Neutron Activation Background in the LUX-ZEPLIN Experiment

LRT 2024
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University of Sheffield
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Neutron Activation

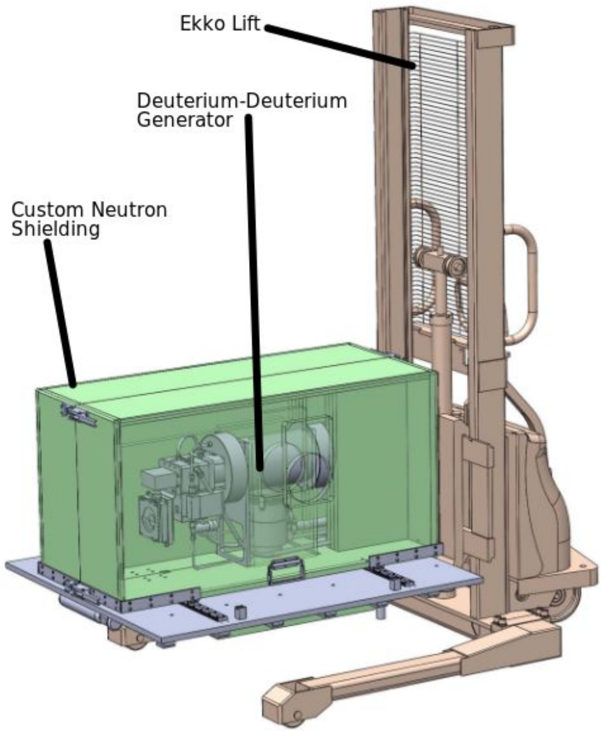
- Neutron interacts with a nucleus, the product can be radioactive
- This can happen through:
    - Neutron Capture
    - Inelastic Scattering
    - (n, 2n) reactions
- This can occur during calibrations, or when xenon is exposed to cosmogenic neutrons on the surface
- We use a range of neutron calibration sources in LZ [1]
- A range of radioactive isotopes can be produced
    - ^{127}**Xe**
    - ^{129m}**Xe**
    - ^{131m}**Xe**
    - ^{133}Xe

[1] The design, implementation, and performance of the LZ calibration systems, J. Aalbers *et al*. JINST 19 (2024) 08, P08027

Neutron sources

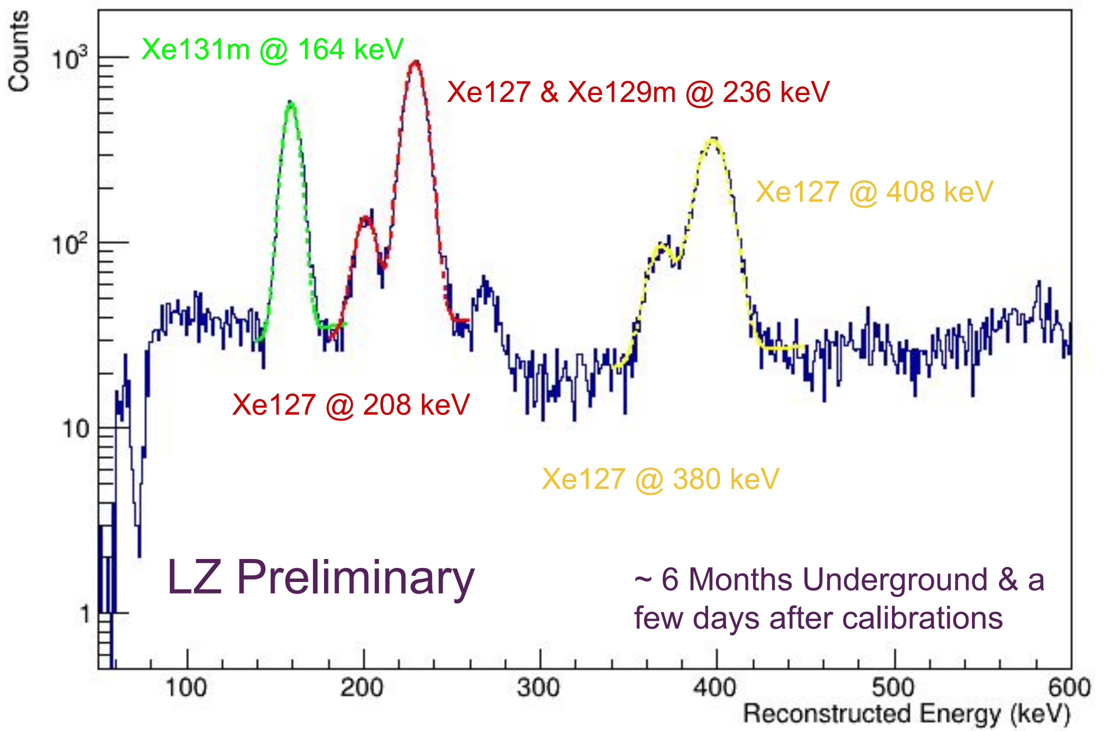
- Three neutron calibration sources used in LZ
- Americium Lithium (AmLi)
  - Broad spectrum source, end point of 1.5 MeV
- Americium Berylium (AmBe)
  - Broad spectrum source, end point of 11 MeV
  - Much higher energy and neutron fluence than AmLi
- Deuterium-Deuterium (DD)
  - Monoenergetic neutrons emitted at 2.45 MeV
- Cosmogenic neutrons prior to being moved underground
  - Due to their short half-lives, most cosmogenic ^{131m}Xe and ^{129m}Xe will have decayed away before data is taken, but ^{127}Xe will remain

LZ DD Generator



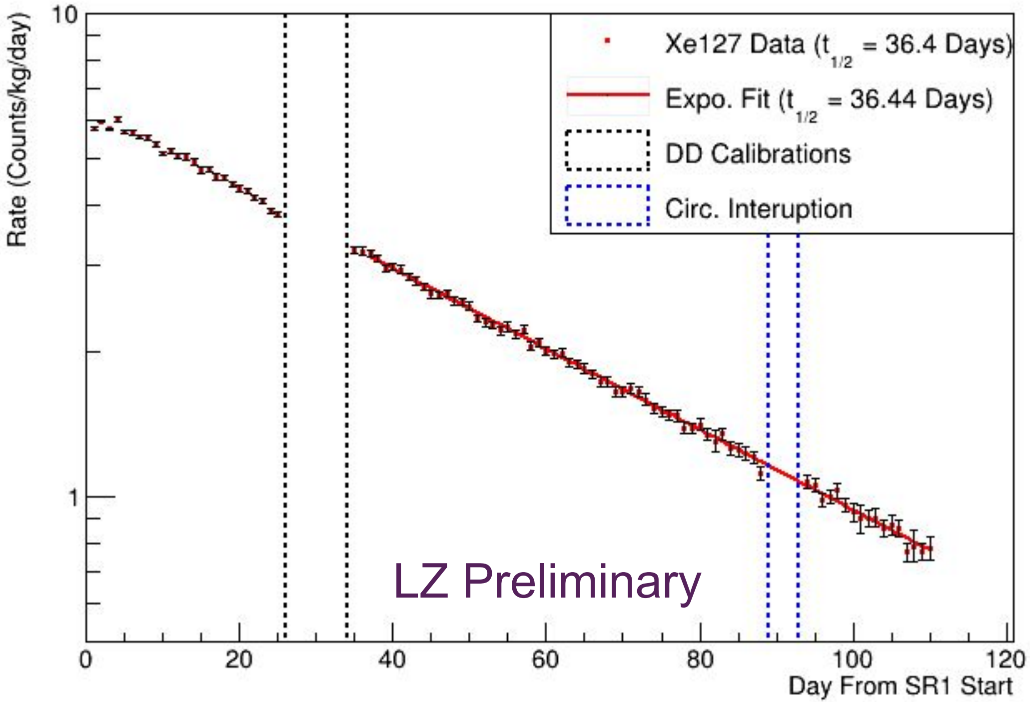
Xe Activation Lines

- Energy spectrum for a single day at the start of WS2022
- The peaks are from the 3 xenon isotopes of interest
  - ^{131m}Xe at 164 keV
  - ^{129m}Xe at 236 keV
  - ^{127}Xe at 203 + (5 or 33) keV and 375 + (5 or 33) keV
- ^{127}Xe a concern for WIMP search due to low energy recoils
  - Gamma escapes leaving X-Ray in FV
- ^{131m}Xe fitted w/ single gaussian, others have a double gaussian; all also include a linear background



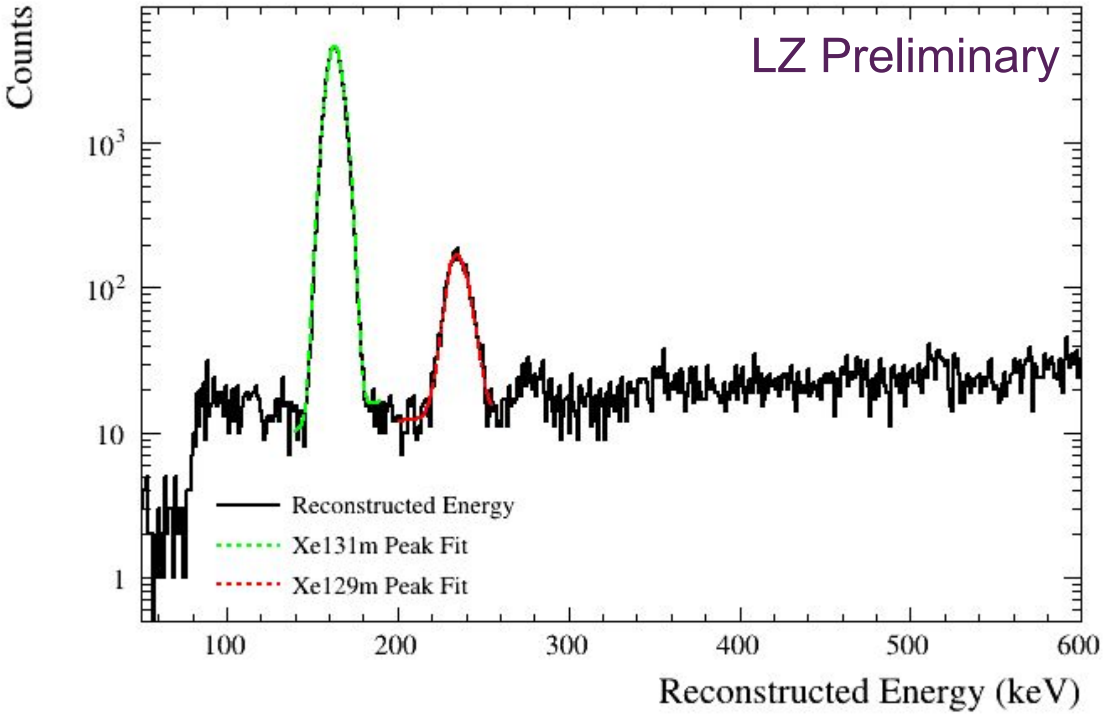
^{127}Xe

- Integral over the peaks from the 375 + (5 or 33) keV decays and scale that by the 47.3% branching ratio to estimate total ^{127}Xe Rate
- This is done for every day in WS2022 to see how decay rate changes, with day 0 being the first day of the WIMP search
- Gap is due to DD calibrations
- Rate increase is not seen as activity is dominated by cosmogenic activation
- Exponential fit (red line)
    - Fitted half-life = 36.44 ± 0.26 days



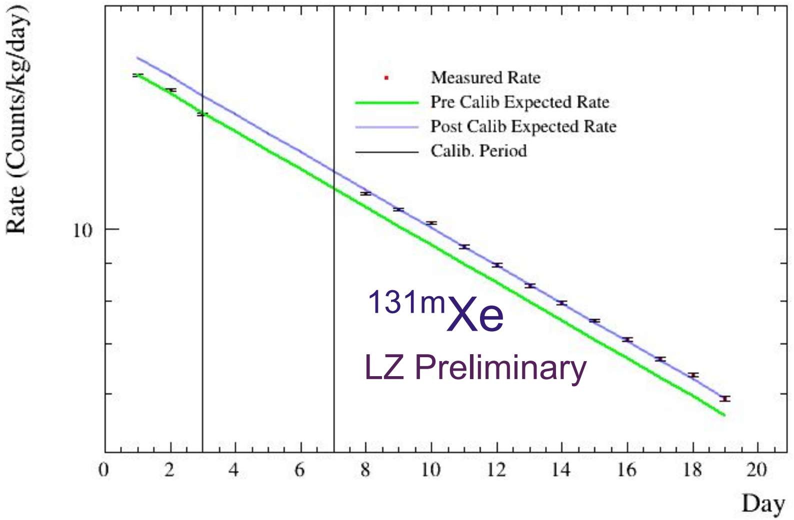
AmLi

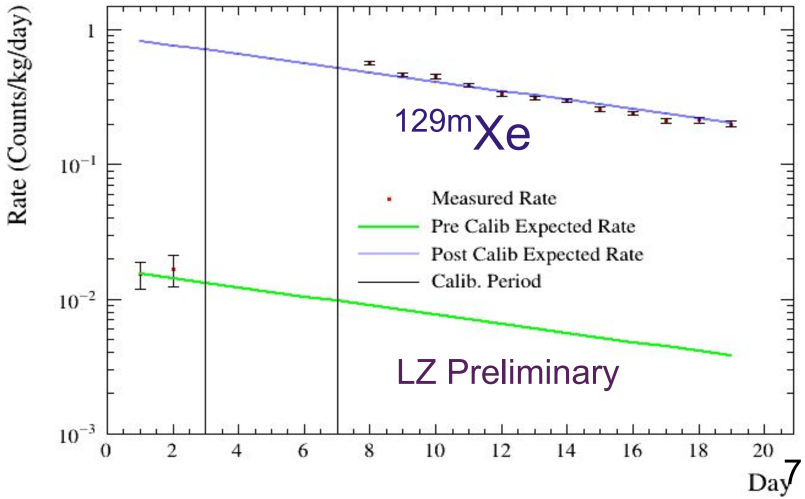
- Looked at data before and after calibrations
- After calibrations shown
- Shortly after ^{131m}Xe injection
- Peaks from ^{131m}Xe and ^{129m}Xe visible
- Single gaussian fitted to both
- Done for spectra before and after calibrations to calculate the change in the decay rate



AmLi

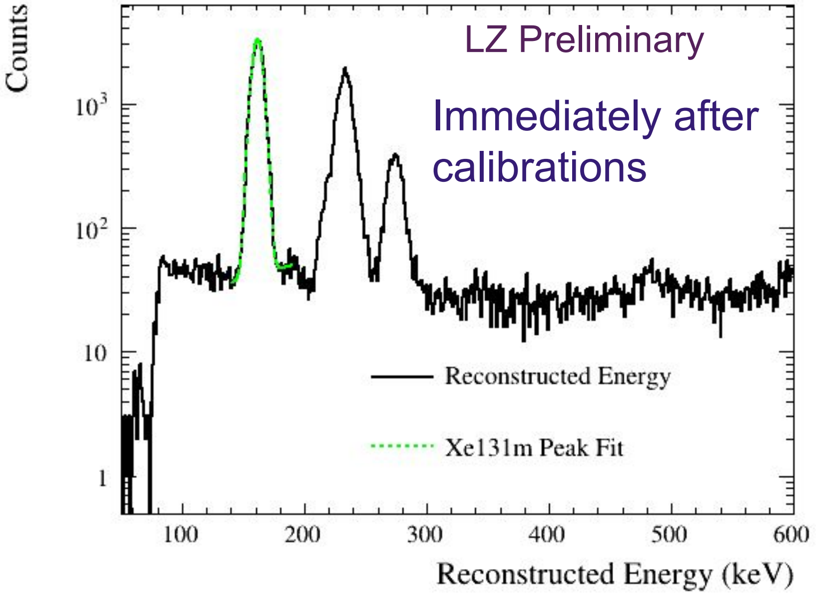
- Calibrations occur after day 3
- Clear increase in rate
- Green line is expected rate from half life and rate on first day
- Blue line is decay rate extrapolated from the rate after the calibrations
- ^{131m}Xe rate elevated due to injections
- Very low rate of ^{129m}Xe means harder to measure rate before calibrations

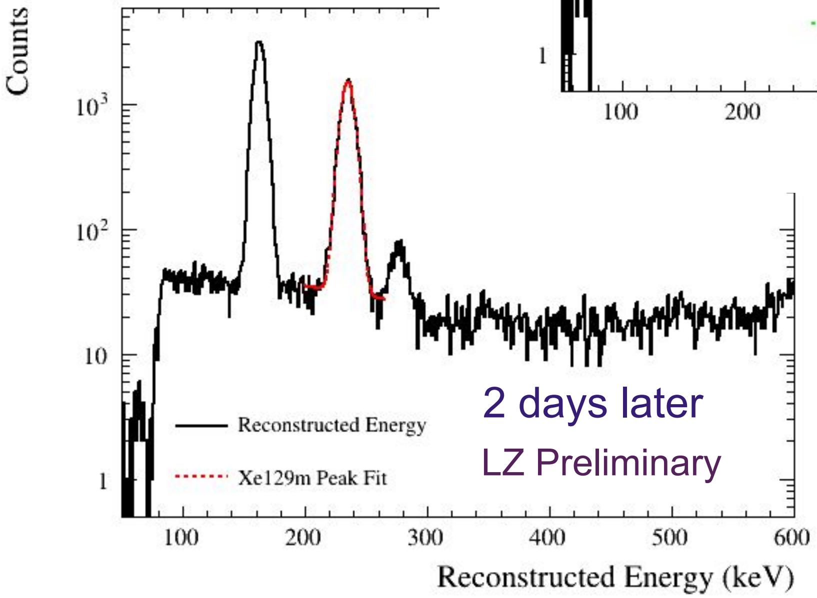




AmBe

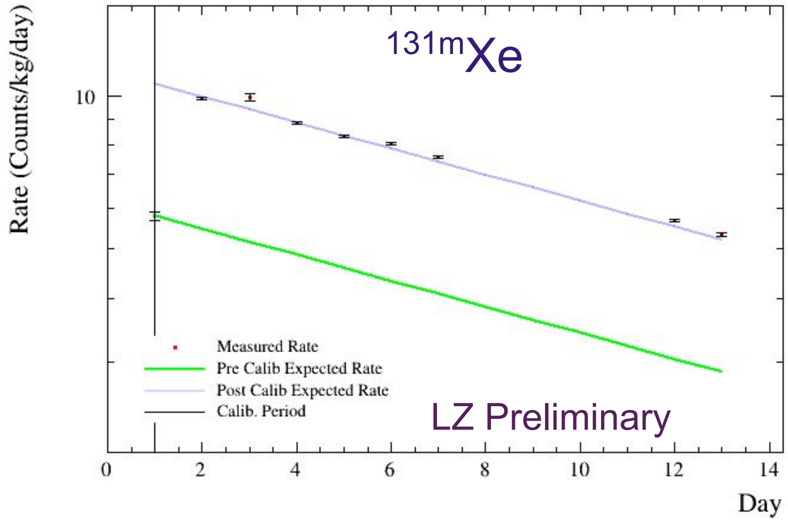
- Same procedure
- ^{129m}Xe peak has shoulder at low energy -> ^{133m}Xe
- Therefore, a later day is used to for the rate
- This rate is then extrapolated backwards

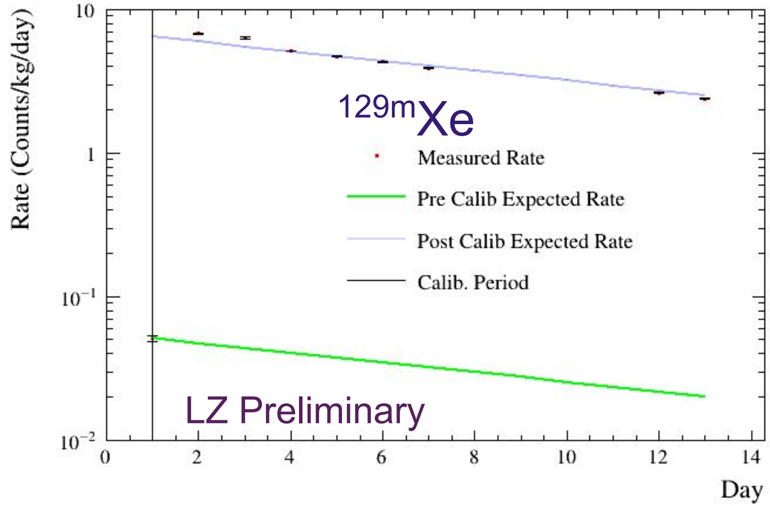




AmBe

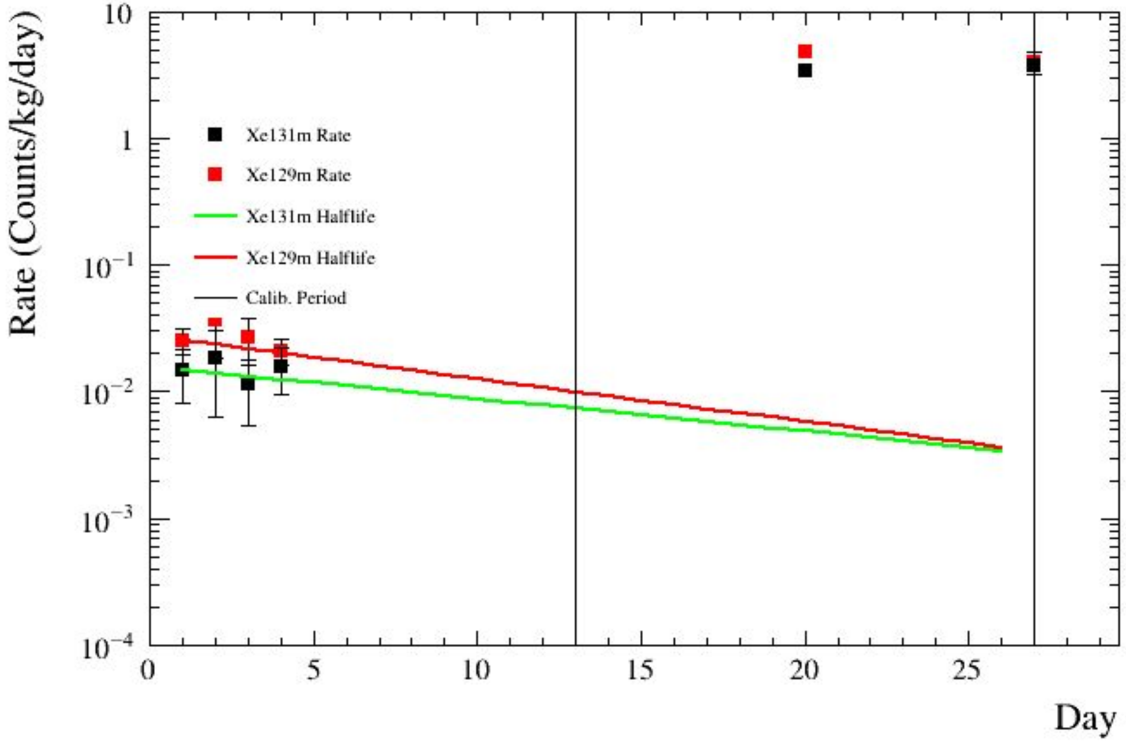
- Very clear increase in rate
- Green line again shows expected activity
- Gap in plot is due to processing issues, data has since been reprocessed
- First 2 points after calibrations come inflated due to the additional shoulder on the peak





DD

- The same process again
- Rate increases by a significantly from the rate before calibrations
  - Over two orders of magnitude
- Data after calibrations limited by other calibrations
- Suitable data during this time is very limited



^{131m}Xe Production Rates

- Considering the amount the decay rate increased and the length of time the calibration took, a production rate can be calculated
- 3 AmLi sources, equidistant around TPC, equal time at top, bottom and midde of TPC
- AmBe positioned the same but only with 1 source

Neutron Source	AmLi	AmBe	DD
Emission Rate	39 neutrons/s (Total)	345 neutrons/s	14 neutrons/s (Reaching TPC)
^{131m}Xe Rate Increase (kg^{-1} day^{-1})	0.5 ± 0.05	4.41 ± 0.13	3.30 ± 0.07
^{131m}Xe Production Rate (kg^{-1} day^{-1})	2.66 ± 0.216	70.08 ± 2.39	5.13 ± 0.31 LZ Preliminary

^{129m}Xe Production Rates

- Considering the amount the decay rate increased and the length of time the calibration took, a production rate can be calculated

Neutron Source	AmLi	AmBe	DD
^{129m}Xe Rate Increase (kg^{-1} day^{-1})	0.55 ± 0.05	5.90 ± 0.04	4.49 ± 0.05
^{129m}Xe Production Rate (kg^{-1} day^{-1})	2.06 ± 0.06	70.56 ± 1.80	6.19 ± 0.13

LZ Preliminary

Comparisons of ^{127}Xe From Cosmogenic Neutrons

- Using the well known ACTIVIA code, the production of ^{127}Xe from cosmogenic neutrons on the surface can be calculated
- This was done using both semi empirical formulae and MENDL data tables
- This was then compared to the measured decay rate at the start of SR1

Measured Decay Rate (kg^{-1} day^{-1})	Semi-Empirical Formulae (kg^{-1} day^{-1})	MENDL-2 (kg^{-1} day^{-1})	MENDL-2p (kg^{-1} day^{-1})
5.78 ± 0.04	2.91 ± 0.13	5.50 ± 0.25	5.85 ± 0.26

LZ Preliminary

^{131m}Xe & ^{129m}Xe Comparisons

- ACTIVIA cannot be used to calculate the rate from neutron calibration sources
- Also GEANT4 cannot be used to simulate the activation of metastable states as the physics lists do not differentiate between the metastable state and short lived states.
- Instead production cross sections from ENDF were used in the following equation to calculate production rates

$$R = \int_0^{E_{max}} \frac{d\phi}{dE} \frac{\sigma(E) L N_A f}{A} dE$$

R = Production Rate (s-1)
σ = Cross section
NA = Avogadro's Number
L = Mean Track Length X xenon density
F = Abundance Fraction
A = Target Isotope Atomic number
ϕn = Neutron Flux (s-1)

Activation by neutron sources: data vs simulations

- ^{131m}Xe: Activation production rate can be calculated accurately except AmBe source
- ^{129m}Xe: Large discrepancy between calculated rate and data, possibly through ENDF missing some possible production cross sections
- Errors are reported errors on source emission and statistical errors from simulations
- Other systematic errors are likely presented but not accounted for

		AmLi	AmBe	DD
^{131m}Xe Production Rate	Measured (kg^{-1} day^{-1})	2.66 ± 0.216	70.08 ± 2.39	5.13 ± 0.31
	Estimated (kg^{-1} day^{-1})	2.76 ± 0.31	45.6 ± 2.7	4.65 ± 0.8
^{129m}Xe Production Rate	Measured (kg^{-1} day^{-1})	2.06 ± 0.06	70.56 ± 1.80	6.19 ± 0.13
	Estimated (kg^{-1} day^{-1})	0.72 ± 0.08	24.48 ± 1.44	3.74 ± 0.64

LZ Preliminary

Conclusions

- The amount of xenon activated by each of the neutron calibration sources used in LZ can be measured
- When done so it is found that the AmBe used generated by far the most ^{131m}Xe and ^{129m}Xe
- The production of ^{127}Xe from cosmogenic neutrons is well modelled by ACTIVIA
- Estimating the production of ^{131m}Xe from AmLi and DD can be done well however there are issues with the predicting the production of ^{129m}Xe

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions

@lzdarkmatter

https://lz.lbl.gov/

250 scientists, engineers, and technical staff

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King’s 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
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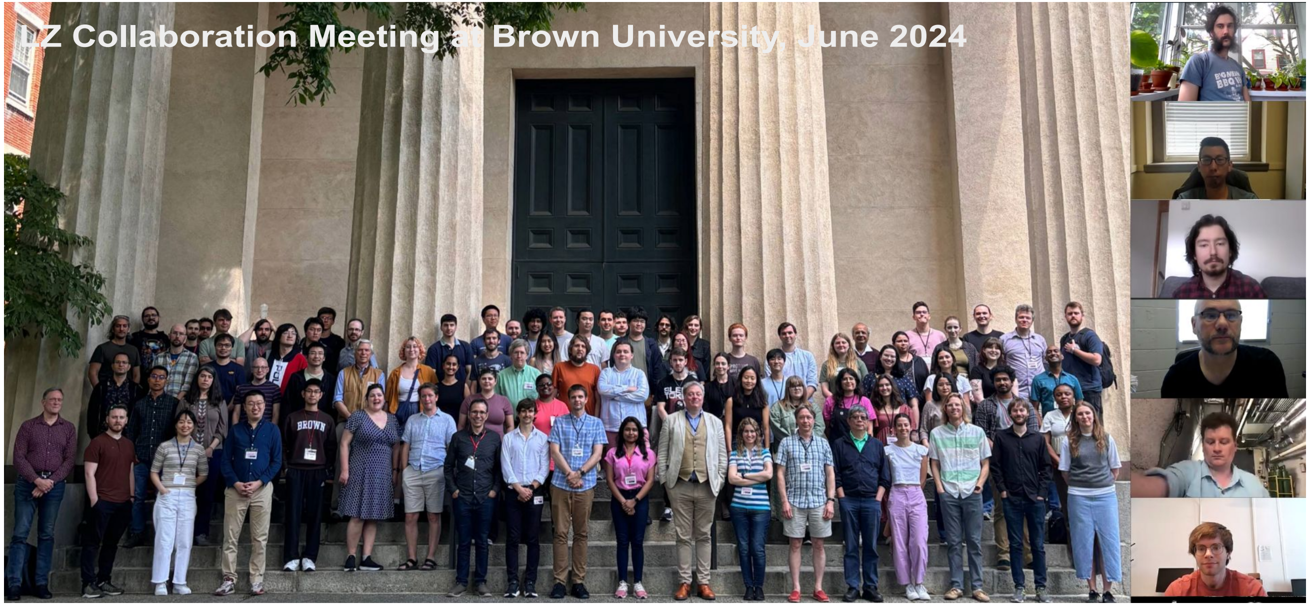

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