# Crystal/glass calorimeter option (electromagnetic sector): input materials

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Mar. 9, 2024

CEPC Calorimeter Weekly Meeting

# Performance: long-crystal design

| Items | Priority | Results / Status | Remarks |
|---|---|---|---|
| Boson Mass Resolution | A | TBD (ongoing studies) | Required BMR < 4% |
| Intrinsic EM energy resolution | A | $1.5 - 2\%/\sqrt{E(GeV)}$ | Geant4 full simulation + digitisation |
| Separation power | | Results for $\gamma/\gamma$ and $\gamma/\pi$; no results for $\pi/\pi$ | gamma/gamma, gamma/hadron, hadron/hadron |
| Lepton ID in jets | | No results | |
| Timing capability | | ~1.3ns (MIP); 0.34ns (shower maximum) | DESY Beamtest results for long BGO bars (40/60 cm) |
| $\pi^0$ reconstruction | | No results | |
| Pile-up at Z-pole | | No results | |

- Priority/importance for performance requirements: (A) must-have; (B) plus; (C) not essential

# Performance: short-crystal design

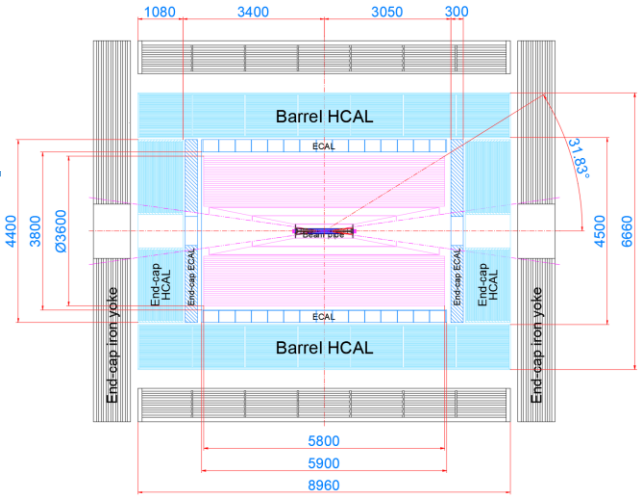
| Items | Priority | Results / Status | Remarks |
|---|---|---|---|
| Boson Mass Resolution | A | 3.6-3.7 % | 1cm³ BGO cubes for Higgs to gluon jets |
| Intrinsic EM energy resolution | A | $1.5 - 2\%/\sqrt{E(GeV)}$ | Geant4 full simulation + digitisation |
| Separation power | | Results for $\gamma/\gamma$ and $\gamma/\pi$; no results for $\pi/\pi$ | gamma/gamma, gamma/hadron, hadron/hadron |
| Lepton ID in jets | | No results | |
| Timing capability | | TBD (ongoing studies) | 1cm³ glass cube: 14 ps (MIP), 5-7 ps (shower maximum)** |
| $\pi^0$ reconstruction | | Simulation results | 1cm³ BGO cubes |
| Pile-up at Z-pole | | No results | |

* **Glass** is a promising option in the form factor of cubes/short bars, in terms of technical feasibility and cost effectiveness

** Based on a reference on 2016 CERN beamtest results (Crystal Clear Collaboration)

# Cost

Mechanics Design by Quan Ji
(Mar. 1, 2024)




Cost table template for ECAL

| Parameter Name | Barrel | Endcaps (x2) | Sum |
|---|---|---|---|
| Inner Radius for ECAL | 1900 mm | 400 mm | NA |
| Length for barrel;<br>Outer radius for endcap | 5900 mm | 1900 mm + $24X_0$<br>(2168.3mm for BGO) | NA |
| Longitudinal Depth | $24X_0$ (268.3 mm BGO) | | NA |
| Modularity | 28 modules in phi,<br>15 rings along Z | No concrete design<br>(ideal cylinder for now) | NA |
| Material Volume ($m^3$) | 19.1 | 6.3 | 25.4 |
| Readout channels | 0.95 M | 0.32 | 1.27 |
| Power dissipation (kW) | | | 25.4 |
| Cost: sensitive materials | | | 76.2 M |
| Cost: FE+BE electronics | | | 3.2 M |

* Note: ECAL endcaps will encompass barrel

(Preliminary) Key components and materials
SiPM (3x3mm²): 9 EUR / pc
Front-end ASIC: 1 EUR / ch
FE+BE electronics: 2.5 EUR / ch
Crystal/glass: *~3 EUR / cm³*
(with a large uncertainty)
Power: ~20 mW / ch

# Technical status: simulation and R&D

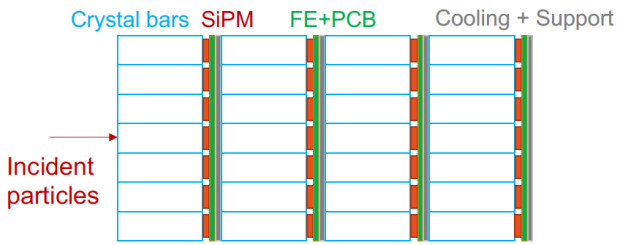
- Status and plans of simulation studies and R&D: details in the table below
- Person power: IHEP (Fangyi Guo, Yong Liu, Baohua Qi, Weizheng Song, Shengsen Sun, Yang Zhang), SIC-CAS (Junfeng Chen), SJTU/TDLI (Jiyuan Chen, Haijun Yang, Zhiyu Zhao)

| Category | Status | Long crystal bars | Short crystal bars |
|---|---|---|---|
| Technical Readiness Level | Full Simulation (system level) | CEPCSW: barrel geometry; reconstruction (ongoing developments) | CEPCsoft: full geometry, Arbor |
| | Full Simulation (module level) | Geant4 simulation, digitisation ( module 40x40x28 $cm^3$) | Geant4 simulation, digitisation (flexible module dimensions) |
| | Prototyping R&D (common) | High pixel density SiPMs (6/10 um pixel pitch), front-end electronics (ASICs), timing resolution | |
| | Prototyping R&D (modules, units) | Crystal module (12x12x24 $cm^3$); long crystal bars (40/60 cm) | No module developments; Short bars (2/4cm) |

# Extra Slides

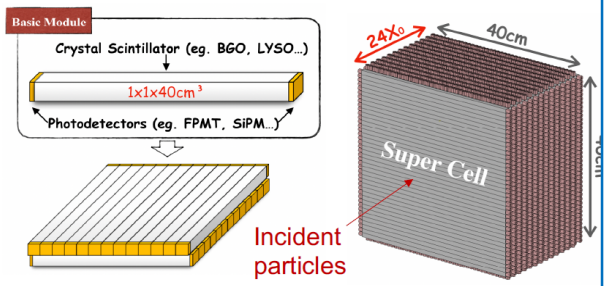
# Designs and EM resolution

## Design 1: short bars



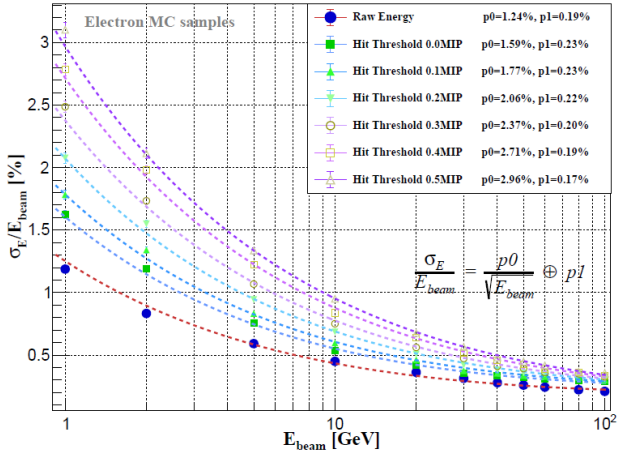

- A natural design compatible with PFA
  - Fine segmentation in Both longitudinal and transverse
  - Single-ended readout with SiPM

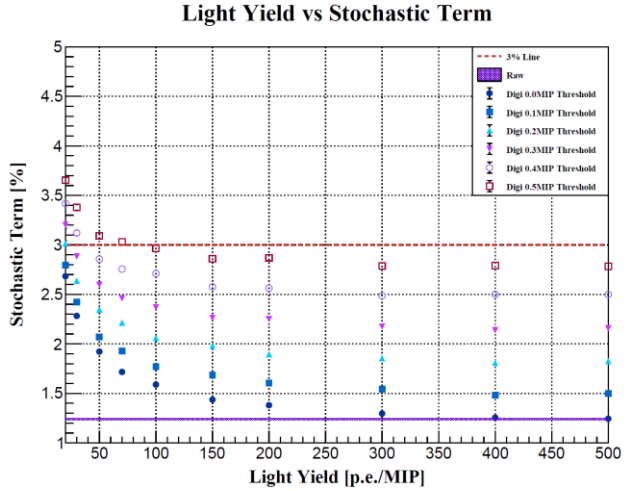
## Design 2: long bars




- Long bars: 1×40cm, double-sided readout
  - Super cell module: 40×40cm
  - Crossed arrangement in adjacent layers
  - Fine longitudinal granularity
- Save #channels and minimize dead materials
- Timing at two sides: positioning along bar

## Geant4 full simulation + digitisation



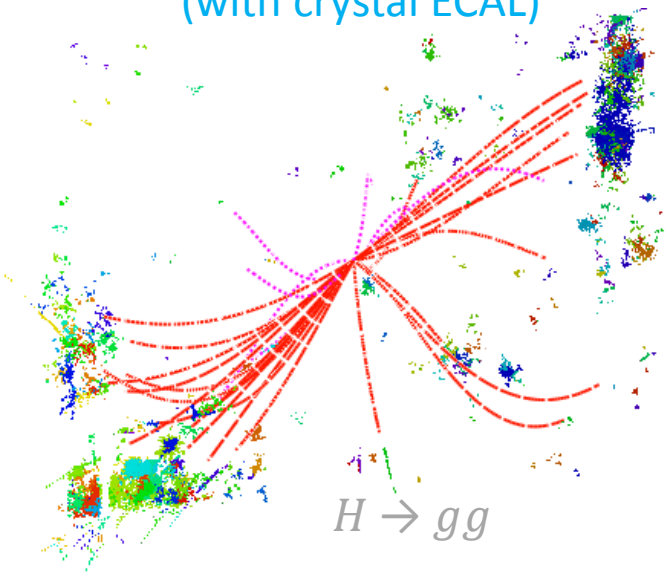

| Key Parameters | Value |
|---|---|
| MIP light yield | ~200 p.e./MIP |
| Dynamic range | $1 - 10^5$ p.e. |
| Energy threshold | ~0.1 MIP |
| Timing resolution | 1ns (→100 ps?) |
| Response non-uniformity | <1% |
| Temperature stability | Stable at ~0.05 ℃ |
| Gap tolerance | ~100 μm |

# Higgs physics performance

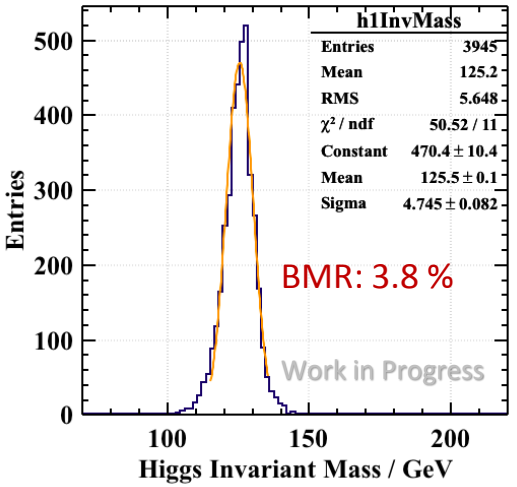
Baohua Qi, Dan Yu (IHEP); Zhiyu Zhao (SJTU)

- Physics potentials with crystals
  - Photons and jets
- Boson Mass Resolution (BMR)
  - Jets ($H \to gg$): 3.8 % → 3.6%
  - Photons ($H \to \gamma\gamma$): 2.1% → 1.2%

Higgs to 2 gluon jets
(with crystal ECAL)



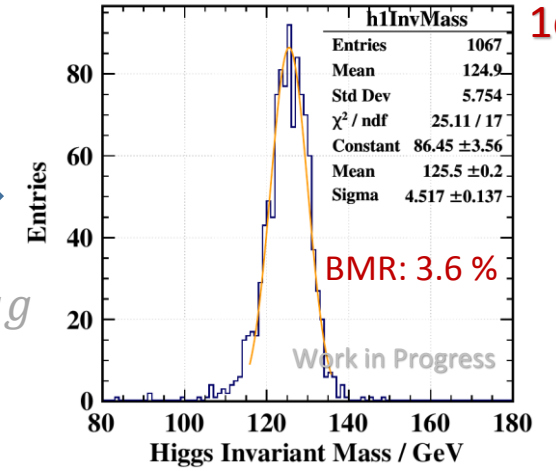

Detector with *SiW-ECAL* option



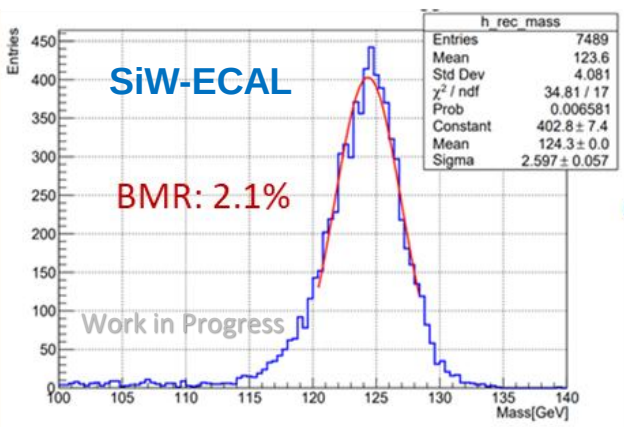

$H \to gg$

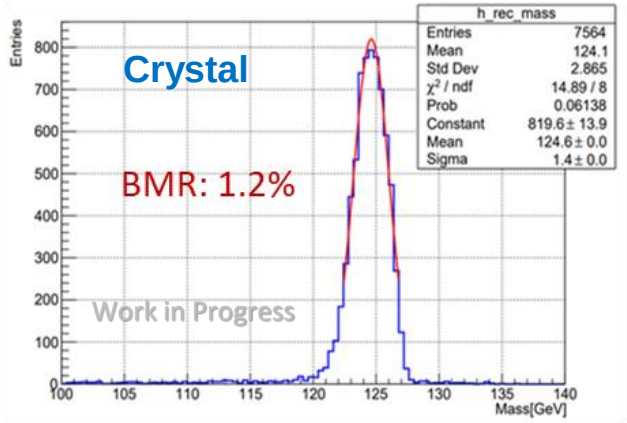
Detector with *crystal ECAL* option

1cm³ cubes




BMR ($H \to \gamma\gamma$)



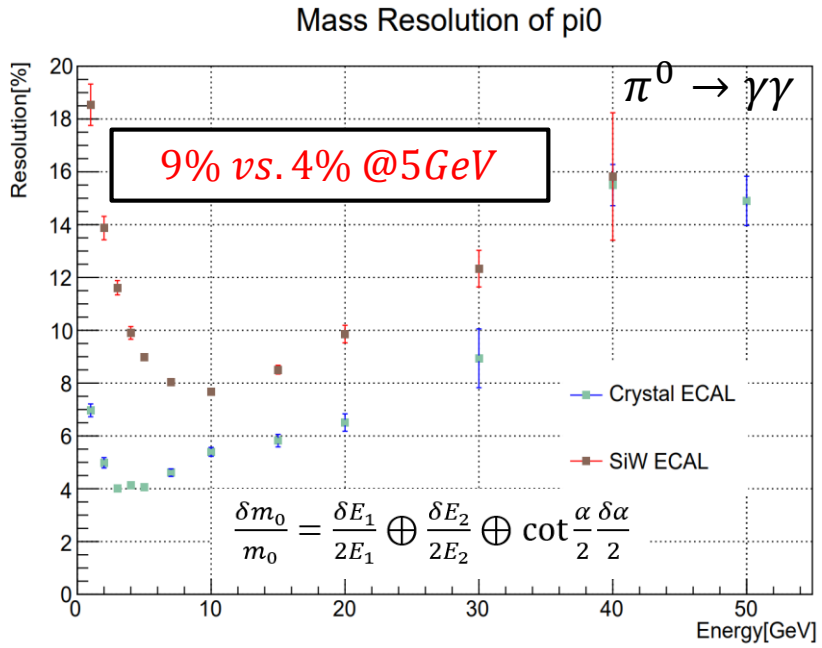
# Flavor physics performance

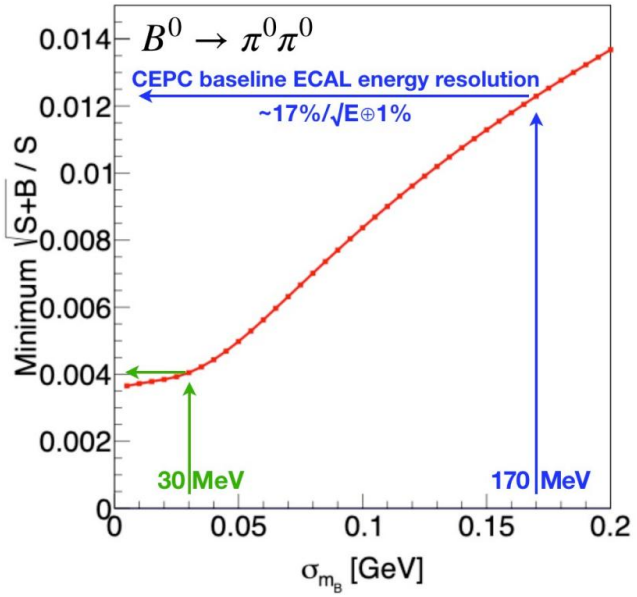
Zhiyu Zhao (SJTU), Yuexin Wang (IHEP)

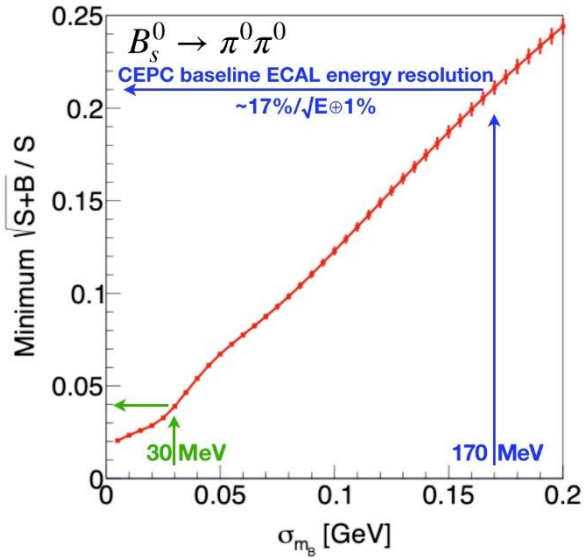
- Crystal ECAL
  - Higher sensitivity to photons and much better EM resolution
- Potentials for $\pi^0/\gamma$ in flavor physics

B0 to pipi @CEPC(CEPC Flavor Physics/New Physics/Detector Technology Workshop, Fudan, 2023), Yuexin Wang

| ECAL Resolution | $\sigma_{m_B}$ (MeV) | $B^0 \to \pi^0\pi^0$ | $B_s^0 \to \pi^0\pi^0$ |
|---|---|---|---|
| $17\%/\sqrt{E}\oplus 1\%$ | 170 | ~ 1.2% | ~ 21% |
| $3\%/\sqrt{E}\oplus 0.3\%$ | 30 | ~ 0.4% | ~ 4% |

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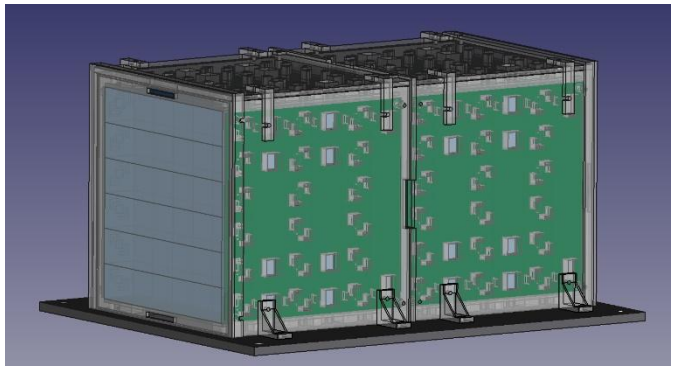
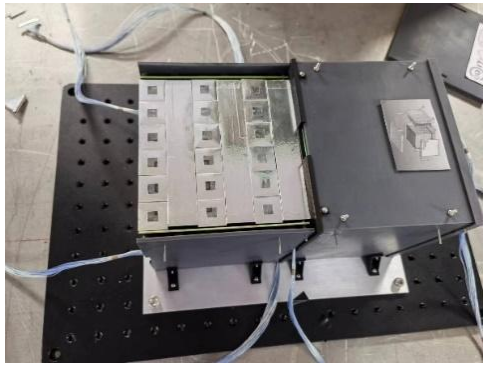
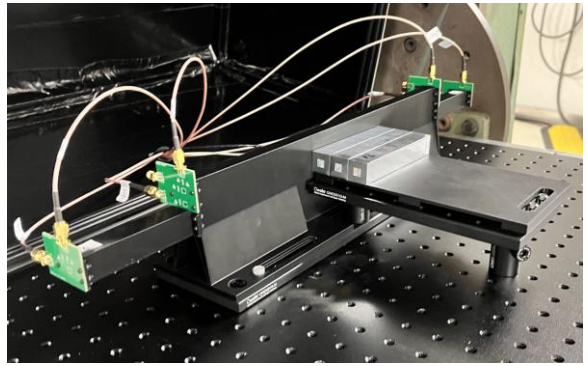
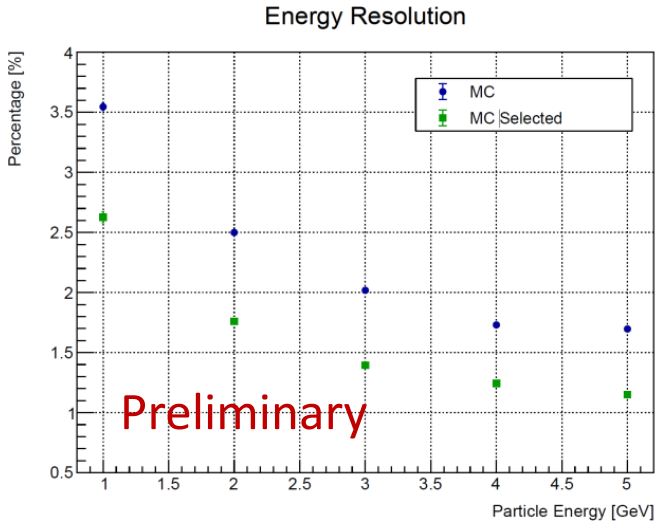
# Crystal ECAL: prototyping and beamtests





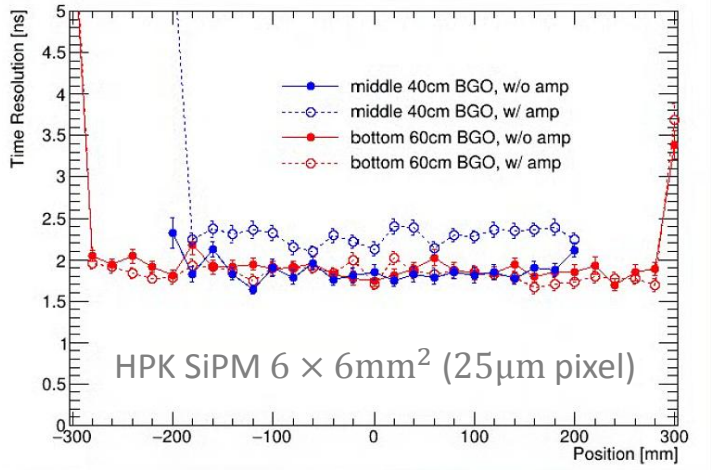


## Expected performance at CERN PS-T9

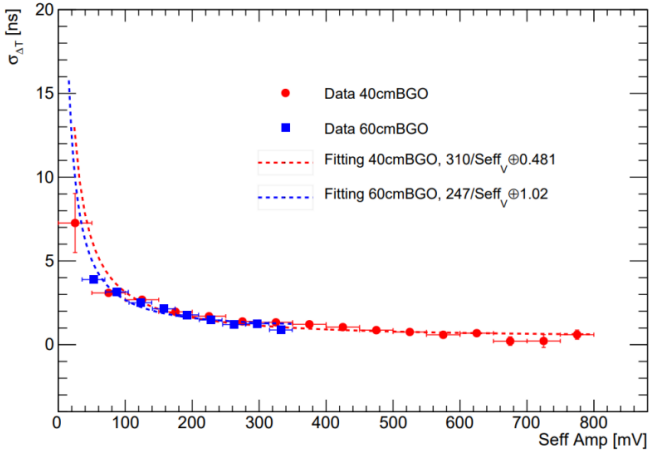



*Based on PS-T9 beamline document: 0.5% (FWHM) of beam spread (from Lattice)*

## Resolution of time difference at two ends




## Time Resolution vs Signal Amplitude




- Timing resolution (MIP level): ~1.8 ns (two ends) → ~1.3ns (single end)
- Timing resolution (upstream crystals as pre-shower): ~0.34 ns (single end for large signals)