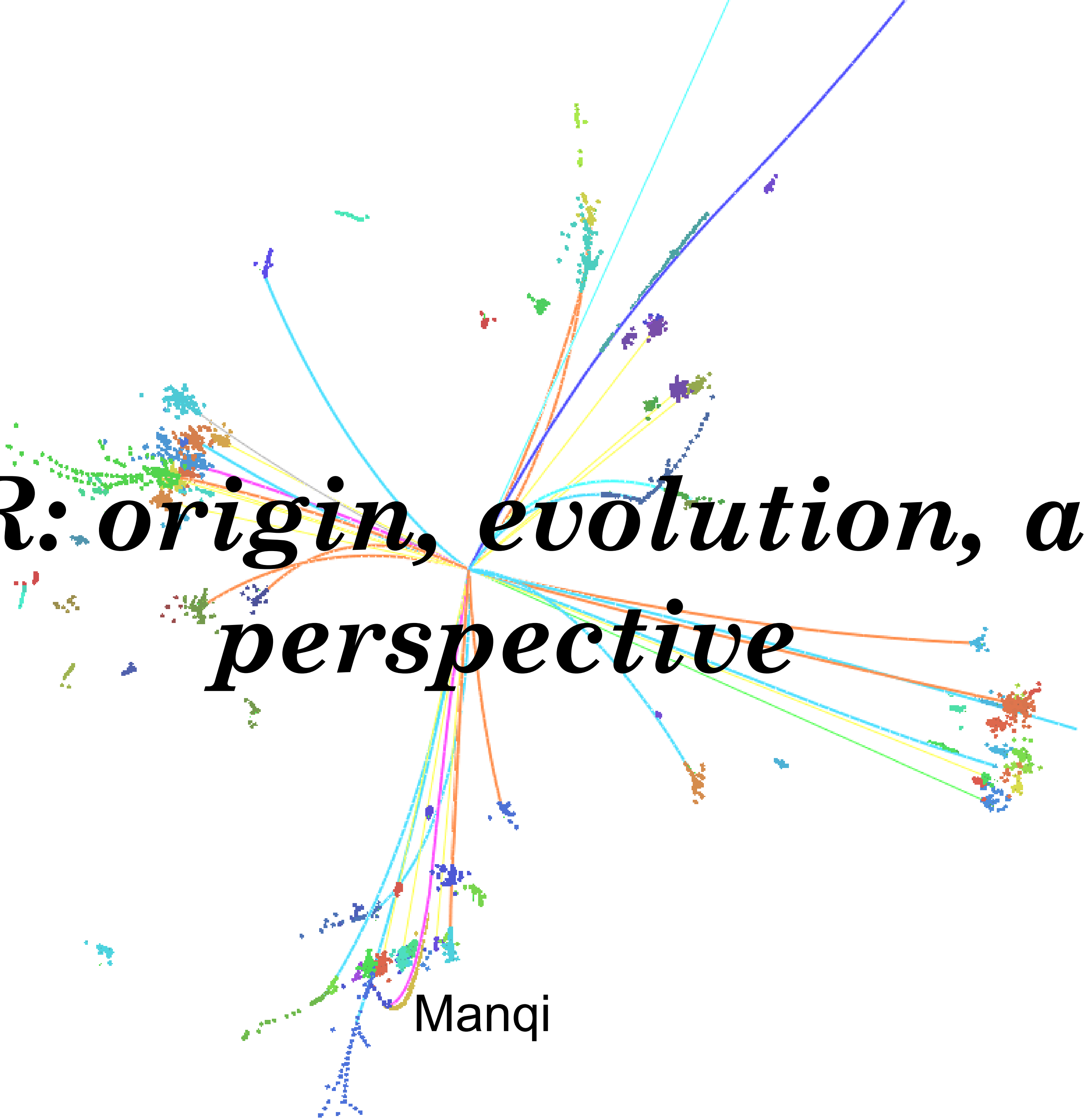


BMR: origin, evolution, and perspective

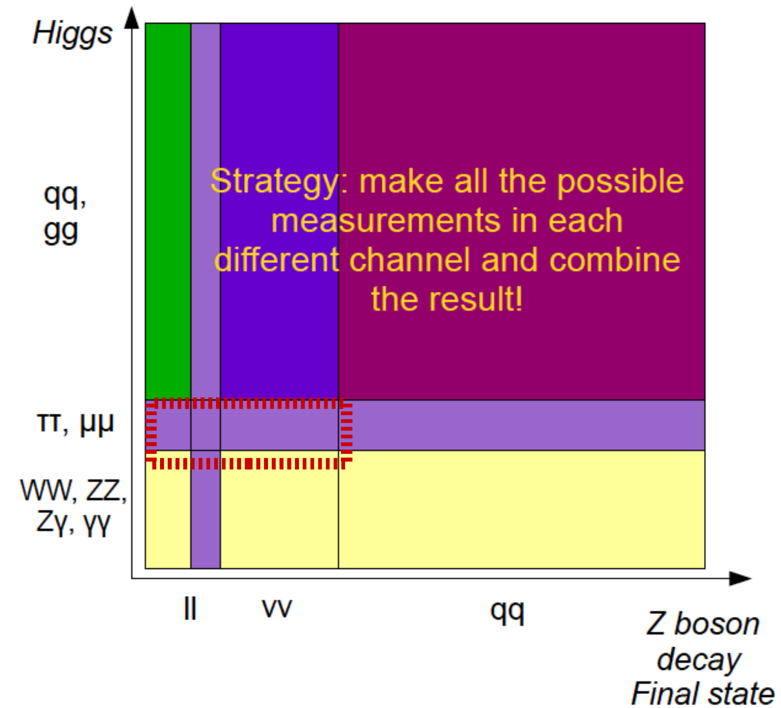
Manqi

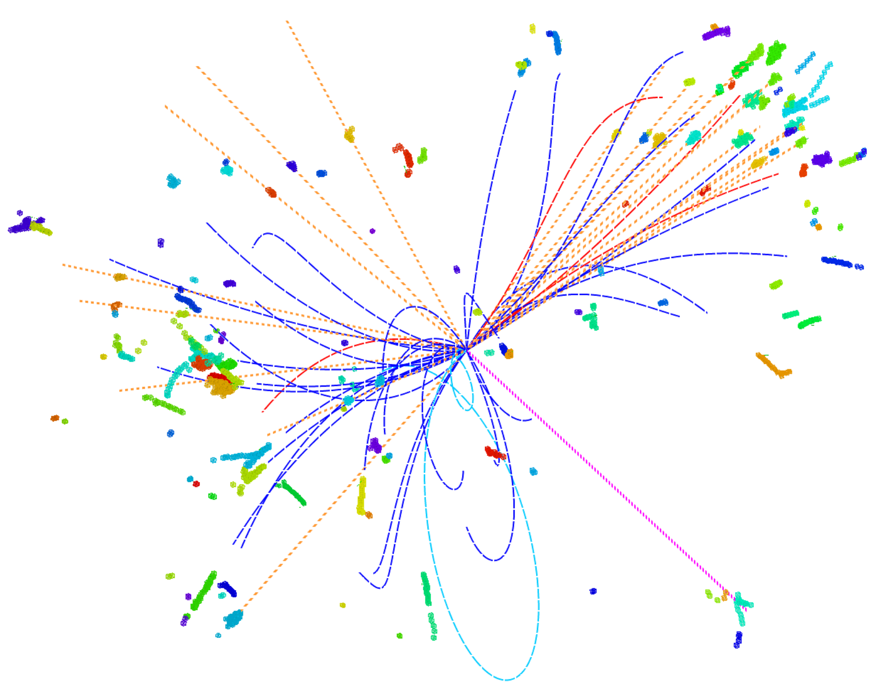
Outline

- The origin: from JER to BMR
- The evolution: 1-1 correspondence reconstruction
- The perspective: BMR of 2%
- The Preliminary performance Diagnosis of the TRD (TDR reference detector)
- Thoughts on the det. Optimization
- P.o.V: performance & measurement at the AI era

Performance requirements

- To reconstruct all Physics Object, especially Jets
  - Z & W: ~ 70% goes to a pair of jets
  - Higgs: ~97% final state with jets (ZH events)
  - Top: t → W + b





- Look inside the jet: **1-1 correspondence reco.**
  - ~ confusion free PFA
  - Larger acceptance...
  - Excellent intrinsic resolutions
  - Extremely stable...
- Be addressed by state-of-art detector design, technology, and reconstruction algorithm!

BMR: the origin

- At PreCDR: described by JER (inherited from ILC)
  - *Vector Boson Fusion process (WW-ZZ separation) requires JER ~ 3%, which is not highly relevant to the CEPC*
  - *JER could not be defined before Jet... which then depends on Jet reconstruction/clustering algorithm...*
  - *Usage of rms_90,*
  - *...*

- BMR: the standard since CDR

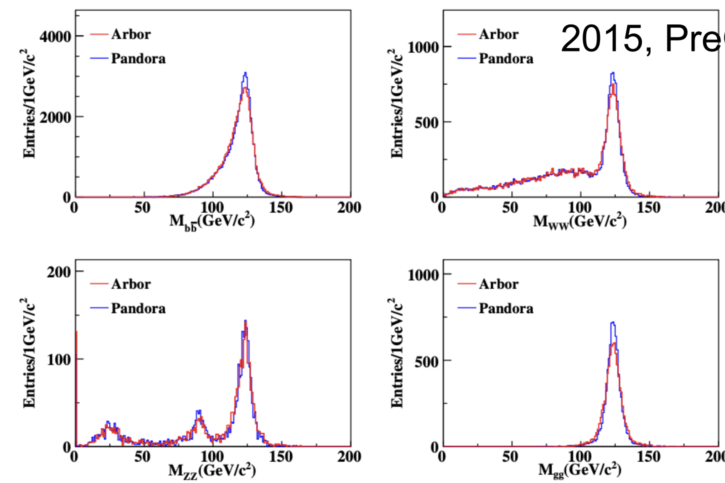
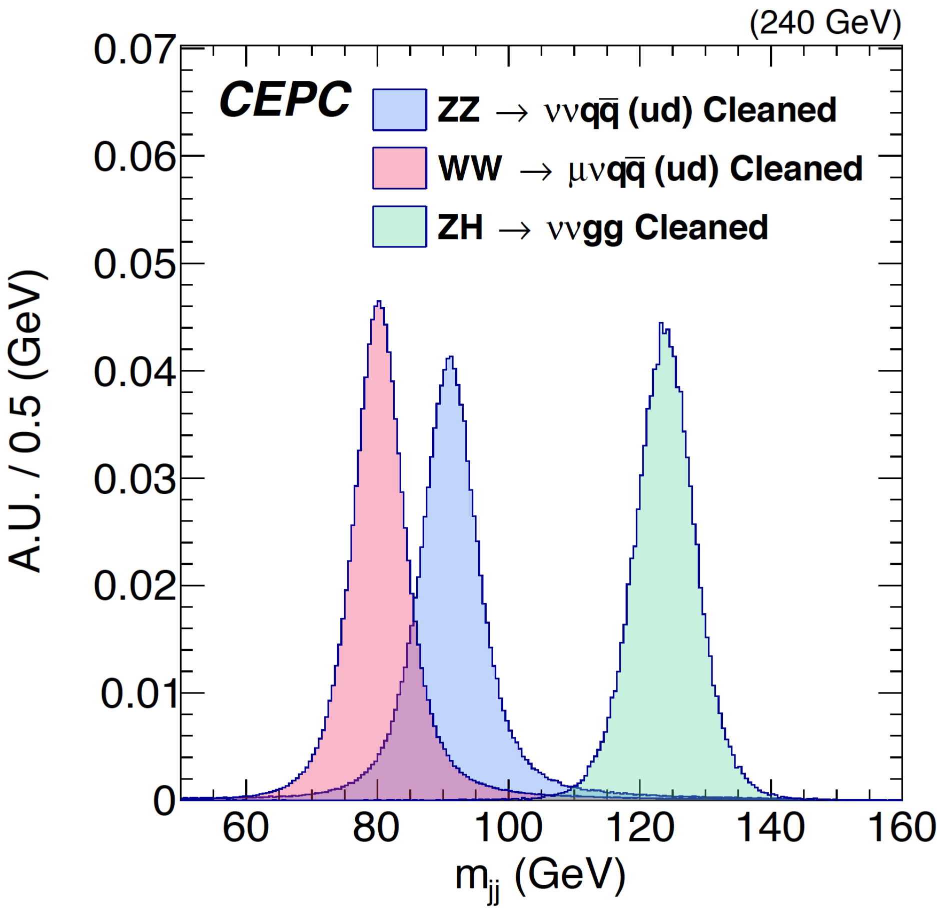
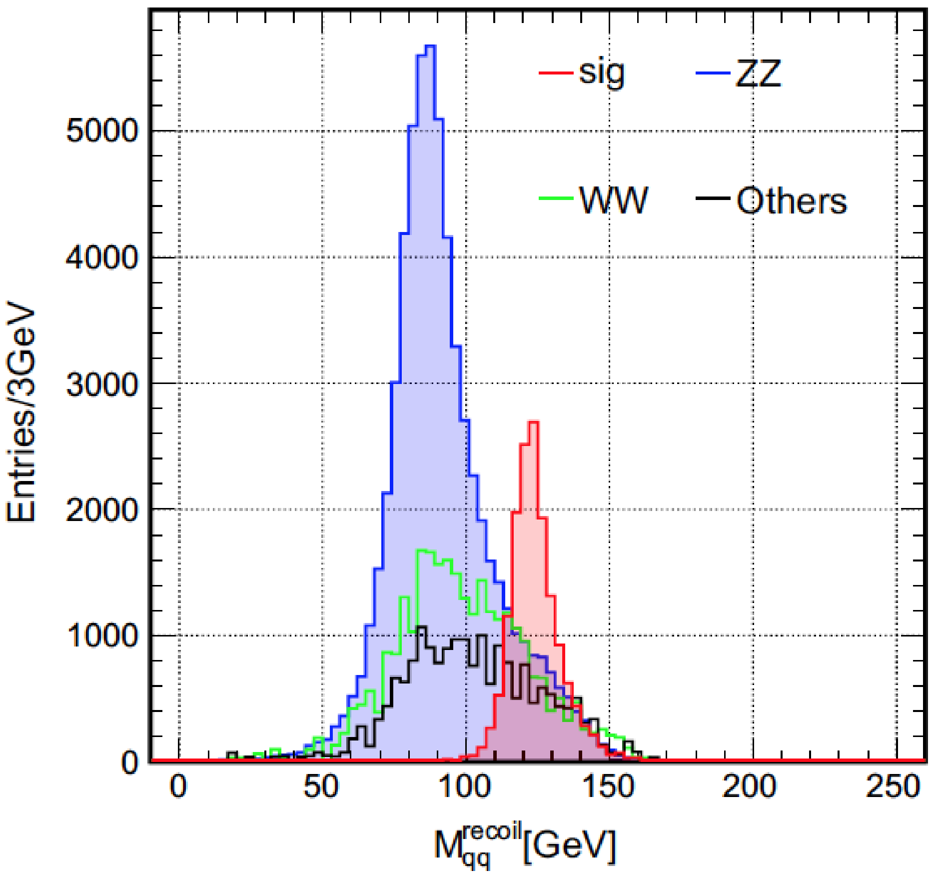


Figure 3.3 Invariant mass of all reconstructed particles of $v\bar{v}H$ events, with Higgs decay into different final states.

charged shower particles, as illustrated in Fig. 3.2. In the ideal case, each incident particle is reconstructed as one tree. With the current configuration, Arbor PFA has slightly worse performance for jet energy resolution than PandoraPFA, see Fig. 3.3.

BMR at CDR





Higgs factory: need BMR < 4% (critical for qqH & qqZ separation using recoil mass to di-jet)

Strongly motivated to improve BMR to 3% or even lower, especially for NP & Flavor

CDR baseline (left plot): BMR = 3.75%

BMR: receipt & comparison to JER

Chinese Physics C Vol. 43, No. 2 (2019) 023001

The Higgs signatures at the CEPC CDR baseline*

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Dan Yu(于丹)[1] Man-Qi Ruan(阮曼奇)[1,2;1)]

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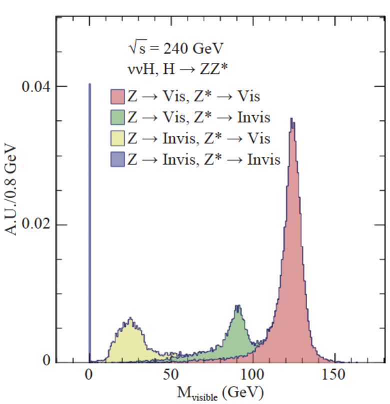
Abstract: As a Higgs factory, the CEPC (Circular Electron-Positron Collider) project aims at precision measurements of the Higgs boson properties. A baseline detector concept, APODIS (A PFA Oriented Detector for the HIggS factory), has been proposed for the CEPC CDR (Conceptual Design Report) study. We explore the Higgs signatures for this baseline design with $\nu\bar{\nu}$ Higgs events. The detector performance for reconstructing charged particles, photons and jets is quantified with $H \to \mu\mu, \gamma\gamma$ and jet final states, respectively. The resolutions of reconstructed Higgs boson mass are comparable for the different decay modes with jets in the final states. We also analyze the $H \to WW^*$ and ZZ^* de

Table 3. Higgs boson mass resolution (sigma/Mean) for different decay modes with jets as final state particles, after event cleaning.

$H \to bb$	$H \to cc$	$H \to gg$	$H \to WW^*$	$H \to ZZ^*$
3.63%	3.82%	3.75%	3.81%	3.74%



← Standard Definition & Process

Relationship to JER→

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Jet performance at the circular electron-positron collider

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[b]Experimental Physics Division, Institute of High Energy Physics, 19B Yuquan Road, Beijing, China

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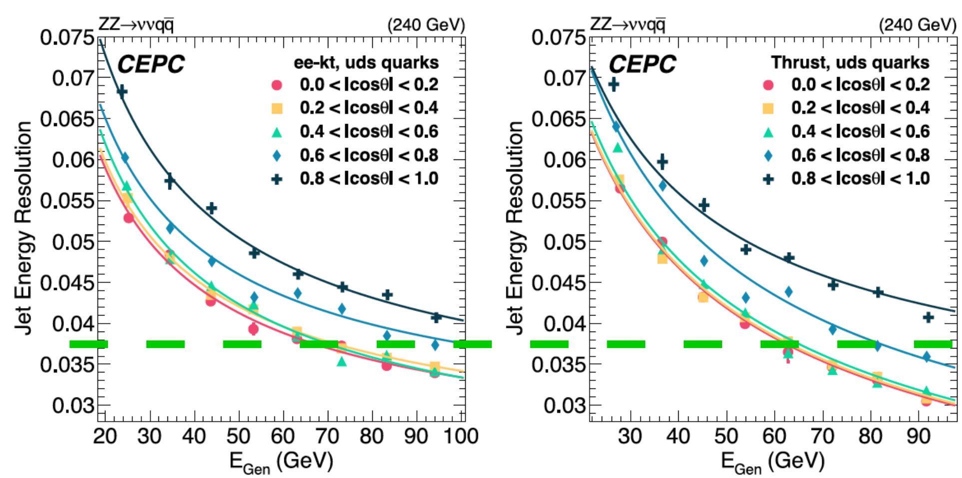
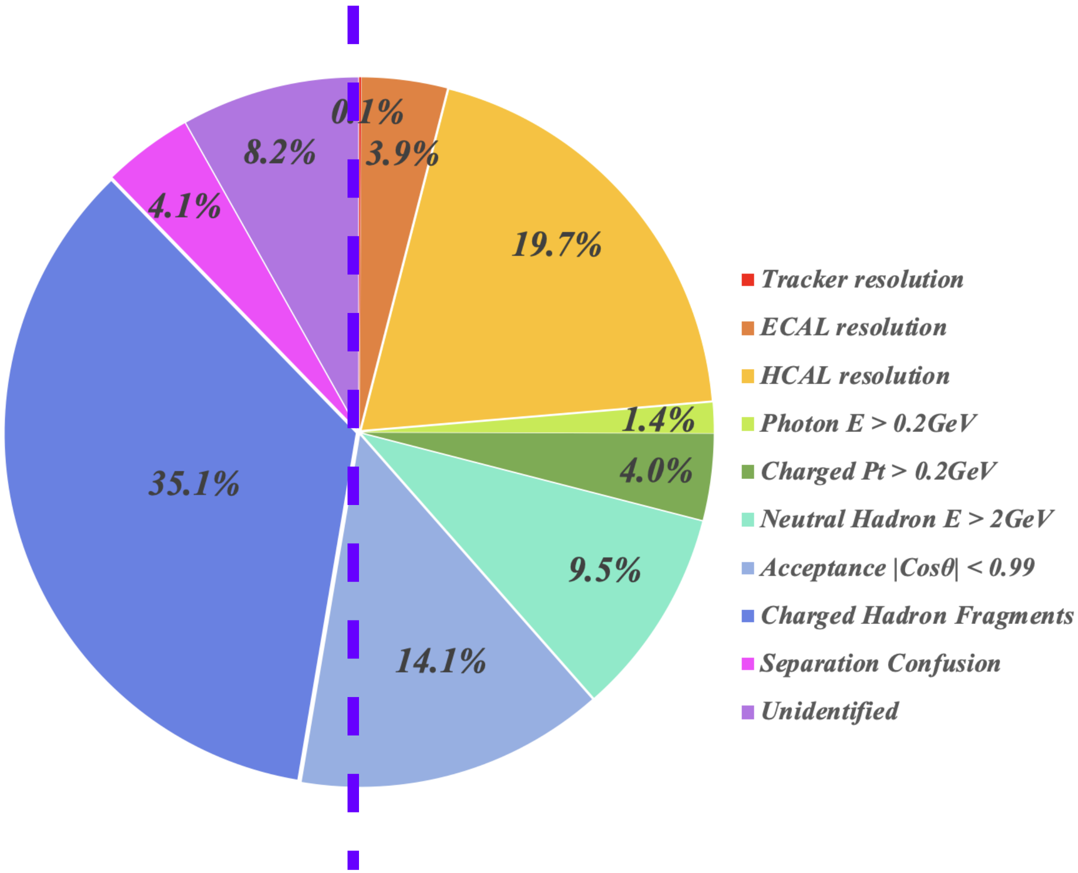


(a) (b)

BMR decomposition @ CDR



- *1st HCAL resolution dominant the uncertainties from intrinsic detector resolution: need better HCAL → R & D of GSHCAL*
- *2nd Leading contribution: Confusion from shower Fragments (fake particles), need better Pattern Reco.*

- *CDR baseline - GRPC HCAL*

GSHCAL: simulation

Nuclear Instruments and Methods in Physics Research A 1059 (2024) 168944

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journal homepage: www.elsevier.com/locate/nima

Full Length Article

GSHCAL at future e^+e^- Higgs factories

Peng Hu [a,b], Yuexin Wang [a,c], Dejing Du [a,b], Zhehao Hua [a,b], Sen Qian [a,b,*], Chengdong Fu [a,b], Yong Liu [a,b], Manqi Ruan [a,b], Jianchun Wang [a,b], Yifang Wang [a,b]

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ARTICLE INFO

Keywords:
Higgs factory
CEPC
HCAL
Glass scintillator

ABSTRACT

The excellent jet energy resolution is crucial for the precise measurement of the Higgs properties at future e^+e^- Higgs factories, such as the Circular Electron Positron Collider (CEPC). For this purpose, a novel design of the particle flow oriented hadronic calorimeter based on glass scintillators (GSHCAL) is proposed. Compared with the designs based on gas or plastic scintillators, the GSHCAL can achieve a higher sampling fraction and more compact structure in a cost-effective way, benefiting from the high density and low cost of glass scintillators. In order to explore the physics potential of the GSHCAL, its intrinsic energy resolution and the contribution to the measurement of the hadronic system was investigated by Monte Carlo simulations. Preliminary results show that the stochastic term of hadronic energy resolution can reach around 24% and the Boson Mass Resolution (BMR) can reach around 3.38% when the GSHCAL is applied. Besides, the key technical R&D of high-performance glass scintillator tiles is also introduced.

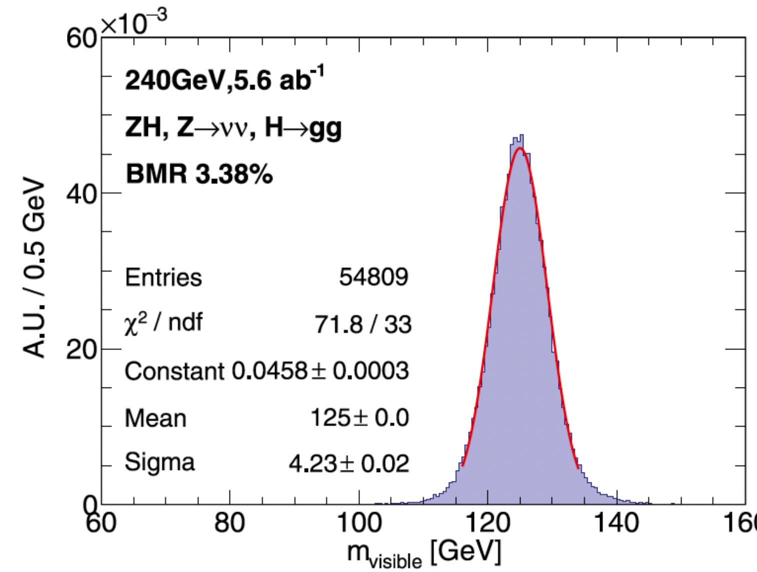
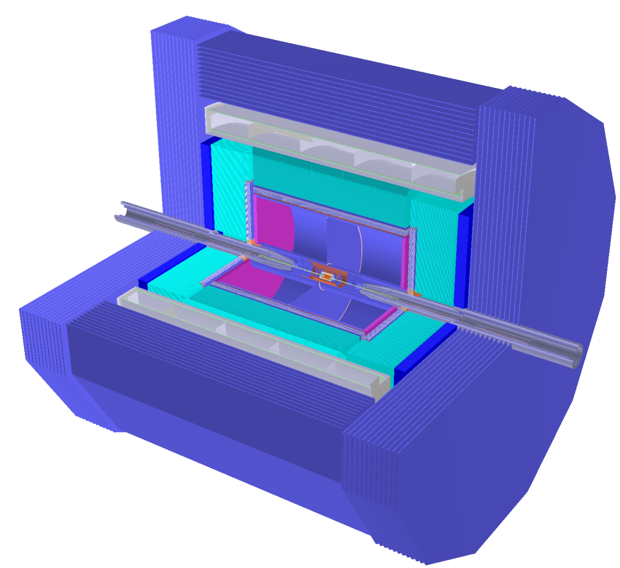


Fig. 5. Distribution of the reconstructed total visible invariant mass for $\nu\bar{\nu}H \rightarrow \nu\bar{\nu}gg$ channel. The distribution is fitted with a Gaussian function extented to ±2 standard deviations.

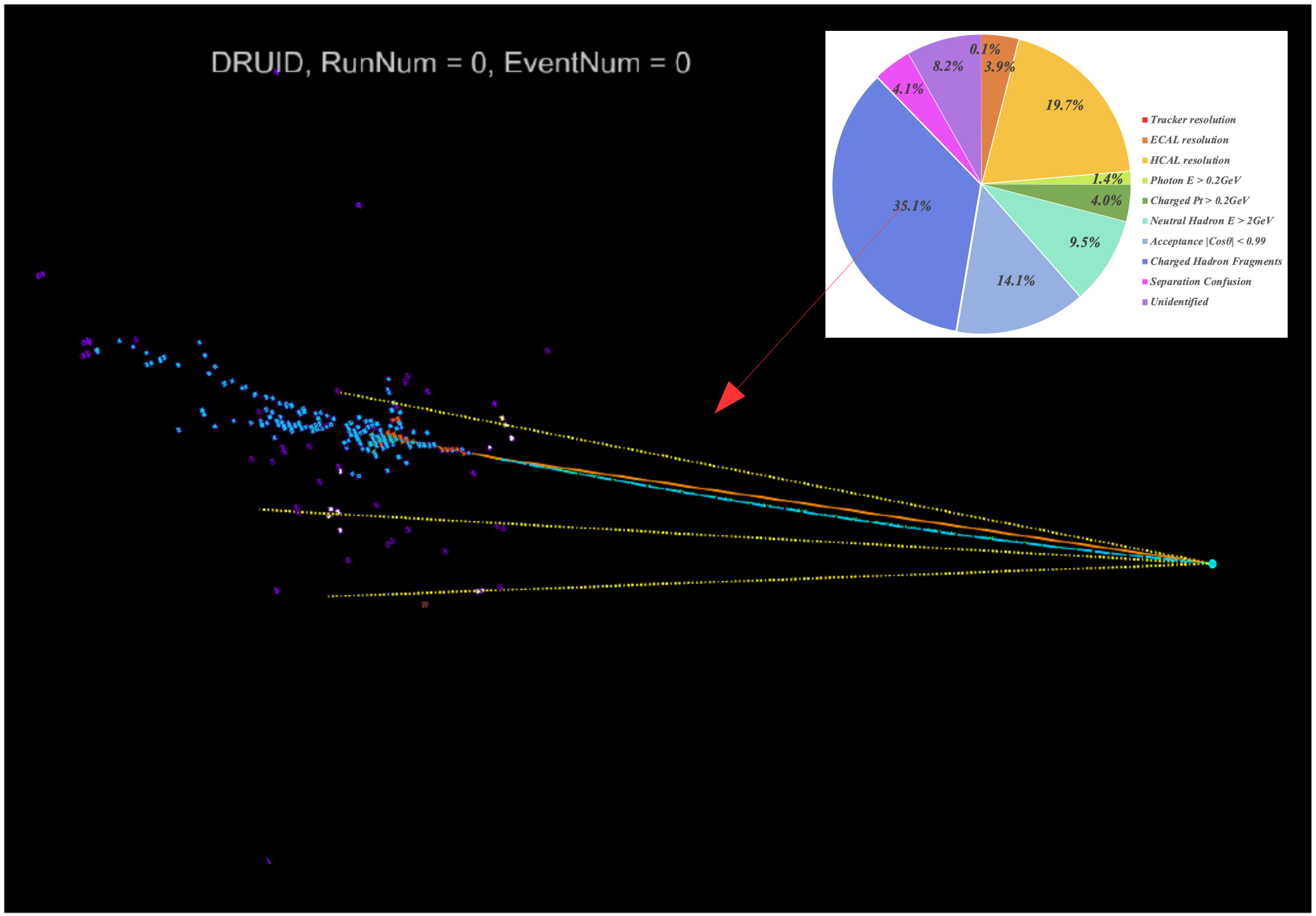
Y. Wang, H. Liang, Y. Zhu et al. *Computer Physics Communications 314 (2025) 109661*

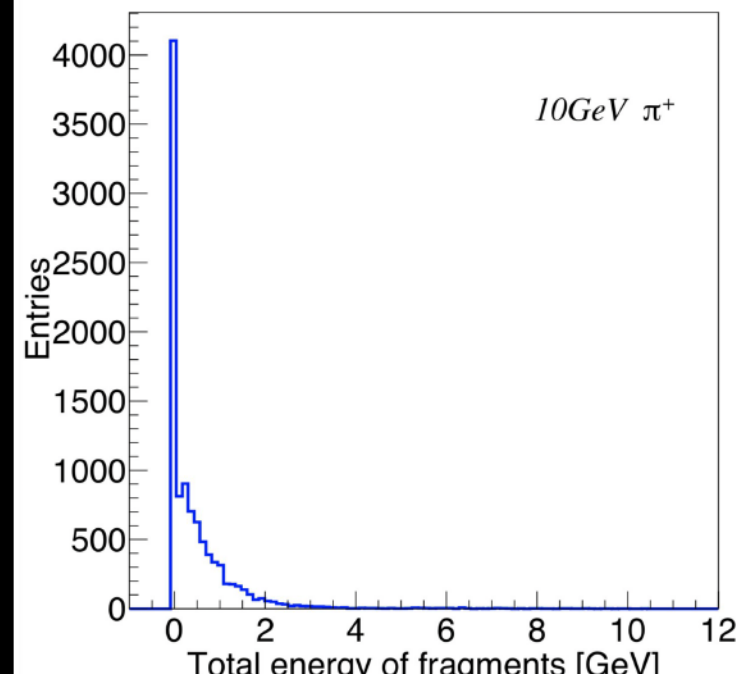
Table A.1
AURORA detector geometry parameters.

Sub-detector	Thickness (mm)	Inner radius (mm)	Outer radius (mm)	Length (mm)	Volume (m^3)	Transverse cell size	#Layers	#Channels
Vertex	-	-	16–60	125–250	-	25 × 25 μm^2	6	5.3×10^8
			155	736				
Si-strip	-	-	300	1288	-	20 μm × 2 cm	3	3.0×10^7
Tracker			1810	4600				
TPC	-	300	1800	4700	47	1 × 6 mm^2	220	2.9×10^6
ECAL	173	1845	2018	5250	15	1 × 1 cm^2	30	2.5×10^7
HCAL	1145	2072	3250	7590	180	2 × 2 cm^2	48	1.8×10^7
Solenoid	700	3275	3975	7750	120	-	-	-
Yoke	1200	4000	5200	10500	470	-	-	-



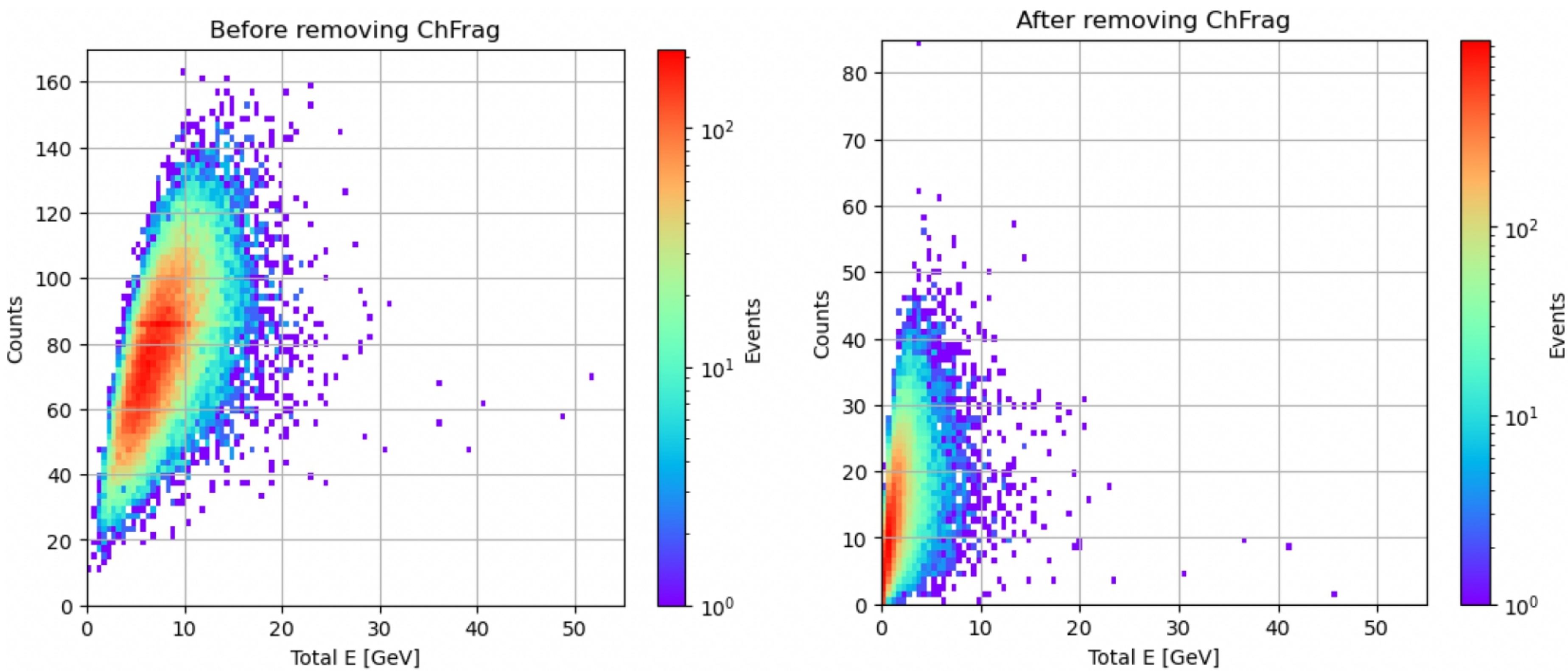
Cluster splitting: the most severe confusions





Time/pattern recognition may help a lot, in identify the charged cluster fragmentations without arise the threshold for the neutral hadron significantly...

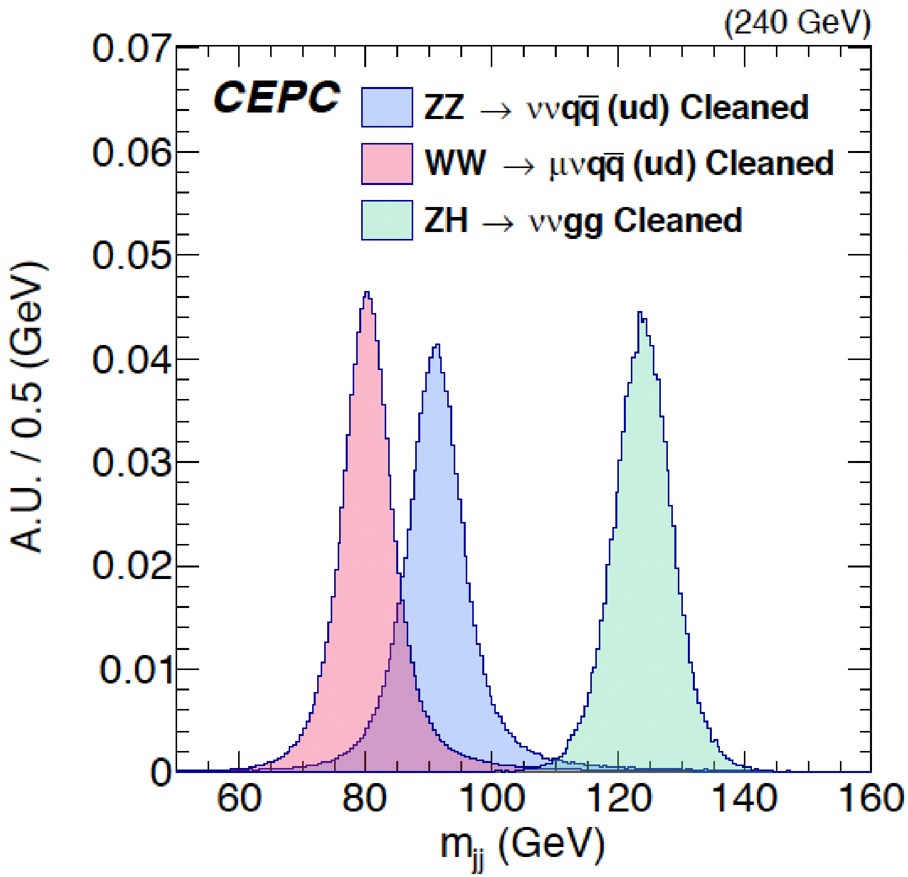
Confusion: frag. Identification & veto

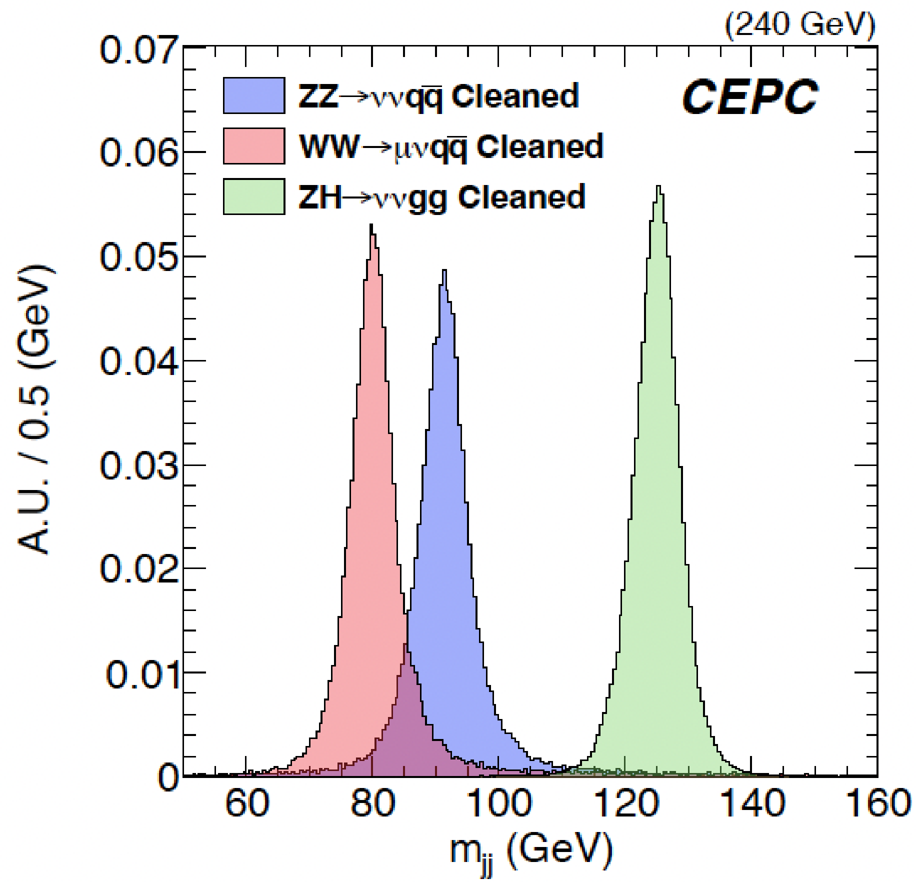


Fake particle originated Confusion reduced by 1 order of magnitude, at nominal vvH, H→gg event, at the cost of create mis-vetoed energy of < 1 GeV.

Frag Total Energy (MPV/Mean): 6.3/7.6 GeV → 0.7/1.4 GeV

BMR of 2.75% reached



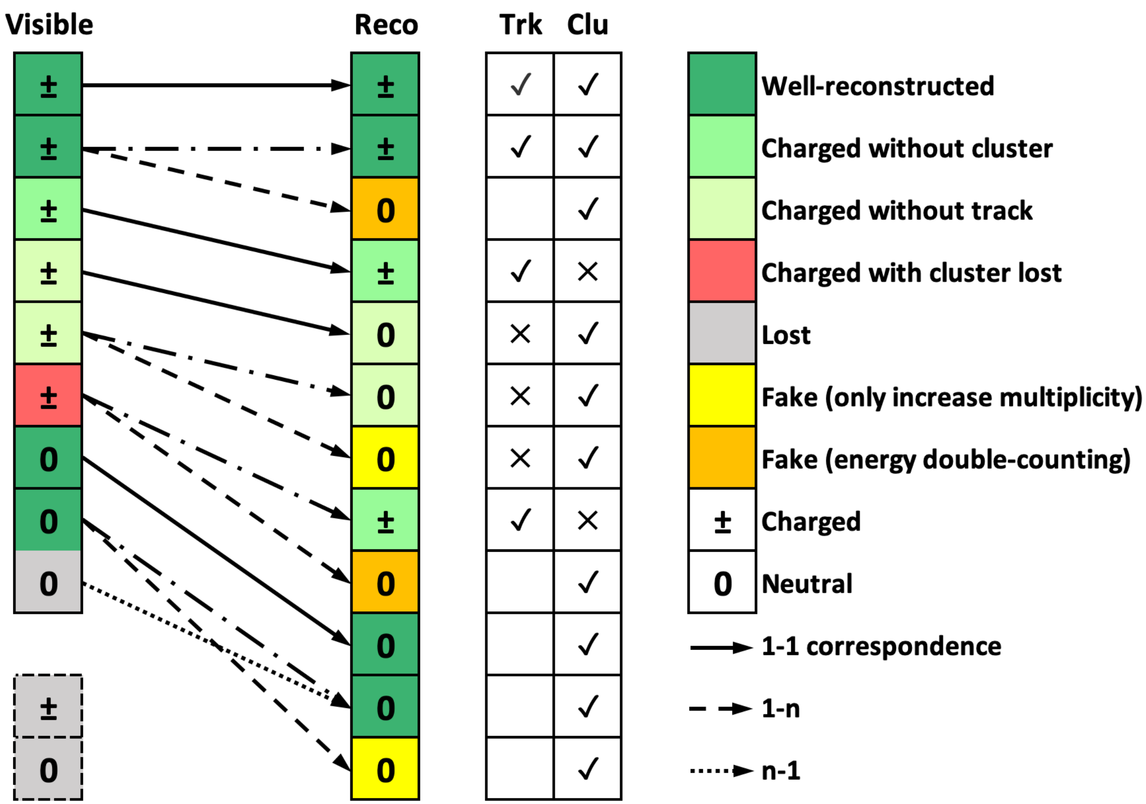


Detector change (usage of high density scintillating glass HCAL): BMR 3.7% → 3.4%;

AI enhanced reconstruction: 3.4% → 2.8%.

Recent update: further optimization + Pid, etc, current value ~2.68%

The evolution: to 1-1 correspondence



Computer Physics Communications 314 (2025) 109661

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Computer Physics Communications

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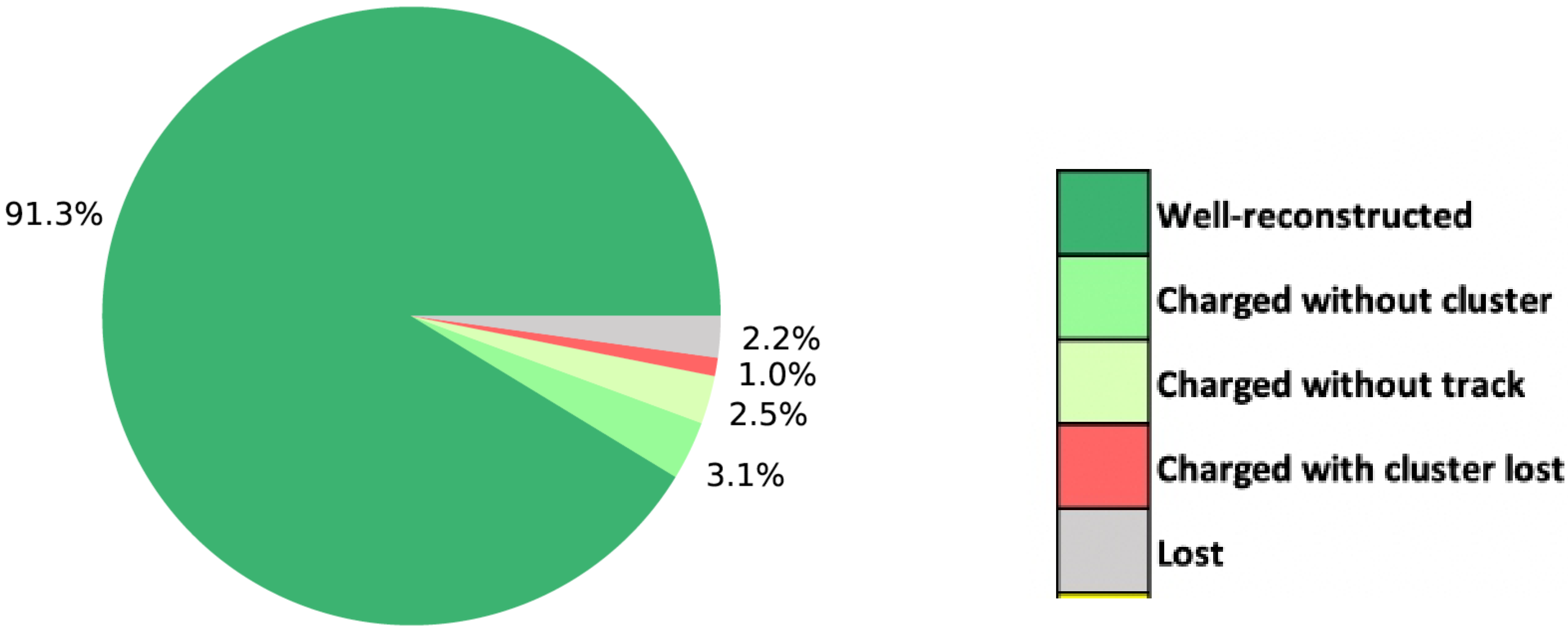
Computational Physics

One-to-one correspondence reconstruction at the electron-positron Higgs factory

Yuexin Wang [a,b], Hao Liang [a,c,d], Yongfeng Zhu [e], Yuzhi Che [a,f], Xin Xia [a,c], Huilin Qu [g], Chen Zhou [e], Xuai Zhuang [a,c], Manqi Ruan [a,c,*]

https://arxiv.org/abs/2411.06939

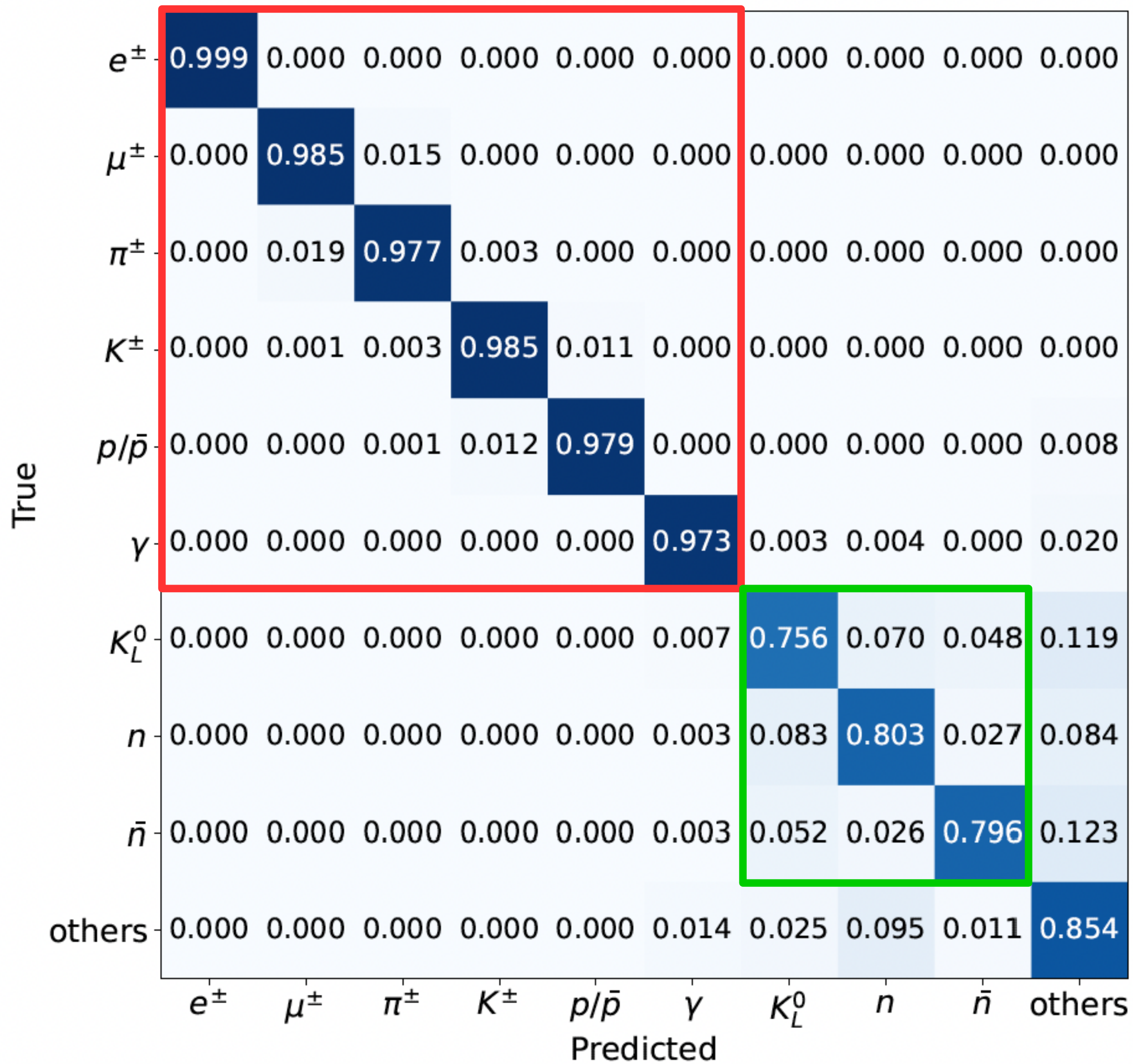
Confusion: frag. Identification & veto

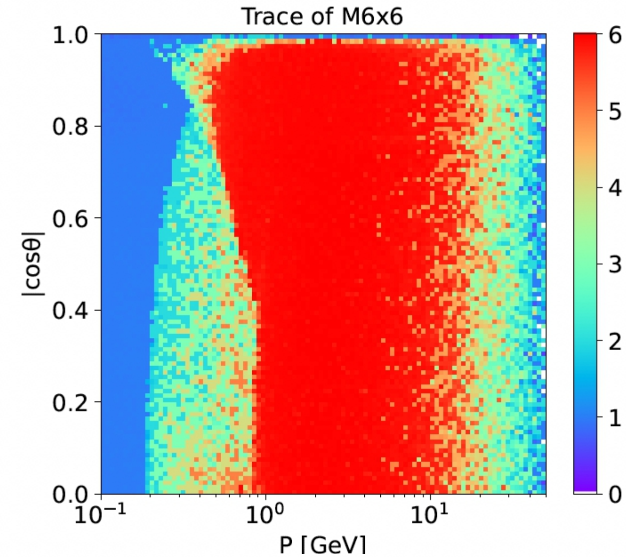


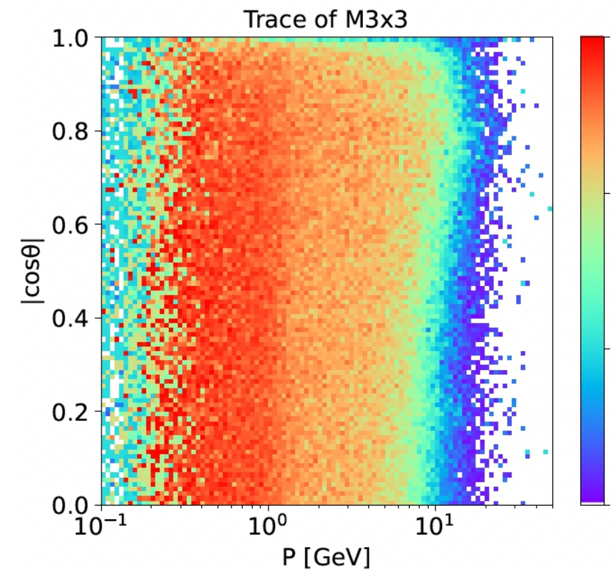
Remaining fragments with total E ~ 1 GeV;

More than 95% of the visible energy preserves 1-1 correspondence;

Pid: differential performance

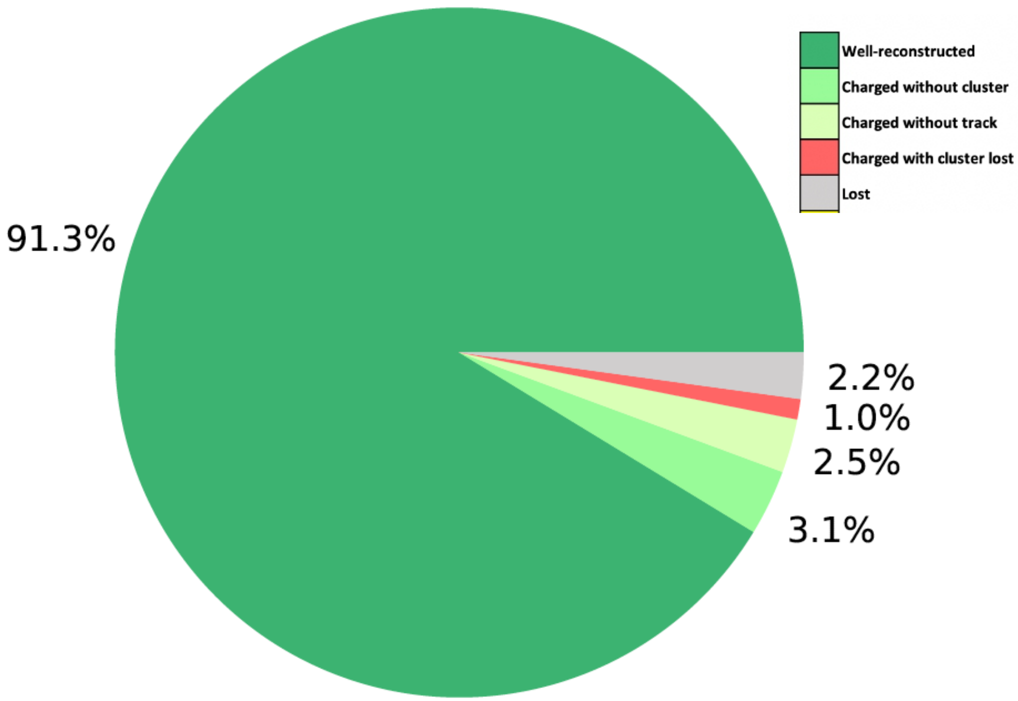


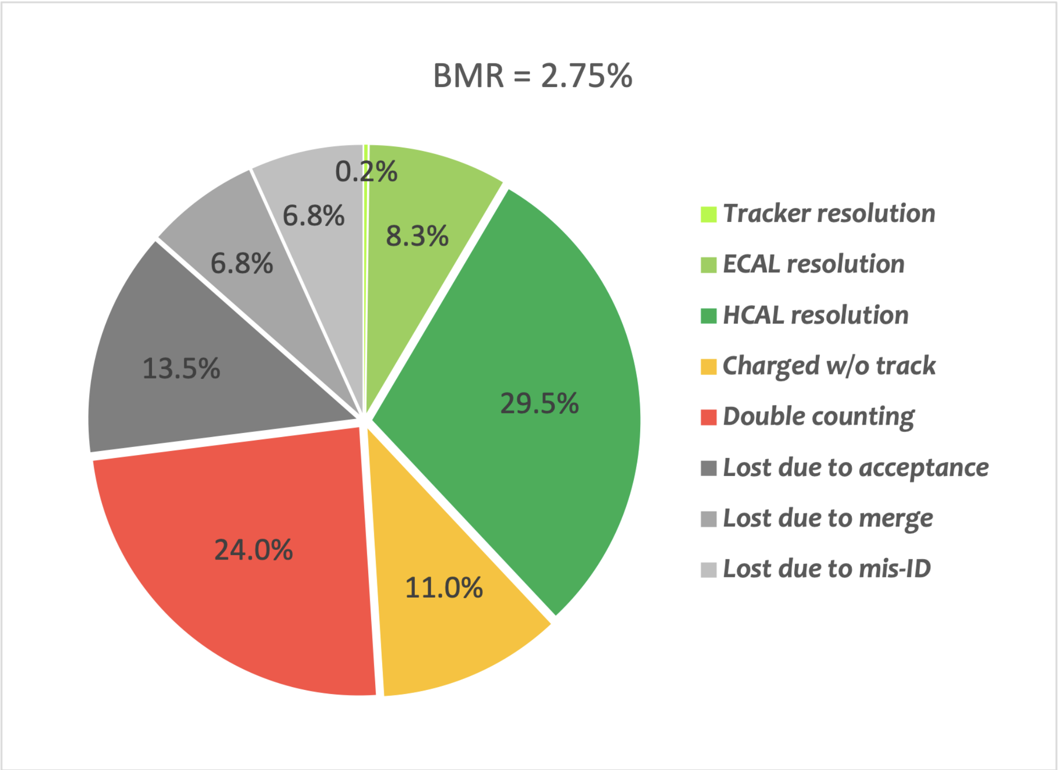




Neutral Hadron ID: 5d Calorimetry with ToF capability (δt~100 ps/hit)

BMR decomposition @ AURORA

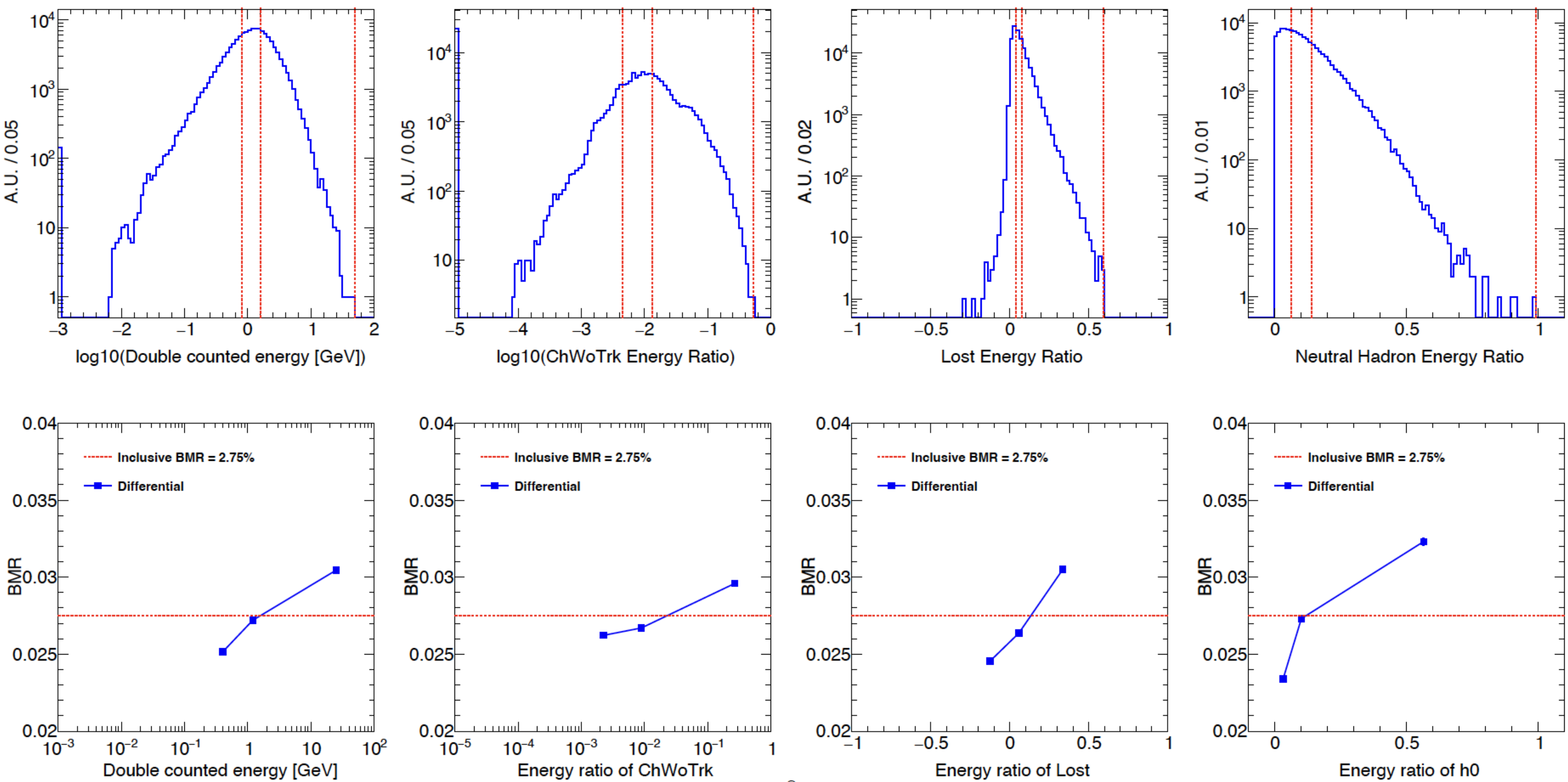




1-1 corresponding type: contributing to the BMR via resolution: ~o(0.1 – 0.001) of its mean value

Double Counting & Lost type: contributing to the BMR ~o(1) to its mean value

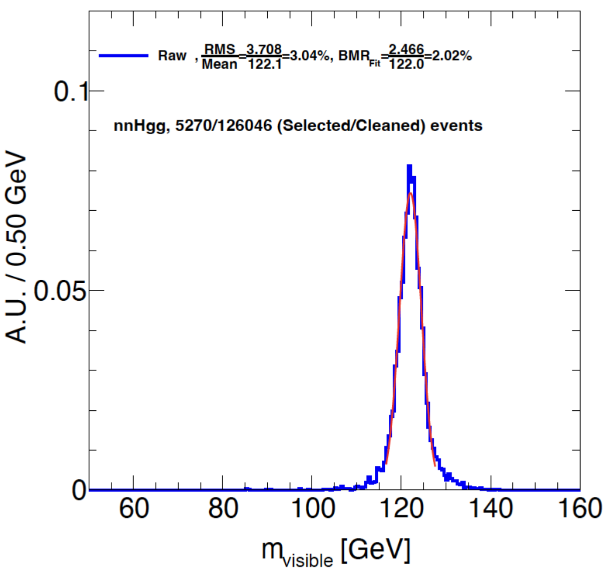
BMR dependence to its components



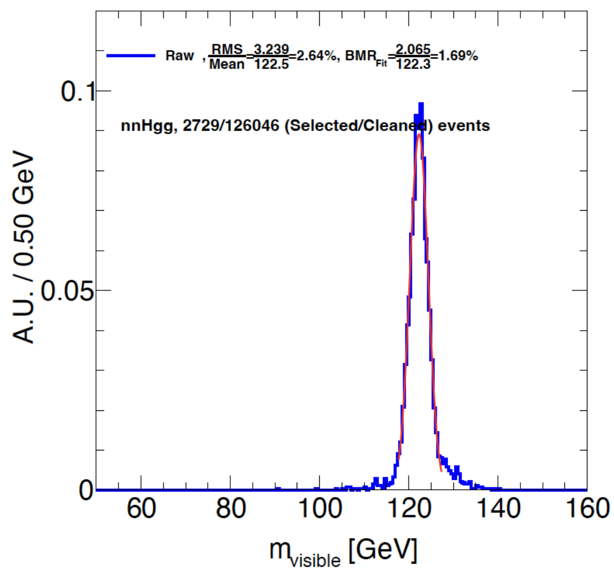
BMR dependence on Cut...

Combined cut (top 1/3 good events)

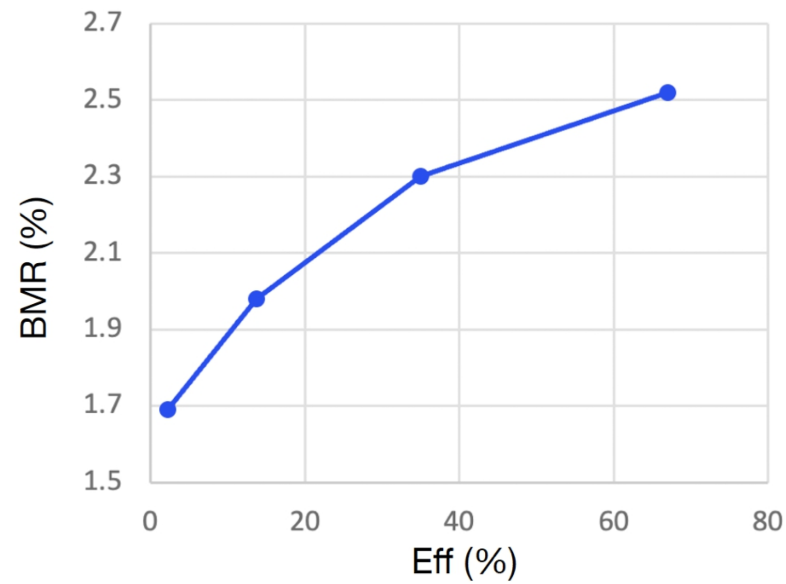
- **Eff ~4.2%**
- **Double count E < 0.8 GeV**
- **ChWoTrk ERatio < 0.0045**
- **Lost ERatio < 0.037**



- **Eff ~2.2%**
- **Double count E < 0.8 GeV**
- **ChWoTrk ERatio < 0.0045**
- **Lost ERatio < 0.037**
- **h0 ERatio < 0.062**



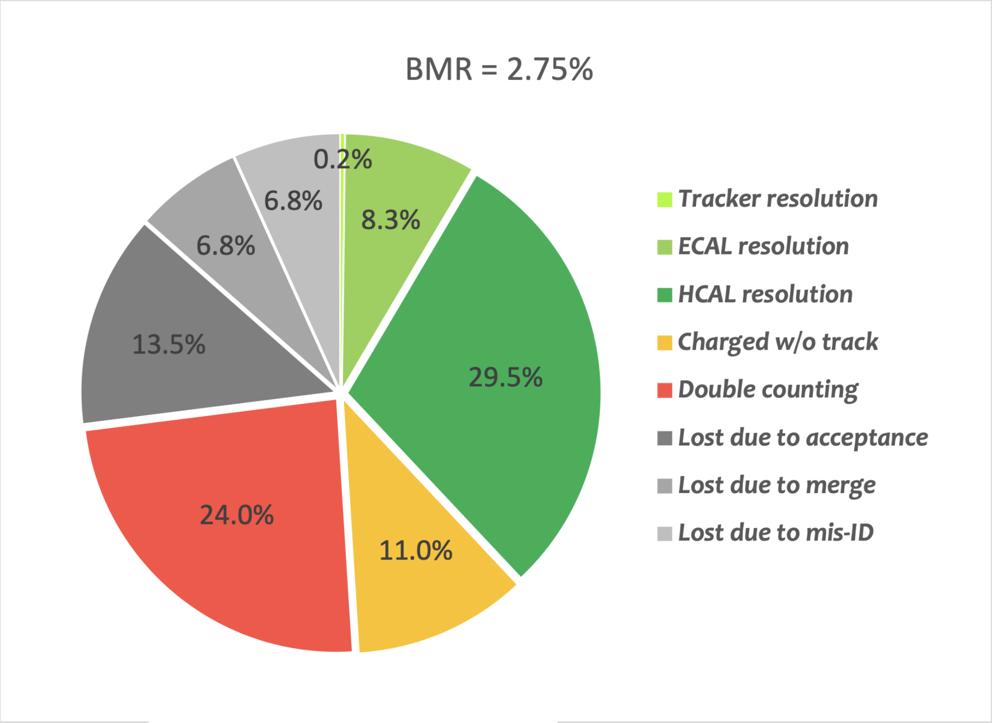
Eff (%)	BMR (%)
2.2	1.69
13.7	1.98
35	2.3
67	2.52

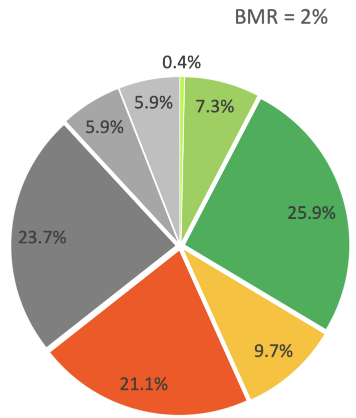


...If the High Values tails could be tamed...

BMR: perspectives

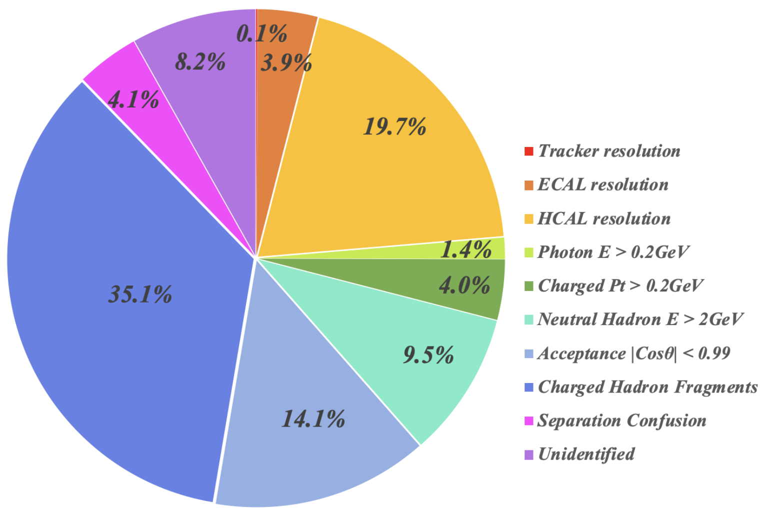
- Resolutions: assume - improved by 50%
  - Crystal ECAL: With efficient control of confusion
  - Detector optimization + Innovative Estimator (Energy, Time, Spatial...) with 5d calorimeter (ToF) & AI: ToF could determine very precisely the energy of low-E hadron – Giving its type identified...
- Charged w/o track: improved by 20% via Improve tracking efficiency, etc
- Double Counting: improved by 60% via Improve matching in the core PFA, i.e., Arbor
- Lost: improved by 15% (mainly at Mis vetoing & Merging, both improving by 30%)
- *Need to better understand, identify & control the impact of secondary particles... (those generated in interactions between primary V.S. Upstream material, plus back-scattering)*



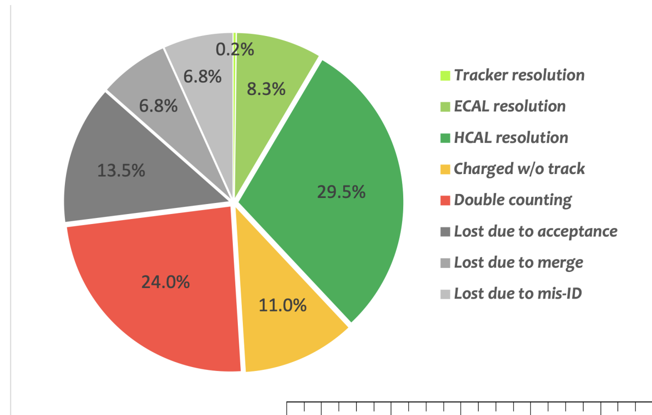


BMR: from CDR to possible future...

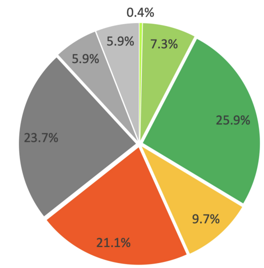
2016 - CDR: BMR ~ 4%

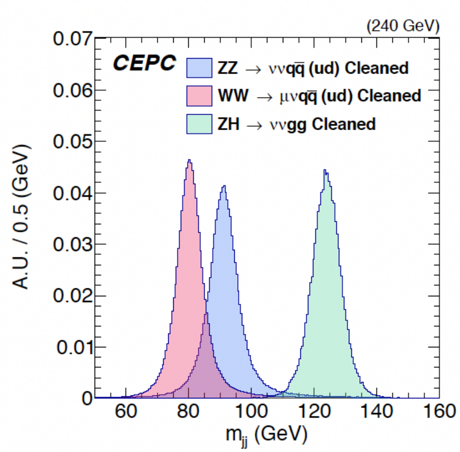


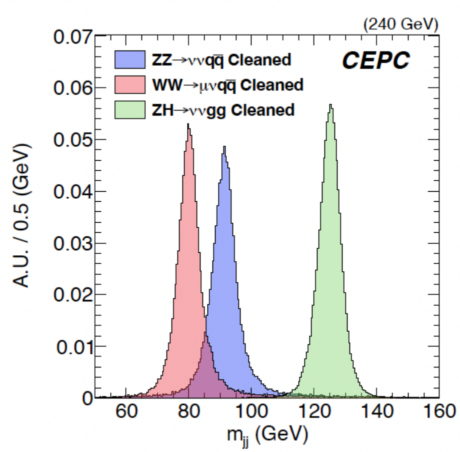
2024 - AURORA: BMR ~ 2.7%

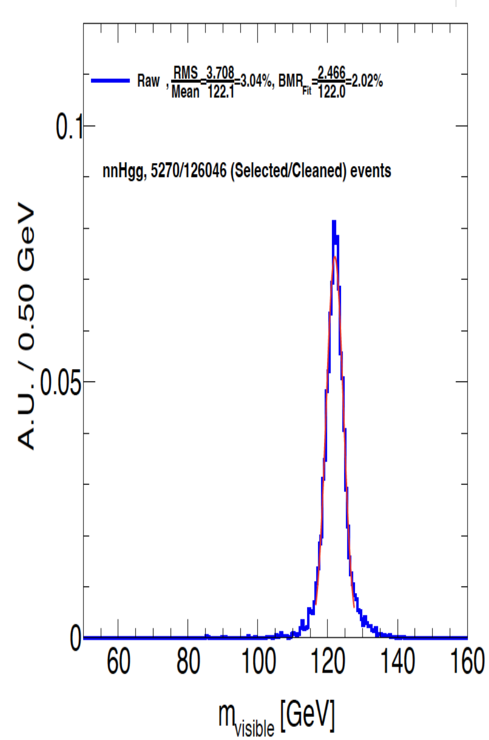


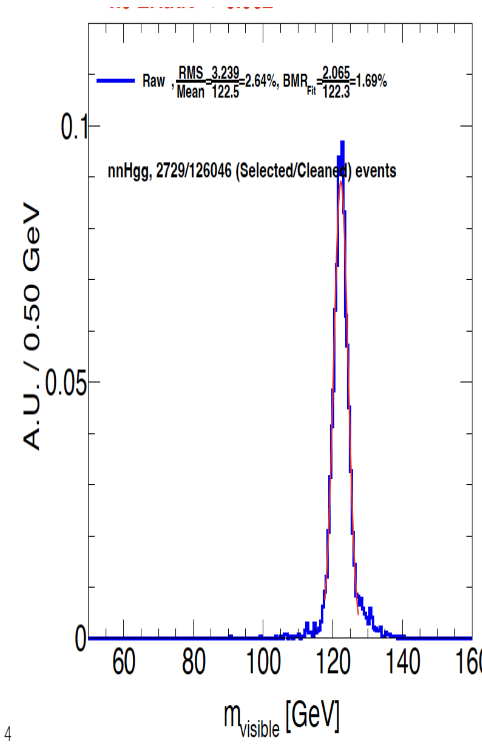
Future: BMR ~ 2.0%



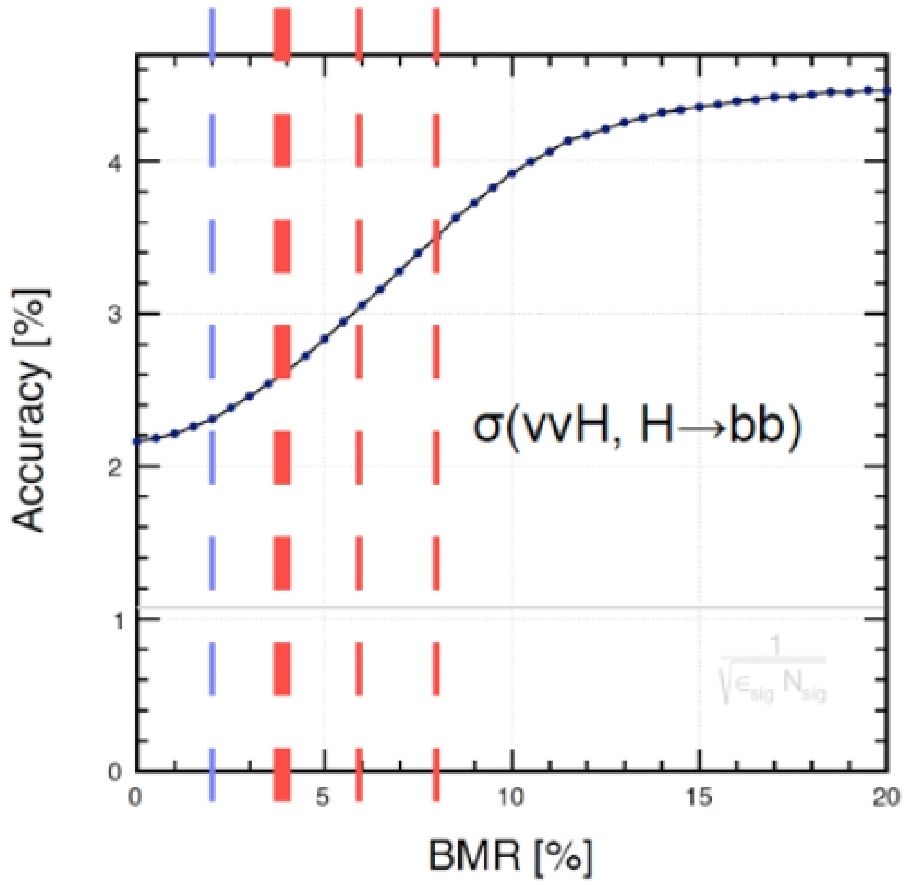


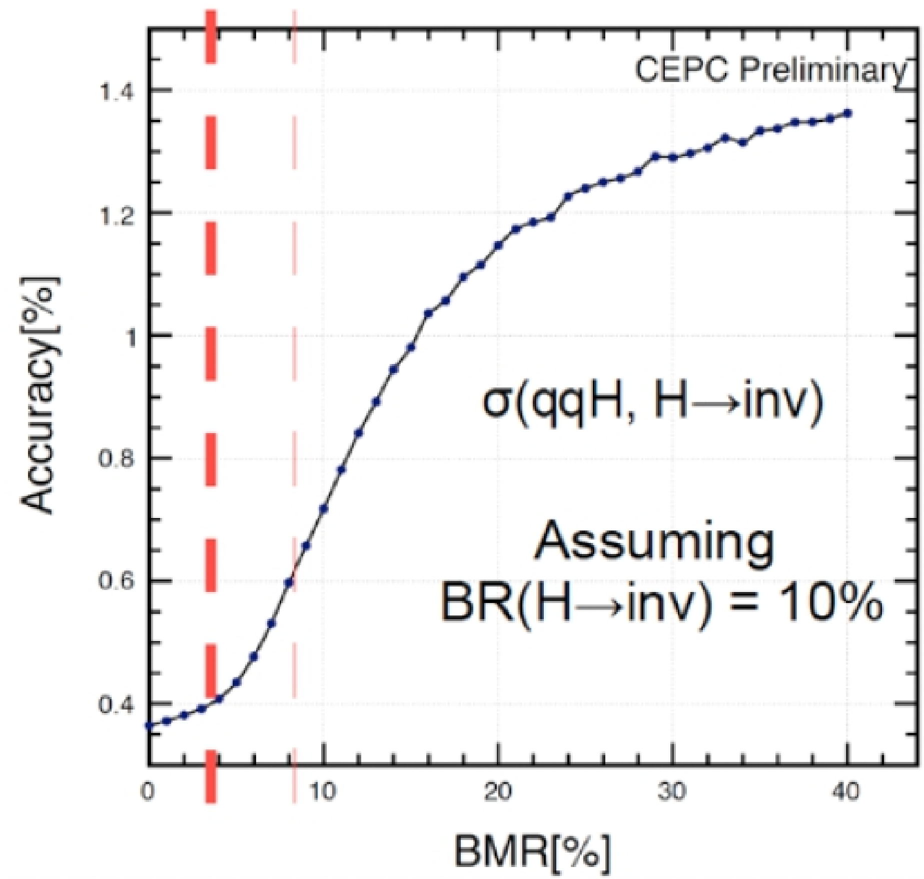






Impact on physics benchmarks...





Accuracies of Higgs measurements improved by ~ o(10%) with conventional analysis...
Critical for g(HZZ) & new physics detection...
Personal Anticipation: larger impact with sophisticated Analysis, i.e., holistic analysis.

Challenges & needed actions...

- Relevant uncertainties, recommend quantification & amelioration A.S.A.P
  - Beam induced background – need PFA in the space time (POST)
  - Event building with Trigger system
  - Geometry acceptance: MDI & FWD design etc
  - Detector stability – mechanic design – simulation & aging study
  - Tracker – Noise, B-Field mapping
  - Calorimeter – Noise, dead zone, inhomogeneity (i.e., attenuation)...
  - Calibration & Monitoring: could be partly addressed by 1-1

Preliminary diagnosis of TRD performance

- In the standard of 1-1 correspondence
  - Visible energy decomposition
  - BMR decomposition
  - Pid

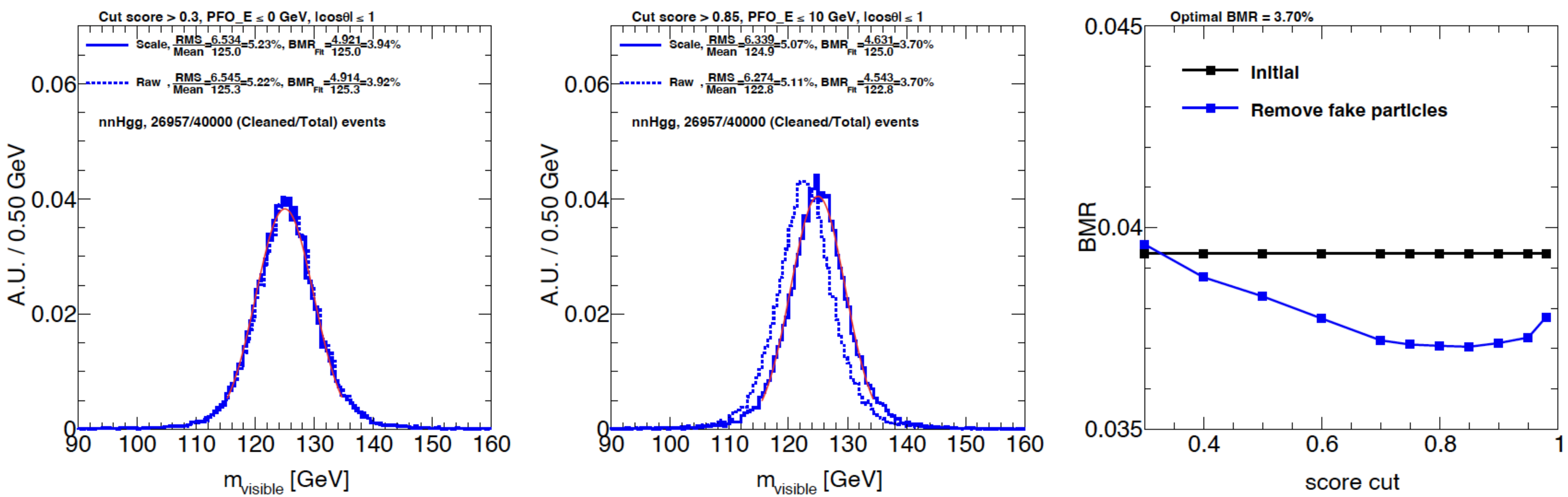
- *This diagnosis needs dedicated MCTruth info, Many Thanks to Fangyi for preparing the sample & update the software*

- *The simulation still has subtitles... especially in the characterize the 2ndary generated in simulation → to be updated.*

Ref-TDR ChFrag veto

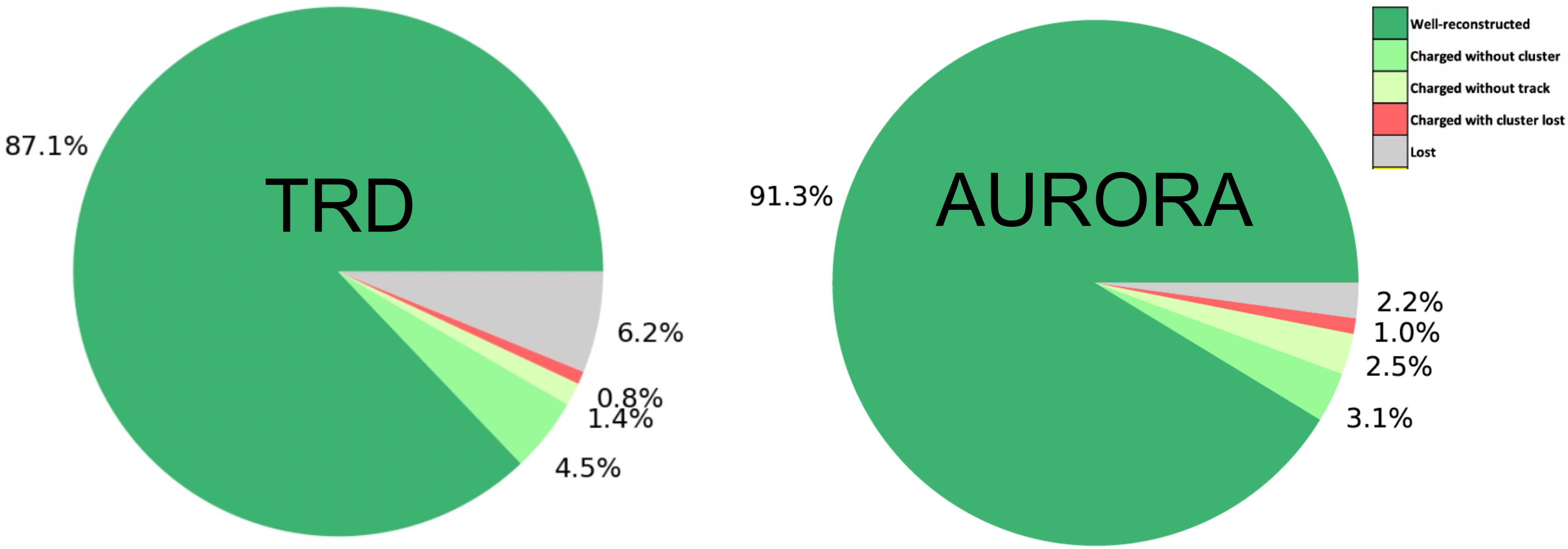
BMR 3.94% -> 3.7% (rel. 6%)

Fangyi's version:
https://code.ihep.ac.cn/guofangyi/cepcsw-release/-/tree/CyberPFA-6.0.8-dev?ref_type=heads
branch CyberPFA-6.0.8-dev



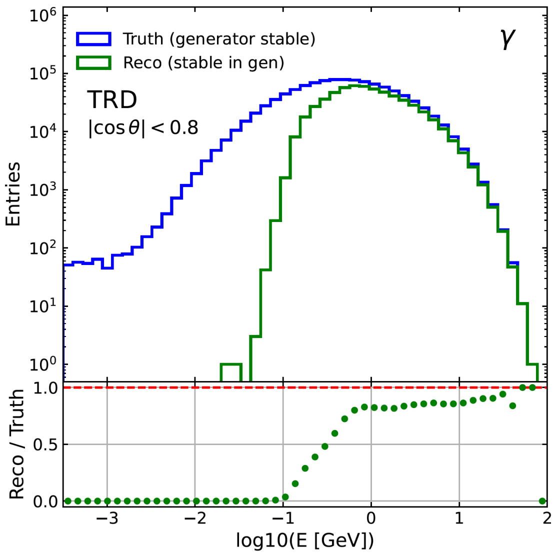
ChFrag Veto: compared to AURORA (3.7/3.4→2.7), much less efficient in TRD as the leading bottleneck is not the fragments

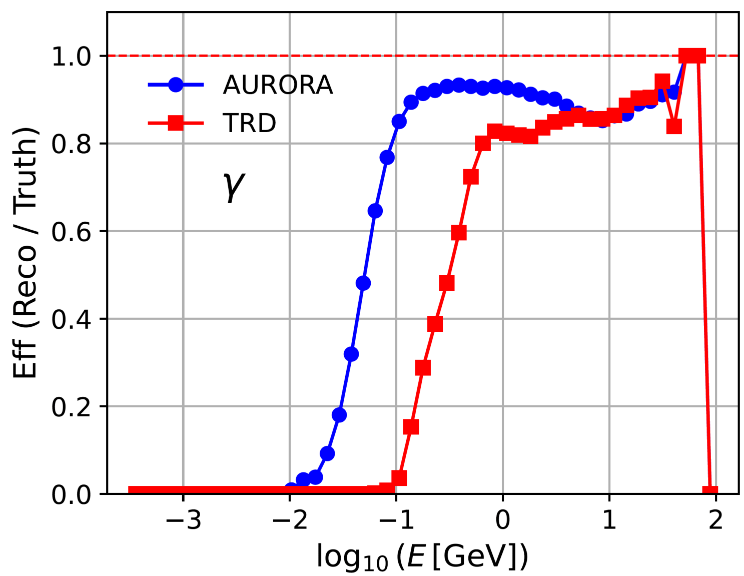
Visible Energy

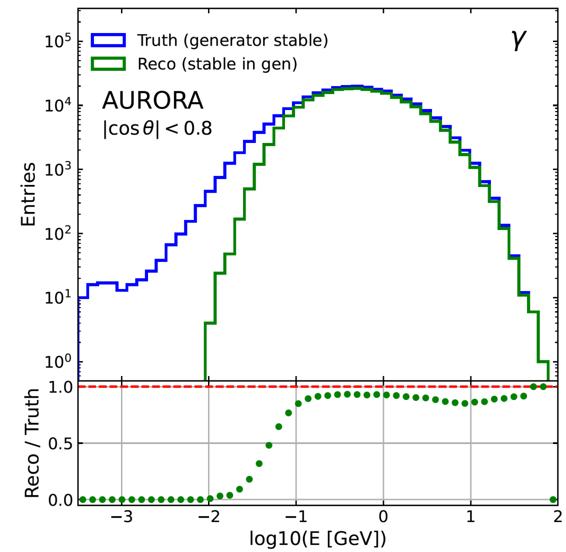


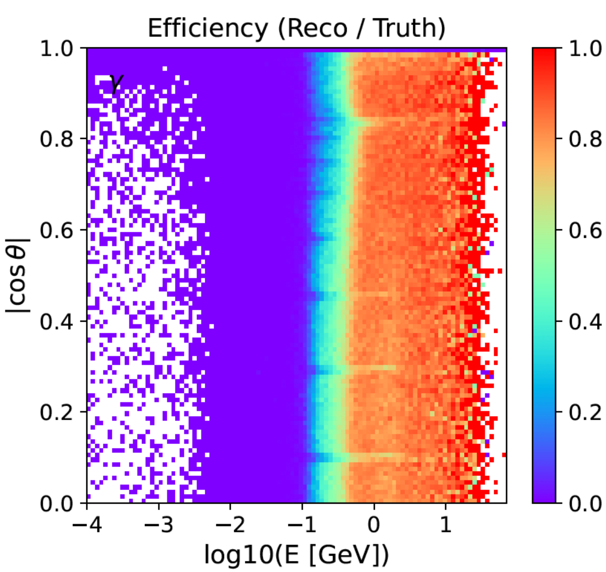
- TDR Ref-det:
  - Ch. wo. Cluster: increased by 50%
  - Ch. wo. Track: reduced to half (Tracking in TRD is actually better)
  - Ch. wi. Cluster Lost: (Double counting) reduced by 20%
  - Lost contribution increased 3 times (5 time if subtract 1% of irreducible Lost due to Acceptance)

Photon reco. efficiency

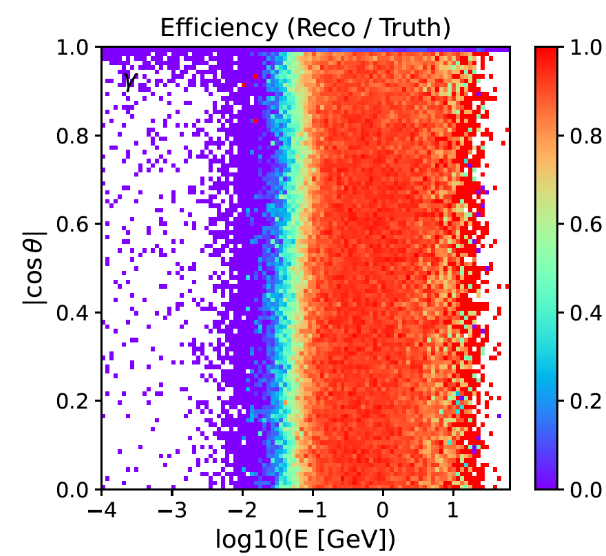




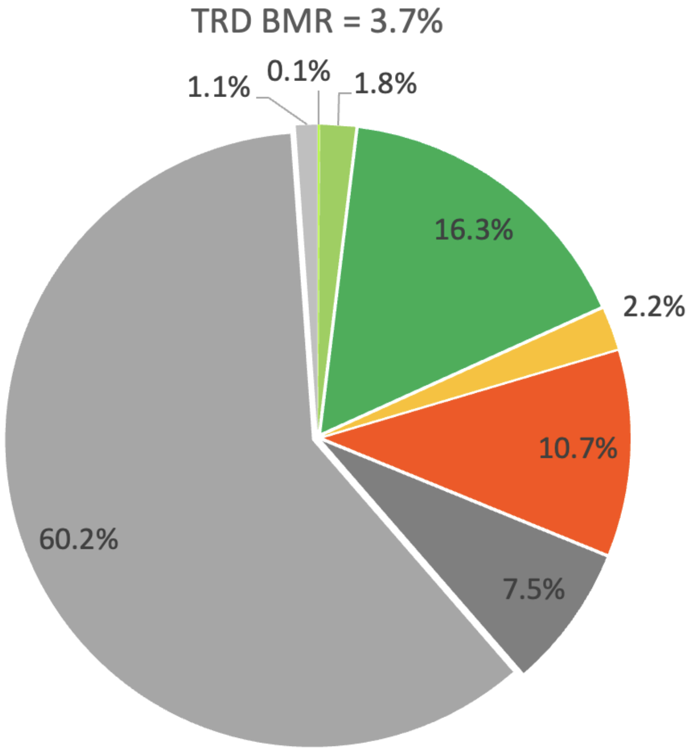


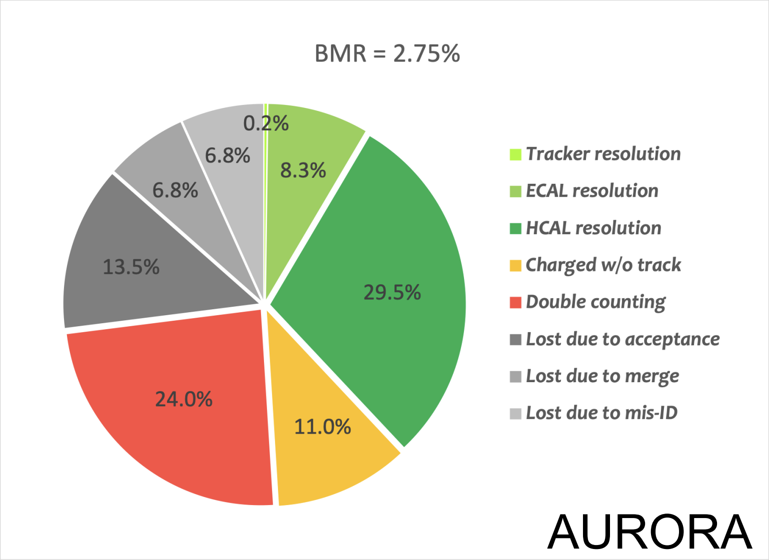


- Converted photon included,
- 10 GeV valley caused mainly by photon merging in pi-0



BMR decomposition

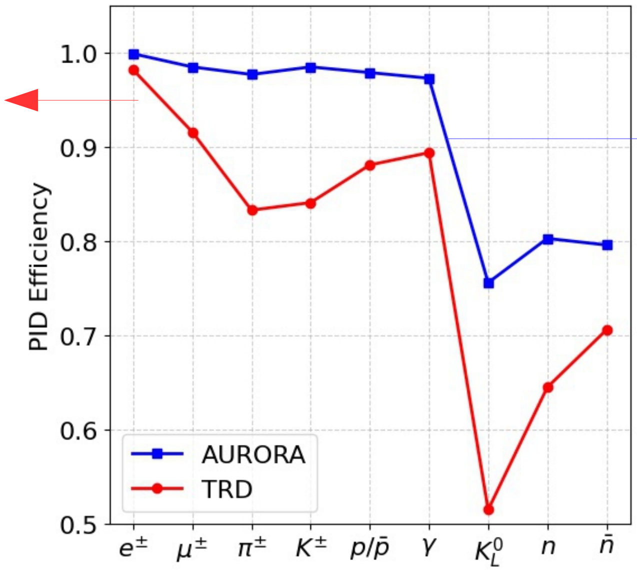




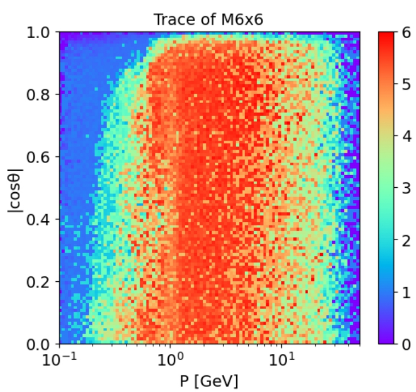
- TRD decomposition: Scaled from AURORA model
- Leading item: Lost due to merge & inefficiency - estimated from two independent methods.
  - Lost Truth Level Particle
  - Lost Total Energy (in taking into account the Double Counted ones).

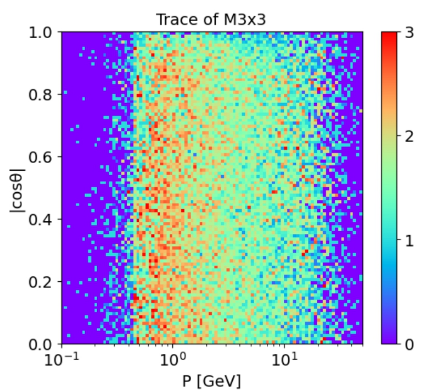
Pid

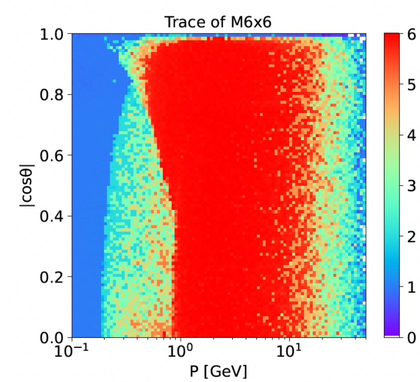
True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.982	0.002	0.005	0.005	0.005	0.000	0.000	0.000	0.000	0.001
$\mu^\pm$	0.002	0.916	0.069	0.010	0.002	0.000	0.000	0.000	0.000	0.001
$\pi^\pm$	0.003	0.064	0.833	0.076	0.022	0.000	0.000	0.000	0.000	0.003
$K^\pm$	0.003	0.007	0.058	0.841	0.088	0.000	0.000	0.000	0.000	0.003
$p/\bar{p}$	0.004	0.001	0.015	0.094	0.881	0.000	0.000	0.000	0.000	0.005
γ	0.000	0.000	0.000	0.000	0.000	0.894	0.037	0.015	0.027	0.027
K_L^0	0.000	0.000	0.000	0.000	0.000	0.116	0.515	0.148	0.180	0.042
n	0.000	0.000	0.000	0.000	0.000	0.051	0.142	0.645	0.117	0.046
$\bar{n}$	0.000	0.000	0.000	0.000	0.000	0.064	0.133	0.072	0.706	0.026
others	0.002	0.002	0.001	0.002	0.001	0.121	0.053	0.099	0.043	0.676

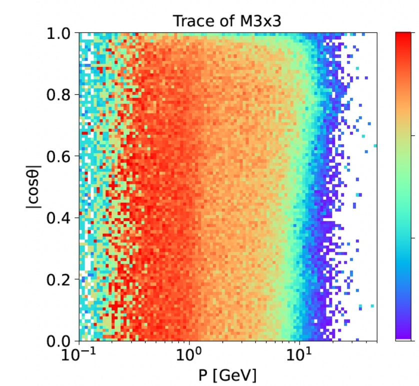


True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\mu^\pm$	0.000	0.985	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.000	0.019	0.977	0.003	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$	0.000	0.001	0.003	0.985	0.011	0.000	0.000	0.000	0.000	0.000
$p/\bar{p}$	0.000	0.000	0.001	0.012	0.979	0.000	0.000	0.000	0.000	0.008
γ	0.000	0.000	0.000	0.000	0.000	0.973	0.003	0.004	0.000	0.020
K_L^0	0.000	0.000	0.000	0.000	0.000	0.007	0.756	0.070	0.048	0.119
n	0.000	0.000	0.000	0.000	0.000	0.003	0.083	0.803	0.027	0.084
$\bar{n}$	0.000	0.000	0.000	0.000	0.000	0.003	0.052	0.026	0.796	0.123
others	0.000	0.000	0.000	0.000	0.000	0.014	0.025	0.095	0.011	0.854







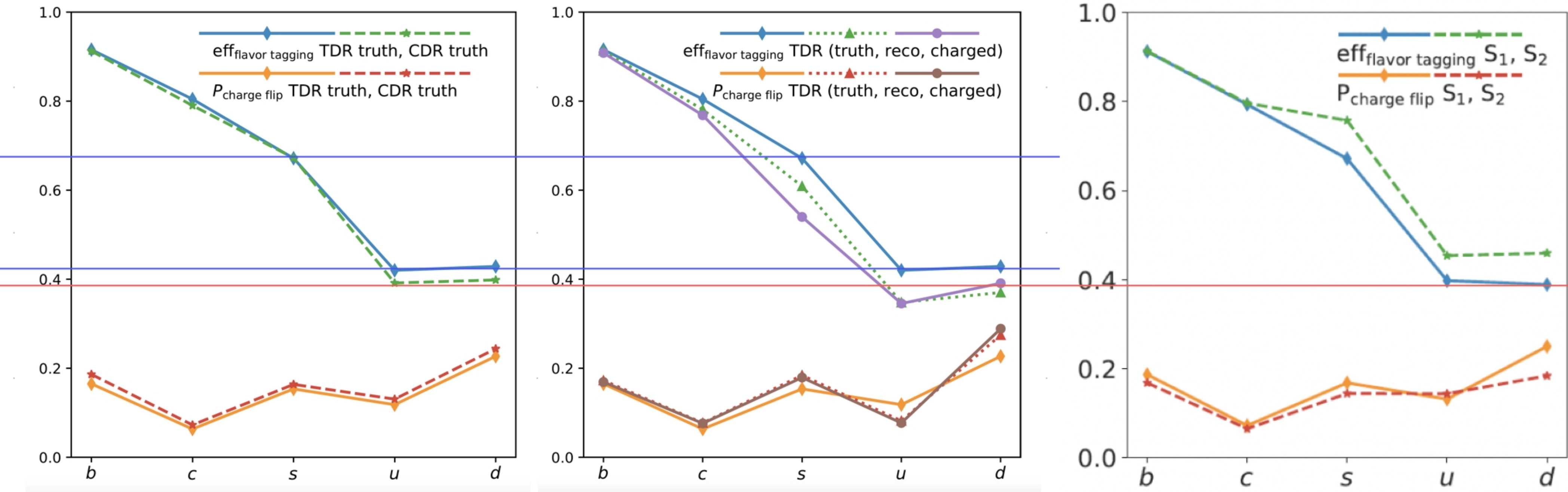


Kaon id: TDR has larger inner TPC radius. To be verified & confirmed quantitatively.

Lepton & neutral Kaon id: relatively limited info. From ECAL in TRD.

Muon det. Info not available in current PFA (both Cyber & Arbor), to be improved.

JoI at TRD, CDR & AURORA (ideal)



Using truth Pid, TRD has better JoI than CDR detector, as it uses longer Barrel + stitching VTX

Pid at TRD is limited, will degrade the H→ss measurement... (software version 0401, not 1-1)

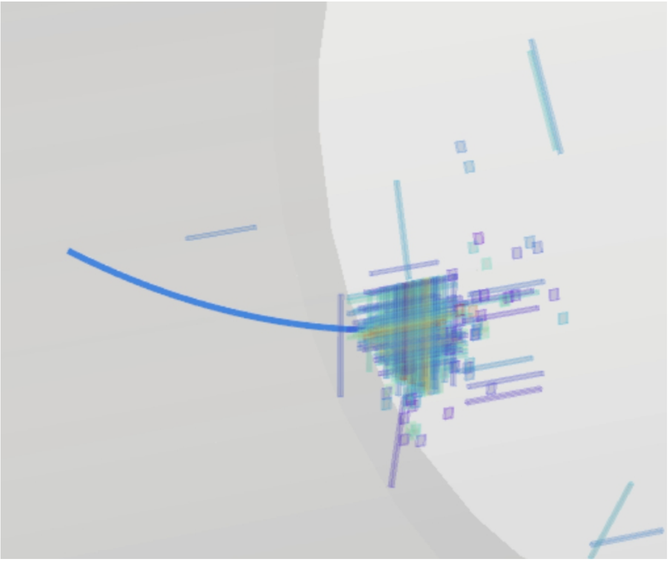
Neutral Hadron ID has strong impact on Light Quark ID: highly appreciated in H→ss

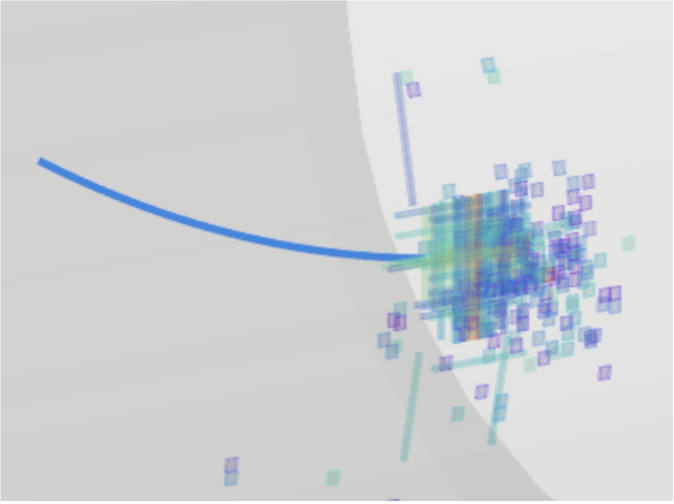
Thoughts on the Det. optimization

- Si-W ECAL: better BMR & Pid
- Xstal ECAL: excellent EM resolution
- 5-d calorimeter is appreciated

- In TRD, the bottleneck is the inefficiency of cluster reconstruction, esp. neutral particles in the jets. Primarily due to the fact that Xbar configuration has large shower volume, causing severer shower overlap – merging

- The current reco need to strength its ability neutral particle reco. While scaling behavior V.S. the bar length & B-Field could be a good starting point.





Thoughts on the Det. optimization

- To minimize the shower volume of incident particles
- To share the task, if necessary, between different det. Technologies
- Propose several concepts, para. to be optimized.

Readout occupies 4% of the ECAL construction cost

Shall we considering ECAL with more readout Channels, and re-optimize its Cell/Bar configuration?

Crystal ECAL: cost estimation

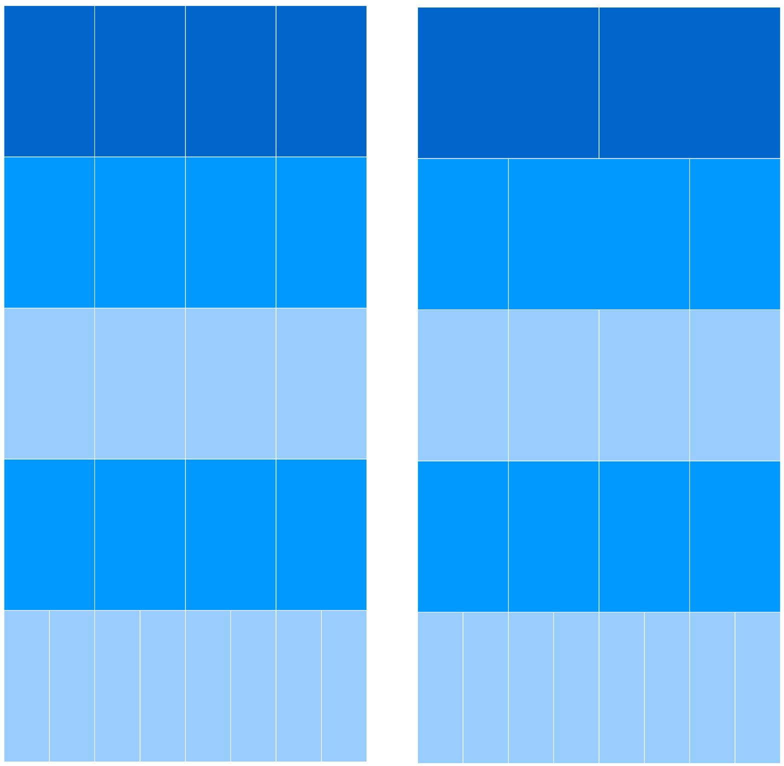
ECAL cost breakdown — Table 7.17

System	Cost (kCHF)
Electromagnetic Calorimeter	114,968
Scintillating Crystal	105,915
SiPM	714
Electronics (FEE)	1,099
Mechanics	3,796
Cooling	96
Installation (3%)	3,349
Extra cost for back-end electronics	2,780

- Crystal ECAL: major cost drivers
  - Crystals: discussions with SIC-CAS; reaching out more vendors
  - SiPMs: experiences of the JUNO-TAO detector (~10m² SiPMs)
  - Electronics (FEE/BEE): inputs from the CEPC electronics team
  - Carbon-fiber mechanical structures: inputs from CF manufacturer(s)

22

Design-1: Crystal/Glass pillars



TDR Total Xstal Volume ~ 24 m^3.

Conceptual para: 5 layers:

First Layer: 1*1*6 cm^3

Last 4 layers: 2*2*6 cm^3

Total readout channels 1.6 Million
Compared to ~ 570 k SiPM readout in Xstal Bar: 7% increase of the ECAL cost.

Needed study: EM resolution evolution with increasing of longitudinal seg (gap, mech, cooling...)

Similar structure could be also used in HCAL, significantly reducing the channel num.

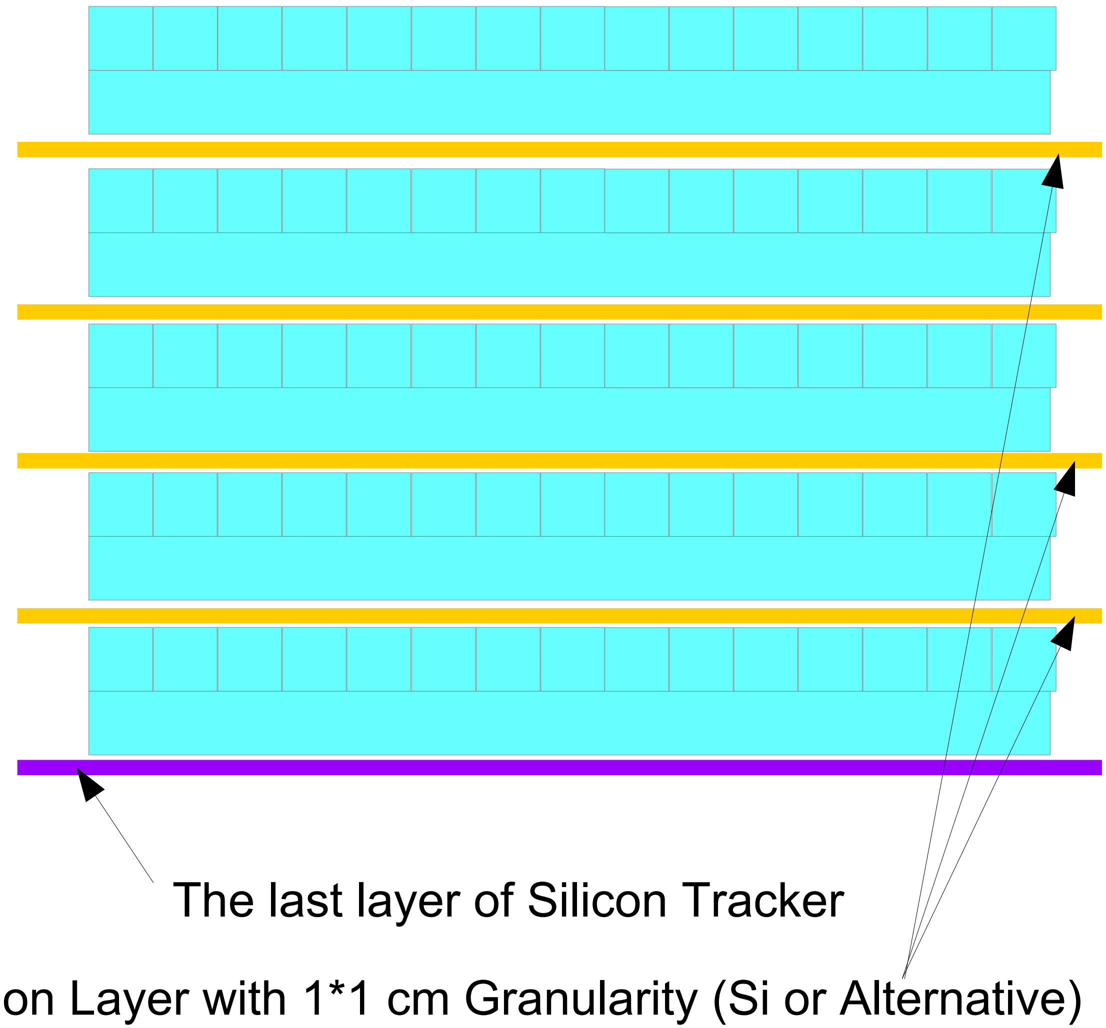
Full absorption HCAL could tolerant much larger cell size, at the cost of glass & total volume increase ~ 10% of the cost.

IP

Full Glass ECAL should also be explored, with much more readout channels.

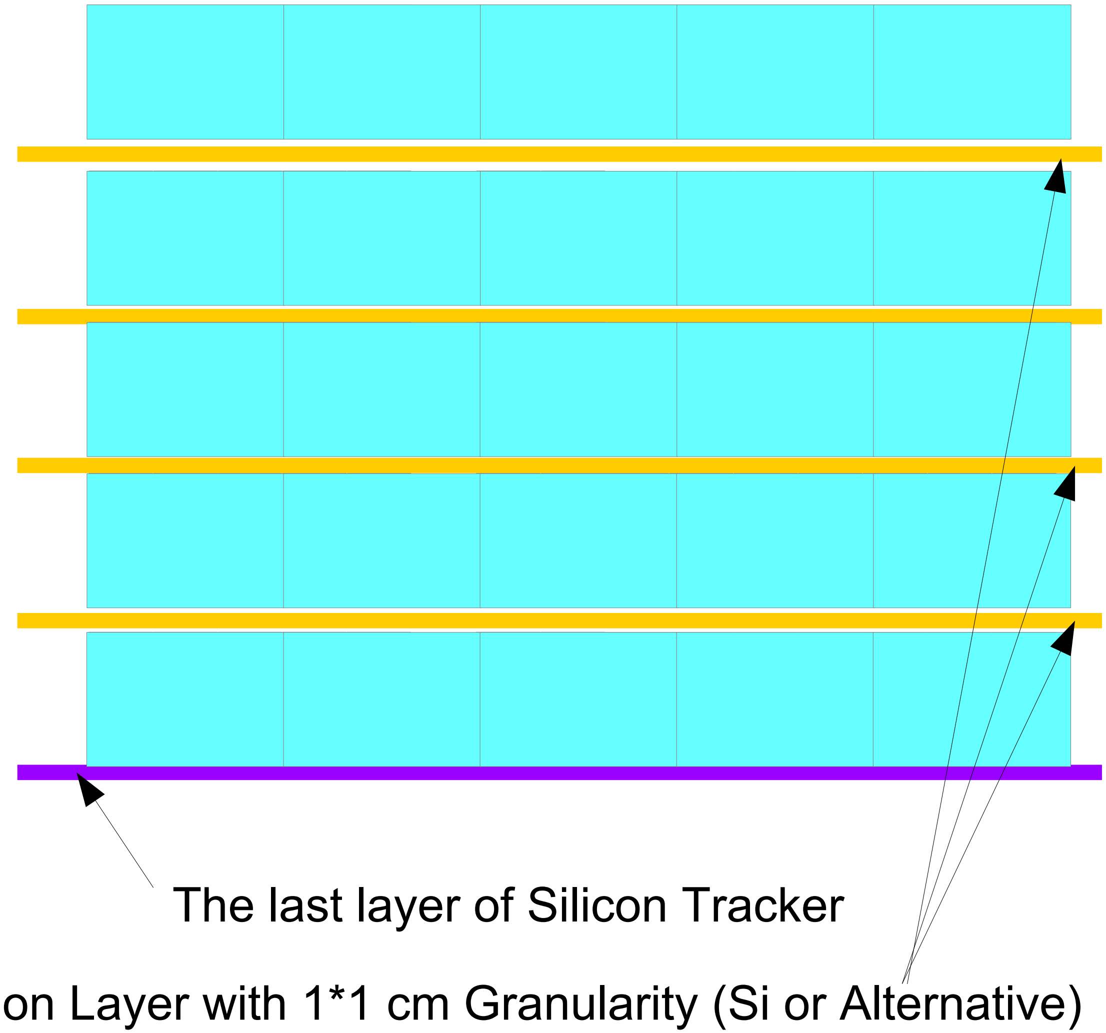
Design-2: Crystal bar + Mesh

- Geometry
  - Total Crystal Volume: 24 m^3
  - Single Crystal Bar Dimension: 2.67cm * 2.67cm * 40cm = 291 cc, In total 80k bars
  - Inner Area: 80 m^2
  - Total Readout Channel:
    - 80000*2 = 160k (Crystal)
    - 800000*4 = 3.2 M (Si)
- Comments
  - Extra material budget ~ o(1%) of the total radiation length is tolerable for the EM resolution ~ 2-3 mm of Cu. per layer

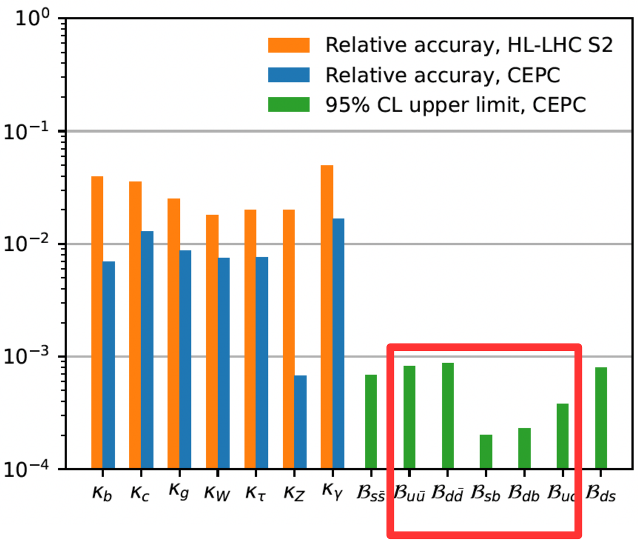


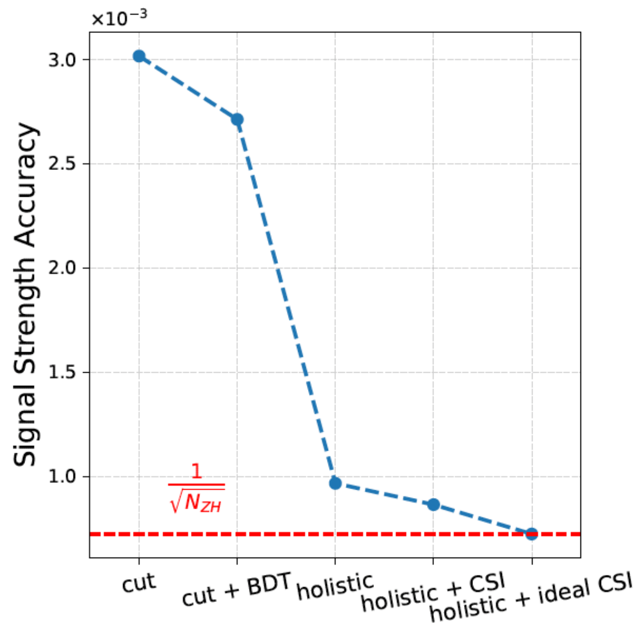
Design-3: Crystal Tile + Mesh

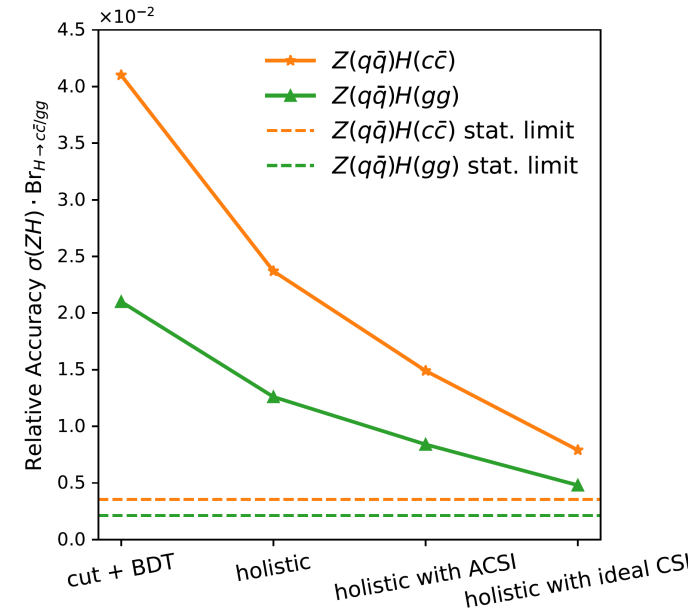
- Geometry
  - Single Crystal Tile Dimension: 6cm *6cm *6 cm = 216 cc
  - Number of Tiles ~ 110 k
  - Inner Area: 80 m^2
  - Total Readout Channel:
    - 110k*(1, 2, 4)? (Crystal)
    - 800000*4 = 3.2 M (Si)
- Comments
  - Should quantify the inhomogeneity response with SiPM couple to larger volume Tile



Performance & Analysis at AI era







- Physics reach significantly enhanced ... showing the irresistible trend
  - Small signal analysis, i.e., H→ss, cc, gg, or its FCNC decays, improves by 3 times to orders of magnitudes
  - Novel methods enabled (i.e., Afb & CKM measurements with JoI, Advanced Color Singlet Identification, ...)
  - Strong impact on σ(ZH), Higgs invisible anticipated.

AI era: Holistic approach

- Feed all reconstructable info. to the classifier – in principle free of human intervene (no need to find Cut variables, etc..). Require excellent detector & reconstruction, where 1-1 serves as a benchmark & standard
- Supervised Learning – Systematic uncertainty control is the challenge, esp. for precision measurements. Relies strongly on accurate simulation
  - Theoretical: need dedicated efforts on theoretical framework, For the Higgs factory, the challenges include high precision perturbative calculation, the hadronization models, and potentially QCD effect like color-reconnection effects
  - Experimental: need profound understanding of the detector response – requires innovative Calibration & Monitoring, plus Digitization & Validation. For which, the 1-1 provides much more observable and ways...
  - Need comparative analysis over the relevant phase space, to control & to understand the scaling behavior, which will also shed light on AI development.
  - Exploration just started
- Longer term... non-supervised learning, or even migrate to LLM/General models...
- Even longer term: Data stream + information compressing using reco + analysis + interpretation... AI is essential, plus we need to set check points & mile stones to quantify and understand its behavior

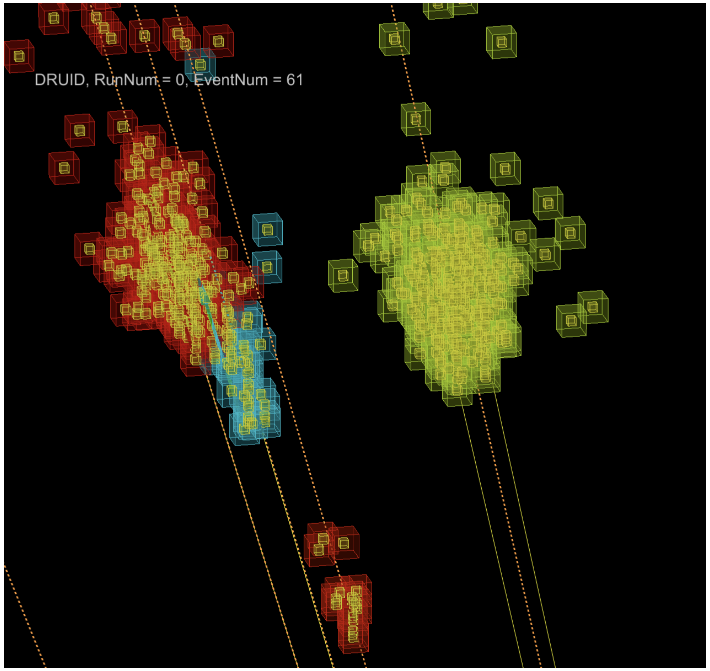
Necessary studies...

- Beam induced backgrounds: comparative studies...
- Event building with realistic detector time response, including electronic pulse shape & time sequence...
- TPC & Tracker:
  - Dependence of dE/dx or dN/dx performance on the shifting distance & readout threshold/Noise
  - Ion distortion VS shielding & possible correction
  - B-Field mapping
  - Mechanic stability
  - Low Pt track reconstruction
- Calorimeter
  - SiPM: response uniformity & Dynamic range, especially towards large Tile/Bar configuration in ECAL
  - Requirement on the Attenuation length...
  - Homogenates in space & stability in time
  - Development of Energy & Time Estimator...
- Dead zone/dead channel tolerance
- Performance degrading with different Noise: rates, intrinsic, and radiation relevant ones
- Calibration Procedure & Monitoring methodologies...

Summary

- We propose and realize the concept of 1-1 correspondence reconstruction
  - Within the reach of current technology & strongly boost the discovery power
  - A novel standard to quantify the global detector performance
- BMR achieved 2.7% at AURORA (CDR detector + GSHCAL), with a future perspective of 2%
  - Roadmap demonstrated
  - Needs lots of developments
- Diagnosis with 1-1, TDR Ref Det
  - Improves its BMR to 3.7% (relative. 6%)
  - The bottle neck is “LOST particle”: inefficiency to reconstruct neutral particles
  - Has limited Pid performance, but better tracking (esp. Low momentum ones). Comparing AURORA with TRD provides quite some inside & possible synergies.
- Propose three different approaches to further optimize the CEPC Detector, ...
- Impact of Beam induced backgrounds & Detector imperfects need to be studied, A.S.A.P.
- ***... Higgs factory should and could have excellent performance ...***

Back up



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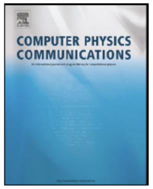

Computational Physics

One-to-one correspondence reconstruction at the electron-positron Higgs factory

Yuexin Wang [a,b], Hao Liang [a,c,d], Yongfeng Zhu [e], Yuzhi Che [a,f], Xin Xia [a,c], Huilin Qu [g], Chen Zhou [e], Xuai Zhuang [a,c], Manqi Ruan [a,c,*]

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[f] China Center of Advanced Science and Technology, Beijing, 100190, China
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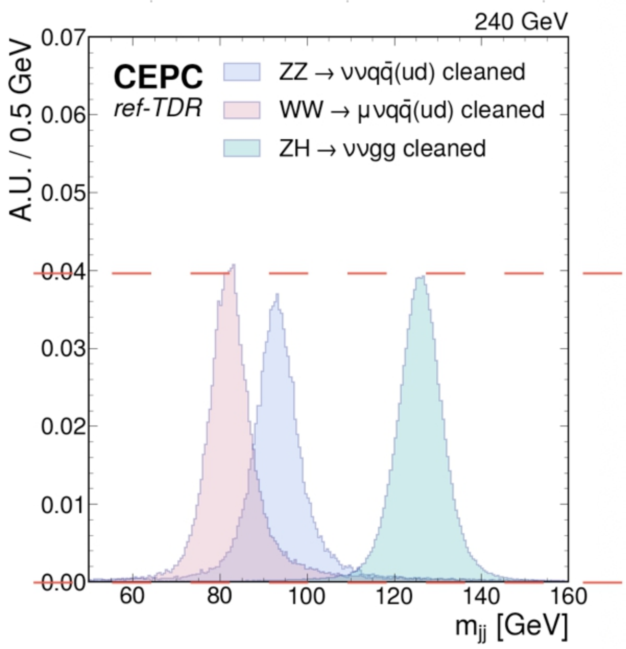
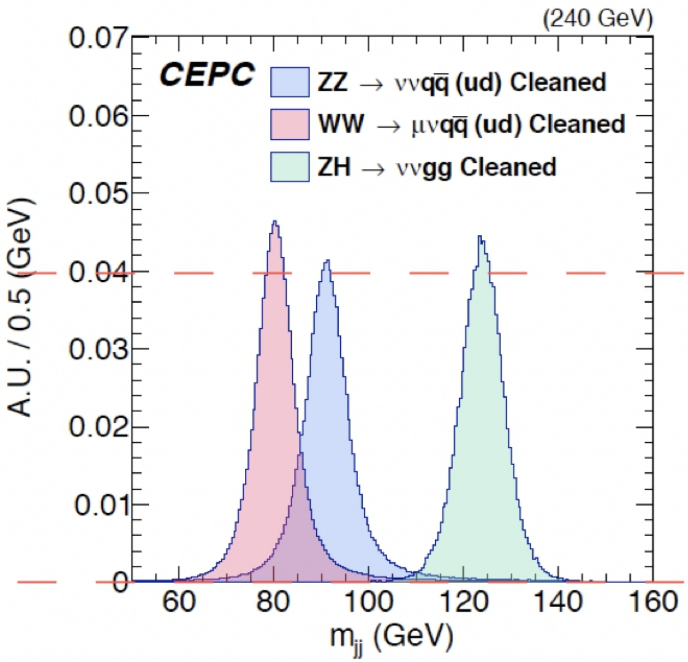
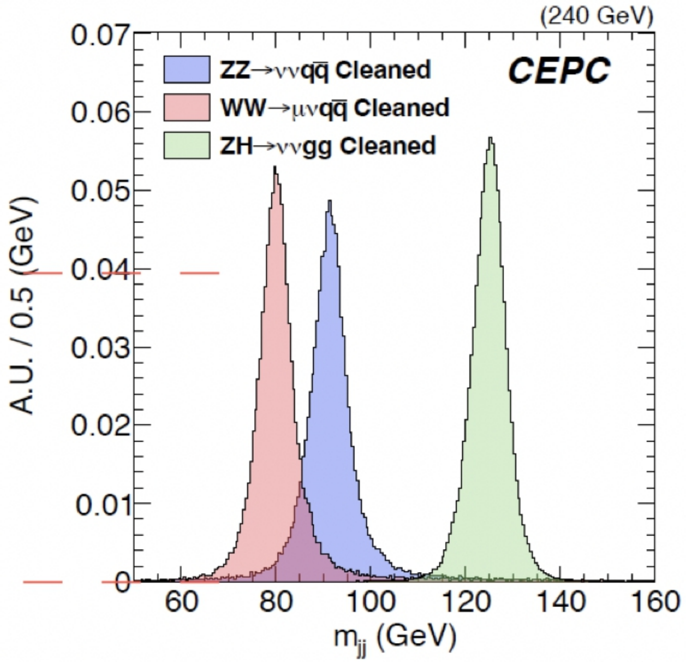
Table A.2
Input variables of ParT.

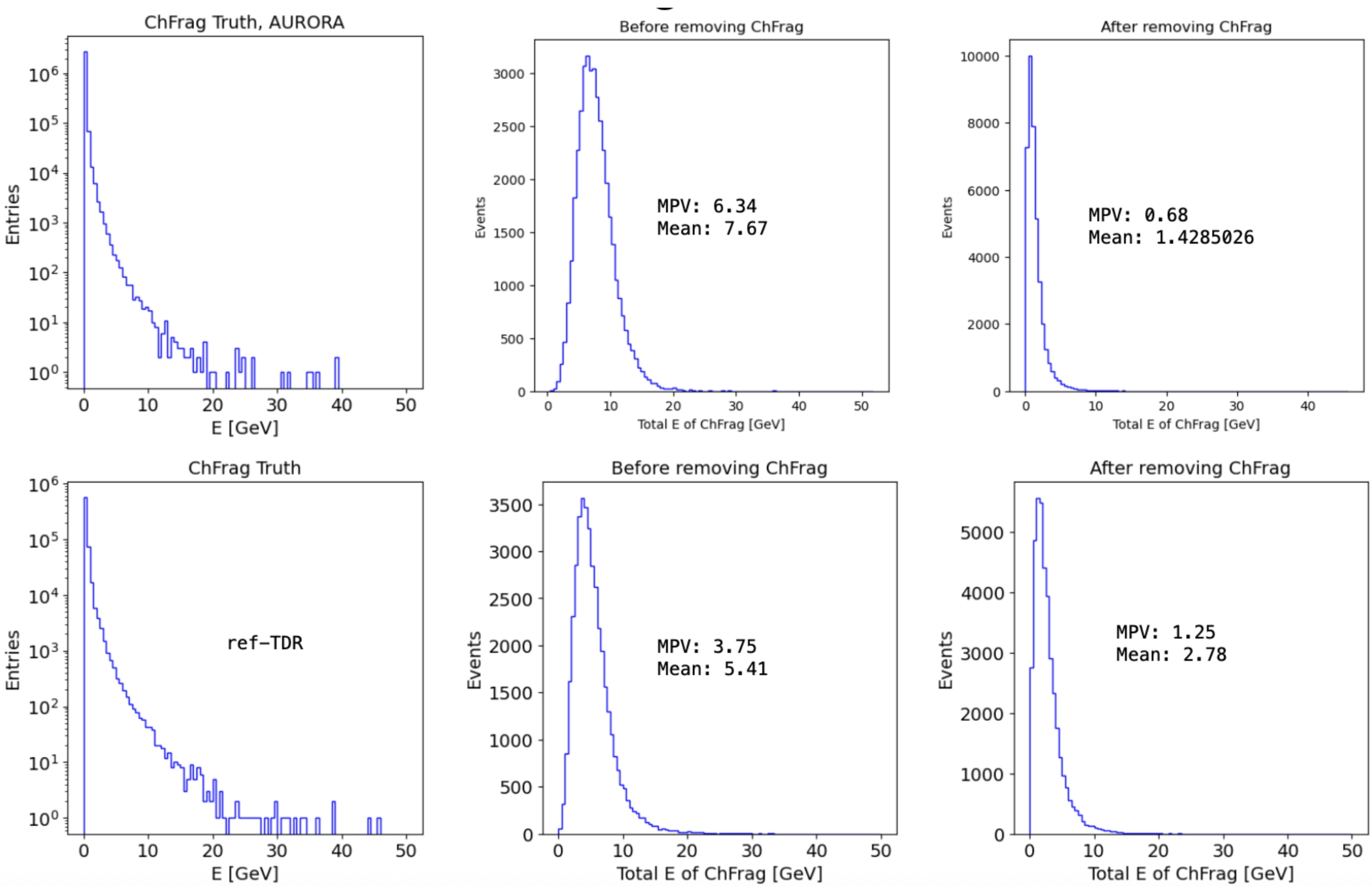
Object level	Observable variables
Reconstructed particle	4-momentum (E, p_x, p_y, p_z) Direction (θ, ϕ) Number of tracks and clusters
Track	Number of hits Endpoint position 3-momentum $(\|\vec{p}\|, p_x, p_y, p_z, p_T)$ $\mathrm{d}E/\mathrm{d}x$ (mean of 5–85% truncation and quartiles)
Cluster	Number of hits Energy Position of shower starting point Position of center of gravity Fractal dimension [58] Second moment (M_2) Distance between ECAL inner surface and shower starting point Distance between ECAL inner surface and center of gravity Distance between ECAL inner surface and the innermost hit Distance between ECAL inner surface and the outermost hit Maximum distance between cluster hits and the track helix (for charged particles) Maximum distance between cluster hits to the axis from the innermost hit to the center of gravity Average distance between cluster hits to the axis from the innermost hit to the center of gravity Hit time spectrum (the fastest time and quintiles) Minimum distance between cluster hits of each other
Closest charged cluster	Number of hits Energy Ratio of E_{cluster} to p_{track}

BMR comparison

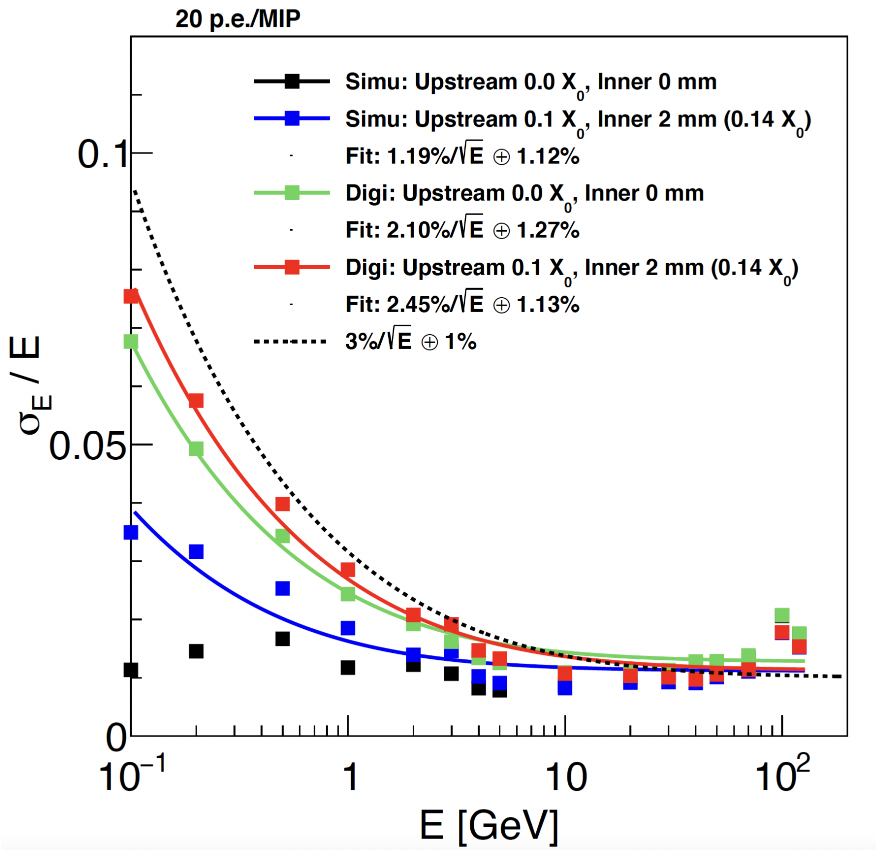


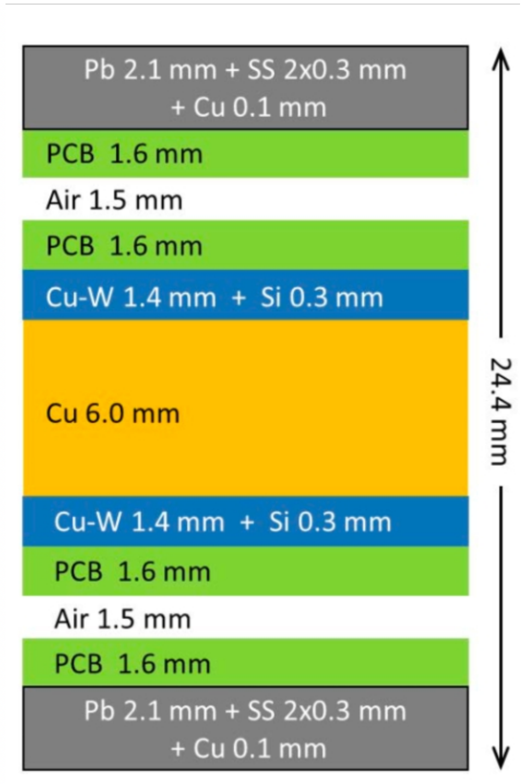





ChFrag Truth, AURORA
Entries
E [GeV]
Before removing ChFrag
Events
Total E of ChFrag [GeV]
MPV: 6.34
Mean: 7.67
After removing ChFrag
Events
Total E of ChFrag [GeV]
MPV: 0.68
Mean: 1.4285026
ChFrag Truth
Entries
E [GeV]
ref−TDR
Before removing ChFrag
Events
Total E of ChFrag [GeV]
MPV: 3.75
Mean: 5.41
After removing ChFrag
Events
Total E of ChFrag [GeV]
MPV: 1.25
Mean: 2.78

EM resolution





CMS HGC Project:

600 m^2 Si + 300 m^2 Sci

Total cost:
69 M CHF ~ 500 M CNY

~~

CEPC:

~ 300 m^2 Positioning Layer

~ o(100) M CNY

- Positioning layer: material budget of ~ 0.2 X0 (3 mm Cu) each, total fraction < 3%
- Compatible with CMS HGC Silicon layer wi cooling; which has much higher data rate & requirement on energy reco. -> further optimization is possible

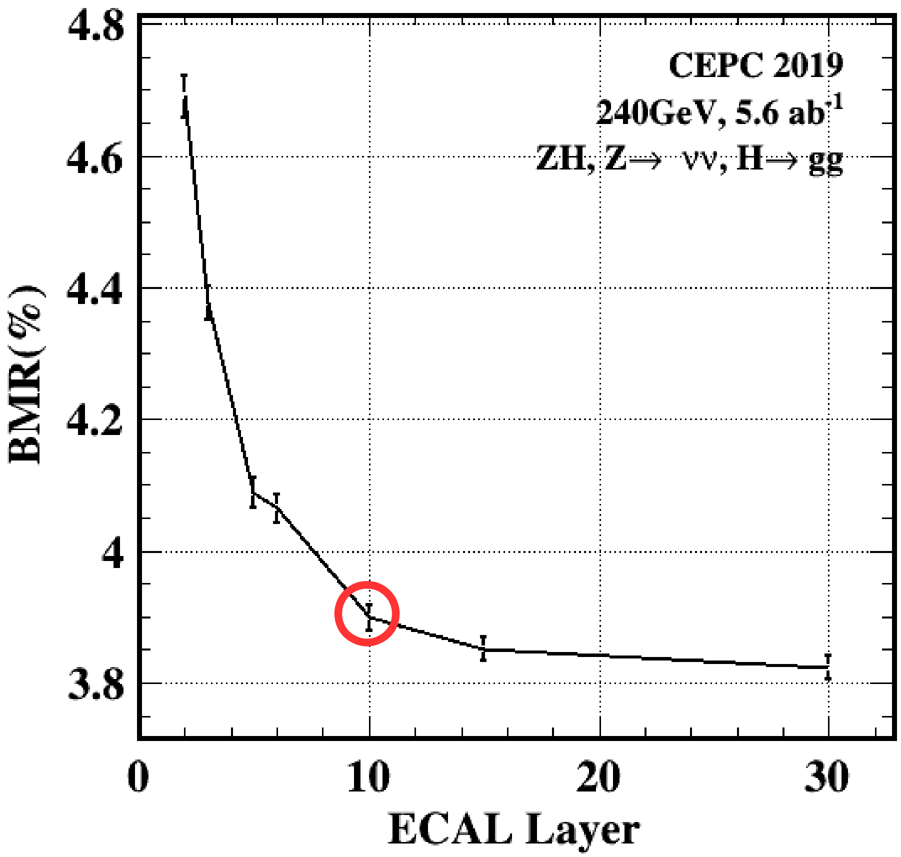
BMR

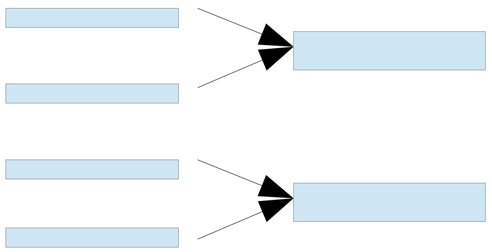
- Optimization study at Baseline – Merge Hits of neighboring layers in longitudinal direction. Compared to 30 Si-W layers, 10 layers has a relative degrading of 2% (3.82 → 3.9)

- 5 double-layers + 4 silicon sensors + advanced algorithm shall comparable to 10 layers... if not better

- Better EM resolution of Xstal ECAL has positive impact on BMR

- BMR shall be comparable to baseline





Color Singlet Identification

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The Higgs→ $b\bar{b}, c\bar{c}, gg$ measurement at CEPC

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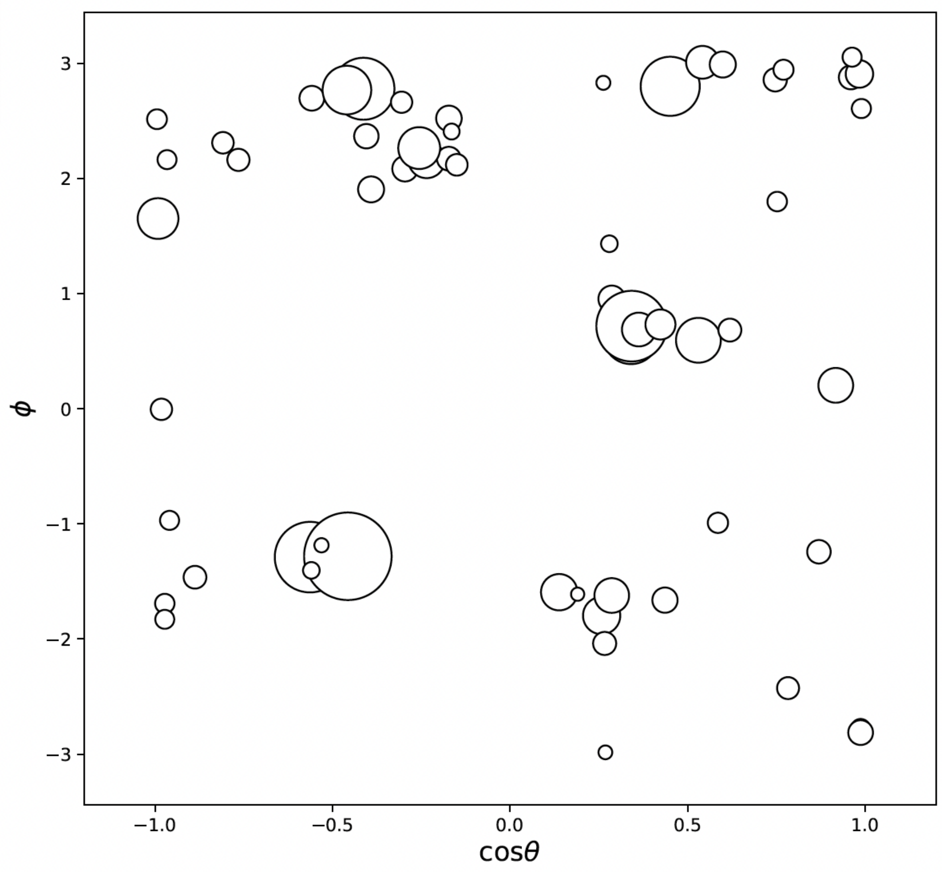
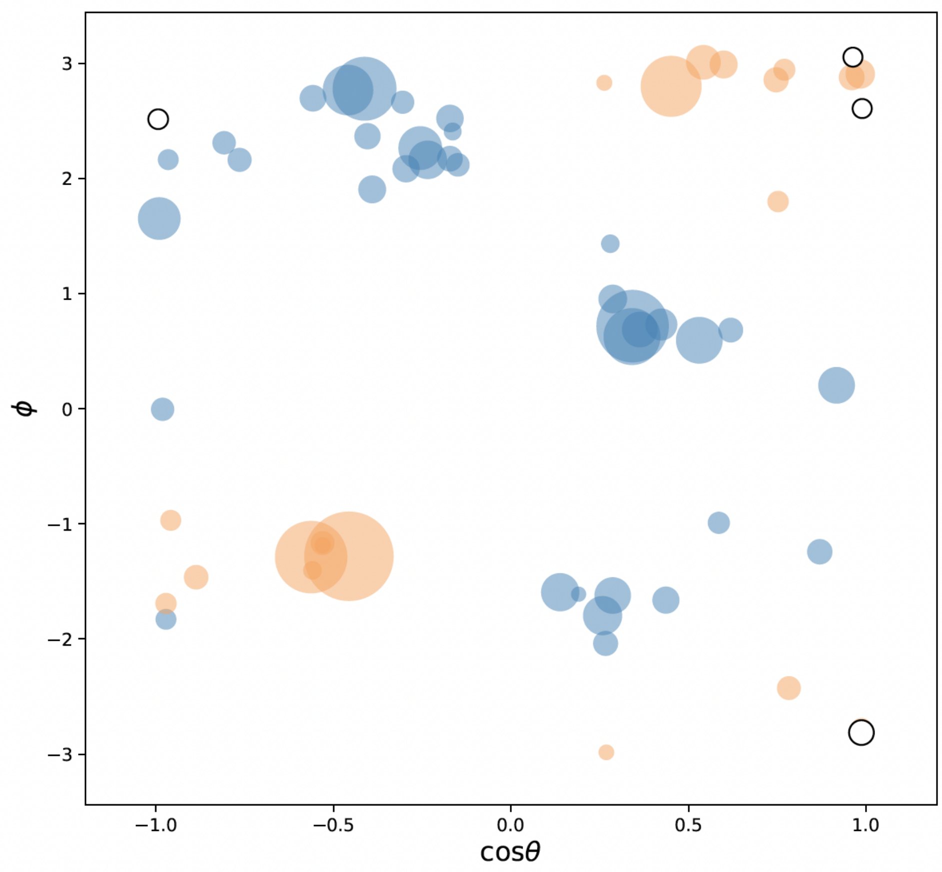
Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

Table 3. The signal strength accuracies for different channels.

- H→cc & gg measurements at qqH channel is much worse vvH channels, despite the former has 3.5 times more signal statistic
- Reason: Failure of Color Singlet Identification – to distinguish the decay products of each Color Singlet
  - Z & H for 240/250 GeV Higgs factory
  - Which Higgs boson for Higgs self-coupling measurements (i.e., at vvHH events at 500 GeV, etc)

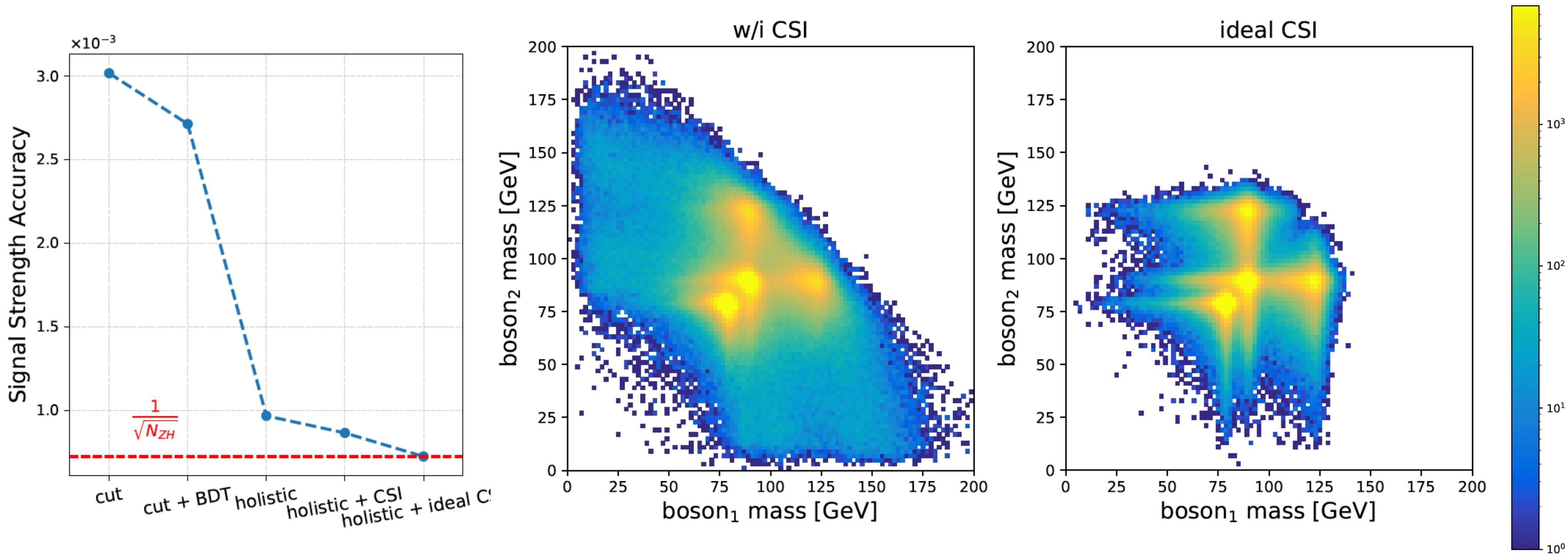
CSI: to group the final state particle





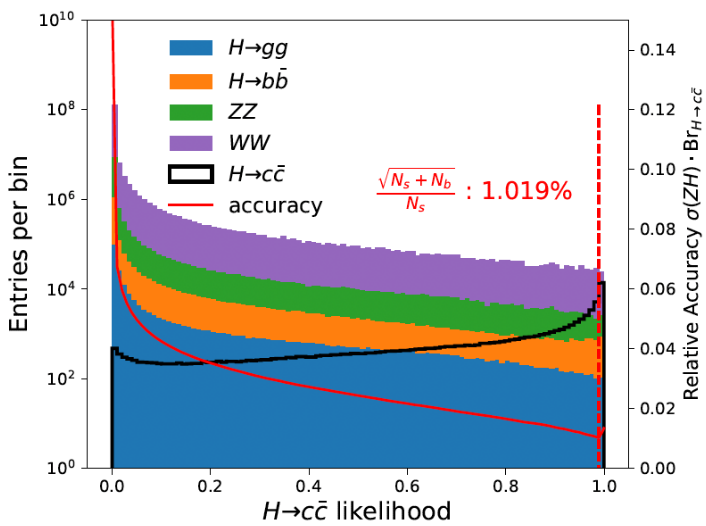
A toy analysis: identify full hadronic ZH signal from ZZ + WW background

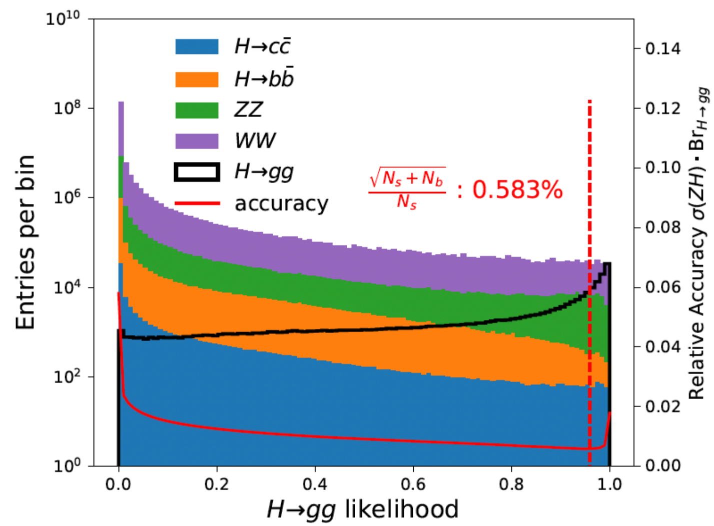
540k ZH + 3.1M ZZ + 47 M WW full hadronic events (~ 5.6 iab), result scale to 20 iab

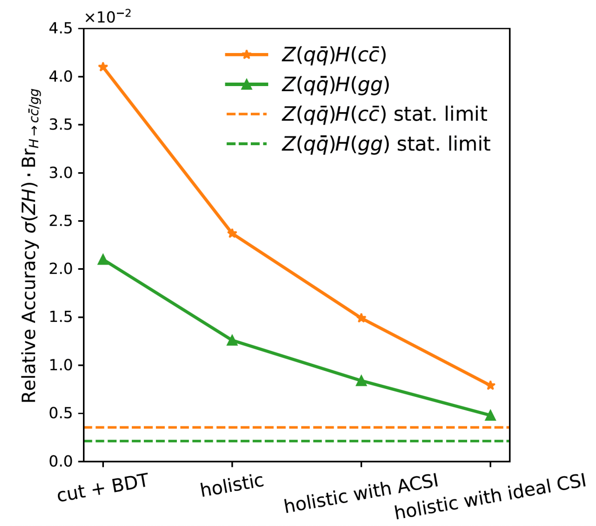


Holistic: use all the reconstructable info to category signal & different background

Measurement of qqH, H→cc, gg





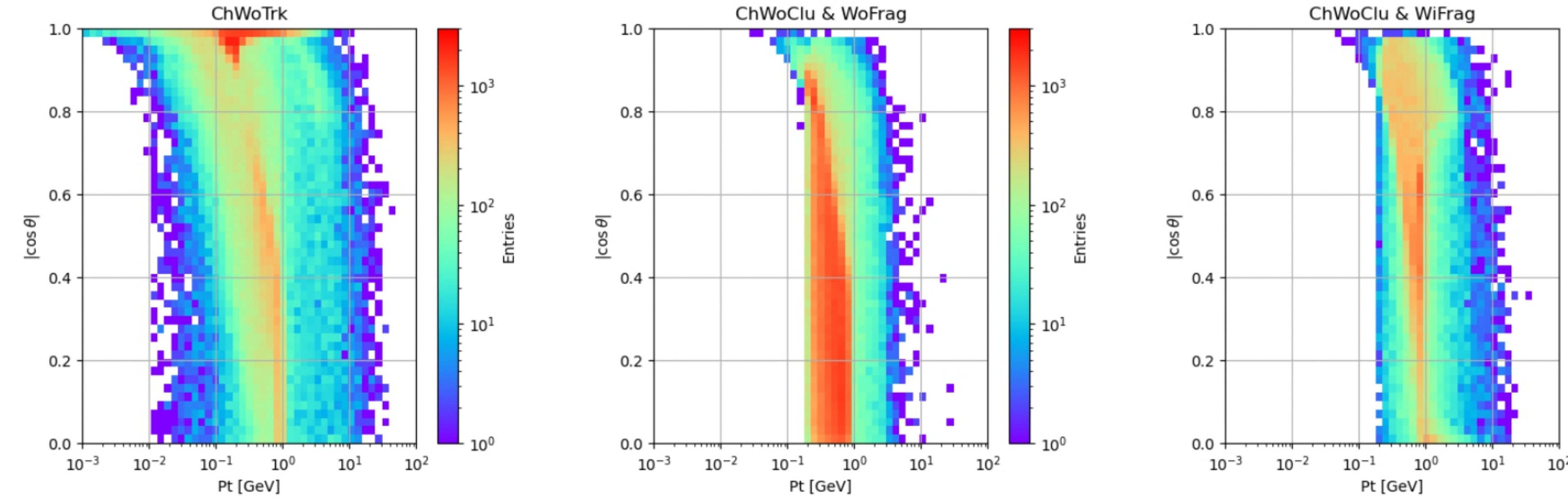


		$H\to c\bar{c}$	$H\to gg$
w/o	holistic	1.82%	1.04%
other SM	holistic with CSI	1.02%	0.58%
background	holistic with ideal CSI	0.41%	0.23%
w/i	conventional (JC + JM)	4.10%	2.10%
other SM	holistic	2.37%	1.26%
background	holistic with CSI	1.49%	0.84%
	holistic with ideal CSI	0.79%	0.48%

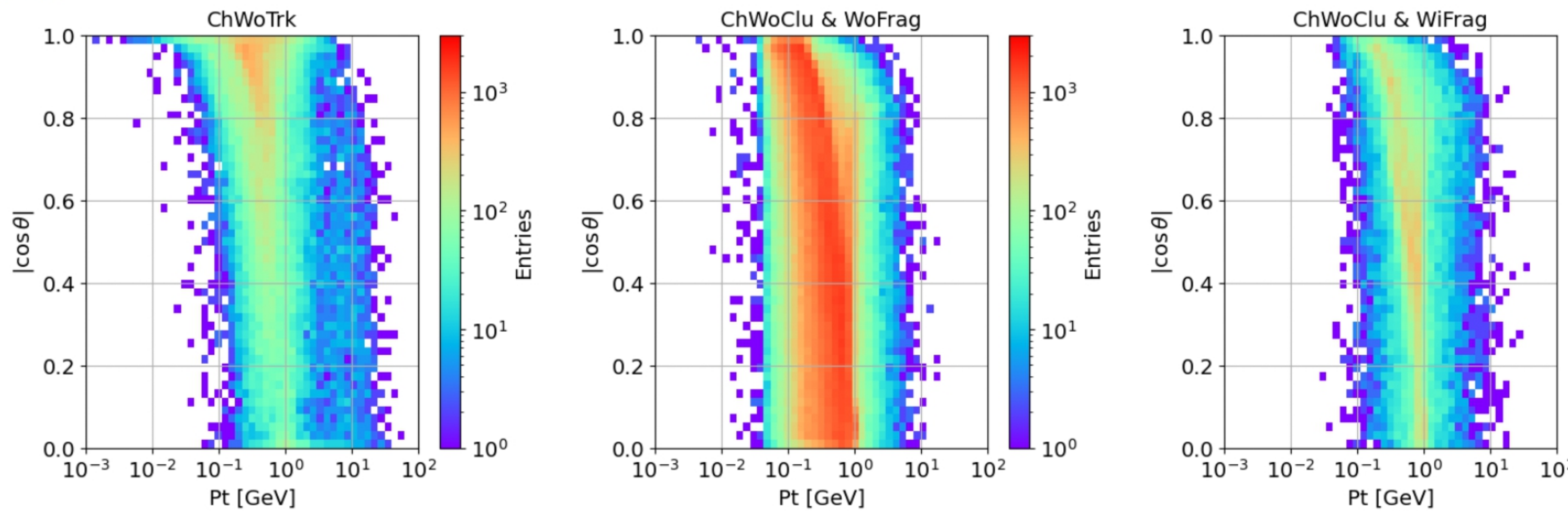
Accuracies improved by 3-4 times with irreducible/full SM backgrounds

Compare to excellent CSI – could be further improved by ~ 2 folds: significant potential - needs further explore....

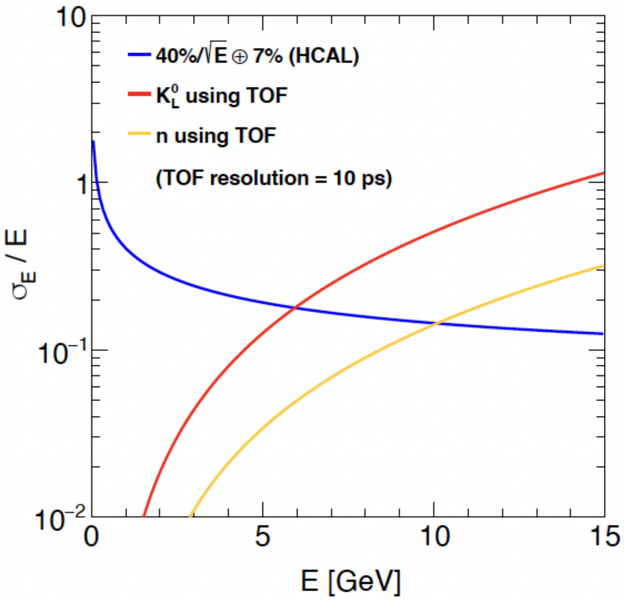
AURORA (SiWECAL+GSHCAL)

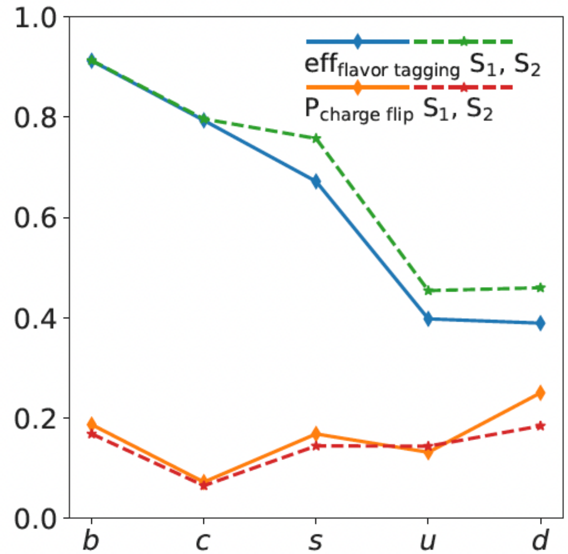


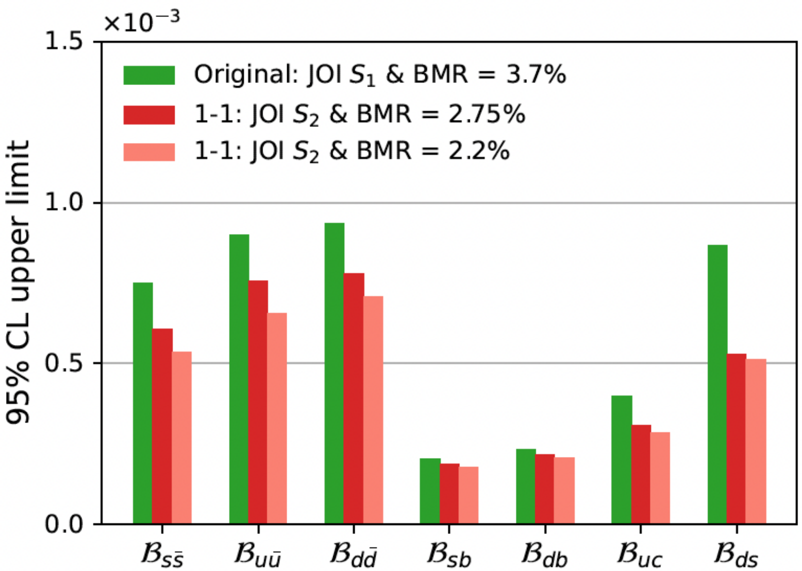
ref-TDR



Perspectives with 1-1 correspondence







- ToF enhanced energy measurement: BMR: 2.8 → 2.2-2.4
  - Need excellent CALO + ToF ~ o(10 ps)
  - Assume Low energy neutrons & secondary particles can be tamed... still very challenge...
- Strongly Boost the light quark ID.
- Benchmark precision improved... up to nearly two times.