Simulation and Reconstruction for the Scintillating-Glass Calorimeter in the AGORA Detector

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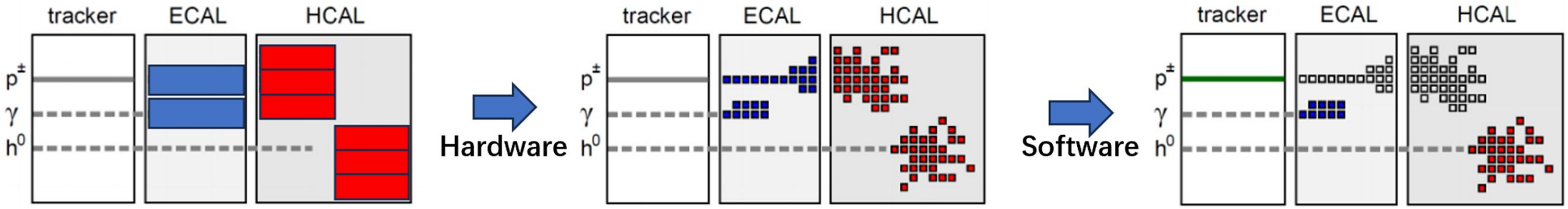
Institute of High Energy Physics, Chinese Academy of Sciences

CEPC Workshop 2026

24 October 2026

Physics Motivation and Calorimetry Requirements

- **Precision Higgs and EW physics** at future e^+ e^- colliders: accurate final-state reconstruction.
- **Jets from hadronic H/W/Z decays:** good energy resolution and shower separation.
- **Particle flow:** reconstruct individual particles to improve jet energy resolution.



Hardware: High granularity

Resolve nearby showers.

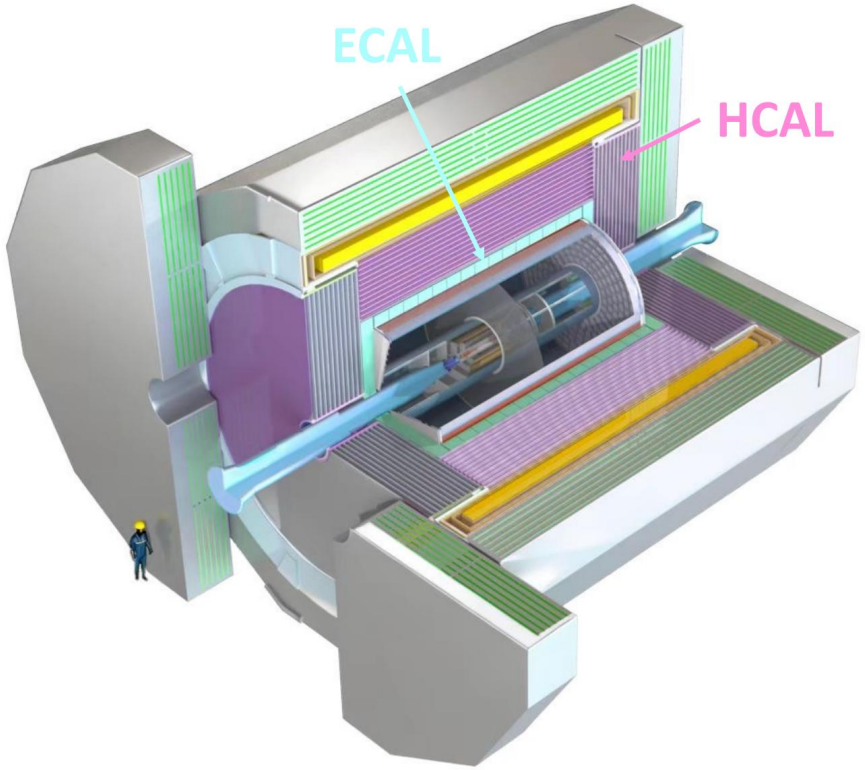
Software: Particle-flow reconstruction

Identify showers and assign energy deposits to particles.

High granularity + reconstruction algorithms → precise jet measurements

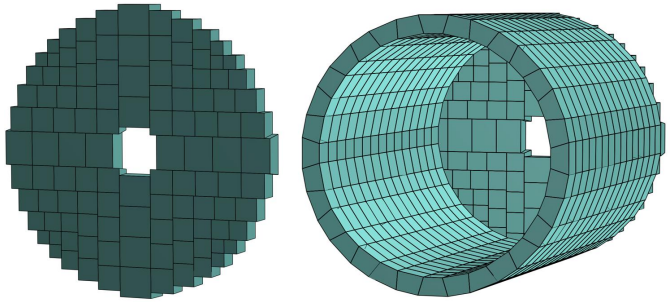
AGORA: The Baseline Detector

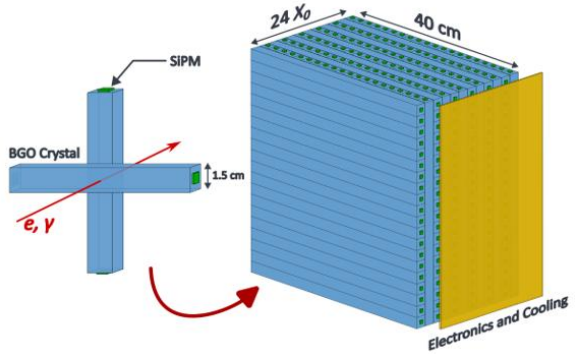
- CEPC Reference Detector TDR released in 2025.
- Now named **AGORA**: Advanced Glass Optimized Research Apparatus.
- AGORA is a PFA-oriented detector concept proposed for CEPC and FCC-ee.



AGORA baseline detector

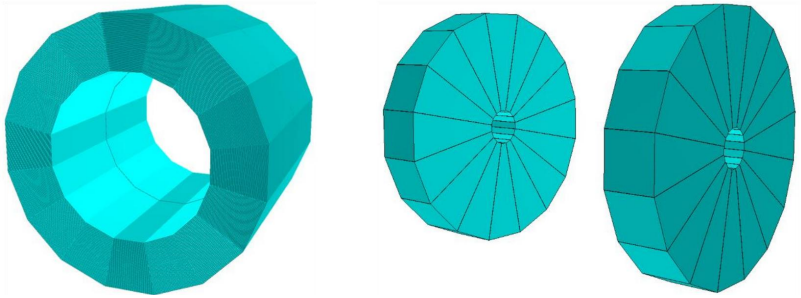
ECAL: Long BGO crystal bars

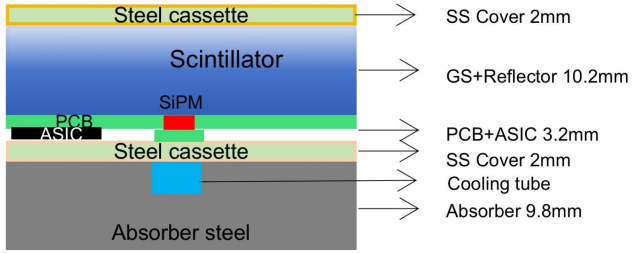




HCAL: Glass–steel sampling calorimeter

Sampling fraction: 30%





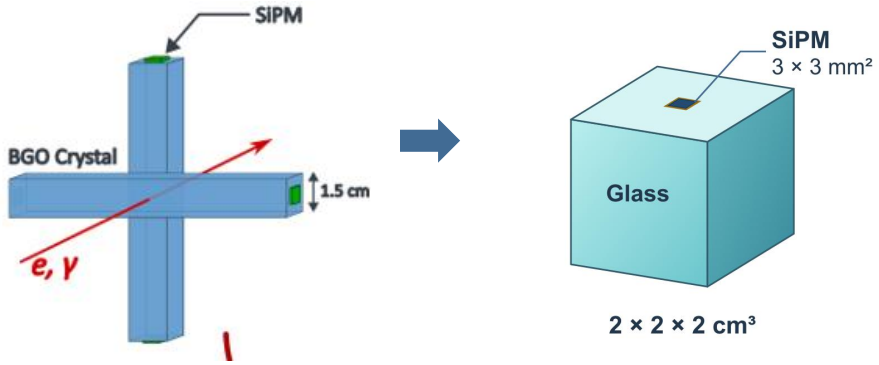
Reference Detector TDR · arXiv:2510.05260

AGORA: From Baseline to Updated Design

- Scintillating glass in both ECAL and HCAL.
- ECAL: long crystal bars → small glass cubes.
- HCAL: 30% sampling fraction → full-absorption design (≥70%).

ECAL: Segmentation and material

Baseline **Updated**



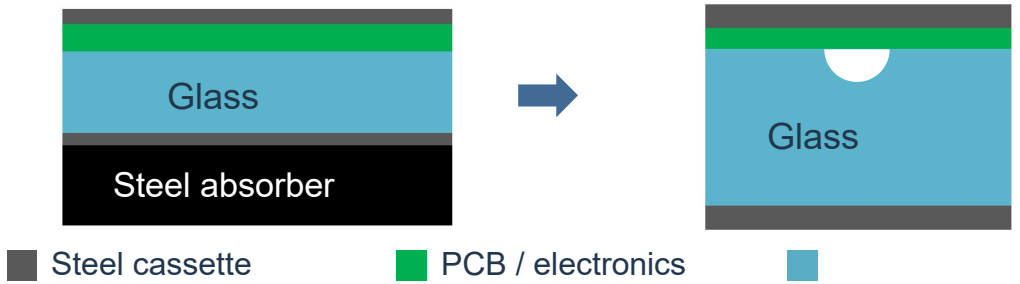
HCAL: Sampling fraction

Baseline

30% sampling fraction

Updated

≥70% sampling fraction



	Baseline	Updated
ECAL	BGO crystal bars $1.3\%/\sqrt{E(GeV)} \oplus 0.7\%$	Glass cubes $3\%/\sqrt{E(GeV)} \oplus 1\%$
HCAL	Glass–iron $30\%/\sqrt{E(GeV)} \oplus 6.5\%$	Glass cubes $< 15\%/\sqrt{E(GeV)} \oplus 4\%$

This talk focuses on software development.
For detailed calorimeter performance studies, see Weizheng's talk and Yushan's poster.

Software Challenges for Glass Calorimetry

Geometry development

The detector design is still evolving and requires rapid iterations for optimization.

Configurable geometry for fast design studies

Glass-cube response

Spatial response nonuniformity affects energy resolution.

Optical simulation captures this effect, but photon tracking in every event is computationally expensive.

Precomputed optical-response maps for digitization

3D particle-flow reconstruction

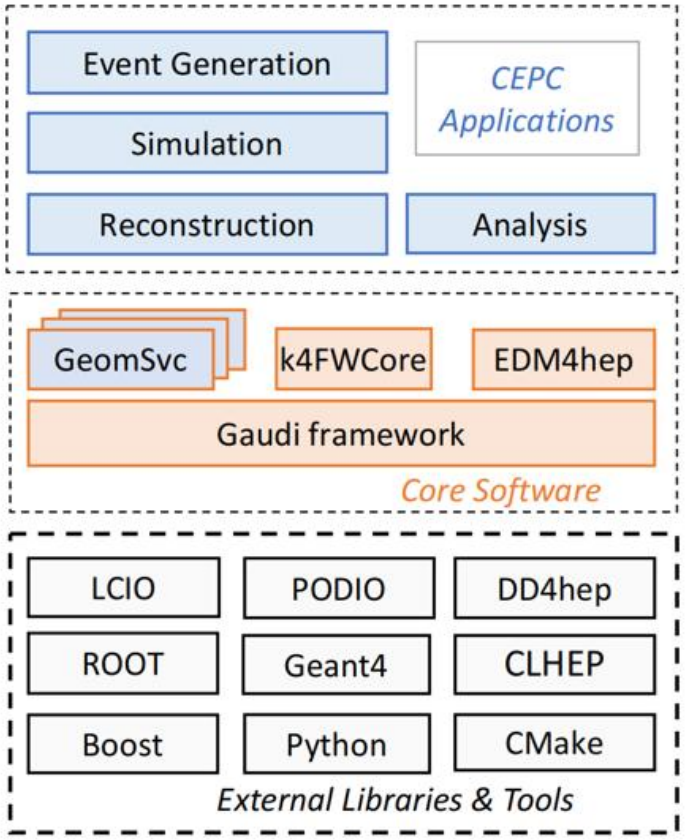
The new glass-cell geometry requires particle-flow reconstruction that exploits full 3D information.

Adapt CyberPFA to 3D glass calorimetry

Glass Calorimeter Simulation and Reconstruction in CEPCSW

- CEPCSW: the CEPC software framework, built on Key4hep.
- Supports the full processing chain from event generation to analysis.

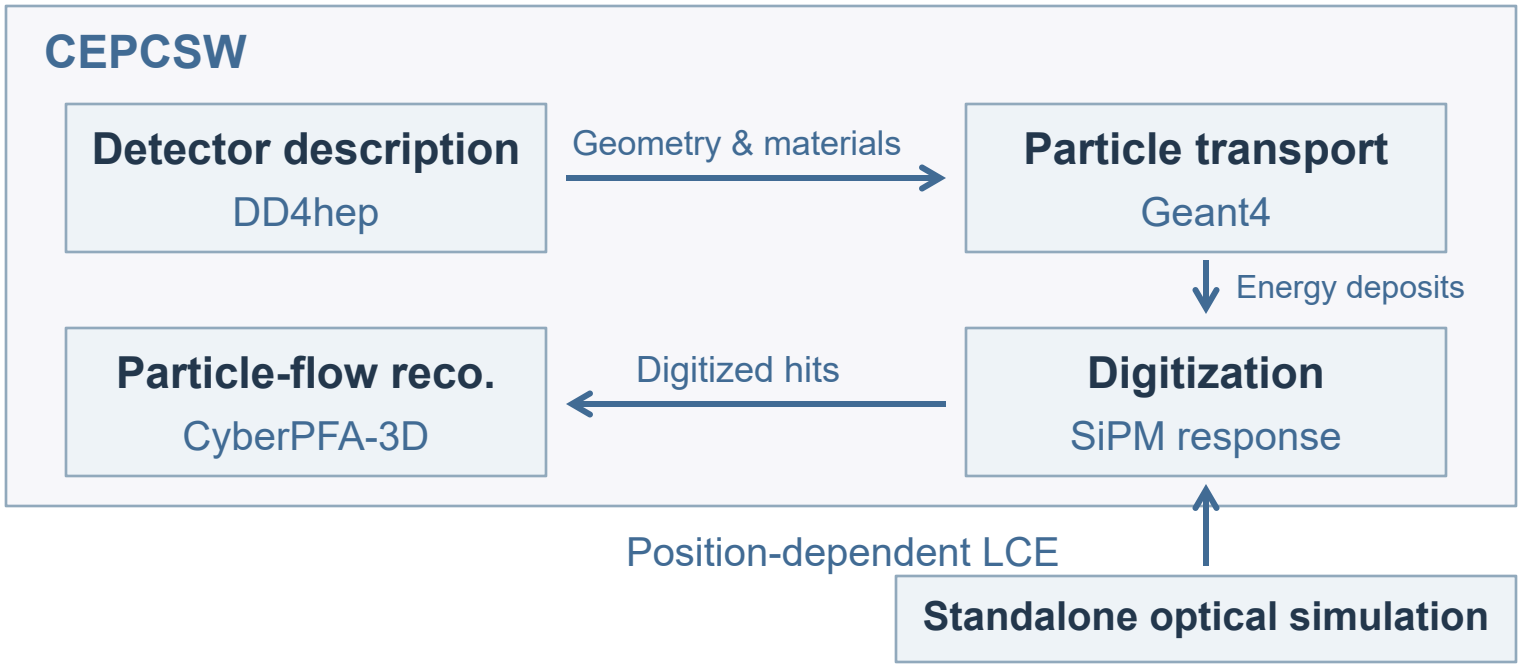
CEPCSW architecture



Gaudi: algorithm and service framework

DD4hep + Geant4: detector description and particle transport

Glass calorimeter workflow



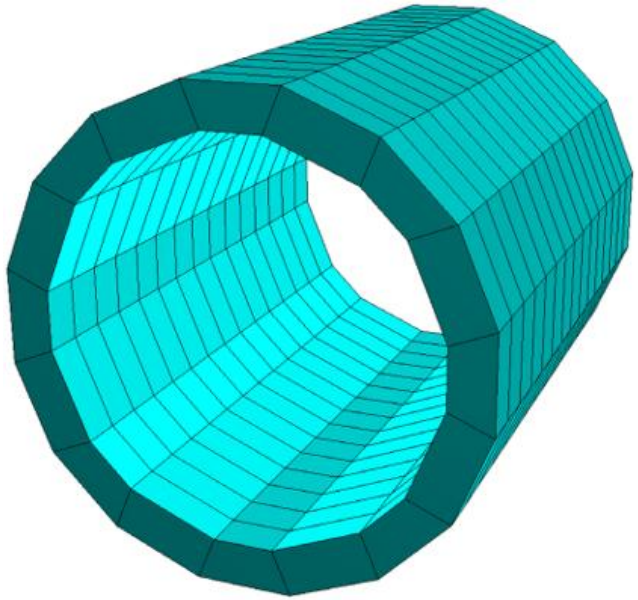
See Tao Lin's talk for more tails on CEPCSW

DD4hep-Based Glass Calorimeter Geometry

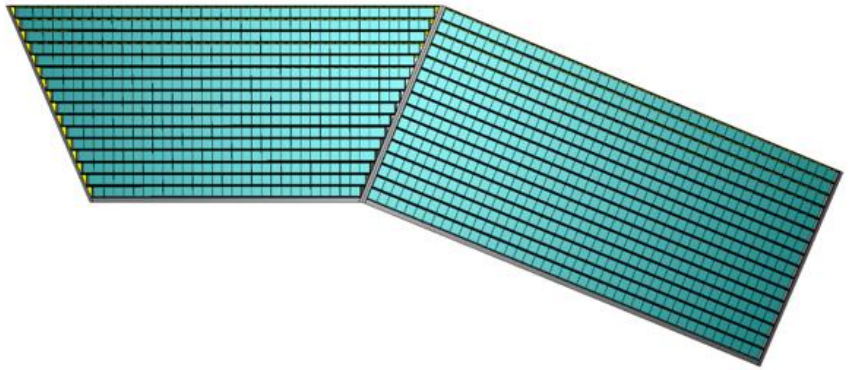
DD4hep: a unified detector description

- Consistent geometry for simulation and reconstruction.
- Configurable dimensions, glass-cell sizes and layer structures for detector optimization.
- Includes both sensitive and passive materials.

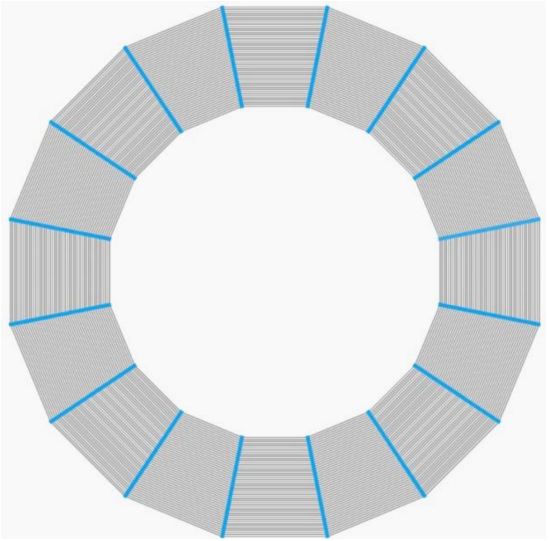
Glass ECAL and HCAL barrel geometries implemented in CEPCSW using DD4hep.



ECAL barrel



Two adjacent ECAL modules



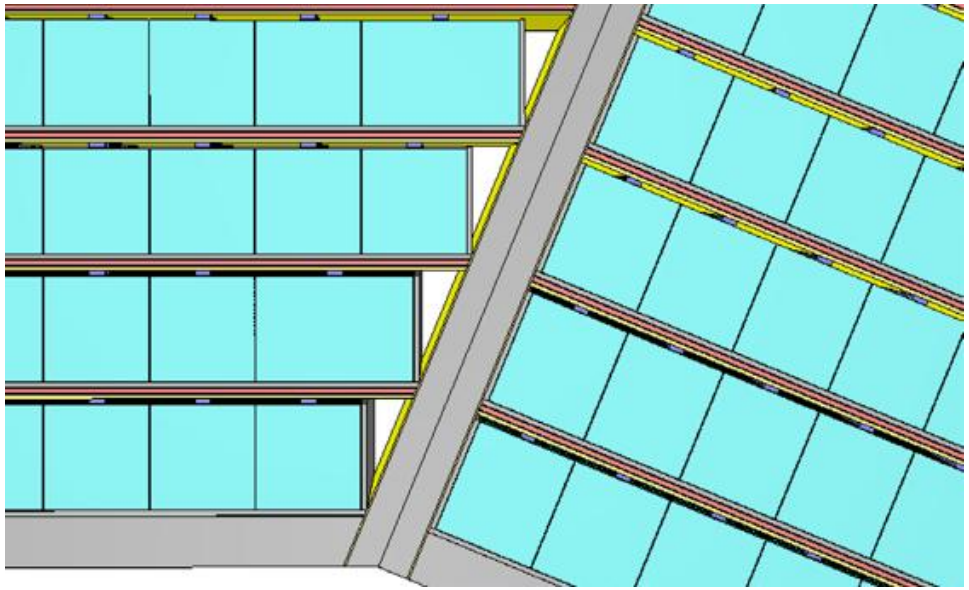
HCAL barrel

Active and Passive Components

Passive materials in a realistic detector affect shower development and energy resolution.

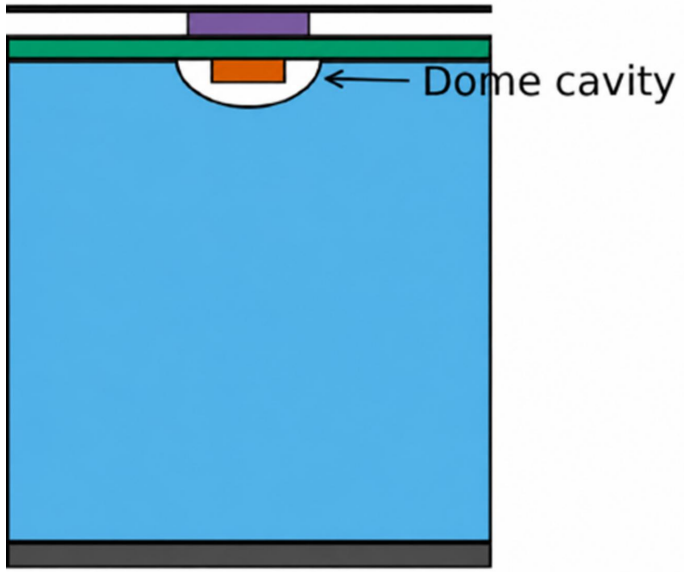
Carbon-fiber supports, SiPMs, PCBs, electronics and cooling are included in the geometry to evaluate their impact on energy resolution.

Module interfaces



Carbon-fiber support between adjacent modules

Glass-cell structure

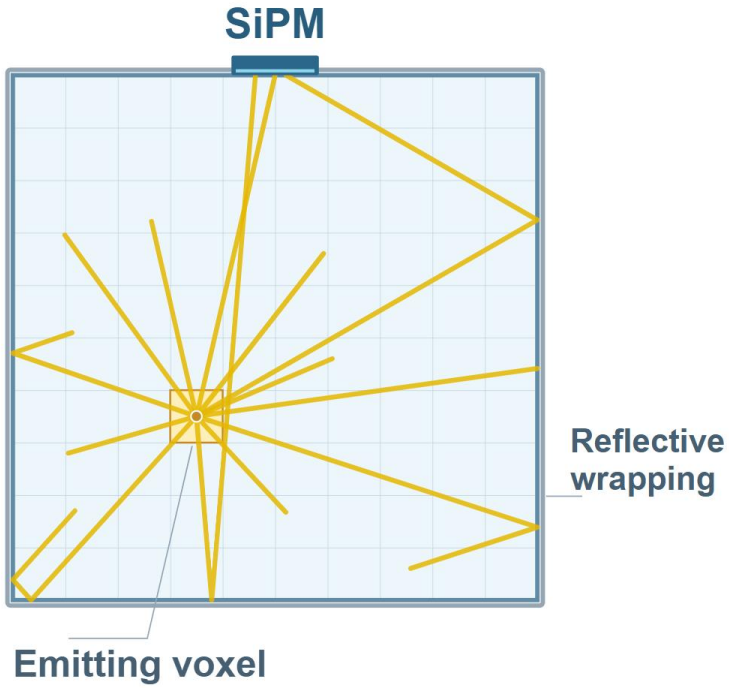


Glass, SiPM, PCB, electronics and cooling

Optical Simulation Strategy

- Spatial response nonuniformity affects the measured energy.
- Optical-photon tracking in every full-detector event is computationally expensive.

Voxel-based optical simulation



Standalone optical simulation

1. Divide a glass cube into voxels; generate optical photons isotropically within each voxel.

2. Simulate bulk absorption, reflective wrapping and SiPM PDE.

3. Calculate effective light collection efficiency (LCE) for each voxel, including PDE.

Current model: wavelength-independent absorption length, reflectivity and PDE.
Ongoing refinement with measured data; wavelength-dependent modeling planned.

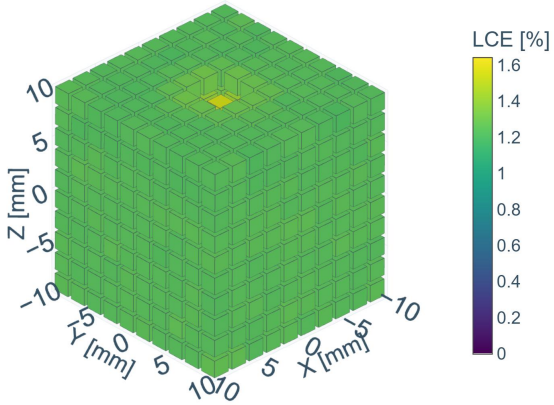
Response Non-uniformity in Glass Calorimeter Cells

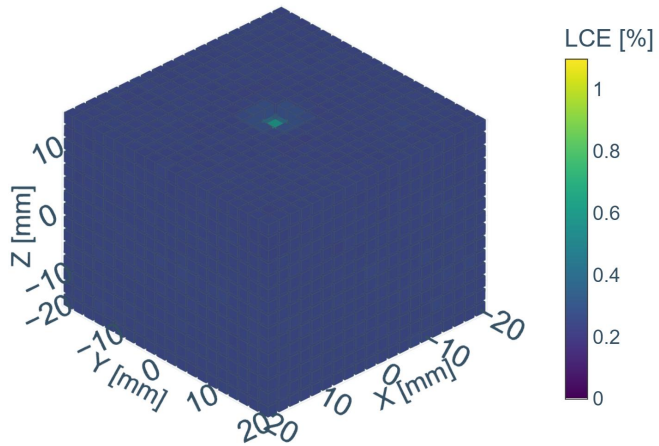
- Optical transport and SiPM collection lead to position-dependent response within each glass cell.
- 3D response maps and Z-averaged XY views illustrate this non-uniformity.

ECAL · 20 × 20 × 20 mm³

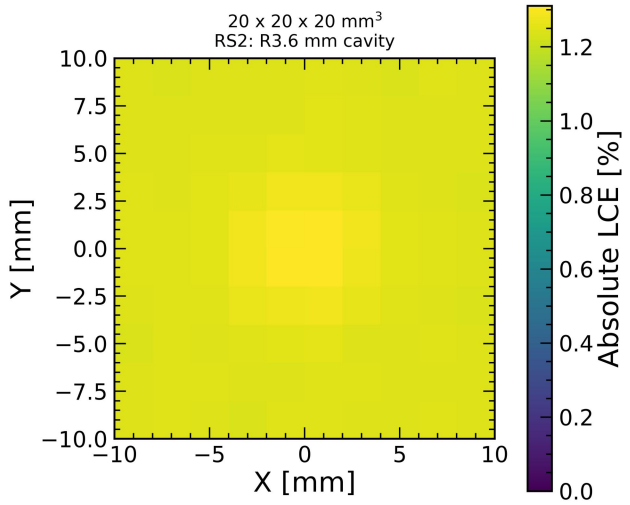
HCAL · 40 × 40 × 30 mm³

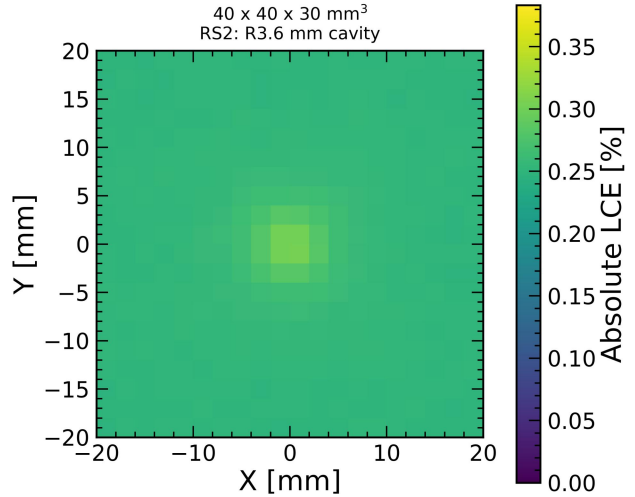
3D LCE





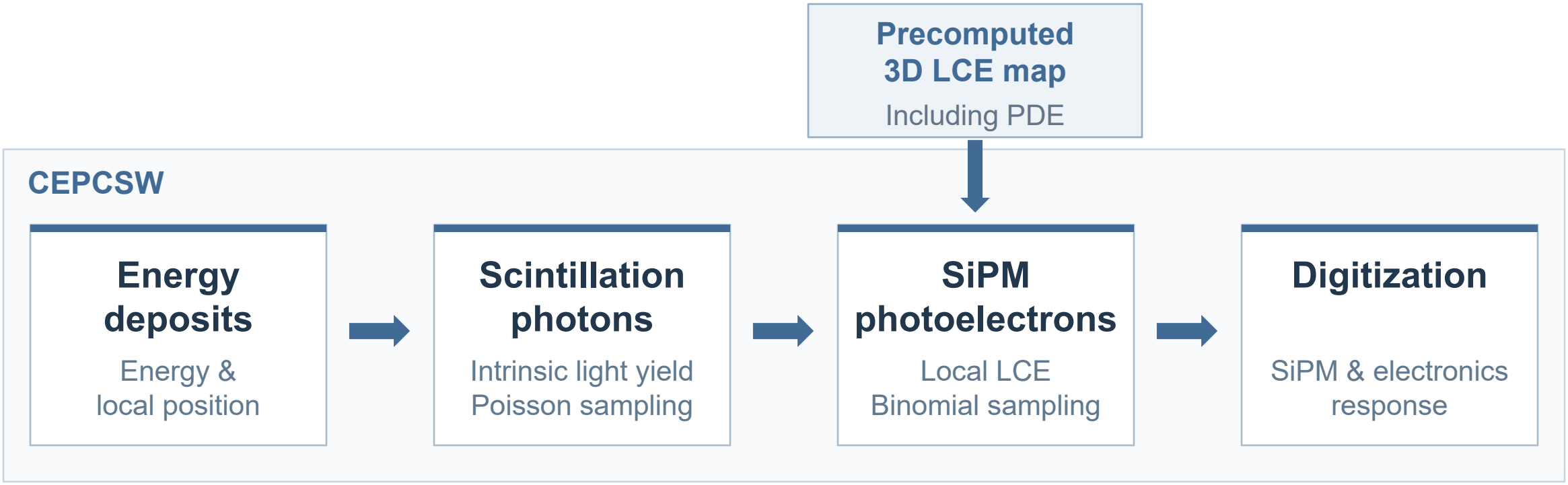
Z-averaged XY





From Energy Deposits to Digitized Signals

- Position-dependent LCE converts energy deposits into SiPM photoelectron counts.
- These photoelectron counts serve as input to digitization.



The digitization model inherits from the CEPC reference detector model.
Its parameters require further study and optimization.

Response Validation and Preliminary Performance Validation

- Cosmic-ray MIP measurements provide an initial check of the response model.
- EM and hadronic energy resolution are evaluated with the cavity design.

MIP response

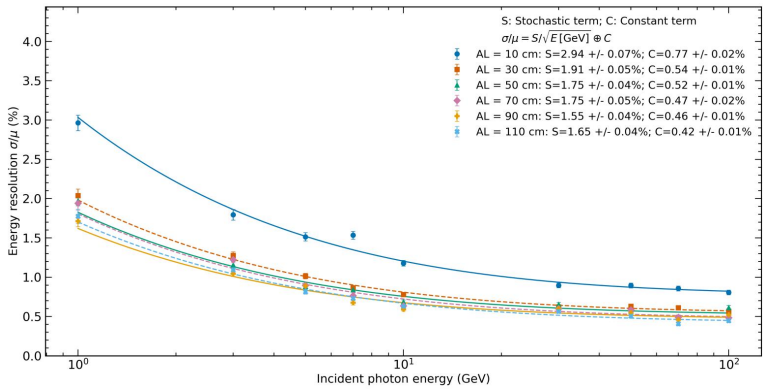
No cavity

	Cosmic-ray data	Simulation
Glass size [cm]	2 × 2 × **2**	2 × 2 × **2.2**
MIP peak [p.e./MIP]	≈180	206

Thicker simulated glass gives a larger energy deposit.

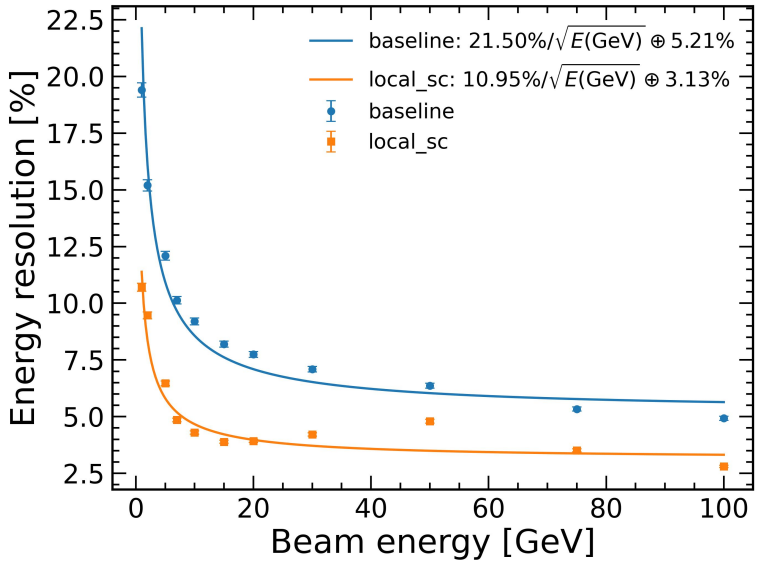
Broad agreement, allowing for the thickness difference.

EM energy resolution



EM energy resolution < 3%/√(E/GeV) is achievable.

Hadronic energy resolution



Raw: 21.50%/√(E/GeV) ⊕ 5.21%

With software compensation: 10.95%/√(E/GeV) ⊕ 3.13%

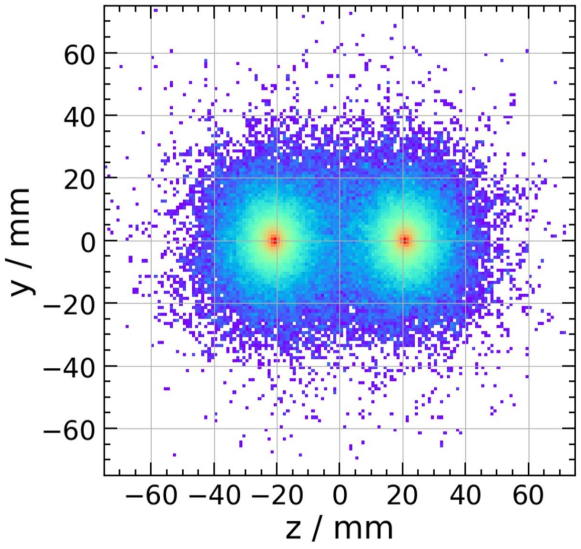
For more details on glass calorimeter performance, see Weizheng Song's talk and Yushan Liu's poster.

Shower Reconstruction with CyberPFA

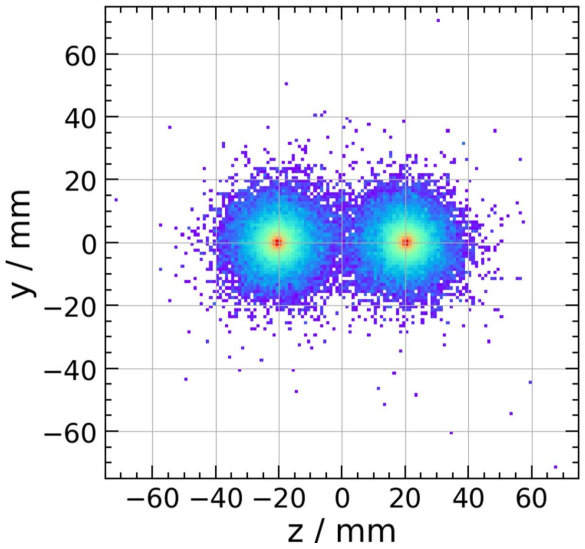
Glass and crystal vs. SiW: larger R_M and smaller λ_I/X_0

More severe shower overlap

Two adjacent 5 GeV EM showers



BGO crystal



Tungsten

CyberPFA

Energy-core identification and shower-energy splitting.

Demonstrated effectiveness in the AGORA baseline design.

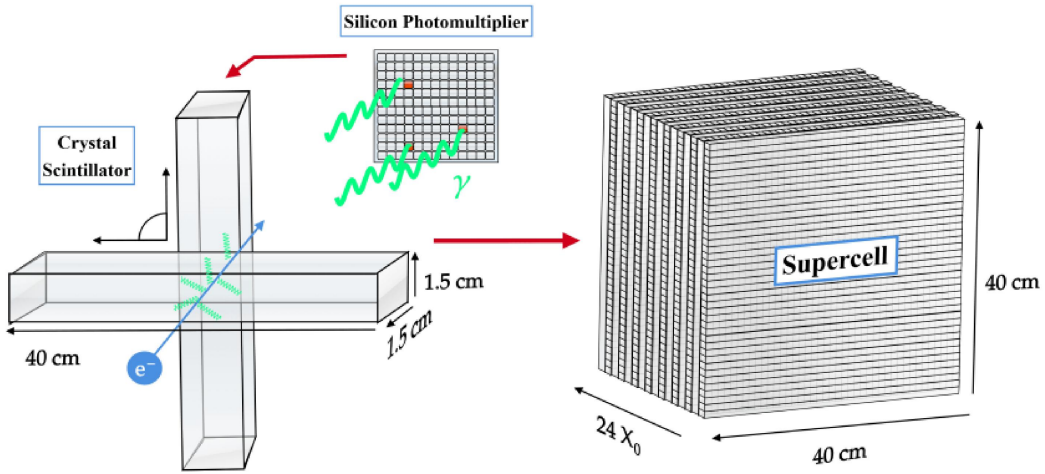
Complementary approaches

Explore hadronic reclustering and fragment handling from Pandora and Arbor.

From Crystal Bars to 3D Glass Cubes

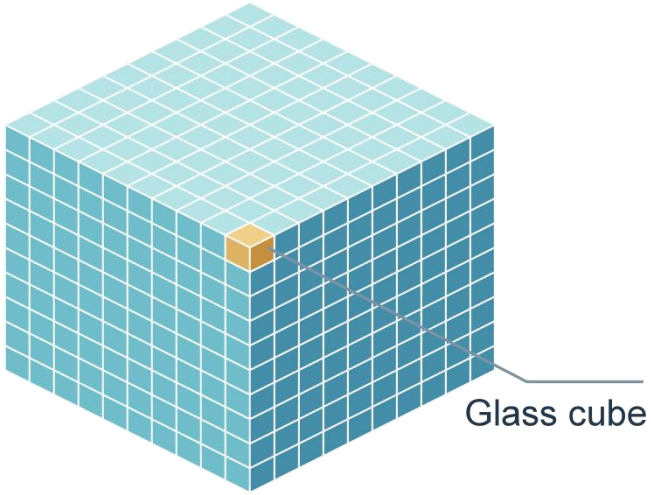
- Preserve energy-core identification while adapting reconstruction to the new geometry.
- Pattern recognition and energy splitting must operate directly in 3D.

Crossed crystal bars



Recognition and energy assignment in two orthogonal 2D projections

Glass cubes



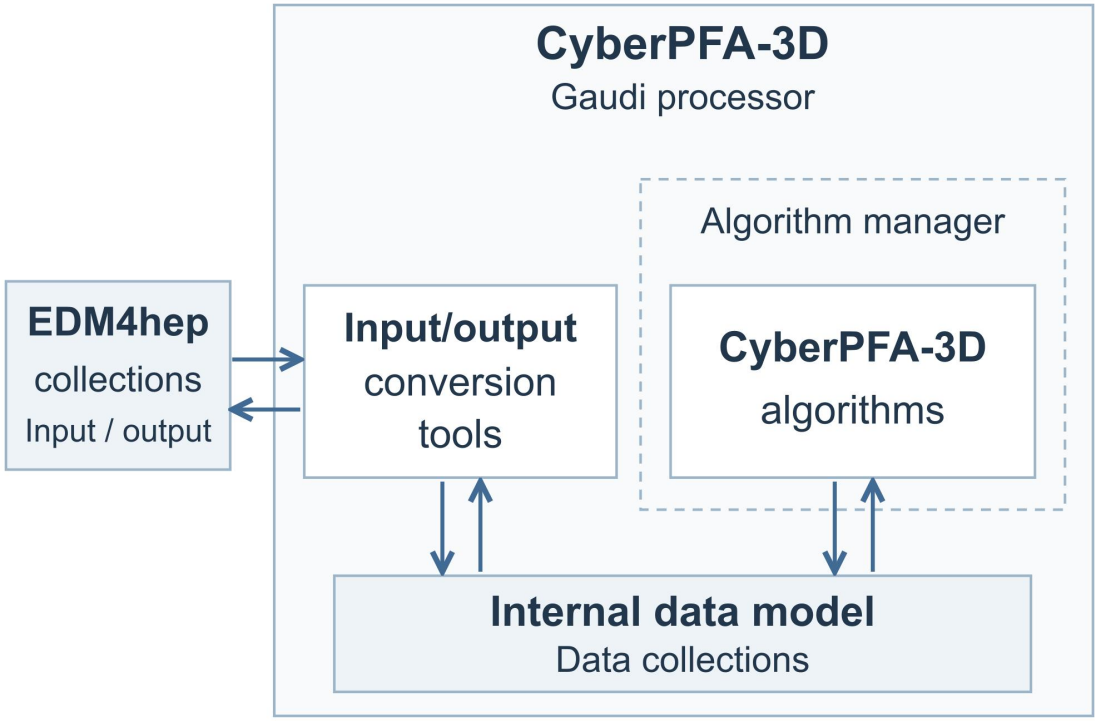
10 × 10 × 10 cubes · schematic

Direct 3D pattern recognition and shower-energy splitting

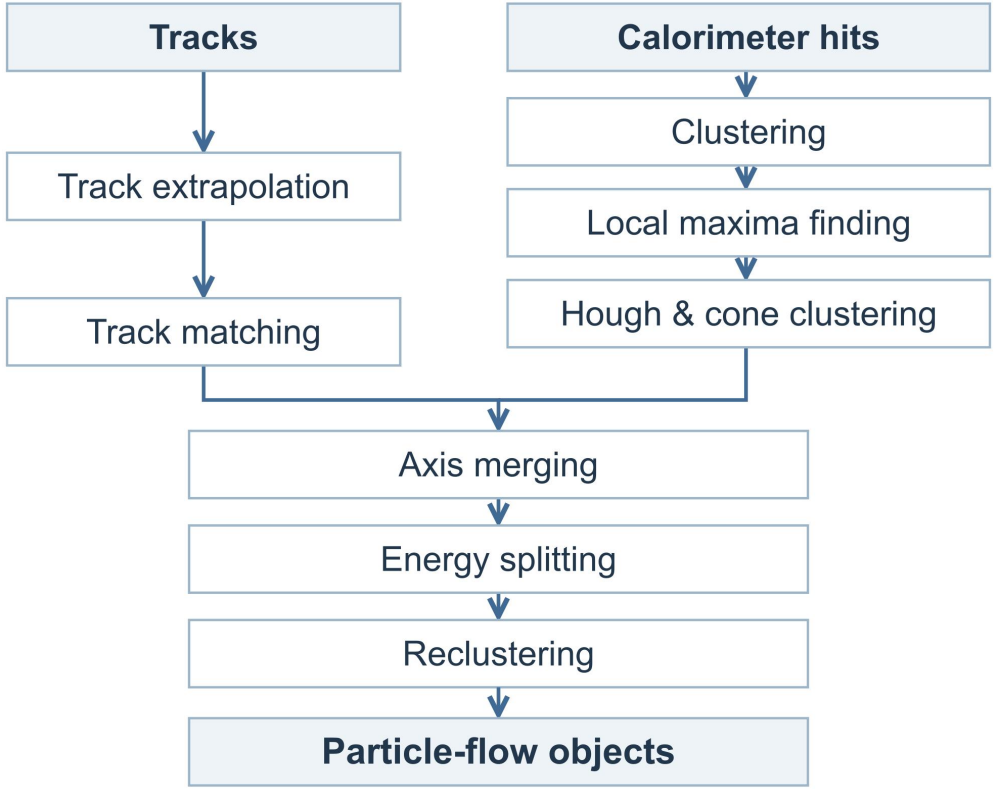
CyberPFA-3D: Architecture and Workflow

- Energy-core identification guides 3D shower reconstruction and energy splitting.
- Input/output tools convert between EDM4hep collections and the internal data model.

Software architecture



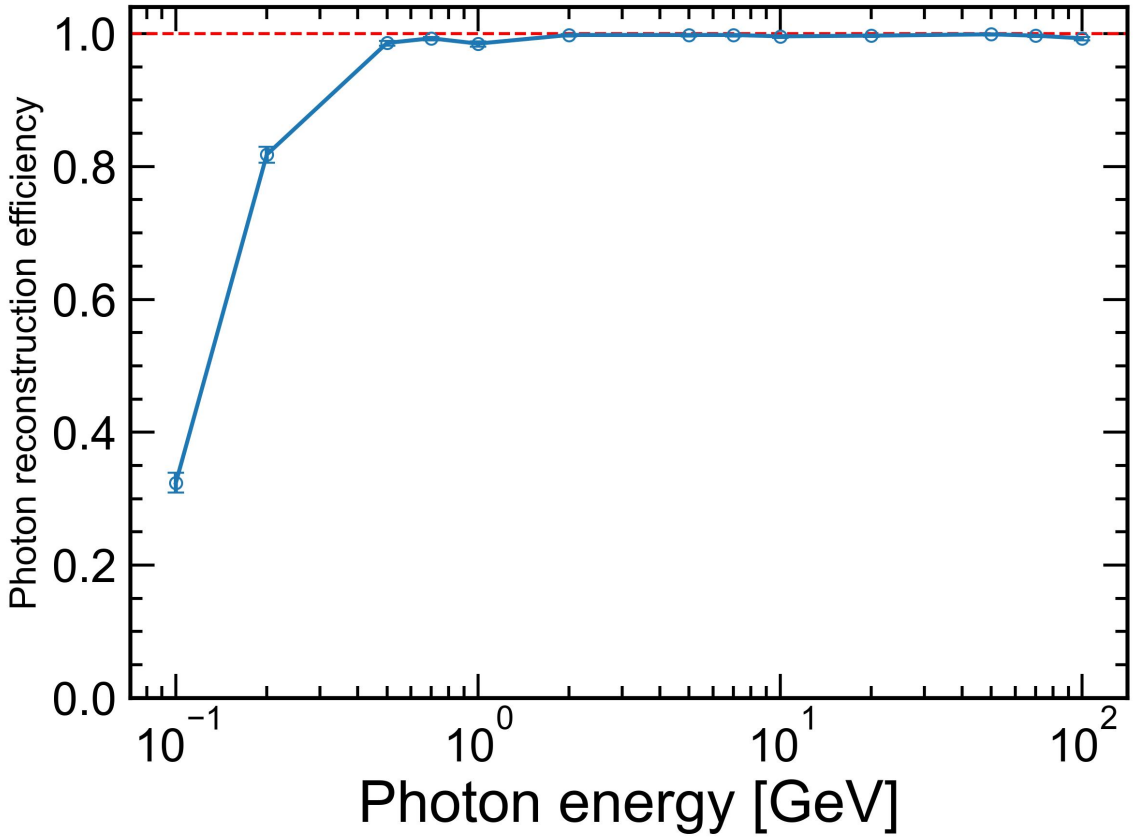
Reconstruction workflow



Implementation is ongoing, towards a complete particle-flow reconstruction chain.

Preliminary Photon Reconstruction Efficiency

- Initial photon results from CyberPFA-3D.
- Efficiency rises rapidly from 0.1 to 0.5 GeV and remains close to 100% for E ≥ 0.5 GeV.



Single-photon sample

E = 0.1, 0.2, …, 100 GeV

87° ≤ θ ≤ 93°; −3° ≤ φ ≤ 3°

Successful reconstruction

- Cluster energy > 90% of total deposited energy
- Photon shower core identified

Preliminary photon efficiency; the full particle-flow reconstruction chain remains under development.

Summary and Outlook

Summary

- **Detector modeling:** Configurable glass ECAL/HCAL barrel geometry in CEPCSW, including active and passive components.
- **Detector response:** Optical-simulation-based 3D LCE maps connect energy deposits to SiPM photoelectron counts, including statistical fluctuations.
- **Reconstruction:** CyberPFA-3D development is underway, with preliminary photon reconstruction efficiency results.

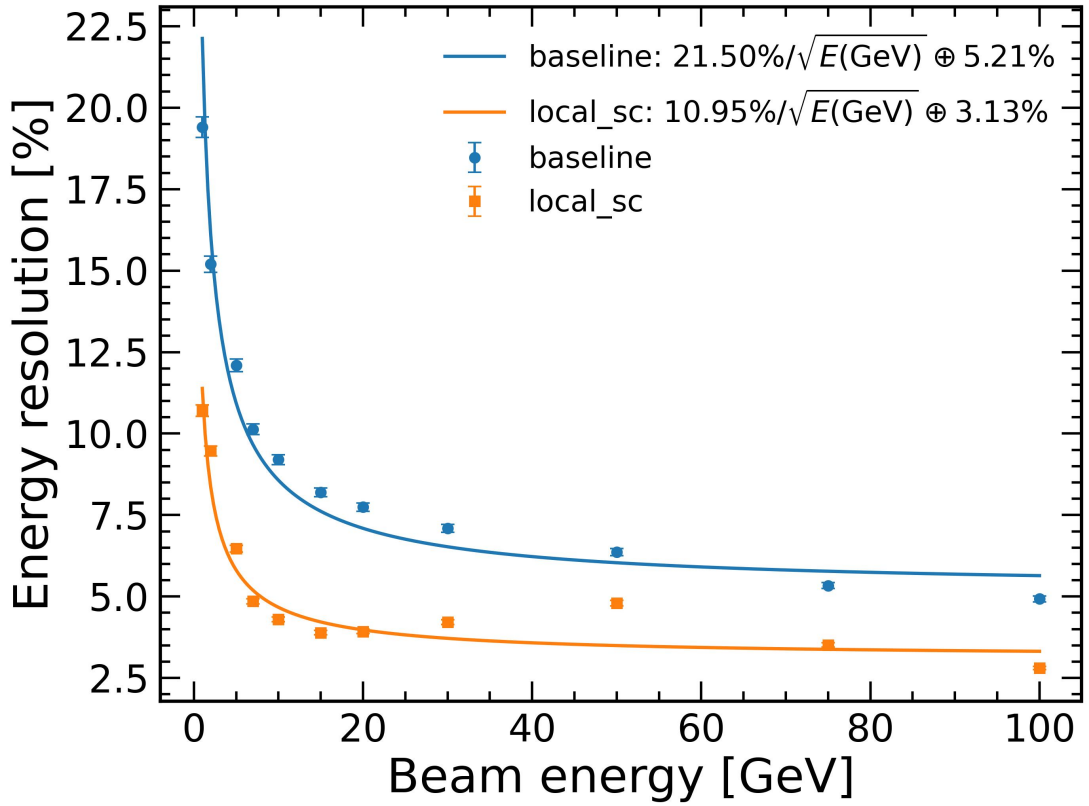
Outlook

- **Detector design:** Further refine and optimize the glass ECAL and HCAL designs.
- **Response and digitization:** Incorporate measured optical properties and wavelength dependence; optimize and validate digitization parameters.
- **CyberPFA-3D:** Advance 3D energy splitting and reclustering towards complete, validated particle-flow and jet reconstruction.

Backup

Software Compensation: Hadronic Performance

- Software compensation (SC): an established approach to improve hadronic energy resolution.
- Local SC weights hits by energy density to balance EM and hadronic shower responses.
- **Significant resolution improvement for scintillating-glass ECAL + HCAL.**

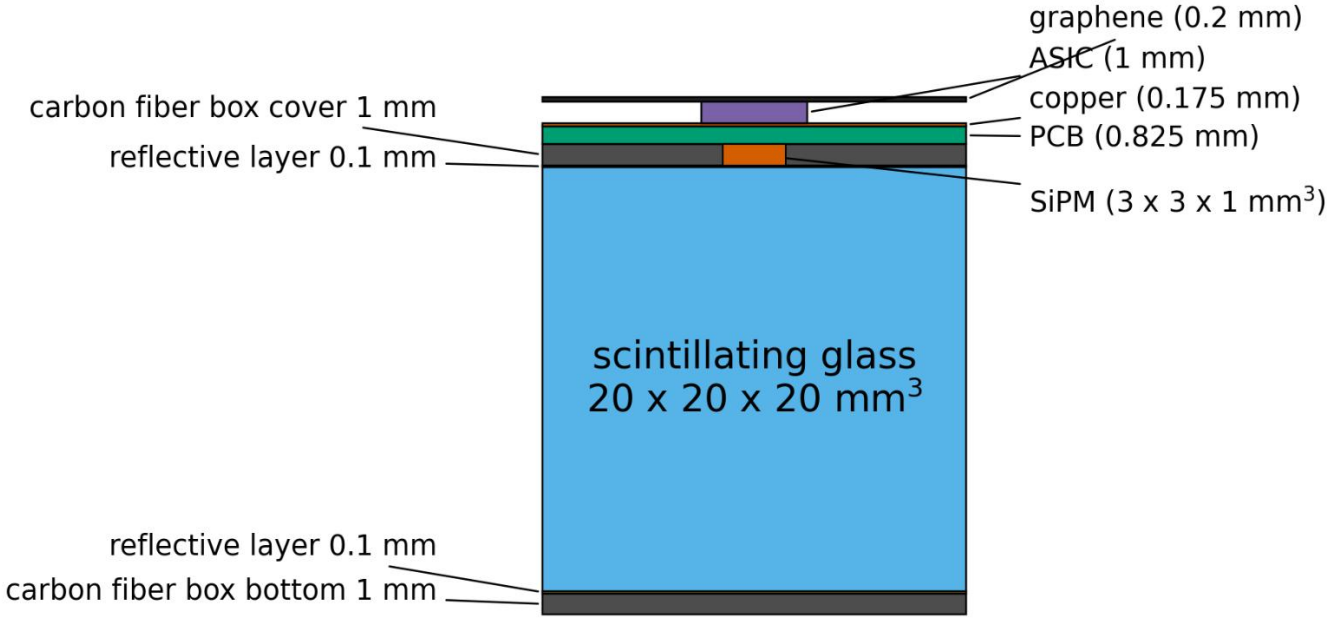


Work in progress. Includes digitization and intra-cell response non-uniformity in both ECAL and HCAL.

SC references: C. Adloff et al., JINST 7 (2012) P09011; Eur. Phys. J. C 77 (2017) 698.

Glass-Cell Structure

Without cavity



With hemispherical cavity

