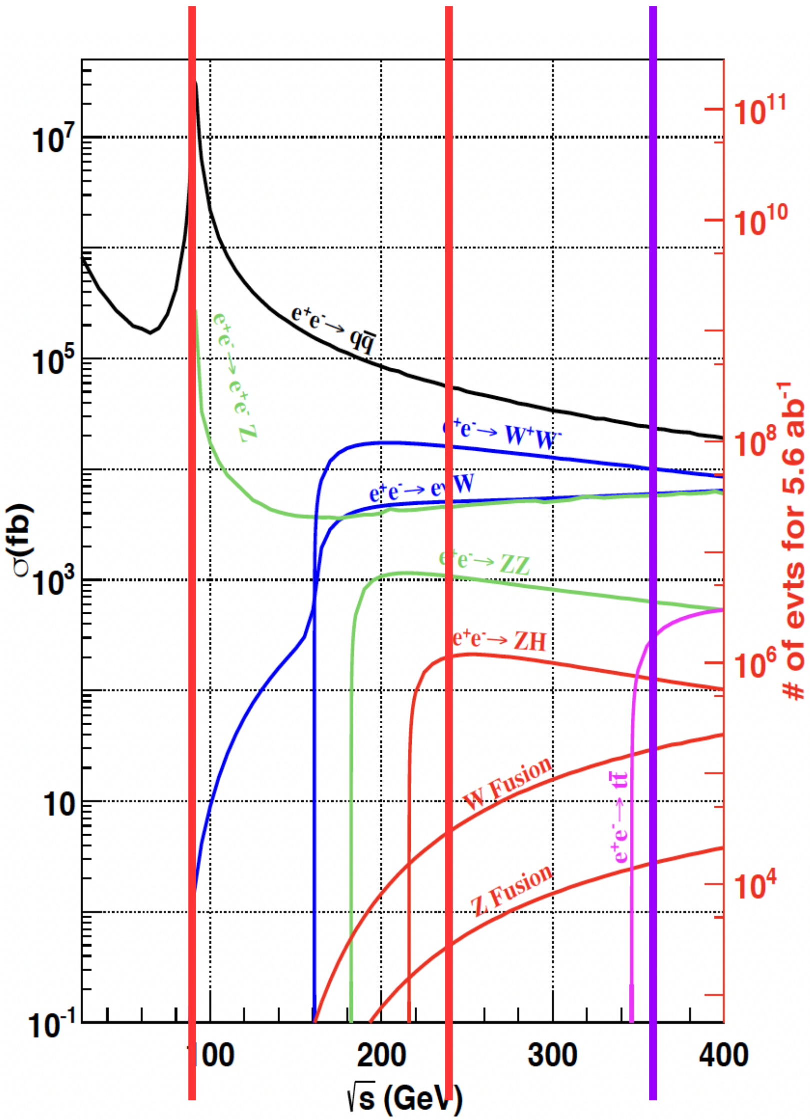
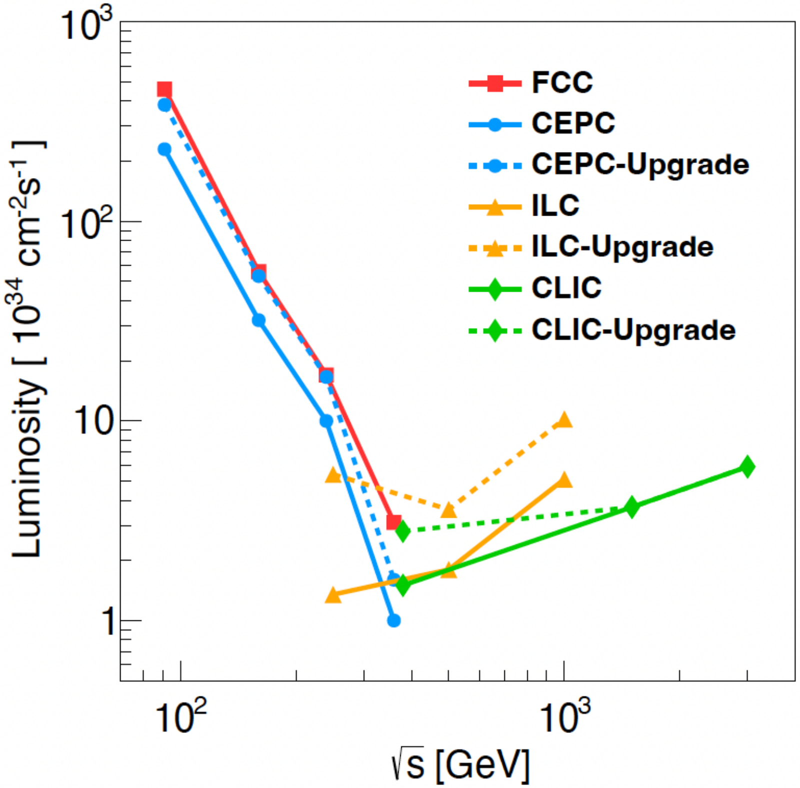
The holistic approach and one-one correspondence reco: AI usage at future Higgs factory

Manqi

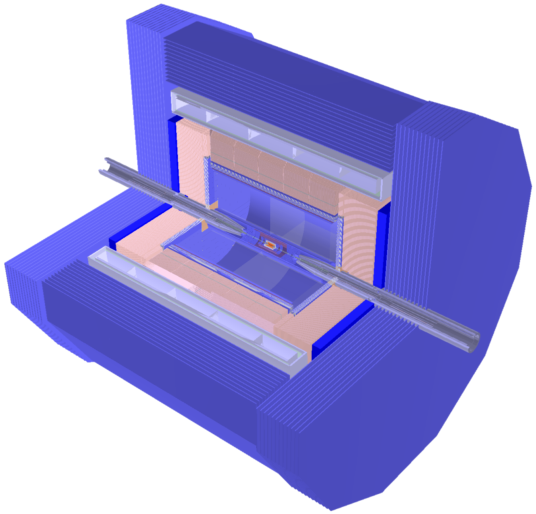
Yields ~ Xsec * Lumi * Time

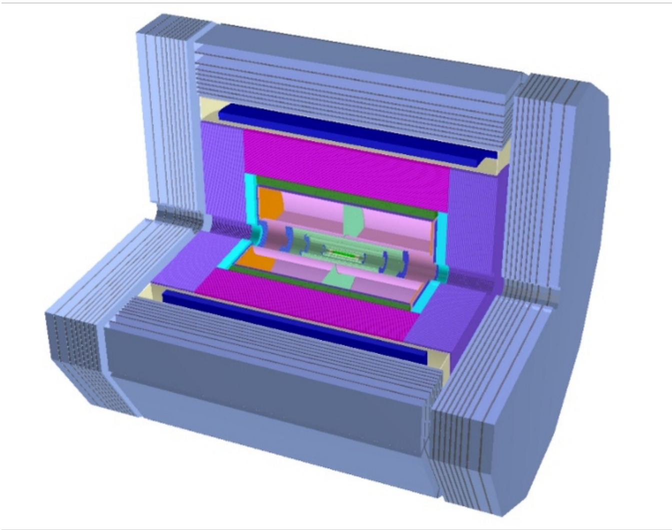


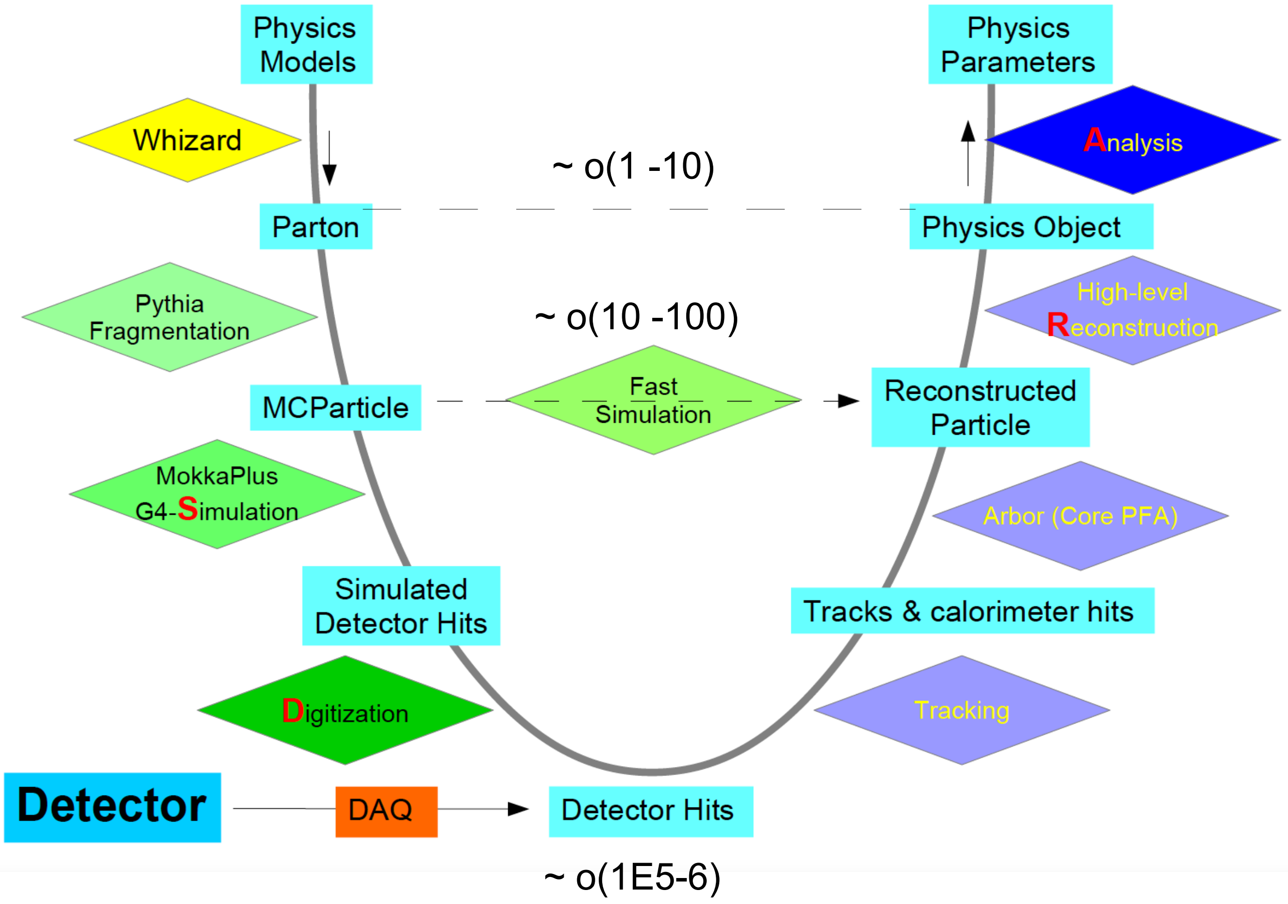


- CEPC: 100 km main ring circumference
- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

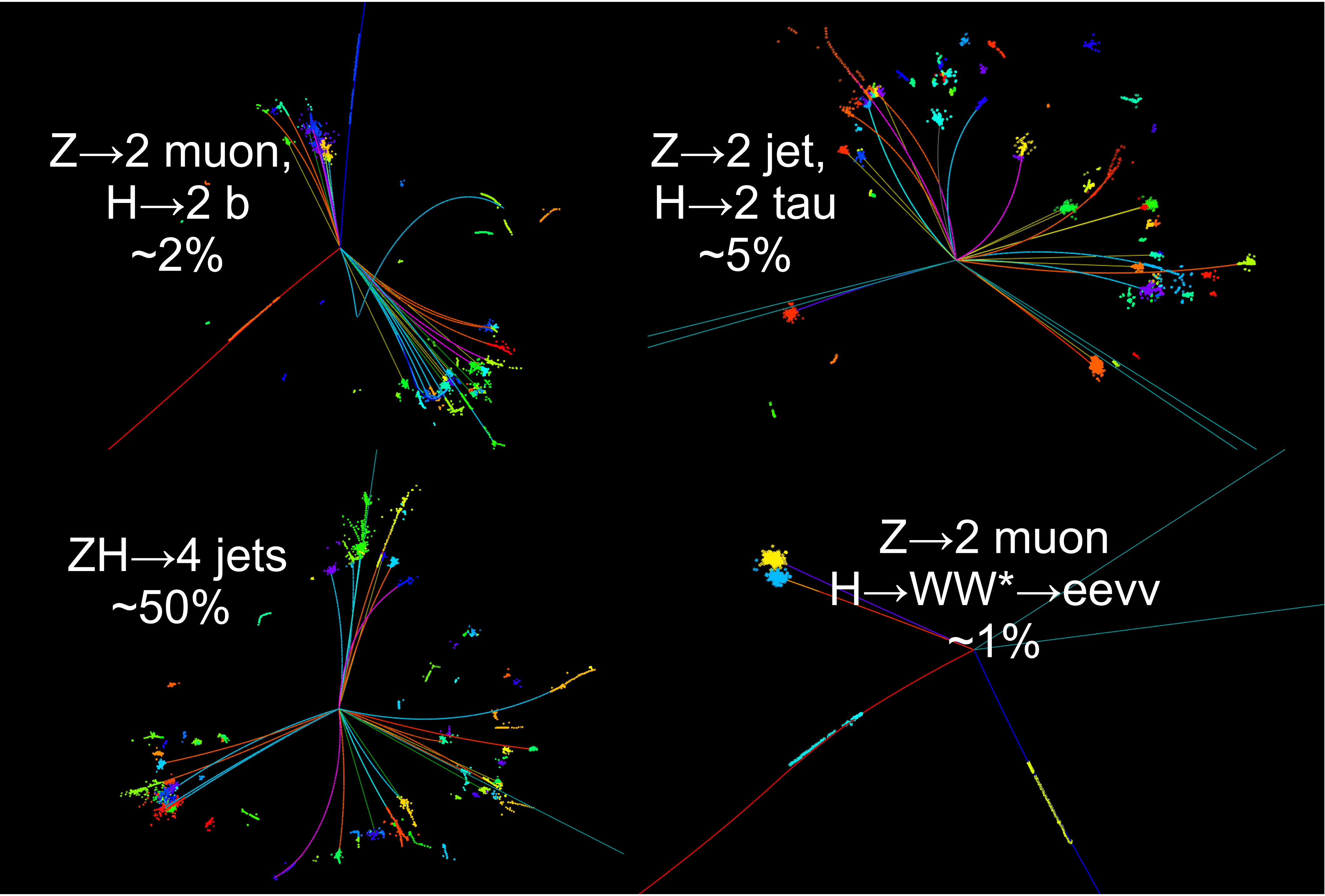
CEPC Detector & Reconstruction



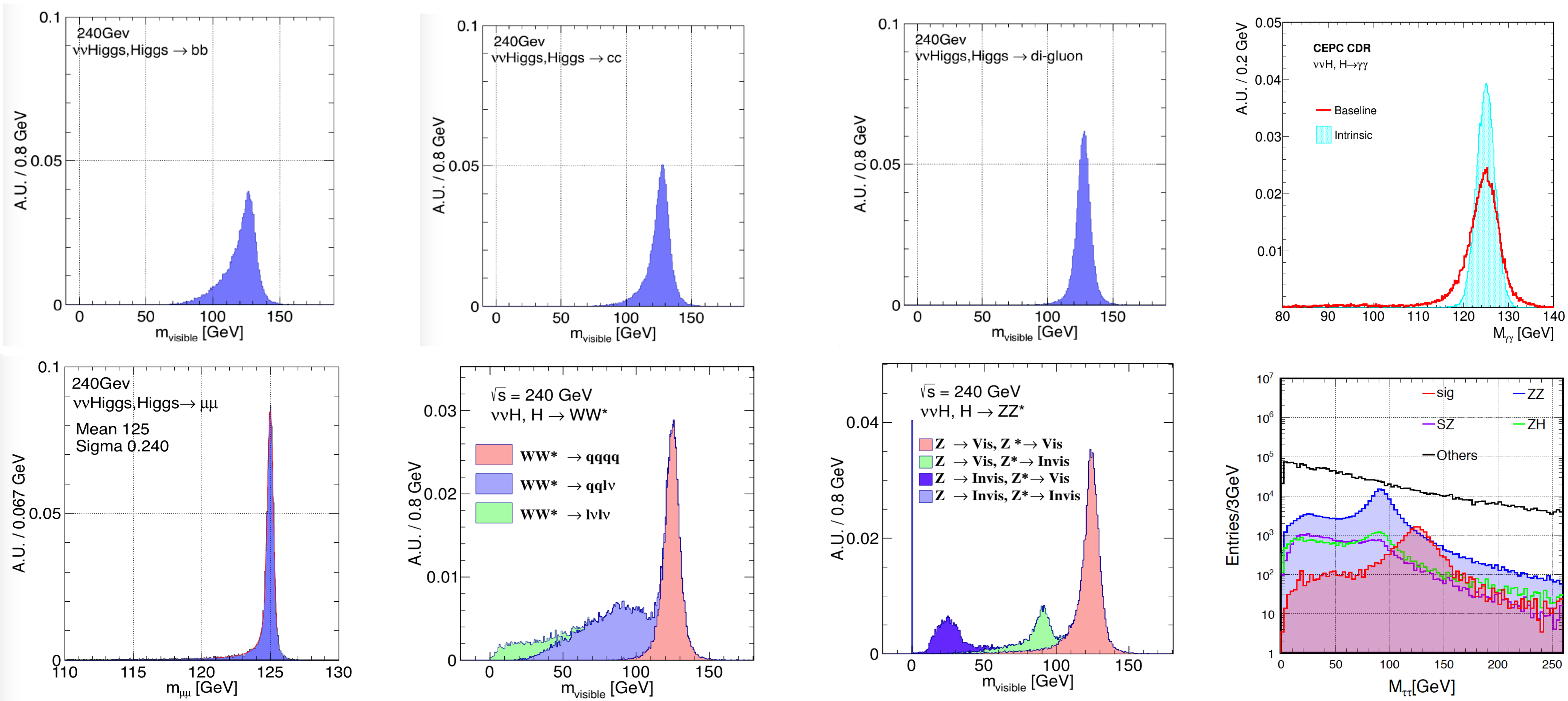




PFA oriented Approach: **Arbor, etc**


Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

Reconstructed Higgs Signatures

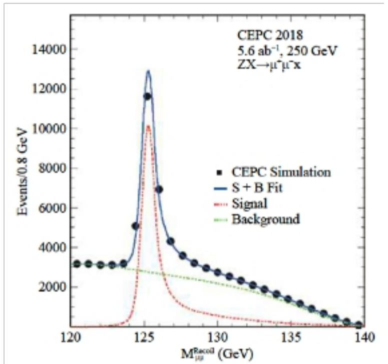


Clear Higgs Signature in all SM decay modes

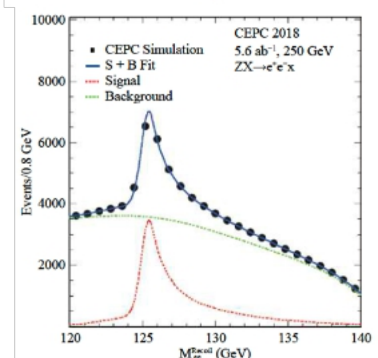
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

Right corner: di-tau mass distribution at qqH events using collinear approximation

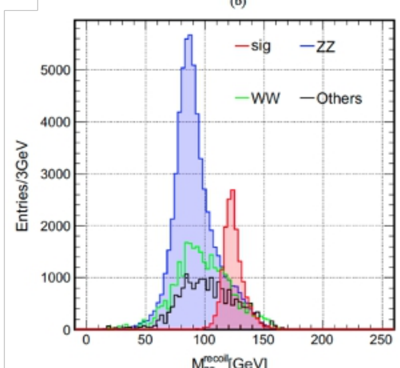
CEPC Physics: 4 Million Higgs + 4 Tera Z...



(a)



(b)



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Precision Higgs physics at the CEPC*

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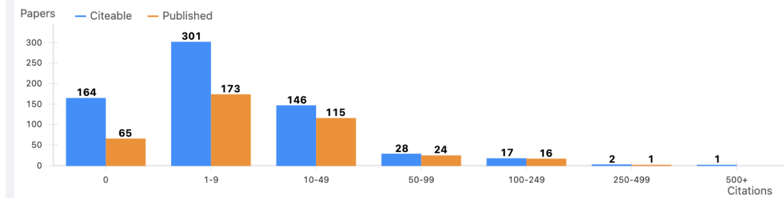


Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

Higgs			W, Z and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M_{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H \to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H \to cc)$	-	2.0%	Γ_Z	2.3 MeV	0.025 MeV
$B(H \to gg)$	-	0.81%	R_b	3×10^{-3}	2×10^{-4}
$B(H \to WW^*)$	2.8%	0.53%	R_c	1.7×10^{-2}	1×10^{-3}
$B(H \to ZZ^*)$	2.9%	4.2%	R_μ	2×10^{-3}	1×10^{-4}
$B(H \to \tau^+\tau^-)$	2.9%	0.42%	R_τ	1.7×10^{-2}	1×10^{-4}
$B(H \to \gamma\gamma)$	2.6%	3.0%	A_μ	1.5×10^{-2}	3.5×10^{-5}
$B(H \to \mu^+\mu^-)$	8.2%	6.4%	A_τ	4.3×10^{-3}	7×10^{-5}
$B(H \to Z\gamma)$	20%	8.5%	A_b	2×10^{-2}	2×10^{-4}
$\mathrm{Bupper}(H \to \mathrm{inv.})$	2.5%	0.07%	N_ν	2.5×10^{-3}	2×10^{-4}

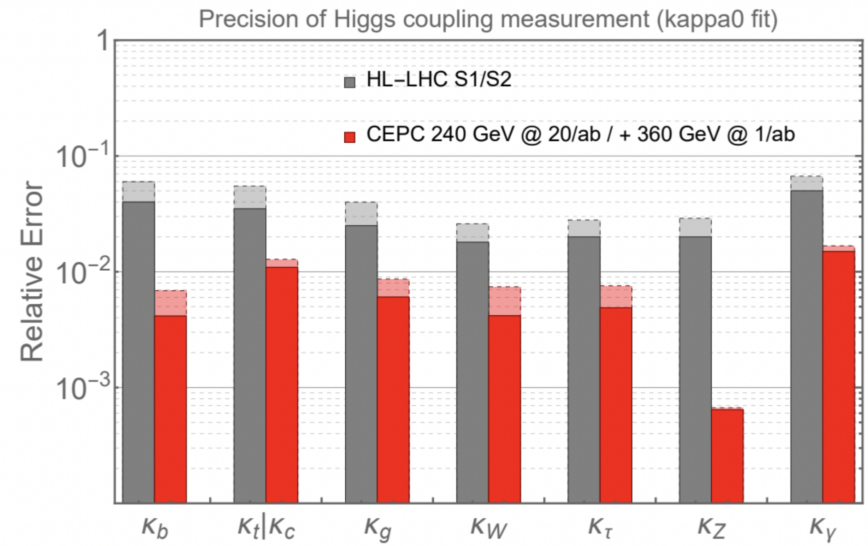
Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

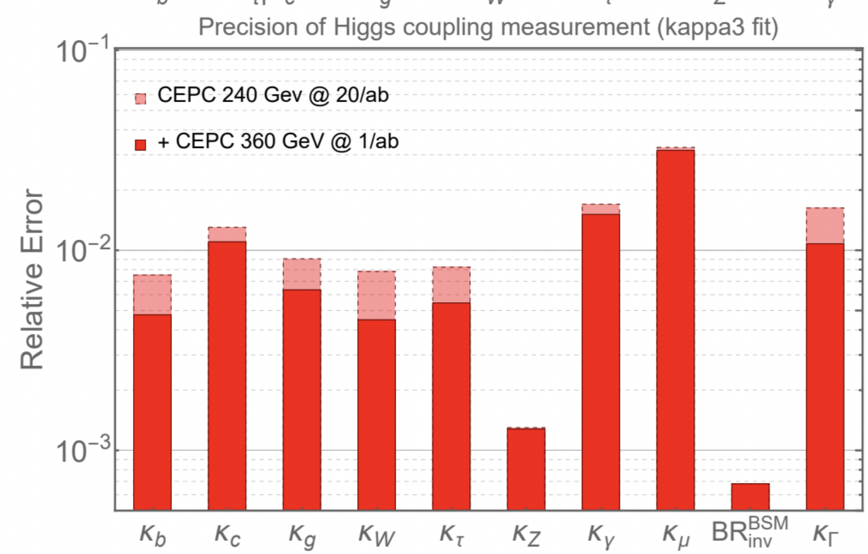
- Higgs: Precisions exceed HL-LHC ~ 1 order of magnitude.
- EW: Precision improved from current limit by 1-2 orders.
- Flavor Physics, sensitive to NP of 10 TeV or even higher.
- Sensitive to varies of NP signal.
- …

White papers +
~300 Journal/AxXiv citables

Higgs & Snowmass White Paper

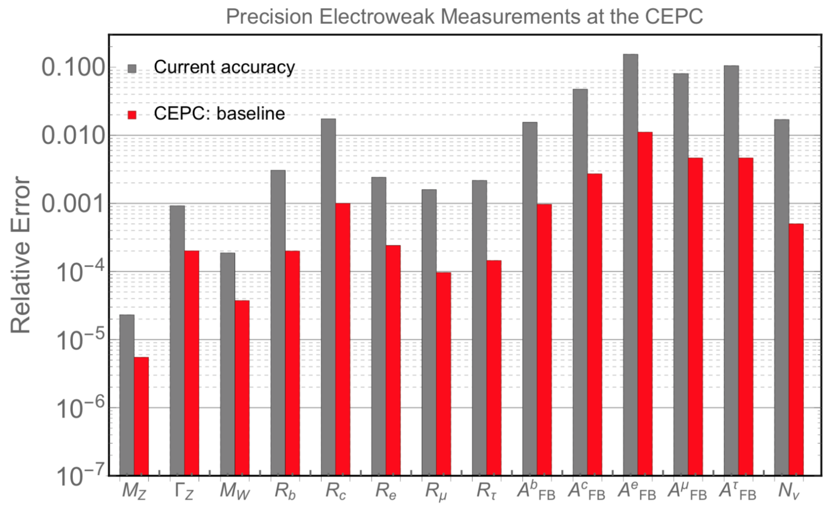
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	ZH	**vvH**	**eeH**
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**		**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%**		
$Br_{upper}(H \to inv.)$	**0.07%**				
Γ_H	**1.65%**		**1.10%**		

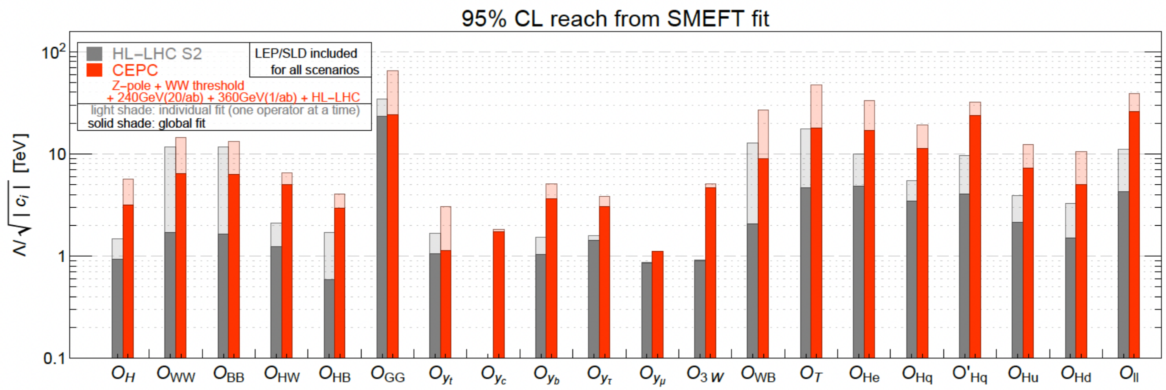


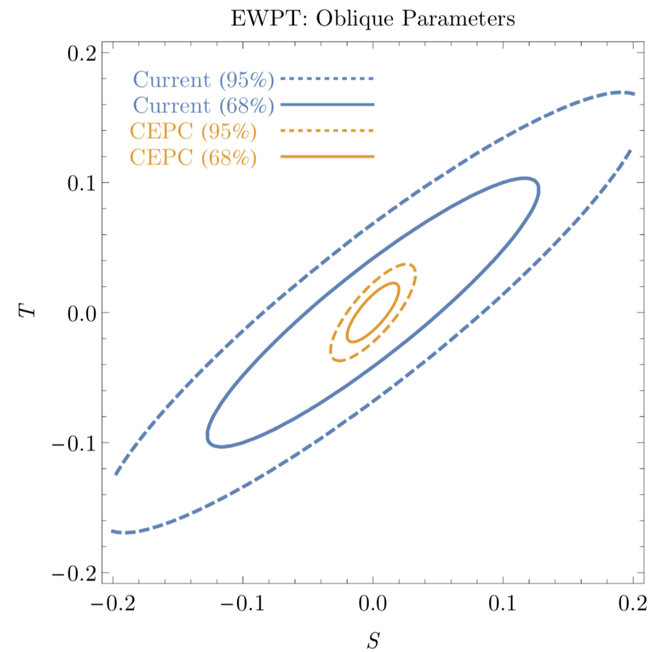


EW measurements & SMEFT

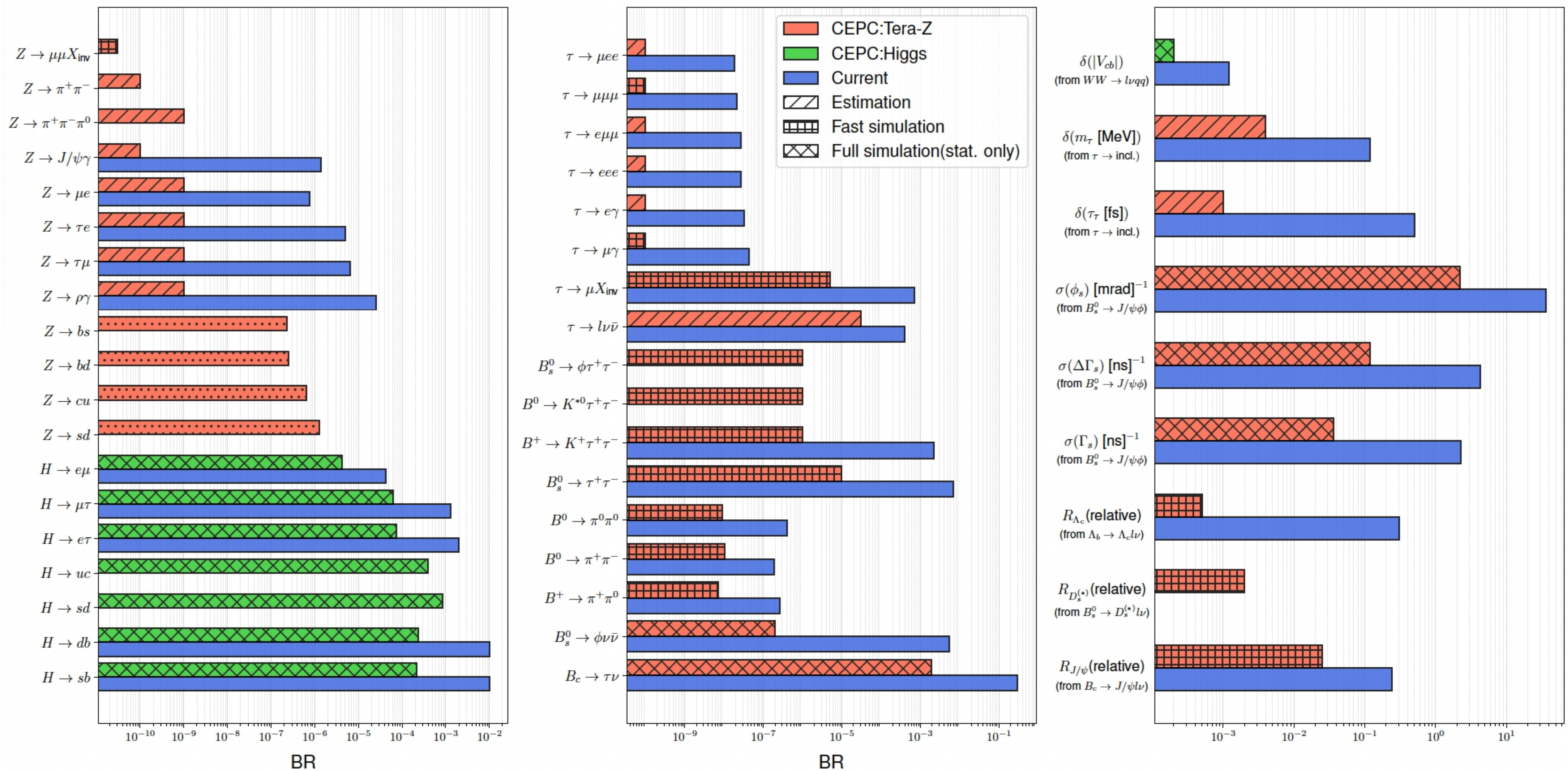
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 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



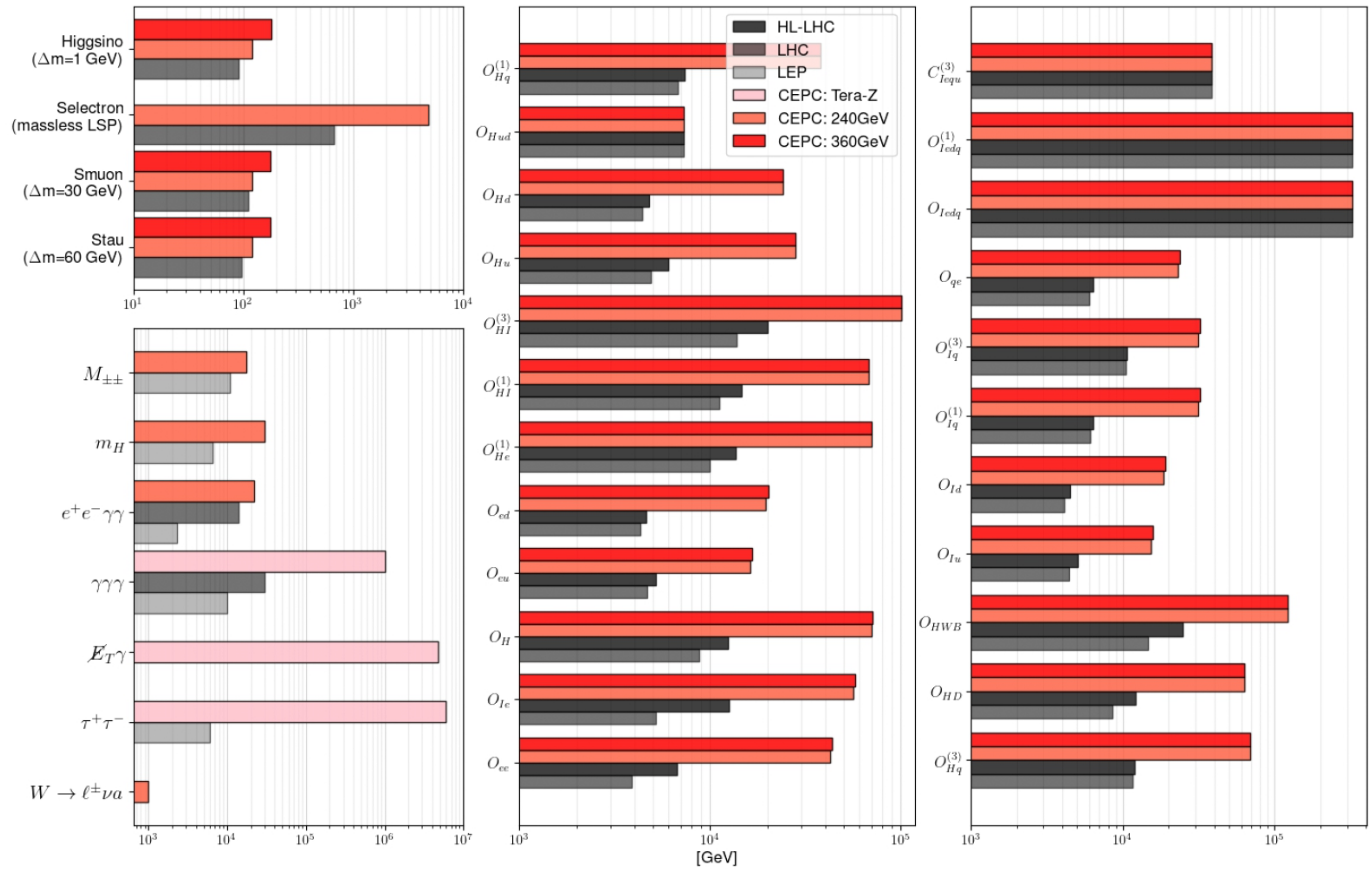
See the non-seen: i.e, Bc→tauv, Bs→Phivv

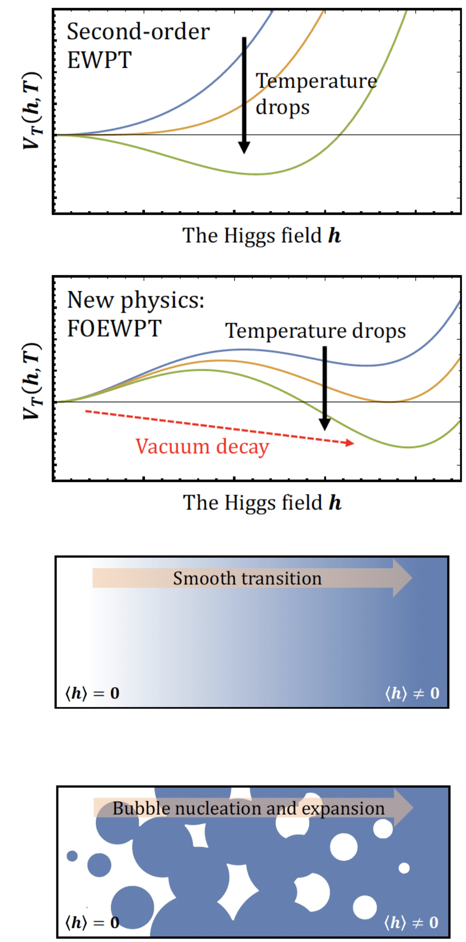
Orders of magnitudes improvements (1 – 2.5 orders...).

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

https://arxiv.org/pdf/2412.19743

New Physics



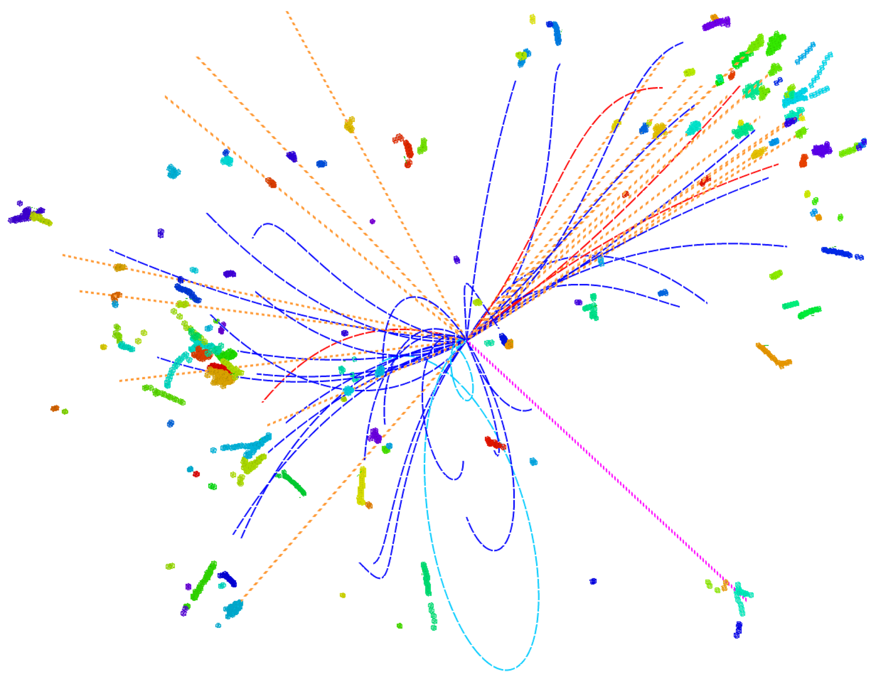


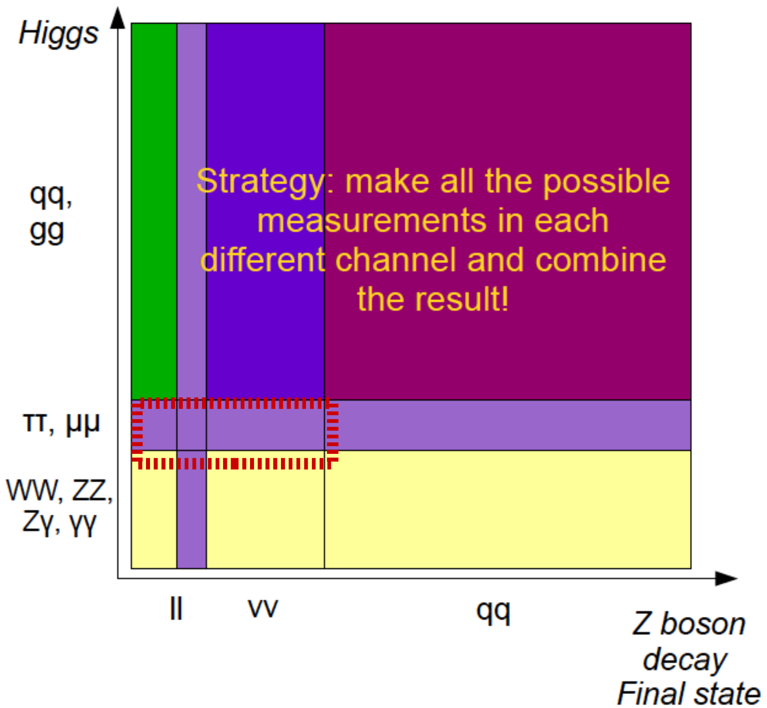
https://arxiv.org/pdf/2505.24810

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

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



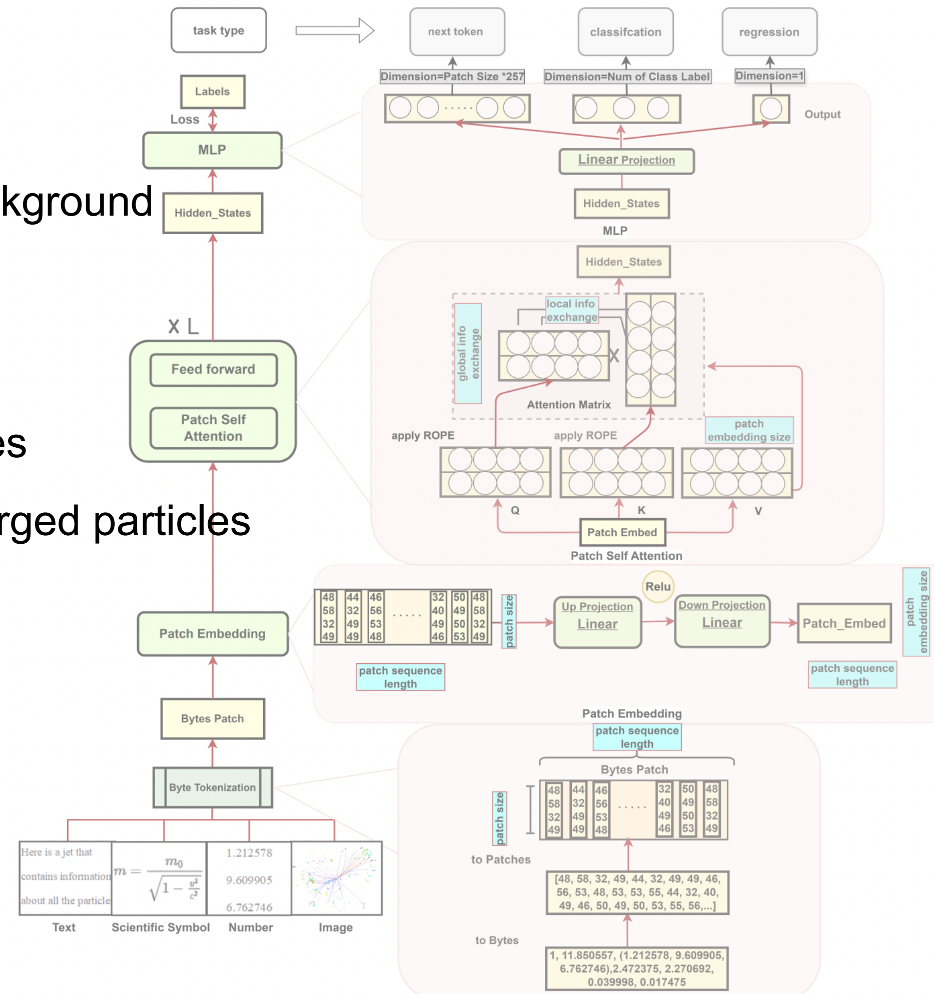


- Look inside the jet: **1-1 correspondence reco.**
  - ~ confusion free PFA
  - Larger acceptance...
  - Excellent intrinsic resolutions
  - Extremely stable...
- Be addressed by state-of-art detector design, technology, and reconstruction algorithm!

Holistic approach

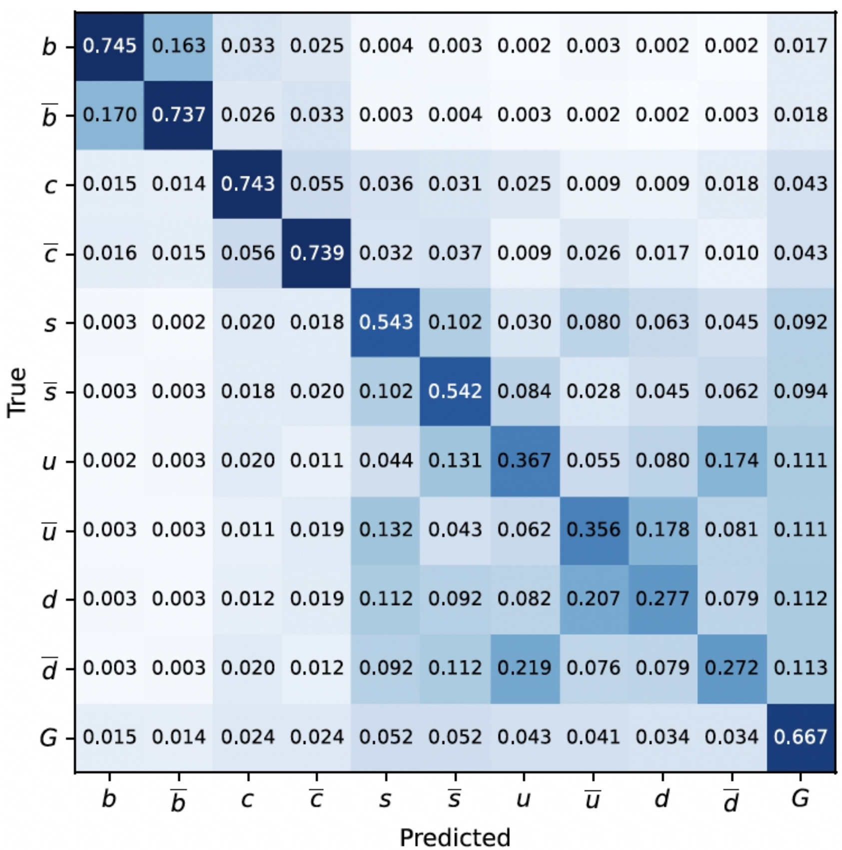
- Provide all reconstructable for **classification**
  - Reco: Jet origin identification
  - Analysis: to distinguish the signal from the background

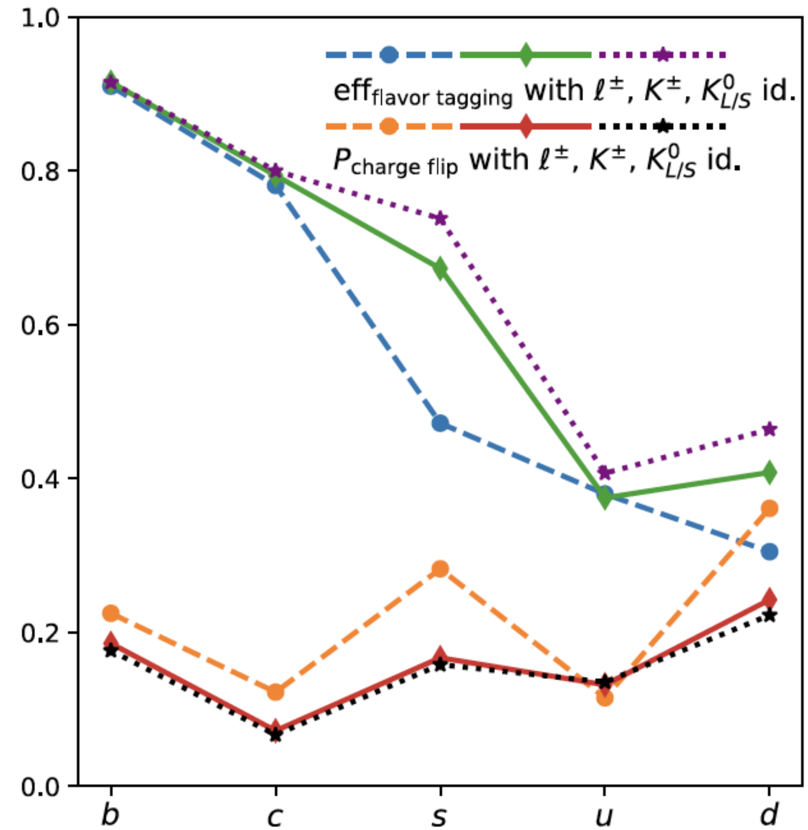
- In the context of 1-1 correspondence/PFA, inputs =
  - 4 momentum + Pid of all reconstructed particles
  - Track impact parameters of reconstructed charged particles
  - Potentially: parenting info
    - Photon to Pi-0, pions to kaon...
    - Color Singlet (from Z or H)
    - ...
  - Uncertainties (as suggested by Vincent)



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

Holistic Reco: Jet origin id

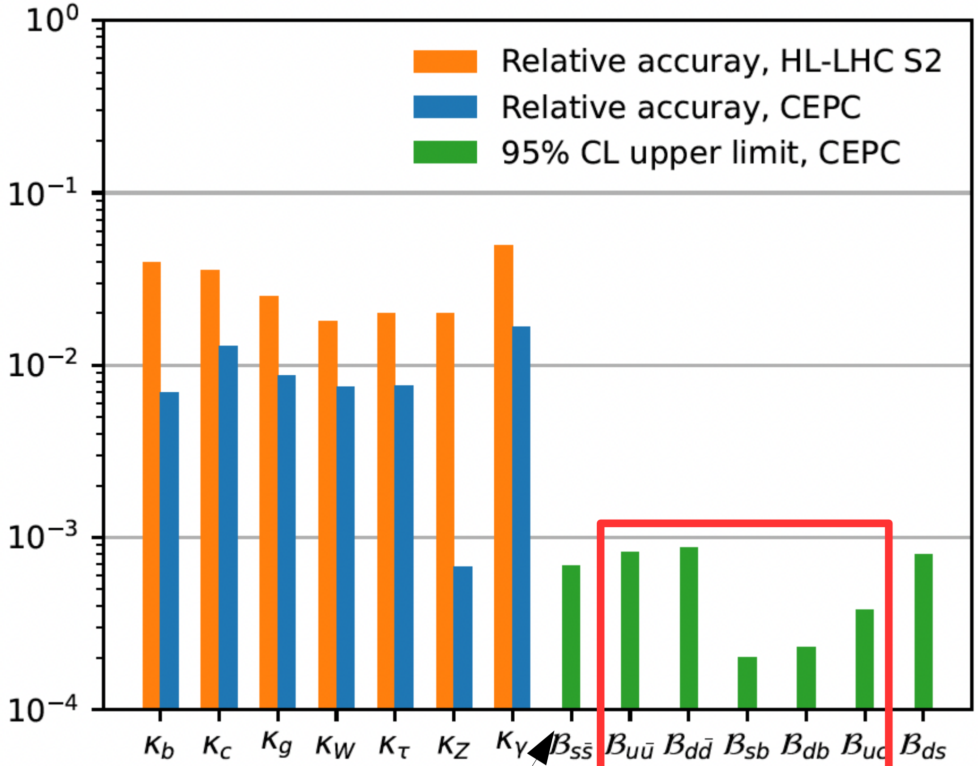


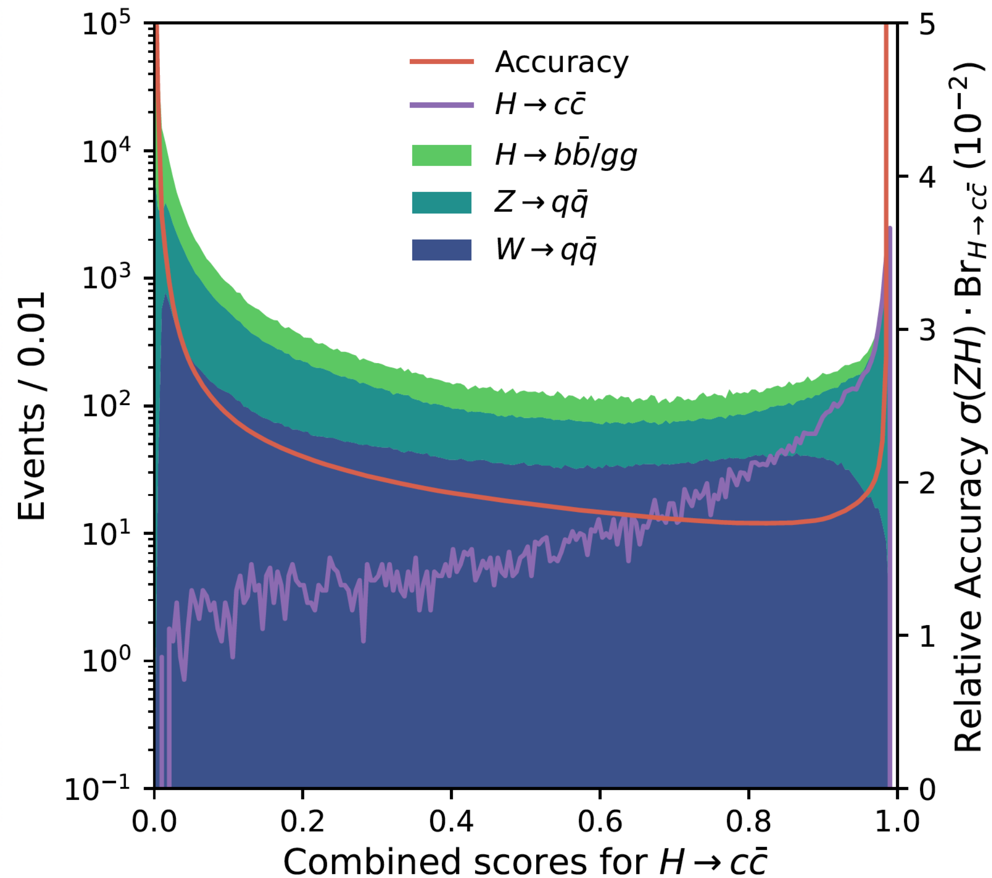


- 11 categories (5 quarks + 5 anti quarks + gluon) identification, realized at Full Simulated di-jet events at CEPC CDR baseline with Arbor + ParticleNet
- Published in PRL *132, 221802 (2024)*. Comment from the referee: *"demonstrate the world-leading performance of tagger", "a "game changer" and opens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

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

Impact on Physics: Higgs & W





Improved by ~3 times

Improved by 1-2 orders of magnitudes

Presumably... firstly quantified

- Compared to Conventional :
  - vvH, H→cc: 3% → 1.7%
  - Vcb: 0.75% → 0.5%
  - Applicable to Vcs, Vts, etc.

Updated result on $\sin^2\theta^l_{eff}$ measurement

Table 2. Sensitivity S of different final state particles.

$\sqrt{s}$/GeV	S of $A^{e/\mu}_{FB}$	S of A^{d}_{FB}	S of A^{u}_{FB}	S of A^{s}_{FB}	S of A^{c}_{FB}	S of A^{b}_{FB}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958	1.087	3.942
130	0.027	3.279	0.531	3.280	0.520	3.261

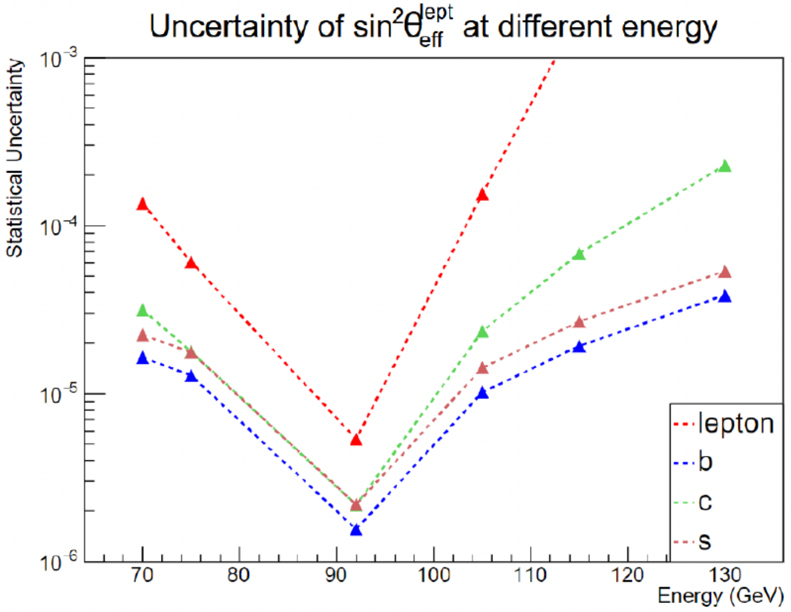
Table 3. Cross section of process $e^+e^- \to f\bar{f}$ calculated using the ZFITTER package. Values of the fundamental parameters are set as $m_Z = 91.1875$ GeV, $m_t = 173.2$ GeV, $m_H = 125$ GeV, $\alpha_s = 0.118$ and $m_W = 80.38$ GeV.

$\sqrt{s}$/GeV	σ_μ/mb	σ_d/mb	σ_u/mb	σ_s/mb	σ_c/mb	σ_b/mb
70	0.039	0.032	0.066	0.031	0.058	0.028
75	0.039	0.047	0.073	0.046	0.065	0.043
92	1.196	5.366	4.228	5.366	4.222	5.268
105	0.075	0.271	0.231	0.271	0.227	0.265
115	0.042	0.135	0.122	0.135	0.118	0.132
130	0.026	0.071	0.068	0.071	0.066	0.069

Verify the RG behavior... using ~1 month of data taking

Expected statistical uncertainties on $\sin^2\theta^l_{eff}$ measurement.

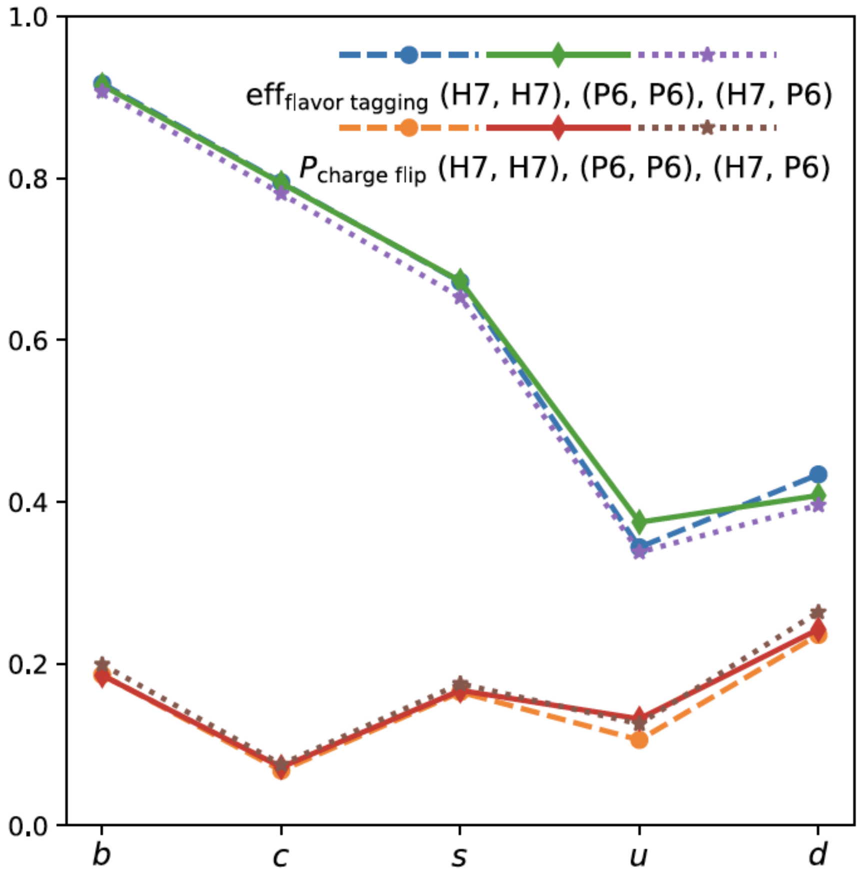
(Using one-month data collection, ~ *4e12/24 Z events* at Z pole)

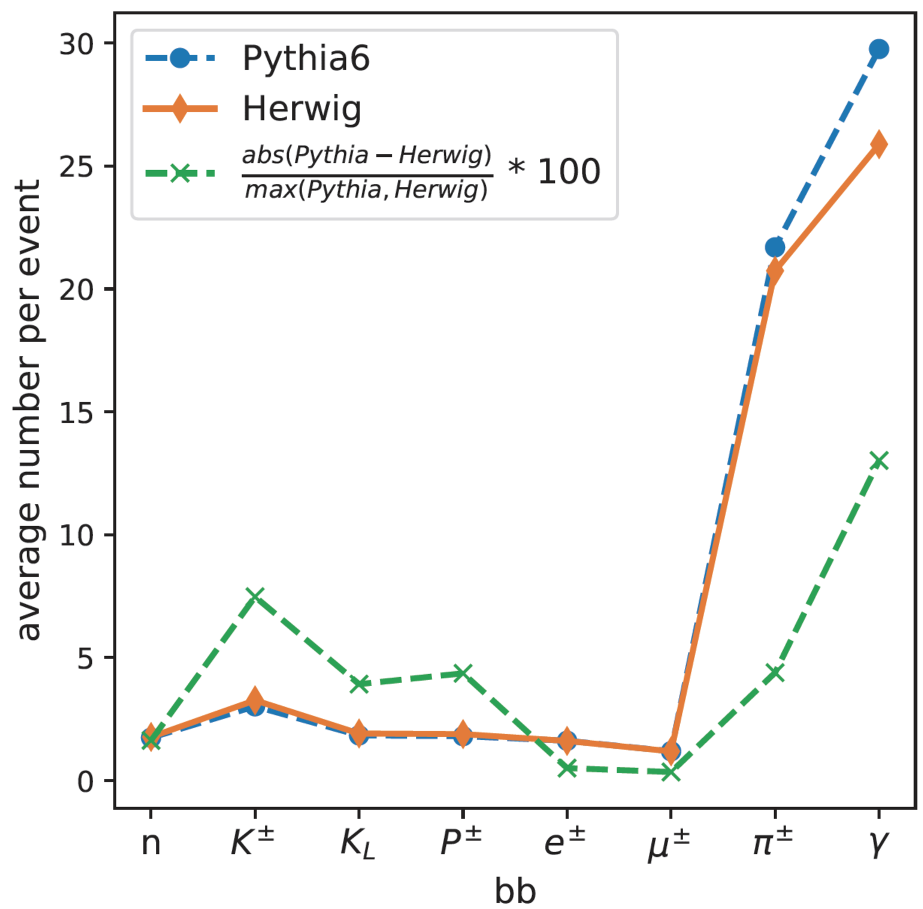


$\sqrt{s}$	b	c	s
70	1.6×10^{-5}	3.2×10^{-5}	2.2×10^{-5}
75	1.3×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
92	1.6×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
105	1.0×10^{-5}	2.4×10^{-5}	1.4×10^{-5}
115	1.9×10^{-5}	6.8×10^{-5}	2.7×10^{-5}
130	3.9×10^{-5}	2.3×10^{-4}	5.4×10^{-5}

...+ Significant impact on Flavor Physics measurements, i.e., those with Bs oscillation...

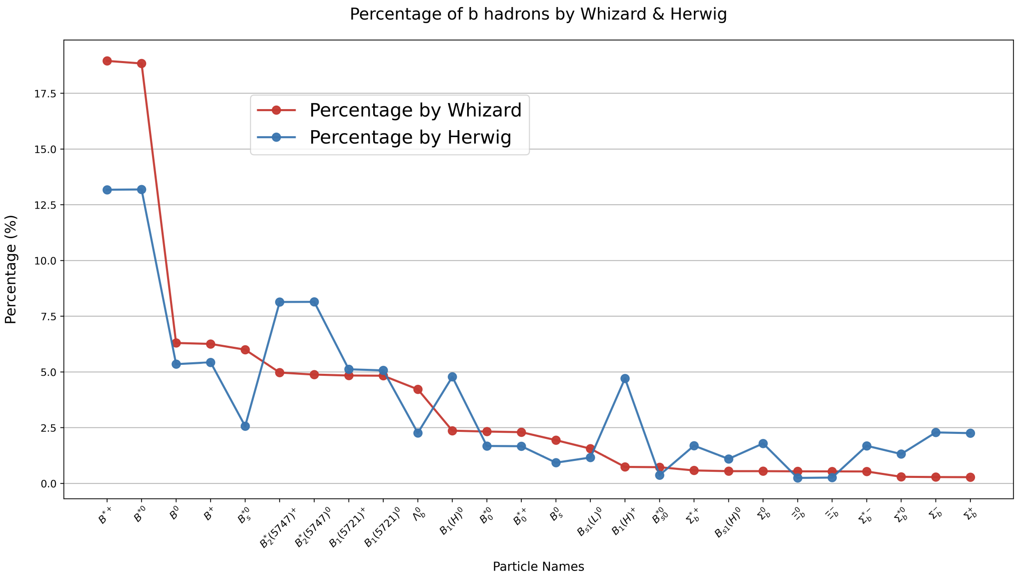
V.S. Hadronization models

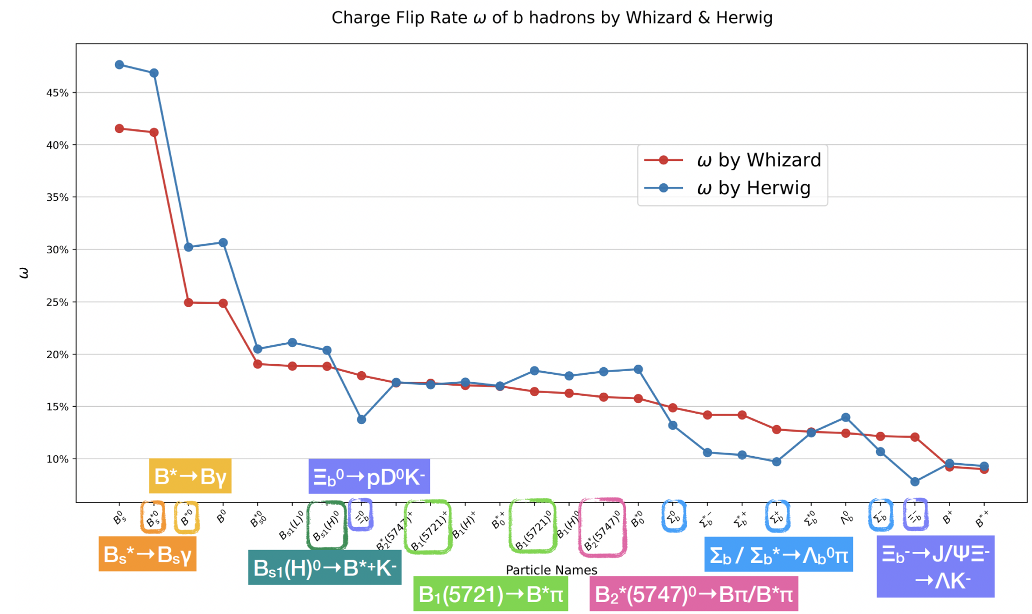


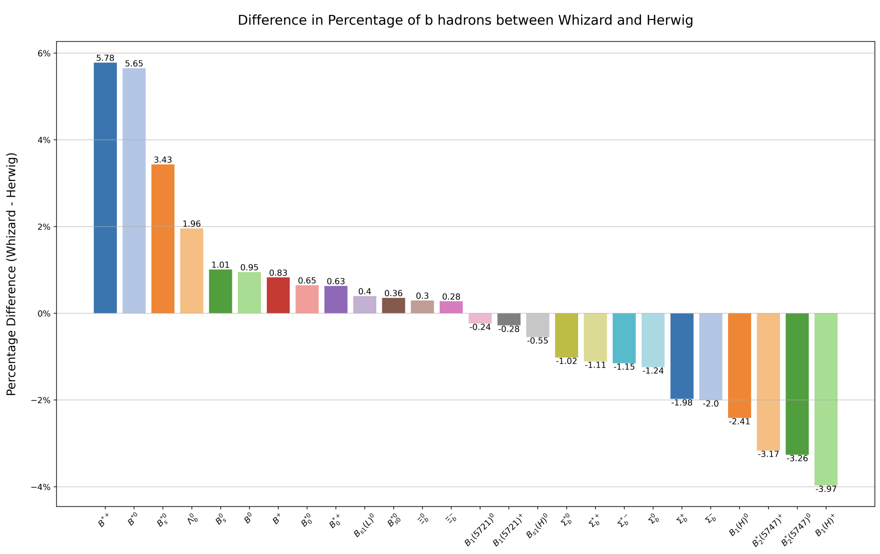


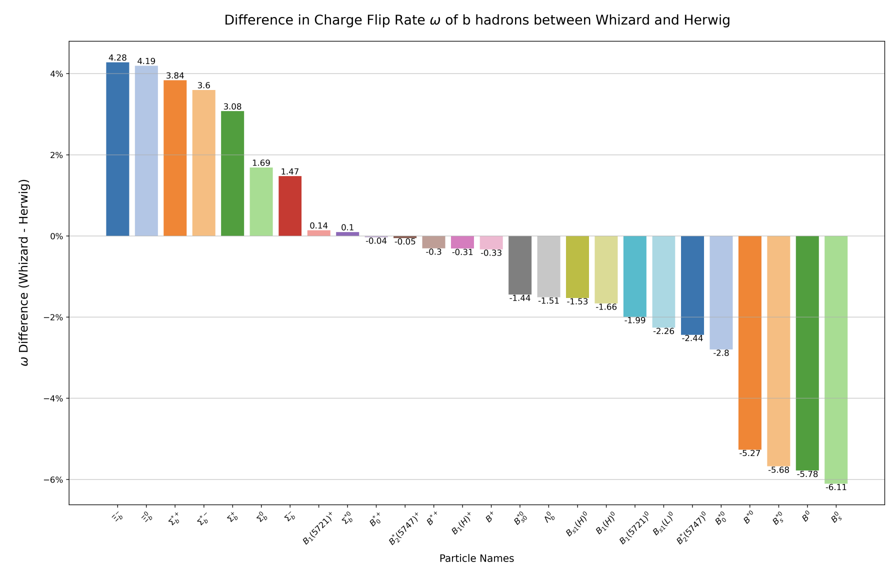
- Different hadronization model have significantly different predictions...

b-jet: leading b-hadrons & flip rates

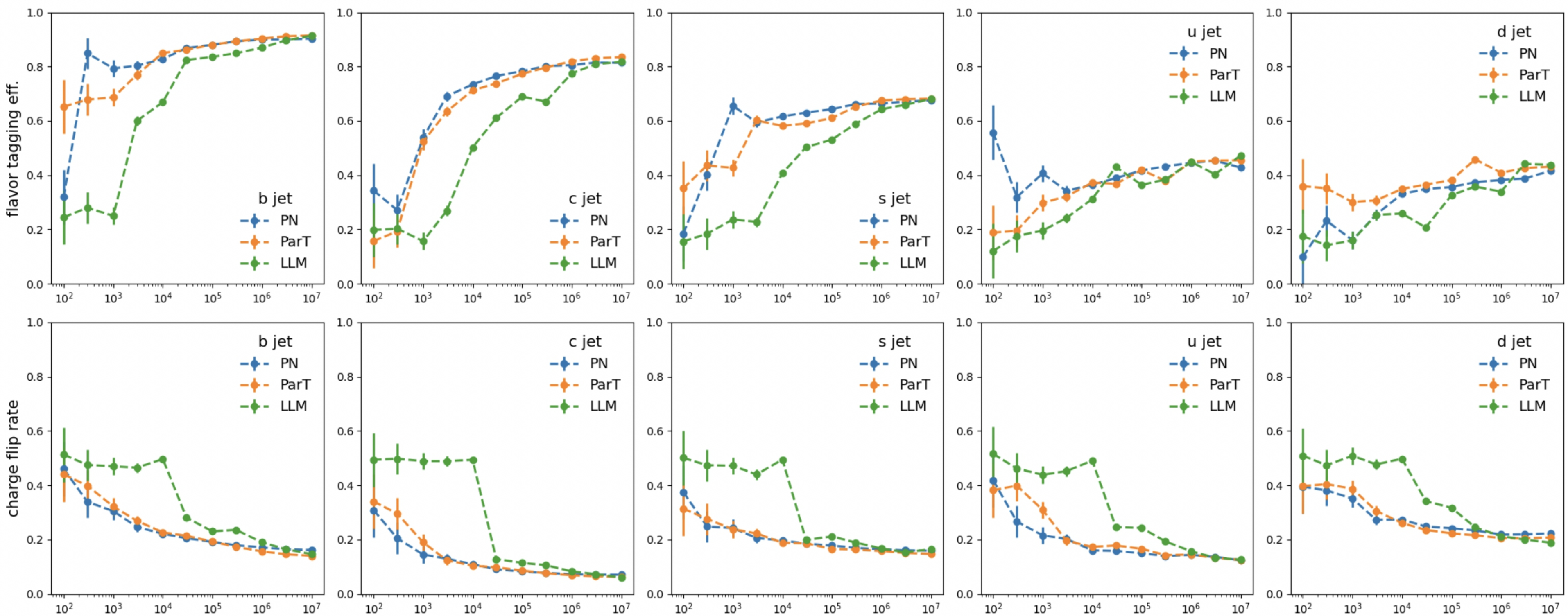








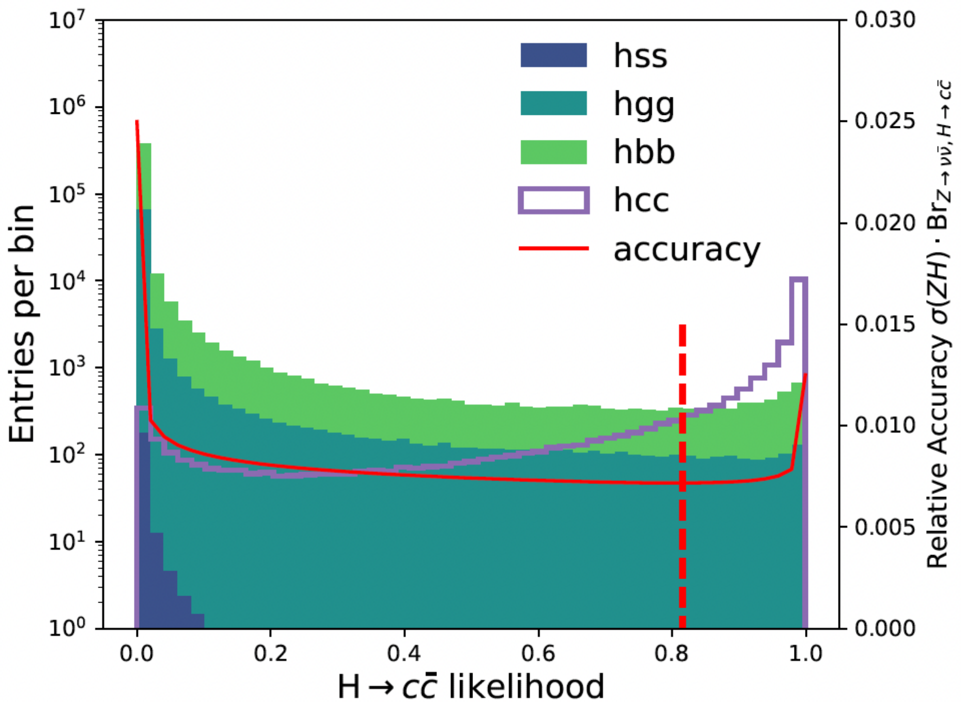
From specialized Models to LLM

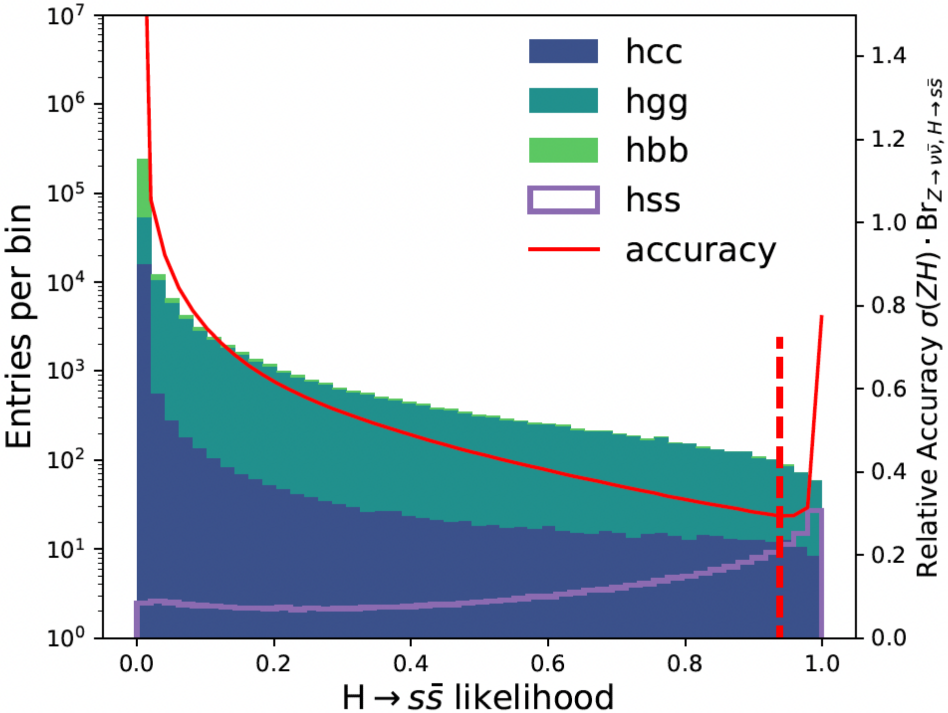


- Comparable result with different scaling behavior
- Para. Numbers: PN 360k, ParT 2.4M, BINBBT(Large Language Base Model) 150 M
- More details at: *https://arxiv.org/pdf/2412.00129*

超对称
Super Symmetry Technologies

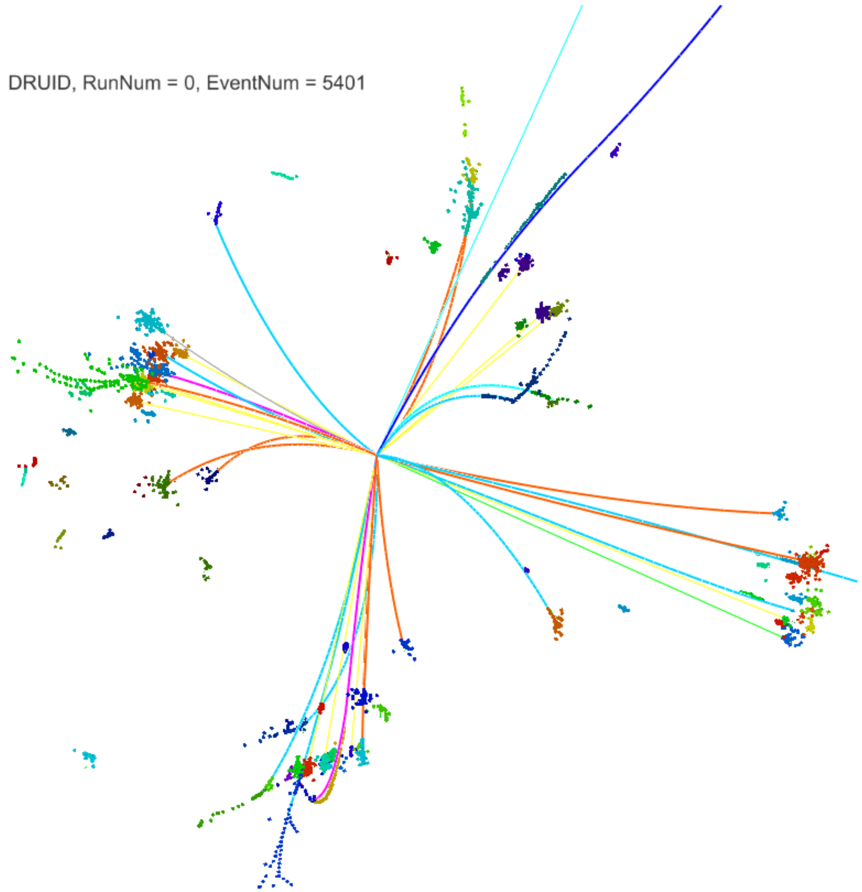
Holistic Analysis: vvH, H→2 jet

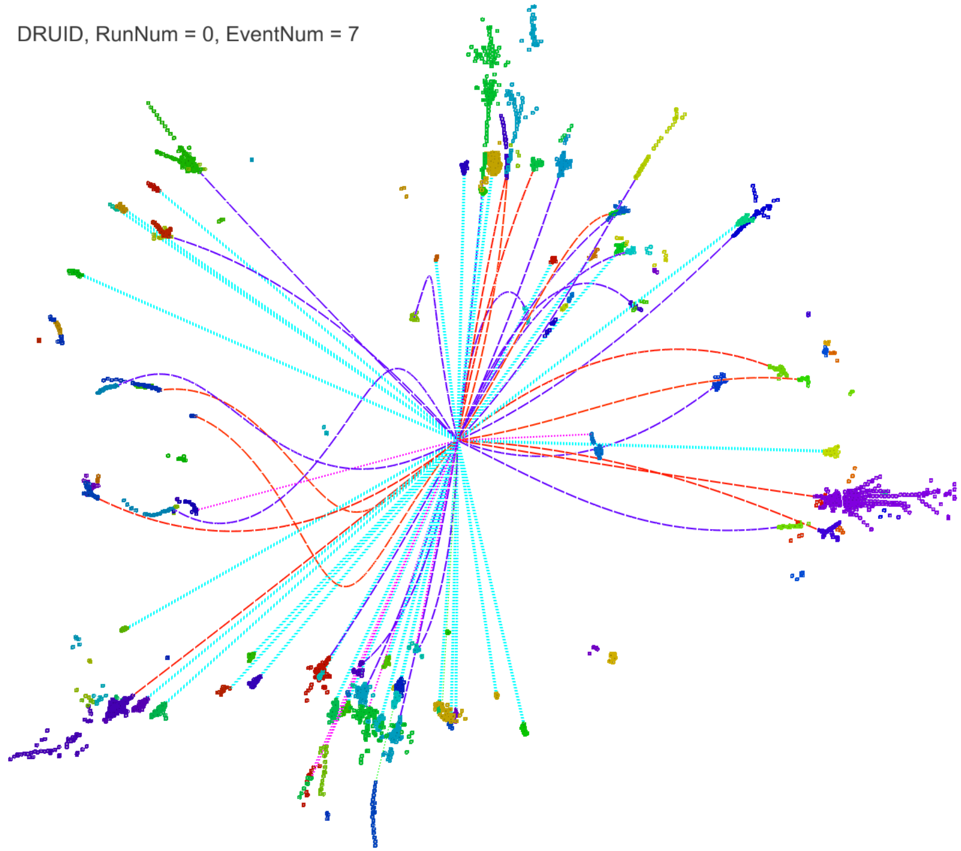




- vvH, H→bb/cc/gg/ss measurements: 4 kinds classification
- Simplified analysis with irreducible background...
- Accuracies: 2-6 times better than previous studies (include other bkgrd, BDT based, etc)
- H→ss: close to confirmation!

Color Singlet Identification





at full hadronic ZH event

CSI: bottleneck for measurement at full hadronic events

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

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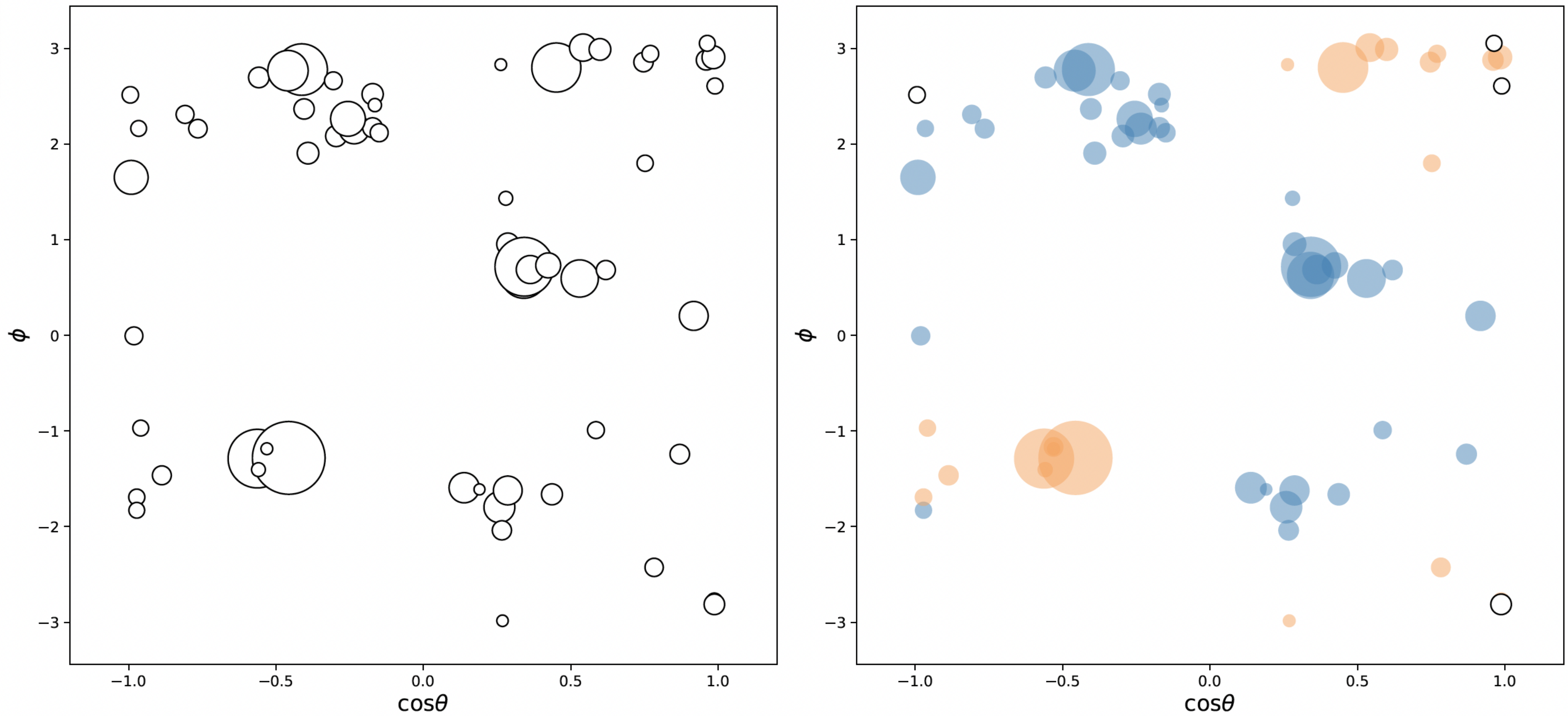
Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

Table 3. The signal strength accuracies for different channels.

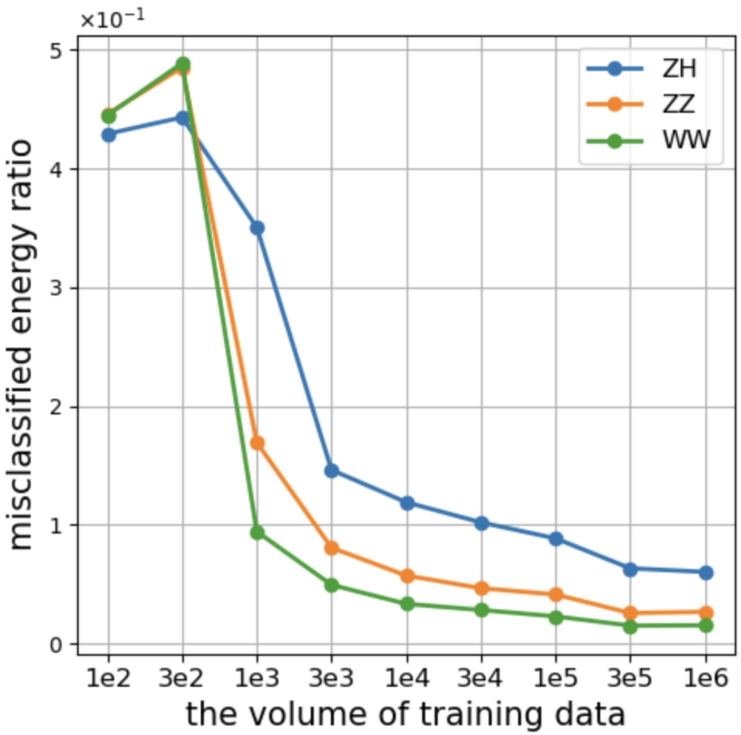
- H→cc & gg measurements at qqH channel is much worse vvH channels, despite the former has 3.5 times more signal statistic
- Reason: Failure of Color Singlet Identification – to distinguish the decay products of each Color Singlet
  - Z & H for 240/250 GeV Higgs factory
  - Which Higgs boson for Higgs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

Advanced CSI using AI

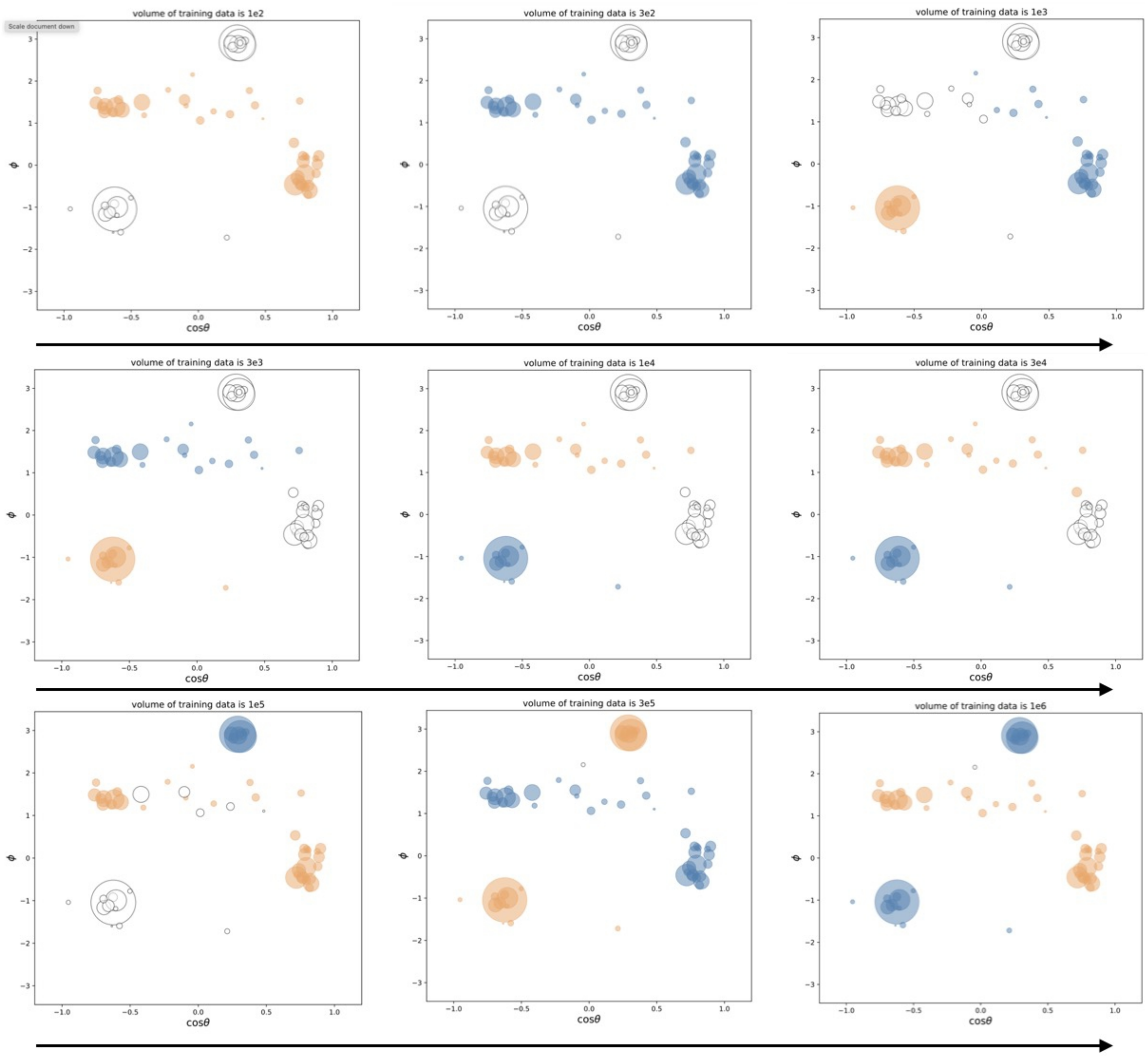


Yongfeng, Hao, Yuexin, etc

Scaling...



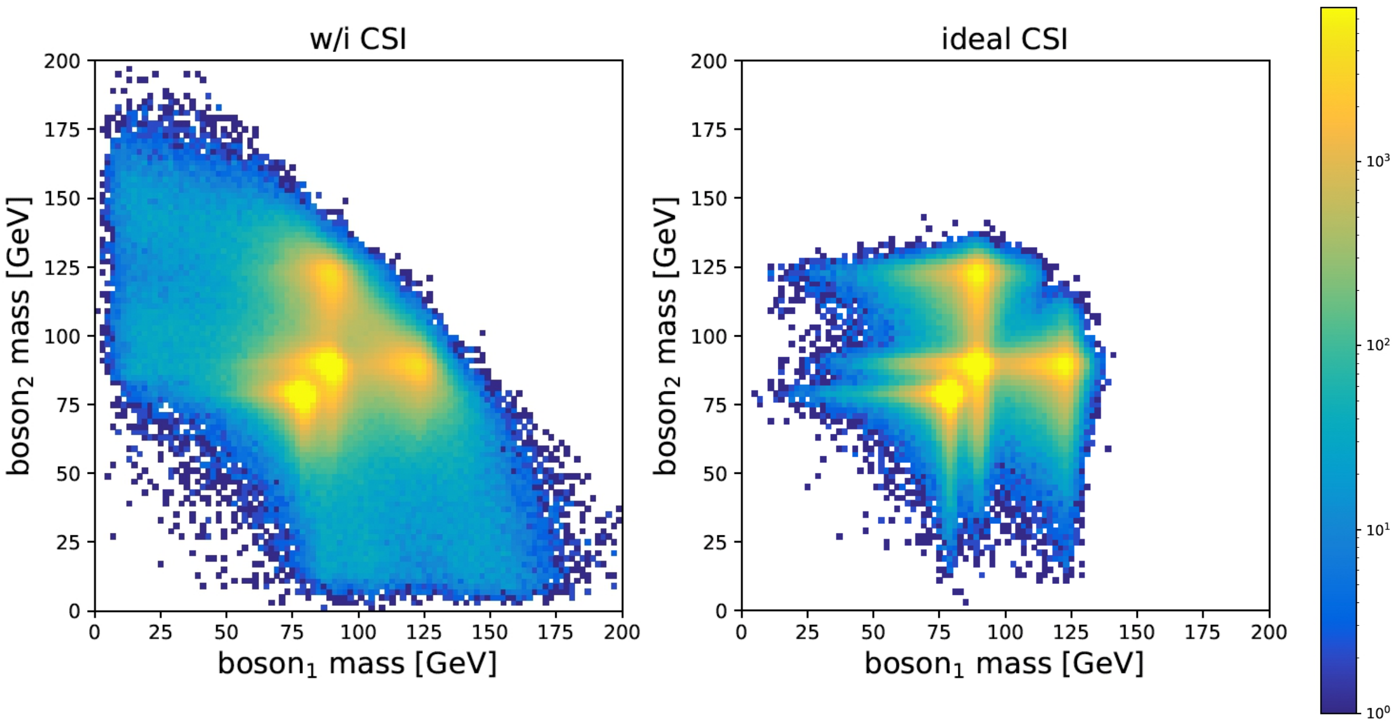
×10⁻¹
ZH
ZZ
WW
misclassified energy ratio
1e2
3e2
1e3
3e3
1e4
3e4
1e5
3e5
1e6
the volume of training data

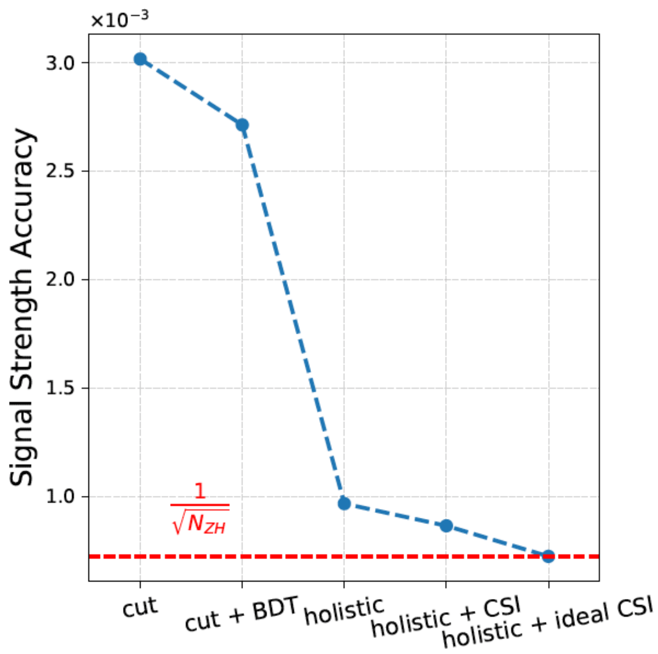


volume of training data is 1e2
volume of training data is 3e2
volume of training data is 1e3
volume of training data is 3e3
volume of training data is 1e4
volume of training data is 3e4
volume of training data is 1e5
volume of training data is 3e5
volume of training data is 1e6
cosθ

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

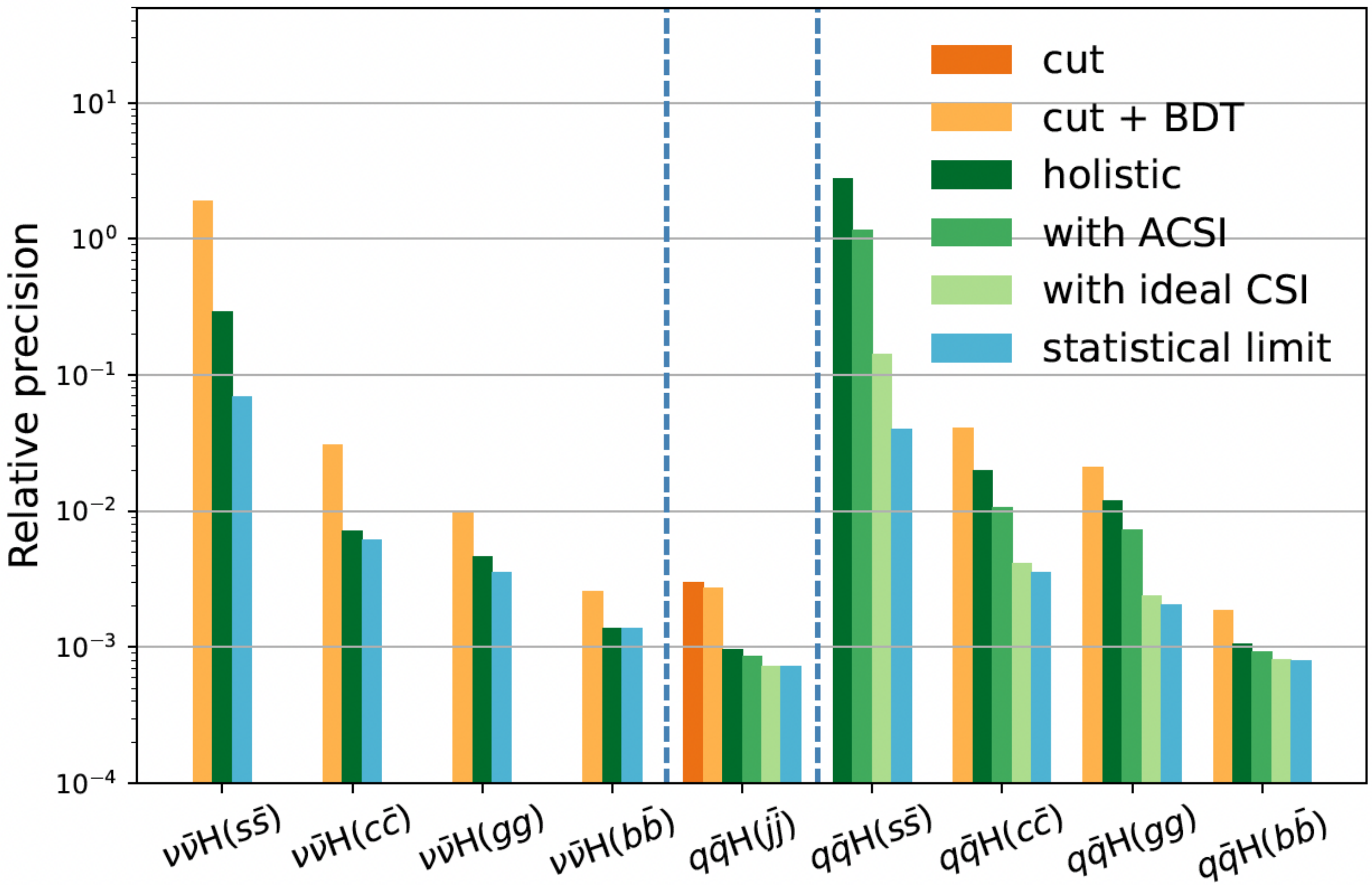
540k ZH + 3.1M ZZ + 47 M WW full hadronic events (~ 5.6 iab), result scale to 20 iab





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

Holistic approach + ACSI



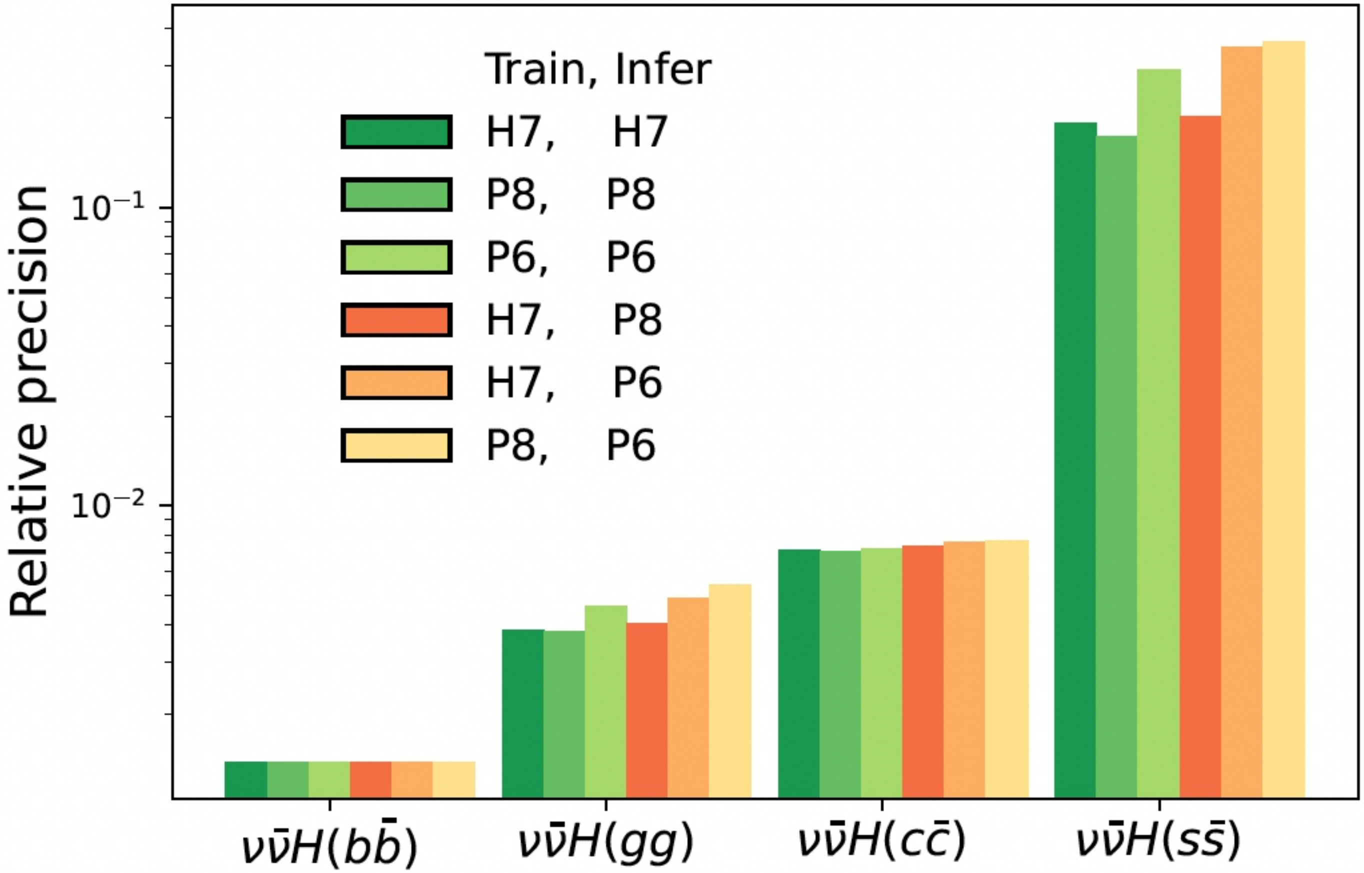
Holistic + ACSI: improves the accuracy by 2 – 6 times

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

Supervised learning: need High Quality MC

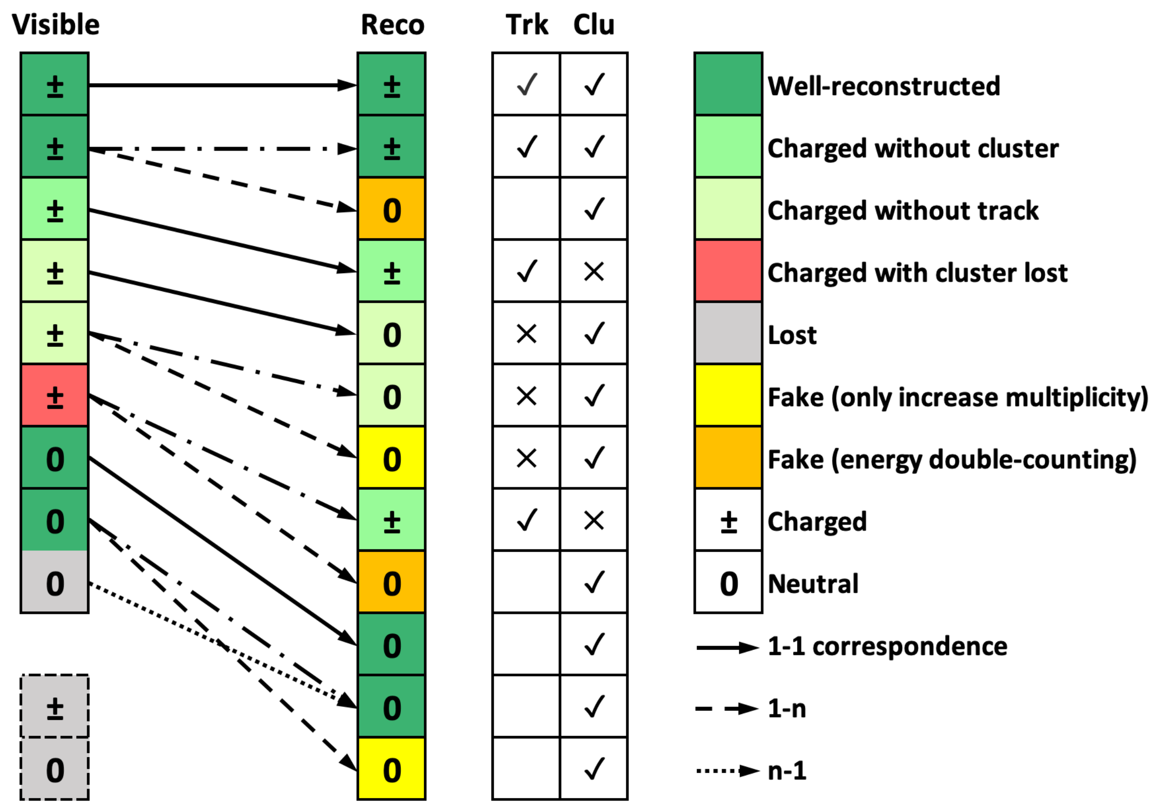


The Holistic approach is in principle free from human intervene...

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

From PFA to 1-1 correspondence

Final state particles



Computer Physics Communications 314 (2025) 109661

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ELSEVIER

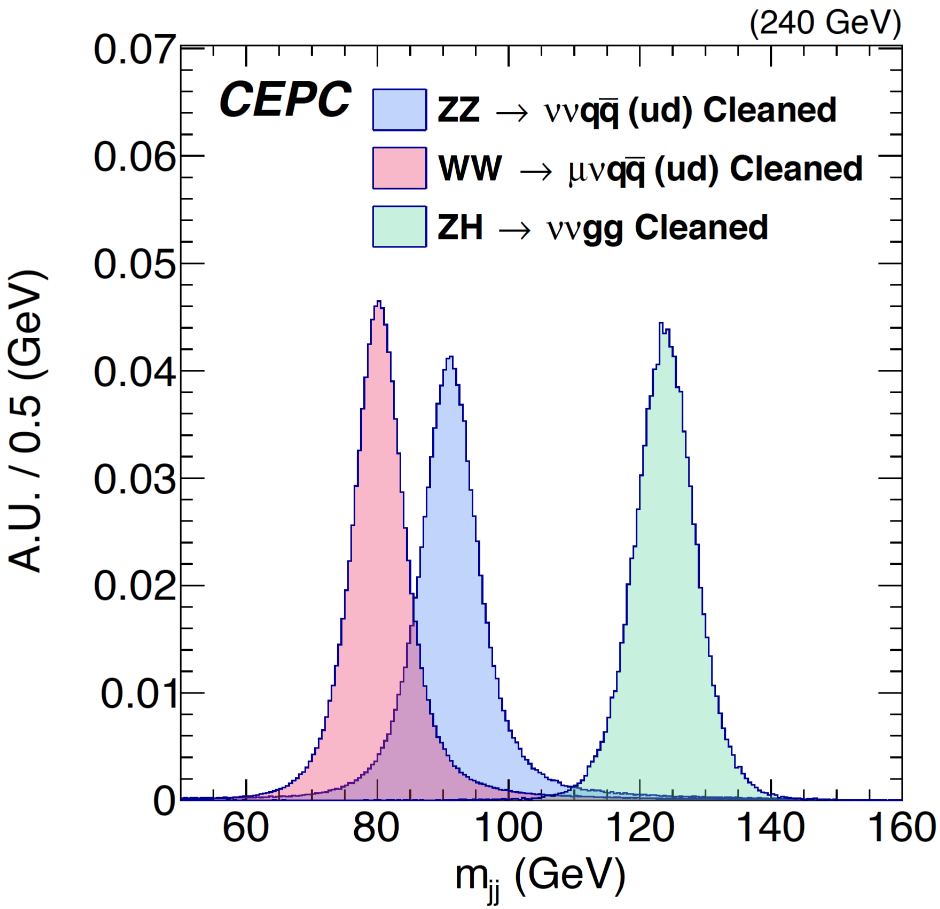
Computational Physics

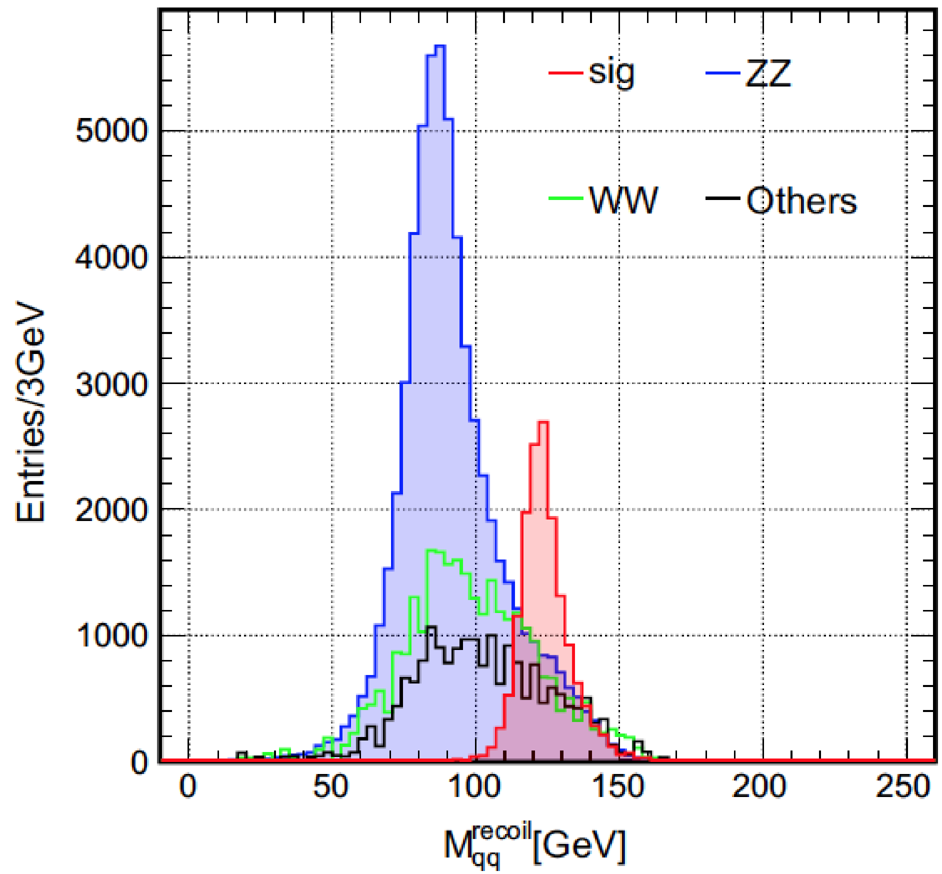
One-to-one correspondence reconstruction at the electron-positron Higgs factory

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

Boson Mass Resolution



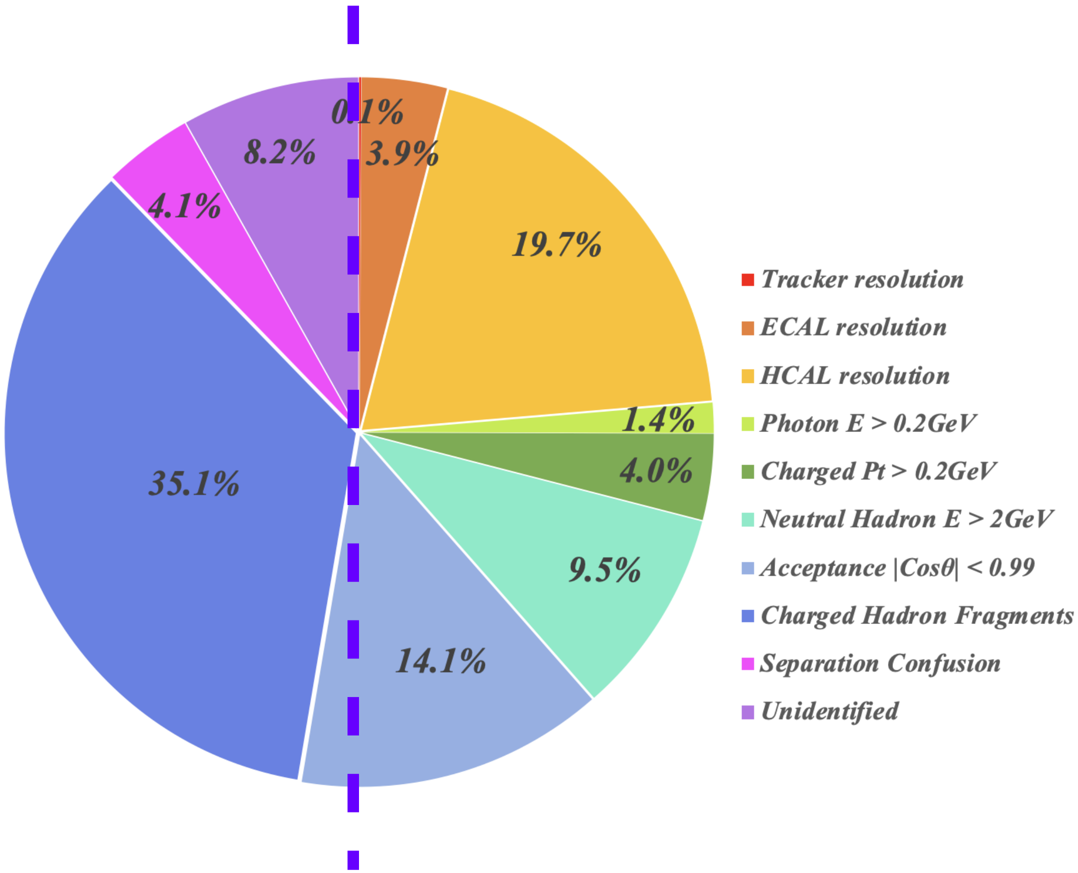


Higgs factory: need BMR < 4% (critical for qqH & qqZ separation using recoil mass to di-jet)

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

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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.

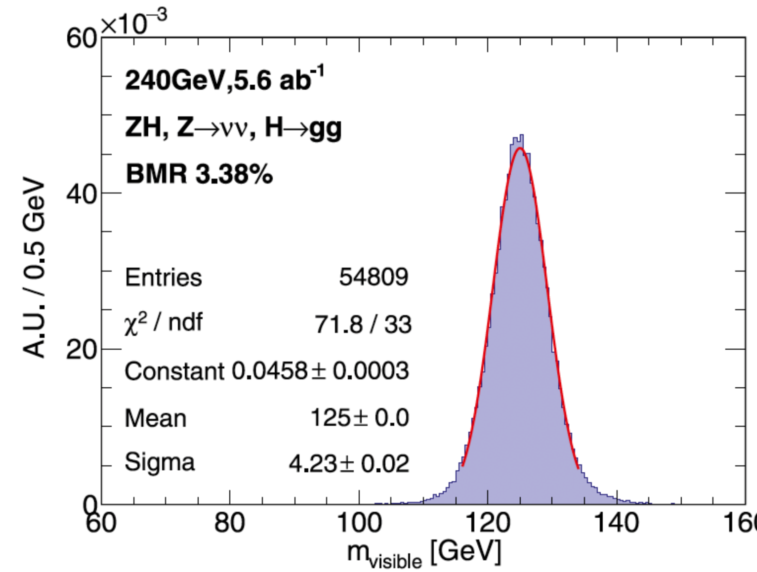
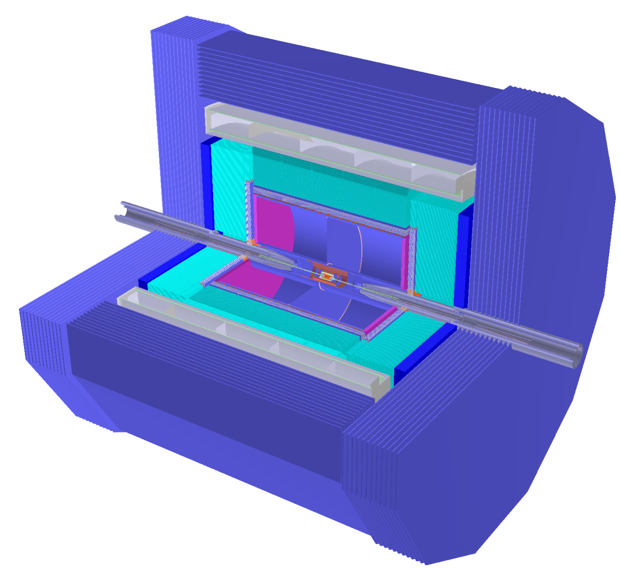


Fig. 5. Distribution of the reconstructed total visible invariant mass for $\nu\bar{\nu}H \rightarrow \nu\bar{\nu}gg$ channel. The distribution is fitted with a Gaussian function extented to ± 2 standard deviations.

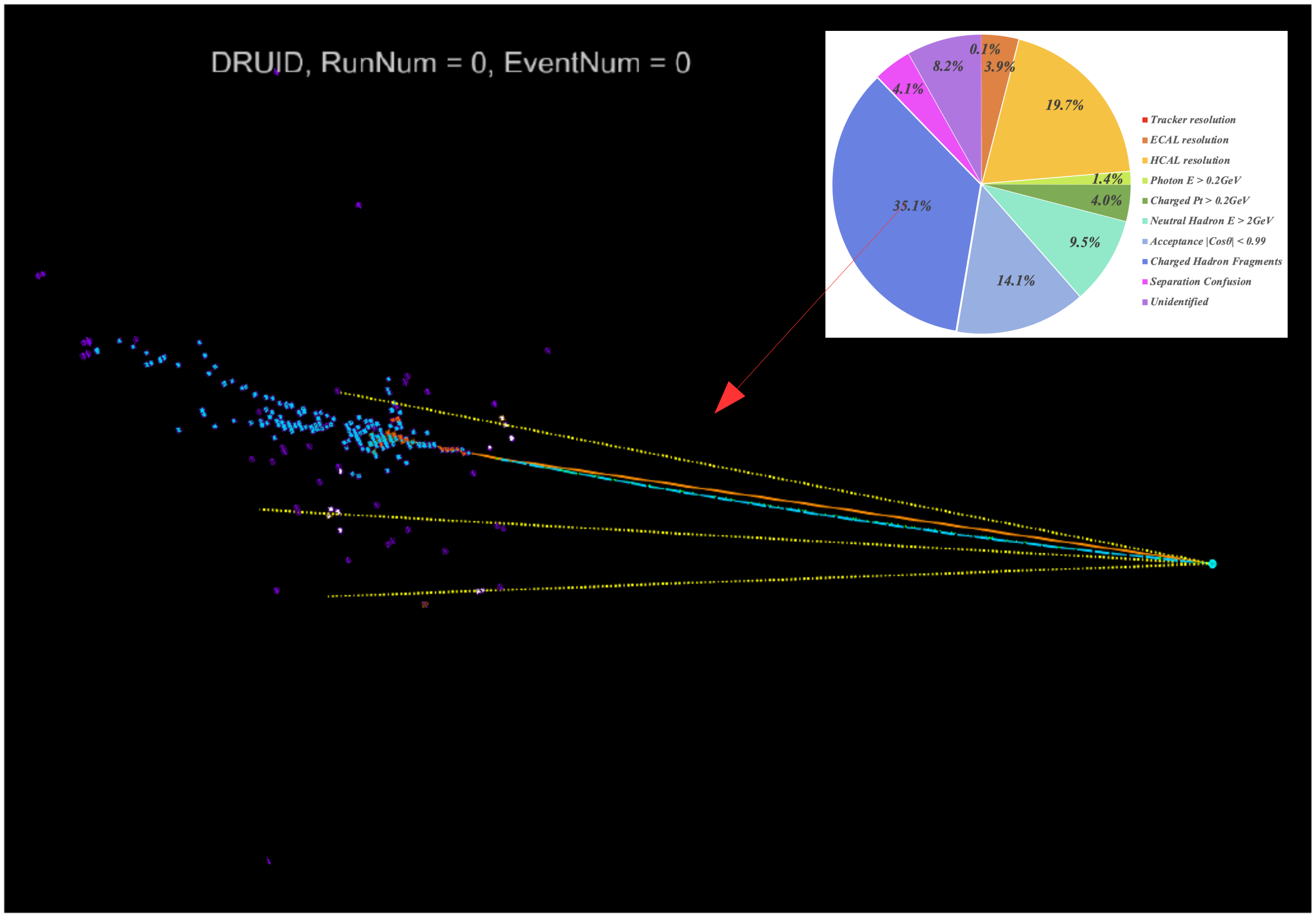
Y. Wang, H. Liang, Y. Zhu et al. *Computer Physics Communications 314 (2025) 109661*

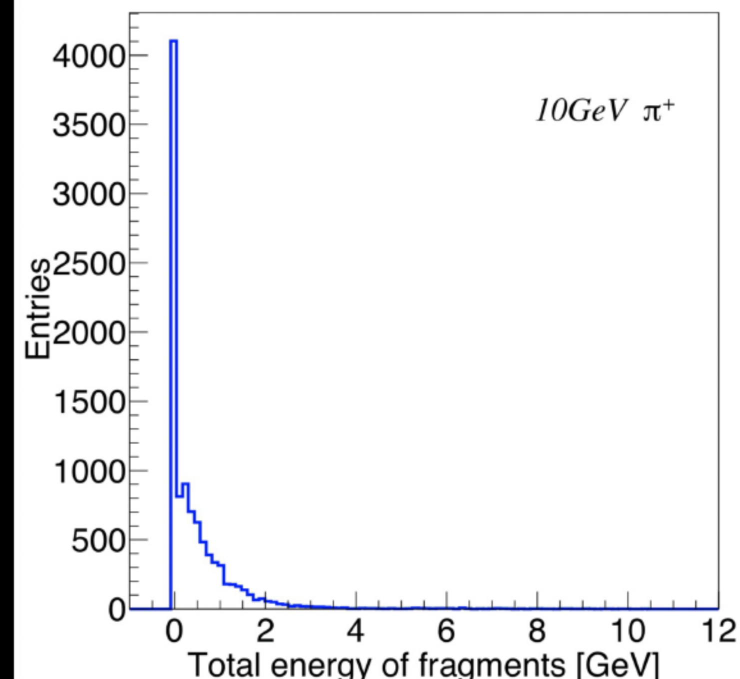
Table A.1
AURORA detector geometry parameters.

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	-	-	-



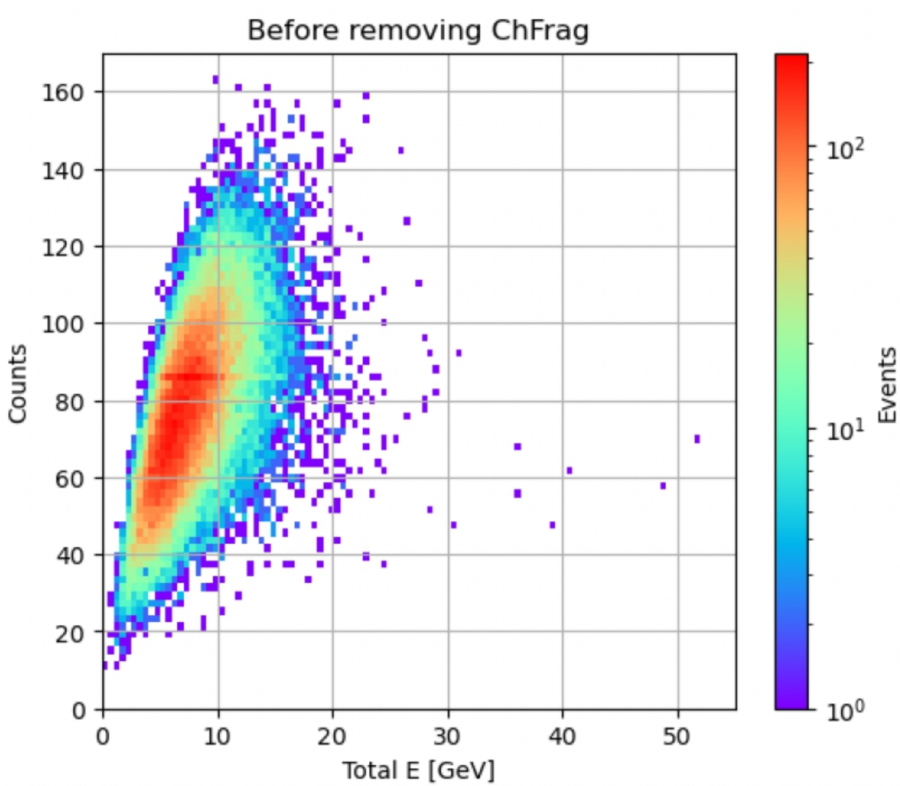
Cluster splitting: the most severe confusions

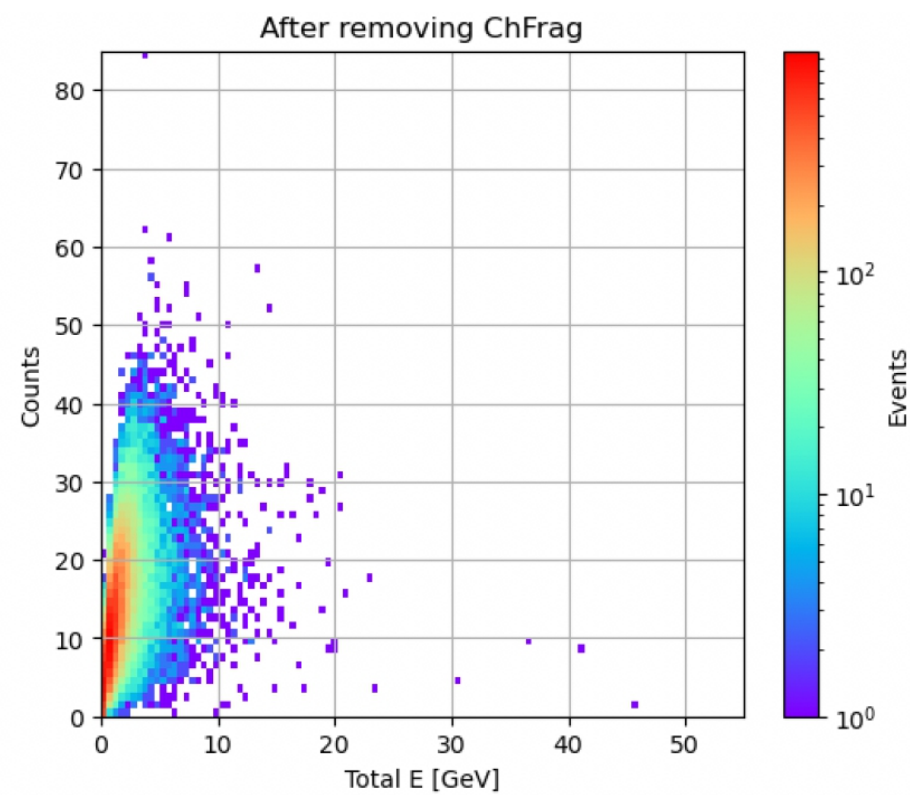




Time/pattern recognition may help a lot, in identify the charged cluster fragmentations without arise the threshold for the neutral hadron significantly...

Confusion: frag. Identification & veto

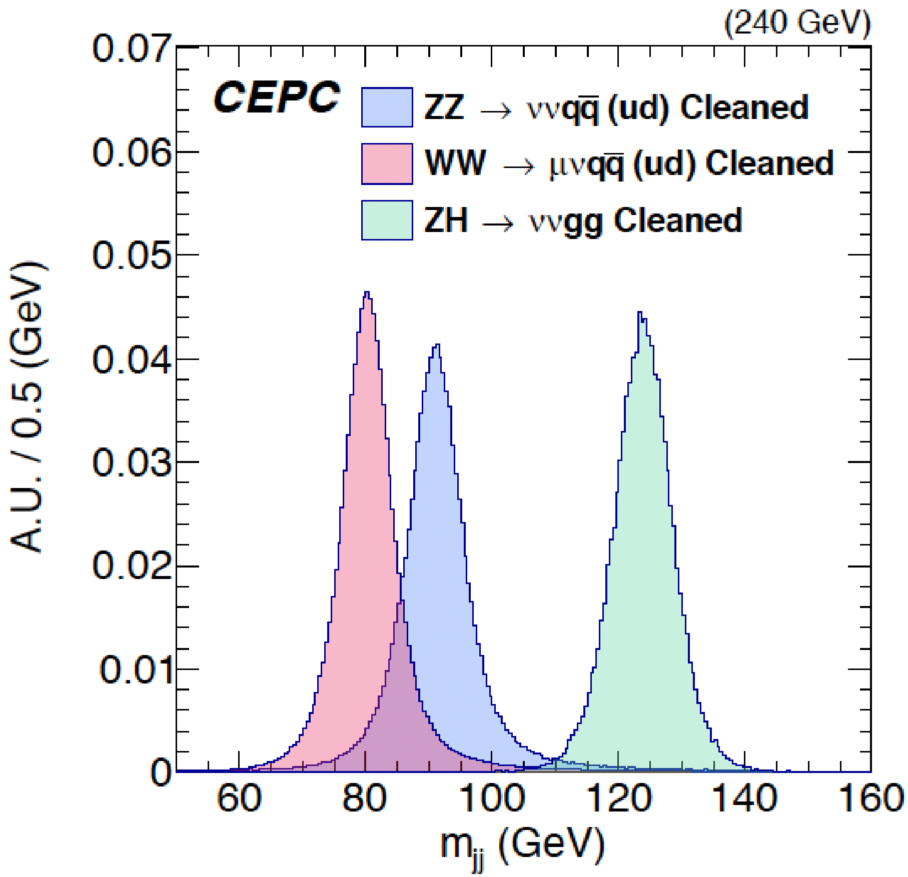


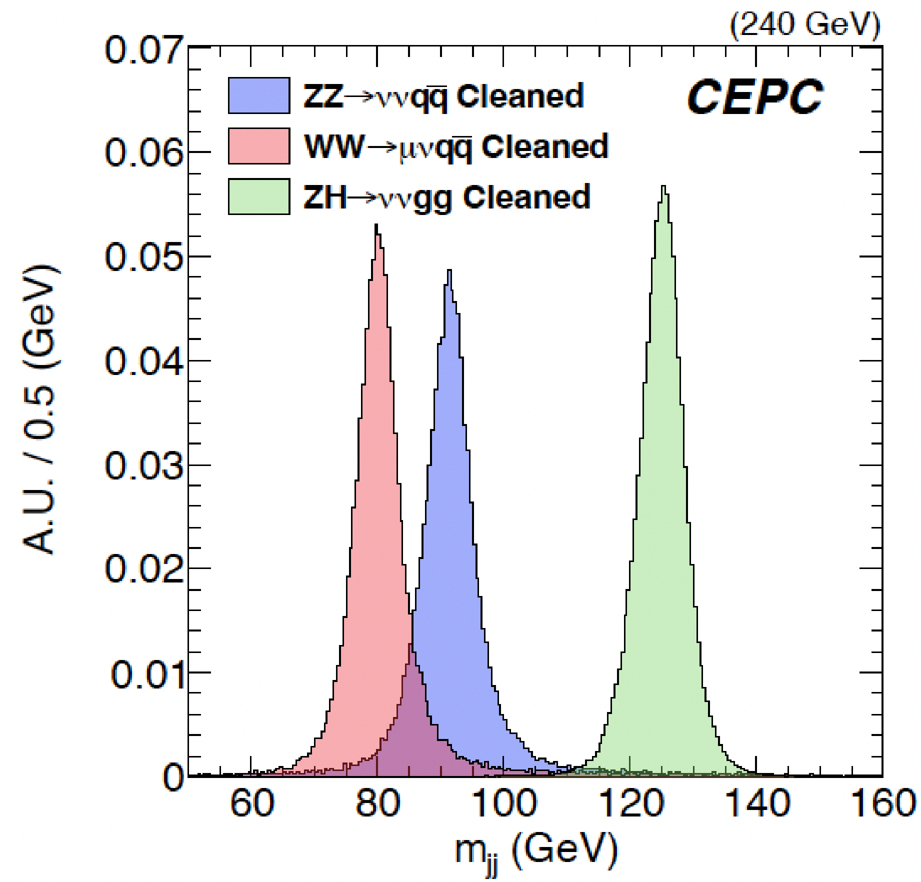


Fake particle originated Confusion reduced by 1 order of magnitude, at nominal vvH, H→gg event, at the cost of create mis-vetoed energy of < 1 GeV.

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

BMR of 2.75% reached



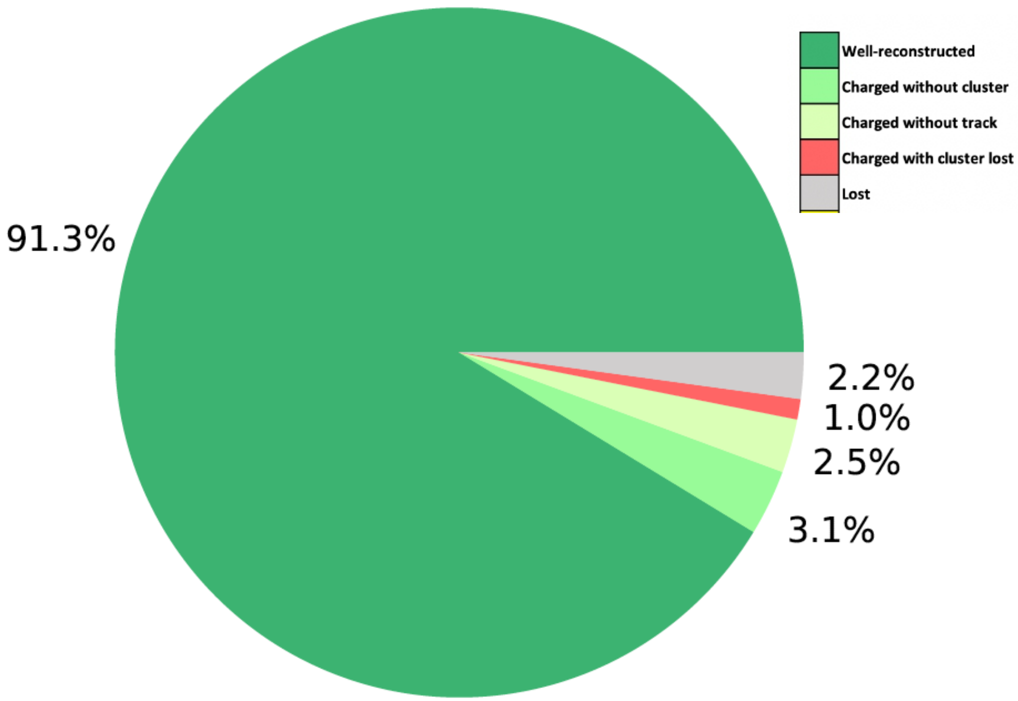


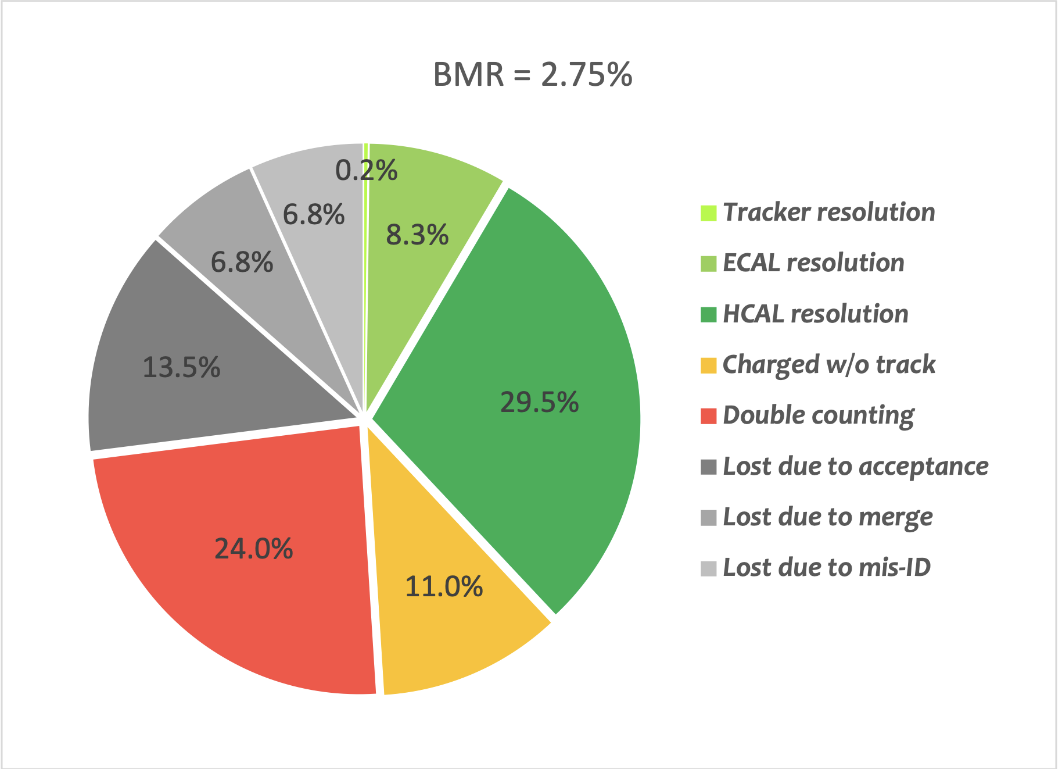
Detector change (usage of high density scintillating glass HCAL): BMR 3.7% → 3.4%;

AI enhanced reconstruction: 3.4% → 2.8%.

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

BMR decomposition @ AURORA



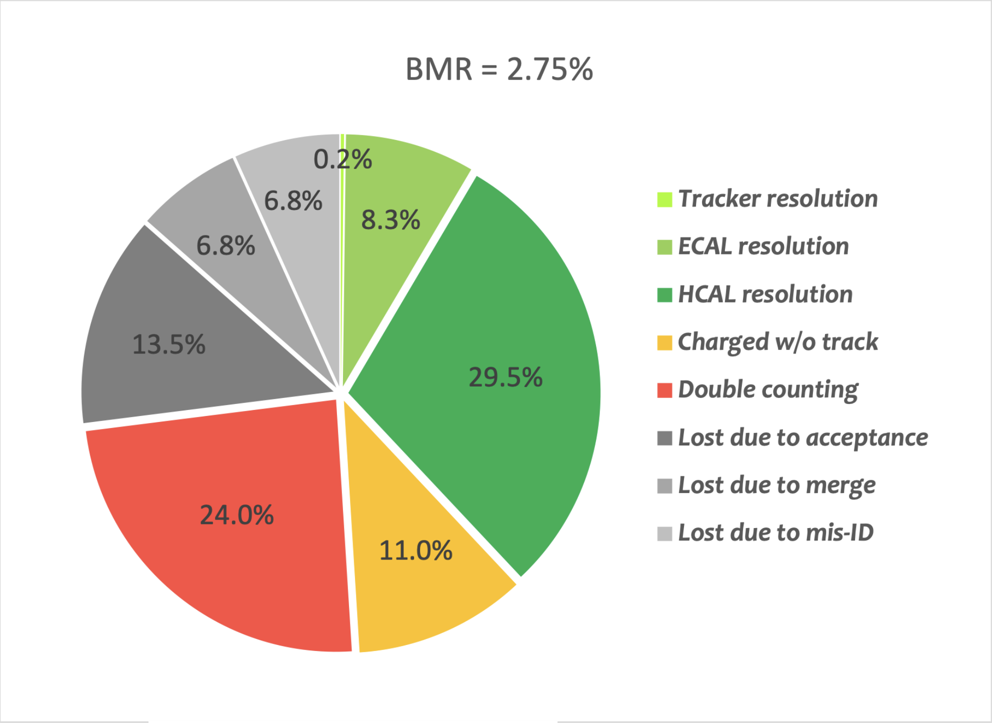


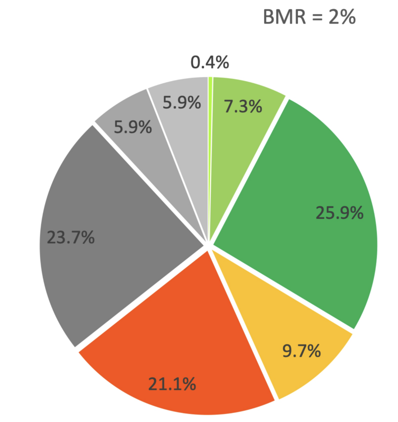
1-1 corresponding type: contributing to the BMR via resolution: ~o(0.1 – 0.001) of its mean value

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

BMR: perspectives

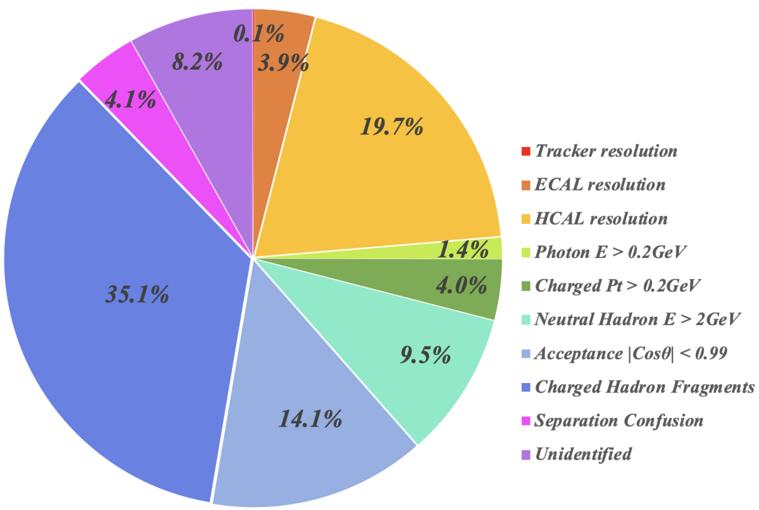
- Resolutions: assume - improved by 50%
  - Crystal ECAL: With efficient control of confusion
  - Detector optimization + Innovative Estimator (Energy, Time, Spatial...) with 5d calorimeter (ToF) & AI: ToF could determine very precisely the energy of low-E hadron – Giving its type identified...
- Charged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



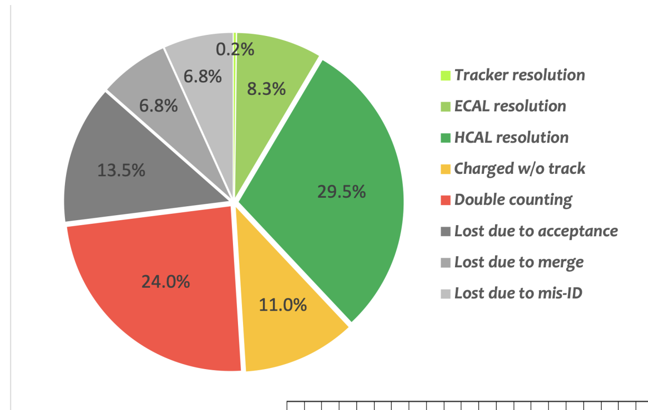


BMR: from CDR to possible future...

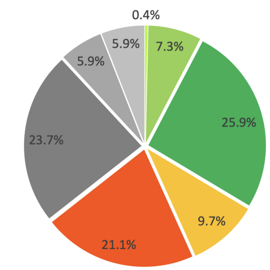
2016 - CDR: BMR ~ 4%

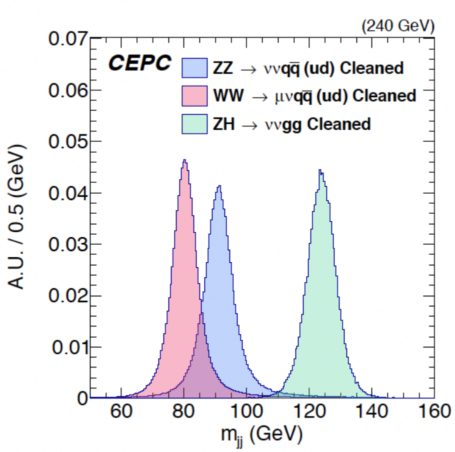


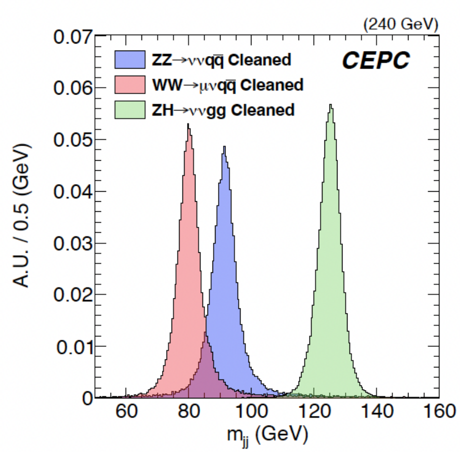
2024 - AURORA: BMR ~ 2.7%

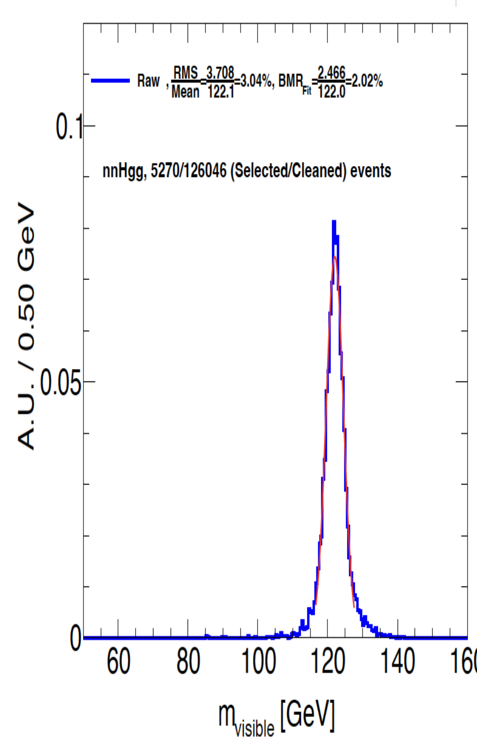


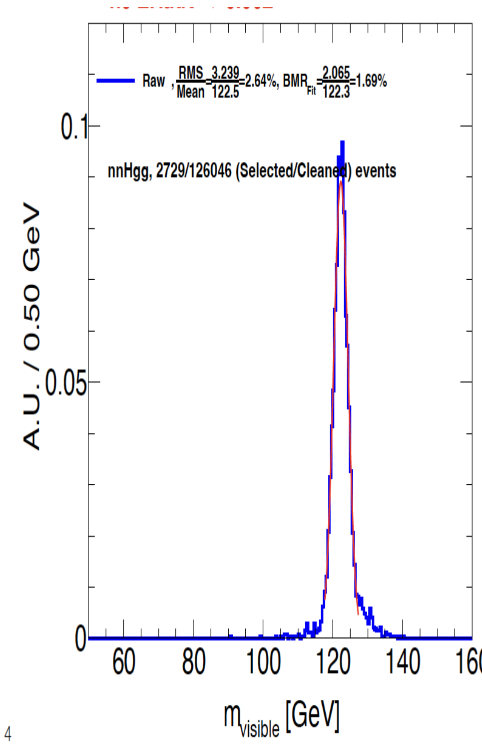
Future: BMR ~ 2.0%





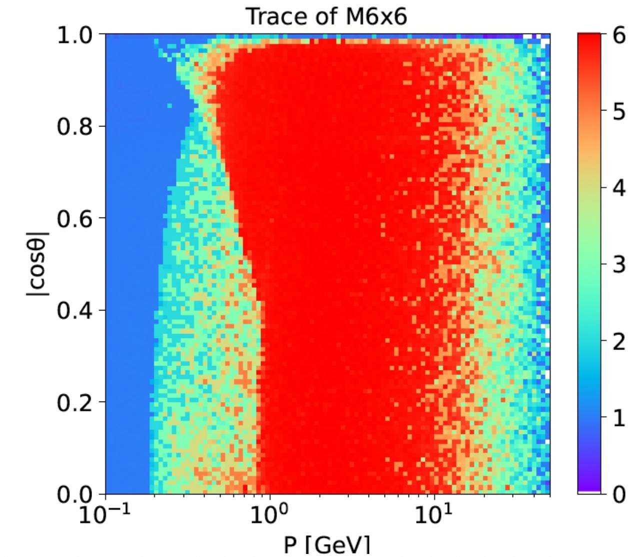


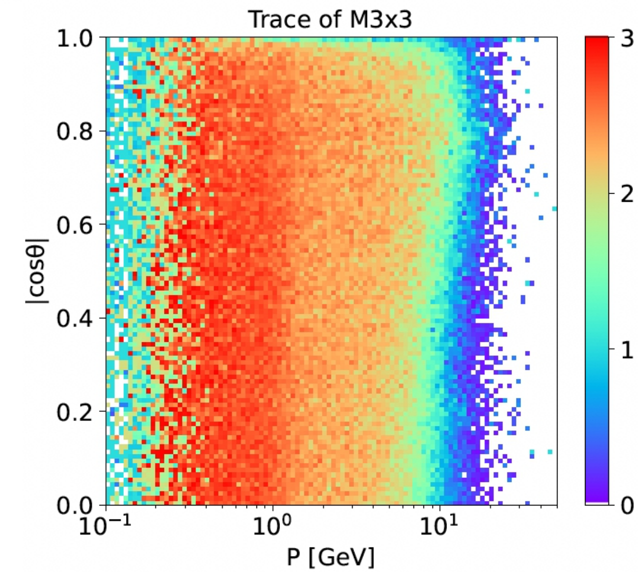




Pid: differential performance

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

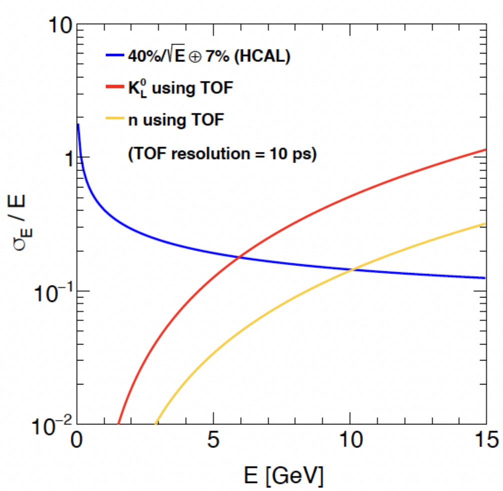


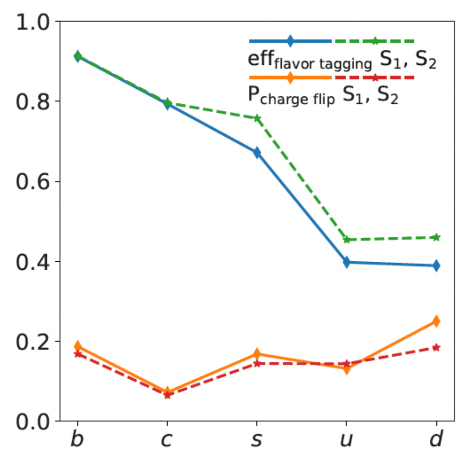


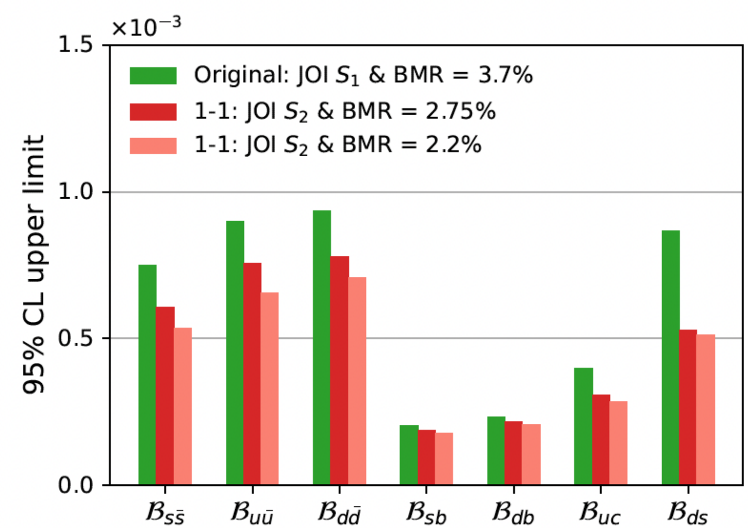
Neutral Hadron ID: 5d Calorimetry with ToF capability (δt~100 ps/hit)

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...

Necessary studies...

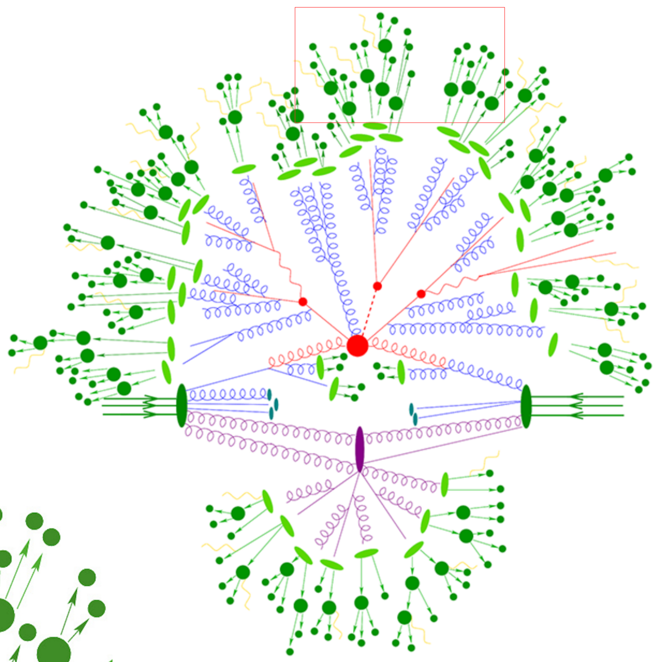
- Beam induced backgrounds: comparative studies...
- Event building with realistic detector time response, including electronic pulse shape & time sequence...
- TPC & Tracker:
  - Dependence of dE/dx or dN/dx performance on the shifting distance & readout threshold/Noise
  - Ion distortion VS shielding & 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...

Summary

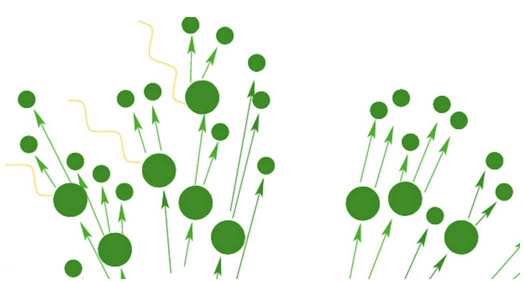
- ***... Higgs factory has strong discovery power to NP, its detector & reconstruction should and could have excellent performance...***
- ***AI as the trend...***
  - *1-1 correspondence reconstruction: excellent PID + BMR of 2.7% (T-1)*
    - *AURORA (CDR detector + GSHCAL), started to evaluate other concepts.*
    - *Roadmap to 2% BMR demonstrated,*
    - *5-d calo is the key*
  - *Holistic approach*
    - *Reco: Jet origin id, highly relevant to 1-1 (T-2)*
    - *Analysis: Holistic + ACSI: enhance the discovery power by ~3 folds (T-3)*
- ***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*
  - *Lots more to explore, with unsupervised, LLM, ... rich interplay & synergies.*
  - ***...***

Future: From leaves to the trees

- The hadronization process is ~ 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 entire tree: reco parenting info 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
- *Synergies with Event building – Trigger + On line + Off line...*

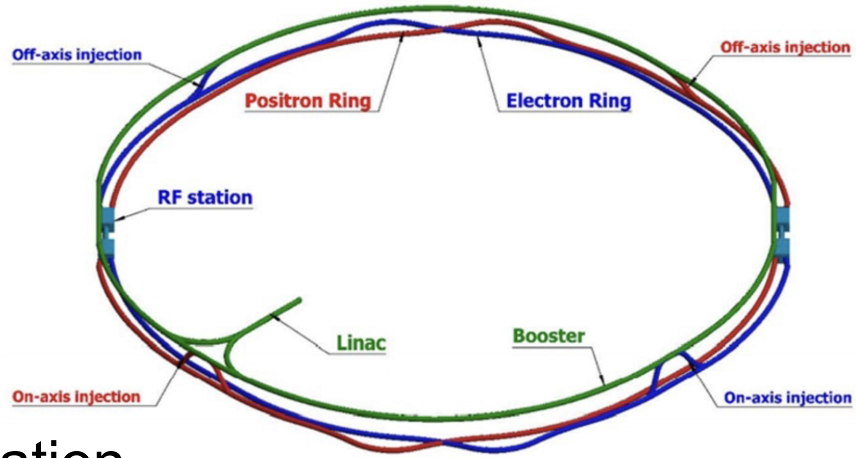
AI era: Holistic approach

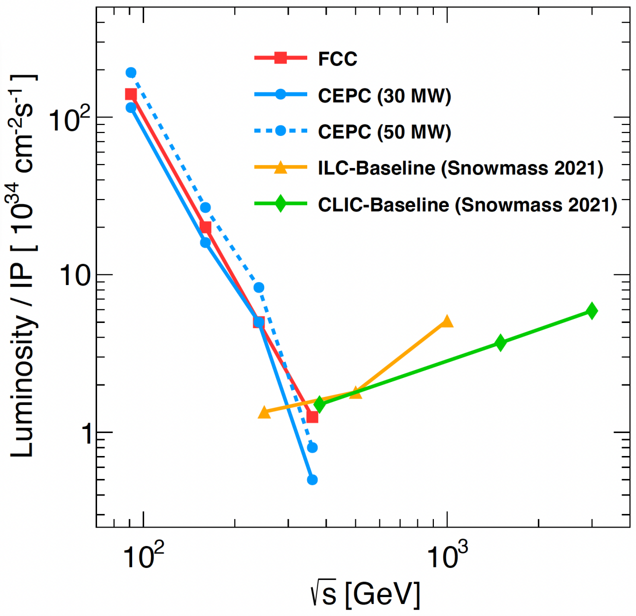
- Feed all reconstructable info. to the classifier – in principle free of human intervene (no need to find Cut variables, etc..). Require excellent detector & reconstruction, where 1-1 serves as a benchmark & standard
- Supervised Learning – Systematic uncertainty control is the challenge, esp. for precision 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

Back up

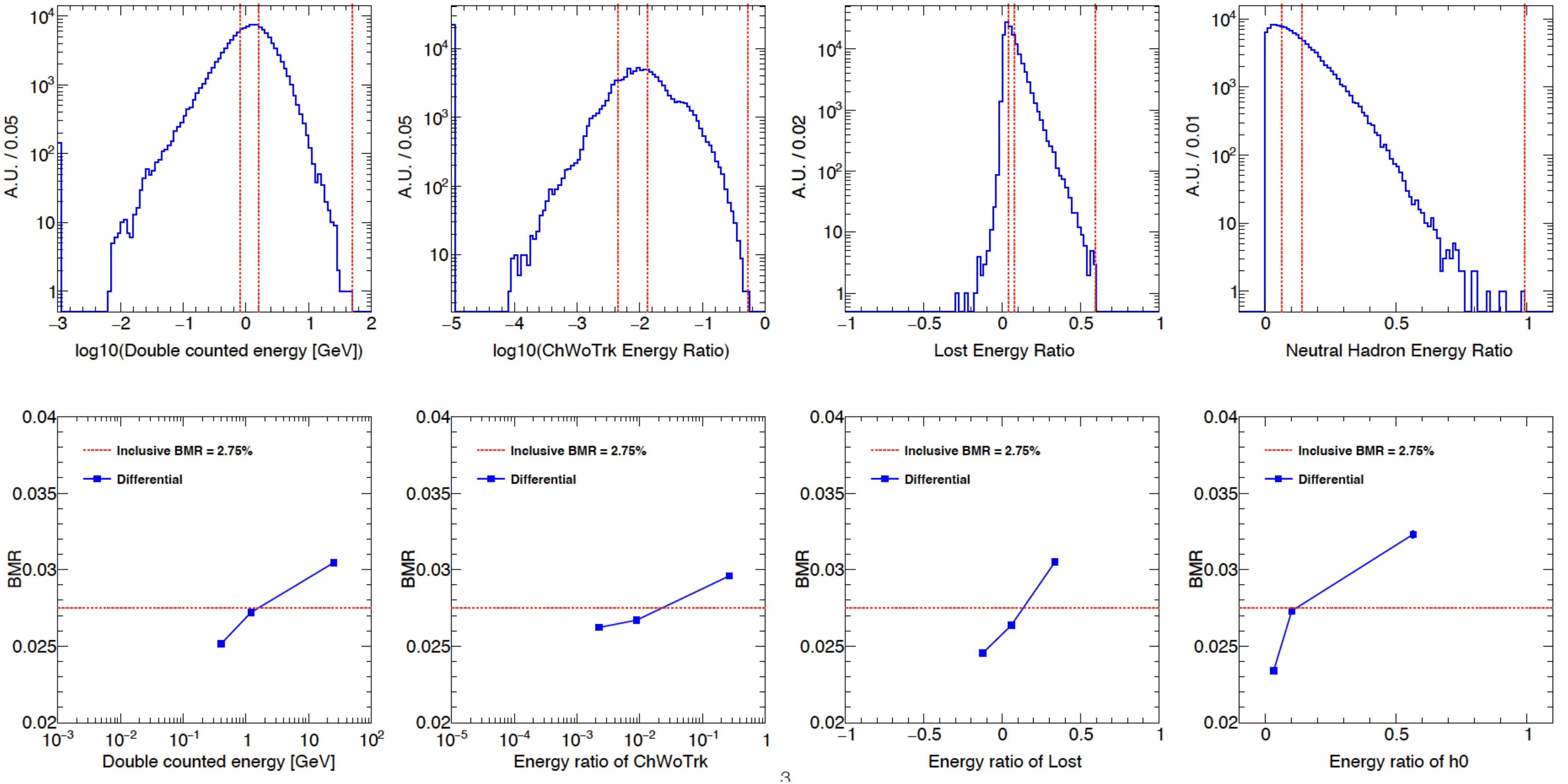
Outline

- CEPC Physics at a glance
- Jet origin identification & Scaling
- Holistic Approach & Color Singlet identification
- 1-1 correspondence reconstruction
- Discussion





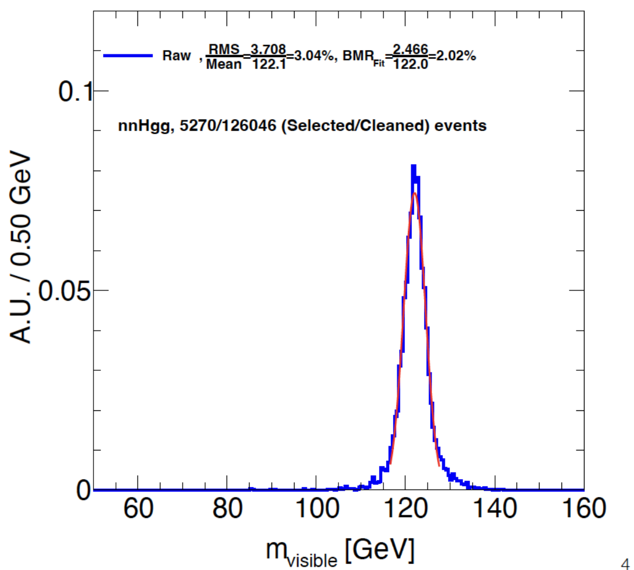
BMR dependence to its components



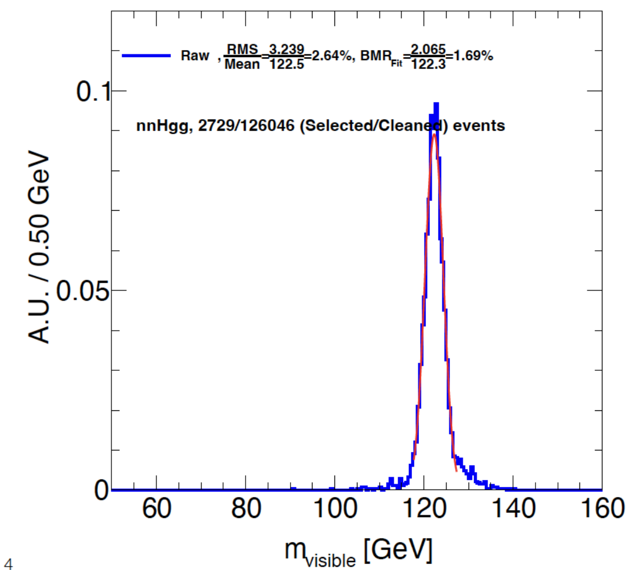
BMR dependence on Cut...

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



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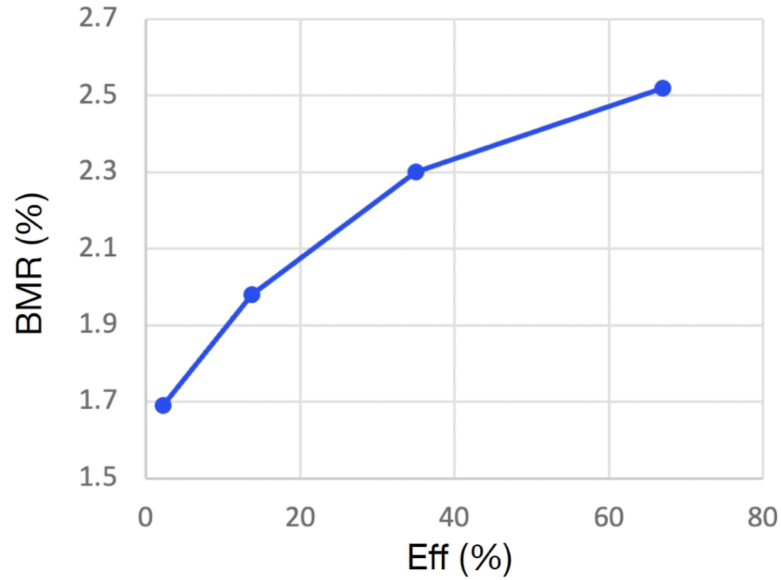
Eff (%)	BMR (%)
2.2	1.69
13.7	1.98
35	2.3
67	2.52



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

BMR: receipt & comparison to JER

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The Higgs signatures at the CEPC CDR baseline*

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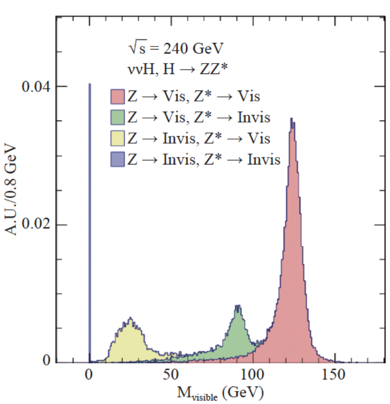
Abstract: As a Higgs factory, the CEPC (Circular Electron-Positron Collider) project aims at precision measurements of the Higgs boson properties. A baseline detector concept, APODIS (A PFA Oriented Detector for the HIggS factory), has been proposed for the CEPC CDR (Conceptual Design Report) study. 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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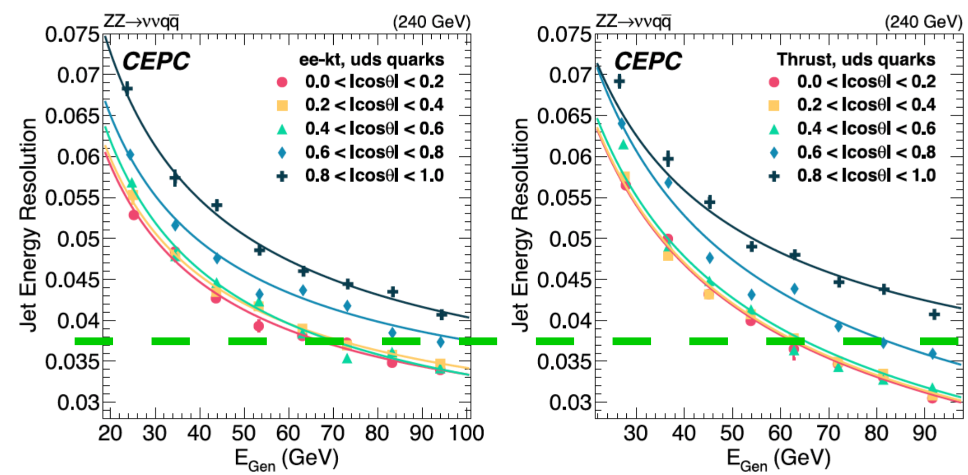


(a) (b)

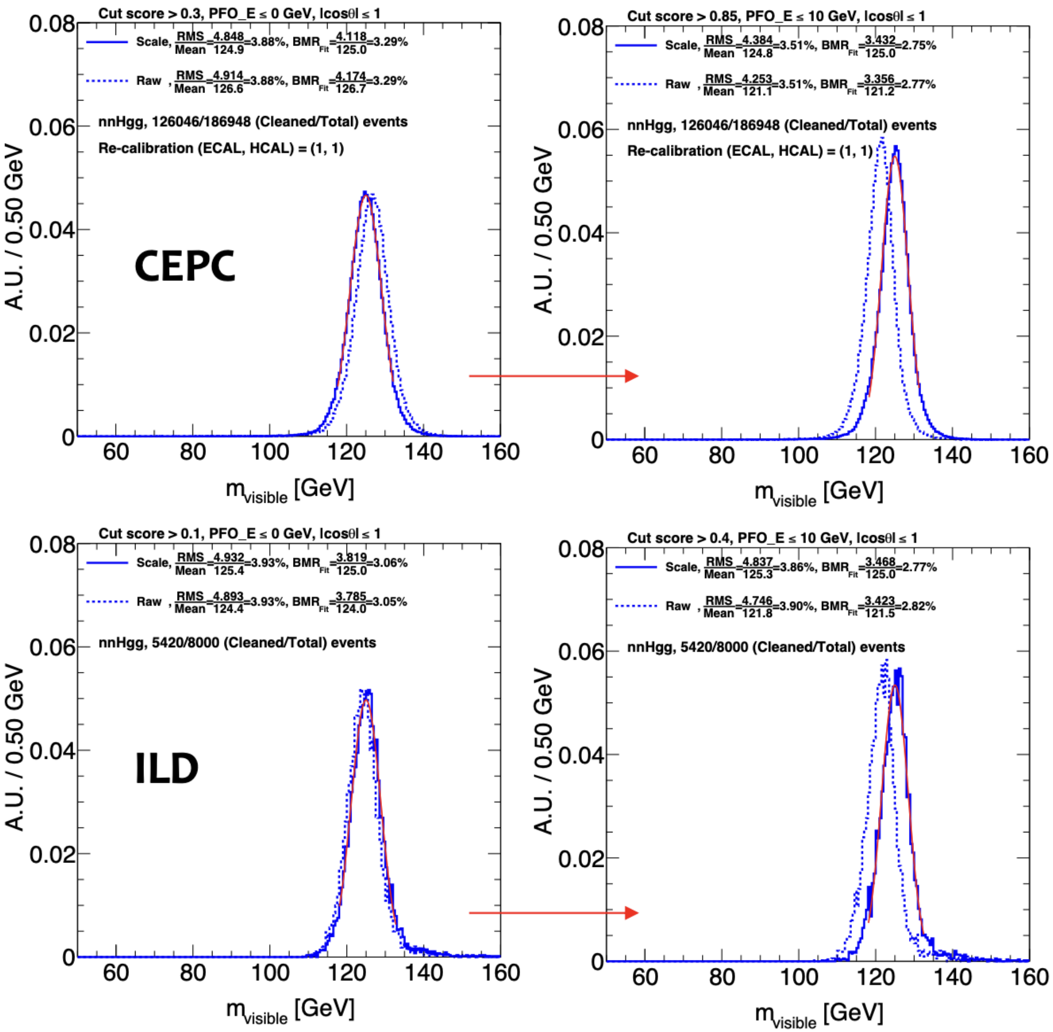
At ILD: Preliminary

- BMR (wo PU) & Pid
- PU study

- Need to further confirm the det. Para + PU condition

Fake particle identification and BMR

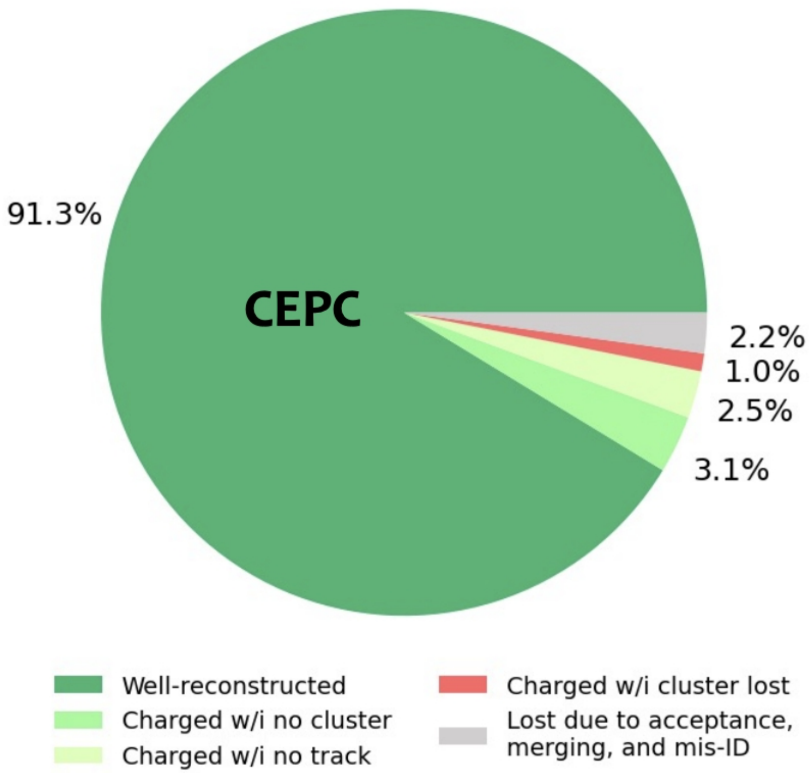
- **Optimal working point (wrt BMR)**
  - CEPC
    - score > 0.85
    - BMR: 3.3% → 2.75% (relative 16%)
    - eff. ~77%, purity ~97.5%
  - ILD
    - score > 0.4
    - BMR: 3.06% → 2.77% (relative 9.5%)
    - eff. ~84%, purity ~72%

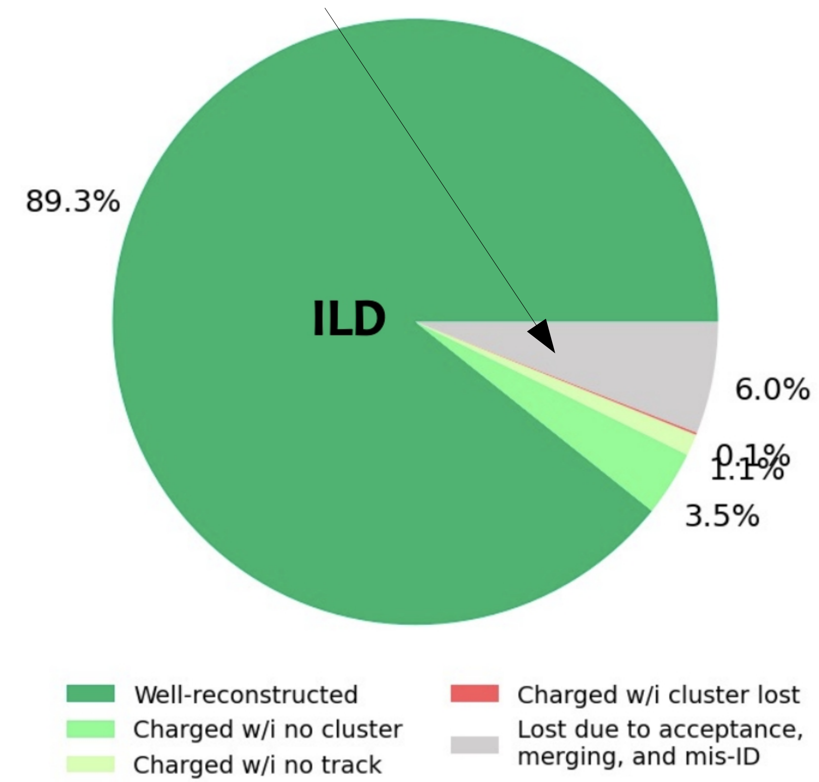


Energy fraction

- **Increased fractions in ILD**
  - Charged w/o cluster
  - Lost (need further decomposition… using 3-stage particle mapping)

Partly due to Pandora create more mult-track PFO





Preliminary! One-one framework needs further polish to be more precise & descriptive

CEPC

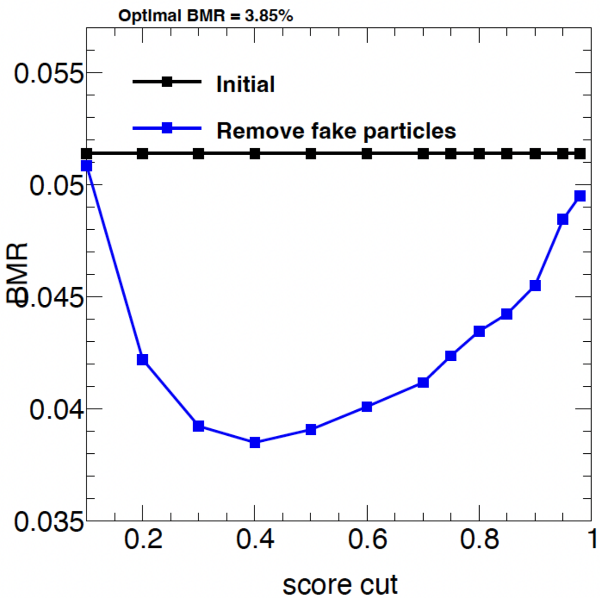
True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\mu^\pm$	0.000	0.985	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.000	0.019	0.977	0.003	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$	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

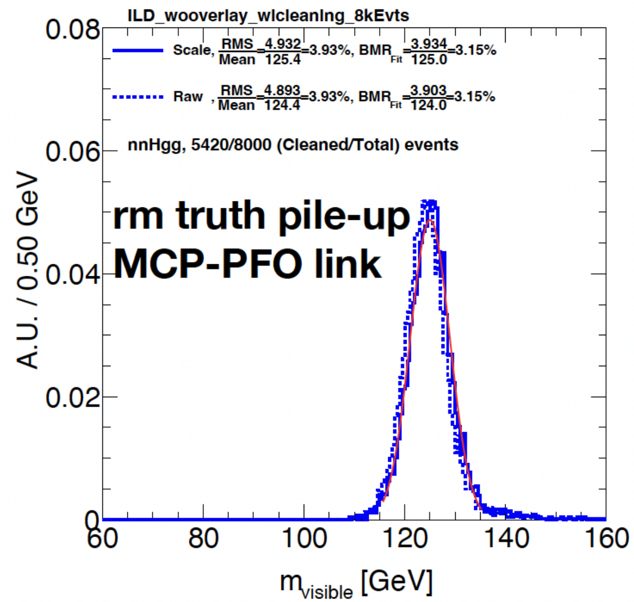
ILD (preliminary)

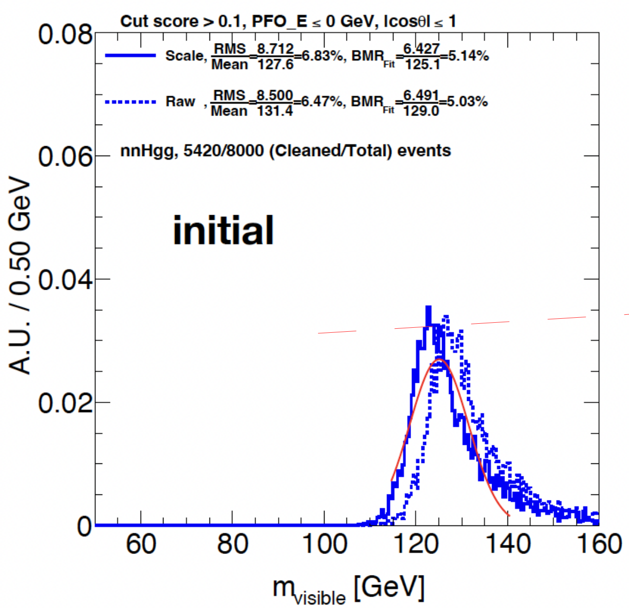
True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.983	0.004	0.003	0.005	0.005	0.000	0.000	0.000	0.000	0.001
$\mu^\pm$	0.011	0.934	0.044	0.009	0.001	0.000	0.000	0.000	0.000	0.001
$\pi^\pm$	0.016	0.088	0.874	0.016	0.004	0.000	0.000	0.000	0.000	0.002
$K^\pm$	0.008	0.010	0.017	0.933	0.028	0.000	0.000	0.000	0.000	0.004
$p/\bar{p}$	0.003	0.001	0.003	0.020	0.949	0.000	0.000	0.000	0.000	0.024
γ	0.000	0.000	0.000	0.000	0.000	0.990	0.002	0.001	0.000	0.006
K_L^0	0.000	0.000	0.000	0.000	0.000	0.011	0.689	0.187	0.039	0.073
n	0.000	0.000	0.000	0.000	0.000	0.008	0.182	0.646	0.077	0.088
$\bar{n}$	0.000	0.000	0.000	0.000	0.000	0.007	0.042	0.087	0.768	0.095
others	0.009	0.049	0.011	0.002	0.006	0.141	0.116	0.086	0.037	0.544

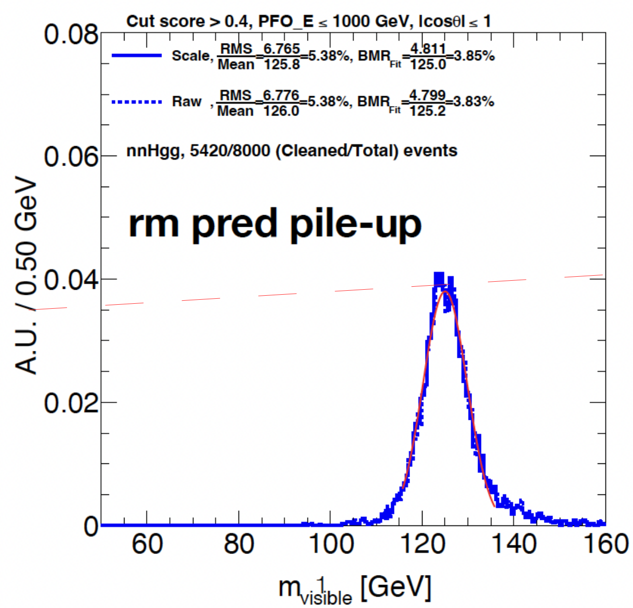
pile-up subtraction

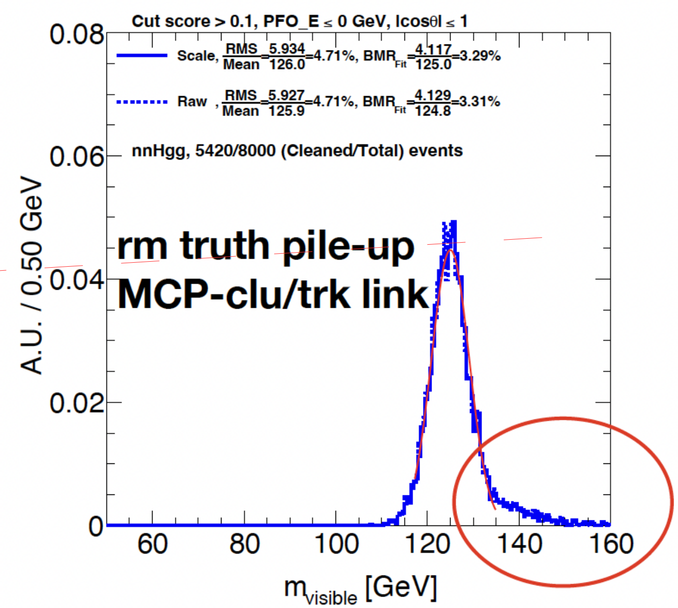
- BMR
  - initial ~5.14%
  - rm pred pile-up 3.85%
  - rm truth pile-up 3.29%
    - using MCP-clu/trk link
  - rm truth pile-up 3.15%
    - using MCP-PFO link



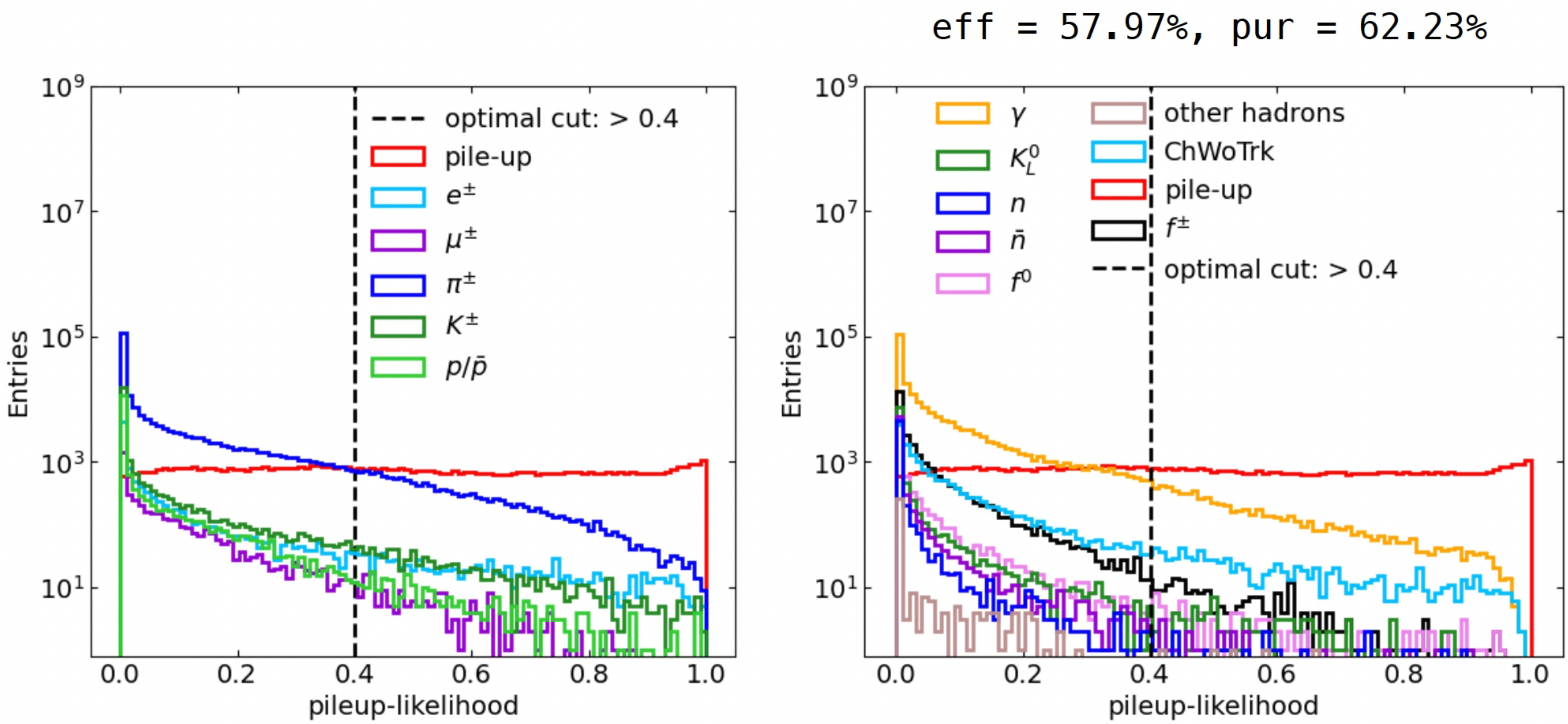








PU pfo identification...



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