Hamamatsu 8-inch HPD R12112
New Preamplifier Test

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Photosensor Workshop in Chiba
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Why Hamamatsu 8-inch HPD?

- Next generation photo detector but not too fancy
- Good charge resolution and time resolution
- Need preamplifier
- Strong temperature dependency

![Example HPD](image1.png)

**Diagram:**
- PMT
- HPD
- Preamplifier board

**Graphs:**
- Frequency vs. counts (counts/dl)
- Output Pulse Height (ch)
  - 1 pe
  - 2 pe
  - 3 pe
  - 4 pe
  - 5 pe
Hamamatsu 8-inch HPD (R12112) HQE with pre-installed preamplifier (by Hamamatsu Photonics)

QE curve: max 35.7%

Output signal
(1, 2, 3 photons peaks are visible!)

~60ns
Akimichi developed compact preamplifiers...
A few PEs pulse with New Amplifier (AMP9a-I)

Higher gain!
No overshoot!

~40ns
Higher gain!

No overshoot!
Maximum LV control value

LVCont. 1.0V (256V)

LVCont. 1.1V (282V)

LVCont. 1.2V (308V)

LVCont. 1.3V (334V)
Charge distribution

![Graphs showing charge distribution]

- Top graph: Peak Voltage [V] vs. count
- Middle graph: Charge [C] vs. count
- Bottom graph: Charge/e (NPEs) vs. count
Setting (all at 20\(^\circ\)C)

- Pico pulse laser:
  - SAWAKI FOLS-12 405nm
  - Pulse width: 500ps

- ND Filter

- PC:
  - IWATSU DS-5534 350MHz/2GS/s
Waveform Data

Fitting Function = pedestal_gauss + signal_gauss + shoulder_exponential
Trigger Efficiency (0.25PE threshold)

HV.Cont. 3.2V, LV.Cont. 1.2V

\[ \chi^2 / \text{ndf} = 219.9 / 82 \]

\[
\begin{align*}
 p0 &= 2050 \pm 23.1 \\
p1 &= -2.863e-15 \pm 7.949e-15 \\
p2 &= 6.985e-13 \pm 4.967e-15 \\
p3 &= 108.8 \pm 4.9 \\
p4 &= 1.478e-11 \pm 4.562e-14 \\
p5 &= 1.216e-12 \pm 3.091e-14 \\
p6 &= 3.796 \pm 0.037 \\
p7 &= 6.968e+10 \pm 5.408e+09 \\
p8 &= 1.265e-11 \pm 8.489e-14 
\end{align*}
\]

total charge = 9.68509e-10
triggered charge = 9.28388e-10
ratio = 0.958574
Charge Resolution and Gain

BLUE     Temp. 20C, LV Cont. 1.00V
GREEN    Temp. 20C, LV Cont. 1.10V
RED      Temp. 20C, LV Cont. 1.20V

Charge resolution

Gain

1x10^8

5x10^7
Charge distribution

<table>
<thead>
<tr>
<th>Charge</th>
<th>LV Cont.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td>1.00V</td>
</tr>
<tr>
<td>GREEN</td>
<td>1.10V</td>
</tr>
<tr>
<td>RED</td>
<td>1.20V</td>
</tr>
</tbody>
</table>

Chi-squared / ndf: 219.9 / 82

Parameters:
- $p_0 = 2050 \pm 23.1$
- $p_1 = -2.863 \times 10^{-15} \pm 7.949 \times 10^{-15}$
- $p_2 = 6.985 \times 10^{-13} \pm 4.967 \times 10^{-15}$
- $p_3 = 108.8 \pm 4.9$
- $p_4 = 1.478 \times 10^{-11} \pm 4.582 \times 10^{-14}$
- $p_5 = 1.216 \times 10^{-12} \pm 3.091 \times 10^{-14}$
- $p_6 = 3.796 \pm 0.037$
- $p_7 = 6.968 \times 10^{-10} \pm 5.406 \times 10^{-09}$
- $p_8 = 1.285 \times 10^{-11} \pm 8.489 \times 10^{-14}$

Charge resolution

BLUE, LV Cont. 1.00V
GREEN, LV Cont. 1.10V
RED,  LV Cont. 1.20V
Cf: Hamamatsu Preamplifier @ -30°C

Gain (with pre-amp)

5x10^7

Charge Resolution

IceCube PMT
Timing resolution
Timing Resolution

Signal timing:
Fixed threshold 5mV (corresponds 0.25 PE)

Trigger Timing:
Get the down slope and take the timing of half of pulse height

Signal time = Signal timing - Trigger Timing
Timing Resolution

Histograms of signal times sliced in charge bins.
Timing Resolution (cont'd)

preliminary

low statistics...
Timing Resolution

The graph shows the timing resolution as a function of the mean charge in the bin. The preliminary results indicate that the timing resolution improves as the mean charge increases, with lower values at higher mean charges. However, the plot also highlights that the results are based on low statistics, which might affect the reliability of the conclusions drawn from the data.
Cf: Hamamatsu Preamplifier

- Time resolution at low temperature: 2.1ns ~ 2.4ns
- Not too bad compared with IceCube PMT (2ns on average)
- Could be improved by removing noise from ground line
- Very mild temperature dependence, stable at least within -25~-35 degrees

<table>
<thead>
<tr>
<th>Temperature</th>
<th>-36 °C</th>
<th>-32 °C</th>
<th>-26 °C</th>
<th>+5 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV Cont.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.8 V</td>
<td>2.1</td>
<td>2.4</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>3.0 V</td>
<td>2.3</td>
<td>2.3</td>
<td>2.1</td>
<td>2.8</td>
</tr>
<tr>
<td>3.2 V</td>
<td>2.1</td>
<td>2.1</td>
<td>2.1</td>
<td>2.6</td>
</tr>
</tbody>
</table>

※LV Cont. is fixed at 0.8 V
Dark noise rate
Noise Rate at Room Temp (30.6°C) with Hamamatsu Preamplifier

![Graph showing noise rate at 30.6°C with different HV control values and threshold settings.]

- **Noise Rate at 30.6°C**
- **HV Control Value (V)**
- **LV Control**
  - 0.7V
  - 0.8V
  - 0.9V
  - 1.0V
- **Noise Rate Hz (threshold 10mV)**
- **500Hz**
- **8kV HV**
- **9.54kV HV**
Noise Rate with New Preamplifier

......

I couldn't make it by this workshop!
Summary

- New preamplifier developed by Akimich Taketa performed better than Hamamatsu preamplifier with:
  - No weird tail shape
  - Higher gain even at the room temperature
  - Better charge resolution
  - Comparable timing resolution (or may be better, need to measure Hamamatsu preamplifier with the same measurement system)
- All features are improved from IceCube 10inch PMT
- Comparisons with new 8inch PMT are not done yet
Next calibration plans

• Dark noise rate

• Currently signal waveform is quite sensitive to background noises (e.g. room light, PC power, etc.). Need to shield the black box more tightly.

• Dynamic range

• Repeat all series of measurements with different temperatures (Hybrid Photo Detectors are very sensitive with operation temperature)
Back up
• HPD requires two control voltages:
  • For bombardment: 8kV~10kV (HV control voltage: 2.8~3.5V)
  • For avalanche: 200~300V (LV control voltage: 0.8~1.1V)
R & D at Low Temperature

• The HPD R12112 is designed for Hyper-K muon veto detector, therefore no low-temperature characteristics is measured.

• At ERI, following characteristics are measured in several low temperatures.
  • Check electric discharge
  • Measuring noise rate with several couplings of Low Voltage and High Voltage
  • Measuring charge response function of one photo electron
  • Measuring gain curve
Experimental Setup (Noise Rate)

- Oscilloscope
- Analog Divider
- Discriminator (5.4mV thres.)
- Clock Generator
- Pulse Count
- Clock Count

Temperature Data Logger
Freezer
Black Box
Noise Rate at -30.5°C

![Graph showing noise rate at different HV control voltages and LV control voltages at -30.5°C.](image)

- Noise Rate at -30.5℃:
  - 500 Hz threshold
  - HV Control (V):
    - 2.8V (8kV HV)
    - 3.35V (9.4kV HV)
  - LV Control:
    - 0.8V
    - 0.85V
    - 0.86V
    - 0.87V
    - 0.88V
    - 0.89V
    - 0.90V

- Graph highlights the relationship between noise rate (in Hz) and HV control voltage, with different curves for each LV control voltage.
Noise Rate at -30.5°C

HV Control (V)

LV cont. > 0.87 V

LV cont. < 0.87 V

High HV
Noise Rate at -34.5°C

![Graph showing noise rate vs. HV control voltage at -34.5°C. The graph includes four lines representing different LV control voltages: 0.7V, 0.8V, 0.85V, and 0.86V, and 0.87V. The HV control voltage ranges from 2.30 to 3.50 V. The graph indicates that at 500Hz, the noise rate is approximately 3.15V (8.85kV HV).]
Operation Voltage Range

- At low temperature:
  - Noise rate is stable (< 300Hz) between HV cont. 2.8V ~ 3.15V
  - However, suddenly electric discharge (noise rate > 100 kHz) starts at higher HV control value
  - At higher anode bias voltage (LV control), noise rate increases up to kHz range
  - Optimal LV cont. range and HV cont. range is sensitive to temperature
- For -25~ -35 degrees, following control voltage range may be safe to test
  - LV control voltage : up to 0.85V
  - HV control voltage : up to 3.1V
Gain and Charge Resolution

- Measured with temperatures -25C and -35C
- Two different LV Control voltage were sampled
  - 0.80V -- Anode Bias Voltage (avalanche voltage) 203.16 V
  - 0.85V -- Anode Bias Voltage (avalanche voltage) 216.28 V
- Three HV Control voltages are sampled
  - 2.7V -- Photocathode Voltage (bombardment voltage) 7617 V
  - 2.9V -- Photocathode Voltage (bombardment voltage) 8166 V
  - 3.1V -- Photocathode Voltage (bombardment voltage) 8714 V
Experimental Setup (Charge Resolution)

- Function Generator
- LED Trigger 10kHz
- Temperature Data Logger
- LED
- Freezer
- Oscilloscope
- Trigger
- Signal
- PC (waveform)
- Black Box
Time Resolution measurement

- Measured with two IceCube DOM main board and Hamamatsu Pico Pulser

Hamamatsu C8898 → Sync. out → DOM MB 1 → Coincidence → DOM MB 2 → Freezer

Signal Out

changed negative signal to positive
Summary

• Strong dependence between temperature and total gain, operation voltages

• Total gain (after pre amplifier) : $6 \times 10^7$

• Charge Resolution is less than 15% : more than 2 times better than IceCube PMT

• Noise rate : $\sim 250$ Hz :

• Time resolution : 2.1~2.4ns

• Need detailed calibration in each temperature range to adjust anode bias gain (LV Cont)

Hamamatsu R12112 could be an alternative of PMT
Next plan

• Improve pre-amplifier

• Need to make a compact connector (if we try to put R12112 to D-Egg shell...)

• Akimichi Taketa (@ ERI) developed the first module! (will be tested in this summer)

• Check heat emittance

• Check power consumption

• Check robustness

• Put the result to simulation and estimate effects to reconstruction at GeV range (for Neutrino Oscillation Tomography of Earth's core)
Fit Results

<table>
<thead>
<tr>
<th>Color</th>
<th>Temp.</th>
<th>LV Cont.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td>-30C</td>
<td>0.80V</td>
</tr>
<tr>
<td>GREEN</td>
<td>-30C</td>
<td>0.85V</td>
</tr>
<tr>
<td>RED</td>
<td>-35C</td>
<td>0.80V</td>
</tr>
<tr>
<td>Magenta</td>
<td>-35C</td>
<td>0.85V</td>
</tr>
<tr>
<td>Khaki</td>
<td>-25C</td>
<td>0.80V</td>
</tr>
<tr>
<td>Yellow</td>
<td>-25C</td>
<td>0.85V</td>
</tr>
</tbody>
</table>
Control Voltage vs Output Voltage (fitted)

\[ \text{Photocathode HV} = 208.5 + 2744 \times x \]

\[ \text{Anode Bias LV} = -6.844 + 262.5 \times x \]
Operation HV control range:
2.8 V (8KV HV) ~ 3.5V (10KV HV)


- Operation LV control range:
  0.8V (200V LV) ~ 1.1V (300V LV)
The 1st trial (early 2015)

- Too much noise (~100kHz) and electric discharge!!

- Hamamatsu tried to fix it, but eventually they send us a replacement. (Because it's hard to fix it once heavy electric discharge happens? We don't know why.)
New HPD 2016 (Serial No.EHD0132)

- Noise Rate: 
  ~250 Hz at -30°C

- IPE Pulse Height: 
  ~10mV

- Charge resolution: 10%

- Large temperature dependence

- Heat?