# Timing resolution and FEBv6 preseries performances

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# Introduction

- Overview of studies performed on the entire camera and on 10 modules equipped with new FEBv6
- All tests performed in the testbench in CEA, Saclay

**Timing performance**

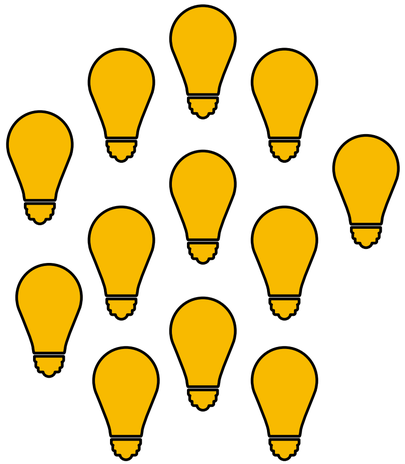
- Single pixel timing precision
- PMT transit time
- Global camera timing precision
- Camera trigger timing accuracy

**Verification of FEBv6**

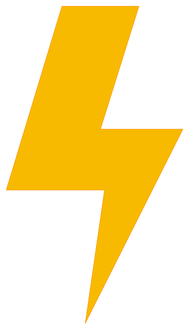
- Deadtime
- Single pixel timing precision
- Linearity

# Light sources

**Flat-Field Calibration (FFCL)**



**Laser**



**Night Sky Background**

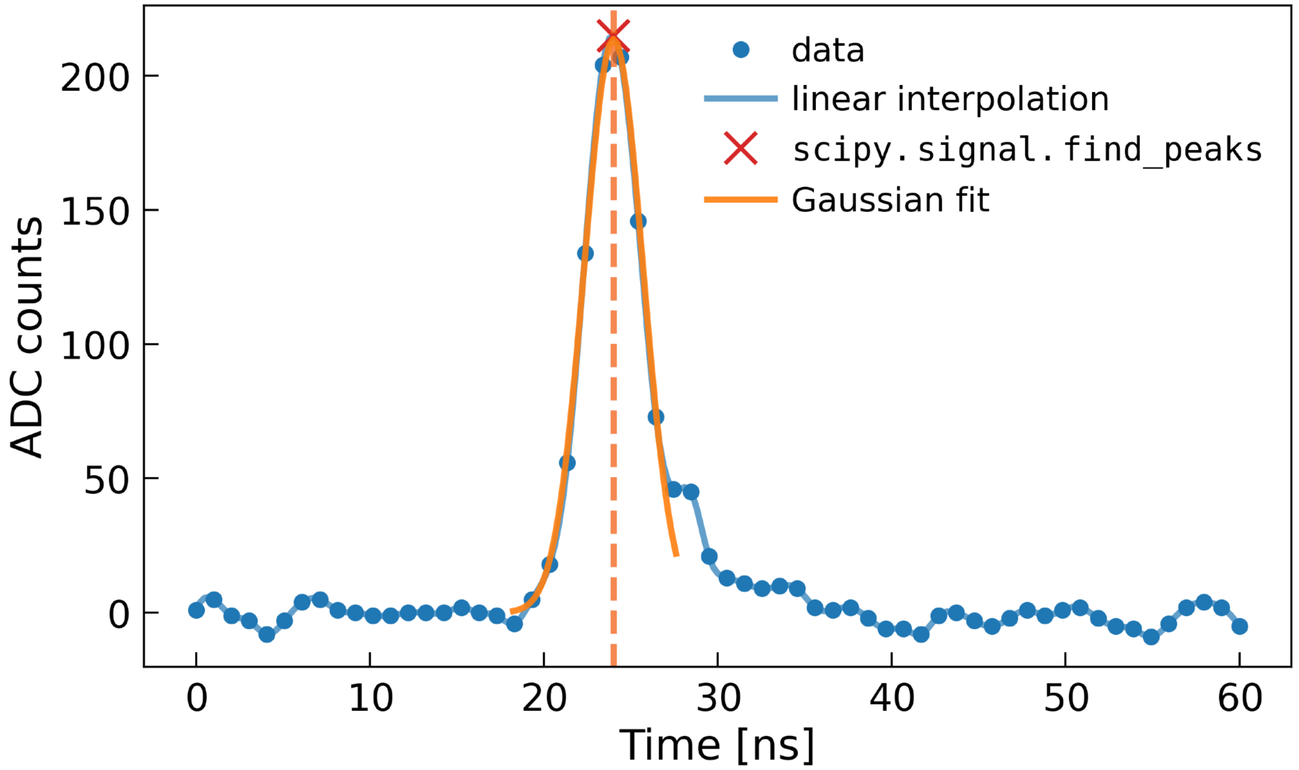
**Random Generator**

**TiCkS module associates UCTS timestamp to the triggered signal**

# TOM calculation

## Measure of the reconstructed signal arrival time of the pulse = temporal position of the pulse maximum in the sampled window

- Time of Maximum (TOM) calculated for each waveform and each pixel
- 2 methods used:
  - Identifying the position of the largest peak of the waveform using the function scipy.signal.find peaks
  - Gaussian fit of the largest peak of the waveform

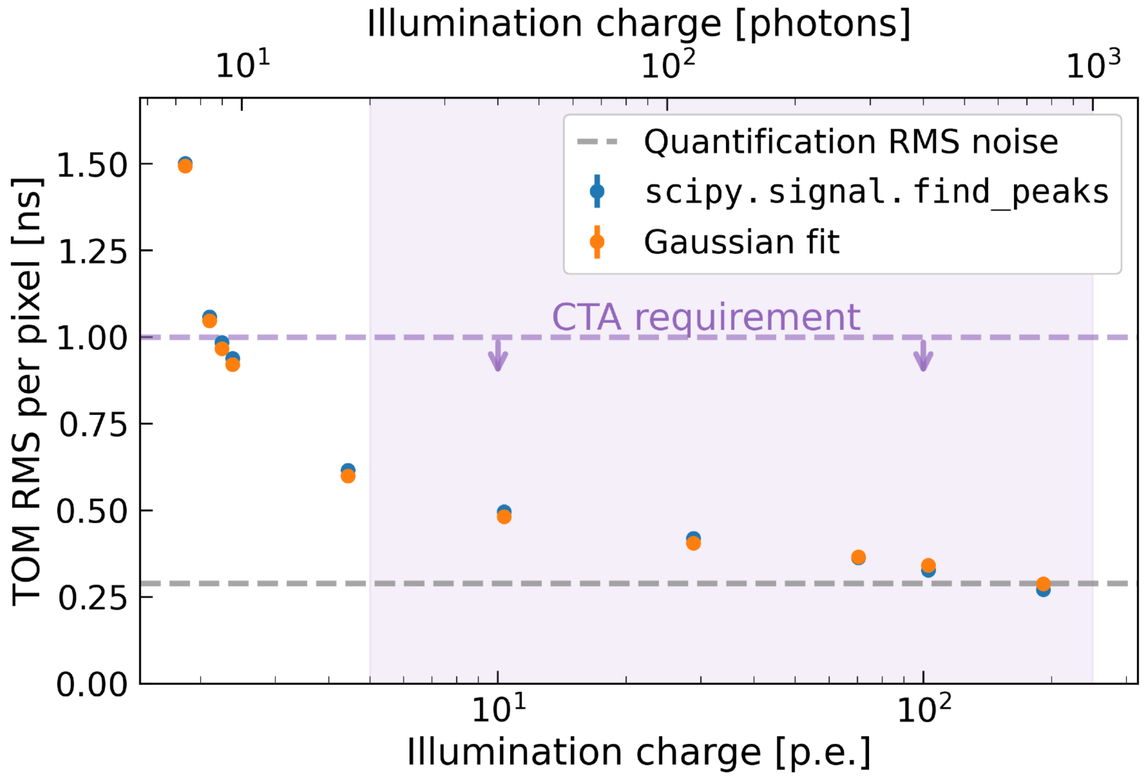


# Timing performance

# Single pixel timing precision

Requirement: the RMS uncertainty on the mean relative arrival time in all pixels does not exceed 1 ns for amplitudes > 20 photons (5 p.e.)

- Camera illuminated by the laser source at a frequency of 1 kHz and intensity between 8.0 — 20 nW (1—200 p.e.)
- Time of maximum of each pulse for each pixel is measured using both methods
- Weighted mean of the RMS over all the pixels

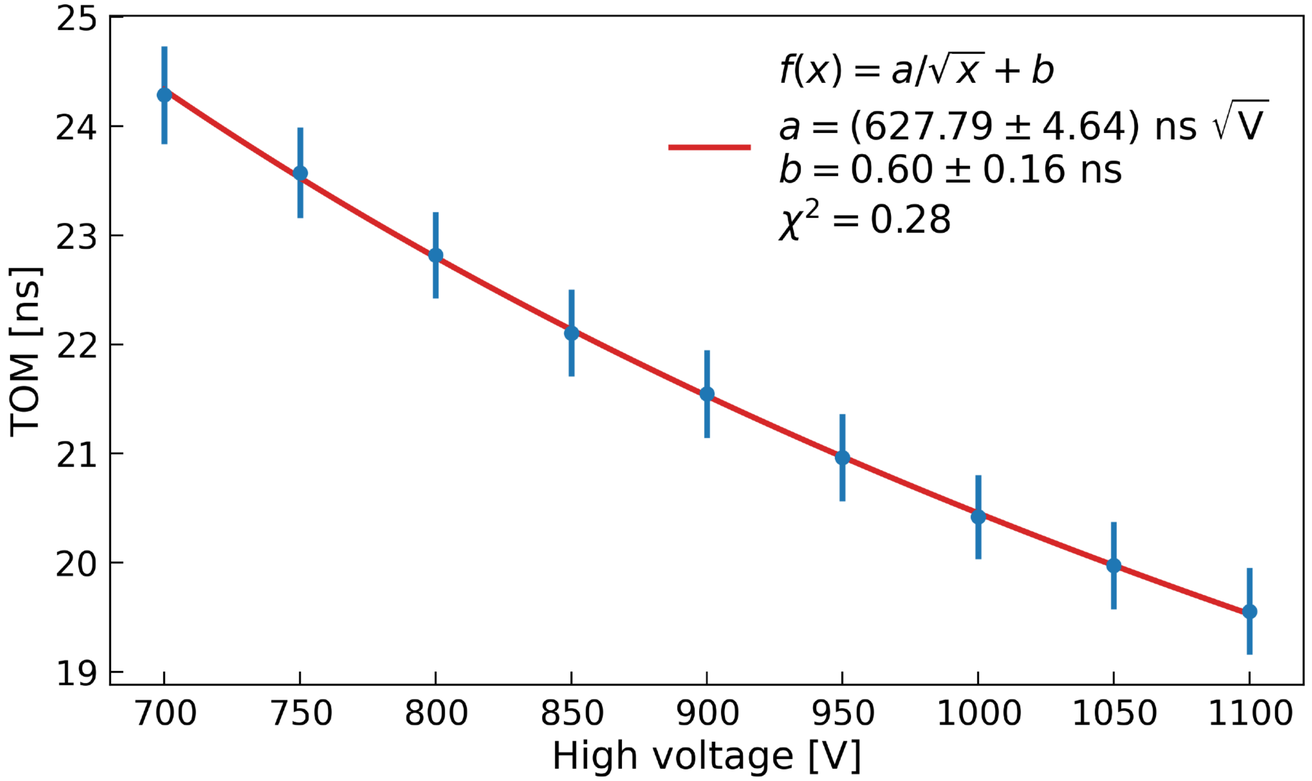



**Single pixel timing precision < 1 ns between 10 — 1000 photons**

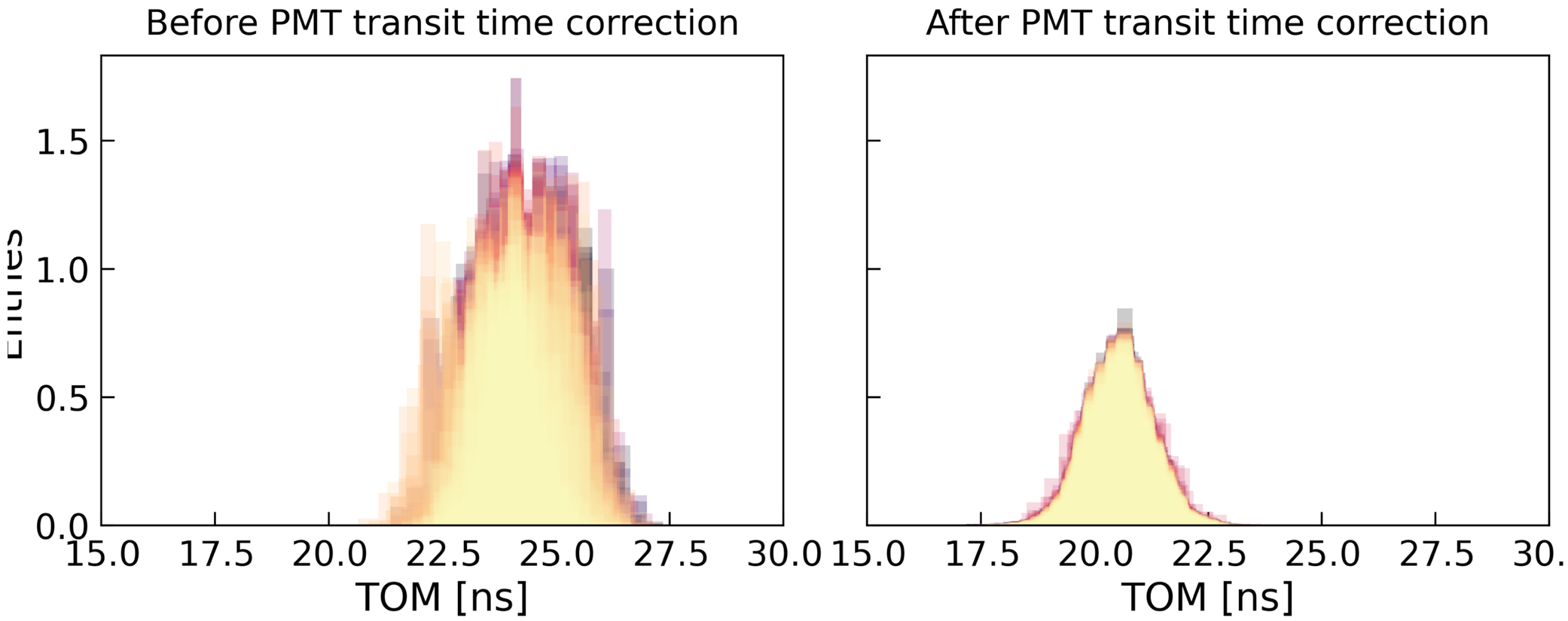
# PMT transit time

## Transfer time of the electron avalanche in the PMT, depending on the high voltage applied to the dynodes

- Each pixel works at a different HV to have the nominal gain of 40000
  → PMTs introduce different delays creating an offset between pixels
- It can be corrected at the analysis level
- Measurements: PMT set to the same HV and illuminated with FFCLS
- Fit performed for each pixel



# PMT transit time

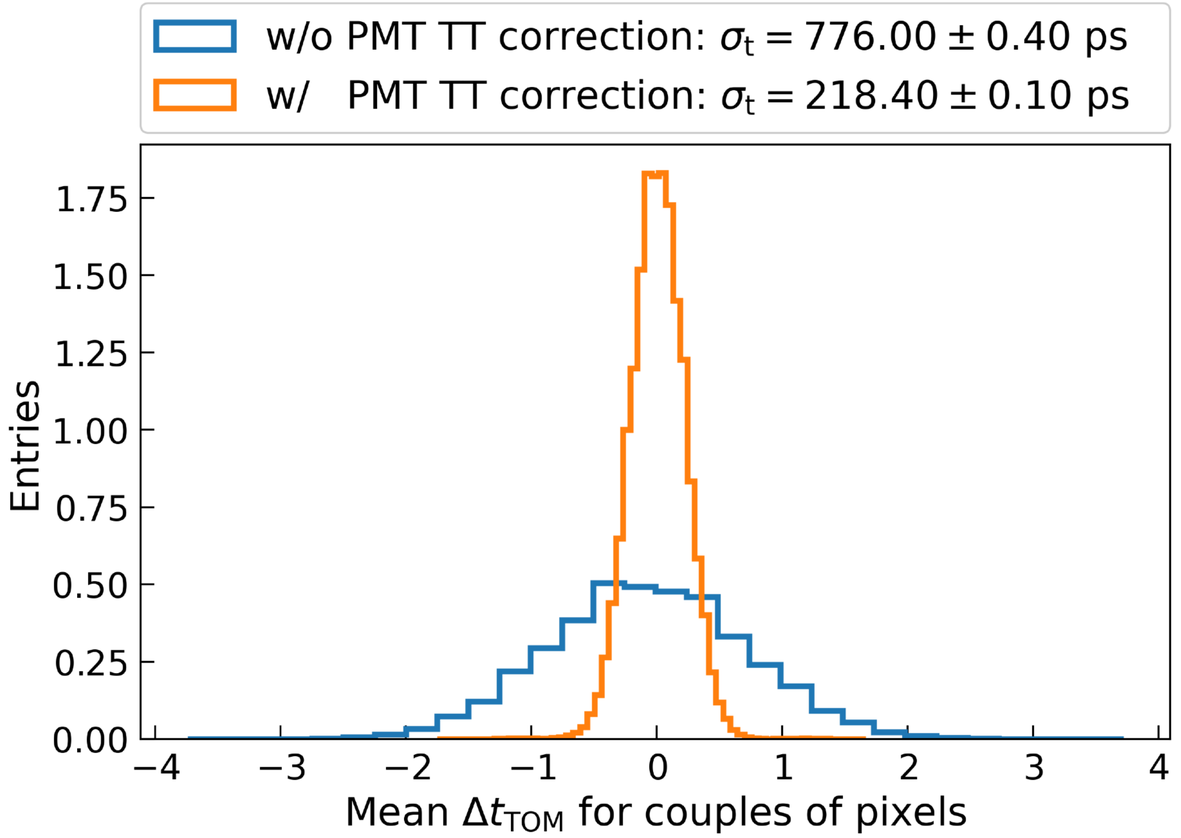



**The TOM of each pixel is shifted to the value of the fit at 1000 V**

# Global camera timing precision

Requirement: the RMS of the Δt for each pair of pixel has to be < 2 ns for an illumination of 5 p.e. and background level of 0.125 p.e./ns

- Camera illuminated with laser source at ~20 p.e.
- TOM for each pixel and each event is calculated
- Δt for each pair of pixel is calculated with and without PMT transit time correction
- Δt reduced from **0.77 ns** to **0.22 ns**



# Camera trigger time accuracy

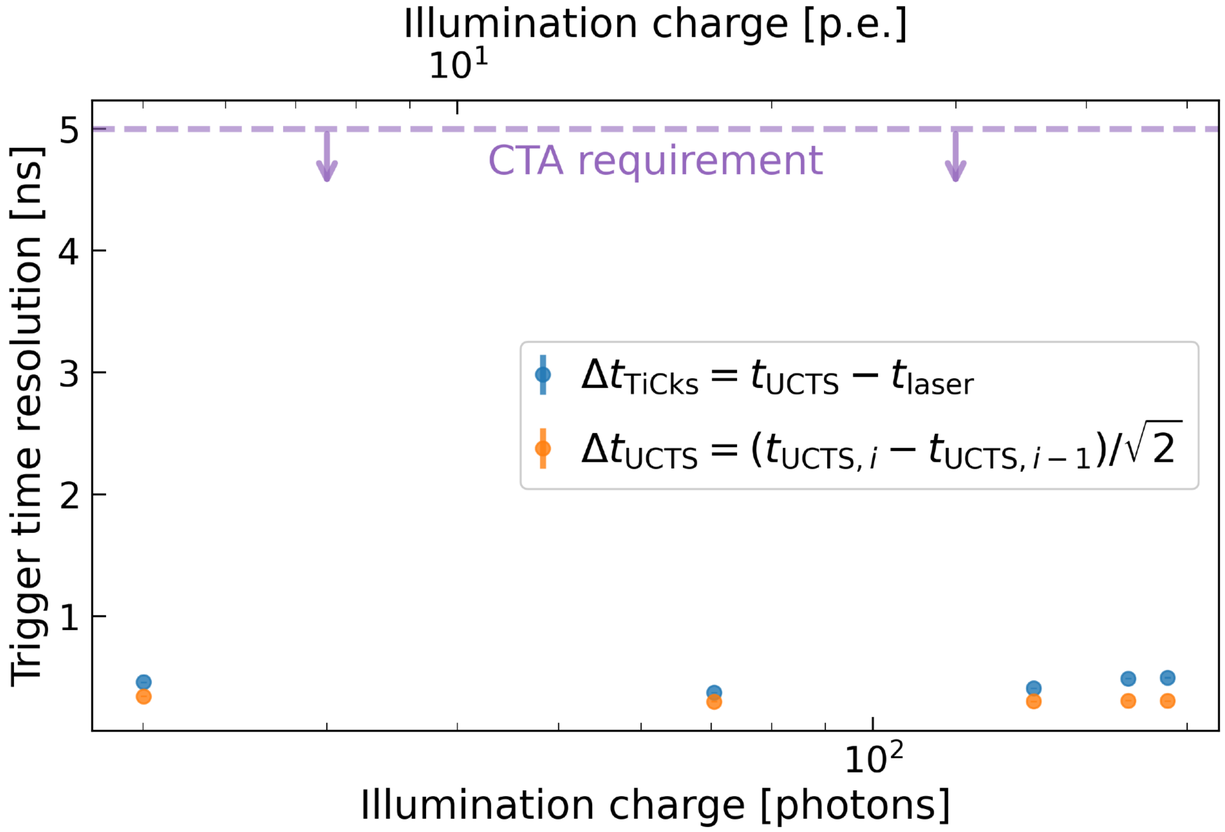
Requirement: the RMS uncertainty on the trigger timestamp for an illumination of 200 p.e. and a background level of 0.125 p.e./ns has to be < 5 ns

- Camera illuminated with laser source with intensity between 2 — 50 p.e.
- For each measurement the start time of the laser flashes are recorded with a TiCkS board:

$$\Delta t_{\mathrm{TiCks}} = t_{\mathrm{UCTS}} - t_{\mathrm{laser}}$$

- Distribution of the time difference of 2 consecutive events giving an upper limit on the accuracy of the timestamps for a periodic input signal:

$$\Delta t_{\mathrm{UCTS}} = t_{\mathrm{UCTS},i} - t_{\mathrm{UCTS},i-1}$$

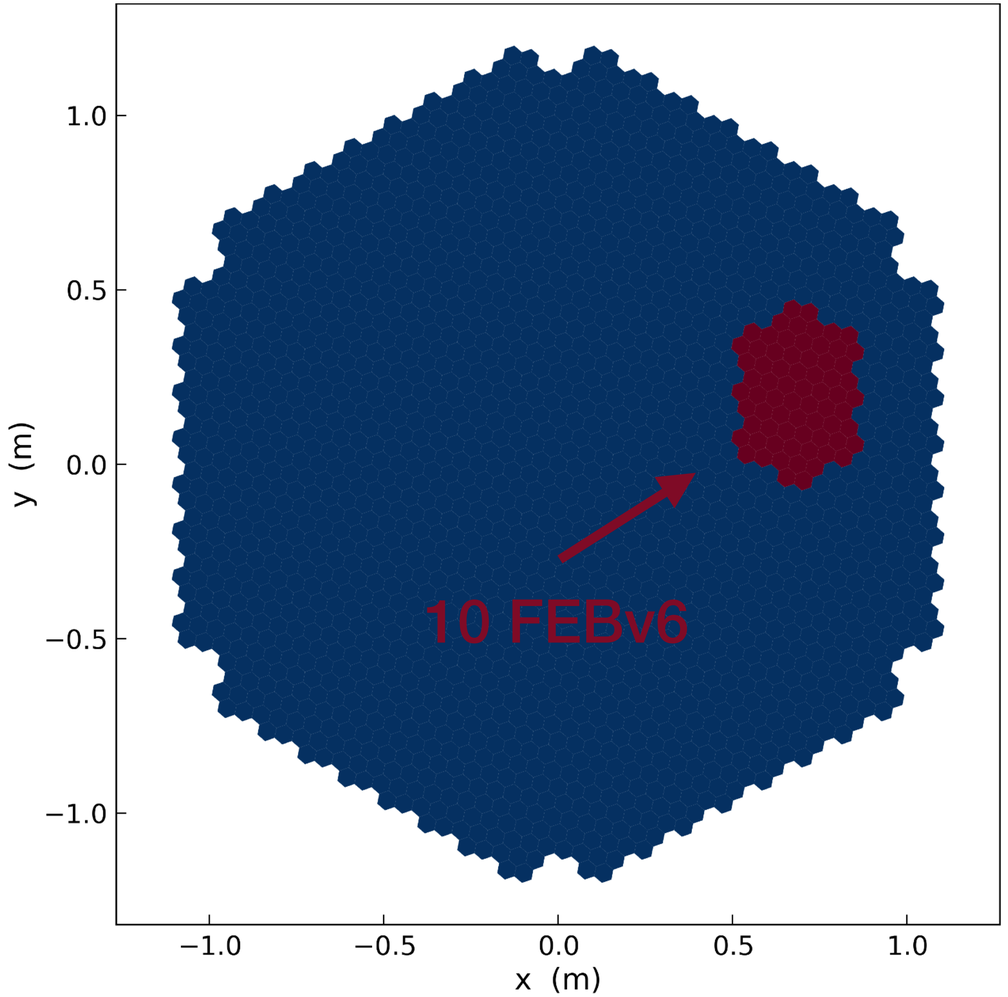


# Verification of the FEB v6

# Front End Board version 6

## Preseries FEBv6 using NECTAr chip v3

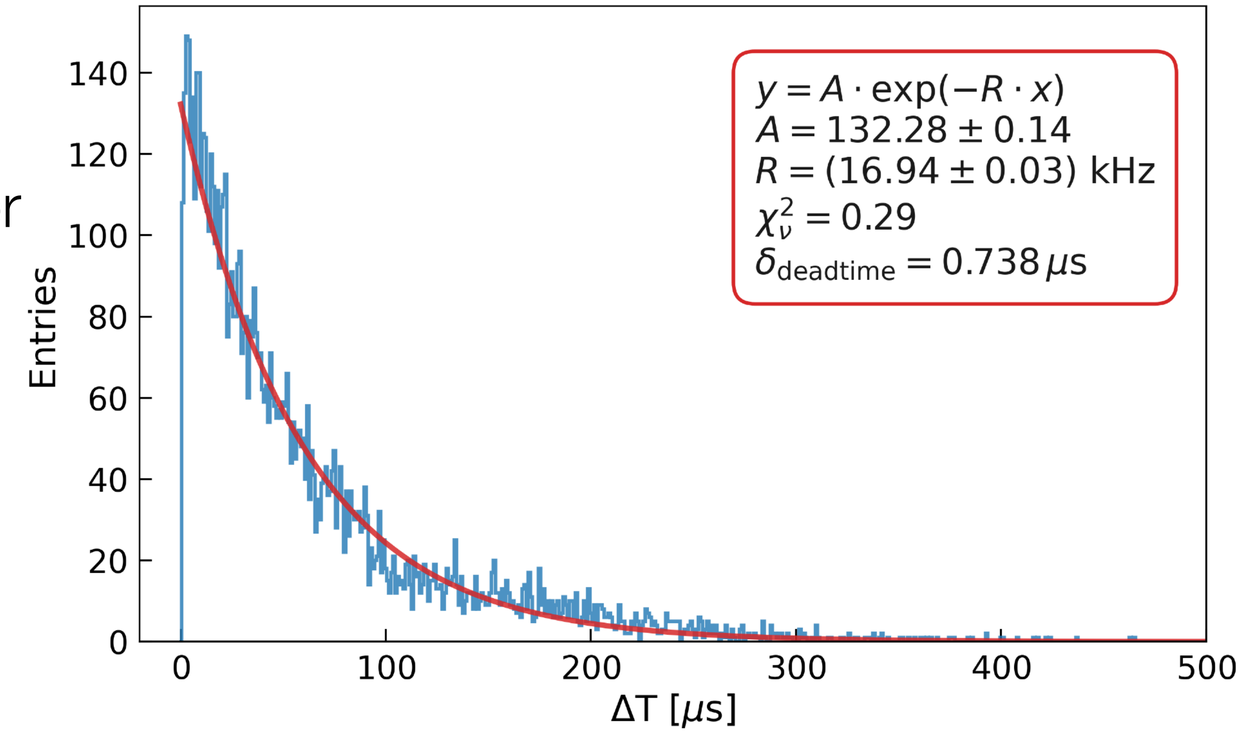
- 10 FEBv6 installed in the NectarCAM camera
- FEBv6 preseries verification
- 3 parameters have been verified:
  - Linearity
  - Deadtime
  - Timing resolution



# FEBv6 deadtime

Goal: show that with new FEBv6 the deadtime is < 5% at 7 kHz trigger rate

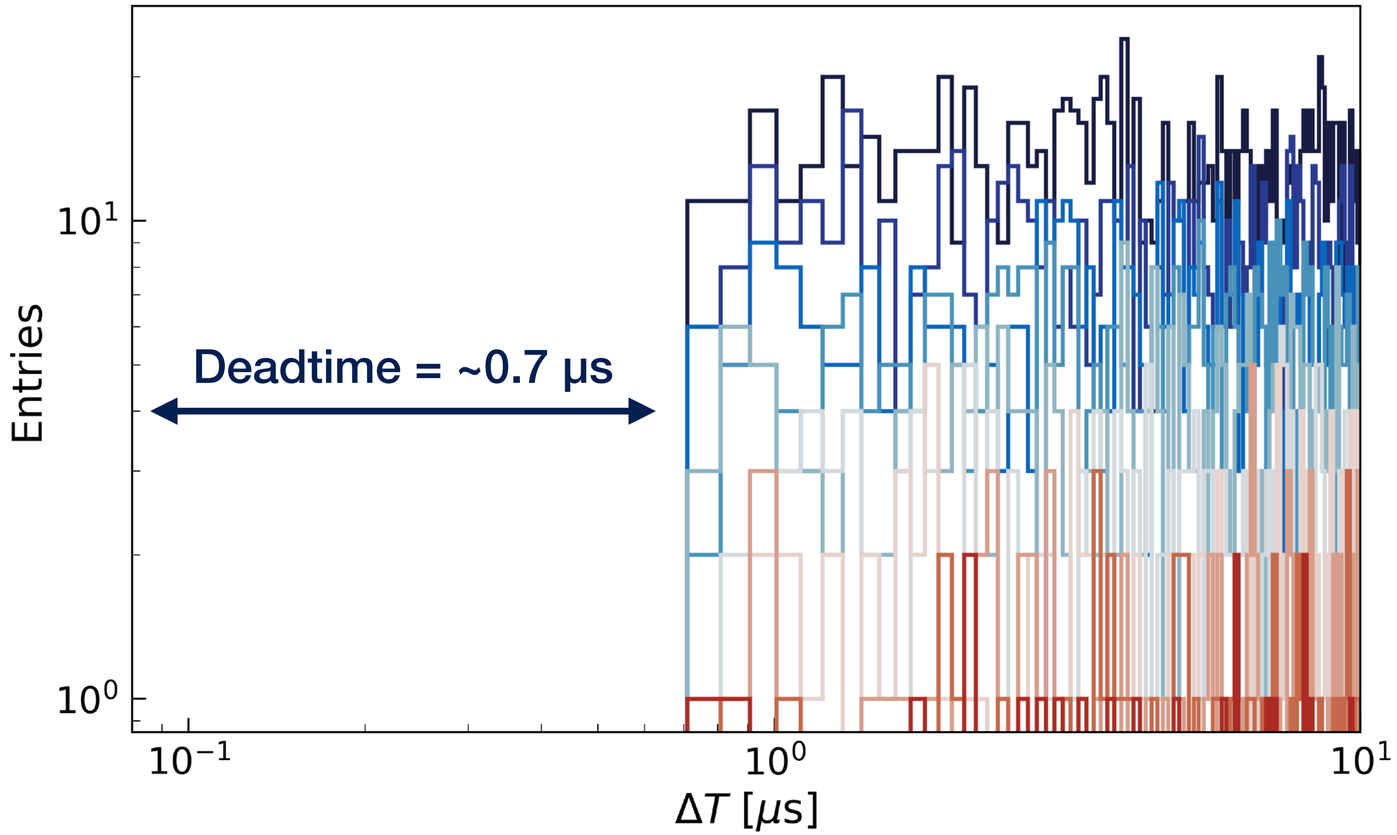
- Deadtime measured for different voltages using 3 random sources:
  - FFCLS + random Poisson generator
  - Laser + random Poisson generator
  - NSB source
- Fit of the ΔT between two consecutive events for each measurement
- Fit results compared to deadtime values from camera server




**ΔT distribution using NSB source at 35 mA**

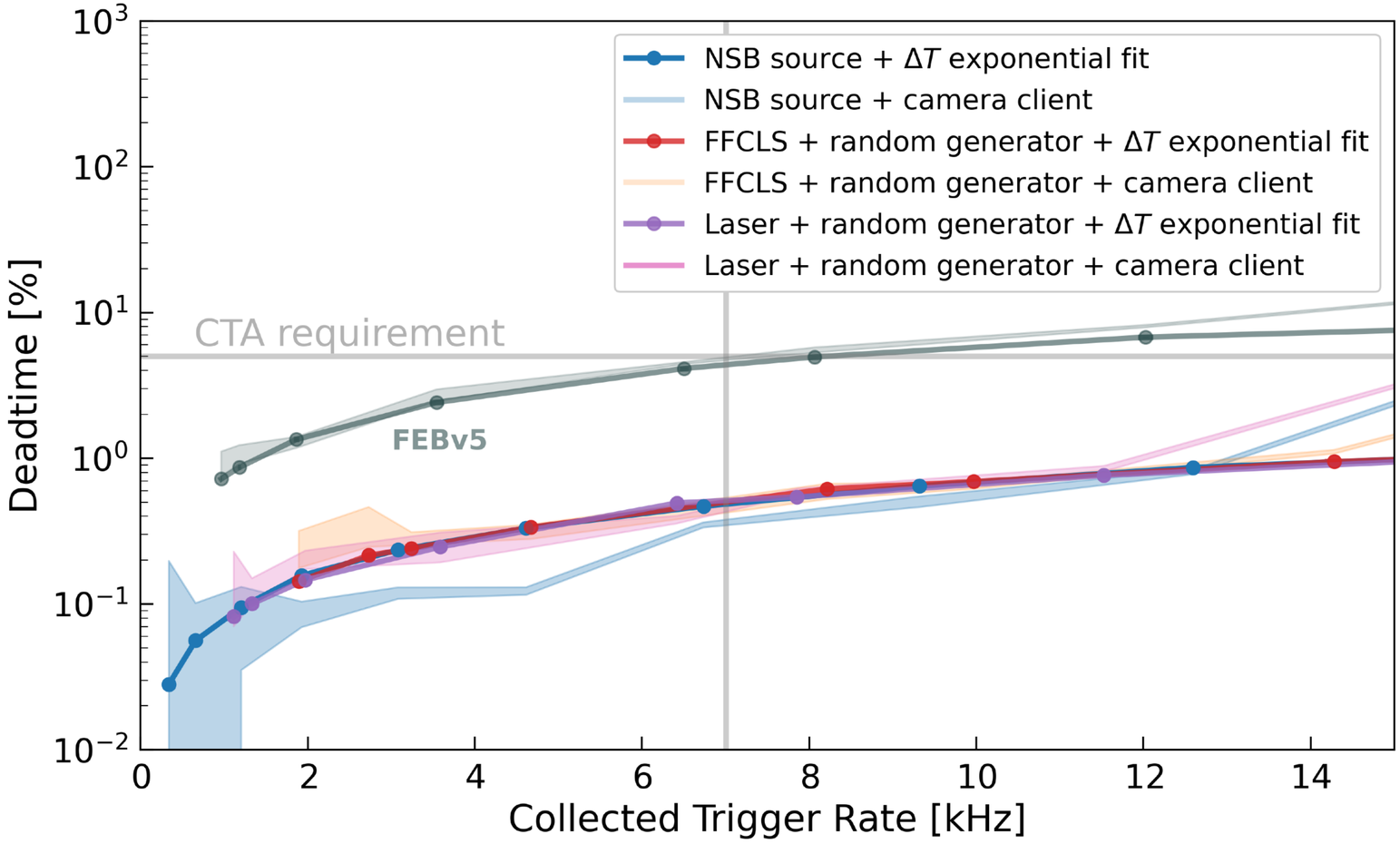
# FEBv6 deadtime

## Deadtime is not dominated anymore by the NECTAr chip




**Combined deadtime using three sources:** $0.745 \pm 0.001\ \mu s$

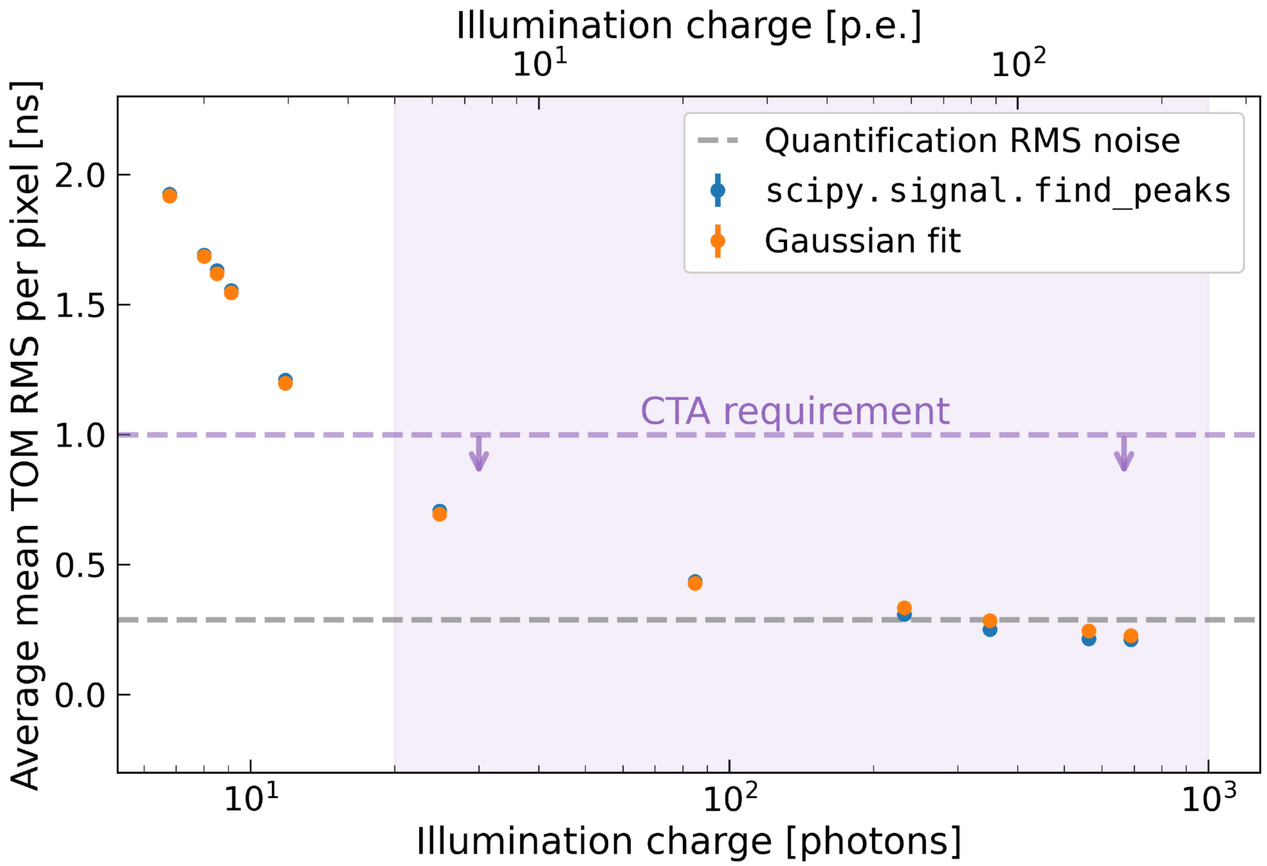
# FEBv6 deadtime




**The deadtime of the new FEBv6 is < 5% at 7 kHz trigger rate**

# FEBv6 single pixel timing precision

- **Requirement:** RMS uncertainty on the mean relative arrival time in the FEBv6 pixels < 1 ns for amplitudes in the range 20 to 2000 photons.
- TOM calculated for each pixel for 11 laser intensities using both methods

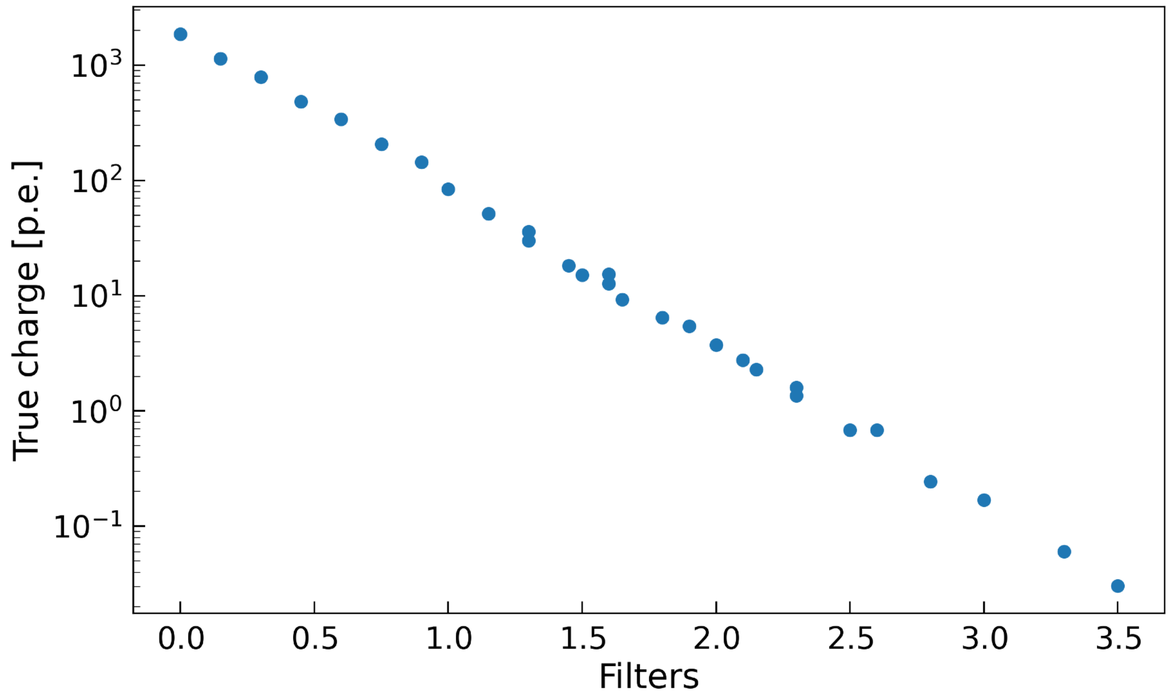



**The mean rms per pixel is below 1 ns for a uniform illumination with amplitude above 20 photons**

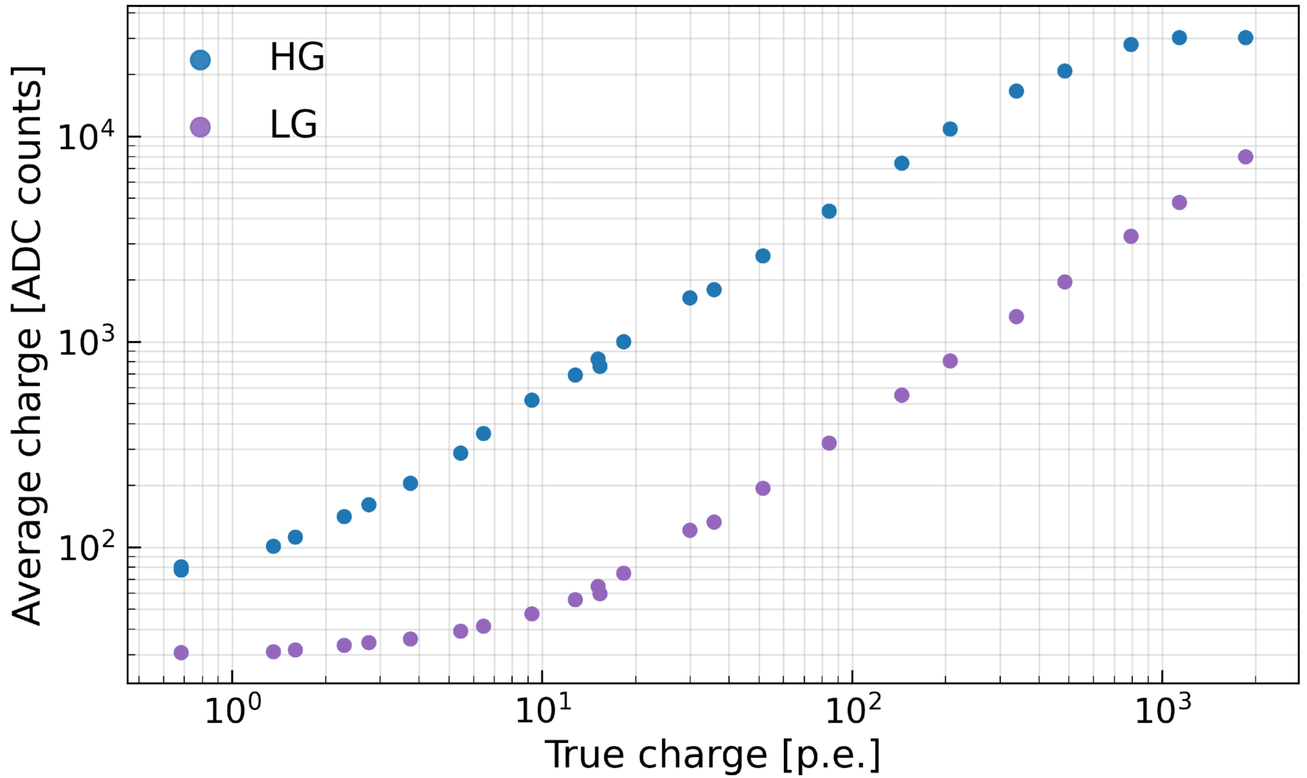
# FEBv6 linearity test

## Goal: to show that the light measured by the new FEBv6 is linearly proportional to the input light

- Linearity describes the output distortion with the increasing of the incident light intensity at a given gain
- Light inputs are created by the FFCLS at 15.5 V and a set of 6 absorptive Edmund filters to obtain a calibrated fraction of the flasher intensity



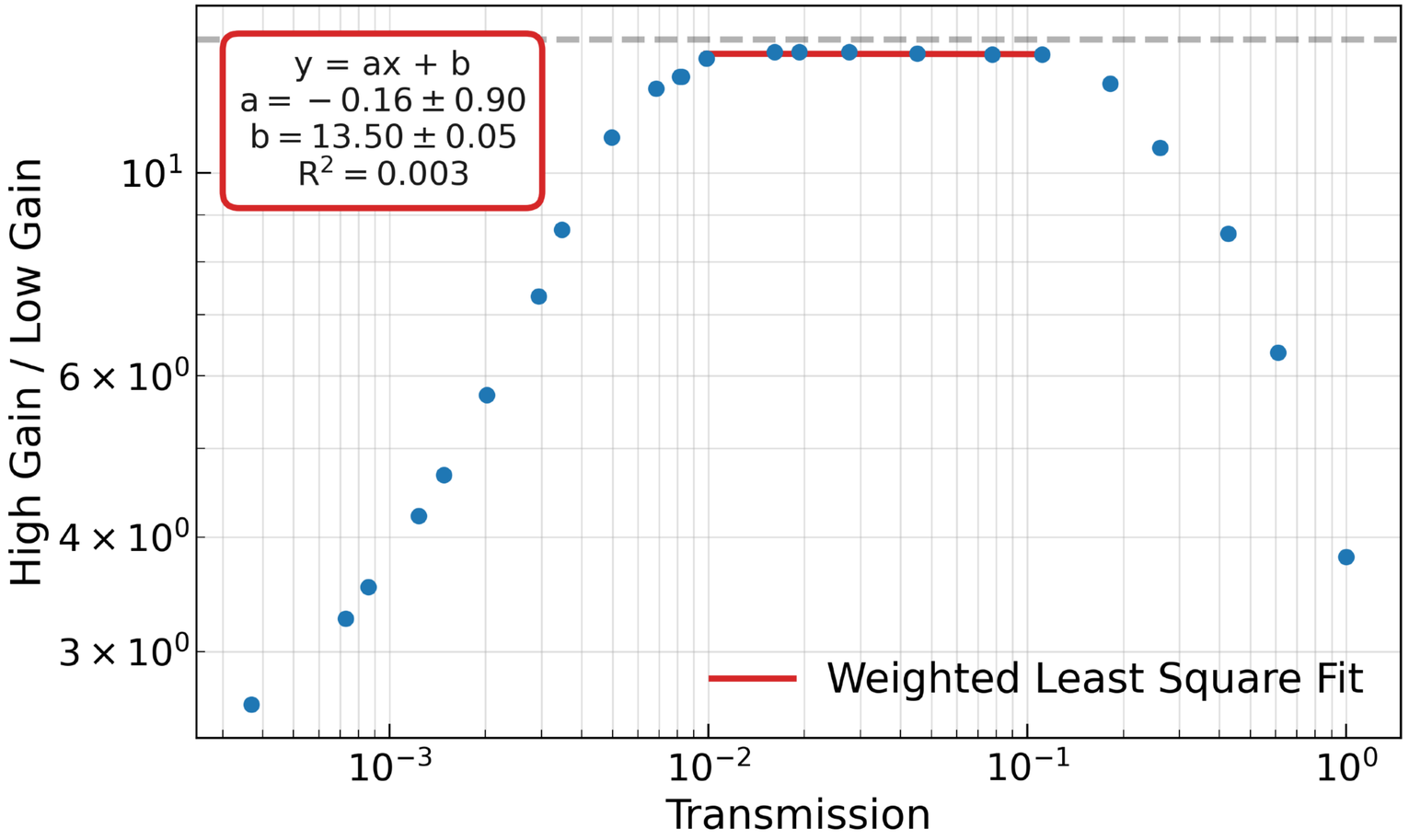
# Average charge over all pixels



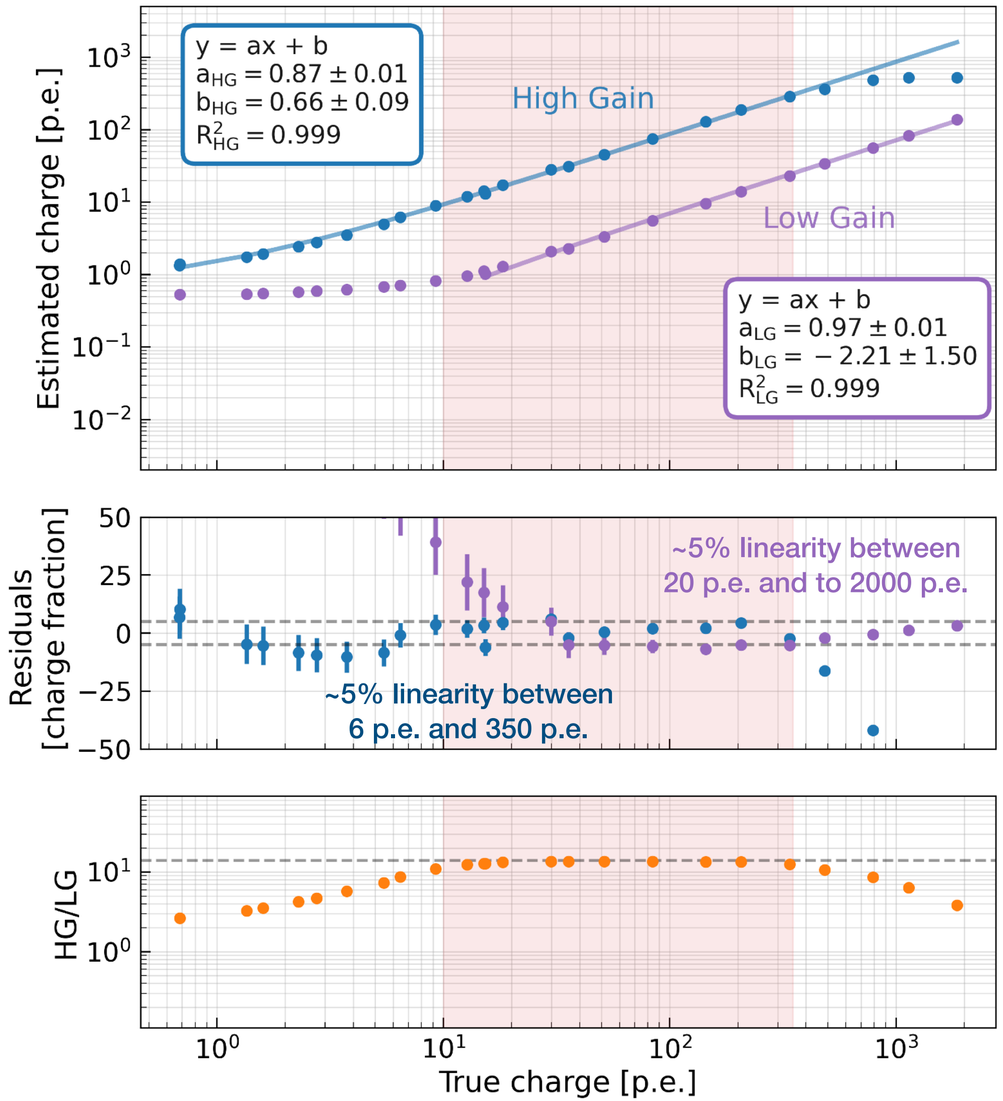

**In order to convert the reconstructed and true charge into units of p.e., it is necessary to correct for the high gain — low gain ratio**

# Gain ratio linear fit

Weighted least square fit performed in the linearity region to obtain the HG/LG ratio



# FEBv6 linearity test




Estimated charge integrated on a window of 18 ns

**Linearity is better than 5% on more than 3 decades**

Gain ratio of 13.40 ± 0.05

# Conclusions

## Timing performance

- Single pixel timing precision < 1 ns for incoming light of intensity  between ~ 10 and ~ 1000 photons
- PMT transit time correction of each pixel calculated and saved in database
- Global camera timing precision is 0.2 ns after correcting for PMT transit time effect
- Timing accuracy coming from the camera trigger timestamp relative to light arrival time is  below 0.5 ns
- **Paper in NectarCAM collaboration review**

# Conclusions

## Verification of FEBv6

- Linearity test shows that the FEBv6 response is linear better than 5% on more than 3 decades
- Deadtime of the FEBv6 is 0.745 +/- 0.001 μs
- Single pixel timing precision of the FEBv6 is below 1 ns for light illumination above 20 photons
- **Paper in preparation**