

TESSERACT

TESSERACT @LSM

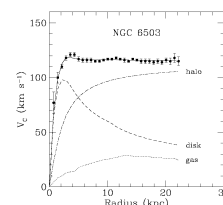
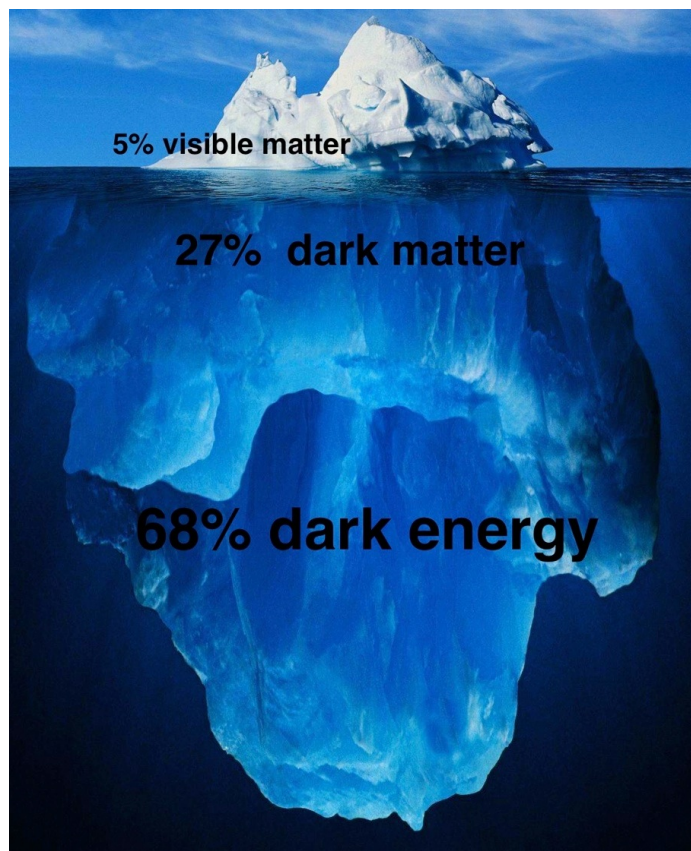
A proposal for a new generation light dark matter search cryogenic experiment underground in Modane

S. Scorza (LPSC)
on Behalf of the Neutrino team

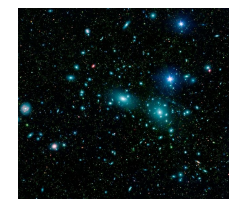


LPSC - CS 30.05.2024





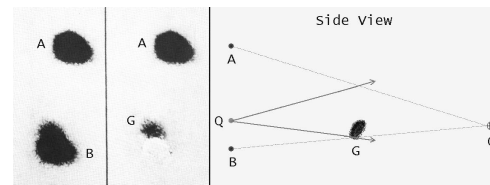
Rotation Curves



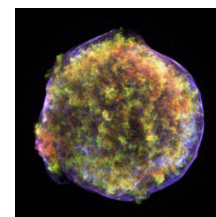
Motion of Galaxies
in Clusters



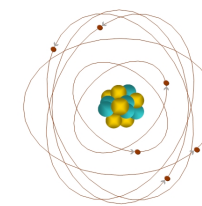
Galaxy
clusters



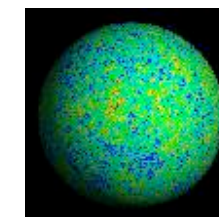
Gravitational Lensing



Supernovae Ia



Big Bang
nucleosynthesis



Microwave
background

- **Low** and **controlled** backgrounds

- **Discrimination** between signal and background

Simultaneous measurements of two signals allows ER/NR discrimination on an event-by-event basis

Detector technology background rejection and fiducialization

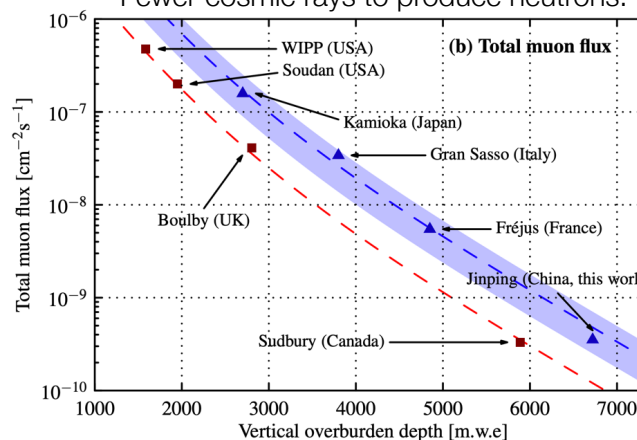
- **Large exposure** (*few events per ton-year*)

- Low energy threshold

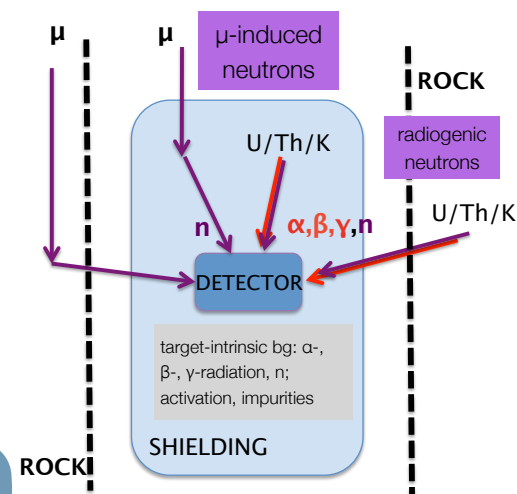
Background limit:
neutrino-nucleus scattering (solar, atmospheric and supernovae neutrinos)

Go deep **underground**

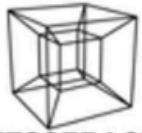
Fewer cosmic rays to produce neutrons.



Material screening and assay
Cleaning and purification techniques
Move underground detector fab and material purification



Passive/Active shielding
Reduce backgrounds from natural (^{238}U , ^{232}Th , ^{40}K) radioactivity



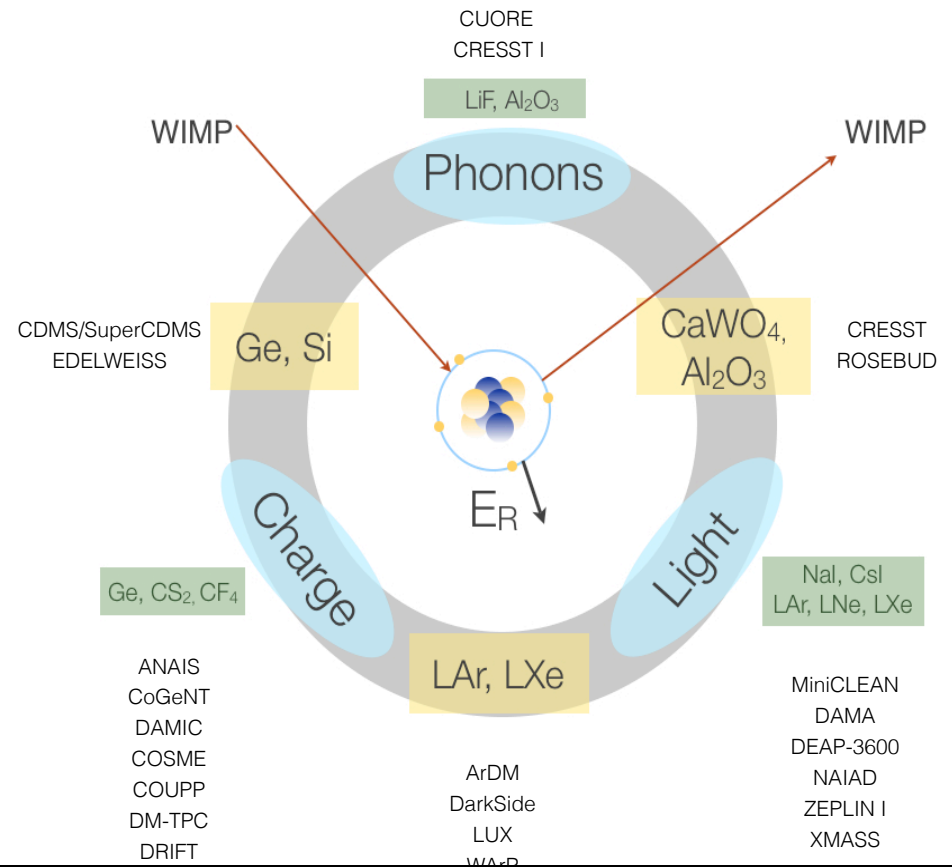
DDM Experiment Wishlist

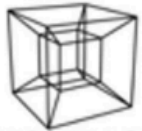
- **Low** and **controlled** backgrounds
- **Discrimination** between signal and background

Simultaneous measurements of two signals allows ER/NR discrimination on an event-by-event basis

Detector technology background rejection and fiducialization

- **Large exposure** (*few events per ton-year*)
- Low energy threshold





DDM Experiment Wishlist

- **Low** and **controlled** backgrounds
- **Discrimination** between signal and background

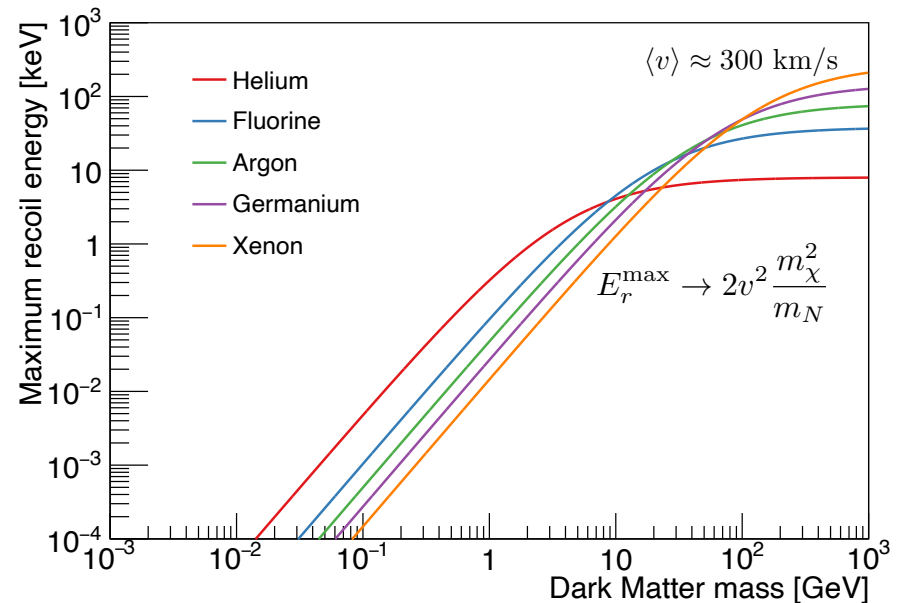
Simultaneous measurements of two signals allows EP/AR discrimination on an event-by-event basis



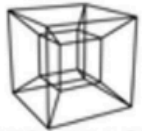
Detector technology for background rejection and fiducialization

- **Large exposure** (*few events per ton-year*)
- Low energy threshold

Transfer of DM kinetic energy inefficient when $M_h \gg M_{DM}$ for elastic scatters



Direct detection of Sub-100 MeV dark matter via nuclear recoil is nearly impossible!



DDM Experiment Wishlist

- **Low** and **controlled** backgrounds
- **Discrimination** between signal and background

Simultaneous measurements of two signals allows EP/AR discrimination on an event-by-event basis

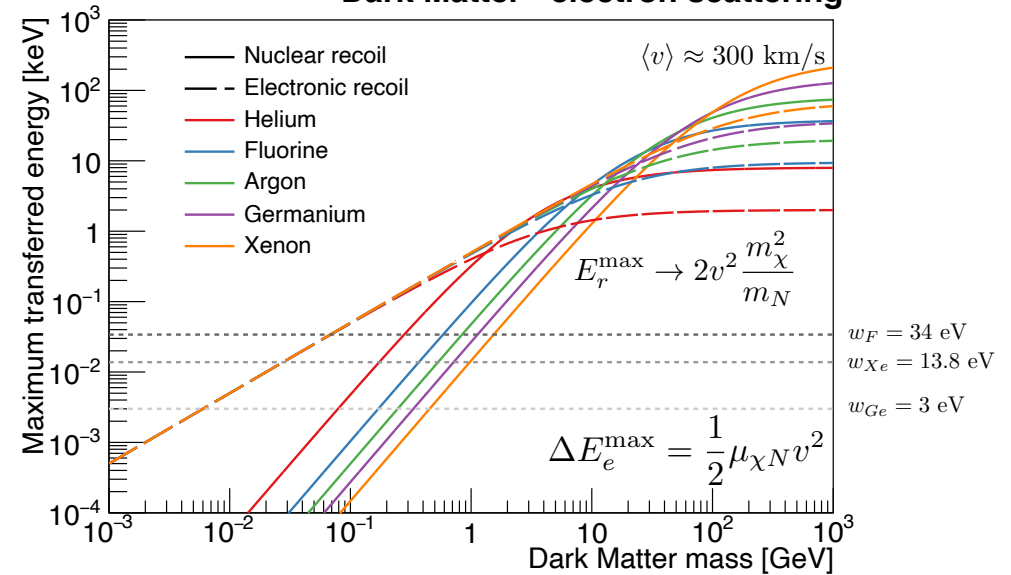


Detector technology for background rejection and fiducialization

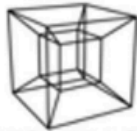
- **Large exposure** (*few events per ton-year*)
- Low energy threshold

Transfer of DM kinetic energy inefficient when $M_n \gg M_{DM}$ for elastic scatters

Dark Matter - electron scattering



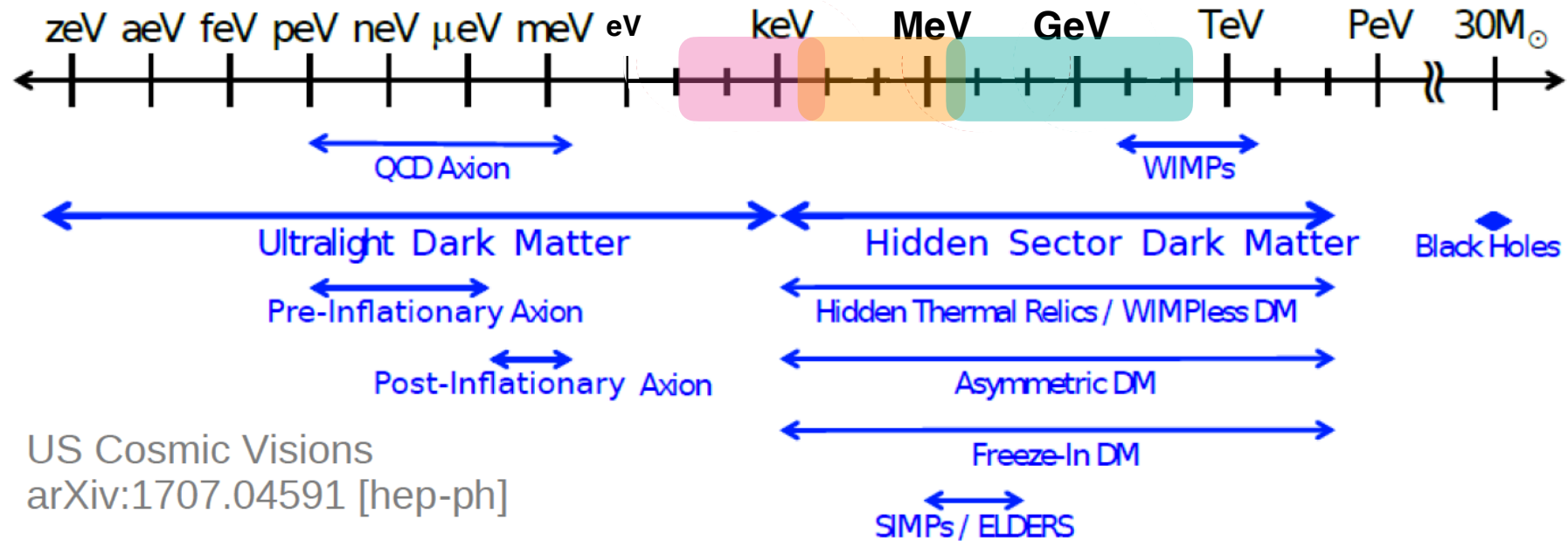
For DM masses below 100 MeV switch to DM-electron scattering searches



TESSERACT

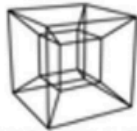
DDM Experiment Wishlist

DM-nucleus scattering (nuclear recoil)
 DM-electron scattering (electron recoil)
 Absorption (electron recoil)



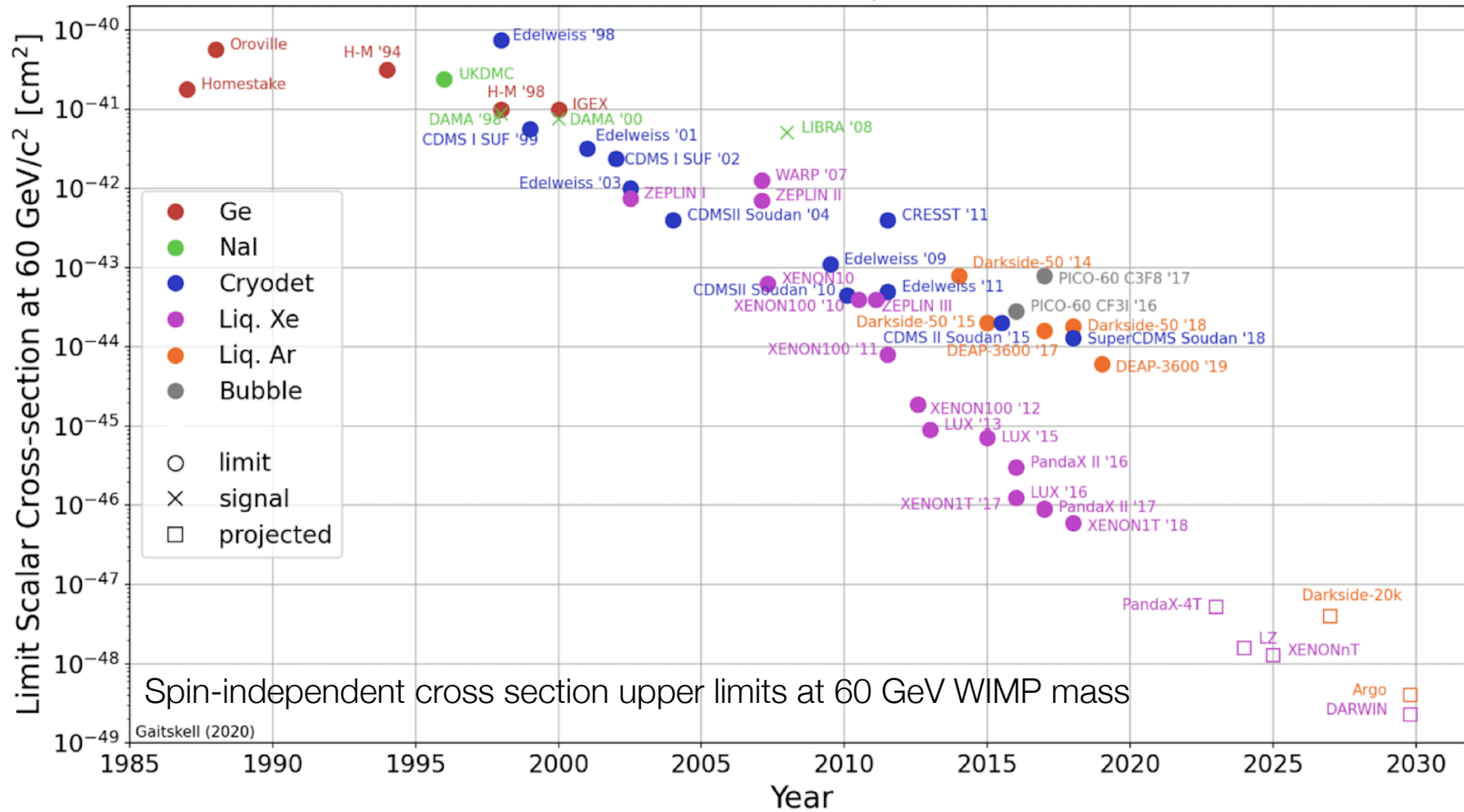
US Cosmic Visions
 arXiv:1707.04591 [hep-ph]

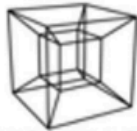




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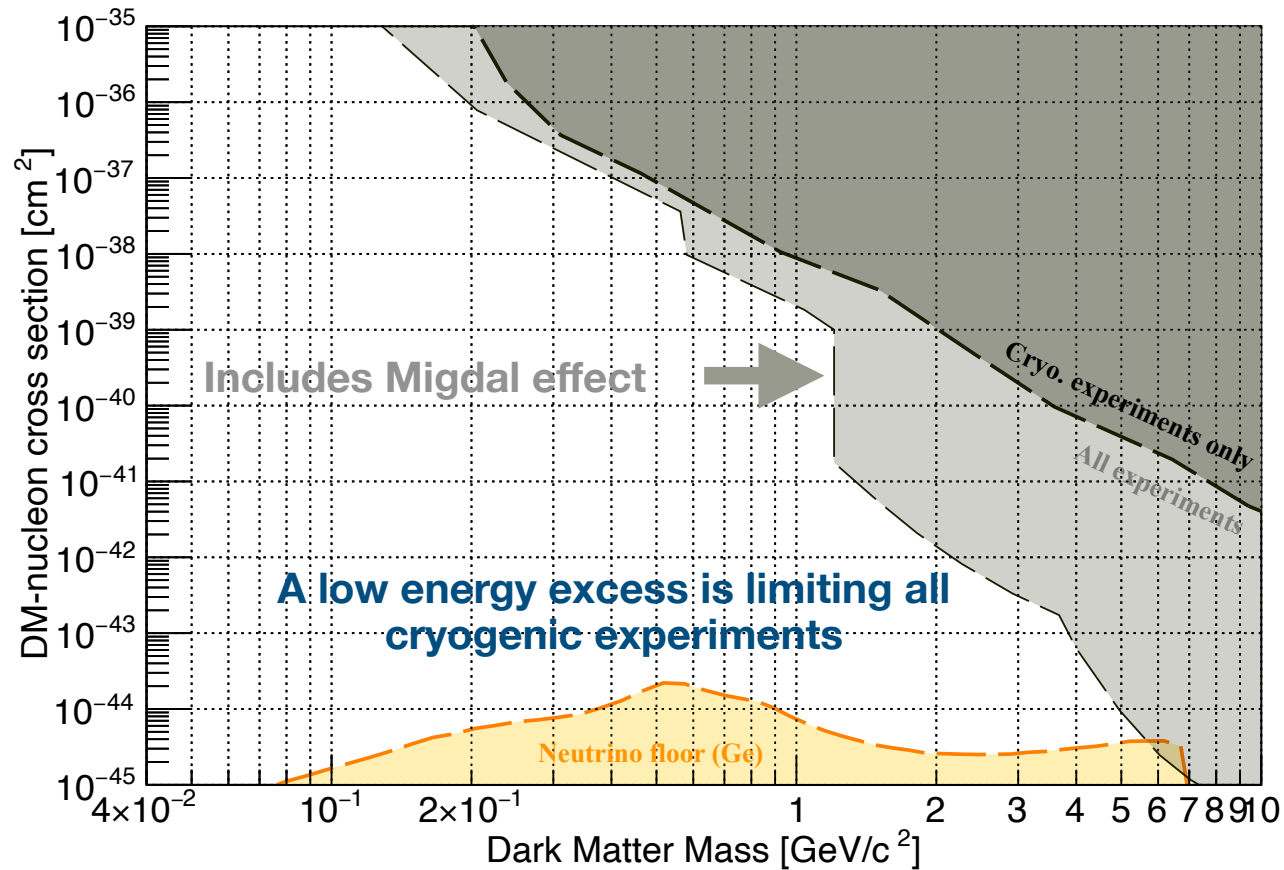
DDM Sensitivities





TESSERACT

Cryogenic DDM



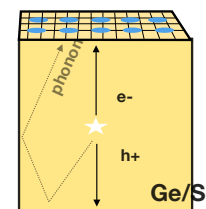
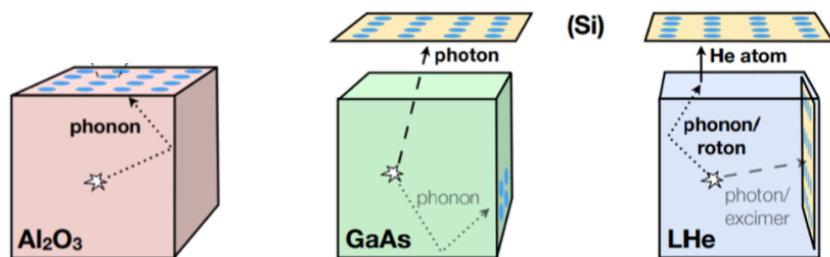
Why cryogenic DDM experiments aren't leading the sub-GeV search region ?

TESSERACT

[Transition Edge Sensors with Sub-Ev Resolution And Cryogenic Targets]
aims at extending the Dark Matter mass search window from meV-to-GeV with ultra low-threshold cryogenic detectors with multiple targets and particle identification capabilities



TESSERACT@LSM: Proposal Experiment at LSM



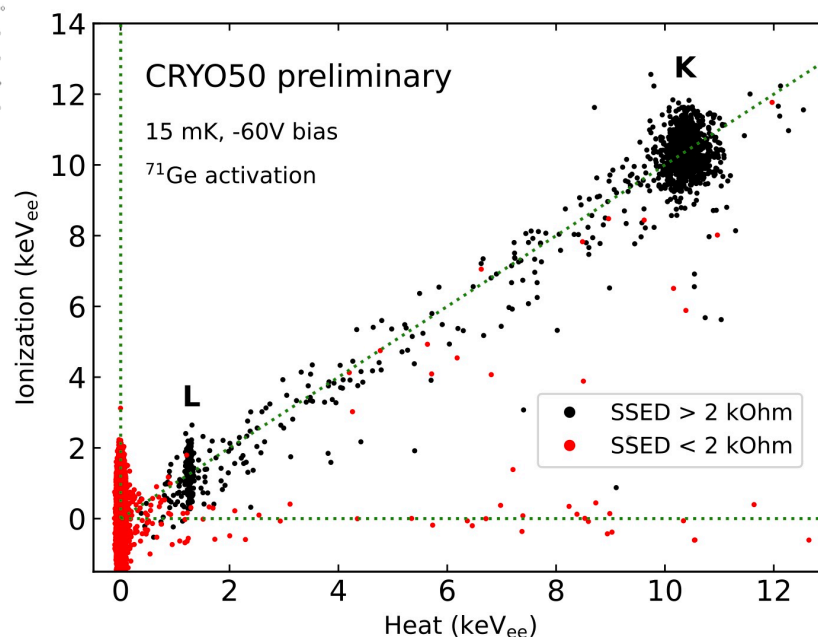
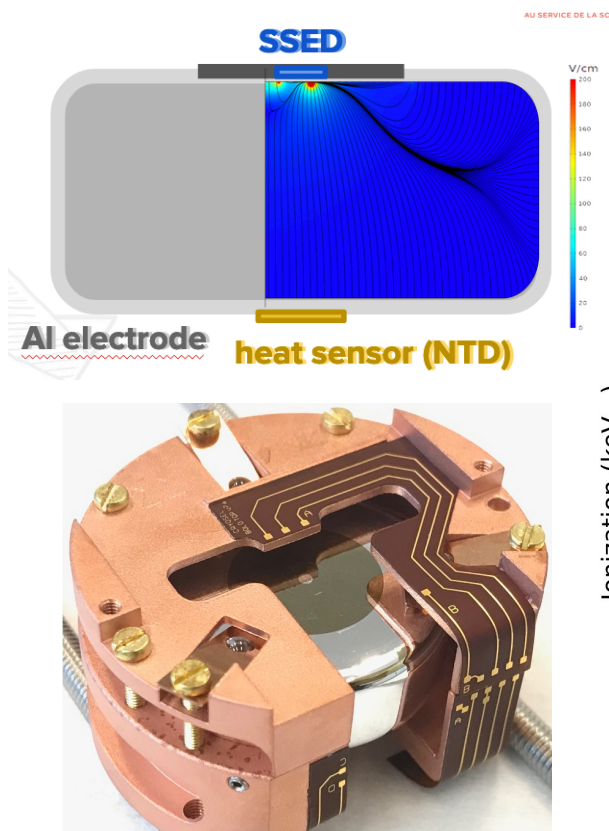
- DOE Funding for R&D and project development began in June 2020 (Dark Matter New Initiative)
- One experimental design, and different target materials with complementary DM sensitivity, all using TES (**Al₂O₃** and **GaAs, LHe**)

TESSERACT @LSM proposal:

1. Add the French semiconductor Ge bolometer technology to the TESSERACT science program
2. Deploy the future TESSERACT experiment at LSM



High-Voltage approach for optimal ERDM sensitivity



CRYOSEL performance goals: 200 V bias + single e-h sensitivity + SSED LEE tagging efficiency > 1000

First R&D results shown at TAUP2023:

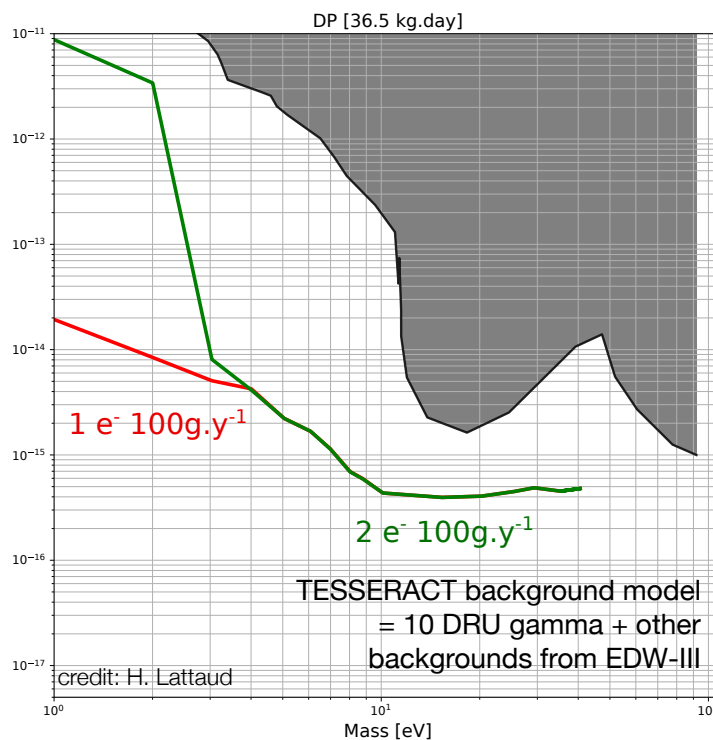
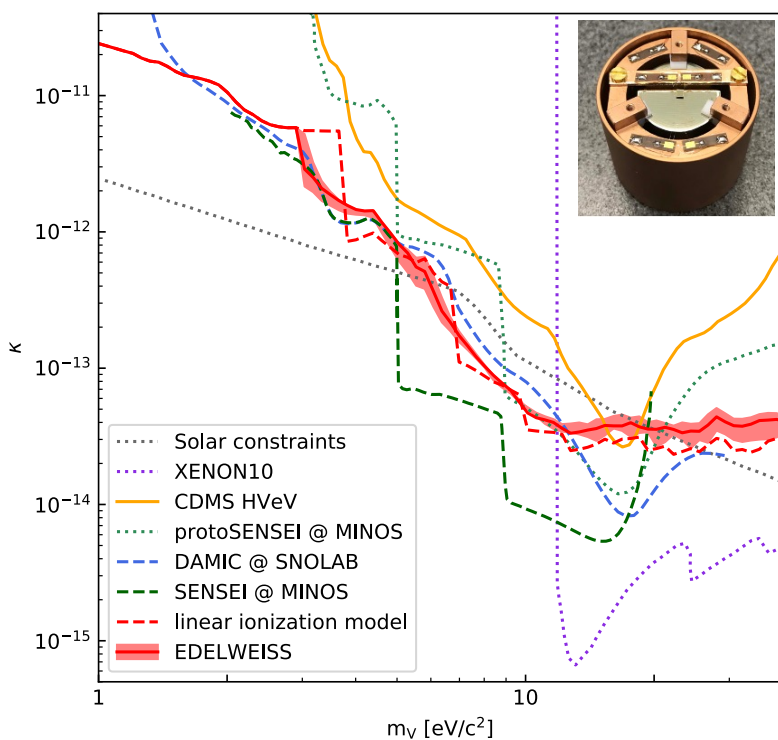
- Stable operation up to 60 V
- Confirmation that first NbSi SSED acts as efficient LEE veto
- New prototype currently being tested with significantly improved performance

For TESSERACT:

- Switch to low-imp. TES for sub-eV SSED energy threshold
- High control of IR backgrounds and charge leakage
- LEE discrimination down single e-h pair
- Exquisite sensitivities to ERDM with LEE discrimination

High-Voltage approach for optimal ERDM sensitivity

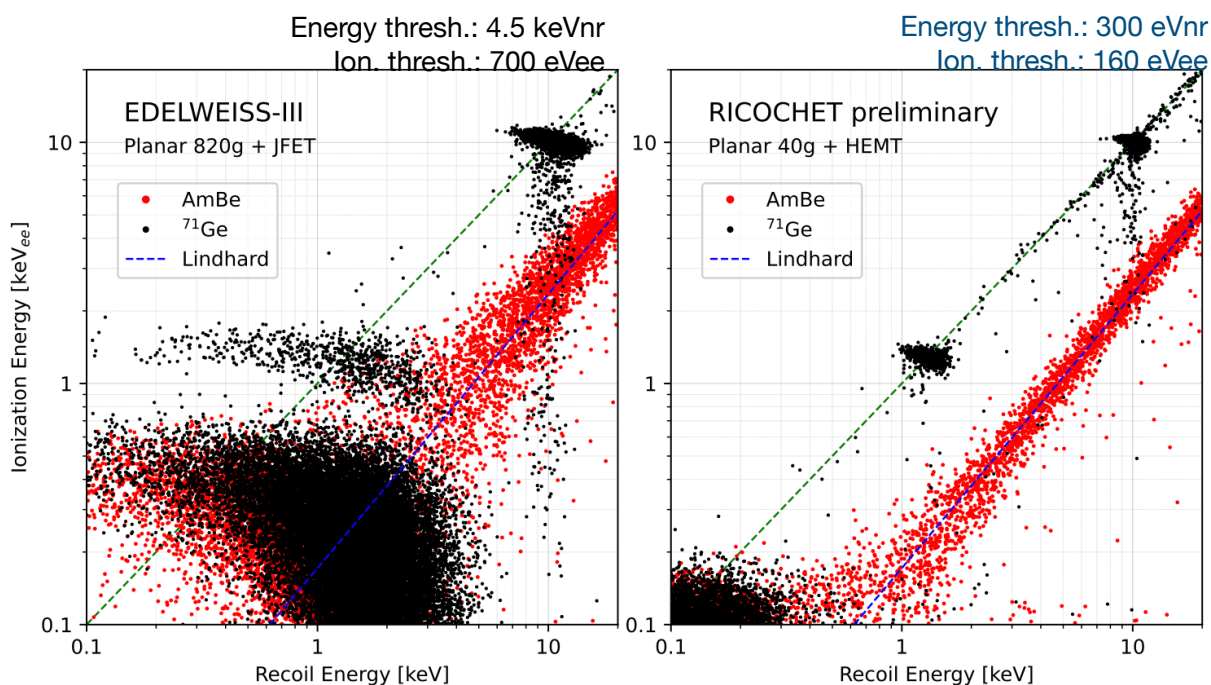
EDELWEISS collaboration, PRL 125, 141401 (2020)



In 2020 EDELWEISS-III achieved one of the best ERDM sensitivity with sub-electron energy resolution with a 33 g Ge crystal operated at 78V.

The HV technology (SSED + TES + 200V) in TESSERACT will allow to achieve orders of magnitude improved sensitivities

Low-Voltage approach for optimal NRDM sensitivity



- ER/NR discrimination threshold has been **improved by about one order of magnitude** w.r.t EDW and SuperCDMS
- Ricochet can now probe reactor neutrinos (CEvNS) and equiv. 3 GeV WIMP with highly efficient LEE and ER rejection

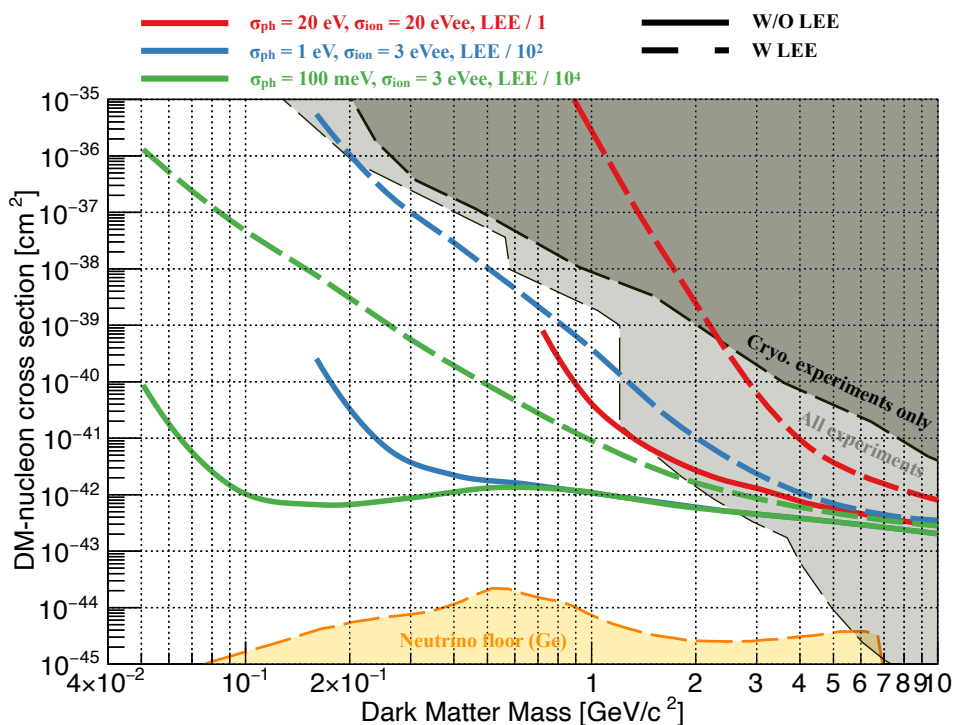
Ricochet resolution goals: 20 eV (heat) + 20 eVee (ionisation) - almost achieved (by a factor of ~2)

For TESSERACT:

- Switch to TES for sub-eV heat energy threshold and reduced LEE, and aiming for 3-6 eVee ion. resolution
- ER/NR identification down to 10s of eVnr + LEE discrimination down to 50 eVnr (Lindhard)
- Ideal for low-mass NRDM with PID

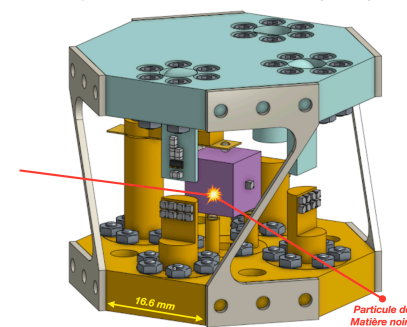
Presented at: TAUP2023, IDM2023, Nobel Symposium 2023 (NS-182 « Dark Matter »)

Low-Voltage approach for optimal NRDM sensitivity



TESSERACT background model = 10 DRU gamma + other backgrounds from EDW-III

credit: J. Colas (FRAMA and RI2 proposals)



The LV technology in TESSERACT will allow to vastly extend the NRDM searches down to 100 MeV with particle ID and LEE rejection in a region of the parameter space inaccessible to non-cryogenic experiments.

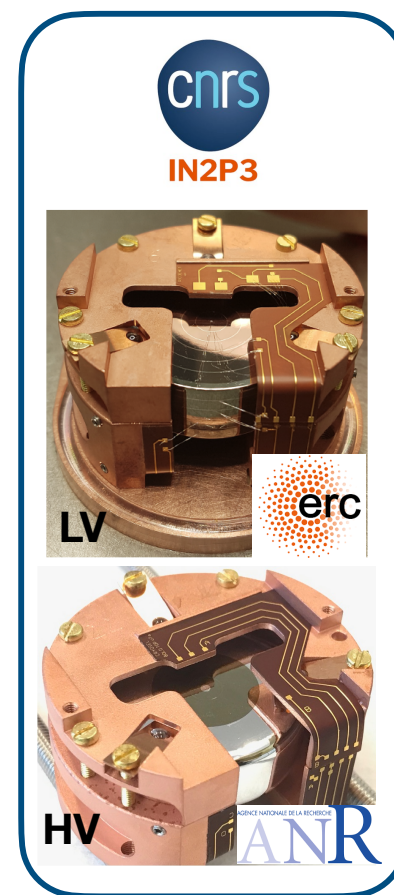


TESSERACT@LSM: Detector technology summary

All detector technologies will be featuring:

1. athermal phonon TES with sub-eV energy thresholds,
2. drastically mitigated LEE (under intense investigation),
3. payloads between 10g to 100g

	Target	Search type	Mass range	LEE rejection	Particle ID
SPICE Polar crystals	Al ₂ O ₃ , SiO ₂	ERDM	100 meV - MeV	Dual TES channel	None
SPICE Scintillator	GaAs	NRDM/ ERDM	eV - MeV MeV - GeV	Phonon/ photon coincidence	Dual Phonon- photon readout
HeRALD LHe	He	NRDM	MeV - GeV	Multiple He4/ photon	Pulse shape discrimination
Semicon. High V	Ge, Si	ERDM	eV - MeV	SSED	None
Semicon. Low V	Ge, Si, C	NRDM	MeV - GeV	Phonon/ ionization coincidence	Dual phonon- ionisation readout

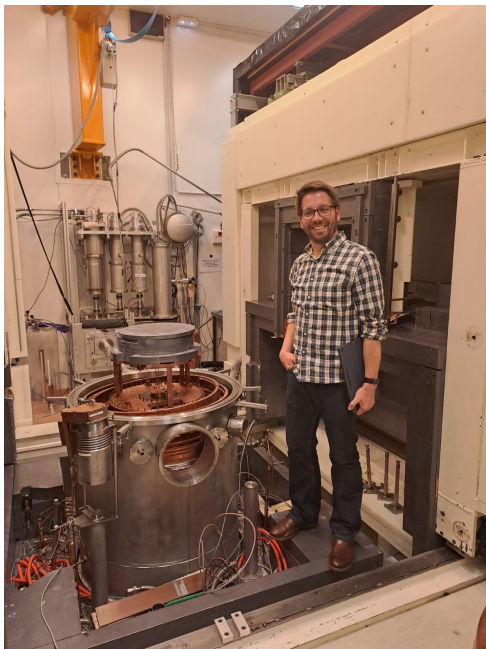


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D. McKinsey January 2022



B. Penning March 2023



S. Hertel May 2024

IN2P3 directorate visit US partners and DOE representatives at UC Berkeley (April 2023)

Since spring 2023: bilateral weekly project management meetings between US and French partners

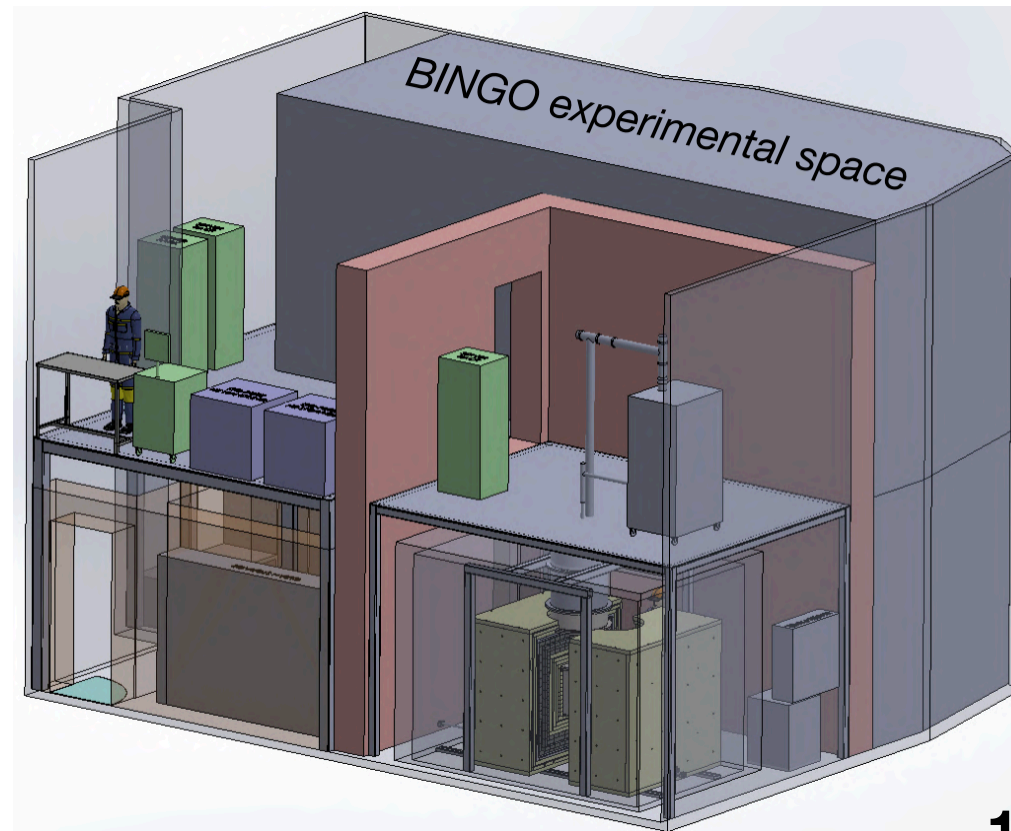
Since January 2024: bilateral weekly meetings on engineering, integration, and simulation

Official joining of IN2P3 in TESSERACT planned in summer 2024



TESSERACT: Integration at LSM

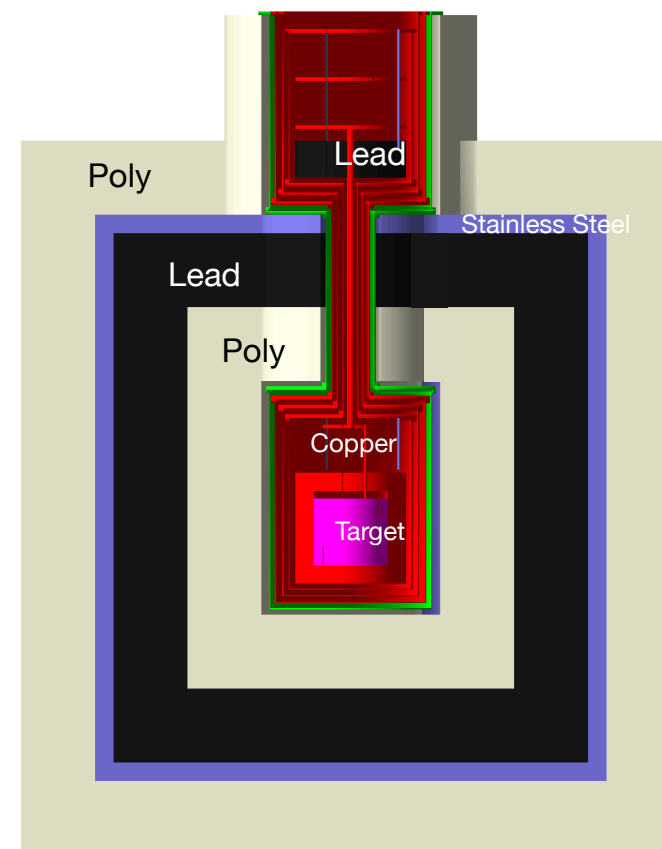
- Two copies of the setup, for enabling both:
 - underground R&D and detector optimisation
 - DM science data taking in parallel
- Each detector technologies is designed to achieve major breakthrough in short time scales (few months) hence allowing fast turnarounds
- The two setups could be (ideally) in the same underground laboratory (LSM).
- Installation of 1st cryostat at LSM in the next 3 years is timely for the TESSERACT collaboration.
- Choice of site(s) discussion in US includes green light from the DOE, to go to LSM.



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Ongoing work on the shielding design for the lowest background possible (few DRU):

- Ongoing simulations predict: ~ 1 DRU ER / $< 1e-3$ DRU NR
- Favoured option with a «neck» that will require significant cryogenic R&D
- Need efficient material screening and assay to start well ahead of construction (Use of GENTIANE + new dual-HPGe)
- Re-use of part of the EDW resources to be shared with other EDW institutes (discussions ongoing)
- Commissioning of the TESSERACT cryostat above-ground (at LPSC)





TESSERACT: WBS

Structure in evolution

Most tasks will be shared among US and French laboratories, with significant overlap and collaborations.

Depending on the allocation of resources that will be decided by the directions of their respective laboratories, the French groups are proposing to take the lead in several tasks:

- **Project management and integration:** Test facilities (IP2I et IJClab) + LSM integration
- **Semiconductor crystals:** Low Voltage (à la Ricochet) + High Voltage (à la CRYOSEL), fabrication and integration
- **Software developments:** data processing, data analysis, slow control + DAQ + monitoring (*specifications to be defined first and discussed internally*)
- **Electronics:** *specifications to be defined first and discussed internally*
- **Low background:** Simulation and screening and material assay

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TESSERACT: Budget

- **TESSERACT is already an existing and funded pre-project from the DOE** dark matter new initiatives program. It started in 2020 and **has already received so far 1.3 M-EUR in funds for equipment, materials, engineering, and project management.** The total pre-project budget from the DOE, *i.e. excluding resources needed to build TESSERACT at LSM*, **is expected to reach 2.8 M-EUR by 2025.**
- **TESSERACT is an IN2P3 Master Project as of Fall 2023.**
- TESSERACT at LSM project, including the addition of the French IN2P3 detector technology to the TESSERACT payload and science reach, **a total budget of 3.5 M-EUR is required.**
 - **DOE review for funding allocation on 02.07.2024**
 - **RI2 (France2030) proposal « TES4DM » approved on 25.04.2024**
Building the next generation semiconducting low-threshold detectors operated in a ultra-low background underground cryogenic facility

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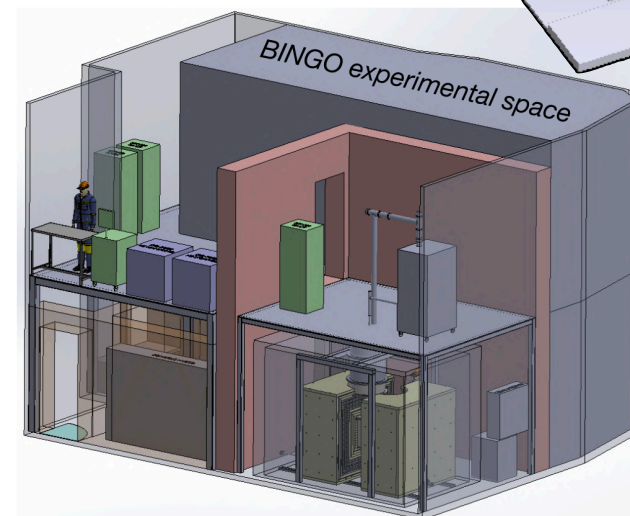
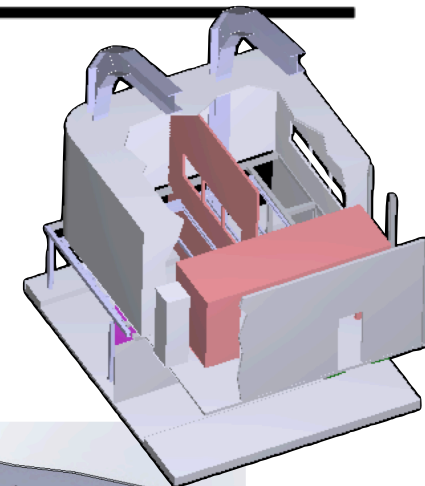
TES4DM: Methodology and deliverables

- **TES4DM technology specifications:**

- Use of Ge/Si crystals to be operated in LV (NR) and HV (ER) modes
- LV design with targeted: 100 meV (phonon) and <10 eVee (ion)
- HV with SSED sensor to tag single e/h pair to reject LEE excess
- Transition from NTD (20eV) to TES athermal sensors (100 meV)
- Understanding and mitigating the LEE —> **Design driver**

- **TES4DM UG facility @ LSM specifications:**

- Designed to operate various technologies for a broad DM search spectrum: Ge/Si, LHe, and polar crystals
- Designed to achieve few DRU background levels
- Designed to be the new LSM DM cryogenic experiment



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1) Detector performance (moderate):

- Benefiting from ongoing R&Ds
 - Ricochet (ERC-StG+ANR) and CryoSel (ANR)
- Technological solutions identified and some validated
- The success of Ricochet and CryoSEL are prerequisite to the success of TES4DM!

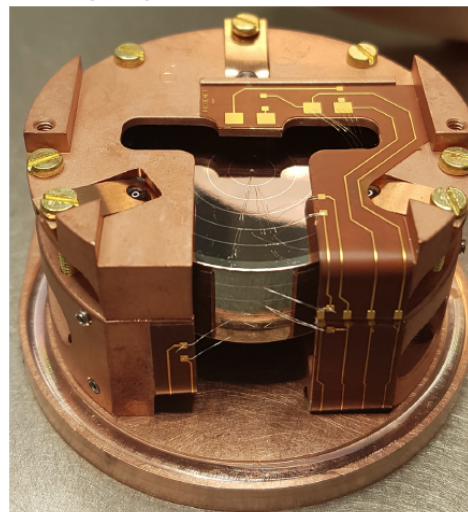
2) Low energy excess (high):

- Limiting all cryogenic experiments today
- « Back up » with active rejection methods

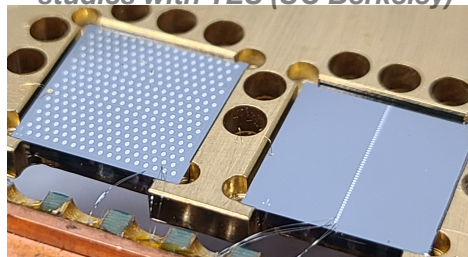
3) Integration at LSM (weak):

- 20+ years of experience of the french teams (EDELWEISS, Ricochet, ...)
- Possible uncertainties on the planning
- High support from IN2P3 and LSM

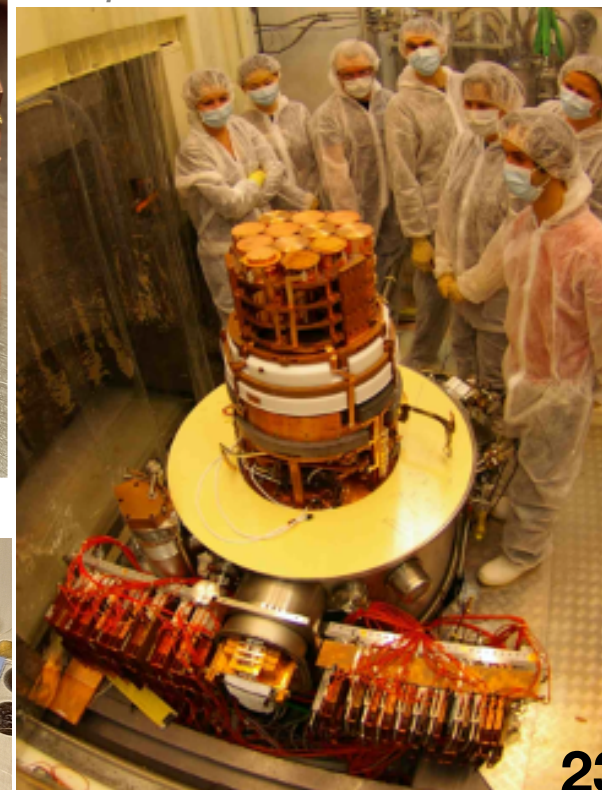
1) 42g Ricochet detector



2) « quasiparticle poisoning » studies with TES (UC Berkeley)



3) Photo of the previous EDELWEISS-III experiment at LSM





TES4DM: Human resources

Preliminary and summarised short-term planning with LPSC implication

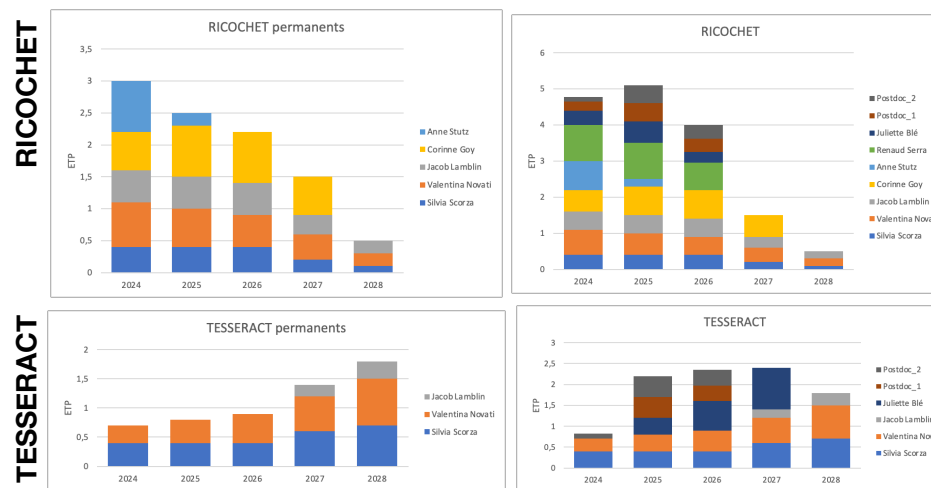
- Strong implication of SERM service [Johann MENU 20% starting Feb 2024; Eric PERBET, 80% from Sept 2024]
- LPSC with LBL is leading the design and integration of the TESSERACT@LSM facility (including cryogenics, simulations, and material selection).
- Likely implication of the LPSC in commissioning the RI2 cryostat at surface (LPSC cleanroom).
- Ongoing implication in the analysis and data-taking of Ricochet detectors in preparation for TESSERACT
- Implication on electronics readout via TES has yet to be defined (discussion ongoing with LPSC electronic service)

TES4DM FR consortium (total : 10 FTE)

LPSC — S. Scorza (Co-PI)

- 1 DR + 1 CR + 1 MdC + 2 IR/IE
- Plateforme nationale: LSM
- Total: ~3 FTE

Planning and allocation of human resources have to be carefully handled to not jeopardise Ricochet's success





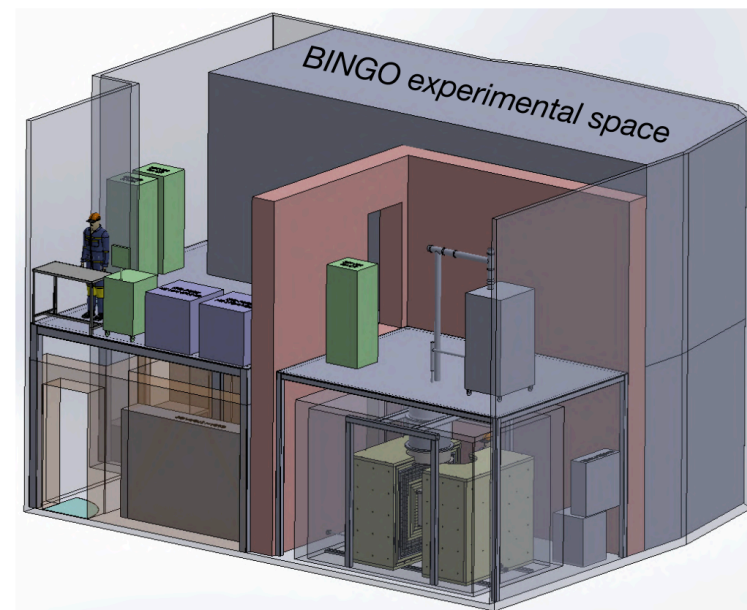
TESSERACT: Conclusion

Extending the Dark Matter mass search window from meV-to-GeV with **ultra low-threshold cryogenic detectors** with **multiple targets** and **particle identification and LEE rejection capabilities** with two identical cryogenic setups installed in the **ultra-low background environment underground at LSM**

Unique opportunity to build the next leading cryogenic light DM experiment at LSM, featuring French bolometer technology, benefiting from decades of experience from EDELWEISS, CUPID, and Ricochet

TESSERACT resources sponsored by UGA and CNRS:

- One UGA TESSERACT postdoc position at LPSC
- One IRGA UGA PhD thesis grant at LPSC to started in the Fall 2024
- Significant fundings to start design studies at LSM and to complete the test facilities at IJCLab and IP2I.



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