Dark Matter searches at Canfranc with NaI: The ANAIS experiment
Outline

• The Canfranc Underground Laboratory
• DM detection by Annual Modulation
• The ANAIS experiment
• R&D NaI for bolometric applications
The Canfranc Underground Laboratory

http://www.lsc-canfranc.es
The history of the LSC

... a laboratory of the UZ

Experiments:
COSME, IGEX, IGEX-DM, NAI-32, ROSEBUD, ANAIS...
Underground facilities

The new laboratory is run by a Consortium between the Spanish Ministerio de Economía y Competitividad, the Government of Aragon and the University of Zaragoza.

Hall B
15 x 10 m², h = 8 m

Hall A
40 x 15 m², h = 10 m

Hall C
HPGe farm

Service facilities: offices, workshop, clean room...
Experiments at LSC

• **ANAIS**
  (DM Annual Modulation with NaI)

• **ROSEBUD**
  (DM scintillating bolometers)

• **BiPo**
  (DBD, Super-NEMO prototype)

• **NEXT**
  (DBD, Enriched $^{136}$Xe TPC)

• **ArDM**
  (DM, Liquid Argon TPC)

• **SuperK-Gd**
  (Material screening for SuperK)

• **GEODYN**
  (Geodynamics observatory)
DM direct detection rate

**Dark halo**
\[ \rho_0 = 0.3 \text{ GeV/cm}^3 \]
\[ V_{\text{rms}} = 270 \text{ km/s} \]

**Earth** (8.5 kpc from galactic center)
DM flux: \(10^8 - 10^{10}\) wimps/m\(^2\) s\(^{-1}\)

**Expected rate:**
\[ \frac{dR}{dE_R} = \frac{\rho_0 M_{\text{det}}}{2 m_W m_{WN}^2} \int_{v_{\text{min}}}^{v_{\text{max}}} f(v) dv^3 \left( \sigma_{SI}^0 F_{SI}^2 + \sigma_{SD}^0 F_{SD}^2 \right) \]

**Standard approach:**
\( \chi \) Elastic scattering with nuclei

**Halo model**

**Spin Independent:**
\[ \sigma_{SI}^0 \propto \frac{m_{WN}^2}{m_{WN}^2} A^2 \sigma_{SI}^{\text{nucleon}} \]

**Spin Dependent:**
\[ \sigma_{SD}^0 \propto \frac{m_{WN}^2}{m_{WN}^2} \sigma_{SD}^{\text{nucleon}} \frac{4}{3} \frac{(J + 1)}{J} \frac{1}{a^2} \left( a_p \langle S_p \rangle + a_n \langle S_n \rangle \right)^2 \]

But also .... Inelastic scattering, Inelastic dark matter, interaction with e\(^-\) ...

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M. Martínez, Fundacion ARAID, Univ. de Zaragoza — Laboratori Nazionali del Gran Sasso, February 2013
Distinctive signal: annual modulation

The movement of the Earth around the Sun induces an annual modulation in the expected rate.

\[ S_k(t) = S_{0,k} + S_{m,k} \cos[\omega(t - t_0)] \]

✓ Cosine behaviour
✓ 1 year period
✓ Maximum around June 1st
✓ Weak effect (<7%)
✓ Only noticeable at low energy
✓ (For NaI, E<6 keVee)
Evidence (8.9 σ C.L.) of an annual modulation of the single-hit events in the (2–6) keV energy region satisfying all the requests of a DM component in the galactic halo
CoGeNT @ Soudan

PPC HPGe (p-type point contact high purity Ge detector)

Reported so far: 15 months of data collection

“Presently available data support the presence of a modulated component of unknown origin, with parameters prima facie compatible with a galactic halo composed of light-mass WIMPs” (2.8 σ C.L.)

Comparison between DAMA and CoGeNT results is model dependent

- PRD 84 (2011) 055014
- JCAP 1108 (2011) 008
- PRD 85 (2012) 043515
- arXiv:1106.6241
- arXiv:1302.0796
- ...

and also the comparison with other experiments with negative results (Xenon, CDMS..)

“Search for an Annual Modulation in a p-Type Point Contact Germanium Dark Matter Detector” PRL 107, 141301 (2011)
NaI Scintillators for DM search

↑ I -> $\sigma_{Si}$ ($\alpha A^2$) ↑

↑ Na -> sensitive to light WIMPS

↑ Sensitive to SD-proton interaction

$^{23}$Na (i.a. 100%): J=3/2 (unpaired proton)
$^{127}$I (i.a. 100%): J=5/2 (unpaired proton)

↑ High light yield (420 nm, well matched with PMTs)

↑ Particle discrimination by pulse shape analysis

↓ Low quenching factor NR/$\beta\gamma$ (Na ≈ 0.3, I ≈ 0.1)

↓ Hygroscopic character

↓ No particle discrimination ($\beta\gamma$/NR) at very low energy
The ANAIS experiment

Annual Modulation with NaI Scintillators


- Looking for DM annual modulation with 250 kg NaI(Tl) scintillators
- To be installed at the new Canfranc Underground Laboratory (start data-taking expected: end 2013)

Same target and technique as DAMA/LIBRA
The ANAIS Hut and the control room already constructed @ LSC Hall B
Mechanical isolation, polyethylene, archaeological and low activity lead required for the whole ANAIS shielding are ready for the mounting.

Active muon vetoes: plastic scintillators to cover maximally the ANAIS shielding
- 12 1000x500x50 mm (lateral faces)
- 4 750x700x50 mm (top face)
  (awaiting delivery)

Anti-Radon box recently mounted in LSC Hall B
(expandable to house the whole ANAIS shielding)
Several models have been considered so far. We have selected **Hamamatsu VLB** based on the radioactivity levels (measured at LSC by HPGe spectroscopy) and quantum efficiency.

<table>
<thead>
<tr>
<th></th>
<th>$^{40}\text{K}$ (mBq/PMT)</th>
<th>$^{232}\text{Th}$ (mBq/PMT)</th>
<th>$^{238}\text{U}$ (mBq/PMT)</th>
<th>$^{60}\text{Co}$ (mBq/PMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low background Electron Tubes Limited 9302B</td>
<td>$420 \pm 50$</td>
<td>$24 \pm 4$</td>
<td>$220 \pm 12$</td>
<td>-</td>
</tr>
<tr>
<td>Low background (LB) Hamamatsu R6233-100</td>
<td>$678 \pm 42$</td>
<td>$68 \pm 3$</td>
<td>$100 \pm 3$</td>
<td>-</td>
</tr>
</tbody>
</table>
| Ultra low background (ULB) Hamamatsu R11065SEL | $12 \pm 7$ | $3.6 \pm 1.2$ | $^{238}\text{U} - 47 \pm 28$
$^{226}\text{Ra} - 8.0 \pm 1.2$ | $4.1 \pm 0.7$ |
| Very low background (VLB) Hamamatsu R6596MOD | $97 \pm 19$ | $20 \pm 2$ | $^{238}\text{U} - 128 \pm 38$
$^{226}\text{Ra} - 84 \pm 3$ | - |

- $\uparrow$ Very low background level
- $\downarrow$ Relatively low Q.E.
- $\downarrow$ Very expensive
- $\downarrow$ radioactivity too high
- $\uparrow$ Q.E. > 33% @ 420 nm
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<td>-</td>
</tr>
<tr>
<td></td>
<td>↓ radioactivity too high</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

42 units of the **Hamamatsu R6956 MOD SEL** model have been purchased.

**VLB PMT**

- OFHC copper housing
- Voltage divider (with Teflon support)
Electronic chain

- 20 detectors x 2 PMTS = 40 channels
- (almost) fully commissioned.
Electronic chain

- 20 detectors x 2 PMTS = 40 channels
- (almost) fully commissioned.

- **Module trigger**: AND of two CFD at phe-level (coincidence window: 200 ns in the test phase, it will be fine tuned for ANAIS)

- **General trigger**: OR of 20 modules
Electronic chain

- 20 detectors x 2 PMTS = 40 channels
- (almost) fully commissioned.

- Module trigger: AND of two CFD at phe-level (coincidence window: 200 ns in the test phase, it will be fine tuned for ANAIS)
- General trigger: OR of 20 modules
- Energy: QDC in 2 (3) dynamic ranges: LE, HE (VHE)
Electronic chain

- 20 detectors x 2 PMTS = 40 channels
- (almost) fully commissioned.

Good low energy estimator: 
Sum(area of the peaks)

- **Module trigger:** AND of two CFD at phe-level (coincidence window: 200 ns in the test phase, it will be fine tuned for ANAIS)
- **General trigger:** OR of 20 modules
- **Energy:** QDC in 2 (3) dynamic ranges: LE, HE (VHE)
- **Pulse sampling:** the two PMT signals are digitalized independently by a CAEN V1729 (chip Matacq) @ 2 GS/s, 12 bit vertical resolution, 1.25 µs window
- **Dead time:** 2.1 ms/event

M. Martínez, Fundacion ARAID, Univ. de Zaragoza – Laboratori Nazionali del Gran Sasso, February 2013
Acquisition & analysis software and Slow control system

- Linux 3.0.0, multithread, root integrated
- Raid5 (2.7 TB) with replication system (rsync)
- Monitor system with alerts via e-mail/sms
- Slow control system monitoring:
  - Temperature (Hut/electronics/Hall B)
  - N₂ flux
  - HV supply
  - Radon concentration @ Hall B
  - Baseline noise
  - Muon rate
  - ...
ANAIS-0 @ LSC

- A 9.6 kg NaI(Tl) (St Gobain) Crystal
- Encapsulated at UZ with ETP copper
- @ LSC from Sep 2011 to Dec 2012

25.4 x 10.2 x 10.2 cm³ NaI(Tl) crystal

(removable) light guides

PMTs (several models tested)

Goals:
- Test ANAIS DAQ (electronic chain & software)
- PMT/guides test
- Fine tuning analysis algorithms
- Background model

Shielding:
- 10 cm roman lead + 20 cm low activity lead.
- 3 active vetoes anti-muons.
- Anti-radon box, adaptable to the complete ANAIS experiment.
ANAIS-0: light collection in different configurations

10 cm length light guides worsen ~30% resolution and light collection

<table>
<thead>
<tr>
<th>Set-up</th>
<th>PTM</th>
<th>Light guides</th>
<th>Resolution (%)</th>
<th>Phe/keV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.4 keV</td>
<td>122.1 keV</td>
</tr>
<tr>
<td>1</td>
<td>ET LB</td>
<td>No</td>
<td>17.6</td>
<td>7.8</td>
</tr>
<tr>
<td>2</td>
<td>Ham LB</td>
<td>Yes</td>
<td>22.3</td>
<td>6.6</td>
</tr>
<tr>
<td>3</td>
<td>Ham ULB</td>
<td>Yes</td>
<td>17.6</td>
<td>7.2</td>
</tr>
<tr>
<td>4</td>
<td>Ham ULB</td>
<td>No</td>
<td>14.4</td>
<td>6.3</td>
</tr>
<tr>
<td>5</td>
<td>Ham VLB</td>
<td>No</td>
<td>15.2</td>
<td>5.9</td>
</tr>
</tbody>
</table>
ANAIS-0 $^{40}$K internal contamination

$^{40}$K : especially harmful at low energy

$^{40}$K ($T_{1/2} = 1.3 \times 10^9$ years)

- $\beta^-$ (89.28%)
  $Q = 1312.1$ keV
  89.28% ($Q_\beta=1312.1$ keV)

- C.E. (10.72%)
  $Q = 1504.8$ keV
  10.67%

- $\gamma$ 1460.8 keV (10.62%)

$^{40}$Ca

$^{40}$Ar

$^{40}$K bulk activity in ANAIS-0:
$$12.7 \pm 0.5 \text{ mBq/kg}$$
ANAIS-0 Event selection

Reject events based on:

- Periods of high rate (after calibrations)
- Cut 0.5 s after a muon (high energy event) in crystal
- **Muon veto to coincidence**
Reject events based on:

- Periods of high rate (after calibrations)
- Cut 0.5 s after a muon (high energy event) in crystal
- Muon veto to coincidence
- **Number of photoelectrons**
  
PMT1< 3 && PMT2<3
ANAIS-0 Event selection

Reject events based on:

- Periods of high rate (after calibrations)
- Cut 0.5 s after a muon (high energy event) in crystal
- Muon veto to coincidence
- Number of photoelectrons

\[ P1s = \frac{area1(100 - 600 \text{ ns}) + area2(100 - 600 \text{ ns})}{area1(0 - 600 \text{ ns}) + area2(0 - 600 \text{ ns})} \]

Rejection of non bulk events: surface events or scintillation of other materials
All the materials used in ANAIS-0 have been screened with a HP-Ge. Apart from the PMTs, only upper limits (95% CL) have been found:

<table>
<thead>
<tr>
<th>Simulated component</th>
<th>Isotope</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper encapsulation</td>
<td>$^{40}$K</td>
<td>&lt; 11 mBq</td>
</tr>
<tr>
<td></td>
<td>$^{232}$Th</td>
<td>&lt; 4.1 mBq</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>&lt; 140 mBq</td>
</tr>
<tr>
<td></td>
<td>$^{226}$Ra</td>
<td>&lt; 2 mBq</td>
</tr>
<tr>
<td></td>
<td>$^{60}$Co</td>
<td>&lt; 0.94 mBq</td>
</tr>
<tr>
<td>Quartz optical window</td>
<td>$^{40}$K</td>
<td>&lt; 12 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{232}$Th</td>
<td>&lt; 2.2 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>&lt; 100 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{226}$Ra</td>
<td>&lt; 1.9 mBq/kg</td>
</tr>
<tr>
<td>Light guides</td>
<td>$^{40}$K</td>
<td>&lt; 21 mBq/guide</td>
</tr>
<tr>
<td></td>
<td>$^{232}$Th</td>
<td>&lt; 4.1 mBq/guide</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>&lt; 120 mBq/guide</td>
</tr>
<tr>
<td></td>
<td>$^{226}$Ra</td>
<td>&lt; 4.7 mBq/guide</td>
</tr>
<tr>
<td>Optical coupling grease</td>
<td>$^{40}$K</td>
<td>&lt; 200 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{232}$Th</td>
<td>&lt; 200 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>&lt; 2000 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{226}$Ra</td>
<td>&lt; 30 mBq/kg</td>
</tr>
<tr>
<td>Archaeological Lead</td>
<td>$^{210}$Pb</td>
<td>&lt; 20 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{232}$Th</td>
<td>&lt; 0.3 mBq/kg</td>
</tr>
<tr>
<td></td>
<td>$^{238}$U</td>
<td>&lt; 0.2 mBq/kg</td>
</tr>
</tbody>
</table>
+ reflectant, mylar, glue, teflon…

![Graph showing contribution to background (Geant4 simulation)](image)

<table>
<thead>
<tr>
<th>Set-up</th>
<th>PMT used</th>
<th>Light guides used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ET LB</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Ham LB</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Ham ULB</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Ham ULB</td>
<td>No</td>
</tr>
</tbody>
</table>
ANAIS-0 Background model

Crystal internal contamination determined by several methods:

- $^{232}$Th and $^{238}$U chains:
  - PSA $\alpha / \beta_\gamma$ discrimination:
  - Identification of Bi-Po sequences

<table>
<thead>
<tr>
<th>Isotope</th>
<th>bulk activity (mBq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}$K</td>
<td>$12.7 \pm 0.5$</td>
</tr>
<tr>
<td>$^{238}$U / $^{234}$U</td>
<td>$0.075 \pm 0.005$</td>
</tr>
<tr>
<td>$^{230}$Th</td>
<td>$0.023 \pm 0.007$</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>$0.098 \pm 0.004$</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>$0.188 \pm 0.005$</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>$0.013 \pm 0.005$</td>
</tr>
<tr>
<td>$^{228}$Th</td>
<td>$0.035 \pm 0.003$</td>
</tr>
</tbody>
</table>
ANAIS-0 Background model

MC simulation of known background components
• PMT and adjacent materials contamination (measured by HPGe)
• internal crystal contamination (estimated by alpha discrimination, Bi-Po events identification and coincidence measurement)
plus some plausible hypotheses ($^{210}$Pb surface contamination in NaI and copper, cosmogenic $^3$H and $^{129}$I in NaI)
successfully explain the measured background:

High energy:

Low energy:

“Background model for a NaI (Tl) detector devoted to dark matter searches” Astrop. Phys. 37 (2012) 60
NaI(Tl) Powder selection

- Goal: <20 ppb of $^{\text{nat}}$K (0.6 mBq/kg)
- Contacts with several scintillator suppliers
- Powder selection based on HPGe measurements at LSC

<table>
<thead>
<tr>
<th></th>
<th>K (ppb)</th>
<th>U (ppb)</th>
<th>Th (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 90</td>
<td>&lt; 0.055</td>
<td>&lt; 0.13</td>
</tr>
</tbody>
</table>

assuming equilibrium in U and Th chains

- Next step: Measure K content by coincidence between two crystals grown with the selected powder

$^{40}$K $\rightarrow^{40}$Ar

1460.9 keV

3.2 keV
NaI(Tl) Crystals encapsulation

12.5 kg NaI(Tl) prototypes:
- 4.75” φ x 11.75” length cylindrical shape
- OFHC copper encapsulation
- Teflon diffusor
- Mylar window for low energy calibration
- Two optical windows

- Two first prototypes arrived to LSC in December 2012 for a low background measurement

- The PMT have been coupled at LSC by the ANAIS team:

  ➔ First step: PMTs directly coupled to the optical window (no light guide)
ANAIS-25 prototypes @ LSC

From December 2012

Shielding:
• 10 cm roman lead
• 20 cm low activity lead
• 3 active vetoes anti-muons.
• Anti-radon box

At least 3 months of data taken will be needed to estimate the $^{40}\text{K}$ bulk content
ANAIS-25 Low energy calibration

A Mylar window for low energy calibration with external sources

Surface effects in 6.4 keV peak

+ other sources ($^{55}$Fe, $^{137}$Cs, $^{133}$Ba)

$^{57}$Co calibration

$^{109}$Cd calibration

Counts

Energy (keV)

Counts

Energy (keV)
## ANAIS-25 prototypes: Resolution

![Graph showing FWHM^2 vs Energy for different prototypes](image)

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Res_{FWHM} (%)</th>
<th>ULB PMTs</th>
<th>VLB PMTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>43.5</td>
<td>43.9</td>
<td></td>
</tr>
<tr>
<td>14.4</td>
<td>24.0</td>
<td>23.5</td>
<td></td>
</tr>
<tr>
<td>22.1</td>
<td>22.6</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>30.8</td>
<td>19.0</td>
<td>20.4</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>11.5</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>11.5</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>122.1</td>
<td>9.6</td>
<td>9.2</td>
<td></td>
</tr>
</tbody>
</table>
ANAIS-25 prototypes: Light collection

Number of phe^-/keV (no light guides)

<table>
<thead>
<tr>
<th>Nphe^-/keV</th>
<th>ANAIS-0 Ham VLB</th>
<th>ANAIS-25 Ham VLB</th>
<th>ANAIS-25 Ham ULB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Via 1</td>
<td>3.66 ± 0.02</td>
<td>7.77 ± 0.04</td>
<td>5.82 ± 0.08</td>
</tr>
<tr>
<td>Via 2</td>
<td>3.71 ± 0.07</td>
<td>8.36 ± 0.66</td>
<td>6.76 ± 0.1</td>
</tr>
<tr>
<td>Total</td>
<td>7.38 ± 0.07</td>
<td>16.13 ± 0.66</td>
<td>12.58 ± 0.13</td>
</tr>
</tbody>
</table>

With 10 cm length light guides we expect a decrease in light collection of ~30%
(final decision will depend on background measurements)

Examples of 4.7 keV pulses (selected by coincidence with $^{121}$Te 573 keV $\gamma$ in the other crystal)

<table>
<thead>
<tr>
<th>Ham VLB</th>
<th>Ham ULB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (eV)</td>
<td>Voltage (eV)</td>
</tr>
<tr>
<td>Time (ns)</td>
<td>Time (ns)</td>
</tr>
<tr>
<td>D05</td>
<td>D05</td>
</tr>
<tr>
<td>D06</td>
<td>D06</td>
</tr>
</tbody>
</table>
## ANAIS-25 prototypes: Cosmogenic activation

We started measuring underground very fast after the arrival of the prototypes → valuable information on cosmogenic activation

<table>
<thead>
<tr>
<th>Production in</th>
<th>Isotope</th>
<th>Half life</th>
<th>Decay mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{127}I$</td>
<td>$^{126}I$</td>
<td>13.11 d</td>
<td>CE, b-</td>
</tr>
<tr>
<td></td>
<td>$^{125}I$</td>
<td>59.4 d</td>
<td>CE</td>
</tr>
<tr>
<td></td>
<td>$^{124}I$</td>
<td>4.18 d</td>
<td>CE, b+</td>
</tr>
<tr>
<td></td>
<td>$^{121m}Te$</td>
<td>154 d</td>
<td>IT, CE</td>
</tr>
<tr>
<td></td>
<td>$^{121}Te$</td>
<td>16.8 d</td>
<td>CE</td>
</tr>
<tr>
<td></td>
<td>$^{123m}Te$</td>
<td>119.7 d</td>
<td>IT</td>
</tr>
<tr>
<td></td>
<td>$^{123}Te$</td>
<td>$&gt;10^{19}$ y</td>
<td>CE</td>
</tr>
<tr>
<td></td>
<td>$^{125m}Te$</td>
<td>57.4 d</td>
<td>IT</td>
</tr>
<tr>
<td></td>
<td>$^{127m}Te$</td>
<td>109 d</td>
<td>IT, b-</td>
</tr>
<tr>
<td></td>
<td>$^{127}Te$</td>
<td>9.35 h</td>
<td>b-</td>
</tr>
<tr>
<td>$^{23}Na$</td>
<td>$^{22}Na$</td>
<td>949.7 d</td>
<td>CE, b+</td>
</tr>
</tbody>
</table>
ANAIS-25 prototypes: Cosmogenic activation

Differential background:
First week (04/12/12 – 12/12/12)
minus last week (31/01/13 – 06/02/13)

- We are still working in the adaptation of the event selection algorithms
- Some cosmogenic isotopes have been identified so far. The lines are decreasing as expected.
ANAIS Schedule

- **Radiopurity measurements of NaI samples**
- **Simulation of the whole ANAIS**
- **Bkg meas of two 12.5 kg prototypes**
- **Growing crystals**
- **Building ANAIS at LSC**

**2011**
- April: Commissioning ANAIS shielding and electronics
- May: Growing & encapsulating prototypes
- June: Definition of growing, encapsulation & crystal testing protocols

**2012**
- April: Simulation of ANAIS-0 background and comparison with measurements
- May: ANAIS0_2 module stable data taking
- June: Radiopurity measurements of NaI samples

**2013**
- March: Testing Ham PMTs in ANAIS-0
- April: Monitoring environmental parameters (Rn air content, T, HV stability, etc)
- May: DAQ hardware and software testing and fine tuning
R&D: NaI for bolometric applications

Motivation: Same target, but: \( \text{NR}/\gamma \) discrimination
\[ Q_{\text{NR}/\gamma} \approx 1 \]

In collaboration with the Advanced Detectors Group (ADG) of the Lisbon University and the Institute d’Astrophysique Spatial (IAS), Orsay (France)
The bolometric technique

The energy deposition is measured as a temperature increment:

$$\Delta T = \frac{E}{C}$$

Ultimate energy resolution: internal energy statistical fluctuation

$$\Delta U_{rms} = \sqrt{K_B T^2 C}$$

Very good energy resolution
Scintillating bolometers

Reflecting cavity (Cu + Ag coat)

Scintillating crystal (absorber)

Thermometer

Optical bolometer Ge disk (~ 25 µm thick)

241Am α source

55Fe source

The energy deposition is measured as a temperature increment

\[ \Delta T = \frac{E}{C} \]

Ultimate energy resolution: internal energy statistical fluctuation

\[ \Delta U_{rms} = \sqrt{K_B T^2 C} \]

Very good energy resolution

The light yield depends on the ionizing power of the incident particle

Particle discrimination by the ratio HEAT/LIGHT

Target \( \text{SrF}_2 \)

M. Martínez, Fundacion ARAID, Univ. de Zaragoza – Laboratori Nazionali del Gran Sasso, February 2013
**Nal for bolometric applications**

Scintillating bolometers are excellent detectors for dark matter (and other rare event) searches:

- Very good energy resolution
- Low energy threshold achievable
- Quenching factor close to 1
- Particle discrimination ($\gamma/\alpha$ and $\gamma/NR$) down to several keV (or several tens of keV)
- Wide target choice

Nal is a very interesting DM target!, but....

- Relatively high specific heat ($\theta_{\text{Debye}}=164$ K)
- Large coefficient of thermal expansion (1% between 300 K and 4 K)
- High hygroscopicity

A possible solution:

Coat the Nal crystal with an appropriate material acting as humidity barrier
Parylene coating

The coating material has to be:

- Transparent in the $\lambda$ of NaI emission
- Resistant to thermal cycles
- Radiopure
- Low heat capacity ($\rightarrow$ very thin films!)
- ...

A possibility: **PARYLENE**

![Parylene C](image)

**Parylene C**

Good humidity barrier!

It can be deposited in very thin films by vapor-phase condensation polymerization
Parylene transmission in NaI emission bands

Adapted from Jeong et al., Synthetic Metals 127 (2002) 189

Fig. 9—Emission spectra of NaI ("pure") excited by Cm\(^{248}\) alpha

Fig. 5—Emission spectra of NaI(Tl) excited by Cm\(^{248}\) alpha particles.

### Parylene radiopurity

**HPGe measurement at LSC on dimer (dichloro-p-cylophane) samples**

<table>
<thead>
<tr>
<th>Activity (mBq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{232}$Th</td>
</tr>
<tr>
<td>26 ± 8</td>
</tr>
</tbody>
</table>

**0.05 counts/cm²/μm/year**

**very low contribution to the background for thin parylene layers**

**UPPER LIMITS AT 90% C.L.**

M. Martínez, Fundacion ARAID, Univ. de Zaragoza  – Laboratori Nazionali del Gran Sasso, February 2013
Parylene-coated NaI(Tl) Low temperature X-ray scintillation

Excitation: X-ray source (40 kV)

Sample inside Ag-coated cavity

- Light output vs Temperature (Si photodiode)

- Light output vs wavelength (fiber spectrometer)

Measurements done at IAS (Orsay)

4He cryostat

Optical fiber (to the optical detector)
Parylene resistance to thermal cycles

Light output measurement before and after the thermal cycle

- Cooling down to 100 K (with a N\textsubscript{2} bath)

  ![Graph](image1)

  Nal(Tl)

  7.5% decrease

- Cooling down to 80 mK (with a dilution unit)
  (Mounting time one week)

  ![Graph](image2)

  Nal pure

  35% decrease

Light detector: PMT faced to the crystal

Excitation: \textsuperscript{137}Cs

Before cooling

After cooling

Loss of adherence in certain areas

M. Martínez, Fundacion ARAID, Univ. de Zaragoza – Laboratori Nazionali del Gran Sasso, February 2013
Parylene resistance to RH

In any case, 2-5 µm parylene allow some days handling but it is not a permanent coating

If the crystals are not kept in dry atmosphere, after one month...

We have not succeeded yet in doing a bolometric measurement with parylene-coated NaI

In parallel we are studying other coating materials
The Canfranc Underground laboratory hosts a multidisciplinary scientific program, with focus on rare events physics. The approved experiments are being installed in the new facilities.

ANAIS is a UZ project that will look for dark matter annual modulation with 250 kg of NaI(Tl) at LSC

- PMTs, shielding, electronics and software are (almost) ready.
- Two 12.5 kg NaI(Tl) prototypes have been constructed with selected NaI(Tl) powder ($^{\text{nat}}$K < 90 ppb at 95% C.L.) and radiopurity is being checked underground. The good light collection allow us to expect an energy threshold below 2 keV. If background requirements are fulfilled, the 250 kg production will start.

R&D is in progress to study coated NaI and NaI(Tl) crystals at low temperature for bolometric applications. Test of light output and resistance to thermal cycles of parylene-coated NaI samples have been performed. The results are not completely satisfactory and other coating materials are being studied.
Grazie!