LPNHE
PARIS

The XENON Group

XENONnT, future experiments (DARWIN/XLZD) and associated R&D (XeLab)

Luca Scotto Lavina – DR, LPNHE
on behalf of the XENON-LPNHE team

XENON

Xe-Lab

DARWIN

xlzd

cnrs IN2P3
Les deux infinis

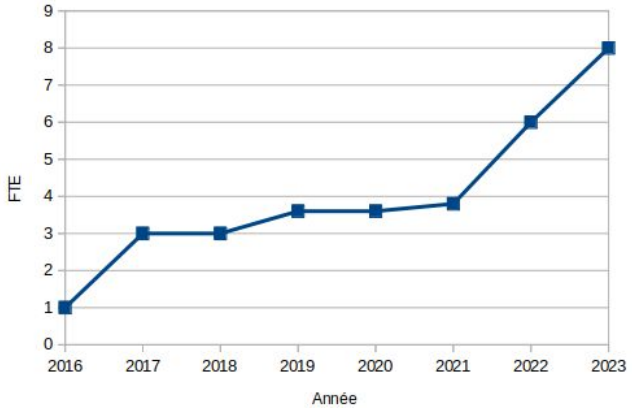
Prepared for the HCERES Commission
November 4th 2023

Current composition of the group

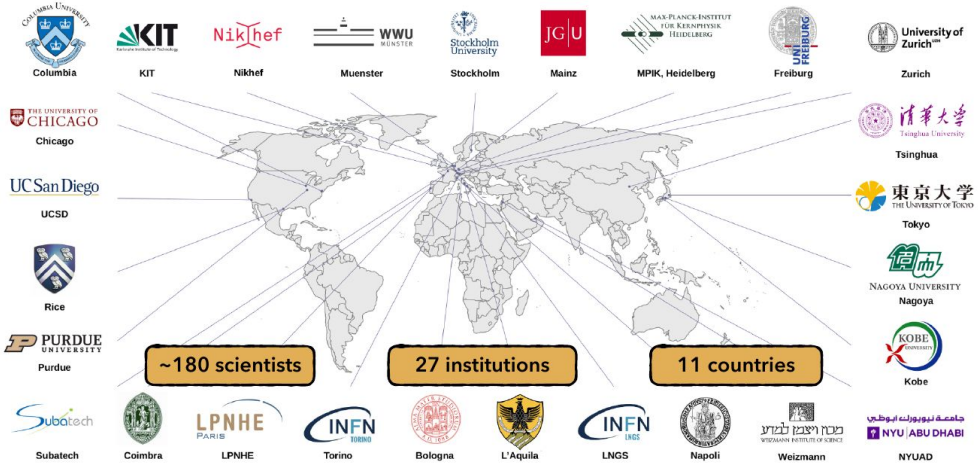
- 2 permanent researchers
  - Luca SCOTTO LAVINA (DR)
  - Bernard ANDRIEU (CR)
- 4 permanent ITs (1.1 FTE)
  - Romain GAIOR (IR → *cherceur experimentaliste*)
  - Nabil GARROUM (IR)
  - Olivier DADOUN (IR)
  - Yann Orain (AI)
- 1 Postdoc
  - Frédéric GIRARD
- 3 PhDs
  - Layos DANIEL GARCIA (50 % LSL, 50 BA %), exp. defence 11/2024
  - Quentin PELLEGRINI (50 % LSL, 50 BA %), exp. defence 09/2025
  - Yongyu PAN (70 % LSL, Fei Gao Tsinghua University 30 %), exp. Defence 09/2026
- Former members

  Erwann MASSON (Postdoc, 2y, 2021-2023), Sid El Moctar AHMED MAOULOUD (PhD, 3y, 2019-2022), Olivier SPIGA (AI, 9m, 2021-2022), Jean-Philippe ZOPOUNIDIS (PhD, 3y, 2017-2020), Ernesto LOPEZ-FUNE (Postdoc, 2y, 2017-2019)

Group size evolution since its creation in 2016



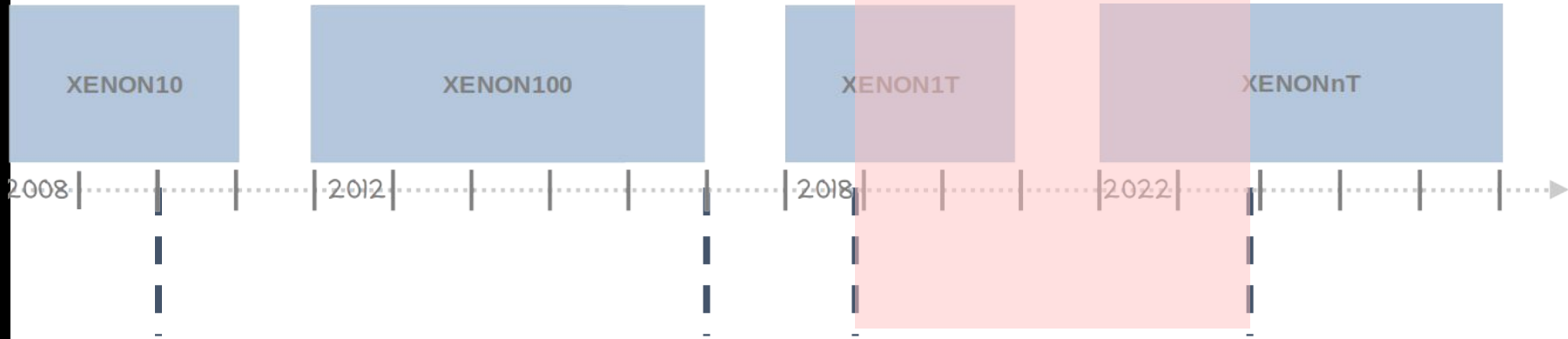
The XENON Collaboration



XENON Collaboration Meeting @ LPNHE, Paris, Sept 2023

Timeline context for the HCERES

- End of XENON1T data taking and final analyses
- XENONnT construction and commissioning
- XENONnT data taking and analysis



Here we will just tell the latest

5 years

Blue bands = science data taking

Outline

Data analysis :

- Completed XENON1T studies (leptophilic dark matter)
- Ongoing XENONnT studies (light dark matter, solar neutrinos, supernova neutrinos)
- Simulation studies on XENONnT proportional scintillation

Technical contributions for XENONnT :

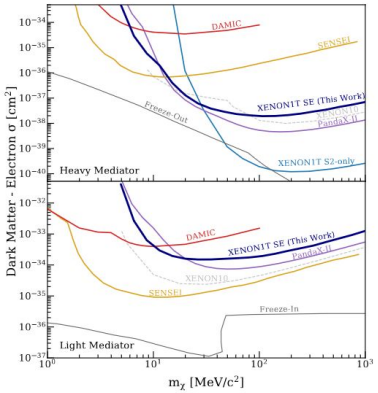
- Installation and commissioning of the Xenon Storage and Recovery system (ReStoX2)
- Leading computing
- Improving Geant4 simulations on electrodes and light propagation
- Data Quality Monitoring
- User Management Tools

LPNHE XENON1T data analyses

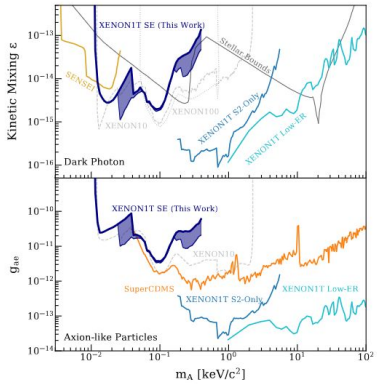
Phys. Rev. D 106, 022001 (2022), arXiv:2112.12116

- **Different dark matter models that can be probed:**
  - Low-E Nuclear Recoils (NR)
    - SI elastic scattering
    - SD elastic scattering (LXe-specific)
    - WIMP-pion coupling
    - Effective Field Theory on WIMPs (+iDM) (LXe-specific)
    - 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 (LXe-specific)
    - Neutrino magnetic moment
  - Rare events
    - Double electron capture (LXe-specific)
    - Gravitational waves
    - Supernova neutrinos
  - New particles
    - **Solar Dark Photons**

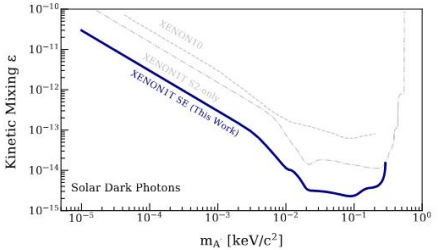
DM-electron scattering
fermion or scalar boson DM candidate scatters off an electron bound in a xenon atom



Vector-boson DM → dark photons
Pseudo-scalar DM → axion-like particles (ALPs)

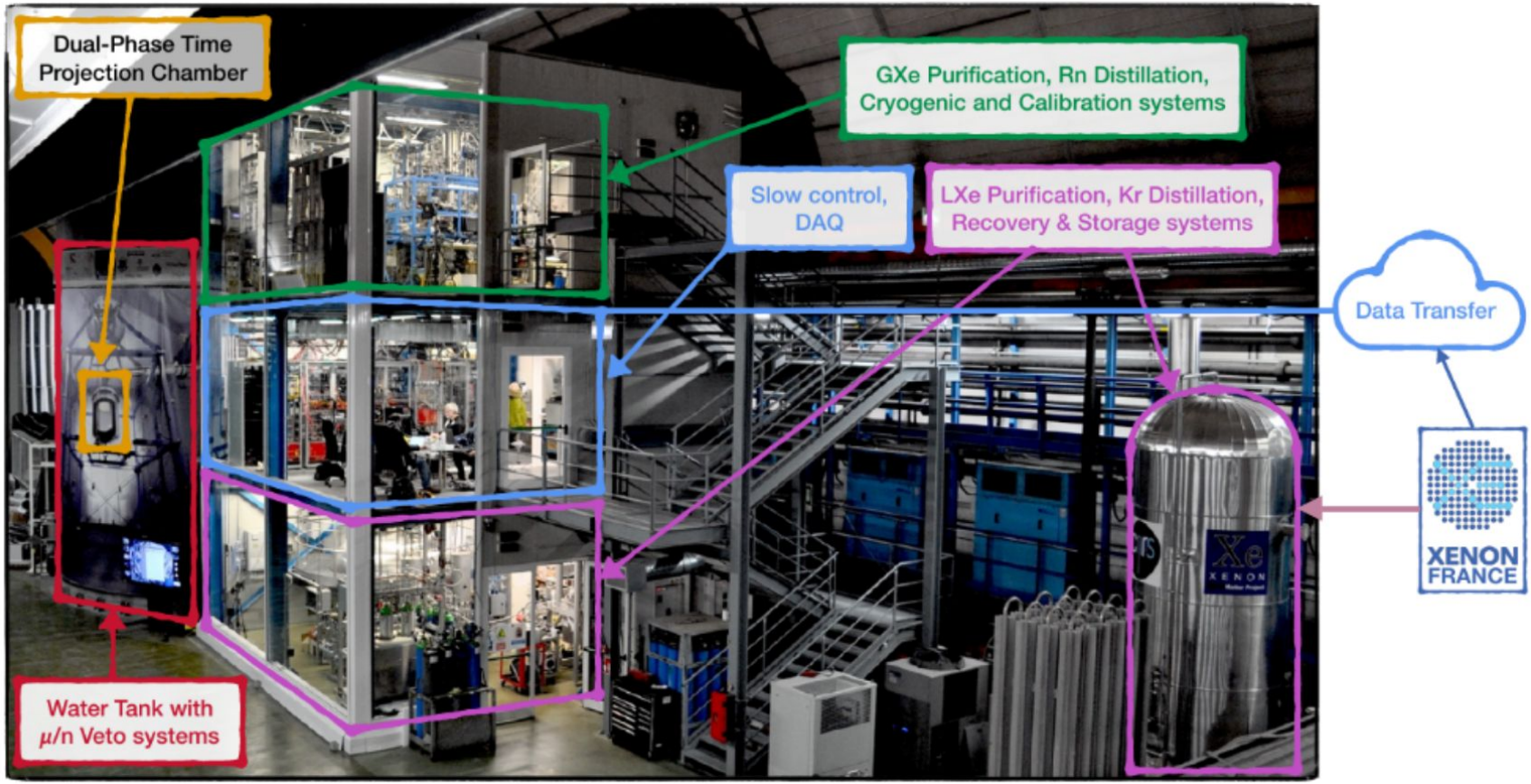


Solar Dark Photons
Higher kinetic energy wrt relic Dark Photons → boosted the 2-5 electrons spectrum

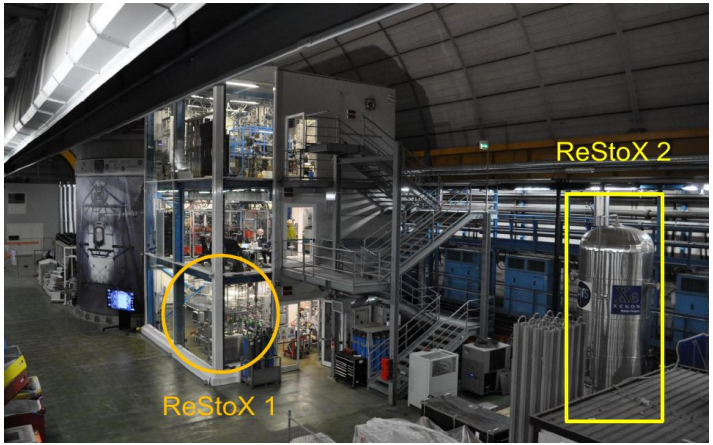


LPNHE main contribution, corresponding author J.P. Zopounidis (PhD thesis)

From XENON1T to XENONnT, the advantages of quick updates



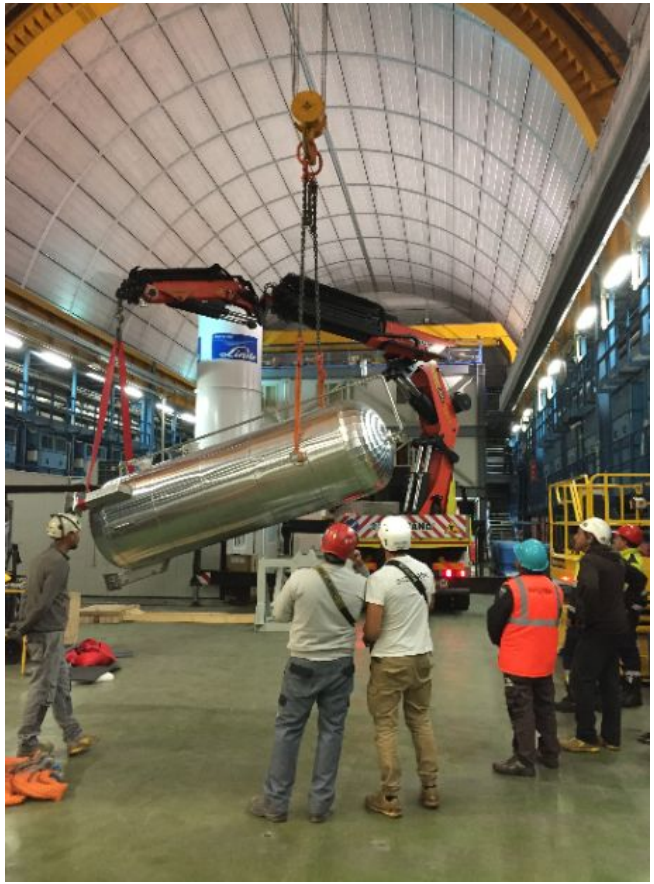
The Recovery and Storage System of XENONnT (ReStoX2)



ReStoX1 : Columbia, Subatech and Mainz

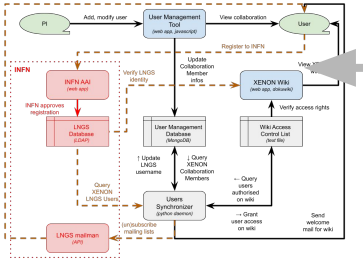
ReStoX2 : 100% contribution of XENON-France (Subatech, LPNHE, LAL). **LPNHE contributed with the inner heat exchanger (DATE)**, SUBATECH with the vessel. Funded by IN2P3 and the two regions : *Pays de la Loire* and *Île-de-France* (DIM-ACAV+)

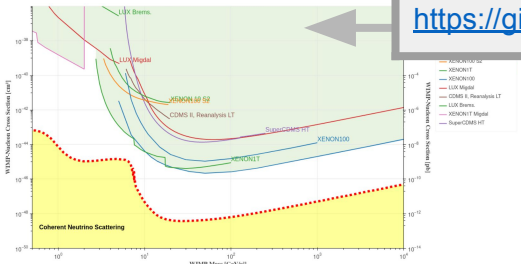
Reached a fast recovery with a rate of 1 tonne / hour !

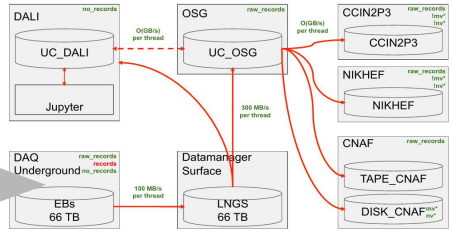


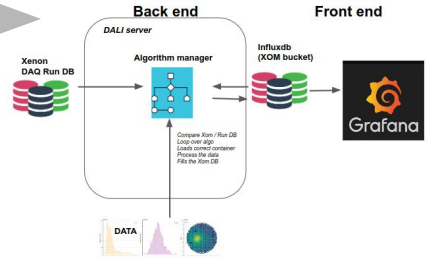
LPNHE : Leading Computing for XENONnT

- Design, installation and commissioning of the computing machines at LNGS
- Development of the data transfer software (aDMIX) : https://github.com/XENONnT/admix
- Development of the Offline Data Quality Monitoring (XOM) : https://github.com/XENONnT/xom
- Development of the User Management System
- GRID Administration
- CC-IN2P3 resources (2.5PB of HPSS, 4M HS06.Hour)
- For the GDR DUPhy : development of a Dark Matter plotter : https://github.com/odadoun/DarkPlotter

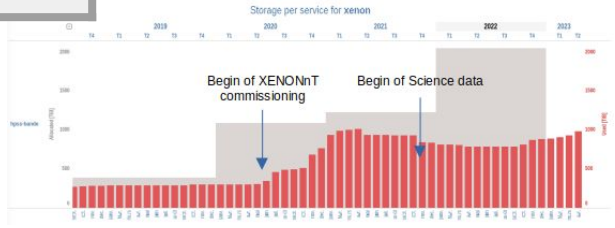








Evolution over time using the CC-IN2P3 web app



Ongoing LPNHE XENONnT data analyses

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  - New particles
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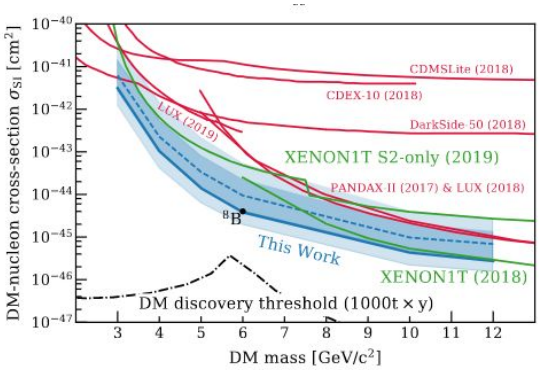
Solar ^{8}B neutrinos

Goals:

- Develop new techniques to **improve sensitivity** near the threshold
- Quantify the **^{8}B neutrinos** component in our background (in XENON1T: 6 events observed in the ROI, 5.38 background expected, whose 2.11 from CEvNS)
- Improve our DM limit at low masses



Challenges (aka, technical contributions):

- Improve S2 simulation
- Study of the biases of the reconstruction algorithms

Q. Pellegrini PhD thesis (ongoing)

Ongoing LPNHE XENONnT data analyses

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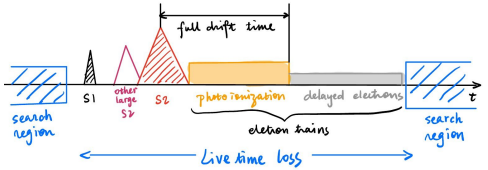
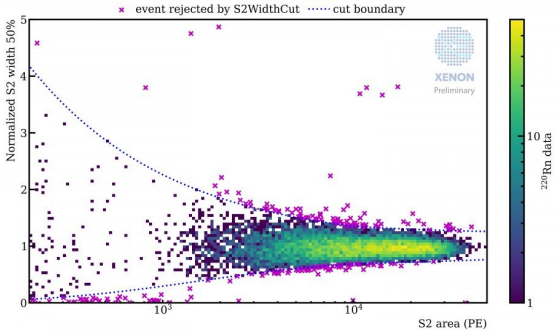
Low mass Dark Matter



Goals:

- Study tiny signals induced by light dark matter
- Single electrons' contamination (develop rejection cuts and background model)
- Improve our DM limit at very low masses (few electrons signal)



Challenges (aka, technical contributions):

- Improve the knowledge on secondary S1s and S2s
- Develop new background rejection cuts

S. el M. Ahmed Maouloud PhD thesis (completed)
Y. Pan PhD thesis (ongoing)

Ongoing LPNHE XENONnT data analyses

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    - **Supernova neutrinos**
  - New particles
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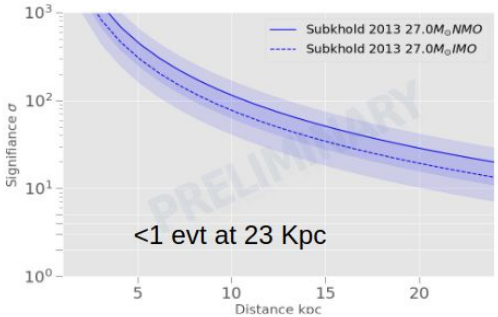
Detection of supernova neutrinos

SNEWS SUPERNOVA EARLY WARNING SYSTEM

Goals:

- Make XENONnT capable to detect promptly neutrinos coming from a supernova via Coherent scattering in the TPC
- Include also the two (water tank based) veto systems signal via Inverse Beta Decay



Challenges (aka, technical contributions):

- Study all SN models
- Background study and sensitivity curves as a function of SN distance
- Developing a reliable MC simulation for vetoes
- Validate MC with real neutrons (AmBe)

L. Daniel Garcia PhD thesis

Ongoing LPNHE XENONnT data analyses

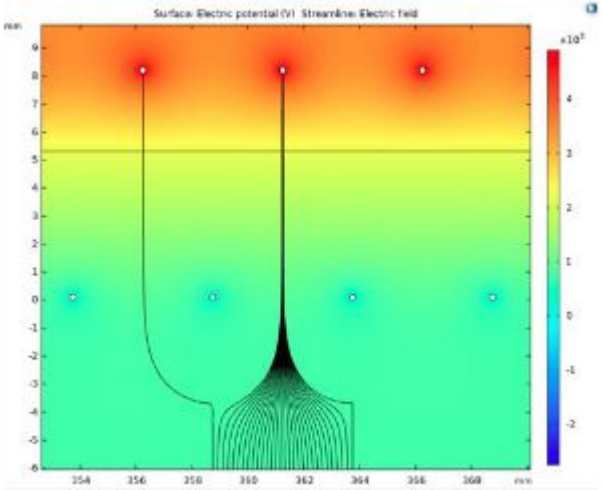
See our poster on simulation !

Electroluminescence and new cathode in MC Geant4 simulation

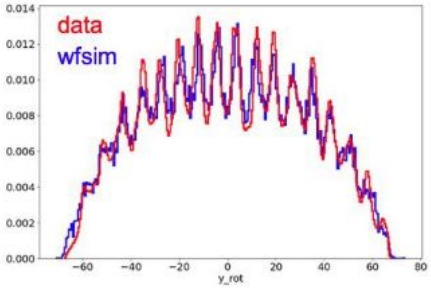
Goals:

- Improving MC simulation on secondary scintillation signal (high impact on any XENON analysis)

GARFIELD++/COMSOL simulation



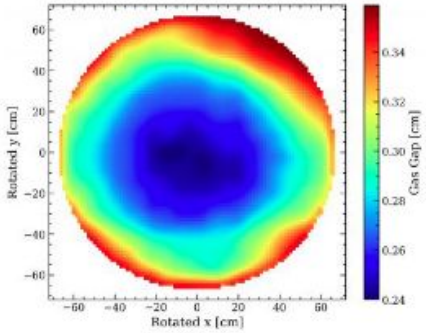
Simulation of shadowing + PMTs pattern perfectly matches with data



Challenges (aka, technical contributions):

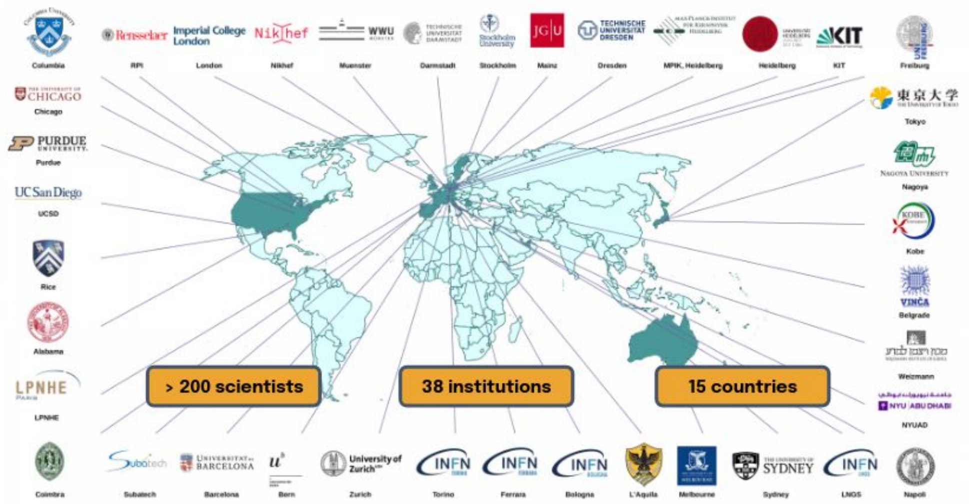
- Studying the shadowing effect
- Simulate the light propagation (each photon separately!)
- Improving the details on electrodes in Geant4 geometry

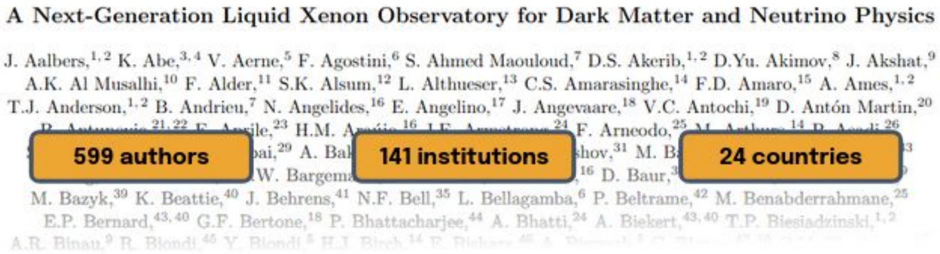
Electrodes sagging



B. Andrieu (CR), O. Dadoun (IR)

The future : DARWIN → XLZD



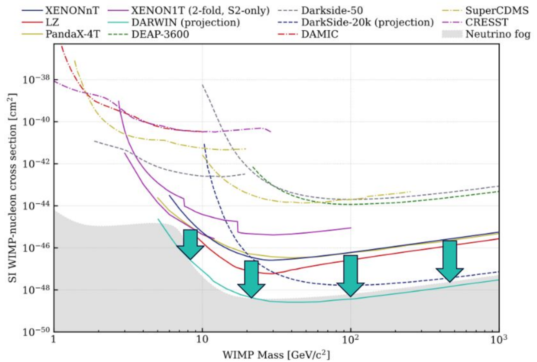

A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

J. Aalbers,[1,2] K. Abe,[3,4] V. Aerne,[5] F. Agostini,[6] S. Ahmed Maouloud,[7] D.S. Akerib,[1,2] D.Yu. Akimov,[8] J. Akshat,[9] A.K. Al Musalhi,[10] F. Alder,[11] S.K. Alsum,[12] L. Althueser,[13] C.S. Amarasinghe,[14] F.D. Amaro,[15] A. Ames,[1,2] T.J. Anderson,[1,2] B. Andrieu,[7] N. Angelides,[16] E. Angelino,[17] J. Angevaare,[18] V.C. Antochi,[19] D. Antón Martin,[20] ... M. Bazyk,[39] K. Beattie,[40] J. Behrens,[41] N.F. Bell,[35] L. Bellagamba,[6] P. Beltrame,[42] M. Benabderrahmane,[25] E.P. Bernard,[43,40] G.F. Bertone,[18] P. Bhattacharjee,[44] A. Bhatti,[24] A. Biekert,[43,40] T.P. Biesiadzinski,[1,2] ...

https://arxiv.org/abs/2203.02309

DARWIN

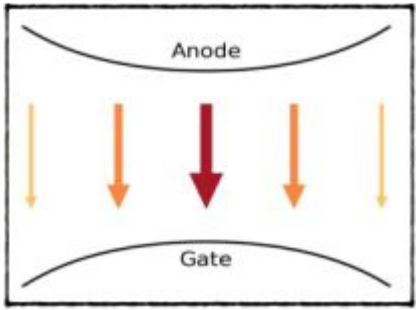
- 2.6 m diameter x 2.6 m height
- 40 t LXe active target
- Two arrays of photosensors (1910 3” PMTs)
- 24 PTFE reflector walls
- Passive and active muon and neutron vetos
- Located at LNGS

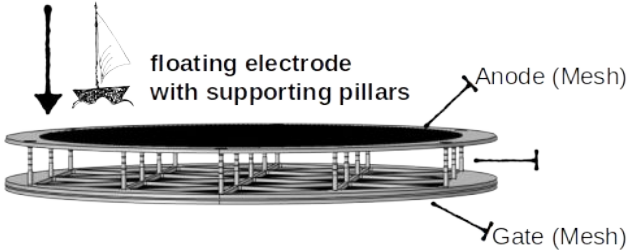


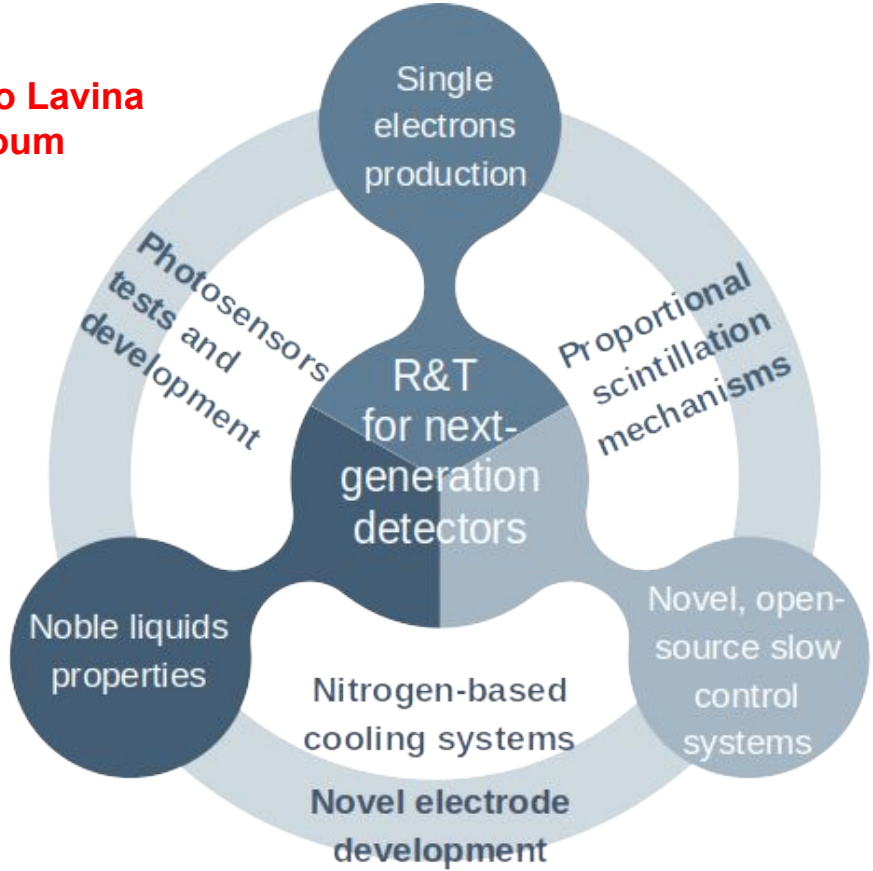
xlzd

The IN2P3 XeLab R&T Project

Scientific leader : L. Scotto Lavina
Technical leader : N. Garroum



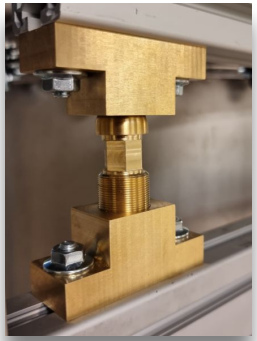




The R&D in France: XeLab and its cryogenic system

See our poster on XeLab !

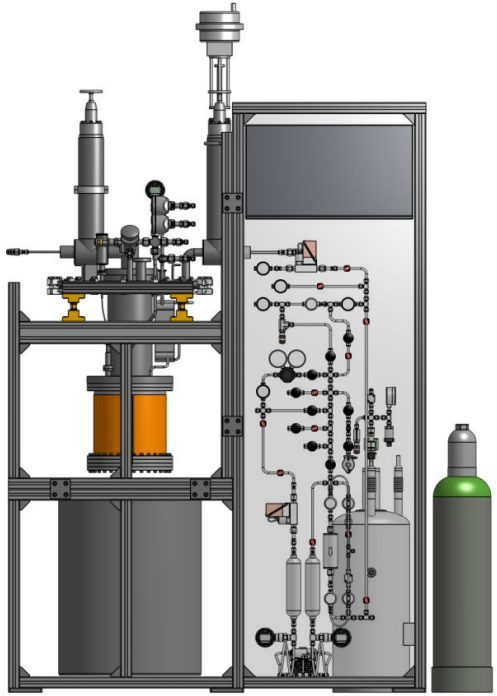
Cryogenics and design : F. Girard
Slow Control : R. Gaior, Y. Pan
Technical support : Y. Orain

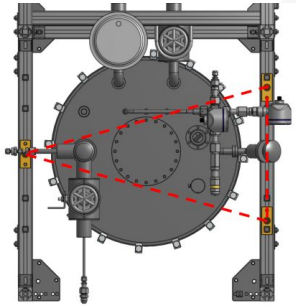


R&D
Levelling system

R&D
Three-way heat exchanger

R&D
Cryostat LN2-cooling with copper belt





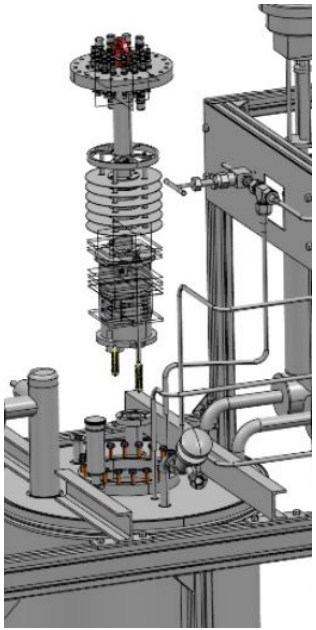
Three levelling systems to define a plane

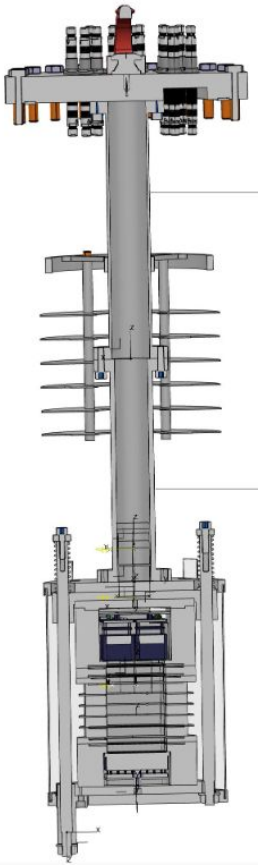
R&D
Storage and recovery system

R&D
Slow Control with RevPI

The R&D in France: XeLab and its TPC

See our poster on XeLab !





Feedthrough

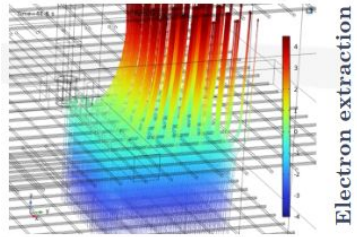
Metal rod

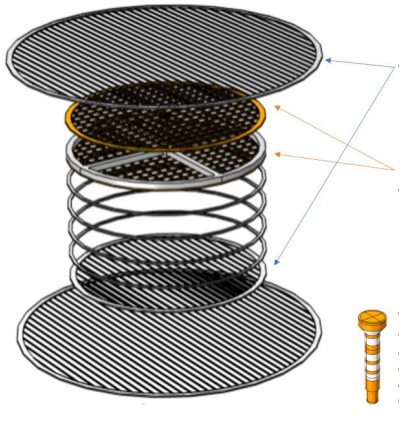
Screens to kill radiative components

Thermically insulating rod

TPC

Studies and simulations : N. Garroum
MC simulation : E. Masson, O. Dadoun
Feedthrough : R. Gaior





Standard electrodes

R&D Floating electrodes

R&D Insulating pillar

R&D in Collaboration with . . .

Germany

International Research Laboratory (IRL) CNRS / Helmholtz Foundation (DMLab).

Three axes of common work for DARWIN:

- Liquid xenon technology
- Electrodes
- Computing

Australia

Submitted an International Research Project (IRP) proposal (LPNHE, Subatech, Sydney and Melbourne)

- DARWIN simulations
- Joint PhDs
- R&D with XeLab (students coming to Paris for short stay)

Conclusions and outlook

XENON1T:

- Physics production completed. LPNHE major contribution to **analysis** : leptophilic dark matter studies

XENONnT:

- LPNHE : strong hardware contribution (**Xenon Storage Systems** and **Computing**)
- LPNHE : **leadership in computing**
- LPNHE : Data analysis on **four topics** : low mass DM, solar neutrinos, SN neutrinos, S2 simulation

DARWIN/XLZD:

- Data taking not before 2032, multi-stage strategy before
- LPNHE : leadership in computing (>2023) and liquid xenon technology (<2023)

XeLab as R&T project towards next-generation detectors:

- **R&T** on: liquid xenon technology (LN2 cooling systems, storage and recovery), electrodes, slow control

Very ambitious program, but already successfully ongoing and compatible with the increasing size of the group (plus, aiming for a MdC Sorbonne experienced on hardware and DM data analysis)

Thanks for your attention

LPNHE
PARIS

The DarkSide group

DarkSide-50 detector

Claudio Giganti – CR, LPNHE

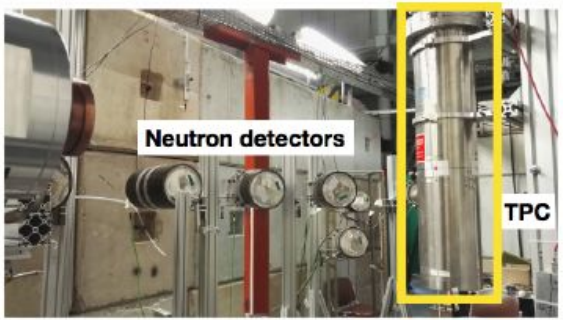
cnrs IN2P3
Les deux infinis

Prepared for the HCERES Commission
November 4th 2023

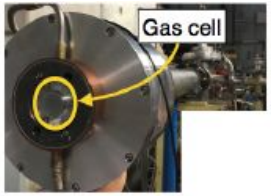
DarkSide group

- The DarkSide activity in the lab **started in 2014**
- Originally formed by two researchers (Sandro De Cecco and Claudio Giganti)
- **Sandro is currently on leave** → Professor at University of Rome where he is working full time on DarkSide
- **Claudio is mostly working on the neutrino physics** → T2K and Hyper-K
- Two PhD students:
  - Anyssa Navrer-Agasson (2016-2019) → defence 09/2019
    - ARIS experiment
    - DarkSide-50 low mass analysis
  - Julie Rode (co-direction with Davide Franco, APC) → defence 09/2022
- **Participation to the DS-50 analysis** (calibration, background model, limits for axions and sterile neutrinos)
- Development of DS-20k reconstruction tools

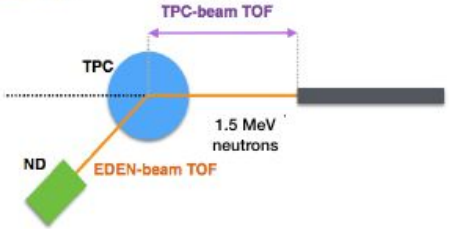
The ARIS experiment

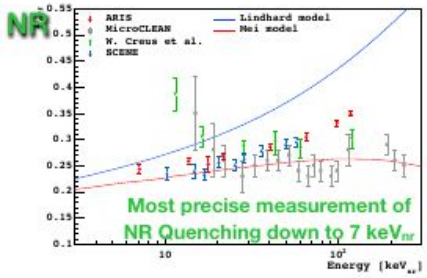


12 days of data taking
at ALTO@IPNO in 2016

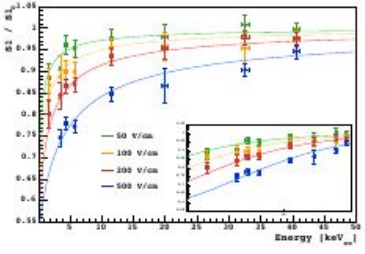


Phys. Rev. D 97 (2018) no.11, 112005





No field



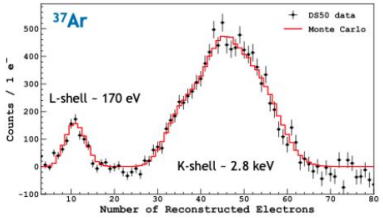
With field

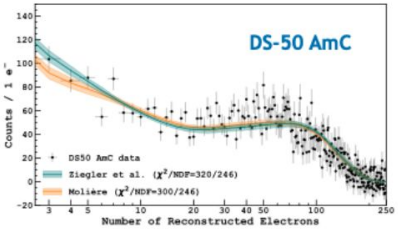
Phys. Rev. D 97 (2018) no.11, 112005

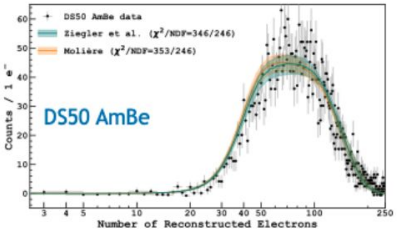
- Experiment proposed by DS French groups
- France/Italy/US collaboration ~ 30 people
- Measure scintillation yield for ER and NR
- Measure quenching (Leff) in the [7,120] keV_{nr} range
- Full description of recombination processes for ER and NR

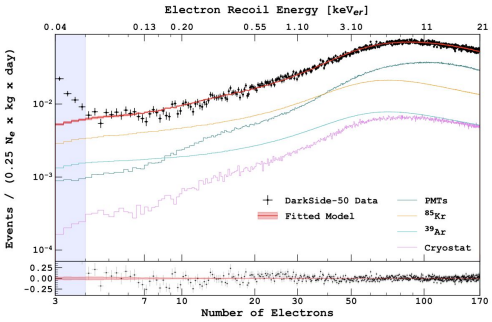
Low mass WIMP searches (2018) and reanalysis (2023)

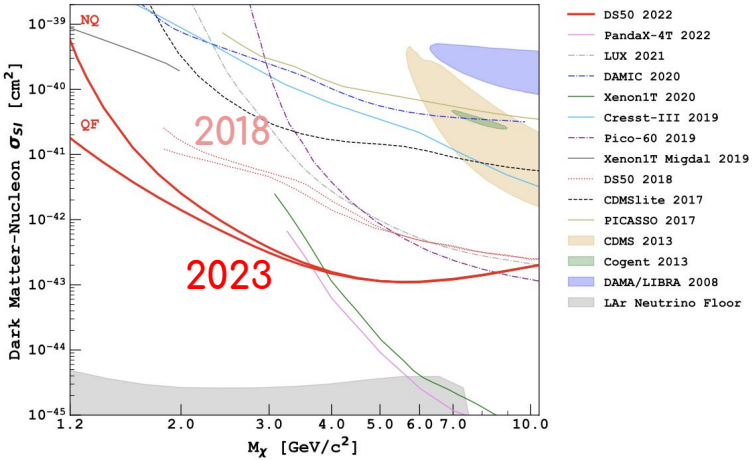
- End of DS-50 data taking → work on a re-analysis of S2 only data
- Goal : understand the observed excess between 4 and 7 electrons
  - New calibration, new selection, new background model
  - Improve by one order of magnitude previous limits with (almost) same data-set











Phys.Rev.D 107 (2023) 6, 063001

Conclusions

- The LPNHE DarkSide group joined the experiment in 2014 and **contributed to the low-mass searches of DS-50**
- The collaboration is now building the next generation, DarkSide-20k, detector
- Unfortunately the small size of the DS group at LPNHE and other commitments of the only permanent researcher involved on DS makes it very difficult to reasonably contribute to this experiment
- **We decided not to take any commitment in the construction of DS-20k**

Material for discussions

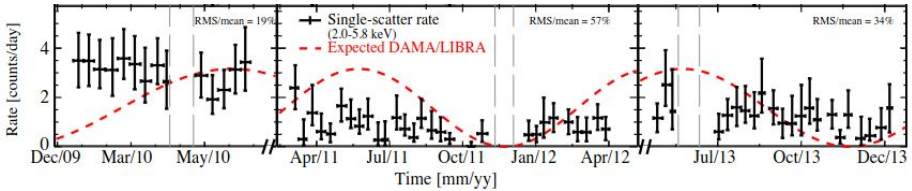
LPNHE XENON1T data analyses

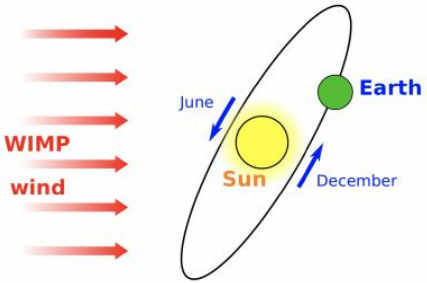
XENON1T: J.P. Zopounidis, PhD thesis, https://tel.archives-ouvertes.fr/tel-03793329

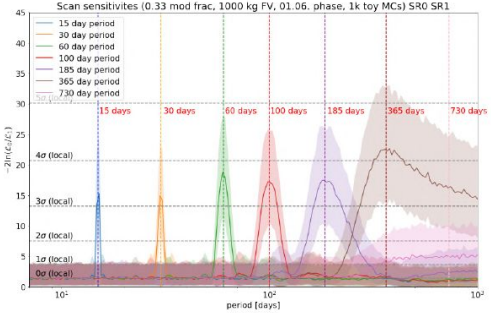
- **Different dark matter models that can be probed:**
  - Low-E Nuclear Recoils (NR)
    - SI elastic scattering
    - SD elastic scattering (LXe-specific)
    - WIMP-pion coupling
    - Effective Field Theory on WIMPs (+iDM) (LXe-specific)
    - Mirror DM
  - Electronic Recoils (ER)
    - Dark Photons
    - 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 (LXe-specific)
    - Neutrino magnetic moment
  - Rare events
    - Double electron capture (LXe-specific)
    - Gravitational waves
    - Supernova neutrinos
  - New particles
    - Solar Dark Photons

Annual modulation

Two publications with XENON100 with 4 years of data:







XENON1T study done at LPNHE, J.P. Zopounidis (PhD thesis)

The scoped mass domains of Dark Matter in a visual way