LZ update:

First LZ results and the UK Data Centre

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for the LZ Collaboration

LZ (LUX-ZEPLIN) Collaboration

35 institutions; 250 scientists, engineers, and technicians

@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 Los Angeles
- 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

LZ Collaboration Meeting – September 8–11, 2021

Thanks to our sponsors and participating institutions!

US Department of Energy
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Underground Research Facility
South Dakota Science and Technology Authority

ibs Institute for Basic Science

Searching for WIMPs

- High mass-energy density, about 25-28% of the total energy density (critical density) of the Universe

  o Energy density of dark matter at the Earth orbit – about 0.3 GeV/cm^3.

- Should be non-relativistic at the time of de-coupling from baryonic matter matter and radiation - cold dark matter (CDM); mass in the range of 1 – 1000 GeV/c^2. (May be extended to smaller or bigger masses.)

- Stable (or at least with lifetime exceeding the age of the Universe).

- Neutral (effect of electromagnetic interactions should be hidden).

- Weakly interacting (hopefully; but only gravitational effects have been seen so far)

  o To ensure the right abundance at the time of decoupling ('freeze-out').

Looking for elastic scattering of WIMPs
off target nuclei (xenon in LZ)

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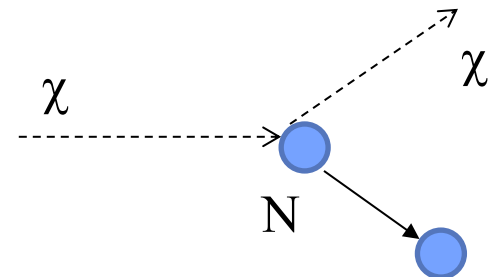
Detection principle
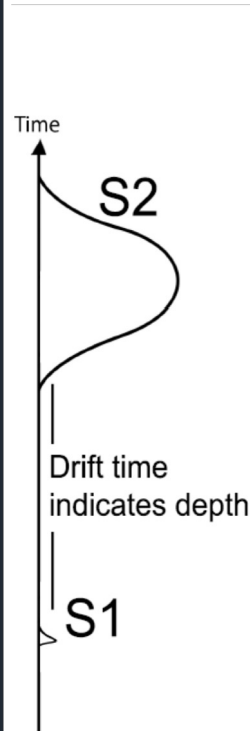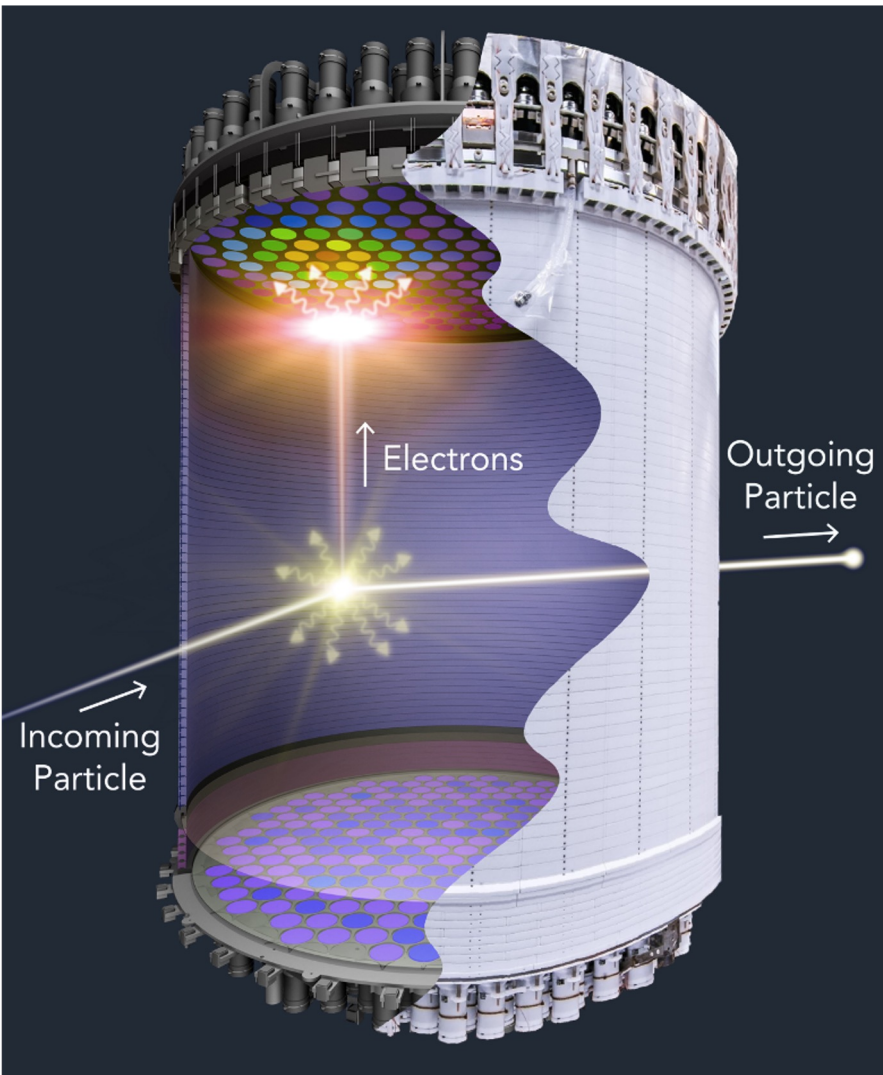
- Xenon – good scintillator.
- Dense → self-shielding.
- Electric field partly prevents electron-ion recombination
  - primary scintillation S1
  - secondary electroluminescence in the gas S2.
- 3D imaging
  - S1 - S2 time delay,
  - pattern of S2 light.
- S2 vs S1 discrimination between electron recoils (ERs from gammas or beta decays) and nuclear recoils (NRs - WIMPs/neutrons).

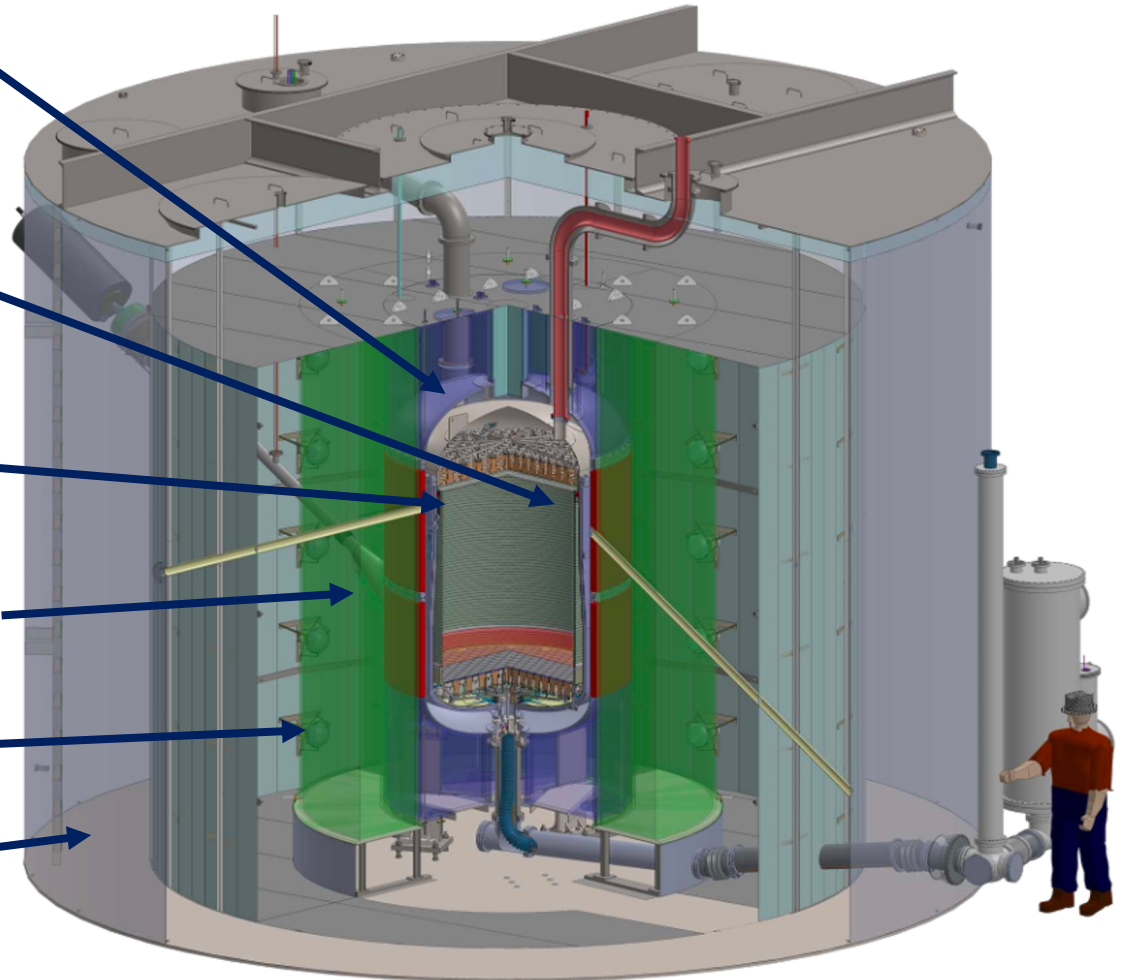# LZ detector design

Titanium cryostat

Liquid xenon (LXe) time projection chamber (TPC); 7 tonnes of LXe
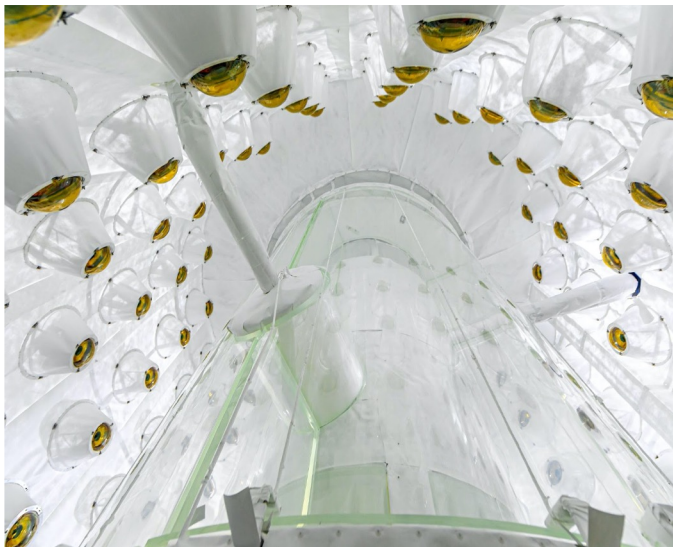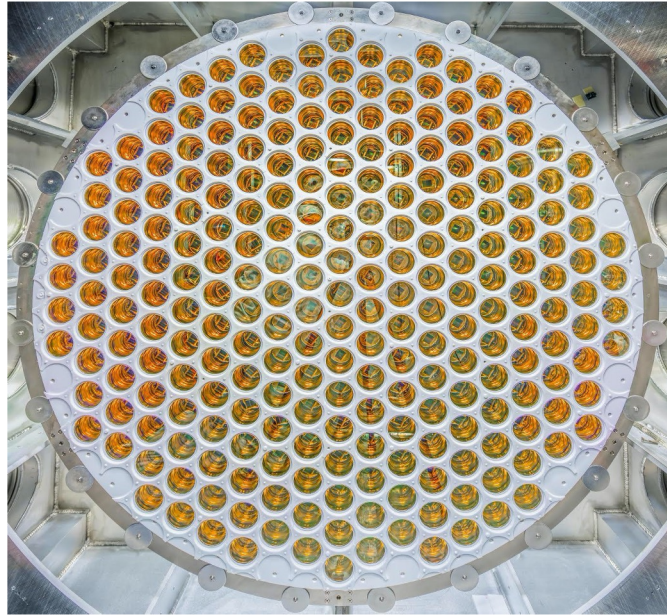
LXe skin (veto)
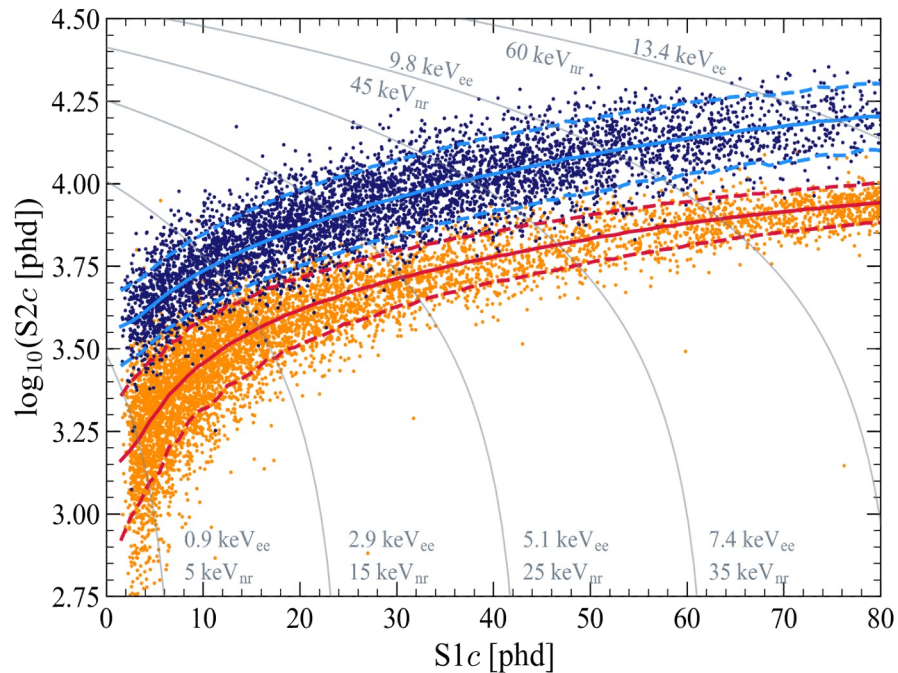
Outer detector, liquid scintillator
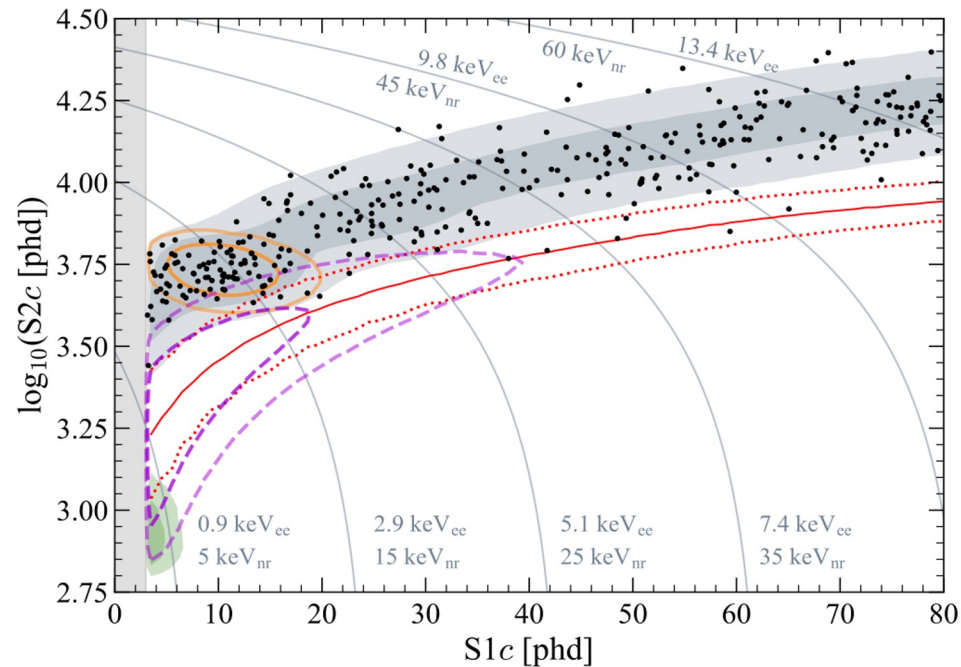
Outer detector PMTs

Water tank

LZ realisation

Calibration and data

CH$_3$T – tritium βs → ERs (blue)
DD – neutrons → NRs (orange)

Data: 335 events in 60.3 live days and 5.5 tonne fiducial mass.

- Excellent performance of the detector but …
- No evidence for WIMPs (as yet…)

Results: limits

- Solid black: observed limit
- Dashed-black: median expected sensitivity
- Minimum exclusion on spin-independent WIMP-nucleon cross section (SI) of 6×10^{-48} cm^2 at 30 GeV
- Comparing to existing limits:
  - ×6.7 improvement at 30 GeV
  - ×1.7 improvement above 1 TeV
 - World-leading result.
- Also spin-dependent limits.
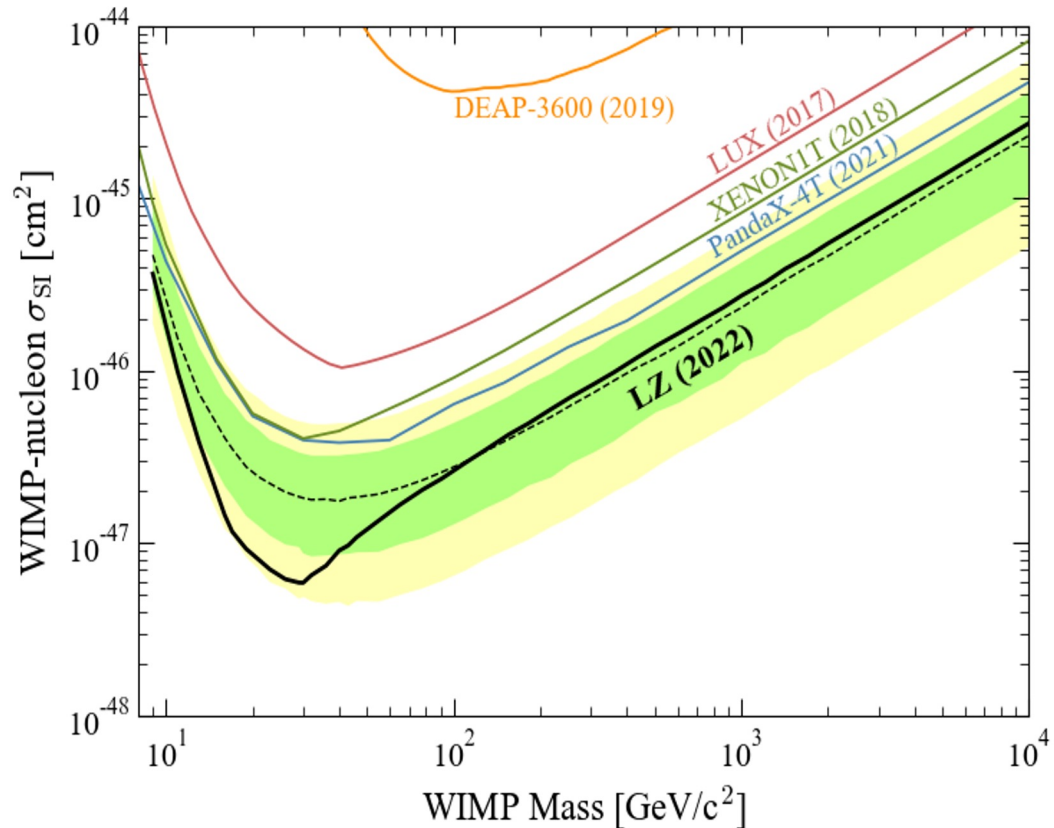
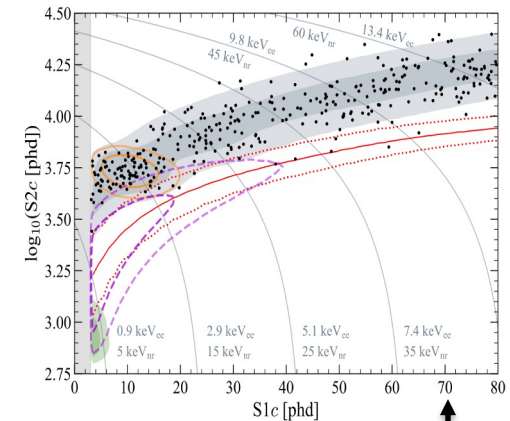- Many more to come:
  - BSM physics: dark matter in EFT, $0\nu\beta\beta$ of ^{136}Xe, extension to low-mass WIMPs, axions,
  - Rare decays in SM.

https://arxiv.org/pdf/2207.03764.pdf

Computing resources: how much do we need?

- Many more calibrations with different sources.

- Many more events recorded (then rejecting multiple scatters, events with veto signals, outside fiducial volume, noise, quality cuts).

- More events at higher energies

- Waveforms recorded with 10 ns precision for a 4.5 ms (with zero suppression)

- …and more than 1000 channels for each event

This is what we start with
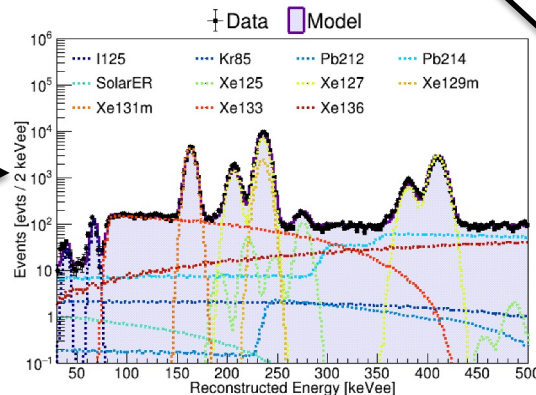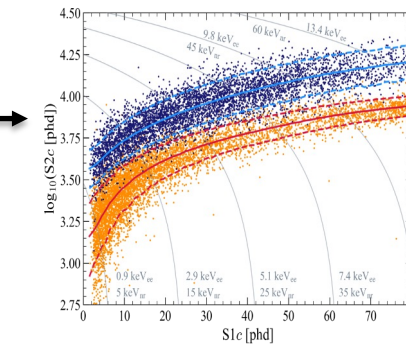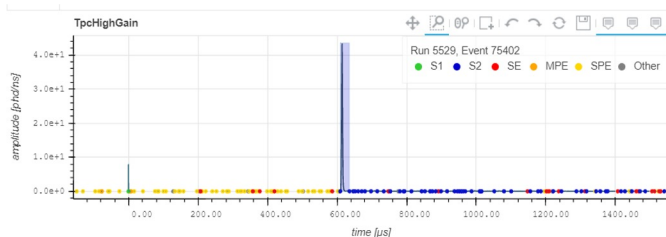
Group	Number of channels
TPC Top High/Low Gain	253/253
TPC Bottom High/Low Gain	241/241
Skin High Gain	131
Outer Detector High/Low Gain	120/120
Fast Sensors	35
Dummy Monitoring	20
Total	**1414**
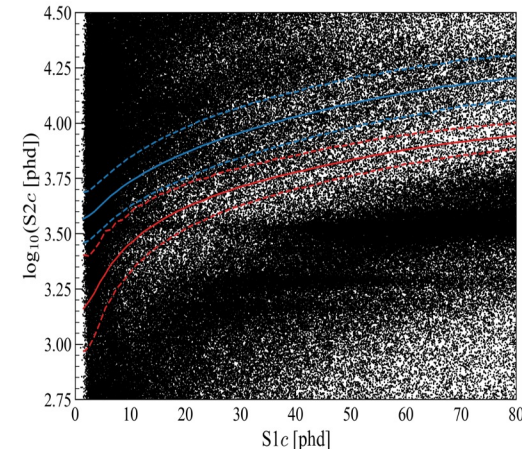
LZ offline computing

- Two data centres with fully redundant design (each site can run data processing, simulation production and store a copy of all the data).

- Data are transferred from SURF to the remote data centres.

- Data rate: ~1 PB/year, including raw, reconstructed, calibrations, etc.

- First processing at the USDC.
  - The UKDC is ready to do primary raw data processing in case of problems with the USDC.

- Data are reprocessed on demand based on calibrations and analysis.

- Reconstructed and simulated data are then available to analysers at both data centres.

Temporary Storage

US Data Center:
- Prompt Processing
- Long-term Archiving
- Supercomputers

UK Data Centre:
- Data Reprocessing
- Sims Production
- Distributed CPUs

Data flow

- Storage at SURF: 192 TB underground and at the surface (each site).

- Can accommodate about 68 days of DM search data - large buffer in case of extended network outage.

- All detector data are processed automatically 24/7 at the USDC.

- All data are archived on tape at the USDC.
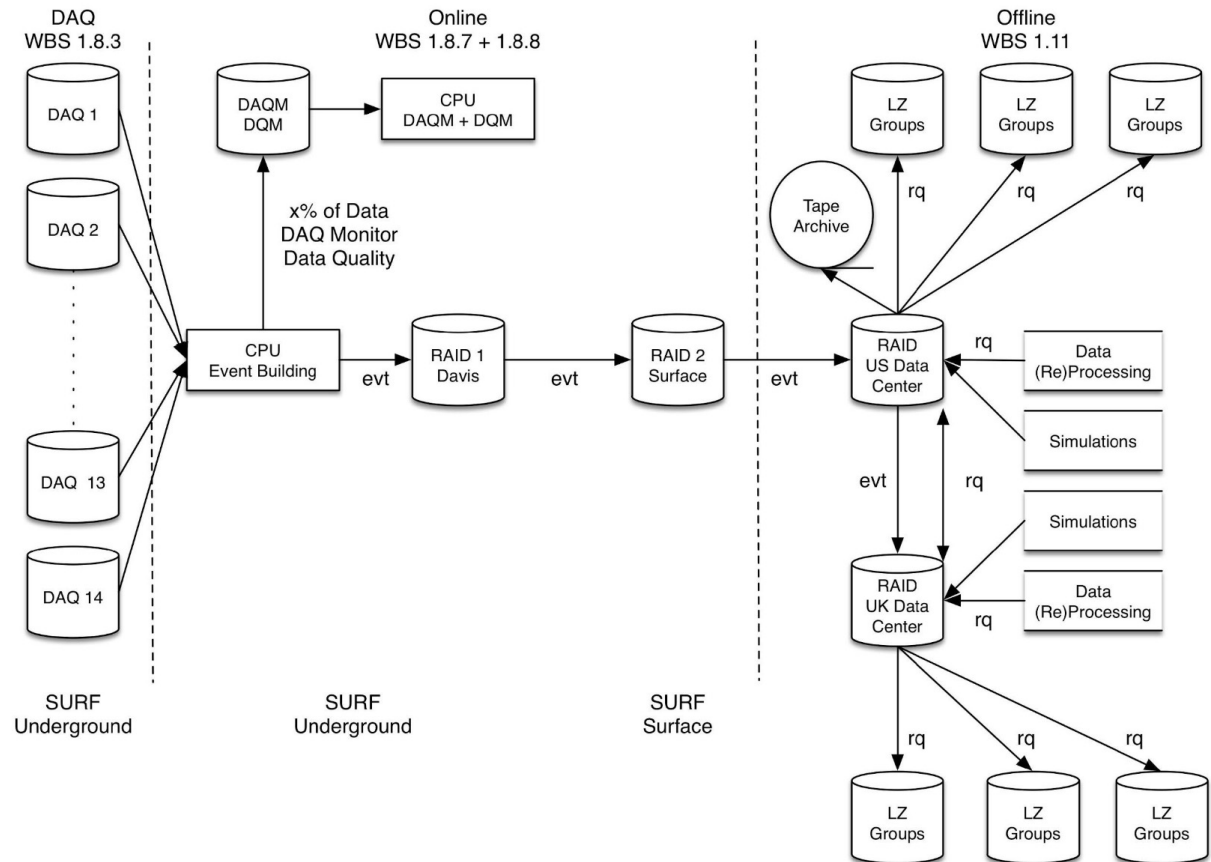
- Data Transfer Software (SURF → USDC ← → UKDC): SPADE (South Pole Archival and Data Exchange) software (used in IceCube and Daya Bay)

- SPADE instances in the US and UK DCs
  - Interface with Data Catalog
  - Automatic checksum validations for all data transfers

LZ Data Centres

- LZ software and analysis tools can run at both DCs.
    - o LZ uses cvmfs (/cvmfs/lz.opensciencegrid.org/) to deliver identical software builds to both DCs and users.
- LZ Conditions Database has 2 instances
    - o A primary instance is at the USDC and a synchronised instance is at the UKDC
    - o Jobs running at the UKDC use UK Conditions DB instance.
- Data Catalog also has 2 replicas (the primary one at the USDC).
- LZ VO voms server:
    - o Was initially hosted at Wisconsin and Imperial
    - o In October 2021 it was moved to GridPP voms server location (https://voms.gridpp.ac.uk:8443/voms/lz).
- Event viewer is available at both DCs.

UK Data Centre

- The UK Data Centre is hosted at Imperial College and uses GridPP resources
  - LZ is using several GridPP sites for data (re)processing and simulations
  - During Mock Data Challenges it became clear there are certain types of events that will intrinsically require between 8-12 GB/core
  - LZ has been granted 300 cores with 12 GB on IRIS
- UKDC uses the DIRAC framework for distributed computing
  - Provides pilot-based job submission framework and data management system.
  - Since start of data taking LZ uses a specially dedicated DIRAC queue CLOUD.UKI-LT2-IC-HEP-lz.uk and also UKI-LT2-IC-HEP-lz.uk.
- LZ storage is hosted at Imperial DC in Slough: currently 7 PB: 5 PB (GridPP) + 2 PB (LZ); 2 PB was added in August 2022.
  - Current usage is 46%
  - Raw and reprocessed data – 1.3 PB
    - Science run 1 (including calibrations): raw data – 390 TB, processed – 240 TB; (3.5 processing attempts on average, up to 6 campaigns)
    - Commissioning: raw data – 290 TB, processed – 270 TB
    - Pre-SR1 – 60 TB.
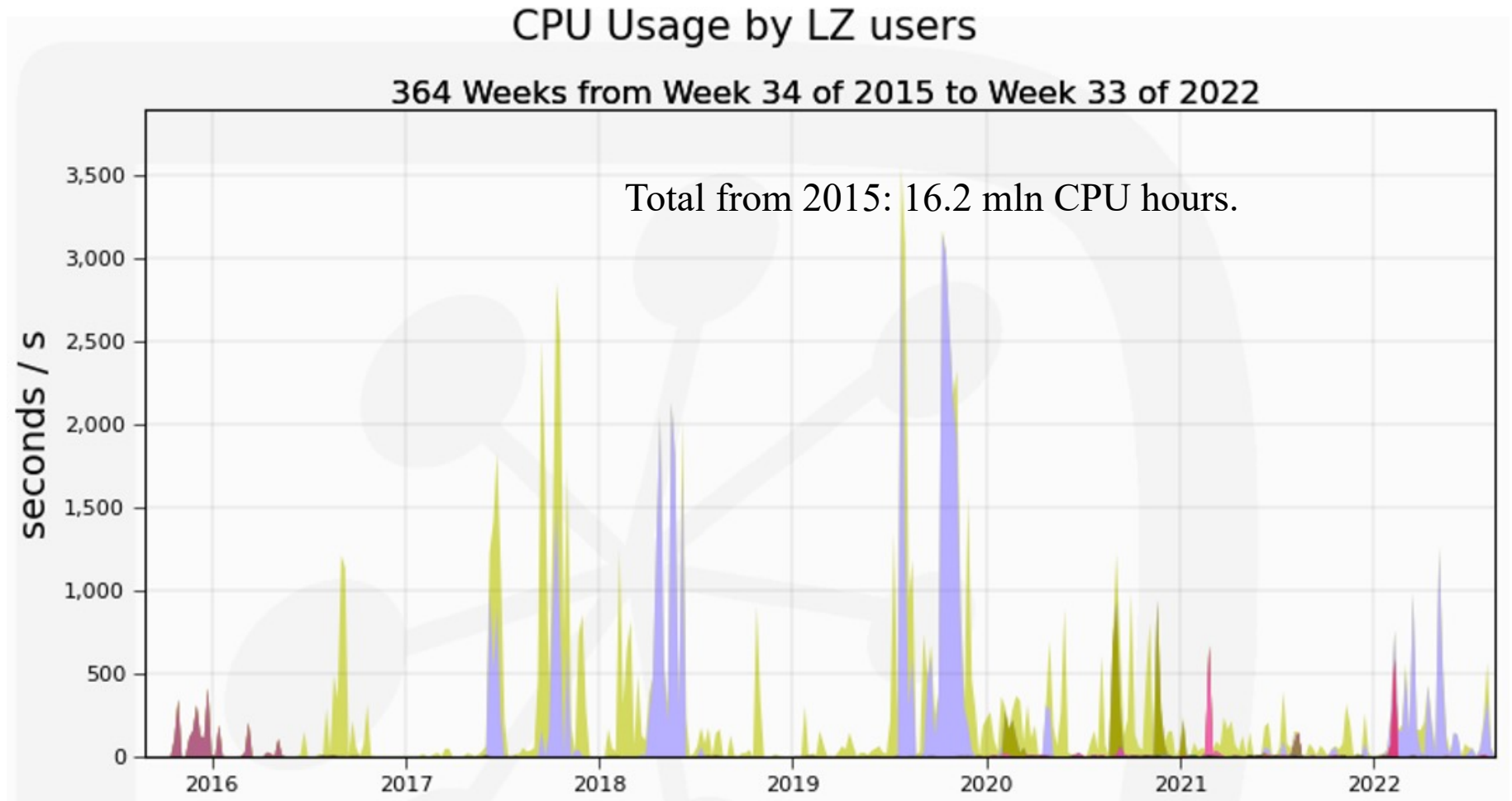 - Also about 1 PB of simulated data to support data analysis.

UK Data Centre

- Access to the UKDC resources with grid certificates + LZ VO membership.

- UKDC team has developed a web-based large-scale production Job Submission Interface (JSI):

  - to simplify handling of requests for large-scale submission of data processing and simulations;

  - reduces manual and time-consuming operations to complete jobs;

  - continuous development of functionalities to give more flexibility in writing and operating scripts;

  - fully tuned to run (re)processing:

  - all (re)processing of data are submitted via JSI.

- 130 billion of events from calibration runs and 220 billion of background events have been simulated on both DCs with about 2/3 on the UKDC.

  - They have been re-processed up to 6 times while tuning the event reconstruction software.

CPU usage
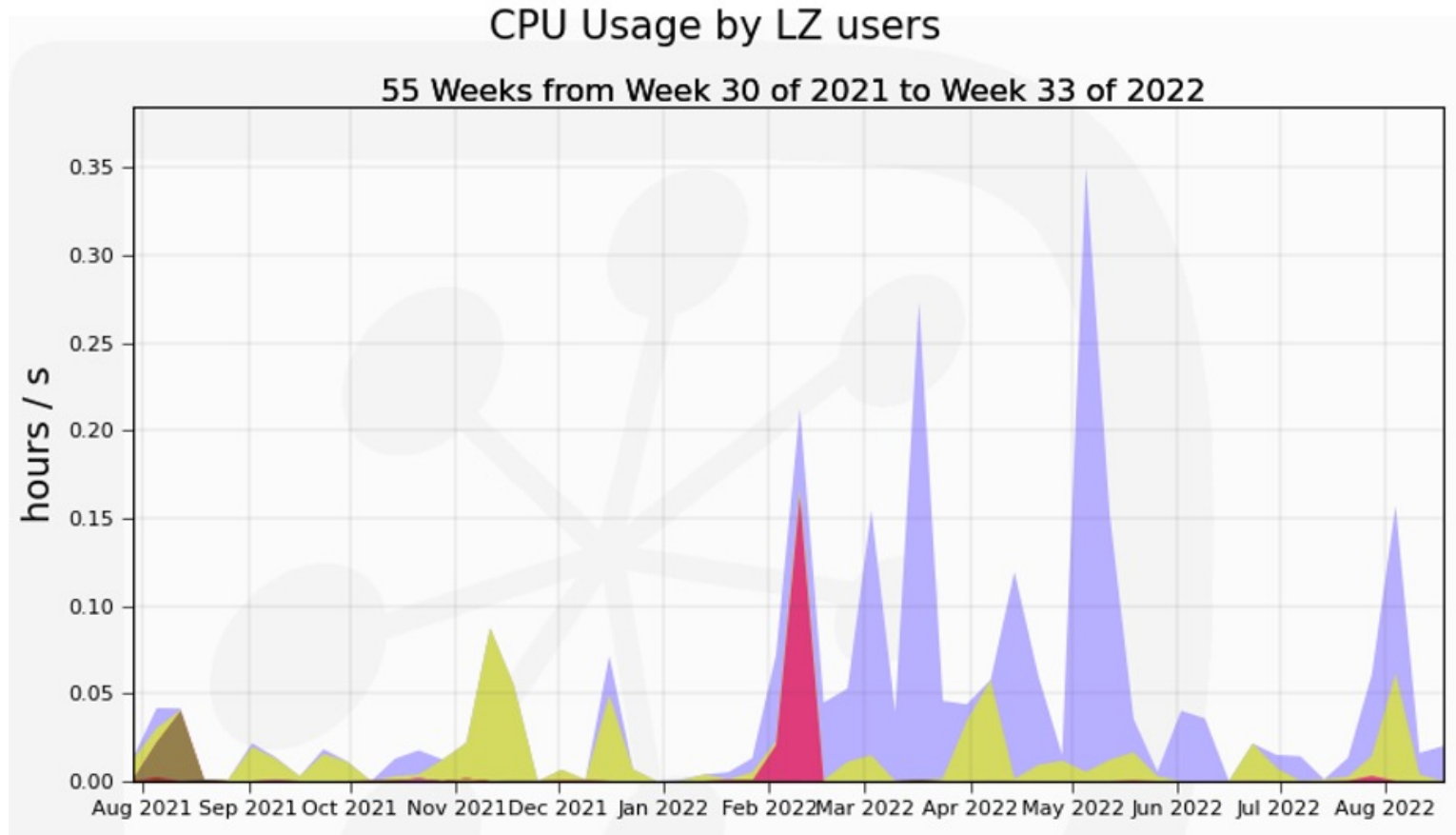
- Since the start of data taking: 1.6 mln CPU hours.
- Purple peaks correspond to data reprocessing.

CPU usage

CPU Usage by LZ users

364 Weeks from Week 34 of 2015 to Week 33 of 2022

Total from 2015: 16.2 mln CPU hours.

Summary

- LZ experiment:
    - Built and operating according to design specifications.
    - Excellent performance during engineering, calibration and the first science runs.
    - Currently the most-sensitive WIMP search experiment in the world for a large range of WIMP masses.
- Computing at the UKDC:
    - 1.6 million CPU hours used since start of data taking in August 2021.
    - UKDC has 7 PB of storage space.
- Many thanks to GridPP and IRIS.
- Many thanks also to the GridPP-LZ team at Imperial (Daniela, Simon and others) and other sites.
- From the science paper: *"We acknowledge additional support from the STFC Boulby Underground Laboratory in the U.K., the GridPP [81, 82] and IRIS Collaborations, in particular at Imperial College London…"*
- Please, continue supporting us! We will deliver good science.