Current & Planned NaI(Tl) Experiments

DM-Ice + KIMS

SABRE

COSINE-100

ANAlS

COSINUS

Boulby

Gran Sasso + Australia

Yangyang

Kamioka

South Pole


July 18, 2017

Within 5 years from today, Frank Wilczek bets that the DAMA signal will not be confirmed.

'Bet is against Katie Freese.
Frank Wilczek bets 1,000-to-1 odds $1,000 vs. $1
I.e. Katie loses $1 max.

Referee is Lars Bergstrom.

Frank Wilczek
COSINE-100 Collaboration

Joint collaboration between KIMS and DM-Ice. 106 kg of NaI(Tl) crystals.
COSINE-100 Shielding

- Plastic Scintillators
- Lead Shielding (20 cm)
- Cu Box (3 cm)
- 2000 L Liquid Scintillator
- NaI(Tl) Crystals
- Tag $^{40}\text{K}$ to veto 3 keV background events
- 40 cm
COSINE-100 Shielding

Plastic Scintillators

Lead Shielding (20 cm)

Cu B

2000 L Liquid Scintillator

Tag $^{40}$K to veto 3 keV background events

Preliminary

+ Data (vetoed)
– Fit
– Subtracted $^{40}$K
COSINE-100 Construction

Dec. 2015


Feb. 2016

Mar. 2016

Apr. 2016

May. 2016


Sep. 2016
COSINE-100 Operation

- Data taking since Sep. 2016
- Stable operation
- > 85% physics data
- 95% good runs

Crystal Trigger Rate: 13 Hz
Muon Detector Rate: 12 Hz

COSINE-100 Accumulated Data

- Total Lived: 211.3 days (87.7%)
- Good Data: 201.6 days (83.7%)

Calibration
Environmental Control & Monitoring

• < 0.1°C temperature fluctuation of crystals in LS
• Online monitoring of 150+ environmental variables
COSINE-100 NaI(Tl) Crystals

- 8 crystals, total 106 kg
- Culmination of R&D program with Alpha Spectra
- U/Th/K below DAMA, $^{210}\text{Po}$ very close
- Light yield $\sim$15 p.e./keV
- Challenge: putting it all together
- Total Background: 2 - 4 x DAMA’s avg.

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Mass (kg)</th>
<th>Powder Type</th>
<th>$^{40}\text{K}$ (ppb)</th>
<th>$^{238}\text{U}$ (ppt)</th>
<th>$^{232}\text{Th}$ (ppt)</th>
<th>$^{210}\text{Po}$ (mBq/kg)</th>
<th>Light Yield (npe/keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.26</td>
<td>Powder B</td>
<td>34.74±4.74</td>
<td>&lt;0.02</td>
<td>1.31±0.35</td>
<td>3.20±0.04</td>
<td>14.67±0.62</td>
</tr>
<tr>
<td>2</td>
<td>9.15</td>
<td>Powder C</td>
<td>60.64±4.64</td>
<td>&lt;0.12</td>
<td>&lt;0.63</td>
<td>2.06±0.03</td>
<td>14.56±0.54</td>
</tr>
<tr>
<td>3</td>
<td>9.16</td>
<td>WIMPScint-II</td>
<td>34.34±3.10</td>
<td>&lt;0.04</td>
<td>0.44±0.19</td>
<td>0.76±0.02</td>
<td>15.75±0.76</td>
</tr>
<tr>
<td>4</td>
<td>18.01</td>
<td>WIMPScint-II</td>
<td>33.32±3.50</td>
<td>&lt;0.3</td>
<td>0.74±0.02</td>
<td>14.69±0.46</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>18.28</td>
<td>Powder C</td>
<td>82.33±5.49</td>
<td>2.35±0.31</td>
<td>2.06±0.03</td>
<td>6.26±0.34</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>12.5</td>
<td>WIMPScint-III</td>
<td>16.79±2.46</td>
<td>&lt;0.018</td>
<td>0.56±0.19</td>
<td>1.52±0.02</td>
<td>14.52±0.51</td>
</tr>
<tr>
<td>7</td>
<td>12.5</td>
<td>WIMPScint-III</td>
<td>18.69±2.79</td>
<td>&lt;0.6</td>
<td>1.54±0.02</td>
<td>14.41±0.50</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>18.28</td>
<td>Powder C</td>
<td>54.25±3.82</td>
<td>&lt;0.9</td>
<td>2.05±0.02</td>
<td>3.27±0.20</td>
<td></td>
</tr>
</tbody>
</table>

DAMA: $<20$ 0.7 - 10 0.5 - 7.5 $<0.5$ 5.5 - 7.5
Event Selection: Fast Event Rejection

- Separate noise via charge ratio of rising edge vs. falling edge

Preliminary
Event Selection: Asymmetry & Charge/Peak

- Additional noise reduction cuts have been developed:
  - Charge asymmetry between 2 PMTs in each crystal
  - Charge/peak: Average charge per SPE
  - BDT
Low Energy Spectrum

- **2 to 4 cnts/keV/kg/day** in region of interest depending on the crystal
- $^{210}\text{Pb} (t_{1/2} = 22\ \text{yr})$, U/Th in Internal components (crystal growing/raw material)
- $^{210}\text{Pb}$ on crystal & PTFE surface
- Cosmogenic components: $^{125}\text{I}$ (59 d), $^{109}\text{Cd}$ (460 d), $^3\text{H}$ (12 yr)
Currently, 10-15% discrepancy at the ROI

Goal <5%
Background in Data vs. Simulations

- Geant4 simulation
- Reproduces data well, cosmogenic activation depends on crystal
- Surface $^{210}\text{Pb}$ is dominant background, followed by $^{40}\text{K}$ internal to crystal

Simulation within R&D array (C3)  
Detector Geometry at COSINE-100

Preliminary
Expected Sensitivity of COSINE-100

*Assumed 2 dru or 4 dru flat backgrounds depending on crystals.

Sensitivity comparable with DAMA’s allowed region.
COSINE-200 (Phase-II)

Goal: Reach background < DAMA (1 dru)
Needs a factor two or more improvement

R&D at IBS in Korea

<table>
<thead>
<tr>
<th>Powder</th>
<th>(^{39}\text{K} \text{ (ppb)})</th>
<th>(^{208}\text{Pb} \text{ (ppb)})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>After</td>
</tr>
<tr>
<td>Astro grade</td>
<td>4.5</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Crystal grade</td>
<td>45.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Cian (99.5%)</td>
<td>180000</td>
<td>1305</td>
</tr>
</tbody>
</table>

Powder purification (Recrystallization)
Crystal growing & Handling
Established a facility at our center
Powder purification (mass production facility for purification under construction)
Expected sensitivity for COSINE-200 (Phase-II)

*Assume 1 dru flat background
Summary

- COSINE-100 = DM-Ice + KIMS w/ goal to test DAMA’s claim for dark matter observation
- COSINE-100 Physics run has started on September 2016
- COSINE-100 = 8 crystals, 106 kg + 2000 liters of LAB-based liquid scintillator veto + muon tagging panels
- Initial performance of COSINE-100 is promising. 2 keV threshold, 2-4 dru at ROI
- Expect to have DAMA-comparable sensitivity in ~2 years
- Continued R&D for higher purity crystals for COSINE-200 (Phase-II)

see also Poster 253: William Thompson