Sub-GeV Dark Matter Searches with EDELWEISS:

New results

[arXiv:220303993]

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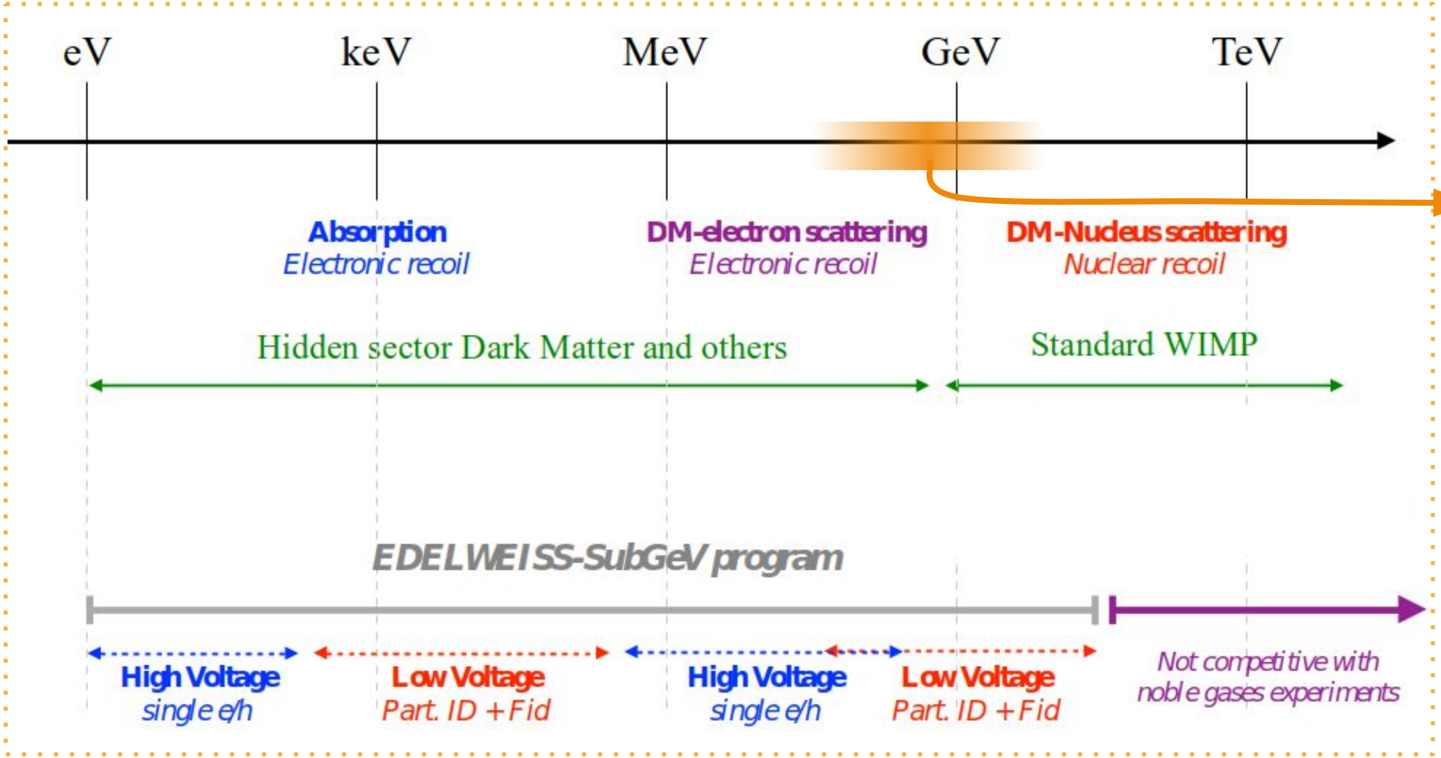
IP2I-Lyon, CNRS/IN2P3

Direct DM detection with EDELWEISS

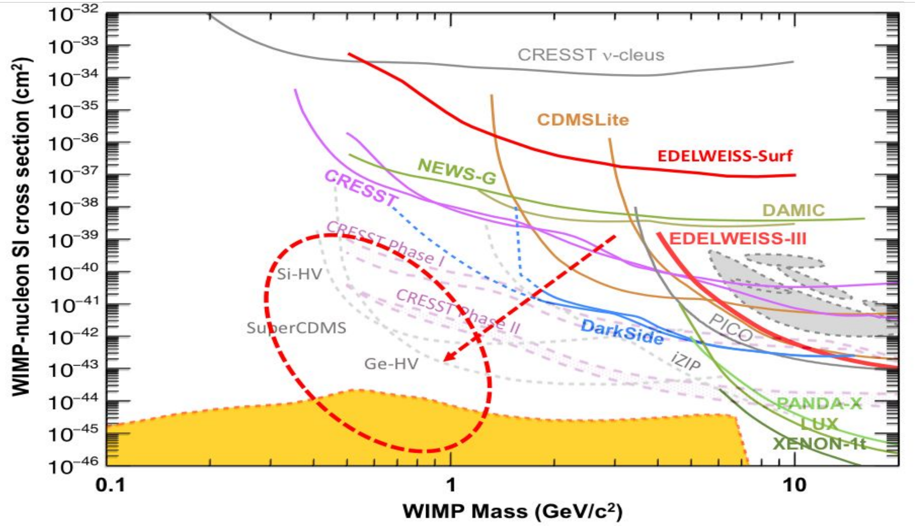


→Challenging search area
→ Many new techniques being proposed
→ Need low threshold (down to single electron)
→ ER/NR discrimination

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

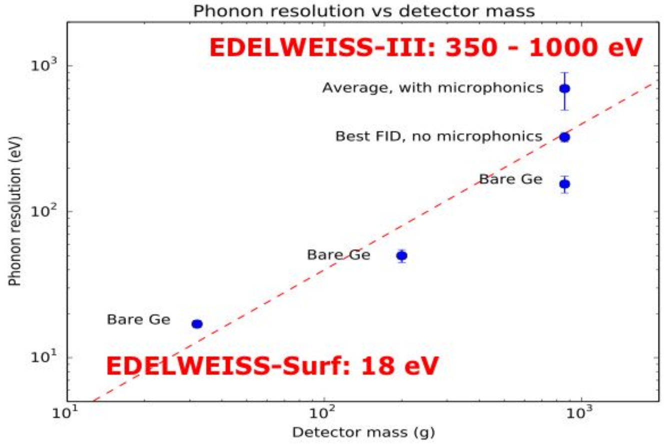
Edelweiss sub-GeV program

Sub-GeV searches → **background limited !**



Goals :

→ particle ID down to 1 GeV/c² and below,
→ improvement of resolutions down to σ_{phonon} = 10 eV (for thresholds) and σ_{ion} = 20 eV (for discrimination at LV),
→ reach cross sections down to 10^{-43} cm²,
→ reduce background.

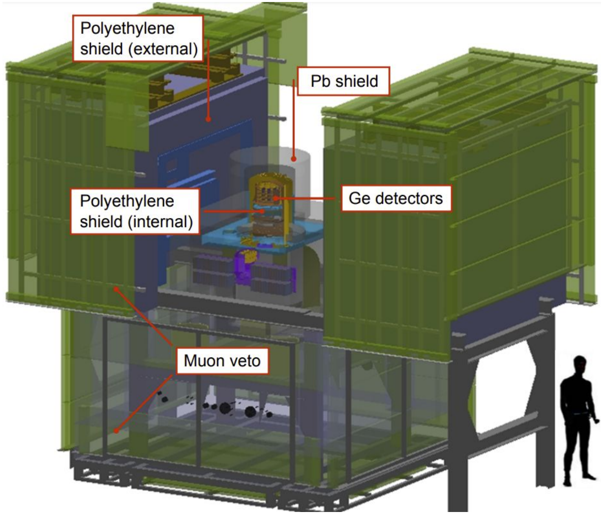


How ?

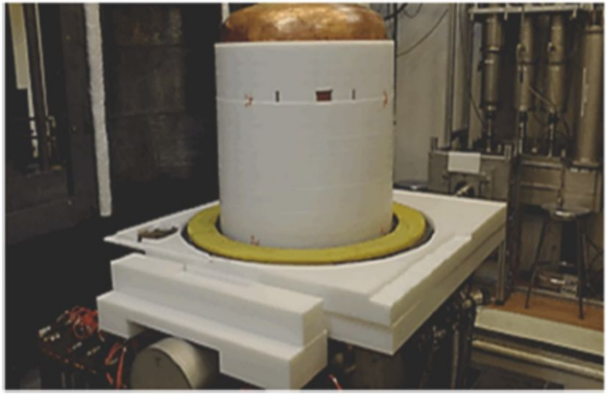
→ Reduce detector mass
EDELWEISS-Surf [PRD 99 082013 (2019)]
33 g Ge bolometer.
→ Apply HV to amplify signals
Electron-DM results [PRL 125, 141401 (2020)]
78 V applied onto 33 g Ge bolometer.
→ Probing bkg using TES
Migdal with NbSi TES [arXiv:2203.03993 (2022)]
200g Ge bolometer operated at 66V

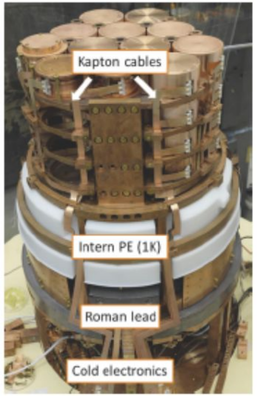
EDELWEISS experiment

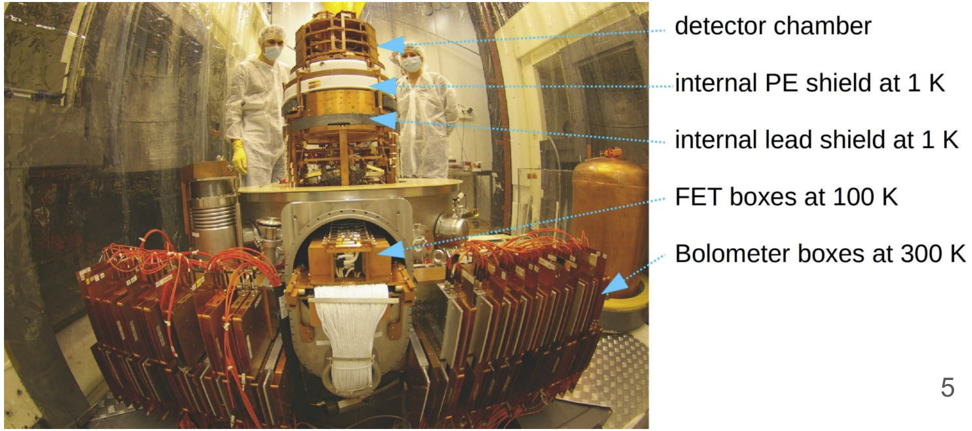
EDELWEISS-III setup at LSM



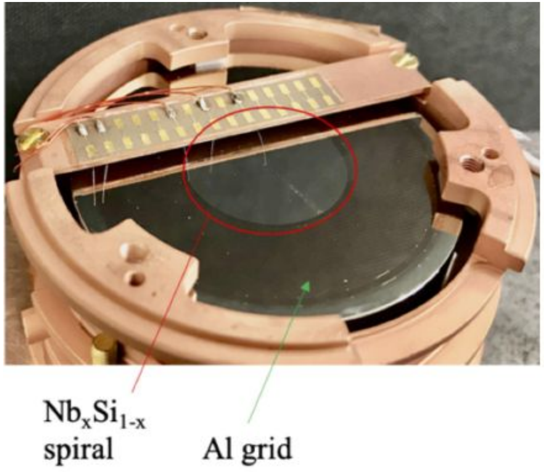
→ LSM : deepest site in Europe, 4800 m.w.e, 5 μ/m²/day
→ Active μ-veto (>98% coverage)
→ Clean room + deradonized air
→ PE and lead shielding
→ Selection of radiopure materials
→ Operated ~ 20mK
→ [arXiv:1706.01070]

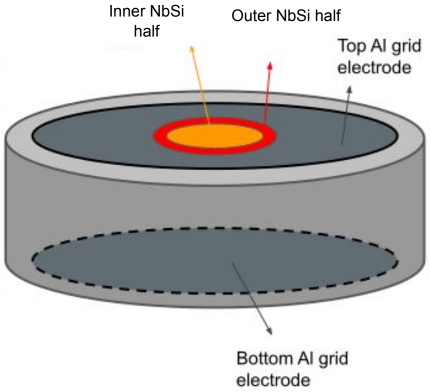


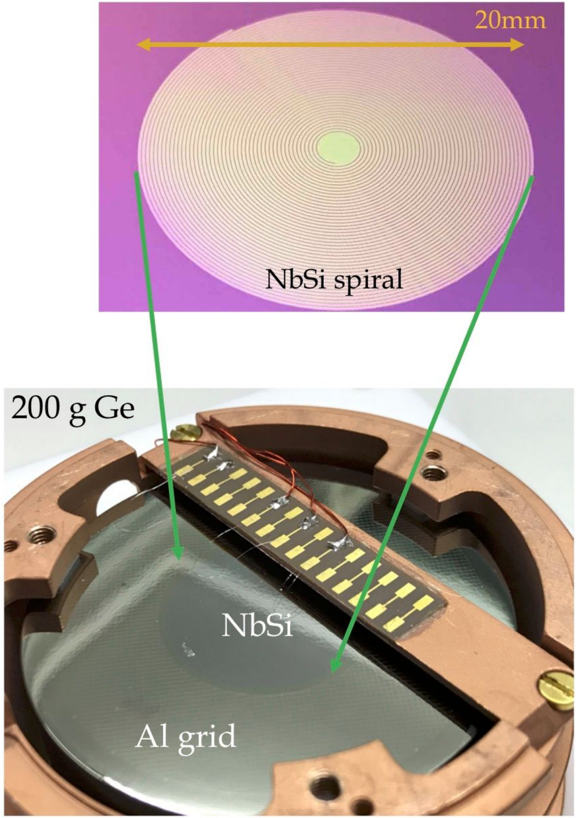




EDELWEISS NbSi TES (NbSi209)



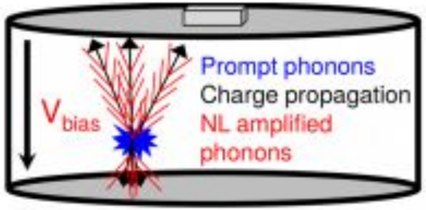




→ 200g Ge bolometer
→ **heat signal:** NbSi Transistor Edge Sensor (TES) lithographed on top surface,
→ **ionization signal:** Al electrodes lithographed on top and bottom surfaces

Neganov-Luke-Trofimov (NTL) amplification

What is NTL ?

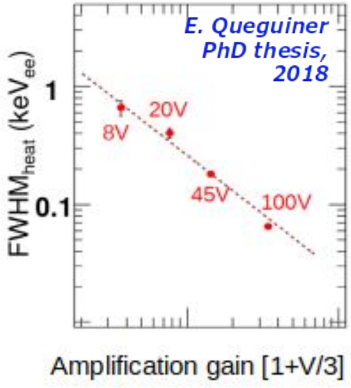


$$E_{heat} = E_{recoil} + E_{Luke} = E_{recoil} + N_p\,\Delta V$$

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

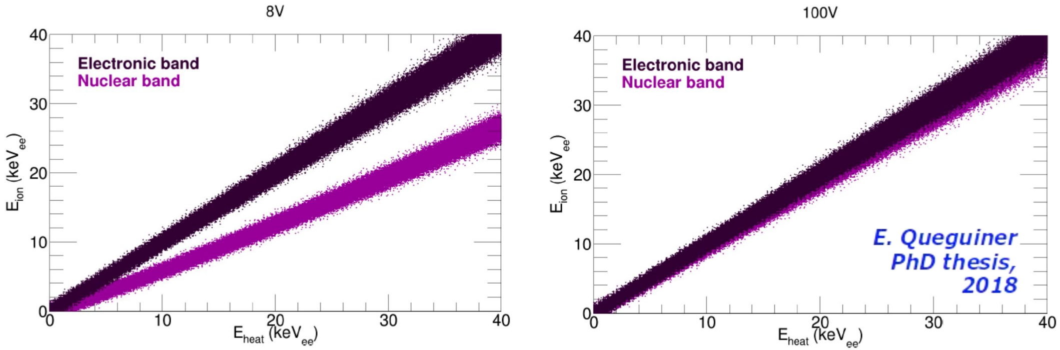
Why use it ?

→ Heat resolution gain by a factor (1+V/3) for e⁻ signals



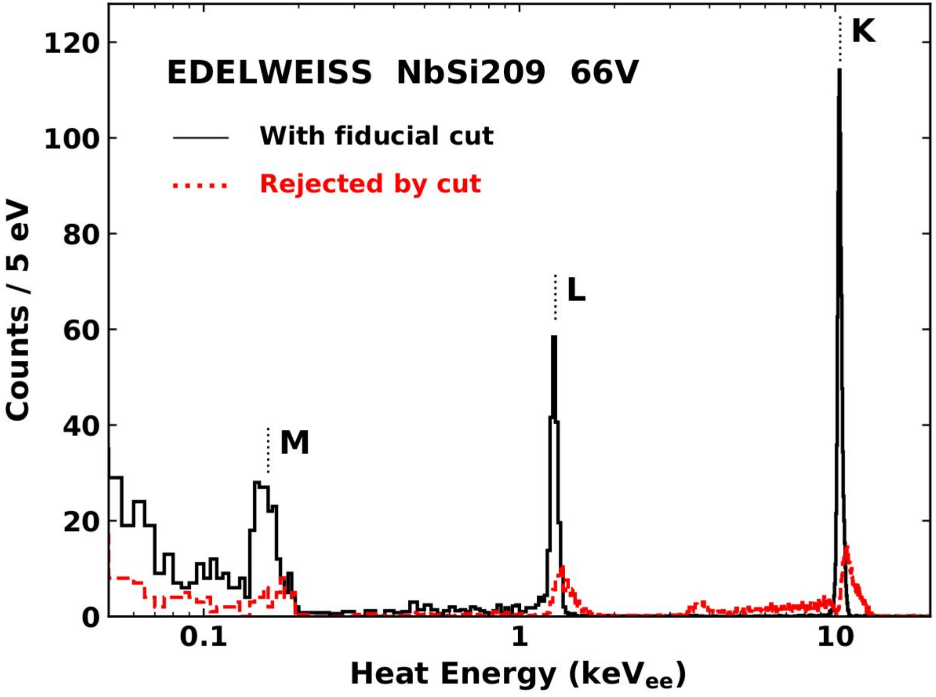
Limits of HV :

→Loss of discrimination between ER and NR bands



Calibration

→ **Calibration from K, L, M, ^{71}Ge decay line,**
→ **Heat baseline resolution 100 eV** on total energy, i.e. **4 eVee** for ER at 66V,
→ Ideal resolution for Migdal DM search !

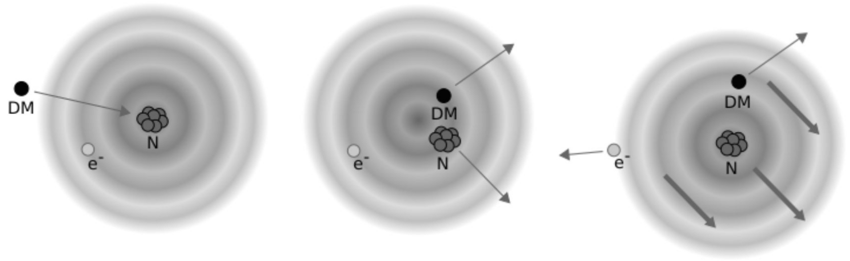


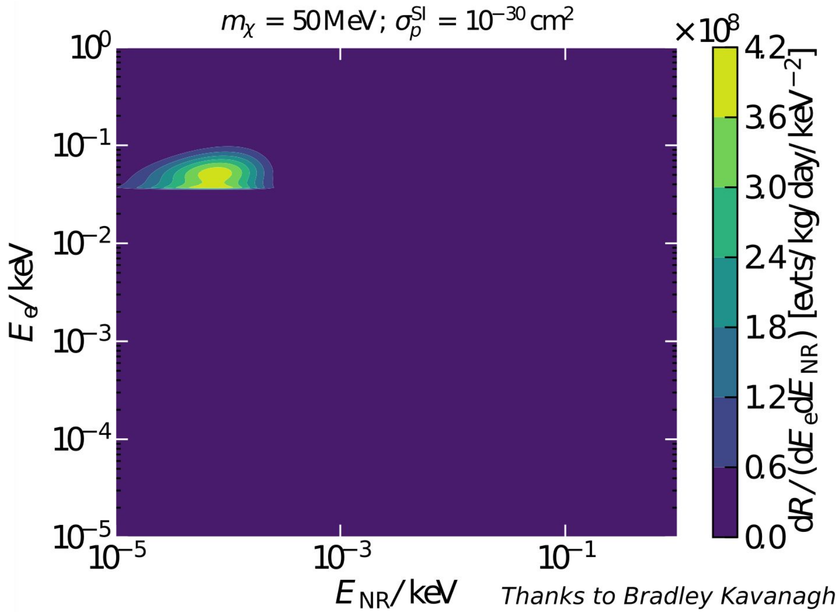
Migdal effect

What is the Migdal effect ?
→interaction DM-nucleus which induces both a NR *and* the ionization of a Ge atom
→ **electronic** signal with NR

Why use it ?
→ for low-mass DM particles, NR induced energy ~1 eV against ~100 eV for Migdal e⁻ yield

In Germanium :
→Ideal target of search for NbSi209 with σ_{heat} = 4 eVee
→Calculations (Ibe et al arxiv:1707.07258) reliable for n = 3 shell-e⁻ (only shell considered here)
→ Migdal electron energy > 35 eV for n=3





Thanks to Bradley Kavanagh

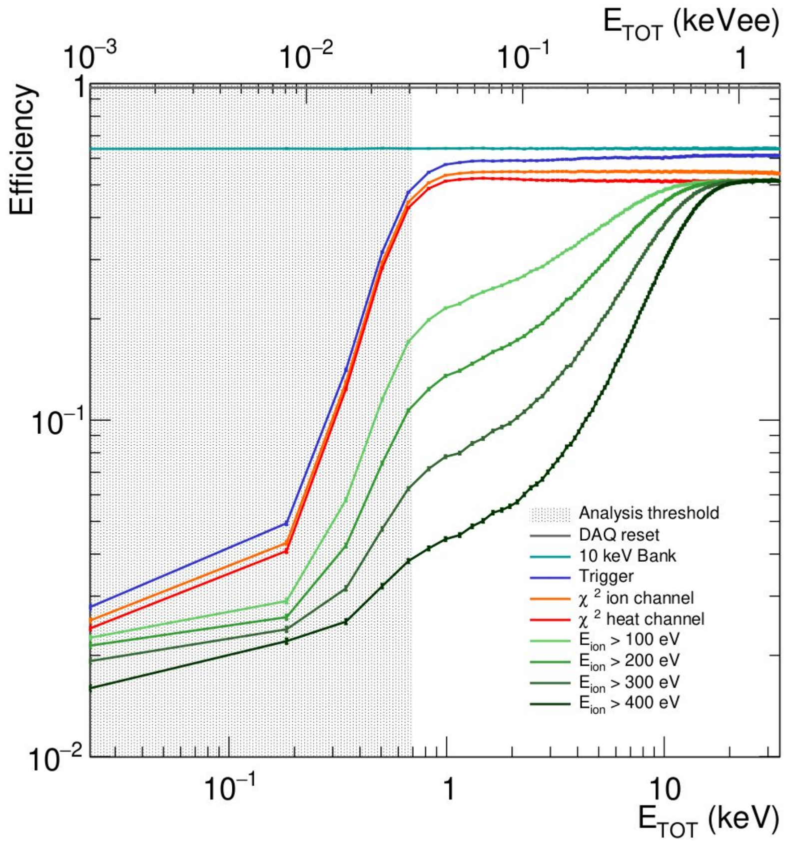
Analysis

Efficiency and selection

Dataset divided in half :
→ **non-blinded** dataset to set analysis cuts
→ **blinded** dataset to perform DM search

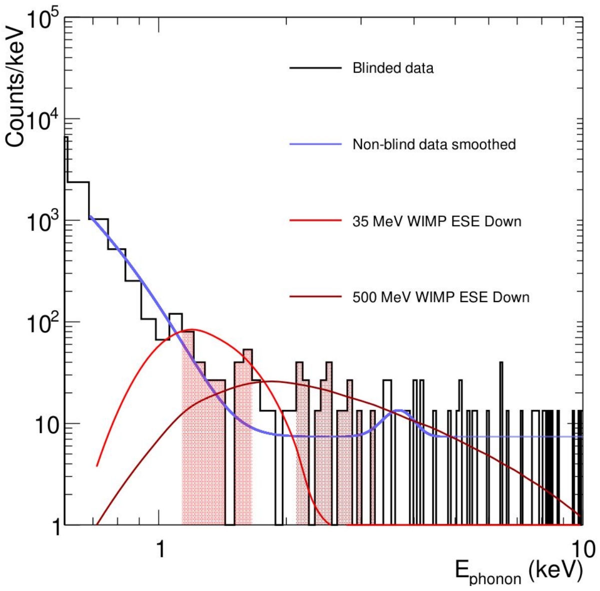
→ **Inject** actual **10.37 keV events, scaled** to desired energy, at **random times** and low rate,
→ **Process** the new datastream as real data

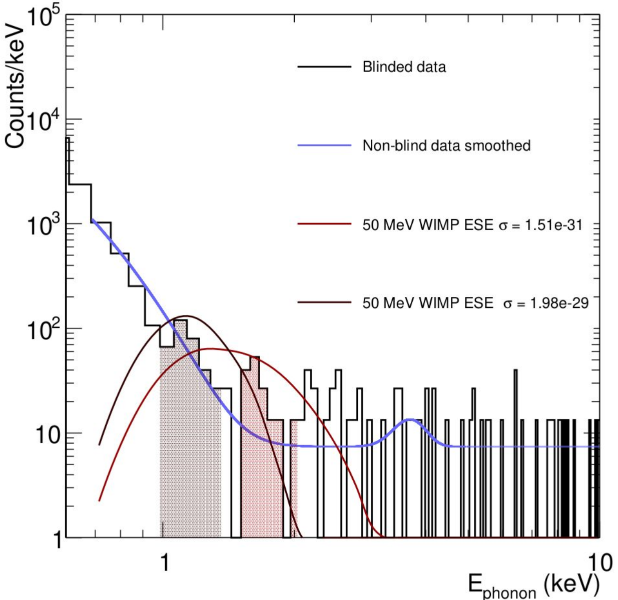
→Require **E_{ion}> 400 eV_{ee}** signal on electrodes (**green**) to **reduce** our bkg compared to **σ_{ion} = 210 eV**. Aggressive, but well-understood cut.



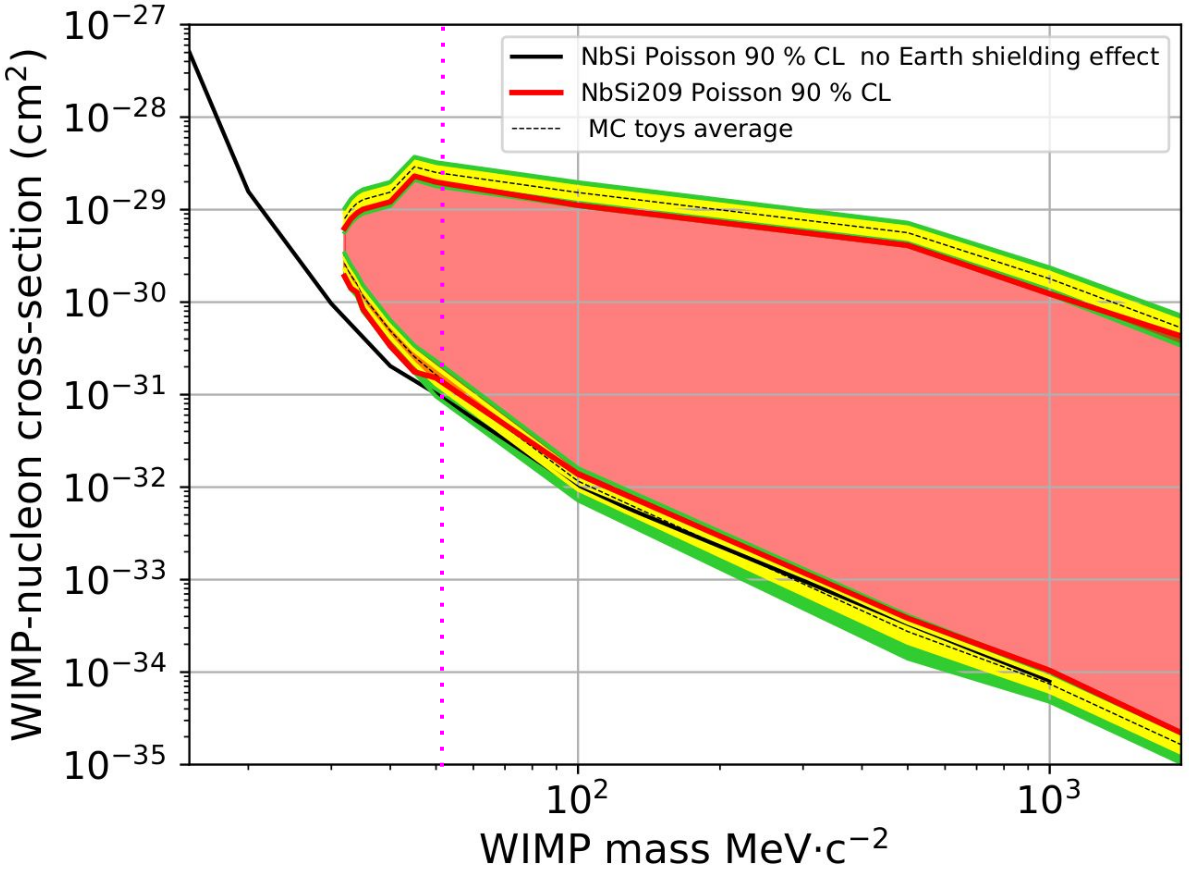
Limit extraction

→ All calculations of Migdal are corrected for **Earth shielding effect** (ESE)
→ **Choice of regions of interest** (RoIs) to maximize S/N ratio **on non-blinded sample**,
→ Use chosen RoIs, 90% C.L. Poisson upper limit **on blinded sample**,
→ *Left* : **Signal** drifts towards **high energies** with DM mass,
→ *Right* : **Signal** shifts down for high cross section due to attenuation of DM flux through rock.





New limit



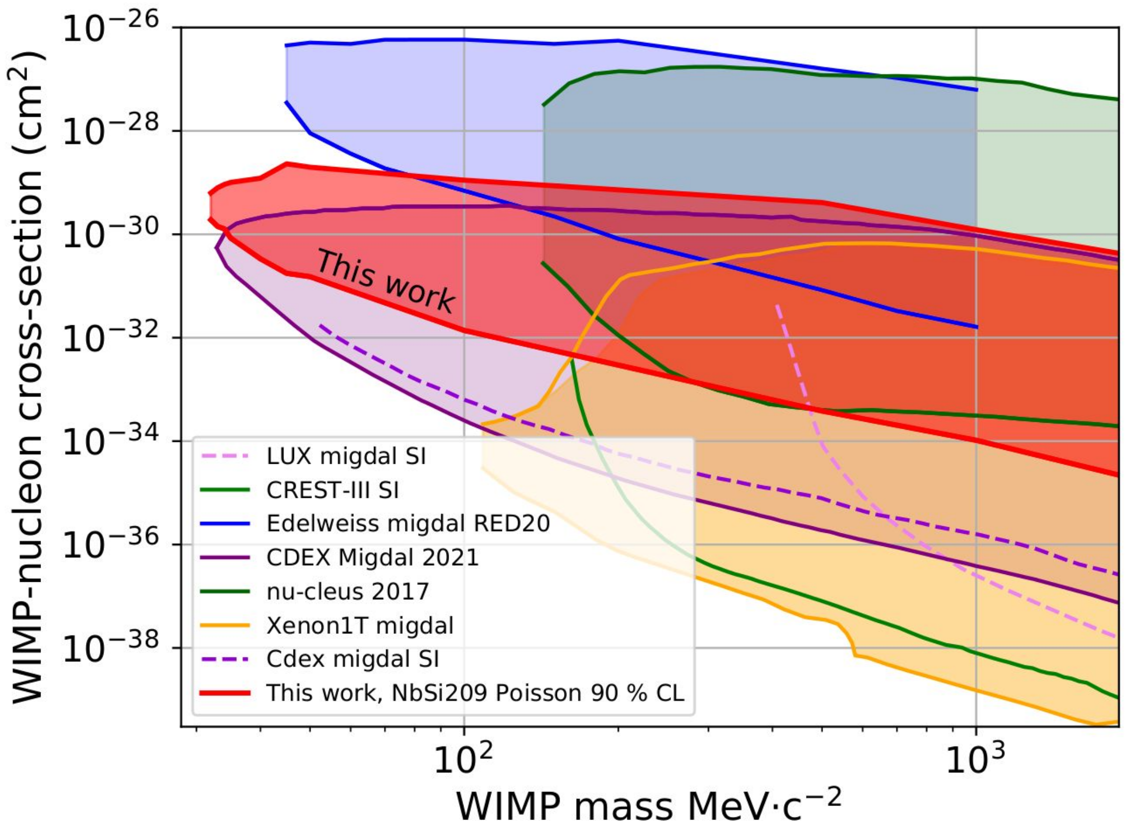
→ 90% C.L. upper limit on cross-section for Spin-Independent interaction through Migdal effect,

→ limited in mass sensitivity because of ESE,

→ Strong ESE effects for M<50 MeV/c^2,

→ MC toys used to probe statistical stability of the results.

New limit

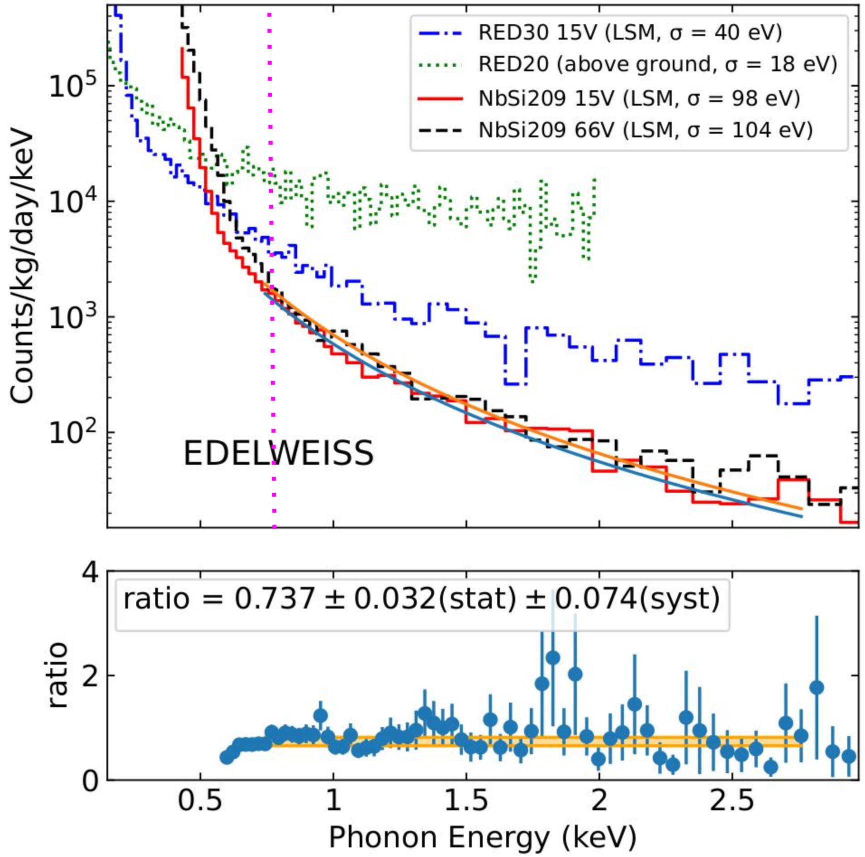


→ Same red contour as previously,
→ New region of parameter space constrained : $\sigma \simeq 10^{-29}$ cm² and M ∈ [32 ; 100] MeV/c²,
→ Several orders of magnitude of improvement compared to EDW-Surf Migdal search (blue contour)
- reduction of bkg
- 4 eVee resolution with TES sensor design

→ Limited by background !

Note: SuperCMDS new results in this mass domain: arXiv:2203.02594

Rate and shape of HO spectrum with NbSi sensor

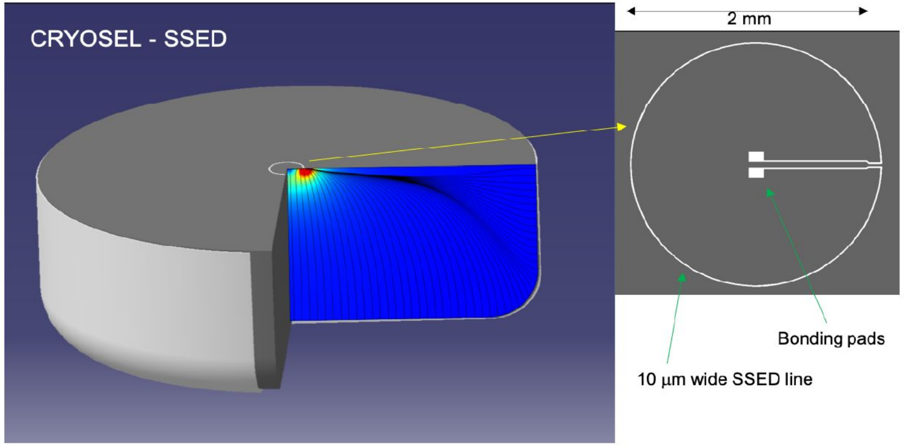


→ **Heat-Only** (HO) background : events not associated to charge creation.

→ **Top** : NbSi209 LV and HV data
→ Compatibility of HV/LV spectra for E_{ph} > 0.8 keV
→ Mostly HO events !

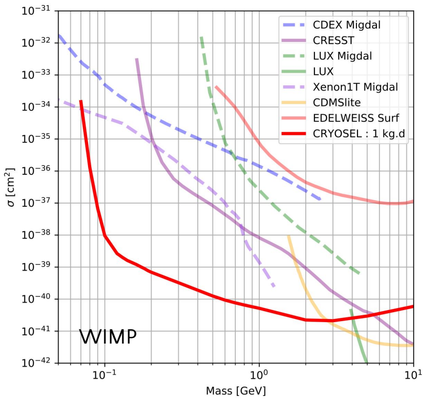
→ **Bottom** : LV/HV ratio of histograms
→ Extract nbr of events producing charges < 0.04%.

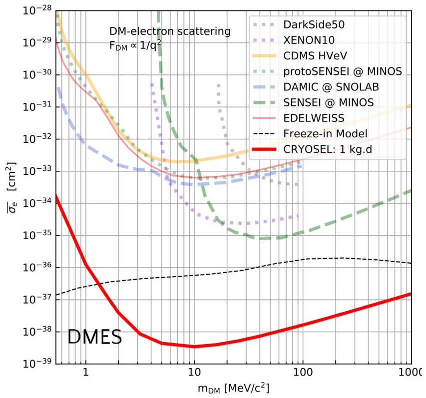
Prospects : CRYOSEL

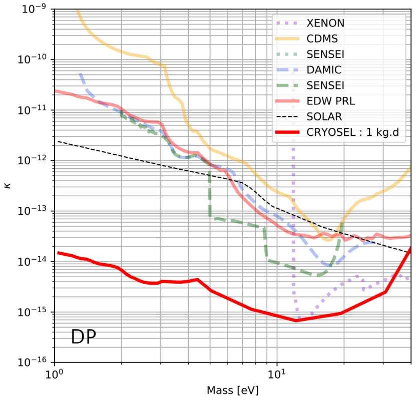


CRYOSEL

→ 40g Ge detector, σ_{phonon} = 20 eV, 200 V bias,
→ SSED "*Superconducting Single Electron Device*", detection of **athermal phonons** from **individual charges** → **discrimination** of HO events,
→ Expect many orders of magnitude **improvement** compared to present-day sensitivity.



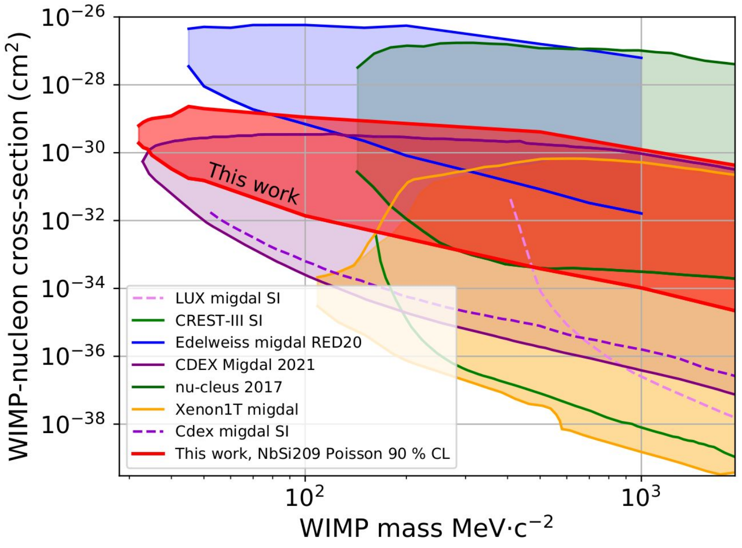




Conclusion

Takeaway messages

→ EDELWEISS collaboration developed new **NbSi TES**-equipped detectors as part of its Sub-GeV program,
→ It allowed to constrain a **new region** of parameter space : $\sigma \simeq 10^{-29}$ cm² and M ∈ [32 ; 100] MeV/c²,
→ Several orders of magnitude of **improvement** compared to EDW-Surf Migdal search (blue contour),
→ Established an **upper limit** on number of events producing charges of 0.04% in data at low energies,
→ Exciting prospects with new **CRYOSEL** detectors.



Thank you!