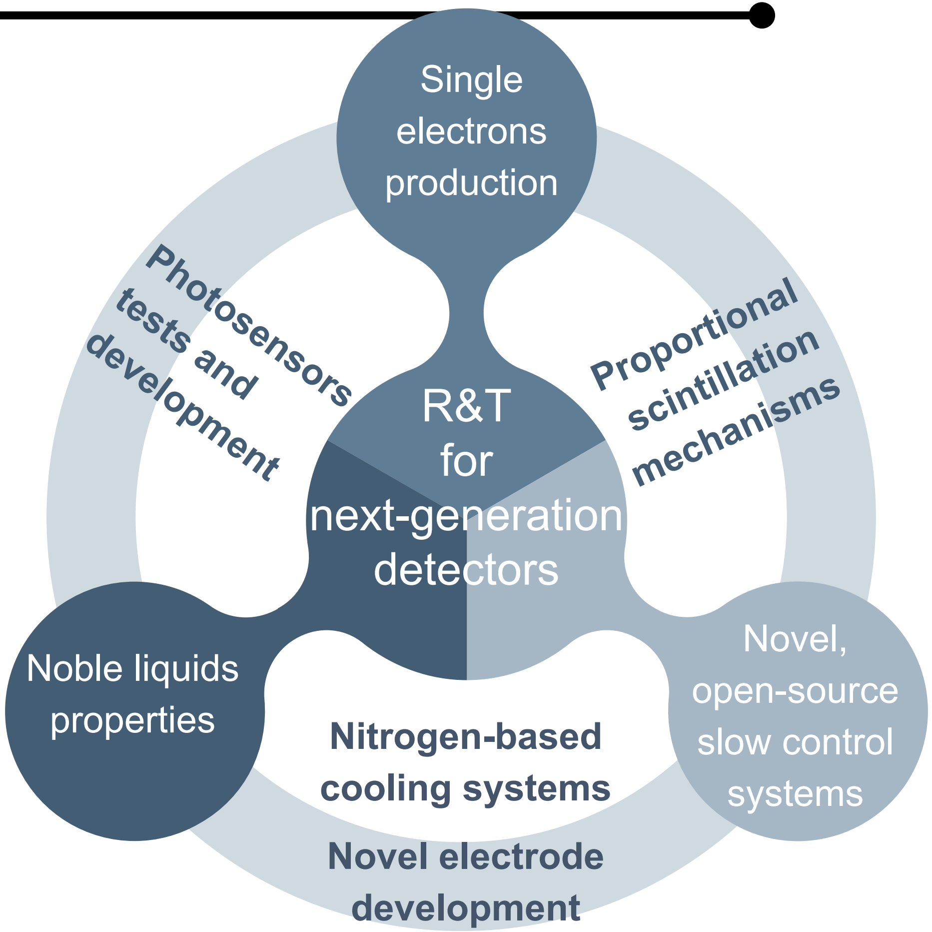
XeLab

A cryogenic setup to host a LXe double phase TPC in Paris

presented by Luca Scotto Lavina - LPNHE
on behalf of the whole XeLab team (LPNHE, Subatech)

XeLab, an R&D meant for DARWIN

- First site in France working with a dual-phase LXe TPC (Subatech has only single, liquid phase)
- Meant as a platform to perform R&D for next-generation detectors
- Funded by IN2P3 with local support by LPNHE and Subatech
- Many side-projects on the way, nice attractor for students



R&T for next-generation detectors

Single electrons production

Noble liquids properties

Novel, open-source slow control systems

Photosensors tests and development

Proportional scintillation mechanisms

Nitrogen-based cooling systems

Novel electrode development

Main priority for XeLab

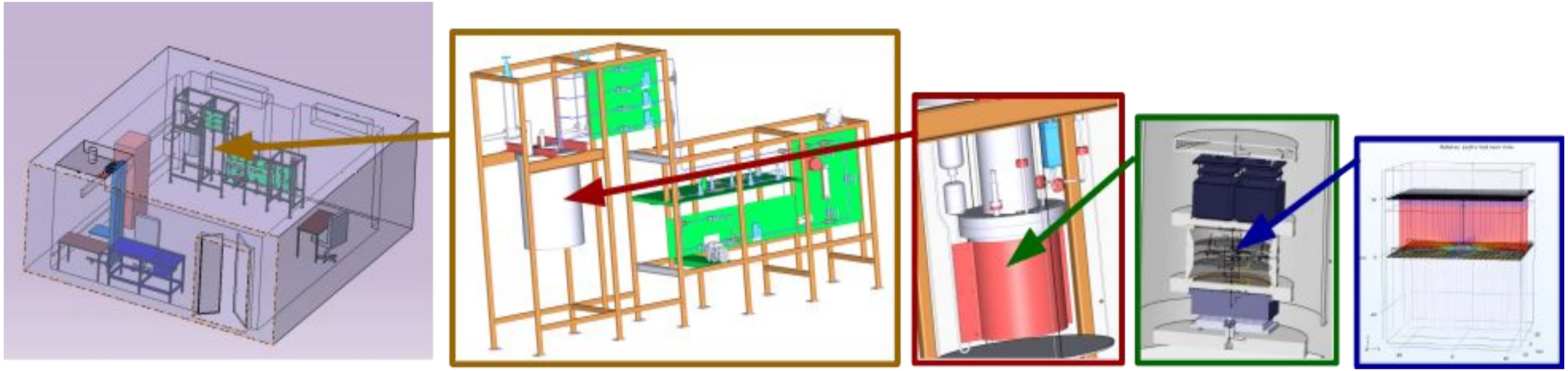
- **XENONnT → challenges to generate ionization signal with current solutions**
- **DARWIN → R&D with alternate solutions (single phase, etc…)**
- **XeLab aims to test the idea of floating electrodes, to keep the double phase and have a TPC design as close as possible to the current ones**

Small TPC to test solutions for large TPCs? Yes, because:

- **We first need to show that this solution, which will certainly reduce some performances (optical transparency), will allow us to have 100% extraction efficiency and high yields (with low voltages), with low penalty on S2 resolution**
- **Then, if successful, we could build a large scale prototype (Pancake?)**

Installation in LPNHE

Dedicated direct line with a 15k liters nitrogen reservoir from Sorbonne, Jussieu

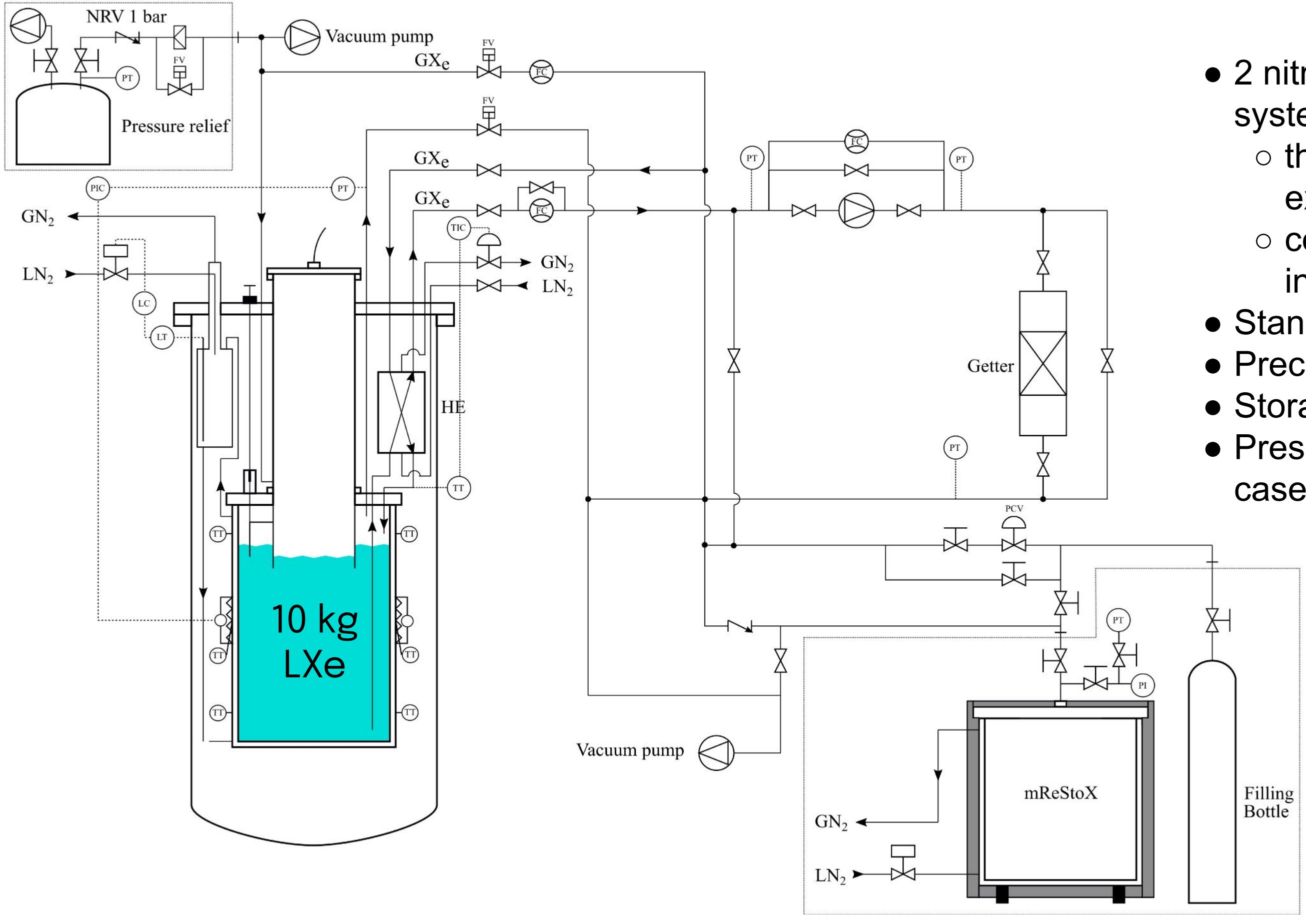


Campus Jussieu, LPNHE, Salle 12-13-SS03

Designed by LPNHE and under construction by DATE company

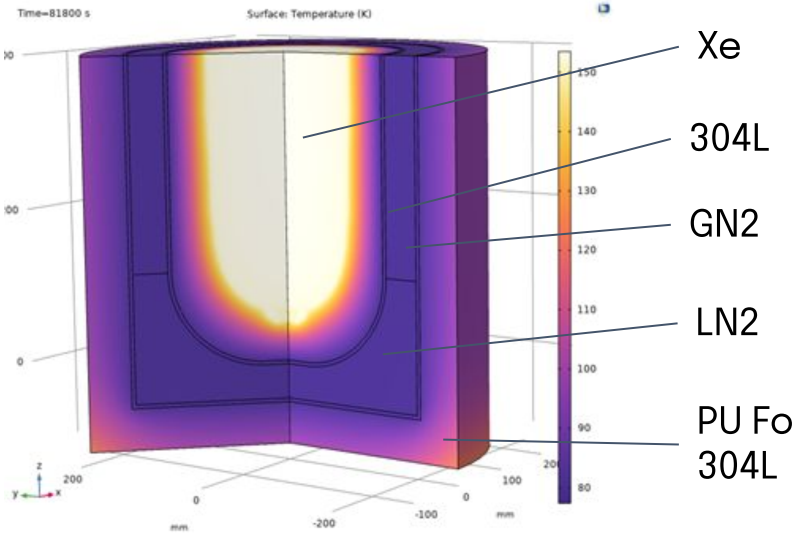
Under design by Subatech

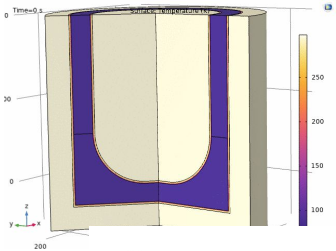
Process & Instrumentation Diagram (P&ID)

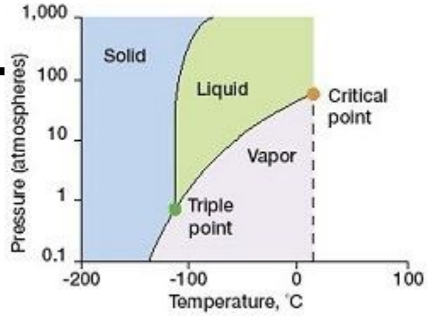


- 2 nitrogen-based cooling systems
  - three-phase heat exchanger
  - cold copper belt around inner cryostat
- Standard purification
- Precise liquid level tuning
- Storage and recovery system
- Pressure release system in case of accident

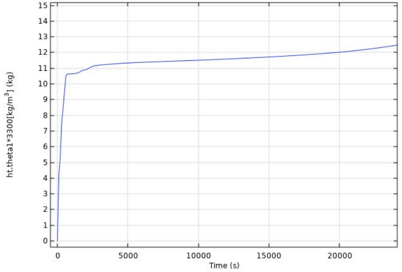
CryoPumping: mResToX



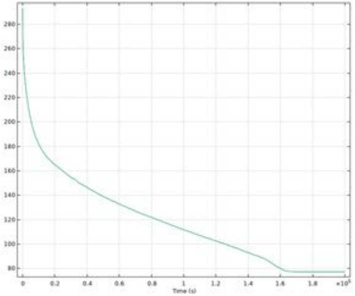




- Use LN2 supply to cryo-pump Xenon, 10Kg
- LN2 level control.
- Phase Change Gas/Solid
- Material Choice: 304L, Ti, insulator…
- Optimization with Comsol: Thermal/mechanics
- Compromise with surface cooling area and volume



6000s, ~2h for cryopumping of full weight of 11Kg, not far from experience, but practice is more complex: Xenon snow formation, LXe flow on the walls, longer cryopumping time.

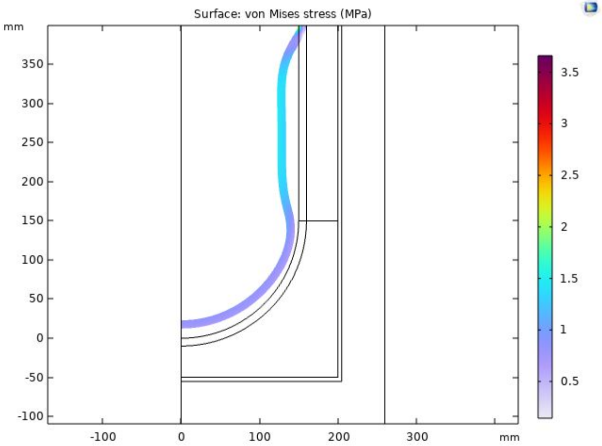


Necessary Cryo-pumping for full volume Time: 48h (85kg)

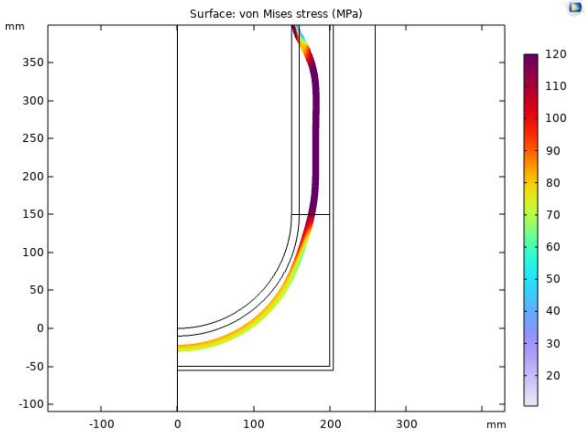
Will be built by Costruzioni Generali

CryoPumping : mResToX mechanical analysis

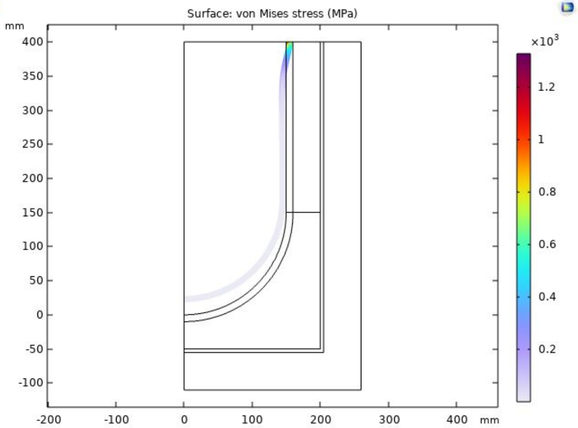
- CryoTank must hold vacuum and pressure
- Yield strength 304L, 250MPa
- 10mm wall thickness



mResToX Under vacuum (line purge)



mResToX Under 100 bar pressure, in case of LN2 loss : Xe Pressure (10Kg, 30°C, 0.025m3): 70bars



Fragile welding area
Need to lower thermal stress buy modifying shape and design of the flange.

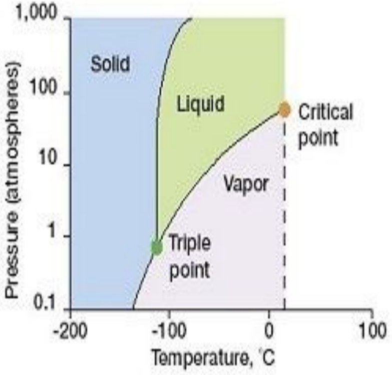
- Integrate thermal mechanical constraints
- Prospecting for a supplier with PED integrated certification

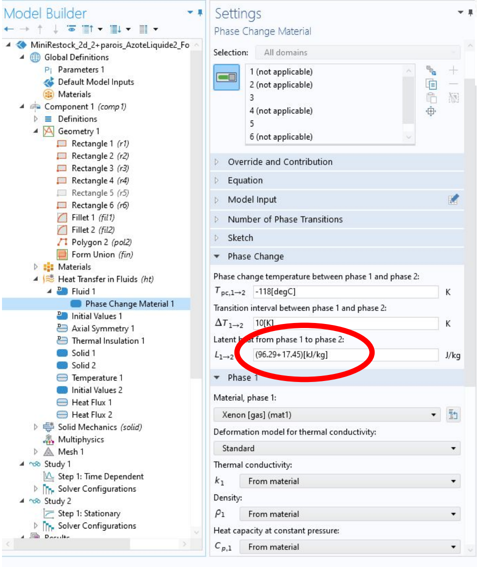
CryoPumping : mResToX temperature analysis

Depending on experiment pressure relative to triple point pressure,
Xenon undergoes 2 paths of phase transitions:
Gas → Solid
Gas → liquid → Solid

We model the worst case, but difficult to add 2 phase change interfaces.

Approximation :
Latent heat of condensation is added to latent heat of solidification.





Phase Change Material

Selection: All domains

1 (not applicable)
2 (not applicable)
3
4 (not applicable)
5
6 (not applicable)

Phase change temperature between phase 1 and phase 2:
$T_{pc,1\to 2}$ -118[degC] K

Transition interval between phase 1 and phase 2:
$\Delta T_{1\to 2}$ 10[K] K

Latent heat from phase 1 to phase 2:
$L_{1\to 2}$ (96.29+17.45)[kJ/kg] J/kg

Material, phase 1: Xenon [gas] (mat1)

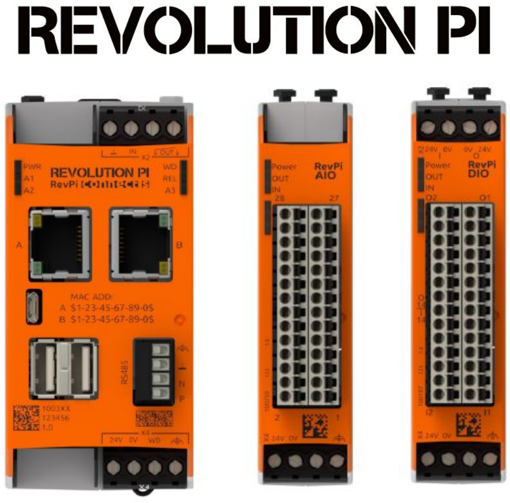
Deformation model for thermal conductivity: Standard

Thermal conductivity:
k_1 From material

Density:
ρ_1 From material

Heat capacity at constant pressure:
$C_{p,1}$ From material

Slow Control…. …and DAQ systems



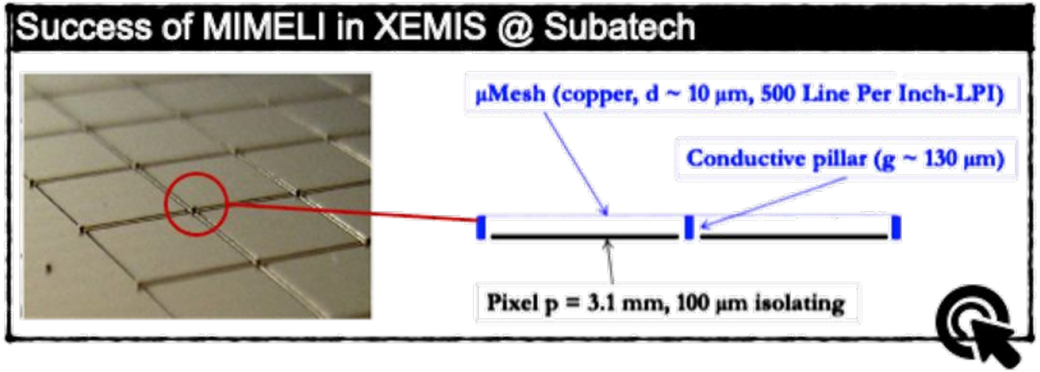
- Open source software
- International standard with CODESYS
- Robust and reliable for monitoring and alarms.
- Monitoring through Grafana

- CAEN V1720 digitizer (8 channels, 12 bits, 250 MS/s)
- HV power generator at 8kV

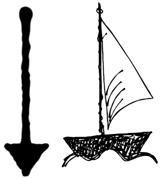
Electrode R&T in XeLab

Goals:

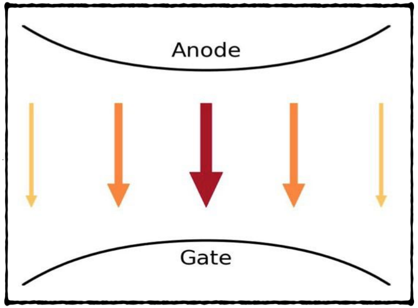
- Minimize mechanical distortion
  → possibility of reducing the grid↔anode distance
  → better energy resolution
- Optical transparency as close as possible to that of parallel wires
- More uniform signal response over x, y



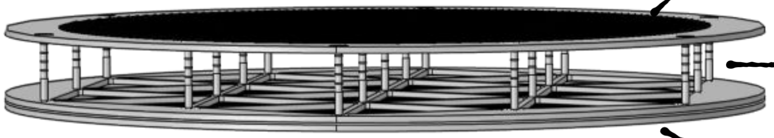
Success of MIMELI in XEMIS @ Subatech



floating electrode with supporting pillars

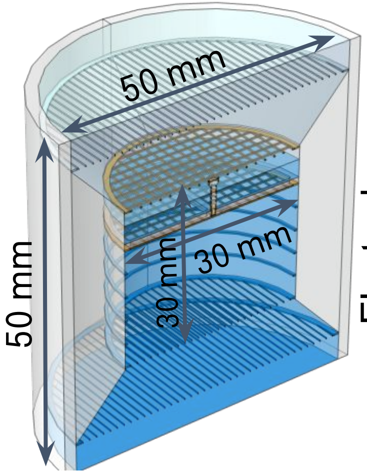


Sagging
Electrostatic force (dominant)
Gravitational force (~ O(1) lower)

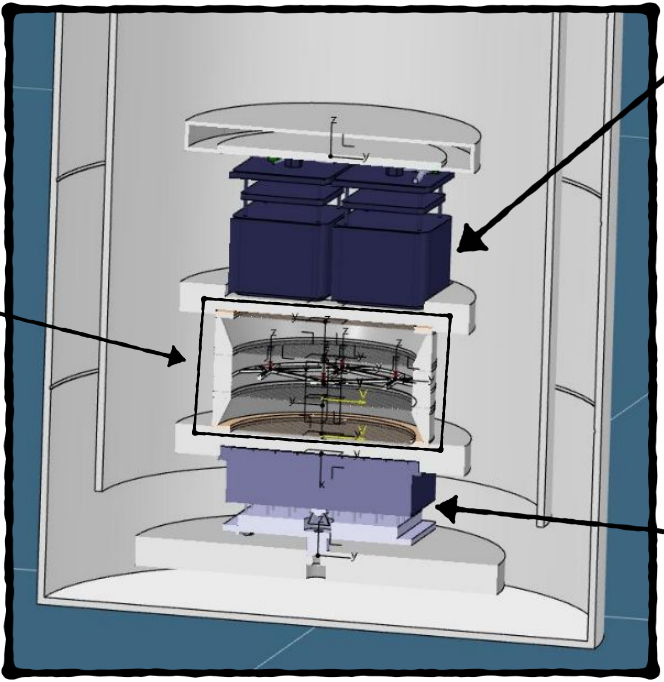


TPC under development

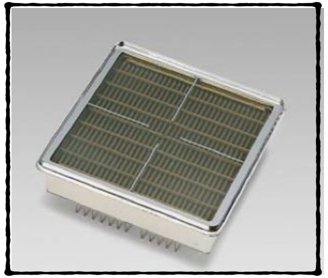
Small-size TPC prototype to test the performance of novel electrode with support pillar



Electrostatic and further mechanic simulation with COMSOL and Ansys

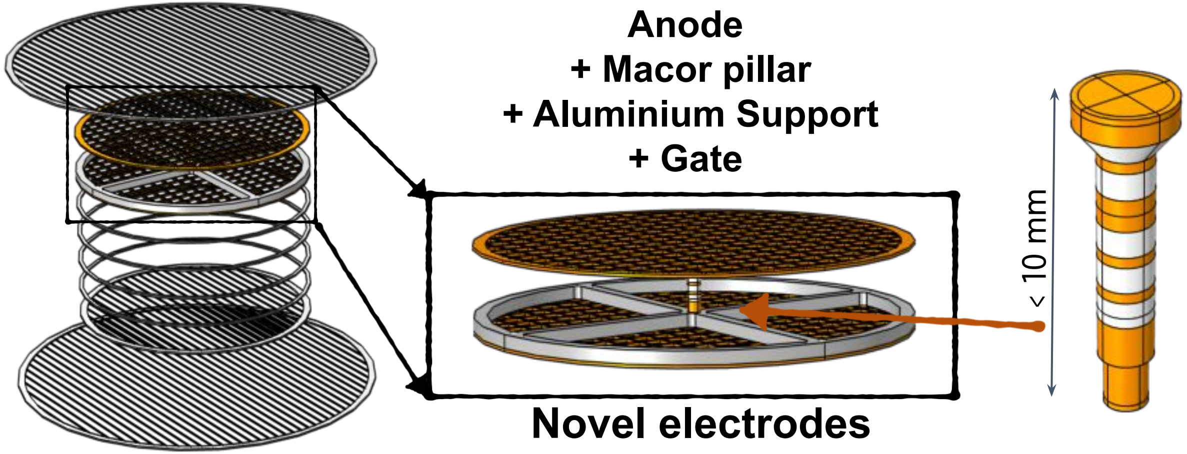


Hamamatsu R8520-406
Effective area: 20.5 x 20.5 mm



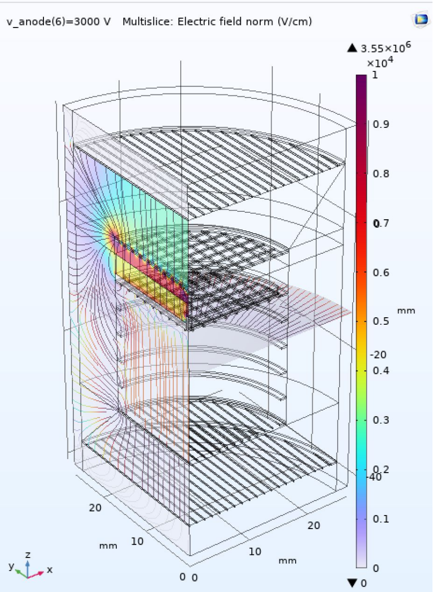
Hamamatsu R12699-406-M4
2 x 2 multianode
Effective area: 48.5 x 48.5 mm

Design of electrodes



Anode
+ Macor pillar
+ Aluminium Support
+ Gate

Novel electrodes

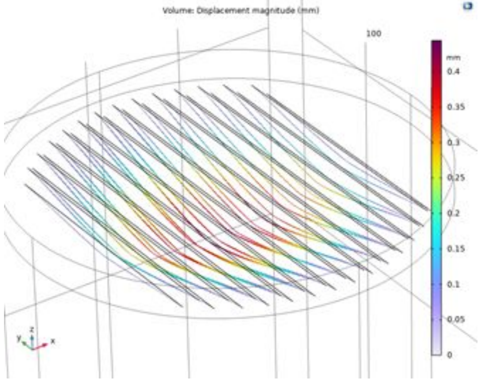


TPC electrodes	Type	Material	Wire diameter	Wire pitch	Transparency	z-Position	Electric potential
Top screen	Parallel wires	Stainless steel	0.05 mm	1.25 mm	96%	10 mm	0 V
Anode [Gantois]	Woven mesh	Stainless steel	0.236 mm	1.736 mm	75%	0 mm	3000 V
Gate [Gantois]	Woven mesh	Stainless steel	0.236 mm	1.736 mm	75%	-6 mm	0 V
Cathode	Parallel wires	Stainless steel	0.05 mm	1.25 mm	96%	-26 mm	-100 V
Bottom screen	Parallel wires	Stainless steel	0.05 mm	1.25 mm	96%	-36 mm	0 V

Modeling of electrodes

Modeling challenges:

- Wires = Small Structures in Wide volume : Electrodes 200µm, TPC : ~1m, Need for a multiscale approach (FEM/BEM)
- Integrate technical feedback from XENONnT to optimize XeLab and then DARWIN
- Make coupled modeling Electrostatic / Mechanical: Balance between electrostatics / Gravity / Archimede / mechanics
- Electrons Tracks to LXe/GXe interface.



Simple Sagging model

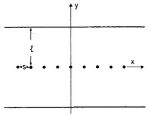


Fig. 55 Principle of construction and definition of parameters in a multiwire proportional chamber. A set of parallel anode wires is mounted symmetrically between two cathode planes (wires or foils).

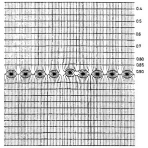
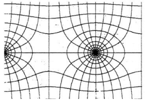
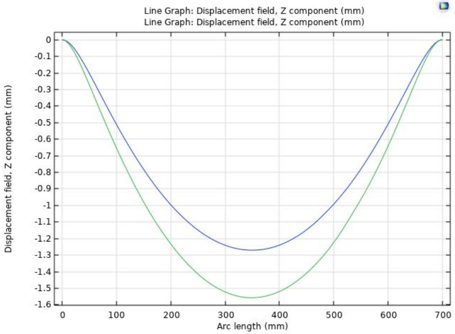


Fig. 56 Electric field equipotentials and field lines in a multiwire proportional chamber. The effect on the field of a small displacement of one wire is also shown[17].



Revisiting : Physics , F. SAULI, CERN 1977



Archimedes effect (E-Field Off)

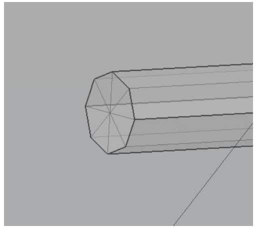
Xelab: Wire electrodes model

Two-way coupling of electrostatic-mechanical force with deformed mesh:

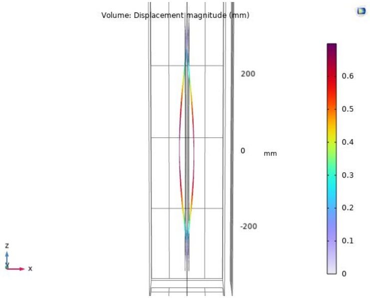
Test with vertical wires (attractives)

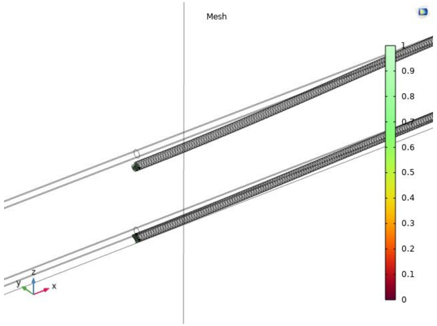
Horizontal wires :

Gravity : volume force
Electrostatic : surface force

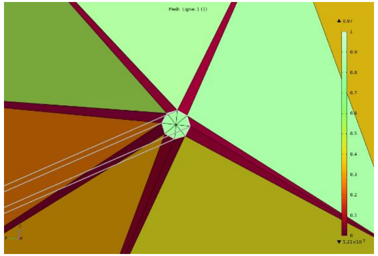


Single wire Meshing

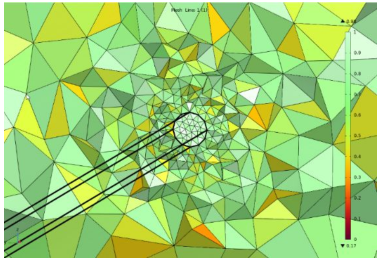




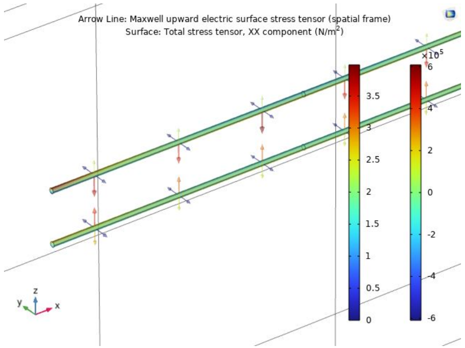
2 way coupling of vertical electrostatic-mechanical wire



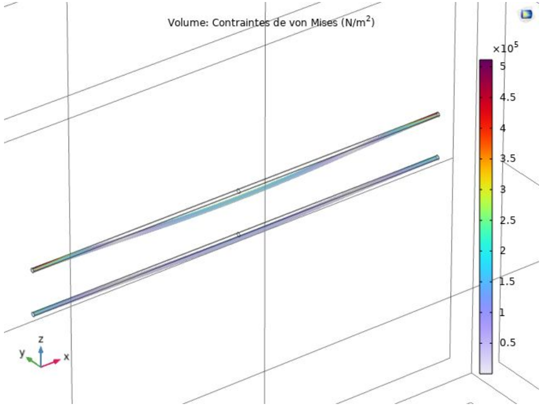
Not Working mesh



Working mesh



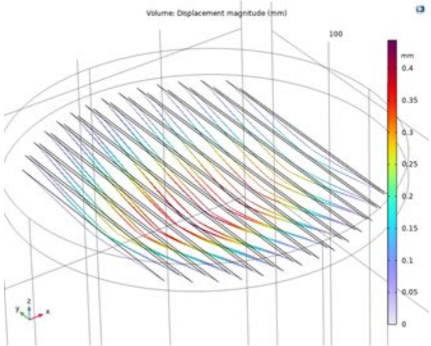
Maxwell Surface stress tensor



2 way coupling of electrostatic-mechanical wire + gravity

Xelab: Wire electrodes model

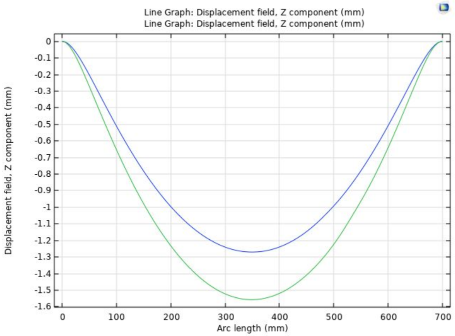
Two-way coupling of electrostatic-mechanical force with deformed mesh



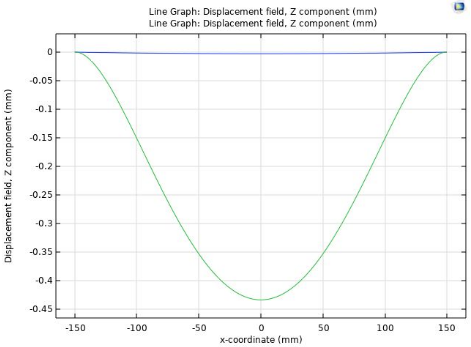
3D Sagging model of wire matrix

More complexity / accuracy :

Triple-way coupling of electrostatic-mechanical-thermal force with deformed mesh:
Gravity : volume force
Thermal retraction: Volume force
Electrostatic : surface force



Sagging of Top and bottom wire with Archimedes force



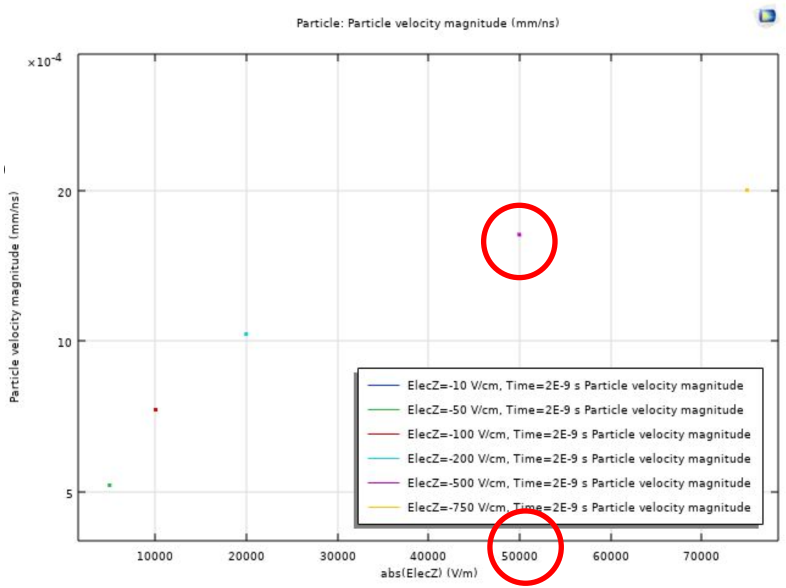
Sagging of Top wire with thermal contraction

Xelab: Electrons / TPC model

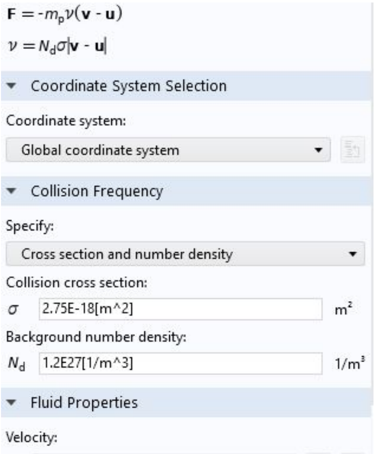
Simple Friction Model,
Find a fit for cross section for
target field

Cross Section = 2,75E-18m²

Typical speed 1,6 E-3 mm/ns



Simple friction model



$$\mathbf{F} = -m_p \nu (\mathbf{v} - \mathbf{u})$$

$$\nu = N_d \sigma |\mathbf{v} - \mathbf{u}|$$

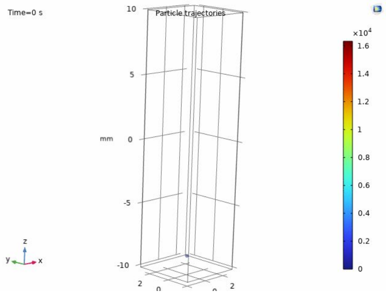
Coordinate system: Global coordinate system

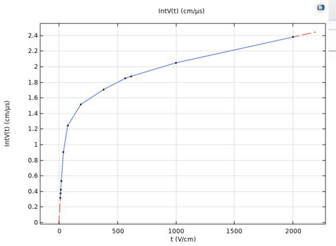
Specify: Cross section and number density

Collision cross section: σ 2.75E-18[m^2] m²

Background number density: N_d 1.2E27[1/m^3] 1/m³

To do : Compare with
Measured drift speed at
different fields.
Add Elastic collisions model,
for more accuracy of the fit.

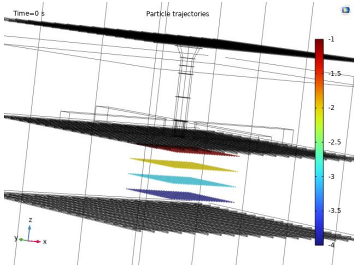




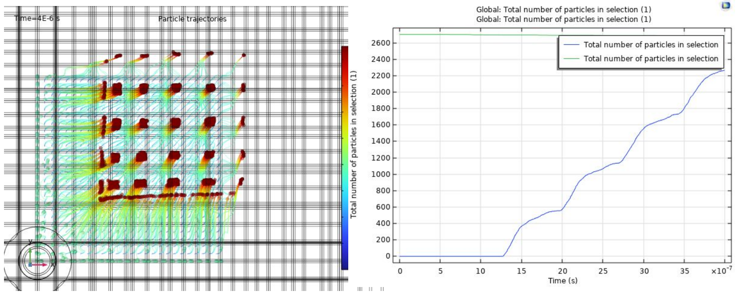
Electron Drift Model in LXe

Xelab: Electrons / TPC model

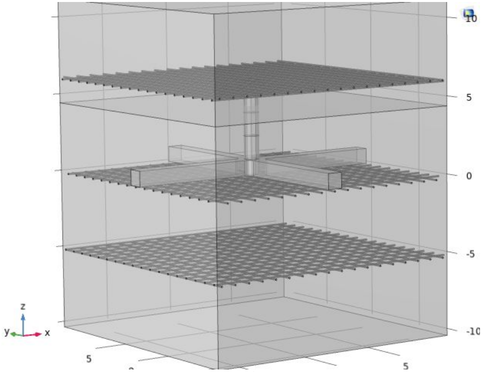
Integration of the electron drift model in the 3D electrostatic model.
Response Function of the TPC , to use with Garfield for photon emission : possible interpolation of the electron exit position at interface.



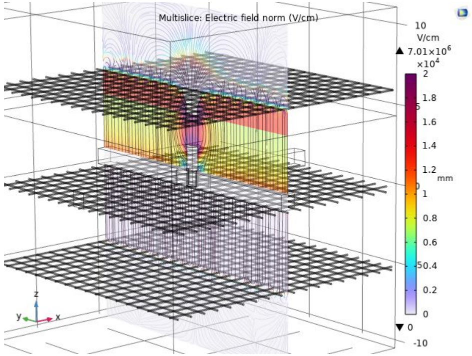
Electrons Release grid in LXe



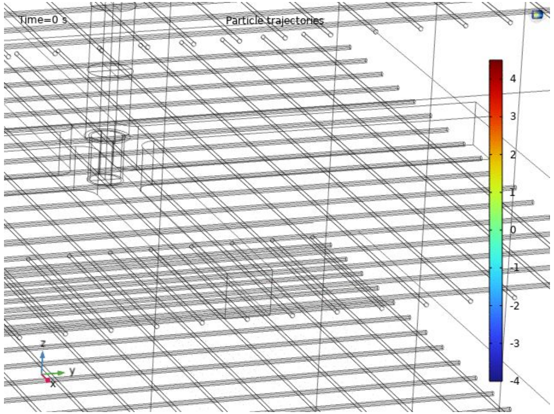
Top View : Electrons Release grid in LXe



Geometry of the TPC electrodes.



E-field with wire electrodes (1mm pitch , 0.1mm wire)



Full Electron Drift path in LXe

The XeLab team

Two groups: LPNHE and Subatech

Luca Scotto Lavina, science leader
Nabil Garroum, technical coordinator

5 researchers (Bernard Andrieu, Sara Diglio, Romain Gaior, Julien Masbou, Dominique Thers)
2 postdocs (Erwann Masson, Yajing Xing) + **Frederic Girard (PhD UZH) from May**

6 engineers / technicians (Arnaud Cadiou, Olivier Dadoun, Eric Morteau, Yann Orain, Julien Simonneau)

plus PhDs

Conclusions and next steps for XeLab

First dual-phase LXe TPC in France for R&T

- A clear roadmap for forthcoming 2-3 years (electrodes, then single electrons), contribution to DARWIN R&D
- Several Innovative side-projects on Engineering and technology:
  - Cryogenics (mReStoX, three-way heat exchanger, copper belt)
  - Slow Control (RevPI, inspired by Freiburg group)
  - Modeling and design of electrodes
- Funding secured, equipment mostly purchased (IN2P3, LPNHE, Subatech)
- Installation of the cryogenic system April 2023 (mReStoX in July)
  - 3 month of commissioning (leaks, cooling, filling and recovery)
  - 1st milestone: TPC ready by the end of 2023