UV Laser Calibration of TASC PD/APD

150624-26 CALET Science TIM

C&T, DH&A Japan: Y.Asaoka

Motivation (As a reminder)

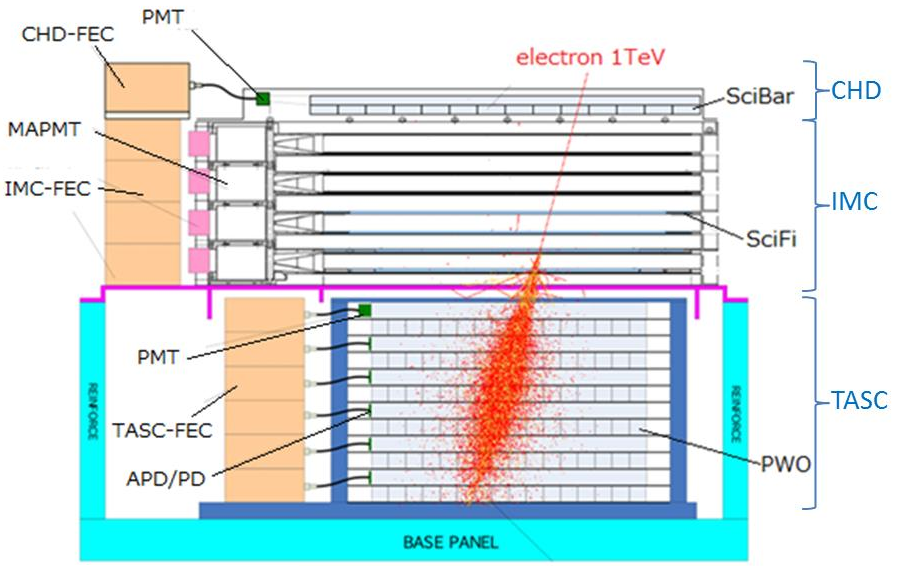
CALET Observation Target

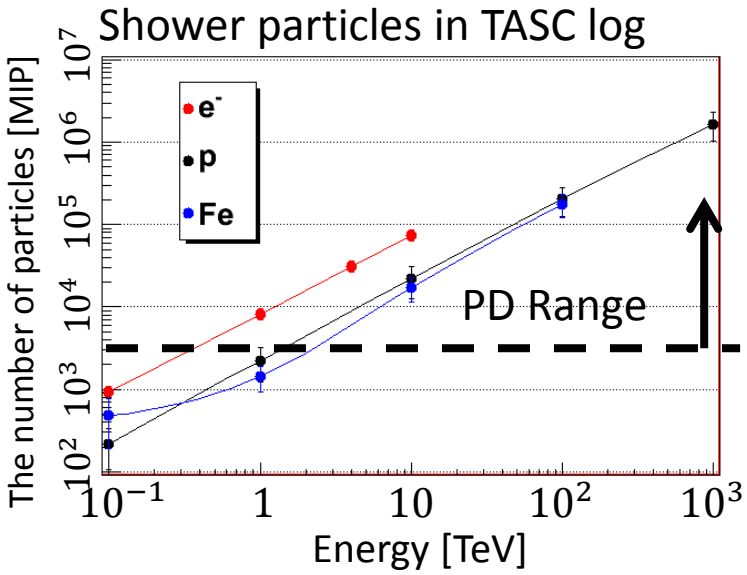
- Electron : 1 GeV – 20 TeV
- Gamma Ray : 4 GeV – 10 TeV
- Nuclei : several 10 GeV – 1000 TeV

TASC Capability

- ●Fine Energy Resolution
  - — 2% > 100GeV (electron)
- ●Powerful Particle ID
  - — proton rejection at 10^5
- ■Broad Energy Range
  - —6 digit dynamic range

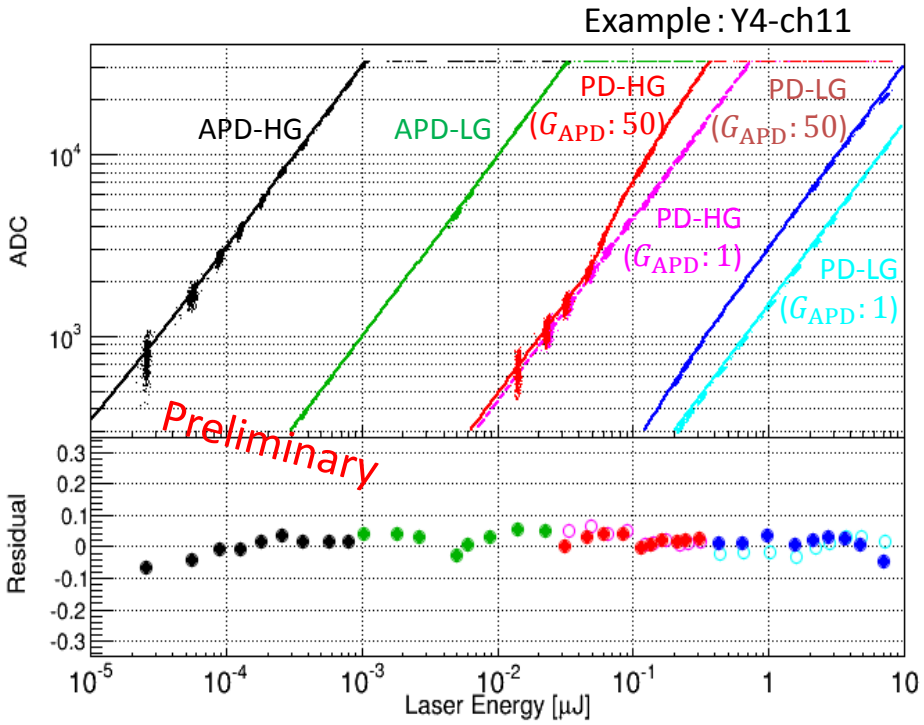
To confirm TASC function and end-to-end calibration, we performed UV pulse laser test to simulate the highest energy CR incidence.





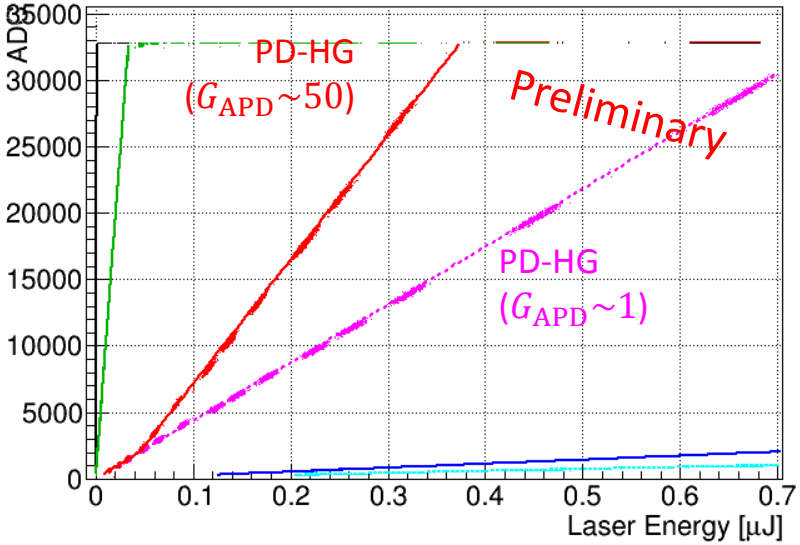
Result of UV Laser Calibration （Example）

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

What is needed for TASC Energy Calibration

From On-Orbit Data

$$
\begin{aligned}
Q_{ah} &= k'_{ah}E \\
Q_{al} &= k'_{al}E \\
Q_{ph} &= \begin{cases} k_{ph}E & \text{if } E < E'^{sat} \\ k_{ph}^{sat}(E - E'^{sat}) + Q_{ph}^{sat} & \text{if } E \geq E'^{sat} \end{cases} \\
Q_{pl} &= \begin{cases} k_{pl}E & \text{if } E < E'^{sat} \\ k_{pl}^{sat}(E - E'^{sat}) + Q_{pl}^{sat} & \text{if } E \geq E'^{sat} \end{cases}
\end{aligned}
$$

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

$$
\begin{aligned}
Q_{ah}^{\text{mip}} &= k'_{ah}E^{\text{mip}} \\
R &= \frac{k_{ph}}{k'_{al}}
\end{aligned}
$$

From UV Laser Calibration Data

$$
\begin{aligned}
Q_{ah} &= k_{ah}E \\
Q_{al} &= k_{al}E \\
Q_{ph} &= \begin{cases} k_{ph}E & \text{if } E < E^{sat} \\ k_{ph}^{sat}(E - E^{sat}) + Q_{ph}^{sat} & \text{if } E \geq E^{sat} \end{cases} \\
Q_{pl} &= \begin{cases} k_{pl}E & \text{if } E < E^{sat} \\ k_{pl}^{sat}(E - E^{sat}) + Q_{pl}^{sat} & \text{if } E \geq E^{sat} \end{cases}
\end{aligned}
$$

PD_E [ADU/uJ]

$$Q_{al}^{sat} = k_{al}E^{sat}$$

[ADU/uJ]

Estimated Error

- estimated error as a function of laser energy

REFERENCE: TASCCalibParams-rev141013.pdf

What is needed for TASC Energy Calibration

From On-Orbit Data

$$Q_{ah} = k'_{ah}E$$
$$Q_{al} = k'_{al}E$$
$$Q_{ph} = \begin{cases} k_{ph}E & \\ k_{ph}^{sat}(E - & \end{cases}$$
$$Q_{pl} = \begin{cases} k_{pl}E & \\ k_{pl}^{sat}(E - E^{sat}) + Q_{pl}^{sat} & \text{if } E \geq E^{sat} \end{cases}$$

Different coefficient is assumed between on-orbit and UV laser calibration
⇒ taking into account of the possible APD gain difference

From UV Laser Calibration Data

$$Q_{ah} = k_{ah}E$$
$$Q_{al} = k_{al}E$$
$$Q_{ph} = \begin{cases} k_{ph}E & \text{if } E < E^{sat} \\ k_{ph}^{sat}(E - E^{sat}) + Q_{ph}^{sat} & \text{if } E \geq E^{sat} \end{cases}$$
$$Q_{pl} = \begin{cases} k_{pl}E & \text{if } E < E^{sat} \\ k_{pl}^{sat}(E - E^{sat}) + Q_{pl}^{sat} & \text{if } E \geq E^{sat} \end{cases}$$

PD: uJ to MIP using 1MIP

$$Q_{ah}^{\text{mip}} = k'_{ah}E^{\text{mip}}$$

I PD/APD coeff.

$$R = \frac{k_{ph}}{k'_{al}}$$

uration point in MIP using APD-CSA saturation point and use coefficient with crosstalk after the saturation point.

$$Q_{al}^{sat} = k_{al}E^{sat}$$

[ADU/uJ]

[ADU/uJ]

Energy scale is determined here. TASC light yield is also calibrated using flight data

Estimated Error

- estimated error as a function of laser energy

RENCE: TASCCalibParams-rev141013.pdf

Parameters for TASC Energy Calibration

REFERENCE: TASCCalibParams-rev141013.pdf

$$
\begin{aligned}
Q_{ah} &= \alpha_{ah} N \\
Q_{al} &= \alpha_{al} N \\
Q_{ph} &= \begin{cases} \alpha_{ph} N & \text{if } Q_{ph} < Q_{ph}^{sat} \\ \alpha_{ph}^{sat}(N - N^{sat}) + Q_{ph}^{sat} & \text{if } Q_{ph} \geq Q_{ph}^{sat} \end{cases} \\
Q_{pl} &= \begin{cases} \alpha_{pl} N & \text{if } Q_{ph} < Q_{ph}^{sat} \\ \alpha_{pl}^{sat}(N - N^{sat}) + Q_{pl}^{sat} & \text{if } Q_{ph} \geq Q_{ph}^{sat} \end{cases}
\end{aligned}
$$

ah: APD-High gain, al: APD-Low gain
ph: PD-High gain, pl: PD-Low gain

$$
\begin{aligned}
\alpha_{ah} &= Q_{ah}^{\text{mip}} \\
\alpha_{al} &= \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
\alpha_{ph} &= R \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
\alpha_{pl} &= R \frac{k_{pl}}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
\alpha_{ph}^{sat} &= R \frac{k_{ph}^{sat}}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
\alpha_{pl}^{sat} &= R \frac{k_{pl}^{sat}}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
Q_{ph}^{sat} &= R Q_{al}^{sat} \\
Q_{pl}^{sat} &= R \frac{k_{pl}}{k_{ph}} Q_{al}^{sat} \\
N^{sat} &= \frac{Q_{al}^{sat}}{Q_{ah}^{\text{mip}}} \frac{k_{ah}}{k_{al}}
\end{aligned}
$$

R	Coefficient Ratio
Q^{mip}_{ah}	1MIP Peak
Q^{sat}_{al}	APD-CSA saturation point
k_{ah}, k_{al}, k_{ph}, k_{pl}	Coefficients of four gains.
k^{sat}_{ph}, k^{sat}_{pl}	Coefficients with crosstalk

Laser Energy to MIP Conversion:

$$E^{\text{mip}} = \frac{R}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}}$$

Parameters for TASC Energy Calibration

REFERENCE: TASCCalibParams-rev141013.pdf

$$
\begin{aligned}
Q_{ah} &= \alpha_{ah} N \\
Q_{al} &= \alpha_{al} N \\
Q_{ph} &= \begin{cases} \alpha_{ph} N & \text{if } Q_{ph} < Q_{ph}^{sat} \\ \alpha_{ph}^{sat}(N - N^{sat}) + Q_{ph}^{sat} & \text{if } Q_{ph} \geq Q_{ph}^{sat} \end{cases} \\
Q_{pl} &= \begin{cases} \alpha_{pl} N & \text{if } Q_{ph} < Q_{ph}^{sat} \\ \alpha_{pl}^{sat}(N - N^{sat}) + Q_{pl}^{sat} & \text{if } Q_{ph} \geq Q_{ph}^{sat} \end{cases}
\end{aligned}
$$

ah: APD-High gain, al: APD-Low gain
ph: PD-High gain, pl: PD-Low gain

$$
\begin{aligned}
\alpha_{ah} &= Q_{ah}^{\text{mip}} \\
\alpha_{al} &= \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
\alpha_{ph} &= R \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
\alpha_{pl} &= R \frac{k_{pl}}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
&= R \frac{k_{ph}^{sat}}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
&= R \frac{k_{pl}^{sat}}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}} \\
Q_{ph}^{sat} &= R Q_{al}^{sat} \\
Q_{pl}^{sat} &= R \frac{k_{pl}}{k_{ph}} Q_{al}^{sat} \\
N^{sat} &= \frac{Q_{al}^{sat}}{Q_{ah}^{\text{mip}}} \frac{k_{ah}}{k_{al}}
\end{aligned}
$$

R Coeffici

Q^{mip}_{ah} 1MIP P

Q^{sat}_{al} APD-CS

k_{ah}, k_{al}, k_{ph}, k_{pl}
Coefficients of four gains.

k^{sat}_{ph}, k^{sat}_{pl}
Coefficients with crosstalk

Number of particles in each TASC log can be calculated with these equations using ADC data from 4 gain channels.

Laser Energy to MIP Conversion:

$$E^{\text{mip}} = \frac{R}{k_{ph}} \frac{k_{al}}{k_{ah}} Q_{ah}^{\text{mip}}$$

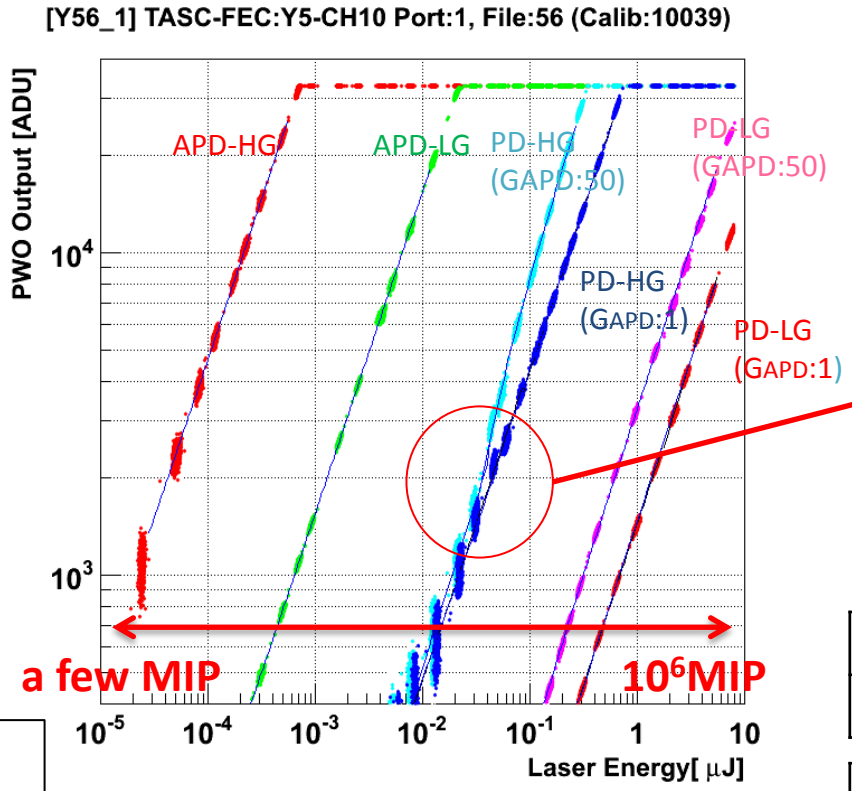
Calibration of TASC using UV Laser

◆ **All PD/APDs in CALET-TASC are calibrated using UV laser**

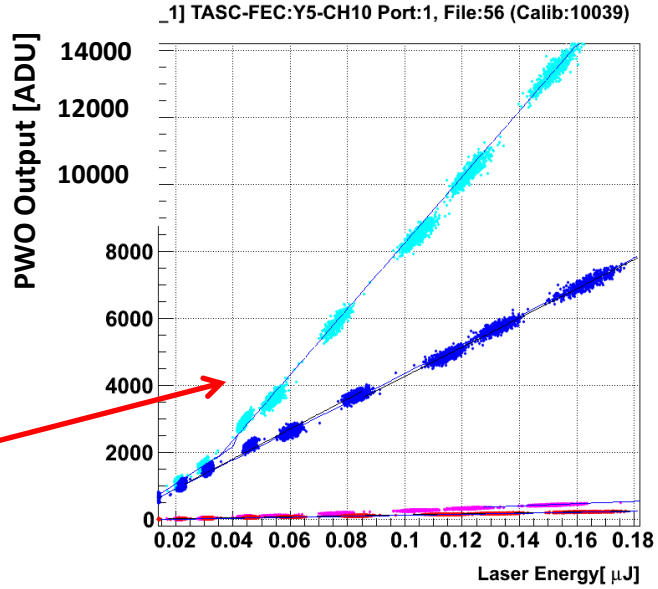
- Calibration data were taken for all 176 PWOS from a few MIP to 10^6 MIP

⇒ Calibration parameters were retrieved using parameters described before

Example of UV Laser calibration data



Input/output relation around APD-CSA saturation



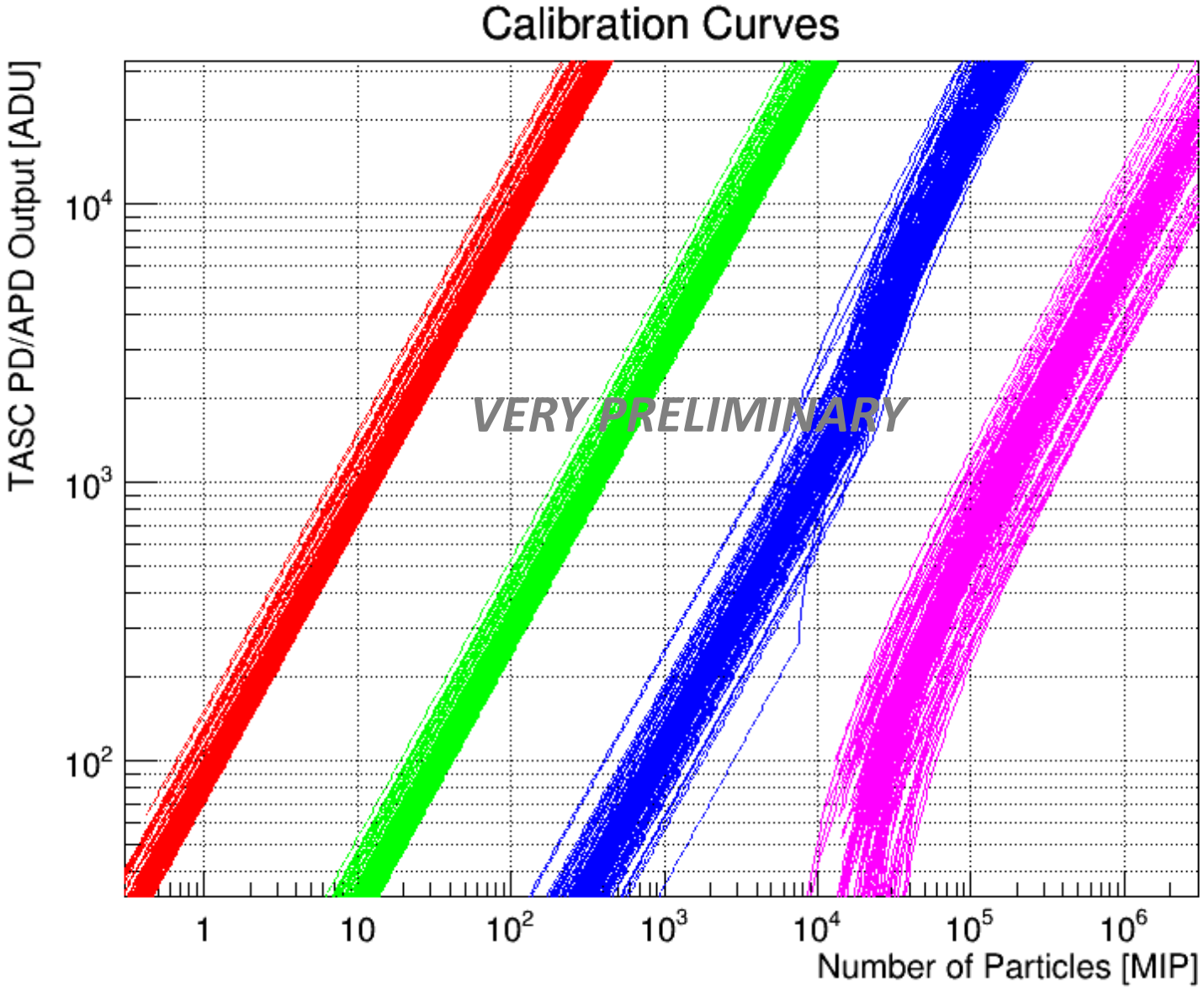
Calibration Parameters

k_{ah}[ADU/uJ]	k_{al}[ADU/uJ]	k_{ph}[ADU/uJ]	k_{ph}^{sat}[ADU/uJ]
2.63×10^7	8.85×10^5	3.57×10^4	6.29×10^4

Q_{ph}^{sat}[ADU]	k_{pl}^{sat}[ADU/uJ]	Q_{pl}^{sat}[ADU]	E^{sat}[uJ]
2.96×10^3	2.11×10^3	9.43×10^1	8.28×10^{-2}

TACS Dynamic Range Calibration using UV Laser

150703 rev.
using improved
MIP calib. params.

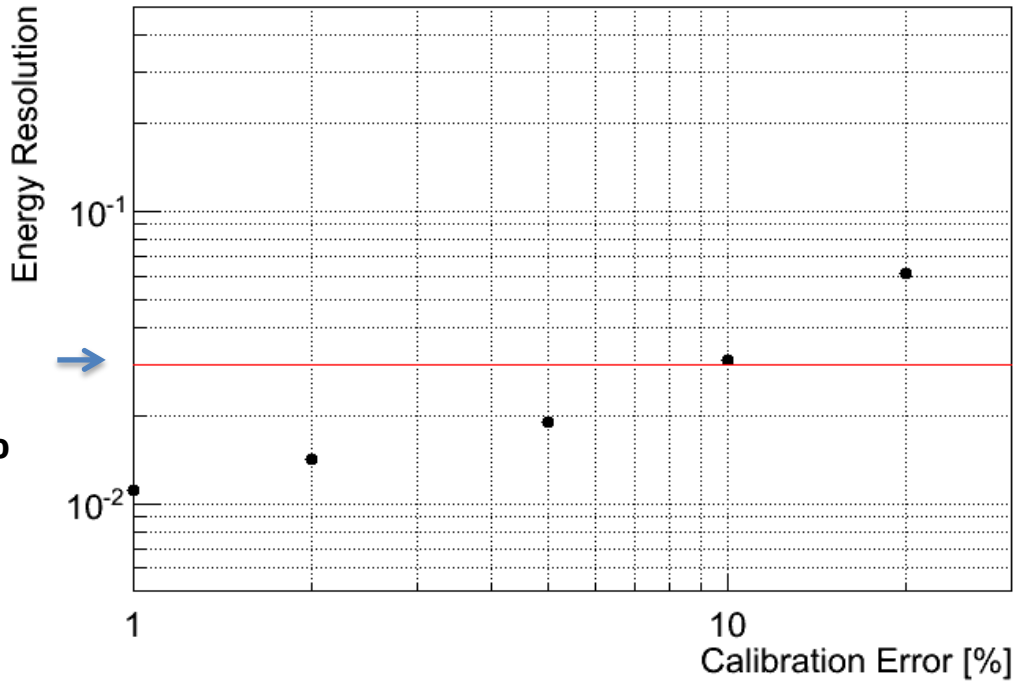


Effect of calibration error to energy resolution

◆ **Assume calibration errors to all channels（1-20%）**

- The influence of calibration error on TASC energy resolution is evaluated using simulation (electrons of 1TeV,68% Containment)

Energy Resolution vs Calibration Error:　electron 1TeV, 68%, simulation



Energy resolution: 3%

➢ **Target resolution of TASC ＝3%**

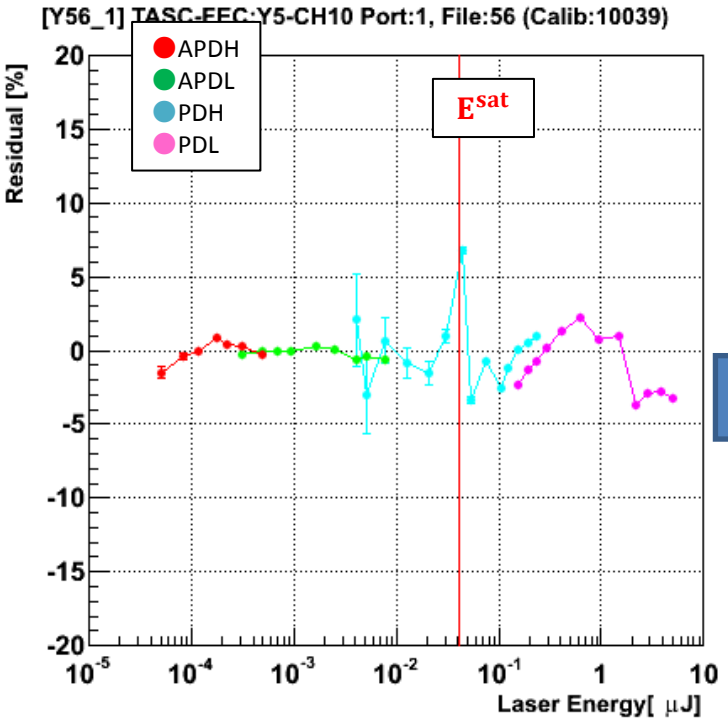
⇒ Calibration error is acceptable up to 10%

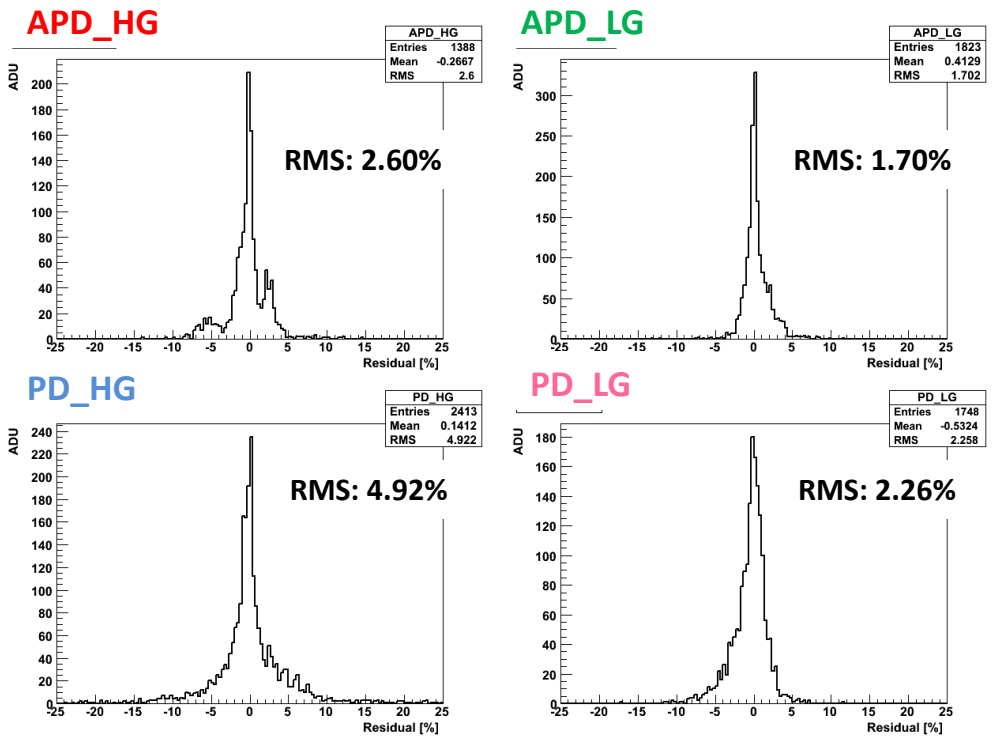
Residual from the calibration function

◆ **The residuals from the fit using UV laser calibration functions**

relative difference of data from calibration function

distributions of residuals for all PD/APDs are plotted in each gain range



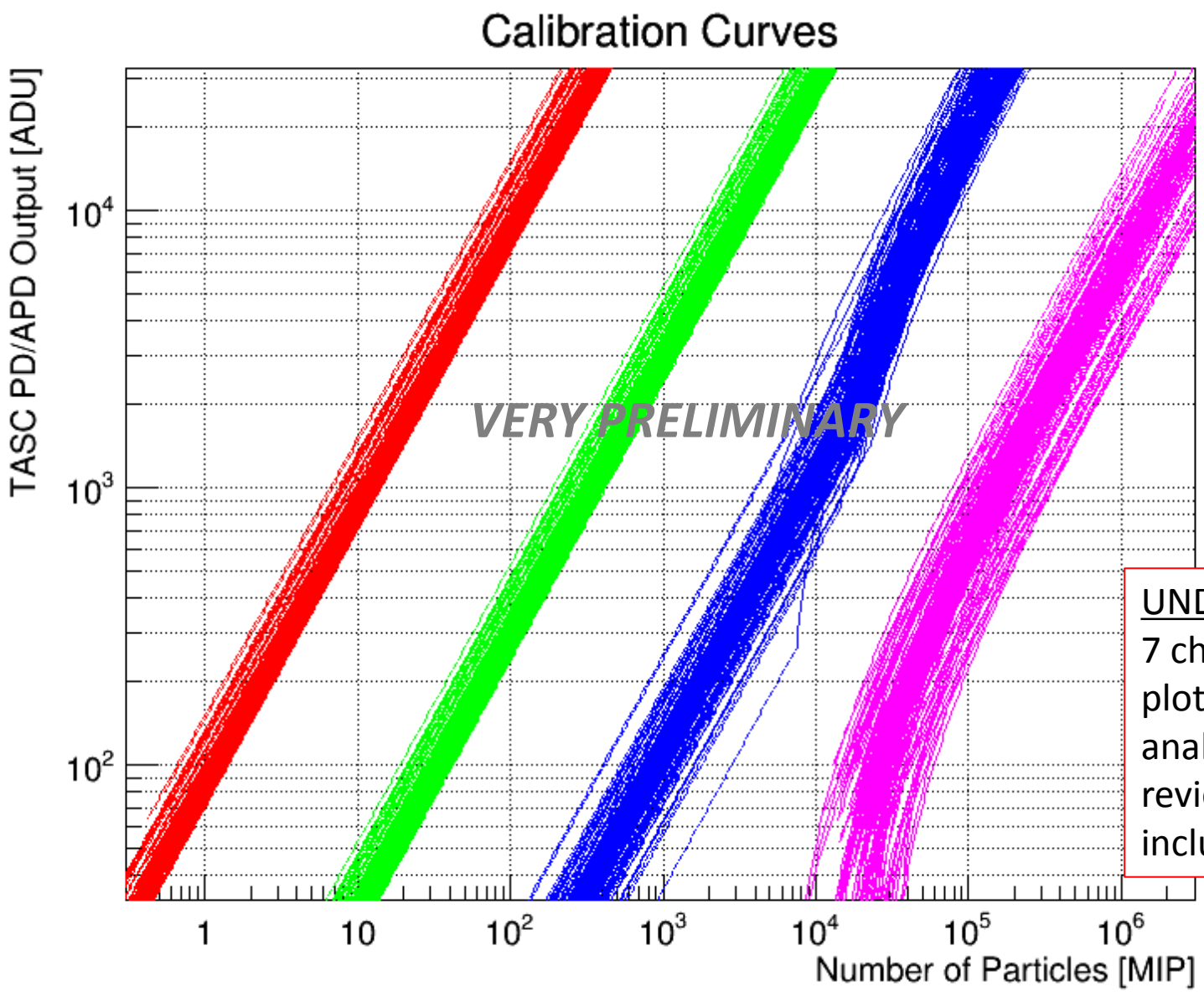


➢ **RMS of the residual distribution in each gain range is below 5%**

- Calibration error is less than 10%

⇒**It is possible to achieve 3% energy resolution**

TACS Dynamic Range Calibration using UV Laser



150703 rev.
using improved
MIP calib. params.

UNDER INVESTIGATION
7 channels are not plotted because of analysis issue. We will review all the results including other channels.

Distribution of Calibration Results

1. [Assign (%8.8X)] [list of fitted parameters %.3e)
   - Coefficients
     - k_aph [ADU/uJ]
     - k_apl [ADU/uJ]
     - k_pdh [ADU/uJ]
     - k_pdh^sat [ADU/uJ]
     - k_pdl [ADU/uJ]
     - k_pdl^sat [ADU/uJ]
   - APD-CSA Saturation Point
     - E_sat [uJ]

     (Following parameters are removed because of redundancy)
     - Q_ph^sat [ADU] = k_pdh*E_sat
     - Q_pl^sat [ADU] .= k_pdl*E_sat

   – for all 16x11 = 176 channels
2. Estimated Errors (under investigation)
3. preliminary result will contain 1. only.

Distribution of Calibration Results

1. [Assign (%8.8X)] [list of fitted parameters %.3e)
   - Coefficients
     k_anh [ADU/uJ]

- Although parameters themselves are ready to be distributed, we found that some of the fitting need to be revisited.
- To avoid not necessary confusion, we would like to postpone the distribution of the TASC dynamic range calibration parameters.
- The extended deadline for distribution would be end of July .

2.
3. preliminary result will contain 1. only.