# Investigation of the electric field uniformity in the ReD detector


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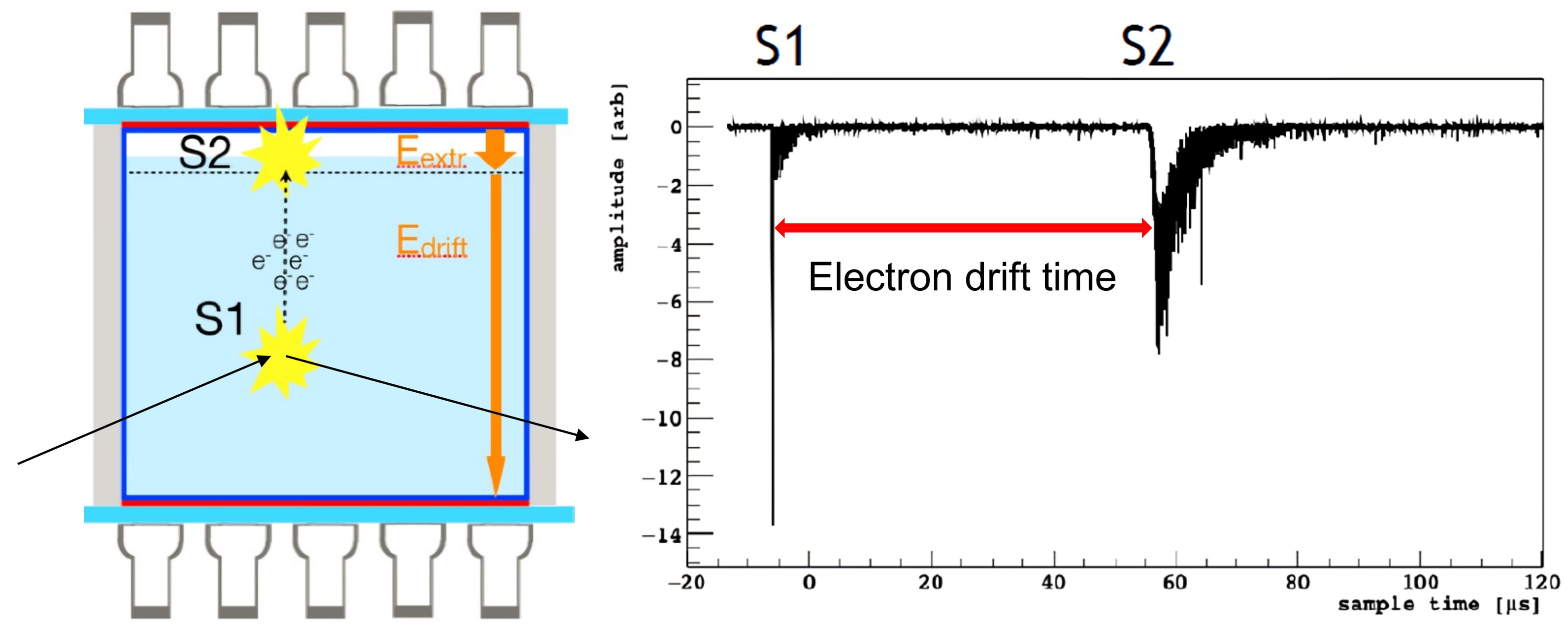
## Introduction

Dark matter remains one of the fundamental problems of particle physics and cosmology that is not explained in the Standard Model (SM). Today, the direct search for dark matter constrains the remaining available parameter space of WIMP mass and spin-independent WIMP cross section.

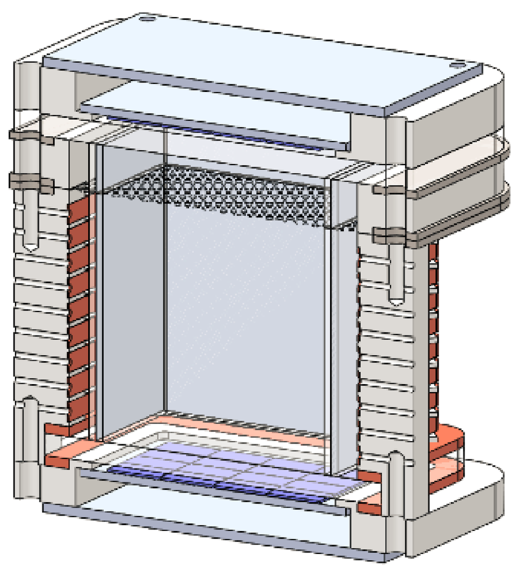



The principle of operation of a two-phase detector

For low mass WIMPs, the strongest limits are obtained using the noble liquid time projection chambers (TPCs) [1,2]. The signal in a dual-phase TPC is observed both from excitation, which results in a direct scintillation, and from ionization of argon. Part of the electron-ion pairs recombine, and the remaining free electrons are drifted towards the liquid surface, by an applied electric field, and are extracted into the gas phase. In the so-called gas pocket, electrons, further accelerated by a stronger electric field, excite the gas atoms producing a secondary scintillation via electroluminescence. The light signals emitted in liquid argon and in gas are called $S1$ and $S2$, respectively. To accurately reconstruct the position of recoil events, it is necessary to know the exact parameters of the electric field in the TPC. Accordingly, the drift field should be as uniform as possible within the drift volume.

## Recoil Directionality Experiment

WIMP directional information is potentially available in a dual-phase Liquid Argon Time Projection Chamber (LAr TPC) by exploiting the recombination effect. Columnar recombination models suggest that the magnitude of the recombination effect should vary with the angle between the field and the track direction. A difference in the electron-ion recombination effect is expected when the ionizing track is either parallel or perpendicular to the electric field.



Schematic drawing of a cross section of the ReD dual-phase LAr TPC

The main goal of the ReD experiment is to demonstrate the WIMP directional sensitivity by using a small scale, dual-phase LAr TPC. The TPC has drift area 5×5×5 cm³ and 5×5×1 cm³ diving bell area, where the gas pocket is formed. The electric fields in the drift area and the diving bell area are separated by an grounded hexagonal grid with 2 mm pitch. The active volume of the detector is enclosed by vertical acrylic-ESR sandwich reflection panels, and by two acrylic windows, on the top (anode) and bottom (cathode). Field uniformity in the drift area is ensured by copper field forming rings.

This report presents the results of modeling the drift field in the TPC for the ReD experiment to determine the potentials of the anode, cathode and rings that provide a homogeneous electrical field in the detector chamber.

## Electric field calculation

To calculate the electric field in the first approximation, a 2D model was used. However, the obtained uniform configurations showed unsatisfactory results due to the limitation of the 2D model for physically correct calculation of the field leakage through the grid separating the drifting and extracted fields.

$$\phi_1 = (E_1 - E_2)s\chi_m + (E_1 + E_2)s\chi_d$$

$$\phi_2 = (E_1 - E_2)s\chi_m - (E_1 + E_2)s\chi_d$$

$$\chi_m = \frac{1}{4\pi}\ln\left(\frac{s}{\pi d}\right) + 0.07\left(\frac{d}{s}\right) + 0.4\left(\frac{d}{s}\right)^2$$

$$\chi_d = 0.25\left(\frac{d}{s}\right) - 0.5\left(\frac{d}{s}\right)^2$$

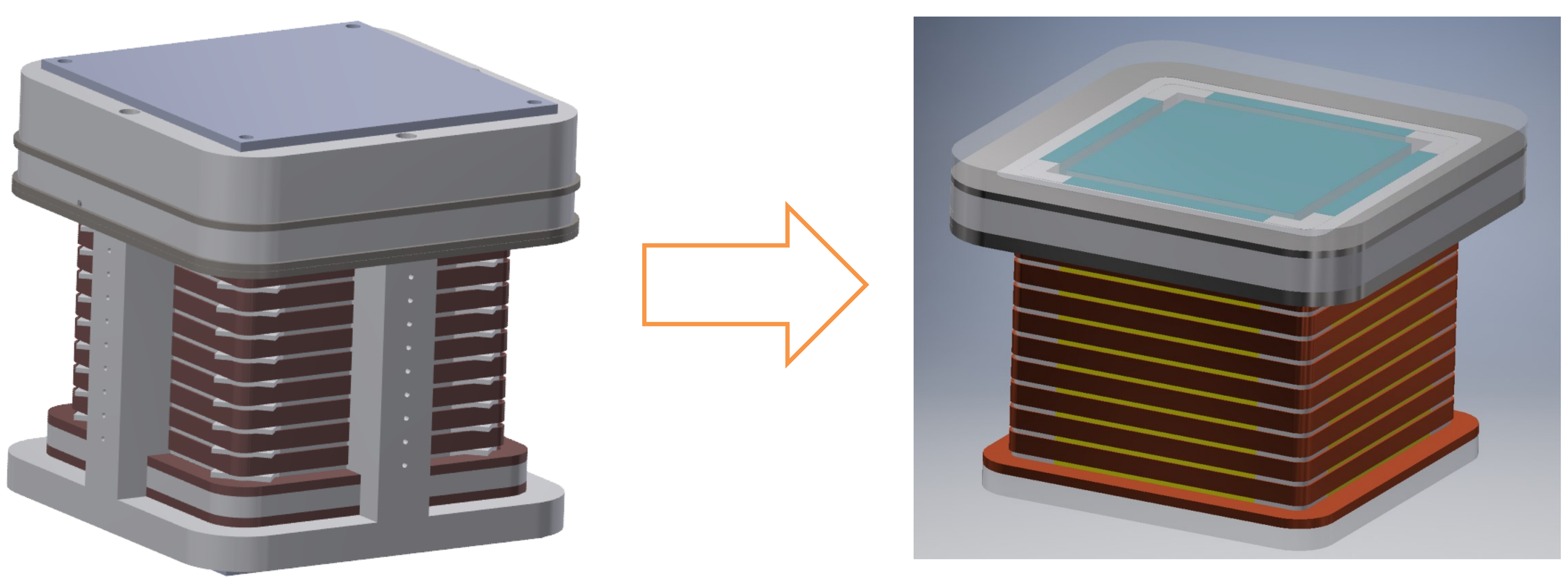
$\phi_1, \phi_2$ – average potentials on the grid surfaces; $E_1, E_2$ – electric field on the two sides of the grid; $s$ – grid pitch; $d$ – wires diameter.

To estimate the actual field leakage through the grid, a semi-empirical formula was used [3]. However, this method does not take into account the edge effects at the chamber walls. Moreover, since this estimate does not take into account the potentials of the field forming rings, it is also impossible to assess their effect on the uniformity of the field.

Thus, to accurately model the electric field in the detector chamber it is necessary to use the 3D model.

## 3D model

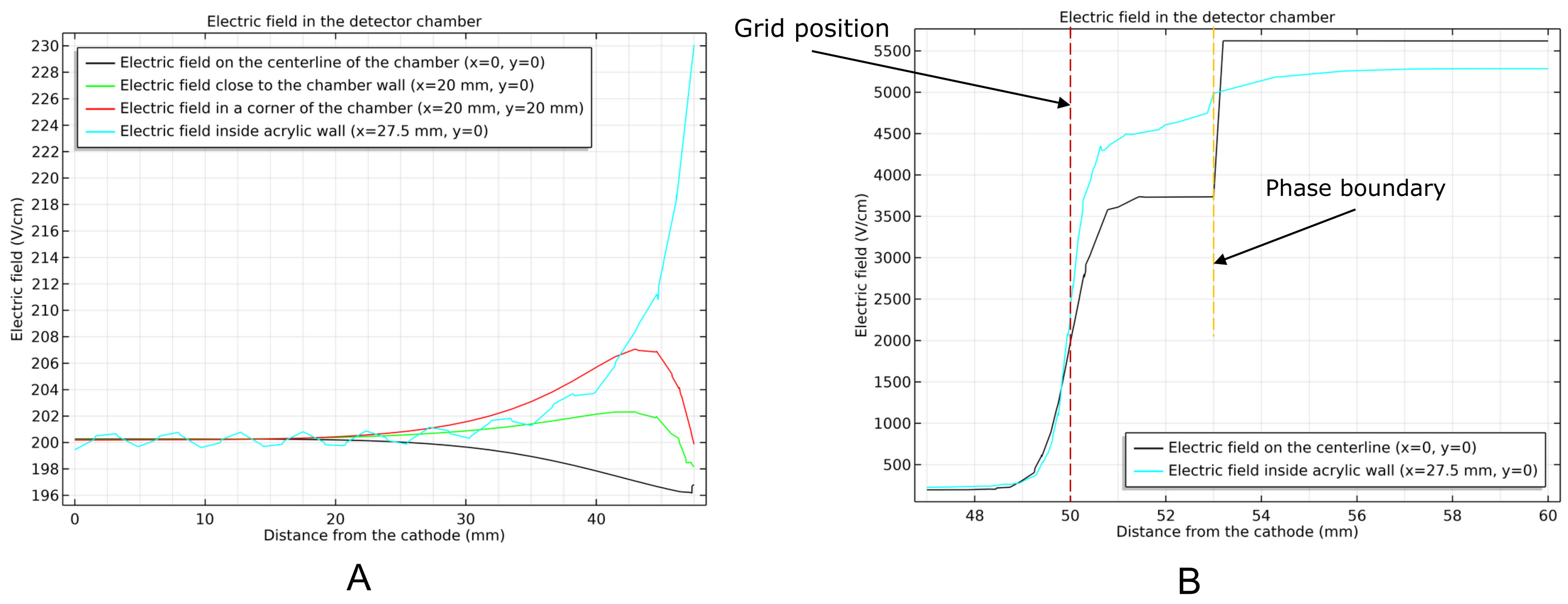
For the calculation, the 3D model of the detector chamber was optimized: external elements and mounting holes were removed, and the number of small elements of complex shapes was minimized.



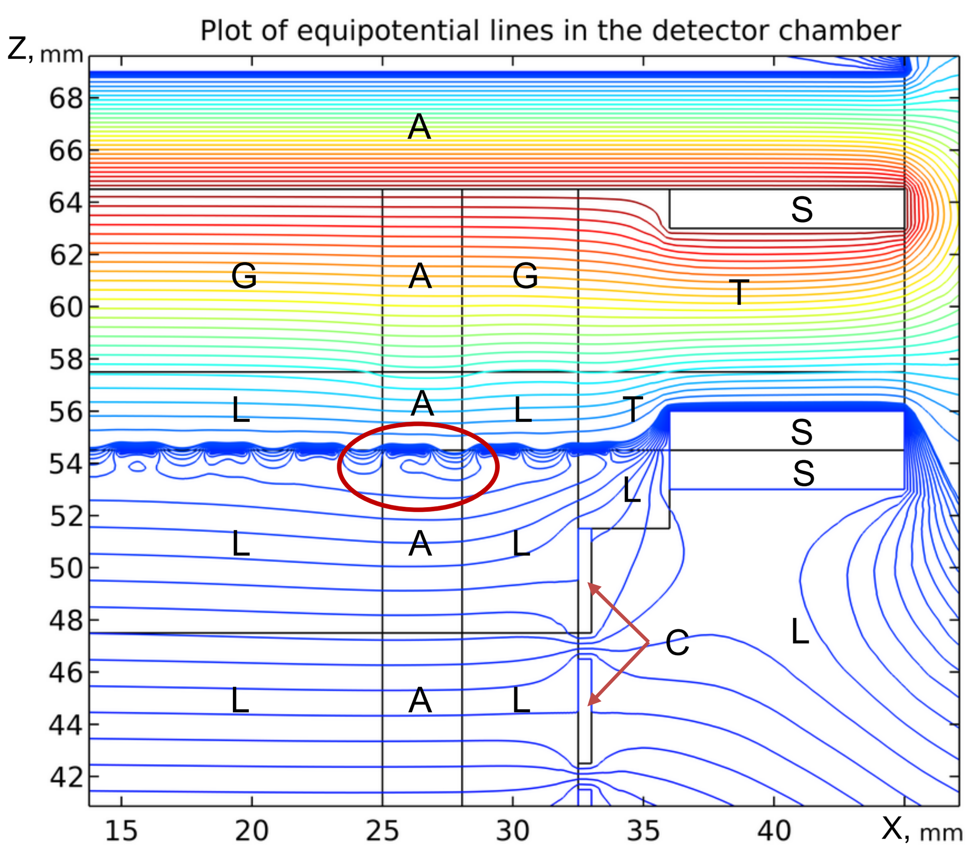
Due to limited computing resources, instead of a physically accurate model, the hexagonal grid presented as infinitely thin surface. According to [2], the grid of crossed wires can be modeled as a grid of crossed infinitely thin strips, which is very similar to this simplification.

## Modeling results

3D model calculations were performed in COMSOL Multiphysics. The homogeneous field configurations obtained from this model are slightly different from those calculated using a semi-empirical formula. To a large extent, this is due to edge effects near the chamber walls caused by the larger field leakage through the grid inside the acrylic walls. The inhomogeneities caused by this effect are ~ 2% for the configuration generating a 200 V/cm drift field: anode potential = 5211 V, cathode potential = -840 V and potential on the first ring = 60 V.



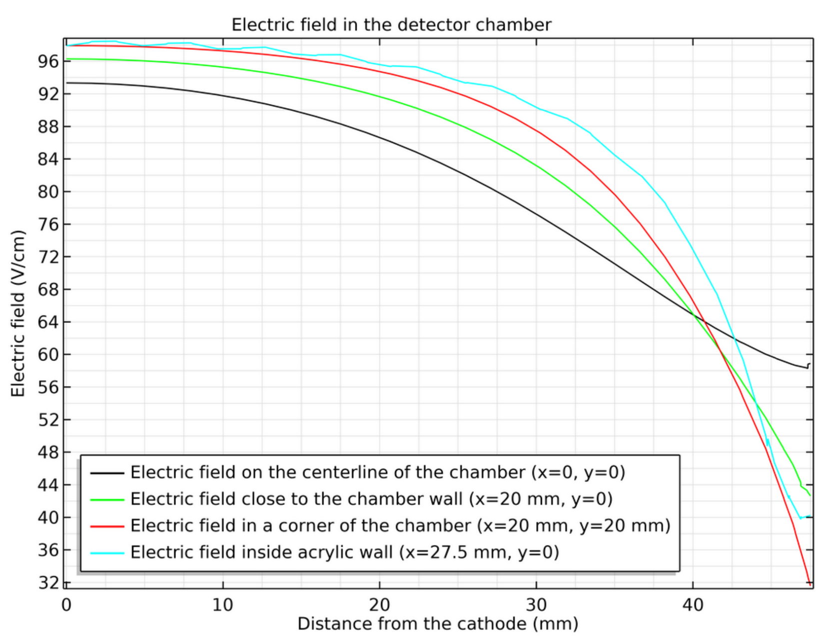

Electric field in drift area (A) and near the grid (B) for configuration: anode potential = 5211 V, cathode potential = -840 V and potential on the first ring = 60 V



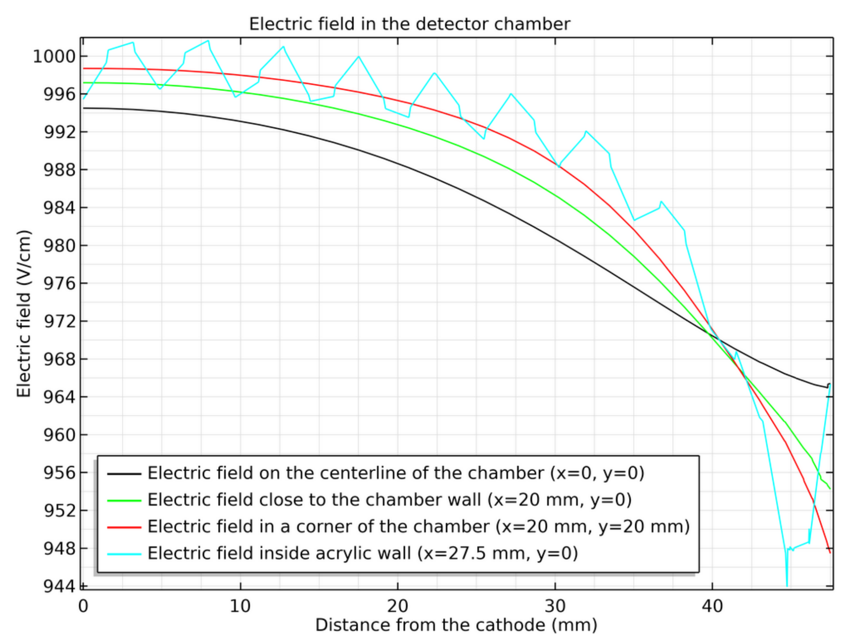

200 V/cm uniform drift field configuration (anode=5211V, cathode=-840V, first ring=60V)

G – Gas argon (ε=1.001)
L – Liquid argon (ε=1.505) [4]
A – Acrylic (PMMA) (ε=2.75) [5]
T – Teflon (PTFE) (ε=2)
S – Steel
C – Copper rings

Configurations previously used in the experiment were obtained on the basis of the 2D model. A comparison of these configurations to those obtained using the 3D model revealed limitations in the 2D model that lead to a non-optimal set of potentials and, consequently, an inhomogeneous electric field. This is especially important for small drift fields (~ 80 V/cm), where field inhomogeneities reach ~ 20%. For comparison, for field configurations with a large drift field, such inhomogeneities are rather small (~ 2%).




Electric field in drift area for configuration: anode potential = 5211 V, cathode potential = -234 V and potential on the first ring = 216 V




Electric field in drift area for configuration: anode potential = 5211 V, cathode potential = -4789 V and potential on the first ring = -289 V

## Conclusions

Calculations based on a 3D model allow:

- take into account the inhomogeneity of the electric field for more accurate reconstruction of the coordinates of events;
- take into account the edge effects on the chamber wall to select the optimal configurations of the cathode, anode, and ring potentials that allow minimizing the drift field inhomogeneities.

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