First Dark Matter Search Results from the LUX-ZEPLIN Experiment

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LIP Lisbon Seminar 2022/12/15

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
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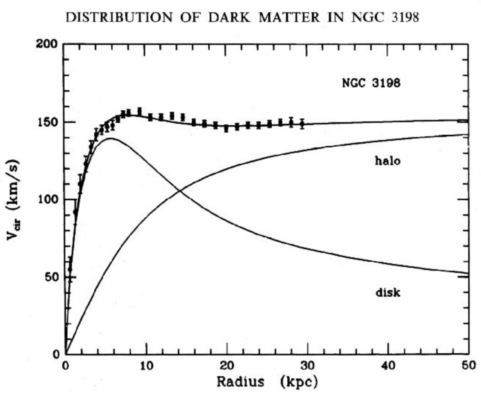
Dark Matter

In 1933, **Fritz Zwicky** noticed a large discrepancy in the mass of the **Coma cluster** when calculated using galactic motion or luminosity.

➔ Some form of non-luminous matter was responsible for binding the cluster together, called it “**dark matter**”.

The pioneer work of **Vera Rubin** on **galaxy rotation curves** also hinted at discrepancies between most observations and the expected from Newtonian dynamics:

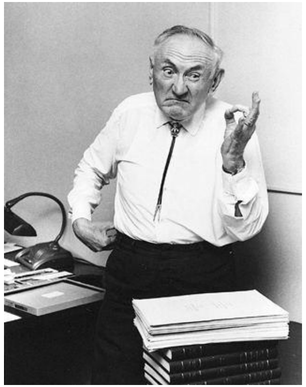


Velocity of stars remained approx. constant at large radii.

Two possible explanations:

1. Newtonian dynamics is insufficient
2. **There is missing mass in the system**

A **dark matter halo** envelops the galaxy and reaches far beyond the galactic disk.



A very upset Fritz Zwicky

Vera Rubin

Dark Matter

Strong consensus among evidences in favor of Dark Matter:

- Cosmic Microwave Background (CMB)
- Big Bang Nucleosynthesis (BBN)
- Large Scale Structure formation
- Baryon Acoustic Oscillations (BAO)
- Galaxy Cluster mergers
- Galaxy rotation curves

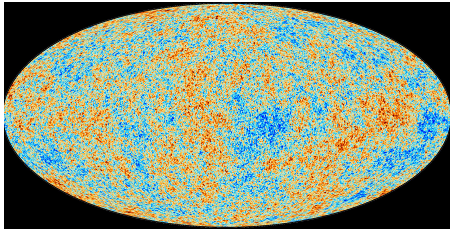
So far, all evidences seem to strongly agree with the existence of **dark matter** and support the **ΛCDM** Standard Model of cosmology.

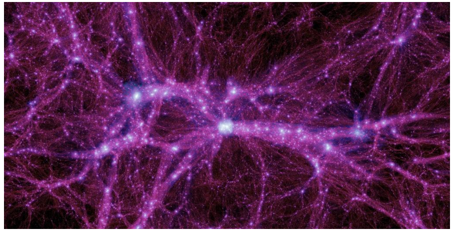
Changes of the CMB power spectrum with the values of some cosmological parameters.

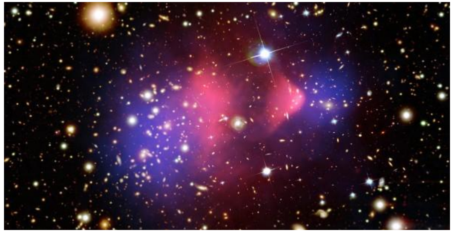
Parameter	Symbol	Value
Hubble constant [km s^{-1} Mpc^{-1}]	H_0	67.66 ± 0.42
Baryon energy density	$\Omega_b h^2$	0.02242 ± 0.00014
Cold Dark Matter energy density	$\Omega_c h^2$	0.11933 ± 0.00091
Total matter energy density	Ω_m	0.3111 ± 0.0056
Dark energy density	Ω_Λ	0.6889 ± 0.0056
Curvature	$\Omega_{\kappa,0}$	0.0007 ± 0.0019
Sum of neutrino masses [eV]	$\sum m_\nu$	< 0.12
Age of the universe [Gy]		13.787 ± 0.020

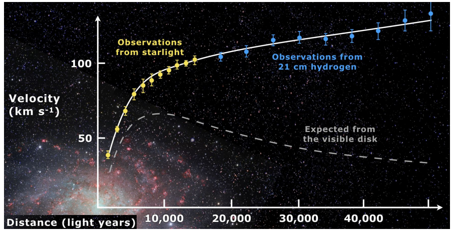
Tien-Tien Yu - Hot Topics on the Cosmic Frontier Colloquium, June 10 ‘22

Gravitational Interactions









SCALE

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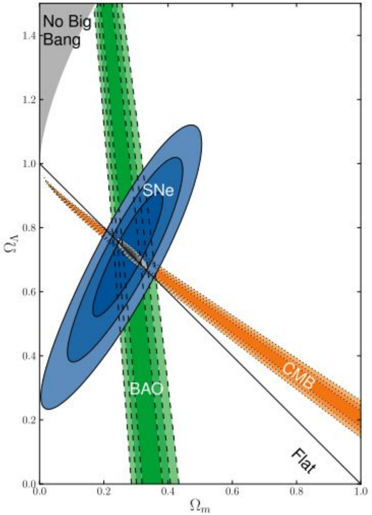
Agreement between data from SNe Ia, CMB and BAO data prior to 2012, over the Ωm−ΩΛ phase-space



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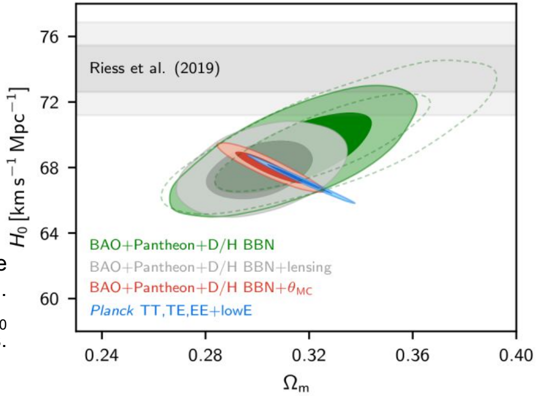
Planck 2018 results (2020) showing the agreement between CMB and BAO+BBN. Also showing the tension on H_0 measurements from Cepheid variables.



Λ - Cold Dark Matter (ΛCDM) model of the universe is the Standard Model of Cosmology.

- The dynamics and evolution of the universe is dominated by dark energy (Λ) and cold dark matter (CDM)

Dark matter and **dark energy** account for roughly 95% of the total mass-energy content of the universe.

Dark matter represents 84% of all matter in the universe.

$$\frac{\kappa}{a^2} = H^2\left(\Omega_r + \Omega_m + \Omega_\Lambda - 1\right).$$

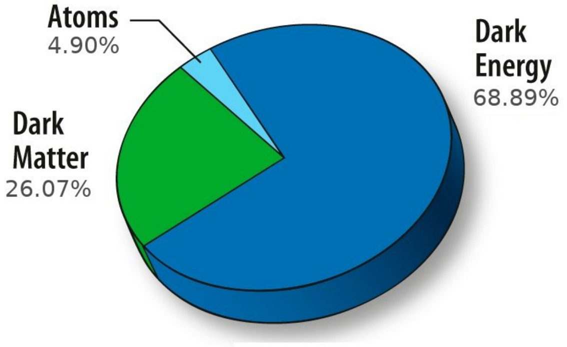
Radiation

Matter

Vacuum

$$\boxed{\begin{aligned} \Omega_i &= \rho_i(t)\frac{8\pi G}{3H^2} \\ \Omega_\Lambda &= \frac{\Lambda}{3H^2} \end{aligned}}$$

Energy-density parameters



The cosmic recipe according to Planck+BAO+BBN

Standard Model of Cosmology (ΛCDM)

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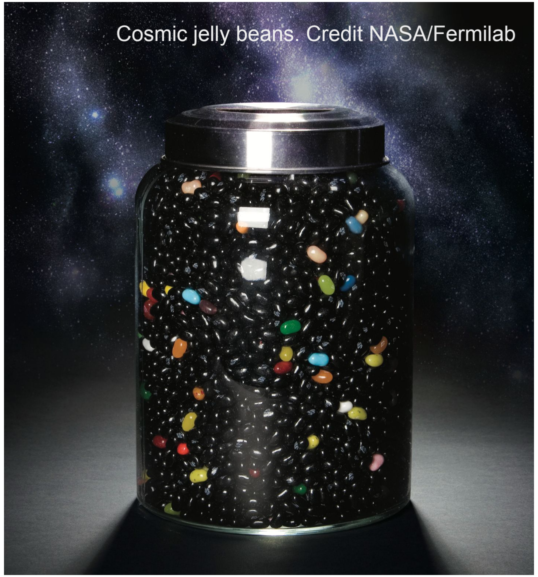
We only understand roughly 5% of the contents of the universe.



Cosmic jelly beans. Credit NASA/Fermilab

What is Dark Matter?

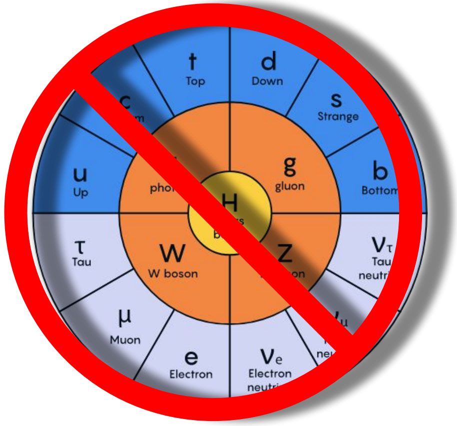
- Does not interact via electromagnetism, hence “dark”
- Interacts gravitationally
- Nearly collisionless
- Stable on the time-scale of the universe
- Non-relativistic, i.e. “cold”
- Abundant (local density of 0.3 GeV/cm^3)

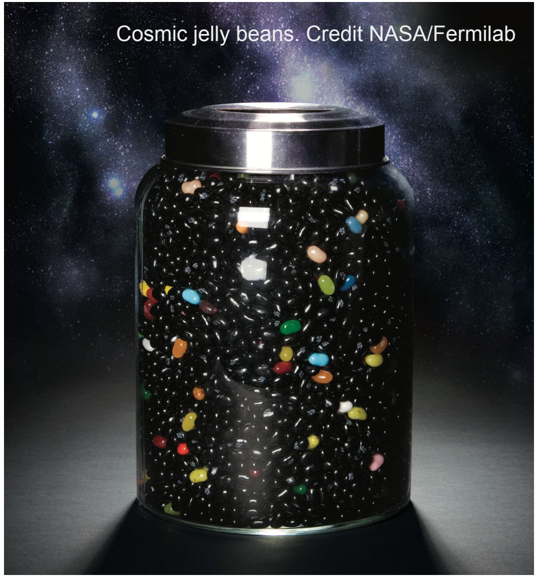
Dark Matter:

Hypothetical “substance” that is **massive, stable or long-lived, chargeless and weakly-interacting** with itself and other matter.

No valid candidate in the Standard Model* ➡ **Physics BSM**

*SM neutrinos contribute to Hot Dark Matter, but cannot explain all observations.





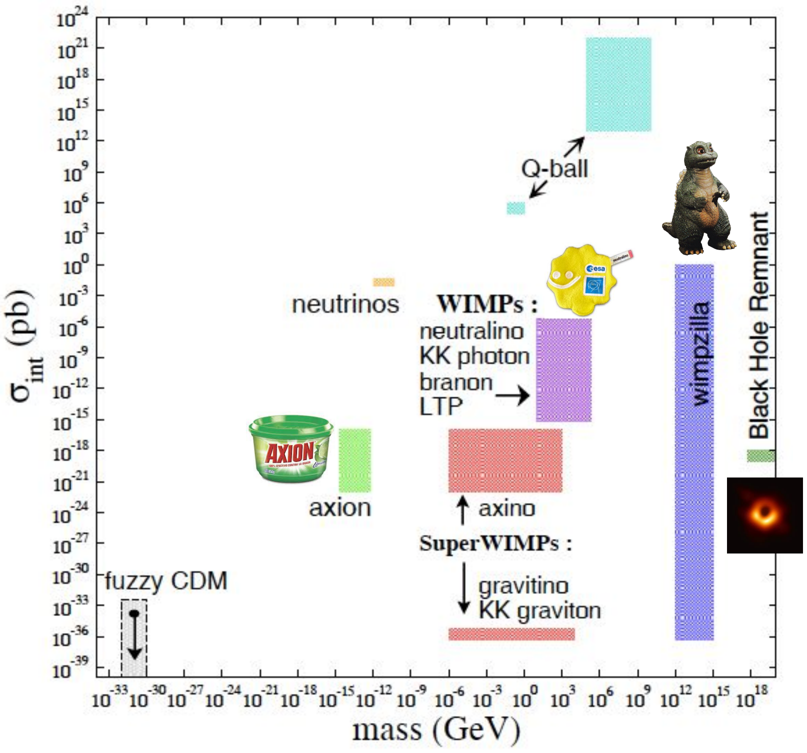
Dark Matter Candidates

A zoo of candidates spanning 80+ orders of magnitude in mass. Examples:

- **Axions** and Axion-like Particles (ALPs)
  - A solution to the QCD strong CP problem.
- **Dark photons** (vector portals to a hidden sector)
- **Neutrinos** (contribute as hot DM)
- **Sterile neutrino** (SM singlet)
  - Well motivated, mass from eV to 10^{15} GeV.
- **Weakly Interacting Massive Particle** (WIMPs)
- **Ultraheavy Dark Matter** (UHDM)
- **Massive Compact Halo Objects** (MACHOs)
  - Mostly excluded, some windows exist.

DM can either be wave-like or particle-like depending on production mechanism and mass scale.

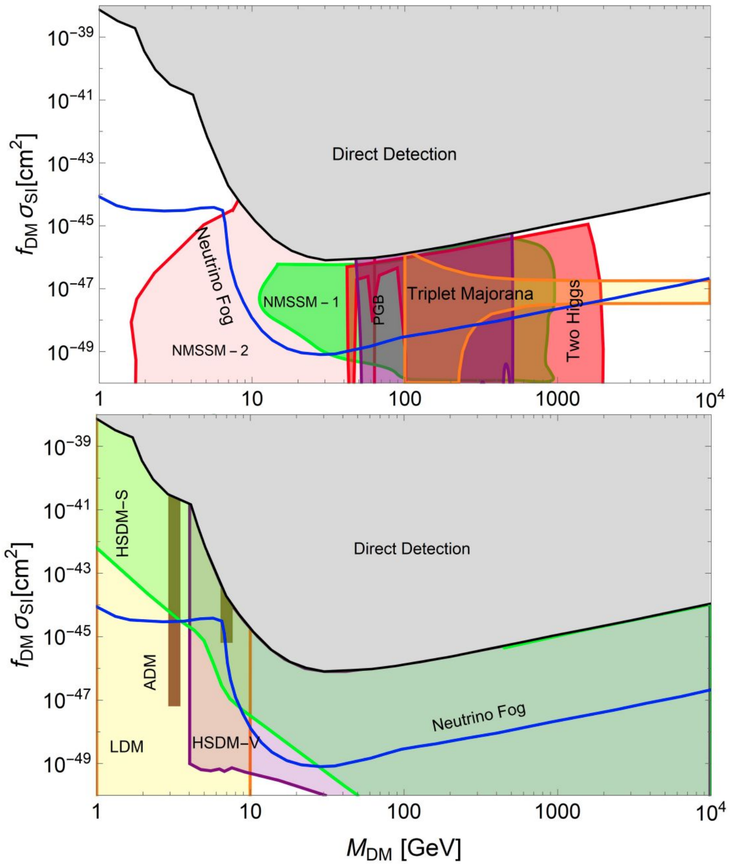
- Different detection strategies



Weakly Interacting Massive Particles (WIMPs)

One of the best motivated candidates for DM

- Thermal relic from the Big-Bang
  - MeV - 100 TeV scale (cosmological bounds)
  - Weak scale interactions leads to correct density today (WIMP miracle)
- Several SM extensions naturally produce WIMP candidates:
  - Visible sector extensions such as SUSY models, twin Higgs, Triplet Majorana, etc.
  - Hidden sectors with Higgs scalar portals, vector portals, asymmetrical DM, light DM, etc.
- Now probing some of the most interesting models from 20 years ago.



DM SI interaction exclusion vs DM mass, with several predicted regions of DM-bearing visible (top) and hidden (bot) sector model. Snowmass2021 CF1-WP1 [2203.08084]

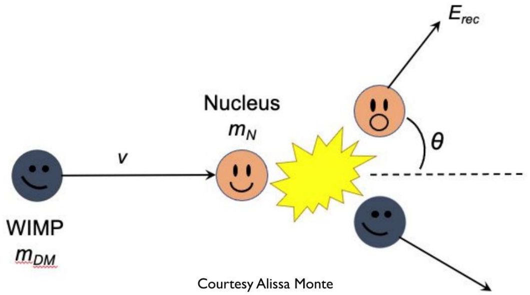
1. **Production in Particle Colliders**
   a. Looking for missing momentum;
   b. LHC can already cover most interesting mass ranges (TeV scale).

2. **Indirect Detection**
   a. Products of annihilation or decay;
   b. Surveys of dwarf spheroidal galaxies;
   c. Axion conversion in strong magnetic fields (of cosmic origin)

3. **Direct Detection**
   a. Searching for dark matter scattering with a target material
   b. Axion conversion in resonance cavities and ASTs

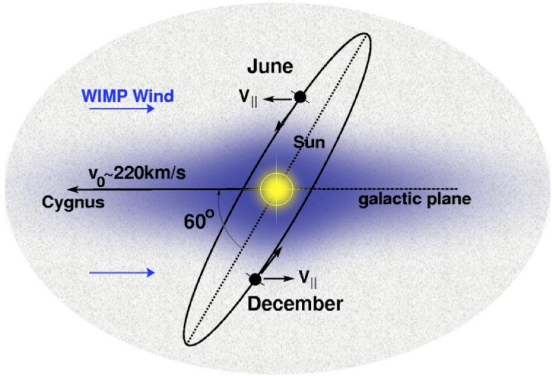
Wait for a DM particle to interact with a sensitive target:

- Very rare process: $\sigma_{WIMP-N} < 1$ femtobarn (10^{-39} cm^2)
- Non-relativistic elastic scattering: small E transfer.
- Kinematics favour interactions with atomic nuclei.



The Solar system is moving across the DM halo:

- A WIMP wind passes through the Earth.
- Billions of WIMPs cross the detector per second.



Considering the current best limit on σ_{WIMP-N} (LZ, this result) and:

- Xe target, **A=131**
- WIMP mass **M_χ = 100 GeV**
- Local DM density **ρ_χ = 0.4 GeV cm^{-3}**
- Earth's velocity in the halo, **v_0= 220 km s^{-1}**

$$R_0 = \frac{2}{\sqrt{\pi}} \frac{N_A}{A} \frac{\rho_{DM}}{M_\chi} \sigma_0 v_0$$

~5 events / tonne of Xe / year

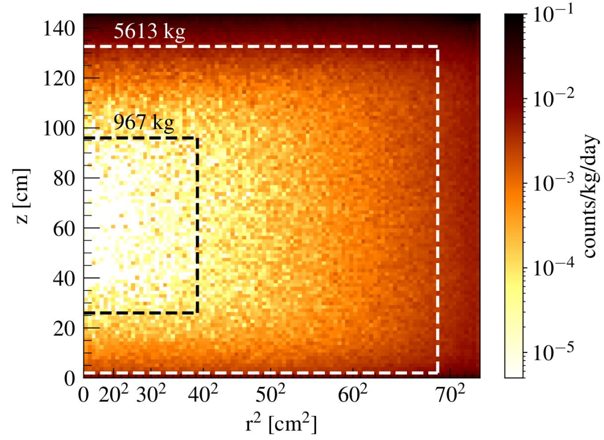
E_R= 3 keV avg. recoil energy

Direct Detection of Dark Matter

Ultra-low background environment is essential!

- ★ Move underground, shield from cosmic rays.
- ★ High radiopurity detector materials.
- ★ Passive and active shielding:
  - ○ Use dense target materials
  - ○ Deploy coincidence/veto detectors
- ★ Good position resolution and fiducialization
- ★ Good energy resolution and threshold

Attenuation of external radiation in the LXe target of LZ (E > 2 MeV)



Xenon as a target for DM searches:

- ★ Liquid Xe is very dense (2.9 g/cm^3)
  - ○ Self-shielding and active vetoing
- ★ High **ionization** and **scintillation** yields
  - ○ 55 ph/keV @10keV ER ; 8 ph/keV @10keV NR
- ★ Transparent to its own scintillation light
- ★ High purity and no long-living natural isotopes*
- ★ High Atomic mass enhances WIMP DM cross-section
  - ○ σ_{WN} proportional to A^2
- ★ Similar masses kinematically enhance energy transfer
  - ○ $M_{Xe} \approx 126$ GeV and $M_\chi \sim O(\text{GeV})$
- ★ Several double beta decay isotope candidates:
  - ○ ^{134}Xe, ^{136}Xe with 2vββ and 0vββ
  - ○ ^{124}Xe with 2v2EC, 2vECβ+ and 2vβ+β+

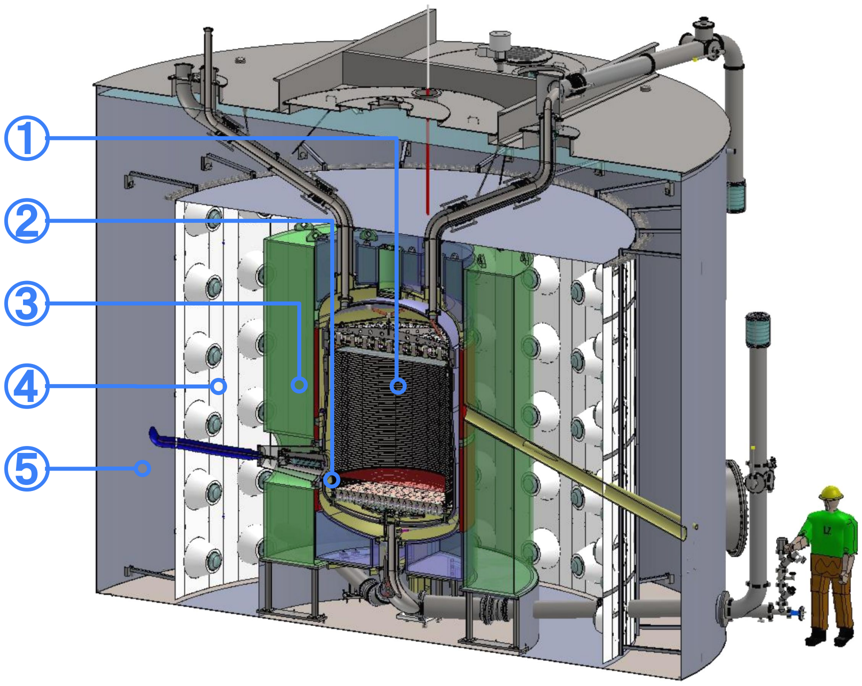
7 tonne dual-phase Xe ultra-low background TPC designed for dark matter searches ① observed by 2 arrays of 253 (top) and 241 PMTs (bottom).

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.

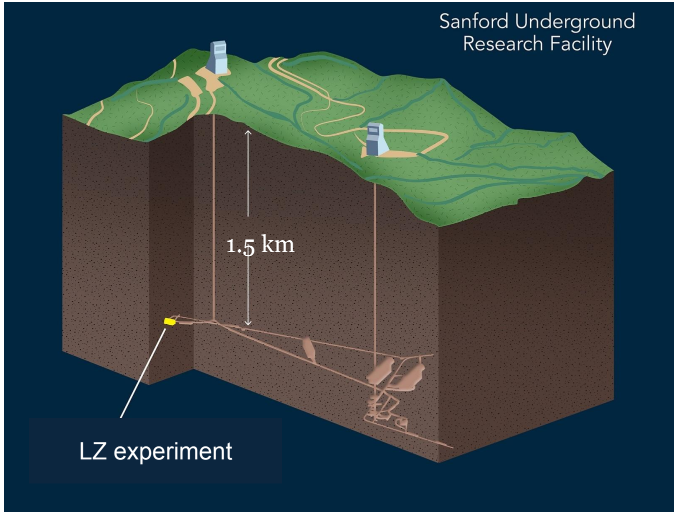


Schematic of the LZ experiment

The LUX-ZEPLIN experiment

LZ is installed at SURF (SD, USA) in the Homestake gold mine at a depth of 4850 ft (1.5 km)

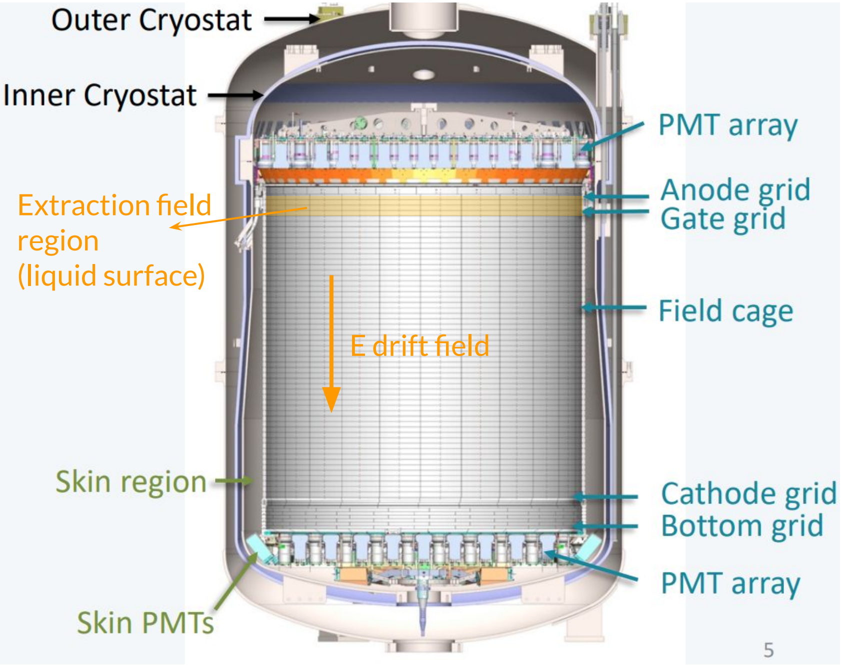
- 4600 m.w.e overburden
- 10 minute elevator ride



The LUX-ZEPLIN experiment

The **liquid Xe 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)
  - made of the most radiopure titanium in the world (Astropart. Phys. 96,1 2017)



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TPC of LZ in the SAL cleanroom

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Detailed view of the bottom grid

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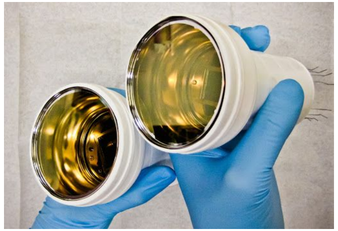

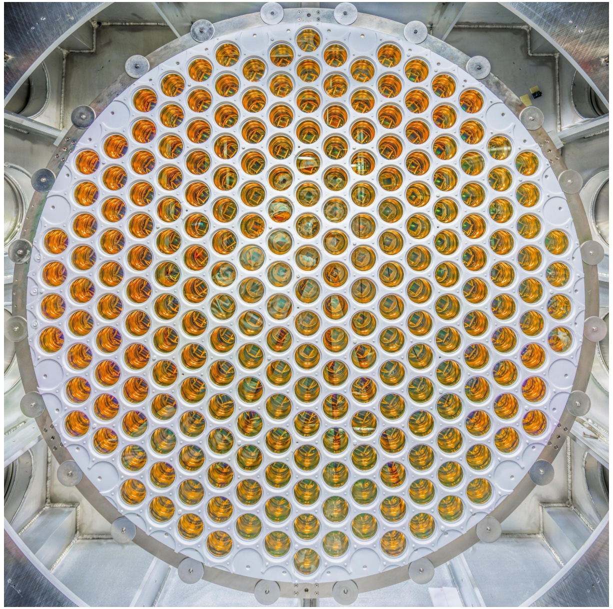

The bottom PMT array

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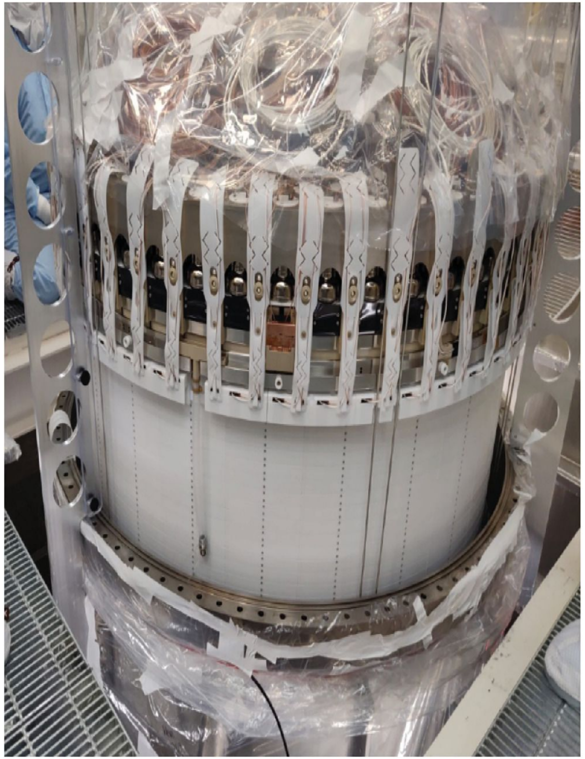
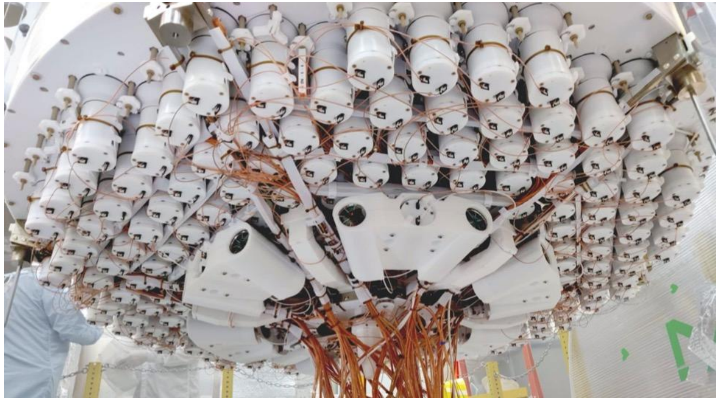


The TPC being lowered into the inner cryostat vessel

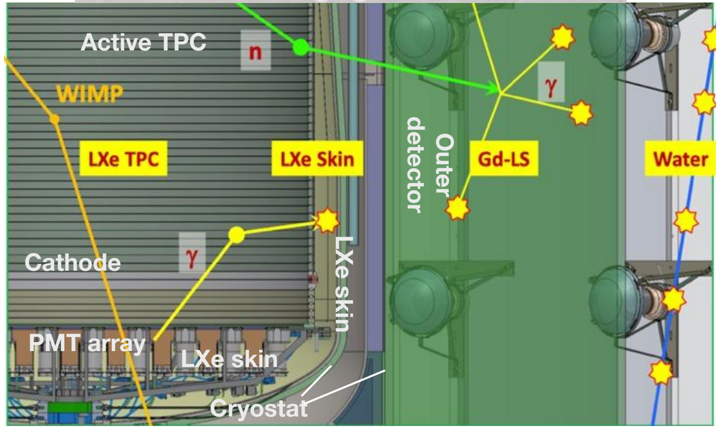
The **Skin detector** surrounds the TPC from the side and bottom:

- ★ 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 to maximize light collection
    - ○ 100 keV threshold in >95% of the volume
- ★ Anti-coincidence detector for γ-rays

Interior of the inner cryostat vessel, covered in PTFE



Below the bottom TPC PMT array, showing the Skin dome PMTs



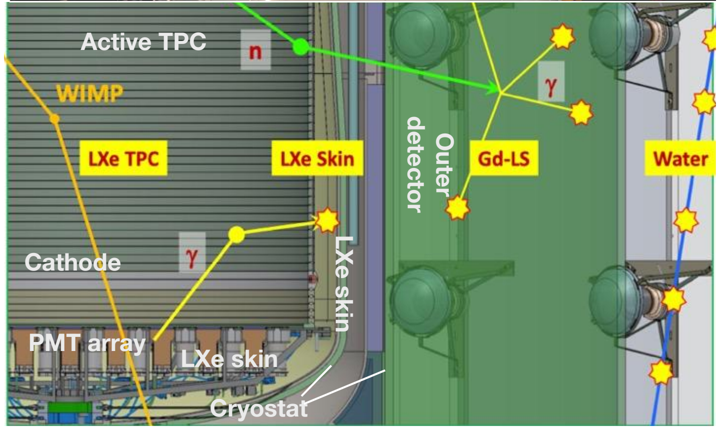
Schematic of the LZ experiment (detail)

The LUX-ZEPLIN experiment

The **Outer Detector (OD)** is a **17.3 tonnes** Gd-loaded liquid scintillator (Gd-LS) with a 120 PMT readout, that surrounds the entire TPC system.

- ★ Main function as active veto (**n**, high-E **γ**, **μ**)
- ★ Gd has high n-capture cross-section and provides a clear capture signature (~8 MeV)
- ★ Neutrons captured in LS (H-rich) produce characteristic 2.2 MeV γ-ray

1. Scintillations yield: **130 phd/MeV**
2. **96.5% veto efficiency** for neutrons that scatter once in the TPC
3. **>99% muon veto efficiency**



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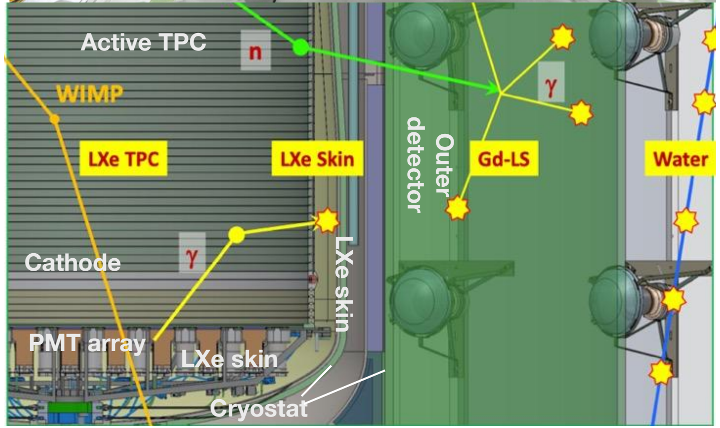

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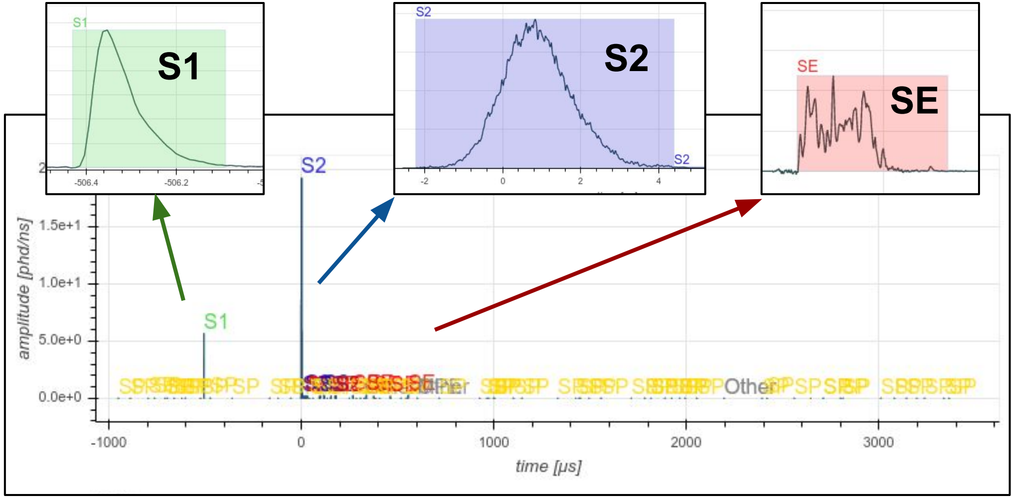
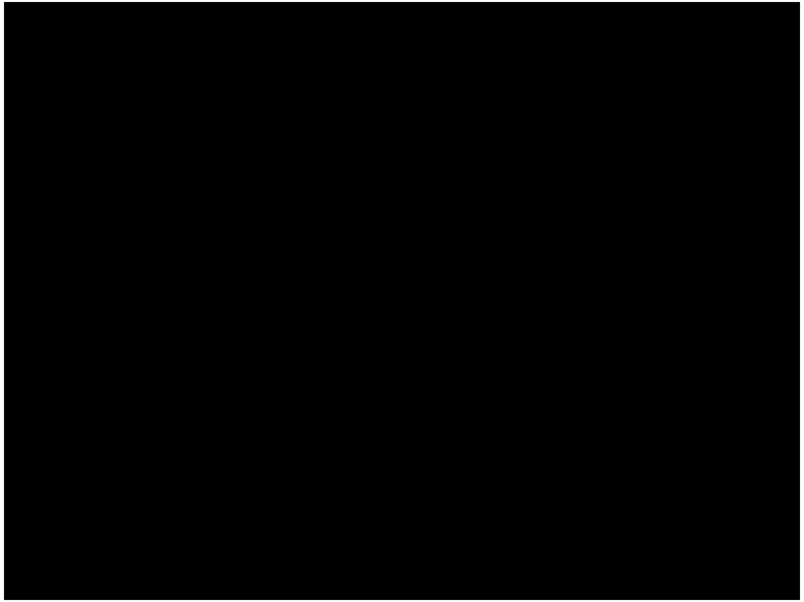
LZ dual-phase TPC: operating principle

1. An energy deposition in the LXe produces **prompt scintillation light (S1)** and ionization electrons;

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





Animation of an interaction within the TPC of the LUX detector - by C. Faham

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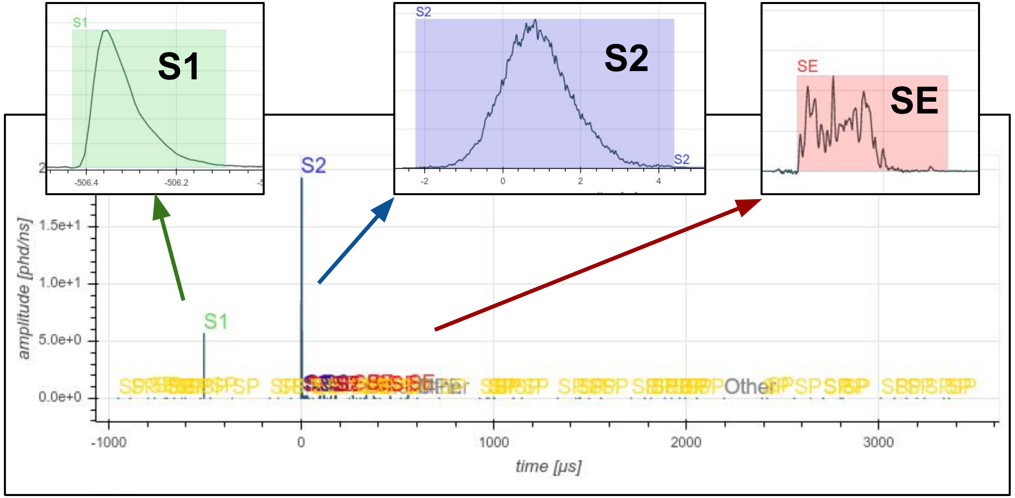
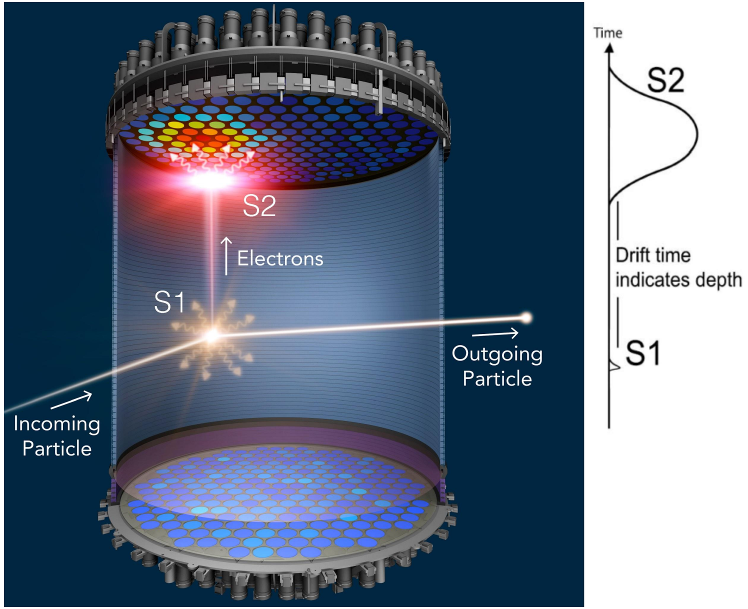
2. The electrons that do not recombine are drifted to the liquid-gas interface and extracted into the gas phase, creating **electroluminescence light (S2)**.





Schematic representation of the signals generated by an interaction within the TPC of LZ

LZ dual-phase TPC: operating principle

★ **Deposited energy is reconstructed using both the S1 and S2 signals.**

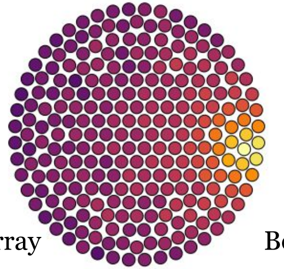
$$E = LW\left(\frac{S1}{g1} + \frac{S2}{g2}\right)$$

W≈13.7 eV;
L is a quenching factor
g_1 & g_2 are detector parameters

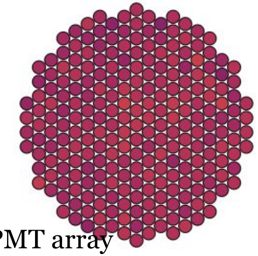
We get a full 3D reconstruction of the interaction:

★ The depth of the interaction can be obtained by the **time difference between the S1 and S2 signals** - σ(Z) < 0.3 cm.

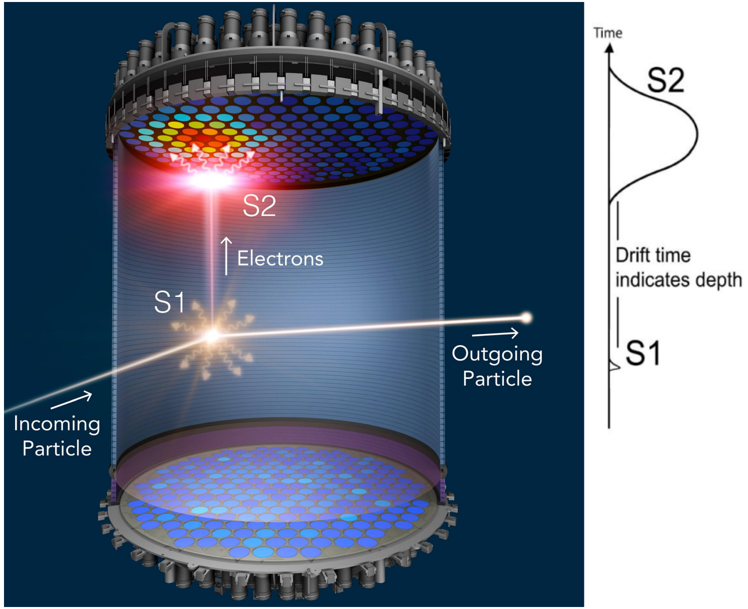
★ The XY position can be reconstructed using the **light pattern generated by the S2** signal on the top PMT array - σ(XY) ~ 3 cm.



Top PMT array



Bottom PMT array

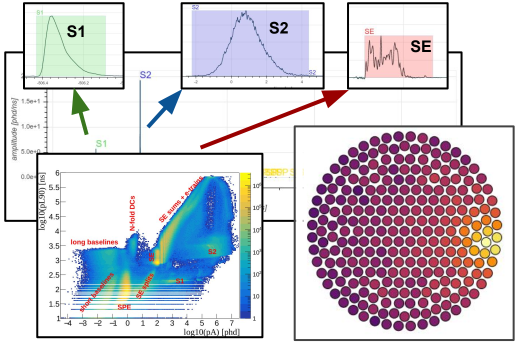


Schematic representation of the signals generated by an interaction within the TPC of LZ

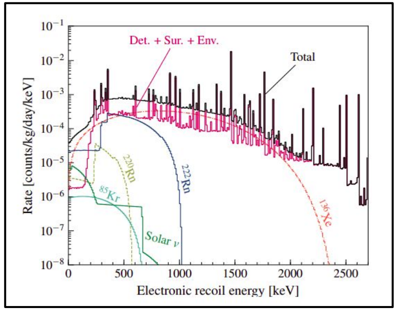
LIP roles in LZ

Data analysis (P. Brás):

- Pulse Finder (F. Neves)
- Pulse Classifier (P. Brás)
- XY Reconstr Mercury (V. Solovov)

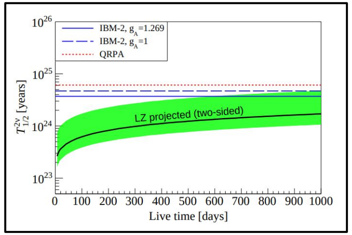


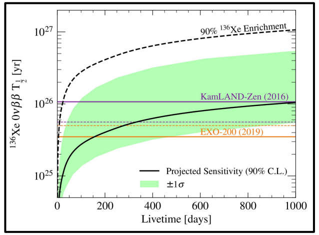
Backgrounds Model.
A. Lindote (former WG lead)



Rare Xenon Decay Searches (A. Lindote, C. Silva**):**

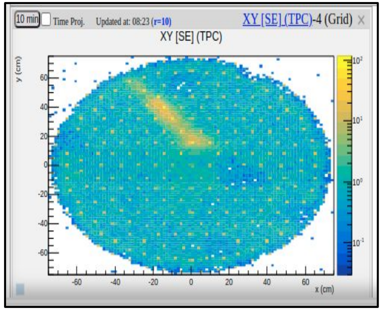
- ^{136}Xe $0\nu\beta\beta$ decay (P. Brás) PRC.102.014602
- ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ (E. Asamar) PRC.104.065501
- ^{124}Xe 2ν2EC (A. Lindote)

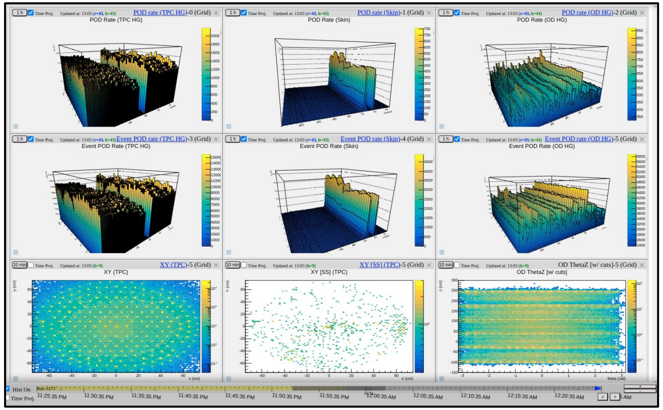




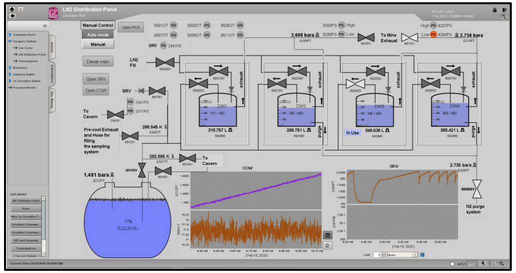
Online Monitor (Underground Performance Monitor)
Lead: F. Neves

*a muon crossing the TPC





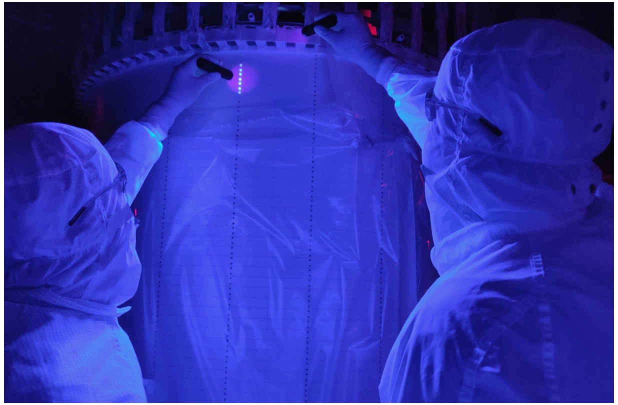
Experiment Control - “LZ nervous system”. Leads: V. Solovov, G. Pereira



Eur. Phys. J. C, 80: 1044 (2020)

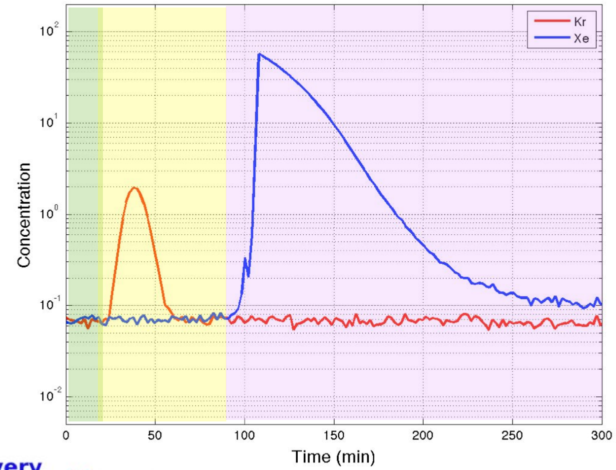
ALL components of LZ were screened for radioactivity

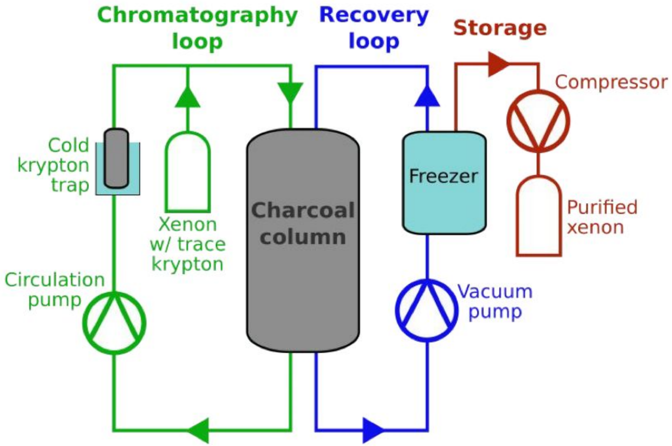
- ★ **~2000 assays** with 13 HPGe detectors, ICP-MS, neutron activation analysis
- ★ All major parts underwent radon emanation before installation
- ★ TPC assembled in radon-reduced clean room
- ★ Dust < 500 ng/cm2 on all LXe-facing surfaces
- ★ Rn plateout on walls < 0.5 mBq/m^2



Time lapse of the LZ TPC being lowered into the ICV at the SAL clean room

- ★ Gas chromatography to remove Kr from Xe
  - ^{nat}Kr reduced to 0.1 ppt g/g ^{nat}Kr/Xe and ^{nat}Ar to a negligible level
- ★ Major operations from January to August 2021
- ★ Continuous purification underground





^{85}Kr is a beta-emitter with 687 keV endpoint

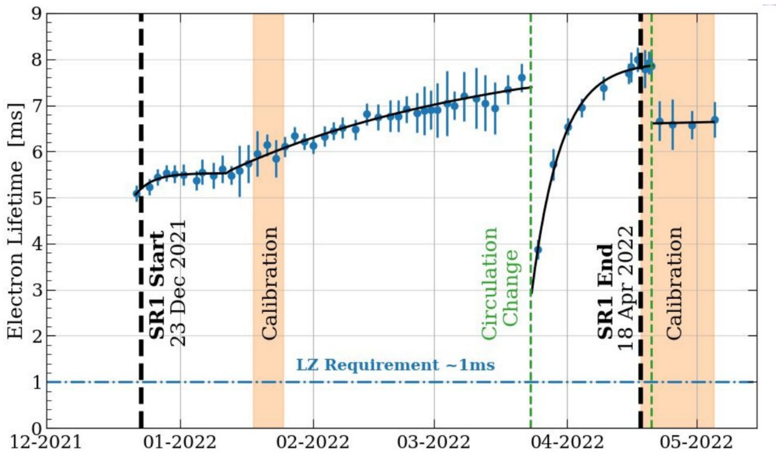
Xenon Circulation System & Cryogenics

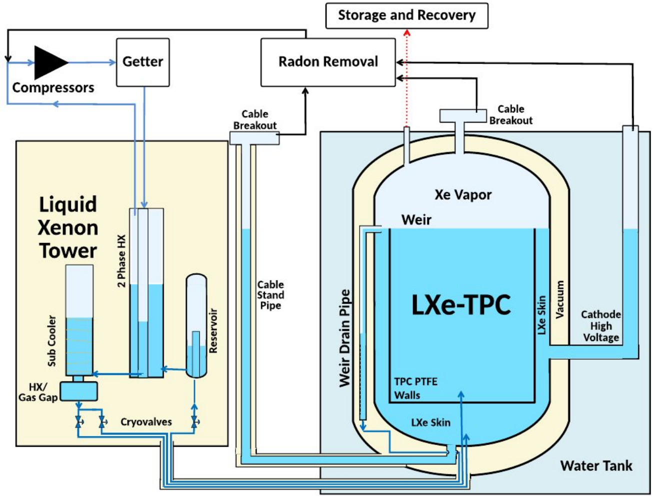
Designed to circulate gas at 500 slpm

- Turnover full Xe mass every 2.4 days
- Up to 600 slpm demonstrated

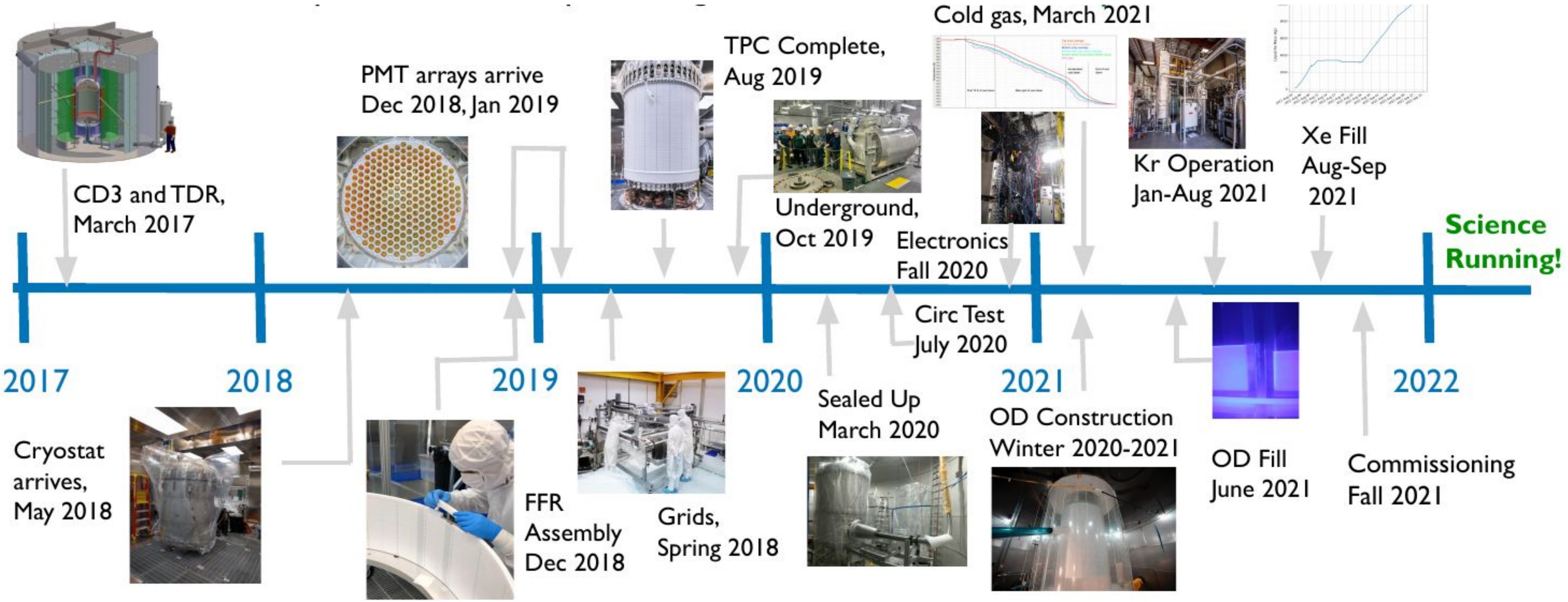
Purification using hot zirconium getter

- Purity ≡ electron lifetime (ELT)
- LZ requirement ELT> 1ms (maximum drift time)
- During SR1 ELT consistently greater than 5 ms





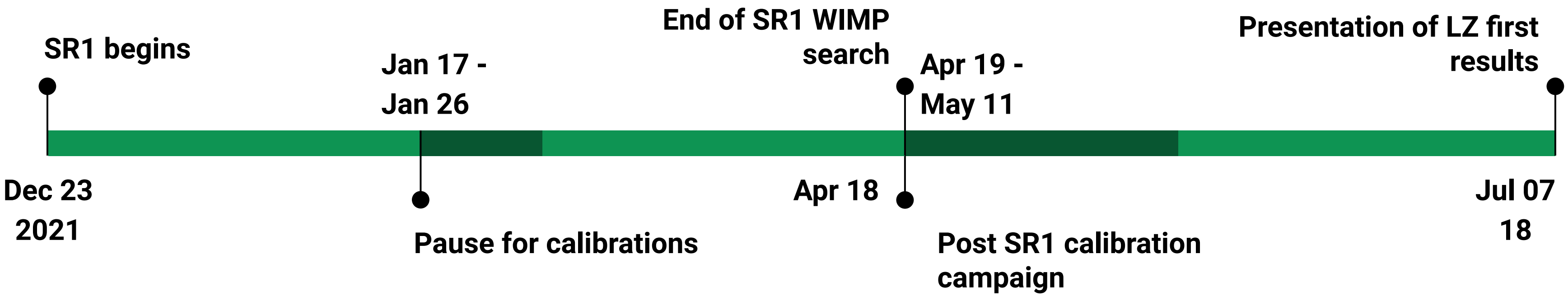
Construction, Deployment and Commissioning



LZ Science Run 1 (SR1)

Planned to collect 60 live-days after completing extensive commissioning and testing campaigns across all detector systems.

- ➔ To prove successful detector operation and expectation for competitive sensitivity to existing results
- ➔ Data collected from 23 Dec 2021 to 11 May 2022 under stable detector conditions.



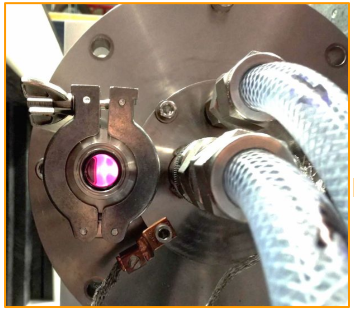
Detector Calibrations

Calibration campaigns are used to characterize the detector response.

- Internal sources mixed in the xenon
- Vertical source tubes for commercial rod sources
- Photo-neutron source
- DD neutron generator

What we want from calibrations:

- Energy studies in all three detectors
  - Best TPC E-resolution for this type of det.
  - Found lower OD threshold than expected!
- Position reconstruction
- Inter-detector timing calibrations
- ER & NR bands



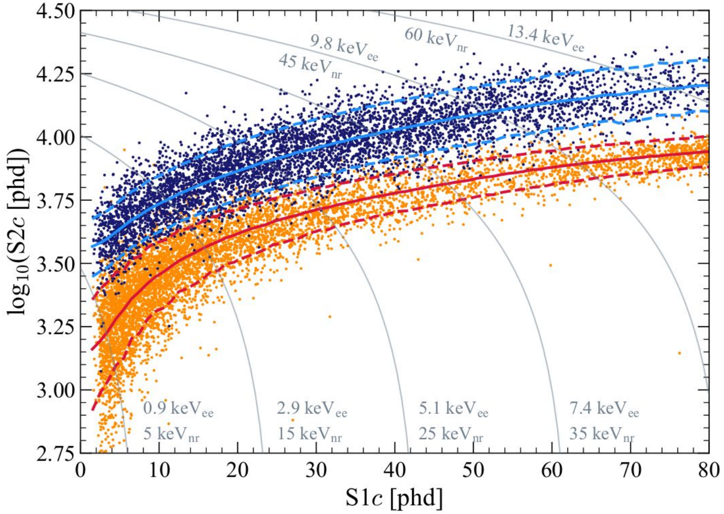
	Nuclide	Type	Energy [keV]	$\tau_{1/2}$
Internal/injected	^{83m}Kr	γ	32.1 , 9.4	1.83 h
	^{131m}Xe	γ	164	11.8 d
	^{220}Rn	α, β, γ	various	10.6 h
	^{3}H	β	18.6 endpoint	12.5 y
	^{14}C	β	156 endpoint	5730 y
External	^{241}AmLi	(α,n)	1500 endpoint $^{(a)}$	432 y
	^{252}Cf	n	Watt spectrum	2.65 y
	^{241}AmBe	(α,n)	11,000 endpoint	432 y
	^{57}Co	γ	122	0.74 y
	^{228}Th	γ	2615	1.91 y
	^{22}Na	γ	511,1275	2.61 y
	^{60}Co	γ	1173 , 1333	5.27 y
	^{133}Ba	γ	356	10.5 y
	^{54}Mn	γ	835	312 d
	^{88}YBe	(γ,n)	152	107 d
	^{124}SbBe	(γ,n)	22.5	60.2 d
	^{205}BiBe	(γ,n)	88.5	15.3 d
	^{206}BiBe	(γ,n)	47	6.24 d
DD generator	DD	n	2450	–
	D Ref.	n	272 → 400	–

The **ratio of S1 and S2 light** can be used to distinguish between particles interacting with atomic e⁻ or the nucleus.

- Electron recoils (ER) produced by γ-rays, betas and neutrinos.
- Nuclear recoils (NR) produced by **neutrons**, neutrinos (CEvNS), alphas and hopefully WIMPs.

Xenon response is modeled with Noble Element Simulation Technique (NEST).

LZ SR1 calibrations with CH_3T (Blue) and DD neutron generator data (orange).



LZ TPC response to ER (blue) and NR (orange) interactions

Measured **99.9% rejection of ER leakage** below the median quantile of a 40 GeV WIMP

Detector Response

G. Pereira, XeSAT 22

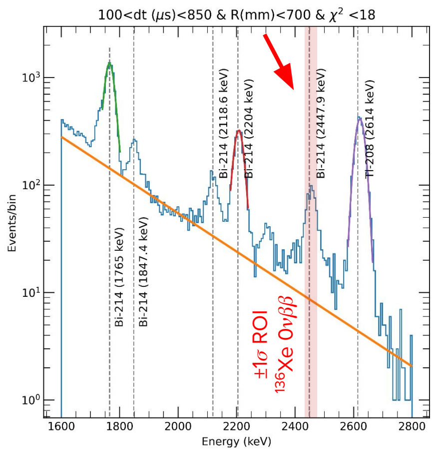
Use mono-energetic ER peaks to determine detector gains (g_1 & g_2)

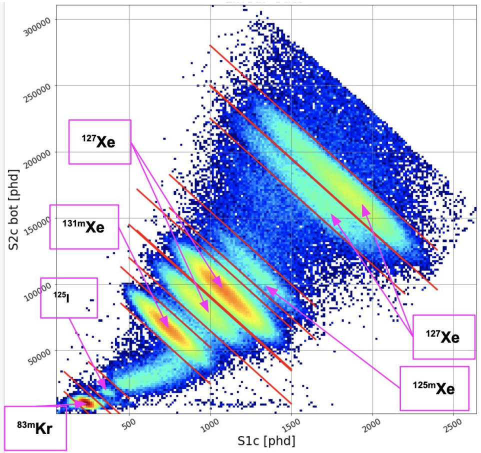
Parameter	Value
g_1^{gas}	0.0921 phd/photon
g_1	0.1136 phd/photon
Effective gas extraction field	8.42 kV/cm
Single electron	58.5 phd
Extraction Efficiency	80.5 %
g_2	47.07 phd/electron

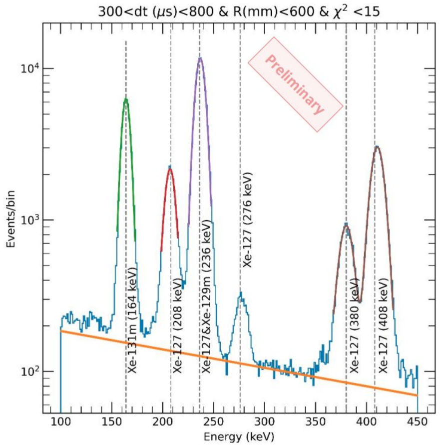
LZ obtained an unprecedented energy resolution for liquid xenon at high energies:

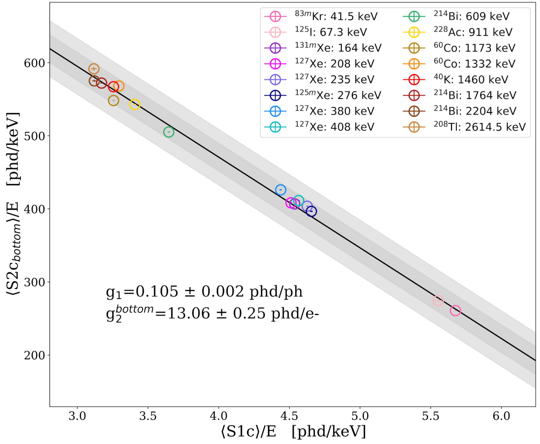
0.64 ± 0.02 % (σ/E) for ^{208}Tl 2614 keV

★ Only using the bottom PMT array to reconstruct energy.









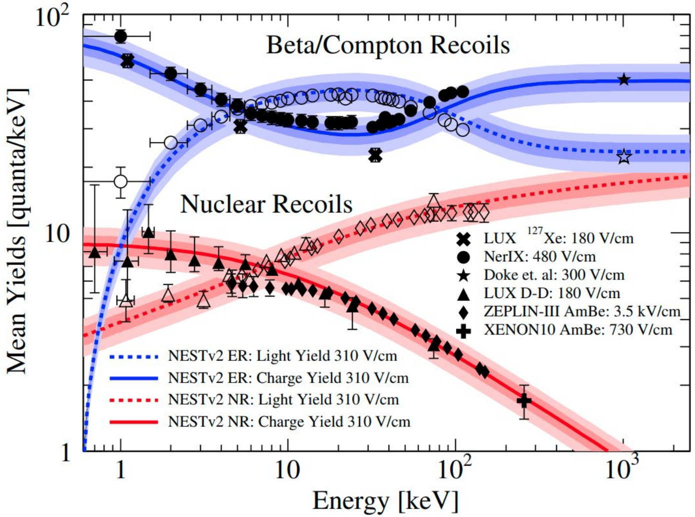
Simulations

Extensive Monte Carlo simulations of BGs from all relevant physics sources:

- ★ Trace radioactivity in detector components
- ★ ^{136}Xe double beta decay
- ★ Solar and atmospheric neutrinos
- ★ Gammas from cavern walls
- ★ Dispersed xenon contaminants
- ★ Surface contaminants
- ★ Cosmogenic backgrounds

Full detector geometry is modeled. Sims include detailed info from material assays and detector response measurements.

Xenon response is modeled with Noble Element Simulation Technique (NEST).

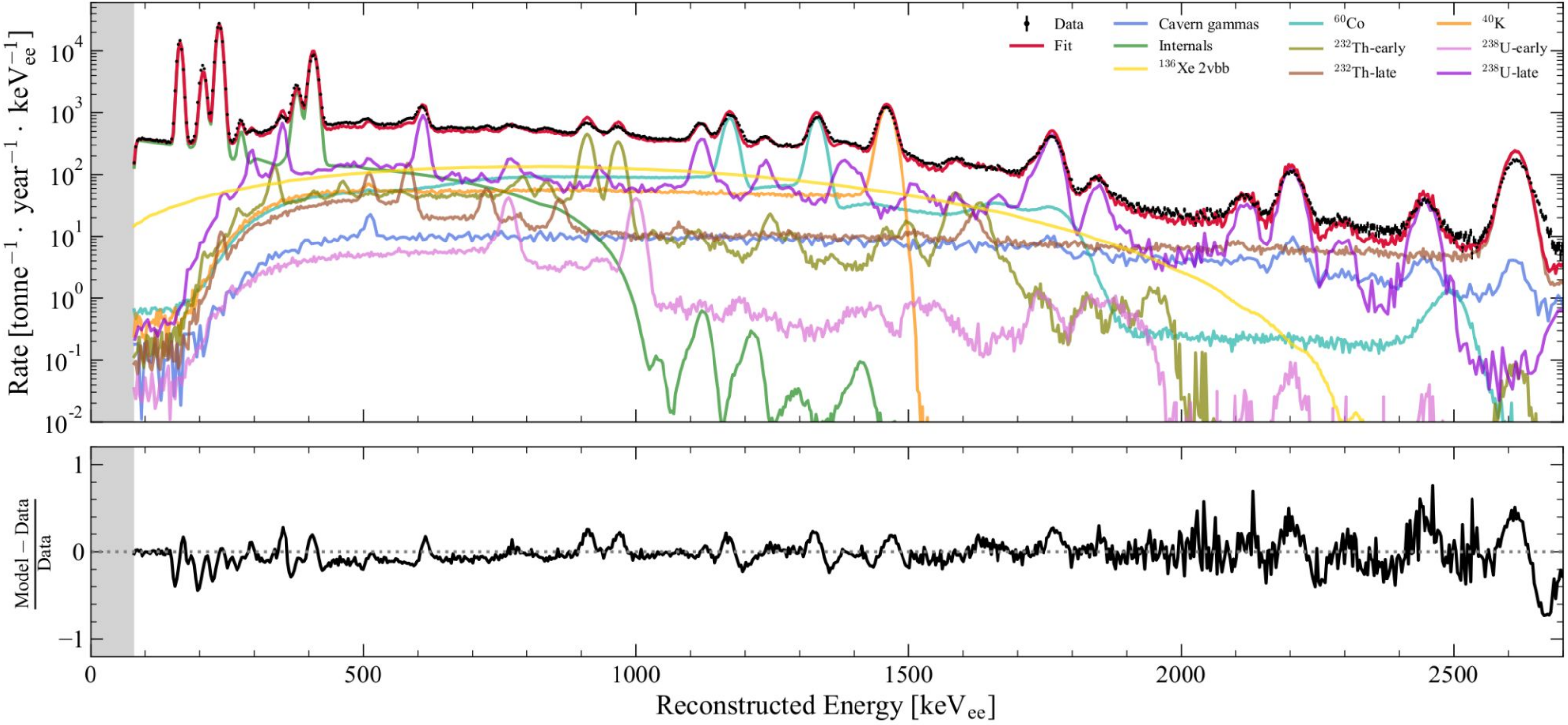


Derived average ionization charge (full markers) and scintillation light (open markers) yields from representative world calibration and background data sets (NEST)

(e-print 2211.17120)

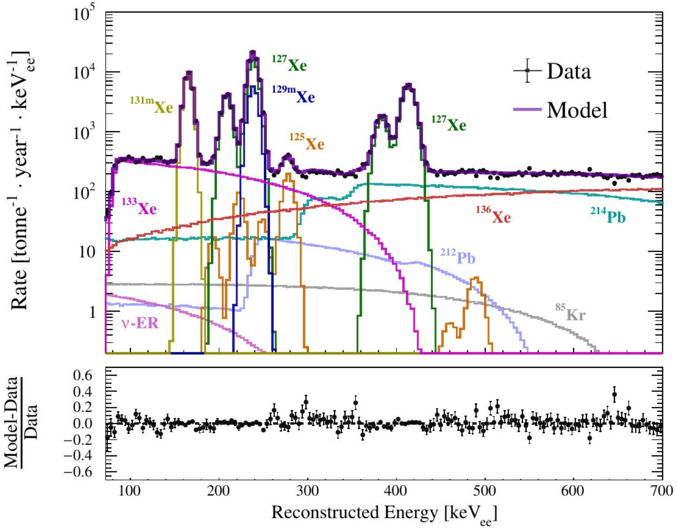
Characterization of all backgrounds across all energies.

- Simulations provide a BG model to compare data to.



BG relevant for WIMP searches:

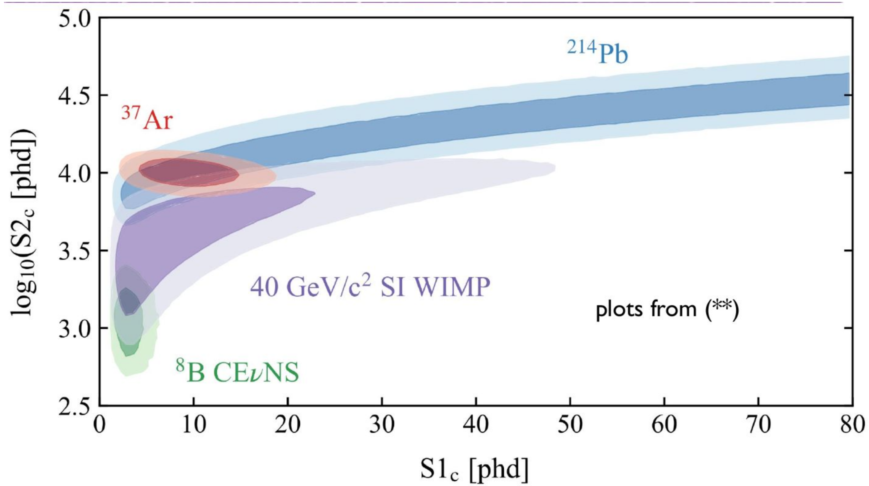
- Dissolved beta emitters:
  - ^{214}Pb (^{222}Rn daughter), ^{212}Pb (^{220}Rn daughter), ^{85}Kr, ^{136}Xe (2 beta)
- Dissolved e-captures (monenergetic x-ray/Auger cascades): ^{127}Xe, ^{124}Xe (2 e-capture), **^{37}Ar**
- Long-lived gamma emitters in detector materials:
  - ^{238}U chain, ^{232}Th chain, ^{40}K, ^{60}Co
- Neutron emission from spontaneous fission and (α,n)
- Solar neutrinos from ^{8}B (NR) and pp (ER) chains
- **Accidental coincidences**.



Backgrounds

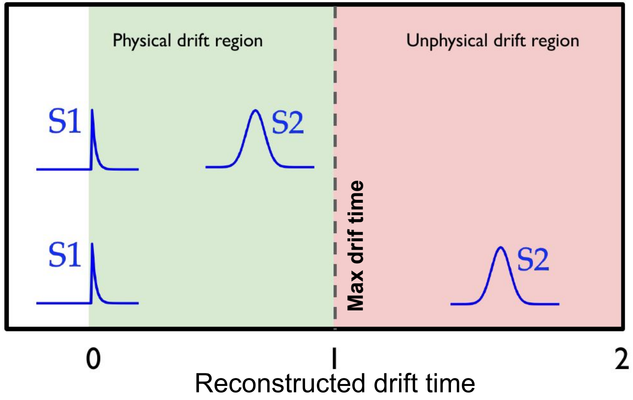
Argon-37 electron capture with $T_{1/2}$ = 35 d and monoenergetic 2.8 keV ER deposition

- Naturally occurring in the atmosphere via $^{40}Ca(n,\alpha)^{37}Ar^*$
- Equilibrium values range from 1-100 mBq/m^3
- Also produced by cosmic spallation of ^{nat}Xe
- Expecting O(100) ^{37}Ar events in SR1 [2201.02858]



Accidentals are unphysical event topologies generated by random coincidence os signals

- Isolated S1s (~1 Hz), isolated S2s (~10^{-3} Hz)
- Pairing of uncorrelated S1 and S2
  - Such events with unphysical drift time can be used to characterize accidentals



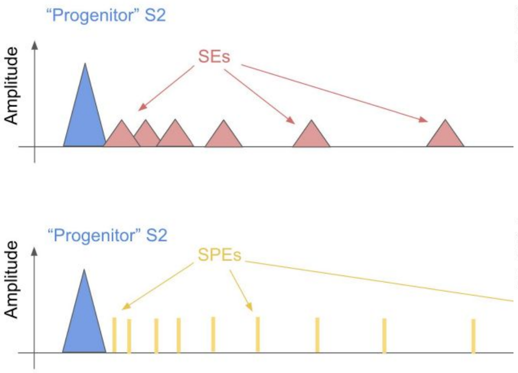
Data Quality

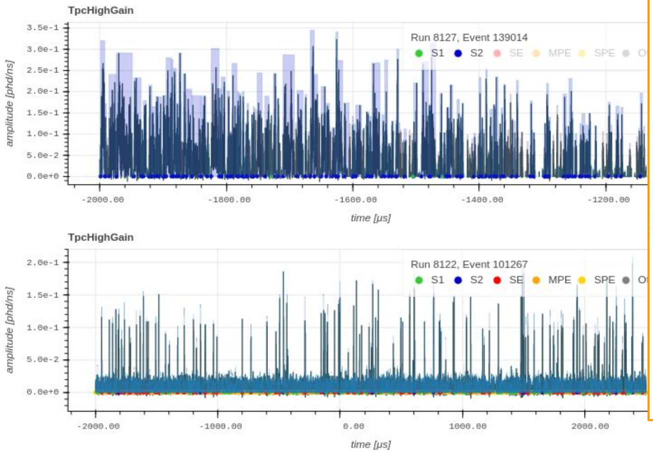
1. Selection of single scatters within a optimized fiducial volume.
2. Identify spurious signals:
   a. Pulse-based cuts: S1 and S2 shape - **signal acceptance loss**
   b. Time-period cuts: exclude periods of detector instability - **livetime impact**

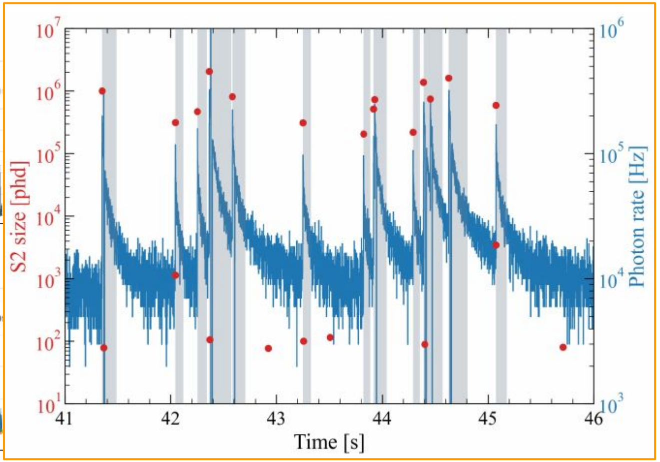
MS topology is excluded

3. Pulse trains cuts: Large S2s induce delayed emission of pulses lasting O(100ms)

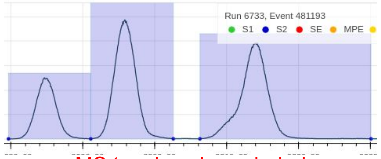
Periods after a large S2 are also excluded - **significant livetime loss**







Data Quality



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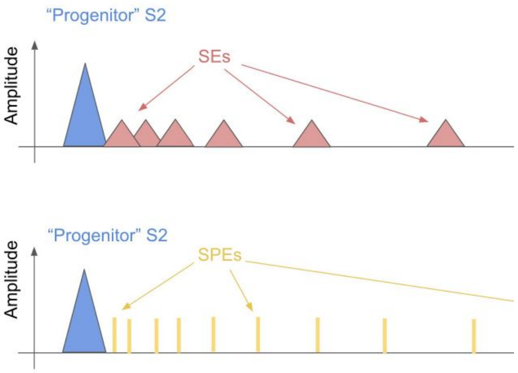
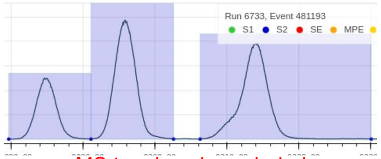


Livetime (LT) impact cuts		
Cut name	**Targeted effect**	**Impact**
Hot spot exclusions	Grid electron emission	3.1% LT removed
Muon holdoff	Glow from TPC-crossing muons	0.2% LT removed
E/ph-train holdoff	**Glow from S2s**	**29.8% LT removed**
High S1 rate exclusions	PMT/HV(?) misbehavior	0.2% LT removed
Bad buffer cuts	DAQ issue, caused by glow from muons & S2s	Deadtime hit, 0.5% LT removed, confirmed with GPS triggers and simple calculation from S2/muon rate
Excess Area cut	Glow from ghost muons/S2s	
Sustained rate cut	Glow from ghost muons/S2s	
Burst noise cut	Electronics noise	Deadtime hit, < 0.001% LT removed



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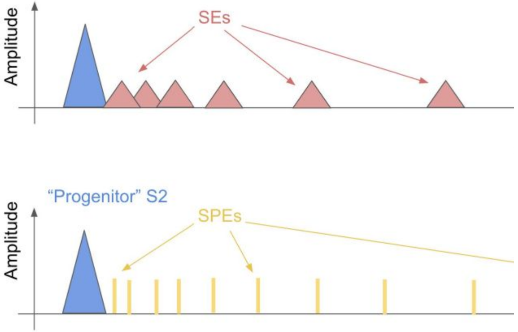
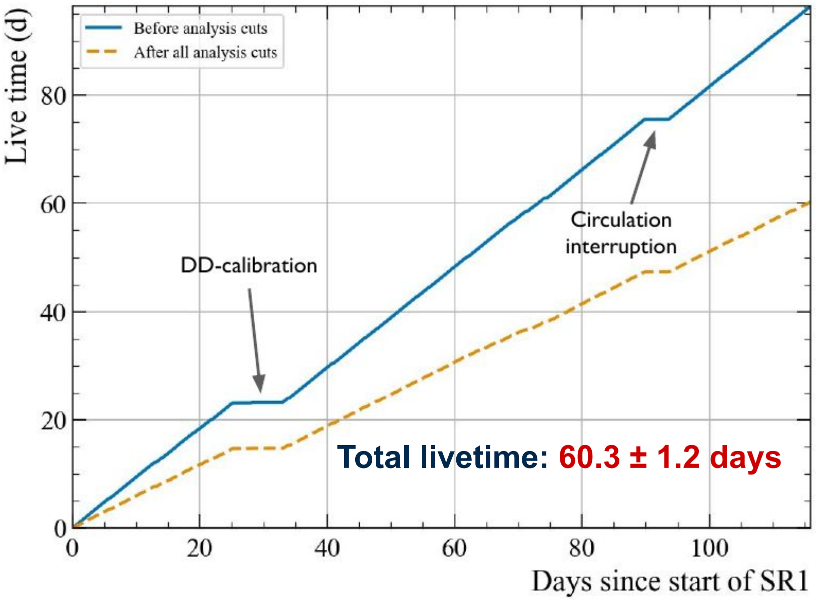


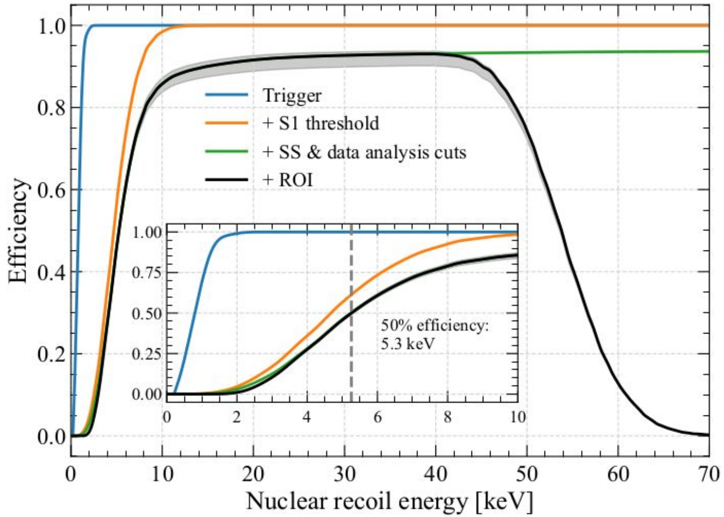


Total livetime: 60.3 ± 1.2 days

Signal Acceptance

- S2 trigger acceptance measured using:
  - Random triggers
  - DD generator data with pulsed plasma trigger
- S1 acceptance dominated by 3-fold coincidence requirement.
- Data selection acceptance measured with calibration sources
- Event classification efficiency measured by visual inspection of +1k neutron calibration events

50% acceptance above 5.3 keVnr

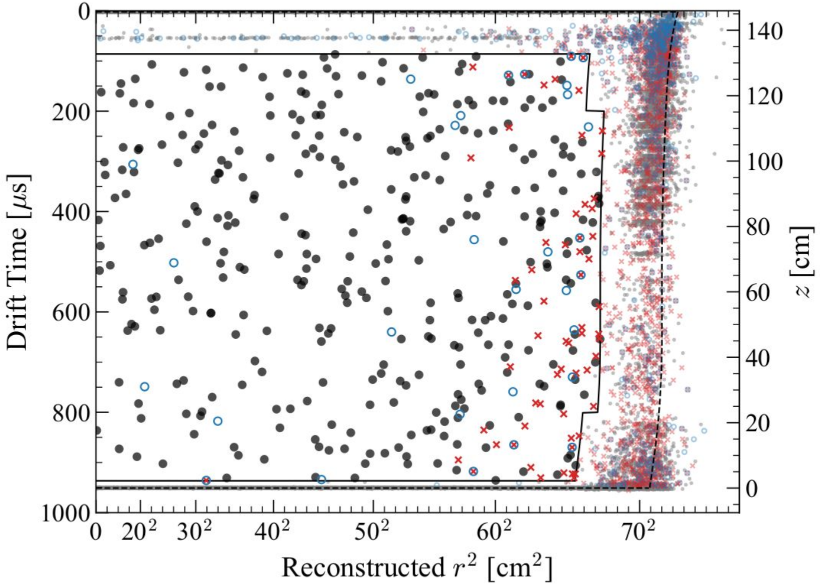


Uncertainty band (gray) from differences in cut acceptances as measured with different calibrations, and statistical uncertainties.

LZ SR1 WIMP-search Results

335 events passed the data quality cuts:

- Black points: events passing all cuts.
- Gray points: events passing all cuts except for fiducial volume.
- Red ×: events failing LXe skin veto cut (mostly ^{127}Xe)
- Blue circle: events failing OD tag veto.



5.5 ± 0.2 tonnes fiducial volume (FV):

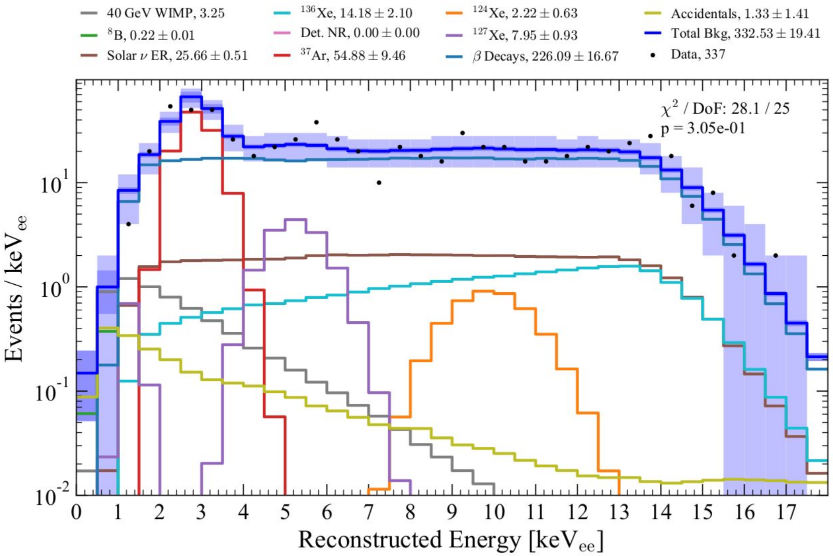
★ Total SR1 exposure of 330 tonne·days.

★ Skin veto allows more radial acceptance.

All backgrounds are within expectation:

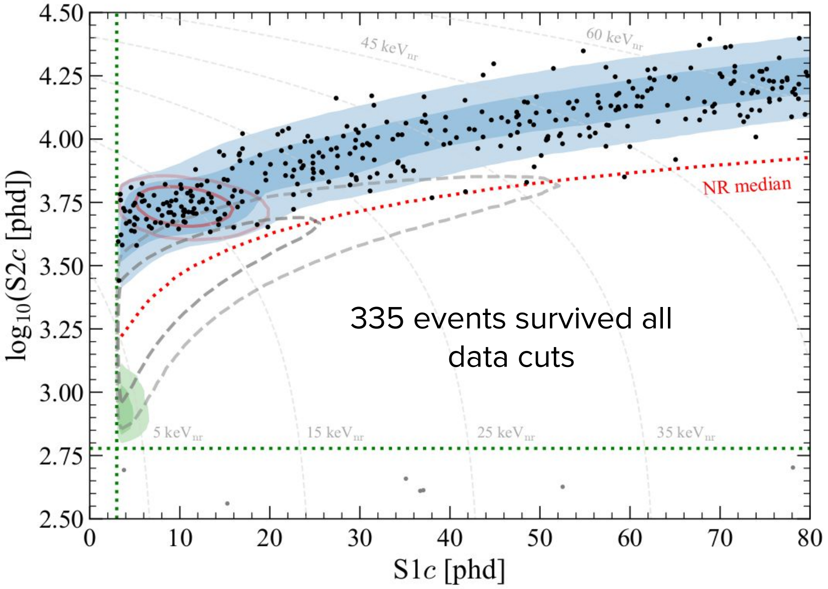
- ★ Data agrees with the background-only model (p-value of 0.96).
- ★ ^{37}Ar excess observed at 2.7 keV, consistent with projected rate.
- ★ Data is shown as black dots. Expected range of stat fluctuations for best fit in blue.

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



- ★ S1 threshold: 3 phd +3-fold coincidence (green vertical line)
- ★ S2 threshold: 600 phd (>10 e^- extracted, green horizontal line)
- ★ Blue band is combined ER background sources
- ★ Dashed gray curves indicate 1- and 2-sigma contours of a 40 GeV WIMP
- ★ Red line is the NR median
- ★ Green band is ^{8}B CEvNS

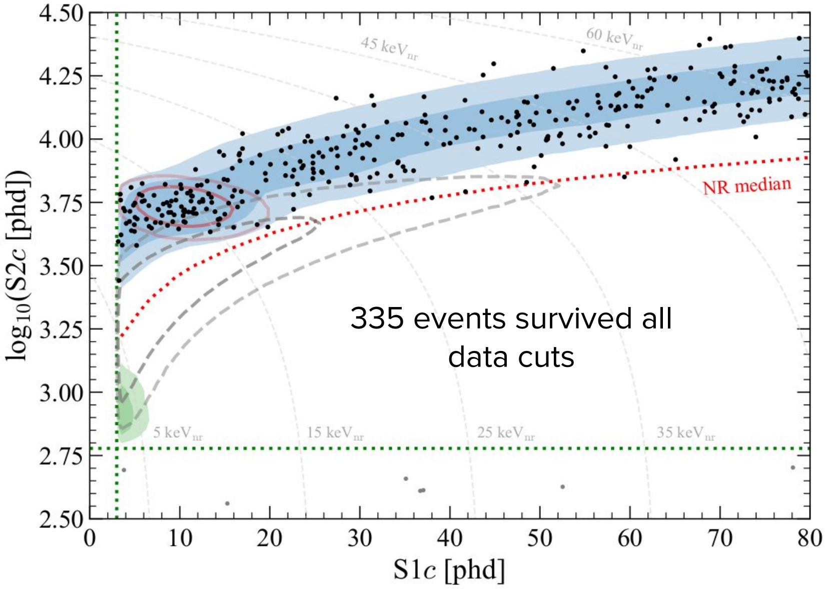
- ➔ 335 events observed
- ➔ 60.3 ± 1.2 live-days
- ➔ 5.5 ± 0.2 tonnes FV



LZ SR1 WIMP-search Results

Using the statistical and astrophysical conventions recommended in Eur Phys J C (2021) 81:907.

- ★ Frequentist, 2-sided profile likelihood ratio (PLR) test statistic
- ★ Signal rate must be non-negative
- ★ Local density of DM: 0.3 GeV/cm^2
- ★ v_0 = 238 km/s; v_{esc} = 544 km/s
- ★ 90% Confidence bands
- ★ Power constrain at π_{crit} = 0.32



No evidence for WIMPs at any mass

Minimum exclusion on WIMP-nucleon cross section:

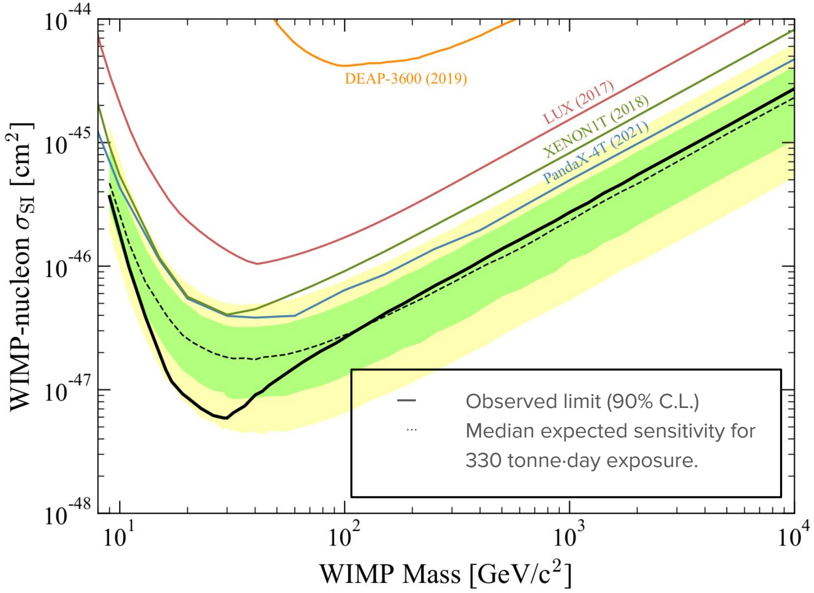
$\sigma_{Wn,SI} < 5.9\times10^{-48}$ cm^2 at 30 GeV

★ ×6.7 improvement at 30 GeV

★ ×1.7 improvement at 1 TeV

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

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



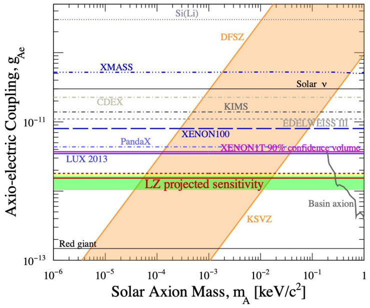
What’s Next?

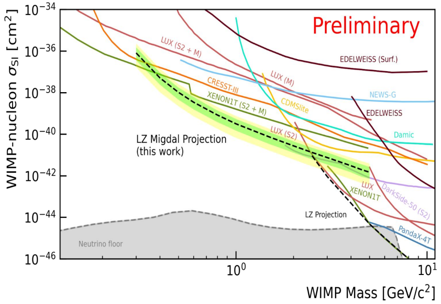
LZ plans to take 1000 live days of data (x17 more exposure)

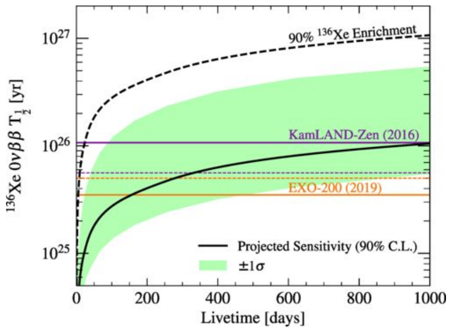
- Will continue to push the limits on WIMP dark matter searches in the upcoming years

Lots of science to do in addition to primary DM search:

- Neutrinoless double beta decay in ^{136}Xe (PRC.102.014602) and ^{134}Xe (PRC.104.065501)
- Rare decays of other xenon isotopes
- Effective field theory couplings for dark matter
- Solar axions, ALPs, neutrino magnetic moment (PRD.104.092009)
- Low mass dark matter searches (S2-only, Migdal effect)
- Leptophilic dark matter
- Mirror dark matter







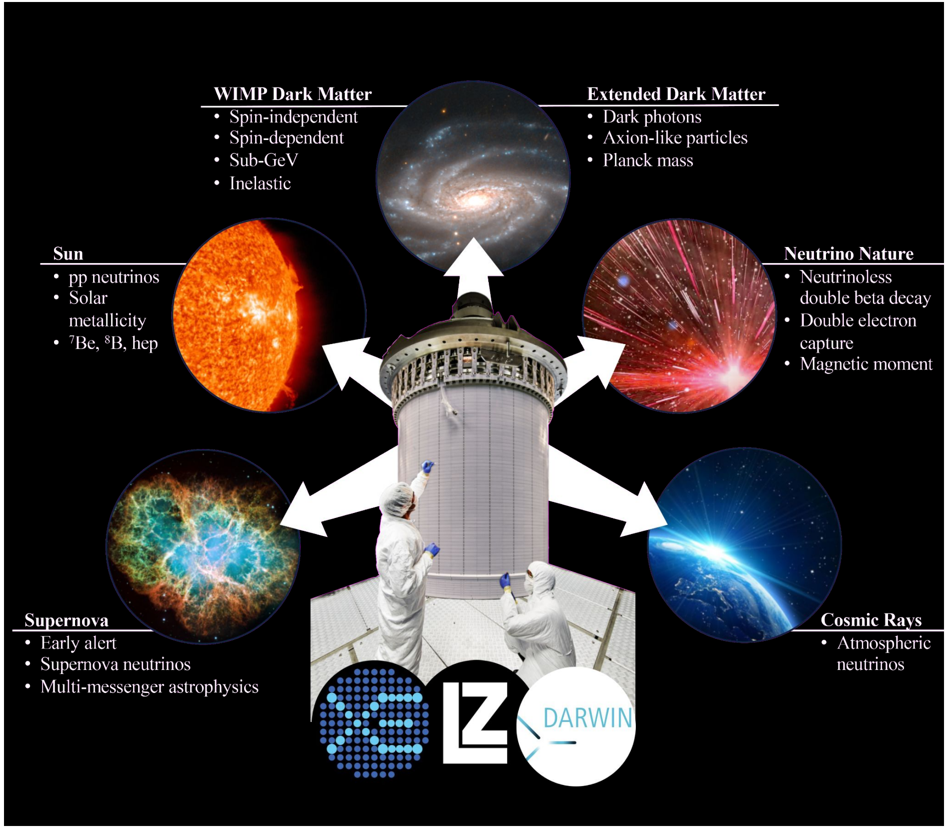
After LZ: XLZD 3rd generation detector

XENON, LZ and DARWIN collaborations took the first steps for a joint 3rd generation experimental effort to probe WIMP DM down to the neutrino fog with a hundred-tonnes scale xenon detector.

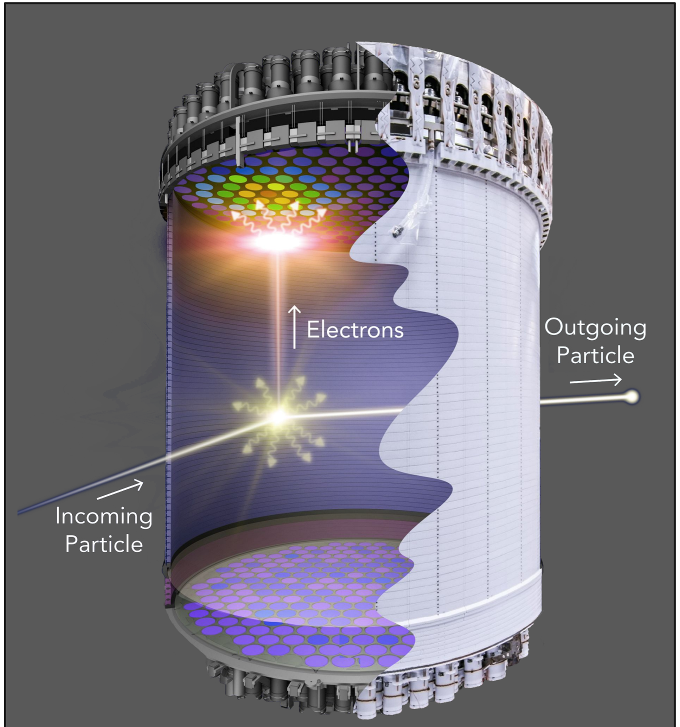
Successful joint XLZD meeting June 27-29 at KIT. https://xlzd.org/

White paper (2203.02309)

Broad science reach:



Thank you!



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Find more graphics here or directly contact Nicolas (UCL)

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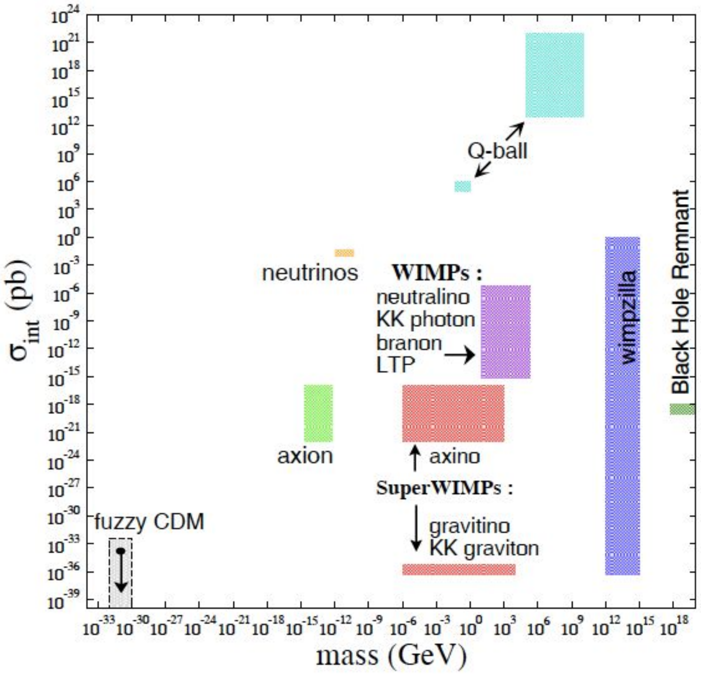
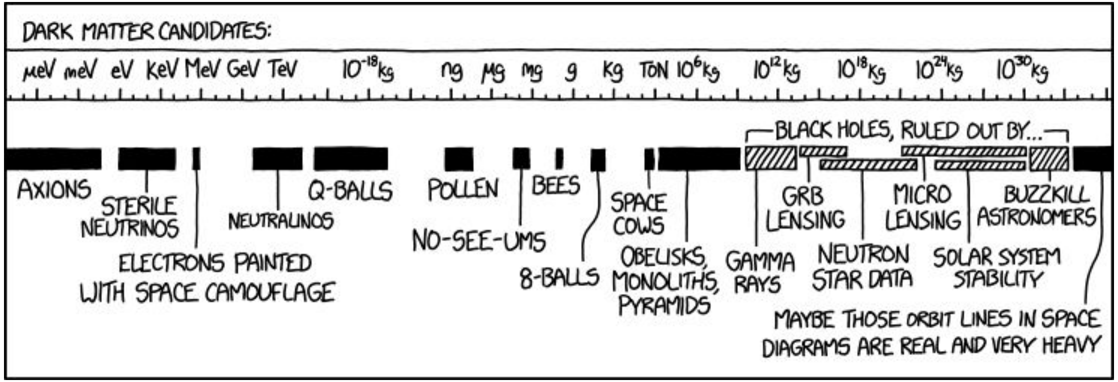
BACKUPS

Abstract

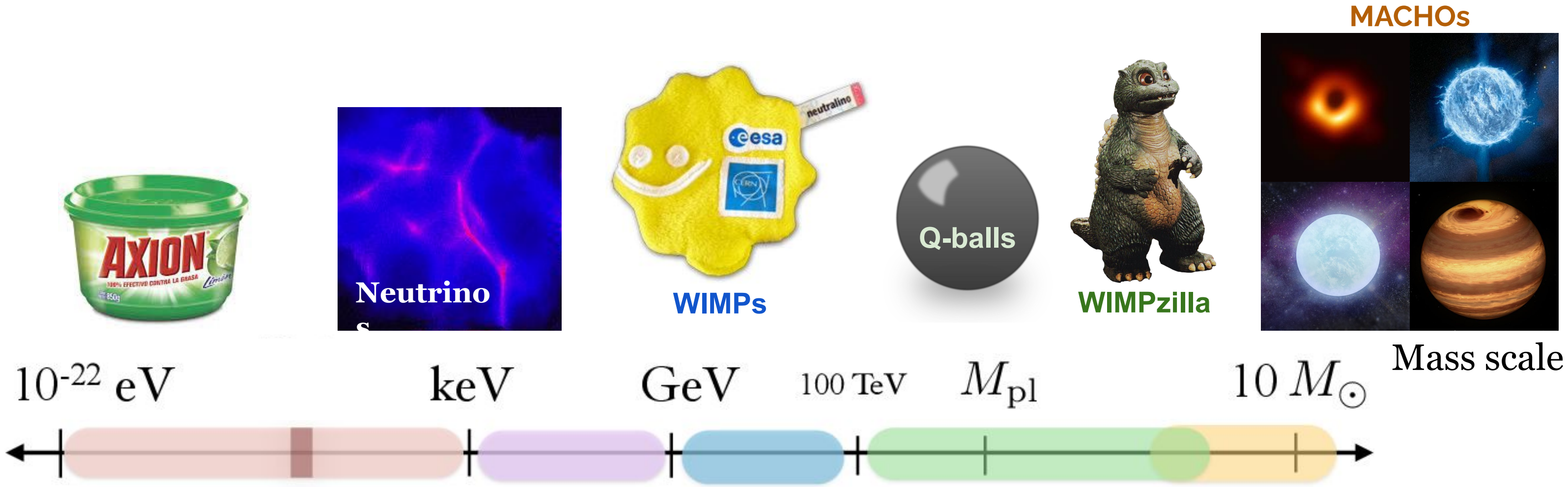
The LUX-ZEPLIN (LZ) experiment is a dark matter detector operating at the Sanford Underground Research Facility in Lead, South Dakota, USA. Its main detector is a 7 tonne dual-phase xenon time projection chamber, built with ultra-low background materials. On July 7th 2022, LZ presented its first science results on the search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs), with an exposure of 60 live-days and a target mass of 5.5 tonnes. With this first science run, LZ has achieved a world-leading limit on spin-independent WIMP-nucleon cross-section for WIMP masses above 9 GeV, reaching a limit of 6.5×10^−48 cm2 for this cross-section and for a 30 GeV WIMP mass at the 90% confidence level. LZ also achieved the best recorded energy resolution at the MeV scale for this type of detector, reaching 0.64% sigma/E at 2.6 MeV. This energy resolution plays a critical role in the searches for the never-observed neutrinoless double beta decay in Xe-136, one of the secondary goals of LZ. With only 60 live-days of data, LZ is already the most sensitive WIMP dark matter detector in the world, and it’s just starting. With the goal of reaching a final exposure of 1000 live-days, LZ will continue to push the limits on WIMP dark matter searches in the upcoming years.

Dark Matter Candidates





Dark Matter Candidates



Helper slides:

https://docs.google.com/presentation/d/1OqSol2nRfcRObyCvOvEMuWmWtgyA1j5dhEZCebge7k8/edit#slide=id.g179a418573a_0_1225

https://docs.google.com/presentation/d/1lb2Rva6Y-MC34YIKva7kxNiKfcOGG2UiVoMDbXqD2Vc/edit#slide=id.g1191b9e4734_0_2504

https://drive.google.com/drive/folders/1DEIgD2wp6oqe83lYOxpYSonoAZK6nnlO

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.

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)