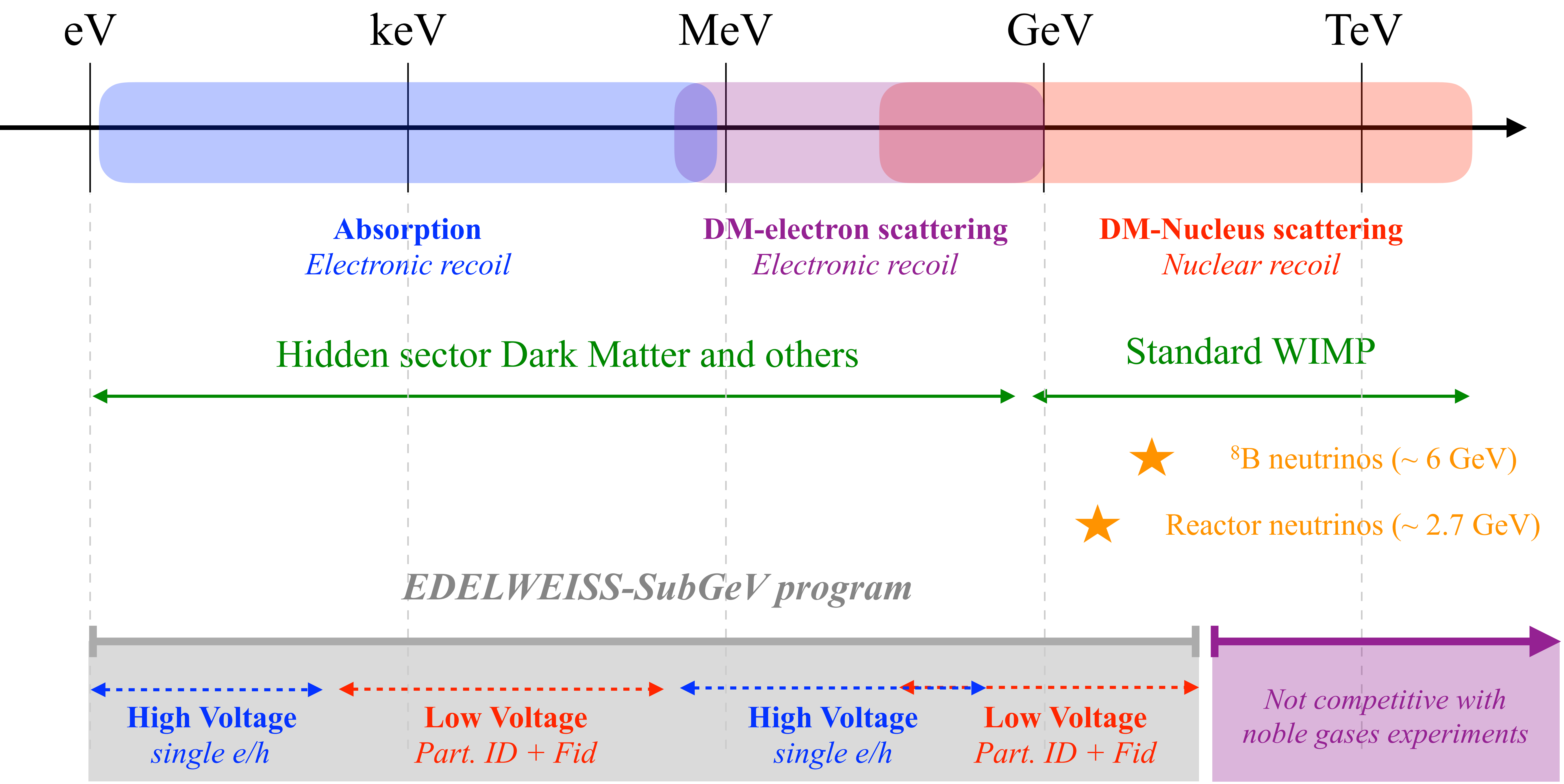
Cryogenic charge and phonon detectors:
EDELWEISS-SubGeV

J. Billard
Institut de Physique Nucléaire de Lyon / CNRS / Université Lyon 1

Light Dark Matter Workshop
Chicago, June 3-7, 2019

EDELWEISS-SubGeV: *Scientific context*



EDELWEISS-SubGeV: *Detector technology*

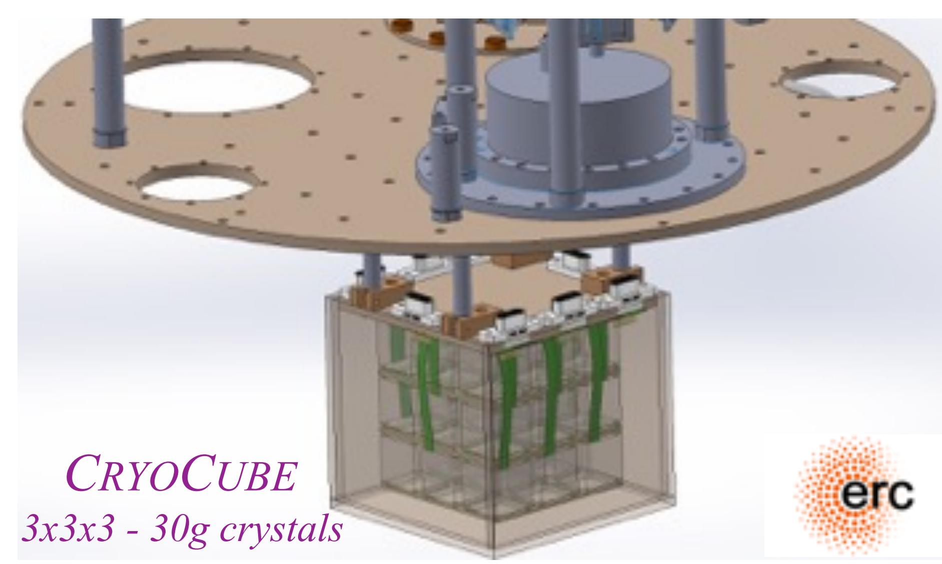
EDELWEISS-SubGeV: aiming for a kg-scale payload of 30 to 200g Ge detectors running in two modes:

- **Low Voltage:** Particle ID - ER/NR/'unknown backgrounds' - and fiducialization *(synergy with Ricochet)*
- **High Voltage:** single-e/h sensitivity by operating in a Neganov-Luke mode

Detector wish list:

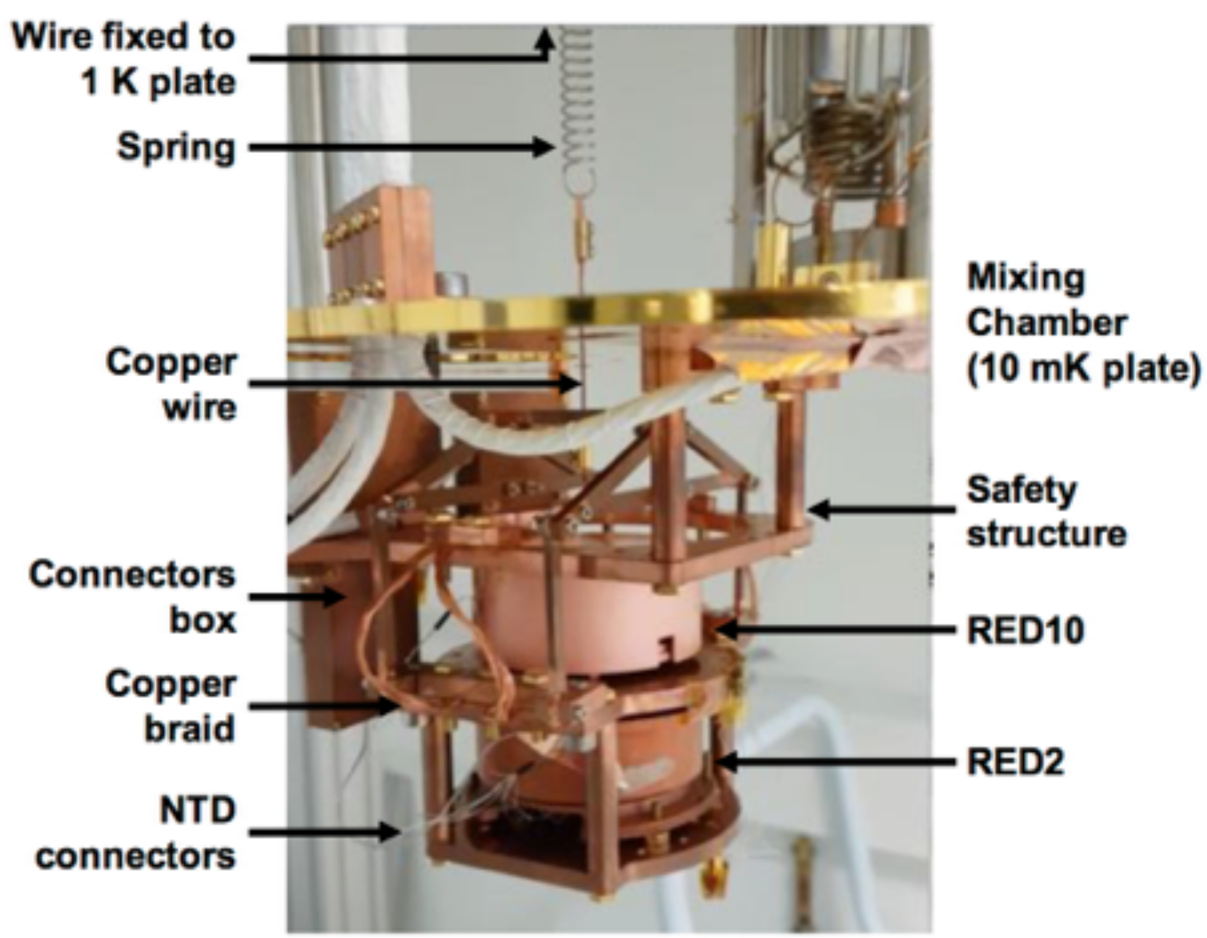
1) Scalability to significant payload: **1 kg (30 to 200 g crystals)**
2) Heat energy resolution (RMS): **10 eV**
3) EM background rejection (LV mode): **$>10^3$**
4) Operation at high voltages (HV mode): **100V**

*Goals 1-to-3 are part of a common effort with the Ricochet collaboration, dedicated to studying CENNS at reactors, in the construction of the CryoCube detector supported by the **ERC-CENNS Starting Grant (2019-2024)***

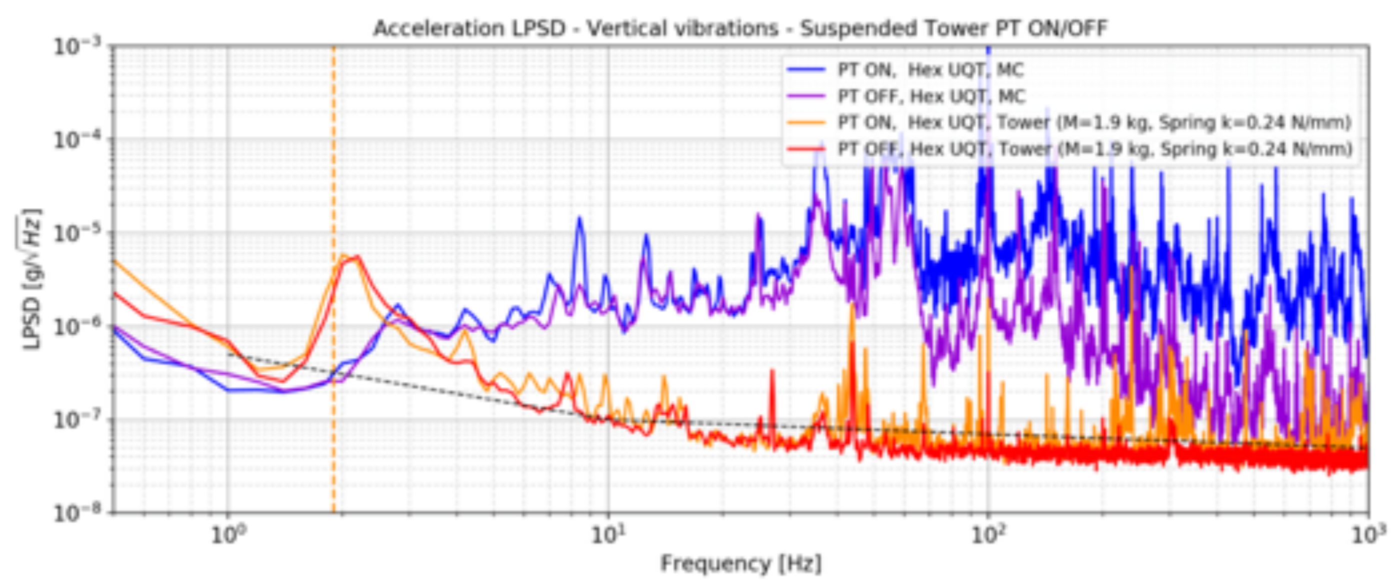


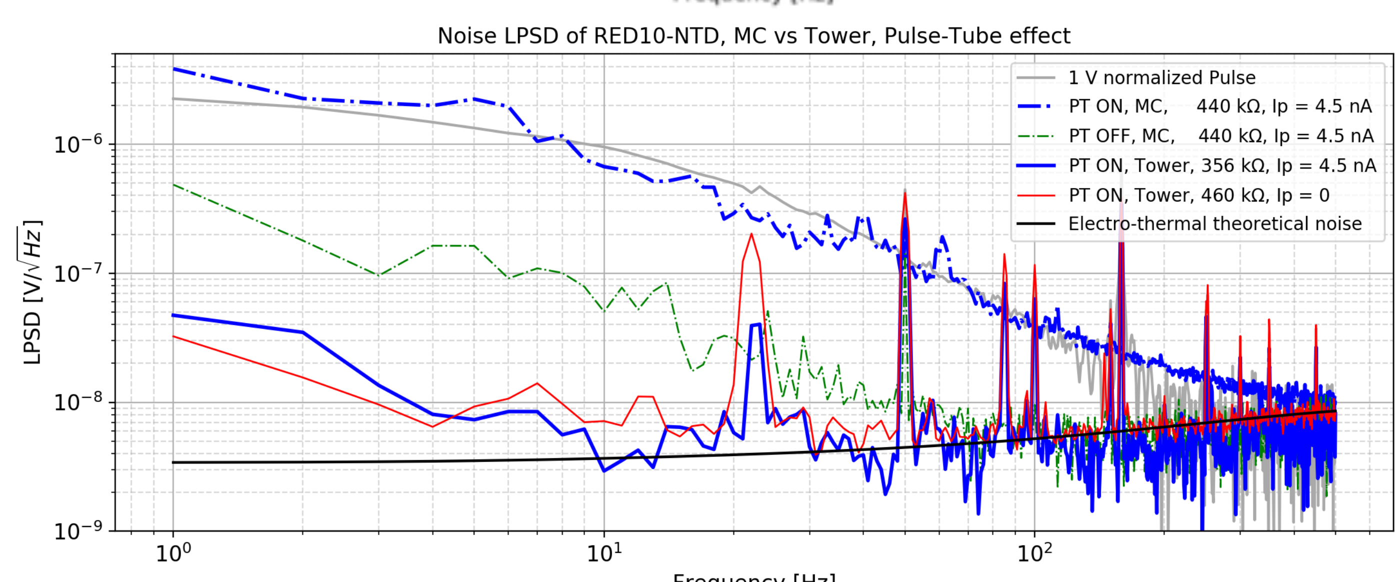
Goal #1: *Scalability and holding system*

- ***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***

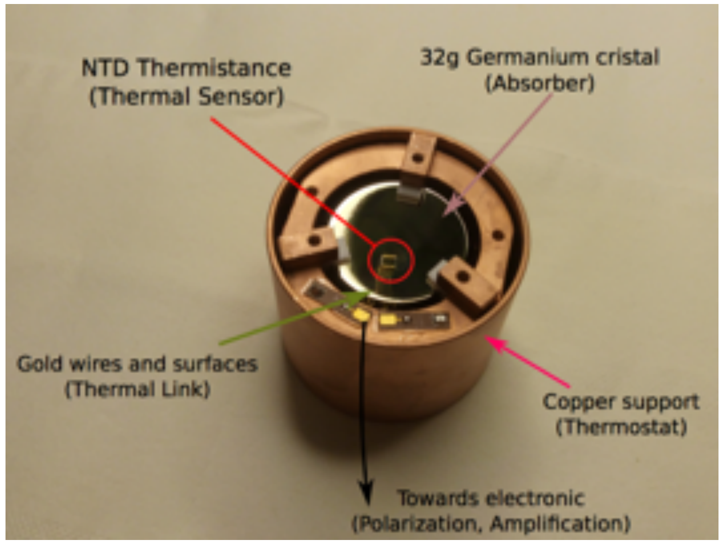


R. Maisonobe et al., JINST **2018**





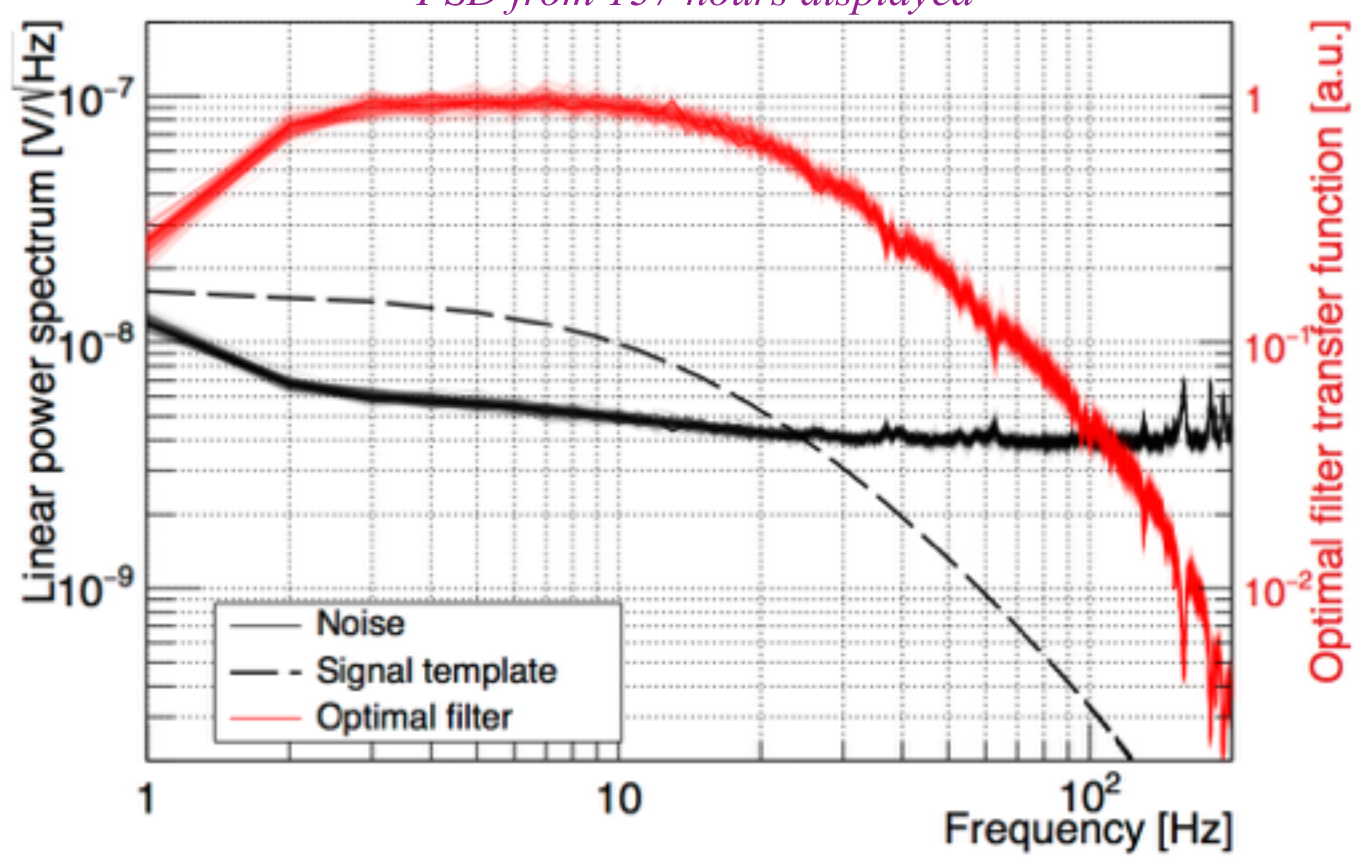
Goal #2: *Heat energy resolution 10 eV (rms)*



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

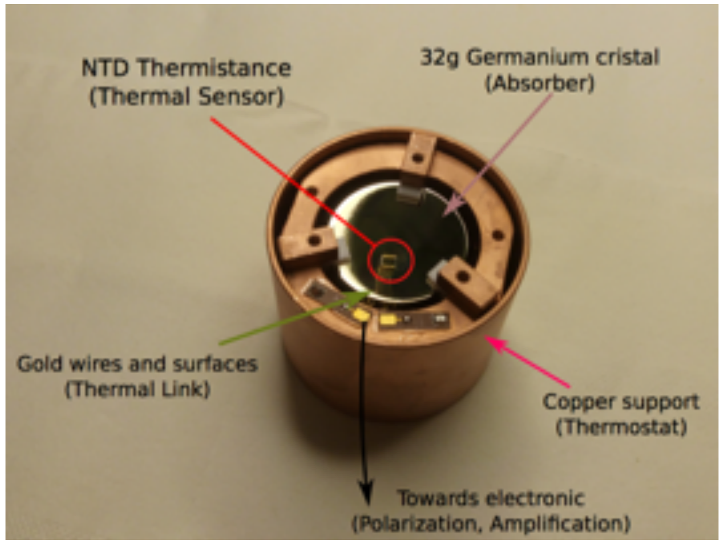
Major accomplishment: **18 eV energy resolution** (RMS)
55 eV energy threshold
with a **33.4 g detector** (Ge)
near perfect stability (~%)

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)

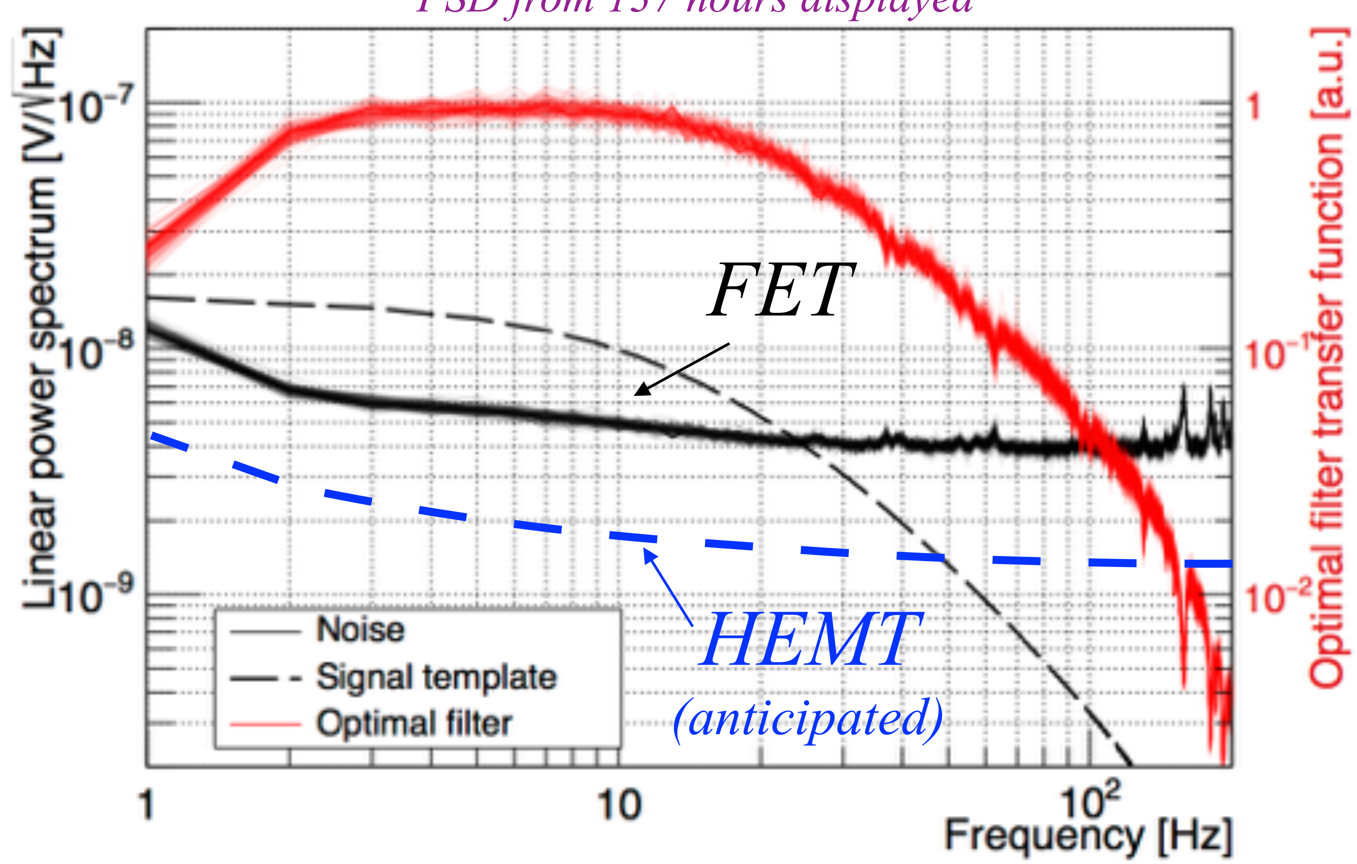
Goal #2: *Heat energy resolution 10 eV (rms)*



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 (~%)

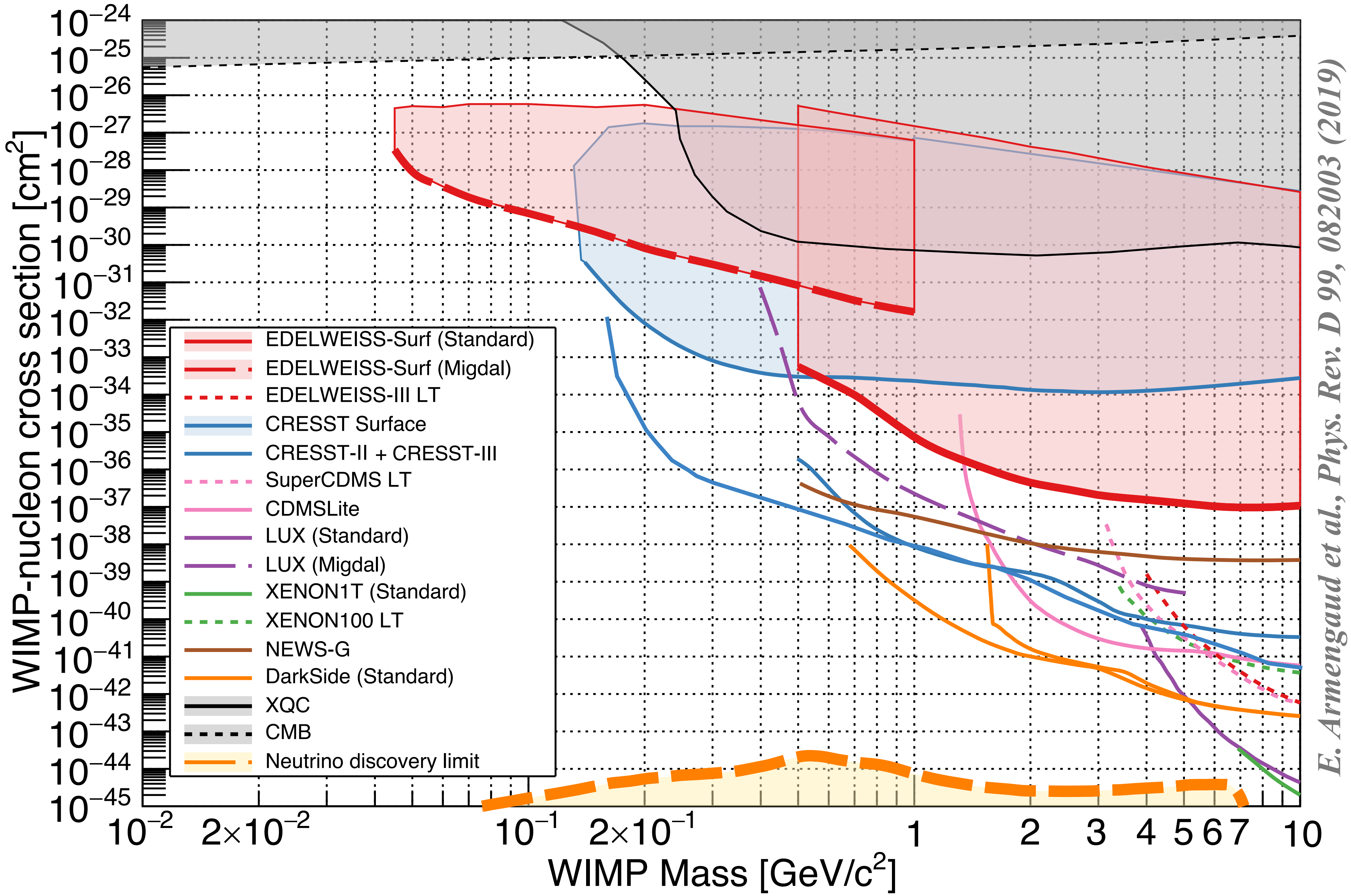
PSD from 137 hours displayed



- 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)

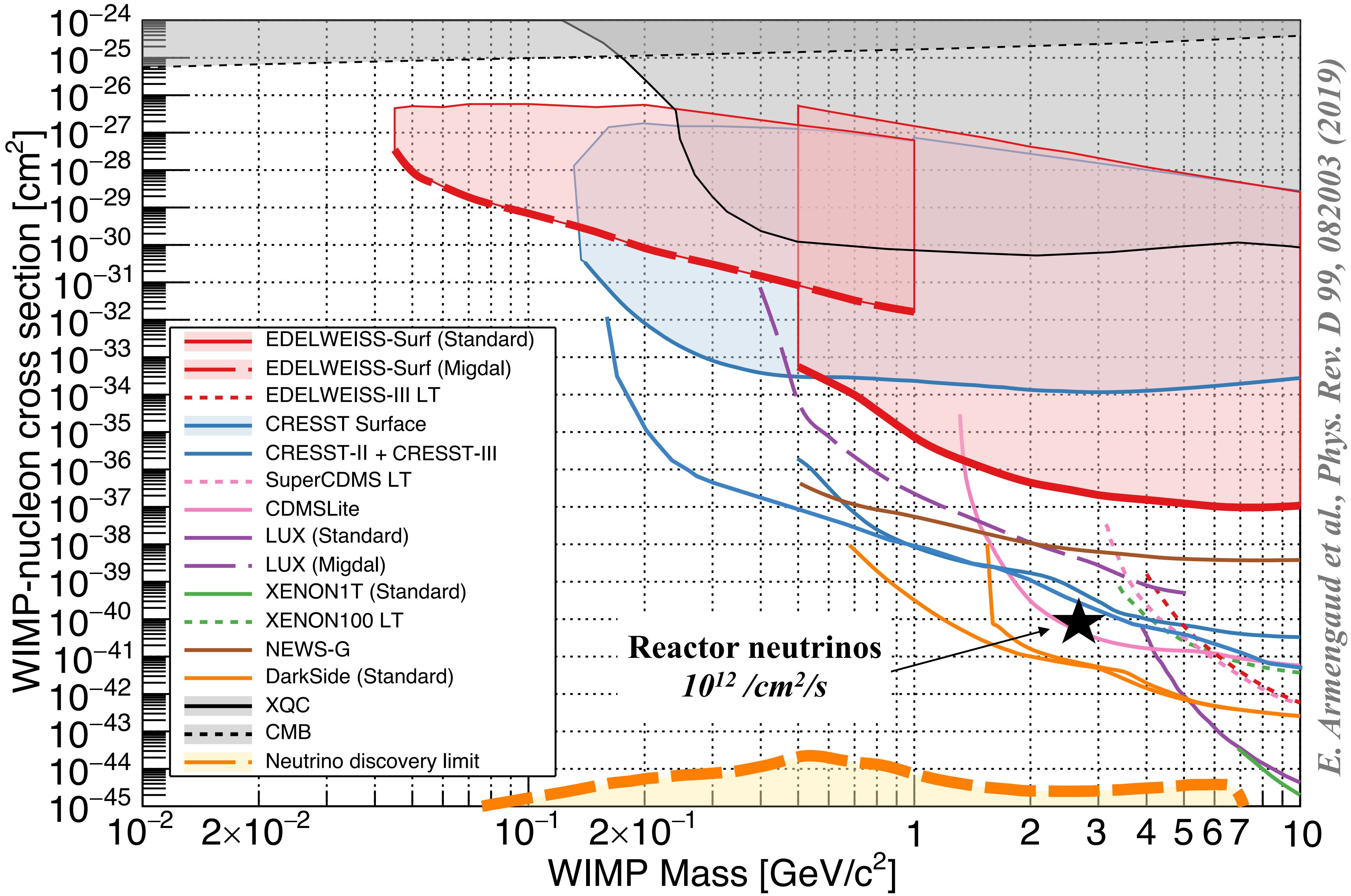
Limited by FET current noise, switch to HEMT in order to reach 10 eV (RMS) on 33.4 g crystals

Goal #2: *Heat energy resolution 10 eV (rms)*



- ***DM - Nucleus interaction:*** first Ge-based limit below 1.2 GeV and best above ground limit down to 600 MeV
- ***Migdal effect***: first DM limit down to 45 MeV limited by Earth-Shielding effect *(B. Kavanagh, 2017)*, which becomes significant > 10^{-31} cm^2 *(plans to measure this effect with the EDELWEISS experimental setup)*

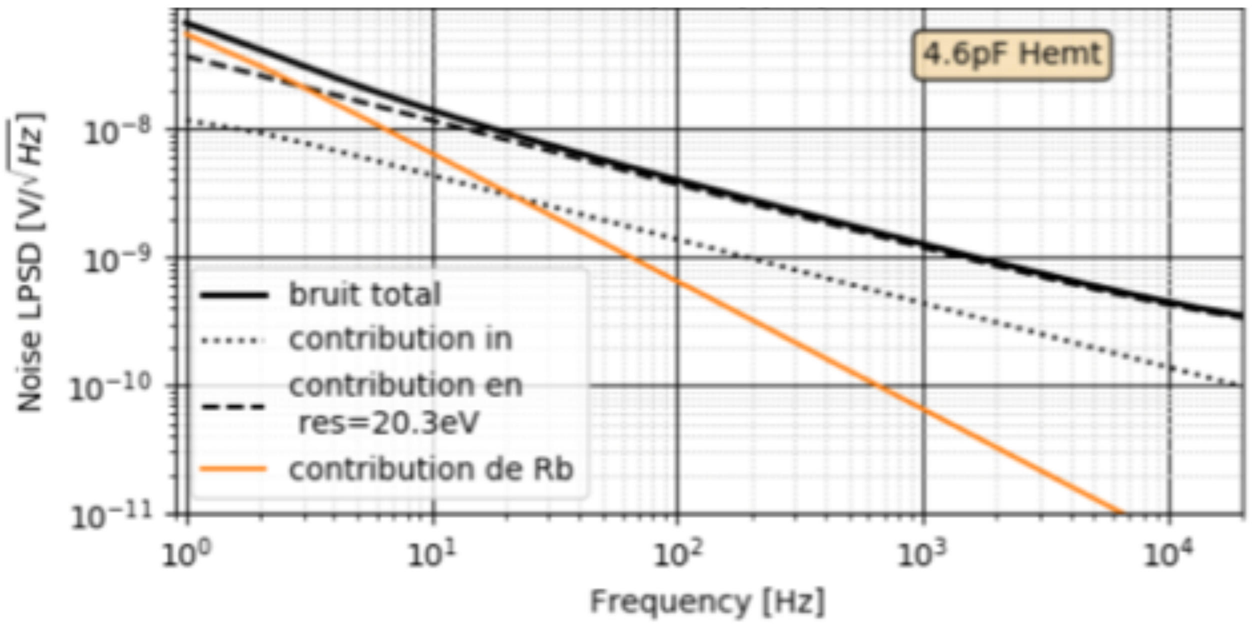
Goal #2: *Heat energy resolution 10 eV (rms)*

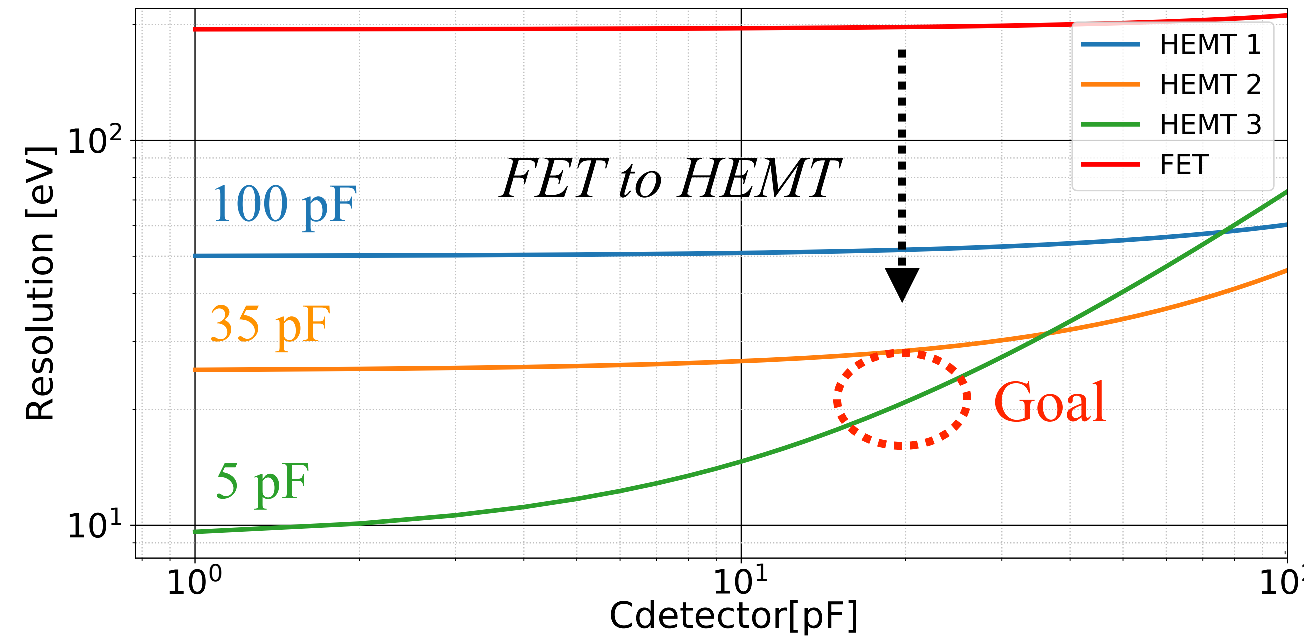


- ***DM - Nucleus interaction:*** first Ge-based limit below 1.2 GeV and best above ground limit down to 600 MeV
- ***Migdal effect***: first DM limit down to 45 MeV limited by Earth-Shielding effect *(B. Kavanagh, 2017)*, which becomes significant > 10^{-31} cm^2 *(plans to measure this effect with the EDELWEISS experimental setup)*

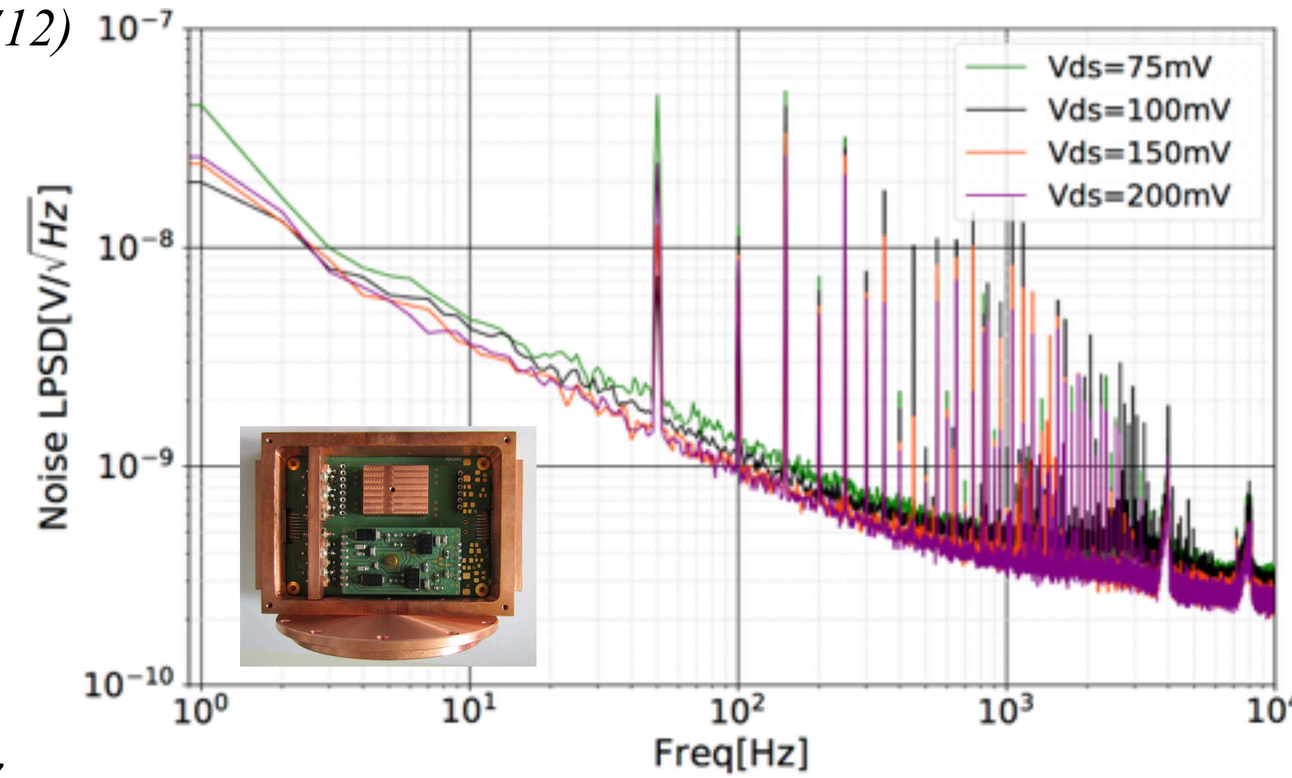
Goal #3: *EM background rejection of $O(10^3)$*

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





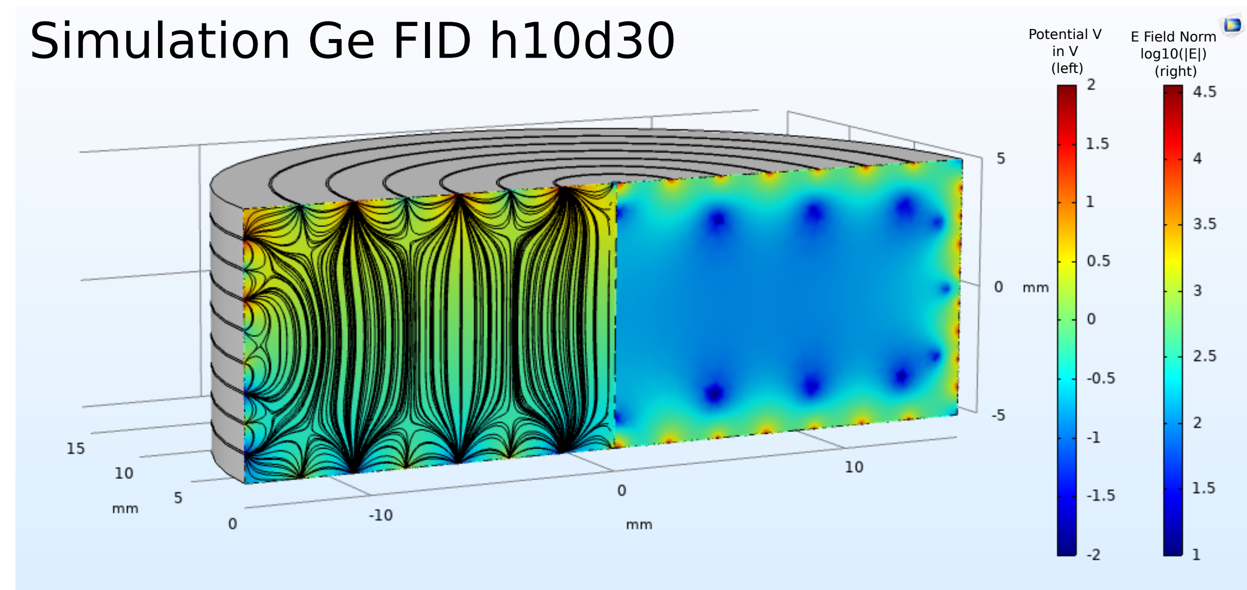
- As initiated by the CDMS-Berkeley group *(arXiv:1611.09712)* we are transitioning to HEMT based preamplifiers.
- HEMT have lower intrinsic noise than JFET
- Work @ 4/1 K allowing to reduce the stray capacitance
- Based on our **data driven HEMT model**, $O(10)$ eV rms reachable with ~20 pF total input impedance
- HEMT characterizations are ongoing
- ***First HEMT-based preamp to be tested in winter 2019 !***
- Synergie with the Ricochet-CryoCube collaboration



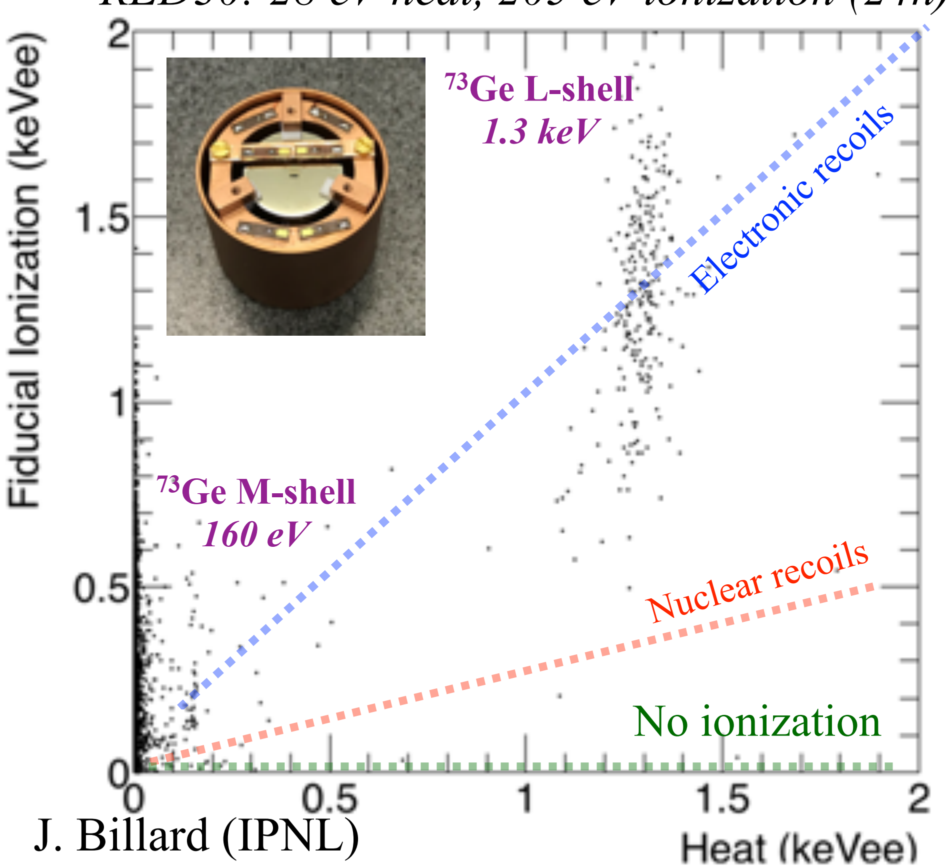
Goal #3: *EM background rejection of O(10^3)*

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

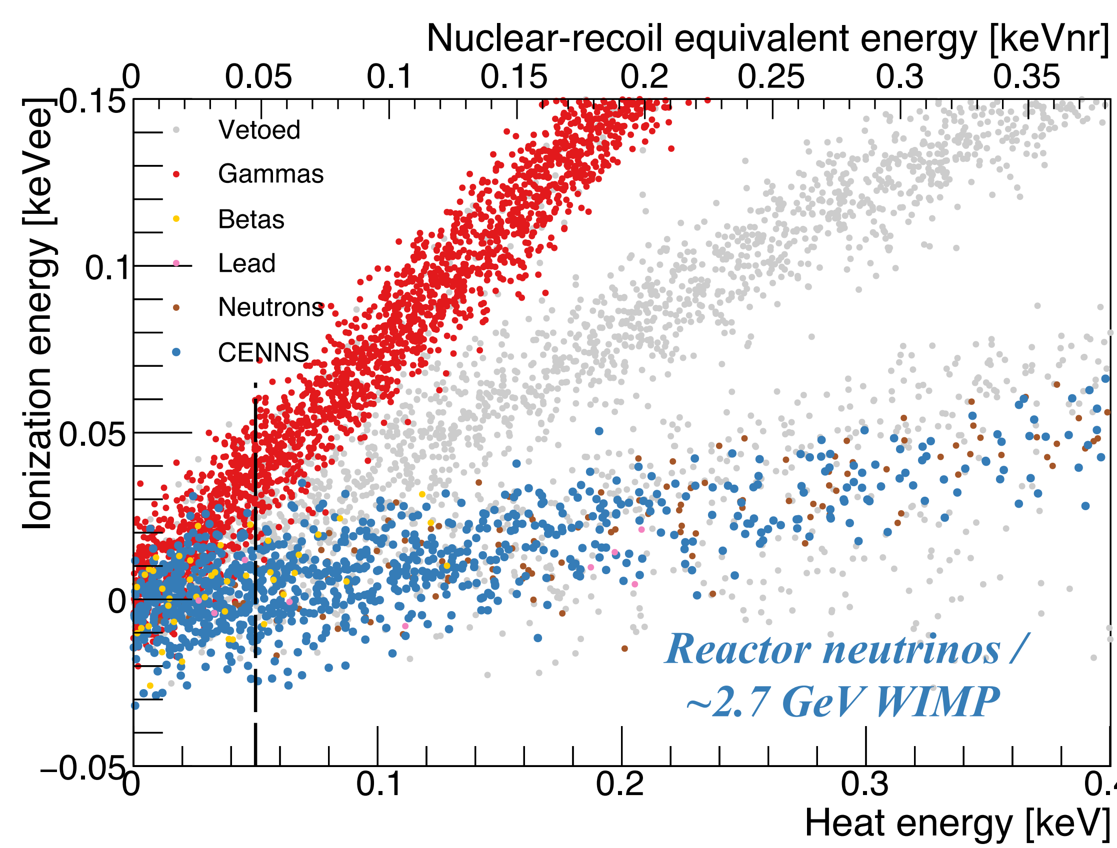
- Design of new electrode scheme with following specs.:
  - *Low input capacitance (10 to 20 pF)*
  - *High surface event rejection efficiency (FID mode)*
  - *Large fiducial volume (75%)*
- Aim at O(10^3) EM background rejection down to 50 eVnr
- Synergie with the Ricochet-CryoCube collaboration



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



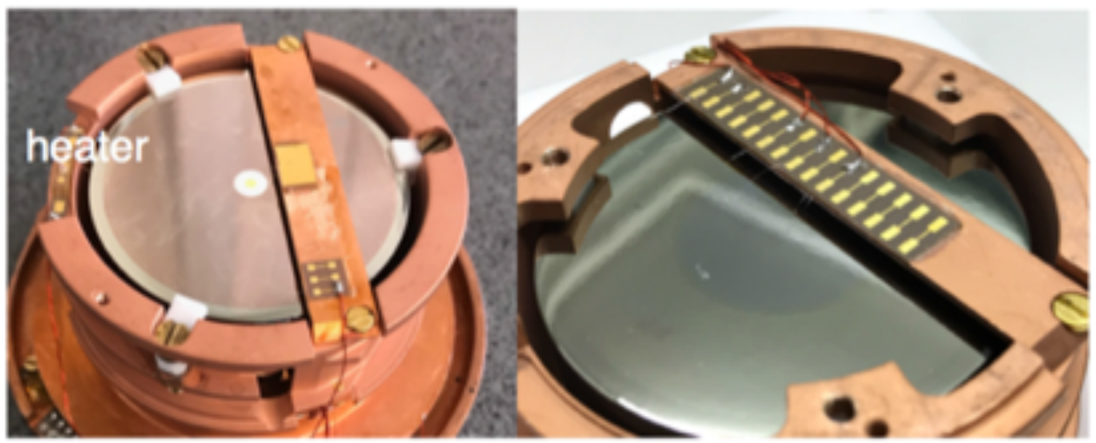
FET to HEMT

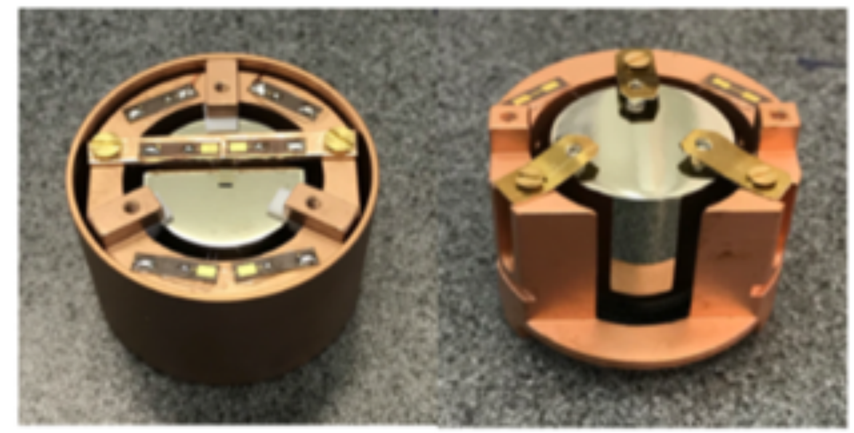


J. Billard (IPNL)

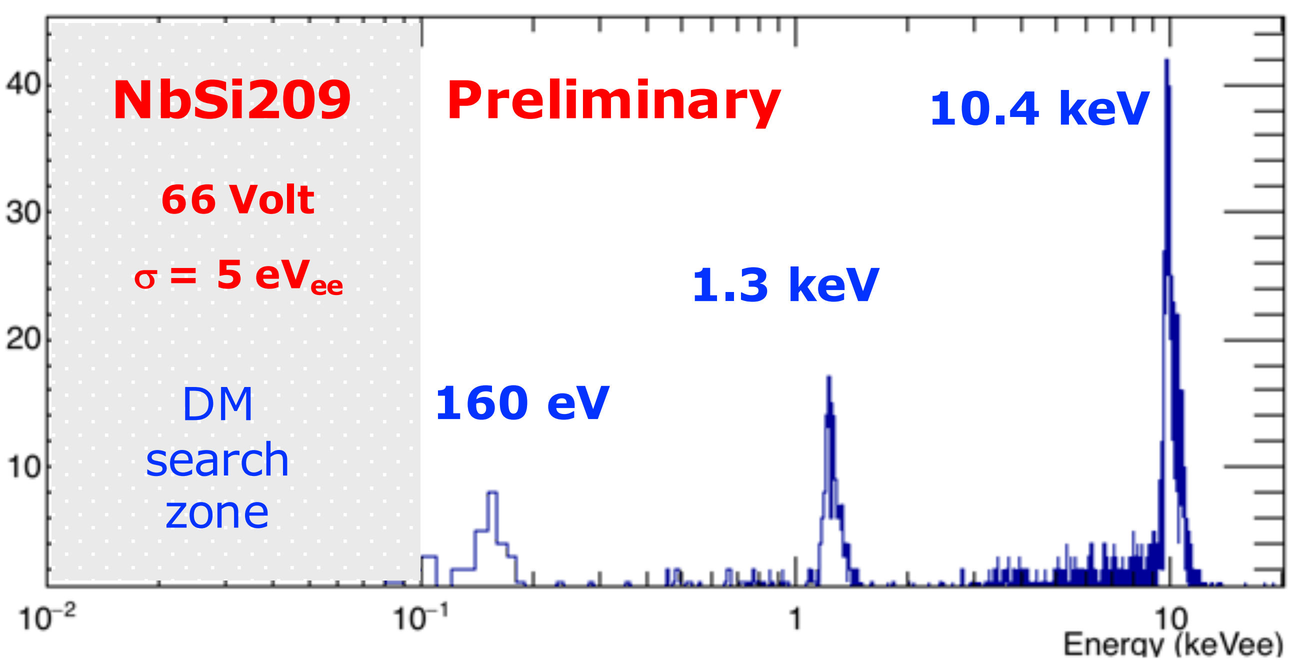
Goal #4: *Operation at high voltage (~100 V)*

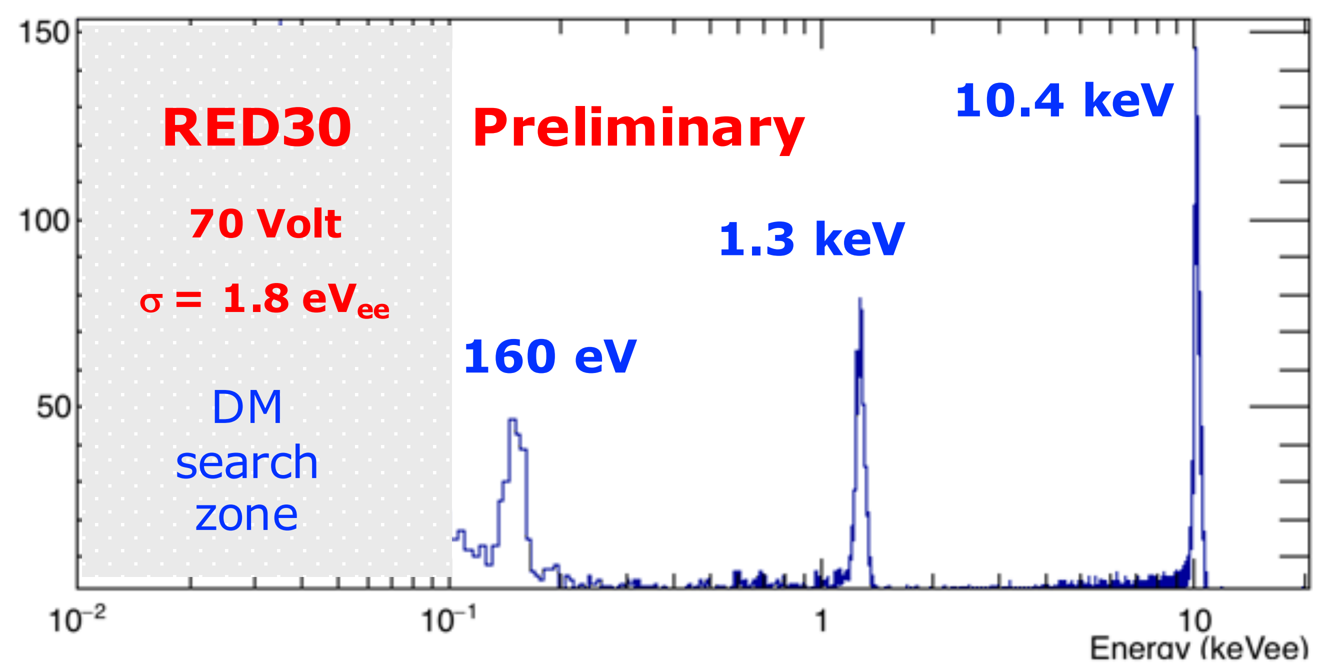
High Voltage: Exploring DM-electron/nucleus interactions with *near* single-electron sensitivity achieved in massive bolometers operated underground (low-background environment ~ 1 - 0.1 DRU).





- **NbSi209: 200g Ge with TES thermal sensor**
- **RED30 : 33 g Ge Al electrodes, NTD thermal sensor**





First EDELWEISS DM-electron scattering and absorption results expected by fall 2019.

Conclusions

Take away points:

- From the last few years, there has been an increasing interest in the low-mass dark matter region motivated by lack of evidence of new physics (e.g. LHC, DM searches, …):
  - *Beyond the standard WIMP Dark Matter scenario*

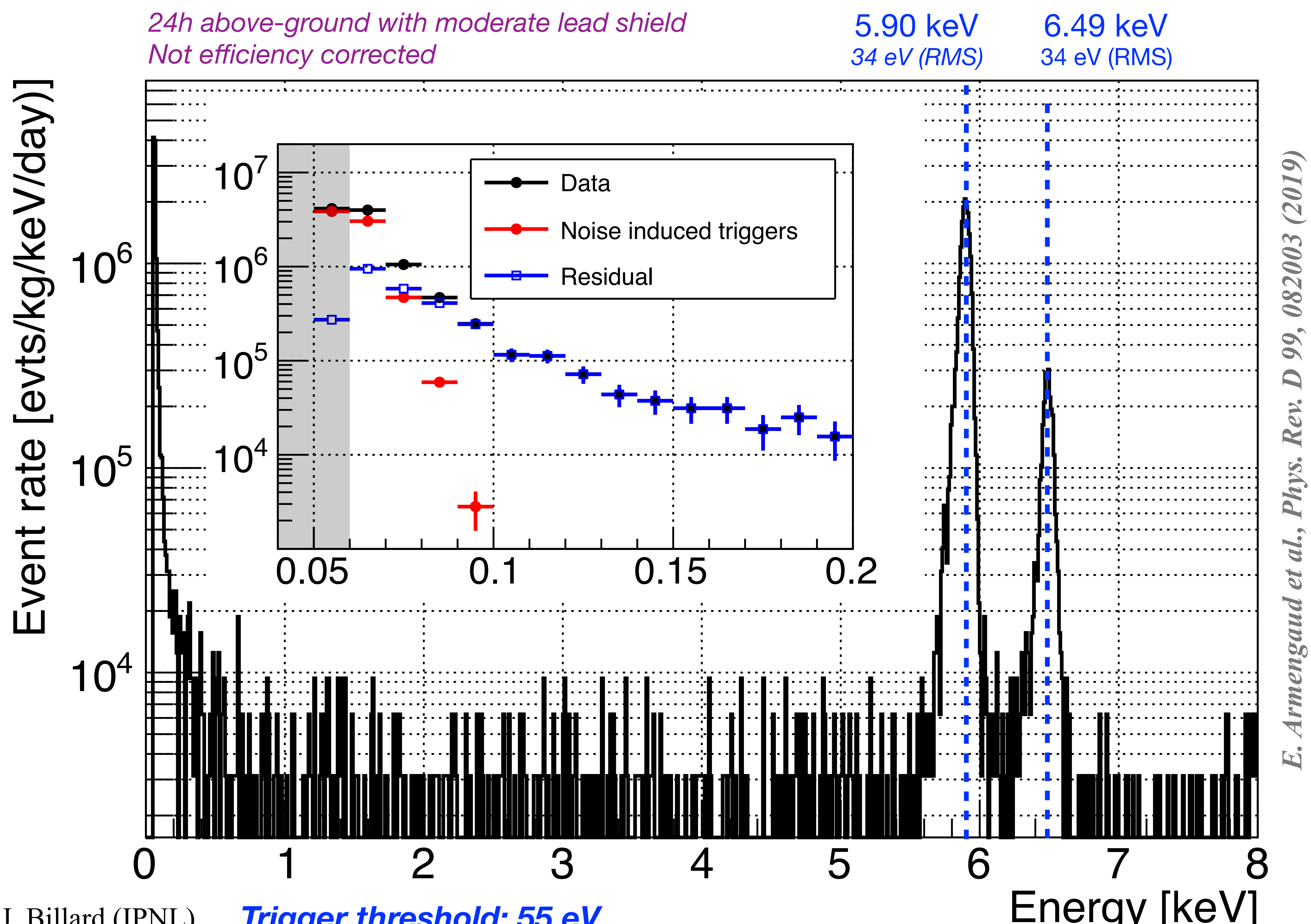
- The EDELWEISS-SubGeV program aims at probing this new region of interest with detectors able to provide:
  - Particle identification and surface event rejection down to 50 eVnr **(Low Voltage)**
  - Single-e/h sensitivity on massive bolometers **(High Voltage)**

- **The low-voltage R&D program** is now focusing on the front-end HEMT preamplifier and electrode design
  - first detector prototypes achieving 10 eV heat and 20 eV ionization resolutions by 2020 ***(Ricochet-CryoCube)***
  - Goal is to reach to reach $O(10^{-43})$ cm^2 from 1 GeV to 10 GeV with 1 kg payload in one year at Modane

- **The high-voltage R&D program** is near single-e/h sensitivity on 33.4 g and 200 g Ge crystals operated at Modane.
  - First science results expected in fall 2019 !

Back-up

Goal #2: *Heat energy resolution 10 eV (rms)*



Trigger threshold: 55 eV

Goal #2: *Heat energy resolution 10 eV (rms)*