Next generation hypernuclear gamma-ray spectrometer: Hyperball-J

Koike, Takeshi
Tohoku University

- Introduction
- Hyperball-J requirements
- Array geometry
- Mechanical cooling
- PWO suppressor
Hyperball related talks

- Physics motivation & experimental overview
  – H. Tamura (Tuesday)
- Hyperball2 (E566) results
  – Y. Ma (Session A1)
- Spin-flip production at J-PARC
  – M. Ukai (Session A1)
- SKS spectrometers for E13 experiment @ J-PARC
  – K. Shirotori (Poster session)
## Evolution of Hyperball

<table>
<thead>
<tr>
<th></th>
<th>Hyperball</th>
<th>Hyperball2</th>
<th>Hyperball-J (Wall)</th>
<th>Hyperball-J (Ball)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong># of Ge det.</strong></td>
<td>14</td>
<td>20 (S14,C6)</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td><strong>Target distance</strong></td>
<td>10/15cm</td>
<td>15cm</td>
<td>13cm &lt; &lt; 21cm</td>
<td>18cm, 19.5cm</td>
</tr>
<tr>
<td><strong>Detector type</strong></td>
<td>Single(60%)</td>
<td>Single(60%)</td>
<td>Single(70%)</td>
<td>Single(70%)</td>
</tr>
<tr>
<td></td>
<td>Clover(20%×4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong># of channels</strong></td>
<td>14</td>
<td>38</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total photo peak eff. @ 1Mev</strong></td>
<td>2.3%(15)</td>
<td>~4%</td>
<td>6.5%*</td>
<td>4.8%*</td>
</tr>
</tbody>
</table>

Efficiency measured/simulated for a point source
*(simulated values by Geant4) × 0.82

HYP06
\(\gamma\)-ray spectrometer required of J-PARC under intense K beam

- **Efficiency, \(\varepsilon\)**
  - \(\gamma\)-\(\gamma\) coincidence \(\to \varepsilon^2\)
- **Resolution**
  - Intrinsic \(\to \) S/N
  - Neutron damage \(\to \) line shape
- **Energy deposit rate**
  - 0.5 TeV/sec \(<<\)
- **Fast suppression**
  - from BGO (1\(\mu\)s) to PWO (100ns)
- **Resolving of pile-up & baseline restoration**
  - Wave form analysis
**Hyperball-J : Ge detector base unit**

**Ge detector**
- Transistor Reset (High energy deposit rate)
- N-type (Radiation damage resistance)
- Relative eff. 70%
- Pulse Tube refrigerator (Minimization of neutron damage effect)

**Background suppressor**
- PWO crystal (fast decay component)
- Cooling unit (Increasing light yield)
- PMT

**Magnetic shield** (SKS fringing filed)
Two array geometries: Wall vs Ball
Wall configuration
(Half of an array is shown.)

- Compact placement of Ge detectors
- Large efficiency
- Angular sensitivity
- High configurability
- Simpler design geometry
- Possible with slim Ge design (mechanical cooling)
- Complex suppression scheme
- Less degree of symmetry
Ball configuration I
(# of det. 30, R=18cm, 19.5cm)

- High symmetry
- Standard configuration
- Less restriction on the size of detector
- Better low energy (Compton) background suppression
- Simpler suppression scheme
- Less efficient
- Non flexible geometry

Designed by N. Chiga
Compton suppression for 1-MeV $\gamma$ ray

Wall

Suppression factor

Ball

Suppression factor
## Hyperball-J: Three configurations

<table>
<thead>
<tr>
<th></th>
<th>Wall</th>
<th>Ball (30)</th>
<th>Ball (27)</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Ge det.</td>
<td>32</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td># of Rings</td>
<td>4 (6,10,10,6)</td>
<td>3 (10,10,10)</td>
<td>3 (9,9,9)</td>
</tr>
<tr>
<td>Dist. from a target center</td>
<td>13cm&lt;\textless 21cm</td>
<td>18cm,19.5cm</td>
<td>16cm,19cm</td>
</tr>
<tr>
<td>Closest dist. to the beam axis</td>
<td>7cm</td>
<td>15.6cm</td>
<td>14.2cm</td>
</tr>
<tr>
<td>Solid angle (% of 4\pi)</td>
<td>35.4%</td>
<td>26.8%</td>
<td>27.0%</td>
</tr>
<tr>
<td>Total photo peak eff. @ 1MeV (point source)</td>
<td>6.5</td>
<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Total PWO volume required</td>
<td>23,800cm$^3$</td>
<td>61,600cm$^3$</td>
<td>51,200cm$^3$</td>
</tr>
<tr>
<td>Detector angles (deg.)</td>
<td>±(70,69,61,40,28)</td>
<td>(90,± 23)</td>
<td>(90, ±35)</td>
</tr>
</tbody>
</table>
Mechanical cooling of Ge det.

- Tohoku & KEK collaboration
- Active development since April, 2006
- **Goal:** Cooling of Ge crystal (70%) to lower than 85K with comparable energy resolution obtained by LN$_2$ cooling (~2keV @1.3MeV)
- Stirling Pulse-Tube cryo-system adopted
  - Low mechanical vibration
  - Compact size
  - Low maintenance (50,000 hrs)
- July, 2006 succeeded in achieving FWHM=1.9keV @ 1.3MeV, but Ge temp.@113K
PWO as a fast suppressor

<table>
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<tr>
<th>Crystal</th>
<th>BGO</th>
<th>PWO</th>
</tr>
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<tbody>
<tr>
<td>Density [g/cm³]</td>
<td>7.23</td>
<td>8.28</td>
</tr>
<tr>
<td>Decay constant [ns]</td>
<td>300</td>
<td>~6</td>
</tr>
<tr>
<td>Absorption rate of γ ray [%]</td>
<td>67</td>
<td>62</td>
</tr>
<tr>
<td>Radiation length (cm)</td>
<td>1.12</td>
<td>0.89</td>
</tr>
<tr>
<td>Light yield [NaI=100]</td>
<td>15</td>
<td>1</td>
</tr>
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</table>

137Cs data taken by M. Mimori
Summary and future

- Hyperball-J, $\gamma$ – ray spectrometer for studies of bound hypernuclear systems at J-PARC (E13)
- Two geometries, and three candidates for the Hyperball-J array design
- Mechanical cooling of Ge detectors
- Fast PWO background suppressors

- Finalizing on the array design for the day-1 experiment (E13)
- Prototype base detector unit (Ge & refrigerator & PWO)
- Wave from readout for full intensity $K$ beam eventually
Ball configuration II
(# of det. 27, R=16cm, 19cm)

Designed by N. Chiga
NEUTRON DAMAGE VERSUS TEMPERATURE

150MeV neutron

Unattenuated resolution ~ 2 keV @ 1.33 MeV

~1.5 x 10^8 n/cm^2
Major requirements to consider in construction of Ge array

- **Efficiency**
  - Arrangement geometry
  - Number of detectors
  - Individual detector efficiency
  - Background suppressor size
- **Resolution**
  - Detector performance
  - Noise reduced environment
- **Background suppression**
  - Suppressor material
- **Modularity**
  - Exchangeability of detectors
- **Compact size**
- **Flexibility/configurability**
- **Symmetry**
- **Cost**
## Hyperball-J: Three configurations

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<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td># of PWO elements</td>
<td>140</td>
<td>160</td>
<td>144</td>
</tr>
<tr>
<td># of PWO element shape</td>
<td>1</td>
<td>5 (Tapered)</td>
<td>5 (Tapered)</td>
</tr>
<tr>
<td>Total volume of PWO</td>
<td>23800cm³</td>
<td>61600cm³</td>
<td>51200cm³</td>
</tr>
<tr>
<td># of PWO case shape</td>
<td>5</td>
<td>2(hex, penta.)</td>
<td>2(hex, penta.)</td>
</tr>
<tr>
<td># of PMT</td>
<td>280</td>
<td>320</td>
<td>288</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
<td></td>
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</table>
backup

• Pulse tube
  – Microphonics
  – History
• PWO
  – Mimori
• waveform
• Prototype
• dimension
Proposed “DAY-1” experiment E13

- Several light hypernuclear experiments are submitted ($^{4}$He, $^{7}$Li, $^{10}$B, $^{11}$B, $^{19}$F).

- $(K^{-}, \pi^{-} \gamma)$ at $p_{K} = 1.5$ GeV/c (500k/spill) (Out going $\pi^{-} \sim 1.4$ GeV/c)

- Experimental setup is determined by these requirements.
The K1.8 Beam line and SKS

**Beam spectrometers**
- BH1,2 : Time-of-flight
- BAC : π⁻ veto \((n=1.03)\)

**SKS**
- SAC : K⁻ veto \((n=1.03)\)
- SFV : K⁻ beam veto
- STOF : Time-of-flight

**DC** : Beam position measurement

**Background Veto**
- SMF : μ⁻ from K⁻→μ⁻+ν
- SP0 : π⁻ from K⁻→π⁻+π⁰

Hyperball-J : γray
Measured vs Simulated efficiency

- Length: 69.6 mm
- Diameter: 71.1 mm
- End cap to crystal: 4 mm
- Al thickness: 1 mm
- Measured Relative efficiency: 67.9%
  - Source distance to the end cap: 250 mm
  - 1.33 MeV gamma

For Simulated efficiency:
- $10^7$ gamma (isotropic)
- 10134 photo peak counts
- Relative efficiency: 82%

Measured eff. = Sim. eff. X 0.82

Diagram: Ge crystal with dimensions 69.6 mm x 80 mm, source at 250 mm distance, and 4 mm thickness.
Initial measurement

FWHM=1.8keV @ 1.33MeV

Conventional LN2 cooling

FWHM=13keV @ 1.33MeV

Pulse Tube mechanical cooling
Fuji Pulse Tube refrigerator OFF
ShapAmp ORTEC 671 6 micro, pole zeroed
FWHM=1.8keV @1.33MeV
FWHM=1.0keV pulser
Fuji Pulse Tube refrigerator ON
ShapAmp ORTEC 671 6 micro, pole zeroed
FWHM=1.9keV @1.33MeV
FWHM=1.1keV pulser
Joint R&D by Tohoku, KEK, Fuji Elect. Sys.

- **April 25, 2006**: First cooling of Ge with Pulse Tube (PT) refrigerator
  - 63K @ Ge crystal, 77K @ cold head

- **May 23, 2006**: Second time cooling and resolution measurement
  - FWHM = 5KeV @1.33MeV $^{60}$Co

- **June 9, 2006**: Third time cooling and resolution measurement
  - Electrical insulation between Ge det. and PT
  - FWHM = 4.7KeV @1.33MeV $^{60}$Co

- **July 13, 2006**: Fifth time cooling and resolution measurement
  - Heat link modification for reduction of microphonics
  - FWHM = 1.9KeV @1.33MeV $^{60}$Co

- **Sept., 2006**: Refrigerator power up, Heat loss and external heat flow reduction improvement in progress
  - 170W @ 55V 86K @ Ge crystal, 70K @ cold head, 77K @ Heat Link

- **Oct., 2006~**: Prototype detector for Hyperball-J
Flash ADC

- Model of Flash ADC $\rightarrow$ V1729 (CAEN)
- Sampling resolution $\rightarrow$ 12bit
- Sampling rate $\rightarrow$ 2GHz
- 1ch $\rightarrow$ 0.5ns

Sample of wave form
Charge sensitive preamplifier

\[ V_{out} \approx \frac{Q_{\text{det.}}}{C_f} e^{-\frac{t}{RC_f}} \]

Changing of \( C_f \) by mechanical vibration -> Microphonics
The cooling mechanism is simply a **heat cycle**.

1→2 : Isothermal absorption (等温吸熱)

2→3 : Adiabatic compression (断熱圧縮)

3→4 : Isothermal heat rejection (等温放熱)

4→1 : Adiabatic expansion (断熱膨張)
Averaged wave forms

Red: -25°C
Blue: 0°C
Green: 20°C
Black: 1 photo-electron
Temperature dependence of wave form

- Integrated area of average wave form.
- Integration time interval $\rightarrow 10$ns.

Saturation point $\rightarrow$ end of wave form

Saturation point:
- $20^\circ\text{C} \rightarrow 50$ns
- $0^\circ\text{C} \rightarrow 70$ns
- $-25^\circ\text{C} \rightarrow 100$ns
Digitized waveform (1)
~single event~

X: Time channel   Y: Voltage channel
Digitized waveform (2)

~multi event~
Digitized waveform (3)

~multi event~
Digitized waveform (4)

~Base-line shift~