# CTAO 報告 245: CTAO大口径望遠鏡のサチュレーションしたPMT波形信号の解析手法の改善

CTAO | LST COLLABORATION

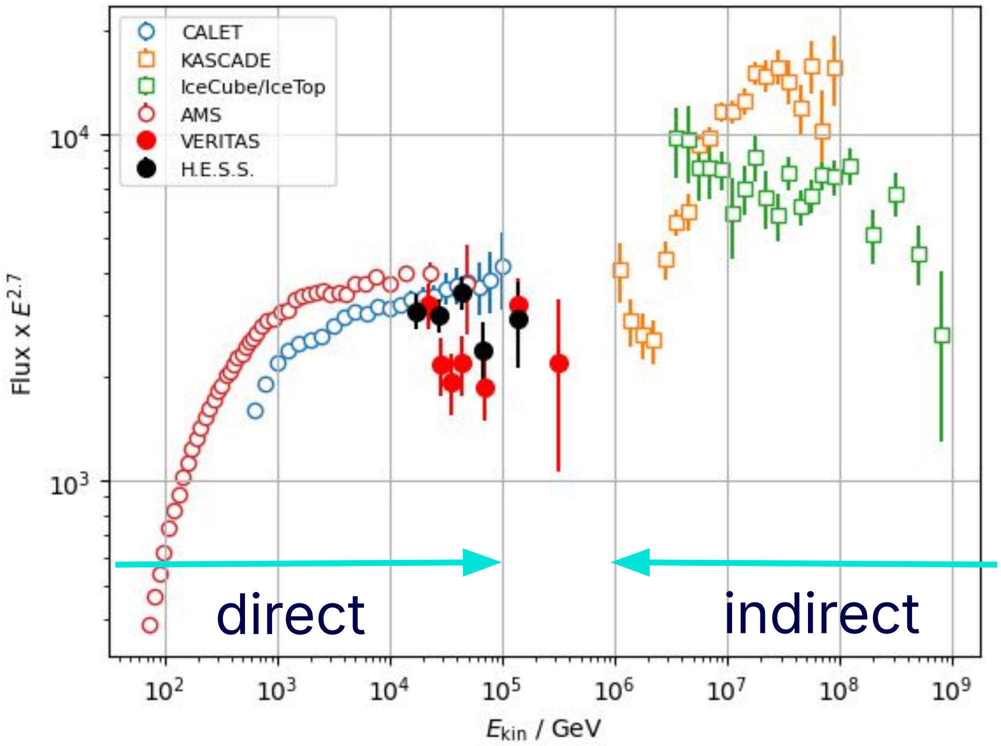
## CTAO report 245: Improving saturated pulse analysis for the Large-Sized Telescope of the CTAO

**Seiya Nozaki (ICRR)**
Y. Inome, H. Ohoka, H. Kubo, S. Gunji, T. Saito, Y. Suda, T. Nakamori,
M. Hashizume, M. Mizuno, T. Yamamoto on behalf of the CTAO-LST project

# Cosmic ray measurement at TeV–PeV

- **Mass composition of TeV-PeV Cosmic Ray (CR)** is crucial to understand the acceleration mechanism and source of Galactic CR
- **Spectral hardening and softening** are observed on the spectrum by multiple experiments
- **sub-PeV range is a gap** between direct and indirect measurements

Cosmic Ray Iron spectrum



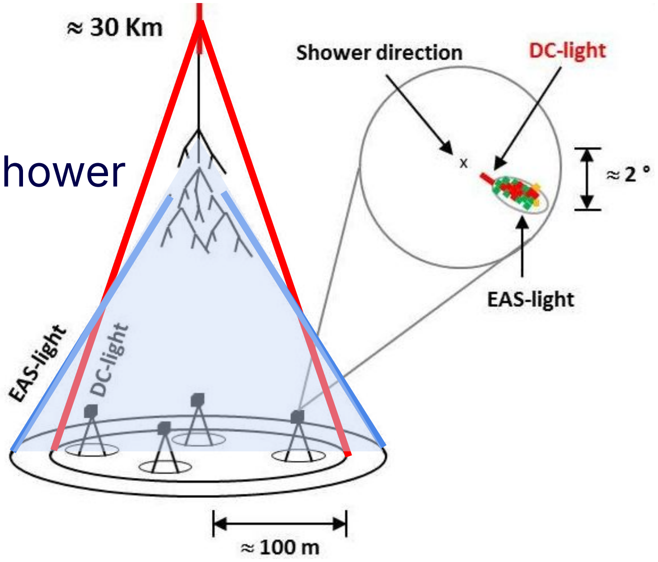
# Direct Cherenkov technique

- Cosmic ray particle itself emits Cherenkov light (Direct Cherenkov: DC) before the first interaction
  - DC light $\propto Z^2$: Iron DC is very bright (1000-3000 pe) and the pulse can be saturated
  - Emitted photon (DC and/or shower) can be more than $10^4$ pe at high energy CR

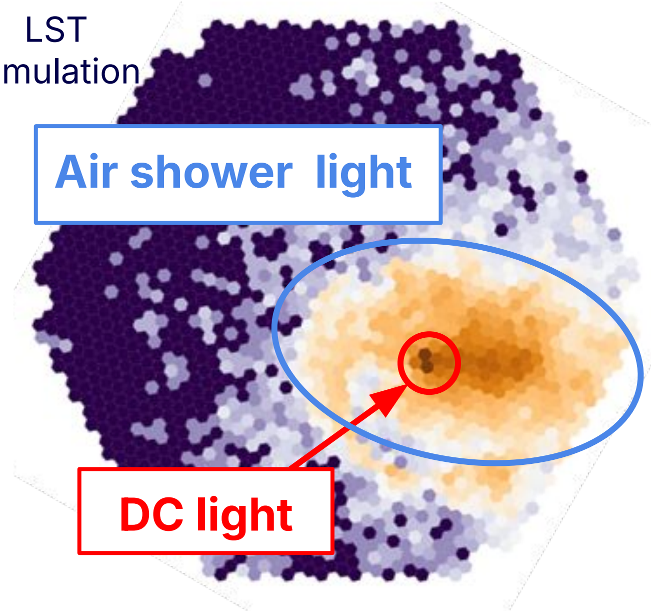
Direct Cherenkov (DC light)

air shower

Cherenkov light from secondary particles (Air shower light)

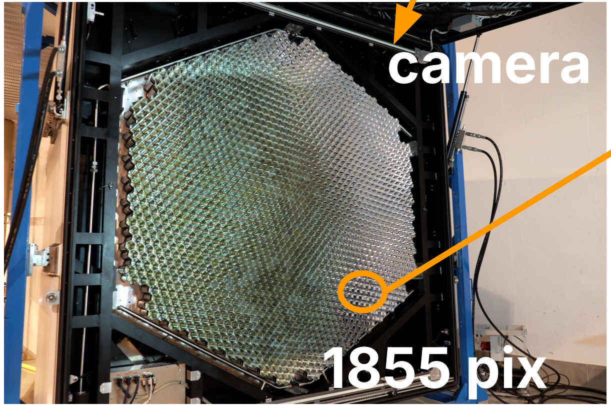



LST Simulation



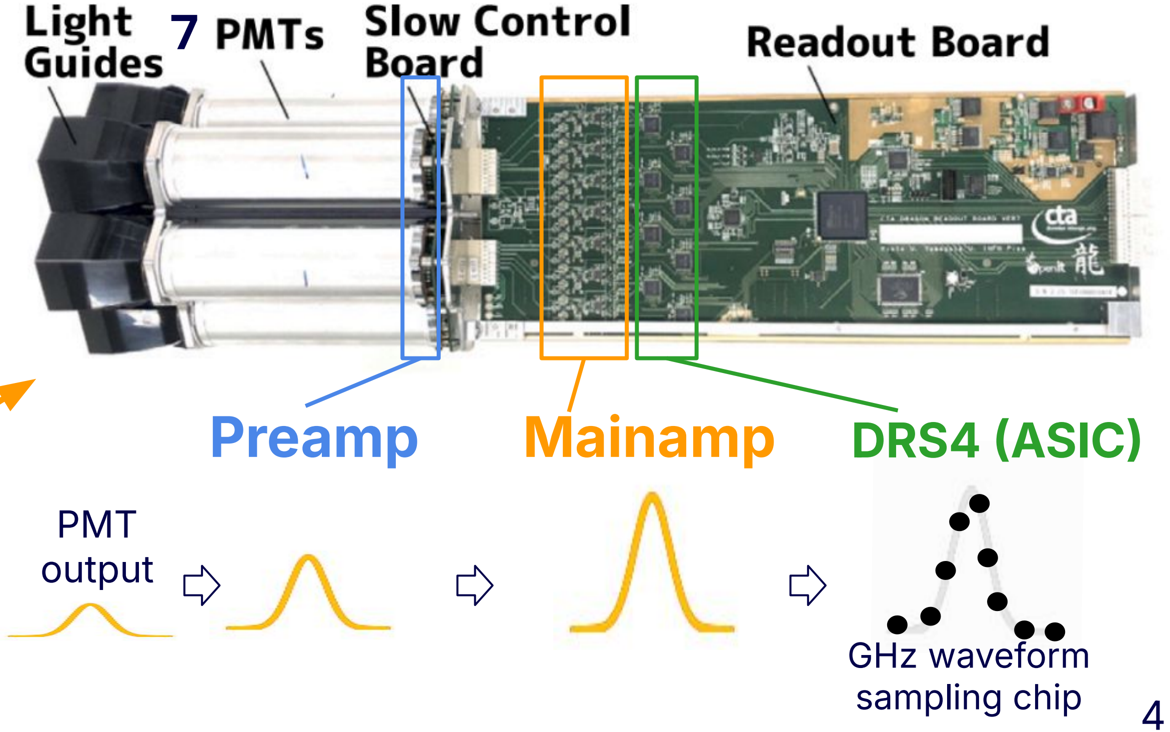

Color: charge (log) [p.e.]

# LST camera

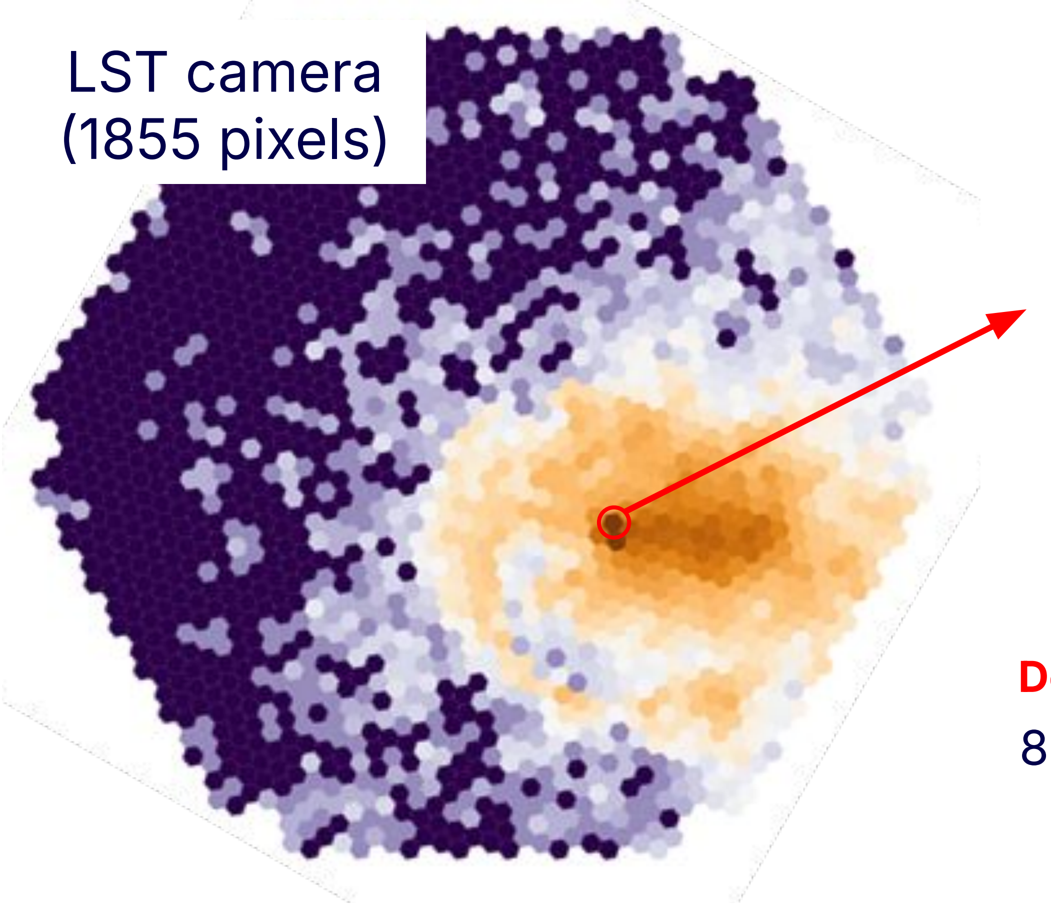

## PMT module

265 module/camera
0.1°/pixel

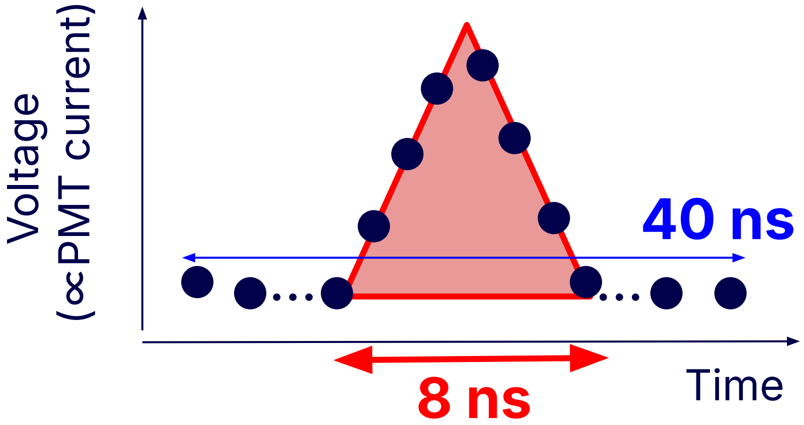


# Charge Integration

LST camera
(1855 pixels)



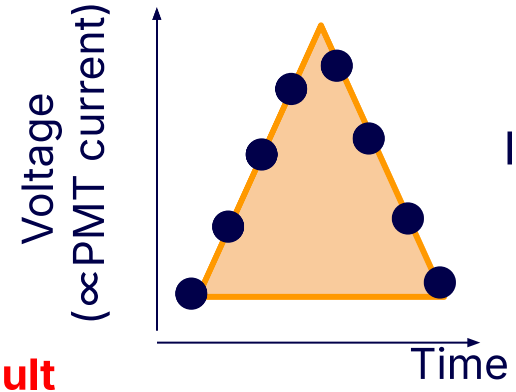
Pulse waveform
(single pixel)



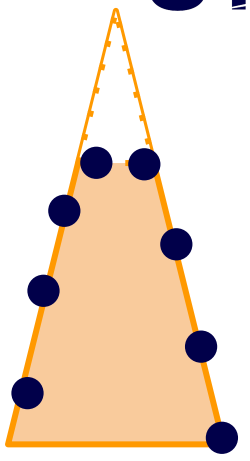

**Default**

8 ns (8 samples) charge integration around the peak position

# Saturation effect




If the signal is saturated



**Default**

8 ns (8 samples) charge integration around the peak position

- Charge can be underestimated
- Data-MC matching is also essential (MC: pulse is just clipped)

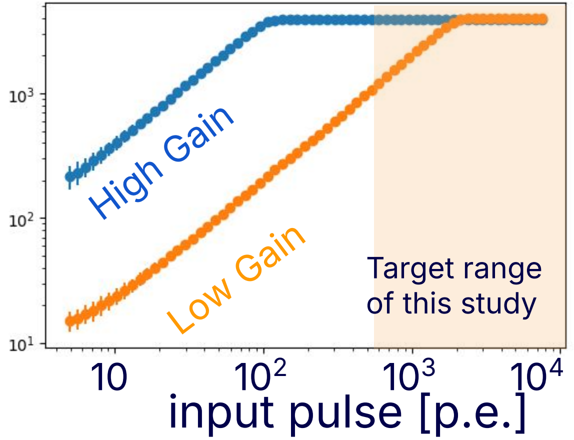
**Scope of this presentation**:

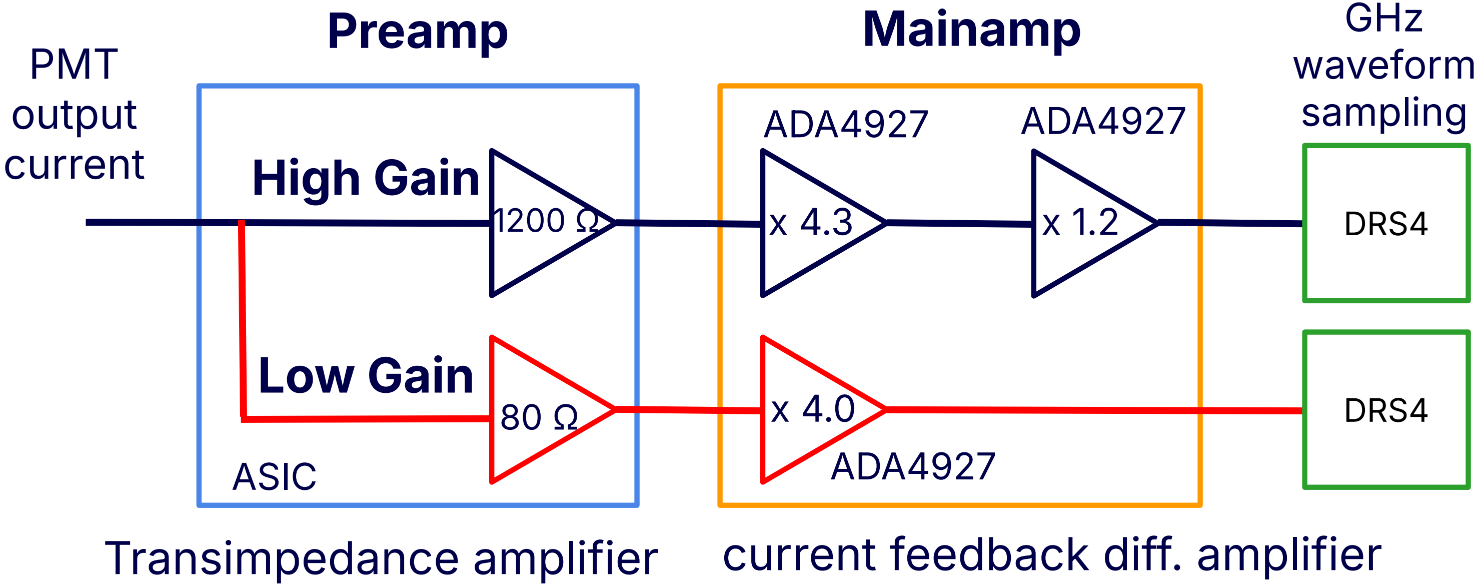
1. Check behavior of the saturated signals with test pulse
2. Verify how to correct saturation with calibration laser data

# Signal line

2 different gain channel for a wider dynamic range

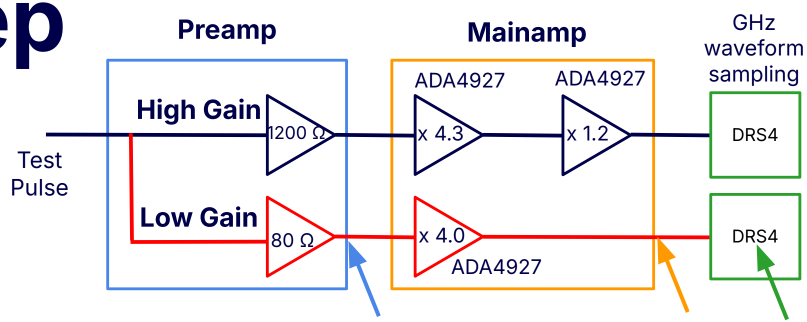
- High Gain: upto 100–200 pe, better bandwidth (300 MHz) for better separation between NSB and Cherenkov signal
- Low Gain: upto 2000–3000 pe



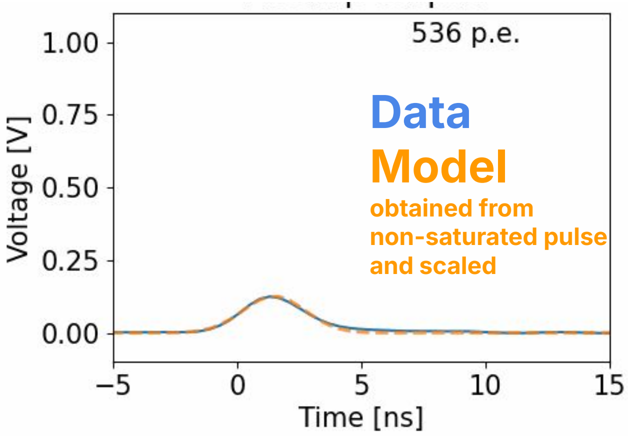



# Pulse shape at each step

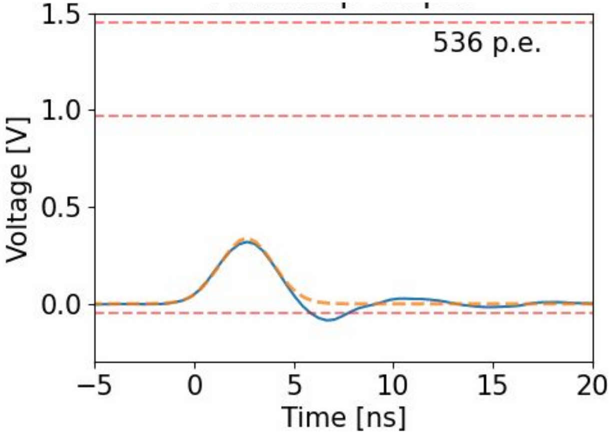
Labo measurement with test pulse instead of PMT signals to check the saturation behavior



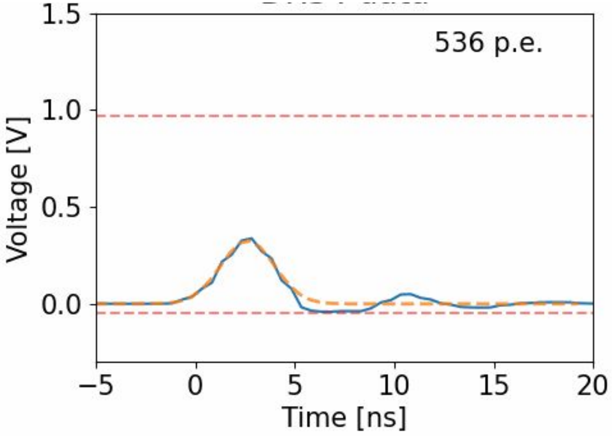

## Preamp




## Mainamp




## DRS4

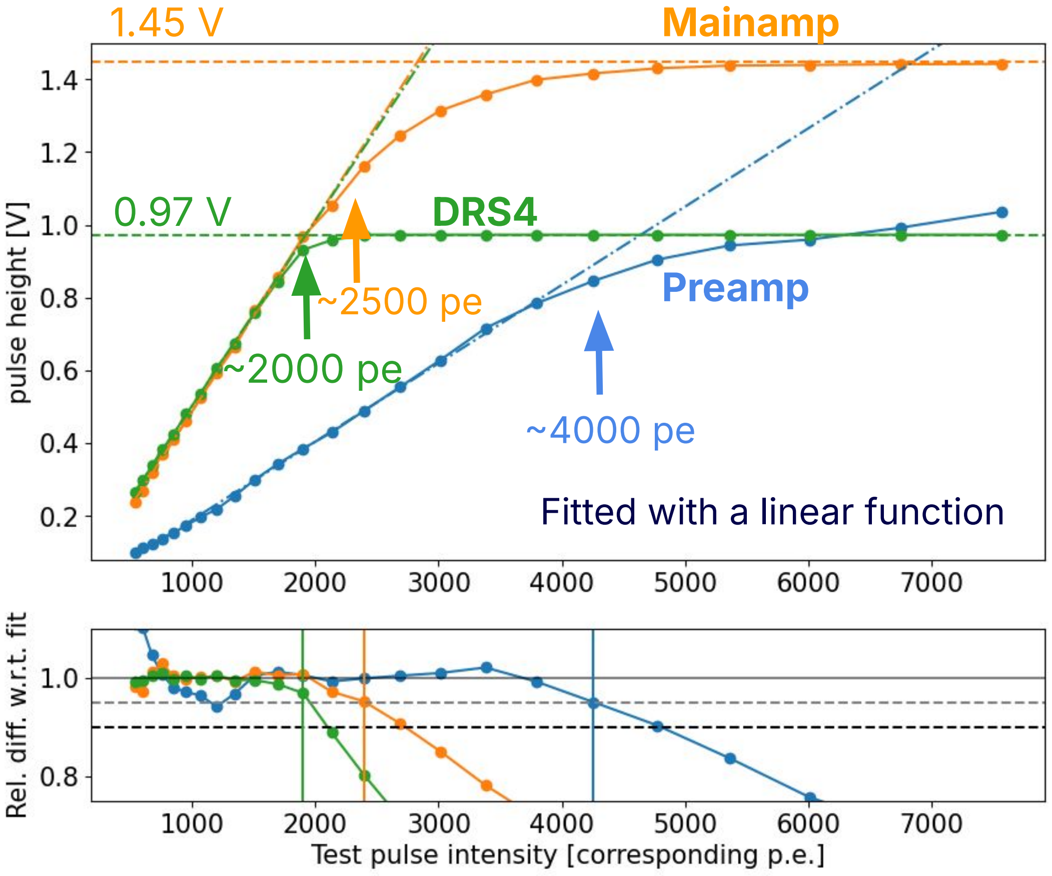



Oscilloscope: MDO3054 (Bandwidth: 500 MHz)
Differential probe: TDP1000 (Bandwidth: 1 GHz)
Average mode (2.5 GHz sampling)

DRS4 data (GHz sampling)
1000 events average

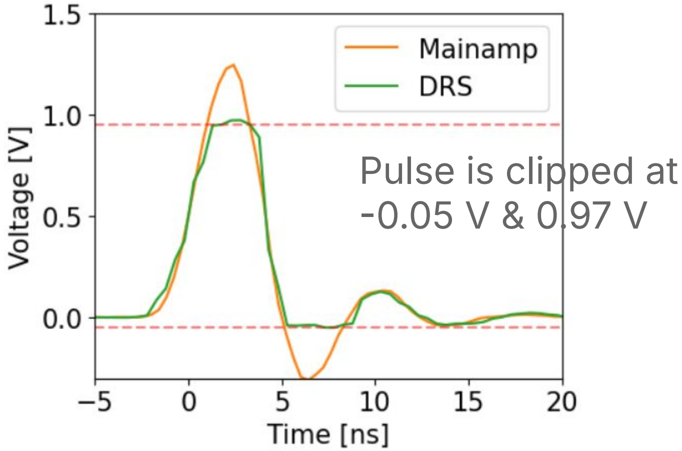
# Pulse height





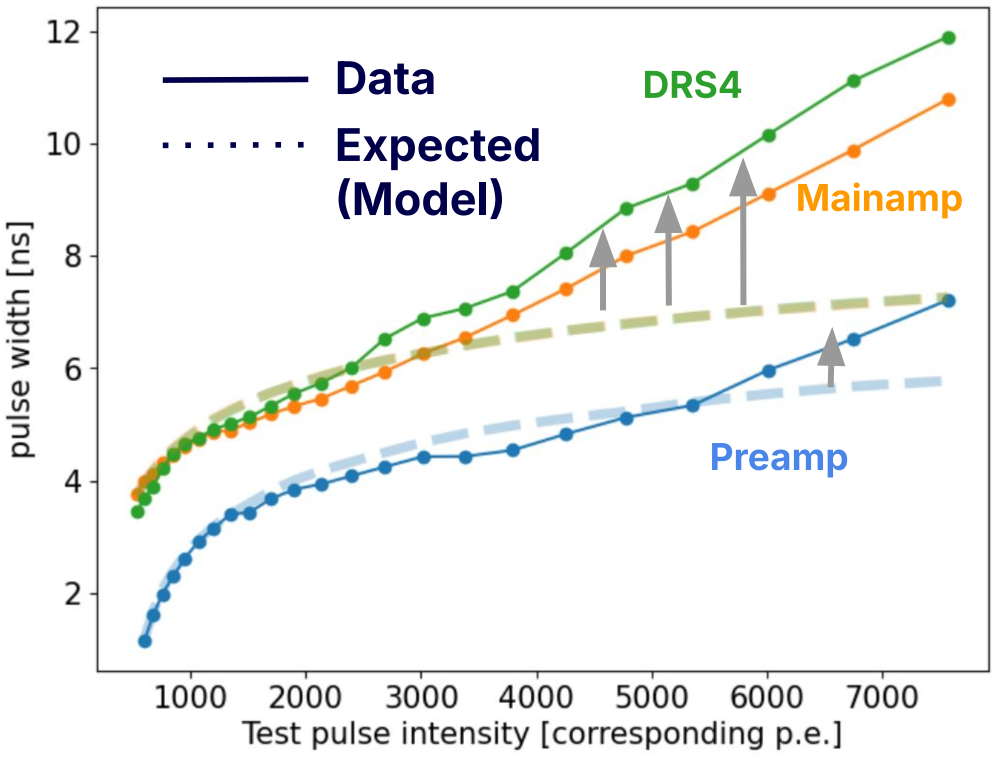

DRS4 pulse height is affected by

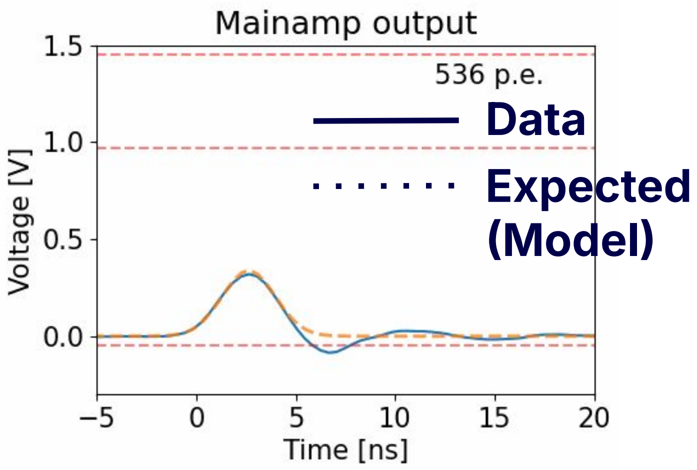
- Amp. saturation
- Clipping due to DRS4 input voltage range



# Pulse width

Time-over-threshold@0.1 V



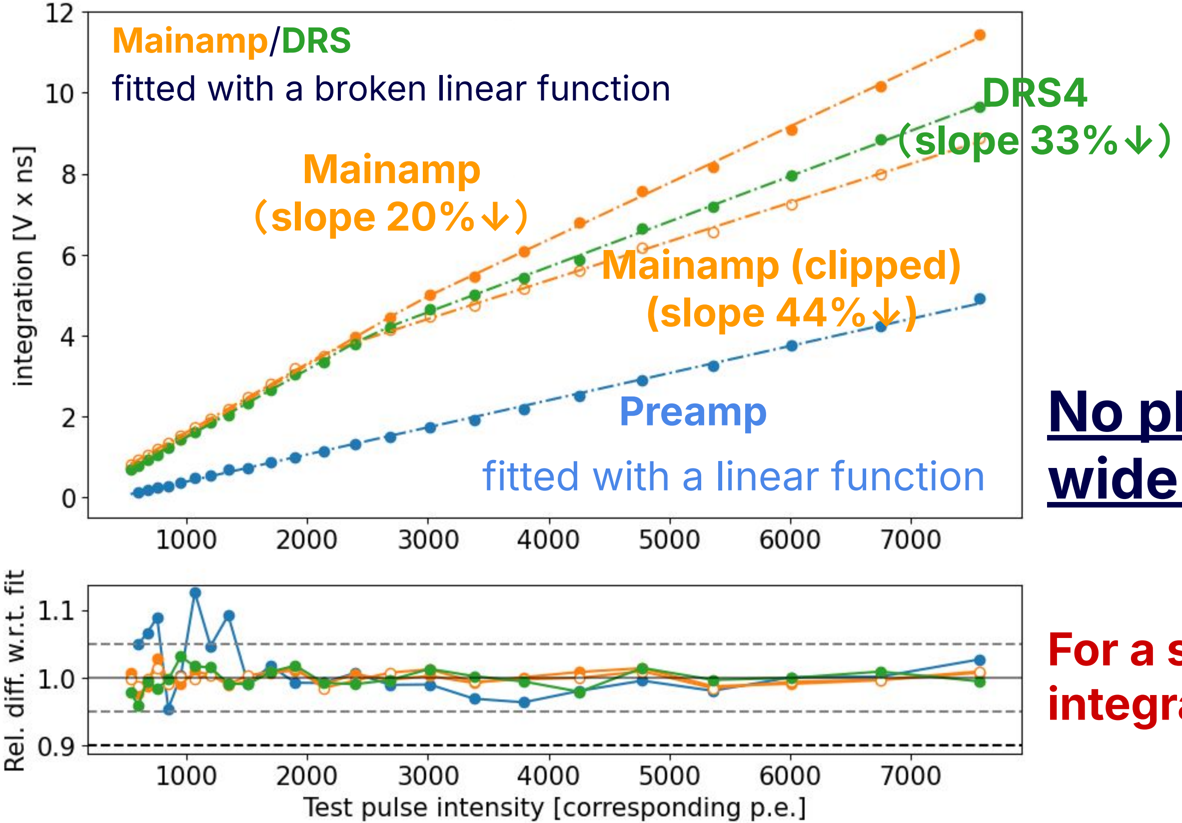




Once the pulse is saturated, **pulse width is getting wider** w.r.t. the expected width.

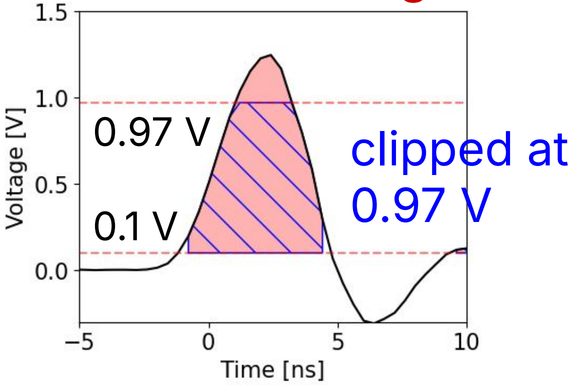
Pulse peak position should be corrected as well.

# Charge

Full waveform integration above 0.1 V




full waveform integration




**<u>No plateau in charge due to wider pulse width</u>**

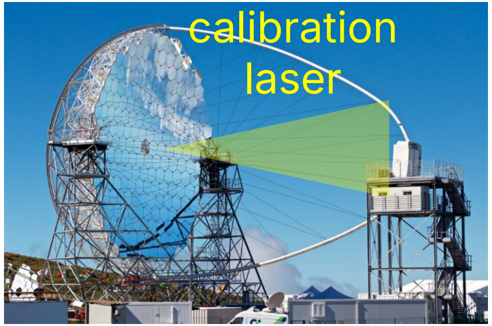
**For a saturated pulse, it is important to integrate the whole pulse waveform**

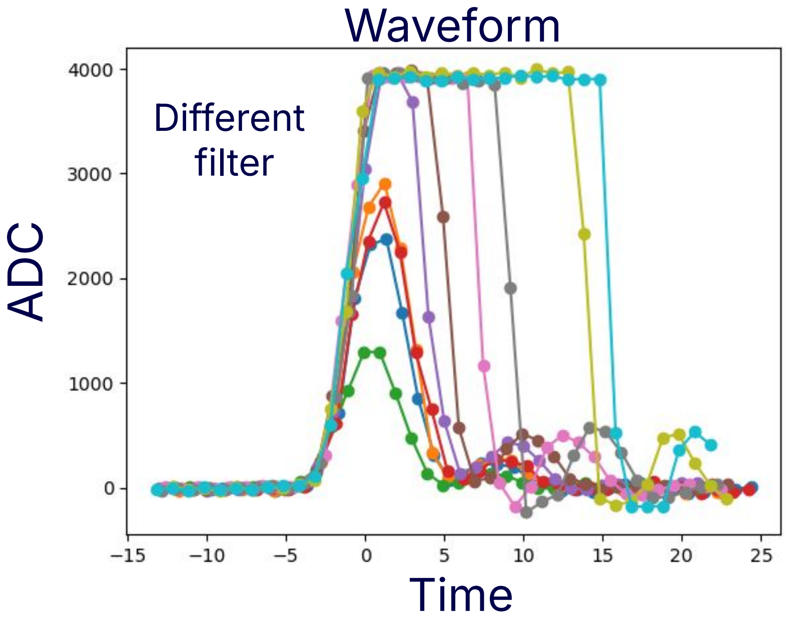
# Test with calibration laser

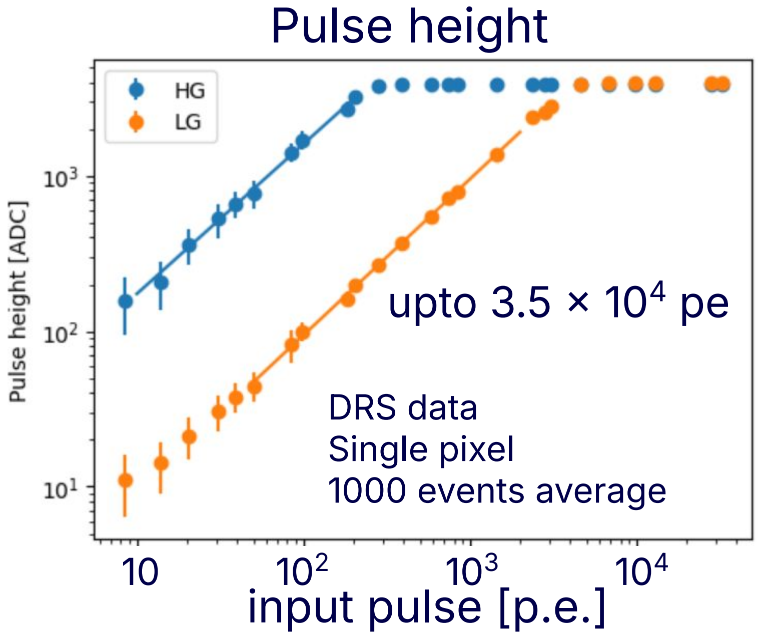
- Calibration laser data were taken with LST-1 camera

※ Laser intrinsic pulse width is wider than test pulse width

**PMT response is also included in this measurement**



# Linearity (charge)

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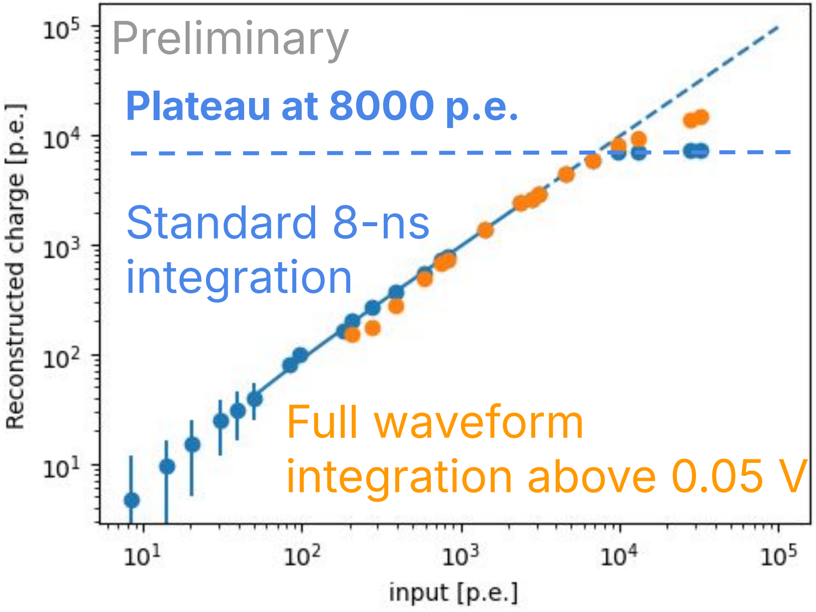
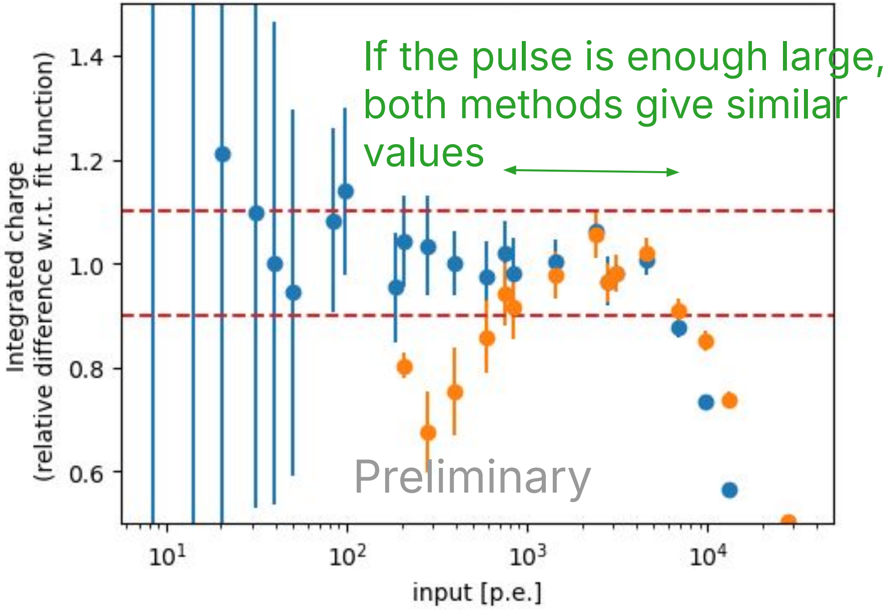
- Linearity < 10% upto ~8000 p.e. with the standard 8 ns charge integration (Data-MC matching is still needed though)

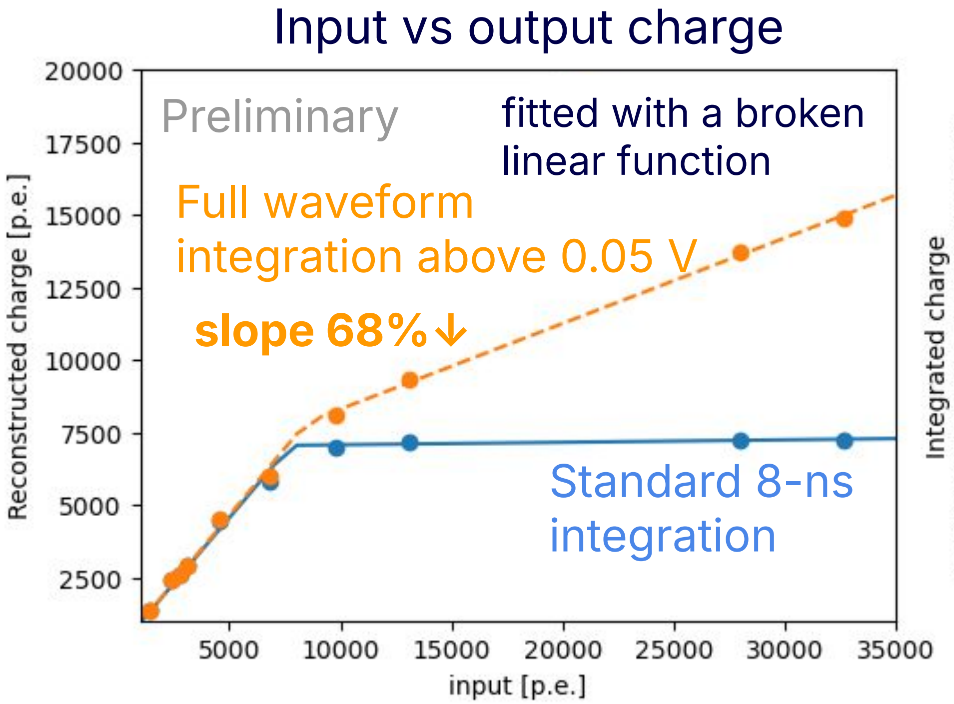
Input vs output charge

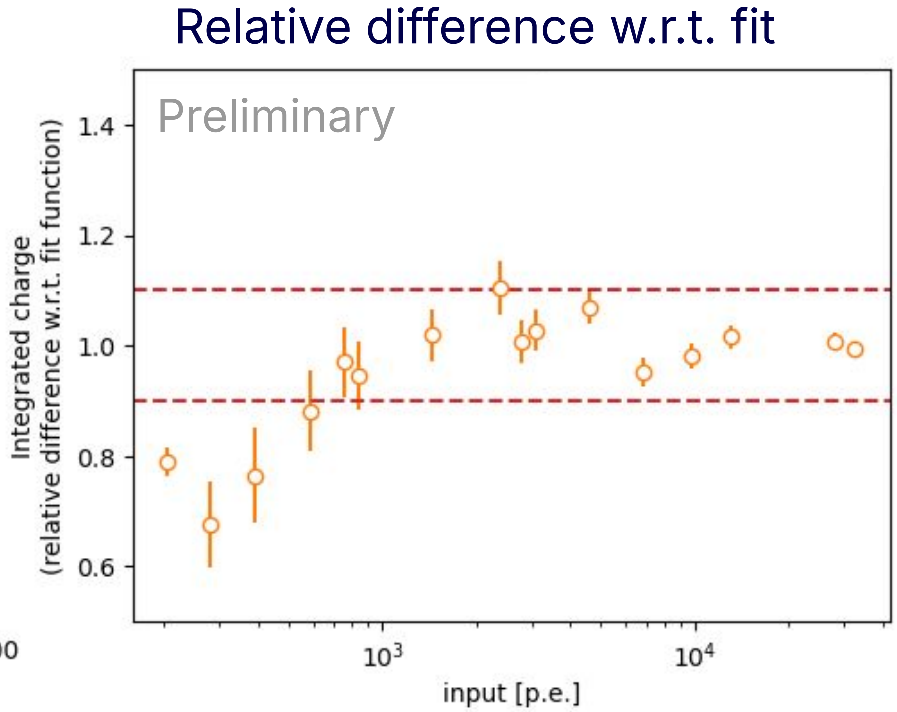



Relative difference w.r.t. fit



# Linearity (charge)

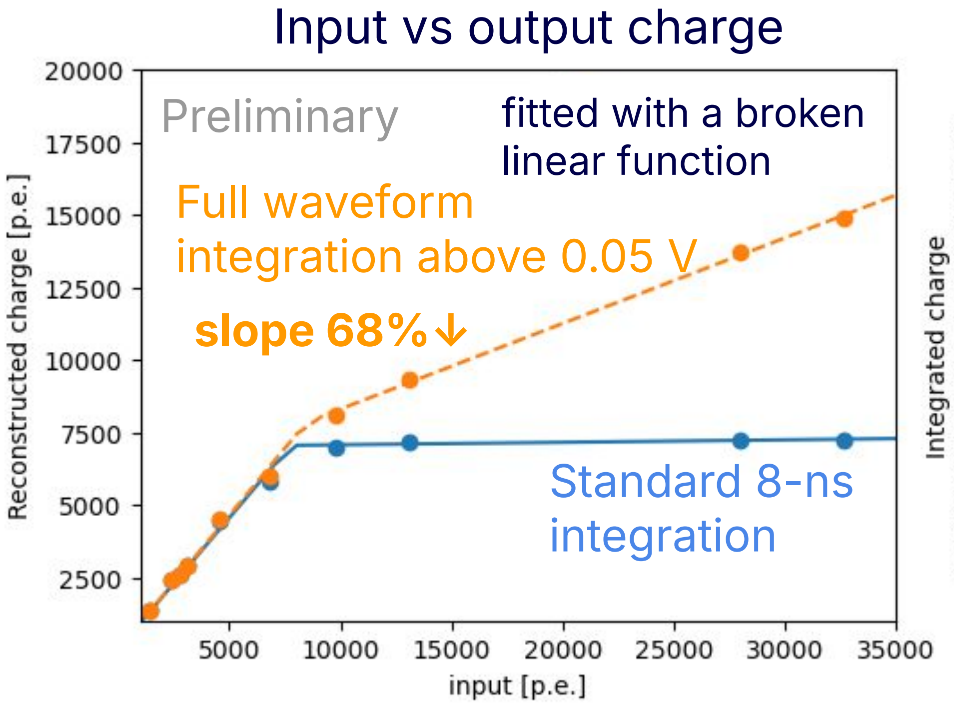


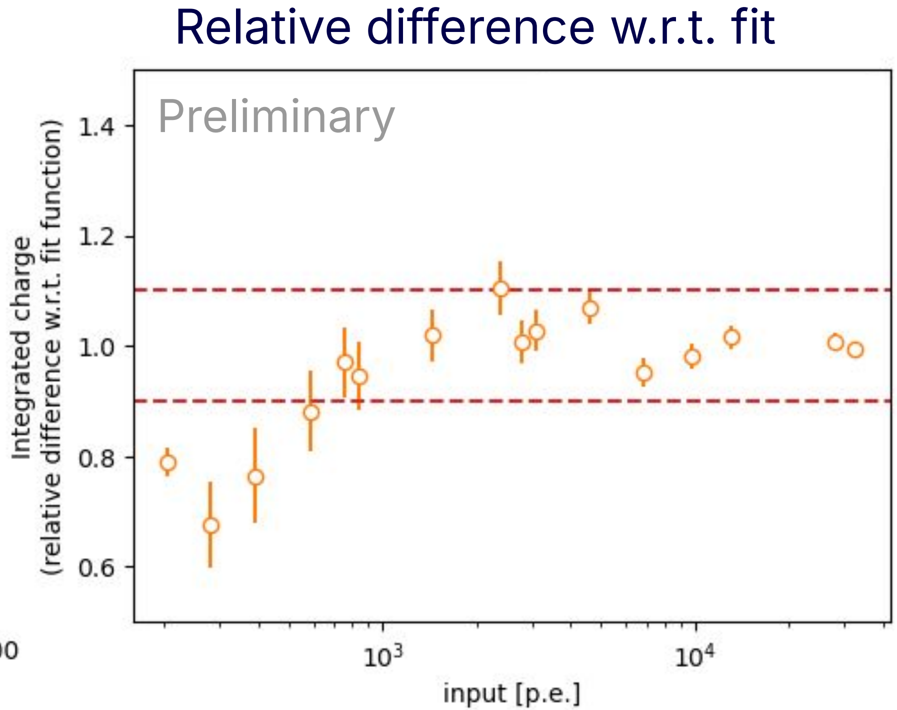




Charge recovery can be possible at least below **3.5×10$^4$ pe**
(**2–3 times larger** than the standard charge integration method)

# Linearity (charge)






DC light: standard integration can recover charge, but data-MC matching is needed

CR events (>100 TeV) can contain pixels with intensity>$10^4$ pe, which can be recovered with pulse waveform integration

# Summary

- Signal saturation can affect cosmic-ray measurements with the LST
- DRS4 pulse height is affected by **amp. saturation** & **clipping** due to DRS4 input voltage range
- **The pulse width becomes wider** than expected once the pulse height is saturated
- As a result of these effects, **no plateaus are observed in the charge** (time vs voltage) linearity plot.
- A **broken-linear function** can be used for saturation correction upto 2–3 × $10^4$ pe (2–3 times larger than usual)