Results from the DM-Ice17

Reina Maruyama, Yale University
on behalf of the DM-Ice collaboration

UCLA Dark Matter 2016
February 19, 2016
DM-Ice17

Location: South Pole, Antarctica
Depth: 2457 m (2200 m.w.e)
Deployment: Dec. 2010
Uptime: > 99%
Exposure: 60.8 kg-yr
Target: NaI(Tl)
Mass: 2 x 8.5 kg

Still going…
DM-Ice-17 Detector

- 36 cm (14”)
- 1.0 m

Components:
- NAIAD NaI Crystal (5”x5”, 8.5 kg)
- Quartz light guides
- 2 IceCube mainboards + HV control boards
- PMTs: 5” ETL 9390UKB
- Stainless Steel Pressure Vessel
- PTFE light reflectors
- IceCube DOM 59
- IceCube DOM 60
- 7 m
Background Model

- PSD to separate γ’s from α’s
- Simulation based on radio assay + internal alphas
- Largest contributions: U/Th/K in crystal & PMTs at <100 keV
- Negligible contribution from the ice

*Phys. Rev. D 90, 092005 (2014)*
DM-Ice17 at Low Energies

< 5 keV: background dominated by:
- $^{40}$K & $^{210}$Pb in NaI(Tl)
- PMTs
- surface $^{210}$Pb & Light guides

<table>
<thead>
<tr>
<th></th>
<th>DM-Ice17</th>
<th>DAMA*</th>
</tr>
</thead>
<tbody>
<tr>
<td>nat$^{40}$K</td>
<td>550 ppb</td>
<td>&lt; 20 ppb</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>55 ppt</td>
<td>0.7 - 10 ppt</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>33 ppt</td>
<td>0.5 - 7.5 ppt</td>
</tr>
</tbody>
</table>

* NIMA 592 (2008) 297–315

Noise & Signal

“thin”

“EMI”

Signal: < 100 keV

Signal: > 100 keV Energy

Cosmogenic $^{125}$I (in the NaI crystal)

Cosmogenic lines verify our energy calibration; this is particularly useful for the prototype since we do not have an in-ice source.

W. Pettus
DM-Ice17 Muon Events

**Muon Flux**

2.93 ± 0.04 muons/crystal/day, 12.3 ± 1.7% modulation amplitude

**IceCube Coincidence**

- 93% of DM-Ice Det-1 muons are coincident with IceCube events
- DM-Ice location information lowers misreconstruction rates and improves location reconstruction through IceCube
  - Little impact on astrophysical parameters

A. Hubbard
Muon-Induced Phosphorescence

• Large energy depositions in NaI(Tl) induce long-lived phosphorescent decay
• Muon energy deposition followed by sharp increase in photon rate
  ➔ low energy pulses with 5.5 s decay time
• Too few muons & not enough photons to look like signal > 1 keV

5.5 ± 0.5 s decay time

Largest events induce tens of millions of photons

A. Hubbard
Annual Modulation Allowed Regions

- Comparing sinusoidal modulation to background subtracted event rates
- Maximum likelihood fits for DAMA & DM-Ice17
- Period / Phase fixed to 1 year / 152.5 days
- Float amplitude

![Graph showing Annual Modulation Allowed Regions](image)

DM-Ice17 4-6 keVee (BF, 68%, 95%, 99%)

Expected dark matter phase

~Oct. 1
~Apr. 1
~Jul. 1

DAMA/LIBRA, 2-4 keVee (99%)
analysis on data from arXiv:1308.5109

Analysis threshold of 4 keV
No modulation observed (bgd limited)
Strongest constraint for WIMP from the Southern Hemisphere

Z. Pierpoint
Event Rates in the Region of Interest

Analysis threshold

40K in crystal

Cut efficiency corrected

Surface 210Pb

Signal acceptance

Data after cuts

PMT, PV etc.

All simulation

WIMP Mass (GeV)

SI WIMP-nucleon cross section (cm⁻²)

DAMA 5σ C.L. Allowed Region

DM-Ice17 90% C.L. Exclusion Limit

Median 90% C.L. Exclusion for Future NaI(Tl) Experiment

Z. Pierpoint
Global NaI(Tl) Collaborative Effort

**ANAIS** + **DM-Ice** + **KIMS**

- 113 kg array
- 55 kg at Yangyang
- 52 kg at Yangyang

- 220 kg combined
- Start data taking by June 2016
- Two years data to test DAMA
Global NaI(Tl) Collaborative Effort

**ANAIS** + **DM-Ice** + **KIMS**

- **113 kg array** at Canfranc
- **55 kg** at Yangyang
- **52 kg** at Yangyang

### Crystal Specifications

<table>
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<tr>
<th>Crystal</th>
<th>natK (40K) (ppb)</th>
<th>238U (ppb)*</th>
<th>232Th (ppb)</th>
<th>α rate (mBq/kg)</th>
<th>Light Yield (pe/keV)</th>
</tr>
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<tbody>
<tr>
<td>NaI-001</td>
<td>40.4 ± 2.9</td>
<td>&lt; 0.02</td>
<td>&lt; 3.2</td>
<td>3.29 ± 0.01</td>
<td>15.6 ± 1.4</td>
</tr>
<tr>
<td>NaI-002</td>
<td>48.1 ± 2.3</td>
<td>&lt; 0.12</td>
<td>0.5 ± 0.3</td>
<td>1.77 ± 0.01</td>
<td>15.5 ± 1.4</td>
</tr>
<tr>
<td>NaI-003</td>
<td>25.3 ± 3.6</td>
<td>&lt; 0.14</td>
<td>0.5 ± 0.1</td>
<td>2.43 ± 0.01</td>
<td>13.3 ± 1.3</td>
</tr>
<tr>
<td>NaI-004</td>
<td>&gt; 116.7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>3.9 ± 0.4</td>
</tr>
<tr>
<td>NaI-005*</td>
<td>40.1 ± 4.2</td>
<td>&lt; 0.04</td>
<td>0.2 ± 0.1</td>
<td>0.48 ± 0.01</td>
<td>12.1 ± 1.1</td>
</tr>
<tr>
<td>NaI-006</td>
<td>&gt; 127.1</td>
<td>&lt; 0.05</td>
<td>8.9 ± 0.1</td>
<td>1.53 ± 0.01</td>
<td>4.4 ± 0.4</td>
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<td>&lt; 20</td>
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* assumes equilibrium

- 2–3 times DAMA’s background w/o 40K and other veto
- bgd dominated by 210Pb
- Start summer 2016
- ~107 kg at Y2L
- 113 kg ANAIS
- Expect results with ~ 2yrs data
- continue R&D to lower background

**KIMS, arXiv:1510.04519**
Yangyang Underground Laboratory

(Korea Middleland Power Co.)
Yangyang Pumped Storage Power Plant

Minimum depth: 700 m
Access to the lab by car (~2km)
NaI Shield Construction

- Outer skeleton (1/4/2016)
- Cu Box
- Acrylic Box
- 20cm Lead (top)
  - only 10cm installed currently
- 20cm Lead (left side)
- slide-in
- source window
- 20cm Lead (bottom)
- 20cm Lead (front)
Many people working hard
Summary

DM-Ice17:
- First Southern Hemisphere search for dark matter annual modulation with NaI(Tl)
- demonstrates South Pole as viable underground location
- Phosphorescence does not seem to account for DAMA’s signal
- Potential IceCube upgrades would enable DM-Ice250 at South Pole

Next:
- $^{40}$K in NaI(Tl) reduced by factor of 20, R&D continues
- KIMS/DM-Ice run to start at Yangyang this summer w/ 100 kg
- Results will be combined with ANAIS
- Stay tuned!
DM-Ice Collaboration

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