Crystal/glass calorimeter option (electromagnetic sector)

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Meeting on CEPC Calorimeter Option Down-Select

Feb. 23, 2024

ECAL: crystal/glass option

- Down-select criteria for calorimetry system: performance

Category	Items	Long crystal bars	Short crystal bars*
Performance	Boson Mass Resolution (BMR < 4%)	TBD (ongoing studies)	3.6-3.7% (1cm³ cubes) for Higgs hadronic decays (jets)
	EM energy resolution	Geant4 full simulation + digitisation: $1.5 - 2\%/\sqrt{E(GeV)}$	
	PID in jets: lepton ID and precision timing	Lepton ID: TBD; Timing resolution (DESY TB): ~1.3ns (MIP); 0.34ns (shower maximum)	Lepton ID: TBD; Timing resolution: 14 ps (MIP), 5-7 ps (shower maximum)**
	π^0 reconstruction	TBD	Simulation: crystal (1cm³ cubes) versus silicon (see page 3)
	Pile-up at Z-pole	TBD	TBD

* **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)

ECAL: crystal/glass option

- Down-select criteria for calorimetry system: cost

Parameter Name	Barrel	Endcaps (x2)	Sum
Inner Radius	1800 mm	400 mm	/
Length for barrel; Outer radius for endcap	5000 mm	1800 mm	/
Depth	24 X0 (26.83 cm BGO)		/
Modularity*	28 modules in phi, 13 rings along Z	TBD (ideal cylinder for now)	/
Crystal Volume	16.2 m^3	5.2 m^3	21.4 m^3
Readout channels*	0.80 M	0.26 M	1.06 M
Power dissipation* (FEE only)			10.6 kW
Crystal cost			64.2 M EUR
SiPMs + ASICs*			10.6 M EUR

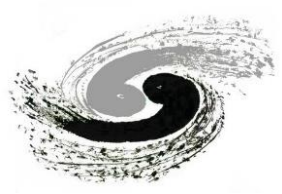
* **Note:** estimates in this table only for the design of ***long bars***

(Preliminary) Key components and materials
SiPM (3x3mm^2): 9 EUR / pc
Front-end ASIC: 1 EUR / ch
Crystal/glass: *~3 EUR / cm^3*
(with a large uncertainty)
Power: ~10 mW / ch (FEE only)

ECAL: crystal/glass option

- Down-select criteria for calorimetry system: TRL

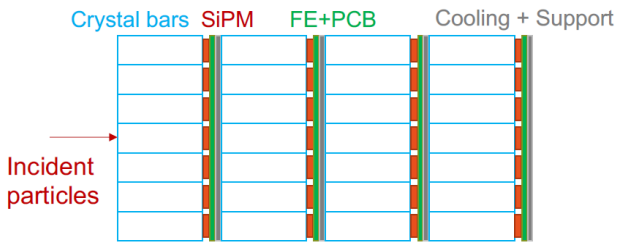
Category	Status	Long crystal bars	Short crystal bars
Technical Readiness Level	Full Simulation (system level)	CEPCSW: barrel geometry; reconstruction (ongoing developments)	CEPCsoft: full geometry, Arbor
	Full Simulation (module level)	Geant4 simulation, digitisation (module 40x40x28 cm^3)	Geant4 simulation, 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

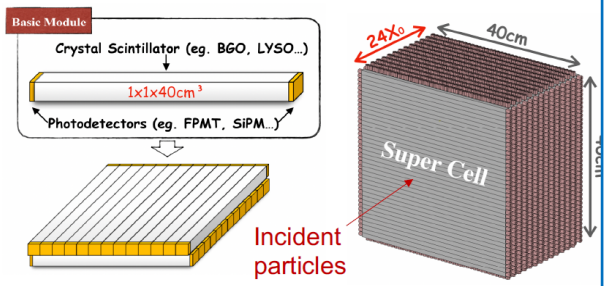
Designs and EM resolution

Design 1: short bars



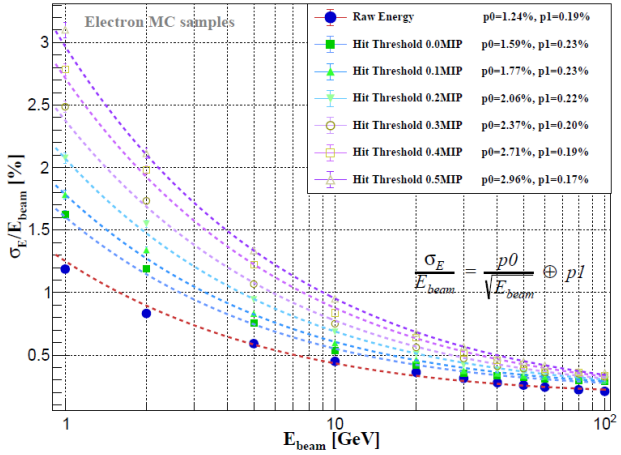
- A natural design compatible with PFA
  - Fine segmentation in Both longitudinal and transverse
  - Single-ended readout with SiPM

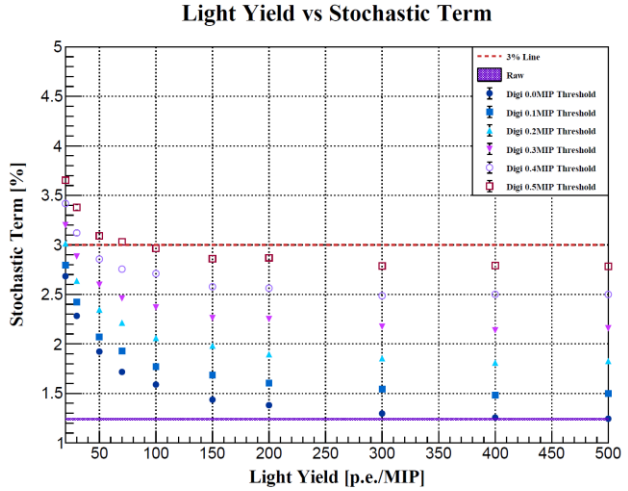
Design 2: long bars



- 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





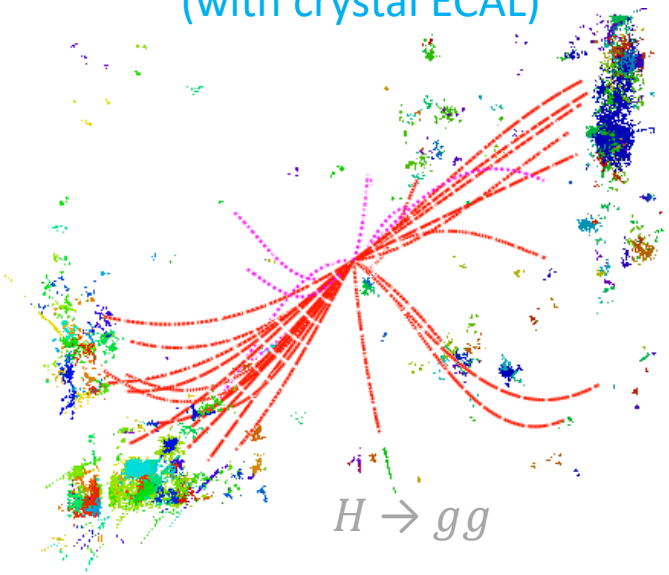
Key Parameters	Value
MIP light yield	~200 p.e./MIP
Dynamic range	$1 - 10^5$ p.e.
Energy threshold	~0.1 MIP
Timing resolution	1ns (→100 ps?)
Response non-uniformity	<1%
Temperature stability	Stable at ~0.05 ℃
Gap tolerance	~100 μm

Higgs physics performance

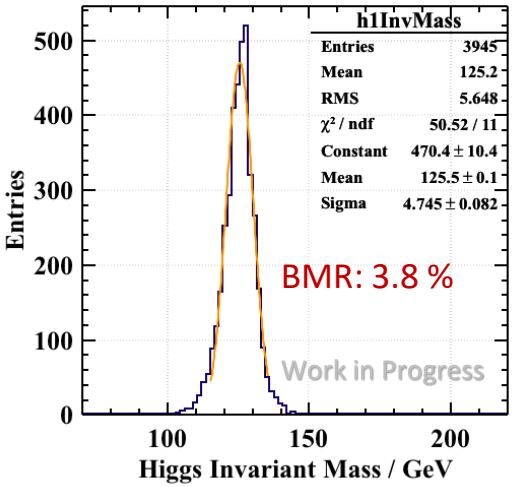
Baohua Qi, Dan Yu (IHEP); Zhiyu Zhao (SJTU)

- 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)



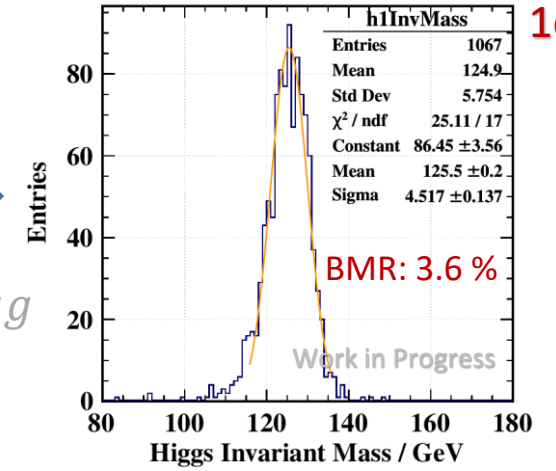
Detector with *SiW-ECAL* option



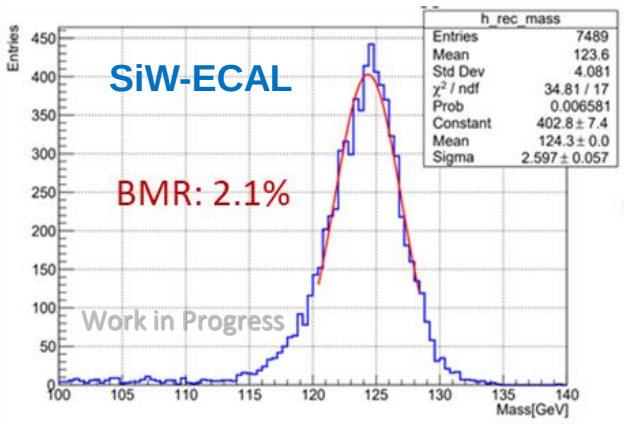
$H \to gg$

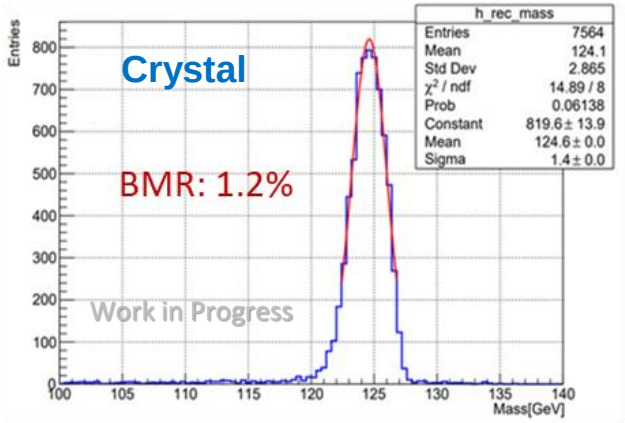
Detector with *crystal ECAL* option

1cm³ cubes



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





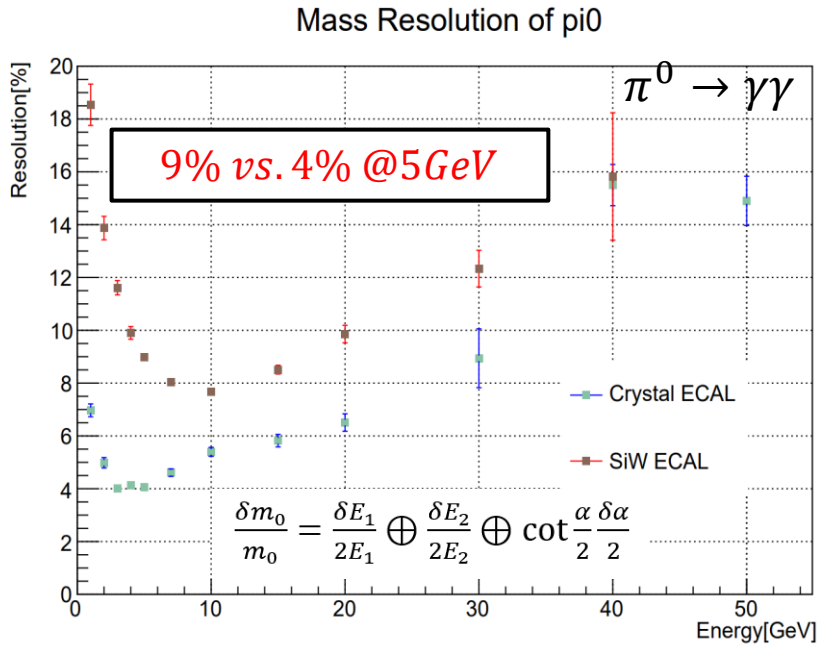
Flavor physics performance

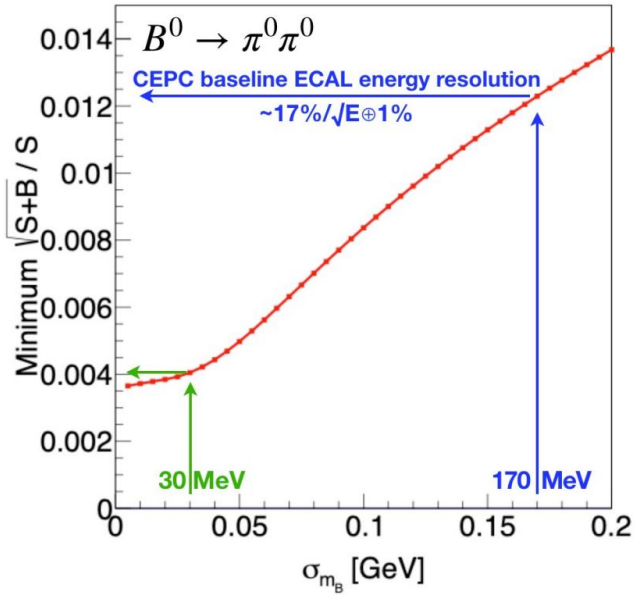
Zhiyu Zhao (SJTU), Yuexin Wang (IHEP)

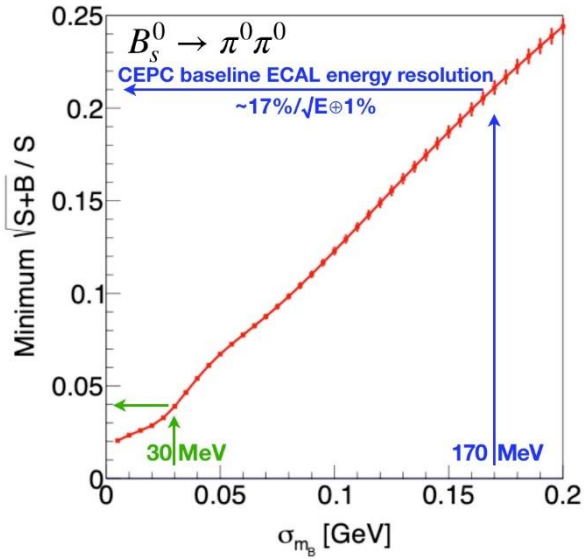
- Crystal ECAL
  - Higher sensitivity to photons and much better EM resolution
- Potentials for π^0/γ in flavor physics

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

ECAL Resolution	σ_{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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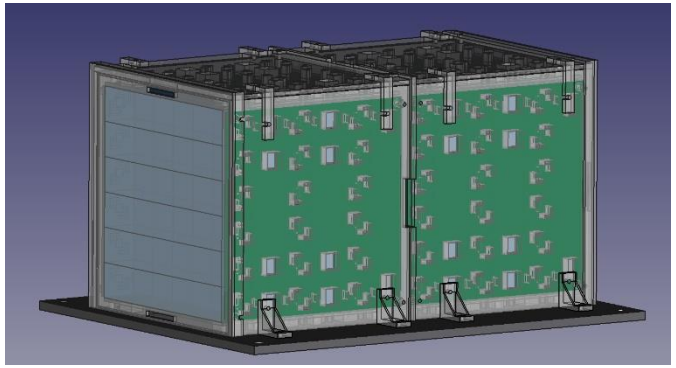
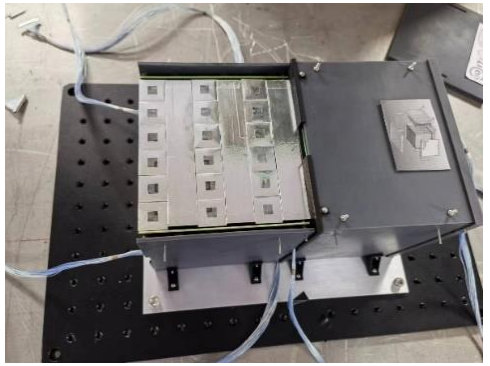
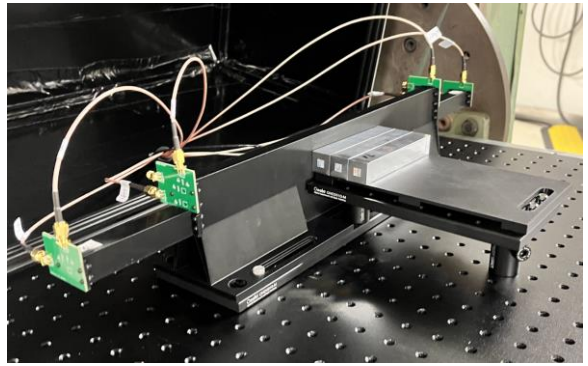
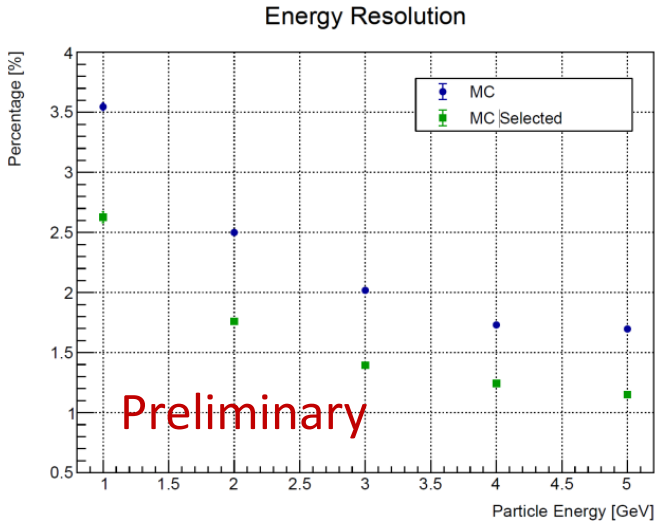
Crystal ECAL: prototyping and beamtests





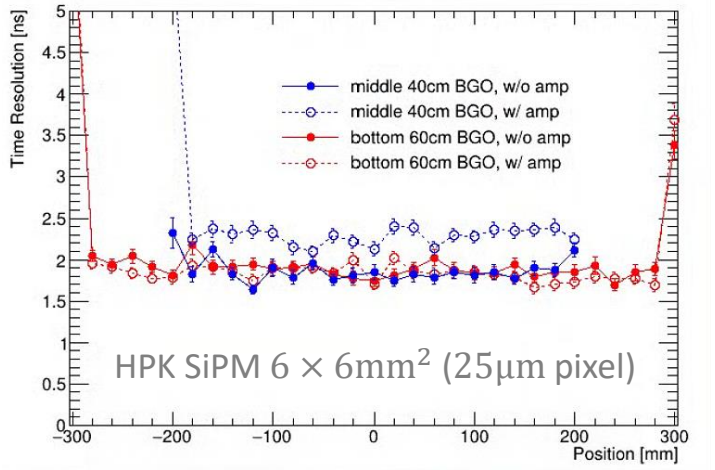


Expected performance at CERN PS-T9

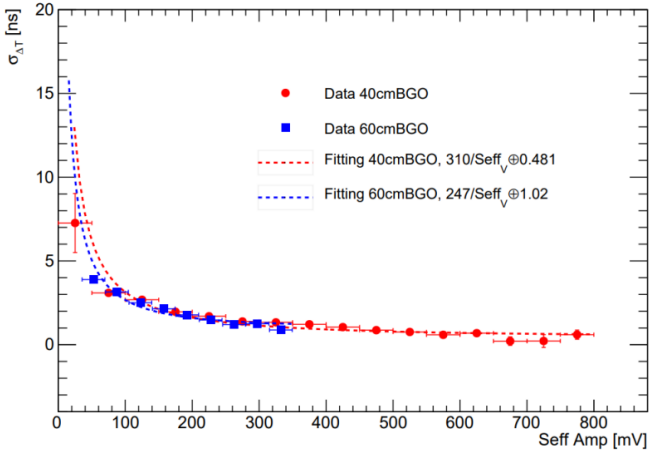


Based on PS-T9 beamline document: 0.5% (FWHM) of beam spread (from Lattice)

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)