Timing Performance of BGO Crystal Bar

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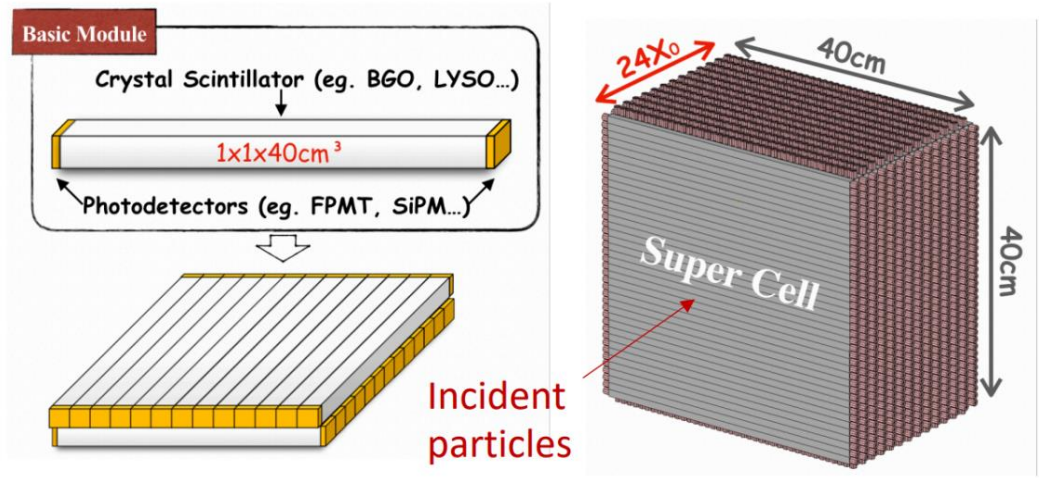
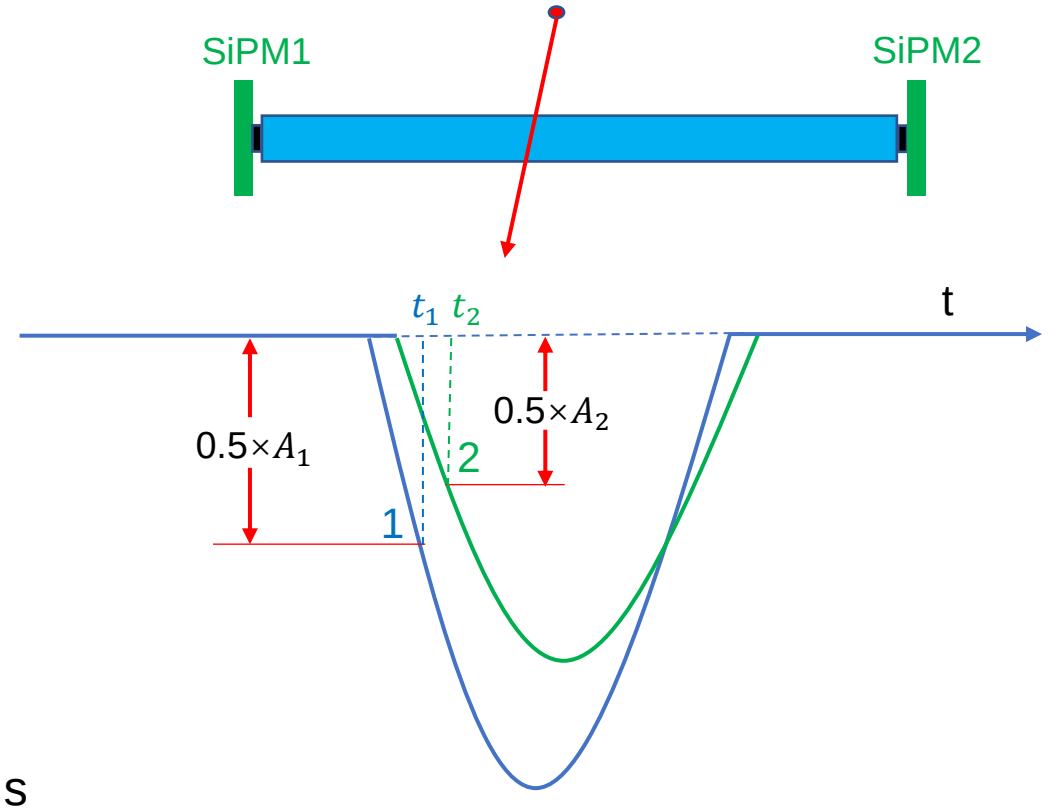
Introduction



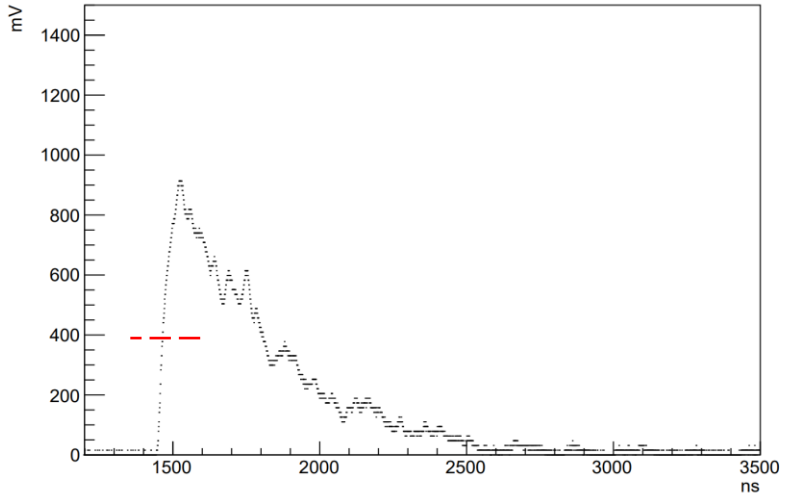


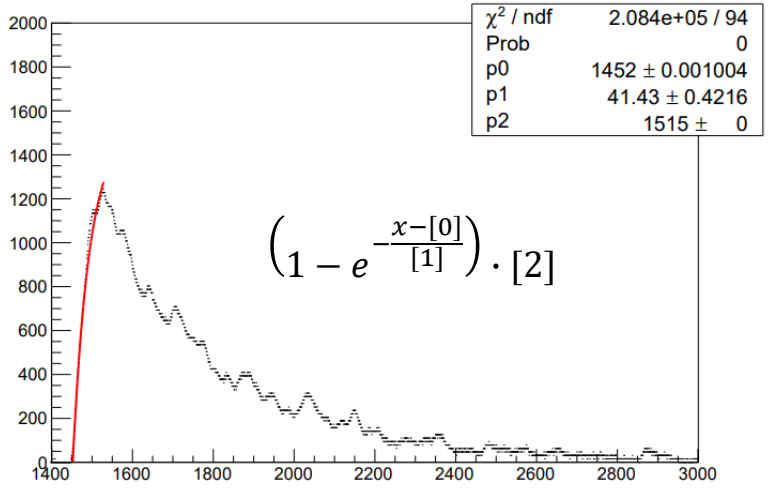
- High granularity crystal ECAL: 5D Detector — x, y, z, E, t
- Study the time resolution of the detector unit: crystal + 2 SiPMs
  - Timing method optimization
  - Time resolution measured with cosmic ray (MIP), and electron beam(EM shower)

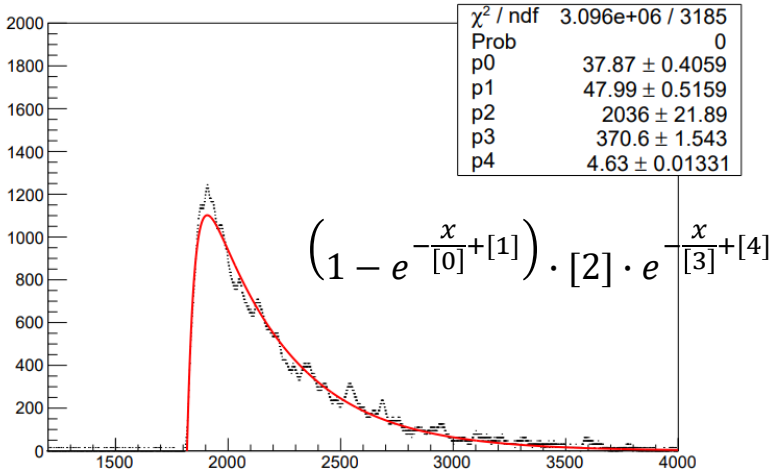
$$T_{res} = \delta_{t_2 - t_1}$$

Timing Methods

- Constant fraction timing with linear interpolation
- Leading edge fitting + CFT
  - CFT on the fitting function to get the timing point
- Waveform fitting + CFT
  - CFT on the fitting function to get the timing point

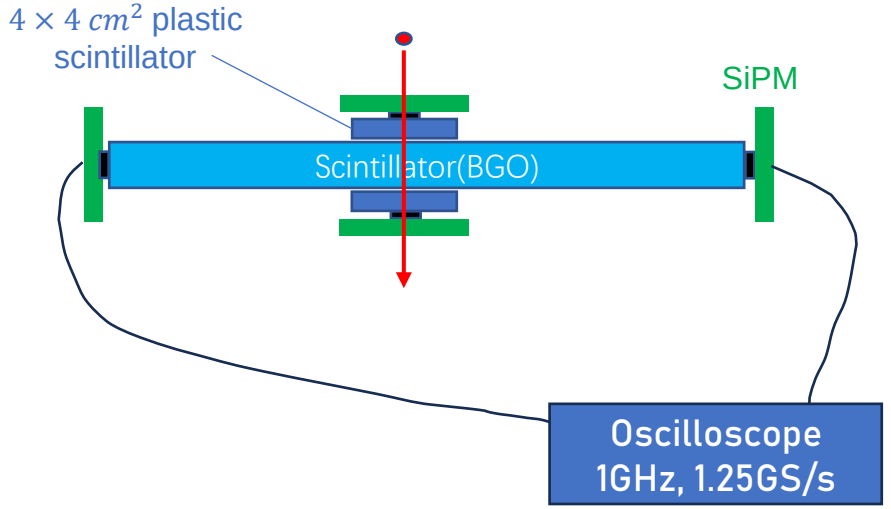


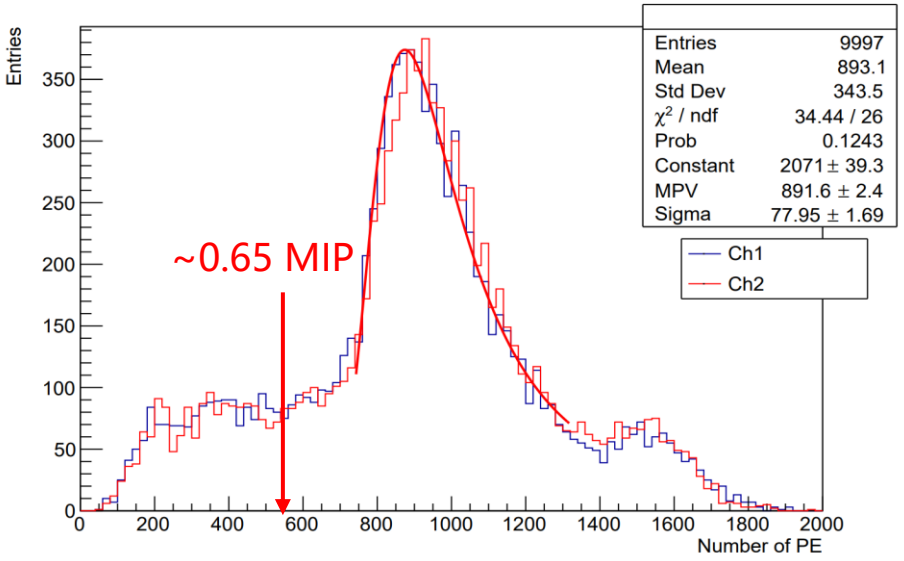


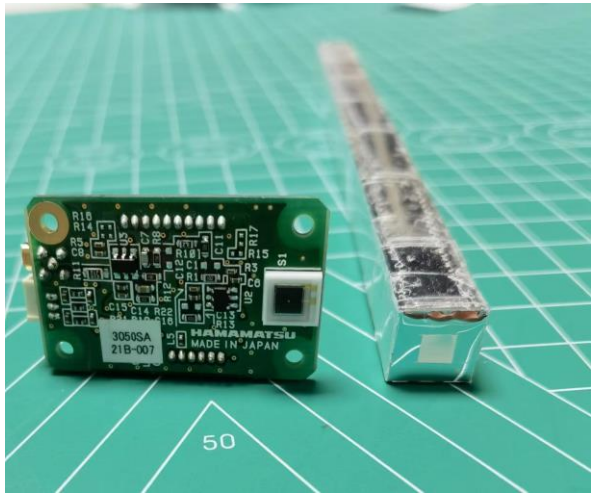


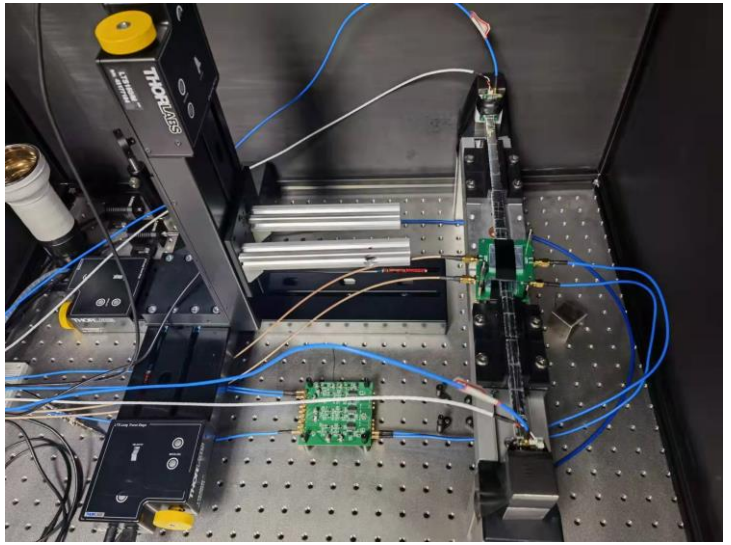
Cosmic Ray Data

- $40 \times 1 \times 1\ cm^3$ BGO covered by ESR, 2 sides readout
- SiPM module: C13360-3050SA, $3 \times 3\ mm^2$ sensor size
  - Signal amplifier(5MHz), power supply, temperature compensation
- ~890+890p.e./MIP, a 0.65MIP cut to effect of amplitude variation on time resolution



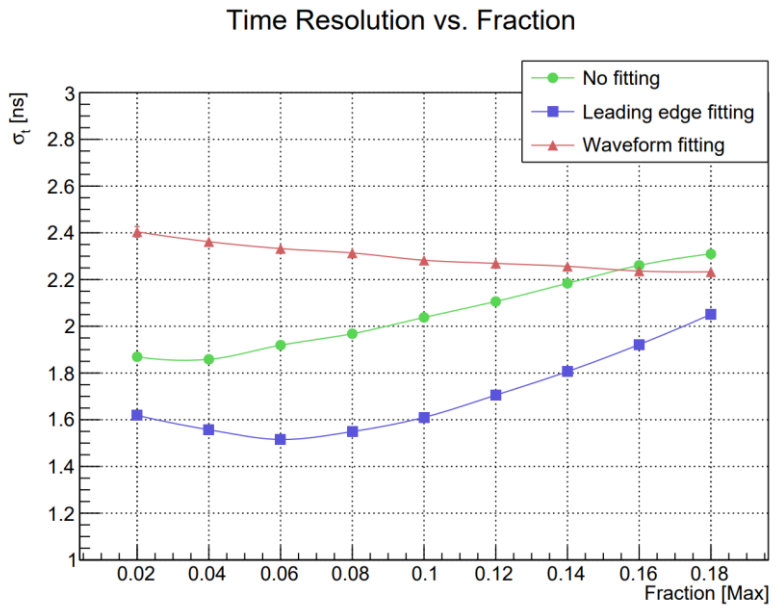


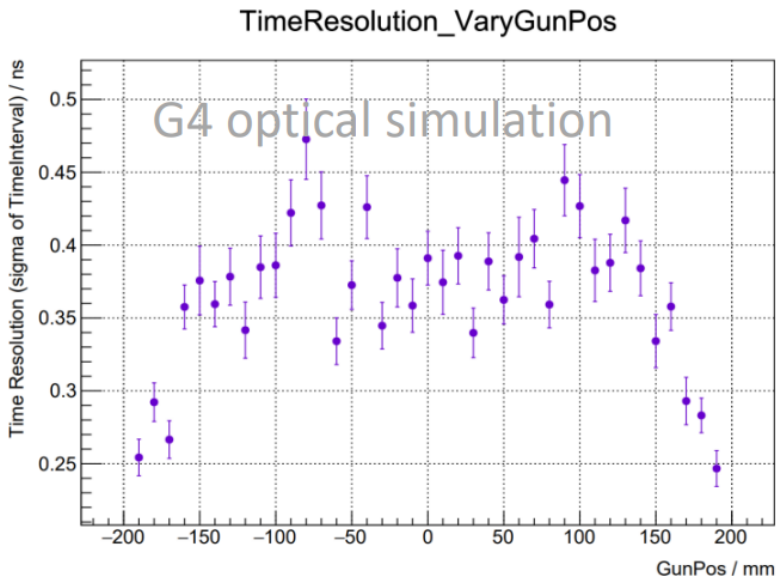




Time Resolution at MIP Level

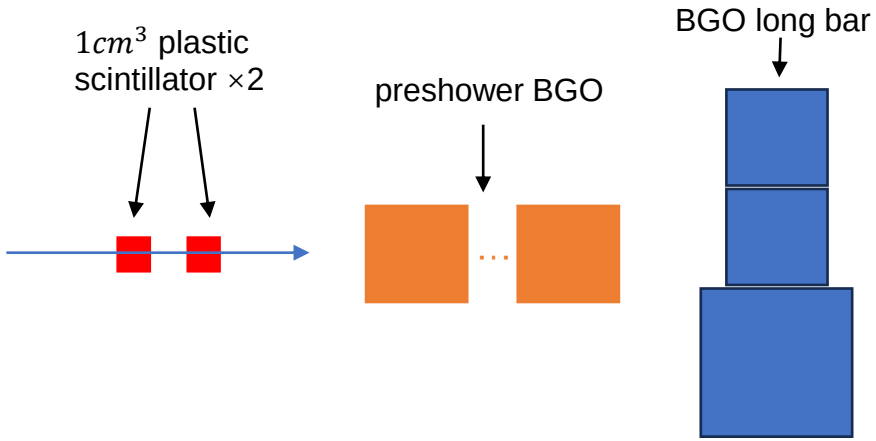
- Time resolution depends on the fraction. The best resolutions can be got with fraction smaller than 20%.
- The leading edge fitting can give the best result, $\frac{1.515}{\sqrt{2}} ns = 1.071 ns$ (single channel)
  - ~15cm space resolution according to the light speed in BGO
  - Ultimate performance(G4 simulation, triggering first photon) ~ 0.4ns

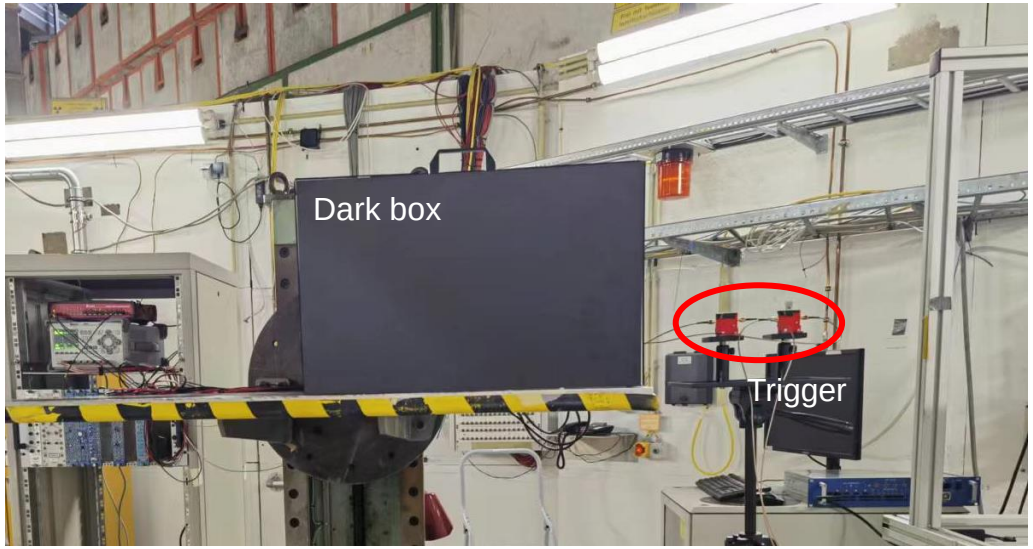


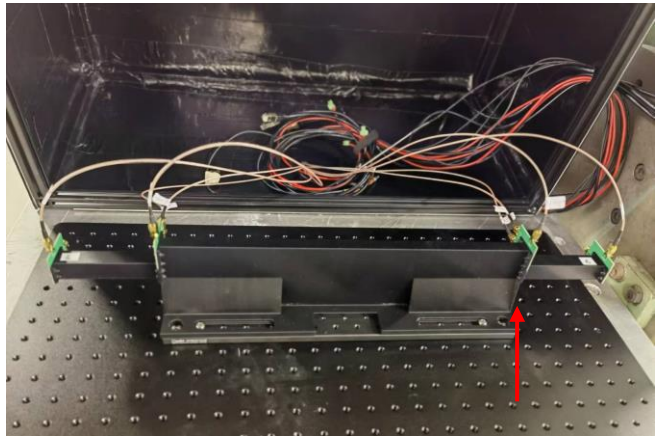


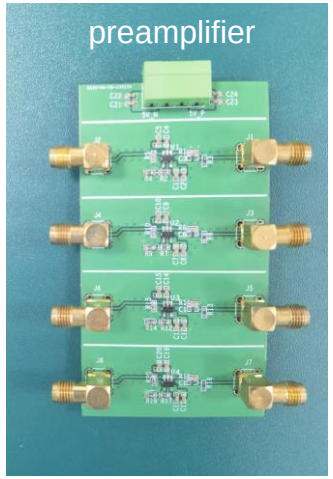
Beam Test

- DESY TB22 5GeV electron beam
- Two $1cm^3$ plastic scintillators provide a trigger signal
- 60/40/4/2cm BGO bar, 3/6mm SiPM, w/ or w/o preamplifier(individual one, ~50MHz)
- Preshower BGO thickness: 1, 3, 5, 7cm



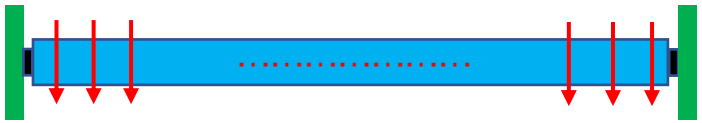






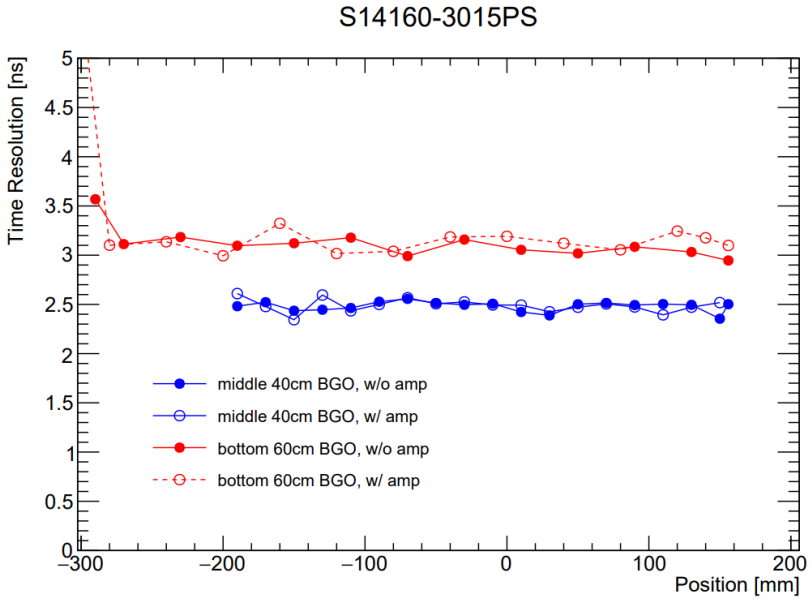
Crystal Scanning

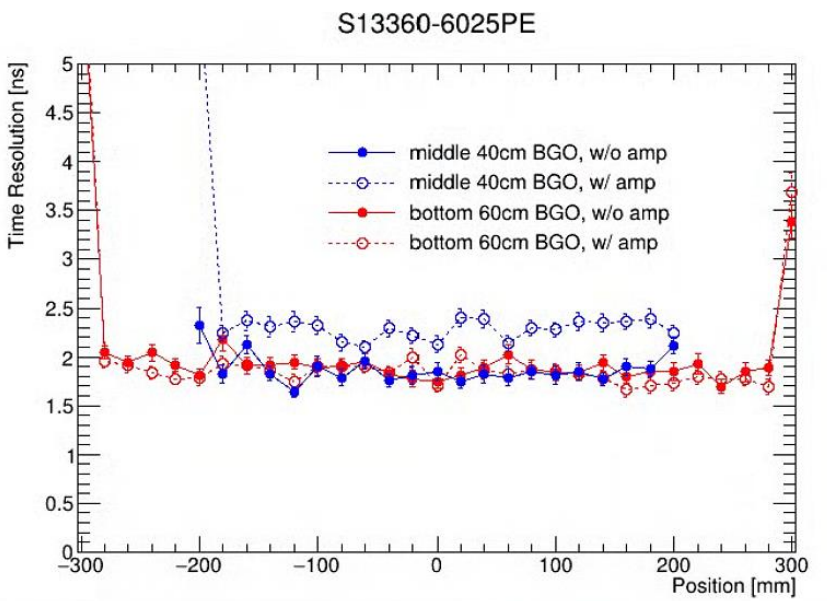
- Scanning along the long crystal bars, and get the time resolution at each point of the crystals with constant fraction timing
  - Time resolution along the crystal bar almost doesn't change
  - S13360-6025PE(2~2.5ns) better than S14160-3015PS(2.5~3ns)
  - The preamplifier has almost no influence(except 40cm BGO with 6mm SiPM)



$60 \times 1.5 \times 1.5/40 \times 1 \times 1\ cm^3\ BGO$

2 sides



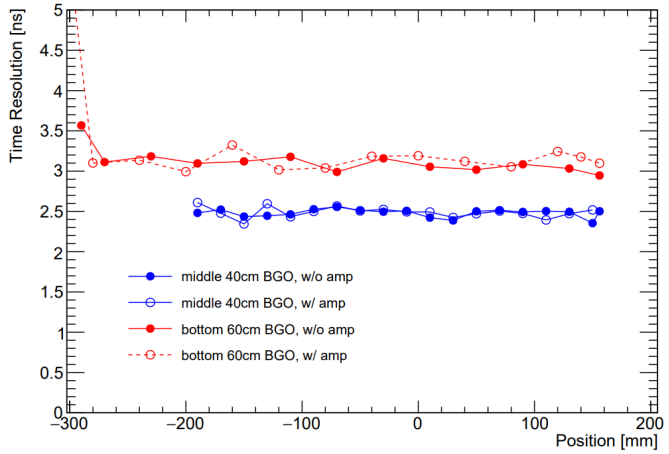


Dependence on Crystal Length

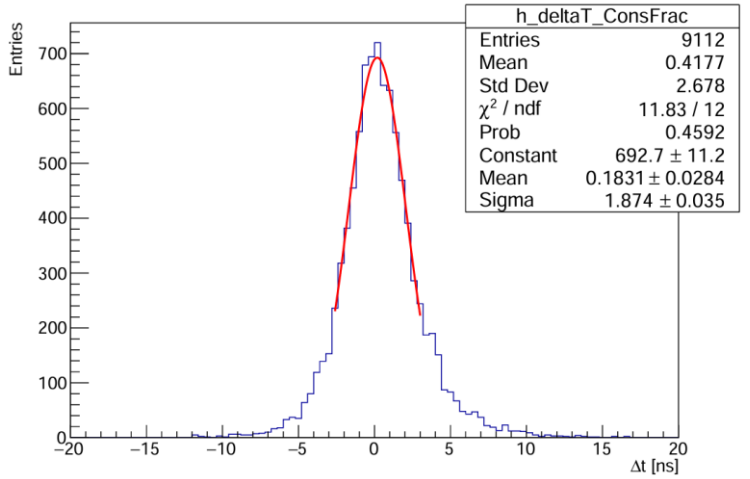
- The shorter crystal has the better time resolution
- SiPM: S14160-3010PS, w/o preamplifier

Crystal size	$60 \times 1.5 \times 1.5\ cm^3$	$40 \times 1 \times 1\ cm^3$	$4 \times 1 \times 1\ cm^3$	$2 \times 1 \times 1\ cm^3$
Time resolution (ns) (2 sides)	3	2.5	1.9	1.5

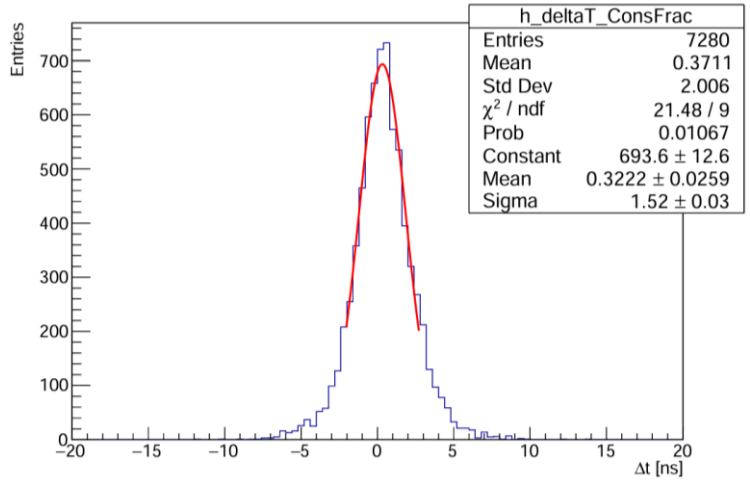
$60 \times 1.5 \times 1.5/40 \times 1 \times 1\ cm^3\ BGO$



$4 \times 1 \times 1\ cm^3\ BGO$

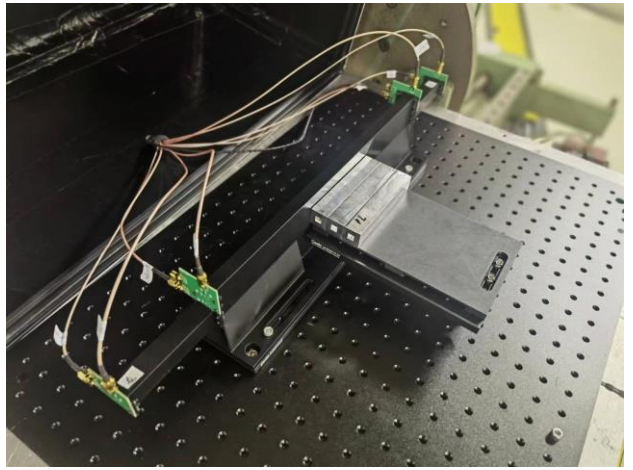


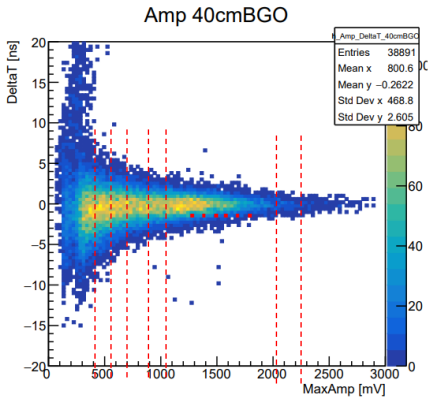
$2 \times 1 \times 1\ cm^3\ BGO$

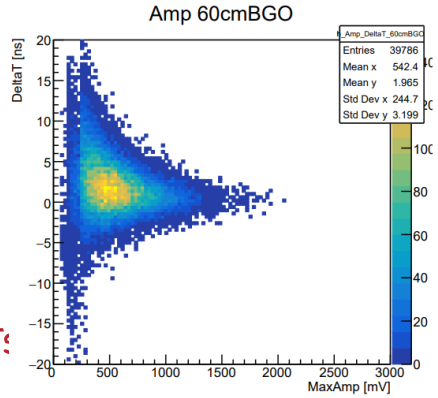


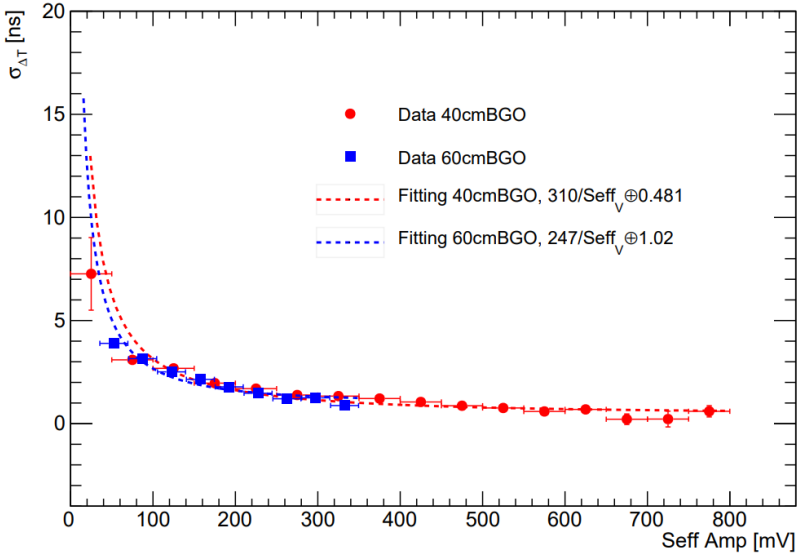
Dependence on Signal Amplitude

- Preshower BGO thickness: 1, 3, 5, 6, 7cm
- SiPM: S13360-6025PE, w/o preamplifier
- Constant term for 40cm BGO: ~$0.5/\sqrt{2} \approx 0.35$ns
- Constant term for 60cm BGO: ~$1/\sqrt{2} \approx 0.71$ns









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

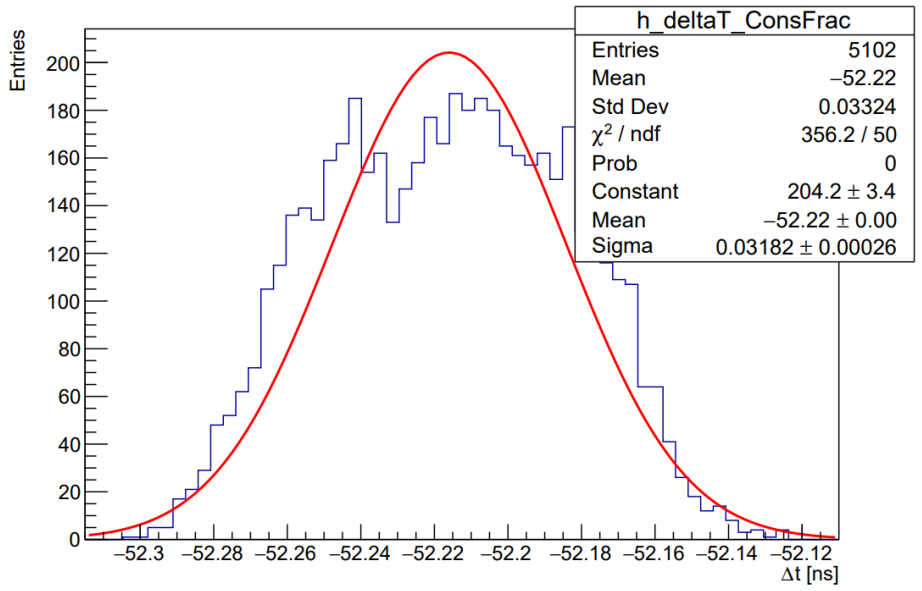
Fitting function: $\sigma(t_1 - t_2) = \frac{A}{S_{eff}} \oplus C$

Summary

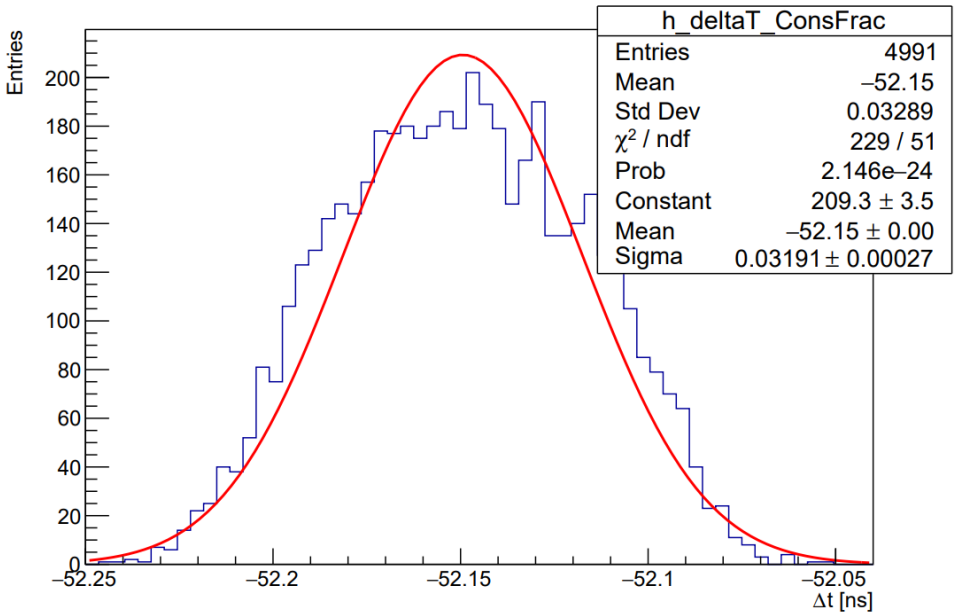
- We tested the time resolution of BGO crystal bars under cosmic rays and electron beam, and studied the influence of different timing methods, crystal lengths, SiPMs, and signal amplitudes on the time resolution.
  - Leading edge fitting is the best method.
  - Time resolution of $40 \times 1 \times 1\ cm^3\ BGO$ is about 1ns at 1-MIP level.
  - The time resolution uniformity of both 40cm and 60cm BGO is quite good.
  - The shorter crystal will have a better time resolution
  - For signals with very high amplitude, the time resolution of the 40cm BGO can reach 0.35ns, while the time resolution of 60cm BGO can reach 0.71ns

Time Resolution of Preamplifier

40cm BGO left



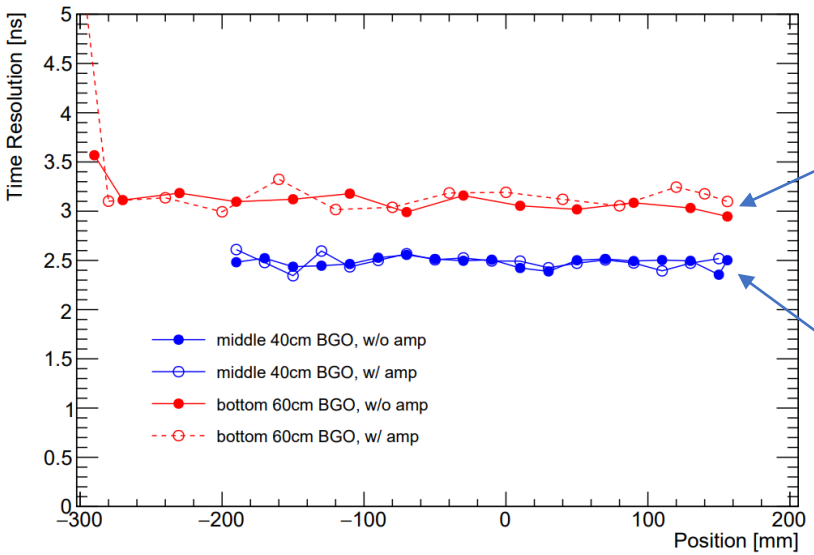
40cm BGO right



Time Resolution Simulation

- 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

DESY 5GeV Beam data



Simulation