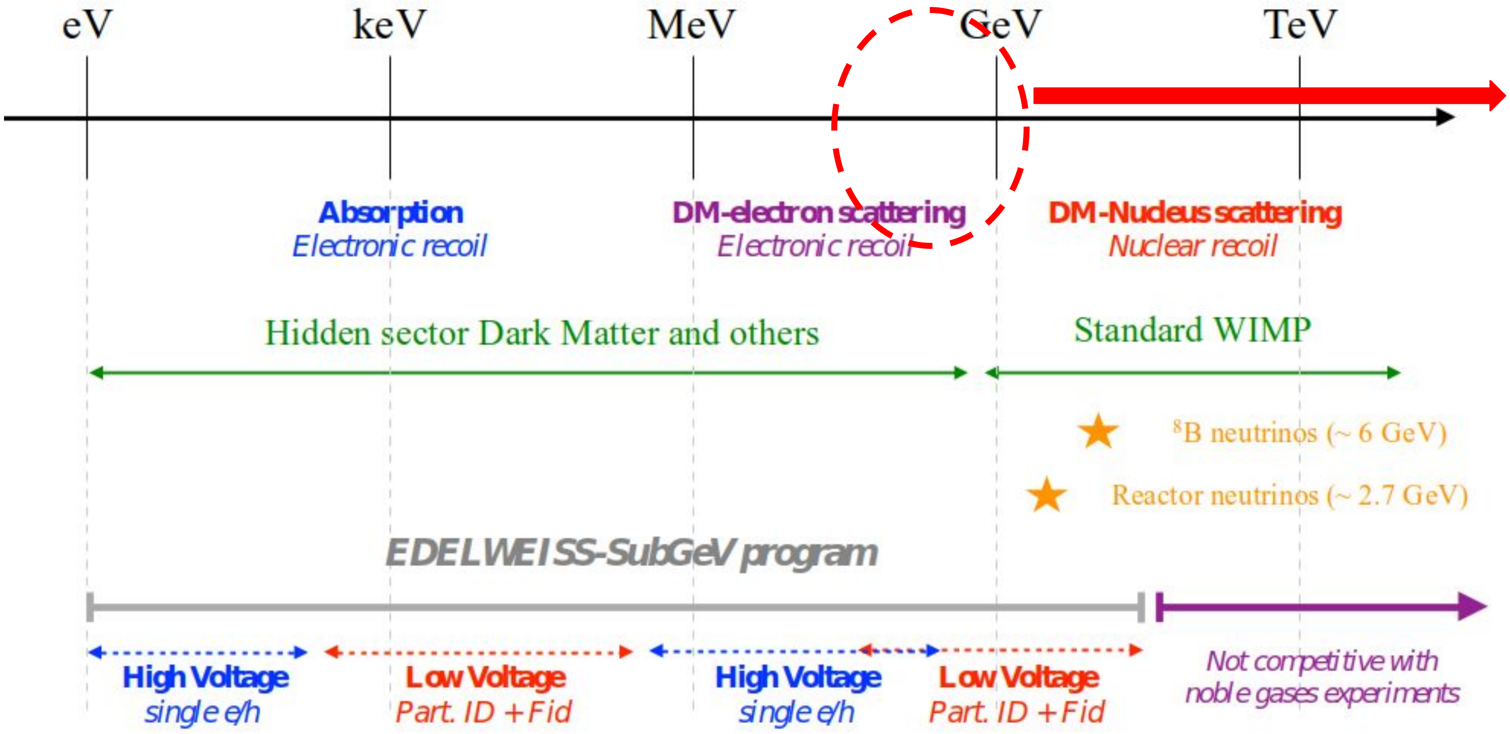
New EDELWEISS sub-GeV Results

H.Lattaud on behalf of the EDELWEISS collaboration
IP2I,CNRS/IN2P3.

A wide playground

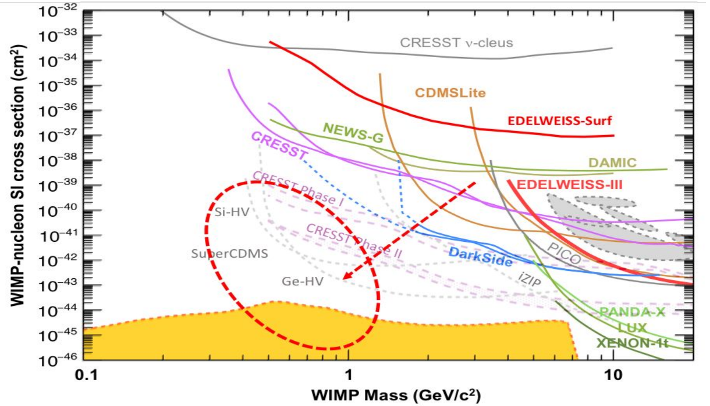


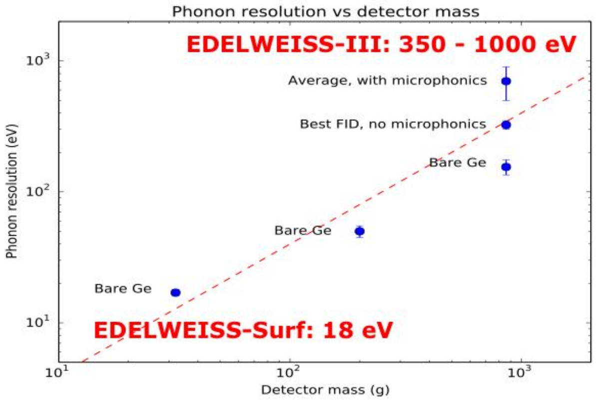
- Challenging search area
- Many new techniques being proposed
- Need low threshold (down to single electron)
- ER/NR discrimination

J. Billard, New Directions in the Search for Light Dark Matter Particles, Fermilab 2019

Edelweiss sub-GeV program

- Current and future projects → Background limited
- For event by event NR ID down to 1 GeV/c² and reach 10^{-43} cm^2
  σ_{phonon} **= 10 eV and** σ_{ion} **= 20 eVee**
- Ionization resolution is key to particle identification + surface rejection: Cold HEMT preamp + low capacitance wiring (joint development with Ricochet)

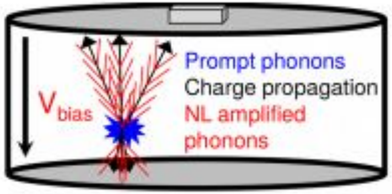




- Reducing detector mass is crucial to reach these goals:
  EDELWEISS-Surf [PRD 99 082013 (2019)]
  33 g Ge bolometer.
- Applying HV to amplify signal, lower threshold and separate NR /ER:
  Electron-DM results [PRL 125, 141401 (2020)]
  78 V applied onto 33 g Ge bolometer.
- Lowering the Impact of Background using new TES sensor on 200g Ge bolometer operated at 66V.
  This presentation.

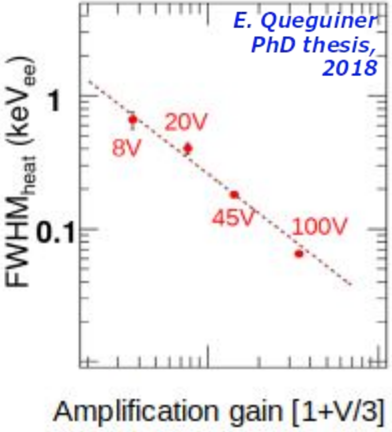
Amplifying signal: Neganov-Luke-Trofimov effect

- Amplification of heat signal due to Np electrons drifting in electric field



$$E_{heat} = E_{recoil} + E_{Luke} = E_{recoil} + N_p \Delta V$$

$$E_{heat} = E_{recoil}\left(1 + \frac{\Delta V}{\epsilon}\right) \quad \text{particle-ID dependent}$$



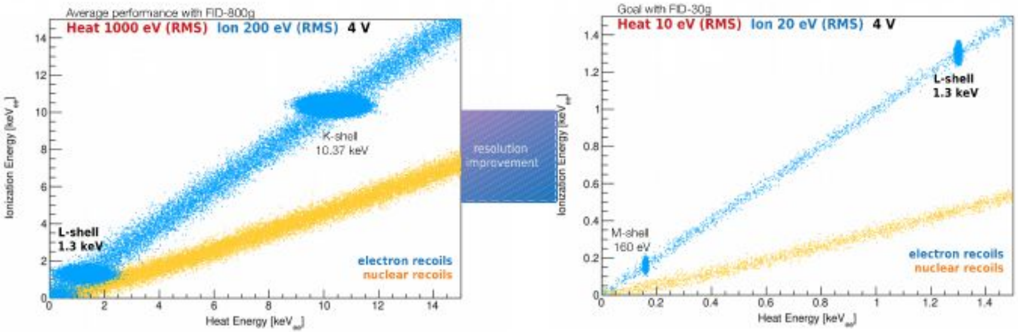
- Amplification proportional to ionization signal and to applied bias
  - Loss of discrimination as heat is dominated by ionization signal
  - Resolution gain by a factor (1+V/3) for e^- signals

EDELWEISS Sub-GeV two modes

Low Voltage Objectives

- 10 eV (RMS) Heat energy resolution
- 20 eV (RMS) Ionization energy resolution

Particle identification & surface event rejection down to 50 eV



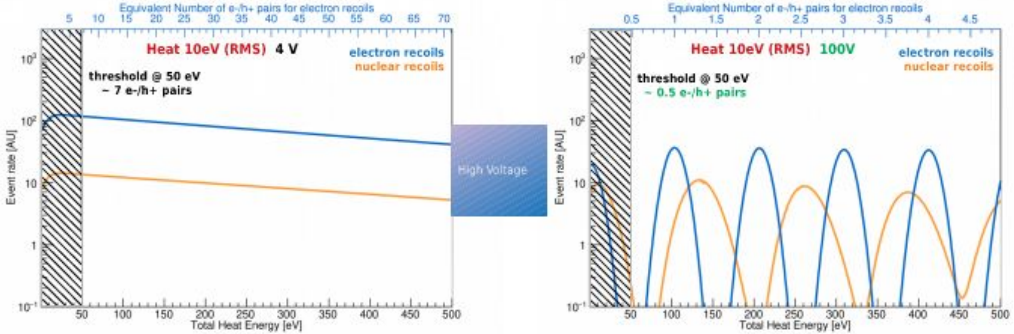
Low-voltage objectives are part of a common effort with the Ricochet collaboration, dedicated to studying CENNS at reactors supported by the ERC-CENNS Starting Grant (2019-2024)

High Voltage Objectives

- 10 eV (RMS) Heat energy resolution
- 100 V with signal amplification only

Single-e/h pair sensitivity with massive (~30g) bolometers

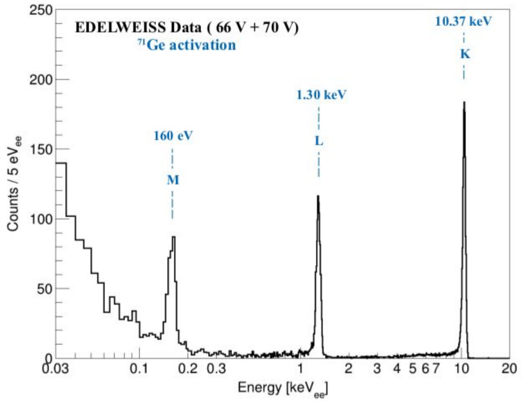
Single **ELE**ctron **N**uclear recoil **DIS**crimination
SELENDIS

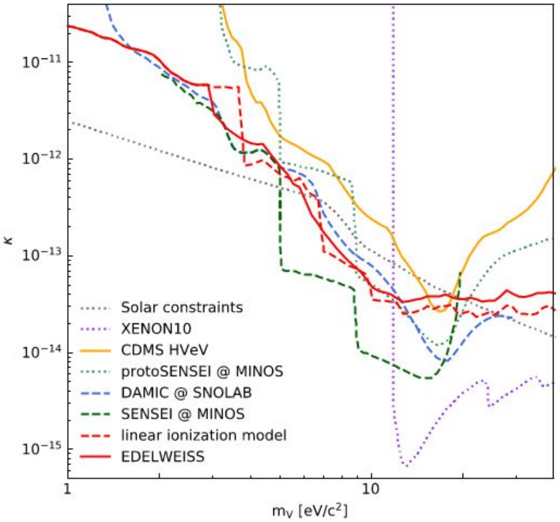


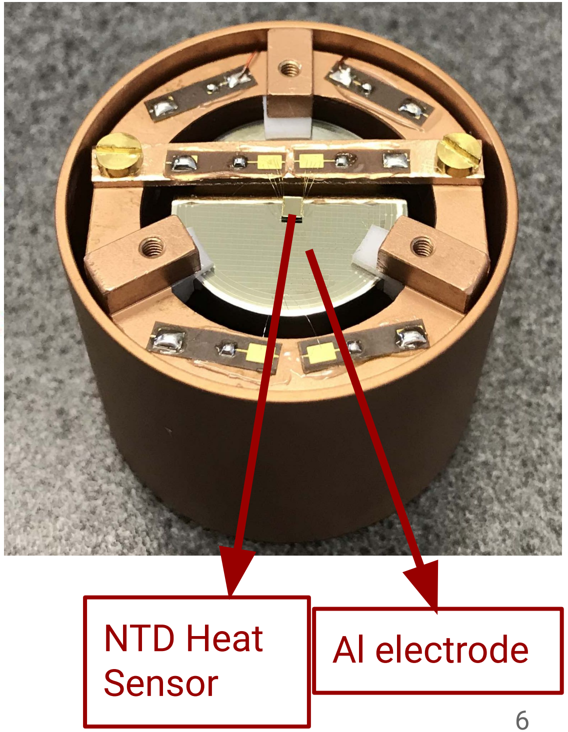
SELENDIS project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 838537

Advance toward Sub-GeV: sub-electron resolution

- Detector RED30: 33g Ge operated at 78V, σ= 1.6x eV (0.54 pair)
- Best Ge sensitivity for DM-e and DP down to 1 eV
- Limited by heat-only background: understanding + control of this background (also observed in other cryogenic detectors) is essential





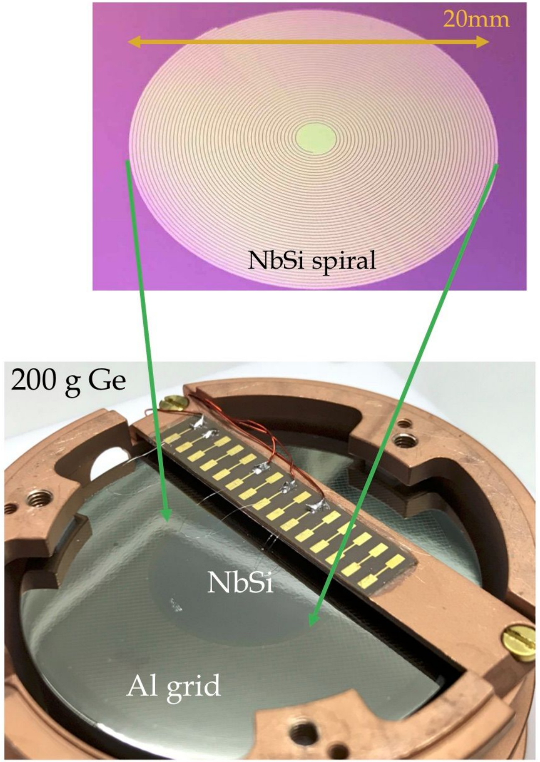


- Explore detector with alternative phonon sensor, to better understand HO background.

EDELWEISS NbSi TES

- 200g Ge bolometer
- NbSi TES thermal sensor lithographed on top surface.
  100 nm thick, 20 mm diameter spiral, 17% of top surface, split in two halves (inner and outer circles).
- Flat surface electrodes: lithographed Al grid (500 μm pitch, 4% coverage) to reduce phonon trapping
- No side electrodes on this detector, stable operation at 66V bias (mitigation of risk of leakage at HV)

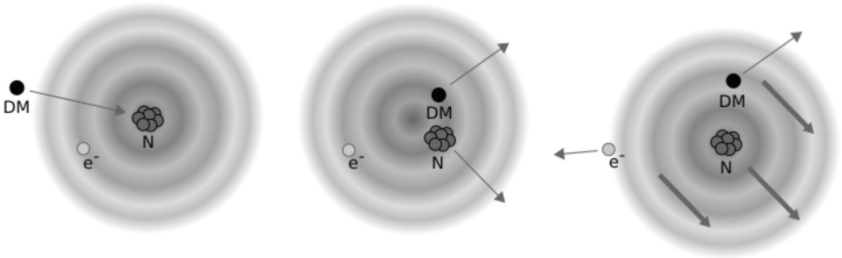
- Part of the longest LSM cool-down: December 2018 - July 2020
- 4 eVee resolution at 66V + reduced HO background: ideal for Midgal searches

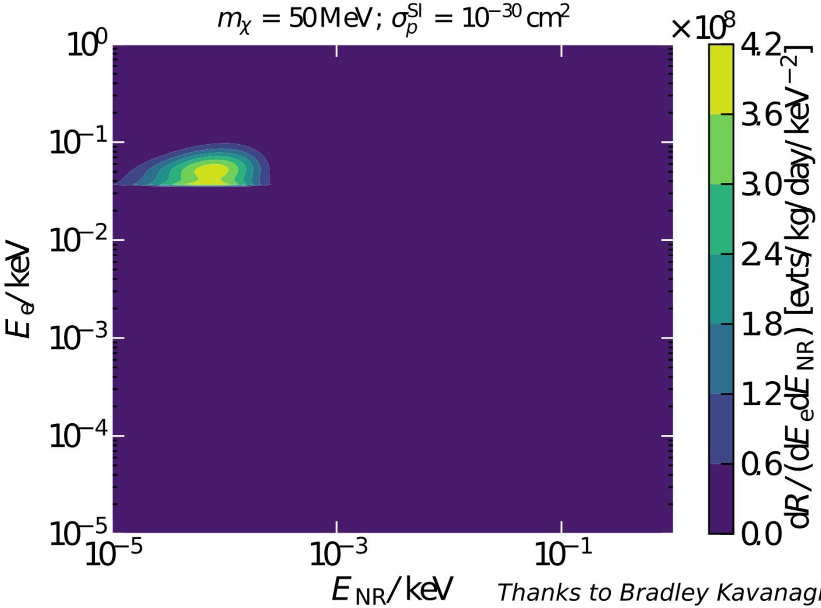


The Migdal effect in a nutshell

- Nuclear recoil is produced simultaneously with an additional electron recoil, with up to few 100 eV energy.
- For WIMP mass << few GeV/c², electron energy very large compare to nuclear recoil (and not affected by quenching)

- Calculation in Ge (Ibe et al arxiv:1707.07258) reliable for n = 3 shell electrons (only shell considered here).
- Migdal electron energy = 35 eV in Ge (Ideal target of search for NbSi209 with σ = 4 eVee)

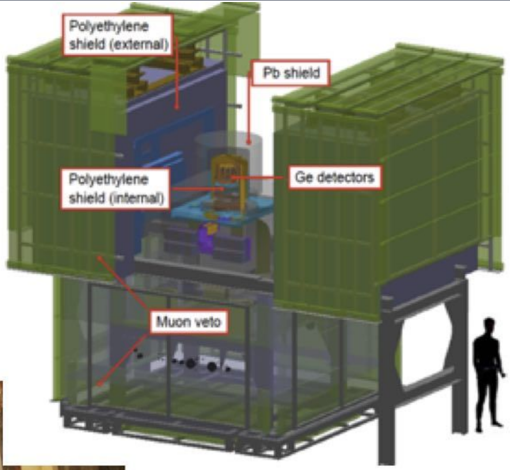


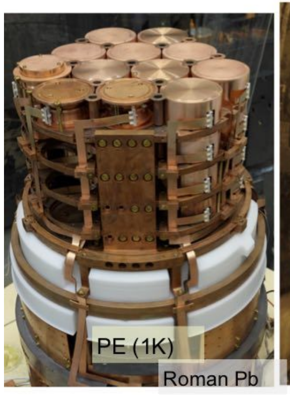


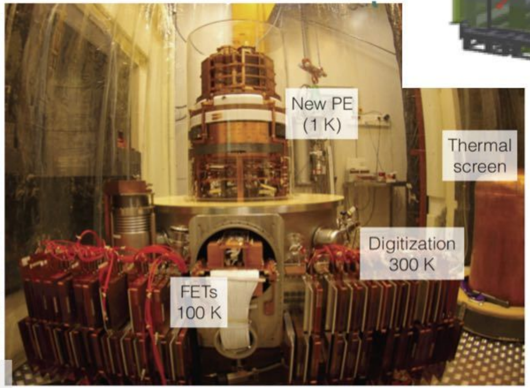
Thanks to Bradley Kavanagh

EDELWEISS–III Setup

- ***LSM: Deepest site in Europe***
  4800 m.w.e., 5 μ/m^2/day
- Clean room + deradonized air
  Radon monitoring down to few mBq/m^3
- Active muon veto (>98% coverage) on mobile shield
- External (50 cm) + internal polyethylene shielding
  Thermal neutron monitoring with ^{3}He detector
- Lead shielding (20 cm, including 2 cm Roman lead)
- Selection of radiopure material







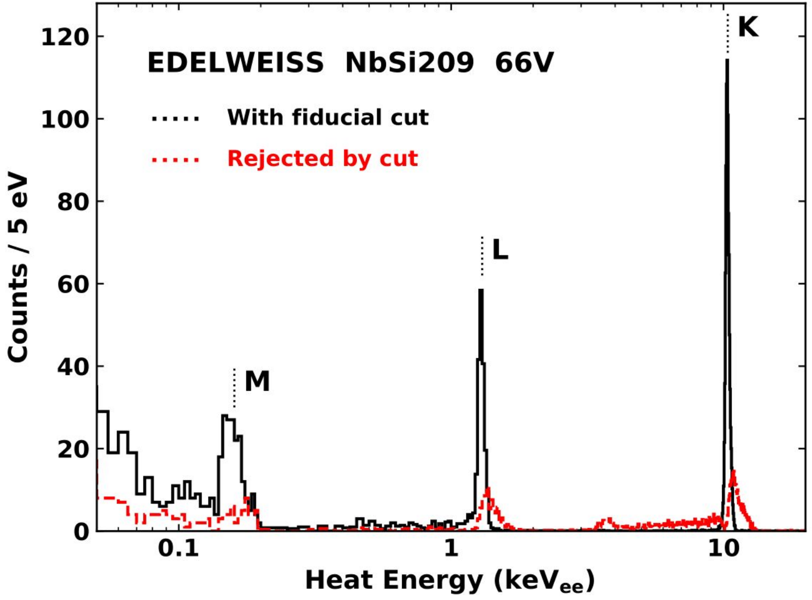
Cryostat can host up to 40 kg detector at 18 mK

Performance of the EDELWEISS-III experiment for direct dark matter searches

[JINST 12 (2017) P08010]

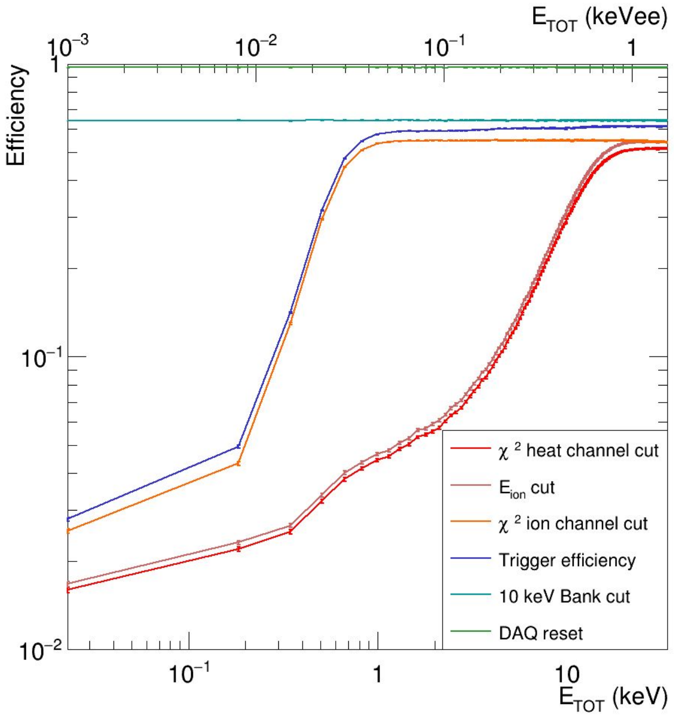
Analysis: Calibration

- Calibration from K, L, M, ^{71}Ge decay line.
- Baseline resolution 100 eV on total energy, i.e. 4 eVee for electron recoils at 66V
- Quality cut to reject spurious events.
- Fraction of events with full charge collection and no extra signal from out-of-equilibrium phonons: 64%



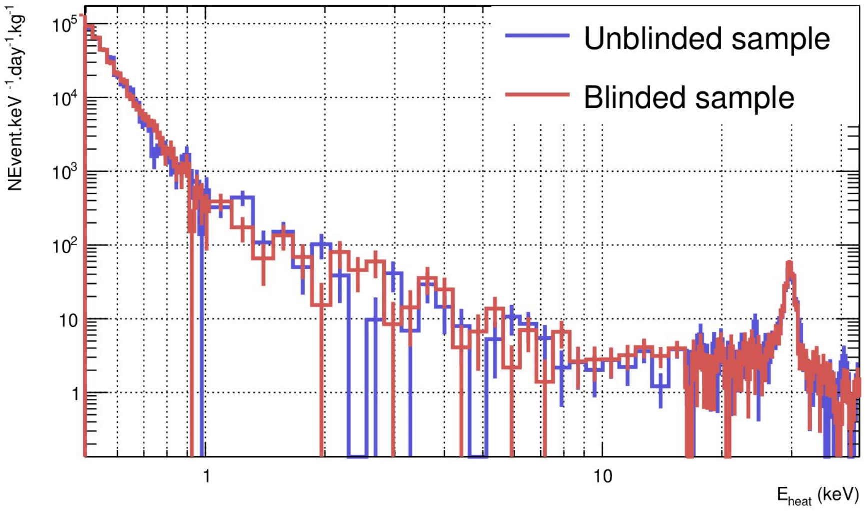
Analysis: Efficiency

- Full pulse simulation: Efficiency determined from injection of actual 10.37 keV events, scaled to desired energy, at random times in entire search data
- Conservatively only consider efficiency for events with full charge collection and no out-of-equilibrium phonons (64%) - green "Bank cut”
- Trigger on heat channel using optimal filter (blue)
- To reduce as much as possible HO background, require > 400 eVee signal on electrodes (brown), compared to σ = 200 eVee. Aggressive, but well-understood cut.
- Loose cuts on chi2 pulse fit (ionization and heat) + equal signal on both NbSi film halves: small effect on efficiency.



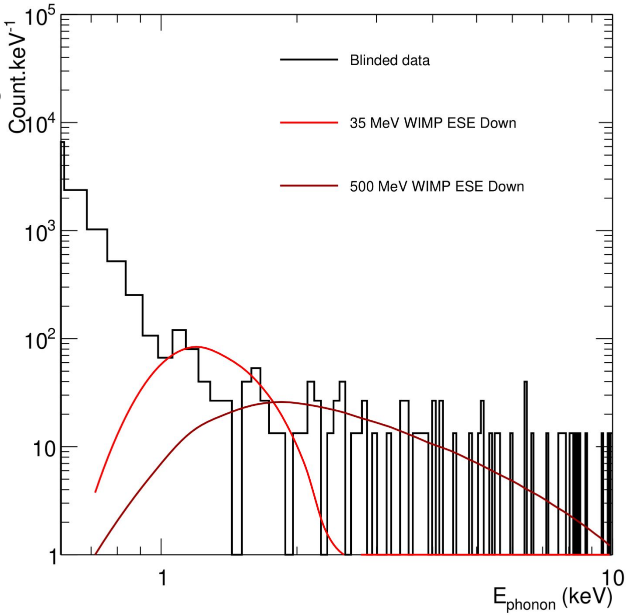
Analysis: strategy

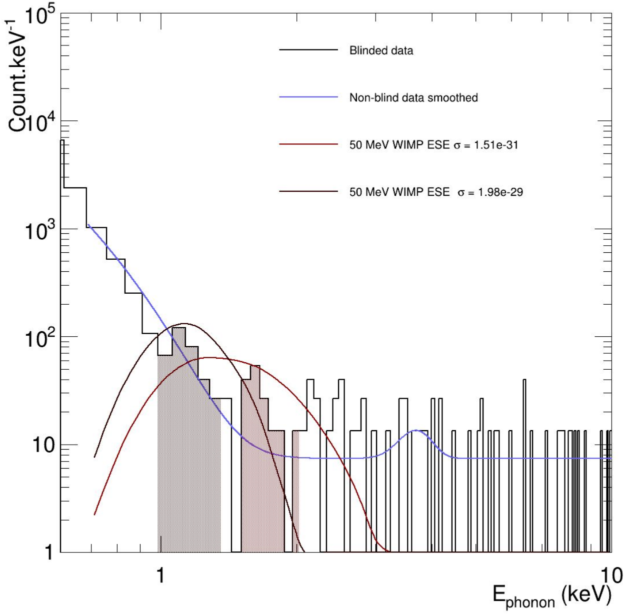
- Poisson upper limit assuming all events are DM candidates, no background subtraction
- Dataset divided in half, 1 over 2 hours blinded
- The other half use to set analysis cut and region of interest
- each set represent 28 days of data



Analysis: limit extraction

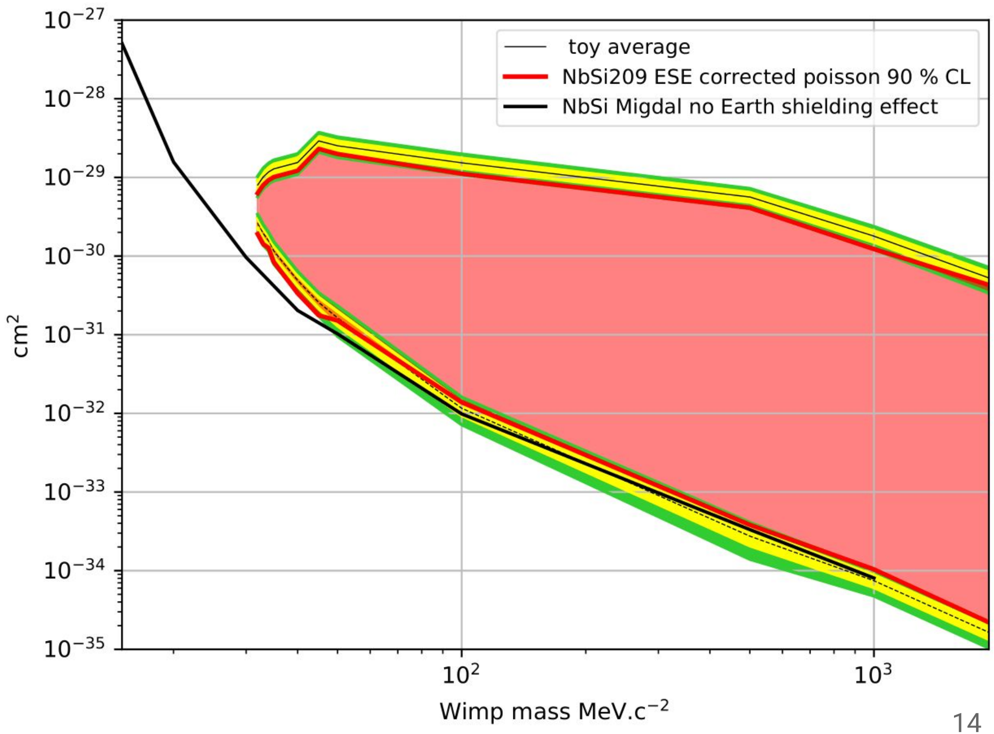
- Region of interest → maximize ratio signal over background in non-blind sample
- Using these fixed ROI, 90%CL Poisson upper limit on rate in blind sample
- Signal corrected for Earth shielding effect (ESE): at too high cross-section, the DM flux cannot reach the detector.
- For a given mass, large ESE effects can change both DM spectrum shape and rate (right)





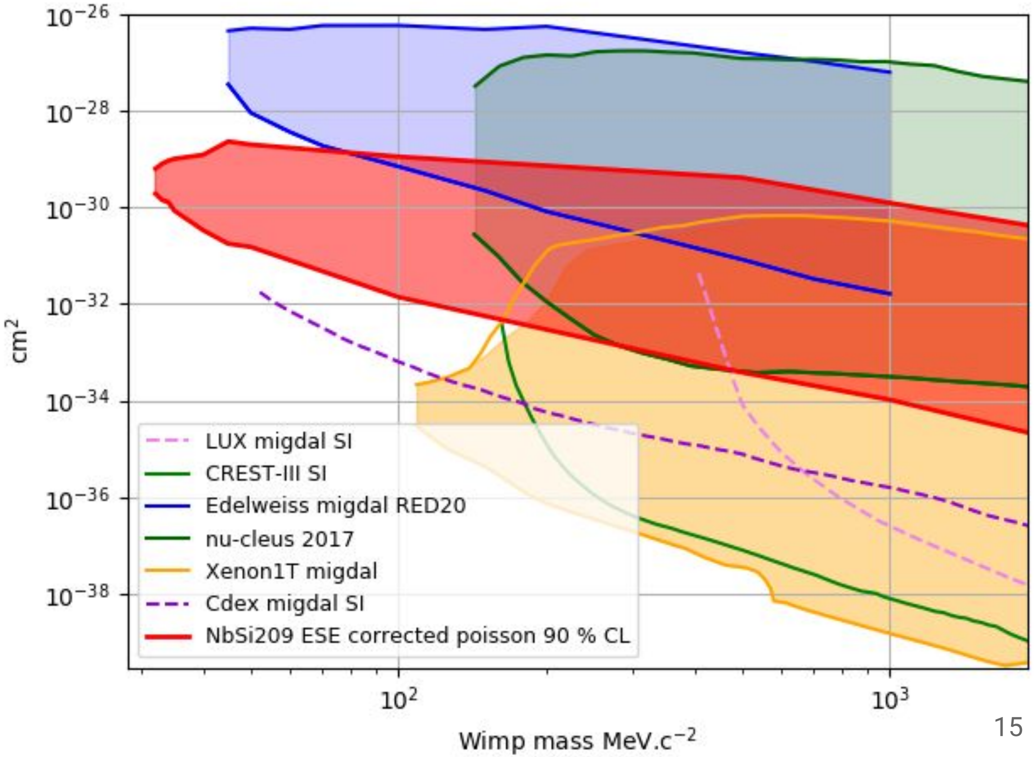
Analysis: Results

- Earth shielding lower the mass range sensitivity
- Strong effect starting at 50 MeV/c²
- MC toys used to probe statistical stability of the results.

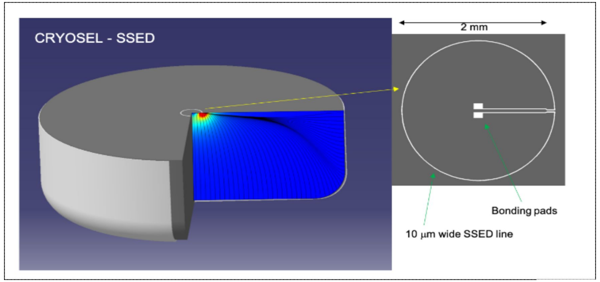


Analysis: Results

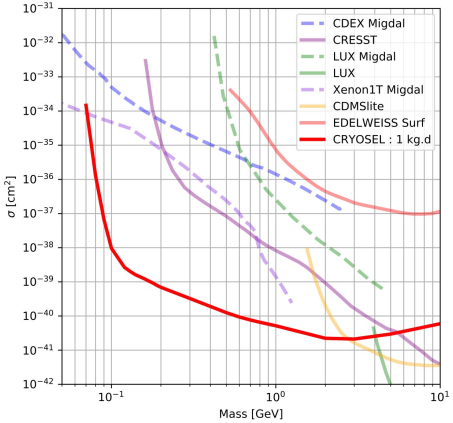
- First result below 50 MeV/c²
- Extend the reach of WIMP search down to 32 MeV/c²
- Improvement relative to previous EDELWEISS results due to deep underground site, improved resolution (with NTL amplification) and improved HO background in new NbSi detector.
- Good sign for the coming EDELWEISS-SubGeV program

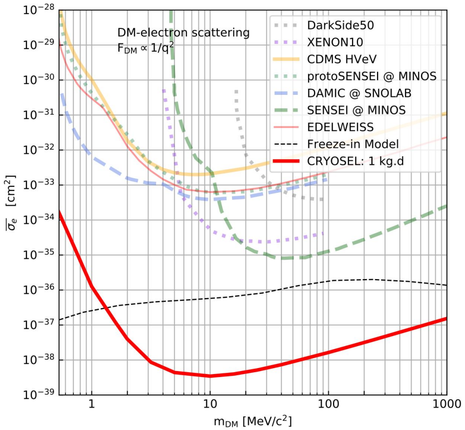


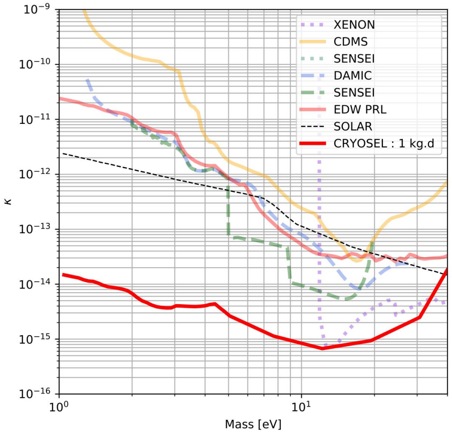
Future: CRYOSEL



- ANR CRYOSEL: 40g Ge detector, σ_{phonon} = 20 eV, sustaining 200 V bias
- SSED detector able to detect athermal phonon emission of individual charges passing through the high-field region in front of it (red dot). Drastic rejection of HO events.
- Expect many orders of magnitude improvement compared to present-day sensitivity, even with 1 kg.d exposure





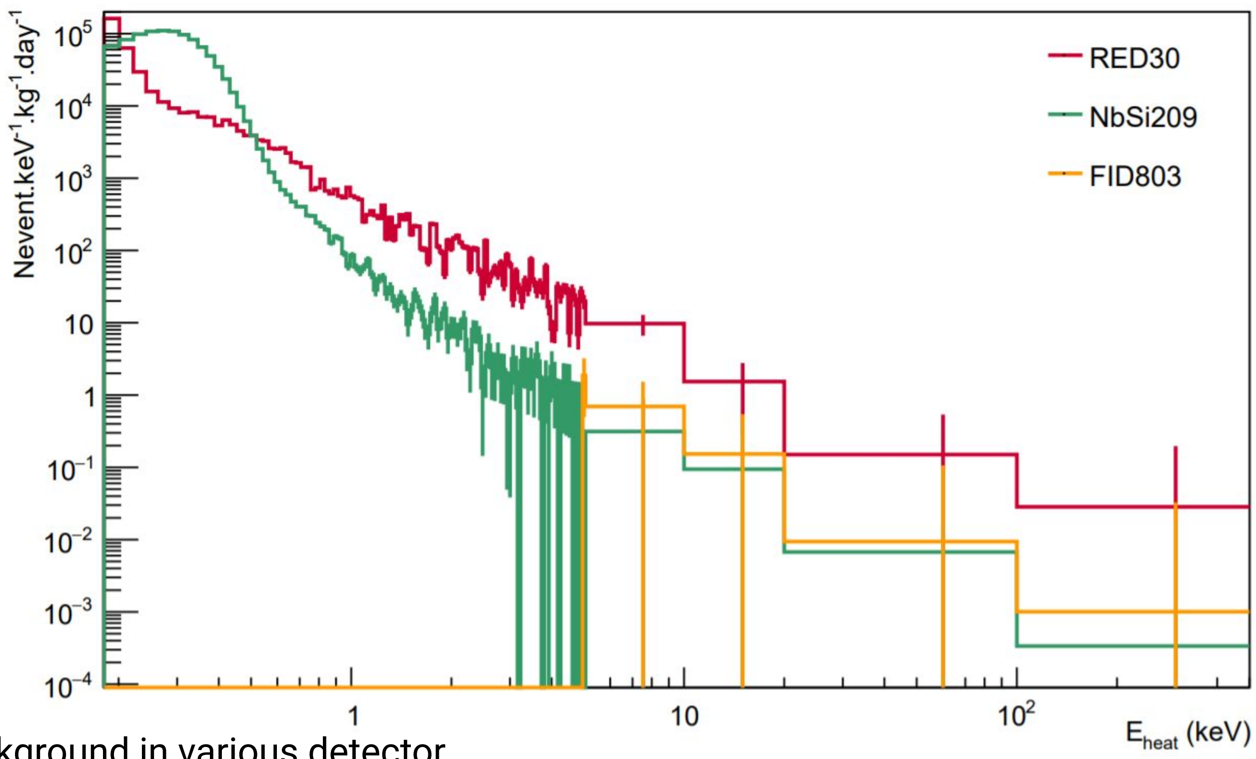


Conclusion

- EDELWEISS-SubGeV:
  - event-by-event rejection at lower mass, exploring both low-bias mode (in synergy with Ricochet) and high-bias mode (ANR CRYOSEL)
  - Progress (and new DM limits) already achieved (17.3 eV phonon resolution, 0.53 e-h+ resolution at 78V)
  - ANR CRYOSEL to master HO background in HV detector and fully open mass range from 1 eV/c^2 to 1 GeV/c^2
- New result with 200g Ge with NbSi Transition Edge Sensor:
  - First EDELWEISS limits using athermal phonon sensor
  - 4 eVee resolution at 66V
  - Reduced background of HO events
  - First Migdal WIMP limits at 32 MeV/c^2

Backups

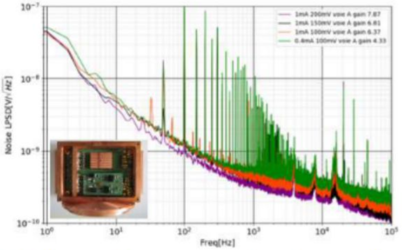
Spectra comparison after cut on E_ion (LV)



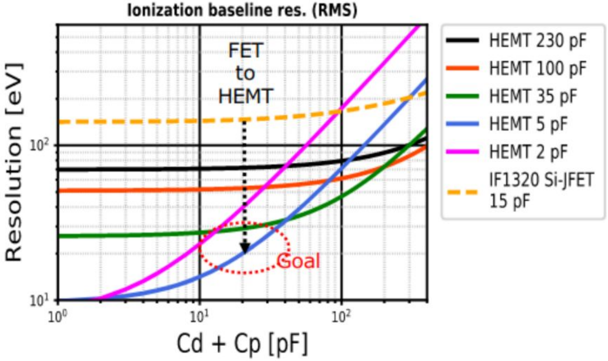
- HO background in various detector

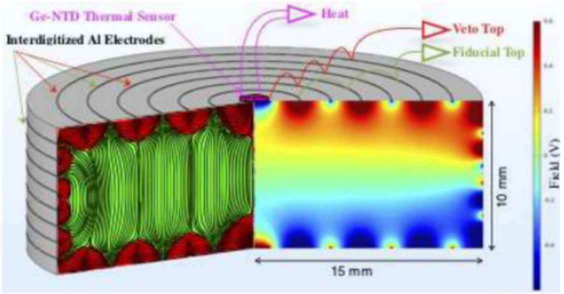
Toward 20 eVee ionization resolution

- Transition from JFET to HEMT
  [Phipps:1611.09712, and **arXiv:1909.02879**]
- Lower intrinsic noise + reduce cabling capacitance by working at 1K or 4K
- Data driven HEMT models show that the goal of 20 eV_{ee} is reachable with ~20 pF total input impedance
- Ongoing HEMT characterizations



- HEMT-based preamp tests end of 2019
- Cryogenics + cabling challenges ahead
- **Work done in synergy with the Ricochet-CryoCube collaboration**





Optimization of 33g FID design: large fiducial volume & low capacitance