Preliminary Analysis & Prospect for Glass HCal PFA Performance in CEPC

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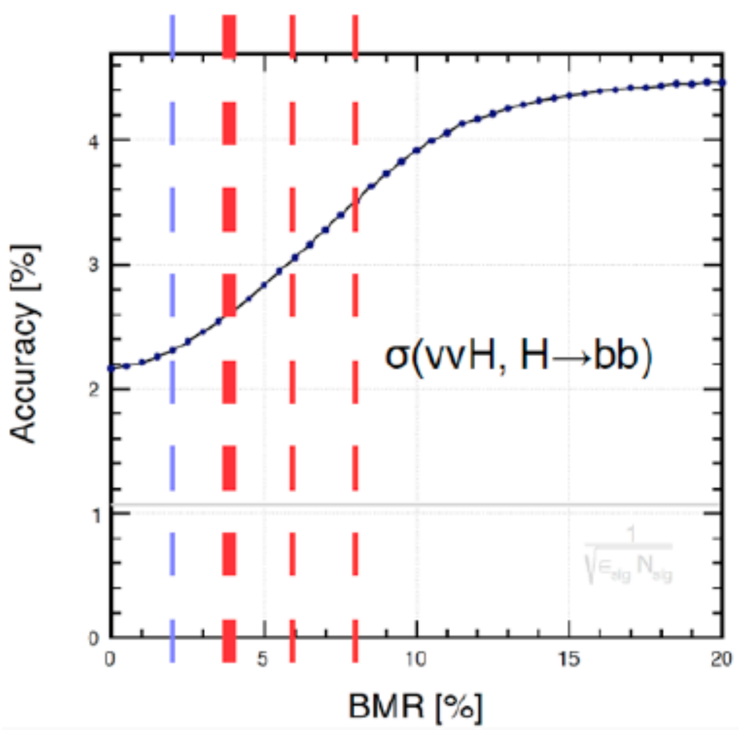
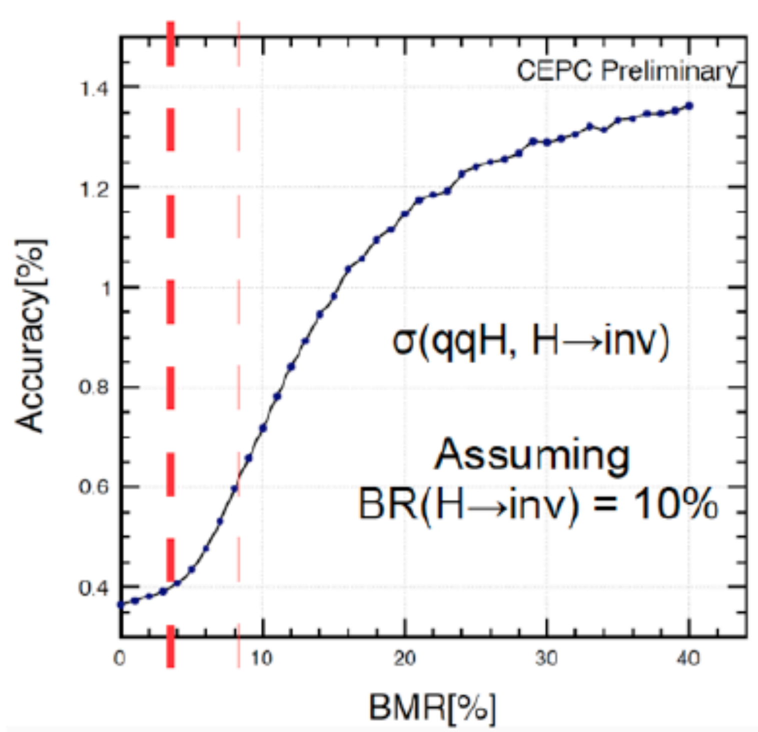
Plan

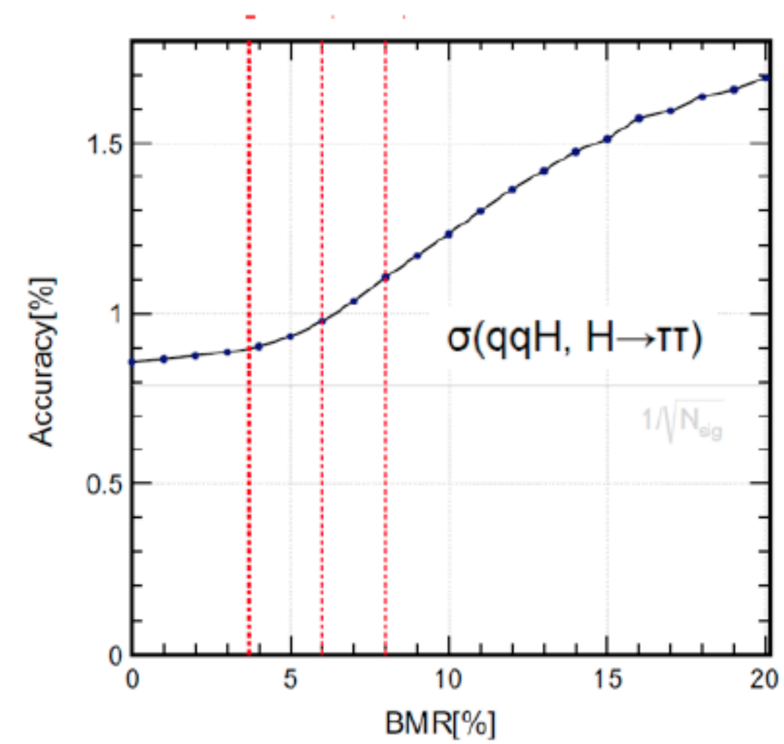
- Motivation:
  - Better boson mass resolution is favored by future new physics and flavor physics research
  - Scintillating glass hadronic calorimetry is a cost-effective option with better HCAL energy resolution
- Performance
  - The BMR using baseline setup & prediction
- Hit profile analysis
  - The hit response and collection efficiency

Motivation

- BMR
  - Achieved 3.8% in CDR
  - Requirement in Higgs Physics: 4%
  - For NP or Flavor: better is better

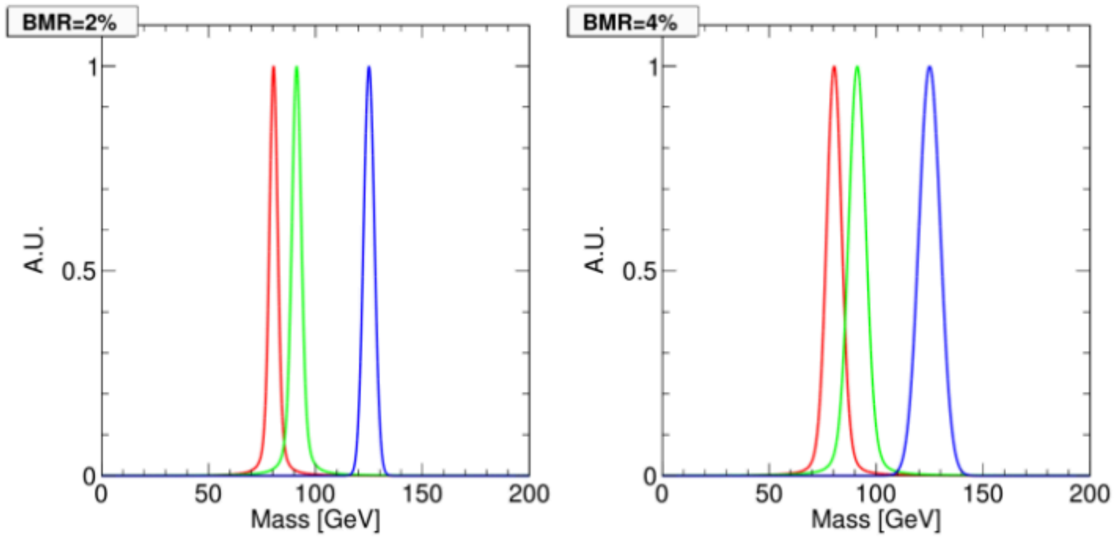






Find more info in <u>Oliver Fisher's talk at CEPCWS2021</u>

Scalar bosons with "tight" mass spectrum



- New resonances could be close to M_W, M_Z, M_H

cf. the 96 GeV excess at LHC, e.g. P. J. Fox and N. Weiner, JHEP **08** (2018), 025

- New resonances with spectrum $\delta m < M_Z - M_W$ possible.
- Difficult example: HEIDI Higgs

$$D_{HH}(q^2) = \left[q^2 + M^2 - \mu(q^2 + m^2)^{\frac{d-6}{2}}\right]$$

$\Rightarrow$ Test if the "Higgs signal" stems from a continuum.

J. J. van der Bij and S. Dilcher, Phys. Lett. B **638** (2006), 234–238

- The Boson Mass Resolution should be as good as possible!

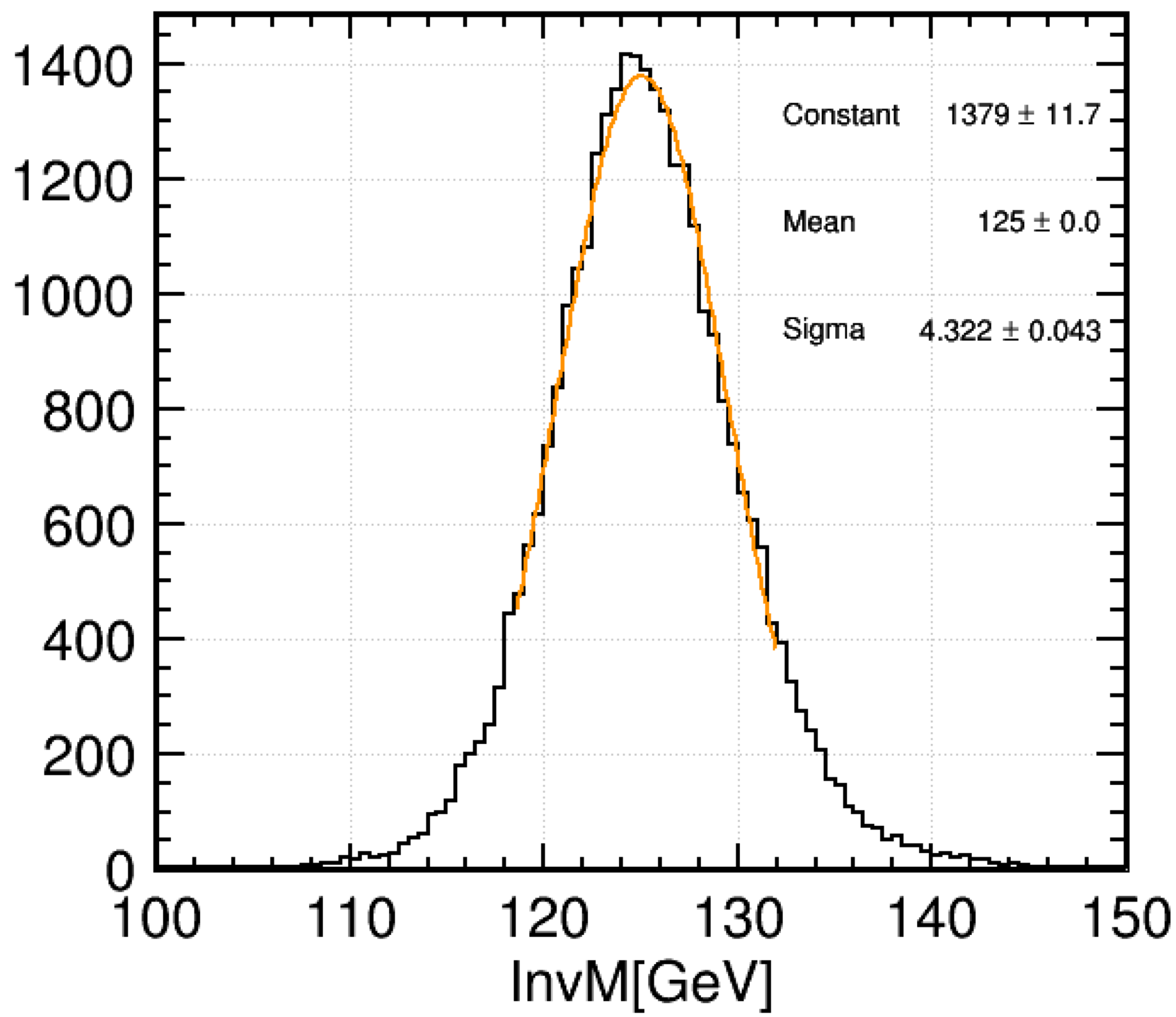
Find more info in Oliver Fisher's talk at CEPCWS2021

Scintillating Glass

- Pros: cost effective, moderate light yield, tunable compositions
- Cons: quality/uniformity, radiation hardnessTwo type of glass tested
- Transparent options:
  - Glass I:
    - 42SiO_2-5Al_2O_3-22BaF_2-9NaF-3CaF_2-3Gd_2O_3-9GdF_3-7TbF_3
    - density=4.2g/cm3
  - Glass II:
    - 25SiO_2 − 30B_2O_3 − 10Al_2O_3 − 34Gd_2O_3: 1Ce+
    - density = 4.94 g/cm3
    - 40mm*40mm*40mm cube, 40 layers (Total thickness 1.6m, volume ~ 140m^3, 2M channels)

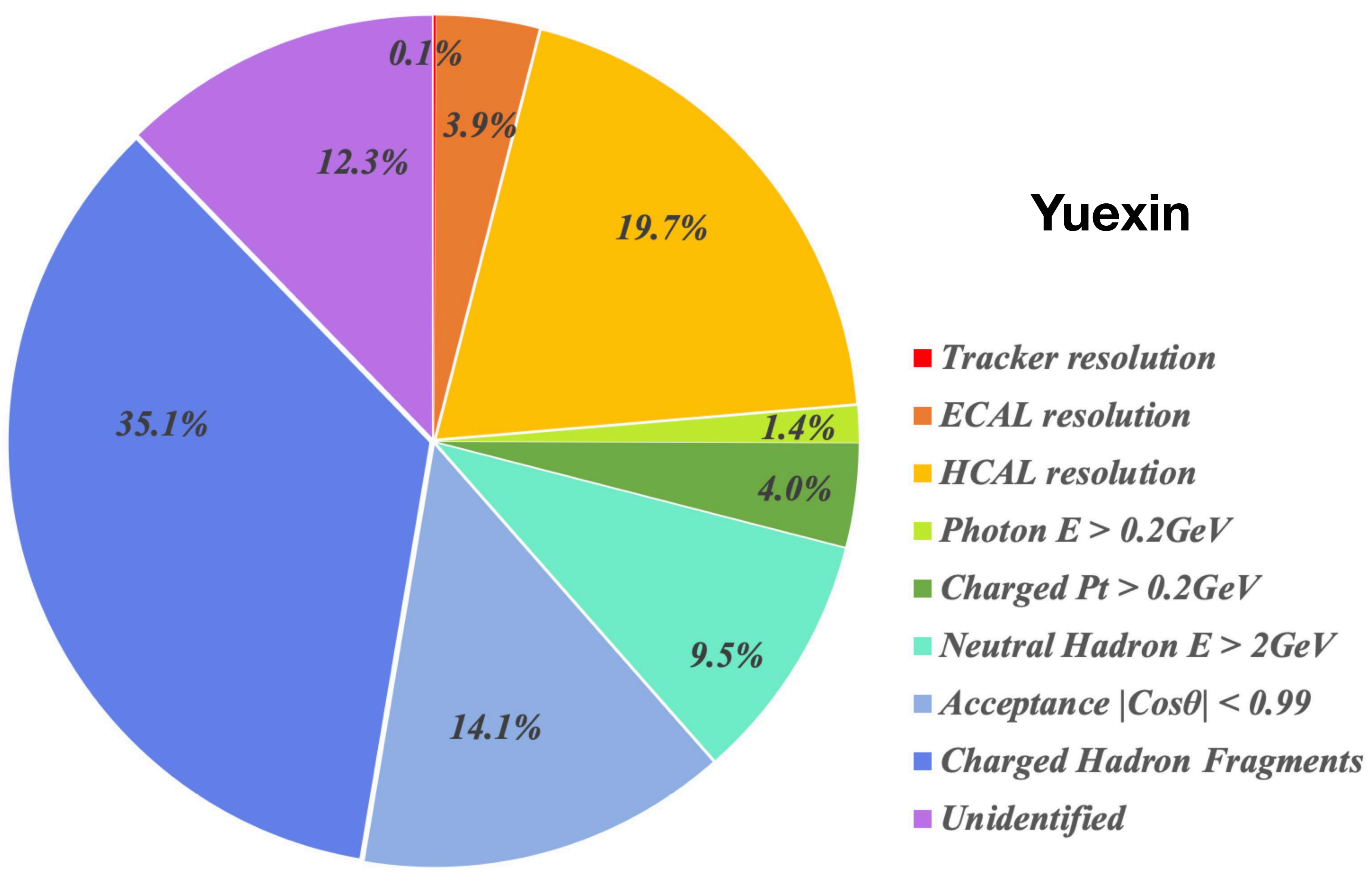
BMR

- The BMR with homogenous glass hcal ~ 3.4%: more than 10% improvement w.r.t. Baseline (3.8%), through Baseline Arbor with hit energy threshold cut and calibration tuning



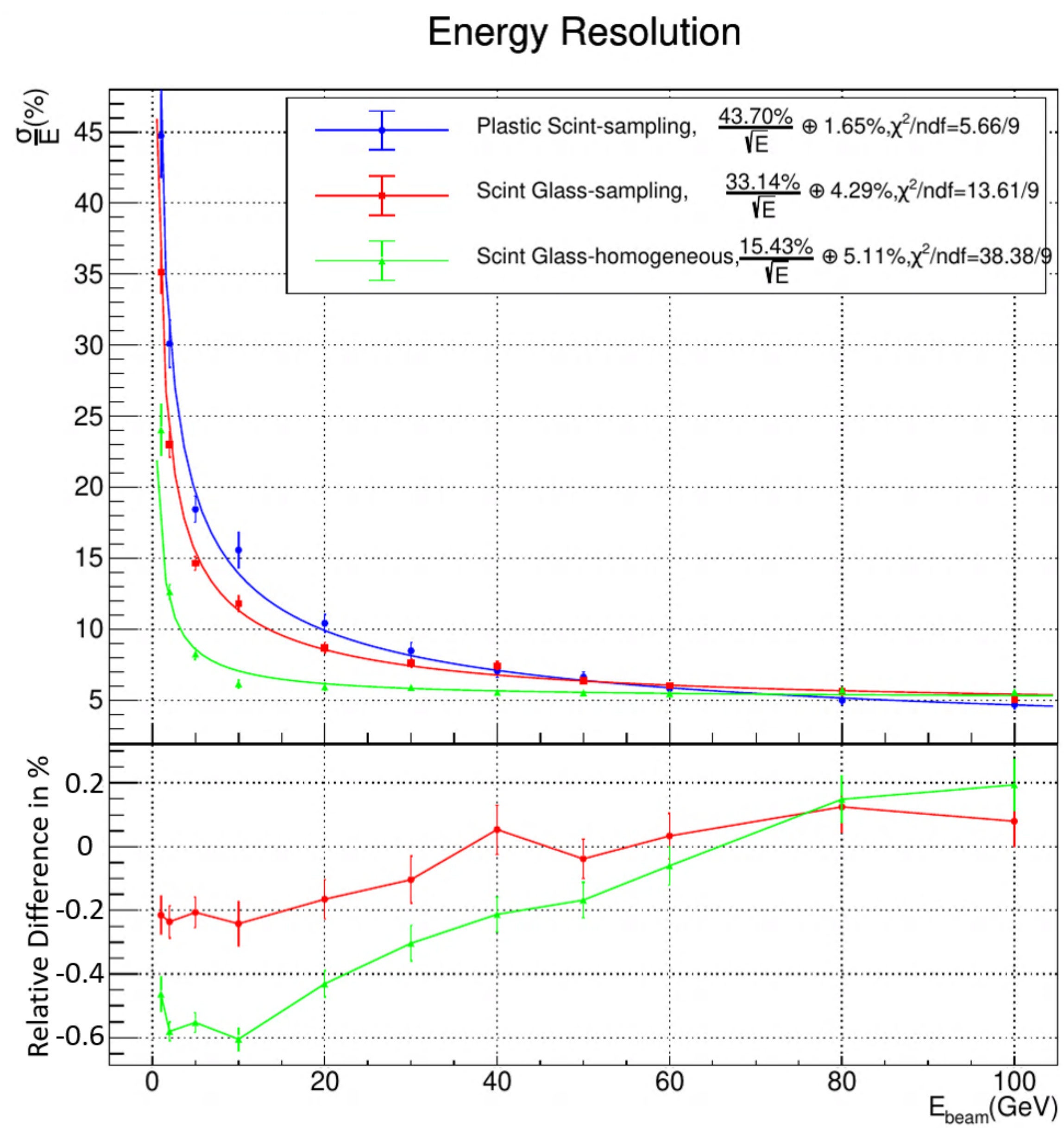
BMR variations predicted by Fast simulation

- BMR can improve 10% if HCal resolution improves ~ 50%



Consistent with Single Particle Energy response…

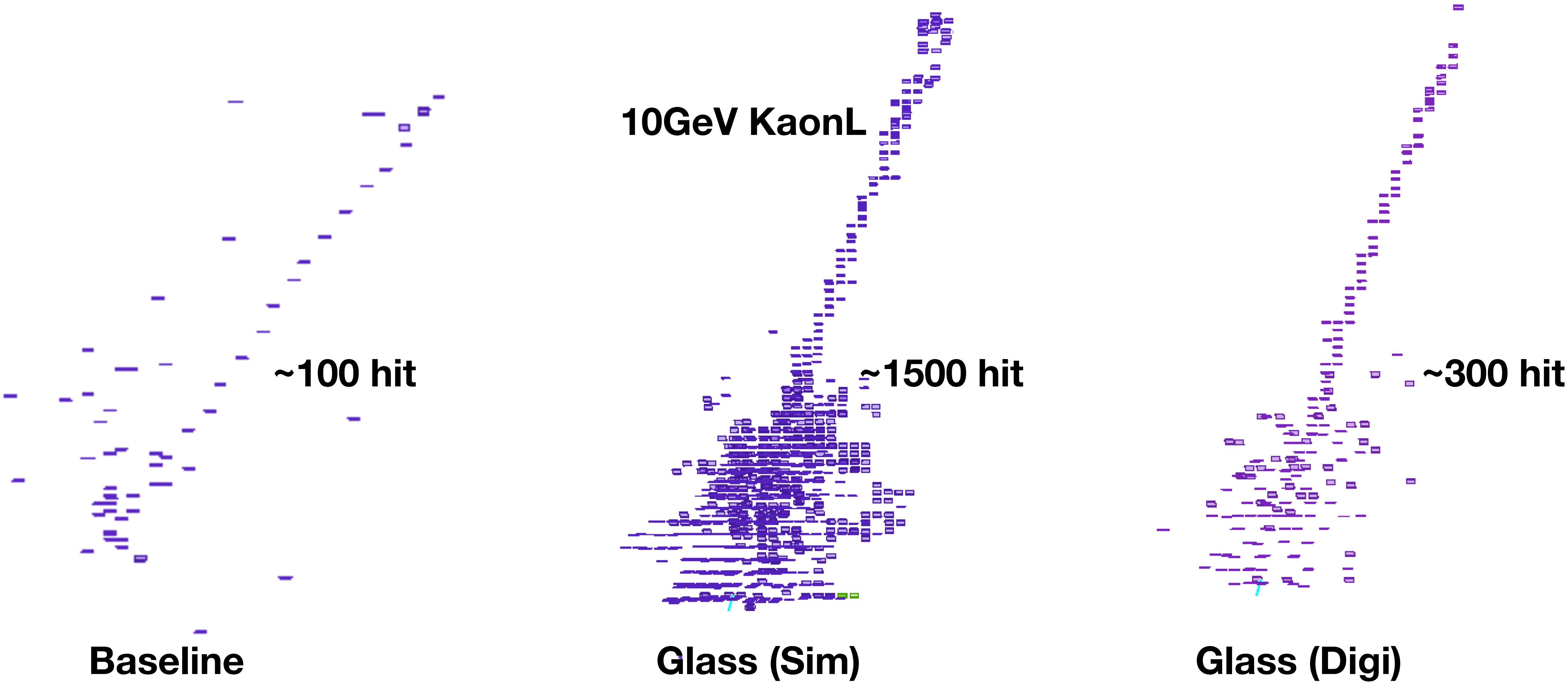
- Potentials: Geant4 simulation with single hadrons (preliminary results)
    - Better hadronic energy resolution in low energy region <30GeV
- Baseline: $60\,\%\sqrt{E} \oplus 6.3\,\%$
- ECAL + HCAL
    - need modeling & further validation…

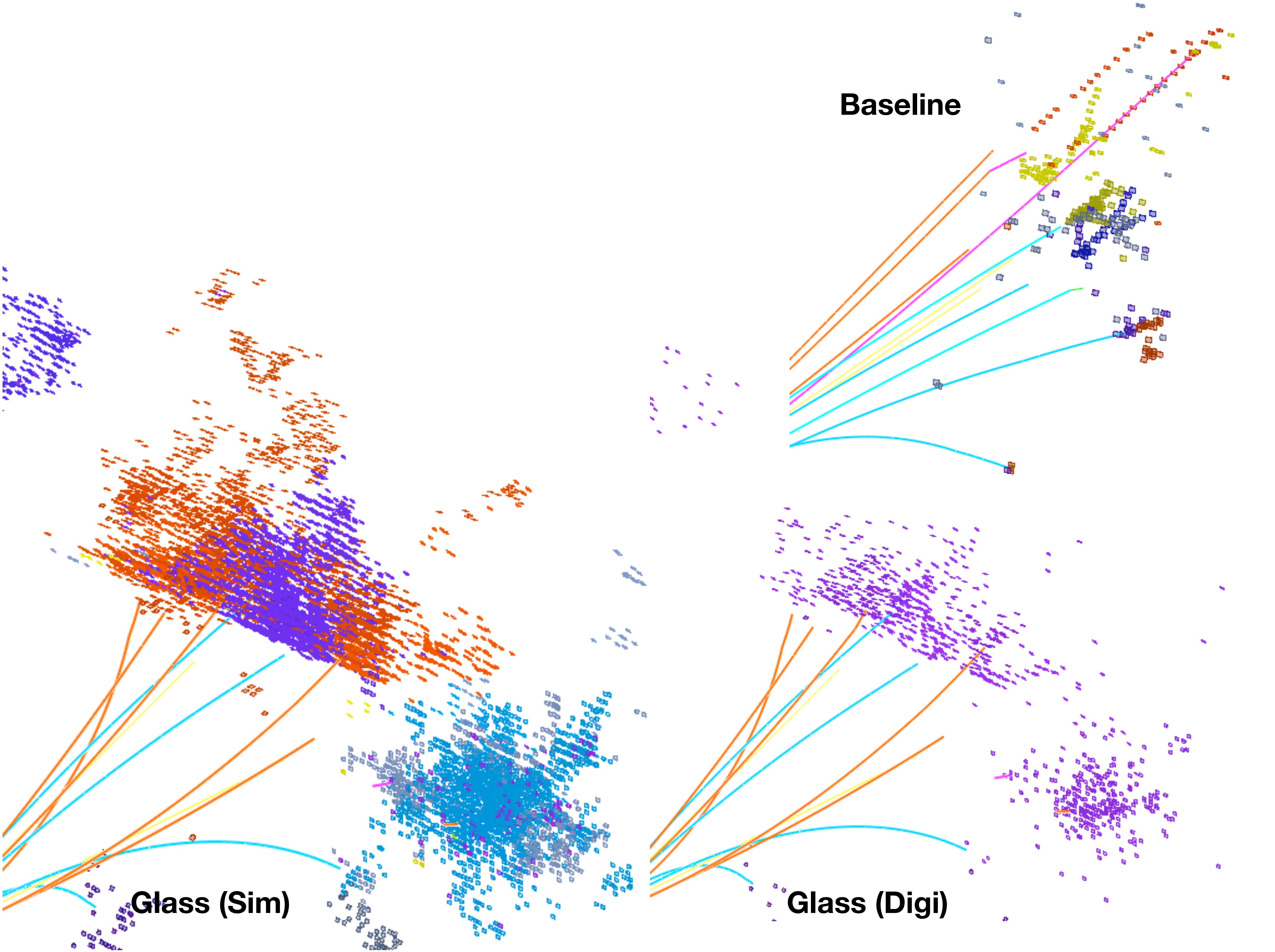


Dejing

Hit Profile Comparison

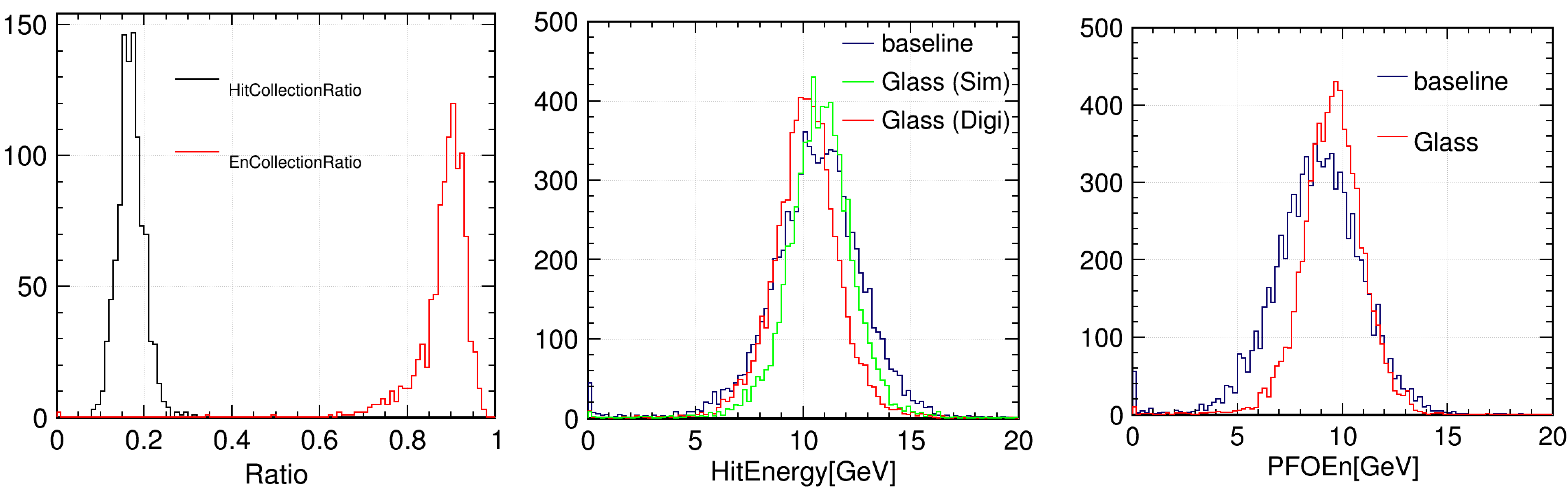
- Challenge for PFA: hit number 1 order of magnitude higher, difficult for clustering & pattern recognition
- To reduce the hit number: Digi threshold: 2.3MeV (~0.1Mip, tuned using BMR)




Baseline
Glass (Sim)
Glass (Digi)

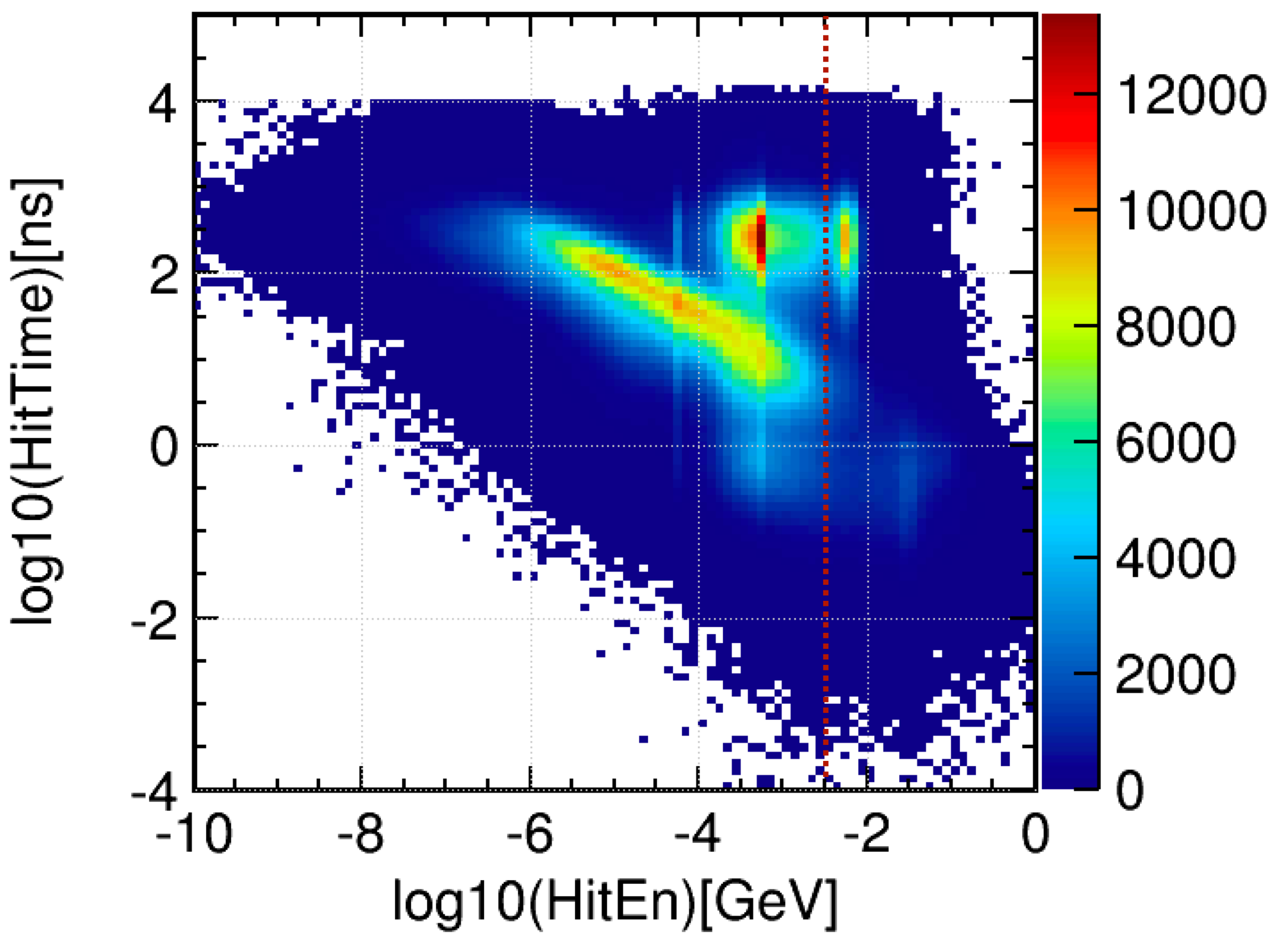
Single Particle

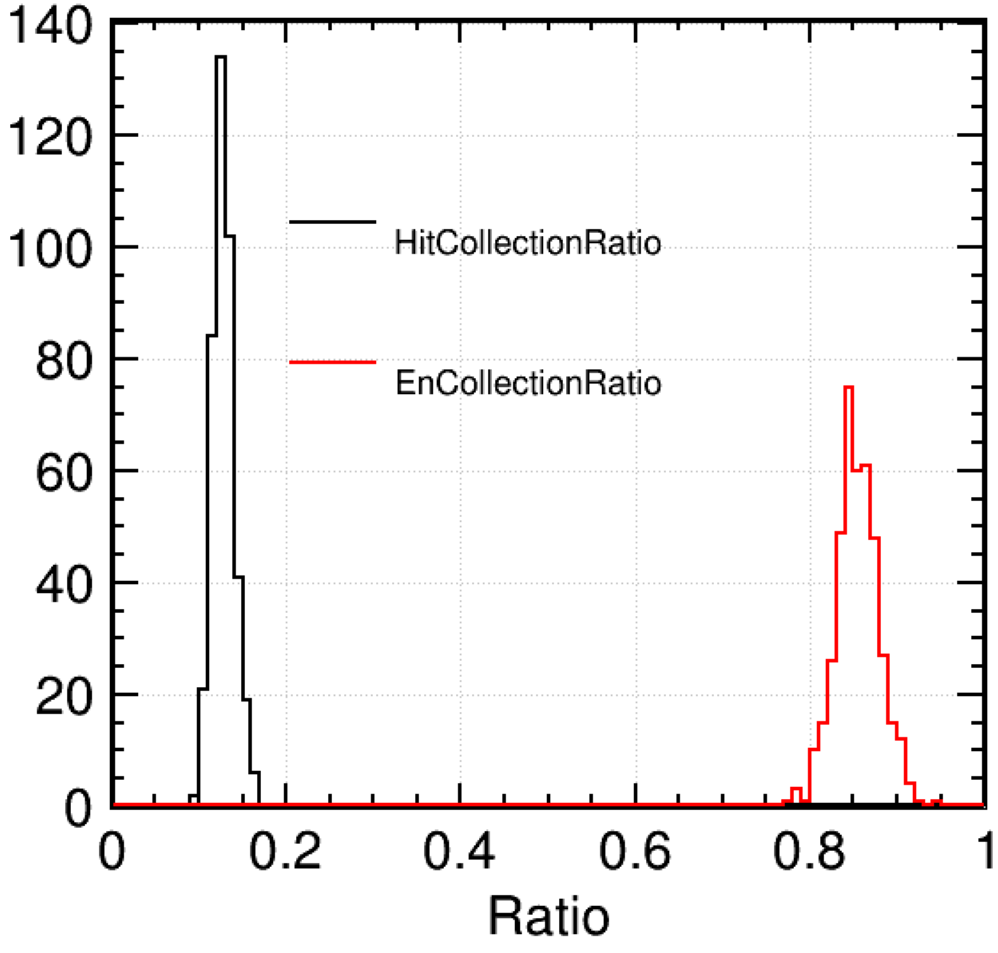
- Digi threshold: 2.3MeV (~0.1Mip)
  - Hit collection efficiency ~ 20%
  - Energy collection efficiency ~ 90%
- PFO resolution for 10GeV kaon can improve 10% if all hits energy are used
  - with similar strategy used in crystal Ecal, i.e., hit absorption after clustering

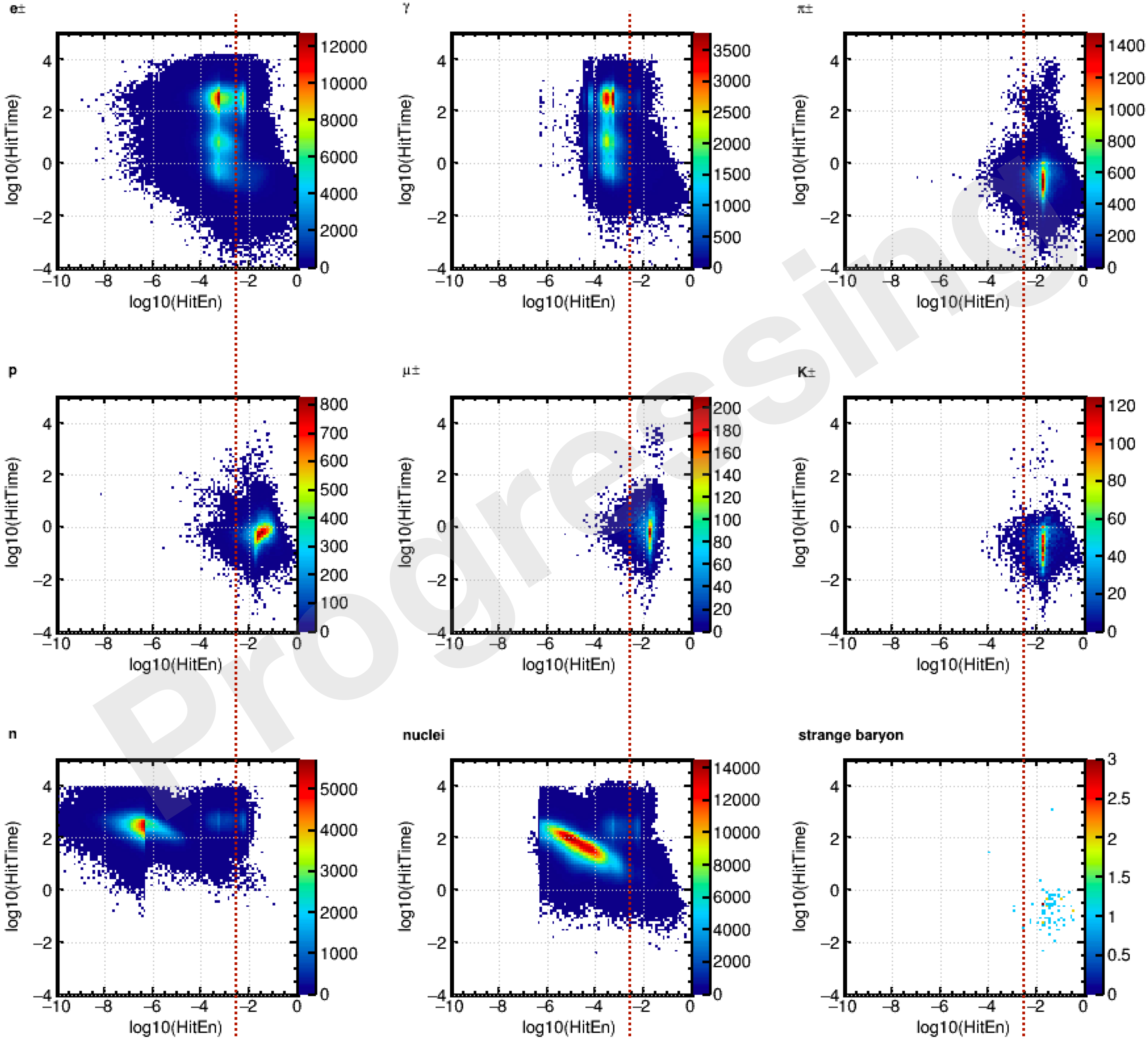


Hit Profile

- Current Threshold: 2.3MeV (~0.1Mip)
  - Time threshold can be also applied to improve
- Hit collection efficiency: 13%
- Energy collection efficiency: 85%

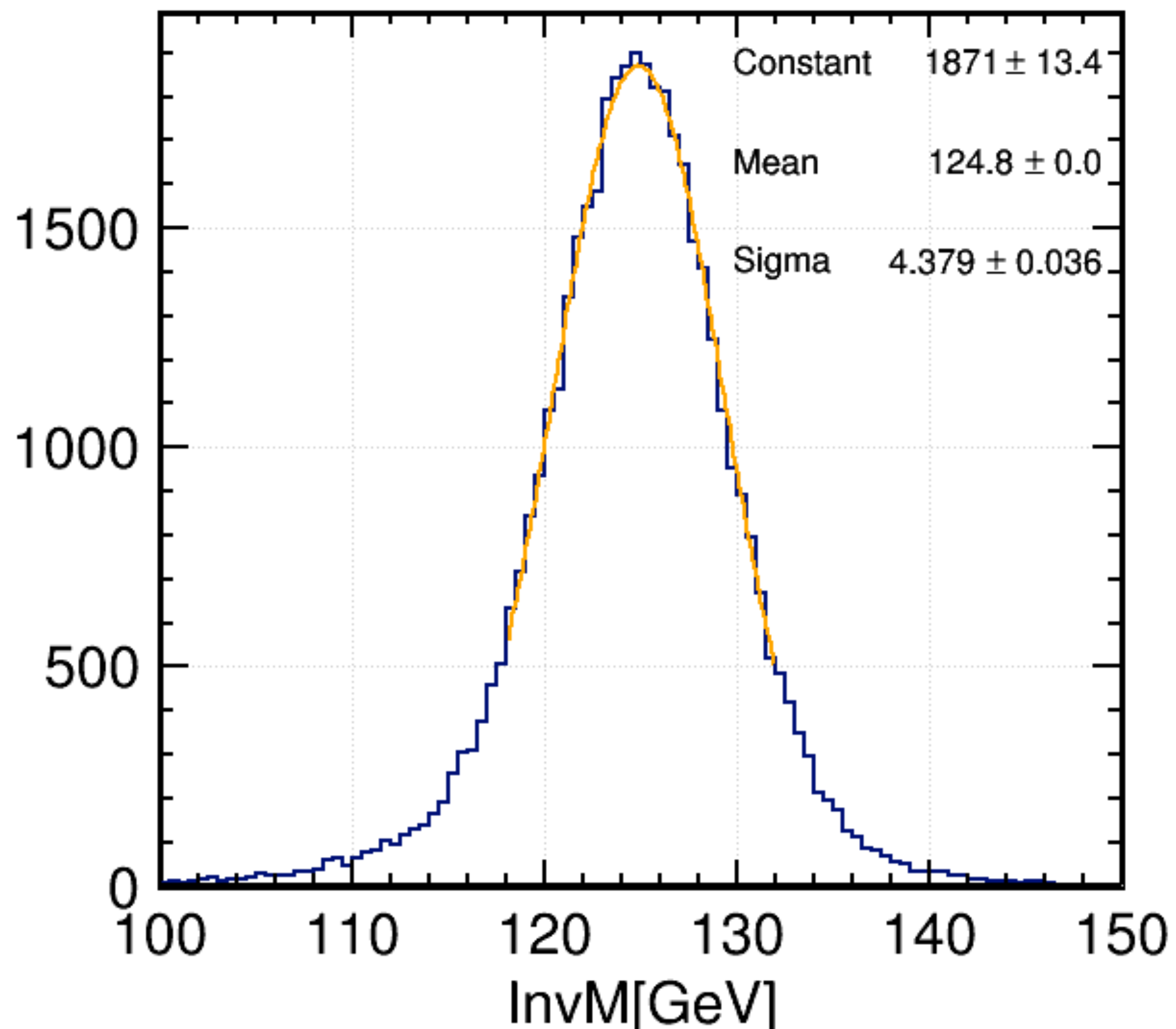





e±
γ
π±
p
μ±
K±
n
nuclei
strange baryon
log10(HitTime)
log10(HitEn)
Progressing

Alternative Option

- Dependence with density
  - another glass option: $42SiO2\text{-}5Al2O3\text{-}22BaF2\text{-}9NaF\text{-}3CaF2\text{-}3Gd2O3\text{-}9GdF3\text{-}7TbF3$
  - Thickness: 23mm (to keep the interaction length per layer unchanged)
  - Result: 3.5%, no significant dependency



Prospect

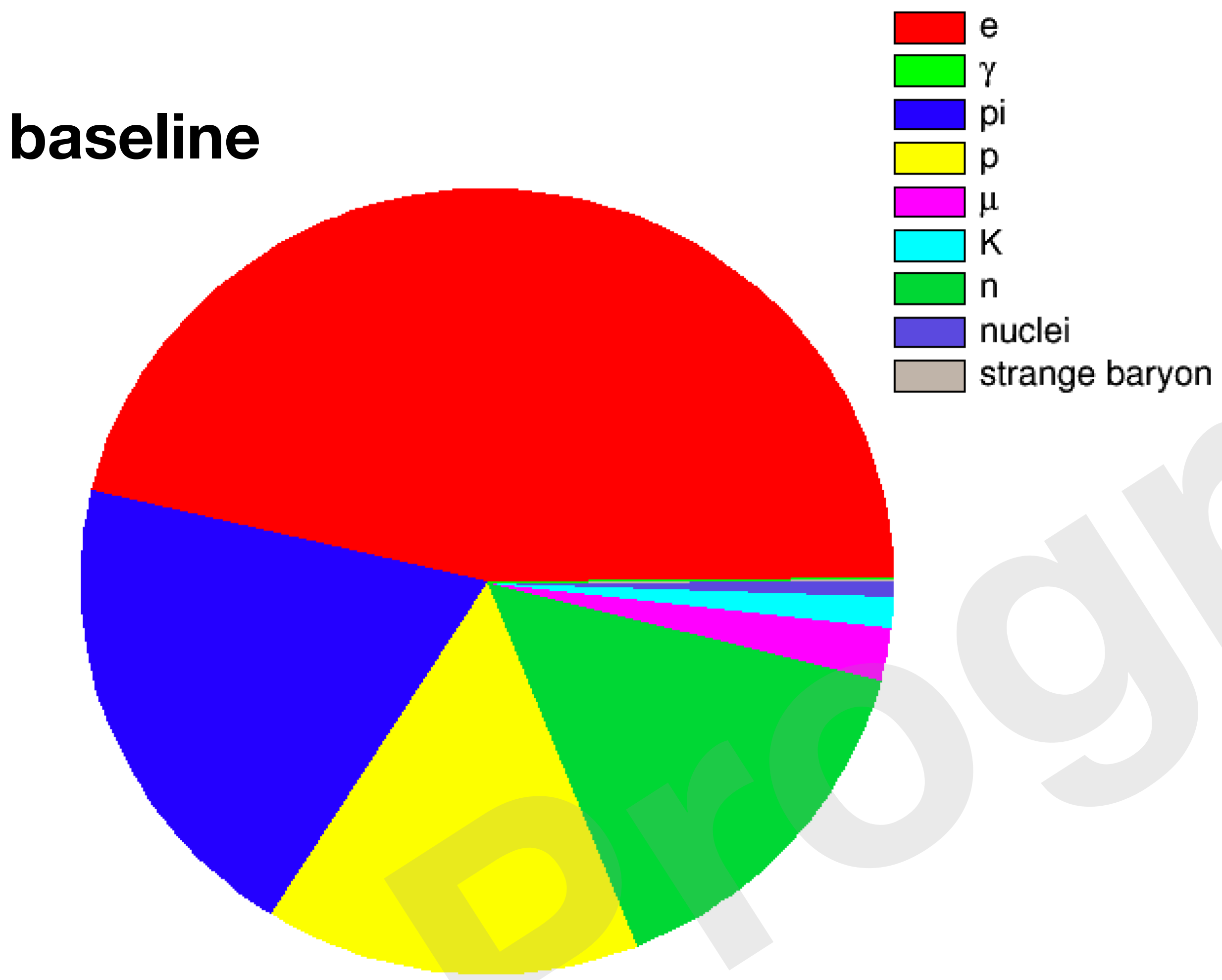
- Reconstruction parameter can be optimized
- A strategy applied in crystal ECAL:
  - use energetic hits for cluster building, all hits are collected in the last step
  - take advantage of both high granularity and good energy resolution
- Significant difference between EM/Had response are observed, software compensation is under considering

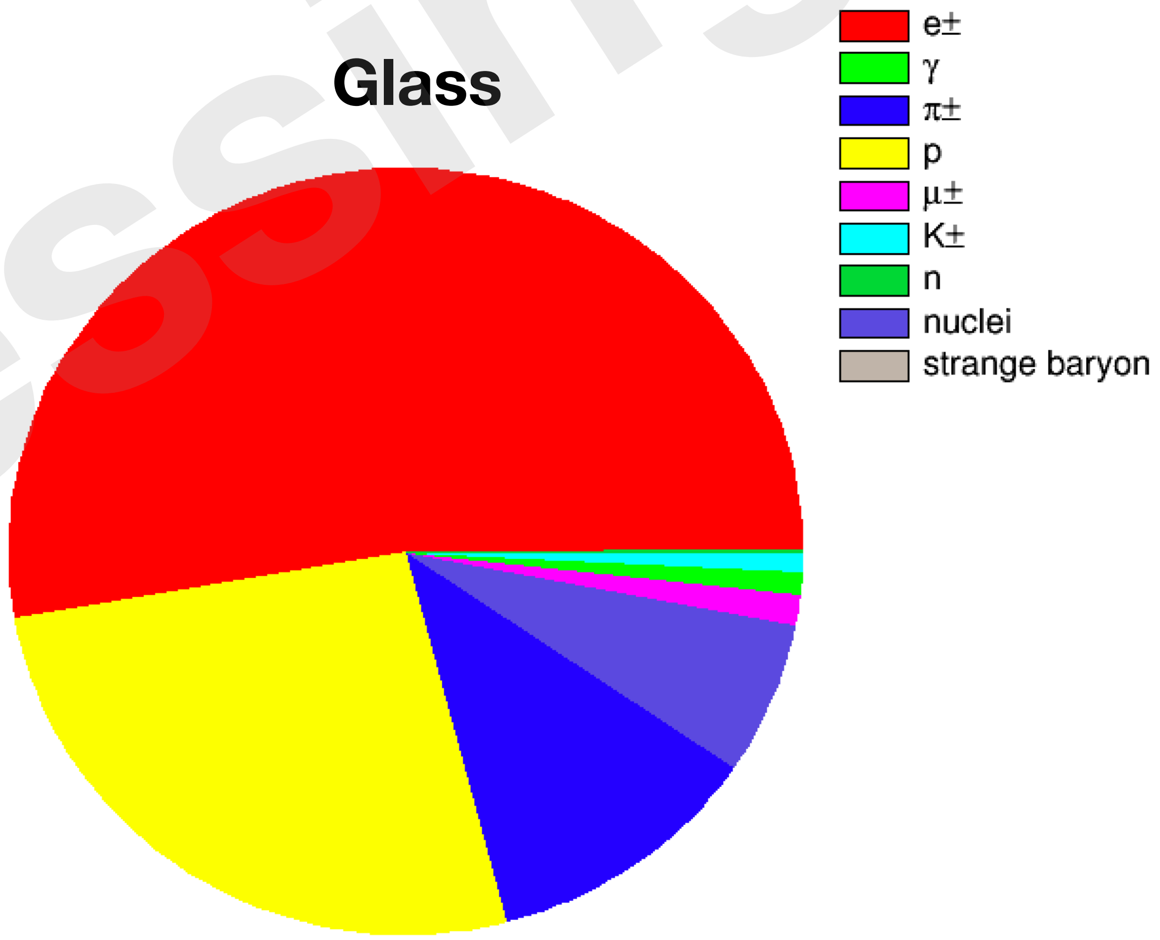
Summary

- Full absorption Glass HCAL improves the BMR by at least 10% w.r.t. Baseline design (3.4% : 3.8%)
  - Archived with simple threshold cut & calibration tuninng
- Observe No significant dependence between Glass density and BMR (fix longitudinal interaction length ~ 5.8λ)
  - Tools ready to scan more glass candidates
- Future perspective: BMR ~ 3%
  - better clustering algorithm, pursing
    - higher hit/energy collection efficiency (12.5%/85%), higher intrinsic energy resolution at Cluster level
    - similar/smaller confusions
  - Better energy estimation, software compensation…
  - Fragmentation veto using Time information
- To do: study the scaling behavior with different cell size.

backup

Hit Energy Weight





Find more info in Yong Liu's talk at IAS

Scintillating glass in ECFA Detector R&D Roadmap

CERN-ESU-017

Main R&D directions in calorimeters with light-based readout

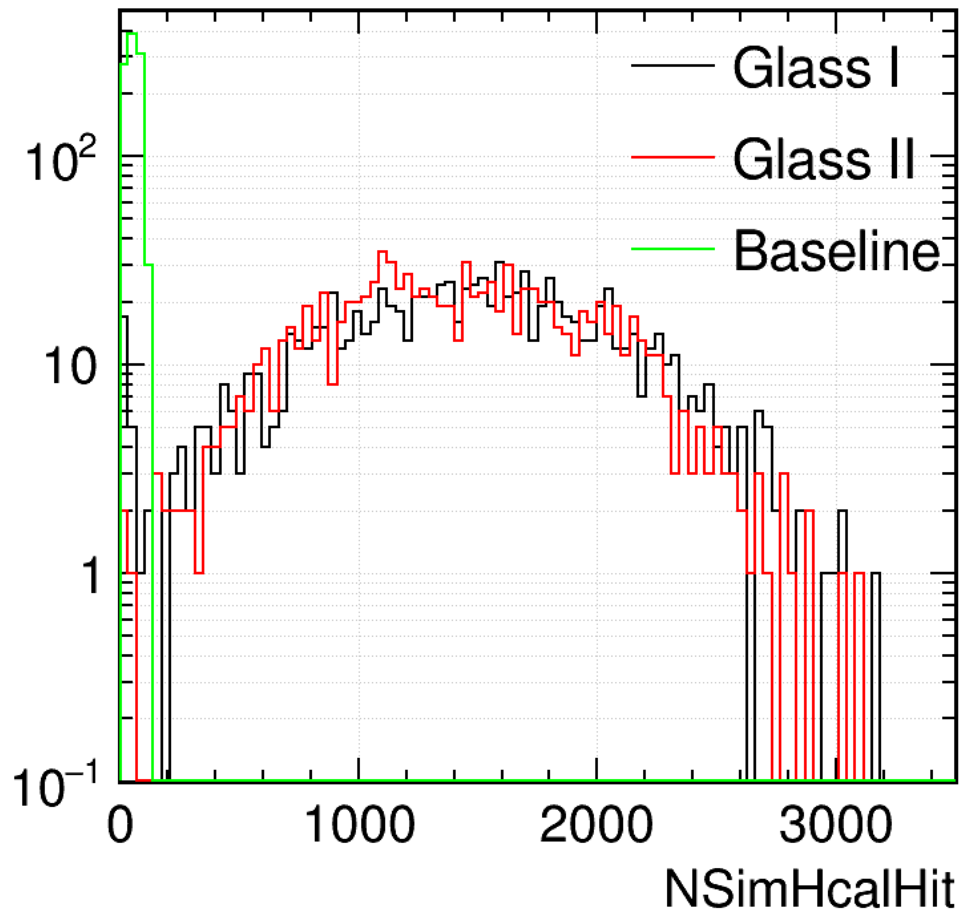
New material technologies
Novel techniques for crystal growth have broadened the range of potential configurations for crystal-based calorimeters, including crystal-fibre EM calorimeters and multiple-readout calorimeters [Ch6-18], [Ch6-19], [Ch6-20]. A SPACAL calorimeter, using co-doped garnet crystal fibres (GAGG, YAG, GYAGG), is proposed for the upgrade of the LHCb ECAL [Ch6-21], for improved energy resolution, shower timing with ten ps precision, and appropriate radiation hardness. Further improvements in radiation hardness will become relevant for future hadron colliders. Heavy scintillating glasses such as DSB : Ce^{3+} are investigated as a cost effective alternative to e.g. the common $PbWO_4$ crystals [Ch6-22], [Ch6-23]. Beyond, new plastic scintillators will be needed to improve radiation hardness and/or for use in multiple-readout options with Čerenkov and scintillation emission. The exploration of 3D-printing technologies in the production of scintillators [Ch6-24], as well as for mass production of precision absorbers in collaboration with industrial partners are promising R&D lines.

6.5 Recommendations

In order to implement the research directions the following set of recommendations is formulated.

- Implementation of DRDT 6.1. Support of R&D on novel optical materials and corresponding readout technologies to optimally prepare for the LHCb Upgrade II (in $\geq$LS4). Experiments such as KLEVER could provide an early use case of developments for LHCb. The development of heavy glasses for the Electron-Ion-Collider should be followed closely and European groups are encouraged to join this effort;

Alternative Option



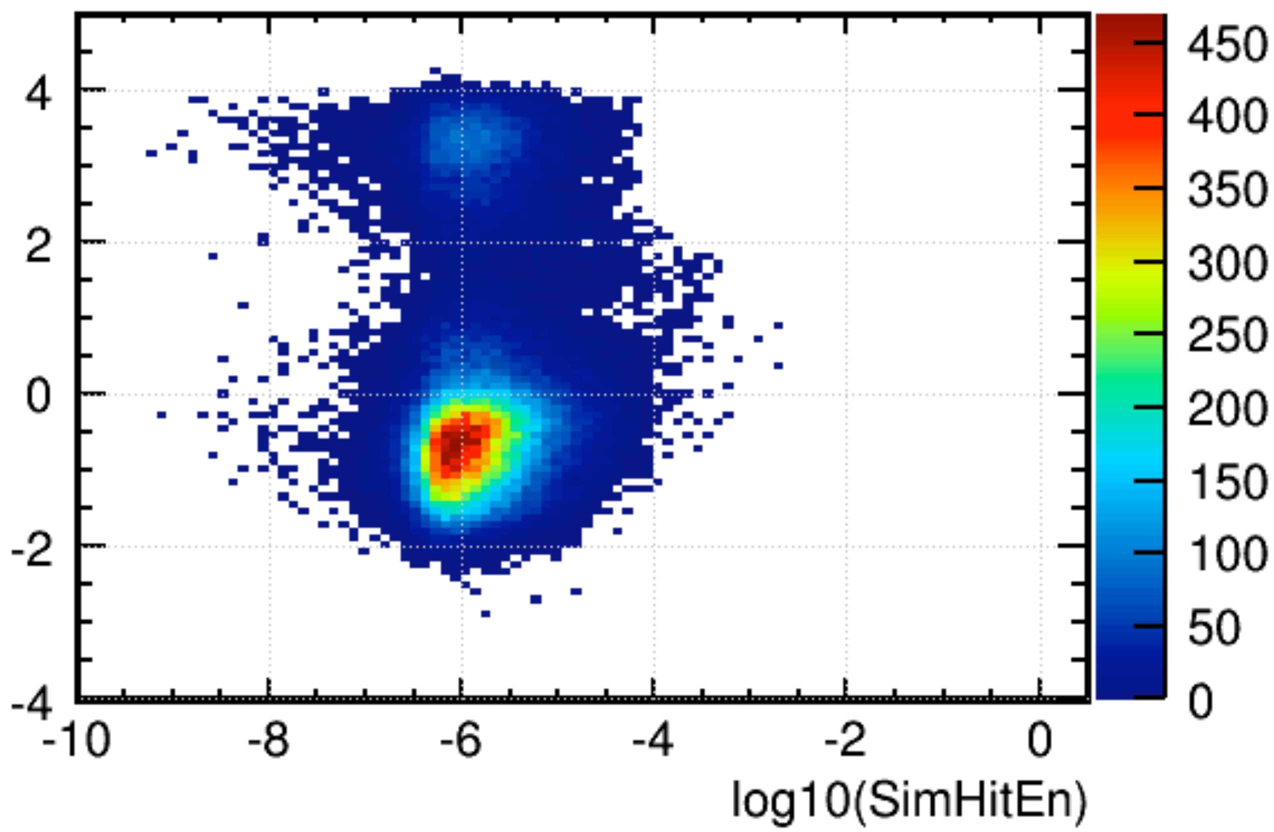
Model

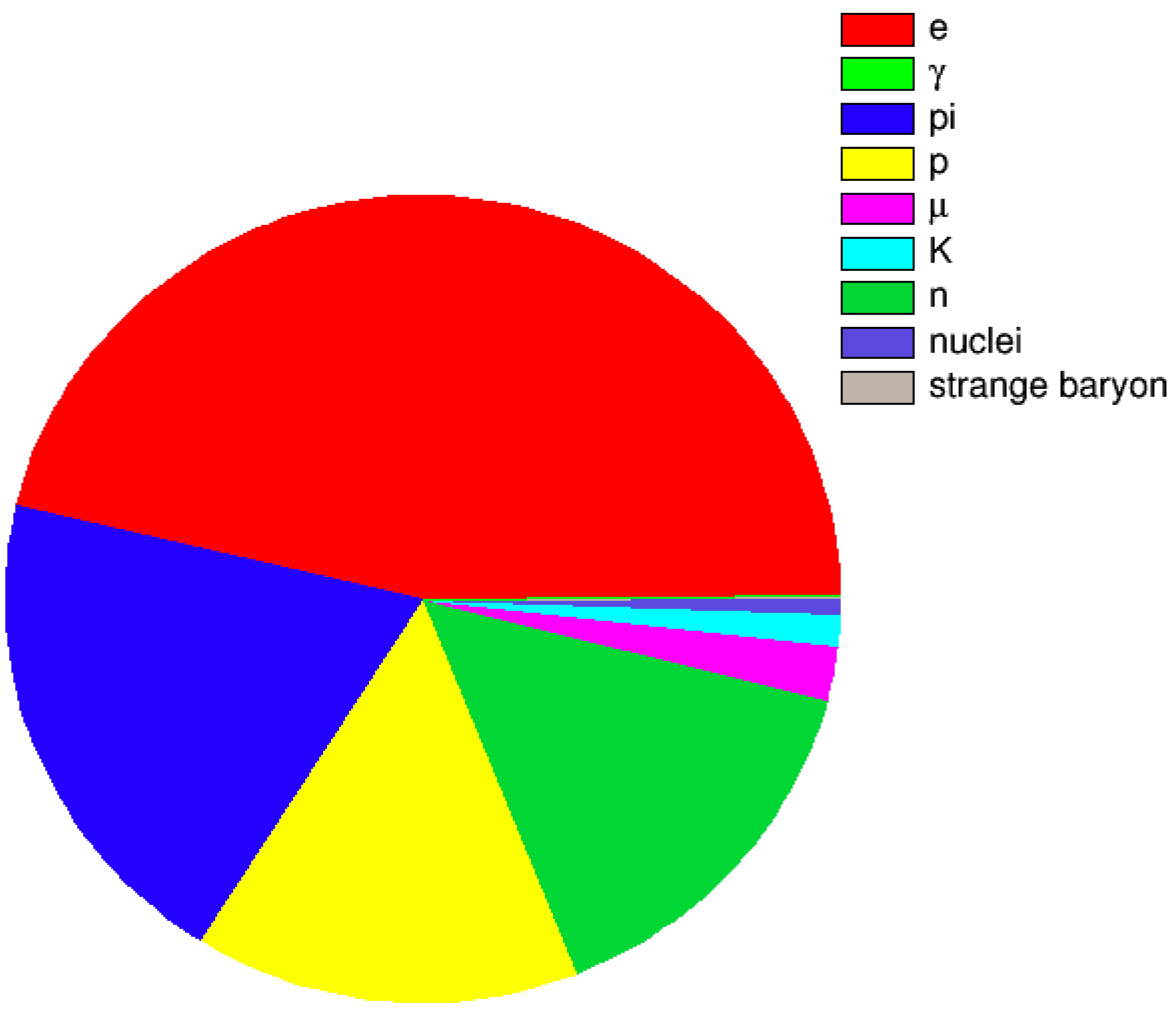
- Baseline: SDHCAL (GRPC, 1mm*1mm cell size)
- Scintillating Glass:
  - Sampling: 15mm Steel + 8mm Glass (40mm*40mm cell size)
  - Homogenous:
    - 23mm*40mm*40mm Glass I
    - 40mm*40mm*40mm Glass II

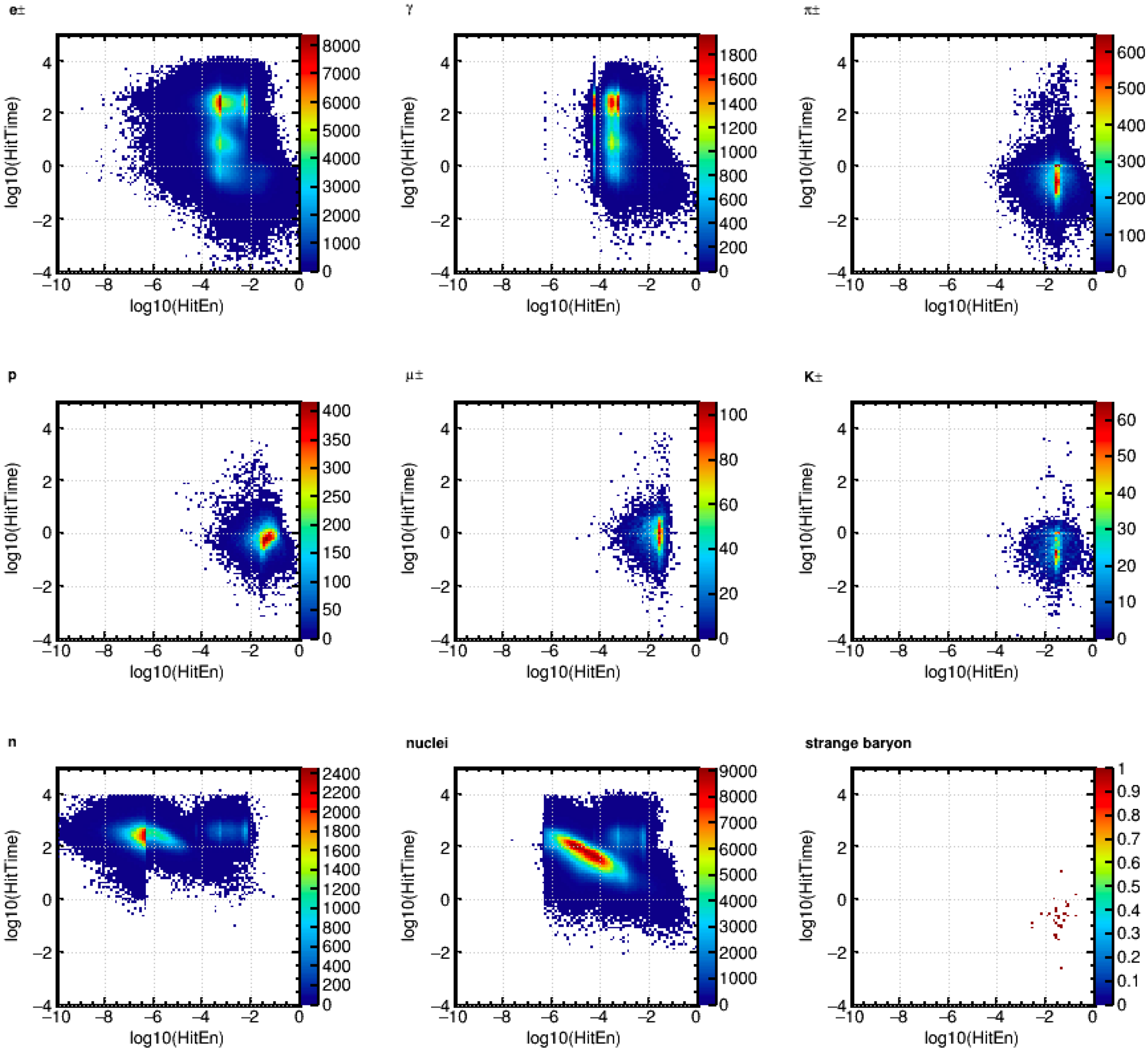
Summary

- Preliminary result shows that the BMR can be efficiently improved (3.8% → 3.4%) with homogenous scintillating glass
- Further improvement is expected with
  - Timing info: 10%
  - PFA optimization: 2-3%
  - software compensation: 2-3%
- The current HCal is rather large, possible to reduce the thickness?

Baseline Hit Profile






e±
γ
π±
p
μ±
K±
n
nuclei
strange baryon
log10(HitTime)
log10(HitEn)