Light DM search with TESSERACT

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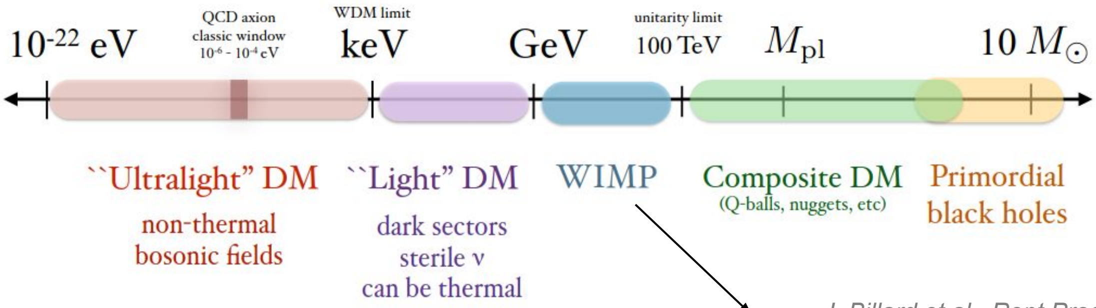
TAUP2025 - 24/08/2025

Motivations

DM candidates : 50 orders of magnitudes in mass



T. Lin

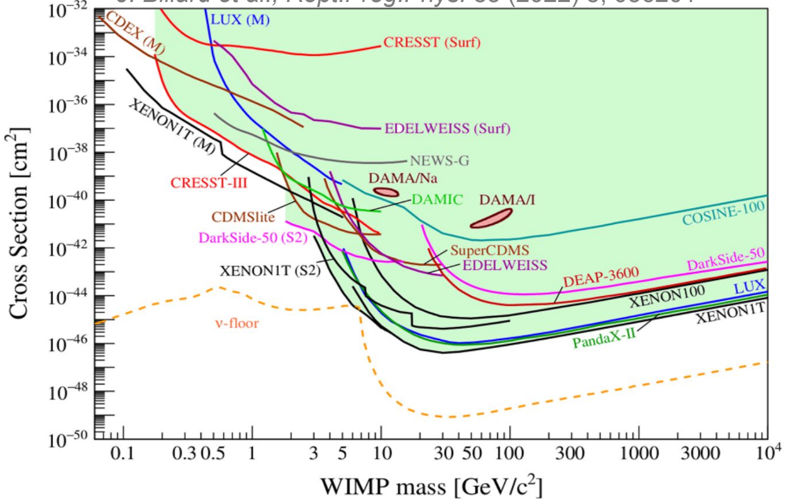
Focus of DM searches for the last decades has been on axion DM (ueV - meV) and standard WIMP (10 GeV - TeV)

The standard WIMP case was highly motivated thanks to the so-called WIMP miracle and the SUSY prediction

After few decades, still no DM signal and ongoing or planned ton-scale experiment are approaching the neutrino limit

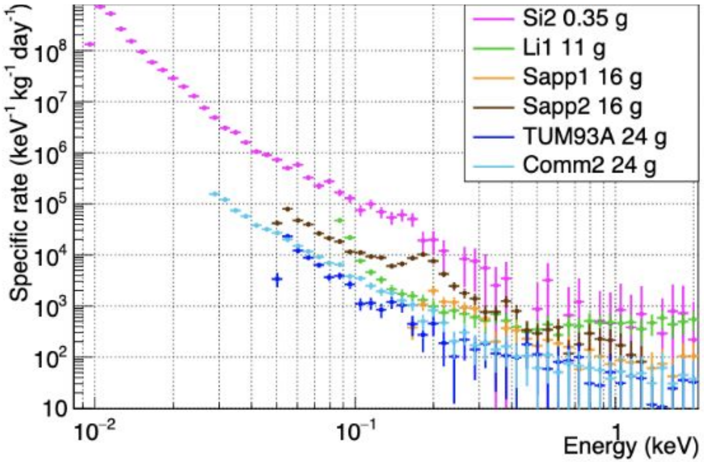
Need for new experiment with broader DM mass range and increased sensitivity to more DM interactions ⇒ use of low threshold cryogenic detectors

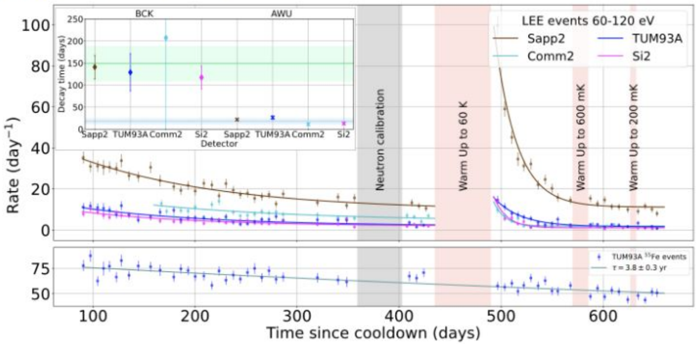
J. Billard et al., *Rept.Prog.Phys.* 85 (2022) 5, 056201



Low Energy Excess

- Currently, all cryogenic experiment which have reached sub keV threshold are seeing a Low Energy Excess (LEE) limiting their DM search
- LEE characteristics : time dependant, non ionising ("Phonon Only"), mostly independent of sites, dependance with holder/vibrations (?)





CRESST collaboration, SciPost Phys.Proc. 12 (2023) 013

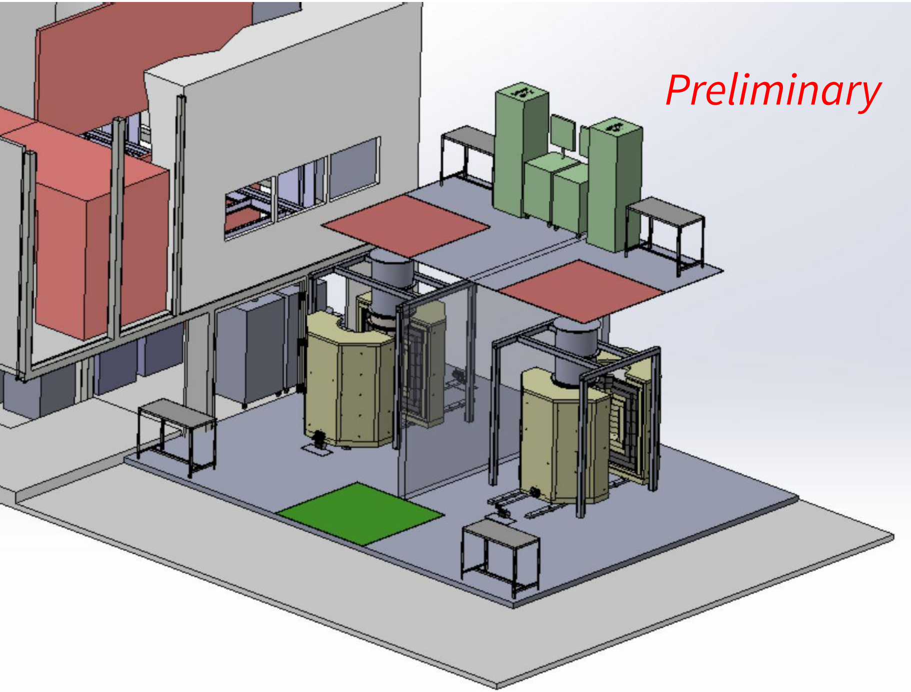
TESSERACT : Proposed experiment at LSM

Transition Edge Sensor with Sub-Ev Resolution And Cryogenic Targets

- Target : extend the DM search window from meV to GeV with ultra-low threshold cryogenic detectors
- Design driver :
  - find the origin of LEE to mitigate it
  - develop technologies that can reject it

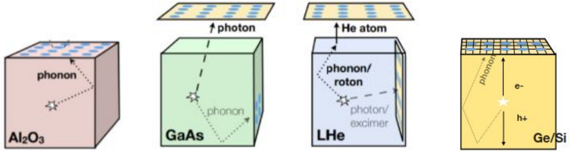
TESSERACT : Proposal experiment at LSM

Transition Edge Sensor with Sub-Ev Resolution And Cryogenic Targets



One experimental design, two cryostats, several targets :

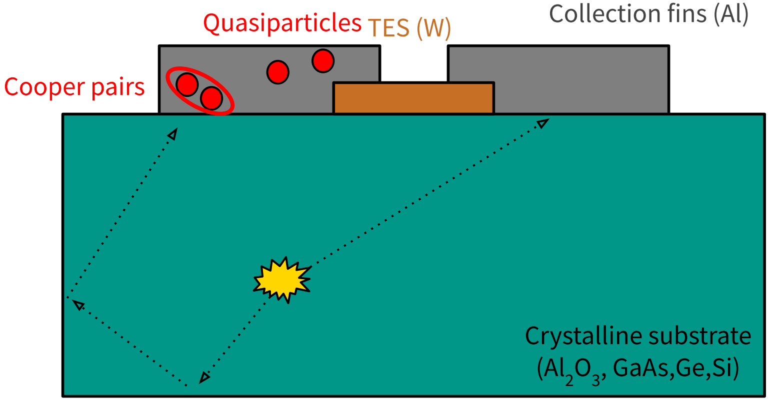
- SPICE (Al_2O_3 and GaAs)
- HeRALD (LHe)
- Ge/Si bolometers



All equipped with new generation TES

Complementary DM sensitivity
Commissioning at Laboratoire Souterrain de Modane

TESSERACT : New generation TES phonon sensors

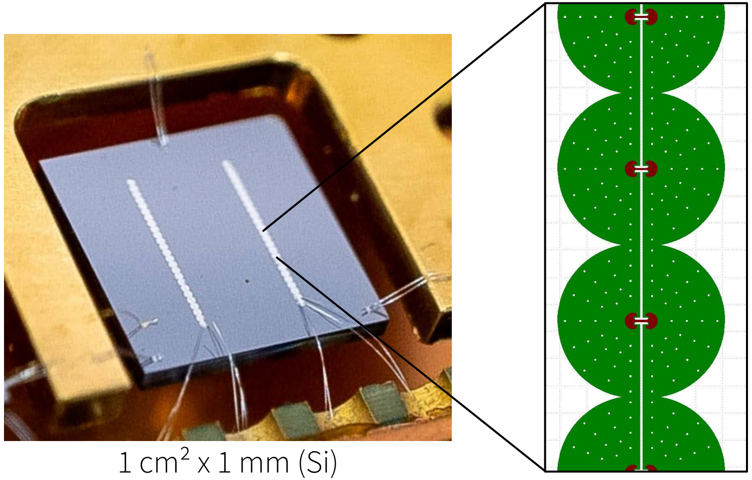


$$\sigma_E \sim \frac{\sqrt{4k_bT_c^2G(\tau_{collect}+\tau_{sensor})}}{\epsilon_{collect}\epsilon_{sensor}}$$

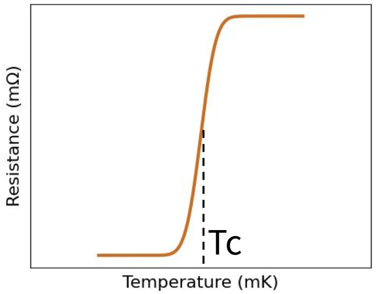
$$\sigma_E \propto V_{det}^{1/2}T_c^3$$

Energy threshold decreases very quickly with T_C

Energy threshold decreases with detector mass

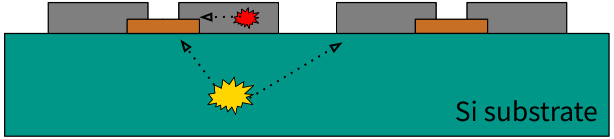


1 cm^2 x 1 mm (Si)

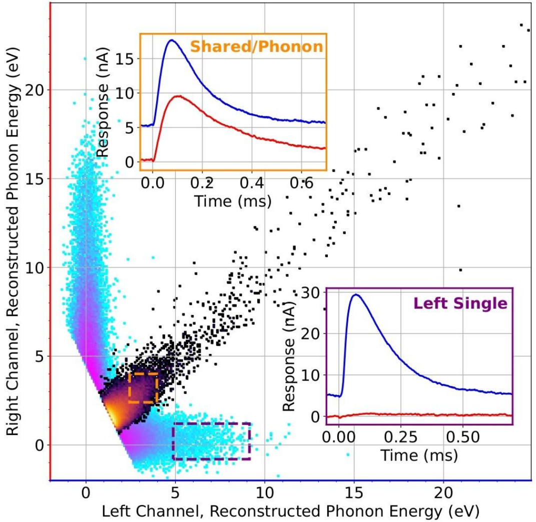


SPICE (Sub-eV Polar Interaction Cryogenic Experiment)

Background discrimination : selection of events shared between both channels

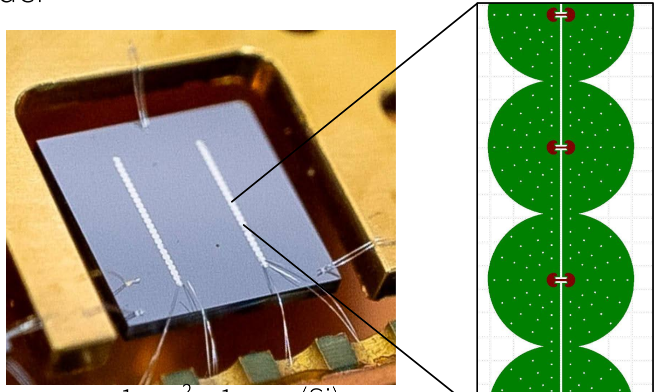


arXiv:2503.03683v2

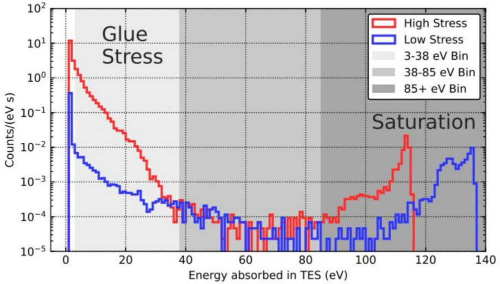


LEE mitigation : Si substrate suspended with Al wires

⇒ suppress a stress induced LEE source from the holder

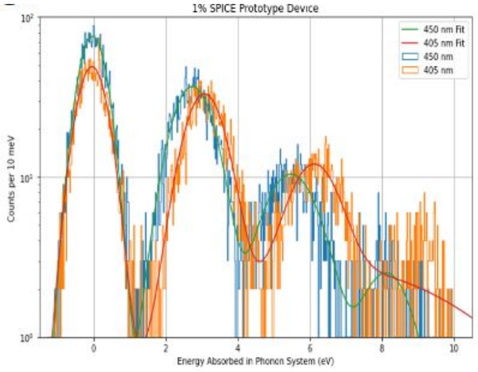


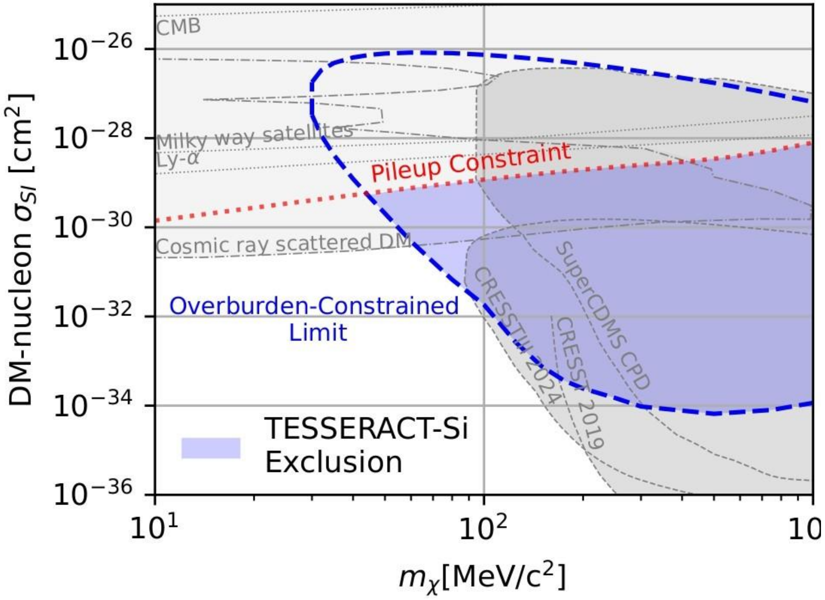
1 cm^2 x 1 mm (Si)



arXiv:2208.02790

Proof of concept : 1st DM limit from above-ground detector

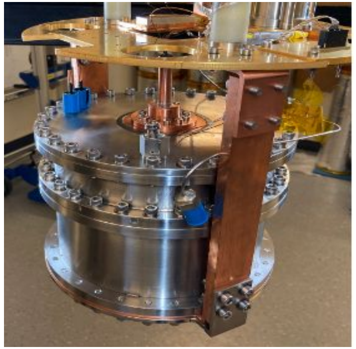




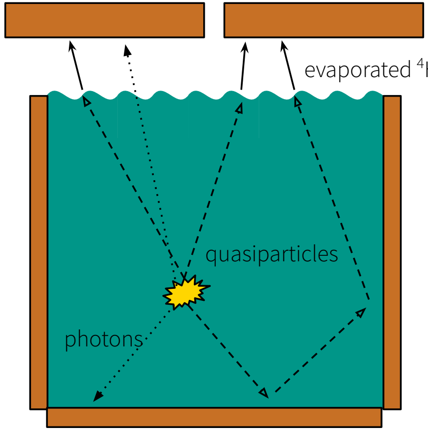
- World leading 258.5 meV baseline resolution leading to eV-scale threshold already achieved with a 0.2 g Si detector and Tc = 50 mK : *arXiv:2505.16092v2*
- Targeted Tc around 15-20 mK recently achieved
- Dark Matter limit published : *arXiv:2503.03683v2*

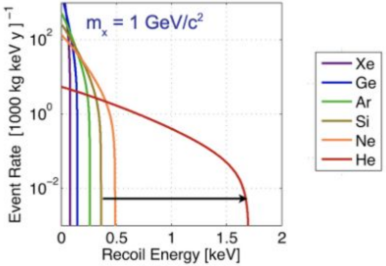
GaAs and Sapphire R&D ongoing

HeRALD (Helium Roton Apparatus for Light Dark Matter)



R. Anthony-Petersen et al., arXiv:2307.11877



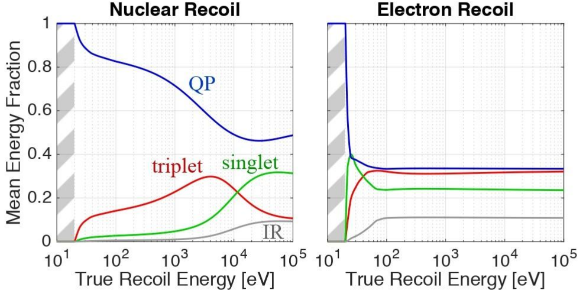


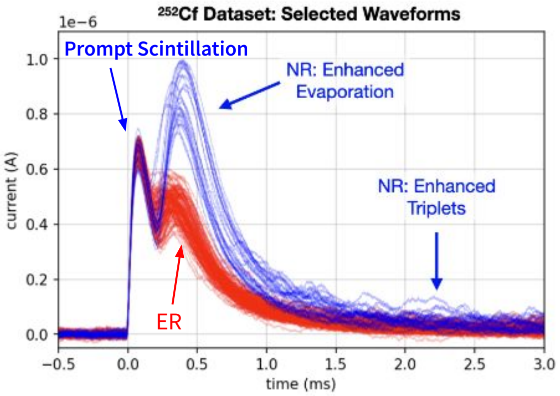
Target : Liquid He

- Light material ⇒ better kinematic matching with LDM
- Extremely radiopure
- No internal stress nor dislocation (LEE source ?)
- Superfluid ⇒ no vibrational coupling with the environment (another LEE source ?)
- Several signal channels :
  - quasiparticles (phonon/roton)
  - singlet ⇒ short lived, decay to emit a 15.5 eV photon
  - triplet ⇒ long lived, ballistic

HeRALD

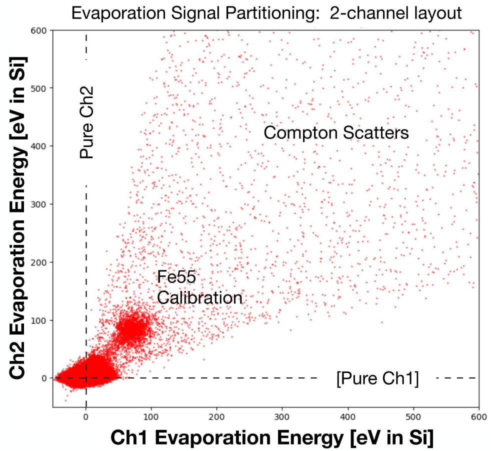
Particle identification thanks to pulse shape discrimination





LEE mitigation strategy (in addition of the intrinsic characteristics of LHe) :

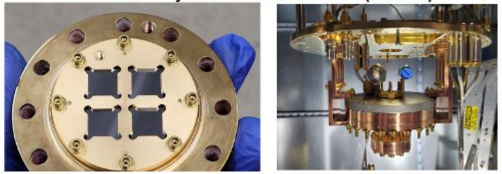
- Several channels above the vacuum
  - Events in calorimeters (LEE) ⇒ single channel
  - Events in ^{4}He ⇒ multiple channels



Near-term HeRALD plans all involve multi-channel evaporation readout and testing the above strategy

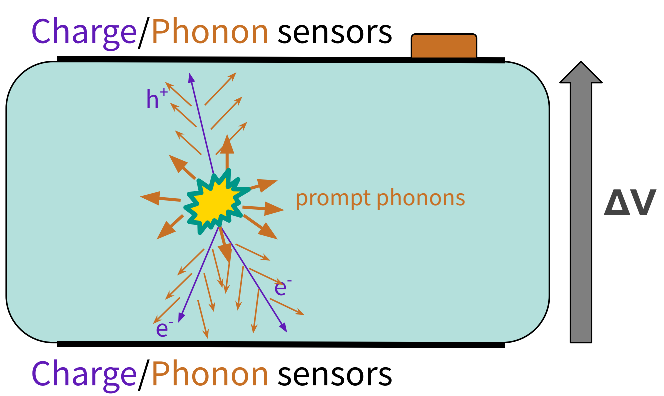
2-Channel Array for HeRALD v0.1 @UMass (3-inch)

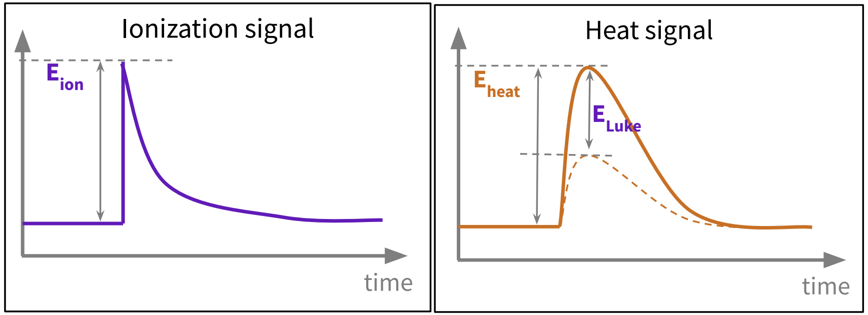
4-Channel Array for HeRALD v0.2 @LBNL (4x 1cm²)



Ge/Si semiconductors

Based on EDELWEISS and Ricochet expertise





$$E_{heat} = E_{recoil} + E_{luke}$$
$$= E_{recoil} + E_{ion}\,\Delta V/\varepsilon_{eh}$$

- Two channels : heat and ionization
- Luke boost ⇒ additional phonons proportional to ΔV

⇓

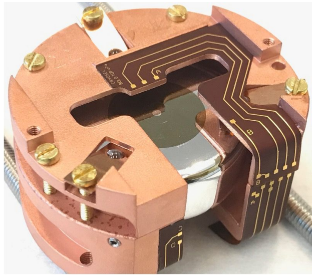
Two working modes : Low Voltage (LV) and High Voltage (HV)

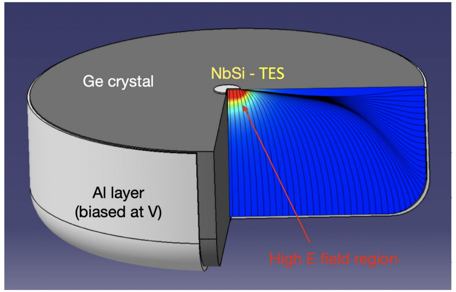
Ge/Si semiconductors HV

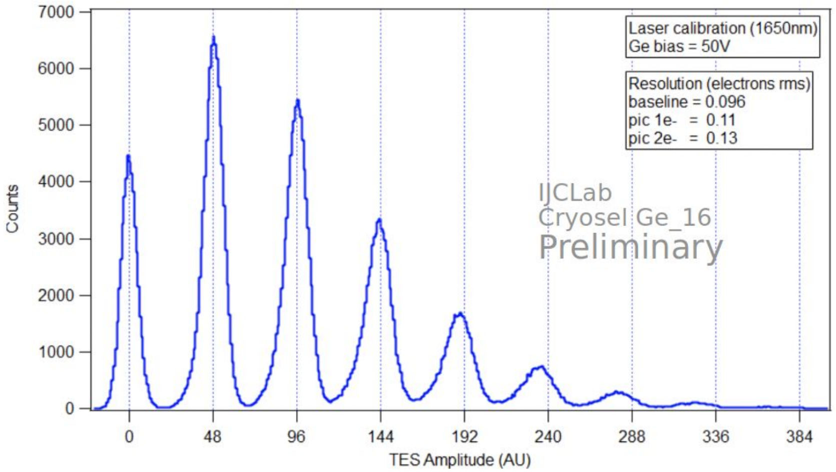
High-Voltage approach for optimal ERDM sensitivity

$E_{heat} = E_{recoil} + E_{ion}\ \Delta V/\varepsilon_{eh}$

$E_{heat} \simeq E_{ion}\ \Delta V/\varepsilon_{eh}$ (HV)







First observation of a single-electron sensitivity in a massive (40g) Ge cryogenic detector !

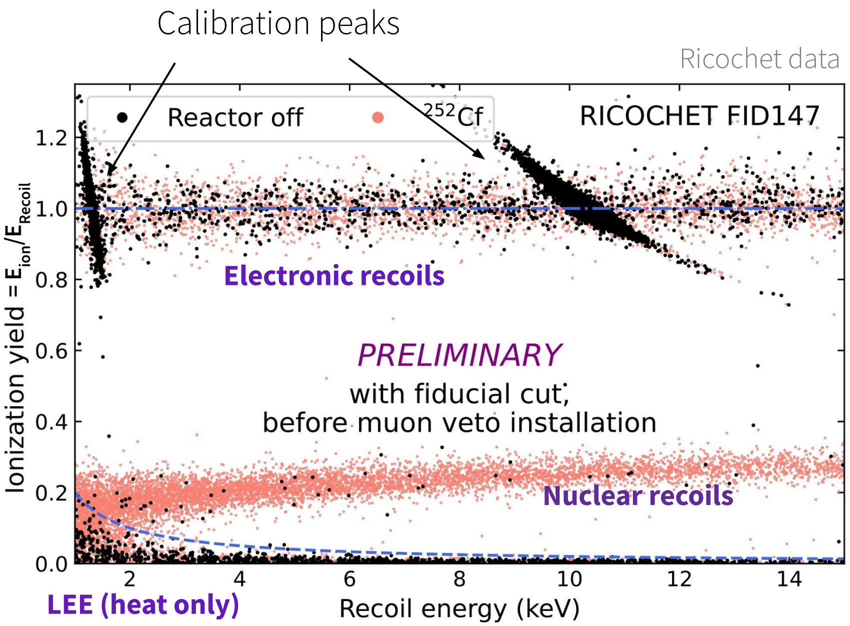
- Low-imp. TES and SQUID readout : **0.1 electron/hole (RMS)**

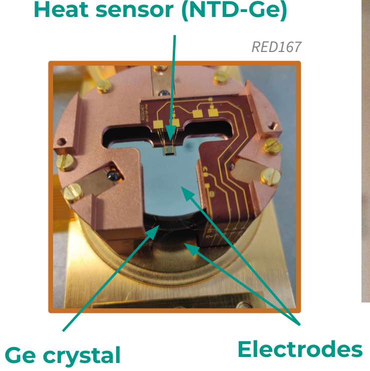
For TESSERACT :

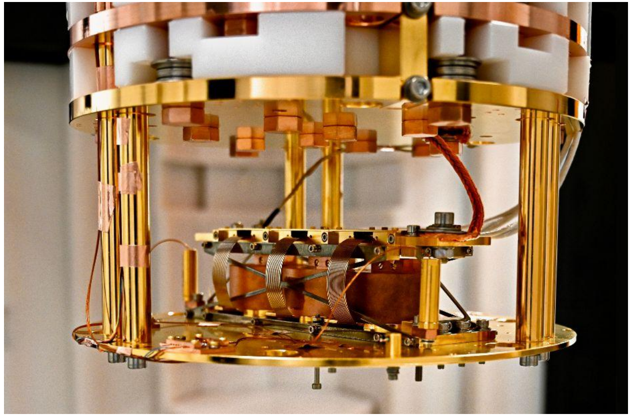
- High control of IR backgrounds and charge leakage
- LEE discrimination down to single e/h pair
- **Exquisite sensitivities to ERDM with LEE discrimination**

Ge/Si semiconductors LV

Low-Voltage approach for optimal NRDM sensitivity







Ricochet Mini-Cryocube

- Double readout heat/ionization ⇒ particle identification
- LEE are non ionizing ⇒ improving the charge resolution is of major importance

Ge/Si semiconductors LV

Low-Voltage approach for optimal NRDM sensitivity

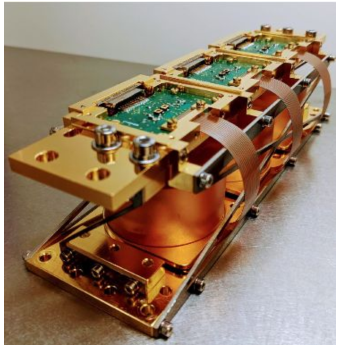
Ricochet Cryocube

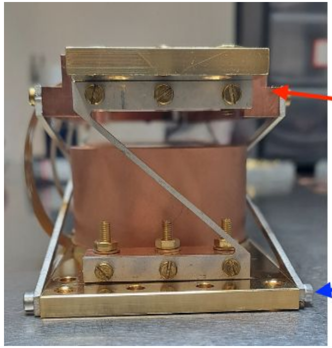
- Looking for : **CENNS**
- Phonon sensor : **NTD-Ge**
- Payload: 3 x **40 g**
- Total capacitance **~45 pF**
- σ_{ion} ~**30 - 40 eVee**
- σ_{heat} **~40 eV**

TES4DM

- Looking for : **DM**
- Phonon sensor : **NTD-Ge ⇒ TES**
- Payload: 4 x **5.35 g (1 cm^3)**
- Total capacitance **~5 pF**
- σ_{ion} ~ **10 eVee**
- σ_{heat} < **1 eV**

Ricochet Coll., Eur. Phys. J. C 84 (2024) 2, 186





HEMT Charge Amplifiers

1K

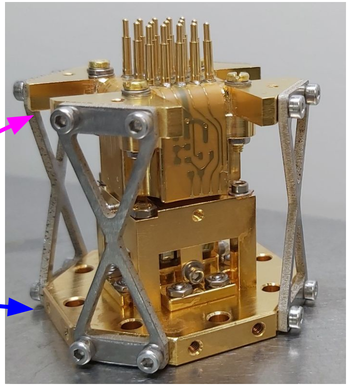
5 cm

100 mK

10 mK

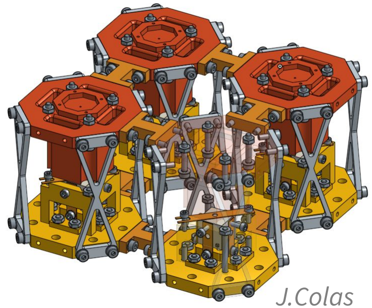
Target and phonon sensor (NTD-Ge)

Prototype



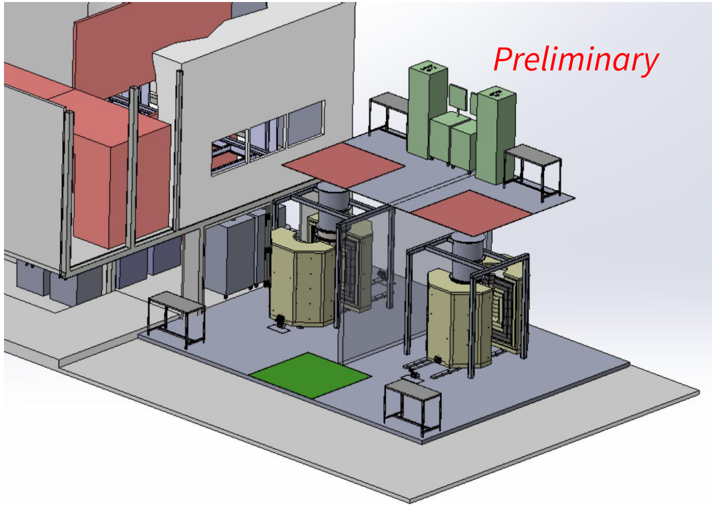
3 cm

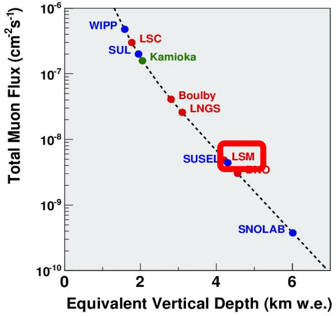
R&D ongoing



J.Colas

TESSERACT : Proposal for an installation in the *Laboratoire Souterrain de Modane* (LSM)





TESSERACT Integration at LSM

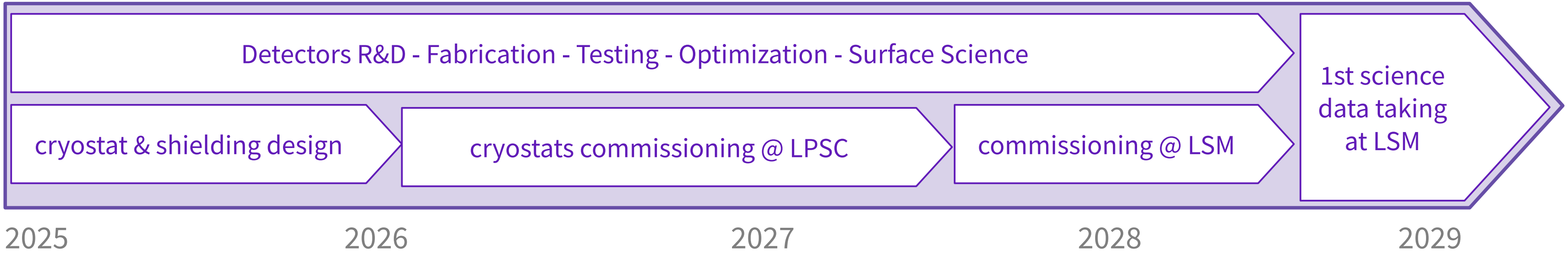
- Two copies of the setup, for enabling both:
  - underground R&D and detector optimisation
  - DM science data taking in parallel
- Targeted background levels of 1 DRU gamma with the possibility to add an active cryogenic veto to further lower the gamma background levels.
- Each detector technologies is designed to achieve major breakthrough in short time scales (few months) hence allowing fast turnarounds
- The two setups will be in LSM between 2027 and 2028

❖ LSM *(Laboratoire Souterrain de Modane)* : deepest site in Europe, 4800 m.w.e, 5 µ/m^2/day
❖ Clean room + deradonized air
❖ PE and lead shielding
❖ Selection of radiopure materials

Conclusion

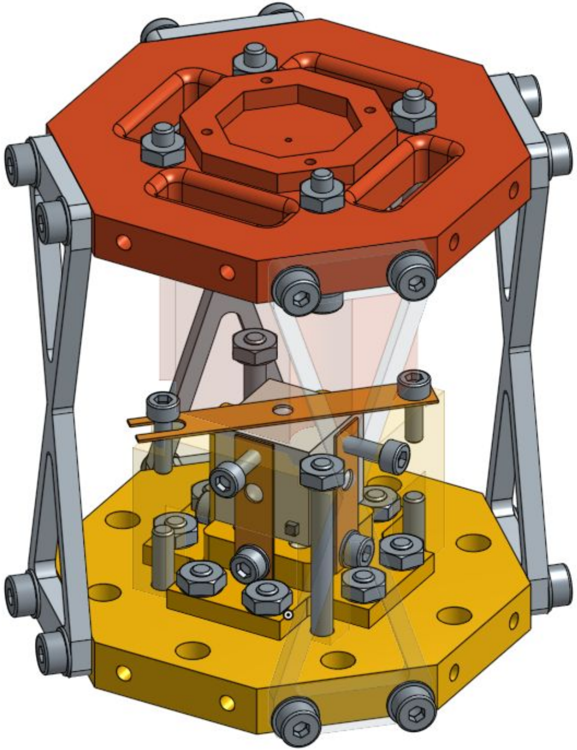
TESSERACT @ LSM

- Different cryogenic targets (Si, Ge, Al_2O_3, GaAs, ^4He)
- LEE mitigation or discrimination strategies
- Particle Identification
- Low impedance TES phonon sensors
- LSM ultra-low background environnement

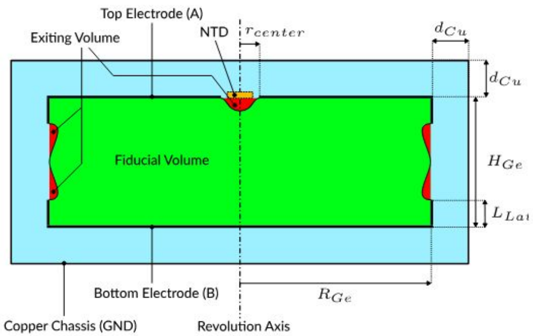


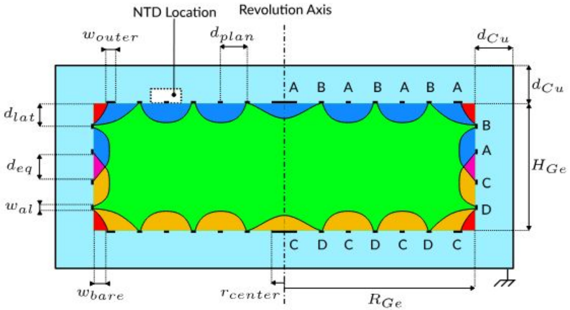
Thank you for your attention

Questions ?

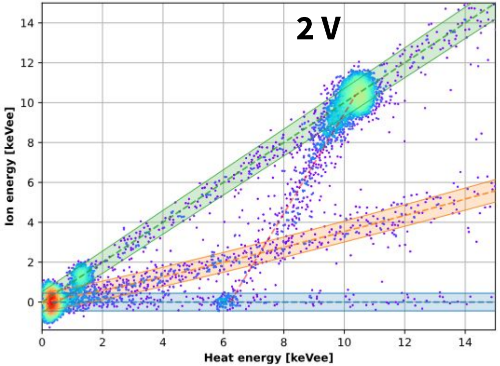


Low-Voltage approach for optimal particle identification (Ricochet style bolometer)



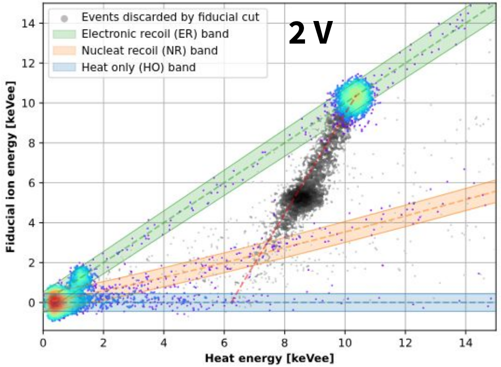


Salagnac & al: arXiv:2111.12438



PL 38

FID 38



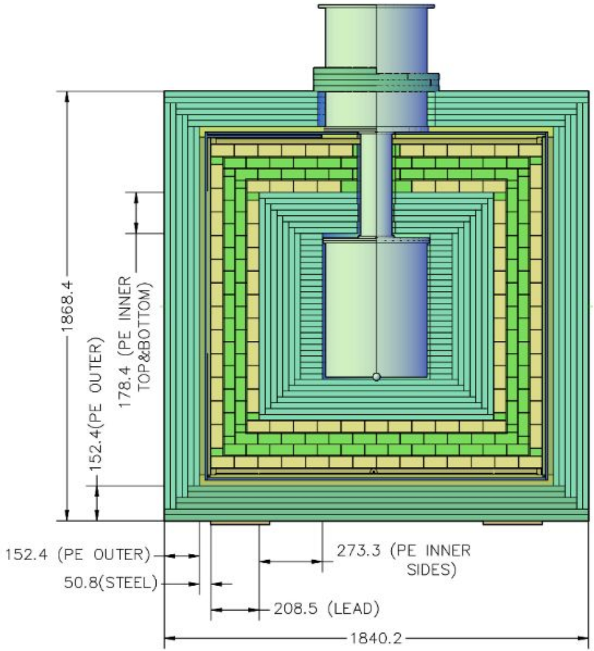
PL 38:

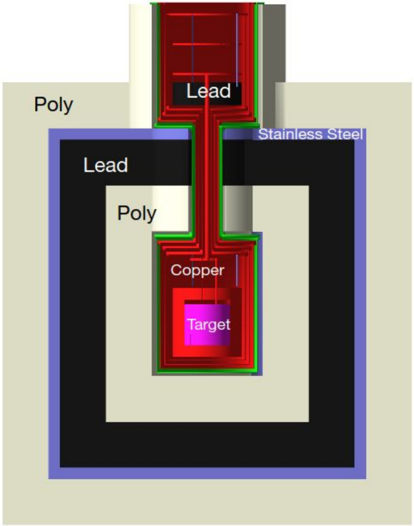
- Incomplete charge coll. **< 10 %**
- Fiducial volume : **96 %**
- Surface event rejection : **NO**
- Total capacitance : **15 pF**

FID 38:

- Incomplete charge coll. **< 1 %**
- Fiducial volume : **62 %**
- Surface event rejection : **YES**
- Total capacitance : **18 pF**

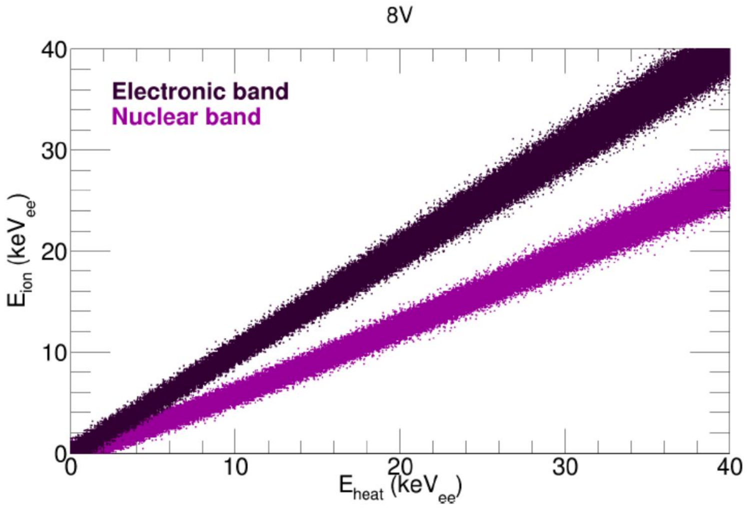
Shielding

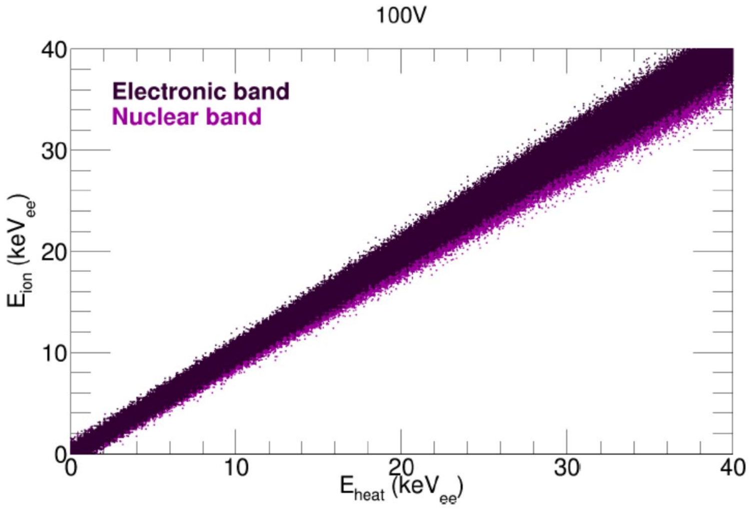

1868.4
152.4(PE OUTER)
178.4 (PE INNER TOP&BOTTOM)
152.4 (PE OUTER)
50.8(STEEL)
273.3 (PE INNER SIDES)
208.5 (LEAD)
1840.2


Poly
Lead
Stainless Steel
Lead
Poly
Copper
Target

Back-up

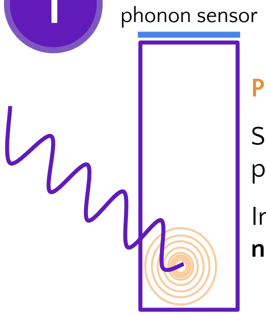
High Voltage loss of Particle Identification





Different kinds of phonons and different sensors

1

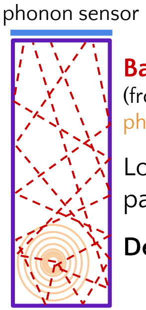


Primary phonons

Short mean free path

In general, **do not reach sensor**

2



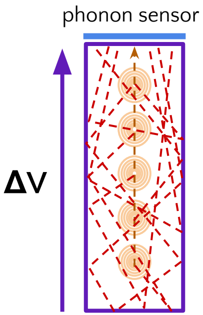
Ballistic phonons
(from decay of primary phonons)

Long mean free path

Detectable in TES

3

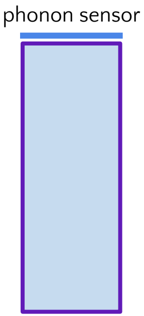
When applying an electric field :



Additional NTL phonons : **primary** + **ballistic** production **along field lines**

→ **primaries** at the end of field lines **detectable in TES**

4



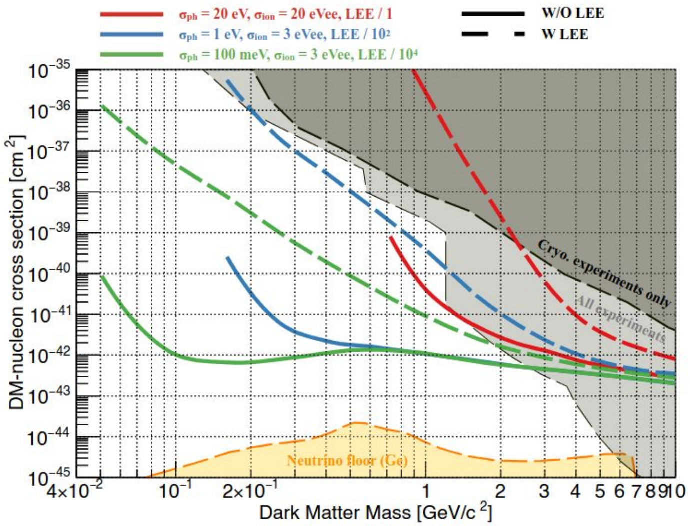
Thermal phonons
(from decay of ballistic phonons)

Detectable in Ge-NTD thermistance (as in RED30)

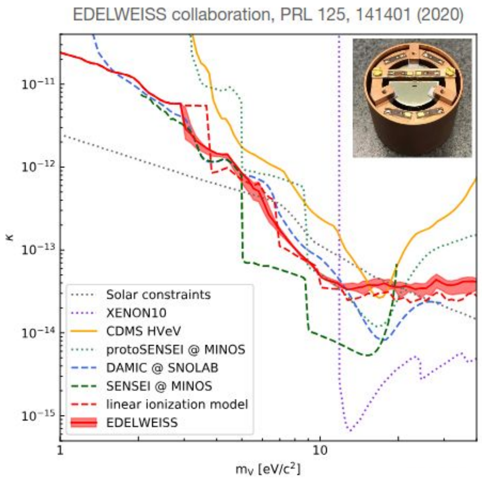
TES sensor

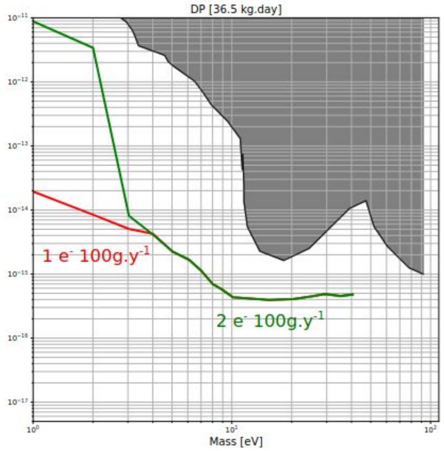
Ge-NTD sensor

Back-up



LV





HV

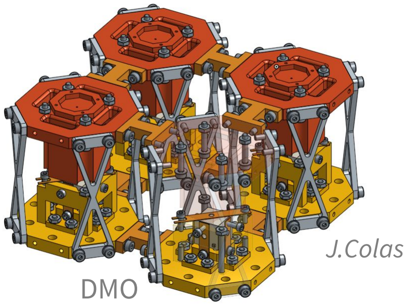
TESSERACT back. model = 10 DRU gamma + other backgrounds from EDW-III

From Ricochet to TESSERACT

Going beyond the Ricochet CryoCube technology

TESSERACT DEMOnstrator (DMO)

- Looking for : **DM**
- Phonon sensor : **NTD-Ge**
- Total capacitance **~5 pF**
- Payload: 4 x **5.35 g**
- σ_{ion} **10 eVee**
- σ_{heat} **~10 - 20 eVph**



- Reduce the detector volume
- Put the HEMT amplificator at < 1 cm from the electrode
- Optimize the holder, COMSOL driven

- Reduce the detector volume
- Optimize NTD dimension
- Low microphonic holder