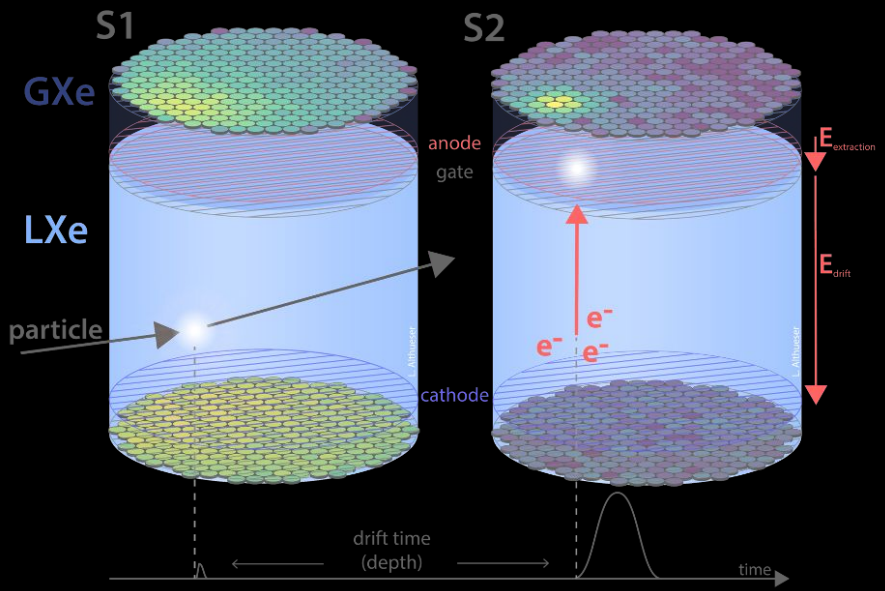
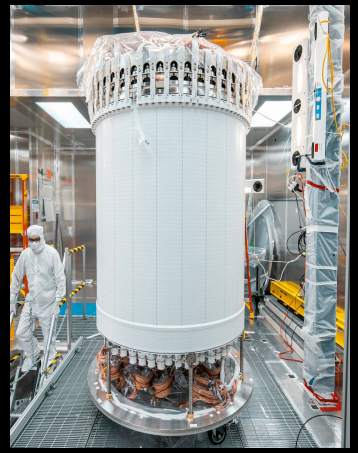
R&Ds in France for next generation LXe TPC

Luca Scotto Lavina, IN2P3/CNRS

Dark Matter Search with Liquid Xenon TPCs today



XENONnT
5.9 t @ LNGS



LZ
7 t @ SURF

PandaX-4T
3.7 t @ JinPing

From the current to the next generation of liquid xenon detectors

XENONnT :
- @LNGS, Italy
- 8.6t total Xe mass

LZ :
- @SURF, US
- 10t total Xe mass

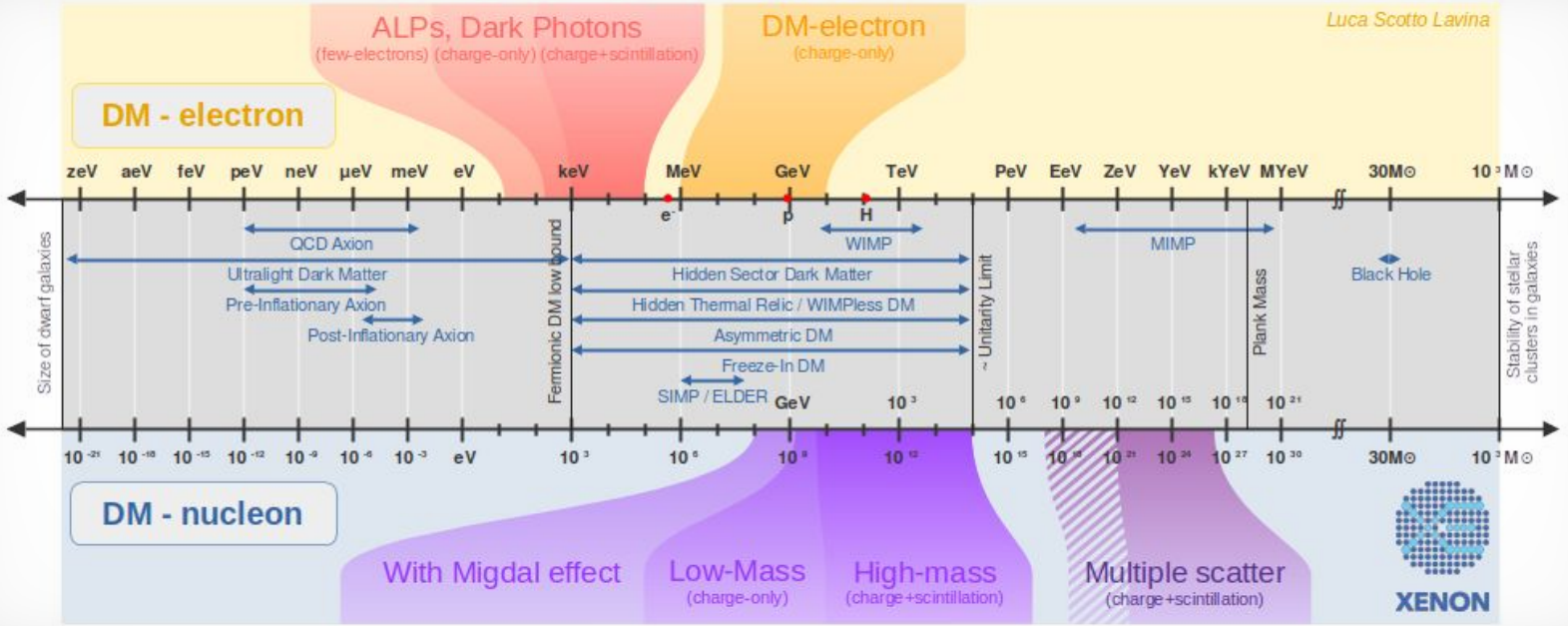
+ DARWIN
- R&D program since a decade to build a 50t total mass

PandaX-4T :
- @JinPing, China
- 6t total Xe mass

XLZD :
- Several sites considered
- 80t total Xe mass

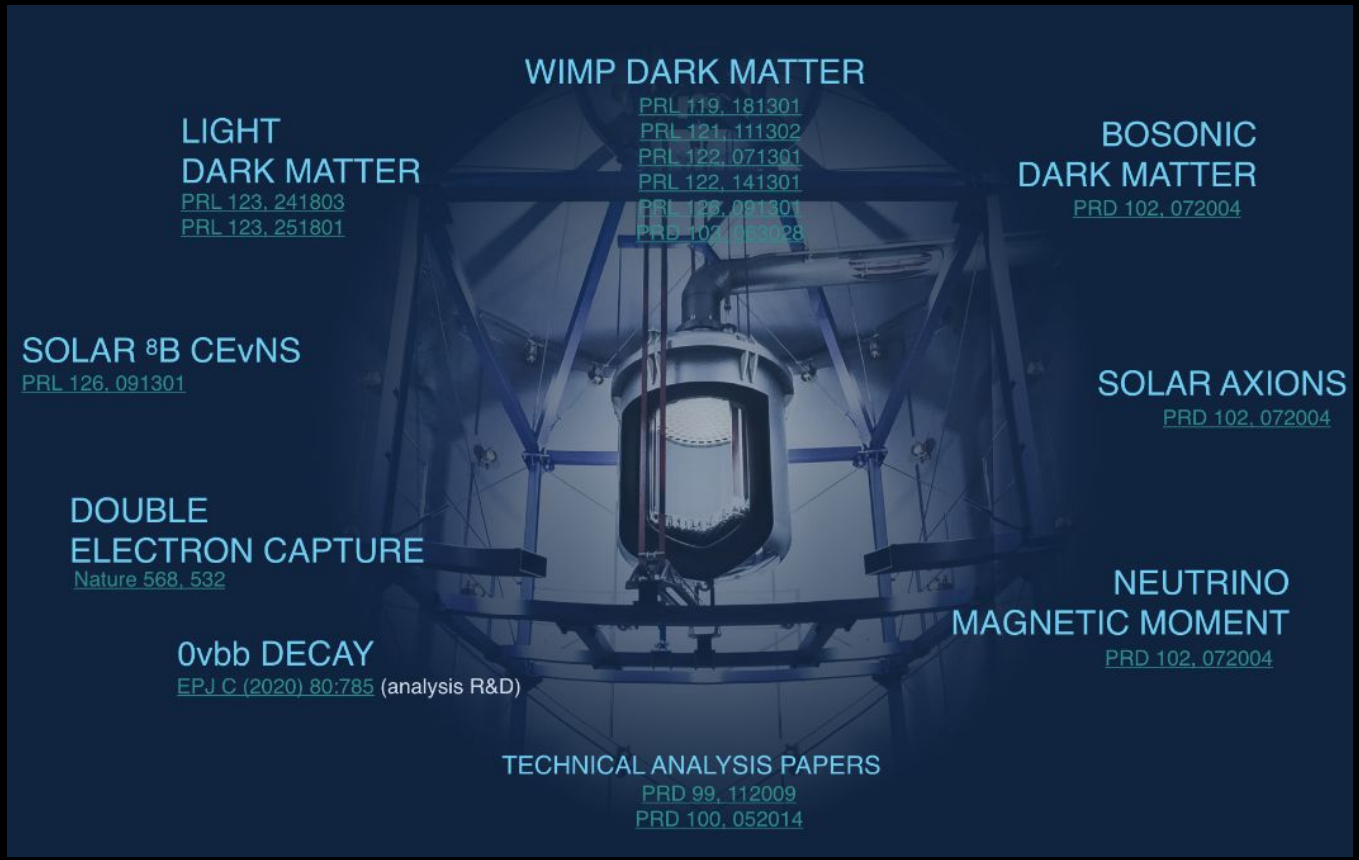
PandaX-xT :
- @JinPing, China
- 20t → 40t total Xe mass

The scoped energy domains



Physics cases

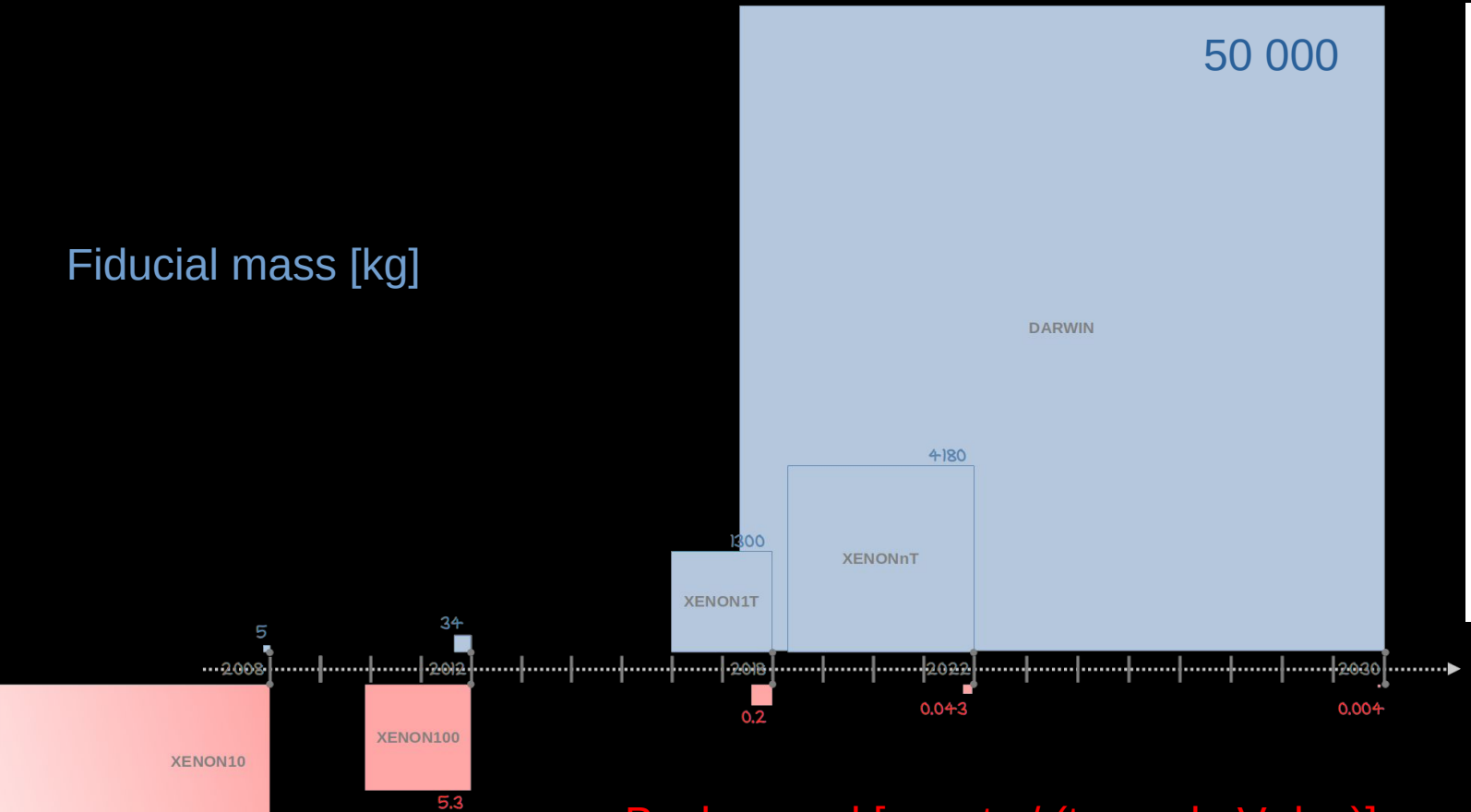
- **Different dark matter models that can be probed:**
  - **Low-E Nuclear Recoils (NR)**
    - SI elastic scattering
    - SD elastic scattering *
    - WIMP-pion coupling
    - Effective Field Theory on WIMPs (+iDM) *
    - Mirror DM
  - **Electronic Recoils (ER)**
    - Dark Photons
    - Bosonic SuperWIMPs, Magnetic dark matter
    - Solar axions and Axion-like Particles
    - Luminous DM
  - **Both (NR+ER)**
    - Inelastic DM
    - Annual modulation search
    - Low mass WIMPs (<10GeV)
    - Multiply-Interacting Massive Particles (MIMPs)
    - Migdal Effect and Bremsstrahlung
- **New physics can be scoped:**
  - **Neutrinos**
    - Solar 8B neutrinos (CEvNS → NR)
    - Neutrinoless double-beta decay *
    - Neutrino magnetic moment
    - Supernovae neutrinos
  - **Rare events**
    - Double electron capture *
    - Gravitational wave search
  - **New particles**
    - Solar Dark Photons



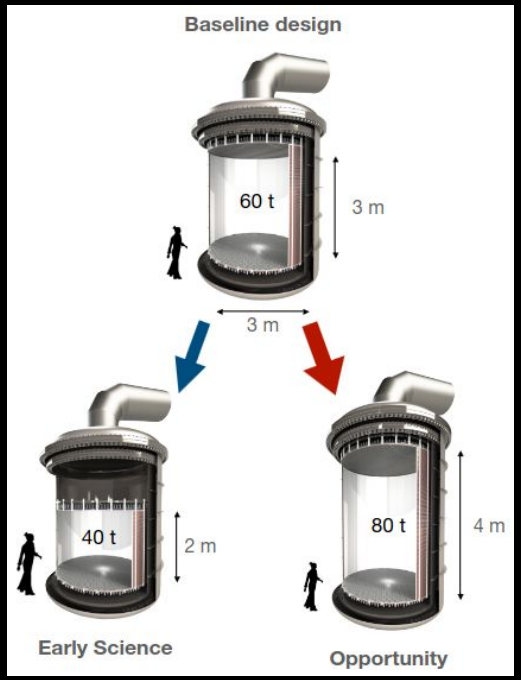
*LXe-specific

Bigger and more silent

Fiducial mass [kg]



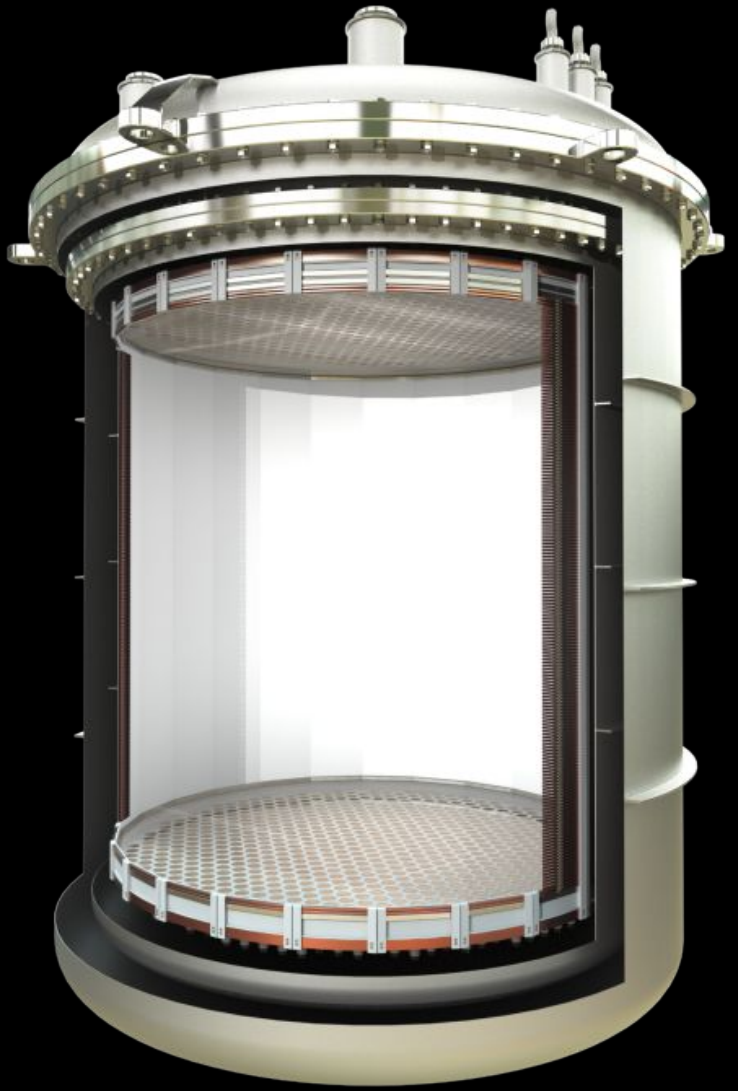
Background [events / (tonne keV day)]



Size matters

New detector → new challenges

- **Design of electrodes**: robustness (minimal sagging/deflection), maximal transparency, reduced e- emission ("hot spots")
- **Electric field**: ensure spatial and temporal homogeneity, avoid charge-up of PTFE reflectors
- **High-voltage** supply to cathode design, avoid high-field regions
- **Light sensors**: reduce backgrounds and DRCs, improve PDE
- **Cryogenic** system and xenon **purification**
- Xenon **storage and recovery** : safety and reliability
- **Computing** : handling up to 2.4 PB / year of data



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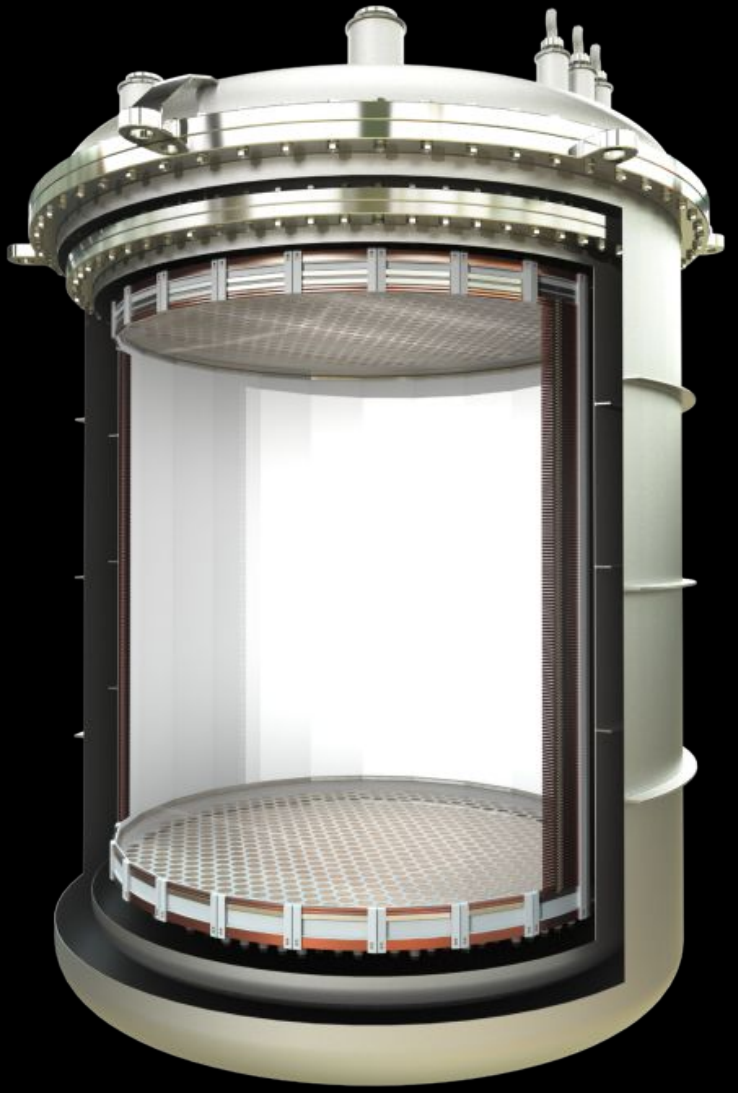
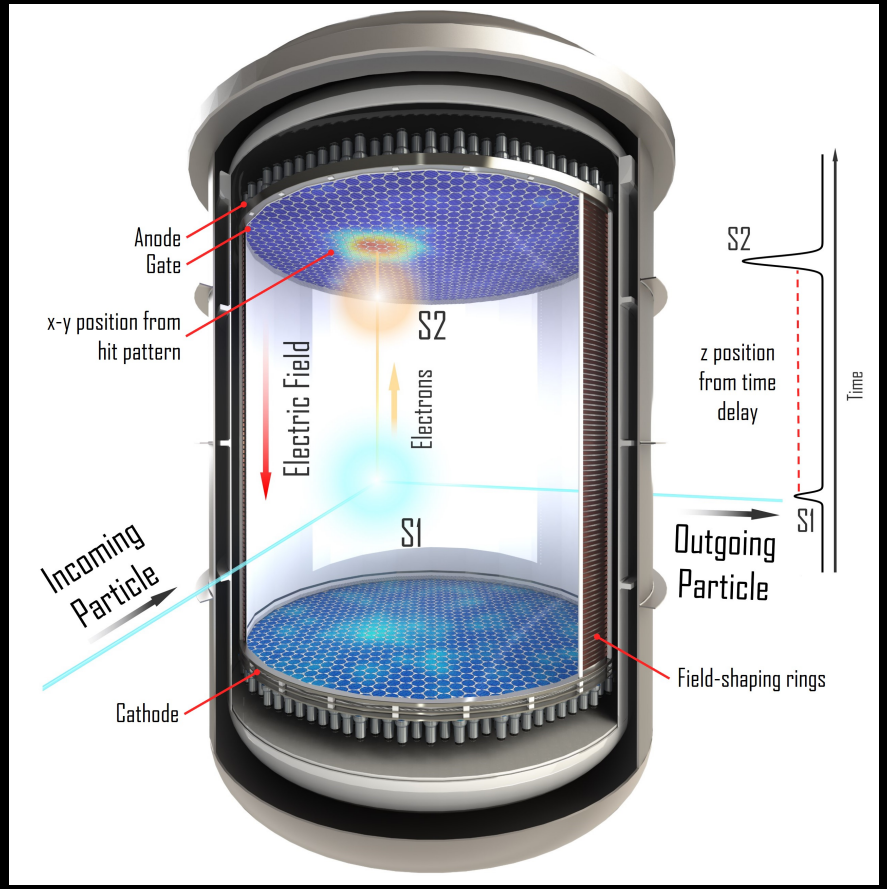
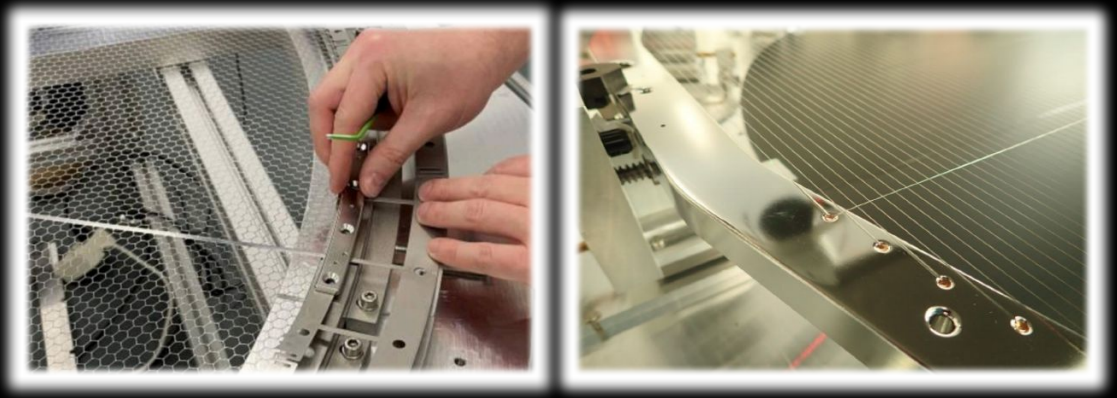


Large-scale TPC : obtaining a high proportional scintillation light

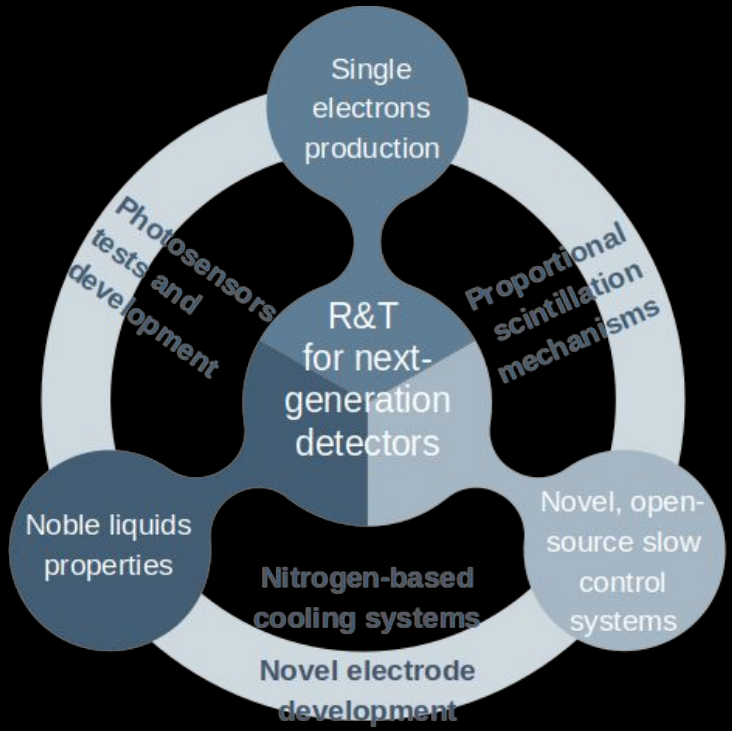


Development of large electrodes allowing :

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

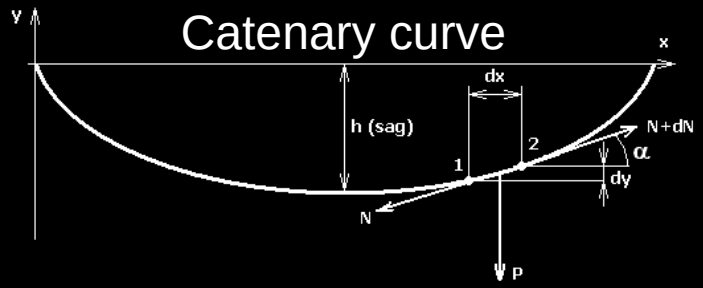


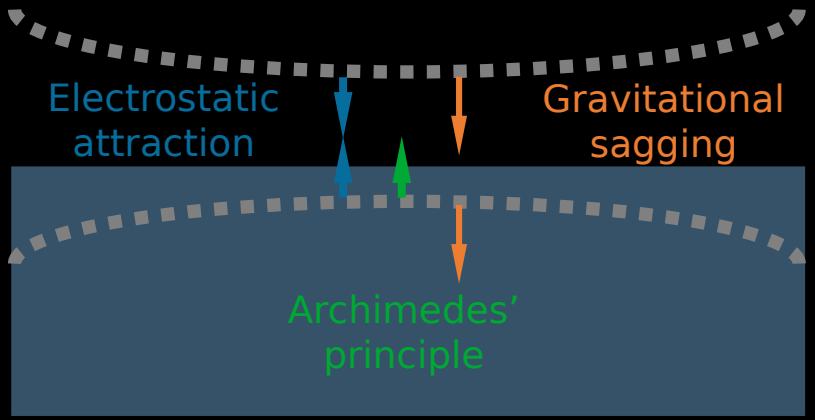
R&T on novel electrodes with the XeLab Project



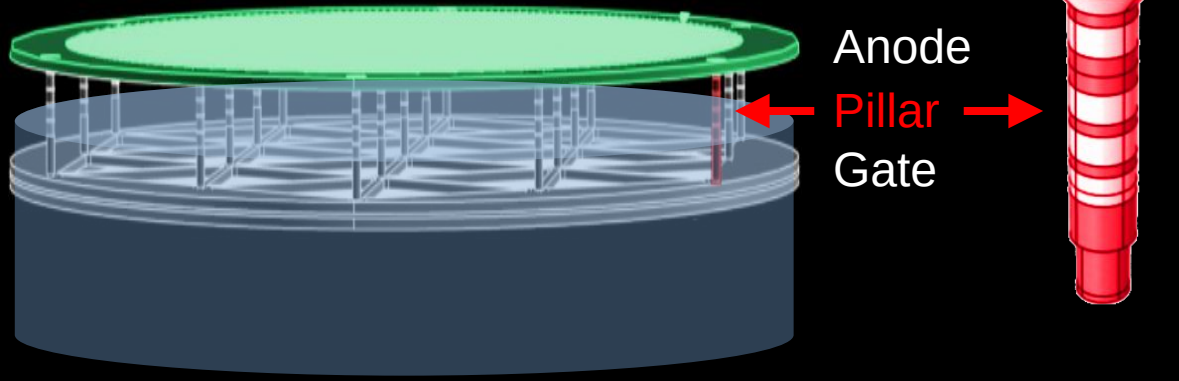
- CNRS/IN2P3 Master Project
- LPNHE and Subatech
- R&D for DARWIN / XLZD
- Part of DRD2 activities
- Presented already in XeSat23 and ICRC23
- Proceedings: https://hal.science/hal-04186811
- Technical paper in preparation

The idea of Spacer-Assisted Floating Electrodes (SAFE)

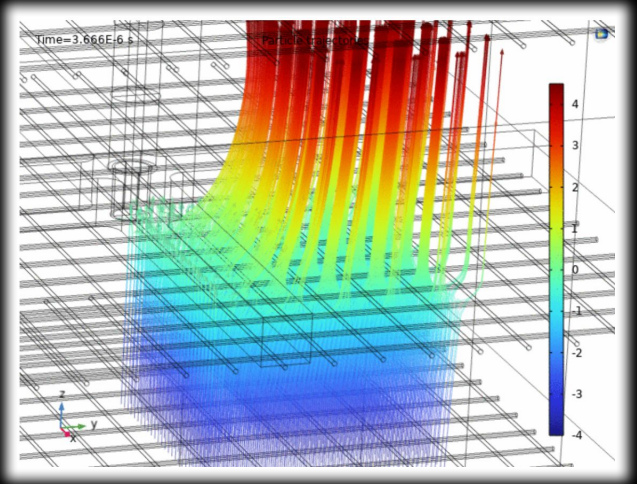




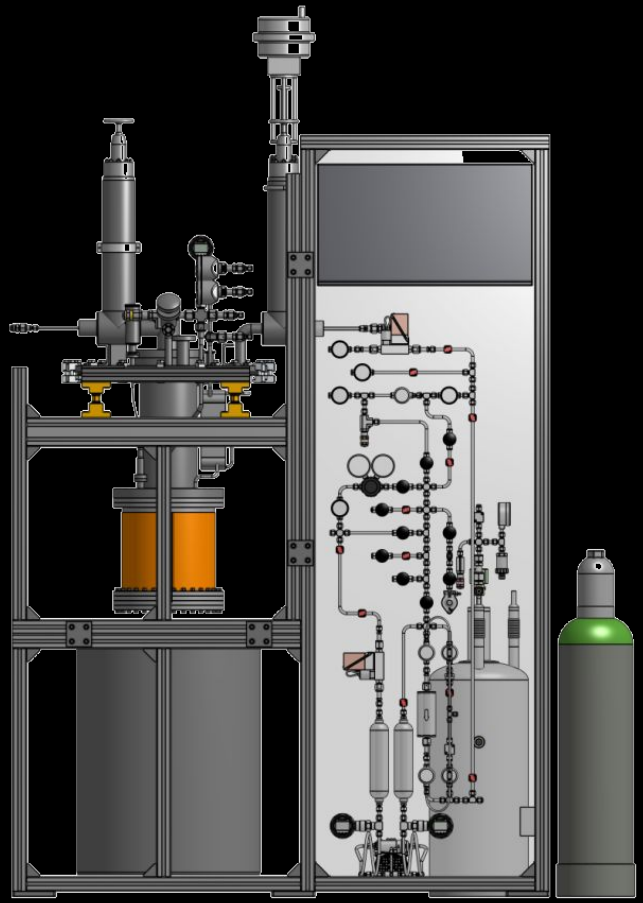
Our idea : “floating” electrodes with supporting pillars



Simulations with COMSOL Multiphysics



R&T with XeLab



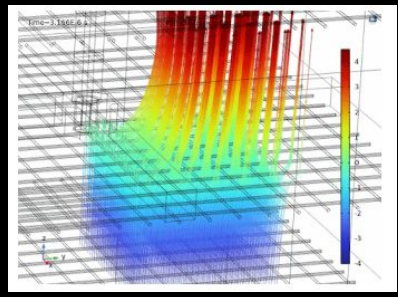
R&D
Levelling system

R&D
Three-way heat exchanger

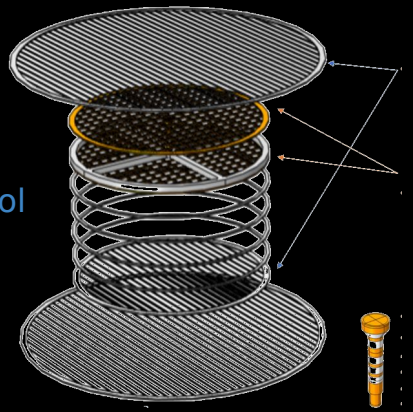
R&D
Cryostat LN2-cooling with copper belt

R&D
Storage and recovery system

R&D
Slow Control with RevPI



R&D
Simulations electrodes

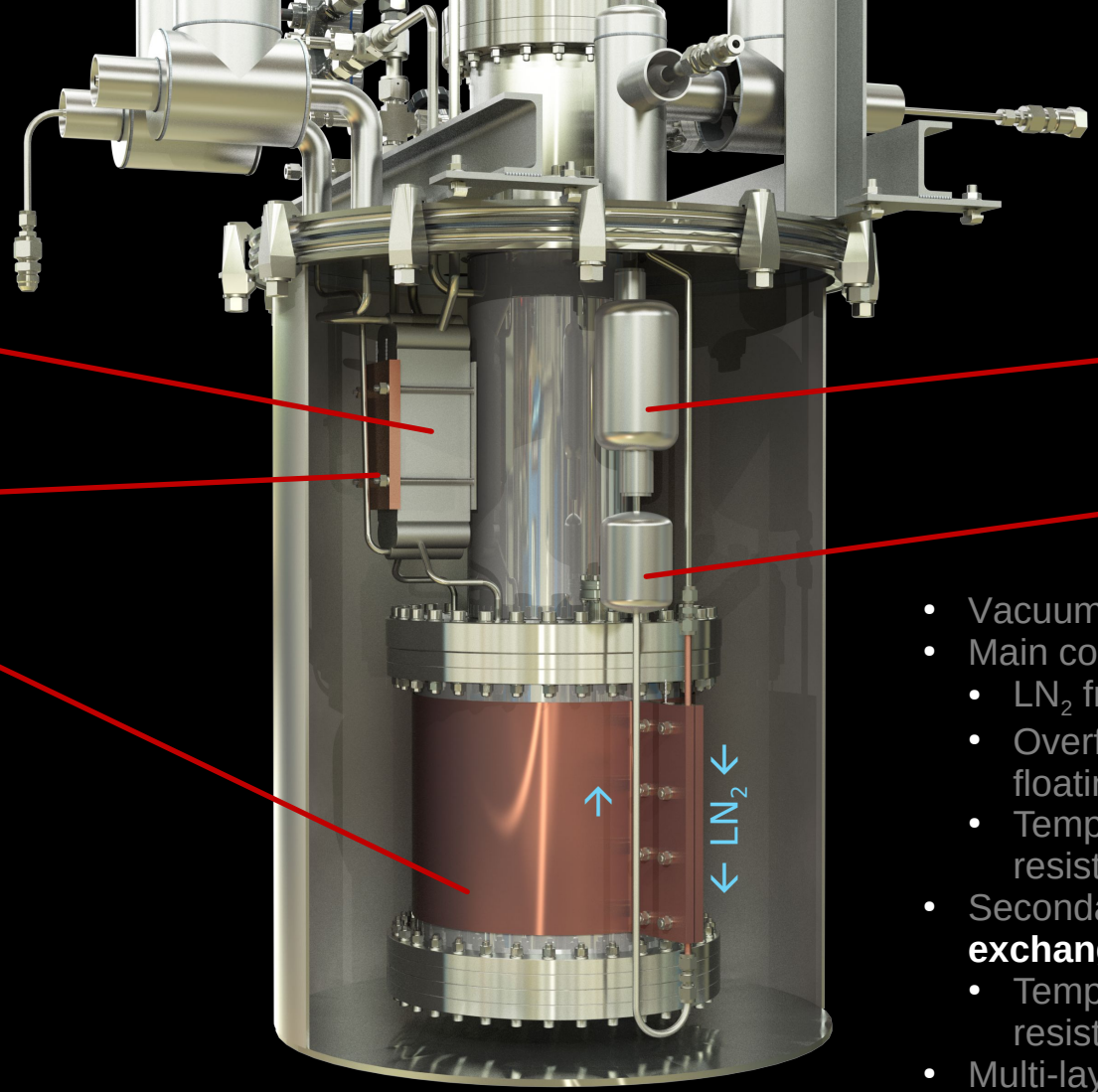


Standard electrodes

R&D
Floating electrodes

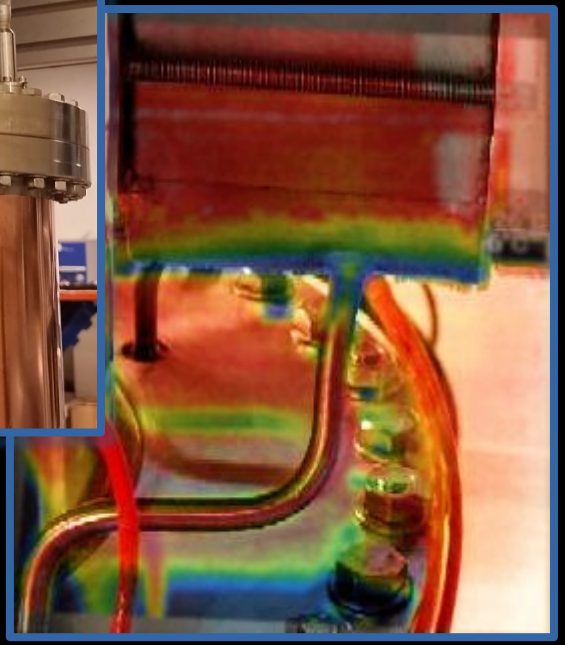
R&D
Insulating pillar

Cryostat

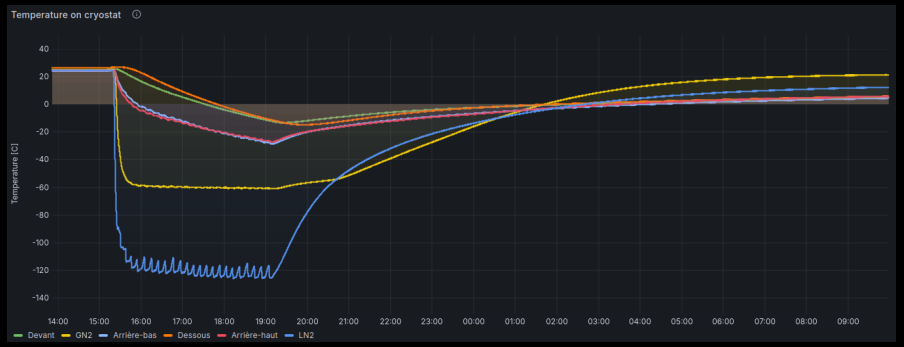


- Vacuum insulated, double-walled
- Main cooling mode: **copper belt**
  - LN_2 from pressurized dewar
  - Overflow prevention from free floating vent
  - Temperature control from heating resistor
- Secondary cooling mode: **heat exchanger**
  - Temperature control from heating resistor
- Multi-layer insulation to prevent radiative losses (not shown)

First cooling tests with the copper belt

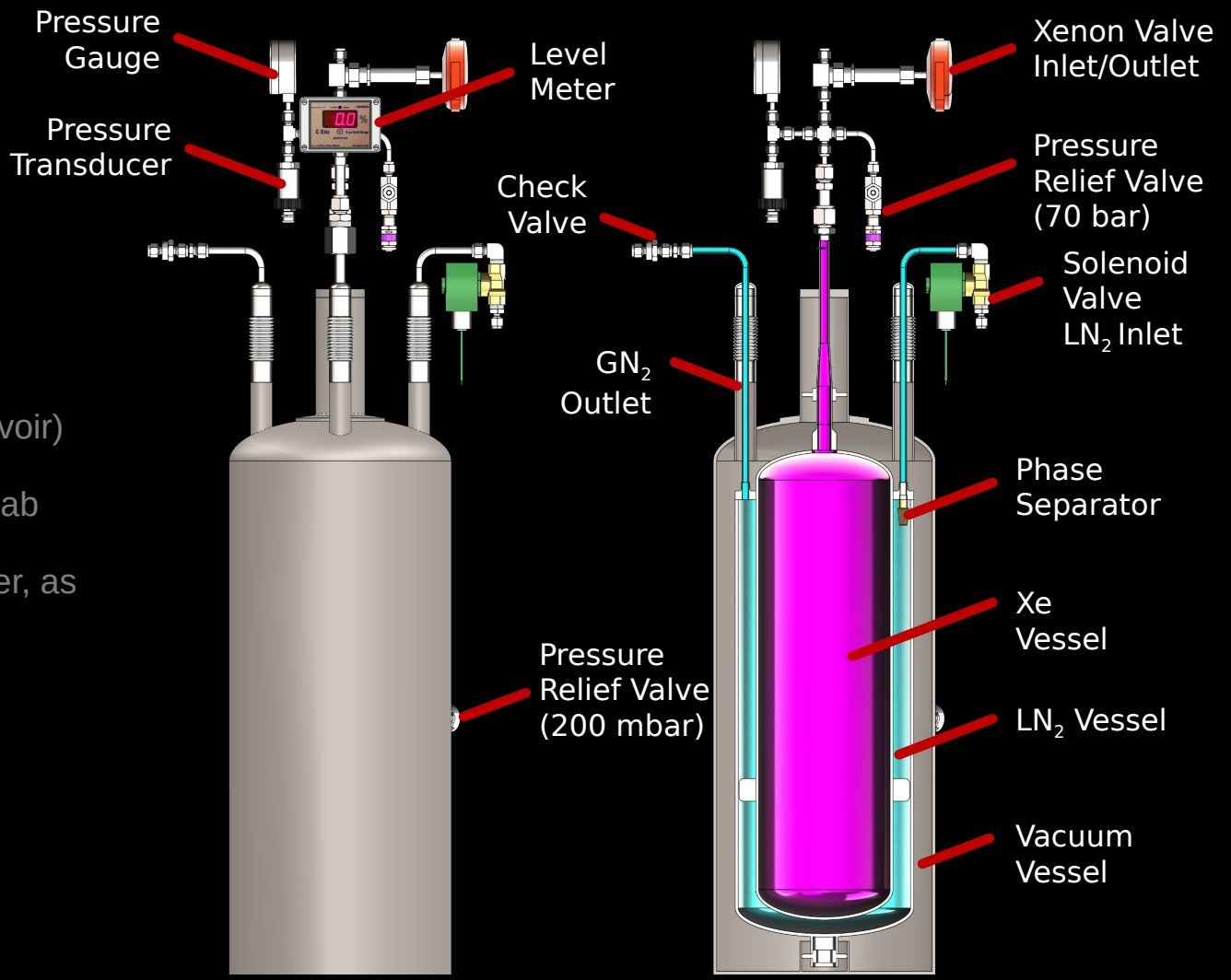


First cooling tests with the three-way heat exchanger



MiniReStoX

- Xenon recuperation and storage
- Three nested vessels
  - Vacuum insulation + MLI
  - Liquid nitrogen (from 15 000 L reservoir)
  - Xenon (max 70 bar)
- Can be kept cold at all time during XeLab operation
  - Immediate xenon recuperation trigger, as needed



Slow Control

- Based on the Revolution Pi technology
- Home-made code (CODESYS)
- Home-made PT100 readout board
- Python MQTT broker to pull the data
- Storage in InfluxDB database
- Data Visualization with Grafana

Slow Control

https://revolutionpi.com/en

Base Module :

REVOLUTION RevPi Connect S 8GB REF 100362

IO Modules :

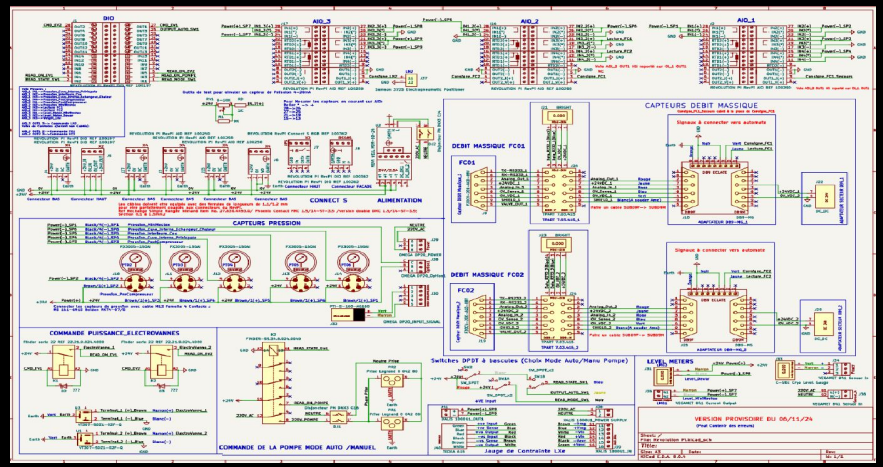
3 x **REVOLUTION PI RevPi AIO REF 100250**

(6 entrées analogues (U = 4, I = 4 , RTD = 2,2 sorties analogiques (U = 2, I = 2)

REVOLUTION PI RevPi DIO REF 100197 (14 Entrées / 14 Sorties)

Alimentation :

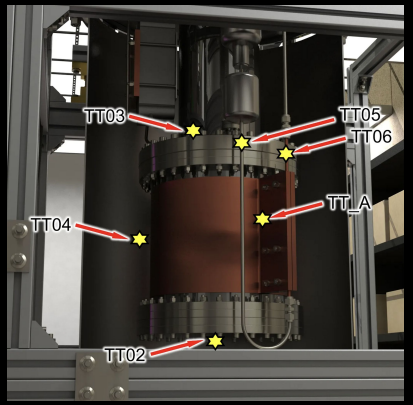
MEAN WELL MDR-60-24 (1,8A *24V = 43,2W)



Capteurs Pression	Autre Capteur Pression	Capteurs Débits Massique	Capteur Niveau	Capteur Niveau	Electrovannes	Pompe / Ventilateurs	Liquid Nitrogen	
OMEGA PX3005-150AI (4-20 mA, 0 - 150 psi)	**Swagelok PTI-S-AG160-12AQ** (4-20 mA, 0 - 160 bar) *relecture* via **OMEGA DP20** assurant le contrôle de l'électrovanne **ASCO 8263K206S1TD0H1.**	**Bronkhorst F-201CV-20k-AGD-88V** (4-20 mA, 0-10 ln/min) avec **TPART + BRIGHT Compact Local Readout / Control Module + Module DB9 Rail DIN** pour réaliser câblage de redirection des alimentations.	***DEMACO C-STIC CRYO LEVEL GAUGE*** (4-20 mA, 0-100%) *relecture via **VEGAMET 841.***	***DEMACO C-STIC CRYO LEVEL GAUGE*** (4-20 mA, 0-100%)	**SMC VT307-5DZ1-02F-Q** piloté par un relais **Finder série 22 REF 22.21.9.024.4000**	Mode Auto /Manu, On/Off via **2 Levier sur panneau** Mise en Marche via relais 220V **FINDER-55.34.8.024.0040** sortie sur 2 prises secteur	**Samson 3725** Positionneur électropneumatique (4-20 mA, 0-100%)	**Xalis 1000U1** Indicateur à entrée Pont de Jauge avec 1 sortie analogique **TEDEA Model 615** Jaune de contrainte 6 fils (-200/200kg)
Qt = 5	Qt = 1	Qt = 2	Qt = 1	Qt = 1	Qt = 2	Qt = 1	Qt = 1	Qt = 1
PT02-PT06	**PT01**	**FC01-FC02**	**LM01**	**LM03**	**SV02-SV03**	**CP01**	**LN2**	**LXe_Weight**
5 Entrées Analogiques (4-20mA)	**1 Entrée Analogique (4-20mA)**	**2 Entrées Analogique (4-20mA) 2 Sorties Analogique (4-20mA)**	**1 Entrées Analogique (4-20mA)**	**1 Entrées Analogique (4-20mA)**	**2 Sortie TOR (0-24V) 2 Entrées Relecture TOR (0-24V)**	**1 Sortie TOR (0-24V) 2 Entrées Relecture TOR (0-24V)**	**1 Sortie Analogique (4-20mA)**	**1 Entrées Analogique (4-20mA)**

Pre-commissioning with Argon, then with Xenon

Run with 2 bar argon
- Duration: 9 days
- First liquefaction of argon
- Demonstration of continuous, stable operation
- At 2 bar:
  - T_{LAr} = 94.29 K
  - T_{LXe} = 177.88 K



Early December 2024, first two xenon fills:
1) 7.45 kg, run time 3 days
2) 10.95 kg, run time 5 days

- Temperature stability ± 5 mK
- System very predictable and responsive
- Filling, operation and recuperation with no loss of xenon

Run over 1 week:
- 2 nights operated at 10.9 kg

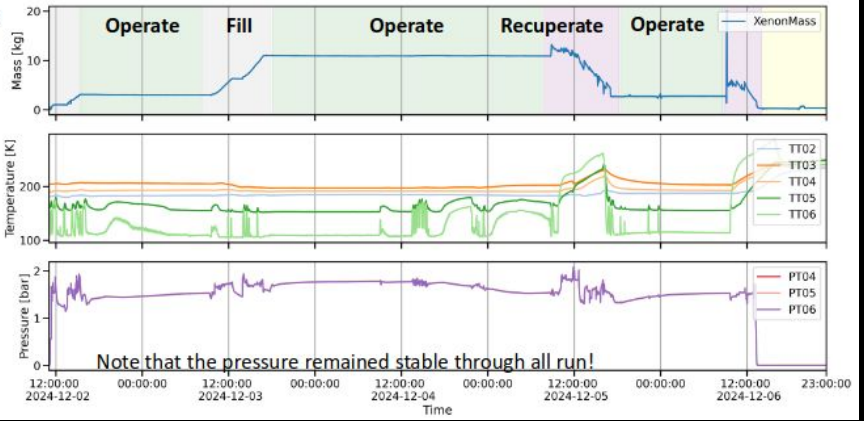
Filling:
- ≈12 hours to fill
- Max 2 kg/hour

Recuperation:
- ≈6 hours*

Most successful run on the 3rd – 4th Dec

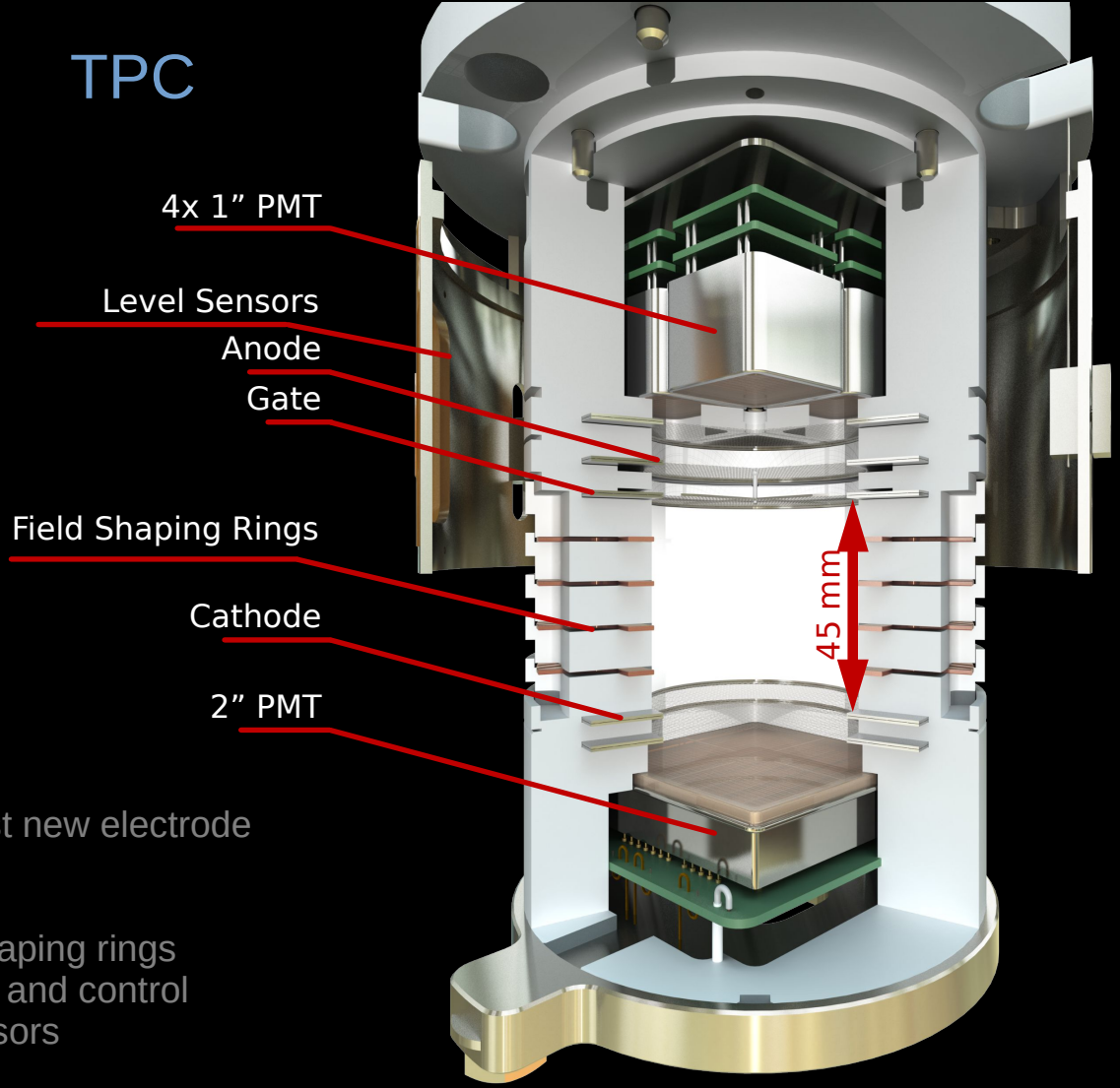
Intervention needed on 4th Dec at 9 PM

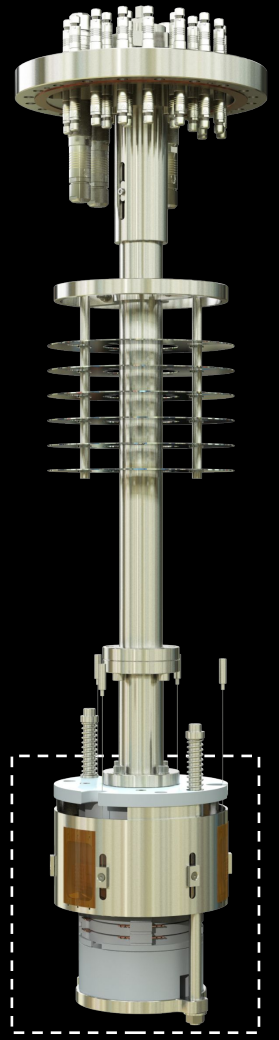
Net Xenon mass change ≈ - 40 ± 100 g



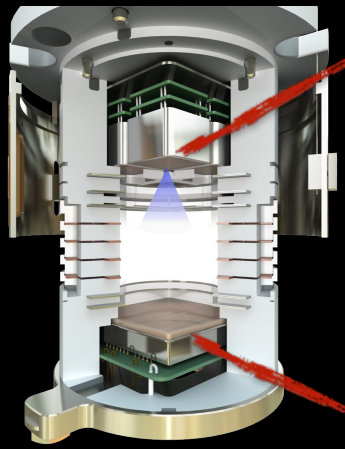
TPC

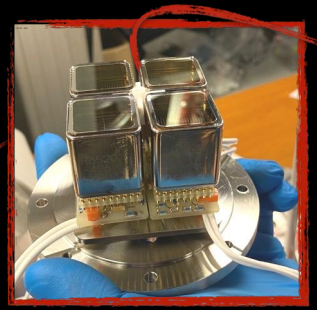
- Designed by Subatech
- Dual-phase TPC to test new electrode designs
- PTFE body (reflector)
- Stainless steel field-shaping rings
- Liquid level monitoring and control
- Hamamatsu photosensors
  - Top: 4x 1” PMT
  - Bottom: 1x 2” multi-anode PMT

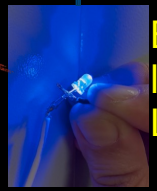




Photosensors and DAQ

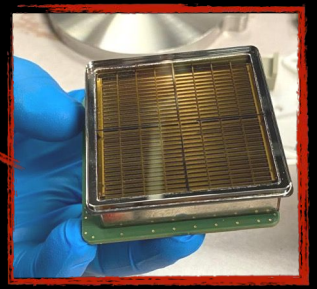




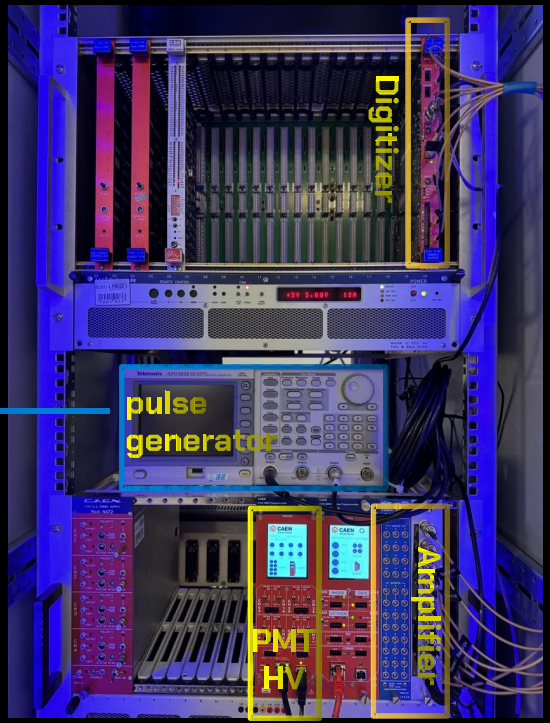


Blue
light
LED

R8520-406
1” single-anode PMT
XENON10 | XENON100



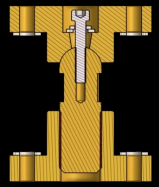
R12699-406-M4
2” multi-anode PMT
Low profile (fast)
75% pho. cath. coverage
High QE at 175 nm: 33%

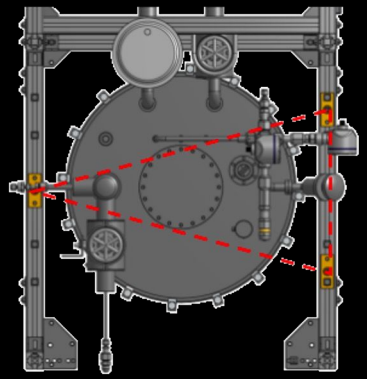


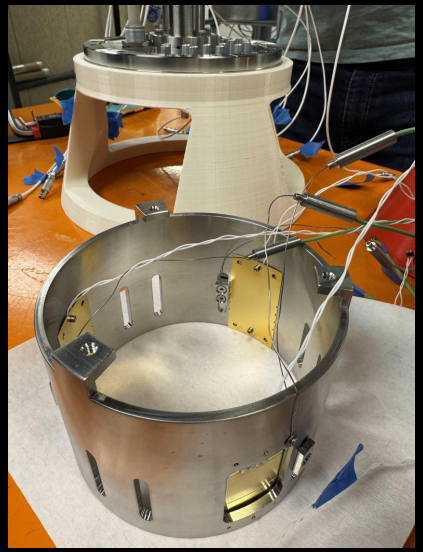
Control and monitoring of proportional scintillation light

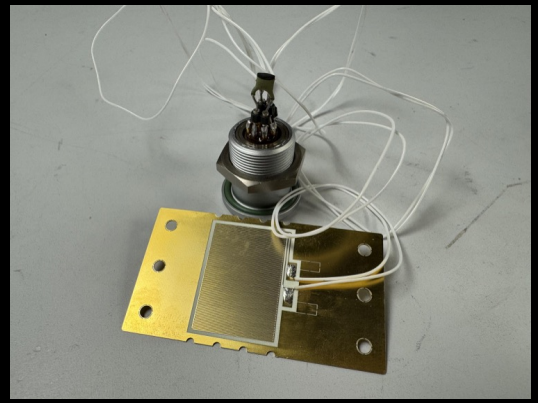
Synergy mechanics and electronics

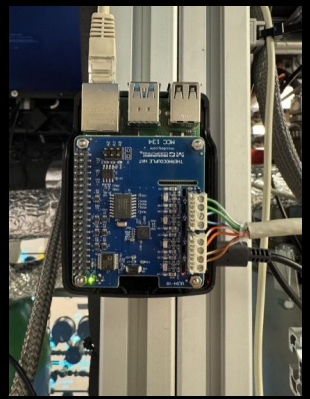
- Planarity of the gas-liquid interface with three regulation points
- Control with three level meters and 3(+1) thermocouples oriented at the same angles





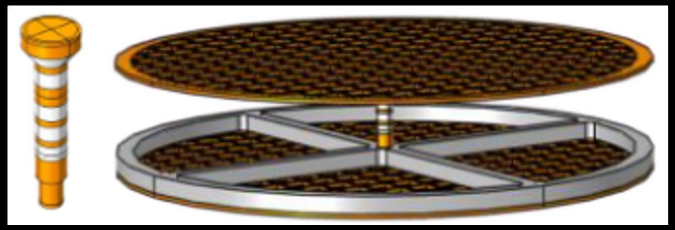




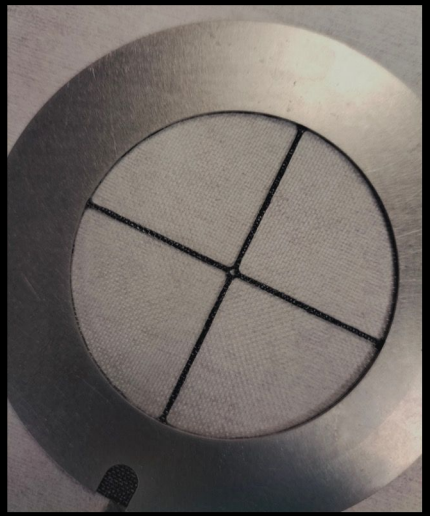


New electrodes design

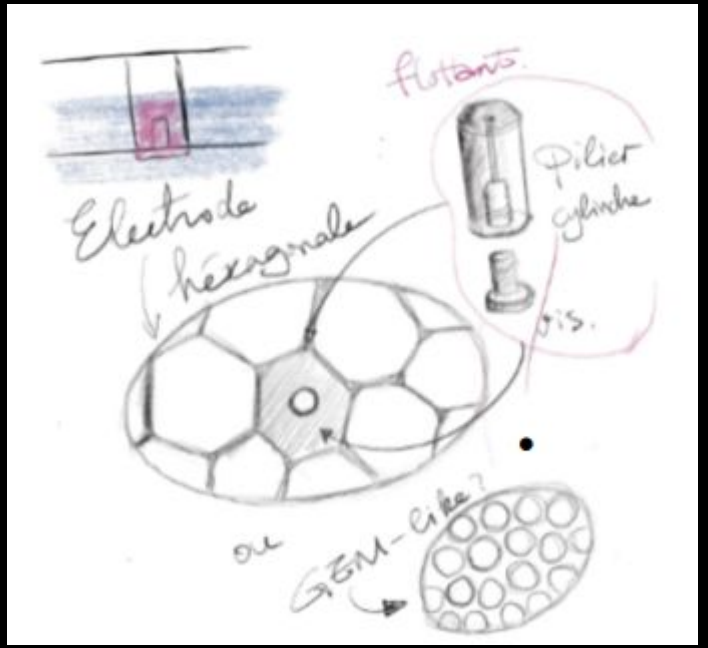
- First electrodes prototype that could host a pillar (Subatech)
- Installed and first tests without pillars
- Designing the pillar and alternative designs



Design #1

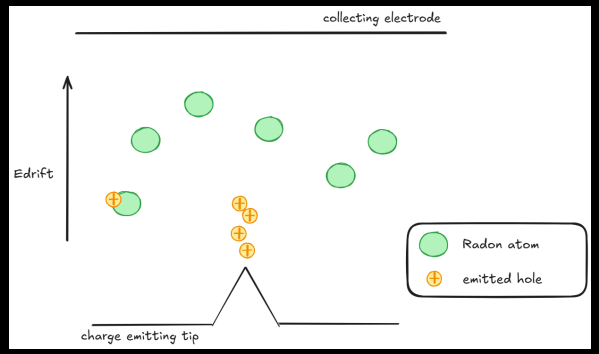


Design #2

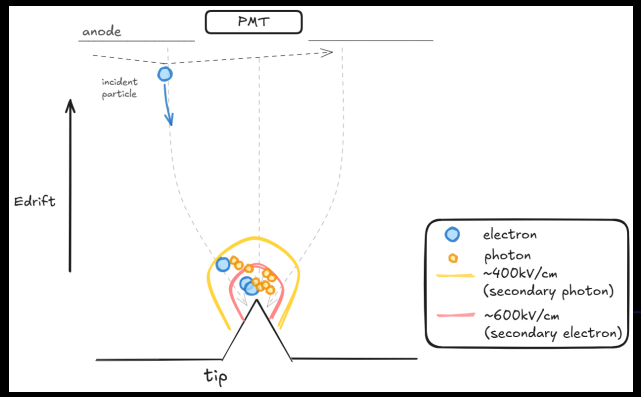


New electrodes design #3

Testing efficiency to capture Radon



Testing efficiency to generate proportional scintillation



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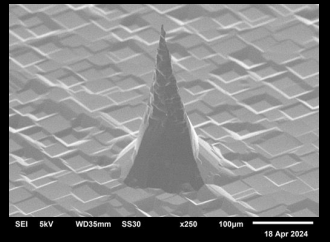
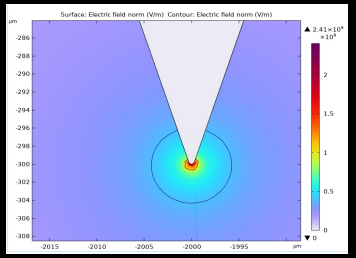
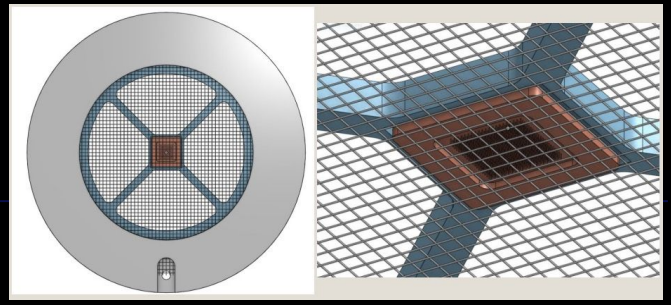
Test liquid-phase secondary scintillation ideas
Compare simulation with experiment
Setup adaptation in XeLab

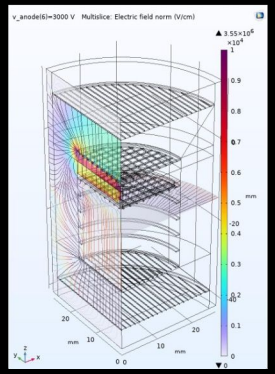


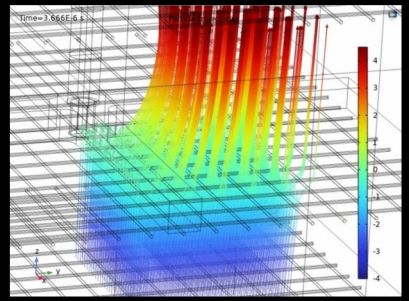


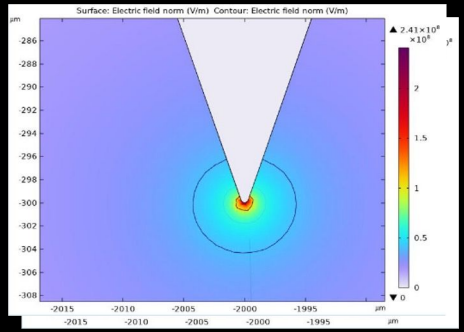


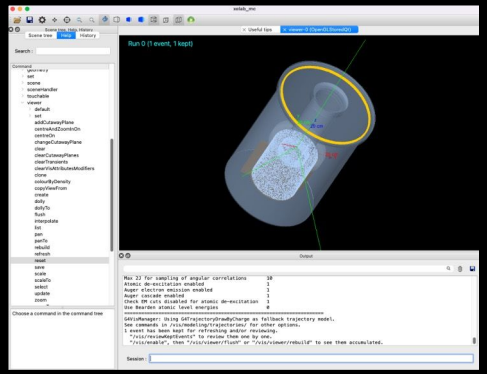
Simulations

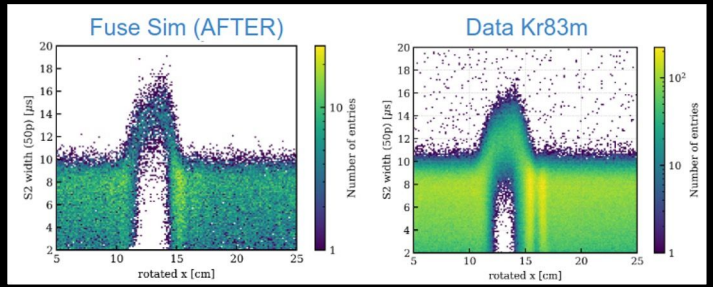
COMSOL











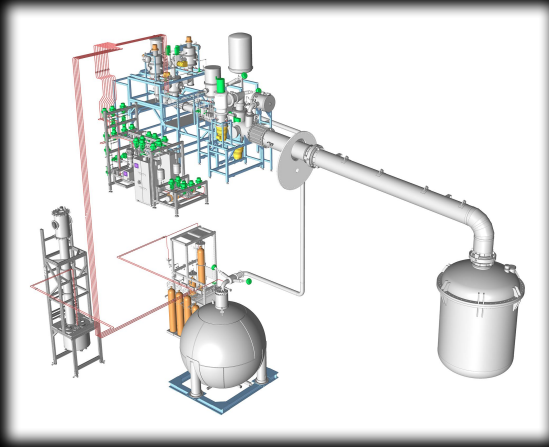
Garfield++ & Geant4

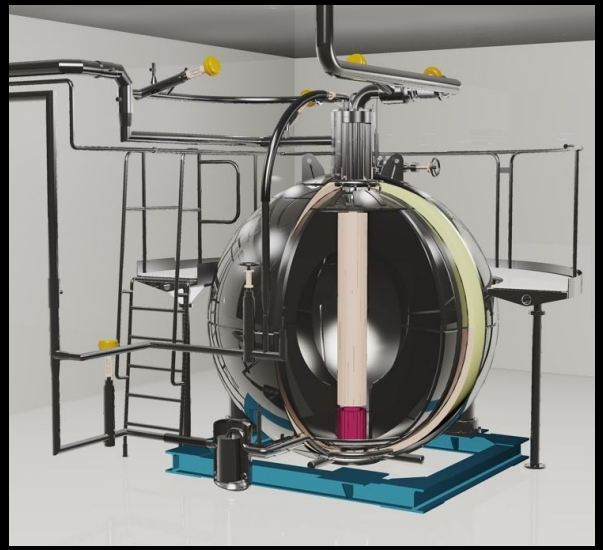
(including comparisons with XENONnT data)

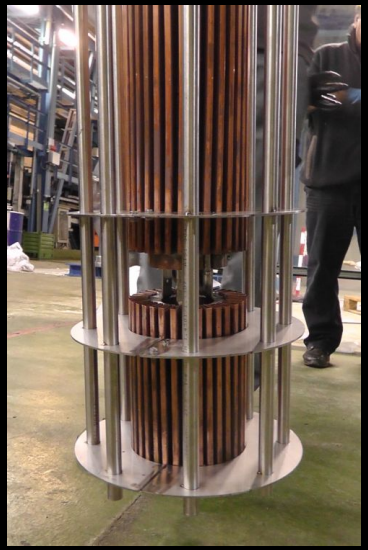
The XENON1T storage and recovery system : ReStoX 1

ReStoX1

- Capacity: 7.6 tons
- Max pressure : 75 bar
- Insulation : double sphere with vacuum and 30 layers of mylar
- Two N_2 cooling systems : inner (heat exchanger) and outer
- Heater to regulate pressure at high precision



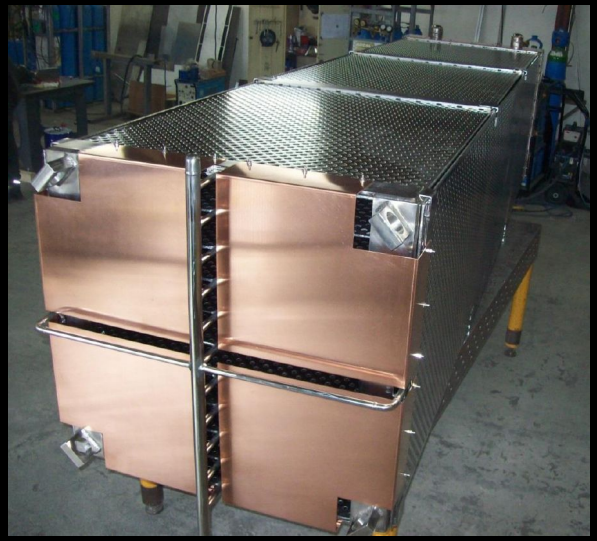


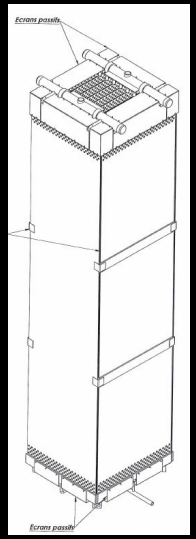


The XENONnT storage and recovery system : ReStoX 2

ReStoX2

- Capacity: 10 tons
- Max pressure : 71.5 bar
- Fast recovery with a N_2 cooling systems by crystalization

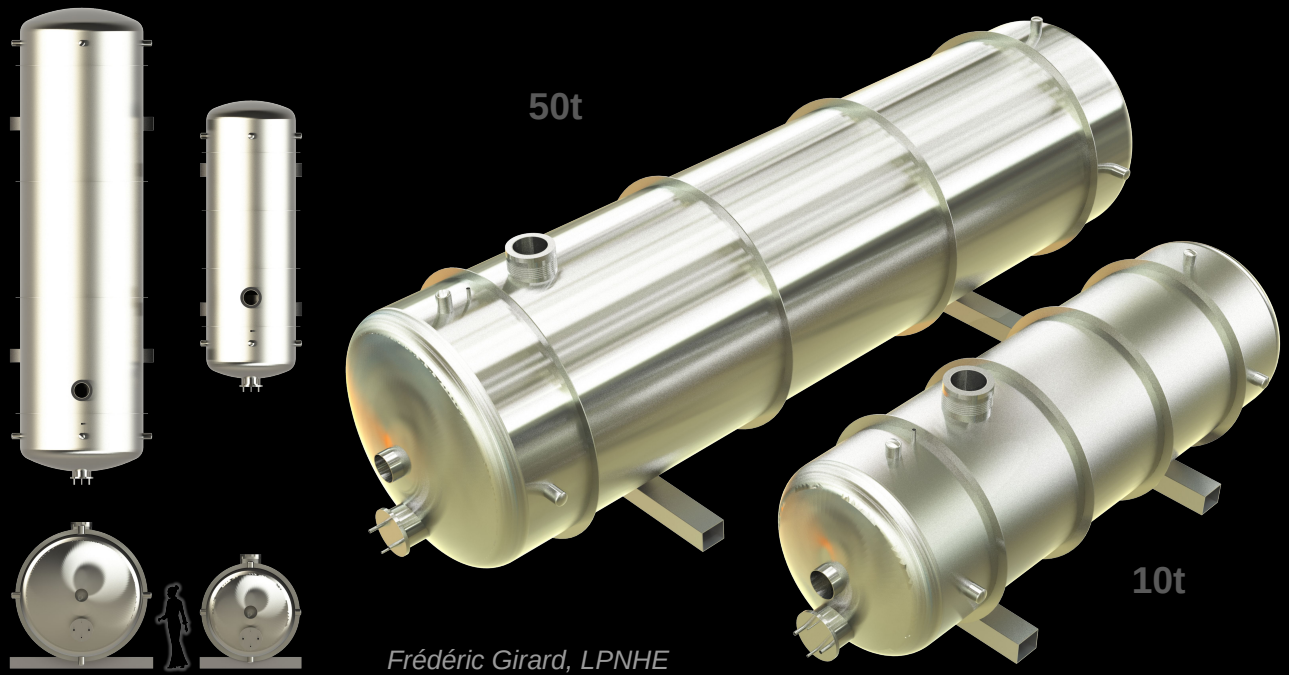




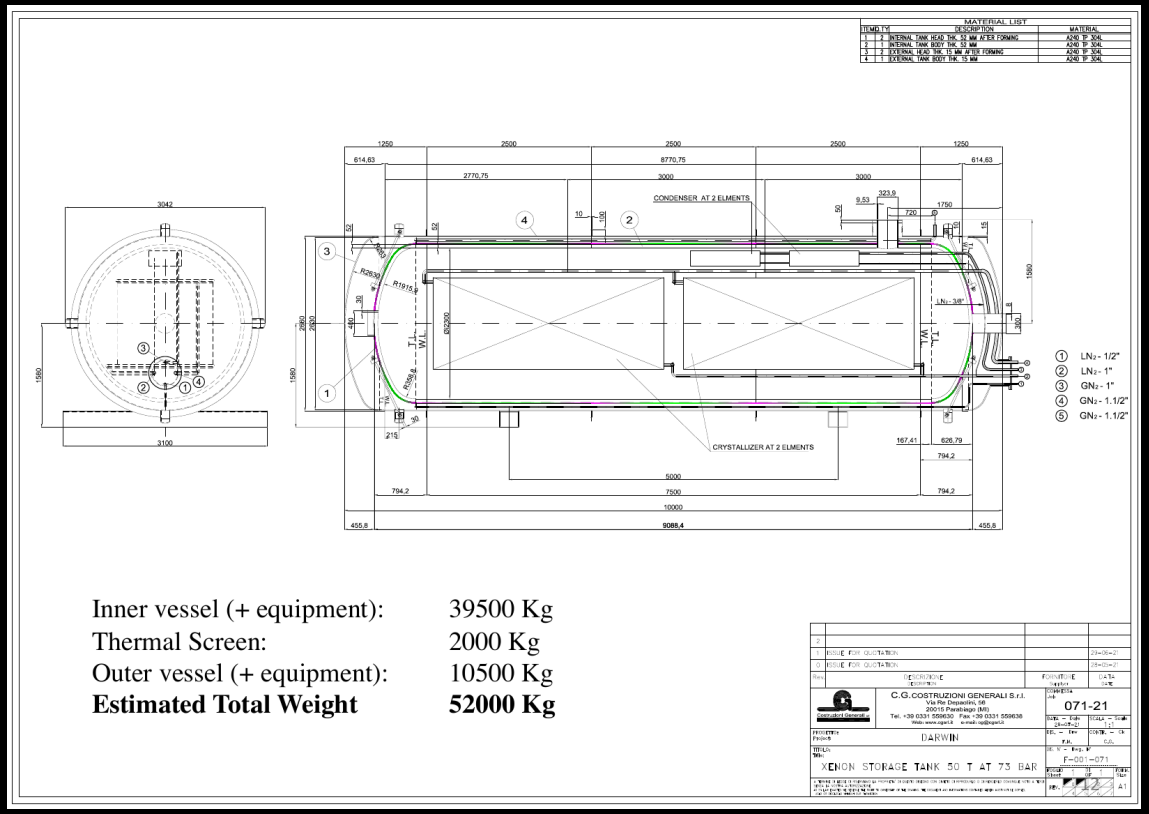
R&D in France for XLZD on storage systems

ReStoX for XLZD

- Two heat exchangers merging the functionalities of ReStoX1 and 2
- Several capacity scenarios, depending on the hosting site
- Capacity: 10 to 50 tons



Design for the 50t storage

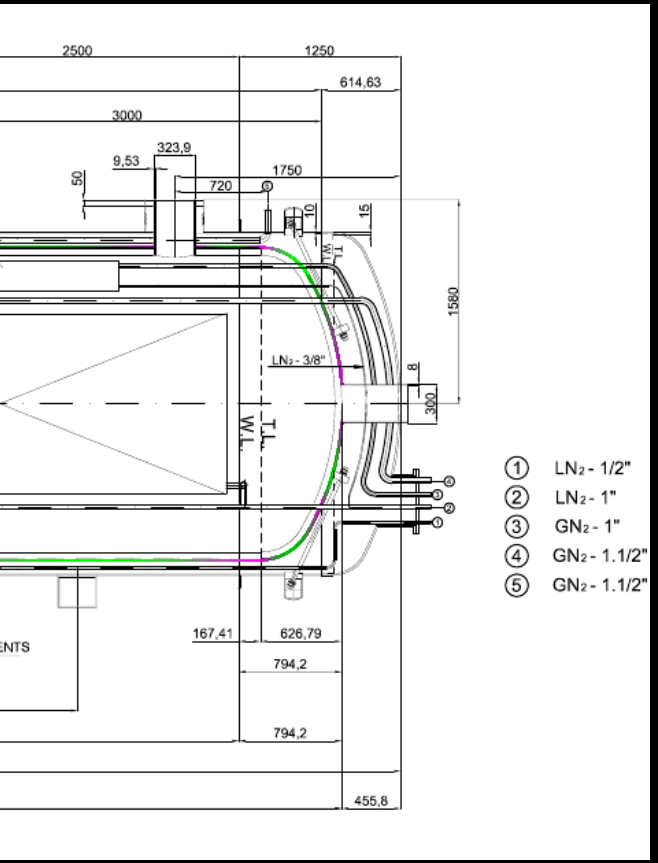


Inner vessel (+ equipment):	39500 Kg
Thermal Screen:	2000 Kg
Outer vessel (+ equipment):	10500 Kg
Estimated Total Weight	**52000 Kg**

Credit : Jean-Marie Disdier, Julien Masbou

Drawings : Costruzioni Generali S.r.l., Parabiago, Milan (Italy)

Cooling based on Nitrogen



Inlet (1) LN_2
→ inner vessel cooling down
→ Outlet (5) GN_2

Inlet (2) LN_2
→ both condenser and crystallizer
→ Outlet (3) GN_2 condenser
→ Outlet (4) GN_2 crystallizer

Conclusion and outlook

Direct Dark Matter Search is a very exciting branch of astroparticle physics

LXe TPCs are, since 15 years, leading the field

Winning strategy : fast and effective upgrades, major technology breaks developed in the field directly on the n^{th}-1 generation detector

Towards the 3^{rd} generation detector → new challenges for which France is expert :

- **Design of electrodes**: robustness (minimal sagging/deflection), maximal transparency, reduced e- emission ("hot spots") → XeLab Project

- Xenon **storage and recovery** : safety and reliability → Design of new ReStoX systems

Thank you


Xe Lab
LPNHE
PARIS
cnrs IN2P3
FC 02
PV 01
MV 03
RV 04
HPMV 11
PR 01
HPMV 02
HPMV 10
HPMV 04
HPMV 05
HPMV 09
HPMV 06
FILLING PORT
HPMV 07
HPMV 08
FC 01
VACUUM PORT
RV 02
04
RV 03