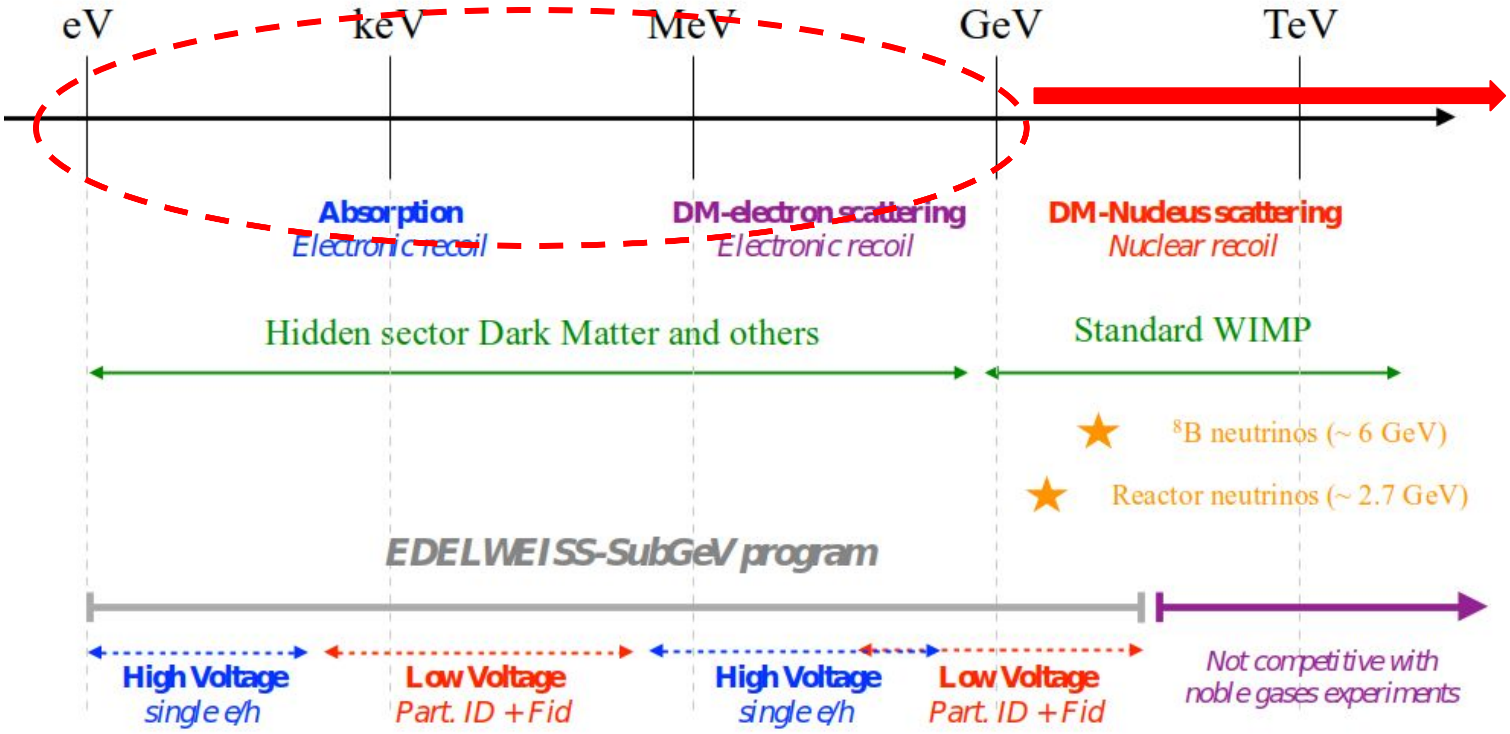
Sub-MeV Dark Matter Searches with EDELWEISS: results and prospects

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

Recent low-mass results :
PRL 125, 141401 (2020)

HEP2021
VIRTUAL EDITION

A wide search playground

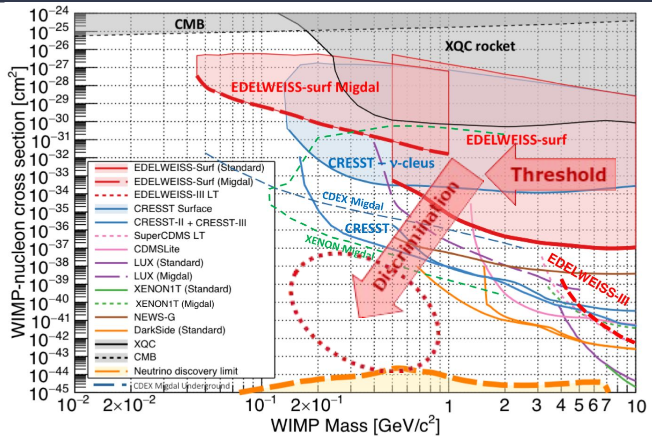


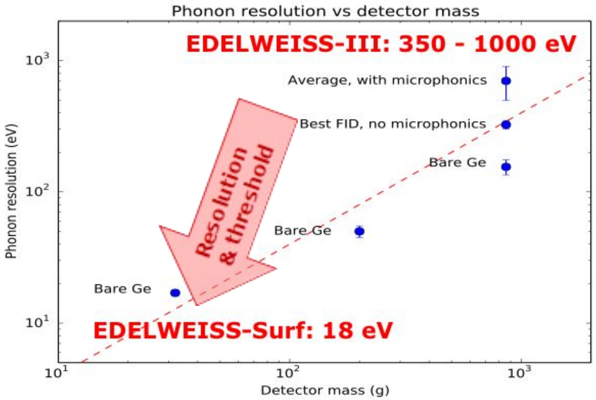
- Challenging search area
- Many new techniques being proposed
- Need low threshold (down to single electron)
- ER/NR discrimination

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

Edelweiss subGeV program

- 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)
  [JLTP 199, 798 (2020)]

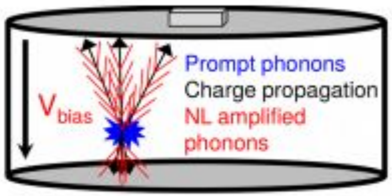




- Reducing detector mass is crucial to reach these goals :
  EDELWEISS-Surf [PRD 99 082013 (2019)]
  33 g Ge bolometer.
- Applying HV to amplify signal, lower threshold and separate NR /ER :
  Electron-DM results [PRL 125, 141401 (2020)]
  78 V applied onto 33 g Ge bolometer.

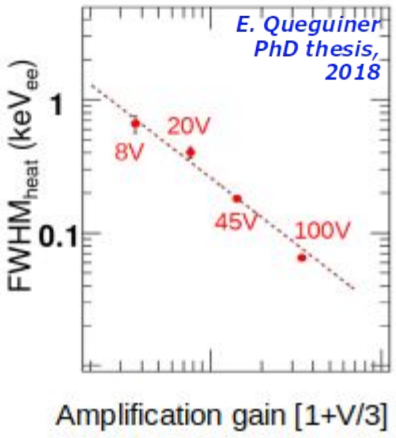
Amplifying signal : Neganov-Luke effect

- Amplification of heat signal due to charges drifting in electric field



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

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



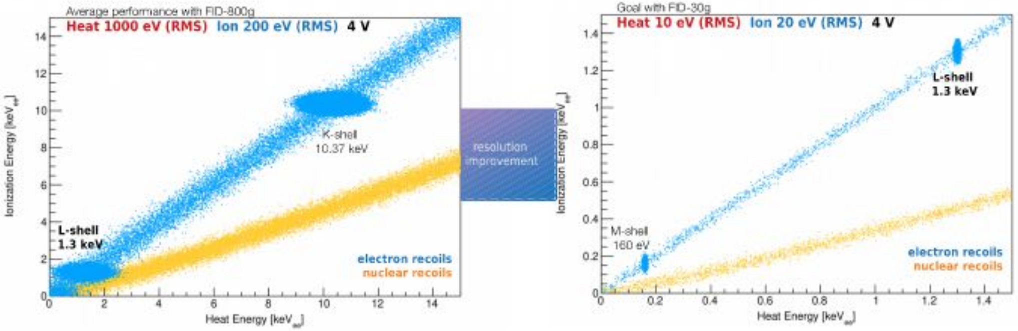
- Amplification proportional to ionization signal and to applied bias
  - Loss of discrimination as heat is dominated by ionization signal
  - Resolution gain by a factor (1+V/3) for e^- signals

EDELWEISS SubGeV 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



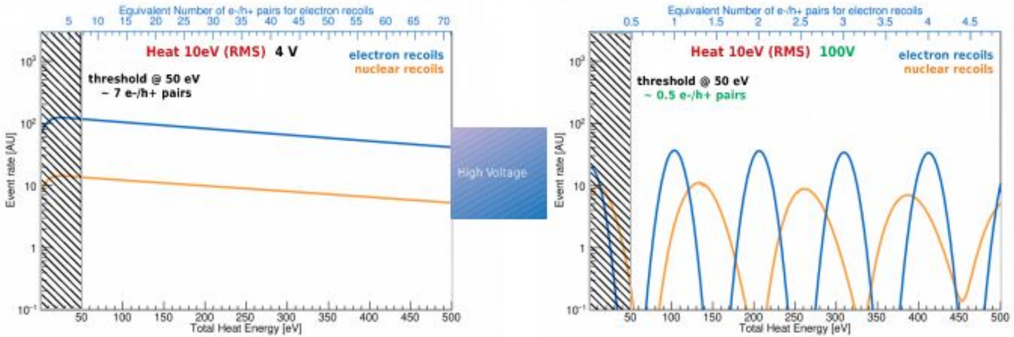
Low-voltage objectives are part of a common effort with the Ricochet collaboration, dedicated to studying CENNS at reactors supported by the ERC-CENNS Starting Grant (2019-2024)

High Voltage Objectives

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

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

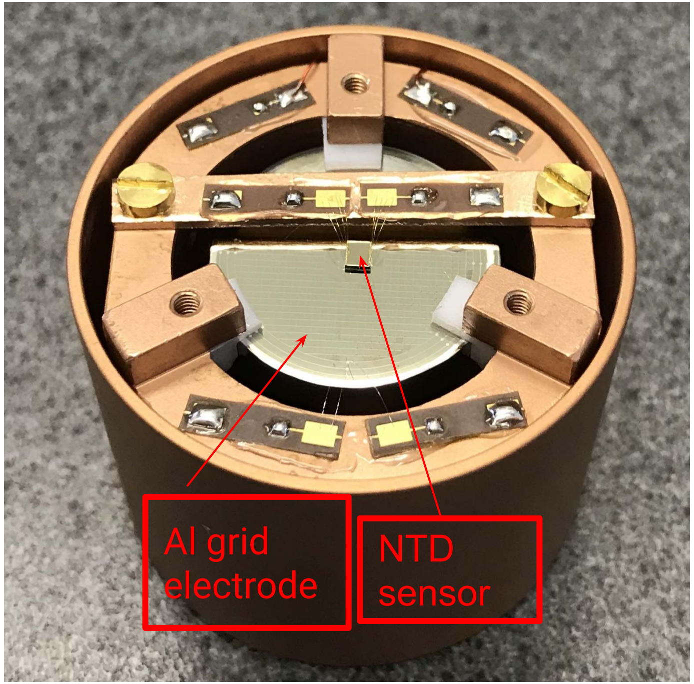
Single **ELE**ctron **N**uclear recoil **DIS**crimination
SELENDIS



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

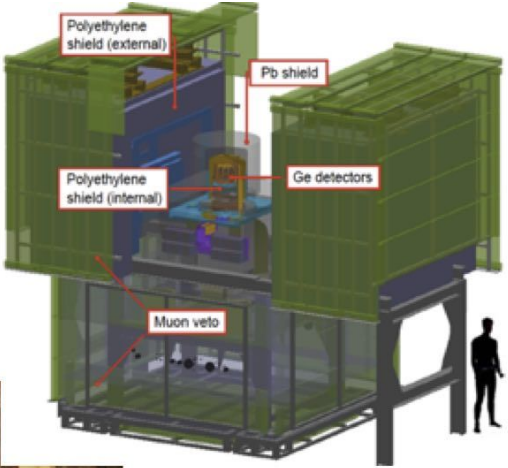
RED30 detector: HV operation [PRL 125, 141401 (2020)]

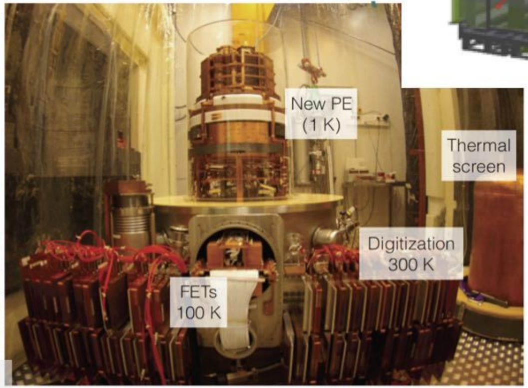
- Similar to EDELWEISS-surf 33 g Ge detector + Al electrodes
- 1 Ge-NTD sensor (1.6 mm^3) glued directly on bottom Ge surface
- Flat surface electrodes: lithographed Al grid (500 µm pitch, 4% coverage) to reduce phonon trapping
- Outer rings of the grid act as separate guard electrodes (outer ~2 mm)
- No side electrodes on this prototype (mitigation of risk of leakage at HV)



EDELWEISS–III Setup

- ***LSM: Deepest site in Europe***
  4800 m.w.e., 5 $\mu/m^2/day$
- 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 ^3He 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]

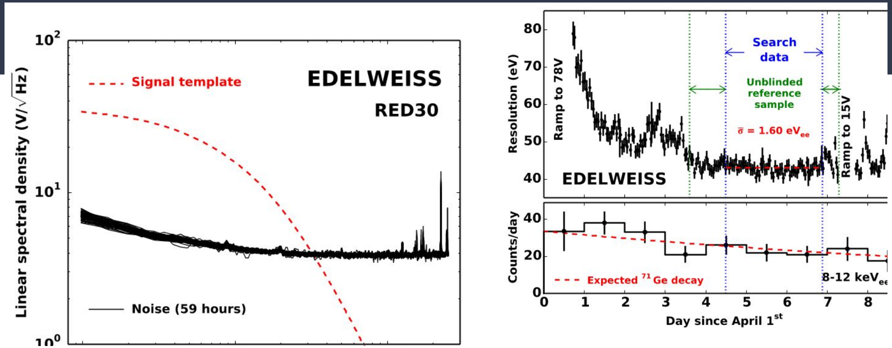
Detector resolution

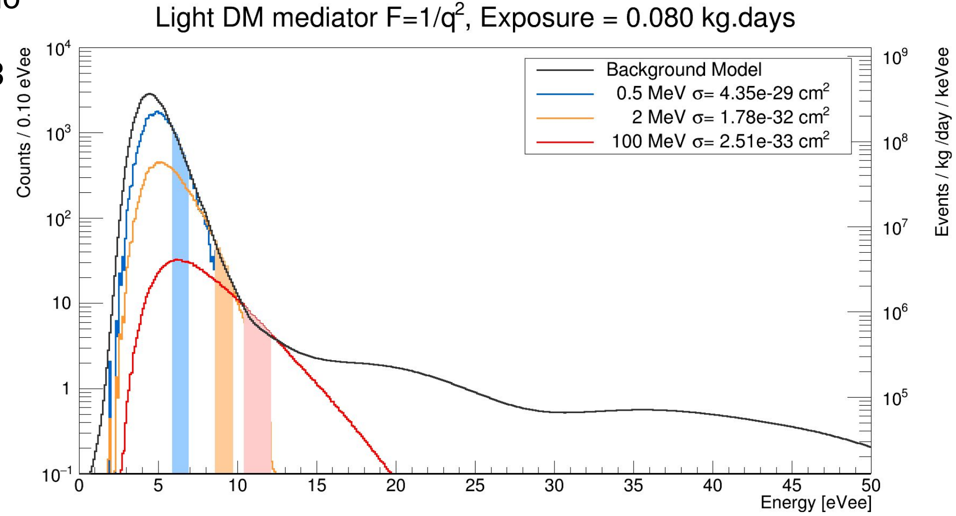
- Dataset : 2.44 days (at 78V) blinded below 1 keV
  - Baseline resolution σ= 42 eV (1.60 eVee)
  - Stable resolution (from random trigger data)
- Reference sample: 1.3 days before/after search data
- Poisson upper limit assuming all events are DM candidates, no background subtraction
- Determine most sensitive range (Region Of Interest) using 1.3 day sample non-blinded data (smoothed with KDE) recorded just before/after the search
- Signal calculation: QEdark

  [R. Essig et al., JHEP05 (2016) 046]

  charge quantization as in SuperCDMS,

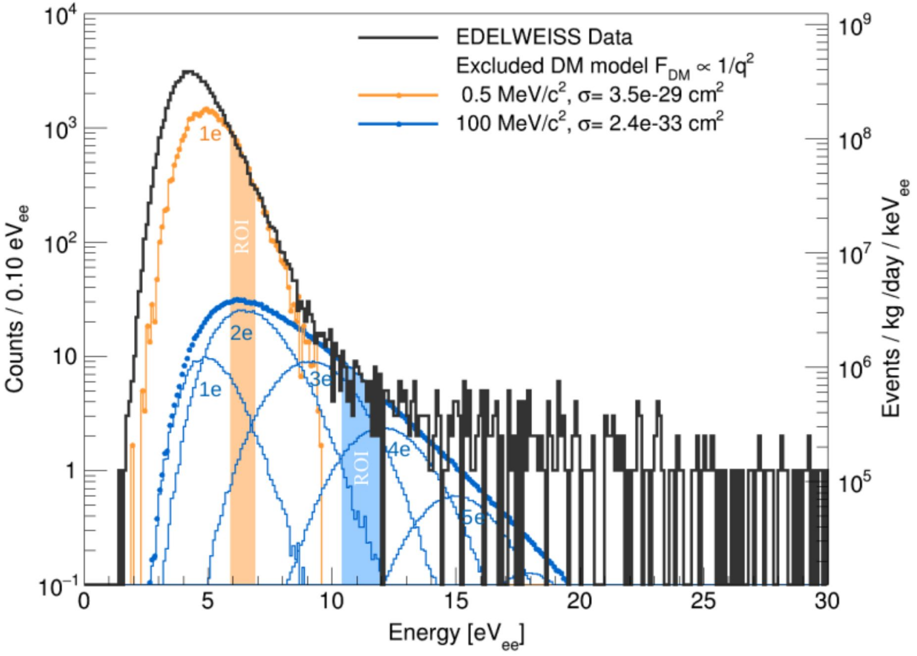
  [PRL 121 (2018) 051301]





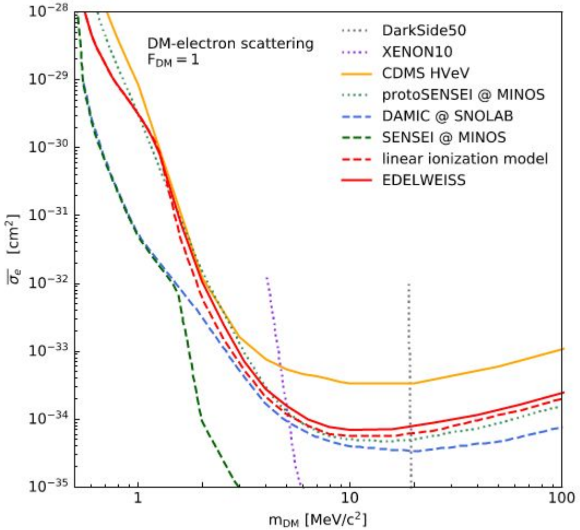
Limit setting strategy

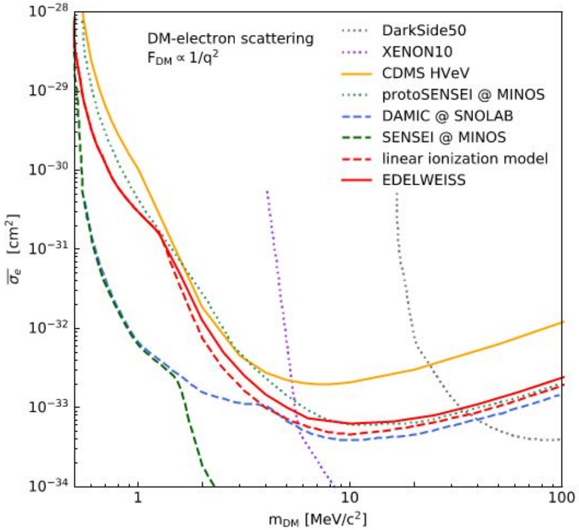
- 90%CL Poisson upper limit on rate in fixed energy range on blinded data (ROI)
- Applied same fixed range to blinded data
- Data below 10 eVee probably dominated by noise blob (readout noise + dark current?)
- Despite not being able to resolve individual number of e-h pairs, observed rates set useful limits on DM models
- M_{DM} < 1 MeV: signal ~ 1 $e^- h^+$ pairs
- M_{DM} >> 10 MeV: limit driven by n= 3 to 4 pairs



Results : DME scattering

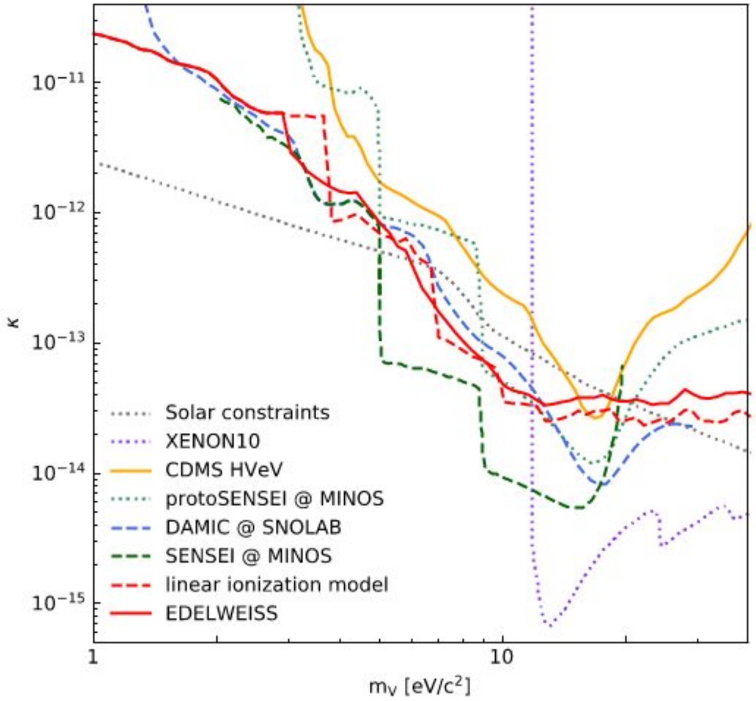
- Sensitivity extends into the domain of sub-MeV DM particles: with resolution σ = 0.53 $e^- h^+$ pairs, there is some sensitivity to single e^- events
- Despite being a first prototype, current sensitivity of 33g Ge bolometer already comparable or better than CDMS 1 g Si bolometer with 10X better resolution
- This is due to lower background level in the 33g bolometer thanks to LSM low-background environment and smaller surface/volume ratio





Results : Dark photon

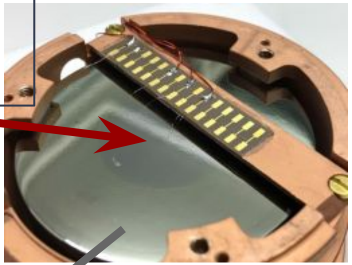
- Smaller gap of Ge wrt Si helps (despite factor x25 better single-electron background in SENSEI)
  [PRL 125, 141401 (2020)]
- Competitive and complementary with Si searches below 5 eV, thanks to different photoelectric cross-section at low energy and lower gap

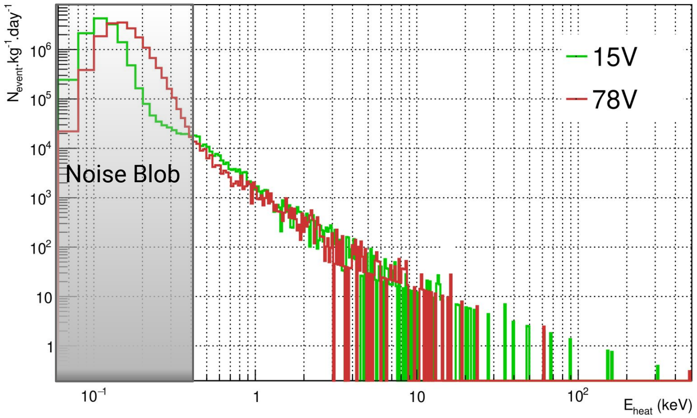


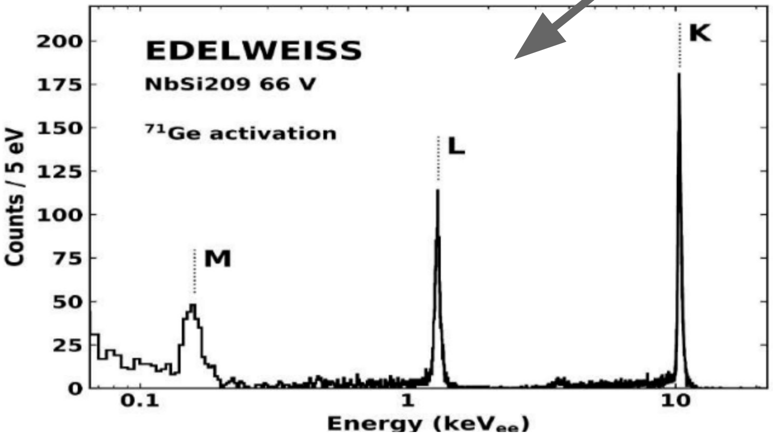
Limitation from Heat Only background

- HO nature of dominant background above 400 eV (15 eVee at 78V)
- Present results limited by low energy HO background.
- Systematic studies of HO population: no clear dominant source identified yet
- Most interesting lead significant reduction in detectors with innovative heat sensor: NbSi thin film Transition Edge Sensors
- <5 eV_{ee} resolution obtained (66 V) at LSM on a 200 g prototype (σ_{phonon}<110 eV)

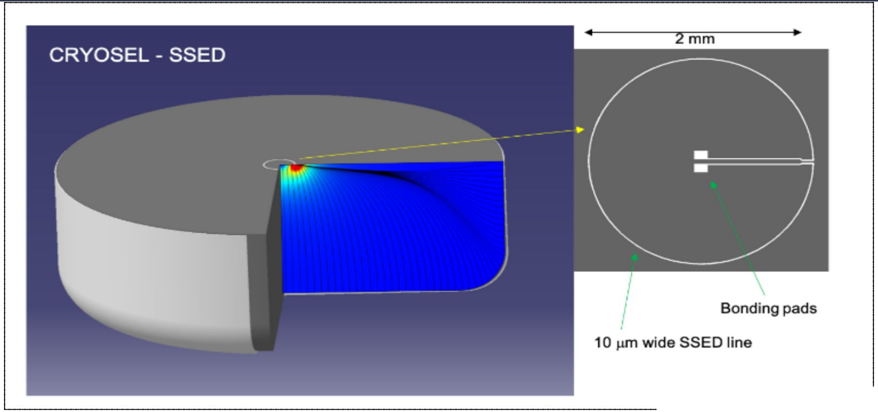
NbSi TES sensor used in ongoing physics analysis



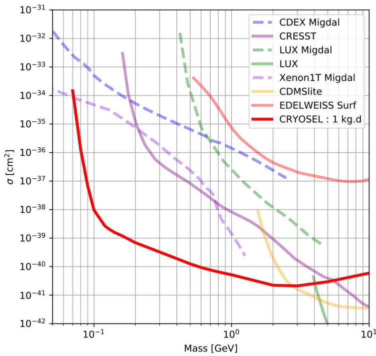


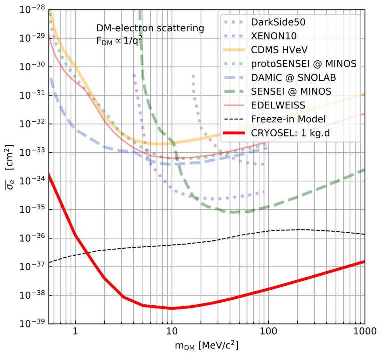


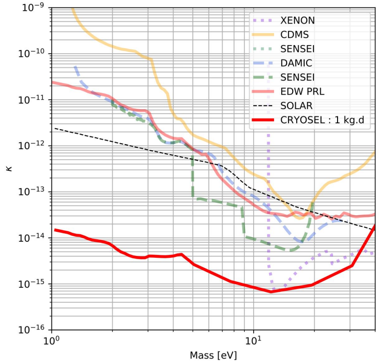
Future HV detectors : CRYOSEL



- CRYOSEL : 30g Ge detector, σ_{phonon} = 20 eV, sustaining 200 V bias
- SSED detector able to discriminate moving charges in events. Expect drastic rejection of HO event
- Projections give order of magnitude of improvement





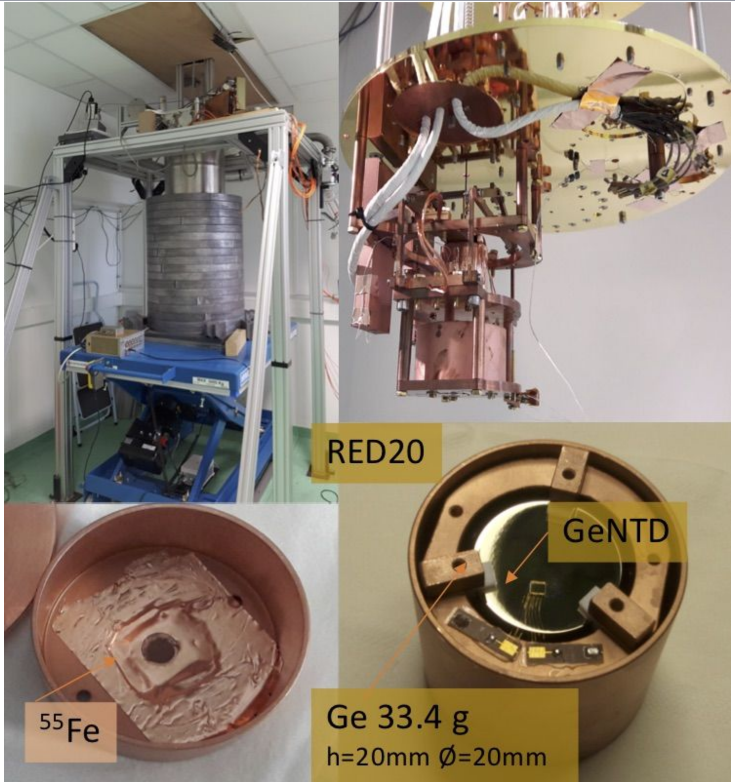


Conclusion

- Explore sub-GeV with event-by-event rejection
- Go to lower mass (sub-MeV for ER signals) with NL boost
- 20 eVee ionization resolution (synergy with Ricochet)
- 10 eV phonon resolution (17.3 eV achieved)
- 100 V (achieved on 800g; σ=0.53 e^-h^+ pairs on 33 g)
- Heat-Only event reduction : not under control yet! ...
- Analysis ongoing with new NbSi TES.
- CRYOSEL project : HV 30g Ge detector able to reject Heat Only event

Backups

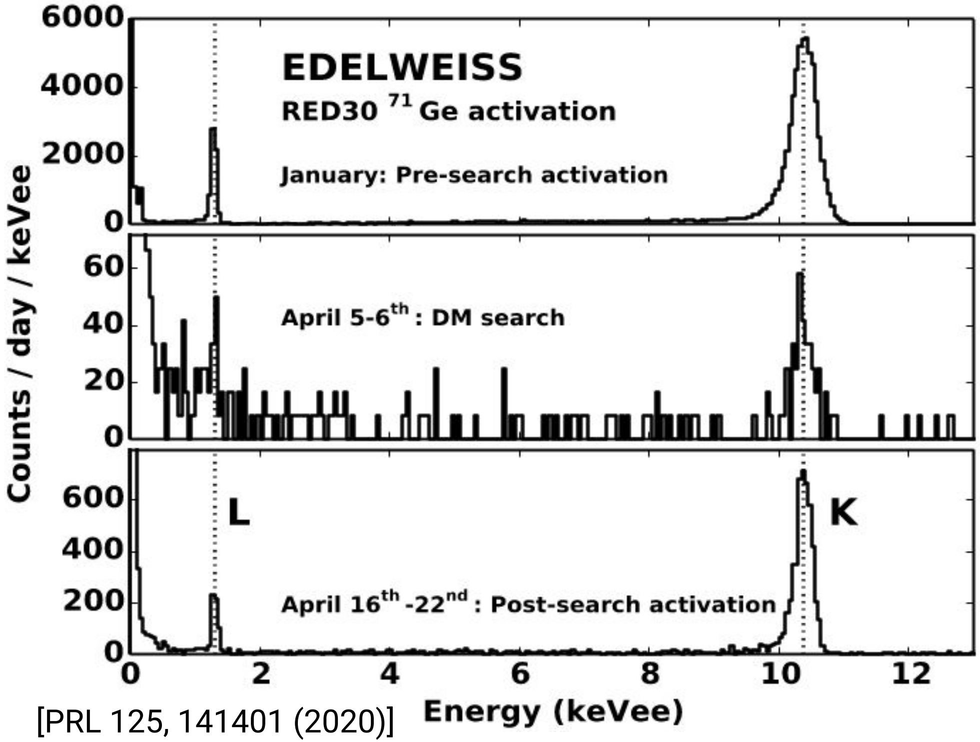
EDELWEISS-Surf Above-ground DM search



- Context: EDELWEISS and Ricochet common R&D for low-threshold detectors performed in 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)
  [NIM A858 (2017) 73]
- < mg/√Hz vibration levels (spring-suspended tower).
  [JINST 13 (2018) No.8 T08009]
- RED20 : 33g Ge with NTD sensor, with no electrodes
  No ER/NR discrimination, but no uncertainty due to ionization yield or charge trapping)
- 55Fe source for calibration

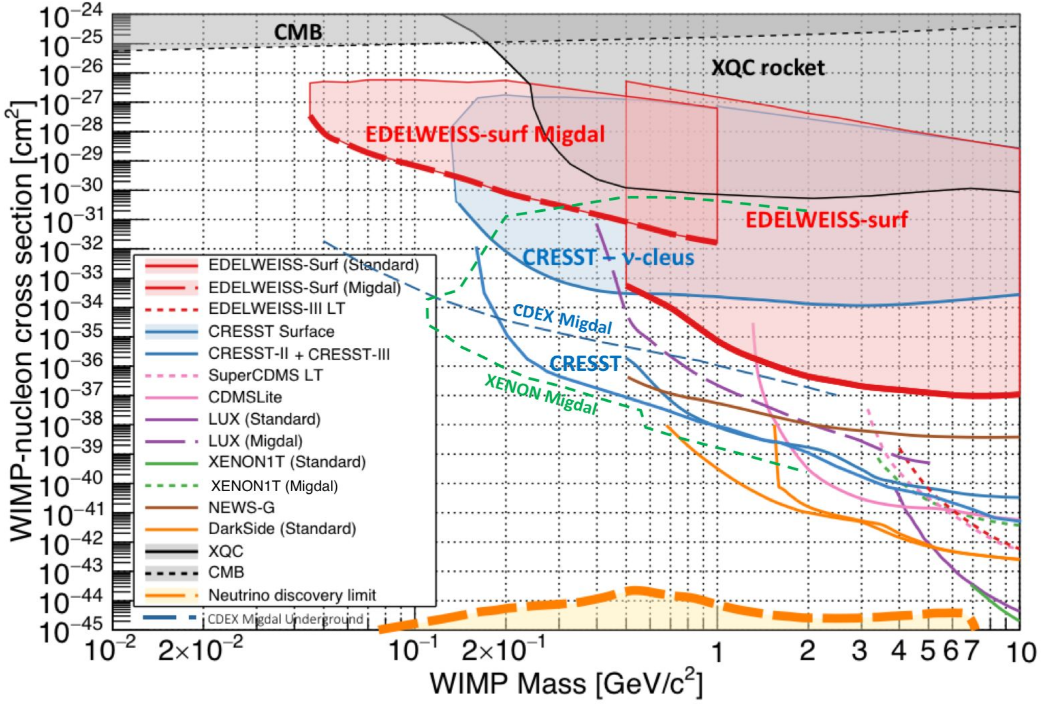
Detector Performance

- Detector characterization using ^{71}Ge 10.37 keV Line activated AmBe neutron source.
  Calibration charge collection fiducial volume.
- April 5st-6th: DM search at highest stable bias (78V) with reduced (but still visible) ^{71}Ge activation σ= 42 eV (1.60 eV_{ee})
- April 10th : in-situ re-activation to confirm the stability of the detector response and obtain reference sample of 10.37 keV events to be used in the data analysis of the DM search data

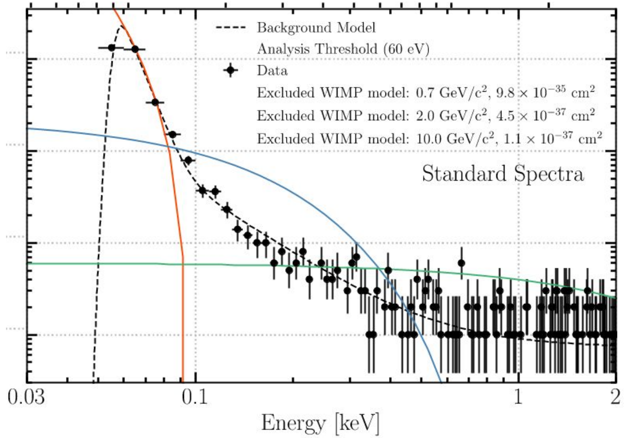


[PRL 125, 141401 (2020)]

Linking above and underground searches



- Shaded area : Earth shielding effect taken into account
- Lines : underground limits

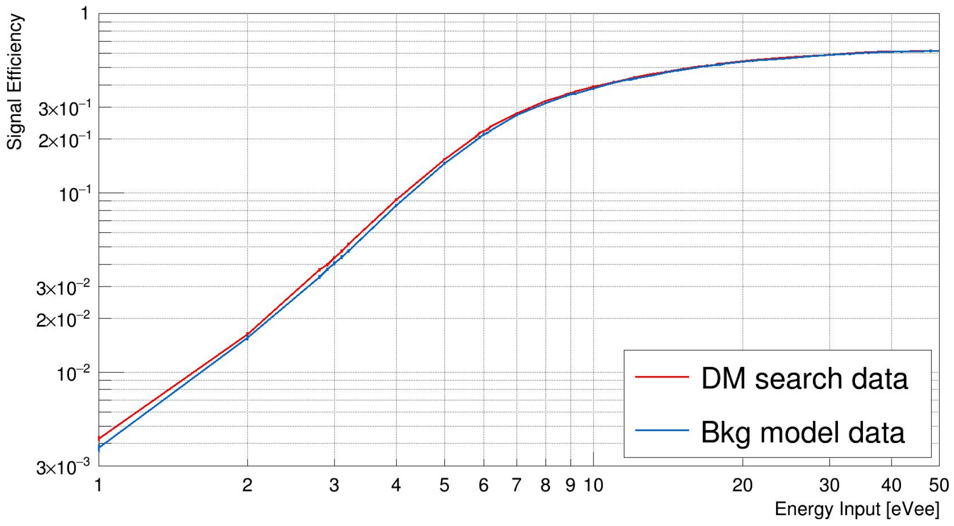


Since then: SuperCDMS-CPD, Arxiv:2007.14289

[PRD 99 082013 (2019)]

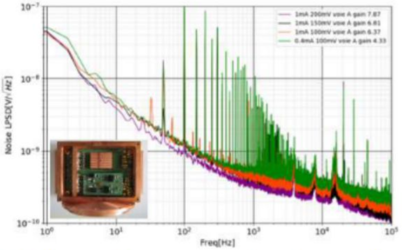
Efficiency

- 10 keV pulse injected onto data stream.
- Pulse taken from event bank.
- Pulse rescaled to desired energy, allowing a refined scan.

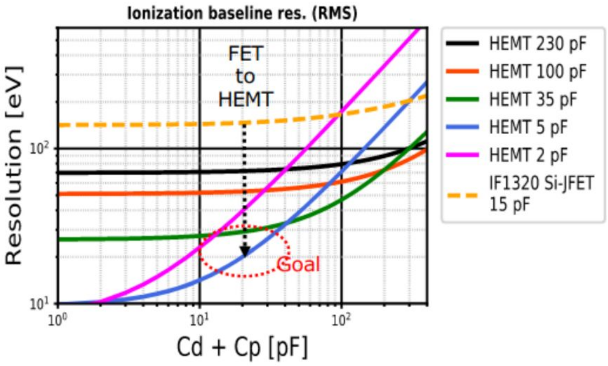


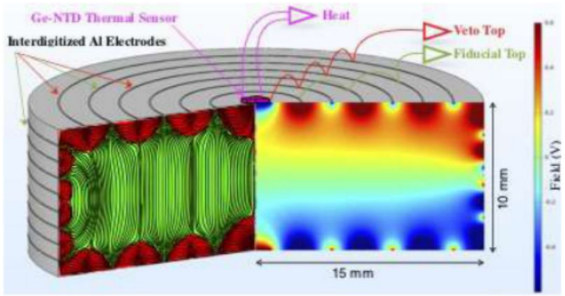
Toward 20 eVee ionization resolution

- 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