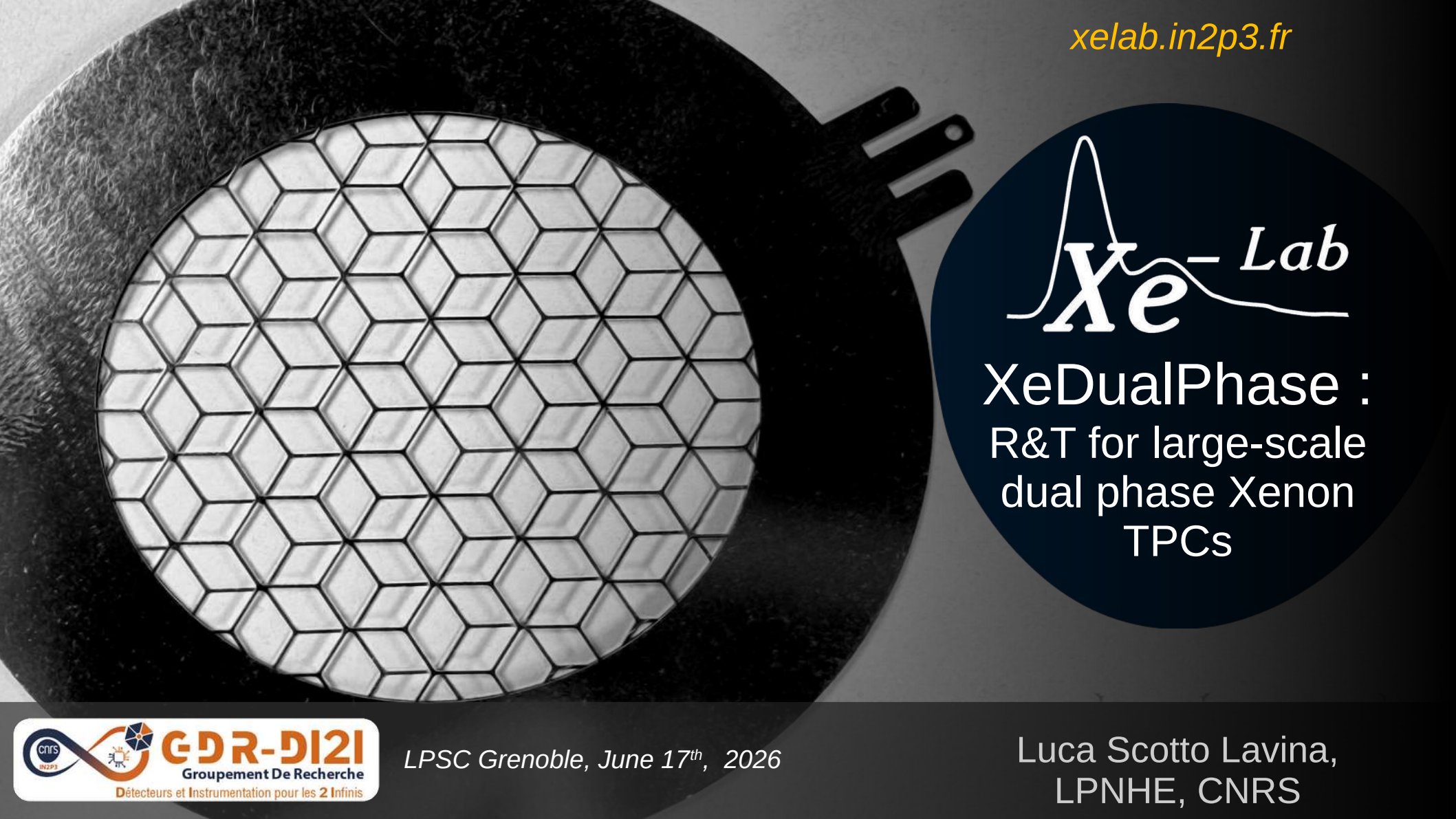


xelab.in2p3.fr

Xe – Lab

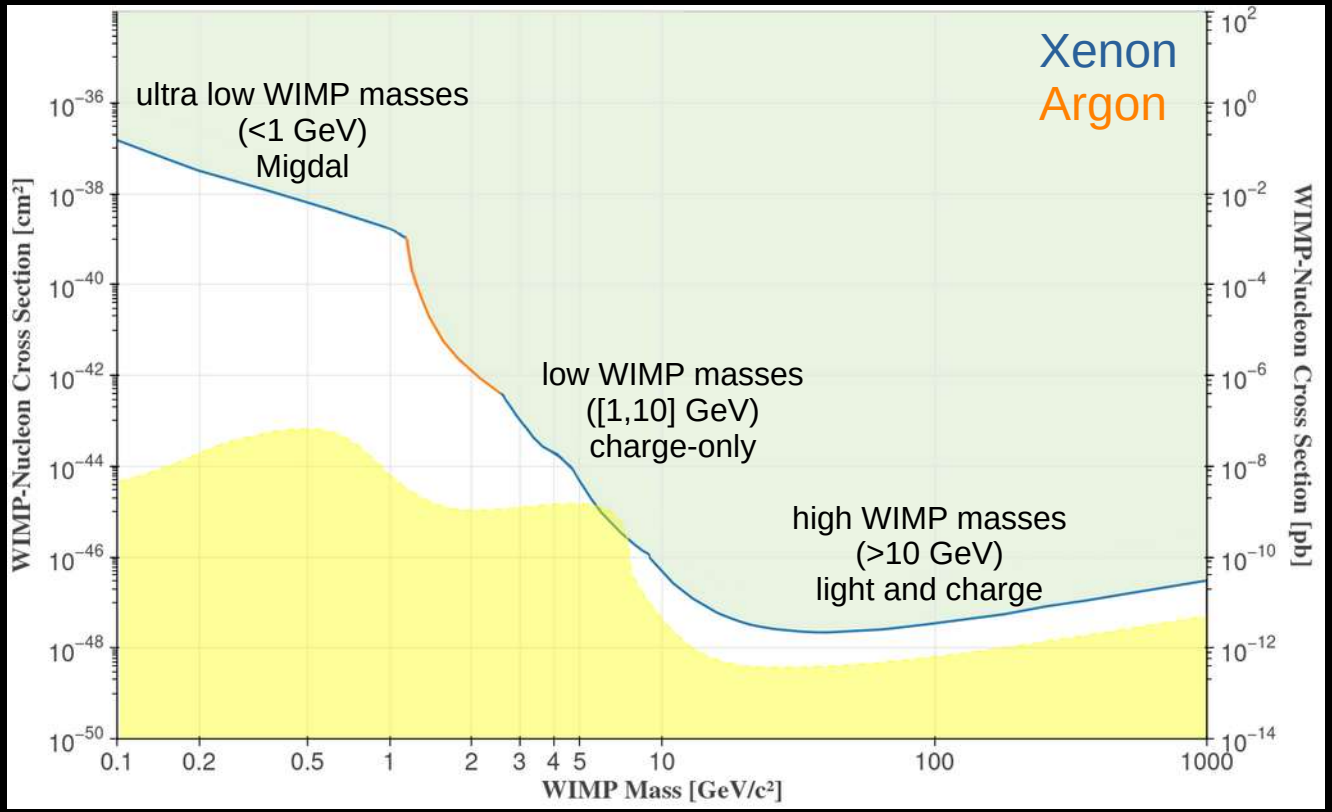
XeDualPhase :
R&T for large-scale dual phase Xenon TPCs

GDR-DI2I Groupement De Recherche
Détecteurs et Instrumentation pour les 2 Infinis

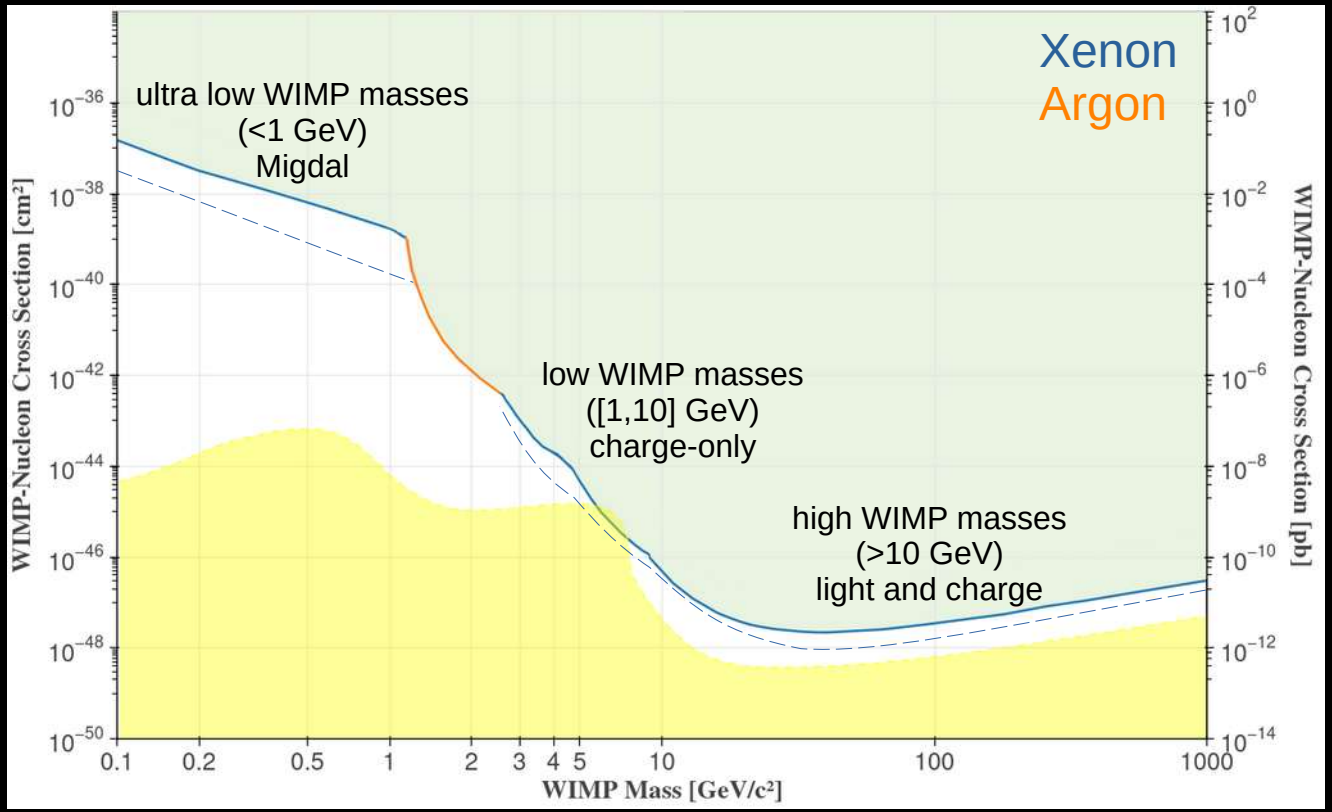
LPSC Grenoble, June 17th, 2026

Luca Scotto Lavina,
LPNHE, CNRS

Current WIMP search



WIMP search at the horizon of 2030



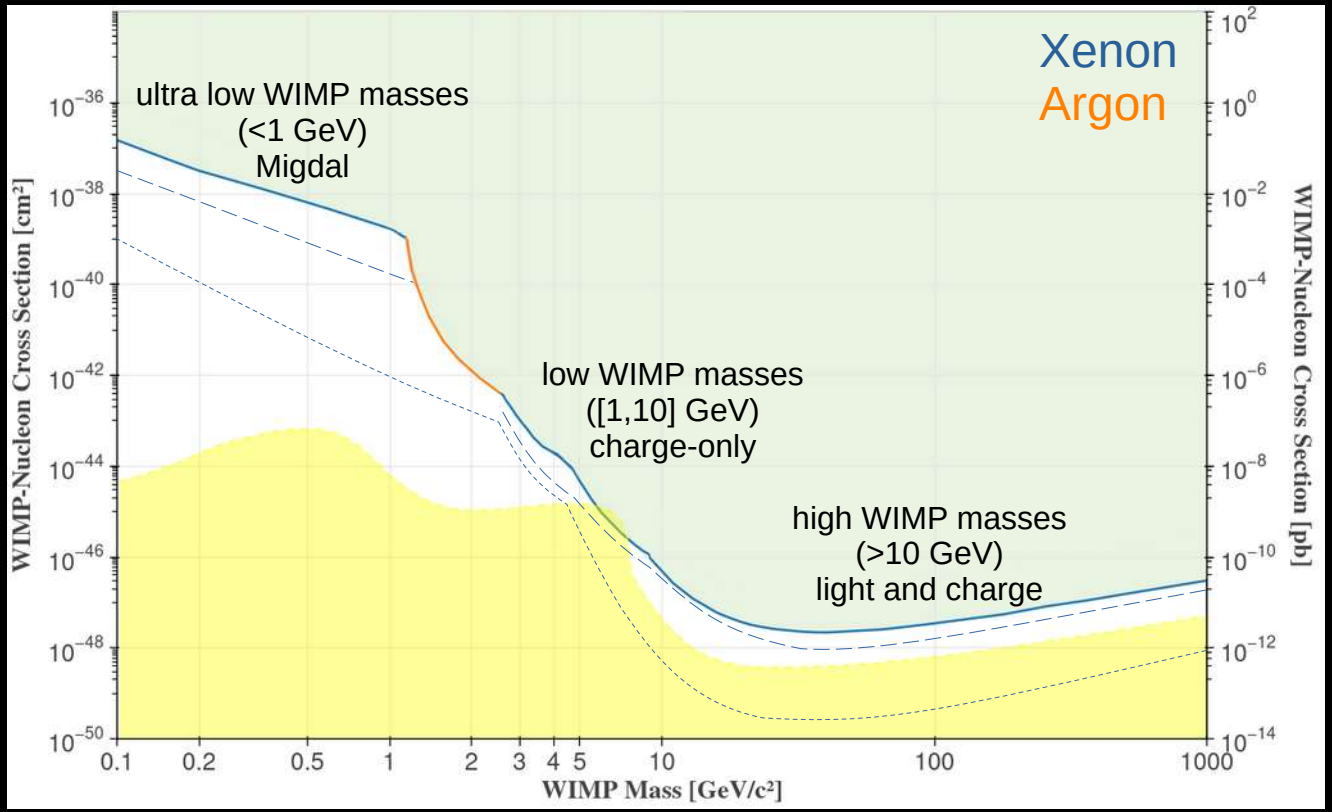
Ultimate WIMP search with XLZD

Key factors of improvement for noble liquid TPCs

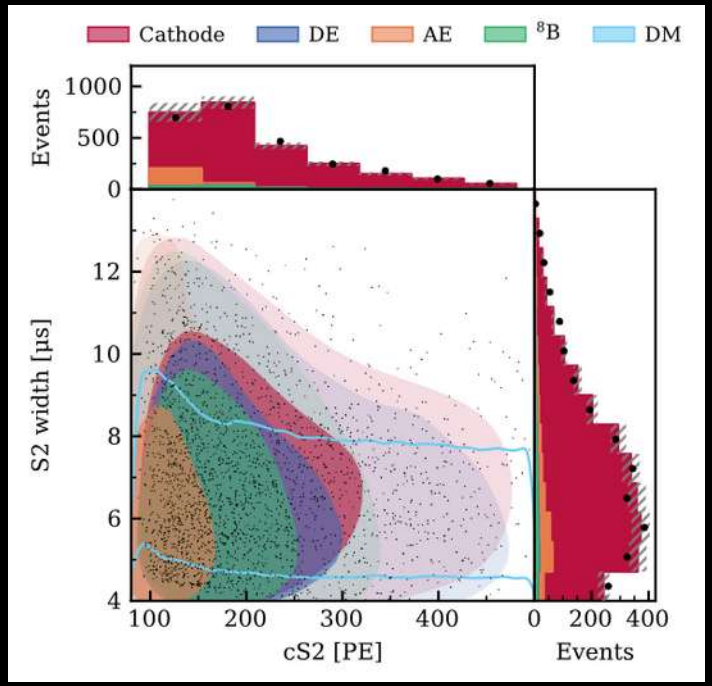
Global key factor :
- √ Scalability

High WIMP mass search:
- √ Low radiogenic impurities

(ultra) low WIMP mass search:
- √ Spurious light and charge

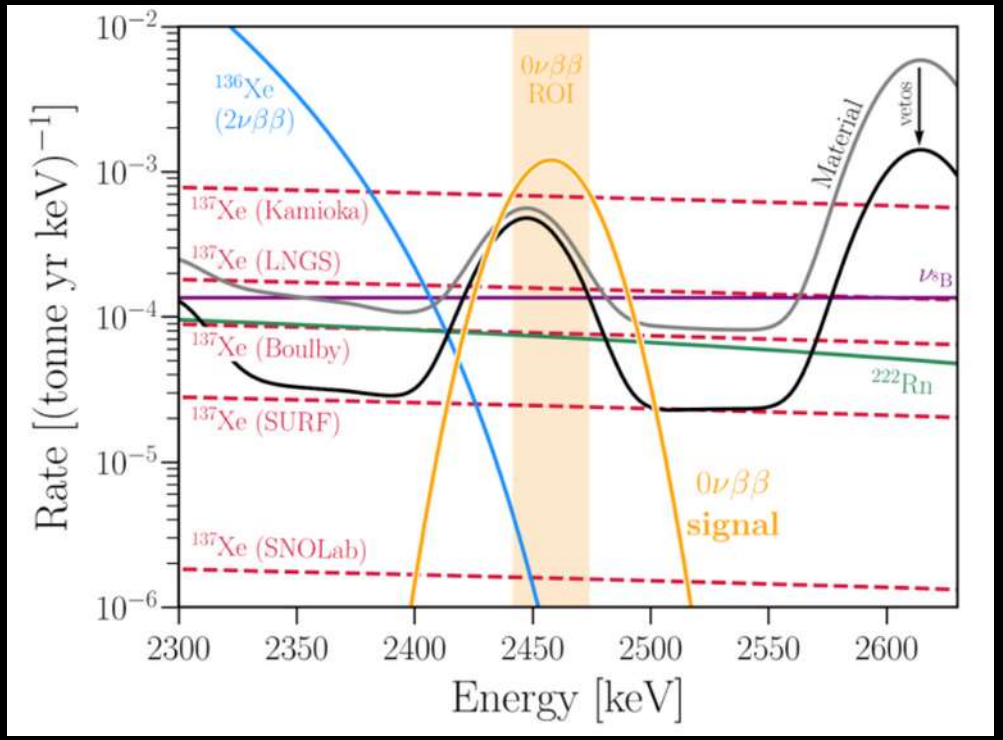


Exemple of background sources for DM and 0vbb



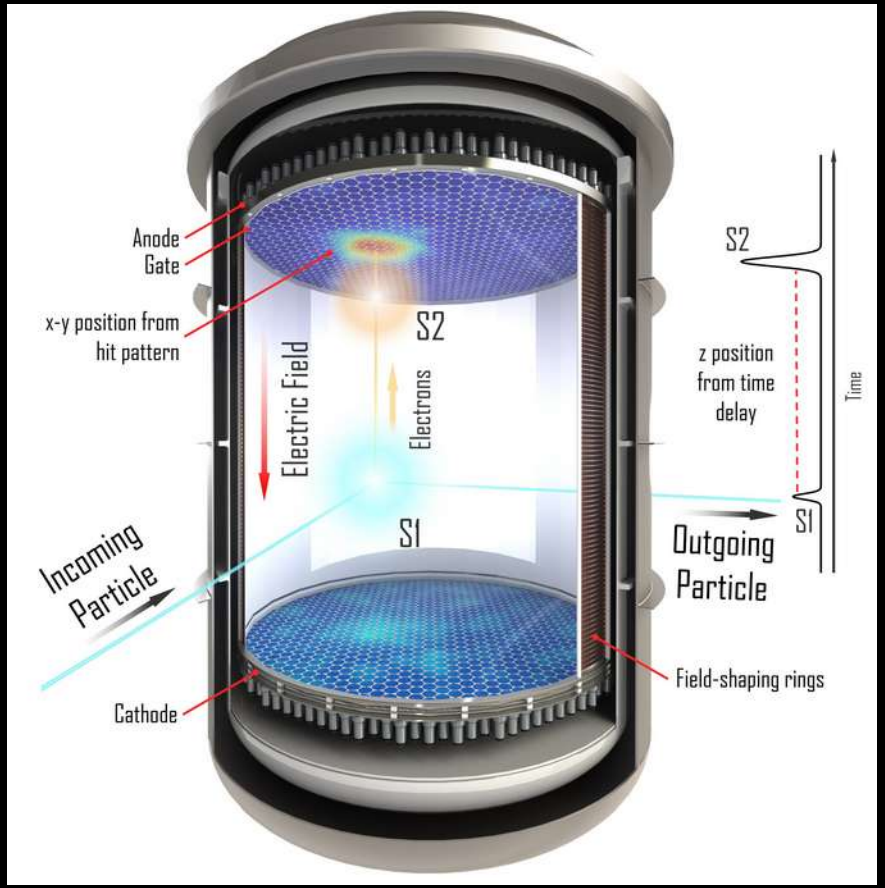
Low energies (S2-only search)

PRL, arXiv:2601.11296



High energies (0vbb)

Among the challenges of large-scale TPC



Development of large electrodes allowing :

- high optical **transparency**
- high electron **extraction efficiency**
- high **S2 gain**
- **uniformity** on x,y position
- low **radioactivity**
- low **fluorescence**
- no electrical **discharges** (hot spots)

XeLab

Arnaud Cadiou, Julien Simonneau, Patrick Le Ray, Eric Morteau (SUBATECH)

XeLab 1st phase (LPNHE, SUBATECH) + UMelbourne

- XeLab IN2P3 R&T funds in 2022
- Cryogenic system installed in 2023
- First entire cycle in 2024 (xenon filling, pre-cooling, xenon liquefaction, xenon recovery)
- TPC completed in 2025 and commissioning
- 2026 : new electrodes ready

XeLab 2nd phase : XeDualPhase

Funds from DIM-ORIGINES Equipment (106k€, 2027-2030)

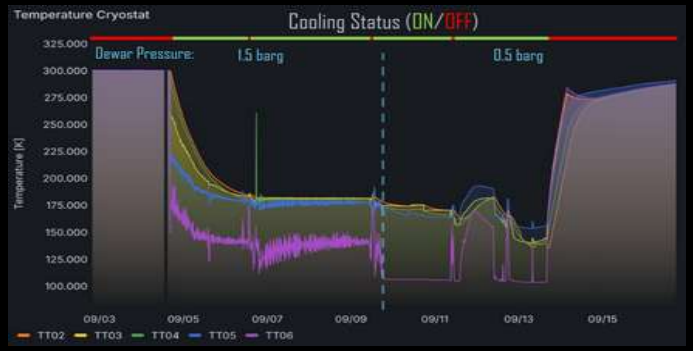
XeDualPhase

R&T on :

- Two alternatives on electrodes : SAFE and FIXED
- Slow Control
- Mechanics
- Cryogenics

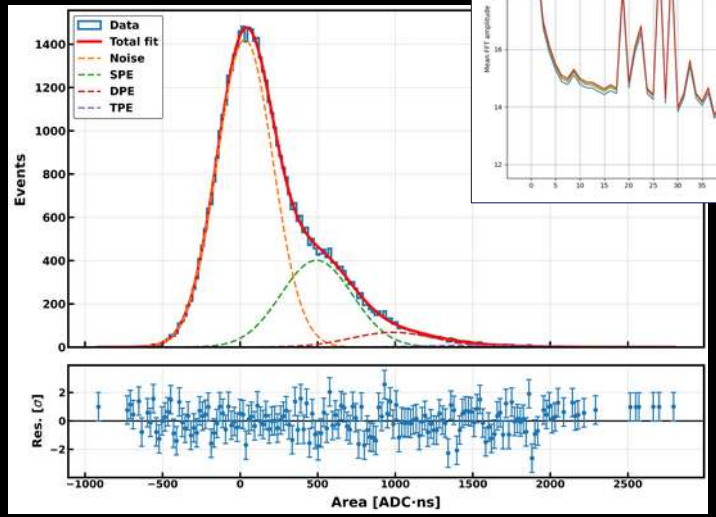
XeLab in action

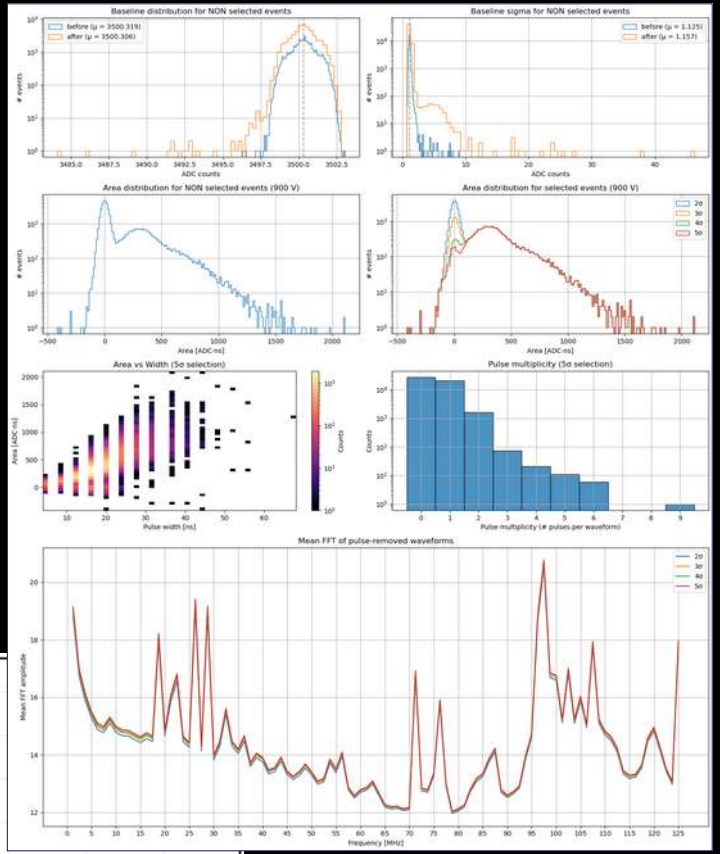
Owen Stanley, PhD (SUBATECH+UMelbourne)
Davide Taglieri, M2 (LPNHE)
Veronica Cazzola, PhD (LPNHE)



- ☑ Vacuum and leak testing (~10^{-6} mbar)
- ☑ Cooling down and liquefaction
- ☑ Xe level transducer and control
- ☑ Cabling - photosensors & electrodes
- ☑ High Voltage ramp-up
- ☑ Cathode HV (up -2kV)
- ☑ Anode HV (up to 5 kV)
- ☑ DAQ and Trigger System
- ☑ PMT signal readout
- ☑ LED test @ room & LXe
- ☑ Electronics & digitizers
- ☑ PMT characterization
- ☑ SPE & dark count & after pulse
- ☑ Electronic noise reduction
- ☑ Amplifier development & testing
- ☑ Test with standard electrode configuration
- ☐ Cs137 calibration – S1 & S2 – e lifetime
- ☐ Kr83m calibration – position reconstruction

SPE calibration

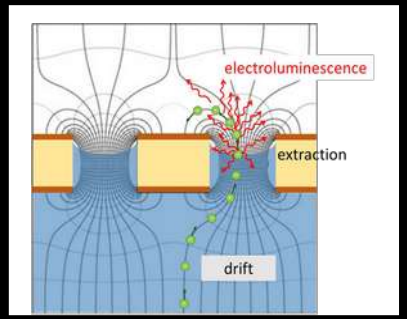




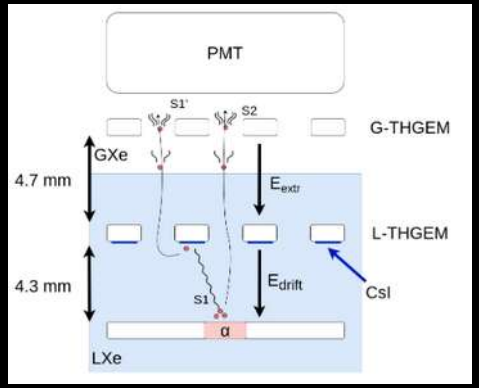
WF online analysis

Alternative mechanisms to amplify the ionization signal

Dual-phase with THGEMs

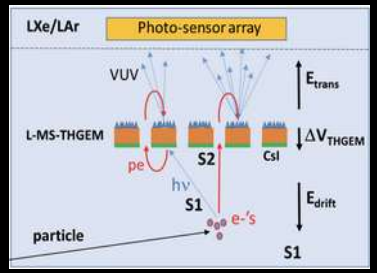


arXiv:2301.12990



arXiv:2409.04338

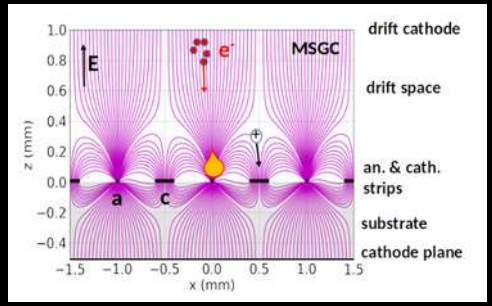
Single-phase with THGEMs and tips



arXiv:2203.01774

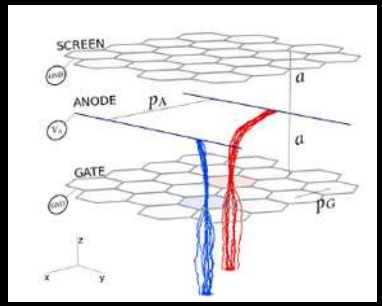
Single-phase with tiny anodes

Microstrips



arXiv:2312.14663

Microwires



arXiv:2405.10687

SAFE: Spacer-Assisted Floating Electrodes

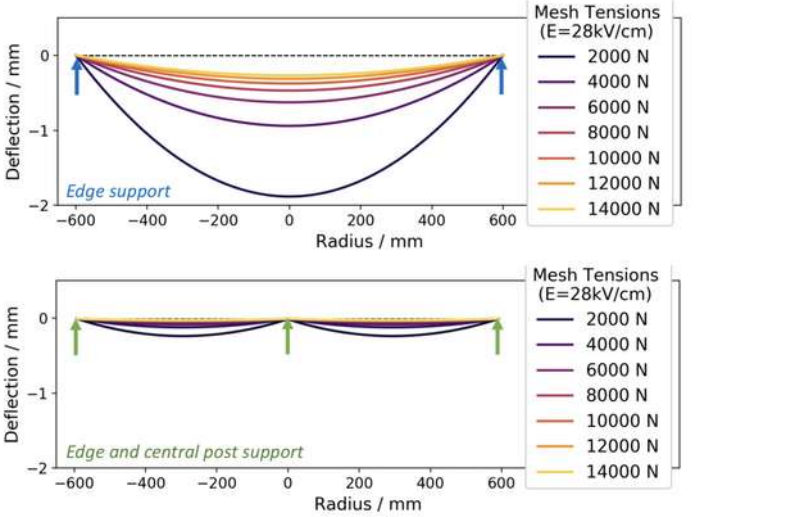


Figure 2. Simulated EL mesh deflection due to electrostatic forces with only edge support (top) or with edge support plus a single central support post (bottom). Dramatic deflection reductions are observed with only a small number of support posts, thus maintaining EL field and gain uniformity.

Previous study on the HV Insulation in HP Xe Gases.
NEXT Collaboration : arXiv:1804.04116

Potential advantages

- mechanically supported large-area geometry
- better control of electrode spacing
- reduced sensitivity to sagging
- stable extraction region

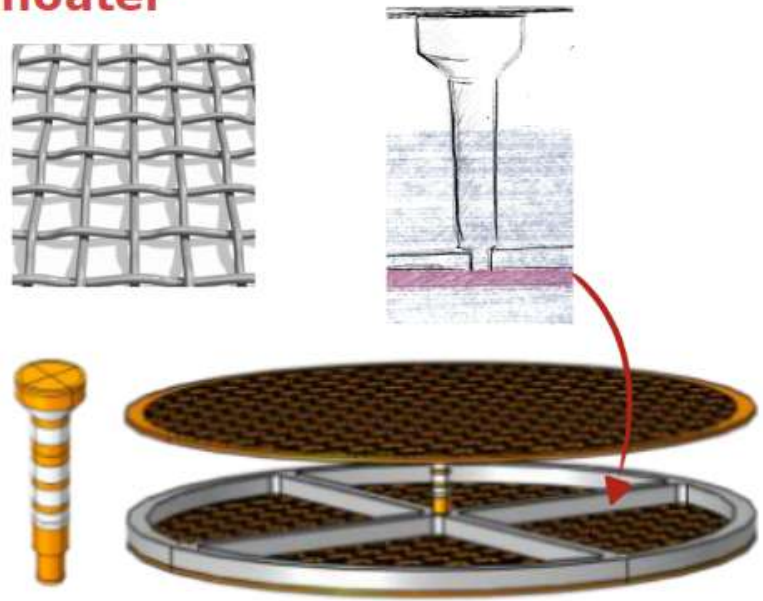
What to test

- mechanical planarity in cryogenic operation
- field enhancement near spacers
- charge accumulation on insulating materials
- S2 uniformity / light collection impact
- spurious electron emission
- discharge / HV stability
- reproducibility over operating cycles
- fluorescence

Presented by Yajing Xing (LPNHE) at XeSat2026

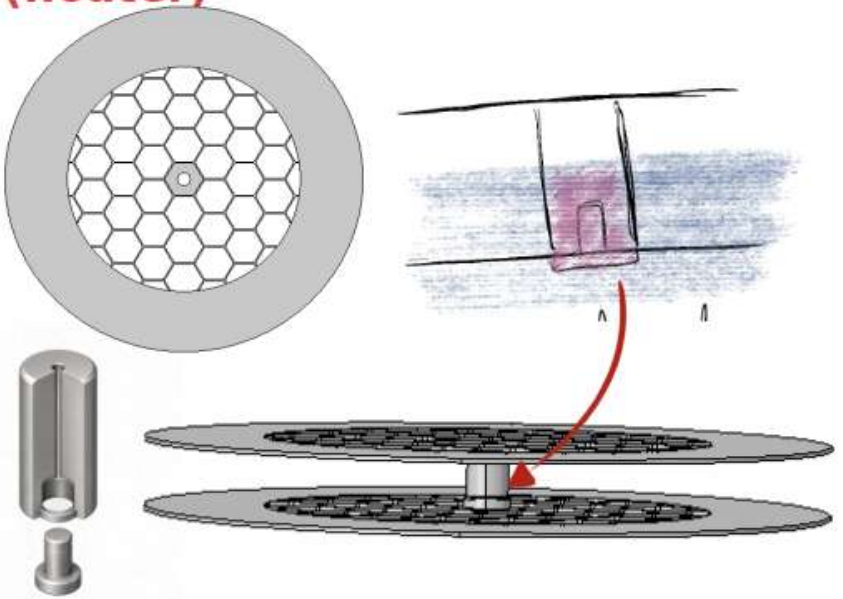
SAFE: Design

Design #1:
Woven grid + 'thin' spacer + floater



Initial design with **supporting floater**

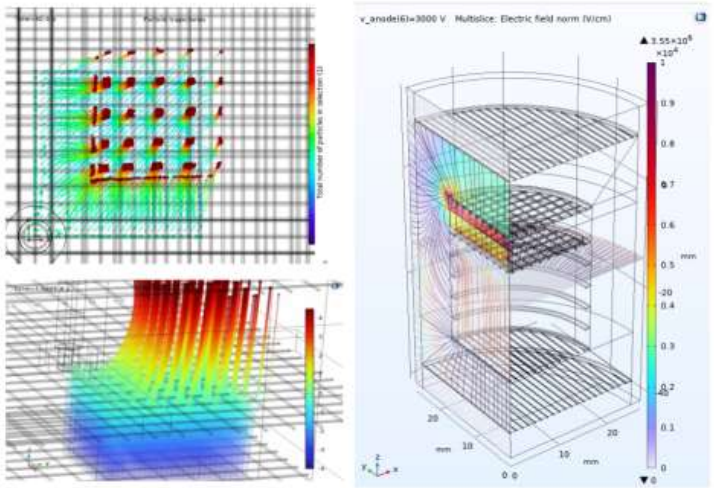
Design #2:
Hexagonal mesh + 'fat' spacer (floater)



Provide a better **optical transparency**

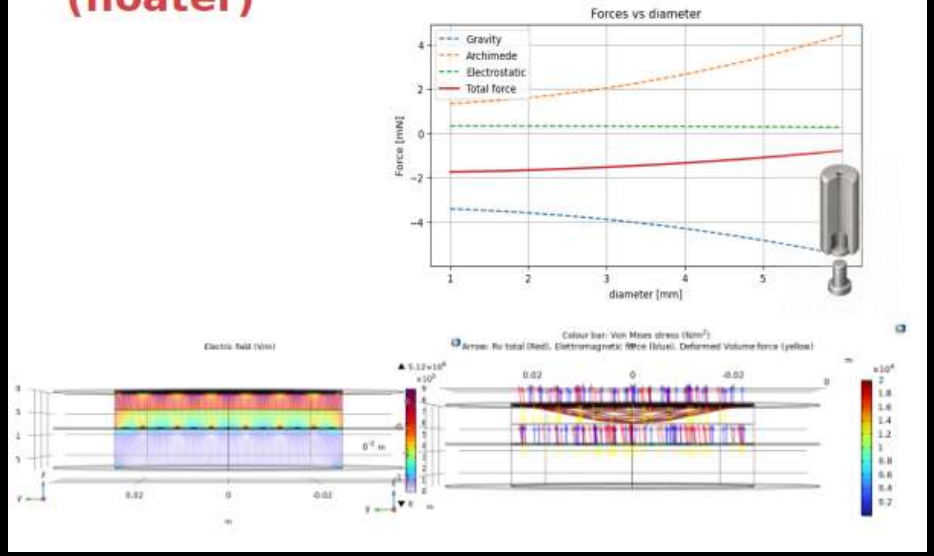
SAFE: Simulations

Design #1:
Woven grid + micro spacer + floater



Study by Nabil Garroum (LPNHE)

Design #2:
Hexagonal mesh + macro spacer (floater)



Study by Veronica Cazzola (LPNHE)

COMSOL Multiphysics | small-size mechanic-electronic coupling simulation is ongoing | challenge on large scale 3D simulation

Presented by Yajing Xing (LPNHE) at XeSat2026

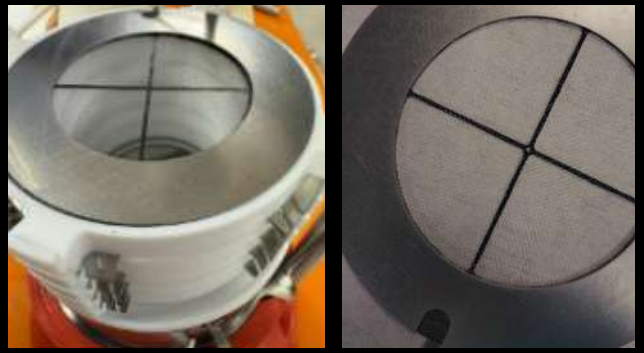
SAFE: Prototyping

HV insulators (spacer) :

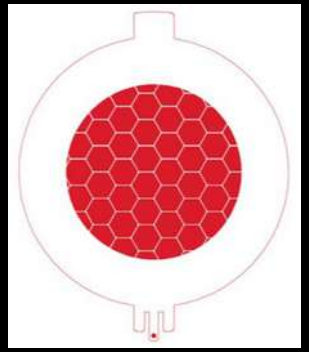
- Material: PEEK, HDPE
- Fabrication: Resin 3D microprinting / Micro machining
- HV testing: CV curve – breakdown/discharge

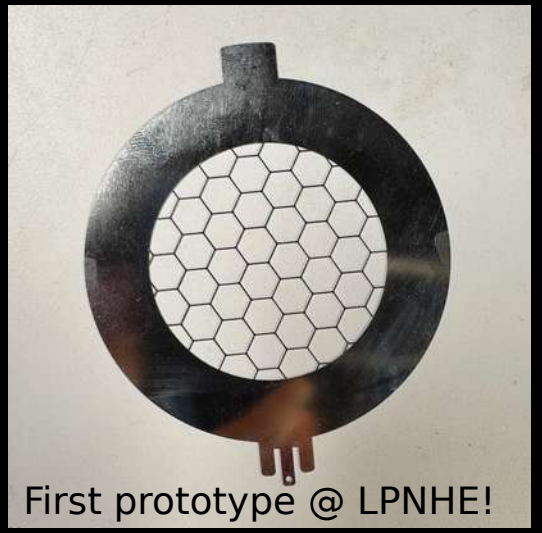
Electrode:

- Material: stainless steel 316L
- Fabrication: Gantois, Machining, SMD stencil, Fiber Laser Metal Cutting @ LPNHE
- Metrology (planarity & defect)



Design #1

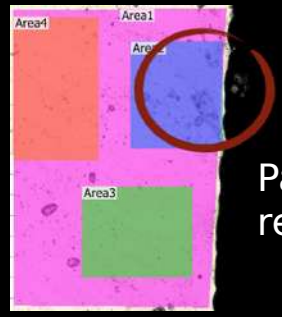




First prototype @ LPNHE!

Design #2 : Gerber file of hexagonal electrode for SMD stencil

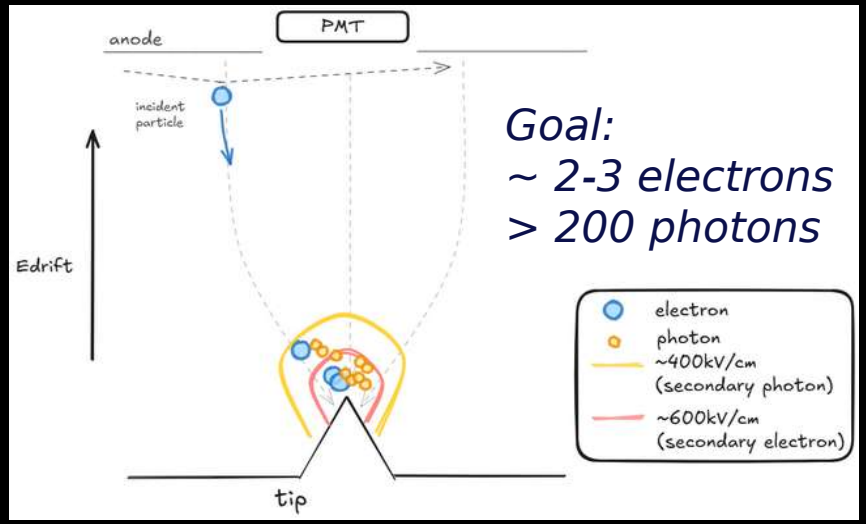
Eric Pierre (LPNHE)

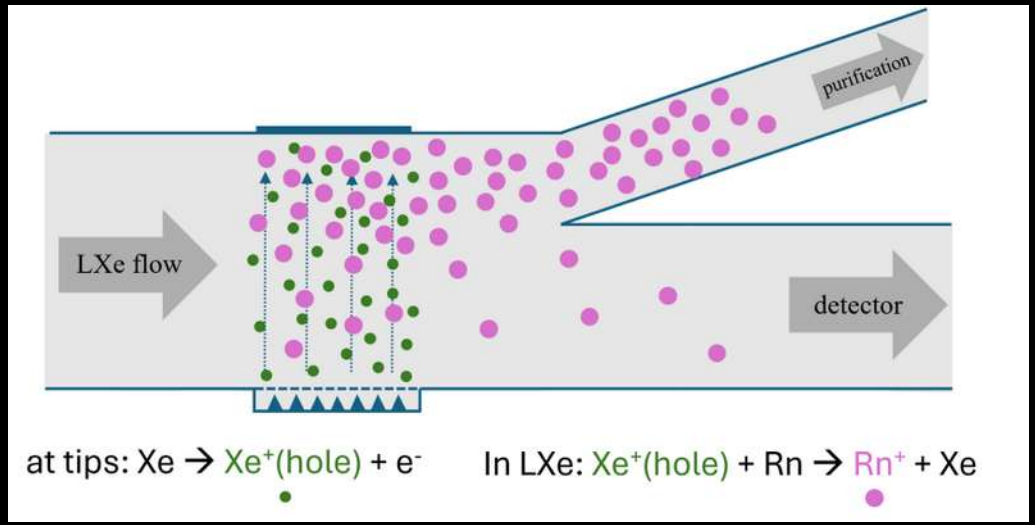


Passivation required

Presented by Yajing Xing (LPNHE) at XeSat2026

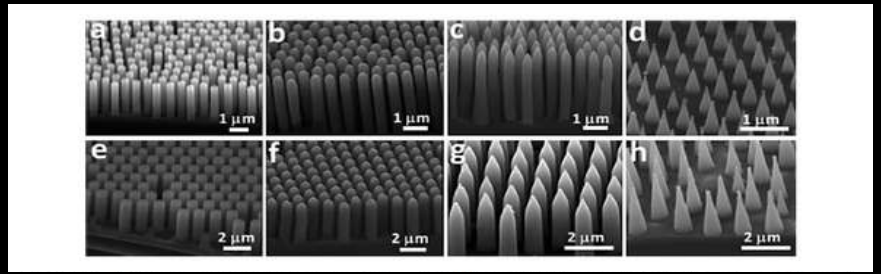
FIXED: Field-Emitter Array In XEnon Detector





Secondary scintillation in liquid-phase

- No liquid - gas interface
- No electrode sagging
- No delayed electrons
- Cleaner S2 signal



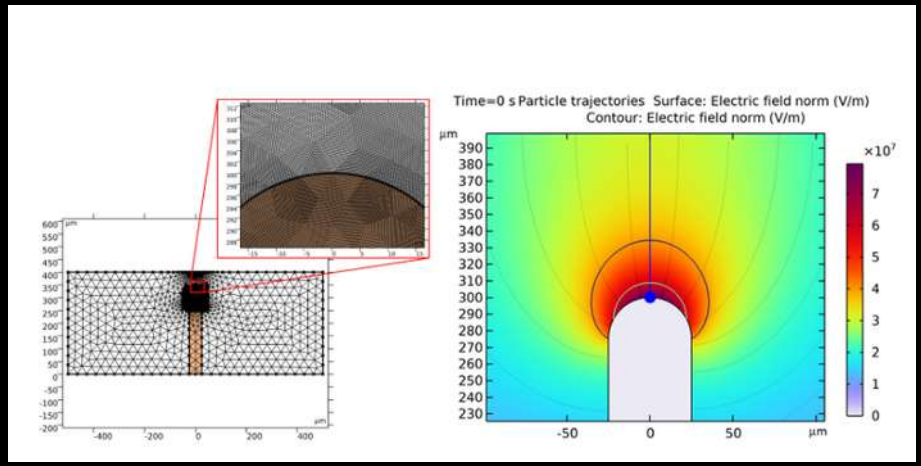
FEA: Microscopic Conductive structure

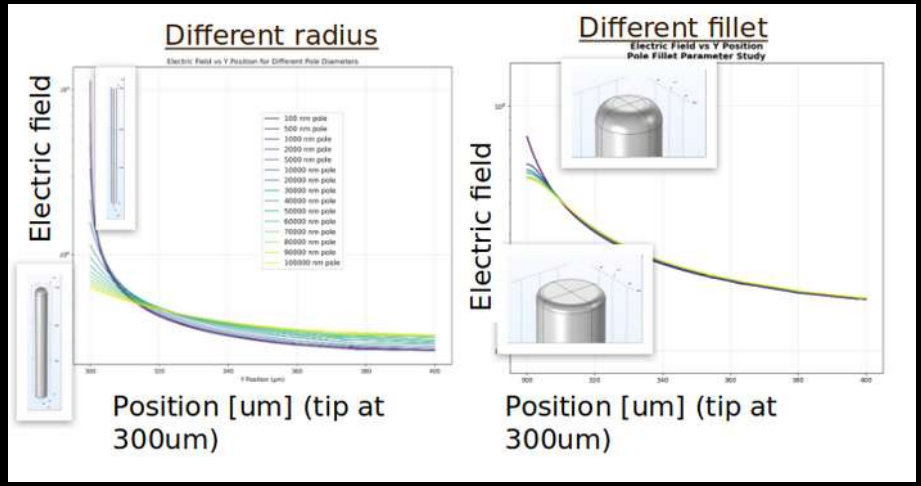
FIXED: Design and Simulations

Study of the optimal shape
- Baseline design: pillar with counter electrode at 100µm
- Vary geometry and compare photon/electron yield

Simulation procedure
1. E-field simulation (COMSOL)
2. Electron tracking (PyCOMES [1])
3. Emission simulation (Param. From [2])

$$\Delta N_e = N_e \theta_0 \exp\left(-\frac{\theta_1}{E(\vec{x}, V_A, d_w) - \theta_2}\right) \Delta\vec{x}, \qquad \theta_2 = 586\ [kV/cm]$$
$$\Delta N_\gamma = N_e \theta_3 (E(\vec{x}, V_A, d_w) - \theta_4) \Delta\vec{x}, \qquad \theta_4 = 399\ [kV/cm]$$

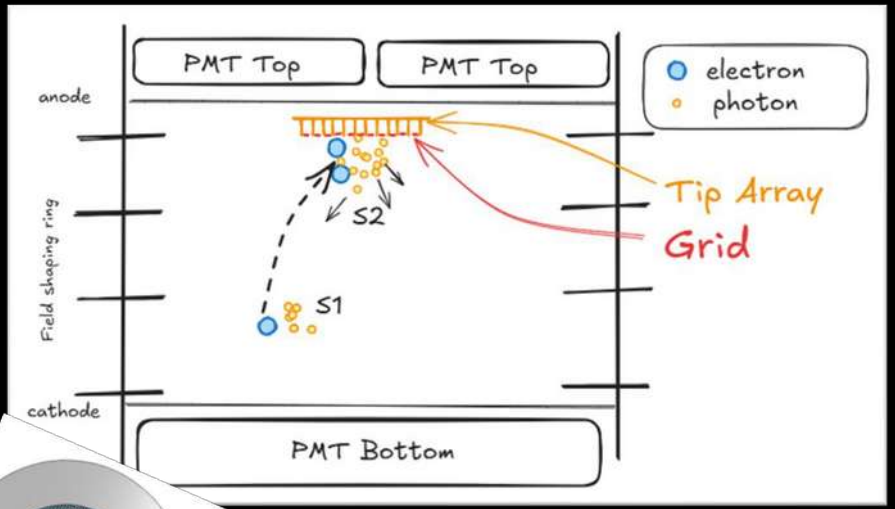




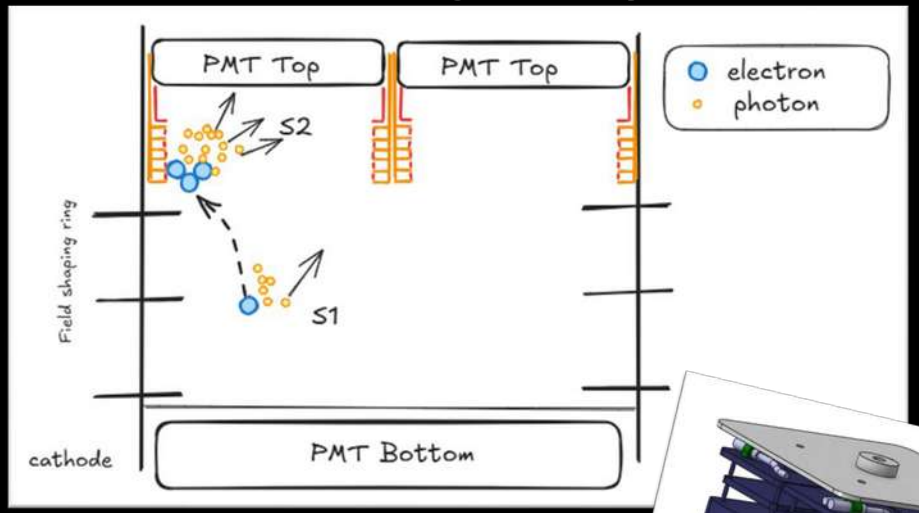
[1] https://github.com/ftoschi/PyCOMes
[2] arXiv:1408.6206v3 / E Aprile *et al* 2014 *JINST* 9 P11012

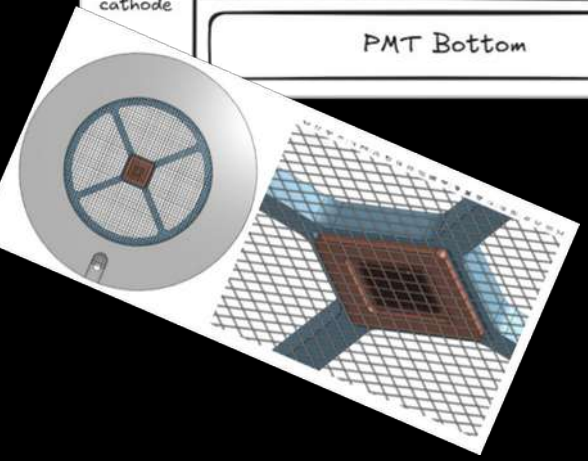
FIXED: Prototyping

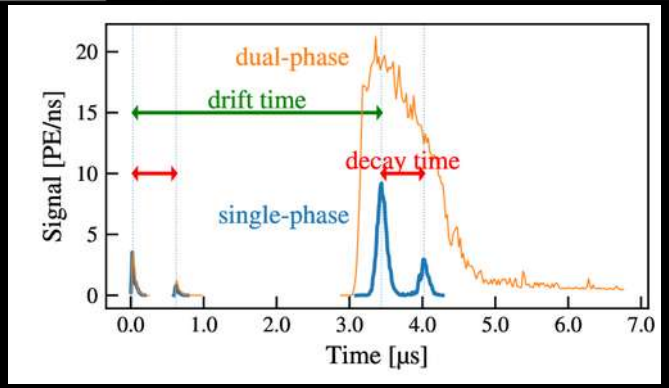
Proof of concept design

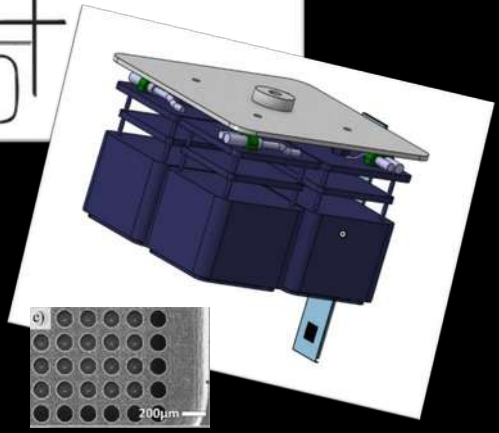


Enhanced geometry









Presented by Romain Gaior (LPNHE→ILANCE) at TYL FJPPN/FKPPN 2026

XeDualPhase : collaborations

XeLab 2nd phase : XeDualPhase
Funds from DIM-ORIGINES Equipment (106k€, 2027-2030)

SAFE : Spacer-Assisted Floating Electrodes

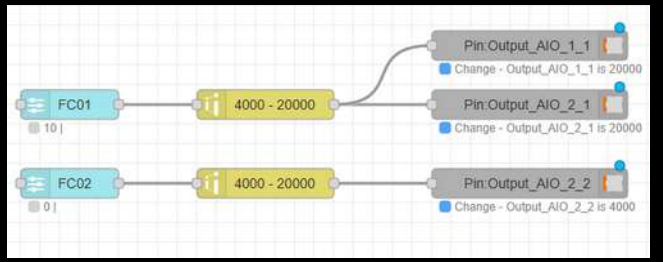
KIT: HV pillars, electrodes construction; Freiburg : large scale electrodes; Muenster : Kr source;
Thanks to IRL DMLab for financial support of visiting activities in Germany
Building a future Collaboration with Nikhef : fluorescence from pillars

FIXED : Field-Emitter Array In XEnon Detector

OTH Regensburg : FEA ; Muenster : FEA-Radon ; IPMU (Tokyo) : prototype
Thanks to IRL ILANCE for financial support of former visiting activities in Tokyo
Now Romain Gaior at ILANCE

Extra R&T : Slow Control

- o Robust
- o Open
- o Flexible
- o Scalable



- Based on **Revolution Pi**
- PT100 readout board
- **Python MQTT** broker to push data
- Data storage on **InfluxDB**
- Display with **Grafana**
- Alarm system with sound and email
- Code initially developed with **CODESYS** now entirely on **python** and **Node-RED** for the web app and actuators

REVOLUTION PI a KUNBUS brand

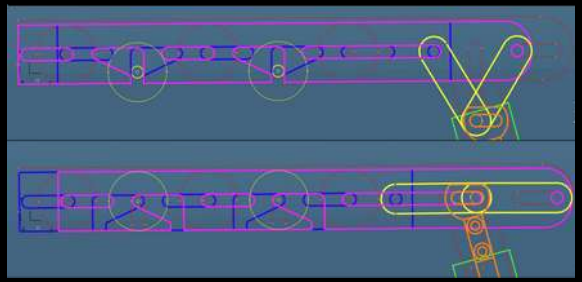
MQTT

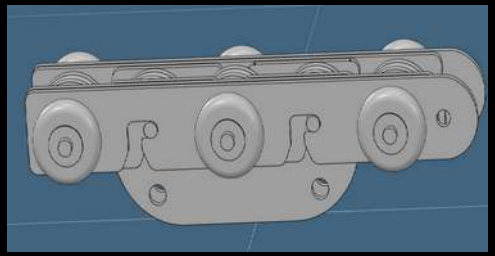
CODESYS

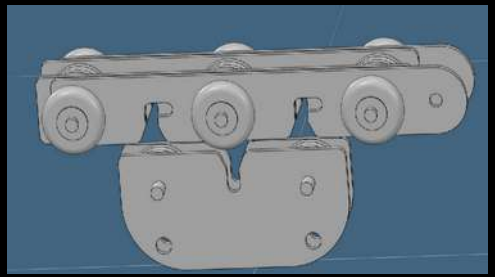
Design and realization by Romain Gaior, Fabien Frerot, Hayato Ledortz-Takeda (LPNHE)

Extra R&T : Mechanics

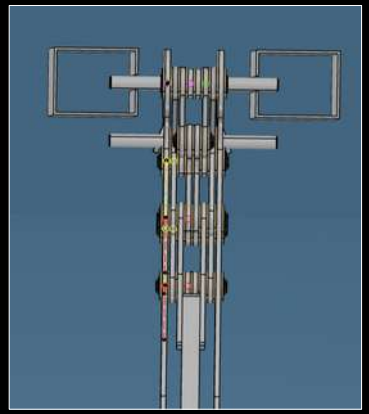
- TPC sliding system (*palan*) entirely designed and prototyped at LPNHE
- It increases safety on operations (avoiding TPC manual manipulation)
- It strongly reduces dead times during TPC upgrades
- Proof of concept made with a plastic prototype with a 3D printer

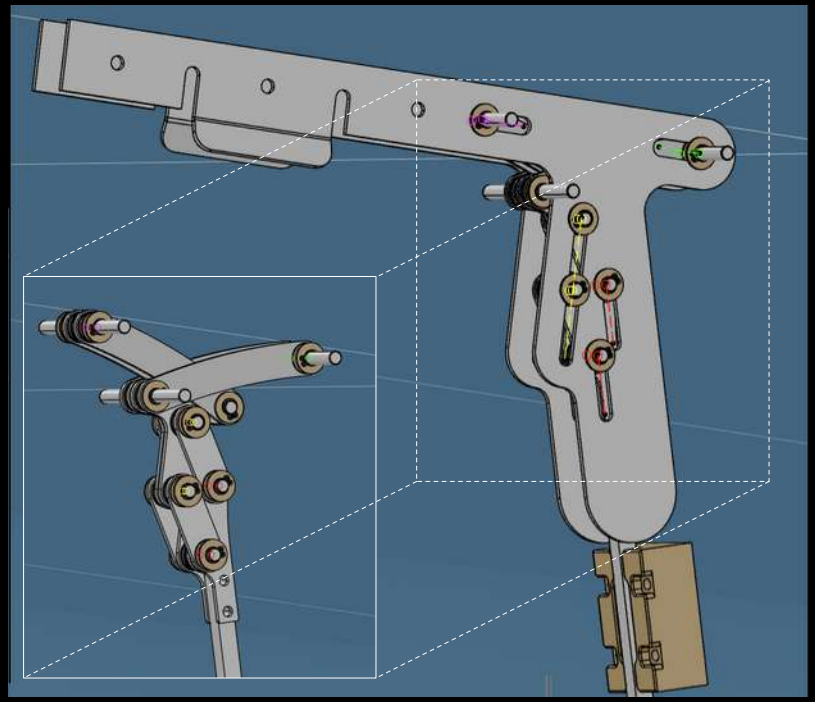






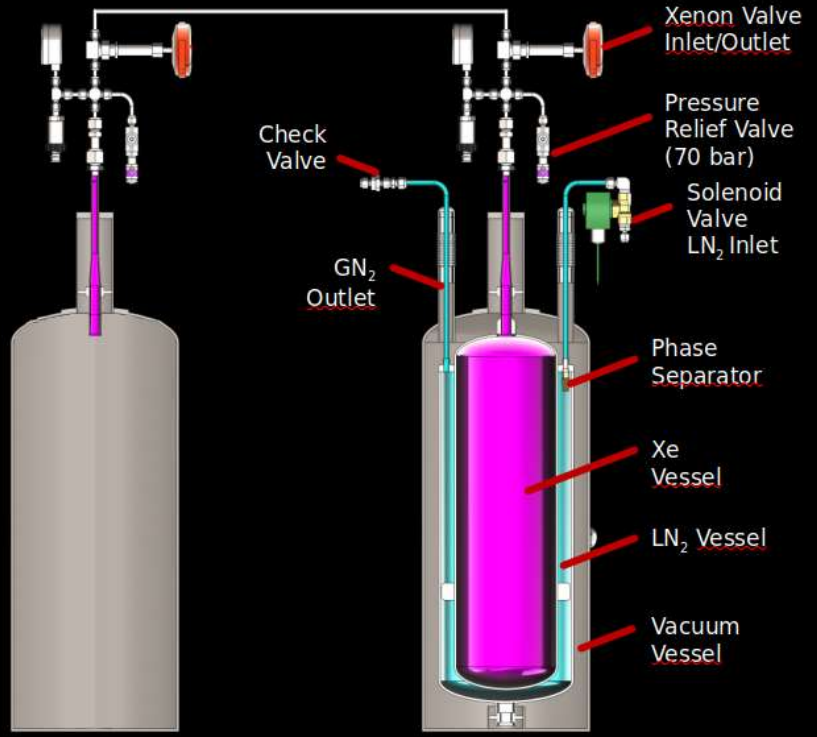
TPC





Design and realization by Sébastien Colinot (LPNHE)

Extra R&T : Cryogenics



20 kg ***20 kg***

50 kg ***11 kg***

Design by Jean-Marie Disdier (Ext contr. LPNHE),
construction by Costruzioni Generali (Parabiago, Italy)

Thank you

- Luca Scotto Lavina (DR), Yajing Xing (McF Sorbonne) : **Scientific Coordinators**
- Olivier Dadoun (IR) : **Technical Coordinator**

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- Bernard Andrieu (CR)
- Veronica Cazzola (PhD, IN2P3)
- Yongyu Pan (PhD, CSC, Sorbonne, IN2P3)
- Davide Taglieri (M2, Sorbonne, Roma La Sapienza)

IT:
- Fabien Frerot (Electronics)
- Sebastien Colinot (Mechanics)
- Romain Gaior (Electronics, ILANCE)
- Hayato Ledortz-Takeda (IT internship)

Many thanks to former contributors:
Frederic Girard (now McGill University, Canada)
Owen Stanley (SUBATECH+UMelbourne)
Lorenzo Principe (SUBATECH+UMelbourne)

SUBATECH team:
Physicists : Dominique Thers, Sara Diglio, Julien Masbou, Nicolas Beaupere
IT : Arnaud Cadiou, Julien Simonneau, Patrick Le Ray, Eric Morteau