Summary of calibration on ground and the application to flight data

Waseda Univ.
Shoji Torii,
Y. Asaoka and Y. Akaike

Notice: This technical data is furnished on the condition that it will be used by and disclosed to the receiving Cooperating agency and its contractors and sub contractors only for the purposes of fulfilling the cooperating agency's responsibilities under the Space Station Intergovernmental Agreement (IGA) and Memorandum of Understanding (MOU).
It shall not be used for any other purpose, nor disclosed or retransferred to any other entity or government without prior written permission of the Japan Aerospace Exploration Agency (JAXA).
Calibration done on ground for Flight Model

- Muon run (by Y.Akaike)
  - Pedestal
  - One MIP peak
  - S/N for one MIP
  - Check for low gain channels

- Calibration necessary on-board by protons and/or heavy nuclei
  - Position dependence
  - Temperature dependence
    - Temperature distribution will be given by an exact thermal analysis using the real data during thermal-vacuum test
  - MIP peak dependence on the rigidity cut-off (i.e. mostly latitude)

- Laser calibration for TASC PWO’s (by Y.Asaoka)
  - Relation between APD-high/low and PD-high/low was measured by UV Laser in dynamic range of several MIPs – $10^6$ MIP
  - Especially, in region of APD signal overflow, the PD signal is affected by small cross talk (~0.1%), which causes a signal equivalent to PD due to the gain difference of about 1000.
    Preliminary fitting curves are given for each channel.

N.B. All of the results shown are PRELIMINARY.
IMC calibration

- Anode
  - Pedestal
  - r.m.s noise
  - Pulse height distribution of muon signals
  - Distribution of hit numbers in each channel

- Dynode sum for Trigger
  - Pulse height distribution of muon signals
Mean of IMC Pedestal

Period: 1

X1  Y1
X2  Y2
X3  Y3
X4  Y4
X5  Y5
X6  Y6
X7  Y7
X8  Y8

CALET-TIM@Pisa
Sigma of IMC Pedestal

Period. ①

X1

X2

X3

X4

X5

X6

X7

X8

Y1

Y2

Y3

Y4

Y5

Y6

Y7

Y8

15/06/24

CALET-TIM@Pisa
An example of Muon signal

![Graph showing counts vs. ADC with different event selections and fit parameters.](graph.png)

- all events
- selected events by tracking
- Fit (Landau convoluted Gaussian)

Summary statistics:
- Entries: 1921840
- Mean: 0.5366
- RMS: 9.261
MPV of IMC muon signals

HV = -800V
Distribution of hit numbers in each channel (X-side)

X1-308
( an example of normal channel)

Pulse height distribution

X1-308

X3-128

X3-288

X4-004

X7-224

“low gain” channels

CALET-TIM@Pisa
Distribution of hit numbers in each channel (Y-side)

Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8

“low gain” channels

15/06/24

CALET-TIM@Pisa
**IMC Dynode**

HV: -800V

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>MPV [ADU]</th>
<th>MPV [ADU]</th>
</tr>
</thead>
<tbody>
<tr>
<td>319.6</td>
<td>329.0</td>
<td>330.5</td>
<td>314.3</td>
<td>320.2</td>
<td>328.2</td>
<td>338.5</td>
<td>320.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary of IMC calibration

• In IMC, most of the anode signals achieve a significant S/N (~7) at ~800 V.

• Even if we supply 600V to X4 and Y4 layers, which is used for High Energy Shower Trigger, one MIP peak can be separated.

• The 7 channels (0.1% in number) are classified as “low gain channel” due to possible disconnection of Scifi to PMT.

⇒ the effect of number of “bad channel” to the detector performance is strictly evaluated (for review of development, see later)

• The gains are adjustable by changing HV supply in unit number of 5, 4 and 5 in each layer.

• The dynode sum signals have an excellent capability to trigger the events over 0.5 MIPs.
CHD calibration

- Pulse height distribution of muon signals
- Muon Peak pulse height (MPV)
- S/N ratio
Pulse Height Distribution
MPV of CHD
S/N of CHD

S: MPV of muon signal
N: r.m.s noise

Graph showing S/N vs channel (ch) with data points marked as X and Y.
Summary of CHD calibration

• CHD channels have excellent performance in overall for MIP calibration with a significant S/N (≈8) to select one MIP.

• Although two channels (Y12 and Y13) looks worse in S/N due to lower signal, these are adjustable by increasing the HV values since the HVs in CHD are supplied independently to each channel.
TASC calibration

- **X1 (PMT in high gain)**
  - r.m.s noise
  - Pulse height distribution of muon signals

- **X2-X8, Y1-Y8 (APD/PD in High gain)**
  - r.m.s. noize
  - Pulse height distribution of muon signals
    (examples of better S/N and worse S/N)
  - S/N distribution for APD high gain
RMS Noise (X1: PMT, X2-Y8: APD-H)

Due to increase of noise from 0.7 fC to 1.0 fC with a similar signal of one MIP (~2.0fC) after assembling, the S/N ratio becomes worse to 1.8 $\sigma$ from 2.8 $\sigma$ on average.
RMS Noise (X2-Y8:PD-H)

Noise is lower than APD on average. The noise in PD channel is not a problem since these are not used for calibration.
TASC X1 PMT high gain: Pulse height distribution by tracking (S/N~20)
TASC Y1 APD high gain: Noise and Signal distribution by tracking (S/N ~2: better layer)
TASC X3 APD high gain: Noise and Signal distribution by tracking (S/N=1~2, a few channels worse)
From our beam test experience, the PWOs with S/N >1.3 can be calibrated by protons.
Summary of TASC calibration

- TASC X1 PMT layer for trigger has excellent S/N ratio ~20. Since the HV of each PMT is independently supplied, the signal can be very similar between different channels.

- In TASC X2-X8 and Y1-Y8 APD high gain channels:
  - The S/N ratio distributes from 0.5 – 2.5 except one channel of 0.3.
  - The channels with S/N over 1.3 will be calibrated by protons, and these with S/N in 0.5-1.3 by Helium and heavier nuclei.
  - Some channels have a time-dependent noise caused at different set up by unknown reasons.

- In TASC X2-X8 and Y1-Y8 PD high gain channels, the noises are relatively smaller than APD.

N.B. The temperature condition was worse (one degree higher) due to malfunction of the ATCS system. Therefore, we can expect larger signals, and the 80% of PWOs will be calibrated by protons as expected in the other tests done at nominal temperature condition.
UV Laser Calibration
Result of UV Laser Calibration (Example)

By scanning pulse laser intensity through 6 order of magnitude, Four APD/PD output responses are measured in detail for all of 176 PWO logs

Cross talk from APD to PD
- After APD-CSA saturates, crosstalk proportional to input charge becomes significant.
- The response looks complicated in the Log-Log plot, but it is just a simple connection of two linear relations.
What is needed for TASC Energy Calibration

From On-Orbit Data
1 MIP at APD High Gain
- APD_H [ADU/MIP]
Relation between PD_H vs APD_L
- PD_H/APD_L

Calibration method:
APD: uJ to MIP using 1MIP
PD: uJ to MIP using 1MIP
and PD/APD coeff.
Calculate saturation point in MIP using APD-CSA saturation point and use coefficient with crosstalk after the saturation point.

From UV Laser Calibration Data
APD-CSA Saturation Point
- APD-L [ADU]
Coefficients
- APD_H [ADU/uJ]
- APD_L [ADU/uJ]
- PD_H [ADU/uJ]
- PD_H(S) [ADU/uJ]
- PD_L [ADU/uJ]
- PD_L(S) [ADU/uJ]

Estimated Error
- estimated error as a function of laser energy
Calibration of TASC using UV Laser

- All PD/APDs in CALET-TASC are calibrated using UV laser
  - Calibration data were taken for all 176 PWOS from a few MIP to $10^6$ MIP
  - Calibration parameters were retrieved using parameters described before

Example of UV Laser calibration data

- Input/output relation around APD-CSA saturation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{ah}$</td>
<td>$2.63 \times 10^7$</td>
</tr>
<tr>
<td>$k_{ai}$</td>
<td>$8.85 \times 10^5$</td>
</tr>
<tr>
<td>$k_{ph}$</td>
<td>$3.57 \times 10^4$</td>
</tr>
<tr>
<td>$k_{ph}^{sat}$</td>
<td>$6.29 \times 10^4$</td>
</tr>
<tr>
<td>$Q_{ph}^{sat}$</td>
<td>$2.96 \times 10^3$</td>
</tr>
<tr>
<td>$k_{pi}^{sat}$</td>
<td>$2.11 \times 10^3$</td>
</tr>
<tr>
<td>$Q_{pi}^{sat}$</td>
<td>$9.43 \times 10^1$</td>
</tr>
<tr>
<td>$E^{sat}$</td>
<td>$8.28 \times 10^{-2}$</td>
</tr>
</tbody>
</table>
Simulation study for impacts to detector performance by degradation of sensors
Gamma-ray 10GeV Angular resolution (IMC)

Acceptable up to 10% in total channel
Electron 100GeV energy resolution (TASC)

Acceptable up to 5 % (~10/192) in total channel
Gamma-ray 100GeV energy resolution (TASC)

Acceptable up to 5 % (~10/192) in total channel
e/p separation at 1 TeV (TASC)

Acceptable up to 5 % (~10/192) in total channel