Characterising Electric Fields in the LUX-ZEPLIN Experiment

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Joint APP, HEPP & NP Conference
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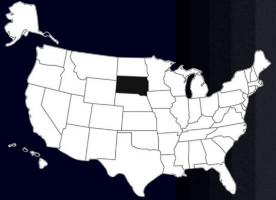
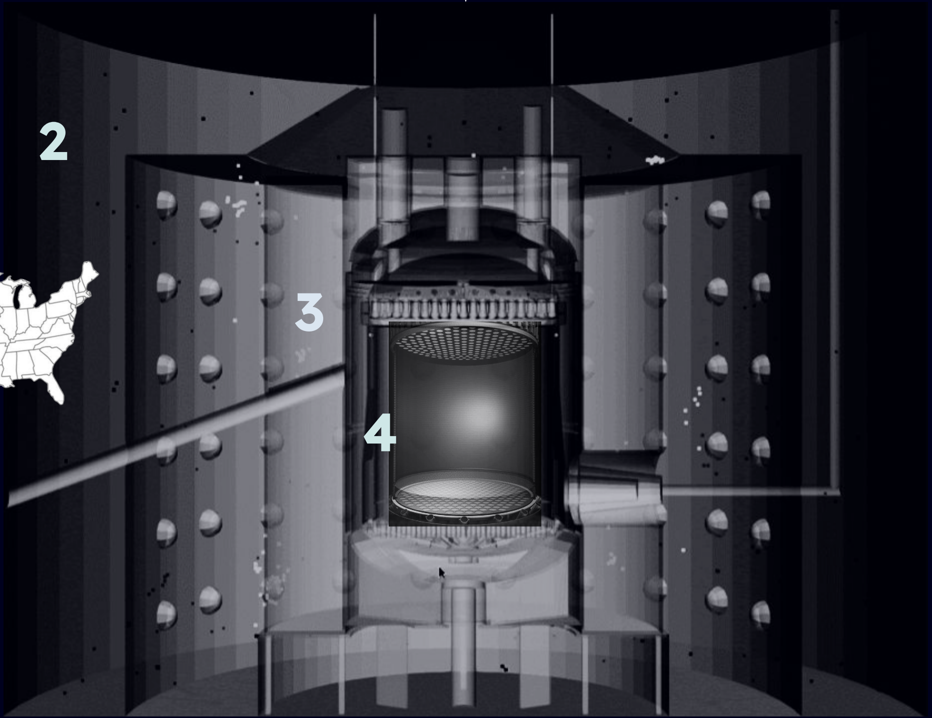
The LUX-ZEPLIN Experiment

4850 ft below surface 1

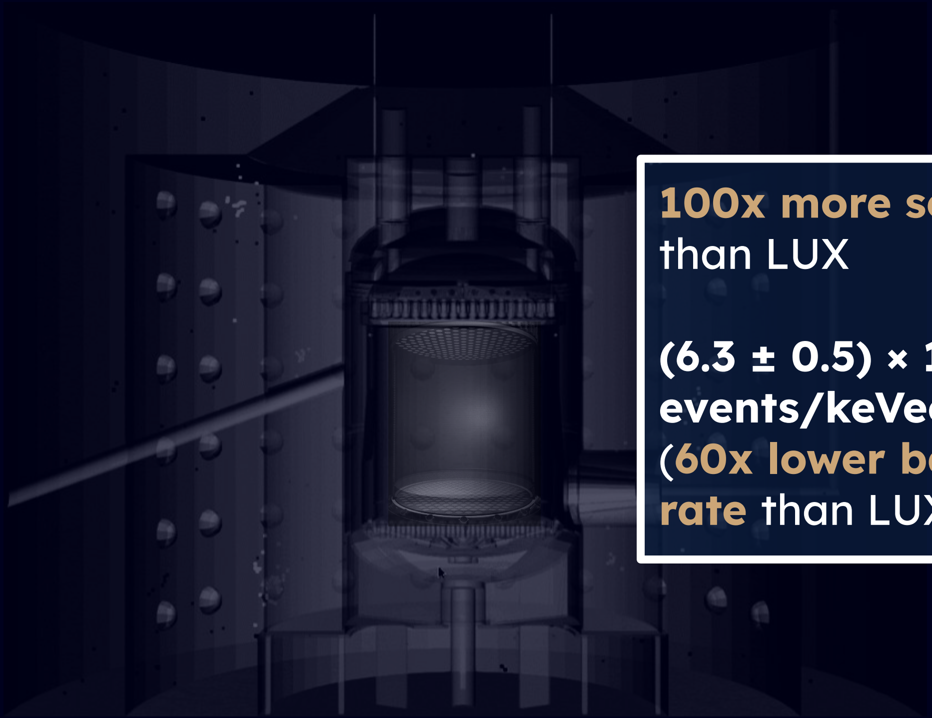
- Sanford Underground Research Lab, SD, US





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

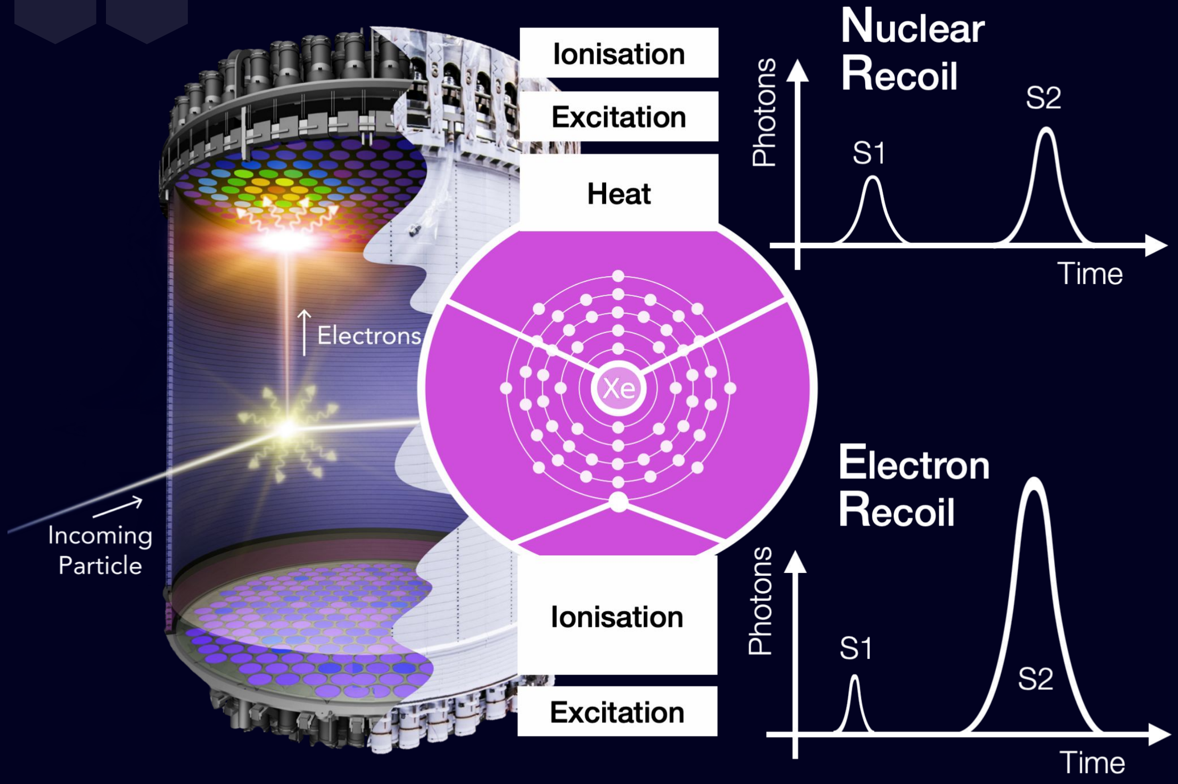
The LUX-Zeplin Experiment



100x more sensitive than LUX

$(6.3 \pm 0.5) \times 10^{-5}$ events/keVee/kg/day (**60x lower background rate** than LUX)

Dual Phase TPCs & Fields



For Single Scatters

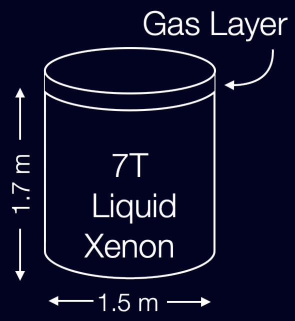
- 3D Event Reconstruction
  - **PMT Hit** Pattern → **xy**
  - **Drift Time** → **z**
- **S2:S1** → **Electronic Recoil (ER) vs Nuclear Recoil (NR)**

- **Recombination is field dependent!**
  - **Strong E field → more charge freed, less light**

- **ER-NR band positions in S1-S2 space changes**

LZ Electric Fields

Dual Phase



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

PMT Array

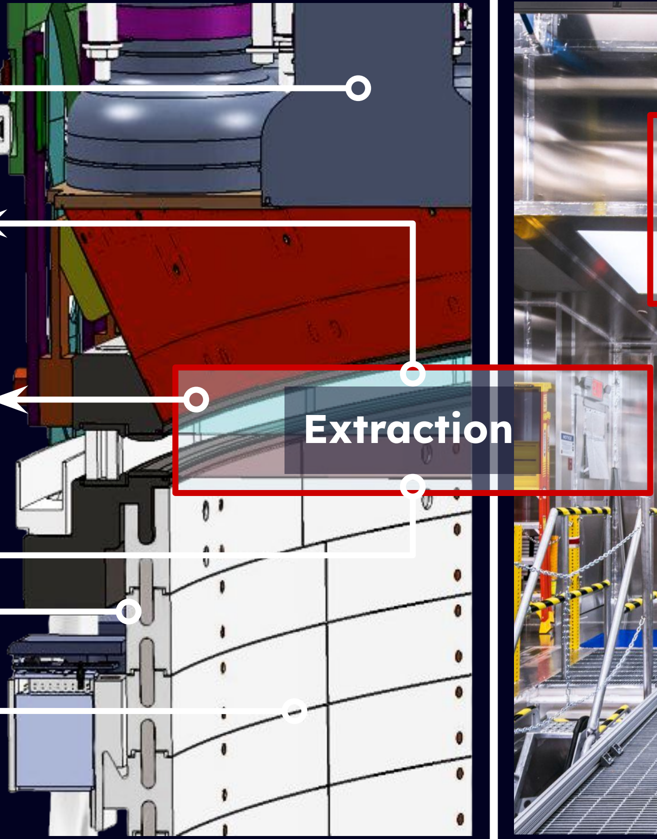
Anode Mesh

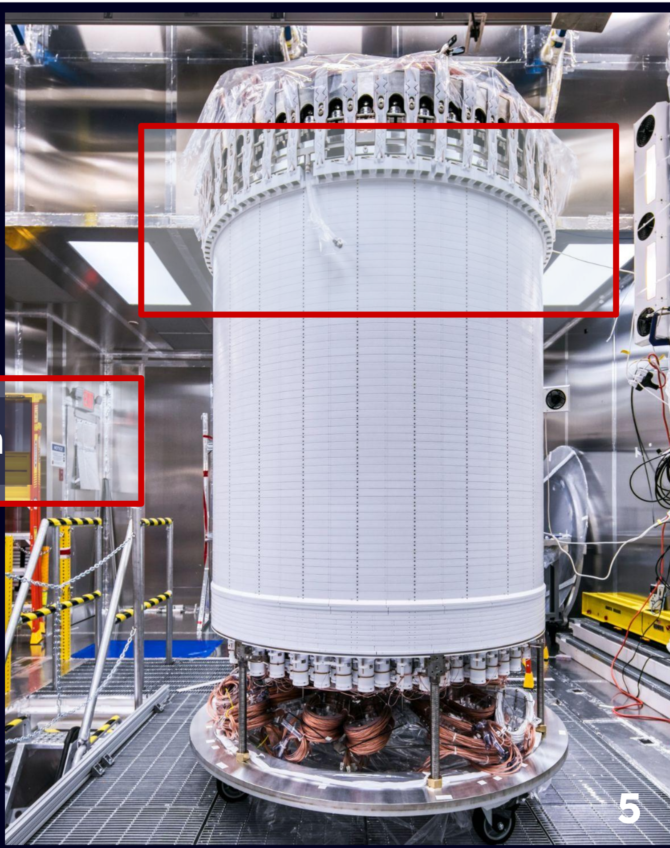
PEEK Spacer
Polyether ether ketone

Gate Mesh

Field Rings

PTFE
Polytetrafluoroethylene (Teflon)



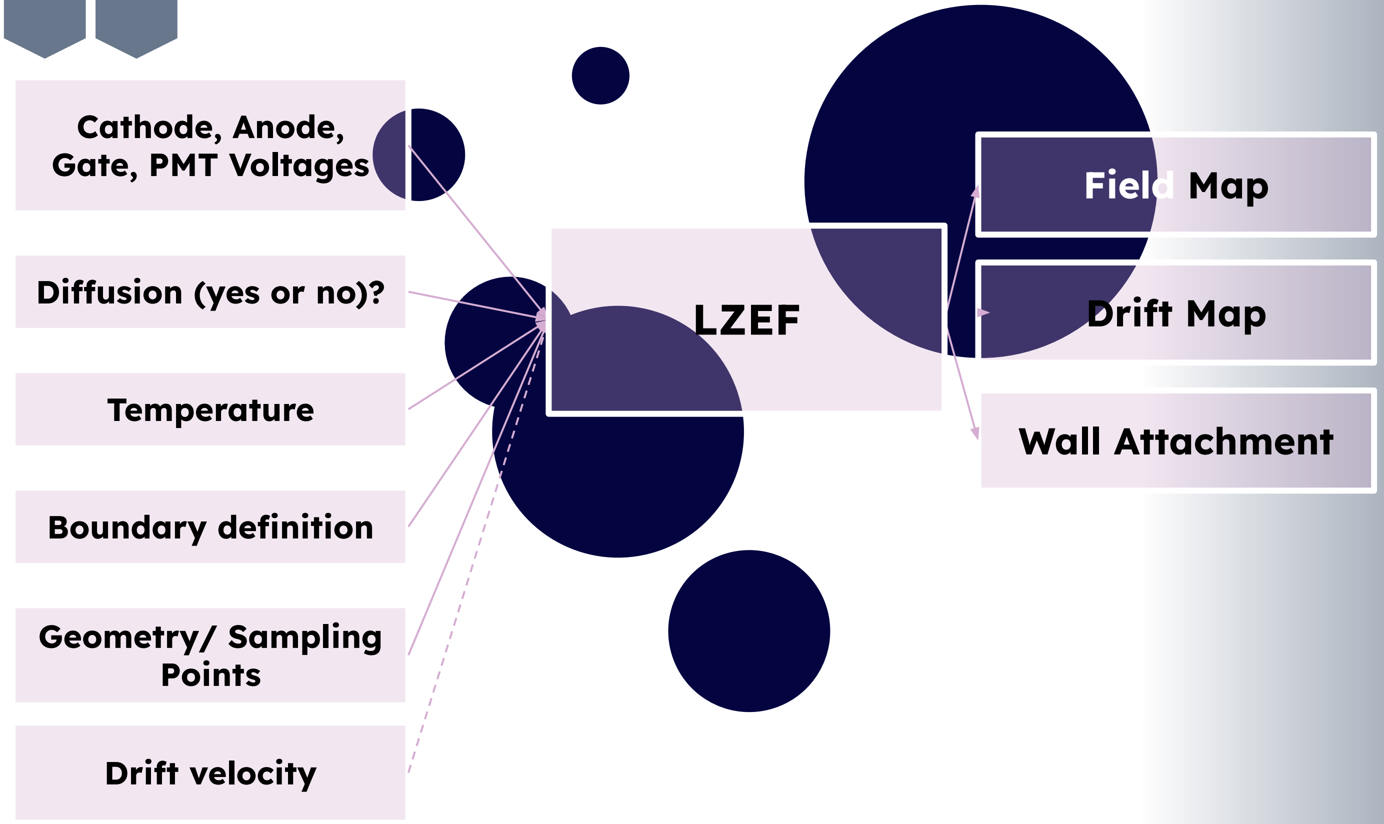


THE LZ ELECTRIC FIELDS PACKAGE

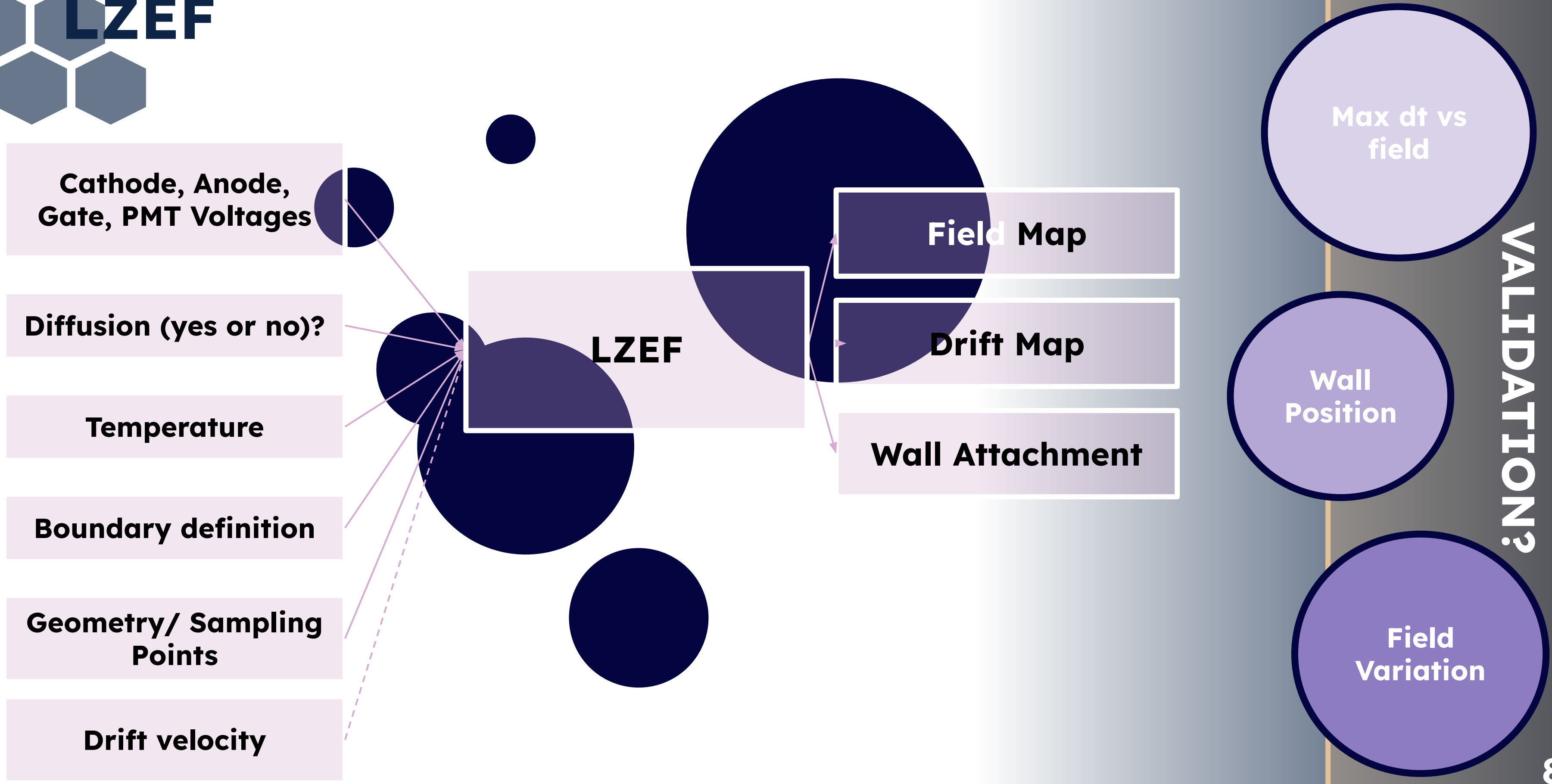
- Cathode, Anode, Gate, PMT Voltages
- Diffusion (yes or no)?
- Temperature
- Boundary definition
- Geometry/ Sampling Points
- Drift velocity

LZEF

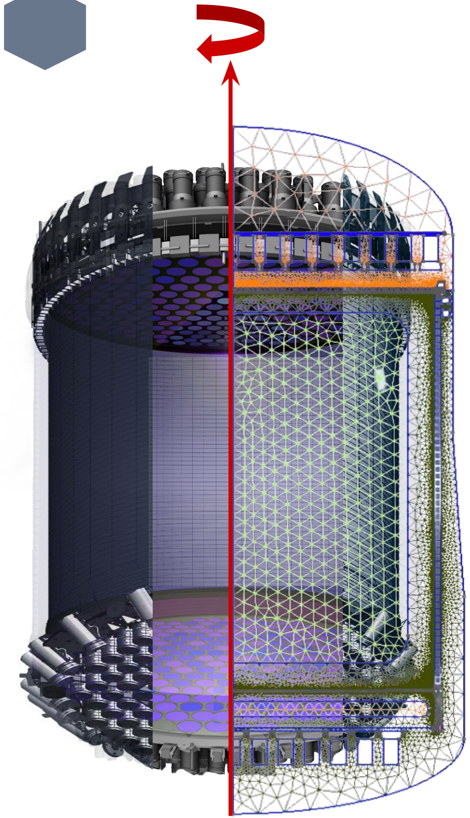
LZEF


Cathode, Anode, Gate, PMT Voltages
Diffusion (yes or no)?
Temperature
Boundary definition
Geometry/ Sampling Points
Drift velocity
LZEF
Field Map
Drift Map
Wall Attachment

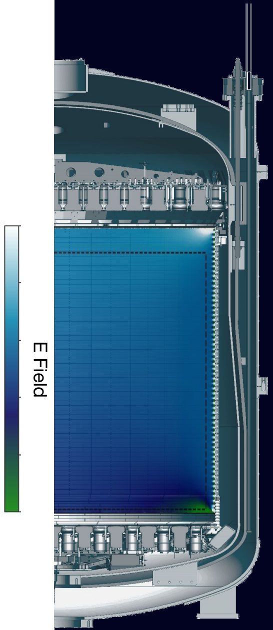
LZEF


Cathode, Anode, Gate, PMT Voltages
Diffusion (yes or no)?
Temperature
Boundary definition
Geometry/ Sampling Points
Drift velocity
LZEF
Field Map
Drift Map
Wall Attachment
Max dt vs field
Wall Position
Field Variation
VALIDATION?

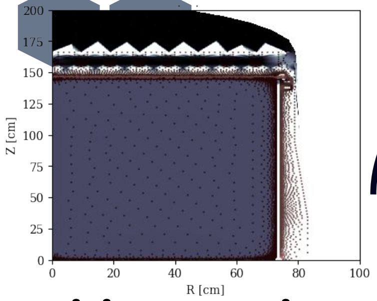
FINITE ELEMENT METHOD: FENICS



- 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

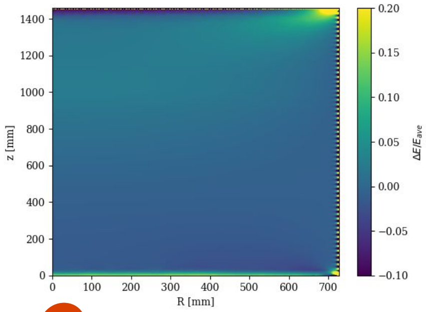


Interpolate fields

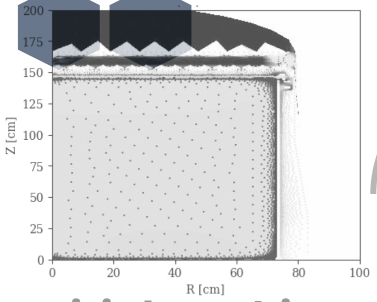


1 **Initial Meshing in GMSH**

Field Map

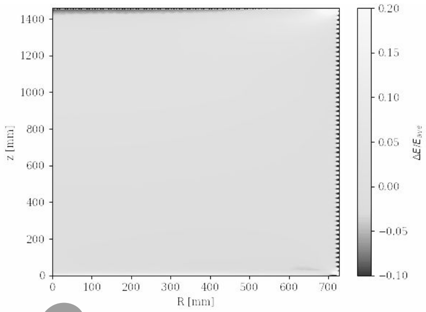


2 **FeniCS**



1 Initial Meshing in GMSH

Field Map

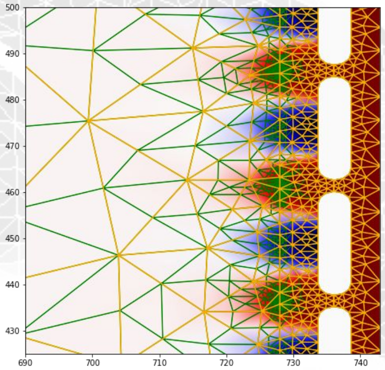


2 FeniCS

3 Delaunay Triangulation in QHULL: Re-Meshing

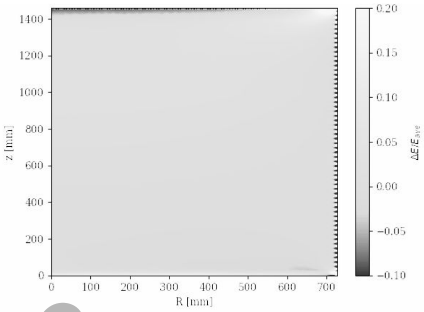
- Points are sampled from along field lines/ drift trajectories
- If field is very different to the mean field then tighter meshing

Towards more parallel field lines ← Region of greater irregularity

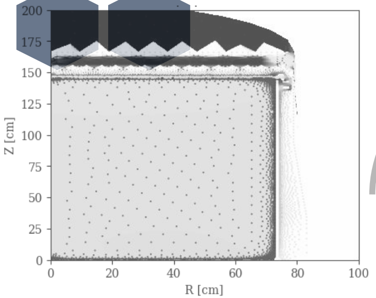


LZEF

Field Map

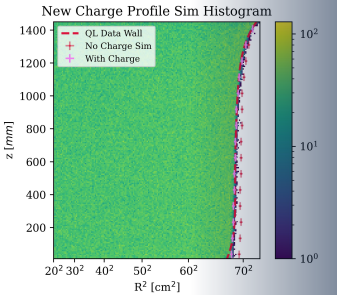


2 FeniCS



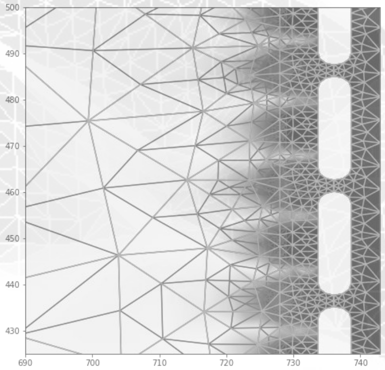
1 Initial Meshing in GMSH

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



Drift Map (S2 R) 4

Towards more parallel field lines ← Region of greater irregularity

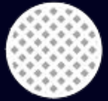


3 Delaunay Triangulation in QHULL: Re-Meshing

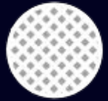
- Points are sampled from along field lines/ drift trajectories
- If field is very different to the mean field then tighter meshing

More Model Details

Anode
Woven mesh
Pitch: 2.5 mm
Diameter: 100 µm
+5.75 kV

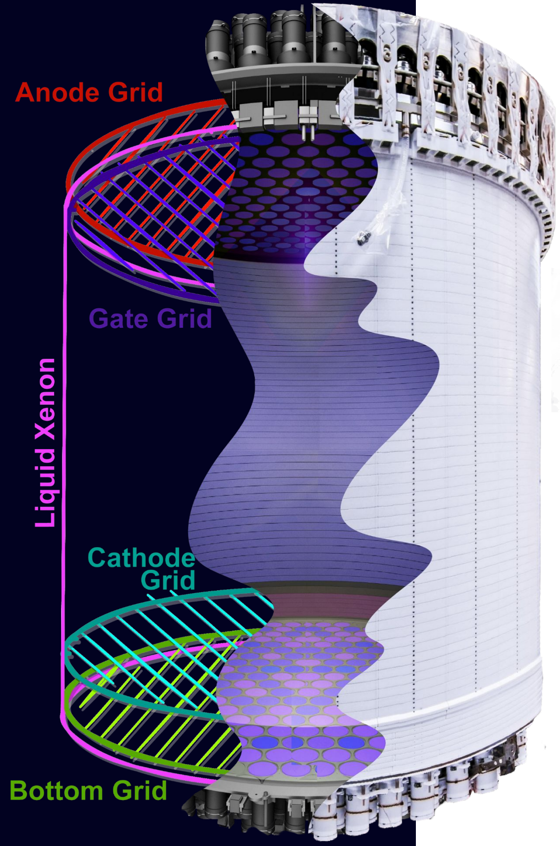


Gate
Woven mesh
Pitch: 5 mm
Diameter: 75 µm
-5.75 kV

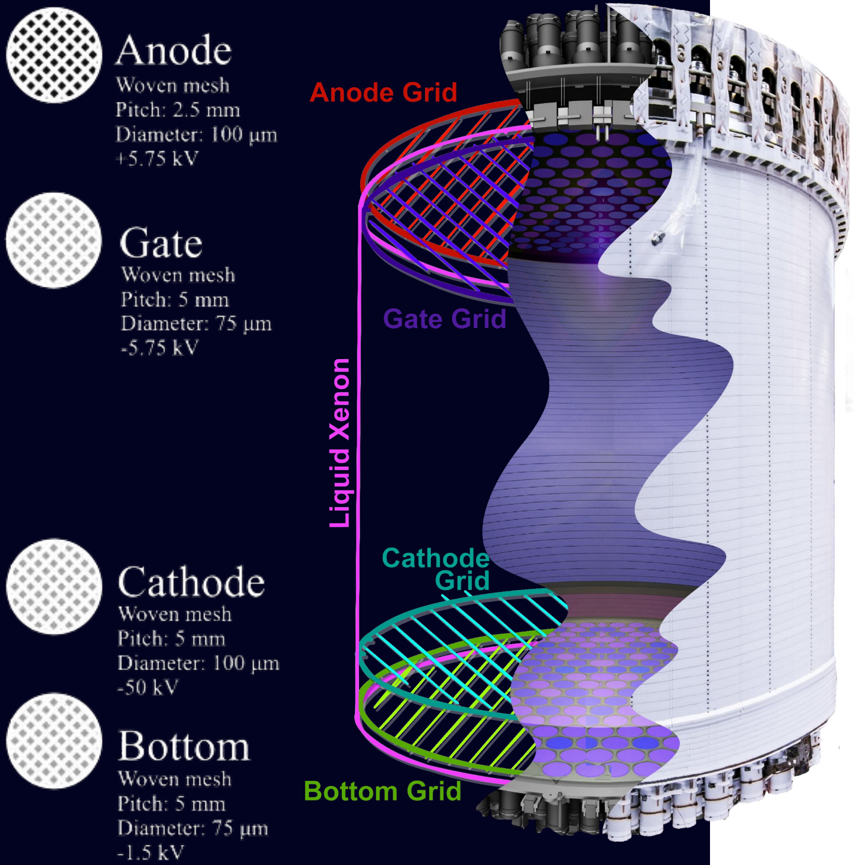


Cathode
Woven mesh
Pitch: 5 mm
Diameter: 100 µm
-50 kV

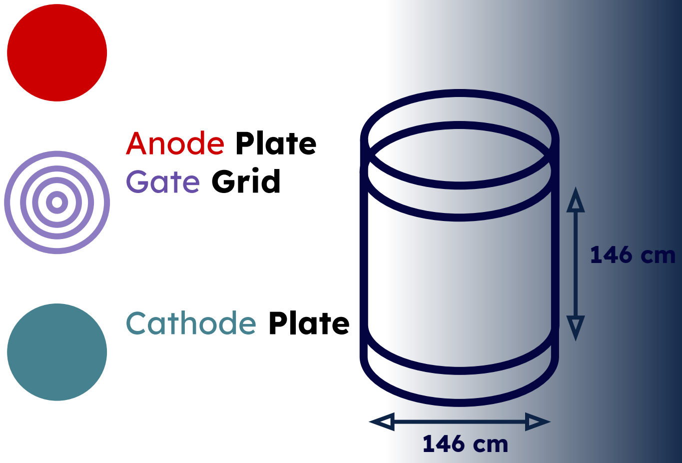
Bottom
Woven mesh
Pitch: 5 mm
Diameter: 75 µm
-1.5 kV



MORE MODEL DETAILS



- **Axisymmetric** (PMTs = annulus, wires = rings)



- Anode **plate** → **correction to gate voltage** to reproduce the correct fields
- **Woven** → **Concentric** grids requires **½ pitch** to reproduce correct fields > 1 pitch from grids

More Model Details

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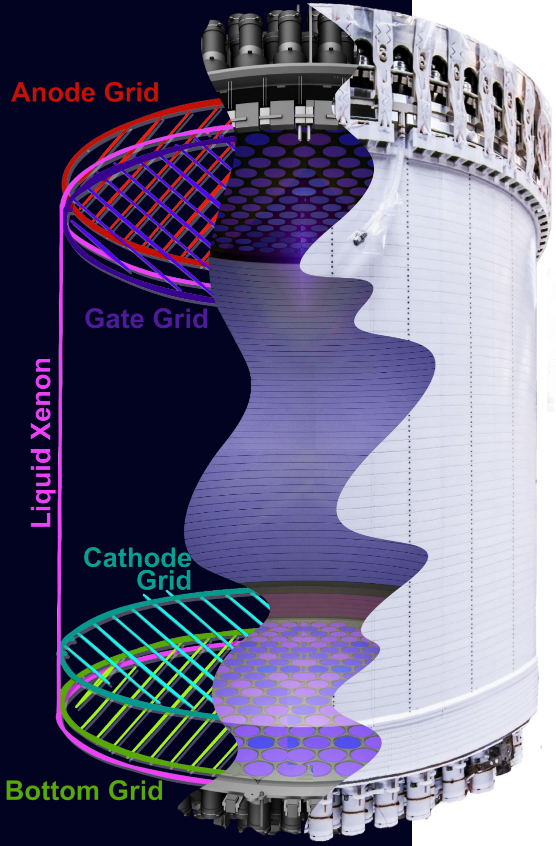
Woven mesh
Pitch: 2.5 mm
Diameter: 100 µm
+5.75 kV

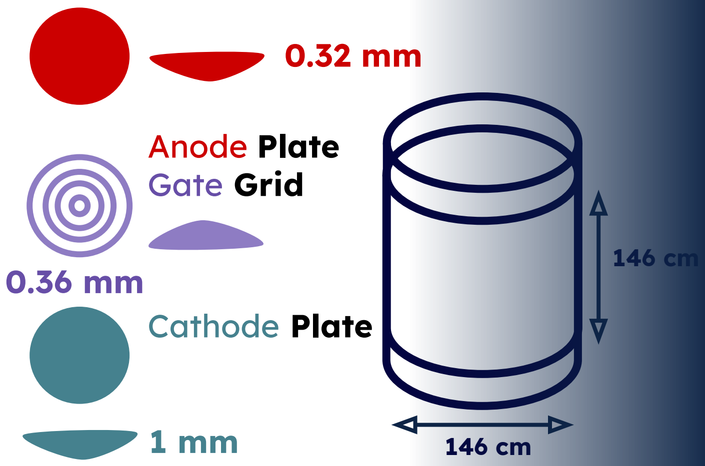
Gate
Woven mesh
Pitch: 5 mm
Diameter: 75 µm
-5.75 kV

Cathode
Woven mesh
Pitch: 5 mm
Diameter: 100 µm
-50 kV

Bottom
Woven mesh
Pitch: 5 mm
Diameter: 75 µm
-1.5 kV



- Modelled with **deflection**

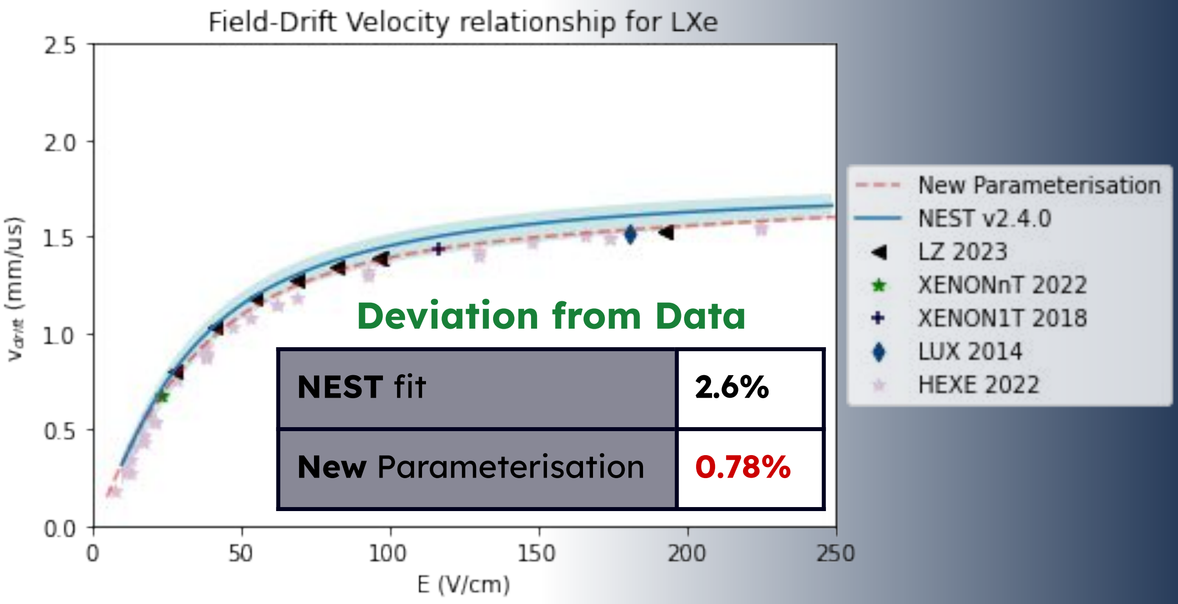


FIELD-VELOCITY RELATIONSHIP IN LXE

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

Select cathode and gate alpha populations:
- Point-like interactions
- Gate: S2 pulses minimally affected due to diffusion

- **Non-trivial relationship** between **p,T,V** and **drift velocity** in LXe
- Can see slight deviation from **NEST** (blue line & band)
- **New parameterisation** was used in LZEF to improve data-sims max drift time match



Deviation from Data

NEST fit	**2.6%**
New Parameterisation	**0.78%**

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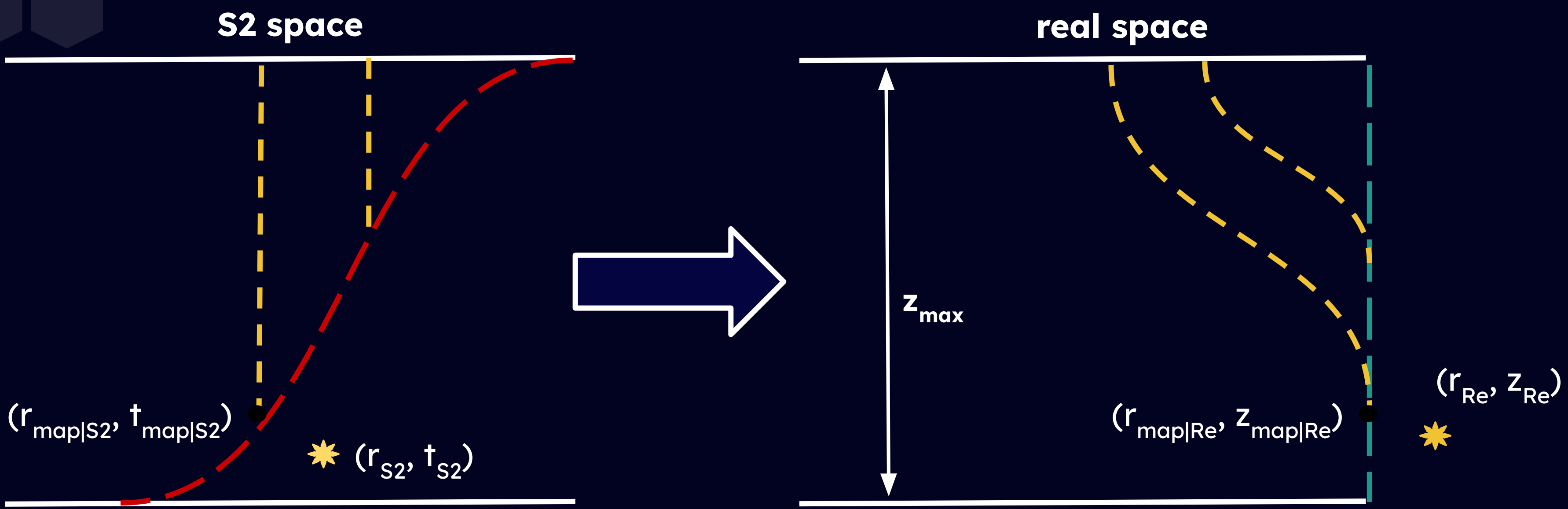
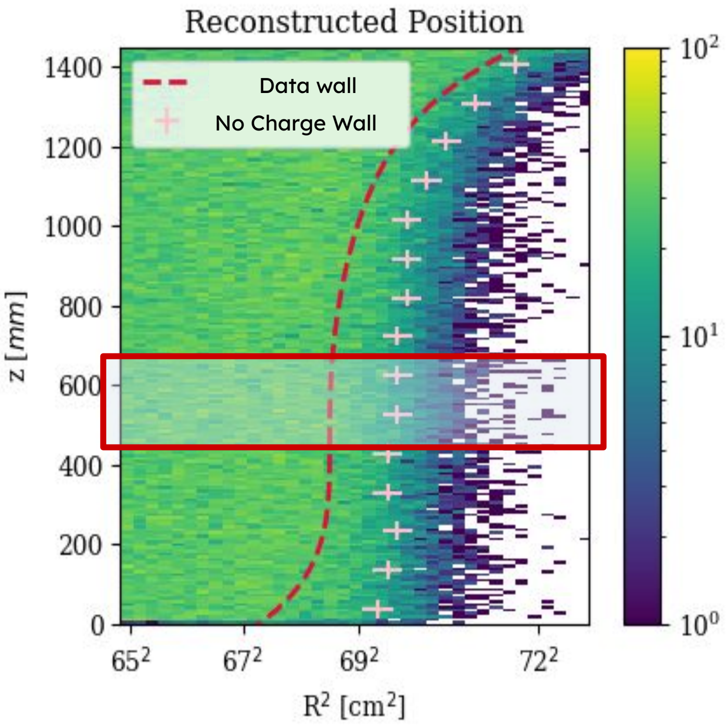
THE WALL



- 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**

DATA-SIMS COMPARISON

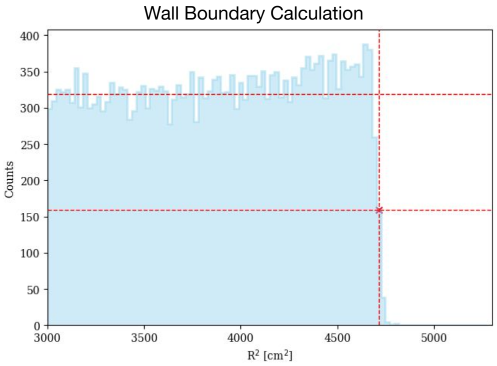
- Can simulate wall position & compare with data

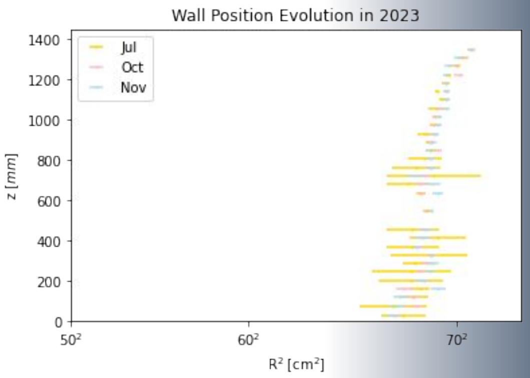


- **Calculation:** *Middle* Radial distribution half max at drop off = wall radius for any drift time bin

- *Right* **No significant time evolution observed over 6 months in data,** we can try and replicate in simulations

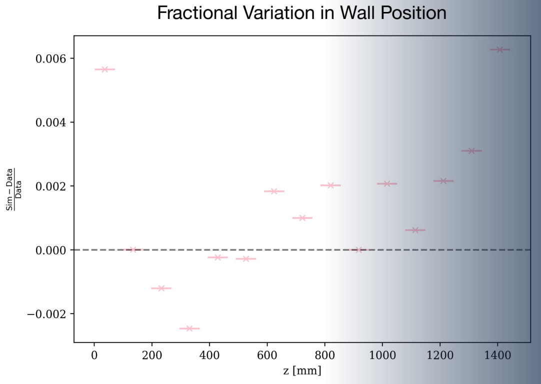
- *Left* Do the wall boundary **match** for simulations and data? ***NOT YET! What are we missing?***



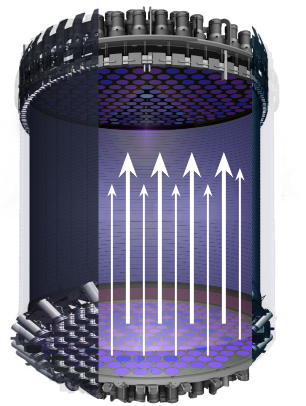


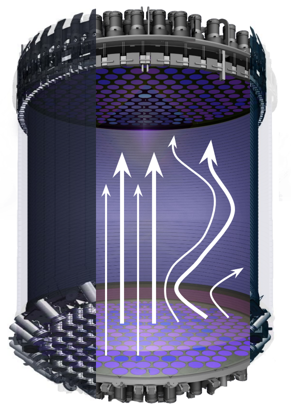
PTFE CHARGE ACCUMULATION

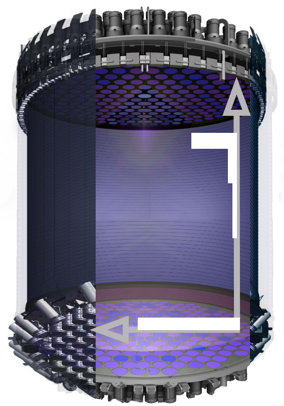
- **New Hypothesis:** Electrons **attracted to PTFE**, wall charging?
- Apply **charge density** on **rings** in **drift time slices** on the **PTFE walls**
- **Minimise residual** of sims vs data wall boundary calculation

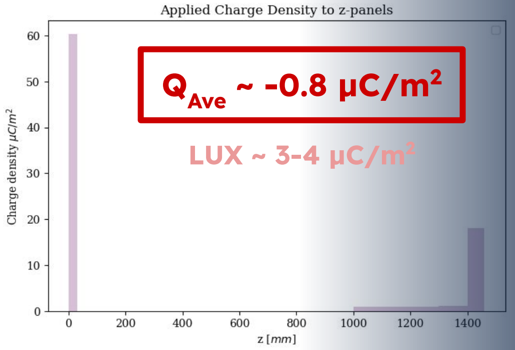


No Wall Charge | **Wall Charge** | **Distribution**



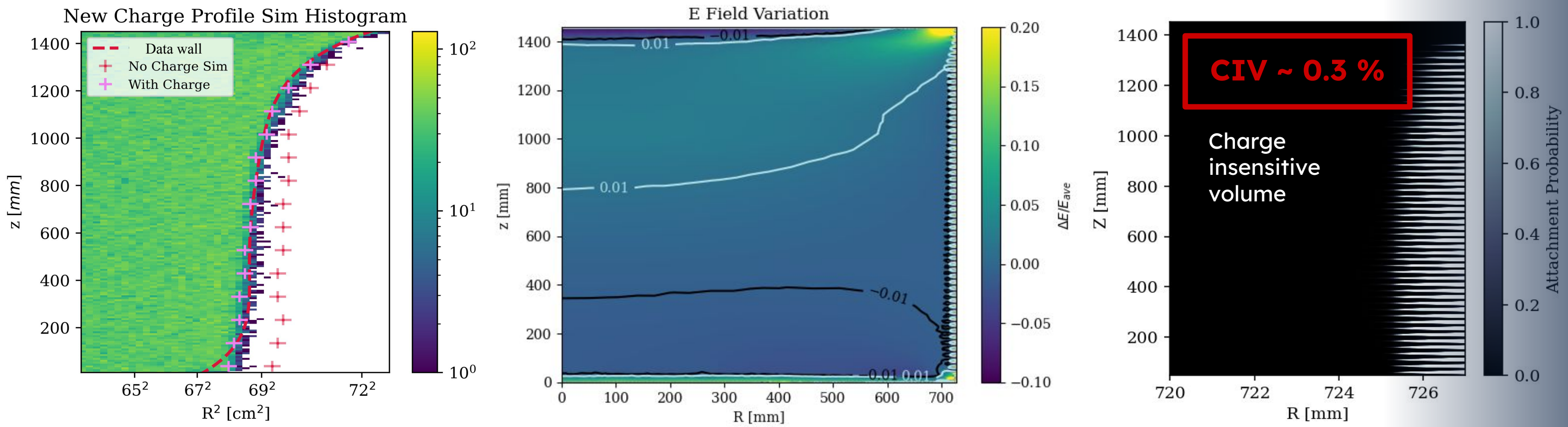






PTFE Charge Accumulation

- *Left* **Agreement between the simulated and observed data wall positions!**
- 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)



^{83m}KR COMPARISON

Recombination is E field dependent:

- Field dep. kicks in for ERs > 10 keV
  - (low recombination)
- In Kr83m, two decay modes
  - 32.1 keV (S1a) Field-dep.
  - 9.4 keV (S1b) ~Field-indep.

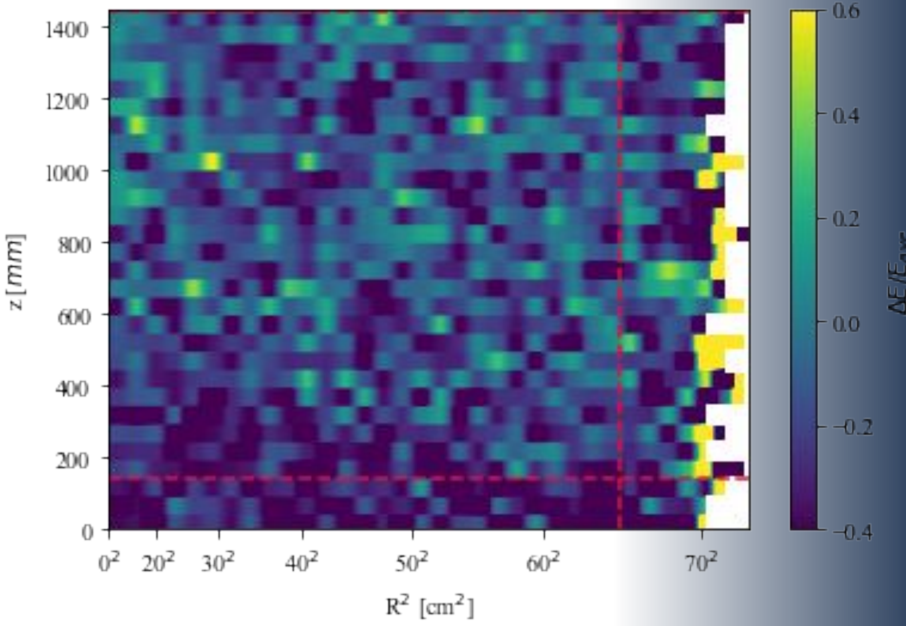
With a weaker field → more recombination

- S1 is enhanced
- So S2 is suppressed
- ^{83m}Kr: S1b/S1a should increase with field
  - Ratio means S1 systematics "cancels"

Cross-check simulations to data

Can see similar trend in field variation with r,z but what about the differences?

^{83m}Kr-Derived Field Variation

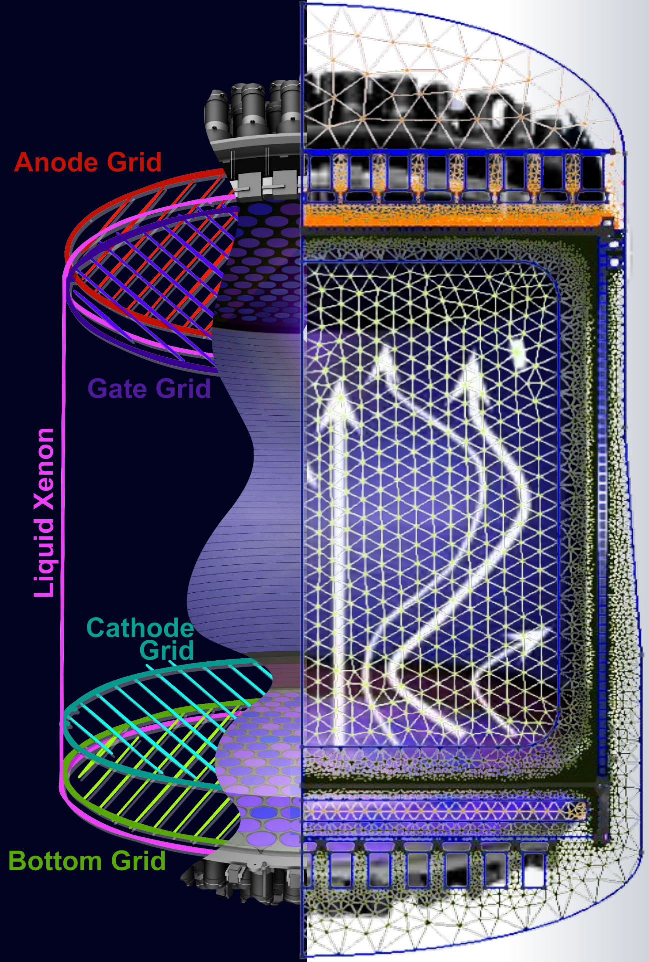


CONCLUSIONS

E fields are **important!**

- Changes in the wall position can affect the resulting field and drift maps significantly

- This **changes our understanding of reconstruction**, which could affect a WIMP search



Currently in LZ, we have achieved a **good match between simulations & data**

Time evolution and Φ dependent studies in progress

THANK YOU!

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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ibs Institute for Basic Science

Sanford Underground Research Facility

Black Hills State University
Brookhaven National Laboratory
Brown University
Center for Underground Physics
Edinburgh University
Fermi National Accelerator Lab.
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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
South Dakota Science & Technology Authority
STFC Rutherford Appleton Lab.
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University of Alabama
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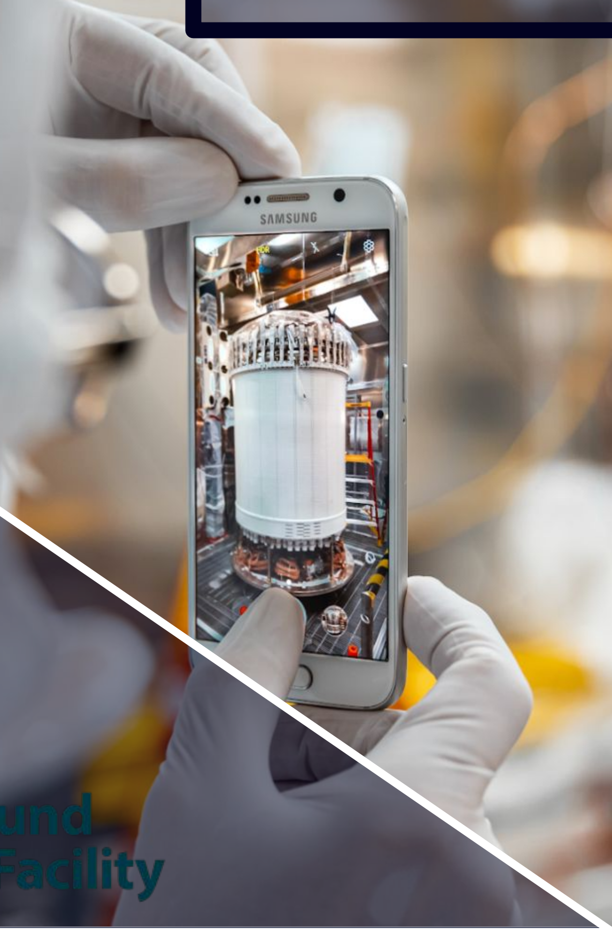
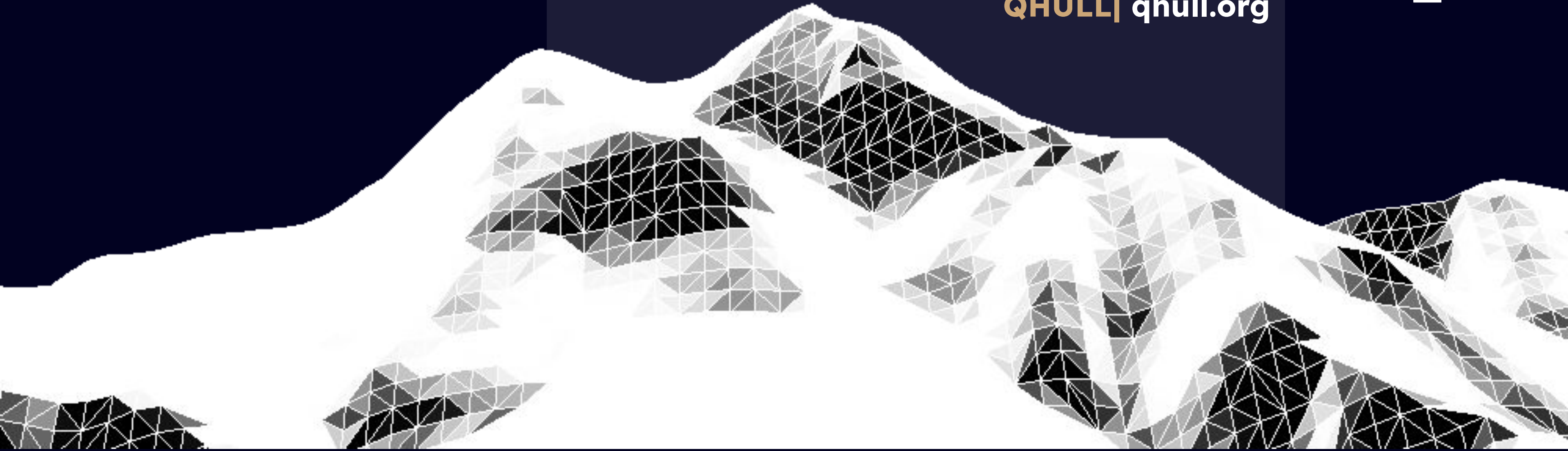


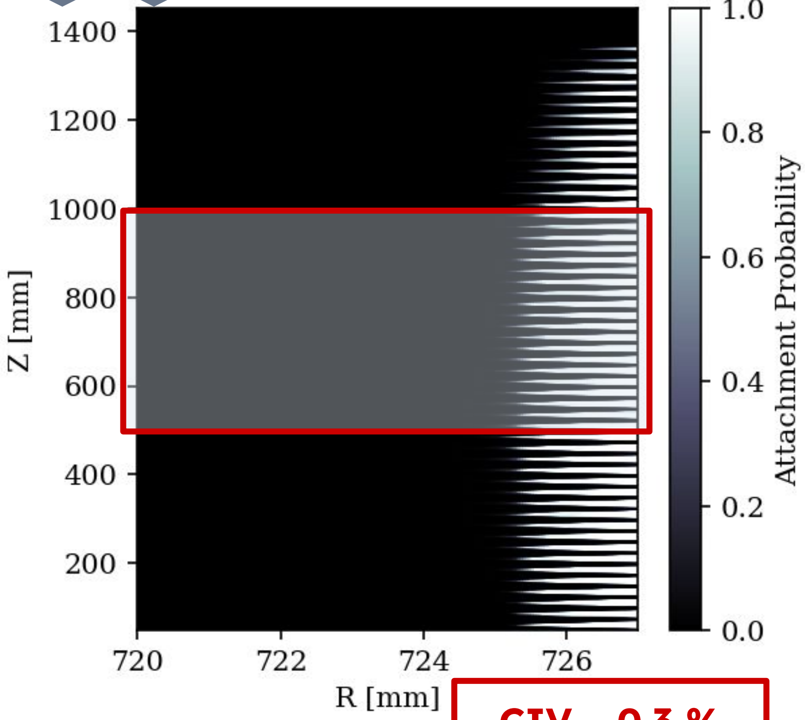
References

LZ Grids| arxiv 2106.06622
LZ Design Report| arxiv 1703.09144
LZ First Results| arxiv 2207.03764
LZ Backgrounds| arxiv 2211.17120

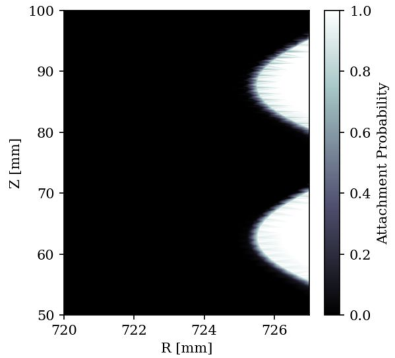
FeniCS| fenicsproject.org
GMSH| gmsh.info
QHULL| qhull.org

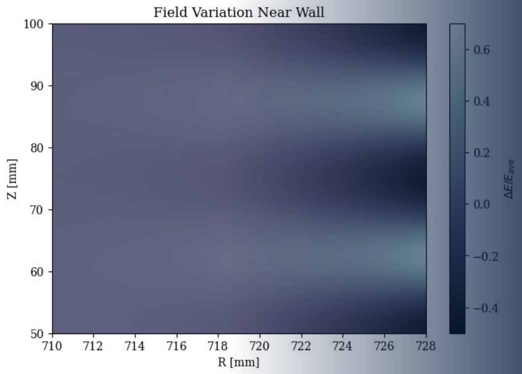


WALL ATTACHMENT



CIV ~ 0.3 %





Field shaping rings → **scalloping** *right*

- Potential wells forming trapping electrons
- Pure geometric effect

With **charge on PTFE, wells enhanced**
Also charge loss from events near wall

- Pb-206, U-238, Th-232, Co-60 on wall
- Rn and Xe daughters near wall