Recent status of the Dark Matter search with EDELWEISS

Valentin Kozlov for the EDELWEISS collaboration

8th Patras Workshop on Axions, WIMPs and WISPs
Chicago and Fermilab
18-22 July 2012
Edelweiss: search for WIMPs @ LSM (France)

- Simultaneous measurement
  - Heat @ 18 mK with Ge/NTD thermometer
  - Ionization @ few V/cm
- Evt by evt identification of the recoil by ratio $Q = \frac{E_{\text{ionization}}}{E_{\text{recoil}}}$
  - $Q = 1$ for electron recoil
  - $Q \approx 0.3$ for nuclear recoil

Ge-bolometers of (F)ID-type

- Depth, meters water equivalent
- Muon intensity, m$^{-2}$ sr$^{-1}$ y$^{-1}$
- 5 $\mu$/m$^2$/day
- 4800 mwe

5 mwe
Edelweiss-2 (3) experimental set-up

- **Edelweiss-3 goal** $\sigma_{\chi-n} = \text{a few} \cdot 10^{-9} \text{ pb}$
- Cryogenic installation (18 mK):
  - Reversed geometry cryostat
  - Can host up to 40 kg of detectors
- Shieldings:
  - Clean room + deradonized air
  - Active muon veto (>98% coverage)
  - PE shield 50 cm (EDW-3: +internal PE)
  - Lead shield 20 cm
- (Many) others:
  - Remotely controlled sources for calibrations + regenerations
  - Radon detector down to few mBq/m$^3$
  - Thermal neutron monitoring (He$^3$ det.)
  - Study of muon induced neutrons (liquid scintillator 1 m$^3$ neutron counter)
- 18 cool-downs operated since 2006
Edelweiss-2 setup: View from 'inside'
Edelweiss-2 setup: View from 'inside'

Cryostat: inside
InterDigitized (ID) design: surface evt rejection

Surface events rejection:

intentional $^{210}\text{Pb}$ source: $6 \times 10^4$ events total
requiring no signal on veto electrodes: 1 event left

→ rejection factor for surface events of $6 \times 10^{-5}$ (90% CL)

→ In case of no other background:

$\sigma_{SI} \sim 4 \times 10^{-10}$ pb (90% CL, $M_\chi = 70$ GeV/c$^2$)

ID-d Detectors: γ rejection & fiducial volume

Gamma rejection

$^{133}$Ba calibration data: fiducial only evts

$1.82 \times 10^5$ events with $20 < E < 200$ keV

($3.5 \times 10^5$ in total)

6 events ("anomalous")

→ $\gamma$–rejection factor of $3 \times 10^{-5}$ NR / $\gamma$

Fiducial volume (ID400): $166 \pm 6$ g => 160 g:

primarily limited by the guard region

→ Measurement with cosmogenic lines: $^{68}$Ge + $^{65}$Zn

→ Consistent with neutron calibration data

→ Consistent with electrostatic model estimation
WIMP search: $E_R > 20$ keV ($2008+2009+2010$)

- 10 ID 400-g detectors
- Total exposure: 427 kg.d
- in 90% NR band, i.e. WIMP RoI: 384 kg.d
- 5 events observed: 4 with $E < 22.5$ keV
  1 with $E = 172$ keV
- Expected background $< 3$ (90% CL)

WIMP Halo:
local density of 0.3 GeV/c$^2$
Maxwellian velocity distribution

\[ v_{\text{rms}} = 270 \text{ km/s} \]
\[ v_{\text{Earth}} = 235 \text{ km/s} \]
\[ v_{\text{escape}} = 544 \text{ km/s} \]

\[ \sigma_{\text{SI}} < 4.4 \times 10^{-8} \text{ pb (90% CL), } M_\chi = 85 \text{ GeV} \]

EDELWEISS + CDMS combined limits

- The use of the same target material allows simple combination of data.

- Simple merger of data sets was chosen prior to any analysis.

EDW: 384 kg.d, [20, 200keV], 5 evts
CDMS: ~379 kg.d, [~10, 100keV], 4 evts

- Other methods have also been tested (see paper).

~50% gain at high WIMP masses.

WIMP search: Low mass (1)

- New independent analysis $E_R < 20$ keV
- Select ID detectors sensitive to nuclear recoils down to 5 keV
- General strategy to select the data set:
  - Keep 4 detectors with sub-keV ionisation and heat baseline resolutions
  - Remove noisy periods
  - $\chi^2$ based cut
  - Exclude coincidences (muon veto, other bolometers)
  - Fiducial cut based on ionisation signal – energy independent
- Best energy estimator to search for nuclear recoils near the threshold:
  \[
  E_{\text{heat}} = \frac{E_{\text{rec}}}{1 + V/3} \left(1 + \frac{V}{3} Q_n(E_{\text{rec}})\right), \quad Q_n(E_{\text{rec}}) = 0.16 E_{\text{rec}}^{0.18}
  \]
- Efficiency loss due to the online trigger ($f(\text{noise})$):
  \[
  \varepsilon_{\text{online}} = 0.5 \left(1 + \text{Erf}\left(\frac{(E_{\text{rec}} - E_{\text{thresh}})}{\sigma \sqrt{2}}\right)/\sigma\right)
  \]
  (tested with gamma calibration on Compton plateau)

$\rightarrow$ Good trigger efficiency @ low energy:
  78 % @ 5 keVnr, 90 % @ 6.3 keVnr

WIMP search: Low mass (2)

Use *ionization signal* for:

- **Fiducial selection**
  - No signal on veto and guard electrodes
  - No difference between fiducial electrodes

- **Ionization cut** (rejection of ionizationless events):
  - $\Delta t < 30 \mu s$ for pulses on fiducial electrodes
  - $E_{\text{ion}} > 1.4 .. 1.9$ keV ($2 \times$ FWHM)

- **Construct $(E_{\text{heat}}, E_{\text{ion}})$ plane**:
  - residual fiducial gamma background along:
    \[
    E_{\text{ion}} = E_{\text{rec}} \left(1 + Q_n \left(E_{\text{rec}} \right) V/3 \right)/(1 + V/3)
    \]
  - width is defined by $\sigma_{\text{ion}}, \sigma_{\text{heat}}$ (independent)

- Define "WIMP search box" in the $(E_{\text{heat}}, E_{\text{ion}})$ plane for each WIMP mass and detector based on:
  - 90% of WIMP signal density, $\rho(E_{\text{rec}}, E_{\text{ion}})$
  - below 95% gamma rejection cut
WIMP search: Low mass, results

- Total fiducial exposure: 113 kg.d
- 3 events observed in the WIMP box (one event for $M_\chi = 10$ GeV)
- Estimated background (5-20 keV):
  - Neutron < 1.7 evt, most probable 1.0 evt (based on Monte-Carlo + activity meas.)
  - Gamma < 1.2 evt
- Limits on $\sigma_{SI}$ derived from Poisson statistics
- Significantly extends EDW limits for $M_\chi = 7-30$ GeV
- Good rejection of surface events!
Towards EDELWEISS-3 (goals 2013)

- 3000 kg∙d exposure (2013)
- \( \sigma_{\chi-n} = 5 \cdot 10^{-9} \text{ pb} \)
- 40 FID800 detectors
  (24 kg fiducial)
- Explore low mass region
- Reduced background

Programme under way, funded.
EDELWEISS-3: new FID800

- ID400 (fid. 160g) => FID400 (300g) => FID800 (600g)

- 2 NTD heat sensors (better heat ch),
  4 ionization channels, instead of 6.
- Larger Fiducial volume (75% vs. 40%)
- No event in NR ($^{133}\text{Ba}: 4\cdot10^5\gamma$’s)
- Fabrication up to 1 FID800 / week
  (mandatory leakage-current tests)

Preliminary

Ge-FID800 (412000 $\gamma$):
No event in Nucl.Recoil band.
Even better than ID’s!
Infrastructure improvements

Within the Edelweiss-2 setup:

- upgrades of muon veto, cryogenics, cabling, shielding
- Improved material selection
- Extra internal PE shield.

<table>
<thead>
<tr>
<th>Background</th>
<th>EDW-2 (evt / kg.d)</th>
<th>EDW-3 (evt / kg.d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma rate</td>
<td>82</td>
<td>14 – 44</td>
</tr>
<tr>
<td>Ambient neutrons</td>
<td>(2.6 - 8.1)\cdot10^{-3} mainly due to cables and connectors</td>
<td>(0.8 – 1.9)\cdot10^{-4}</td>
</tr>
<tr>
<td>Muon-induced neutrons</td>
<td>&lt; 1\cdot10^{-3}</td>
<td>&lt; 2\cdot10^{-4}</td>
</tr>
</tbody>
</table>

- Modify electronics and DAQ (scalability): 240 channels + auxiliary detectors
- New event-based readout
- More analysis tools
  - **Kdata**: ROOT-based, multi-tier, db, …
µ-induced background study

1. GEANT4 simulations

2. 307 live days or 481 kg.d

3. GEANT4 (no scaling!)
   Measured excess
   (793 live days, 272 hits)

To probe $10^{-10} \div 10^{-11}$ pb

Background $10^{-3}$ evt/kg/yr

150 kg $\rightarrow$ 1 ton Cryo detector; 2015 (150kg) 2018 (1 ton)

Multi-target (Ge, CaWO$_4$)

CRESST + EDELWEISS + ROSEBUD + ... ;

2 experiments (different nuclei, different techniques), e.g. 1 bolometric, 1 noble liquid;

Fréjus road safety tunnel: excavation started !

unique option for LSM extension !
**Summary & Outlook**

- EDELWEISS-2 final analysis of one year (2009-2010):
  \[4.4 \cdot 10^{-8} \text{ pb}, \text{ eff. exposure: } 384 \text{ kg.d}\]
  - Phys Lett B 702 (2011) 329

- EDELWEISS-2 data are combined with CDMS
  - Phys. Rev. D 84, 011102 (2011)

- Low WIMP mass analysis:
  \[1.0 \cdot 10^{-5} \text{ pb for } M_\chi = 10 \text{ GeV}, \text{ eff. exposure: } 113 \text{ kg.d}\]
  - arXiv:1207.1815v1

- EDELWEISS-3 scientific goal is a few \(10^{-9}\) pb
  e.g. \(5 \cdot 10^{-9}\) pb, eff. exposure of 3000 kg.d (125 live days in 2013);

- New Ge-FID800 (600g fiducial), improved background rejection

- Upgrades of the set-up and DAQ

- Various background studies

- Road to 1 ton experiment, EURECA
The EDELWEISS Collaboration

• CEA Saclay (IRFU & IRAMIS)
• CSNSM Orsay
• IPN Lyon
• Institut Néel Grenoble
• KIT Karlsruhe (IKP, IEKP, IPE)
• JINR Dubna
• Oxford University
• Sheffield University

• Detectors, electronics, acquisition, data handling, analysis
• Detectors, cabling, cryogenics
• Electronics, cabling, low radioactivity, analysis, detectors, cryo
• Cryogenics, electronics
• Vetos, neutron detector, background, analysis, electronics
• Background, neutron, radon monitors
• Detectors, cabling, cryogenics, analysis
• MC simulations

≈ 50 persons (30 FTE);
11 PhD students;
5 post-docs;
4 countries
BACKUP SLIDES
ID Calibration

\( \gamma \) calibrations with \(^{133}\text{Ba}\)

cosmogenic \( \gamma \) lines

n calibrations with AmBe

heat & ionization energy [keV]

Recoil energy [keV]

counts/2keV
**EDW-2 background:**
neutrons from rock & materials

<table>
<thead>
<tr>
<th>Source</th>
<th>Material</th>
<th>Neutron events (384 kg×days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall walls</td>
<td>Rock</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Hall walls</td>
<td>Concrete</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Shielding</td>
<td>Polyethylene</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Shielding</td>
<td>Lead</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>Support</td>
<td>Stainless steel</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Support</td>
<td>Mild steel</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>Warm electronics</td>
<td>PCB</td>
<td>1.0±0.5</td>
</tr>
<tr>
<td>1K connectors</td>
<td>Aluminium</td>
<td>0.5±0.2</td>
</tr>
<tr>
<td>Thermal screens, crystal supports</td>
<td>Copper</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Coaxial cables</td>
<td>PTFE</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Crystal holders</td>
<td>PTFE</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Electrodes</td>
<td>Aluminium</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>&lt;3.1</strong></td>
</tr>
</tbody>
</table>