中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Simulation studies on the HCAL with scintillating glass tiles

Dejing Du, Yong Liu, BaoHua Qi

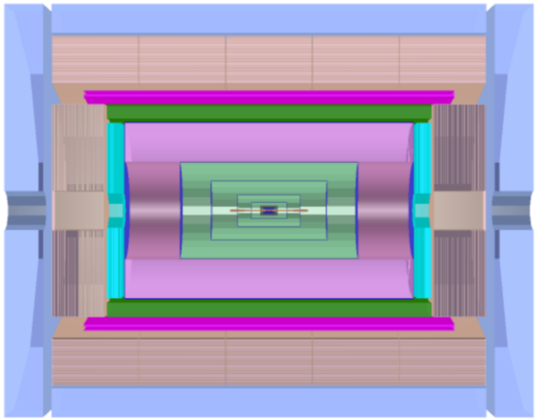
CEPC Physics and Detector plenary Meeting
April 21, 2022

Outline

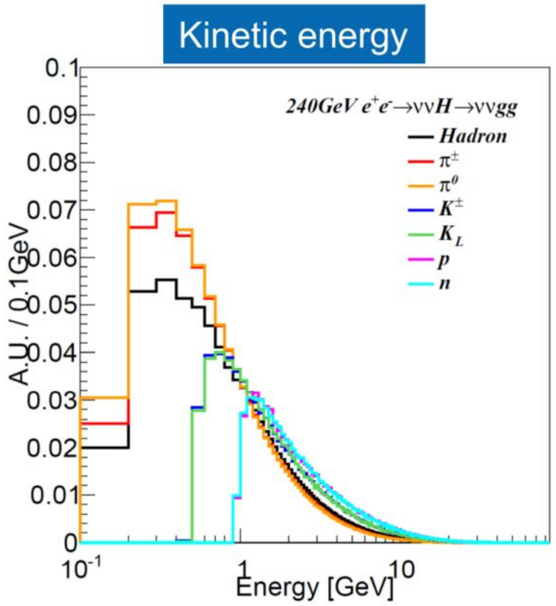
- Motivations
- Simulation of HCAL with scintillating glass (single hadrons)
  - Preliminary performance comparison
  - Hadronic energy resolution
    - Impact of density and light yield
    - Varying thickness of glass tiles and steel plates
- A single scintillating glass tile
  - MIP response: optical simulation and cosmic ray test
  - Uniformity scan
  - Vary transverse size
- Summary

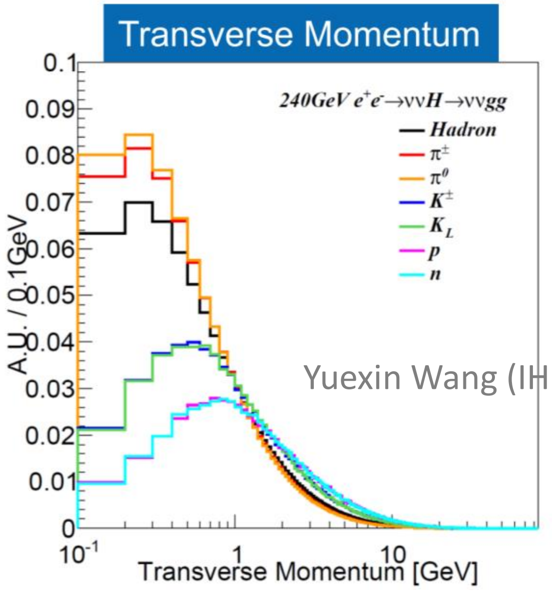
Motivations

- CEPC physics programs
  - Hadronic decays of Higgs/Z/W bosons: abundant hadrons (<10 GeV) within jets
- CEPC 4^{th} concept detector: crystal ECAL + scintillating glass HCAL
  - A leap in terms of sampling fractions
  - Aim to improve the energy resolution: esp. the hadronic resolution



Calorimeters: crystal ECAL and Scintillating Glass HCAL



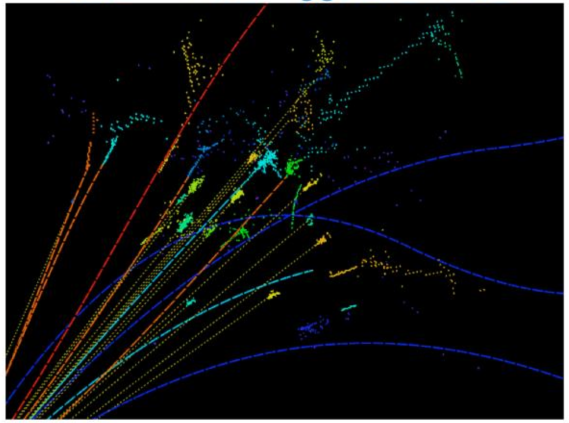


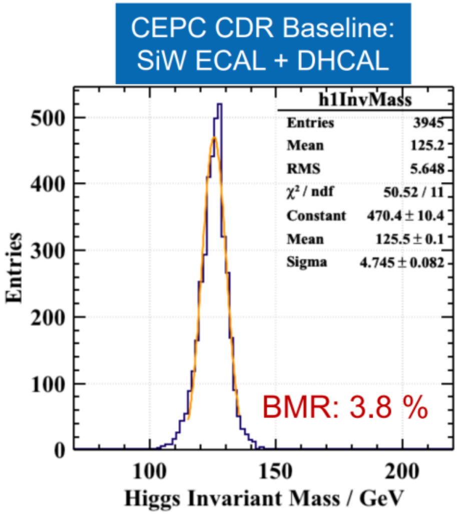
Yuexin Wang (IHEP)

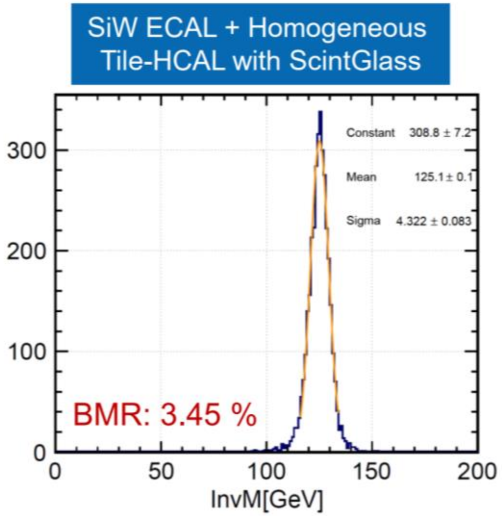
Motivations

- CEPC physics programs
  - Hadronic decays of Higgs/Z/W bosons: abundant hadrons (<10 GeV) within jets
- <u>CEPC 4^{th} concept detector</u>: crystal ECAL + scintillating glass HCAL
  - A leap in terms of sampling fractions
  - Aim to improve the energy resolution: esp. the hadronic resolution
  - Physics performance target: Boson Mass Resolution(BMR) 4%→3%

$ZH(Z \rightarrow \nu\nu, H \rightarrow gg)$ at 240 GeV







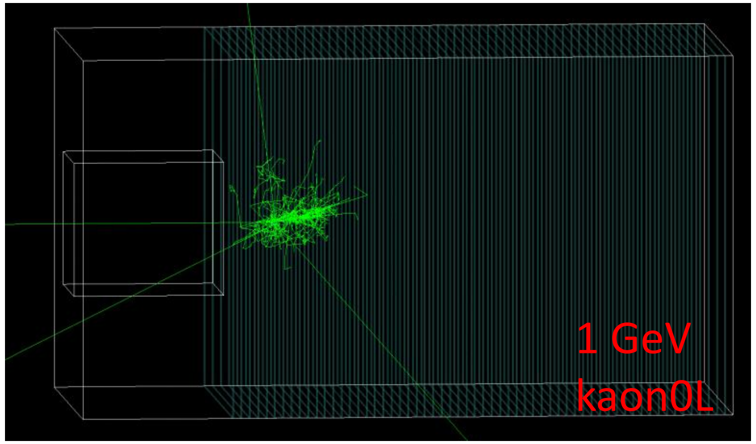
Dan Yu (IHEP)

Outline

- Motivations
- Simulation of HCAL with scintillating glass (single hadrons)
  - Preliminary performance comparison
  - Hadronic energy resolution
    - Impact of density and light yield
    - Varying thickness of glass tiles and steel plates
- A single scintillating glass tile
  - MIP response: optical simulation and cosmic ray test
  - Uniformity scan
  - Vary transverse size
- Summary

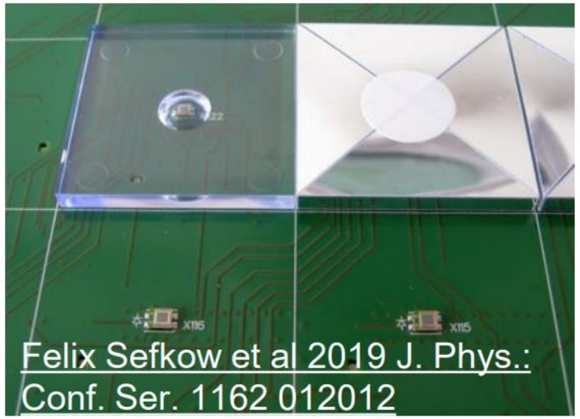
HCAL: setup in Geant4 simulation

- HCAL geometry
  - Transverse plane: $108 \times 108cm^2$
    - Tile size: $3 \times 3\mathrm{cm}^2$
  - 60 longitudinal layers, each with
    - Scintillator: 3mm
    - PCB: 2mm
    - Absorber (steel): 20mm



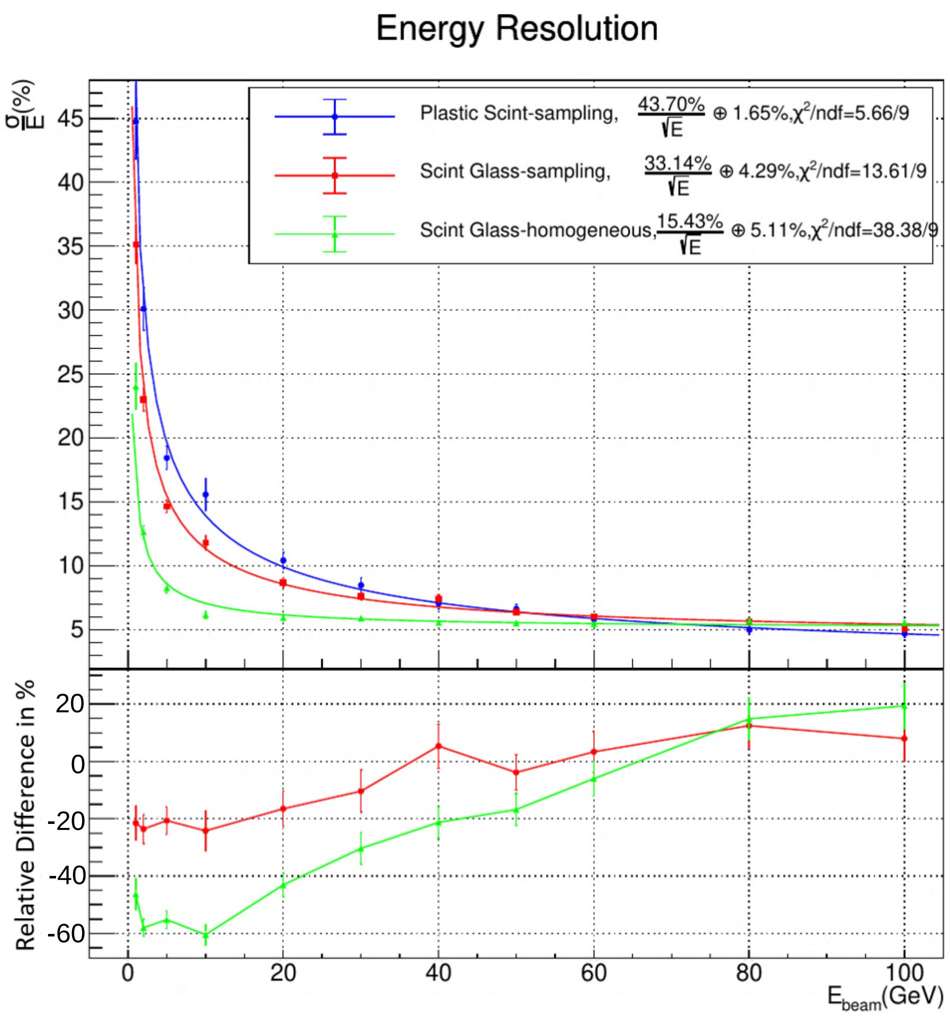
- Scintillator materials
  - Plastic scintillator as baseline reference
  - Replace plastic scintillator with scintillating glass
    - Component: $B_2O_3 - SiO_2 - Al_2O_3 - Gd_2O_3 - Ce_2O_3$
    - Density = 4.94 g/cm^3

"SiPM-on-Tile" design for HCAL



Note: HCAL with 40 layers in CEPC CDR as baseline.
Hereby use 60 layers to evaluate leakage effects

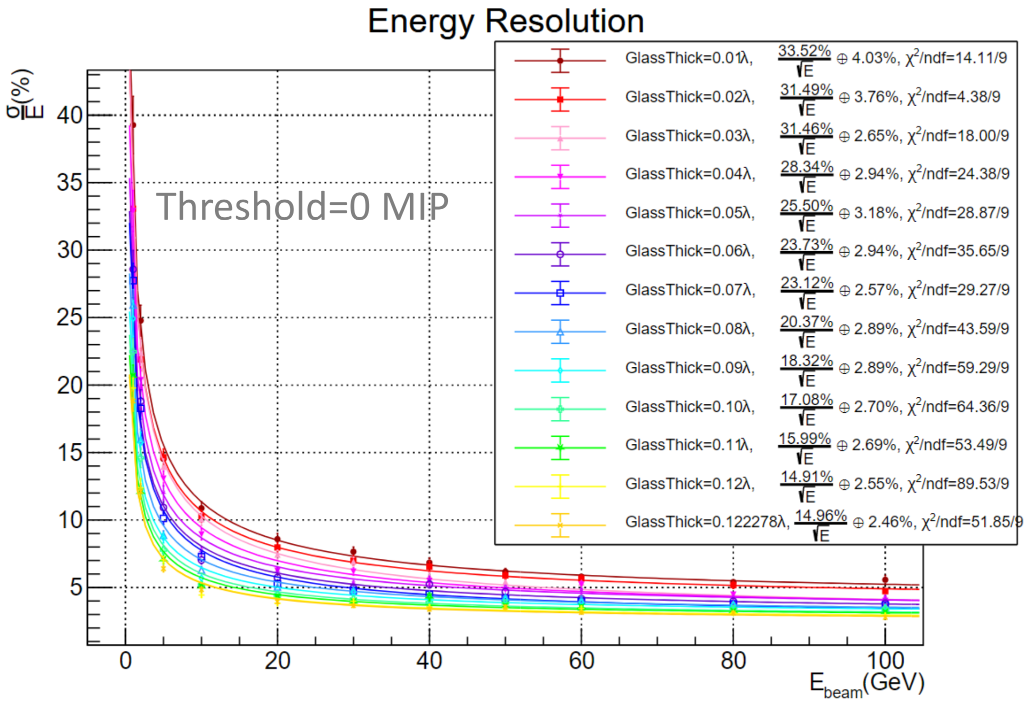
HCAL: plastic scintillator vs scintillating glass

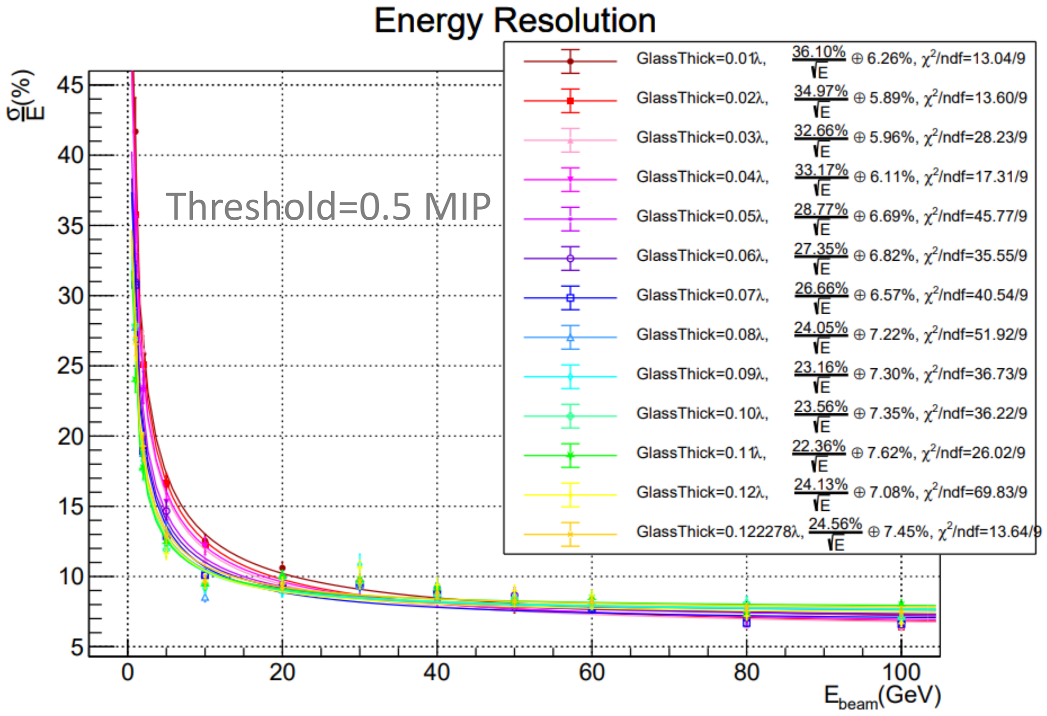


- Incident particle: K_L^0 (1-100GeV)
- Preliminary performance comparison
  - Same thickness of sensitive materials: 3mm
  - No energy threshold applied
- Scintillating glass: better hadronic energy resolution in low energy region (<30GeV)
  - Note that majority of hadrons in jets at CEPC are with low energy
- Further issue: constant term
  - More details in the next pages
  - "Software compensation" technique is a feasible option

Impact of thickness to hadronic energy resolution

- Incident particle: 1-100GeV K_L^0
- Varying thickness: scintillating glass tiles and steel plates
  - Each layer fixed with ~0.12λ_I : the same as AHCAL (3mm plastic tile, 20mm steel)





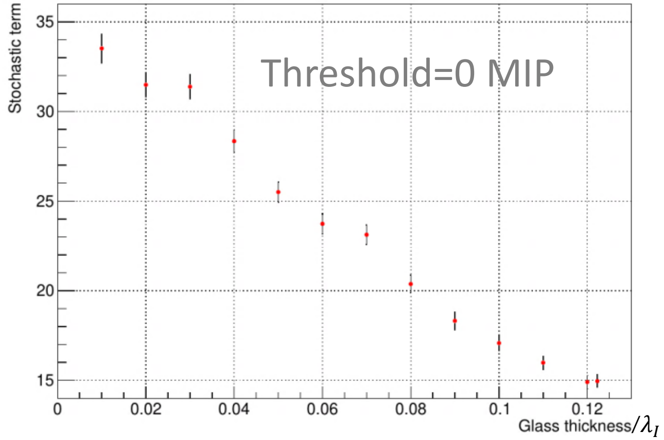
- Energy threshold significantly impacts hadronic energy resolution
- The empirical formula $(A/\sqrt{E(GeV)} \oplus C)$ can not well describe curves
  - (Note the χ^2/ndf values) Not fully follow the Poisson distribution

Orange curve corresponds to the homogeneous HCAL

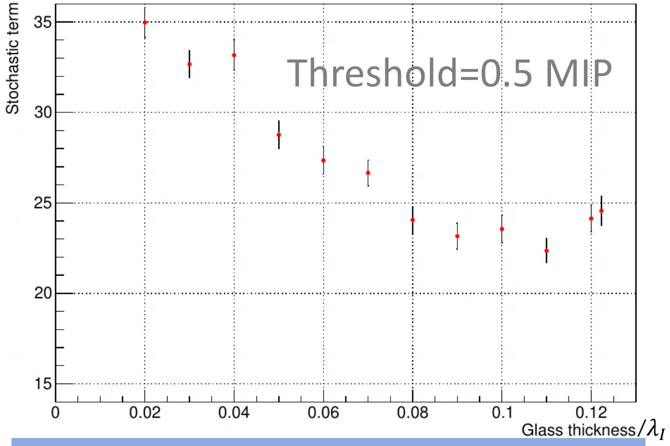
Impact of thickness to hadronic energy resolution

- Varying thickness: scintillating glass tiles and steel plates
- Extraction of stochastic and constant terms

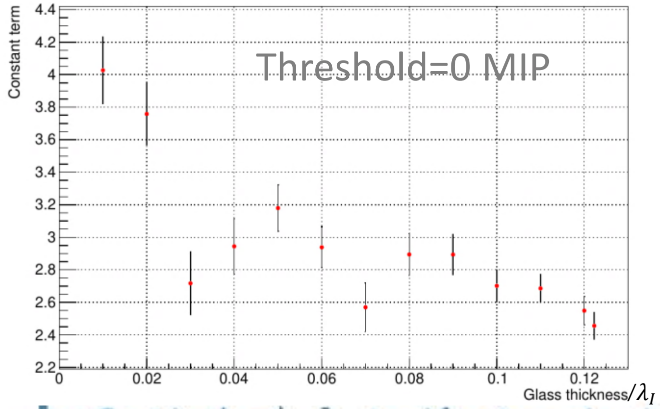
Stochastic term vs. glass thickness



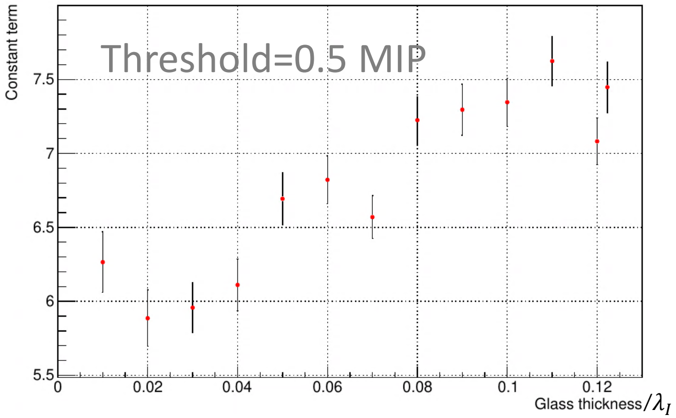
Stochastic term vs. glass thickness



Constant term vs. glass thickness

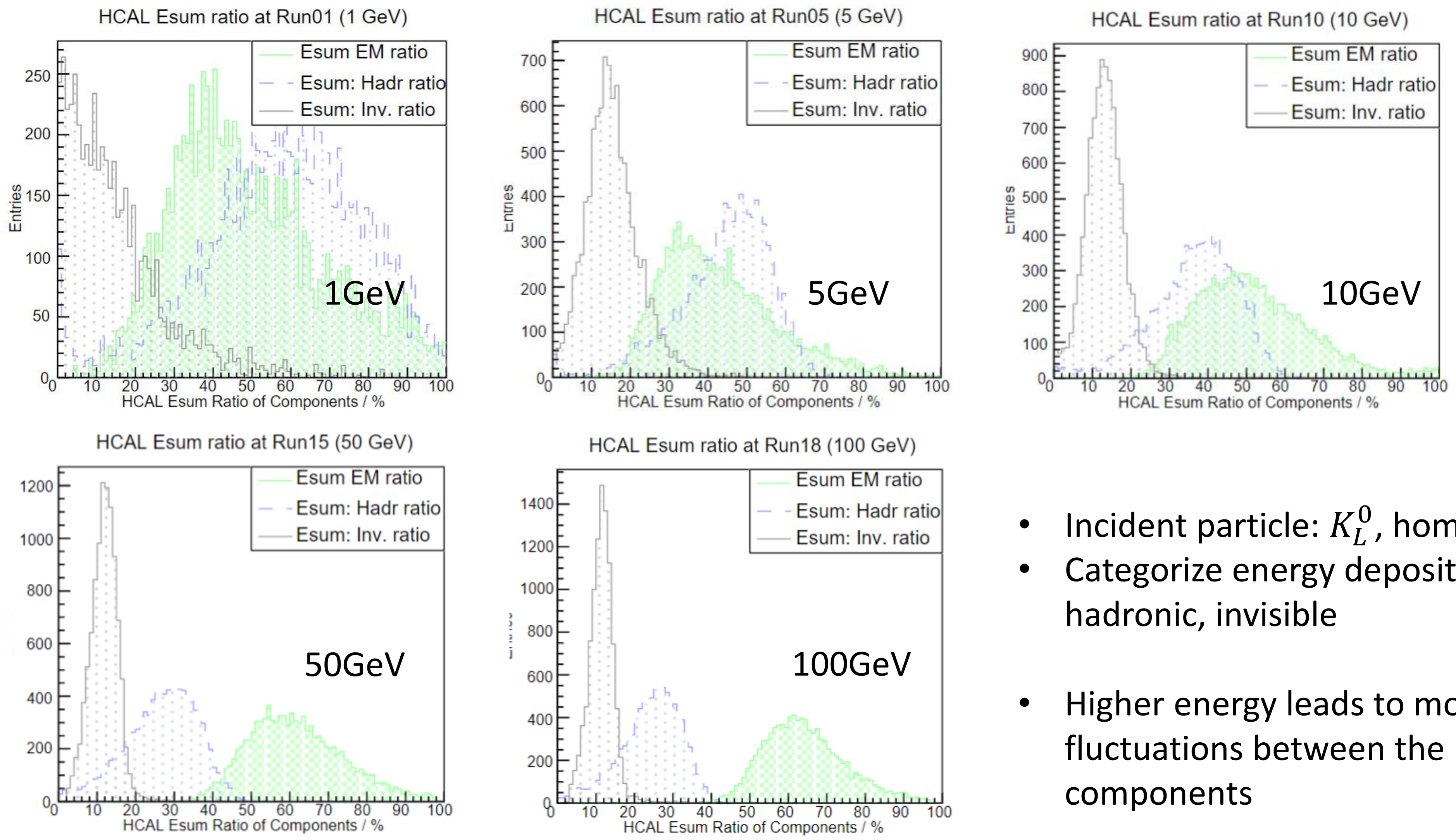


Constant term vs. glass thickness



- Energy threshold has a significant impact on the curve: energy resolution vs. glass thickness
- With the 0.5 MIP threshold, resolution will not be improved when glass thicker than 0.08 λ_I
- Higher threshold significantly degrades the constant term

Categorize energy depositions



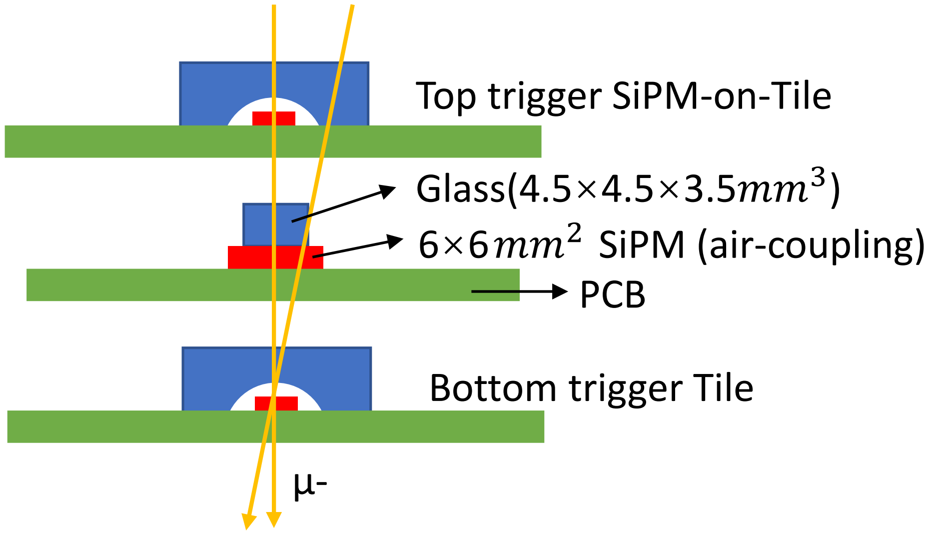
- Incident particle: K_L^0, homogeneous HCAL
- Categorize energy depositions: EM, hadronic, invisible

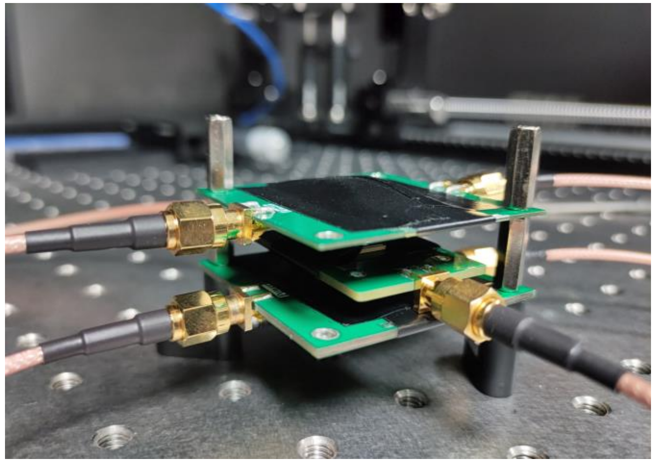
- Higher energy leads to more significant fluctuations between the EM and hadronic components

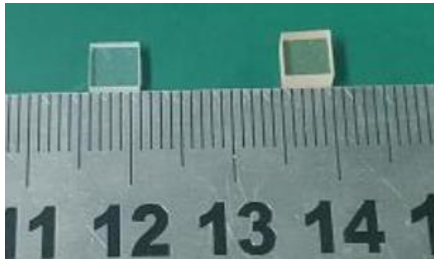
Outline

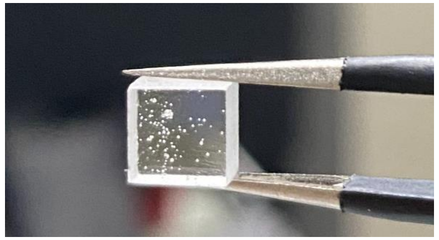
- Motivations
- Simulation of HCAL with scintillating glass (single hadrons)
  - Preliminary performance comparison
  - Hadronic energy resolution
    - Impact of density and light yield
    - Varying thickness of glass tiles and steel plates
- A single scintillating glass tile
  - MIP response: optical simulation and cosmic ray test
  - Uniformity scan
  - Vary transverse size
- Summary

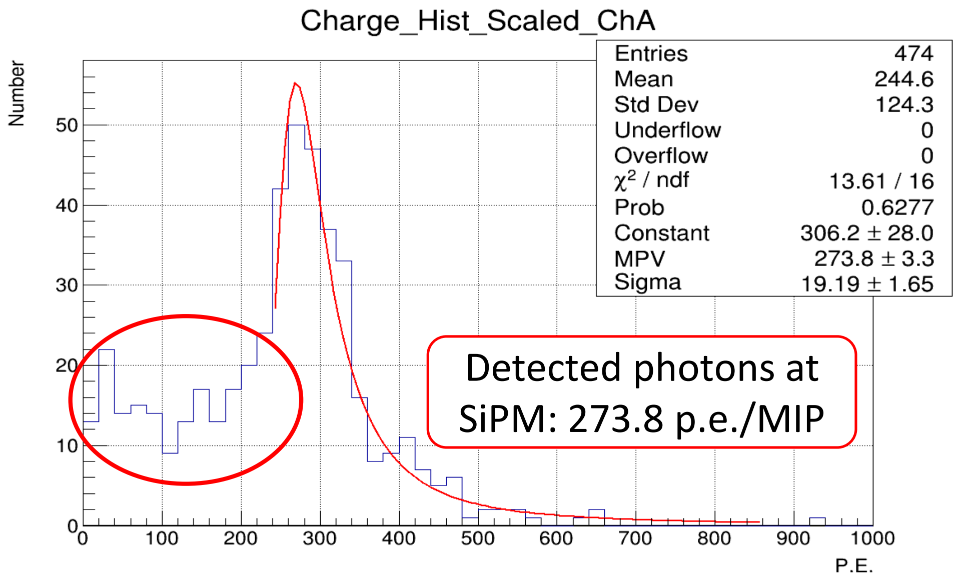
MIP response: cosmic-ray test setup and result







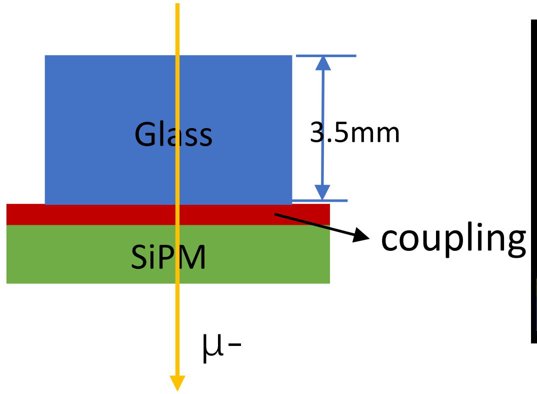


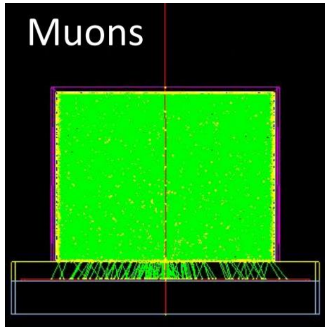


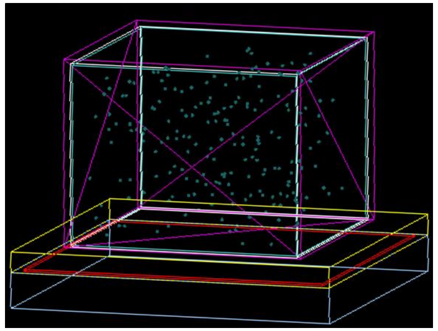
- MIP response: 274 p.e./MIP
- Plastic scintillator triggers cover larger area than sample does, some cosmic rays cross part of the sample

MIP response: optical simulation setup and result

- Simulation setup
  - Scintillating glass ($4.5\times4.5\times3.5mm^3$)
  - $6\times6\ mm^2$ SiPM , air-coupling
  - Small air bubbles are included
- Incident particle: 1 GeV mu- (regard as MIP particle)

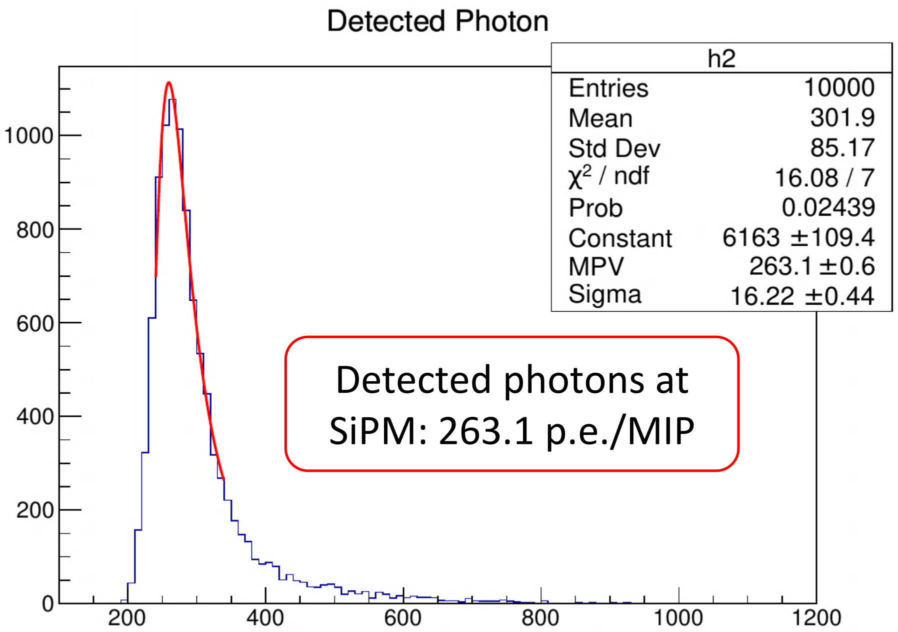






Properties of scintillating glass
- Component: $B_2O_3 - SiO_2 - Al_2O_3 - Gd_2O_3 - Ce_2O_3$
- Density: 4.94 g/cm^3
- Refractive index: 1.67
- Transmission: 63%
- Emission peak: 394 nm
- Light yield: 881 ph/MeV

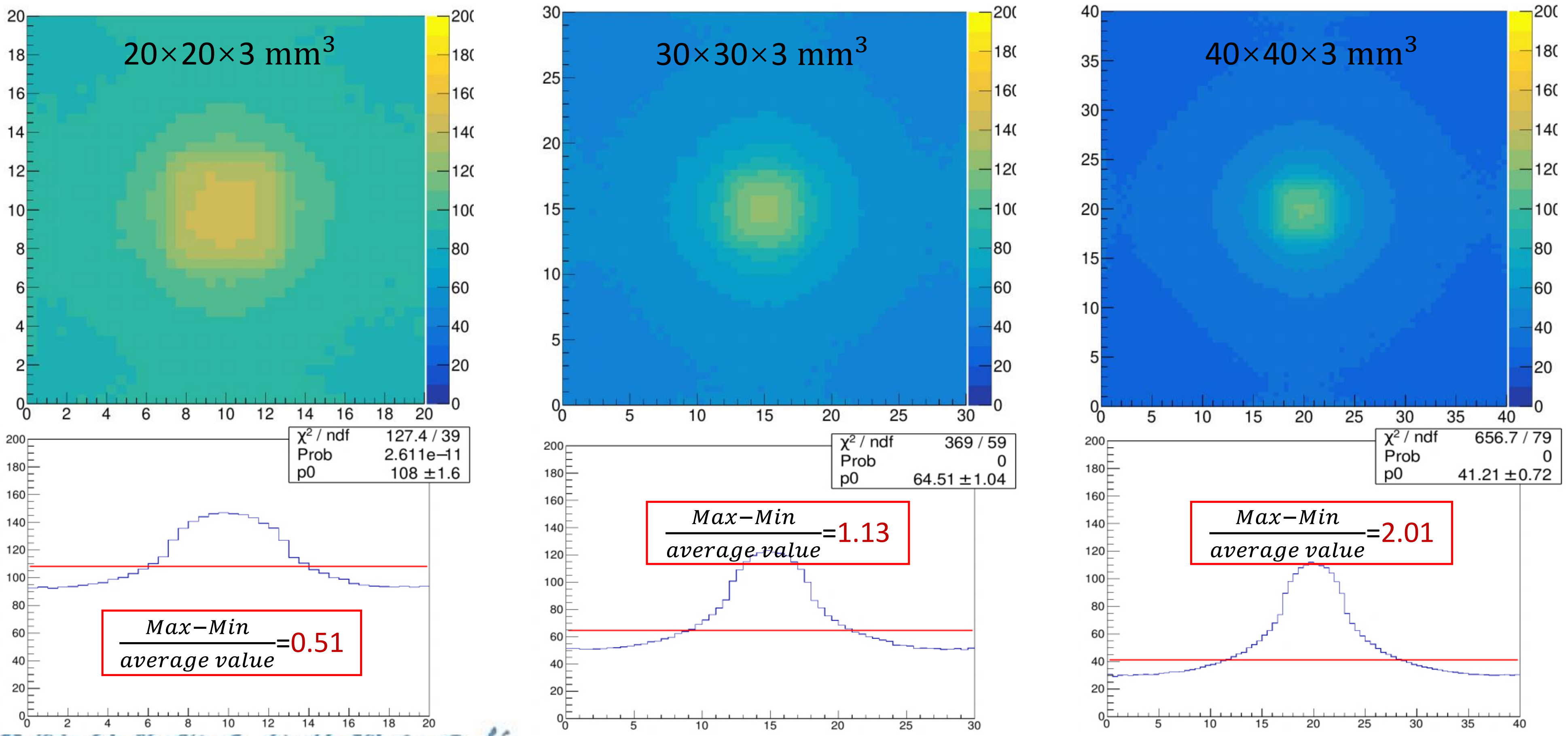
(All data based on measurements)



- MIP response
  - Energy deposition: 2.0 MeV/MIP
  - Detected photons: 263 p.e./MIP
- The simulation result is consistent with cosmic-ray test result
  - difference < 4%

Uniformity scan for a scintillating glass tile

- Assuming change glass size does not affect its properties
- Uniformity scan: 1 GeV mu-, change hit positions
- Larger tile size leads to fewer detected photons and worse uniformity

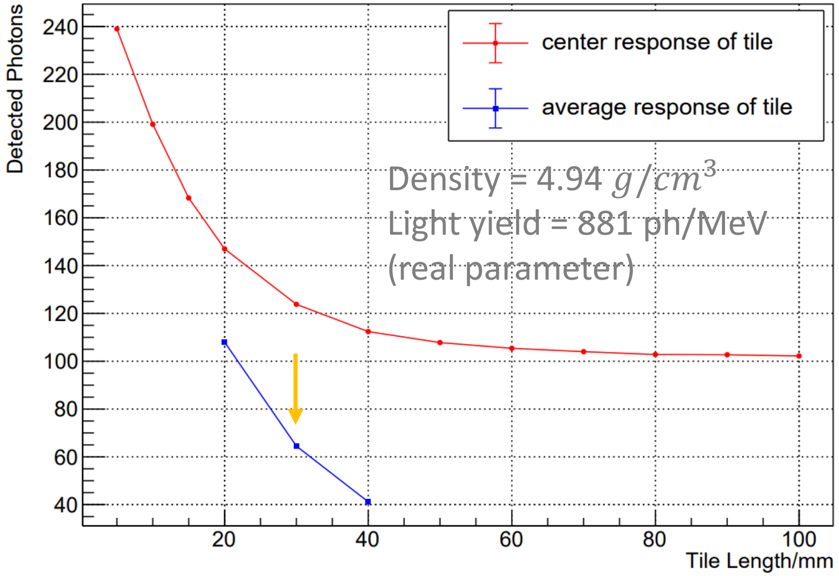


Impact of scintillating glass tile size

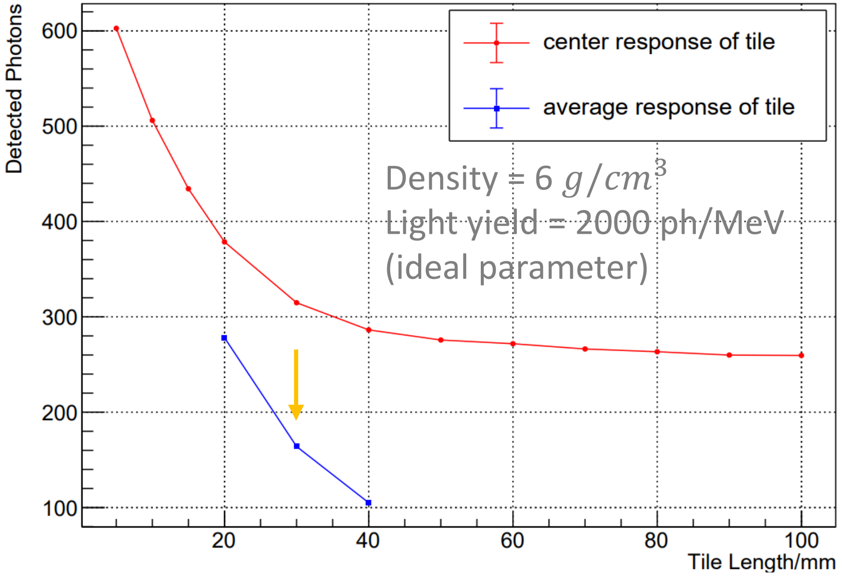
- Assuming change tile size does not affect its properties
- Incident particle: 1 GeV mu-, center position

Vary transverse size, fixed tile thickness at 3 mm (AHCAL baseline design)

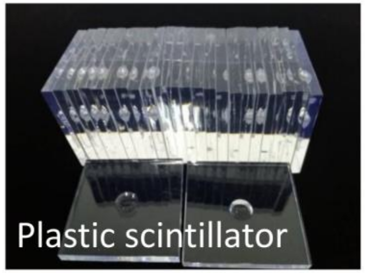
Detected photons vs. tile size



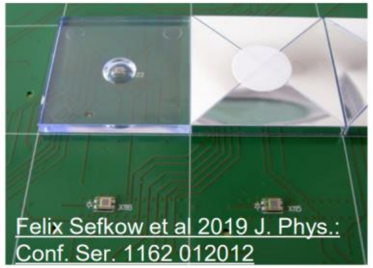
Detected photons vs. tile size



Tiles for AHCAL (30x30x3mm)



"SiPM-on-Tile" design for HCAL



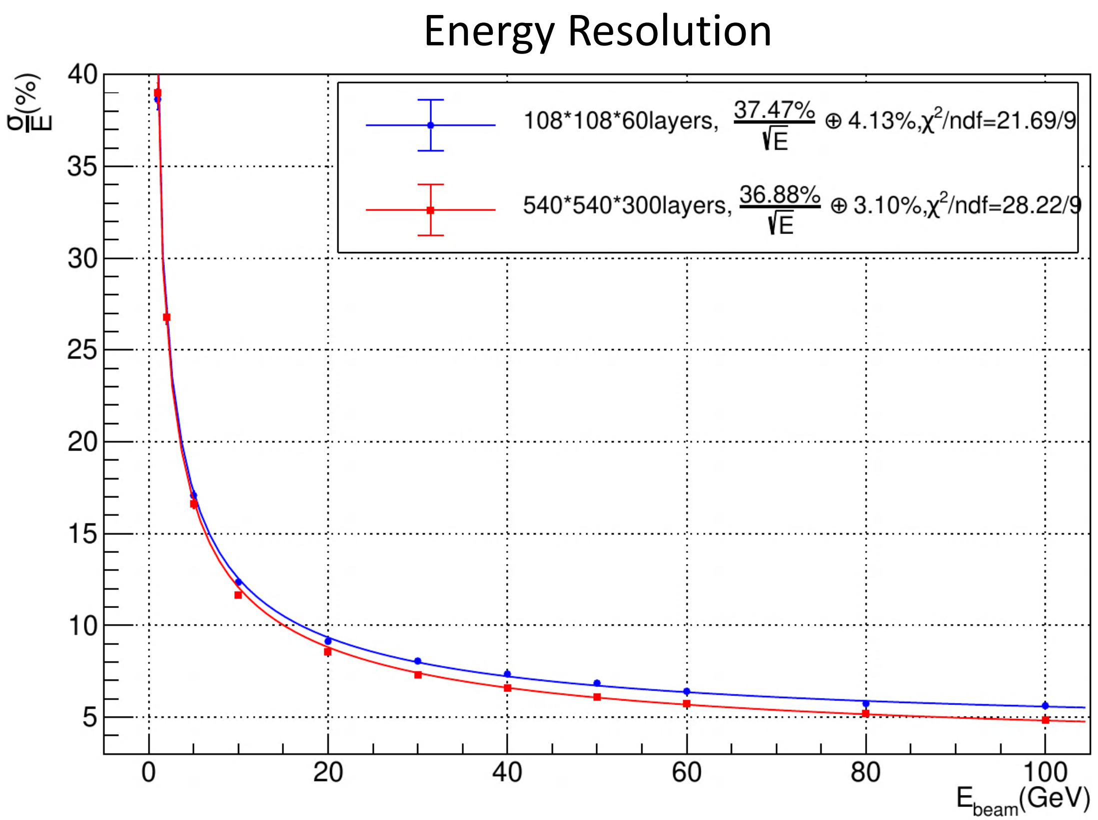
- Realistic parameter: ~65 p.e./MIP not enough (using large size 6×6 mm^2 SiPM)
- Ideal parameter: ~160 p.e./MIP → smaller size SiPM
- Next plans:
  - Study the impact of SiPM size
  - Improve uniformity through tile-designs: "SiPM-on-Tile" is a feasible option
  - Scintillating glass R&D: improve density and light yield

Summary

- A novel HCAL concept with high-density scintillating glass
  - To improve energy resolution, especially hadronic energy resolution
- Scintillating glass HCAL performance in simulation
  - Preliminary performance comparison
  - Hadronic energy resolution versus glass thickness
    - To further improve the energy resolution: “Software compensation” technique or “Dual-readout” technique
- Studies with a single scintillating glass tile (size in mm)
  - Optical simulation result is consistent with cosmic-ray test result
  - Simulation: impact of uniformity and tile size
    - Next plan: improve uniformity, study the impact of SiPM size

Backups

HCAL: evaluate leakage effects

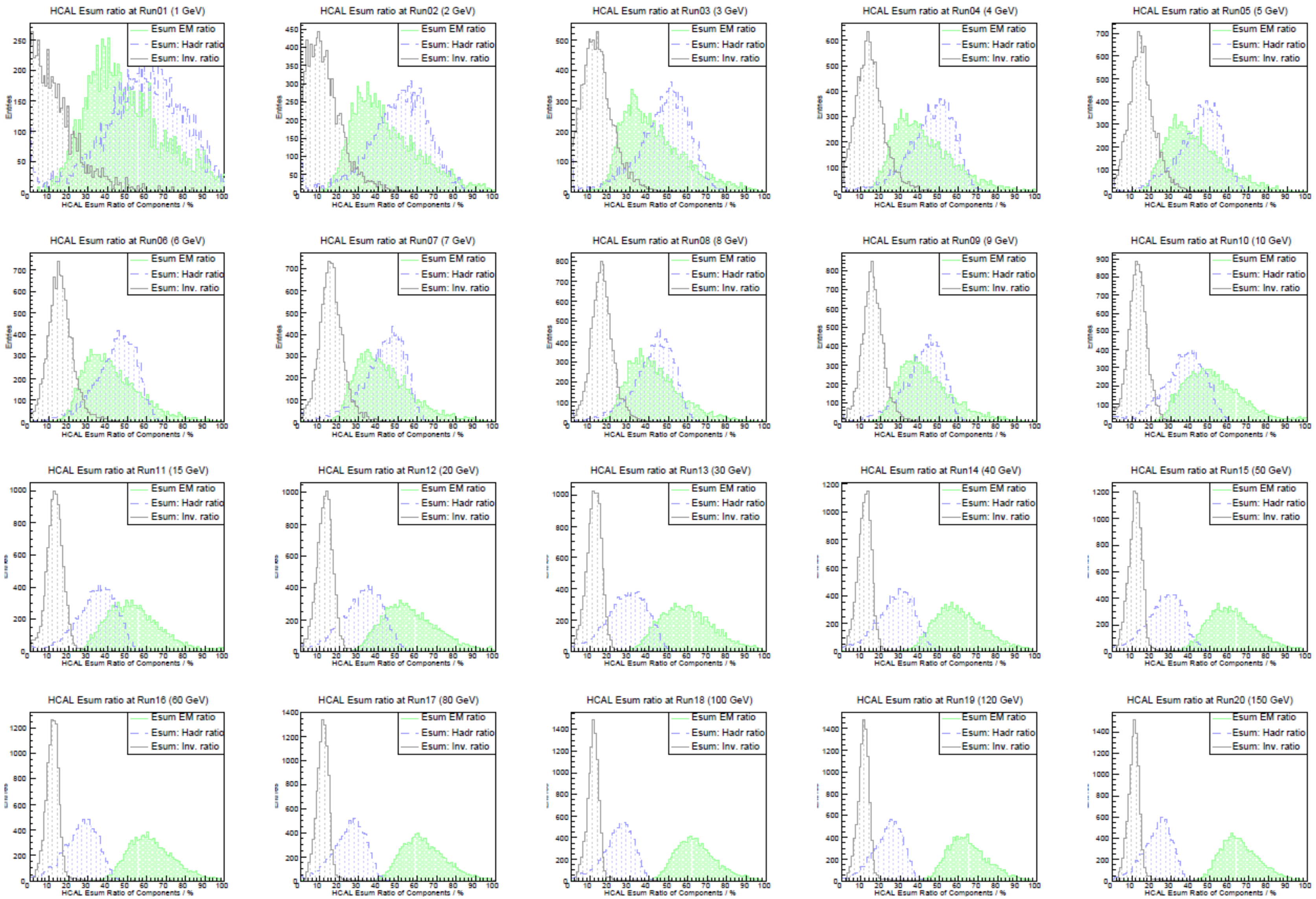


- Geometry size
  - Baseline: 108cm×108cm×60layers(~1.5m)
  - Ideal: 540cm×540cm×300layers(~7.5m)
- Incident particle: kaon0L (1-100 GeV)

- The impact of shower leakage to energy resolution in the 60 layer is estimated (~1% level)

Scintillating glass HCAL: energy deposition with K_L^0

Categorize energy depositions: EM, hadronic, invisible



Scintillating glass HCAL: energy deposition with K_L^0

Energy sum