The search for 0νββ decay of ^{136}Xe with the LZ experiment

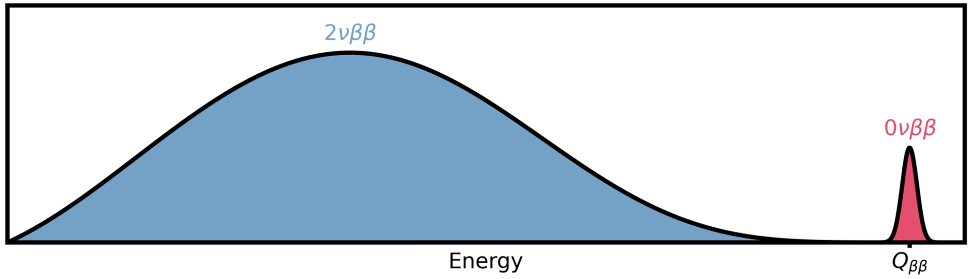
Illustration by Sandbox Studio, Chicago with Ana Kova

Aiham Al Musalhi – TeVPA 2026

on behalf of the LZ collaboration

Neutrinoless double-beta (0νββ) decay

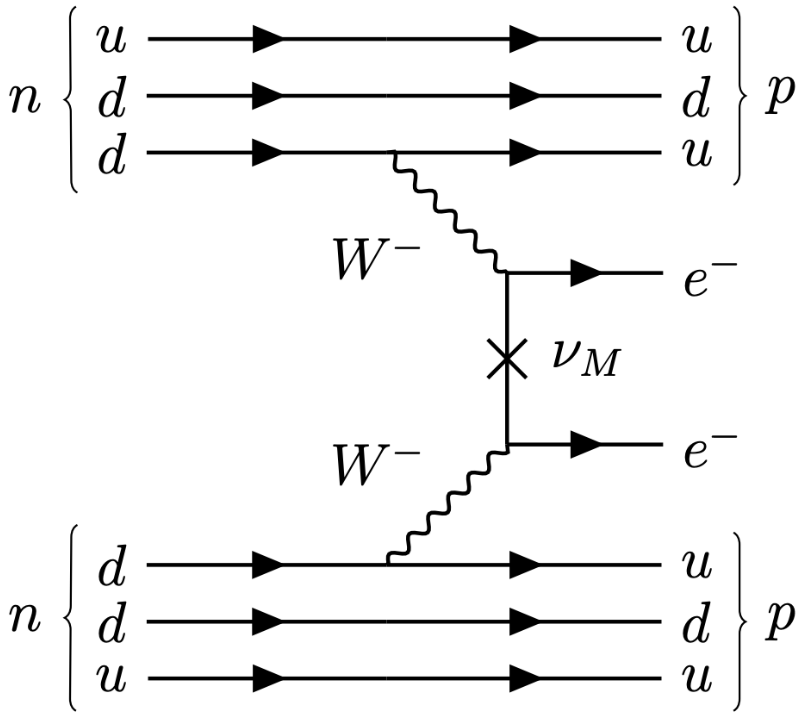
Flagship experimental search with deep implications for fundamental physics



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

$$\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} = g_A^4\, G_{0\nu}^{\beta\beta} \left|M^{(0\nu)}\right|^2 \frac{\langle m_{\beta\beta}\rangle^2}{m_e^2}$$

observed half-life — phase space — nuclear matrix element — effective Majorana mass



Rare event searches

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

$$T_{1/2}^{0\nu\beta\beta} \geq \frac{\epsilon\eta N_A}{M_A}\sqrt{\frac{M_T t}{R_b \Delta E}} \ln 2$$

- isotopic abundance (η)
- target mass (M_T)
- exposure time (t)
- signal efficiency (ϵ)
- background rate (R_b)
- energy search window (set by energy resolution) (ΔE)

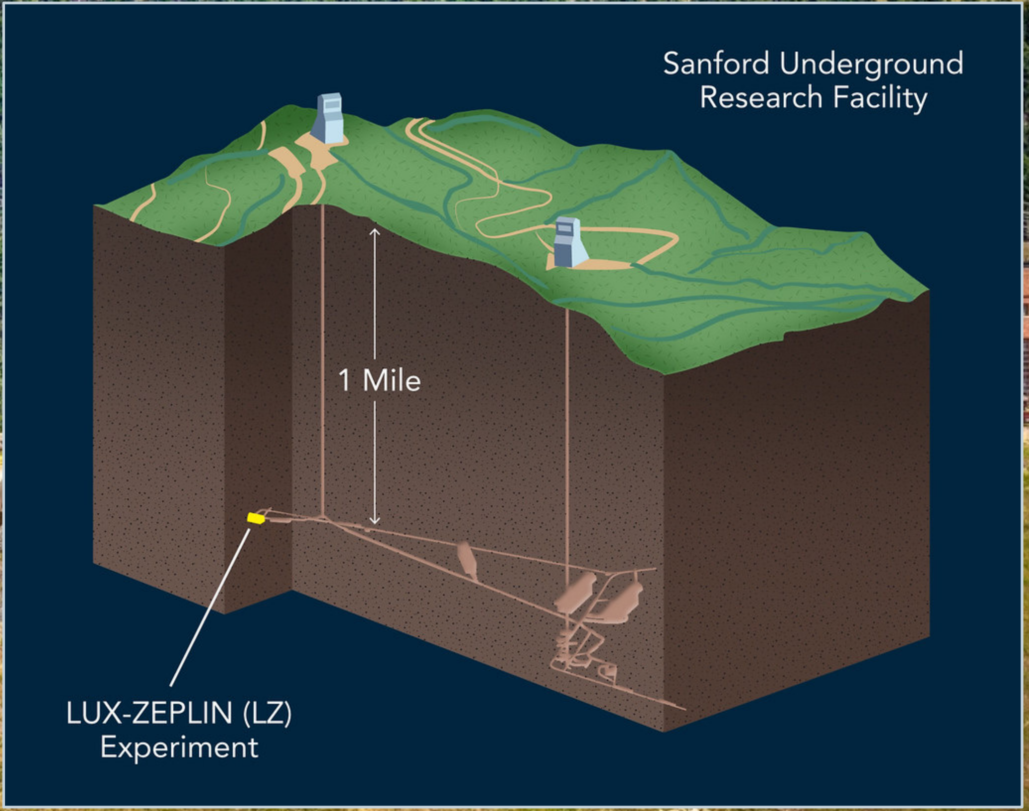
The LZ experiment

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

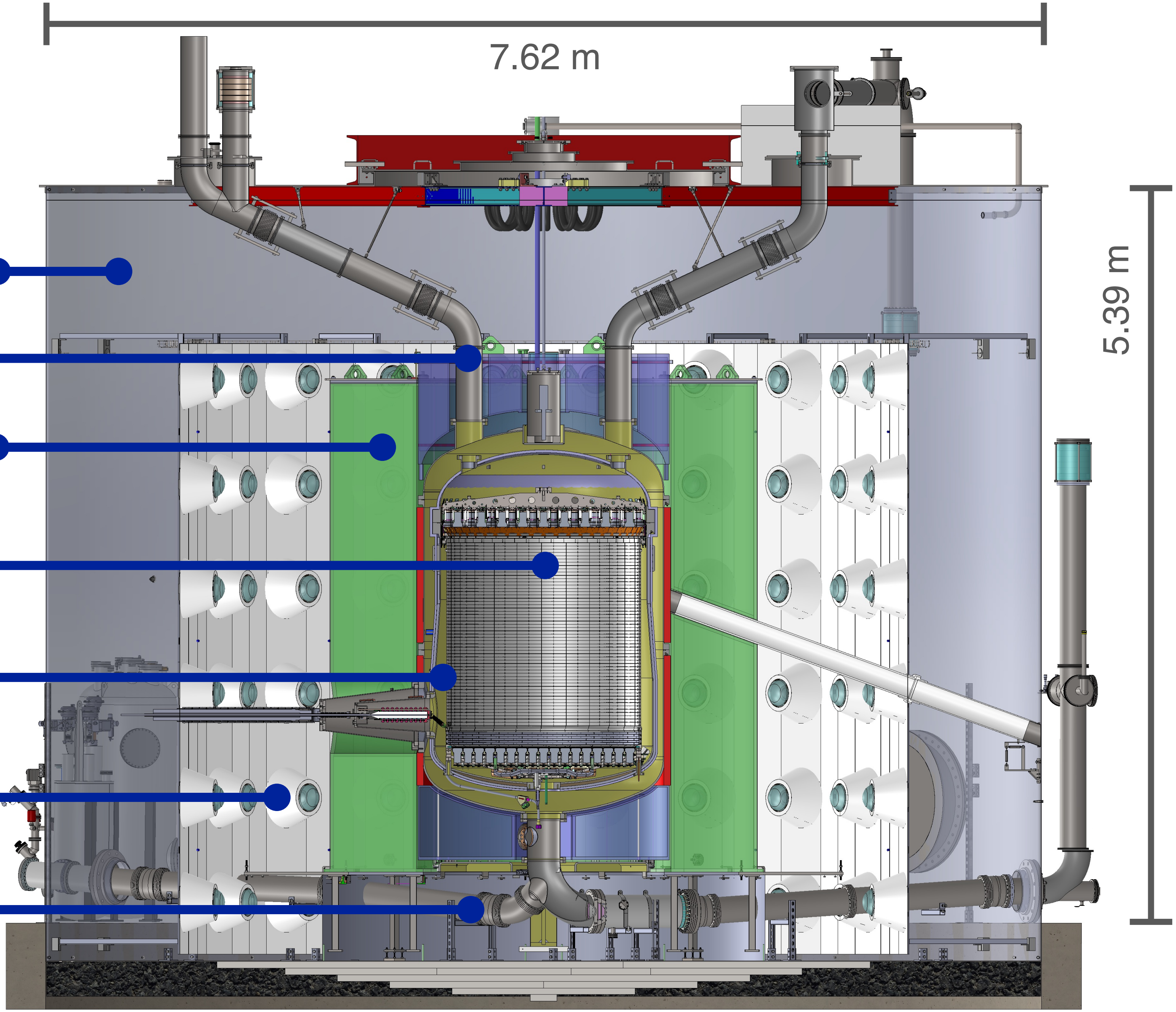
LZ is a rare event detector!

Satisfied criteria

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

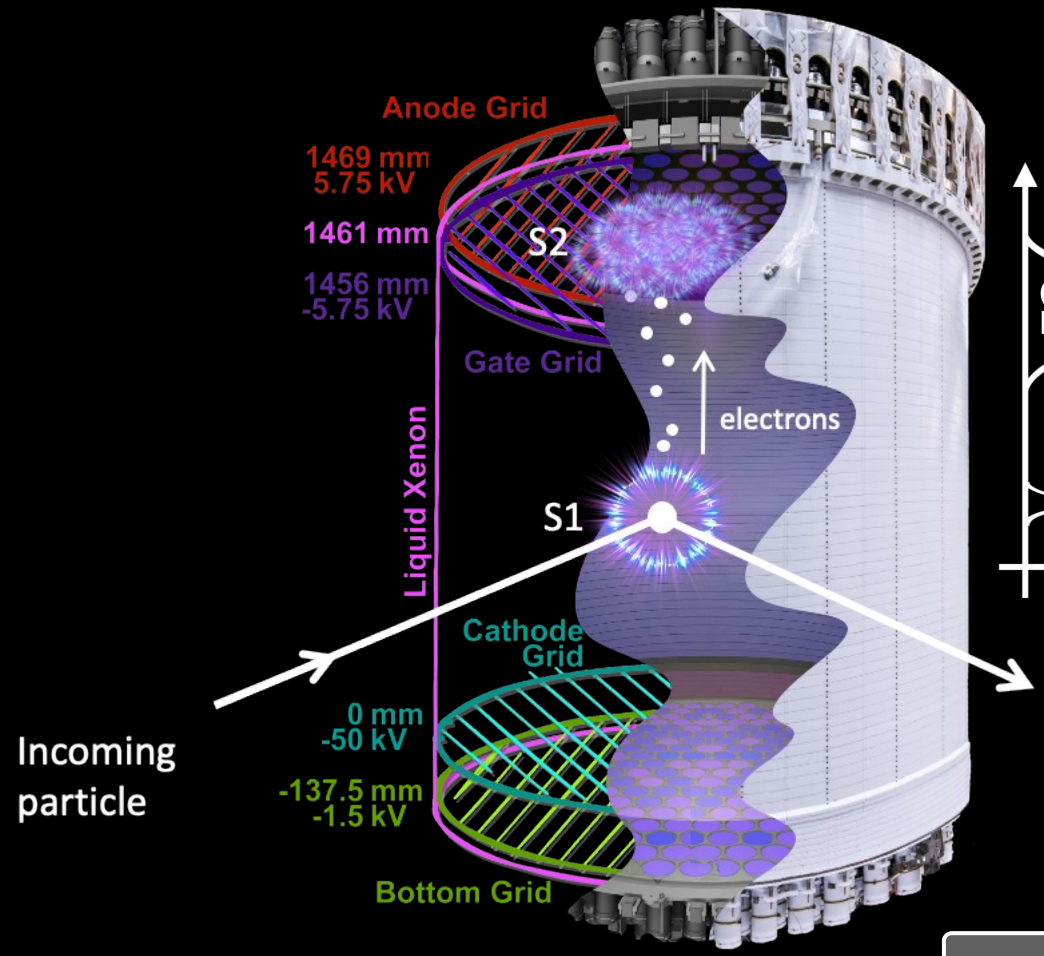


The LZ detector

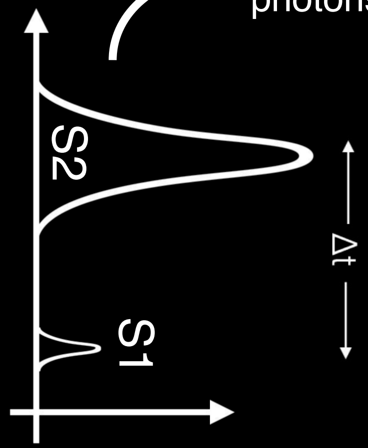


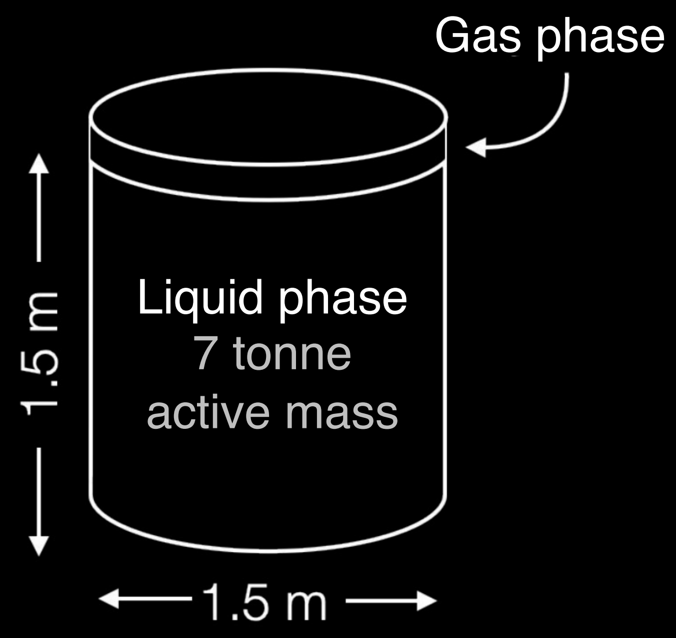
J. NIM A953, 163047 (2019)

The time projection chamber (TPC)



S1 & S2 sizes measured in “photons detected” (phd)





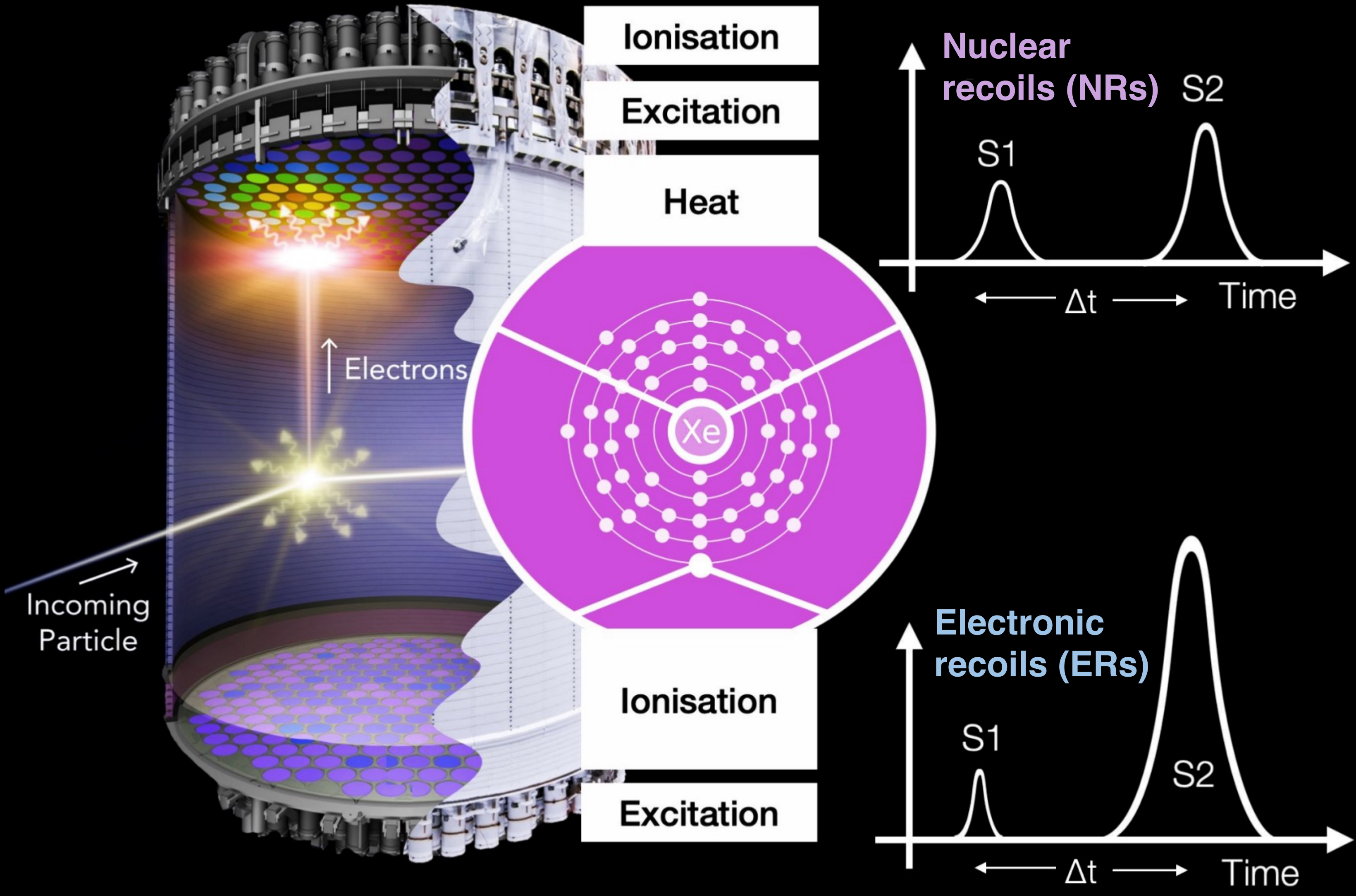
Scatter in liquid xenon

S1: prompt scintillation signal

S2: secondary electroluminescence signal

Light detected by photomultiplier tube (**PMT**) arrays

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

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

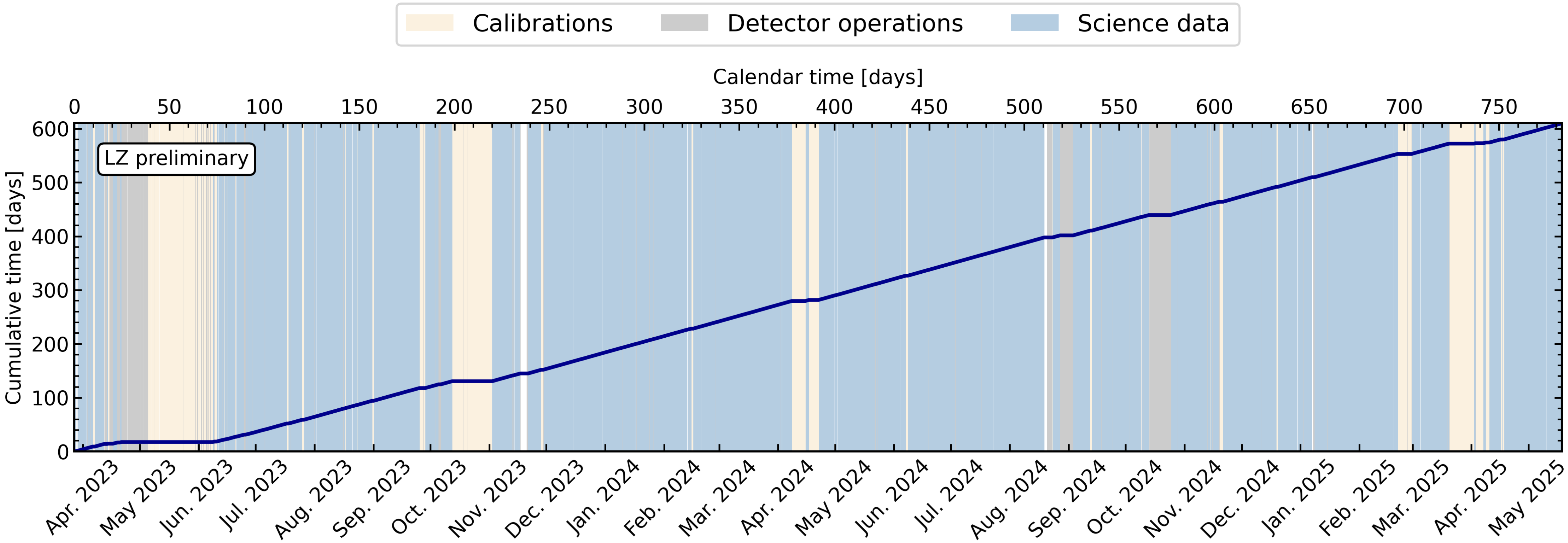
(LZ preliminary)

effective charge gain (bottom array); (11.8391 ± 0.2761) phd/electron

photon detection efficiency (liquid); (0.1102 ± 0.0024) phd/photon

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

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)

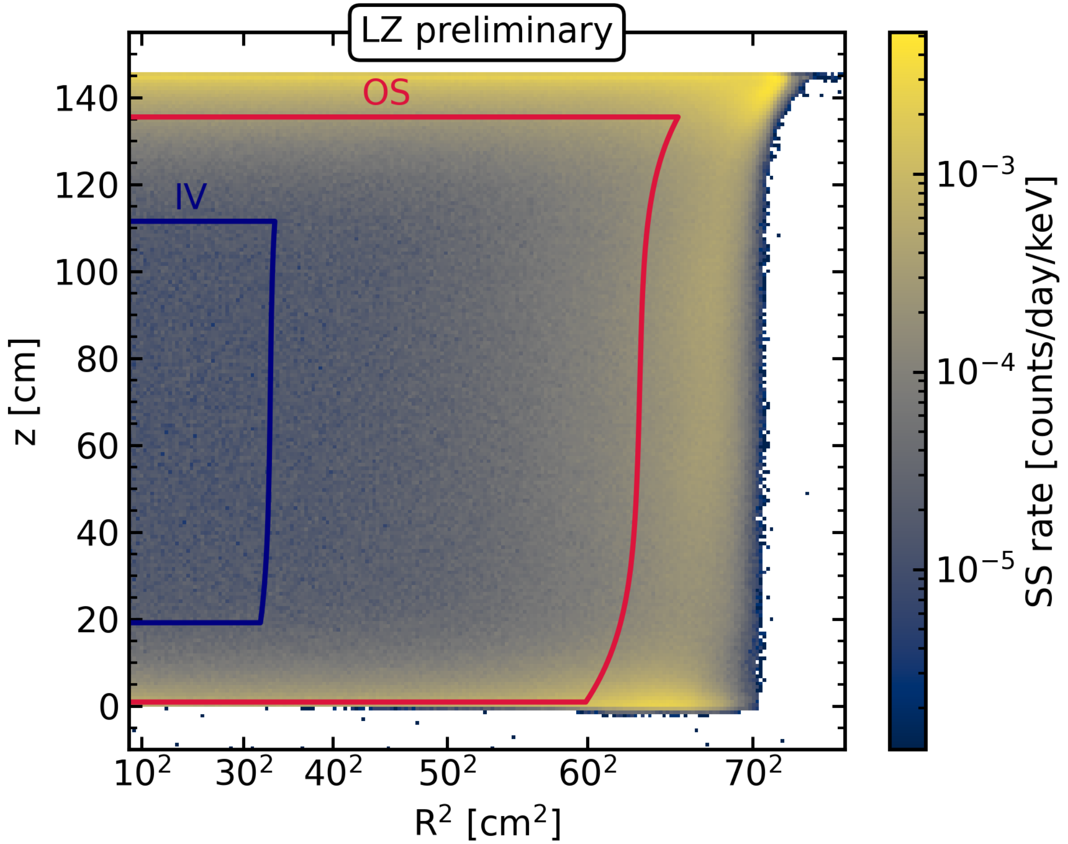
Event selection

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

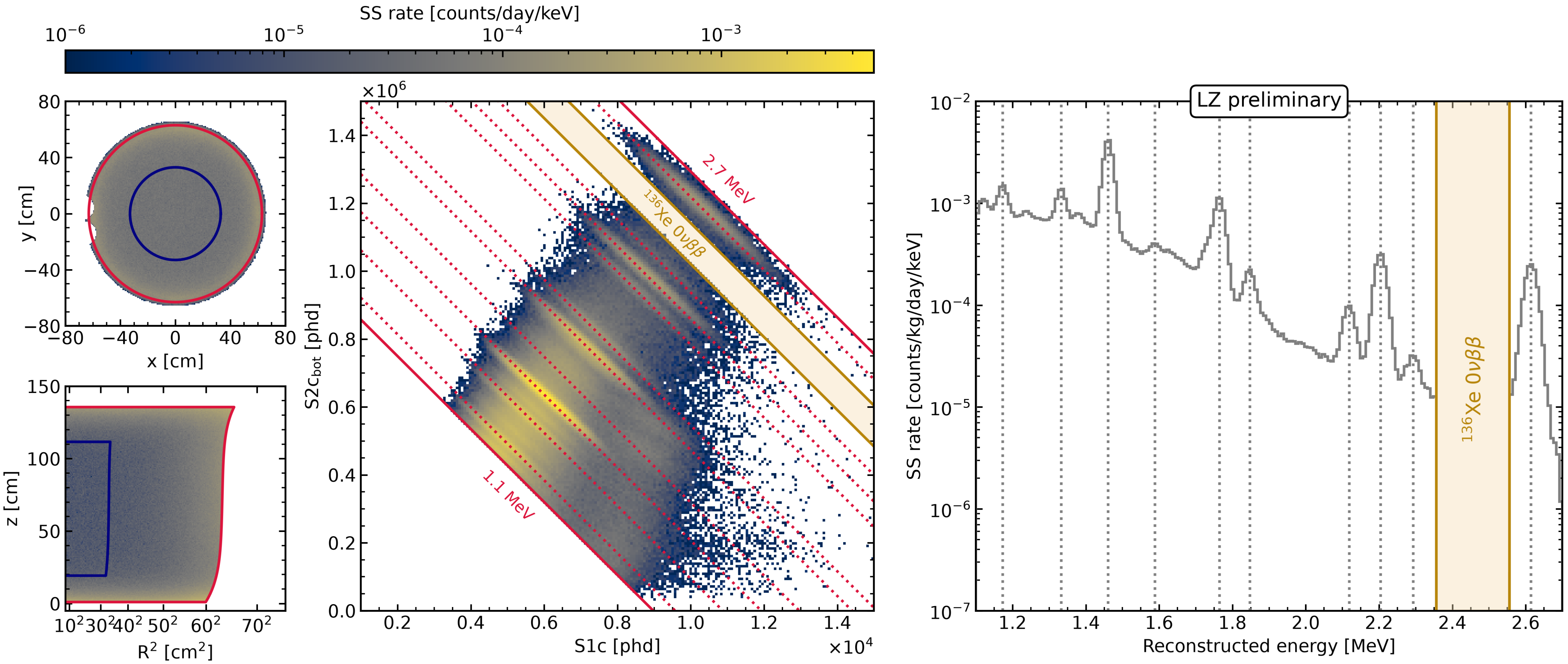
Search within **1.1–2.7 MeV region of interest** (ROI), with ($Q_{\beta\beta}$ ± 100) keV ***blinded***

Selection is reduced with

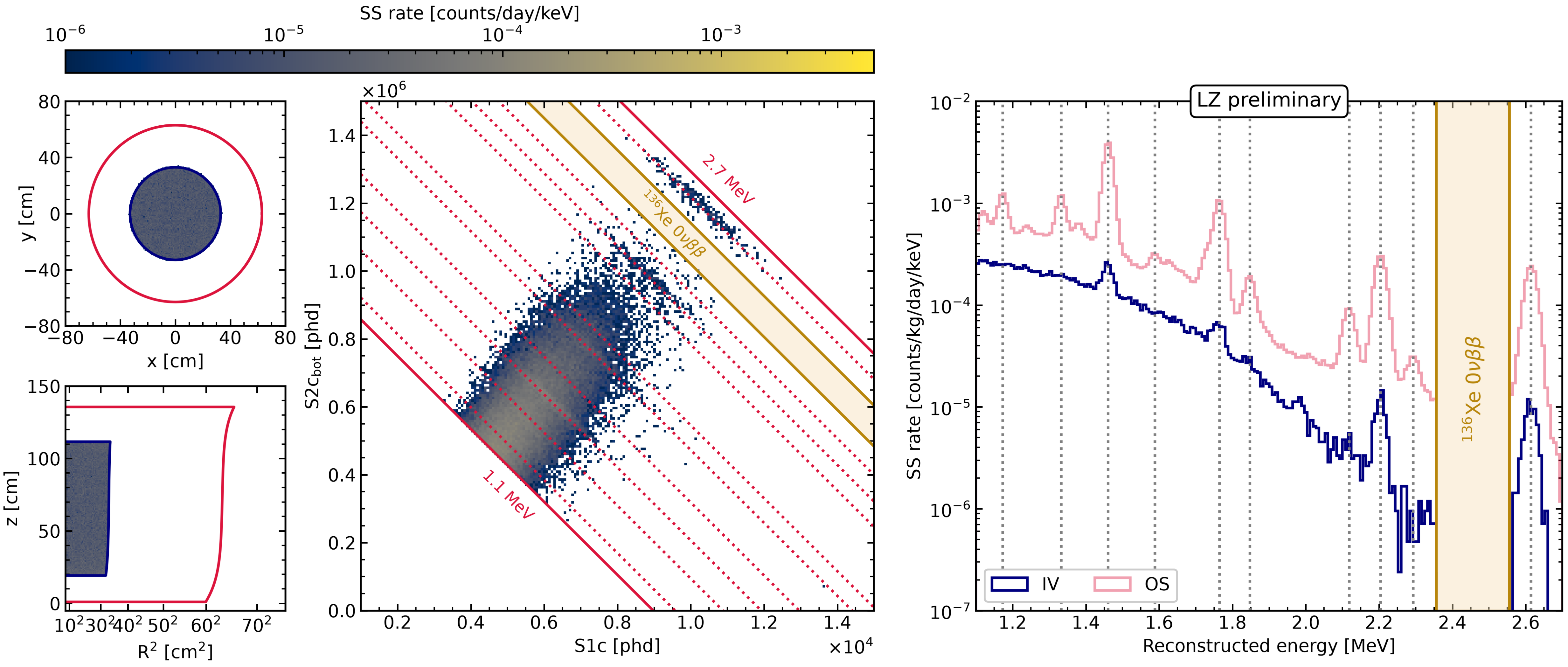
- **Data quality cuts** and **temporal exclusions**
- **Anti-coincidence veto tags** in skin and OD
- **Fiducial volume** (FV) to negate edge effects and define a stable region; *split* into
  - **Inner volume** (IV) – clean one-tonne partition with high sensitivity
  - **Outer shell** (OS) – surrounding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



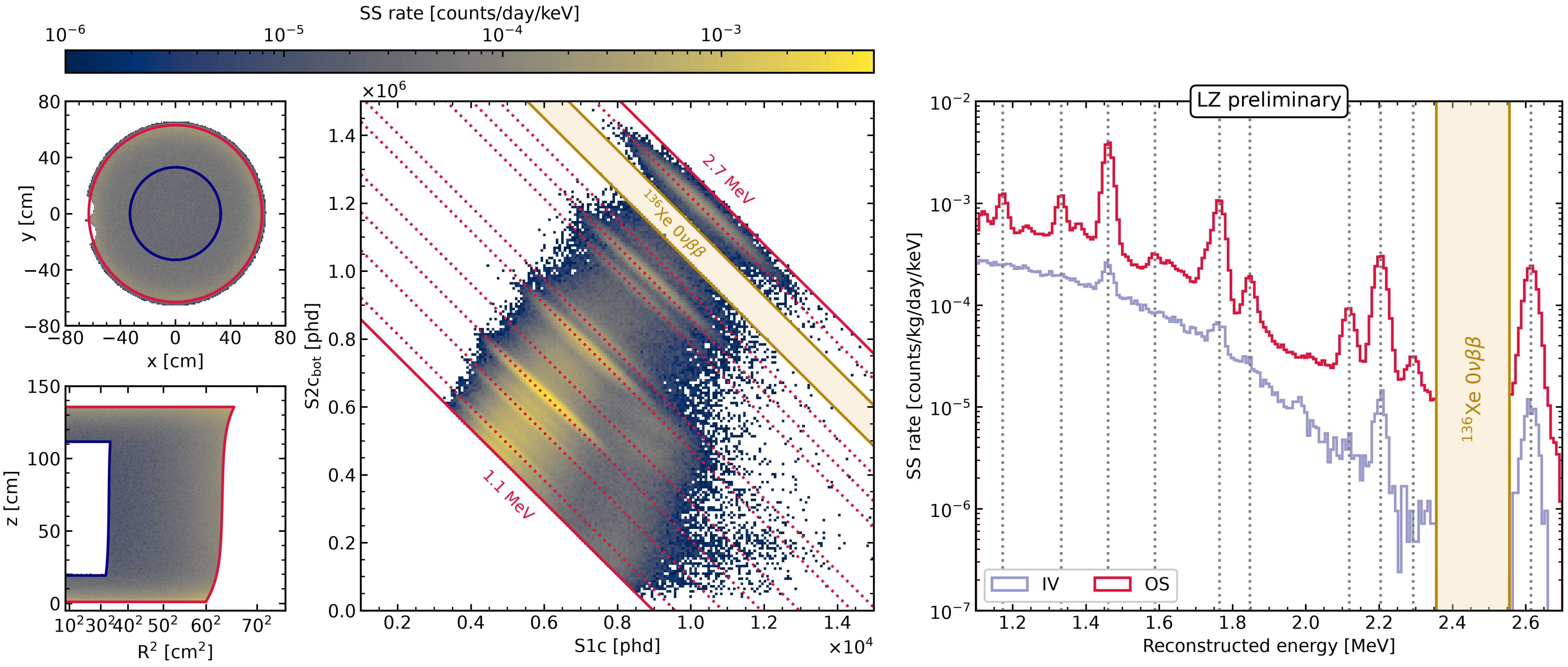
Event selection



Event selection



Event selection



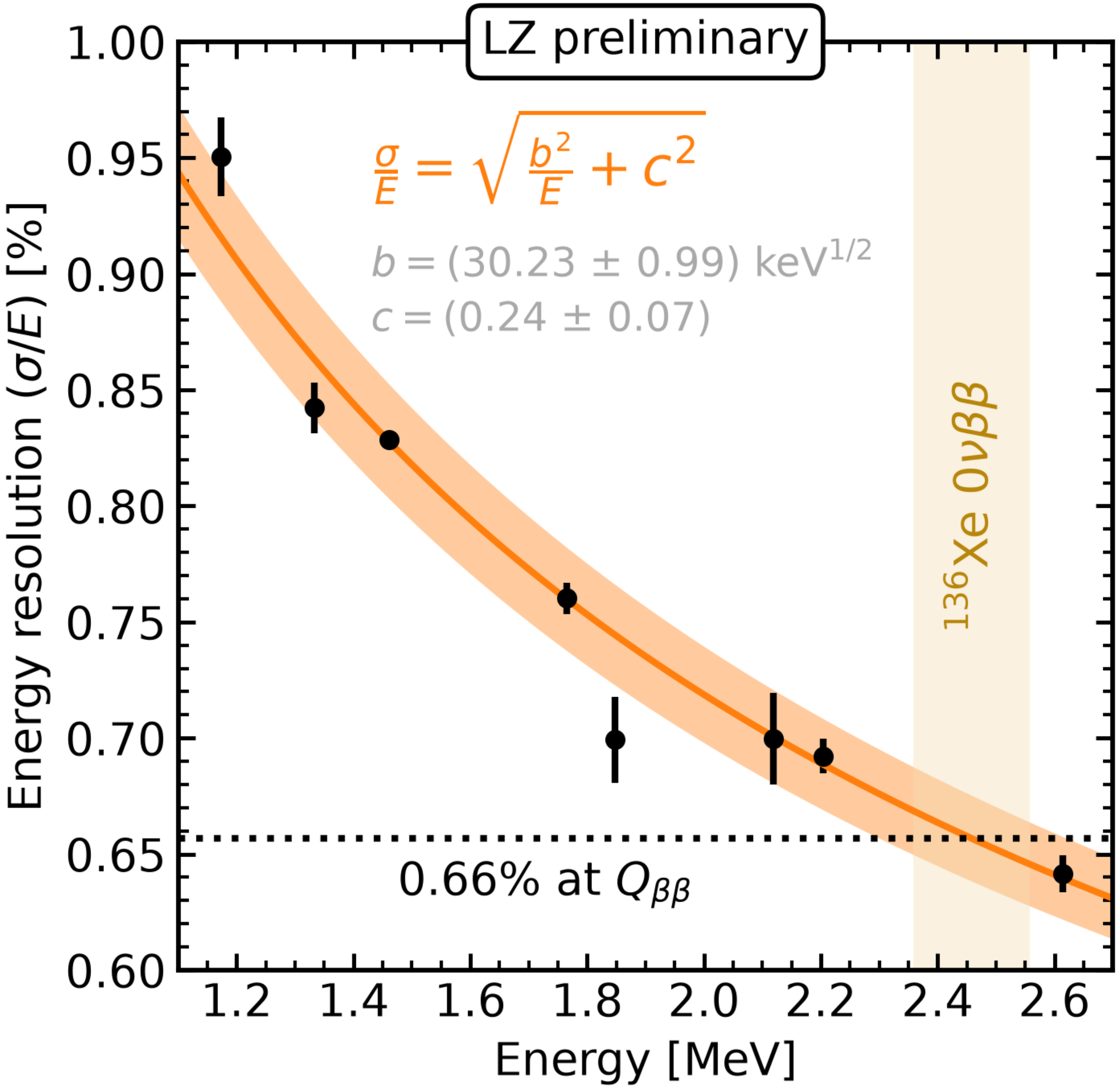
*conservative 1% resolution assumed in sensitivity paper
Phys. Rev. C 102, 014602 (2020)

Energy reconstruction

- Novel **signal correction procedure** developed with multidimensional splines
- **Energy reconstruction** accurate to within ±0.01%
- Excellent energy resolution achieved* ⇒ **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



*informed by LZ assay measurements in **EPJ C 80, 1044 (2020)**

Backgrounds

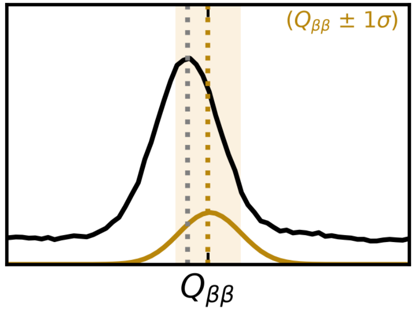
External γ rays form most of the background

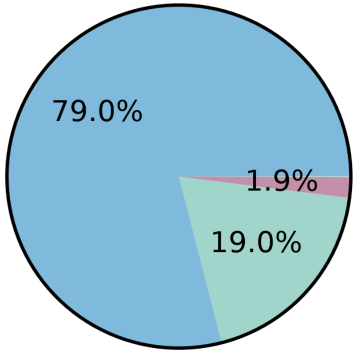
These primarily originate from*

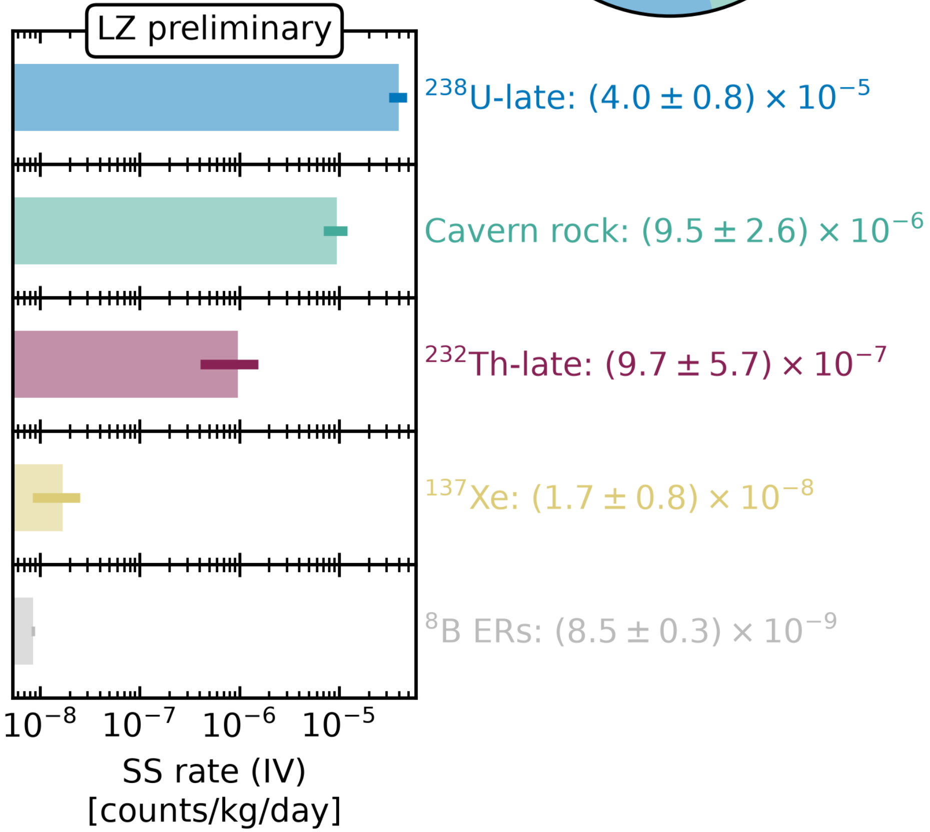
- ^{232}Th and ^{238}U chains in **detector materials**
  ⇒ **^{214}Bi 2447.7 keV γ rays** *most dominant*
- ^{208}Tl γ rays from surrounding **cavern rock**

Other sources

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





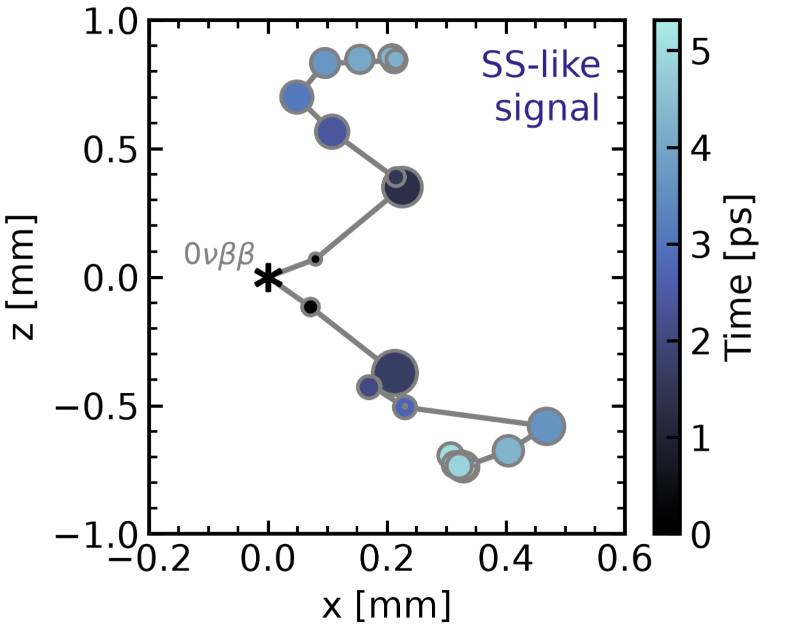


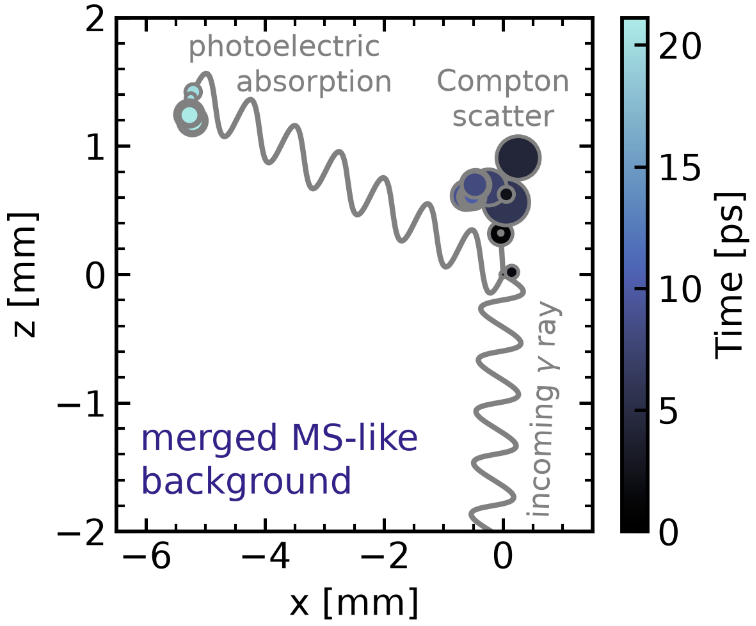
SS-MS discrimination

Majority of **0νββ 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 ~3–8 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**





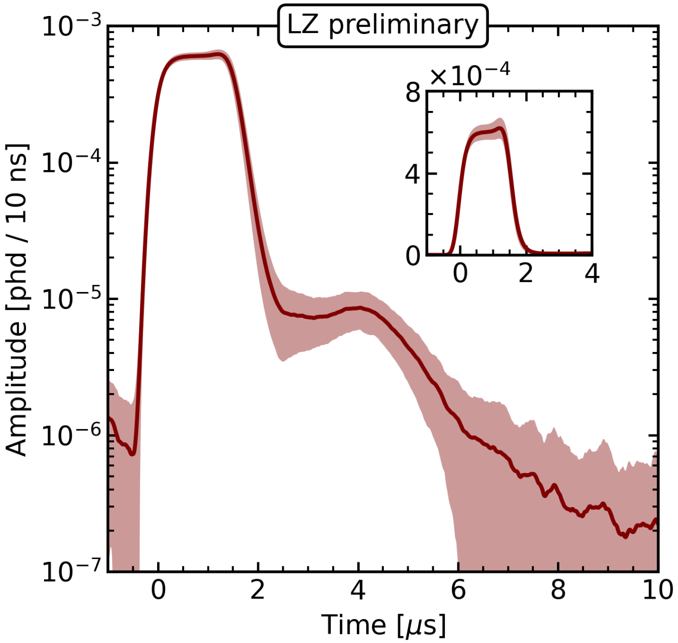
S2 deconvolutions

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

S2 = **e⁻ track** * **IRF** * **longitudinal diffusion**

continuous e⁻ track (dE/dz); modelled with **δ-functions**

impulse response function (IRF); shape of non-diffused S2 (data-driven)



Gaussian smearing introduced as e⁻ drift upwards

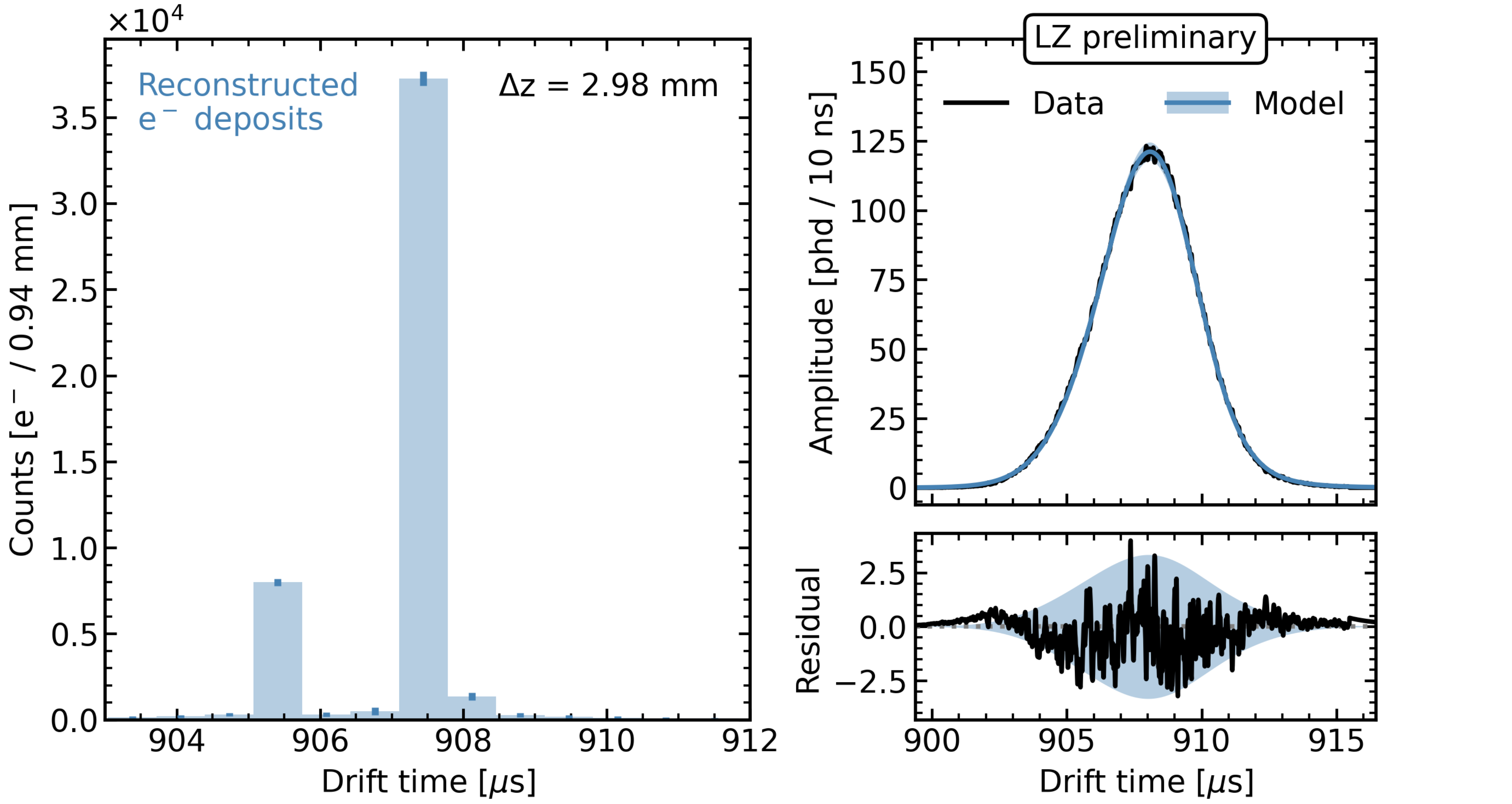
$$\mathcal{G}\left(0, \sqrt{2D_L t_d / v_d^2}\right)$$

Diffusion effects and IRF can be **deconvolved*** from S2s to **reconstruct e⁻ tracks!**

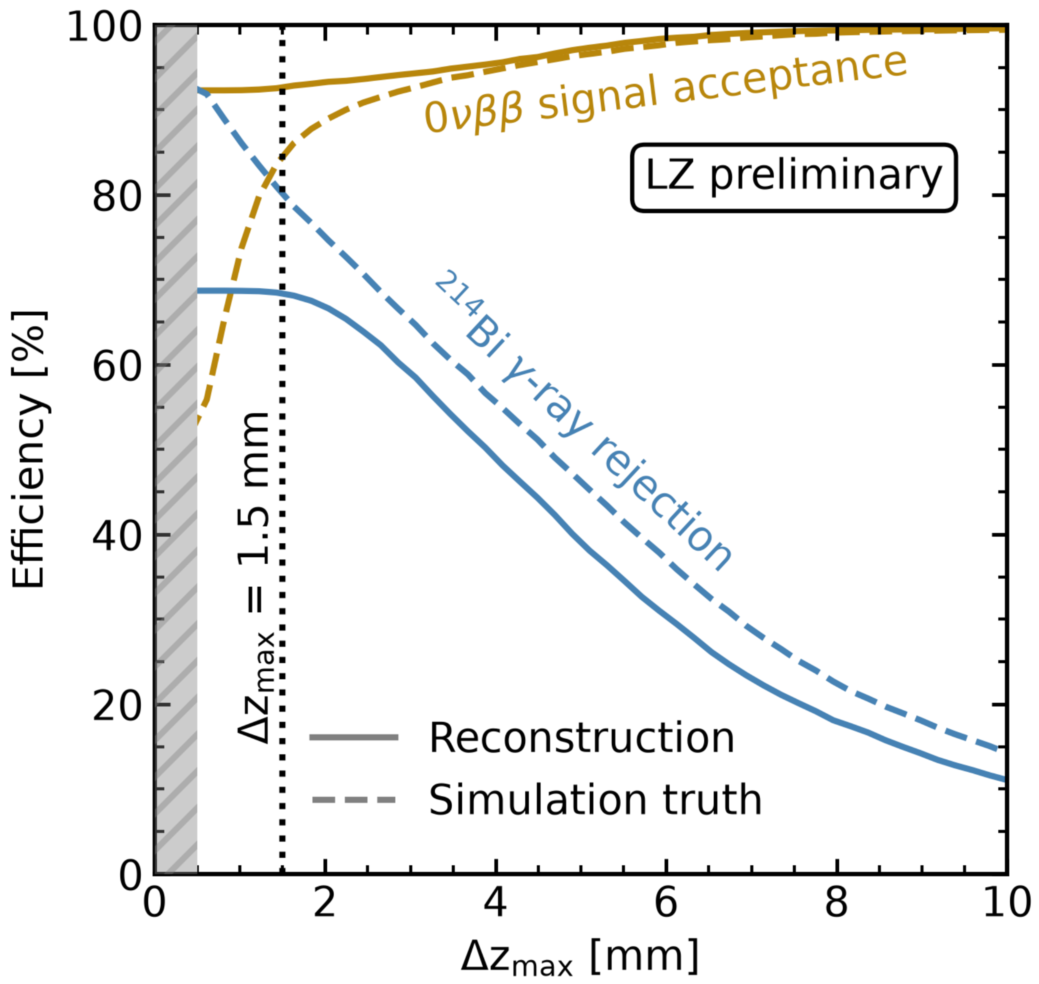
(computationally intensive; only applied to IV)

S2 deconvolutions

We can infer Δz from the **reconstructed** e⁻ tracks

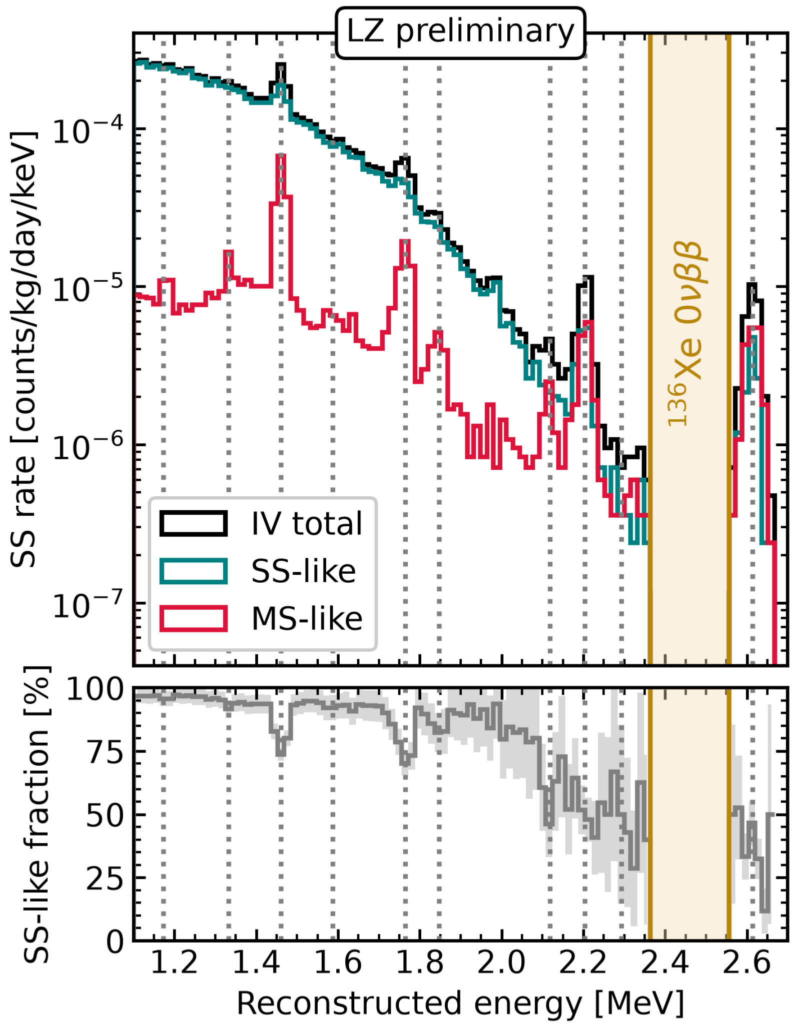


S2 deconvolutions



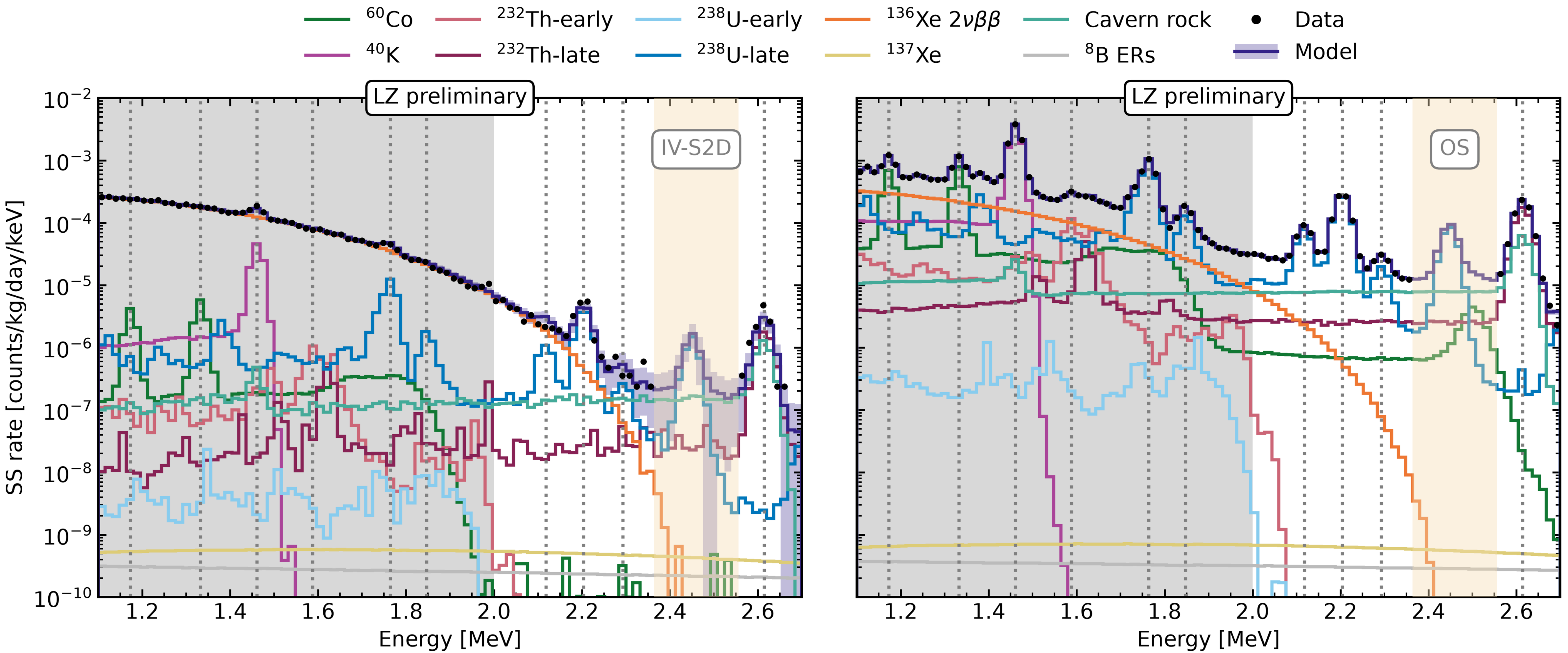
~8% of IV events removed by cut at **Δz < 1.5 mm**

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

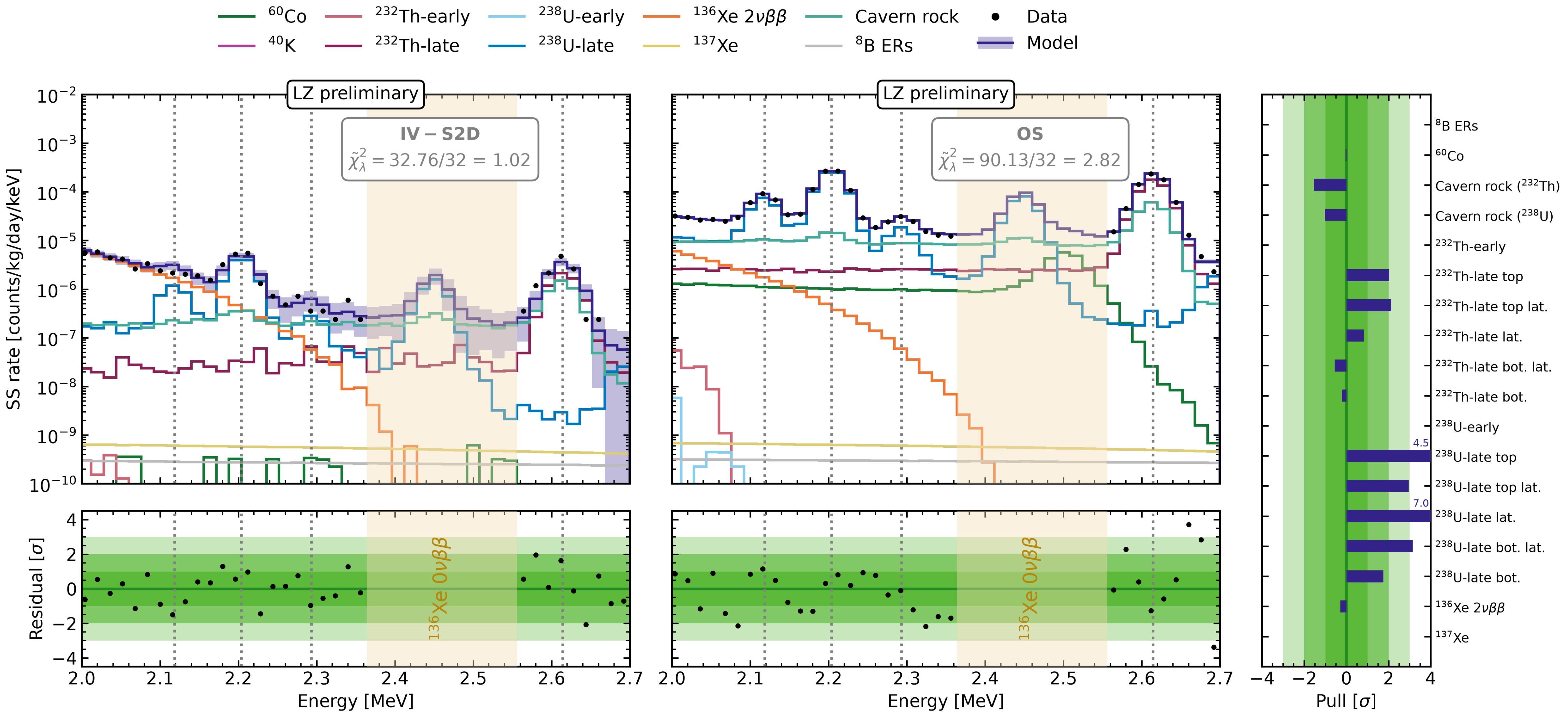


Wide ROI model

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



Blinded results

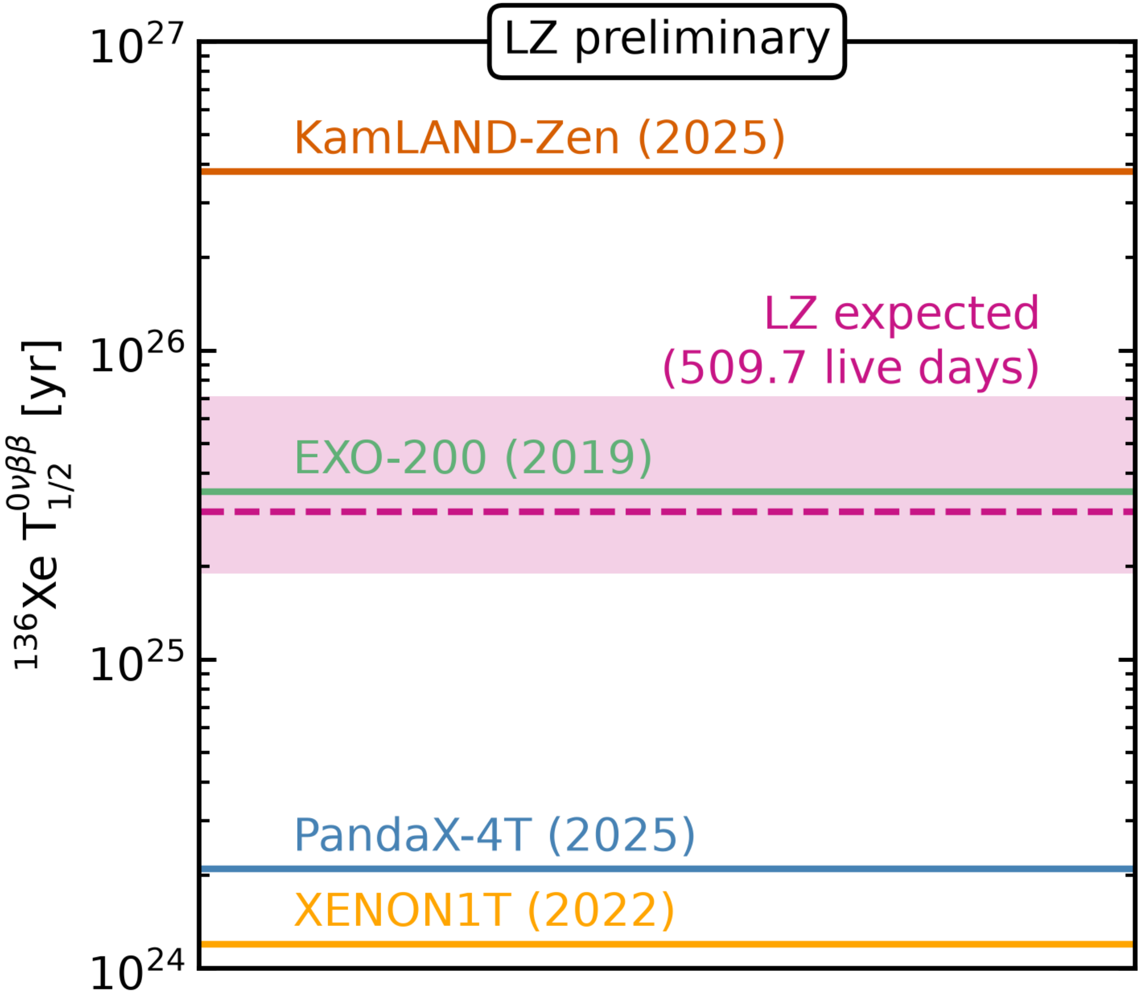


Summary

Blinded median expected **sensitivity** towards ^{136}Xe 0νββ decay in LZ is at **~3.0 × 10^{25} years** (for 509.7 live days)

Intend to **unblind** very soon; stay tuned for first results!

This is an **energy-only result**, with plenty of extensions on the horizon as LZ continues to accrue more data



Thanks for listening!

@lzdarkmatter

The LZ collaboration

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

Science and Technology Facilities Council

U.S. DEPARTMENT OF ENERGY

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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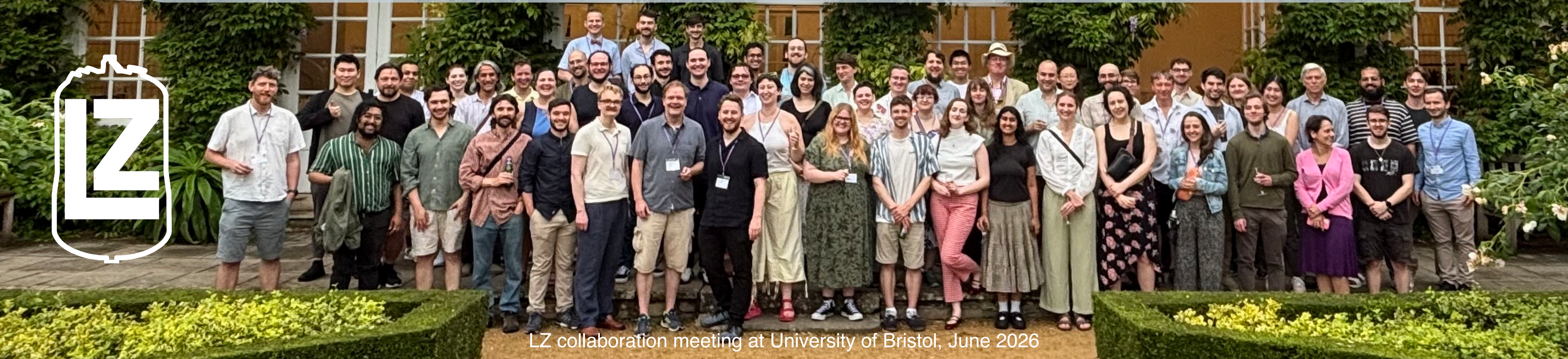
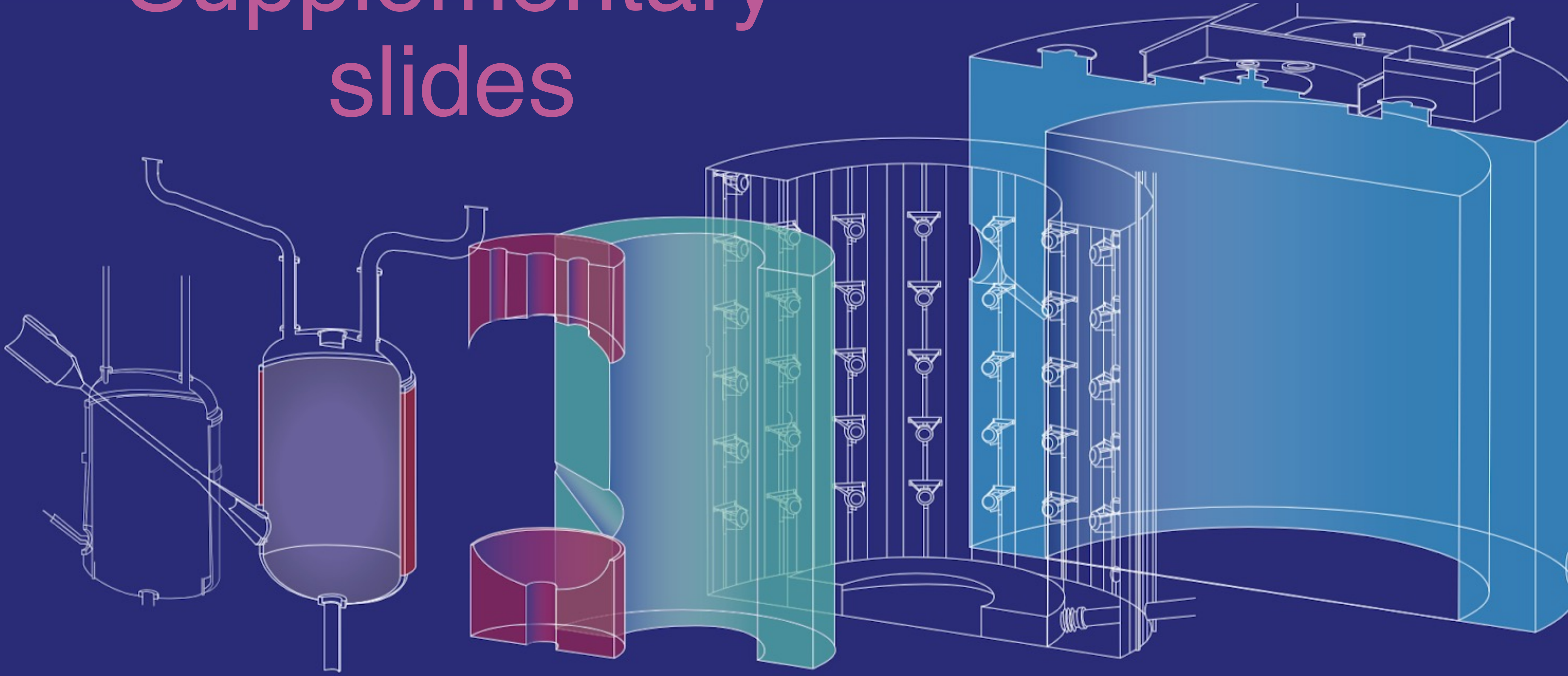
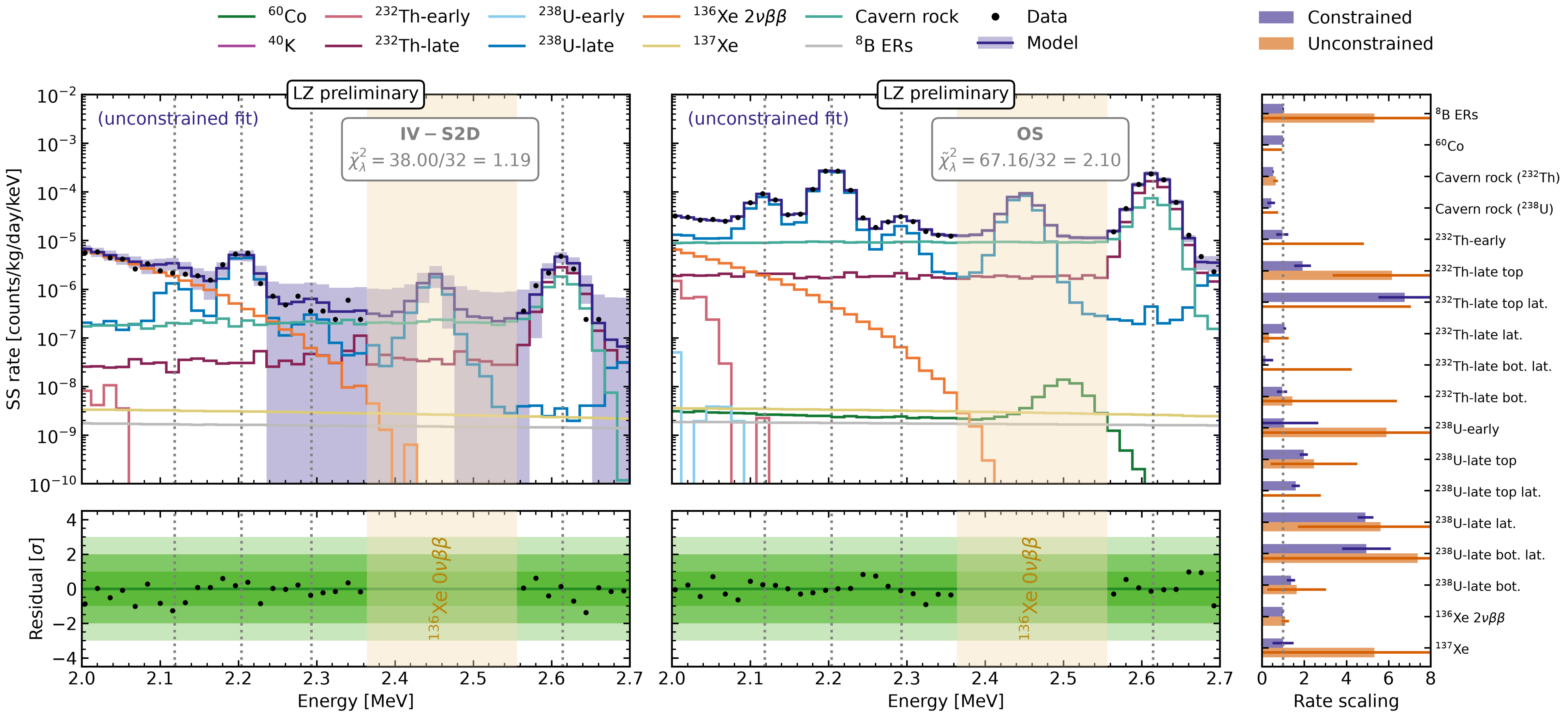


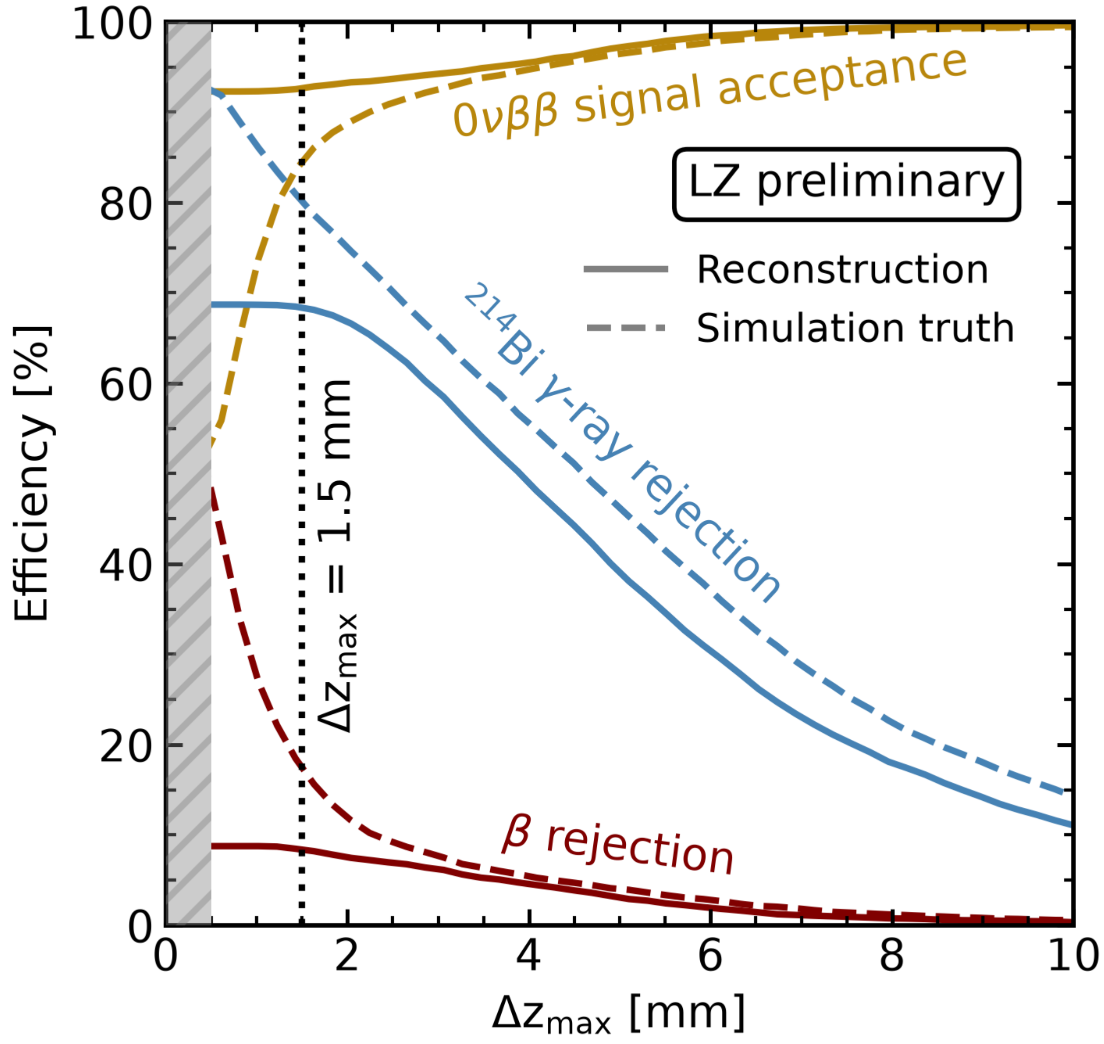
LZ collaboration meeting at University of Bristol, June 2026

Supplementary slides

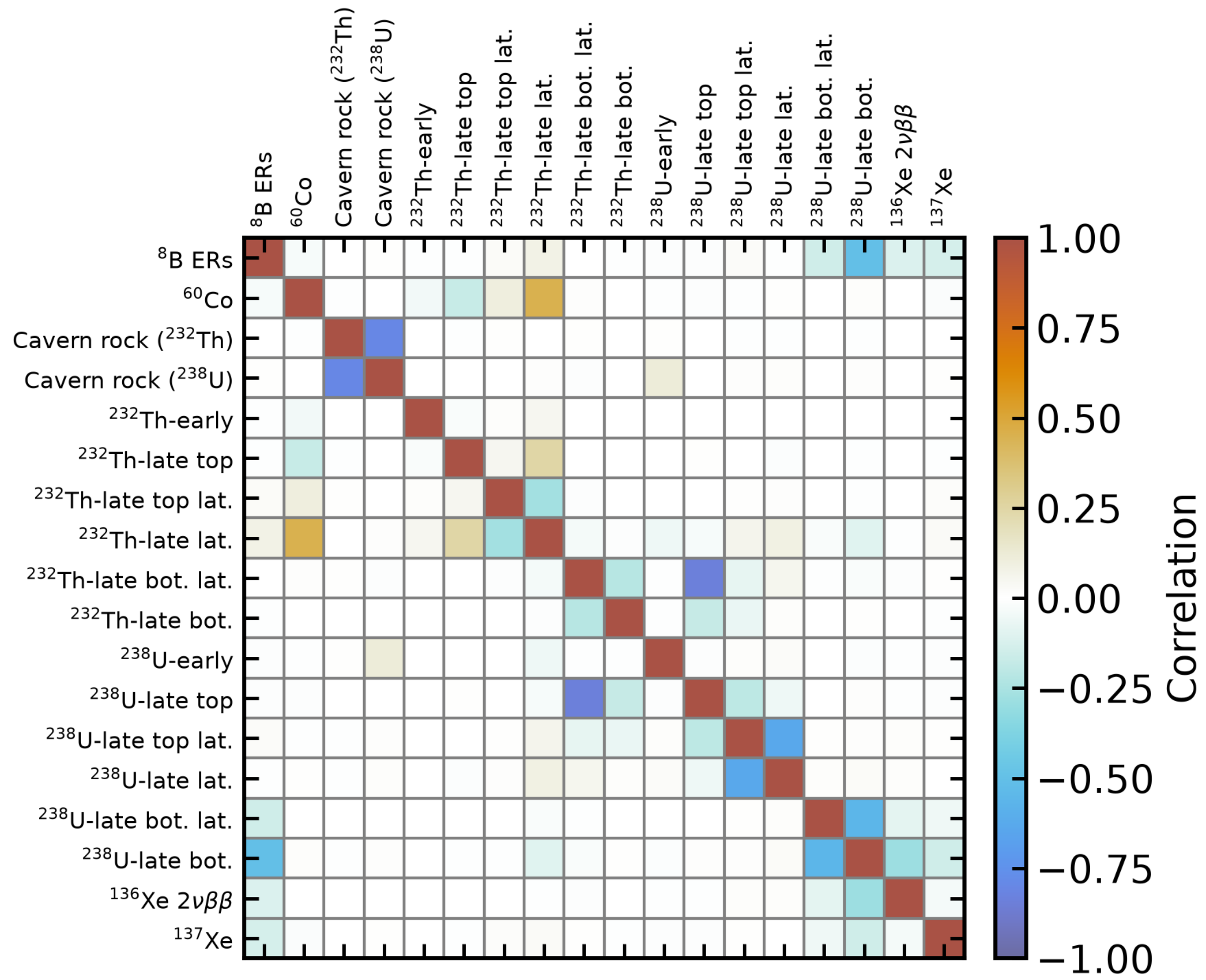


Results – tight ROI (unconstrained fit)





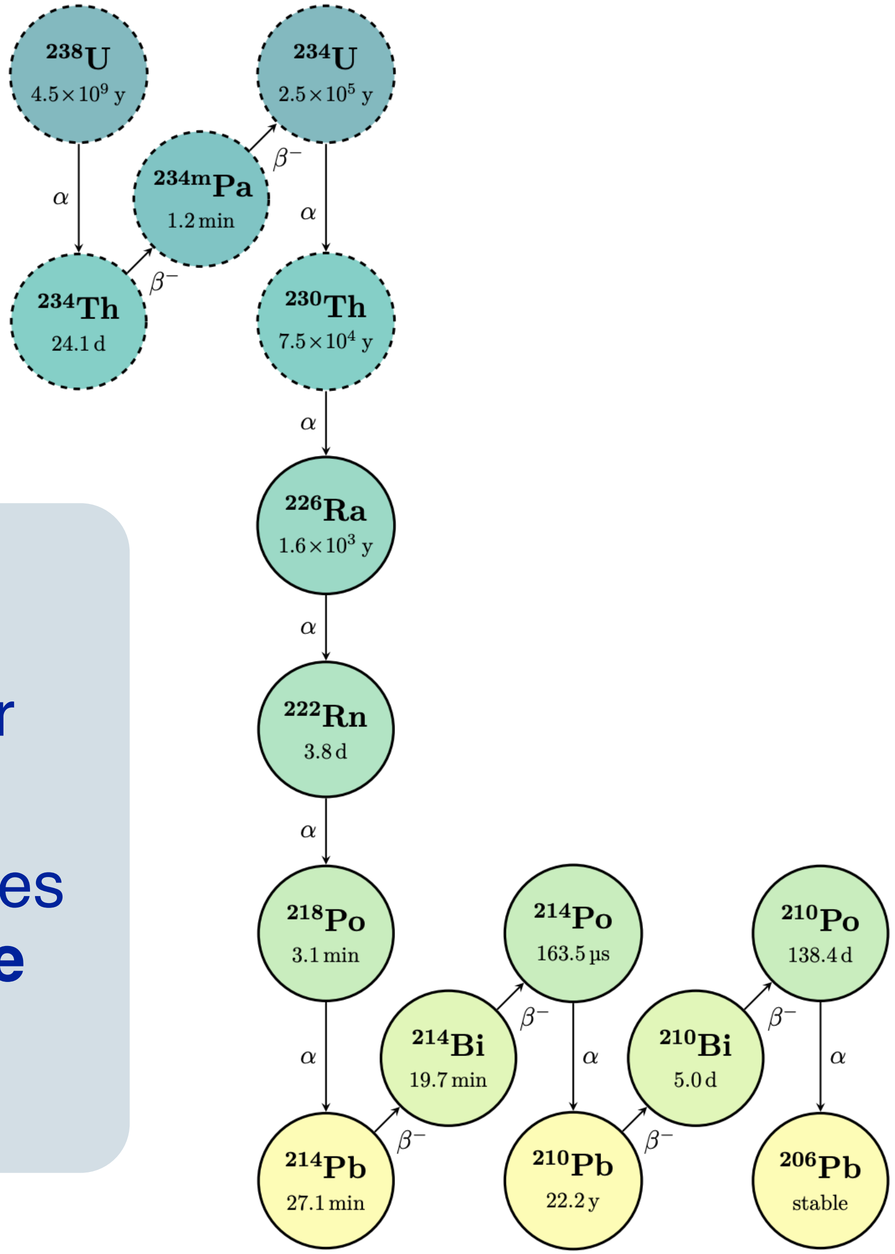
100
80
60
40
20
0
0
2
4
6
8
10
Efficiency [%]
Δz_max [mm]
0νββ signal acceptance
LZ preliminary
Reconstruction
Simulation truth
214Bi γ-ray rejection
Δz_max = 1.5 mm
β rejection

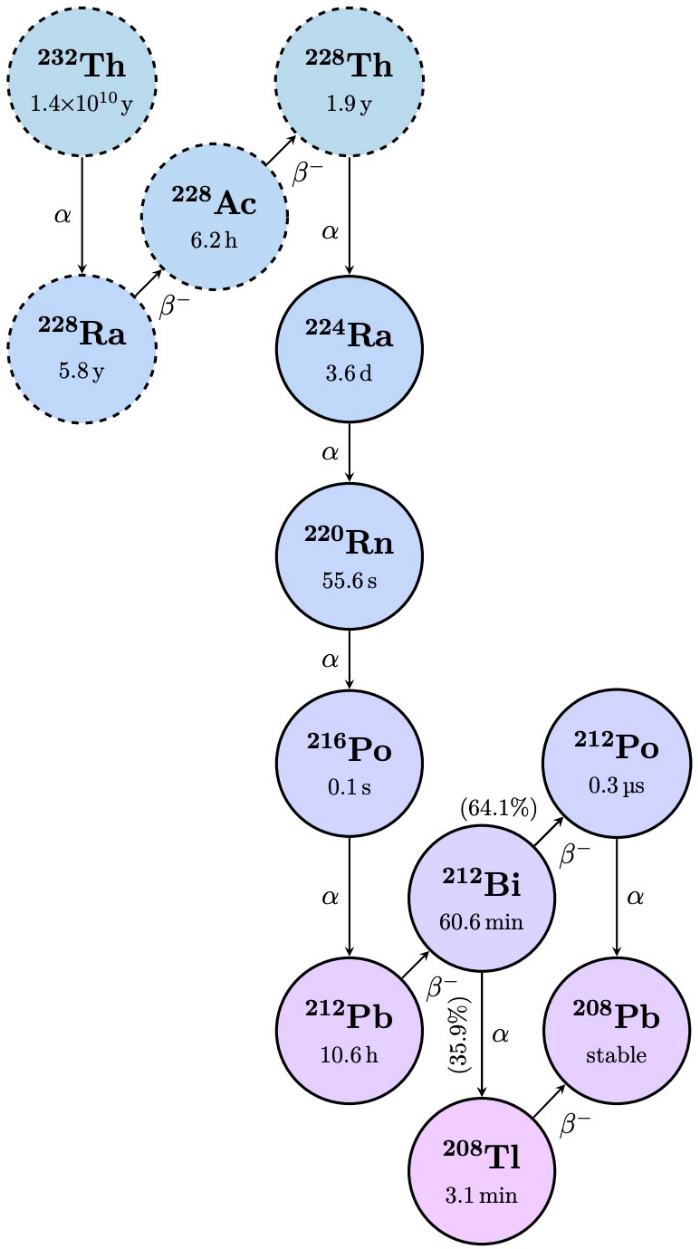


8B ERs
60Co
Cavern rock (232Th)
Cavern rock (238U)
232Th-early
232Th-late top
232Th-late top lat.
232Th-late lat.
232Th-late bot. lat.
232Th-late bot.
238U-early
238U-late top
238U-late top lat.
238U-late lat.
238U-late bot. lat.
238U-late bot.
136Xe 2νββ
137Xe
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Correlation

Decay chains

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

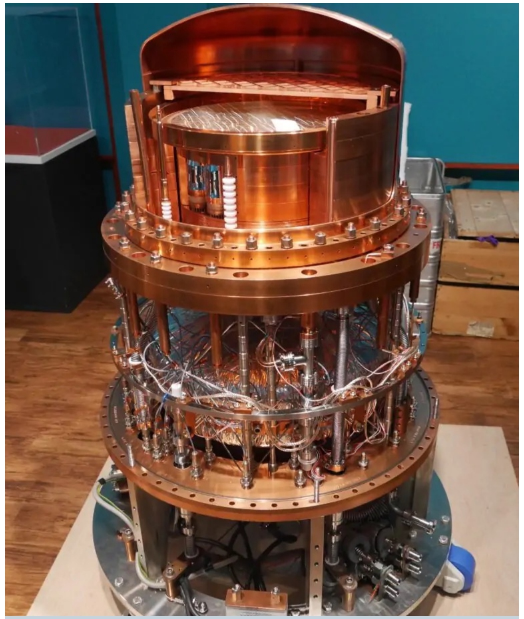




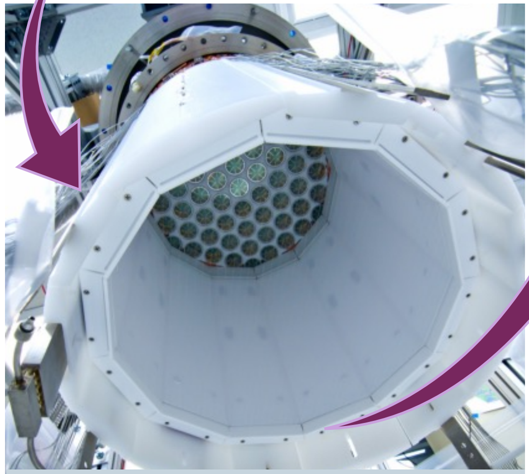
Xenon detectors

Why xenon?

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



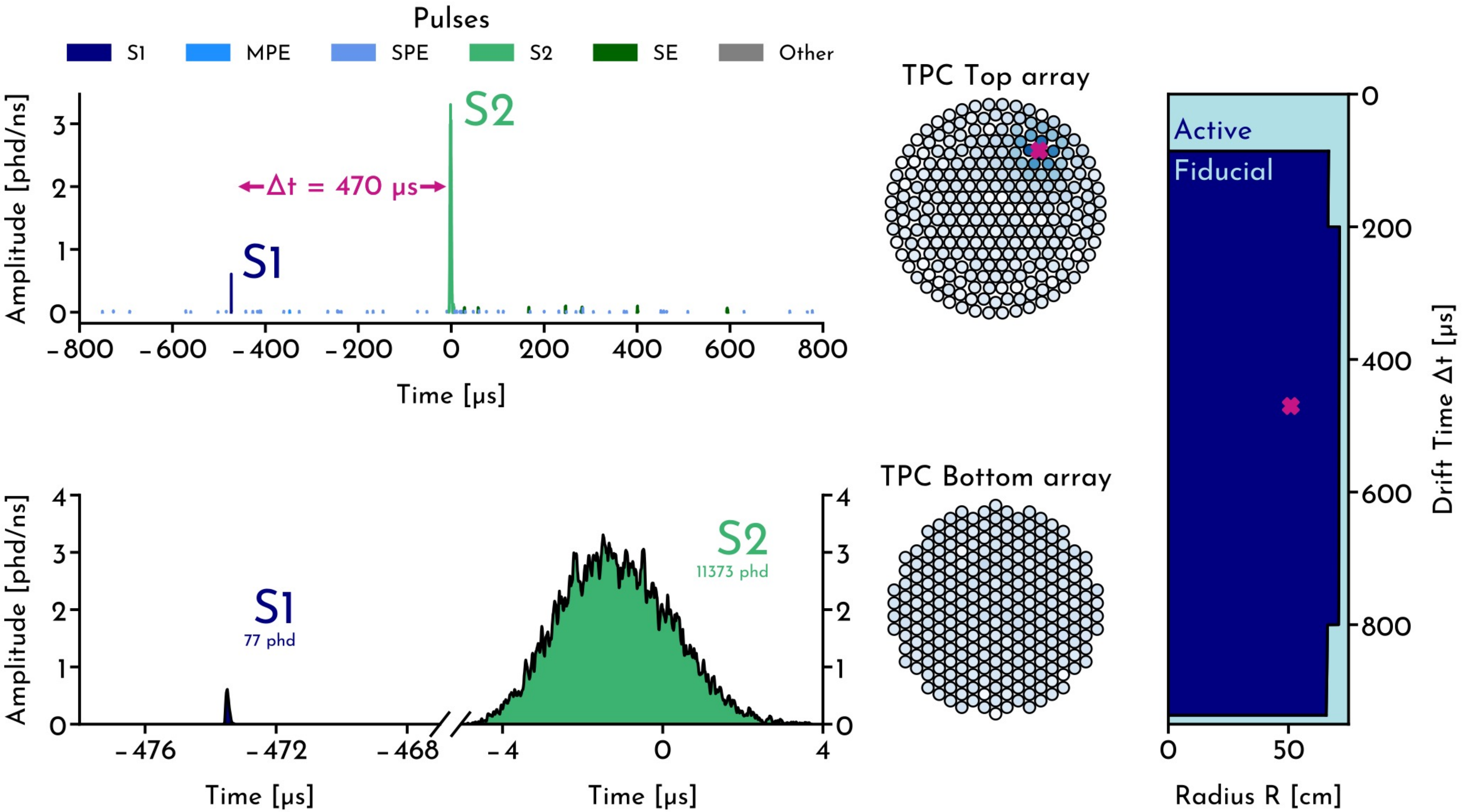
ZEPLIN-III – 12 kg (7 kg)



LUX – 250 kg (100 kg)

LZ – 7000 kg (5500 kg)

Example of a good event



Veto detector subsystems