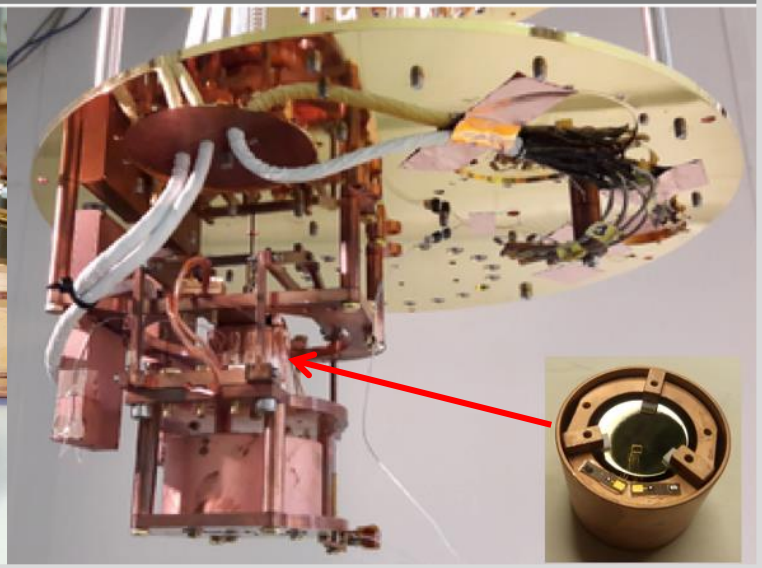
Karlsruhe Institute of Technology

Recent results from Dark Matter searches with EDELWEISS

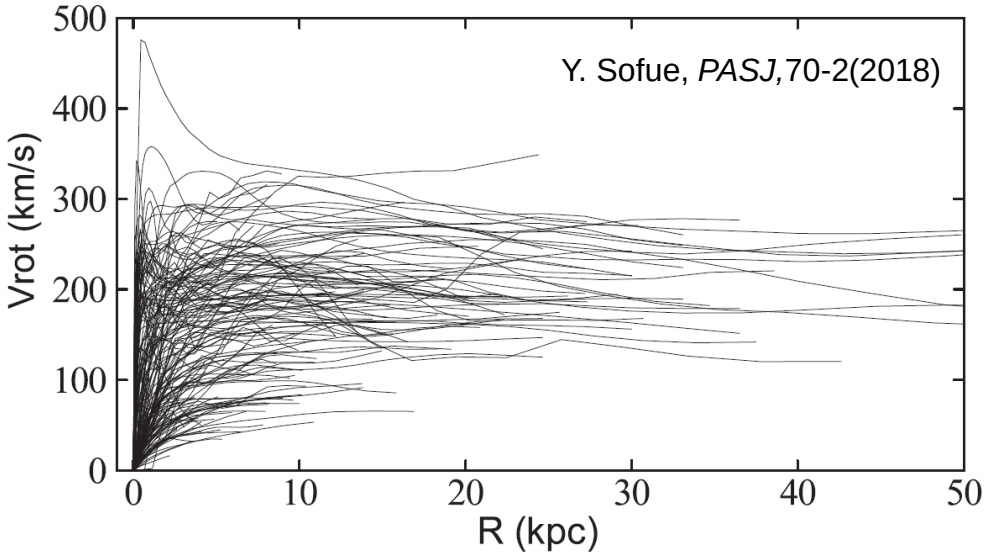
PATRAS, Freiburg 3.-7.06.2019

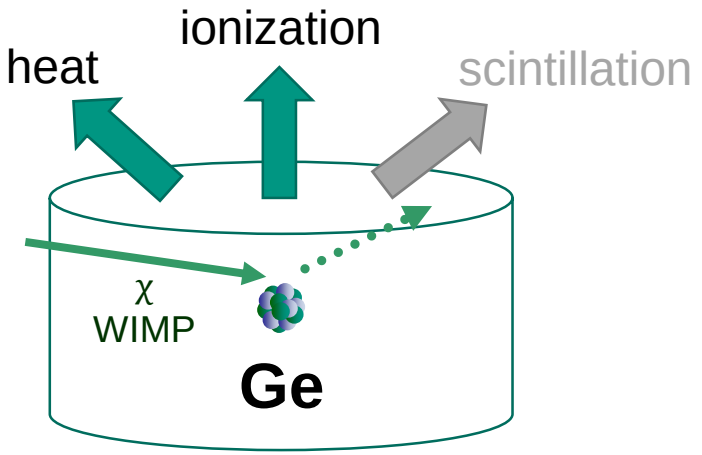
Bernhard Siebenborn on behalf of the EDELWEISS collaboration

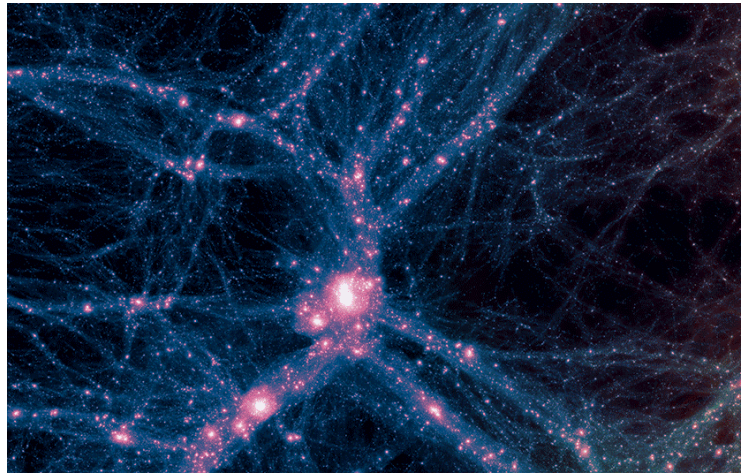


WIMPs as Dark Matter

- Rotation curves of galaxies → DM halo
- Assume DM particle candidate: WIMP
  - gravitation
  - additional “weak” interactions
- WIMP-nucleus scattering in detector
- Kinematics → keV-scale recoils
- Potential for WIMP discovery in a detector via combination of
  - heat
  - Ionization
  - scintillation
- Unknown parameters:
  - cross section (SI / SD)
  - WIMP mass







credit to Illustris Collaboration

EDELWEISS collaboration

EDELWEISS 2016 @ KIT

France
CEA Irfu/Iramis (Saclay)
CSNSM (Orsay)
Institut Néel (Grenoble)
IPNL (Lyon)
LPN (Marcoussis)

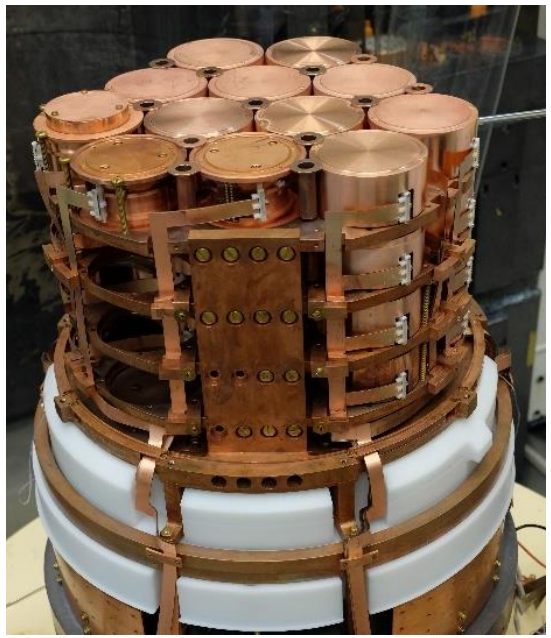
Germany
KIT (Karlsruhe)

Russia
JINR (Dubna)

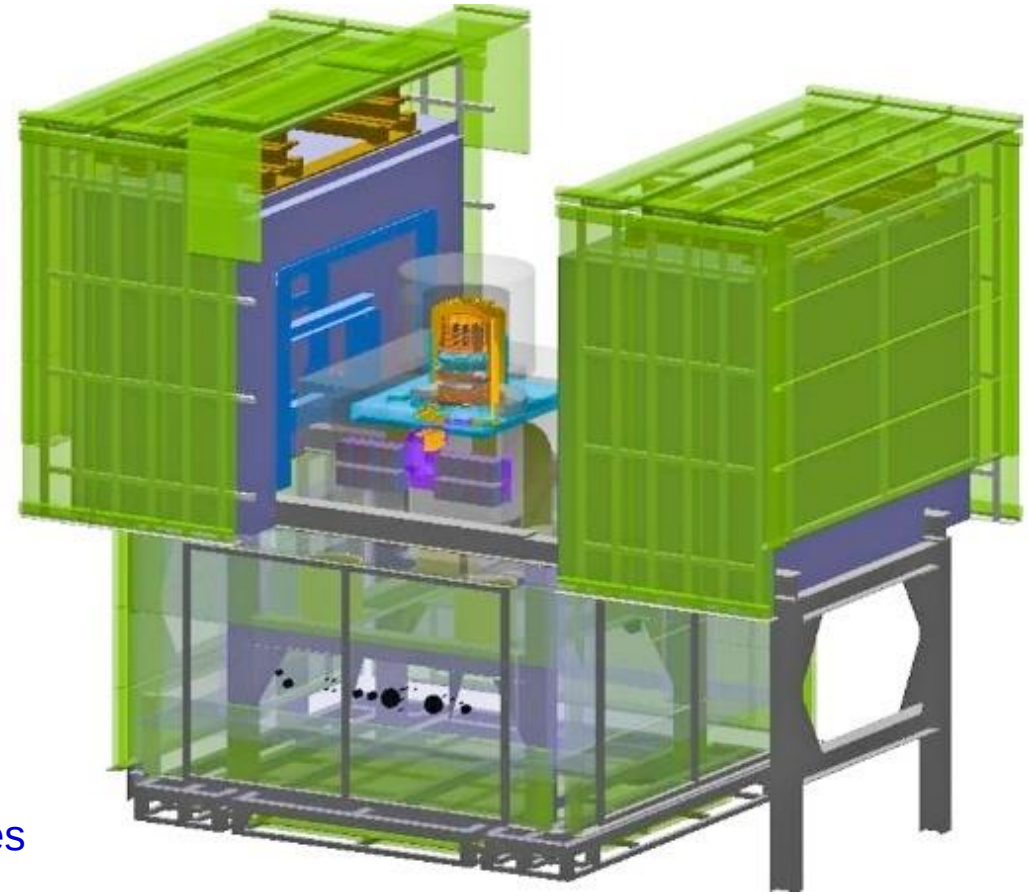
GB
University of Oxford
University of Sheffield

EDELWEISS-III setup

- Laboratory: LSM, ~4800 m.w.e. rock overburden (deepest in Europe) → 5 μ/m^2/d
- Active muon veto + PE + Pb shield
- Clean room, de-radonised air → 10-20 mBq/m^3
- Cryostat hosting up to 40 kg of detectors at 18 mK
- Selection of radio pure material



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

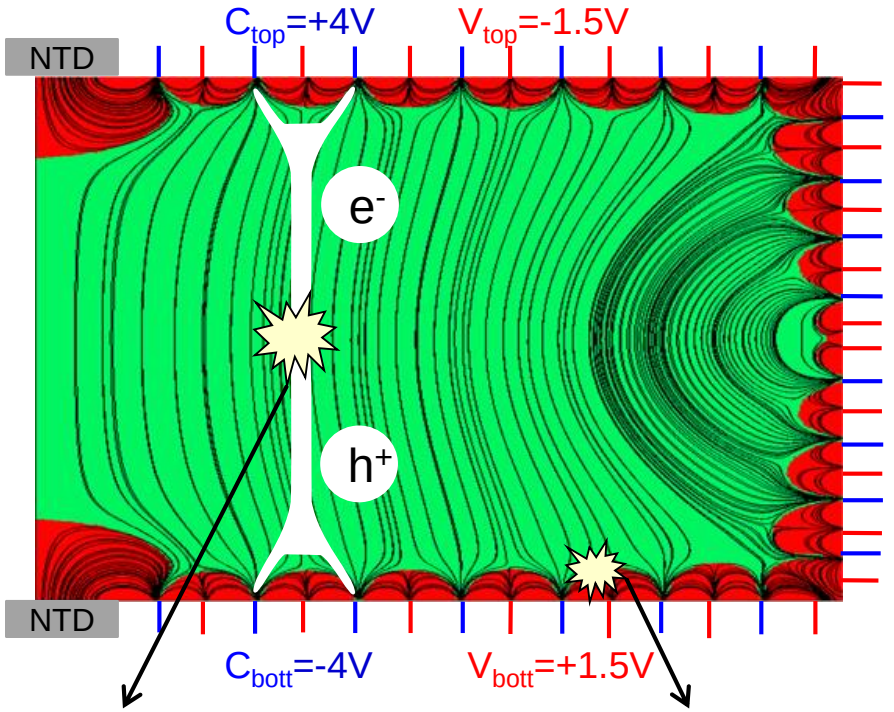


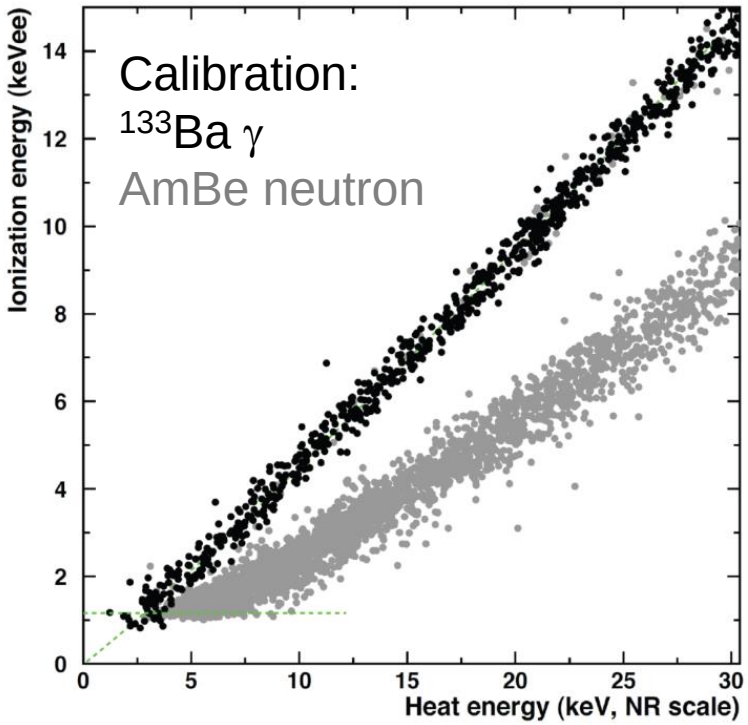
EDELWEISS-III detectors

- ~870 g mono-crystal high purity Ge detectors
- 2 heat sensors per detector (GeNTDs)
- Electrodes: Al rings covering all faces

T_{op} = 18 mK

surface event rejection ~10^{-5}
PLB 681 (2009) 305–309





- Clear **event-by-event** separation down to ~ keV energy (nuclear recoils)

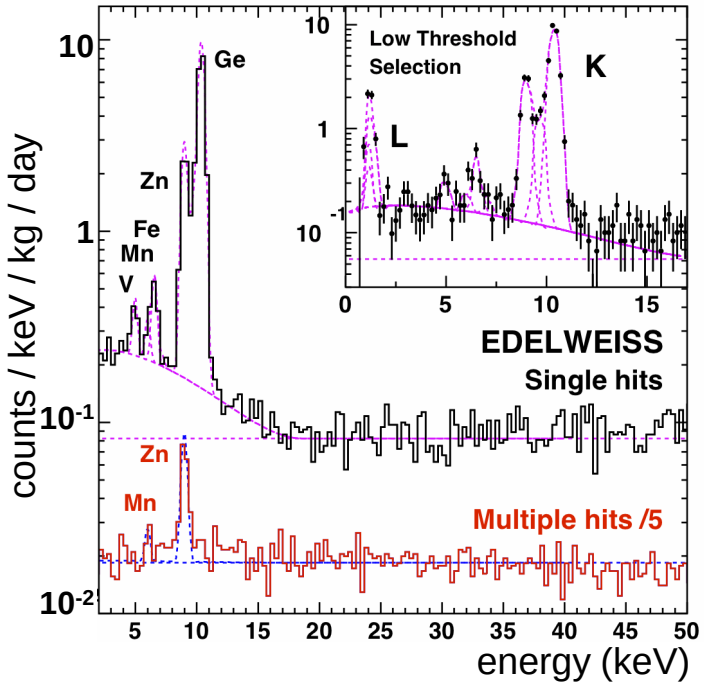
Bulk/Fiducial event:
Signal on C_{top}&C_{bott}

Surface event:
Signal on C_{bott}&V_{bott}

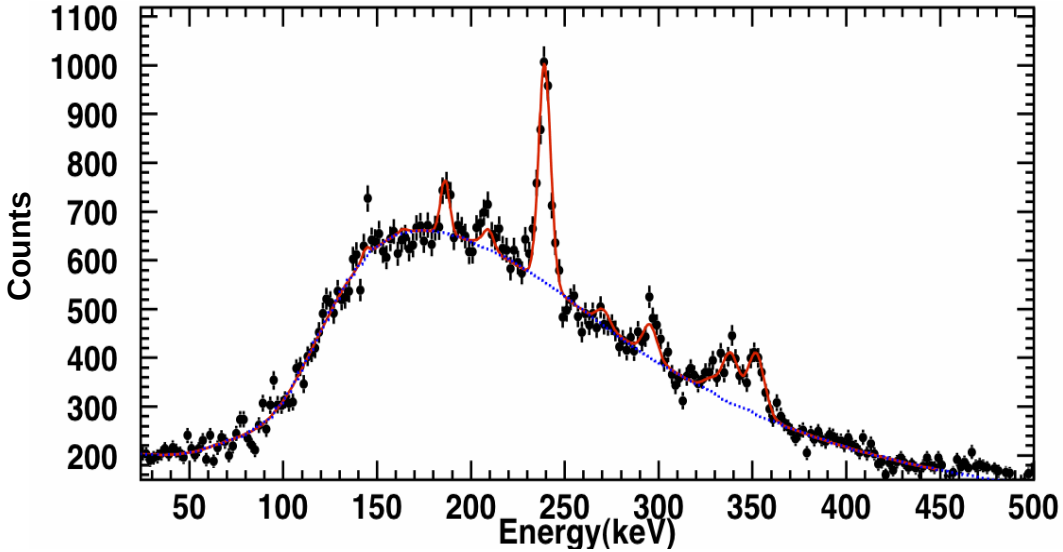
Axion-like particle searches (e^- recoils)

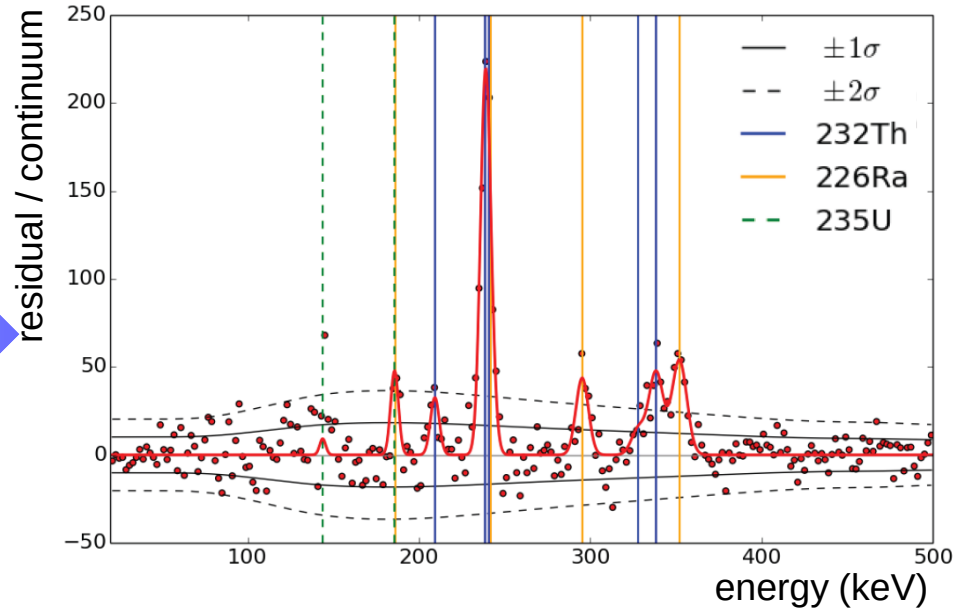
- Starting point: study of **electron recoil spectrum** of cosm. activ.
  - Threshold: 0.8 keV_{ee} to 2 keV_{ee}
  - low background thanks to surface rejection
- Analysis extended to higher energy for line search up to 500 keV_{ee}
- Intensities of observed peaks consistent with known Th/U lines
- Baseline resolution: 193 eV_{ee}

Astropart. Phys. 91 (2017) 51



E. Armengaud et al., Phys. Rev. D 98, 082004 (2018)



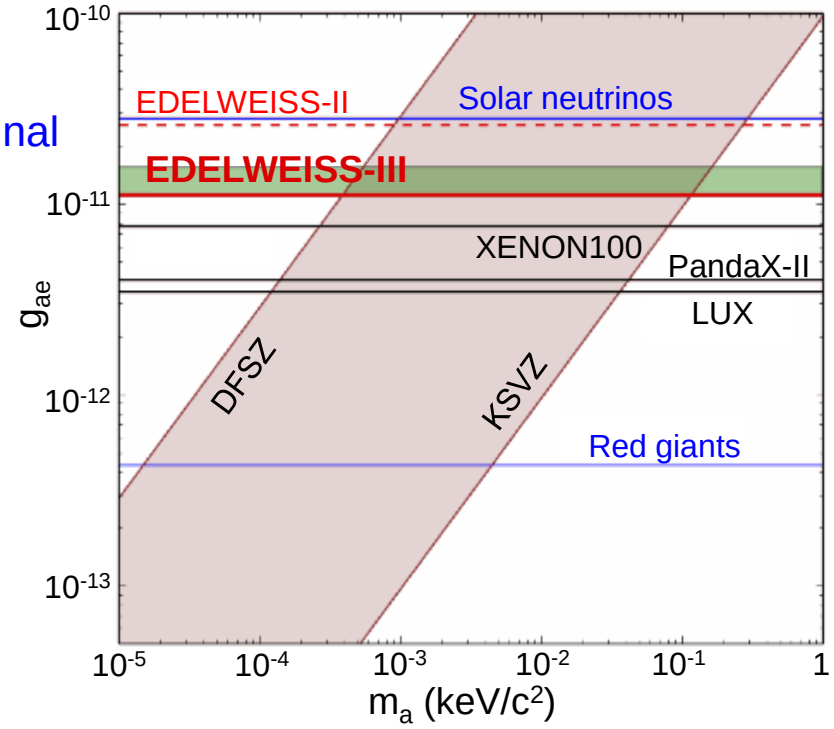


ALP and dark photon results (e^- recoils)

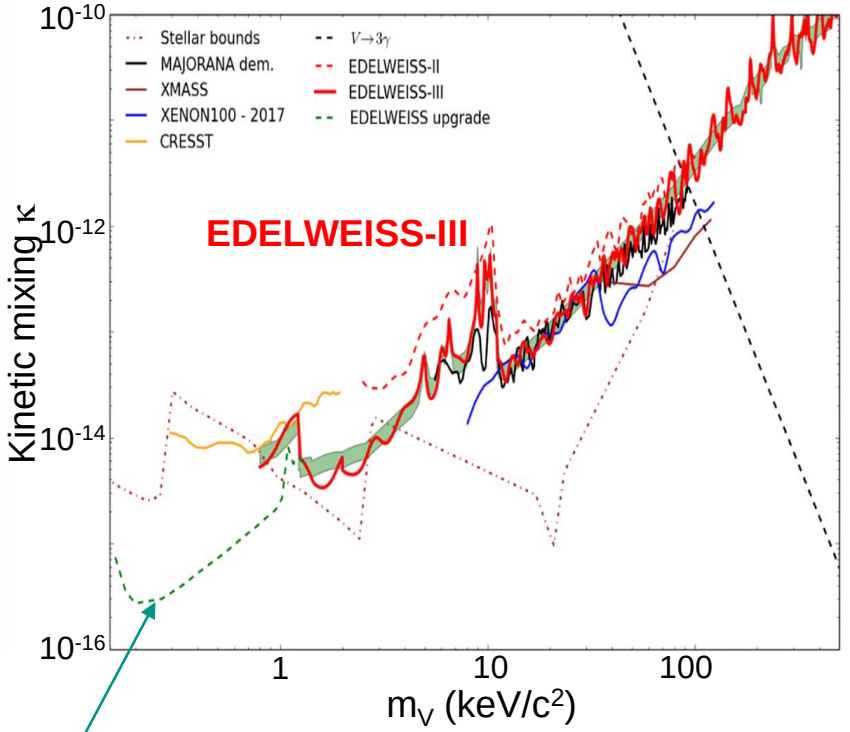
Emission of Axion/ALPs from the sun keV-scale Bosonic DM

Compton-
Bremsstrahlung-
Recombination-
De-excitation-like signal

CBRD signal



Kinetic coupling κ of dark photon



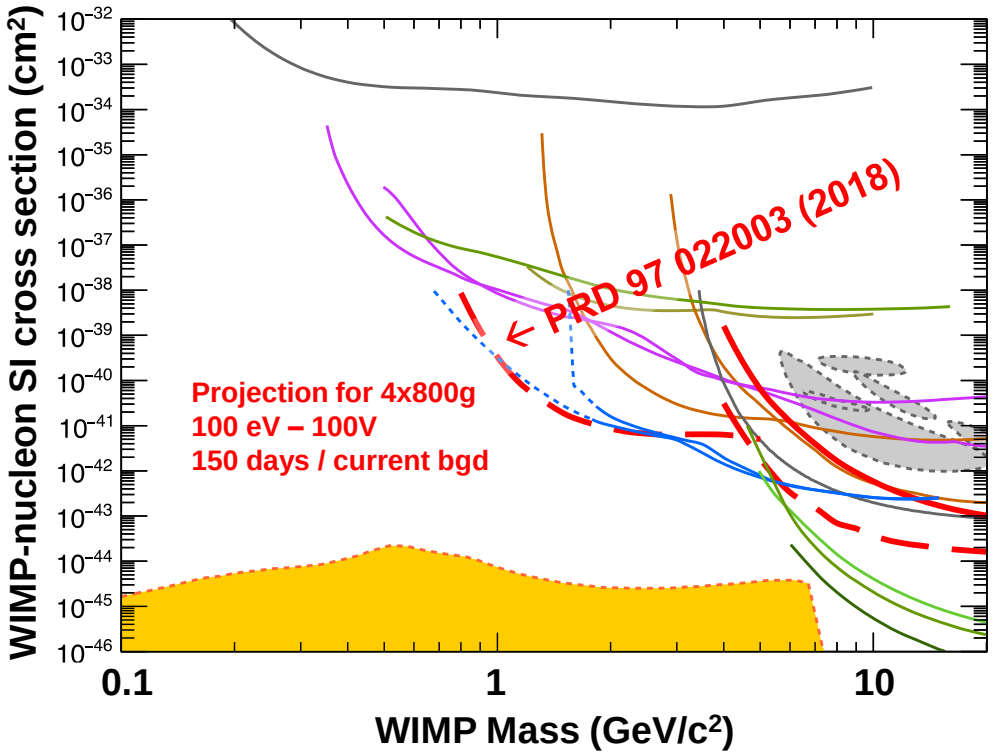
- Best Ge-based limits < 6 keV (thanks to surface rejection)
- Start to explore < 1 keV

E. Armengaud et al., Phys. Rev. D 98, 082004 (2018)

expected sensitivity with improved ionization channel
→ HEMT

from EDELWEISS-III to SubGeV masses

Complete study based on present measured backgrounds and resolutions *vs* possible improvements:



EDELWEISS-III legacy

- Excellent performance of ER- and surface rejection
- Ionization resolution is essential for rejection of backgrounds
- Heat resolution and exposure is limited by cryogenic noise

the future:

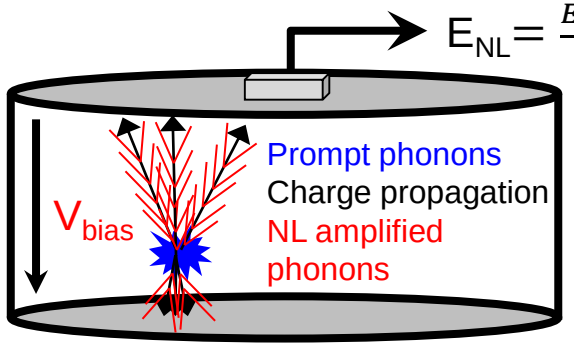
Progressing towards 1 GeV/c^2 and 10^{-43} cm^2 with event-by-event discrim.

Requires new detector generation with improved σ_{phonon} and σ_{ion}

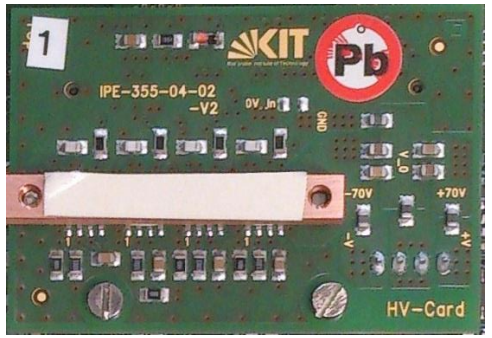
Goals: σ_{phonon} **= 10 eV (18 eV already achieved)**

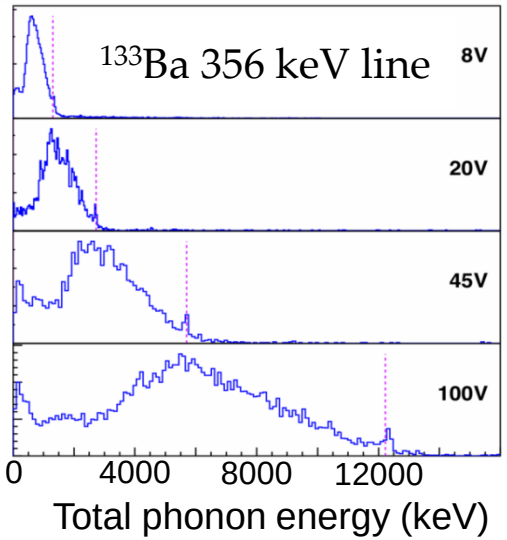
σ_{ion} **= 20 eV_{ee} (feasible with HEMT amplifier)**

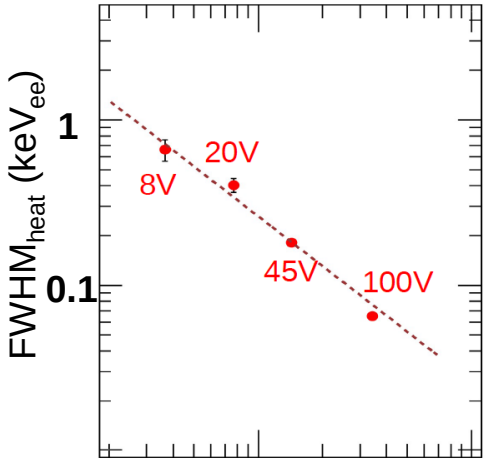
NL-boost with EDELWEISS detectors



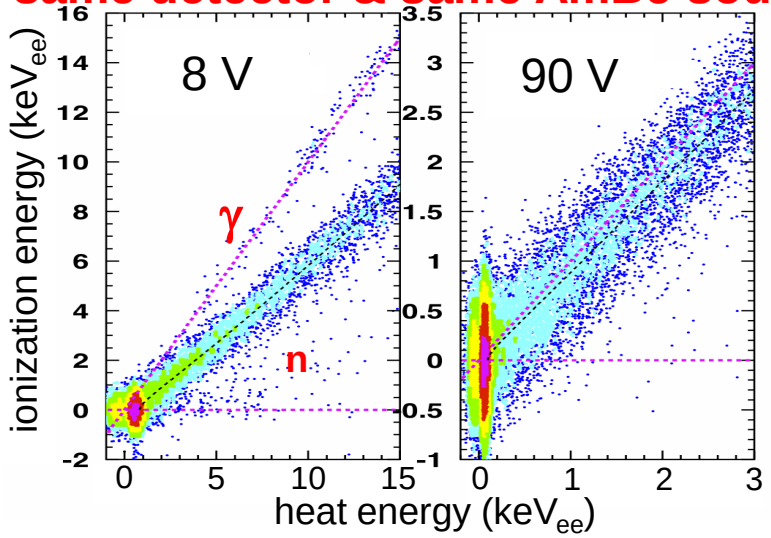
- ✓ 100 V on detector already achieved
- ✓ observe nuclear recoils down to ~0.1 keV_{ee}
- ✓ full ion.+heat readout possible at any V







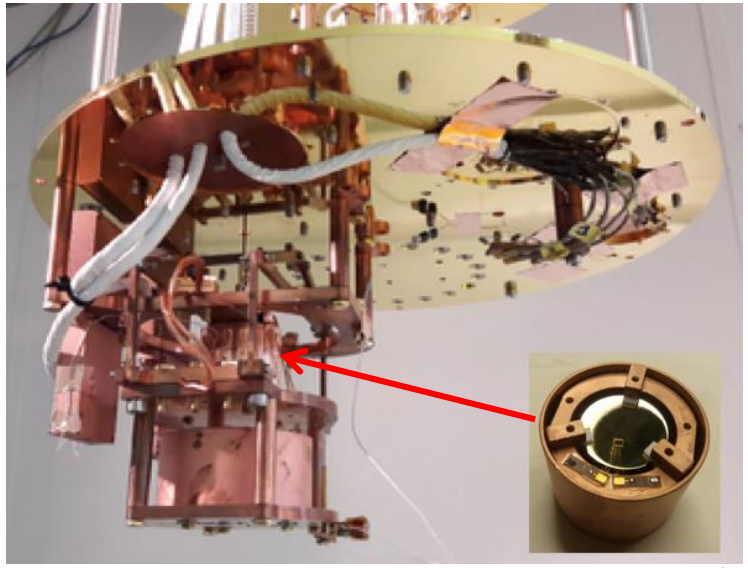
same detector & same AmBe source



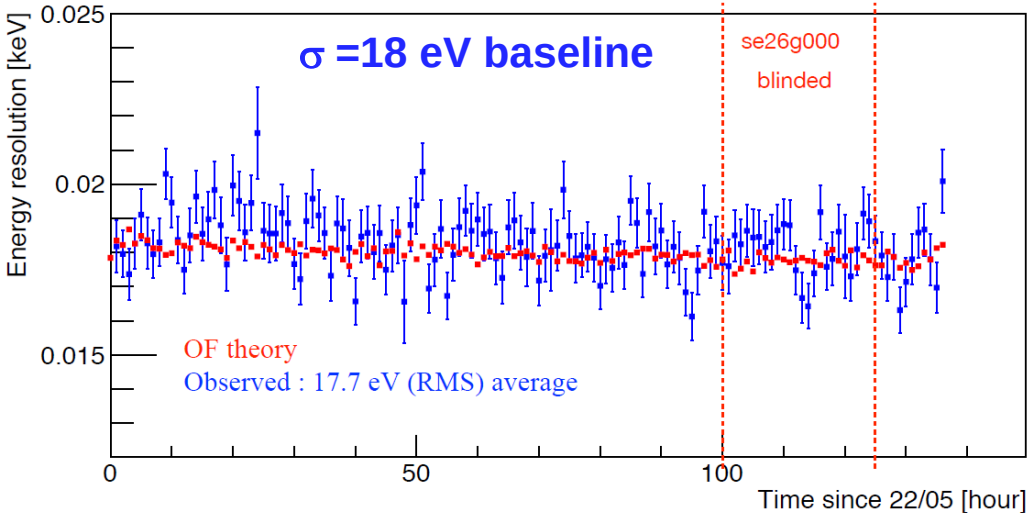
EDELWEISS R&D at surface

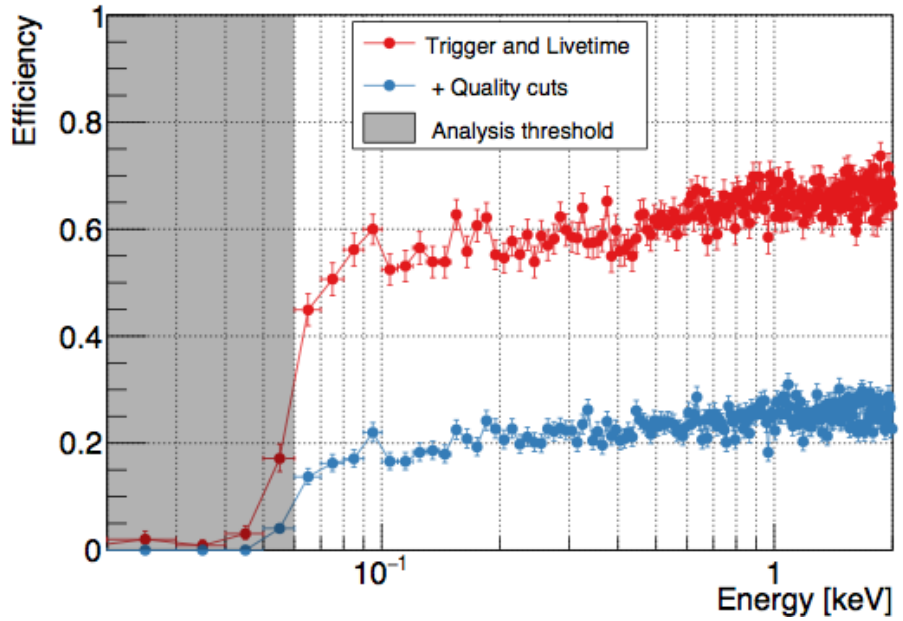
- above ground lab: overburden < 1 m
- dry cryostat (Cryoconcept)
- vibration mitigation: suspended detector
- smaller Ge detectors: m_{Ge} = 33.4 g
- phonon sensor: Ge-NTD
- low energy calibration:
  - ^{55}Fe x-ray source
  - neutron activation of Ge

Resolution improvements on a 32g HPGe



- R&D with 32g HPGe combined with the objective of testing the above-ground sensitivity to sub-GeV WIMPs
- *optimized* NTD heat sensor on a 32 g crystal, no electrodes (i.e. 1 keV = 1 keV_{NR}) J. Billard et al., JLTP(2016)184:299
- kept at 17 mK in IPNL low-vibration dilution fridge R. Maisonobe et al., JINST (2018)13T08009
- one day blinded for WIMP search in [0-2] keV region
- 60eV analysis threshold

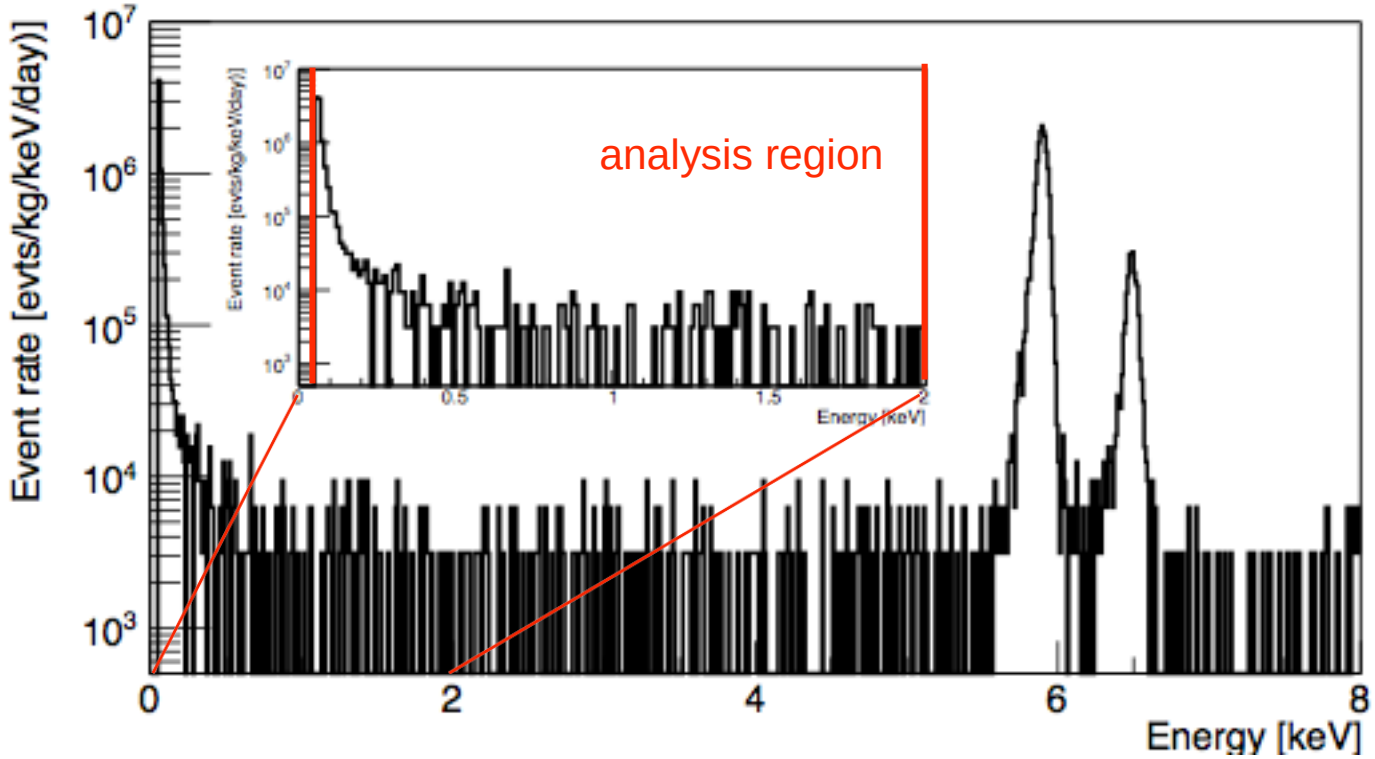




Unblinding the data

- No surprise:

  blinded day = carbon copy of preceding + following days



8000 dru 0.6-2.0 keV

4000 dru > 7 keV

- Find maximal WIMP rate compatible with total number of counts observed in the pre-defined windows
  → 90% CL on WIMP signals as function of WIMP mass

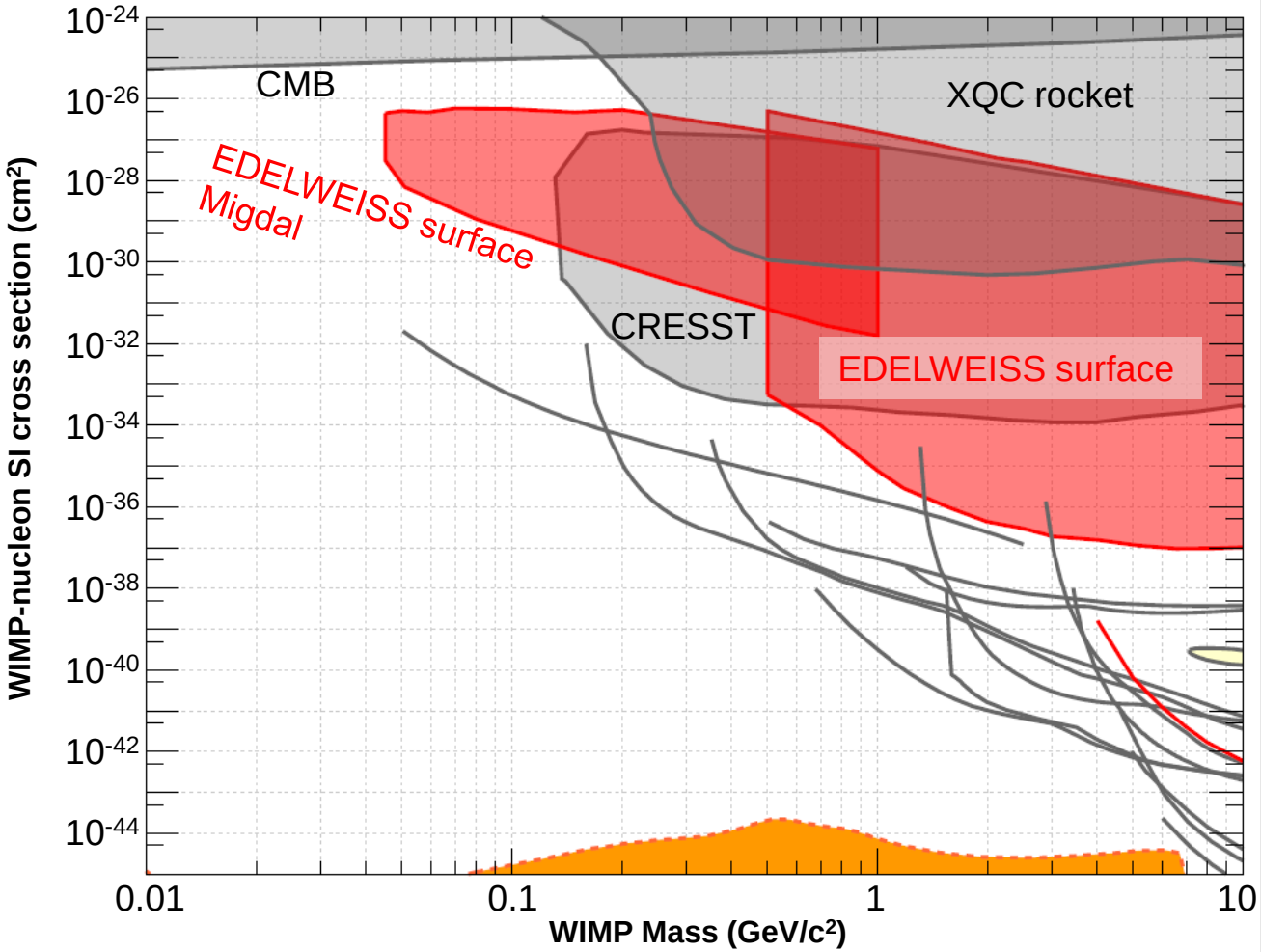
EDELWEISS surface results

Best surface limit down to 600 MeV/c^2: SIMP

First sub-GeV limit with Ge, down to 500 MeV/c^2

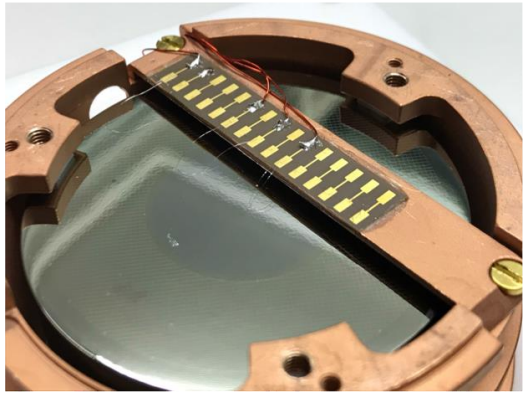
Achieved resolution on a smaller detector exceeds by x5 the original goal with 800 g detectors

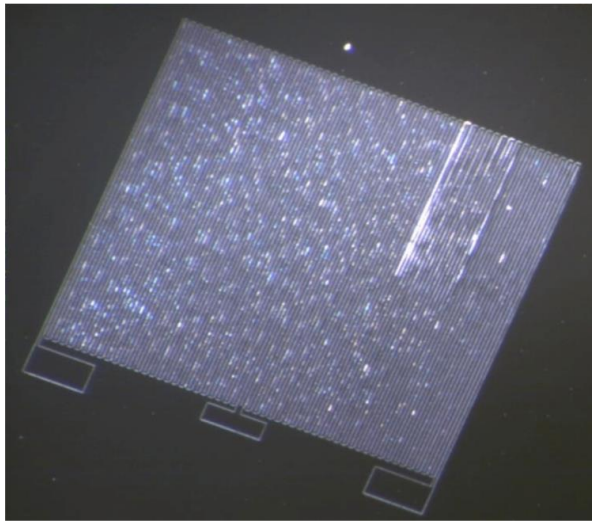
Small detectors with lower thresholds to be combined with expertise acquired on HV: threshold reduction by factor $(1+V_{bias}/3)$ in keV_{ee}

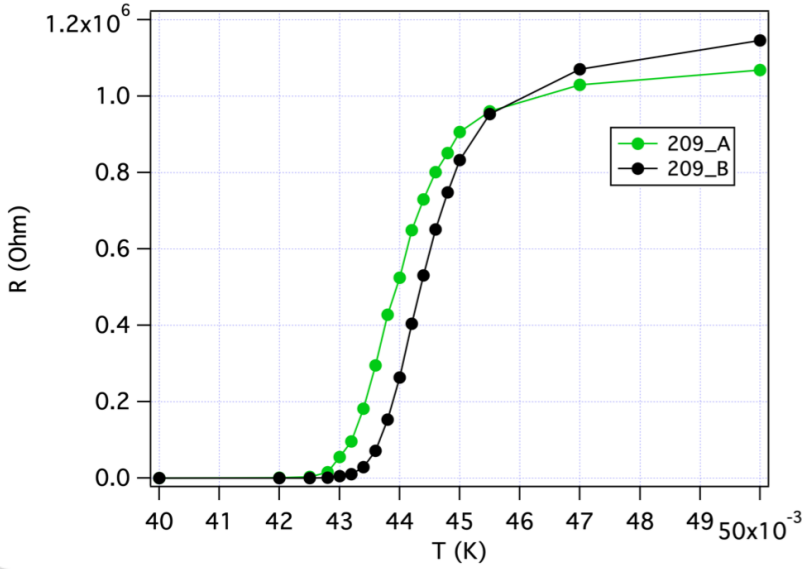


EDELWEISS R&D: heat sensors

NbSi transition edge sensor



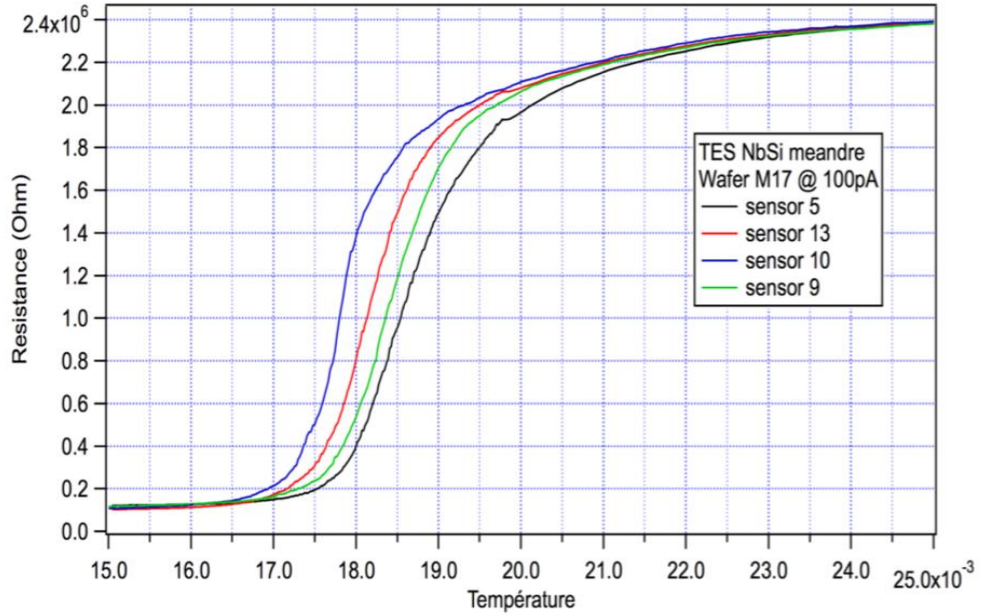




S. Marnieros, HDR (2014)
http://hal.in2p3.fr/tel-01088881/document

NbSi TES on thermal chip:
- high impedance
- on sapphire or germanium chip

→ should reach <10 eV resolution (RMS) with standard JFET pre-amplifiers



EDELWEISS R&D: ionization readout, HEMT

development of HEMT based pre-amplifiers

- amplification at 4 K stage of cryostat
- → shorter cabling → reduced impedance
- → better signal / noise

modified electrode configuration

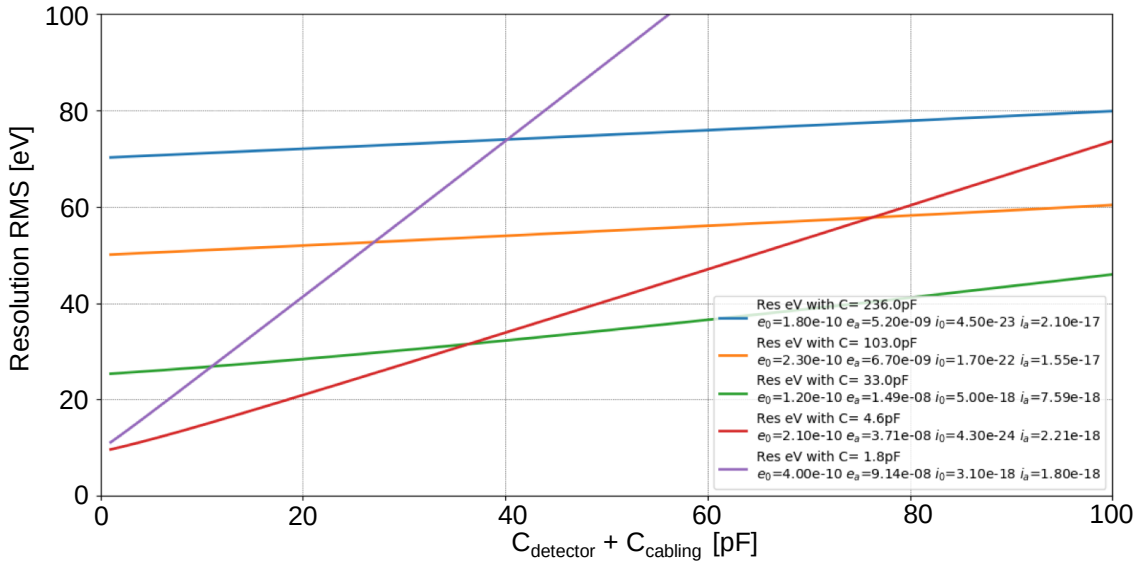
- spacing: 2 mm → 4 mm
- less capacitance (heat + electric)

targeting 50 eV_{ee} (RMS)

- possible with 50-80 pF effective capacitance

20 eV_{ee} (RMS)

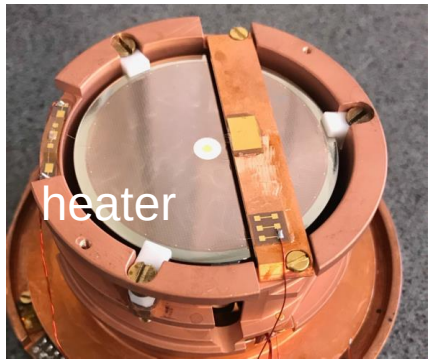
- possible with ~20 pF readout channel
- → requires cryostat upgrade

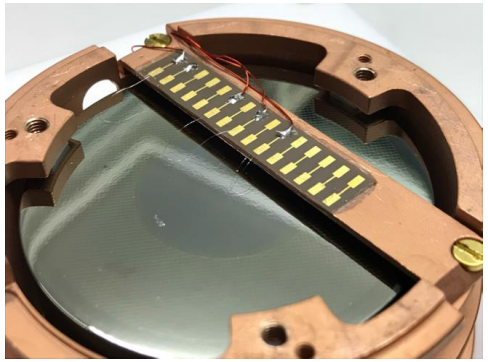


Currently ongoing EDELWEISS run in LSM

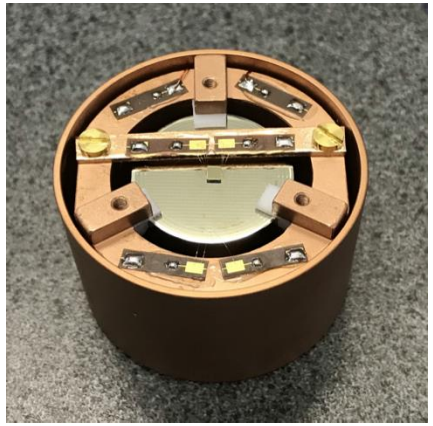
Calibration : KLM ^{71}Ge from neutron activation
3.7 GBq AmBe source (~2x10^5 neutrons)

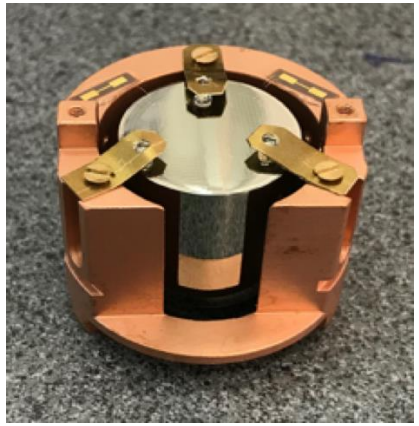
NbSi 209
200g Ge
TES sensor

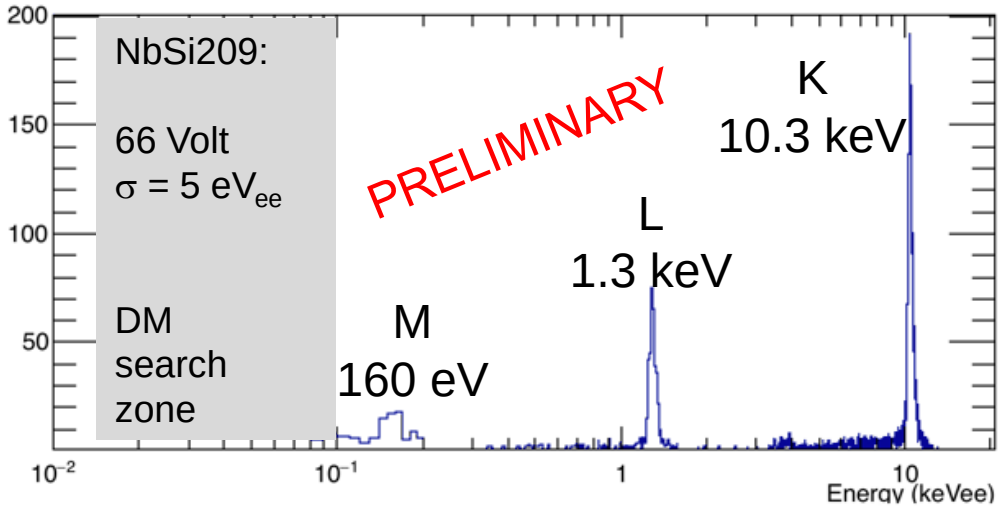


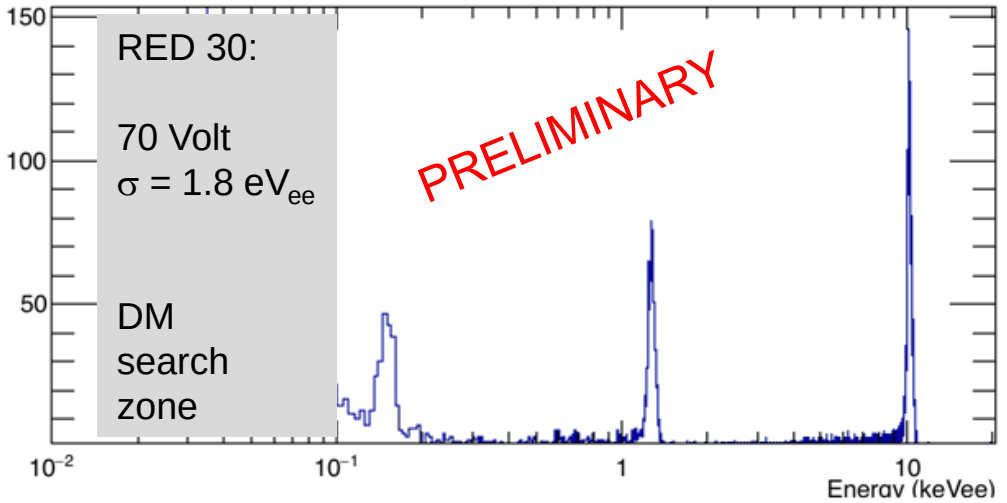


RED 30
33g Ge
NTD sensor



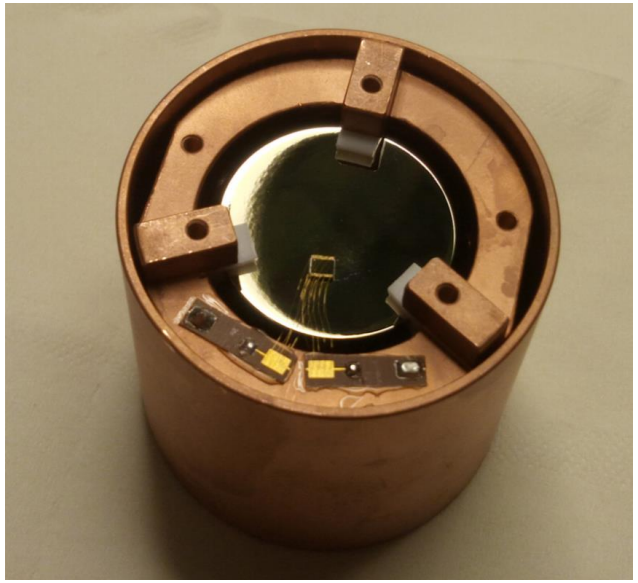






Conclusions

- An 18 eV phonon energy resolution and the possibility to apply analysis energy threshold of 60 eV have been achieved thanks to the coupling of the NTD-Ge thermal sensor to the detector and the excellent noise environment of the facility

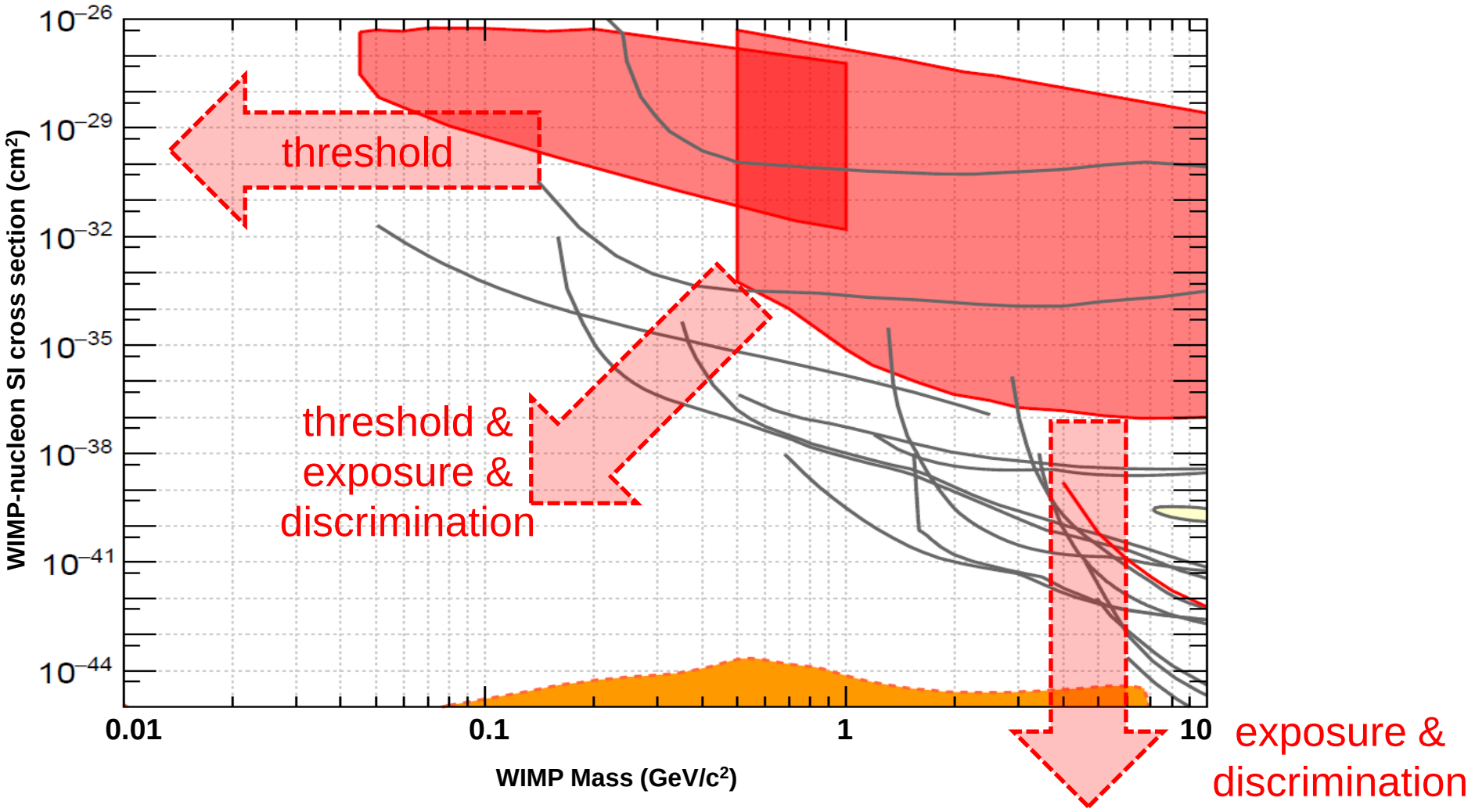


- First sub-GeV spin-independent dark matter limit based on a germanium target, and the most stringent, nuclear recoil based, above-ground limit on spin-independent interactions above 600 MeV/c^2 for the EDELWEISS collaboration

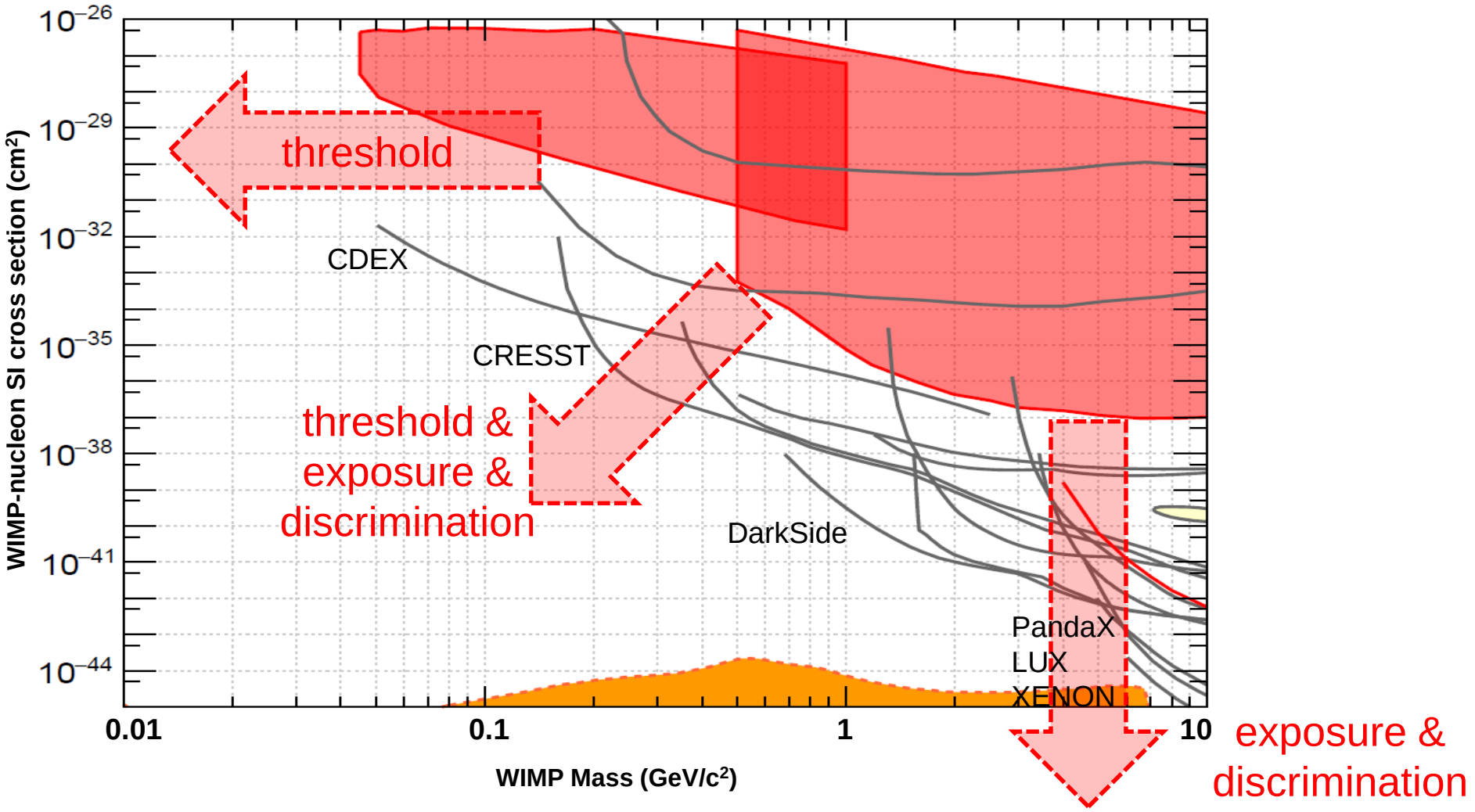
- Interpretation of the DM search results in the context of Strongly Interacting Massive Particles (SIMPs) with exclusion of new regions of the available parameter space in consideration of Earth-shielding effects

- Considering the Migdal effect, extension of the DM search to lower masses and first exclusion of particles with masses between 45 - 150 MeV/c^2 with cross sections from 10^{-29} to 10^{-26} cm^2

Outlook: Ge detector technology



Backup 1:


threshold
CDEX
CRESST
threshold &
exposure &
discrimination
DarkSide
PandaX
LUX
XENON
exposure &
discrimination
WIMP-nucleon SI cross section (cm²)
WIMP Mass (GeV/c²)
10⁻²⁶
10⁻²⁹
10⁻³²
10⁻³⁵
10⁻³⁸
10⁻⁴¹
10⁻⁴⁴
0.01
0.1
1
10