The ANAIS-112 experiment at the Canfranc Underground Laboratory

- Goals and history
- Detectors, shielding and DAQ
- Detector response
- Radiopurity and background
- Sensitivity

ANAIS (Annual modulation with NAI Scintillators) intends to confirm the DAMA/LIBRA modulation signal using the same target and technique in a different environment at the Canfranc Underground Laboratory (Spain).

ANAIS-112: 3x3 matrix of 12.5 kg NaI(Tl) modules → 112.5 kg active mass

Experimental requirements:
- Energy threshold at or below 2 keV$_{ee}$
- Background as low as possible below 10 keV$_{ee}$ (at or below a few cpd/keV/kg)
- Very stable operation conditions
After a commissioning run, ANAIS-112 is scheduled to start **dark matter run** this week.
Detectors

Nine modules produced by Alpha Spectra Inc following low radioactivity protocols

<table>
<thead>
<tr>
<th>Detector</th>
<th>Quality powder</th>
<th>Received at Canfranc in</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0, D1</td>
<td>&lt;90 ppb K</td>
<td>December 2012</td>
</tr>
<tr>
<td>D2</td>
<td>WIMPScnt-II</td>
<td>March 2015</td>
</tr>
<tr>
<td>D3</td>
<td>WIMPScnt-III</td>
<td>March 2016</td>
</tr>
<tr>
<td>D4, D5</td>
<td>WIMPScnt-III</td>
<td>November 2016</td>
</tr>
<tr>
<td>D6, D7, D8</td>
<td>WIMPScnt-III</td>
<td>March 2017</td>
</tr>
</tbody>
</table>

- **NaI(Tl) crystals** grown from selected ultrapure NaI powder and housed in OFE copper
- Mylar **window** allowing low energy calibration
- Two Hamamatsu R12669SEL2 **photomultipliers** coupled to each crystal at Canfranc clean room
  - Low background and high Quantum Efficiency
  - Radioactivity screening at Canfranc

12.5 kg each 4.75” diameter 11.75” length

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
ANAIS is located inside a hut in hall B at Canfranc laboratory under 2450 m.w.e

Radon-free calibration system for simultaneous calibration using $^{109}$Cd sources

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
Data acquisition

• DAQ hardware and software designed and tested in previous ANAIS set-ups
  – Individual PMT signals digitized and fully processed
  – Trigger at phe level for each PMT signal
  – AND coincidence in 200 ns window
  – Redundant energy conversion by QDC
  – Trigger in OR mode among modules

• Muon detection system implemented to:
  – tag muon related events
  – monitor onsite muon flux

• Slow control operative:
  – Monitoring: external Rn, humidity, P, T
  – N₂ flux
  – PMT HV
  – Stability checks: gain
  – trigger rate

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
Detector response

- Excellent **duty cycle**

- Outstanding **light collection** measured in all modules at different set-ups: \(~15\text{ phe/keV}\)


A factor of 2 larger than the published light collection for DAMA/LIBRA detectors

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
• **Triggering** below 1 keV$_{ee}$: bulk $^{22}$Na and $^{40}$K events identified by coincidences with high energy gammas

\[ 0.9 \text{ keV} \quad 3.2 \text{ keV} \]

- Effective **filtering** protocols for PMT noise
  - Multiparametric cuts on:
    - Number of peaks in the pulse (n>2 in each PMT)
    - Temporal parameters of the pulse
    - Asymmetry in light sharing

A **blank module** will be set-up to monitor non NaI(Tl) scintillation events and build a “blank” population for the study of annual modulation systematics

C. Cuesta et al., EPJ C 74 (2014) 3150

Acceptance efficiency curves from external calibration data

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
Radiopurity and background

Detailed **background models** for first modules operated in Canfranc, based on Geant4 Monte Carlo simulation and accurate quantification of **background sources**

- **Internal activity** directly assessed (mainly $^{40}$K, $^{210}$Pb)
- **Cosmogenic activity** in crystals quantified from ANAIS-25 data
- **Activity from external components** measured with HPGe detectors at Canfranc


**D2:** simulated contributions vs data (89.5 d, data from 2015)

$^{40}$K and $^{22}$Na peaks and $^{210}$Pb (bulk+surface) and $^3$H continua are the most significant contributions in the very low energy region

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
Radiopurity and background

- Determination of potassium content in NaI(Tl) crystals

$^{40}$K: measured by identifying coincidences

C. Cuesta et al., Int. J. Mod. Phys. A. 29 (2014) 1443010

Estimate from last 30.1 days (June-July) in ANAIS-112

(statistical uncertainty ~10%)

<table>
<thead>
<tr>
<th>Detector</th>
<th>$^{40}$K (mBq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0</td>
<td>1.1</td>
</tr>
<tr>
<td>D1</td>
<td>1.4</td>
</tr>
<tr>
<td>D2</td>
<td>0.9</td>
</tr>
<tr>
<td>D3</td>
<td>0.7</td>
</tr>
<tr>
<td>D4</td>
<td>1.0</td>
</tr>
<tr>
<td>D5</td>
<td>1.0</td>
</tr>
<tr>
<td>D6</td>
<td>1.1</td>
</tr>
<tr>
<td>D7</td>
<td>1.0</td>
</tr>
<tr>
<td>D8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

DAMA/LIBRA crystals: ~20 ppb K = 0.6 mBq/kg $^{40}$K

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
Radiopurity and background

- Activity of $^{232}$Th, $^{238}$U determined by alpha rate following PSA and analysis of BiPo sequences at a level of a few μBq/kg, but $^{210}$Pb out of equilibrium.

The origin of $^{210}$Pb contamination has been under study in collaboration with Alpha Spectra.

<table>
<thead>
<tr>
<th>Module</th>
<th>Average alpha specific activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>D5</td>
<td>0.75 ± 0.01 mBq/kg</td>
</tr>
<tr>
<td>D6</td>
<td>0.76 ± 0.01 mBq/kg</td>
</tr>
<tr>
<td>D7</td>
<td>0.75 ± 0.01 mBq/kg</td>
</tr>
<tr>
<td>D8</td>
<td>0.72 ± 0.01 mBq/kg</td>
</tr>
</tbody>
</table>

Very similar alpha rate in the latest produced crystals, lower than in the previous ones.
Radiopurity and background

- Background at high energy from ANAIS-112 data

First 29.2 days (March-April)
Last 30.1 days (June-July)

Instability in last data being solved
Radiopurity and background

- **Background at low energy** from ANAIS-112 data
  (Filtered spectra but with no cut efficiency correction yet)

Cosmogenics still decaying for D4-D8

$^{210}\text{Pb}$ contribution at $\sim50$ keV region, consistent with the measured alpha specific activity

First 29.2 days (March-April)

Last 30.1 days (June-July)

Instability in last data being solved

S. Cebrián, TAUP2017, Sudbury, 25th July 2017
Radiopurity and background

- **Summary of crystal activity** (from last 30.1 days in ANAIS-112)

<table>
<thead>
<tr>
<th>Detector</th>
<th>$^{40}$K (mBq/kg)</th>
<th>$^{210}$Pb (mBq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0</td>
<td>1.1</td>
<td>3.15</td>
</tr>
<tr>
<td>D1</td>
<td>1.4</td>
<td>3.15</td>
</tr>
<tr>
<td>D2</td>
<td>0.9</td>
<td>0.70</td>
</tr>
<tr>
<td>D3</td>
<td>0.7</td>
<td>1.8</td>
</tr>
<tr>
<td>D4</td>
<td>1.0</td>
<td>1.8</td>
</tr>
<tr>
<td>D5</td>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>D6</td>
<td>1.1</td>
<td>0.76</td>
</tr>
<tr>
<td>D7</td>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>D8</td>
<td>0.6</td>
<td>0.72</td>
</tr>
<tr>
<td>average</td>
<td><strong>1.0</strong></td>
<td><strong>1.5</strong></td>
</tr>
</tbody>
</table>
**Sensitivity**

**Detection limit** at 90% C.L. for a critical limit at 90% C.L. for ANAIS-112

- Estimated **average background** from D0-D5 measured levels (corrected for cut efficiency)
- 2-6 keV_{ee} region
- 5 years

**ANAIS-112** can detect the annual modulation in the 3σ region compatible with the DAMA/LIBRA result

90% probability of detecting an annual modulation signal at 90% C.L.

S. Cebrián, TAUP2017, Sudbury, 25th July 2017

I. Coarasa et al, arXiv:1704.06861v1
Sensitivity

Detection limit at 90% C.L. for a critical limit at 90% C.L. for ANAIS-112

- Estimated average background from D0-D5 measured levels (corrected for cut efficiency)
- 2-6 keV$_{ee}$ region
- 5 years

Model-independent annual modulation

**Factor of Merit:** from the variance of the estimator of the modulated amplitude

$$FOM = \left( \frac{2 \cdot B}{\Delta E \cdot M \cdot T_M \cdot \varepsilon} \right)^{\frac{1}{2}}$$

**Detection Limit** for annual modulation amplitude:
for ANAIS-112 parameters

$$L_D = (8.40 \pm 0.25) \cdot 10^{-3} \text{ cpd/kg/keV}_{ee} \quad (90\% \text{ C.L.})$$

**ANAIS-112** has a detection limit for annual modulation lower than the measured amplitude by DAMA/LIBRA: $0.0112 \pm 0.0012$ cpd/kg/keV$_{ee}$

S. Cebrián, TAUP2017, Sudbury, 25$^{th}$ July 2017

I. Coarasa et al, arXiv:1704.06861v1
Summary and outlook

✓ **ANAIS detectors:** modules from Alpha Spectra characterized at Canfranc
  - Outstanding **light collection** of $\sim 15$ phe/keV and **triggering** at 1 keV$_{ee}$
  - **Background models** provide a good description of measured data at all energy ranges: crystal contamination is the dominant background source giving $^{210}$Pb, $^{40}$K, $^{22}$Na and maybe $^3$H the most relevant contributions
    - Acceptable **K content** reached
    - **$^{210}$Pb problem** addressed by means of dedicated tests with Alpha Spectra

✓ **ANAIS-112:** data taking using **112.5 kg (3x3 crystal matrix)** ongoing
  - Shielding, electronics, DAQ, slow control installed in the first months of 2017
  - Successful commissioning run to assess response and background of new modules
  - Analysis protocols ready following the experience from first modules
  - Data taking expected to go on in these conditions during the next two years
    - Control populations (muon-related events, blank module…) available
    - Blind annual modulation analysis foreseen
  - Plan to make ANAIS data public after use to allow independent analysis

The **ANAIS-112 dark matter run** underway at **Canfranc** with good prospects to test the DAMA/LIBRA modulation signal using same target and technique

S. Cebrián, TAUP2017, Sudbury, 25th July 2017