Studies on Time Resolution of BGO Long Crystal Bar

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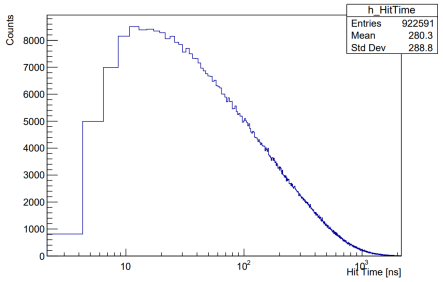
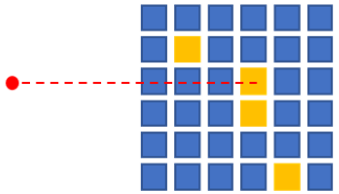
Workflow for Time Resolution Simulation

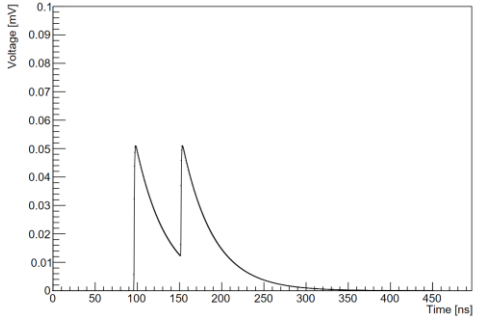
5GeV e-

detected time of scintillation photon





Pixel waveform



G4 optical simulation for crystal unit

Photon hit time

SiPM laser test

Single photon waveform

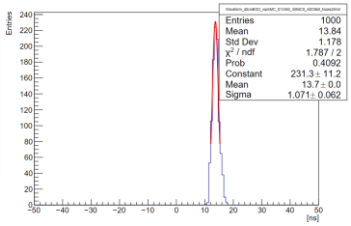
Toy MC of SiPM

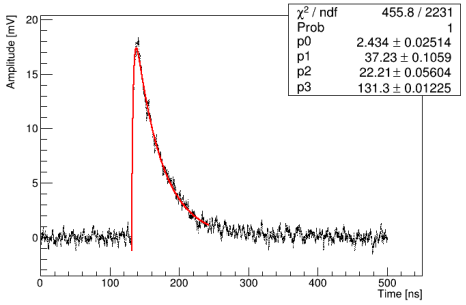
Pixels' fired time

Waveform simulation (digitization)

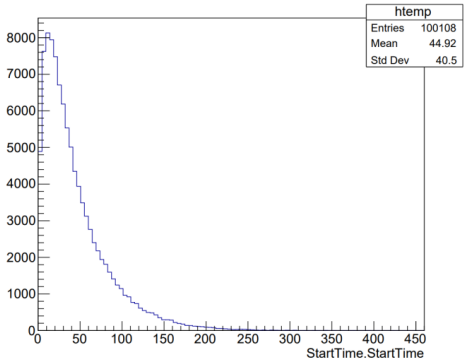
Waveform

Time resolution

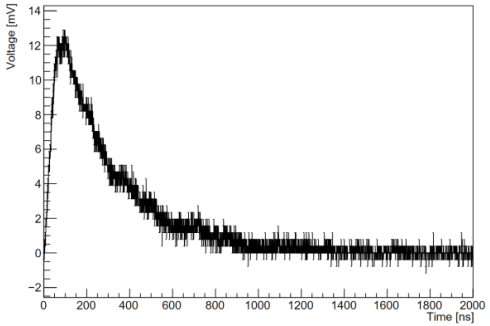




Waveform fitting to get the time constant of leading and falling edge



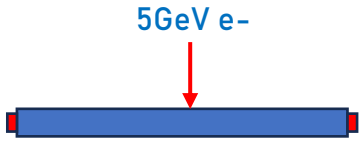
Fired time of all the pixels

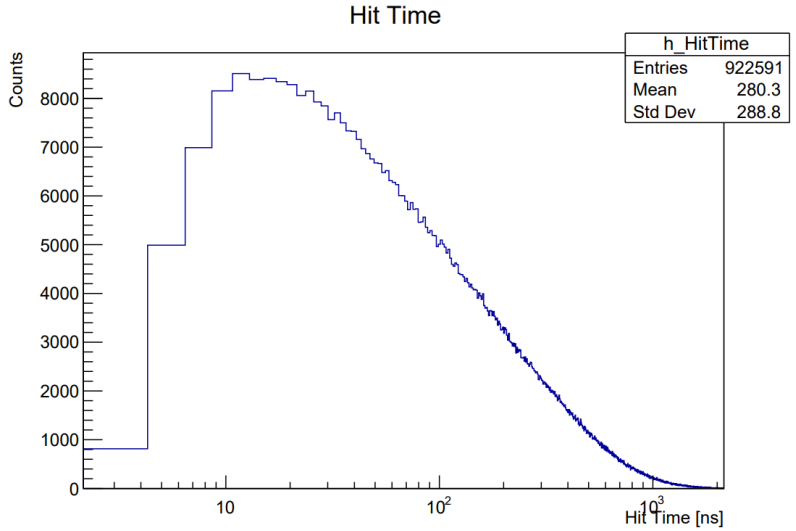


Total waveform

Optical Simulation for Crystal Unit

- Get the time distribution of scintillation photon hitting on SiPM
  - $1 \times 1 \times 40cm^3/1.5 \times 1.5 \times 60cm^3$ BGO crystal bar
  - $3 \times 3\mathrm{mm}^2$ SiPM(S14160-3015PS)



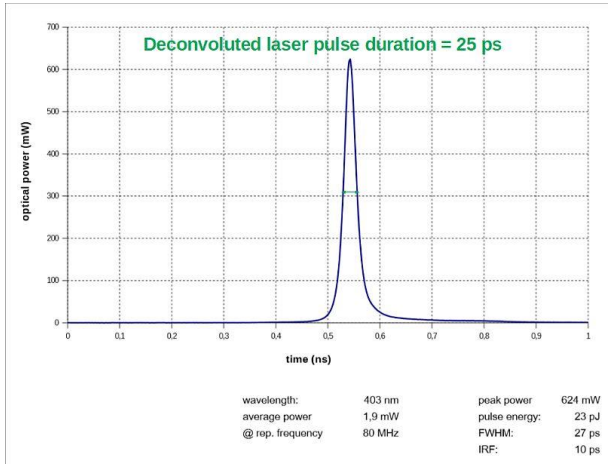


SiPM Laser Test And Waveform Fitting

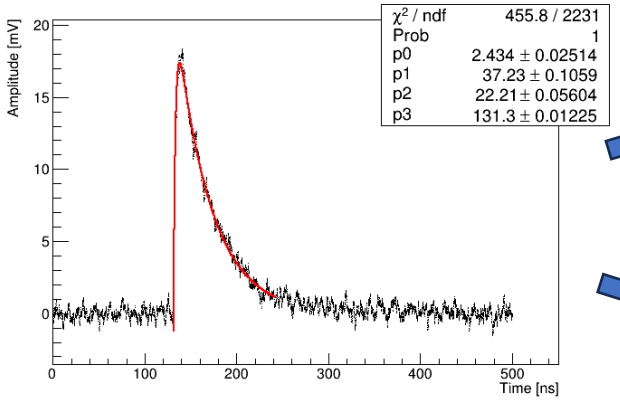
- Get a function to describe the single photon waveform of SiPM
- Fitting with a function to get the two time constants τ_1 and τ_2 , which determine the width of leading edge and falling edge
  - First fitting the entire waveform
  - Then fitting the leading edge and falling edge to get τ_1 and τ_2, respectively

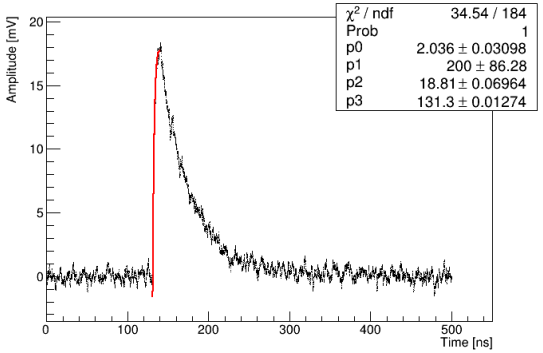
$$\left(1 - e^{\frac{-(x-x_0)}{\tau_1}}\right) \cdot A \cdot e^{\frac{-(x-x_0)}{\tau_2}}$$

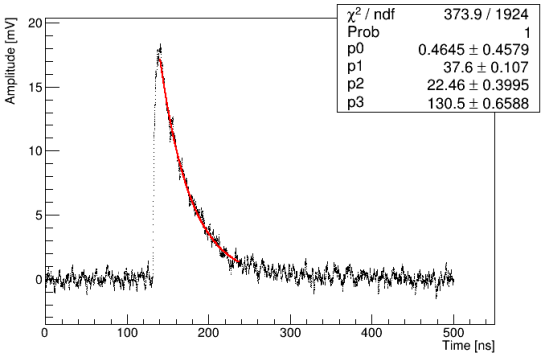
- τ_1 : discharging time constant
- τ_2: charging time constant
- A, x_0: amplitude and position



Waveform output by SiPM

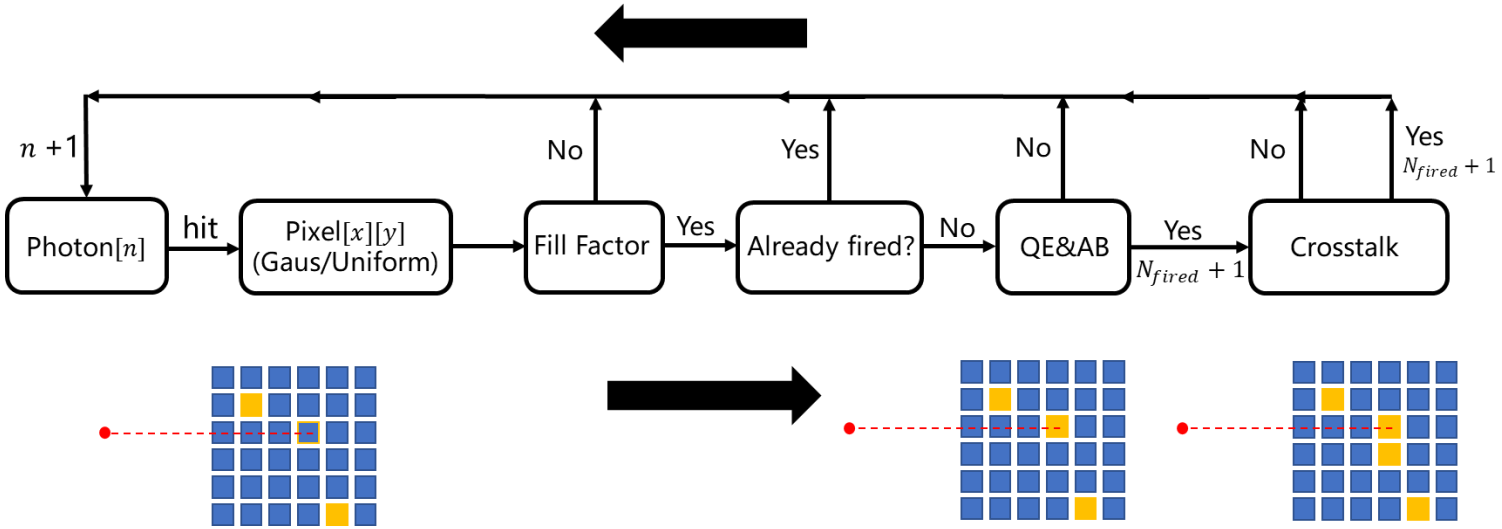




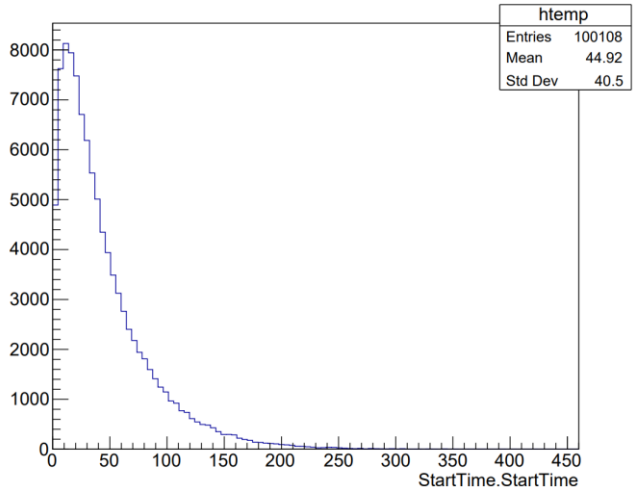


Toy Monte Carlo of SiPM

- Get fired time of SiPM pixel, which would be used in waveform simulation
  - Incident time of photon comes from Geant4 optical simulation
  - Uniform light spot on SiPM
  - BGO emission spectrum
  - SiPM pixel density, PDE spectrum, crosstalk, pixel recovery effect

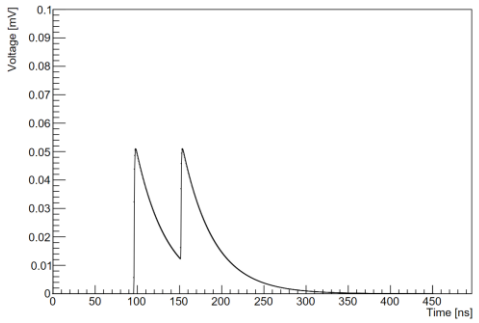


Fired time of all the pixels



Waveform Simulation

- Waveform simulation of SiPM with full digitization
  - Integrate pixel waveform to get the entire waveform
    - Recovery effect exists when photons hit on the same pixel
    - Pixel waveform function from laser test and fitting
  - Sampling rate: 2.5GHz
  - ADC bit : 8
  - Gaussian white noise: 0.2/0.38mV for 40/60cm BGO(from testbeam data)
  - Amplification and QDC correction



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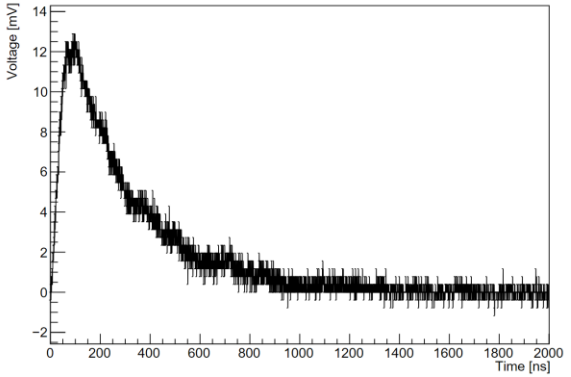
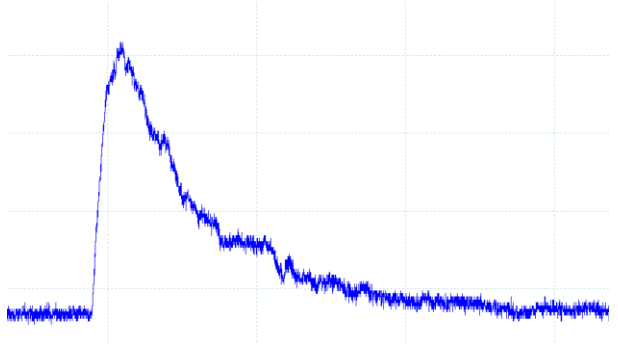
Waveform from simulation

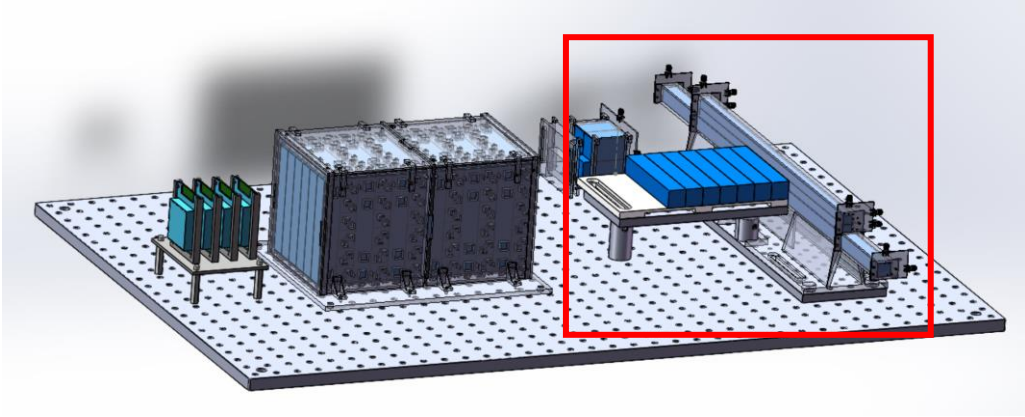


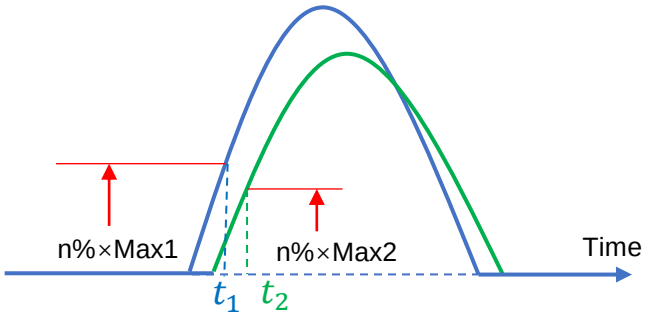
Waveform from data



Time Resolution

- Timing method: 10% CFD
- ~30% difference between simu and data, but the gap between 40/60cm BGO is almost the same(~0.5ns)
  - Fluctuations of number of p.e., single p.e. waveform and crystal uniformity need to be considered

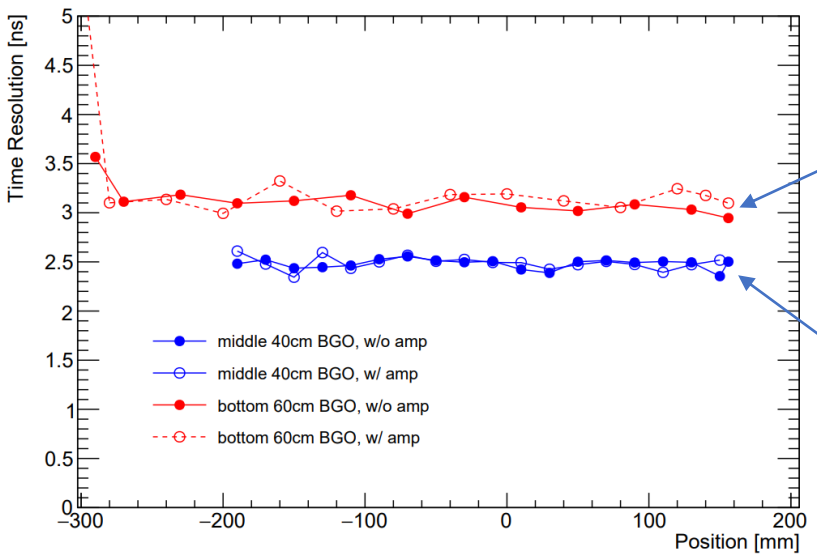




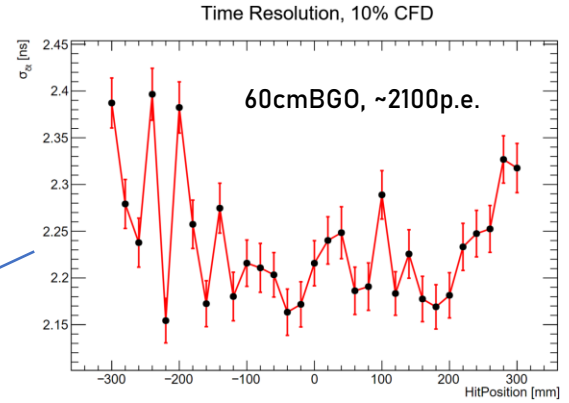
$$\Delta T = t_1 - t_2$$

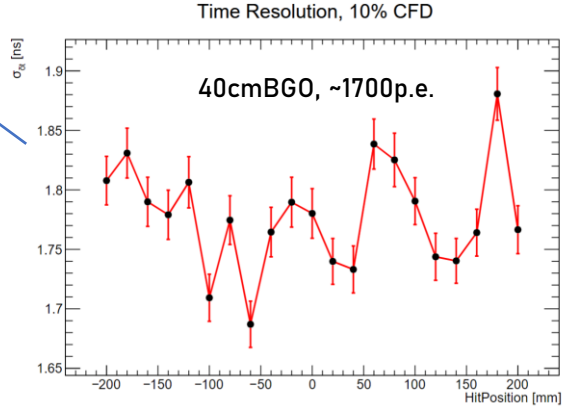
$$Time\ Resolution = \sigma_{t_1 - t_2}$$

DESY 5GeV Beam data



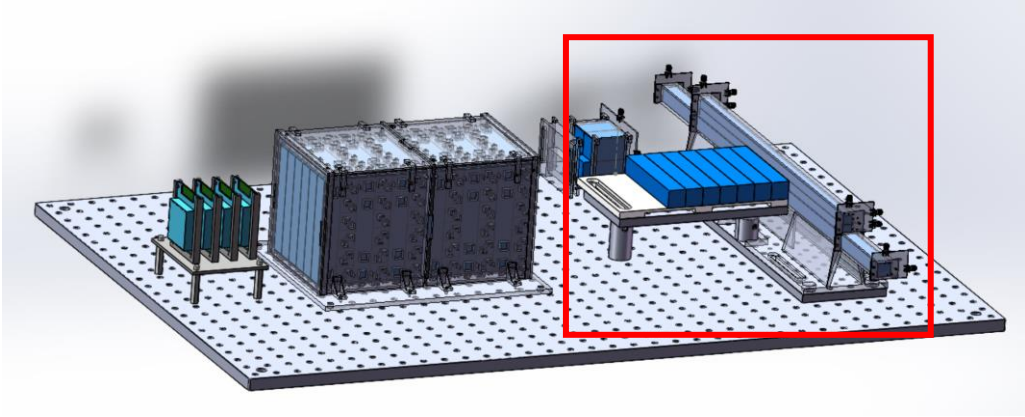
Simulation



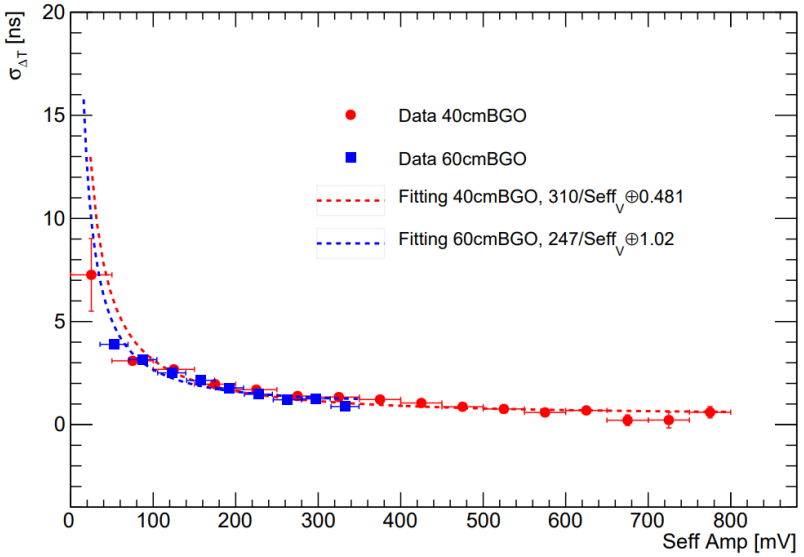


Time Resolution with Pre-Shower Crystals

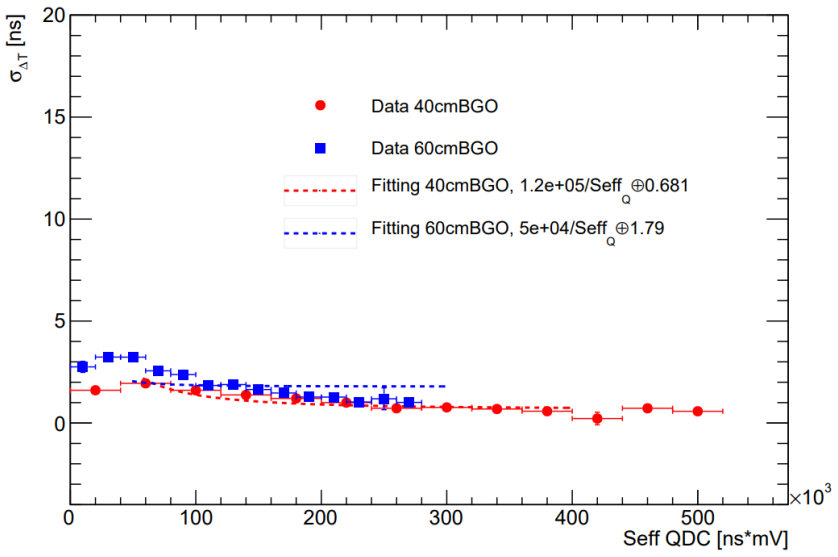
- SiPM: S13360-6025PE
- Preshower BGO thickness: 1, 3, 5, 6, 7cm
- Time resolution of extremely large signal is about 0.5ns/1ns for 40cm/60cm BGO
  - Entries>100 & $\pm 1\sigma$ fitting



better Seff Amp: $V_1 \cdot V_2 \cdot \sqrt{{V_1}^2 + {V_2}^2}$



Seff Amp: $Q_1 \cdot Q_2 \cdot \sqrt{{Q_1}^2 + {Q_2}^2}$



Fitting function:

$$\sigma(t_1 - t_2) = \frac{A}{S_{eff}} \oplus C$$

https://doi.org/10.1016/j.nima.2017.03.065

Next

- Simulate the time resolution as a function of energy deposit.
  - Light yield calibration for G4 optical simulation
  - Simulate with preshower

- Measure the devices in lab to get the intrinsic resolution of BGO.