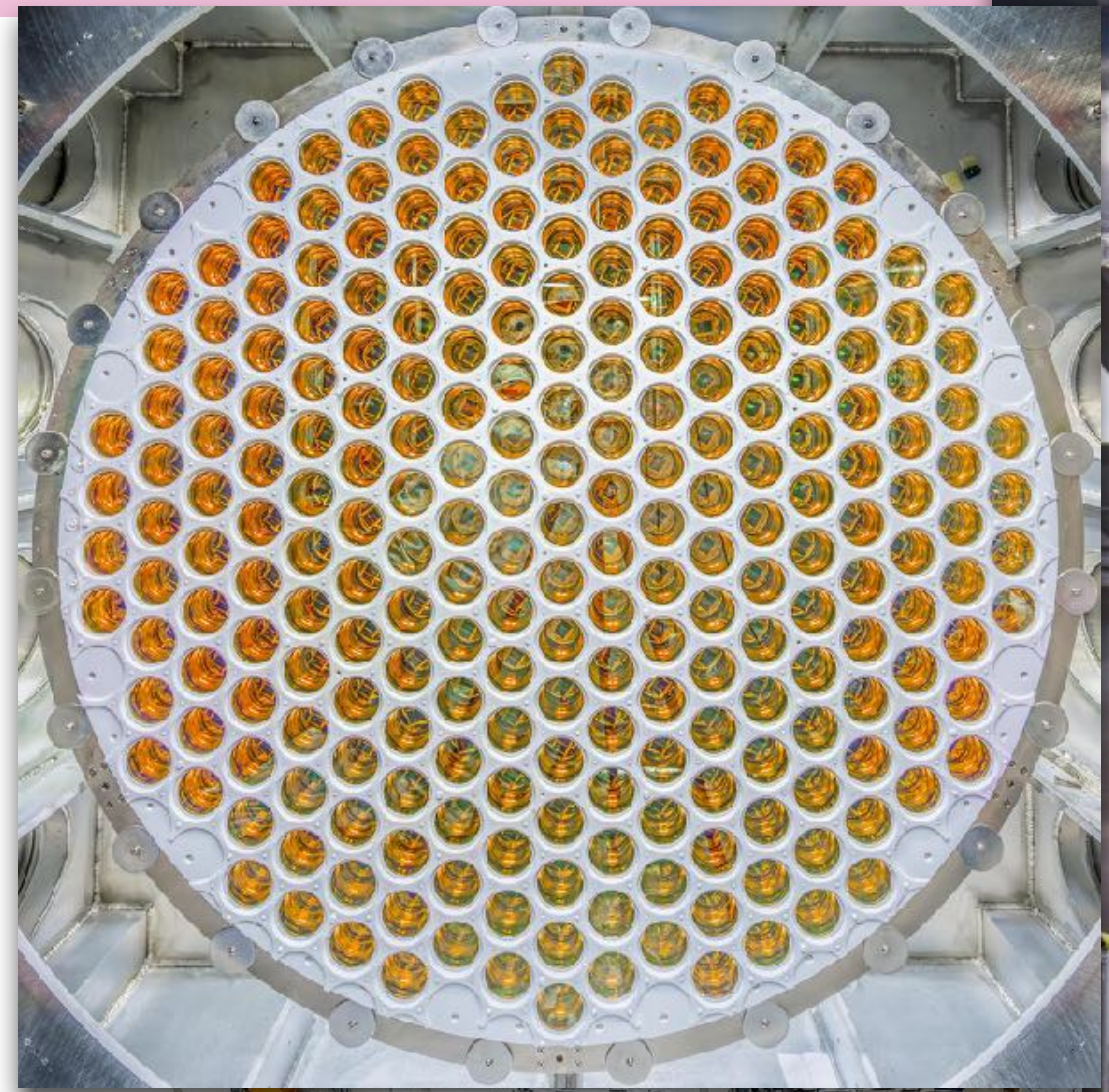
Krypton removal system at SLAC

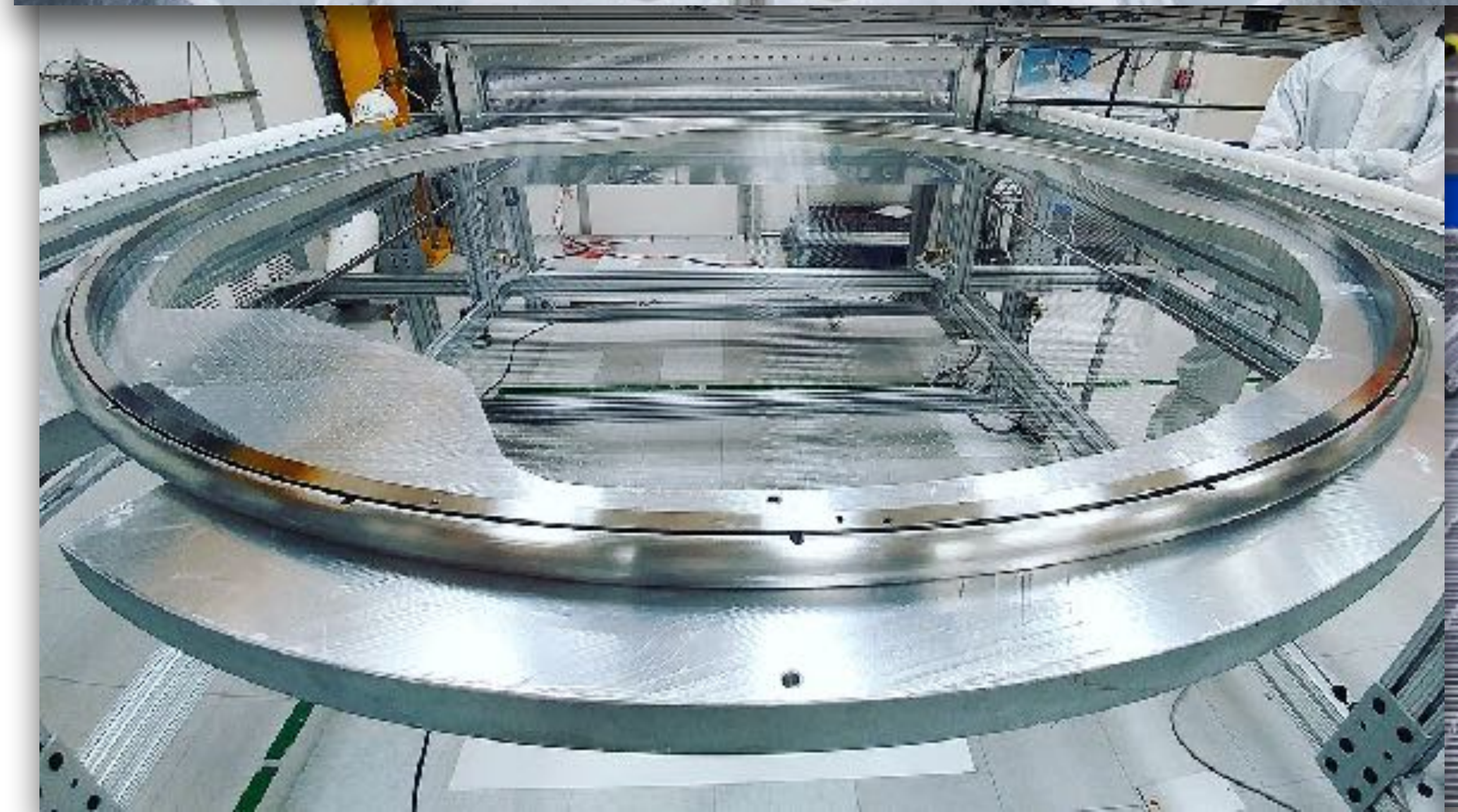
Radon reduction system at SURF

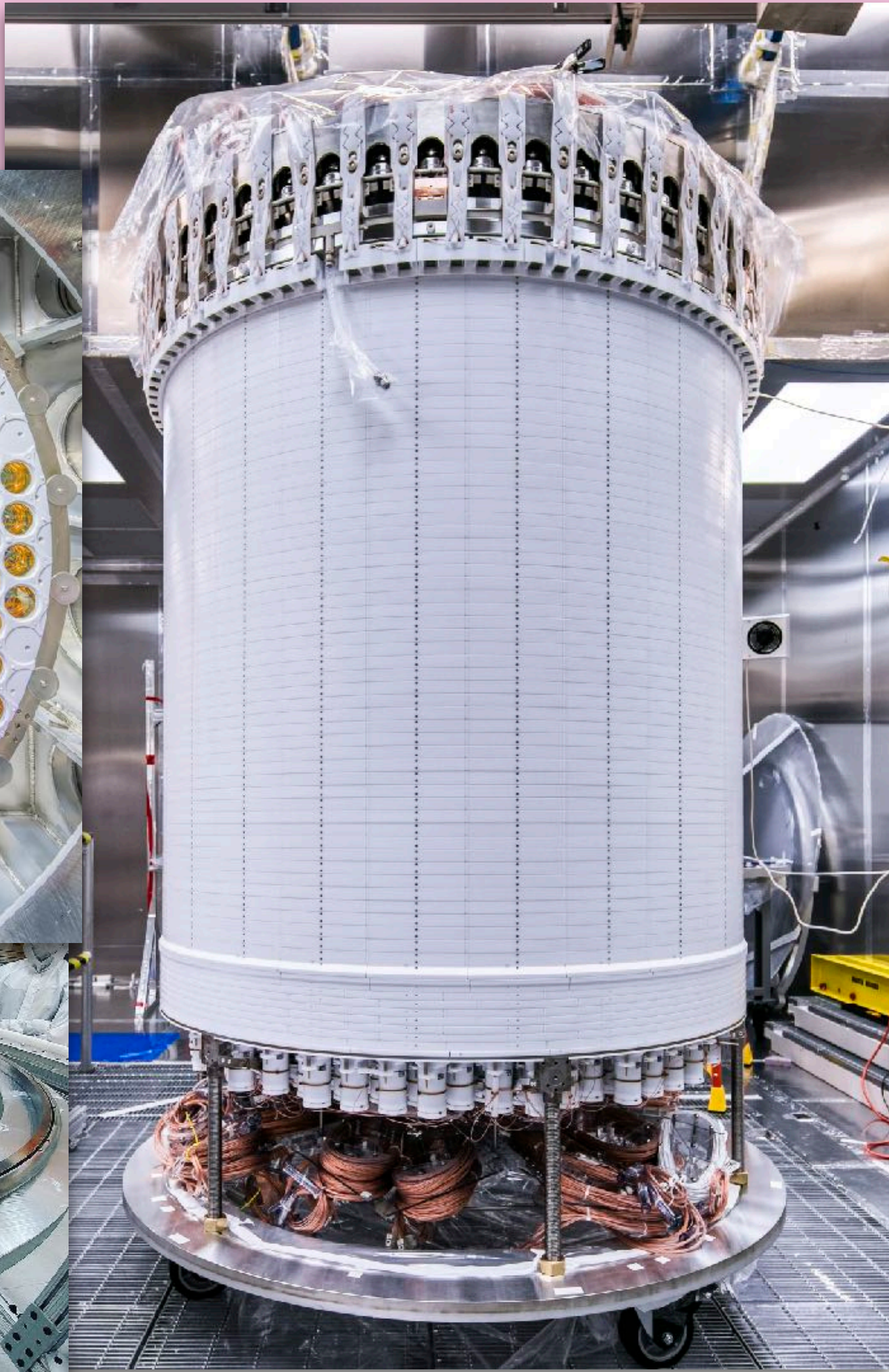


Time Projection Chamber

- 2 PMT arrays of Hamamatsu R11410-22 PMTs (494 total)
- 4 electrodes/grids woven on specialized looms and **passivated** to reduce e-emission*
- 57 field rings embedded in reflective PTFE → **190 V/cm drift field**
- TPC completed August 2019
- Inserted into ICV at surface assembly lab

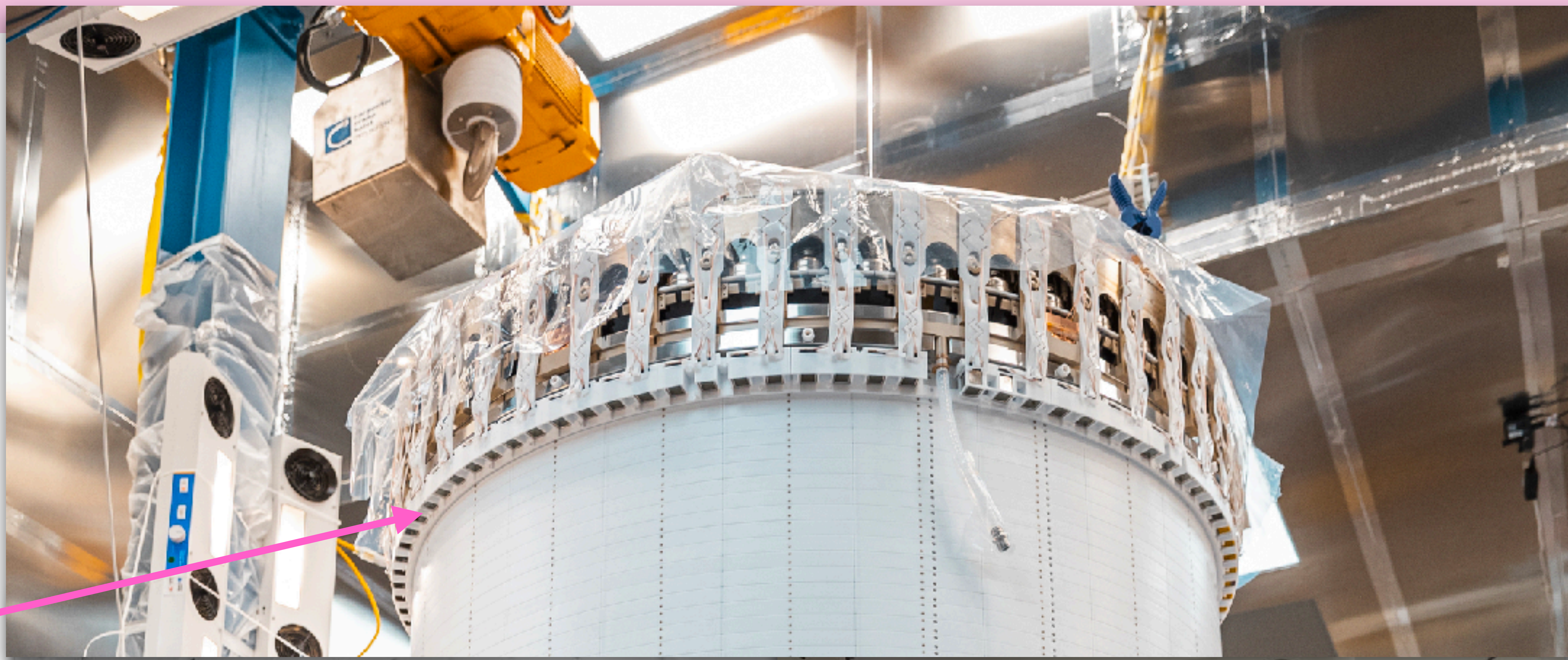


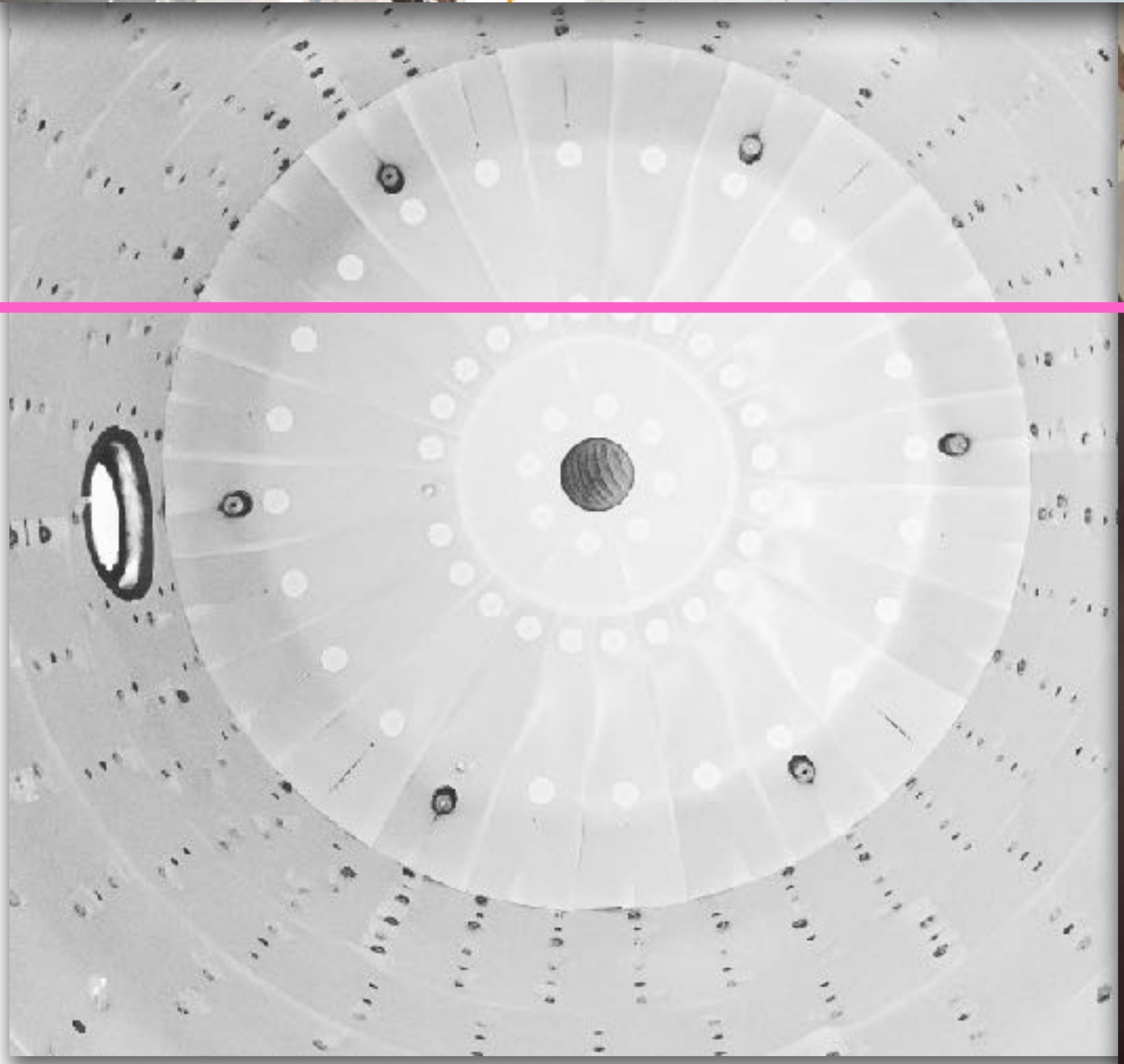




Liquid Xenon Skin Detector

- 2T of active xenon between the ICV and the TPC field cage
  - Optically isolated from TPC
  - 93 1” R8520 PMTs in ice cube trays at the top
  - 20 side + 18 dome 2” R11410 PMTs at the bottom
- Expected to be **>95% efficient** at tagging γ-rays





Titanium Vessels

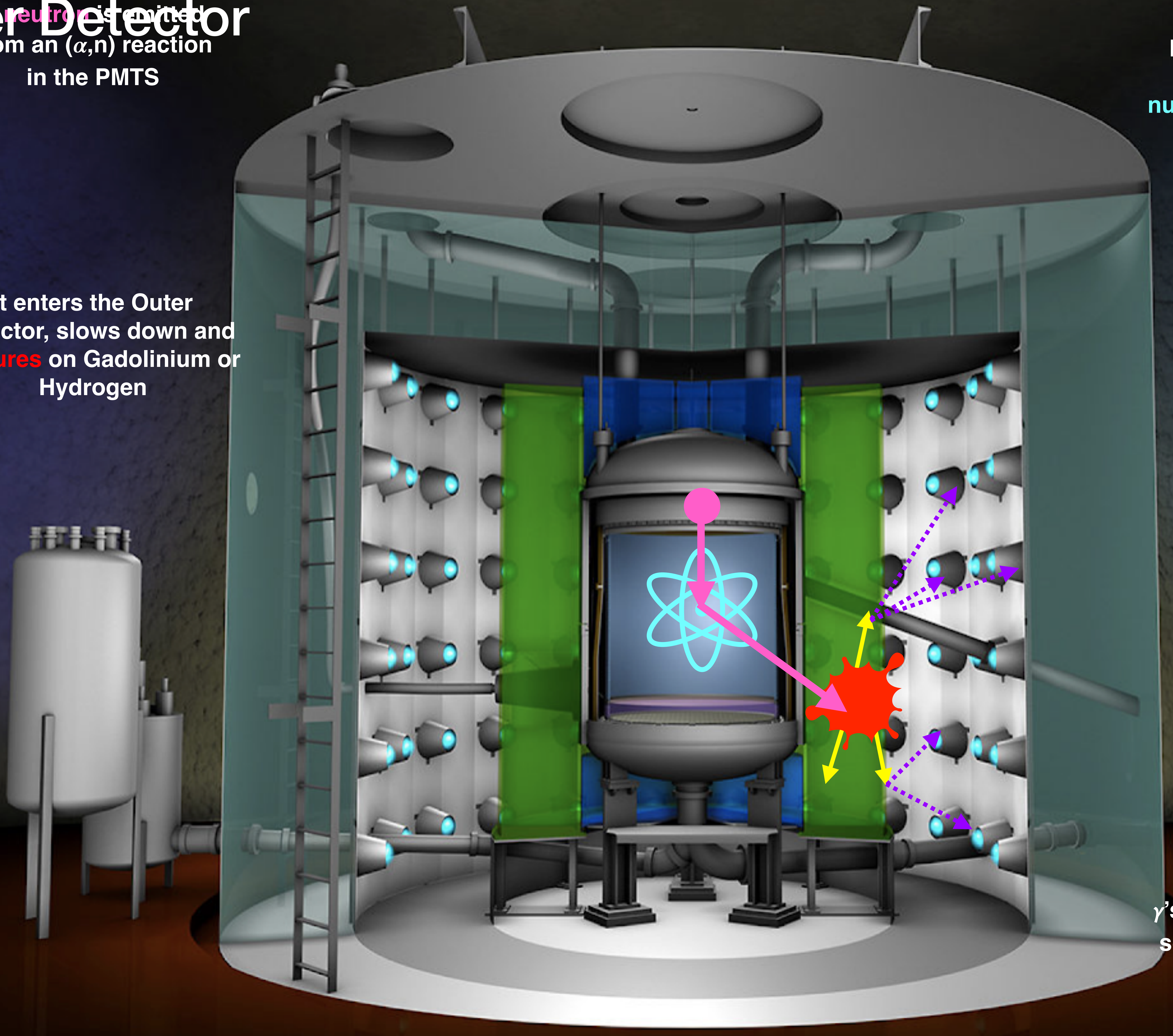
ICV at the Surface Assembly Lab

ICV being lowered into OCV

ICV and OCV in place in water tank

Inner vessel installed in the water tank December 2019

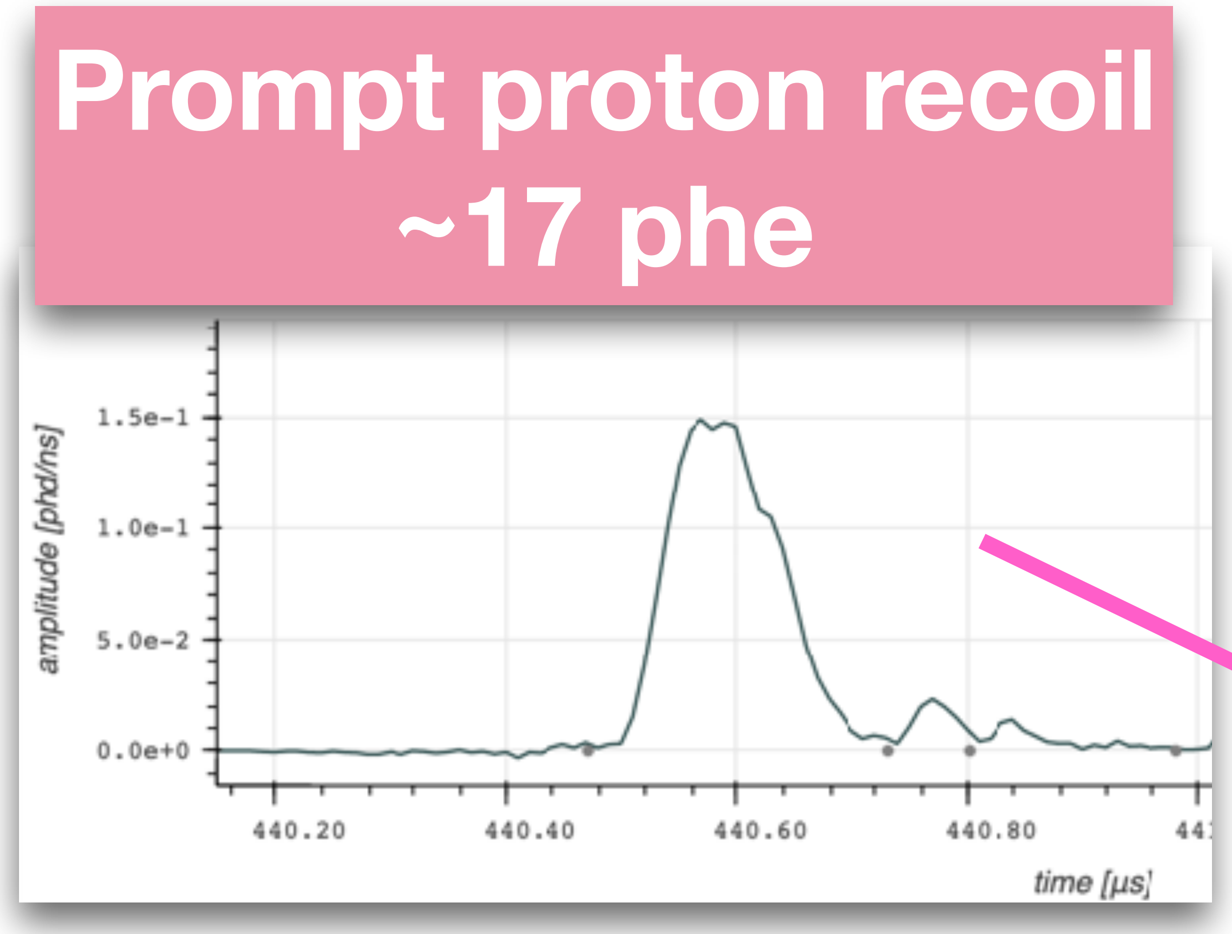
The LZ Outer Detector

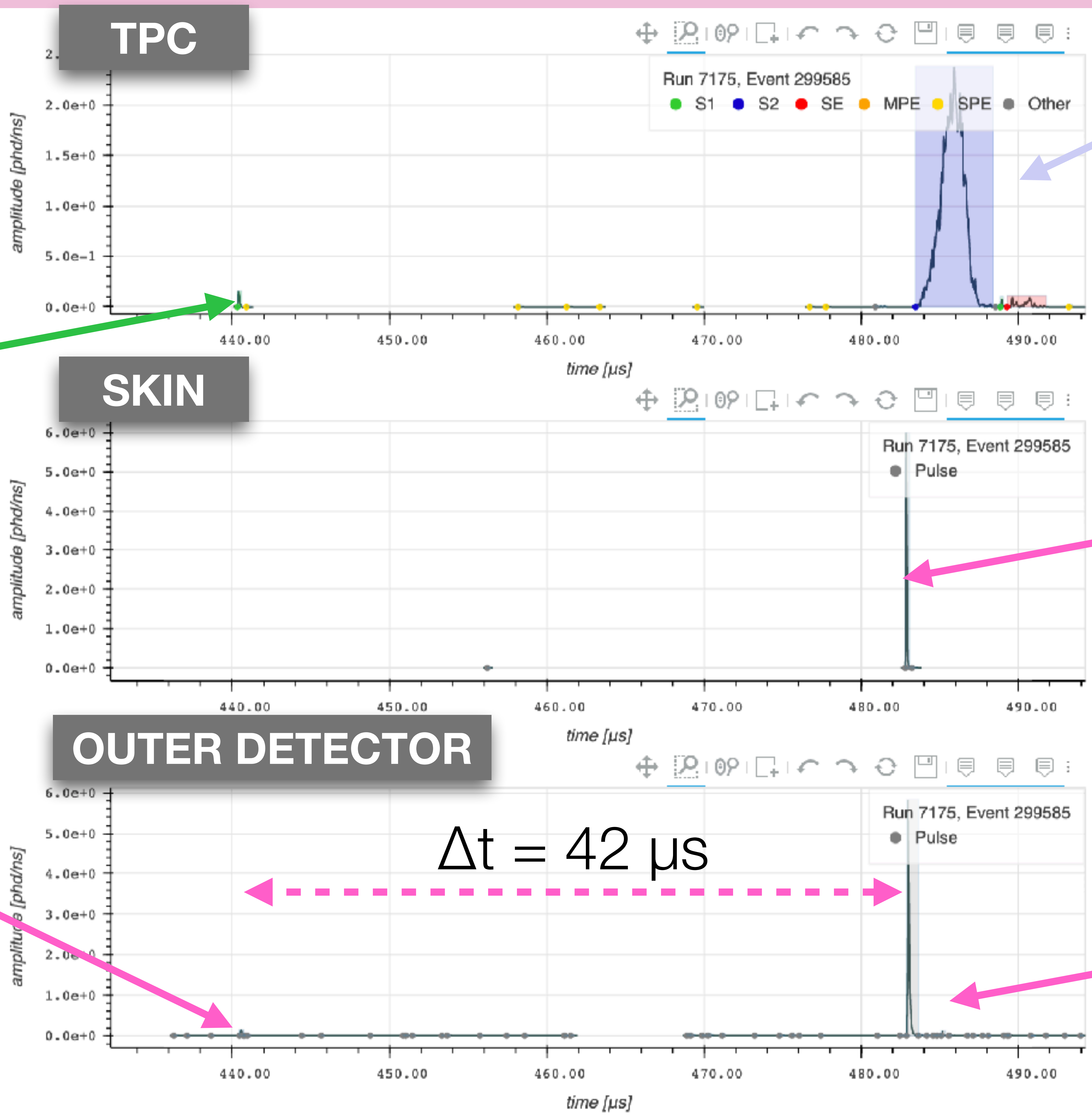


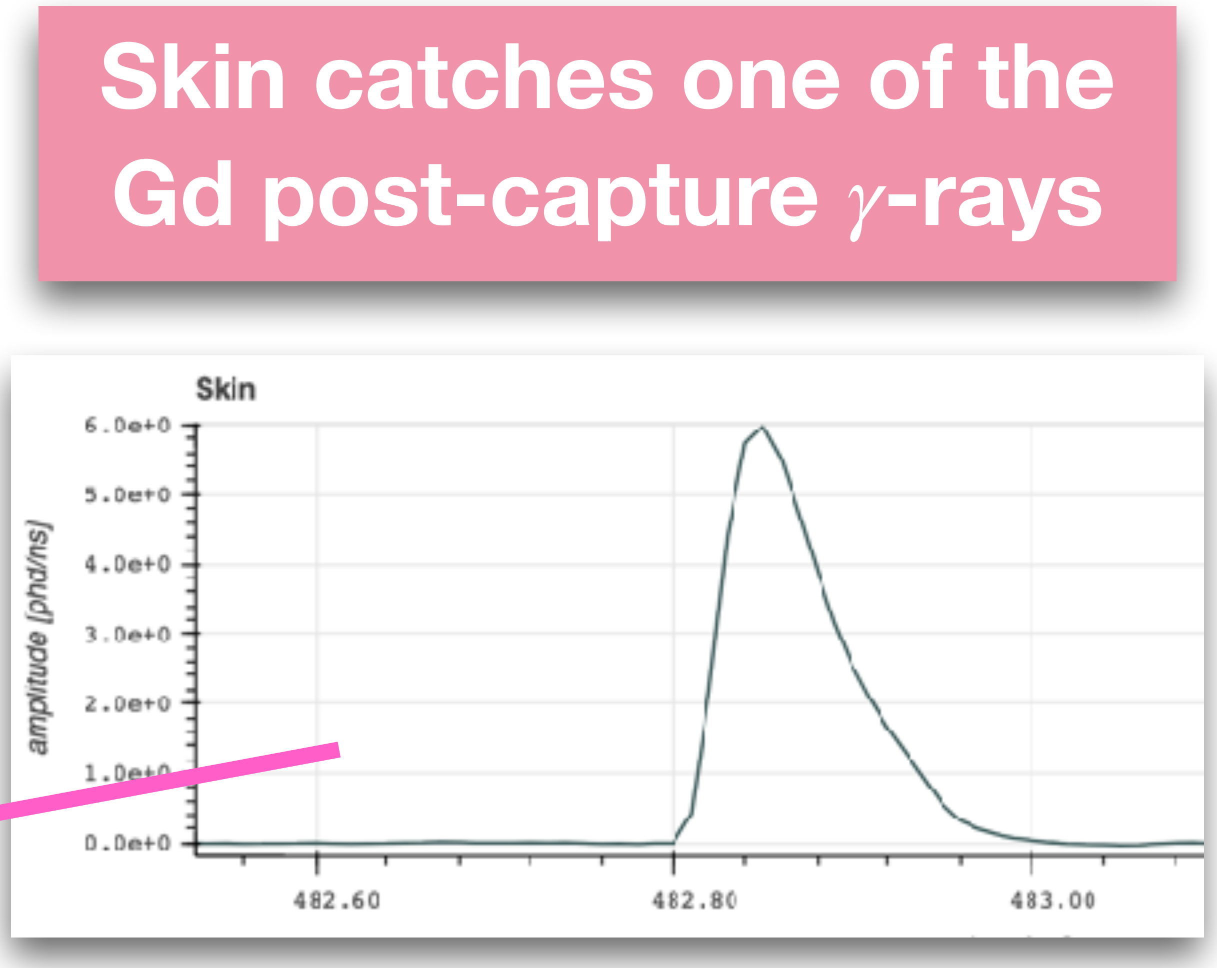
Three Detector System

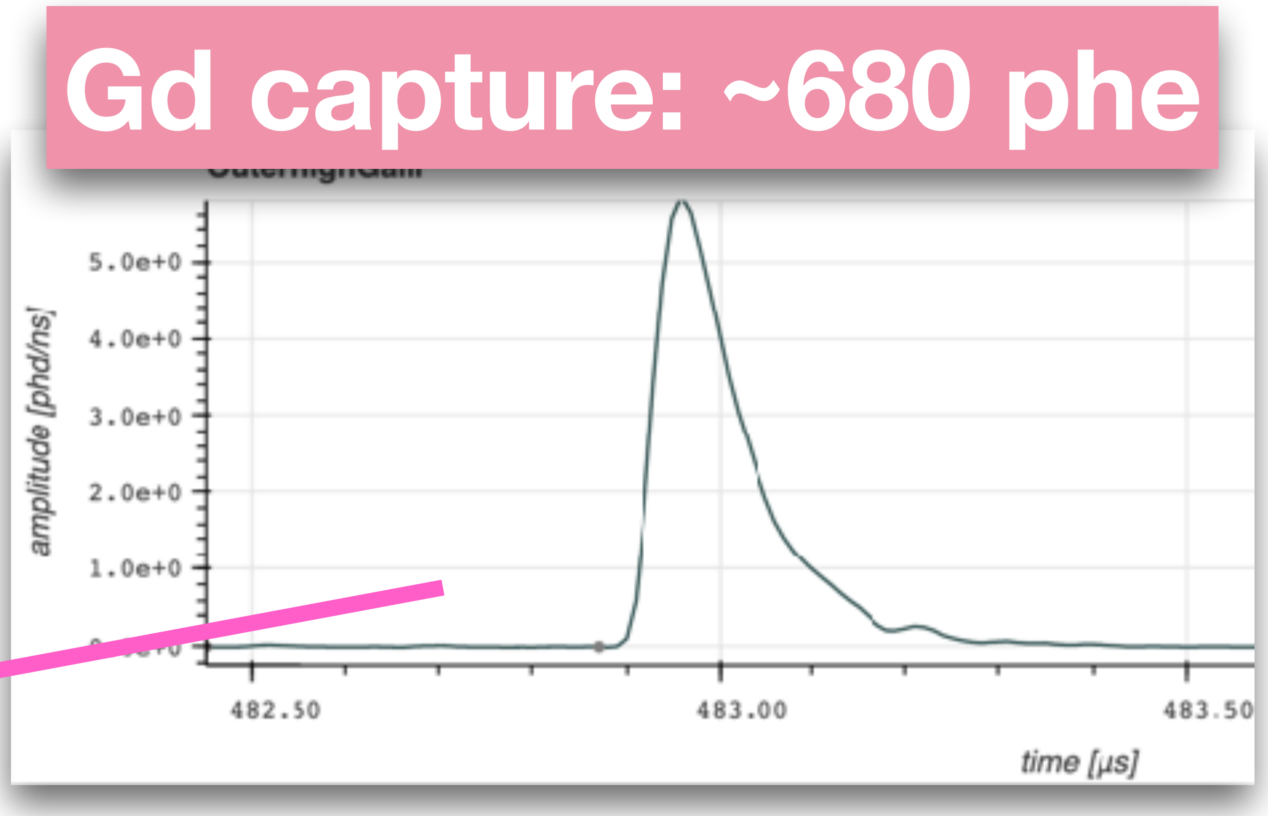
~30 keV$_{nr}$ nuclear recoil
Single scatter in TPC
Tagged by the OD

(From DD calibration data)

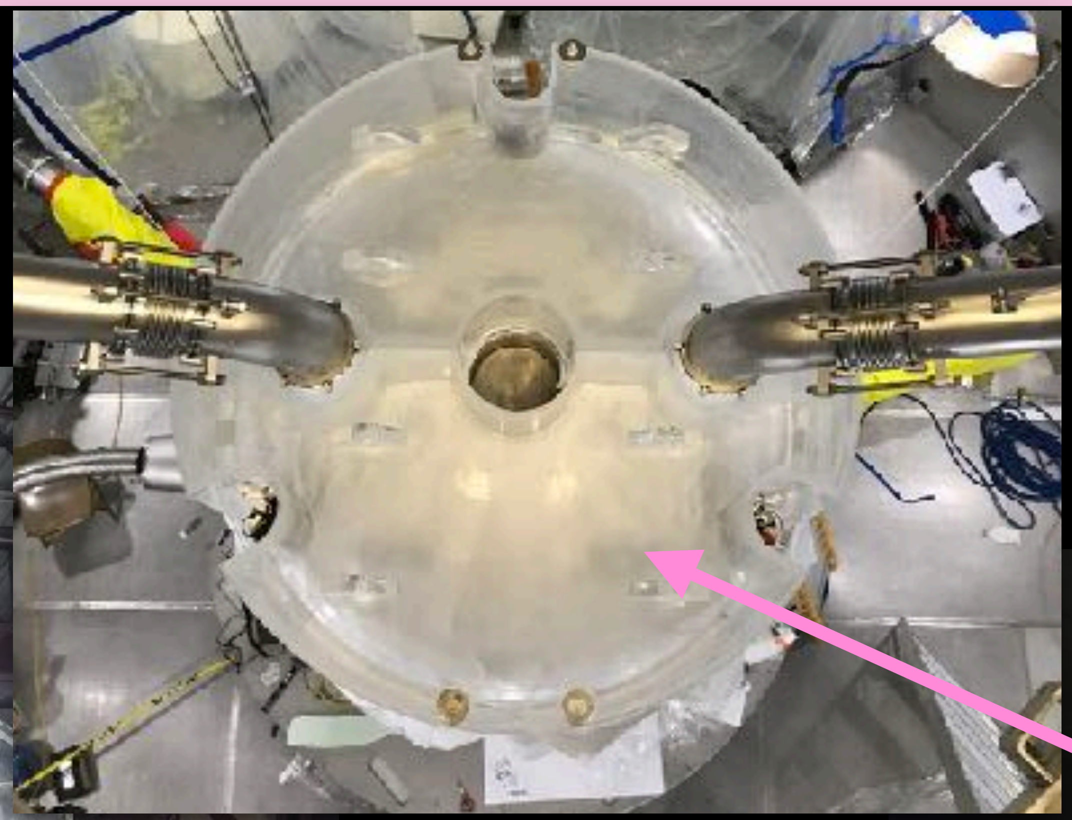


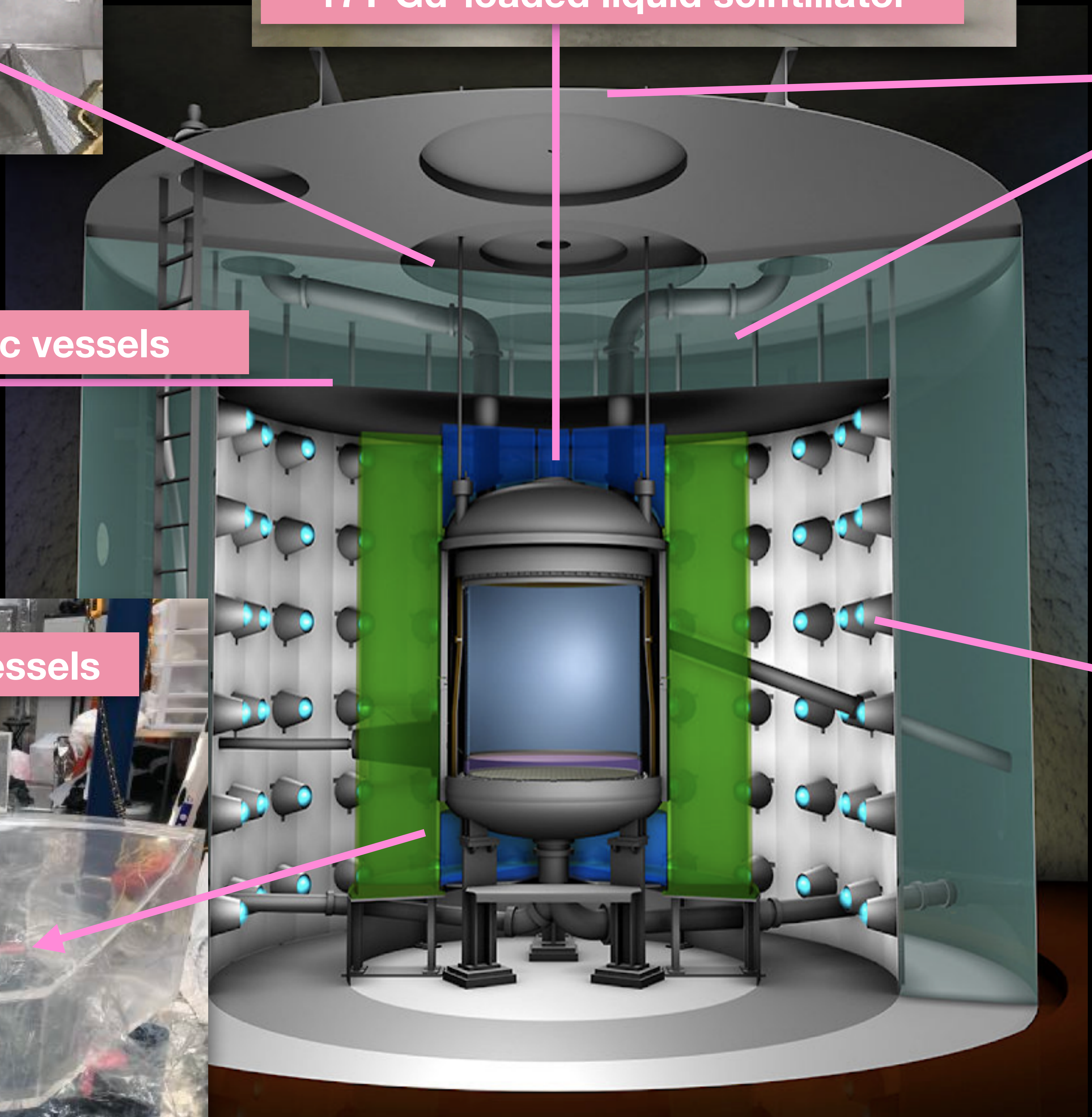






Outer Detector





Outer Detector Installation

Side vessel lowering into water tank

Post-acrylic cleaning yoga

PMT and tyvek installation

All acrylic vessels in place!

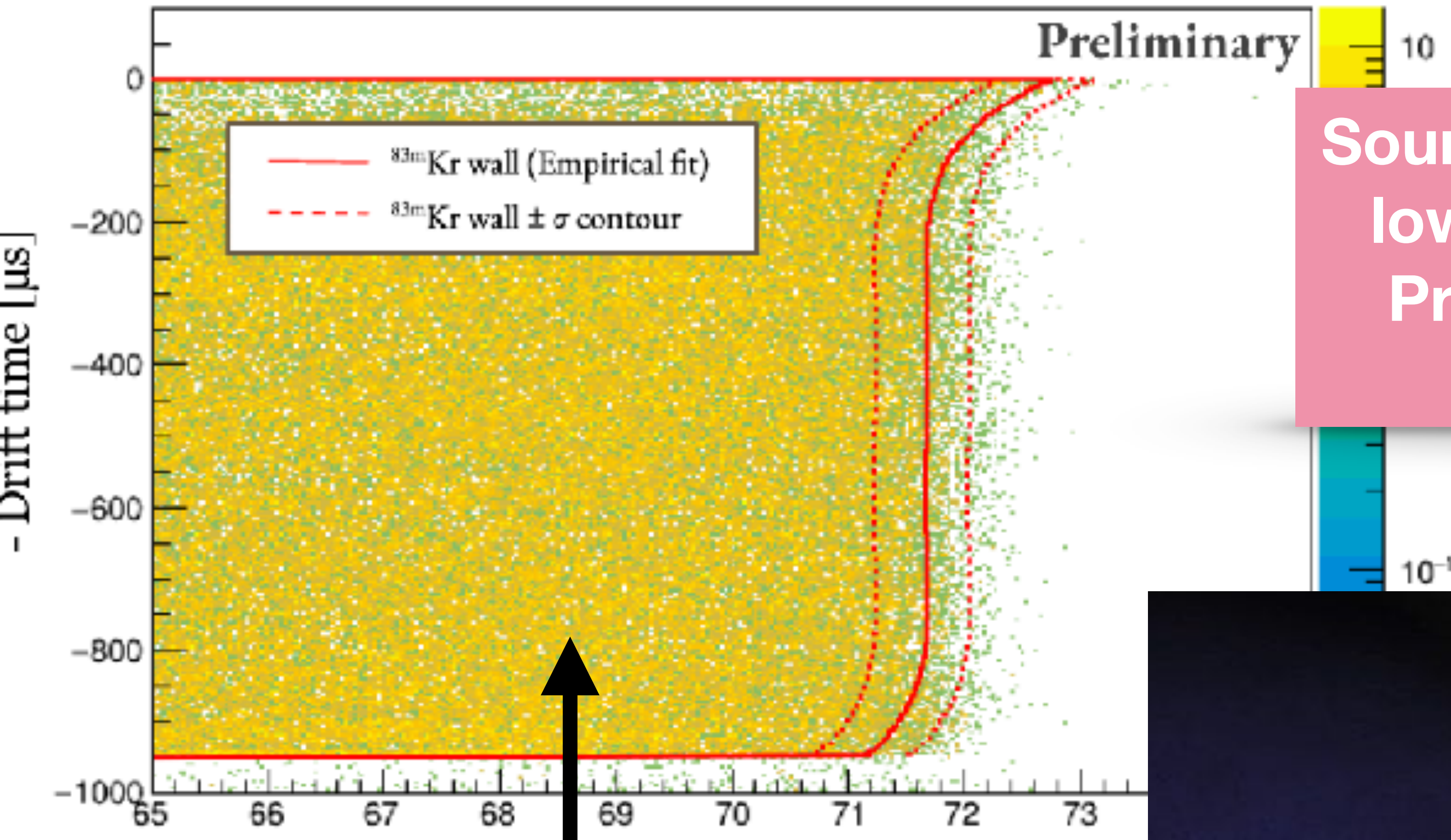
Top tank fill system installation

OD construction completed spring 2021

Calibration of LZ

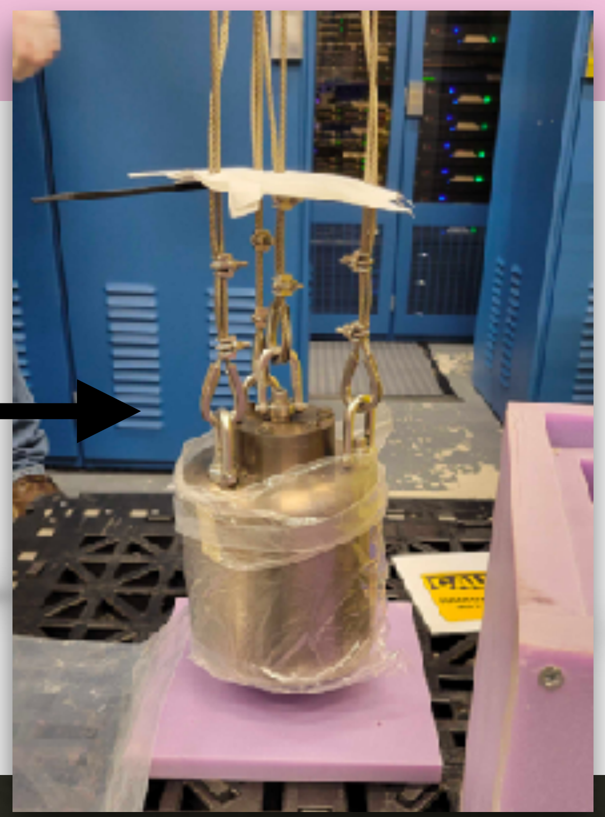
Dr. Sally Shaw - sally@physics.ucsb.edu

Calibration Systems

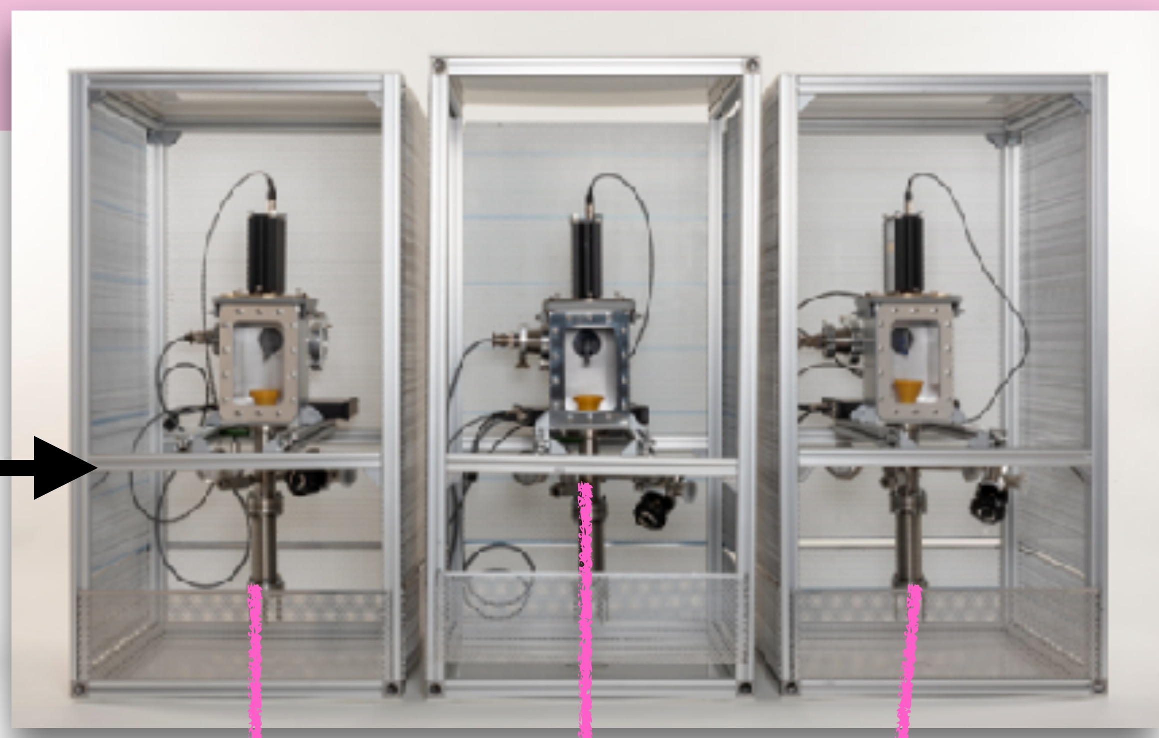


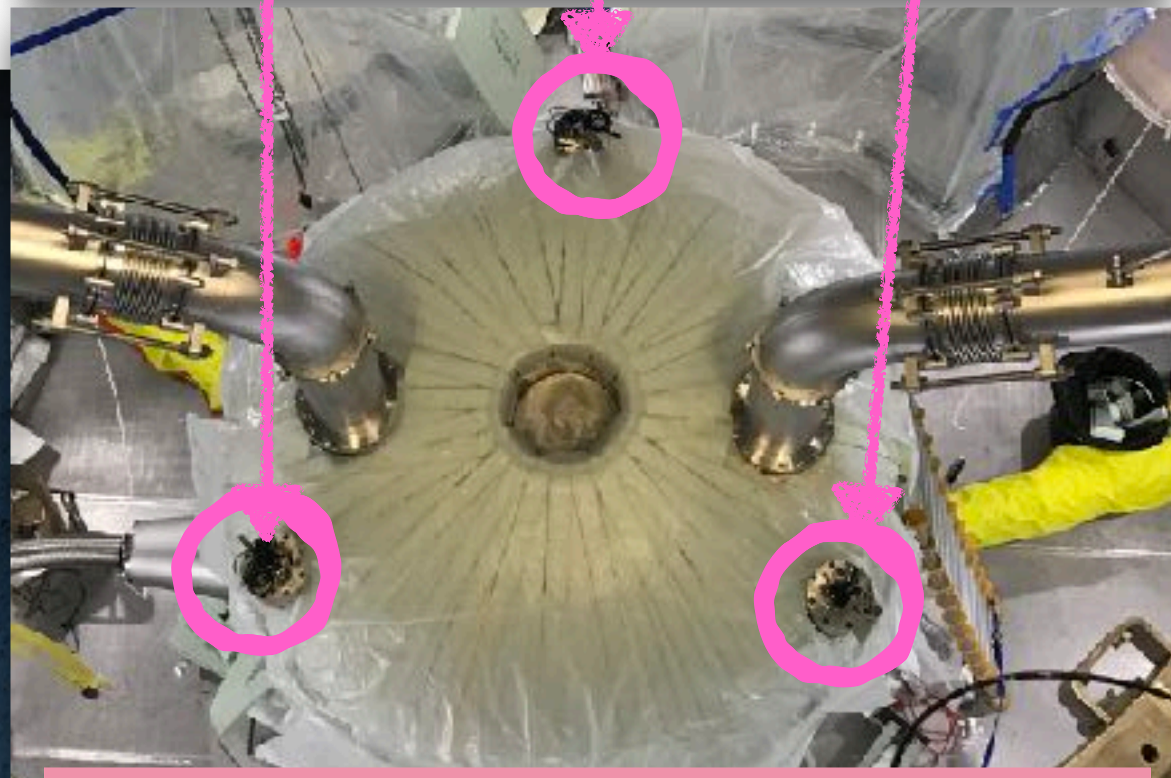
^{83m}Kr injection data used to determine position of wall

Source in tungsten shield lowered to top of OCV
Produces low energy neutrons

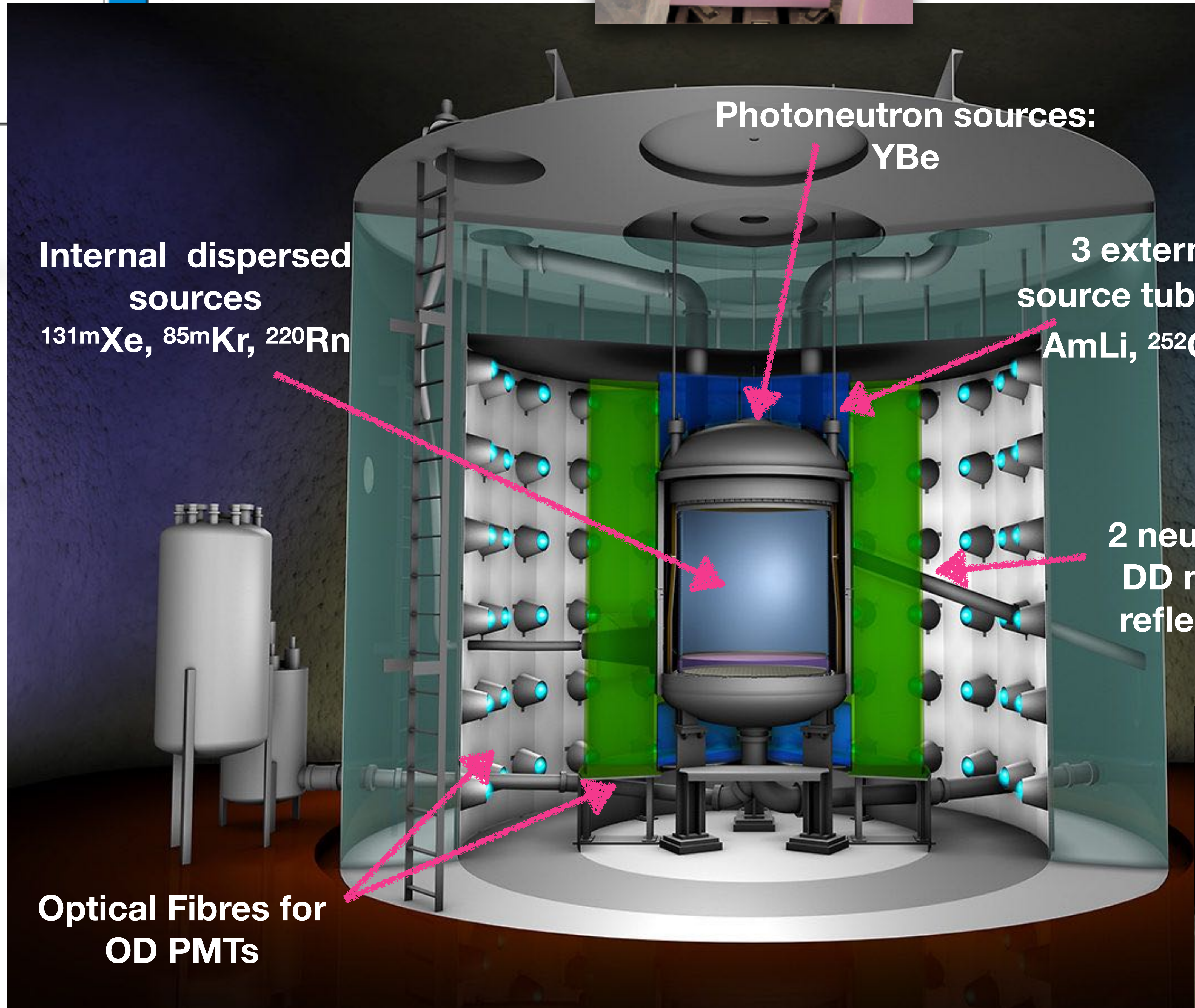


γ sources loaded in on upper deck and lowered to specified Z via computer-controlled motors





3 source tubes enter here and sit in vacuum space between Outer and Inner Vessels



Photoneutron sources: YBe

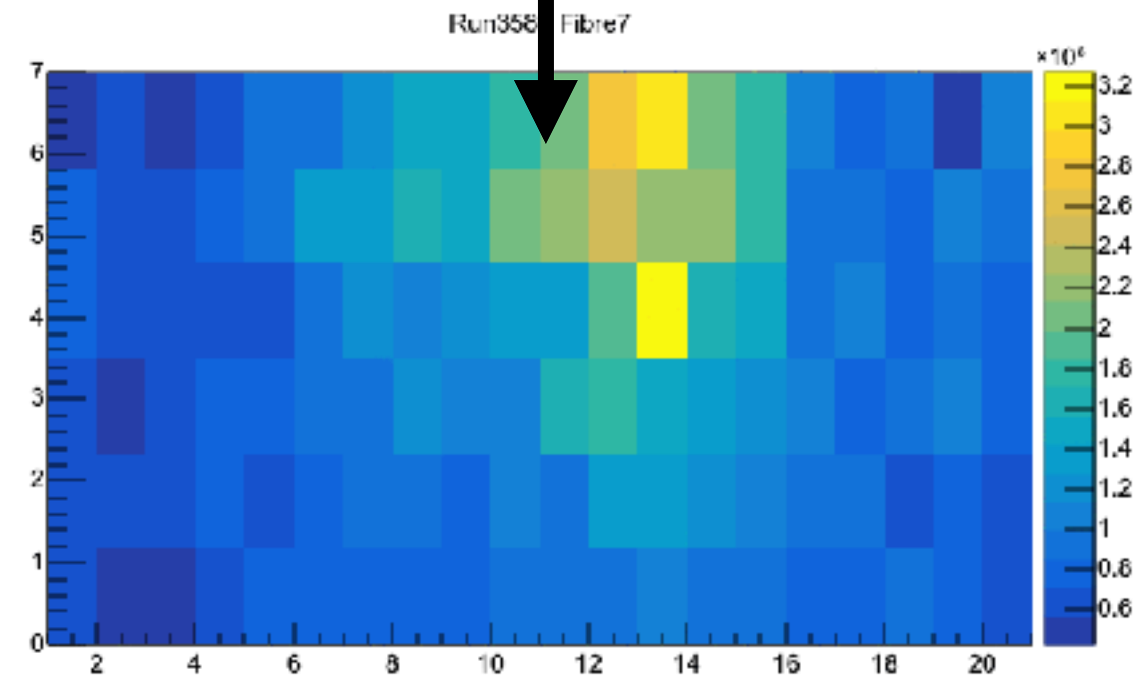
Internal dispersed sources
^{131m}Xe, ^{85m}Kr, ^{220}Rn

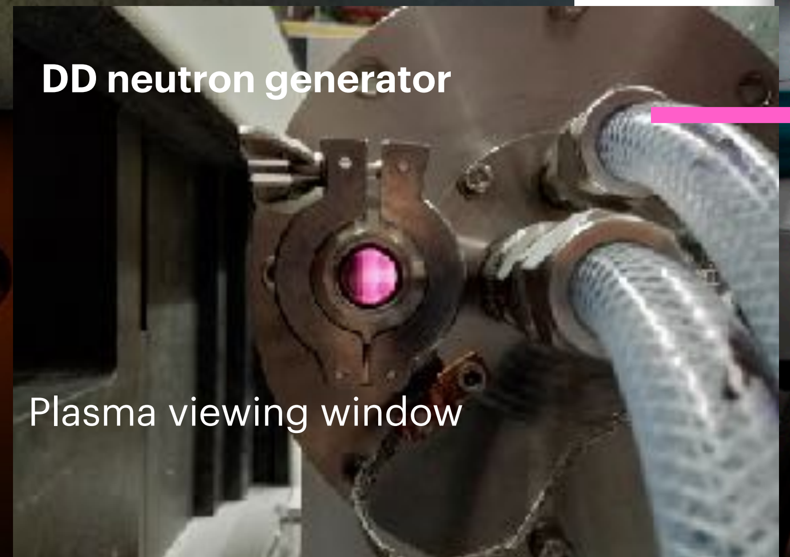
3 external calibration source tubes - neutrons & γ
AmLi, ^{252}Cf, ^{22}Na, ^{228}Th…

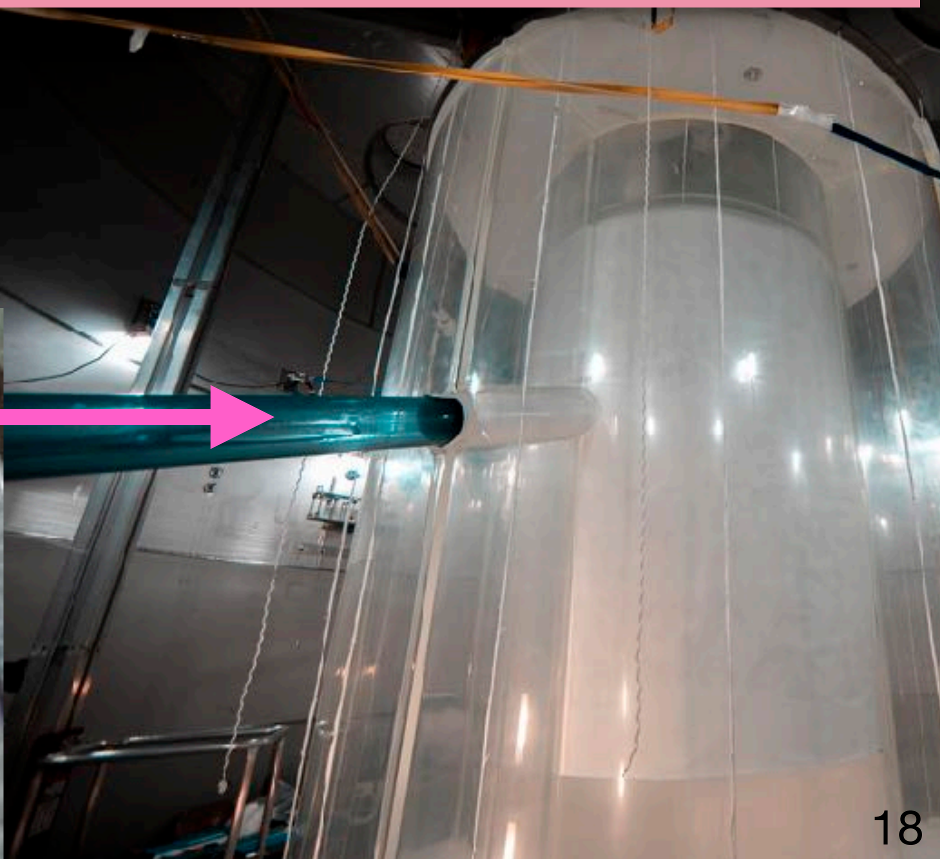
2 neutron conduits: DD neutrons, D_2O reflector neutrons

Optical Fibres for OD PMTs

OD Optical Calibration System Injection



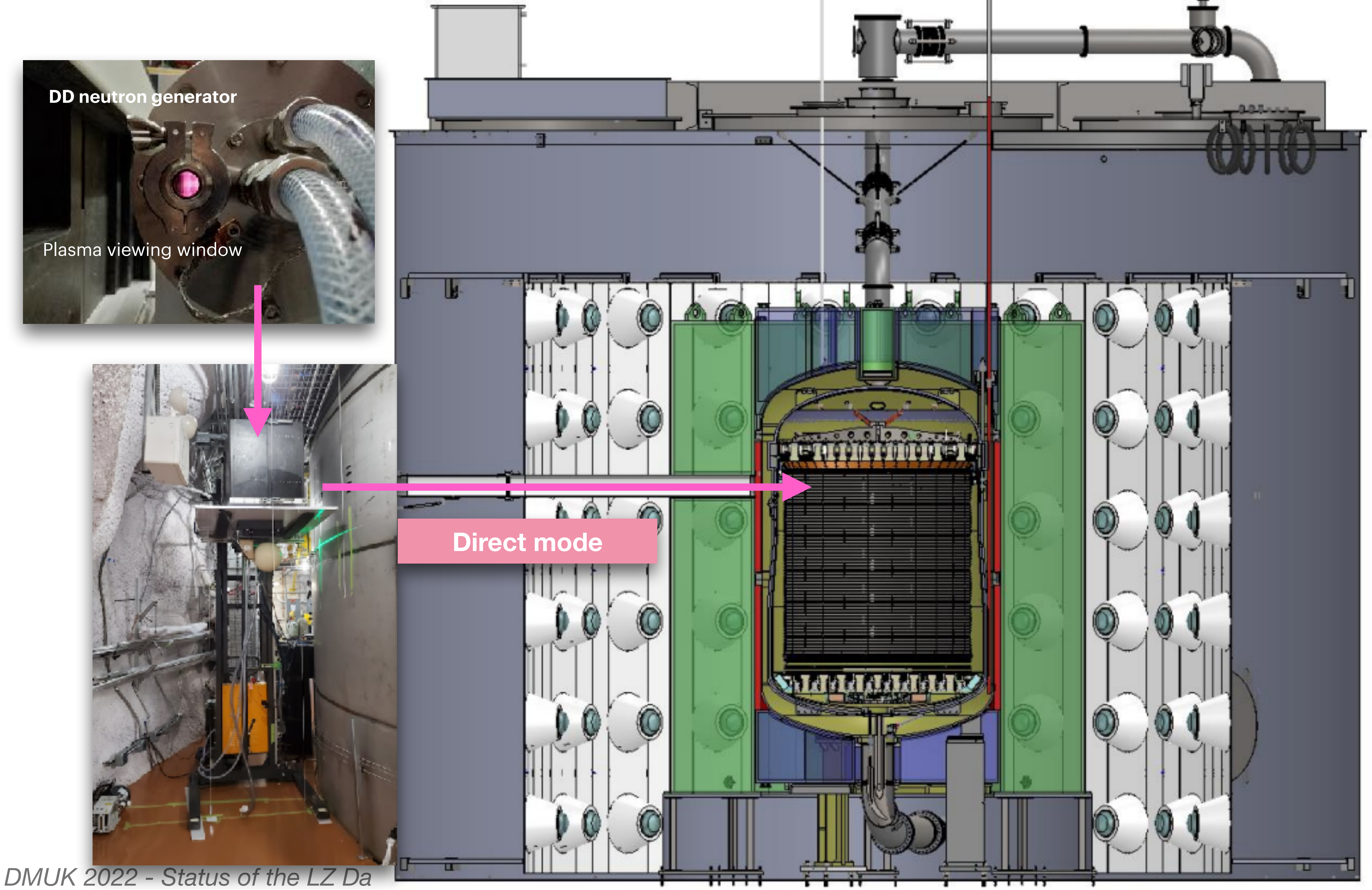


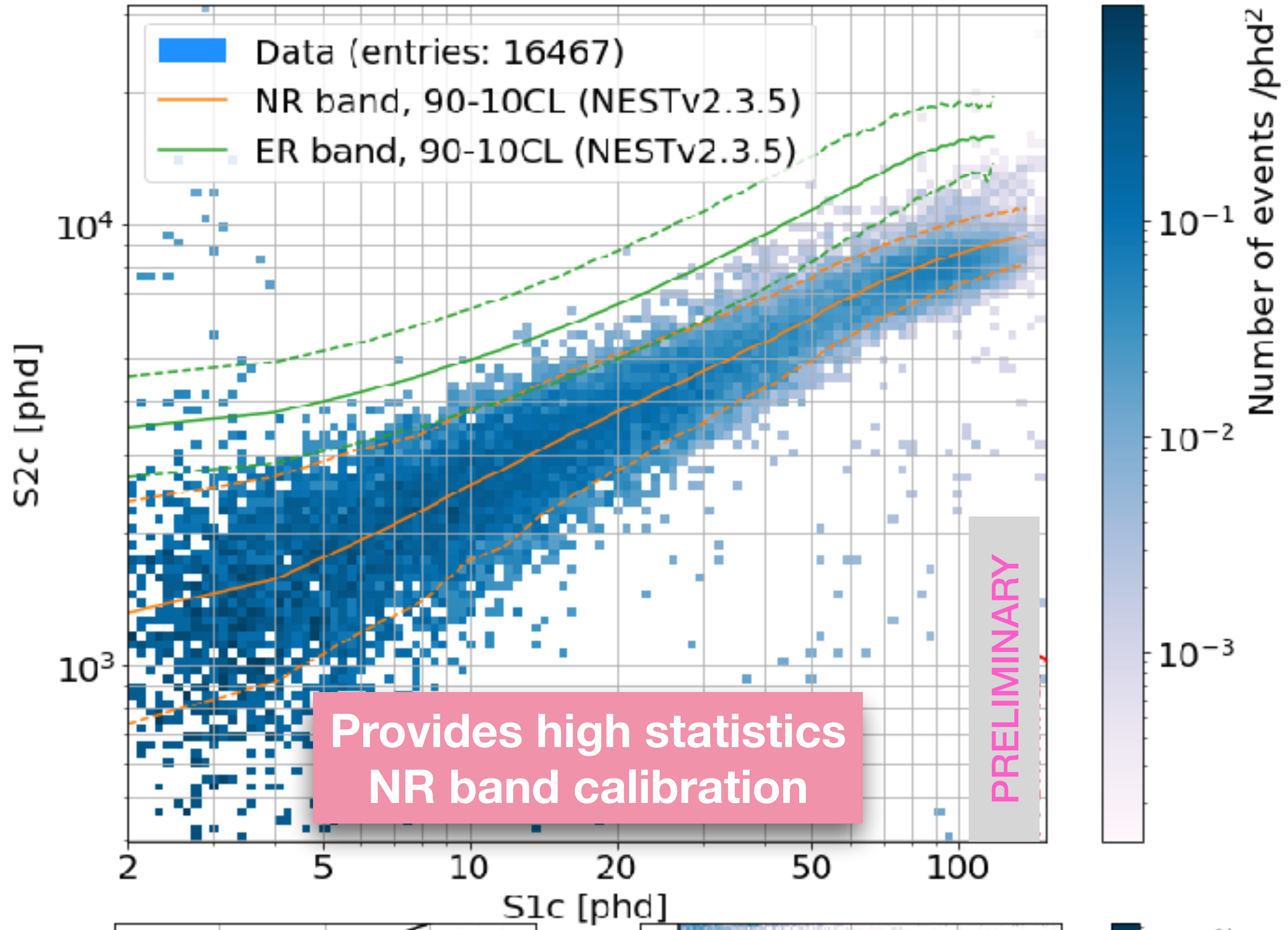


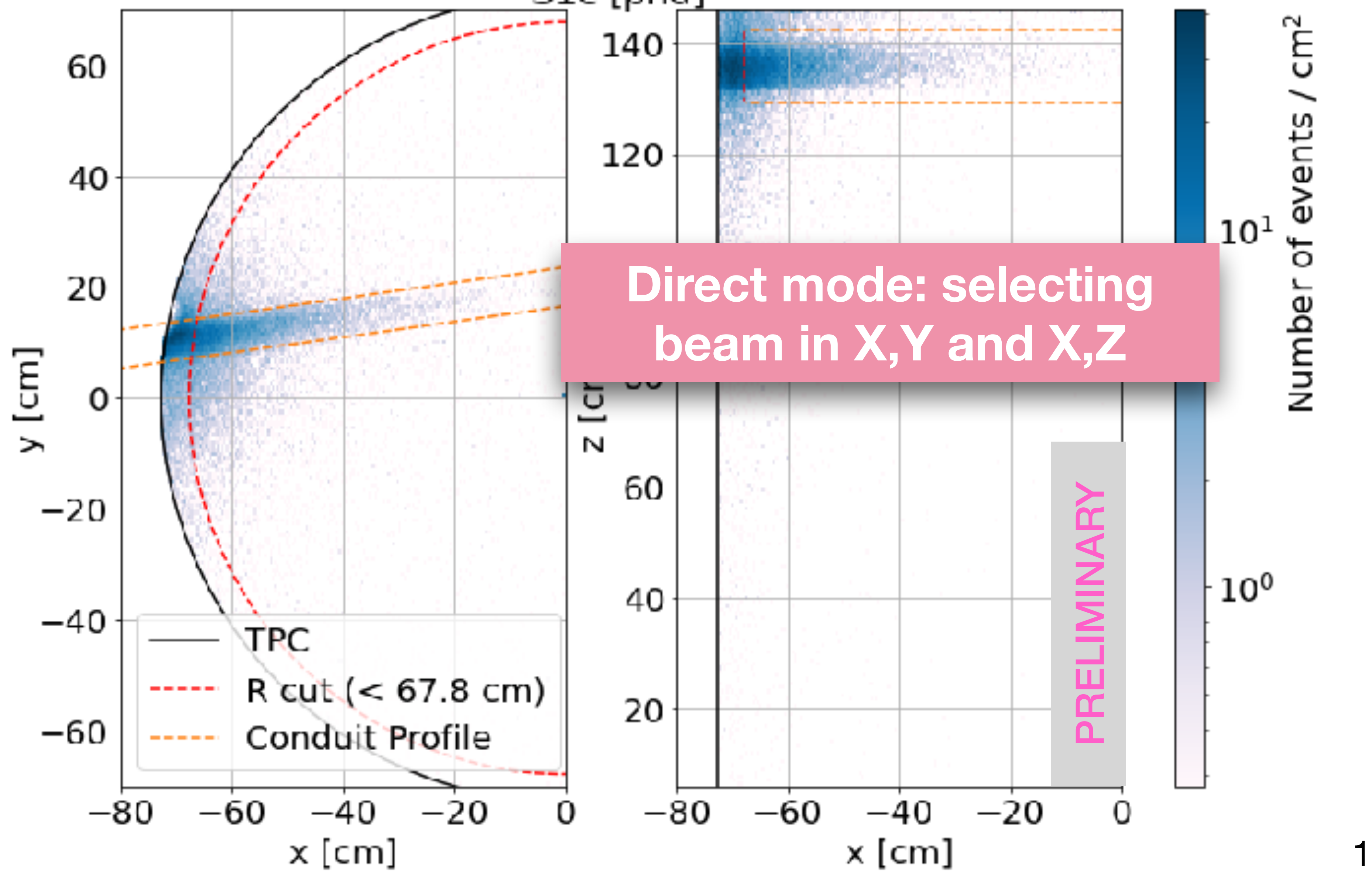
DD Neutron Calibration

Direct mode: monoenergetic 2.45 MeV neutrons from deuterium-deuterium fusion fired into TPC through conduits

Reflector mode: reflect neutrons from D or H for a lower energy calibration

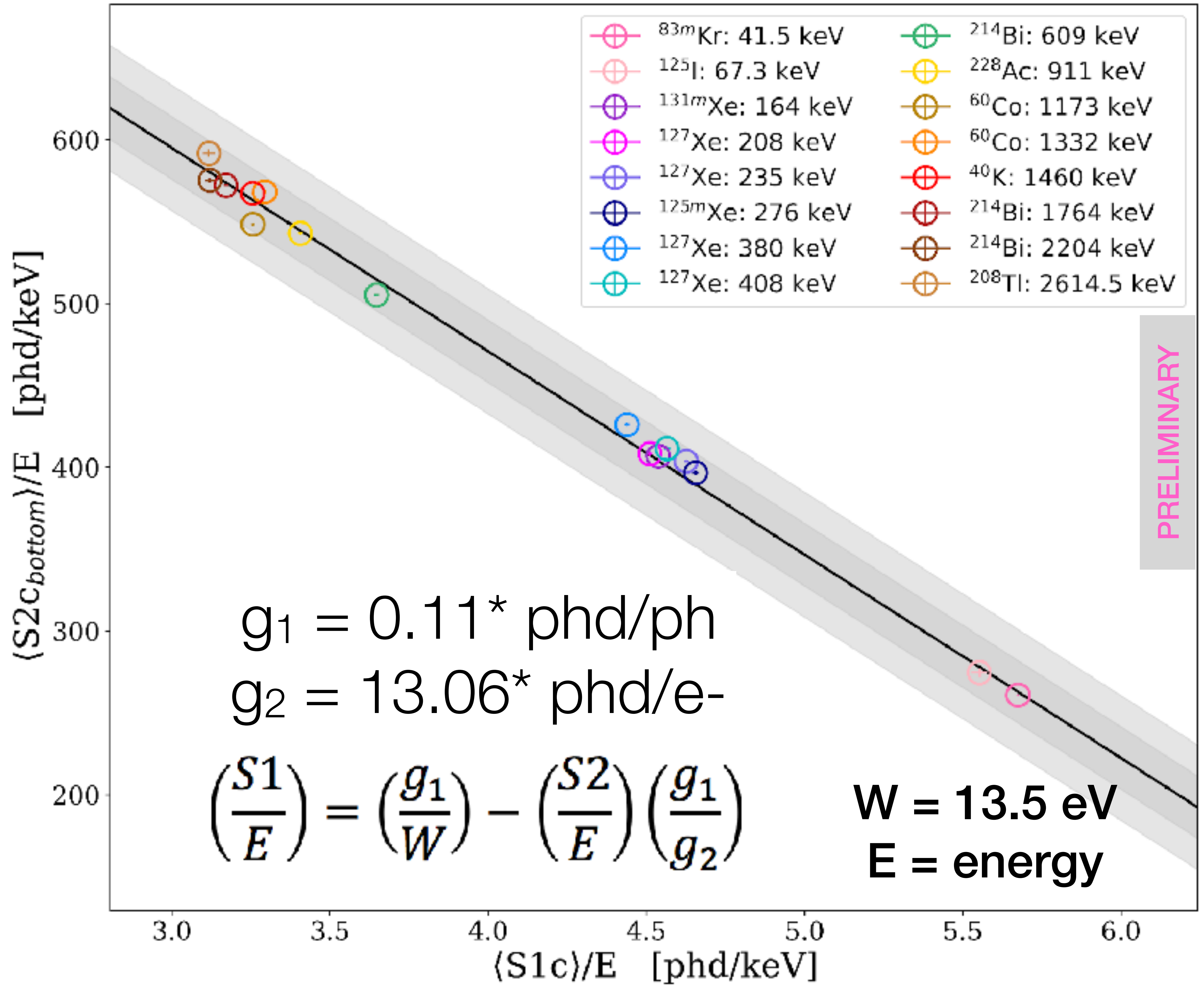




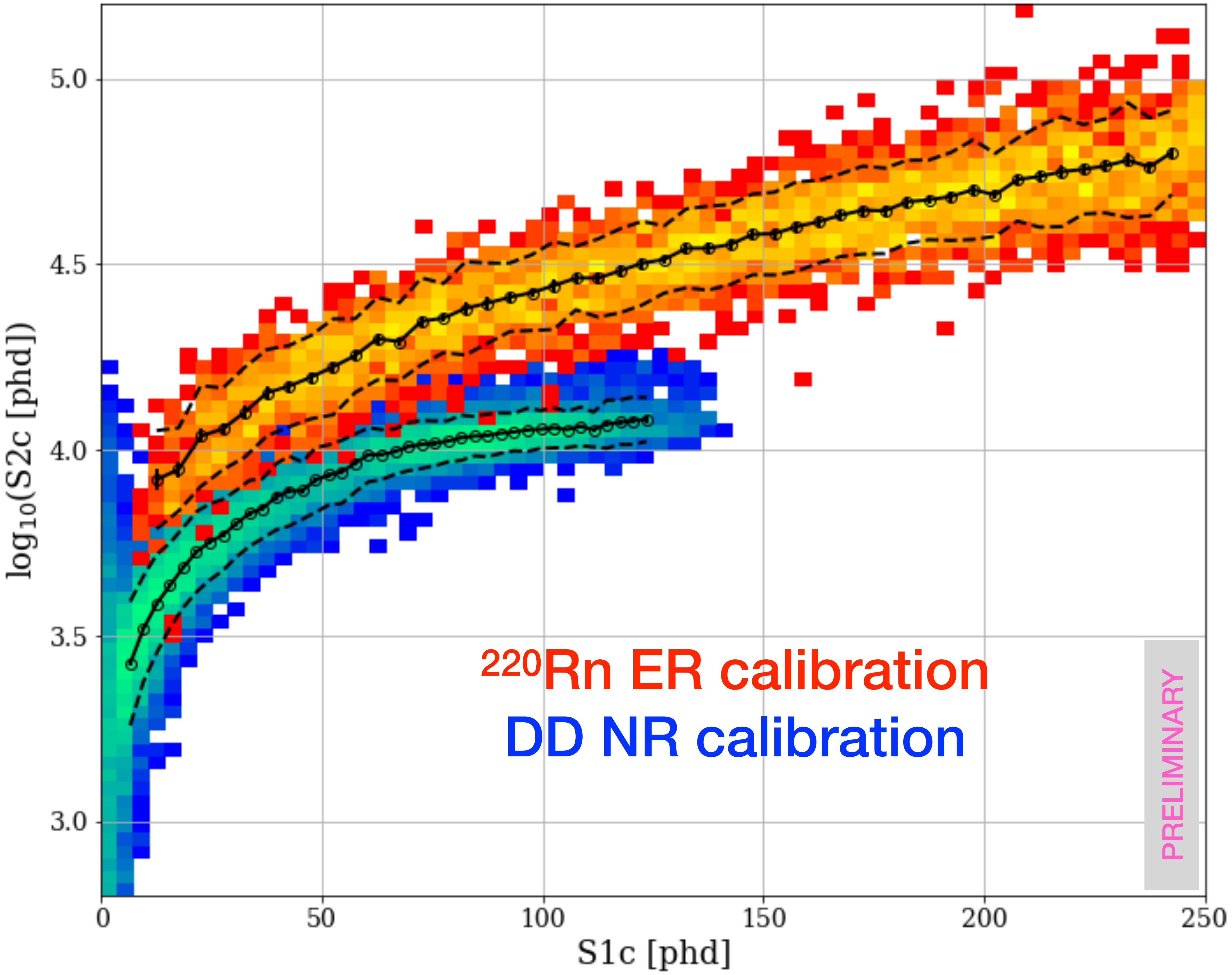


Detector Response

Mono-energetic ER peaks used to determine initial detector gains through a **Doke plot analysis**



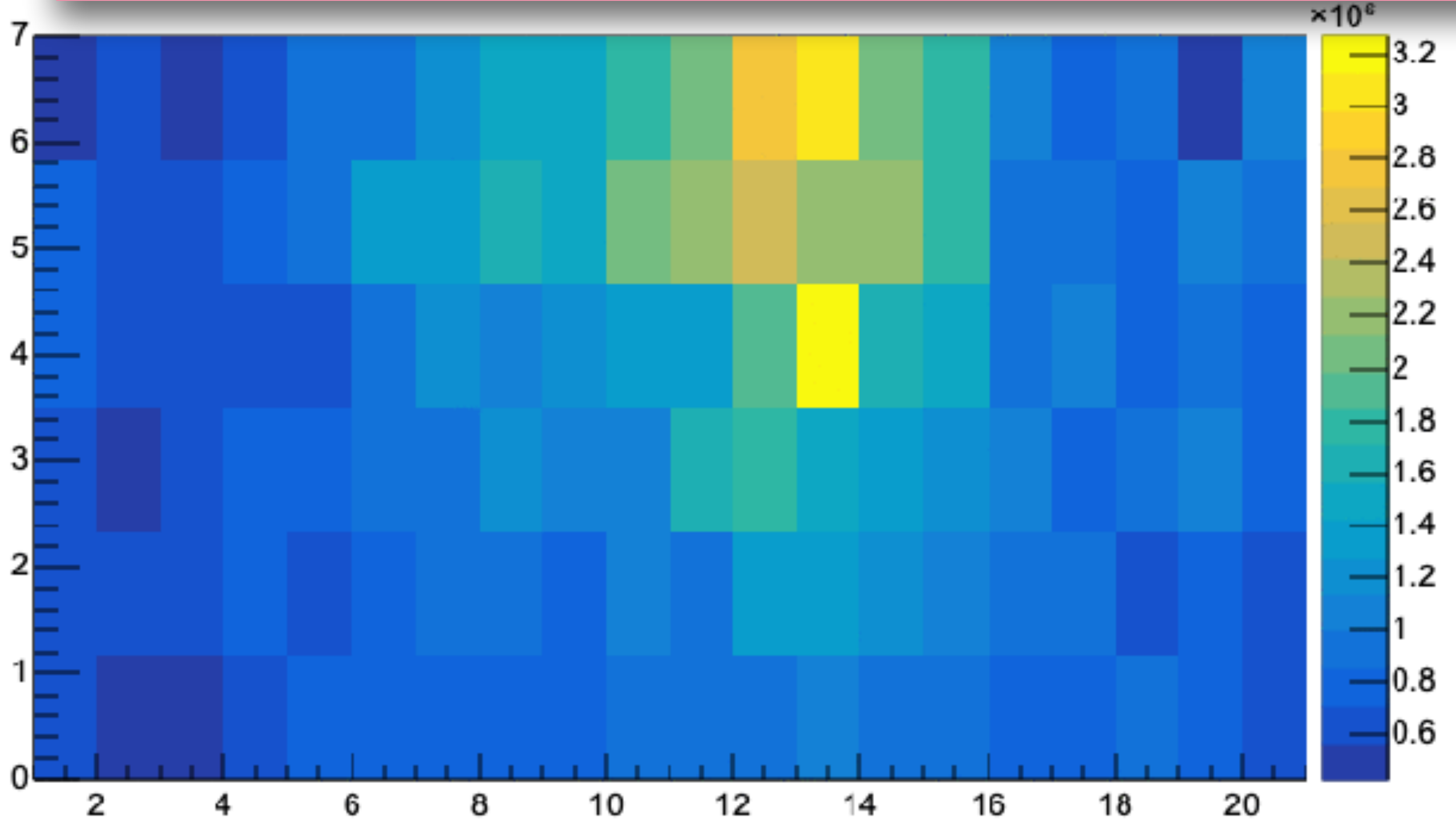
ER & NR bands characterised through ^{220}Rn injection and DD, NEST tuned to provide final g_1 & g_2

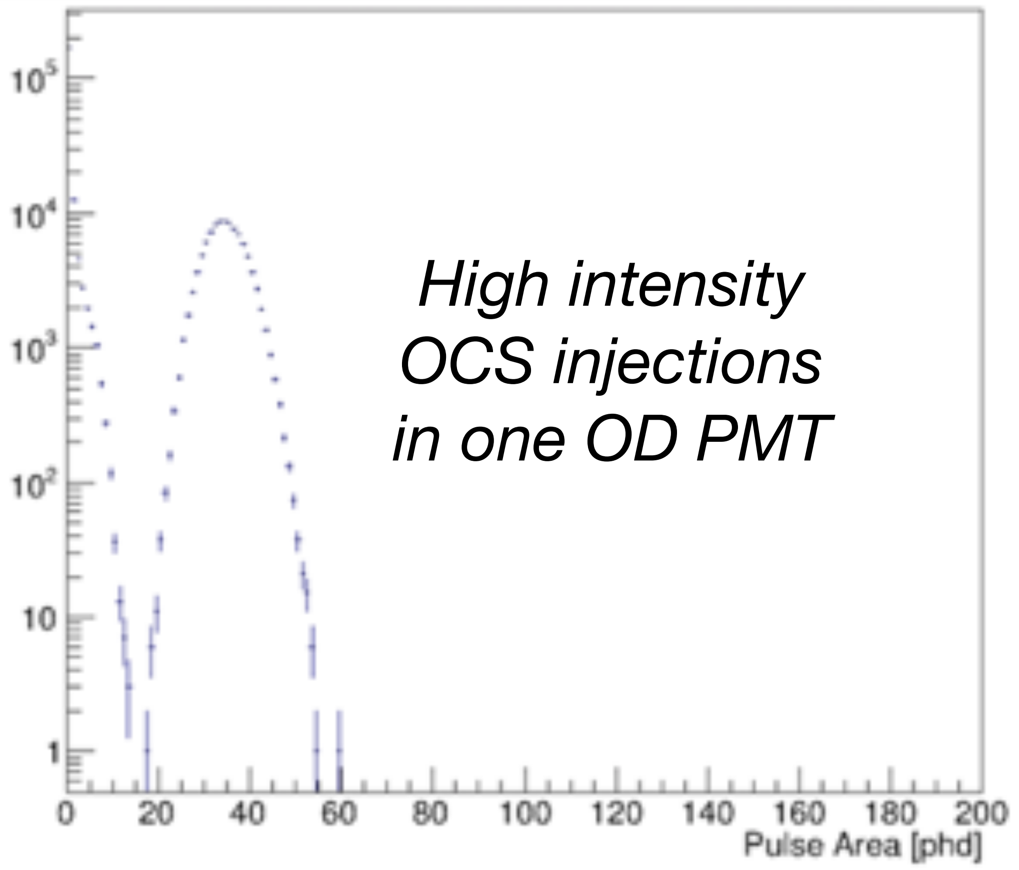


g_1 & g_2 still subject to change for final analysis

Outer Detector Calibration

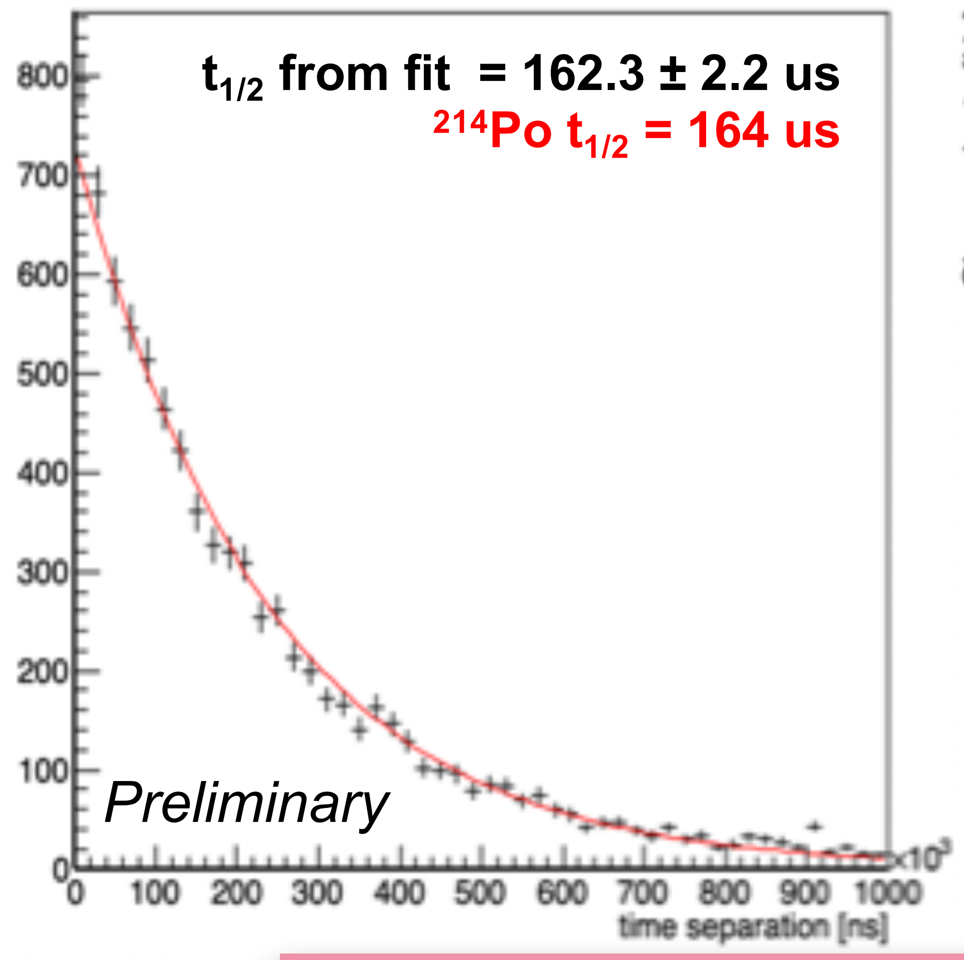
Regular PMT monitoring with Optical Calibration System



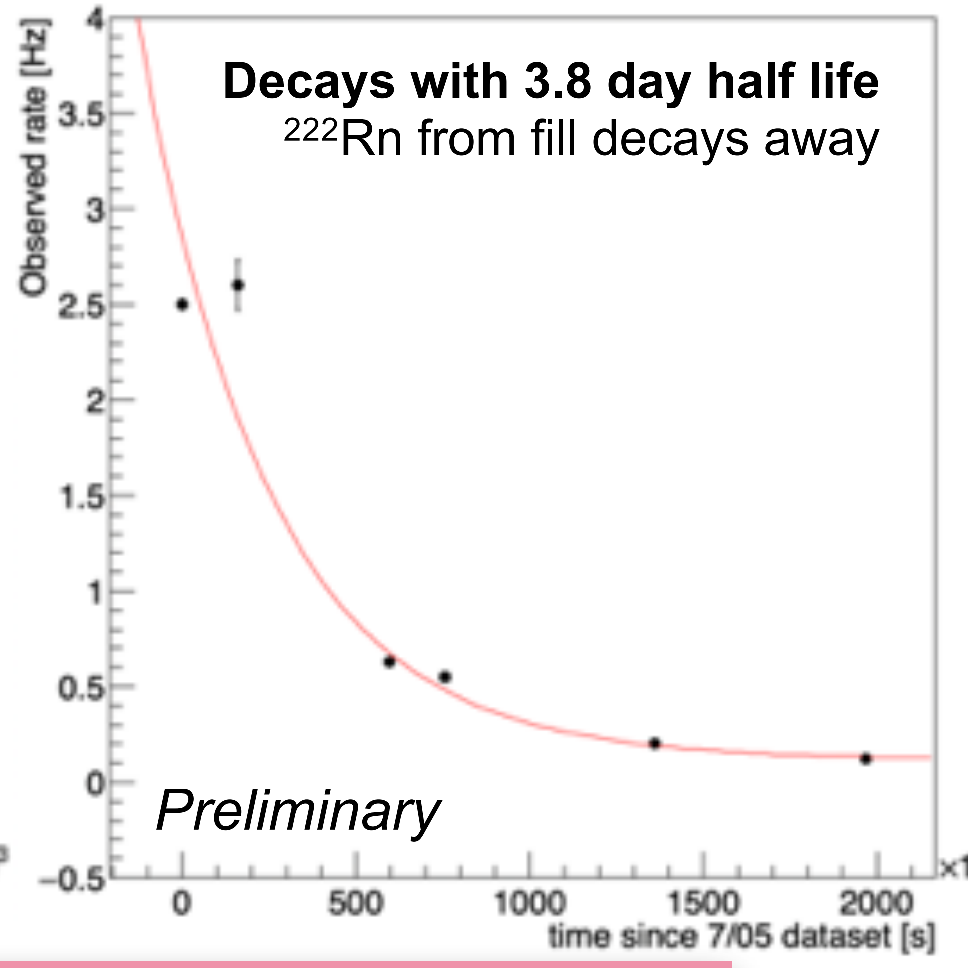


In-situ BiPo calibration after scintillator fill

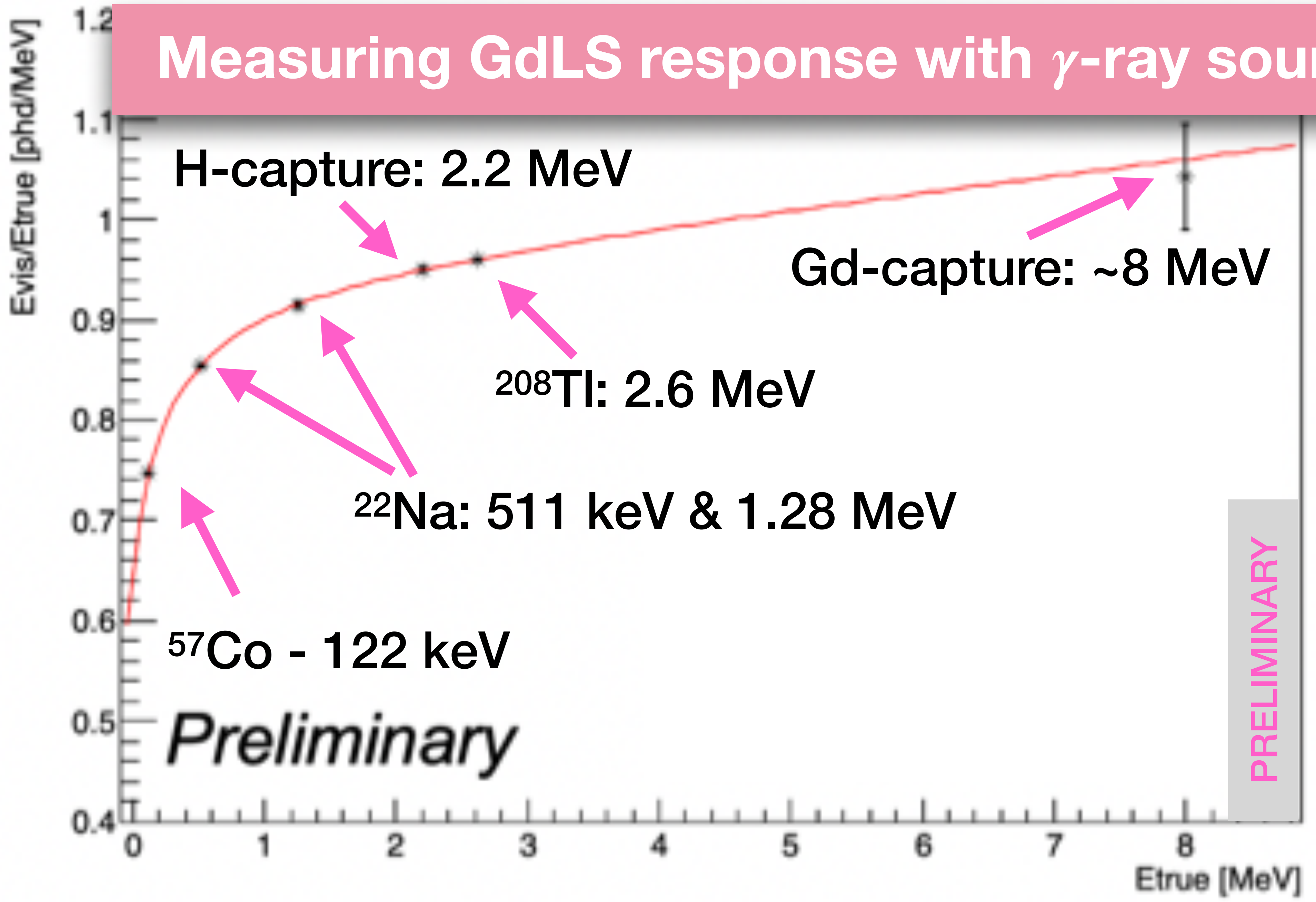
Measured BiPo time separation



BiPo rate over time

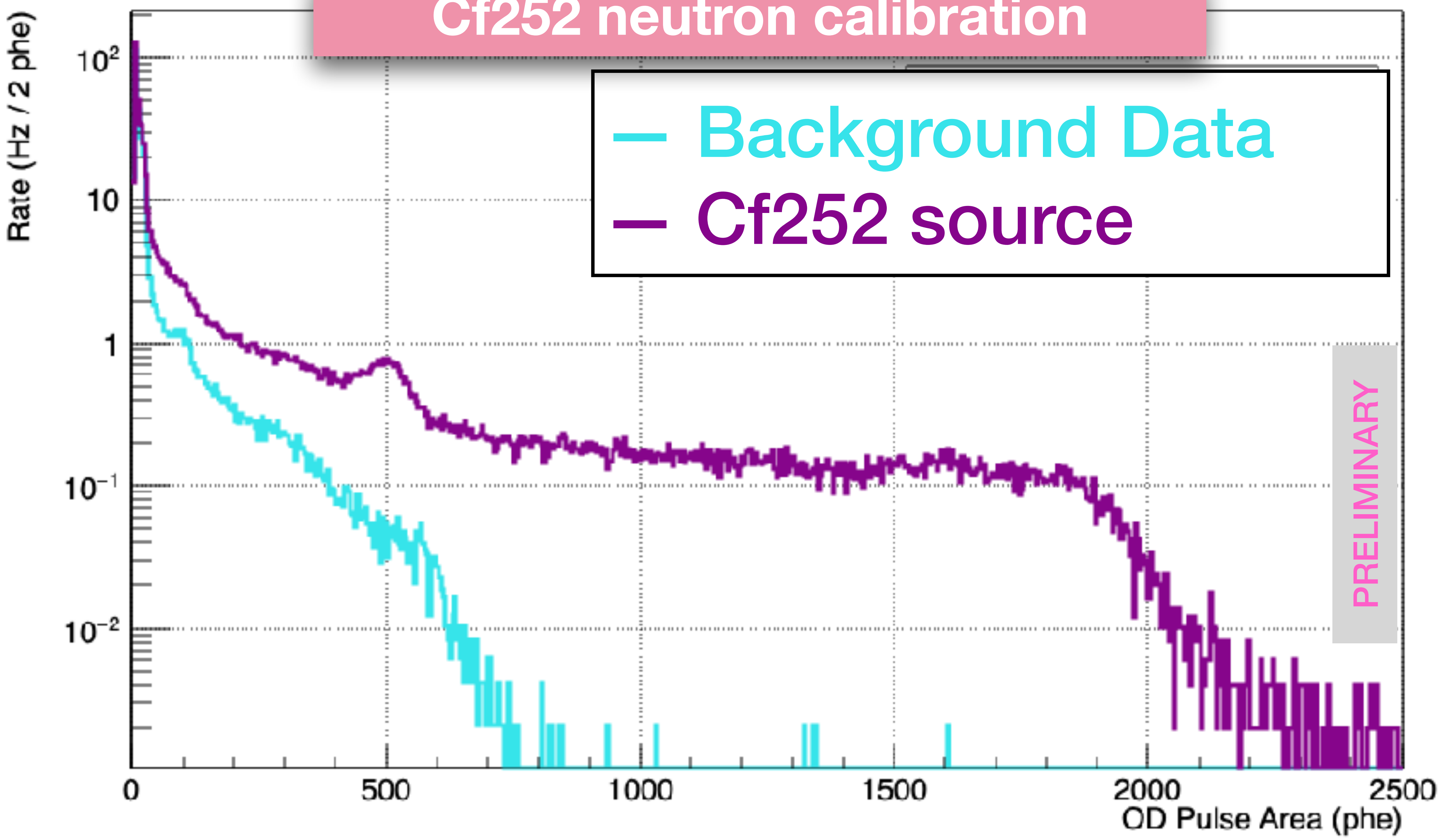


Measuring GdLS response with γ-ray sources and neutrons



Experiment	phe/MeV
RENO	150
Borexino	438
Daya Bay	162
Kamland	200
SNO+	300
LZ OD	230

Cf252 neutron calibration



Backgrounds

Cleanliness and Background Mitigation

- **Detector materials**
  - Radio-assay campaign
  - gamma-screening
  - ICPMS
  - NAA
- **Rn emanation**
  - Four Rn emanation screening sites
  - Two portable Rn assay panels
  - 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 contact surfaces
  - Rn-daughter plate-out on TPC walls < 0.5 mBq/m^2
- **Xenon contaminants**
  - ^{85}Kr, ^{39}Ar
  - Charcoal chromatography @ SLAC
  - Final natKr/Xe <300 ppq
- **Cosmogenics and externals**
  - 4300 m.w.e. underground
  - Instrumented Xe skin region
  - GdLS outer detector
  - High purity water shield


Cleanliness protocols!


HPGe screening at Boulby

Radon reduction system at SURF


Charcoal chromatography columns at SLAC

Backgrounds

ER Backgrounds:

- γ-rays & β-decays from ^{238}U, ^{232}Th chains
- ^{60}Co, ^{40}K
- Xenon lines
- ^{222}Rn, ^{220}Rn and ^{85}Kr in the LXe

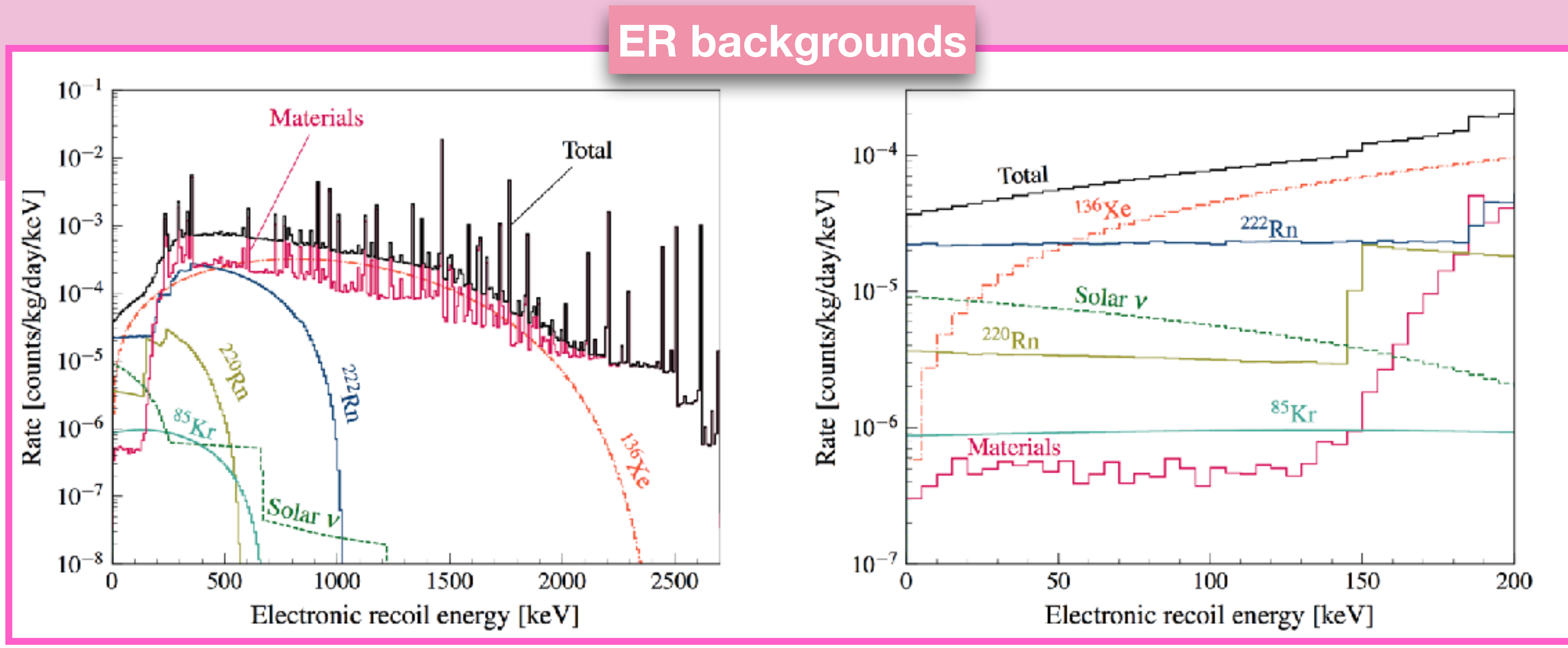
NR Backgrounds

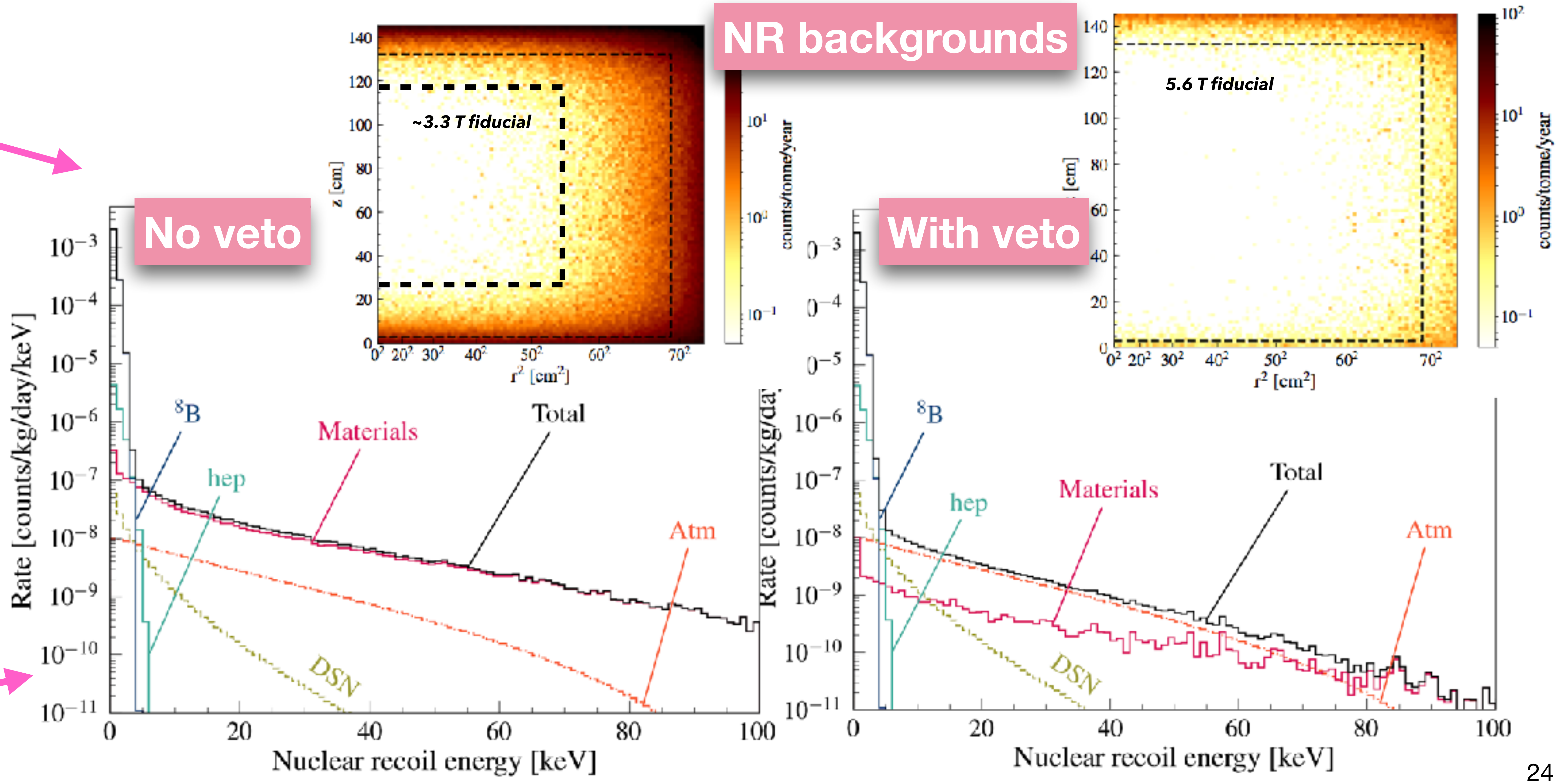
- Neutrons from (α,n) & spontaneous fission in detector components
- ^{8}B solar neutrinos
- Wall background (mis-reconstructed ion recoils)

Key for reducing background:

- Fiducialisation (self-shielding)
- Single scatter cuts
- Energy cuts
- Dual veto system (skin and OD)

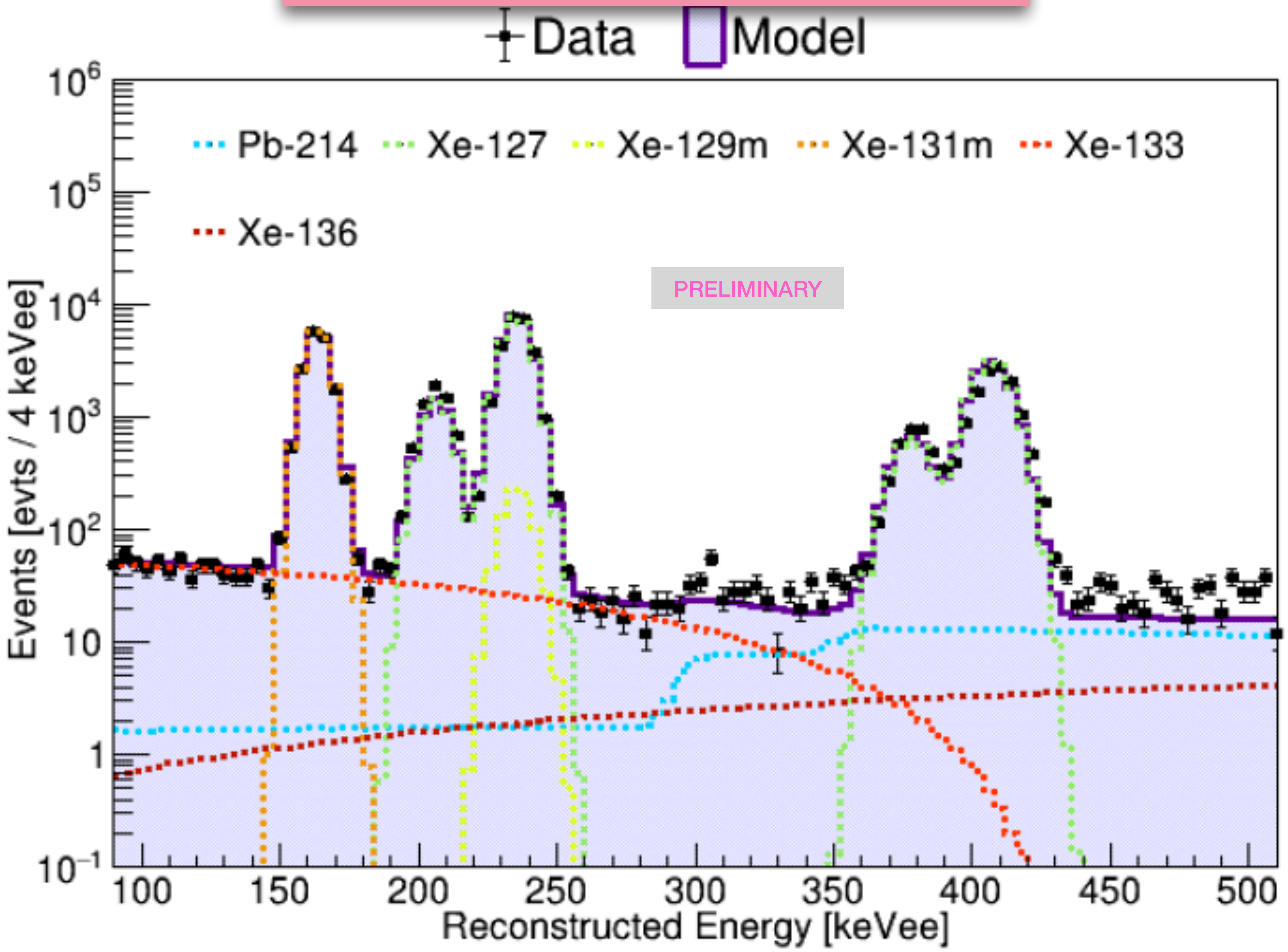
OD reduces NR backgrounds and allows maximal fiducial volume

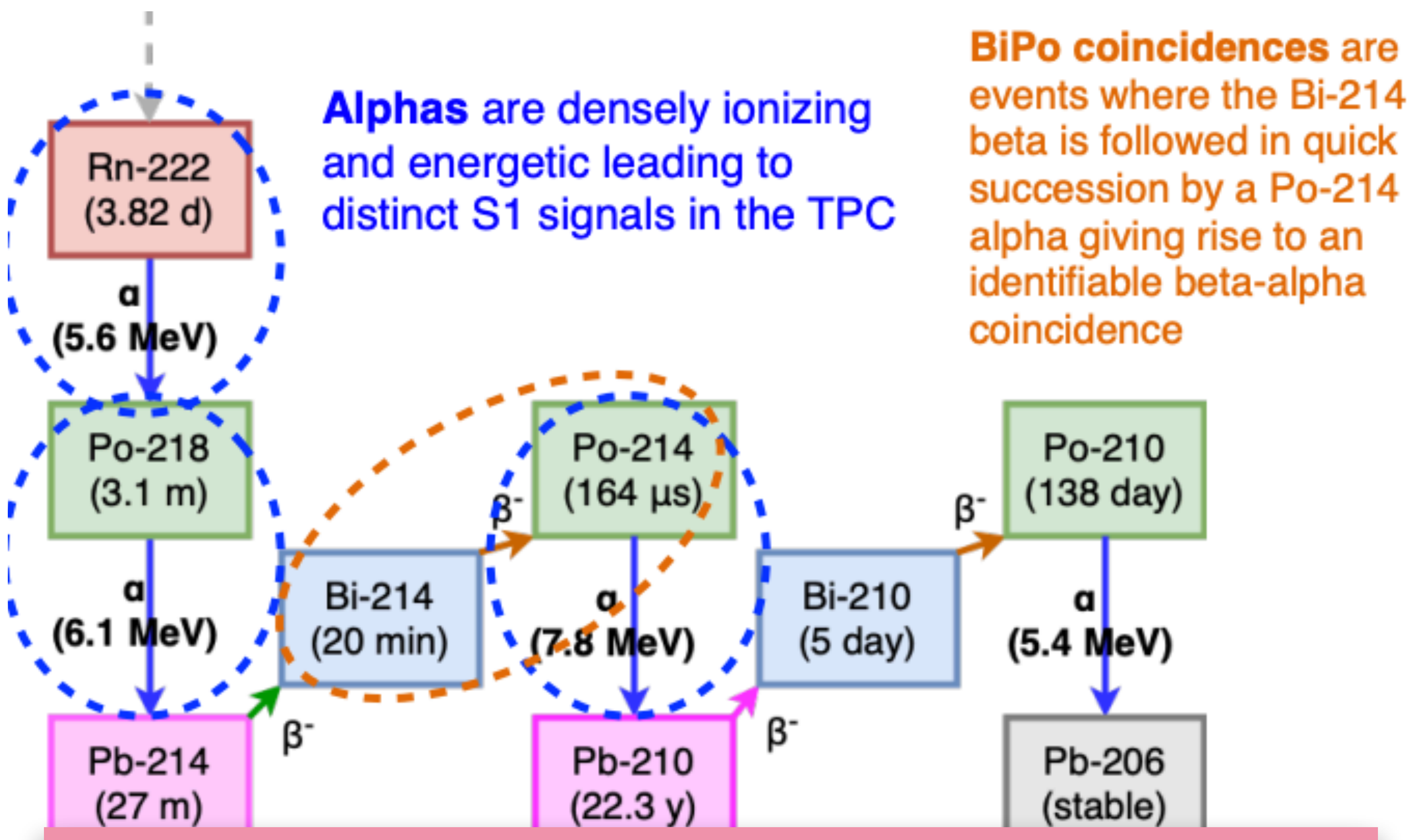




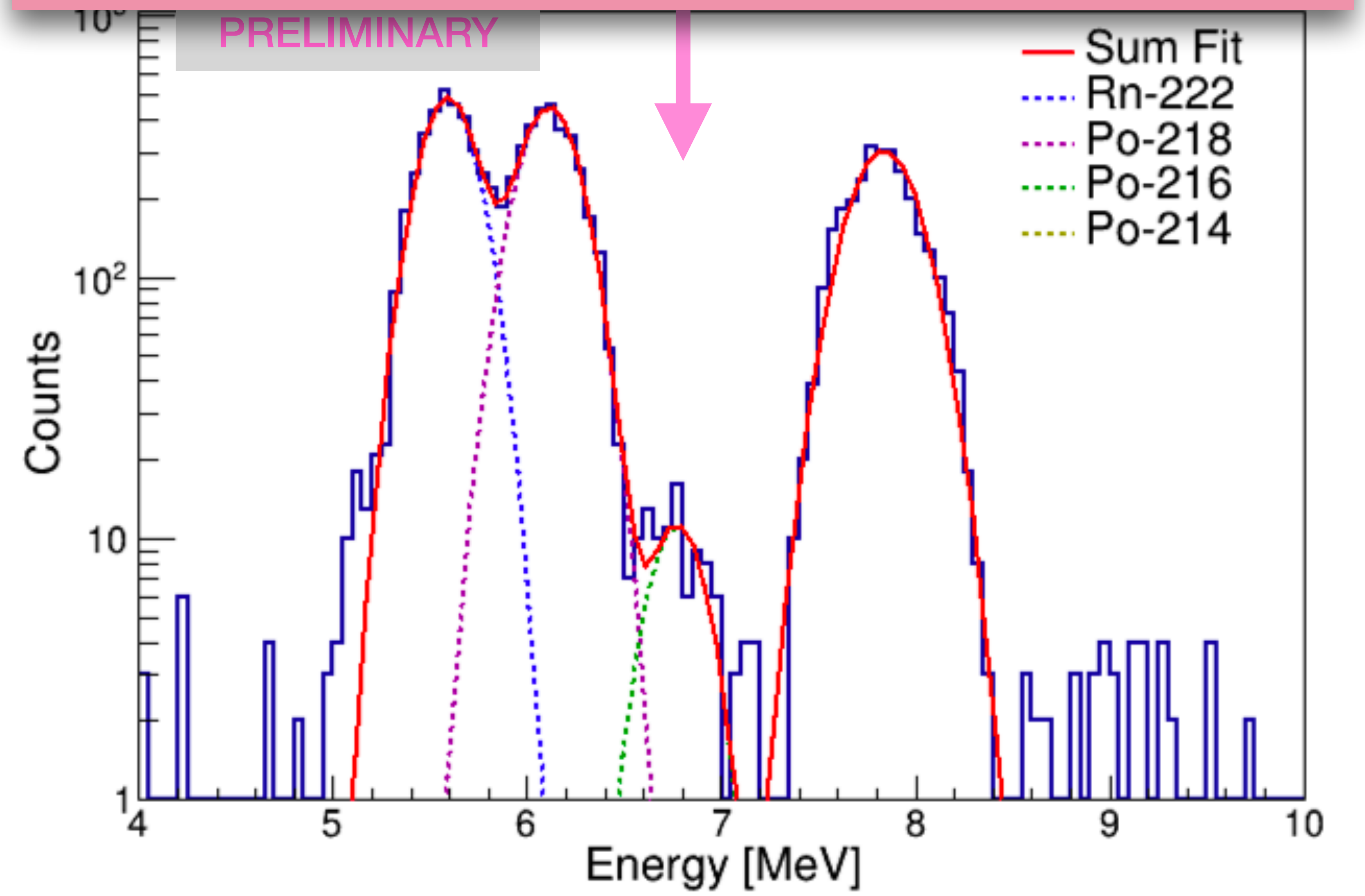
Measuring LXe Backgrounds

First fits of background simulations to data



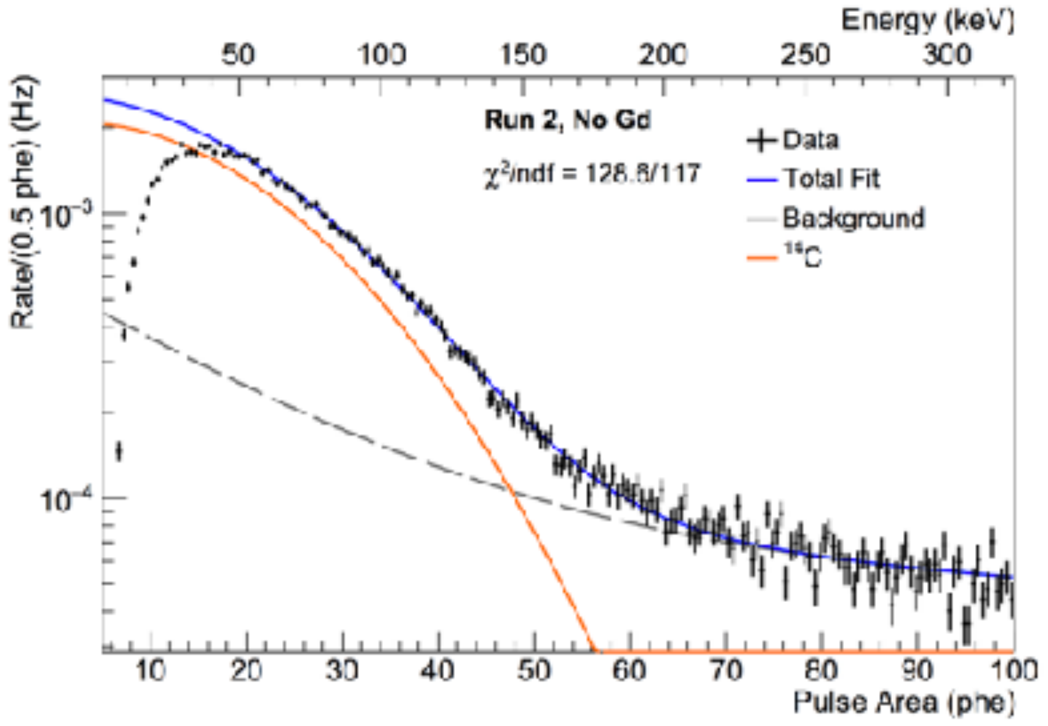


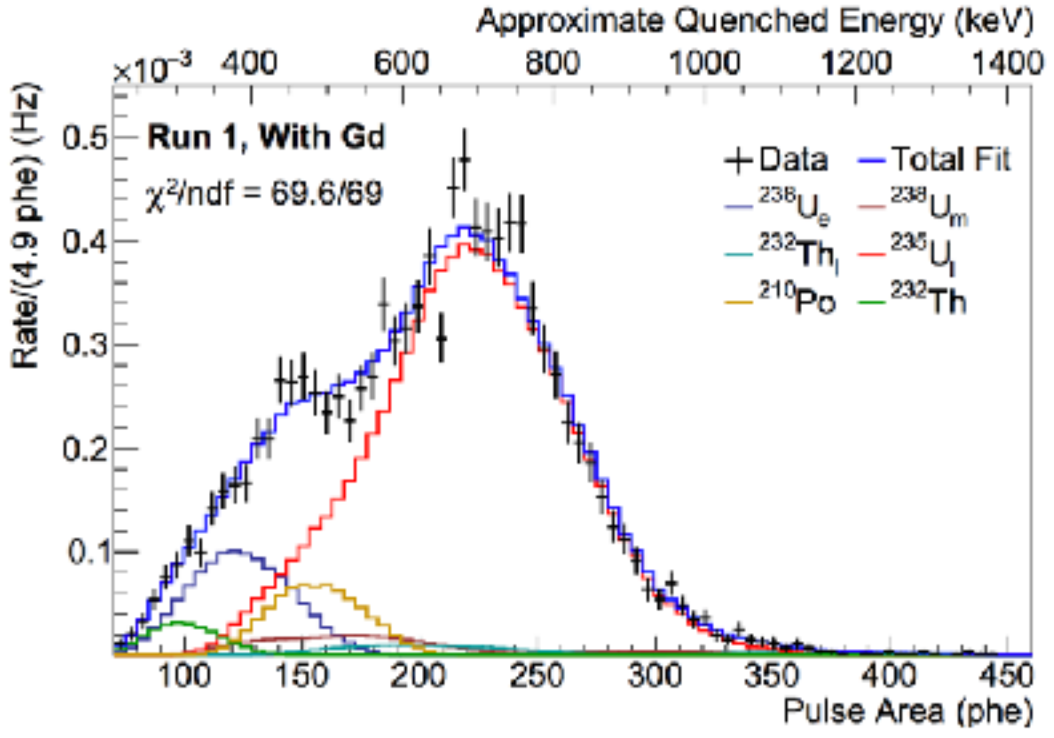
^{222}Rn & ^{220}Rn chain alpha populations within expected range



Outer Detector Backgrounds

Measuring GdLS Internal Backgrounds





LS Screener ran inside water tank in 2017 and measured backgrounds in 23 kg of GdLS

arXiv:1808.05595

Sensitive to **all** decays in the scintillator: **α,β,γ**

Measured a huge range of contaminants, including some we didn't expect! ^{176}Lu, ^{147}Sm, ^{235}U ! → more purification of Gd powder

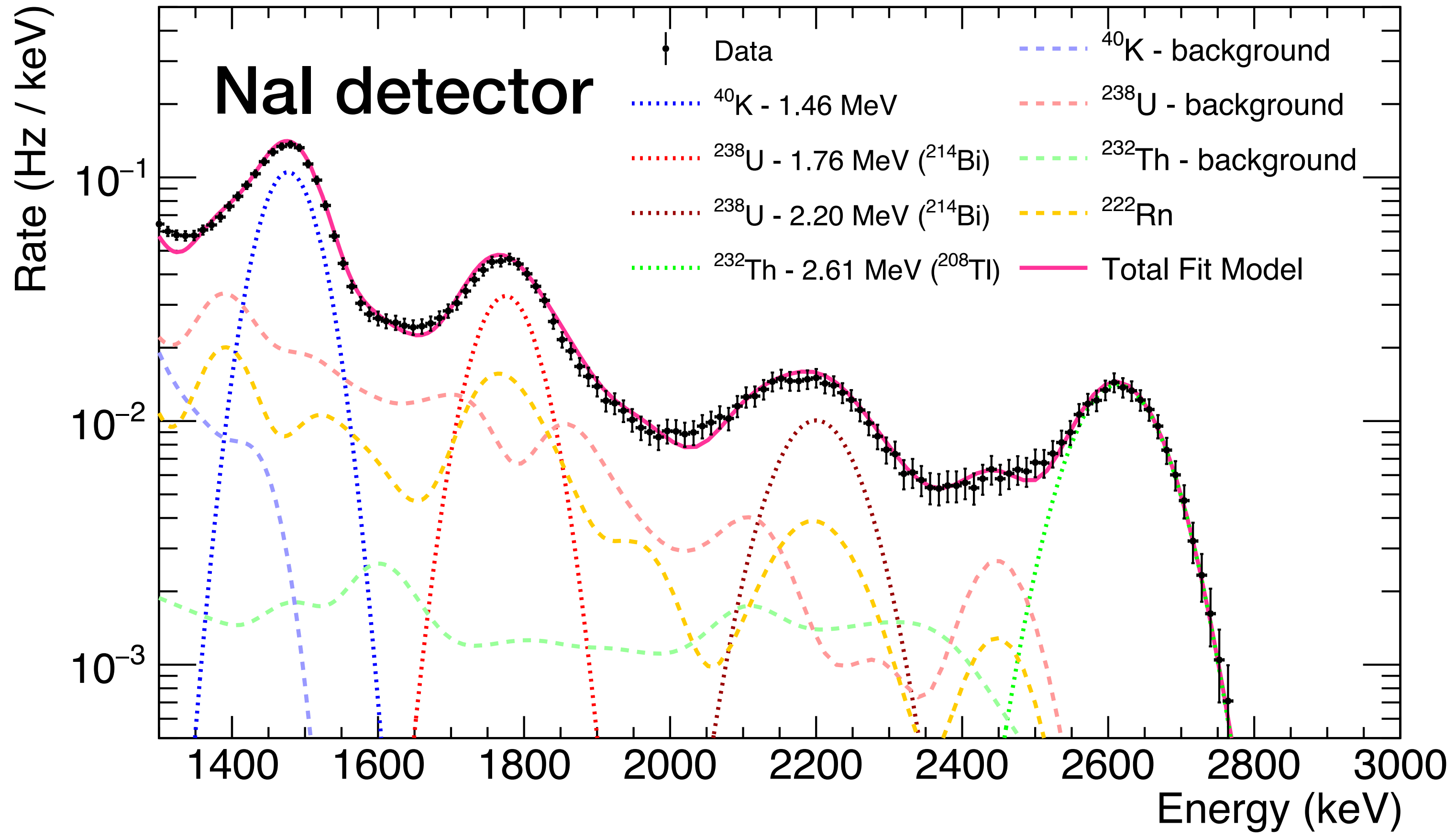
Measuring the Cavern Background

arXiv:1904.02112

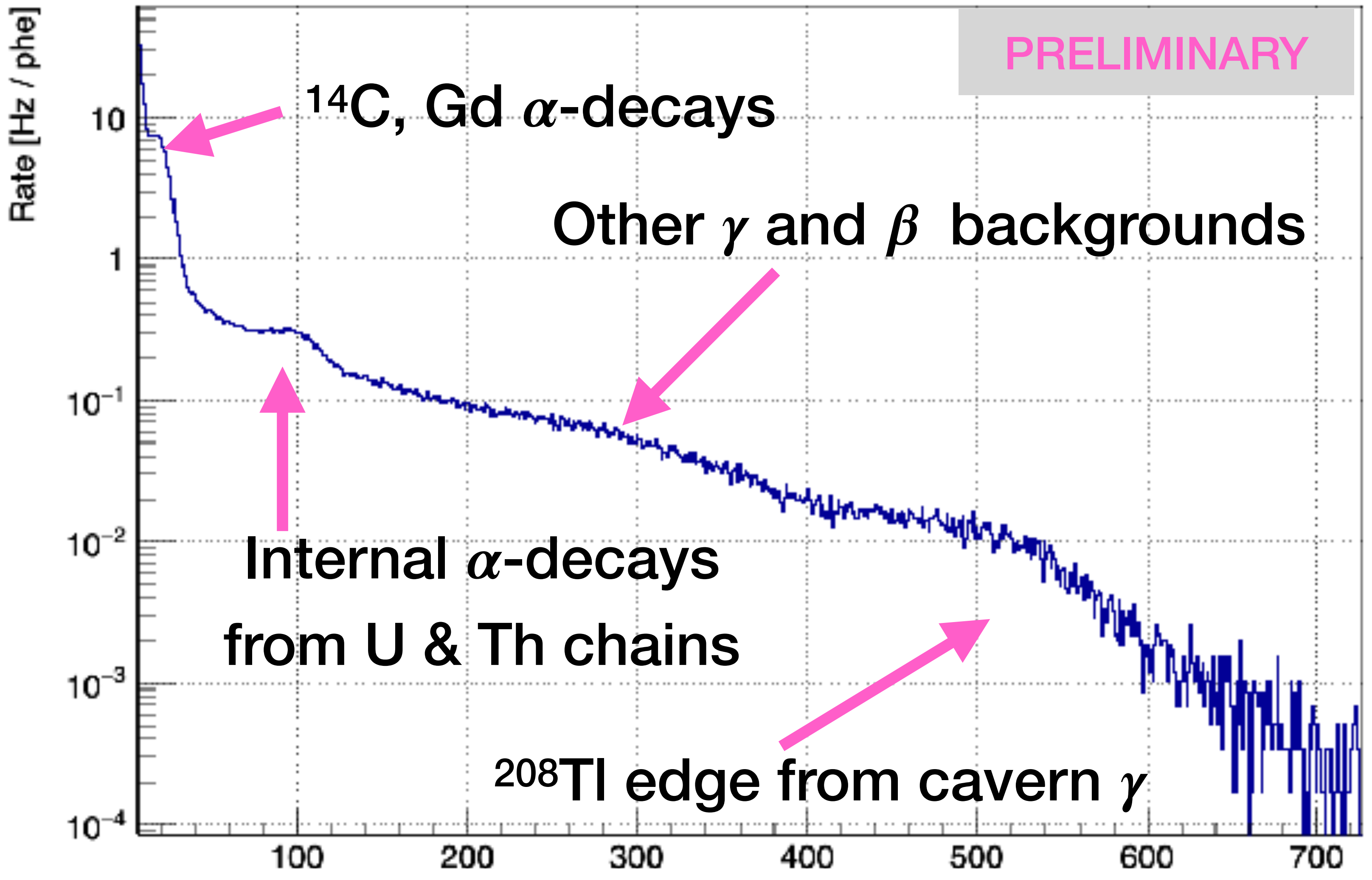
Total γ-flux

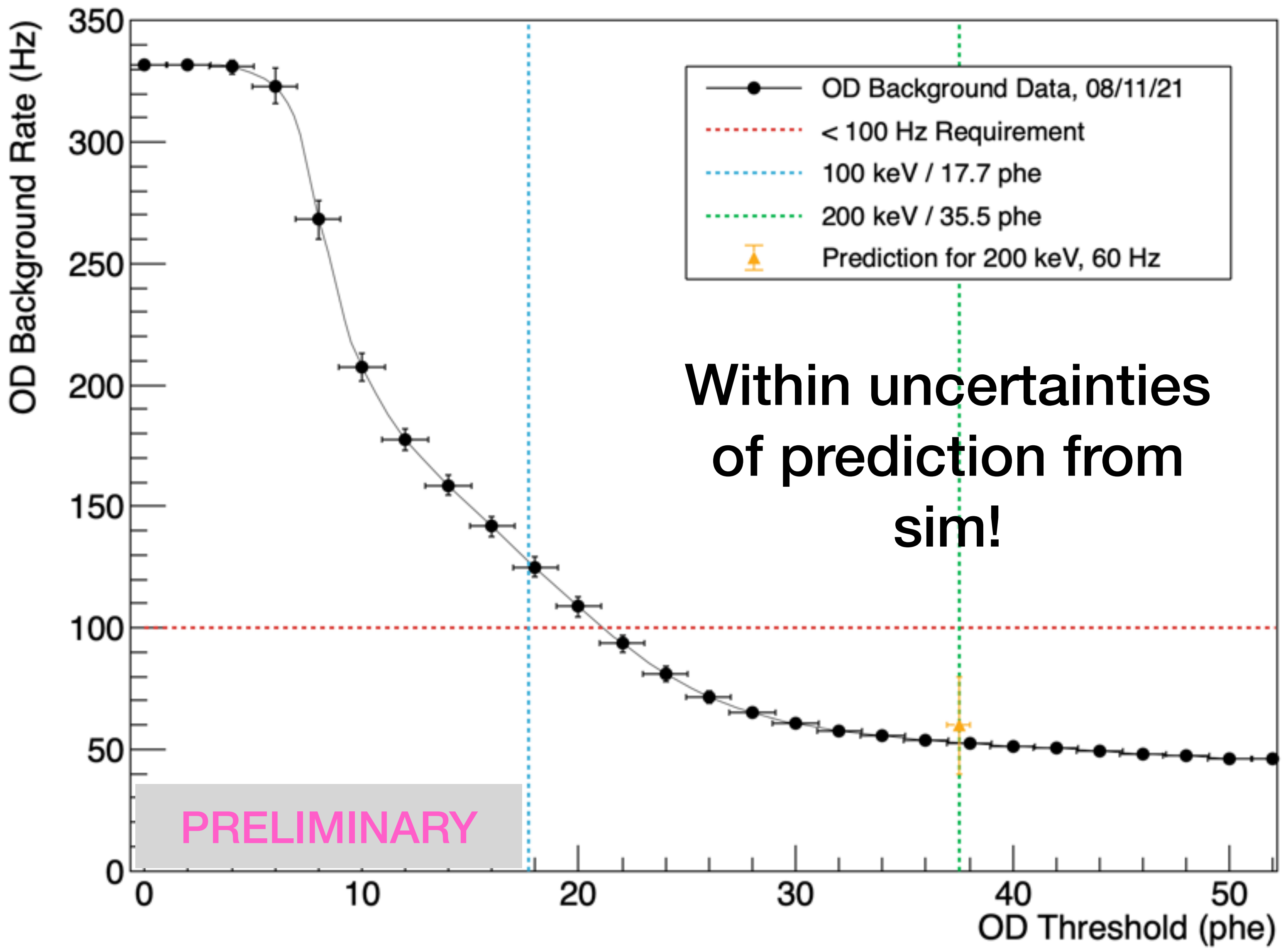
1.9 ± 0.4 γ cm^{-2} s^{-1}

Sprayed concrete radioactivity found to dominate the cavern flux



Measuring the OD Background



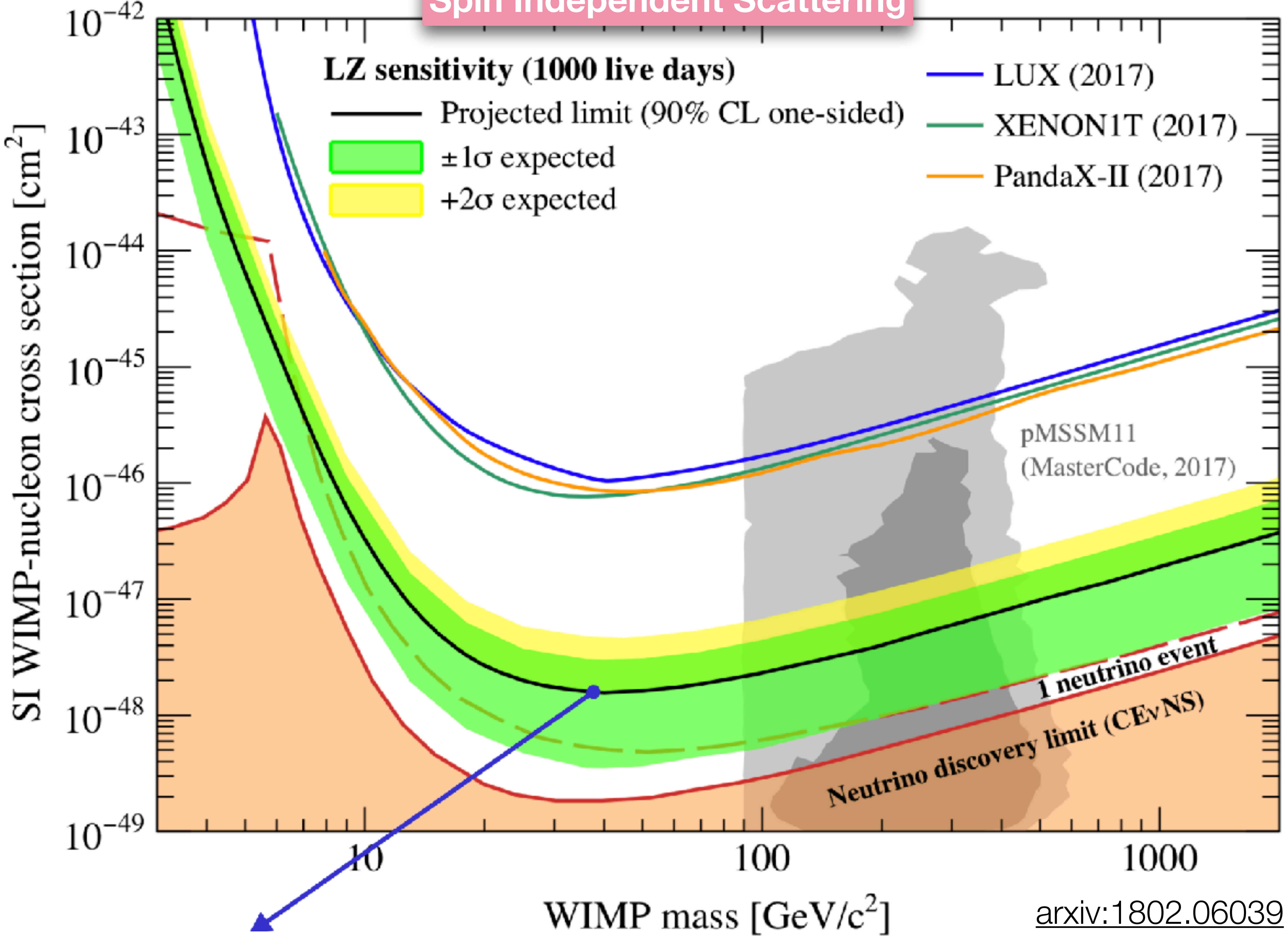


Sensitivity & Physics Reach

LUX - ZEPLIN

LZ Sensitivity Projections

Spin Independent Scattering

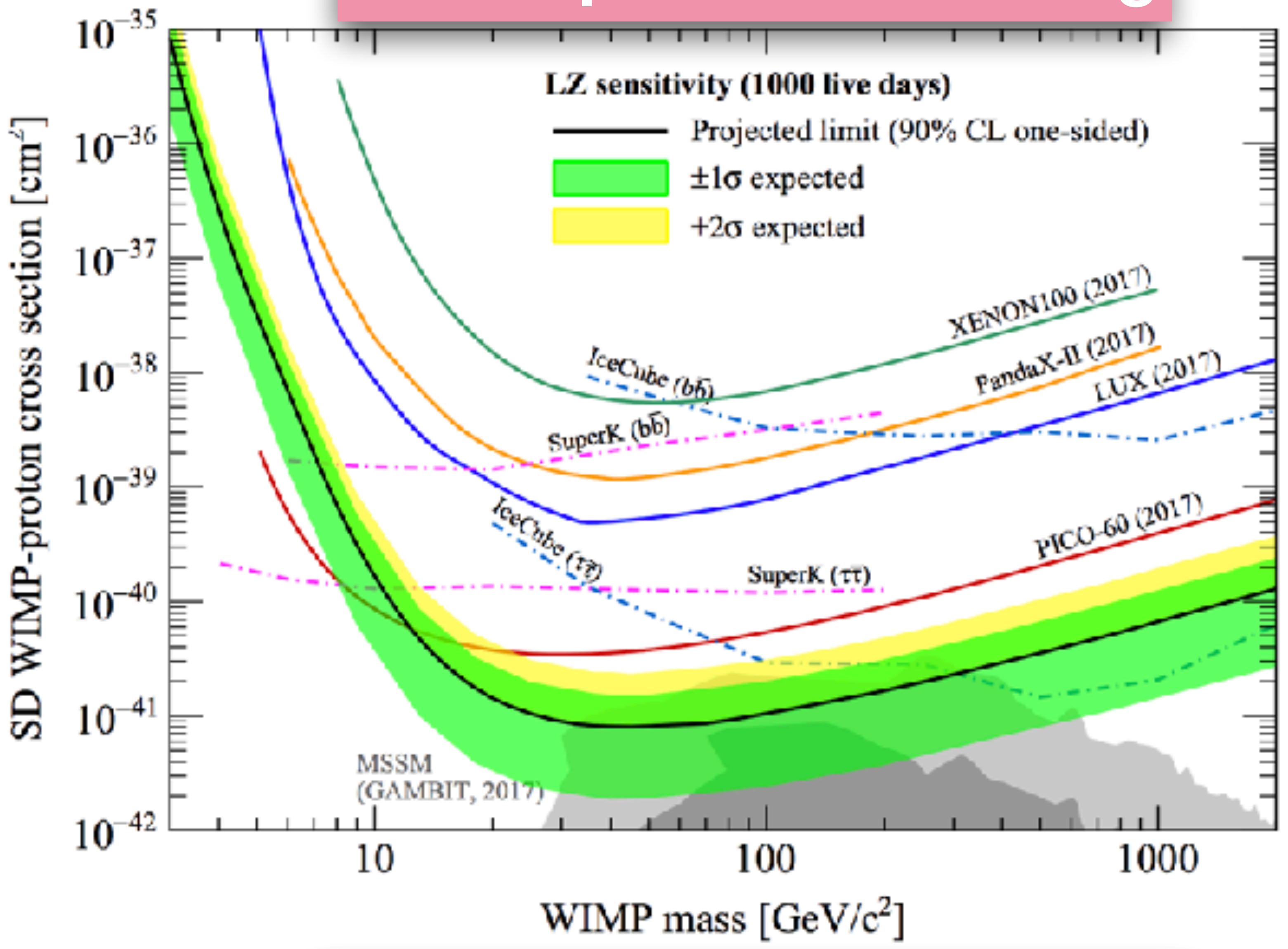


1.4×10^{-48} cm² @ 40 GeV/c²

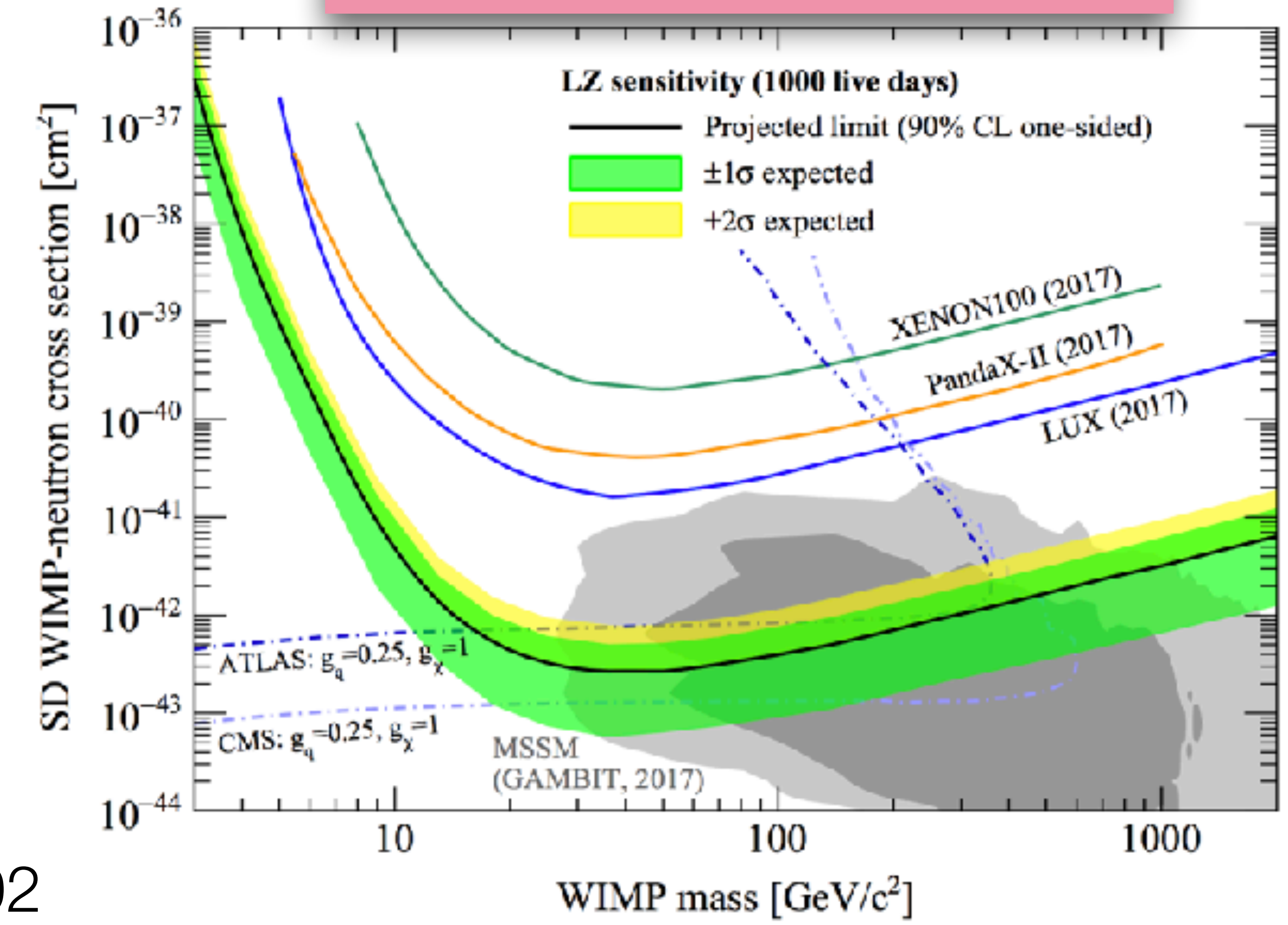
arxiv:1802.06039

Phys. Rev. D **101**, 052002

WIMP-proton scattering



WIMP-neutron scattering



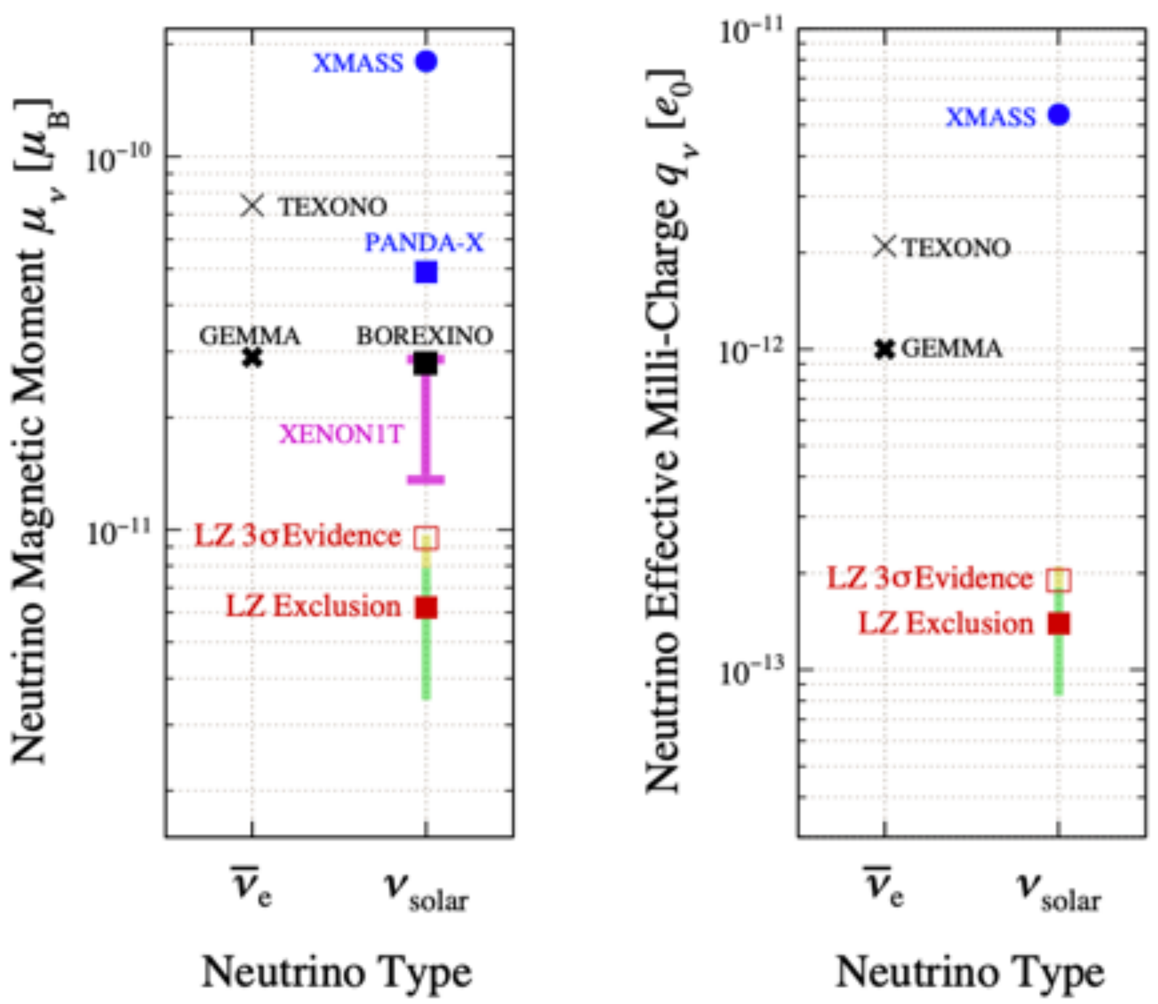
LZ Physics Reach

LZ physics reach extends beyond vanilla WIMPs:

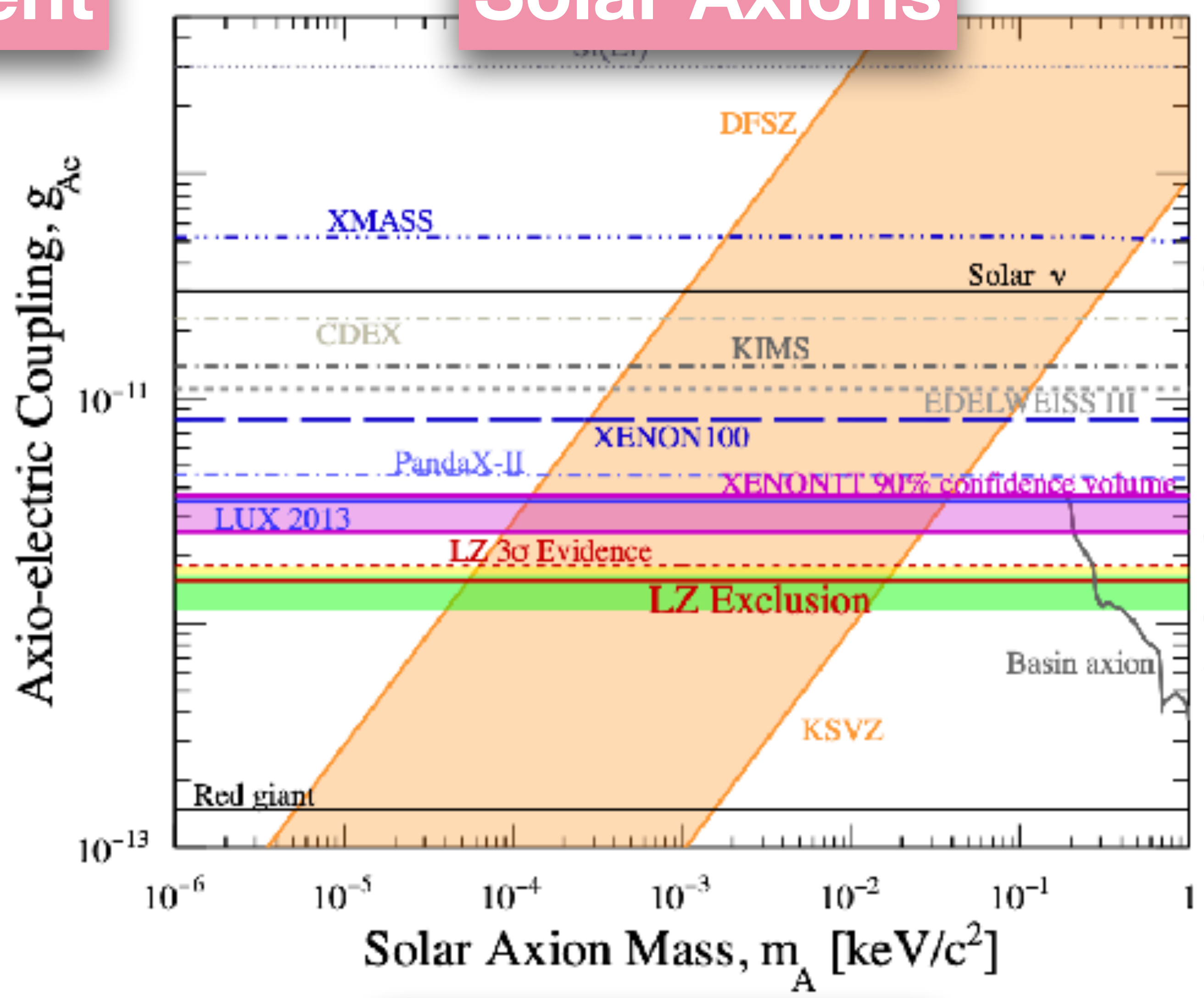
- Solar axions
- Axion-like particles (ALPs)
- 2νββ of ^{134}Xe with competitive sensitivity to 0νββ
- Enhanced sensitivity to low mass DM through Migdal effect
- Leptophilic dark matter
- Neutrino magnetic moment
- Mirror dark matter

arxiv:2102.11740
arxiv:2104.13374

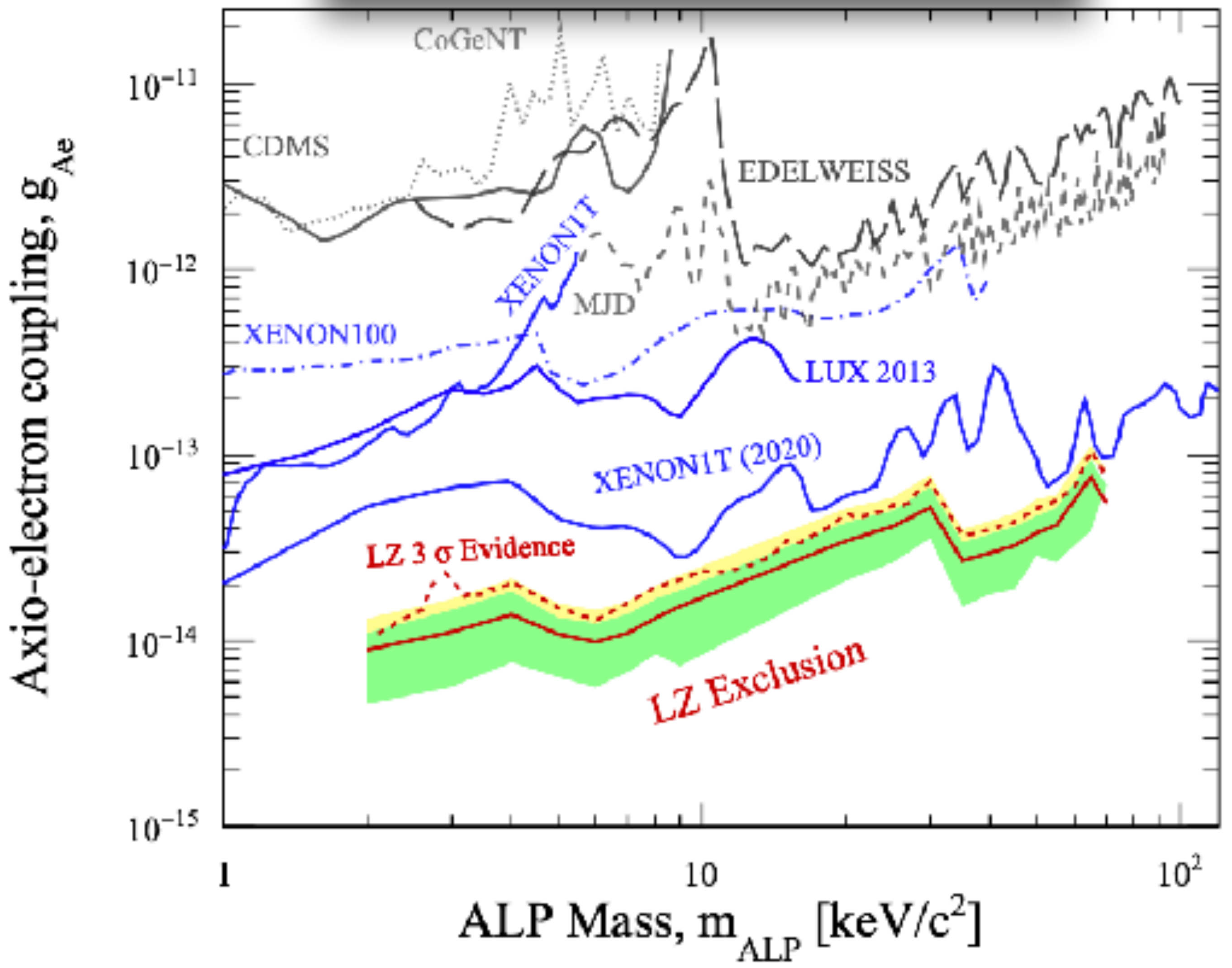
Neutrino magnetic moment



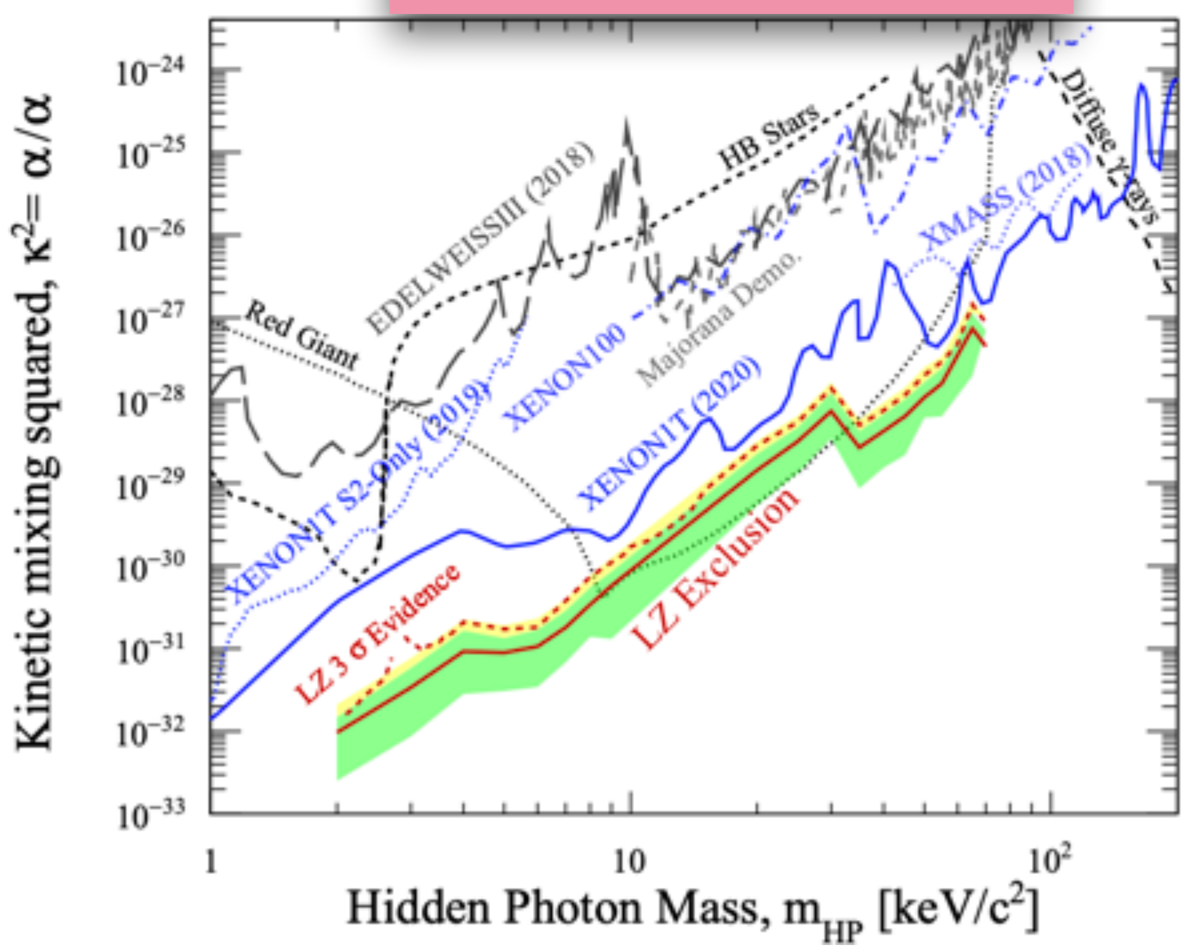
Solar Axions



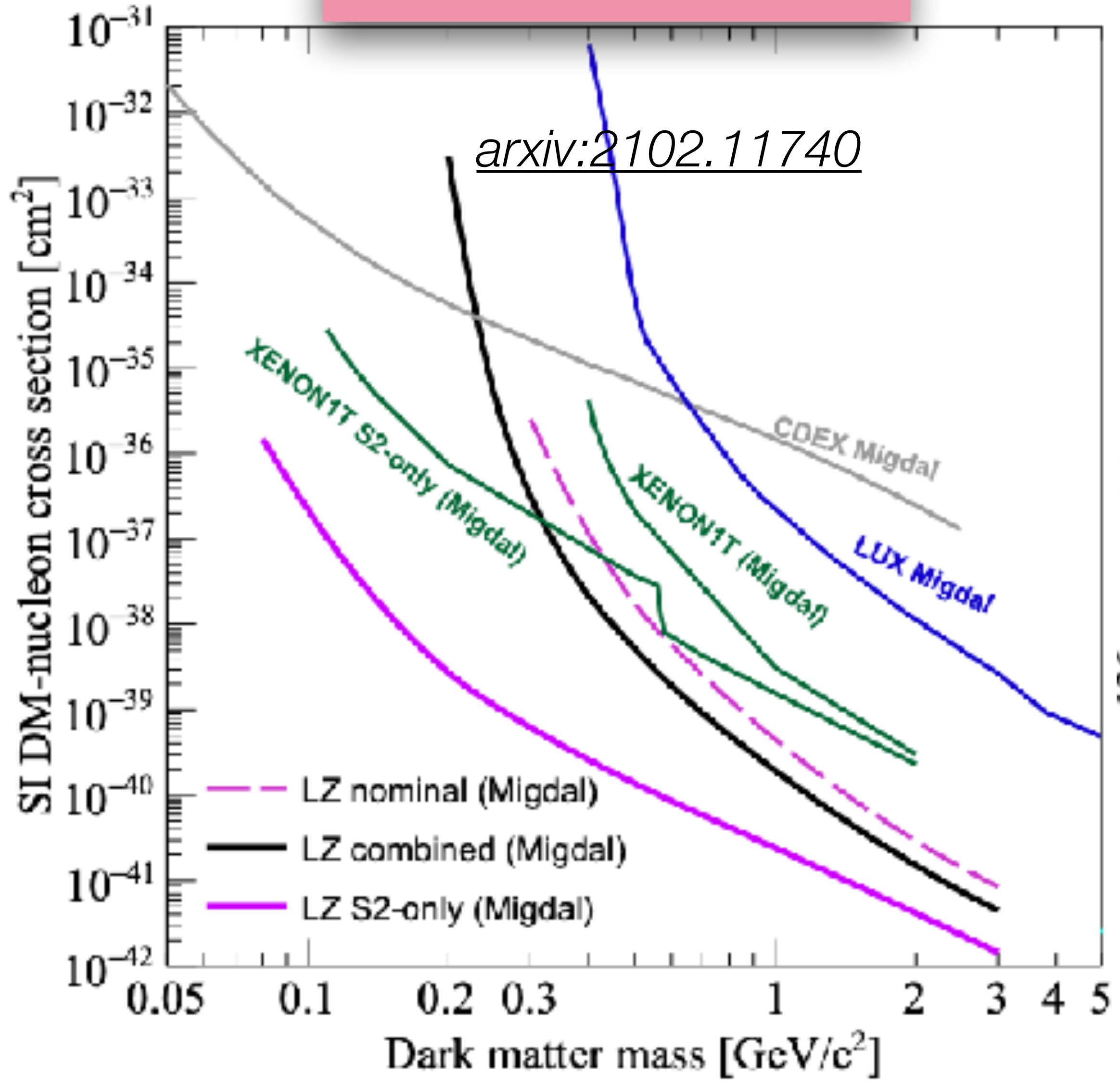
Axion-Like Particles



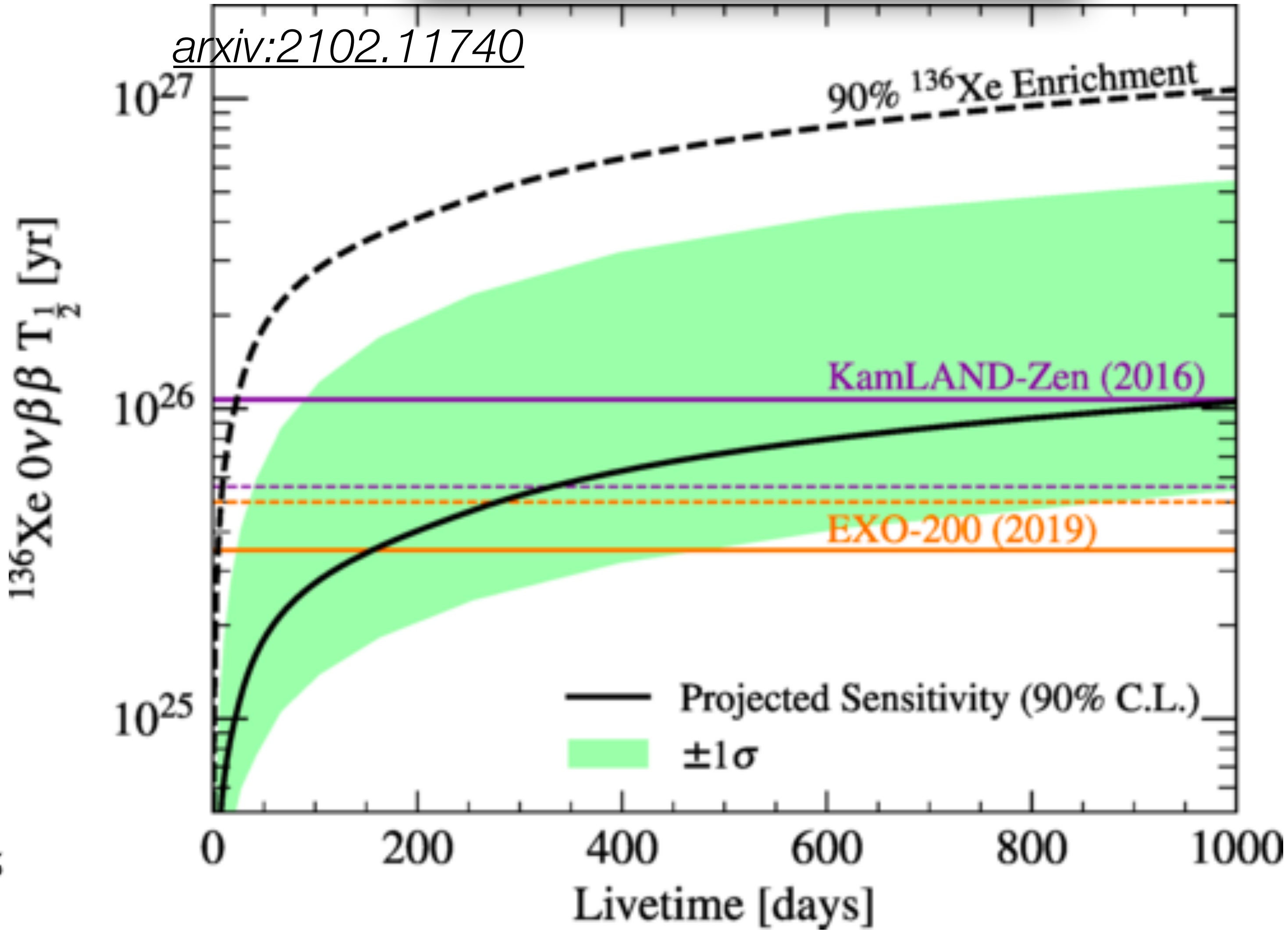
Hidden Photons



Low mass DM



134Xe 0νββ decay



Acknowledgements

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Wisconsin, Madison

US UK Portugal Korea

Sanford Underground Research Facility
South Dakota Science and Technology Authority

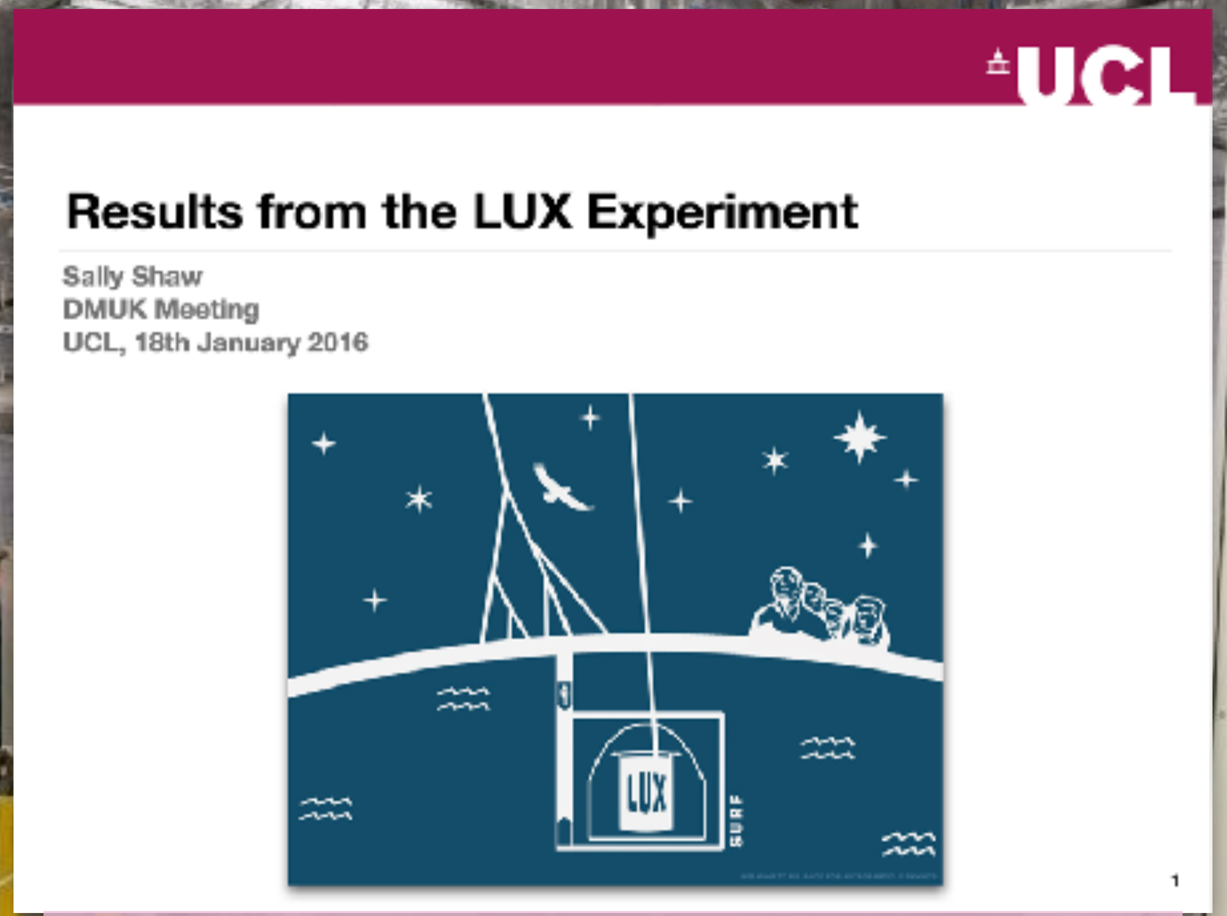
UKRI Science and Technology Facilities Council

ibs Institute for Basic Science

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

- LZ is a multi-physics experiment, primed for detection of WIMPs
- Commissioning completed, currently taking **science data,** and **extensive analyses underway**
- Expected 40x improvement in sensitivity on current limits, sensitive to non-WIMP physics
- **First science results expected this year!**



My last talk at DMUK just before I left the UK!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