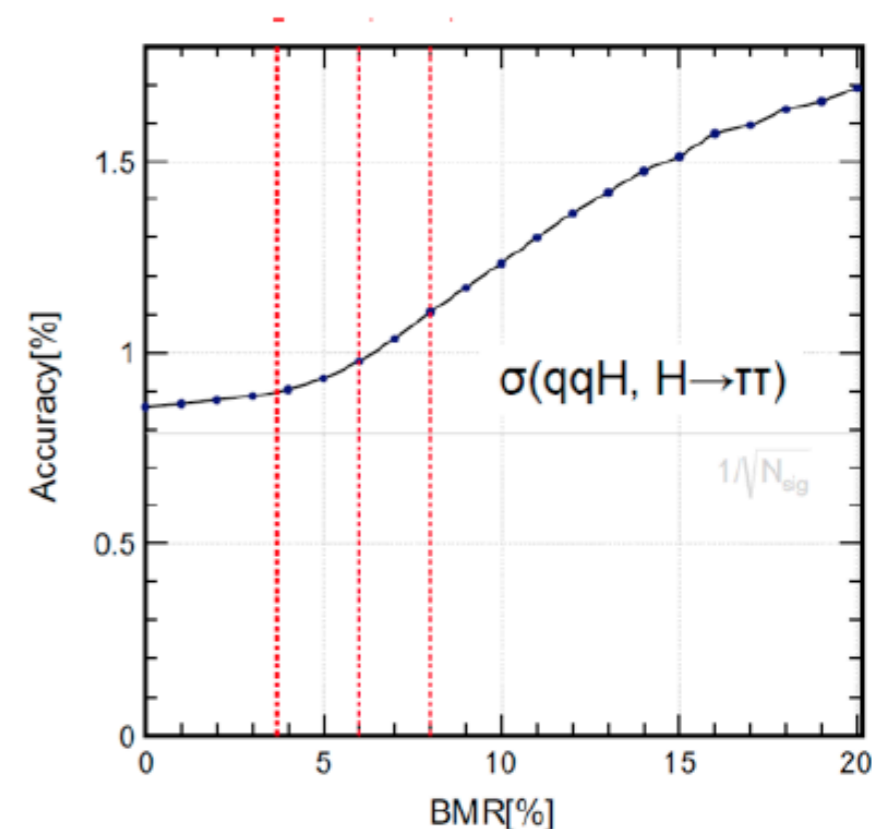
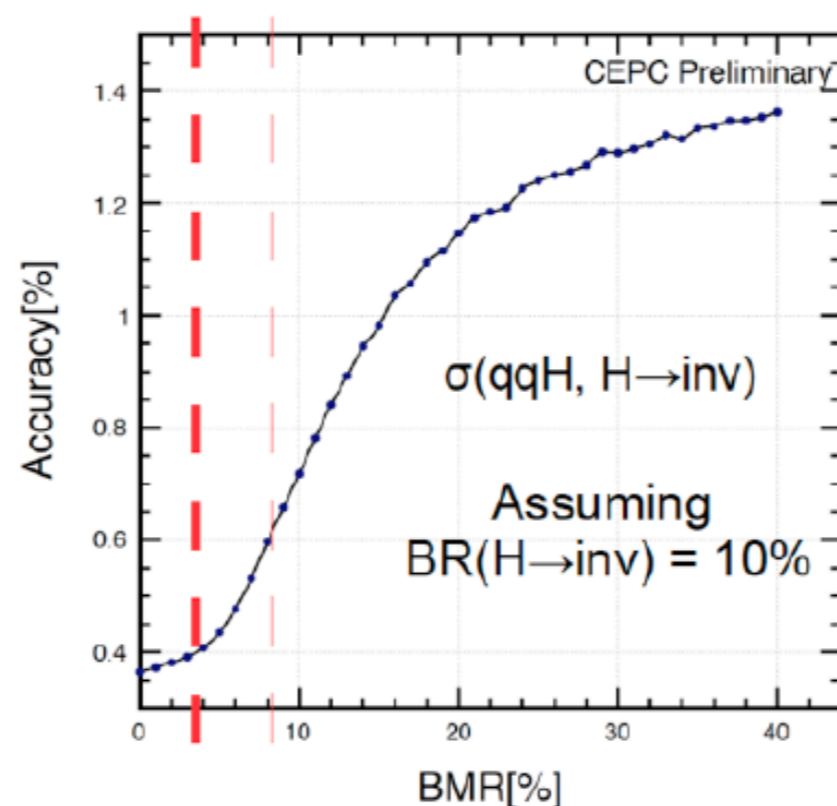
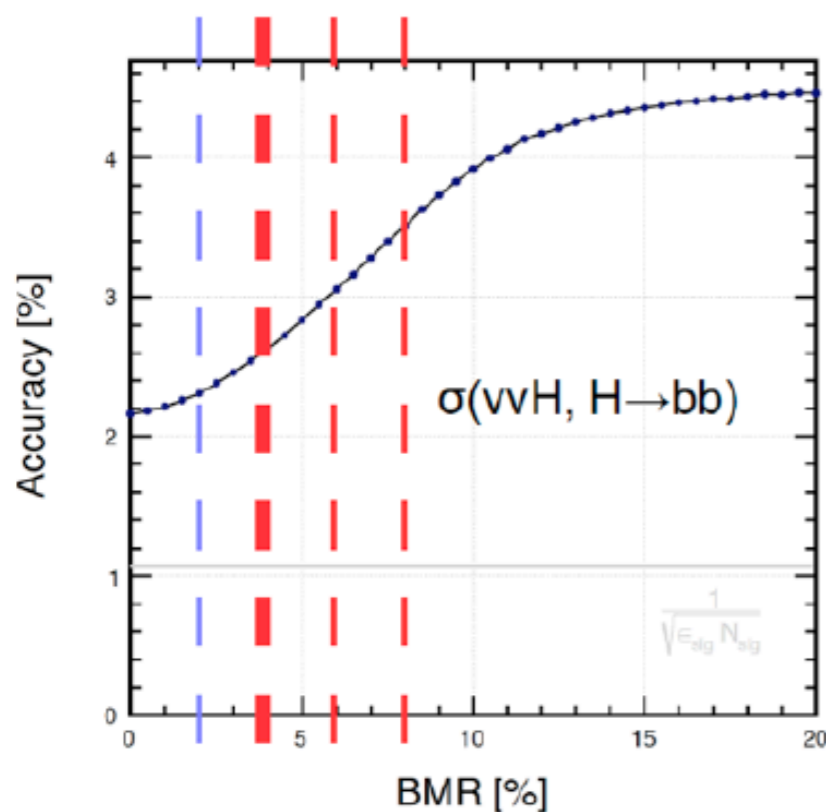

PRELIMINARY ANALYSIS & PROSPECT FOR GLASS HCAL PFA PERFORMANCE IN CEPC

TOC

- Motivation: Better boson mass resolution (BMR)!
- Full absorption Glass HCAL
 - BMR improves by at least 10%
 - Interpretation: Fast Sim prediction & Hit profile comparison
- Variations: BMR at different
 - Thickness & cell geometry - readout channels;
 - Glass density
 - Physics list
- Prospects:
 - Different Hit selection & clustering algorithms
 - Fragmentation veto
 - Realistic digitization (homogeneity, noise level, ...)

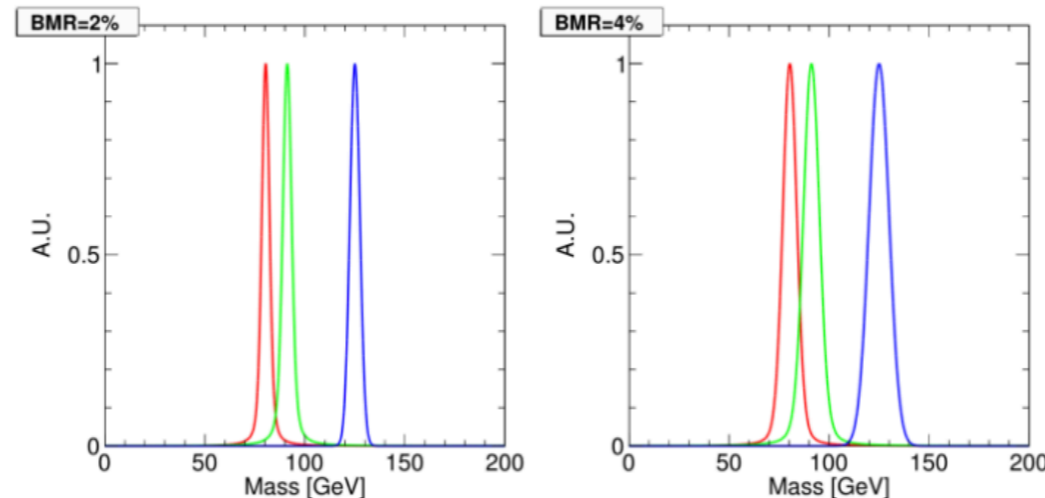
MOTIVATION

- BMR: boson mass resolution, for W/Z/H separation
- In CDR, BMR achieved 3.8% for baseline detector
- Requirement in Higgs Physics: 4% BMR



For NP or Flavor: better is better

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

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

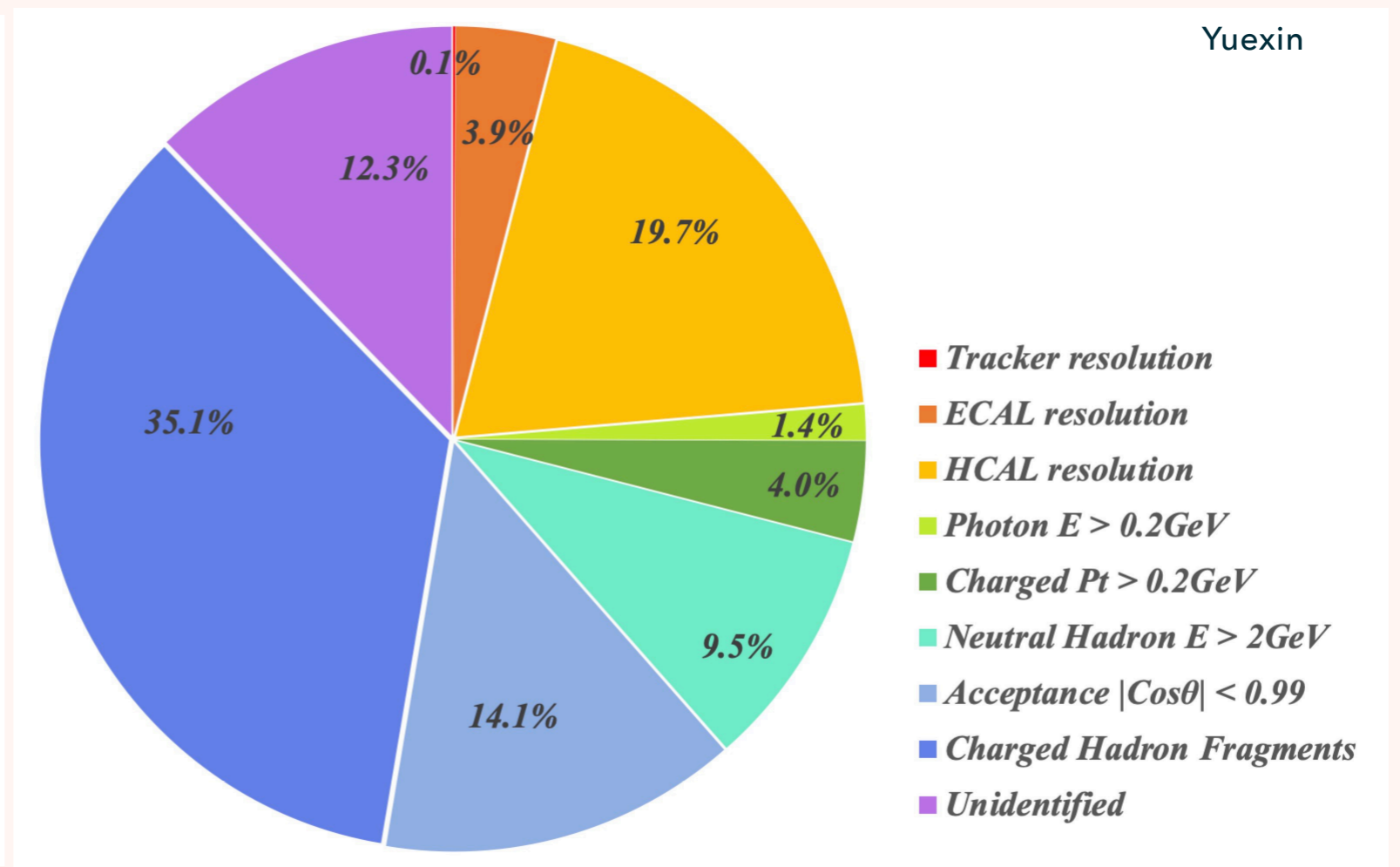
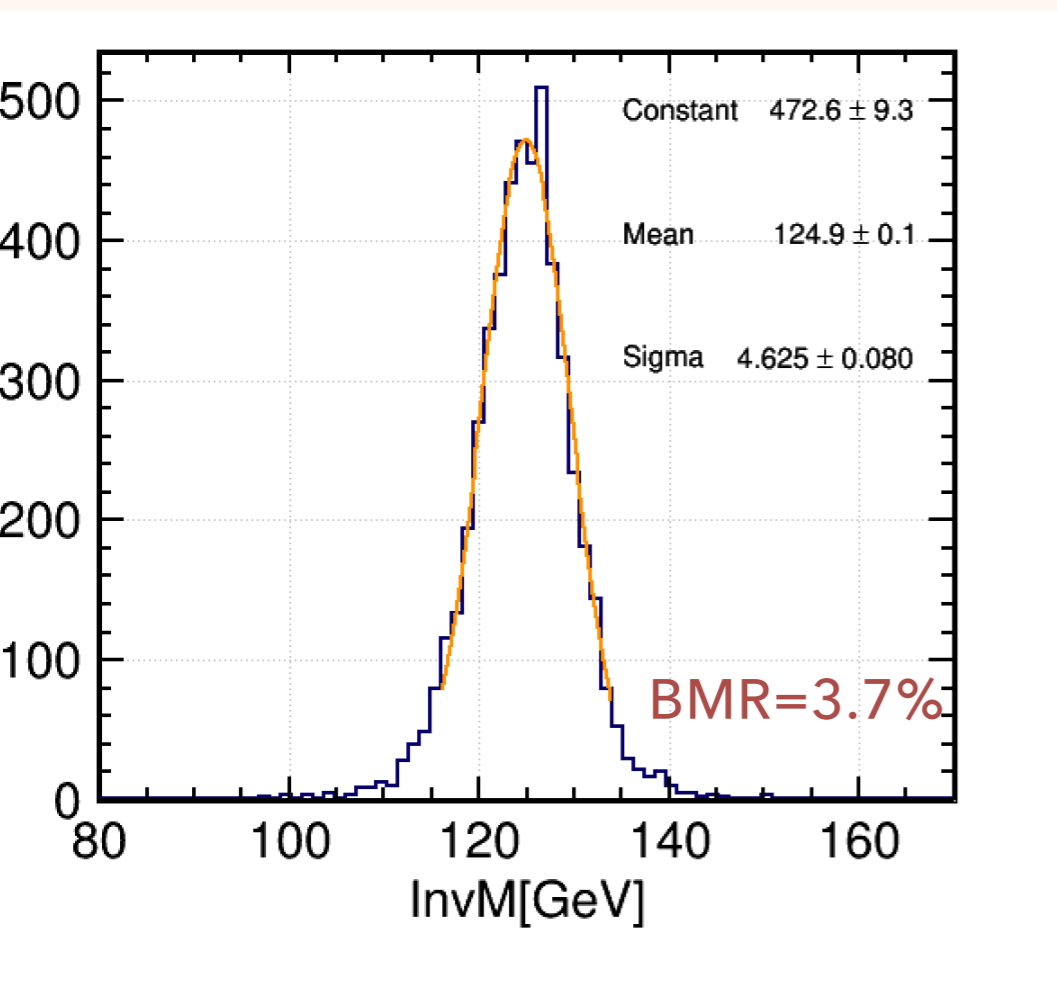
⇒ Test if the “Higgs signal” stems from a continuum.

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!

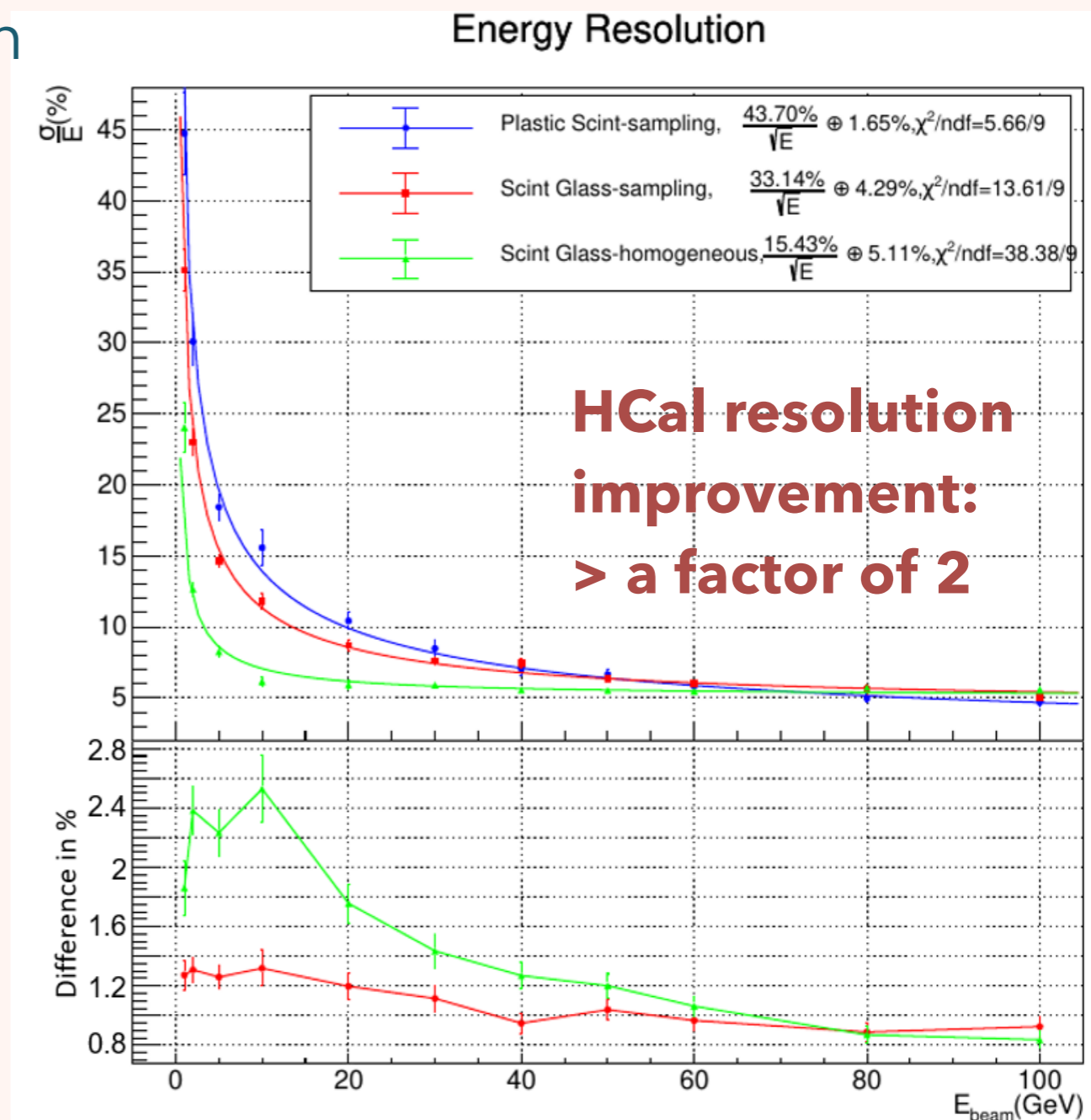
WHERE TO IMPROVE

- BMR variations predicted by Fast simulation
- BMR can improve 10% if HCal resolution improves 2 times



WHY SCINTILLATING GLASS?

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



by Dejing

SCINTILLATING GLASS HCAL

➤ Pros: cost effective, moderate light yield, tunable compositions

➤ Cons: quality/uniformity, radiation hardness

➤ Transparent options:

➤ Glass I:

➤ $42SiO_2 - 5Al_2O_3 - 22BaF_2 - 9NaF - 3CaF_2 - 3Gd_2O_3 - 9GdF_3 - 7TbF_3$

➤ density = 4.2 g/cm³

➤ Glass II:

Main option in this talk

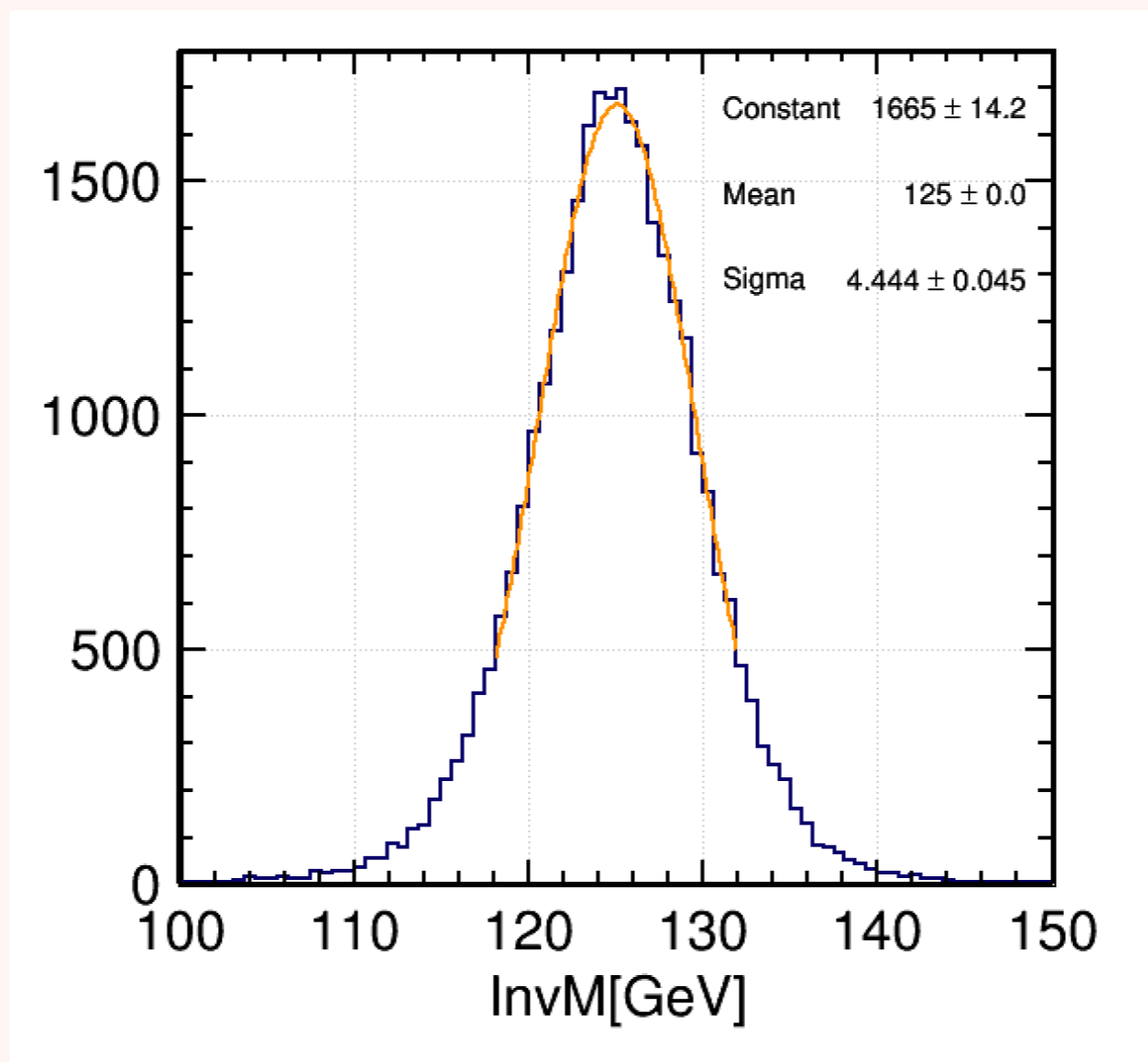
➤ $25SiO_2 - 30B_2O_3 - 10Al_2O_3 - 34Gd_2O_3: 1Ce+$

➤ density = 4.94 g/cm³

➤ 40mm*40mm*40mm cube, 30 layers (Total thickness 1.2m, volume ~ 180m³, 3M channels)

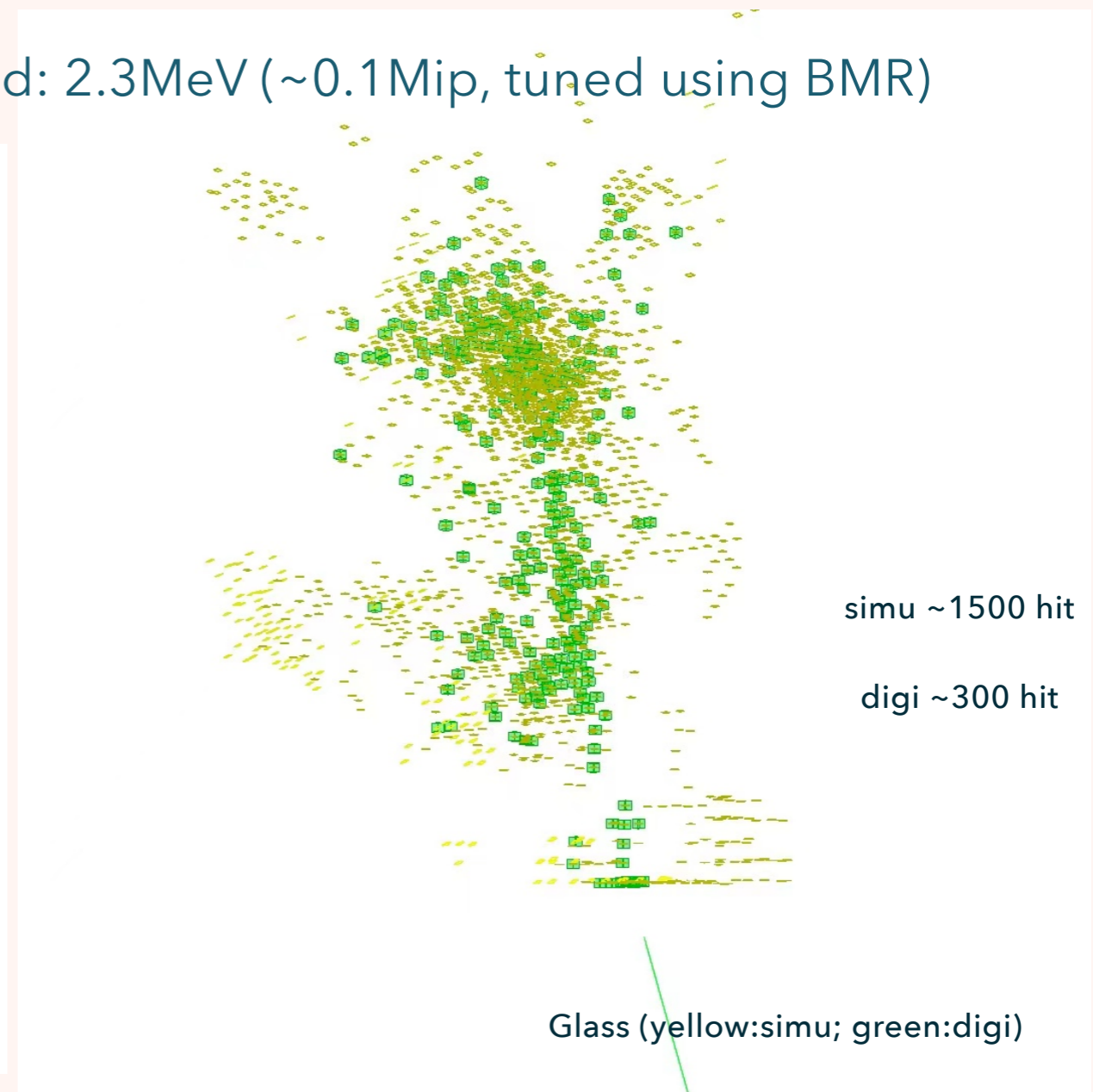
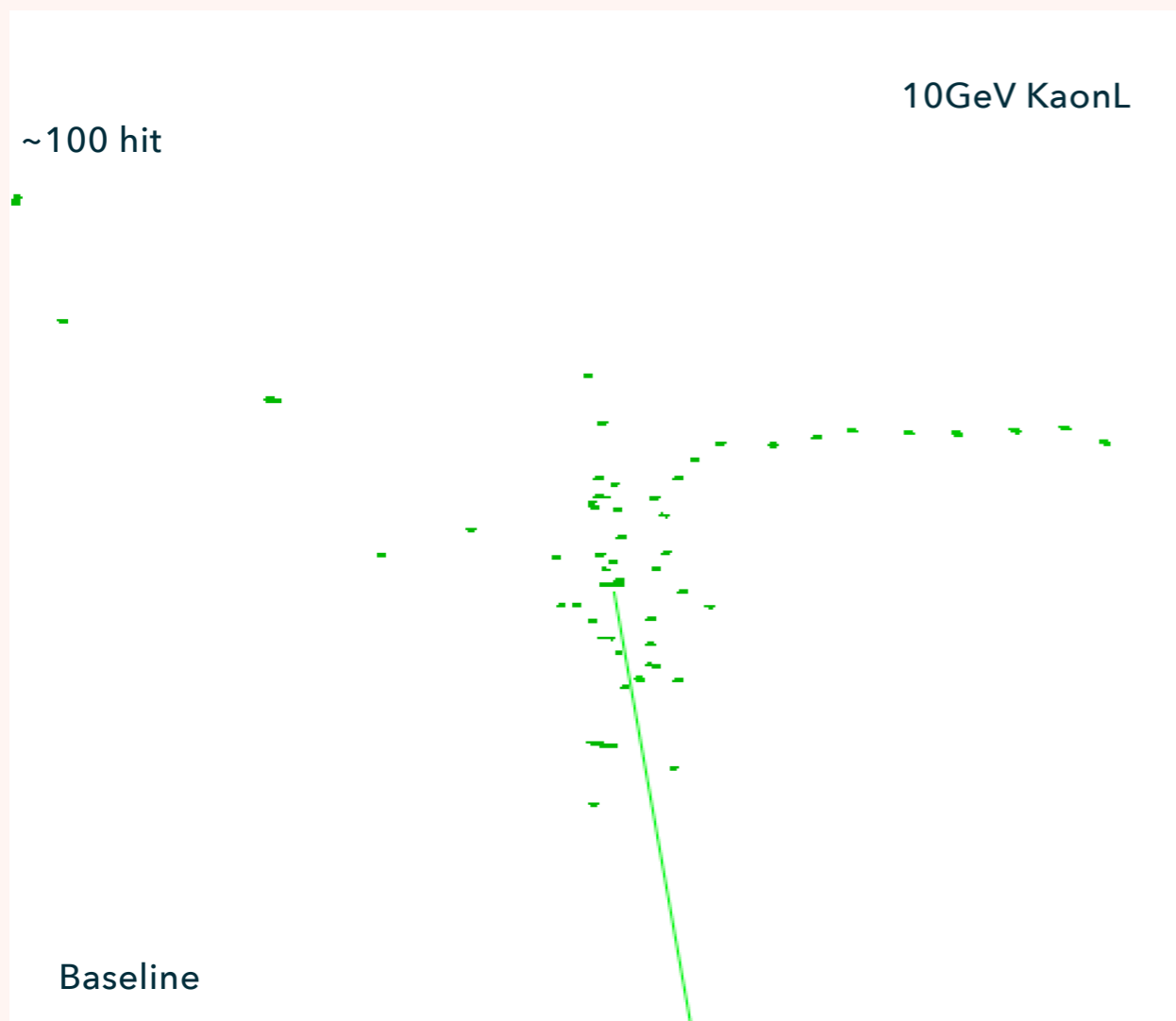
HOW GOOD WE GET

- The BMR with homogenous glass hcal $\sim 3.5\%$: 10% improvement w.r.t. Baseline (3.8%), through Baseline Arbor with hit energy threshold cut and calibration tuning



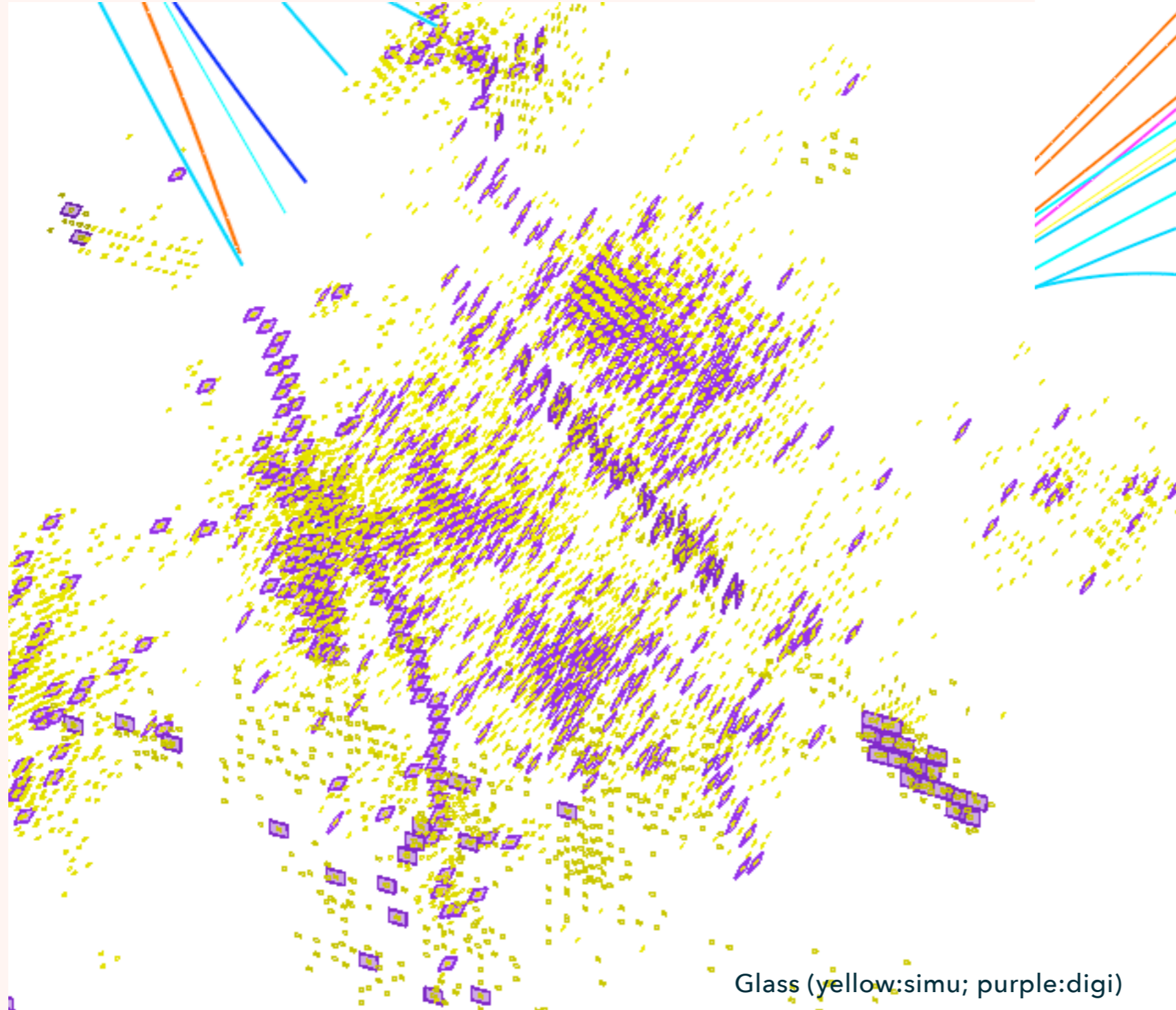
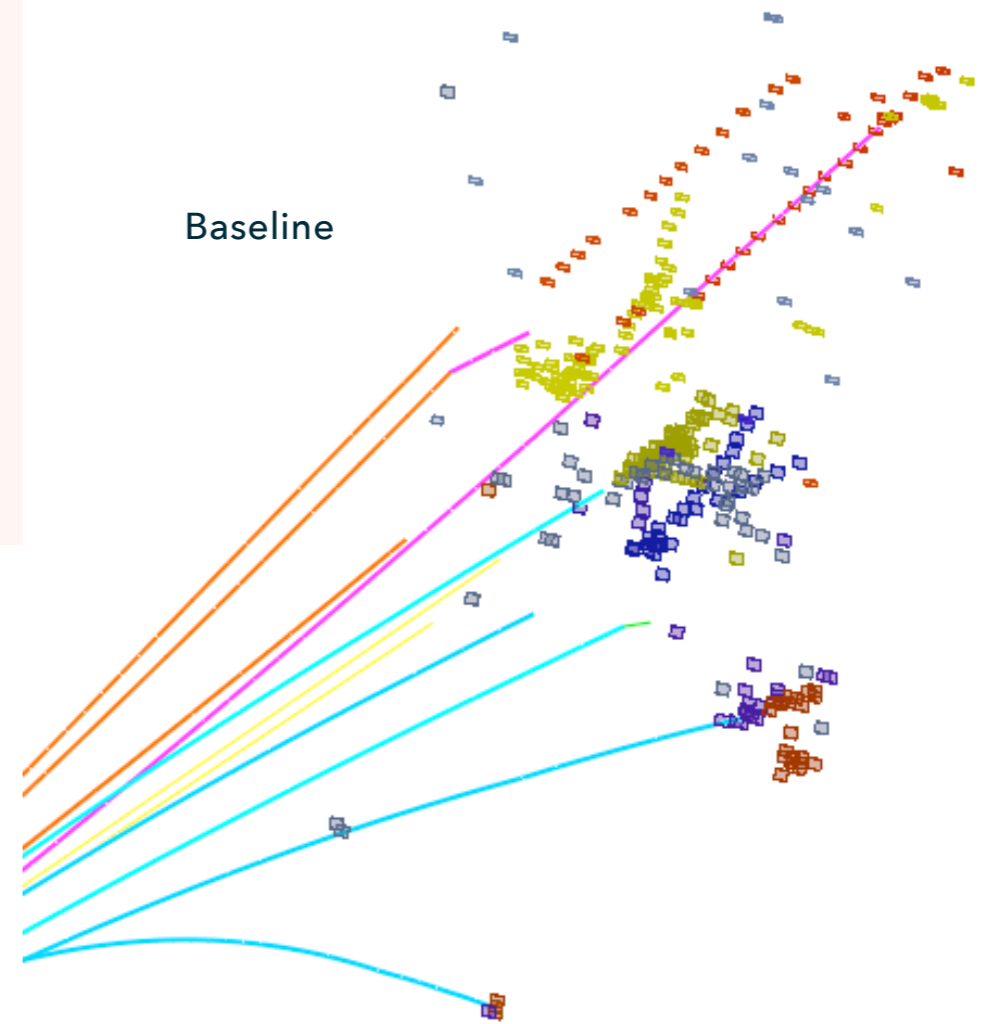
HIT PROFILE COMPARISON

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



HIT PROFILE COMPARISON

Baseline



Glass (yellow:simu; purple:digi)

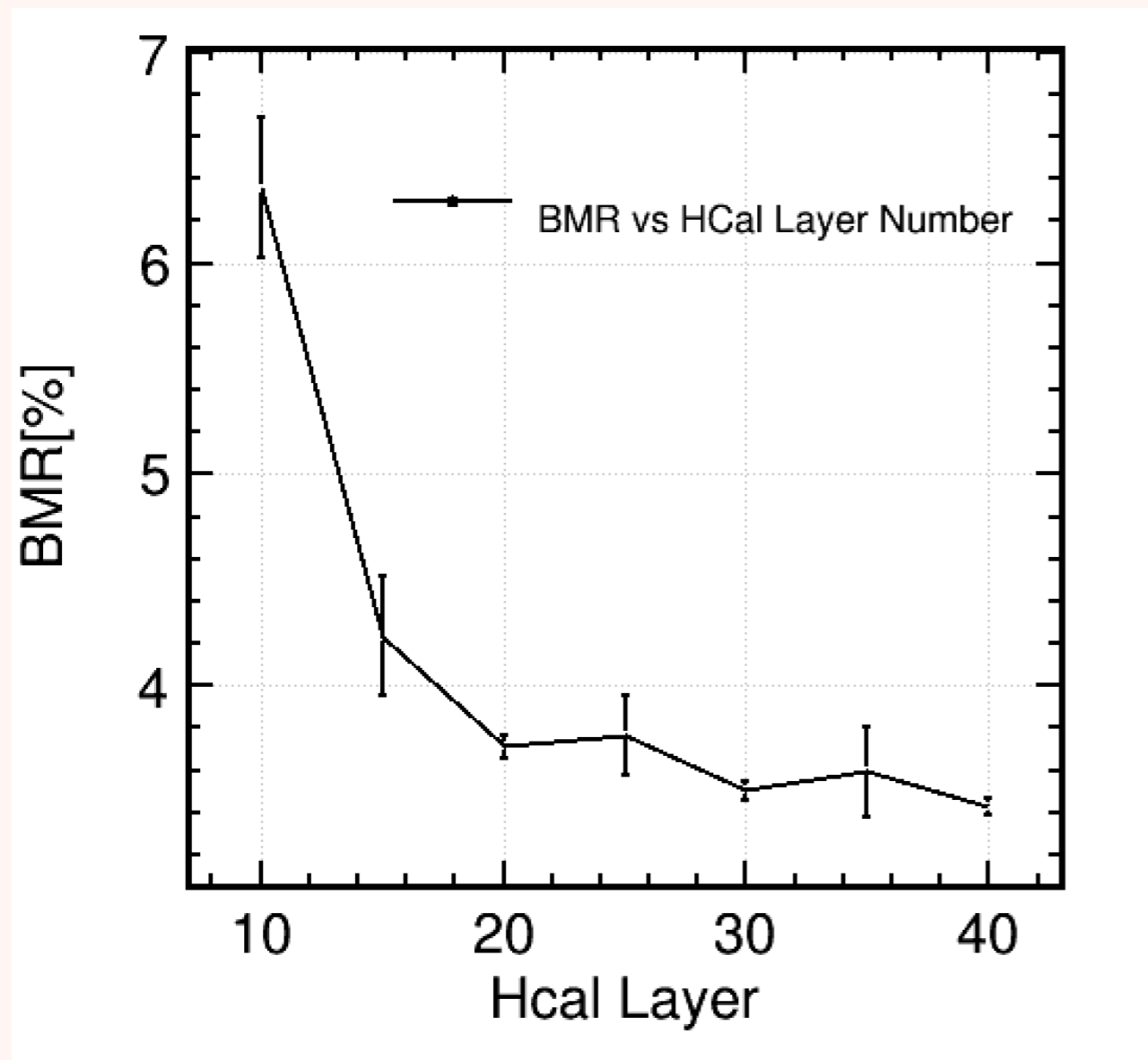
VARIATION

BMR at different

- **Thickness & cell geometry - readout channels**
 - **Glass density**
 - **Physics list**
-

TOTAL THICKNESS DEPENDENCE

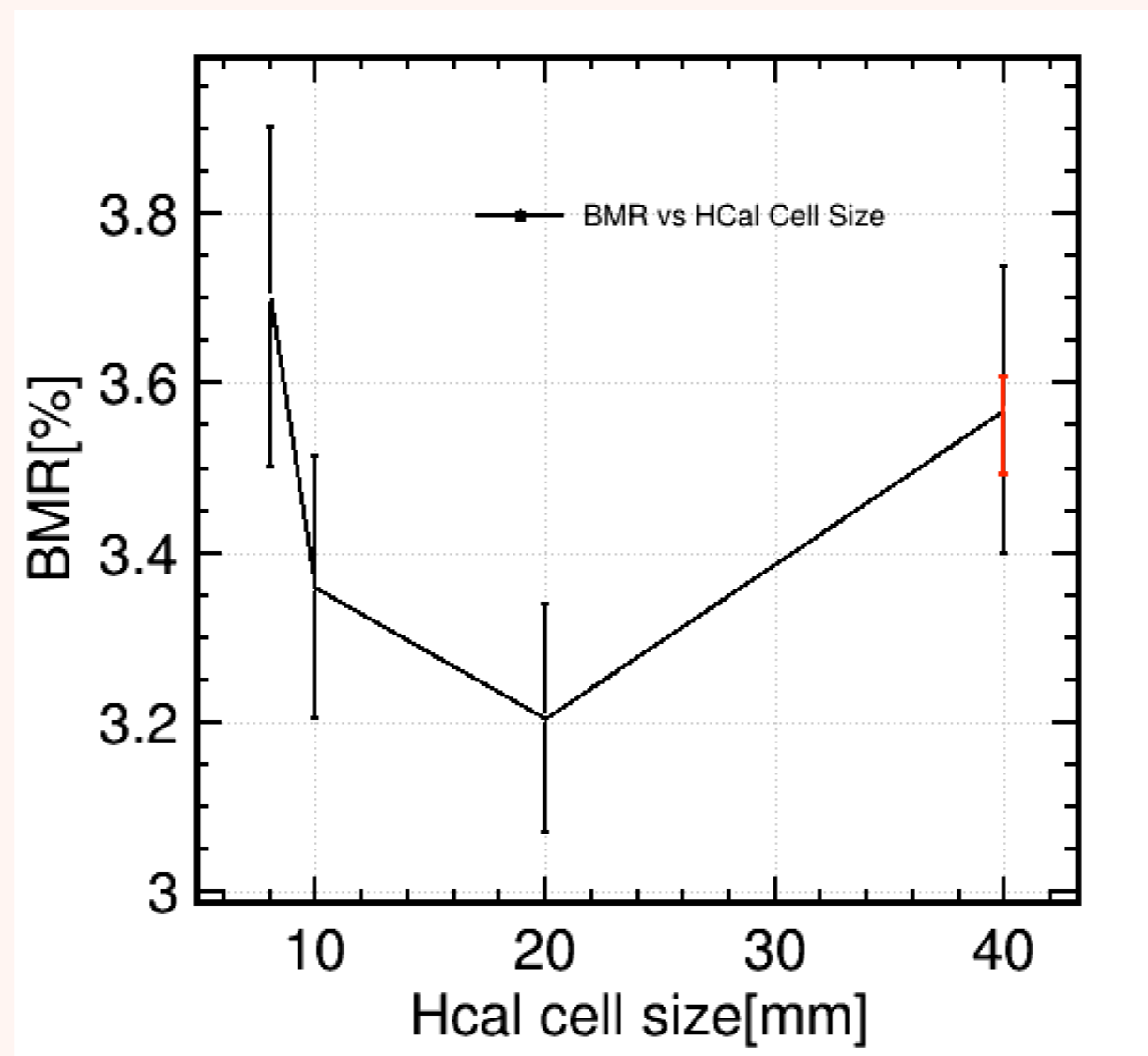
- Layer number changed while thickness of each layer unchanged



N Layer	Channel	N RadL	BMR(%)
40	4.6M	5.8 λ	3.4
30	3M	4.4 λ	3.5
20	1.6M	2.9 λ	3.7
10	0.7M	1.5 λ	6.3

CELL SIZE DEPENDENCE

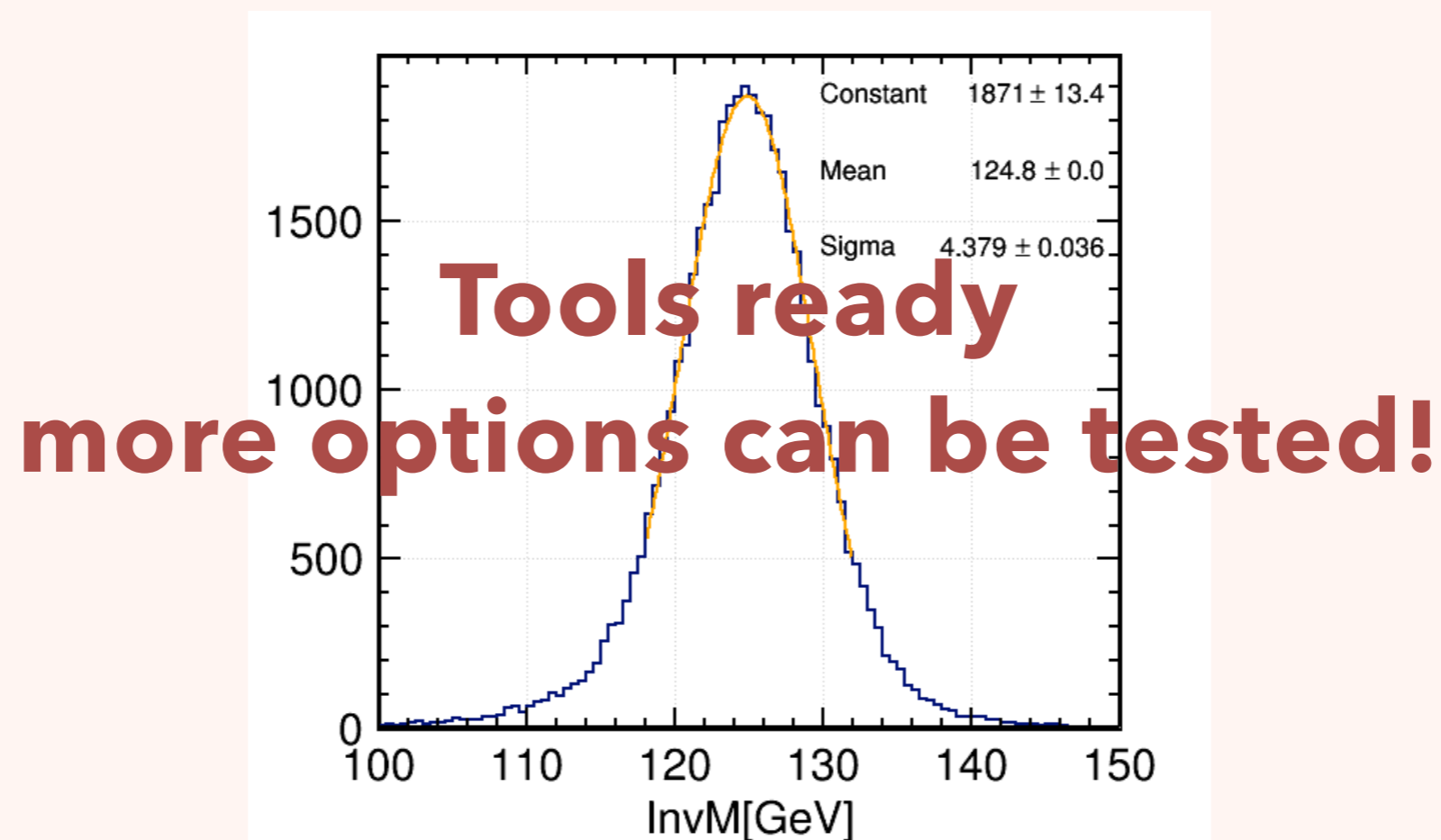
- Transverse cell size scanning: use 1mm*1mm cell to merge larger cells
- Algorithm development needed (for small sizes)



ALTERNATIVE OPTION

thickness(mm)	density(g/m3)	N Layer	BMR(%)
23	4.2	40	3.4
40	4.9	40	3.4

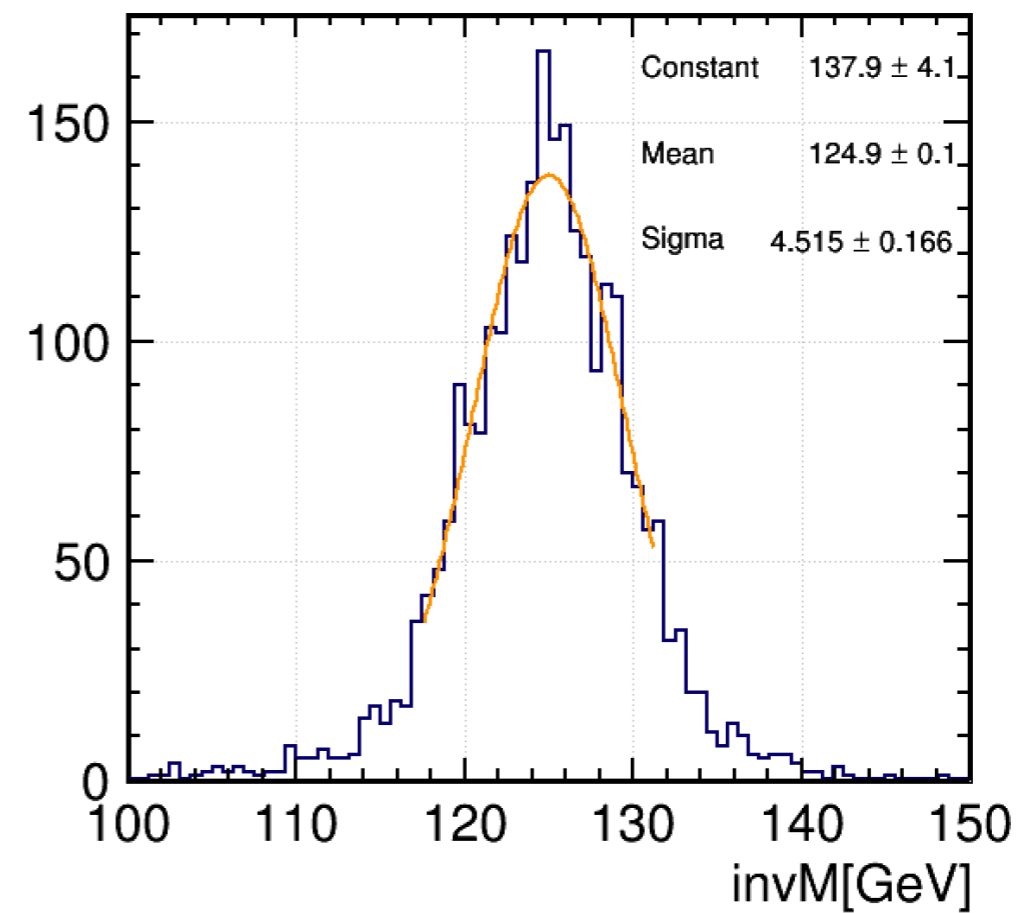
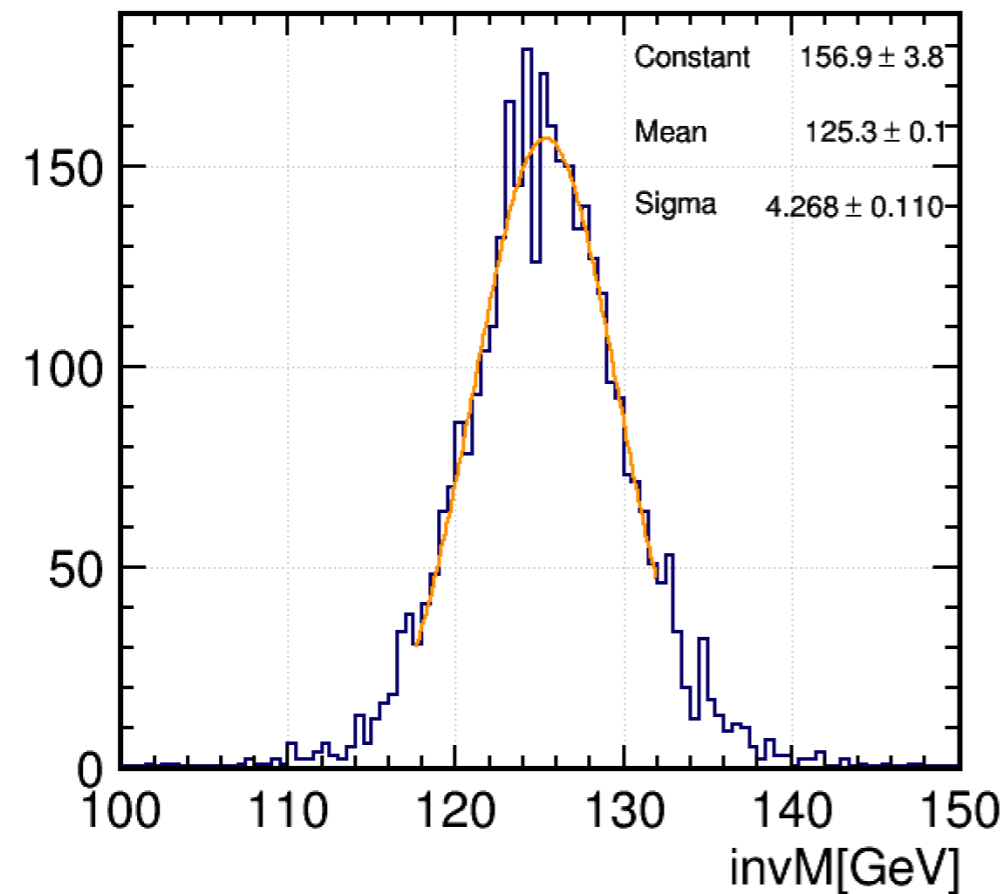
no significant dependency



$42\text{SiO}_2-5\text{Al}_2\text{O}_3-22\text{BaF}_2-9\text{NaF}-3\text{CaF}_2-3\text{Gd}_2\text{O}_3-9\text{GdF}_3-7\text{TbF}_3$

READOUT DEPENDANCE

PCB	Cu Thickness(mm)	Layer	BMR(%)
0.1	0.1	40	3.4
2	0.1	40	3.4
2	2	40	3.6



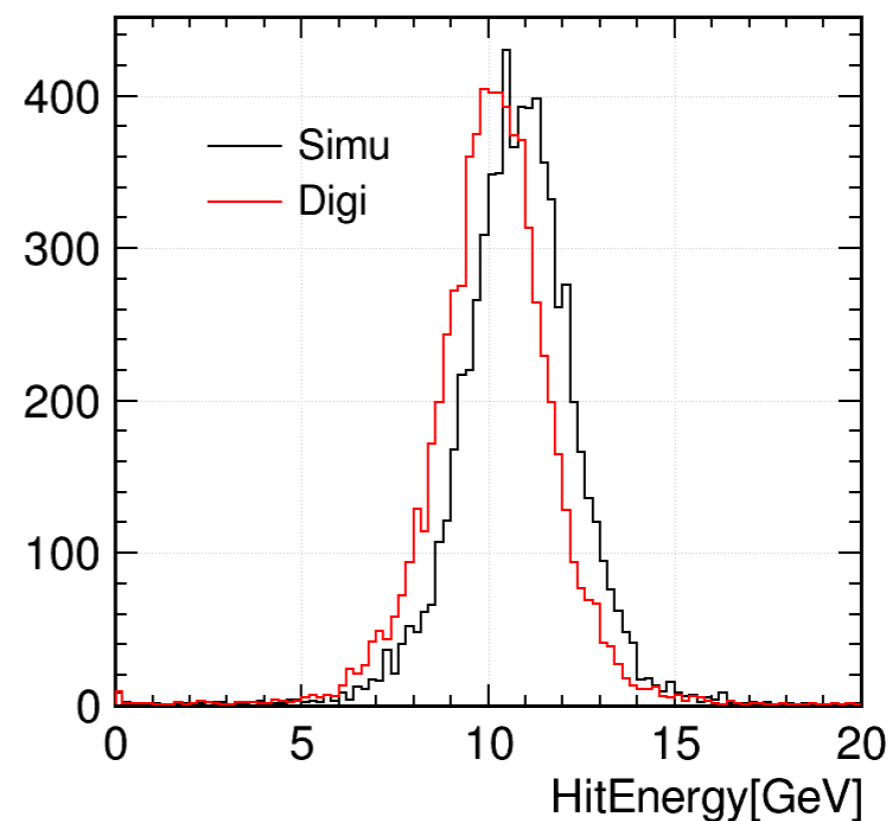
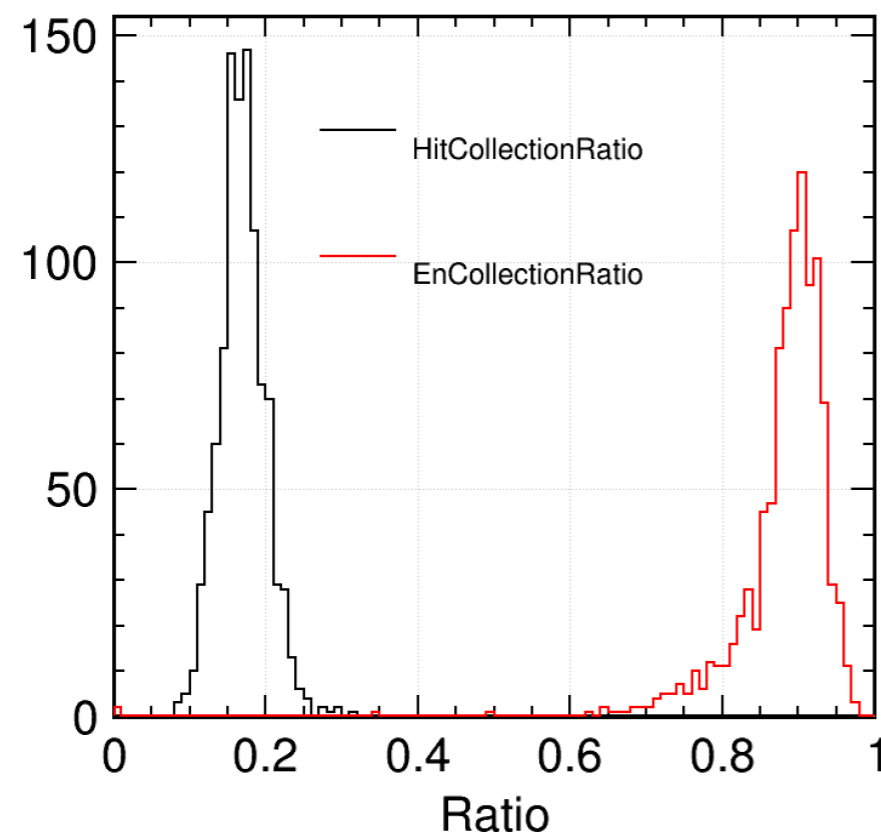
PROSPECT

- 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

AIM: BMR ~ 3.0%

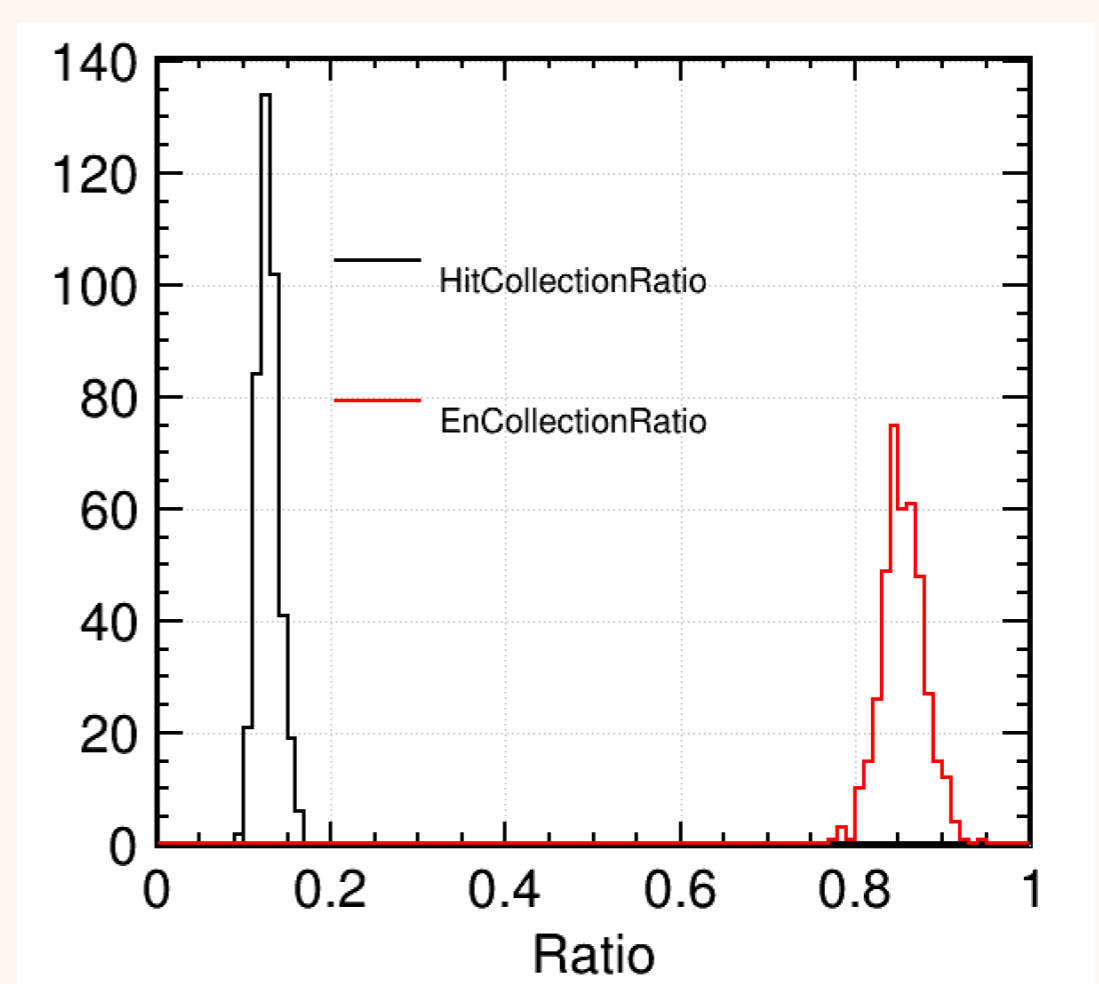
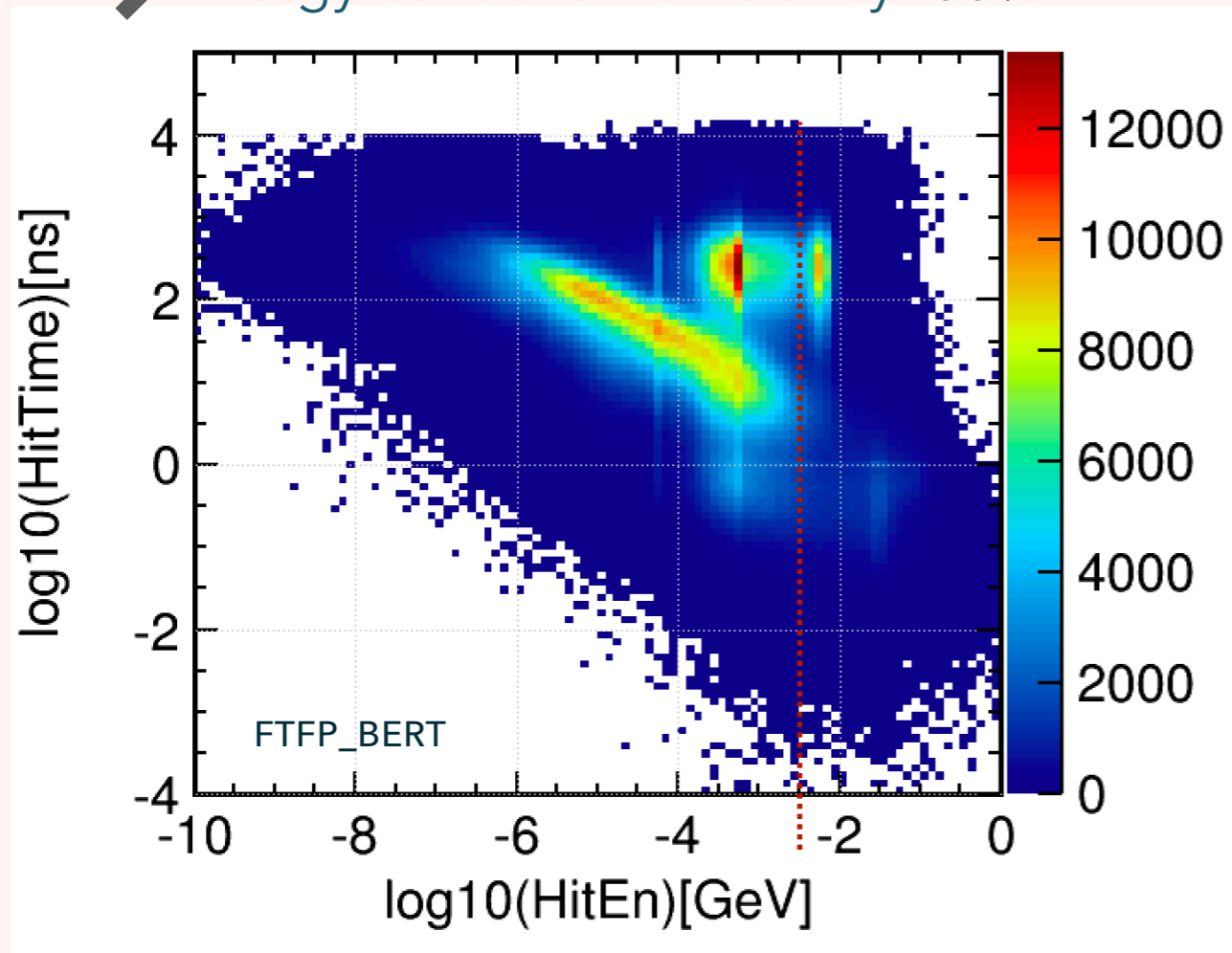
HIT & CLUSTERING

- Digi threshold: 2.3MeV (~ 0.1 Mip)
 - Hit collection efficiency $\sim 20\%$
 - Energy collection efficiency $\sim 90\%$
- PFO resolution for 10GeV kaon can improve 8% if all hits energy are used
 - with similar strategy used in crystal Ecal, i.e., hit absorption after clustering



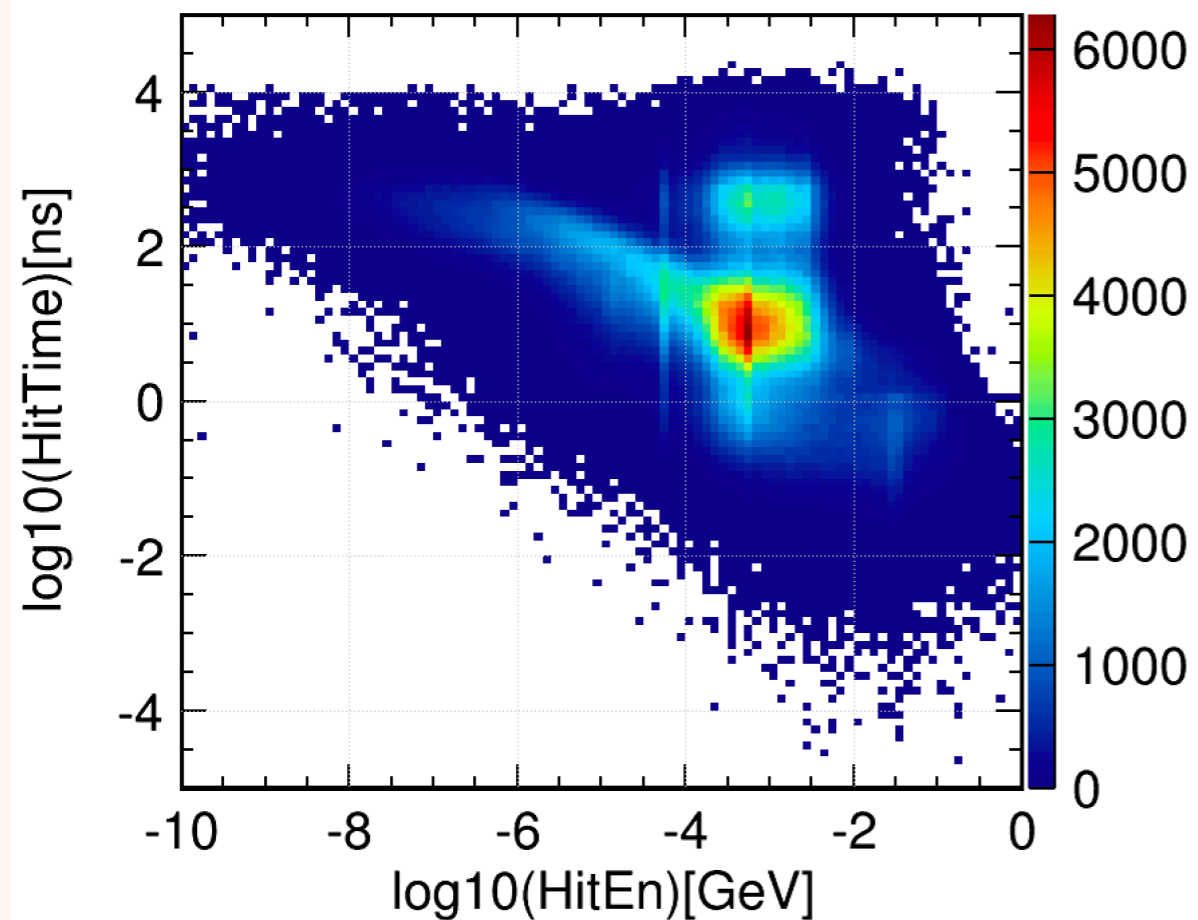
HIT PROFILE

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

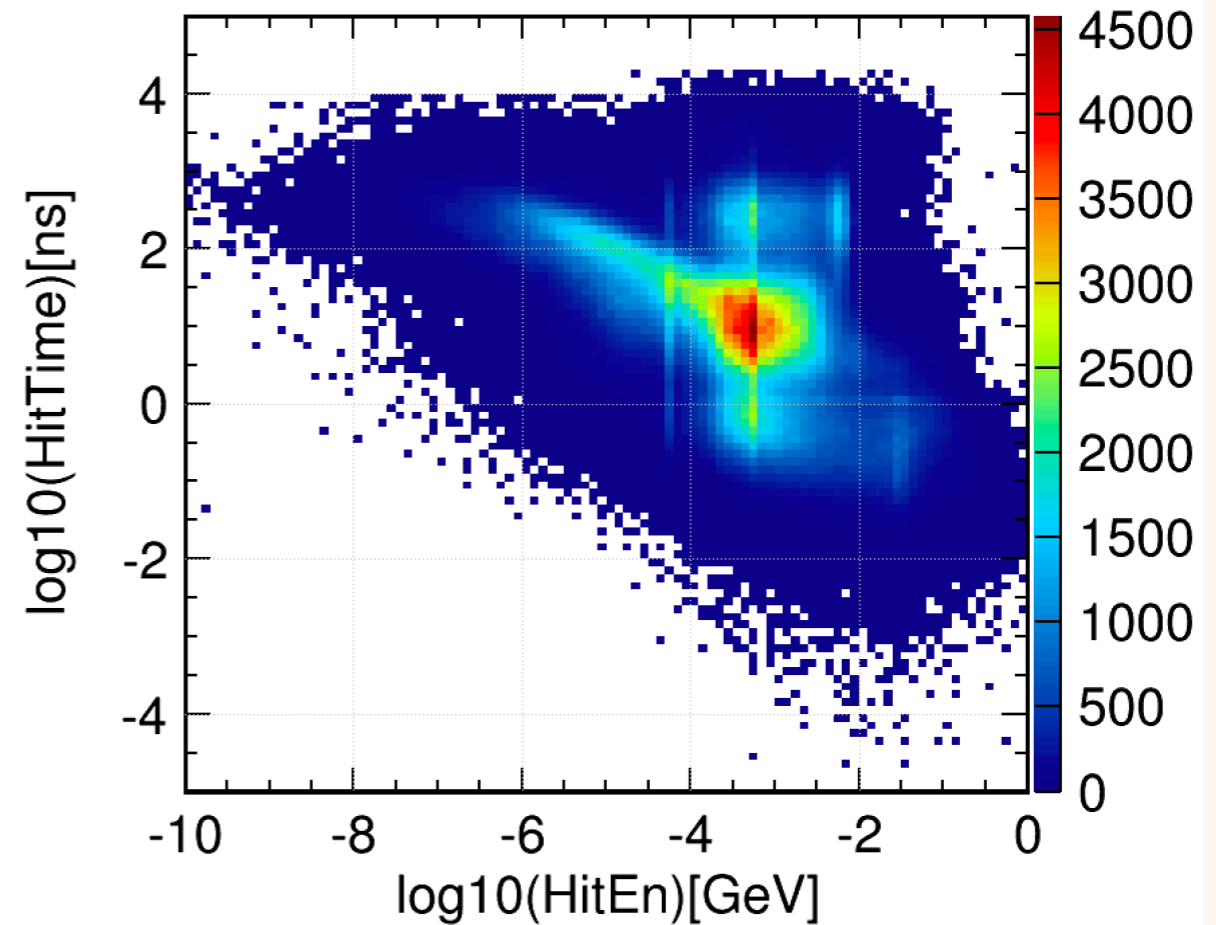


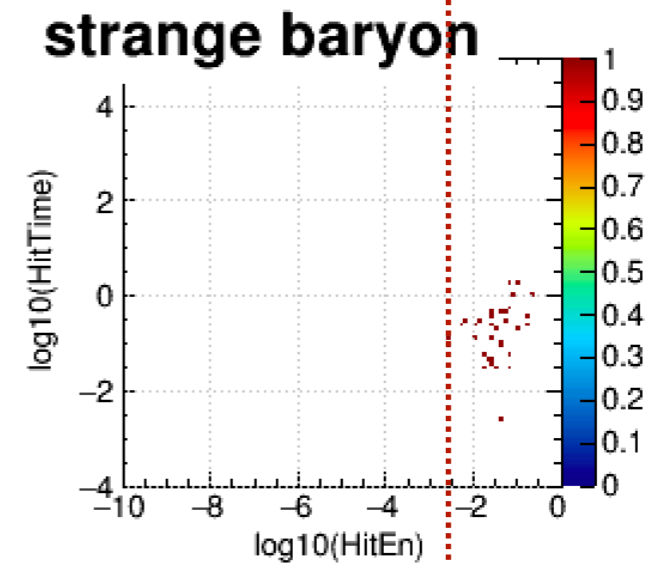
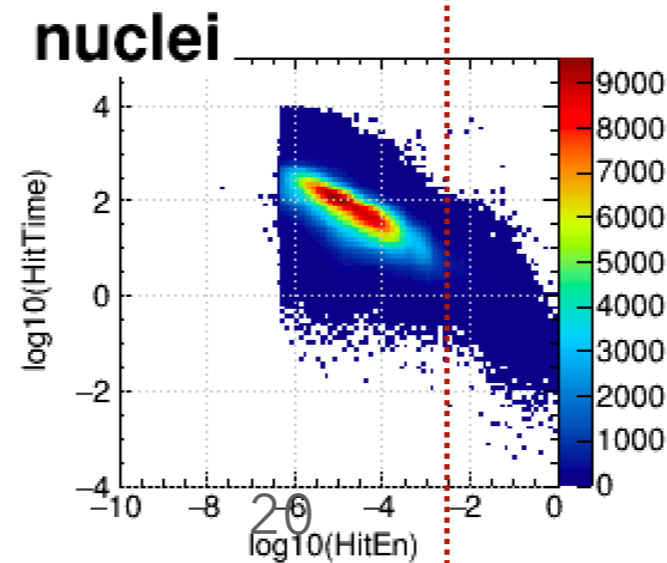
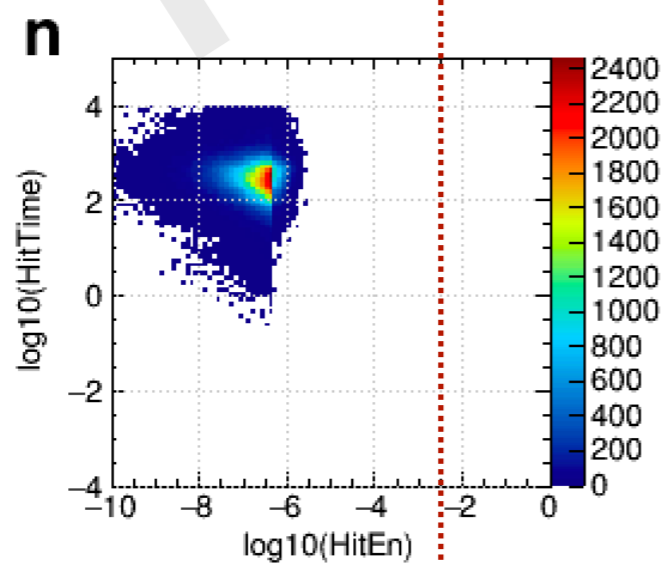
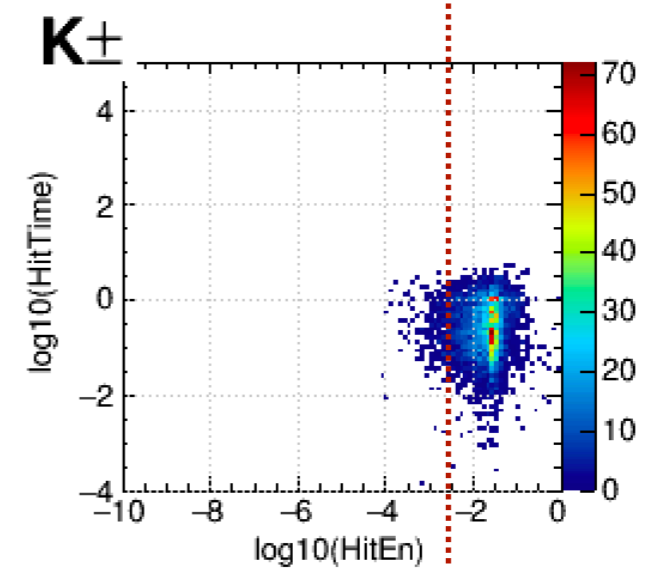
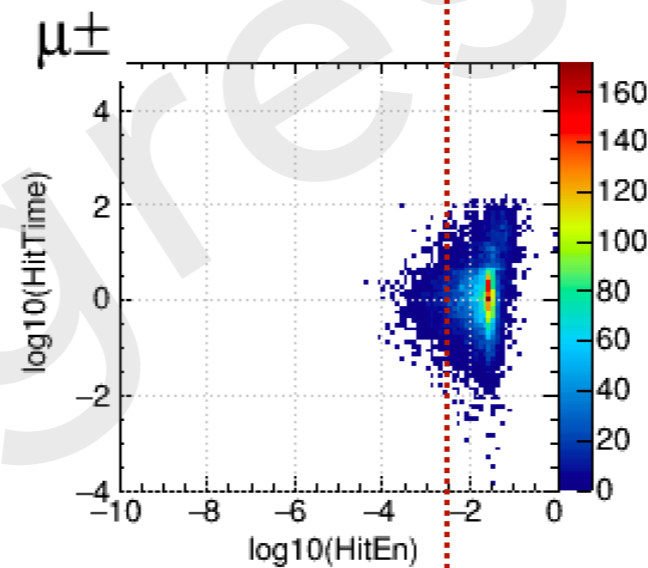
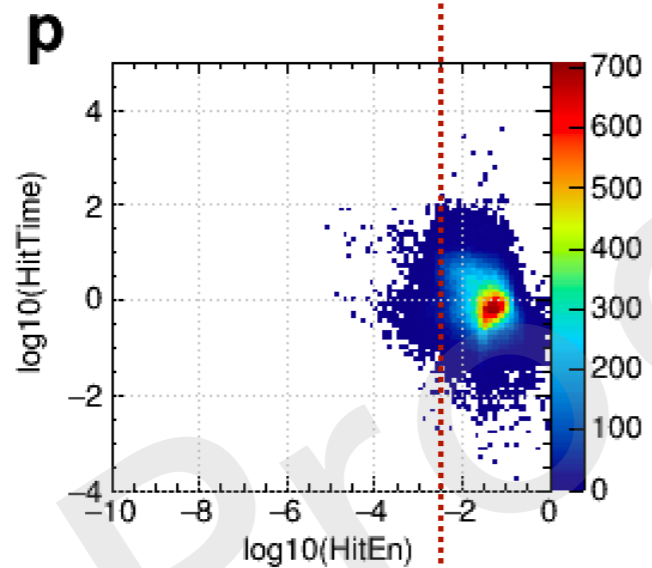
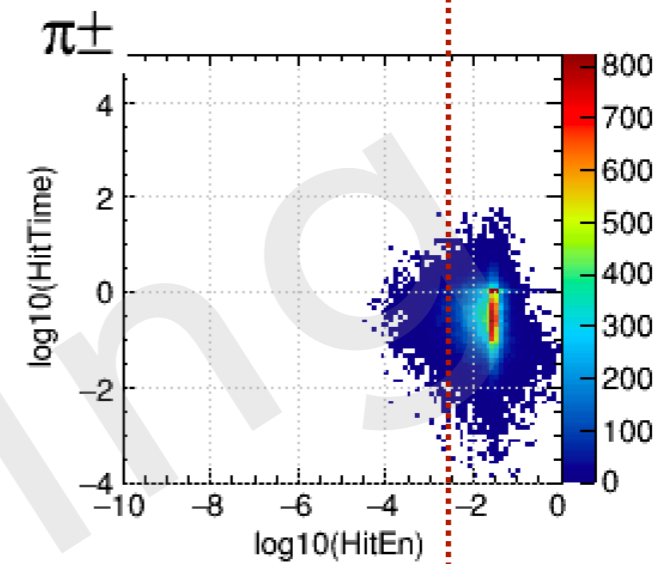
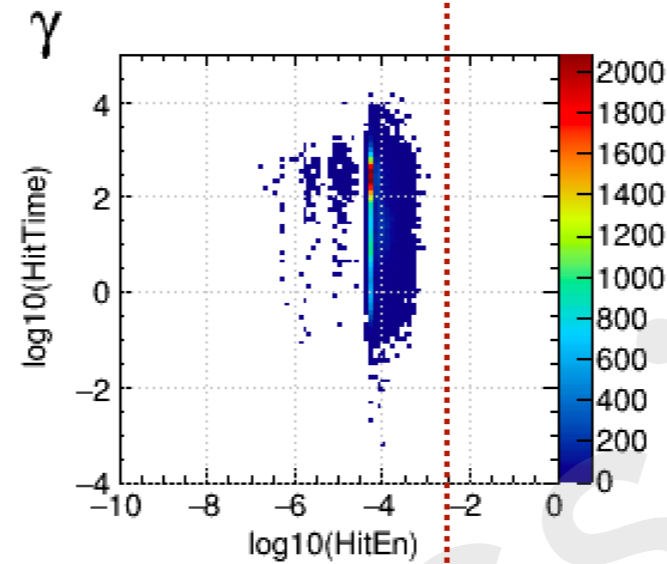
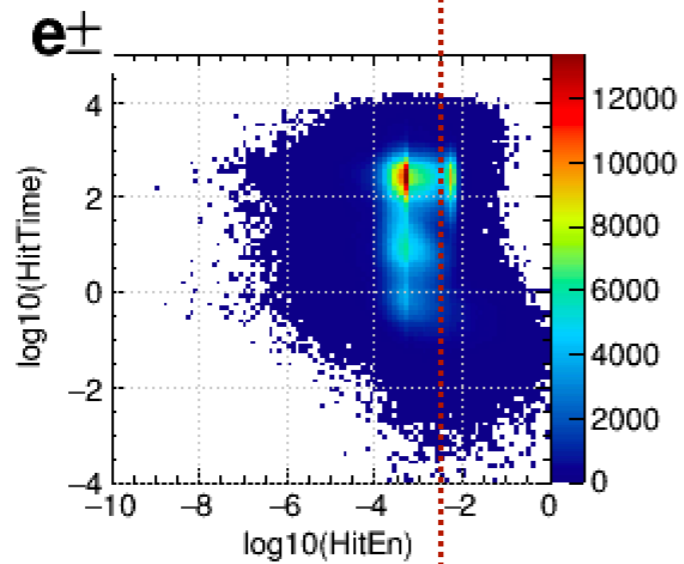
PHYSICS LIST

QBBC



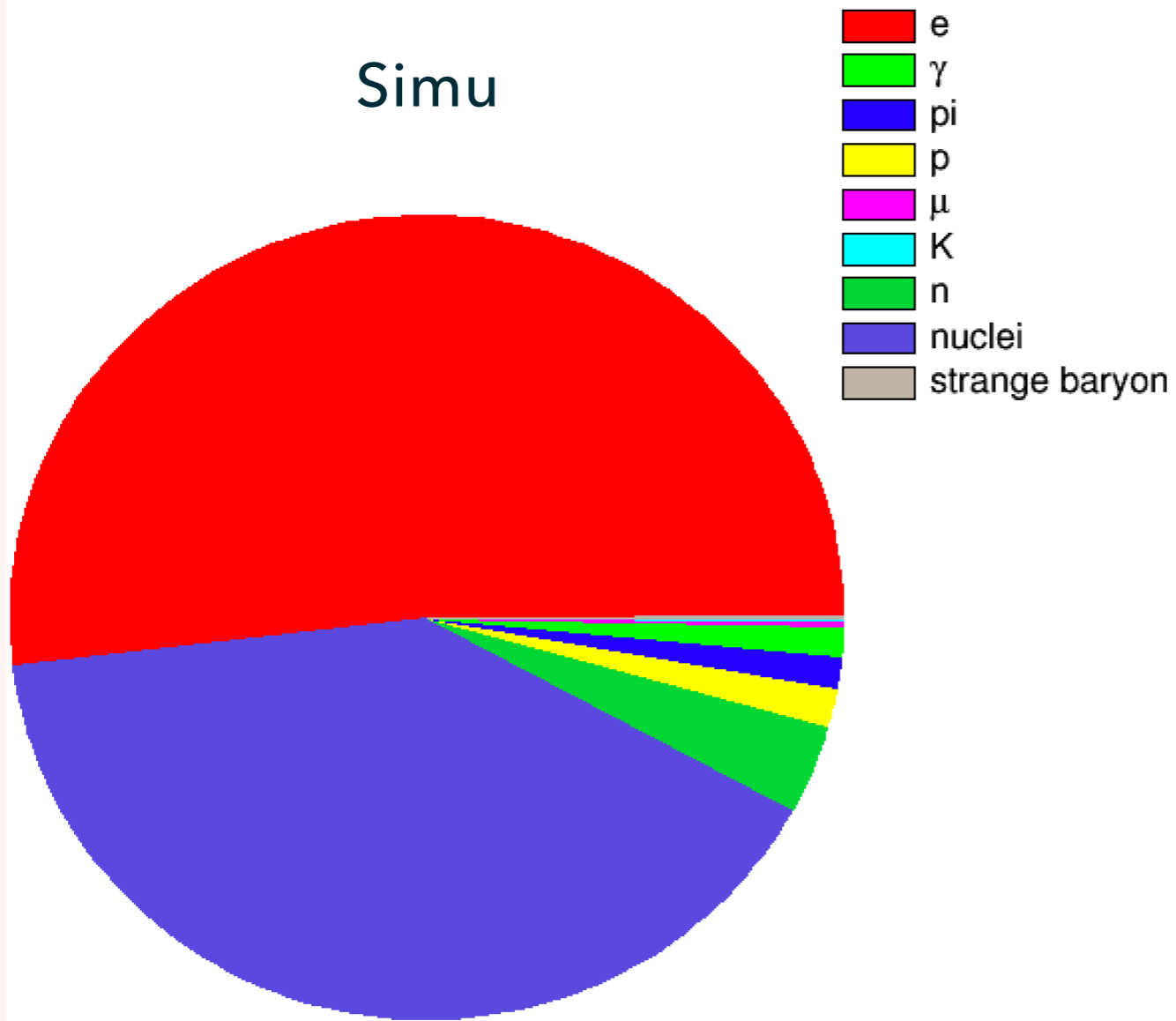
QGSP_BIC



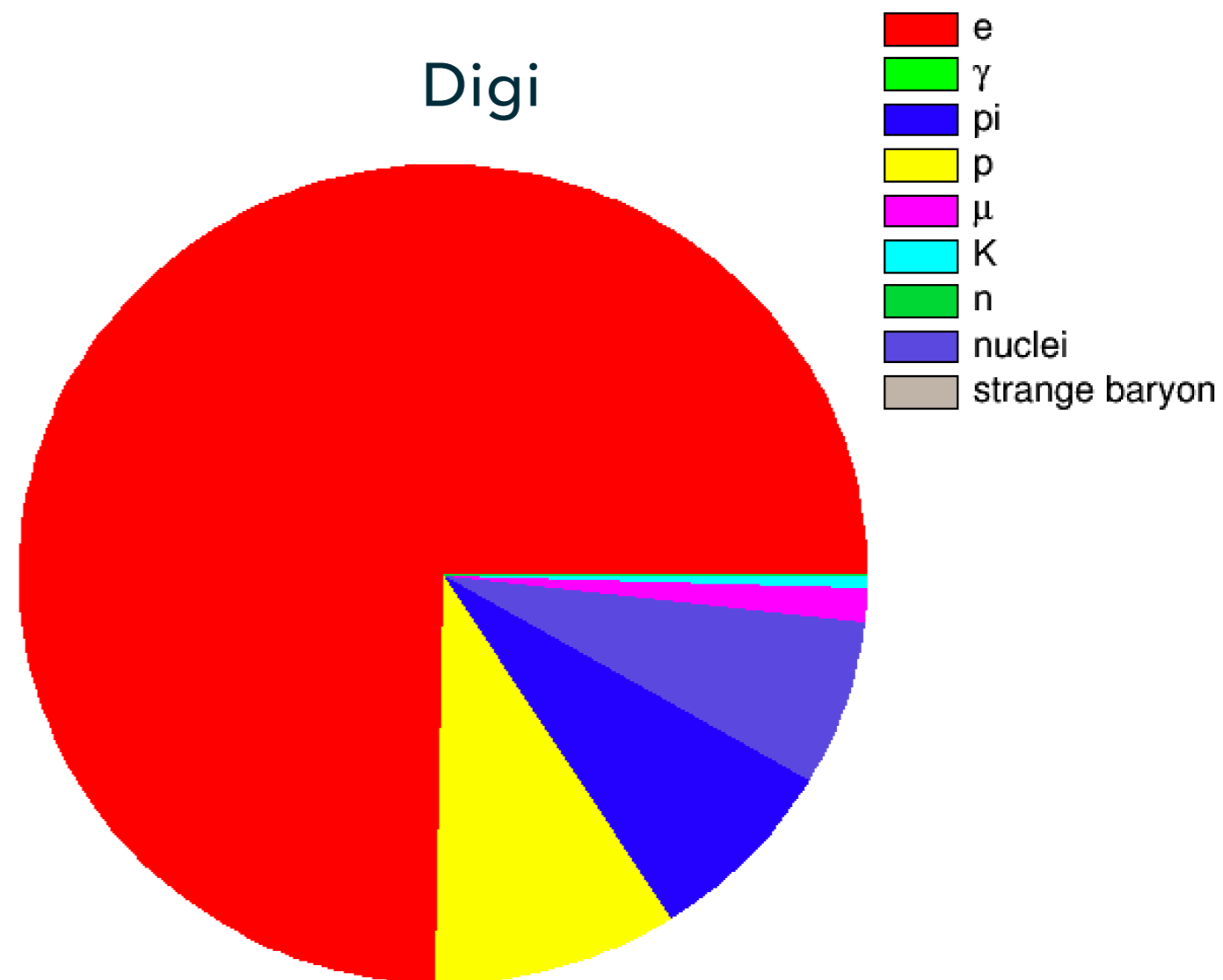


HIT NUMBER CONTRIBUTION

Simu

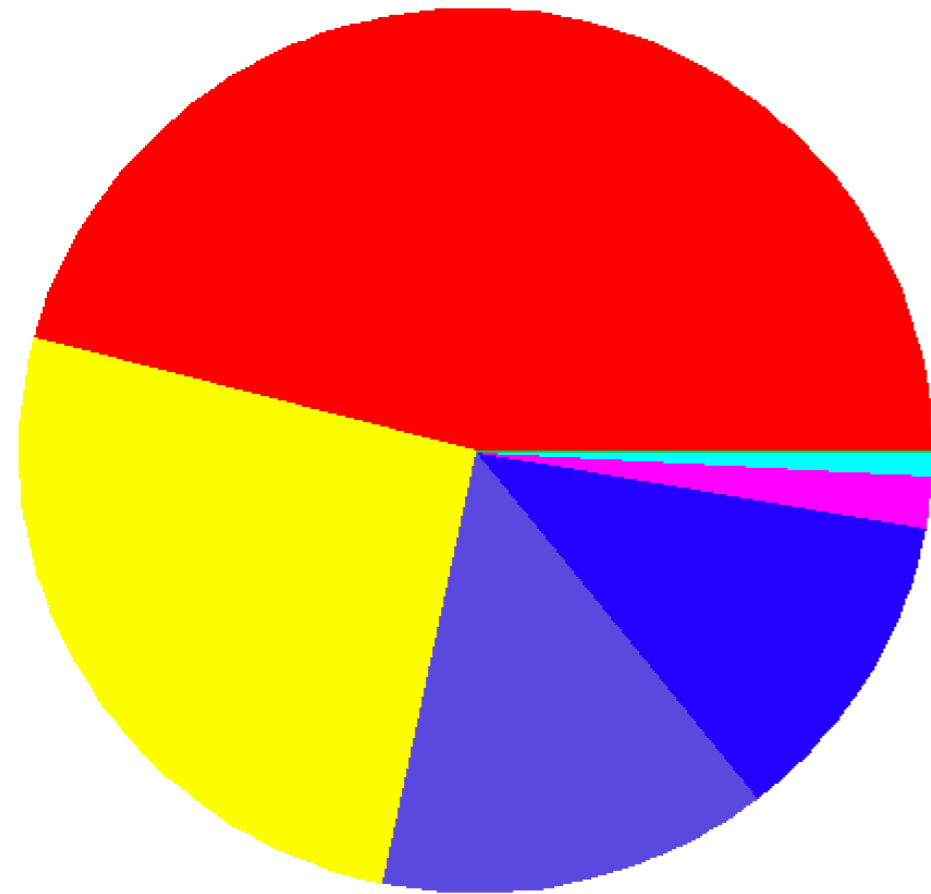
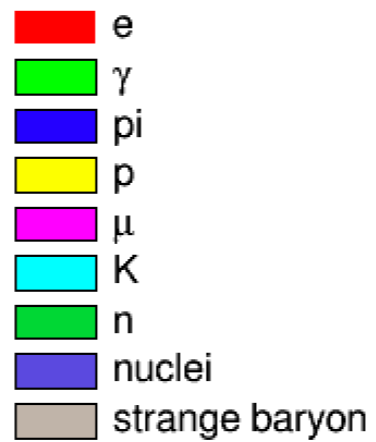


Digi

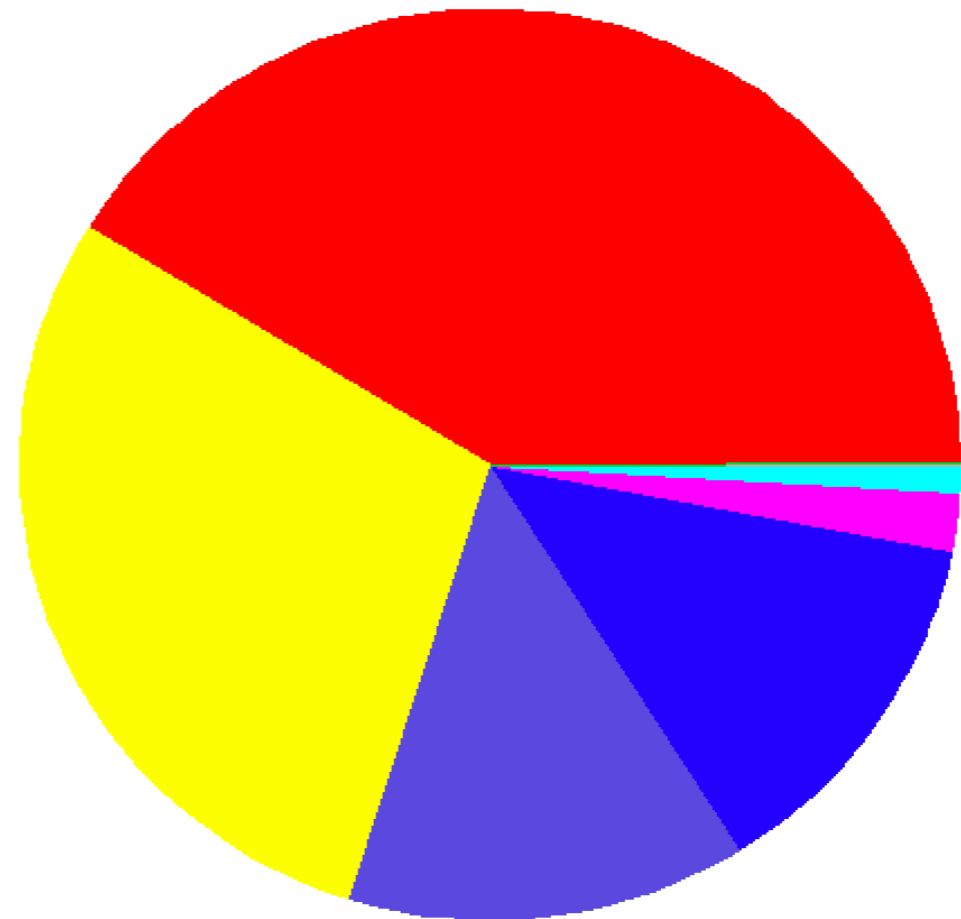
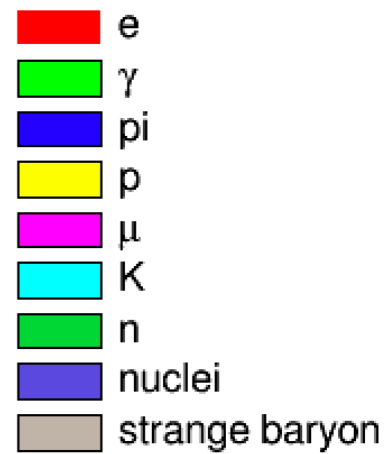


ENERGY CONTRIBUTION

Simu



Digi



CLUSTER TIME ANALYSIS

➤ Detector Time Response: smear the truth hits time with a Gaussian distribution (resolution depend on energy)

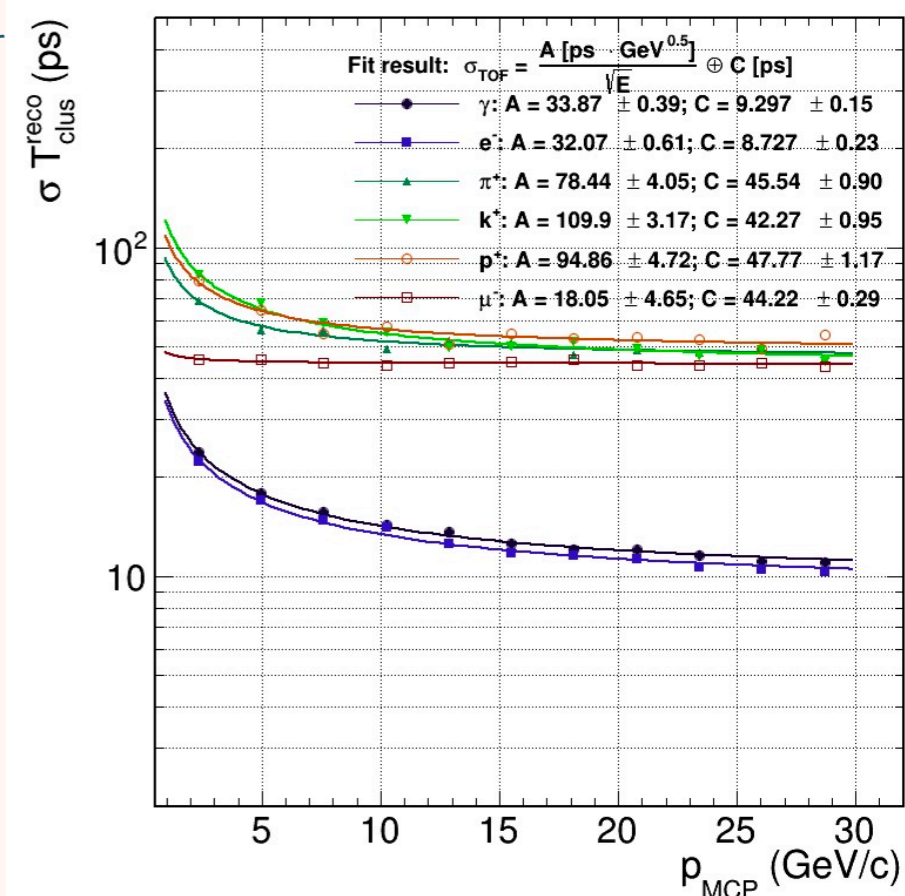
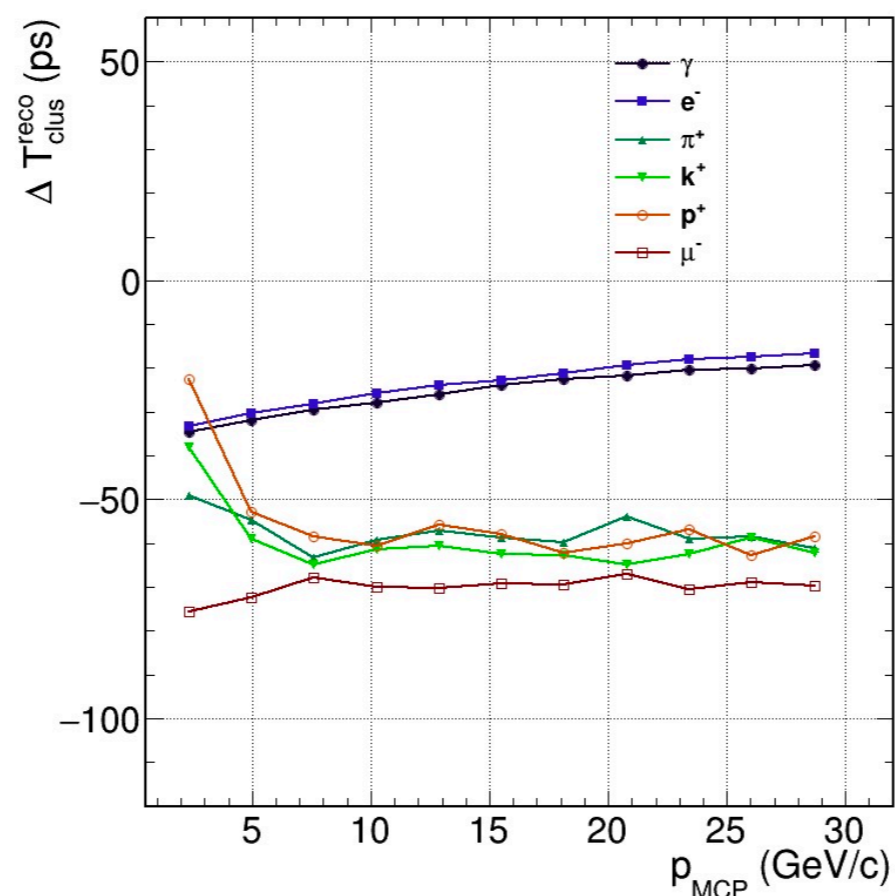
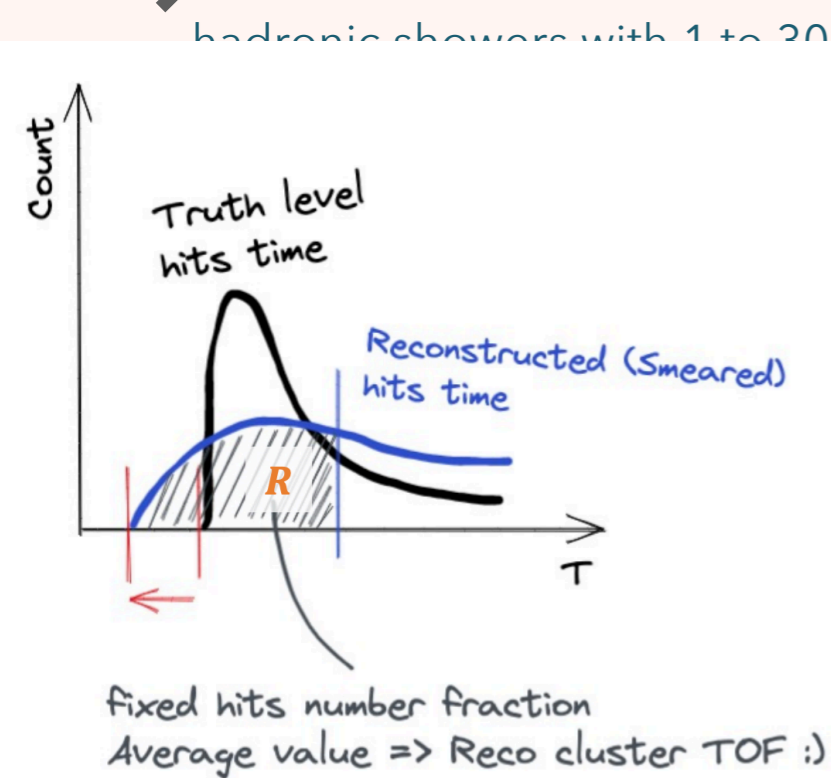
➤ Delay time: $T_{delay}^{reco} = T_{hit}^{reco} - \frac{L_{IP \rightarrow hit}}{c}$

➤ Reconstructed cluster time: the average time using the fast part (effective hit fraction R) of hit

$$T_{cluster}^{reco} = \frac{1}{N \cdot R} \sum T_{decay}^{reco}$$

➤ Good linearity: when the intrinsic time resolution is scaled by a factor from 0.1 to 100, the reconstructed TOF resolution scaled by the same factor

➤ for EM showers with 1 to 30 GeV, optimized effective fraction $R \sim 0.9$, corresponding resolution $10 \sim 30$ ps, for hadronic showers with 1 to 30 GeV, optimized effective fraction $R \sim 0.8$, corresponding resolution $10 \sim 30$ ps



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 tuning
- Observe No significant dependence between Glass density and BMR (fix longitudinal interaction length $\sim 5.8\lambda$)
 - Tools ready to scan more glass candidates
- Scaling behavior analyzed with different cell size (longitudinal)
- Future perspective: BMR $\sim 3\%$
 - better clustering algorithm, pursuing
 - 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
 - Realistic digitization (homogeneity, noise level, light ...)

THANK YOU!



虎年大吉
万事如意

BACKUP

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.

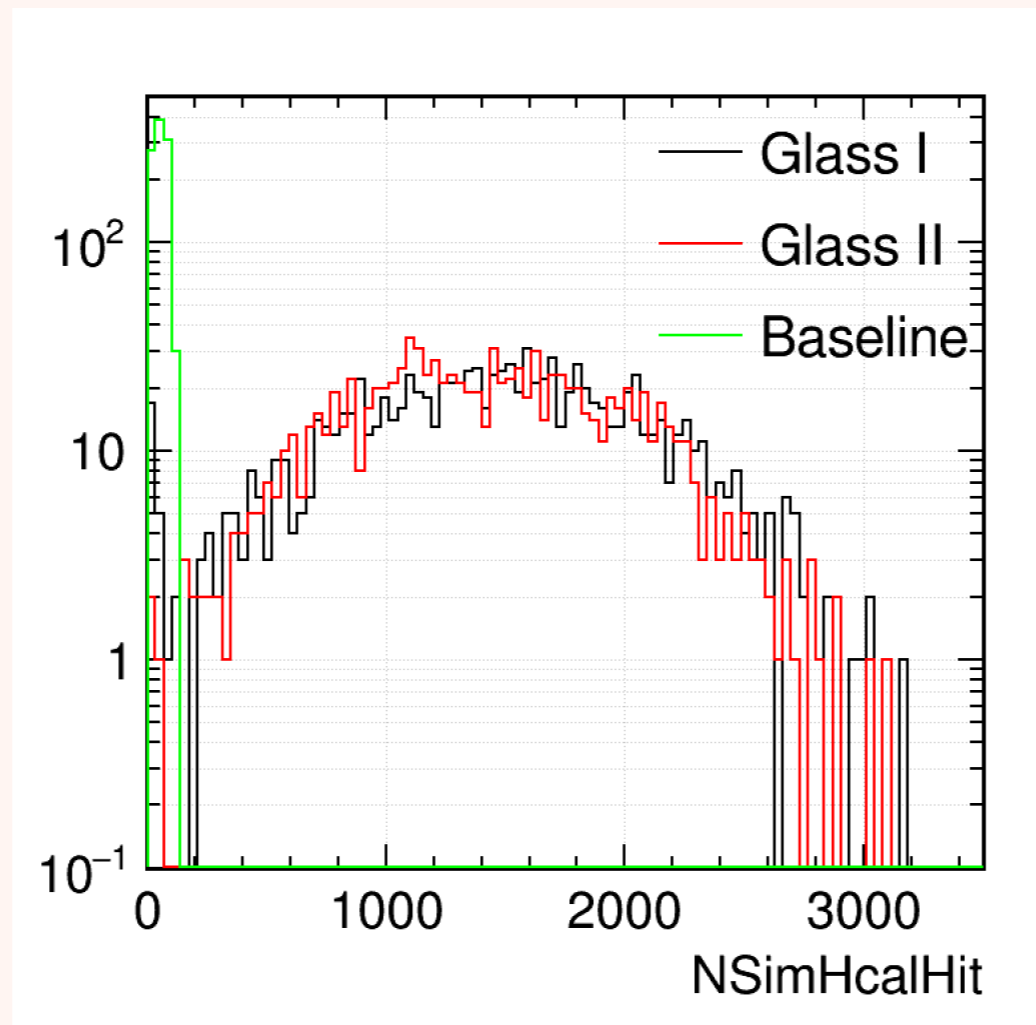
6.5 Recommendations

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 $\geq \text{LS4}$). 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

