Direct search for Dark Matter with the EDELWEISS-III experiment: new WIMPs results

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CEA/SPP
On behalf of the EDELWEISS collaboration
Outline

- WIMP direct detection in a nutshell
- The EDELWEISS-III collaboration
- The set-up and the detectors
- Low-mass WIMP search
- Conclusions & Perspectives
Detection of the energy deposited due to elastic scattering off target nuclei

- Ge crystal: event ID from measurements of ionization and phonon energies
- Elastic scattering of a WIMP deposits small amount of energy into recoiling nucleus (~ few 10s of keV)
- Expected rate: < 1 interaction per kg per year
- Radioactive background of most materials gives higher rate
WIMP direct detection

Detection of the energy deposited due to elastic scattering off target nuclei

- Ge crystal: event ID from measurements of ionization and phonon energies
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Our needs:
- Low thresholds
- High exposure
- Background rejection
EDELWEISS-III: the collaboration

- CEA Saclay (IRFU & IRAMIS)
  - Detectors, electronics, acquisition, data handling, analysis

- CSNSM Orsay
  - Detectors, cabling, cryogenics

- IPN Lyon
  - Electronics, cabling, low radioactivity, analysis, detectors, cryo.

- Institut Néel Grenoble
  - Cryogenics, electronics

- Karlsruhe KIT + IPE
  - Vetos, neutron detectors, background

- JINR Dubna
  - Background, neutron and radon detectors

- Oxford University
  - Detectors, cabling, cryogenics, analysis

- Sheffield University
  - MC simulation

~ 50 people / 4 countries

LSM @ Fréjus tunnel

\( \gamma : \text{Astrop. Phys.} \ 9 \ (1998) \)
EDELWEISS-III: the set-up (a)

- **Cryogenic installation (18 mK):**
  - Reversed geometry cryostat
  - up to 40 kg of detectors

- **Shieldings:**
  - Clean room + deradonized air (10 mBq/m$^3$)
  - Active muon veto (>98% coverage)
  - 50 cm PE shield
  - 20 cm Lead shield

- **(Many) others:**
  - Remotely controlled sources for calibrations + regenerations
  - Radon detector sensitive down to few mBq/m$^3$
  - He$^3$ neutron detector: thermal neutron monitoring inside shields - sensitivity $10^{-9}$ n/cm$^2$/s)
  - liquid scintillator 1 m$^3$ neutron counter: study of muon induced neutrons
Polyethylene shielding (n)
50cm for moderation

Lead shielding ($\beta$, $\gamma$)
18cm + 2cm ancient lead

Copper cryostat ($\beta$, $\gamma$)
thermal shielding
- extra 10 cm below detectors
- PE shield
- extra 15 cm Roman Pb (1K)
The EDELWEISS-III detectors: FID

36 x Full Inter-Digitized 800 g HP-GeDetector
FID detector scheme

Full Inter-Digitized 800 g HP-Ge Detector

Diameter: 7 cm
Height: 4 cm

2 heat channels - NTD technology
4 ionisation channels
The EDELWEISS detectors: basic principle

Simultaneous measurement
- Heat @ 20 mK with Ge/NTD thermometer
- Ionization @ few V/cm with Al electrodes
Evt by evt identification of the recoil

Most backgrounds (e, γ) produce electron recoils
Yield (Ionization/recoil) ~1

WIMPs and neutrons produce nuclear recoils
Yield (Ionization/recoil) ~0.3

Surface Events
Charge collection shared between one veto and its neighbor fiducial electrodes, e.g. C & D

Bulk Event
Charge collected on fiducial electrodes B & D
Data taking: the status

WIMP data-taking
July 2014 – April 2015
• Restart in June 2015
• 36 detectors installed, while 24 FID800 were used (cabled)
⇒ More than 14kg of Fiducial mass in Germanium

<table>
<thead>
<tr>
<th></th>
<th>Baseline (keV)</th>
<th>356 keV (keV)</th>
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</thead>
<tbody>
<tr>
<td>FWHM Ion</td>
<td>&lt;0.6</td>
<td>&lt;10</td>
</tr>
<tr>
<td>FWHM Heat</td>
<td>&lt;1.0</td>
<td>&lt;15</td>
</tr>
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</table>

Average resolution for WimpSearch detectors

Baseline (keV) 356 keV (keV)
FWHM Ion <0.6 <10
FWHM Heat <1.0 <15
Detector performance of the selected FID

Unblinded a small fraction of the data set, Aug – Dec 2014

- Allows us to prepare the analysis
- Exposure 35 kg.d after cuts
- After 6 months of data taking: demonstration with a first data set one detector with good baselines and low threshold
  \[\Rightarrow\] expect \(\sim\)7 other detectors with similar performance

<table>
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<tr>
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<th>EDW-III subsample (1 x FID800)</th>
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<tbody>
<tr>
<td>exposure</td>
<td>35 kg.days</td>
</tr>
<tr>
<td>threshold</td>
<td>3.6 keVnr</td>
</tr>
<tr>
<td>FWHM ion fid</td>
<td>0.54 keVee</td>
</tr>
<tr>
<td>FWHM heat</td>
<td>0.33 keVee</td>
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Improved performances at low energies
Good \(\gamma\)/neutron discrimination down to
1 keVee in Ionization
3 keVnr in Heat
First low mass WIMPs data

Define a rough region of interest

- Singles
- $1.5 < E_{\text{heat}} < 15 \text{ keVee}$
- $0 < E_{\text{ion}} < 15 \text{ keVee}$
- $E_{\text{veto}} < 5\sigma$

We use Boosted Decision Trees within this ROI:
Combine the 6 variables (4 ionisation and 2 heat) for Signal/Background discrimination

Model WIMP signal and backgrounds within this ROI

Background models are data driven:
- Use regions without signal (sideband) to build the model
- Use calibrations as crosscheck
One boosted decision tree (BDT) per WIMP mass

Conservative limit: w/o background subtraction

Minimization of Poisson(exp. bkg)/N_Wimp for BDT cut value

→ either 0 or 1 evts observed according to WIMP mass
First low mass WIMPs results

- limits in agreement with previous projections
- ongoing: cross checks with profile likelihood
- already competitive results for small subset of available data
• Low mass WIMP analysis shows competitive results with small data set.

• x10 more data is available: 
  -> expect fast improvement in sensitivity
  -> Ongoing cross-check with profile likelihood
• Ongoing ‘standard WIMP mass’ analysis
• HEMT R&D to lower ionization threshold
• Restart data-taking in June 2015

R&D on HV (Neganov-Luke amplification)
- x100 reduction on Heat-Only events
- 100 eV (RMS) ion & heat
- 350 kg-days
EDELWEISS-II
ID 400 g  (160 g fiducial mass)

EDELWEISS-III
FID 800 g  (~600 g fiducial mass)

ID Rejection factor: $3\pm1 \times 10^{-5}$

FID Rejection factor $< 6 \times 10^{-6}$
First low-mass WIMP search with a subsample of Edelweiss-III data

- after 6 months of data taking: demonstration with a first data set
- one detector with good baselines and low threshold
- expect ~7 other detectors with similar performance

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<th>EDW-II (4 x ID400)</th>
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<tbody>
<tr>
<td>exposure</td>
<td>35 kg.days</td>
<td>113 kg.days</td>
</tr>
<tr>
<td>threshold</td>
<td>3.6 keVrr</td>
<td>≈ 5 keVrr</td>
</tr>
<tr>
<td>FWHM ion fid</td>
<td>0.54 keVee</td>
<td>0.72 keVee*</td>
</tr>
<tr>
<td>FWHM heat</td>
<td>0.33 keVee</td>
<td>0.82 keVee*</td>
</tr>
</tbody>
</table>

*best detector

DAQ online trigger efficiency for the detector

method 1: coincidences
method 2: livetime weighted
method 3: analytic average
**Gamma background @ low energy**

Event Rate in 20-200 keV (events/kg.day)

<table>
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<tr>
<th>Volume</th>
<th>Fiducial</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>7.3 (10%)</td>
<td>12.8 (10%)</td>
</tr>
<tr>
<td>Brass</td>
<td>14.7 (20%)</td>
<td>22.9 (18%)</td>
</tr>
<tr>
<td>Brass in Cu</td>
<td>6.9 (9.4%)</td>
<td>10.3 (8%)</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>2.6 (3.5%)</td>
<td>4.6 (3.6%)</td>
</tr>
<tr>
<td>Teflon</td>
<td>2.2 (3%)</td>
<td>4.0 (3%)</td>
</tr>
<tr>
<td>Connectors</td>
<td>39.7 (54%)</td>
<td>63.1 (50%)</td>
</tr>
</tbody>
</table>

Highest contribution ~50% from connectors (delrin PTFE + pin Mill-Max + pressfit Mill-Max + socket Mill-Max + kapton)

**BUT not yet limiting the EDELWEISS-III sensitivity!**
Radiogenic neutron background (simulation)

Fiducial volume selection $E_{\text{ion\_veto}} < 3$ keV
Total mass = 620g x N(FIDs)
Running 1 year

<table>
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<tr>
<th>Selection:</th>
<th>Detector:</th>
<th>24 FIDs</th>
<th>36 FIDs</th>
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<tr>
<td>$E_{\text{th}} &gt; 10$ keV $E_{\text{th_aux}} &gt; 3$ keV</td>
<td>Singles 10-200 keV</td>
<td>1.2 (2)</td>
<td>1.7 (2)</td>
</tr>
<tr>
<td>$E_{\text{th}} &gt; 10$ keV</td>
<td>Multiples</td>
<td>3.8 (5)</td>
<td>6.1 (8)</td>
</tr>
<tr>
<td>$E_{\text{th}} &gt; 20$ keV $E_{\text{th_aux}} &gt; 10$ keV</td>
<td>Singles 20-200 keV</td>
<td>0.9 (8)</td>
<td>1.4 (2)</td>
</tr>
<tr>
<td>$E_{\text{th}} &gt; 20$ keV</td>
<td>Multiples</td>
<td>2.7 (4)</td>
<td>4.2 (6)</td>
</tr>
</tbody>
</table>

Energy spectra and neutron yields in each material calculated via SOURCES4A, then neutrons are propagated in the set-up using GEANT4 code.

Errors are statistical errors + errors on radio purity when available.

Evaluation of radiogenic neutron contributions from shielding and walls is ongoing.

Neutron rate from cryostat & electronics <1.7e-4 events/kg.day factor >10 better than EDW-II
EURECA + SuperCDMS

# EURECA = EDELWEISS + CRESST + ROSEBUD + ... ;
# To probe $10^{-46} - 10^{-47}$ cm$^2$ (phase 1,2)
# Agreed collaboration with SuperCDMS @SNOLAB
# SuperCDMS: US-based exp. using Ge & Si-detectors, currently running 10kg of detectors in Soudan
# Builds on earlier collaborative work between EDELWEISS-II & CDMS, Phys. Rev. D 84, 011102(R) (2011)
# Cryostat at SNOLAB: up to 400kg (need 15mK $\rightarrow$ WG Cryo)
# Plan to swap individual detectors and towers
# Multi-target: Ge, Si & CaWO$_4$:
  - Space for up to 400 kg
  - Phase 1: 50kg EURECA + 50kg SuperCDMS
# Phase 1: $< 10^{-46}$ cm$^2$ planned installation 2018
  but significantly improve at lower mass!
# Prospects for tonne-scale experiment at LSM or SNOLAB