Multiphysics Simulation of Space Charge and Electric Field for Liquid Argon Neutrino Detector

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Abstract

The DUNE experiment (http://www.dunescience.org/) is an international collaboration of more than 100 research institutes and universities (among them CERN and Fermilab) which is taking the challenge of building the next-generation experiment for the study of neutrino particles. The aim is to measure the least known properties of neutrinos with unprecedented precision in order to unveil the finer structure of theory of fundamental forces and improve our knowledge of the processes at the origin of the universe.

The detector conceived to detect neutrinos consists of a gigantic cryogenic apparatus able to keep 700,000 tons of liquid Argon at the temperature of 87 K. An electric field of about 0.5 kV/cm is produced in the liquid volume by a field cage (Figure 1).

Neutrinos interacting with the Argon nuclei produce ionizing particles, the ionization charge is drifted in the electric field to the top surface of the detector where the electron streams are amplified by a dedicated apparatus (LEM) before being digitized. The space-time information of the drift electrons provides a 3-D image of the neutrino interaction. Exact knowledge of the electric field configuration is therefore crucial for a precise reconstruction of the neutrino interaction topology. Unfortunately several effects induce deviation from the ideal uniform electric field.

1) Ionization from cosmic muons generates a large amount of space charge.

2) Space charge drifting towards the anode reacts with the O2 impurity (attachment) naturally present in the liquid Argon.

3) Ar+ ions drift towards the cathode.

4) Electrons in the LEM amplification stage induce additional Ar ionization.

5) Another distortion is due to the intrinsic geometrical of the field cage.

6) The cryogenic vessel is not perfectly isolated, therefore the convection in the liquid is present to due thermal exchange through the vessel walls.

Some of the above processes are time-dependent: for example the instantaneous local charge density of each species, as a consequence of their mutual reactions. Altogether a detailed description of such a physical system requires a multiphysics simulation which combines

• Electrostatics
• Transport diluted species and
• Thermal convection.

A 3D-time-dependent simulation has been developed including all the physical process from the cosmic ray flux, the species reactions, the thermal properties of the materials and the field cage configuration (Figure 2,3 and 4). The resulting map electric field map is now used by the DUNE collaboration as one the most import input of the overall detector

simulation. The physics motivation, the model definition and the results along with their application will be presented.

Reference

R. Acciarri et. at., "Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) : Volume 4 The DUNE Detectors at LBNF - DUNE Collaboration", arXiv:1601.02984 [physics.ins-det], FERMILAB-DESIGN-2016-04, http://inspirehep.net/record/1414945?ln=en, 2016.

Figures used in the abstract

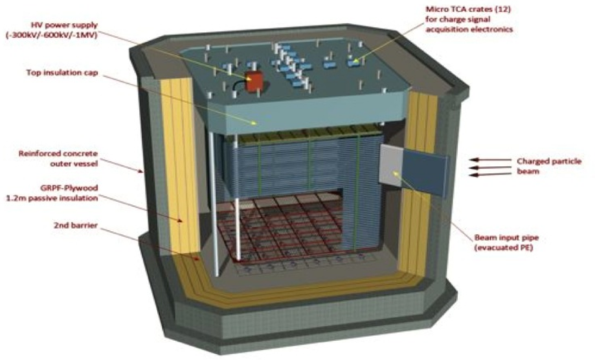

Figure 1: Detector prototype setup.

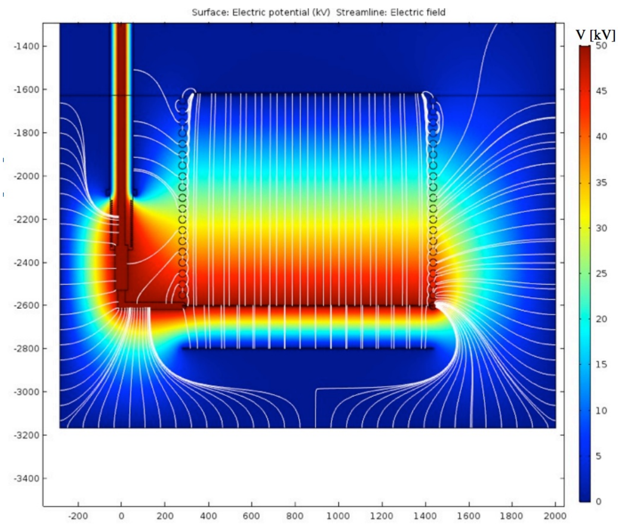

Figure 2: Electric filed configuration.

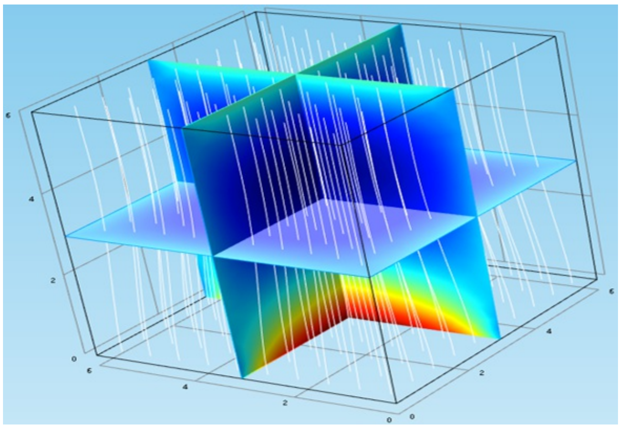

Figure 3: Electric field line distortion due to the spatial charge distribution (at the equilibrium).

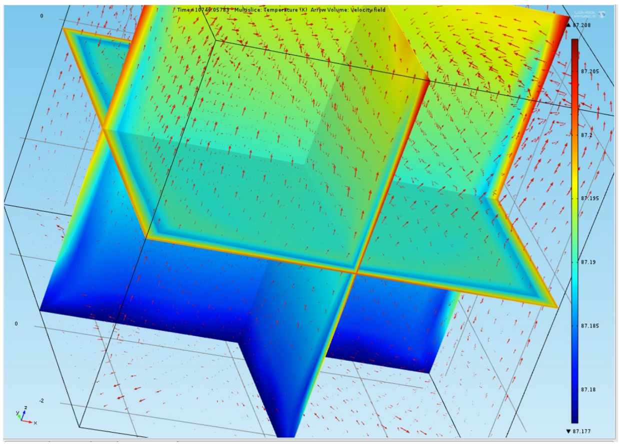

Figure 4: Convection lines of space charge due to convective motion.