Development of Future Electromagnetic Calorimeter Technologies and Applications for the Electron-Ion Collider with GEANT 4 Simulations

Zhaozhong Shi (Massachusetts Institute of Technology)

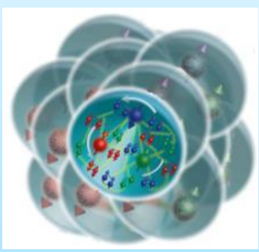
Email: zzshi@mit.edu

Abstract

The Electron-Ion Collider is a future collider planned to be built at BNL in about 2030. It will provide physicists with high luminosity and highly polarized beams with a wide range of nuclei species at different energies, covering an extensive kinematic range. The EIC physical goals include measuring the generalized parton distribution from Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP) experiments, performing precision 3D imaging of the nuclei structure, studying color confinement and hadronization mechanisms, and understanding the spin structure of the proton. In order for the EIC to achieve its physics goals, a high-resolution electromagnetic calorimeter (EMCAL) is required to measure electrons and photons and to achieve good particle identification. We propose two design options for EIC EMCALs. The first technique is to improve the resolution tungsten/scintillating fiber (W/SciFi) EMCAL being built for sPHENIX with new technologies. The other possibility is to develop tungsten/shashlik (W/shashlik) EMCAL with better readout configuration to achieve better energy and position resolution. In this work, we will present the performance of sPHENIX W/SciFi EMCAL and the GEANT 4 detector simulation results of W and Pb shashlik EMCAL shower profiles, energy resolution, and merging probability π^0 for future EIC experiments.

EIC Scientific Program

Cold QCD Physics

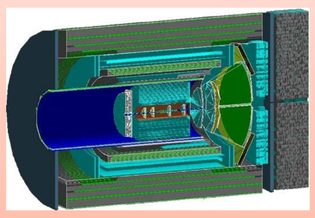


- Precision 3D imaging of nucleons and nuclei
- Color confinement
- Proton spin structure

Accelerator R&D

- High luminosity with a wide range of ion species
- Novel linear accelerator technologies

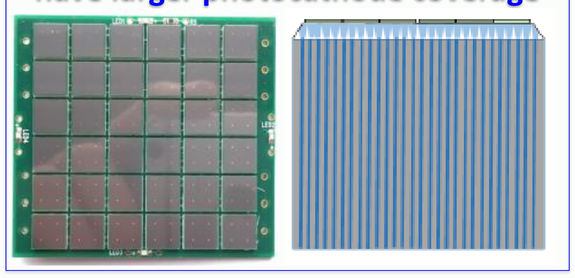
Detector R&D



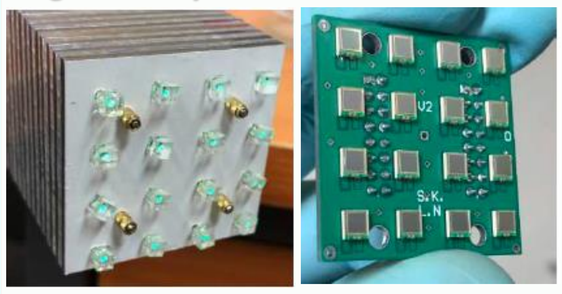
- Fast readout electronics
- Full silicon pixel tracking detectors with fast timing and excellent space time resolution
- High granularity EMCAL

EIC EMCAL Design Options

W/SciFi SPECAL design with more SiPMs and shorter light guides to have larger photocathode coverage



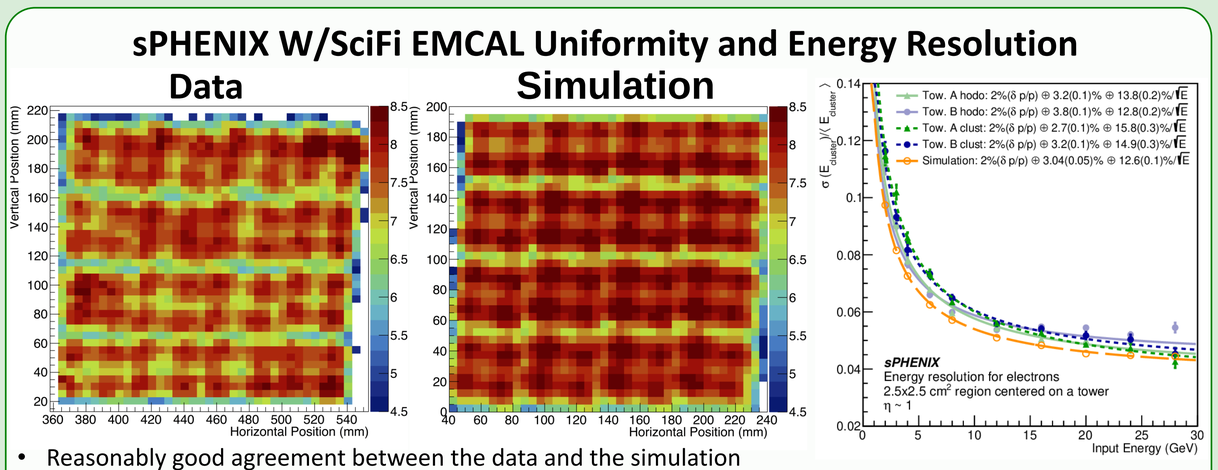
W/Shashlik tower design with high granularity and efficient readout



Proposed Novel Technologies

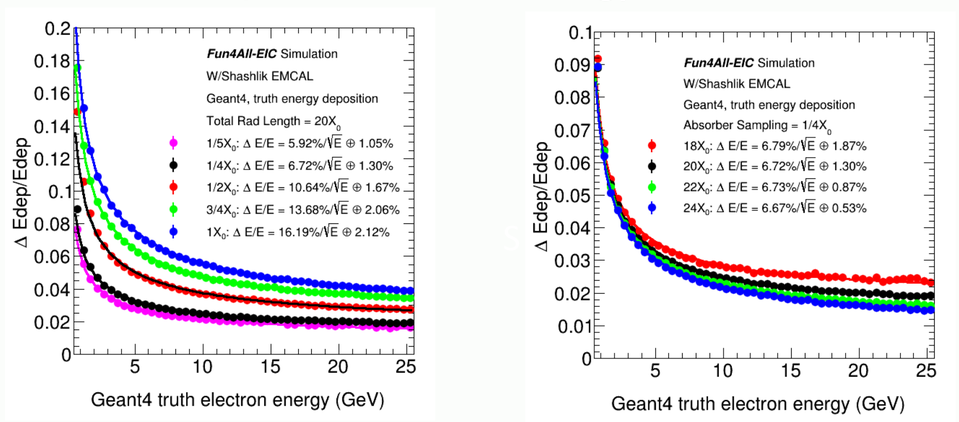
- W absorber for EMCAL to allow compact design to save space, which is a prime factor for EIC experiments
- Novel SiPMs with 6 × 6 mm² 15 µm pixel size to improve light collection efficiency and uniformity
- High granularity shashlik calorimeter with SiPM readout on every fiber

sPHENIX W/SciFi EMCAL Uniformity and Energy Resolution



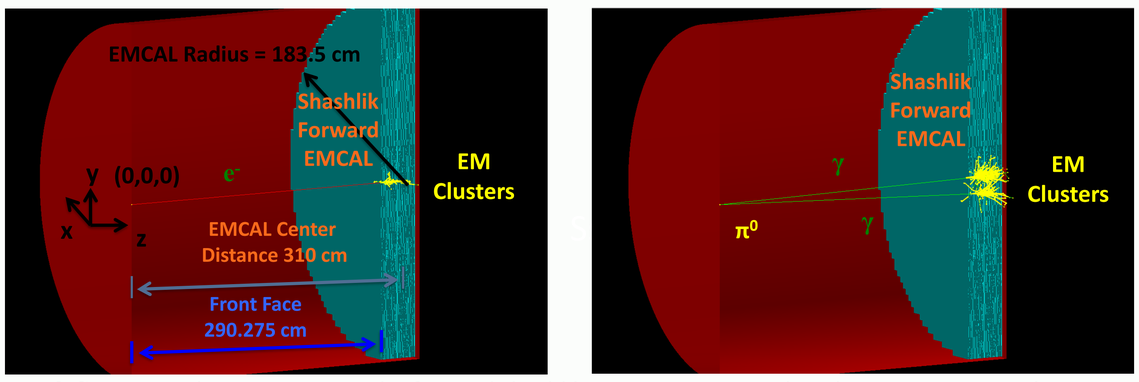
- Reasonably good agreement between the data and the simulation
- Significant non-uniformity, particularly between the block boundaries and the center of four blocks → position dependent correction with the simulations
- The uniformity and energy resolution both meet the requirements to achieve sPHENIX physics goals

W/Shashlik EMCAL Energy Resolution



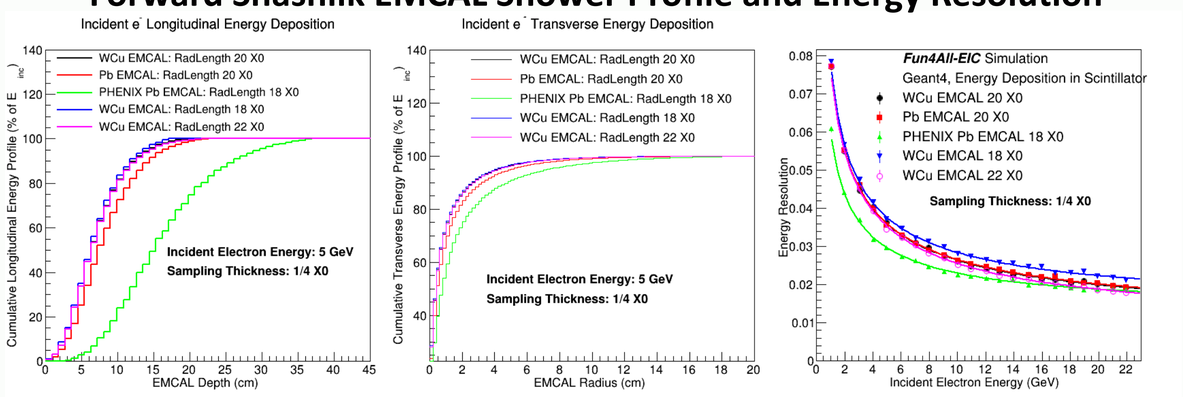
- The statistical term of the shashlik EMCAL improves as the sampling frequency increases
- The constant term of the shashlik EMCAL improves as the total radiation length increases
- This work has been included in the EIC Yellow Report and ECCE and EIC Calorimetry workshops

Event Displays of EIC Shashlik Forward EMCAL



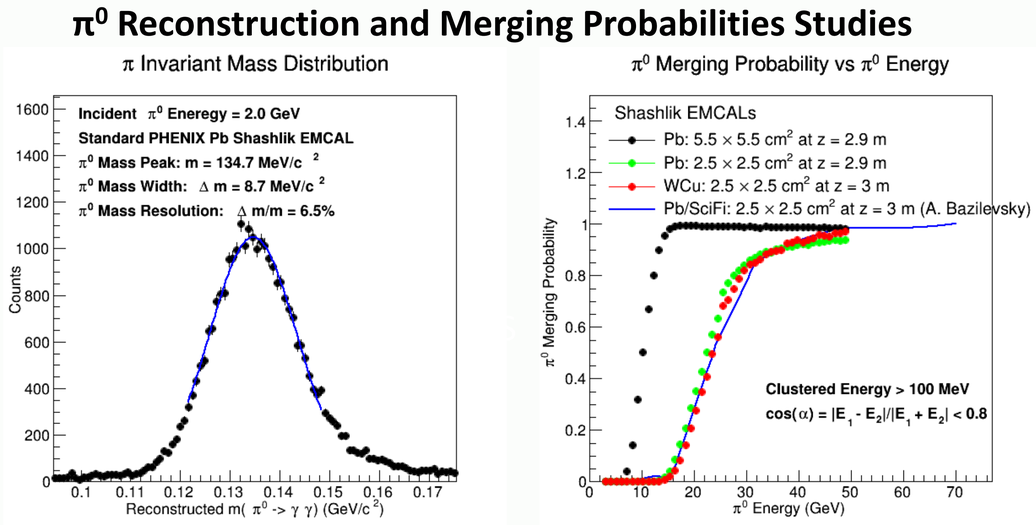
- **Left figure:** an electron entering the forward shashlik EMCAL at a normal angle creating an EM shower with detailed information about the experimental setup, used to characterize its general performance
- **Right figure:** a 1 GeV π^0 decaying into two photons and entering the EMCAL at a normal angle creating two EM showers, used to reconstruct π^0 and study the merging probability of the two photon clusters into one

Forward Shashlik EMCAL Shower Profile and Energy Resolution



- **PHENIX EMCAL as reference:** Pb Shashlik EMCAL with total radiation length of 18 X0, scintillator thickness of 1.5 mm, and tower granularity about 5.5 × 5.5 cm²
- **WCu:** an alloyed with 80% W and 20% Cu as the absorber material for EIC shashlik EMCALs
- **Longitudinal shower profile – effective radiation length:** PHENIX > Pb > WCu
- **Simulated Moliere radius:** WCu = 2.65 cm, Pb = 3.15 cm, PHENIX = 4.15 cm, reasonably consistent with the expected one WCu = 2.5 cm, Pb = 3.3 cm, and PHENIX = 4.5 cm
- **Energy resolution stochastic term:** WCu > Pb > PHENIX
- **Constant term:** PHENIX (18 X0) ~ WCu(18 X0) > WCu (20 X0) ~ Pb (20 X0) > WCu (22 X0)

π^0 Reconstruction and Merging Probabilities Studies



- π^0 merging probability decreases with finer granularity → reconstruct π^0 up to higher energy
- Strong dependence on granularity while weak dependence on Moliere radius within our parameters range
- Extend the kinematic acceptance of DVCS and DVMP measurements for GPD extraction
- Presented in EIC eRD1 Report and EIC Calorimetry workshops

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