Status of the COSINE-100

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On behalf of the COSINE-100 collaboration
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Sejong University, Seoul, Korea
The COSINE collaboration

Joint collaboration between KIMS and DM-Ice to search for dark matter interactions in NaI(Tl) scintillating crystals.

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14 institutes, ~50 members
The relative velocity between DM particles in galactic halo and detectors varies over the year.

Approximately sinusoidal modulation for the recoil rate of DM at keVee energies.

Peaks at early June.

Modulation observed by DAMA/LIBRA

Motivation: The DAMA annual modulation signal, to be confirmed with independent measurements by the same NaI(Tl) target material
COSINE-100 experiment

Located at Yangyang underground laboratory (Y2L), South Korea, with ~700 m rock overburden.

Yangyang Pumped Storage Power Plant

1000 m

700 m

IBS, Daejeon

Seoul

Y2L

~3 hours

~4 hours

Google.com
COSINE-100 operation
Plastics scintillators

Purpose: To tag cosmic ray muon events

- 37 panels of plastic scintillator (EJ-200), 3cm thick
- Wrapped with diffuse reflector and attached with light guides to 2" PMTs.

Muon rate

H. Prihiitiadi et al 2018 JINST 13 T02007
Crystal-LS Coincidence Events

Liquid scintillator Energy spectrum

Vetoed events in Crystal2

Data (vetoed)
Fitting
Subtracted $^{40}$K

$\gamma$ (1460 keV)

$^{40}$K

Vetoed events in Crystal2 ~70% of $^{40}$K tag by LS

Preliminary
Low energy noise

The multi-variate analysis:

Boosted decision tree (BDT) techniques are applied to separate noise from the beta/gamma events.

Average waveforms

Signal efficiency

~70% Efficiency at 2 keV

Status of the COSINE-100 – P. Adhikari
Average count rate at 2-6 keV is “3.5 counts/day/kg/keV”
Crystal bkg. generally follows Powder bkg.
Background Assessment

4 Channel (low energy, high energy, single hit, multiple hit) simultaneous fitting

2-6 keV region not used in fitting

WIMP Search data

59.5 days of Data

8 single-hit spectra are fit simultaneously with an assumed SHM (Standard Halo Model) WIMP signal as described in C. Savage et al., JCAP 04, 39 (2009).

Crystal-6 fitting results

Status of the COSINE-100 – P. Adhikari
COSINE-100 excludes DAMA/LIBRA-phase1’s signal as spin independent WIMP with Standard Halo Model in NaI(Tl)

Consistent with null results from other direct detection experiments with different target materials
Annual modulation analysis: Preliminary, Blinded

400 days of data

Crystals 1, 5, and 8 are excluded in this analysis due to excessive PMT noise and low light yield.

9% of data

Crystals Averaged Rate, 2-6 keV

\[
\begin{array}{|c|c|}
\hline
\chi^2 / \text{ndf} & 19.25 / 26 \\
\text{Prob} & 0.8257 \\
\text{amp} & -0.001736 \pm 0.02848 \\
\text{period} & 365.2 \pm 0 \\
\text{phase} & 152.5 \pm 0 \\
\hline
\end{array}
\]

Unblinding soon. Stay tuned!
Other searches

Solar Axion

Inelastic boosted dark matter

SuperWIMP

Status of the COSINE-100 – P. Adhikari
Growing low radioactive NaI(Tl) Crystals at CUP

Light Yield: ~ 10.4 p.e./keV, K-40: ~100 ppb

Saturated alpha rate 3.52 ± 0.26 mBq/kg

Status of the COSINE-100 – P. Adhikari
The COSINE-100 experiment was installed at Y2L and runs smoothly for about two years.

COSINE-100 confirms that DAMA’s modulation signal cannot be from standard WIMP & SHM with NaI(Tl).

Modulation analysis is on-going.

Much progress made in developing the capabilities to grow and encapsulate radio-pure NaI(Tl) crystals at IBS-CUP

Analysis with lower threshold is underway
BACKUP
8 crystals with total mass of ~106 kg

Preliminary background values estimated both at R&D and COSINE setup

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Mass (kg)</th>
<th>Size (inches diameter×length)</th>
<th>Powder</th>
<th>$\alpha$ Rate (mBq/kg)</th>
<th>$^{40}$K (ppb)</th>
<th>$^{238}$U (ppt)</th>
<th>$^{232}$Th (ppt)</th>
<th>Light Yield (PEs/keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal-1</td>
<td>8.3</td>
<td>5.0 × 7.0</td>
<td>AS-B</td>
<td>3.20 ± 0.08</td>
<td>34.7 ± 4.7</td>
<td>&lt;0.02</td>
<td>1.3 ± 0.4</td>
<td>14.9 ± 1.5</td>
</tr>
<tr>
<td>Crystal-2</td>
<td>9.2</td>
<td>4.2 × 11.0</td>
<td>AS-C</td>
<td>2.06 ± 0.06</td>
<td>60.6 ± 4.7</td>
<td>&lt;0.12</td>
<td>&lt;0.6</td>
<td>14.6 ± 1.5</td>
</tr>
<tr>
<td>Crystal-3</td>
<td>9.2</td>
<td>4.2 × 11.0</td>
<td>AS-WSII</td>
<td>0.76 ± 0.02</td>
<td>34.3 ± 3.1</td>
<td>&lt;0.04</td>
<td>0.4 ± 0.2</td>
<td>15.5 ± 1.6</td>
</tr>
<tr>
<td>Crystal-4</td>
<td>18.0</td>
<td>5.0 × 15.3</td>
<td>AS-WSII</td>
<td>0.74 ± 0.02</td>
<td>33.3 ± 3.5</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
<td>14.9 ± 1.5</td>
</tr>
<tr>
<td>Crystal-5</td>
<td>18.3</td>
<td>5.0 × 15.5</td>
<td>AS-C</td>
<td>2.06 ± 0.05</td>
<td>82.3 ± 5.5</td>
<td>2.4 ± 0.3</td>
<td>7.3 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>Crystal-6</td>
<td>12.5</td>
<td>4.8 × 11.8</td>
<td>AS-WSIII</td>
<td>1.52 ± 0.04</td>
<td>16.8 ± 2.5</td>
<td>&lt;0.02</td>
<td>0.6 ± 0.2</td>
<td>14.6 ± 1.5</td>
</tr>
<tr>
<td>Crystal-7</td>
<td>12.5</td>
<td>4.8 × 11.8</td>
<td>AS-WSIII</td>
<td>1.54 ± 0.04</td>
<td>18.7 ± 2.8</td>
<td>&lt;0.6</td>
<td>&lt;0.6</td>
<td>14.0 ± 1.4</td>
</tr>
<tr>
<td>Crystal-8</td>
<td>18.3</td>
<td>5.0 × 15.5</td>
<td>AS-C</td>
<td>2.05 ± 0.05</td>
<td>54.3 ± 3.8</td>
<td>&lt;1.4</td>
<td>3.5 ± 0.3</td>
<td></td>
</tr>
</tbody>
</table>

DAMA

< 0.5     < 20  0.7−10  0.5−7.5  5.5−7.5
Event rate

Crystal trigger rates versus time (in hours) for the first physics run (48 days).

All of the crystals show stable behavior throughout this running period and the rest of data-taking.
Low energy region (Region of interest)

~3.5 counts/day/keV/kg in the (2-6) keV energy

Dominant contributions from 210Pb and 3H.

2-6keV single hit dru level

<table>
<thead>
<tr>
<th></th>
<th>Crystal-1</th>
<th>Crystal-2</th>
<th>Crystal-3</th>
<th>Crystal-4</th>
<th>Crystal-6</th>
<th>Crystal-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>0.10 ± 0.02</td>
<td>0.20 ± 0.02</td>
<td>0.10 ± 0.01</td>
<td>0.10 ± 0.01</td>
<td>0.05 ± 0.01</td>
<td>0.05 ± 0.01</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>2.50 ± 0.10</td>
<td>1.69 ± 0.09</td>
<td>0.57 ± 0.05</td>
<td>0.71 ± 0.05</td>
<td>1.46 ± 0.07</td>
<td>1.50 ± 0.07</td>
</tr>
<tr>
<td>Other ($\times 10^{-4}$)</td>
<td>7.0±0.1</td>
<td>15±1</td>
<td>7.3±0.1</td>
<td>7.7±0.1</td>
<td>14±1</td>
<td>14±1</td>
</tr>
<tr>
<td>Cosmogenic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^3$H</td>
<td>2.35 ± 0.90</td>
<td>0.81 ± 0.40</td>
<td>1.54 ± 0.77</td>
<td>1.97 ± 0.66</td>
<td>0.69 ± 0.67</td>
<td>0.58 ± 0.54</td>
</tr>
<tr>
<td>$^{109}$Cd</td>
<td>0.05 ± 0.04</td>
<td>0.009 ± 0.009</td>
<td>0.13 ± 0.06</td>
<td>0.33 ± 0.16</td>
<td>0.09 ± 0.09</td>
<td>0.09 ± 0.09</td>
</tr>
<tr>
<td>Other</td>
<td>0.02 ± 0.01</td>
<td>0.05 ± 0.02</td>
<td>0.05 ± 0.03</td>
<td>0.05 ± 0.03</td>
<td>0.05 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>0.64 ± 0.64</td>
<td>0.51 ± 0.51</td>
<td>1.16 ± 0.51</td>
<td>0.22 ± 0.16</td>
<td>0.34 ± 0.20</td>
<td>0.38 ± 0.21</td>
</tr>
<tr>
<td>External</td>
<td>0.03 ± 0.02</td>
<td>0.05 ± 0.04</td>
<td>0.03 ± 0.02</td>
<td>0.03 ± 0.02</td>
<td>0.04 ± 0.03</td>
<td>0.03 ± 0.02</td>
</tr>
<tr>
<td>Total simulation</td>
<td>5.68 ± 1.04</td>
<td>3.28 ± 0.67</td>
<td>3.57 ± 0.76</td>
<td>3.41 ± 0.75</td>
<td>2.74 ± 0.61</td>
<td>2.70 ± 0.51</td>
</tr>
<tr>
<td>Data</td>
<td>5.64 ± 0.10</td>
<td>3.27 ± 0.07</td>
<td>3.35 ± 0.07</td>
<td>3.19 ± 0.05</td>
<td>2.62 ± 0.05</td>
<td>2.64 ± 0.05</td>
</tr>
</tbody>
</table>
Examples of Signal Events

3 keV

100 keV

> 1 MeV
400 days of data

Side band: Multiple-hit (2-6 keV)

Side band: Single-hit (6-10 keV)

Side band data fit well with simple exponential models built from the known cosmogenic components.

Crystals 1, 5, and 8 are excluded in this analysis due to excessive PMT noise and low light yield.