



UNIVERSITY OF  
LIVERPOOL

# LUX-ZEPLIN & XLZD

Sean Hughes



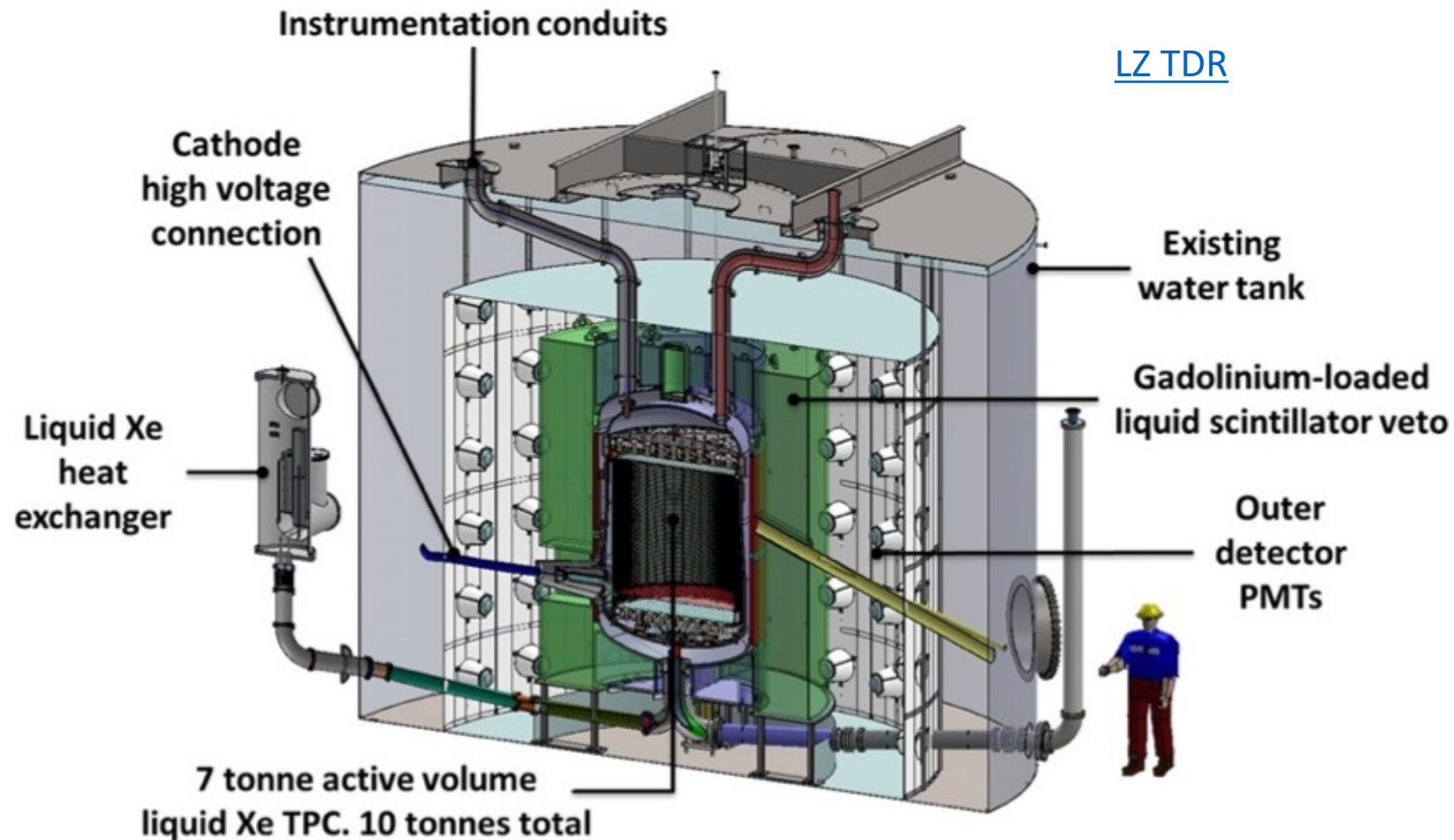
# About me

- Born in Littleborough, Greater Manchester
- Undergraduate studies at the University of Liverpool (MPhys)
  - Master's and PhD project on **The Mu3e Experiment**
  - Under the supervision of Nikolaos Rompotis and Joost Vossebeld
- Viva last November
- Joined as a PDRA in December for the Xenon Futures program

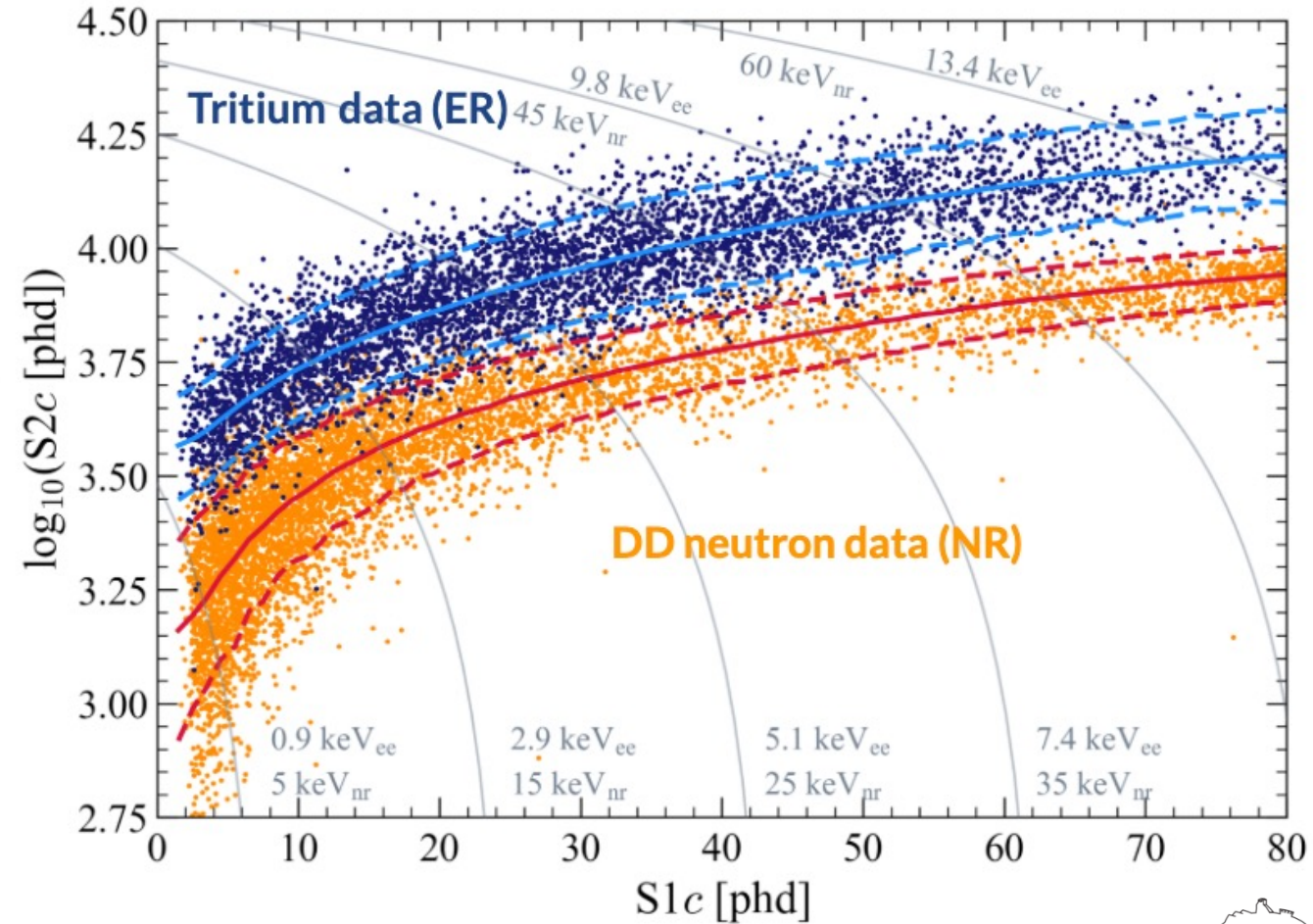
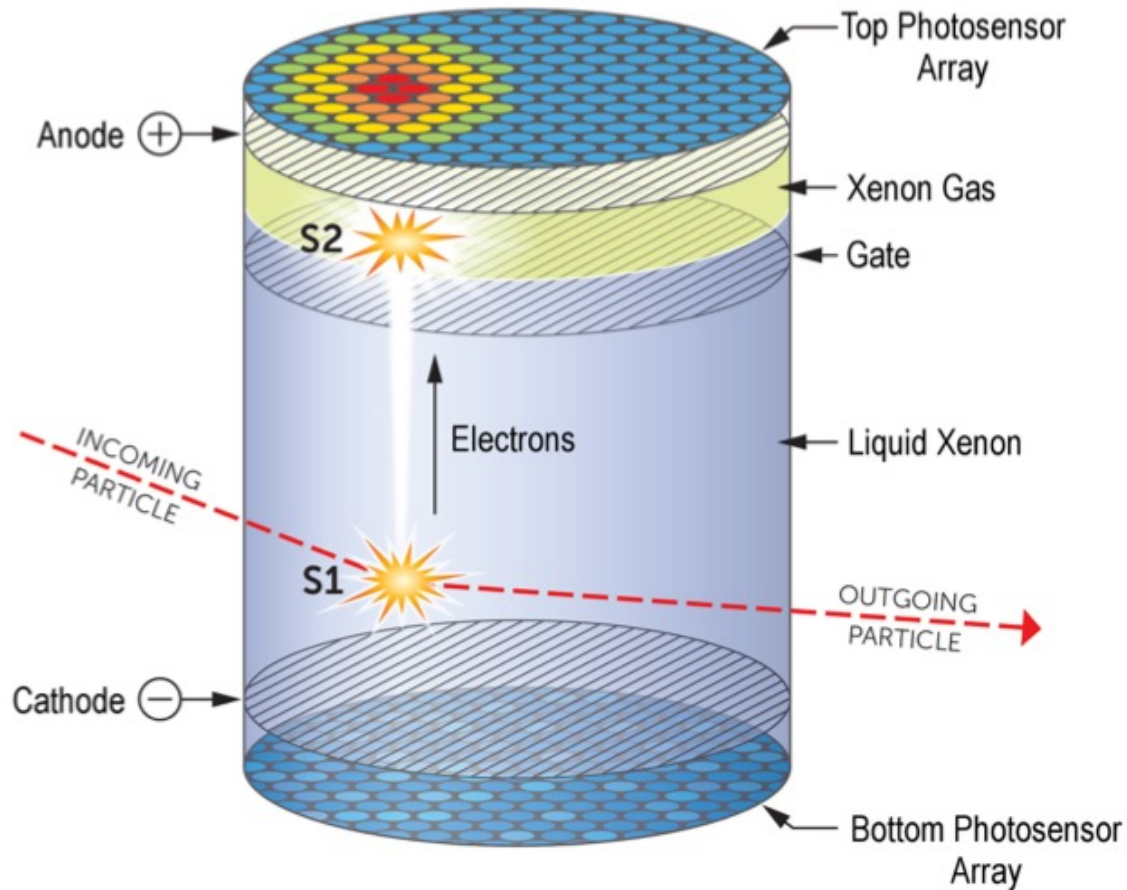


# XLZD/LZ – Experiment for Direct Detection of Dark Matter

- Group leader:
  - **Prof. Sergey Burdin**
- PDRAs:
  - Ewan Fraser
  - Sean Hughes
- Electronics Engineer:
  - Balint Bogdan
- PhD students:
  - Sam Woodford
  - Megan Carter (at SURF)
  - Tea Hall



# XLZD/LZ – Operating Principle



Electronic Recoil (ER) and Nuclear Recoil (NR) Discrimination calibration





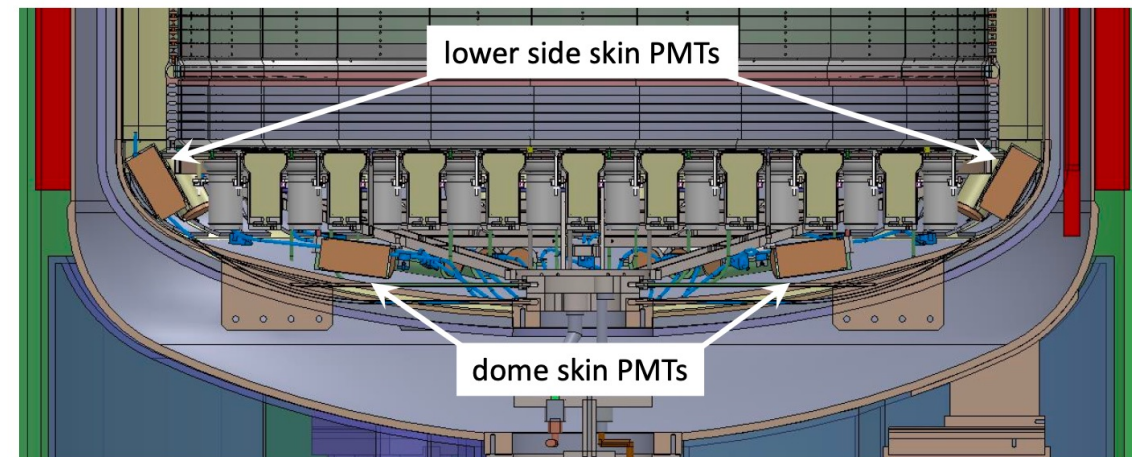
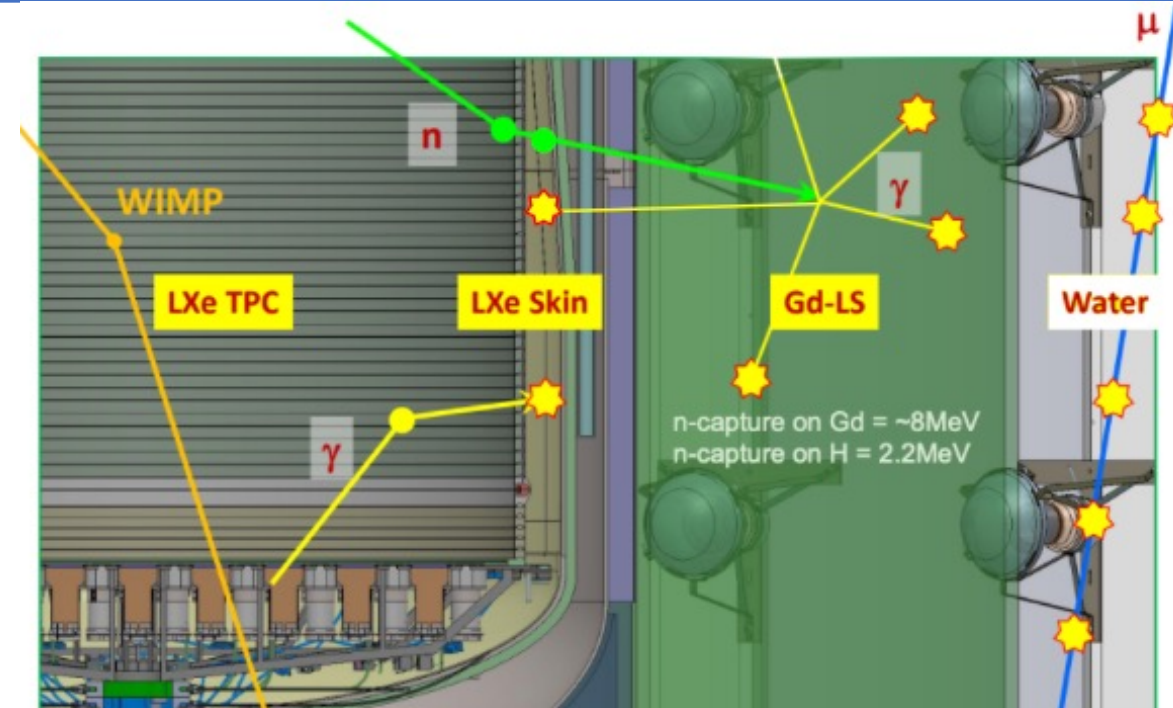
# LZ – Skin & Outer detector

- **Skin detector:**

- 2 tonnes of LXe surrounding the TPC
- ~130 1" or 2" Hamamatsu PMTs
- Veto for gamma rays with  $78 \pm 5 \%$  efficiency
- Reduces ER background

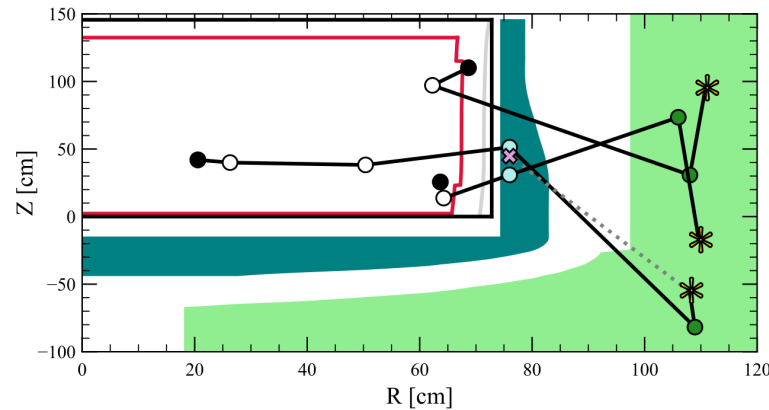
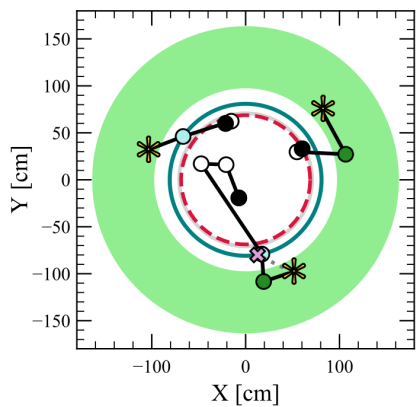
- **Outer detector:**

- 17 tonnes of Gadolinium loaded liquid scintillator (Gd-LS) contained within acrylic
- 120 8" Hamamatsu PMTs
- $89 \pm 3 \%$  SS neutron tagging efficiency observed using AmLi neutron source
- Constrains rate of SS neutron background

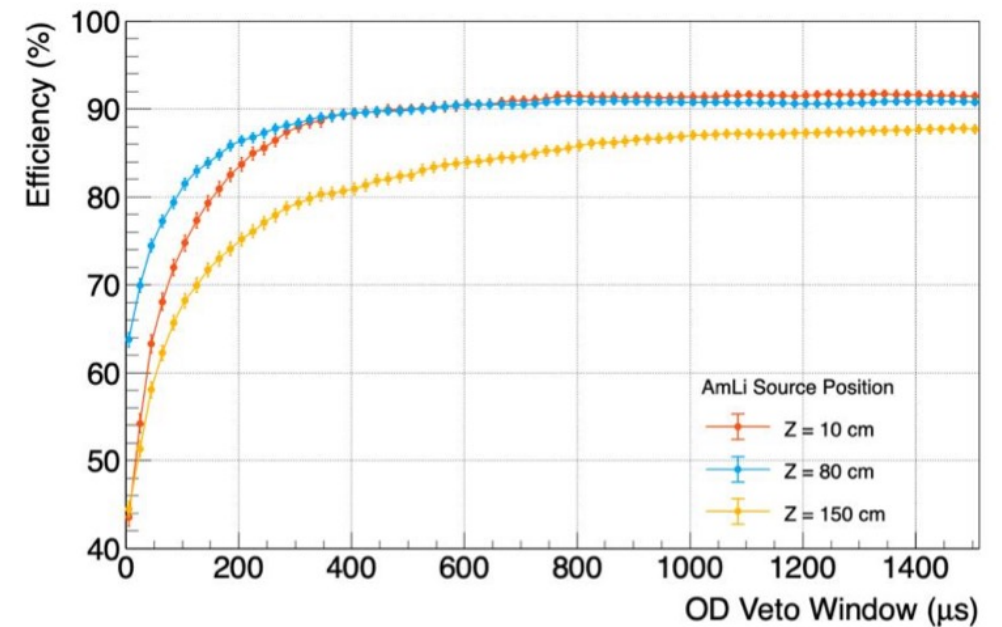


# LZ – Skin & Outer detector

- Outer detector calibration system developed by Liverpool to calibrate and monitor PMT health
  - OCS paper [here](#) and on [arxiv](#)
  - Currently in operation
- Neutron veto (in)efficiency estimated through use of AmLi source
- Neutron outer detector veto efficiency estimated to be  $89 \pm 3 \%$



Sam presenting at IOP on the LZ outer detector



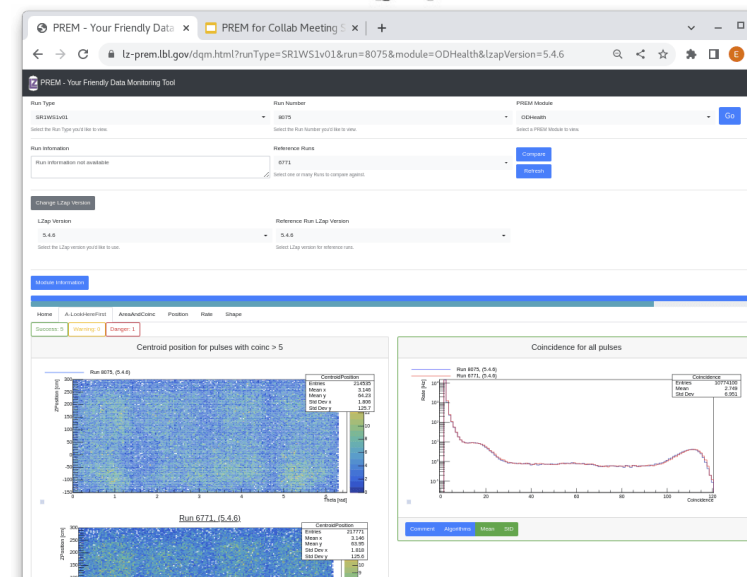
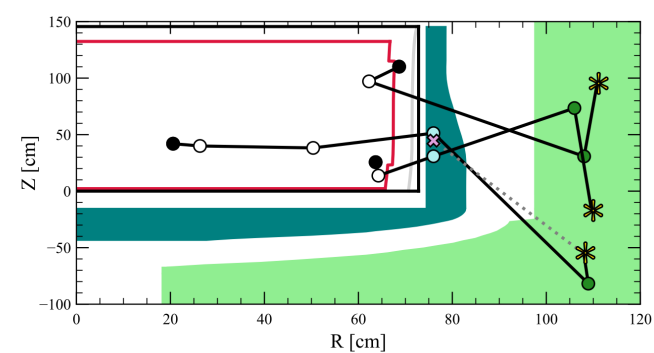
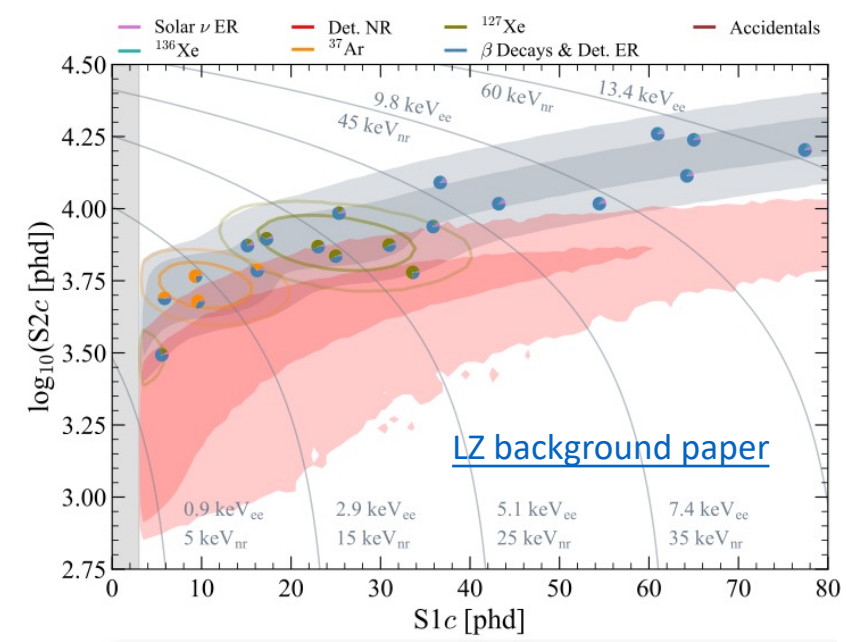


# LZ – Vetoes and Neutrons, data quality

- LZ Veto and Neutron group co-lead by **Ewan Fraser**
- Neutrons are main source of background for WIMP search
- Number must be constrained
- Responsible for data quality management
- **Physics Readiness Monitor (PREM)**



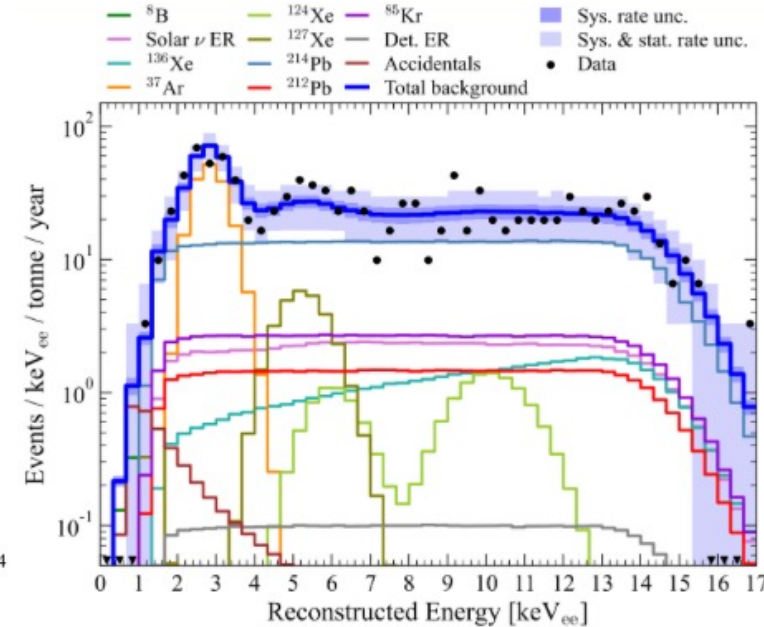
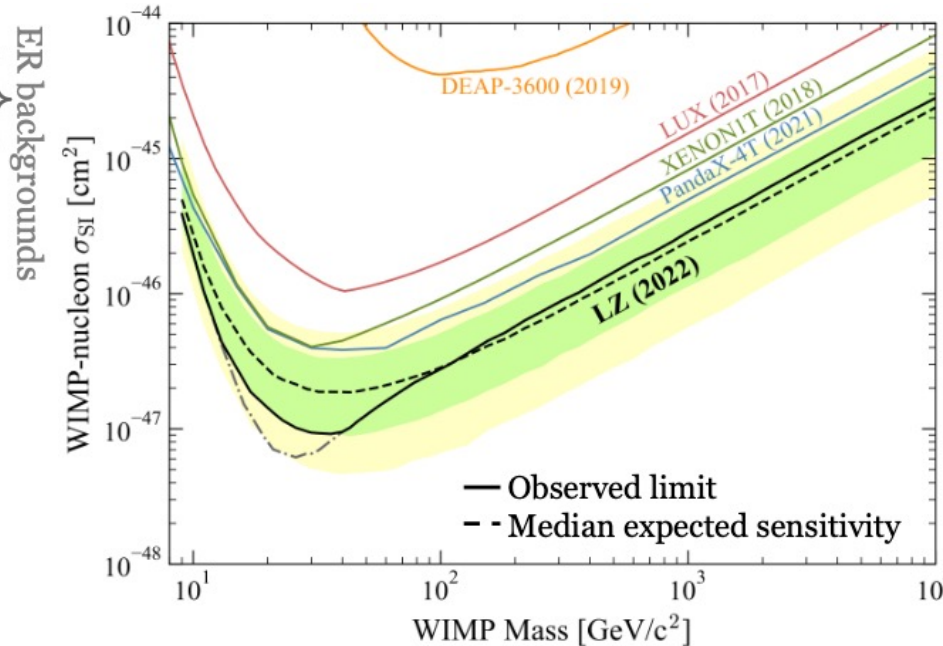
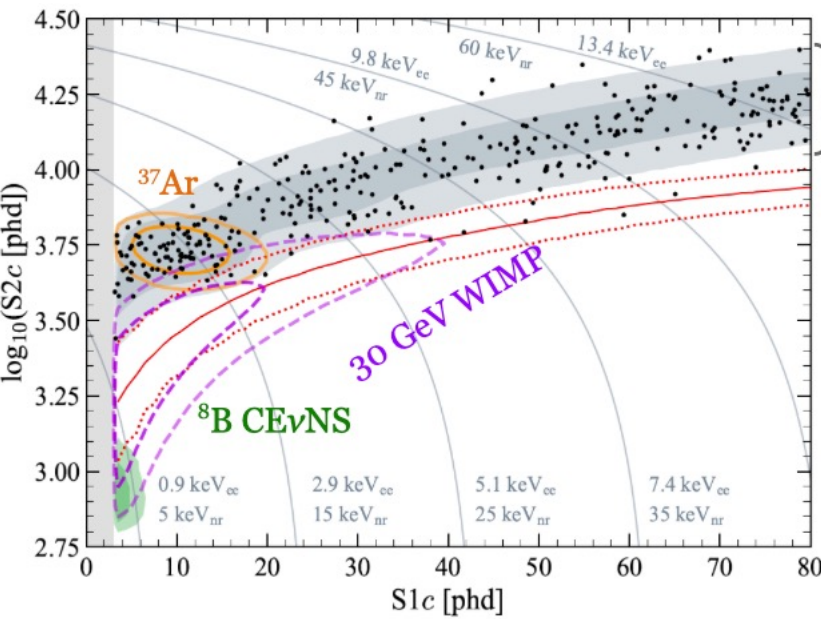
Ewan giving a presentation at IOP on the status of LZ



# LZ – Latest WIMP Result

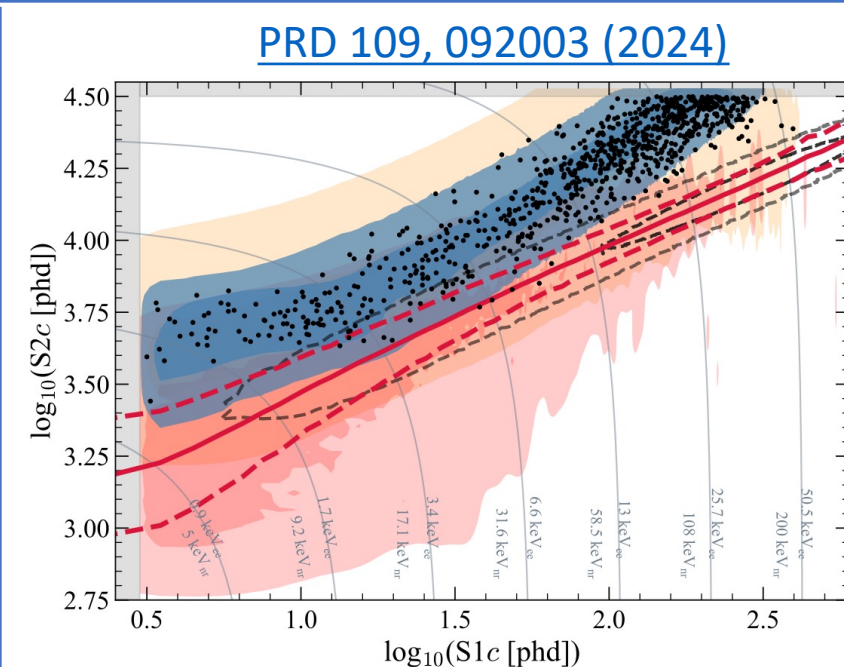
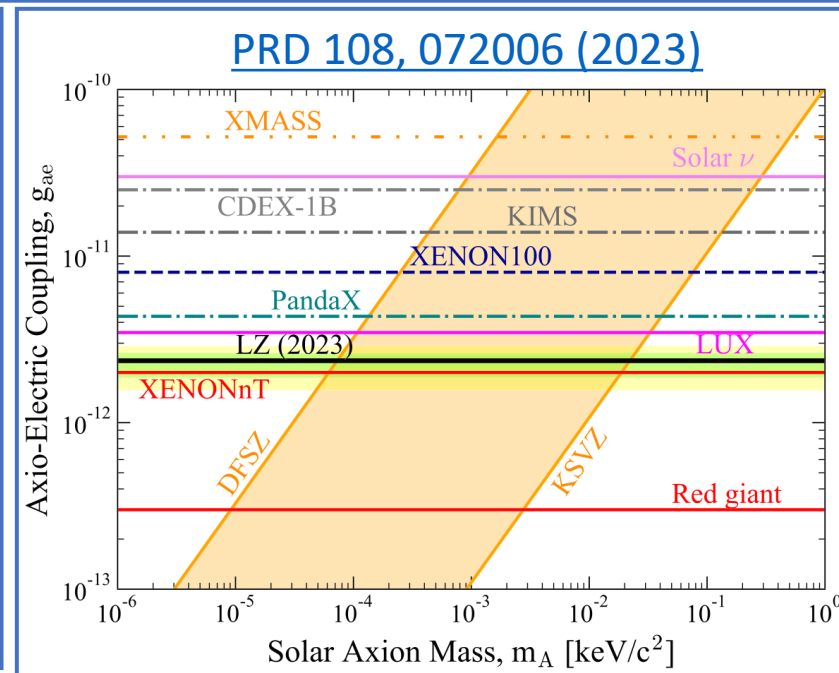
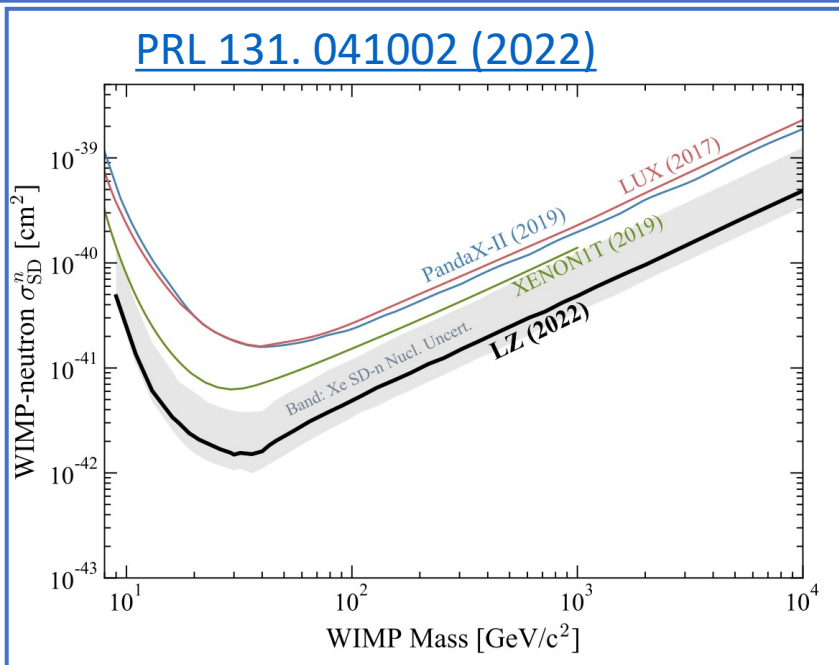
- LZ first science run (SR1) was 60 live days
- 335 events in final dataset with 5.5 t fiducial volume
- Profile likelihood ratio shows data is consistent with background only hypothesis – **zero WIMP events**
- Best limit of  $9.2 \times 10^{-48} \text{ cm}^2$  at  $36 \text{ GeV}/c^2$

Source	Expected Events	Fit Result
$^{214}\text{Pb}$	$164 \pm 35$	-
$^{212}\text{Pb}$	$18 \pm 5$	-
$^{85}\text{Kr}$	$32 \pm 5$	-
Det. ER	$1.4 \pm 0.4$	-
$\beta$ decays + Det. ER	$215 \pm 36$	$222 \pm 16$
$\nu$ ER	$27.1 \pm 1.6$	$27.2 \pm 1.6$
$^{127}\text{Xe}$	$9.2 \pm 0.8$	$9.3 \pm 0.8$
$^{124}\text{Xe}$	$5.0 \pm 1.4$	$5.2 \pm 1.4$
$^{136}\text{Xe}$	$15.1 \pm 2.4$	$15.2 \pm 2.4$
$^8\text{B}$ CE $\nu$ NS	$0.14 \pm 0.01$	$0.15 \pm 0.01$
Accidentals	$1.2 \pm 0.3$	$1.2 \pm 0.3$
Subtotal	$273 \pm 36$	$280 \pm 16$
$^{37}\text{Ar}$	$[0, 288]$	$52.5^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/ $c^2$ WIMP	-	$0.0^{+0.6}$
Total	-	$333 \pm 17$



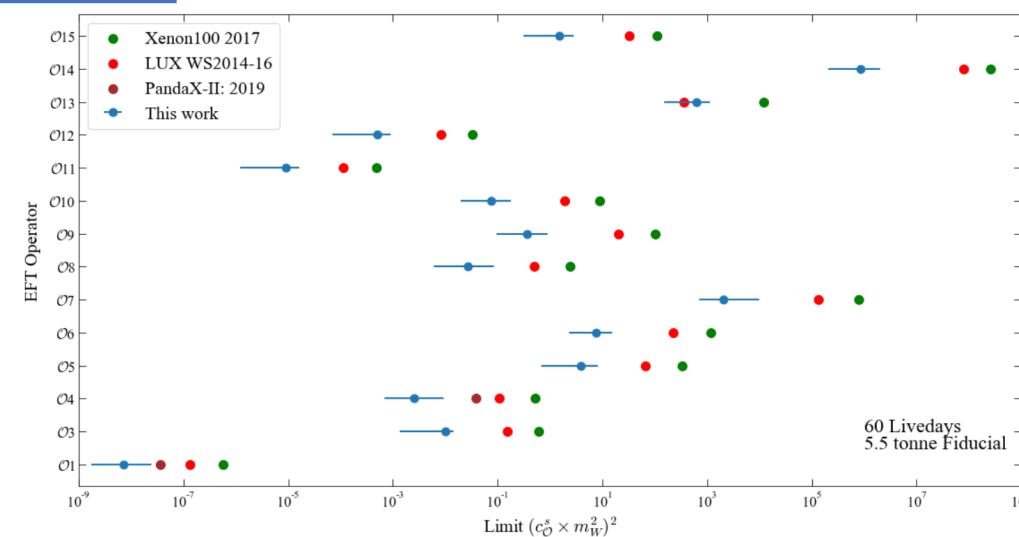


# LZ – Recent analyses



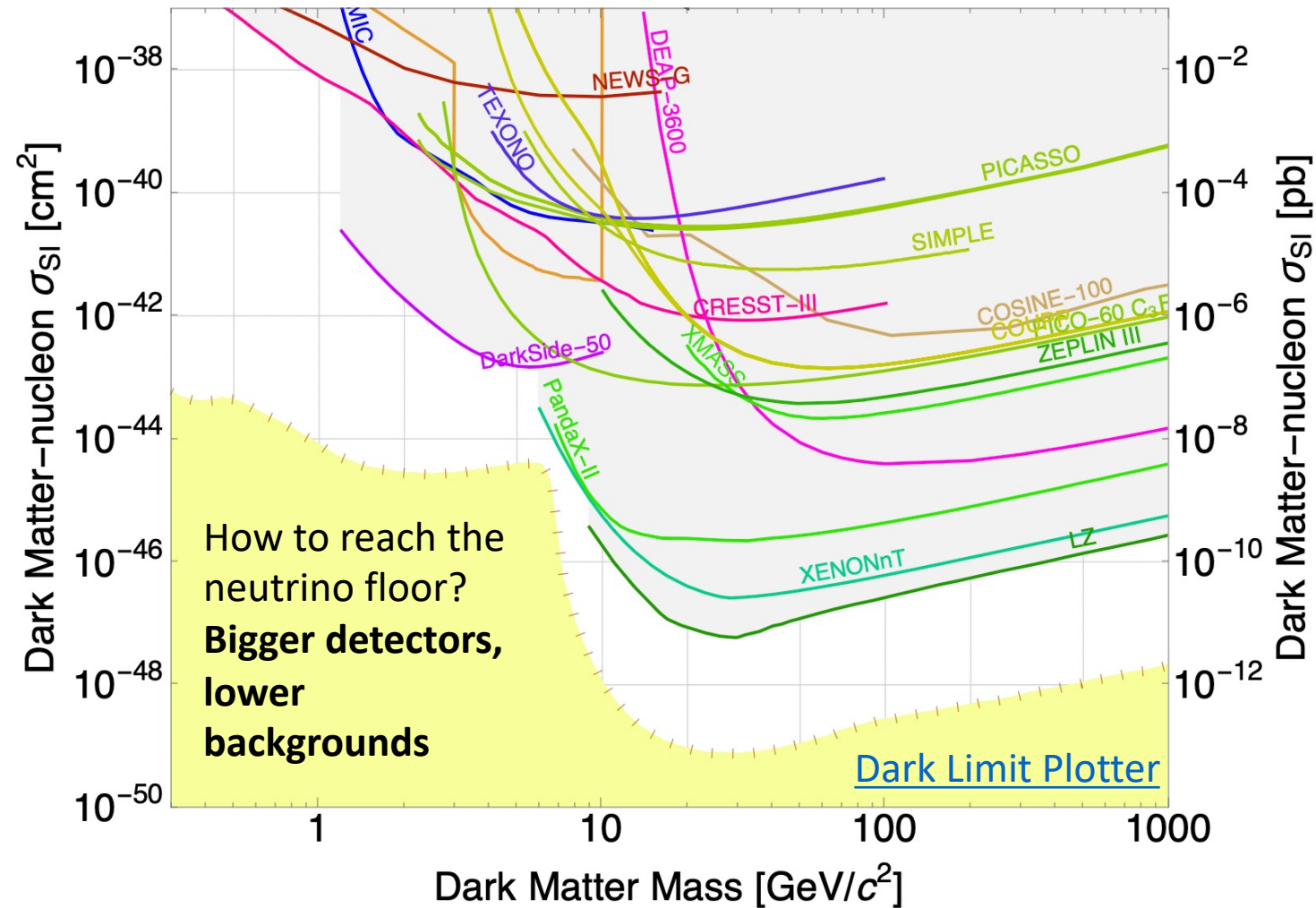
- Since WIMP search, other analyses have been conducted

- Spin dependent WIMP search
- Solar axion search
- Effective Field Theory analyses
- Ultra heavy dark matter search



# LZ – Summary

- Dual-phase TPC with 7t liquid Xenon as target mass
- LZ produced the most stringent WIMP mass limit
- Other analyses ongoing:
  - Effective Field Theory
  - Neutrinoless double beta decay
  - Spin dependent WIMP search
- Signed MoU to join larger experiment  
=> XLZD





# XLZD & the Xenon Futures program

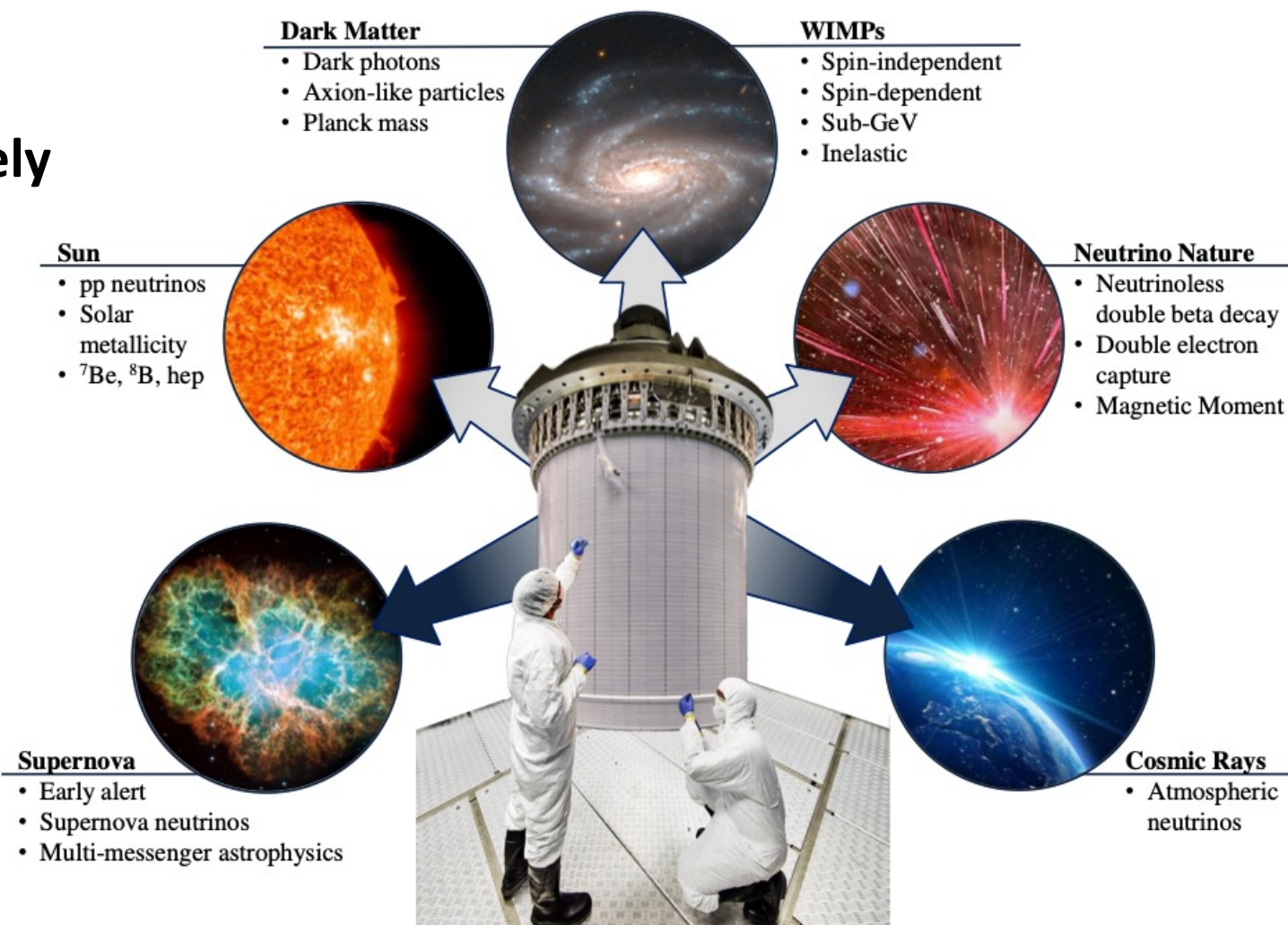
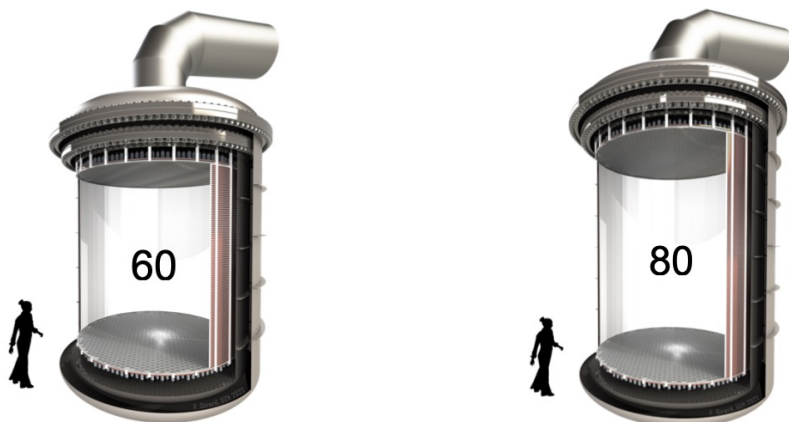
- MoU signed in 2021 by **XENONnT**, **LUX-ZEPLIN**, **DARWIN**
  - Consortium established – **XLZD**
- Frequent meetings with collaborators, yearly collaboration meetings
  - Last was April 2024 @ RAL





# XLZD – Overview

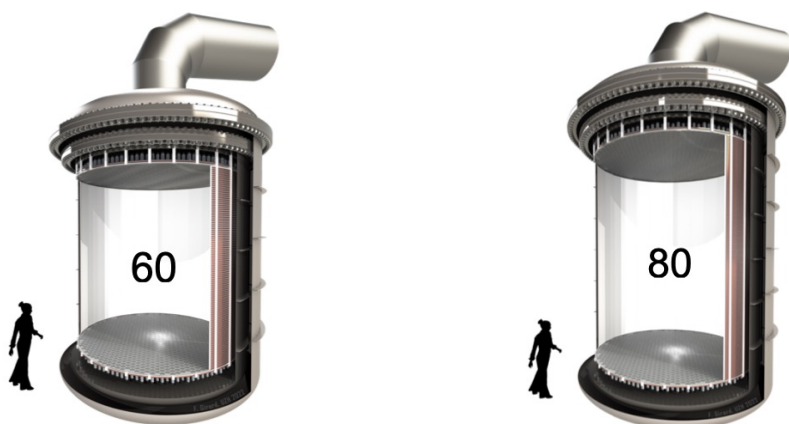
- Next generation xenon-based detector
  - Dual phase TPC
  - Multi-purpose observatory
- 60t -> 80t of (active) LXe target mass
- Will reach neutrino floor and **definitively** rule out or discover WIMPS
- Can be used also to study the neutrino sector – rich physics program
  - Neutrinoless double beta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



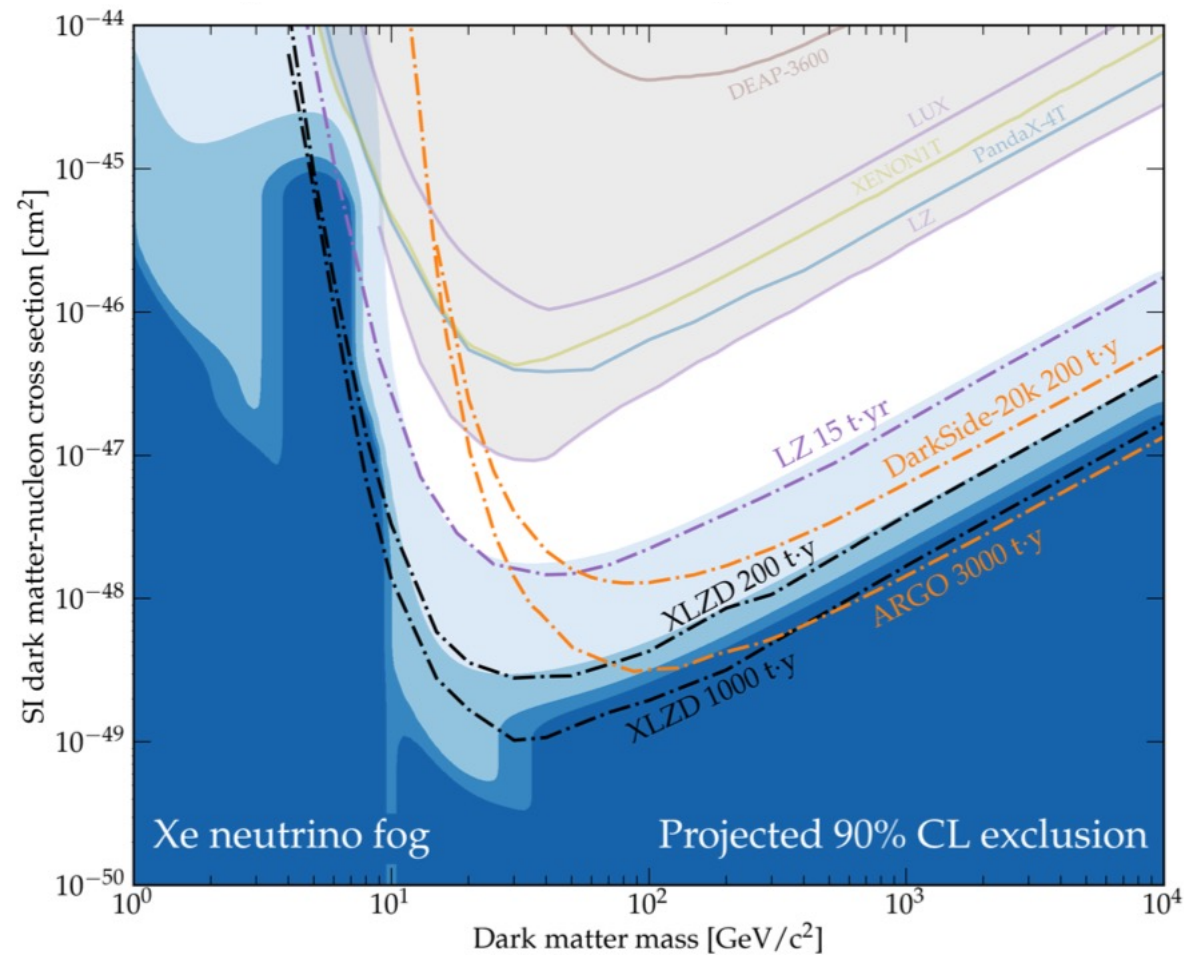


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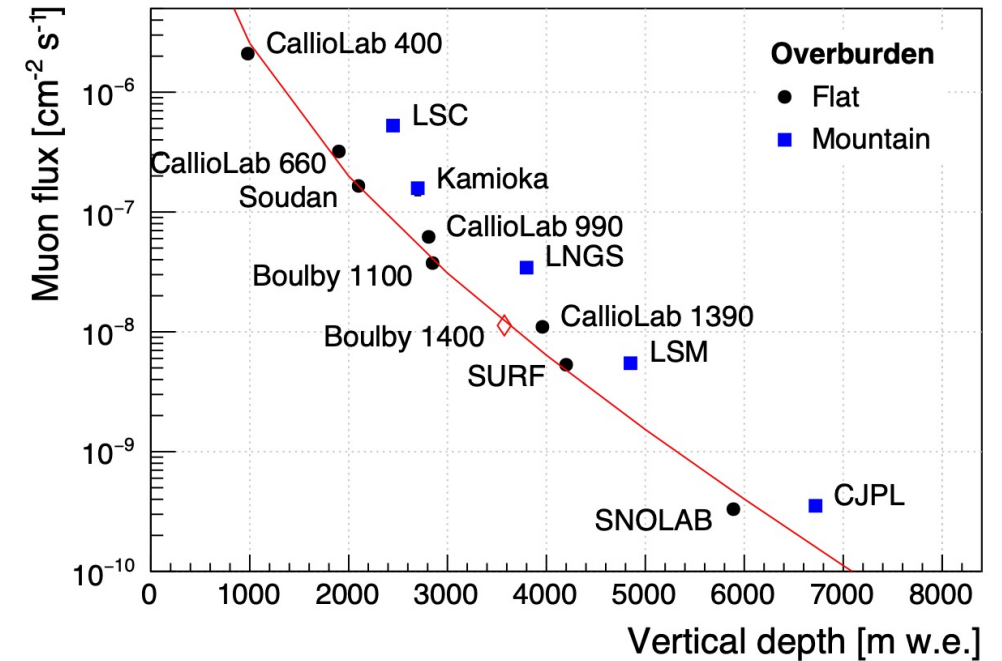


[arXiv:2203.08084](https://arxiv.org/abs/2203.08084)



# 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)

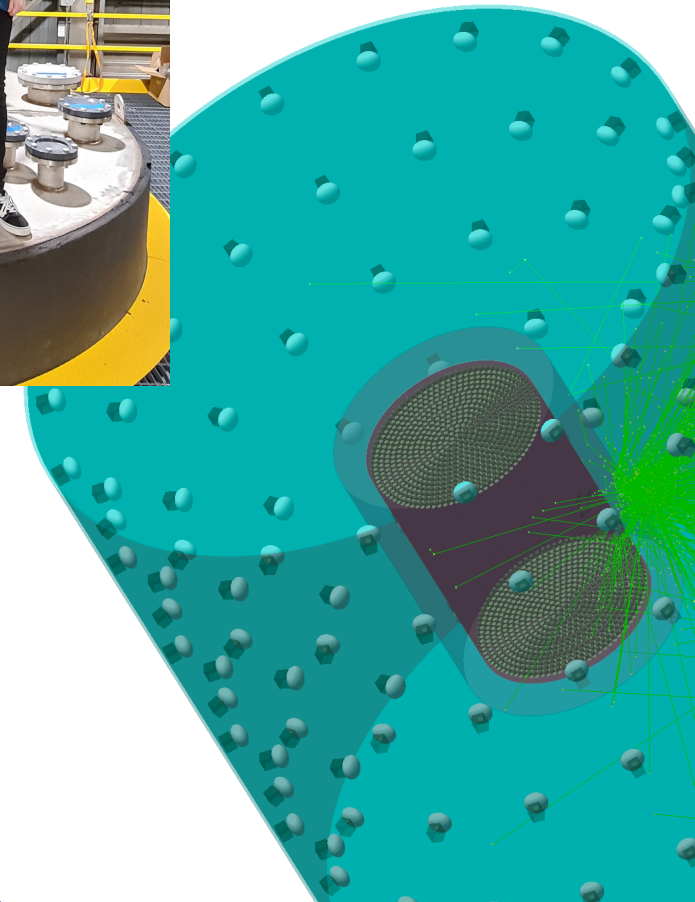


# XLZD – Xenon Futures

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



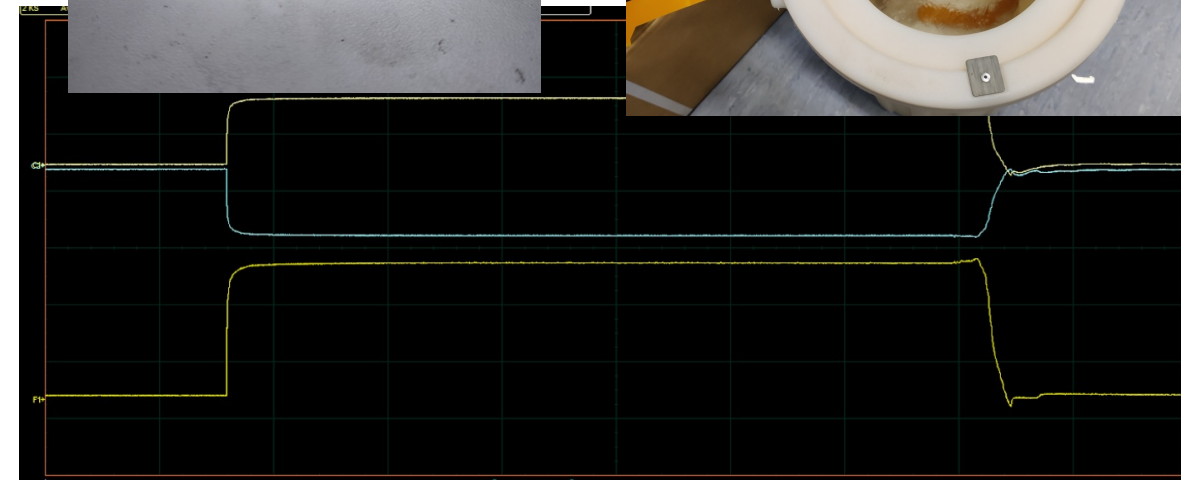
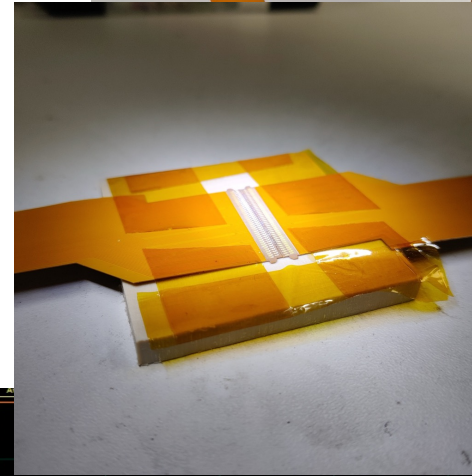
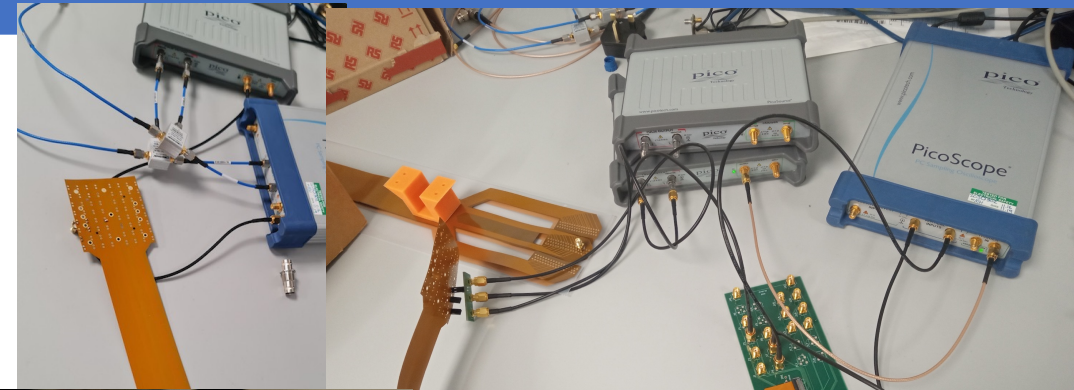
Sergey, Megan, and myself visiting the 30 t demonstrator at BNL in March





# XLZD – Xenon Futures

- Assisting with construction of Xenia for **Xenon Futures 2** work package
- Flex tapes constructed for use in Xenia:
  - Wirebonded (2 x 550 mm)
  - 550 mm
  - 750 mm
- Characterisation of tapes ongoing for different track geometries
  - TDR/TDR measurements in differential mode
  - Radiation assays at Boulby
- Moving onto optimisation and design of the **XLZD outer detector**
- Use of simulation is vital
- WbLS testbed to be built in Liverpool
  - Compare (Gd-)WbLS, (Gd-)Water,





# Summary

- Exciting Dark Matter physics program here at the University
- Ongoing experiment (LZ) currently taking data with a working detector
- Major contributions from Liverpool collaborators
  - Optical calibration system
  - Neutron veto efficiency
  - Data quality management
  - Physics Readiness Monitor
- XLZD R&D program is ongoing and ramping up
  - Liverpool heavily involved in simulation work and outer detector design
  - Applied for Infrastructure Funding for XLZD Preliminary Activities (3.5 years) and now waiting for (positive) outcome

