New large aperture, hybrid photo-detector and photomultiplier tubes for gigantic water Cherenkov ring imaging detectors

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For Hyper-Kamiokande working group
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ICRR, Univ. of Tokyo., Kyoto Univ. ,Hamamatsu K.K.
Contents

• Goal of development of new photo-sensors
• Introduction of new photo-sensors for a gigantic water Cherenkov detector
• Overview of development
• Development status
  – Performance evaluation
  – The Proof-test in a water tank
• Future plan
• Summary
The goal of detector development

**New photo-sensor**

for gigantic water Cherenkov detector, mainly Hyper-Kamiokande.

| ID (50cm) | 99000 |
| OD (20cm) | 25000 |

We need...
- Low cost!
- High performance!

**Physics Topics**

- Neutrino physics/astrophysics
  - Long Baseline experiment
  - Atmospheric neutrino
  - Solar neutrino
  - Super Nova neutrino
- Proton decay

**Requirement**

- Wide energy range (GeV ~ MeV)
- Self trigger
- Short dead time
- Long Term Operation

- Wide range of p.e.
- 1 p.e. sensitivity
- ~ns time resolution
- Low dark rate
- Stability of performance
- Durability over 10 years
Principle of HK photo-sensors

Photo-sensors are provided by Hamamatsu K.K.

PMT

- 2kV dynode (Venetian Blind)
- New, but similar to old one

New!

HPD

- 8kV
- Avalanche Diode (AD) @Bias 300V (×400)
- New!

Higher Voltage ~8kV!

→ Some problem?

Low Risk!

Established technology

Experience of 10 years operation

Is there value to work for new sensors? → See benefit.

High Risk!
Performance of HK photo-sensors

All photo sensor has High QE (HQE) option! (22% → 30%)

<table>
<thead>
<tr>
<th>PMT R3600</th>
<th>PMT R12860</th>
<th>HPD R12850 (w/o amp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>$10^7$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>T.T.S.</td>
<td>~5.5ns (FWHM)</td>
<td>~2.7ns (FWHM)</td>
</tr>
<tr>
<td>C.E.</td>
<td>80%</td>
<td>93%</td>
</tr>
<tr>
<td>P/V @1p.e.</td>
<td>1.4</td>
<td>&gt;2.5</td>
</tr>
</tbody>
</table>

New technology must be verified. → **The Proof-test**

Expected better performance must be confirmed → **Performance evaluation**
• As a first step, we start with 20cmφ HPD and HQE R3600 (HQE cathode + old PMT).
  • We have started the first proof-test in this autumn.
• As a next step, HQE 50cmφ HPD and new type PMT are going to be prepared.
• We will select photo detector for HK by 2016
Contents of development

Both performance evaluation and the proof-test to use in a water tank are needed.

Performance evaluation

- All new photo sensor
  - 1 p.e. sensitivity
  - Timing resolution
  - Dark rate
  - Gain

- HPD only
  - Noise of avalanche diode
  - Rate tolerance of pre-amp

The Proof-test @ Kamioka mine, Japan

- Trial use of new photo-sensors in 200-ton water tank
- Check feasibility and few years stable operation.
- Establish detailed procedure to use new photo-sensors in a Cherenkov water tank.

Detailed performance (Gain)
- Temperature dependence
- Magnetic dependence
- Uniformity

R&D of ancillary equipment for HPD

- HV module, Pre-amp....
The prototype of 20cmφ HPD

Prototype of 20cmφ HPD

AD (5mmφ)

30cm

Preamp

~300V

Filter

AD

AD

8kV

HV Module

Water-proof Housing

LV Power Supply

① 10V

HV module power source

② 1~4V

Control of HV output

Gain: \( \sim 5 \times 10^7 \) @350V AD Bias

P/V : \( \sim 4 \)

Dark Rate

\( \sim 3 \text{kHz} \) @ 0.5 p.e.

1p.e. TTS \( \sigma = 0.86\text{ns} \)
The first study for HQE option

- HQE R3600 is prepared for the first proof test.
- About 30% QE is achieved.
- Dark Rate is most concerning issues related to HQE option.

Gain: $\sim 1\times 10^7$

P/V : $\sim 1.4$

*Consistent with NQE R3600

Dark Rate

$\sim 20\text{kHz} @ 0.25 \text{ p.e.}$

*0.25p.e. is standard threshold level for NQE R3600 in SK
Preparation for installation

- We checked basic performance and safety operation in water.
- We checked durability by 1 month operation without failure

Mass production of prototype
- Ten 20cmφ HPD
- Seven 50cmφ HQE R3600

Pre-selection
- Pre-calibration
- 1p.e. resolution and dark rate check → Comparable or better performance than NQE R3600
- Flasher check

Eight of 20cmφ HPD and five of 50cm HQE R3600 were installed.
Gain adjustment (Pre-calibration)

**HPD**
- Target gain is determined to get the best 1p.e. resolution
- Gain is tuned by tuning avalanche gain with fixed 8kV HV.

**HQE**
- Target gain is same level as NQE gain at 1p.e.
The proof test

• Construction was carried out from middle of Jul. to end of August.

• The first proof test start from Sep. 2013

• Eight of 20cmφ HPD and five of HQE R3600 are installed with 227 of NQE R3600.
The history of the first proof test until now

<table>
<thead>
<tr>
<th>Work history</th>
<th>Current PD status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aug.</strong></td>
<td><strong>PD</strong></td>
</tr>
<tr>
<td>• Pre-calibration</td>
<td><strong>Status</strong></td>
</tr>
<tr>
<td>• Photo-sensor</td>
<td>• HPV module failure</td>
</tr>
<tr>
<td>Installation</td>
<td>• High dark rate</td>
</tr>
<tr>
<td>• DAQ, slow monitor</td>
<td>• Low frequency noise</td>
</tr>
<tr>
<td>Preparation</td>
<td>◎</td>
</tr>
<tr>
<td><strong>Sep.</strong></td>
<td># of all HPDs</td>
</tr>
<tr>
<td>• 1p.e. measurement</td>
<td><strong>8</strong></td>
</tr>
<tr>
<td>• Dark Rate</td>
<td></td>
</tr>
<tr>
<td>• Calibration</td>
<td><strong>PD</strong></td>
</tr>
<tr>
<td>• 9MeV γ</td>
<td><strong>Status</strong></td>
</tr>
<tr>
<td>• Multi p.e.</td>
<td>• High dark rate</td>
</tr>
<tr>
<td>(Xe lump)</td>
<td>◎</td>
</tr>
<tr>
<td><strong>Oct.</strong></td>
<td># of all HQE R3600 PMT</td>
</tr>
<tr>
<td><strong>Nov.</strong></td>
<td><strong>5</strong></td>
</tr>
</tbody>
</table>
1 p.e. measurement

1p.e. can be seen in the tank with both HPD and HQE PMT.

- **HPD**:
  - Pedestal (w/ >1.5mV cut)
  - 1 p.e. Resolution ~30% (σ)
  - 1 p.e. region

- **HQE/NQE**:
  - 1 p.e. Resolution ~50% (σ)

**Timing resolution @1p.e.**

- **20cmφ HPD**
- **50cmφ HQE**
- **50cmφ NQE**

- **HPD**: 1.2ns (σ)
  - HPD shows better resolution than other photo-sensors
HPD Multi p.e. measurement

Multi p.e. can be recognized by HPD due to its good p.e. separation.

Measurement Setup

External trigger

W/o light source

1 p.e. 2 p.e. 3 p.e. 4 p.e.

Linearity

Resolution

Number of Photoelectrons

\[ \chi^2 / \text{ndf} \]

\[ \Delta \text{Prob} \]

\[ p0 \]

\[ p1 \]

\[ 0.07892 \pm 0.01833 \]

\[ 3.722 \pm 0.01093 \]

\[ 0.008992 \pm 0.001479 \]

\[ 0.00376 \pm 0.009764 \]

\[ 13.03 / 2 \]

\[ 0.0635 \pm 0.00088982 \]

\[ -0.09754 \pm 0.007676 \]
Dark Rate

- At each threshold level dark rate of six HPDs are lower than average dark rate of NQE PMT.
- HQE PMT dark rate is still high.
  1. HQE need longer time to stabilize? → Confirm few month later.
  2. The first HQE large aperture PMT → Improve by sophistication of production process?

**Dark Rate Distribution @ End of Nov.**

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 cmφ HPD</td>
<td>-4 mV</td>
</tr>
<tr>
<td>50 cmφ HQE</td>
<td>-1 mV</td>
</tr>
<tr>
<td>50 cmφ NQE</td>
<td>-1 mV</td>
</tr>
</tbody>
</table>

* Gain: ~1.5×10^7
HQE gain is tuned to get same charge as NQE with multi p.e. light,
Next step

20cmφ HPD, HQE R3600 Proof-test
• Basic performance in the tank will be confirmed by end of this year.
  • 1p.e. resolution, timing resolution, QE
• Rate and light yield of flasher will be check by end of this year.
  → Feedback to 50cmφ HPD development.
  → HV module & pre-amplifier improvement
• The long term stability of gain and dark rate will be measured.

50cmφ HQE HPD (R12850) new type 50cmφ HQE PMT(R12860)
• Hamamatsu K.K. are going to prepare and we are starting measurement.

For All new photo-sensors
• Detail measurement
Summary

• We have been developing new high QE photo-sensors for Hyper-Kamiokande project.
• We have started the first proof-test of 20cm φ HPDs and high QE R3600 in 200-ton water tank.
  – HPDs show better performance such as timing resolution and 1p.e. resolution.
  – A HPD failure happens because of HV module problem.
  – All HQE PMTs are working and show similar performance to NQE PMTs except for dark rate. It may need more time to stabilize.
  – We keep monitoring to confirm stable operation including stability check of gain and dark rate.
• As next step, HQE 50cm φ HPDs and B&L type PMTs will be measured from this or next month for the proof test.
• Detailed performance evaluation and study of AD, HV module and pre-amplifier are starting.
• HK photo-sensor will be selected by 2016
QE measurement
Safety check

• 簡単に結果を書くべき？
• 書くなら，proofテストの前か？
Issues

• Flasher study
  – HPD needs higher voltage than PMTs,

• Pre-amplifier improvement, HV module R&D is ongoing.

• AD noise study
The current status of first proof test

Current work

<table>
<thead>
<tr>
<th>Month</th>
<th>Tasks</th>
</tr>
</thead>
</table>
| Aug.  | • Pre-calibration
| Sep.  | • Photo-sensor Installation
| Oct.  | • DAQ, slow monitor preparation
| Nov.  | • 1p.e. measurement
|       | • Dark Rate
|       | • Calibration
|       | • 9MeV γ
|       | • Multi p.e. (Xe lump)

<table>
<thead>
<tr>
<th>PD Serial#</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHD0073</td>
<td>× HV module failure</td>
</tr>
<tr>
<td>EHD0074</td>
<td>○ High dark rate</td>
</tr>
<tr>
<td>EHD0078</td>
<td>○ External noise</td>
</tr>
<tr>
<td>EHD0080</td>
<td>◎</td>
</tr>
<tr>
<td>EHD0083</td>
<td>◎</td>
</tr>
<tr>
<td>EHD0091</td>
<td>○ Low frequency noise</td>
</tr>
<tr>
<td>EHD0092</td>
<td>○ High dark rate</td>
</tr>
<tr>
<td>EHD0095</td>
<td>◎</td>
</tr>
<tr>
<td>ZP0007</td>
<td>○ High dark rate</td>
</tr>
<tr>
<td>ZP0012</td>
<td>○ External noise</td>
</tr>
<tr>
<td>ZP0015</td>
<td>◎</td>
</tr>
<tr>
<td>ZP0021</td>
<td>○ External noise</td>
</tr>
<tr>
<td>ZP0022</td>
<td>◎</td>
</tr>
</tbody>
</table>