Low-mass WIMP searches with EDELWEISS

EDELWEISS-III:
Performance, results, background model

EDELWEISS-LT:
Prospects for ~GeV scale masses, first calibrations

EDELWEISS-DMB8:
Prospects for the $^8$B region

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The EDELWEISS-III Experiment

- Direct detection of WIMPs, germanium target
- 20 kg Ge total, 870g units
- Ionization + Heat
- Simple & robust design
  - Important for scalability to large arrays
  - Initially designed for >20 GeV WIMPs and ~3000 kgd
  - Extended down to 5 GeV given achieved resolutions

- Laboratoire Souterrain de Modane
  - Deepest in Europe: 5 μ/m²/day
EDELWEISS Setup

- Clean room + deradonized air
  
  *Rn monitoring down to few mBq/m³*

- Active muon veto (>98% coverage)

- External (50 cm) + internal polyethylene shielding
  
  *Thermal neutron monitoring with $^3$He detector*

- Lead shielding (20 cm, incl. 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 (arXiv: 1706.01070)
Fully InterDigitized electrode design

- ~870g detectors ($\phi=70$ h=40 mm)
- 2 GeNTDs heat sensor per detector
- Electrodes: concentric Al rings (2 mm spacing) covering all faces
- XeF$_2$ surface treatment to ensure low leakage current (<1 fA) between adjacent electrodes


Surface event rejection

*Phys Lett B 681 (2009) 305-309*

- Bulk event: charges collected by $C_1$ and $C_2$: $V_1$ and $V_2$ act as veto
- Surface events: charges collected by either $C_1V_1$ or $C_2V_2$
Nuclear recoil calibration + discrimination

- Clear event-by-event separation down to 5 keV energy recoils
- Response to nuclear recoils calibrated down to the analysis threshold for low-mass WIMP searches

\(1 \text{ keV}_{ee} \text{ heat} = 2.5 \text{ keV nuclear recoil}\)

[arXiv:1706.01070]
**Gamma rejection & Surface rejection**

- Rejection tested with >5000 kgd equivalent samples  
  [arXiv:1706.01070]
- $\gamma$ rejection factor: < 2.5 x 10^{-6}
- Surface evts rejection ($^{210}$Pb+$^{210}$Bi $\beta$, $^{210}$Po $\alpha$, $^{206}$Pb recoils): < 4 x 10^{-5}
EDELWEISS-III 3000 kgd data set

- 161 days of physics data with 24 FIDs (2014-2015)
- 24 FID with good resolutions and threshold < 5 keV\textsubscript{ee} (performance studies, coincidences)
- 19 FID with < 2 keV\textsubscript{ee} (used for study of cosmogenics + \(^{3}\text{H}\), etc.)
- 8 lowest threshold FIDs used for low-mass WIMP search

Clear 10 keV peak on all FIDs
Low-Mass analysis & background model

- Analysis with Boosted Decision Tree [JCAP05 (2016) 019]
- Analysis with Profile Likelihood [EPJC 76 (2016) 548]

Data-driven background models based on sidebands
Low-Mass analysis & background model

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Data-driven background models based on sidebands

First measurement of cosmogenic production of $^3$H in Ge [AstroPart. 91 (2017) 51] + S. Scorza talk on Wednesday
Low-Mass analysis & background model

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Data-driven background models based on sidebands

Multiple-detector events: fast neutron flux measurement
Low-Mass analysis & background model

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Data-driven background models based on sidebands

Clear identification of different components

Surface $\beta$, Pb

8 detectors combined 496 kg-days
Low-Mass analysis & background model

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Data-driven background models based on sidebands
Origin under investigation

8 detectors combined
496 kg-days

Heat-Only
Well reproducible over >years
Low-Mass analysis

- Analysis with Boosted Decision Tree [JCAP05 (2016) 019]
- Analysis with Profile Likelihood [EPJC 76 (2016) 548]

- Improvement by x20 to x150 between 7 and 10 GeV wrt EDELWEISS-II

- Limited by heat-only background: identification and rejection using the $\sigma=230$ eV resolution on ionization

- Ionization resolution is key for rejection

- Heat resolution is key for low thresholds
Prospects for GeV-range masses

- [ArXiv:1707.04308]: Complete study based on present measured backgrounds and resolutions vs possible improvements

1. Use of Luke-Neganov boost to lower thresholds (up to 100V bias)

2. Improve heat resolution
   \[ \sigma_{\text{heat}} = 500 \text{ eV} \rightarrow 100 \text{ eV} \]
   (x5 gain in sensitivity already achieved on 200 g detectors)

3. Reduction x100 of heat-only background

4. Improve ionization resolution
   \[ \sigma_{\text{ion}} = 200 \text{ eV}_{ee} \rightarrow 100/50 \text{ eV}_{ee} \]

Also: effect of improved neutron/gamma background (+ increased mass) in the environment planned for SuperCDMS at SNOLAB

Heat thresholds can be improved by applying larger bias voltages

- Heat signal boosted by Neganov-Luke effect \((\sim\text{Joule heating, factor } [1+V_{\text{bias}}/3])\)
- Loss of ionization-based bkg discrimination: method benefits low-mass searches only \(\rightarrow 10^{-41}\text{ cm}^2\) with 500 kgd and current bkgs

✔ 100V bias already achieved
✔ Observe nucl. recoils down to \(\sim 0.1\text{ keV}_{ee}\)
✔ First WIMP Data@100V analysis underway

\[\text{FWHM (keV}_{ee}\) vs. Luke boost = 1 + V/3\]

\[\text{EDELWEISS Preliminary}\]

\[\text{133Ba}\]

\[356\text{ keV line}\]

\[\gamma, n\]

Same detector same source

July 24th, 2017
EDELWEISS-LT: Heat-only background

- Standard signals on both NTDs but none on any electrodes
- Many studied hypotheses, none conclusive so far
  - Noise, cryogenics, stress from detector suspension or from glueing, natural radioactivity...
- New detector configurations being tested to study these hypotheses
  - Deported NTD glued on separate sapphire wafer
  - Photolithographed high-impedance NbSi TES sensitive to athermal phonons
- Dominant at low energy, but sufficiently reproducible for analysis of present 100V data & for EDELWEISS-LT: operation of 4x870g at 100V for 150 days in current LSM backgrounds
Ionization improvements

- Cold front-end: replace JFET @100K with HEMT (High Electron Mobility Transistor) @4K
- Can be operated at 4K: shorter cabling -> reduced capacitance -> better signal/noise
- Successful HEMT amplifier with sub-100 eV resolution operated on a CDMS-II detector
  [A. Phipps et al., arXiv:1611.09712]
- EDELWEISS electrode design with lower capacitance:
  2 → 4 mm spacing already achieved. Goal: reach 50 eV_{ee}.

EDELWEISS-DMB8:
Operation of a 200 kg array @8V (with nuclear recoil discrimination) in the improved background environment of SuperCDMS @ SNOLAB

Probing the region of the coherent scattering of ^{8}\text{B} solar ν' s with resolution and discrimination
Ionization improvements: EDELWEISS-DMB8

Coherent nuclear scattering from solar $^8$B neutrinos mimic a $\sim 6$ GeV WIMP with $\sigma \sim 4.4 \times 10^{-45}$ cm$^2$

Probe with discrimination and resolution ($\sim 10\%$) a bkg that will soon become relevant for WIMP searches near 6 GeV/c$^2$.

EDELWEISS-DMB8:
Operation of a 200 kg array @8V (with nuclear recoil discrimination) in the improved background environment of SuperCDMS @ SNOLAB

Probing the region of the coherent scattering of $^8$B solar $\nu$'s with resolution and discrimination
Conclusions

- **EDELWEISS-III**
  - Robust design, good reproducibility of performances
    - [arXiv:1706.01070]
  - Detailed description of backgrounds
    - [JINST 11 (2016) P10008]
  - Improved ionization resolution & thresholds lead to x40 improvement of WIMP sensitivity at ~5-10 GeV wrt EDELWEISS-II.
    - [Astropart. 91 (2017) 51]
    - [JCAP05 (2016) 019]
    - [EPJC 76 (2016) 548]

- **Prospects in the GeV-WIMP range:** **EDELWEISS-LT**
  - Improve thresholds x10 using boost from 8 to 100V (achieved)
  - $10^{-41}$ cm$^2$ achievable at LSM with 4 detectors with present levels of backgrounds
  - [arXiv:1707.04308]

- **Prospects for WIMPs in the $^8$B region:** **EDELWEISS-DMB8**
  - 50 eV ionization resolution to obtain pure nuclear recoil sample + 10% resolution on recoil energy: clear spectral identification of $^8$B ν
    - [arXiv:1707.04309]
  - Use HEMT preamplifier + reduce electrode capacitance (reduction by a factor of 2 of number of electrodes achieved)
  - $\sim$200 kg FIDs at SNOLAB to complement nicely the SuperCDMS-SNOLAB reach