SubGeV Dark Matter searches with EDELWEISS

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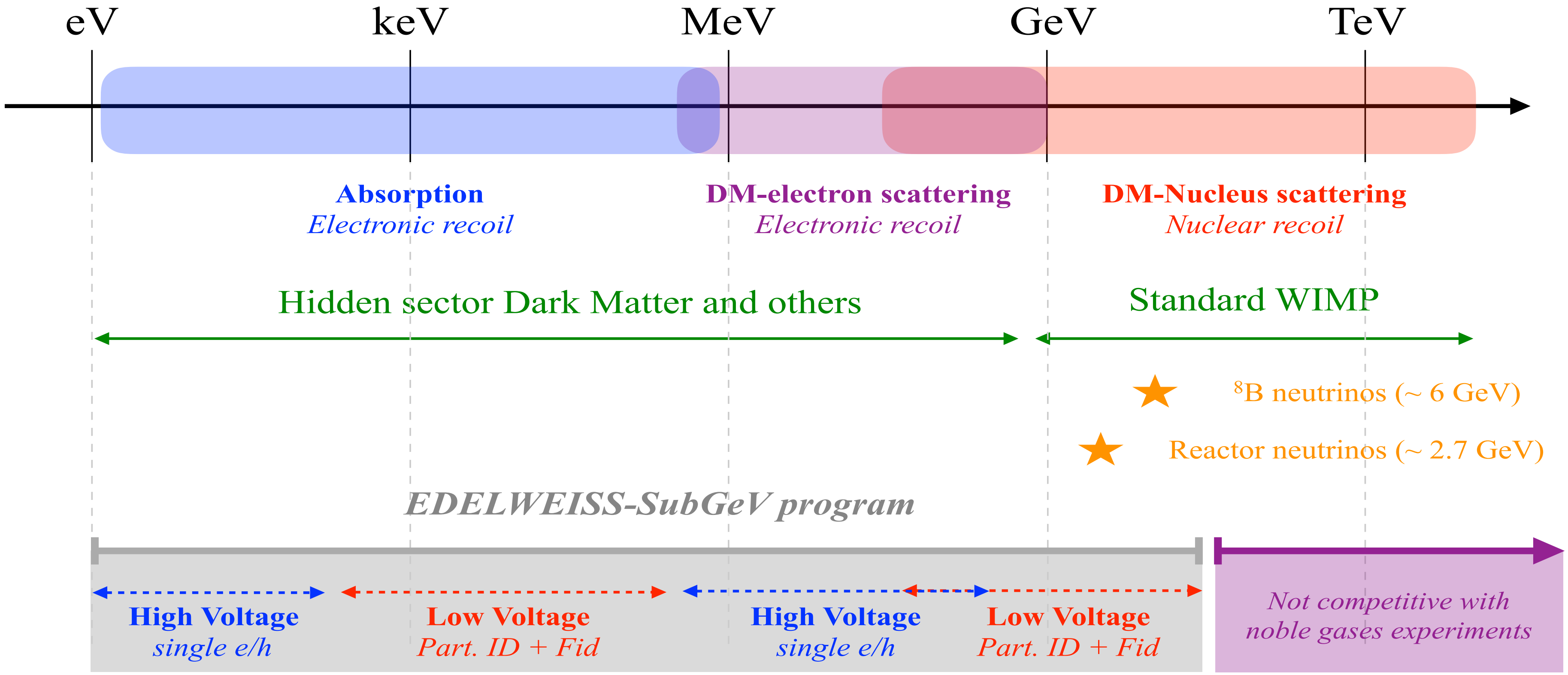
on behalf of the EDELWEISS collaboration

MILANO 22-26 JULY 2019 LTD 18 LOW TEMPERATURE DETECTORS

Outline

- The scientific context
- EDELWEISS-III : setup & FID detectors
- From EDW-III to EDW-SubGeV
  - Axion-like limits
  - Above-ground activities: EDW-Surf
  - LSM results: EDW R&D
- Conclusions and Prospectives

The scientific context



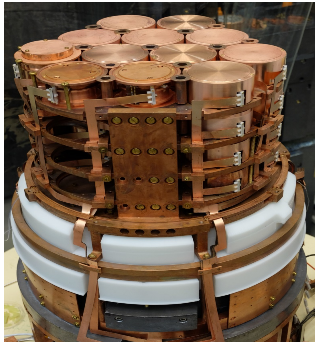
Courtesy of J. Billard

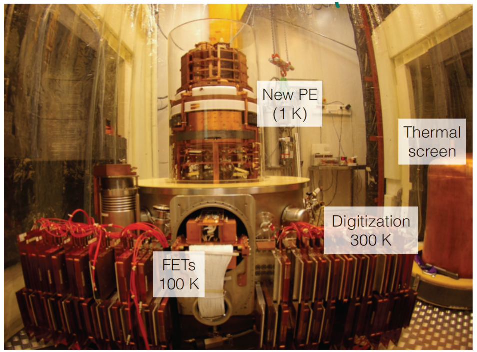
The EDELWEISS setup

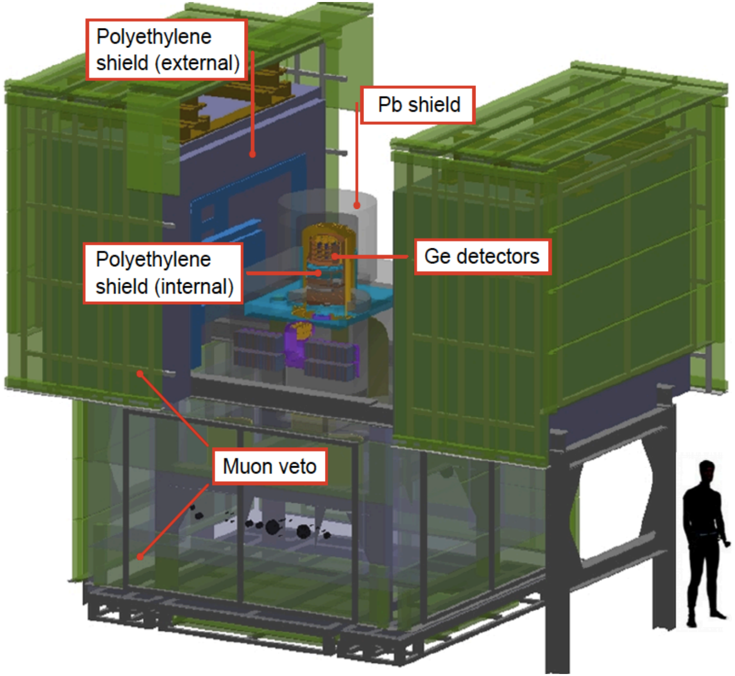
- ***LSM: Deepest site in Europe: 4800 m.w.e., 5 μ/m²/day***
- Clean room + deradonized air

  Radon monitoring down to few mBq/m³
- Active muon veto (>98% coverage) on mobile shield
- External (50 cm) + internal polyethylene shielding

  Thermal neutron monitoring with ³He detector
- Lead shielding (20 cm, including 2 cm Roman lead)
- Selection of radiopure material



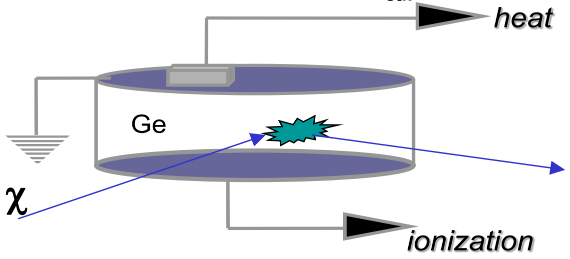




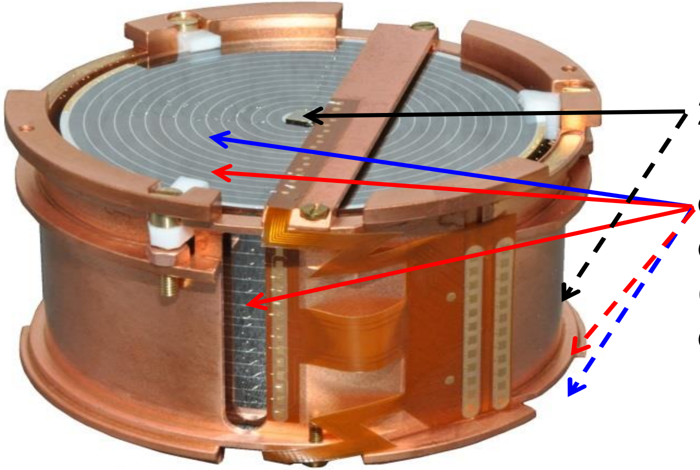
Performance of the EDELWEISS-III experiment for direct dark matter searches
[JINST 12 (2017) P08010]

The EDELWEISS-III detectors

Heat: $\Delta T = E/C_{cal}$



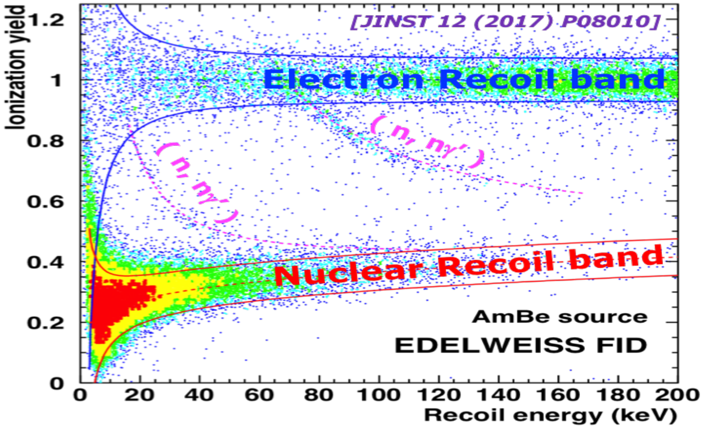
Ionization: $N_{pairs} = E/\varepsilon_\gamma$ or ε_n



870 g Ge

2 GeNTD heat sensors

electrodes:
concentric Al rings
(2mm spacing)
covering all faces



Ø=70mm, h=40 mm

Operated at
T = 18 mK

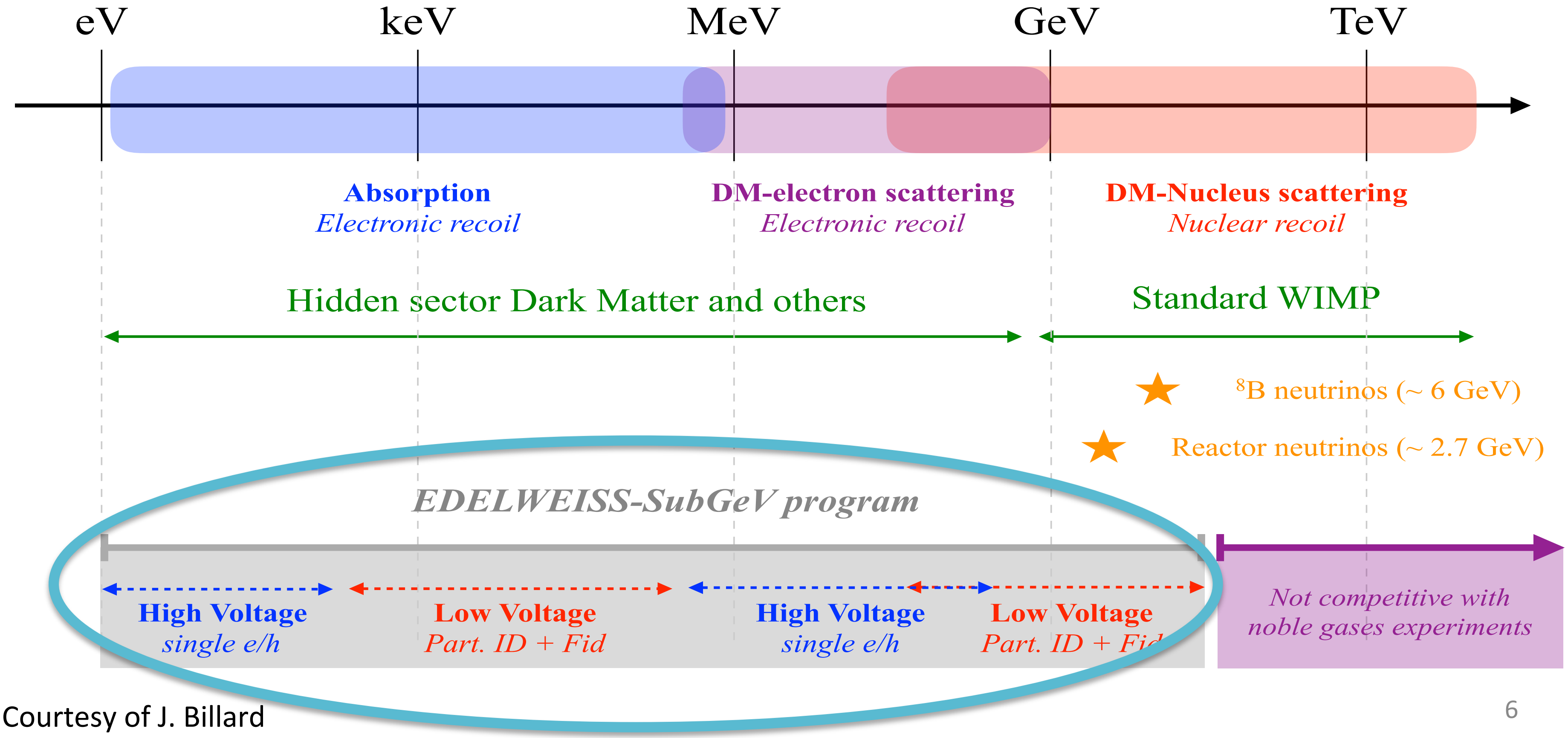
Ionization:

- ε_γ = 3 eV/(e-hole pair) for electron recoils (γ,β)
- ε_n ~ 12 eV /(e-hole pair) for nuclear recoils (neutrons, WIMPs)
- $\varepsilon_\gamma/\varepsilon_n$ = ionization quenching Q ➞ $E_{ion} = Q\,E_{recoil}$ in keV_{ee}

Heat:

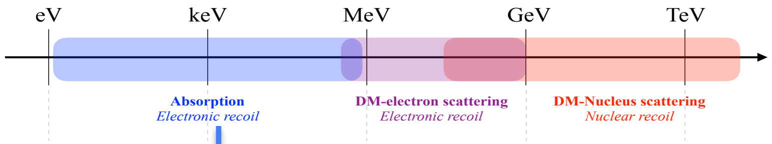
- direct measurement of ALL the energy, irrespective of particle ID

The EDELWEISS SubGeV programme

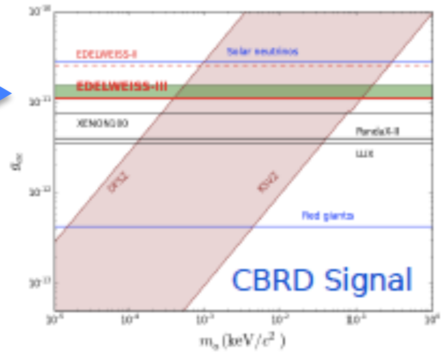


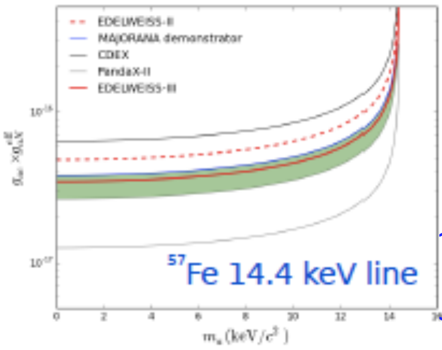
Courtesy of J. Billard

Electron recoil analysis: axion-like limits



Emission of axions/ALPs from the Sun



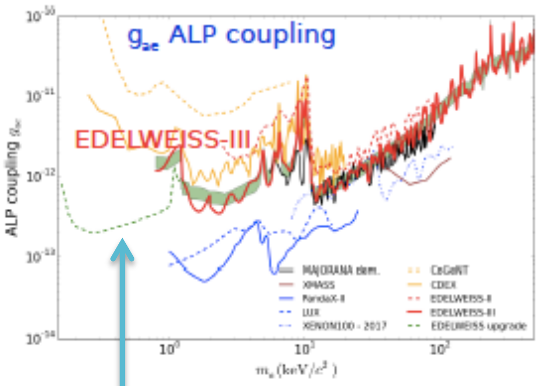


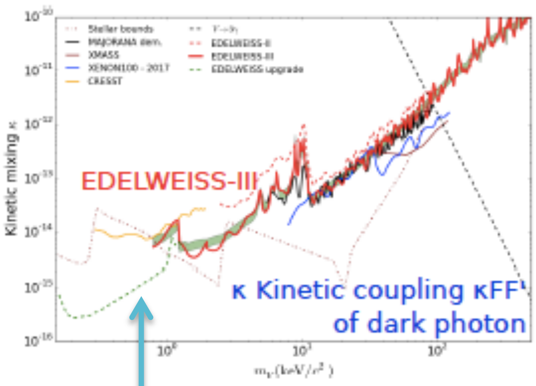
PRD 98 082004 (2018)

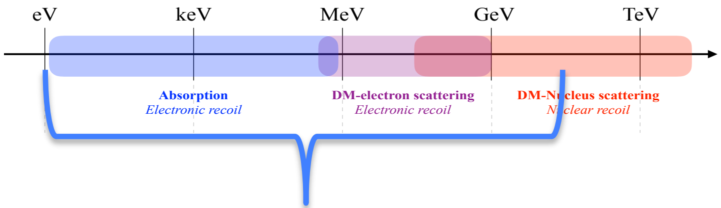
Absorption of keV-scale Bosonic DM

- Best Ge-based limit < 6 keV (thanks to surface rejection)
- Start to explore < 1 keV

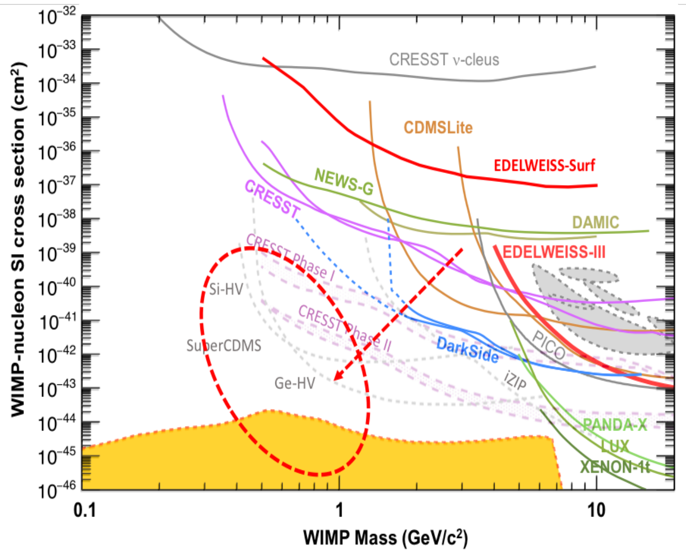
- Surface rejection (i.e. ionization resolution) very important to reduce low-energy ER backgrounds
- Improvements foreseen in the 100 eV – 1 keV region with improved ionization (here: σ = 35 eV_{ee} with HEMT readout)



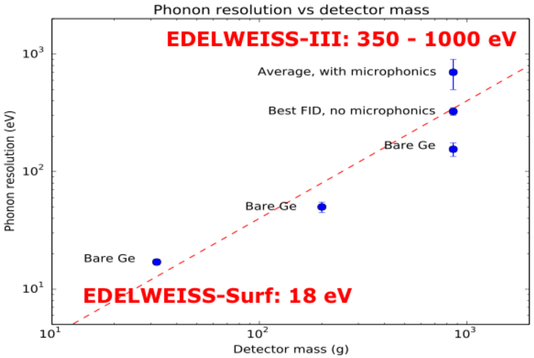




EDELWEISS SubGeV program

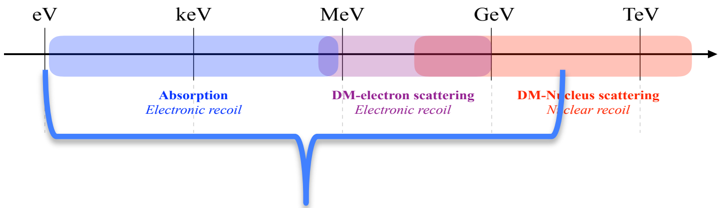


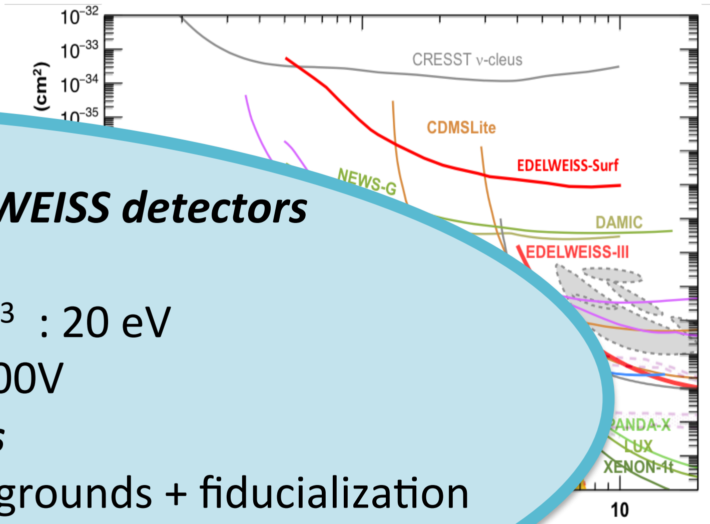
- Current+future projects: background limited
- Event-by-event rejection even at 1 GeV/c^2 and 10^{-43} cm^2 requires a new generation of detectors
- *An event-by-event rejection with ~1 kg.y requires* $\boldsymbol{\sigma_{phonon} = 10\ eV}$ **and** $\boldsymbol{\sigma_{ion} = 20\ eV_{ee}}$



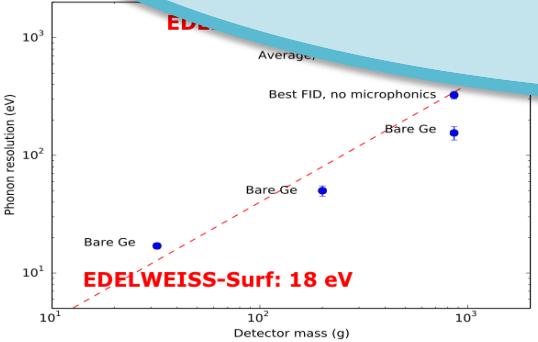
- Keeping the ability to **apply HV** to EDELWEISS detectors is important to reduce thresholds in ER searches
  - For NR: depends a lot on quenching
- *Reducing the detector from 860 to 33 g is worth it if the resolution goals are met*

EDELWEISS SubGeV program





- Current+future projects: l
- Eve
  r
- A
  σ_{phono}



3 main pillars to be reached by the EDELWEISS detectors

- Heat energy resolution : 10 eV (RMS)
- EM background rejection (LV mode) > 10^3 : 20 eV
- Operation at high voltages (HV mode): 100V

Two running modes

Low Voltage: Particle ID – ER/NR/ unknown backgrounds + fiducialization

High Voltage: single e/h sensitivity thanks to the Neganov-Luke mode

...WEISS detectors is

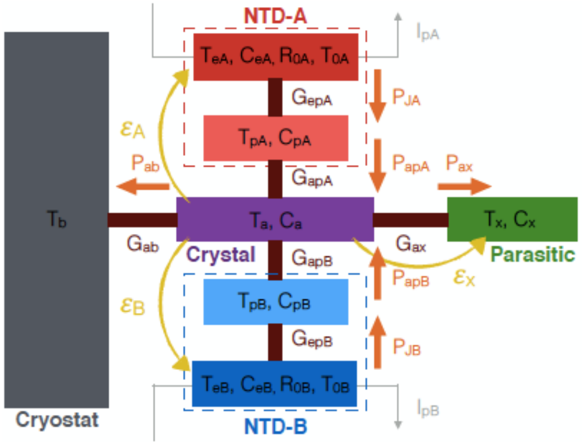
...esholds in ER searches

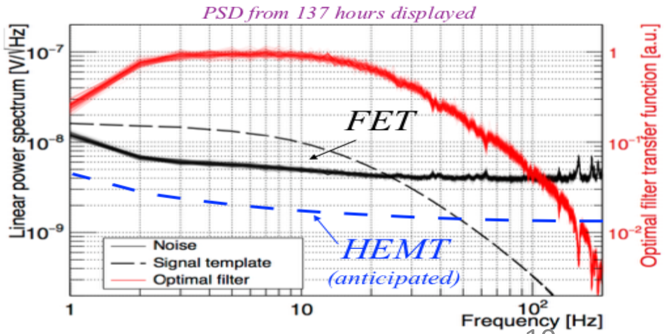
- For NR: depends a lot on quenching

- *Reducing the detector from 860 to 33 g is worth it if the resolution goals are met*

How to reach 10 eV phonon resolution

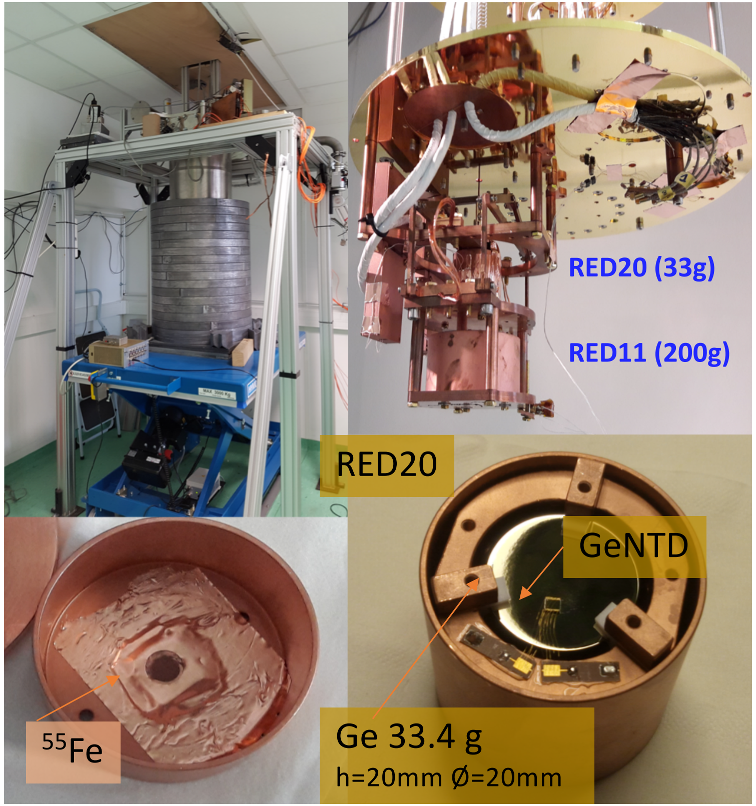
- Intense above ground R&D on NTD sensor
- Development of a detailed thermal model for the heat channel to optimise the choice of the best configuration
- Test of different glues
- Investigation of alternative sensors: NbSi TES
- Limited by FET current noise: replacing JFETs @ 100K with HEMTs @ 1K should provide additional x2 needed in resolution





EDELWEISS-Surf: an above-ground DM search

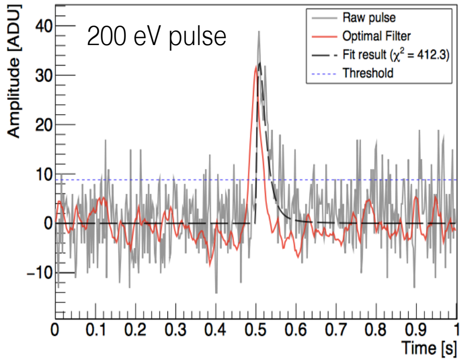
- Easy-access surface lab @ IPN-Lyon
- <1 m overburden: ideal for SIMP search (strongly interacting DM)
- Dry cryostat (CryoConcept) with <30h cool-down (fast turnover ideal for detector R&D)
- Vibration mitigation: < μg/√Hz vibration levels obtained in spring-suspended tower
- RED20: 33.4 g Ge with NTD sensor, with no electrode
  - No ER/NR discrimination, but no uncertainty due to ionization yield or charge trapping
- Low energy calibration:
  - ^{55}Fe x-ray source for calibration
  - Ge neutron activation
- Small 0.03 kg.day exposure

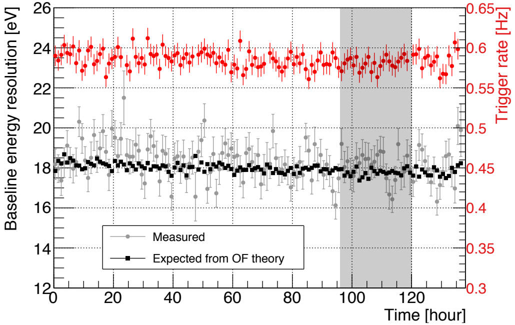


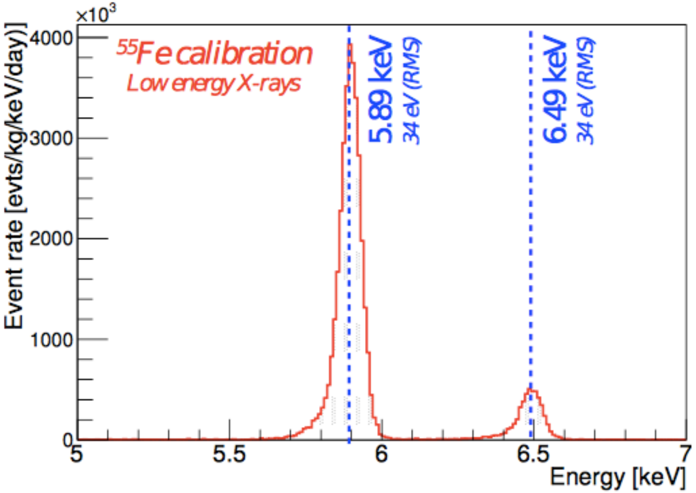
Phys. Rev. D 99, 082003 (2019)

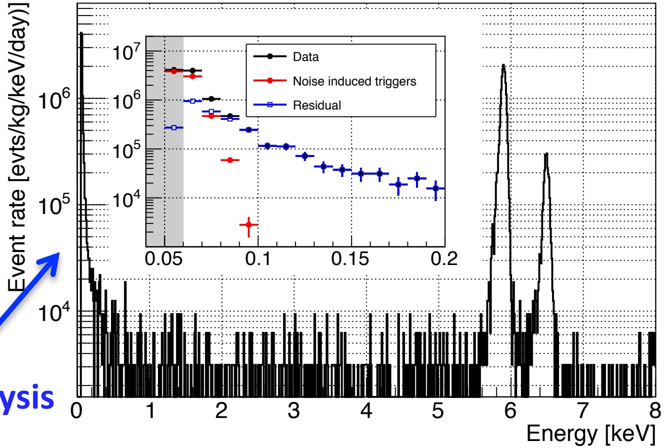
Pulses, calibration, resolution and energy spectrum

- Optimal filter fit to pulses
- Stability of noise & resolution over 137h of data taking
- 1 day set aside a priori for blind search
- **Baseline: σ = 17.8 eV**









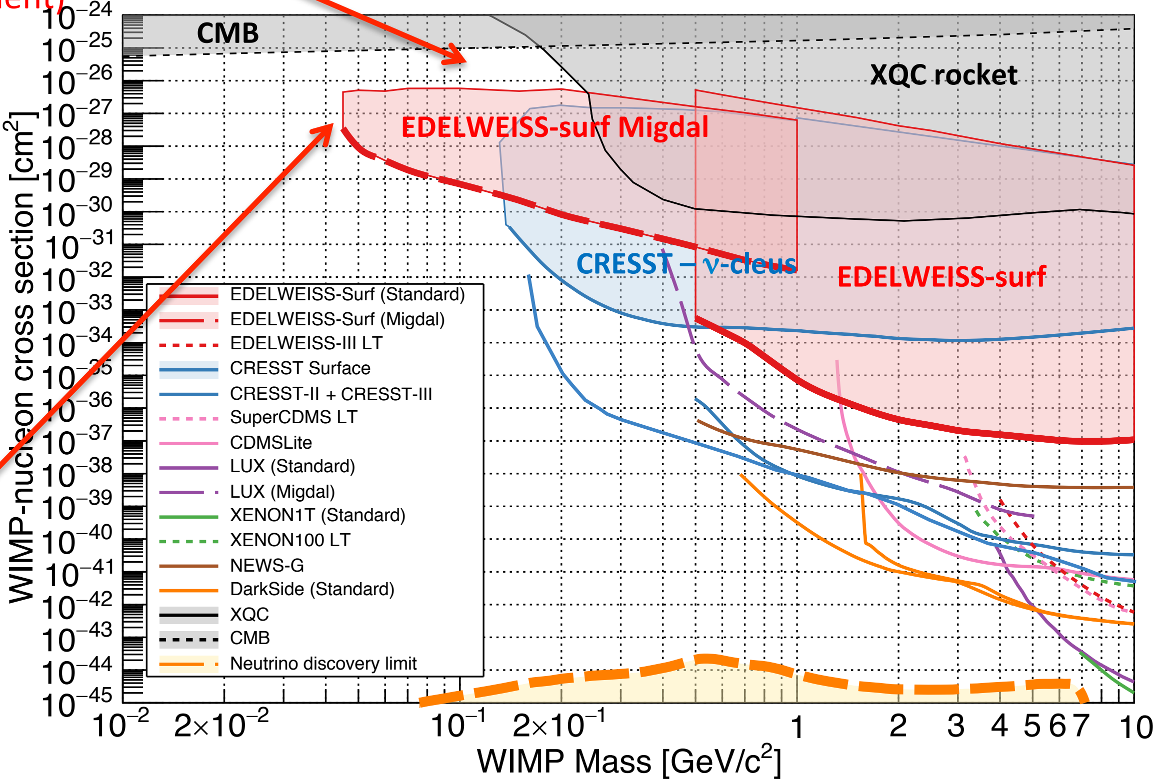
60 eV analysis threshold

Filling the SubGeV region

DM – nucleus interaction

- First Ge-based limit below 1.2 GeV and best above-ground limit down to 600 MeV (SIMPs)
- Considering Migdal effect: first DM limit down to 45 MeV limited by Earth-Shielding effect

Stronger upper cutoff for Migdal (subleading component)

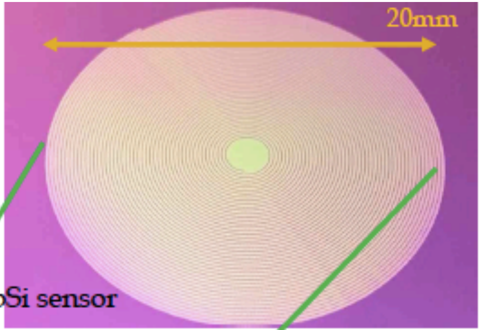


Sharp 45 MeV/c^2 cutoff due to ES effect on velocity

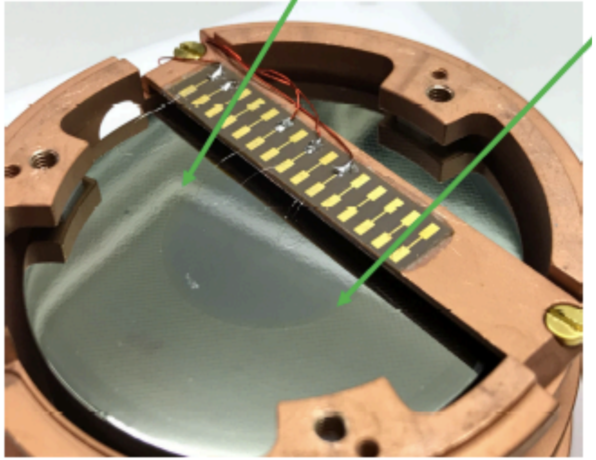
10 eV with high impedence NbSi TES sensor

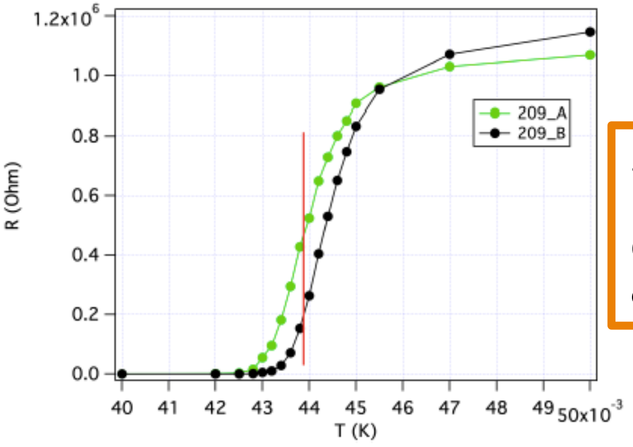
NbSi209 @ LSM

100mm thick, 20mm diameter spiral NbSi sensor
Lithography
On a 200 g HP-Ge crystal (48 x 20 mm)



NbSi TES: alternative sensor for the heat channel
Nb_xSi_{1-x}: amorphous compound
x> 13% → superconductor
Directly done by lithography on the crystal or on sapphire/germanium chip
High impedence – compatible with standard JFET
Goal: 10 eV RMS

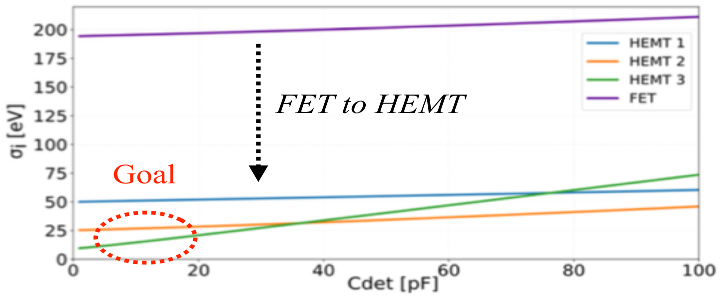


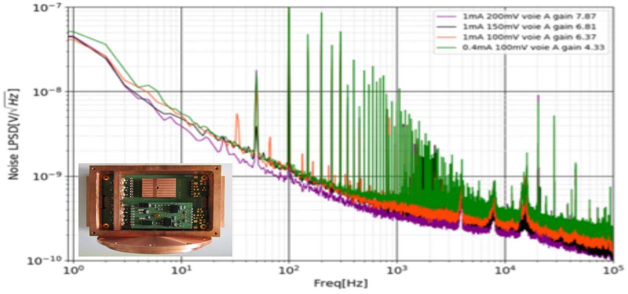


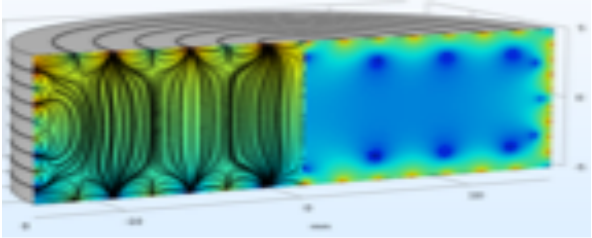
330 nV/keV on A, 658 nV/keV on B
Phonon: σ_A=183 eV, σ_B=125 eV
Combined:
σ=113eV or 5eV_{ee} @ 66V

How to reach 20 eV ionization resolution

- Transition from JFET to HEMT (as initiated by the CDMS-Berkeley group, arXiv:1611.09712)
- Lower intrinsic noise than JFET
- Reduction of the stray capacitance by working at 1K or 4K
- Thanks to a data driven HEMT model, the goal of 20 eV_{ee} is reachable with ~20 pF total input impedance
- Ongoing HEMT characterizations
- HEMT-based preamp tests foreseen by end of 2019
- Cryogenics + cabling challenges ahead



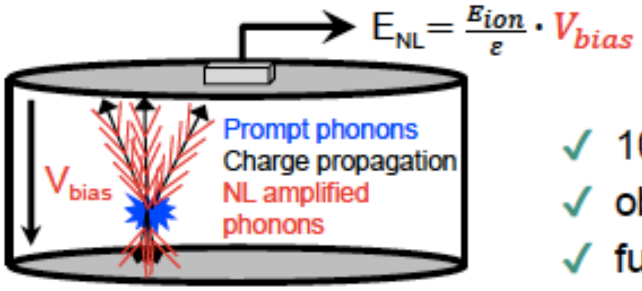




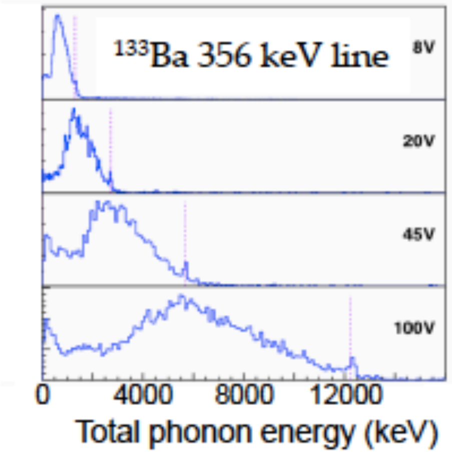
Optimization of 38g FID design: large fiducial volume & low capacitance

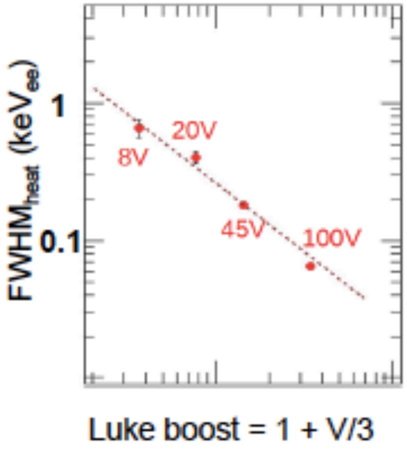
See A. Juillard – poster #373

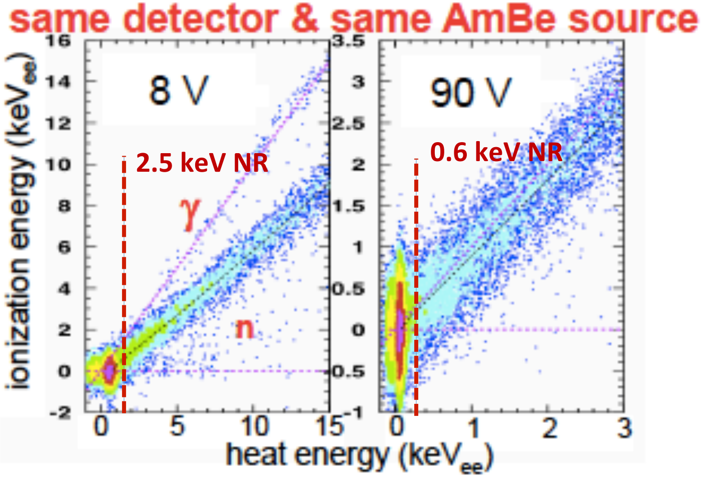
How to reach 100V with Neganov-Luke boost

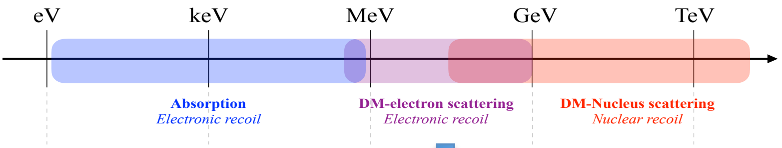


- ✓ 100 V on detector already achieved
- ✓ observe nuclear recoils down to ~0.1 keV_{ee}
- ✓ full ion.+heat readout possible at any V





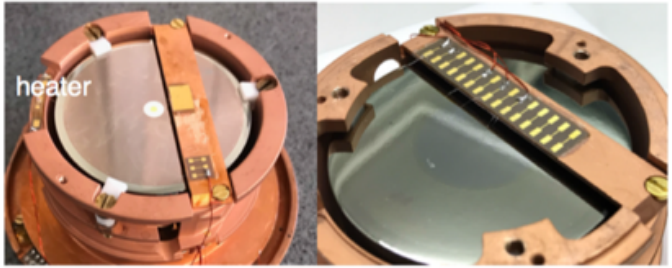


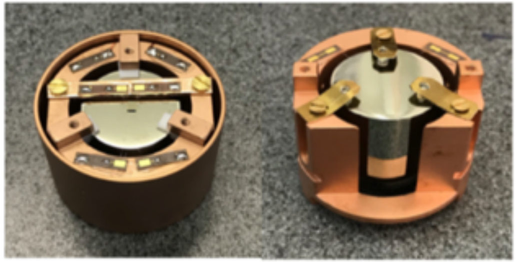


High voltage operation @ LSM

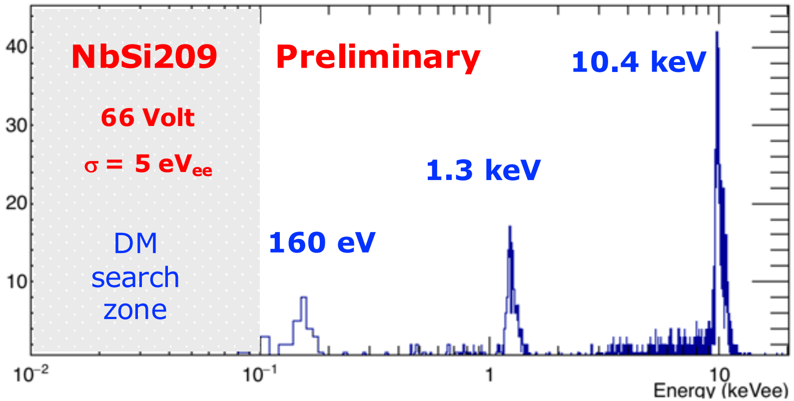
Exploring DM-electron/nucleus interactions with *near* single-electron sensitivity achieved in massive bolometers operated underground @LSM

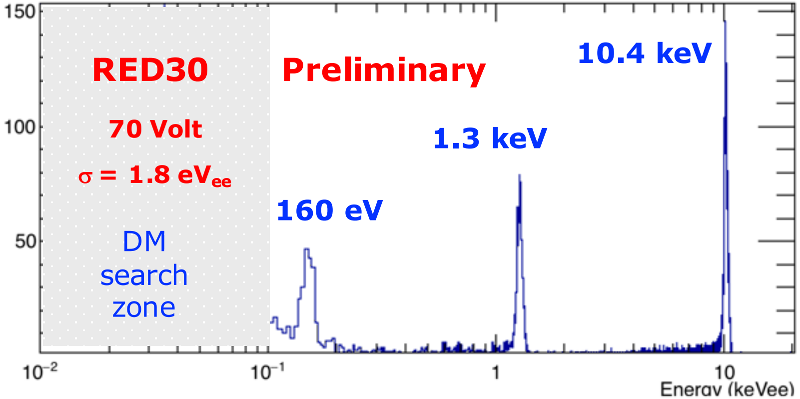
KLM ^{71}Ge from neutron activation
3.7 GBq AmBe source (2×10^5 neutrons)





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





Conclusions

- There is an increasing interest in the low-mass dark matter region motivated by lack of evidence of new physics at LHC (e.g. SUSY):

  → *Beyond the standard WIMP Dark Matter scenario*
- **EDELWEISS-SubGeV** program aims at probing **MeV-GeV particles** via **ER and NR interactions** with new detectors:
  - Reduce detector mass to improve resolutions & thresholds -> **confirmed by EDELWEISS-Surf**
  - Particle ID and surface event rejection down to 50 eV_{NR} **(Low Voltage)**
  - Single-e/h sensitivity on massive bolometers **(High Voltage)**
- **Low-voltage R&D program** focusing on front-end HEMT preamplifier and low-capacitance electrode design

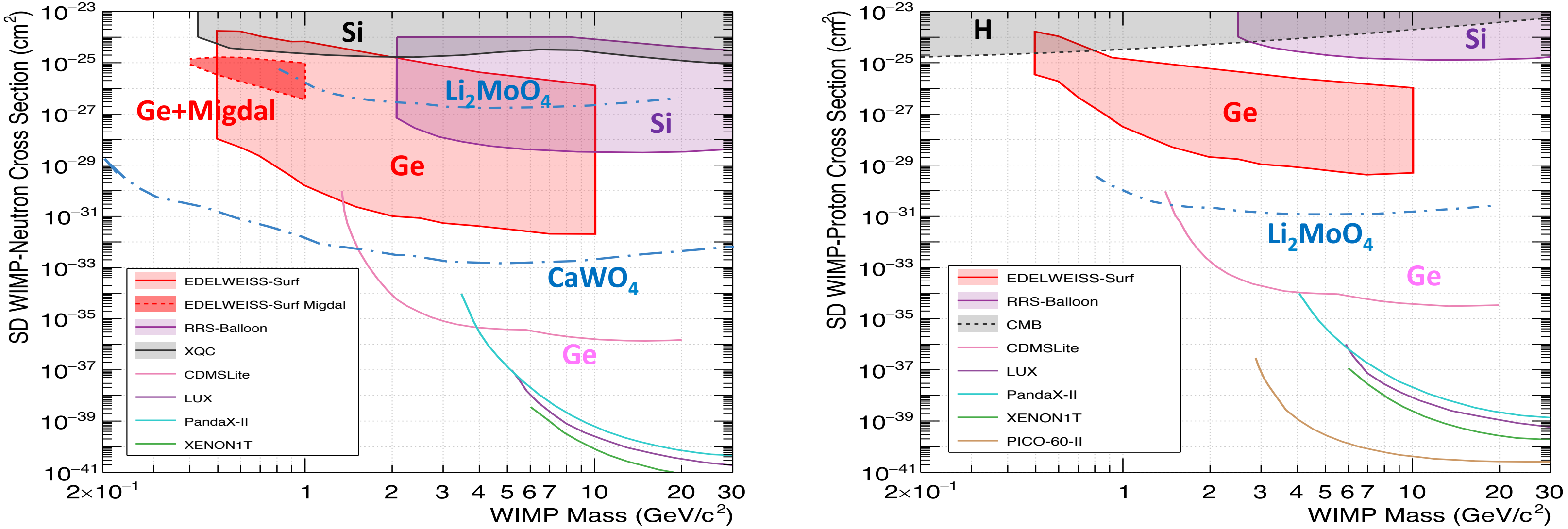
  → objective: σ = 10 eV (phonon) + 20 eV_{ee} (ionization)

  → *Goal is to reach to reach $O(10^{-43})$ cm^2 with background rejection at 1 GeV, with 1 kg payload in one year at Modane*
- **High-voltage R&D program,** advancing well with near single-e/h sensitivity achieved on 33.4 g and 200 g Ge crystals operated at Modane.
- ***New EDELWEISS science results expected in fall 2019 – STAY TUNED***

- BACKUP SLIDES

Spin-dependent cases

- Unfortunately, ^{14}N has both p and n spin: *shielding from atmosphere*
- Large cross-section → dramatic ES effects (especially on Migdal limits)
- Blue dot-dashed: CRESST surface Li_2MoO_4 [arXiv:1902.07587] and underground $CaWO_4$ [arXiv:1904.00498] – SIMP contour calcs. underway



Consider instead **inelastic scattering**. In particular, look for the possible ionisation of an electron after a DM-nucleus interaction - "**Migdal Effect**"

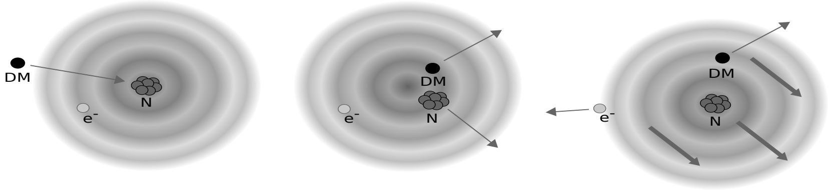
- Consider ionization effects of e^- cloud due to sudden boost of nucleus in DM collision

  Calculated in Ibe et al, JHEP 03 (2018) 194

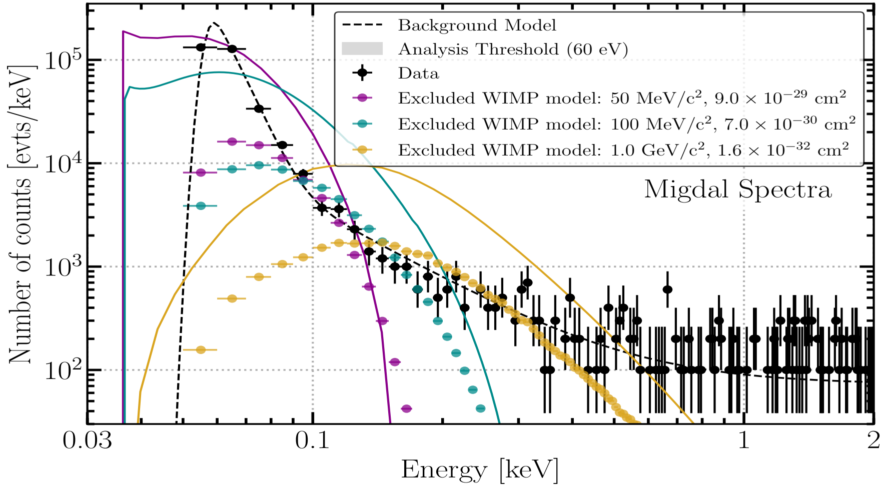
- Use M shell (n=3) only in Ge
  - K, L electrons too tightly bound
  - n=4 affected by band structure

- Injection of electronic energy in the sub-keV to keV range
  - <1% probability
  - Negligible for >10 GeV/c^2 WIMPs
  - In RED20 (only heat): add energy from both NR and ER
  - ***Robust signal >100 eV even for DM masses <100 MeV/c^2***

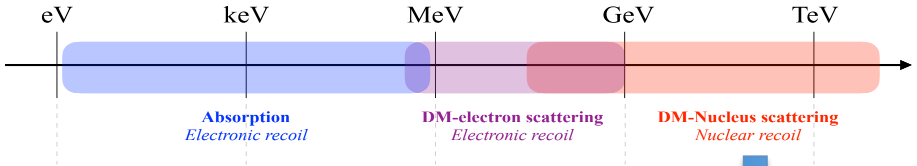
Dolan et al, PRL 121, 101801 (2018)



Not yet observed, but calculable



Limit on Low-Mass WIMPs



- 8 selected detectors: low trigger thresholds and good noise conditions
- Resolution: $\sigma_{ph} = 200$ eV, $\sigma_{ion} = 220$ eV$_{ee}$
- A total fiducial exposure of 496 kg.days after quality cuts
- Analysis with BDT/Profile Likelihood
- EDW-III Improvement by $\times 20$ to $\times 150$ between 7 and 10 GeV w.r.t EDW-II
- Limited by heat-only background
  $\rightarrow$ identification and rejection using ionization channel