UNIVERSITY OF LIVERPOOL

LZ & XLZD

Liverpool Group

Ewan Fraser

May 2025

LZ + XLZD Liverpool Group

MPhys Students:
- Brandon Crowley
  - CNN for veto position reconstruction ft. Tea
  - PhD @ Liverpool

PhD Students:
- Bethan Twigg
  - Incoming, starting next academic year
- Tea Hall
- Megan Carter
- Sam Woodford
  - Now a post-doc @ Edinburgh
  - XLZD!

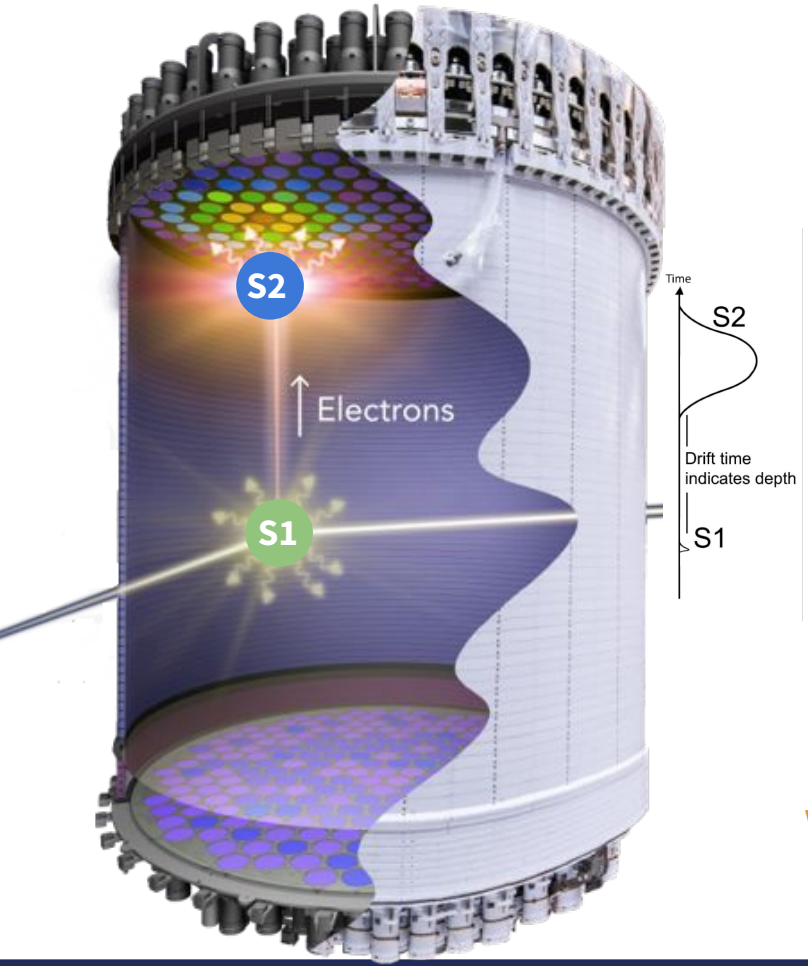
Research Associates:
- Sean Hughes - XLZD
- Ewan Fraser - LZ

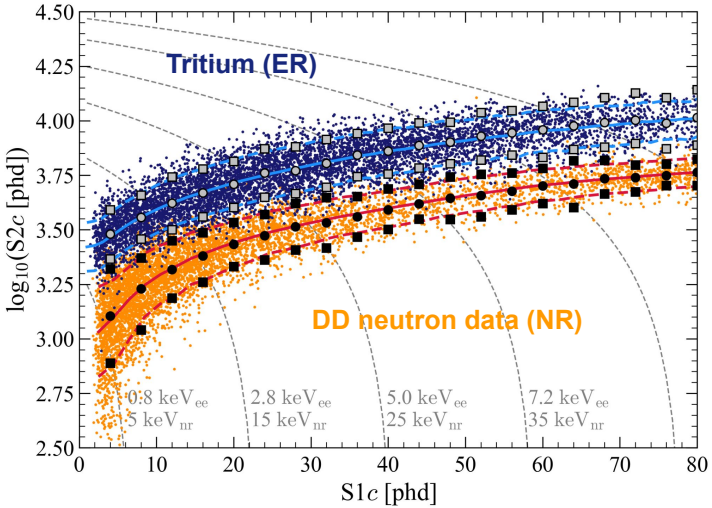
Prof. Sergey Burdin

Sam Woodford's Viva

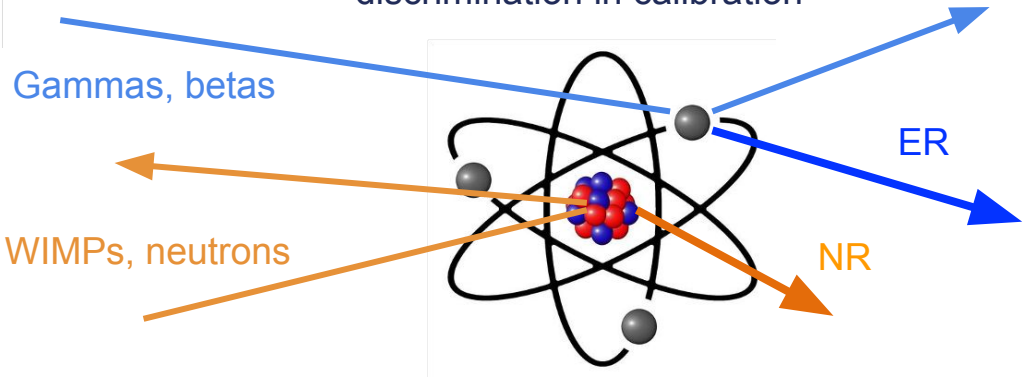
Thesis: LZ's WS2024, Vetoes and Data Quality

Dark Matter Search with LXe TPC

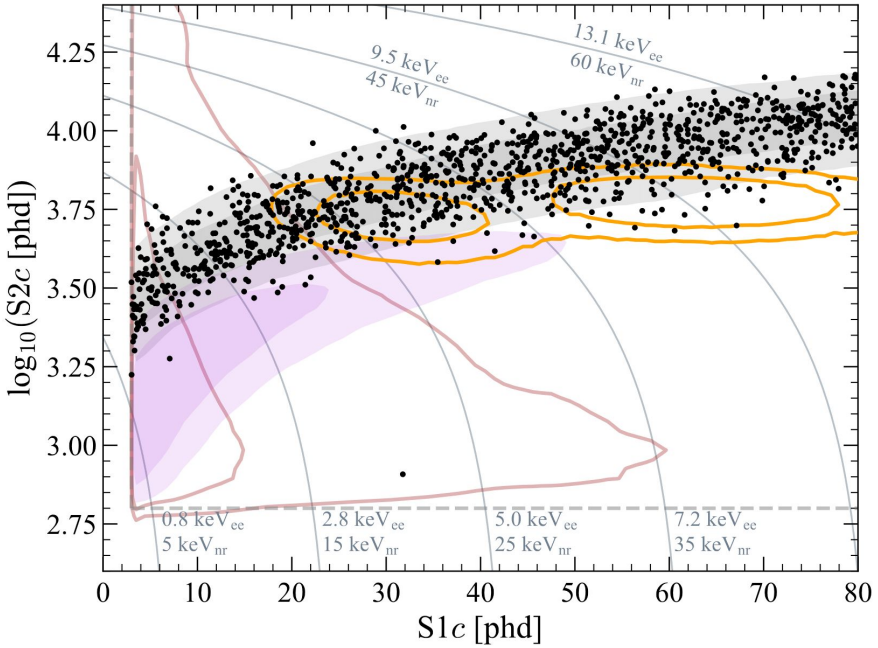


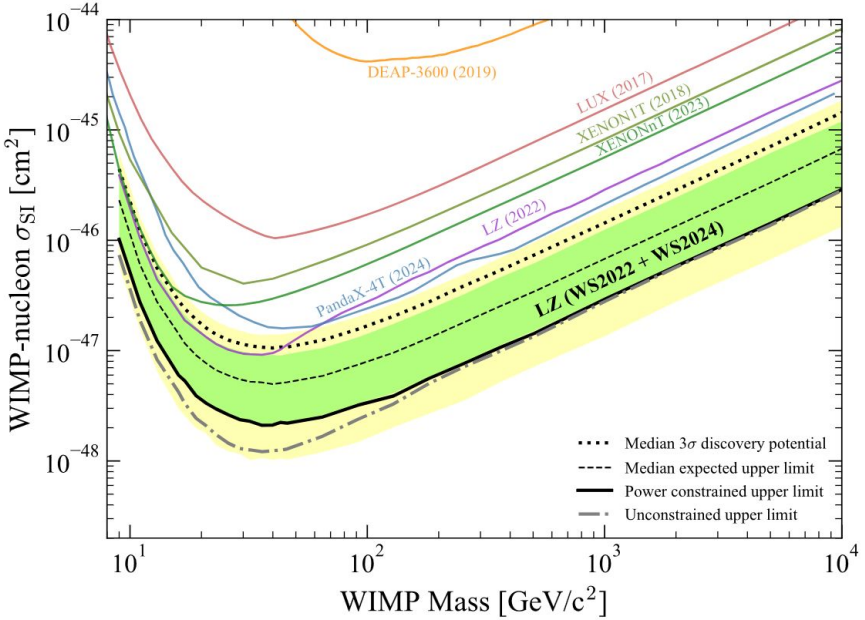


2024 Electronic Recoil (ER) and Nuclear Recoil (NR) discrimination in calibration



WIMP Search 2024 Results

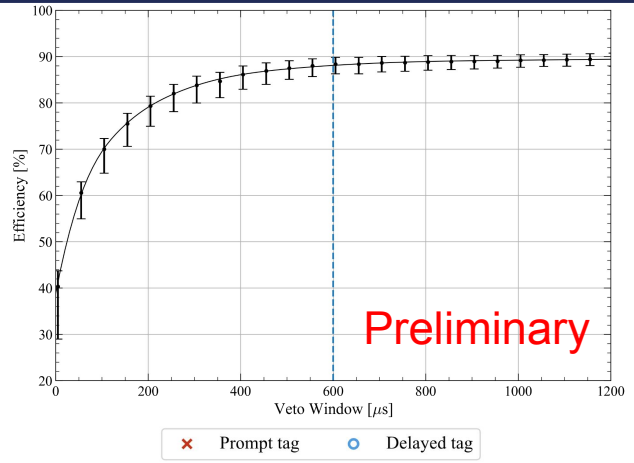


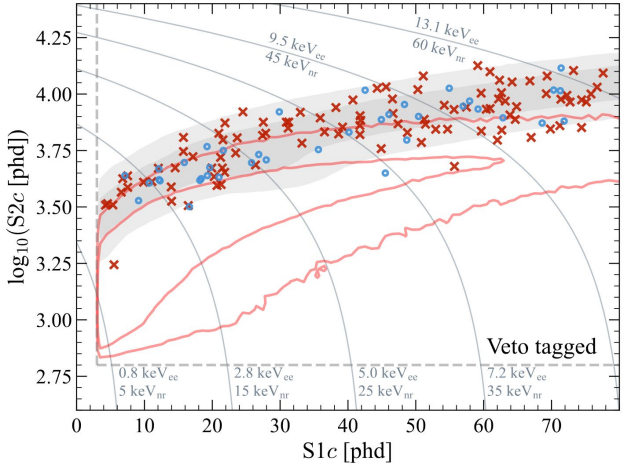


- Final exposure: 4.2 tonne years LXe from 280 live days
- Results are consistent with a background only hypothesis
- Best limit from combined analysis of $\sigma_{SI}=2.1\times10^{-48}$cm^2 for 36GeV/c^2

Neutrons & Vetoes

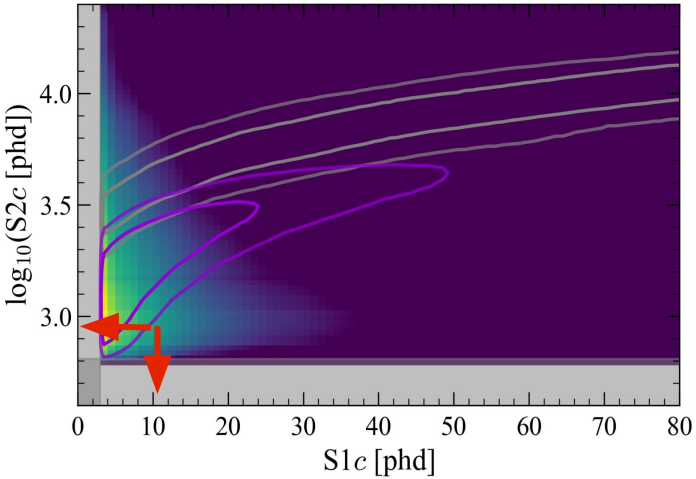
- Coordination of Vetoes & Neutron background group
- Neutrons are the only WIMP Search (WS2024) NR background
  - If they single scatter
- Outer Detector + Skin veto:
  - 89±3% neutron veto efficiency from AmLi calibration
  - 3% deadtime, (false veto rate * veto window length)
- Constrain the likely number of neutron events in WS2024
- Veto tagged sideband fit
  - Expectation $0^{+0.2}$ single scatter neutrons for WS2024
- Infer from the number of multiple scatter neutrons
  - 0.3±0.2 single scatter neutrons for WS2024



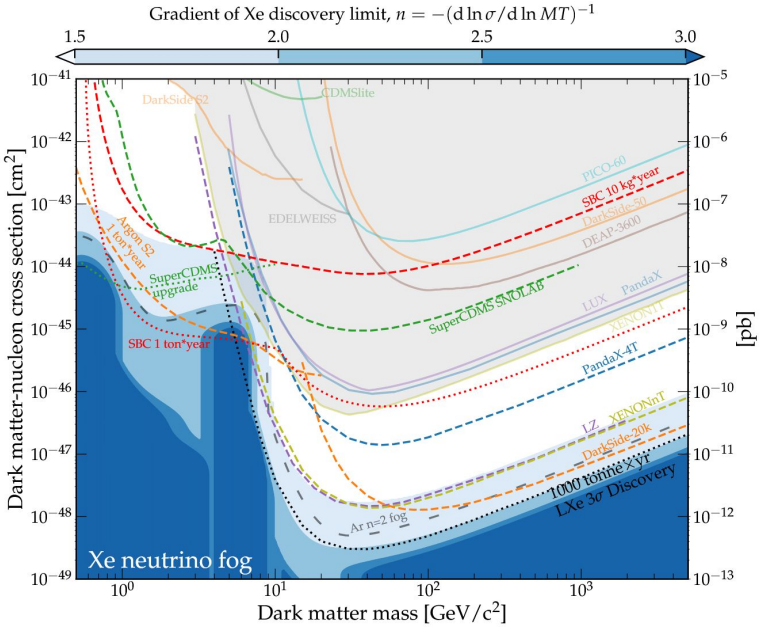


Low Mass WIMP Search

- WS2024 lowest WIMP mass tested 9 GeV/c^2
- Extend search to lower masses O(GeV)
- New background expected!
  - CEνNS from ^{8}B solar neutrinos



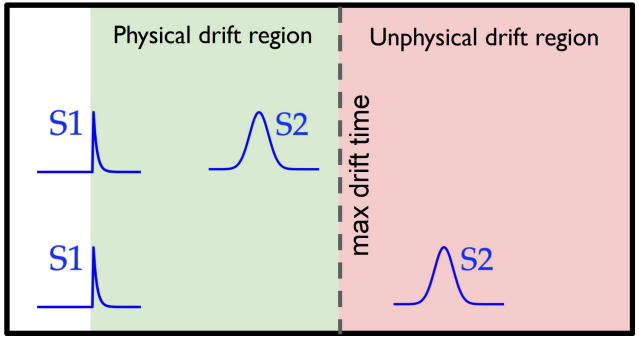
LZ accidental background PDF



Snowmass 2021 - 2203.08084

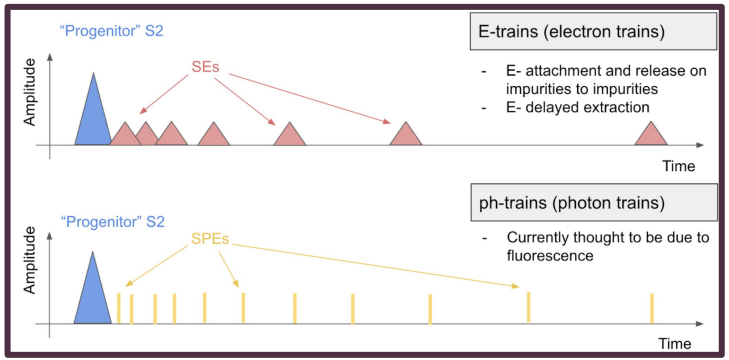
Data Quality

- Coordination of LZ's Data Quality group
- Accidental backgrounds most prevalent at low energies
  - Coincidence of isolated S1 and S2 pulses
- Pile-up photons or electrons can appear to be isolated S1s and isolated S2s respectively
- Exclusion of time periods with elevated background rates



Accidental background events

- Contemporaneous and retrospective data quality monitoring
  - Online: Underground Performance Monitor (UPM)
    - Primarily monitors PMT and Trigger health
  - Offline: Physics Readiness Monitor (PREM)
    - Detector health, which data should be included in WS



Photon and electron trains

XLZD & the **Xenon Futures** program

- MoU signed in 2021 by **X**ENONnT, **L**UX-**Z**EPLIN, **D**ARWIN
  - Collaboration formed end of 2024 => **XLZD**
- Frequent meetings with collaborators, yearly collaboration meetings
  - Next is June 2025 @ LNGS
- Xenon Futures program concluded late March 2025
- Pivoted fully towards XLZD project
  - Sergey leading WP2 (Outer Detector)
- Working towards bringing the definitive direct detection experiment to **Boulby**

  => XLZD@Boulby
  - Working towards CDR -> late 2025

XLZD White Paper & Design book

The XLZD Design Book: Towards the Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

J. Aalbers[1], K. Abe[2], M. Adrover[3], S. Ahmed Maouloud[4], D. S. Akerib[5,6], A. K. Al Musalhi[7], F. Alder[7],

A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

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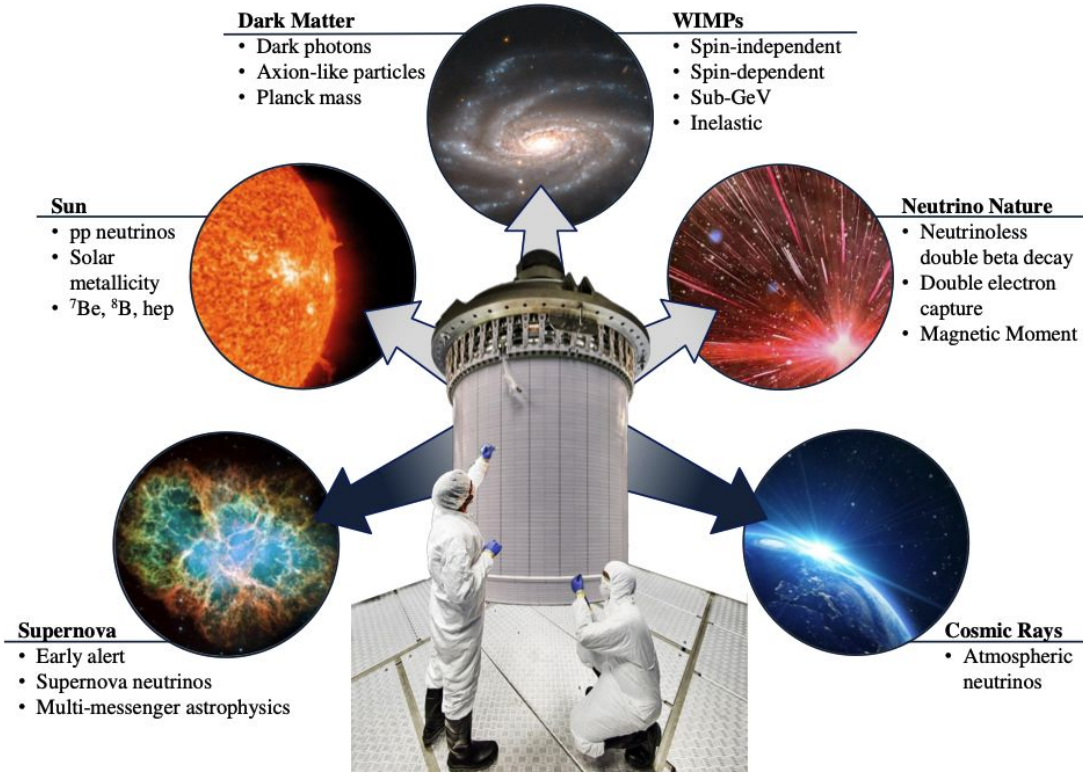
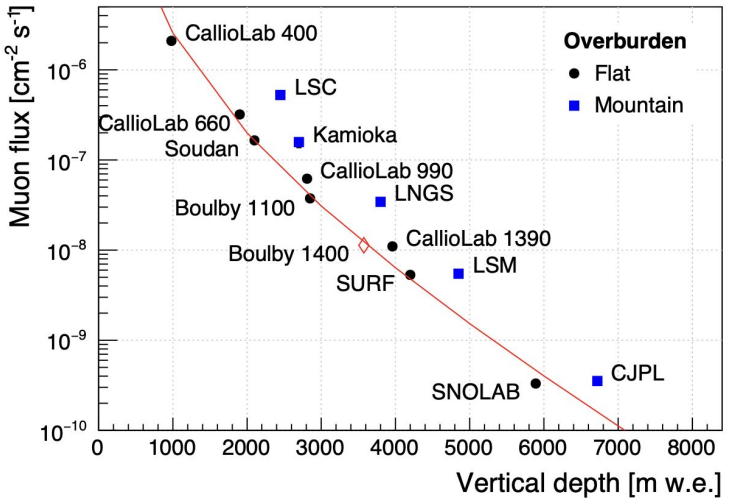
XLZD – Overview

- Next generation xenon-based detector
  - Dual phase TPC
  - Multi-purpose observatory
- 60t -> 80t of (active) LXe target mass
- Will reach neutrino floor and **definitively** rule out or discover WIMPS
- Can be used also to study the neutrino sector – rich physics program
  - Neutrinoless double beta decay
  - Astrophysical sources



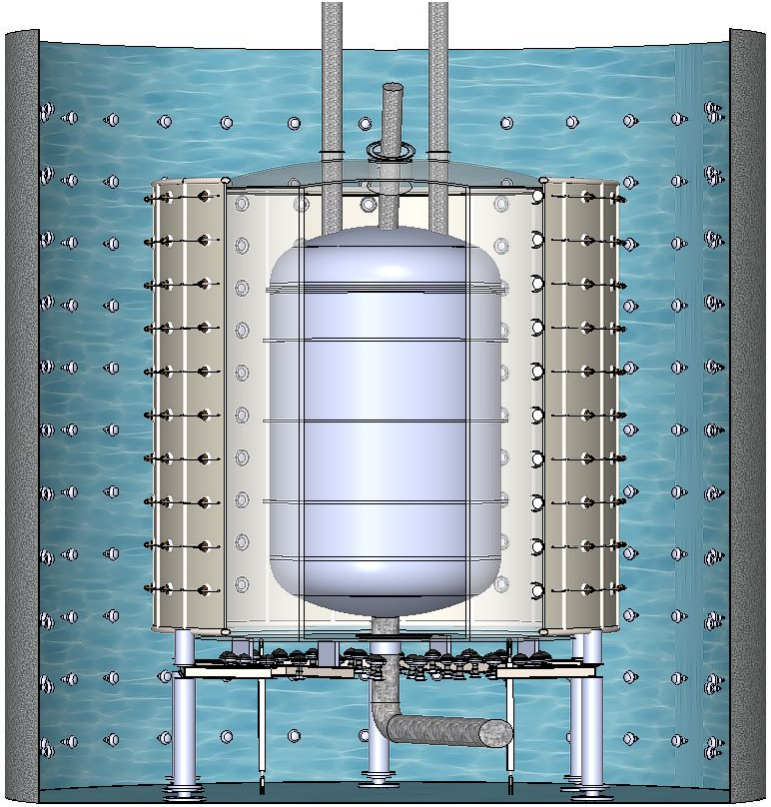
XLZD – Possible locations

- Five sites have submitted their intention to host XLZD:
  - Kamioka, Japan
  - SNOLAB, Sudbury
  - SURF, South Dakota
  - Boulby, North Yorkshire
  - LNGS, Gran Sasso
- Each site has advantages and disadvantages
- Determines which technologies can be used in the experiment
- Boulby has rich Dark Matter history:
  - Hosted the ZEPLIN experiment
  - Boulby Underground Germanium Suite (BUGS)



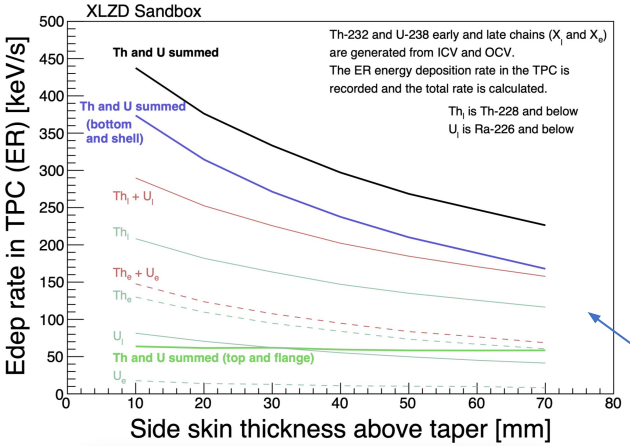
XLZD

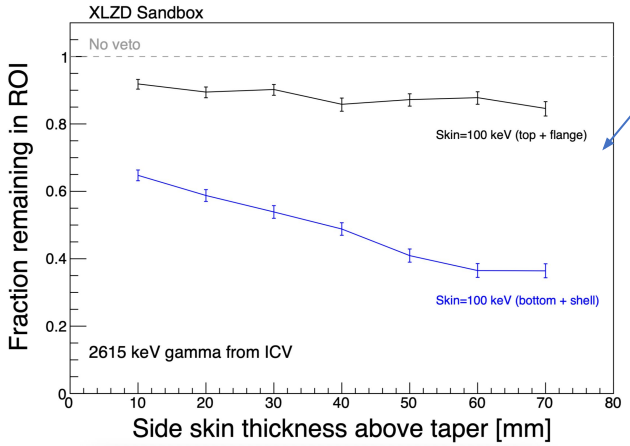
- Geant4-based software developed by Liverpool
  - XLZD Sandbox
- Enables for optimisation of the various subsystems
- Benchmarking possible with RAT-PAC2
- Focus with Liverpool: The design of the Outer Detector
  - Transfer of expertise from LZ -> XLZD
    - Neutron Veto Efficiency
    - Position reconstruction
- Maximise for neutron veto efficiency, test various new technologies
  - Selection of OD media: **Gd-Water, Gd-WbLS, Gd-LS**?
  - Synergy with collaborators across the world
    - BUTTON and 30t BNL demonstrator



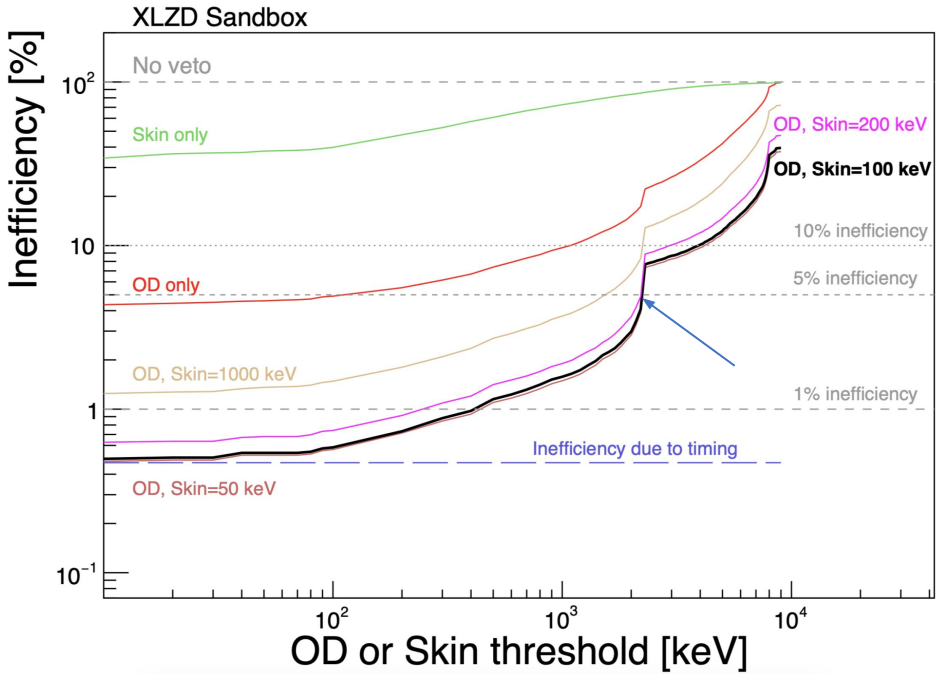
CAD from James Coleman-Mills

Physics Studies





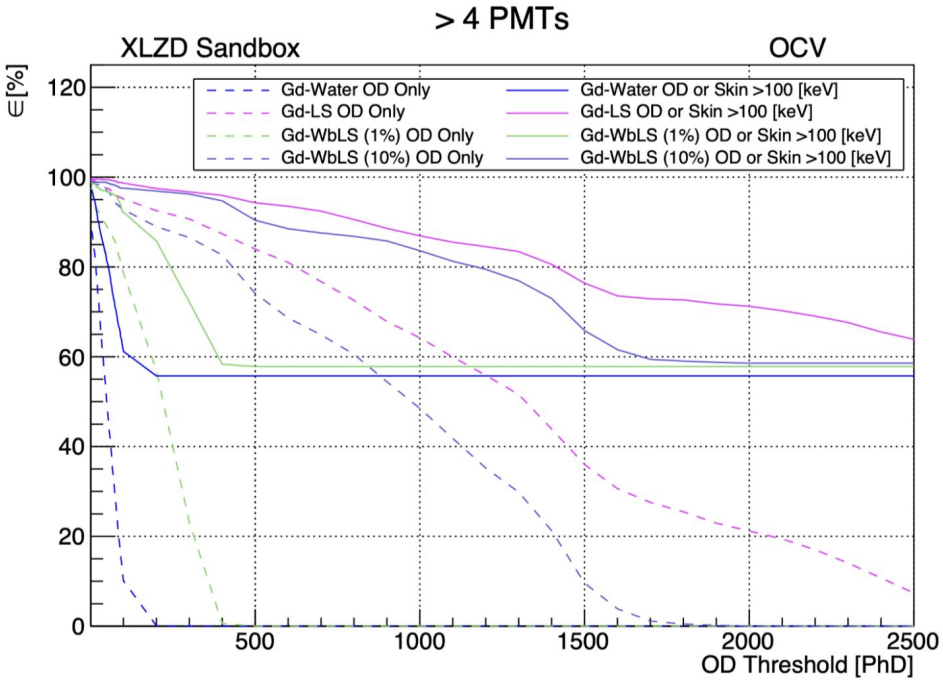
Optimising Skin thickness

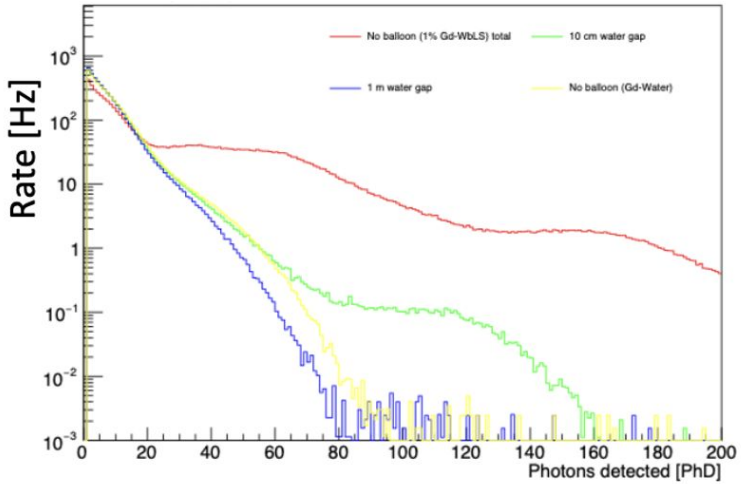


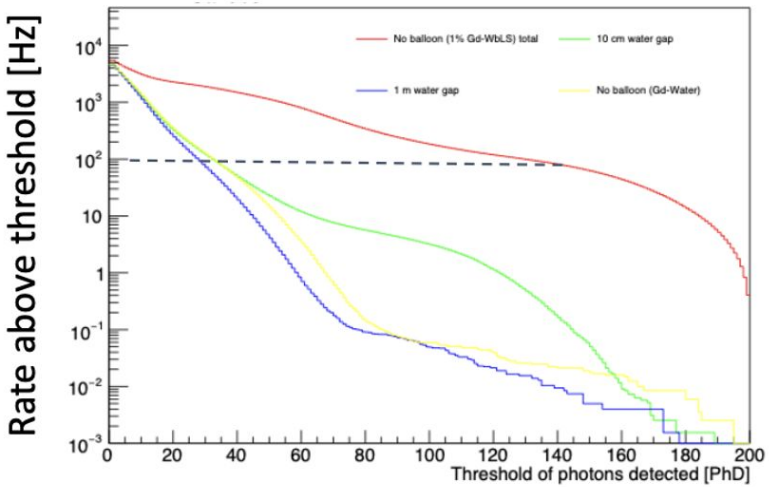
Using only threshold in energy:

Semi-medium agnostic view (0.1% Gd): Skin + OD can together surpass 95 % tagging efficiency

Physics Studies







When looking at photons detected, story becomes a little more complicated:

If PMTs are set inside the WbLS => rate from PMTs is too high!

Studies ongoing to minimise the rate…

Conclusion

- Conclusions of XF3 -> Pivoted to XLZD
- Significant contributions from Liverpool towards the XLZD@Boulby initiative
  - Development of XLZD Sandbox
  - Prototyping ongoing
- Working towards CDR late this year!