

The search for $0\nu\beta\beta$ decay of ^{136}Xe with the LZ experiment

Aiham Al Musalhi – Xe $0\nu\beta\beta$ workshop II (2026)
on behalf of the LZ collaboration

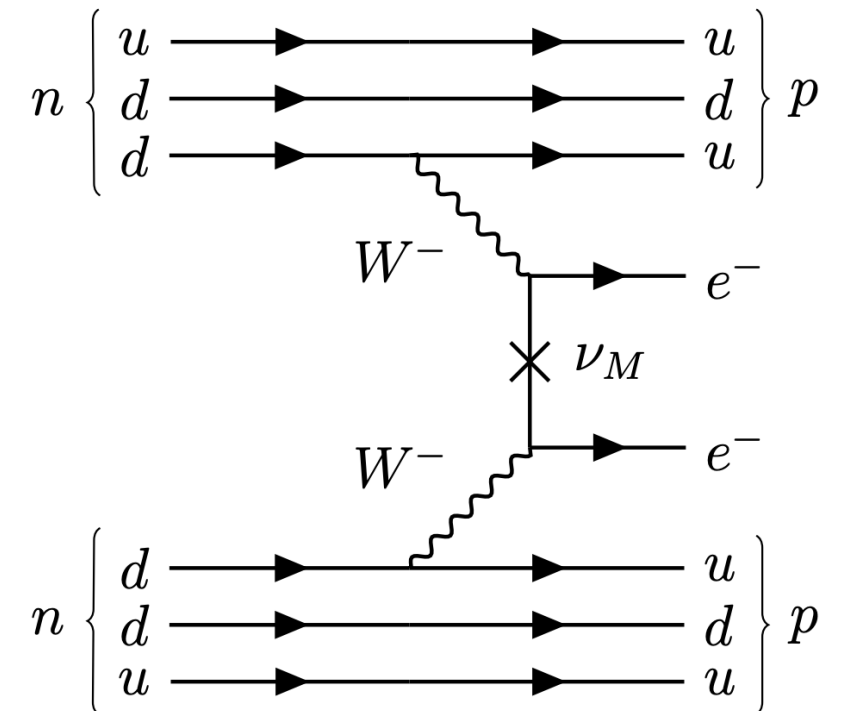
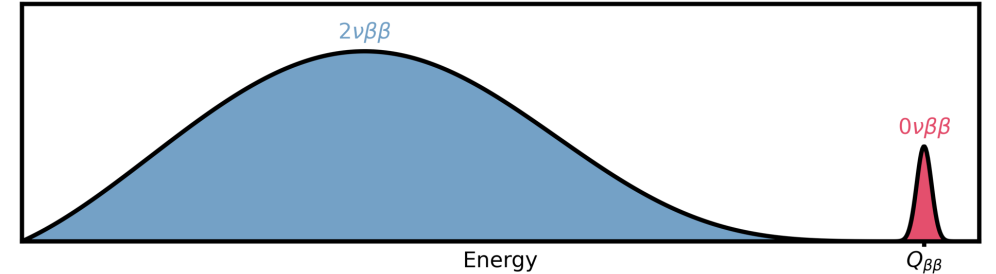


Neutrinoless double-beta ($0\nu\beta\beta$) decay

Flagship experimental search with deep implications for fundamental physics

- Tests for **Majorana** nature of neutrinos
- Demonstrates **lepton number violation** ($\Delta L = 2$)
- Linked to matter-antimatter **asymmetry**
- Sensitive to absolute **neutrino mass scale**

$$\underbrace{\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1}}_{\text{observed half-life}} = g_A^4 \underbrace{G_{0\nu}^{\beta\beta}}_{\text{phase space}} \underbrace{|M^{(0\nu)}|^2}_{\text{nuclear matrix element}} \underbrace{\frac{\langle m_{\beta\beta} \rangle^2}{m_e^2}}_{\text{effective Majorana mass}}$$



Rare event searches

For a typical **background-limited counting experiment**, the key parameters are:

The diagram shows the equation for the half-life of a neutrinoless double beta decay ($T_{1/2}^{0\nu\beta\beta}$). The equation is:
$$T_{1/2}^{0\nu\beta\beta} \geq \frac{\epsilon \eta N_A}{M_A} \sqrt{\frac{M_T t}{R_b \Delta E}} \ln 2$$
 Red boxes highlight the parameters: ϵ (signal efficiency), η (isotopic abundance), N_A (Avogadro's number), M_A (molar mass), M_T (target mass), t (exposure time), R_b (background rate), and ΔE (energy search window). Red lines connect the labels to the corresponding parameters in the equation.

isotopic abundance

target mass

exposure time

signal efficiency

background rate

energy search window (set by energy resolution)

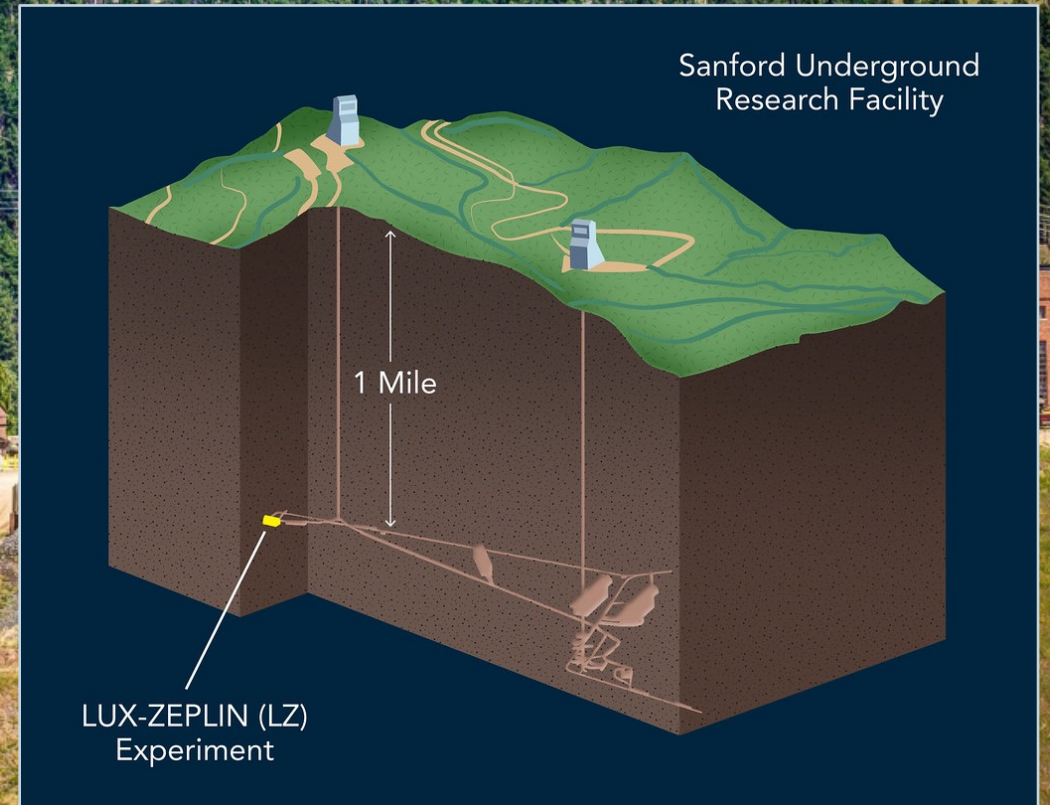
The LZ experiment

LZ is a rare event detector!

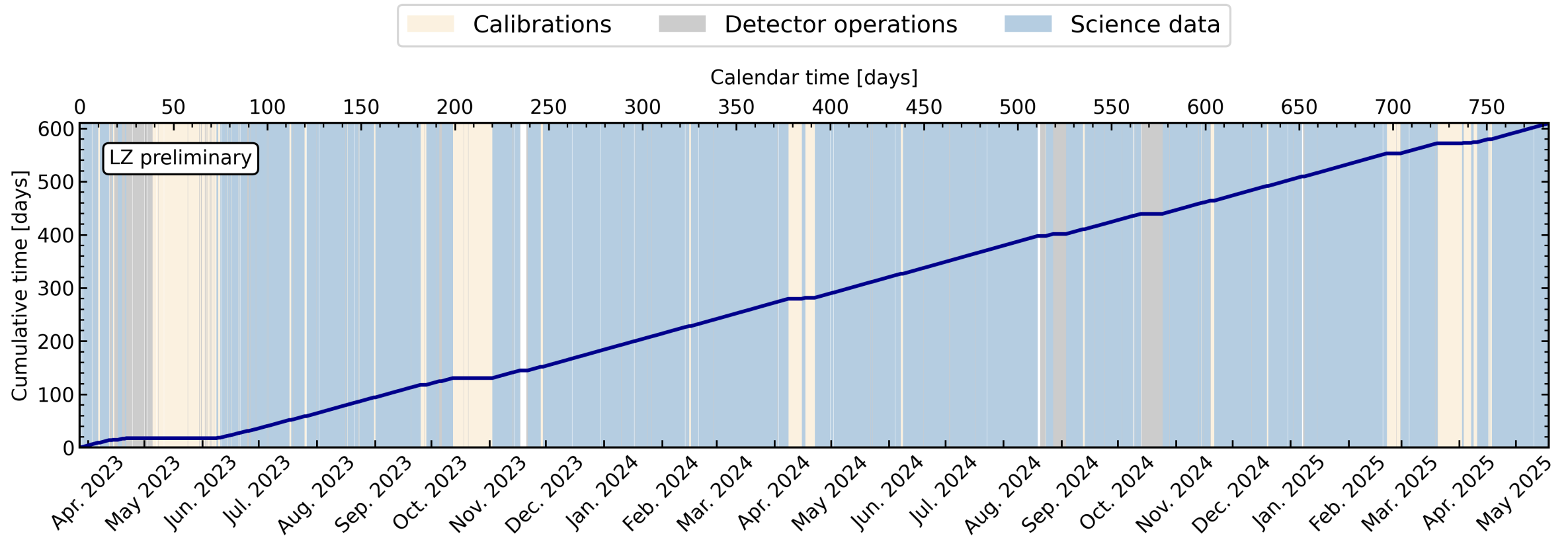
LUX-ZEPLIN (LZ) is **dark matter** direct detection experiment in the Davis Cavern, **1480m underground** in Lead, South Dakota

Satisfied criteria

- Suitable candidate; ^{136}Xe
- Large target mass
- Long-term operation
- Low-background environment
- Great energy resolution



Data acquisition timeline



Utilise **509.7 live days** here (after cuts), from ongoing LZ run at 97 V/cm drift field
⇒ **~0.7 tonne-year ^{136}Xe isotopic exposure** (at natural composition)

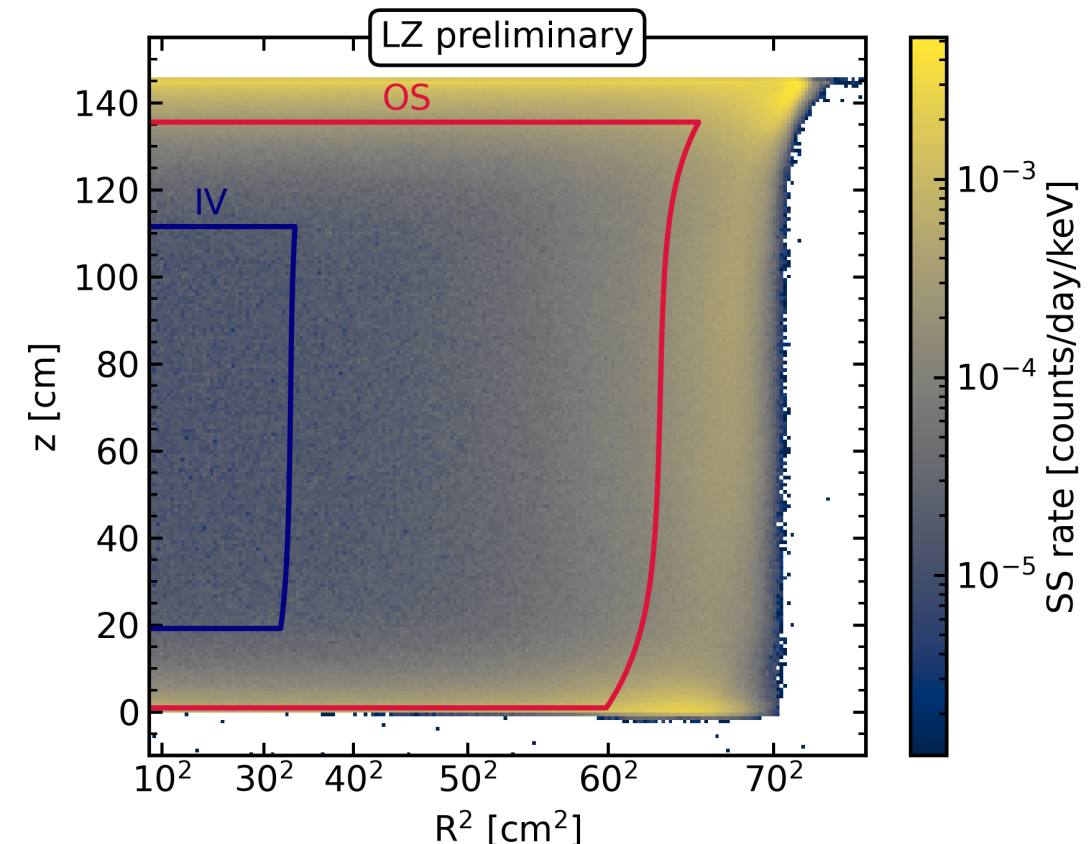
Event selection

($Q_{\beta\beta} = 2457.83$ keV for ^{136}Xe)

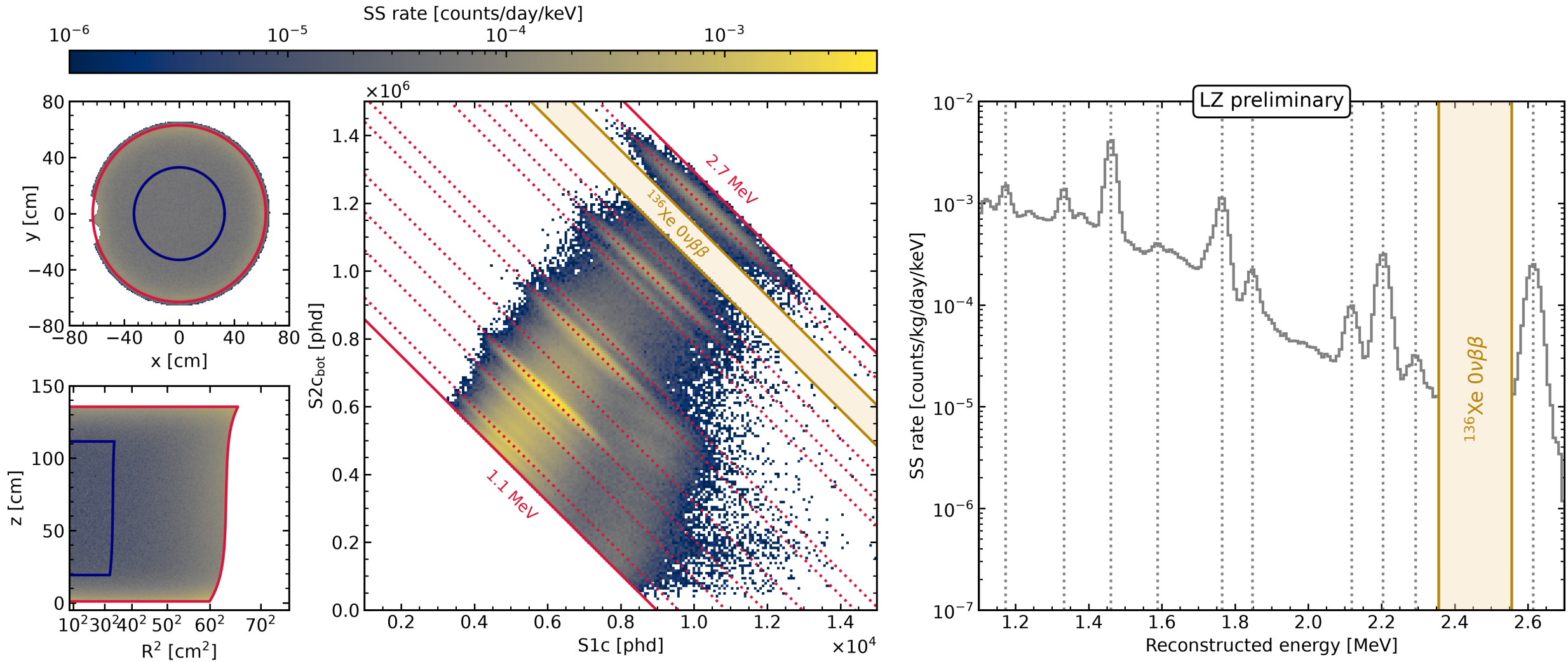
Search within **1.1–2.7 MeV** region of interest (ROI), with ($Q_{\beta\beta} \pm 100$) keV **blinded**

Selection is reduced with

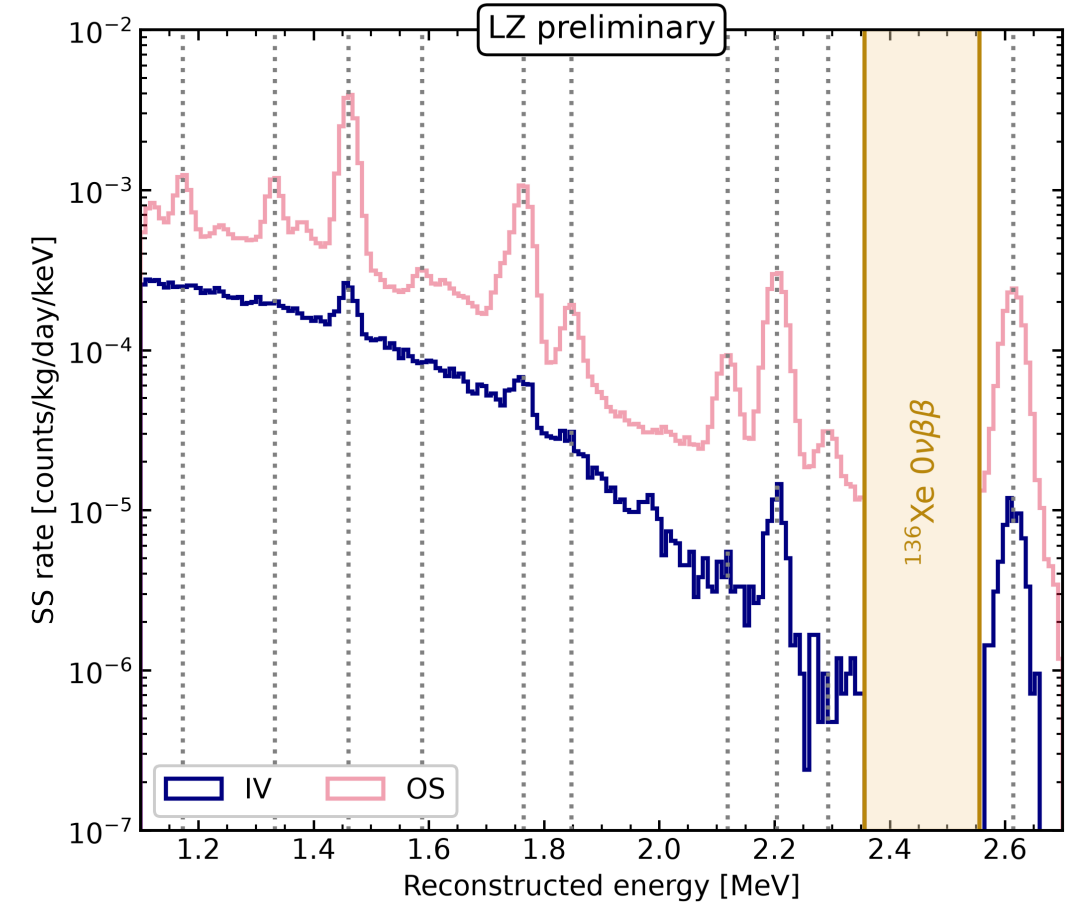
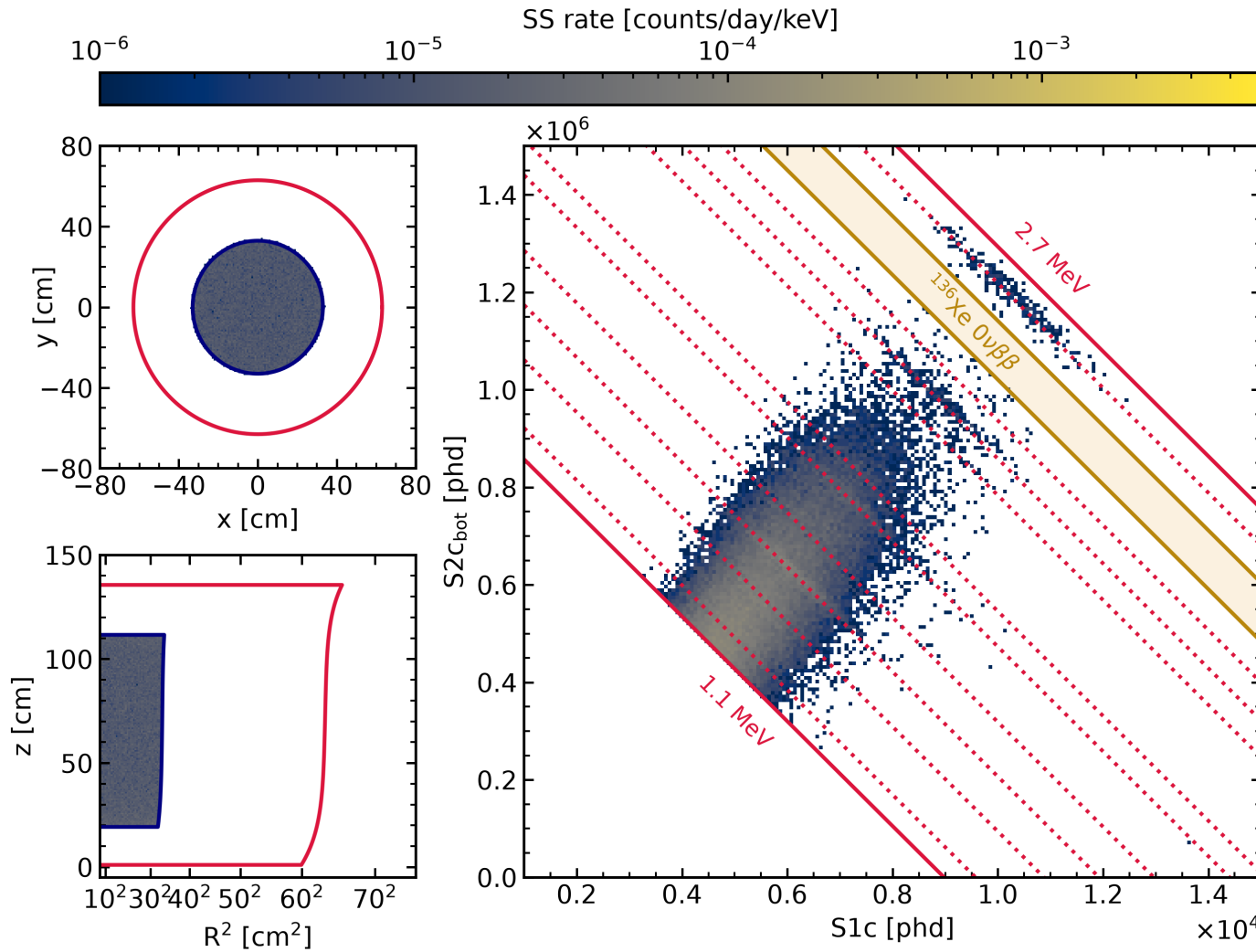
- Data quality cuts and temporal exclusions
- Anti-coincidence veto tags in skin and OD
- Fiducial volume (FV) to negate edge effects and define a stable region; *split* into
 - Inner volume (IV) – clean one-tonne partition with high sensitivity
 - Outer shell (OS) – surrounding space for background constraints



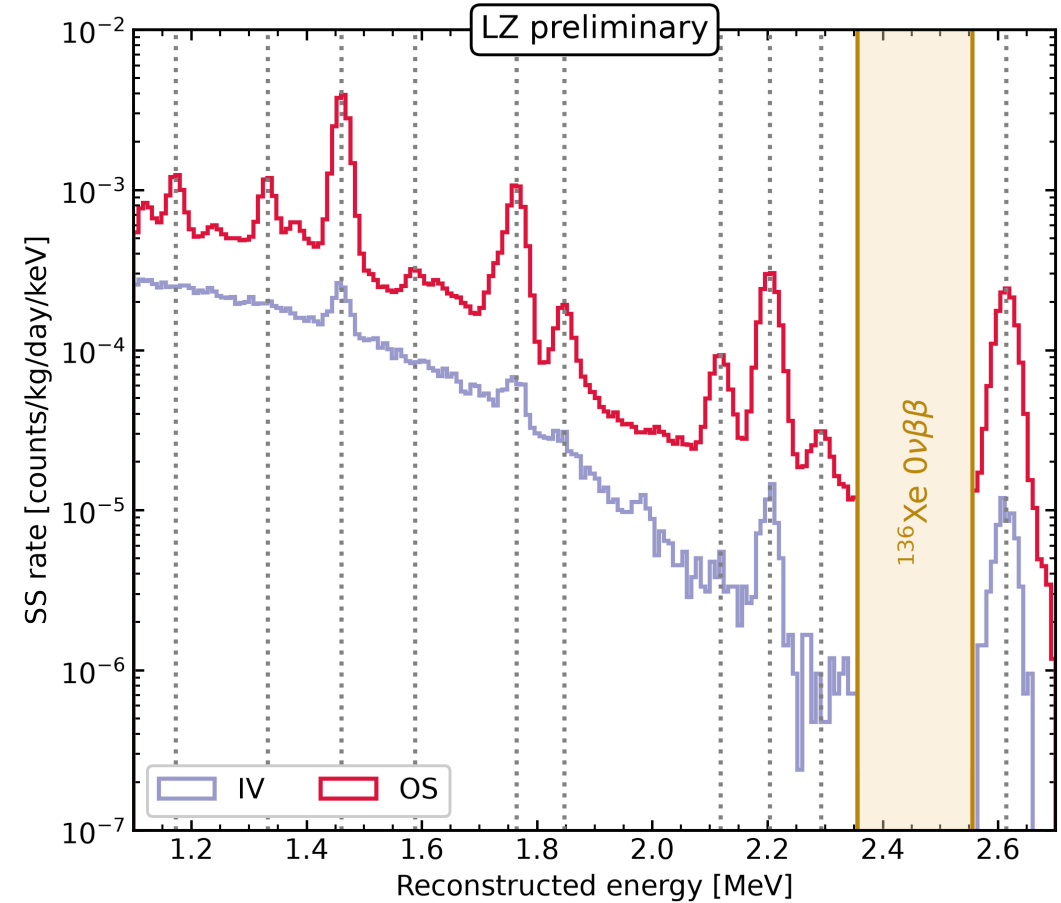
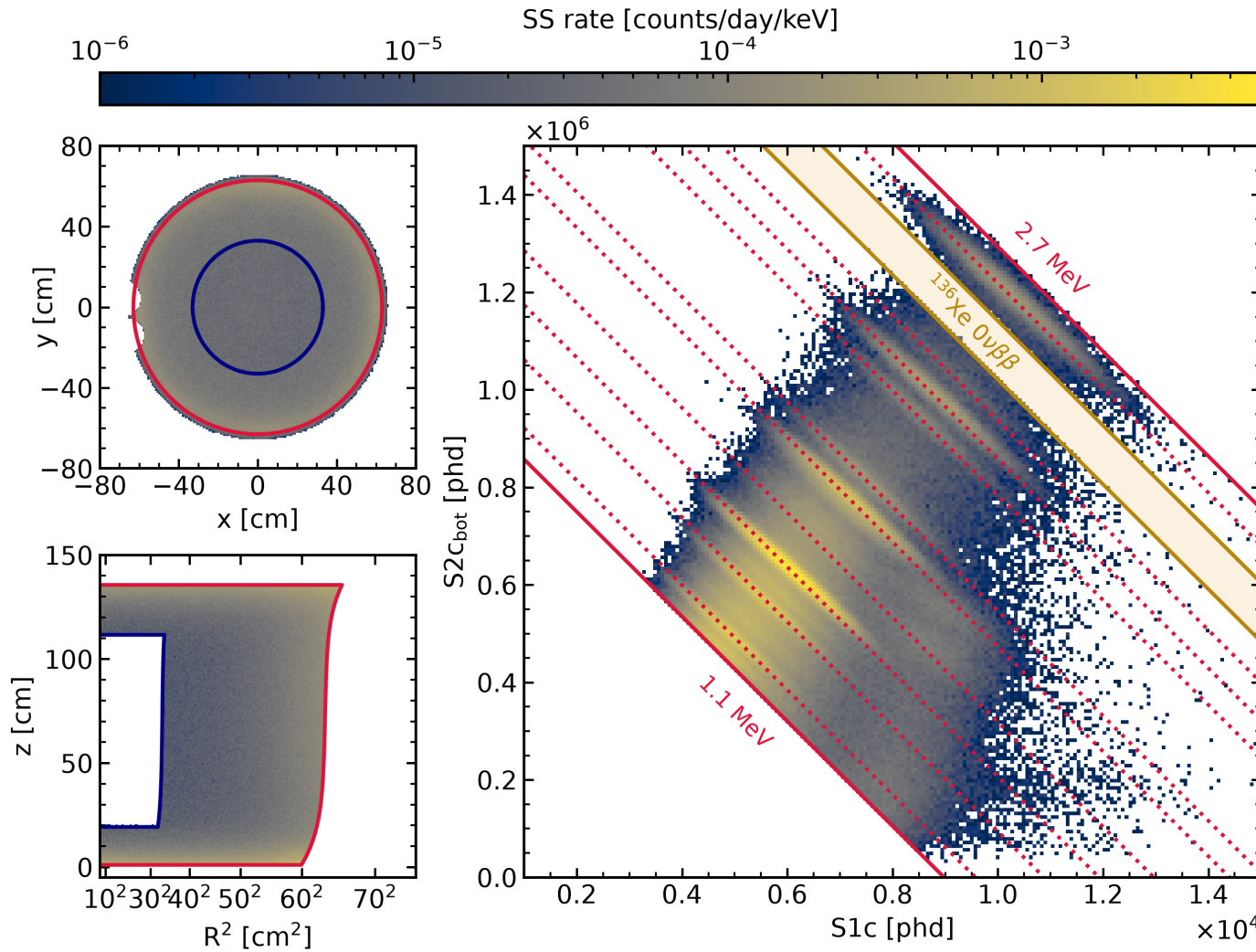
Event selection



Event selection



Event selection

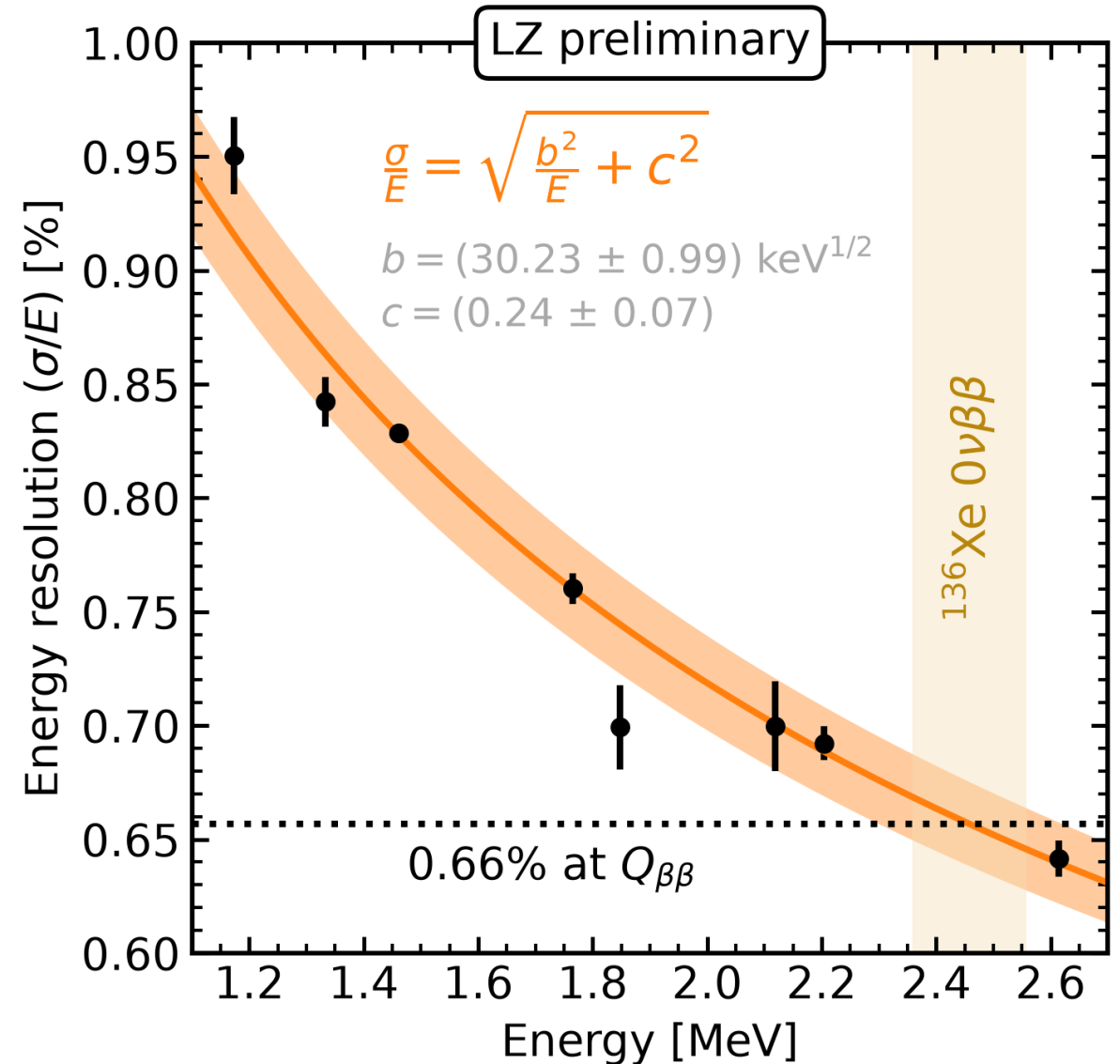


Energy reconstruction

- Novel **signal correction procedure** developed with multidimensional splines
- **Energy reconstruction** accurate to within $\pm 0.01\%$
- Excellent energy resolution achieved*
 $\Rightarrow$ **0.66% at $Q_{\beta\beta}$**

This facilitates better **background rejection** (narrower signal region)

- Approaches **analytical limit** of what is possible with a TPC; to be highlighted in upcoming dedicated paper



Backgrounds

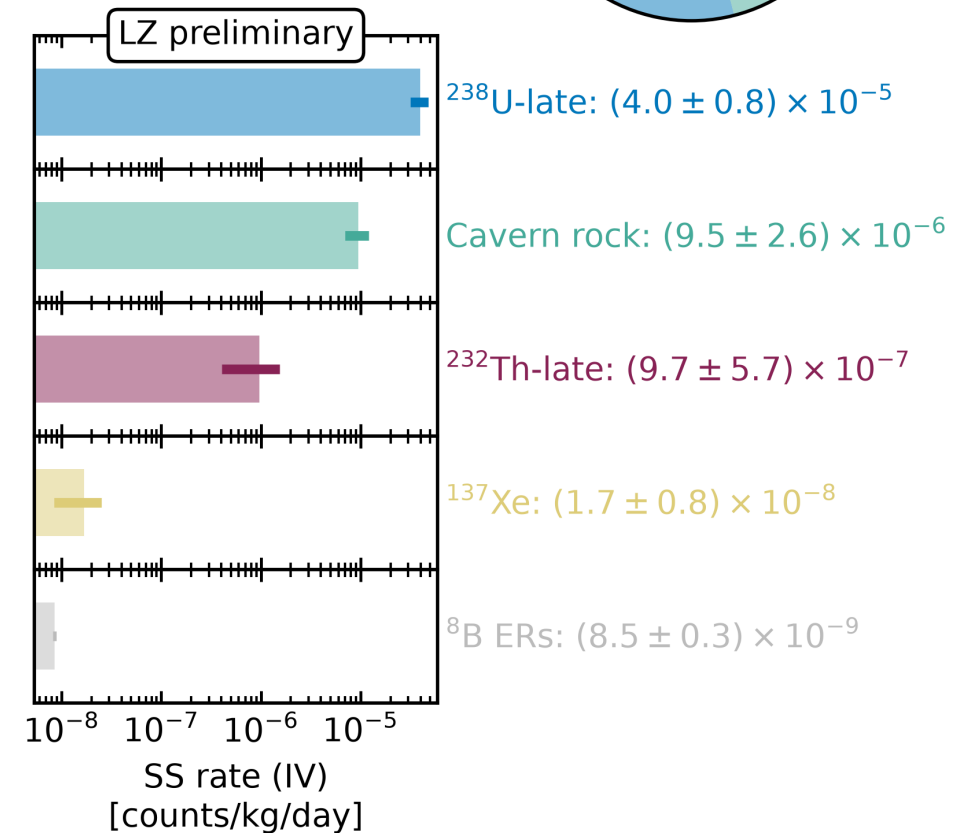
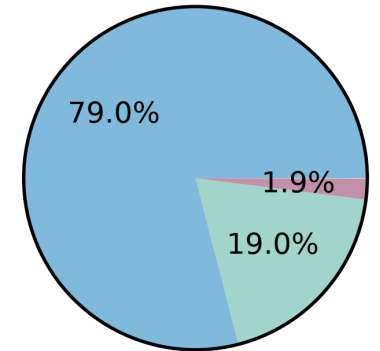
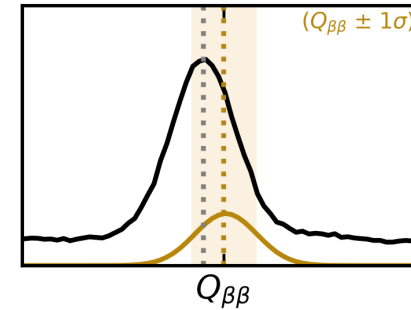
External γ rays form most of the background

These primarily originate from*

- ^{232}Th and ^{238}U chains in **detector materials**
⇒ **^{214}Bi 2447.7 keV γ rays** *most dominant*
- ^{208}Tl γ rays from surrounding **cavern rock**

Other sources

- Internals (^{137}Xe β s from neutron activation, ^8B ν ERs, neutron inelastics, muon spallation);
⇒ these are **subdominant**
- **Merged multi-site backgrounds**

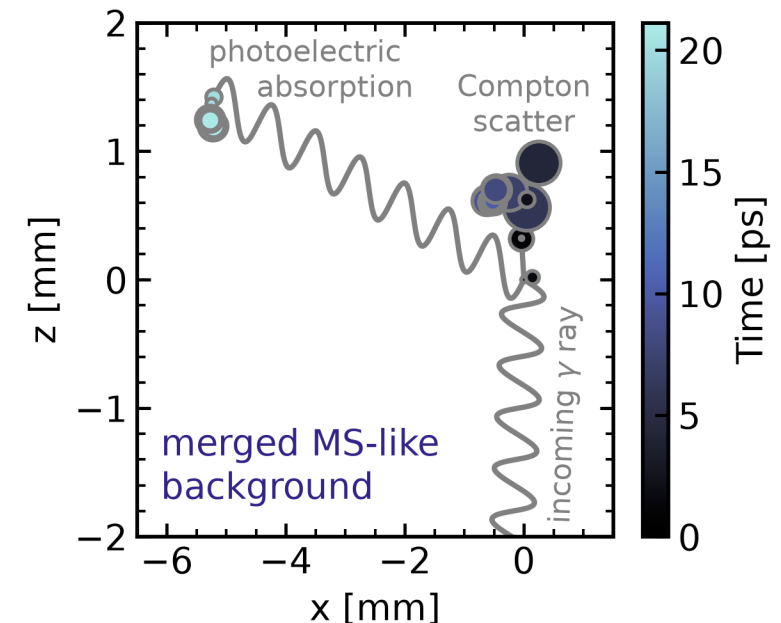
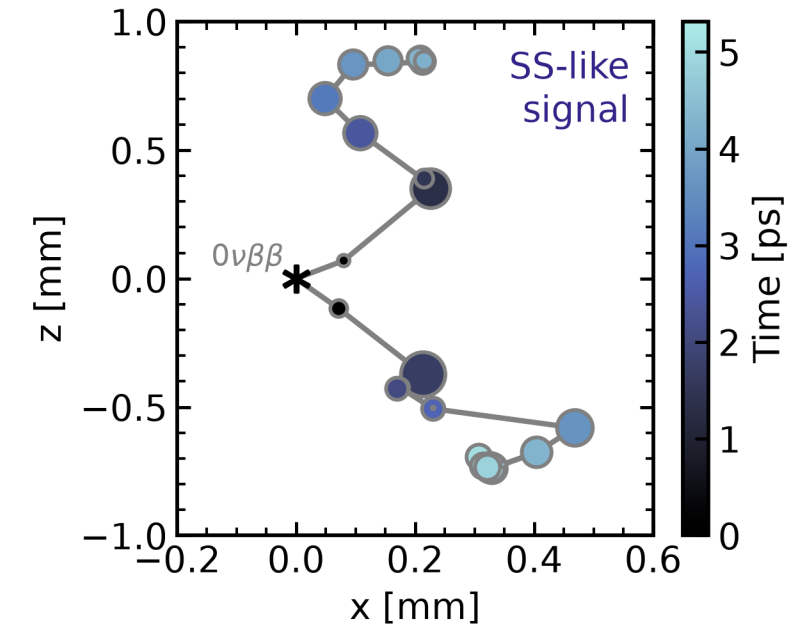


SS-MS discrimination

Majority of $0\nu\beta\beta$ signal events are **single-site (SS)**, and **γ -ray backgrounds** are mostly **multi-site (MS)**

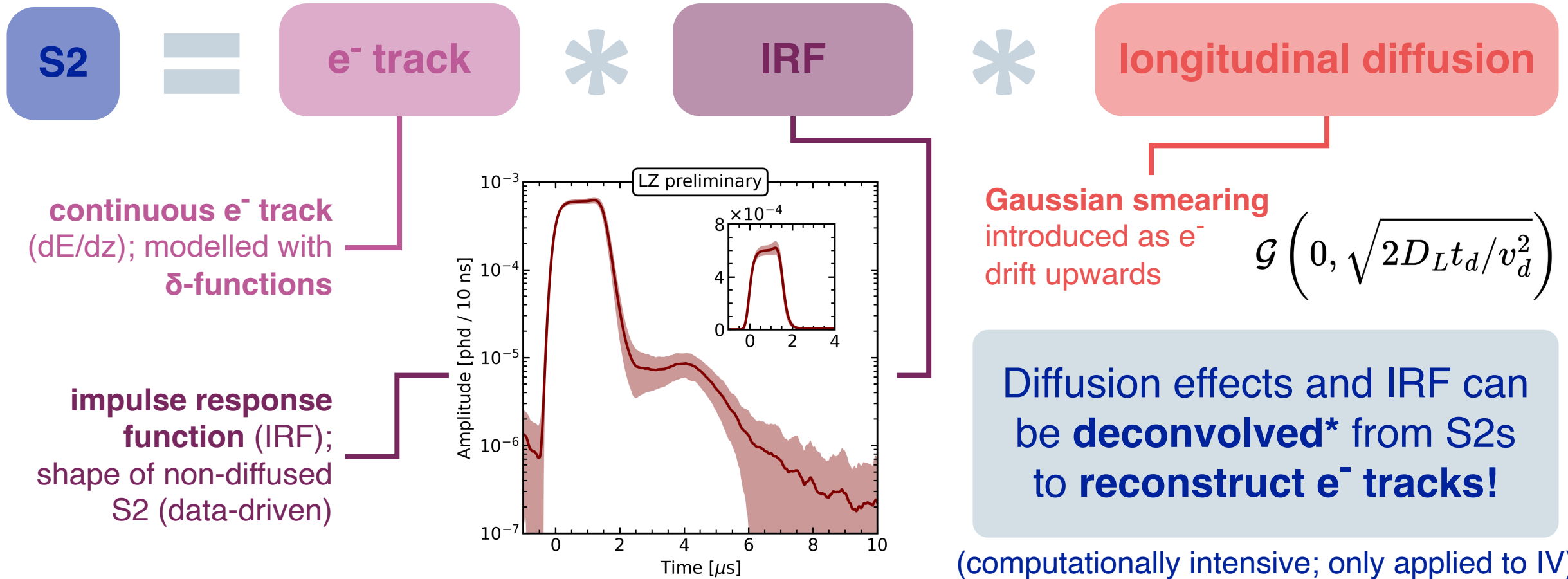
- Ability to distinguish between scatters is dictated by the **position resolution**, predominantly in **z**
- Typical **vertical vertex resolution (Δz)** is $\sim 3\text{--}8$ mm, which depends on drift time
- **Unresolved (merged) MS** events contaminate the SS sample with more background

This can be addressed with powerful **discrimination techniques** applied at the **waveform level**



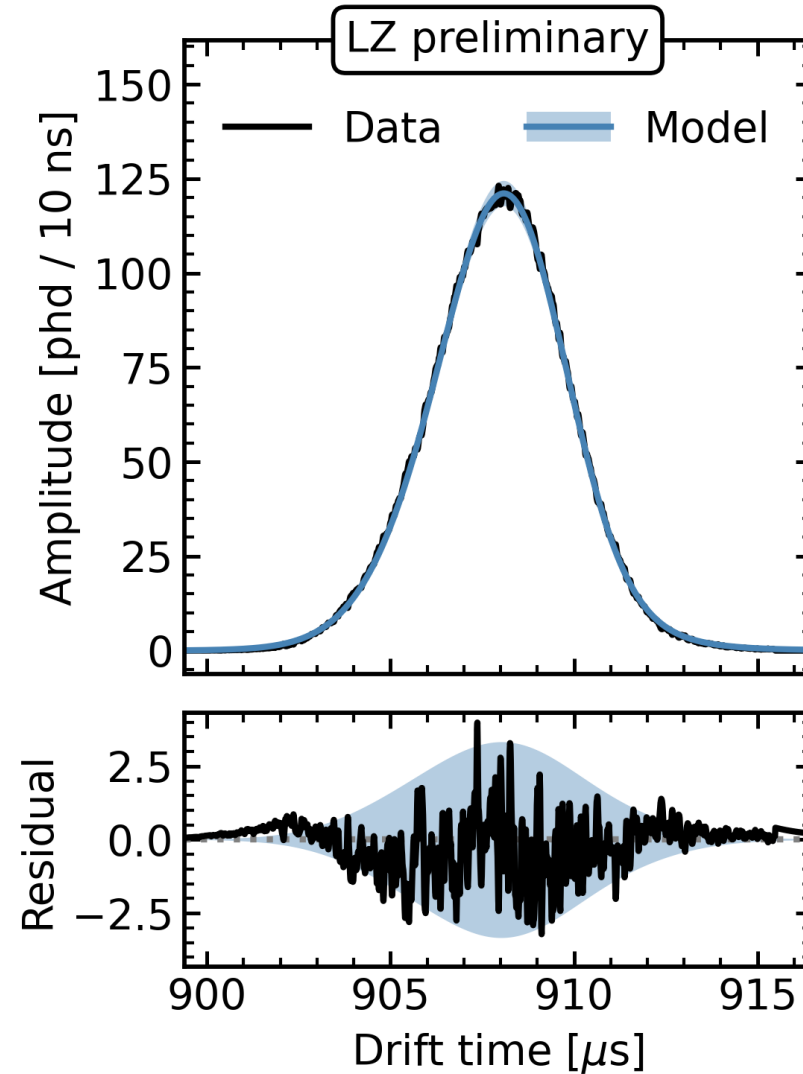
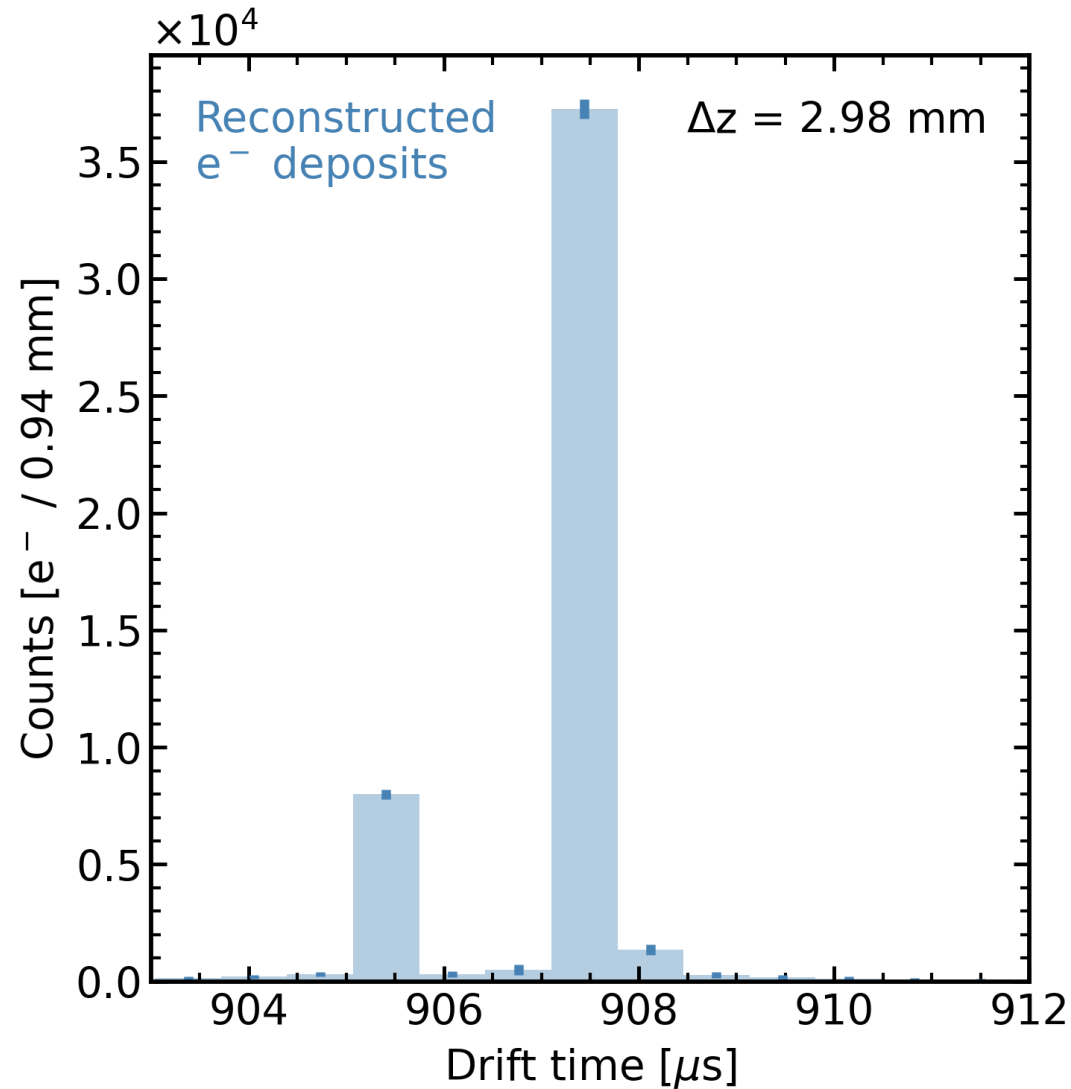
S2 deconvolutions

A typical **S2 waveform** can be constructed as a **convolution** of 3 effects

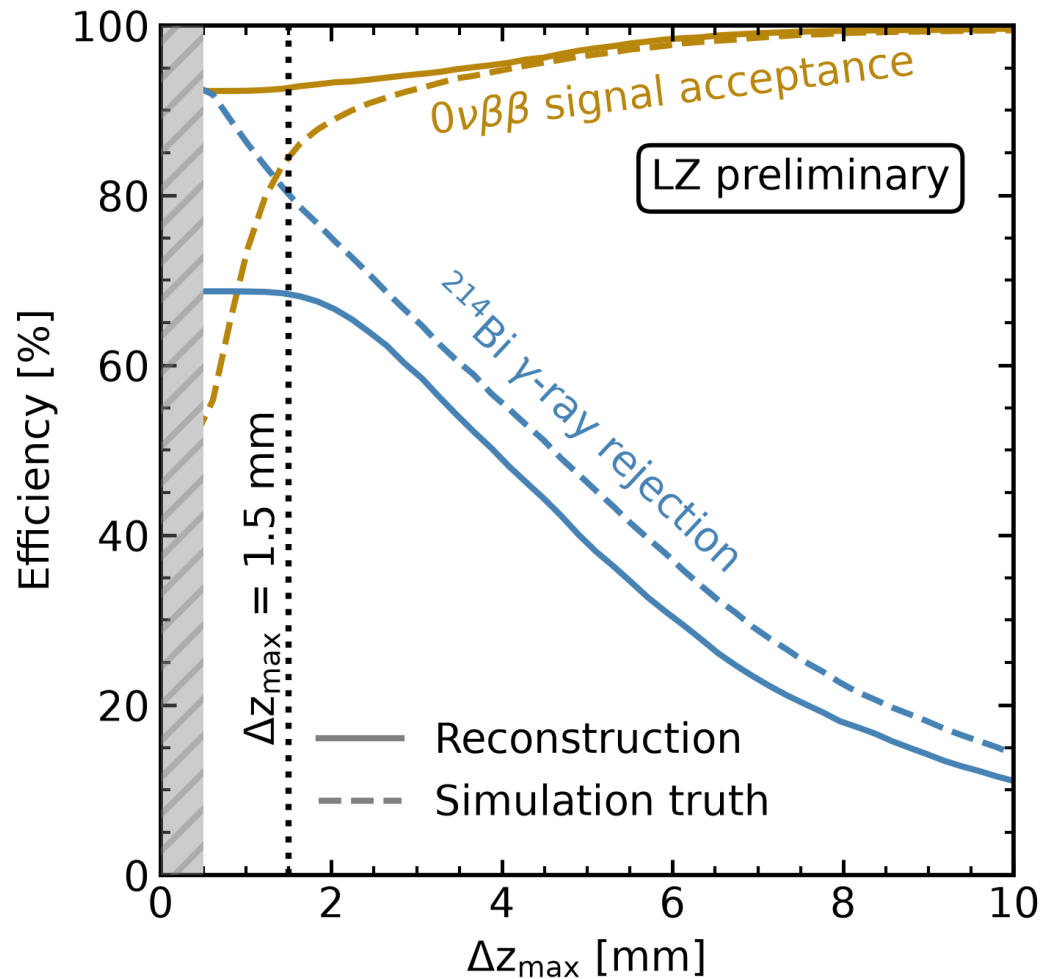


S2 deconvolutions

We can infer Δz from the **reconstructed** e^- tracks

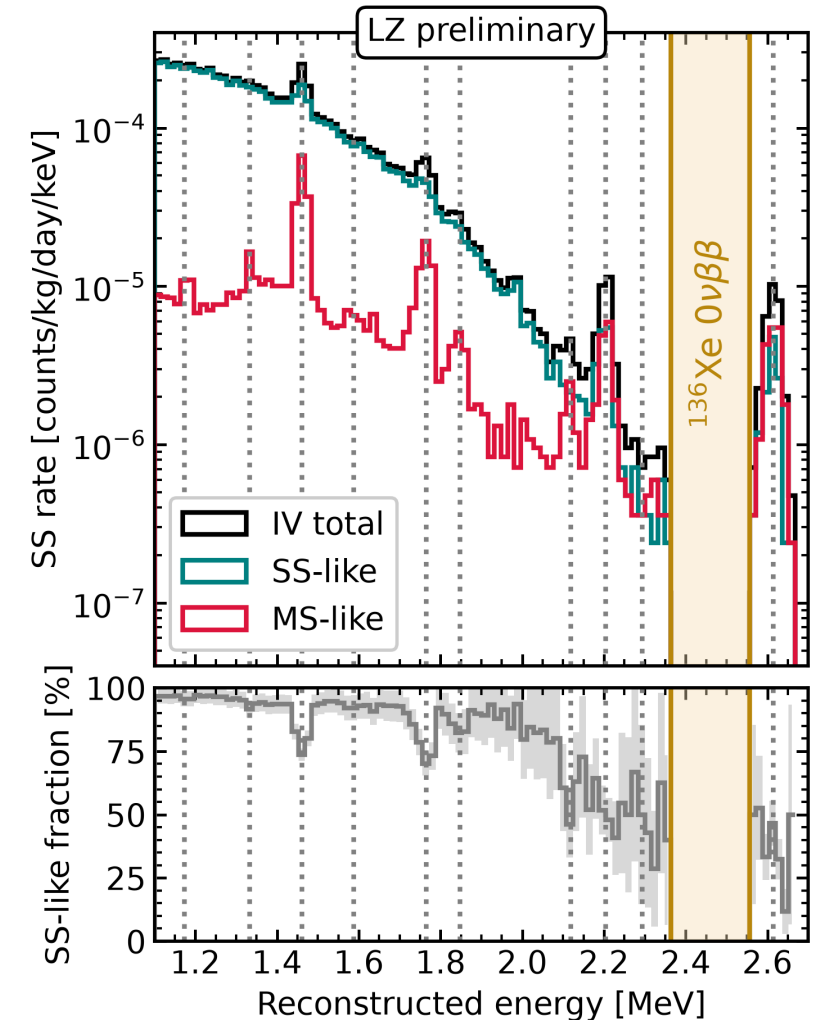


S2 deconvolutions



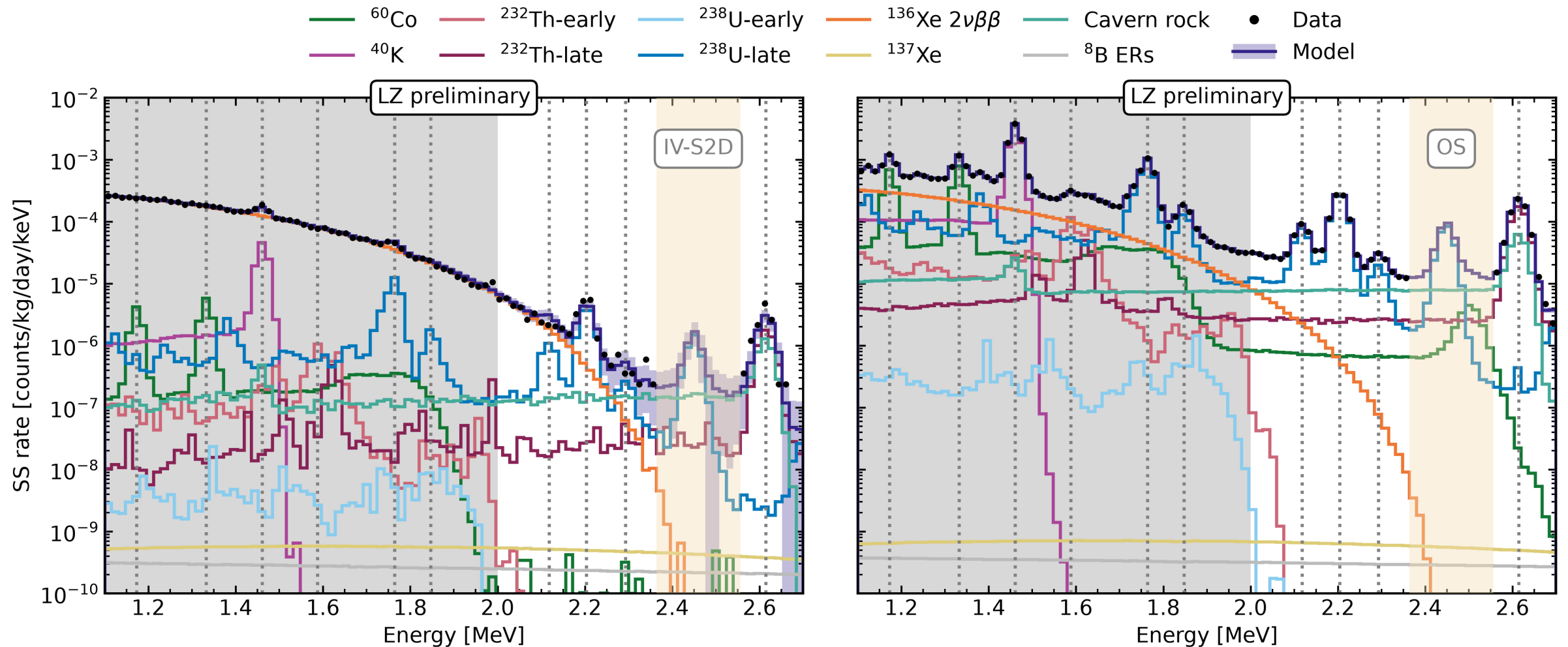
~8% of IV events removed by cut at $\Delta z < 1.5$ mm

92.6% signal acceptance (~80.7% total), > 61.7% rejection

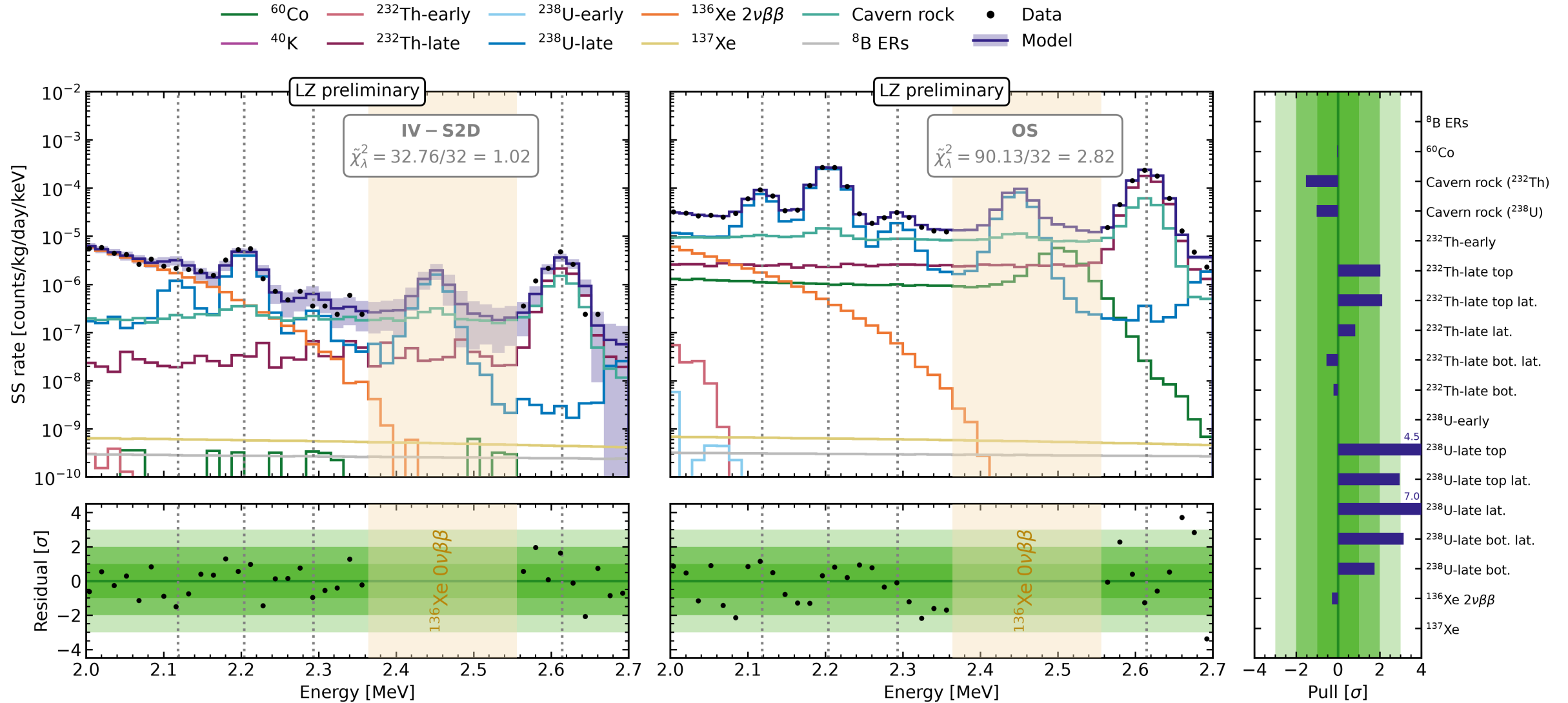


Wide ROI model

For this result, focus on well-modelled > 2 MeV range



Blinded results



Summary

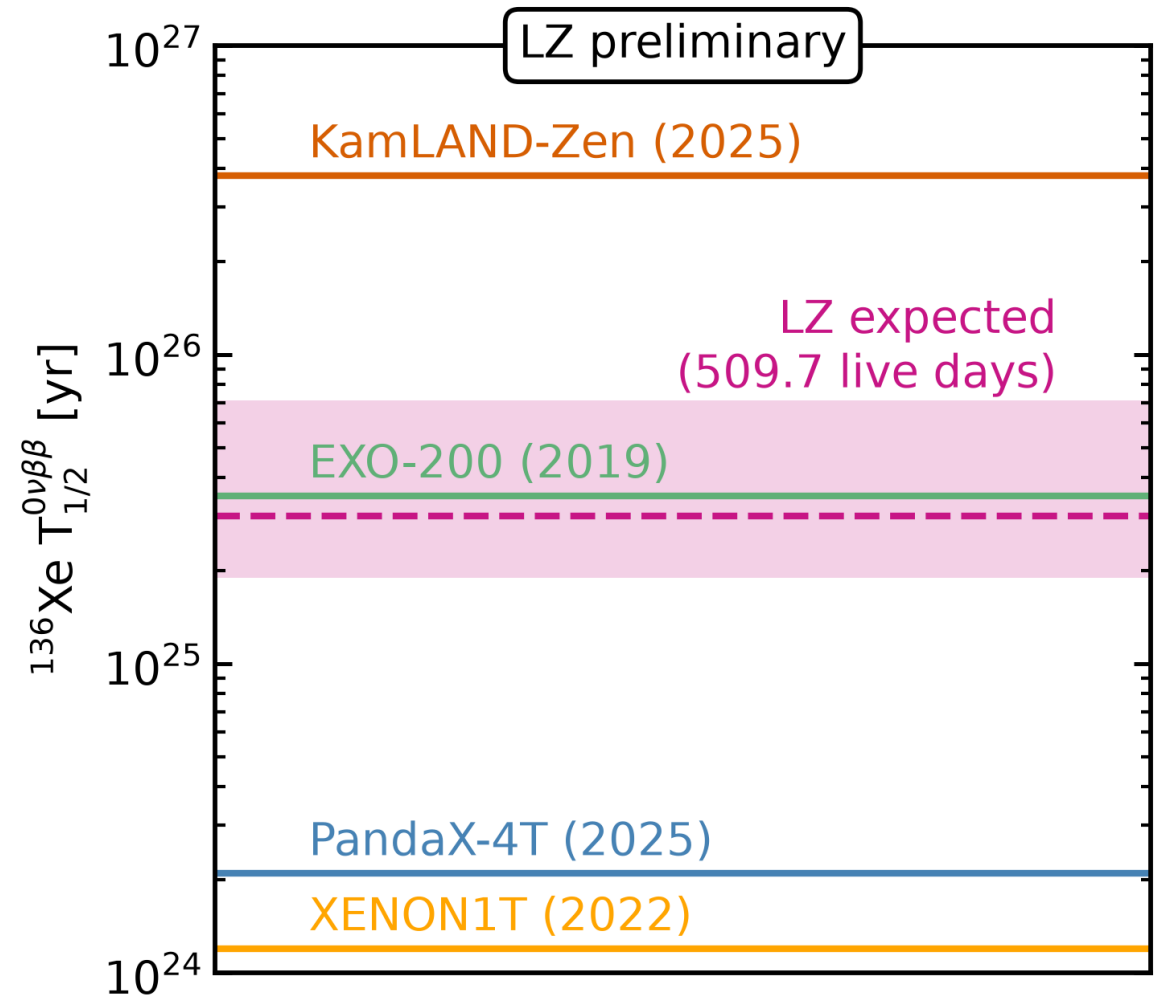
Reported several points of success

- Bottom-up **background model** based on **assays**, broadly agrees with data
- Achieved great **energy resolution**, maintained throughout long datasets
- Developed **deconvolution technique** to improve γ -ray background rejection

⇒ **LZ was not optimised for $0\nu\beta\beta$** , but initial result is a strong contender

Underlying assumptions for **XLZD sensitivity study** informed by this

Blinded median expected half-life sensitivity at $\sim 3.0 \times 10^{25}$ years





@lzdarkmatter

Thanks for listening!

The LZ collaboration

39 institutions with over 250 scientists, engineers, and technical staff



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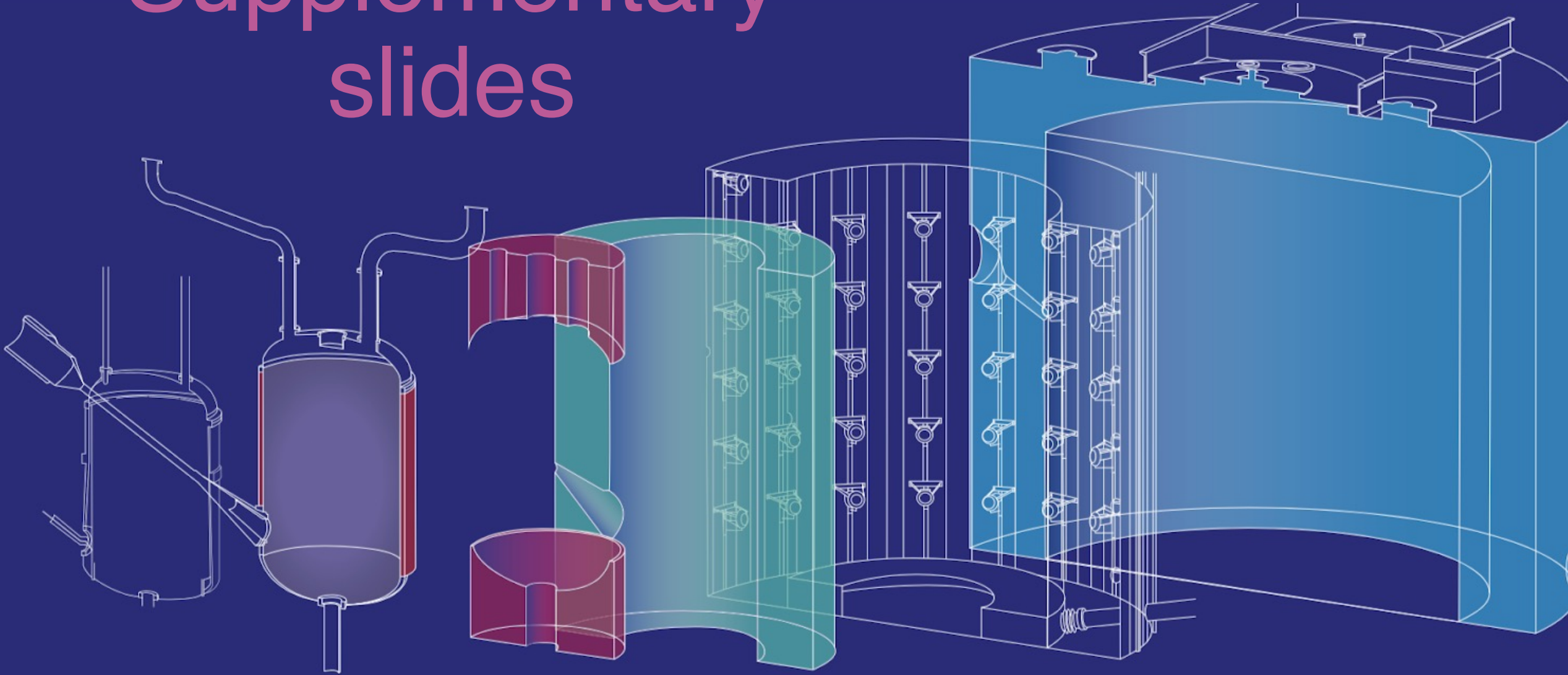
Asia

Oceania

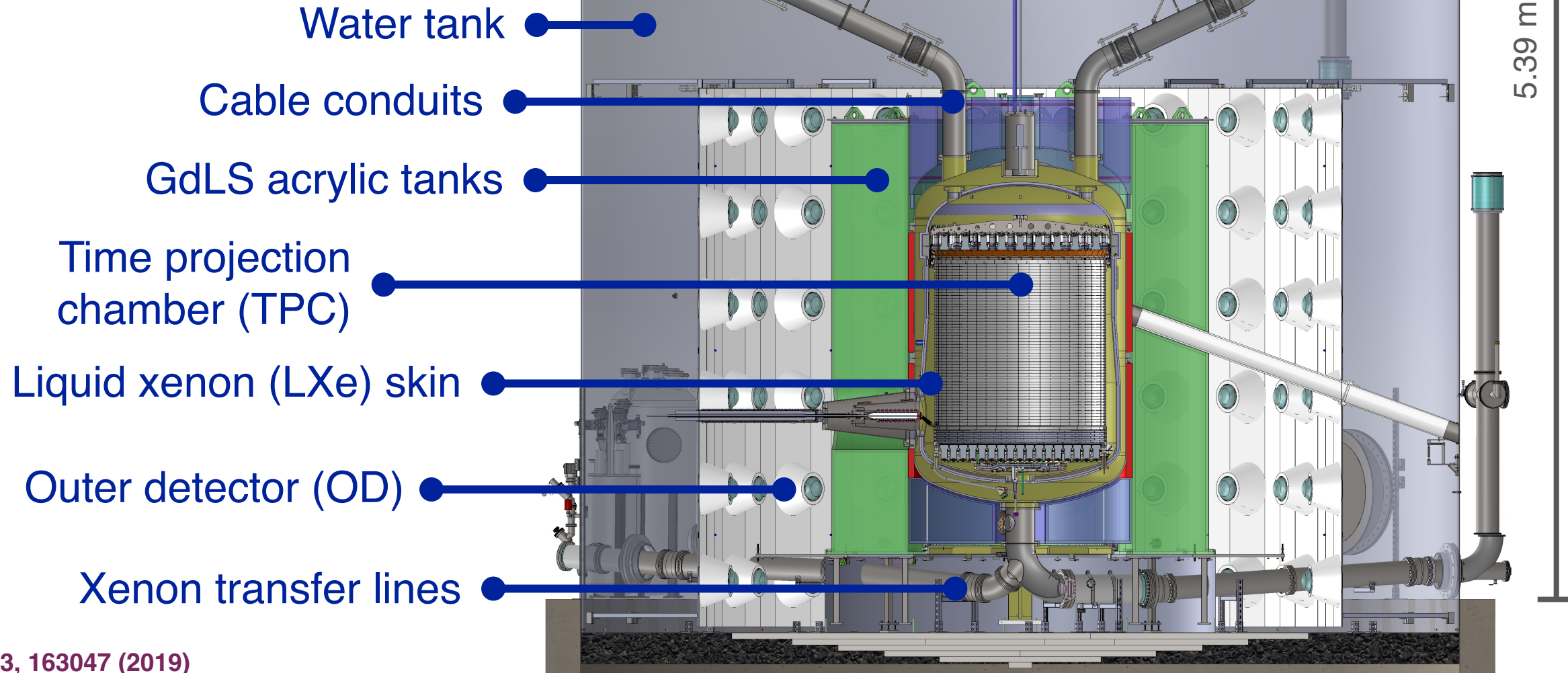


LZ collaboration meeting at University of Bristol, June 2026

Supplementary slides

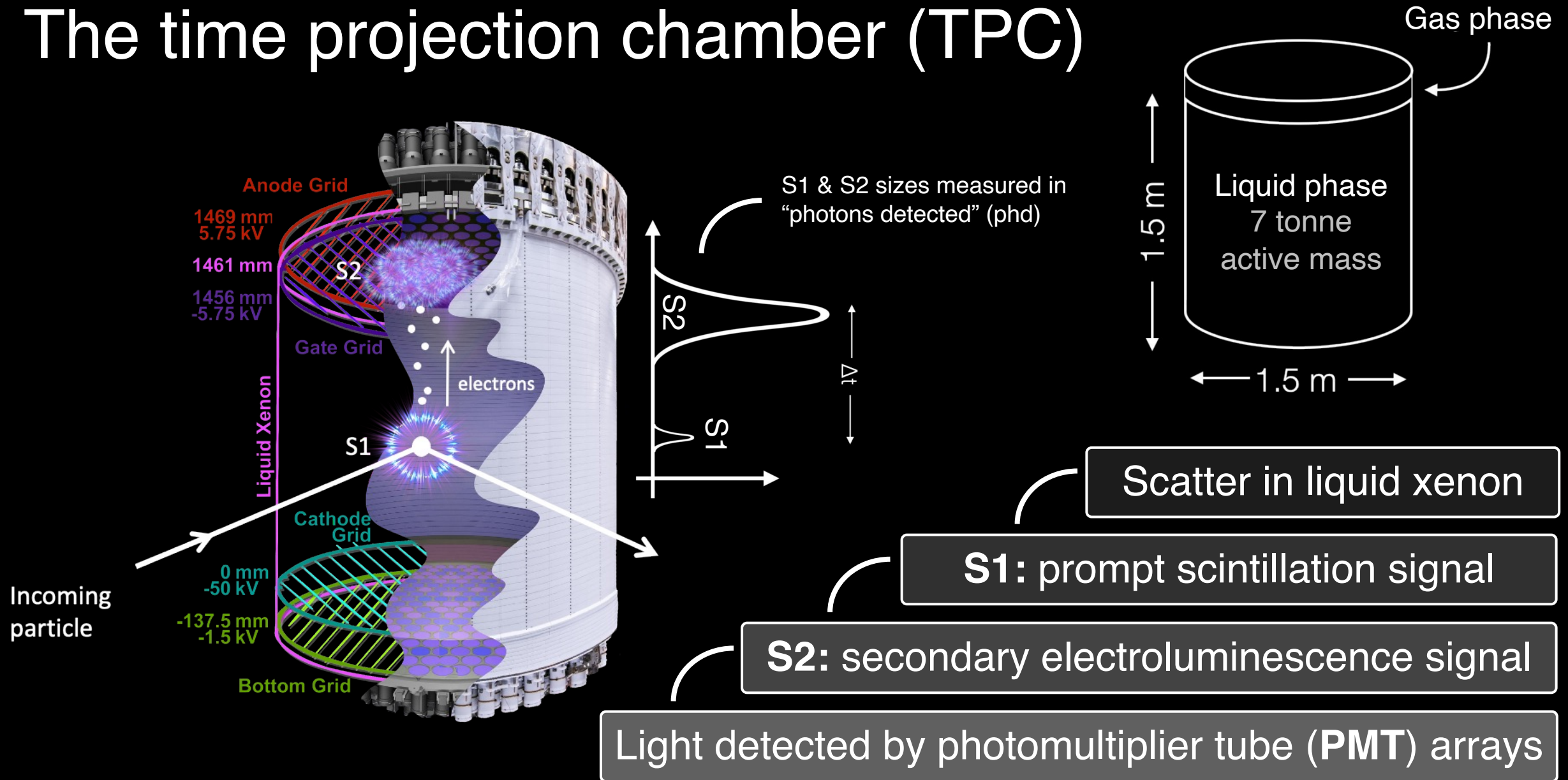


The LZ detector

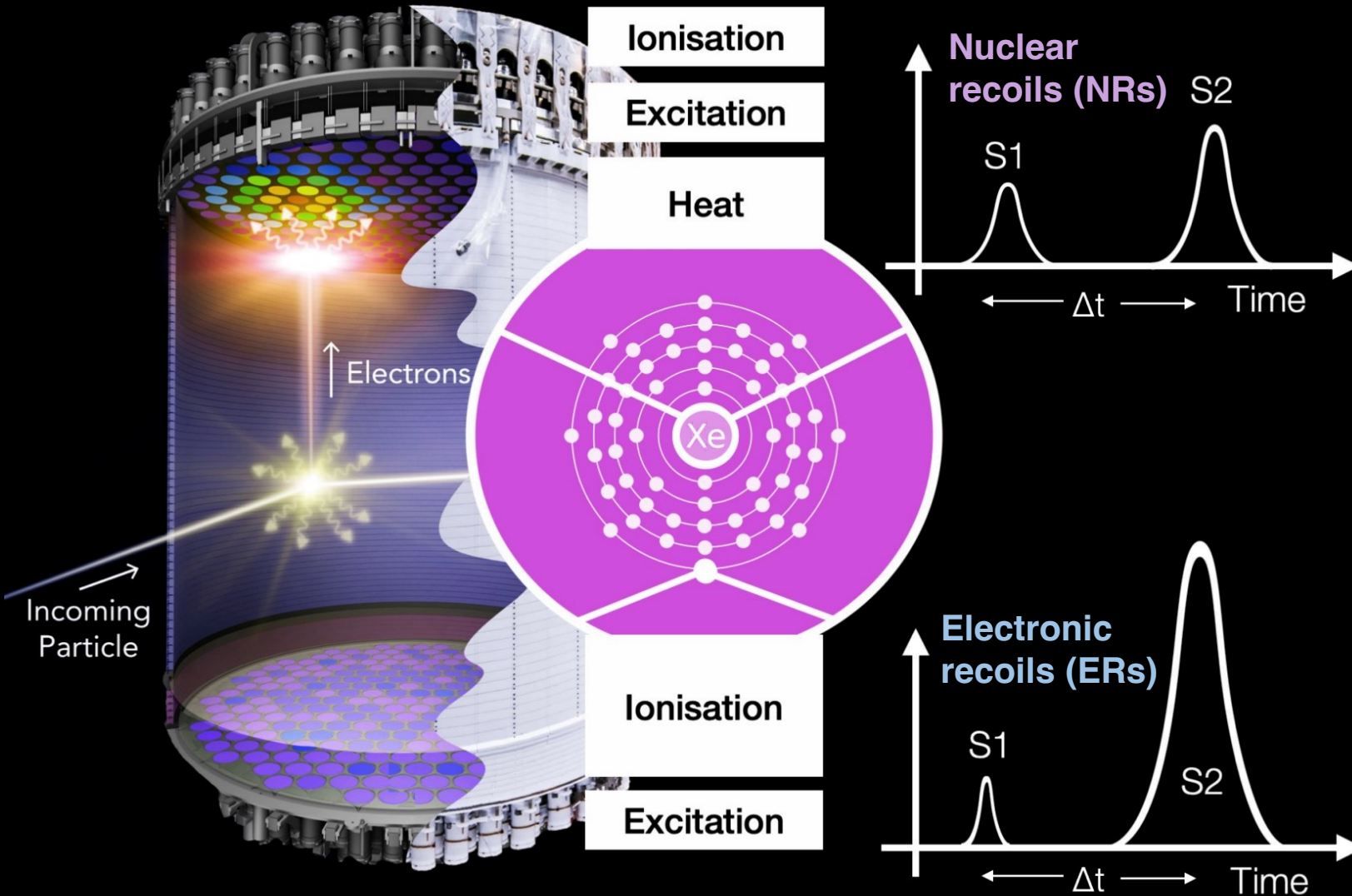


J. NIM A953, 163047 (2019)

The time projection chamber (TPC)



The time projection chamber (TPC)



Position reconstruction
from top-array hit map
(x, y) and drift time (z)

Discrimination between
nuclear recoils (NRs) and
electronic recoils (ERs)
via ratio of (S1, S2)
observables

The time projection chamber (TPC)

(S1, S2) corrected for detector effects and combined for **energy reconstruction***

*bottom PMT array used to avoid S2 saturation effects

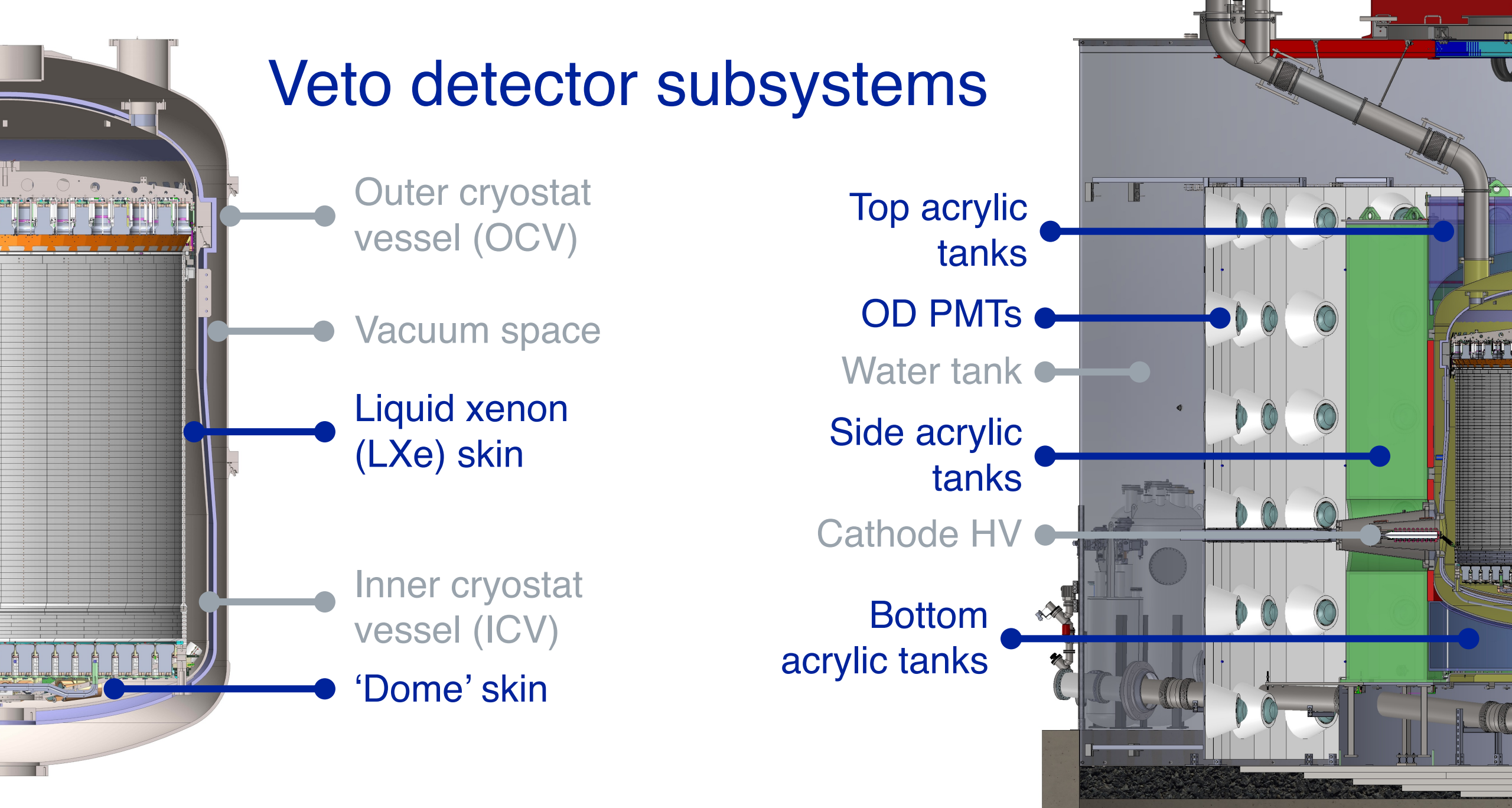
$$E = W \left(\frac{\overbrace{S1c}^{\text{number of photons}}}{\underbrace{g_1}_{\text{number of electrons}}} + \frac{\overbrace{S2c_{\text{bot}}}^{\text{number of photons}}}{\underbrace{g_2^{\text{bot}}}_{\text{number of electrons}}} \right)$$

mean energy required to produce electron-ion pair;
13.5 eV

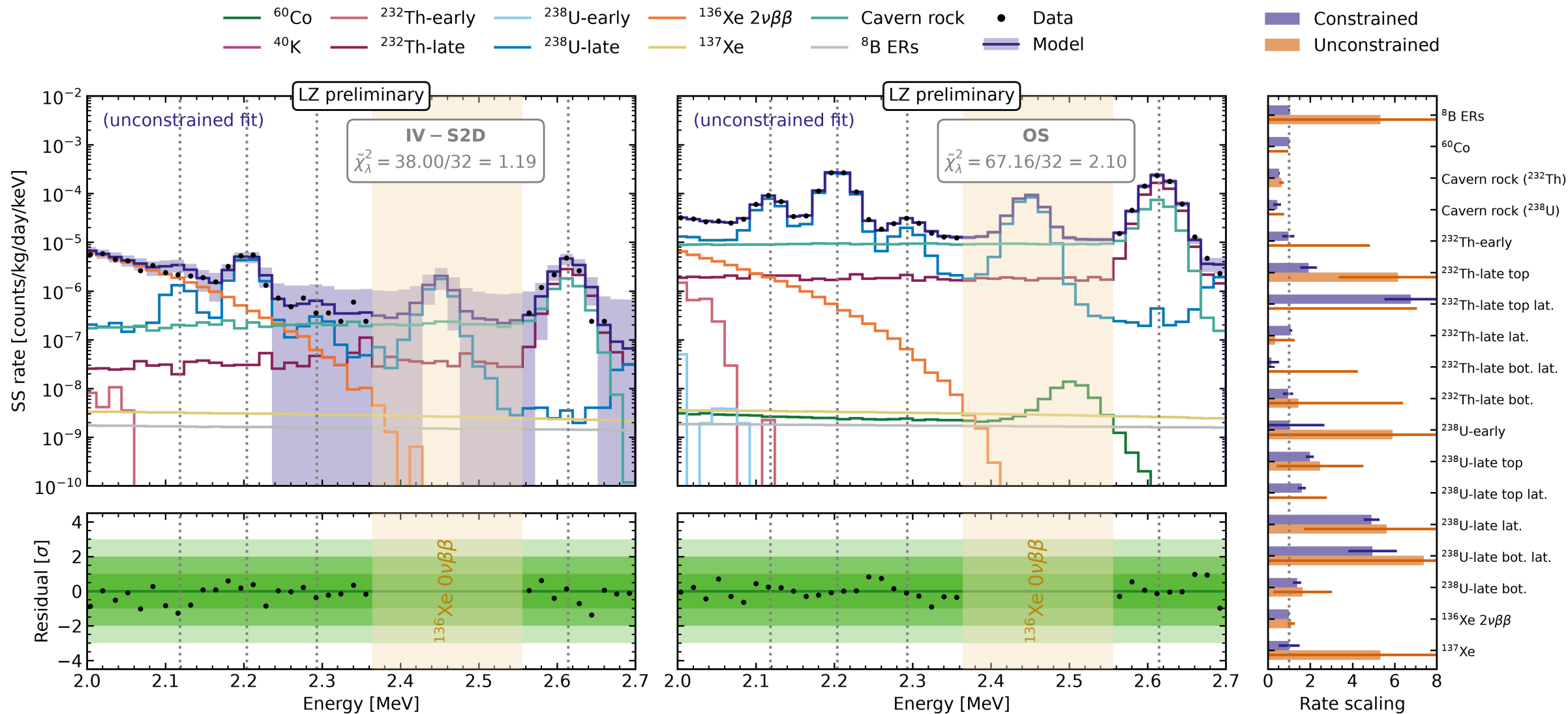
(LZ preliminary)

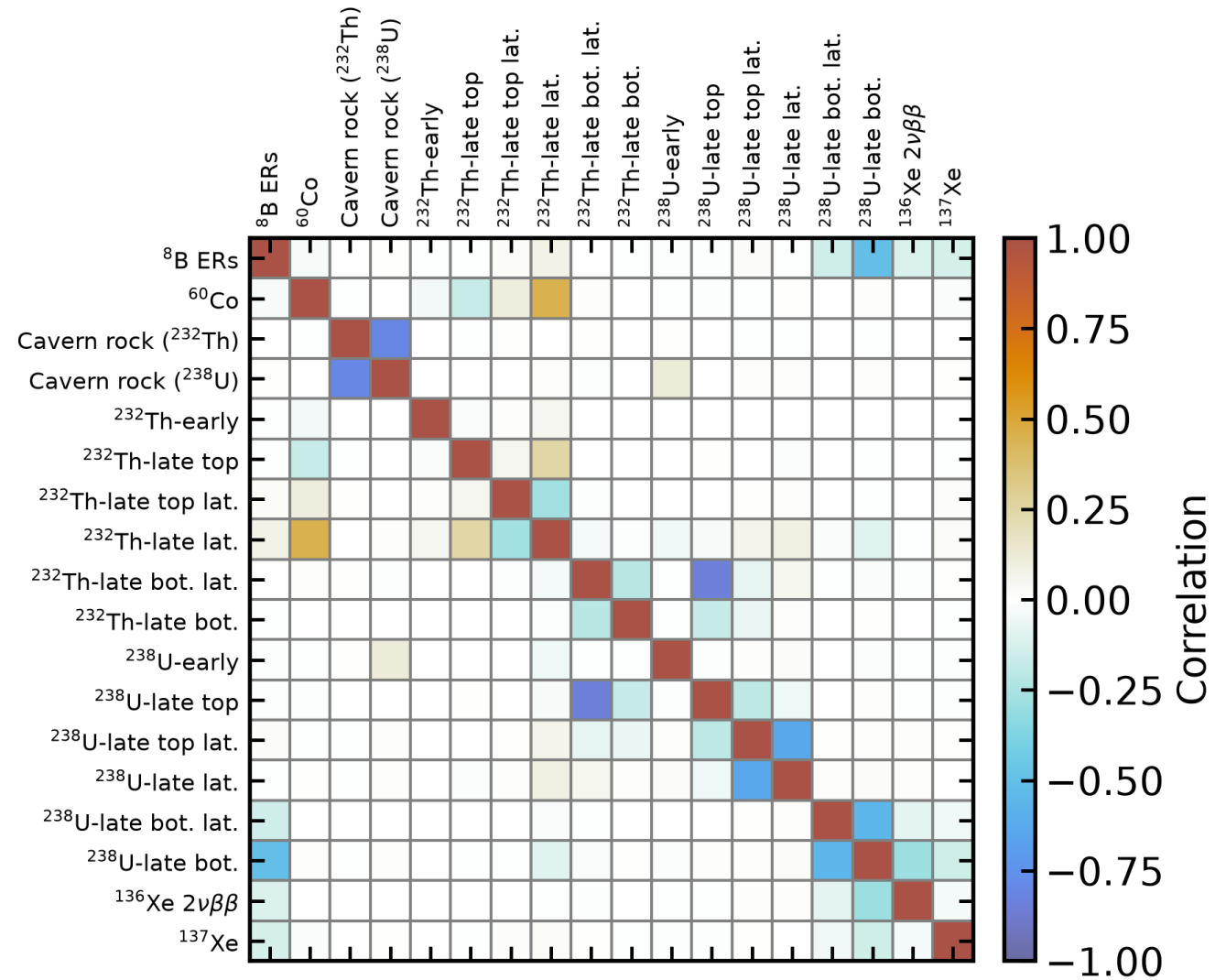
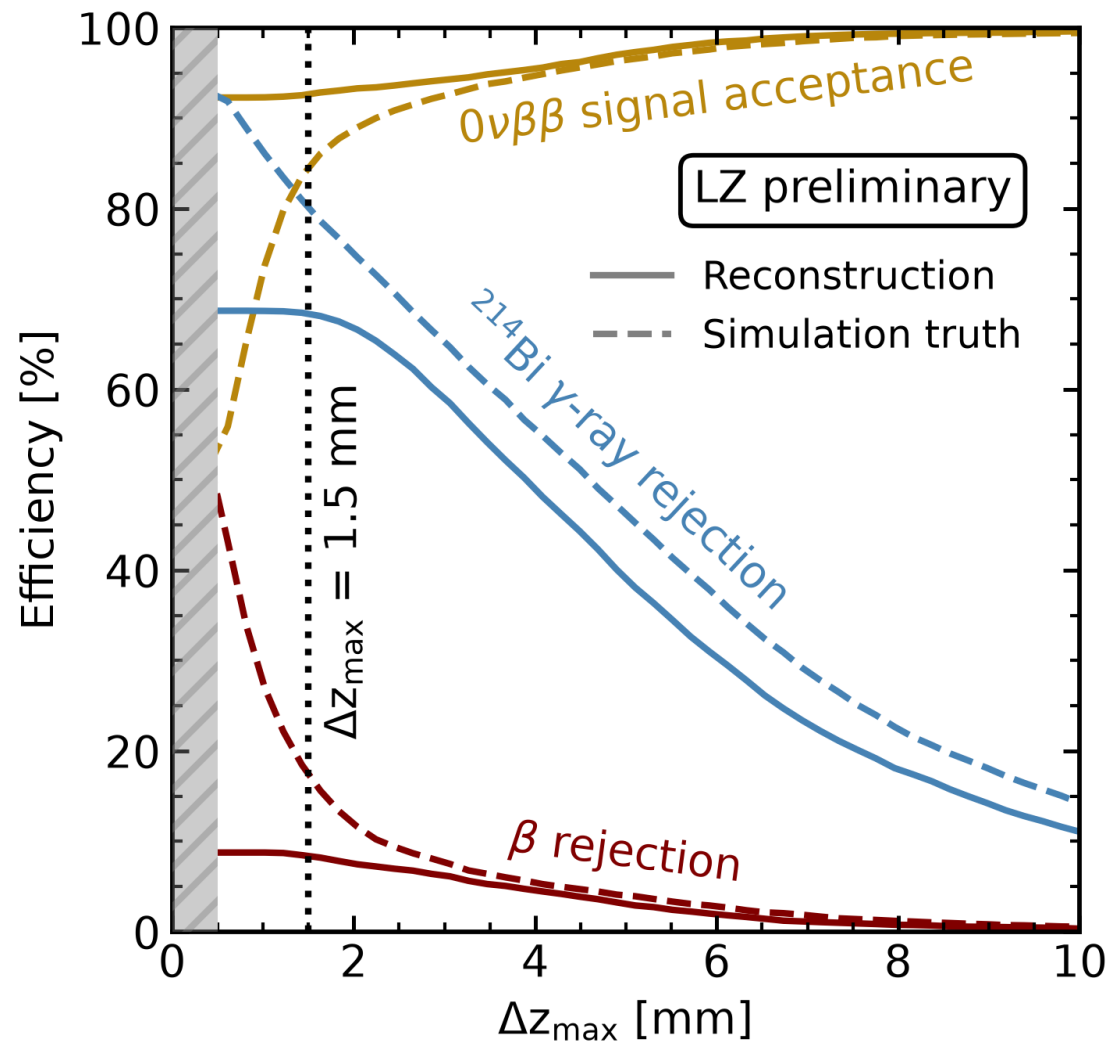
- effective charge gain (bottom array);
(11.8391 ± 0.2761) phd/electron
- photon detection efficiency (liquid);
(0.1102 ± 0.0024) phd/photon

Veto detector subsystems

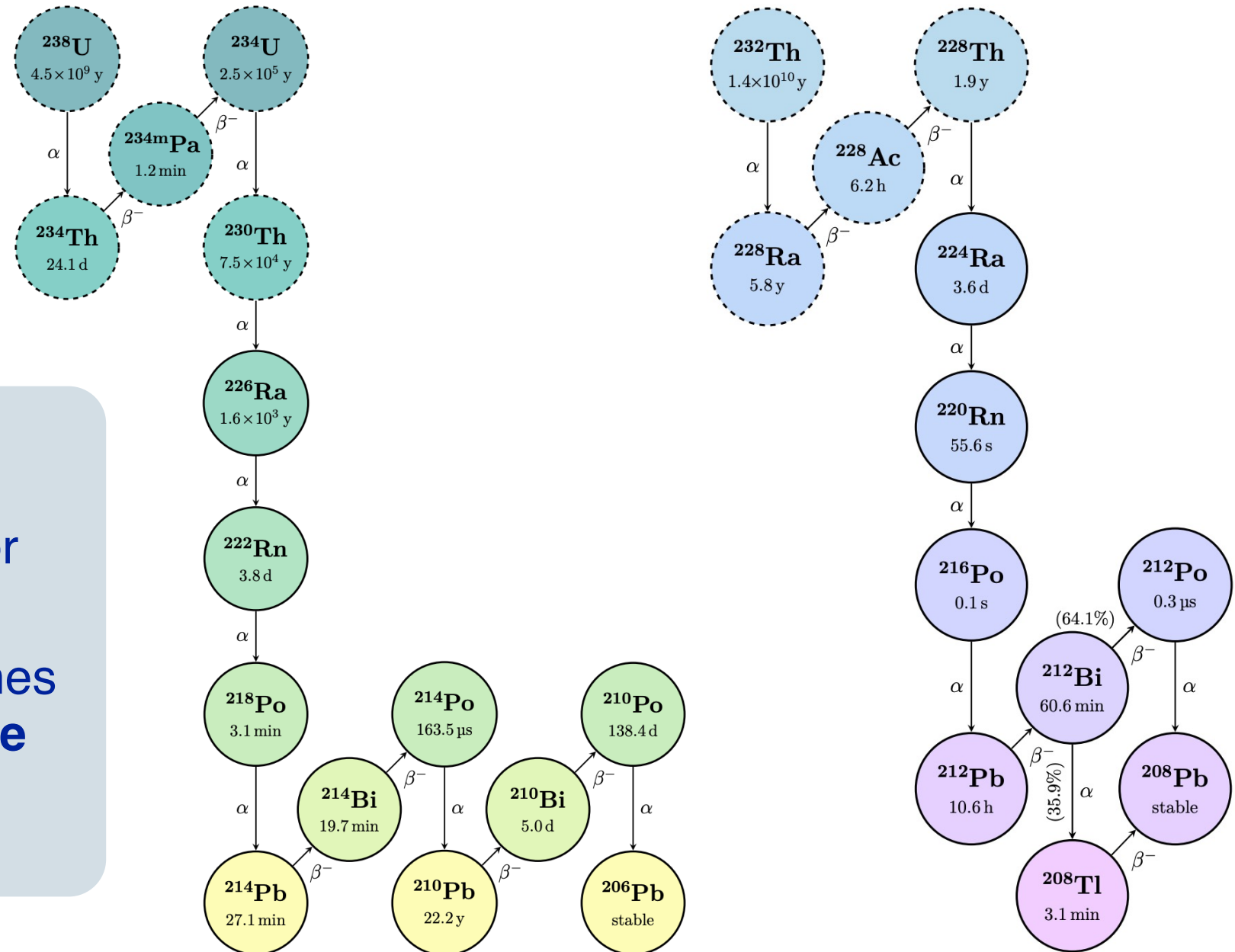


Results – tight ROI (unconstrained fit)





Decay chains

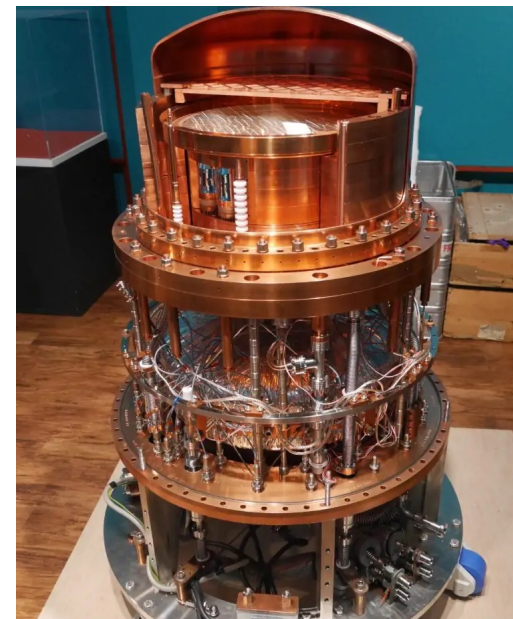


- **Primordial chains** embedded in detector materials
- Dashed & solid outlines represent **early & late** stages of each chain

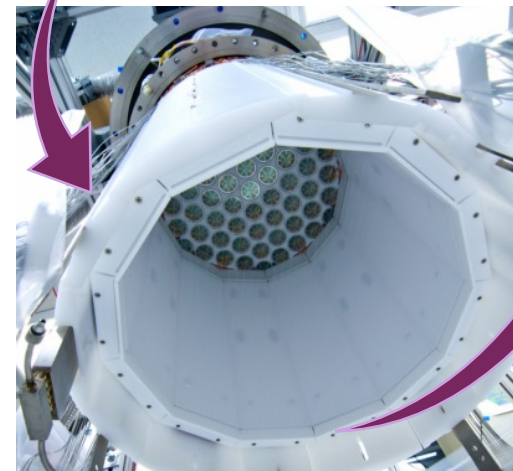
Xenon detectors

Why xenon?

- Coherent nuclear scaling ($\sigma \propto A^2$)
- Greatest **charge & light yield** of all noble elements
- Very dense $\Rightarrow$ **self-shielding** (short attenuation scale)
- Inert & highly **purifiable**
- Highly scalable $\Rightarrow$ **large target mass**



ZEPLIN-III – 12 kg (7 kg)



LUX – 250 kg (100 kg)



LZ – 7000 kg (5500 kg)

Example of a good event

