Recent results from the EDELWEISS-III Dark Matter search

52nd Moriond Conference, 19.03.2017 – 24.03.2017
Very High Energy Phenomena in the Universe

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Direct search for Dark Matter

- **Ionization**
  - Ge, CF$_3$I, C$_3$F$_9$
  - 10% energy

- **Heat**
  - Al$_2$O$_3$, LiF
  - 100% energy
  - Slowest
  - Cryogenics

- **Light**
  - NaI, liq.Xe
  - 1% energy
  - Fastest
  - No surface effects

- **Target**
Direct search for Dark Matter

CoGeNT, CDEX, PICO

DAMIC

Ge, CF$_3$I, C$_3$F$_9$

10% energy

Ionization

DarkSide, DEAP-3600

liquid Xe/Ar

LUX, PandaX-II, XENON100, XENON1T

Nal, liqu.Xe

DAMA/LIBRA, DM-Ice, ANAIS, KIMS, SABRE

CDMSlite

Ge, Si

EDELWEISS, SuperCDMS

Heat

Al$_2$O$_3$, LiF

CRESST-1

100% energy slowest cryogenics

CRESST

Target

Light

1% energy fastest no surface effects

CaWO$_4$, BGO
Liquid noble gas vs. cryogenic bolometers

Cryogenic detectors
low thresh, high energy resolution

Liquid noble gas:
- target mass, low bgd

Billard, Strigari, Figueroa-Feliciano
PRD 89 (2014)
Muon intensity, $m^{-2}\text{sr}^{-1}\text{y}^{-1}$

Depth, meters water equivalent

5 $\mu$/m$^2$/day

4800 mwe (deepest in Europe)
EDELWEISS-III FID800 detectors

\[ \Delta T \sim E_{\text{heat}} = E_{\text{recoil}} + E_{\text{NTL}} \]

\[ T_{\text{op}} = 18 \text{mK} \]

additional heat by drifting charges (Neganov-Trofimov-Luke effect):

\[ E_{\text{NTL}} = N \cdot e \cdot U \]

Ø=70mm, h=40mm 2 GeNTDs heat sensors

Electrodes: concentric Al rings

XeF\(_2\) surface treatment: to ensure low leakage current (<1 fA) between adjacent electrodes

JLTP(2014)176:182
**EDELWEISS FID800 detectors**

**Fully InterDigitized ~870g HPGe detectors**

- Bulk/Fiducial event: Signal on $C_{\text{top}}$ & $C_{\text{bott}}$
- Surface event: Signal on $C_{\text{bott}}$ & $V_{\text{bott}}$

**Challenges:**
- Low event rate: $<1$ evt/kg/year
- Small energy deposit: $\mathcal{O}(\text{keV})$
- Background events by: $\beta$, $\gamma$, $n$, $\mu$ – induced background

- $C_{\text{top}} = +4V$
- $V_{\text{top}} = -1.5V$
- $C_{\text{bott}} = -4V$
- $V_{\text{bott}} = +1.5V$

EDELWEISS experimental setup

Cryostat

\( \text{e}^+, \text{e}^-, \gamma \), Pb shield

\( \mu \), Muon Veto

\( n \), Polyethylene shield

EDELWEISS DAQ system

FPGA based DAQ system
Hardware and software trigger, event based read out
Integration of external detectors: Muon-Veto
Option to change individual bias voltage 0V→±70V
Continuous digitization (100kHz, 16bit), optional: 40MHz, 16bit
Nuclear recoil calibration - event discrimination

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

(1 keV$_{ee}$ heat = 2.5 keV nuclear rec.)
Event rejection of γ and surface events

- γ rejection factor: $< 5.6 \times 10^{-6}$
  *Updated now to $< 2.5 \times 10^{-6}$ with additional detectors + statistics*
- Surface event rejection ($^{210}\text{Pb} + ^{210}\text{Bi}$ β, $^{210}\text{Po}$ α, $^{206}\text{Pb}$ recoils): $< 4 \times 10^{-5}$
  *JLTP(2014)176:870*

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**EDELWEISS FID**

$^{133}\text{Ba}$ calibration (937977 γ)

>5000 kg.day equivalent

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**Before rejection**

- $^{210}\text{Pb}$ β
- $^{210}\text{Bi}$ β
- $^{206}\text{Pb}$
- $^{210}\text{Po}$ α

**After rejection**

- 10^5 kg.day equivalent

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**EDELWEISS FID800**
EDELWEISS-III 2014-2015 science run

161 days of physics data with 24 FIDs: >3000 kgd total exposure

- Low ER bkg: 19 FIDs used in first measurement of cosmogenic production of $^3$H in Ge
  
  arXiv:1607.04560

- 8 lowest threshold FIDs used for low-mass WIMP search

- 161 days of physics data with 24 FIDs: >3000 kgd total exposure

<0.1dru
Low mass WIMP search with likelihood analysis

\[ P_{\text{tot}}(\sigma, \mu \mid m_\chi) = \frac{1}{v} \left[ \mu_\chi P_\chi(m_\chi) + \sum_i \mu_i P_i \right] \]

\[ \mathcal{L}(\sigma, \mu \mid m_\chi) = \prod_{n=1}^{N} P_{\text{tot}}(E_{\text{heat}}^n, E_{\text{ion}}^n) \times \prod_i \text{Gauss} \left( \mu_i \mid \mu_i^{\text{exp}}, \sigma_i \right) \times \text{Poisson} \left( N \mid v \right) \]
Results of the likelihood analysis

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\[ \mathcal{P}_{\text{tot}}(\sigma, \mu \mid m_\chi) = \frac{1}{v} \left[ \mu_\chi \mathcal{P}_\chi(m_\chi) + \sum_i \mu_i \mathcal{P}_i \right] \]

\[ \mathcal{L}(\sigma, \mu \mid m_\chi) = \prod_{n=1}^{N} \mathcal{P}_{\text{tot}}(E_{\text{heat}}^n, E_{\text{ion}}^n) \times \prod_i \text{Gauss}(\mu_i \mid \mu_i^{\text{exp}}, \sigma_i) \times \text{Poisson}(N \mid v) \]

\[ m_\chi = 4\text{GeV/c}^2 \text{ excluded at 90}\%CL \]

Ionisation

Heat
First results of EDELWEISS-III phase

- Improvement by x20 to x150 between 7 and 10 GeV wrt EDELWEISS-II
- Limited by heat-only bkd: identification and rejection using the $\sigma = 230$ eV resolution on ionization
- Ionization resolution is key for rejection
- Heat resolution is key for low thresholds
EDELWEISS 2018 goals: 4x100

Challenges:

1. “Heat only” events
   \( \rightarrow \) x100 reduction

2. HEMT transistor read out
   \( \rightarrow \sigma_{\text{ion}} = 200\text{eV} \rightarrow 100\text{eV} \)

3. NTL effect read out
   \( \rightarrow V_{\text{bias}} = 8\text{V} \rightarrow 100\text{V} \)

4. Improved heat sensors
   \( \rightarrow \sigma_{\text{heat}} = 500\text{eV} \rightarrow 100\text{eV} \)
Challenge 1: Detector R&D: reducing heat only events

- Dominant (&reproducible) background at low energy
- Noise, cryogenics, stress from detector suspension: excluded as sources of this background
- Remaining suspect: stress from gluing, avoided via:
  - Two “deported NTD”, glued on separate sapphire wafer
  - Photo-lithographed high-Ω NbSi TES, sensitive to athermal phonons
Challenge 2: Detector R&D: HEMT read out

- JFET → HEMT
  - Reduced intrinsic noise
  - Lower heat load
  - Operates at 4K stage
    - → shorter cabling
    - Reduced capacitance
    - Better SNR

- Successful HEMT amplifier with sub-100 eV\textsubscript{RMS} ionization resolution

A. Phipps et al., arXiv:1611.09712
collaboration between SuperCDMS and EDELWEISS

A. Phipps et al., arXiv: 1611.09712
Challenge 3: Lower threshold by increased bias voltage

Neganov-Trofimov-Luke effect

\[ \Delta T \sim E_{\text{heat}} = E_{\text{recoil}} + E_{\text{NTL}} \]

\[ E_{\text{NTL}} = N \cdot e \cdot V_{\text{bias}} \]

Detector bias upgrade:

\[ V_{\text{bias}} = 8V \rightarrow 140V \]

Pair creation in Ge:
1 keV \rightarrow 340 e^{-}h^{+} pairs

Sensitivity goal: <100 eV

Ionization signal measured in heat channel

\[ \rightarrow \text{No particle discrimination at threshold} \]

Prompt phonons
Charge propagation
NTL amplified phonons

\[ ^{133}\text{Ba calibration} \]
356keV \( \gamma \)-line
Challenge 3: 
Lower threshold by increased bias voltage

Neganov-Trofimov-Luke effect

\[ \Delta T \sim E_{\text{heat}} = E_{\text{recoil}} + E_{\text{NTL}} \]

\[ E_{\text{NTL}} = N \cdot e \cdot V_{\text{bias}} \]

Detector bias upgrade:

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Pair creation in Ge:
1 keV \rightarrow 340 e^{-}h^{+} pairs
Sensitivity goal: <100 eV

Ionization signal measured in heat channel → No particle discrimination at threshold → Ionization as diagnostic signal at higher energy
Surface event discrimination by rise time

A. Broniatowski et al. PLB681(2009)305

Rise time as complementary surface rejection:

- 95% "surface" rejection
- 4.4% efficiency loss "fiducial"

(yet restricted to $E_{\text{ion}} > 100\text{keV}$)

EDW-III 40MHz digitizer
Detector R&D and MC studies of charge migration

$^{241}$Am(g, 60keV) 
Pb, $d=1\text{mm}$

N. Foerster et al., JLTP(2016)184:845

$V_B = -V_D = 2V$
$V_A = V_C = 0V$

$V_B = -V_D = 50V$
$V_A = V_C = 0V$

N. Foerster, PhD thesis 2017
Challenge 4: Detector R&D: Thermal model & heat sensor

- Better understanding of heat signal
  - Thermal modeling of signal, verified with dedicated R&D
  - Identification of sensitivity to ballistic phonons
  - Identification of parasitic heat capacity

- Sensitivity of 200 nV/keV
  - (x6 wrt present FIDs) achieved on 250 g test detectors

J. Billard et al., JLTP(2016)184:299
EDELWEISS 2018 goal

EDW-III 350 kg.d, EDW-III background assumed

100V, $\sigma=100\text{eV(heat)}$

$1/100$ reduction of heat only

$350\text{kg.d bgd-free}$

$8\text{V}, \sigma=100\text{eV(ion)}$

JLTP(2016)184:308

EPJC (2016) 76:548

reachable in current LSM setup in 2018
Conclusion and Outlook

EDELWEISS-III results 2016

EDW-III goals 2018

going beyond (35kg x 1000days)

no neutron-bgd, 0.1 x Compton

WIMP-Nucleon Cross Section (SI) (cm²)

WIMP Mass (GeV/c²)

100V
8V
350kg-days

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Conclusion and Outlook

Going beyond:
SuperCDMS +
EDELWEISS at
SNOLab

EDELWEISS-III results 2016

EDW-III goals 2018

35 ton-days