Probing new physics with Coherent Elastic Neutrino-Nucleus Scattering and the future Ricochet experiment

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on behalf of the Ricochet collaboration

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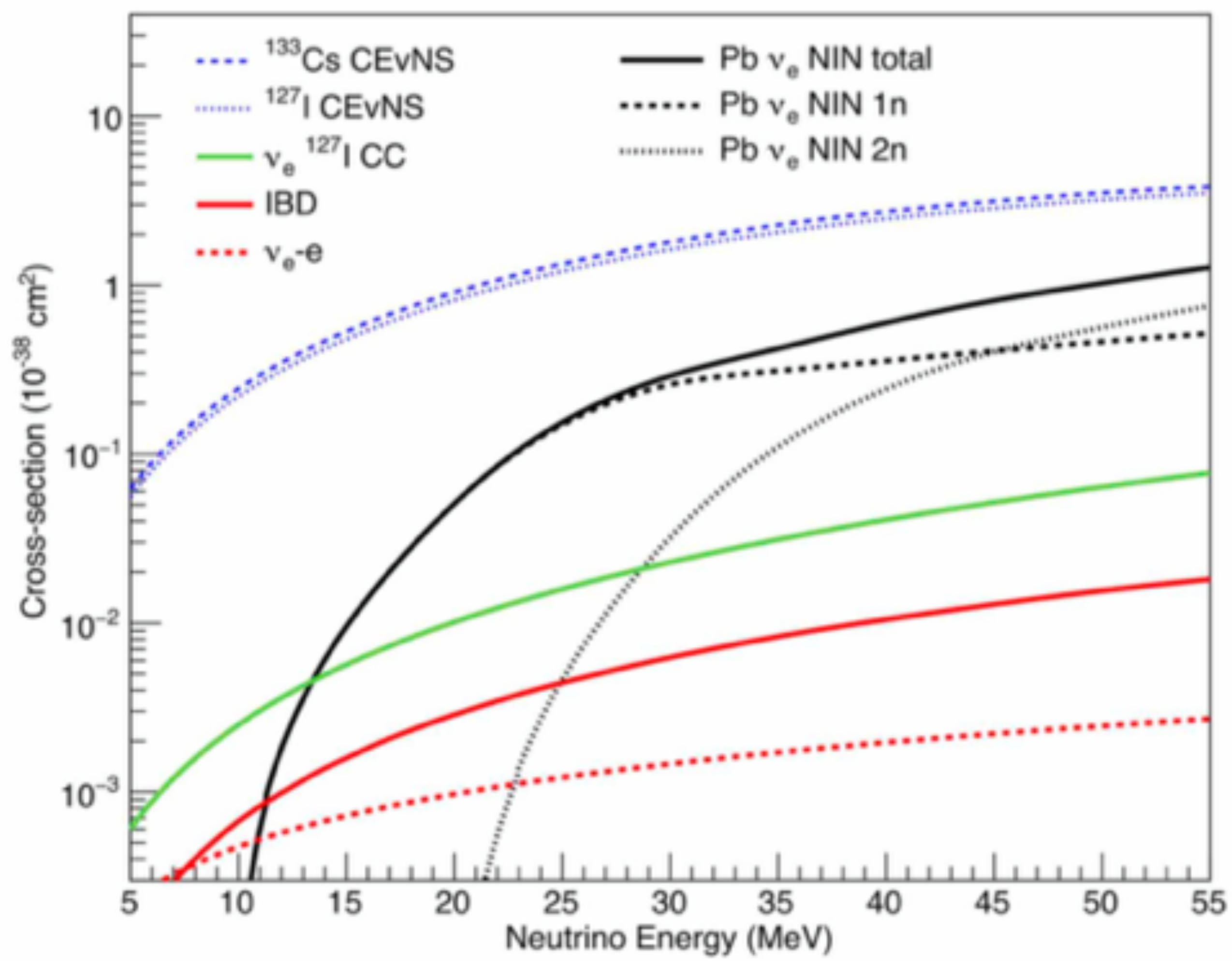
LTD 18, Milano, 23rd of July 2019

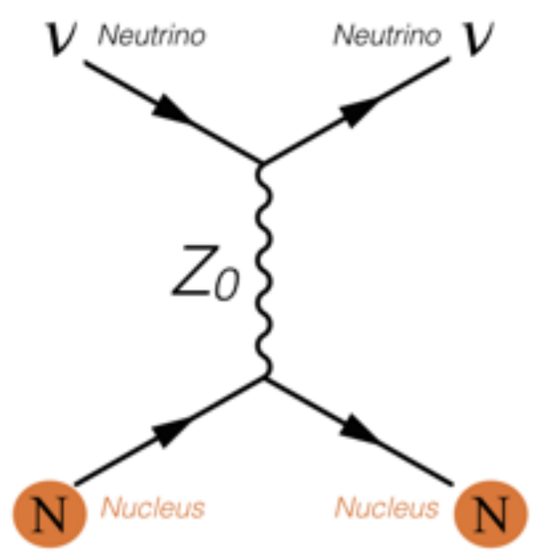
CENNS: The process

Coherent **E**lastic **N**eutrino-**N**ucleus **S**cattering (CENNS)

$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)$$

D. Akimov et al., Science 2017





- Largest neutrino cross section at low energies by few orders of magnitude:
  - *From ton-scale experiments to kg-scale ones !*
- No energy threshold
- First detected by COHERENT in 2017
- Unexplored process offering a new probe for BSM physics:
  - *Calls for low-energy and high-precision measurement*

CENNS: @ reactors

- NuGEN: 1 x 1 kg + 3 x 1.5 kg of germanium — V. Belov et al 2015 JINST 10 P12011
- CONUS: 4-100 kg of germanium — JHEP 1703 (2017) 097
- TEXONO: 1kg of germanium — Nucl.Instrum.Meth. A836 (2016) 67-82
- Connie: Si detector at Angra Reactor in Brasil — JINST 11 (2016) P07024
- RED100: Xe detector at Kalinin Reactor — JINST 12 (2017) C06018
- MINER: GeSi at a non-commercial Reactor — Nucl.Instrum.Meth. A853 (2017) 53
- NU-CLEUS — Eur. Phys. J **C77** (2017) 506
- BASKET — see C. Nones - Poster 366
- BULLKID — see I. Colantoni - Poster 290

Cryogenic experiment & R&D programs for **sub-100 eV** CENNS measurement

RICOCHET
A Coherent Neutrino Scattering Program

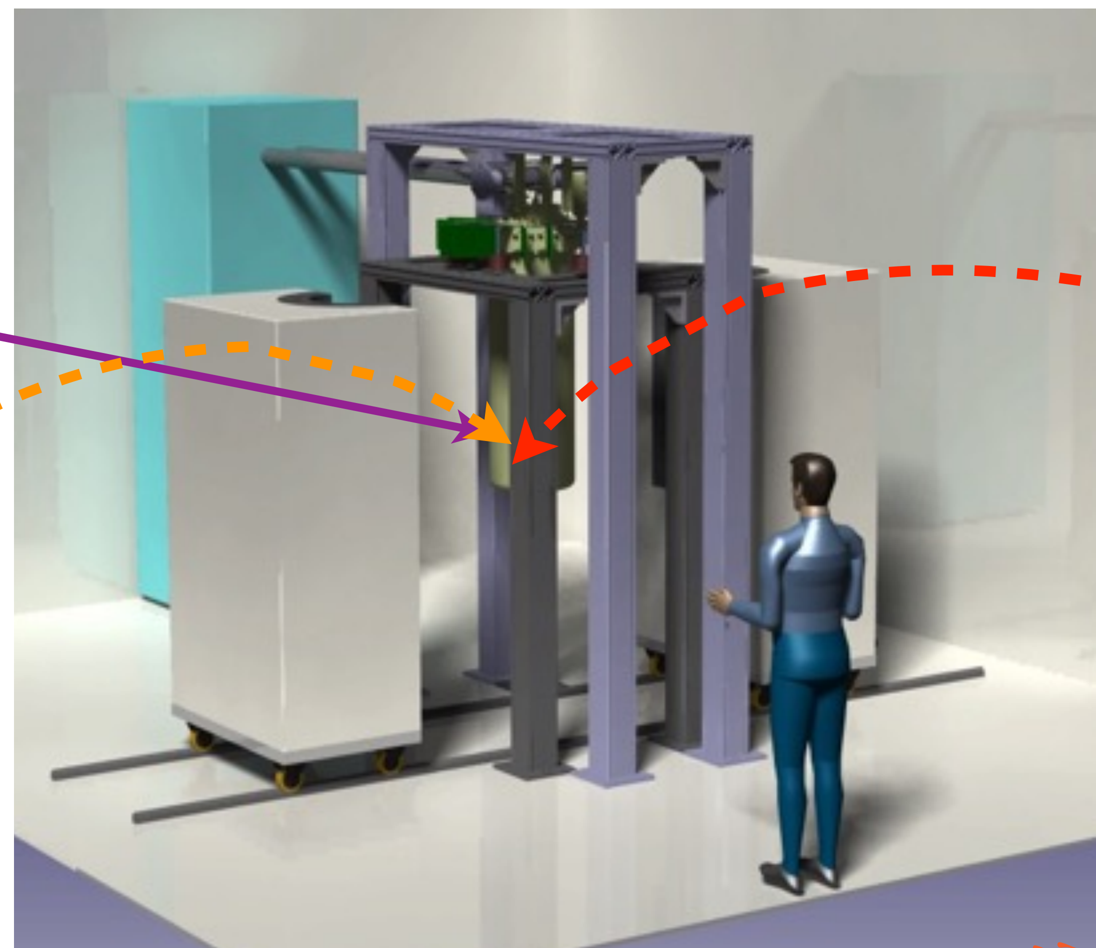
J. Billard et al., J Phys. G (2017)

RICOCHET: *A future low-energy neutrino observatory*

« The first low-energy kg-scale CENNS neutrino observatory combining multi-target and multi-technology cryogenic detectors » Proposal paper: *J. Billard et al., J. Phys. G (2017)*

Q-ARRAY
Zn & Al detectors

HEISING-SIMONS FOUNDATION



CRYOCUBE
Ge & Zn (& Si?)

erc
CNRS IN2P3 Les deux infinis

RICOCHET
A Coherent Neutrino Scattering Program

Northwestern University
NÉEL
The University of Wisconsin Madison
LPSC Grenoble
CSNSM
IPNL
MIT
UMASS AMHERST

RICOCHET: *searching for nuclear reactor site*

MITR: A. Leder *et al.*, JINST 2018

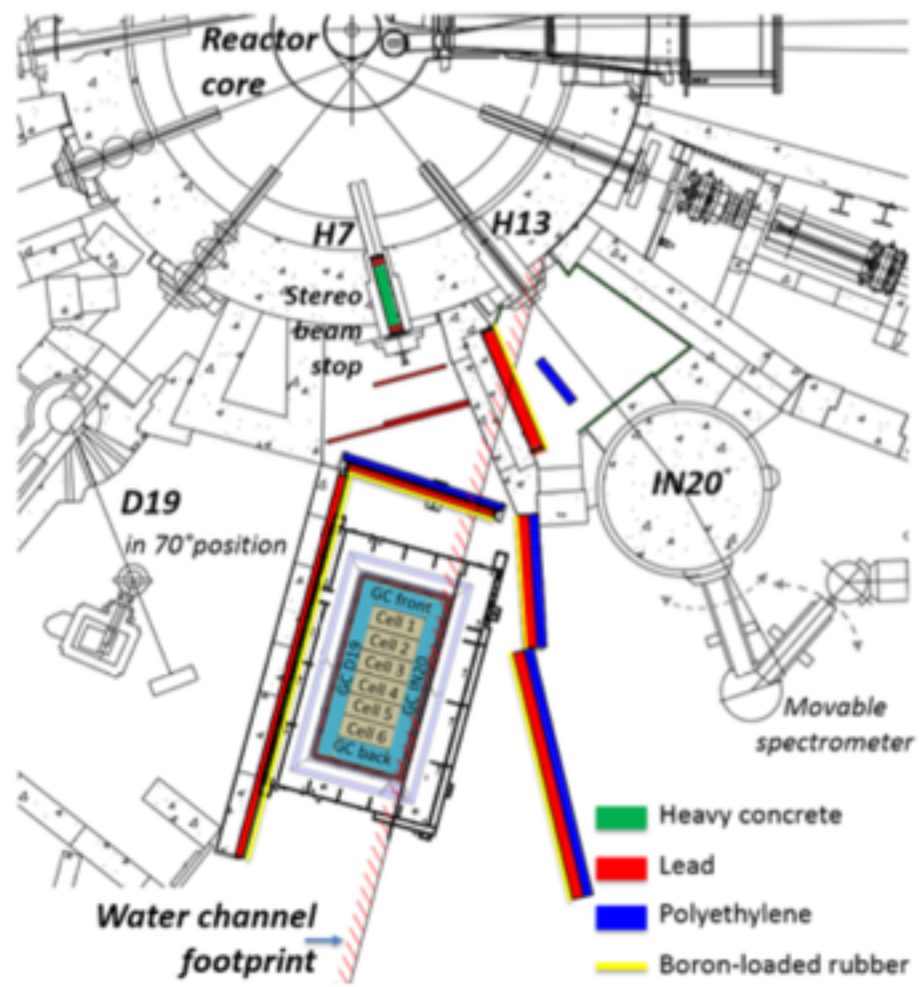
- 4 m from 5.5 MWth core
  $\rightarrow 4.5 \times 10^{11}$ ν/cm^2/s at the detector
- Low overburden :
  $\rightarrow$ high cosmic background
- High level of correlated reactor background
- 4 weeks ON and 1 week OFF cycles

ILL: STEREO Collab., JINST 2018 $\Rightarrow$ LOI send to ILL

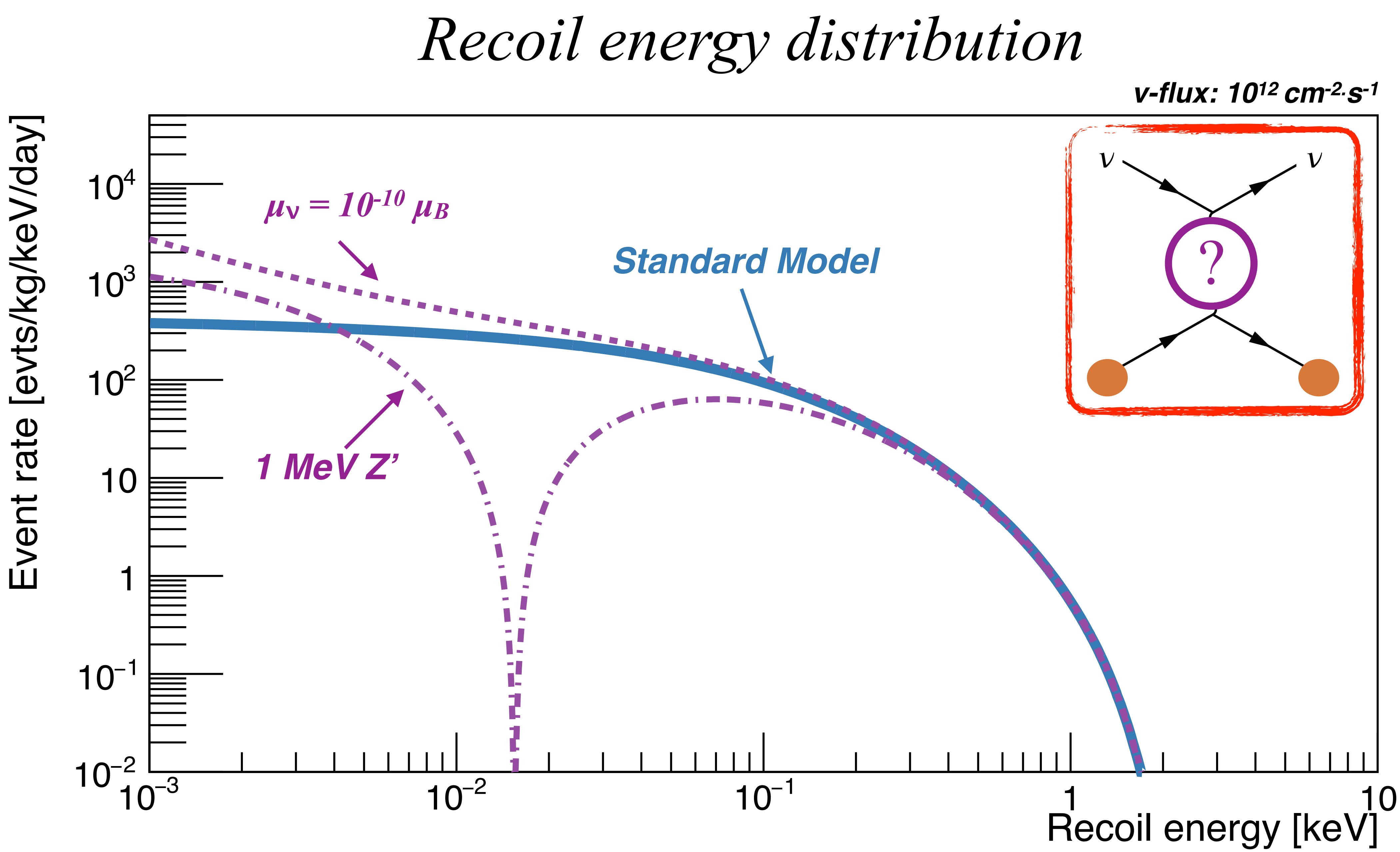
- 7 m from 58 MWth core
  $\rightarrow 1.6 \times 10^{12}$ ν/cm^2/s at the detector
- 15 m.w.e overburden :
  $\rightarrow$ reduction factor 2 to 3 of muon flux
- 3 or 4 cycles of 50 days
  $\rightarrow$ good ON / OFF ratio
- Close to reactor and neighboring experiments
  $\rightarrow$ High level of reactor correlated background
- Use Stereo casemate
  $\rightarrow$ Benefit from Stereo experience and background characterization

Chooz – Near Site: J. Billard, *et al.*, J. Phys. G 2017

- 400 m from two 4.25 GWth cores
  $\rightarrow \sim 5 \times 10^{10}$ ν/cm^2/s at the detector
- No reactogenic background
- Uniquely high overburden: 120 m.w.e
- Rare OFF reactor periods



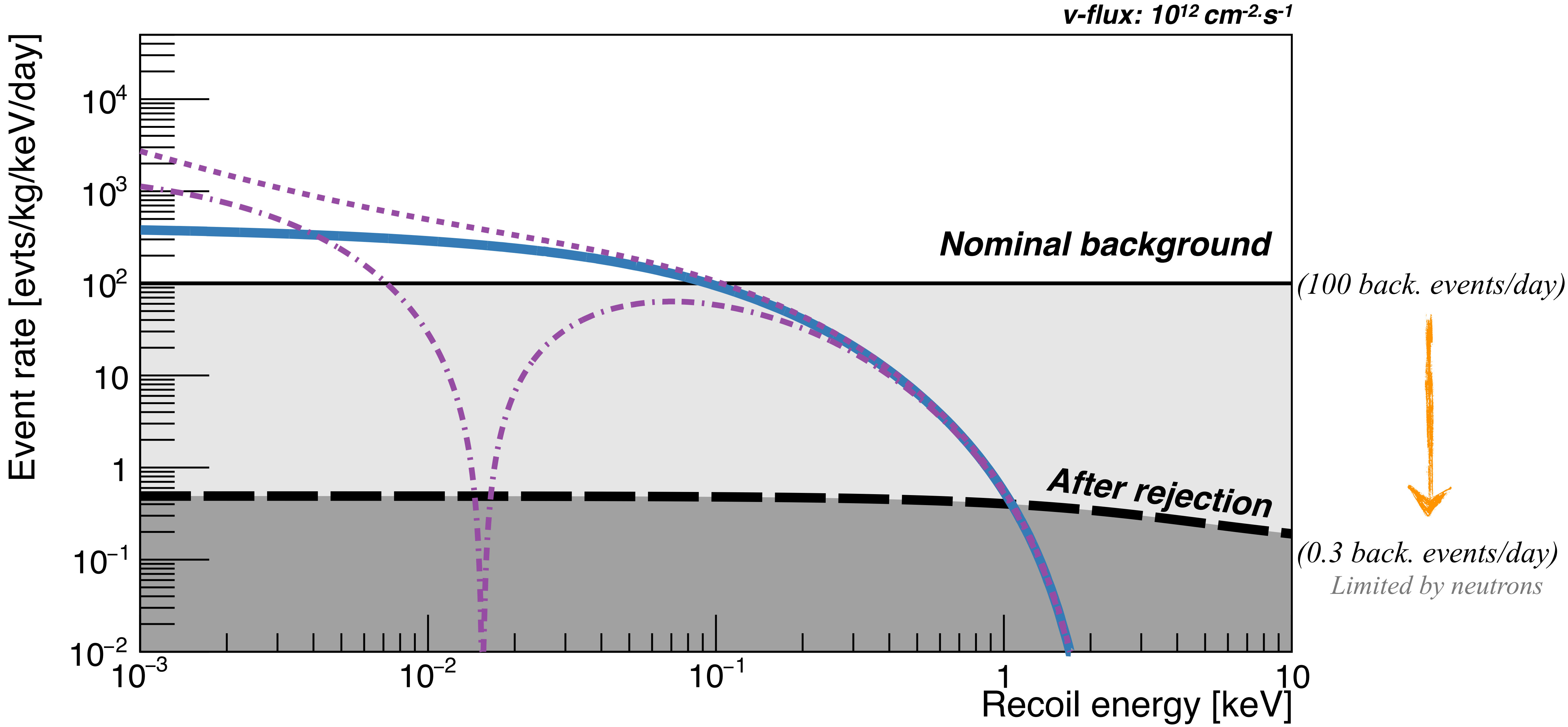
Ricochet: *searching for new physics*



New physics signatures will arise at the lowest energies
Calls for very low-energy thresholds: O(10) eV

Ricochet: *searching for new physics*

Backgrounds, backgrounds, backgrounds, …



20 CENNS events/day: ***5 sigma CENNS detection in a couple of days !***

1 % precision measurement after one year

Ricochet: *Detector technology innovation (CryoCube)*

Detector wish list:

1) Very low energy threshold: ***O*(10) eV**
2) EM background rejection: **$>10^3$**
3) Significant target mass: **1 kg**
4) Target complementarity: **Ge and Zn**

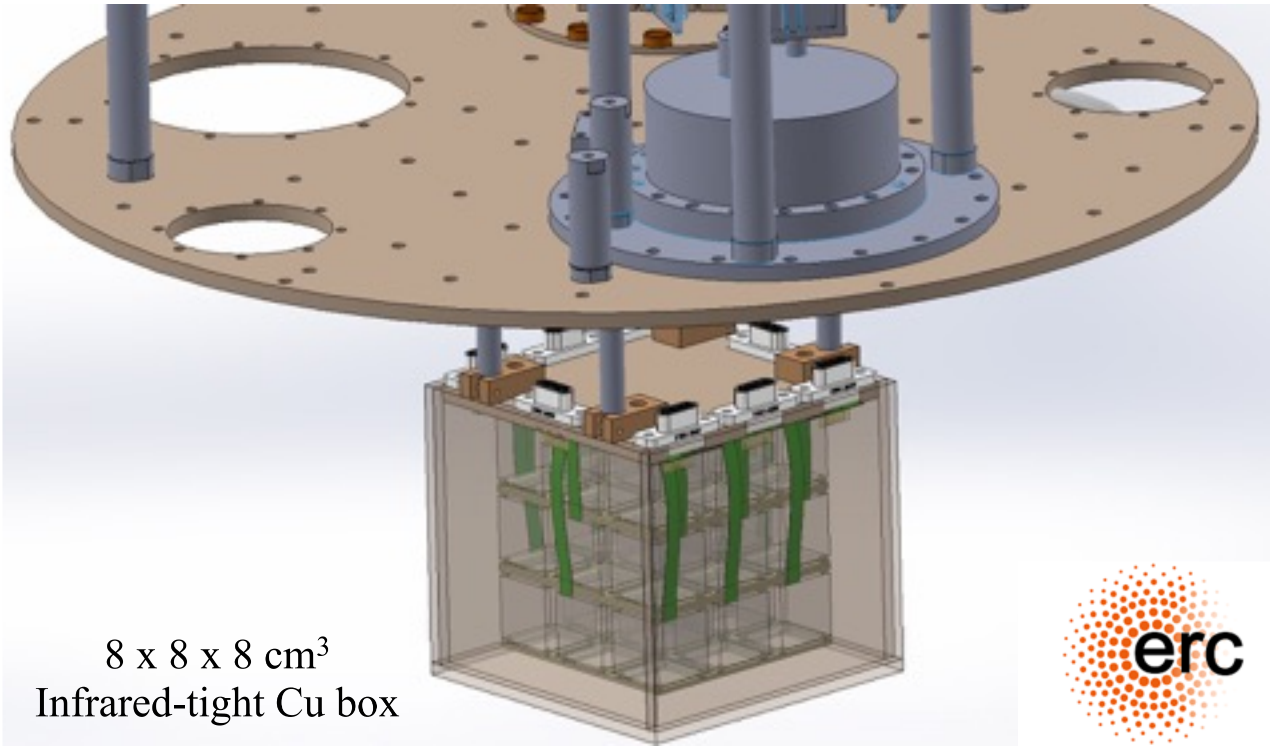
*<u>Key feature</u>: Achieve **Particle Identification** down to O(10) eV with a rejection $>10^3$*

<u>CRYOCUBE BASELINE DESIGN</u>

An array of 27 x 30 g cryogenic detectors (20 mK)

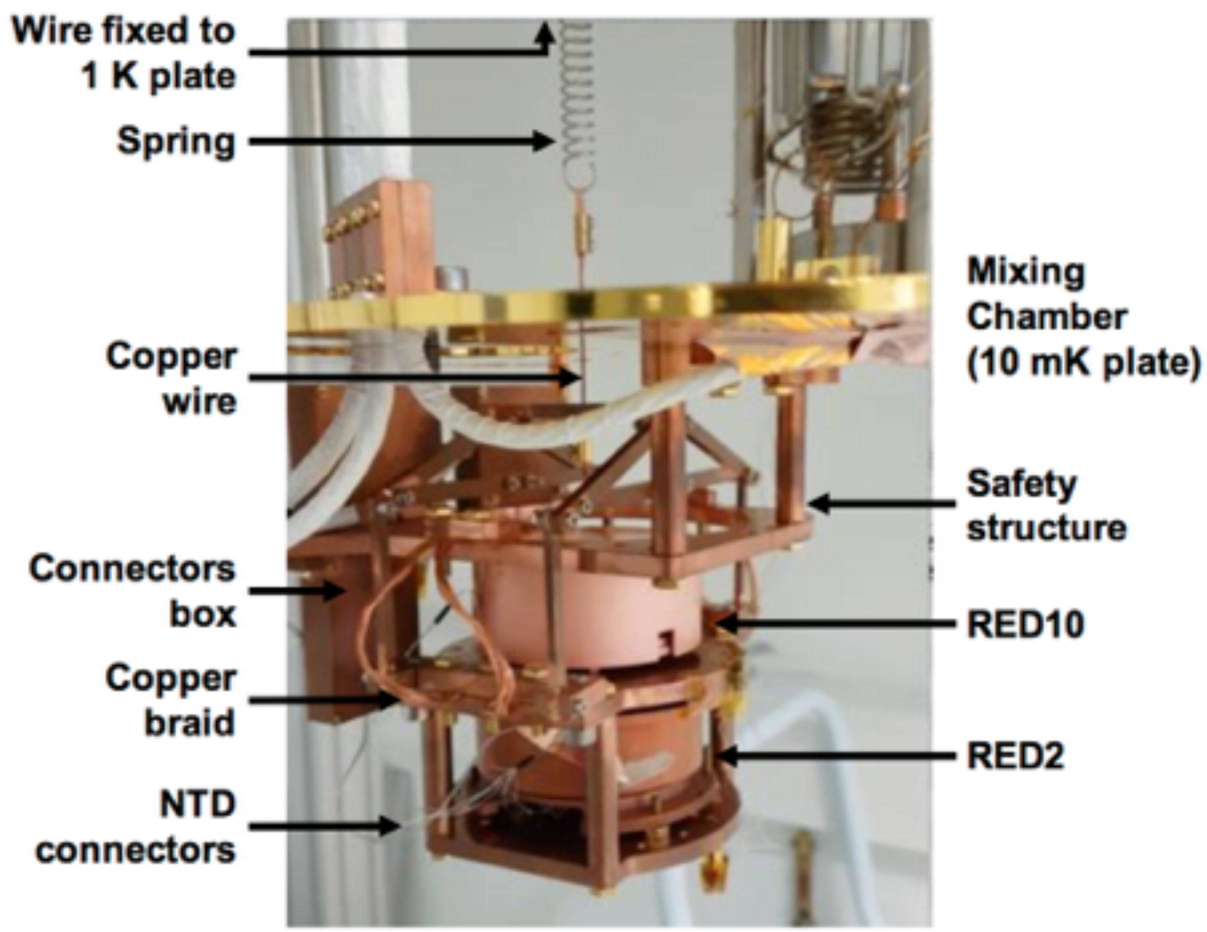
- 50 % of Ge semiconductors
- 50 % of Zn superconductors

Total: 1 kg with a minimum level of complexity

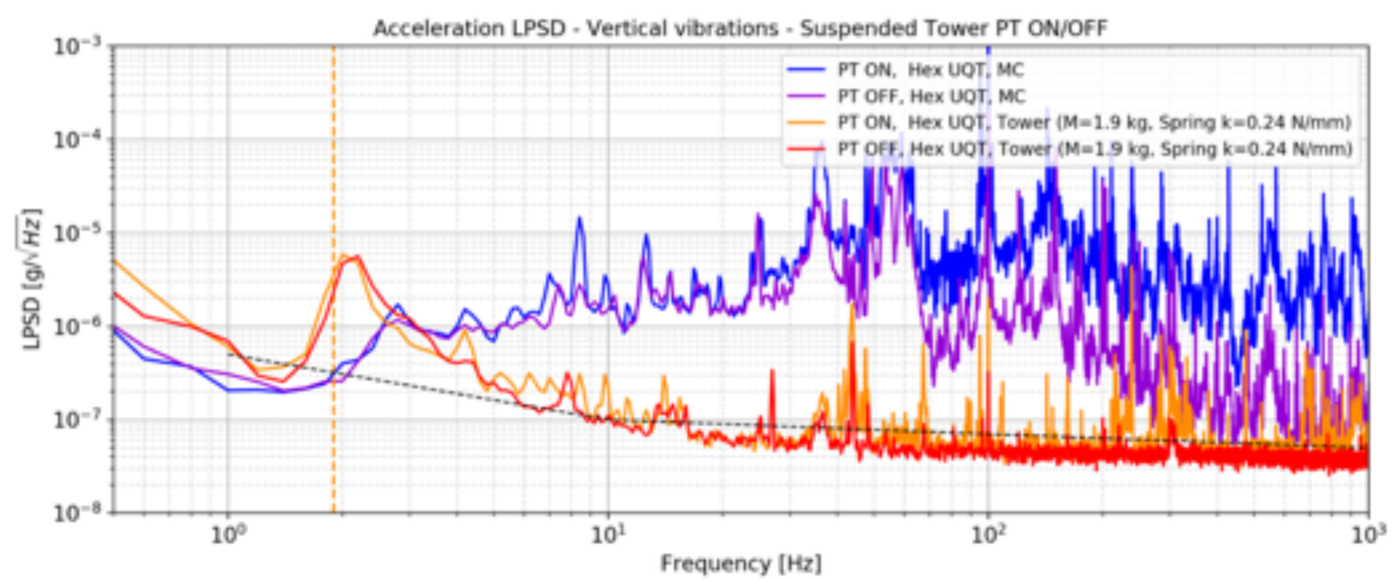


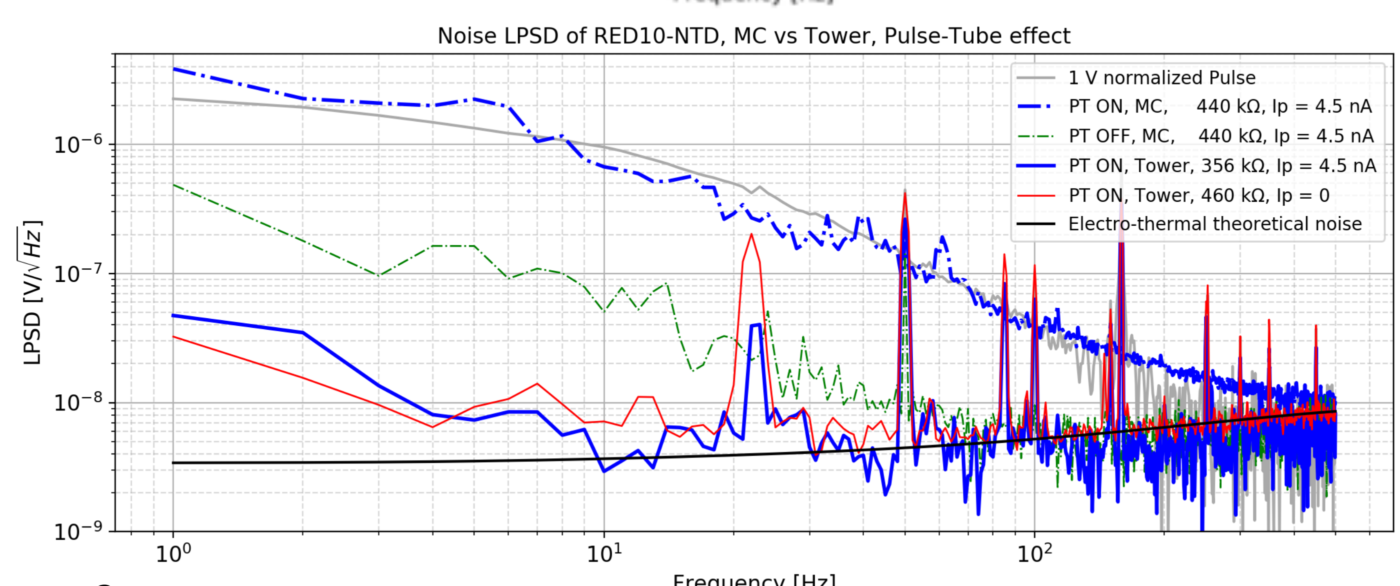
CryoCube: *Scalability and holding system*

- ***High impedance sensors (NTD, NbSi TES and electrodes) are highly sensitive to microphonics***
- Highly efficient cryogenic suspension system designed to host kg-scale payloads:
  - sub micro-g/sqrt{hz} level over the detector bandwidth (*limited by accelerometer sensitivity*)
- Detectors are now running in optimal conditions, only ***limited by thermodynamic and electronic noises***
- ***5 detector tower in September***

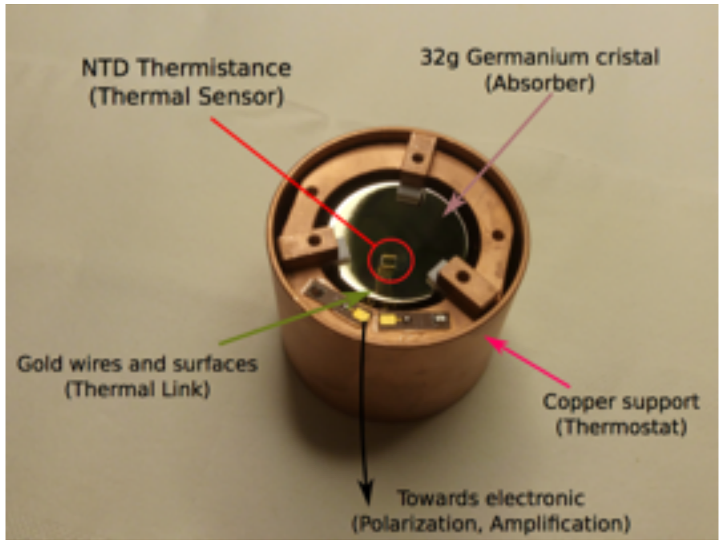


R. Maisonobe et al., JINST **2018**





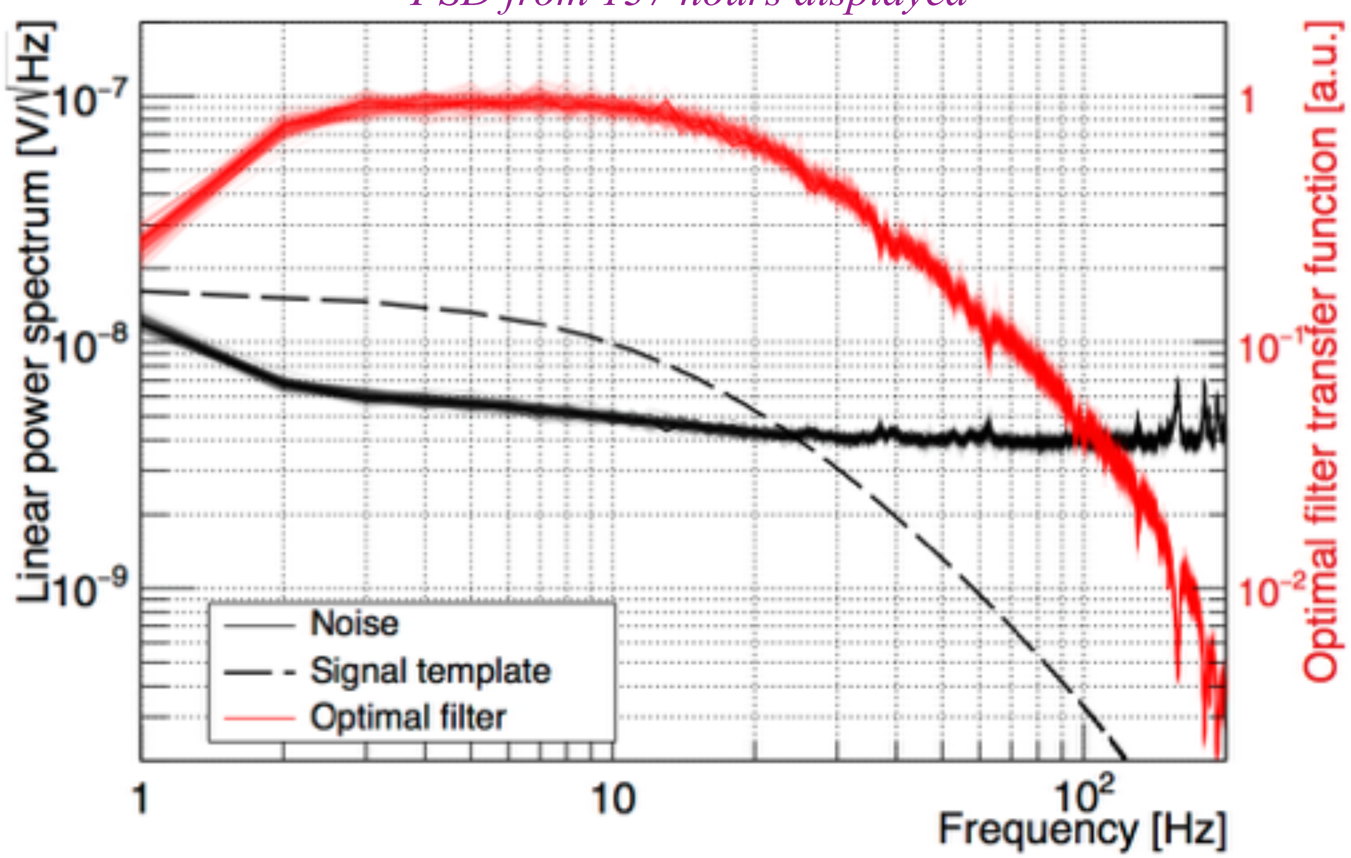
CryoCube: *Heat energy resolution 10 eV (rms)*



E. Armengaud et al., Phys. Rev. D 99, 082003 (2019)

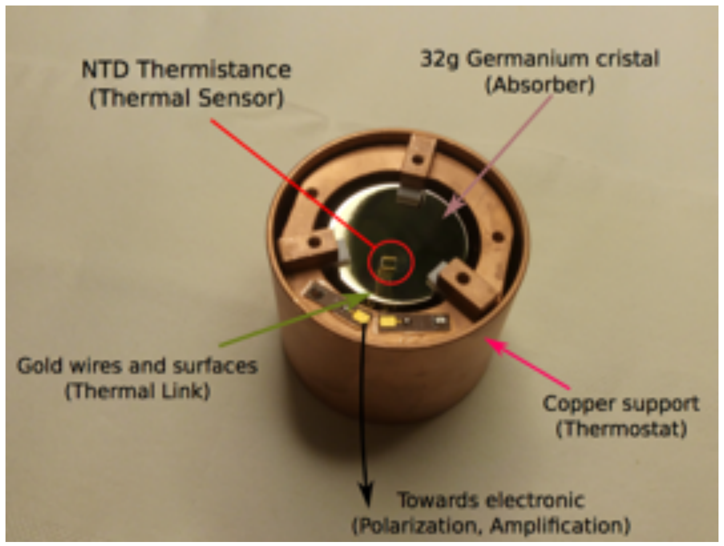
Major accomplishment: **18 eV energy resolution** (RMS)
55 eV energy threshold
with a **33.4 g detector** (Ge)
near perfect stability (~%)

PSD from 137 hours displayed



- Optimisation of thermal design based on a **fully data driven electro-thermal modeling** *(D. Misiak et al., in preparation)*
- Large improvement on heat energy resolution:
  - 20 eV (RMS) on four 33.4 g Ge crystals
  - 50 eV (RMS) on a 200 g Ge crystals
  - *Achieved in above-ground operation (IPNL)*
- Thanks to enhanced thermal response sensitivity and improved noise conditions (suspension)

CryoCube: *Heat energy resolution 10 eV (rms)*



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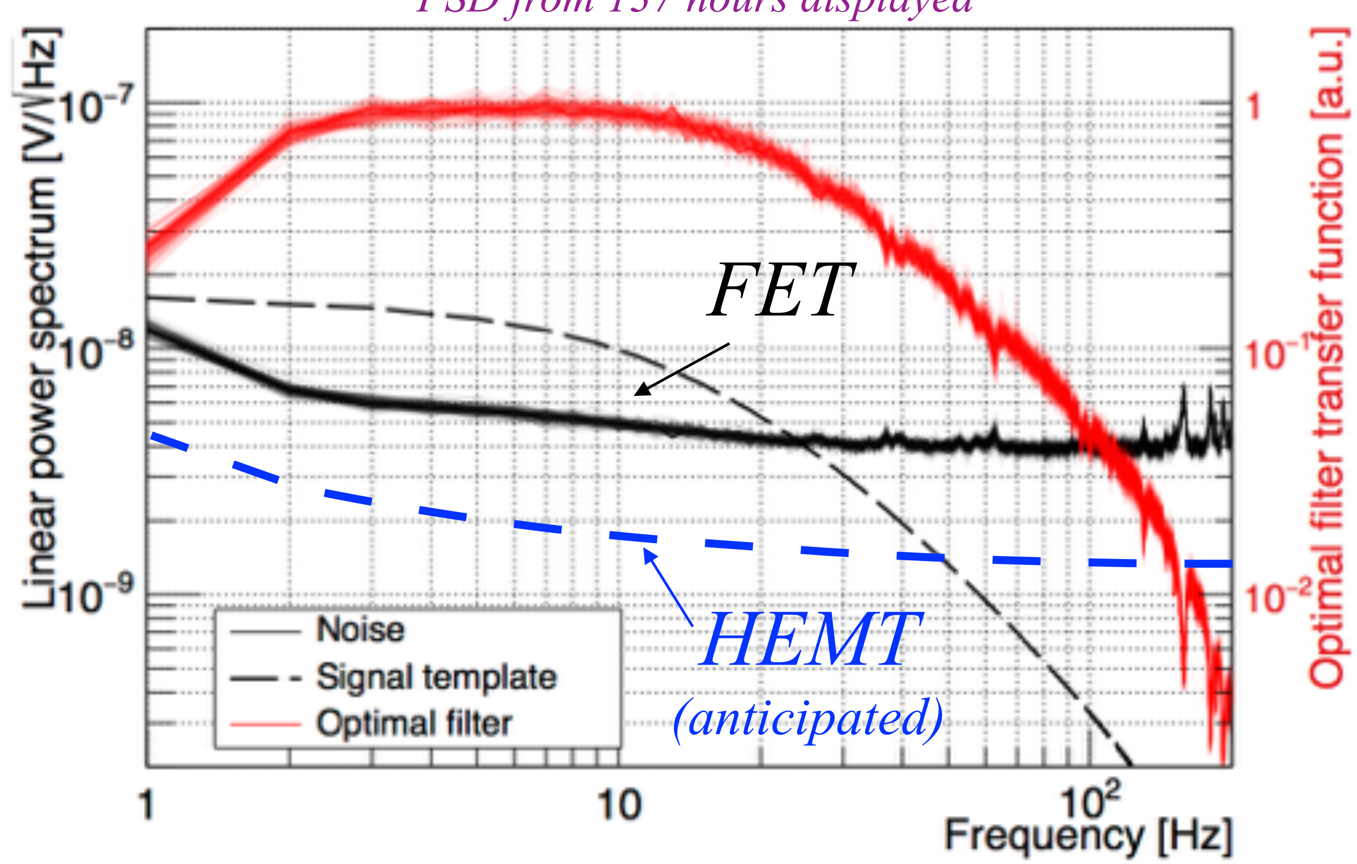
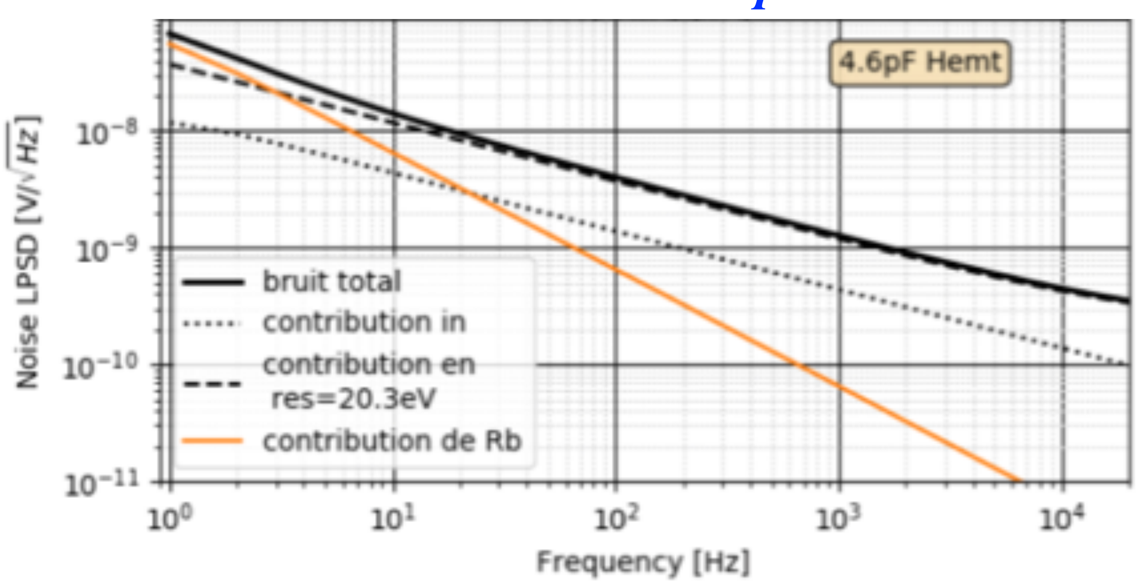


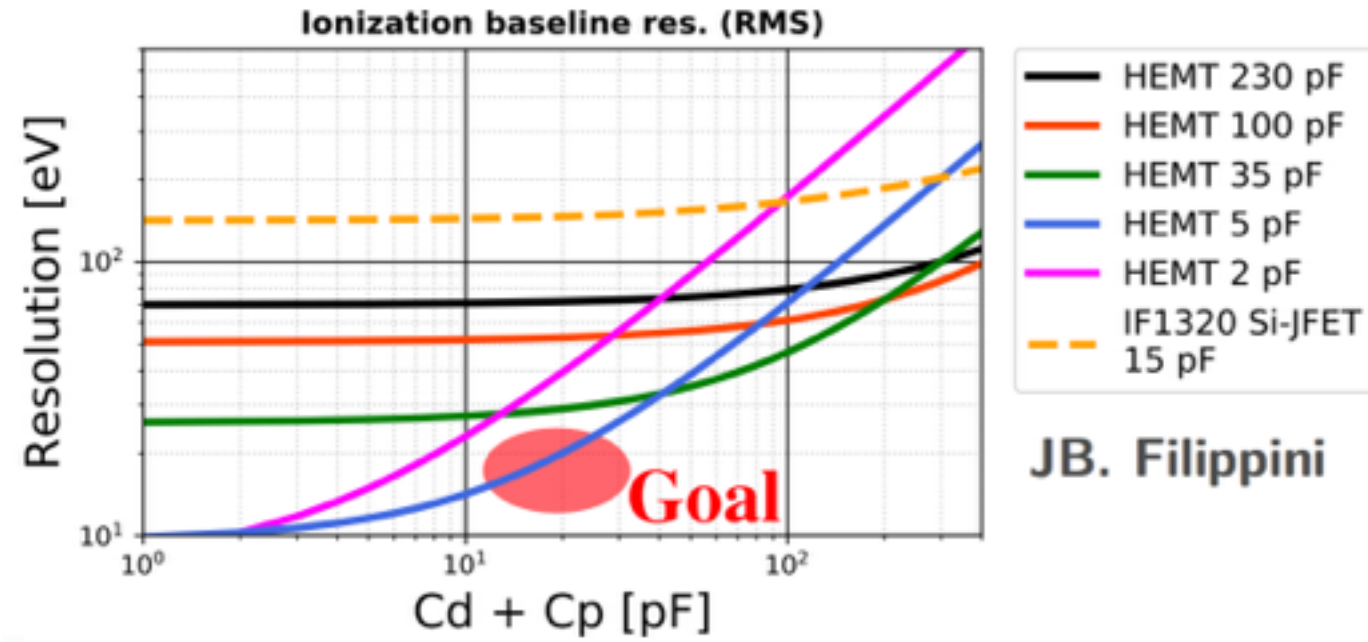
Limited by FET current noise, switch to HEMT in order to reach 10 eV (RMS) on 33.4 g crystals

CryoCube: *EM background rejection of O(10^3)*

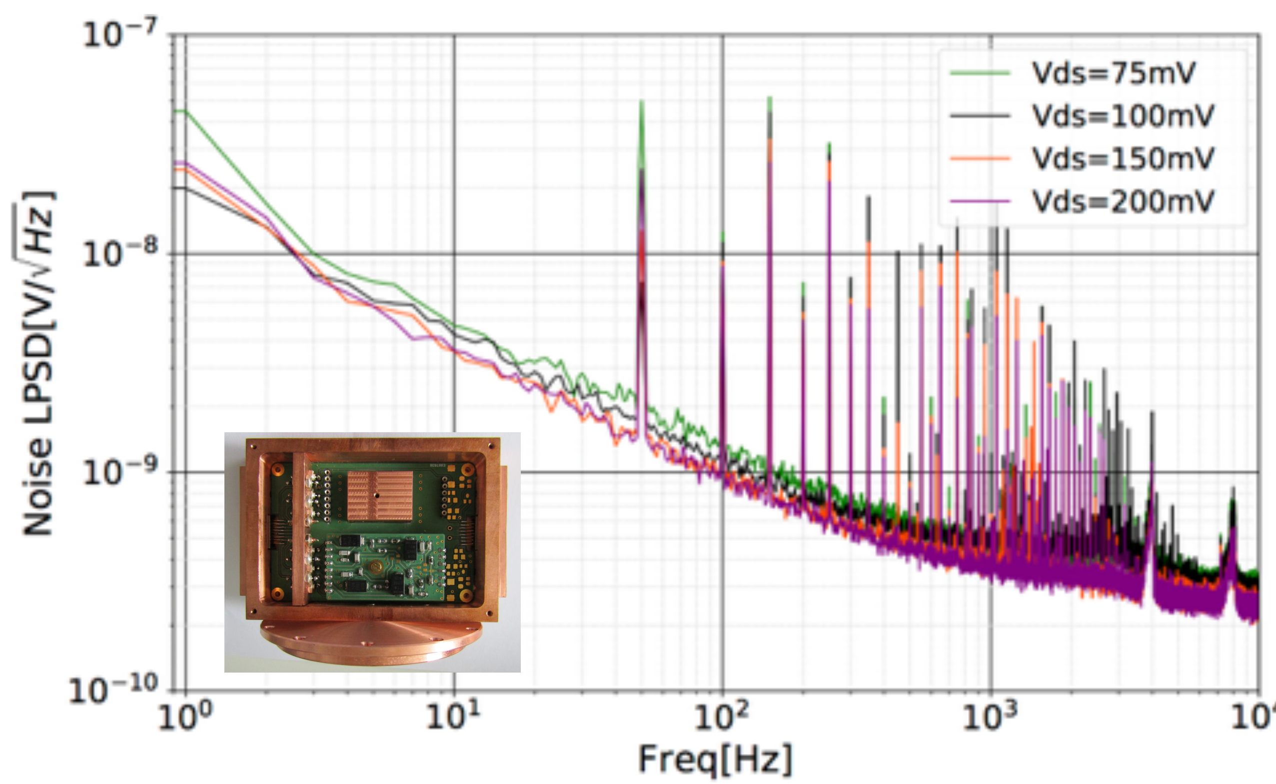
20 eV ionization resolution: *HEMT preamplifiers + new electrode design*

See A. Juillard - poster 373





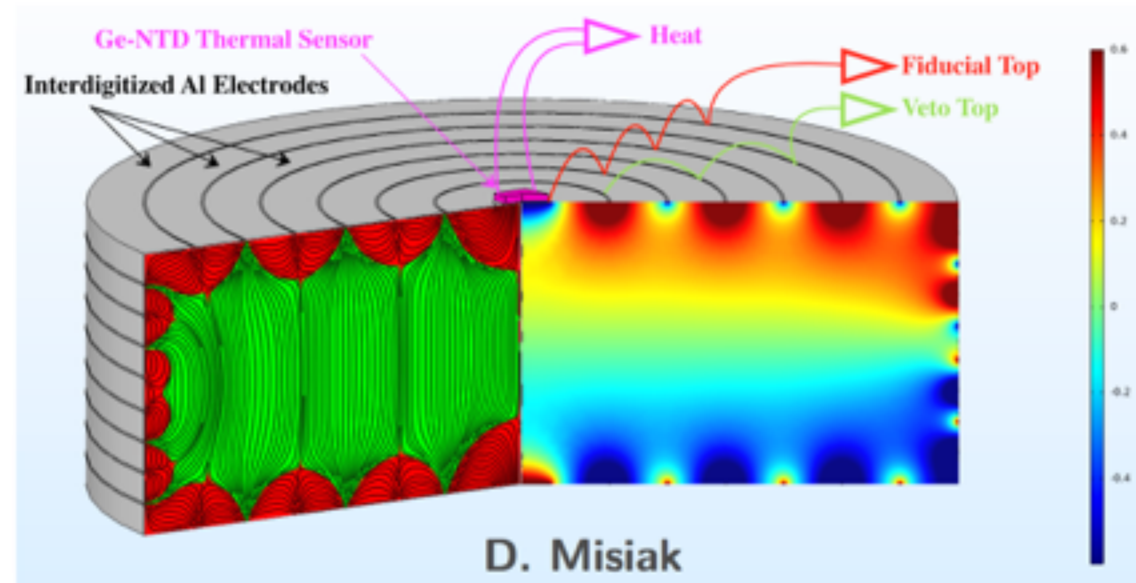
- As initiated by the CDMS-Berkeley group *A. Phipps et al. NIM-A 2019,* we are transitioning to HEMT based preamps.
- HEMT have lower intrinsic noise than JFET
- Work @ 4/1 K allowing to reduce the stray capacitance
- Based on our **data driven HEMT model**, *O*(10) eV rms reachable with ~20 pF total input impedance
- HEMT characterizations are ongoing
- ***First HEMT-based preamp to be tested in winter 2019***
- Synergie with the EDELWEISS collaboration



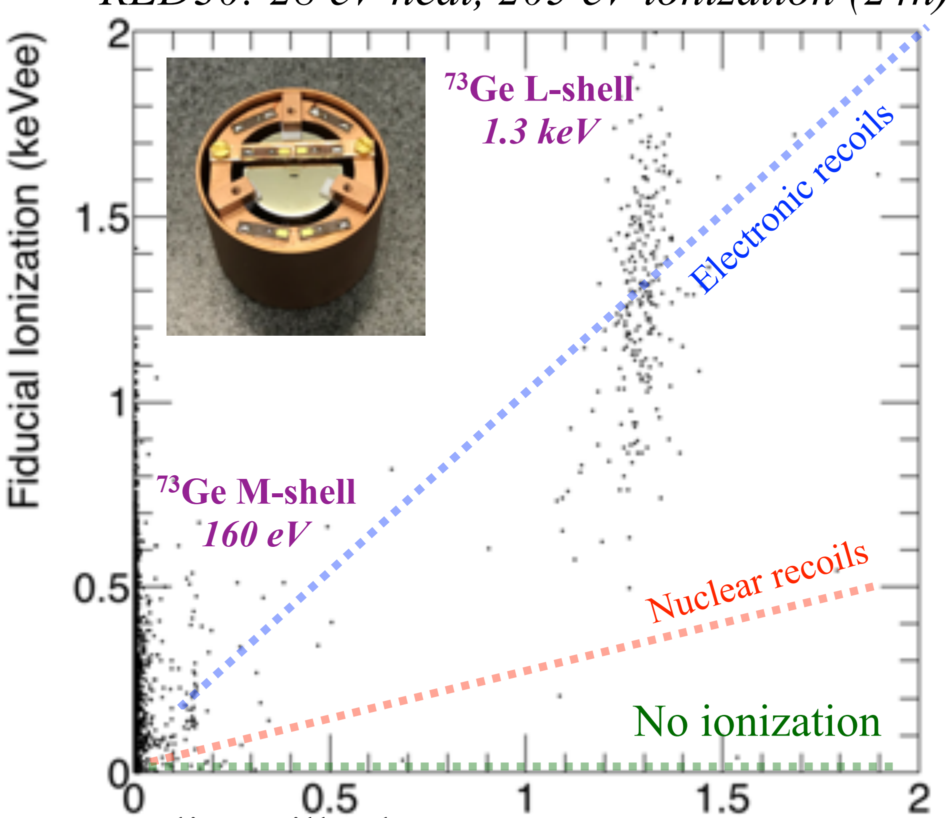
CryoCube: *EM background rejection of O(10^3)*

***20 eV ionization resolution:** HEMT preamplifiers + new electrode design*

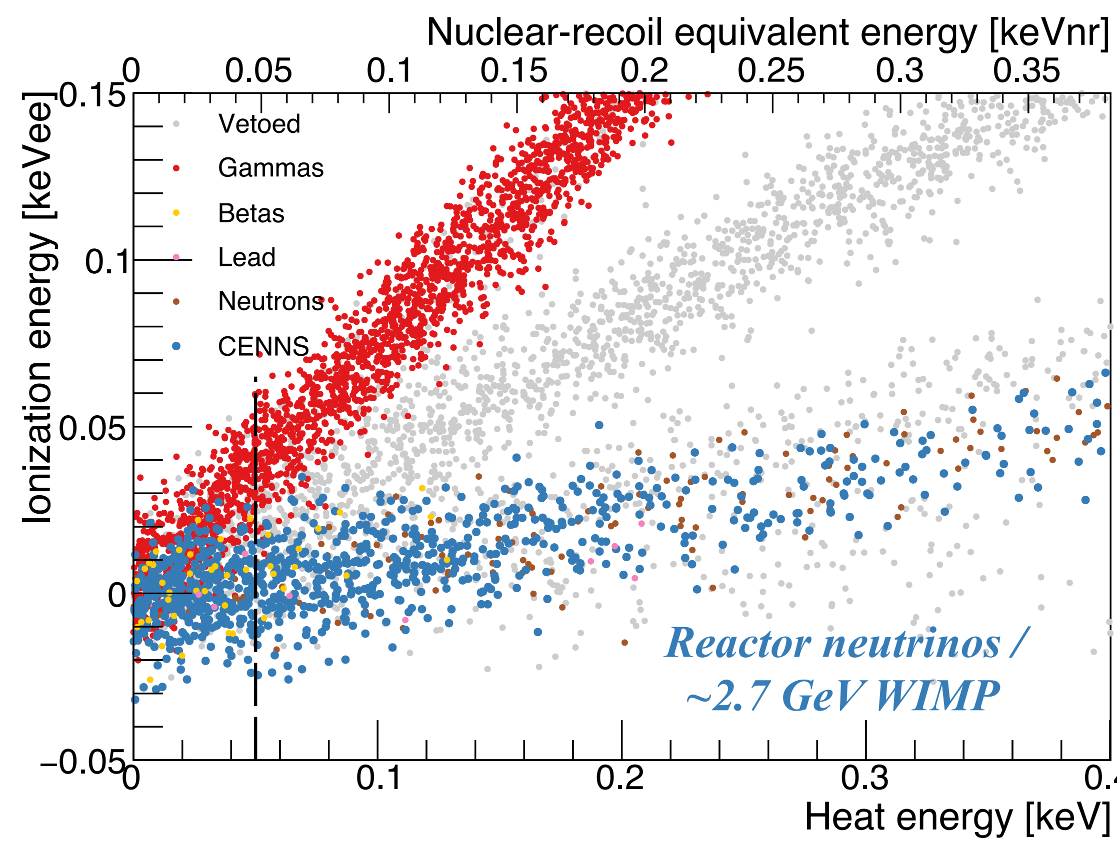
- Design of new electrode scheme with following specs.:
  - *Low input capacitance (10 to 20 pF)*
  - *High surface event rejection efficiency (FID mode)*
  - *Large fiducial volume (75%)*
- Aim at O(10^3) EM background rejection down to 50 eVnr
- Synergie with the EDELWEISS collaboration



RED30: 28 eV heat, 205 eV ionization (24h)



FET to HEMT

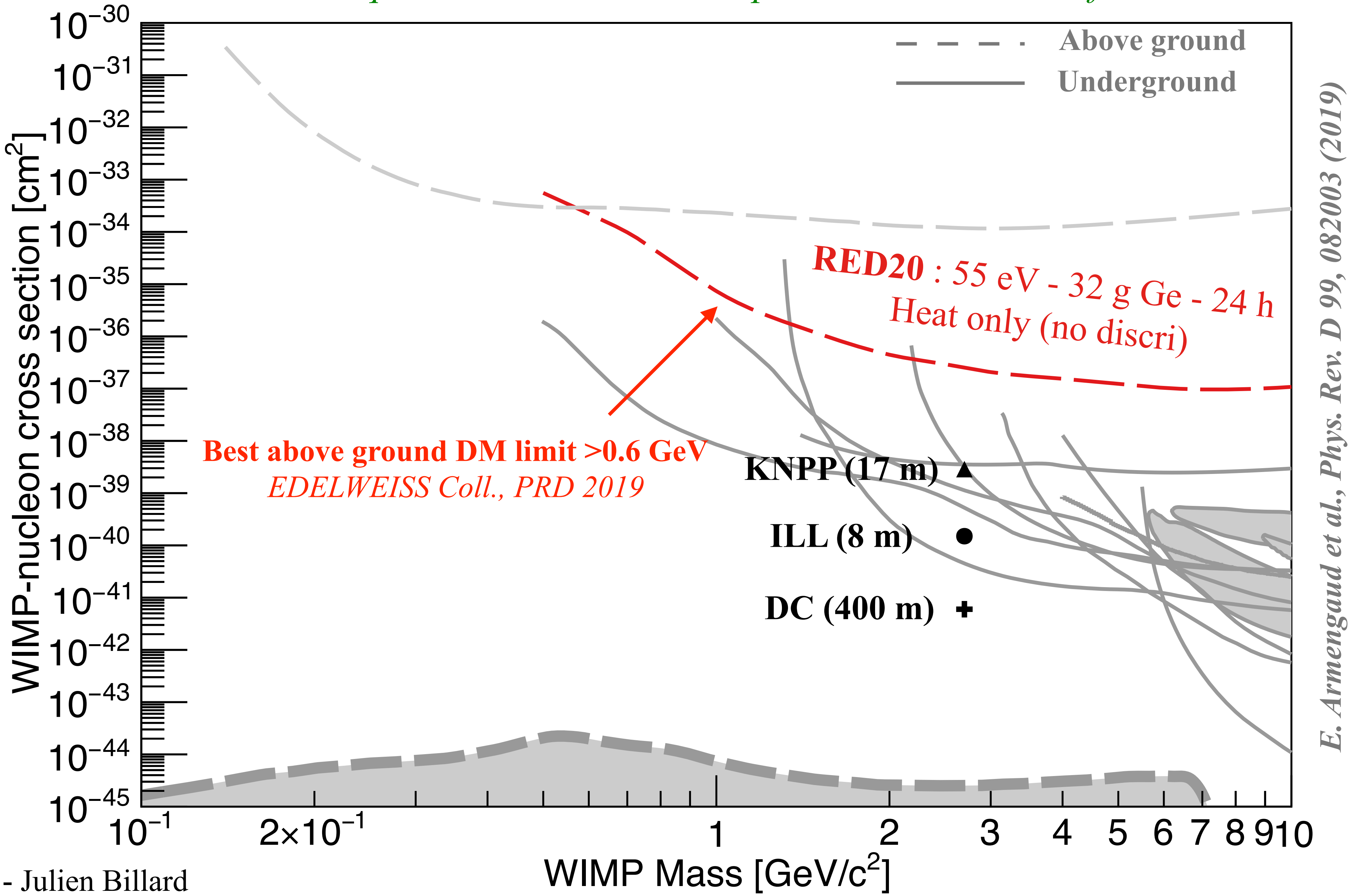


Ricochet/CryoCube: *Present sensitivity to CENNS*

Neutrino-WIMP equivalent model ***independent of target material***

CENNS signal from reactor neutrino is similar to a 2.7 GeV WIMP !!

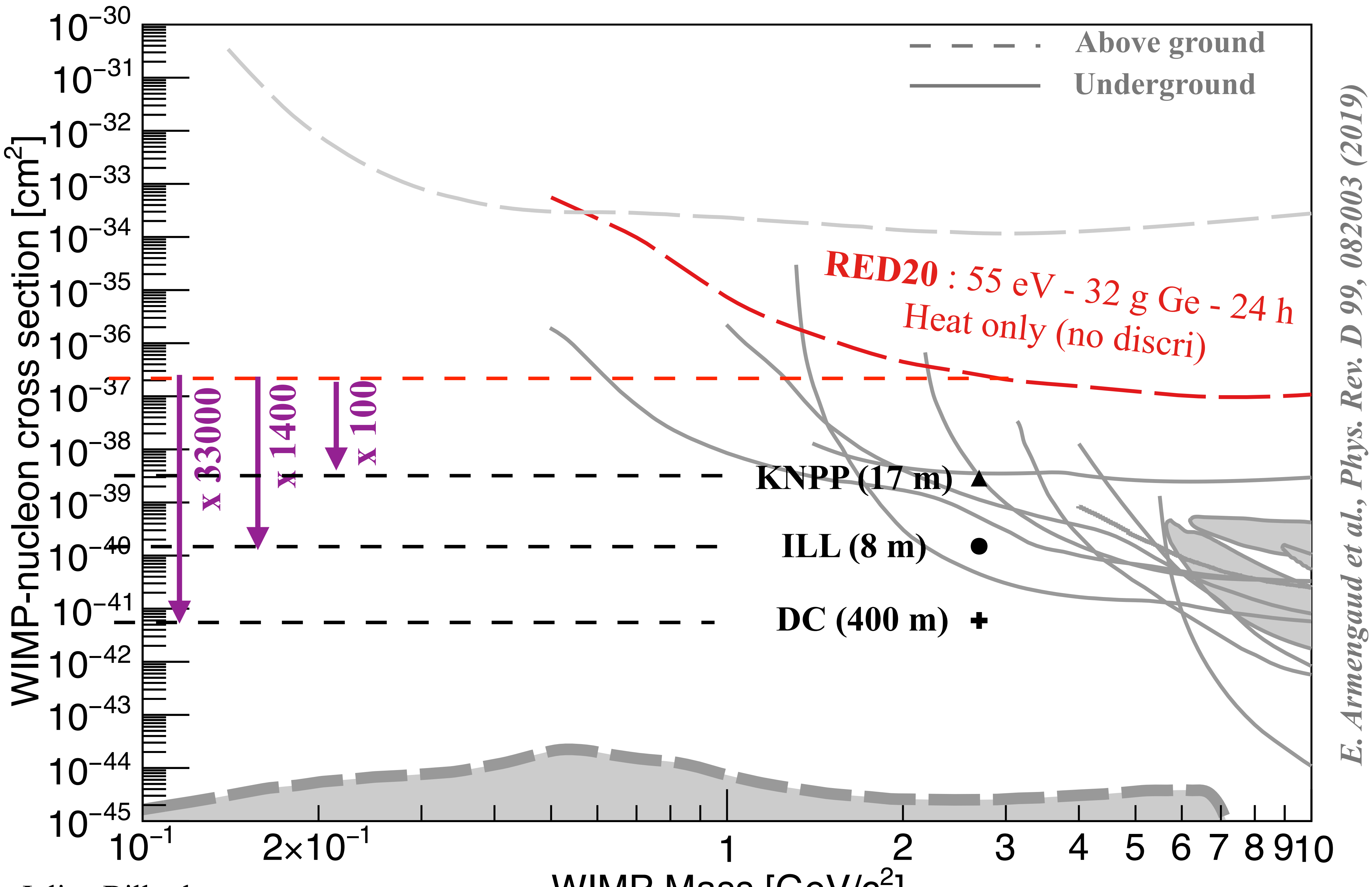
The equivalent cross section depends on the neutrino flux



Ricochet/CryoCube: *Present sensitivity to CENNS*

Sensitivity improvement needed towards CENNS sensitivity @ reactors

We need to do as well as the best cryogenic DM experiments but from aboveground !!

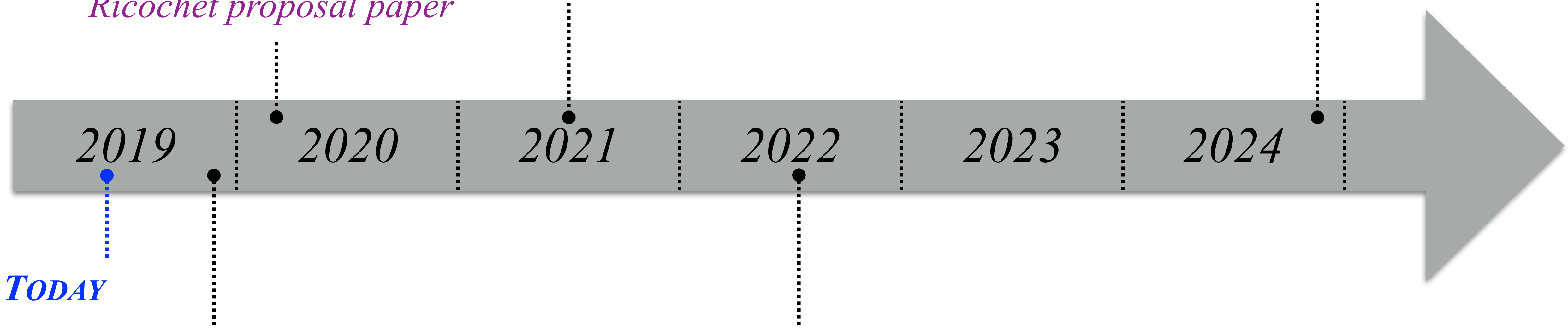


RICOCHET: *Anticipated timeline*

2021:
Ricochet's technical design completed (mechanics, cryostat, cabling, and warm elec.).

2024:
Deliver the first low-energy (sub-100 eV) high-precision (%-level) CENNS measurement after 1 year of data taking

2020:
Ricochet proposal paper



End-2019:
Nuclear site decision and first version of Ricochet's experimental setup

2022:
Deployment of the Ricochet experiment at the chosen nuclear reactor site.
CRYOCUBE anticipated delivery date

Conclusion

Since its first detection by the COHERENT collaboration in July 2017, CENNS has become a burgeoning field of research

A very exciting process that has yet to be explored:

- from ton-scale to kg-scale neutrino experiments *(ideal for nuclear reactor monitoring)*
- New probe for physics beyond the SM *(new massive mediators, anomalously large NMM, …)*
- Required for upcoming precision neutrino oscillation measurements *(Non Standard Interactions)*
- Astrophysics wise: drives supernovae dynamics and the neutrino floor to DM direct searches

Growing interest in measuring this process in Europe: RICOCHET, NuCLEUS are forming a consortium. ***Both supported with ERC Starting Grants.***

Ricochet is the only sub-100 eV CENNS experiment investigating **particle identification** *(for both known and unknown backgrounds)* to ***provide a decisive %-level CENNS measurement by 2024.***

Ricochet's onsite integration anticipated in 2022.

Ricochet/CryoCube: *Present sensitivity to CENNS*

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