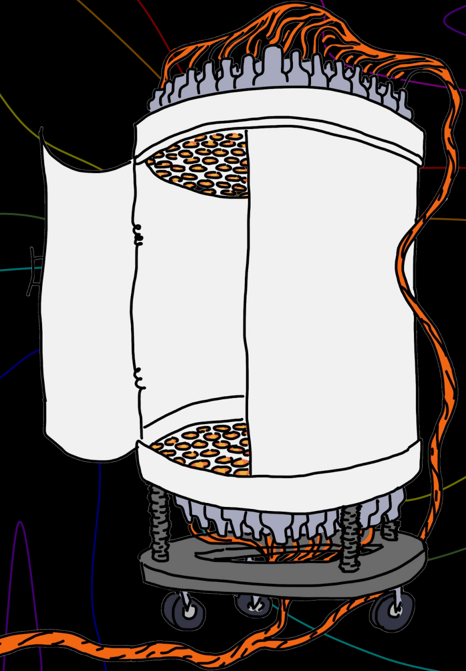


Status of the LUX-ZEPLIN experiment

A direct search for dark matter

18th July 2024

Nicolas Angelides
IMPERIAL
(on behalf of the LZ Collaboration)

America Europe Asia Oceania

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Fermi National Accelerator Lab.
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- Northwestern University
- Pennsylvania State University
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
- University of California Santa Barbara
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Rochester
- University of Wisconsin, Madison

38 Institutions
250 scientists, engineers, and technical staff

LZ

Brown University - June 2024

- Edinburgh University
- Imperial
- Royal Holloway University of London
- STFC Rutherford Appleton Lab
- University of Bristol
- University College London
- University of Liverpool
- University of Oxford
- University of Sheffield
- LIP Coimbra
- University of Zurich

- University of Sydney

- Center for Underground Physics

SANFORD UNDERGROUND RESEARCH FACILITY

Swiss National Science Foundation

ibs Institute for Basic Science

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

UKRI

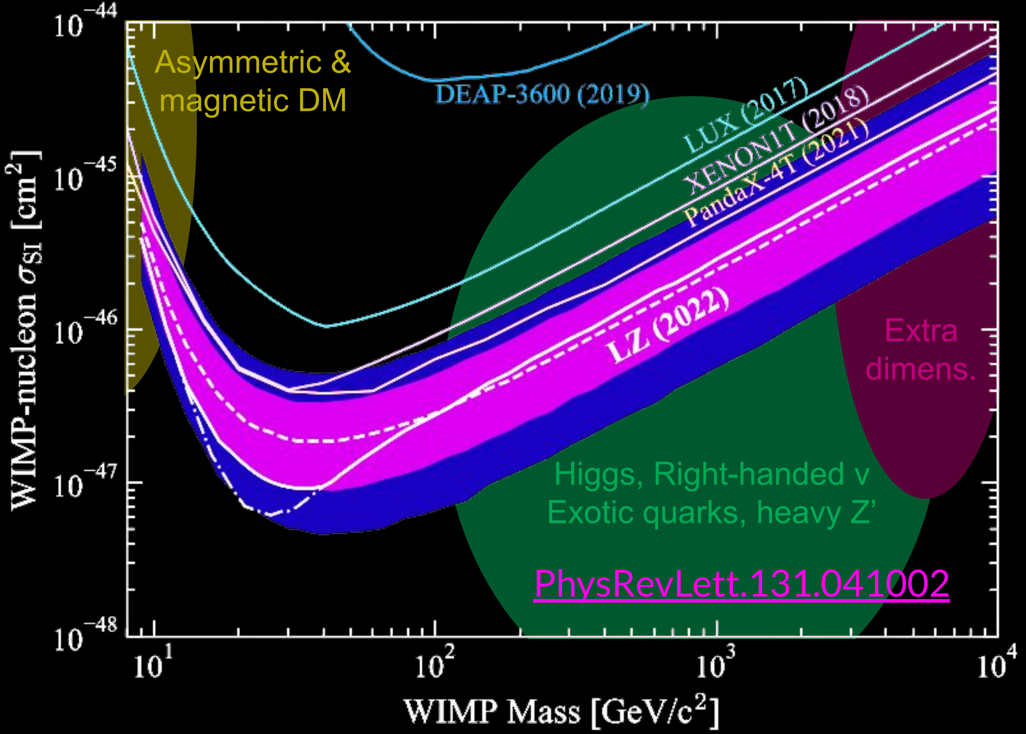
Science and Technology Facilities Council

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

No WIMPs Observed Yet…

- How we got here?
- What now?
- The future 🌈

First Science Run (2022) 90% CL upper limit for Spin Independent WIMP-nucleon scattering

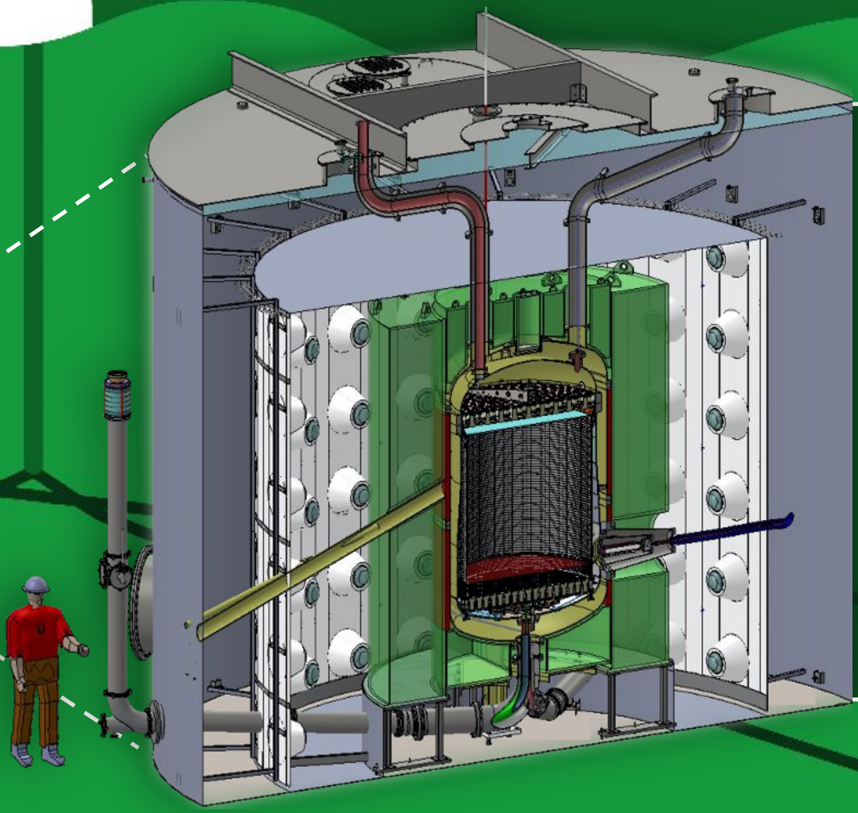


SURF
Lead, SD

The LZ experiment

↑
4850 ft.
below
ground
↓

↑
Operating
in the
Davis
Cavern



Multi-detector system:

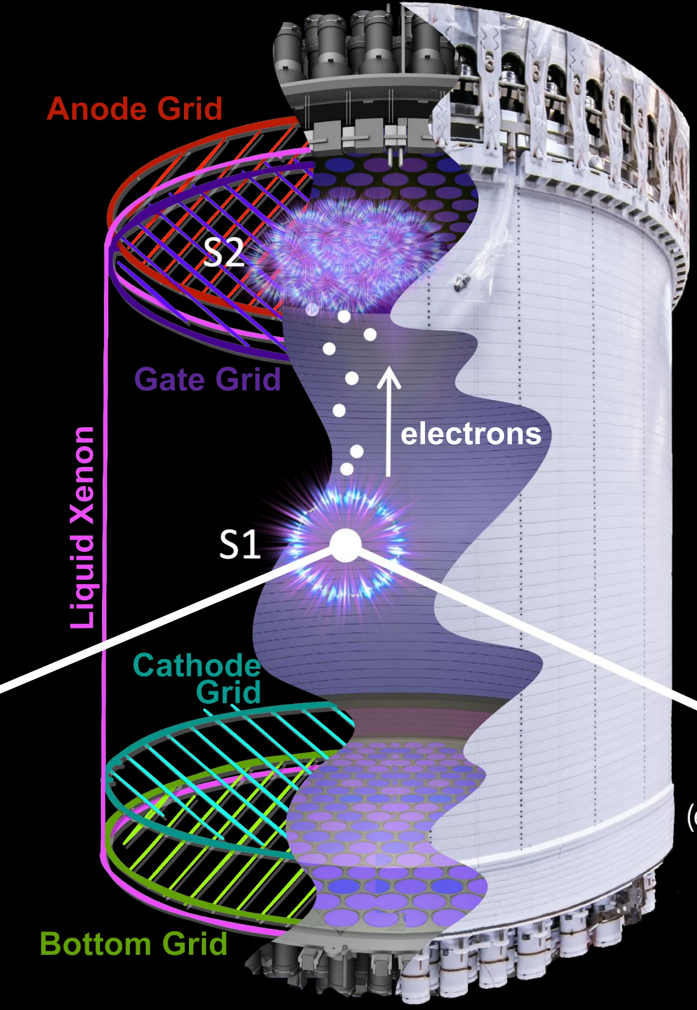
Xe TPC
- -7 tonnes of LXe
- -1.5 m tall and wide

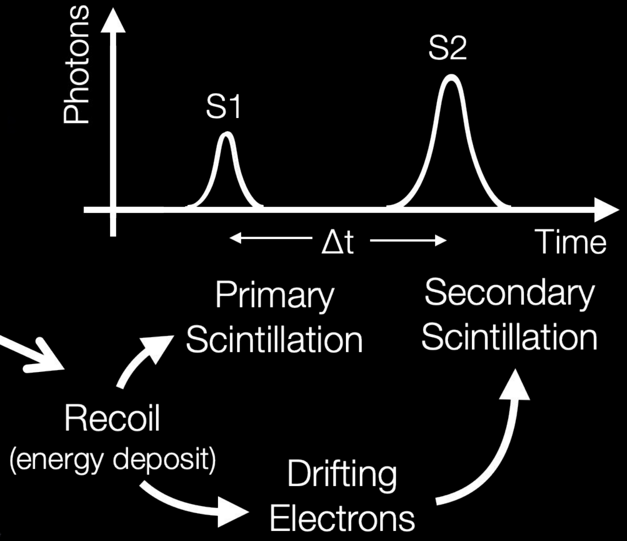
Xe Skin
- -2 tonne LXe, optically isolated
- -Anticoincidence mostly for γ-rays

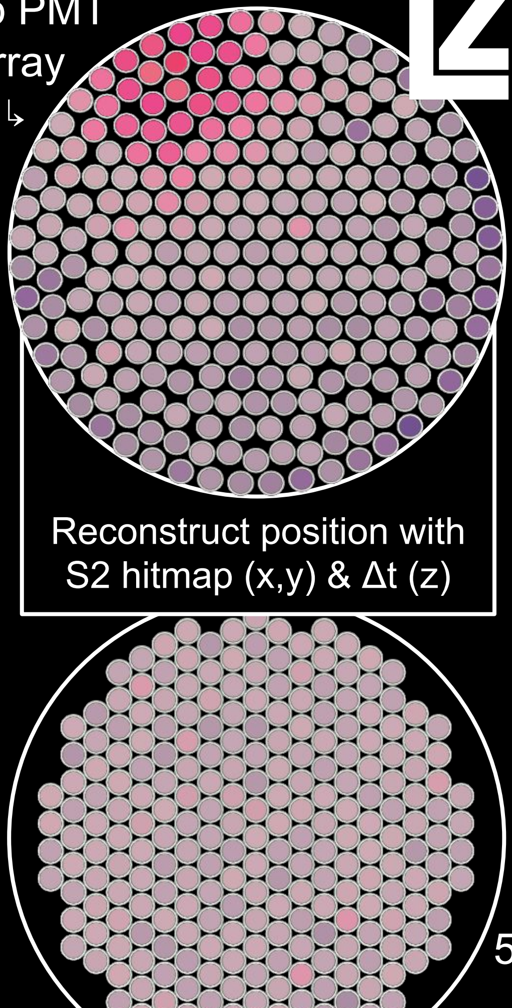
Outer detector (OD)
- -17 tonne GD-loaded liquid scintillator
- -Anticoincidence mostly for neutrons

← New neighbors

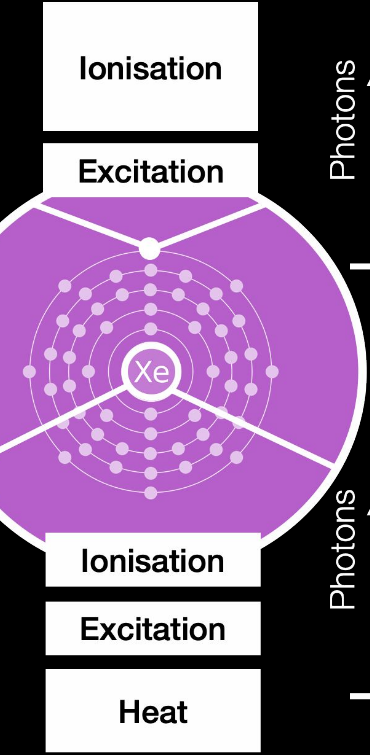
Time Projection Chamber

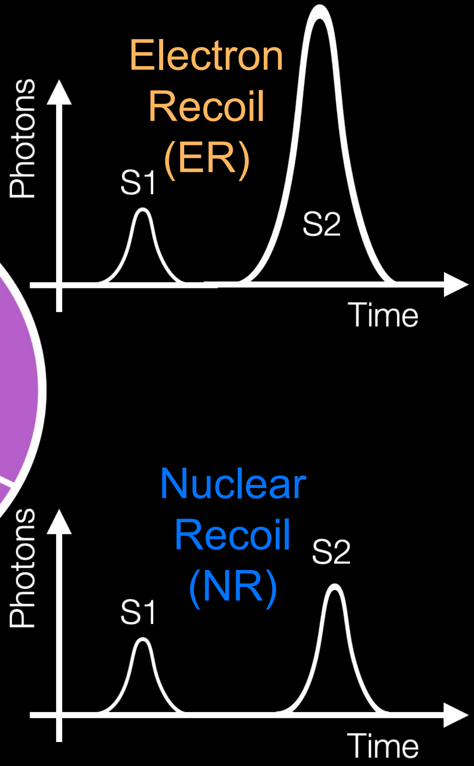


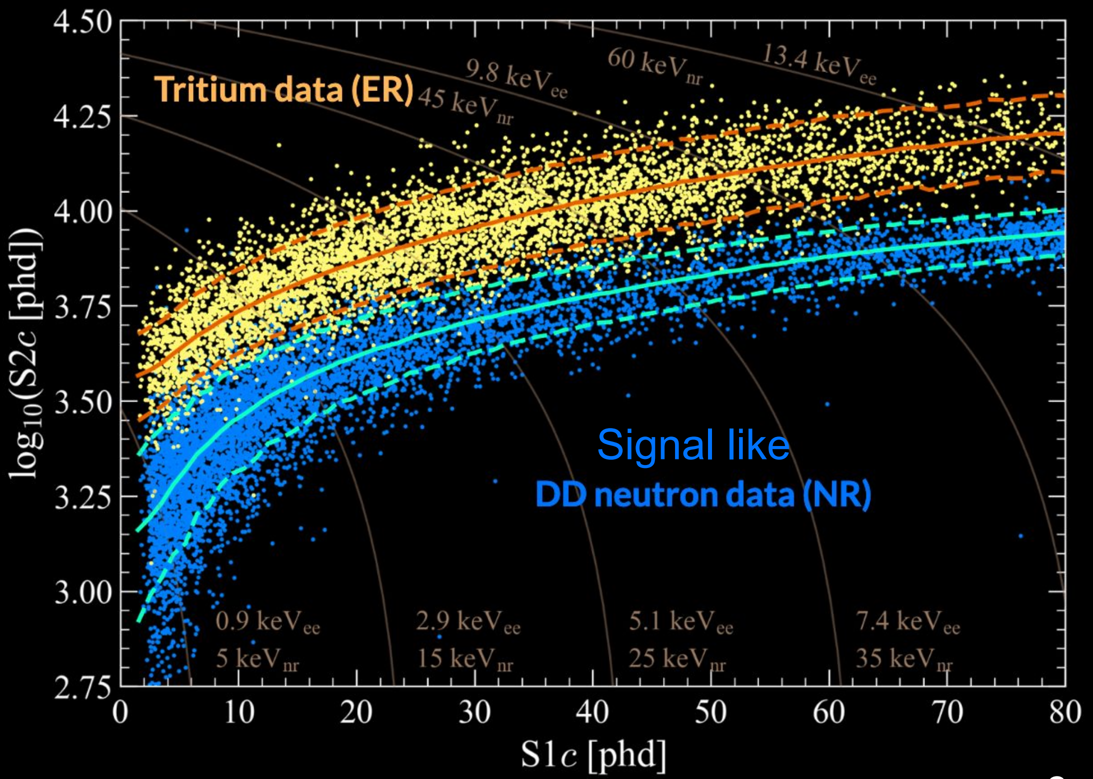




Discrimination & Calibration





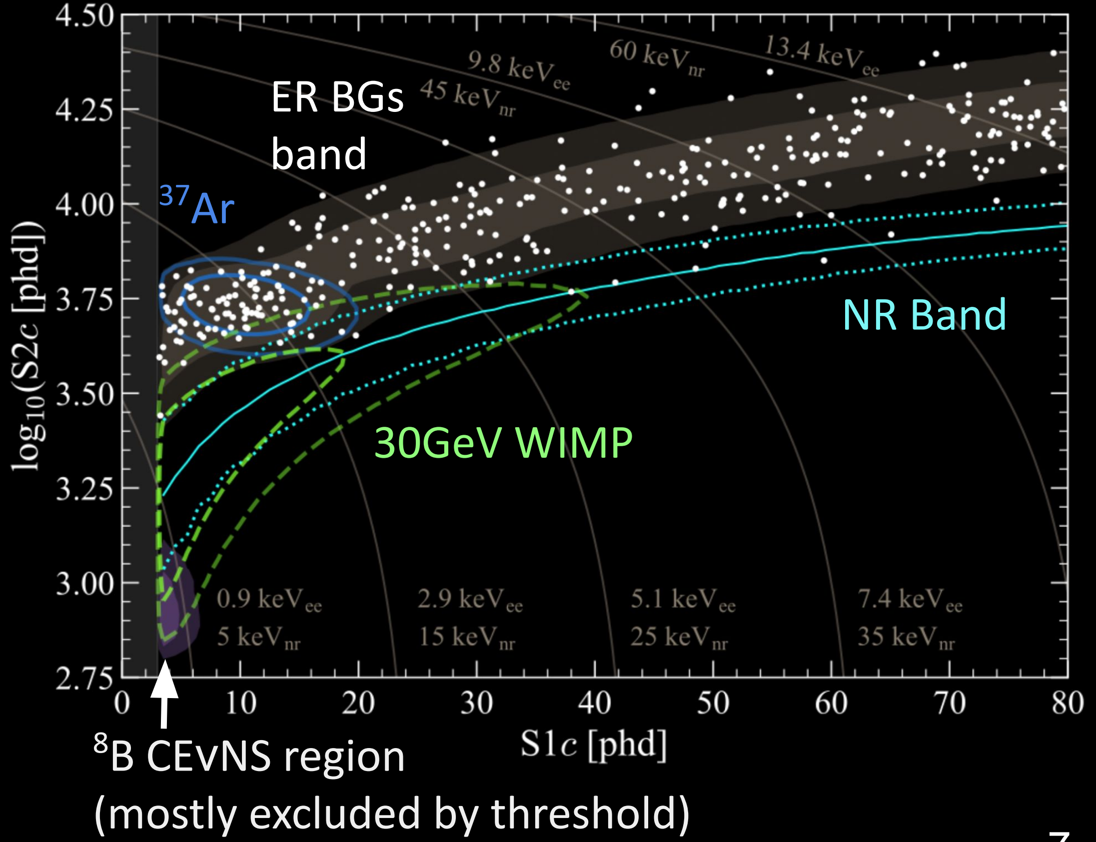


PhysRevLett.131.041002

First science run

- 60 days
- 335 Events (after all cuts)
- 5.5 tonne fiducial
- >97% PMTs operational
- Ar-37 contribution has decayed away

99.9% rejection of ERs below the NR median
&
88% n-tagging efficiency (AmLi)



PhysRevLett.131.041002

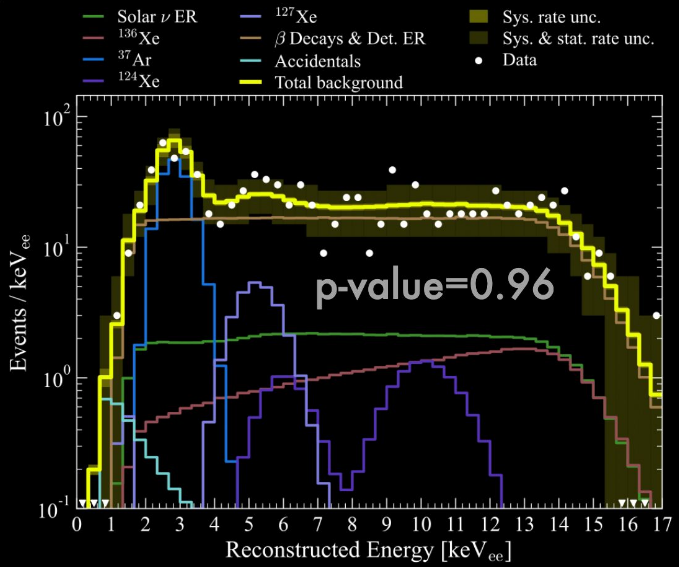
Background Model Fit

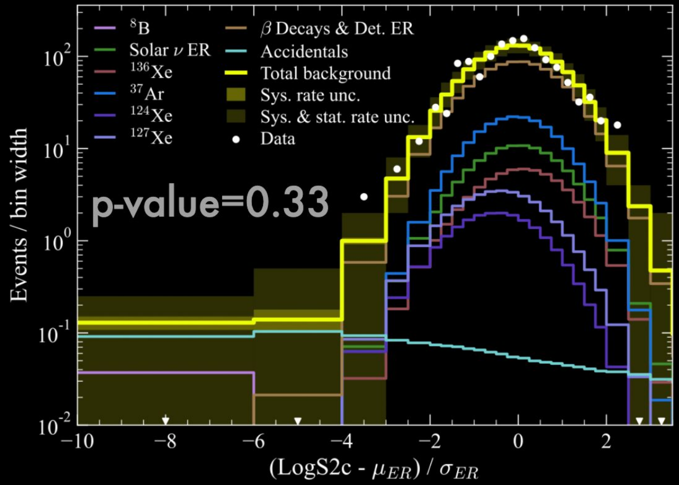
For all tested WIMP masses, best fit is zero events

Source	Expected Events	Fit Result
β decays + Det. ER	215 ± 36	222 ± 16
ν ER	27.1 ± 1.6	27.2 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.1 ± 2.4	15.2 ± 2.4
^{8}B CEνNS	0.14 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	273 ± 36	280 ± 16
^{37}Ar	[0, 288]	$52.5^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	–	333 ± 17

More info in the next talk (Dan Kodroff)

PhysRevLett.131.041002

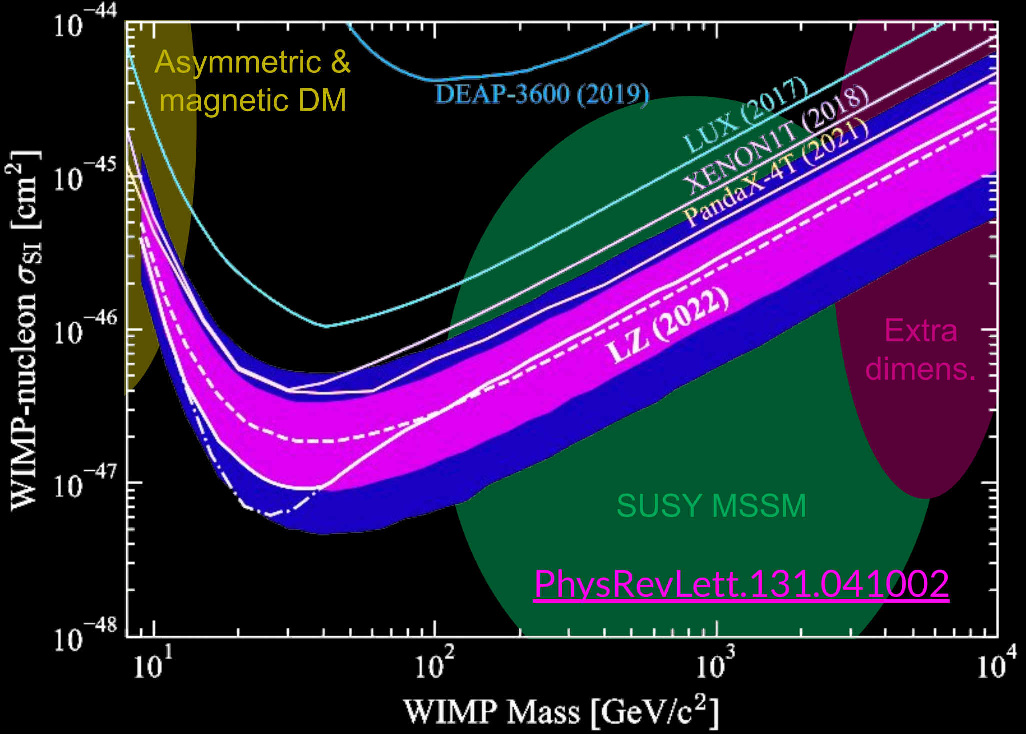




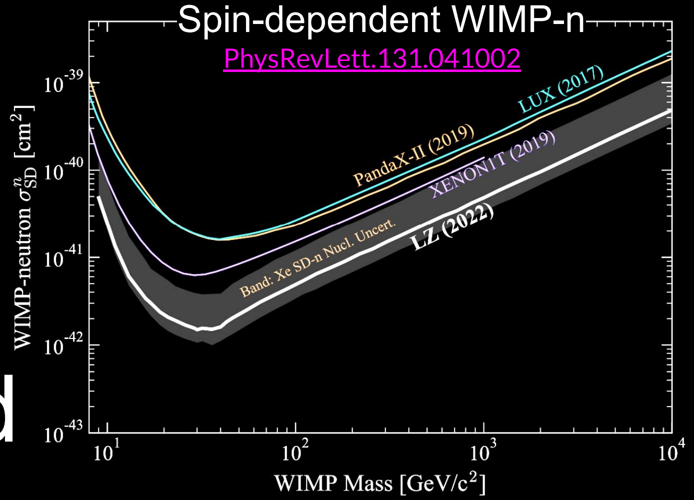
No WIMPs Observed Yet…

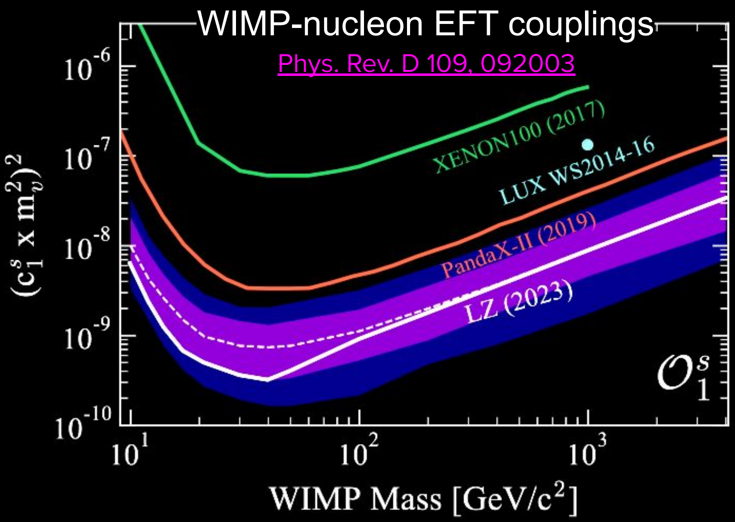
- How we got here?
- What now?
- The future 🌈

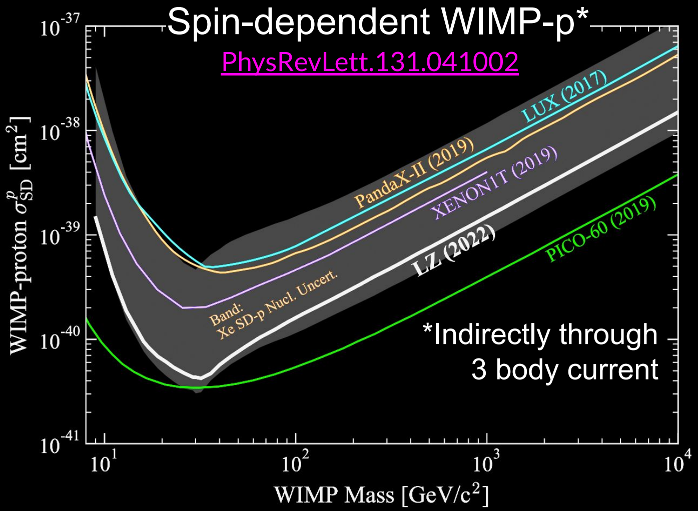
First Science Run (2022) 90% CL upper limit for Spin Independent WIMP-nucleon scattering

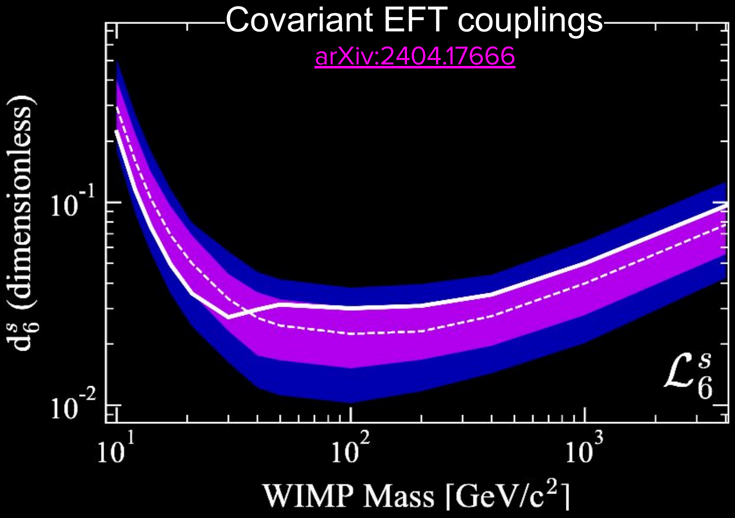


Beyond vanilla WIMP

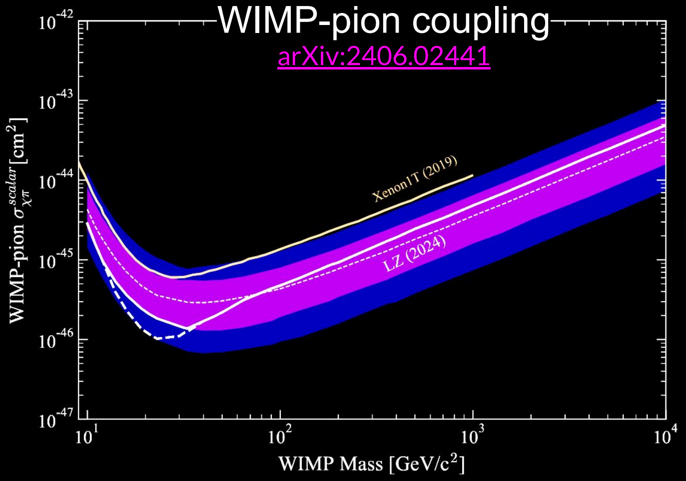


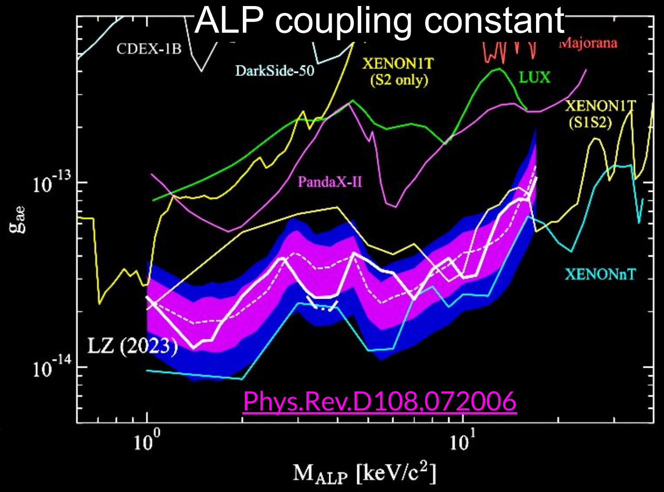


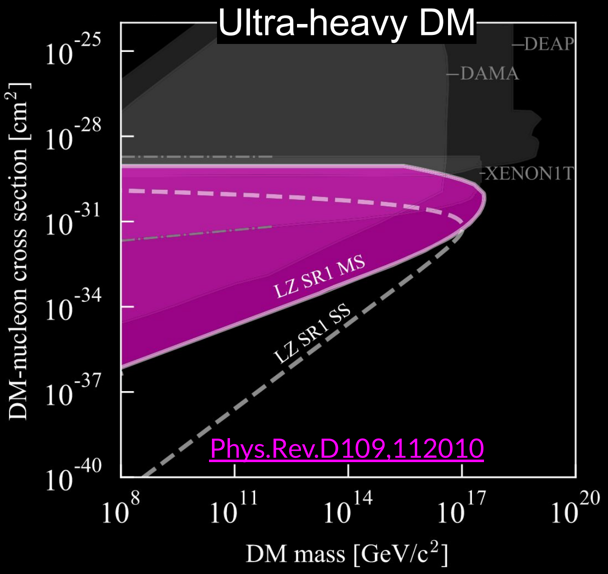


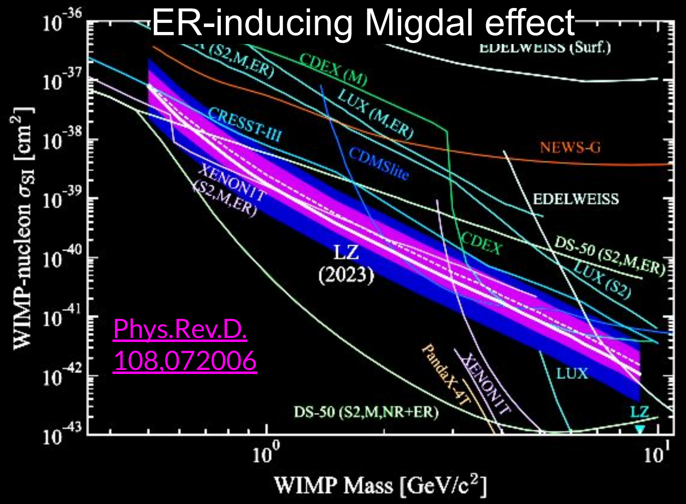


Beyond vanilla WIMP





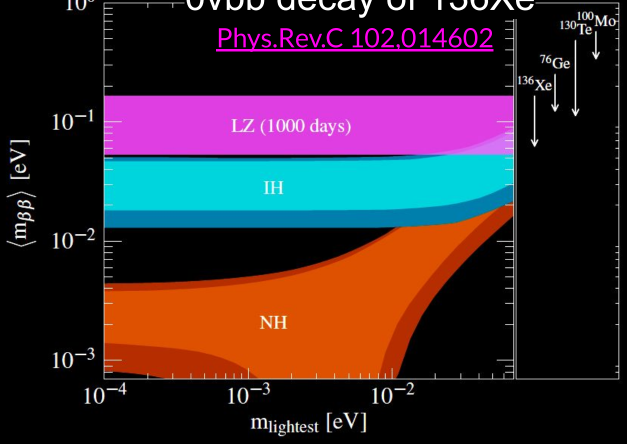




And much more…

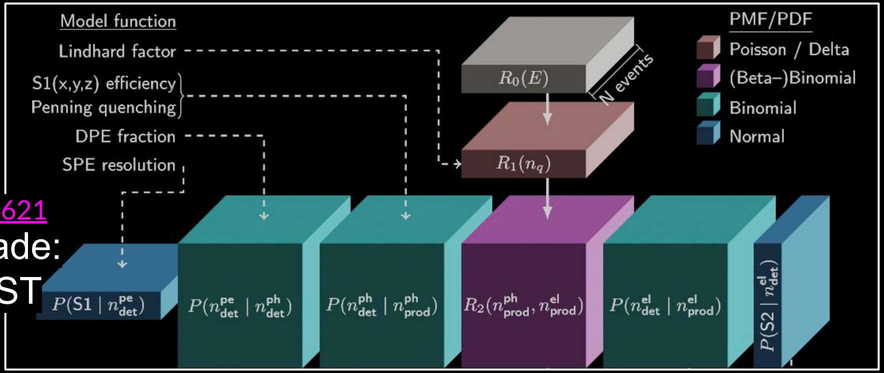
0vbb decay of 136Xe

Phys.Rev.C 102,014602

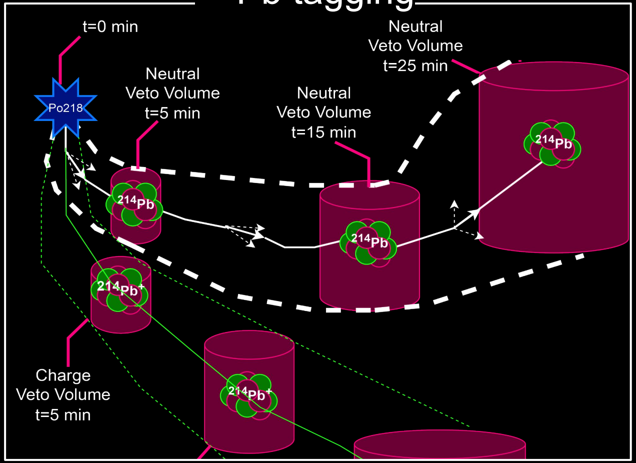


arXiv:2204.13621

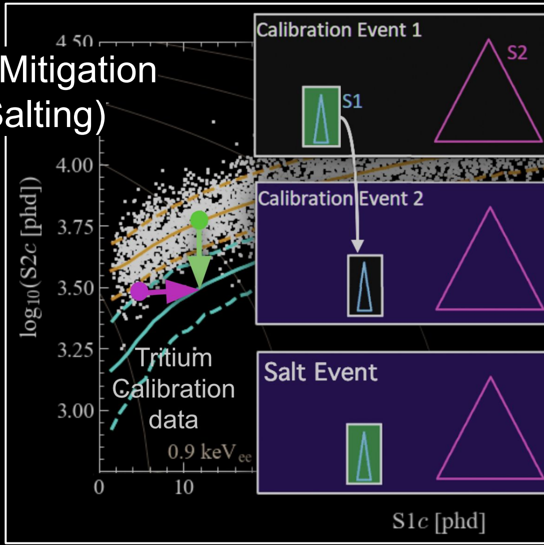
Stats upgrade: FlameNEST



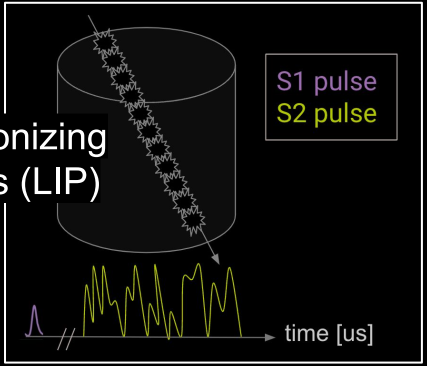
^{214}Pb tagging



Bias Mitigation (Salting)



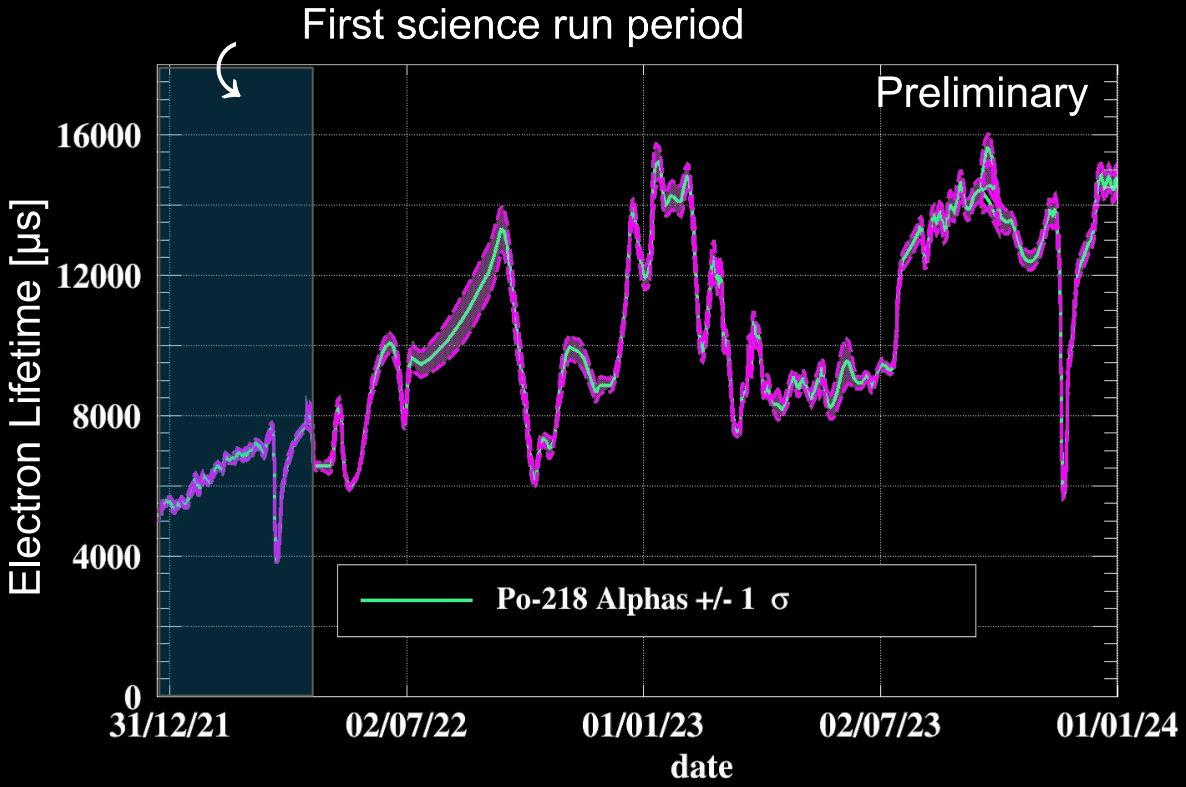
Lightly ionizing particles (LIP)



… including ^{8}B CEvNS discovery, SN readiness …

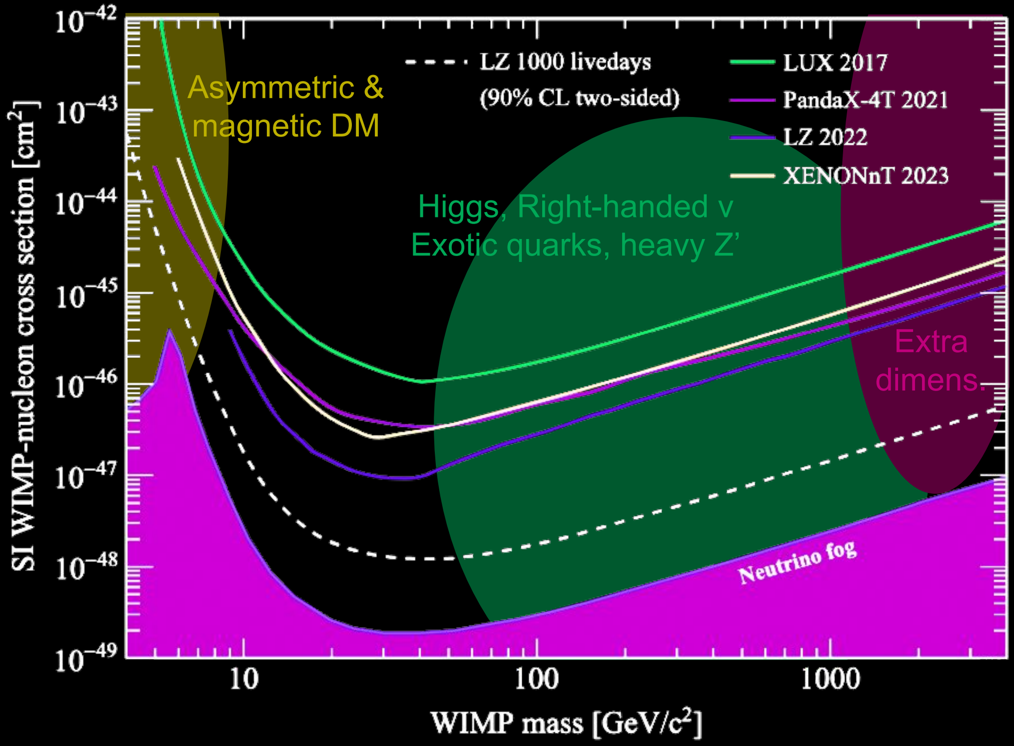
Keep taking good data

- No major down times since first science run
- Purity maintained well above requirements
- Regular Calibrations (calibration overview: arXiv:2406.12874v2)



No Dark Matter Observed Yet…

- How we got here?
- What now?
- The future 🌈

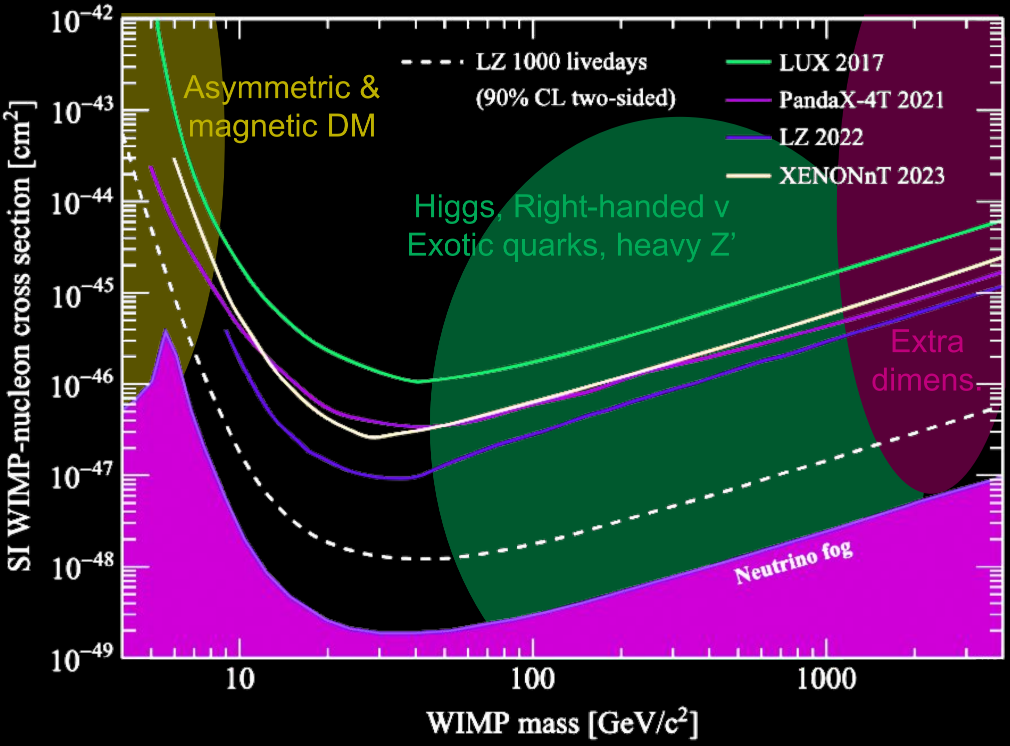


Phys.Rev.D101,052002

The future of LZ

- 1000 liveday exposure goal, only 60 published so far)
- Keep expanding physics output
- Keep improving analysis

New WIMP search results by the end of 2024

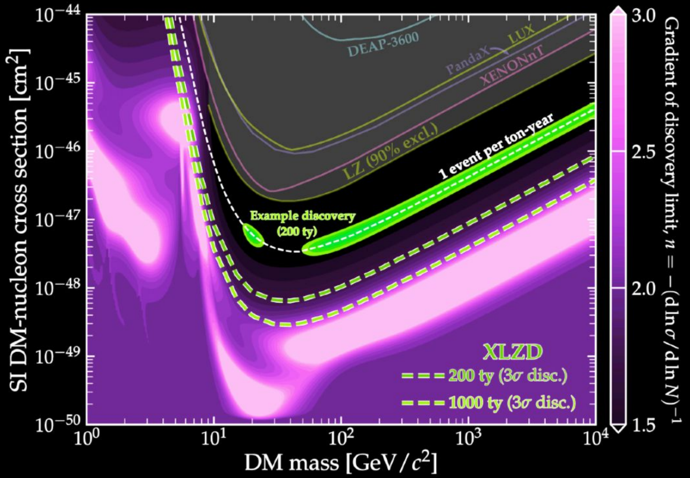


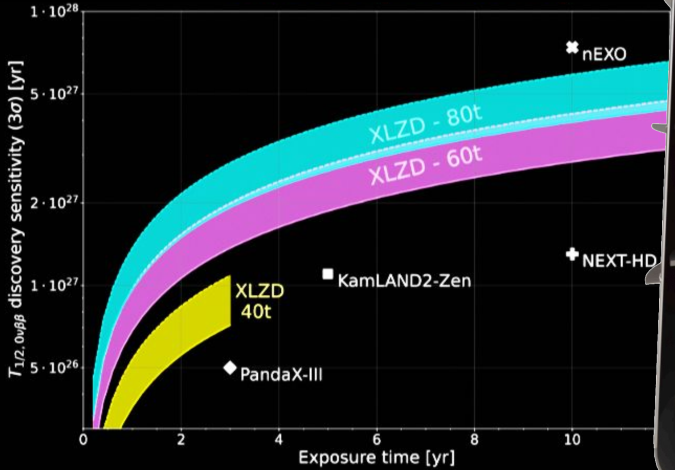
Phys.Rev.D101,052002

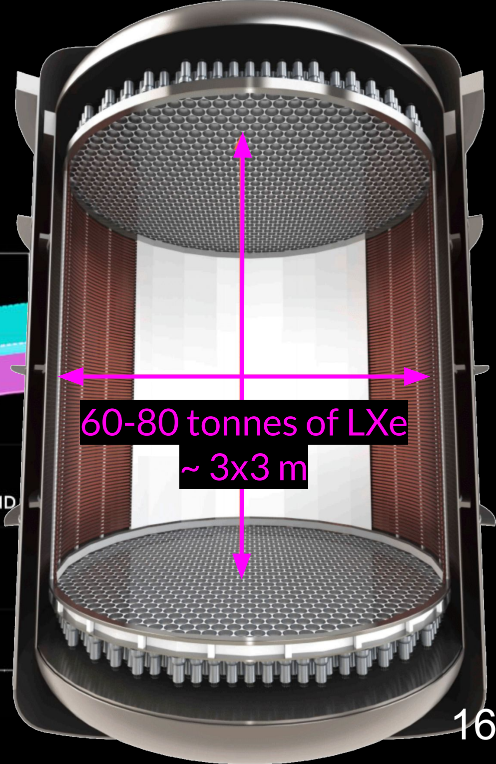
Beyond LZ

XENON + LZ + DARWIN collaborations

Aim to build the definitive rare event observatory

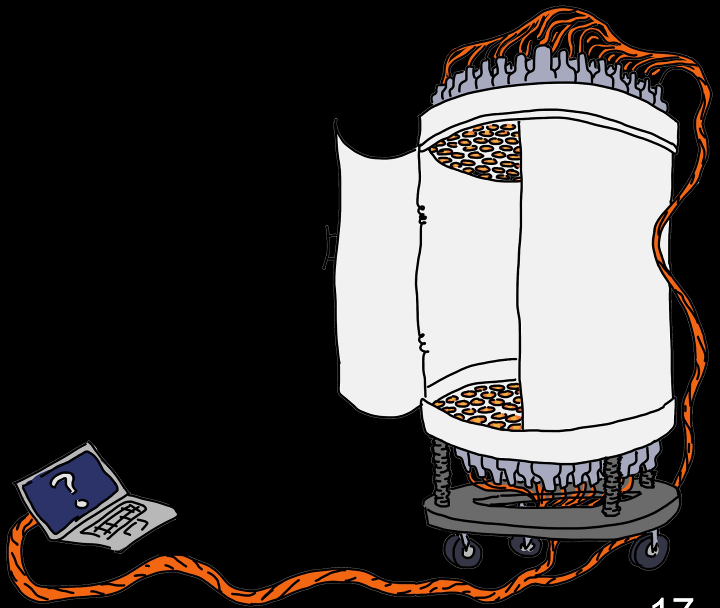




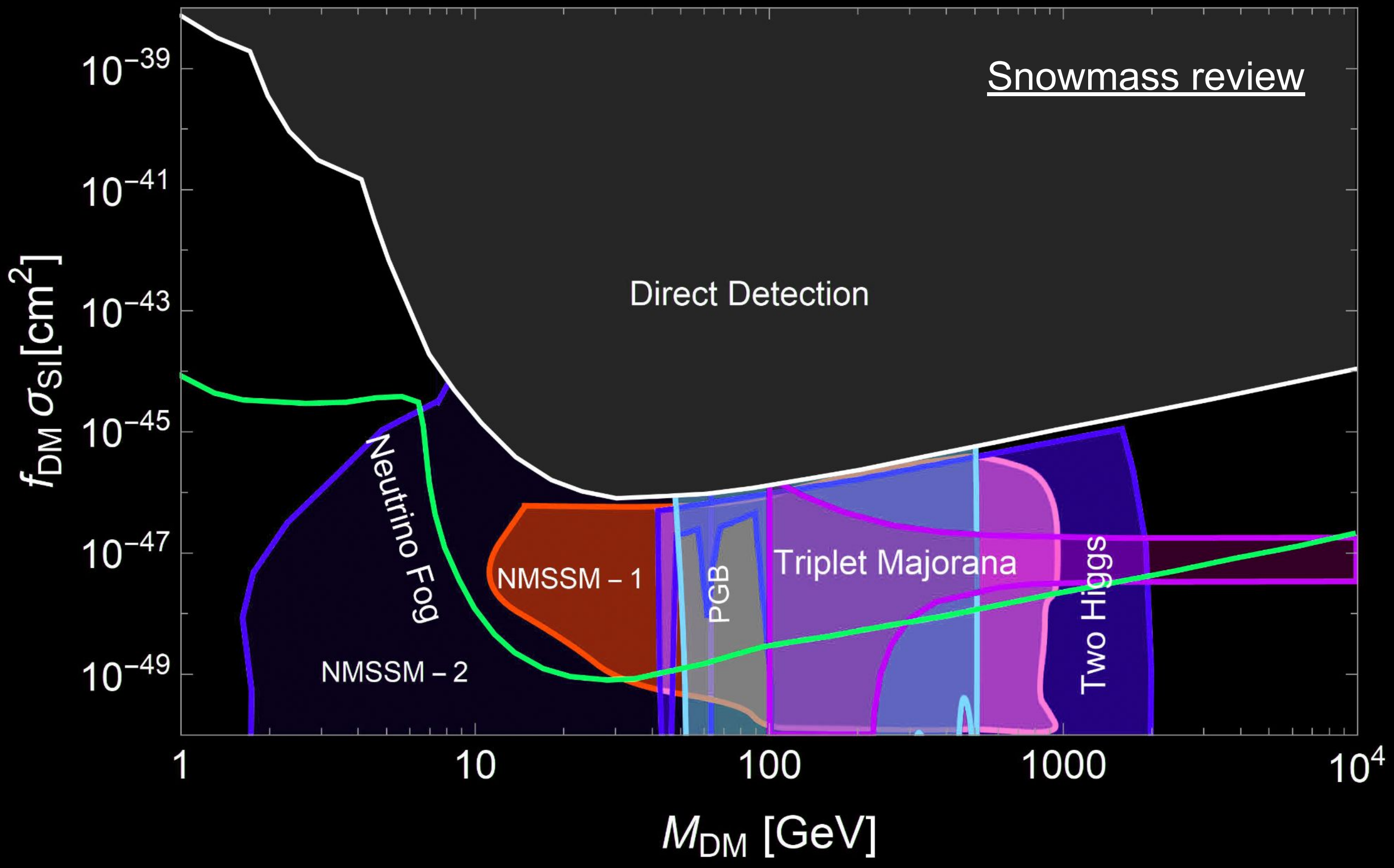


J.Phys.G:50 013001

Thank you



Back-up



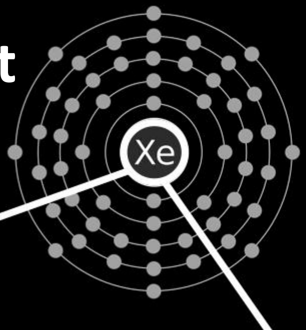
Weakly Interacting Massive Particle (**WIMP**)

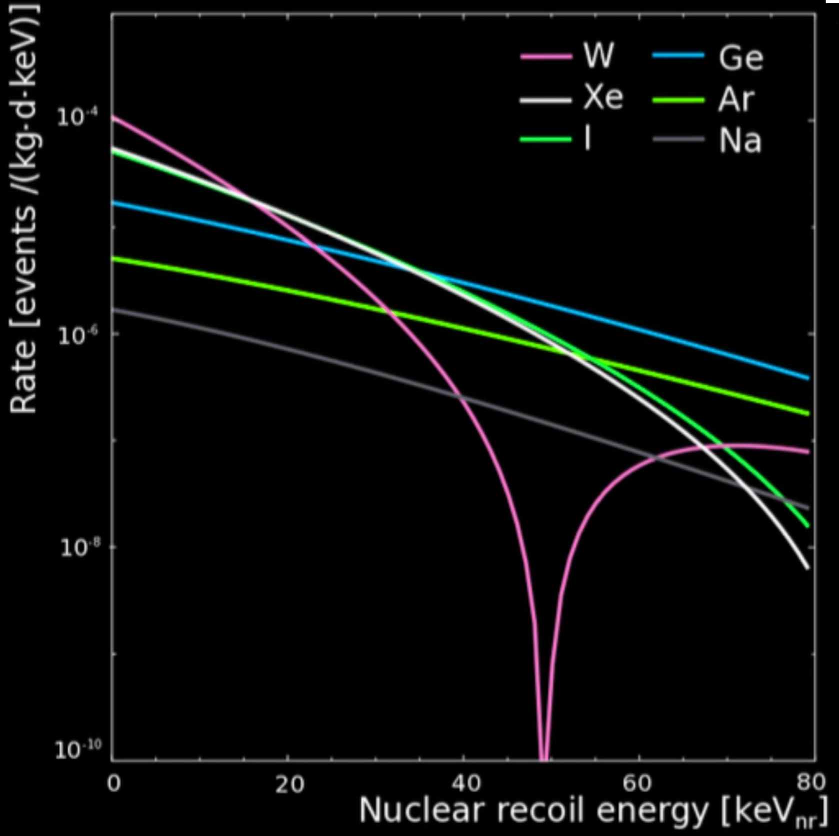
WIMP Scattering

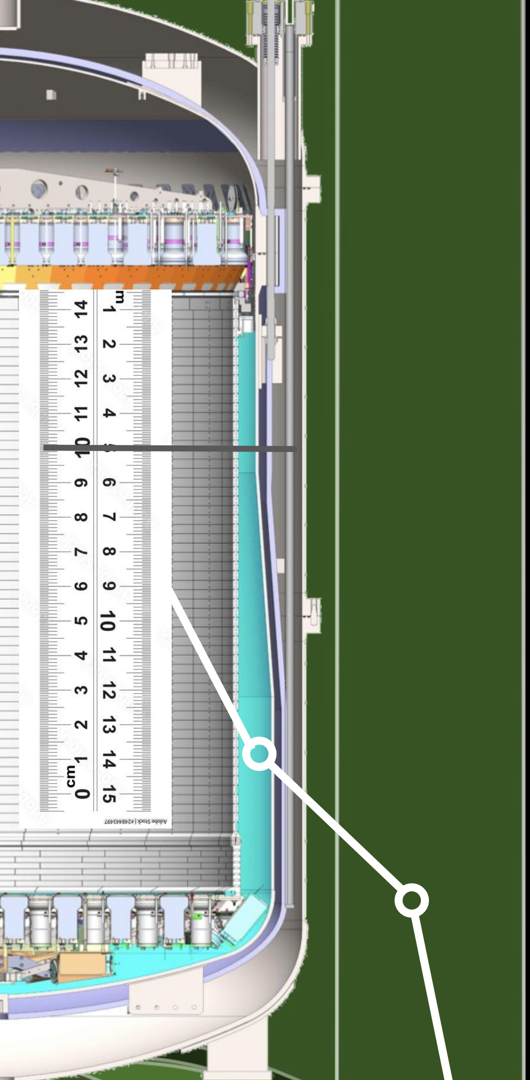
Standard Halo Model: MB velocity distribution @ 0.3GeV/cm^3

Small recoils O(10 keV)
→ Need low threshold

A few events per year
→ Need lots of target mass







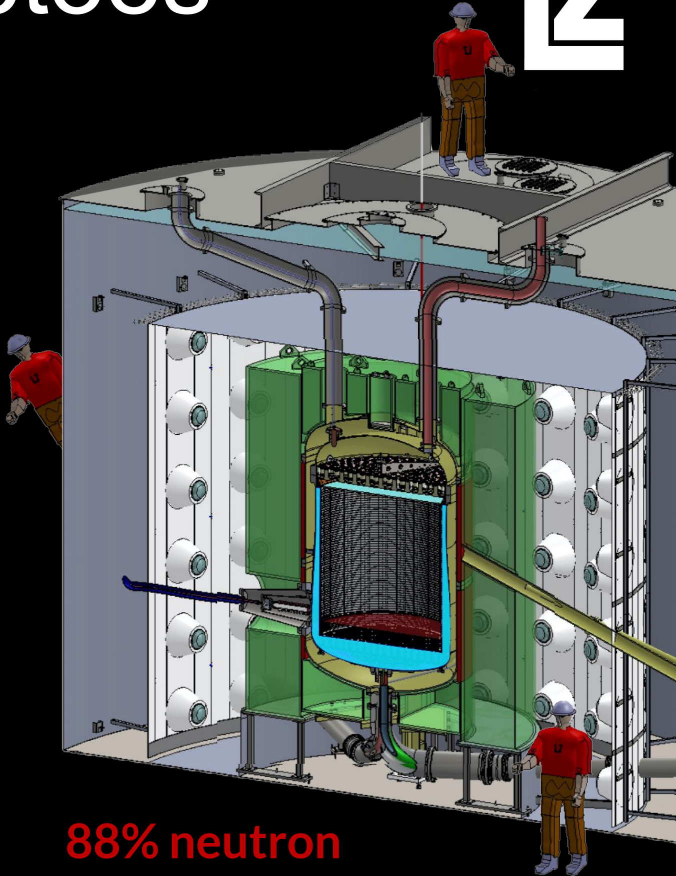
Coincidence Vetoes

LXe Skin:

- 2t of LXe
- 1” & 2” PMTs
- Optically isolated
- Veto γ-rays

The Outer Detector (OD):

- 17t of Gd-doped liquid scintillator in acrylic
- 120x 8” PMTs
- Veto γ-rays and neutrons



88% neutron tagging efficiency

Possible contaminants

- Uranium and Thorium
  - Produce α, β, and γ
  - Secondary neutron production through α-n
  - Produce Rn which, as a gas, diffuses
- Krypton and argon dissolved in xenon
  - β and γ decaying isotopes
- Other radioactive elements— ^{60}Co and ^{40}K are most common
- Cosmic activation
- Cavern wall radioactivity

Mitigation

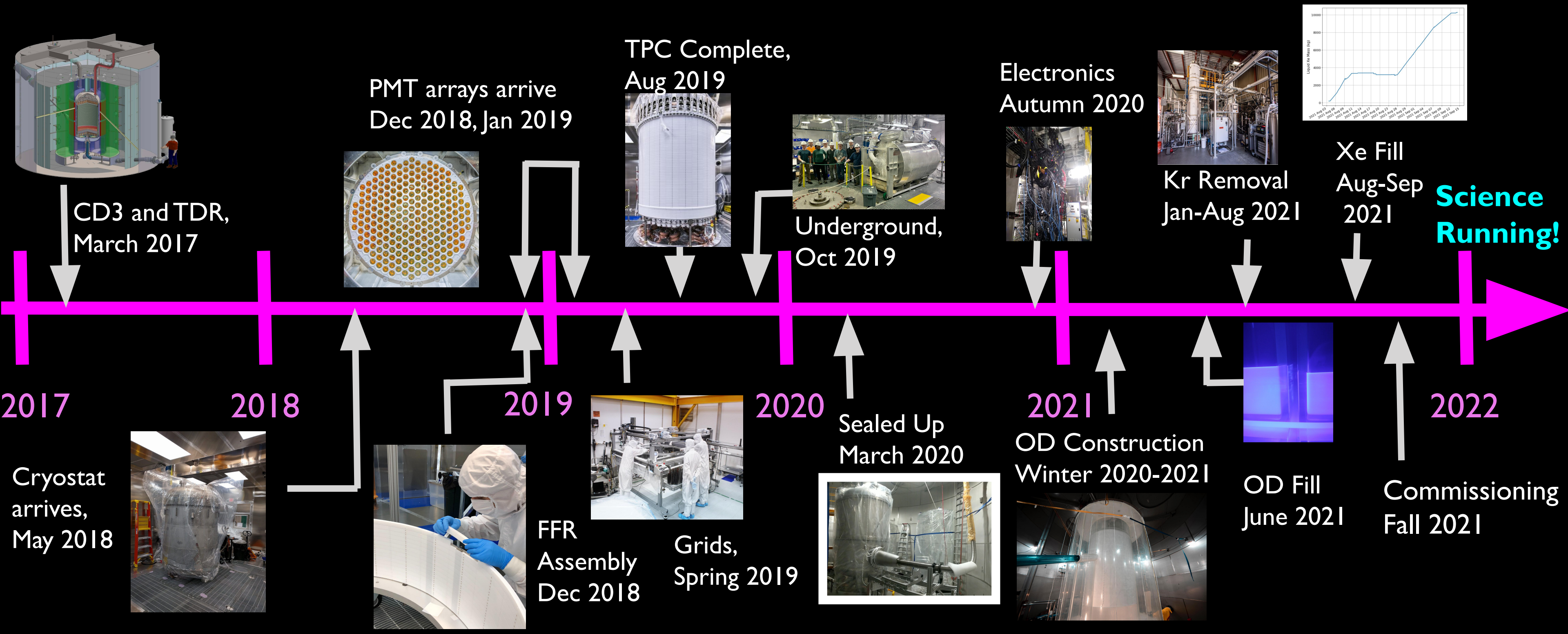
- Enormous screening program for all materials
  - Ge detectors, ICPMS, Rn emanation, Neutron activation analysis
- Clean Assembly
  - Rn-reduced cleanroom (and dust reduction)
- Xe purification
  - ^{39}Ar and ^{85}Kr removal with charcoal chromatography
  - In-situ

HPGe counters at SURF

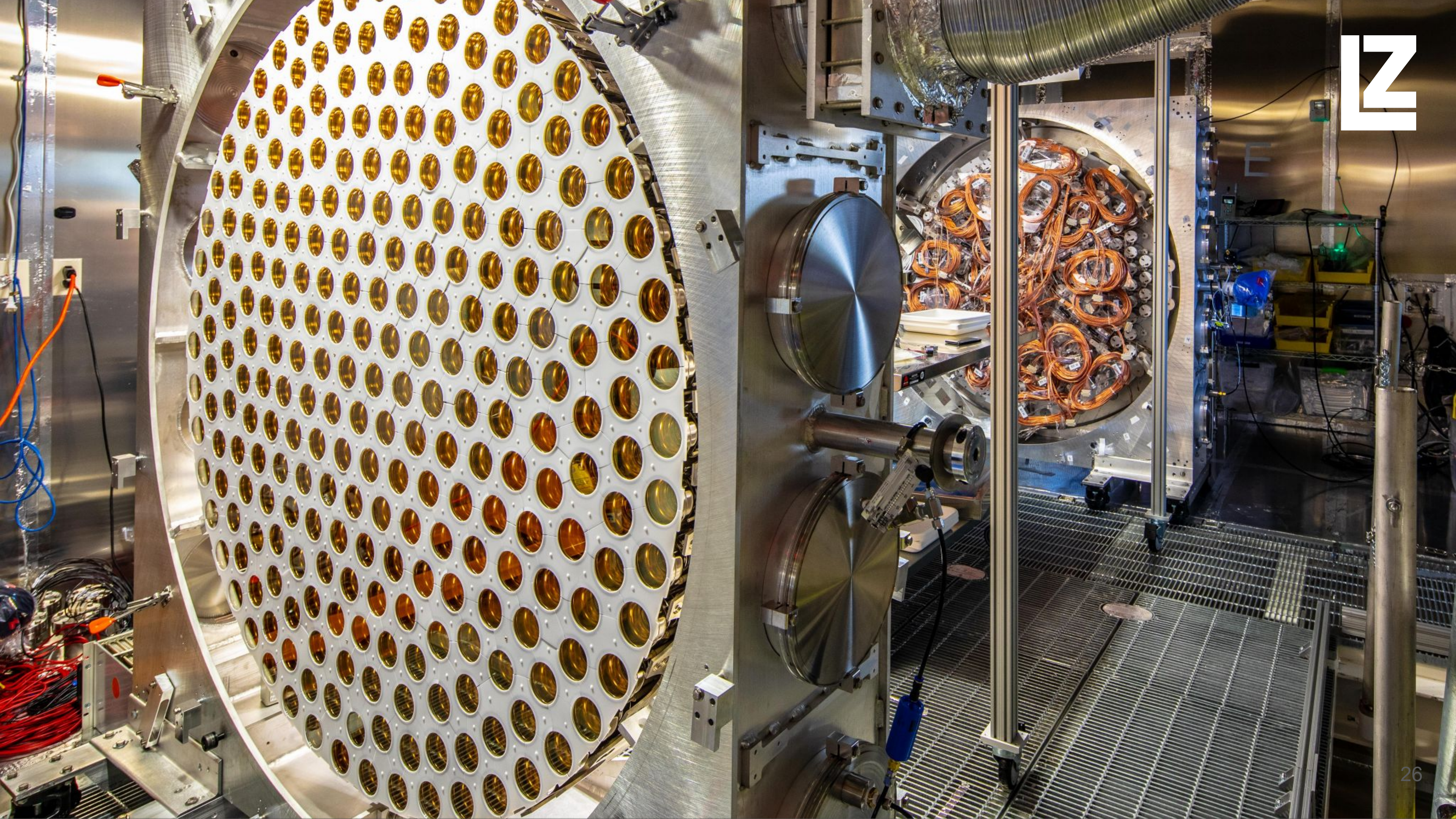
ICPMS UCL

Boulby BUGS

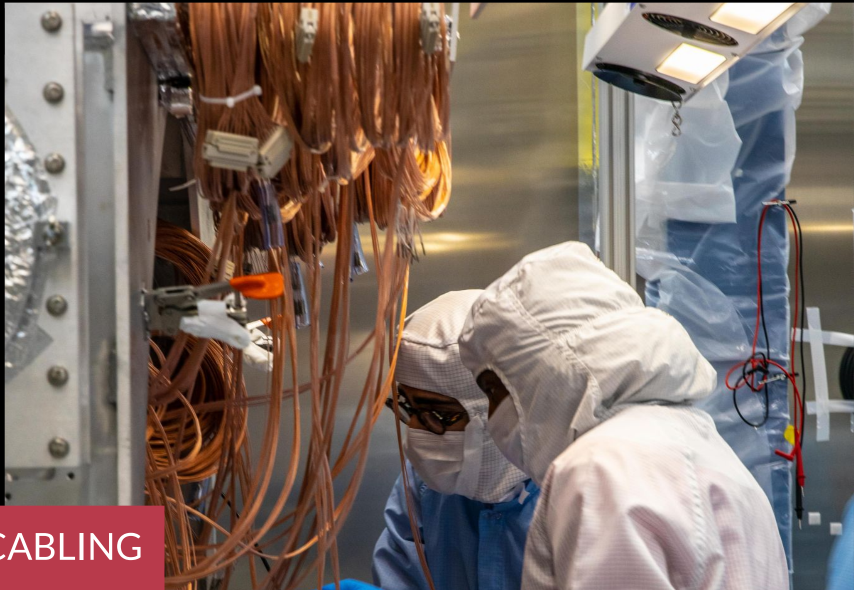
Timeline


CD3 and TDR,
March 2017
PMT arrays arrive
Dec 2018, Jan 2019
TPC Complete,
Aug 2019
Underground,
Oct 2019
Electronics
Autumn 2020
Kr Removal
Jan-Aug 2021
Xe Fill
Aug-Sep
2021
Science
Running!
2017
2018
2019
2020
2021
2022
Cryostat
arrives,
May 2018
FFR
Assembly
Dec 2018
Grids,
Spring 2019
Sealed Up
March 2020
OD Construction
Winter 2020-2021
OD Fill
June 2021
Commissioning
Fall 2021

Radon reduced cleanroom at SURF (surface) at < 4 mBq/m^3 Operated as Class 100 (ISO 5)



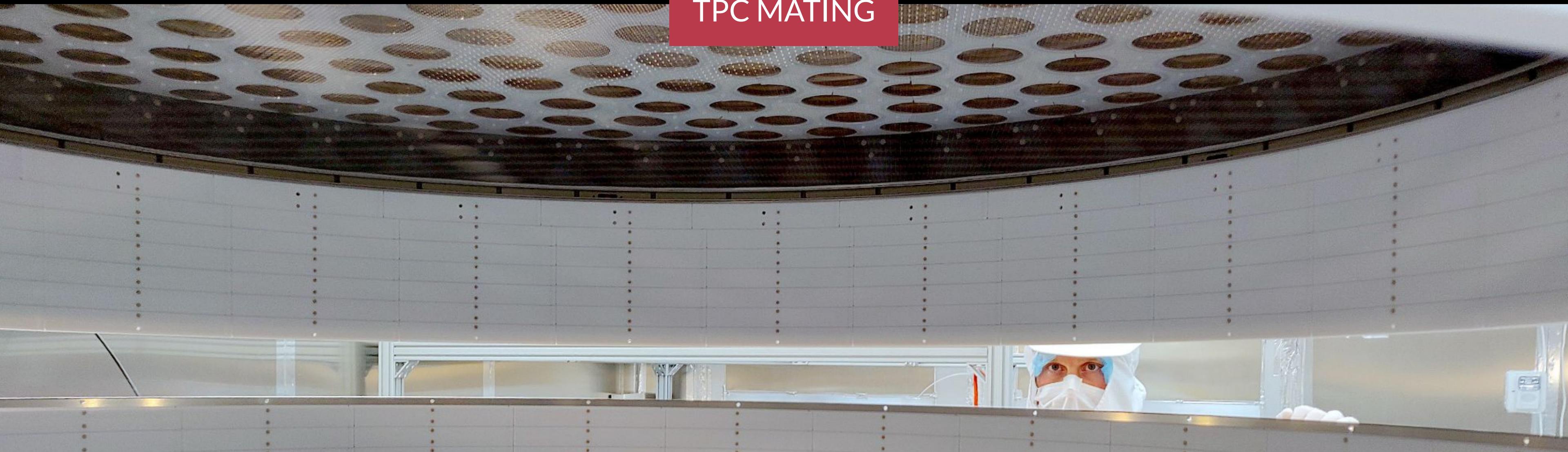
GRID CONSTRUCTION

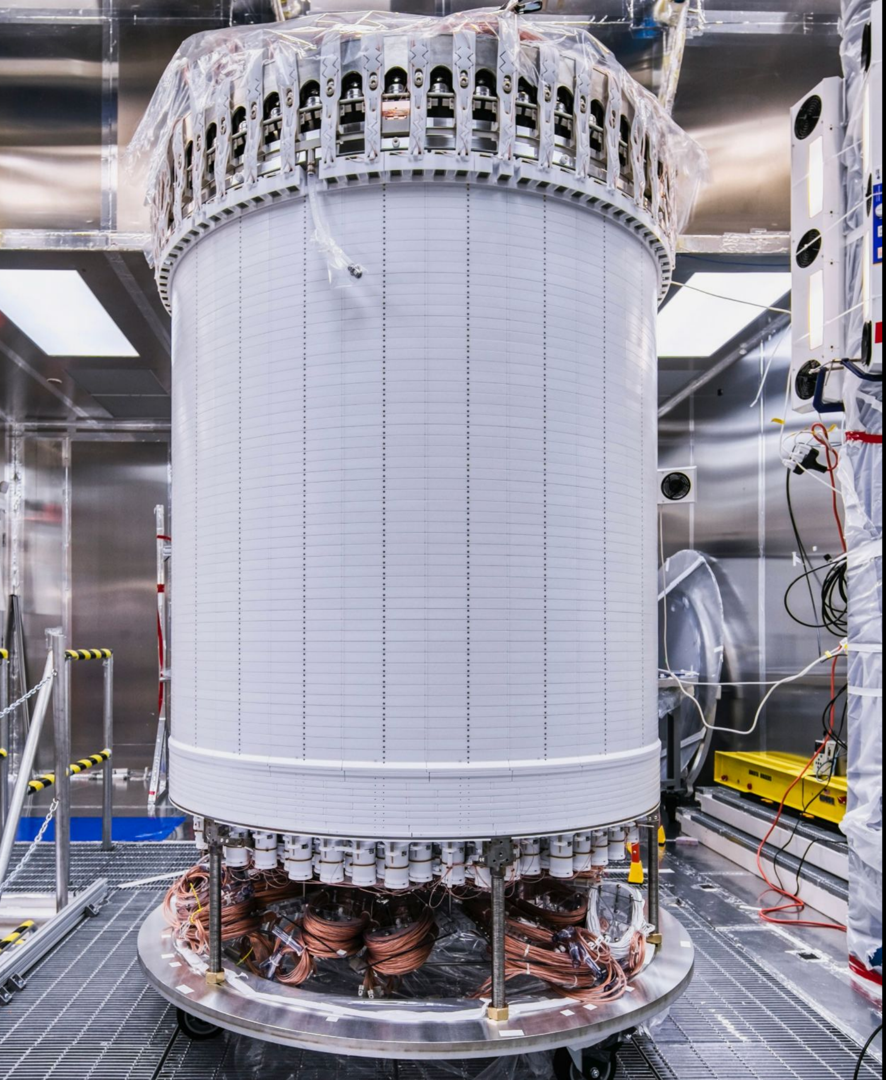


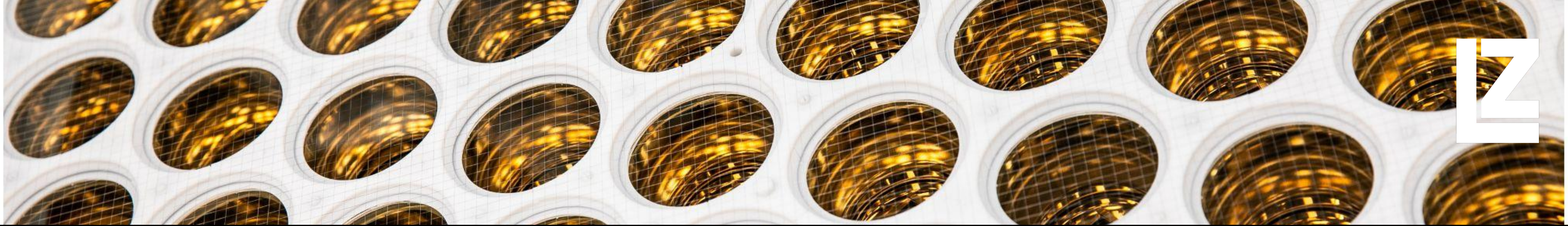
ARRAY CABLING

FIELD CAGE ASSEMBLY

TPC MATING

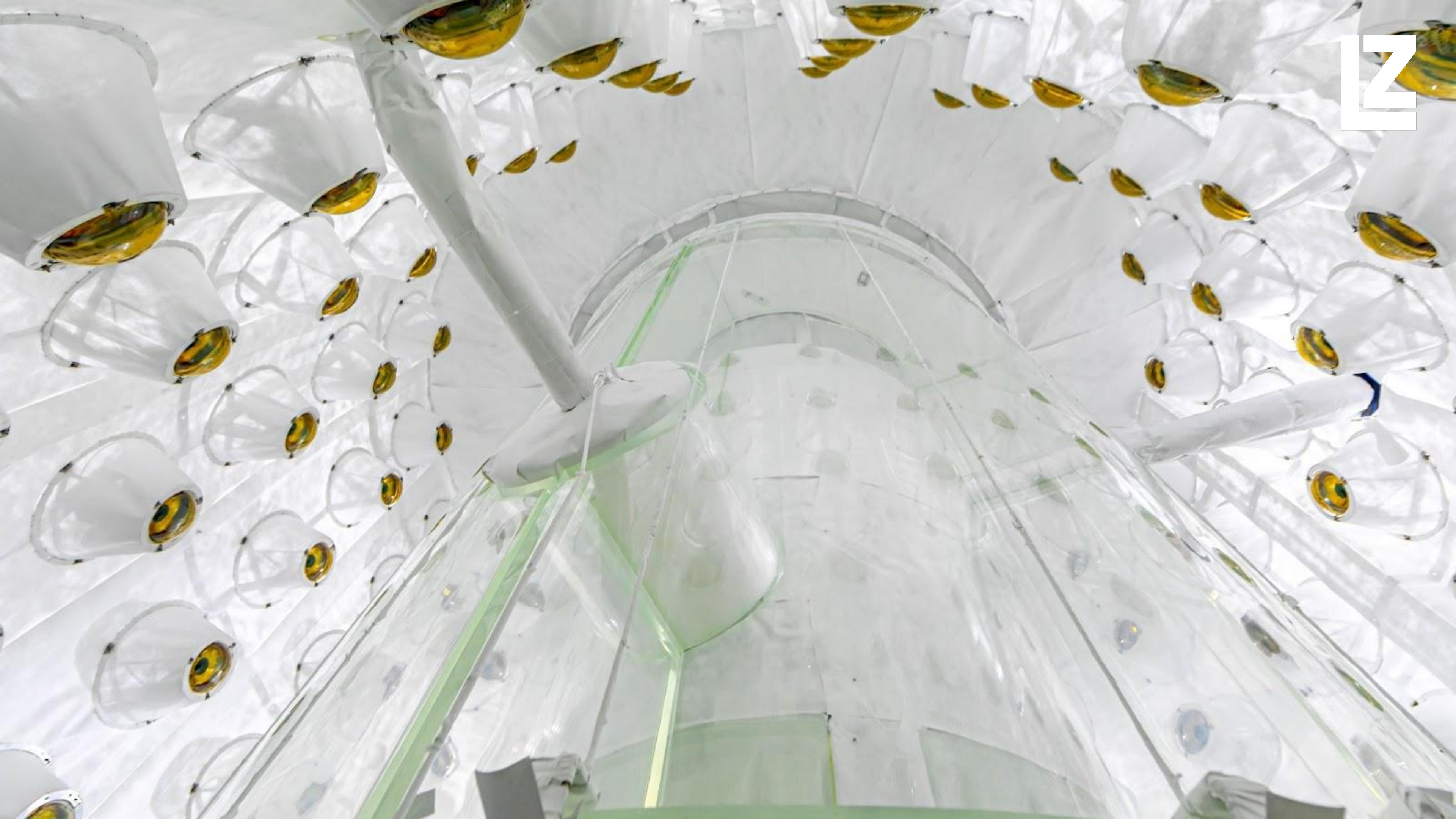






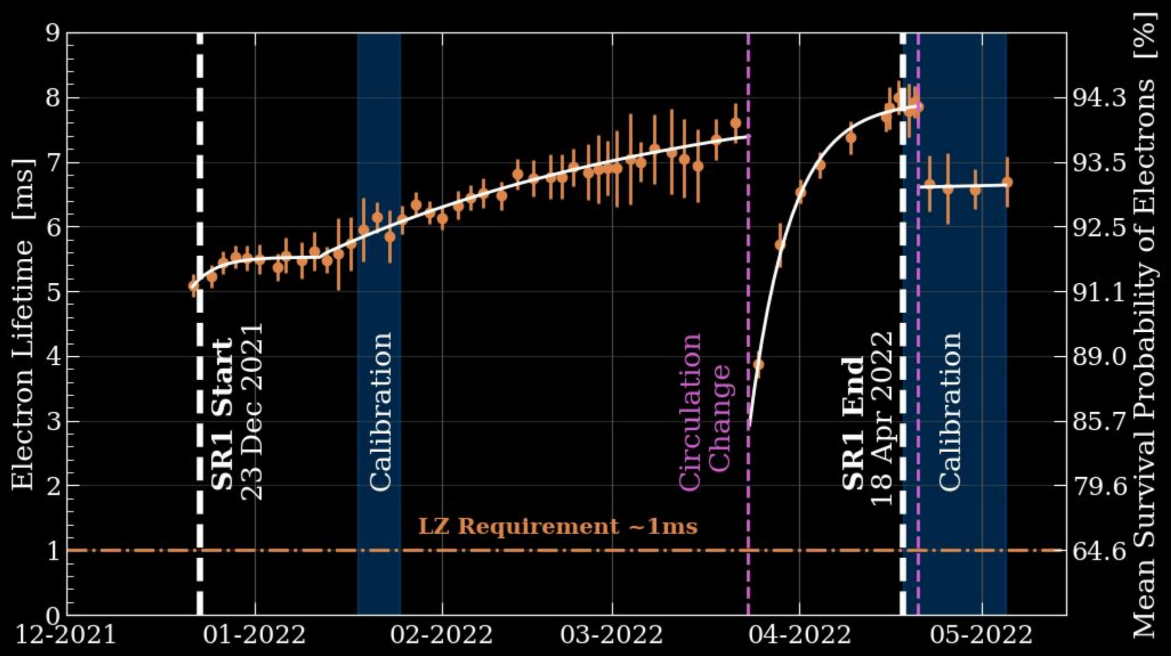

UG TRANSPORTATION

INNER CRYOSTAT INSERTION


LZ

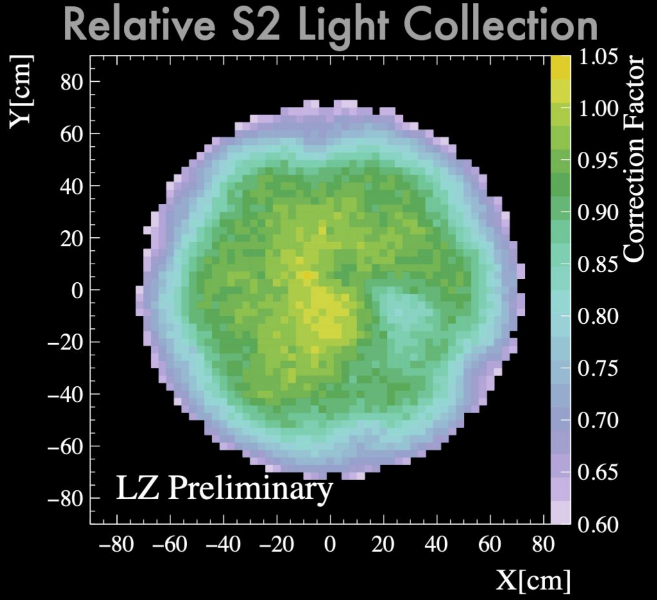
Science Run 1

- Livetime 60 days
- PMTs: >97% operational throughout run
- Liquid: 174.1 K (0.02%)
- Gas: 1.791 bar(a) (0.2%)
- Gas circulation: 3.3t/day
- Drift field: 193 V/cm (4% in fiducial volume)
- Extraction: 7.3 kV/cm in Gas (8 kV gate-anode ΔV)



Calibrations

- Spatial non-uniformity corrections
- ER band response
- NR band response
- Veto efficiencies
- Data selection efficiency



ER:

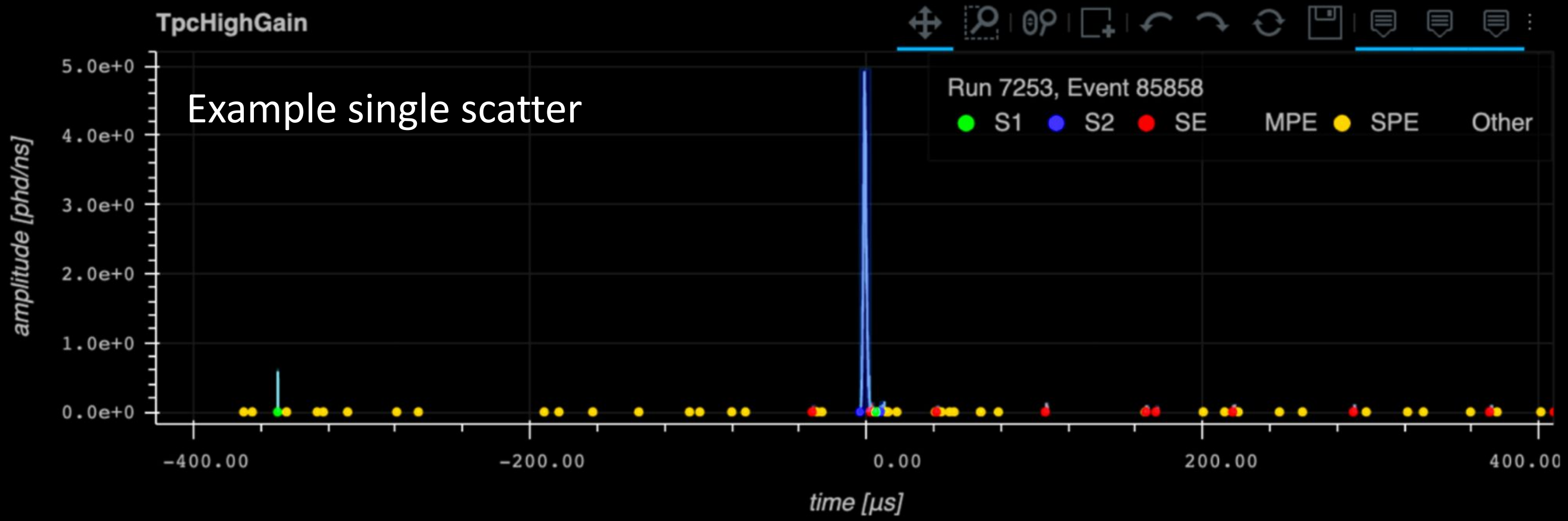
- 83mKr: monoenergetic ERs, 32.1 keV and 9.4 keV
- 131mXe: monoenergetic ER, 164 keV
- CH3T (tritium): continuum betas, 18.6 keV
- Activation lines

NR:

- Deuterium-deuterium (DD): triggered 2.45 MeV neutrons
- AmLi: continuum neutrons, isotropic
- Alphas
- And more (220Rn, YBe, 252Cf, 22Na, 228Th, etc)

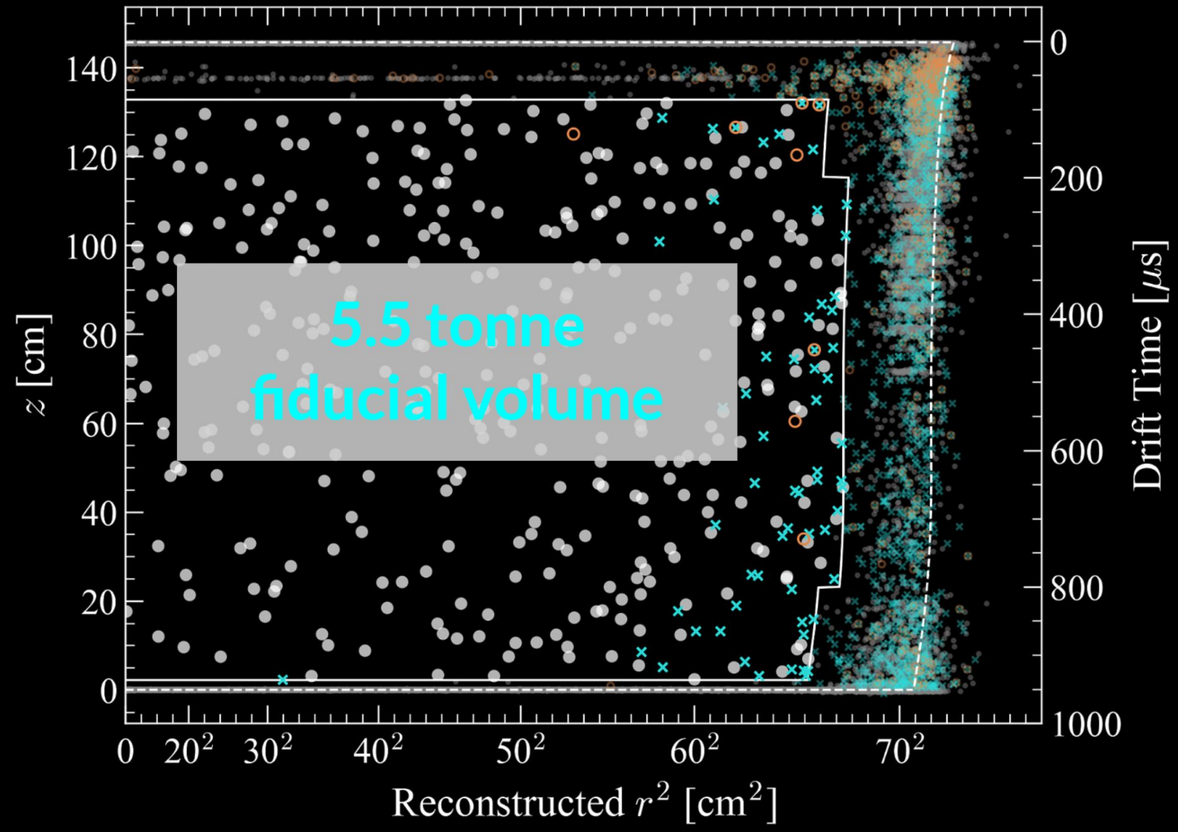
Looking for WIMPs

- One S1 (photons) followed by one S2 (drifted electrons) with no activity in the veto
- Pulses are classified based on their parameters (pulse shape, area and hit pattern)

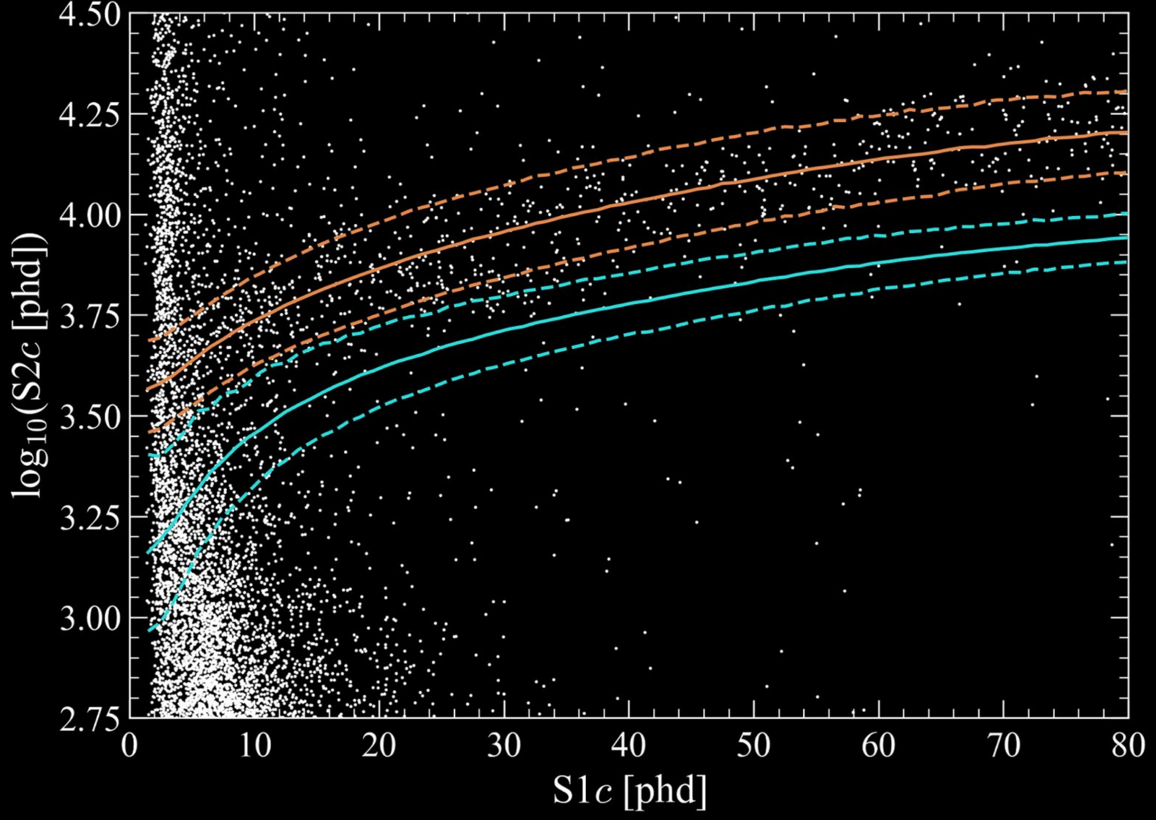


All Single Scatters

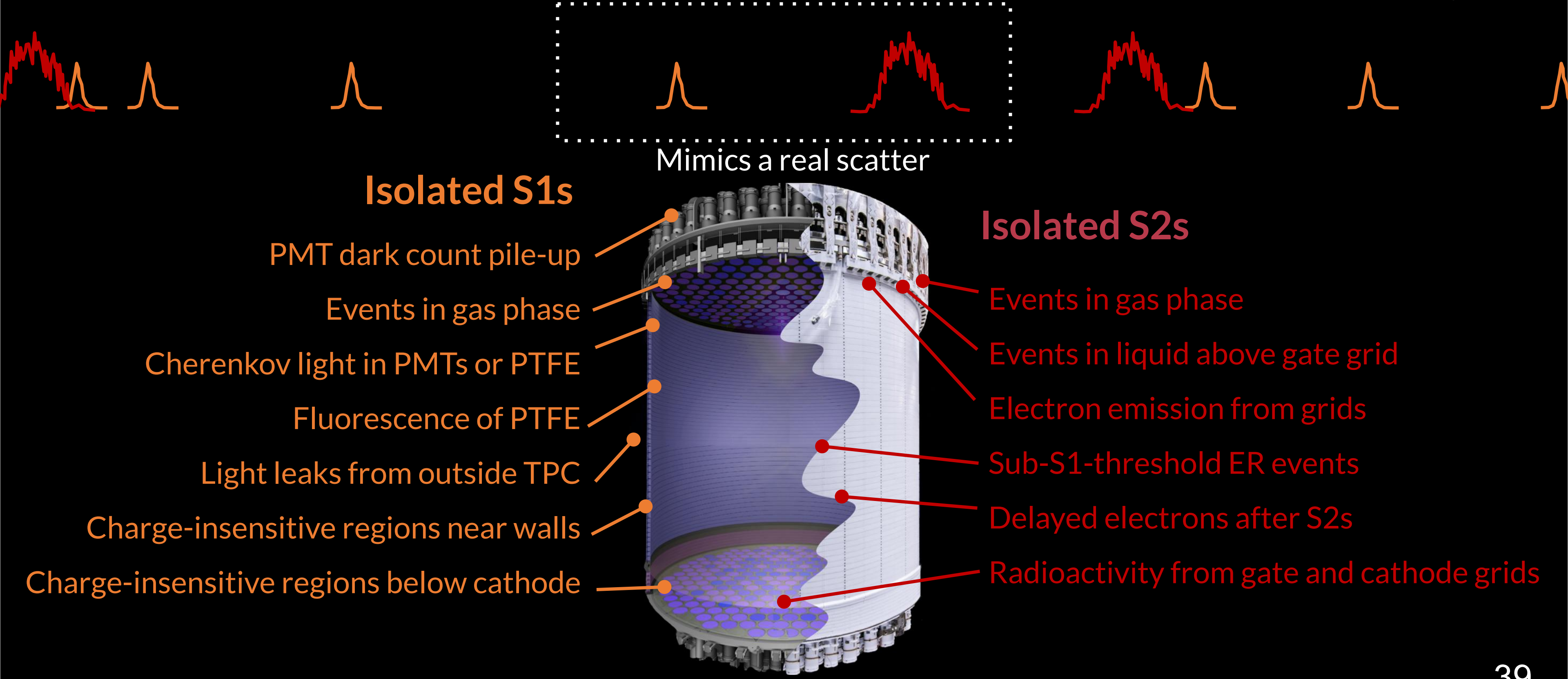
- ● Events surviving all selections
- × Skin-prompt-tagged events
- ○ OD-prompt-tagged events



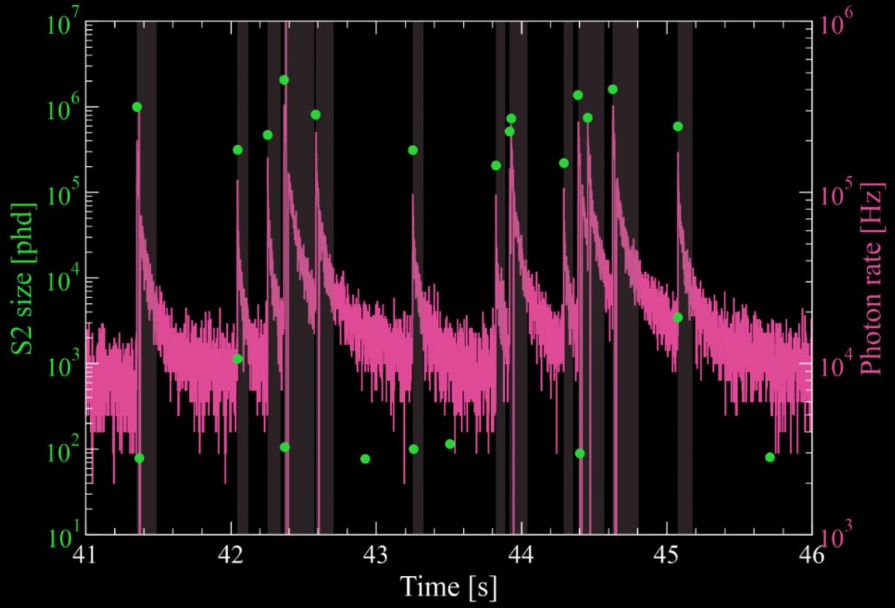
After FV & Veto Cuts



Accidental Signals

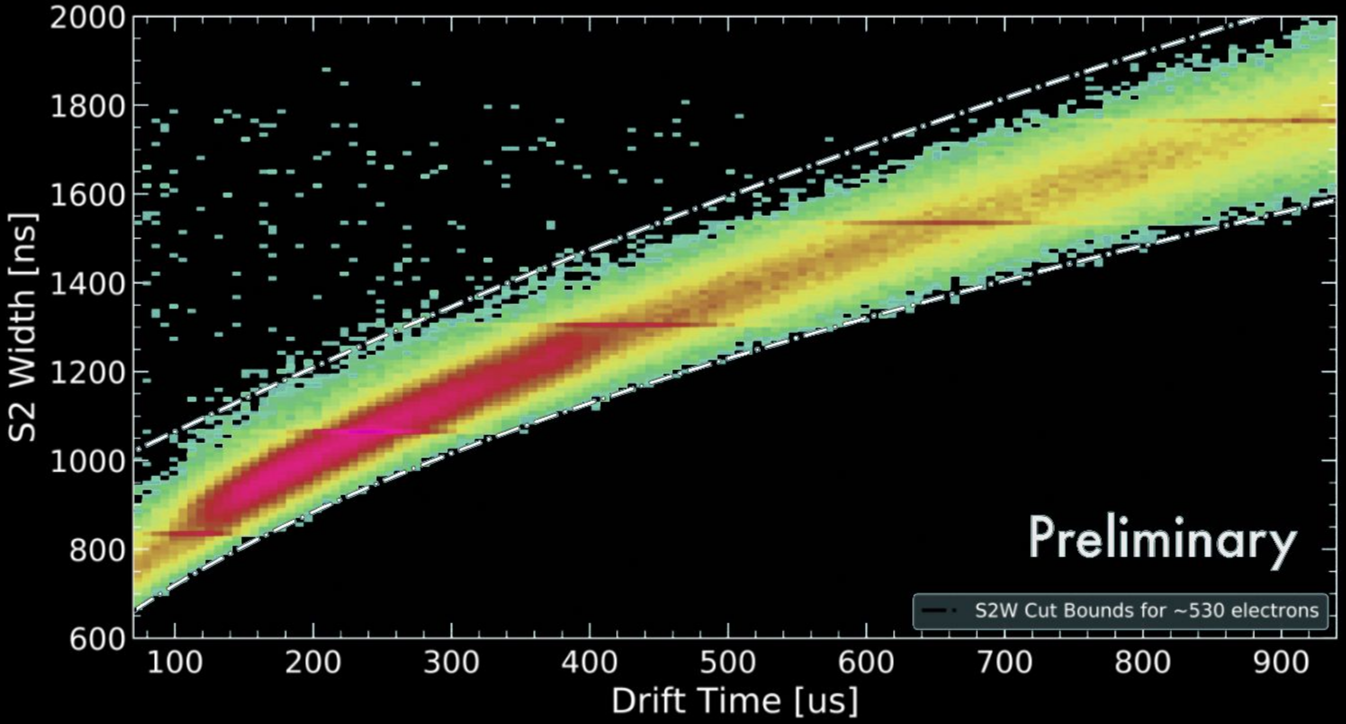


Electron & Photon trains



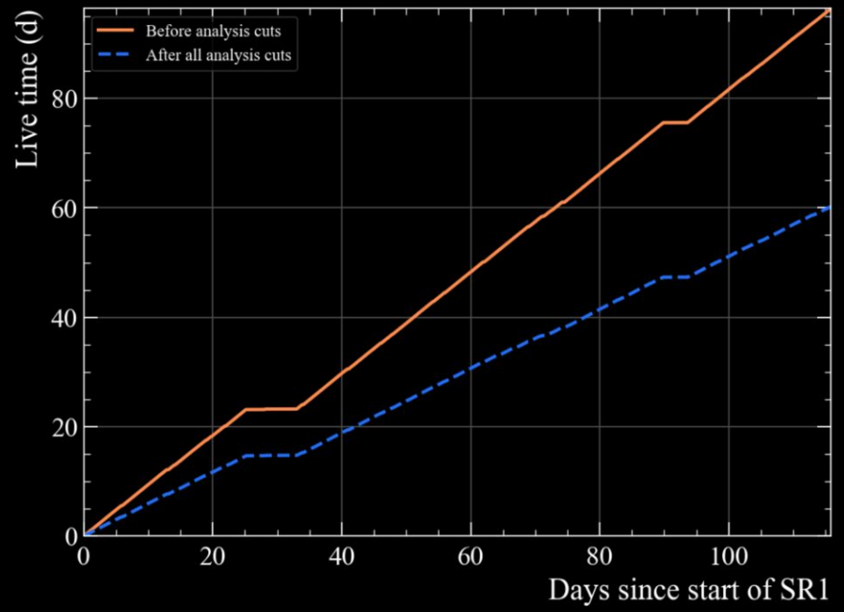
Analysis hold off after S2s which is proportional to the size of the S2 (big impact on livetime - 29.8% cut)

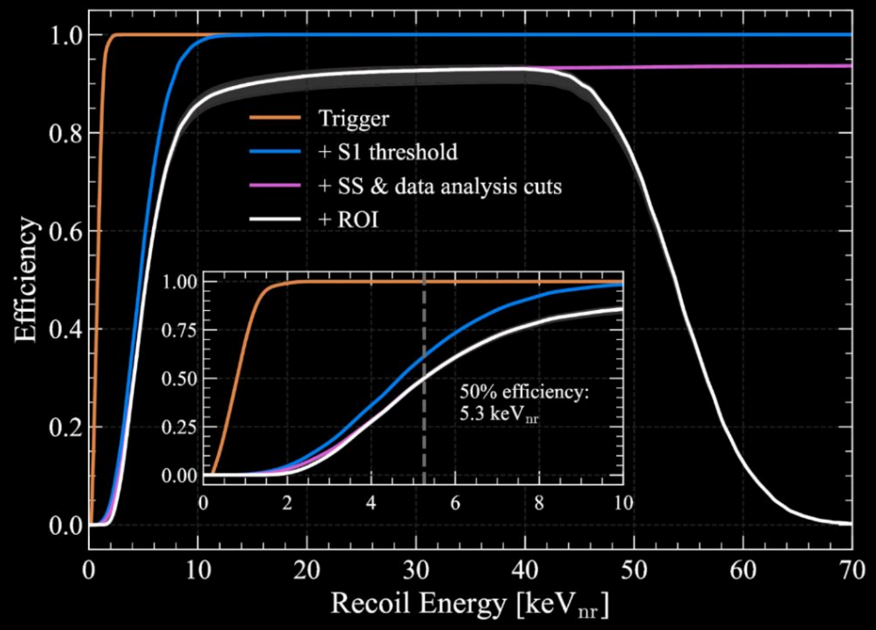
Data Quality Cut Example



Relationship between S2 shape and Drift time exploited to reject accidentals

Data Quality





Requiring 3-fold coincidence dominates lowest energy threshold

50% efficiency at 5.3 keV NR

Backgrounds

~Flat energy spectra

within ROI

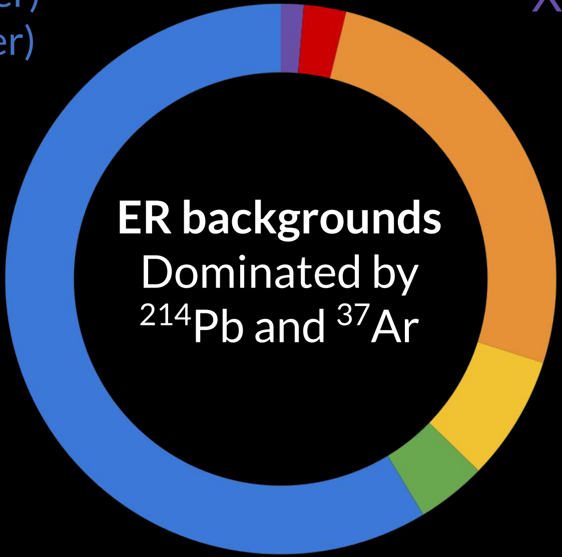
Dissolved radiogenic contaminants

- ^{214}Pb (^{222}Rn daughter)
- ^{212}Pb (^{220}Rn daughter)
- ^{85}Kr

^{136}Xe ($2\nu\beta\beta$)

Solar neutrinos (ER)

- pp
- ^{7}Be
- ^{13}N



Mono-energetic spectra

dissolved electron captures

^{37}Ar (activation)

^{127}Xe

^{124}Xe (double e-capture)

NR backgrounds:

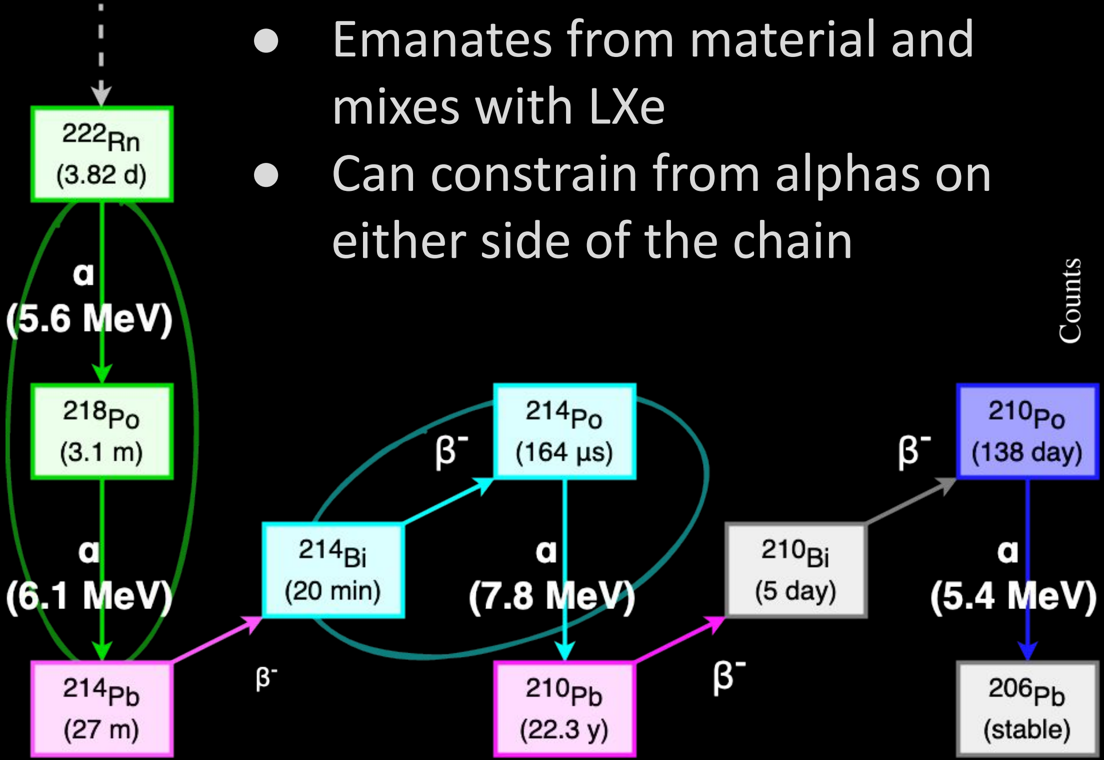
- Neutron emission from spontaneous fission and (α,n)
- ^{8}B solar neutrinos

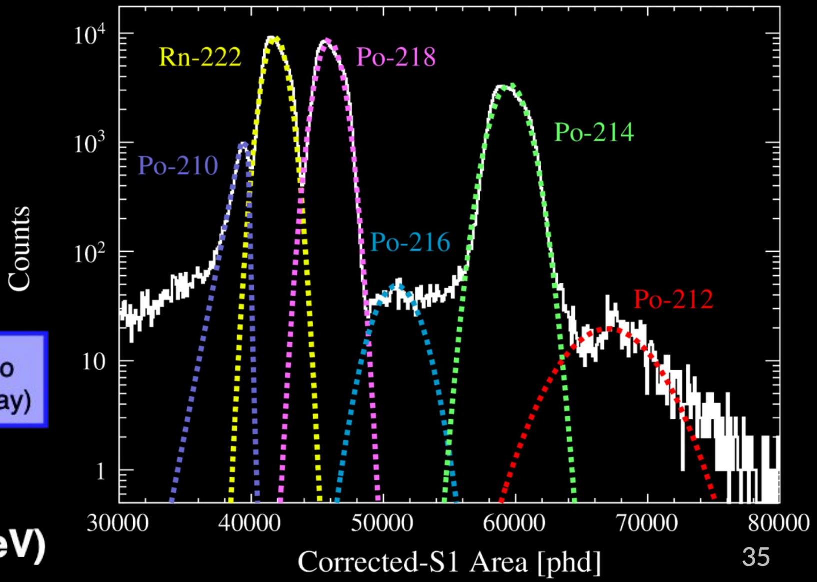
Expected in ROI:

ER: 276 + [0, 291] for 37Ar
NR: 0.15

Radon

- Emanates from material and mixes with LXe
- Can constrain from alphas on either side of the chain

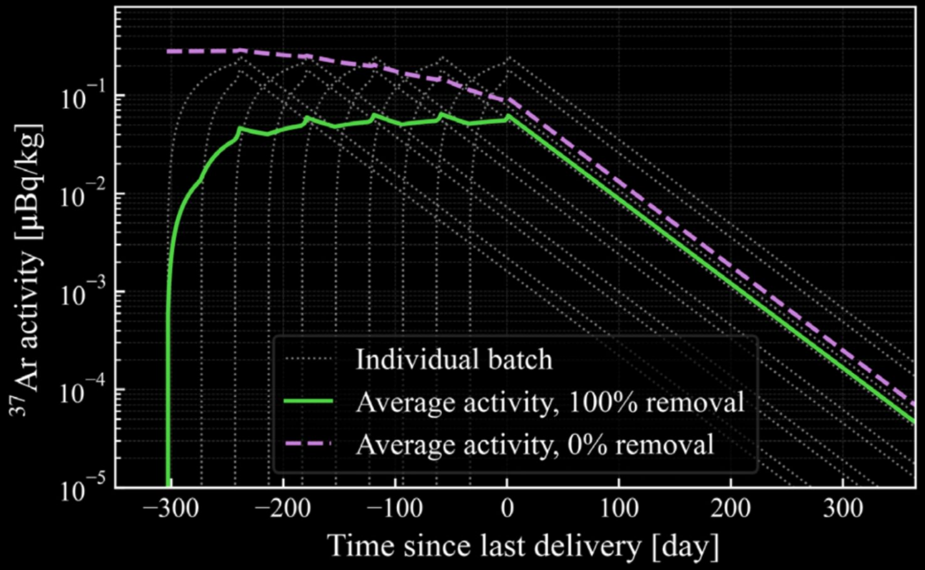




β-decay with **naked** branch (no accompanying gamma) resulting in **low energy recoils**

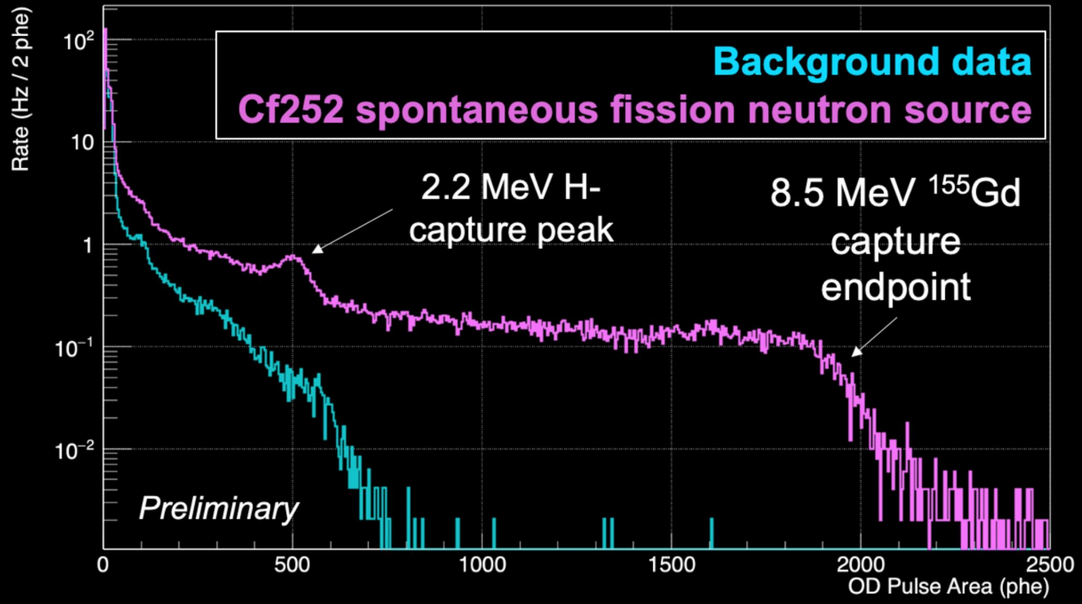
Argon-37

- Electron capture, $t_{1/2}$ = 35 d, monoenergetic 2.8 keV ER deposition
  - Produced by cosmic spallation of natural xenon
- Activity constrained ^{37}Ar activity based on Xe delivery schedule

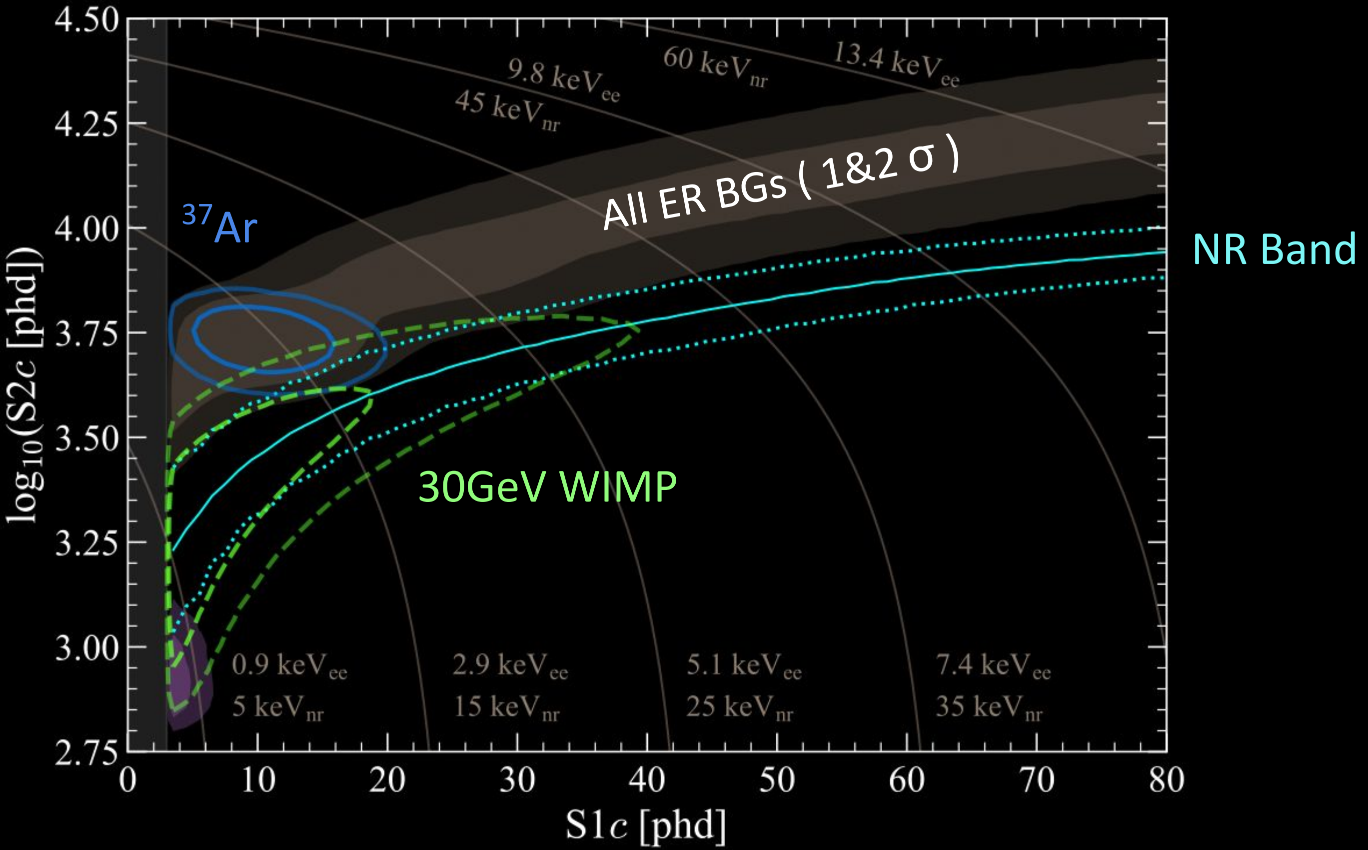


Neutrons

- Neutron captures in the OD produce γ-ray up to 8.5 MeV
- Measured neutron tagging efficiency: 88.5±0.7%
- In situ constraint on neutron background: 0+0.2 neutron events

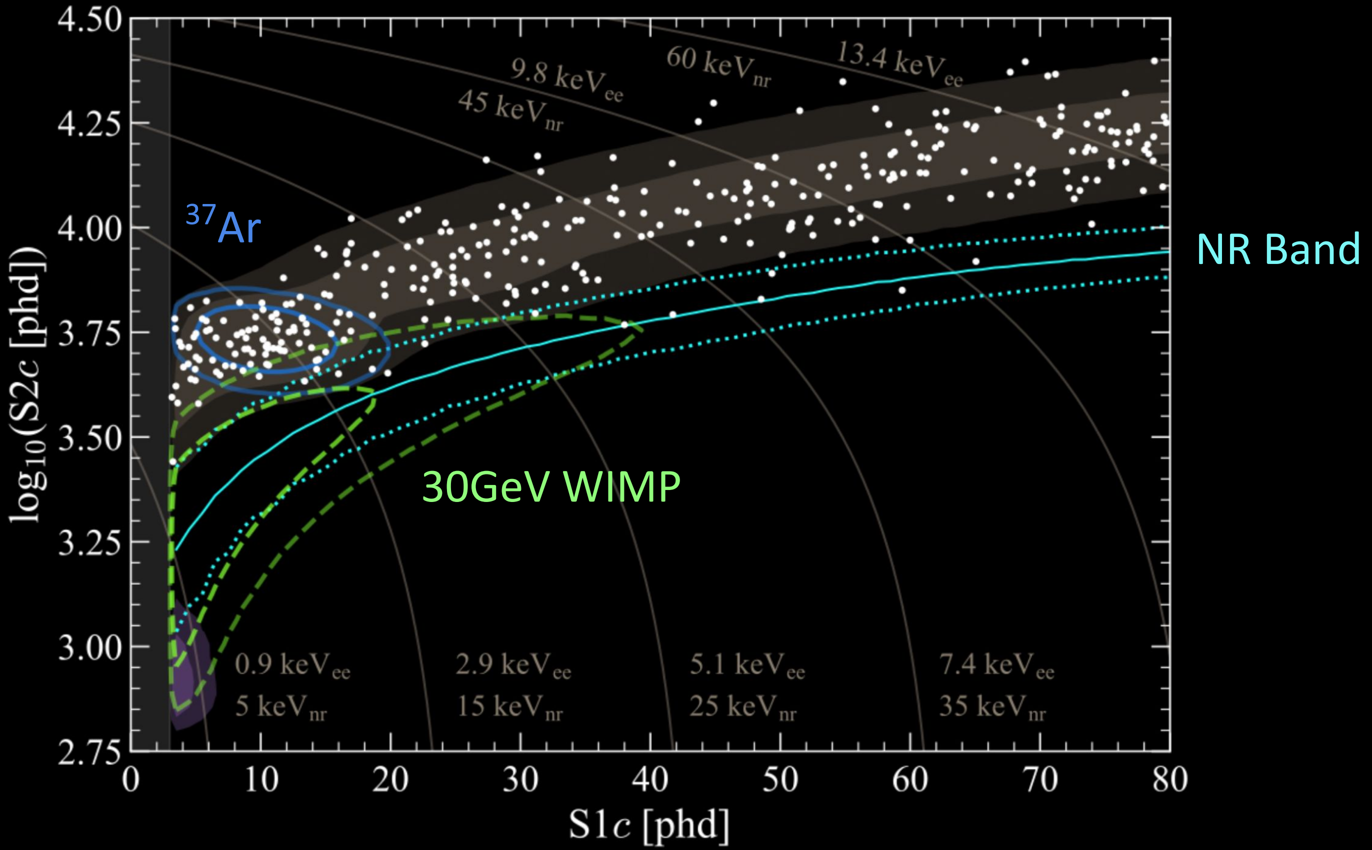


BG Model



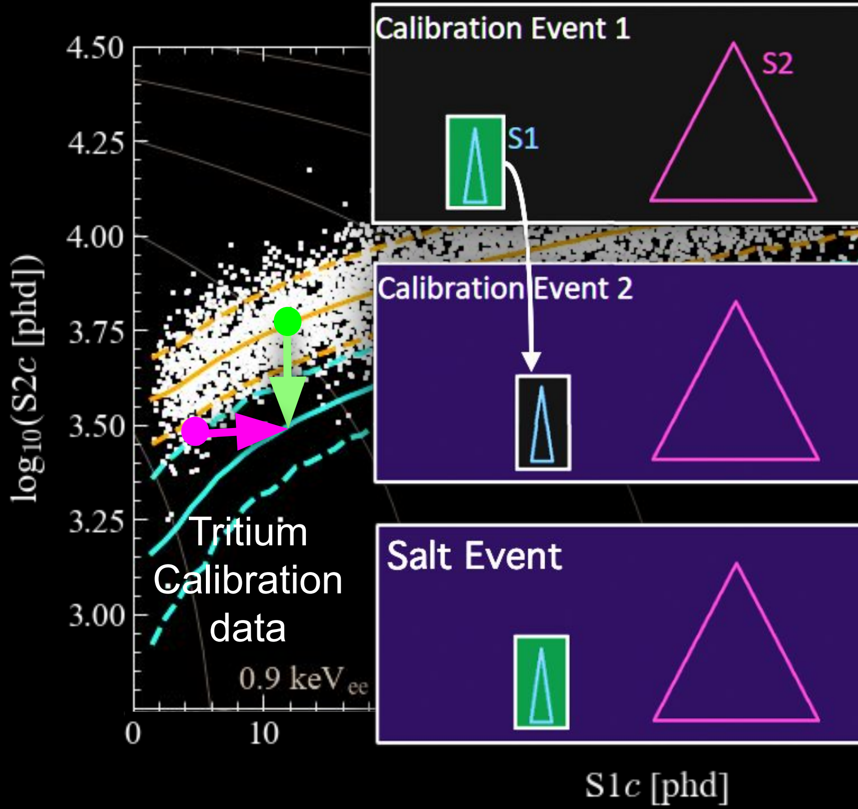
All ER BGs (1&2 σ)
^{37}Ar
NR Band
30GeV WIMP
9.8 keV$_{ee}$
45 keV$_{nr}$
60 keV$_{nr}$
13.4 keV$_{ee}$
0.9 keV$_{ee}$
5 keV$_{nr}$
2.9 keV$_{ee}$
15 keV$_{nr}$
5.1 keV$_{ee}$
25 keV$_{nr}$
7.4 keV$_{ee}$
35 keV$_{nr}$
log$_{10}$(S2c [phd])
S1c [phd]
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
0
10
20
30
40
50
60
70
80

SR1 ROI & Data Quality Cuts



Improve the analysis: Salting

- Overcome human biases in the analysis of the data (Bias Mitigation)
- Assemble salt event from calibration data and inject
- Salt all science data
    - WIMP salt
    - High energy salt
    - Light WIMPs/8B salt
- Unsalt after freezing analyses



Improve the analysis: Statistics

- Using public library Flamedisx: expands dimensionality and complexity
- Offers an alternative way of treating shape-varying parameters to template morphing (Python-based and GPU-scalable)
- Moving towards combined likelihood with first science run data and useful sidebands (tagged BGs)