Status and perspectives of Direct Dark Matter searches

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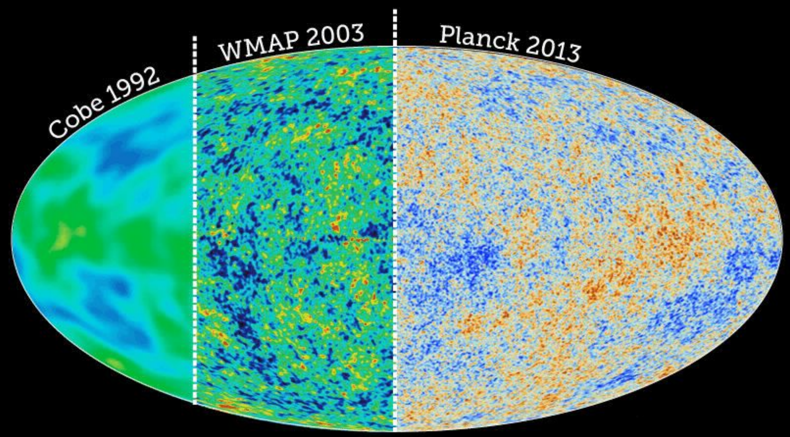
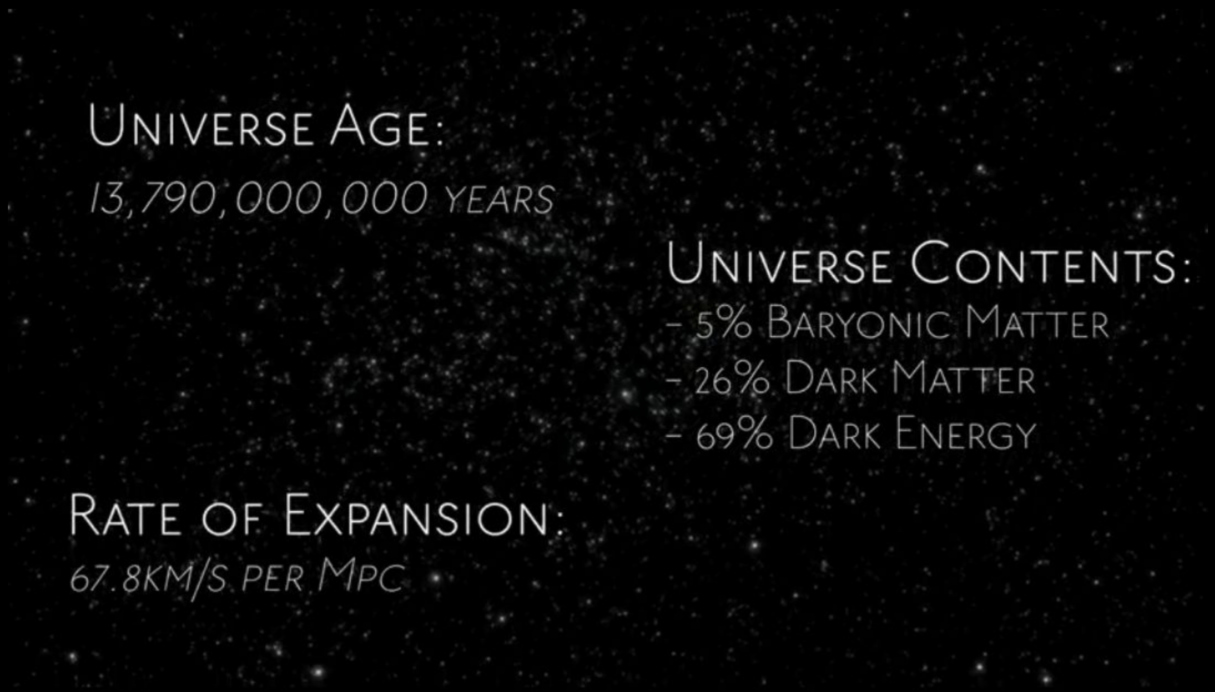
AstroParticle Symposium
Université Paris-Saclay

Intro

An essential part of the standard cosmological model





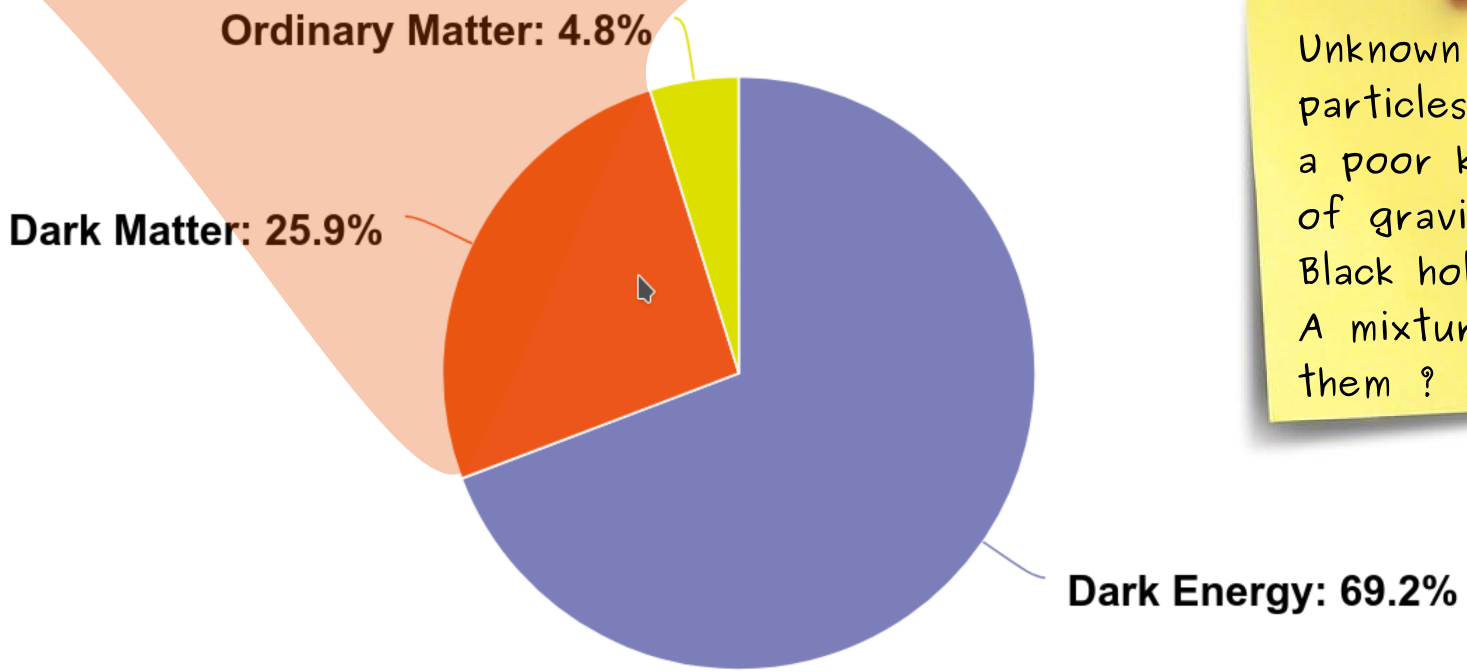
The known and the unknown

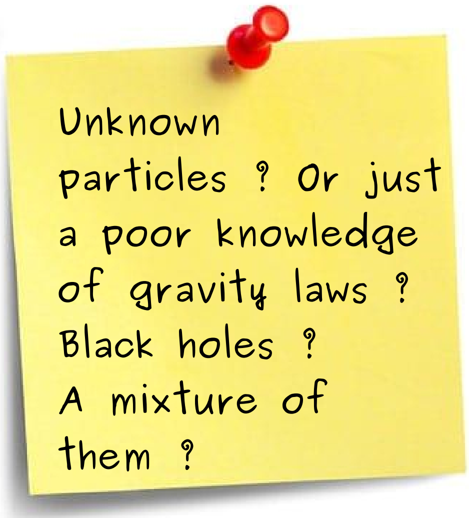
Particle candidates :

- Weakly Interacting Massive Particles (WIMPs) (WIMP miracle, SUSY, …)
- Axions (QCD axions and Axion-Like Particles)
- Sterile neutrinos (~keV → "warm" DM)
- A dark sector ?

Alternatives :

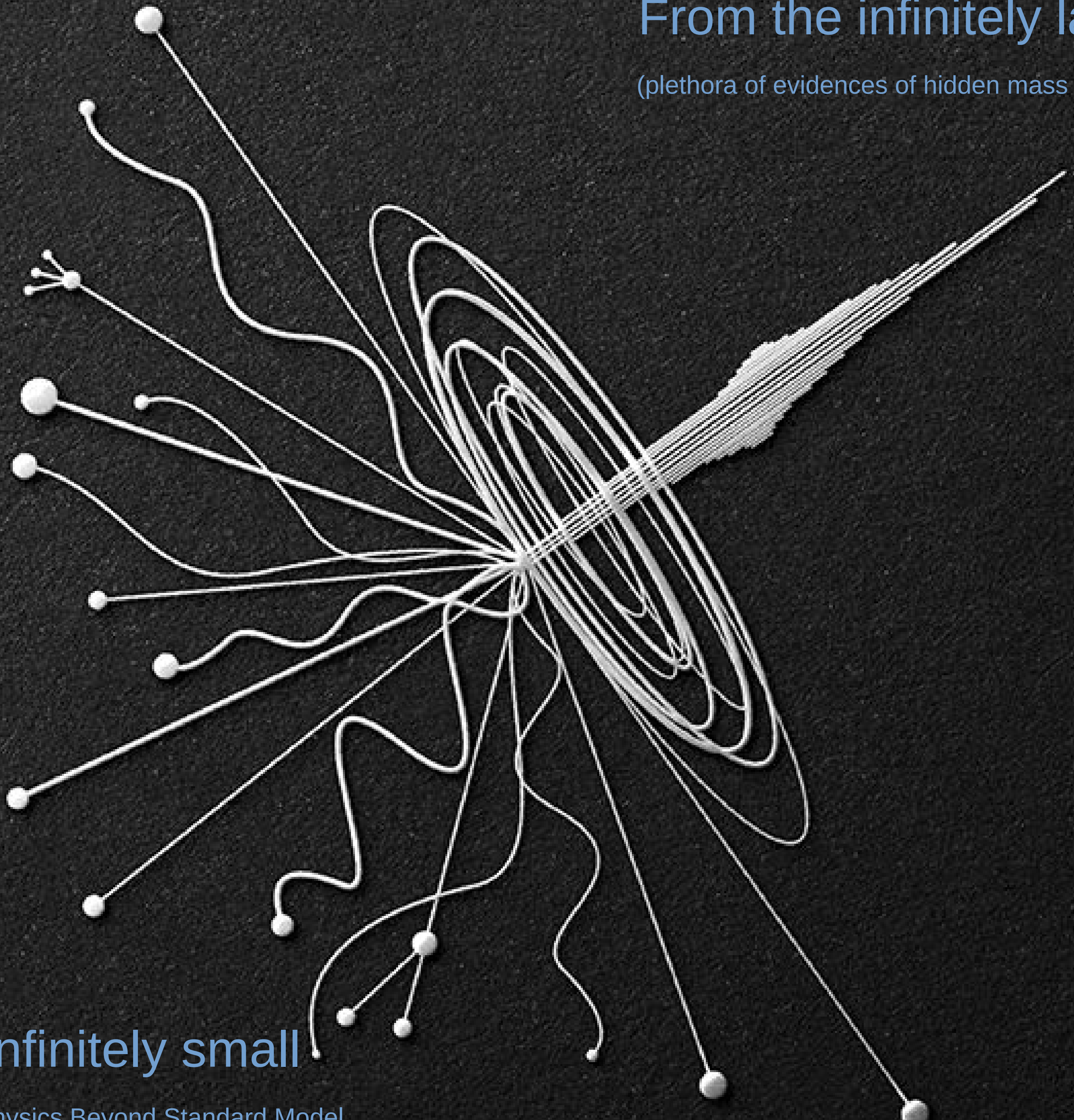
- Primordial black holes
- MACHOs
- Modifications of gravity





From the infinitely large . . .

(plethora of evidences of hidden mass in our Universe)



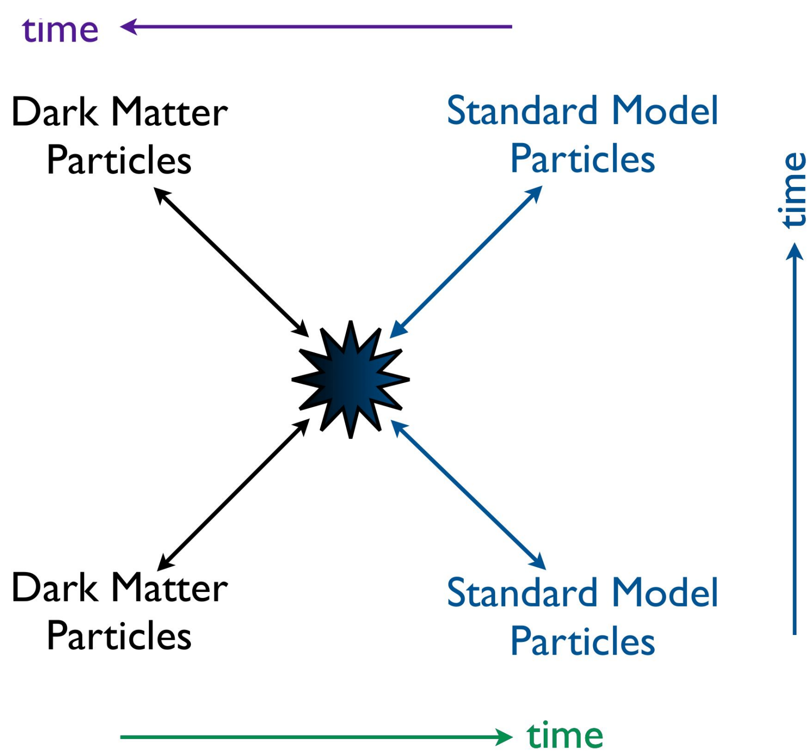
. . . to the infinitely small

(this might be a sign of Physics Beyond Standard Model
of Particle Physics and/or Gravity)

Hunting Dark Matter with Particle Physics

Make ! → "Detection" with colliders : measuring missing P_T
(CMS, ATLAS @ LHC)

Each of them has their own assumptions. Possible to combine their results with some caveats



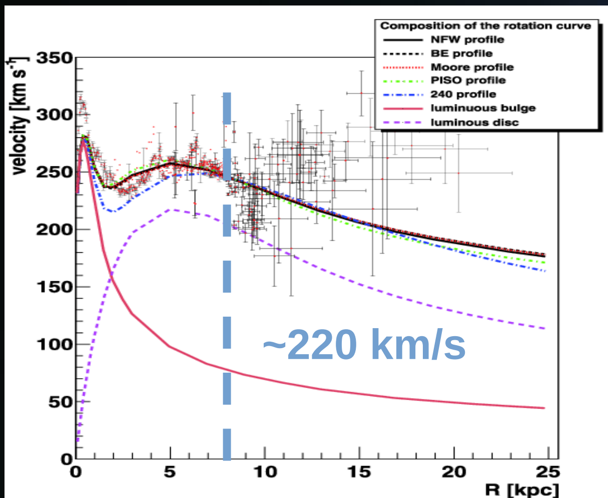
Shake ! → Direct detection of galactic DM :

on earth scattering off a detector nuclei

(Xe, Ar, Ge, NaI, Si, ...)

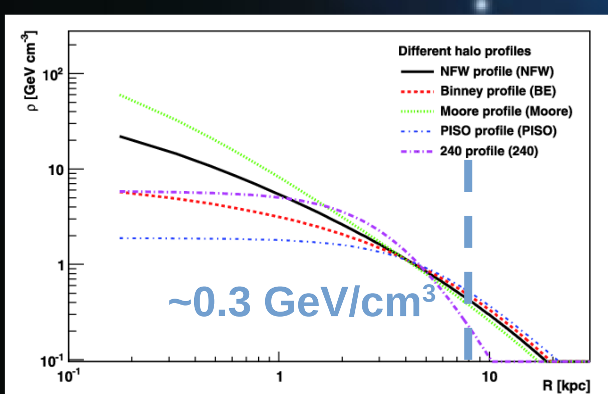
Break ! → Indirect detection of cosmic DM : annihilation
(AMS, PAMELA, CTA, IceCube, ...)

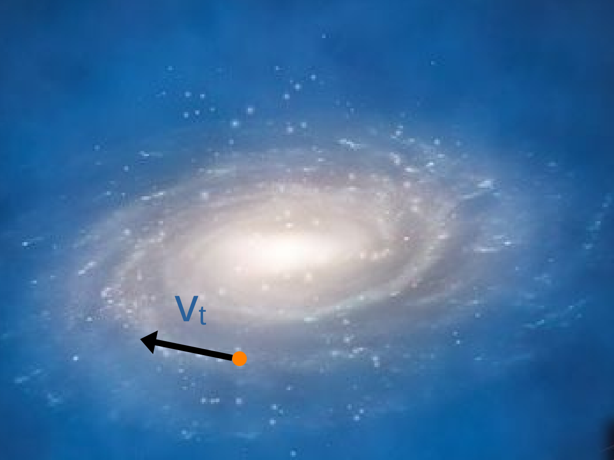
Assumptions of Direct Dark Matter search



Its velocity against us
and its density

M. Weber, W. de Boer, Astron.Astrophys.509:A25,2010

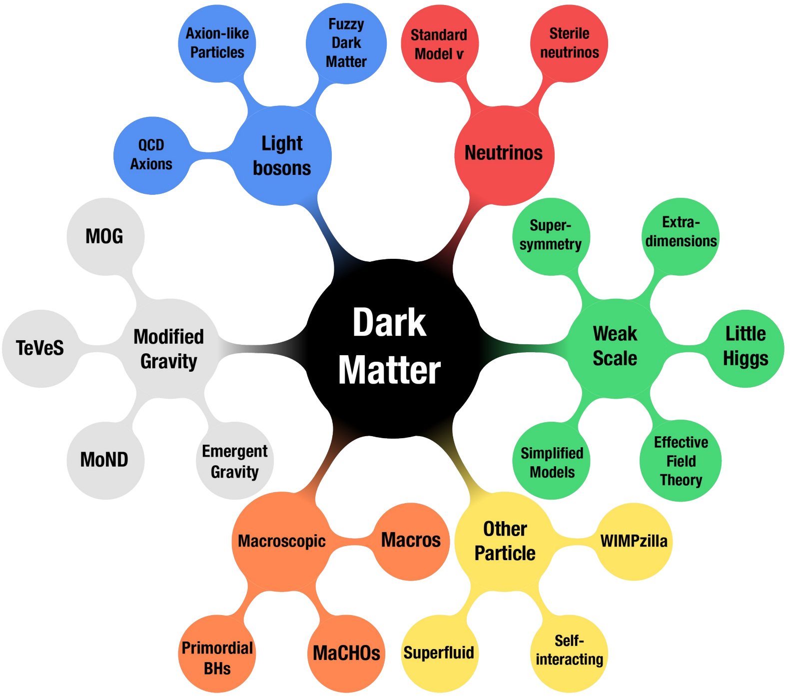




Dark
Matter
Halo

Dark Matter "wind" coming
from a well defined
direction (Cygnus
constellation)

Fantastic Beasts and Where to Find Them



(if 300 neV)
one billion of
billions in a liter

~0.3 GeV/cm³

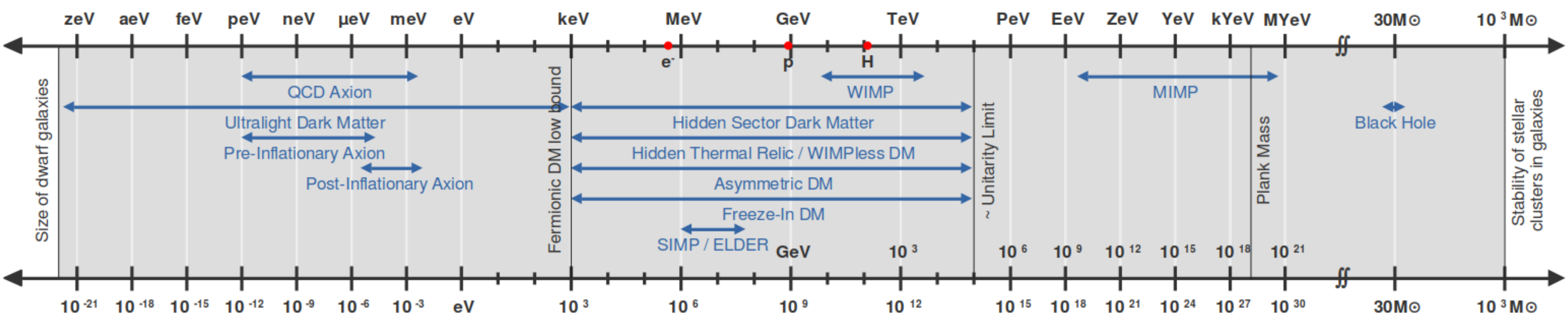
(if 30 GeV)
ten in a liter

axion

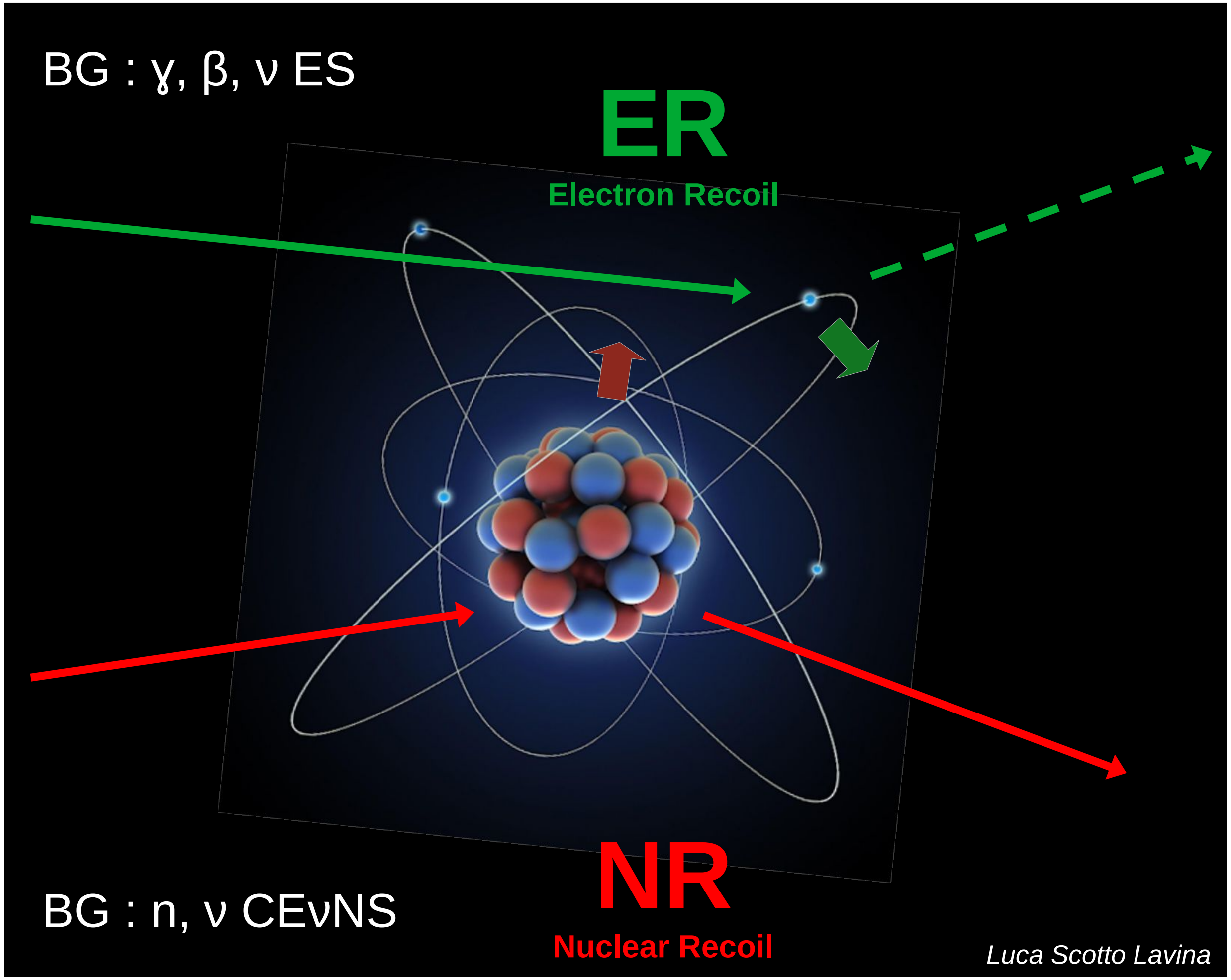
a

WIMP

χ



Which target and which mechanism ?

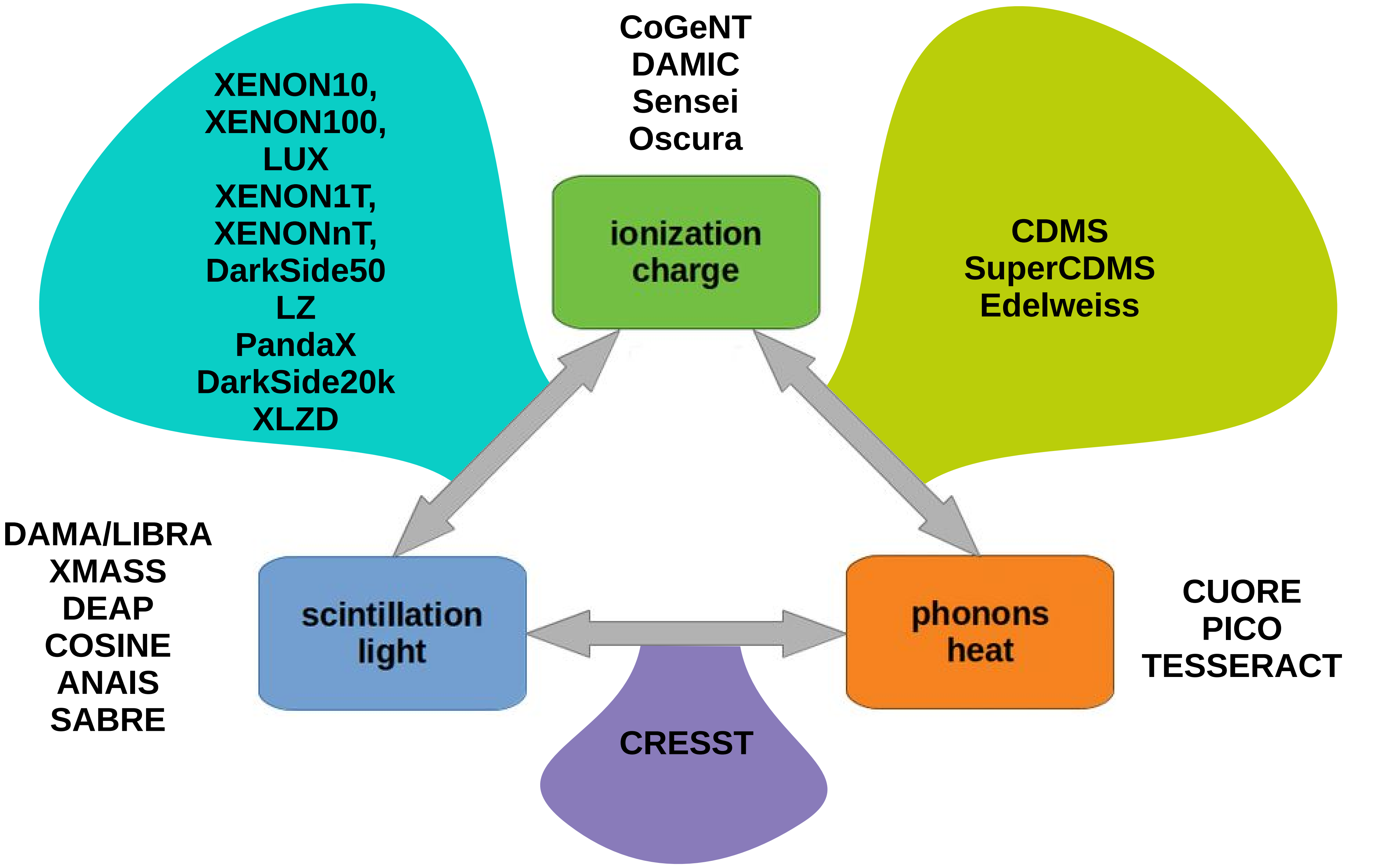


- DM-e
- ALPs
- Dark photons
- ...

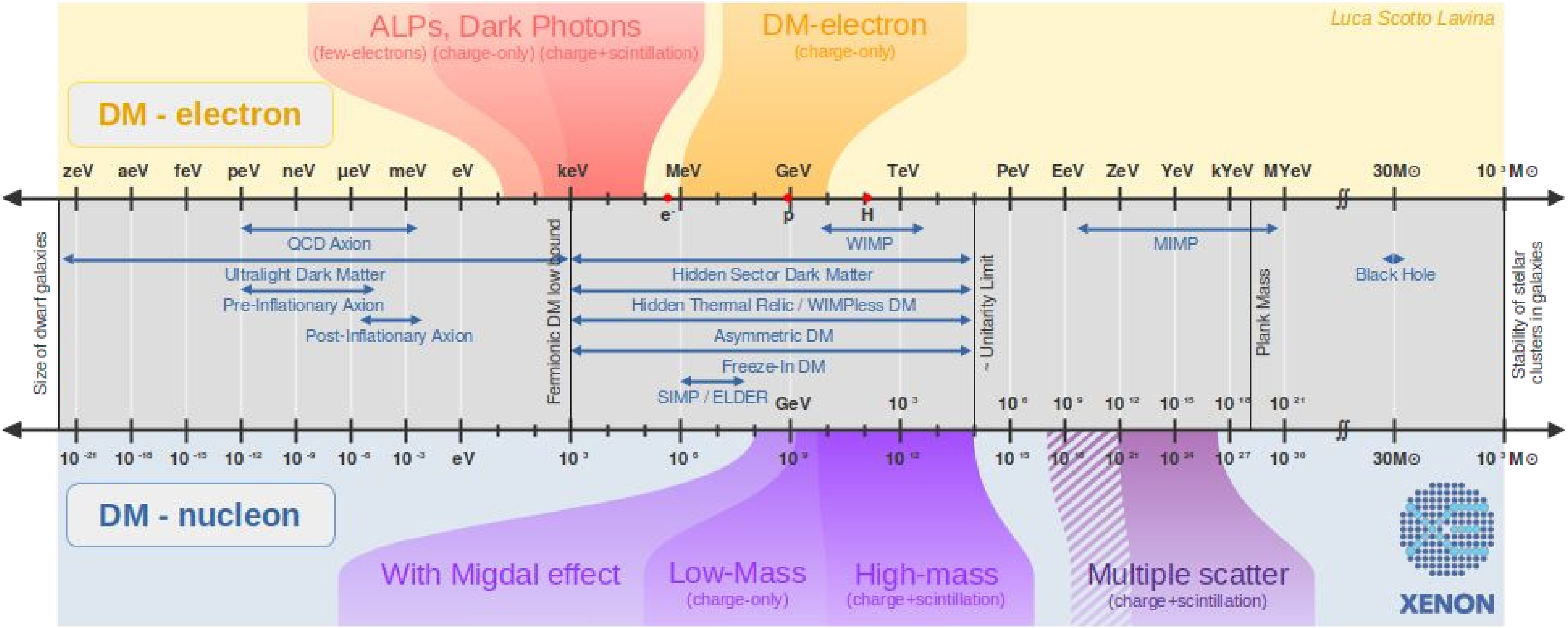
- WIMPs
- MIMPs
- ...

Also :
- SD vs SI
- Elastic vs inelastic
- Light vs heavy mediator

Energy recoil : the observables

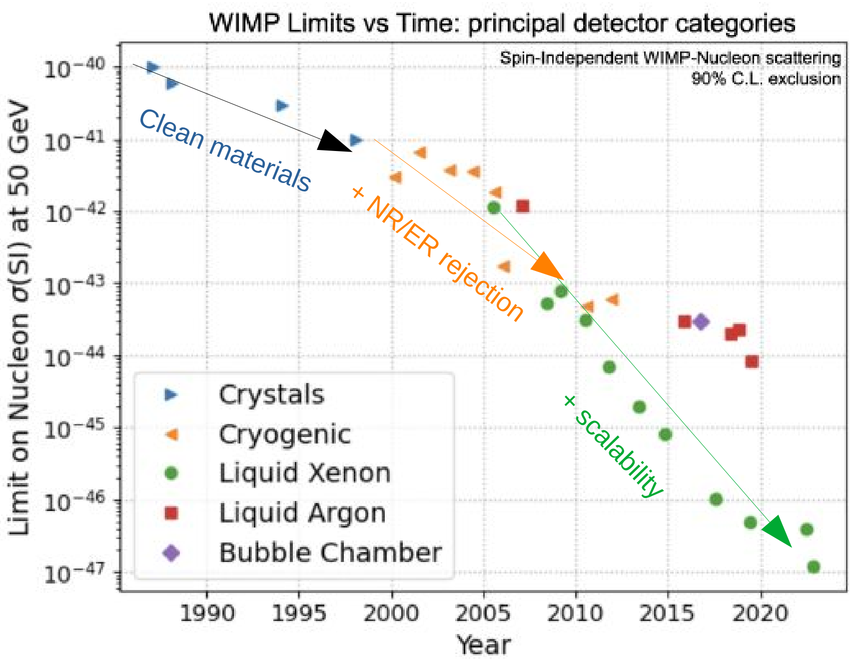


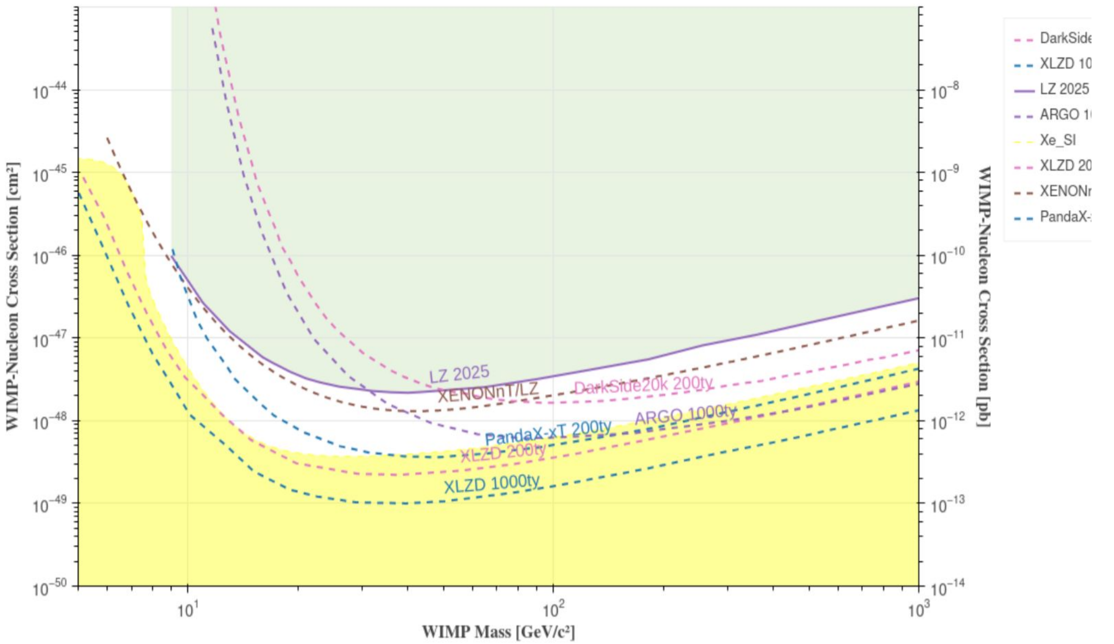
Example of scoped energy domains



WIMPs domain (>10 GeV)

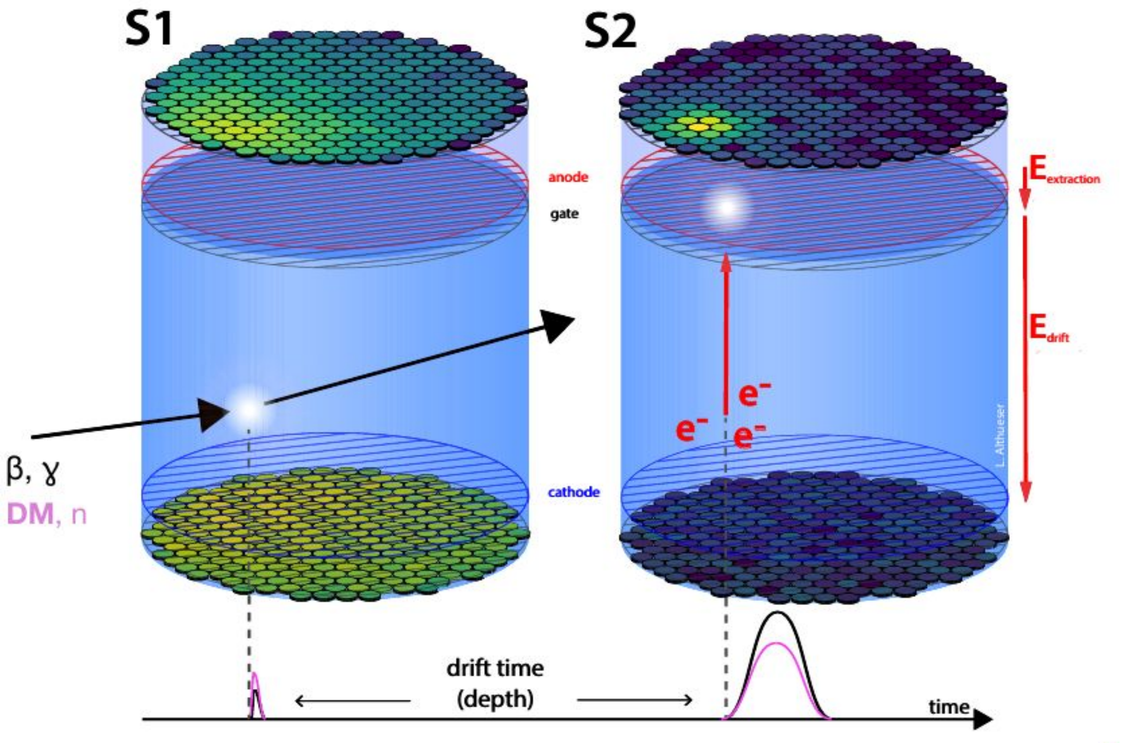
WIMPs domain (m>10 GeV)





Dual-phase noble targets TPCs

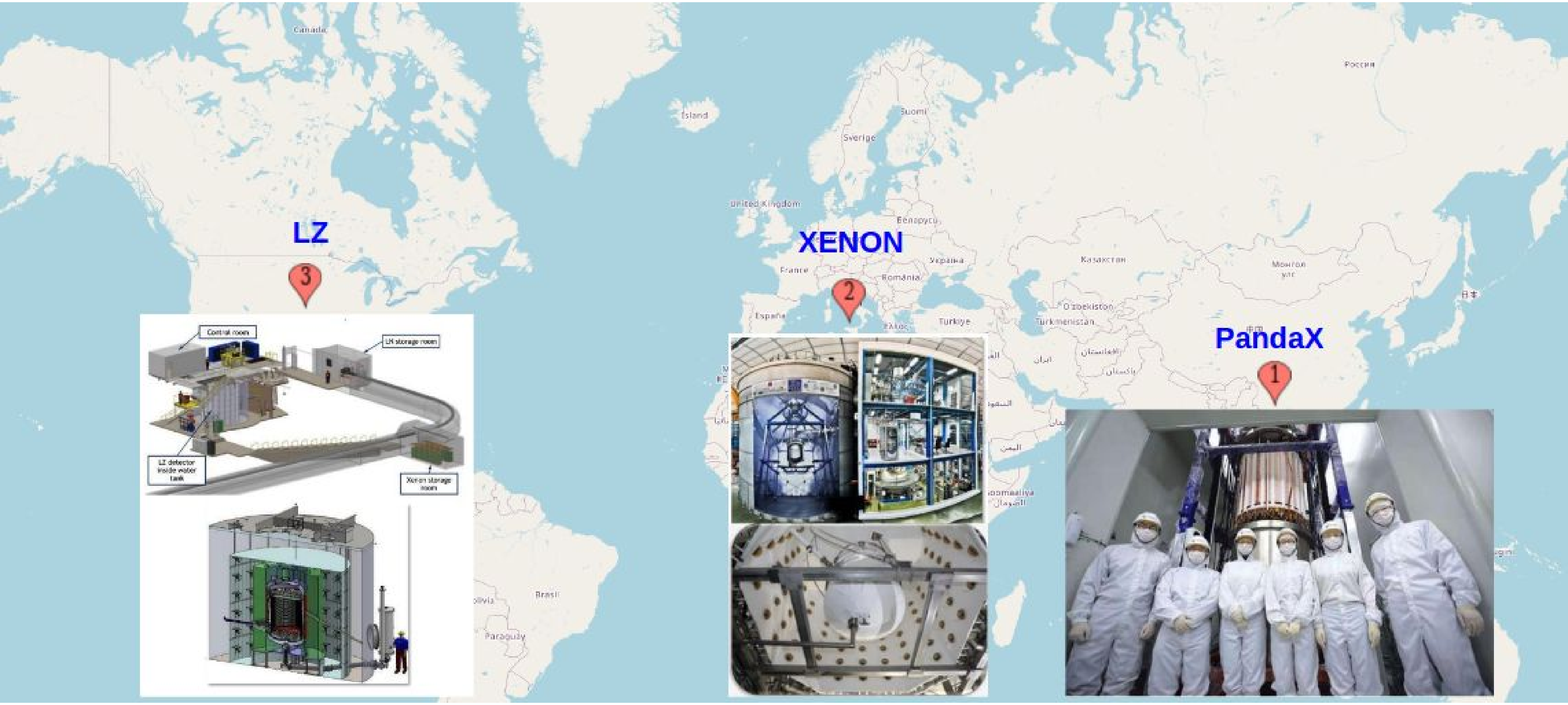
(Xenon and Argon)



- No long-lived isotopes (Xe only)
- Odd and even isotopes (Xe only) → SD
- Self-shielding
- Recoil discrimination

- S1, S2 → event energy
- S2 image → xy coordinate
- S1-S2 timing → z coord.
- S2/S1 → recoil type
- S1 PSD (Ar only) → recoil type

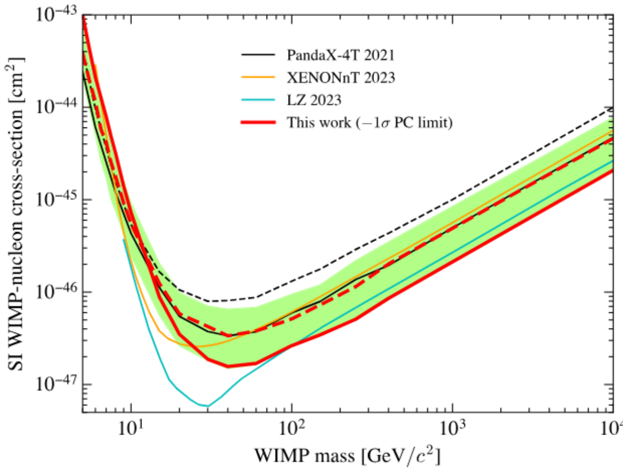
High WIMP mass : LXe TPCs rule



State of the art of liquid xenon detectors

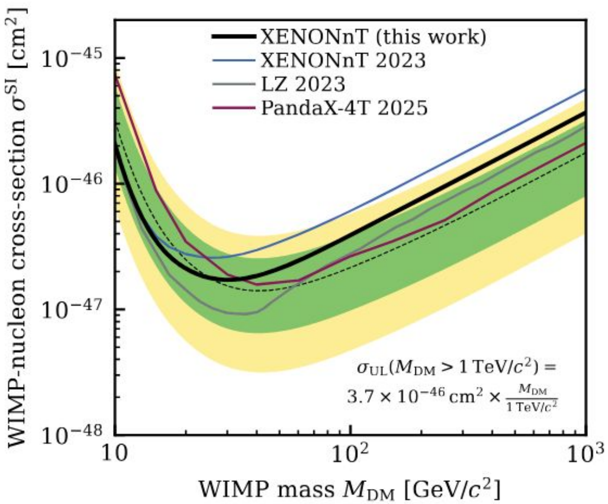
PandaX-4T :
- @JinPing, China
- 6t total Xe mass
- 1.54 t y exposure

PRL 134, 011805 (2025)



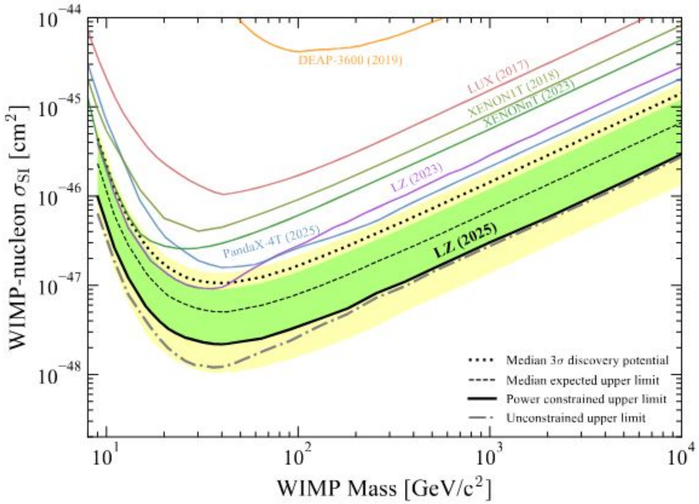
XENONnT :
- @LNGS, Italy
- 8.6t total Xe mass
- 3.1 t y exposure

PRL accepted, (2025), arXiv:2502.18005



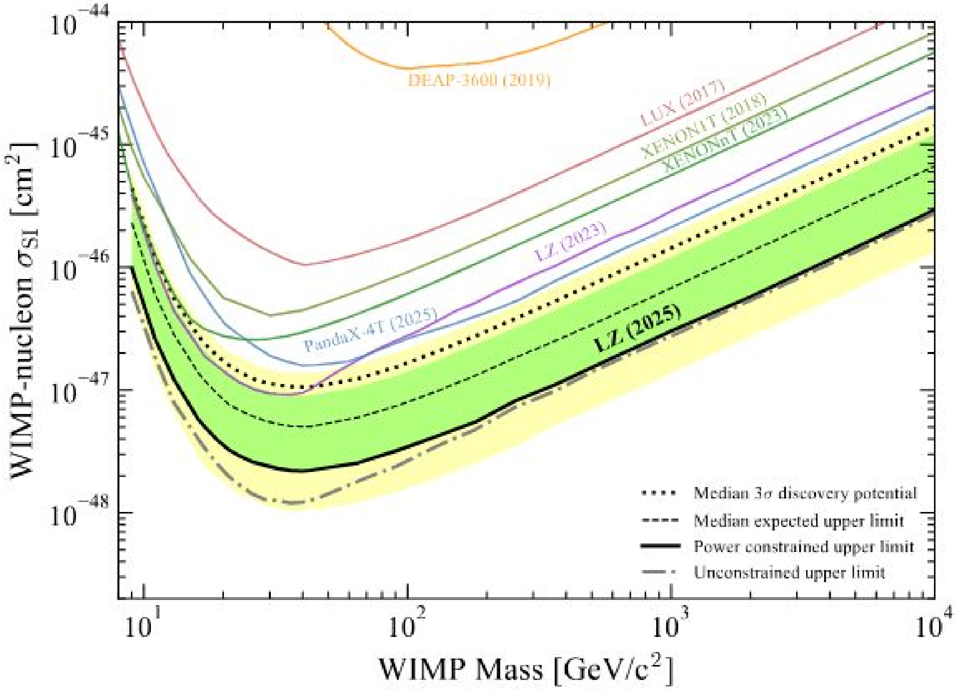
LZ (best limit):
- @SURF, US
- 10t total Xe mass
- 4.2 t y exposure

PRL 135, 011802 (2025)



Downwards fluctuations

To **constrain large downwards fluctuations**, the limit is subjected to a power-constraint : arXiv:1105.3166



LZ results (2025) :
4.2 ± 0.1 tonne-years from 280 live days
(of which 3.3 are new with respect to 2022 results)

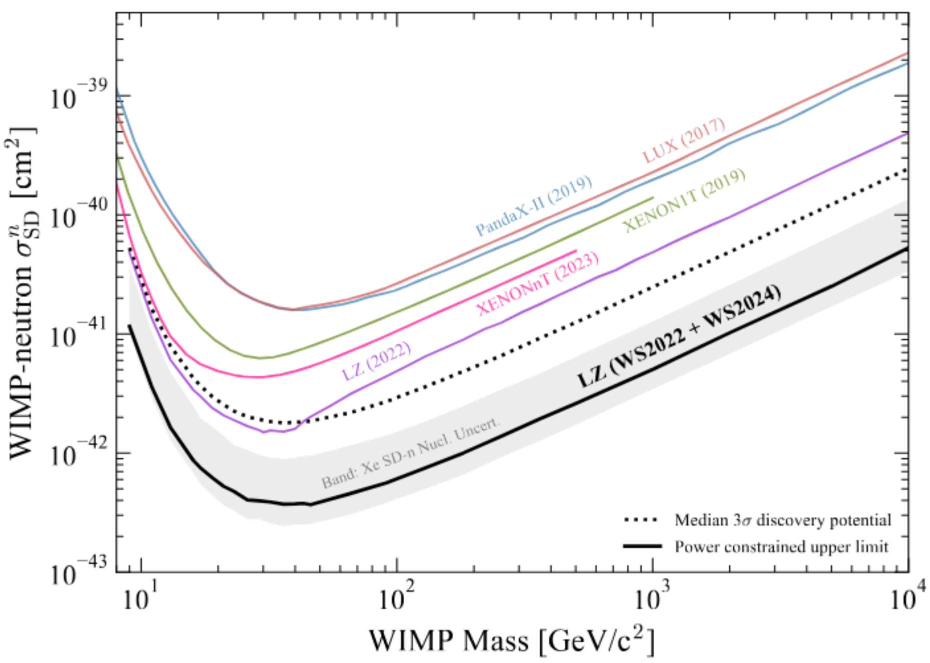
Source	Pre-fit Expectation	Fit Result
^{214}Pb βs	743 ± 88	733 ± 34
^{85}Kr + ^{39}Ar βs + det. γs	162 ± 22	161 ± 21
Solar ν ER	102 ± 6	102 ± 6
^{212}Pb + ^{218}Po βs	62.7 ± 7.5	63.7 ± 7.4
Tritium+ ^{14}C βs	58.3 ± 3.3	59.7 ± 3.3
^{136}Xe $2\nu\beta\beta$	55.6 ± 8.3	55.8 ± 8.2
^{124}Xe DEC	19.4 ± 3.9	21.4 ± 3.6
^{127}Xe + ^{125}Xe EC	3.2 ± 0.6	2.7 ± 0.6
Accidental coincidences	2.8 ± 0.6	2.6 ± 0.6
Atm. ν NR	0.12 ± 0.02	0.12 ± 0.02
^{8}B+hep ν NR	0.06 ± 0.01	0.06 ± 0.01
Detector neutrons	$^{a}0.0^{+0.2}$	$0.0^{+0.2}$
40 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	1210 ± 91	1203 ± 42

- Full curve : 90% C.L. limit with a power-constraint (-1σ) to restrict it at or above the median unconstrained upper limit
- Dot-dashed curve : no power contraint applied

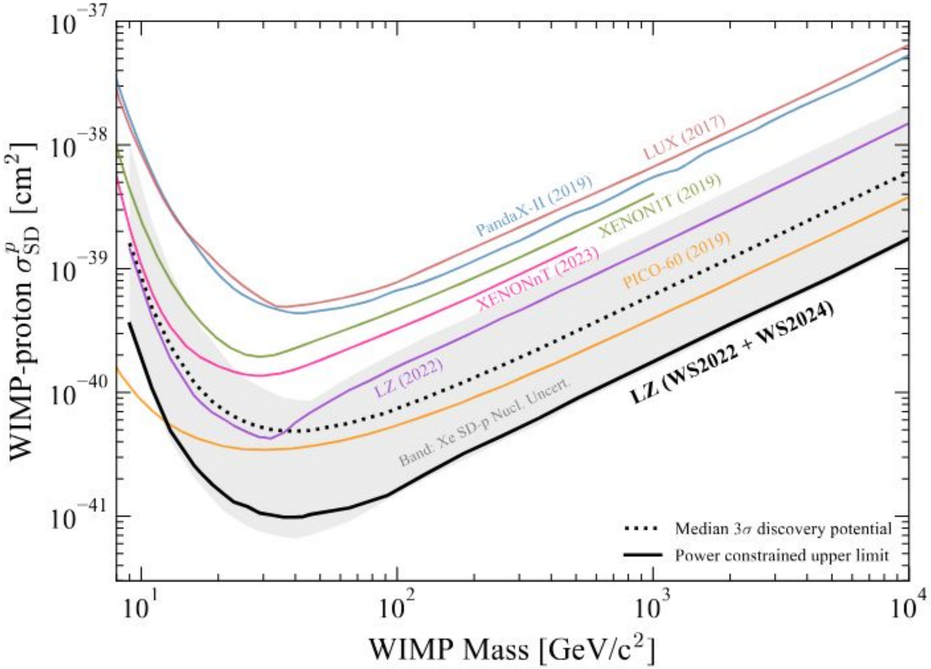
Spin Dependent interactions

LZ results (2025) :
4.2 ± 0.1 tonne-years from 280 live days

Coupling with neutron



Coupling with proton



First time LXe explored
new territory after PICO
(bubble chambers)

PRL 135, 011802 (2025), arXiv:2410.17036

WIMP-Nucleon Effective Field Theory Couplings

- Non relativistic effective field theory (NREFT)
- WIMP-nucleon interaction described by :

$$i\frac{\vec{q}}{m_N}, \quad \vec{v}^{\perp} \equiv \vec{v} + \frac{\vec{q}}{2\mu}, \quad \vec{S}_{\chi}, \quad \vec{S}_N$$

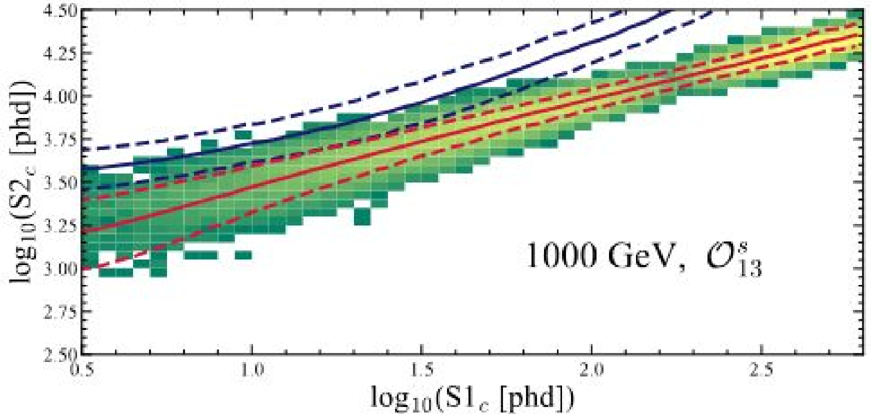
- 15 independent and dimensionless operators :

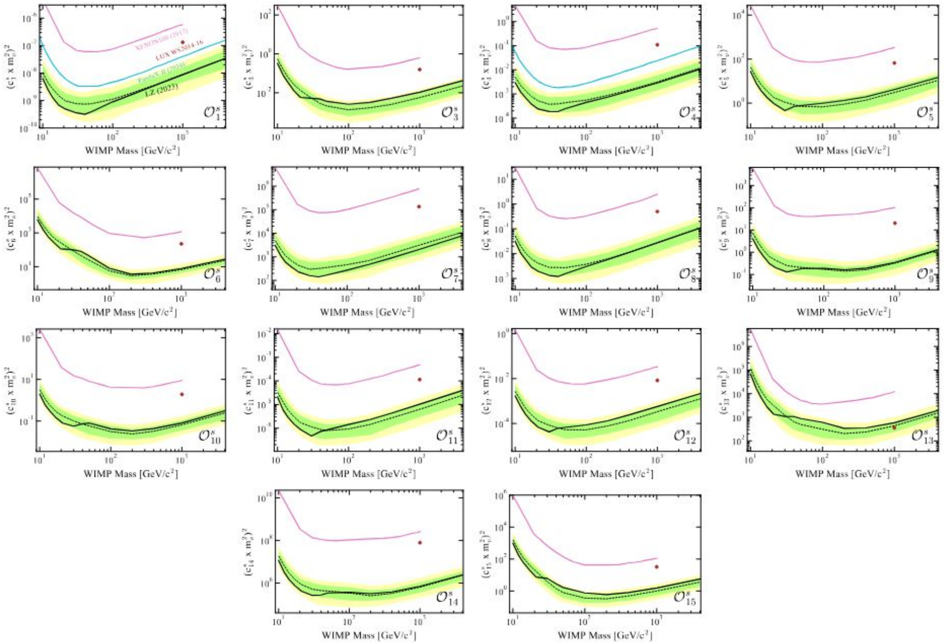
$$\begin{aligned}
&\mathcal{O}_1 = 1_{\chi} 1_N, \quad \mathcal{O}_2 = \left(v^{\perp}\right)^2, \quad \mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}\right), \\
&\mathcal{O}_4 = \vec{S}_{\chi} \cdot \vec{S}_N, \quad \mathcal{O}_5 = i\vec{S}_{\chi} \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}\right), \\
&\mathcal{O}_6 = \left(\vec{S}_{\chi} \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right), \quad \mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^{\perp}, \\
&\mathcal{O}_8 = \vec{S}_{\chi} \cdot \vec{v}^{\perp}, \quad \mathcal{O}_9 = i\vec{S}_{\chi} \cdot \left(\vec{S}_N \times \frac{\vec{q}}{m_N}\right), \\
&\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}, \quad \mathcal{O}_{11} = i\vec{S}_{\chi} \cdot \frac{\vec{q}}{m_N}, \\
&\mathcal{O}_{12} = \vec{S}_{\chi} \cdot \left(\vec{S}_N \times \vec{v}^{\perp}\right), \quad \mathcal{O}_{13} = i\left(\vec{S}_{\chi} \cdot \vec{v}^{\perp}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right), \\
&\mathcal{O}_{14} = i\left(\vec{S}_{\chi} \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \vec{v}^{\perp}\right), \\
&\mathcal{O}_{15} = -\left(\vec{S}_{\chi} \cdot \frac{\vec{q}}{m_N}\right)\left(\left(\vec{S}_N \times \vec{v}^{\perp}\right) \cdot \frac{\vec{q}}{m_N}\right).
\end{aligned}$$

- Evaluate the scattering amplitude by assuming a single operator

- Two papers :
  - XENON1T, *Phys. Rev. D 109, 112017 (2024)*
  - LZ, *Phys. Rev. D 109, 092003 (2024)*

LZ, Phys. Rev. D 109, 092003 (2024)

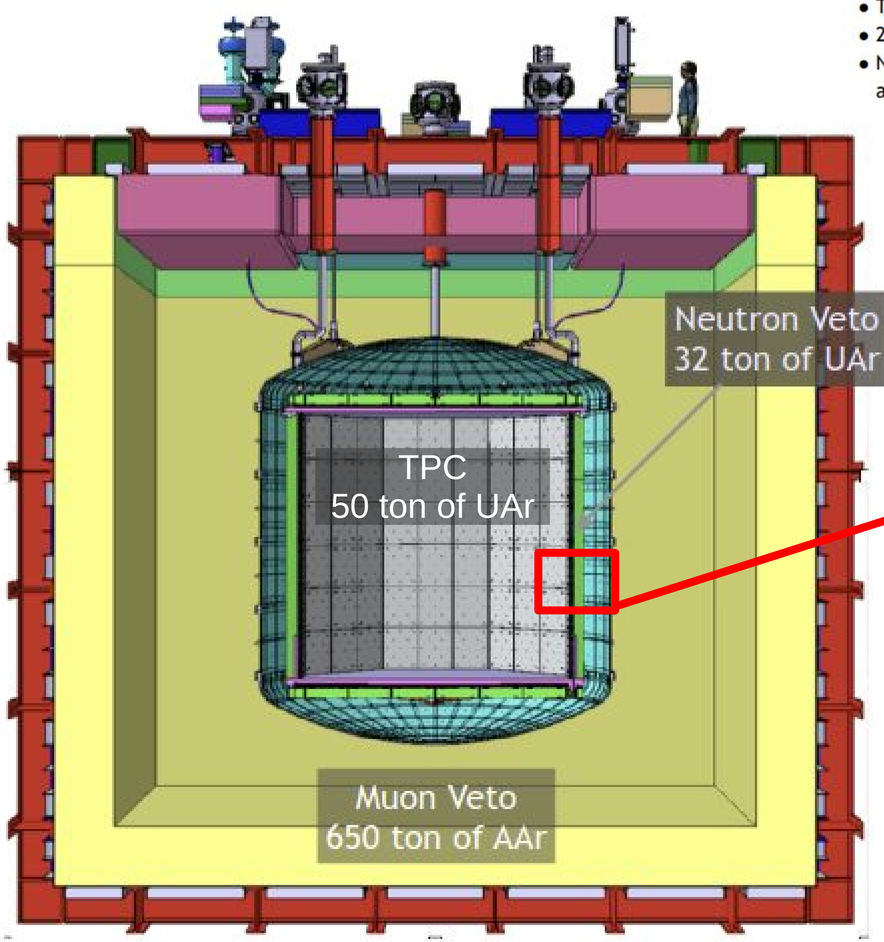


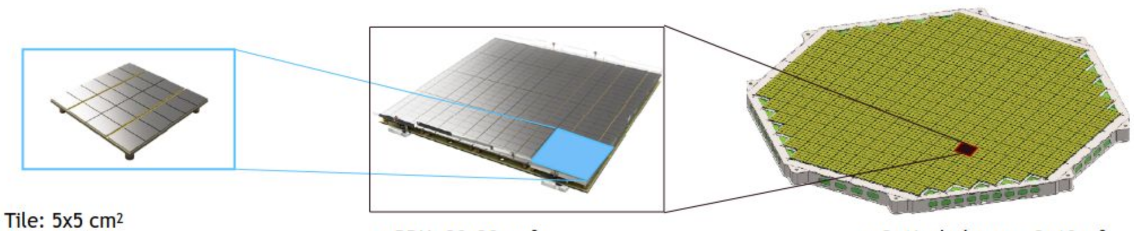


WIMPs domain (>10 GeV)

Future detectors

DarkSide-20k



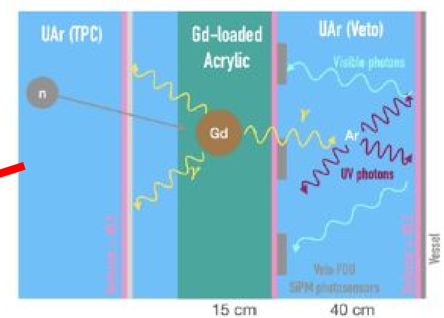


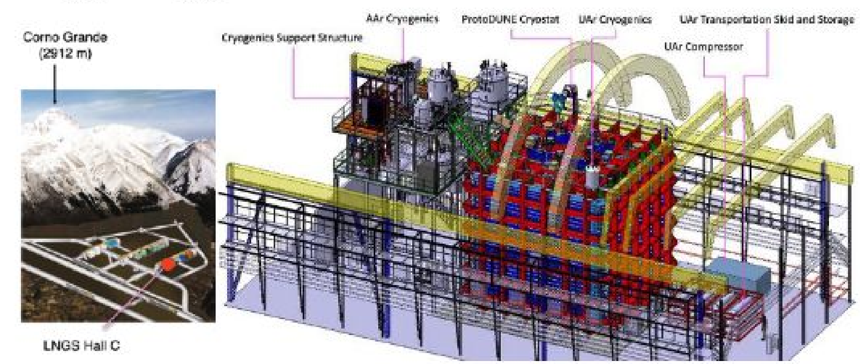
- Tile: 5x5 cm²
- 24 SiPMs directly mounted on a FEB
- NUV-HD-CRYO developed by FBK and produced by LFoundry

- PDU: 20x20 cm²
- 16 Tiles Assembled on a Motherboard
- 4 readout Channel

- Optical planes: ~2x10 m²
- Total PDUs used (TPC): 528
- Readout Channels: 2112

Photodetectors to be installed at NOA (Nuova Officina Assergi)



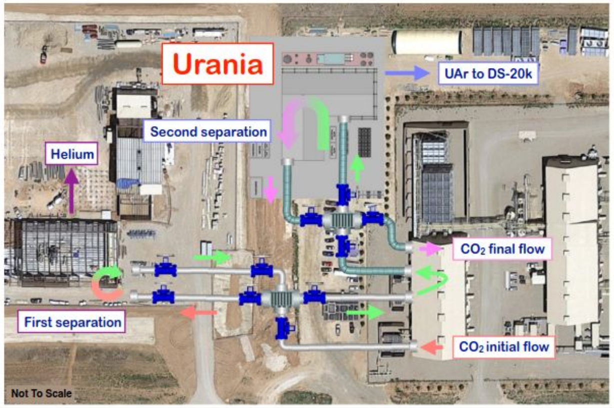


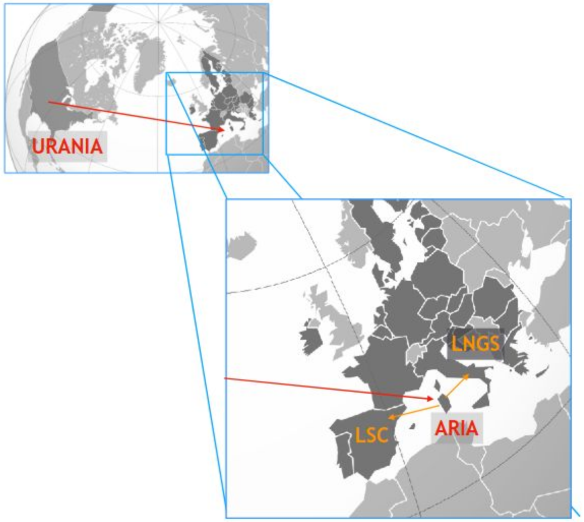
Towards DarkSide-20k : impurities reduction

Extraction with Urania

Expansion of the industrial scale plant in Cortez, to reach capacity of **250 kg/day** of Underground Argon

Initial purity: 99.99%





Purification with ARIA

~350 m distillation column in Seruci mine (Sardinia)

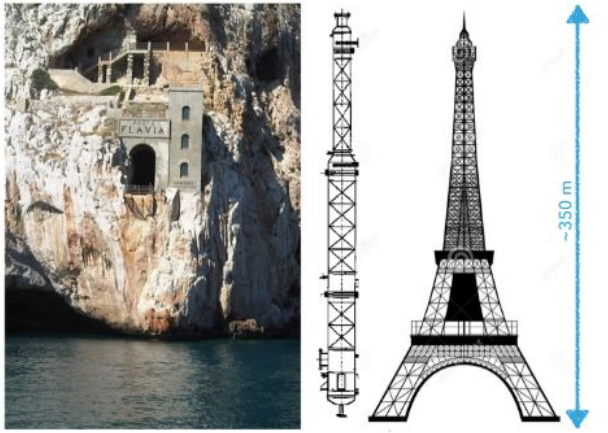
Process 0 (1 tonne / day) with 10^3 reduction of all chemical impurities

14 years for 50 tons ← x10 $^{39}Ar/^{40}Ar$ reduction at the rate of 10 kg/day

The demonstrator column (26 m) successfully tested in 2019 with LN2 and in 2021 with argon

Isotopic separation of Ar-36, Ar-38, and Ar-40 has been demonstrated.

Successful test installation of the first module (of 28 central ones) in the mine shaft



Xenon : towards the 3rd generation of 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

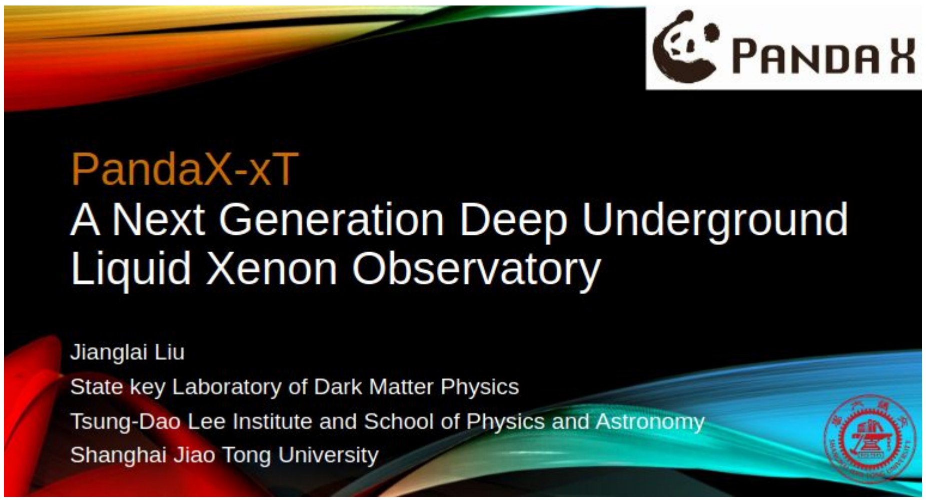
XLZD (XENON+LZ+DARWIN):
Several sites considered
80t total Xe mass (60t active)

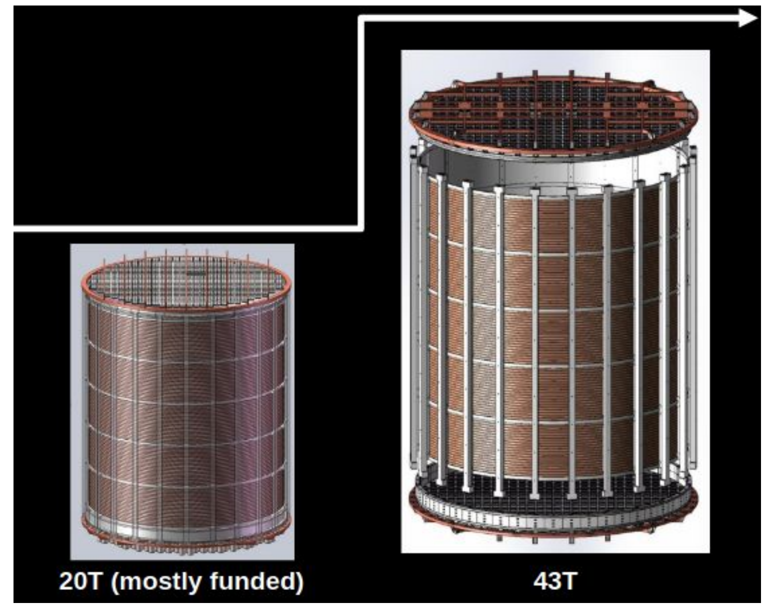
PandaX-4T :
@JinPing, China
6t total Xe mass

PandaX-xT :
@JinPing, China
43t total Xe mass

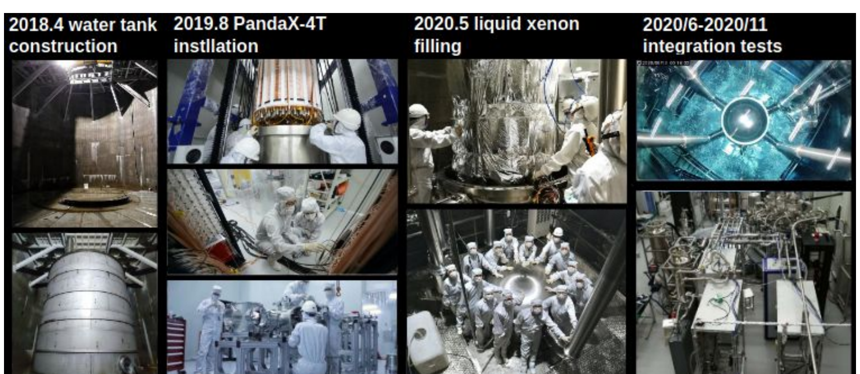
PandaX-xT

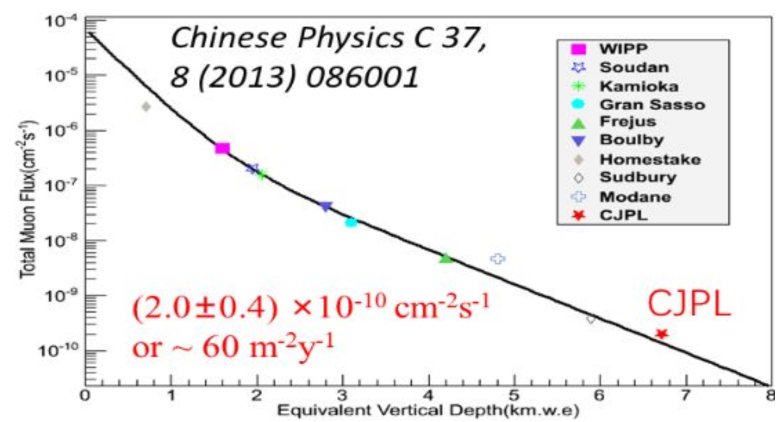
- April 2025 : International Open Meeting for PandaX-xT
  - https://indico-tdli.sjtu.edu.cn/event/2934/
- Including theory and phenomenology talks and a visit to Jinping Laboratory
- Staged approach : first 20T, then 43T





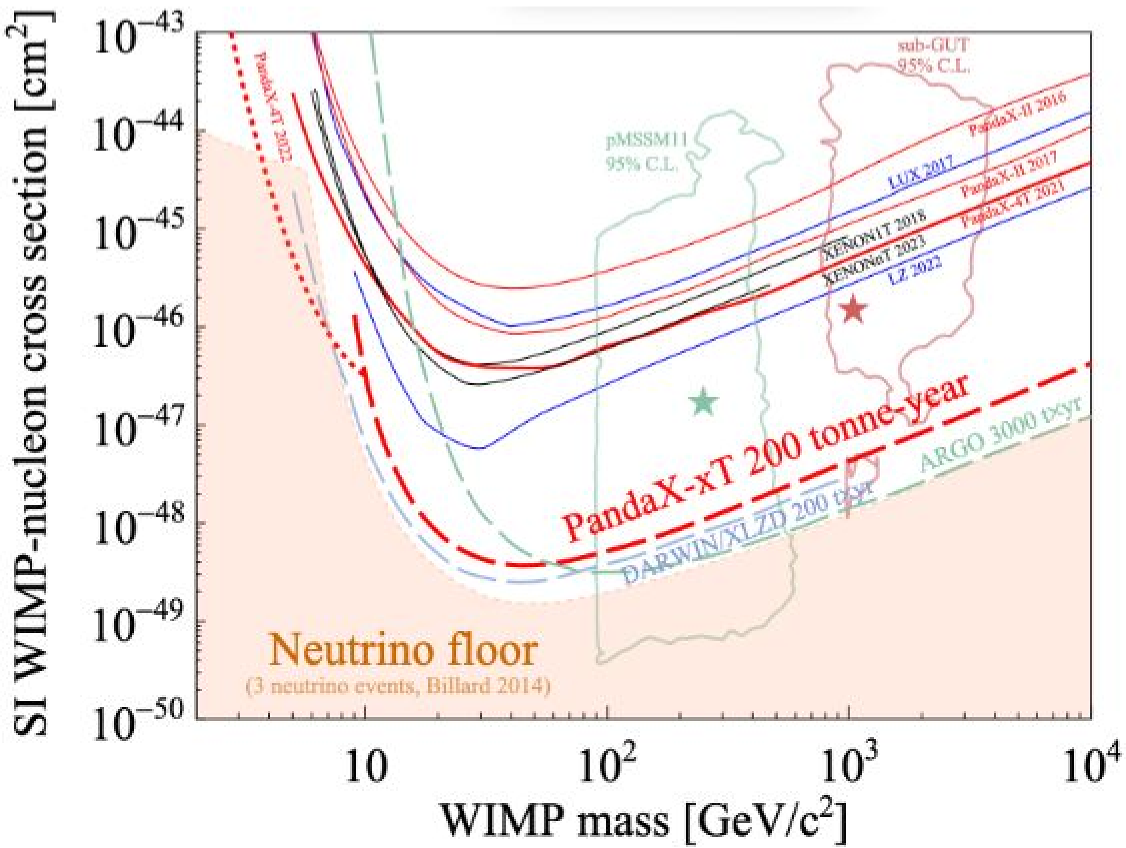
Timeline of the previous PandaX-4T

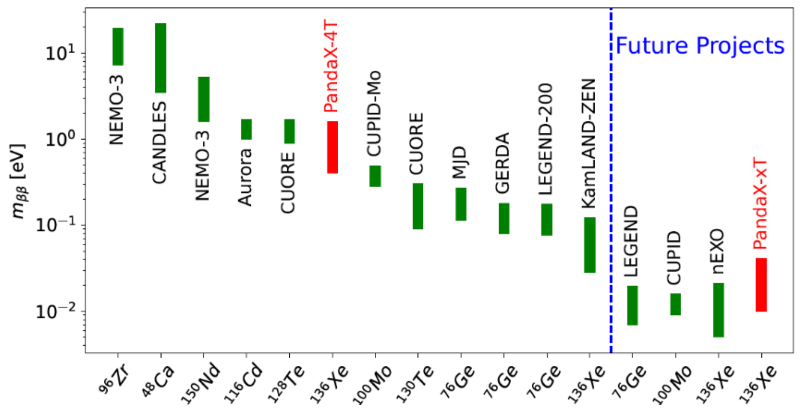


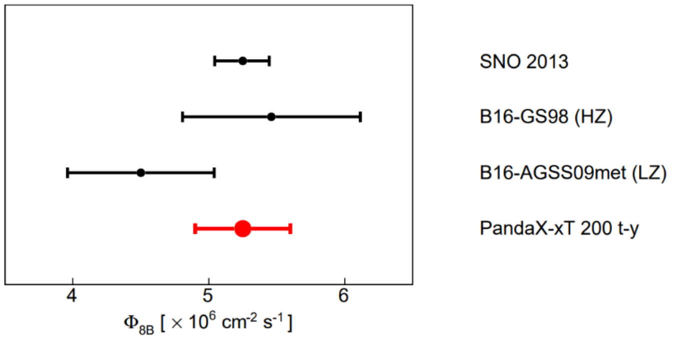


PandaX-xT : physics reach

- Results assuming 43 tonnes of fiducial mass

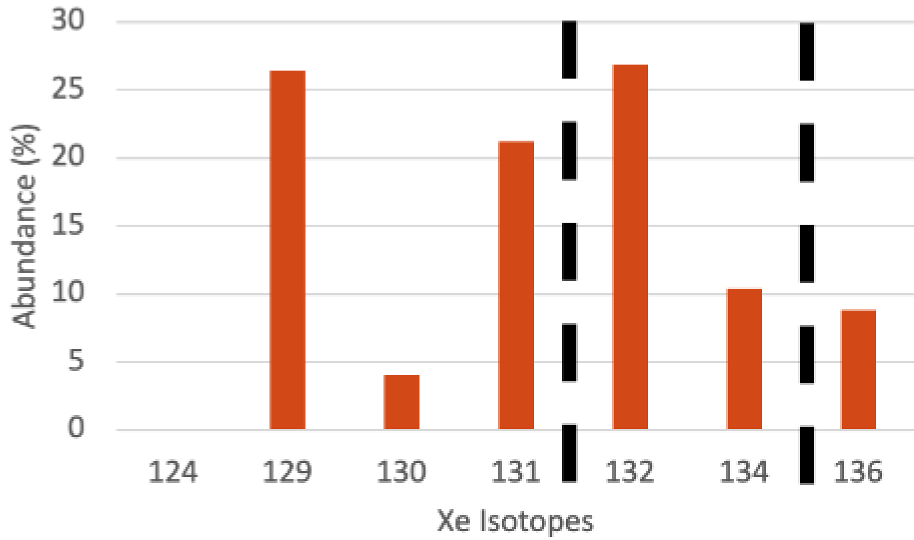


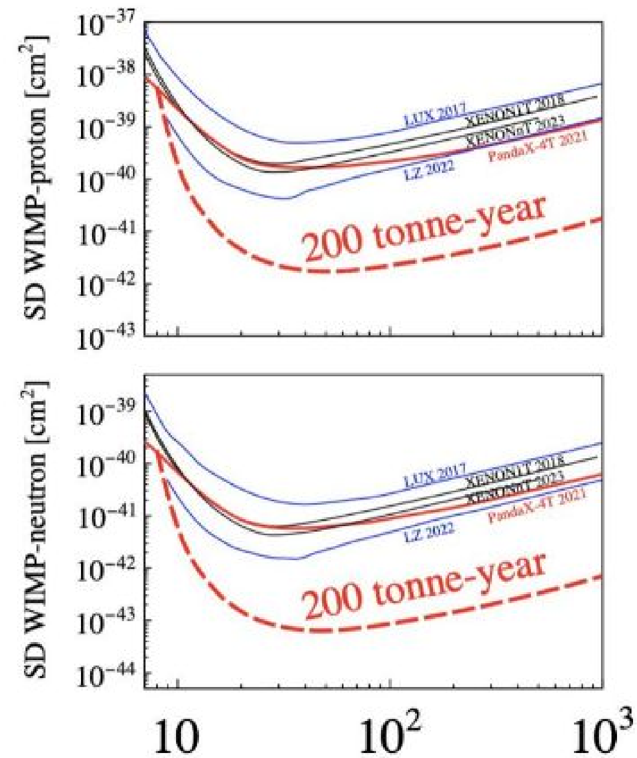


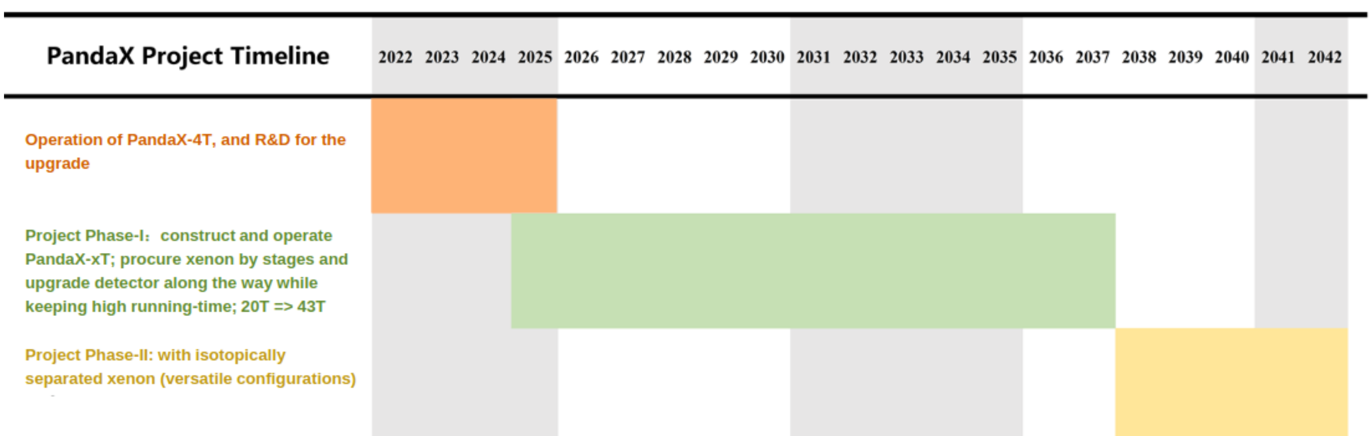


PandaX-xT : timeline and future ideas

- Timeline and future performances





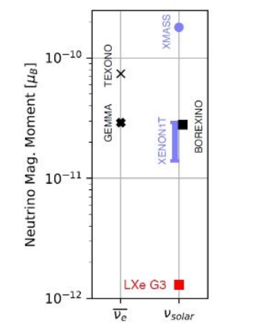


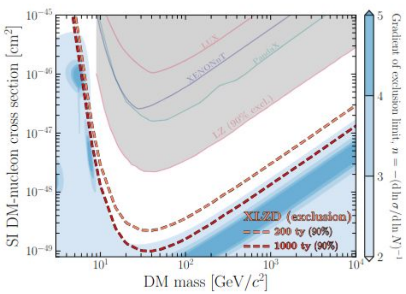
XLZD, a dark matter detector ?
No, an astroparticle observatory

XLZD is an **astroparticle observatory**, allowing not only dark matter search, but also neutrino physics and many other physics opportunities

- ‘Snomass’ White paper : *J. Phys. G: Nucl. Part. Phys. 50 (2023) 013001, arXiv:2203.02309*
- XLZD Design Book : *Eur. Phys. J. C (2025) 85: 1192, arXiv:2410.17137v1*

arXiv:2203.02309





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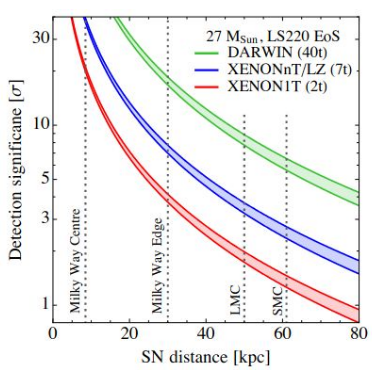
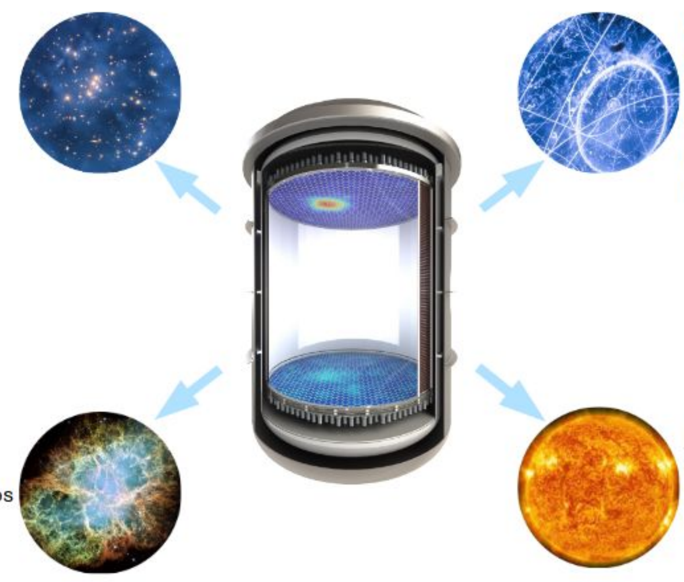


Phys. Rev. D 94 (2016) no.10, 103009

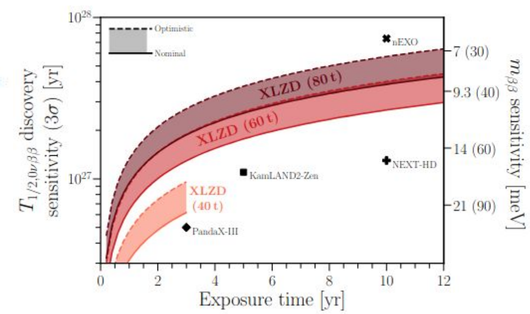
Dark Matter
WIMPs
Sub-GeV
Inelastic
Axion-like particles
Planck mass
Dark photons

Neutrino nature
Neutrinoless double beta decay
Neutrino magnetic moment
Double electron capture

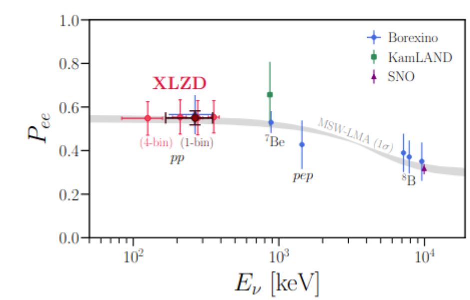


Supernovae
Early alert
Supernova neutrinos
Multi-messenger astrophysics

Sun
pp neutrinos
Solar metallicity
^{7}Be, ^{8}B, hep

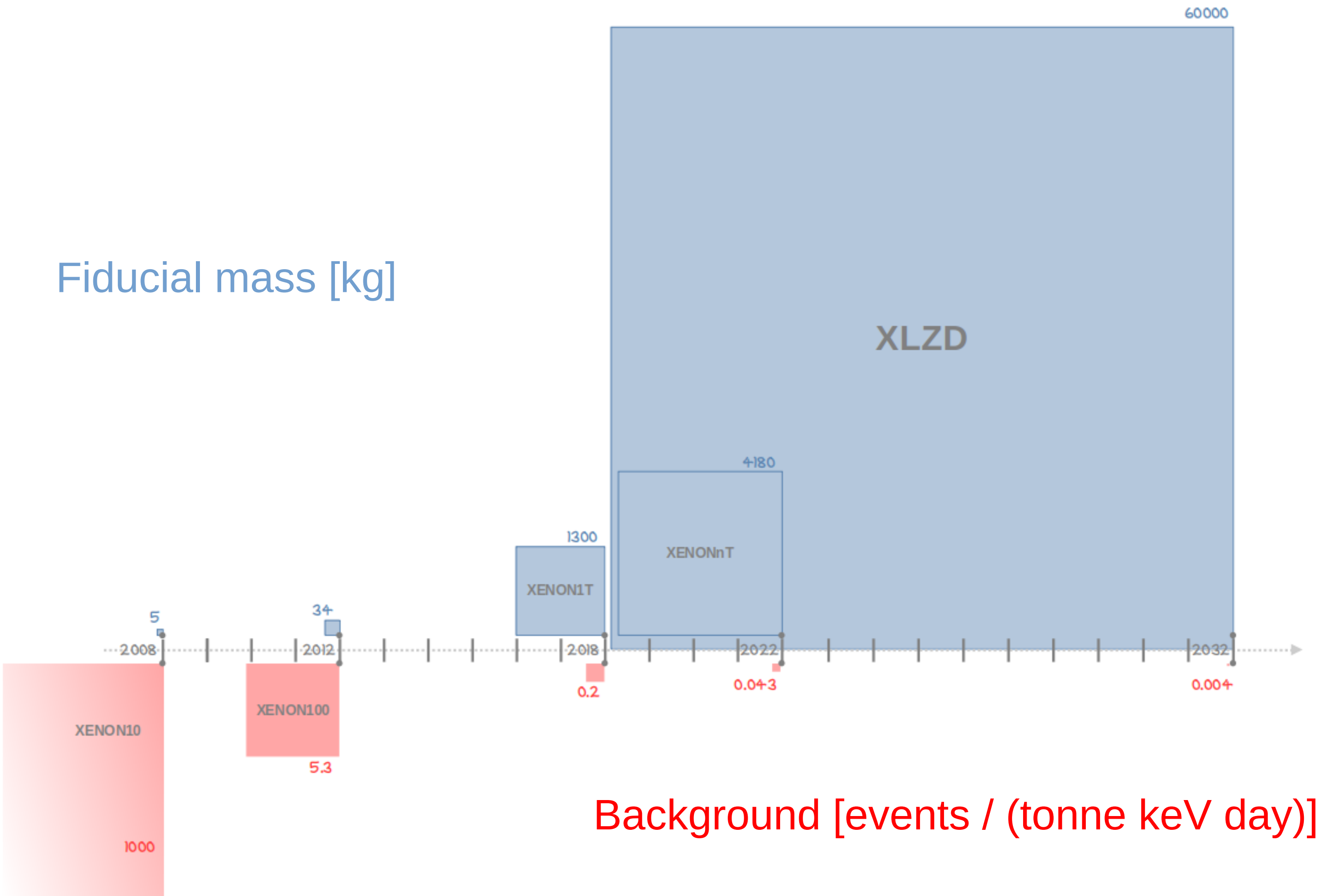


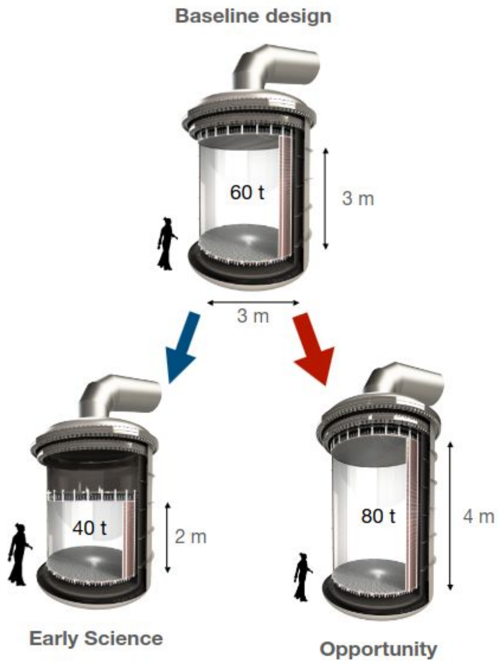
arXiv:2410.17137v1



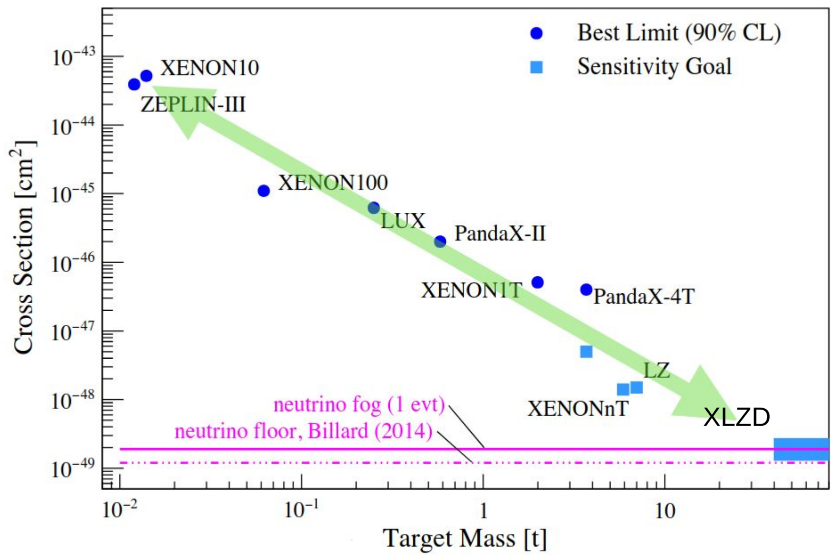
arXiv:2410.17137v1

The power of scalability



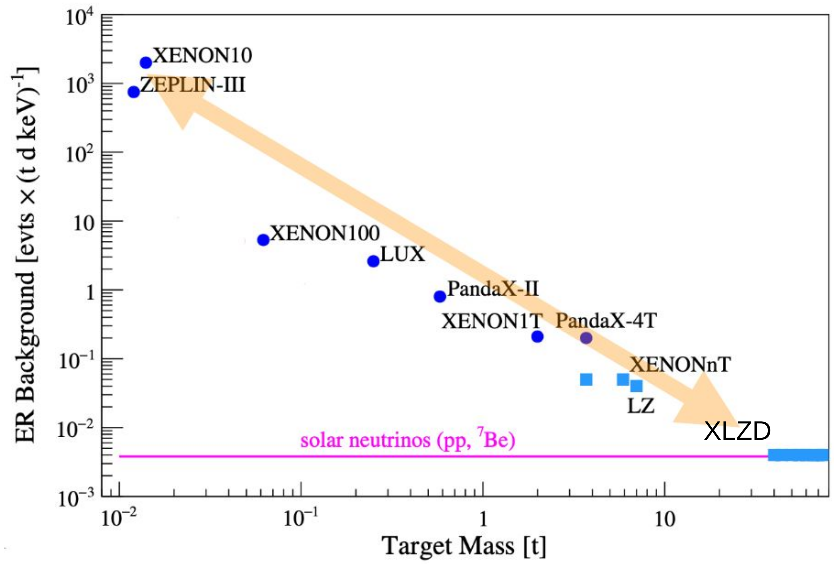


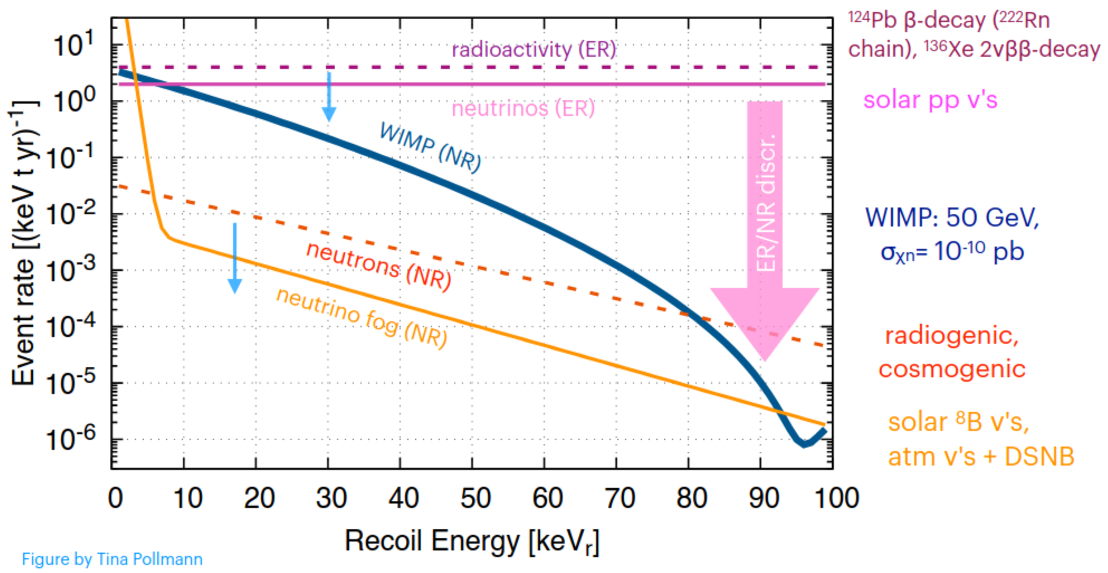
XLZD goals



Main goal : quasi “background-free” exposure of 200 t y for dark matter search

ER and NR backgrounds limited uniquely by neutrino-induced events





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

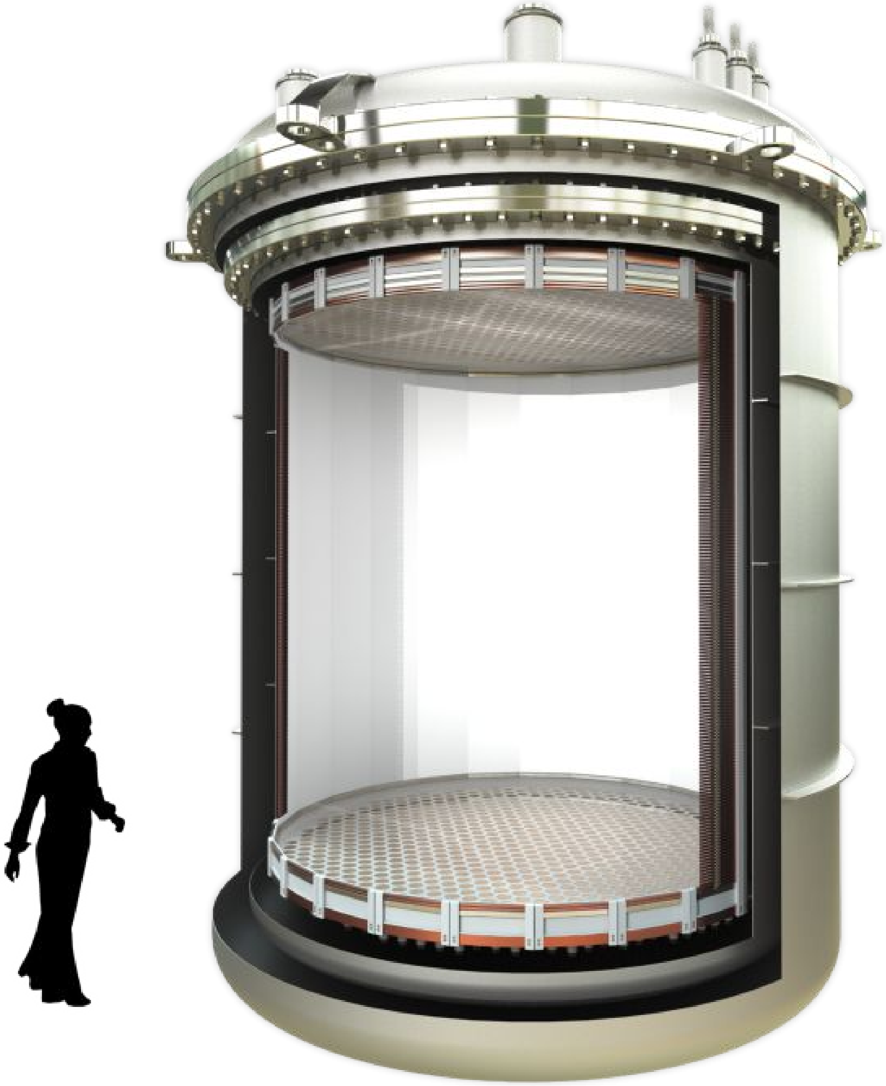
High-voltage supply to cathode design, avoid high-field regions

Light sensors: reduce backgrounds and DRCs, improve PDE

Cryogenic system and xenon **purification**

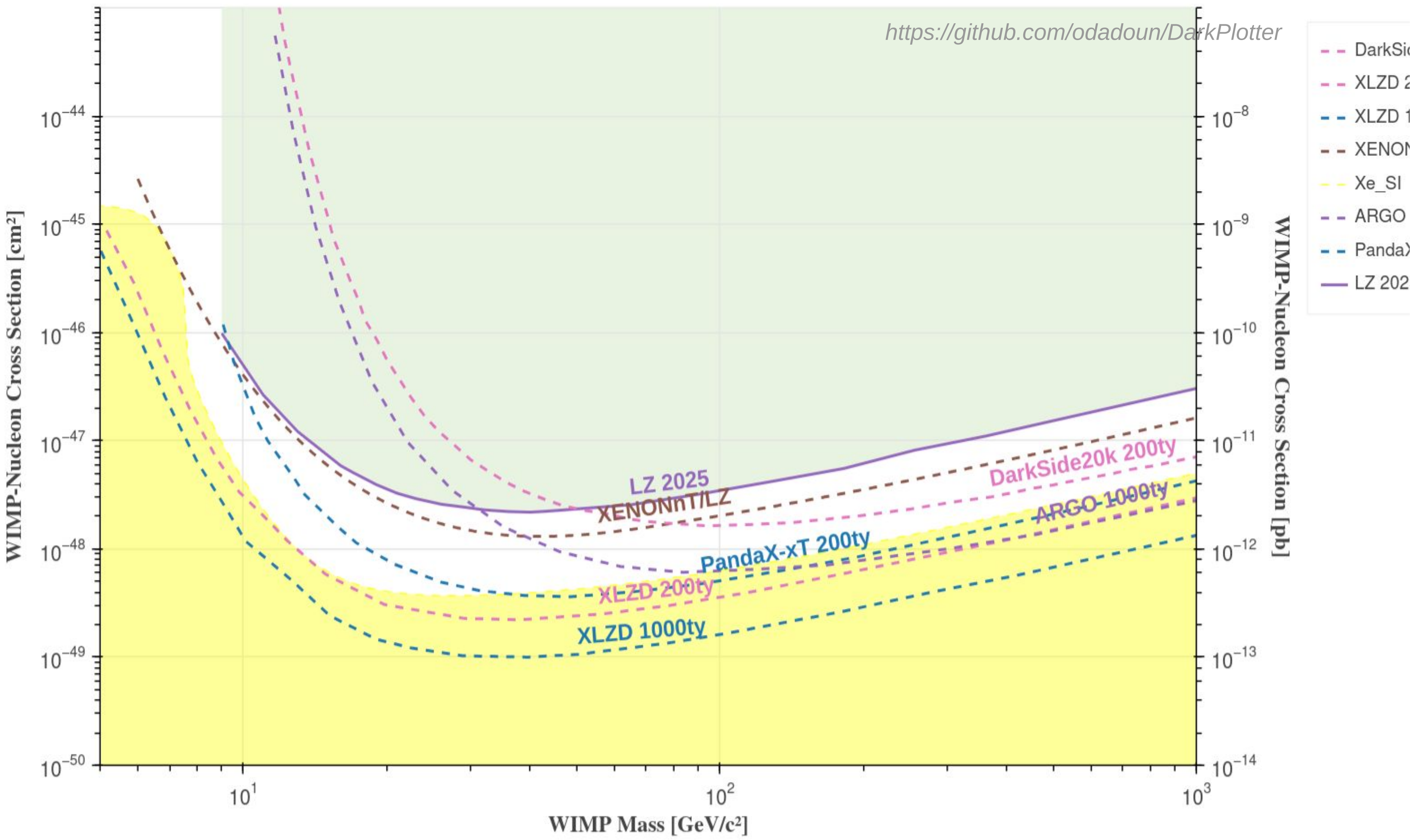
Xenon **storage and recovery** : safety and reliability

Computing : handling up to 2.4 PB / year of data



Frédéric Girard, LPNHE

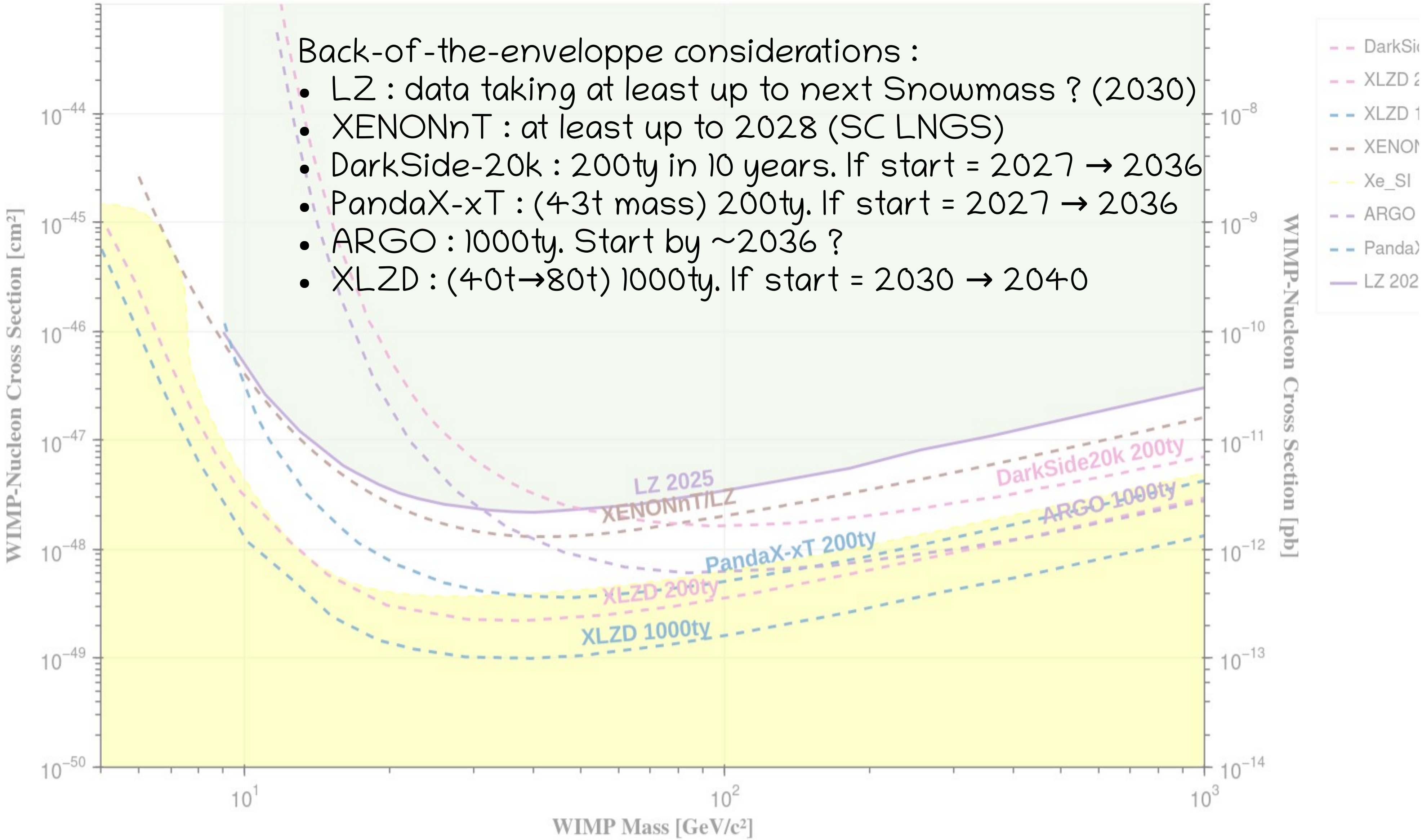
Comparison with future experiments



Timeline of future experiments

Back-of-the-enveloppe considerations :

- LZ : data taking at least up to next Snowmass ? (2030)
- XENONnT : at least up to 2028 (SC LNGS)
- DarkSide-20k : 200ty in 10 years. If start = 2027 → 2036
- PandaX-xT : (43t mass) 200ty. If start = 2027 → 2036
- ARGO : 1000ty. Start by ~2036 ?
- XLZD : (40t→80t) 1000ty. If start = 2030 → 2040

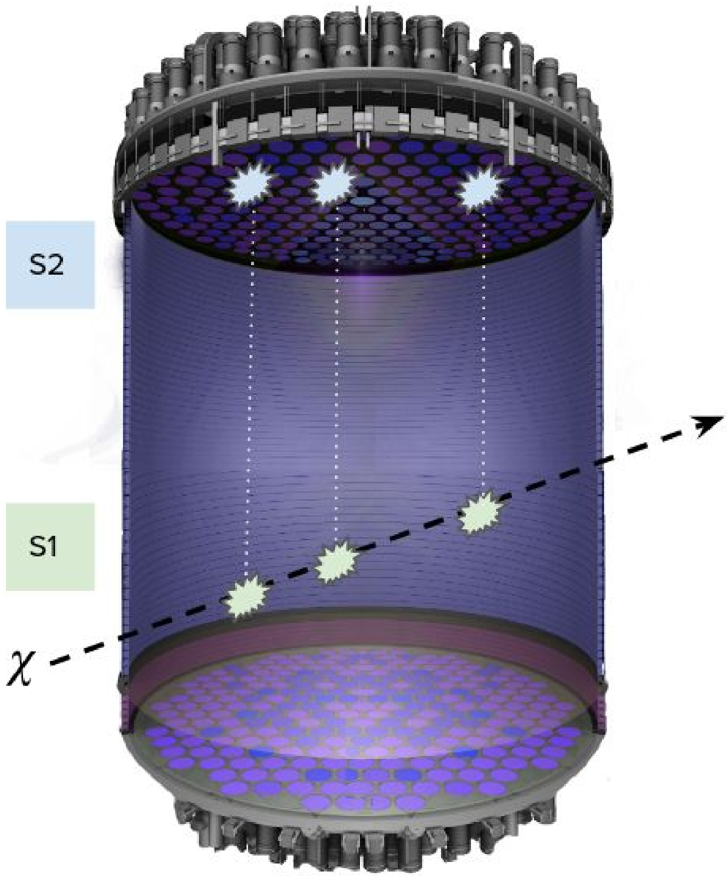


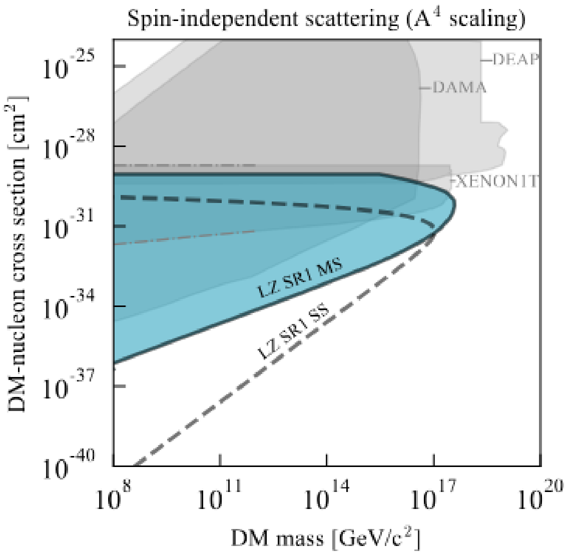
MIMPs domain

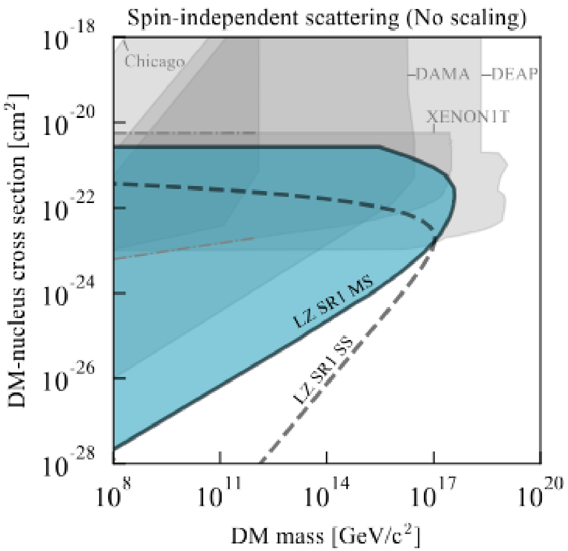
Even higher masses : MIMPs

Mass close to the Planck mass

→ Multiply-Interacting Massive Particles (MIMPs)







XENON1T : Phys. Rev. Lett. 130, 261002, arXiv:2304.10931

LZ : Phys. Rev. D 109, 112010, arXiv:2402.08865v1

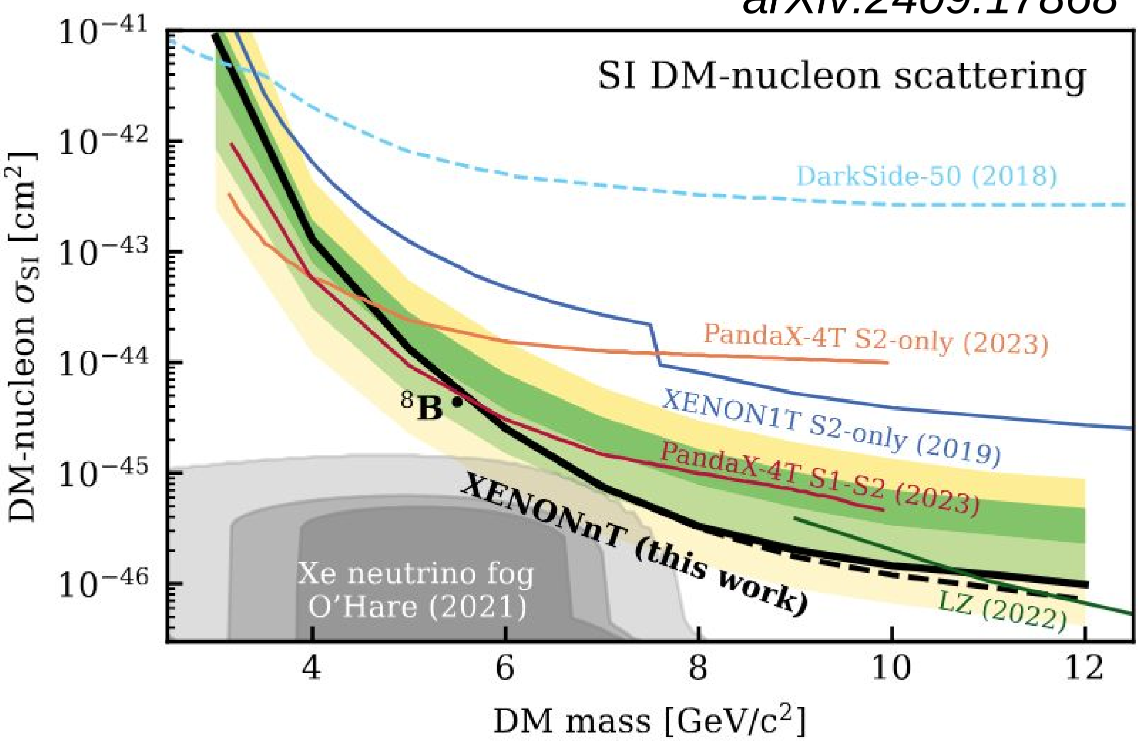
« WIMPs » close to ^{8}B neutrino floor

(1 to 10 GeV)

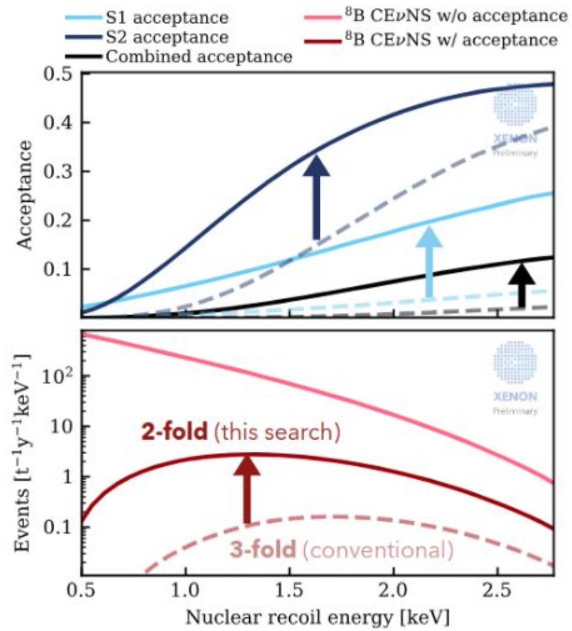
Low masses close to ^{8}B neutrinos : liquid xenon rules

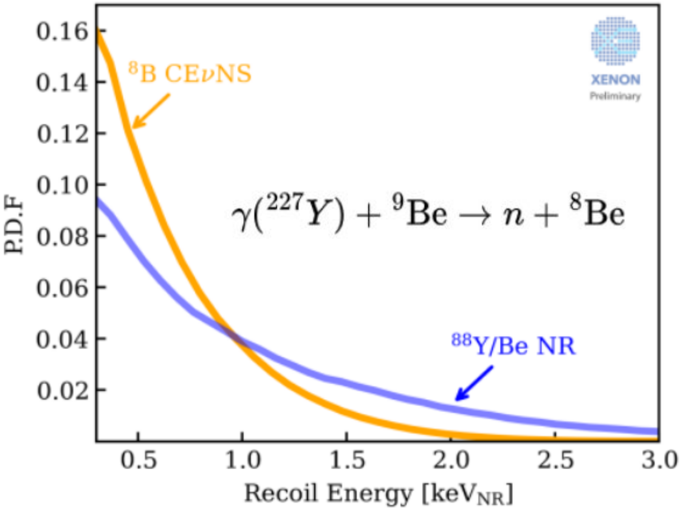
XENONnT results (2024) :
3.51 tonne-years

arXiv:2409.17868



Phys.Rev.Lett. 133 (2024) 191002

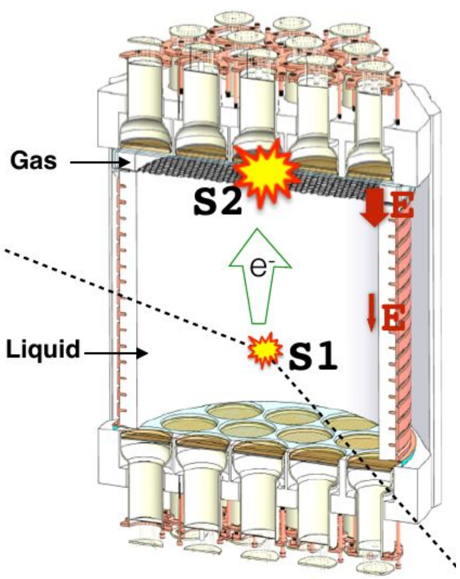




XENONnT analysis features :

- Passing from the traditional 3-fold to a 2-fold PMT **coincidence**
  - Drawback : increase of **accidental** concidences background
- Two **BDTs** on the S1 and S2 peak
- Temporal (S2/ΔT) and spatial **correlations** with preceding events

Low masses < 4 GeV : DarkSide-50

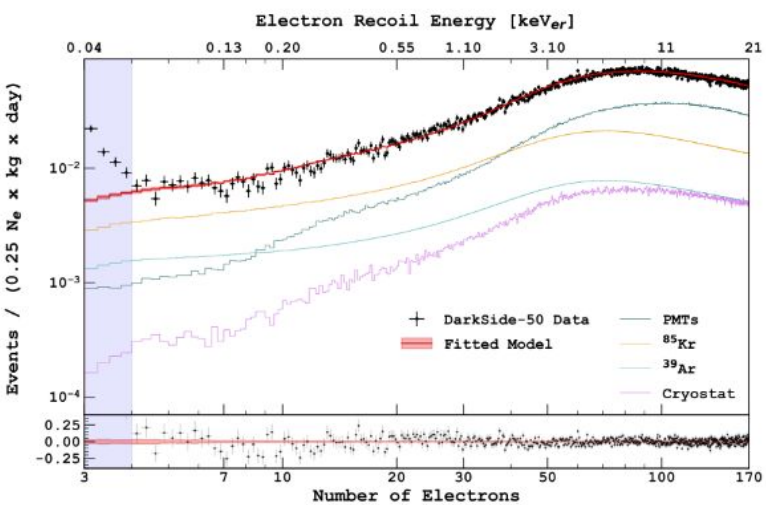


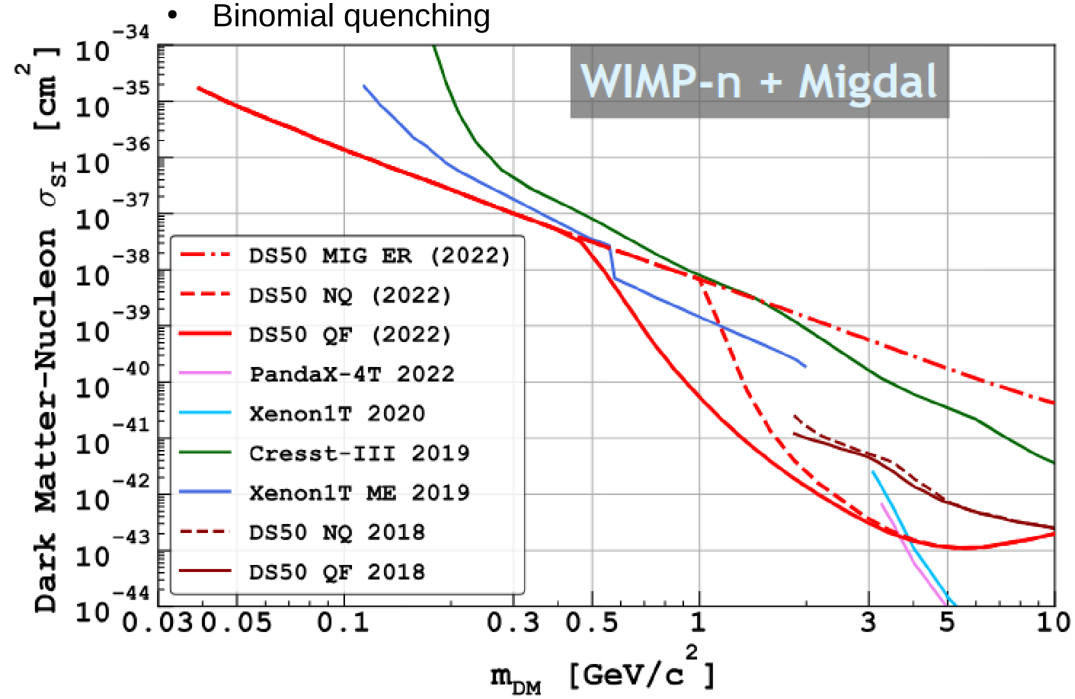
- Scintillation (S1)
  - Detection efficiency (g1) ~ 16%

- Ionization (S2)
  - Efficiency to extract 1 e- in the gas pocket ~ 100%
  - Amplification factor (g2) = ~23 pe / e-

DarkSide-50, Phys. Rev. D 107 (2023) 063001
DarkSide-50, Phys. Rev. Lett. 130 (2023) 101001
DarkSide-50, Phys. Rev. Lett. 130 (2023) 101002

Quenching fluctuations, two approaches :
- No Quenching (unphysical but conservative)
- Binomial quenching

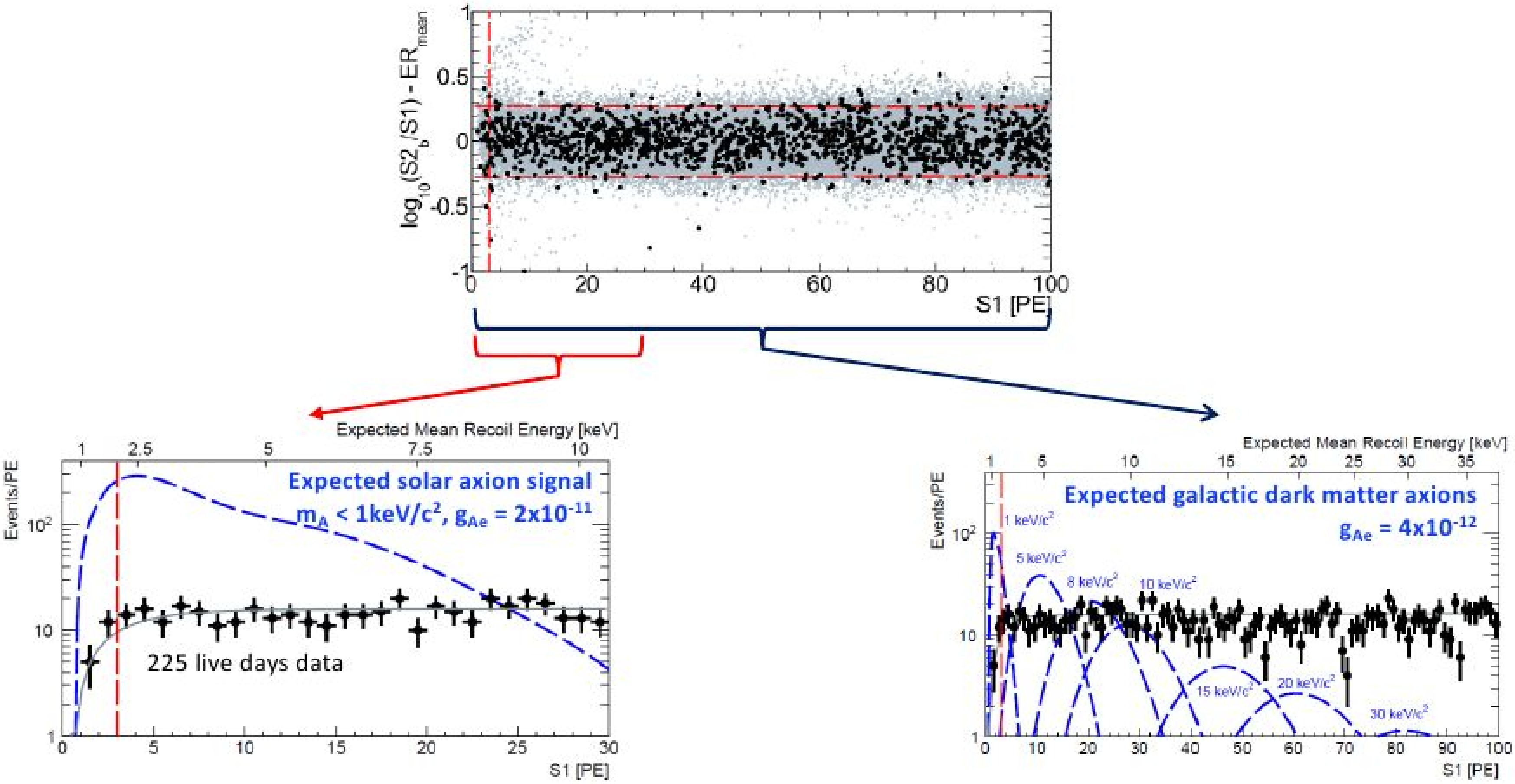




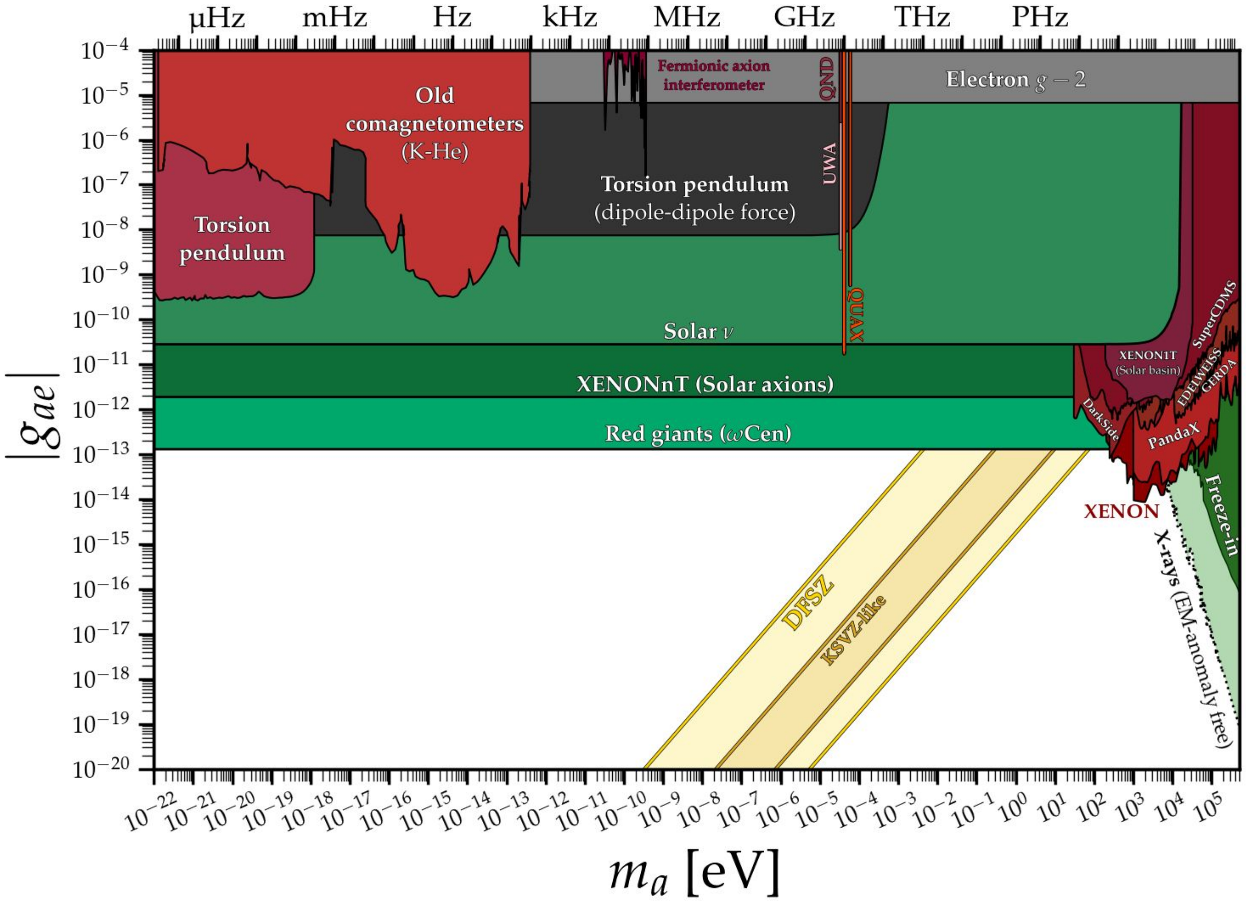
Leptophilic Dark Matter

Warm Dark Matter → Axions search

- Origins of axion type particles: galactic dark matter and production in the Sun
- Coupling of axions and axion-like dark matter particles (ALP) to LXe target medium via axio-electric effect („absorption“ of axion and emission of electron from the atomic shell)
- Signal expected to appear in the electronic recoil band (as opposed to WIMPs)

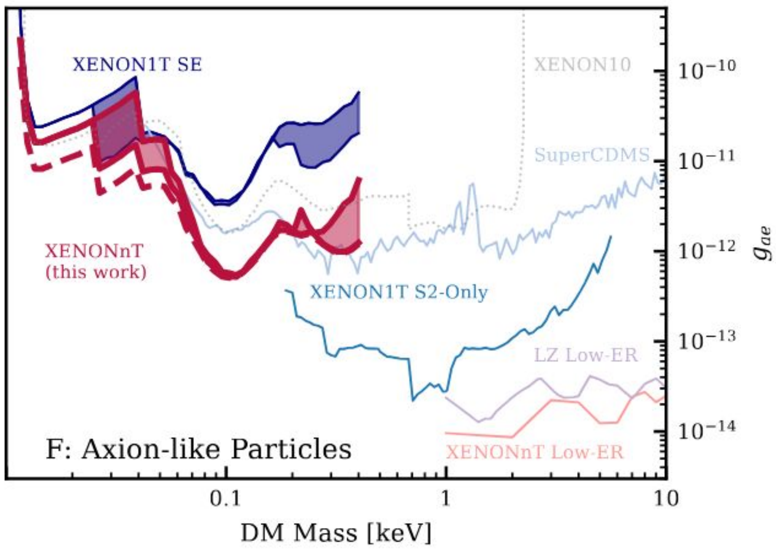


Warm Dark Matter → Axions search



For noble liquids, curves are a combination of several analyses :

- Standard S1+S2
- S2-only analysis
- 1-to-few electron analysis

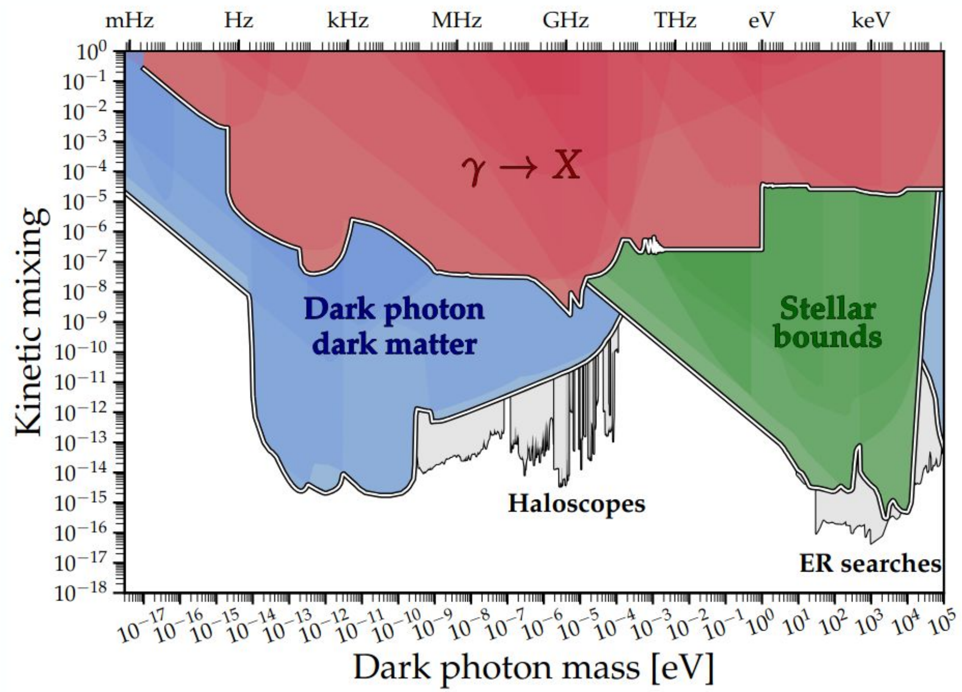


Dark Photons

- Arise from a U(1) extension of the Standard Model
- A dark electromagnetic field mixes with the SM photon
- Dark Matter searches exploit the fact that dark photons can oscillate into regular photons, producing luminous signals

"Kinetic mixing"

$$\mathcal{L} \supset -\frac{\chi}{2} F_{\mu\nu} X^{\mu\nu} \qquad (\chi \ll 1)$$



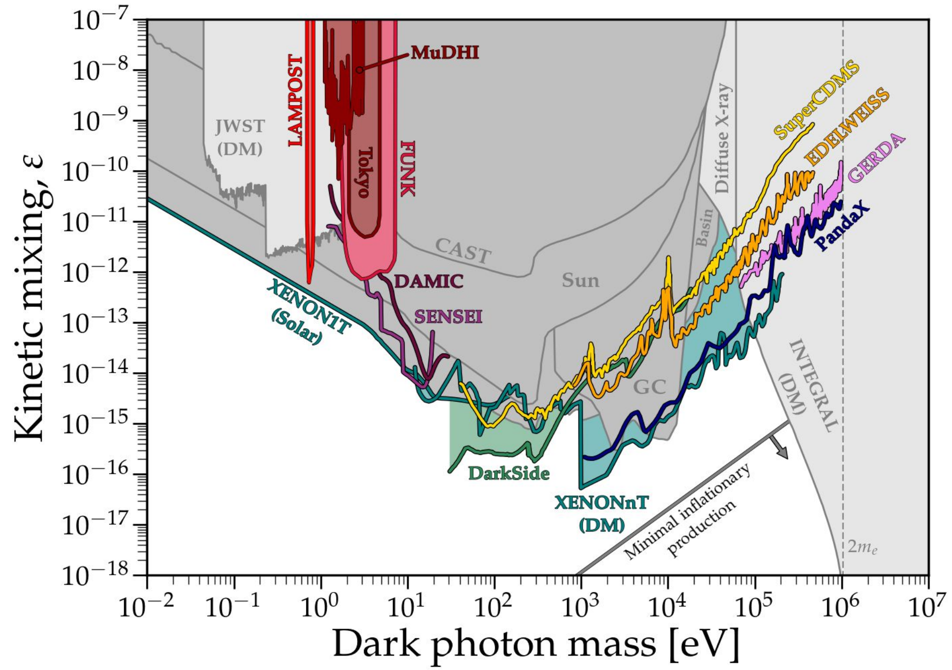
Leading results :

- **From skipper CCDs:**

DAMIC@SNOWLAB
SENSEI (2023) *arXiv:2312.13342*
SENSEI (2024) *arXiv:2410.18716*
DAMIC-M

- **From noble liquids:**

DarkSide-50
XENON1T
Panda-X
XENONnT
LZ



Light-WIMPs (sub-GeV Dark Matter)

At low masses, DM-electron scattering kinematics is more optimal than DM-nucleon scattering for experiments

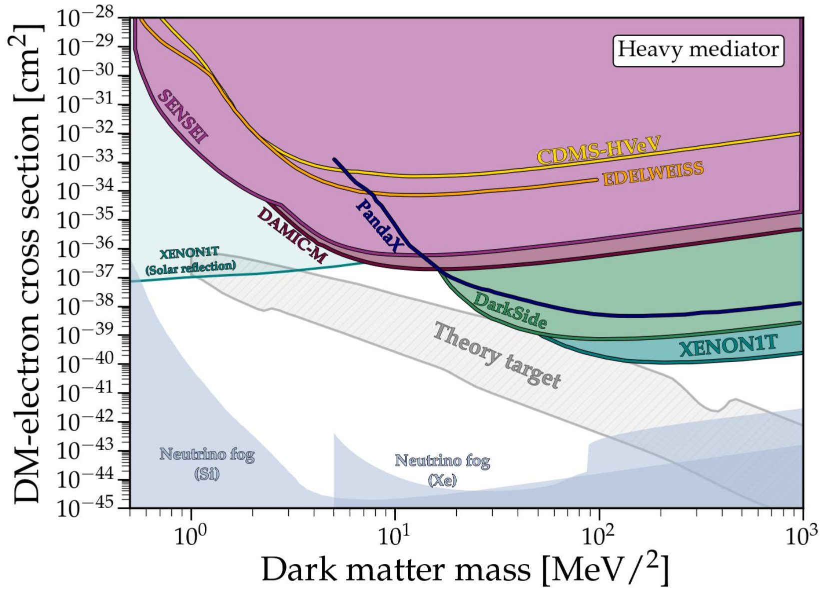
Leading results :

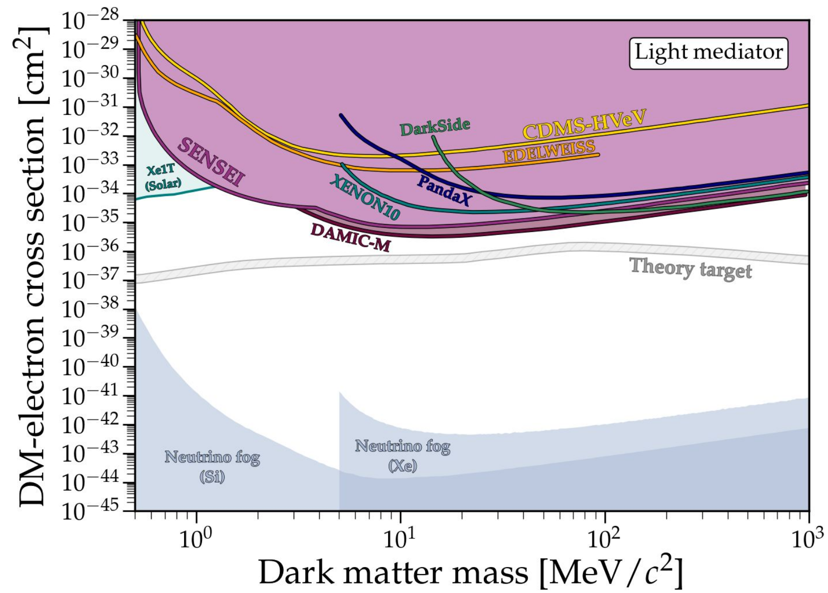
- **From skipper CCDs:**

DAMIC@SNOWLAB
SENSEI (2023) *arXiv:2312.13342*
SENSEI (2024) *arXiv:2410.18716*
DAMIC-M

- **From noble liquids:**

DarkSide-50
XENON1T
Panda-X
XENONnT
LZ

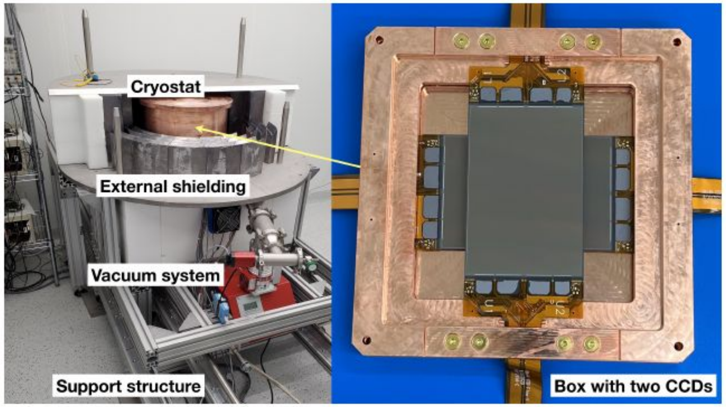




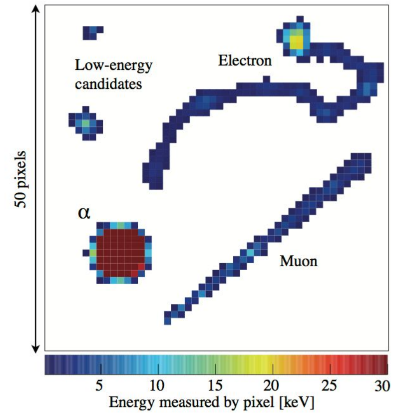
Dark Matter with Skipper-CCDs

Main idea : ultralow-noise electronics in combination with repetitive, nondestructive readout of a thick, fully depleted charge-coupled device (CCD)

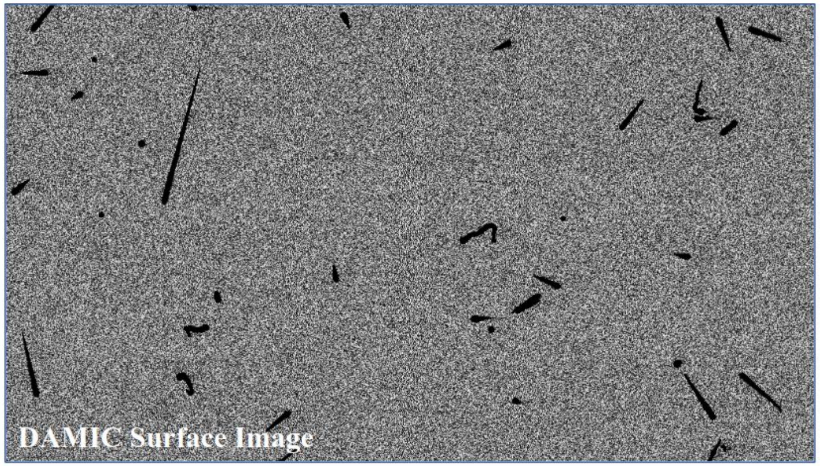
Three detectors : SENSEI, DAMIC @ SNOWLAB, DAMIC-M

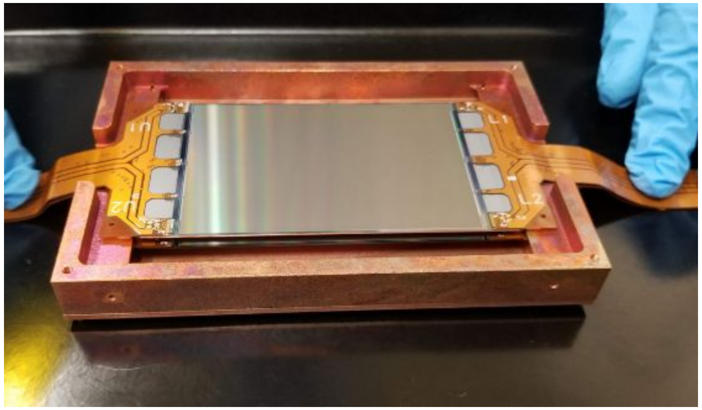


DAMIC-M

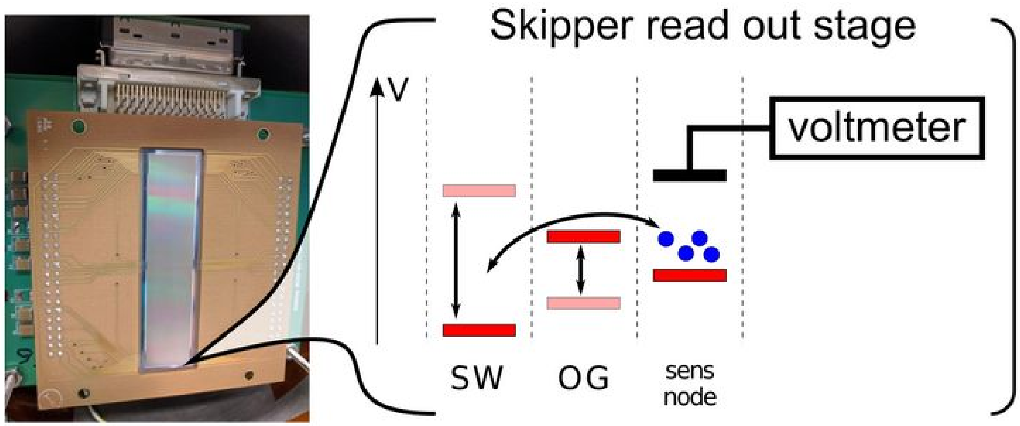


Particle ID



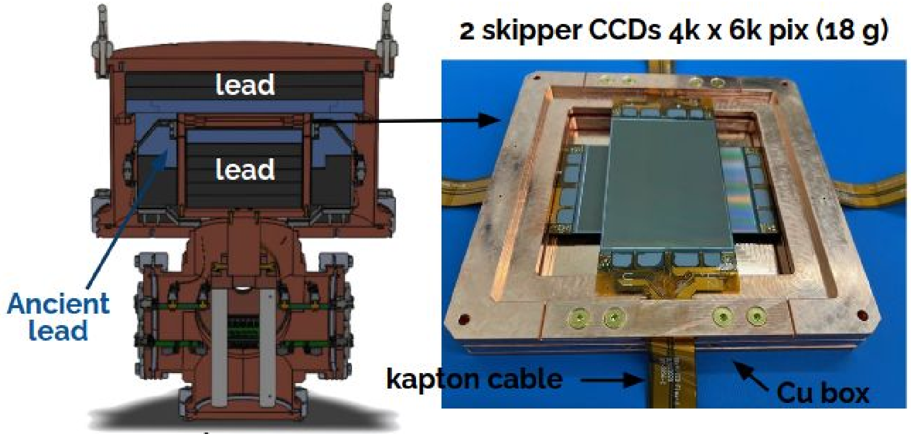


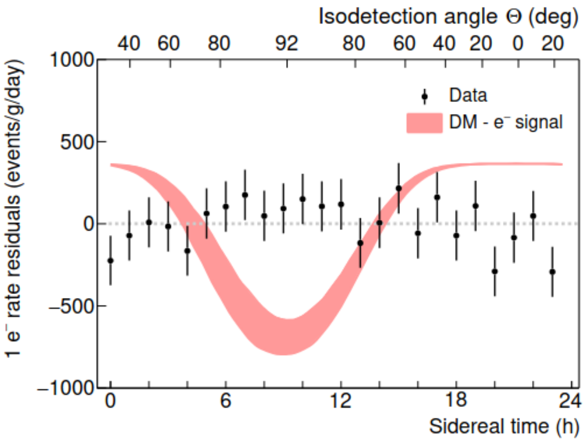
DAMIC @ SNOWLAB



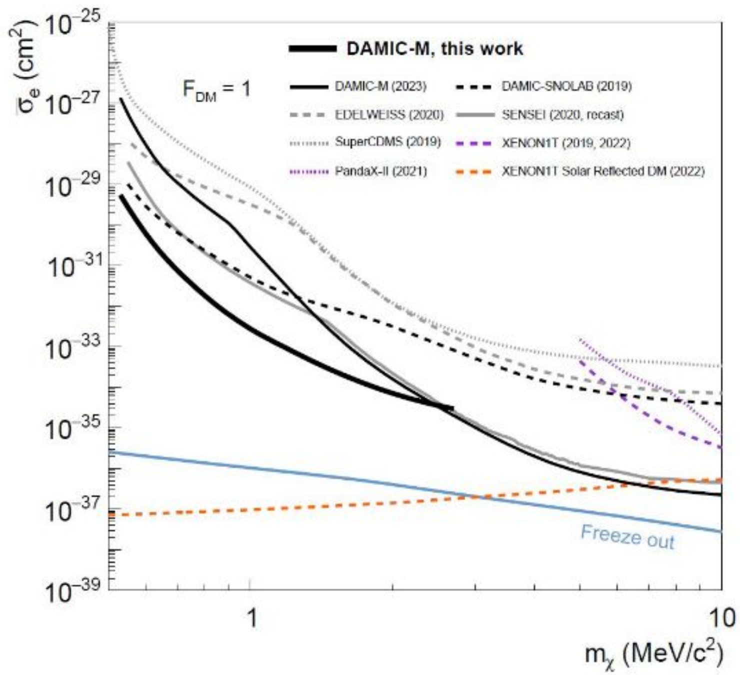
SENSEI

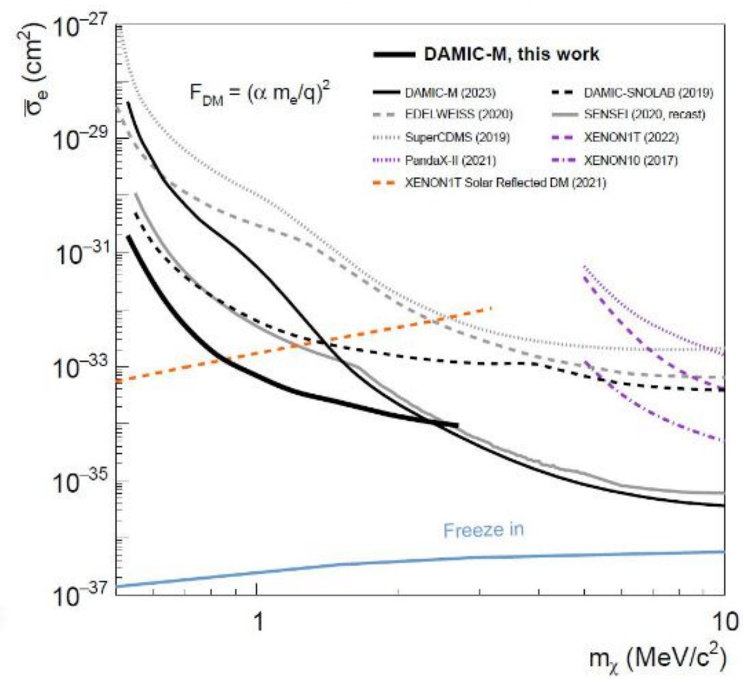
DAMIC-M Low Background Chamber
+ daily modulation analysis





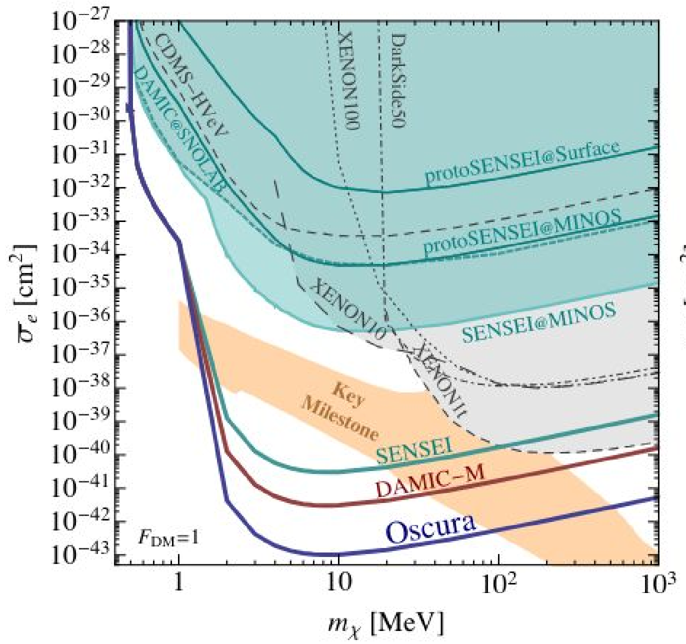
Daily modulation (due to interactions in the Earth) analysis improves up to ~2 orders of magnitude their analysis with the same dataset

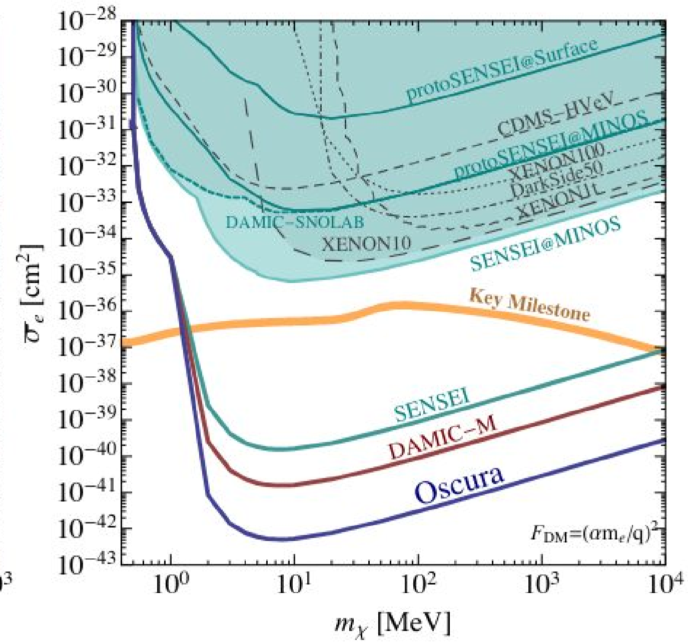




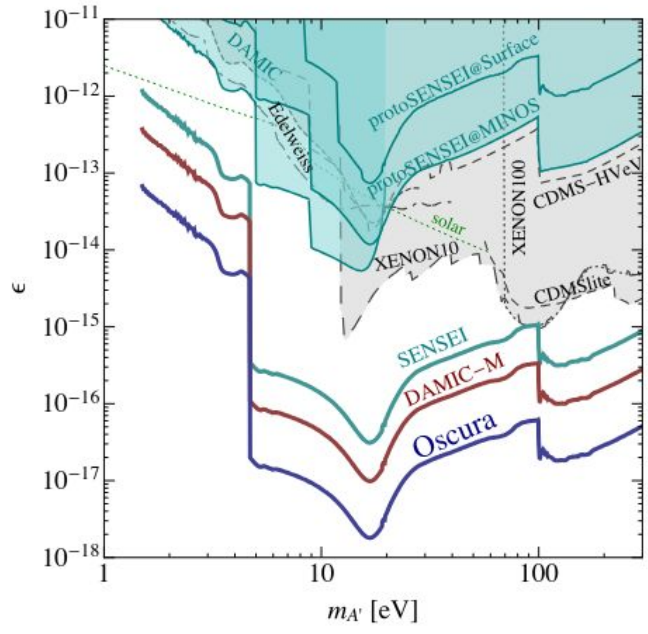
Next generation experiments : Skipper-CCDs

DM-electron scattering



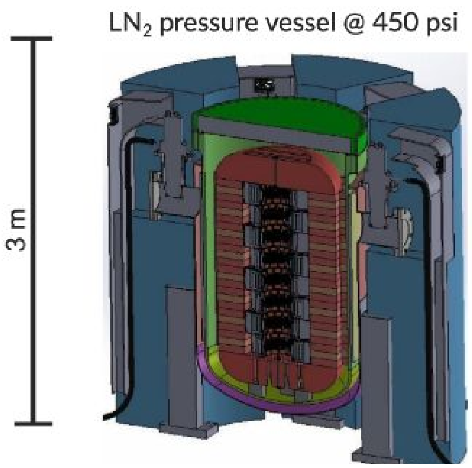


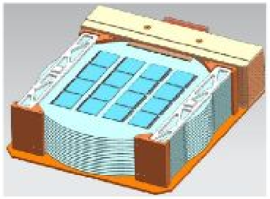
Dark photons



Skipper-CCD is now a well estabilished technology

To gain sensitivity it needs to
- Increase target mass
  - Silicium thickness
  - High number of devices
- Improve background





	SENSEI	DAMIC-M	Oscura
n. of CCDs	50	200	20000
mass (kg)	0.1	1	10
bkg (dru)	10	0.1	0.01
Lab	SNOLAB	LSM	SNOLAB (likely)

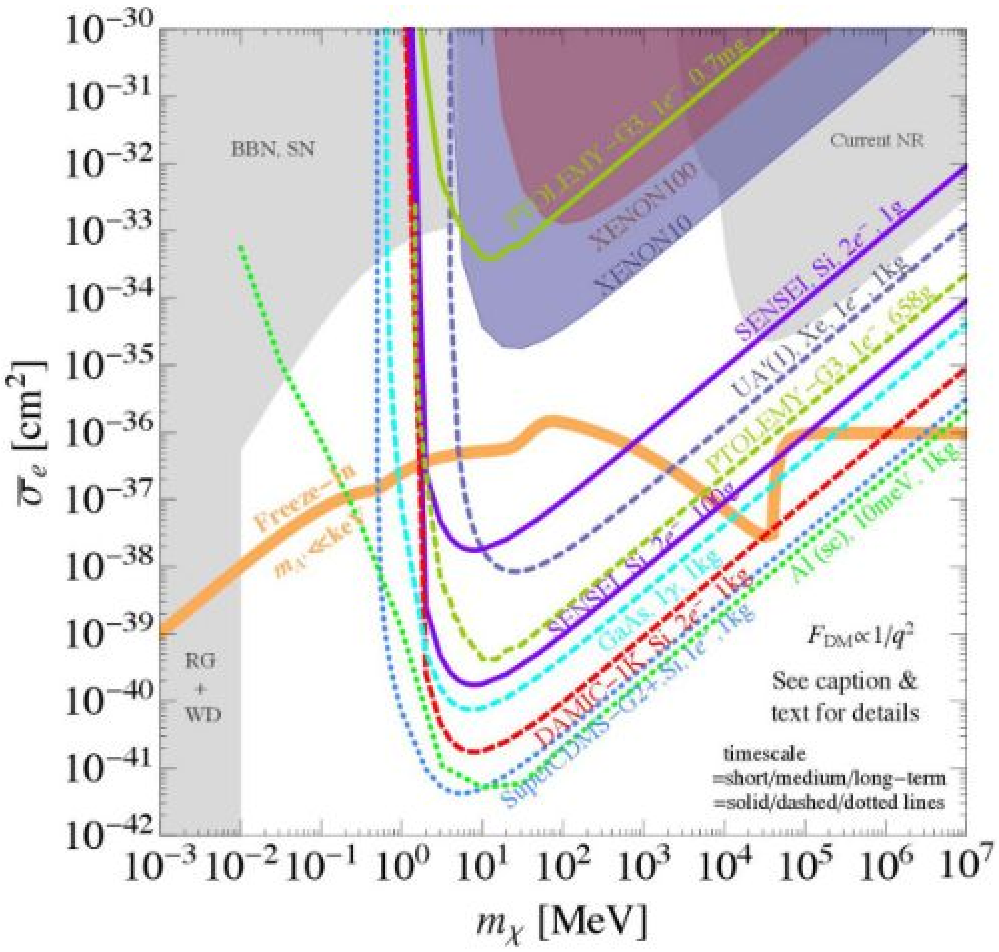
OSCURA merges the expertise from the two collaborations DAMIC and SENSEI

The OSCURA experiment : *arXiv:2202.10518v2*

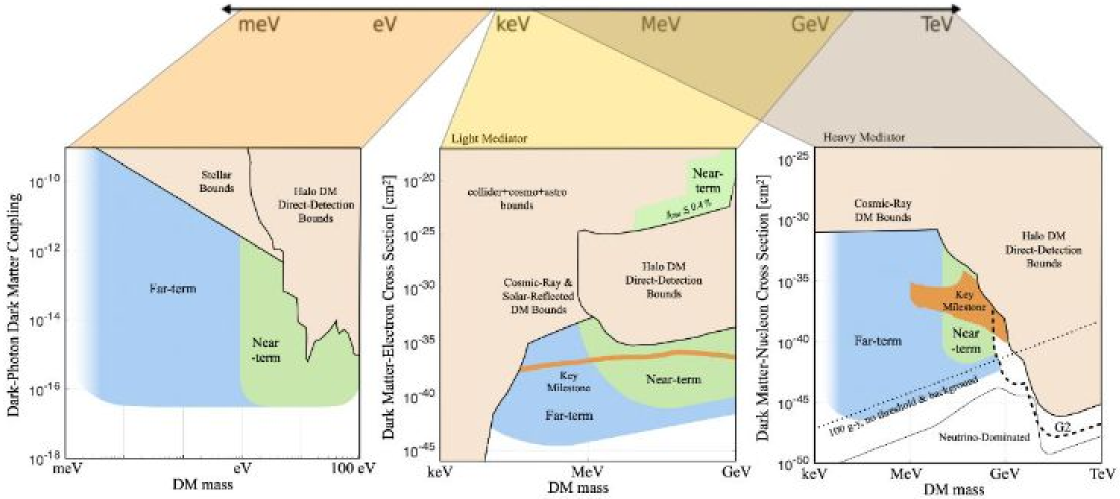
Very light Dark Matter

Very light dark matter with phonons

- TES-based Crystal Detectors
  - TESSERACT (SPICE)
- Superfluid Helium Detectors
  - TESSERACT (HeRALD)
  - DELight (using Magnetic Micro Calorimeters)
- MKID-based Detectors
  - BULLKID
- Superconducting Qubit Sensors
  - Cosmic Quantum (CosmiQ) at FNAL
  - SQUATs



Very light dark matter with phonons : Tesseract

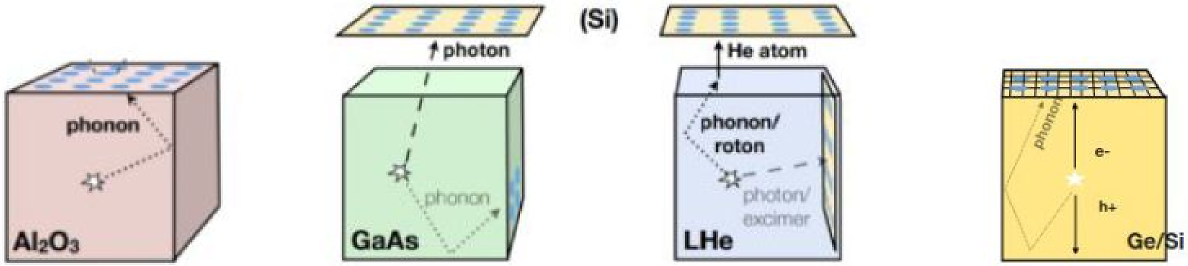


ER : 100 meV – MeV
No PID, SP

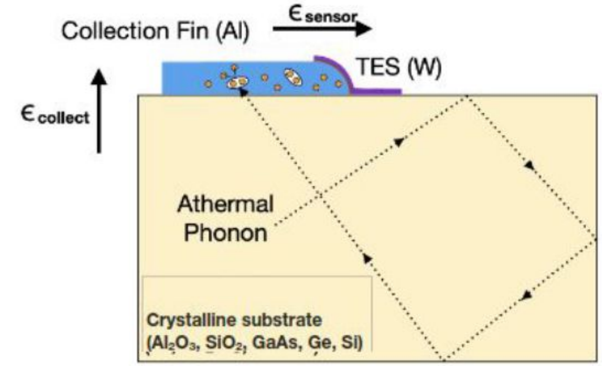
ER : eV – MeV
NR : MeV - GeV
PID : photon - phonon

NR : MeV - GeV
PID : PSD

NR : 100 MeV – 10 GeV
PID : PSD



SPICE (Al_2O_3 and GaAs) HeRALD (LHe) TES4DM (Ge/Si)



$$\sigma_E \sim \frac{\sqrt{4 k_b T_c^2 G(\tau_{collect} + \tau_{sensor})}}{\epsilon_{collect}\epsilon_{sensor}}$$

$$\sigma_E \propto V_{det}^{1/2} T_c^3$$

Energy threshold decreases with detector mass

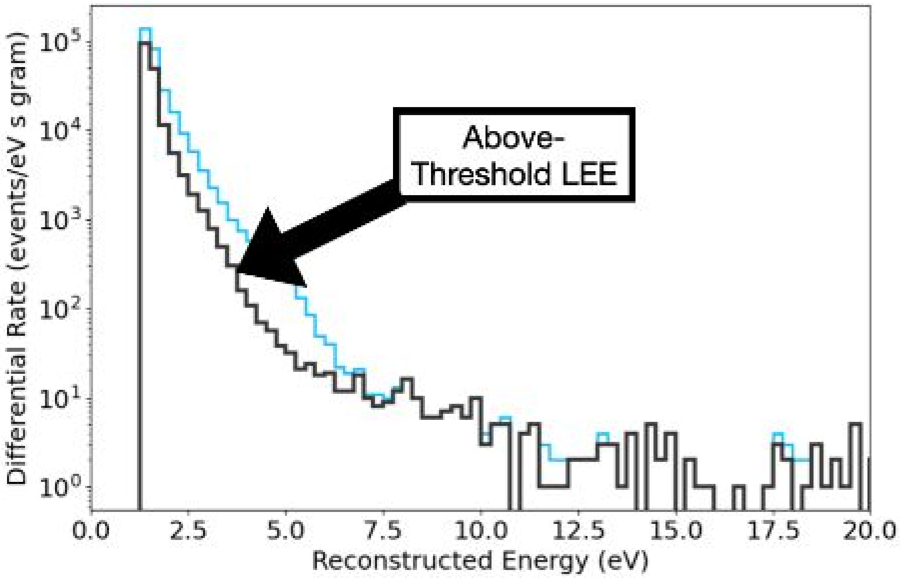
Energy threshold decreases very quickly with Tc

Low-E excess in cryogenics experiments

Observation of a strong Low Energy Excess (LEE) of events in ALL low-threshold cryogenic experiments limiting their DM sensitivity

The LEE is both :

- the largely dominating background at the lowest energies
- limiting the phonon baseline energy resolution



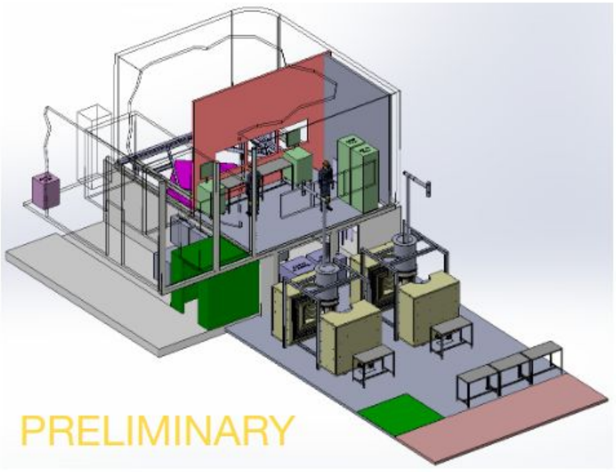
TESSERACT @ LSM : timeline

TESSERACT moved to the Project phase

Multiple target materials allow for exploration of different types of interactions and dark matter particle masses

Multiple signal channels and coincidence-based background rejection to reject backgrounds, especially the LEE

Moving to Modane in 2028 for low-background searches starting in 2029



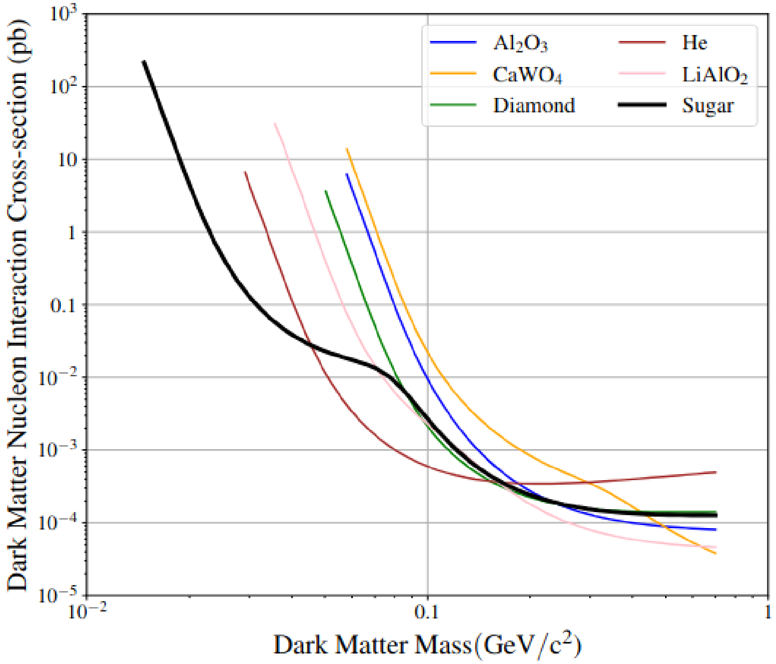
What about sugar ?

SWEET Project :

- Hydrogen, given its light mass, is theoretically the best target for light Dark Matter search
- Organic compounds are rich of Hydrogen
- Phonon detection using sucrose crystals ($C_{12}H_{22}O_{11}$)
- Preprint : *arXiv:2510.00068*

The SWEET project: probing sugar crystals for direct dark matter searches

A. Bento*†, F. Casadei*, E. Cipelli*, S. Di Lorenzo*, F. Dominsky*§, P. V. Guillaumon*‡¶, D. Hauff*, A. Langenkämper*, M. Mancuso*, B. Mauri*‖, C. Moore***, F. Petricca*, F. Pröbst*, M. Zanirato*
*Max-Planck-Institut für Physik, D-85748 Garching, Germany
†LIBPhys-UC, Departamento de Fisica, Universidade de Coimbra, P3004 516 Coimbra, Portugal
‡Instituto de Física da Universidade de São Paulo, São Paulo 05508-090, Brazil
Email: §dominsky@mpp.mpg.de, ¶pedro.guillaumon@mpp.mpg.de, ‖bmauri@mpp.mpg.de **moore@mpp.mpg.de



Axions

Axions, coupling to the photon

Haloscopes :

- Lumped element + LC
  - m_a ~ O(10 peV - 100 eV)
  - ν ~ O(MHz)

ABRACADABRA, **DMRadio**

- Microwave cavities
  - m_a ~ O(10 µeV)
  - ν ~ O(GHz)

ADMX, HAYSTAC, CAPP, GrAHal, ORGAN, QUAX, CAST-CAPP, RADES

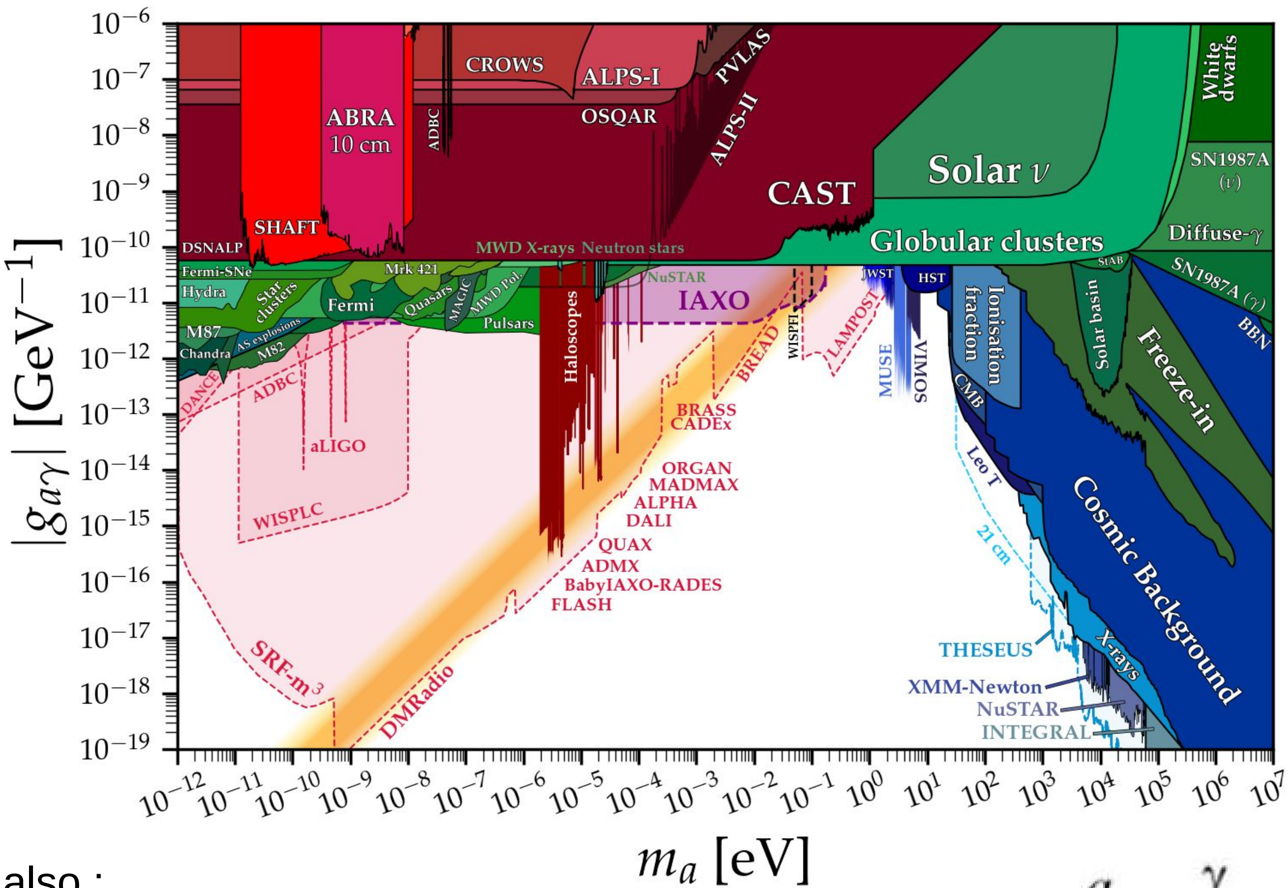
- Dielectric
  - m_a ~ O(100 µeV)
  - ν ~ O(10-100 GHz)

BREAD, BRASS
MADMAX

- Plasma
  - m_a O(100 µeV)
  - ν ~ O(10-100 GHz)

ALPHA

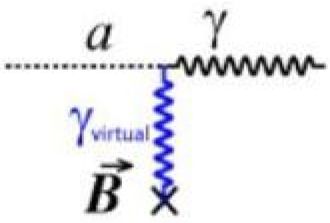
The phenomenology mostly based on the axion coupling with photons



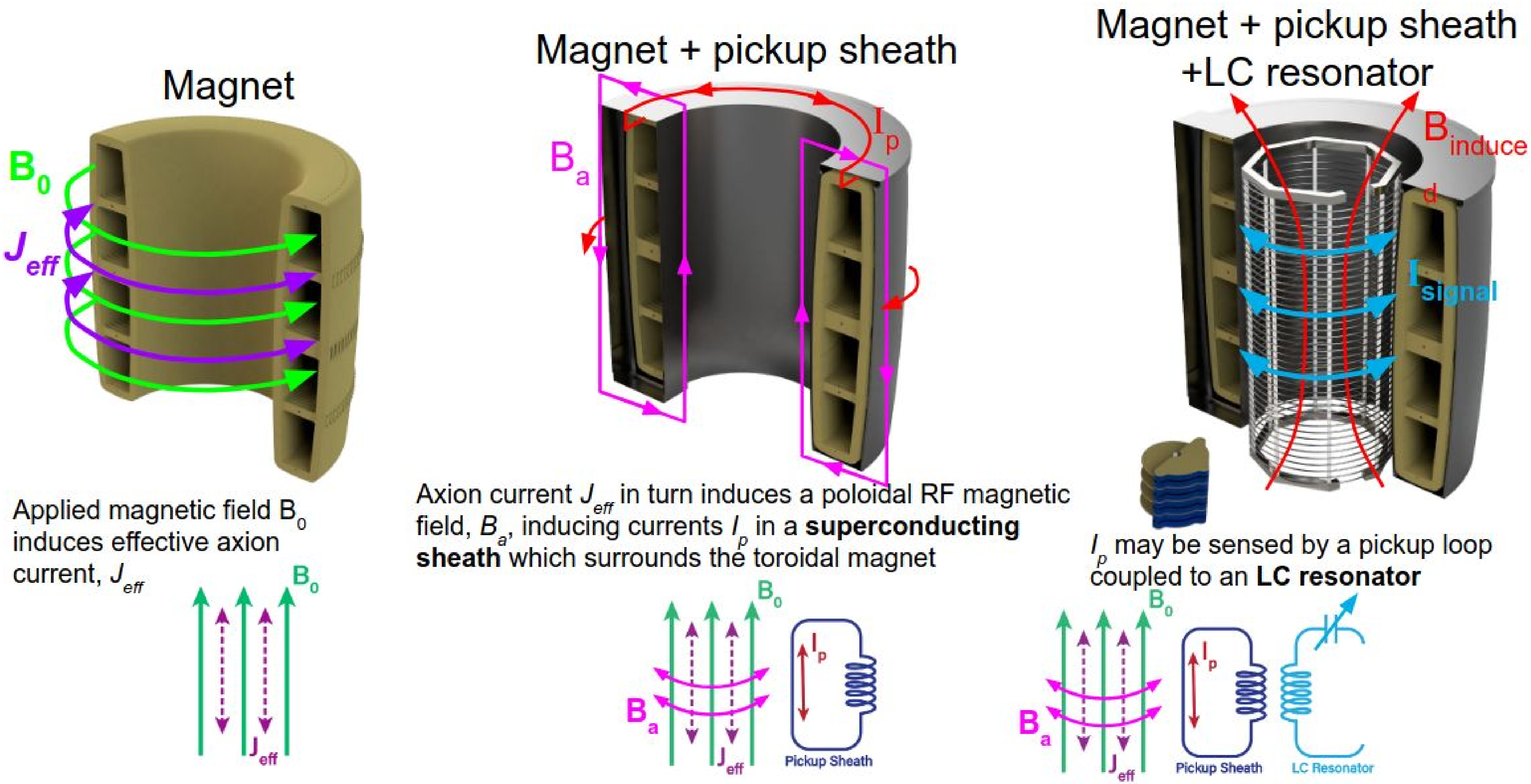
Plot from https://cajohare.github.io/AxionLimits/

But also :

- Light-shining-through-wall (ALPS)
- Helioscopes (CAST)

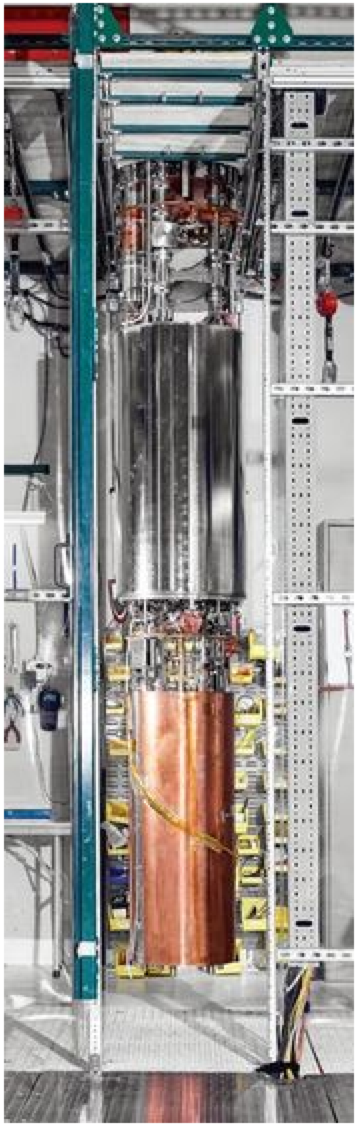


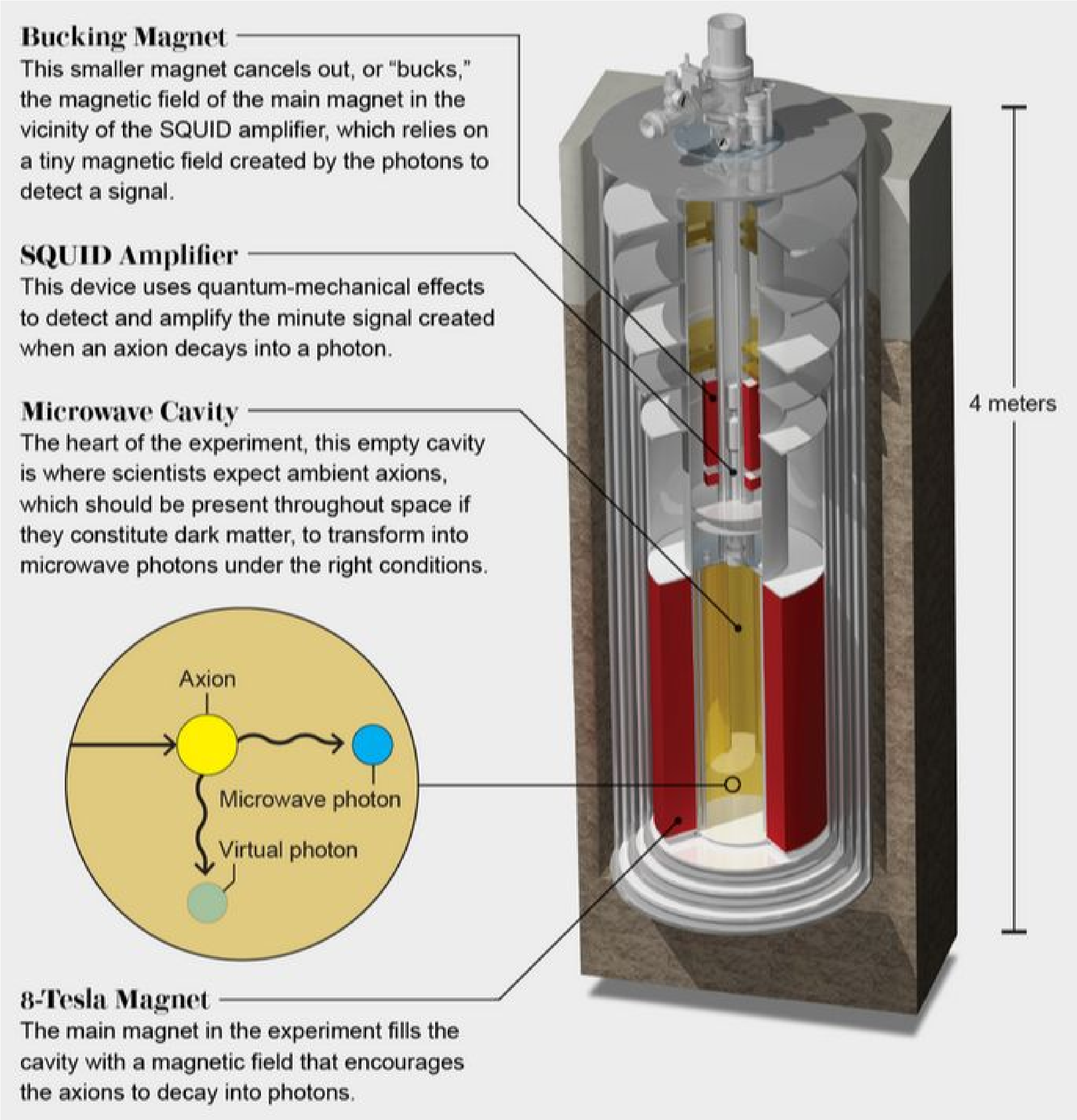
Example of lumped element detection : DMRadio



Alex Droster, IDM 2024

Example of cavity haloscope : ADMX



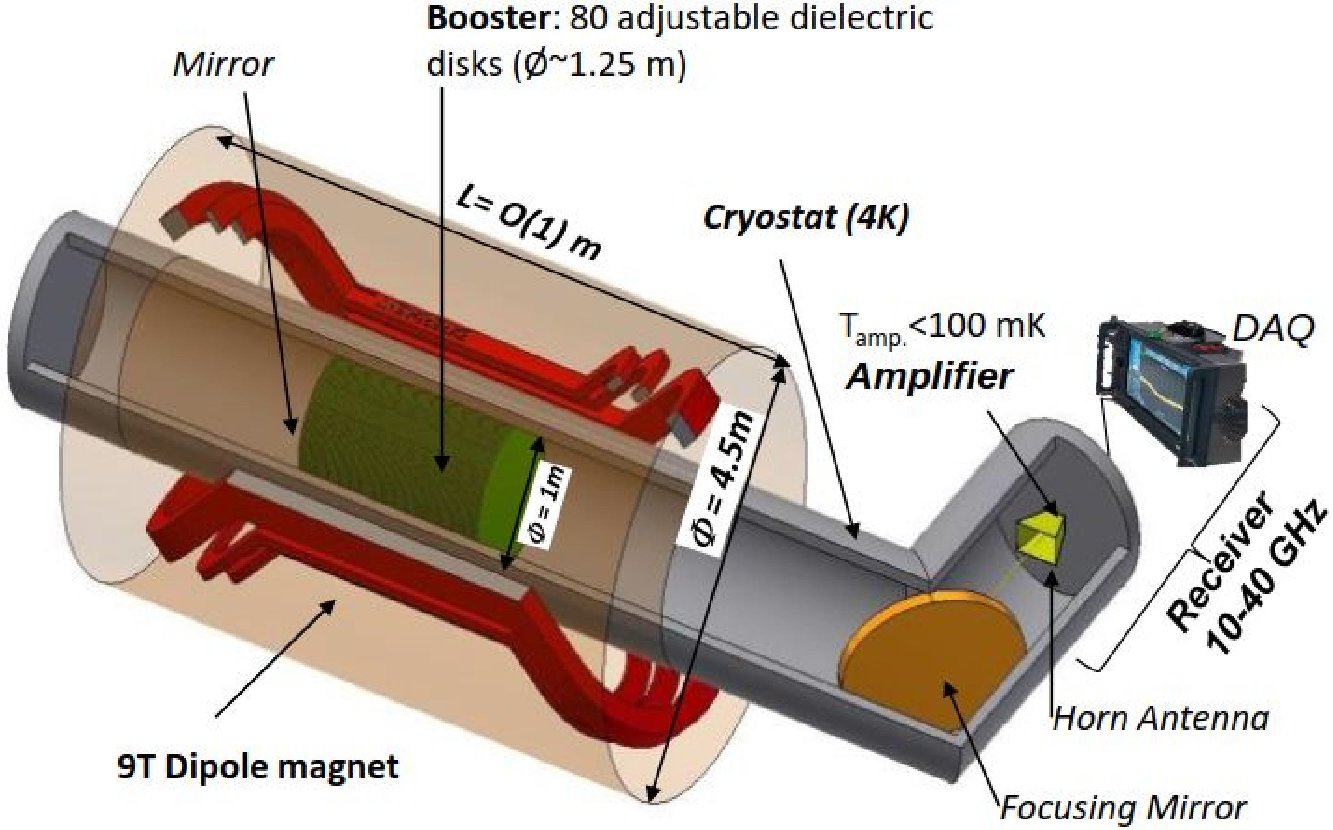


Example of dielectric haloscope : MadMax

- Constructive interference of coherent photons emitted at the disk surface + resonant enhancement (~leaky resonator cavities) : boost factor β^2 wrt mirror only
- Axion mass scan: by moving discs with piezo motors (µm precision) at 4K under 10 T

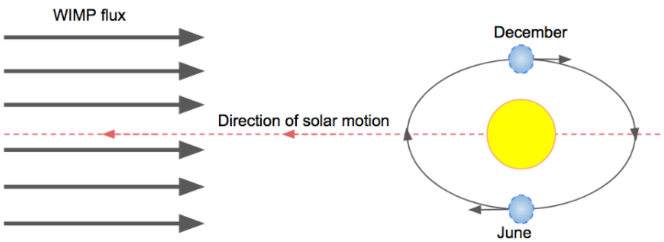
$$P_{sig} = 10^{-22}\ \mathrm{W} \times \left(\frac{\beta^2}{50000}\right) \times \left(\frac{B_e}{10\ \mathrm{T}}\right)^2 \times \left(\frac{A}{1\ \mathrm{m}^2}\right) \times C_{a\gamma}^2$$

$$|C_{a\gamma}| = \left(\frac{|g_{a\gamma}|}{2\times 10^{-14}\ \mathrm{GeV}^{-1}}\right)\left(\frac{100\ \mu\mathrm{eV}}{m_a}\right)$$



Scoping DAMA results

Annual Modulation and DAMA experiment



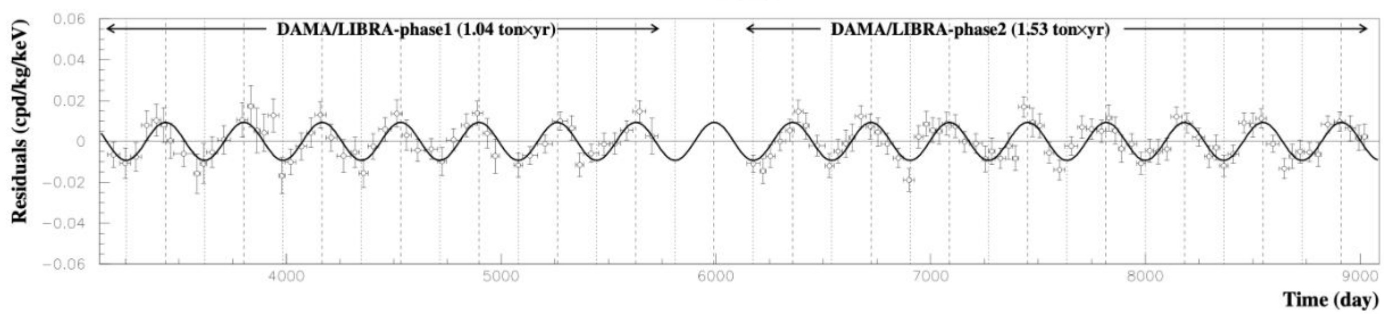
DM Rate

$$R(E) = R_0(E) + R_m(E)\cos(\omega(t - t_0))$$

Non-Modulating DM rate

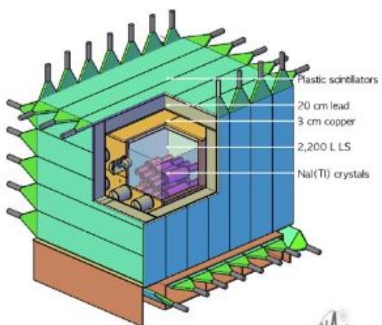
Modulating DM rate

R. Bernabei et al., Annual Modulation results from DAMA/LIBRA, 2023



The DAMA/LIBRA Experiment has been running for 20+ years

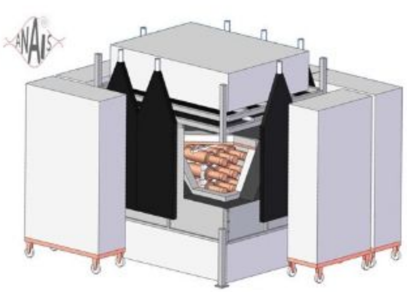
- Located at **LNGS**
- Total mass **250 kg of NaI(Tl)**
- Observed **~0.01 cpd/kg/keV** modulation in the 1-6 keV (second phase) energy range
- **12.9 σ** significance



COSINE-100

100 kg NaI(Tl)

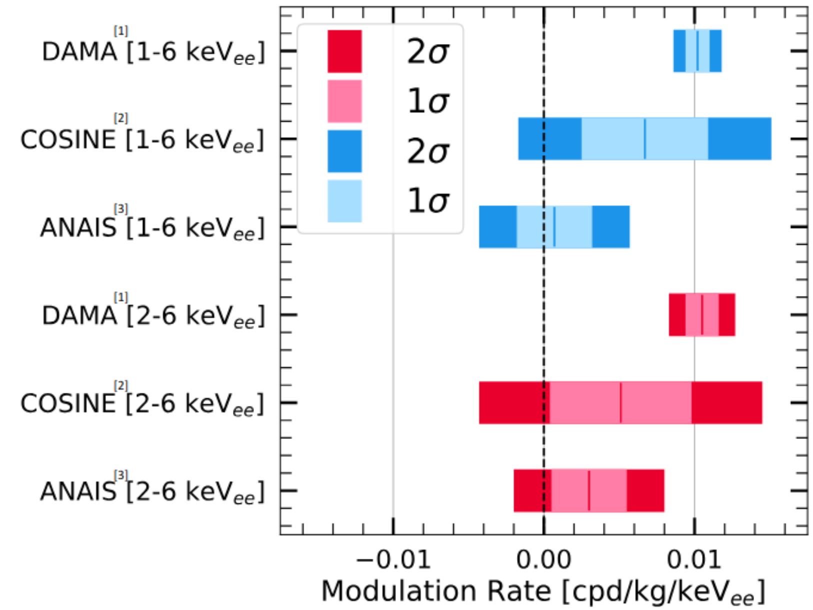
Yang Yang National Laboratory, South Korea



ANAIS-112

112 kg NaI(Tl)

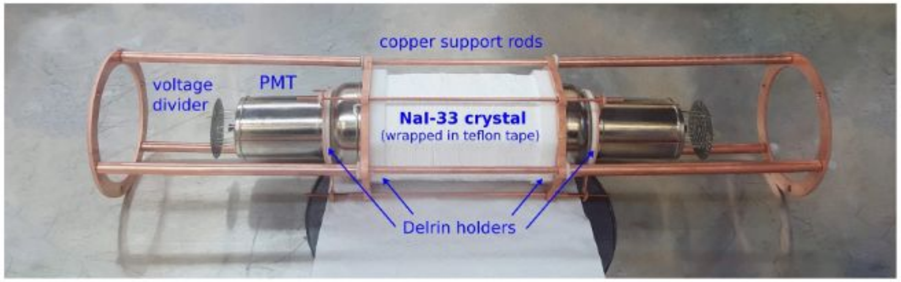
Canfranc national laboratory, Spain



Material : courtesy of Owen Stanley, Melbourne, talk given at GDR DUPhy, Lyon

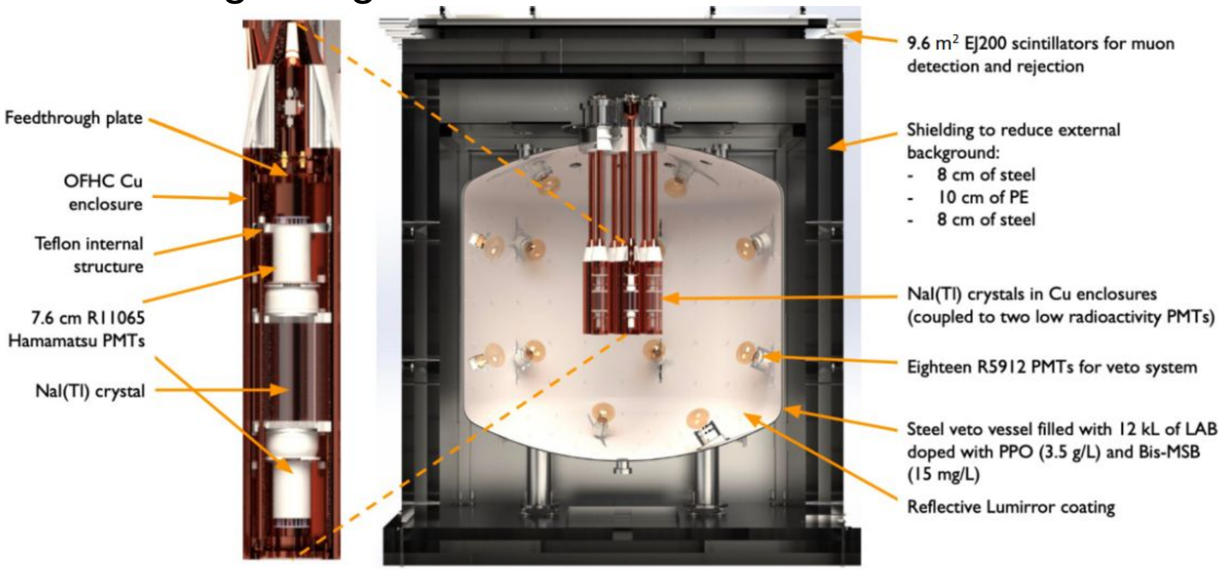
Next generation experiments : DAMA verification
(or exclusion)

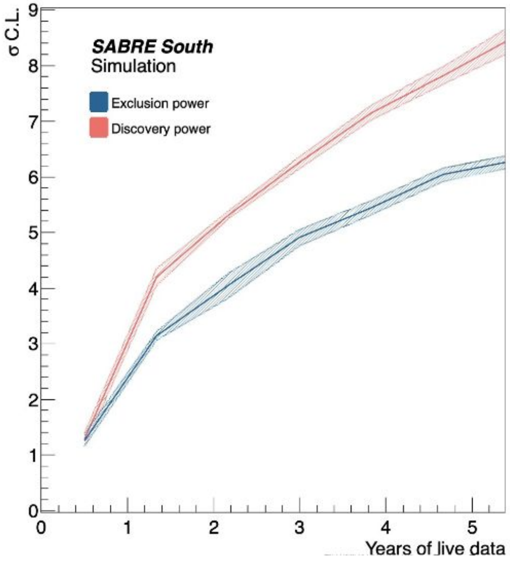
- Using same core detection technology as in DAMA (NaI)
- Two detectors in the two hemispheres :
  - SABRE-North (LNGS) same environment of DAMA
  - SABRE-South (SUPL)



Many **common** points :
- Same crystal growth powder and crystal PMTs
- Same DAQ and software frameworks
- Exchange of engineering knowledge

However, **different** in :
- Shielding design





Material : courtesy of Owen Stanley, Melbourne, talk given at GDR DUPhy, Lyon

Concluding comments

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

A plethora of experiments is hunting Dark Matter using any **mass range** and any **physics model** experimentally accessible

High **complementarity** of different techniques.

For WIMPs**, neutrino floor** has been already « touched » (XENONnT CEvNS @ ^{8}B)

Experiments put significant **pressure on WIMP model** but WIMPs are not yet ruled out

During **next decade** we will withness the approaching to the neutrino floor everywhere from m=1GeV (discovery or end of experimentally accessible WIMP paradigm?)

We will also withness novel **emerging techniques** designed specifically for alternative models (light dark matter)

Thank you