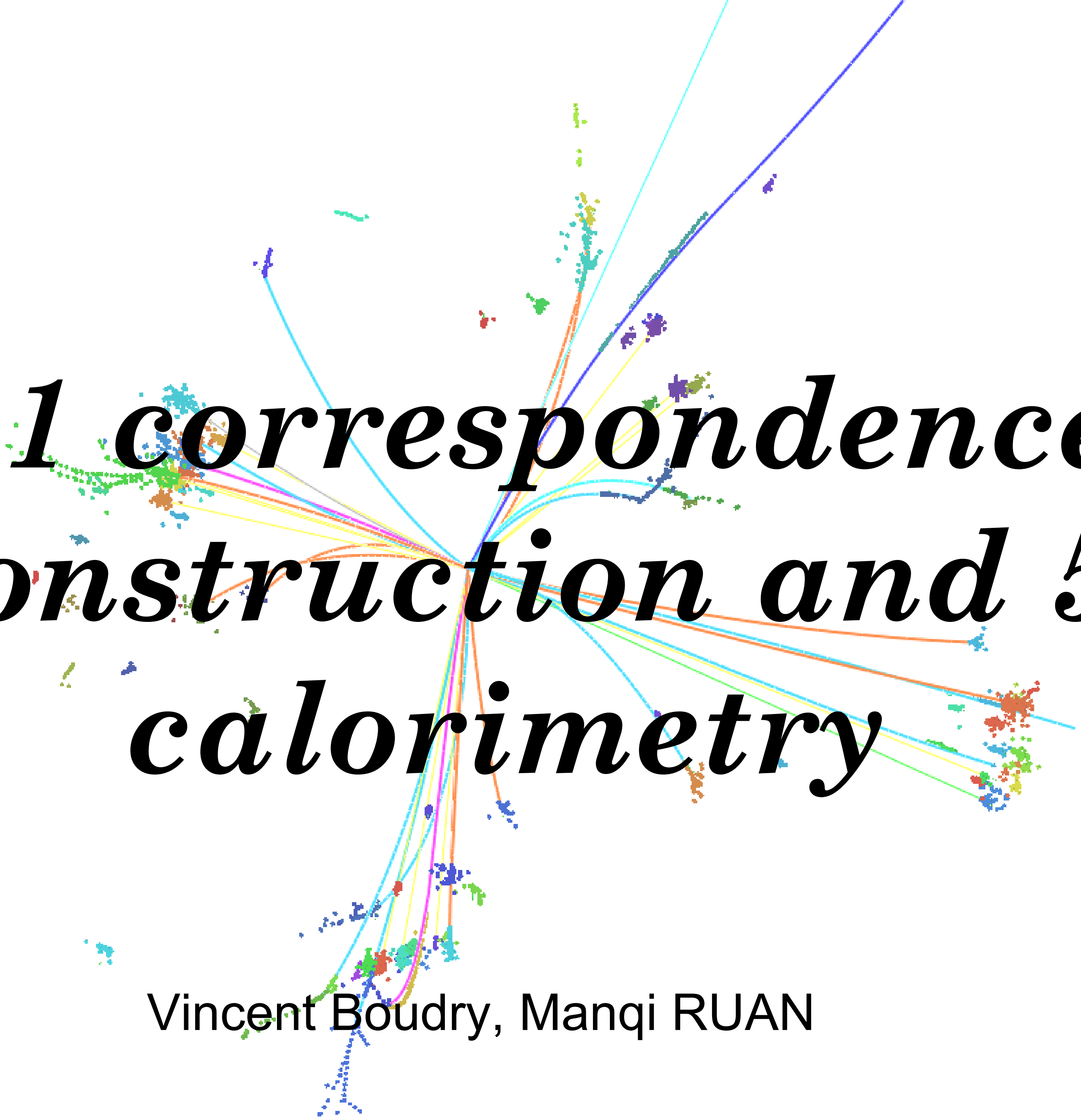
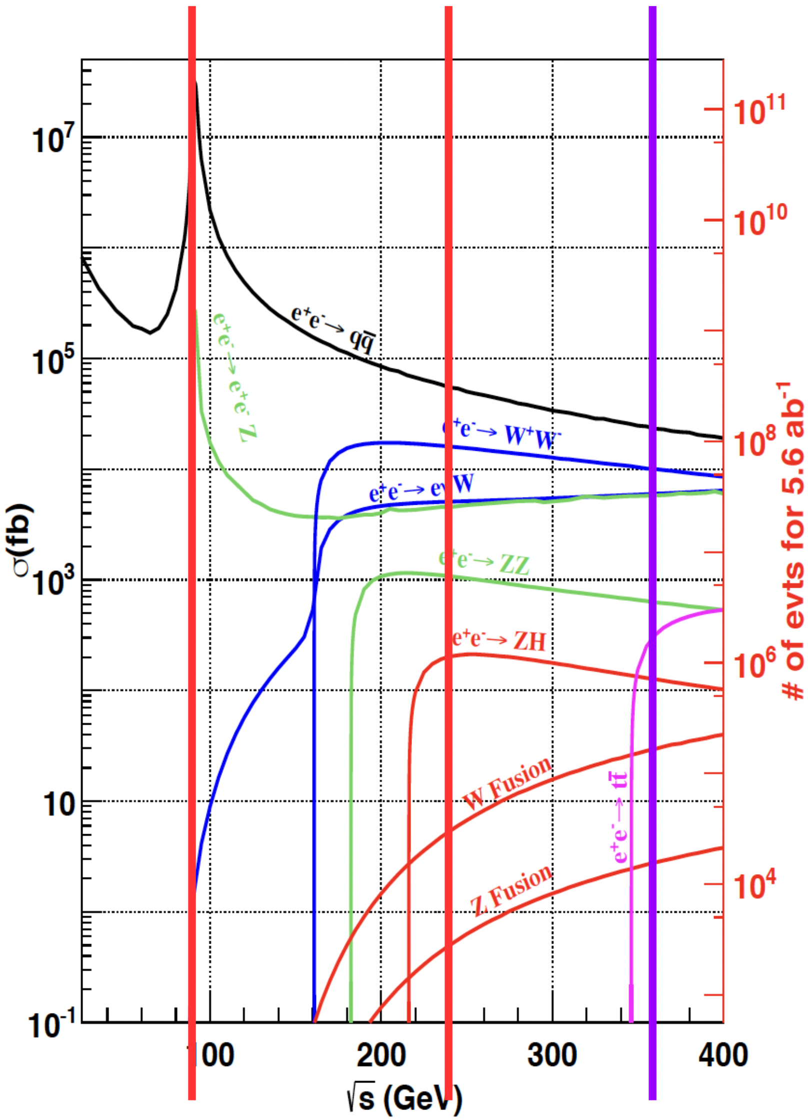
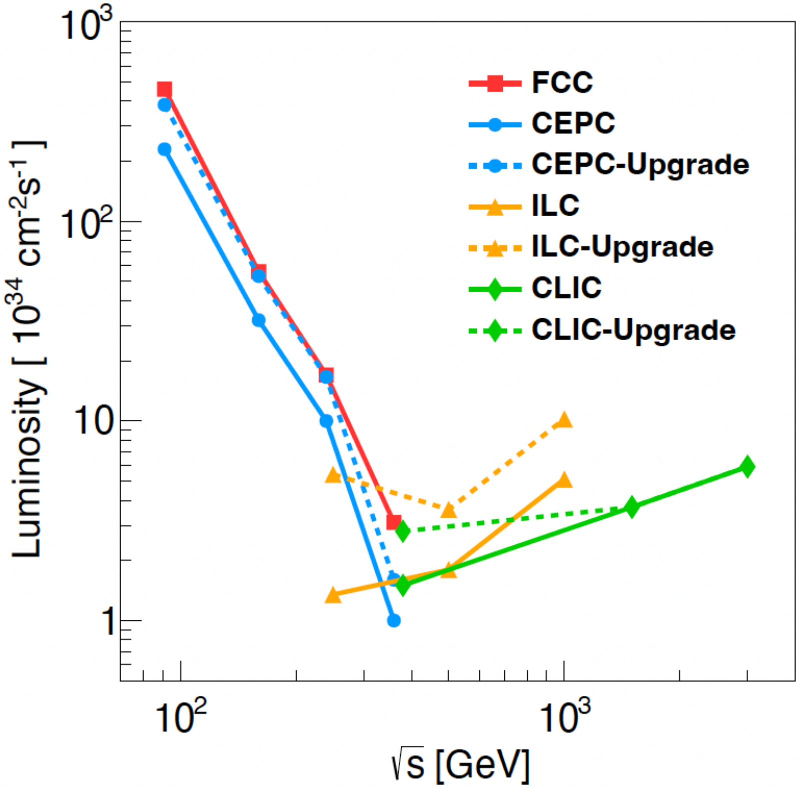
1-1 correspondence reconstruction and 5-d calorimetry



Vincent Boudry, Manqi RUAN

Yields ~ Xsec * Lumi * Time





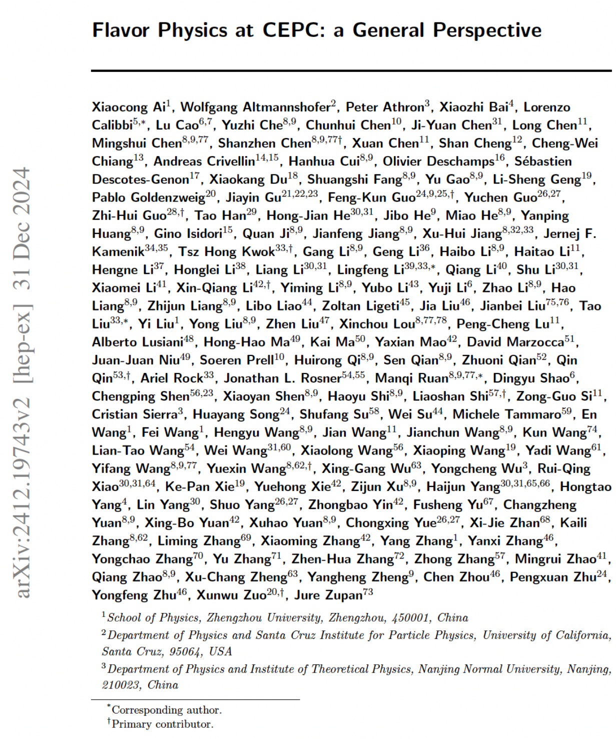
- CEPC: 100 km main ring circumference
- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

CEPC Physics


Chinese Physics C Vol. 43, No. 4 (2019) 043002

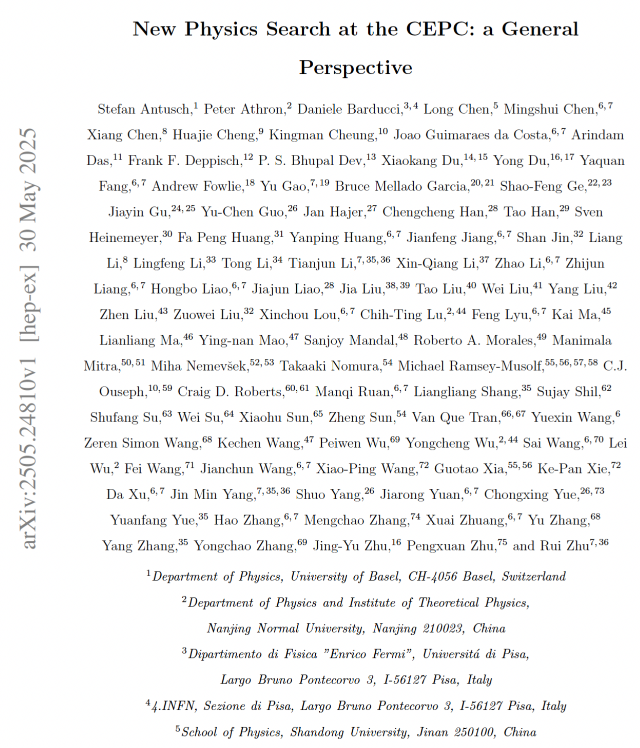
Precision Higgs physics at the CEPC*

https://arxiv.org/abs/1810.09037


arXiv:2412.19743v2 [hep-ex] 31 Dec 2024

Flavor Physics at CEPC: a General Perspective

https://arxiv.org/abs/2412.19743


arXiv:2505.24810v1 [hep-ex] 30 May 2025

New Physics Search at the CEPC: a General Perspective

https://arxiv.org/abs/2505.24810

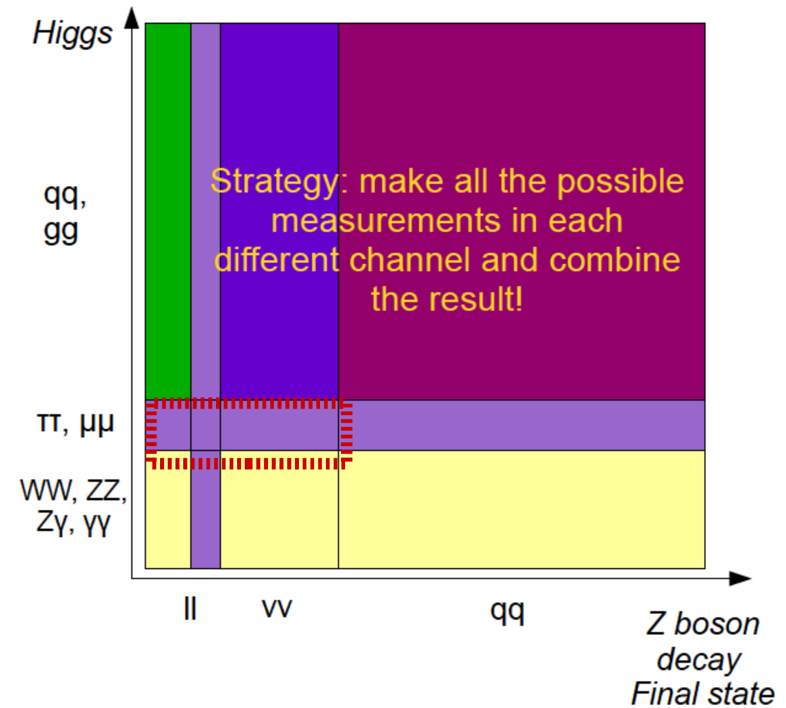
Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

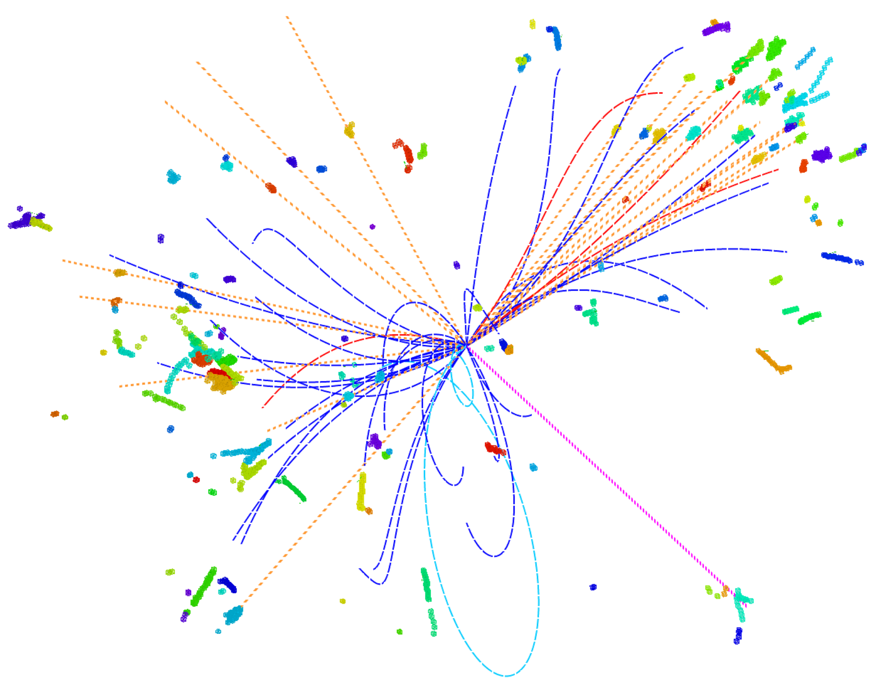
- Higgs: Precisions exceed HL-LHC ~ 1 order of magnitude.
- EW: Precision improved from current limit by 1-2 orders.
- Flavor Physics, sensitive to NP of 10 TeV or even higher.
- Sensitive to varies of NP signal.
- …

White papers +
~400 Journal/ArXiv citables

Performance requirements

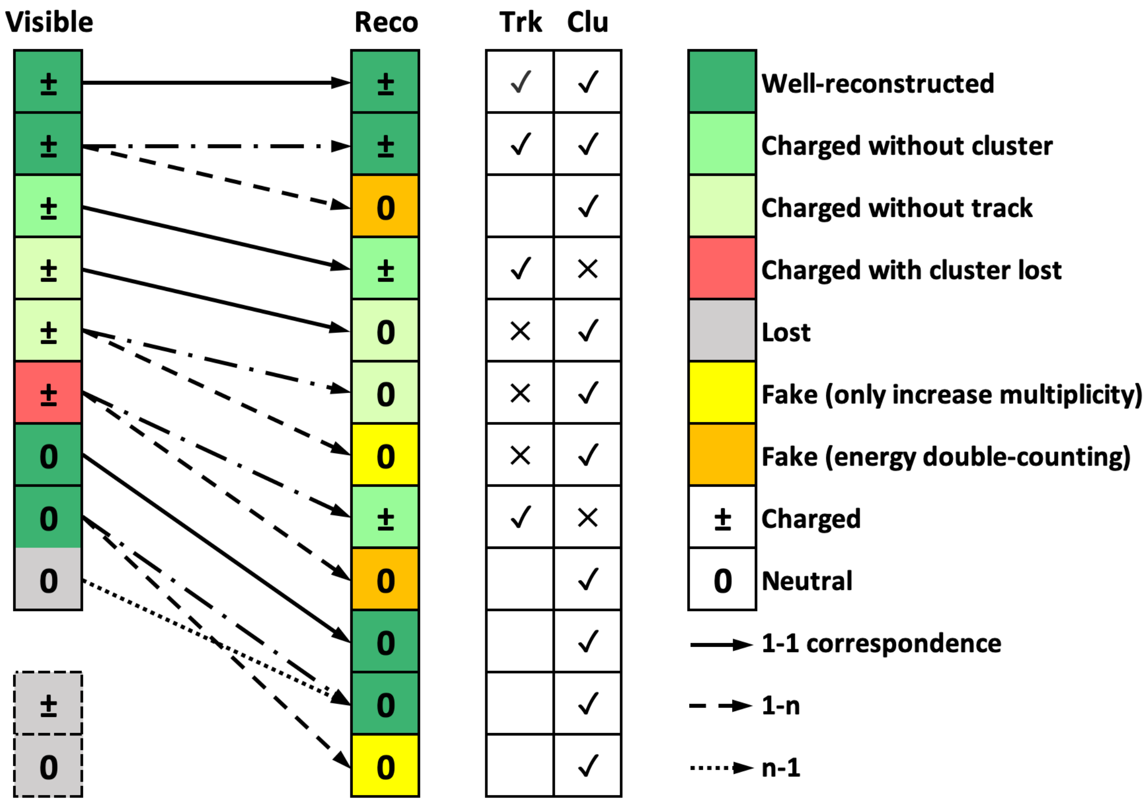
- To reconstruct all Physics Object, especially Jets
  - Z & W: ~ 70% goes to a pair of jets
  - Higgs: ~97% final state with jets (ZH events)
  - Top: t → W + b





- 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!

1-1 correspondence




Computer Physics Communications 314 (2025) 109661
Contents lists available at ScienceDirect
Computer Physics Communications
journal homepage: www.elsevier.com/locate/cpc
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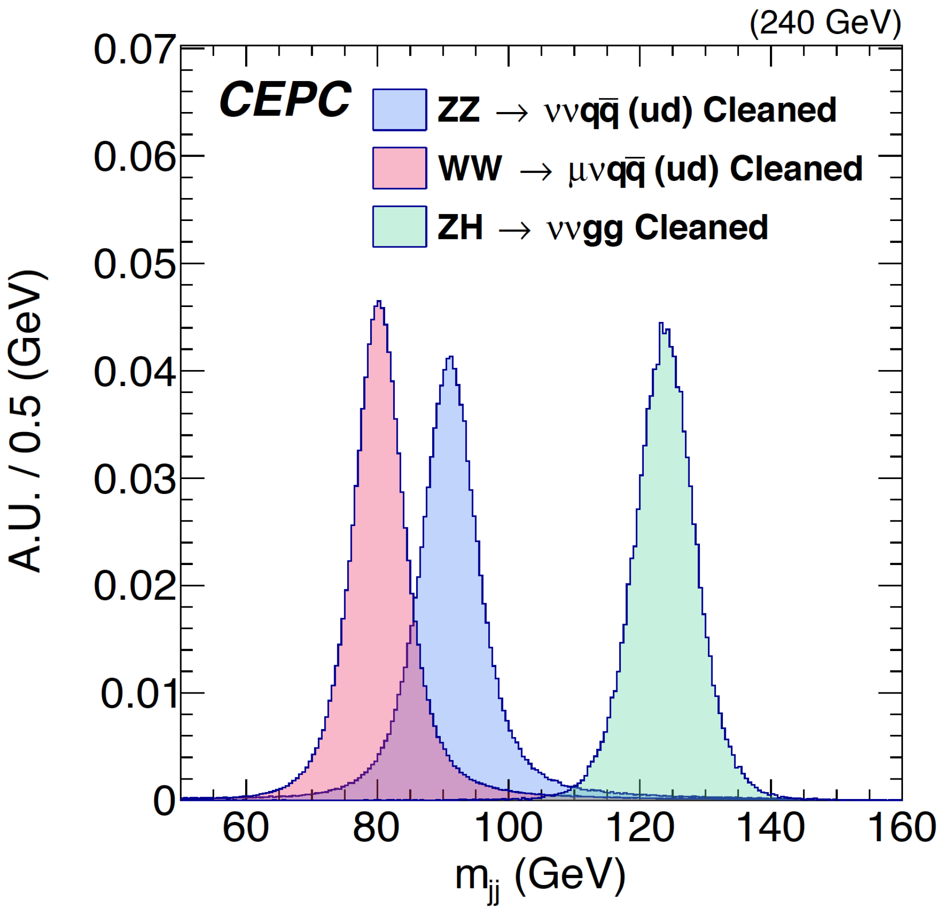
Computational Physics

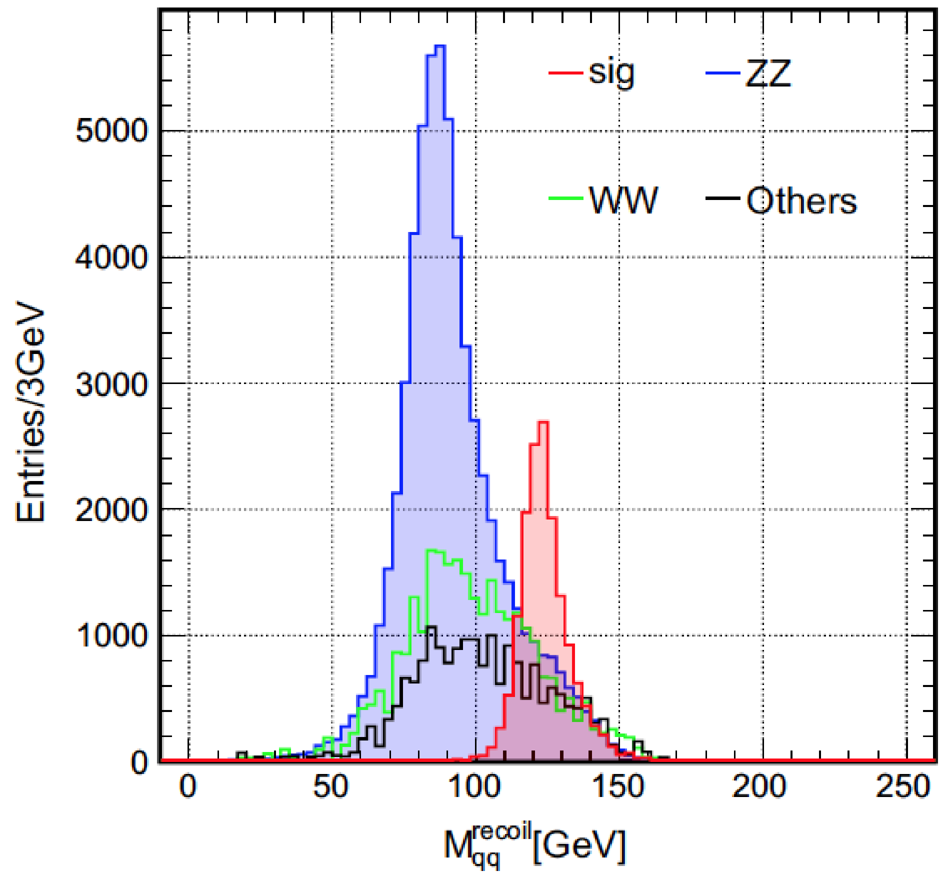
One-to-one correspondence reconstruction at the electron-positron Higgs factory

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

BMR at CEPC CDR



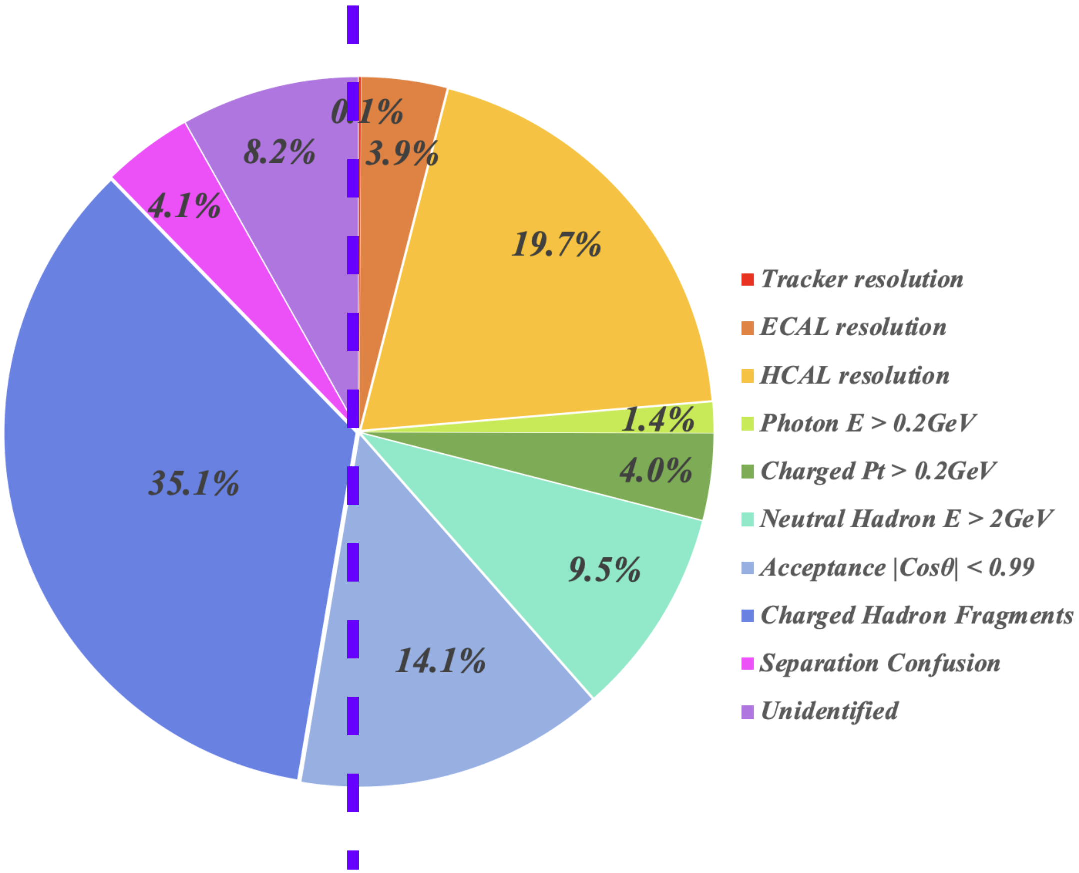


Higgs factory: need BMR < 4% (critical for qqH & qqZ separation using recoil mass to di-jet)

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

CDR baseline (left plot): BMR = 3.75%

BMR 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

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

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]

[a] Institute of High Energy Physics, Chinese Academy of Sciences, 19B Yuquan Road, Shijingshan District, Beijing 100049, China
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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.

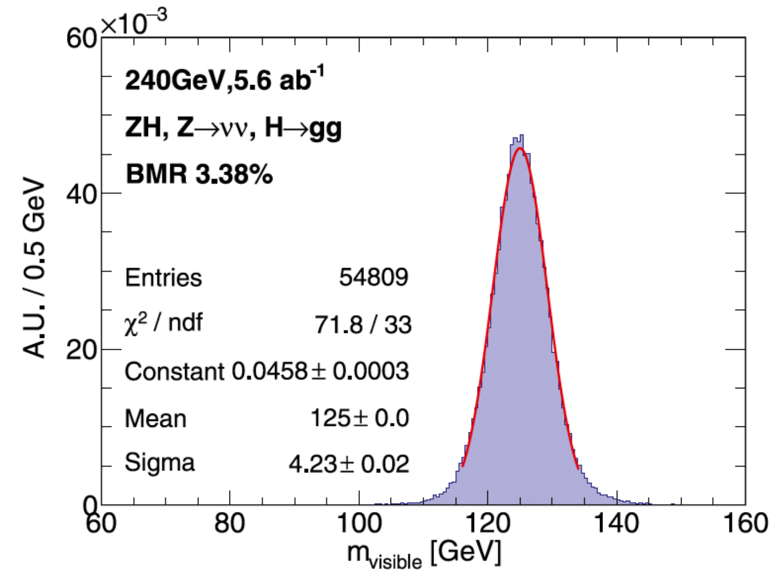


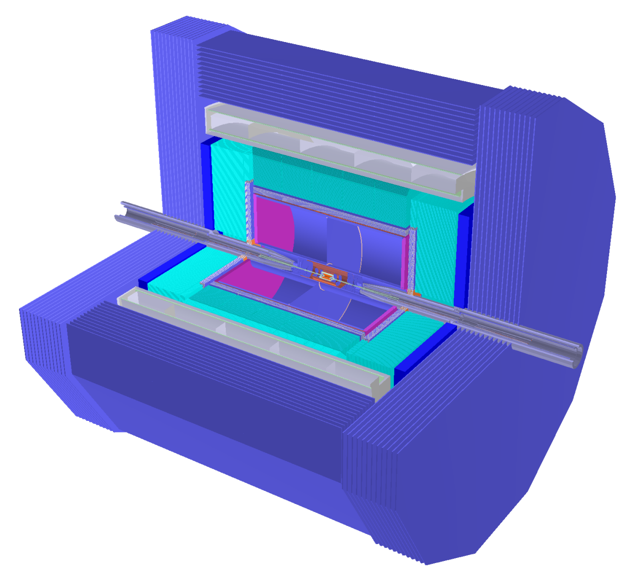
Fig. 5. Distribution of the reconstructed total visible invariant mass for $\nu\bar{\nu}H \rightarrow \nu\bar{\nu}gg$ channel. The distribution is fitted with a Gaussian function extented to ±2 standard deviations.

AURORA Concept： SiW (5d) + GSHCAL (5d)
Time resolution ~ 100 ps/hit

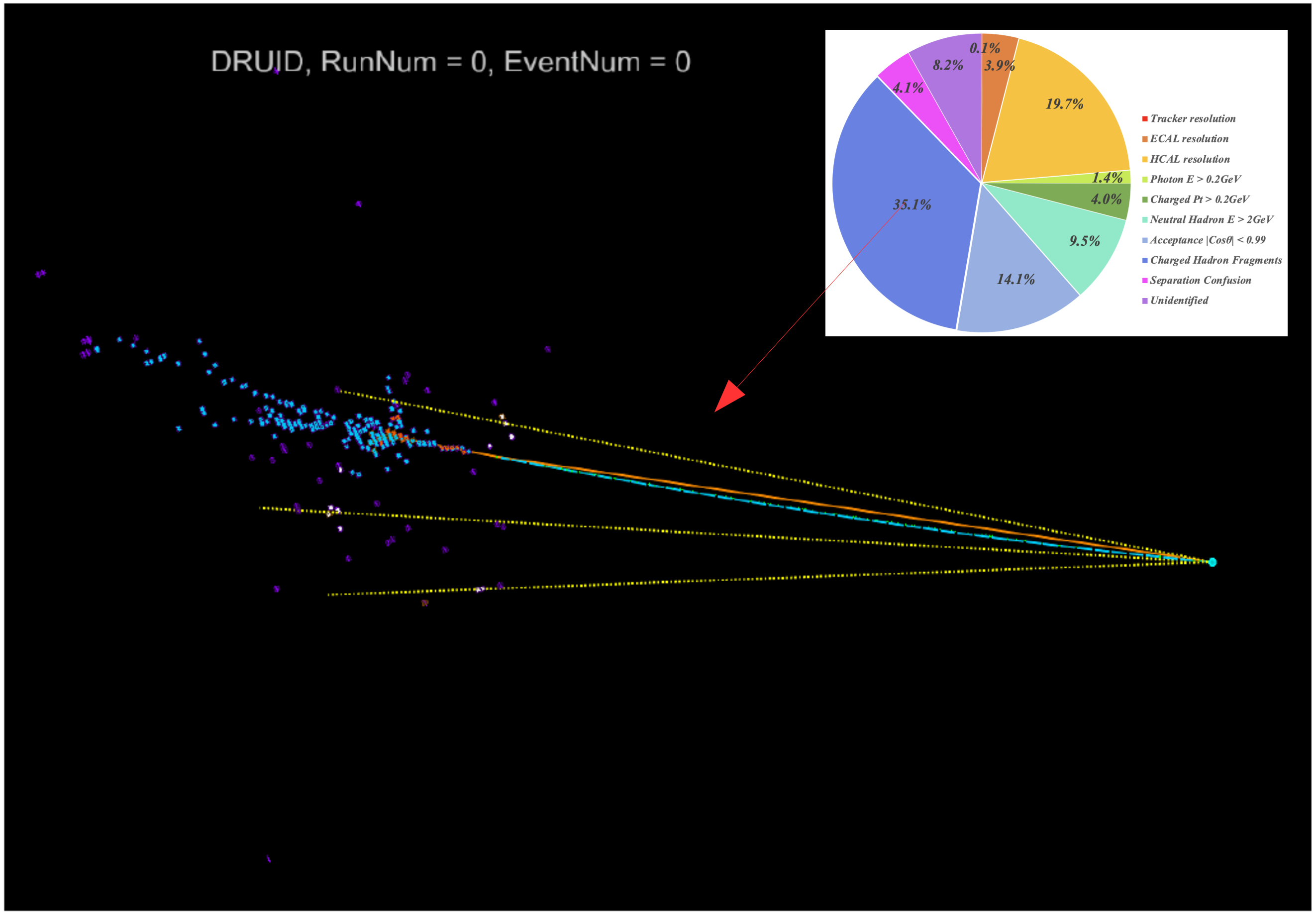
Y. Wang, H. Liang, Y. Zhu et al. *Computer Physics Communications 314 (2025) 109661*

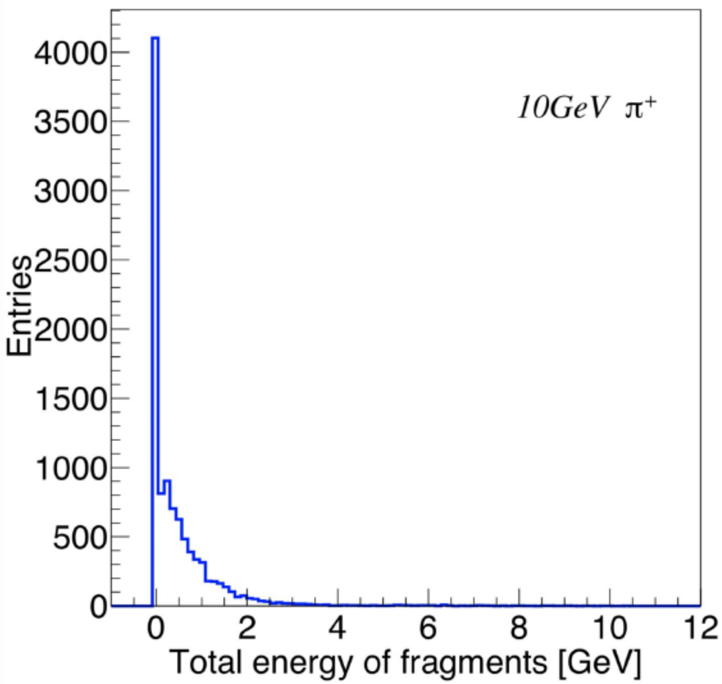
Table A.1
AURORA detector geometry parameters.

Sub-detector	Thickness (mm)	Inner radius (mm)	Outer radius (mm)	Length (mm)	Volume (m³)	Transverse cell size	#Layers	#Channels
Vertex	-	-	16–60 155	125–250 736	-	25×25 μm²	6	5.3×10^8
Si-strip Tracker	-	-	300 1810	1288 4600	-	20 μm × 2 cm	3	3.0×10^7
TPC	-	300	1800	4700	47	1×6 mm²	220	2.9×10^6
ECAL	173	1845	2018	5250	15	1×1 cm²	30	2.5×10^7
HCAL	1145	2072	3250	7590	180	2×2 cm²	48	1.8×10^7
Solenoid	700	3275	3975	7750	120	-	-	-
Yoke	1200	4000	5200	10500	470	-	-	-



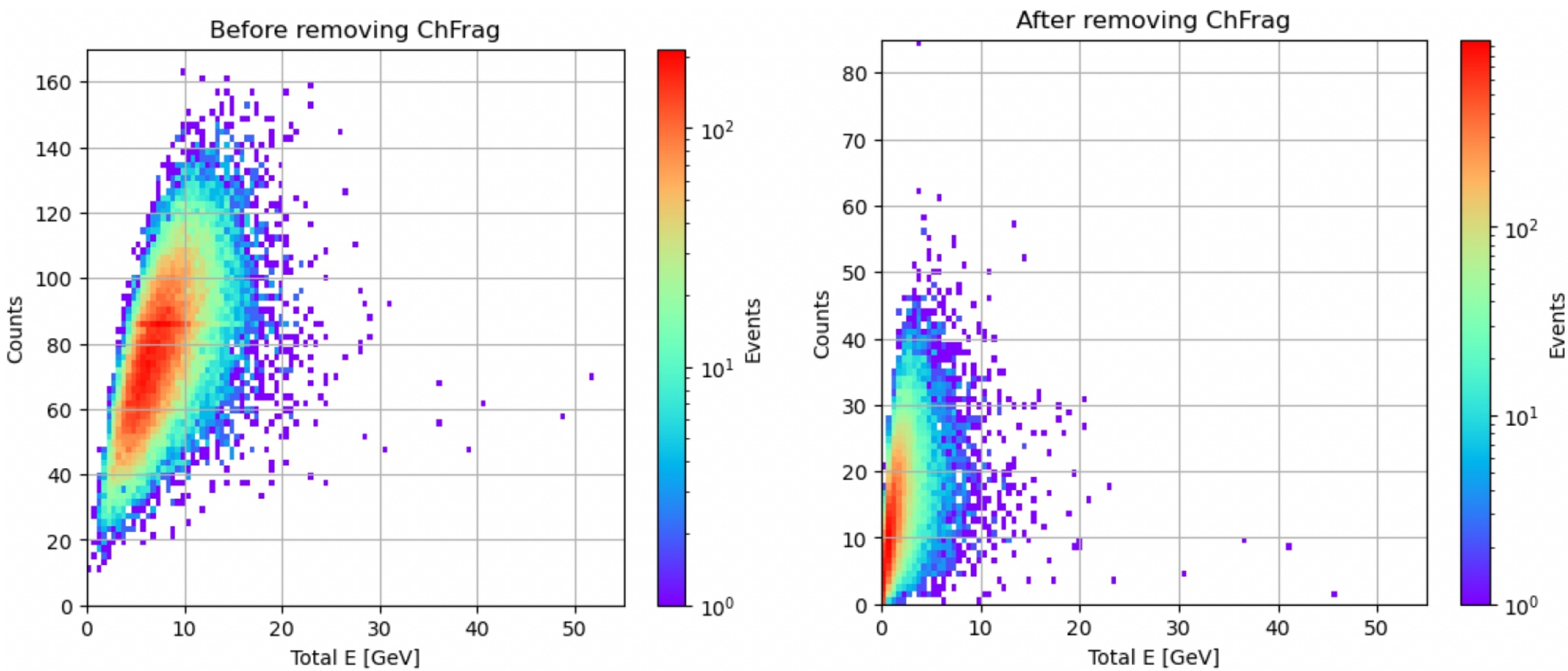
Cluster splitting: the most severe confusions





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

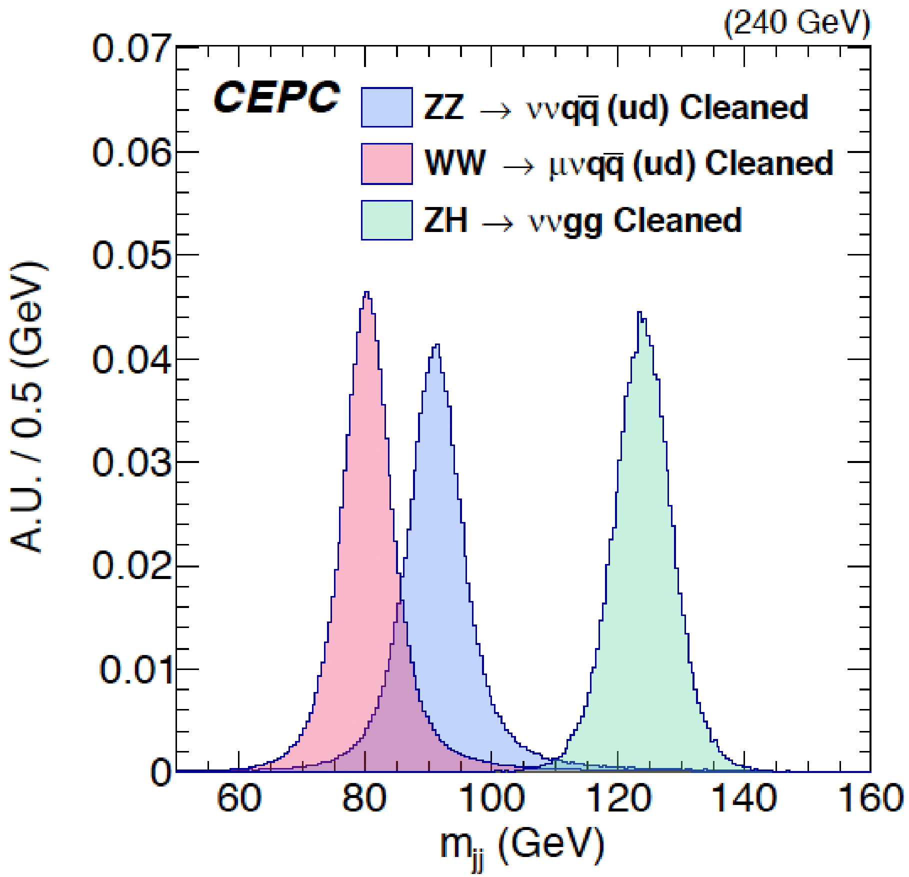
Confusion: frag. Identification & veto

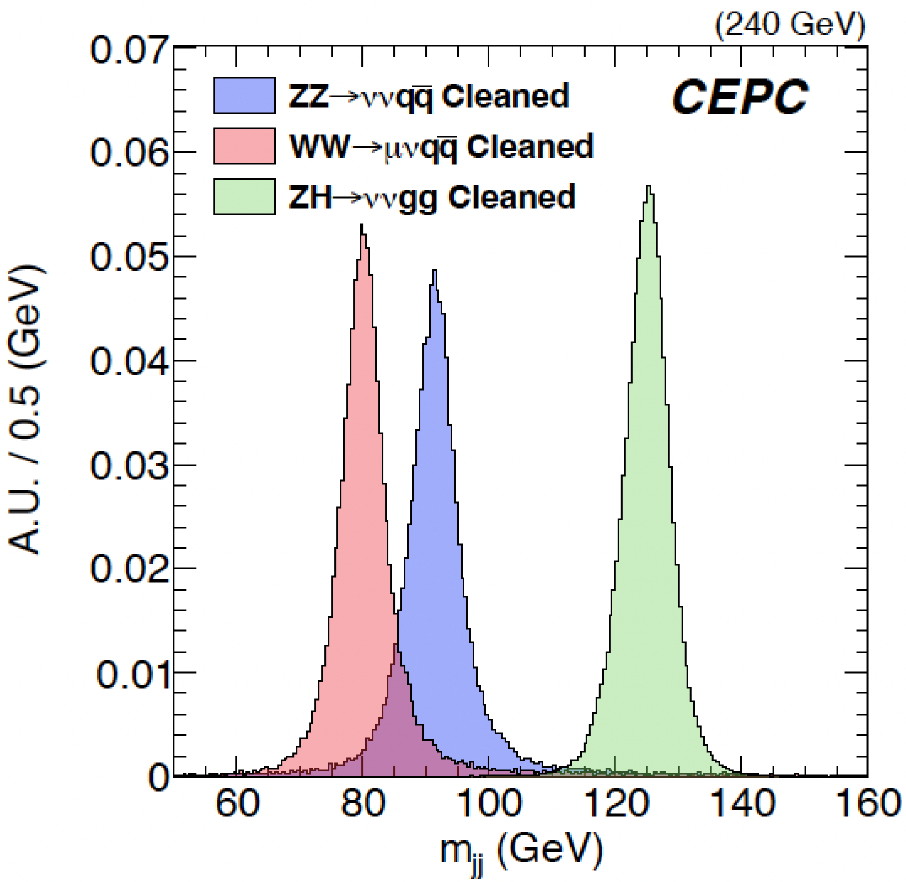


Fake particle originated Confusion reduced by 1 order of magnitude, at nominal vvH, H→gg event, at the cost of create mis-vetoed energy of < 1 GeV.

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

BMR of 2.75% reached



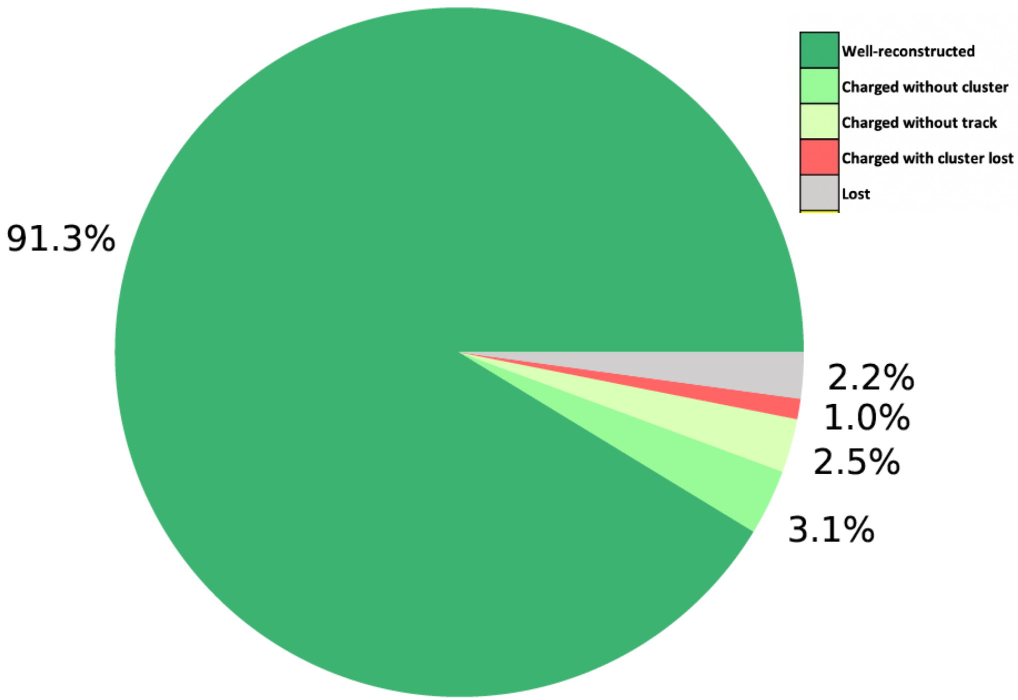


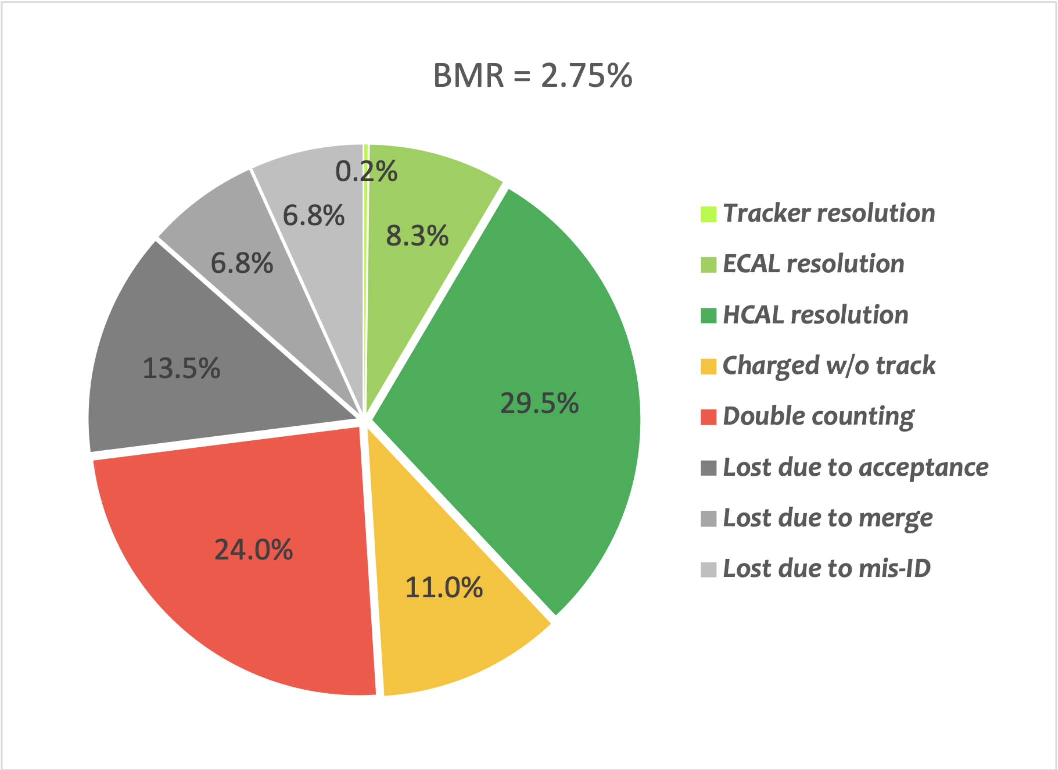
Detector change (usage of high density scintillating glass HCAL): BMR 3.7% → 3.4%;

AI enhanced reconstruction: 3.4% → 2.8%.

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

1-1 & BMR decomposition @ AURORA



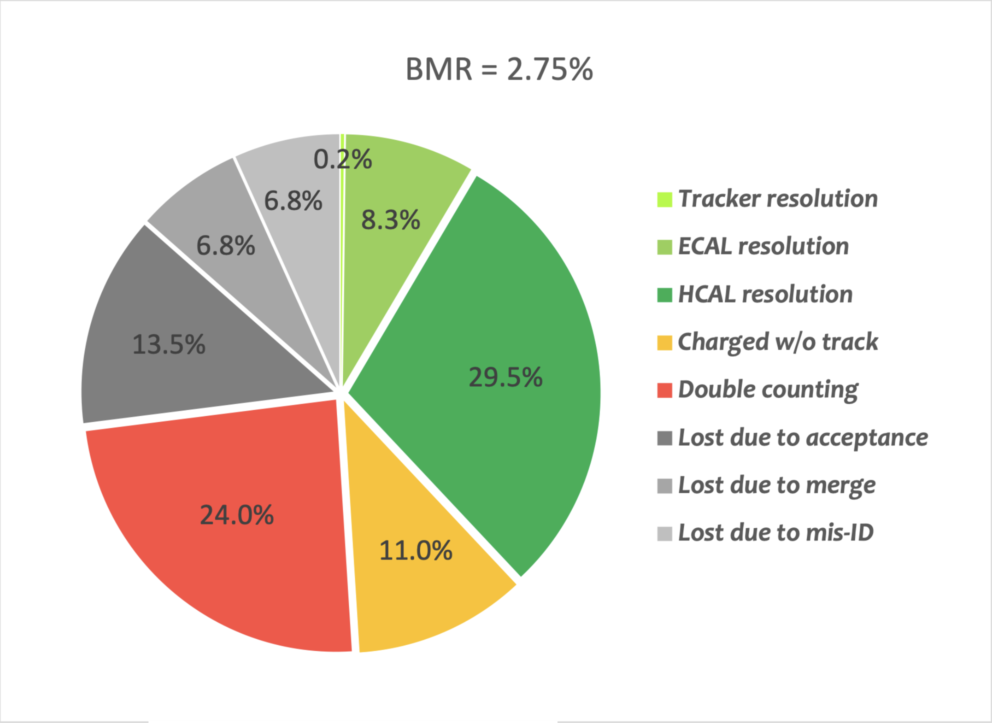


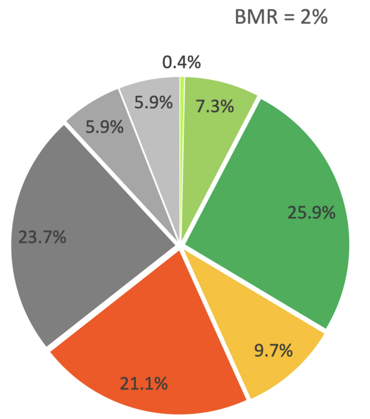
1-1 corresponding type: contributing to the BMR via resolution: ~o(0.1 – 0.001) of its mean value

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

BMR: perspectives

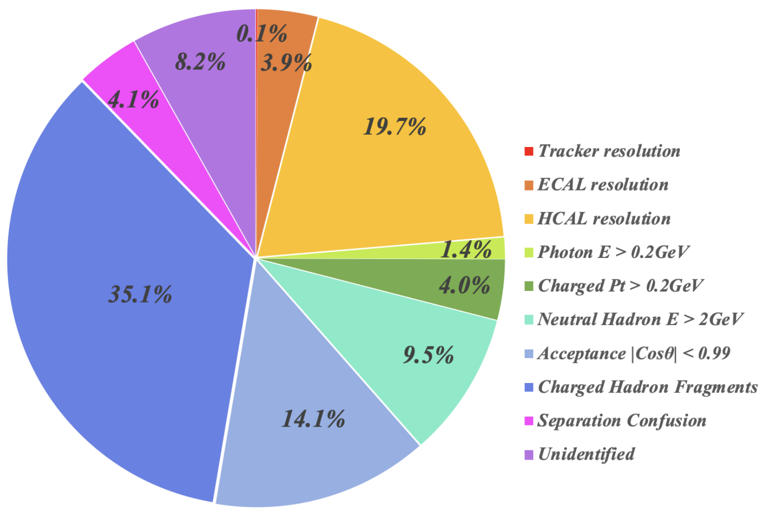
- Resolutions: assume - improved by 50%
  - Crystal ECAL: With efficient control of confusion
  - Detector optimization + Innovative Estimator (Energy, Time, Spatial...) with 5d calorimeter (ToF) & AI: ToF could determine very precisely the energy of low-E hadron – Giving its type identified...
- Charged 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)*



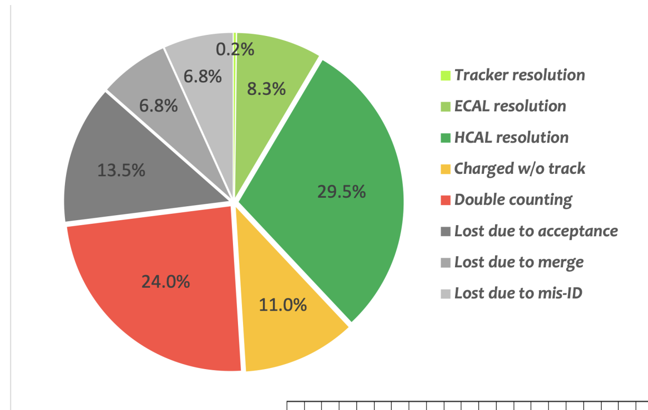


BMR: from CDR to possible future...

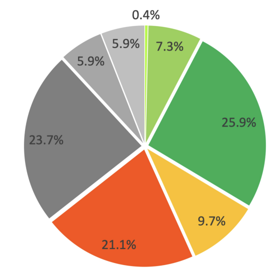
2016 - CDR: BMR ~ 4%

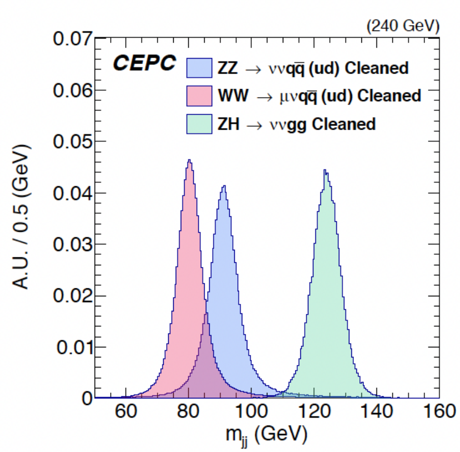


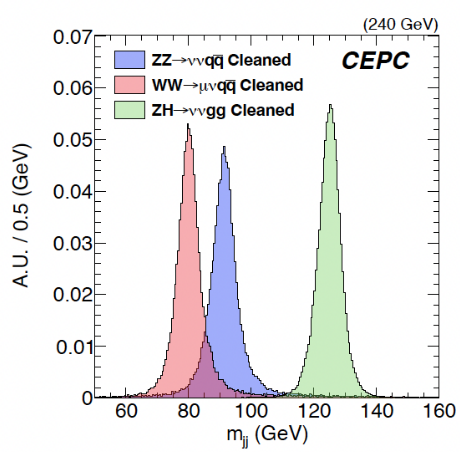
2024 - AURORA: BMR ~ 2.7%

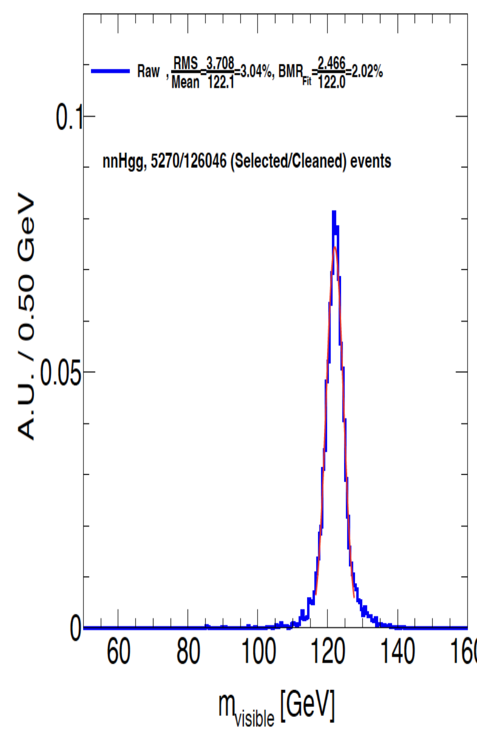


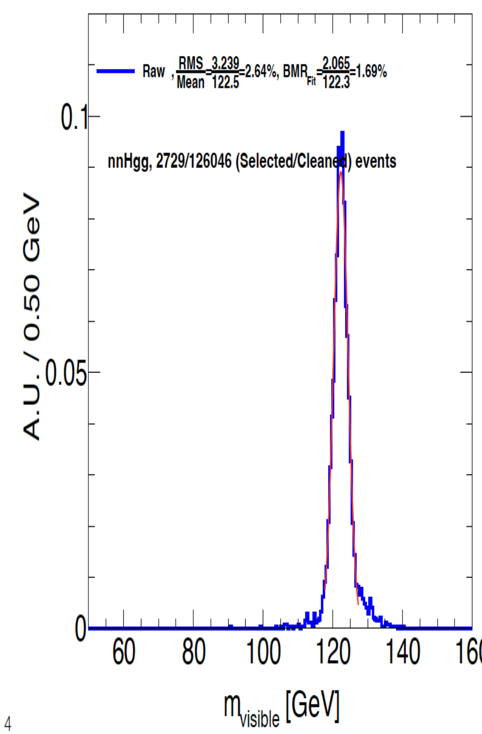
Future: BMR ~ 2.0%





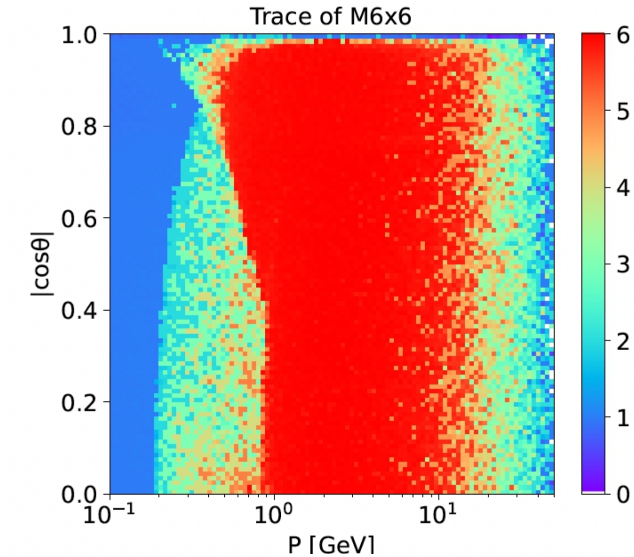


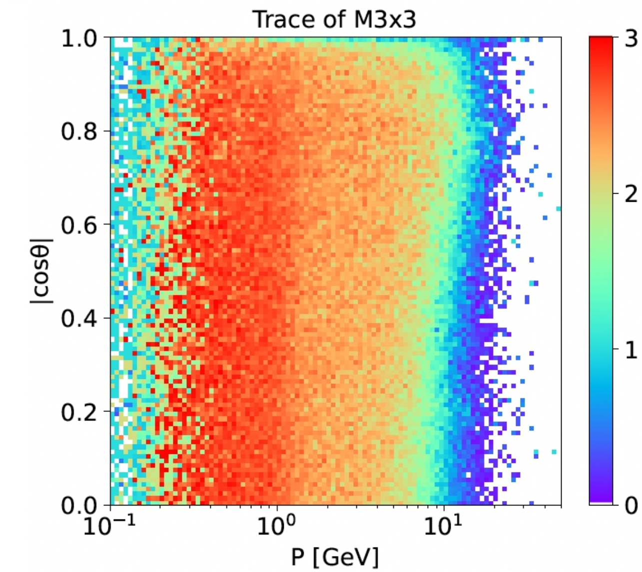




Pid: differential performance

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

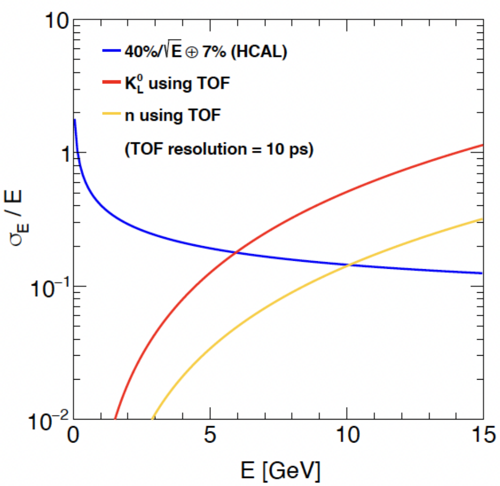


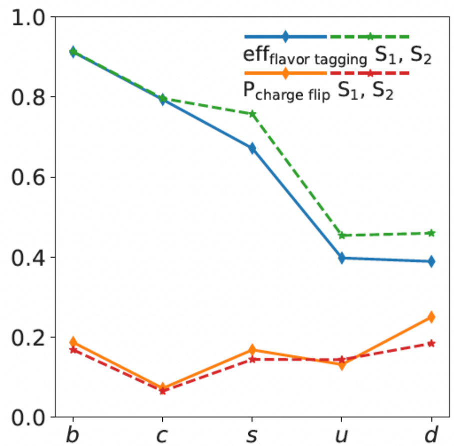


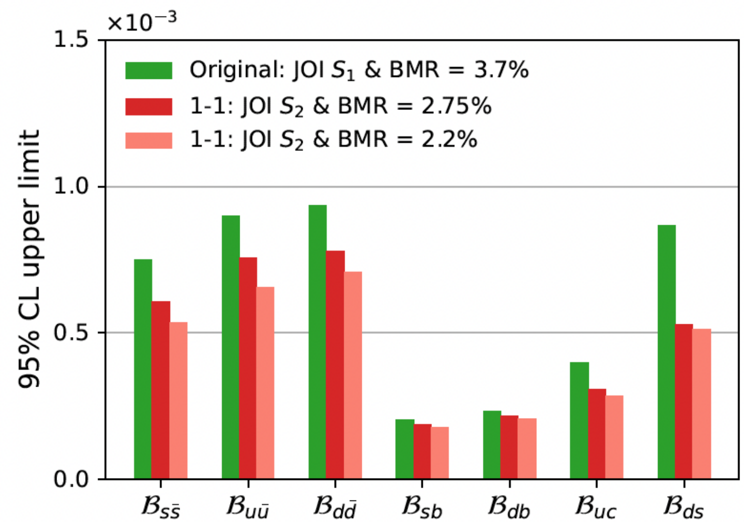
Neutral Hadron ID: 5d Calorimetry with ToF capability (δt~100 ps/hit)

Perspectives with 1-1 correspondence

Jet (hadronic events) with Calo	Jet with PFA Charged in Tracker Neutral in Calo	Jet with 1-1 Charged in Tracker + **ToF** Neutral in Calo + **ToF**



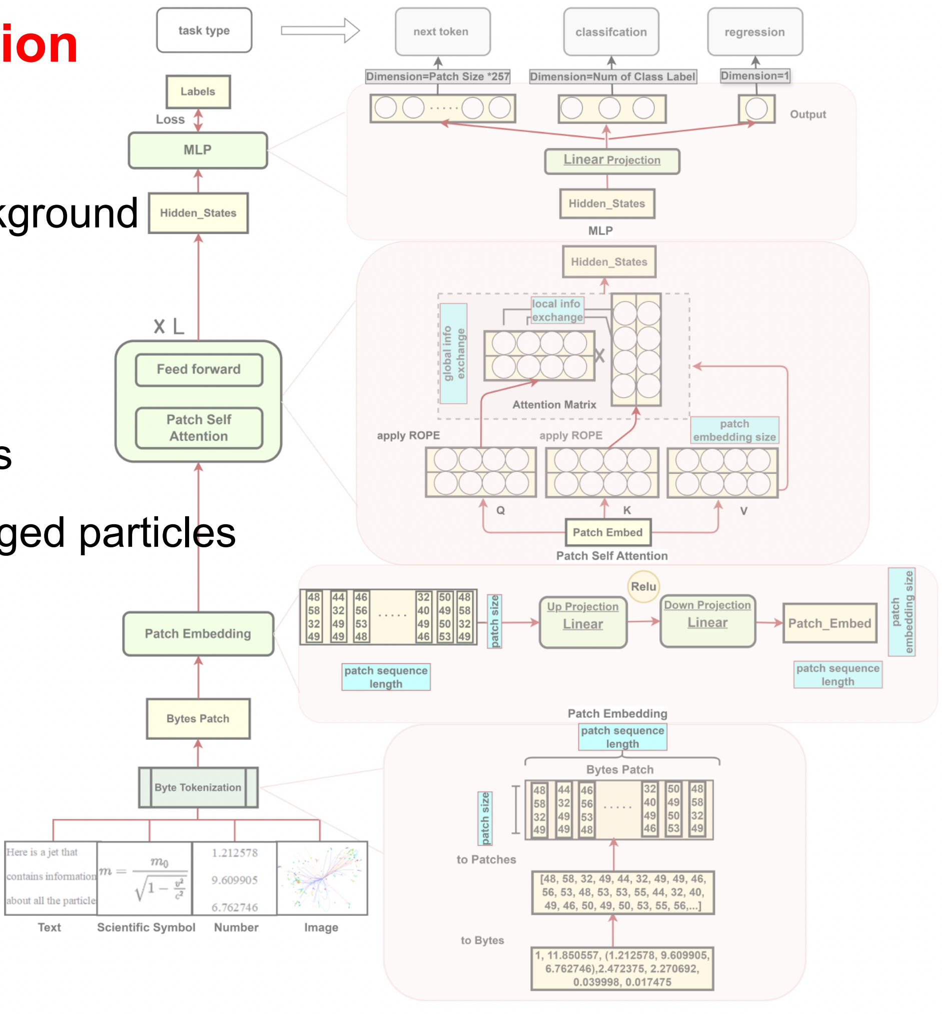




- 5d calo is critical: ToF for all visible particle, thus Pid...
- ToF enhanced energy measurement: expecting BMR: 2.8 → 2.2-2.4, Strongly Boost the light quark ID.
  - Need excellent CALO + ToF ~ o(10 ps)/Cluster
  - Assume Low energy neutrons & secondary particles can be tamed... still challenge...

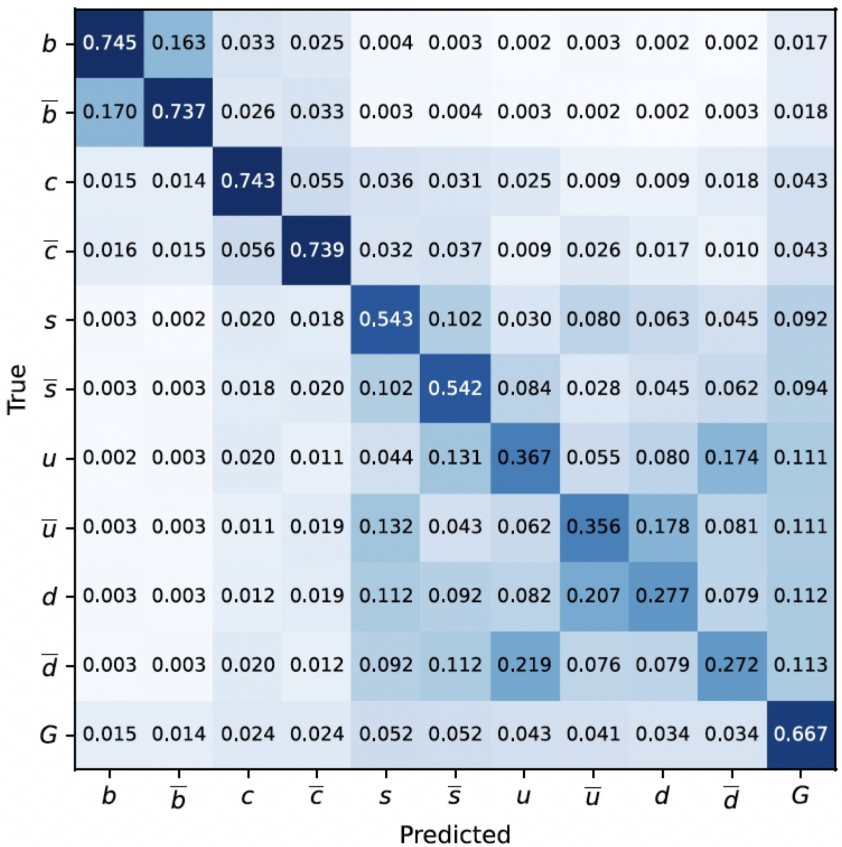
Holistic approach

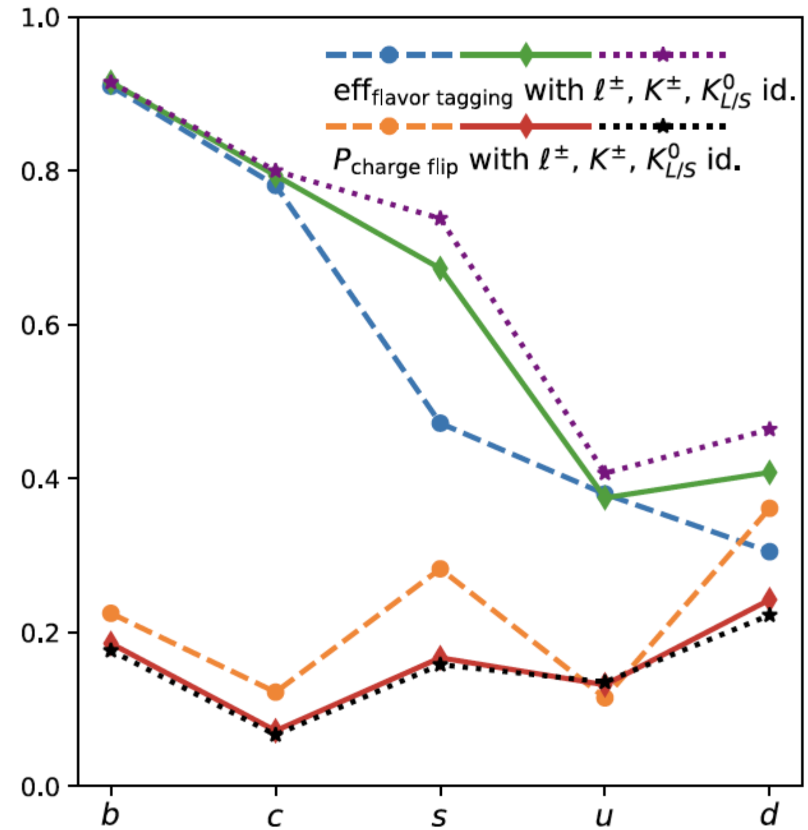
- Provide all reconstructable for **classification**
  - Reco: Jet origin identification
  - Analysis: to distinguish the signal from the background
- In the context of 1-1 correspondence/PFA, inputs =
  - 4 momentum + Pid of all reconstructed particles
  - Track impact parameters of reconstructed charged particles
  - Potentially: parenting info
    - Photon to Pi-0, pions to kaon...
    - Color Singlet (from Z or H)
    - ...
  - Uncertainties...



- Challenge: high quality simulation, knowledge of Detector response & Theory/interpretation models...

Reco: Jet origin id

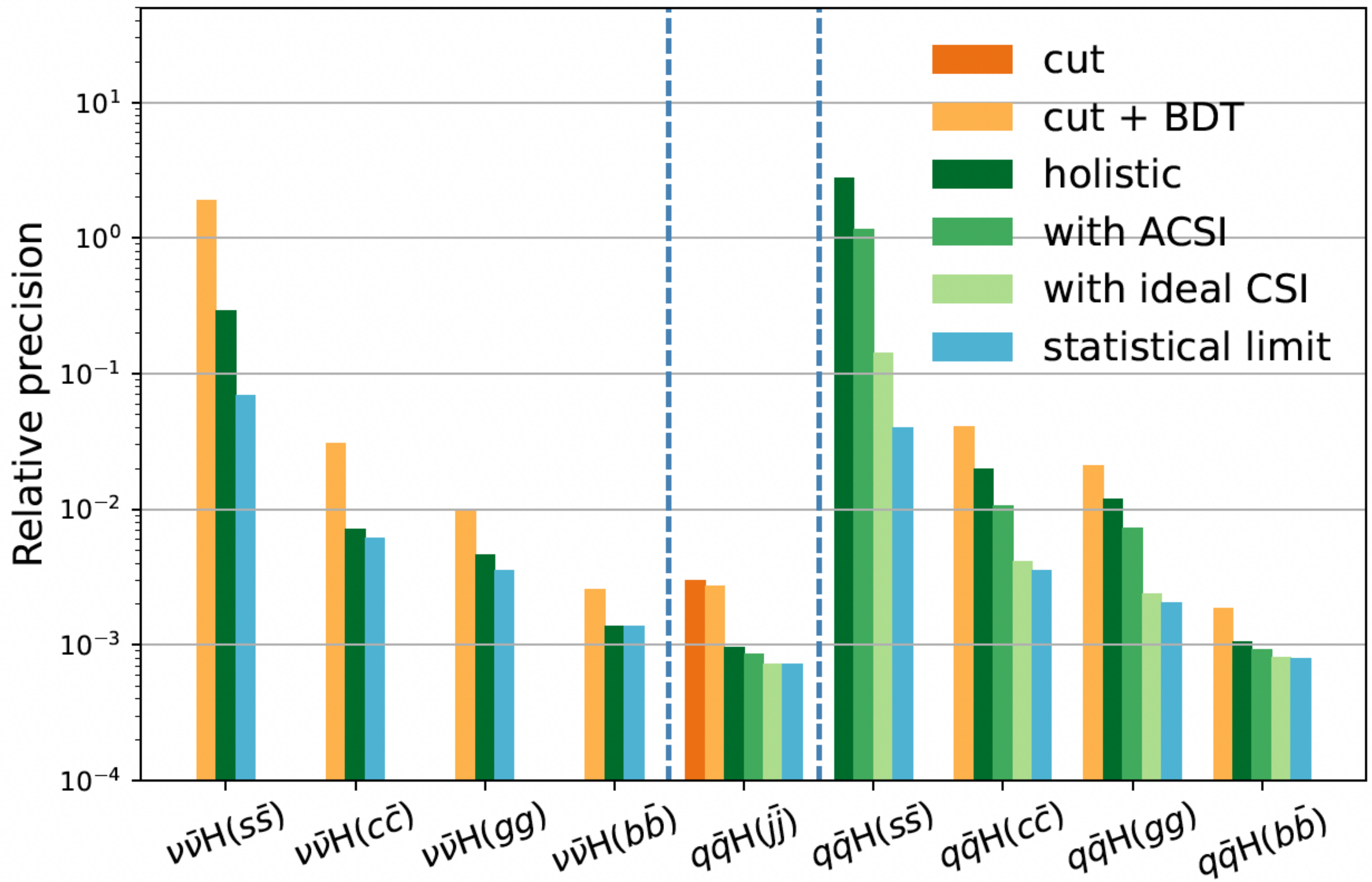




- 11 categories (5 quarks + 5 anti quarks + gluon) identification, realized at Full Simulated di-jet events at CEPC CDR baseline with Arbor + ParticleNet
- Published in PRL *132, 221802 (2024)*. Comment from the referee: *"demonstrate the world-leading performance of tagger", "a "game changer" and opens new horizons for precision flavor studies at all future experiments."*

https://arxiv.org/abs/2310.03440
https://arxiv.org/abs/2309.13231

Holistic approach + ACSI



Holistic + ACSI: improves the accuracy by 2 – 6 times

ACSI makes a leap even from Holistic, but still has significant room to improve...

H→ss within the reach...

https://arxiv.org/pdf/2506.11783

Towards the 5D calorimtry

Detector

- CE-E region
  - $1.1cm^2$ hexagonal **300μm** Si
  - **SKIROC2-CMS** chips

Timing performance

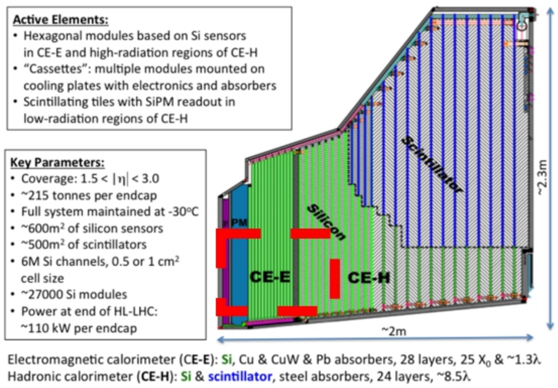
- Single channel

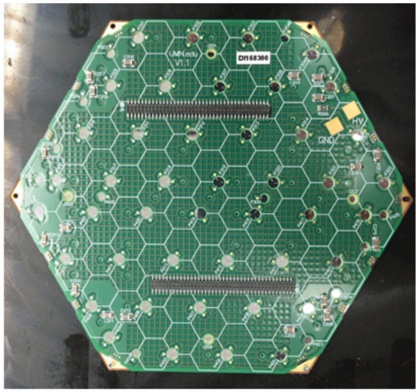
$$\sigma^2(E) \sim \left(\frac{13.5\text{ns} \cdot \text{MIP}}{E}\right)^2 + (62\text{ps})^2$$

- Positron showers

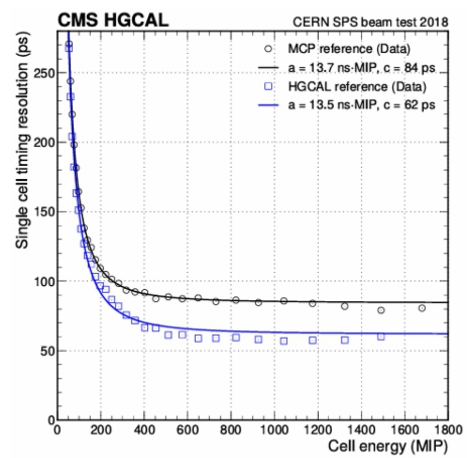
$$\sigma^2(E) \sim \left(\frac{1.9\text{ns} \cdot \text{GeV}}{E}\right)^2 + (16\text{ps})^2$$

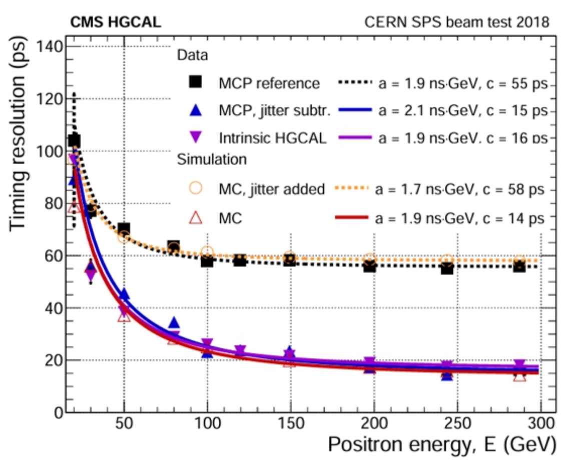
SiW ECAL is expected to have better performance with thicker Si Wafers





Design of the CMS HGCAL





Timing performance of HGCAL Test beam results
Left: single channel, right: positron showers

2025/7/23 22

DESY Beam Tests 2025/03

1 week 3–10/03/2025

SiW-ECAL:

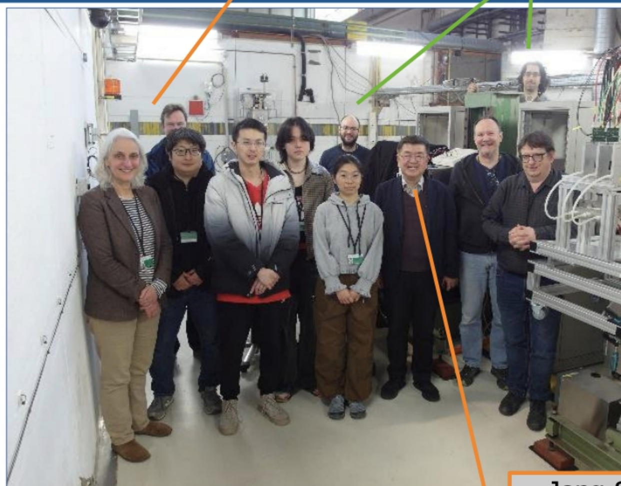
- 2 new ASU FEv2.1
- 1 ASU COB
- No Tungtens

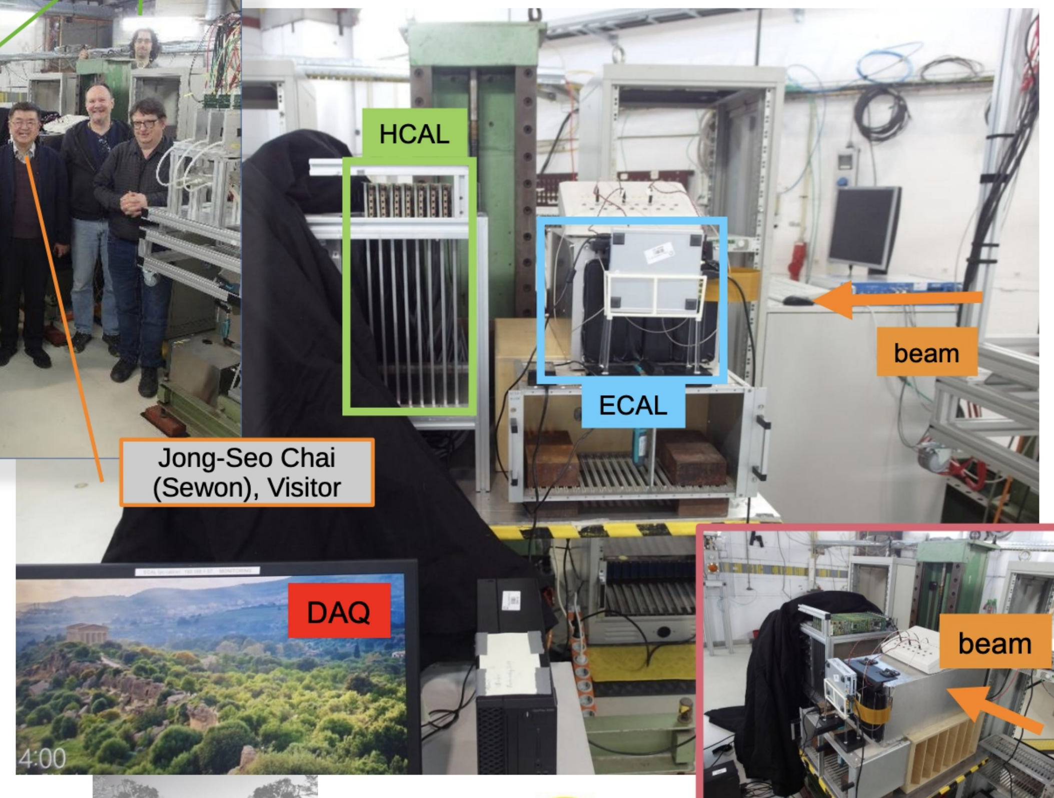
AHCAL:

- "Airstack" with 7 short layers

Running:

- 3 days ECAL Stand alone
  - ½ d. install + commissioning
  - Positions scans : uniformity & mip/noise resp.
- 4 days AHCAL
  - ½ d install + repair
  - Scans & TDC runs





The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)".

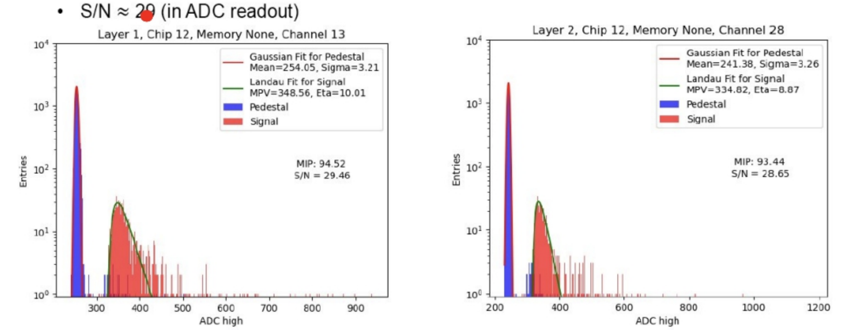
"Toshiko Yuasa"
France Japan
Particle Physics Network
(TYL-FJPPN)

Some results on the SiW-ECAL

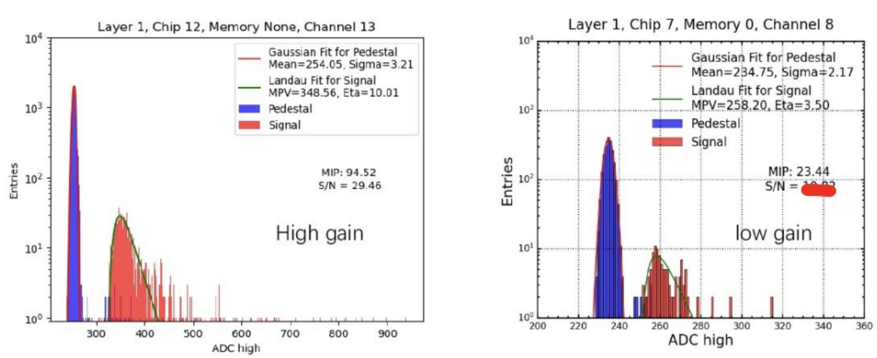
Xin XIA (IJCLab)

IJCLab S/N ratio for single channel

- Data: From hold_value scan run (hold value = 130), with high gain of Feedback capacitances
- Pedestal: adc_high[hitbit_high == 0]; Signal: adc_high[hitbit_high == 1].
- For ASU1 and ASU2:
  - MIP ≈ 93 ADC count
  - S/N ≈ 29 (in ADC readout)

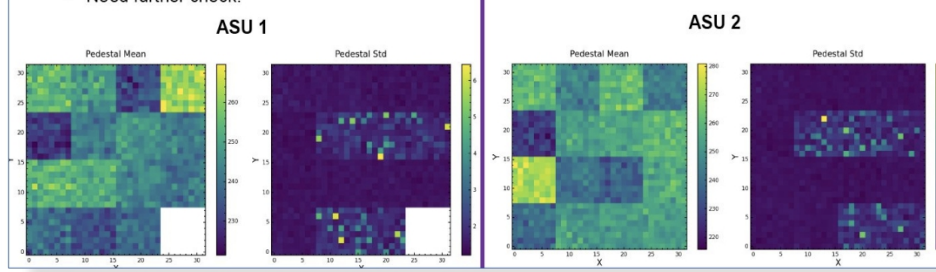


MIP value for different gains of Feedback capacitances



IJCLab Pedestal map of pedestal run

- Data: From pedestal runs
- For each channel:
  - Select adc_high[hitbit_high == 0 & badbcid == 0] get the distribution
  - Fit the distribution with gaussian function to get the mean and sigma value
- In each chip, the pedestals are relatively consistent.
- But in some chips, the pedestal sigma is higher than 4 because of two peaks.
- Need further check.



New FEV2.1 preliminary results:

- High S/N ration (MIP MPV/Noise StdDev) ~ 30 in readout branch
- Run in lower gain mode possible
- Very few cells masked

WS 2025 @Barcelona | 17/06/2025 11/21

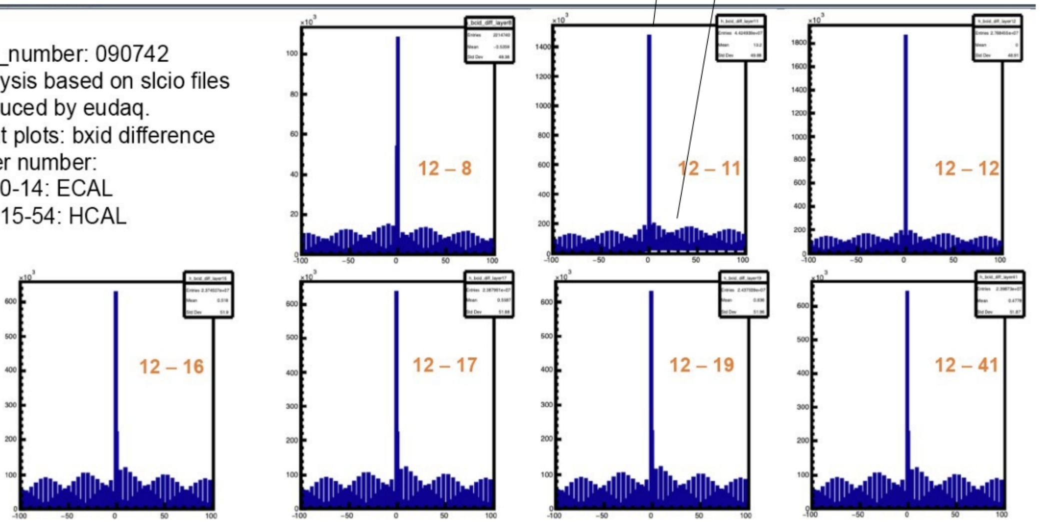
Synchronization ECAL–AHCAL

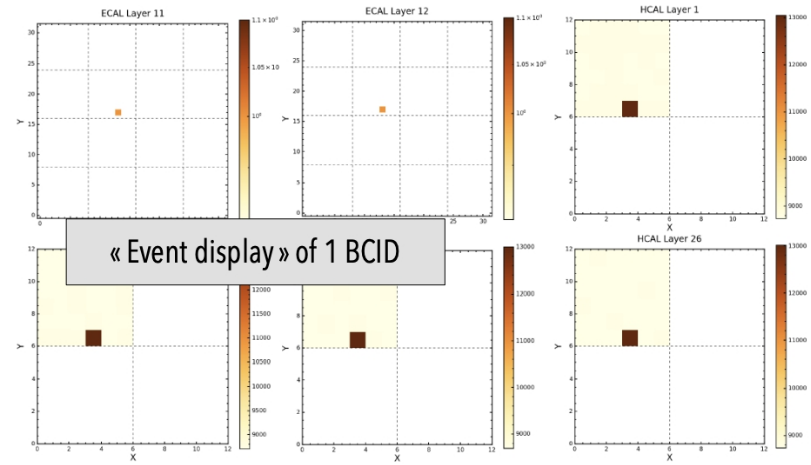
Aim: consolidate the Digitization, including timing

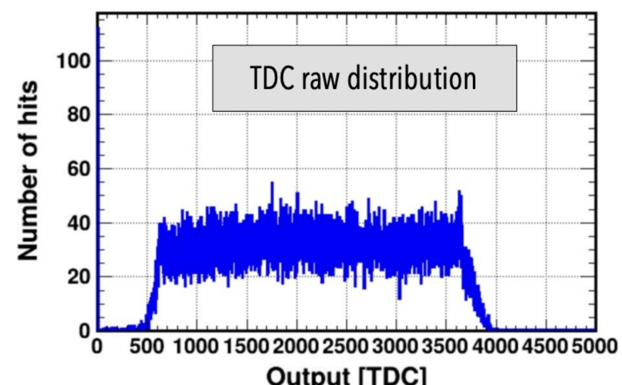
Set-up identical to 2022

– Same setting as in 2022
  - Bunch Clock cycle offsets (BCID's)
  - Reconstructed ΔBCID's OK
  - TDC information being analysed

- Run_number: 090742
- Analysis based on slcio files produced by eudaq.
- Right plots: bxid difference
- Layer number:
  - 0-14: ECAL
  - 15-54: HCAL

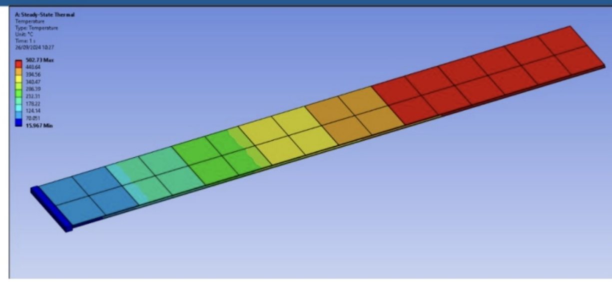






ECAL adaptation : flat cold plate, preliminary thermal studies

Uniform solutions:



"Standart Slab":

- 8 ASU (1440mm)z, 8192 ch / 128 ASICs
- 100 W

Passive cooling: Cu of 2mm (W, C ignored)

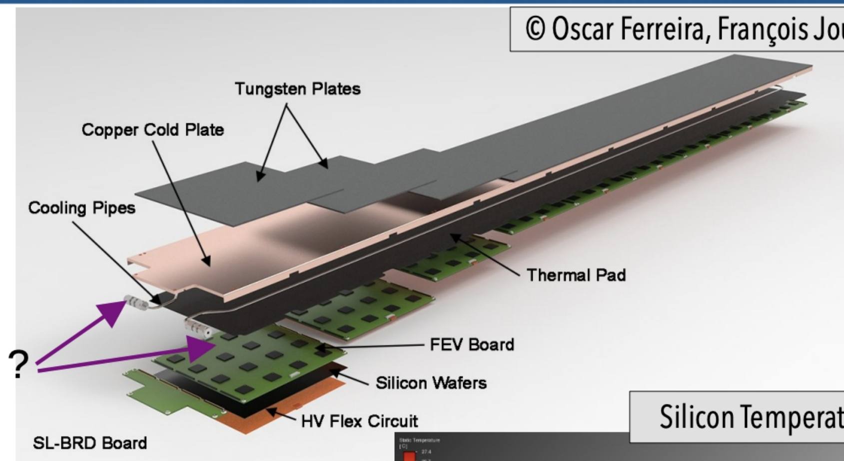
Adiabatic, but for heat bridge at the end

ΔT = 500°C on Wafer surface at $t = \infty$

Status:

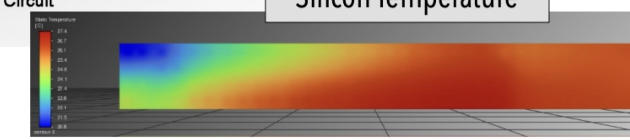
- Limited flow of water seems enough…
- Now looking into pipe in 4-mm Cu layer
  - Replaces ~1 mm of W
- To be validated on simulations

© Oscar Ferreira, François Joubert @ LLR



Connections ?

Silicon Temperature



"Standart Slab":

- 8 ASU (1440mm), 8192 ch / 128 ASICs
- 128 W (1W/ASIC ~16 mW /ch)

Active cooling:

- 4 mm Cu plate with 1/8″ Stainless Steel Tubing
- 0.2 ℓ/min of water @ 15°C

Adiabatic, but for heat bridge at the end

ΔT = 6.6C on Wafer surface at $t = \infty$

Summary

- ***... Higgs factory has strong discovery power to NP, its detector & reconstruction should and could have excellent performance...***
- ***AI as the trend...***
  - *1-1 correspondence reconstruction: excellent PID + BMR of 2.7%*
  - *Holistic approach, enhances the discovery power of Higgs factory by ~ 3 folds*
- ***5d calorimetry: essential for 1-1, align with HL-LHC upgrade & steady progress in prototyping for Higgs factory***
  - *SiW: excellent S/N, good homogeneity, TDC info available, cooling addressed*
  - ***...***
- ***Multiple challenges need to be addressed... with intriguing prospects...***
  - *Precise Simulation is critical to utilize supervised learning, which request profound understanding of relevant factors – be developed iteratively*
  - *To explore other methodologies: non/weakly-supervised, enhanced, LLM...*
  - *Lots more to explore, with unsupervised, LLM, ... rich interplay & synergies.*
  - ***...***

Back up

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 for scintillating materials...
  - 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...

Conclusions

SiW-ECAL

- 2 new board produced and put in beam for low-E response
- Preliminary results very promising: OK for production of + 13 new ones
- Will provide input for Digitization code adjustement

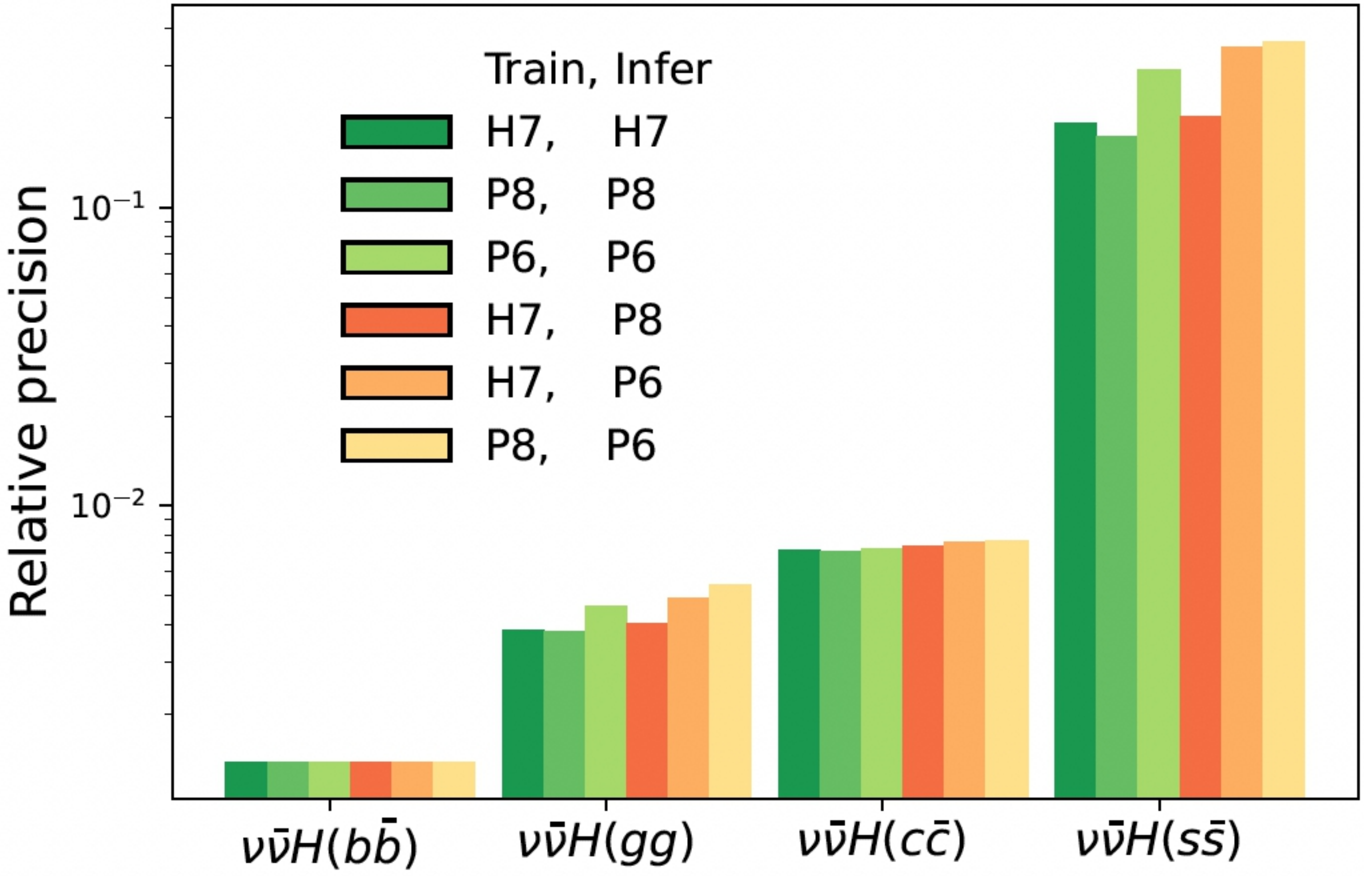
SiW-ECAL Future test:

- **2026**, with full uniform stack of 15 layers, then a long slab
  - Will be used for small experiments (EBES, LUXE, Lohengrin) → operational experience
  - Design will serve a basis for future μ-Electronics

Coming developments:

- Thin Cold-Plate prototyping + Interfaces (SiW-ECAL)
  - Re-optimisation of **absorbers** + **timing** + **`digital modes'**
- Re-design the PCBs on the basis of new ASICs
  - I2C communication (HGCAL protocols)
- Re-design of DAQ
  - Rates estimations on-going in all calorimeters
- Should aim at scalable prototypes by early 2030's
  - Reminder: 8 years of building for large calos

Supervised learning: need High Quality MC

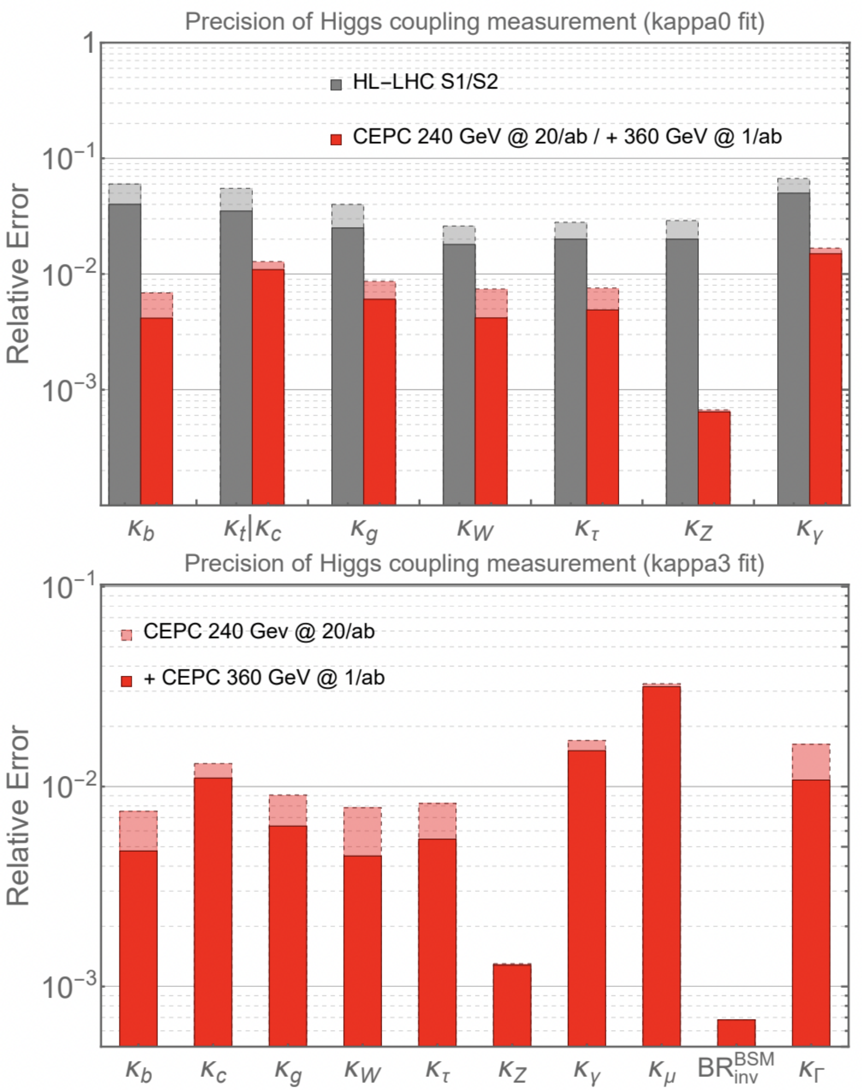


The Holistic approach is in principle free from human intervene...

Human define the goal (the signal), AI serves as the mean...

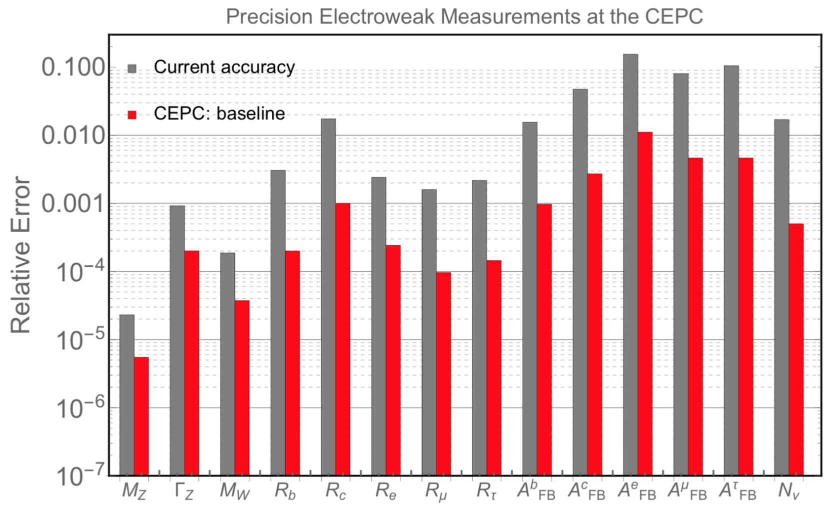
Higgs

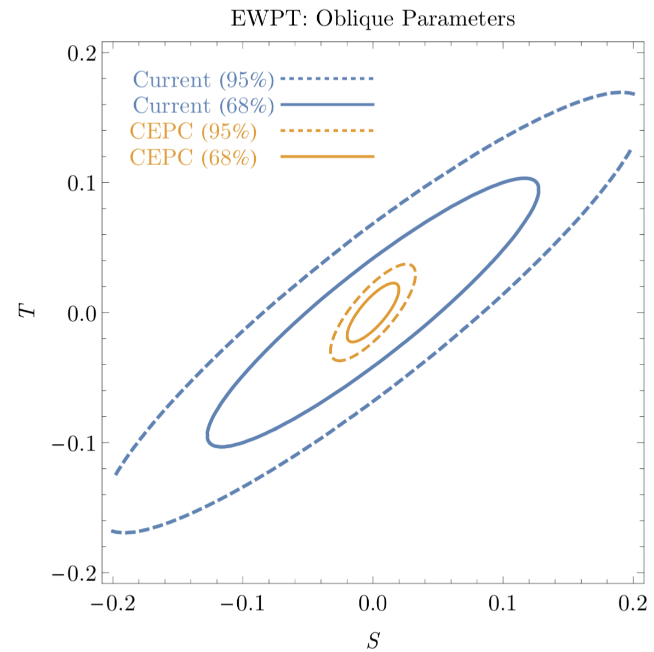
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	ZH	**vvH**	**eeH**
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**		**20%**	**21%**	
$H \to \tau\tau$	**0.42%**		**2.10%**	**4.20%**	**7.50%**
$H \to \gamma\gamma$	**3.02%**		**11%**	**16%**	
$H \to \mu\mu$	**6.36%**		**41%**	**57%**	
$H \to Z\gamma$	**8.50%**		**35%**		
$\mathrm{Br}_{upper}(H \to inv.)$	**0.07%**				
Γ_H	**1.65%**		**1.10%**		

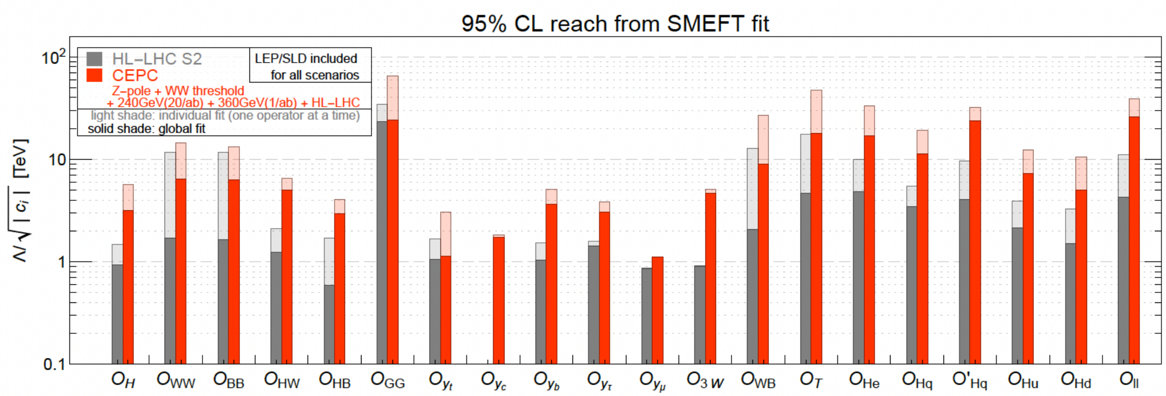


Plus EW & SMEFT

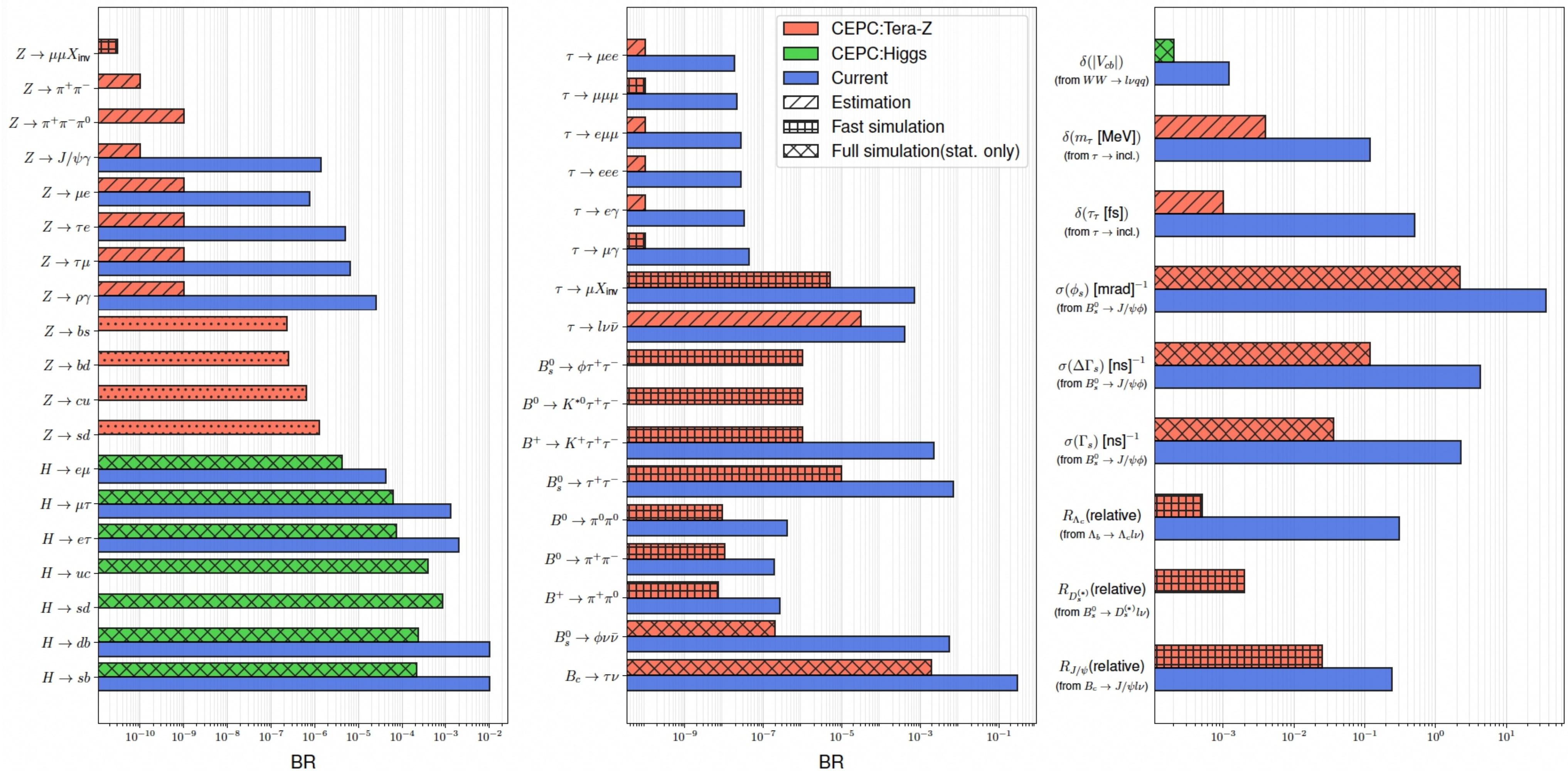
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta \Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta \Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5} (1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta \sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale







Flavor physics



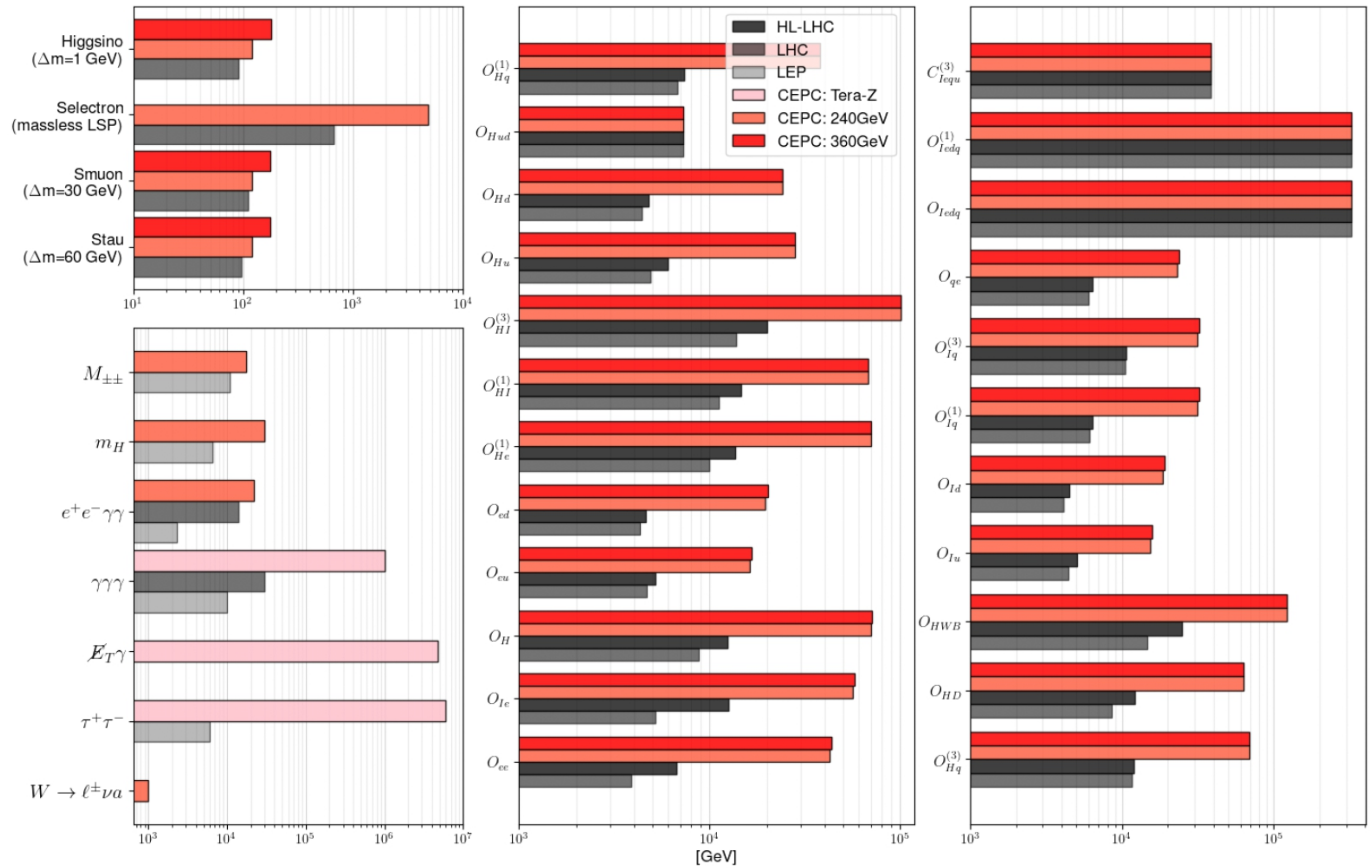
See the non-seen: i.e, Bc→tauv, Bs→Phivv

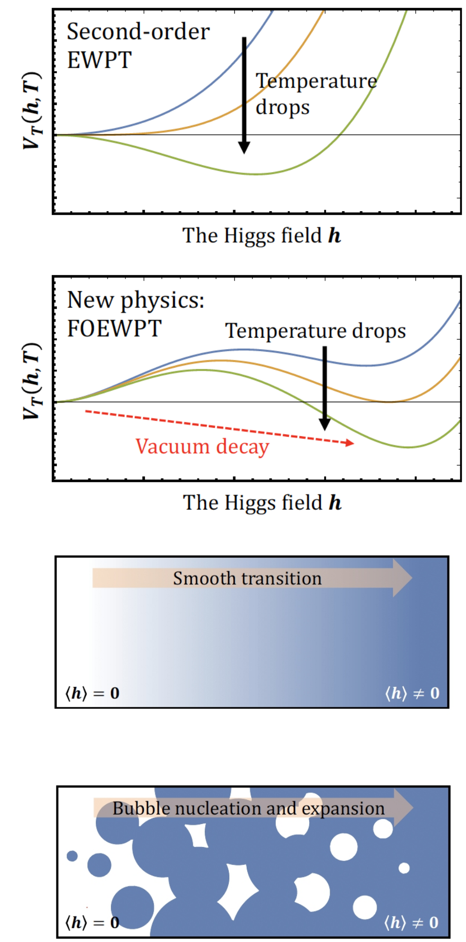
https://arxiv.org/pdf/2412.19743

Orders of magnitudes improvements (1 – 2.5 orders...).

Access New Physics with energy scale of 10 TeV, or even above

Direct New physics search



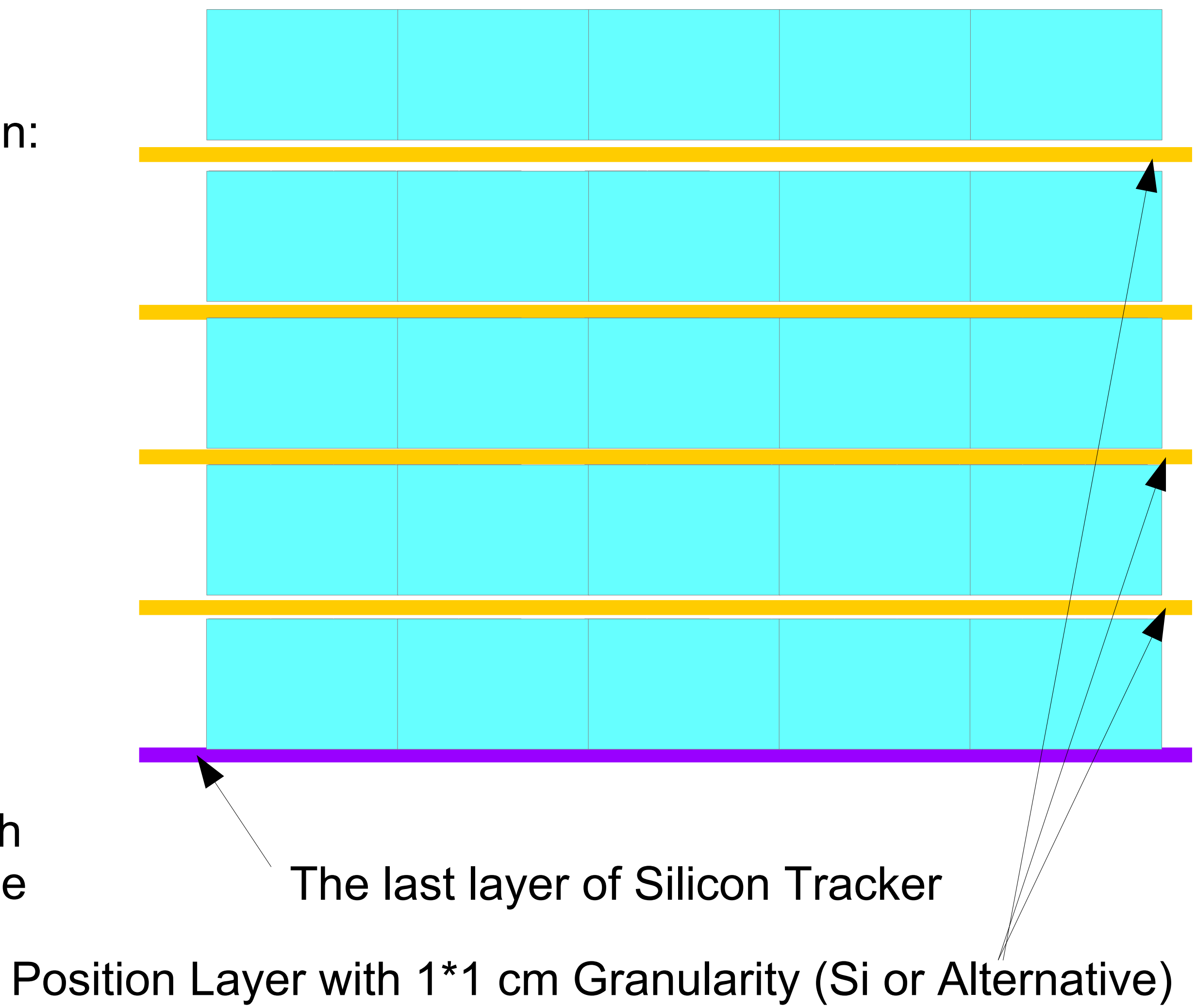


https://arxiv.org/pdf/2505.24810

Matter Origin, Dark matter...
Access to NP ~ 100 TeV...

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



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

2015, PreCDR

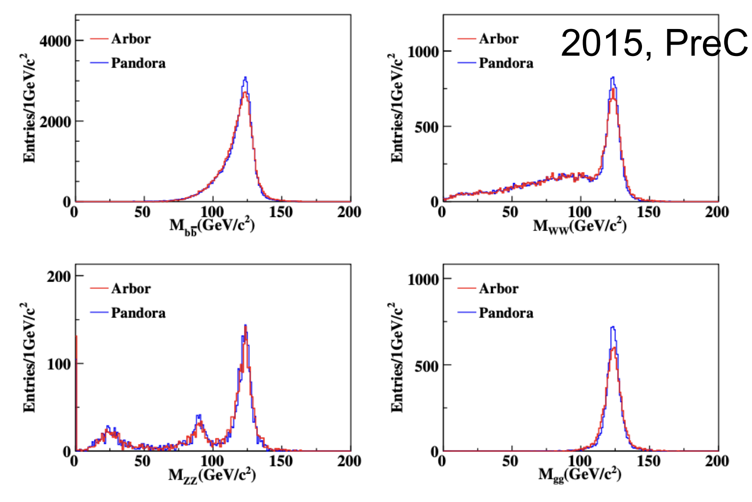


Figure 3.3 Invariant mass of all reconstructed particles of $v\bar{v}H$ events, with Higgs decay into different final states.

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: 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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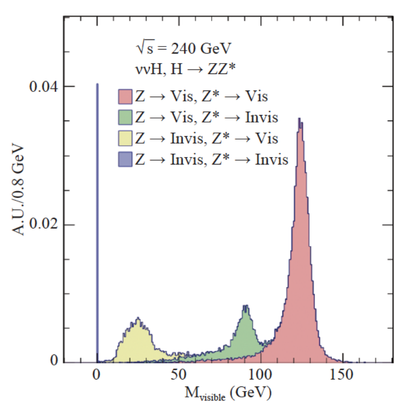
Abstract: As a Higgs factory, the CEPC (Circular Electron-Positron Collider) project aims at precision measurements of the Higgs boson properties. A baseline detector concept, APODIS (A PFA Oriented Detector for the HIggS factory), has been proposed for the CEPC CDR (Conceptual Design Report) study. 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^* decay modes, where a clear separation between different decay cascades is observed.

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→

JINST
Published by IOP Publishing for Sissa Medialab
Received: January 15, 2021
Accepted: April 13, 2021
Published: July 21, 2021

Jet performance at the circular electron-positron collider

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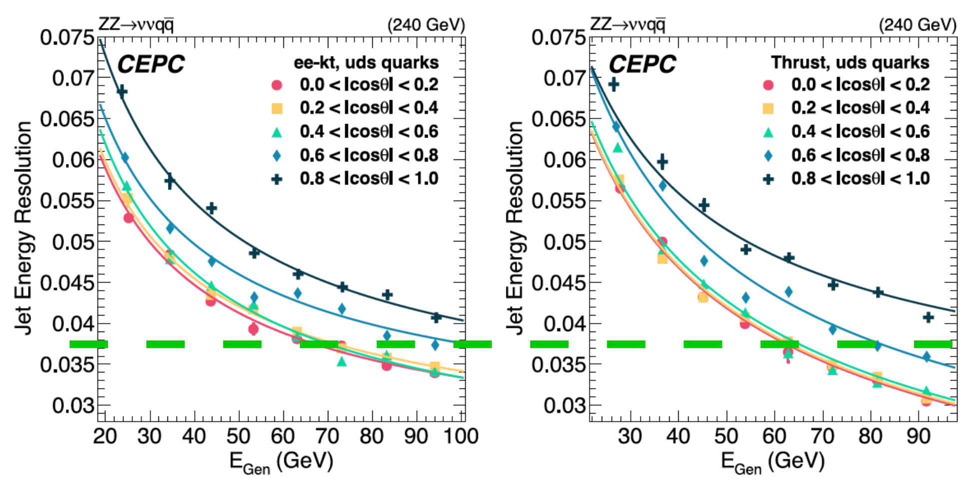
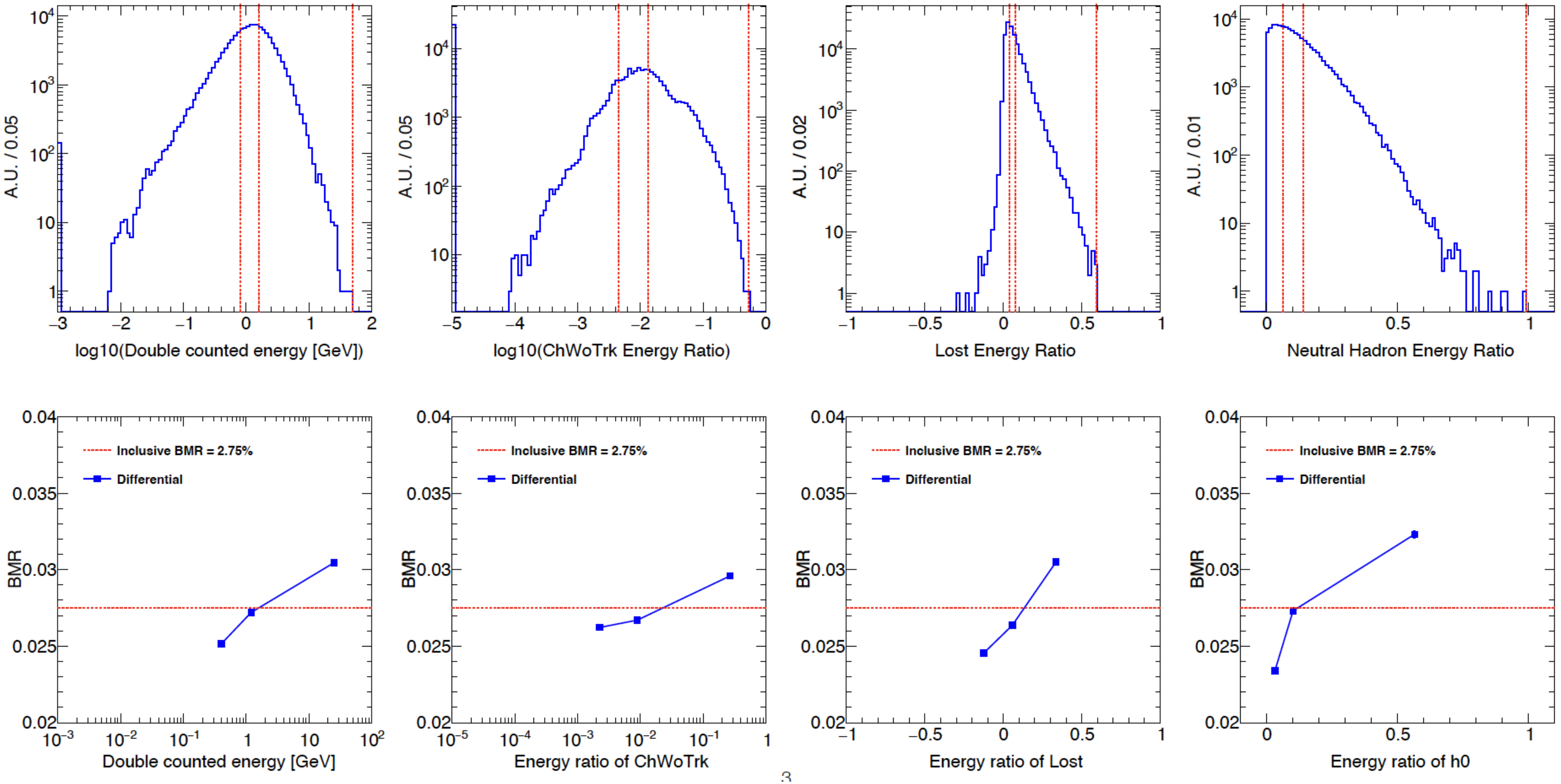


(a) (b)

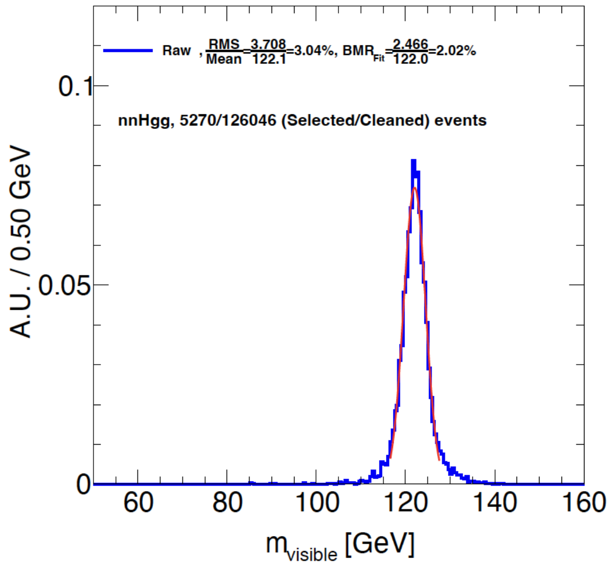
BMR dependence to its components



BMR dependence on Cut...

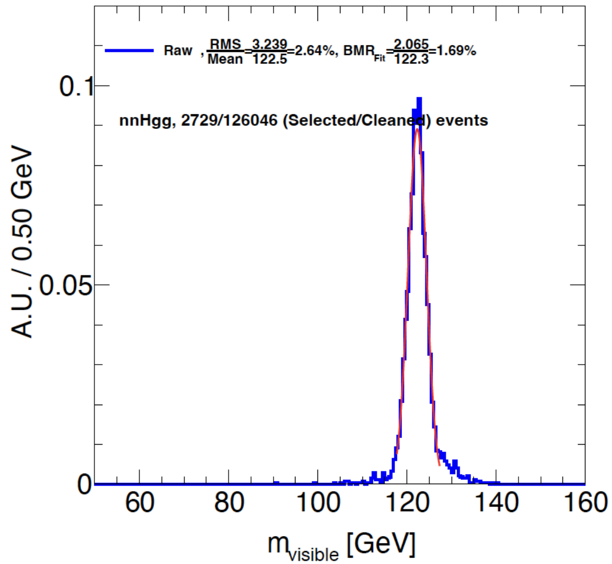
Combined cut (top 1/3 good events)

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

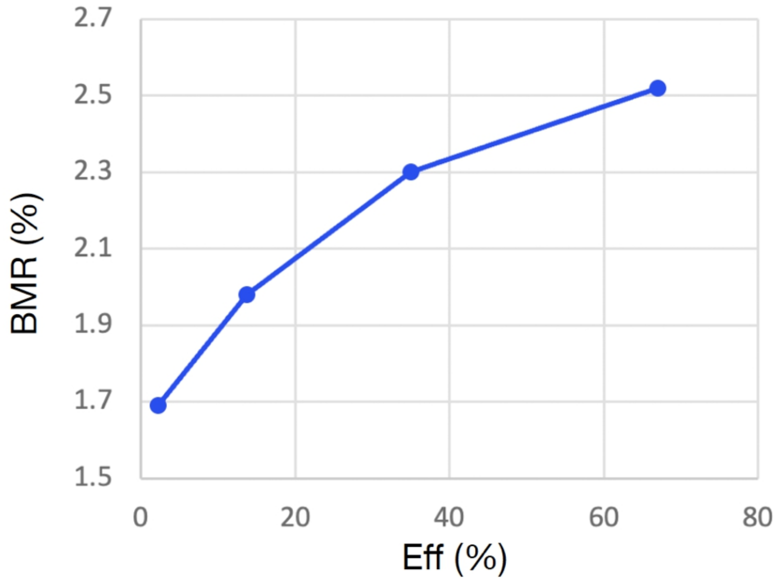


4

- **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

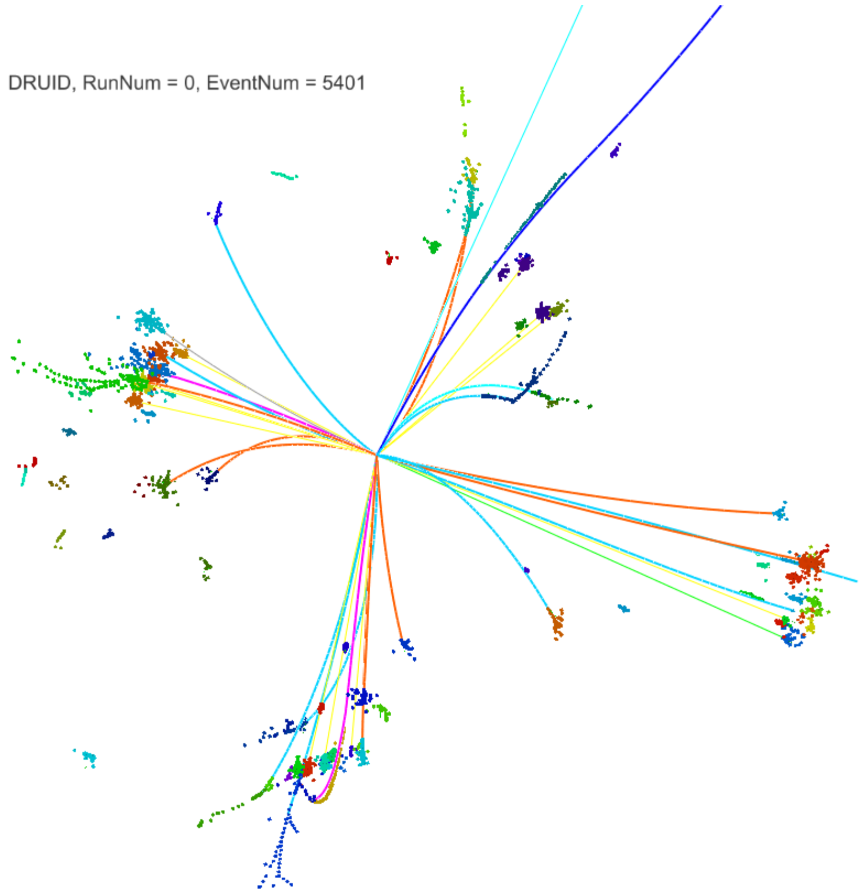


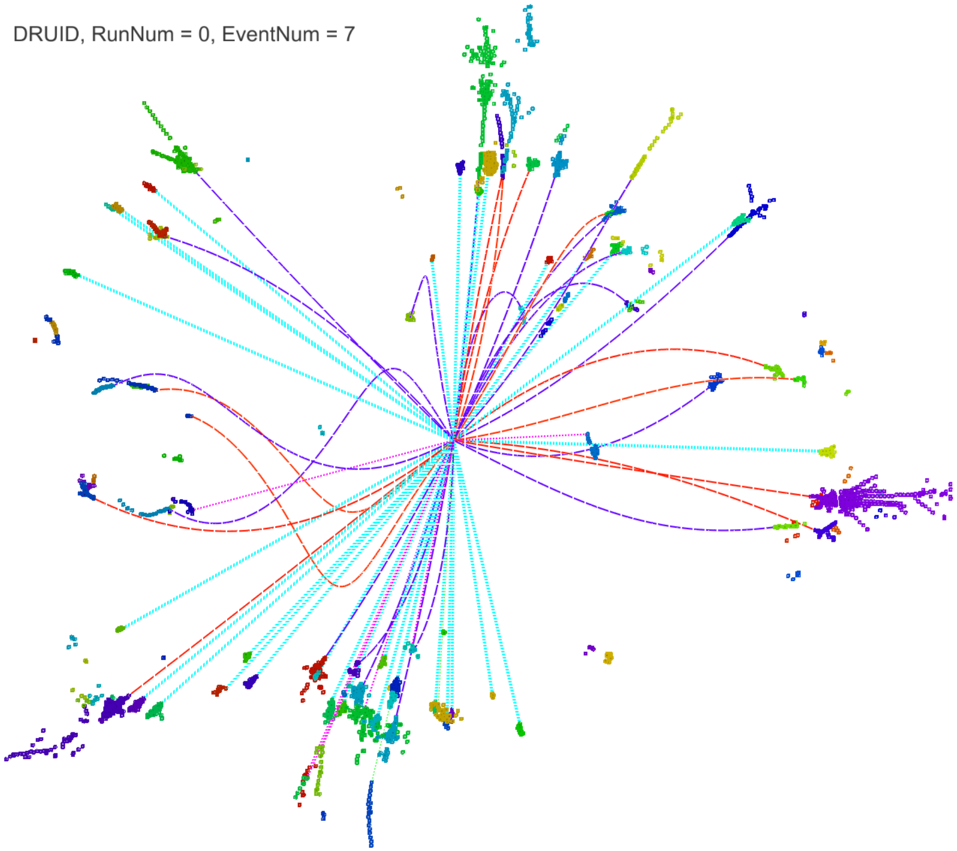
...If the High Values tails could be tamed...

Idea 1: 5d calorimeter optimization

- 5d calorimeter is a must.
- Standard Framework to quantify its performance & impact, and for the ref. of optimization
  - Spatial, energy & time resolution at Single Particle & Physics events benchmarks
  - Pid & BMR
- Critical output - deliverables
  - Regression algorithm with AI
    - To measure the Energy & ToF of Clusters: essential to reach BMR ~ 2%
    - Could be extended to position/direction reco.
  - 5d performance specification & reference configurations
    - Timing resolution at single cell + timing cell/layer arrangement in the entire calo.
    - Benchmarked to Pid performance, especially neutral hadron id

Color Singlet Identification





at full hadronic ZH event

Color Singlet Identification

PUBLISHED FOR SISSA BY SPRINGER
RECEIVED: *March 11, 2022*
REVISED: *September 9, 2022*
ACCEPTED: *November 11, 2022*
PUBLISHED: *November 16, 2022*
JHEP11(2022)100

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

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University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing 100049, China
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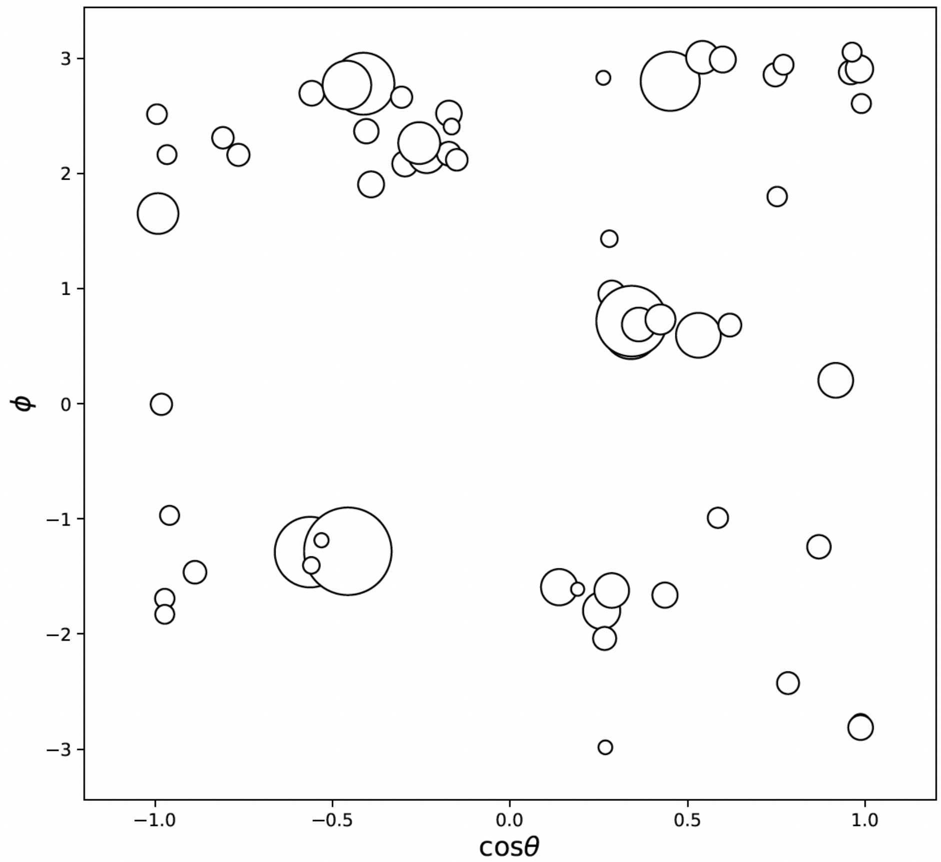
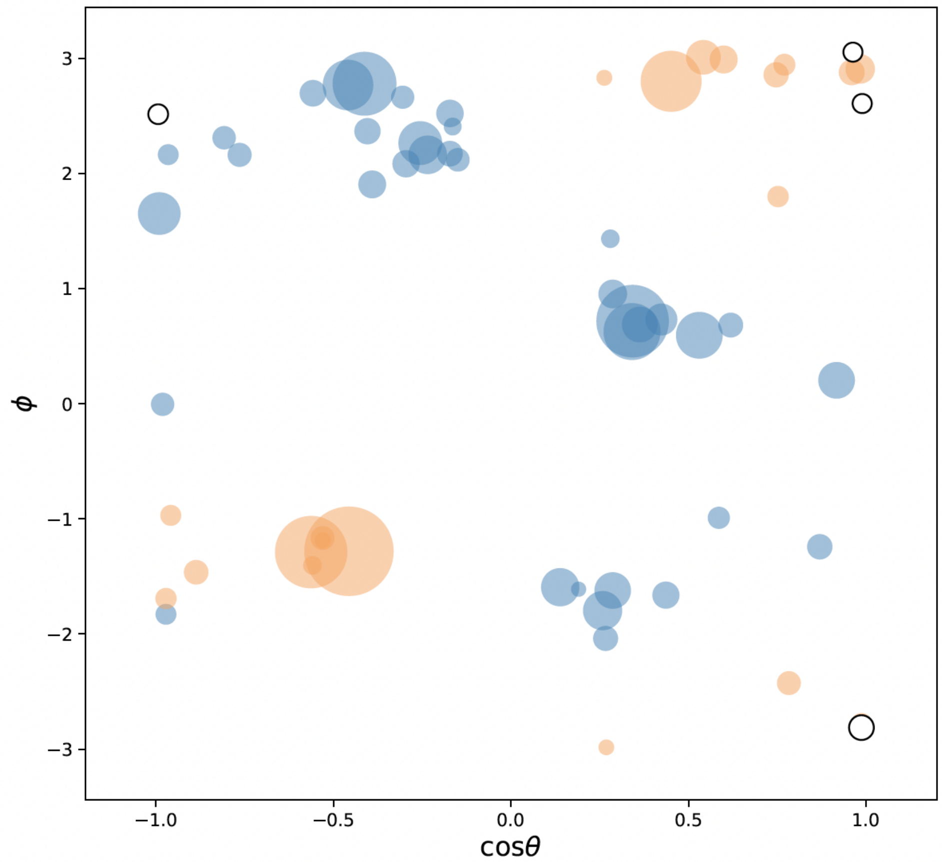
Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

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)

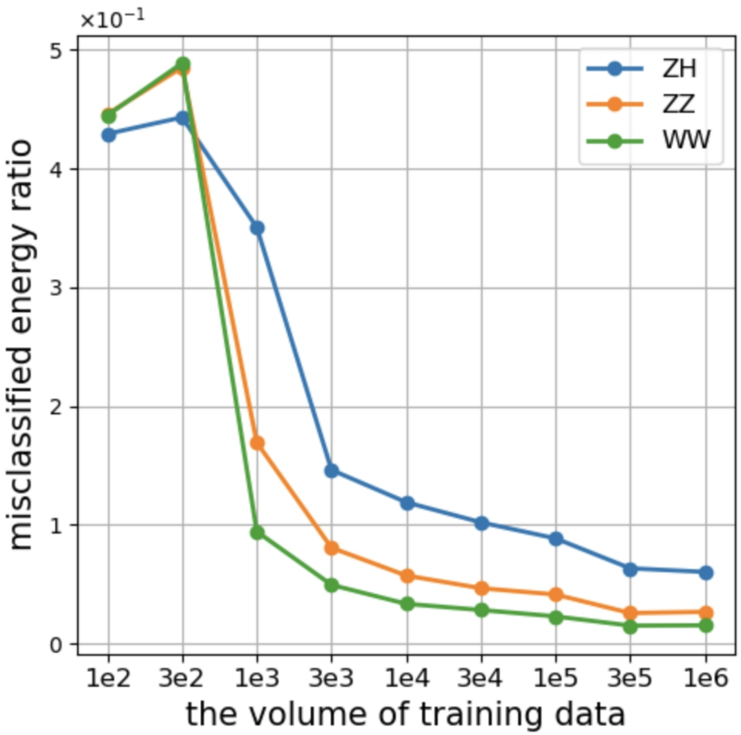
Advanced CSI using AI

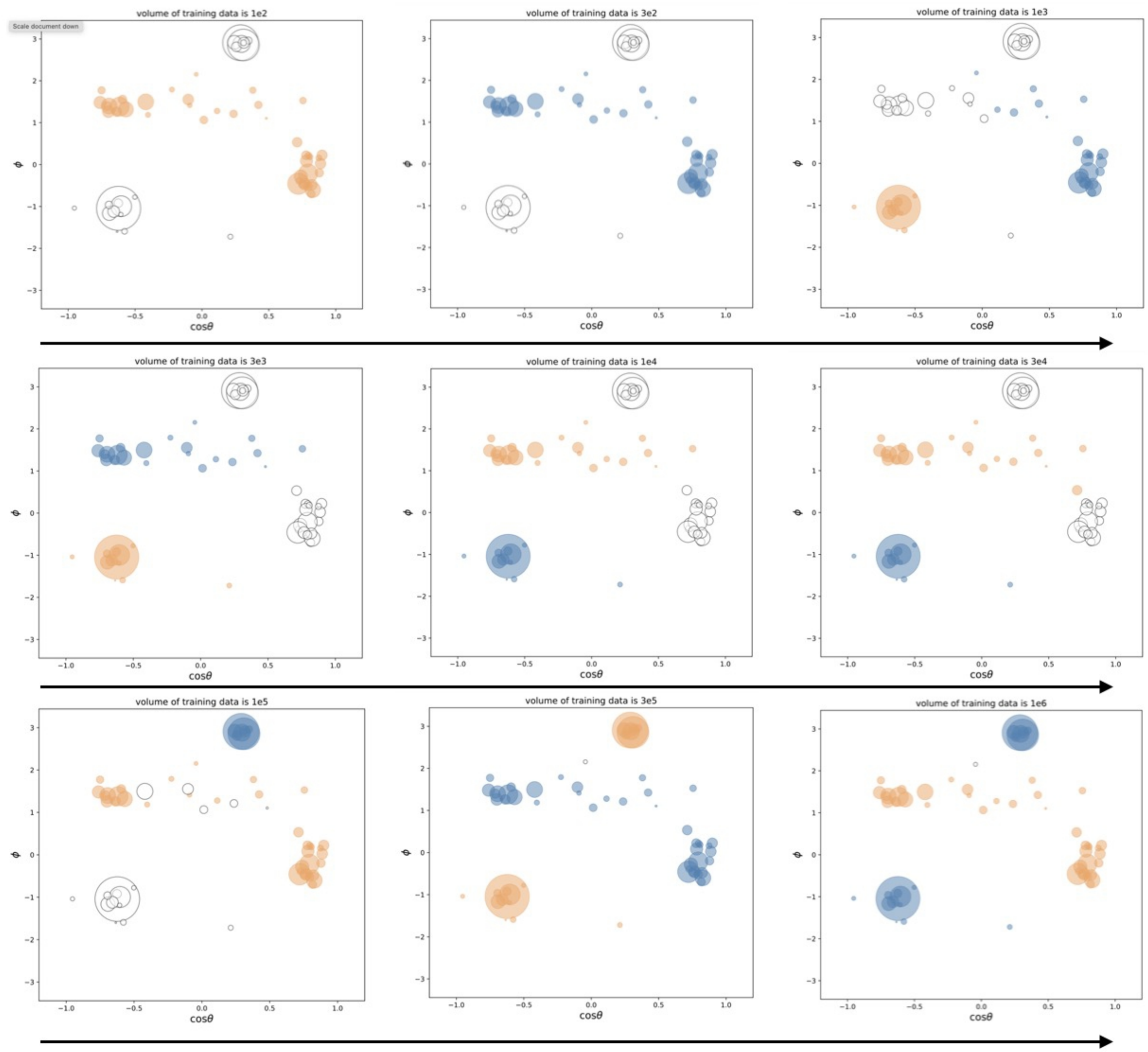




Yongfeng, Hao, Yuexin, etc

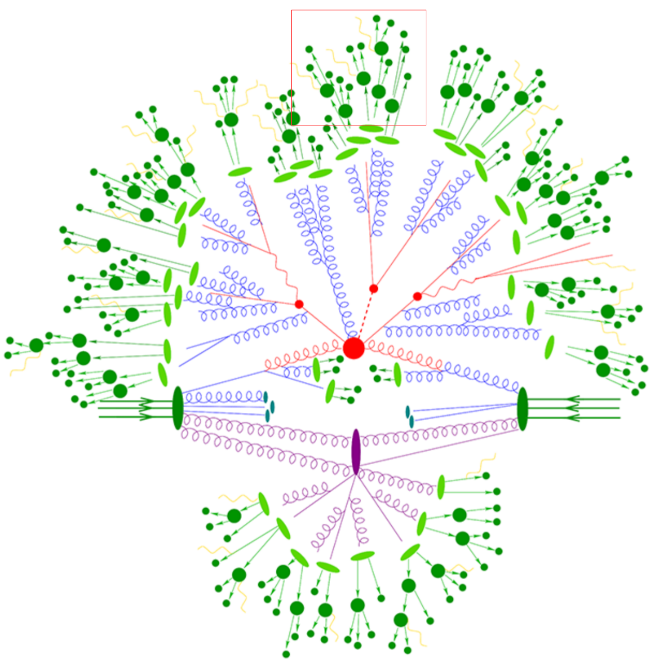
Scaling behavior





Idea 2: From leaves to the trees

- The hadronization process is also tree like
  - PFA & 1-1 corresponding Committed to reconstruct well the leaves – the final state particles that actually interacts with detector/calorimeter
  - Possible to identify the cascading history of final state particles
    - Pi-0,
    - K_short, Lambda, *EPJP (2020) 135:274*
    - Phi, *PRD 105, 114036 (2022)*
    - ...
    - Tau, D, B...
- Impact:
  - Essential for Flavor & New Physics
  - Enhance Jet Origin Identification
- Methodology: Comparative analysis
  - Conventional + AI



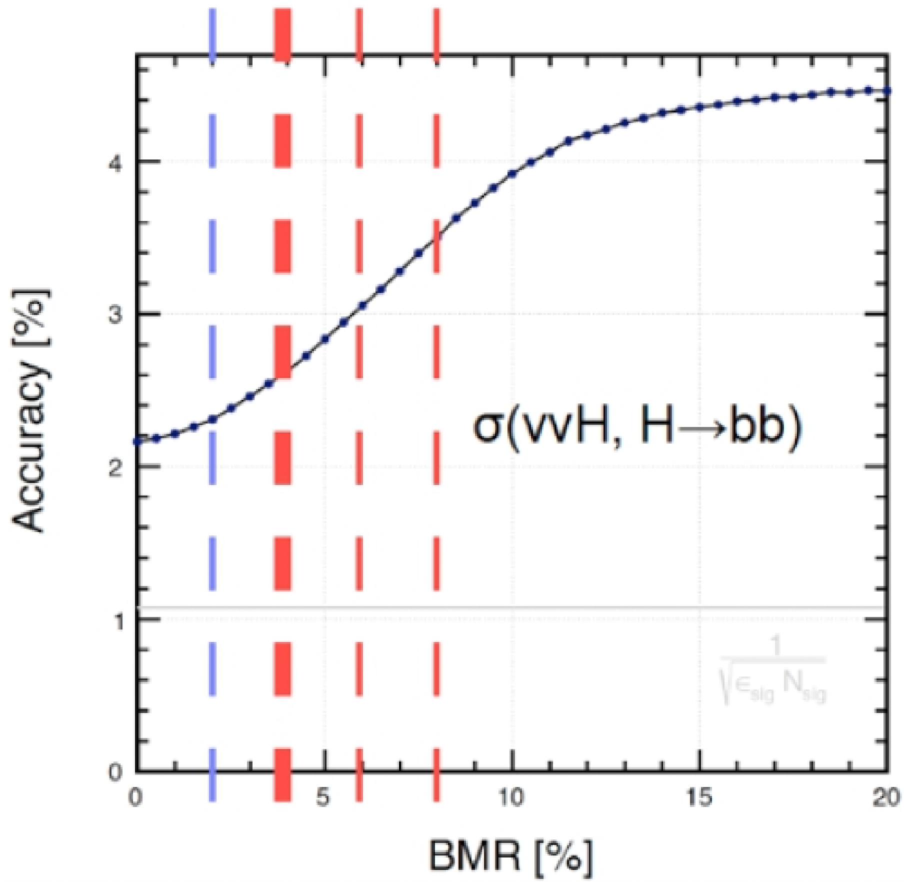
Idea 3: global measurements with multi-class classification

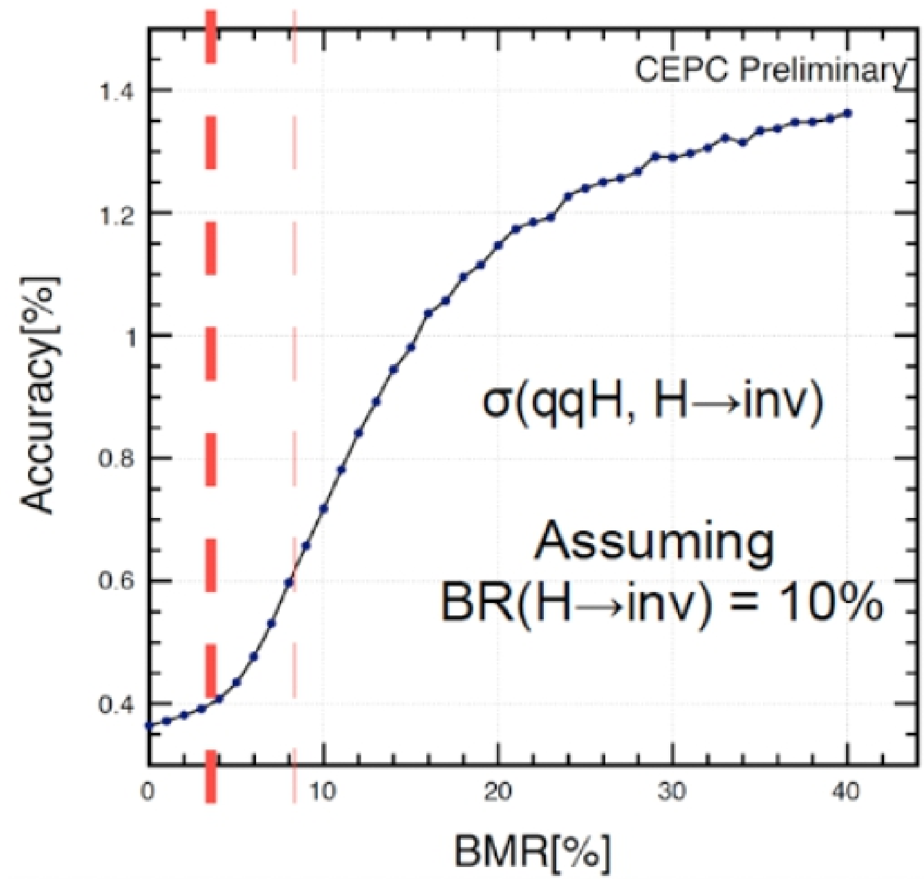
- Extend the holistic approach to sufficiently large group of event classification ~ o(100) classes of Higgs events + critical SM backgrounds.
  - Higgs signal: {llH, vvH, qqH}*Br(H->X)
  - SM backgrounds
    - {WW, ZZ}*{non, semi, full hadronic} + Single Z/W*{non, semi hadronic} + ...
    - 2 fermion
    - *Di-photon (mostly pile up), more relevant to Linear Collider*
    - *Beam induced background + Noise...*
    - ...
- Impact
  - Simultaneously measure large number of channels
  - Benchmarks for optimization, in a end-end way: express the entire detector + recon capability in terms of, i.e., global migration matrix

Idea 3: high value measurements

- H->ss:
  - Good enough det + ~o(20) iab will probably leads to 5-sigma confirmation
- Higgs width: separate W fusion from ZH (i.e., with vvqq final state)
- qqH, H->inc, for the g(HZZ) measurements
- Higgs self coupling
-
- Could be well extended, especially with EW sectors...

Impact on physics benchmarks...

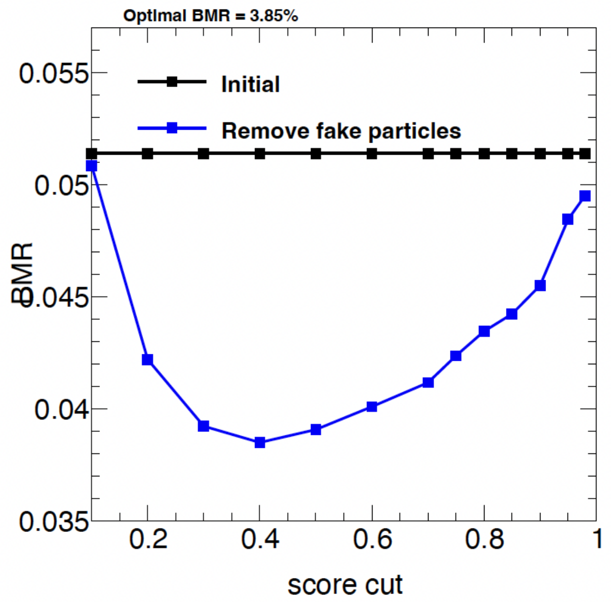


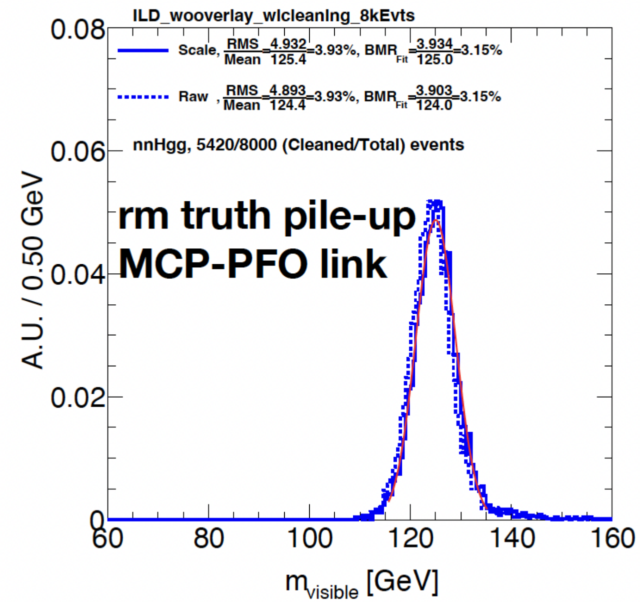


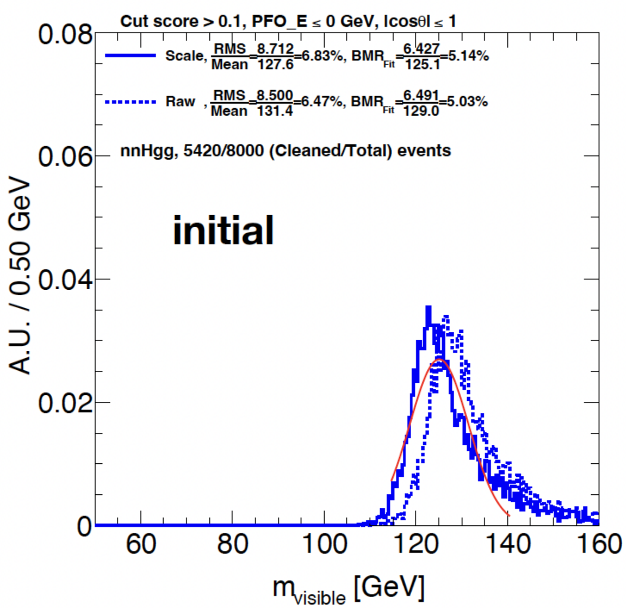
Accuracies of Higgs measurements improved by ~ o(10%) with conventional analysis...
Critical for g(HZZ) & new physics detection...
Personal Anticipation: larger impact with sophisticated Analysis, i.e., holistic analysis.

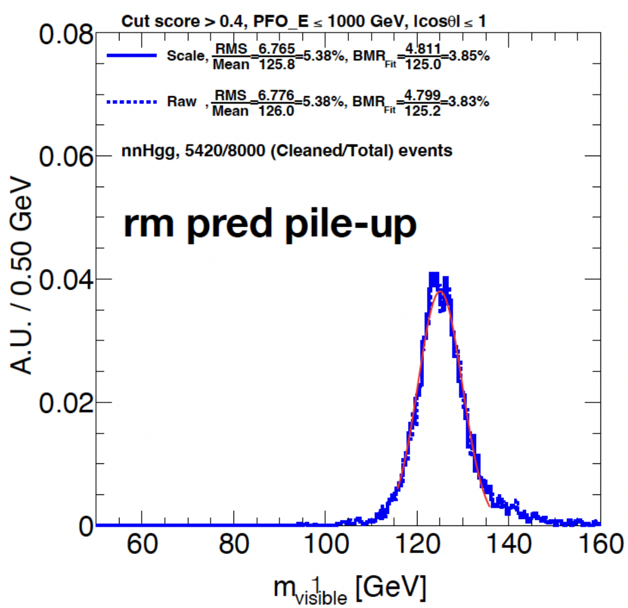
pile-up subtraction

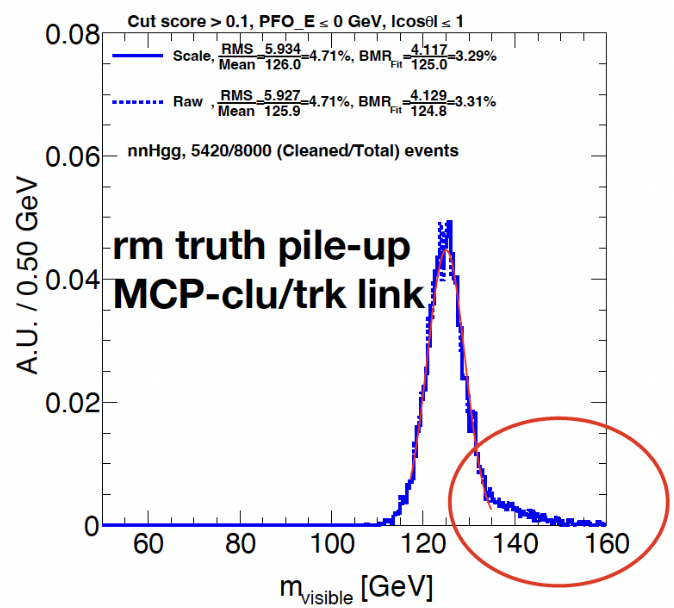
- **BMR**
  - **initial ~5.14%**
  - **rm pred pile-up 3.85%**
  - **rm truth pile-up 3.29%**
    - **using MCP-clu/trk link**
  - **rm truth pile-up 3.15%**
    - **using MCP-PFO link**









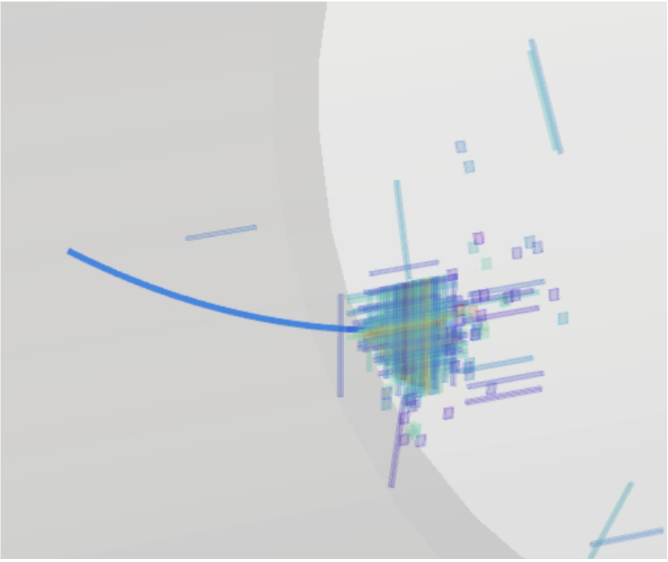


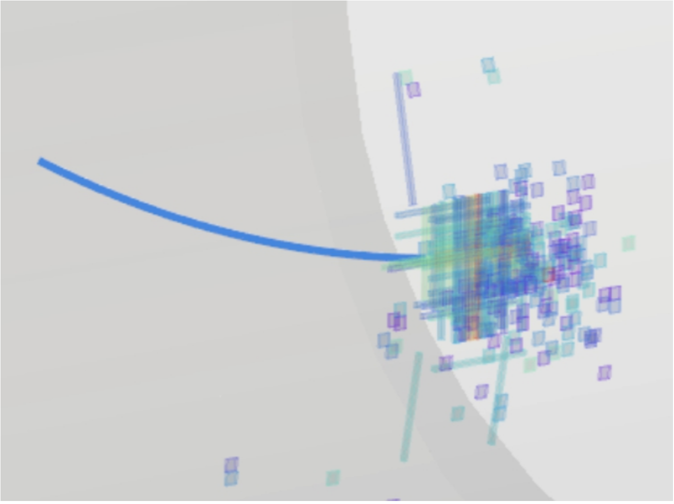
Thoughts on the Det. optimization

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

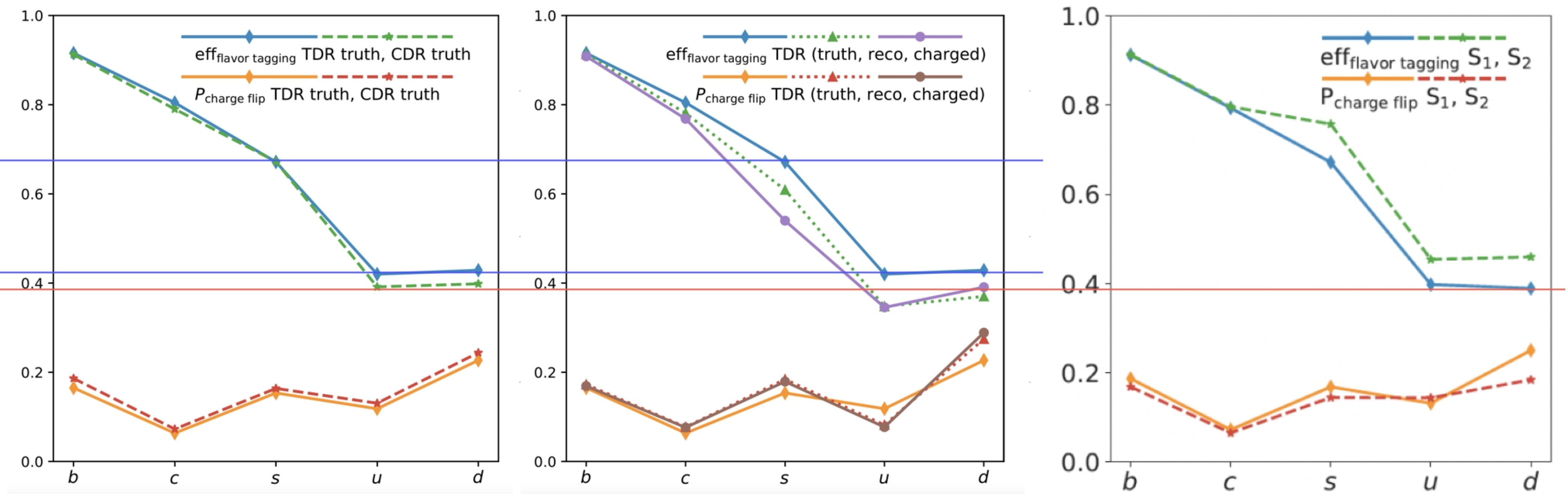
- In TRD, the bottleneck is the inefficiency of cluster reconstruction, esp. neutral particles in the jets. Primarily due to the fact that Xbar configuration has large shower volume, causing severer shower overlap – merging

- 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.





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

BMR comparison