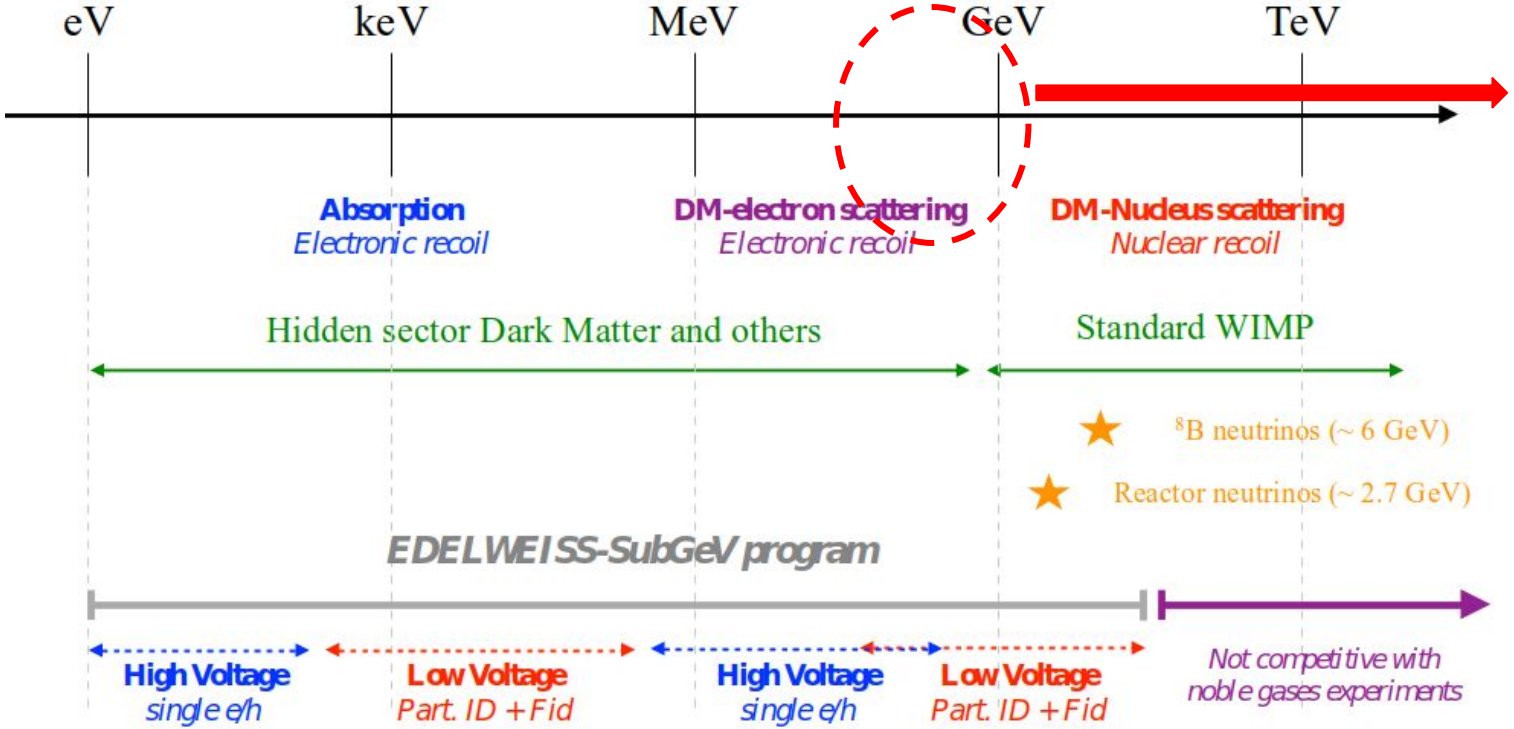
SubGeV Dark Matter searches with EDELWEISS

Recent low-mass results
PRD 99, 082013 (2019) & PRL 125, 141401 (2020)

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

A wide playground

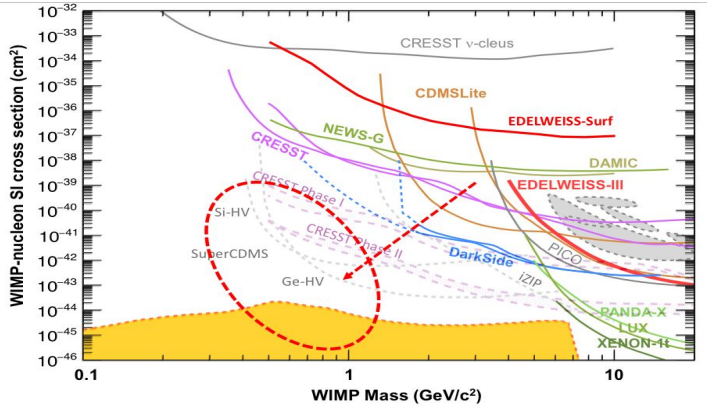


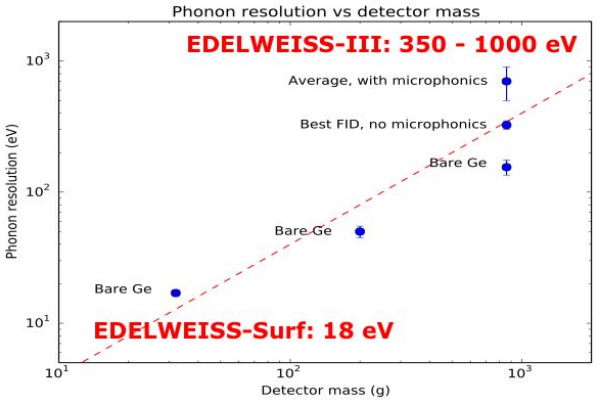
- Challenging search area
- Many new techniques being proposed
- Need low threshold (down to single electron)
- ER/NR discrimination
- Limitation from Quenching uncertainties

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

Edelweiss subGeV 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)

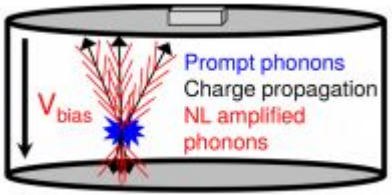




- Reducing detector mass is crucial to reach these goals :
  EDELWEISS-Surf [PRD 99 082013 (2019)]
  33 g Ge bolometer.
- Applying HV to amplify signal, lower threshold and separate NR /ER :
  Electron-DM results [PRL 125, 141401 (2020)]
  78 V applied onto 33 g Ge bolometer.

Amplifying signal : Neganov-Luke effect

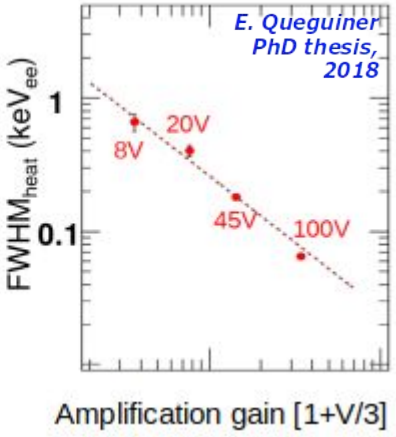
- Amplification of heat signal due to charges drifting in electric field



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

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

- 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

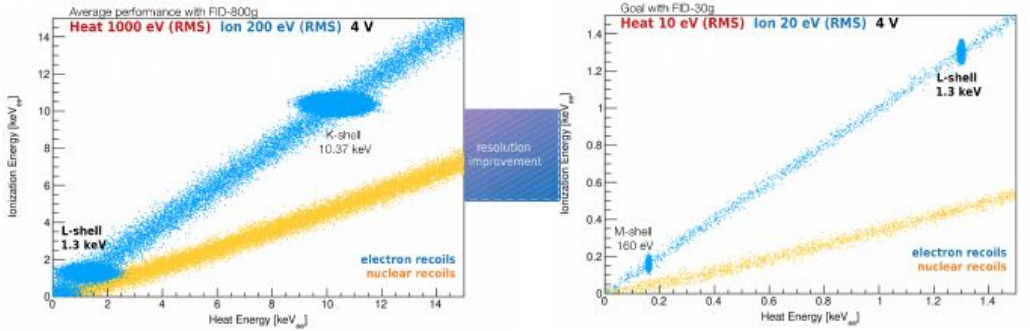


EDELWEISS SubGeV two modes

Low Voltage Objectives

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

Particle identification & surface event rejection down to 50 eV



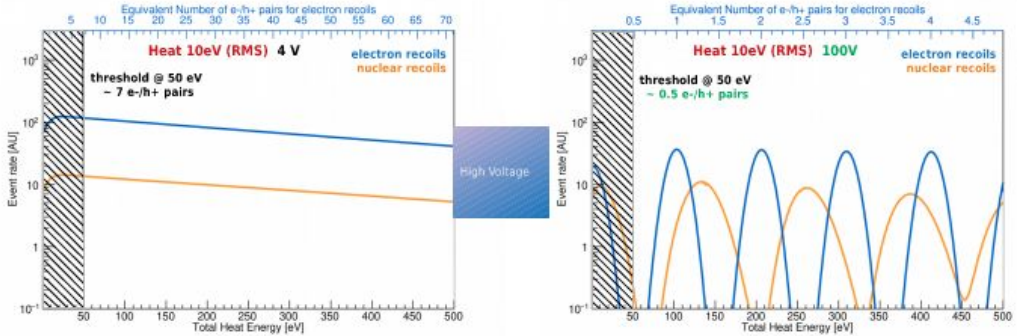
Low-voltage objectives are part of a common effort with the Ricochet collaboration, dedicated to studying CENNS at reactors supported by the ERC-CENNS Starting Grant (2019-2024)

High Voltage Objectives

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

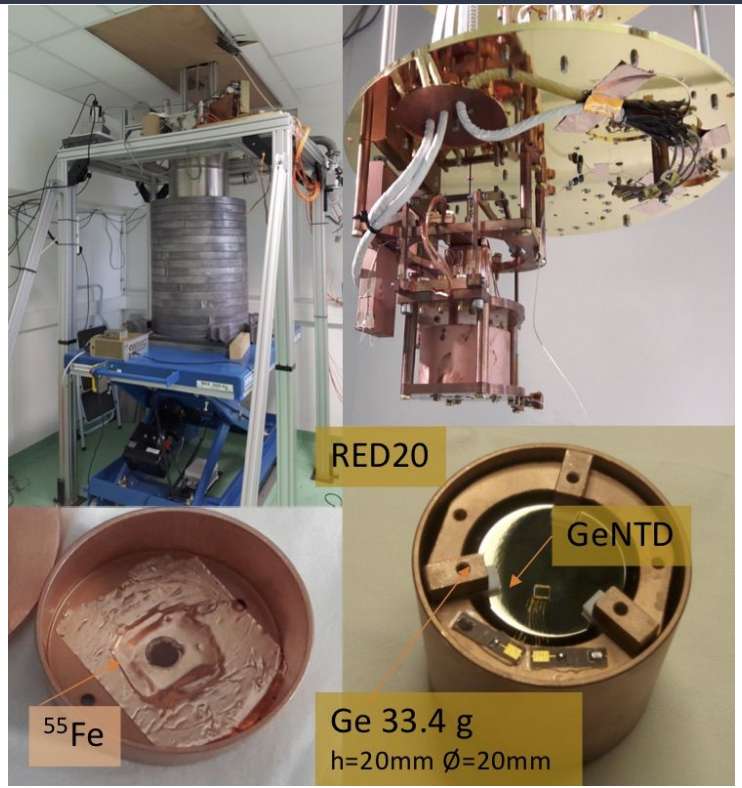
Single-e/h pair sensitivity with massive (~30g) bolometers

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



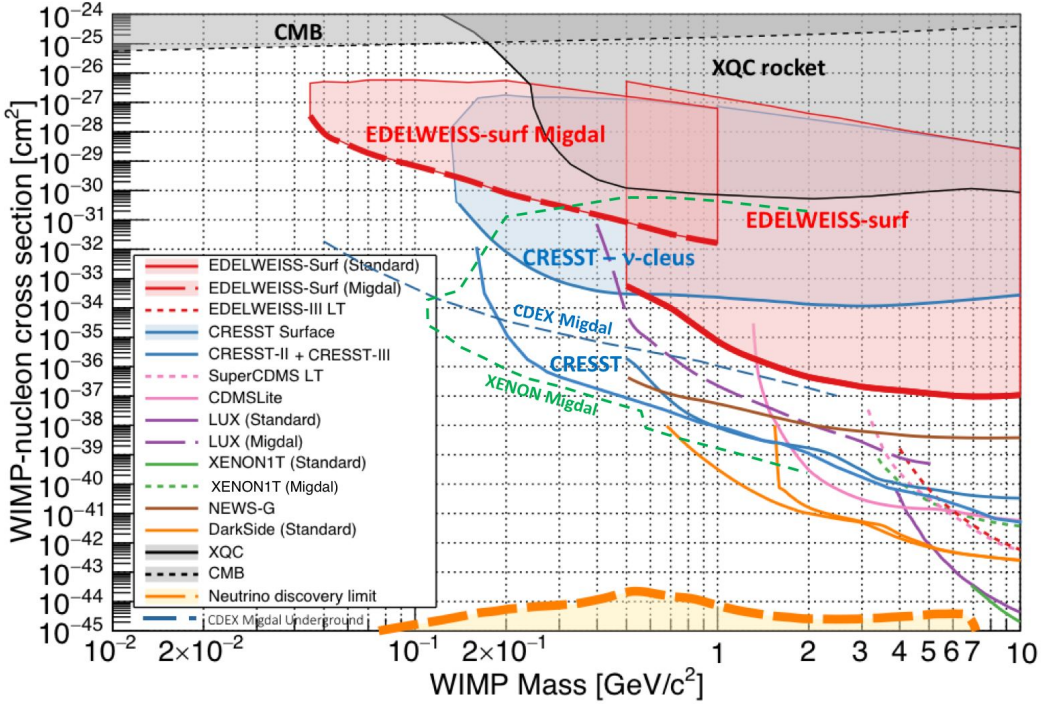
SELENDIS project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 838537

EDELWEISS-Surf Above-ground DM search



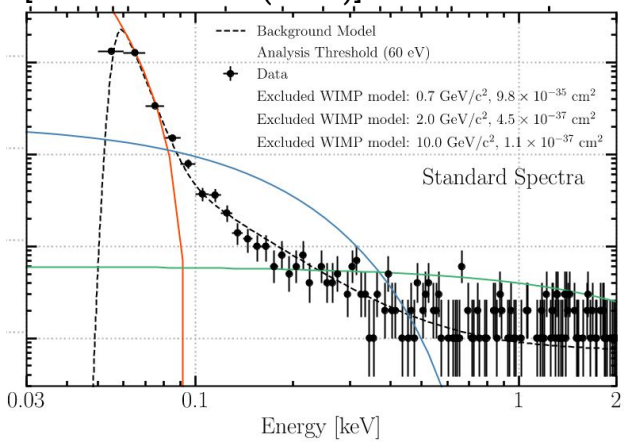
- Context: EDELWEISS and Ricochet common R&D for low-threshold detectors performed in easy-access surface lab @ IP2I-Lyon
- <1 m overburden: ideal for SIMP search (strongly interacting DM)
- Dry cryostat (CryoConcept) with <30 h cool-down (fast turnover ideal for detector R&D)
  [NIM A858 (2017) 73]
- < mg/√Hz vibration levels (spring-suspended tower).
  [JINST 13 (2018) No.8 T08009]
- RED20 : 33 g Ge with NTD sensor, with no electrodes
  No ER/NR discrimination, but no uncertainty due to ionization yield or charge trapping
- ^{55}Fe source for calibration

Linking above and underground searches



- Shaded area : Earth shielding effect taken into account
- Lines : underground limits
- Coverage of parameter space below 150 MeV/c^2 for large cross-section only possible in surface
- First NR-based limit with Ge below 1 GeV/c^2

[PRD 99 082013 (2019)]

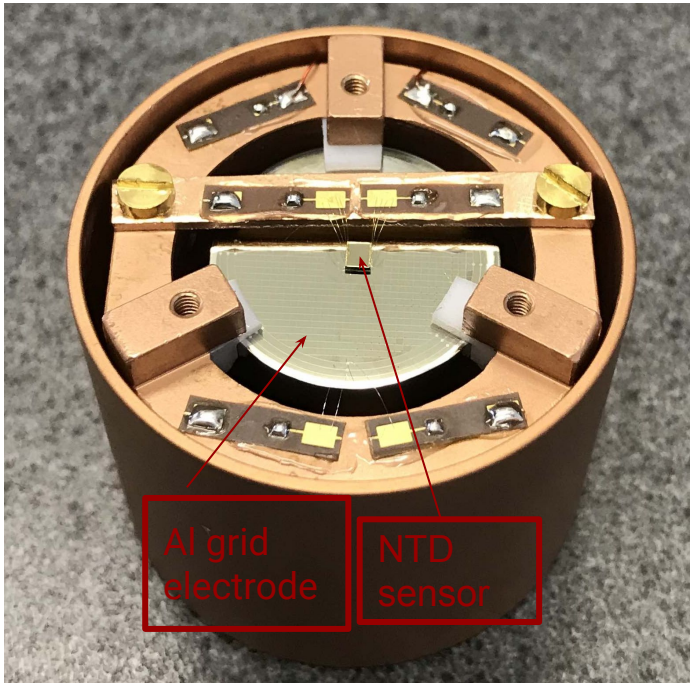


Since then:
SuperCDMS-CPD, arxiv:2007.14289

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

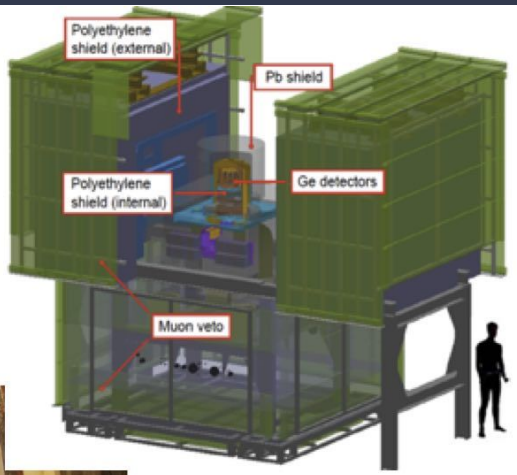
- Similar to EDELWEISS-surf detector + Al electrodes
- Operated underground at LSM, reduced muon flux (5 μ/m^2/day)
- 1 Ge-NTD sensor (1.6 mm^3) glued directly on bottom Ge surface
- Flat surface electrodes: lithographed Al grid (500 μm pitch, 4% coverage) to reduce phonon trapping
- Outer rings of the grid act as separate guard electrodes (outer ~2 mm)
- No side electrodes on this prototype
  (mitigation of risk of leakage at HV)

- Part of the longest LSM cool-down : December 2018 - July 2020



EDELWEISS-III 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



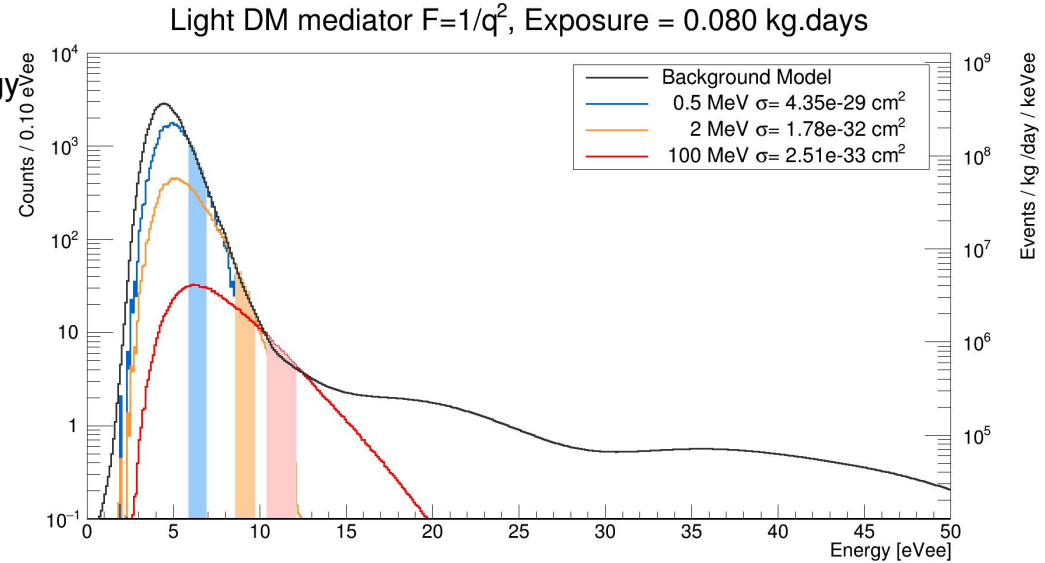
Cryostat can host up to 40 kg detector at 18 mK

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

[JINST 12 (2017) P08010]

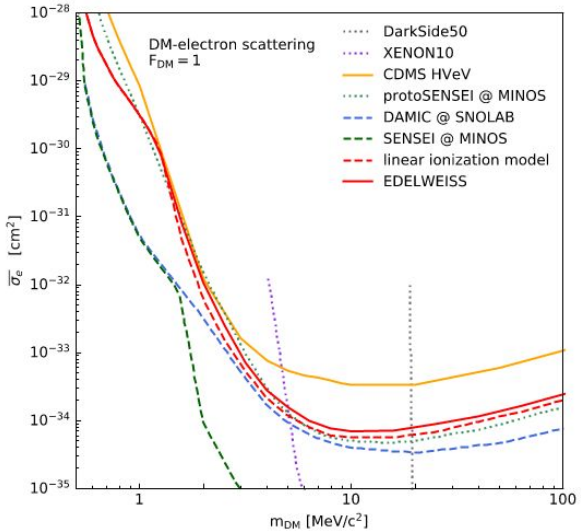
Limit setting strategy

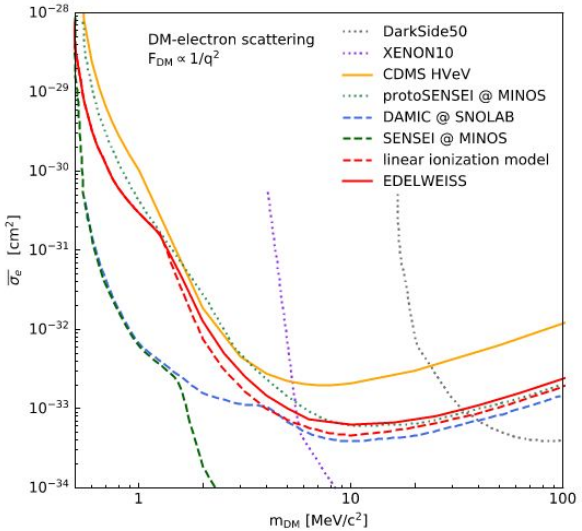
- Poisson upper limit assuming all events are DM candidates, no background subtraction
- 90%CL Poisson upper limit on rate in fixed energy range
- Determine most sensitive range using 1.3 day sample non-blinded data (smoothed with KDE) recorded just before/after the search
- Signal calculation: QEdark
  [R. Essig et al., JHEP05 (2016) 046]
  charge quantization as in SuperCDMS,
  [PRL 121 (2018) 051301]
- Applied same fixed range to blinded data



Results : DMe⁻ scattering

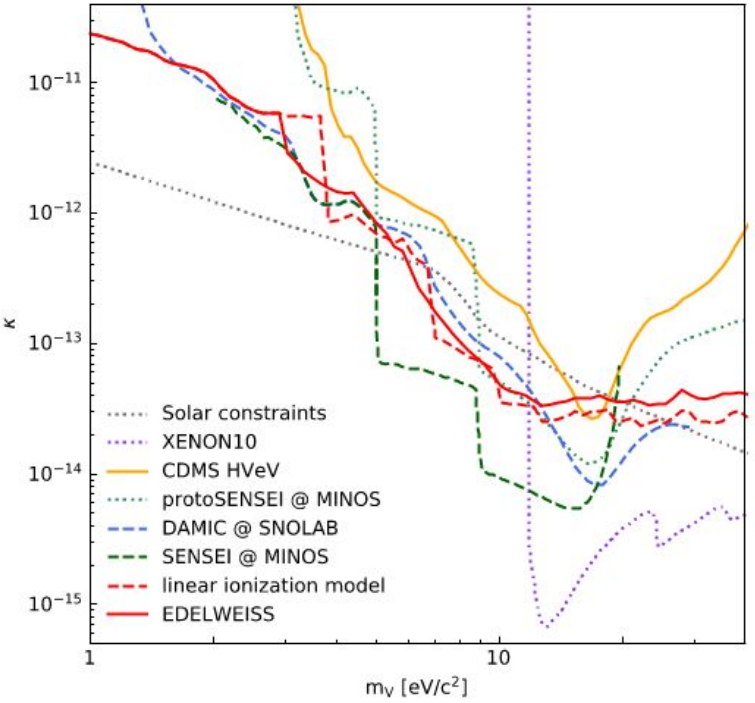
- Sensitivity extends into the domain of sub-MeV DM particles:
  with σ = 0.53 e-h pairs there is some sensitivity to single-e- events
- Despite being a first prototype, current sensitivity of 33g Ge bolometer already better than CDMS 1 g Si bolometer





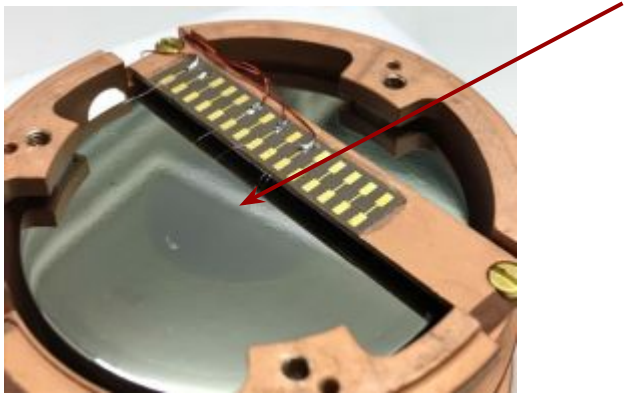
Results : Dark photon

- Smaller gap of Ge wrt Si helps below ~5 eV (despite factor x25 lower 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

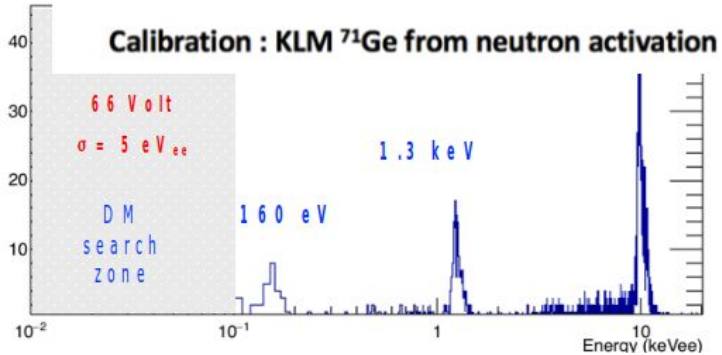


Limitation from Heat Only background

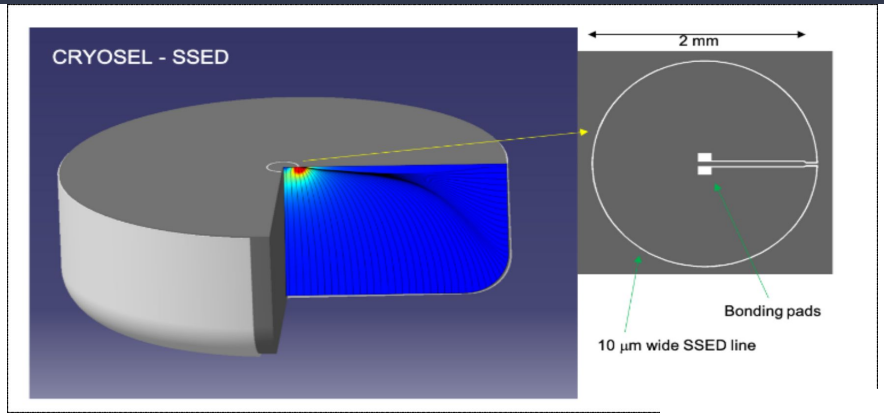
- Previous Result limited by low energy HO background.
- Present (but at smaller rate) in detector sensitive to athermal phonons



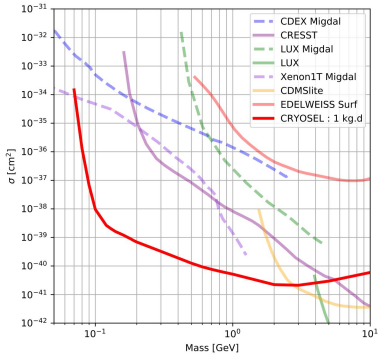
NbSi TES sensor used in ongoing physics analysis

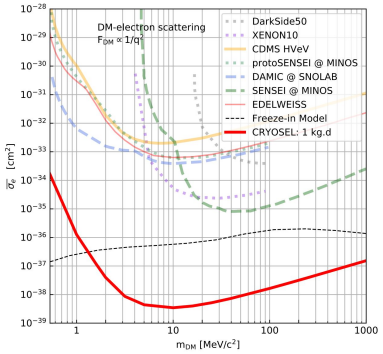


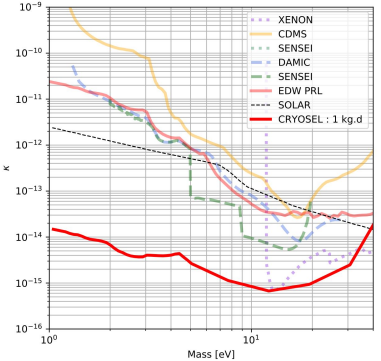
Future : CRYOSEL



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







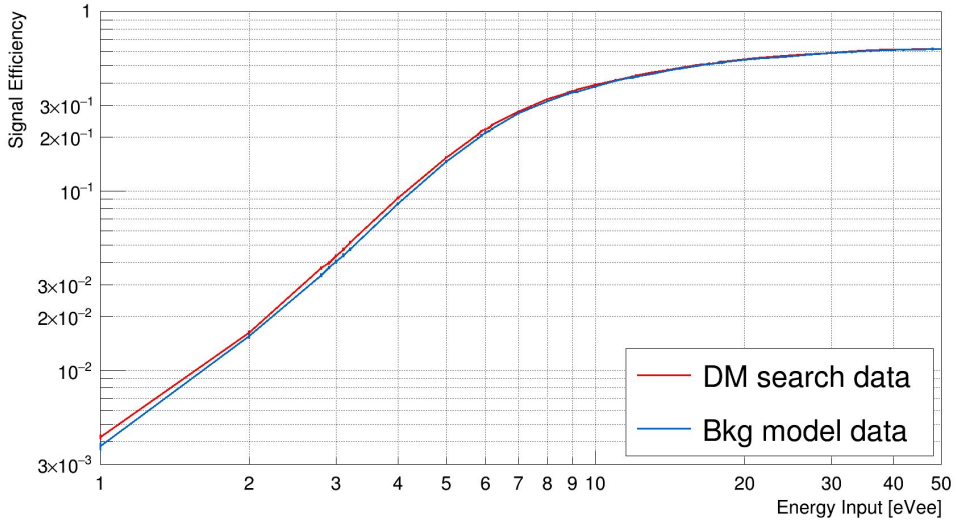
Conclusion

- 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

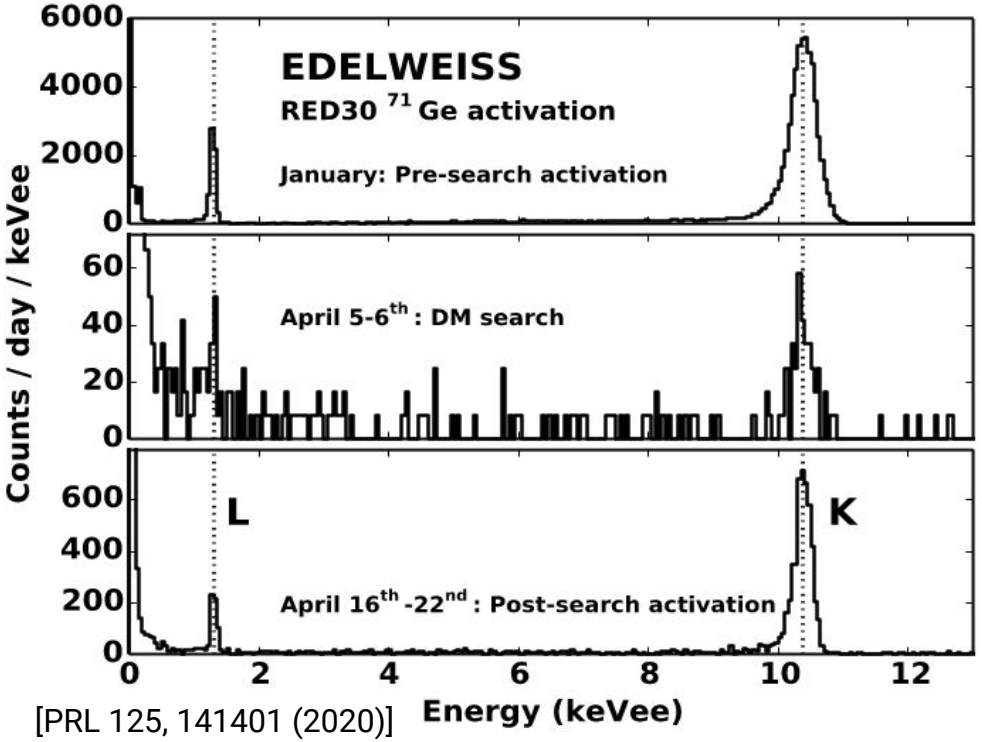
Efficiency

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



Detector studies

- Detector characterization using ^{71}Ge
- 10.37 keV Line.
  Calibration charge collection fiducial volume.
- April 1st-7th 2019: DM search at highest stable bias (78V) with reduced (but still visible) ^{71}Ge activation
- 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)]