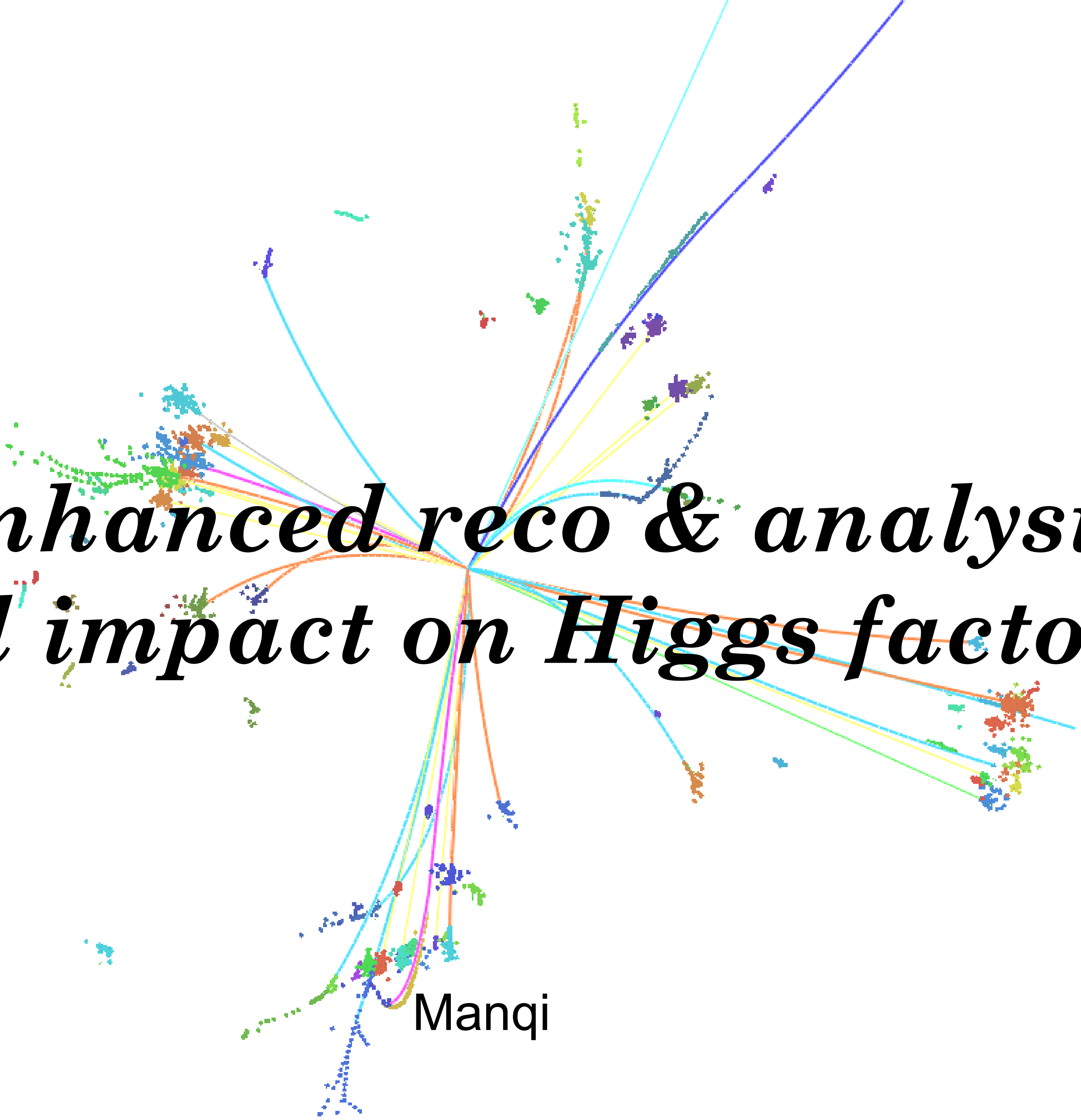
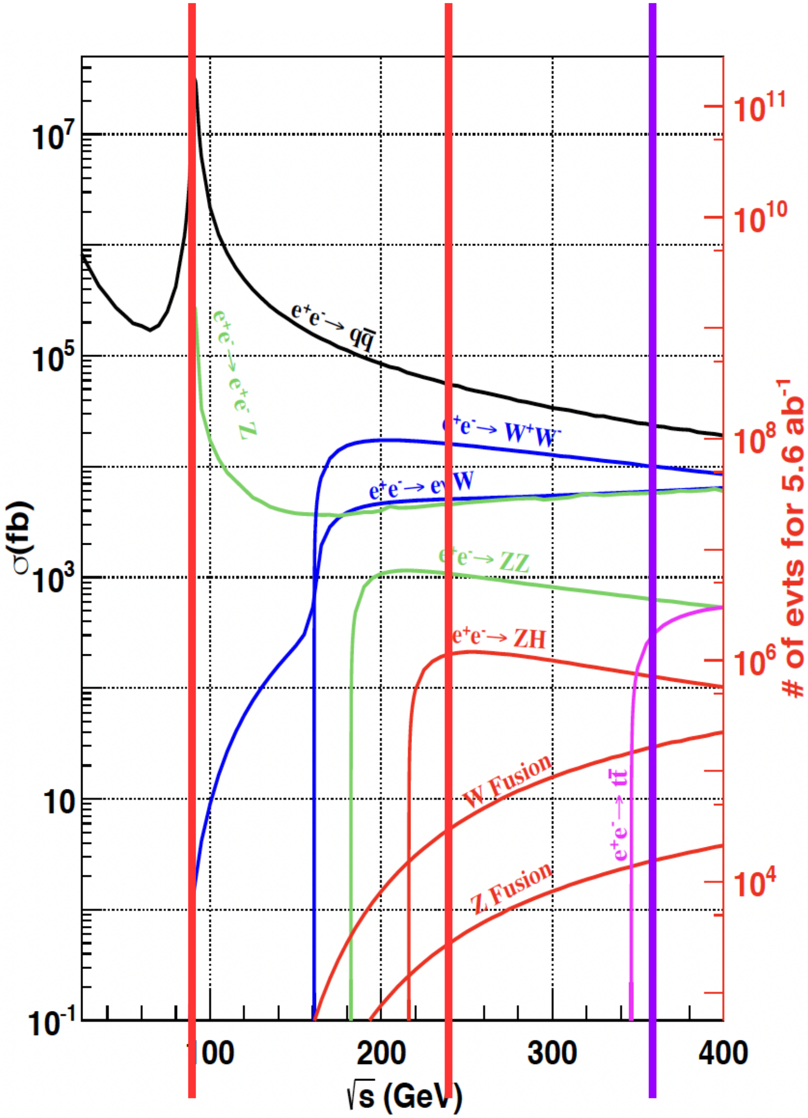
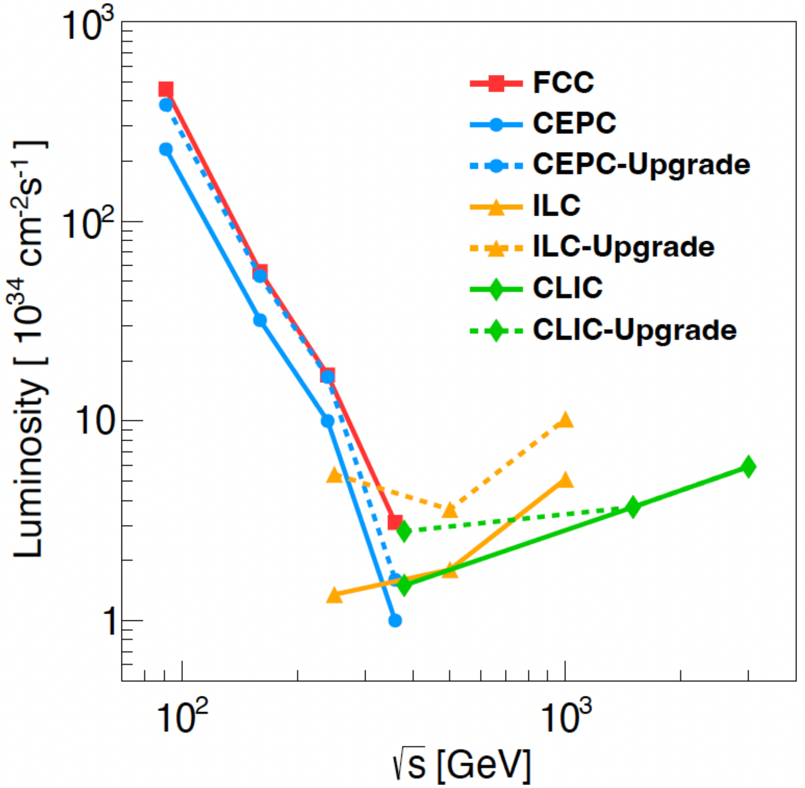
AI enhanced reco & analysis – and impact on Higgs factory



Manqi

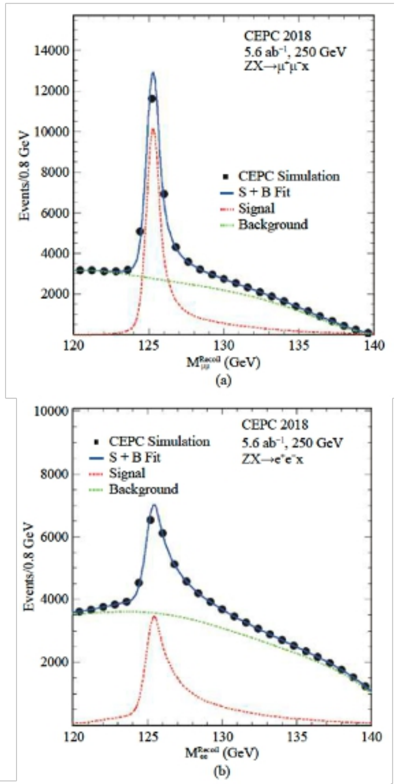
Yields ~ Xsec * Lumi * Time

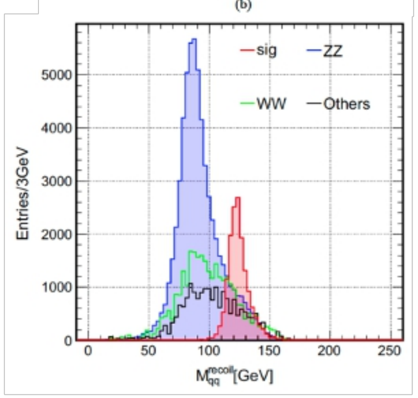




- CEPC: 100 km main ring circumference
- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

CEPC Physics



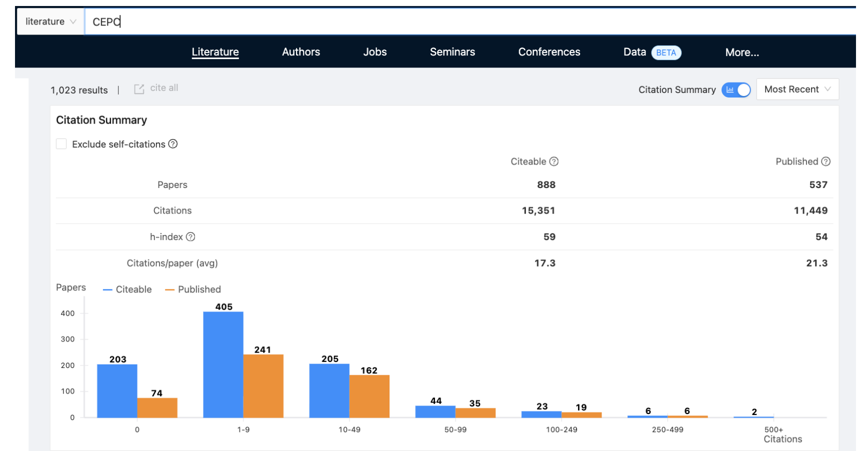



Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

Received 9 November 2018, Revised 21 January 2019, Published online 4 March 2019

043002-1



Higgs: 2019 Chinese Phys. C 43 043002, see also 1810.09037

Snowmass Whitepaper: 2205.08553v1

Flavor: Accepted by CPC (July 4th), 2412.19743v2

New Physics: Submitted to CPC (July 17th), 2505.24810v1

EW white paper: in progress. Plan to submit to ArXiv ~ Nov.

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

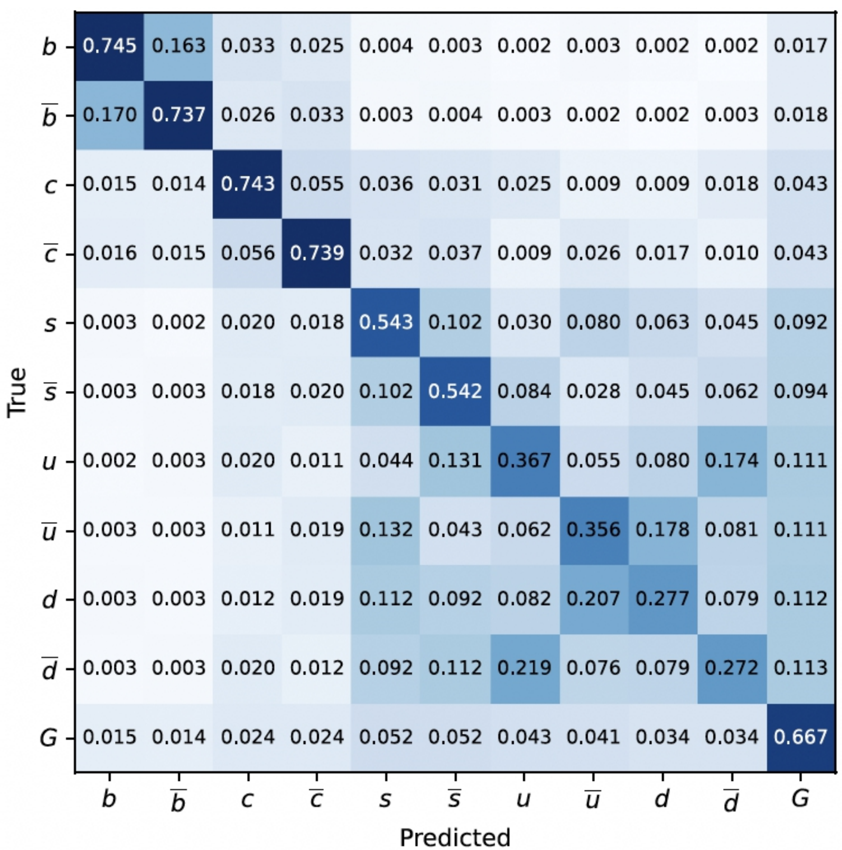
Holistic approach:
Using all reconstructable for **classification**

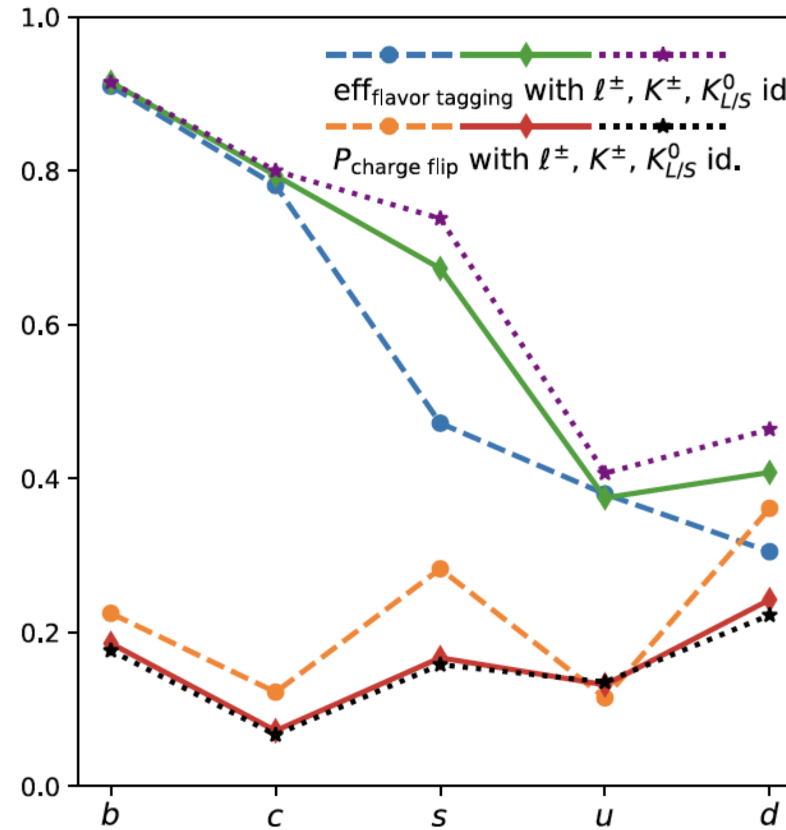
- Reconstructable: with current detector design (1-1 correspondence/Particle Flow), could be
  - 4 momentum + type (Pid) info of all reconstructed particles
  - Track impact parameters of reconstructed charged particles
  - Potentially: parenting info of reconstructed particle
  - ...

- Classification tasks:
  - Reco: Jet origin identification
  - Analysis: to distinguish the signal from the background
  - ...

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

Holistic Reco: Jet origin id

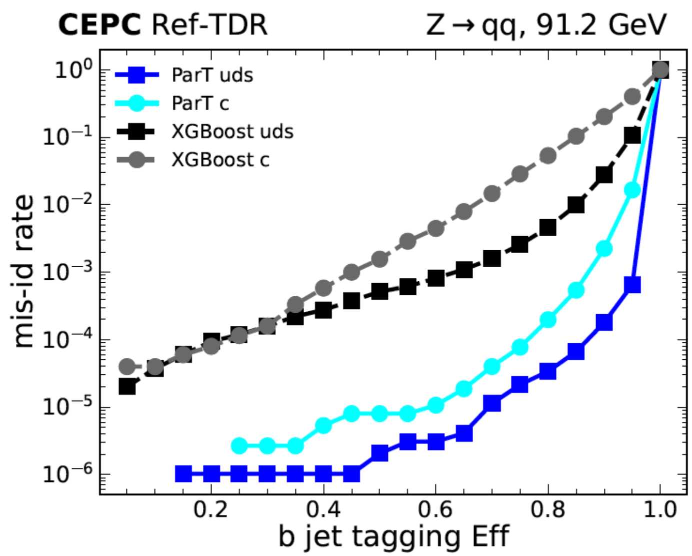


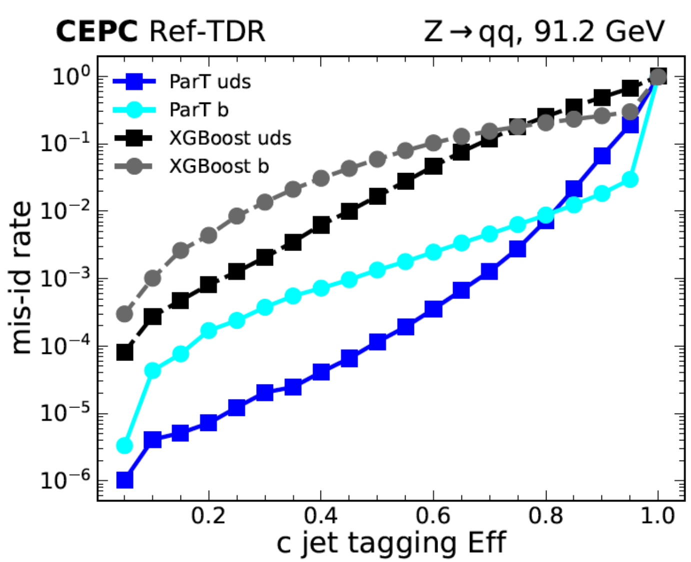


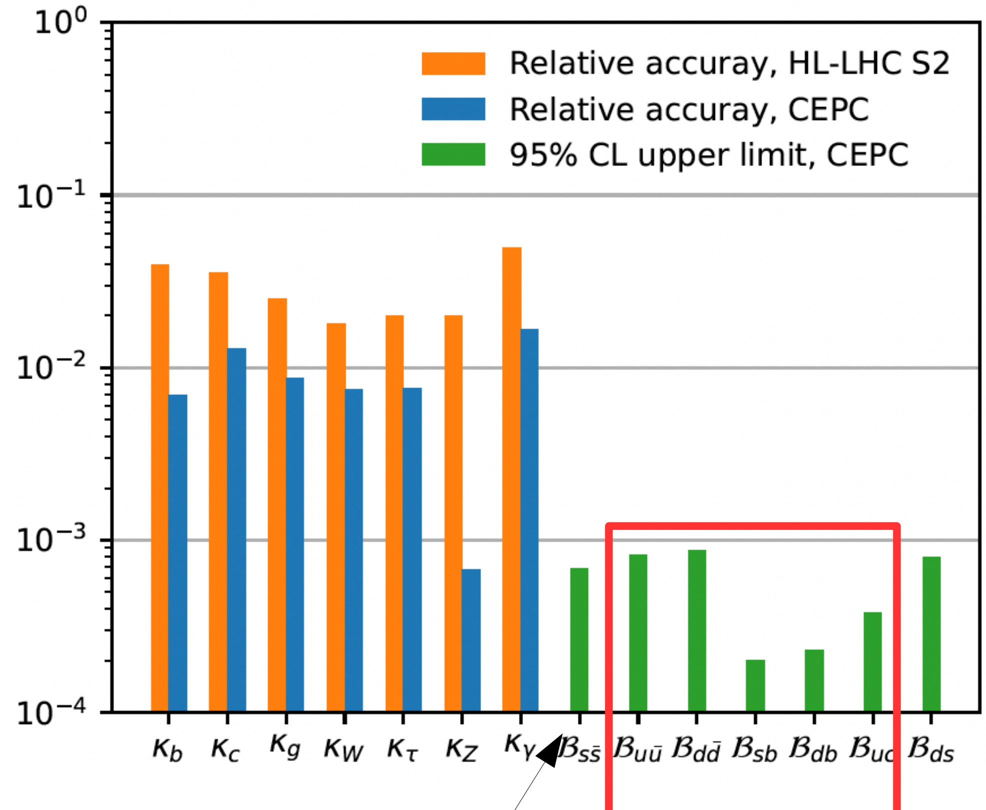
- 11 categories (5 quarks + 5 anti quarks + gluon) identification, realized at Full Simulated di-jet events at CEPC CDR baseline with Arbor + ParticleNet
- Published in PRL *132, 221802 (2024)*. Comment from the referee: *"demonstrate the world-leading performance of tagger", "a "game changer" and opens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







Improved by ~3 times

Improved by 1-2 orders of magnitudes
~ 2 folds improvement at H->cc & Vcb

Presumably... firstly quantified

Updated result on $\sin^2\theta_{eff}^{l}$ measurement

Table 2. Sensitivity S of different final state particles.

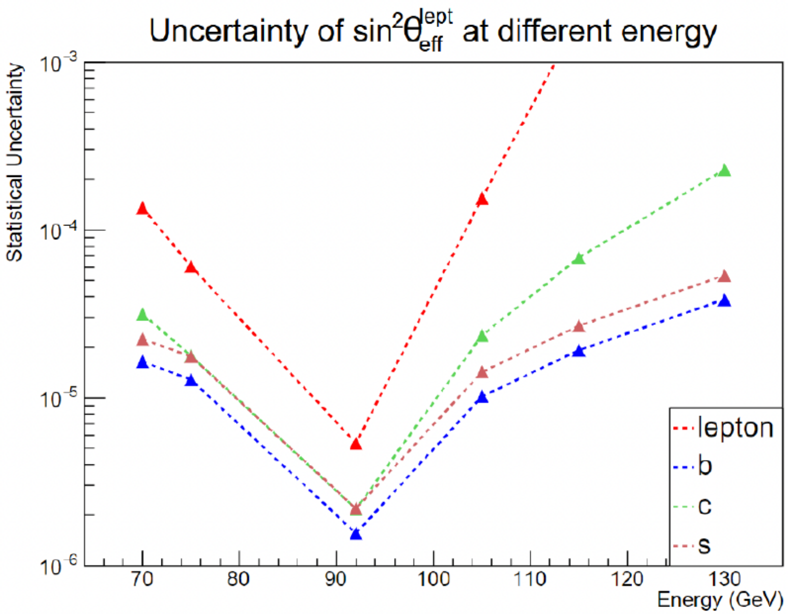
$\sqrt{s}$/GeV	S of $A_{FB}^{e/\mu}$	S of A_{FB}^{d}	S of A_{FB}^{u}	S of A_{FB}^{s}	S of A_{FB}^{c}	S of A_{FB}^{b}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958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

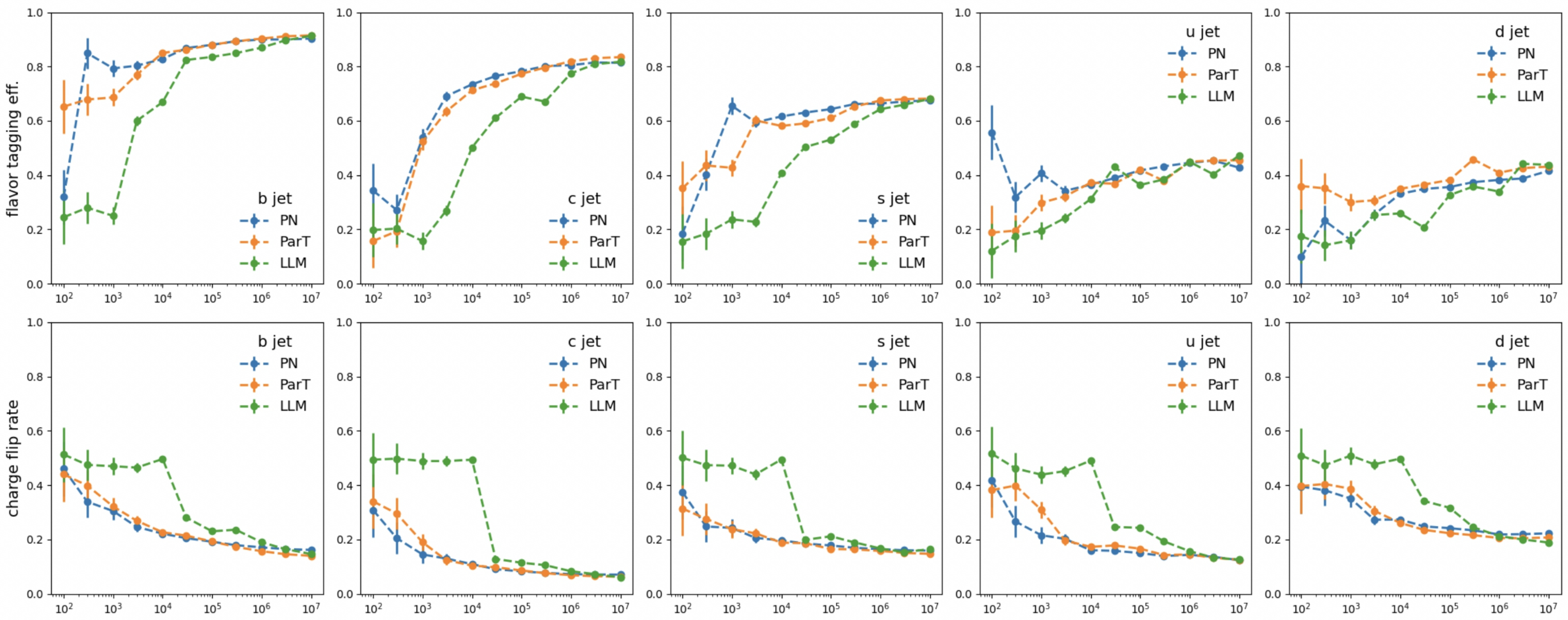
Expected statistical uncertainties on $\sin^2\theta_{eff}^{l}$ measurement.
(Using one-month data collection, ~ *4e12/24 Z events* at Z pole)



$\sqrt{s}$	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...

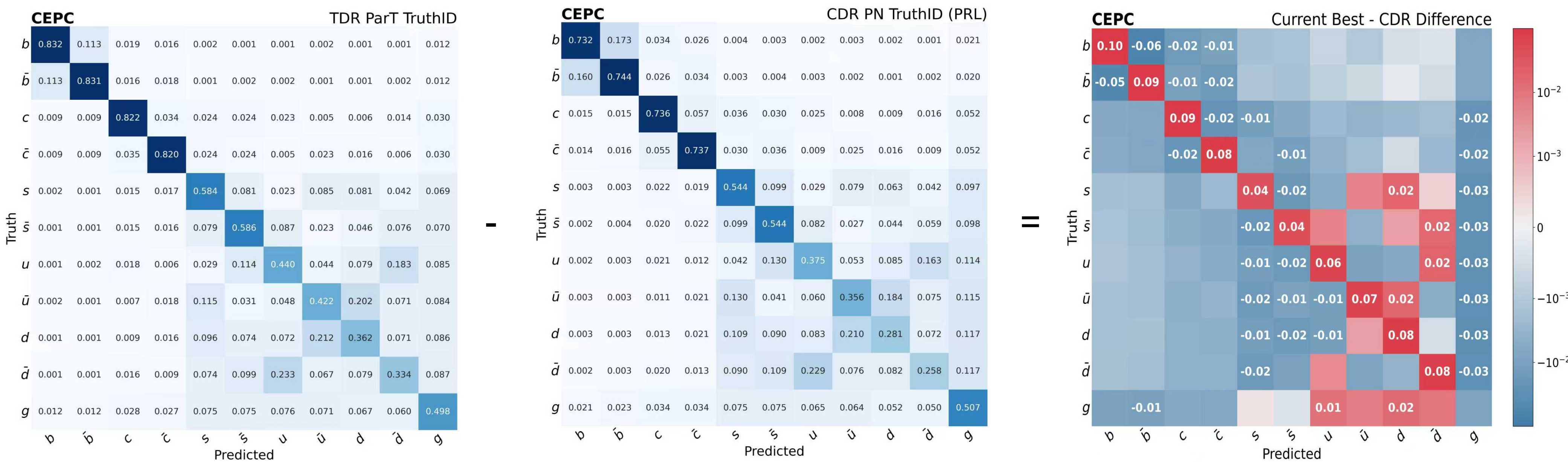
From specialized Models to LLM



- 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*

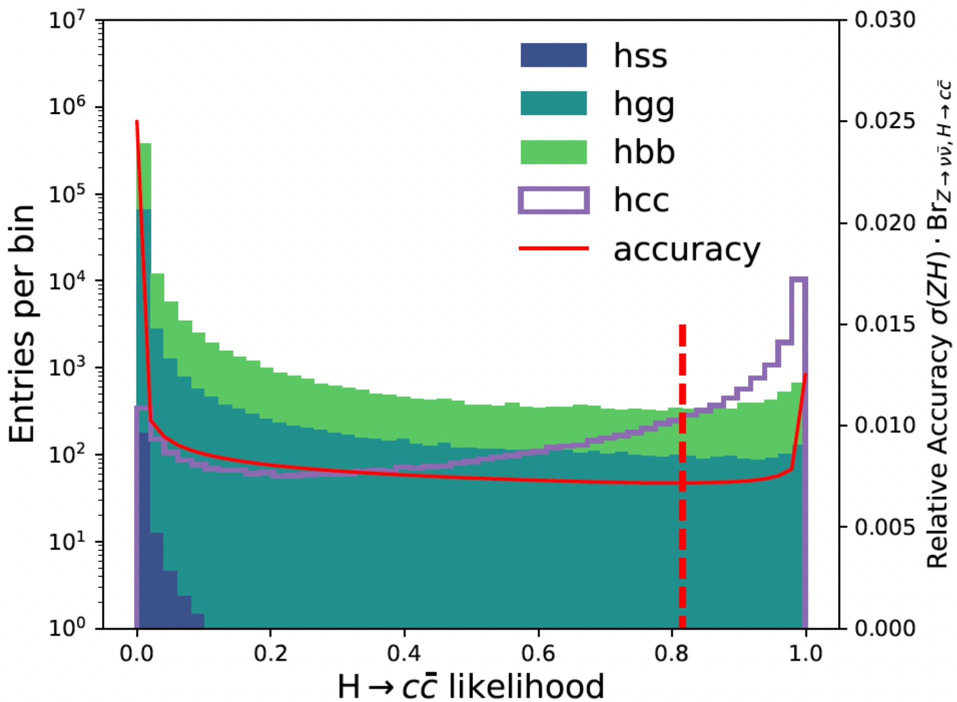
超对称
Super Symmetry Technologies

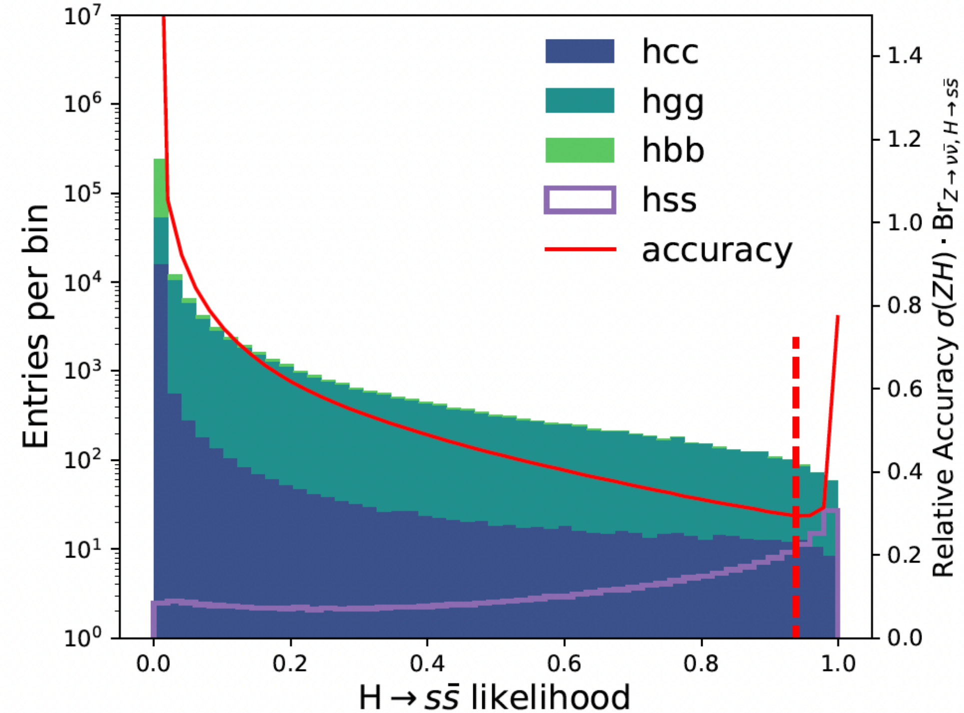
Recent updates... preliminary



- Current Best: ~ 10% improvements in M11
  - Change AI architecture, with extend input variables
  - Vertex optimization
  - ...
- To do:
  - *Scan on generator/hadronization models,*
  - *Better reconstruction of intermediate particles (pi0, phi, Lambda, Kshort, etc)...*

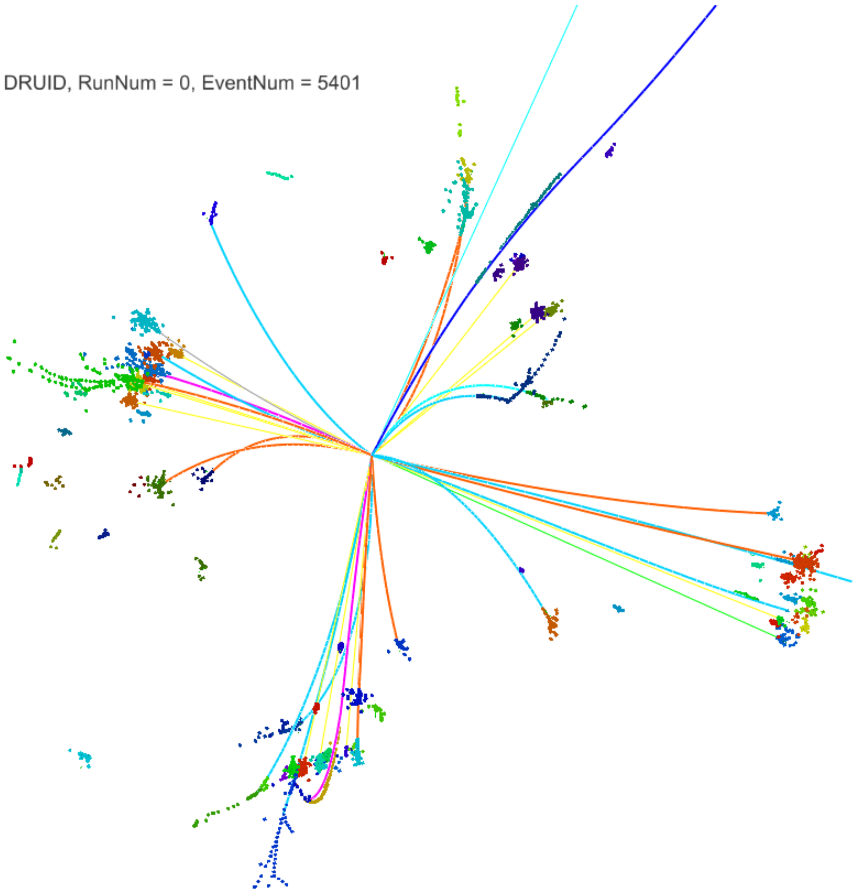
Holistic Analysis: vvH, H→2 jet

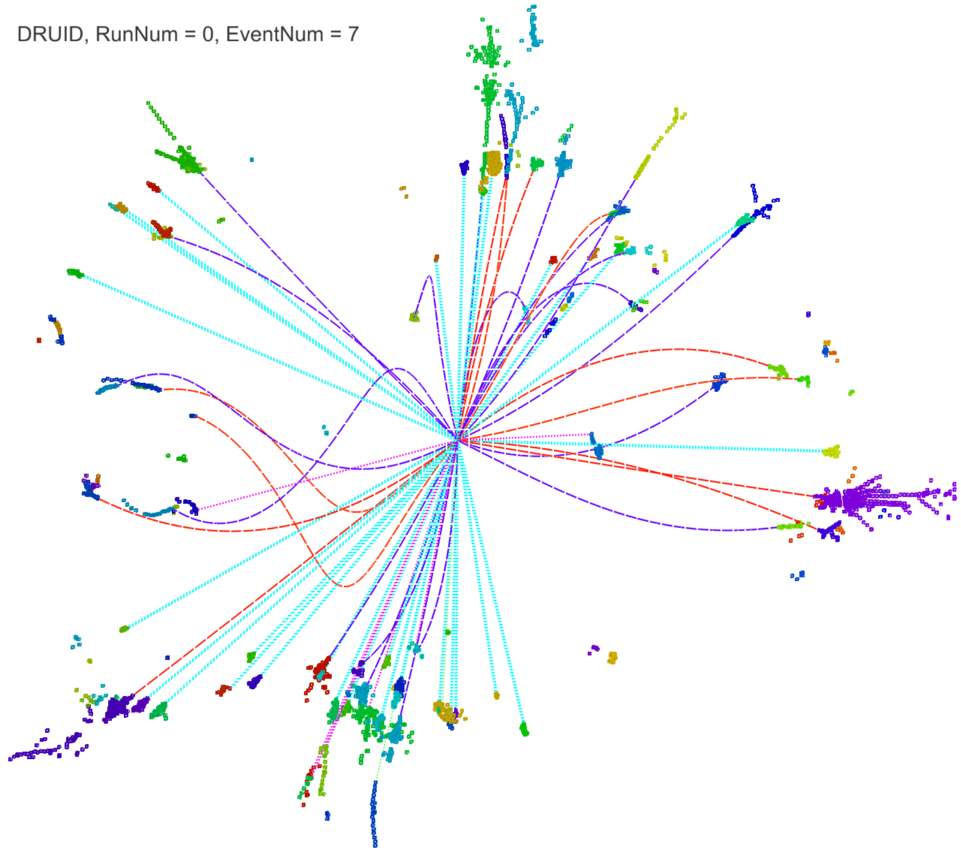




- vvH, H→bb/cc/gg/ss measurements: 4 kinds classification
- Simplified analysis with irreducible background...
- H→bb/cc/gg: close to the statistic limits - 2-6 times better than previous studies (include other bkgrd, BDT based, etc)
- H→ss: close to confirmation!

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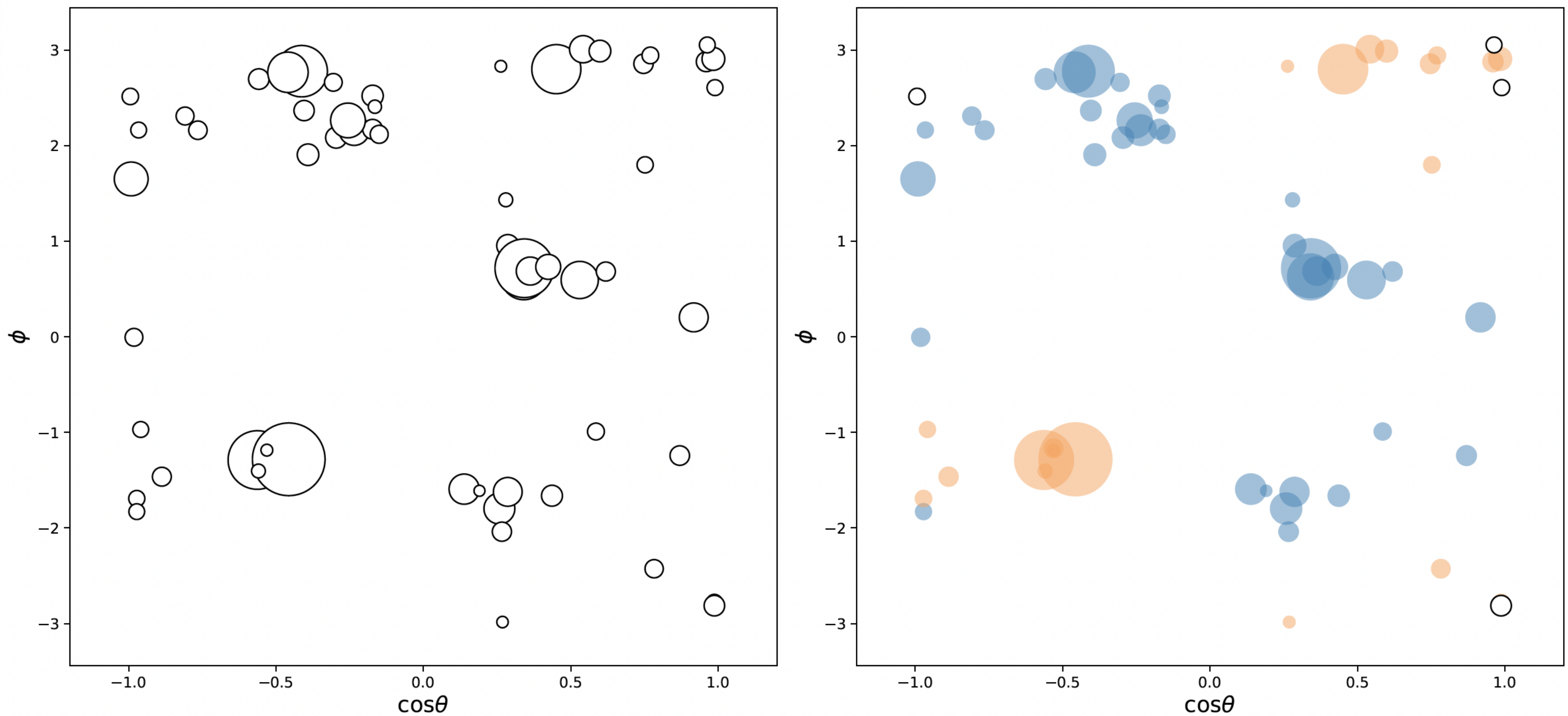
Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

Table 3. The signal strength accuracies for different channels.

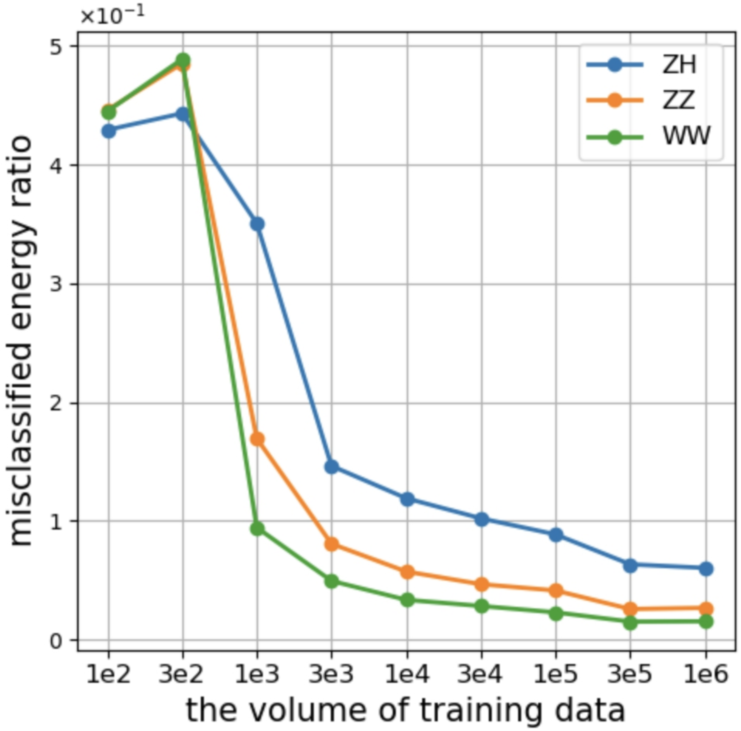
- H→cc & gg measurements at qqH channel is much worse vvH channels, despite the former has 3.5 times more signal statistic
- Reason: Failure of Color Singlet Identification – to distinguish the decay products of each Color Singlet
  - Z & H for 240/250 GeV Higgs factory
  - Which Higgs boson for Higgs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

Advanced CSI using AI

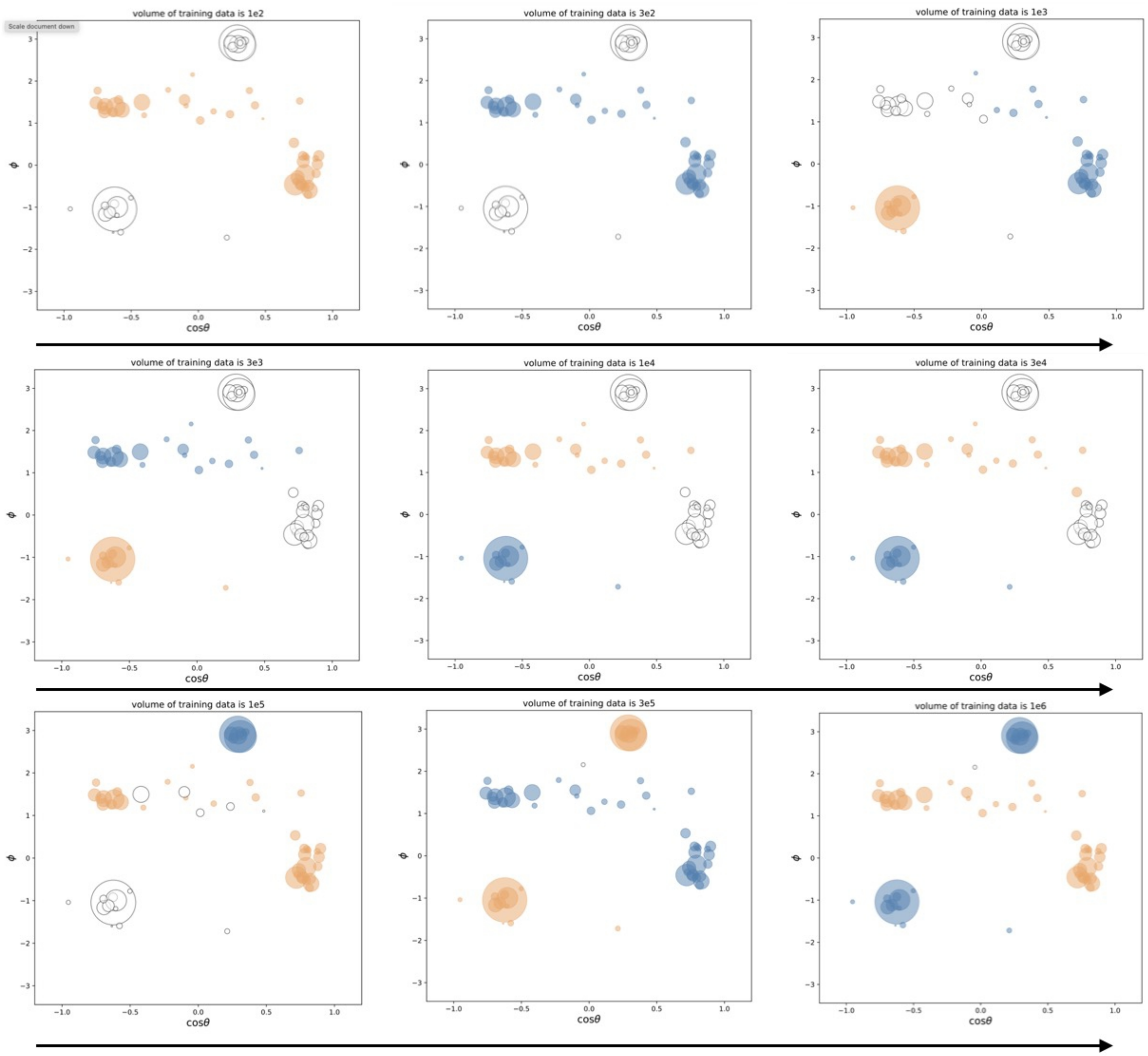


Yongfeng, Hao, Yuexin, etc

Scaling...

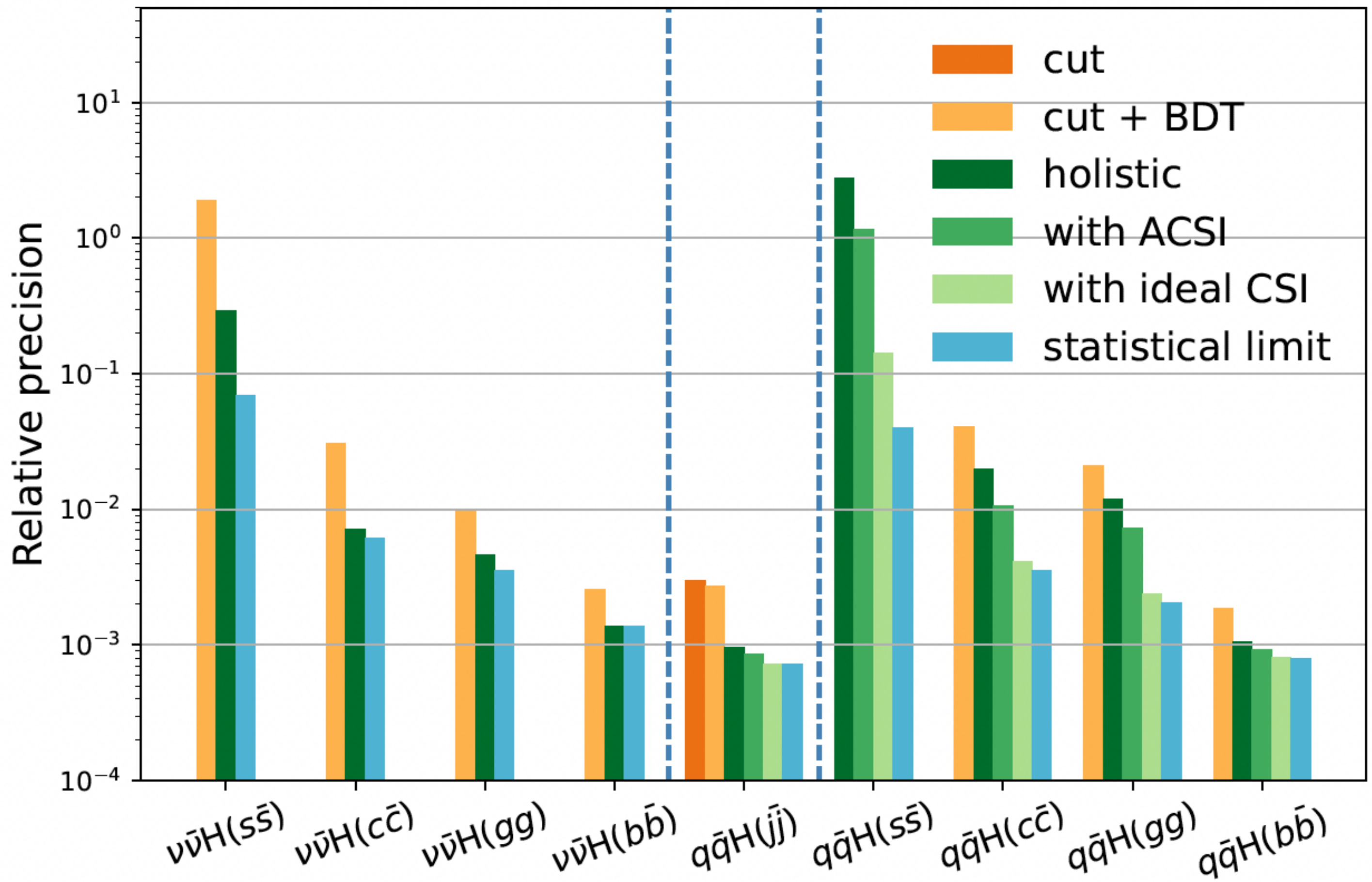


×10⁻¹
misclassified energy ratio
the volume of training data
1e2
3e2
1e3
3e3
1e4
3e4
1e5
3e5
1e6
ZH
ZZ
WW



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

Holistic approach + ACSI



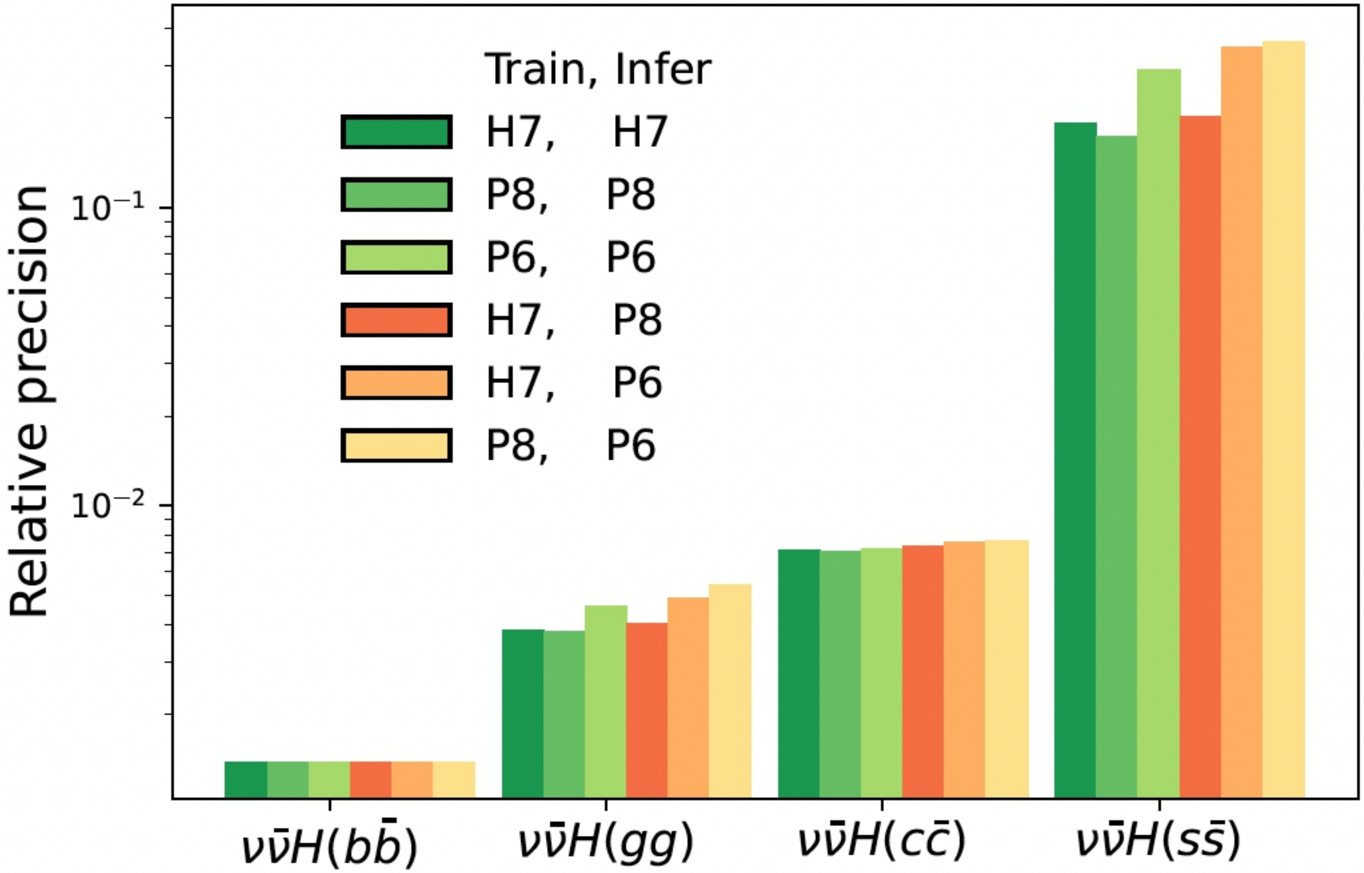
Holistic + ACSI: improves the accuracy by 2 – 6 times

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

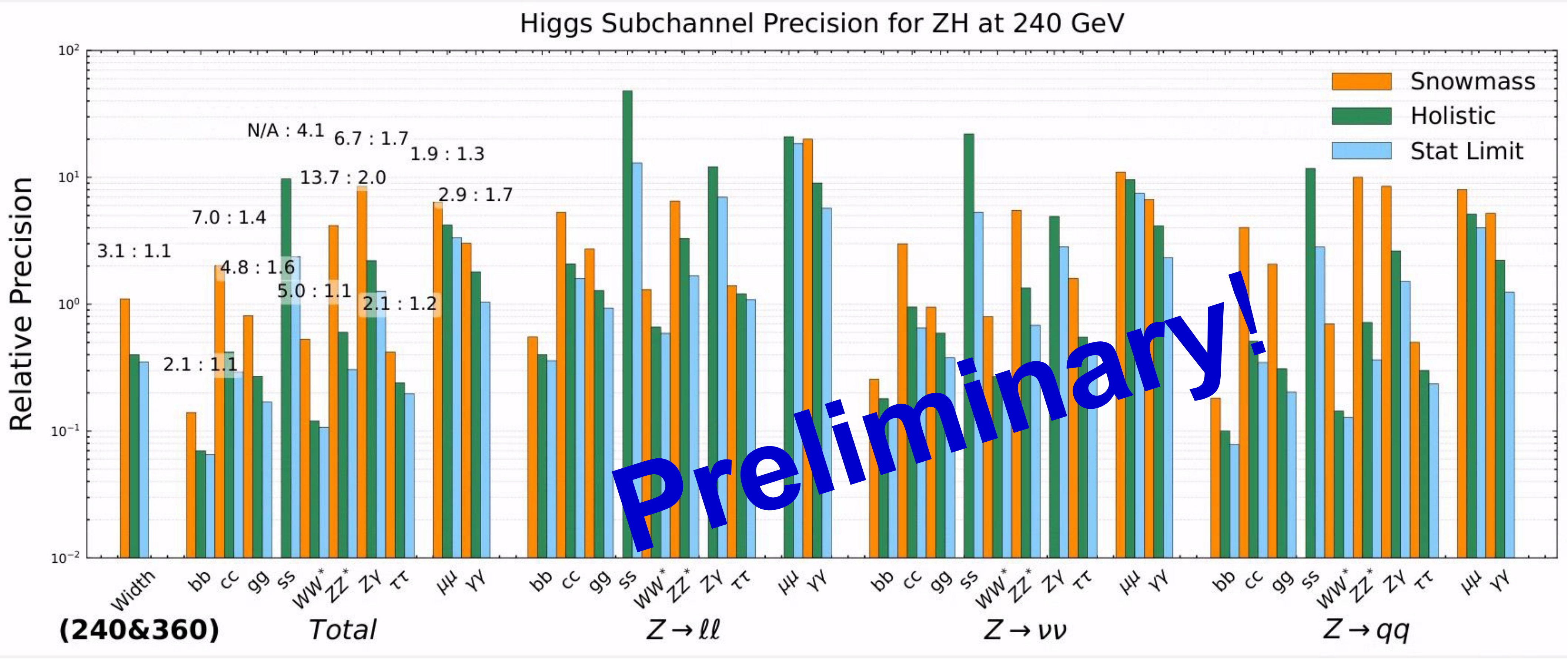
Supervised learning: need High Quality MC



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

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

Anticipated Higgs measurements

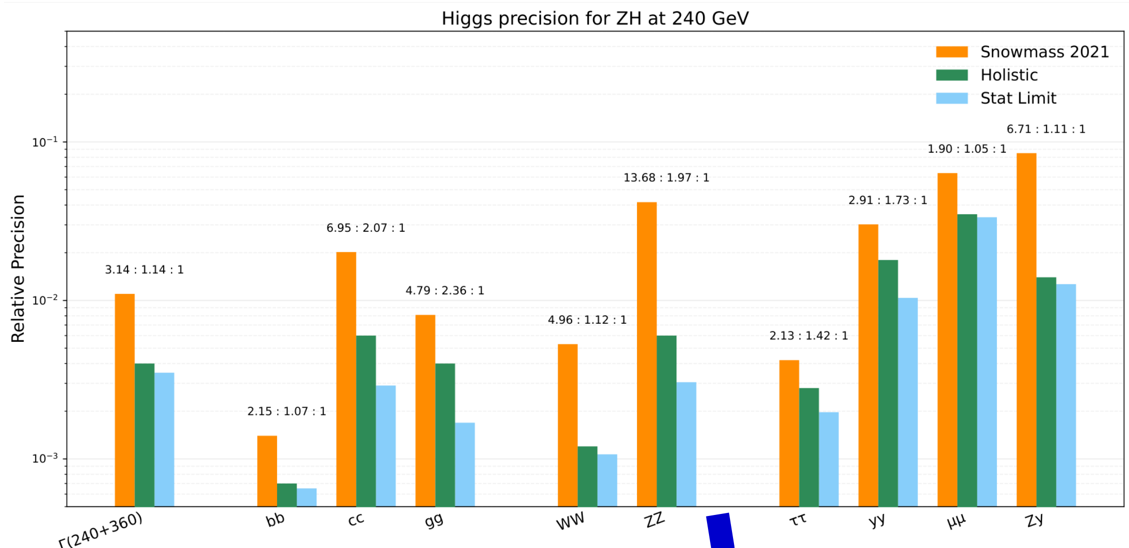


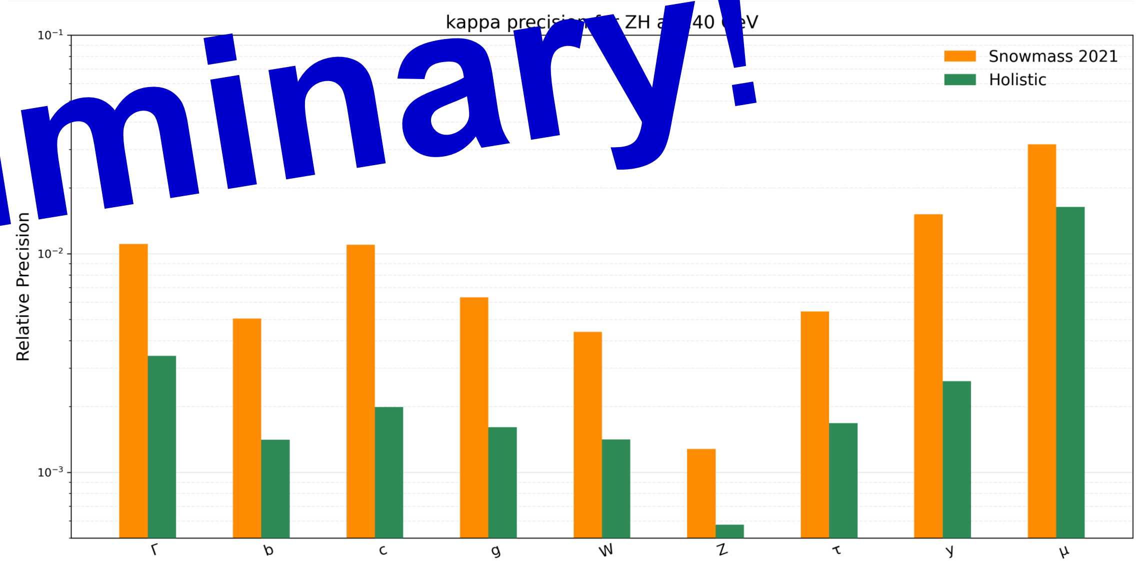
With Holistic approach..

Higgs measurements & interpretation

Table 10: The projected precision for Higgs measurements at the CEPC for ZH and vvH production modes, no systematic and theoretic uncertainty included. The branching ratio for invisible decays is given as a 95% C.L. upper limit. The precision for the Higgs total width (Γ_H) is derived from a global κ-fit combining all channels. The 'Impr.' column indicates the improvement factor, defined as the ratio of the previous uncertainty to the current one. A dash (—) indicates that the value is not applicable or unavailable.

Channel	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}	
	Prec. (%)	Impr.	Prec. (%)	Impr.
ZH Production				
Inclusive	0.13	2.0	0.25	5.6
$H \to bb$	0.07	2.0	0.5	1.8
$H \to cc$	0.6	3.4	2.6	3.4
$H \to gg$	0.4	2.0	1.7	2.0
$H \to WW$	0.12	4.4	0.6	4.7
$H \to ZZ$	0.6	7.0	2.9	6.9
$H \to \tau\tau$	0.28	1.5	1.4	1.5
$H \to \gamma\gamma$	1.8	1.7	7	1.6
$H \to \mu\mu$	3.5	1.8	23	1.8
$H \to Z\gamma$	1.4	6.0	8	4.3
$H \to ss$	18	—	—	—
$\mathrm{Br}_{\mathrm{upper}}(H \to \mathrm{inv.})$	0.10	—	—	—
vvH Fusion Production				
$H \to bb$	0.9	1.7	0.6	1.8
$H \to cc$	5	[illegible]	4	[illegible]
$H \to gg$	3.2	[illegible]	[illegible]	2.0
$H \to WW$	1.3	[illegible]	[illegible]	[illegible]
$H \to ZZ$	4	[illegible]	[illegible]	4.0
$H \to \tau\tau$	3.3	—	[illegible]	[illegible]
$H \to \gamma\gamma$	13	—	[illegible]	2.0
$H \to \mu\mu$	25	—	27	2.1
$H \to Z\gamma$	8	—	10	—
Higgs Total Width, Γ_H (from global fit)				
from 240 GeV data	0.55	3.0	—	—
from 360 GeV data	—	—	0.9	3.5
from Combined data	0.4	2.7	—	—

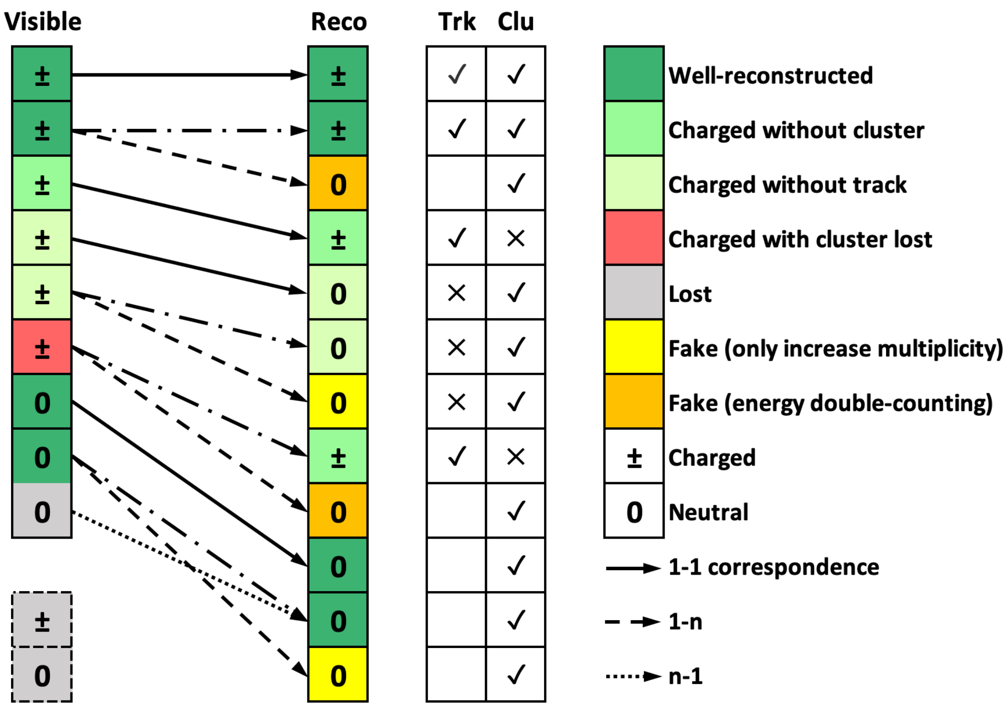




Preliminary!

1-1 correspondence reconstruction

Final state particles



https://arxiv.org/abs/2411.06939

Computer Physics Communications 314 (2025) 109661

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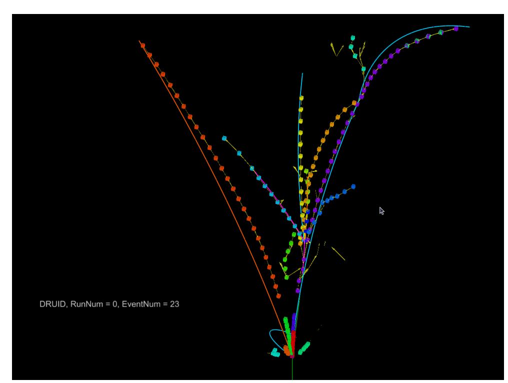
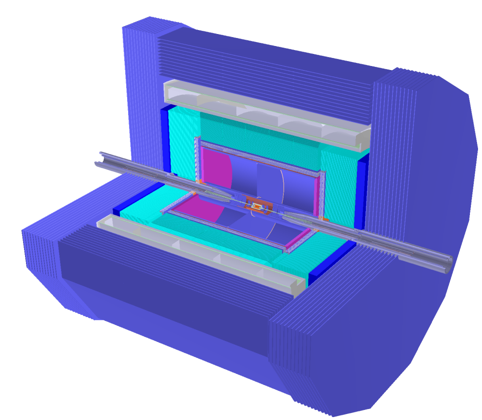
journal homepage: www.elsevier.com/locate/cpc

Computational Physics

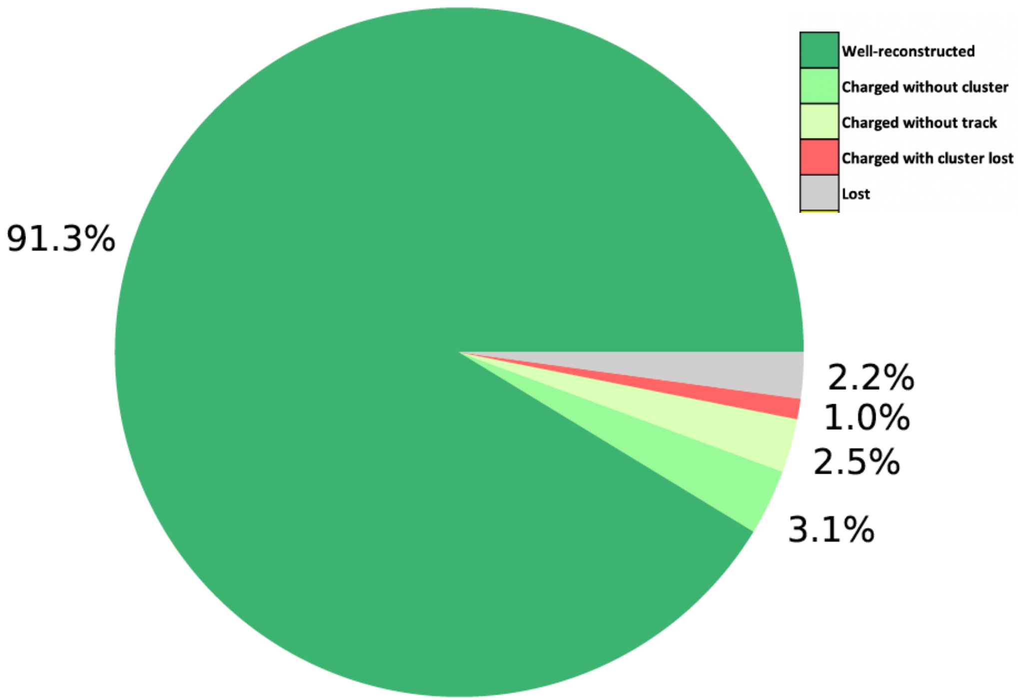
One-to-one correspondence reconstruction at the electron-positron Higgs factory

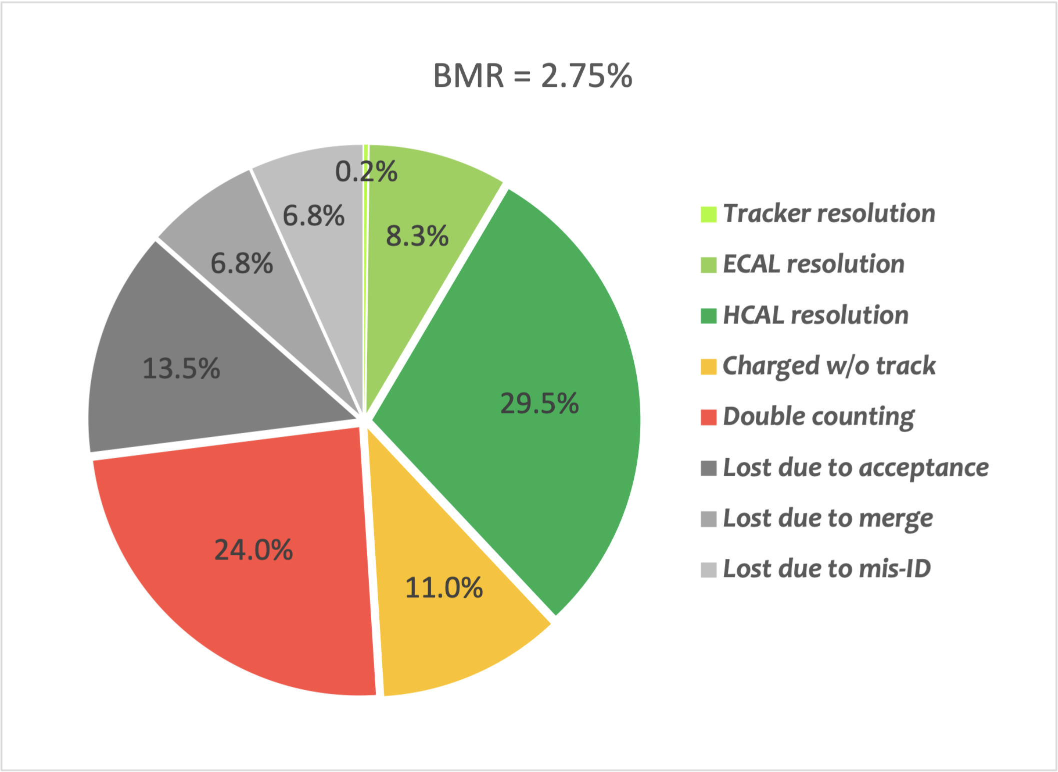
Yuexin Wang [a,b], Hao Liang [a,c,d], Yongfeng Zhu [e], Yuzhi Che [a,f], Xin Xia [a,c], Huilin Qu [g], Chen Zhou [e], Xuai Zhuang [a,c], Manqi Ruan [a,c,*]





BMR decomposition @ AURORA



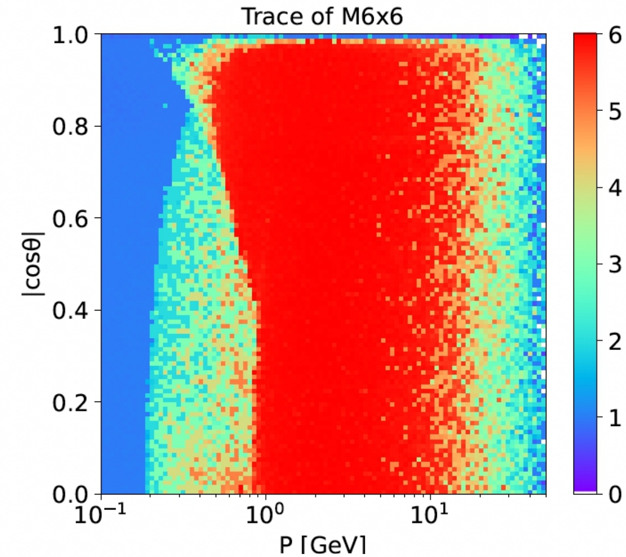


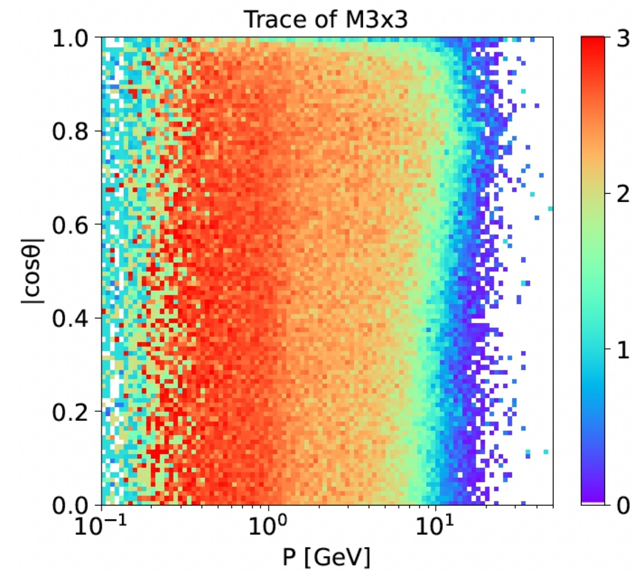
1-1 corresponding type: contributing to the BMR via resolution: ~o(0.1 – 0.001) of its mean value

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

Pid: differential performance

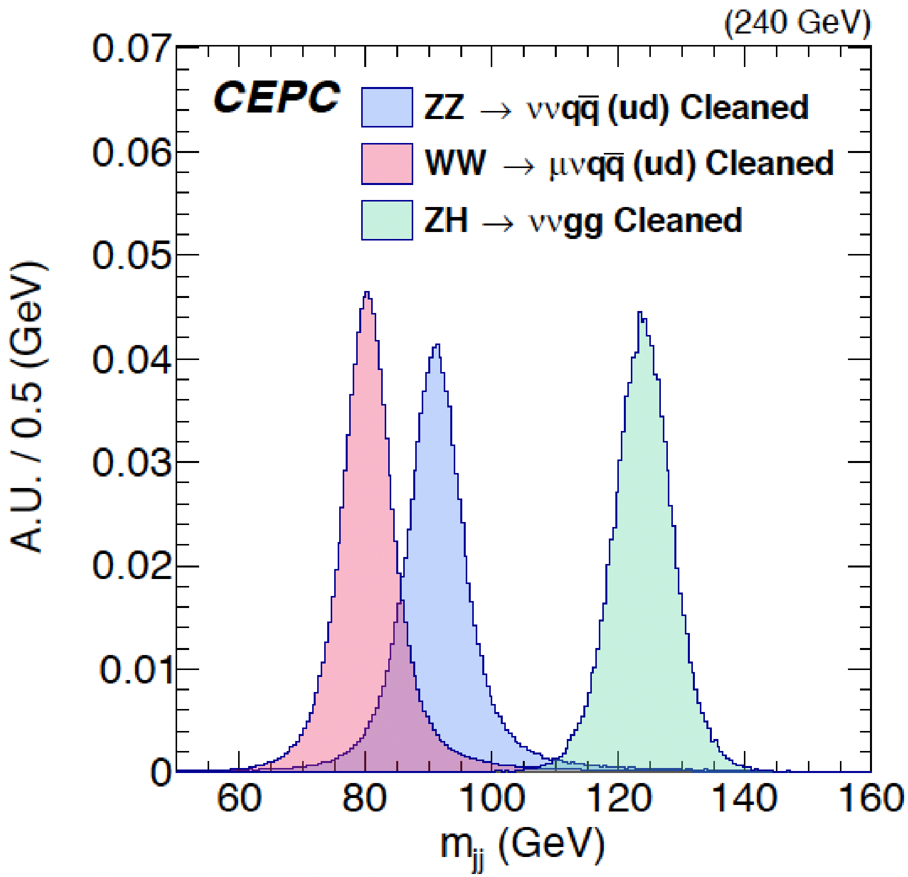
True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\mu^\pm$	0.000	0.985	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.000	0.019	0.977	0.003	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$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

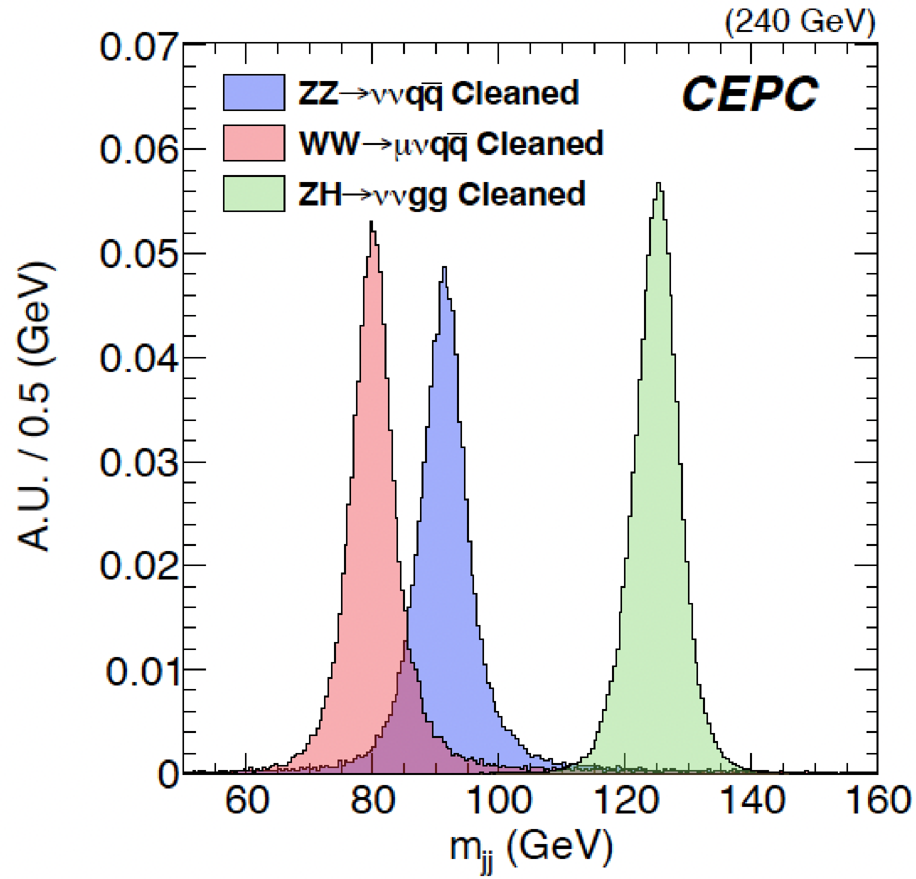




Neutral Hadron ID: 5d Calorimetry with ToF capability (δt~100 ps/hit)

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%

Necessary studies...

- Hadronization & impacts...
- Beam induced backgrounds & machine protection
- 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 Noise: rates, intrinsic, and radiation relevant ones
- Calibration Procedure & Monitoring methodologies...
- ...

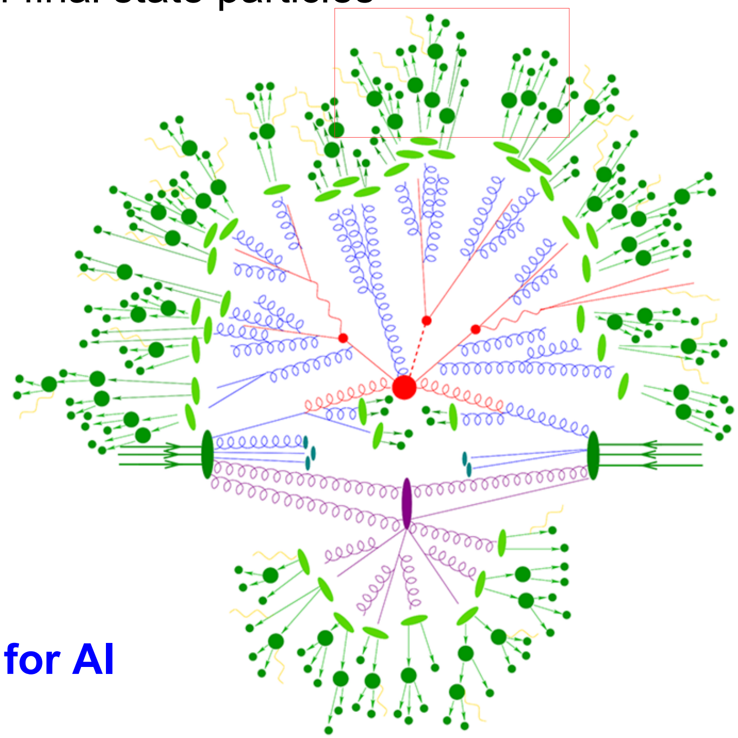
Targeted studies

- Usage of Timing
  - **Clustering with time**
  - **PFA of the Space Time**... such that not only reconstruct all final state particles, but correctly associate them with different VTX & sources...
    - Beam Induced Background is essential
    - To be addressed by Event building – Trigger + On/Off line
- ***Holistic approach with sufficient categories (Multi-heads identification)***
  - ~o(100) categories is sufficient... to identify almost all physics events at a Higgs factory
    - Higgs generation & decay modes
    - Major SM processes...
  - ~o(10) is probably sufficient for Z factory
  - Free of human intervene – in principle
  - ...

- ***Color singlet identification & iteration with QCD studies***

Targeted studies

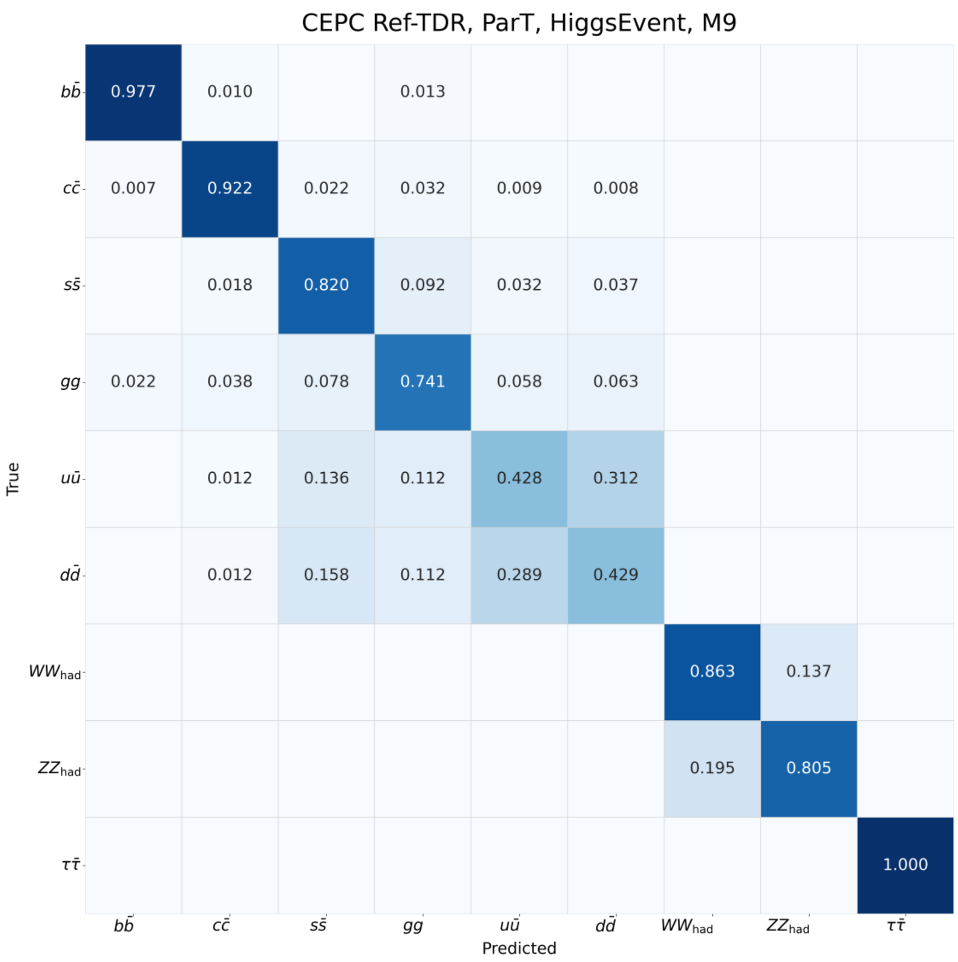
- **From leaves to the Tree:**
  - The hadronization process is ~ tree like
  - PFA & 1-1 corresponding committed to reconstruct well the leaves – the final state particles that actually interacts with detector/calorimeter
  - Possible to identify the entire tree: reco parenting info of final state particles
    - Pi-0,
    - K_short, Lambda, *EPJP (2020) 135:274*
    - Phi, *PRD 105, 114036 (2022)*
    - *B→D→K→pi0→gamma...*
    - ...
- **Further explorations**
  - Usage of AI in theoretical Interpretation
  - Hadronization modeling
  - **Performance benchmarks & Interpretability studies for AI**
  - ...



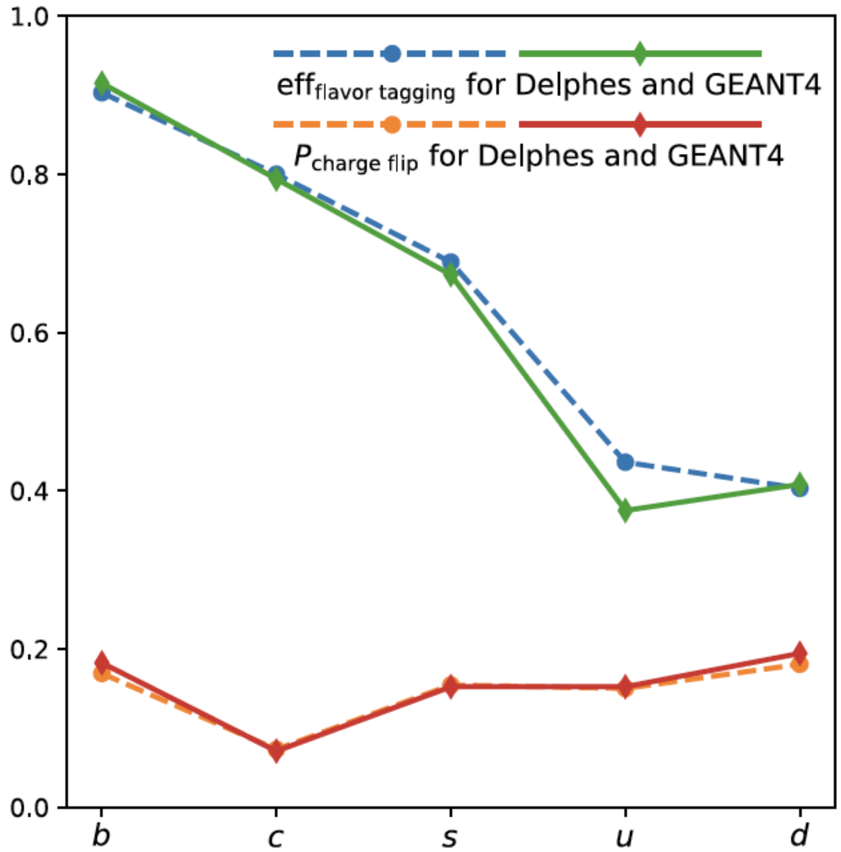
Summary

- ***... Higgs factory has strong discovery power to NP, its detector & reconstruction should and could have excellent performance...***
- ***AI could strongly enhance the discovery power of Higgs factory: 3 times & more...***
  - *Holistic approach*
    - *Reco: Jet origin id, 'see' the quark & gluons...*
    - *Analysis: Processing in principle free from Human intervene.*
      - *+ ACSI for full hadronic events*
  - *1-1 correspondence reconstruction: excellent PID + BMR of 2.7%*
    - *5-d calo is the key*
- ***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.*
  - *...*

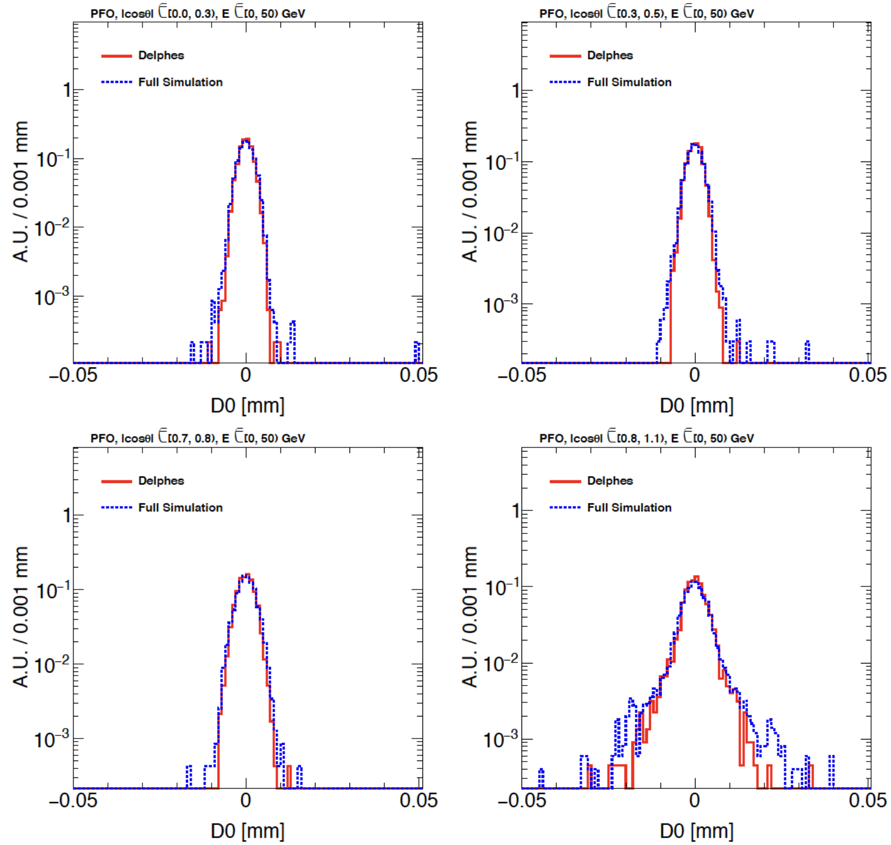
Back up


CEPC Ref-TDR, ParT, HiggsEvent, M9
True
Predicted
$b\bar{b}$
$c\bar{c}$
$s\bar{s}$
gg
$u\bar{u}$
$d\bar{d}$
WW_{had}
ZZ_{had}
$\tau\bar{\tau}$
0.977 0.010 0.013
0.007 0.922 0.022 0.032 0.009 0.008
0.018 0.820 0.092 0.032 0.037
0.022 0.038 0.078 0.741 0.058 0.063
0.012 0.136 0.112 0.428 0.312
0.012 0.158 0.112 0.289 0.429
0.863 0.137
0.195 0.805
1.000

Fast/Full Simulation



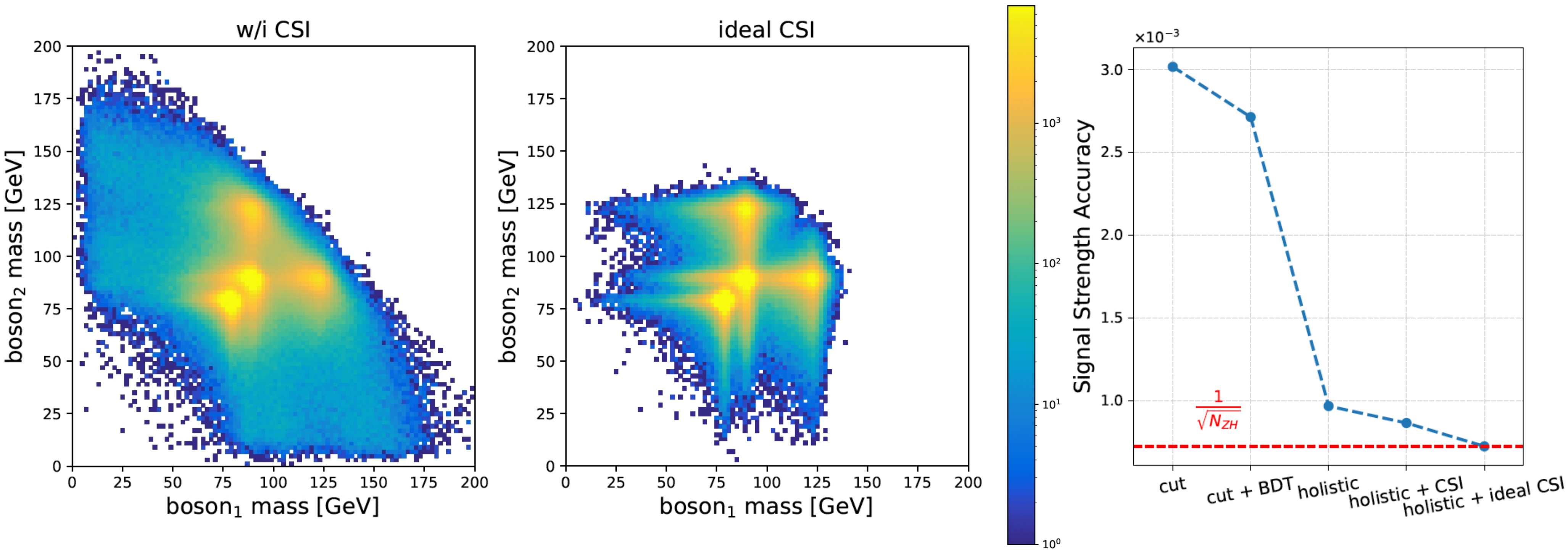
Z->μμ (91.2 GeV)



- Delphes ~ Perfect PFA (1 – 1 correspondence..)

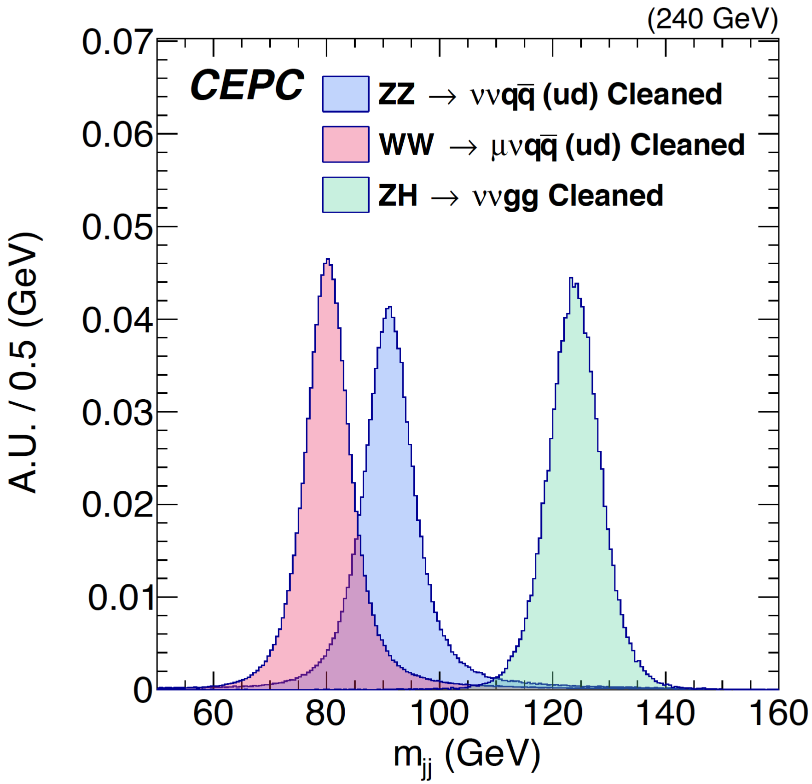
A toy analysis: identify full hadronic ZH signal from ZZ + WW background

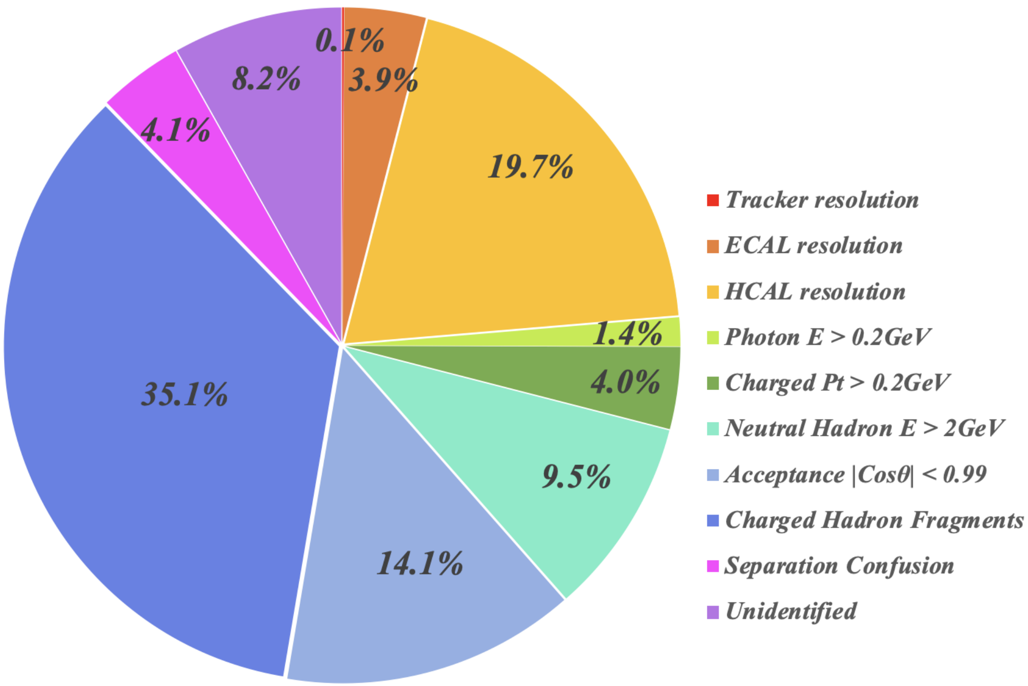
540k ZH + 3.1M ZZ + 47 M WW full hadronic events (~ 5.6 iab), result scale to 20 iab



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

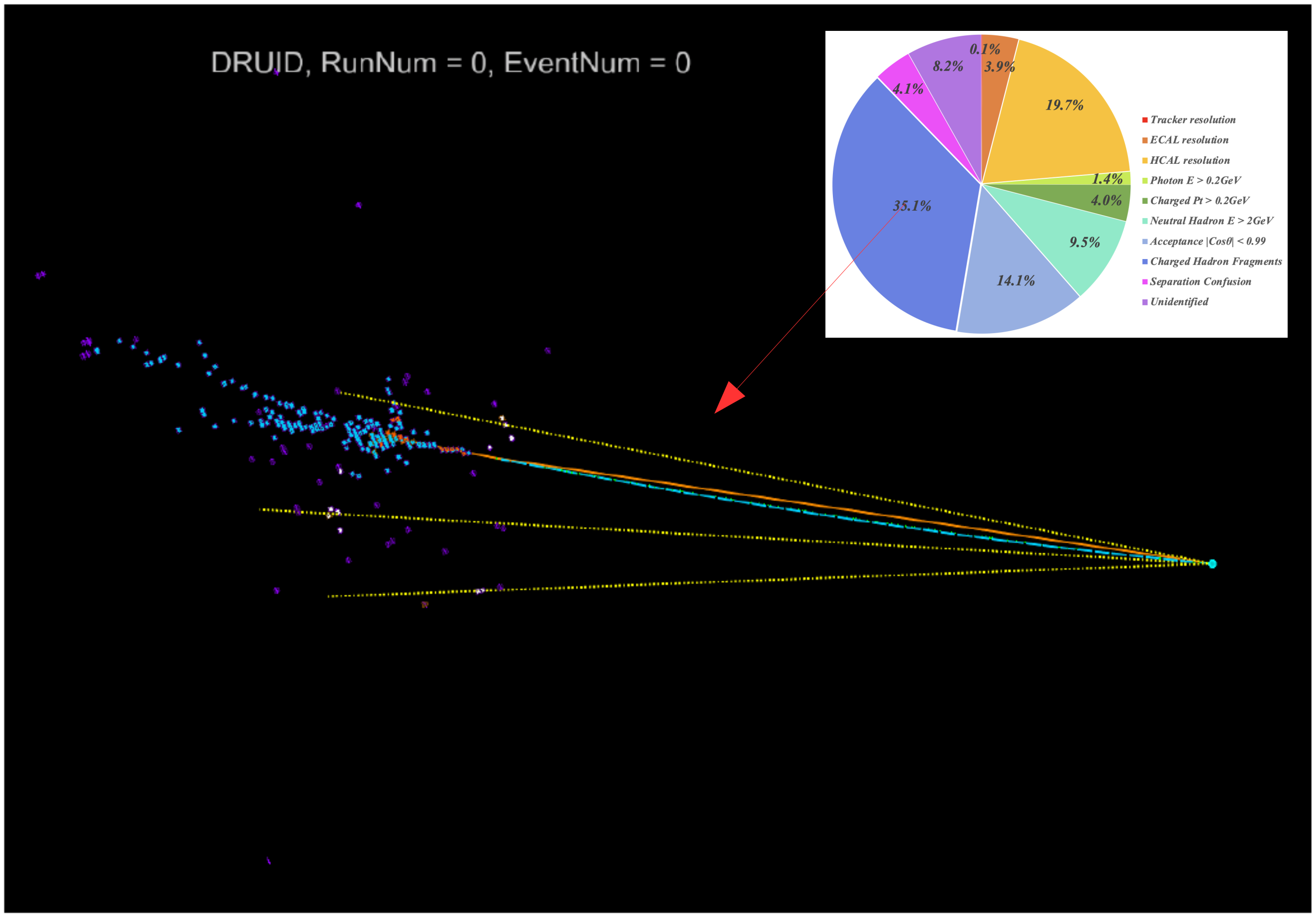
Boson Mass Resolution

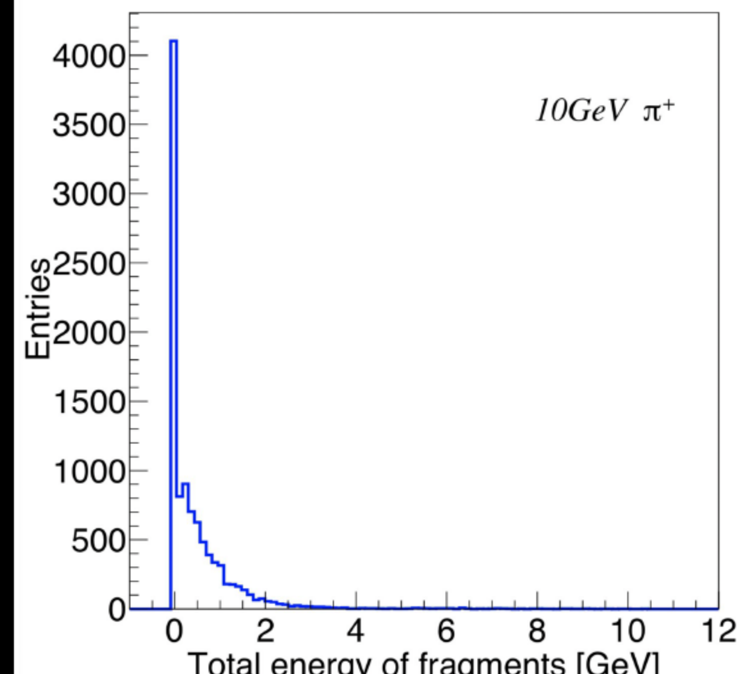




- *Higgs factory: need BMR < 4% (for qqH & qqZ separation using di-jet recoil mass), which CDR/TDR reached this goal*
- *1st HCAL resolution dominant the uncertainties from intrinsic detector resolution: need better HCAL → R & D of GSHCAL*
- *2nd Leading contribution: Confusion from fake particles, need better Pattern Reco.*

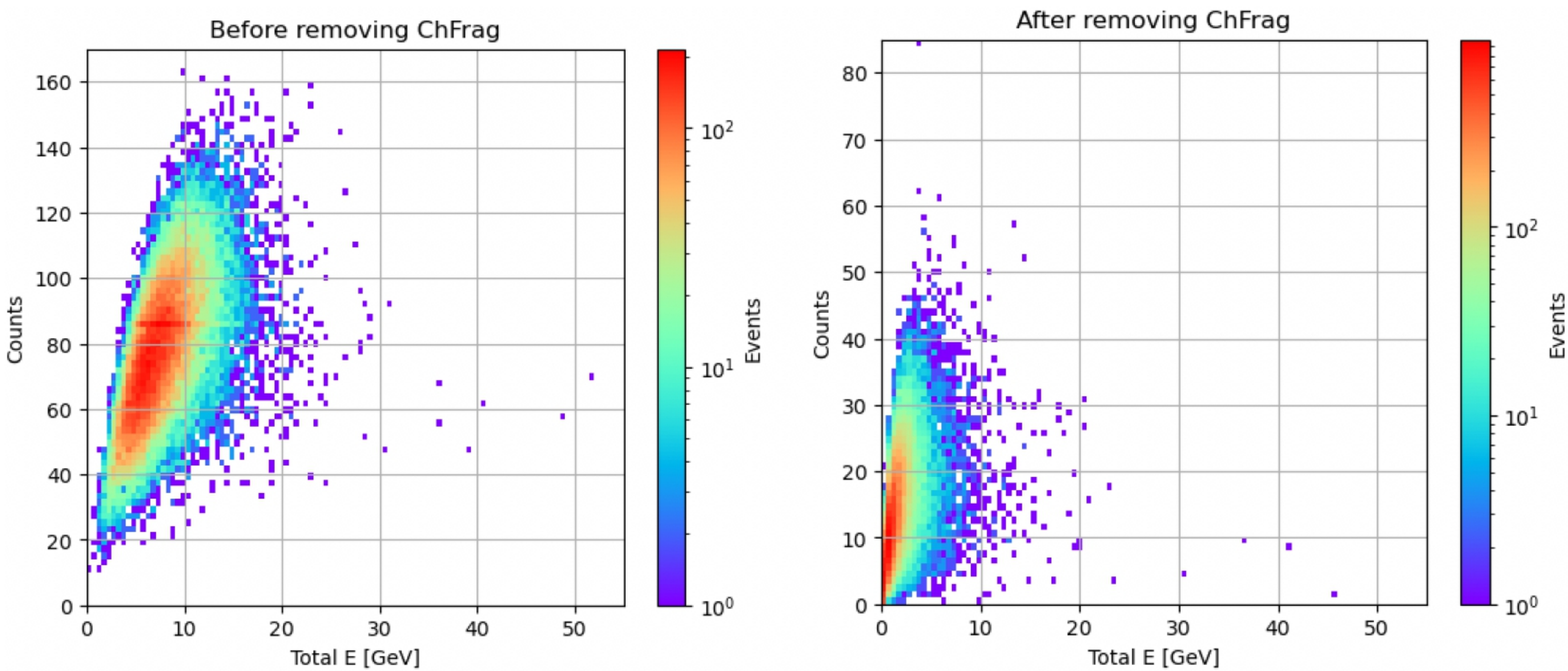
Cluster splitting: the most severe confusions





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

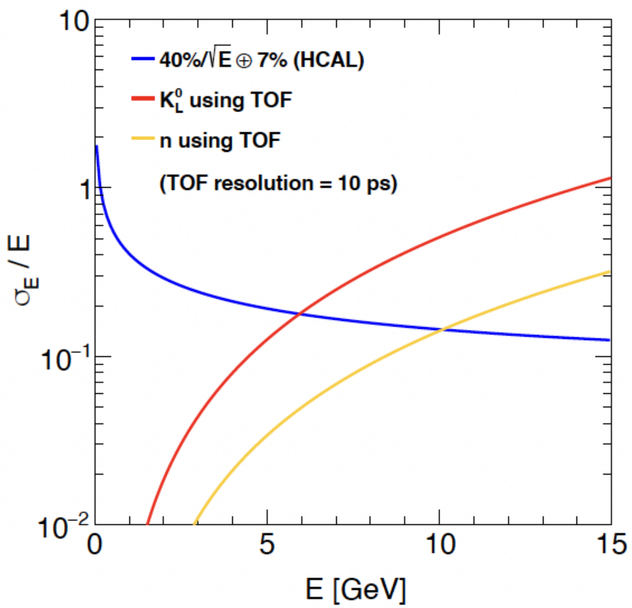


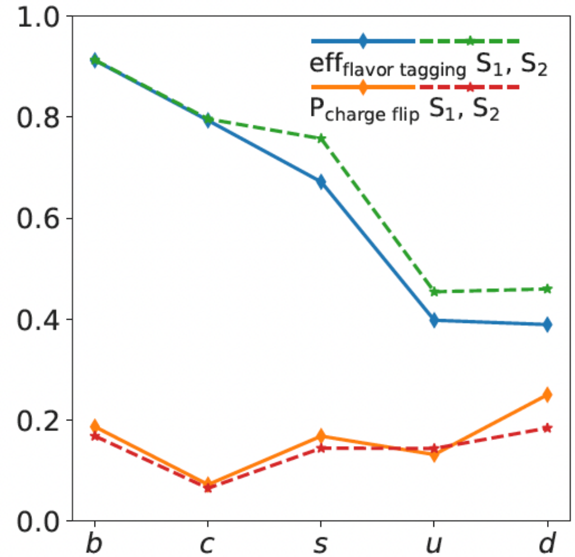
Fake particle originated Confusion reduced by 1 order of magnitude, at nominal vvH, H→gg event, at the cost of create mis-vetoed energy of < 1 GeV.

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

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**

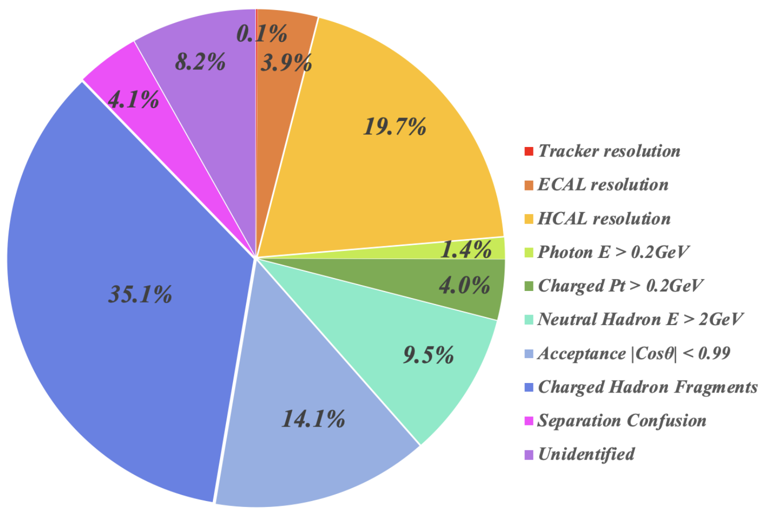




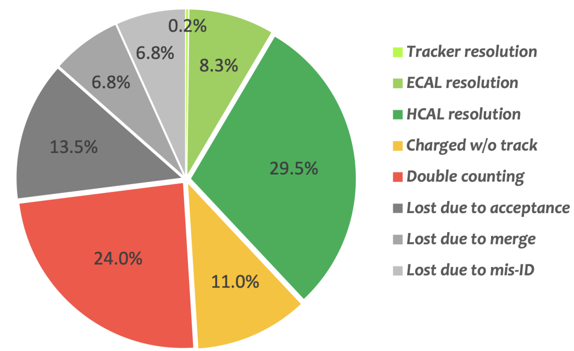
- 5d calo is critical: ToF for all visible particle, thus Pid...
  - Assume Low energy neutrons & secondary particles can be tamed... still challenge...

BMR evolution...

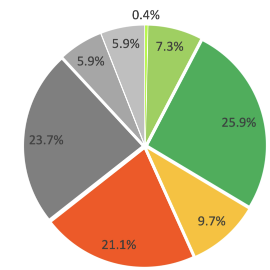
2016 - CDR: BMR ~ 4%

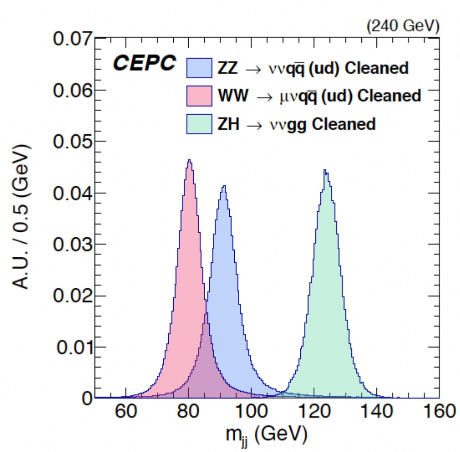


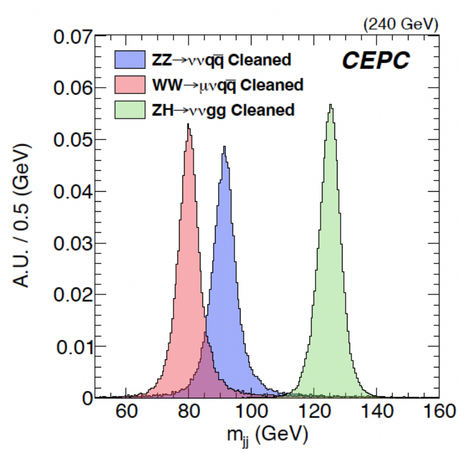
2024 - AURORA: BMR ~ 2.7%

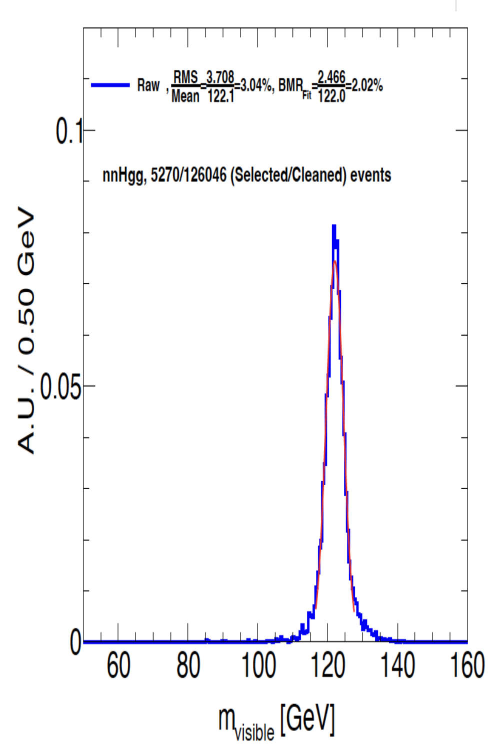


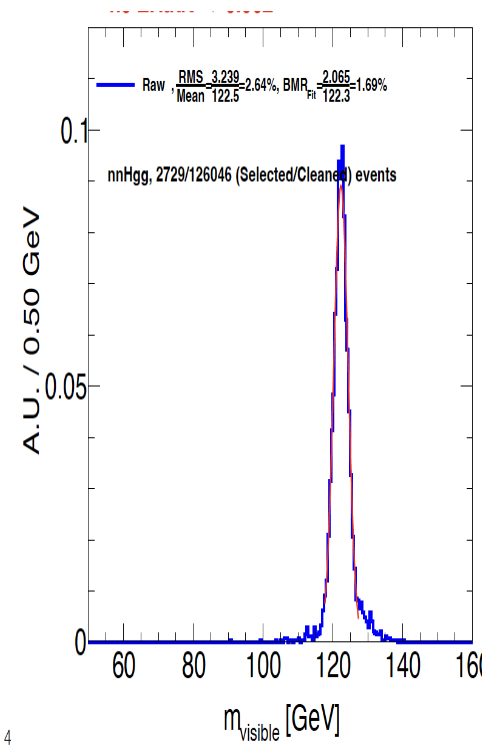
Future: BMR ~ 2.0%



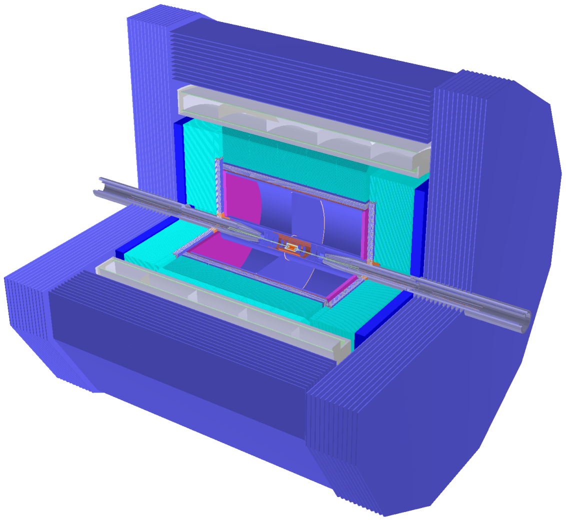




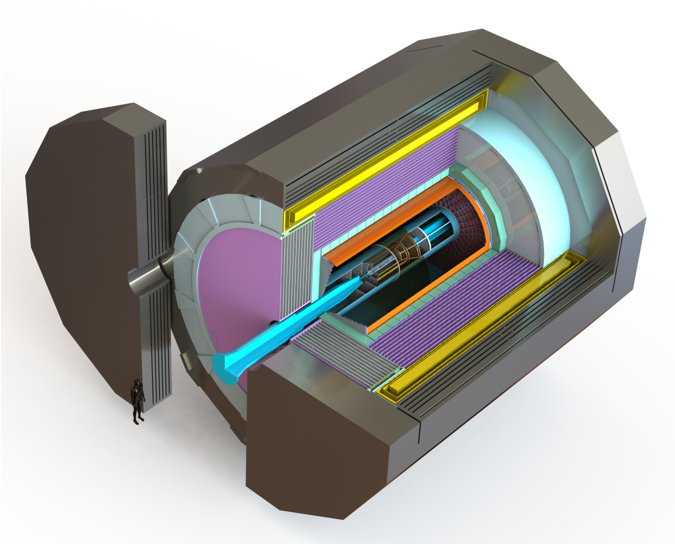




PFA: excellent or good enough...



- **So what**
  - Holistic Approach
    - Jet Origin ID (Fast/Full Sim)
    - Higgs analyses (Fast)
  - Color Singlet identification (Fast)

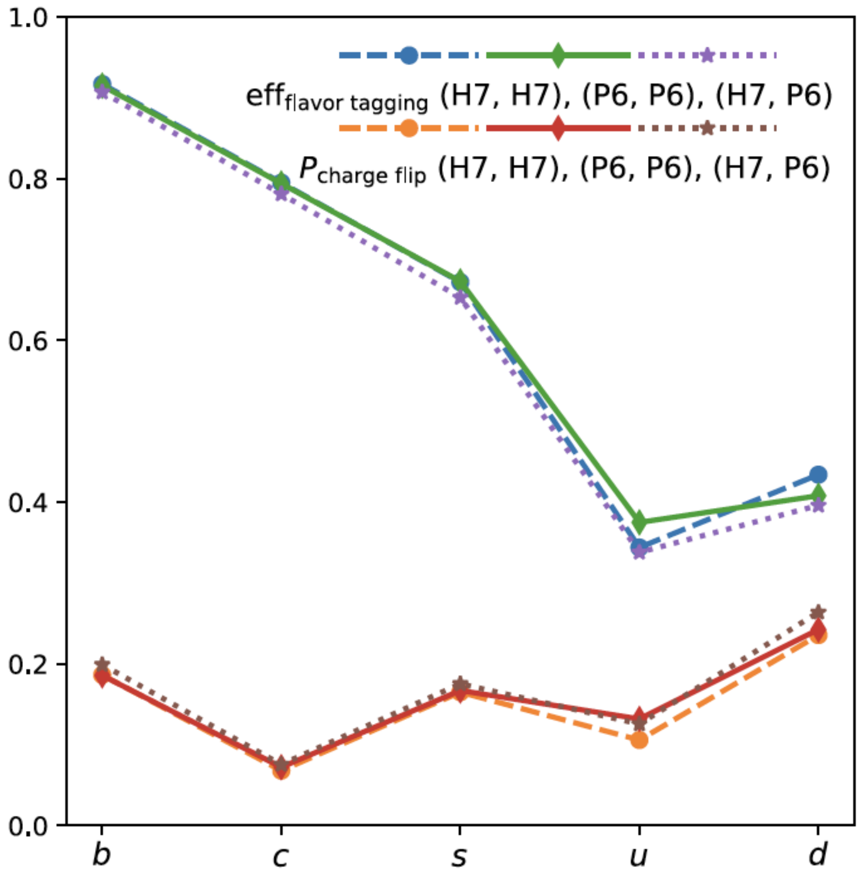


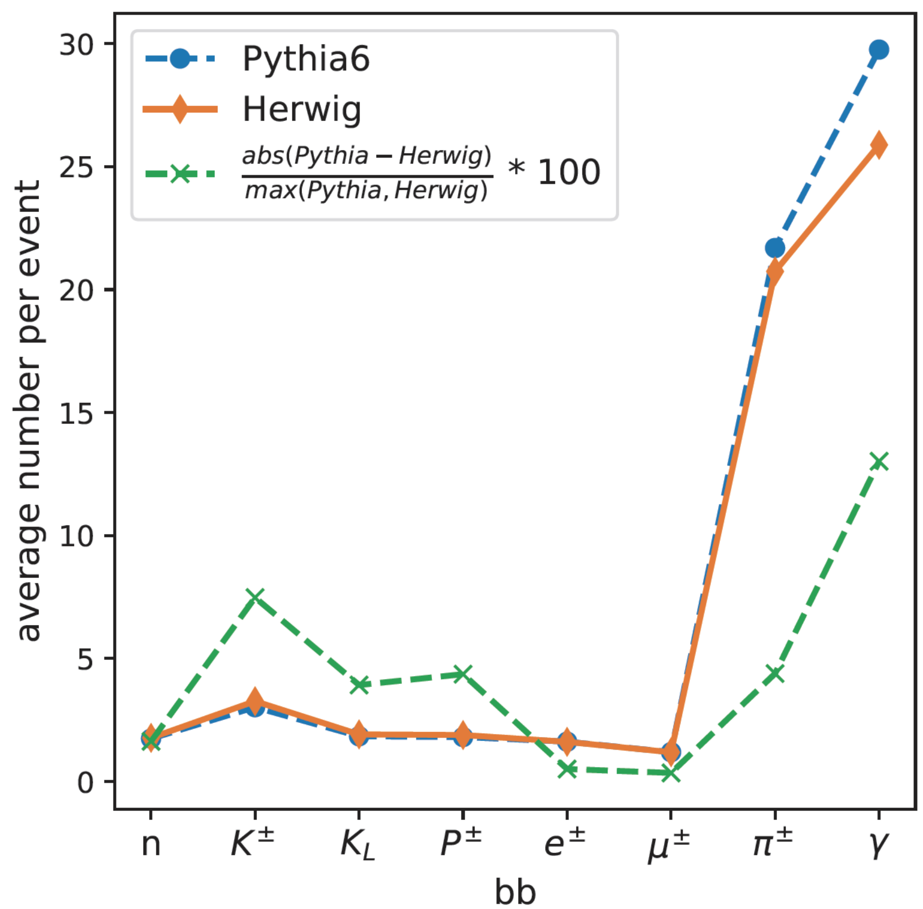
- **How**
  - to quantify the performance?
    - 1-1 correspondence
  - to reach?
    - Example: Arbor + AI @ Aurora (Full Sim)
- Discussion: Requests, Wish list...

Excellent ~ ultimate performance

Good enough ~ for certain purpose, not be the leading limitation...

V.S. Hadronization models

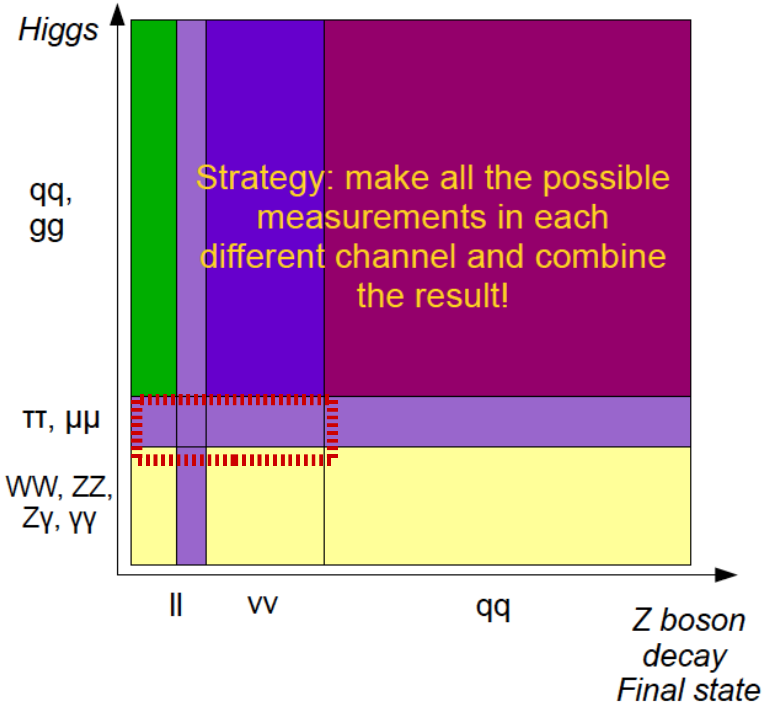


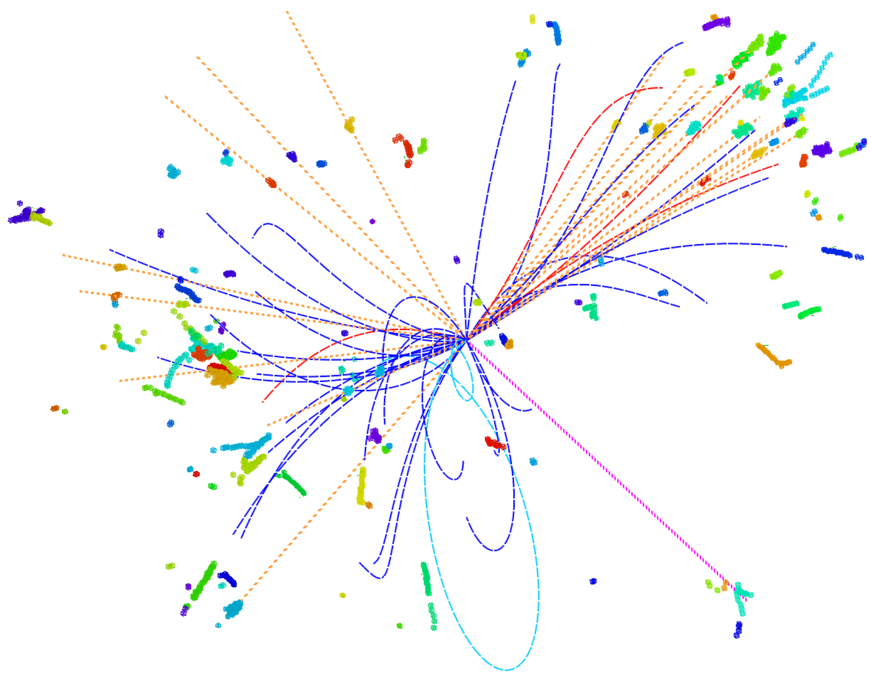


- Much severer descriptions.. in exclusive measurements (i.e., specific hadron generation, decay, etc)

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!

GSHCAL: simulation

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Full Length Article

GSHCAL at future e^+e^- Higgs factories

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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.

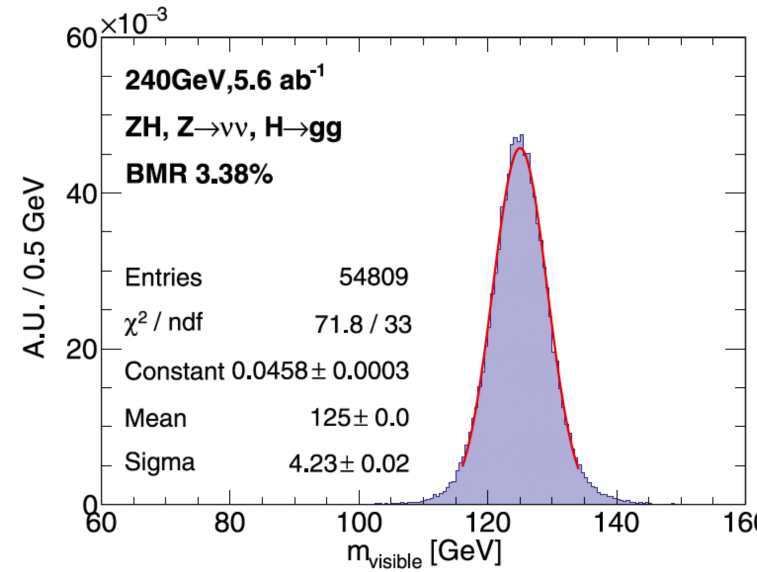
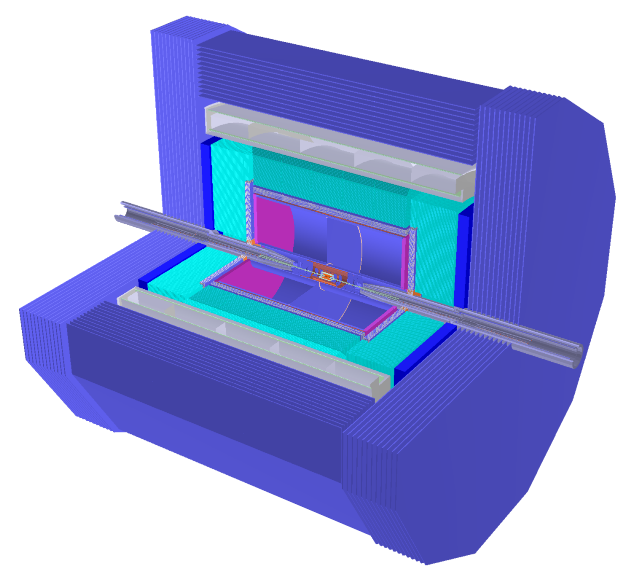


Fig. 5. Distribution of the reconstructed total visible invariant mass for $\nu\bar{\nu}H \rightarrow \nu\bar{\nu}gg$ channel. The distribution is fitted with a Gaussian function extented to ±2 standard deviations.

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

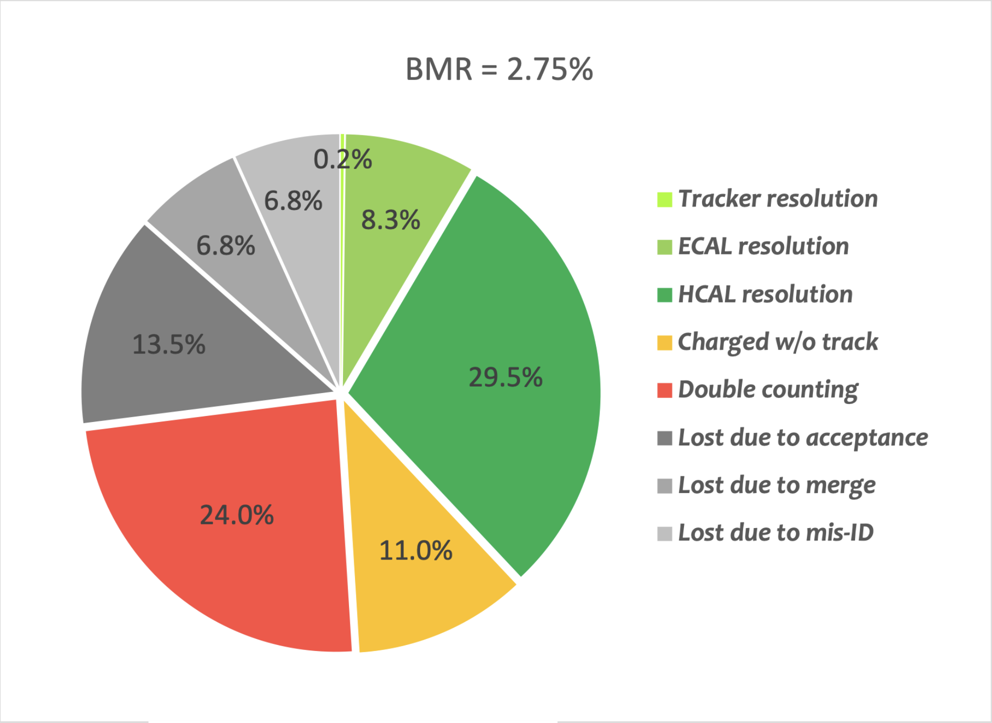
Table A.1
AURORA detector geometry parameters.

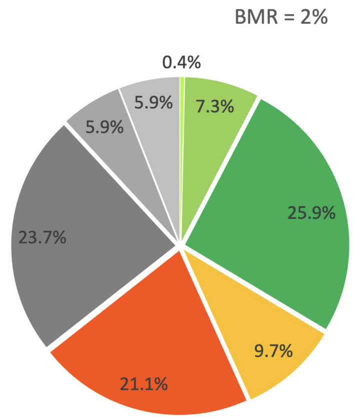
Sub-detector	Thickness (mm)	Inner radius (mm)	Outer radius (mm)	Length (mm)	Volume (m^3)	Transverse cell size	#Layers	#Channels
Vertex	-	-	16–60	125–250	-	25 × 25 μm^2	6	5.3×10^8
			155	736				
Si-strip	-	-	300	1288	-	20 μm × 2 cm	3	3.0×10^7
Tracker			1810	4600				
TPC	-	300	1800	4700	47	1 × 6 mm^2	220	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	-	-	-



BMR: perspectives

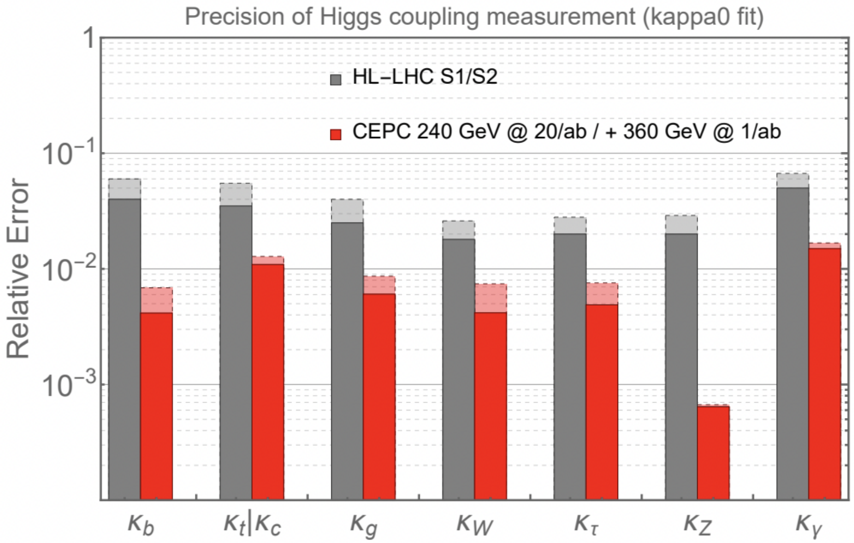
- Resolutions: assume - improved by 50%
  - Crystal ECAL: With efficient control of confusion
  - Detector optimization + Innovative Estimator (Energy, Time, Spatial...) with 5d calorimeter (ToF) & AI: ToF could determine very precisely the energy of low-E hadron – Giving its type identified...
- Charged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

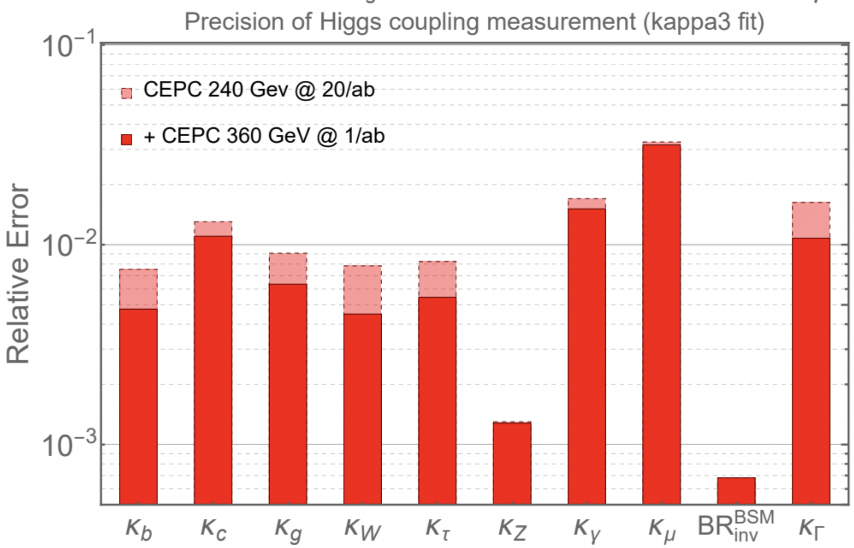




Higgs

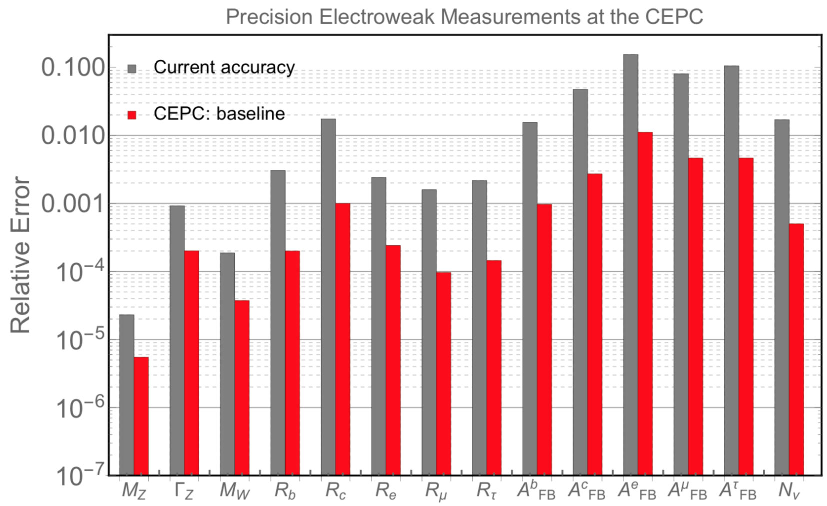
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	ZH	**vvH**	**eeH**
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**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

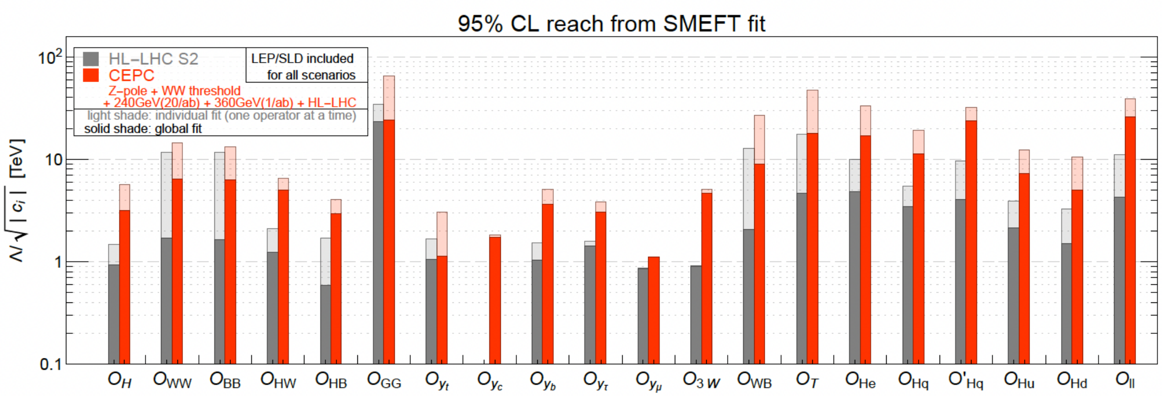


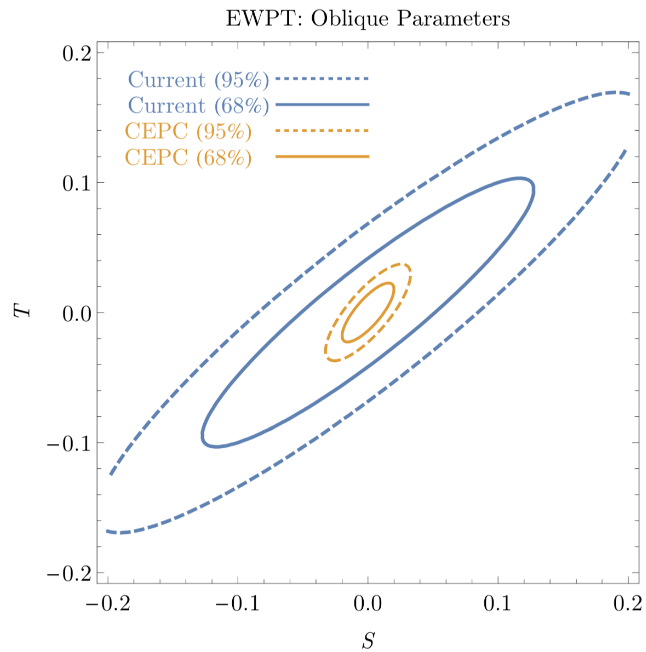


Plus EW & SMEFT

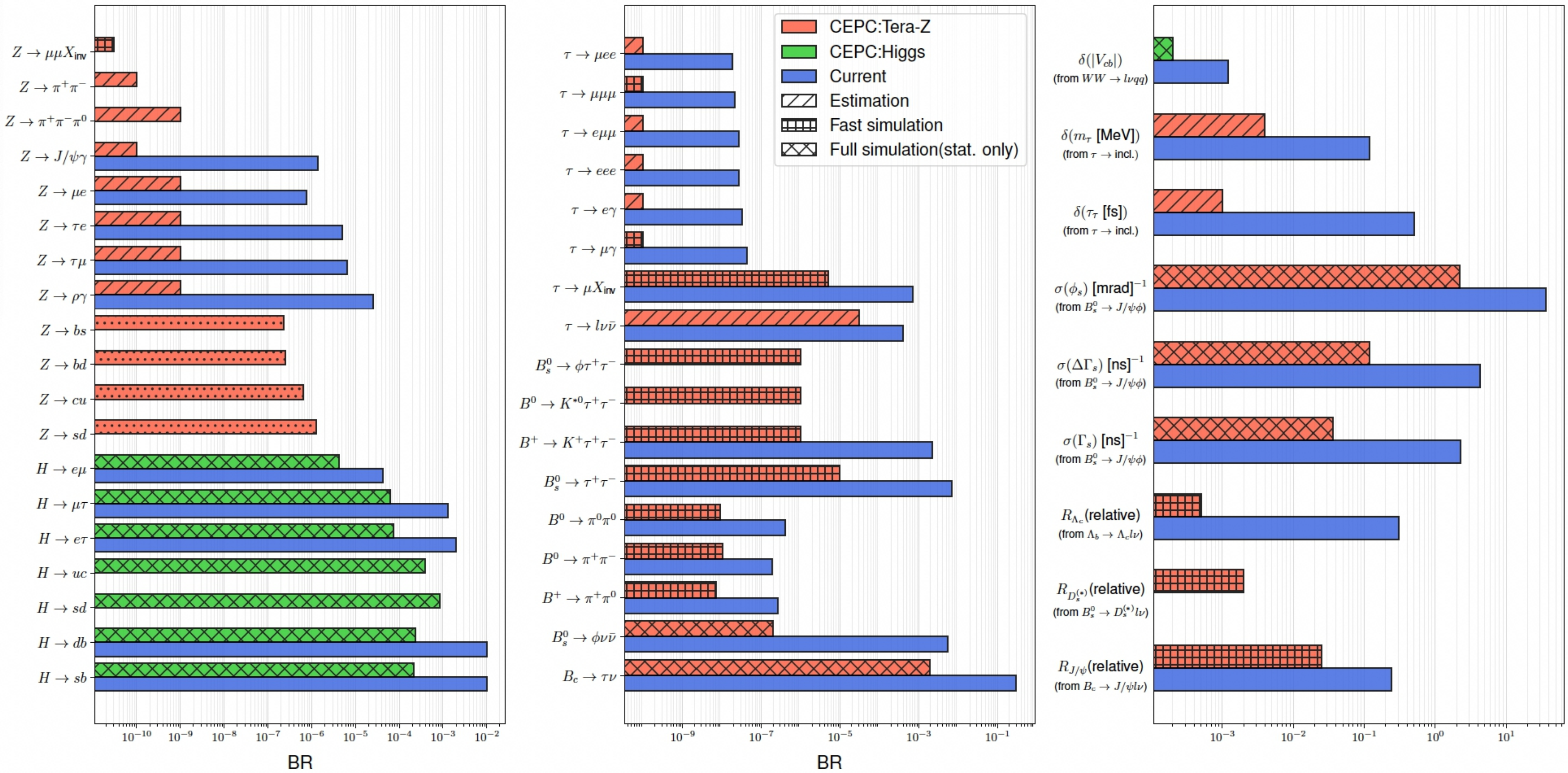
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49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



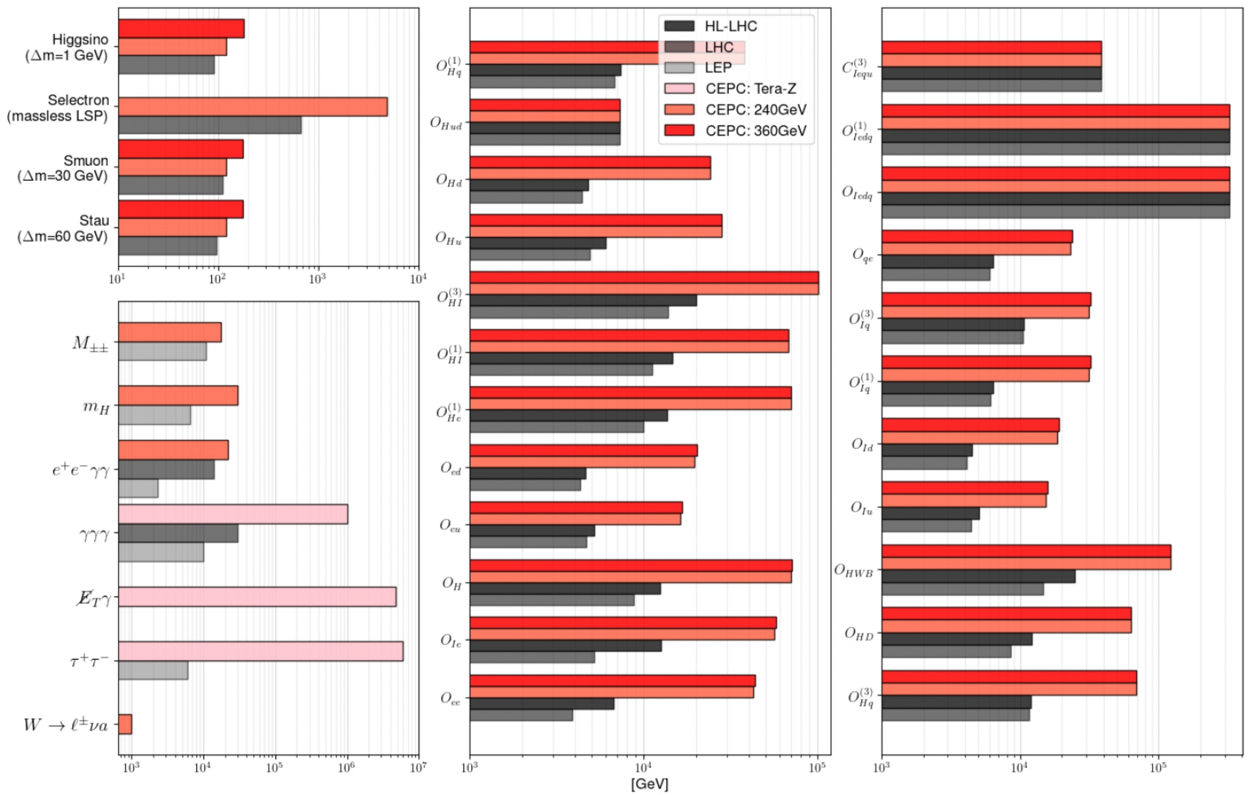
See the non-seen: i.e, Bc→tauv, Bs→Phivv

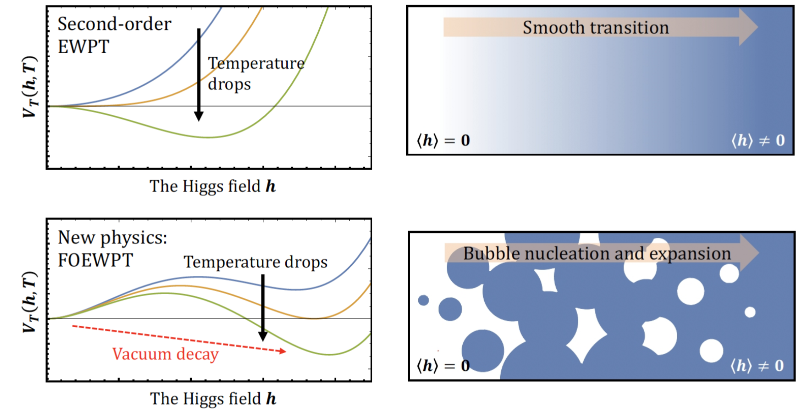
Orders of magnitudes improvements (1 – 2.5 orders...).

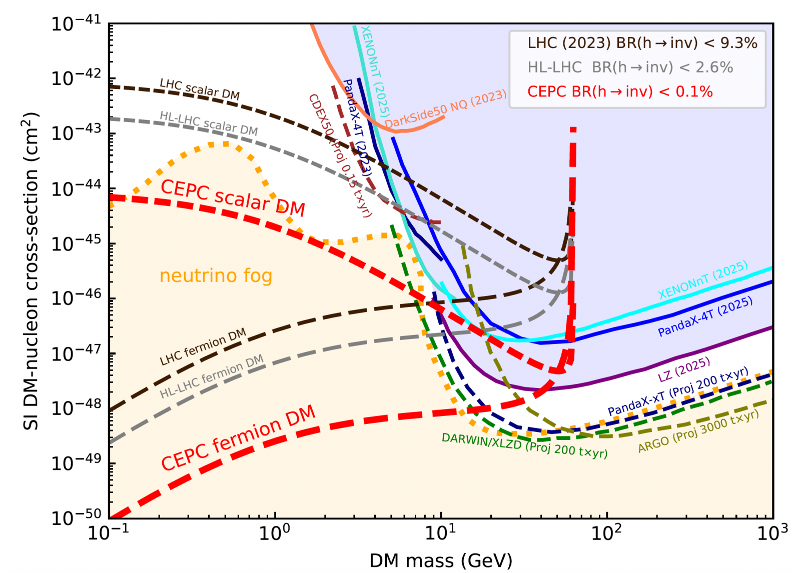
Access New Physics with energy scale of 10 TeV, or even above

https://arxiv.org/pdf/2412.19743

Direct New physics search



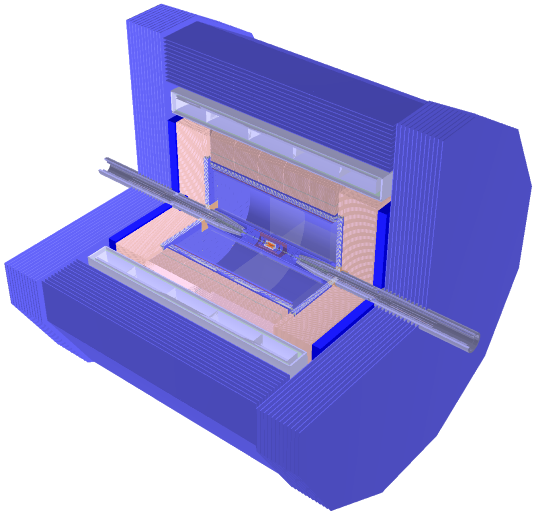


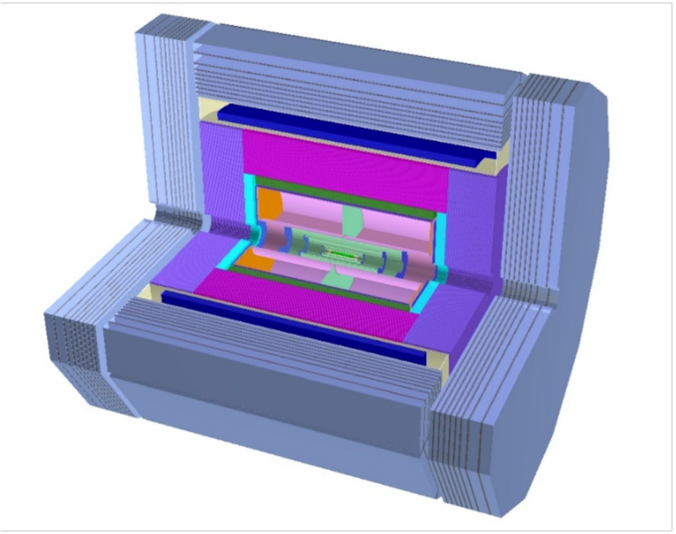


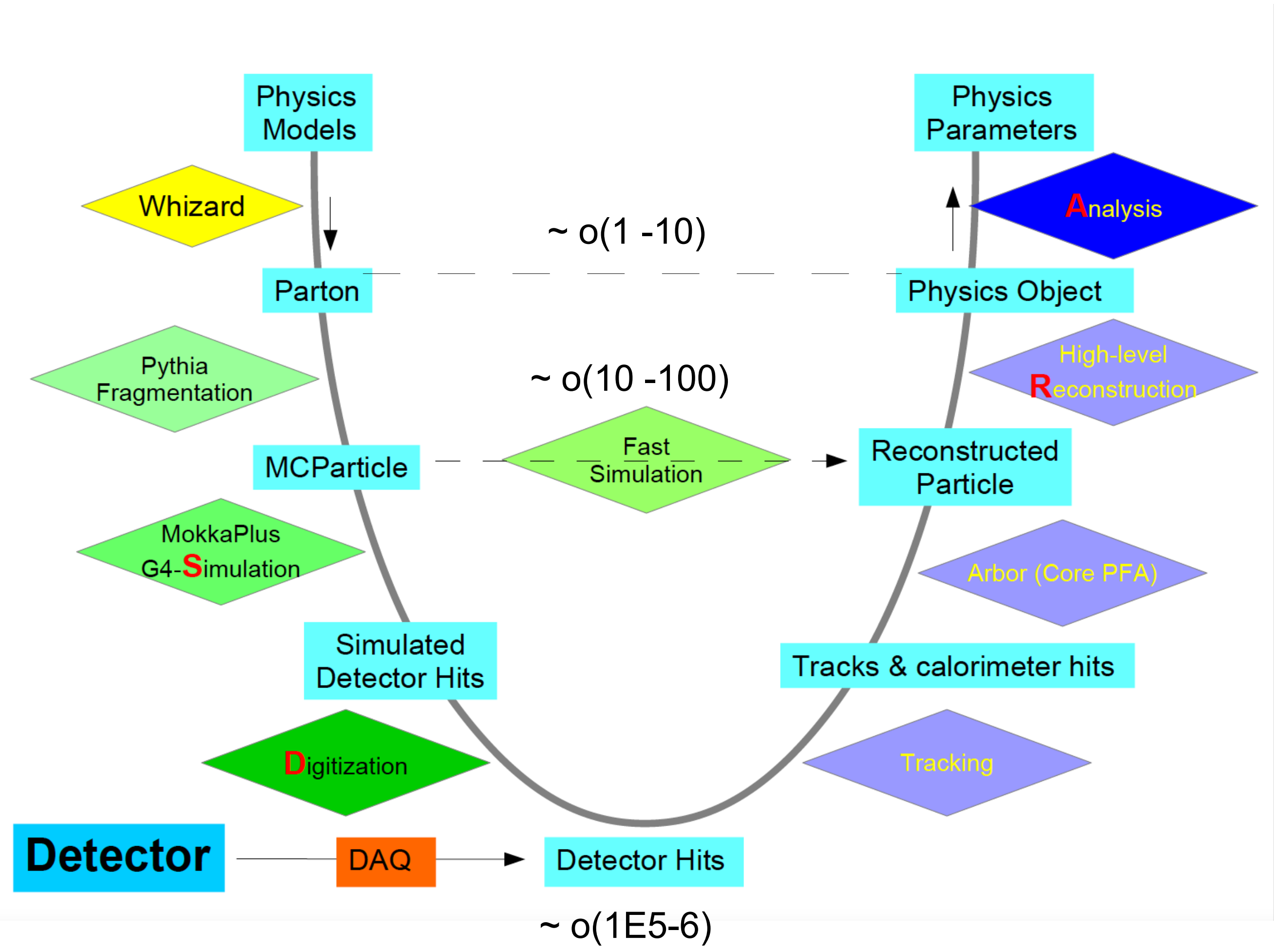
Matter Origin, Dark matter...
Access to NP ~ 100 TeV...

https://arxiv.org/pdf/2505.24810

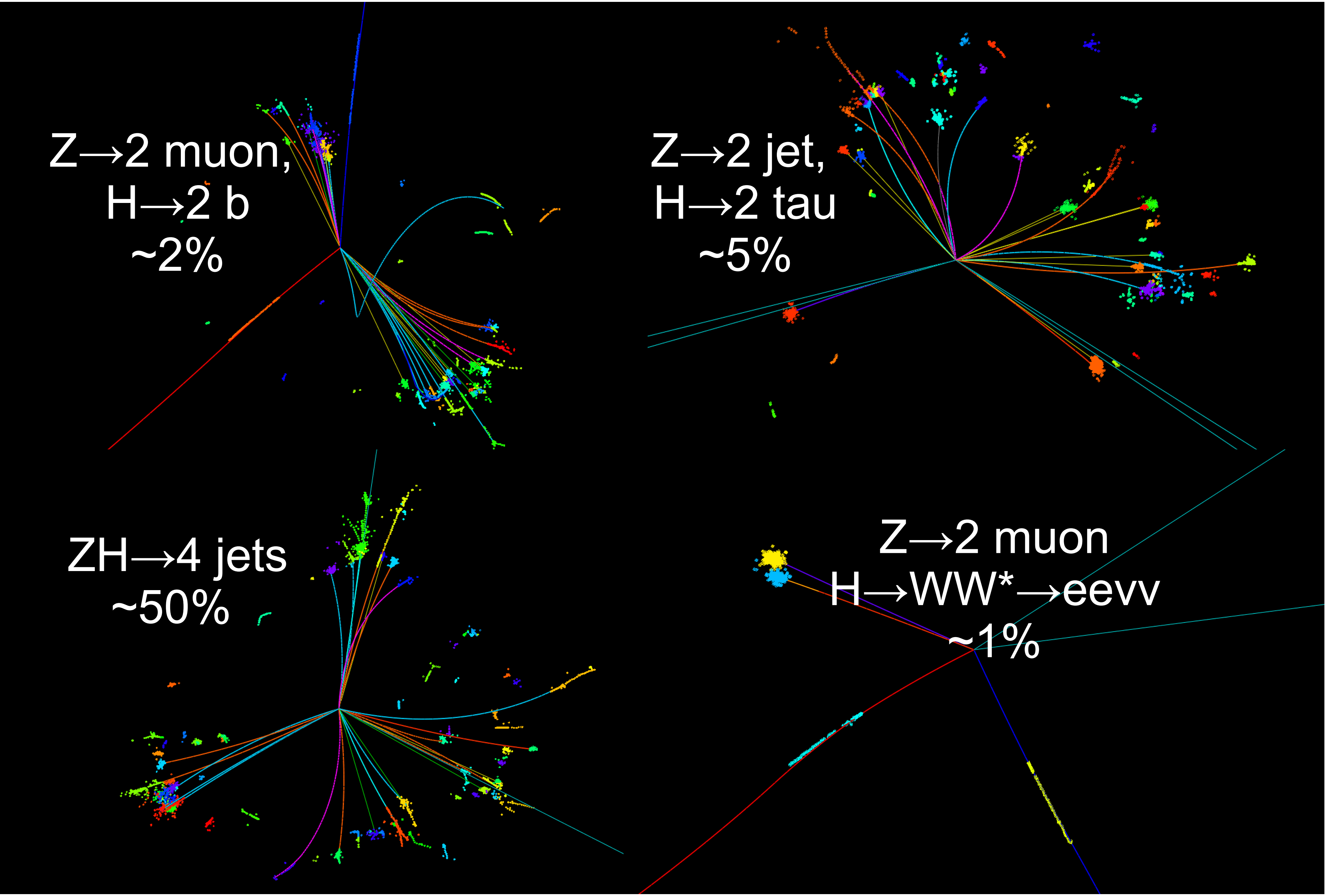
CEPC Detector & Reconstruction







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%