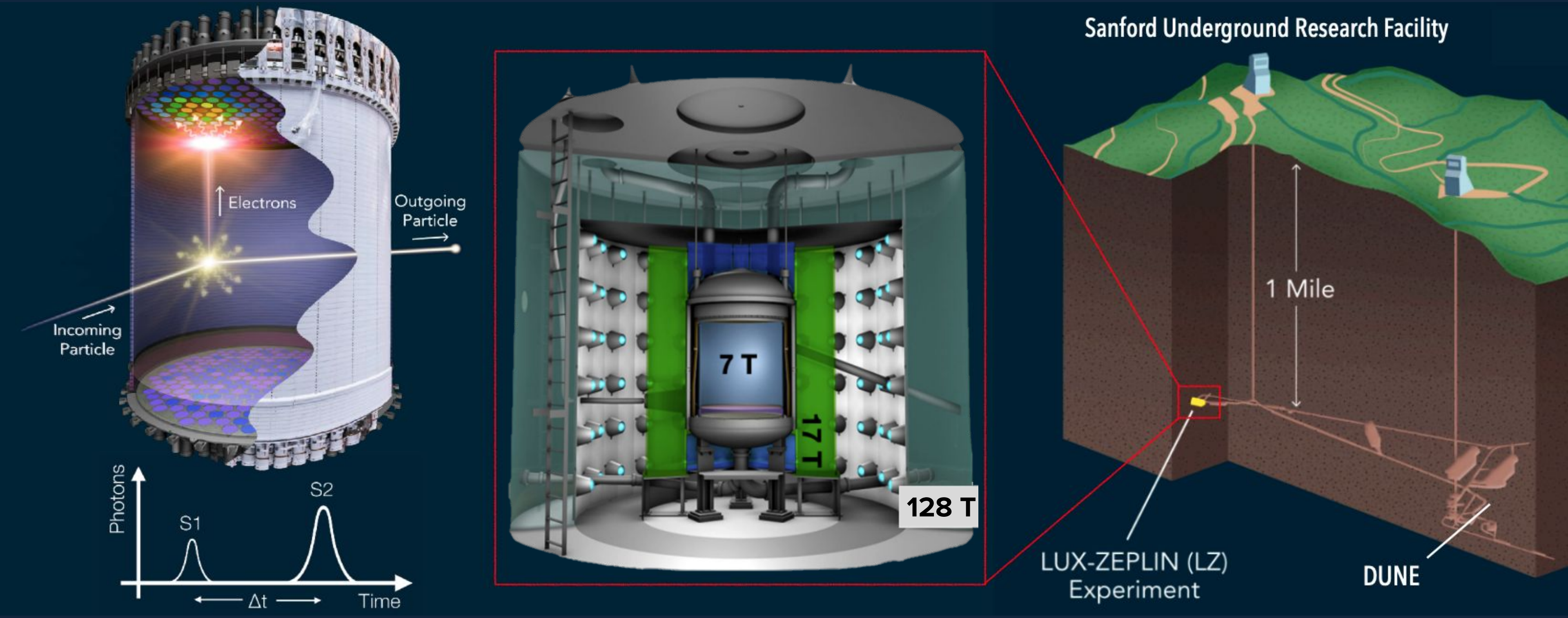
UNIVERSITY OF LIVERPOOL

LZ Outer Detector: Calibrations & Data Monitoring

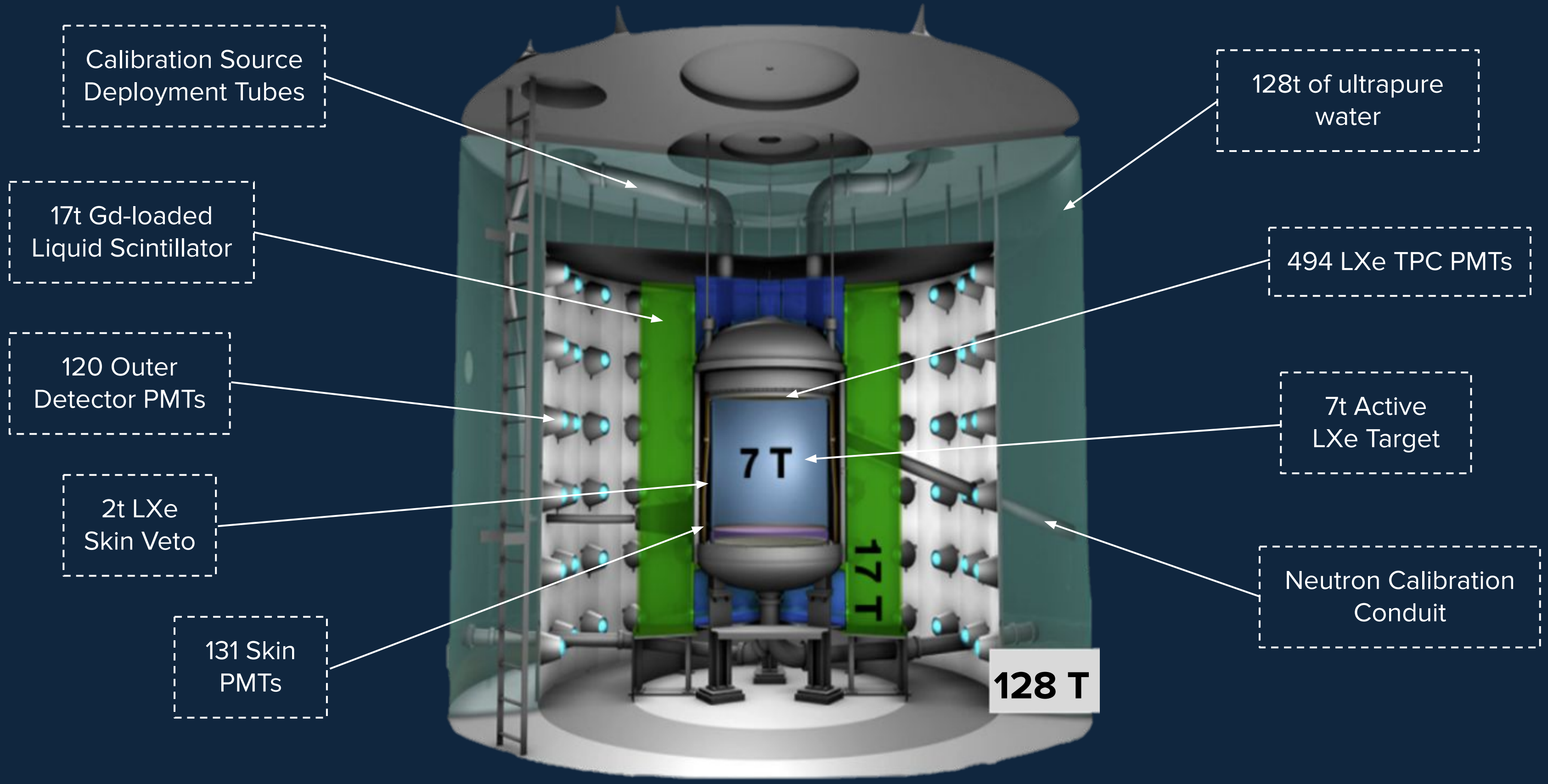
HEP Annual Meeting 2023

Sam Woodford

Introduction to LZ

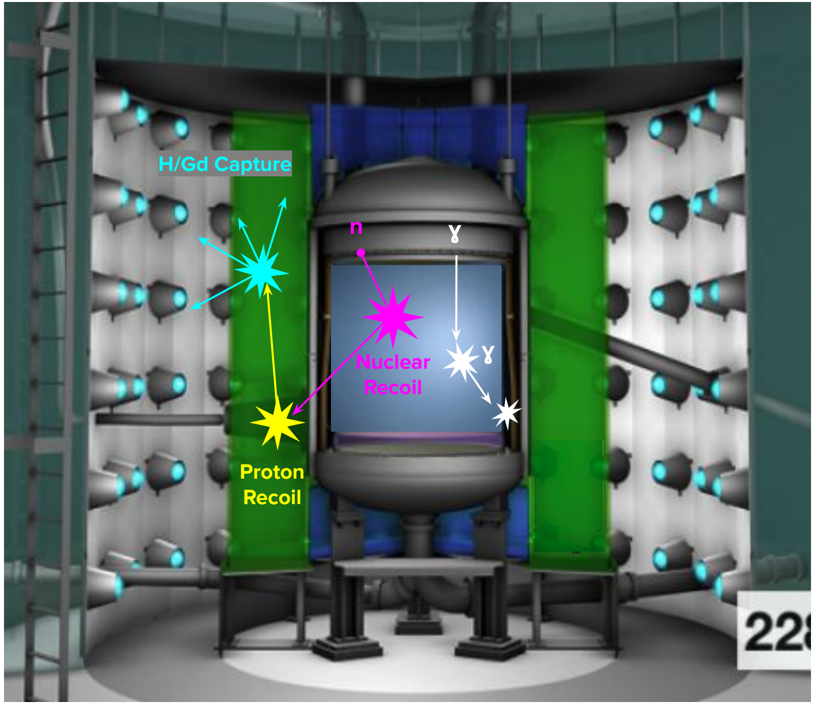


LZ: Detector Overview

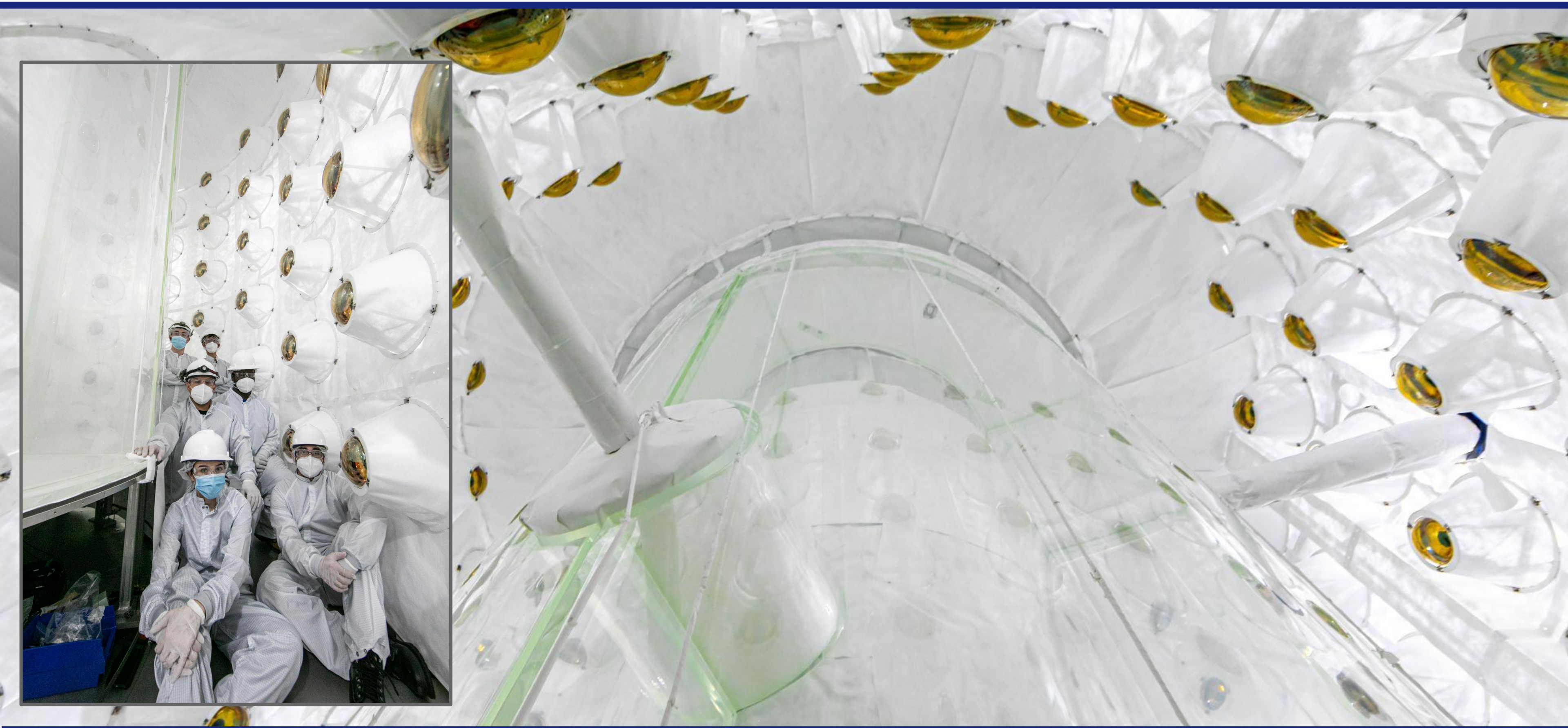


Motivation for Outer Detector

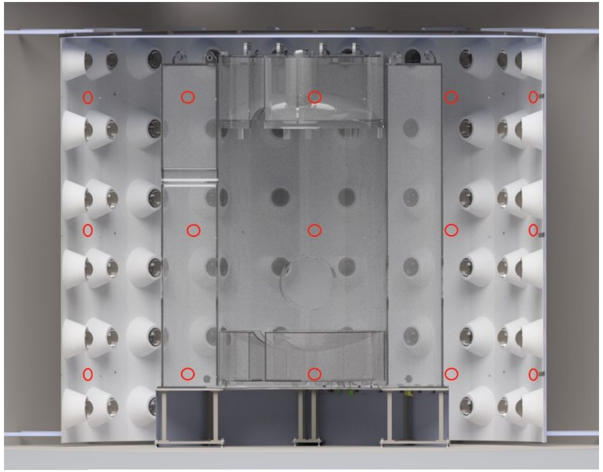
- A dark matter particle that scatters with LXe will only deposit energy in the TPC, not in surrounding materials.
- Surrounding materials produce backgrounds that can mimic WIMP-like signals:
  - Nuclear recoils via neutron scattering
  - Electron recoils via ɣ-ray scattering
- To account for the backgrounds, a veto system (skin + OD veto) was designed to surround the TPC:
  - Verify any dark matter signal was not induced by a background
  - Increase the fiducial volume in the TPC



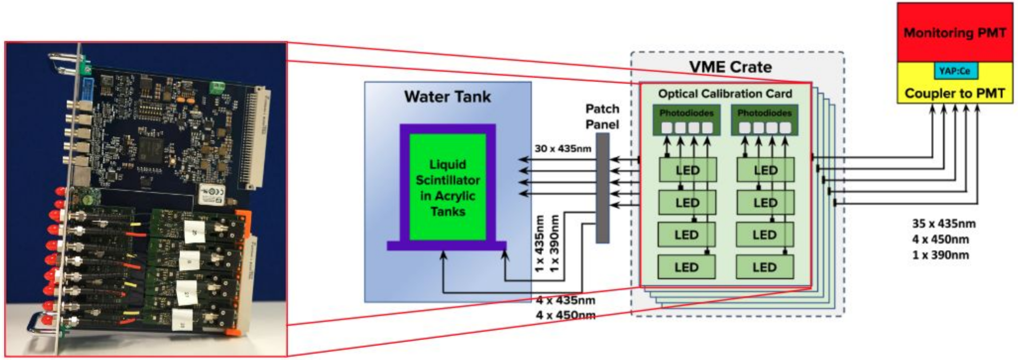
Outer Detector



OD PMT Calibration: OCS



- Calibration and monitoring of the 120 8” R5912 OD PMTs achieved via Liverpool’s LED-driven Optical Calibration System (OCS)
- 30 optical fibre injection points situated within the OD PMT array
- LEDs of wavelength 435nm used to match the peak wavelength and quantum efficiency of the OD PMTs, along with scintillation light from GdLS.
- A ‘Monitoring PMT’ is also used to observe the long-term stability of the OCS.



OD PMT Calibration: SPE Response

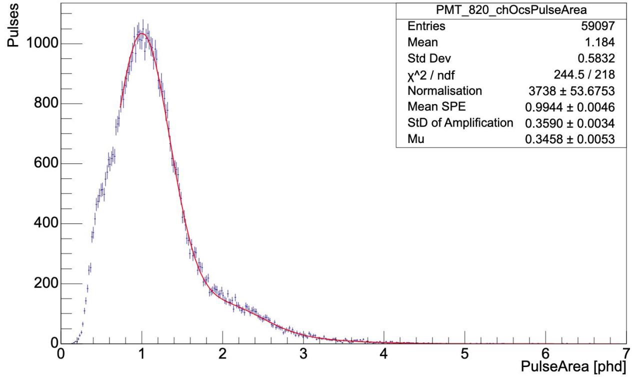
- At each PMT's operational gain, the mean pulse area resulting from a single photoelectron (SPE) emitted from the photocathode will differ in each OD PMT.
- Measurement of the mean SPE value for a PMT provides a calibration constant to convert pulse area from mVns to photons detected (phd). Analysis can therefore be carried out in phd, ensuring that each PMT's contribution to a pulse in the OD is evaluated equally.

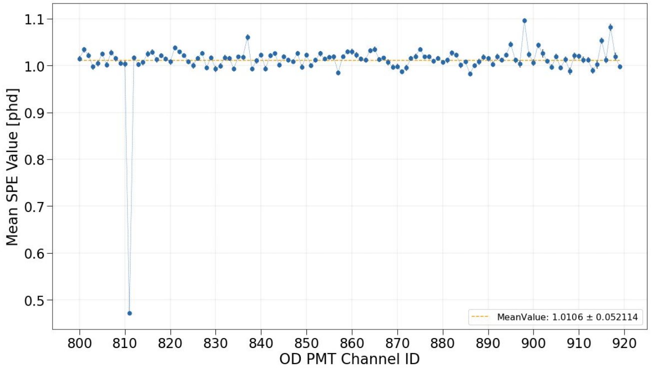
Incident photons on photocathode produce photoelectrons via photoelectric effect (Poisson distributed). *P(n;μ)* is the probability of n photoelectrons being observed with a mean *μ*.

If the coefficient of multiple photoelectron emission (MPE) by the first dynode is large and the coefficient of MPE collection by the first few dynodes is 1, multiple-dynode system response to a single photoelectron may be approximated by a Gaussian distribution

$$S_{ideal}(x) = P(n;\mu) \otimes G_n(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \frac{1}{\sigma_1\sqrt{2n\pi}} \exp\left(-\frac{(x-nQ_1)^2}{2n\sigma_1^2}\right).$$

- μ - mean number of photoelectrons collected at first dynode.
- Q_1 - Average charge at PMT output for 1 photoelectron.





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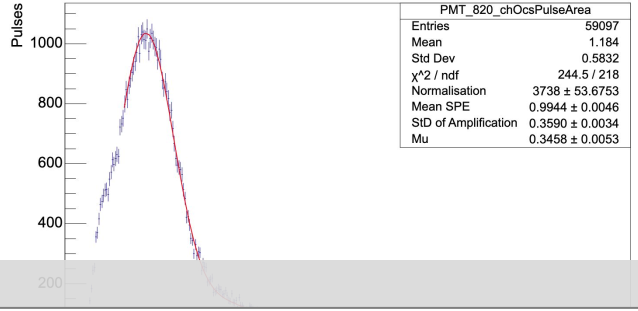
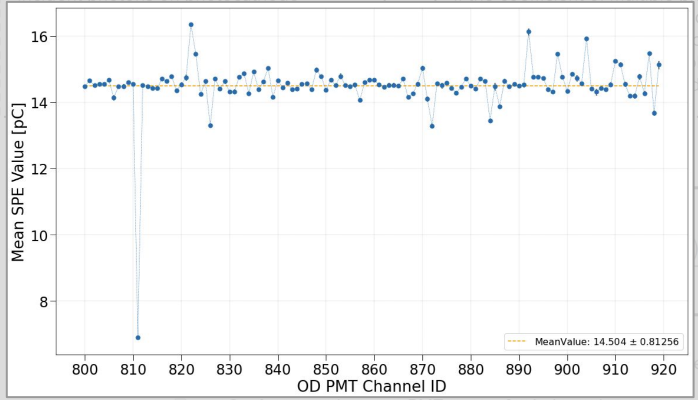
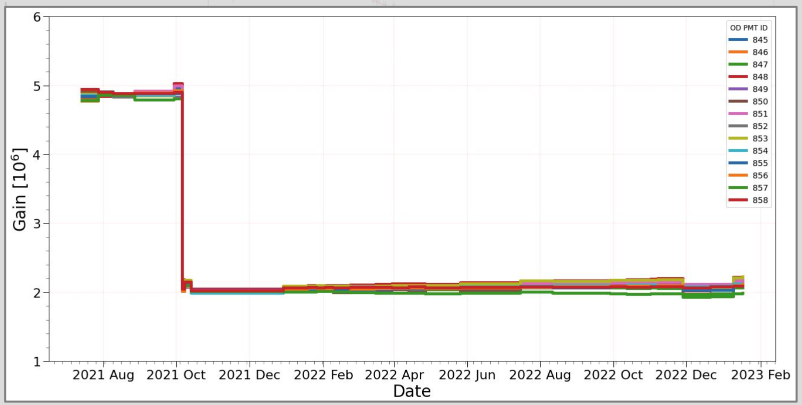
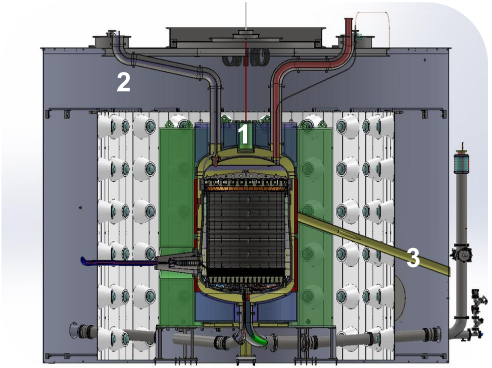




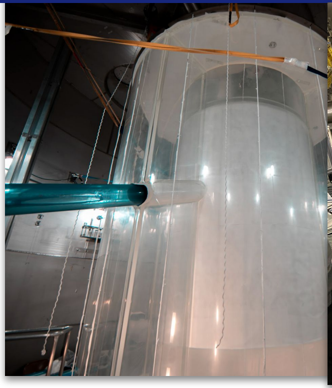


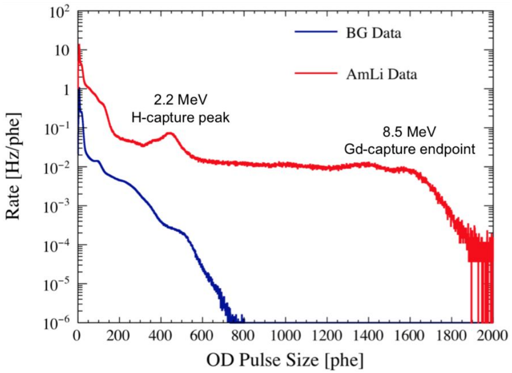
OD Calibration: Source Deployment

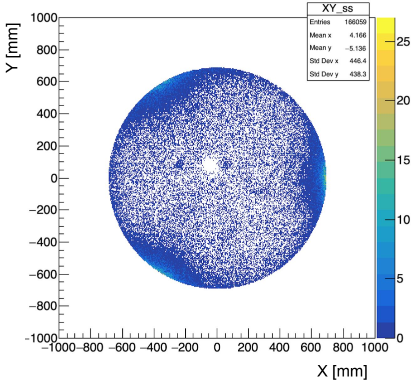
Three types of controlled radioactive source deployment used in LZ:

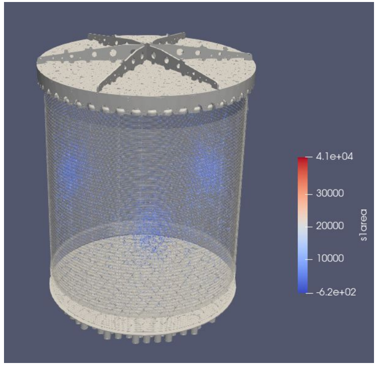


1. Photoneutron sources: YBe. Lowered into the detector above the tungsten shield.
2. Three external CSD tubes - neutrons and gammas (AmLi, Cf-252 and Th-228). Lowered to various fixed Z positions.
3. 2 neutron conduits: DD neutrons and D_2O reflector. One horizontal, one angled, used for localised NR calibrations using DD generator.







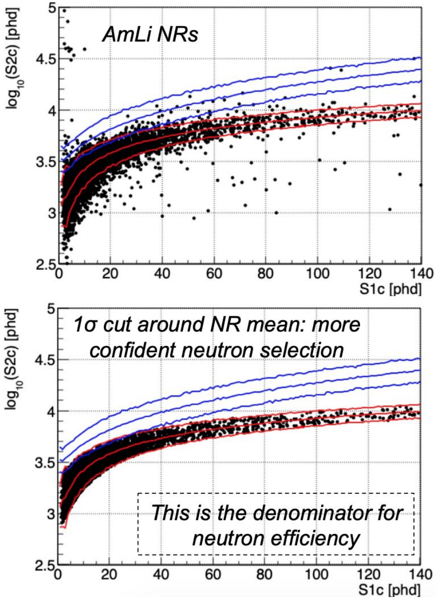


OD Gamma & Neutron Tagging

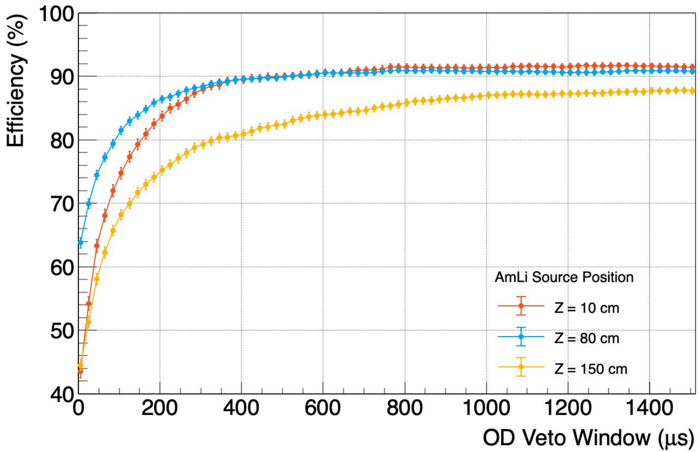
Coincident TPC and OD events removed to reduce backgrounds producing γ-rays and neutrons.

γ-rays: Remove events with a prompt signal in the OD within **±0.3 μs** of the TPC S1 pulse, based on proton recoils in DD calibrations.

Neutrons: Neutrons can thermalise in detector materials and those that capture on H or Gd in the OD can be tagged by an OD pulse (> **5 coincidence**) of greater than **~200 keV** within **1200 μs** after the TPC S1. An area threshold of 200 keV (37.5 phe) has a **background rate** of **43 Hz**, with an attributed **5% deadtime**.



After factoring for accidental coincidences of AmLi gammas and neutrons with single scatter nuclear recoils in the TPC, we have a tagging efficiency of **(89 ± 3) %**.

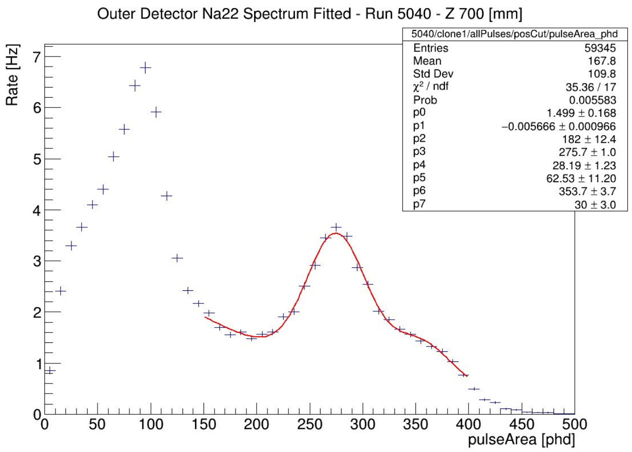


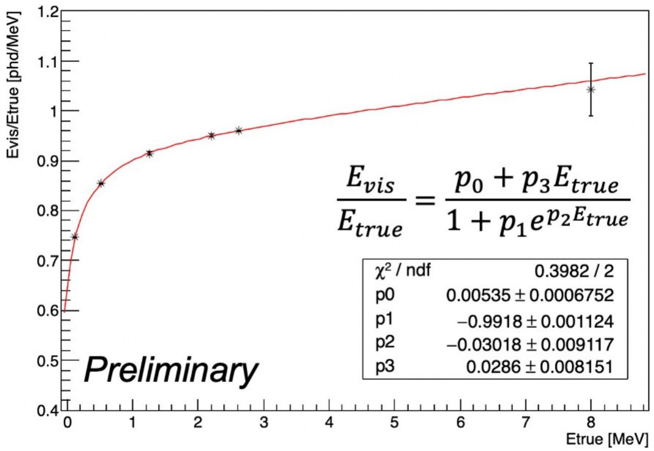
Points are corrected for accidental coincidences & pileup using observed rate in random triggered windows.

OD Energy Calibration

OD Energy calibration is fundamental to LZ being able to demonstrate an understanding of the Outer Detector.

- ❏ Allows us to understand the nonlinearity of the optical response at low energies, and the different light collection efficiencies at different Z, θ and r positions.
- ❏ The optical response to energy deposited in the OD facilitates assessment of the pulse area spectra to determine which physical interactions made substantial contributions. Energy calibration also enables the communication of the OD veto threshold selected, expressed in keV.

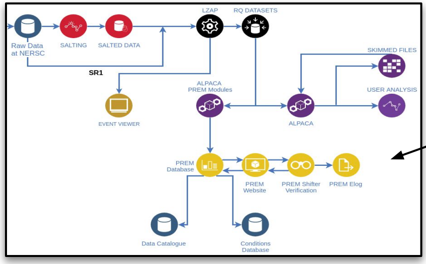




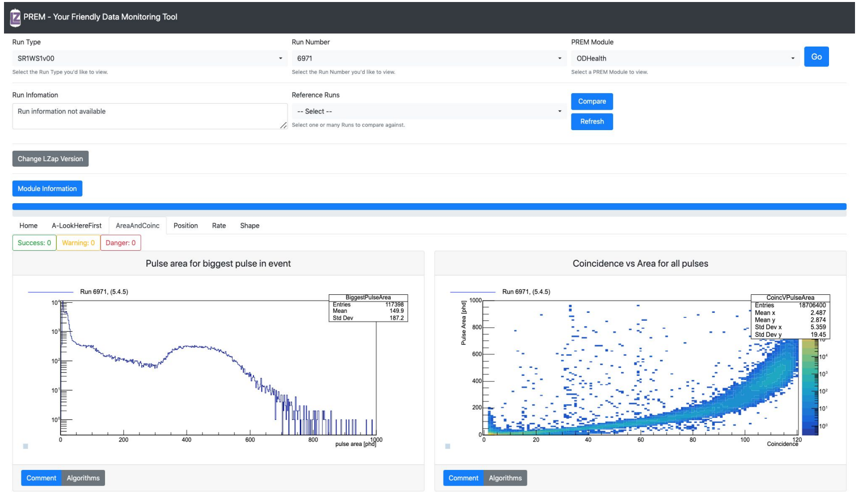
Tracking OD Performance: PREM

Physics REadiness Monitor

- The official offline Data Quality Monitor
- Creates JSON objects containing the analysis outputs and pushes these to a website
- Website allows quick and easy viewing of data modules for monitoring and comparisons over different data runs



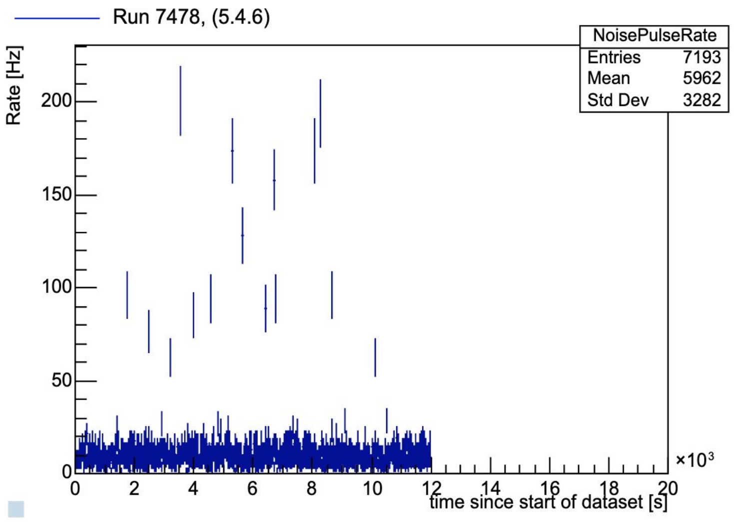
PREM in LZ Dataflow



Allows us to look at SPE response and other OD behaviour over a long period of data-taking

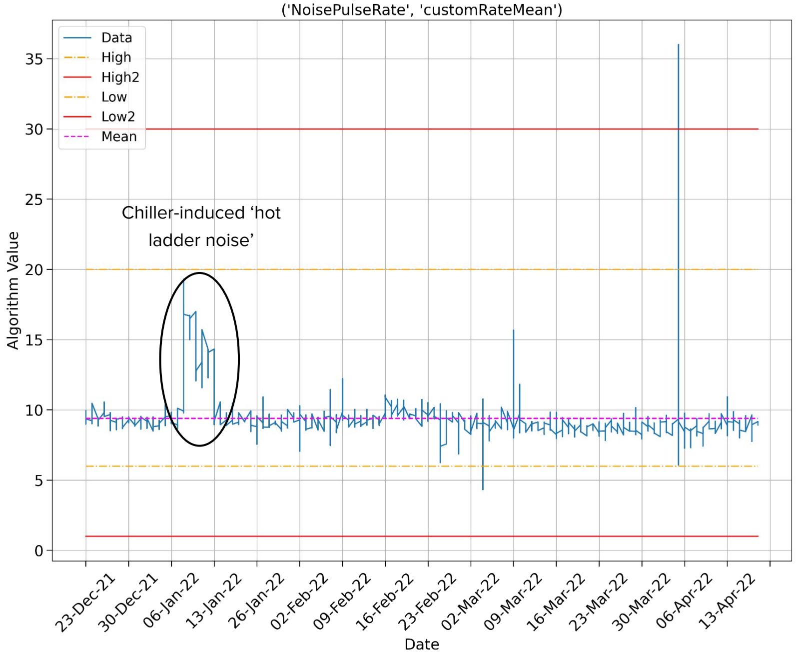
Plots & Algorithms: ODHealth

Rate of noise-like pulses



Comment Algorithms customRateMean

Rate of noise pulses (PF100ns < 0.35) in the OD (no requirements on event trigger type). Livetime calculated as the sum of all open event windows regardless of trigger type.

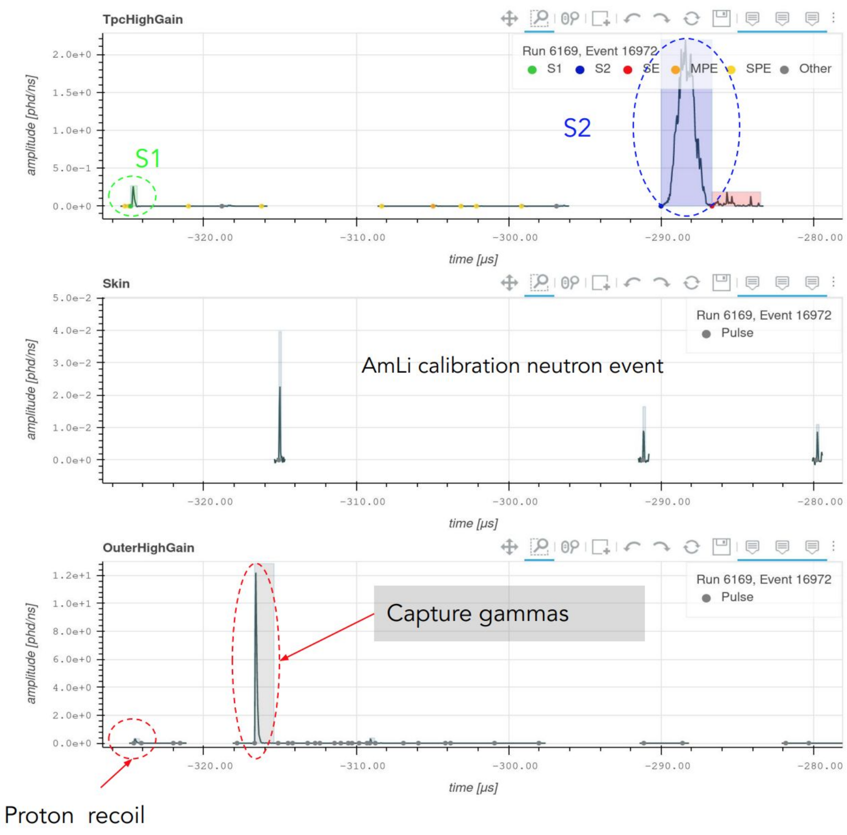


Thank You!


RETURN AIR
LZ
Sanford
Underground Research Facility
RETURN AIR

Backup Slides

Event in the OD



Here we have an AmLi calibration neutron event.

- AmLi is used for measuring the Nuclear Recoil band in the TPC.
- We see a proton recoil in the OD with a pulse area of 41 phd.
- The neutron is captured on the Gadolinium.
- Subsequent pulse is a result of gamma emission due to the capture.

OD Contribution to WIMP Search

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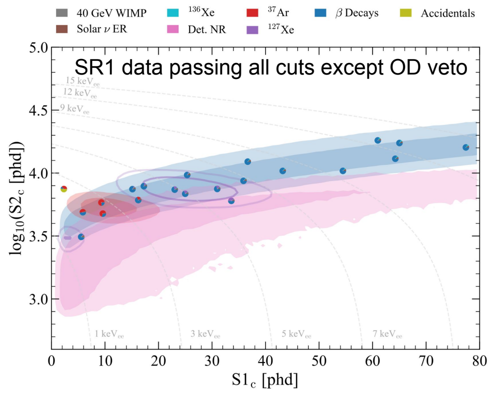
Neutron Background

Due to the neutron tagging efficiency, there is an expectation of ~8 times more neutrons with an OD tag than those events without. In contrast, a false rejection probability of **5%** for the OD veto was chosen in the SR1 data quality cuts, so 5% of non-neutron backgrounds have an accidental OD-tag.

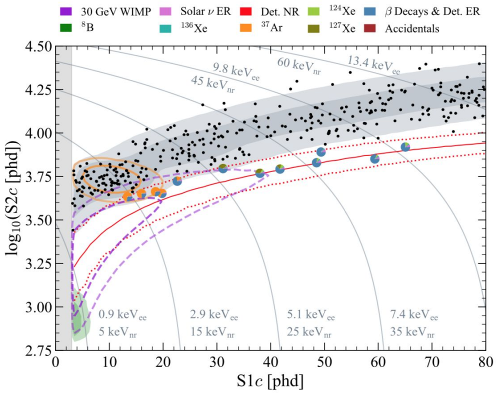
The best-fit result for the number of neutrons in this sample was: 0.0+0.8. The resulting shape of the log-likelihood profiled in the amount of neutron background was also used for the shape of the constraint on the neutron population in the WS fit.



Impact on WIMP Search

With (89 ± 3)% OD veto efficiency, the predicted neutron background in the WIMP fit region was found to be: 0.0+0.2 events [3].

SR1 data is consistent with simulation estimate of 0.06 events in 60 live-days. It is expected in SR2, with an increase in detector live-time, that we will begin to see a low number of neutron events.



RHS: Result of the log-likelihood fit for the 335 SR1 events that passed all physics and data quality cuts in corrected log(S2)-S1 space. The fit shows that it is unlikely a non-tagged neutron or WIMP was observed, with those events in the NR band, represented as pie charts, likely to have been contributed by ER leakage from 37Ar, β-decays and other ER, or Xe activation backgrounds.