First Results of the LUX-ZEPLIN Dark Matter Experiment

Paulo Brás

Jornadas Científicas do LIP 2022

The LUX-ZEPLIN (LZ) Collaboration

@lzdarkmatter
https://lz.lbl.gov/

- 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

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Thanks to our sponsors and participating institutions!

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Office of Science

Science and Technology Facilities Council

Sanford Underground Research Facility
South Dakota Science and Technology Authority

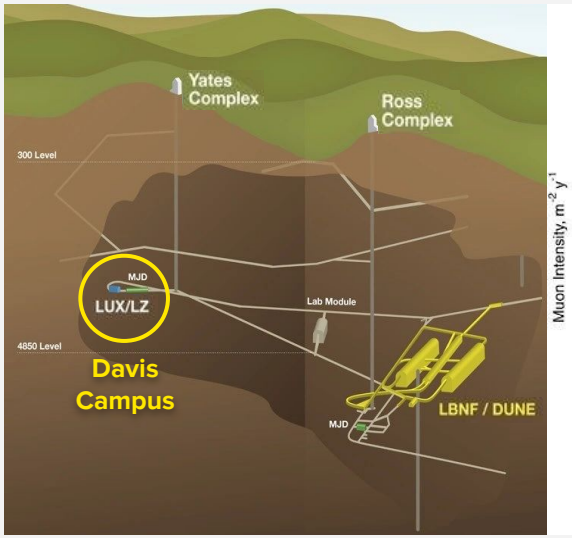
FCT Fundação para a Ciência e a Tecnologia

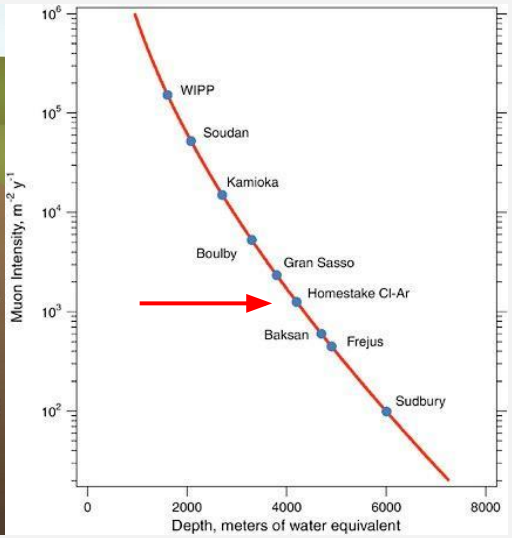
IBS Institute for Basic Science

Sanford Underground Research Facility (SURF)

LZ is installed at SURF in the Davis Campus (Homestake experiment) at a depth of 1.5 km (4850 ft level)

- 4300 m.w.e overburden
- 10^6 muon flux reduction
- 10 minute elevator ride





The LUX-ZEPLIN experiment

7 tonne dual-phase Xe ultra-low background TPC designed for dark matter searches ① observed by 2 arrays of 253 (top) and 241 PMTs (bottom).

Rare event observatory: Dark matter, rare xenon decays, neutrino interactions, axions, etc.

Two additional detectors for background modeling and mitigation:

★ 2 t Xe "Skin" detector surrounding the TPC with a 131 PMT readout ②

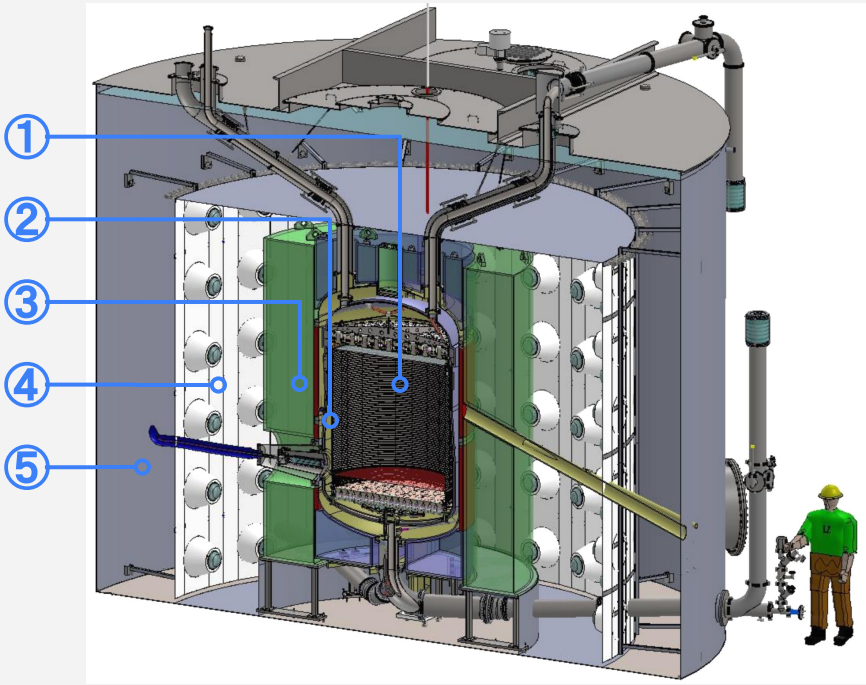
★ 17.3 t Gd-loaded liquid scintillator Outer Detector ③ with a 120 PMT readout ④

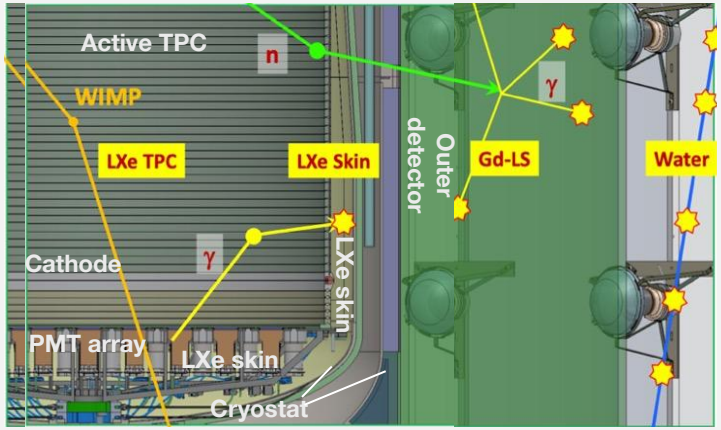
All instrumented volumes submerged in a 228 t water shield ⑤ also working as a muon veto.

Veto efficiency (Water Cherenkov + Skin + OD):

- 88.5% for neutrons (measured)
- > 70% for gamma rays (projected)

➢ Maximize fiducial volume!





LZ dual-phase TPC

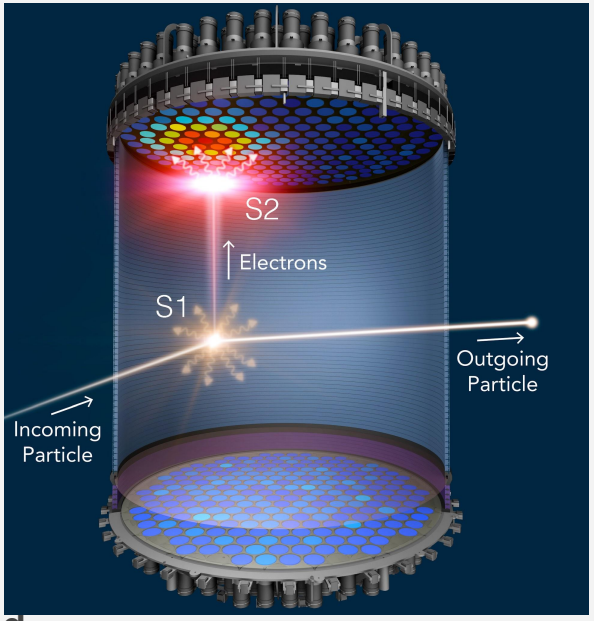
An energy deposition in the LXe produces scintillation light and ionization electrons.

1. The **scintillation light (S1)** is promptly detected.
2. The electrons that do not recombine are drifted to the liquid-gas interface and extracted into the gas phase, creating **electroluminescence light (S2)**.

★ Deposited energy is reconstructed using both the **S1 and S2 signals**.
- g_1 = photon detection efficiency; g2 = ionization gain

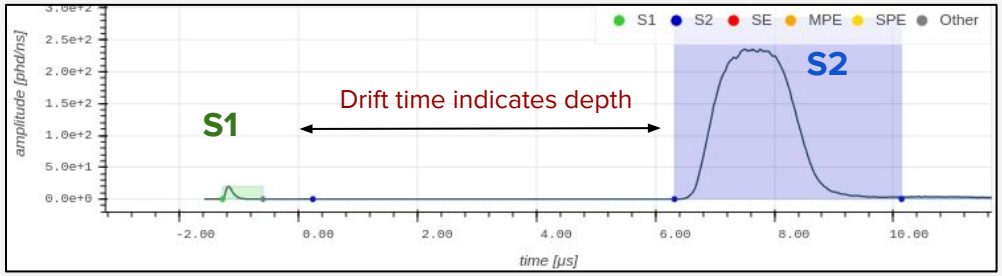
★ Depth of the interaction can be obtained by the **time difference between the S1 and S2 signals** - O(mm) resolution

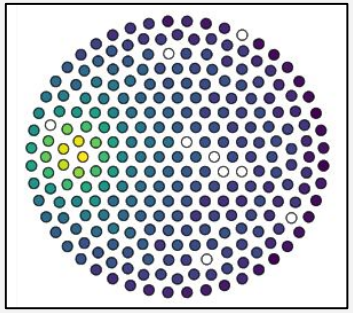
★ XY position can be reconstructed using the **light pattern generated by the S2** signal on the top PMT array - O(cm) resolution



$$E = W\left(\frac{S1}{g1} + \frac{S2}{g2}\right)$$

Interplay between N_γ and N_e due to recombination effects

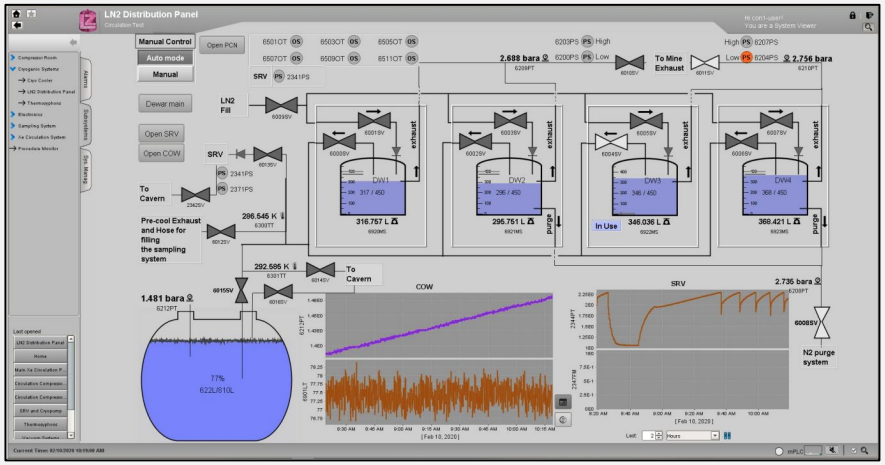




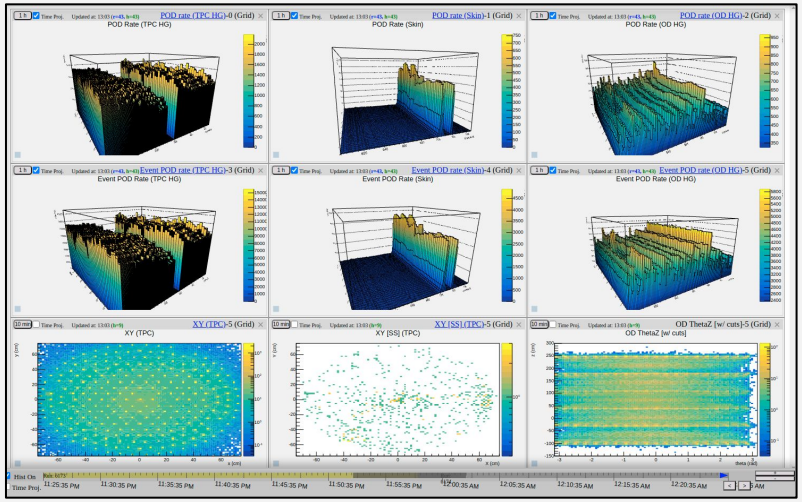
DarkMatter Group Roles in LZ

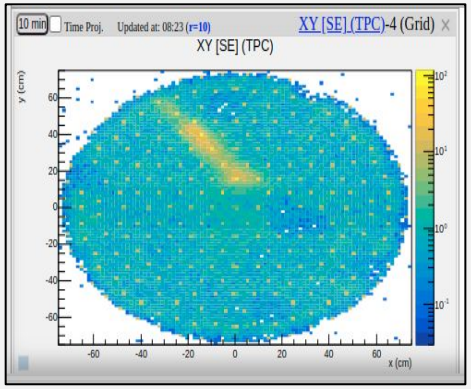
Experiment Control - "The nervous system of LZ" (V. Solovov, G. Pereira)

- Implementing supervisory control and monitoring of the experiment, interfaces with major subsystems, GUI, alarms and automation



Underground Performance Monitor - Online tools for monitoring detector health (F. Neves)



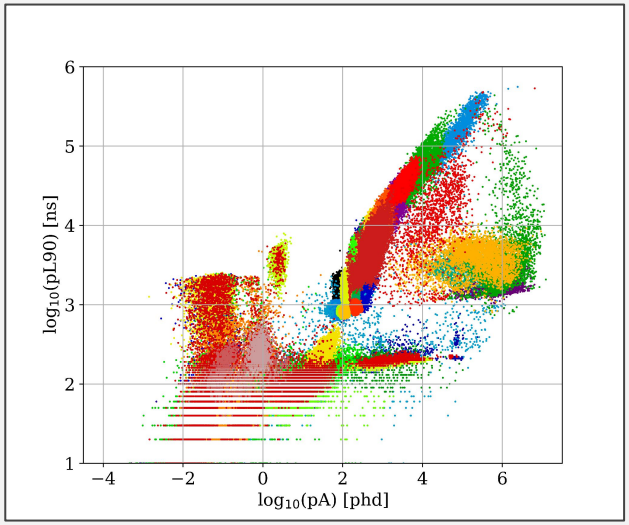


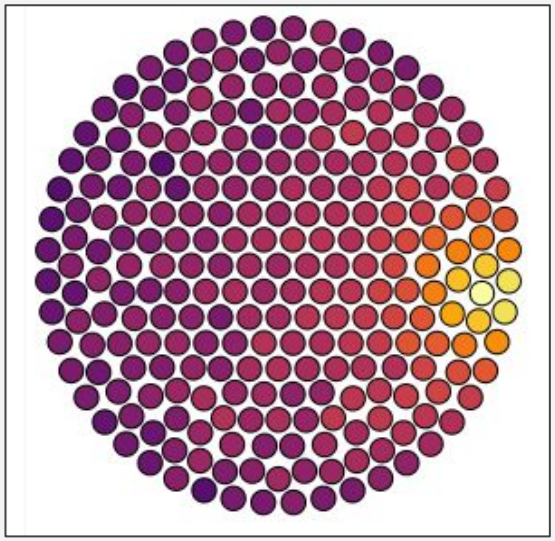
*a muon crossing the TPC

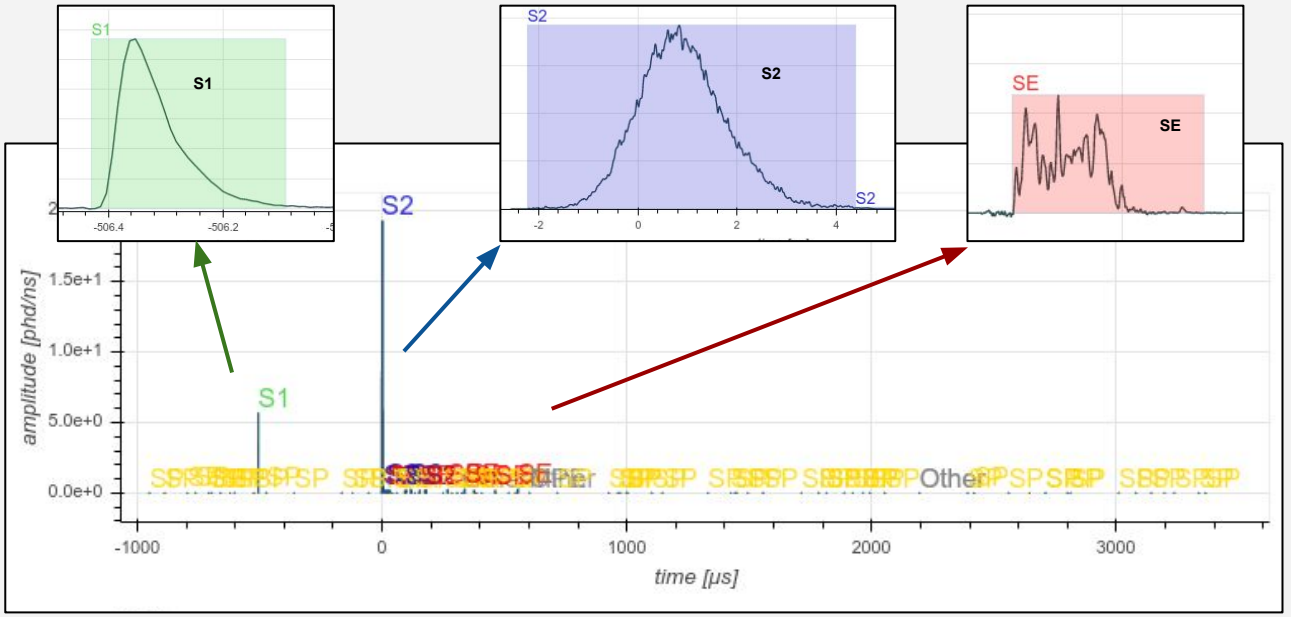
DarkMatter Group Roles in LZ

Data analysis: Responsible for 4 critical data processing software modules:

- Pulse Finder (F. Neves)
- Pulse Classifier (P. Brás)
  - Machine Learning Eur.Phys.J.C 82 (2022)
- Gain Matcher (F. Neves)
- Position Reconstruction Mercury (V. Solovov)

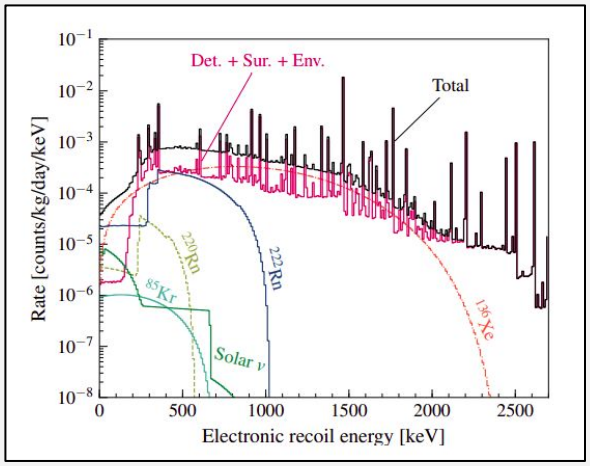


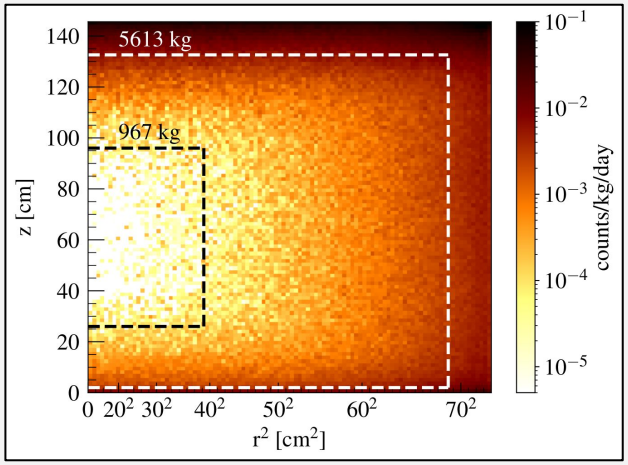




DarkMatter Group Roles in LZ

Backgrounds Model: Interfacing simulations and detector material assays (A. Lindote, former WG lead)





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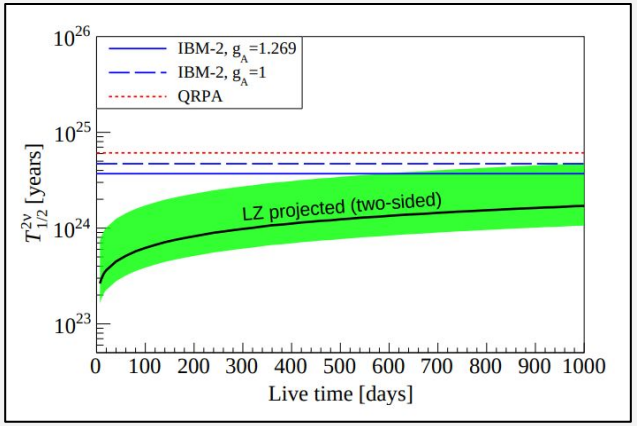
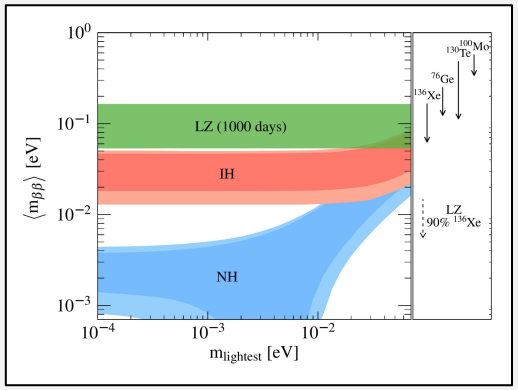
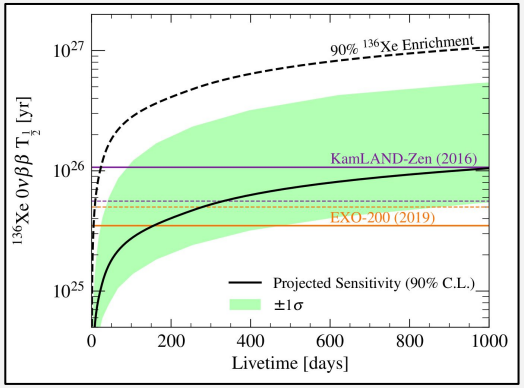
- ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ (E. Asamar) PRC.104.065501
- ^{124}Xe 2ν2EC in LUX (A. Lindote) J.Phys.G 47 (2020)

A. Lindote & C. Silva (former WG leads)







Energy Reconstruction - G. Pereira, V. Solovov, C. Silva.

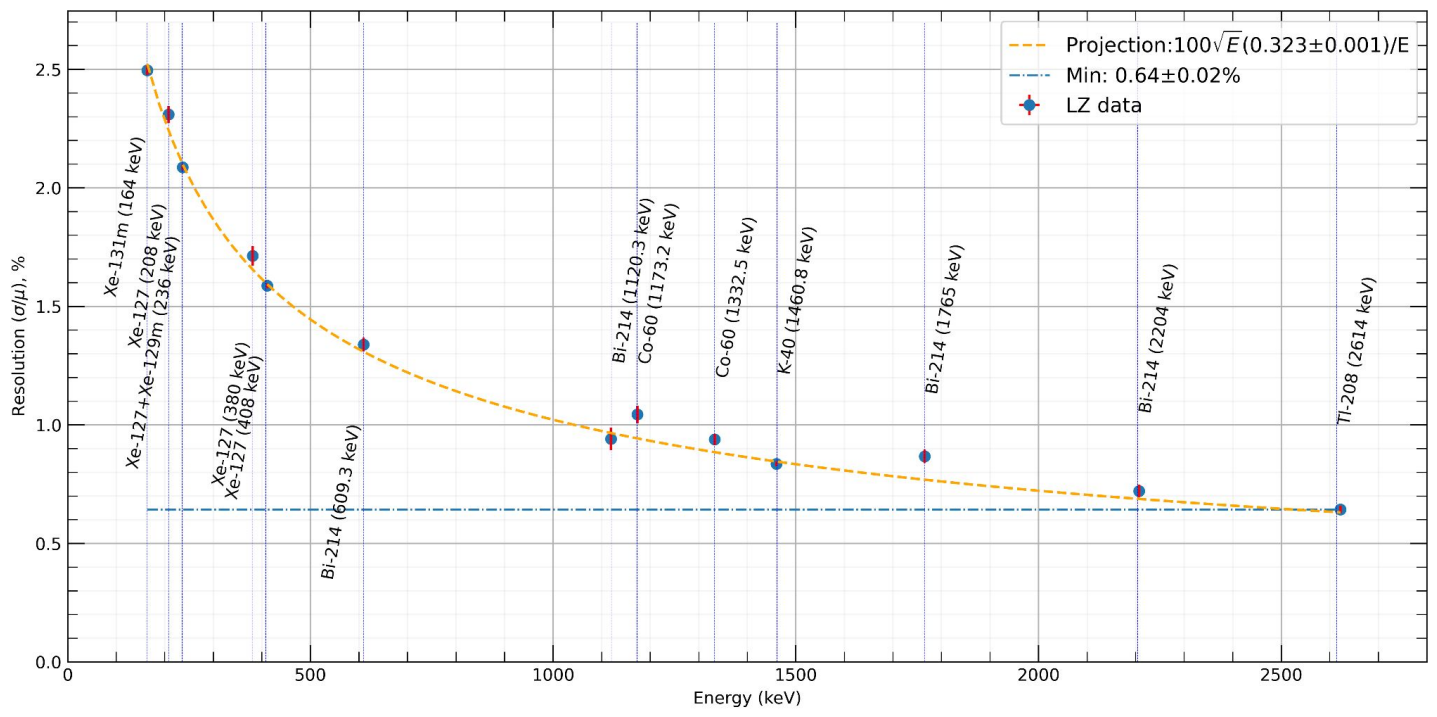
LZ obtained an **unprecedented energy resolution** for liquid xenon at high energies:

0.64 ± 0.02 % for Tl-208 (2614 keV)

Only the bottom PMT array is used to reconstruct energy.

Corrections: RZ, XYZ, PMT gain, e-livetime and Mercury light collection.

➔ Results presented at XeSAT Conference by Guilherme last month.



Energy Reconstruction - G. Pereira, V. Solovov, C. Silva.

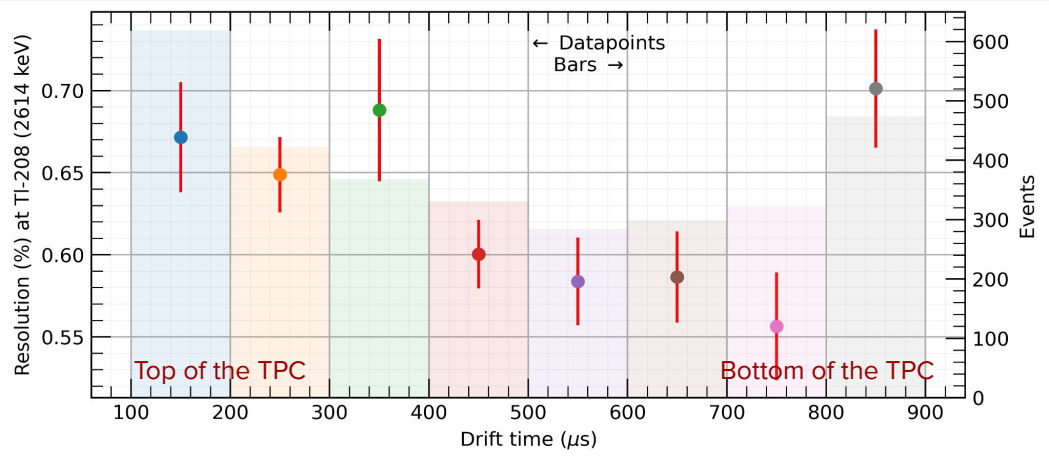
Resolution of **0.56 ± 0.03% at 2614 keV** for the bottom part of the detector:

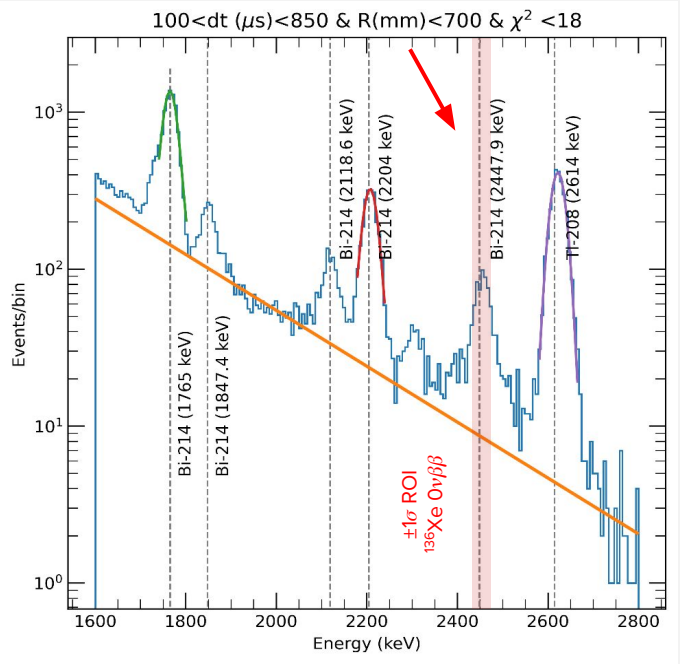
➔ Improved S1 collection in the bottom PMT array.

Depth-dependent variations still under investigation.

➔ Degradation of resolution due to saturation effects (top) and spatial corrections and gain mixing (bottom).

E-resolution is a very important parameter for ^{136}Xe $0\nu\beta\beta$ decay searches ($Q_{\beta\beta}$ = 2458 keV)





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➔ 32% dead time mostly due to hold-off after large S2 pulses.

Fiducial volume of 5.5 tonnes:

➔ **Total SR1 exposure of 330 tonne·days.**

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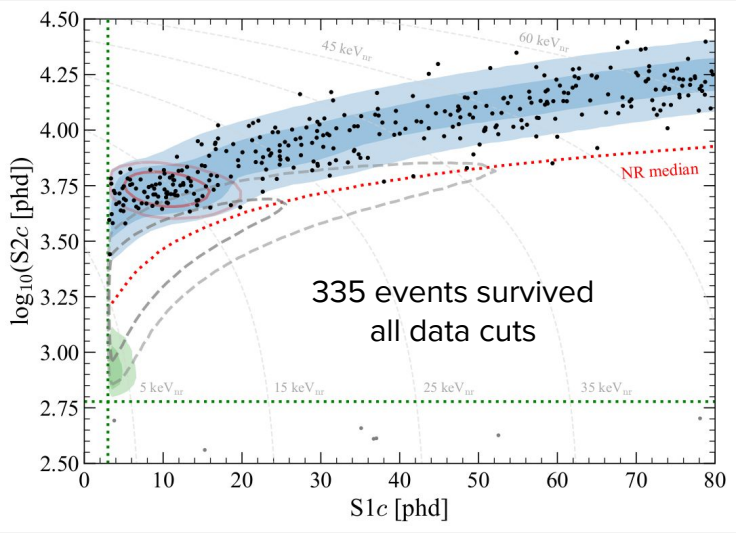
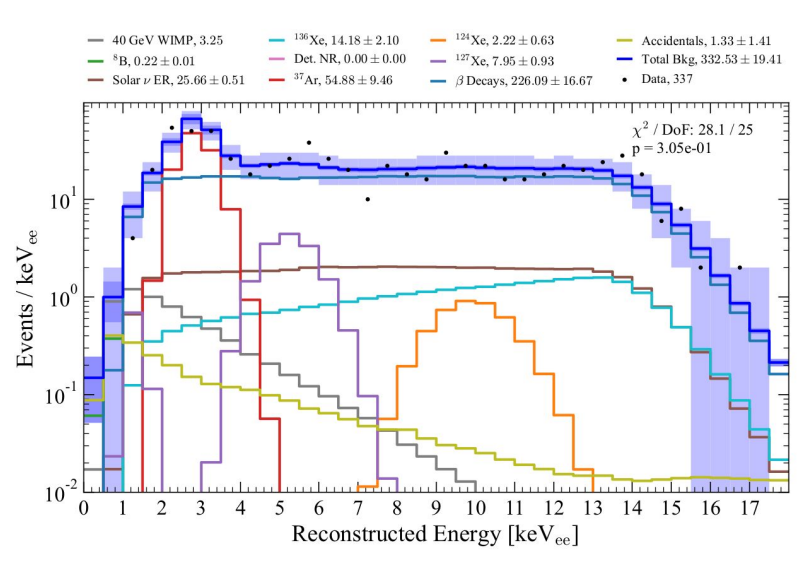




Electronic-equivalent energy spectrum for WIMP-search ROI

Limit on the SI WIMP-nucleon Cross-section

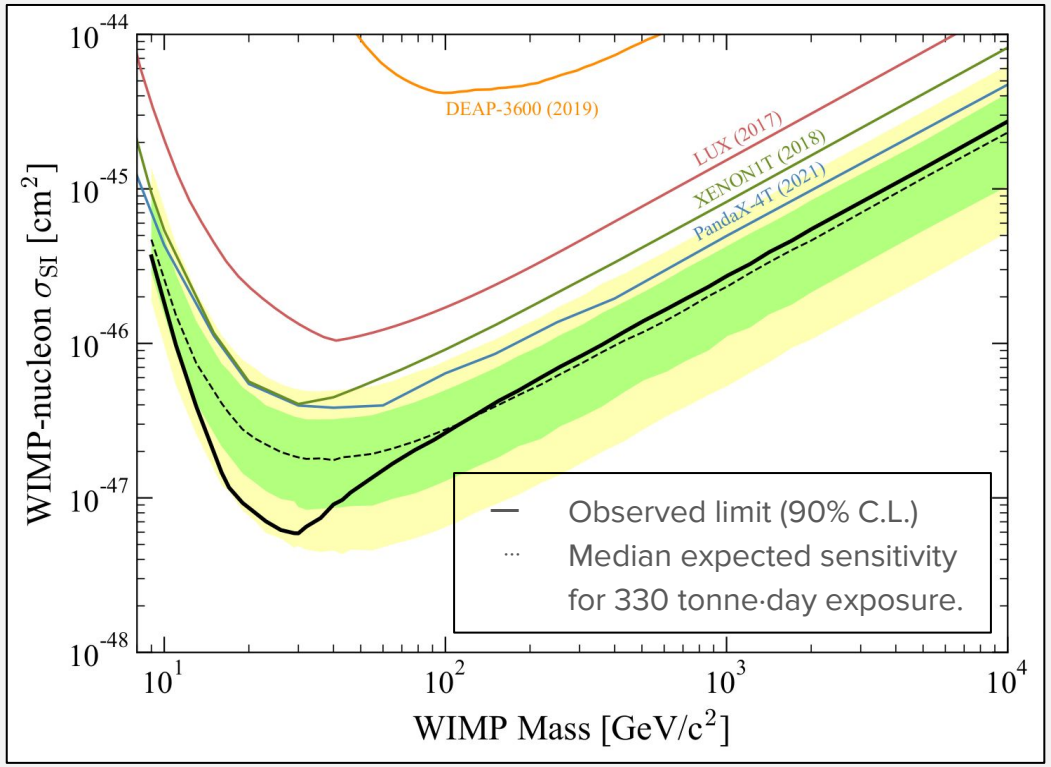
LZ found **no evidence of WIMPs** at any mass.

Minimum exclusion on spin-independent WIMP-nucleon cross section of:

$$\sigma_{Wn,SI} < 5.9\times10^{-48}\ cm^2 \text{ at } 30\ GeV$$

- ×6.7 improvement at 30 GeV
- ×1.7 improvement above 1 TeV

With only 60 live-days of data, LZ is already the most sensitive WIMP dark matter detector!



Our result in the media

Dark matter: search for the invisible begins in an old gold mine

Search | The Guardian | International edition

News website of the year

UNIVERSO

O detector de matéria escura mais sensível do mundo também tem portugueses

O detector Lux-Zeplin quer ser o primeiro a observar partículas de matéria escura: uma

Público

Expresso

SOCIEDADE

Portugal envolvido no detetor de matéria escura do Universo "mais sensível"

Portugal participa no detetor de matéria escura "mais sensível"

Portugal faz parte de um consórcio internacional envolvido no detetor de matéria escura do Universo "mais sensível alguma vez construído", de acordo com os primeiros

Berkeley Lab Researchers Record Successful Startup of LUX-ZEPLIN Dark Matter Detector at Sanford Underground Research Facility

INVESTIGAÇÃO

Cientistas mostram que a experiência de matéria escura LZ é a mais sensível do mundo

UNIVERSIDADE

Coimbra: Cientistas mostram que a experiência de matéria escura LZ é a mais sensível do mundo

86-5183 • July 7, 2022

NEWS PARTICLE PHYSICS

ScienceNews

A supersensitive dark matter search found no signs of the substance — yet

The LZ experiment will continue its dark matter search for about 5 years

AP Associated Press + Follow View Profile

Huge underground search for mysterious dark matter begins

By SETH BORENSTEIN, AP Science Writer - Yesterday 8:52 PM

零組件 行動裝置 網路

世上最靈敏暗物質探測器，取得首份研究成果

SCIENCE + TECHNOLOGY

How UCLA's Alvine Kamaha helped build the world's most sensitive dark matter detector

Thanks to the physicist's expertise, the LUX-ZEPLIN has now begun its hunt for the universe's most elusive particles

विज्ञान

एक सुपरसेंसिटिव डार्क मैटर सर्च में पदार्थ के कोई संकेत नहीं मिले - फिर भी

Summary

The LIP Group is undertaking **several critical tasks** within LZ.

The **first science run with the LZ detector** was completed successfully:

- All 3 detectors are performing within expectations, or better:
  - LXe TPC has unprecedented energy resolution at MeV scale.
- Backgrounds are within expectations **∽25 counts/keVee/tonne/year**
- With 60 live-days and a 330 tonne·day exposure, **LZ has the world-leading exclusion limit on SI WIMP-nucleon cross section at 5.9×10^{-48} cm2 at 30 GeV**
  - Paper submitted yesterday!

The xenon community is teaming up to prepare the next (3rd) generation of dark matter detectors:

- The XLZD Consortium was created between the LZ, XENON and DARWIN collaborations - see Alex talk next for more details.

Thank You!

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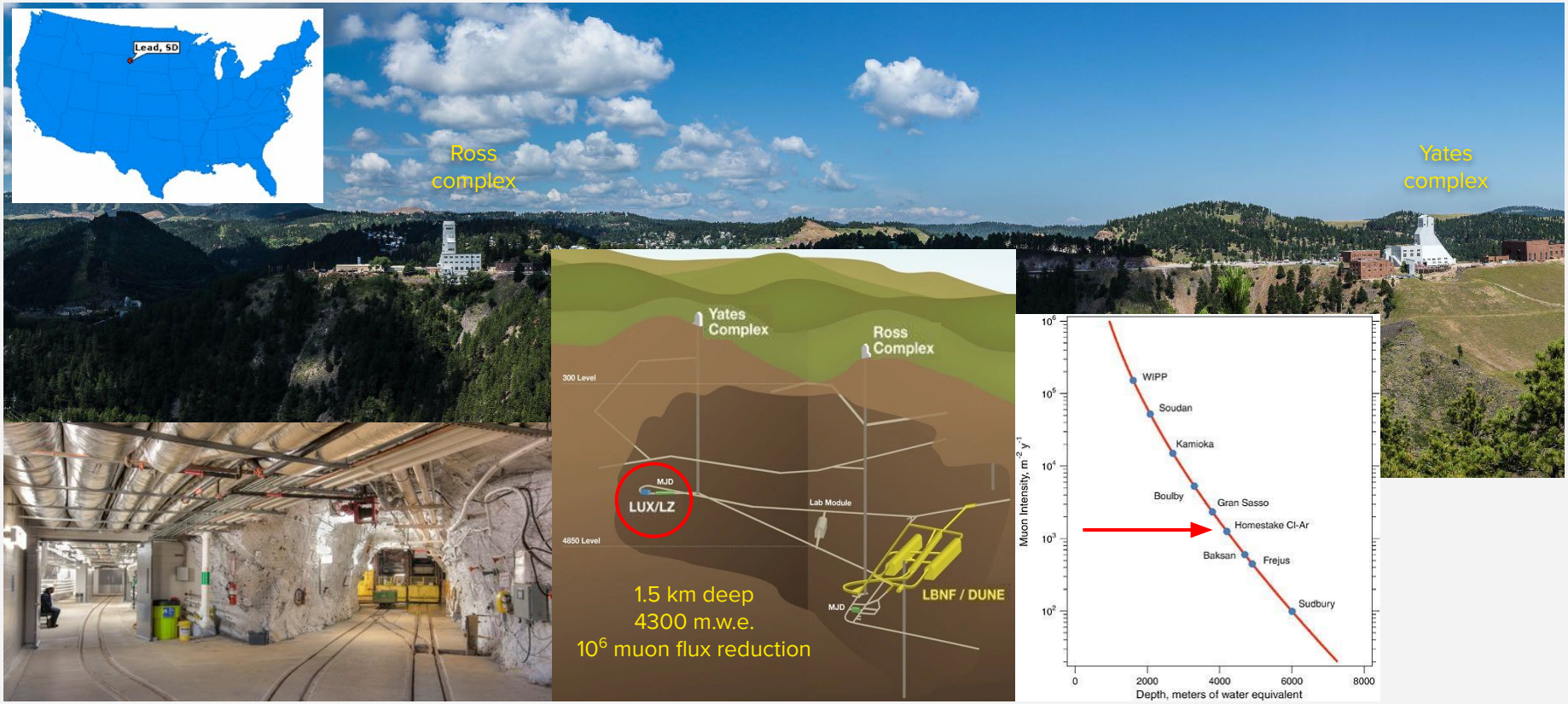

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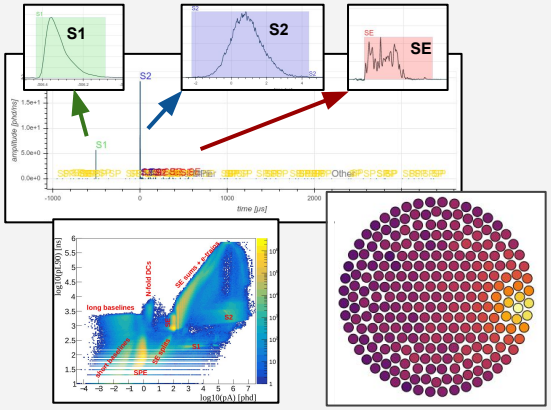
- Pulse Classifier (P. Brás)
- Position Reconstruction Mercury (V. Solovov)



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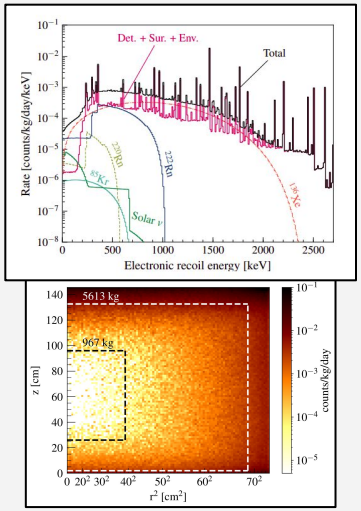

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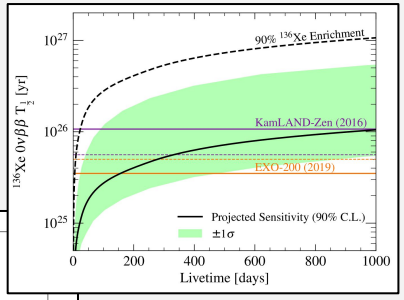
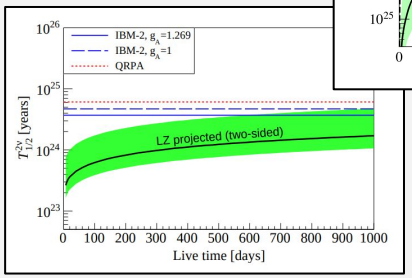
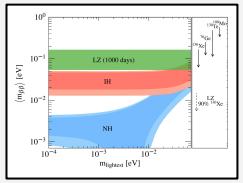
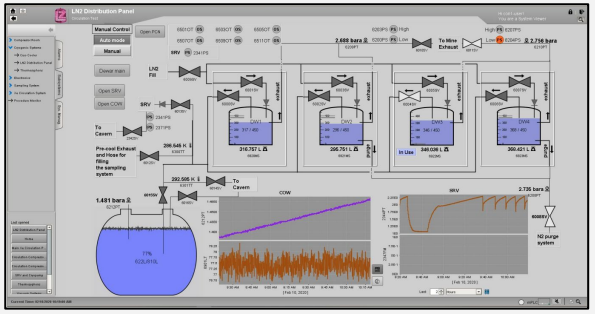






Experiment Control - "LZ nervous system"
Leads: V. Solovov, G. Pereira



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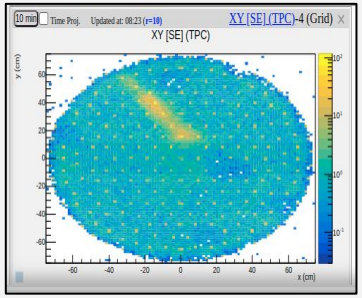
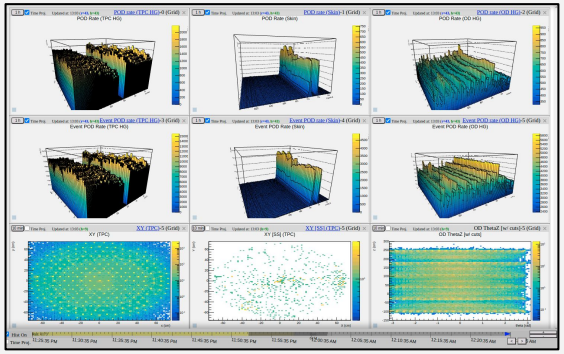


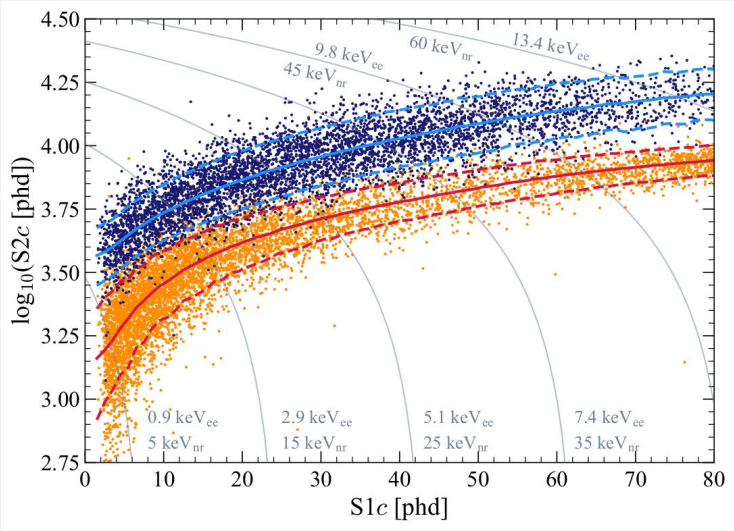
*a muon crossing the TPC

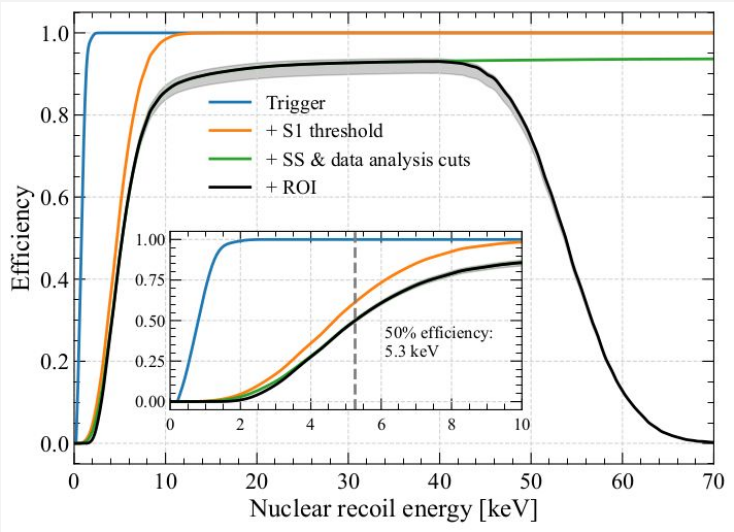


First Science Run and LZ Detector Performance

Calibrations of the ER and NR response:

- ➔ Tritium used to calibrate the ER band.
- ➔ DD neutrons used for the NR band.
- ➔ Both are consistent with the models.





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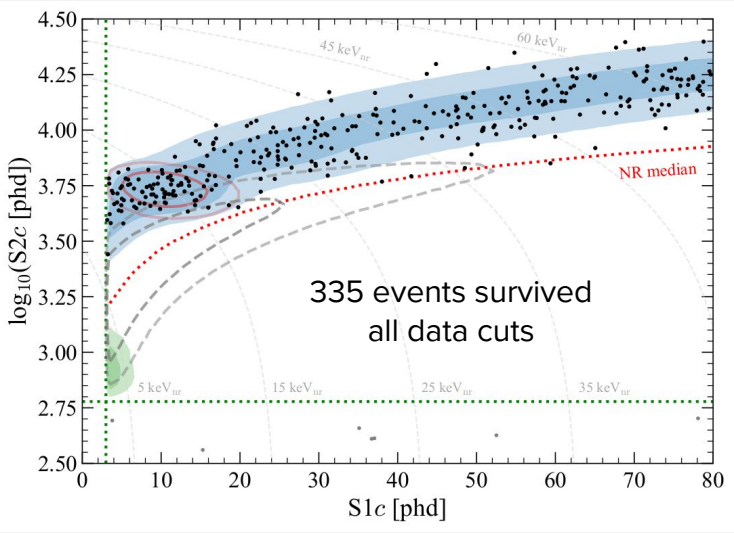
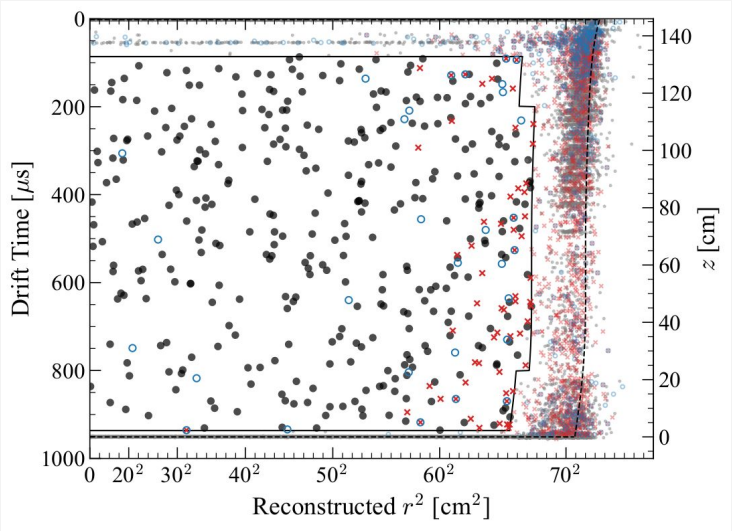
× LXe Skin tagged events

◯ OD tagged events





The LUX-ZEPLIN experiment

The TPC is the main detector of LZ:

- **PTFE light reflector cage** with 145.6 diameter
  - >97% reflectivity for 178 nm VUV Xe scint.
  - Field cage rings shape the drift field
- **4 woven steel grids** provide the electric fields
  - Drift field across 145.6 cm of LXe
  - Extraction field across liquid-gas interface
- **494 Hamamatsu R11410-22 PMTs**
- Double walled **cryostat vessel** for support and thermal insulation (LXe @ 175.8 K and 1.8 bar)

The **Skin detector** surrounds the TPC:

- 2 tonnes of Xe between TPC and Cryostat
- Instrumented with 1' and 2' PMTs on top and bottom
- Inner cryostat inner wall also lined with PTFE

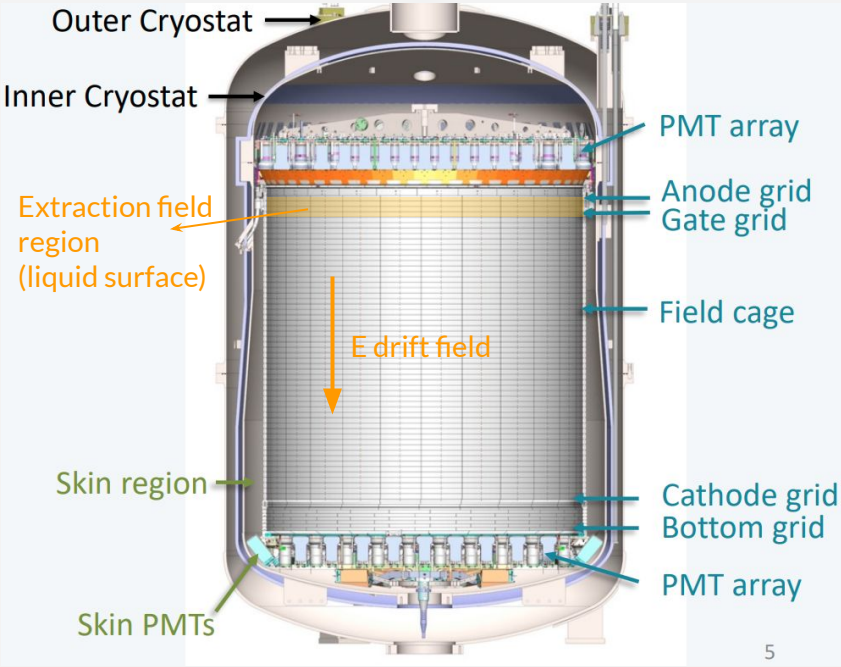


Fig. - Schematic of the LZ TPC