Electric Fields and their Effects in the LUX-ZEPLIN Experiment

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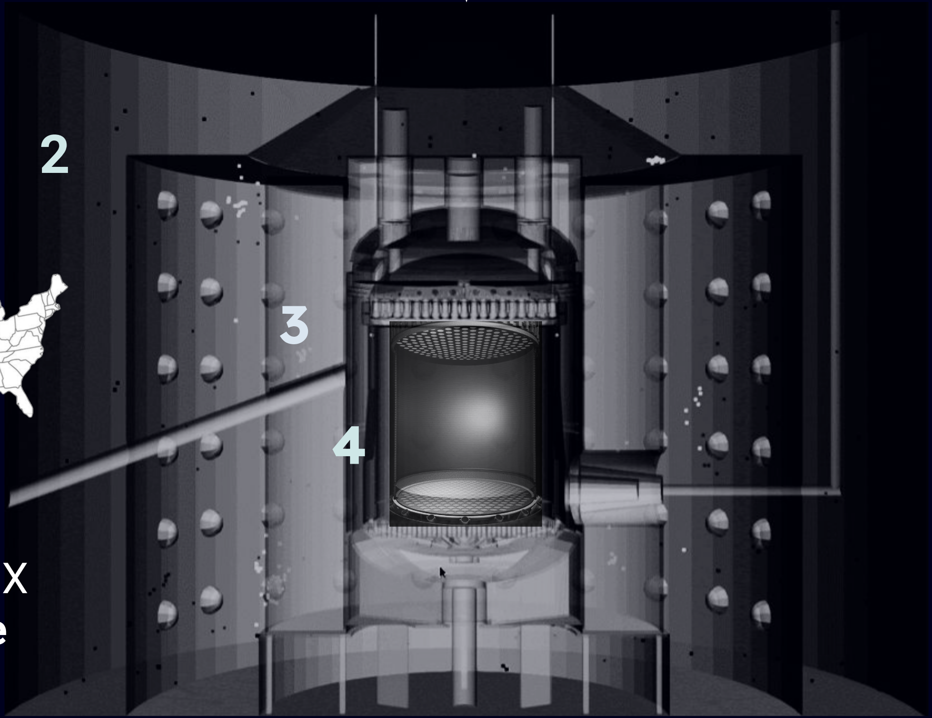
University of Oxford

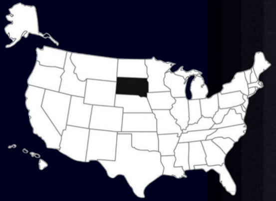
LIDINE 2024
26th-28th Aug 2024

THE LUX-ZEPLIN EXPERIMENT

4850 ft below surface 1



- Sanford Underground Research Lab, SD, US

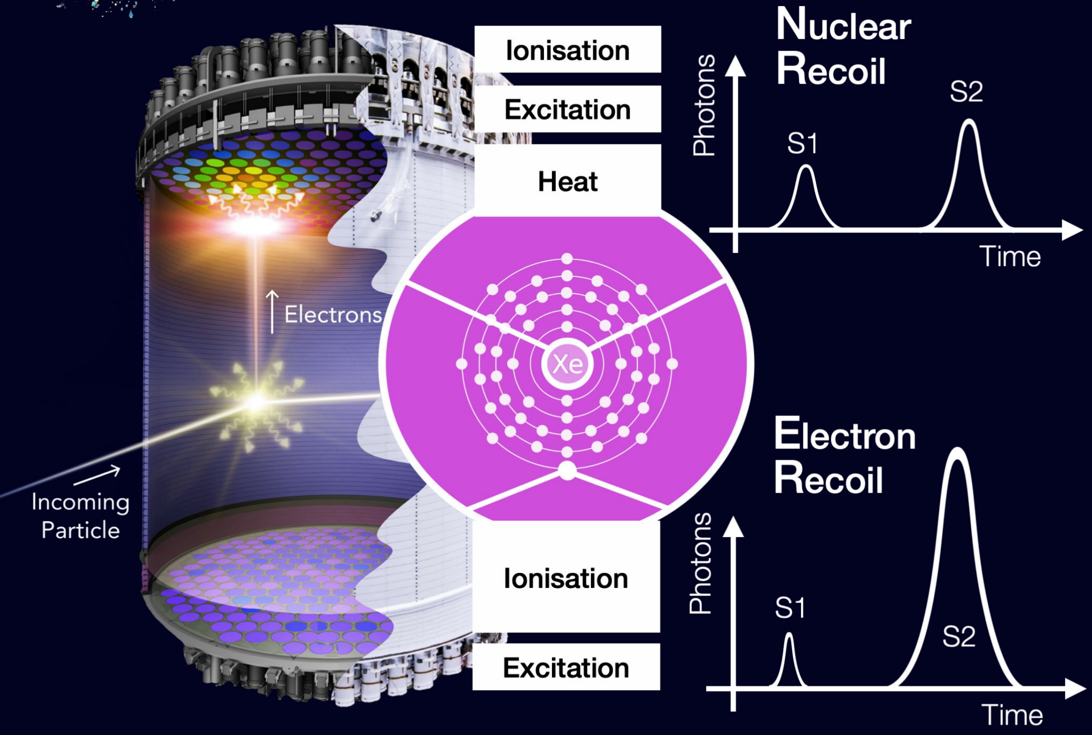


- **60x lower background** than LUX
- **100x** more **sensitive**

- Dual Phase Xe
- **Quadruple** Nested Detector

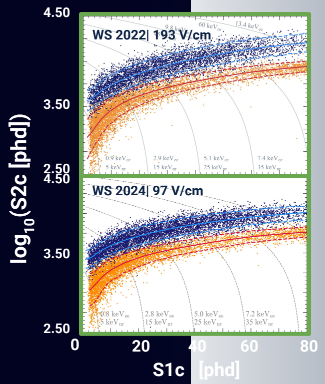
- **More details in Amy's great talk on WS 2024 Results!**

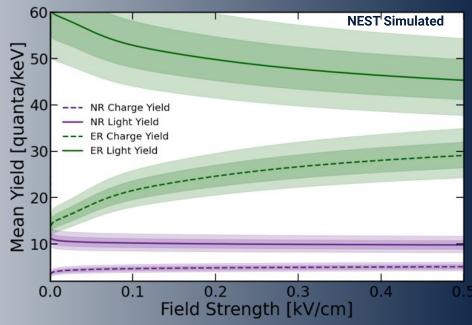
DUAL PHASE TPCS & FIELDS



For **Single Scatters**

- **3D Event Reconstruction**
  - **PMT Hit** Pattern → **xy**
  - **Drift Time** → **z**
- **S2:S1 → Electronic Recoil (ER) vs Nuclear Recoil (NR)**

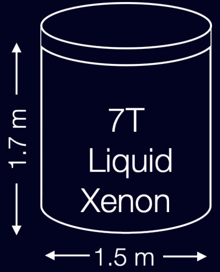




- **Recombination is field dependent!**
  - **Strong E field → more charge freed, less light**
- **ER-NR band positions in S1-S2 space changes**

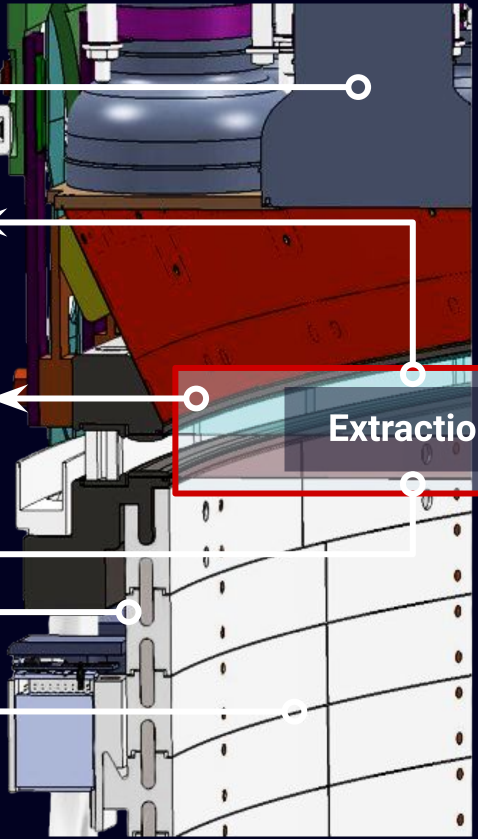
LZ TPC GEOMETRY & MATERIALS

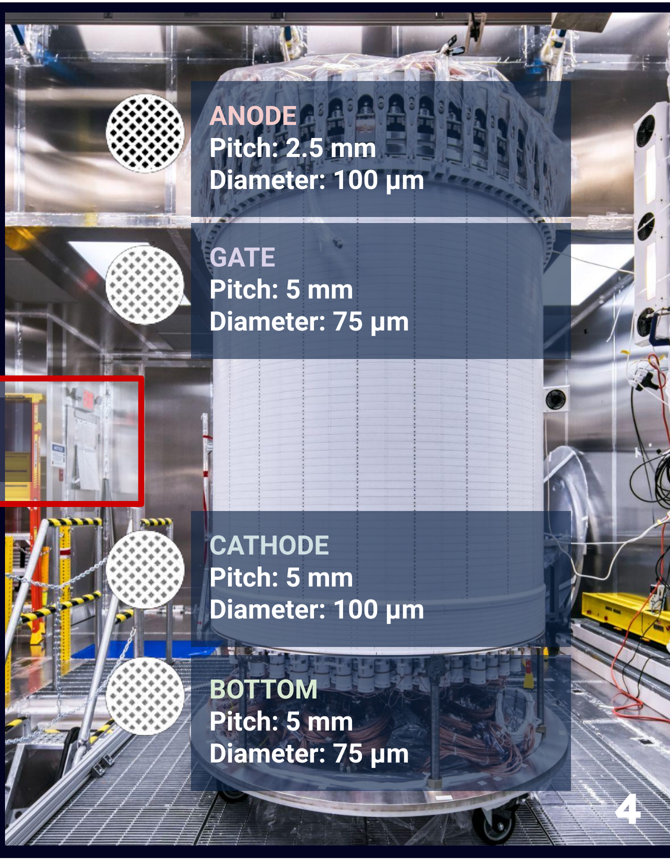
Dual Phase



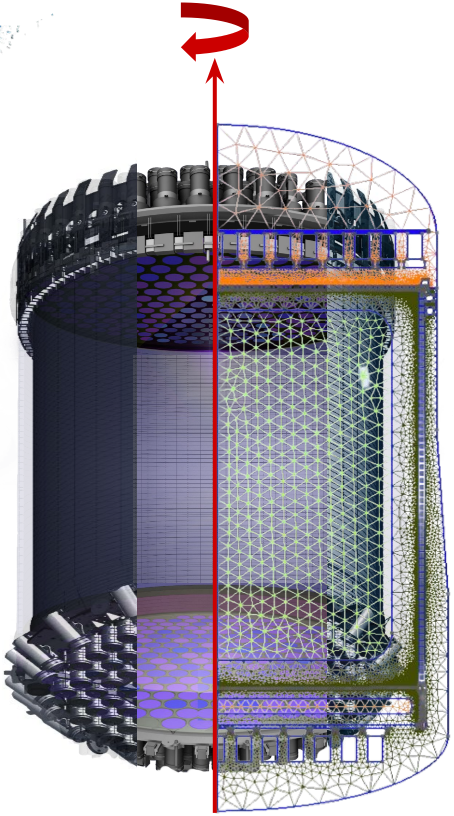
Dielectric Constants κ

$\kappa_{LXe} = 1.875$
$\kappa_{GXe} = 1$
$\kappa_{PTFE} = 2.1$
$\kappa_{PEEK} = 3.2$

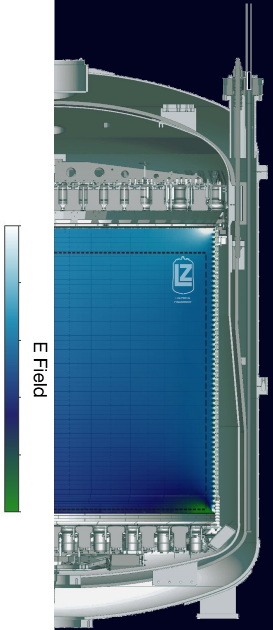




FINITE ELEMENT METHOD: FENICS



- Poisson's Equation is solved in **FeniCS**
- 2D axisymmetric model is used
- Mesh generated in **GMSH**
    - **Manual** setting of mesh
    - More points sampled in regions where non-uniform fields expected

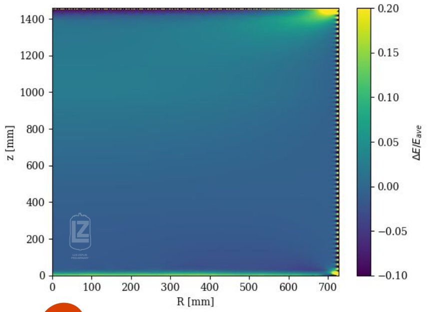


Interpolate fields

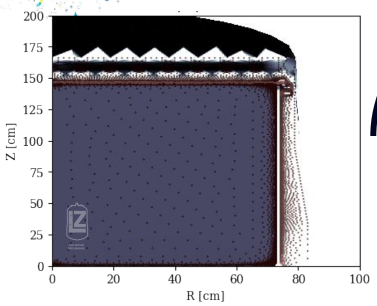
FeniCS| **fenicsproject.org**
GMSH| **gmsh.info**

LZEF

Field Map



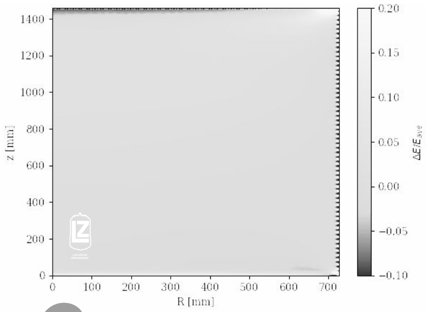
2 **FeniCS**

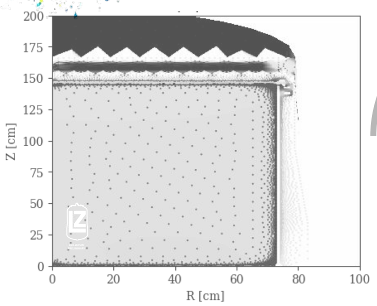


1 **Initial Meshing in GMSH**

LZEF

Field Map





2 FeniCS

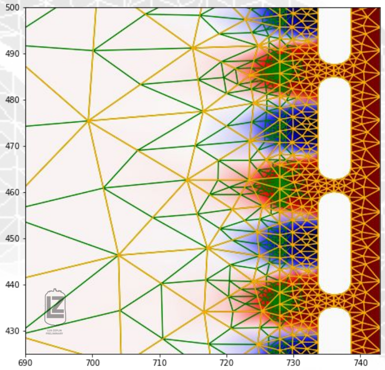
1 Initial Meshing in GMSH

3 Delaunay Triangulation in QHULL: Re-Meshing

QHULL| qhull.org

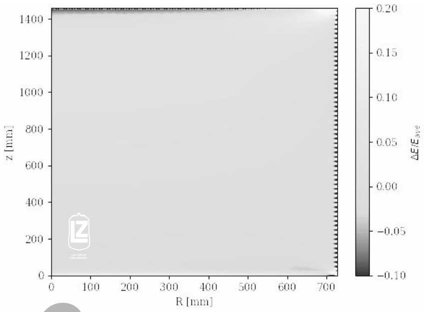
- Points are sampled from along field lines/ drift trajectories
- If field is very different to the mean field then tighter meshing

Towards more parallel field lines ← Region of greater irregularity



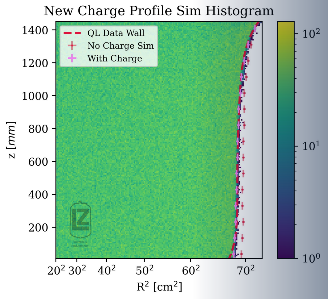
LZEF

Field Map

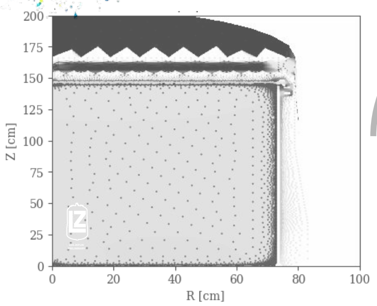


2 FeniCS

Electron bombs from each point in modified mesh → bidirectional mapping until a boundary is reached produces drift trajectories

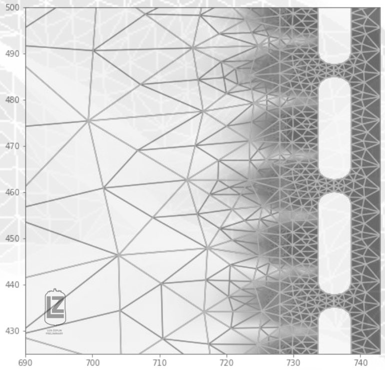


Drift Map (S2 R) 4



1 Initial Meshing in GMSH

Towards more parallel field lines ← Region of greater irregularity



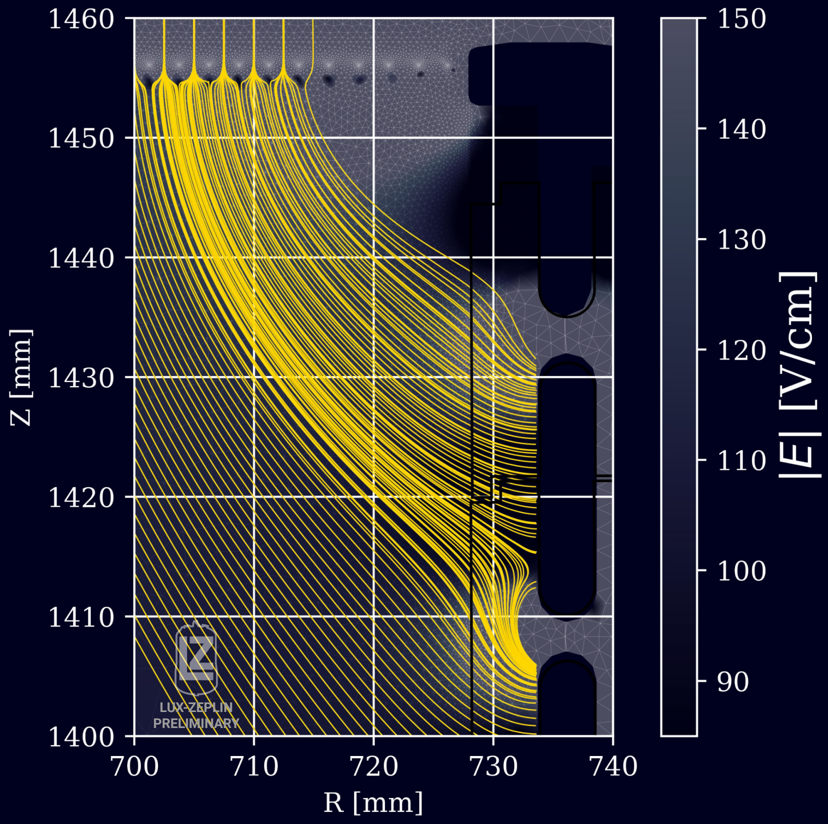
3 Delaunay Triangulation in QHULL: Re-Meshing

- Points are sampled from along field lines/ drift trajectories
- If field is very different to the mean field then tighter meshing

ELECTRIC FIELDS| VALIDATION 1

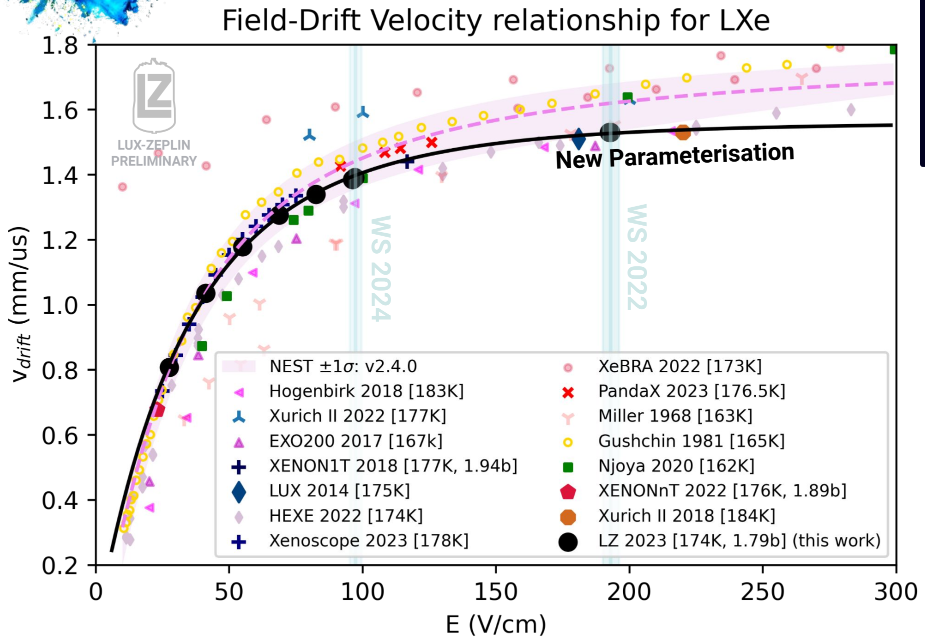
Max dt vs field

- A model for **drift velocity as a function of field** is needed to ensure faith in **position reconstruction**
- Quick check: Does the **maximum drift time** observed match simulations



ELECTRON DRIFT VELOCITY

$V_{drift} = z/\Delta t$



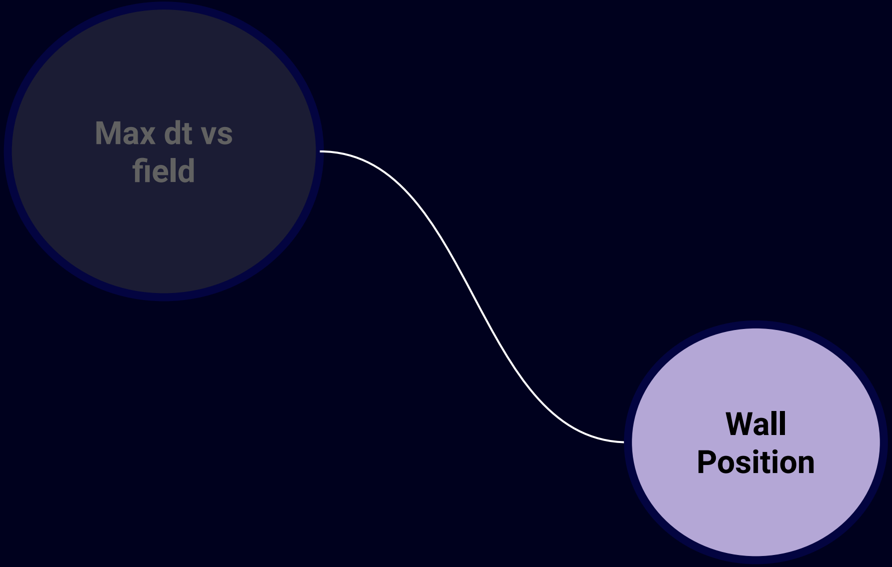
NEST fit dev. (sims-data diff.)	**2.6%**
New Parameterisation dev.	**0.78%**

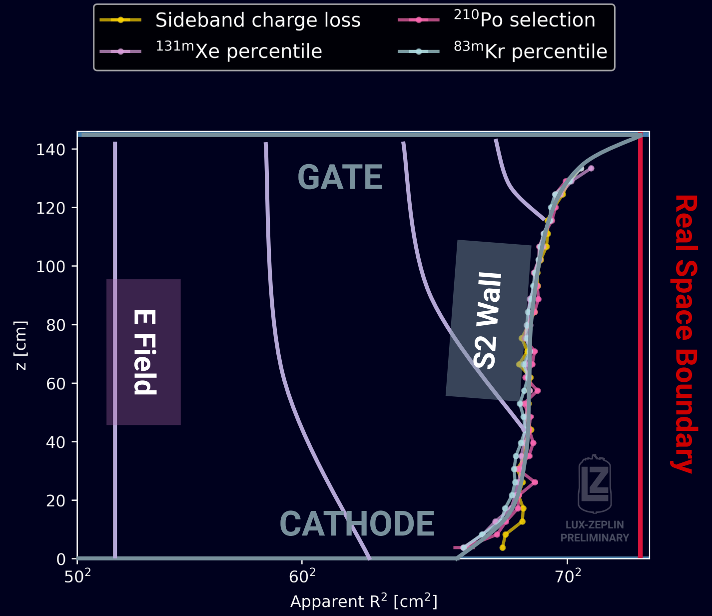
Select **cathode** and **gate alpha** populations:

- Point-like interactions
- Gate: S2 pulses minimally affected due to diffusion

- **Non-trivial relationship** between **p,T** and **drift velocity** in LXe
- **New parameterisation** was used in LZEF to improve data-sims max drift time match
- This is consistent with Cohen-Lekner's theory of two free mean paths
  - **Energy transfer Λ_0** (structure-independent)
  - **Momentum transfer Λ_1** (structure-dependent therefore field-dependent)

ELECTRIC FIELDS| VALIDATION 2





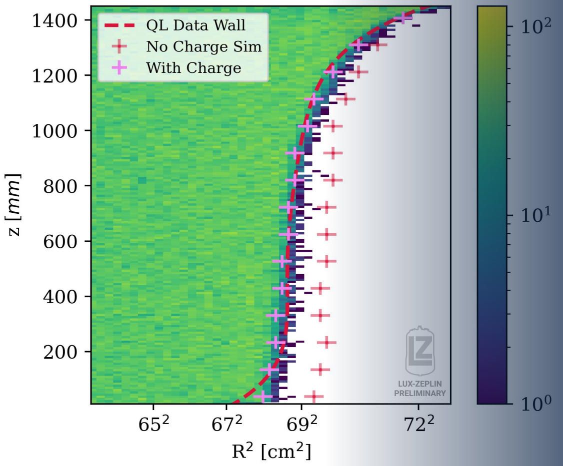
- S-shape of wall in S2-reconstructed space due to field inhomogeneities, ICV shape & diffusion

- **Field map** informs the translation between **S2 r & physical r** via the **drift map**

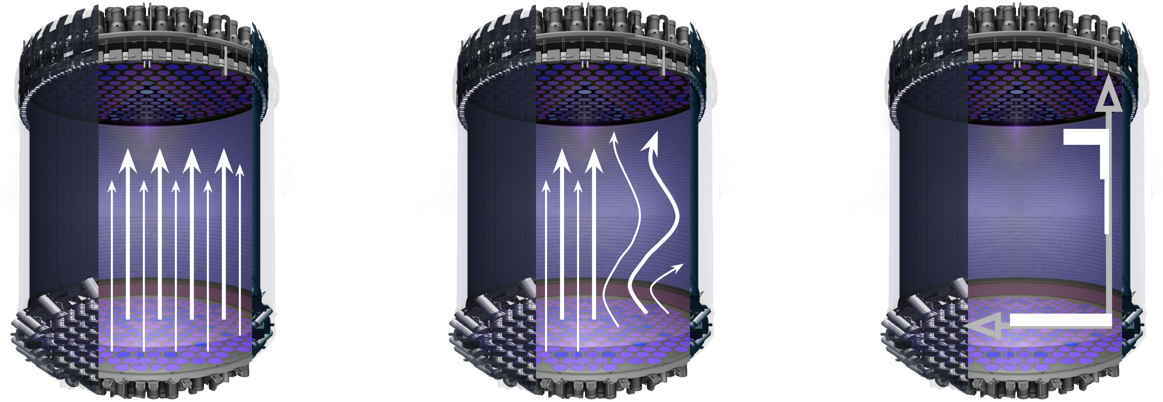
PTFE CHARGE ACCUMULATION

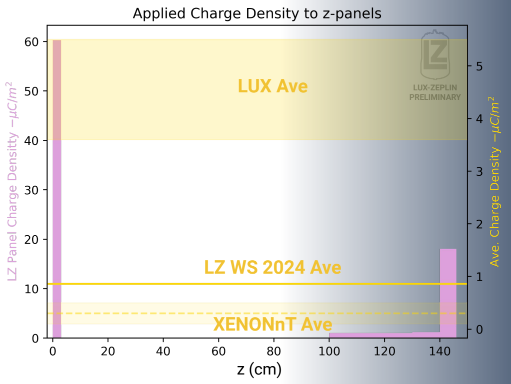
- **Hypothesis:** Electrons **attracted to PTFE**, wall ‘charging’?

- Apply **charge density** on **rings** in **drift time slices** on the **PTFE walls**
- **Minimise residual** of sims vs data wall boundary calculation



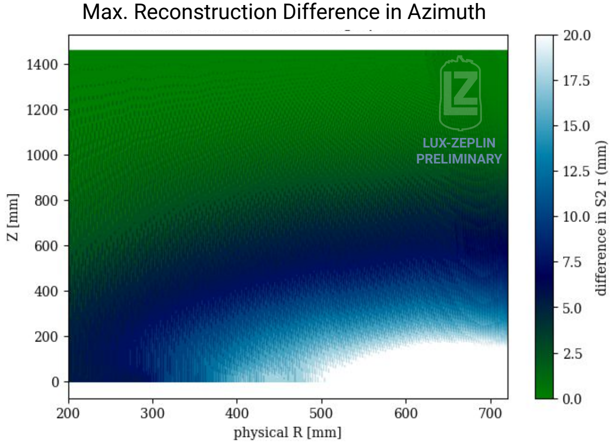
No Wall Charge **Wall Charge** **Distribution**

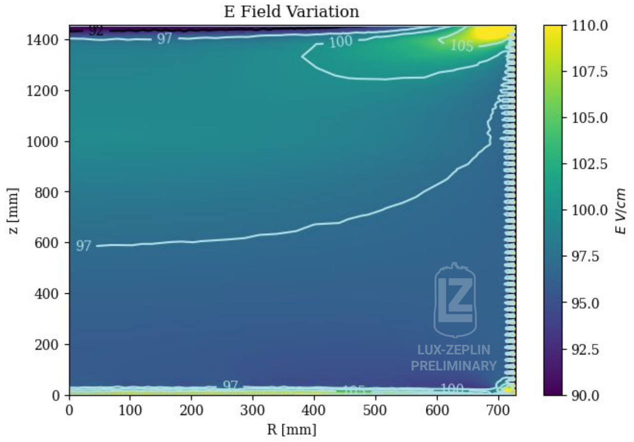


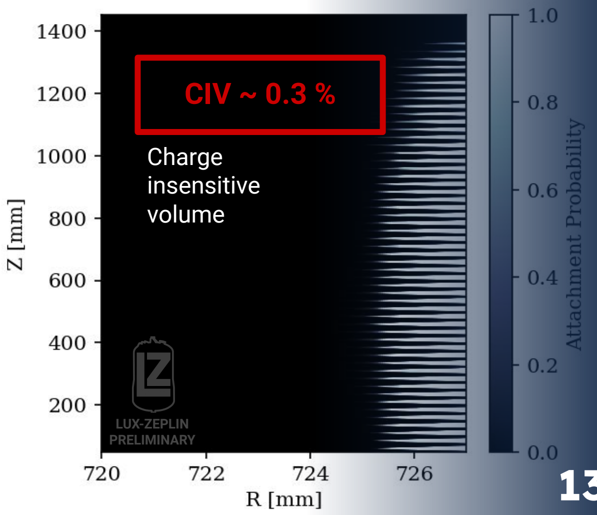


PTFE CHARGE ACCUMULATION

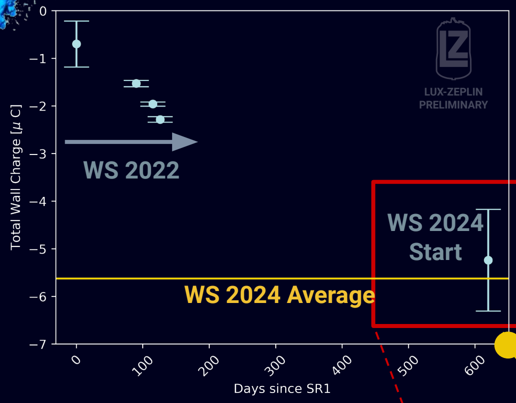
- Left **Effect of variation in position reconstruction for varying E field configurations**
- Field map middle shows variation of field with r (**negligible < 1%**) & z (**~18%**)
- **Attachment Probability** right: The probability that an electron generated at a certain point in r,z gets "lost" to the wall (i.e. doesn't make it up to the ER)



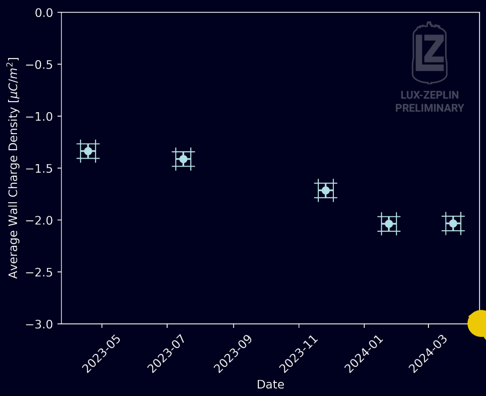




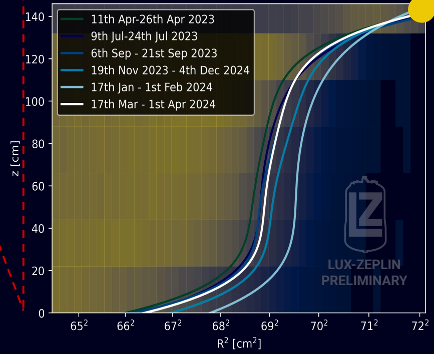
PTFE CHARGE DYNAMICS



- **PTFE charge build up** evident from charge density profiles required for **"wall match"**
- From WS 2022 → WS 2024 the required charge increases



- Within WS 2024, there is a period of time where the wall appears to **"discharge"**



- Average charge density in fact continues to **increase**
- Very localised high-density region of charge required to produce the observed wall position

ELECTRIC FIELDS| VALIDATION 3

Max dt vs field

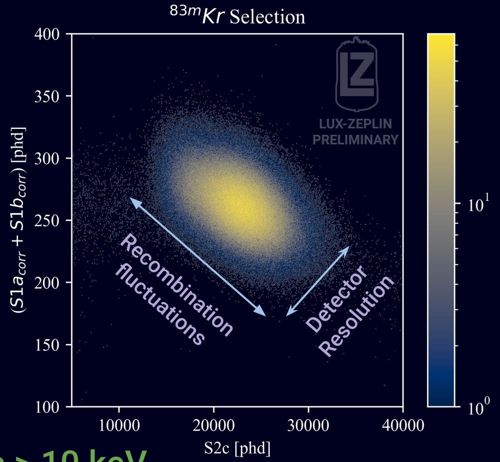
Wall Position

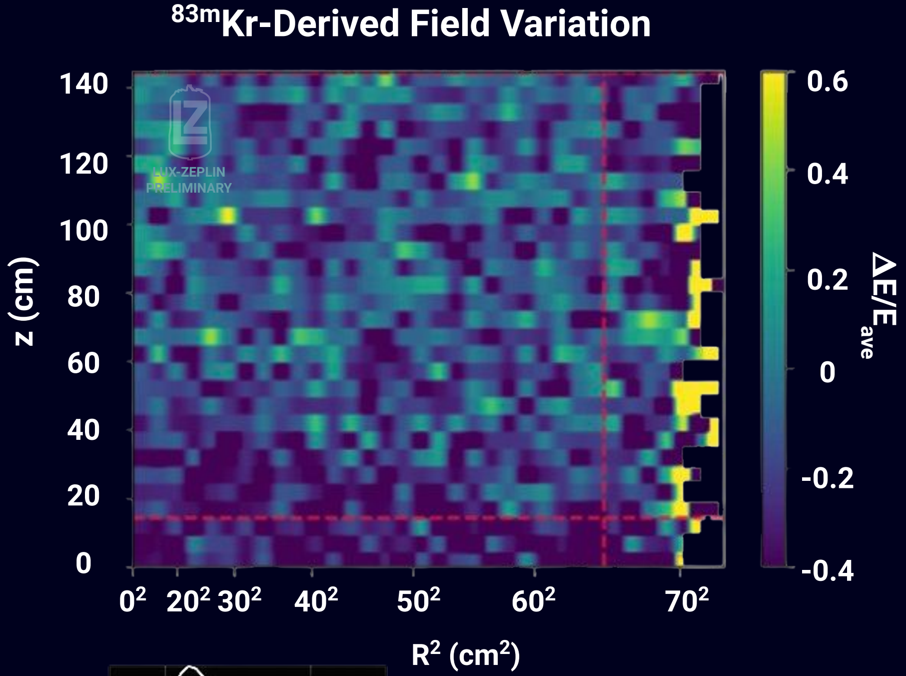
Field Variation

- **Dispersed calibration sources** can be used to directly extract field maps too - a more apples-to-apples comparison, albeit with caveats

FIELDS FROM Kr83m

Cross-check simulations to data





- Field dep. kicks in for ERs > 10 keV
  - (low recombination)

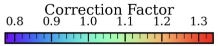
With a weaker field → more recombination

- S1 is enhanced
- So S2 is suppressed

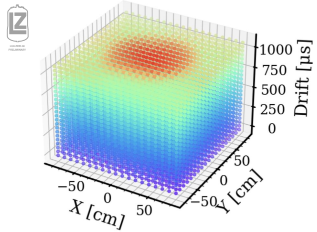
- ^{83m}Kr: S1b/S1a should increase with field
  - Ratio means S1 systematics "cancels"

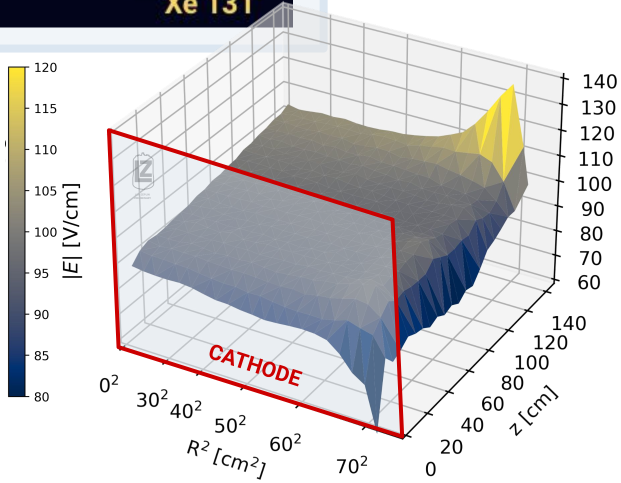
FIELDS FROM Xe131m

- Rn 222 alphas used to derive light collection efficiency as a function of xyz
- LCE-corrected S1 for Xe 131m reveals field dependence (ERs)



Rn 222 S1 Correction Map



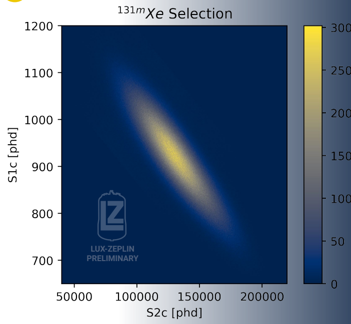


Kr 83m	Xe 131m	Sim ϕ-Ave.
97.0 ± 0.8	97.8 ± 0.4*	97.3 ± 2.2

FV-Averaged E Field (V/cm)

*Using NEST γ model

Xe 131m Selection



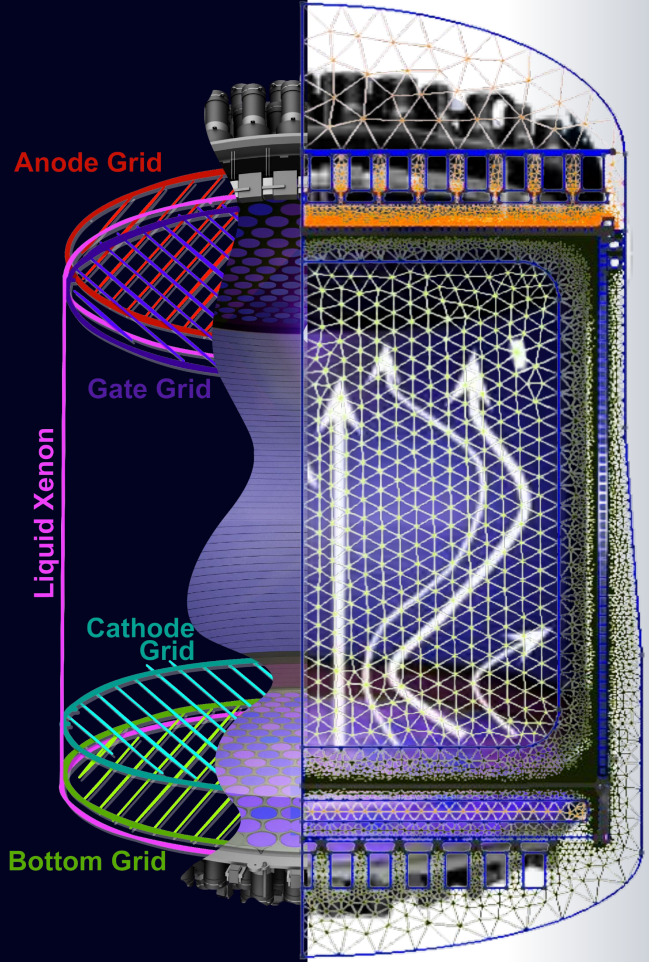
Non-Trivial!

Photon Yield - Field Relationship

		Energy (keV)	Photons (per 100 disint.)	
$\gamma_{1,0}$(Xe)		163,930 (8)	1,942 (26)	
XL	(Xe)	3,64 - 5,3	8,12 (16)	
$XK\alpha_2$	(Xe)	29,459	15,5 (4)	$K\alpha$
$XK\alpha_1$	(Xe)	29,779	28,7 (7)	
$XK\beta_3$	(Xe)	33,562		
$XK\beta_1$	(Xe)	33,625	8,31 (22)	$K'\beta_1$
$XK\beta_5''$	(Xe)	33,881		
$XK\beta_2$	(Xe)	34,415		
$XK\beta_4$	(Xe)	34,496	1,96 (7)	$K'\beta_2$
$XKO_{2,3}$	(Xe)	34,552		

CONCLUSIONS

- By considering PTFE's triboelectric properties, a close match has been achieved between the simulated and data-observed wall shapes
- Improved understanding of position reconstruction due to this!



- Updated drift velocity-field relationship also improves match to within 1%
- Kr83m and Xe131m injected calibration source recombination data derive field maps in agreement with each other
- Xe131m used for the first time to derive field maps

THANK YOU!

Swiss National Science Foundation

UKRI Science and Technology Facilities Council

ibs Institute for Basic Science

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References

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LZ Design Report| arxiv 1703.09144
LZ First Results| arxiv 2207.03764 | https://doi.org/10.1103/PhysRevLett.131.041002
LZ Backgrounds| arxiv 2211.17120 | https://doi.org/10.1103/PhysRevD.108.012010
Cohen, Lekner Theory of Hot Electrons| https://journals.aps.org/pr/pdf/10.1103/PhysRev.158.305

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