STATUS OF KIMS EXPERIMENT

2012.11. 6 Juhee Lee and KIMS Collaboration for PPC2012 @ KIAS
Contents

- Introduction to KIMS
- The latest publication - *Astropart. Phys. 35 (2012) 781*
  PRL 108 181301(2012)
- Recent results - Background study,
  Annual Modulation, Channeling effect
- Future Plans - Upgrade of PMTs and NaI(Tl)
- Summary
Introduction to KIMS

1. The location of Y2L for WIMP search
   - The Muon flux in the detector room: $2.7 \times 10^{-3} \text{ m}^2/\text{s}$
2. **Detector**

- 12 CsI(Tl) crystals, each $8 \times 8 \times 30$ cm$^3$ (8.7kg), w/ 3" PMTs (9269QA)

- Measured light yields for gammas: $\sim 5$ p.e./keV
- SI + SD interaction search for the WIMP-nucleon scattering

<table>
<thead>
<tr>
<th>Isotope</th>
<th>J</th>
<th>Abun</th>
<th>$&lt;Sp&gt;$</th>
<th>$&lt;Sn&gt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{133}$Cs</td>
<td>7/2</td>
<td>100%</td>
<td>-0.370</td>
<td>0.003</td>
</tr>
<tr>
<td>$^{127}$I</td>
<td>5/2</td>
<td>100%</td>
<td>0.309</td>
<td>0.075</td>
</tr>
</tbody>
</table>

- Background level: $2 \sim 3$ cpd/kg/keV: slide #12
- Pulse shape discrimination (PSD): slide #8
3. **The shielding setup**

- External gammas (<< internal BG): HPGe measurement
- Neutrons (~ zero): ~100 days Bc501A measurement w/ the time analysis
- N2 gas flow inside the setup

- Muon Det. : supply the veto signals to CsI(Tl) (6~7 counts /hr)
4. **DAQ**
   - Trigger condition: 4 p.e. for two PMTs
   - DAQ rate: < 6 Hz.
   - 400 MHz FADC (10 bit) with x 100 preAmp.
     & 64 MHz SADC (12 bit) with x 10 preAmp.
   - Stability check - By monitoring of temperature, electric power etc.
   - CsI(Tl) temp.: 20~21.6 (depending on the positions) ± 0.2 °C
5. Calibration

- Electron recoil energy calibration w/ bar type sources of $^{241}\text{Am}$ (59.54 keV $\gamma$)

- Nuclear recoil energy calibration (in Seoul National University)
  - For small sample crystals of each detector in Y2L
  - $^{241}\text{Am}/^{9}\text{Be}$ 300 mCi, 2.4 MeV neutron beam (in progress)
  - Nuclear recoil event sample - PDF as a function of LMT10 (the PSD value) for each $E_{\text{meas}} (F_{NR})$

\begin{equation}
\langle t \rangle = \frac{\sum_{i=1}^{n} A_i t_i}{\sum_{i=1}^{n} A_i}, \quad LMT10 = \log \langle t \rangle
\end{equation}
The latest publication

  - Surface alphas (SA) - main backgrounds from Rn progenies.
  - W/ Radon double detector (A & B)

- From SA sample events - PDF of LMT10 ($F_{SA}$)

---

CsI(Tl) A : Rn progenies contaminated one

CsI(Tl) B : Alpha tagging detector

Aluminium thin foil 6 μm

![Diagram of detectors and energy distribution](image)
The latest publication

- 1 year of data (Sep. 2009 – Aug. 2010)
- PMT noise rejection cuts
  - Reference data: from the PMT dummy detector
  - Different characteristics from multiple hit events (Compton scattering events) and nuclear recoil events
The latest publication

  - By Bayesian Analysis Tool
  - The most probable ratios for $F_{NR}$, $F_{SA}$ and $F_{\gamma}$ for each $E_{meas}$
  - Efficiency corrections for the nuclear recoil event limits

\[ F = f_N F_{NR} + f_S F_{SA} + (1-f_N-f_S) F_{\gamma} \]

(for 6 keV bin of Det 9)

Red 1σ
Black 90% c.l.

3.6-5.8 keV (2-4 keV in DAMA)
90% c.l. is 0.0098 cpd/kg/keV
< 0.0183 cpd/kg/keV modulation signal of DAMA
The latest publication


[ SI cross section limit ]

[ SD cross section limit ]
Recent Results

1. **Background study by using e/γ events** (by J. K. Lee in preparation)
   - $^{134}$Cs/ $^{137}$Cs - in CsI(Tl), $^{238}$U/$^{232}$Th/$^{40}$K - in PMT glue
   - For data - Energy calibration w/ 59.54 (241Am), 605, 796 keV ($^{134}$Cs)
   - Charge asymmetry correction

![Single hit graph](image1)

![Multiple hit graph](image2)
1. **Background study by using α events** (by S. S. Myung submit to NIMA)
   - $^{238}\text{U}/^{232}\text{Th}$ - in CsI(Tl)
     - Better energy resolution w/ two corrections of the charge asymmetry and the saturation
     - Quenching factor measurement
     - Fit data w/ MC events generated by $f$
   - Bkg. level ~ 0.008 cpd/ kg/keV
   - Time analysis can underestimate U/Th activity.

Recent Results

<table>
<thead>
<tr>
<th>detector</th>
<th>$^{238}\text{U}$</th>
<th>$^{234}\text{U}$</th>
<th>$^{222}\text{Rn}$</th>
<th>$^{210}\text{Po}$</th>
<th>$^{212}\text{Th}$</th>
<th>$^{228}\text{Th}$</th>
<th>$^{220}\text{Ra}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>109.05</td>
<td>246.36</td>
<td>7.89</td>
<td>75.37</td>
<td>21.51</td>
<td>25.61</td>
<td>7.89</td>
</tr>
<tr>
<td>1</td>
<td>84.79</td>
<td>220.59</td>
<td>11.91</td>
<td>16.82</td>
<td>34.77</td>
<td>33.21</td>
<td>11.73</td>
</tr>
<tr>
<td>2</td>
<td>101.56</td>
<td>226.11</td>
<td>7.58</td>
<td>27.11</td>
<td>29.63</td>
<td>36.97</td>
<td>9.61</td>
</tr>
<tr>
<td>3</td>
<td>15.32</td>
<td>45.29</td>
<td>5.34</td>
<td>23.21</td>
<td>7.11</td>
<td>17.72</td>
<td>6.15</td>
</tr>
<tr>
<td>4</td>
<td>33.19</td>
<td>97.12</td>
<td>4.18</td>
<td>2.35</td>
<td>17.23</td>
<td>9.43</td>
<td>4.71</td>
</tr>
<tr>
<td>5</td>
<td>14.90</td>
<td>44.68</td>
<td>3.05</td>
<td>8.05</td>
<td>6.53</td>
<td>7.40</td>
<td>3.70</td>
</tr>
<tr>
<td>6</td>
<td>22.60</td>
<td>65.86</td>
<td>11.15</td>
<td>2.83</td>
<td>9.62</td>
<td>22.65</td>
<td>9.62</td>
</tr>
<tr>
<td>7</td>
<td>73.64</td>
<td>165.87</td>
<td>7.98</td>
<td>1.81</td>
<td>11.63</td>
<td>21.57</td>
<td>8.73</td>
</tr>
<tr>
<td>8</td>
<td>14.03</td>
<td>35.07</td>
<td>5.22</td>
<td>11.72</td>
<td>7.97</td>
<td>14.73</td>
<td>6.63</td>
</tr>
<tr>
<td>9</td>
<td>2.11</td>
<td>19.60</td>
<td>2.11</td>
<td>5.79</td>
<td>7.26</td>
<td>7.25</td>
<td>3.63</td>
</tr>
<tr>
<td>10</td>
<td>6.42</td>
<td>22.64</td>
<td>6.42</td>
<td>271.30</td>
<td>3.53</td>
<td>6.95</td>
<td>3.48</td>
</tr>
<tr>
<td>11</td>
<td>7.83</td>
<td>19.30</td>
<td>0.97</td>
<td>28.81</td>
<td>4.49</td>
<td>3.84</td>
<td>1.92</td>
</tr>
</tbody>
</table>

\[ f = P0(^{238}\text{U} + \ldots + ^{210}\text{Po}) + P1(^{232}\text{Th} + \ldots + ^{212}\text{Po}) + \]
\[ P2(^{234}\text{U}) + P3(^{234}\text{U} + ^{230}\text{Th} + ^{226}\text{Ra}) + \]
\[ P4(^{232}\text{Th}) + P5(^{228}\text{Th} + ^{224}\text{Ra}) + \]
\[ P6(^{210}\text{Po}). \]
Recent Results

2. **Annual Modulation** (by J. H. Choi in preparation)
   - 2.5 year of data (Sep. 2009 – Feb. 2012), 75.53 ton·days

   - Due to an outage of electricity or an abnormal termination of computers, sometimes not a full month data

   - For data - PMT noise cuts and the efficiency correction (w/ multiple hit events, in next slide), No PSD
Recent Results

2. Annual Modulation
   - Cut efficiency from multiple hit data
2. **Annual Modulation**
   - Single hit events after all cuts and efficiency correction (except Det10 for its high background rate)
Recent Results

2. Annual Modulation

3-6 keV

- Similar $E_{\text{meas}}$ bin w/ DAMA's 2-4 keV bin from quenching factor correction.

- After fitting data w/ $R$, $A_{\text{mod}}$ can be extracted.

\[
R = A_{\text{decay}} e^{\frac{t - t_0}{\tau}} + \text{bkg.} \\
+ A_{\text{mod}} \cos \left( \frac{2\pi}{365} \left( t - t_{\text{peak}} \right) \right)
\]

( $t_0$ : 1. sep. 2009, $\tau$ : 2.98 y. $t_{\text{peak}}$ : 153 d. (2. Jun.))

2012-11-05
Recent Results

2. Annual Modulation

3-6 keV

- $A_{\text{decay}}$ has the same decay time as $^{134}\text{Cs}$. ($\tau : 2.98 \text{ y}$)
- The $bkg.$ level of 2 keV bin is higher than other energy bin. More bkg. reduction is needed.

- $A_{\text{mod}}$
  - $\sigma : 0.0008 \pm 0.0068$ cpd/kg/keV
  - 90% c. l : 0.0119 cpd/kg/keV
Inconsistent with DAMA's modulation signal independent of halo model.
Recent Results

3. Channeling effect

IEEE TNS. 59. 5 (2012) 2346 (by J. H. Lee et. al.) and in preparation

  - KIMS PSD method might lose some nuclear recoil events relevant to the channeling effect.

- Channeling effect: When recoil ions go through the symmetry axes/planes

From the ion cascades after the recoil

\[ E_{\text{recoil}} \rightarrow E_{\text{phonon}} + E_{\text{ionization}} + E_{\text{damage}} \]

Enhanced light yield due to the enhanced ionization

However, gamma like events? (cf. alpha events)
Stopping power may be the more important thing.
Recent Results

3. **Channeling effect**
   - $E_{\text{meas}}$ reproduction for a $E_{\text{recoil}}$ in the monocrystalline CsI(Tl)
     - To know the channeling effect on $E_{\text{meas}}$

   ① By simulation (TRIM/MARLOWE) : $E_{\text{ionisation}}$ distribution

   ② Scintillation efficiency model based on Birk's formula : Conversion to $E_{\text{meas}}$

   ③ PDF of $E_{\text{meas}}$ spectrum (*Landau-Gaussian funtion*) for amorphous and monocrystalline cases
Recent Results

3. Channeling effect
   - Exp. setup

2. 3 keV σ for 18.4 keV $E_{\text{recoil}}$

\[ \theta = 45^\circ : E_{\text{recoil}} = 10.8 \text{ keV} \]
\[ 60^\circ : 18.4 \text{ keV} \]
\[ 90^\circ : 36.6 \text{ keV} \]

XRD pattern of 3 planes on the CsI(Tl)

PSD power of a neutron detector
Recent Results

3. Channeling effect
   - $E_{\text{meas}}$ spectrum for $E_{\text{recoil}}$ w/ a small deviation
     - Normalized by # of events below 10 keV

Solid - Measured total evts.
Dashed - Reproduced total evts.
Blue - Reproduced gamma contaminated evts.
Recent Results

3. **Channeling effect**
   - Zoom in below $E_{\text{recoil}}$
     - To consider symmetry axes and planes in CsI(Tl) represents data well.

*Criteria of the range selection*

**Blue** : partial channeling

$<E_{\text{meas}}>$normal $+ 3\sigma_{\text{normal}} < E_{\text{meas}} < E_{\text{recoil}} - 2\sigma_{\text{recoil}}$

**Red** : full channeling

$E_{\text{recoil}} - 2\sigma_{\text{recoil}} < E_{\text{meas}} < E_{\text{recoil}} + 2\sigma_{\text{recoil}}$

- Channeling effect is $\sim 3\%$ in partial.
- PSD cut seems to be reasonable.
Future Plans

1. **Upgrade of PMTs** (tested by K. W. Kim)

<table>
<thead>
<tr>
<th></th>
<th>U</th>
<th>Th</th>
<th>K</th>
<th>Unit: mBq/PMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present (9269QA)</td>
<td>83</td>
<td>48</td>
<td>1866</td>
<td></td>
</tr>
<tr>
<td>Plan (R11065)</td>
<td>33</td>
<td>1.9</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

- High K content: at the coupling of Quartz and Borosilicate glasses at the center of PMT body.
- The Cherenkov light from $^{40}\text{K}$ decay in the glass or weak glass scintillation may be the origin of the PMT noise.
- With new PMT and surface alpha reduction from the polishing, **we can reduce by $\sim 1\text{cpd/kg/keV}$**
- With this lower bkg level, low mass WIMP search is possible.

2012-11-05
### Future Plans

<table>
<thead>
<tr>
<th>PMT comparisons</th>
<th>R6956MOD (R6233MOD)</th>
<th>R11065</th>
<th>9269QA</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIBRA NEW</td>
<td>KIMS NEW</td>
<td>KIMS OLD</td>
<td></td>
</tr>
<tr>
<td>Photocathode</td>
<td>SBA</td>
<td>Bialkali</td>
<td>RbCs</td>
</tr>
<tr>
<td>Window</td>
<td>Borosil</td>
<td>Quartz</td>
<td>Quartz</td>
</tr>
<tr>
<td>Effective Dia.</td>
<td>70</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>Borosil</td>
<td>Metal</td>
<td>Quartz+ Borosil</td>
</tr>
<tr>
<td>QE(500,550,600)</td>
<td>20,7,5,2.3</td>
<td>22,11,5</td>
<td>18,11,3</td>
</tr>
<tr>
<td>Gain</td>
<td>1X10^6</td>
<td>5X10^6</td>
<td>1X10^6</td>
</tr>
<tr>
<td>U (mBq/PMT)</td>
<td>128</td>
<td>33</td>
<td>83</td>
</tr>
<tr>
<td>Th(mBq/PMT)</td>
<td>20</td>
<td>1.9</td>
<td>48</td>
</tr>
<tr>
<td>K (mBq/PMT)</td>
<td>97</td>
<td>32</td>
<td>1866</td>
</tr>
<tr>
<td>Dark counts (kHz)</td>
<td>0.5</td>
<td>3</td>
<td>0.6</td>
</tr>
<tr>
<td>Afterpulse (x 10^-3)</td>
<td>~5.0</td>
<td>0.4</td>
<td>~10</td>
</tr>
<tr>
<td># of pe/keV</td>
<td>7.7</td>
<td>8.8</td>
<td>6.1</td>
</tr>
</tbody>
</table>

2012-11-05
Future Plans

After pulse comparisons

LIBRA NEW
R6956MOD
(1200V)

KIMS NEW
R11065
(1650V)

KIMS OLD
9269QA
(1277V)
Future Plans

2. Pure NaI(Tl)

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Exp.</th>
<th>U (ppt)</th>
<th>Th (ppt)</th>
<th>K (ppb)</th>
<th>Background Level (/keV kg day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI</td>
<td>DAMA</td>
<td>2-10</td>
<td>1-6</td>
<td>~ 20</td>
<td></td>
</tr>
<tr>
<td>LIBRA</td>
<td>0.7-10</td>
<td>0.5-7.5</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANAIS</td>
<td>400</td>
<td></td>
<td></td>
<td>&gt;10</td>
<td></td>
</tr>
<tr>
<td>CsI</td>
<td>KIMS</td>
<td>0.75</td>
<td>0.38</td>
<td>&lt;10</td>
<td>~3</td>
</tr>
</tbody>
</table>

- It is possible to add several NaI(Tl) crystals to KIMS.
- We are developing low background NaI(Tl) crystals from scratch in collaboration with Signa-Aldrich company & DM-ICE group.
- Sigma-Aldrich company made first low-K NaI powder in June 2012.
- Normal NaI powder (crystal grade) ~300ppb vs.
  New one (astro grade) ~4ppb (Claimed by Sigma-Aldrich)
- We are confirming their results now.
SUMMARY

- 1 year data with 100 kg CsI(Tl) data analyzed with PSD method. DAMA Iodine region is inconsistent with KIMS NR rate limit.
- Stringent limit of spin-dependent proton cross section is given.
- Background levels of 12 detectors are well understood.
- 2.5 year data is analyzed without PSD for the annual modulation → null modulation limit inconsistent with the level of DAMA’s modulation amplitude: final numbers are underway.
- Channeling & quenching factor studies produced first data.
- Planned upgrades will reduce the background further.