Development of Hybrid Photo-Detector for the Hyper-Kamiokande Project

Seiko Hirota (Kyoto Univ.)
For Hyper-Kamiokande working group
2013. 2.14 @VCl

ICRR, Univ. of Tokyo., Kyoto Univ. IPMU, Hamamatsu K.K.
Outline

• Hyper-Kamiokande Project (HK)
• Hybrid Photo-Detector (HPD)
  – Development of 8-inch HPD
    • Performance evaluation
    • Check for practical use
    • Proof-test plan in 200t water tank
  – Schedule
• Summary
Introduction
Super-Kamiokande in Kamioka, Japan for many topics in physics and astronomy

Large water tank! Many (11129) PMTs!
Large Water Cherenkov Detector

For
- Neutrino detection
- Proton decay search

Rare events!

Detect Cherenkov ring

For better sensitivity
- Larger water tank
- More photo sensors
Hyper-Kamiokande Project
HK Base Line Design

Next generation underground water Cherenkov Detector!

@ Kamioka, Japan
Depth 648 m

Volume 0.99Mt
Super-Kamiokande*1 : 50kt
Hyper-Kamiokande Project
HK Base Line Design

Next generation underground water Cherenkov Detector!

@ Kamioka, Japan
Depth 648 m

Volume 0.99Mt
Super-Kamiokande : 50kt

Outer Detector

Proton Decay

Inner Detector

Cherenkov Light

Cross Section
Hyper-Kamiokande Project
HK Base Line Design

Next generation under ground water Cherenkov Detector!

20-inch PMT: 99000
(Super-Kamiokande: 11129)

8-inch PMT: 25000
(Super-Kamiokande: 1885)

MANY photo-sensors!!

@ Kamioka, Japan
Depth 648 m

Volume 0.99 Mt
Super-Kamiokande: 50 kt

54 m
40 m
40 m
247 m
48 m

Kamioka, Japan
Hyper-Kamiokande Project
HK Base Line Design

Next generation under ground water Cherenkov Detector!

@ Kamioka, Japan
Depth 648 m

MANY photo-sensors!!

20-inch PMT: 99000
(Super-Kamiokande: 11129)

8-inch PMT: 25000
(Super-Kamiokande: 1885)

Alternative candidate,
Hybrid Photo-Detector (HPD) with
- Higher performance
- Lower mass production cost

is being developed for HK
## Hybrid Photo-Detector

### Conventional

**20-inch PMT**
- A large photo cathode
- Gain: $10^6 \sim 10^7$ (Dynode: $\sim 2kV$, Electron: $e$)

### Newly Developing

**HPD**
- Bombardment Gain: $\sim 400 @ 8kV$
- Avalanche Gain: $\sim 100 @ 250V$

**Avalanche Diode (AD)**
- Gain: $10^4 \sim 10^5$ ($\sim 400_{bombardment} \times 100_{AD}$)
- Electron: $e$
Advantage

- Large gain on 1st step: Better photon separation
- Faster transition time: Better timing resolution
- Strong electric field: Better collection efficiency

<table>
<thead>
<tr>
<th></th>
<th>HPD (expected)</th>
<th>20-inch PMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon separation (P/V* page13)</td>
<td>~5</td>
<td>1.9</td>
</tr>
<tr>
<td>Timing resolution (σ)</td>
<td>~1ns</td>
<td>2.2ns</td>
</tr>
<tr>
<td>Collection efficiency</td>
<td>~95%</td>
<td>75%</td>
</tr>
</tbody>
</table>

- Simple structure: Low mass production cost!
- Axial symmetry: Uniformity

Disadvantage

- NO experience to use HPDs in water
- NO experience to run for long time*
- Small gain
- Concerning about 8kV (2kV in PMTs)

*HK is expected to run for more than a few tens of years
Goal of HPD R&D for HK

Goal

• We want to develop two size of HPD for HK.
  – 20-inch HPD
  – 8-inch HPD

How to overcome disadvantage

• To confirm feasibility of practical usage as water Cherenkov Detector,
  – Test HPDs in 200t water tank
  – Evaluate actual performance of HPDs compared with PMTs
Design of 8-inch HPD module

Size for Outer Detector!

Preamp

PMT (20<inch)

Signal

Range of sensitive wavelengths

300 - 650 nm

Typical voltage

Photocathode

8 kV

AD bias

260 V

Gain

4 – 10^4

Single-photon resolution

σ

20 %

Transition time spread

σ

620 ps

20% ns

1% p.e.

%10 mV

×2

Power LV 10V

Control LV < 4V

Water-proof Housing

→ enable operation of HPDs in water!

by Hamamatsu Photonics K.K.

Selko Hirota @VCl 2013
HPD Performance
Excellent Photon discrimination!
Excellent photon separation!
Peak to valley ratio (P/V) ~8.9 (ref: 1.9@PMT)
Better signal efficiency 80~90% (@Thr. in valley region)
Excellent photon separation!
Peak to valley ratio (P/V) ~8.9  (ref: 1.9@PMT)
Better signal efficiency 80~90% (@Thr. in valley region)
With optimized Bias Voltage....

Gain (HPD + preamp) $\sim 2.8 \times 10^7$

1p.e. resolution $\sim 35$

P/V (charge) $\sim 7$

✓ Tune AD bias voltage under break down voltage to maximize p.e. resolution

Gain Curve

Photon Separation (charge distribution)

To break down voltage (Increase noise)

(Better separation)
Dark Hit Rate is critical to trigger rate, because HK events are recognized by coincidence of hits in photo sensors (= Self trigger)

- Dark Rate @ threshold must be stable and low for trigger rate
- 3kHz @ threshold for 1p.e. events (HPD Serial# 0057)

ref) 4kHz@0.25p.e. (20-inch PMT in Super-K tank)
1p.e. transition time spread (TTS) is \(~1.3\text{ns}\) with preamp and 70m cable.

- Only HPD, 1p.e. TTS (\(\sigma\)) is \(0.62\text{ns}\) reported by Hamamatsu
- 20-inch PMT \(~2.2\text{ns}\)
- HPDs show good timing resolution.
# Current 8-inch HPD performance

<table>
<thead>
<tr>
<th></th>
<th>8” HPD for Proof Test</th>
<th>20” PMT (in Super-K: R3600)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amplification</strong></td>
<td>Bombardment + AD</td>
<td>Dynode</td>
</tr>
<tr>
<td><strong>HV</strong></td>
<td>8kV + AD Bias 350V</td>
<td>2kV</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td>$10^4$<del>$10^5$ (</del>$10^7$ with amp)</td>
<td>$10^6$~$10^7$</td>
</tr>
<tr>
<td><strong>1p.e. P/V</strong></td>
<td>5~7</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>1p.e. Resolution</strong></td>
<td>~35%</td>
<td>~150%</td>
</tr>
<tr>
<td><strong>Dark Rate</strong></td>
<td>~3kHz-40kHz (~25°C) @ 0.5 p.e.</td>
<td>~4kHz (~13°C) @0.25p.e.</td>
</tr>
<tr>
<td></td>
<td>~3kHz-40kHz (~25°C) @ 0.5 p.e.</td>
<td>Different measurement condition from in case of HPDs</td>
</tr>
<tr>
<td><strong>TTS</strong></td>
<td>~1.3ns @1p.e. with preamp and 70m cable (Only HPD, 0.62ns)</td>
<td>~2.2ns @1p.e.</td>
</tr>
</tbody>
</table>

*Seiko Hirota @VCI 2013*
HPD Proof-test
Disadvantage
✓ NO experience to use HPDs in water
✓ NO experience to run over 10 years.

We must check....
☐ Long-term Stable operation
☐ Usability as water Cherenkov Detector

Durability Check  ~ Jan. 2013
✓ We tested 5 HPDs.
✓ 1HPD was alive more than 1 month.
✓ NO failure during 30k times HV (8kV) switching (equivalent to 5 years operation for 8 HPDs assuming 200t water tank test. Page21)

<table>
<thead>
<tr>
<th>HPD Serial No.</th>
<th>HV applying time</th>
<th>HV switching time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0056</td>
<td>33 days</td>
<td>22490</td>
</tr>
<tr>
<td>0057</td>
<td>33 days</td>
<td>2350</td>
</tr>
<tr>
<td>0058</td>
<td>17 days</td>
<td>8087</td>
</tr>
<tr>
<td>0062</td>
<td>37 days</td>
<td>900</td>
</tr>
<tr>
<td>0072 (in Water)</td>
<td>16 days</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>136 days</strong></td>
<td><strong>33281 times</strong></td>
</tr>
</tbody>
</table>
1 HPD was mounted in a small water tank to confirm safety operation with 8kV applied.

<table>
<thead>
<tr>
<th>Items</th>
<th>Trigger</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flasher</td>
<td>PMT coincidence</td>
<td>&lt;0.003Hz</td>
</tr>
<tr>
<td>Leak Current</td>
<td>Clump Sensor2</td>
<td>0 / 14h.</td>
</tr>
<tr>
<td>Discharge</td>
<td>Antenna, Clump Sensor1, HPD signal</td>
<td>&lt;0.1Hz</td>
</tr>
</tbody>
</table>

- Confirm safety operation of 1 HPD in this set up.
- We will check safety operation of all HPDs for next proof test in 200t tank (Next Page).
1 HPD was mounted in a small water tank to confirm safety operation with 8kV applied.

<table>
<thead>
<tr>
<th>Items</th>
<th>Trigger</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flasher</td>
<td>PMT coincidence</td>
<td>&lt;0.003Hz</td>
</tr>
<tr>
<td>Leak Current</td>
<td>Clump Sensor2</td>
<td>0 / 14h.</td>
</tr>
<tr>
<td>Discharge</td>
<td>Antenna, Clump Sensor1, HPD signal</td>
<td>&lt;0.1Hz</td>
</tr>
</tbody>
</table>

- Confirm safety operation of 1 HPD in this set up.
- We will check safety operation of all HPDs for next proof test in 200t tank (Next Page).
1 HPD was mounted in a small water tank to confirm safety operation with 8kV applied.

<table>
<thead>
<tr>
<th>Items</th>
<th>Trigger</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flasher</td>
<td>PMT coincidence</td>
<td>&lt;0.003Hz</td>
</tr>
<tr>
<td>Leak Current</td>
<td>Clump Sensor2</td>
<td>0 / 14h.</td>
</tr>
<tr>
<td>Discharge</td>
<td>Antenna, Clump Sensor1, HPD signal</td>
<td>&lt;0.1Hz</td>
</tr>
</tbody>
</table>

✔ Confirm safety operation of 1 HPD in this set up.
✔ We will check safety operation of all HPDs for next proof test in 200t tank (Next Page).
Next Plan: Proof-test in 200t tank

To confirm feasibility of HPDs as Cherenkov detector.
✓ Both 8-inch and 20-inch HPDs will be tested.
✓ Check stability for few years.
✓ Compare HPDs to 20-inch PMTs in terms of practical usage.
✓ We will start for 8 of 8-inch HPDs in this year at first!

200t tank
✓ Prepared by EGADS collaboration
✓ For verification study of Gd doped water Cherenkov detector to catch $\nu$ by tagging neutrons with Gd.

Be replaced with HPDs

---

20-inch PMT (Total: 240) @ Kamioka
### Schedule of HPD R&D

<table>
<thead>
<tr>
<th>Year</th>
<th>Season</th>
<th>8 inch HPD</th>
<th>20 inch HPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Spring</td>
<td>Proof test 200t tank</td>
<td>Performance Evaluation (detail)</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td>Proof Test in 200t tank</td>
</tr>
<tr>
<td>2015</td>
<td>Spring</td>
<td></td>
<td>Uniformity • B-field/Temp. dependence</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td>Determine HK photo sensor !</td>
<td></td>
</tr>
</tbody>
</table>

Plan to finish our HPD study by 2016.
Summary

• Hybrid Photo-Detector (HPD) is being developed for Hyper-Kamiokande.

• **Prototype of the 8-inch HPD was developed and tested.**
  – The HPD shows **better performance** than PMTs.
  – **Durability for a month usage and safety operation in water** were checked.

  ➔ We will check feasibility of HPDs in 200t water tank since 2013

• The proof test and performance evaluation of both 8-inch and 20-inch HPD will continue until 2016. Our R&D has a possibility to improve the sensitivity of Hyper-Kamiokande by photo-sensor upgrades.
Backup
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Target Schedule**

- **Construction start** assuming budget being approved from JPY2016

- access tunnels, waste rock tunnels
- cavity excavation
- concrete, liner
- PMT support, PMT installation
- photo-sensor R&D
- preparation for glass valve, PMT production
- PMT production
- water filling
- Operation