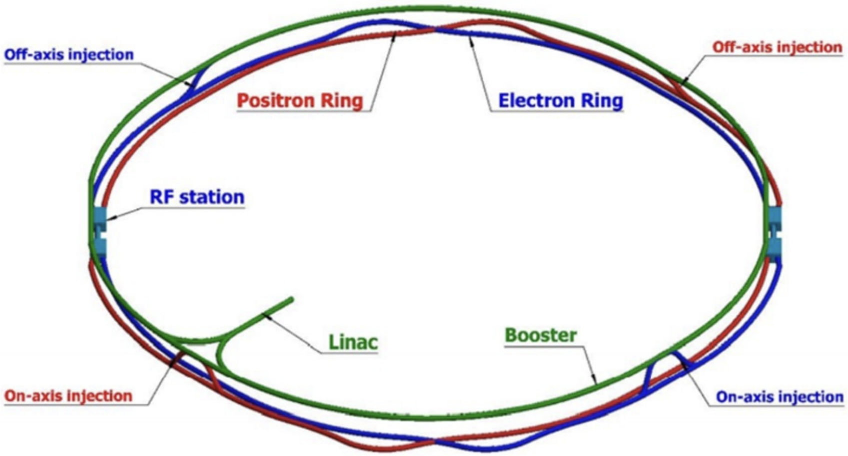
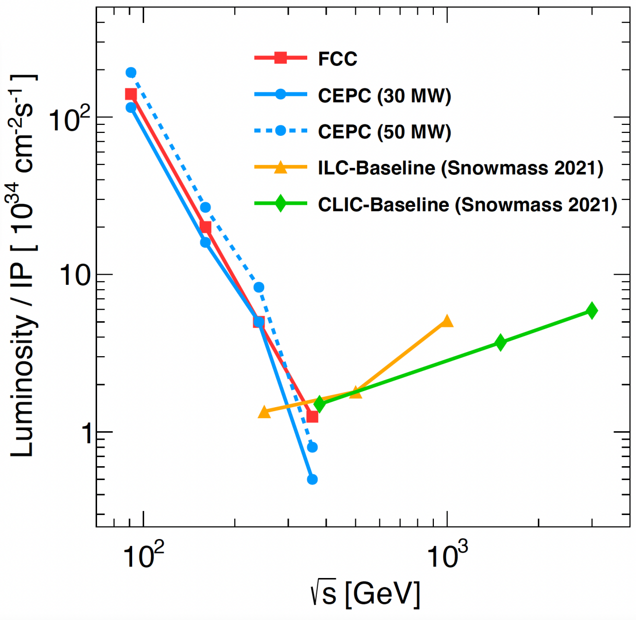
Trilogy of event reconstruction at electron positron Higgs factory

Manqi

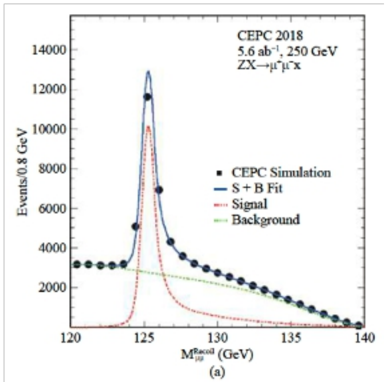
Outline

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

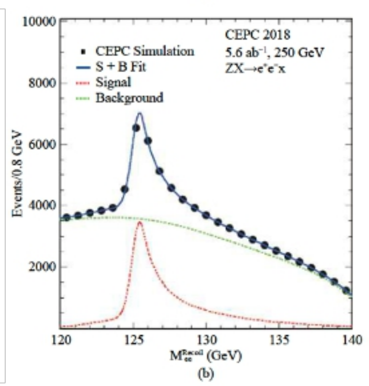




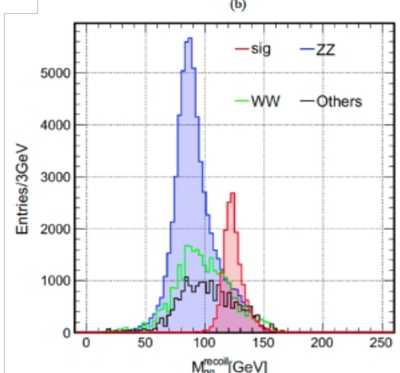
CEPC Physics: 4 Million Higgs + 4 Tera Z...



(a)



(b)

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Precision Higgs physics at the CEPC*

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

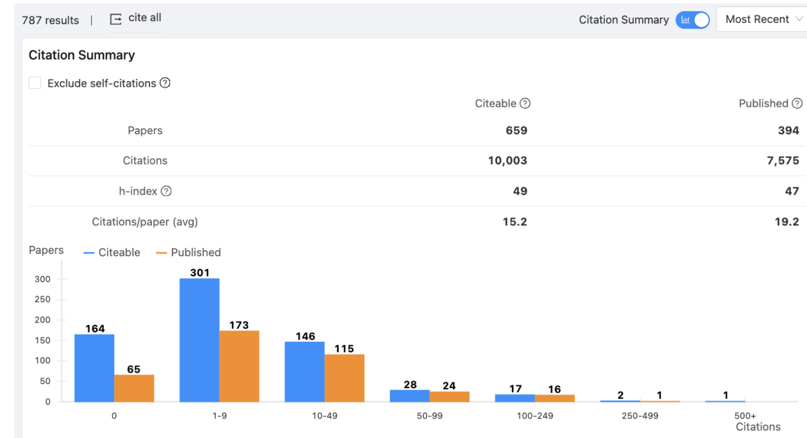


Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

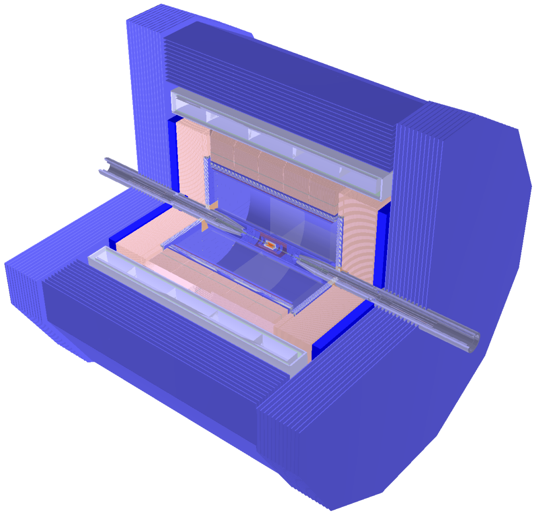
Higgs			*W, Z* and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M_{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H\to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H\to cc)$	-	2.0%	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}
$Bupper(H\to inv.)$	2.5%	0.07%	N_ν	2.5×10^{-3}	2×10^{-4}

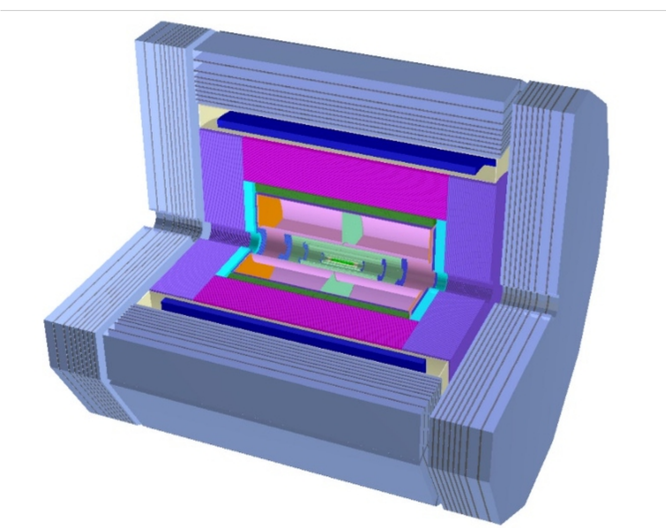
Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

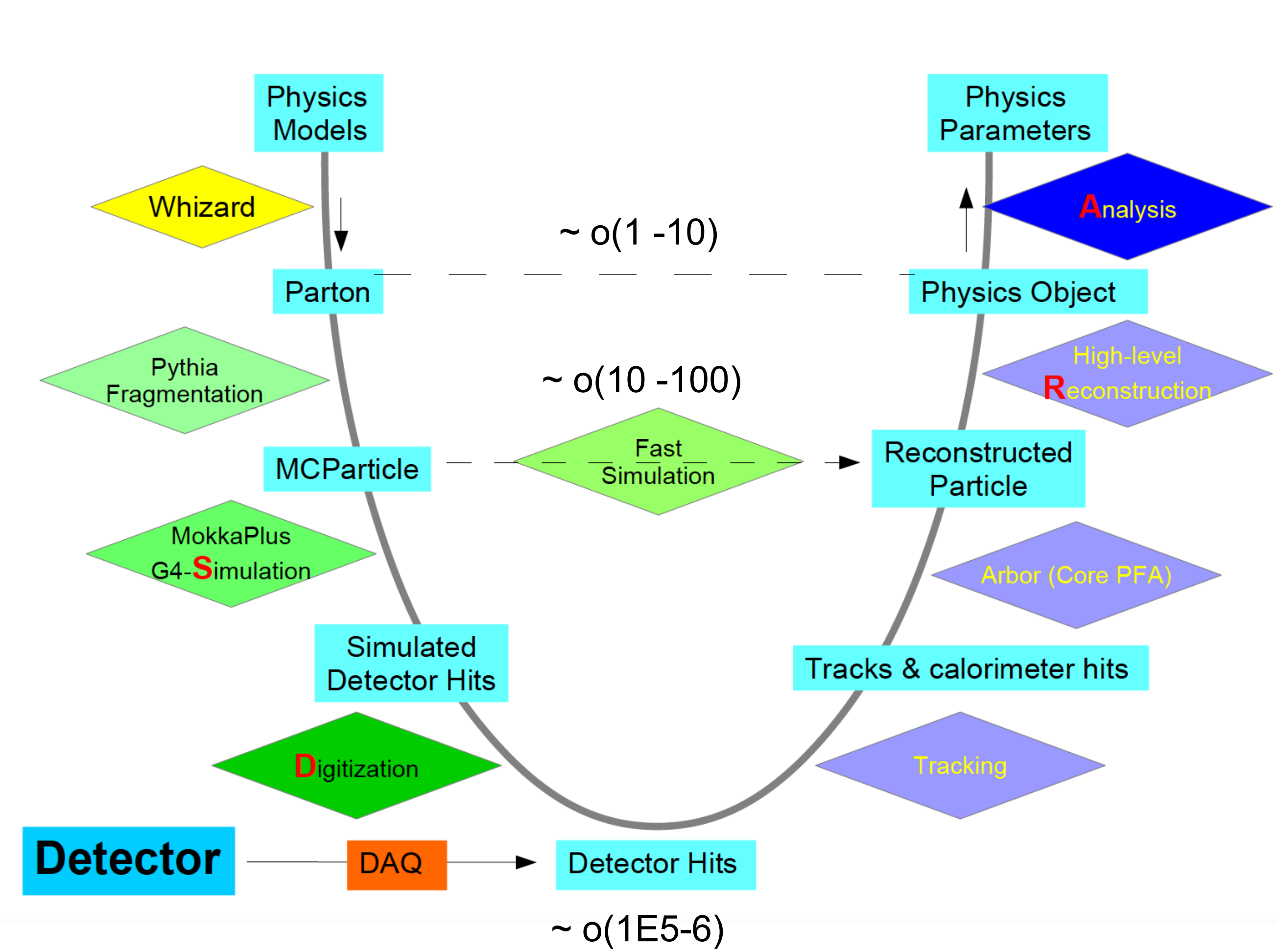
- Higgs: Precisions exceed HL-LHC ~ 1 order of magnitude.
- EW: Precision improved from current limit by 1-2 orders.
- Flavor Physics, sensitive to NP of 10 TeV or even higher.
- Sensitive to varies of NP signal.
- …

White papers +
~300 Journal/AxXiv citables

CEPC Detector & Reconstruction



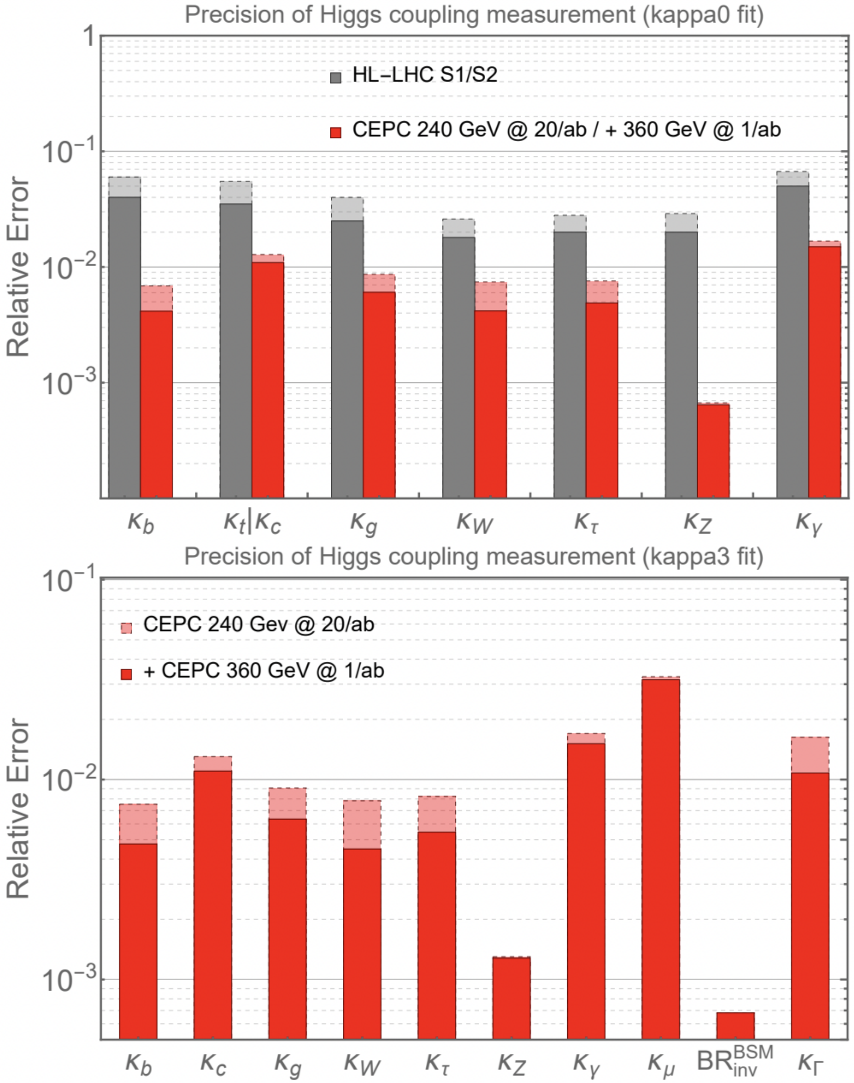




Full simulation reconstruction Chain with **Arbor, etc**

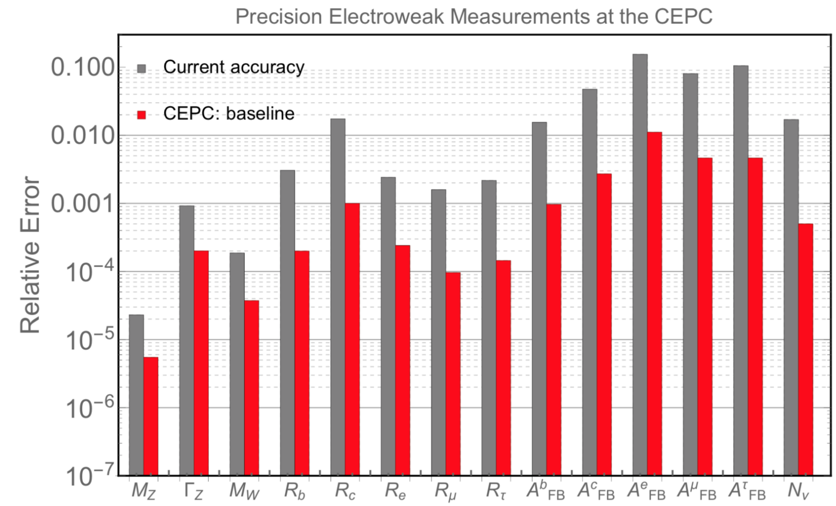
Higgs & Snowmass White Paper

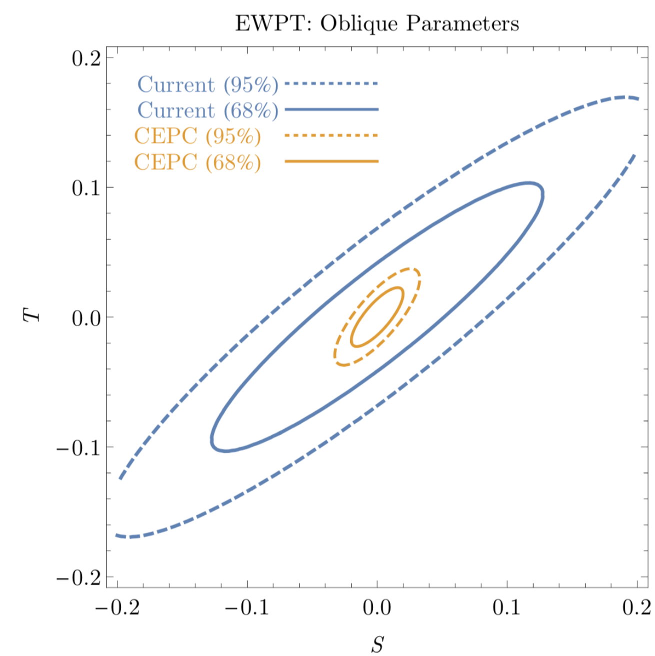
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	ZH	**vvH**	**eeH**
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**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

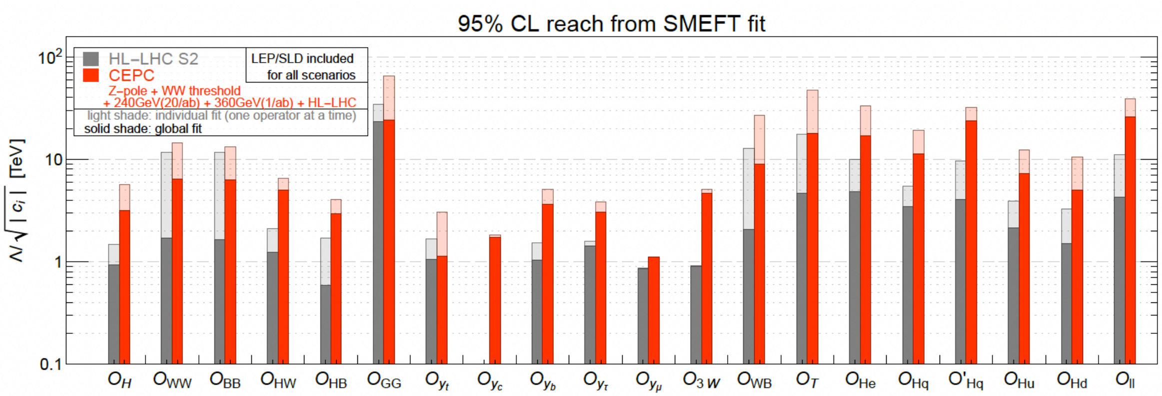


EW measurements & SMEFT

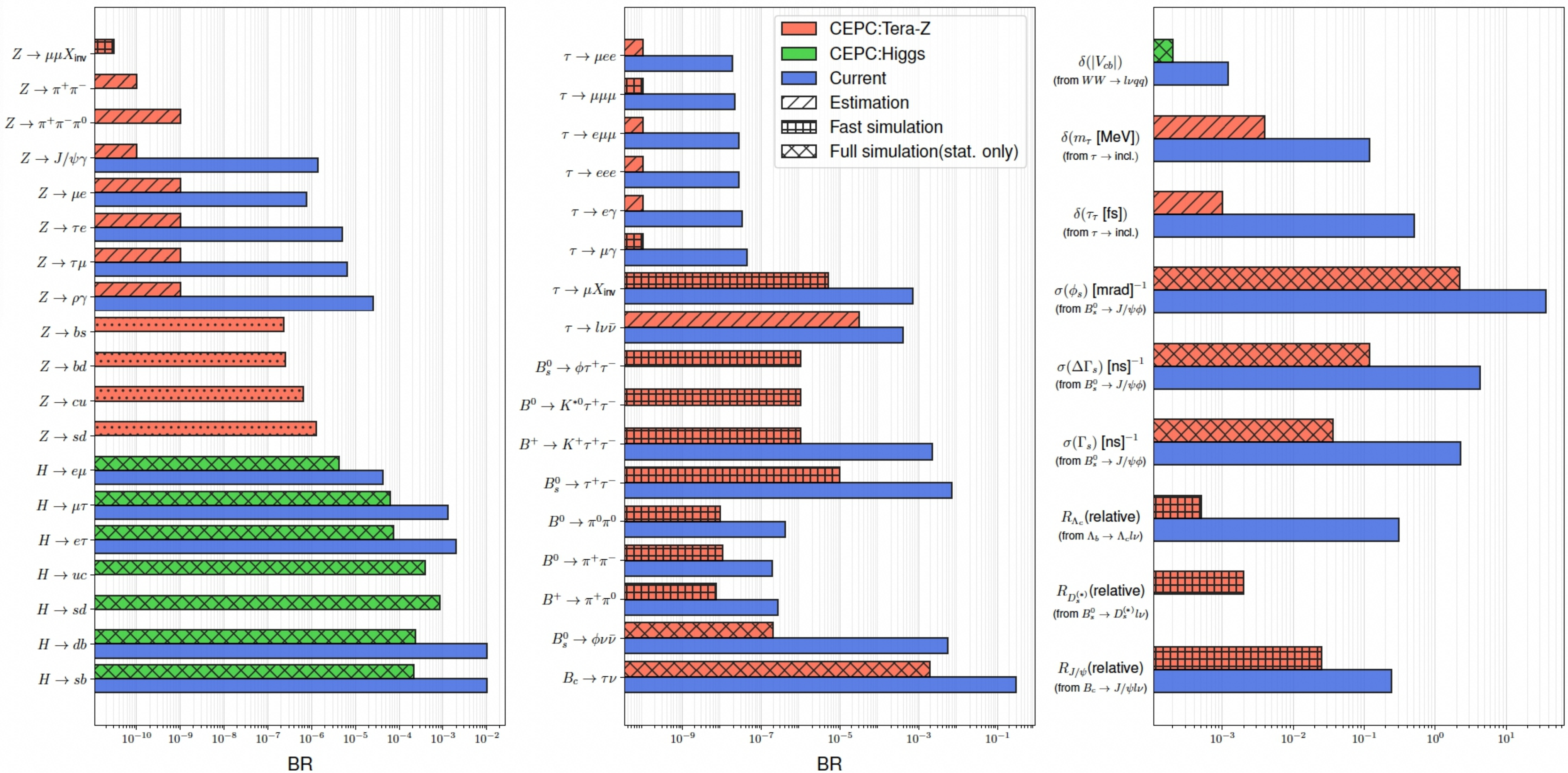
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta \Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta \Gamma_W$	49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



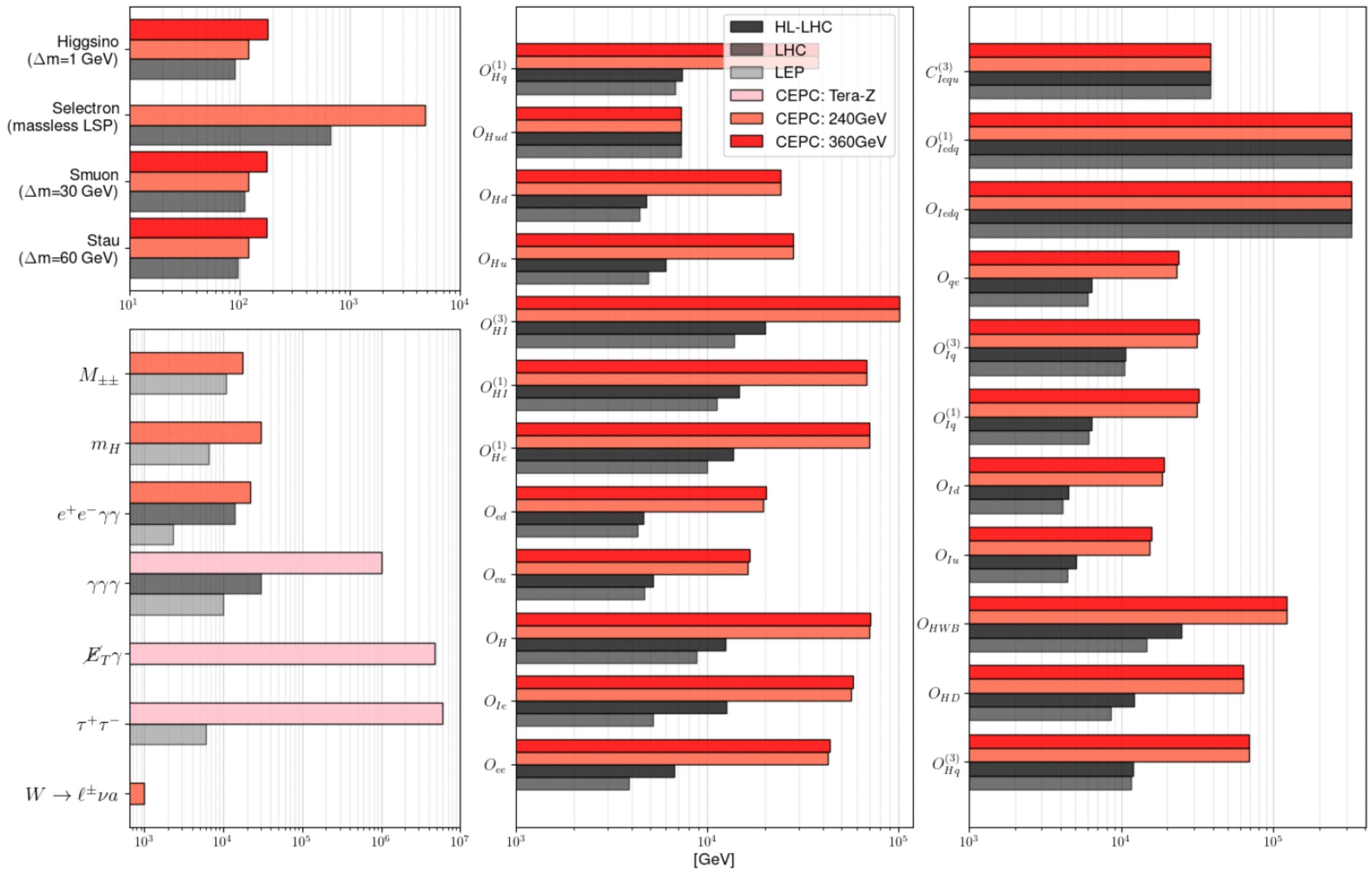
See the non-seen: i.e, Bc→tauv, Bs→Phivv

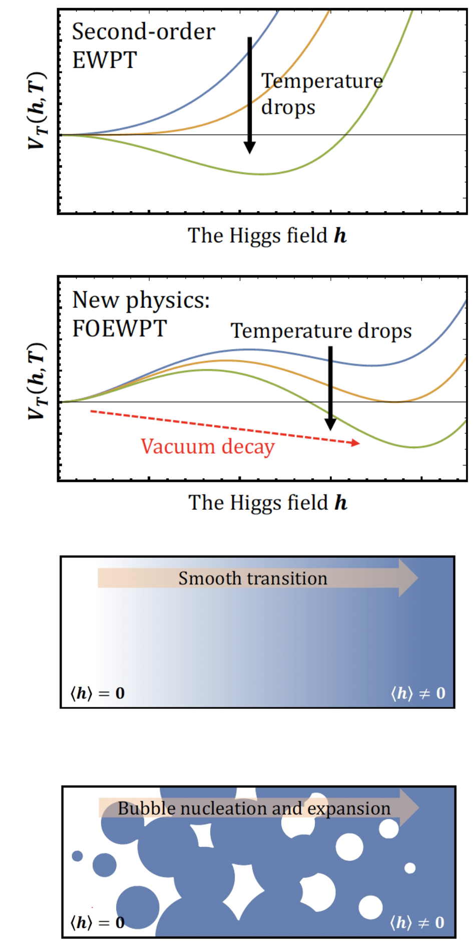
https://arxiv.org/pdf/2412.19743

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

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

New Physics



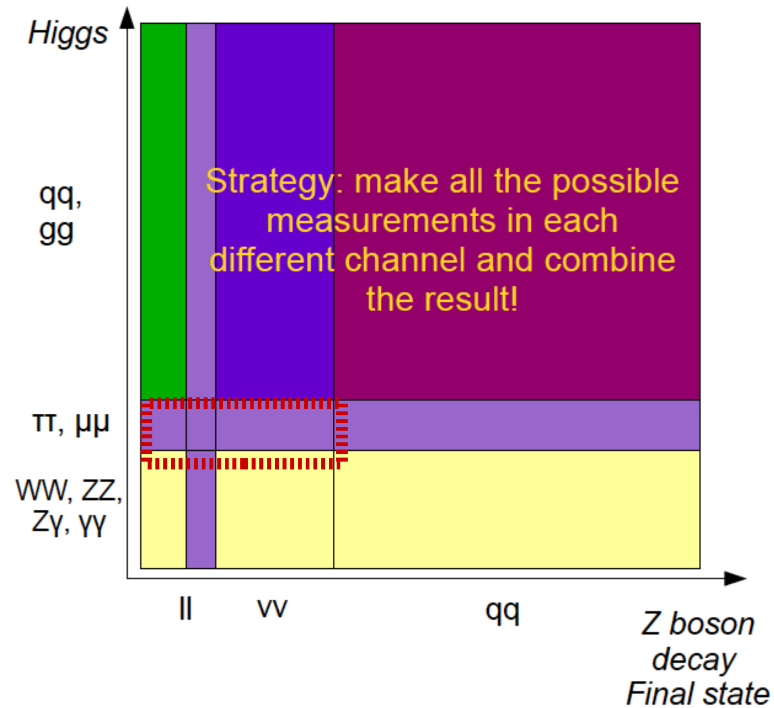


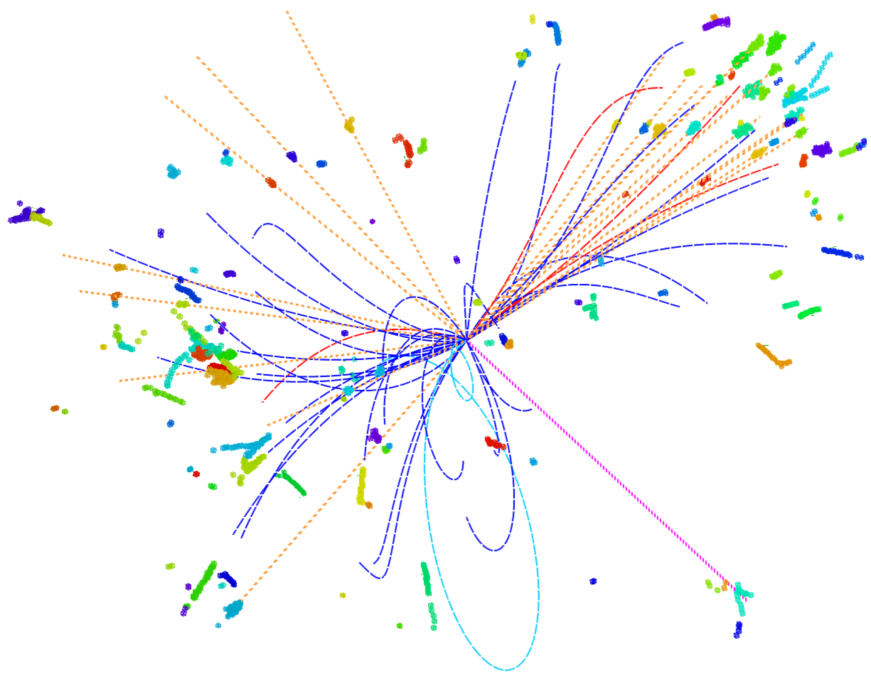
https://arxiv.org/pdf/2505.24810

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

Performance requirements

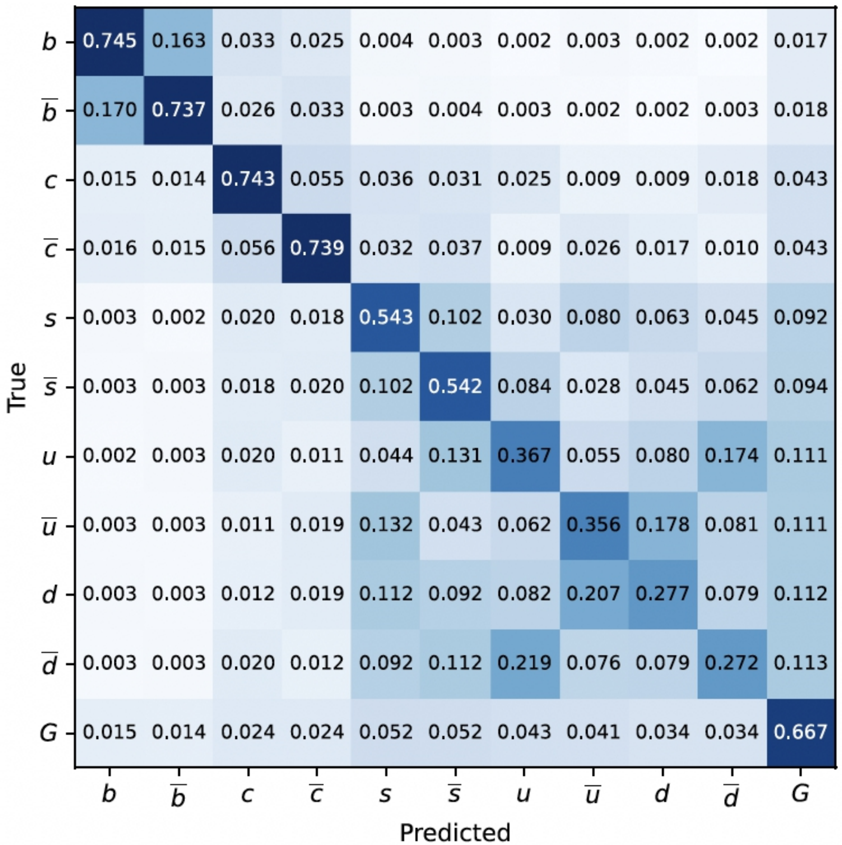
- To reconstruct all Physics Object, especially Jets
  - Z & W: ~ 70% goes to a pair of jets
  - Higgs: ~97% final state with jets (ZH events)
  - Top: t → W + b

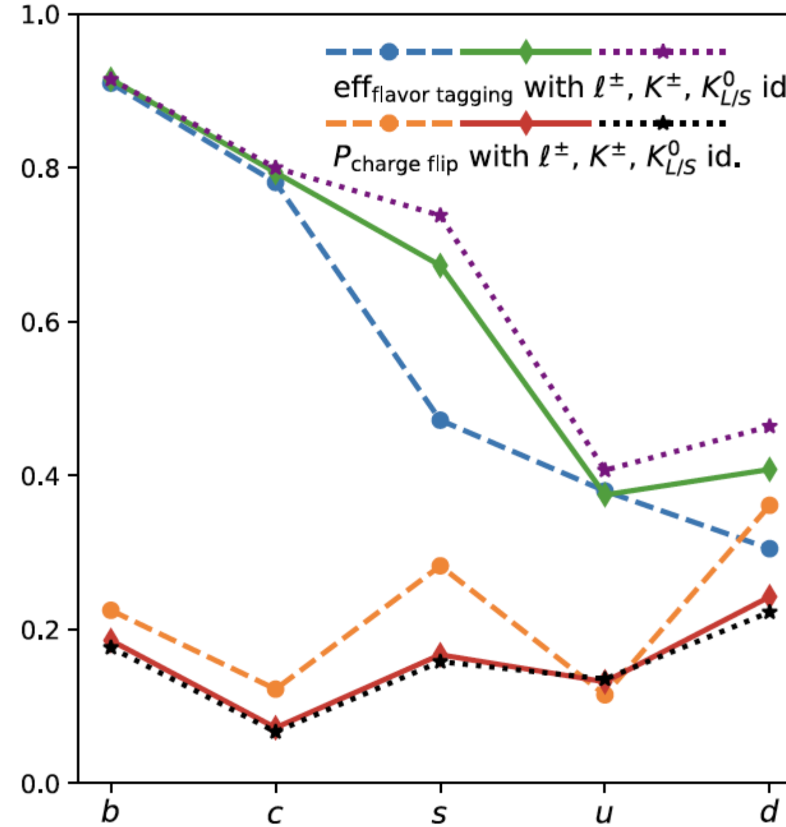




- Look inside the jet: **1-1 correspondence reco.**
  - ~ confusion free PFA
  - Larger acceptance...
  - Excellent intrinsic resolutions
  - Extremely stable...
- Be addressed by state-of-art detector design, technology, and reconstruction algorithm!

Jet origin id

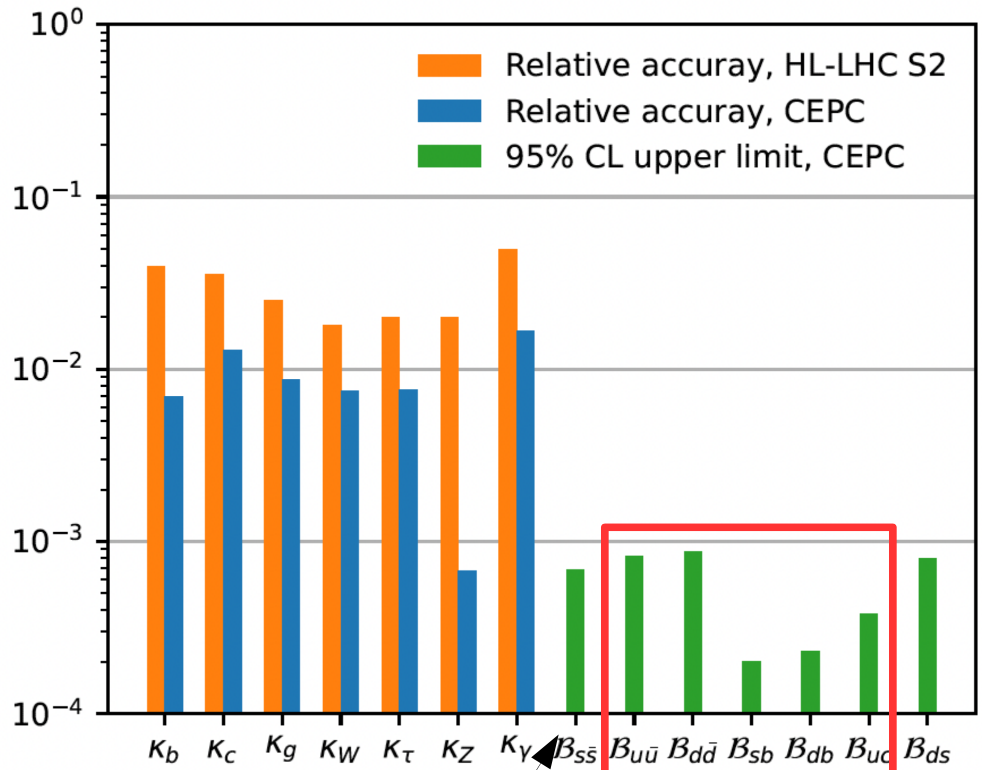




- 11 categories (5 quarks + 5 anti quarks + gluon) identification, realized at Full Simulated di-jet events at CEPC CDR baseline with Arbor + ParticleNet
- Published in PRL *132, 221802 (2024)*. Comment from the referee: *"demonstrate the world-leading performance of tagger", "a "game changer" and opens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

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

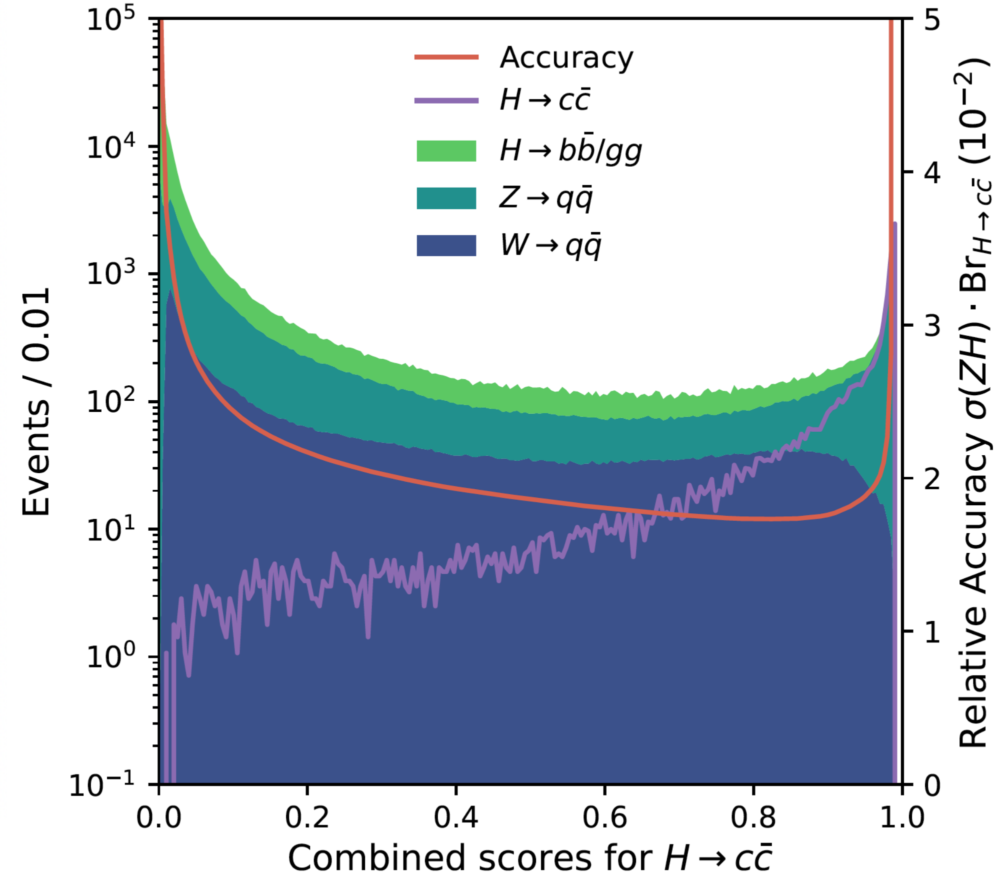
Impact on Physics: Higgs & W



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

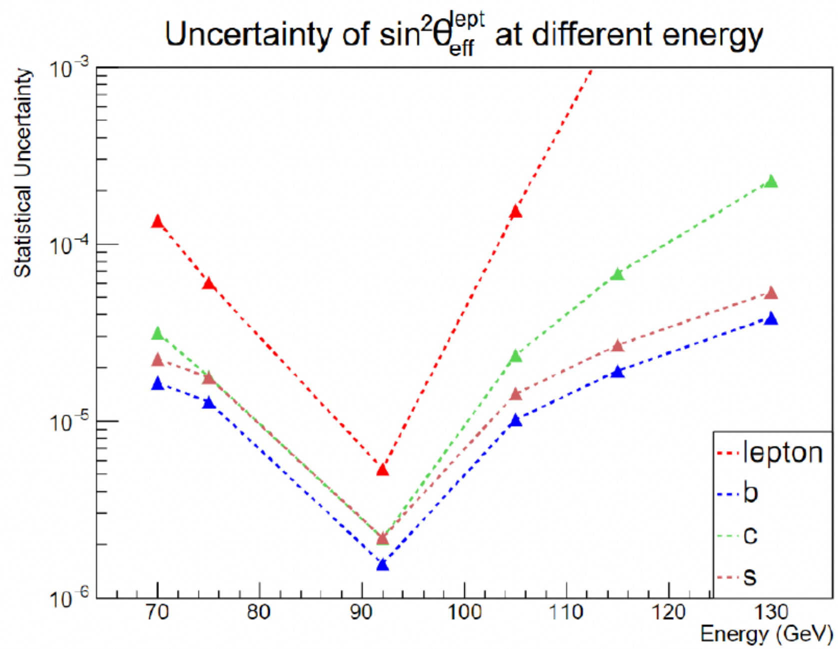
Table 3. Cross section of process $e^+e^- \to f\bar{f}$ calculated using the ZFITTER package. Values of the fundamental parameters are set as m_Z = 91.1875 GeV, m_t = 173.2 GeV, m_H = 125 GeV, α_s = 0.118 and m_W = 80.38 GeV.

$\sqrt{s}$/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.

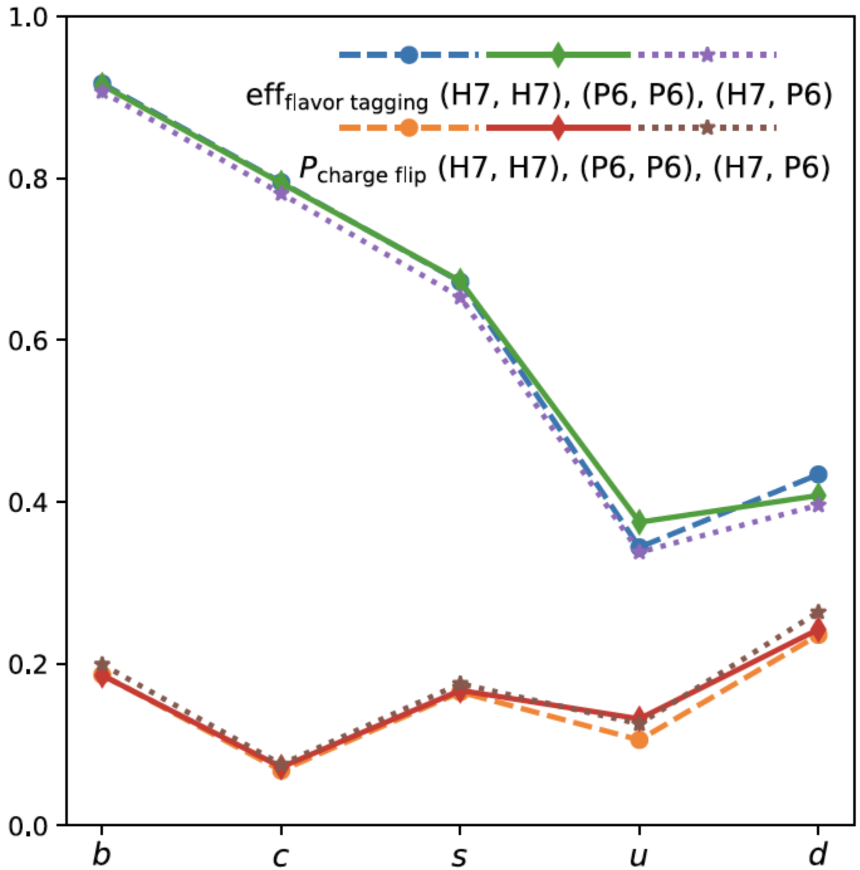
(Using one-month data collection, ~ *4e12/24 Z events* at Z pole)

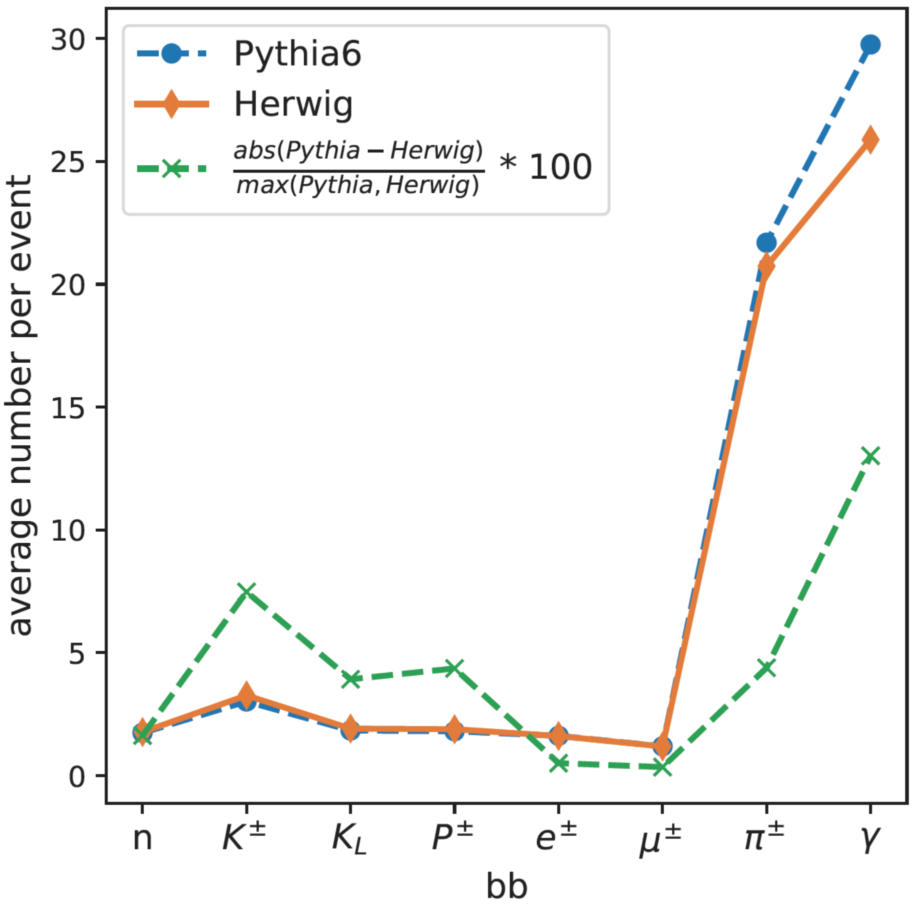


$\sqrt{s}$	b	c	s
70	1.6×10^{-5}	3.2×10^{-5}	2.2×10^{-5}
75	1.3×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
92	1.6×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
105	1.0×10^{-5}	2.4×10^{-5}	1.4×10^{-5}
115	1.9×10^{-5}	6.8×10^{-5}	2.7×10^{-5}
130	3.9×10^{-5}	2.3×10^{-4}	5.4×10^{-5}

...+ Significant impact on Flavor Physics, especially those with Bs oscillation...

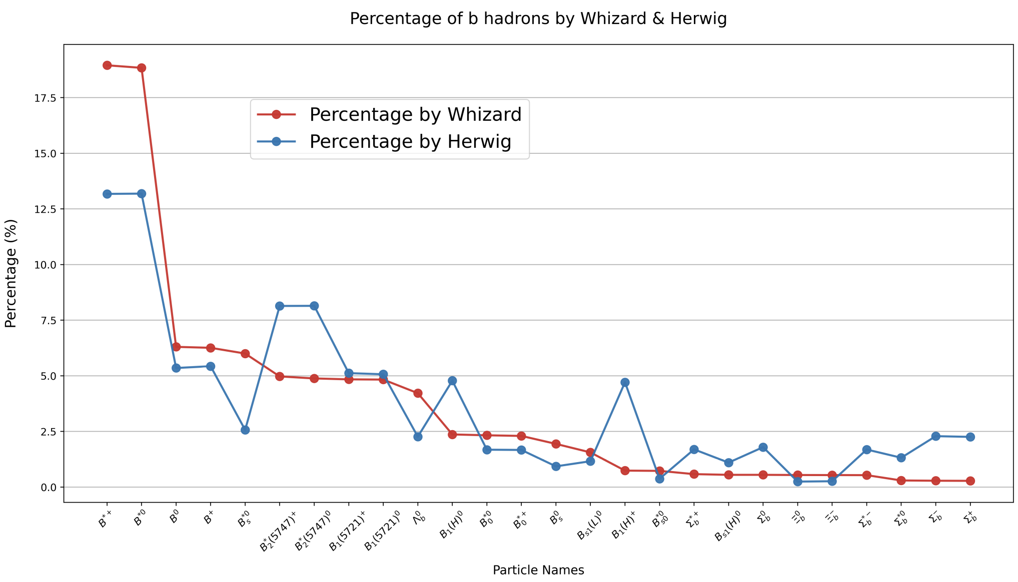
V.S. Hadronization models

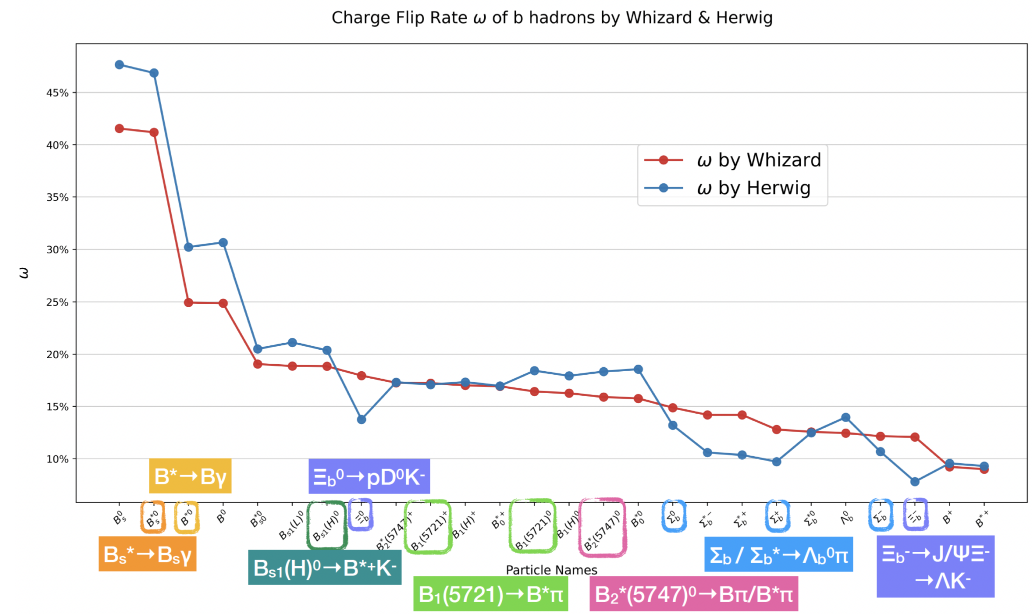


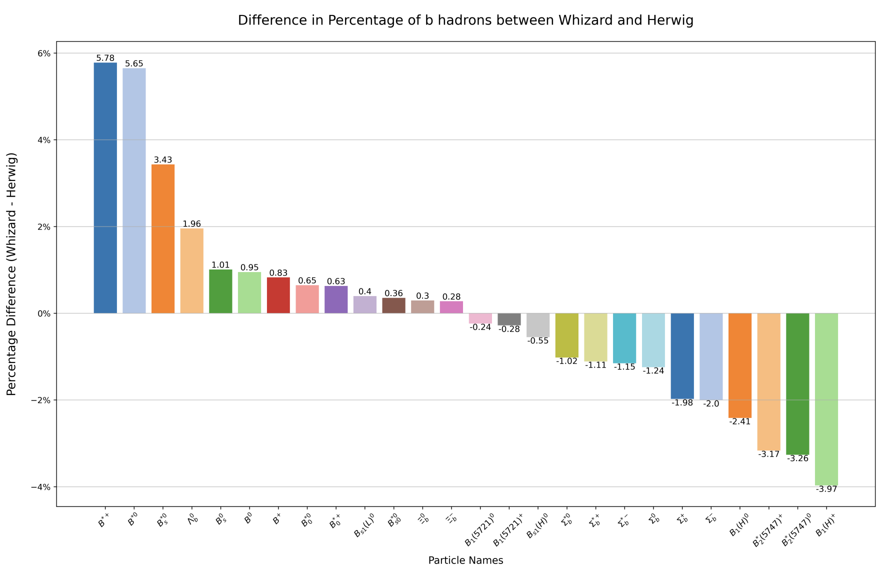


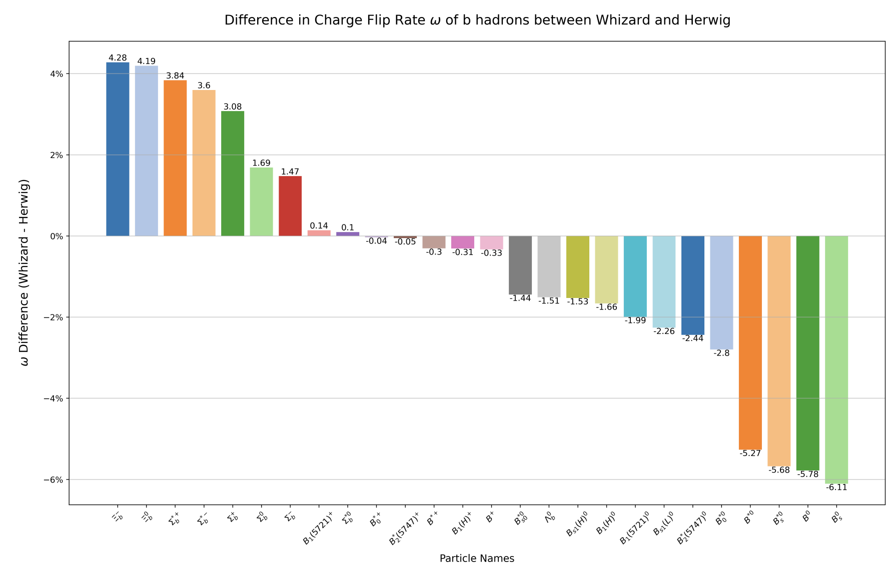
- Different hadronization model have significantly different predictions...

b-jet: leading b-hadrons & flip rates

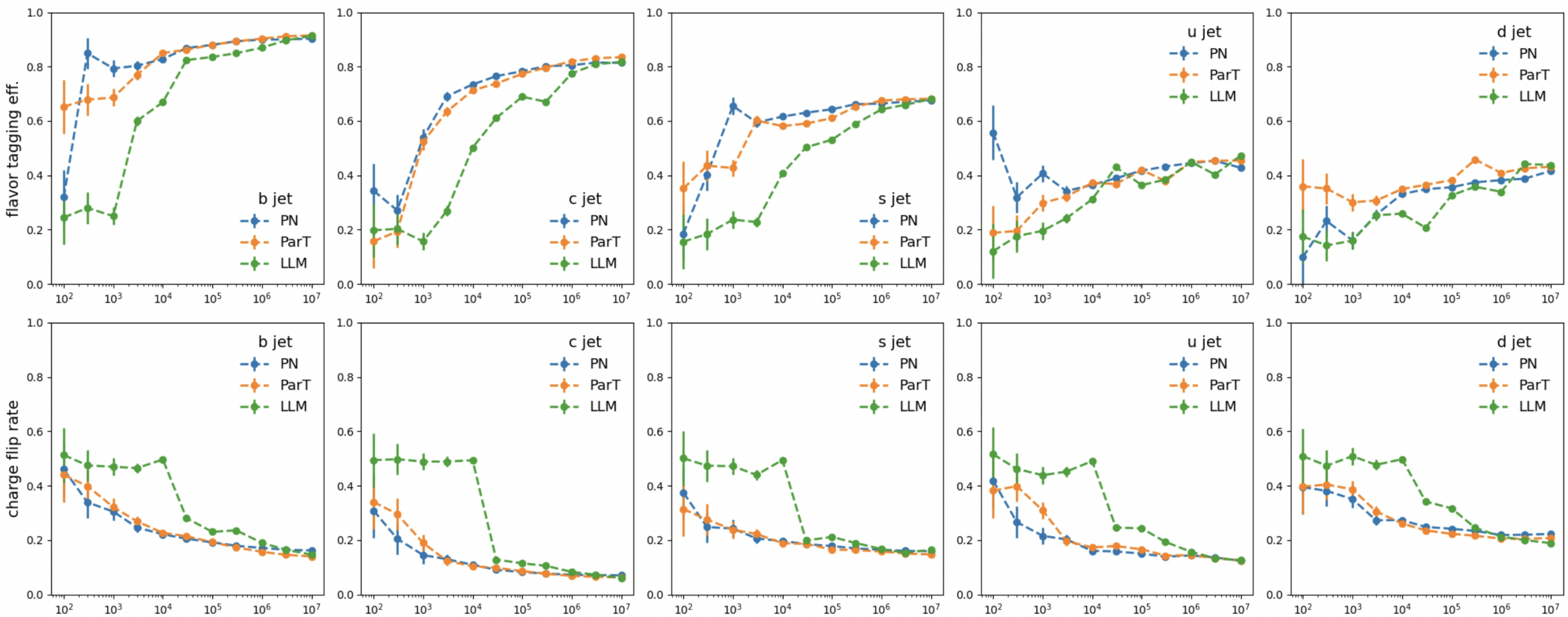








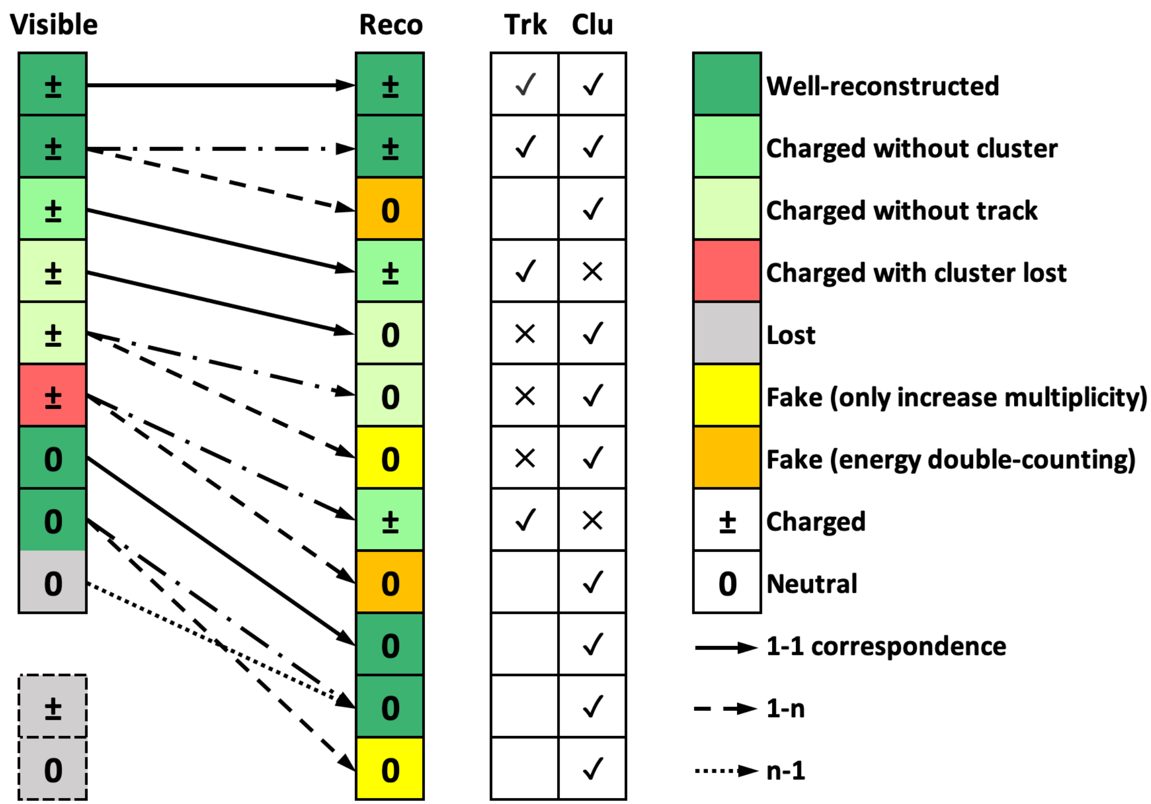
From specialized Models to LLM



- 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

PFA evolution: to 1-1 correspondence



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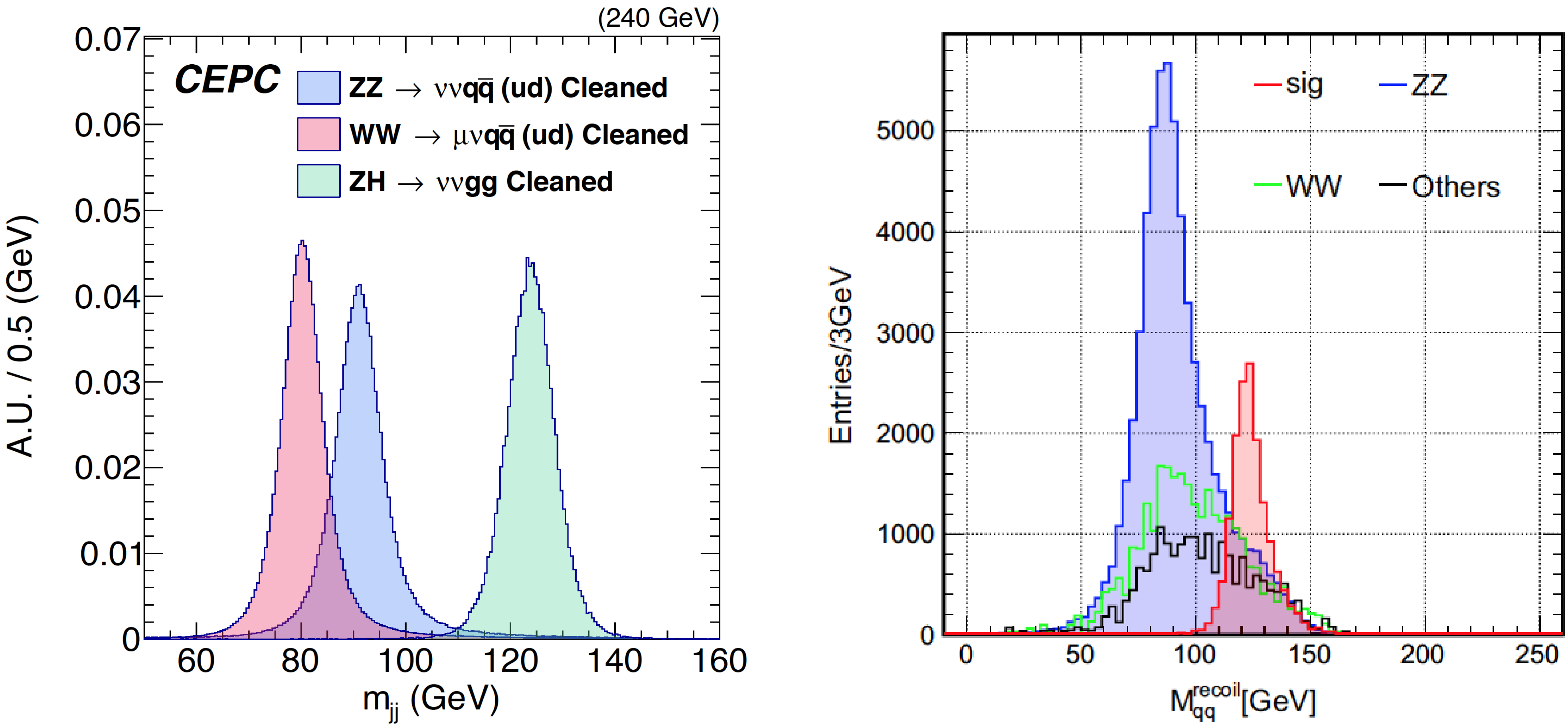
Computational Physics

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

Boson Mass Resolution (BMR)

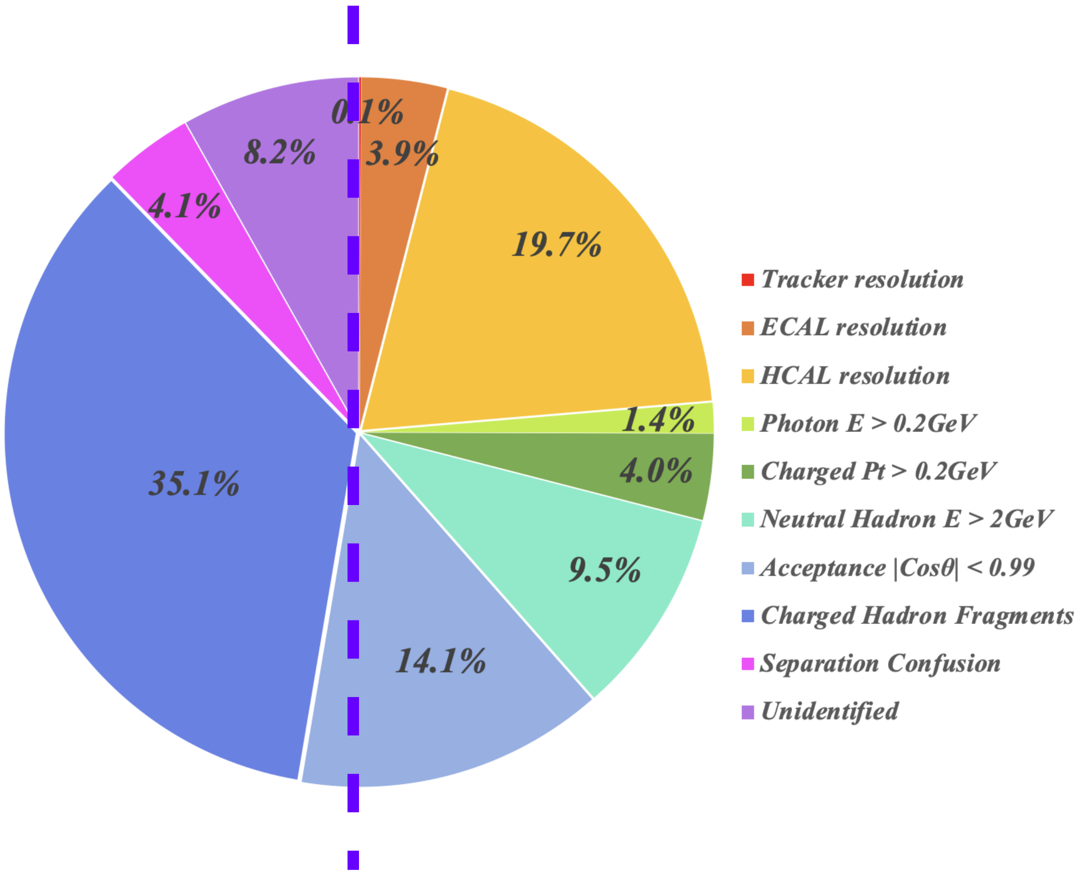


Higgs factory: need BMR < 4% (critical for qqH & qqZ separation using recoil mass to di-jet)

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

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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:
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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.

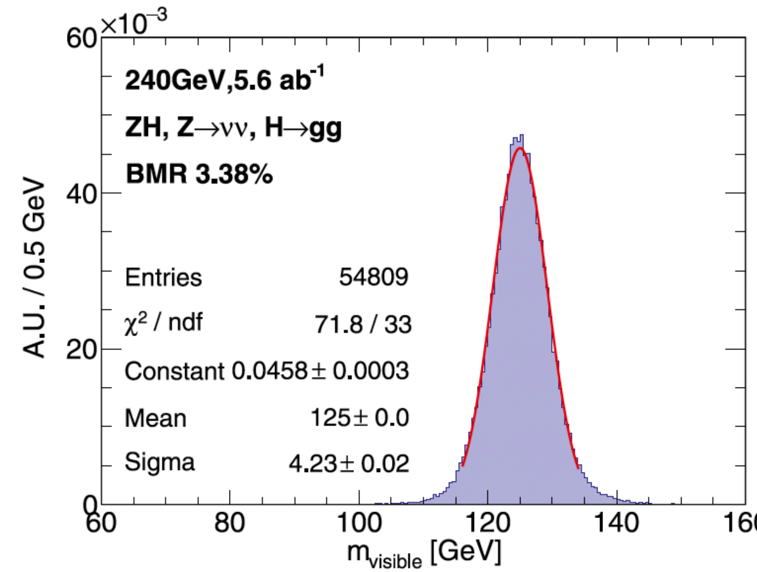
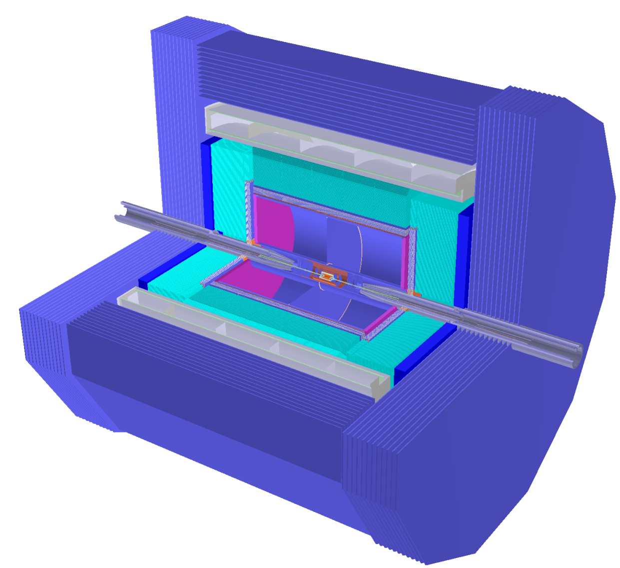


Fig. 5. Distribution of the reconstructed total visible invariant mass for $\nu\bar{\nu}H \to \nu\bar{\nu}gg$ channel. The distribution is fitted with a Gaussian function extented to ±2 standard deviations.

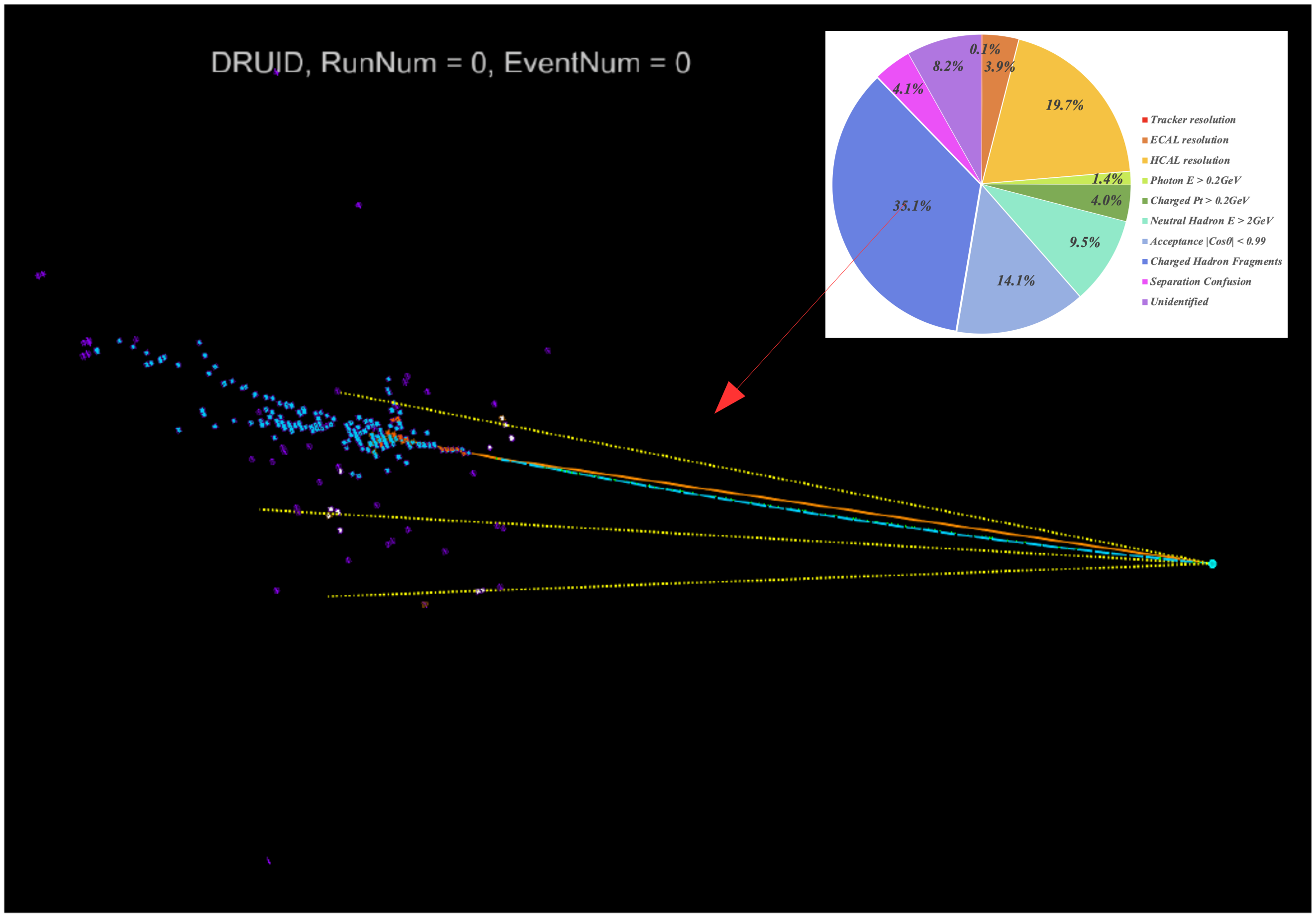
Y. Wang, H. Liang, Y. Zhu et al. *Computer Physics Communications 314 (2025) 109661*

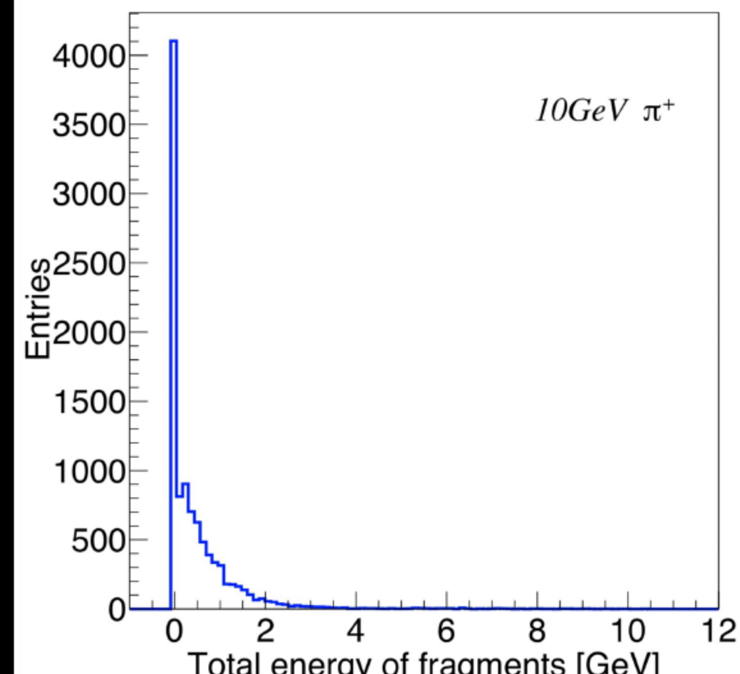
Table A.1
AURORA detector geometry parameters.

Sub-detector	Thickness (mm)	Inner radius (mm)	Outer radius (mm)	Length (mm)	Volume (m^3)	Transverse cell size	#Layers	#Channels
Vertex	-	-	16–60 155	125–250 736	-	$25\times25\ \mu m^2$	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	$1\times6\ mm^2$	220	2.9×10^6
ECAL	173	1845	2018	5250	15	$1\times1\ cm^2$	30	2.5×10^7
HCAL	1145	2072	3250	7590	180	$2\times2\ cm^2$	48	1.8×10^7
Solenoid	700	3275	3975	7750	120	-	-	-
Yoke	1200	4000	5200	10500	470	-	-	-



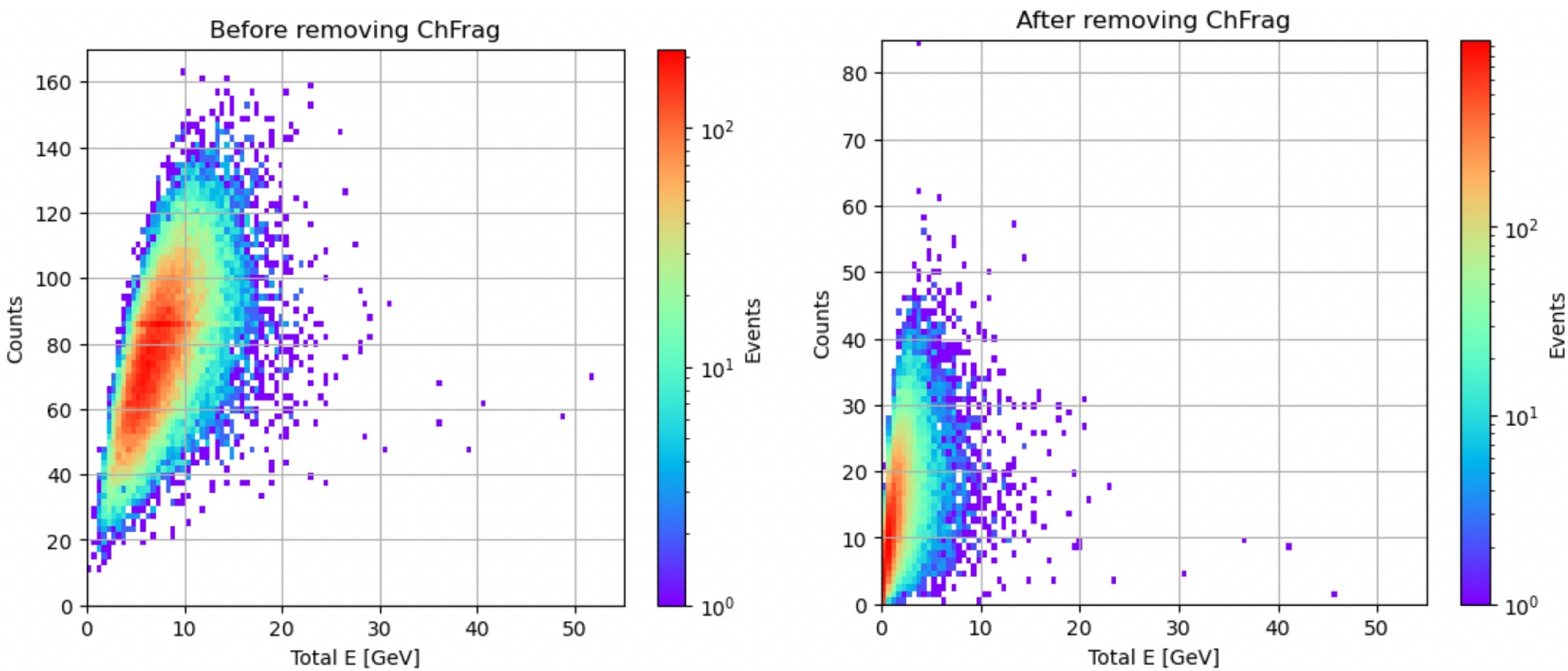
Cluster splitting: the most severe confusions





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

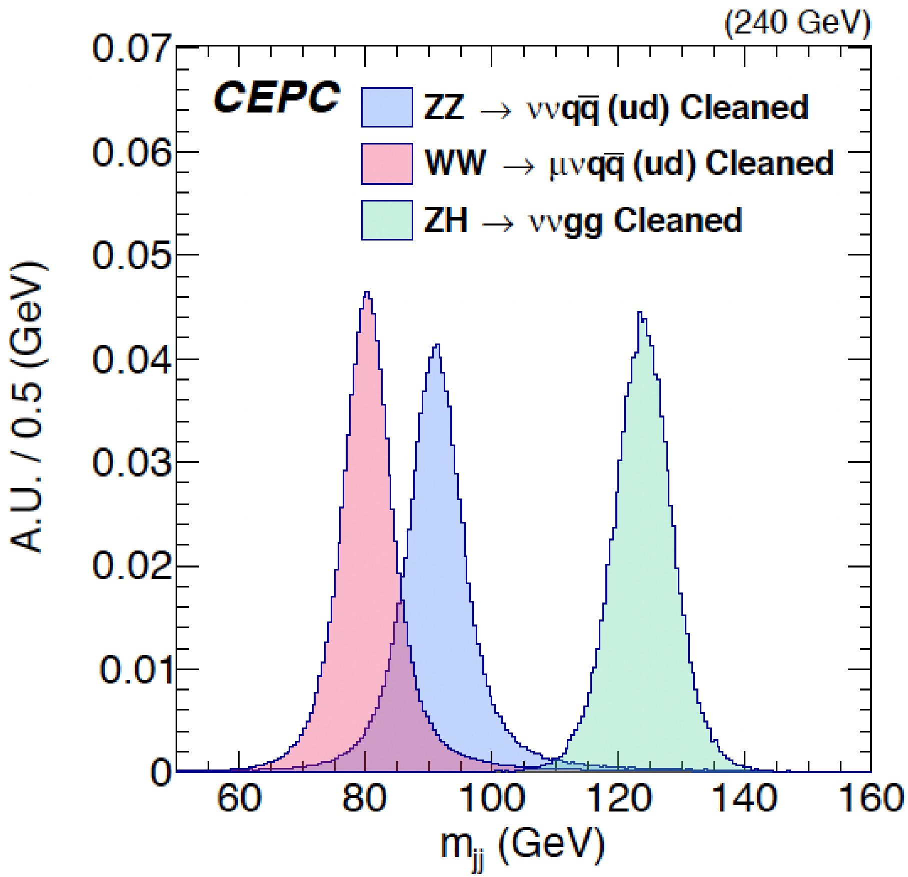
Confusion: frag. Identification & veto

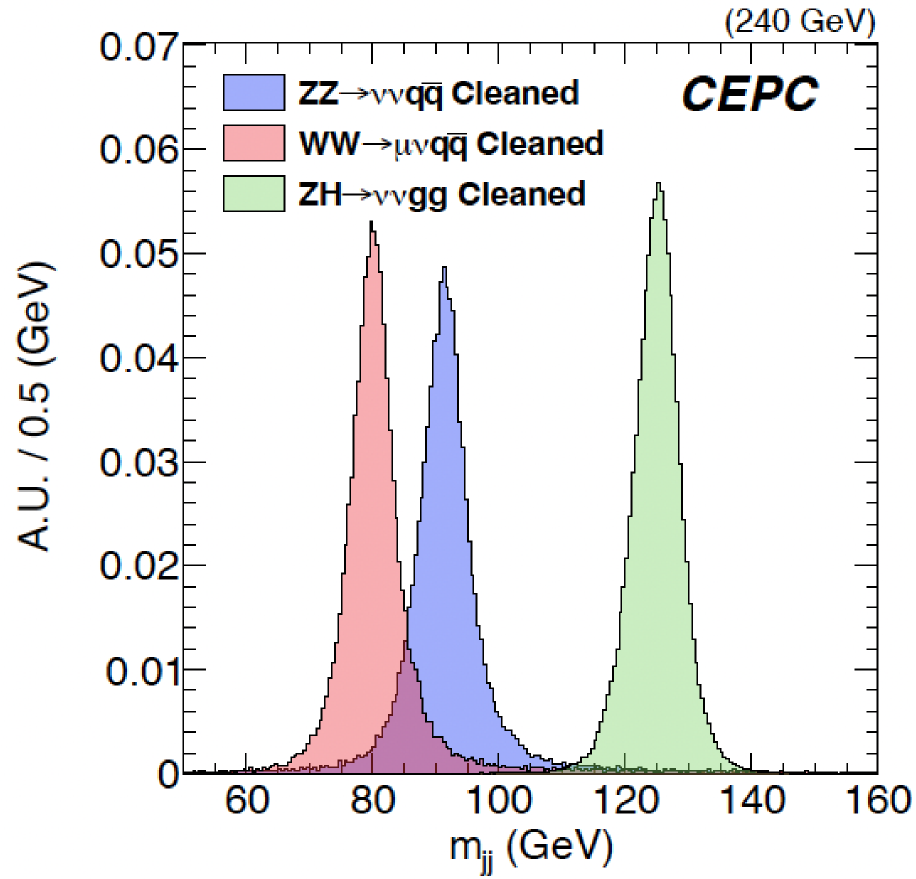


Fake particle originated Confusion reduced by 1 order of magnitude, at nominal vvH, H→gg event, at the cost of create mis-vetoed energy of < 1 GeV.

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

BMR of 2.75% reached



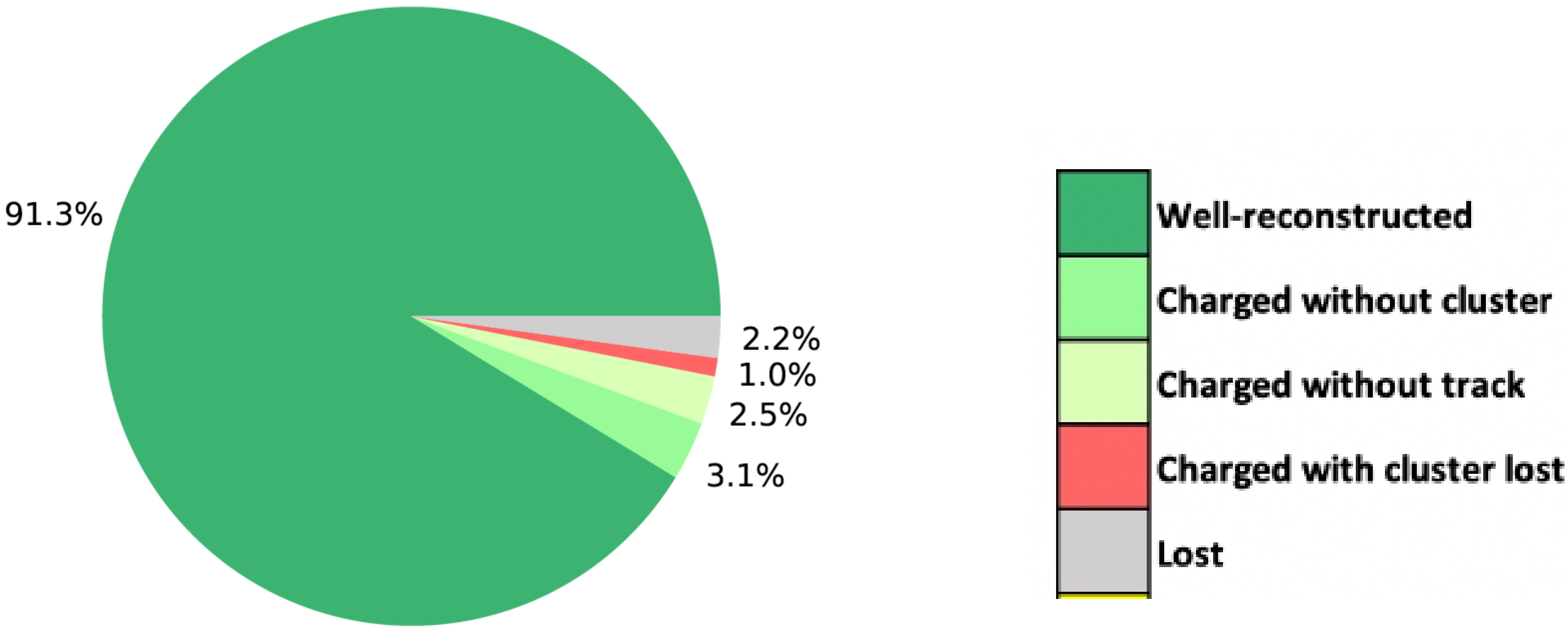


Detector change (usage of high density scintillating glass HCAL): BMR 3.7% → 3.4%;

AI enhanced reconstruction: 3.4% → 2.8%.

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

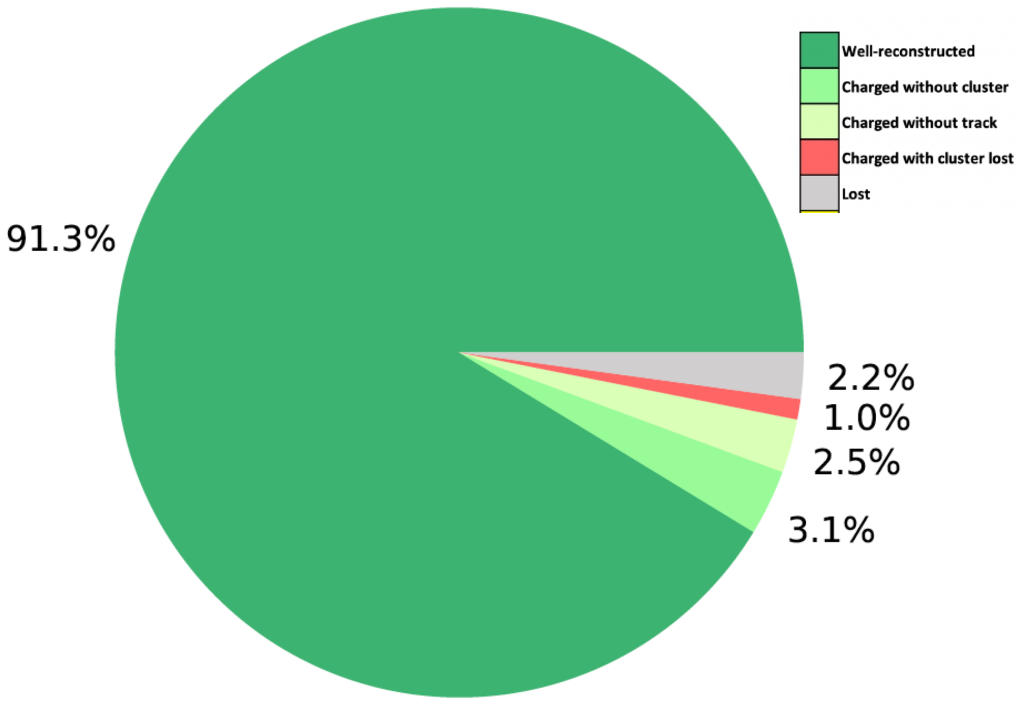
Confusion: frag. Identification & veto

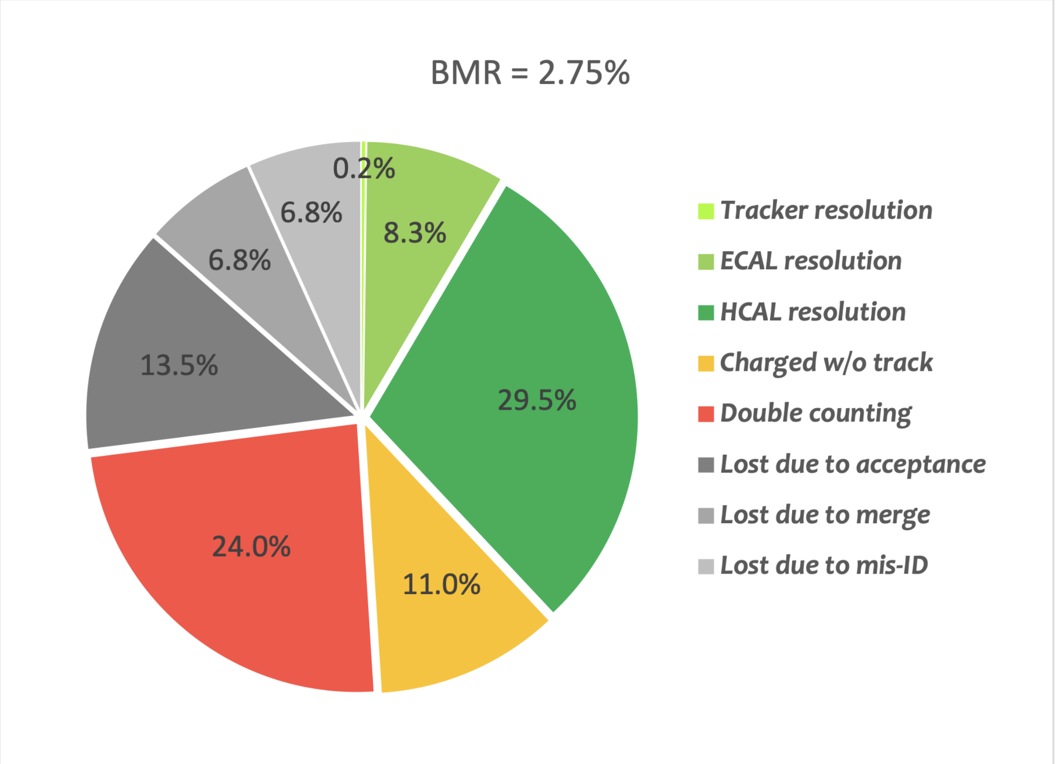


Remaining fragments with total E ~ 1 GeV;

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

BMR decomposition @ AURORA

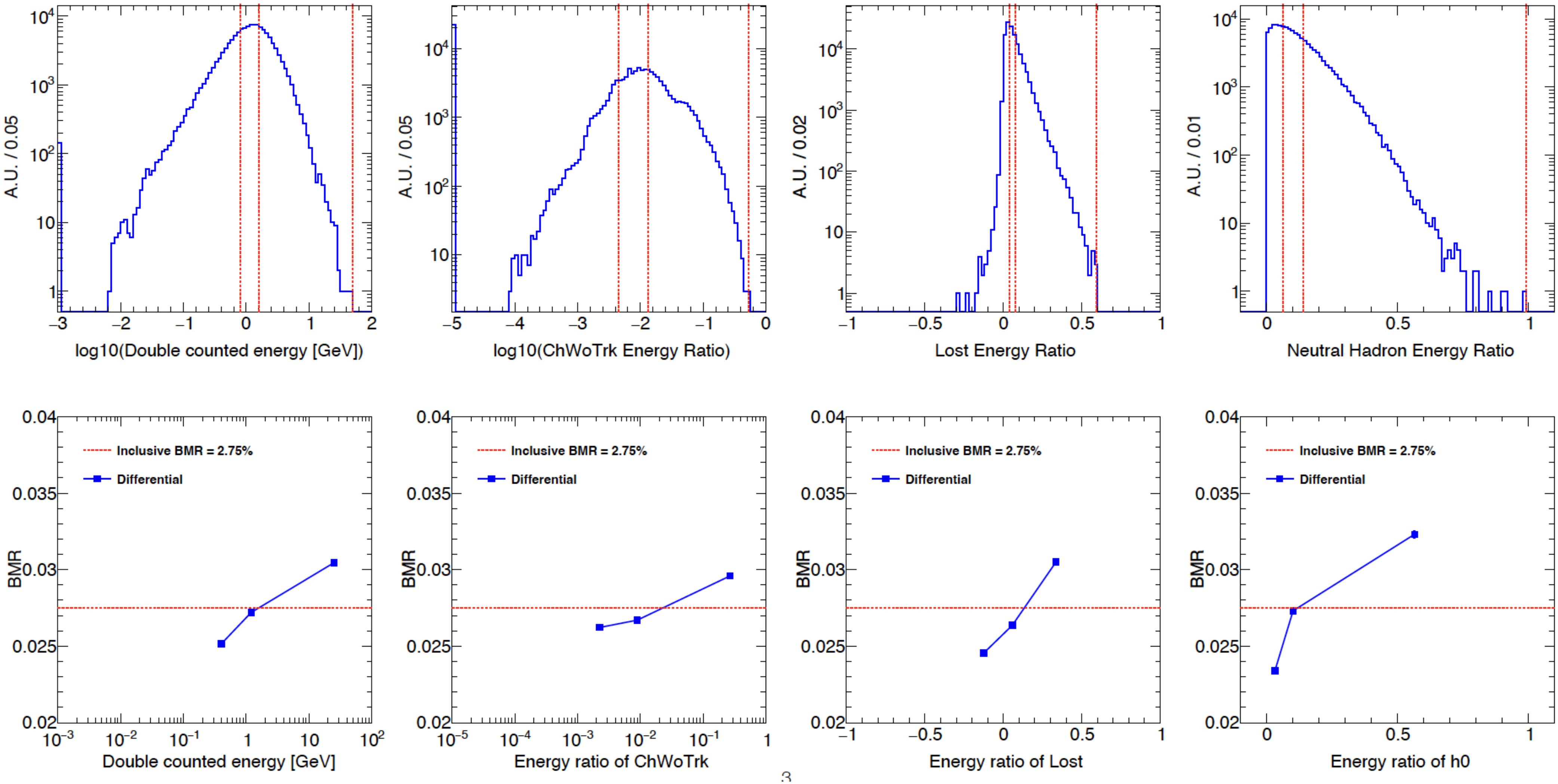




1-1 corresponding type: contributing to the BMR via resolution: ~o(0.1 – 0.001) of its mean value

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

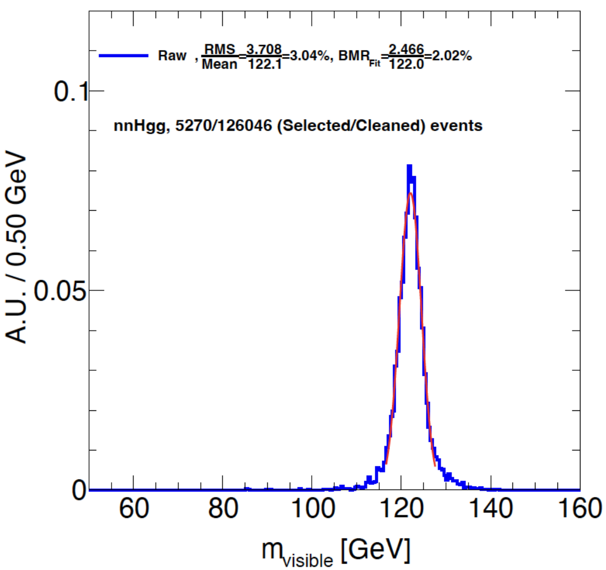
BMR dependence to its components



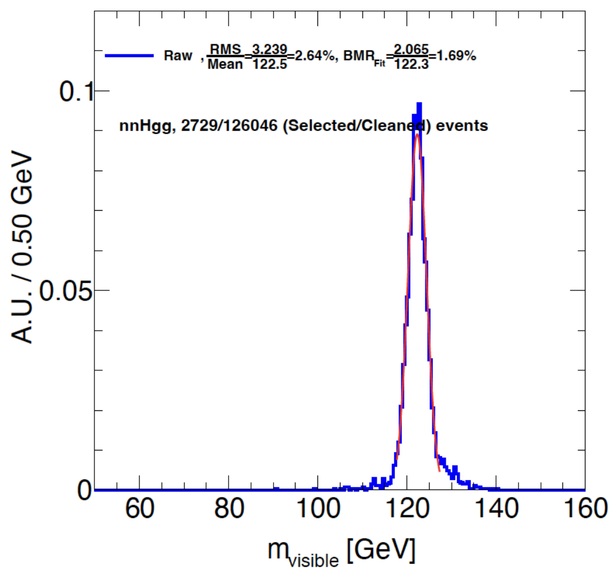
BMR dependence on Cut...

Combined cut (top 1/3 good events)

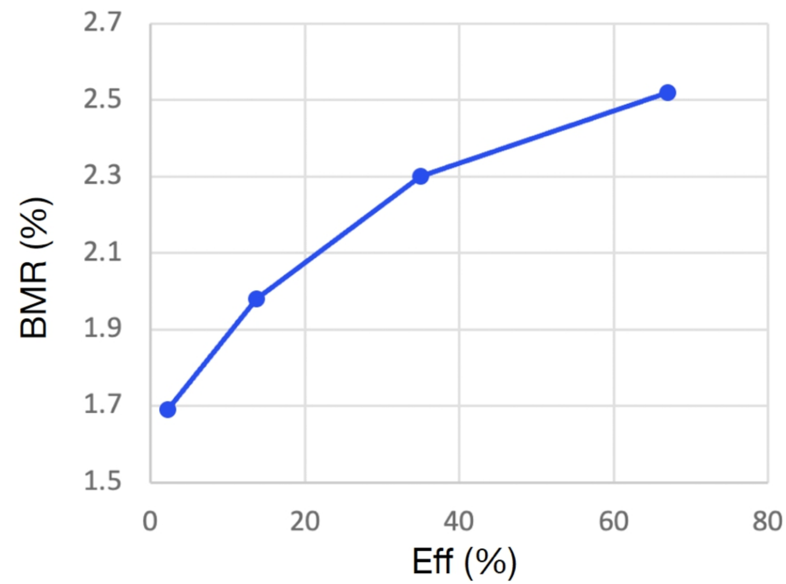
- **Eff ~4.2%**
- **Double count E < 0.8 GeV**
- **ChWoTrk ERatio < 0.0045**
- **Lost ERatio < 0.037**



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



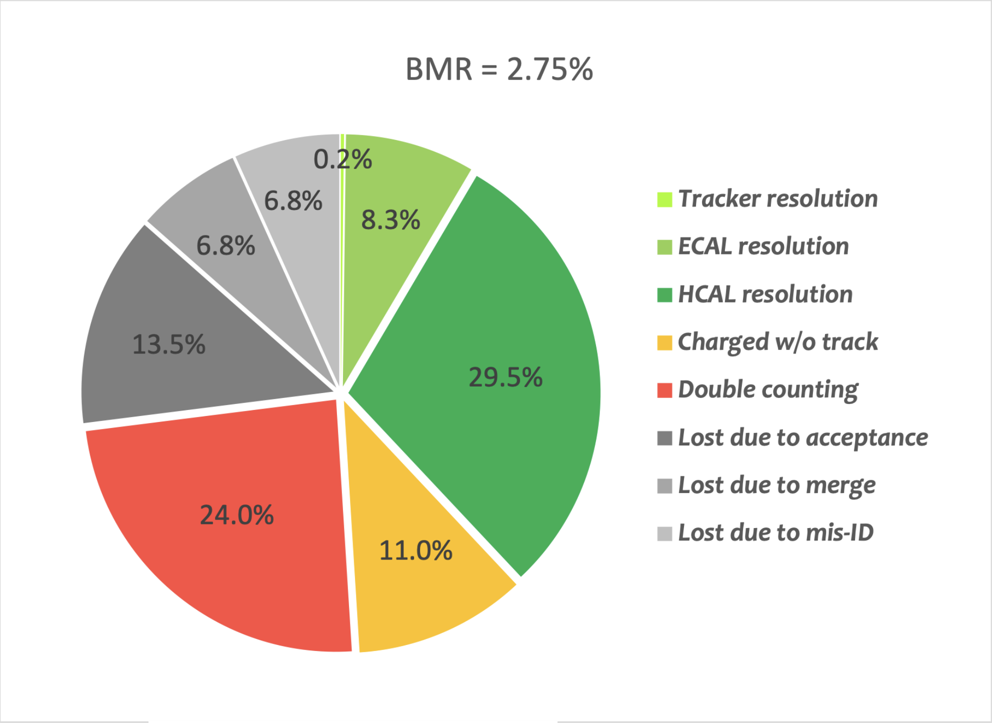
Eff (%)	BMR (%)
2.2	1.69
13.7	1.98
35	2.3
67	2.52

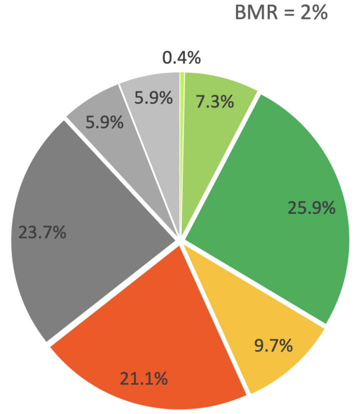


...If the High Values tails could be tamed...

BMR: perspectives

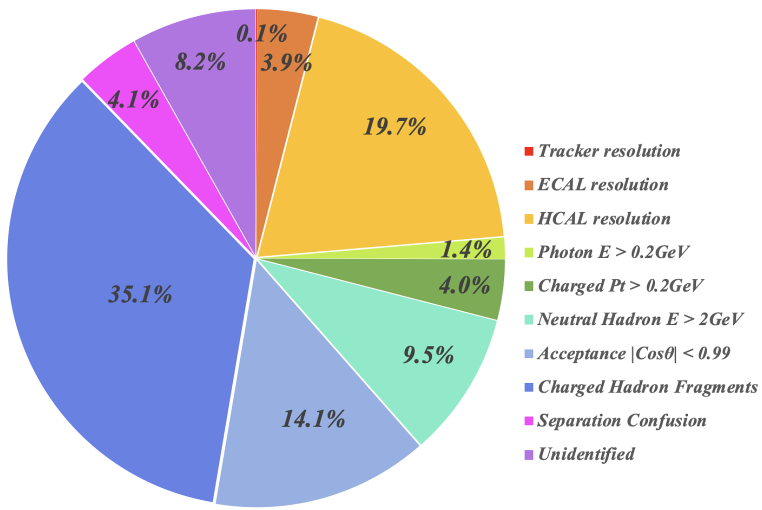
- Resolutions: assume - improved by 50%
  - Crystal ECAL: With efficient control of confusion
  - Detector optimization + Innovative Estimator (Energy, Time, Spatial...) with 5d calorimeter (ToF) & AI: ToF could determine very precisely the energy of low-E hadron – Giving its type identified...
- Charged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



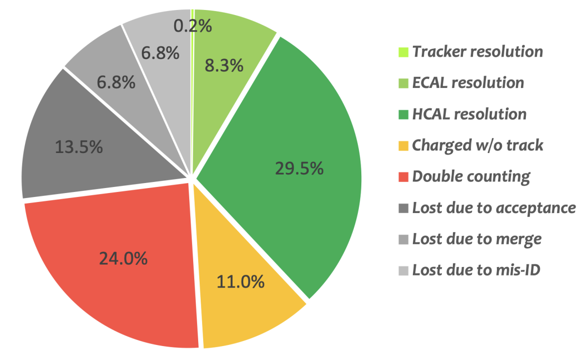


BMR: from CDR to possible future...

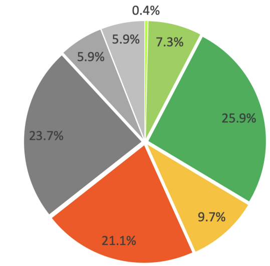
2016 - CDR: BMR ~ 4%

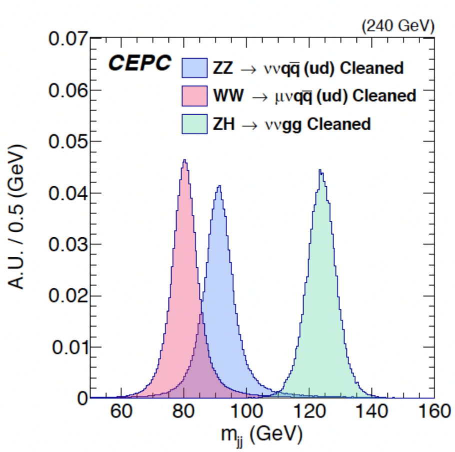


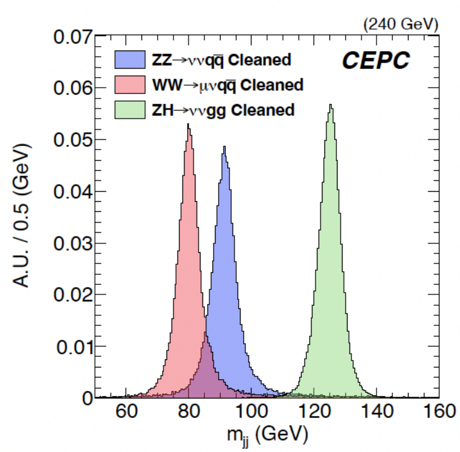
2024 - AURORA: BMR ~ 2.7%

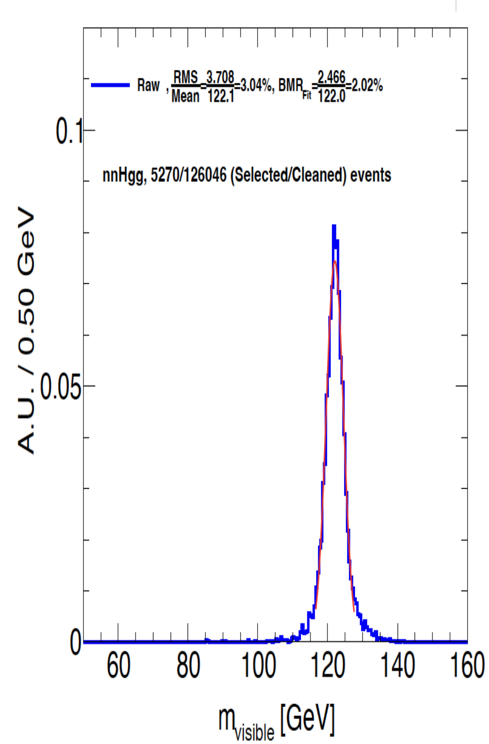


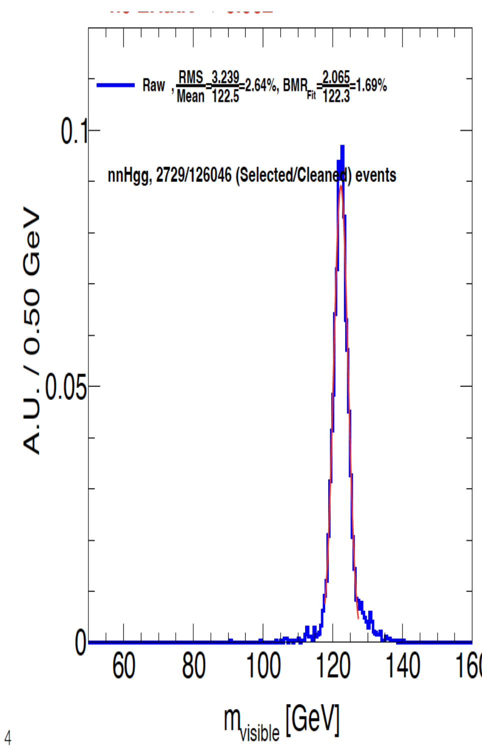
Future: BMR ~ 2.0%



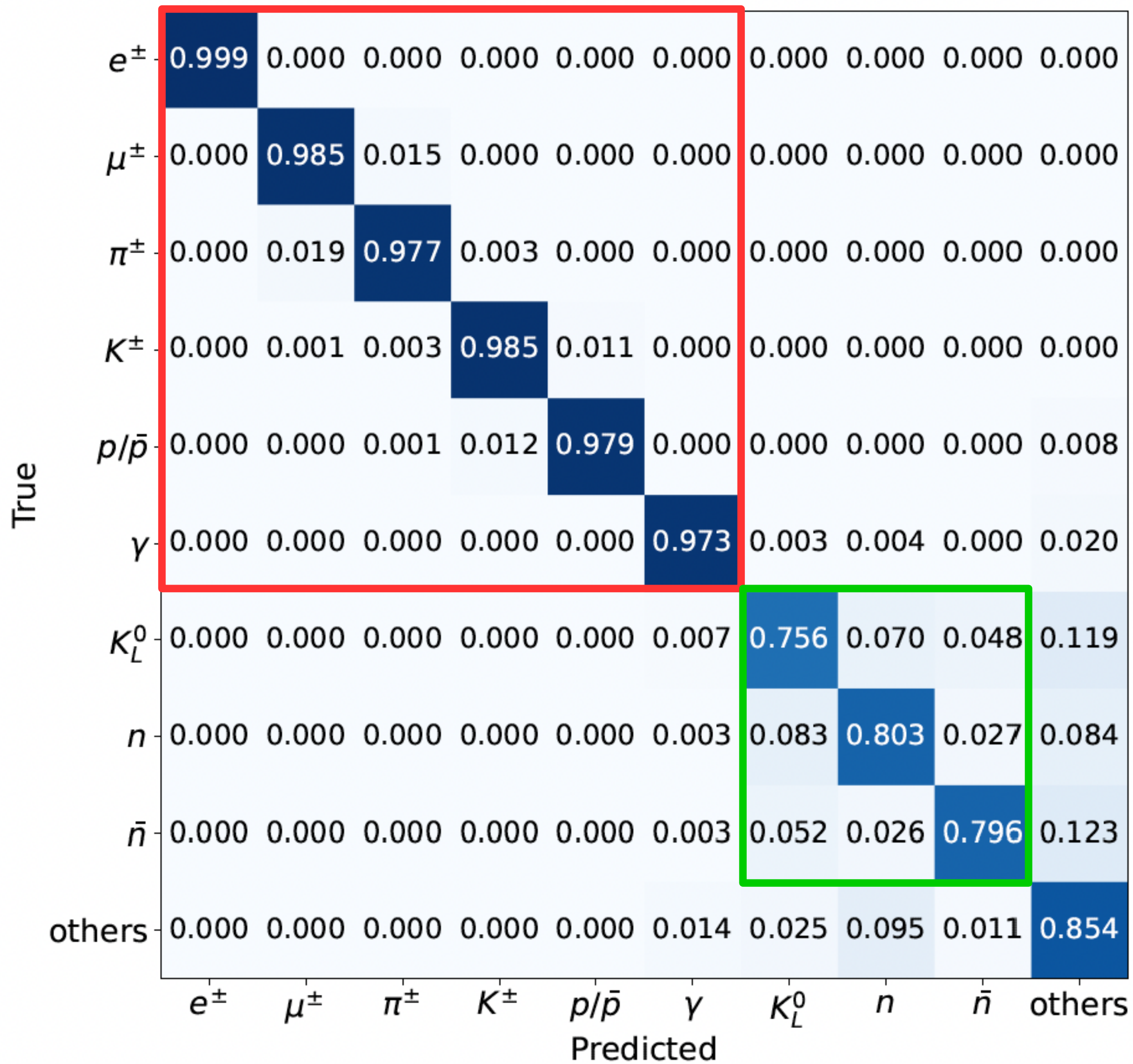


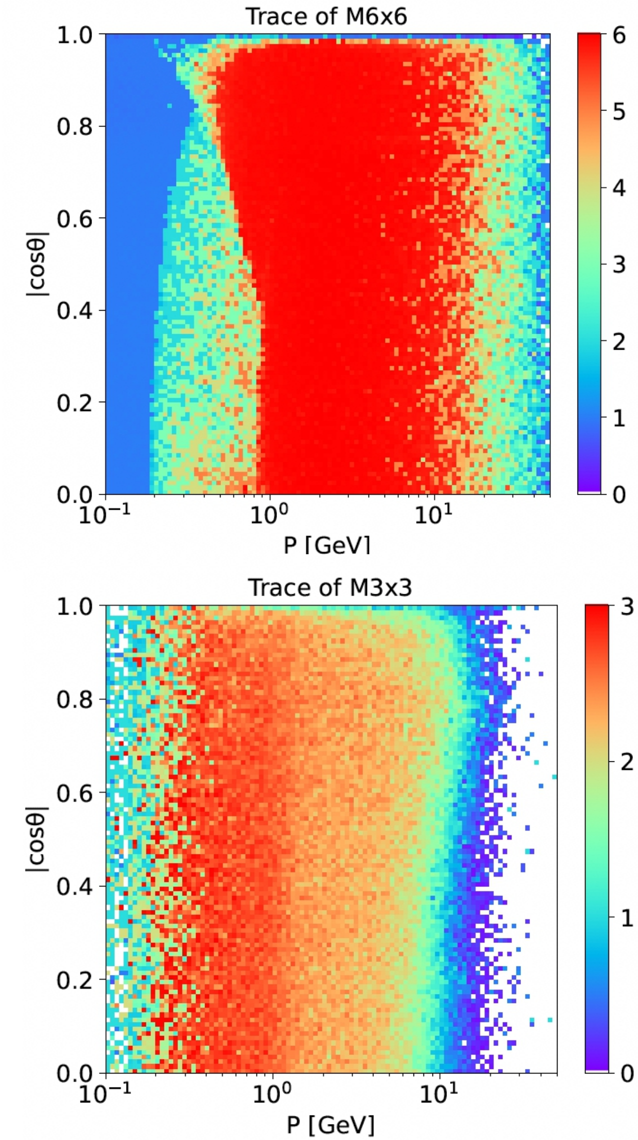






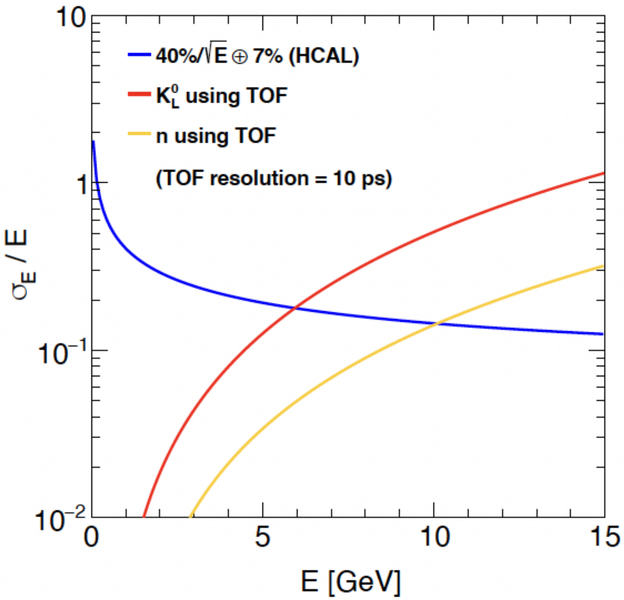
Pid: differential performance

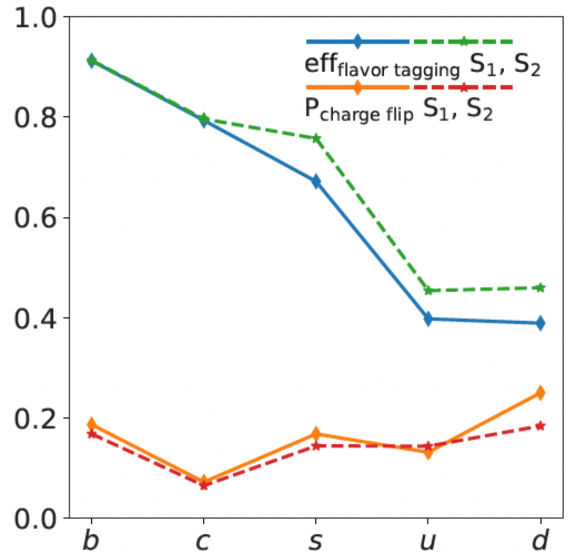


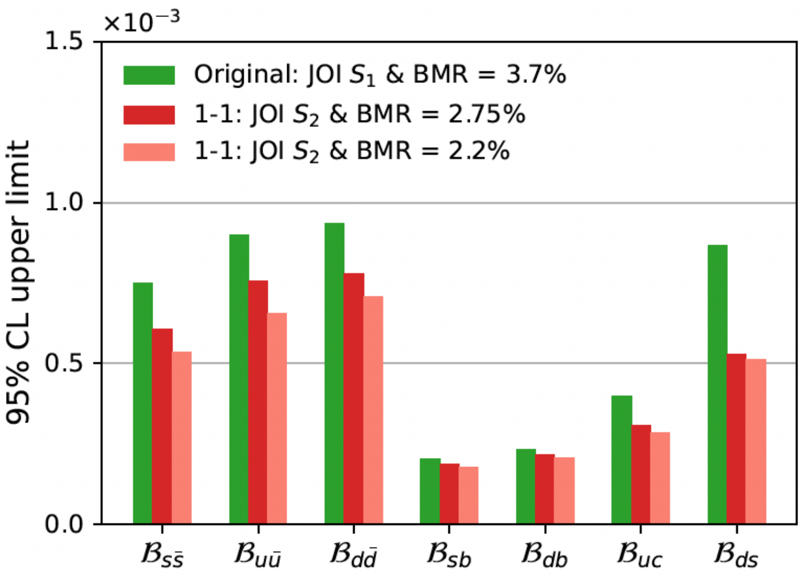


Neutral Hadron ID: excellent Calorimetry with ToF capability (δt~100 ps/hit)

Perspectives with 1-1 correspondence







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

Color Singlet Identification

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JHEP11(2022)100

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

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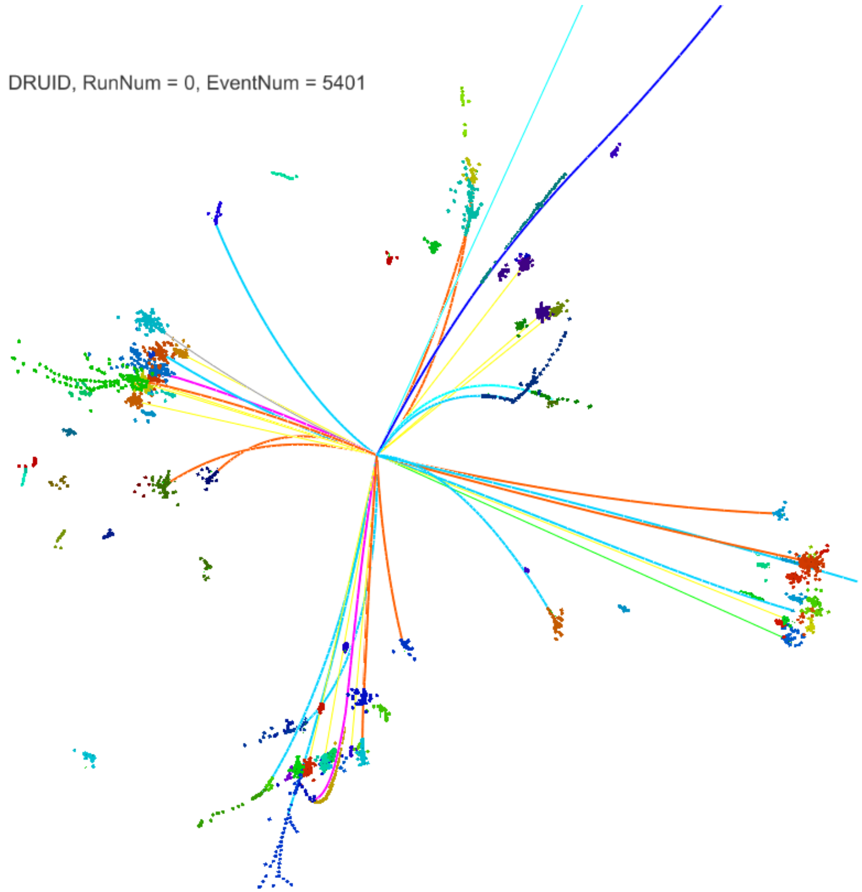
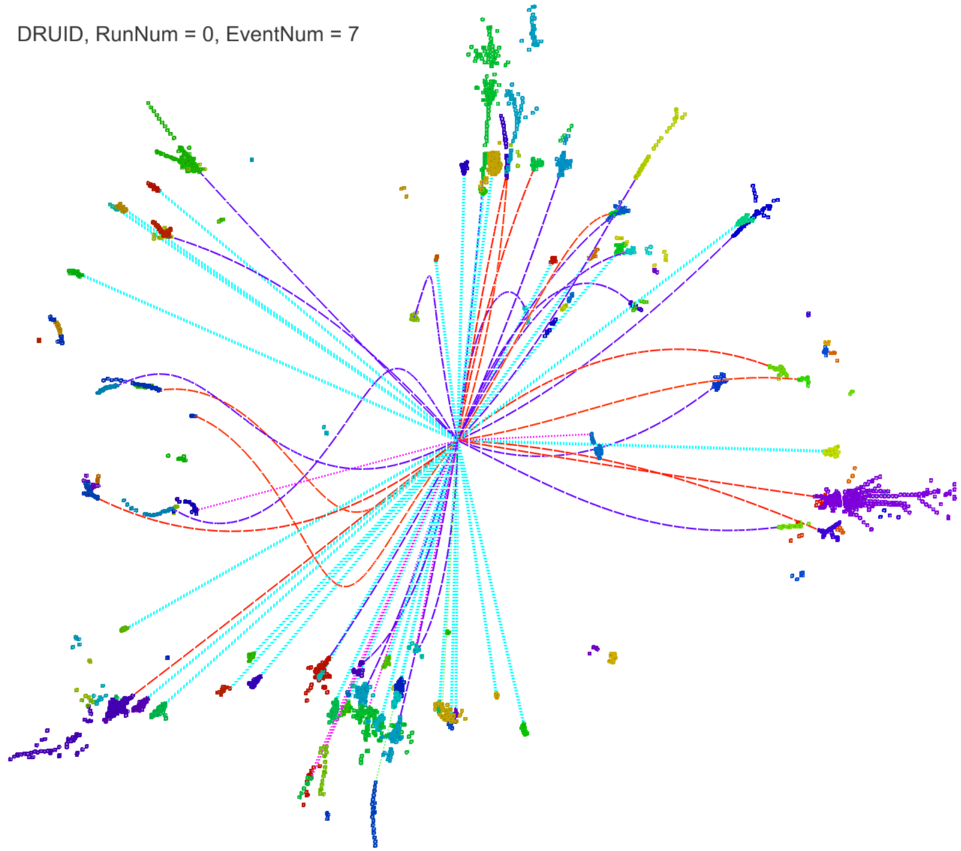
Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

Table 3. The signal strength accuracies for different channels.

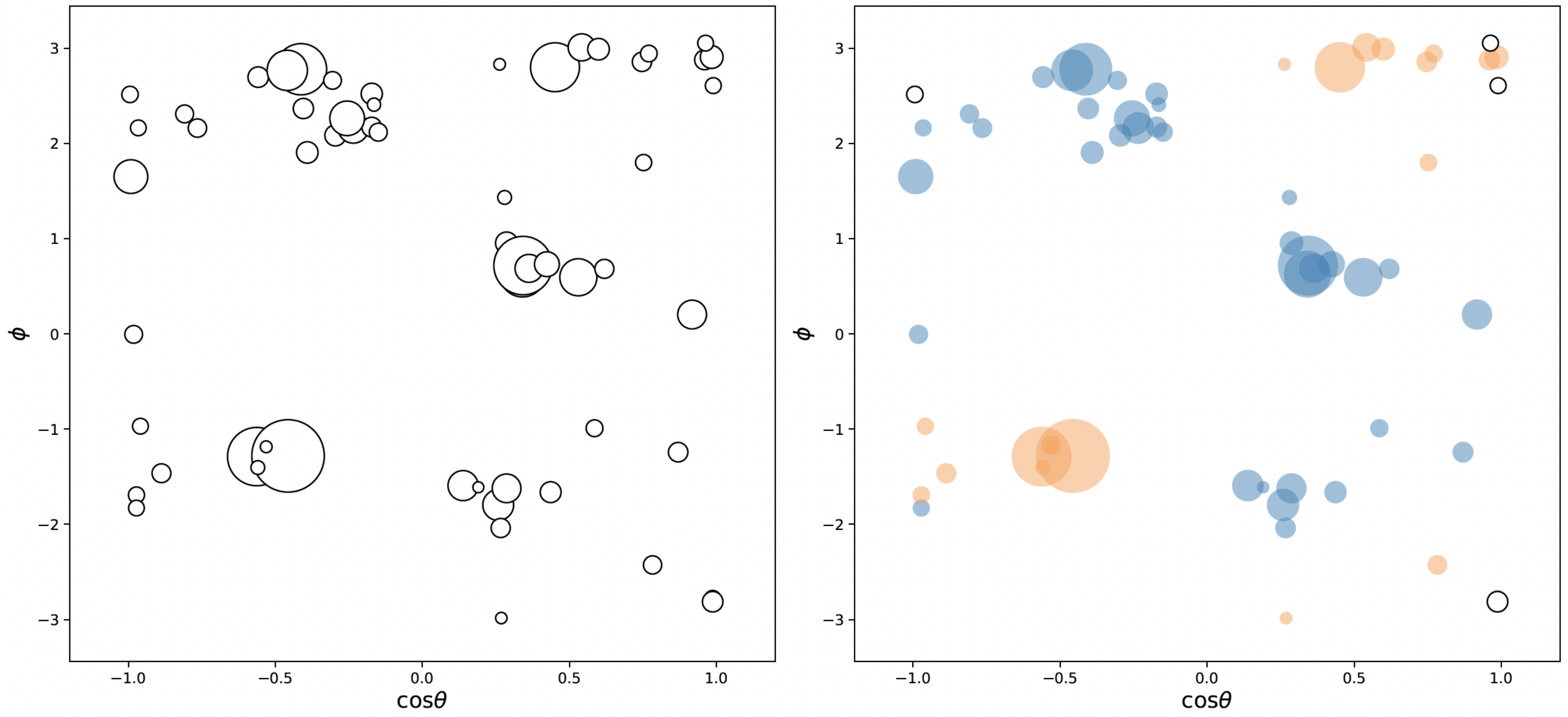
- H→cc & gg measurements at qqH channel is much worse vvH channels, despite the former has 3.5 times more signal statistic
- Reason: Failure of Color Singlet Identification – to distinguish the decay products of each Color Singlet
  - Z & H for 240/250 GeV Higgs factory
  - Which Higgs boson for Higgs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

4 jet configuration...





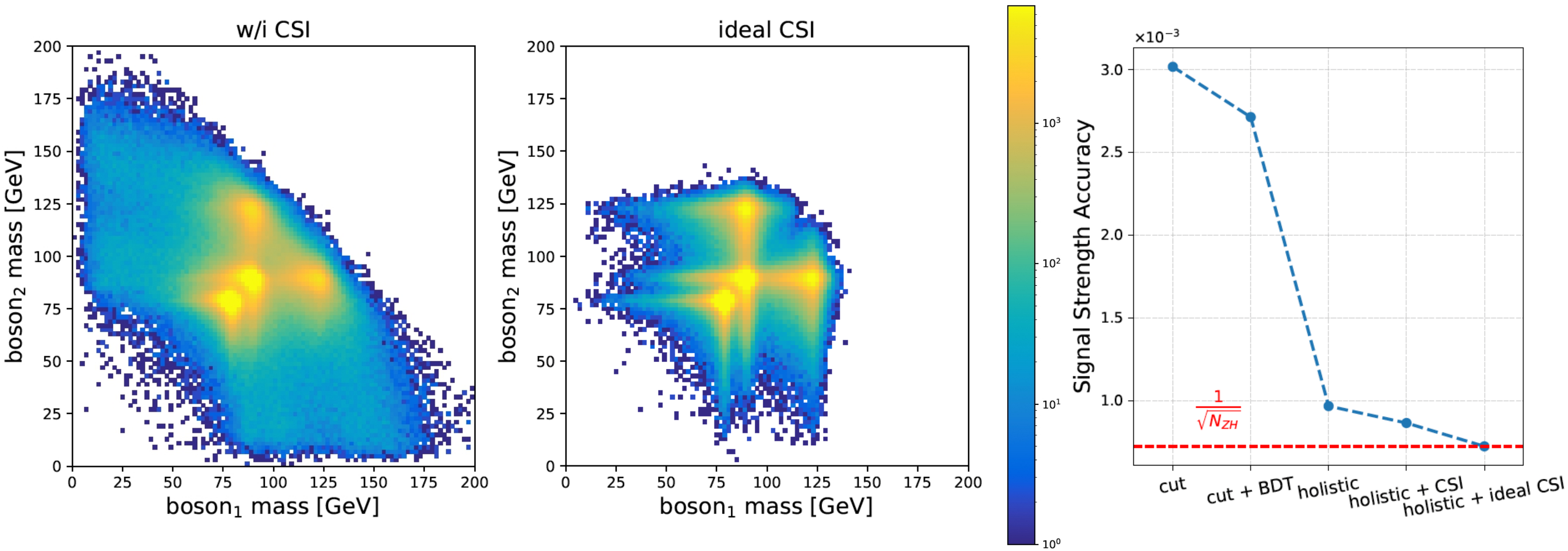
Advanced CSI using AI



Yongfeng, Hao, Yuexin, etc

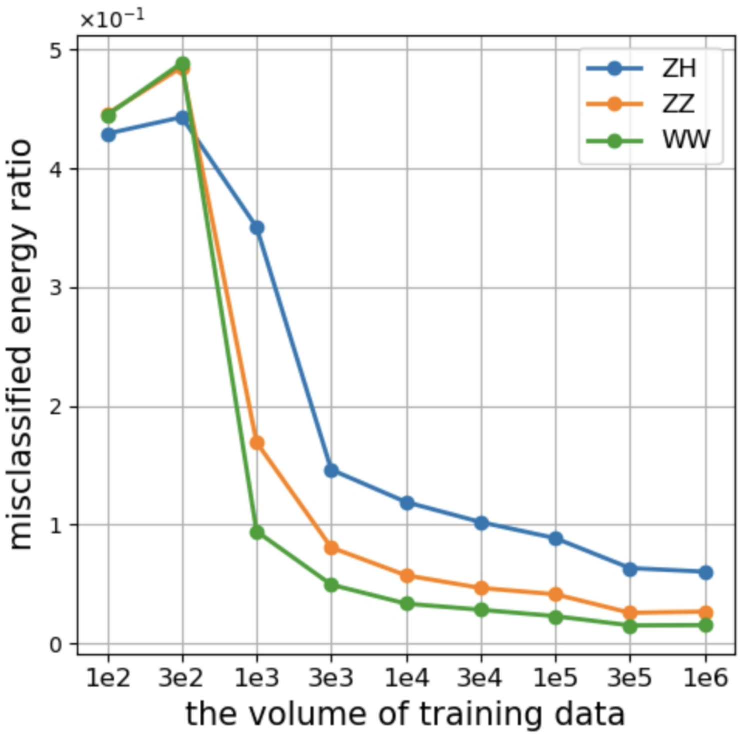
A toy analysis: identify full hadronic ZH signal from ZZ + WW background

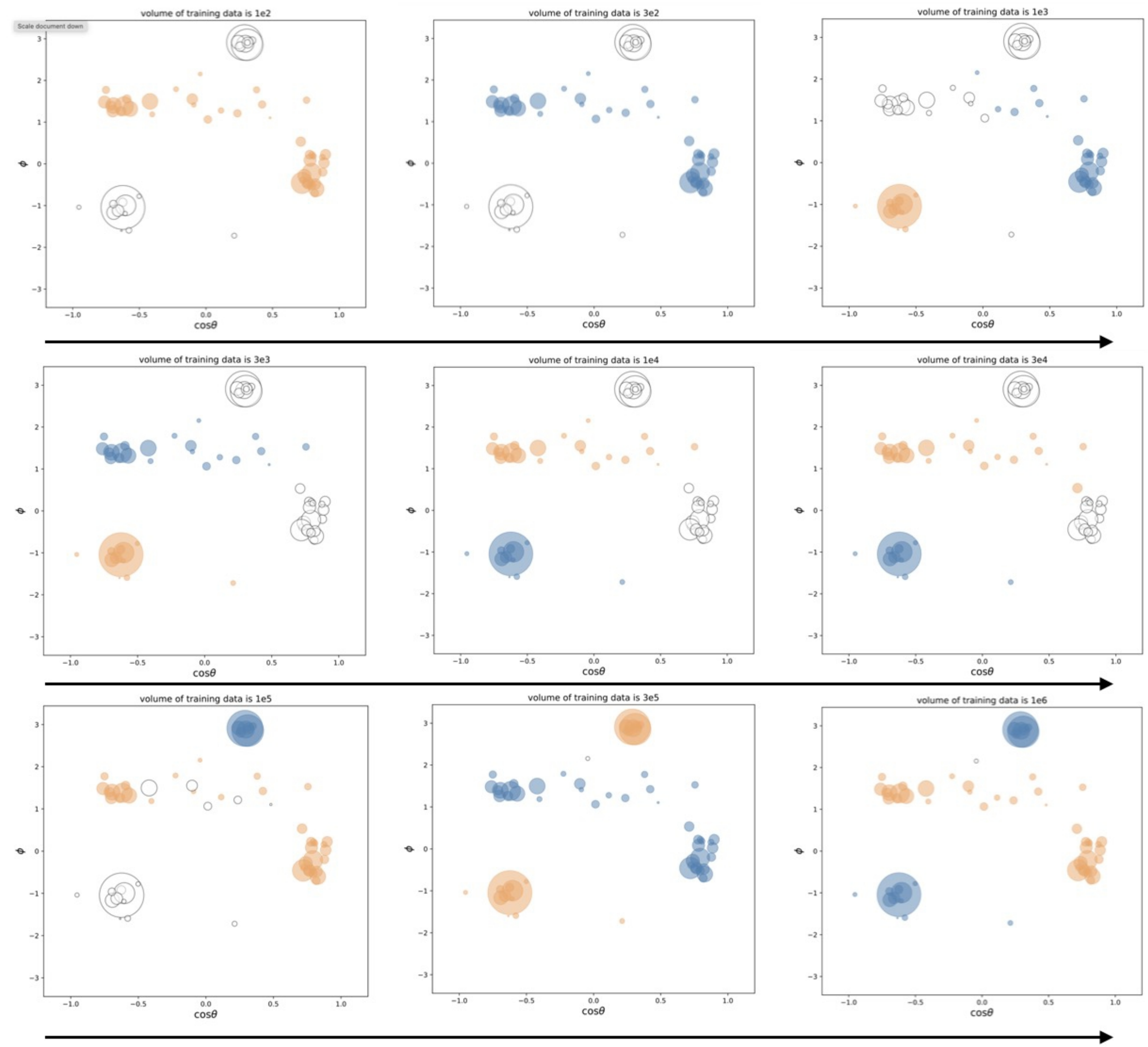
540k ZH + 3.1M ZZ + 47 M WW full hadronic events (~ 5.6 iab), result scale to 20 iab



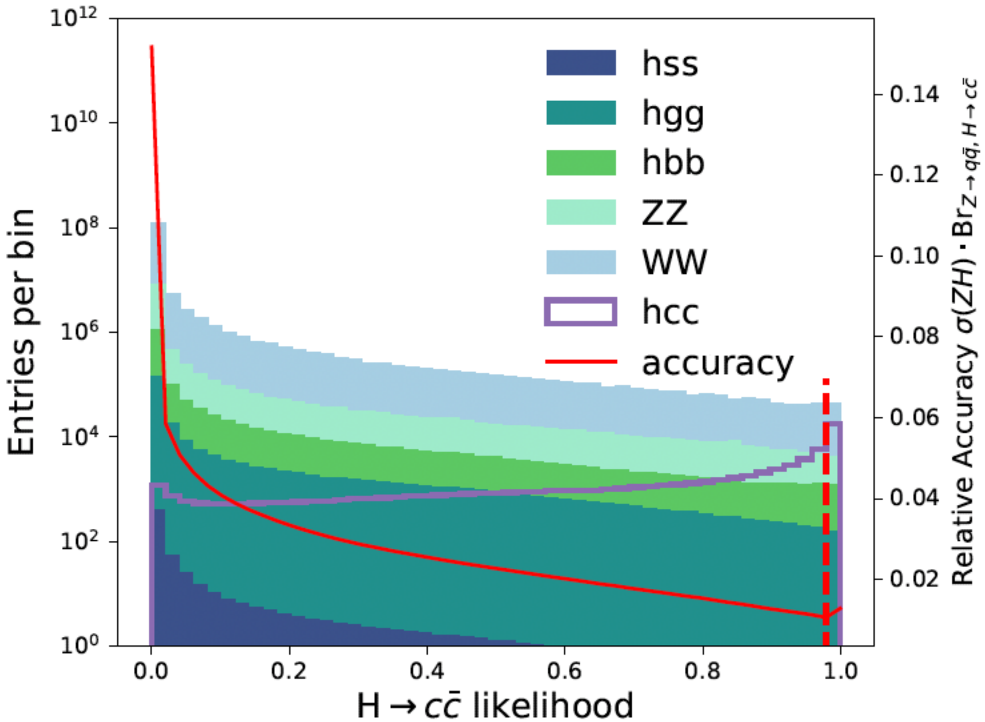
Holistic: use all the reconstructable info to category signal & different background

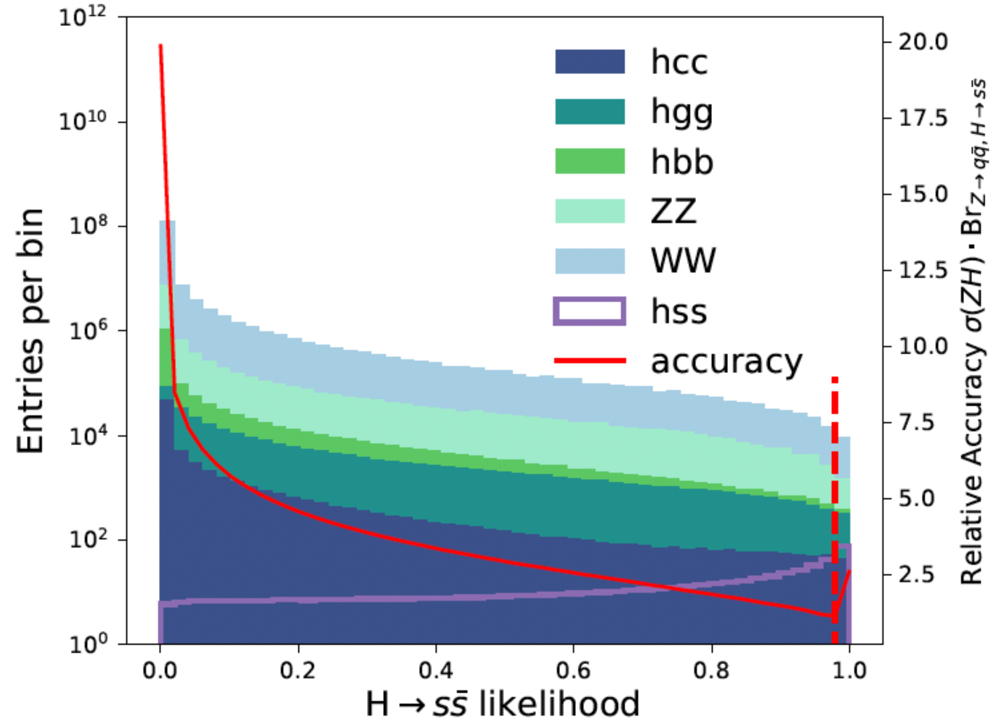
Scaling behavior





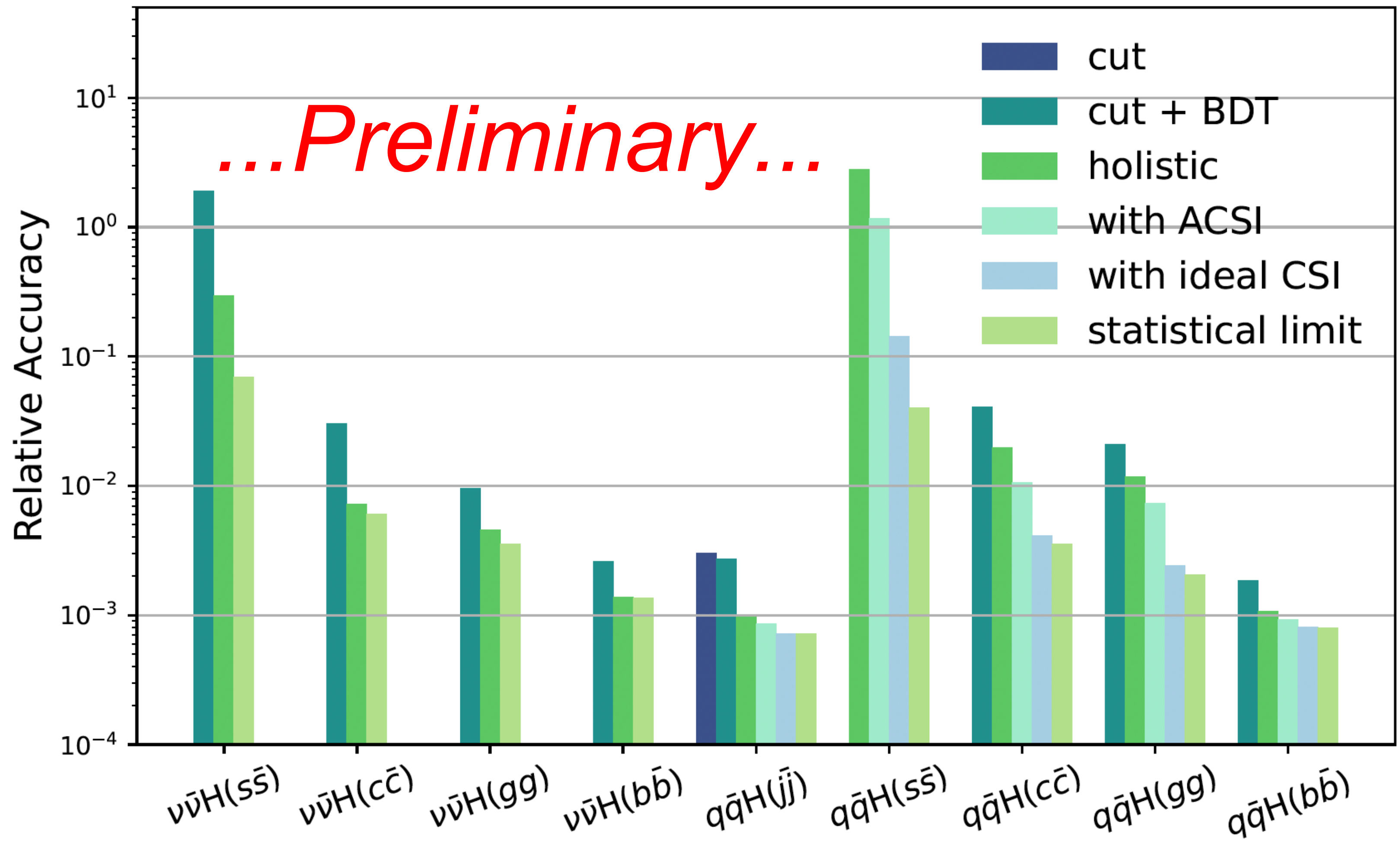
Measurement of qqH, etc





	$Z(\nu\bar{\nu})H$				$Z(q\bar{q})H(q\bar{q}/gg)$	$Z(q\bar{q})H$			
	$H\to b\bar{b}$	$H\to c\bar{c}$	$H\to gg$	$H\to s\bar{s}$		$H\to b\bar{b}$	$H\to c\bar{c}$	$H\to gg$	$H\to s\bar{s}$
cut + BDT	0.26%[5]	3.04%[5]	0.96%[5]	190.00%[15]	0.27%	0.19%[5]	4.10%[5]	2.10%[5]	-
holistic	0.14%	0.72%	0.46%	29.34%	0.097%	0.11%	1.96%	1.05%	279.39%
holistic with CSI	-	-	-	-	0.087%	0.09%	1.03%	0.73%	114.20%
holistic with ideal CSI	-	-	-	-	0.072%	0.08%	0.41%	0.24%	14.32%
statistical limit	0.14%	0.61%	0.36%	6.91%	0.072%	0.08%	0.35%	0.21%	4.02%

Holistic approach + ACSI



Holistic + ACSI: improves the accuracy by 2 – 5 times.
ACSI makes a leap even from Holistic, but still has quite some margin to improve...
H→ss within the reach...

Meta questions

- Problem categorization
  - Identification problem: JoI, Pid, 1-1 correspondence (from Arbor)
  - Grouping problem: Color singlet id, tracking, clustering, ...
  - Assessment/regression problem: such as energy/momentum/time estimation, fitting
  - What's the most suited corresponding AI architecture, or general AI, and Why?
- AI for HEP, and HEP for AI (HEP → Science)
  - HEP, as a mature & vivid field, has the potential to impact the AI development, i.e., interpretability analysis
- Be relax, and have fun!...

Summary

- Higgs factory: extremely rich physics requires excellent performance
- **Trilogy**: Significantly enhance the discovery power & alter the experiments design
  - Jet Origin ID: 'see' quark & gluon as lepton & photon
    - *...A “game changer” and opens new horizon for precise flavor studies at all future experiments...*
  - 1-1 correspondence, Should & Could for the Higgs factory... or maybe generally future HEF
    - Present, temporally, the ultimate goal for det. Pattern recognition...
    - Provide much more detailed info for system monitoring & systematic control
  - Holistic Approach + Advanced CSI: New Paradigm for analysis - Task sharing between Human & AI:
    - Human specify the end
    - AI as the mean – while the processing is in principle free from human intervene
- Bottleneck Shifts & Lots to be explored
  - Confusion → Det. Acceptance & resolution...
  - Clever variable selection → High Quality MC: better QCD modeling, high precision calculation, detector calibration – monitoring, event building...
  - Interplay between Particle Physics & AI...

Resources

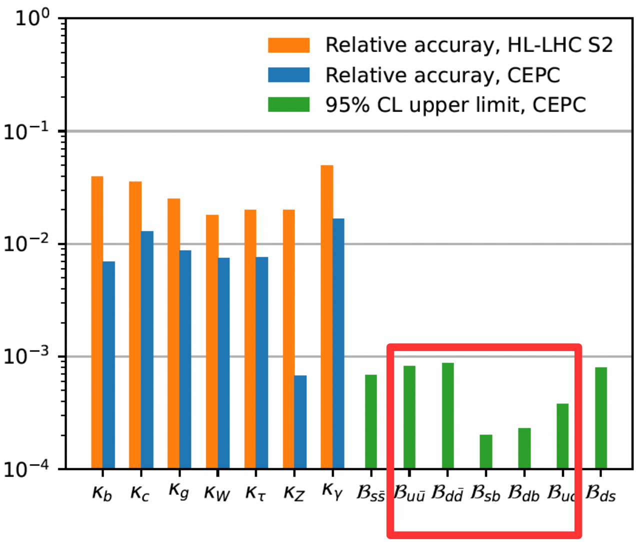
- Jet Origin id: zhuyongfeng@pku.edu.cn
- https://github.com/ZHUYFgit/CEPC-Jet-Origin-Identification/tree/main

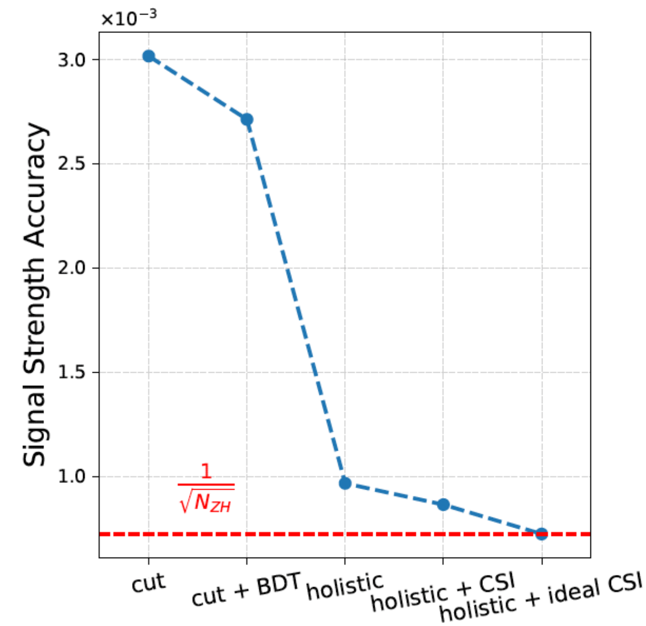
- LLM (BINBBT):
- https://github.com/supersymmetry-technologies/bbt-neutron

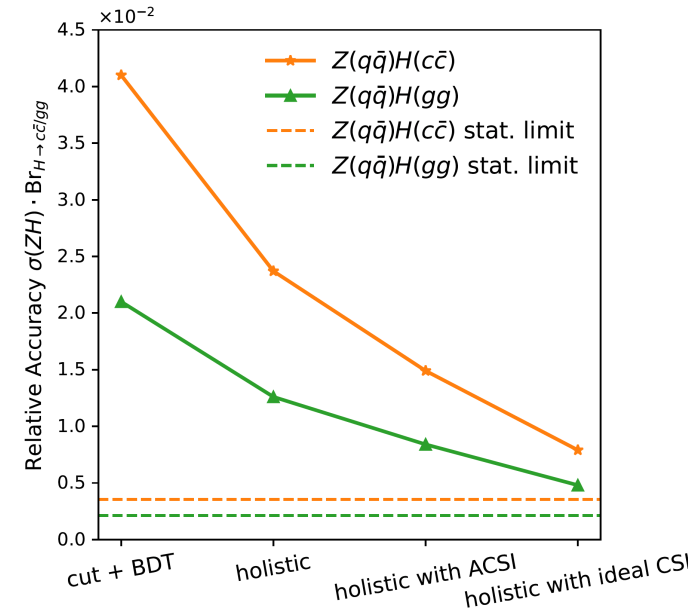
- 1-1 Correspondence: wangyuexin@ihep.ac.cn
- Source deposition in construction...

Back up

Performance & Analysis at AI era

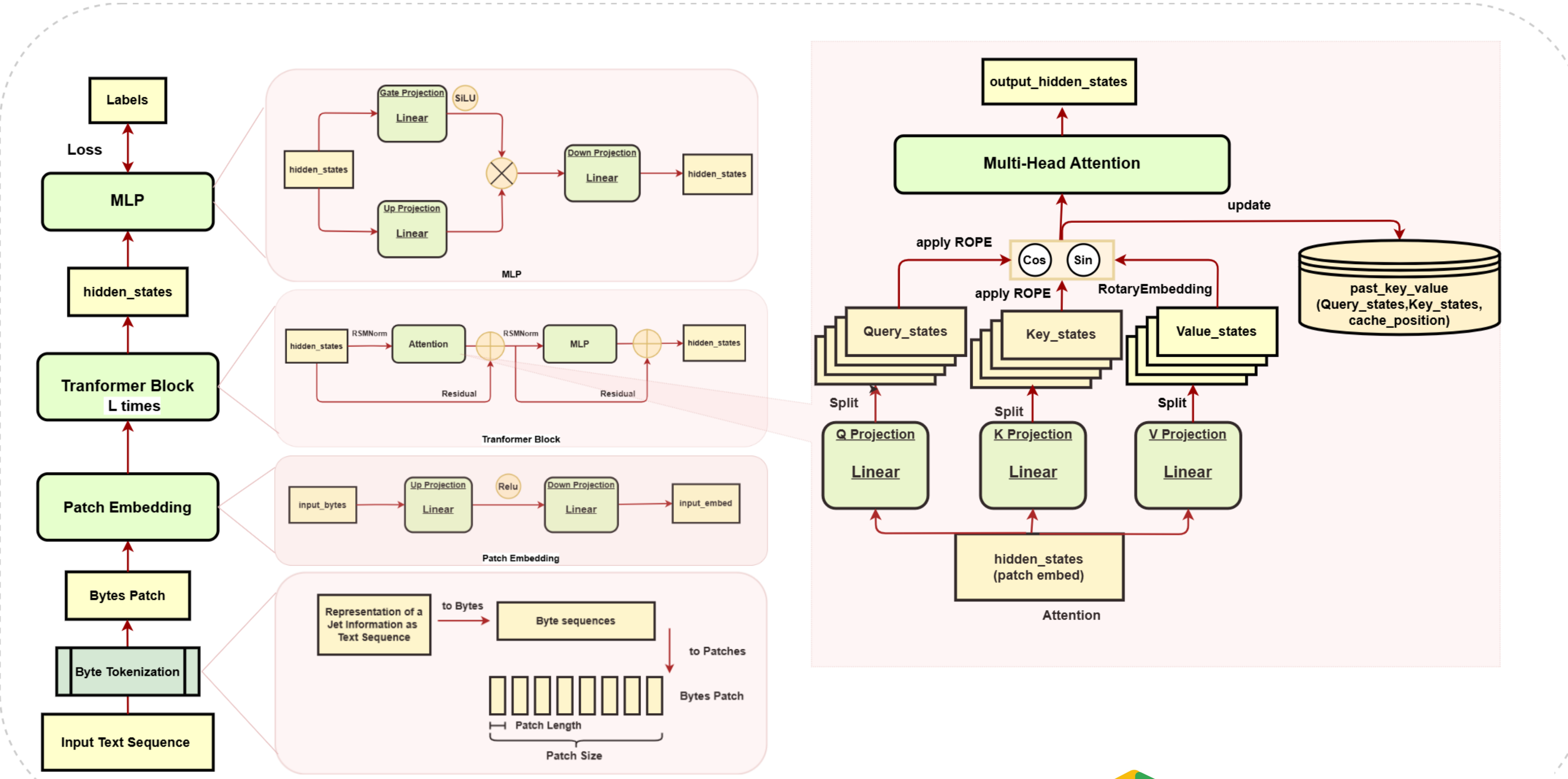






- Physics reach significantly enhanced ... showing the irresistible trend
  - Small signal analysis, i.e., H→ss, cc, gg, or its FCNC decays, improves by 3 times to orders of magnitudes
  - Novel methods enabled (i.e., Afb & CKM measurements with JoI, Advanced Color Singlet Identification, ...)
  - Strong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

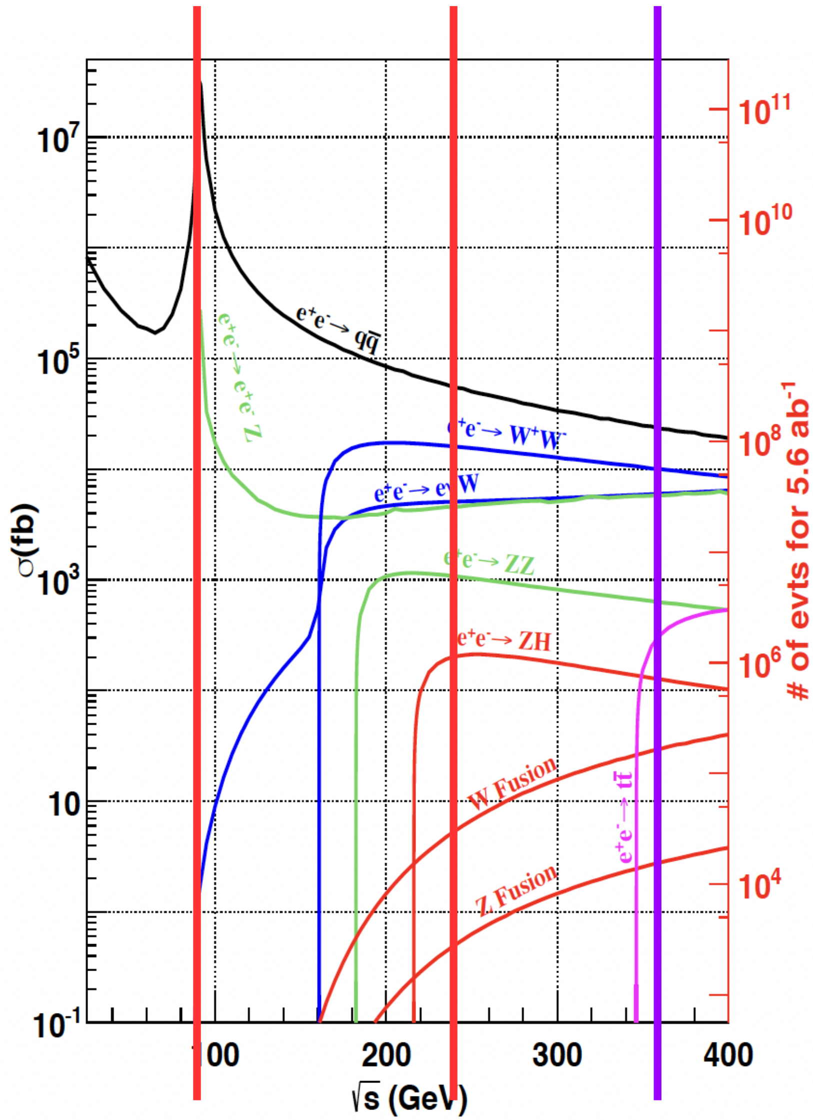
Recent update: from specialized Models to LLM

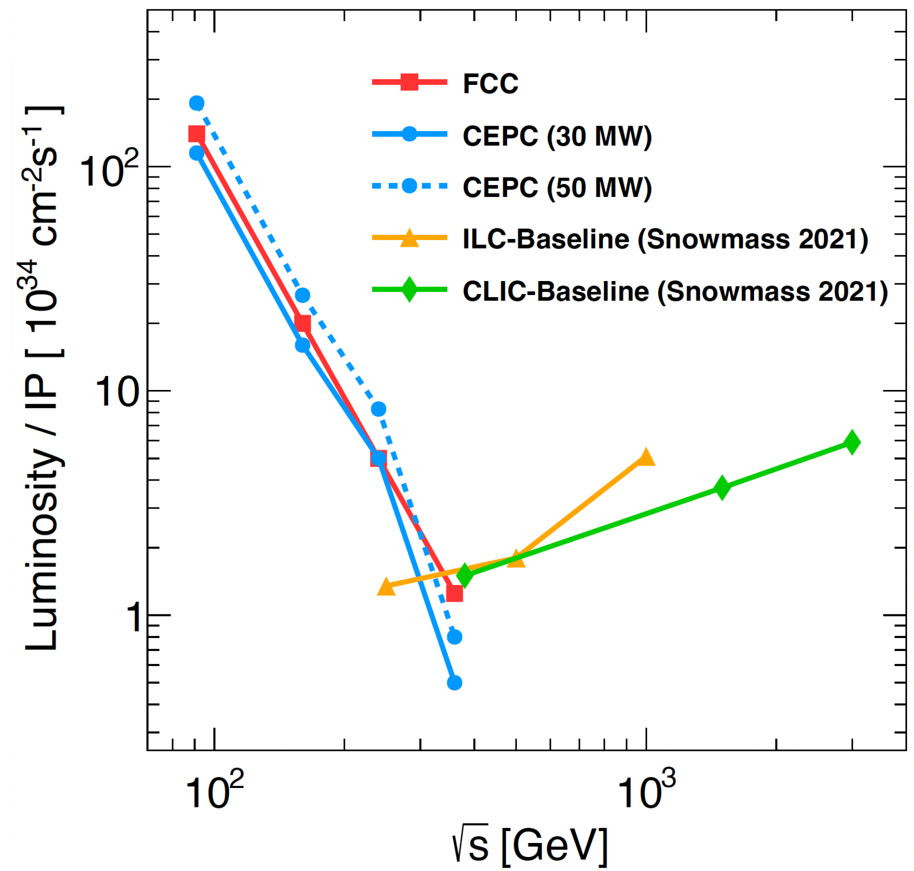


BIN-BBT Model

- New tokenization method to address numeric problems at LLM

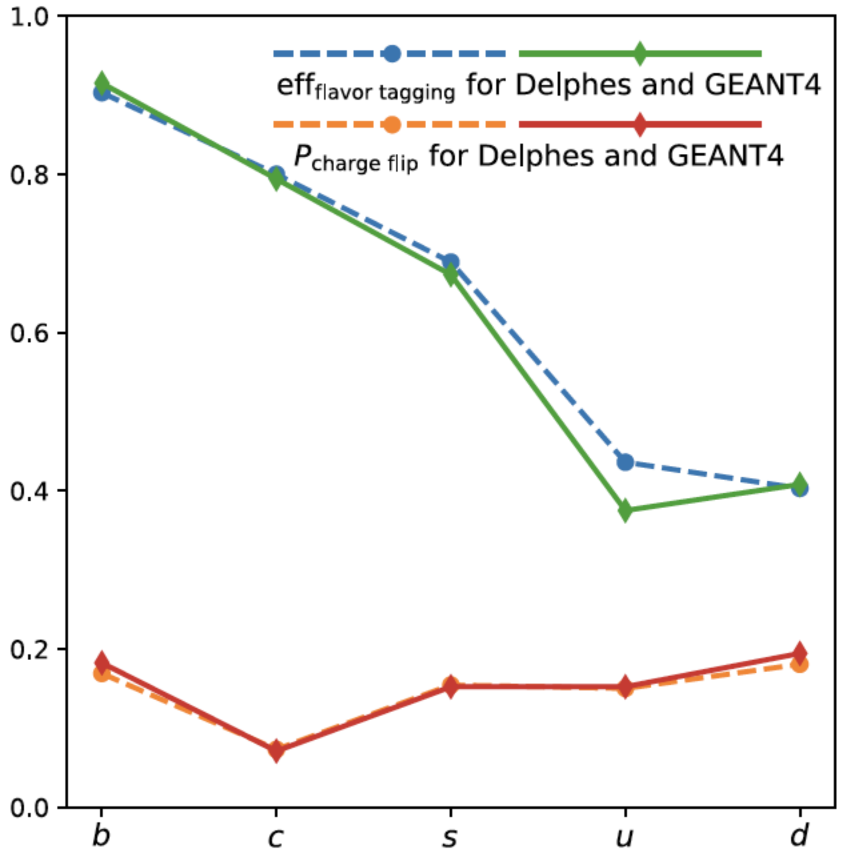
Yields ~ Xsec * Lumi * Time



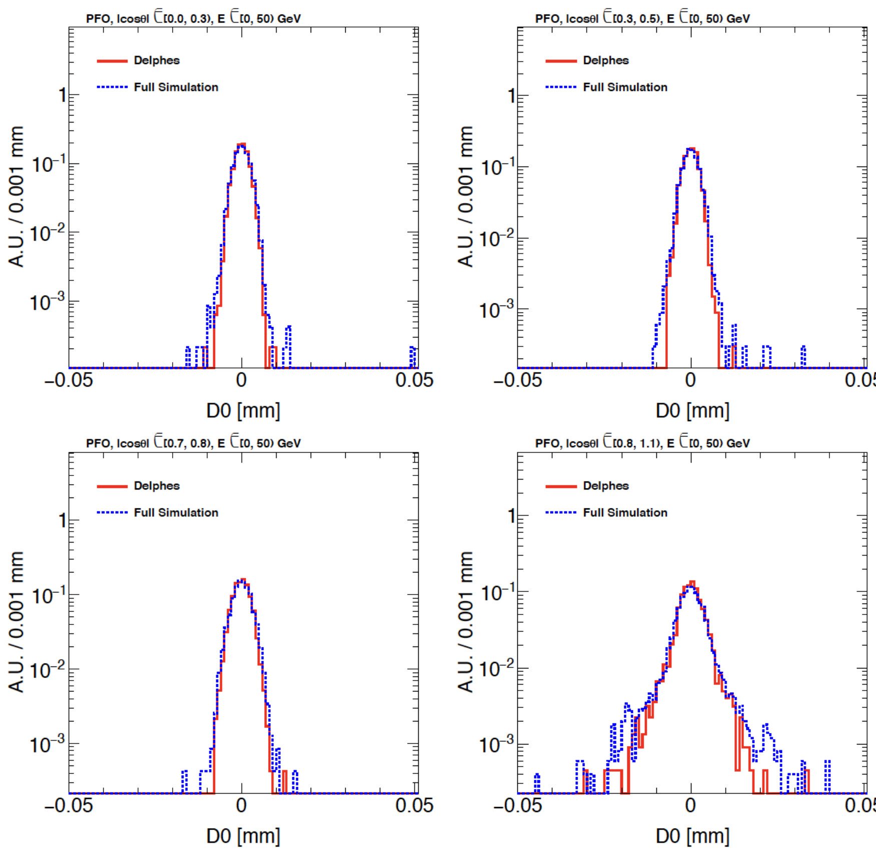


- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

Fast/Full Simulation

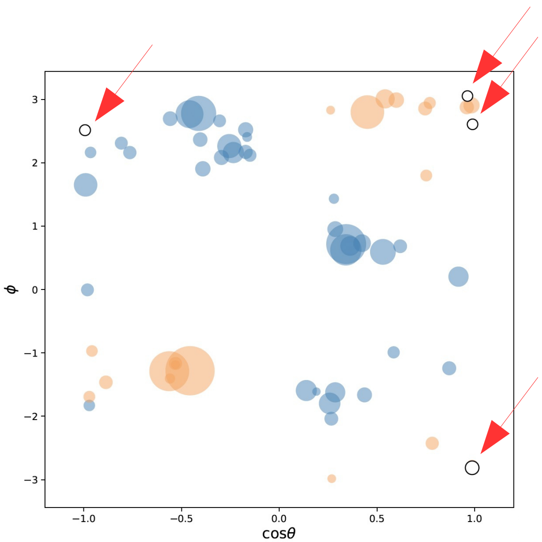


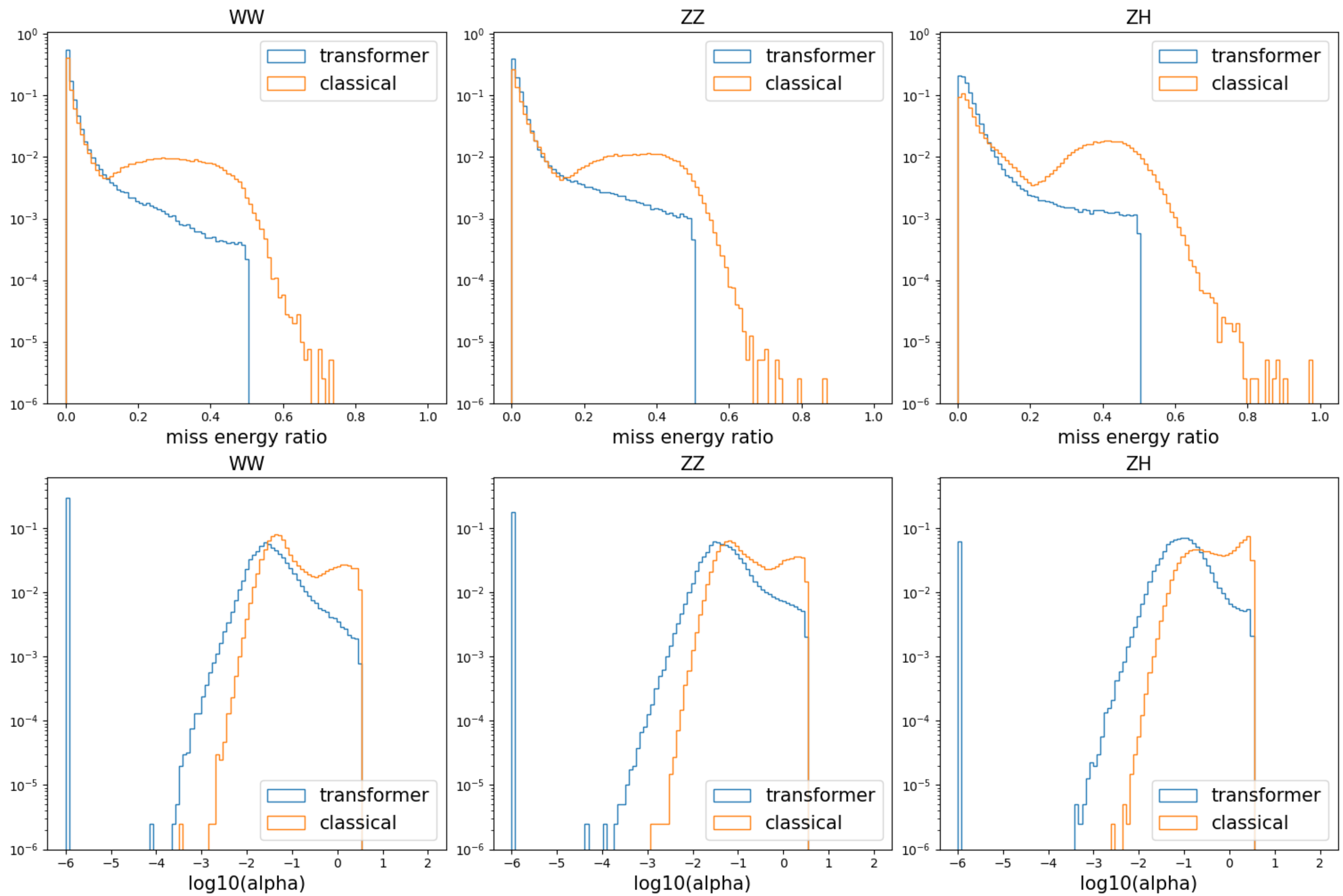
Z->μμ (91.2 GeV)

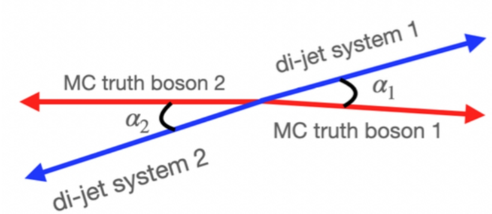


- Delphes ~ Perfect PFA (1 – 1 correspondence..)

CSI: classical VS AI (Transformer)







Classical: Jet Clustering + Matching with min(Chi-2)

1-1 Correspondence

Holistic description of physics events

Efficient & interpretable information compression: (o(1E5) Hits → o(100) reco particles)

~ Confusion Free PFA + Excellent Particle identification

~ New method for the detector monitoring & measurements

arXiv > hep-ex > arXiv:2411.06939

Search...

Help | Adva

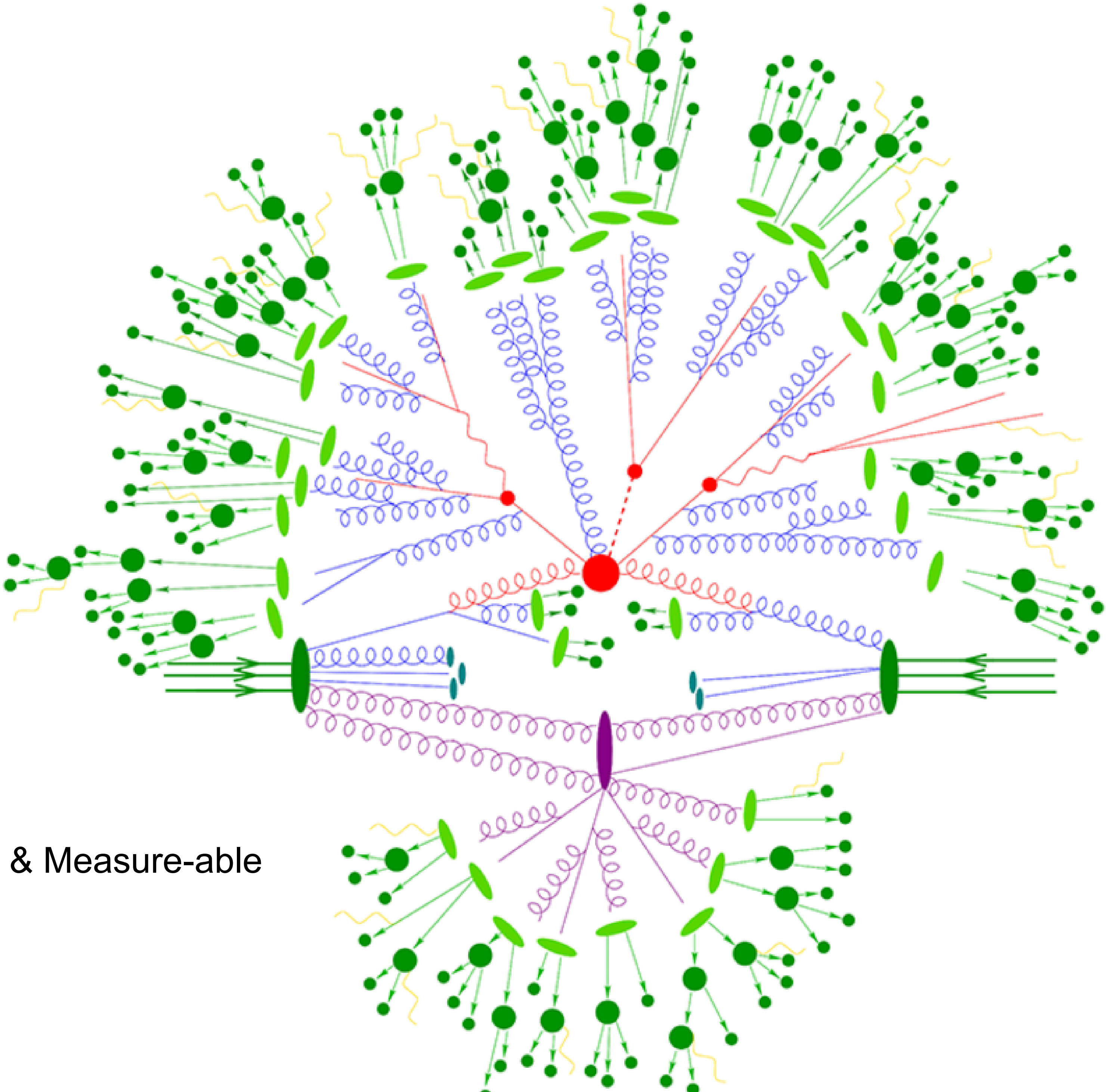
High Energy Physics – Experiment

[Submitted on 11 Nov 2024]

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

Yuexin Wang, Hao Liang, Yongfeng Zhu, Yuzhi Che, Xin Xia, Huilin Qu, Chen Zhou, Xuai Zhuang, Manqi Ruan

We propose one-to-one correspondence reconstruction for electron-positron Higgs factories. For each visible particle, one-to-one correspondence aims to associate relevant detector hits with only one reconstructed particle and accurately identify its species. To achieve this goal, we develop a novel detector concept featuring 5-dimensional calorimetry that provides spatial, energy, and time measurements for each hit, and a reconstruction framework that combines state-of-the-art particle flow and artificial intelligence algorithms. In the benchmark process of Higgs to di-jets, over 90% of visible energy can be successfully mapped into well-reconstructed particles that not only maintain a one-to-one correspondence relationship but also associate with the correct combination of cluster and track, improving the invariant mass resolution of hadronically decayed Higgs bosons by 25%. Performing simultaneous identification on these well-reconstructed particles, we observe efficiencies of 97% to nearly 100% for charged particles ($e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, $p/\bar{p}$) and photons (γ), and 75% to 80% for neutral hadrons (K_L^0, n, $\bar{n}$). For physics measurements of Higgs to invisible and exotic decays, golden channels to probe new physics, one-to-one correspondence could enhance discovery power by 10% to up to a factor of two. This study demonstrates the necessity and feasibility of one-to-one correspondence reconstruction at electron-positron Higgs factories.

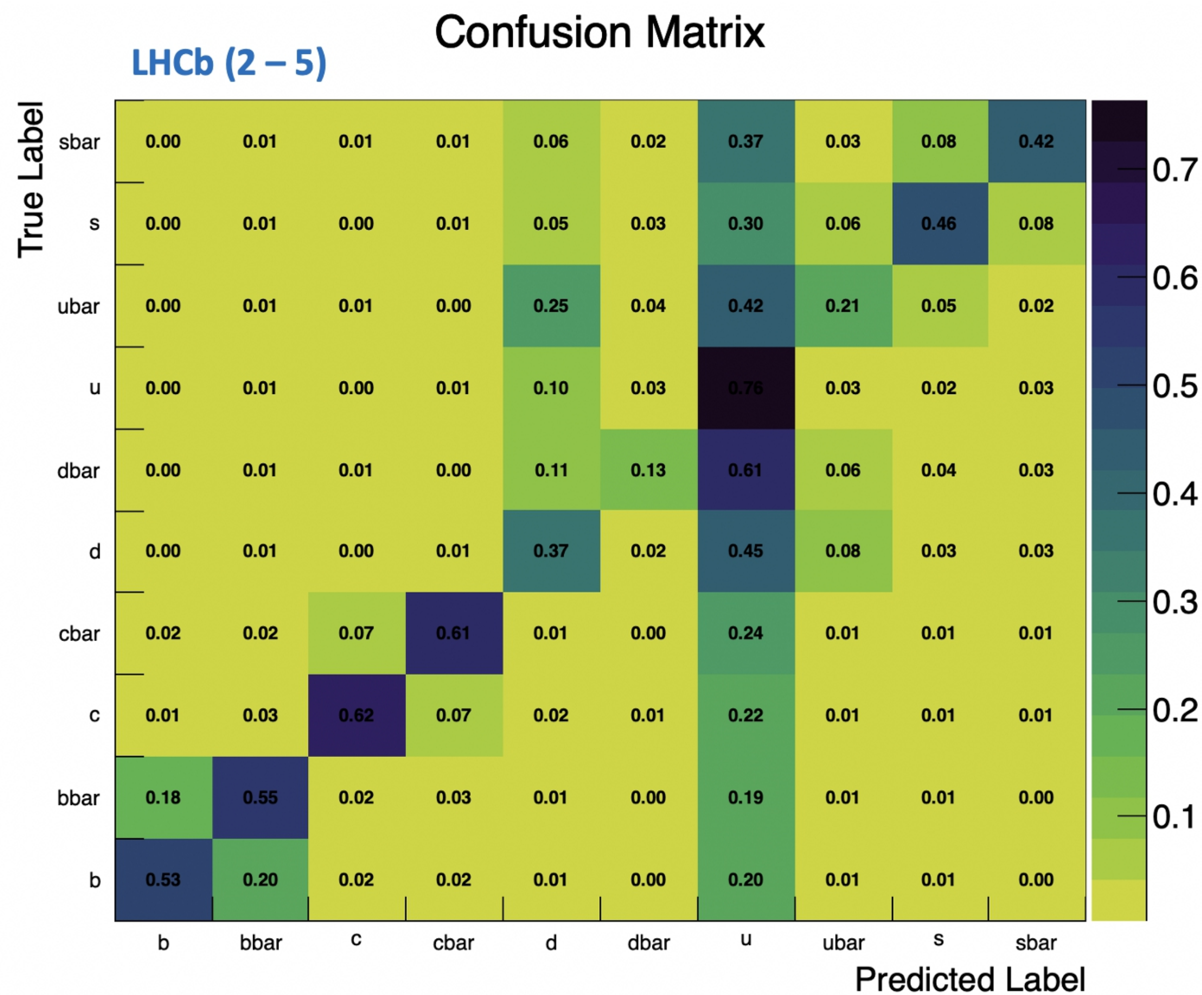


Calculable & Measure-able

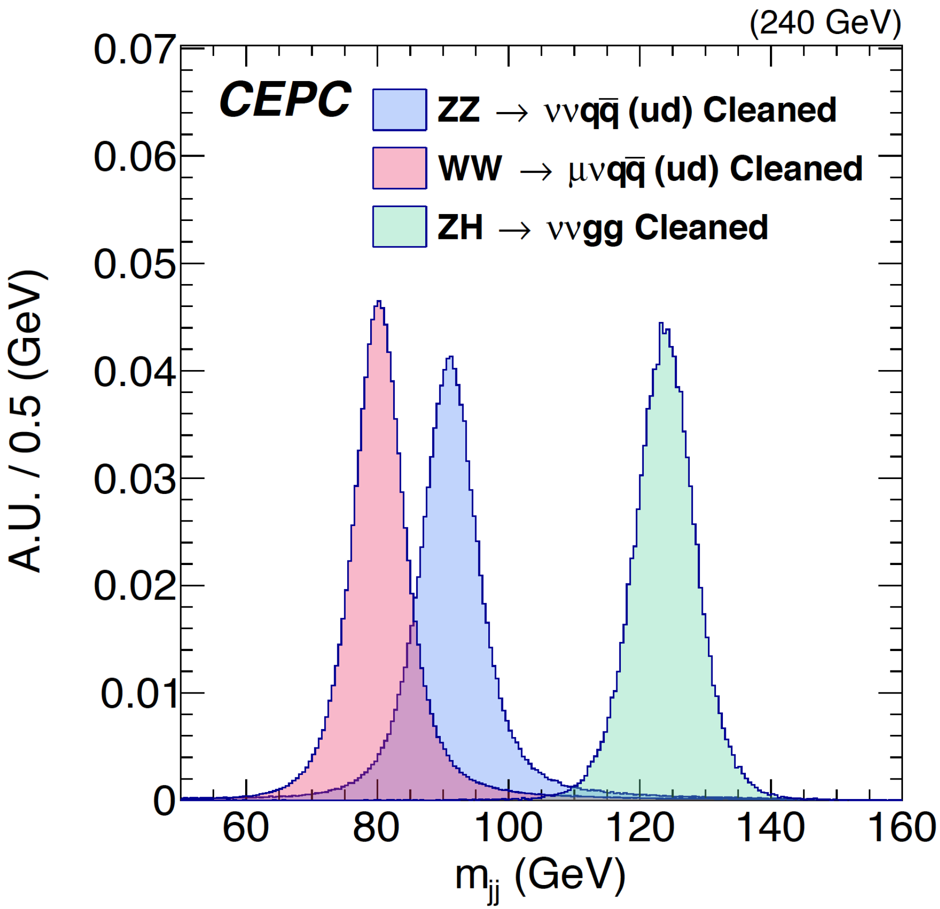
Preliminary test on LHC

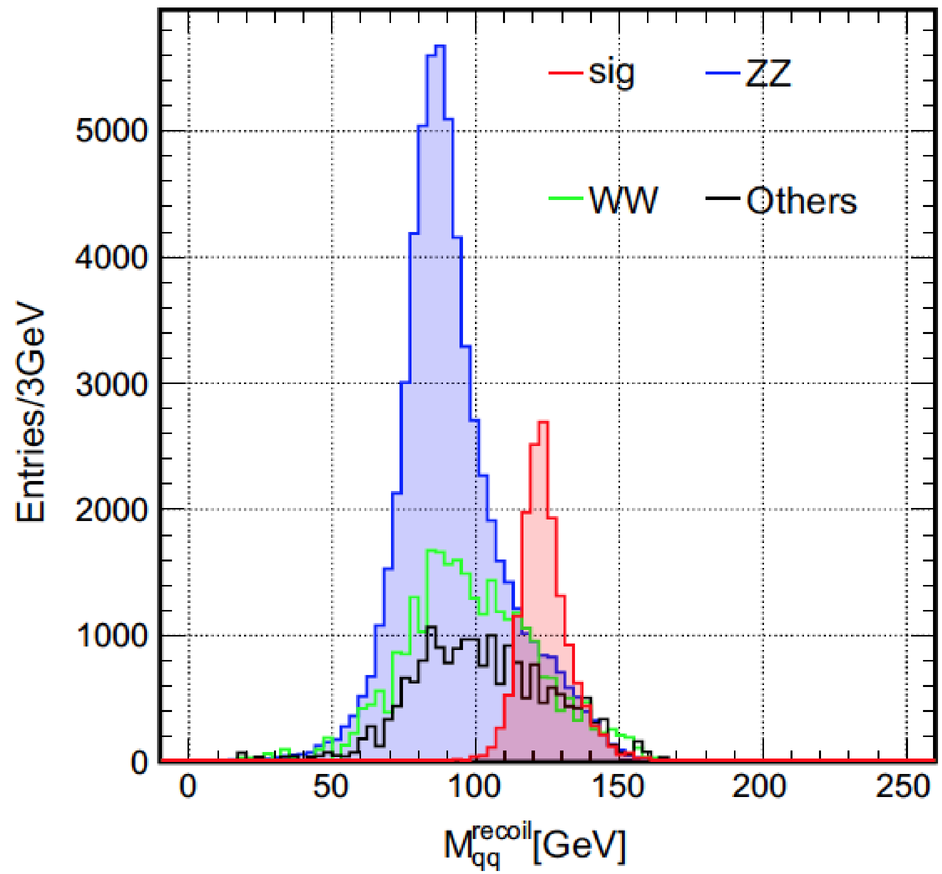
Jet origin identification at LHC energy LHCb acceptance

- Truth level information:
  - PID
  - Kintematics
  - Vertex
- Round 200,000 jets used for training
- Asymmetry between u/ubar, d/dbar



Boson Mass Resolution: Key Per. Para



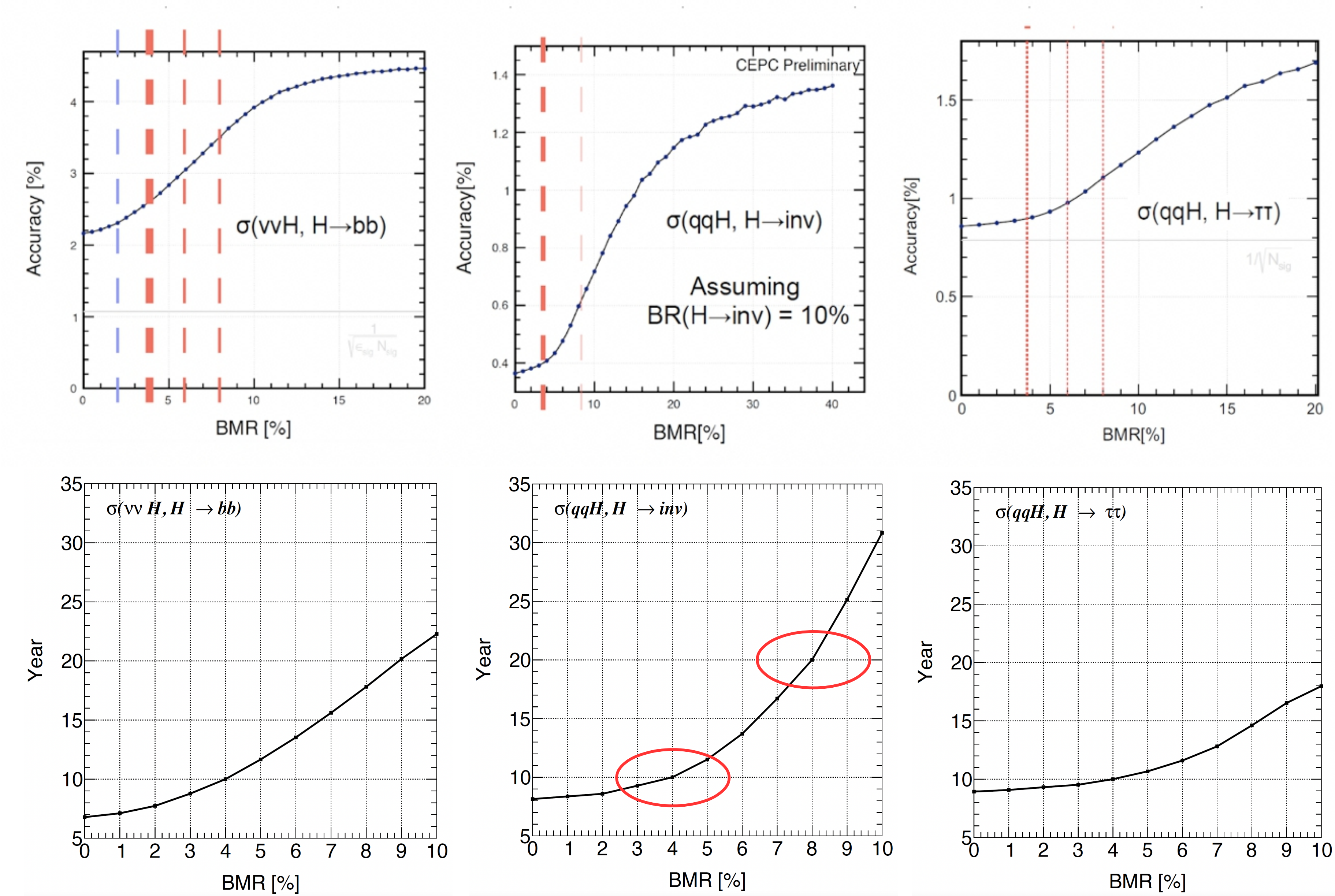


Higgs factory: need BMR < 4% (critical for qqH & qqZ separation using recoil mass to di-jet)

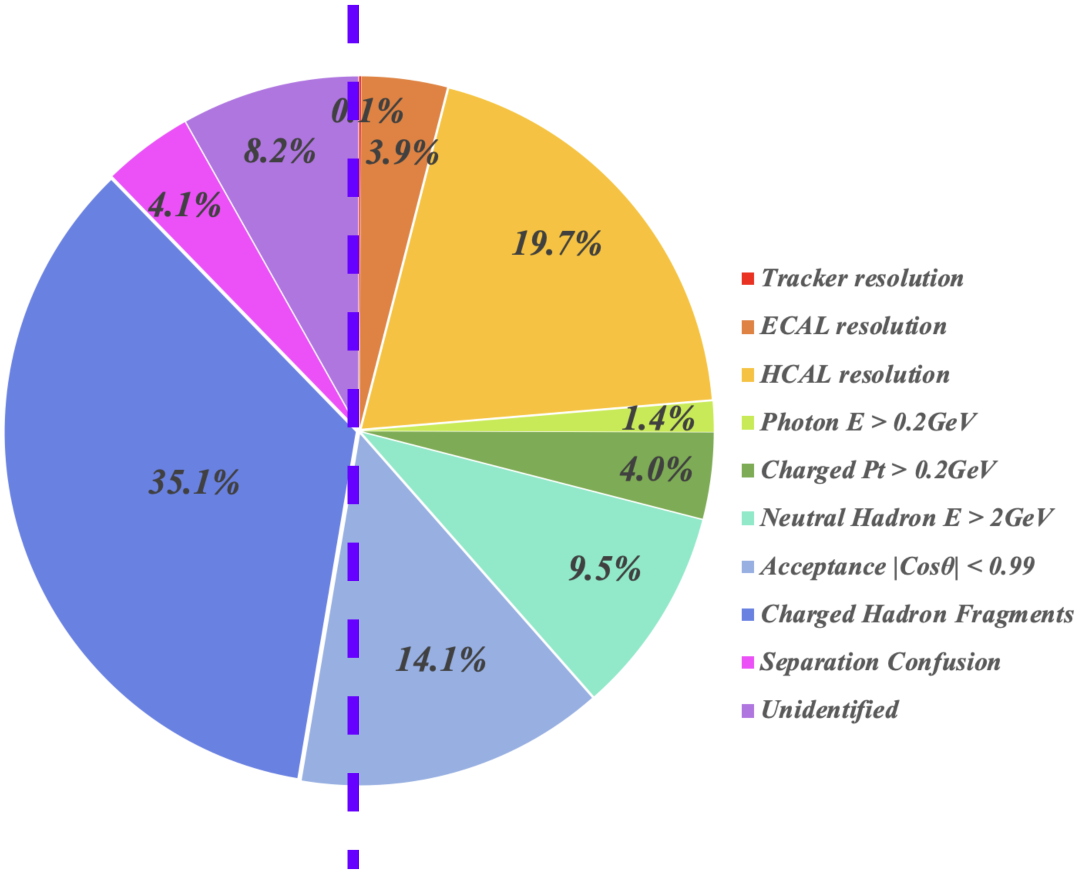
Strongly motivated to improve BMR to 3% or even lower, especially for NP & Flavor

CDR baseline (left plot): BMR = 3.75%

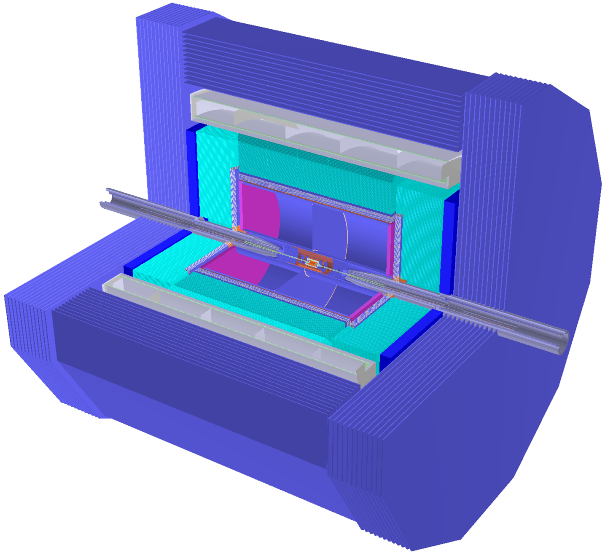
BMR: impact on critical measurements



BMR decomposition @ CDR baseline

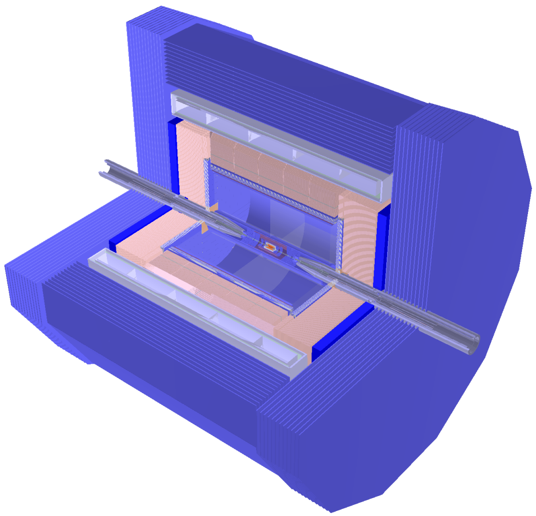


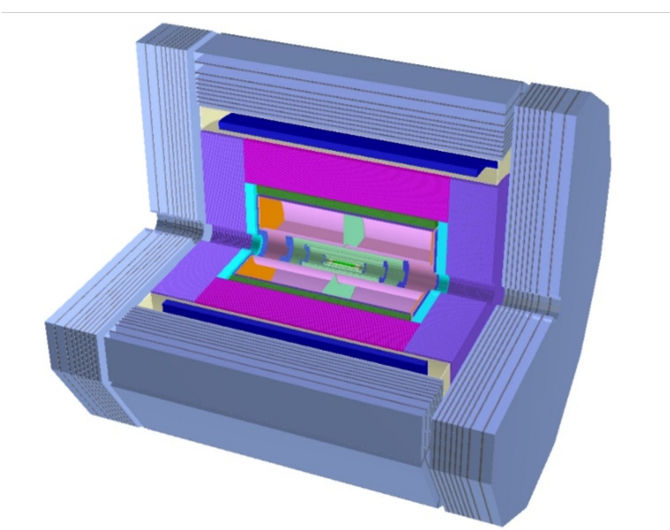
- *1st HCAL resolution dominant the uncertainties from intrinsic detector resolution: need better HCAL → usage of GSHCAL*
- *2nd Leading contribution: Confusion from shower Fragments (fake particles), need better Pattern Reco.*

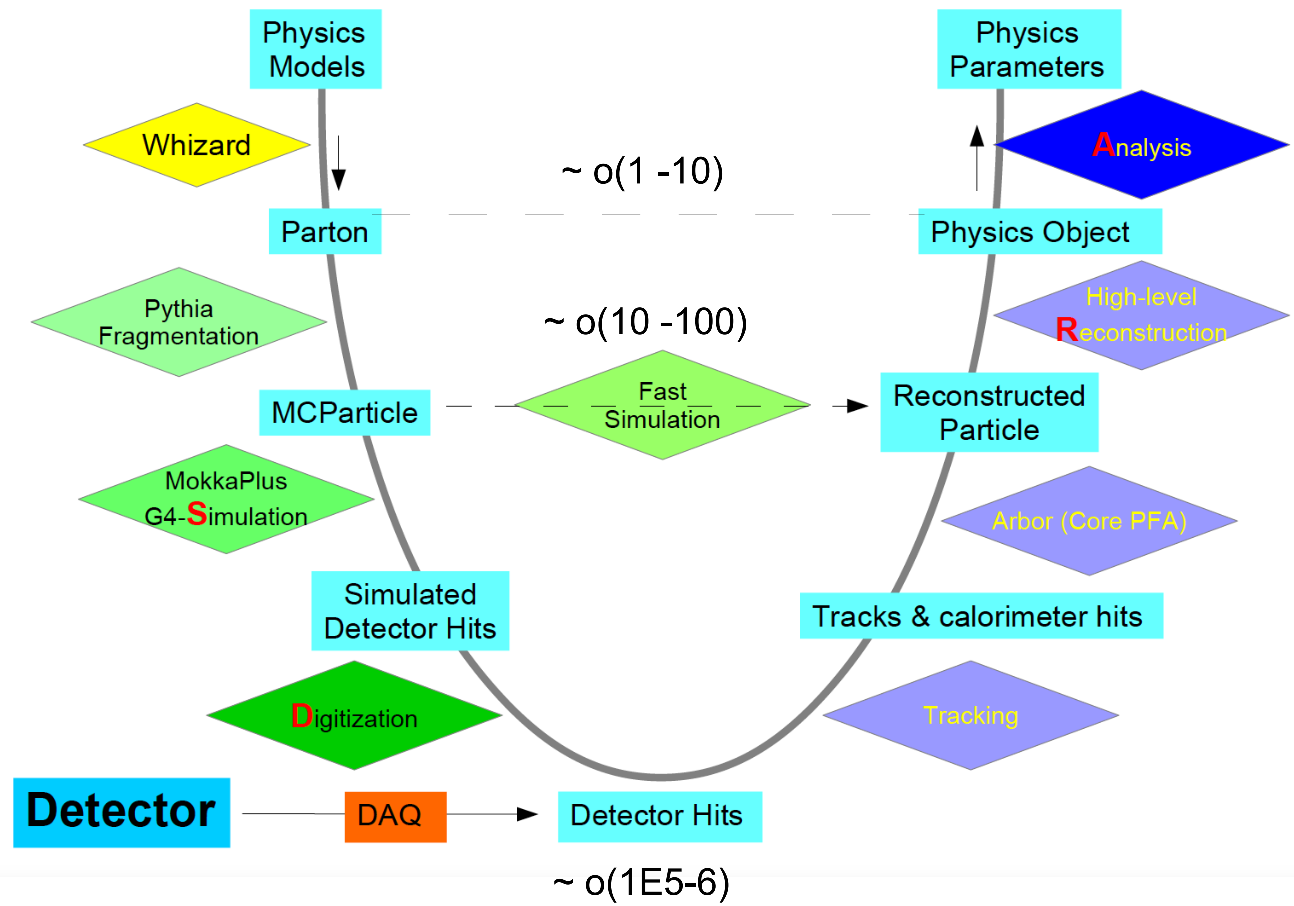


- *CDR baseline - GRPC HCAL*

CEPC Detector & Reconstruction





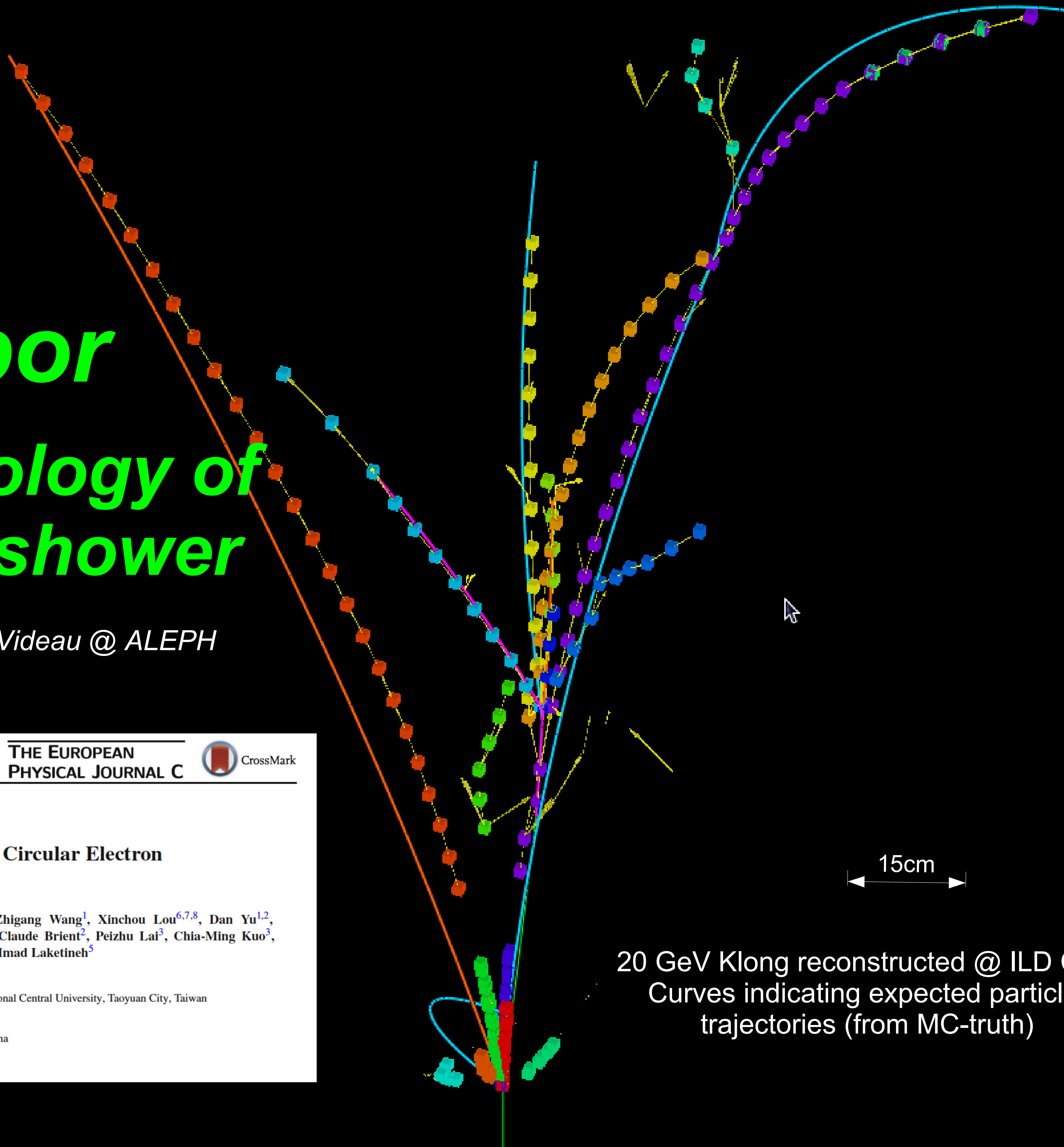


Full simulation reconstruction Chain with **Arbor, etc**

Arbor

Tree topology of particle shower

Ori. Idea from Henri Videau @ ALEPH



20 GeV Klong reconstructed @ ILD Calo
Curves indicating expected particle trajectories (from MC-truth)

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https://doi.org/10.1140/epjc/s10052-018-5876-z

THE EUROPEAN PHYSICAL JOURNAL C

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Special Article - Tools for Experiment and Theory

Reconstruction of physics objects at the Circular Electron Positron Collider with Arbor

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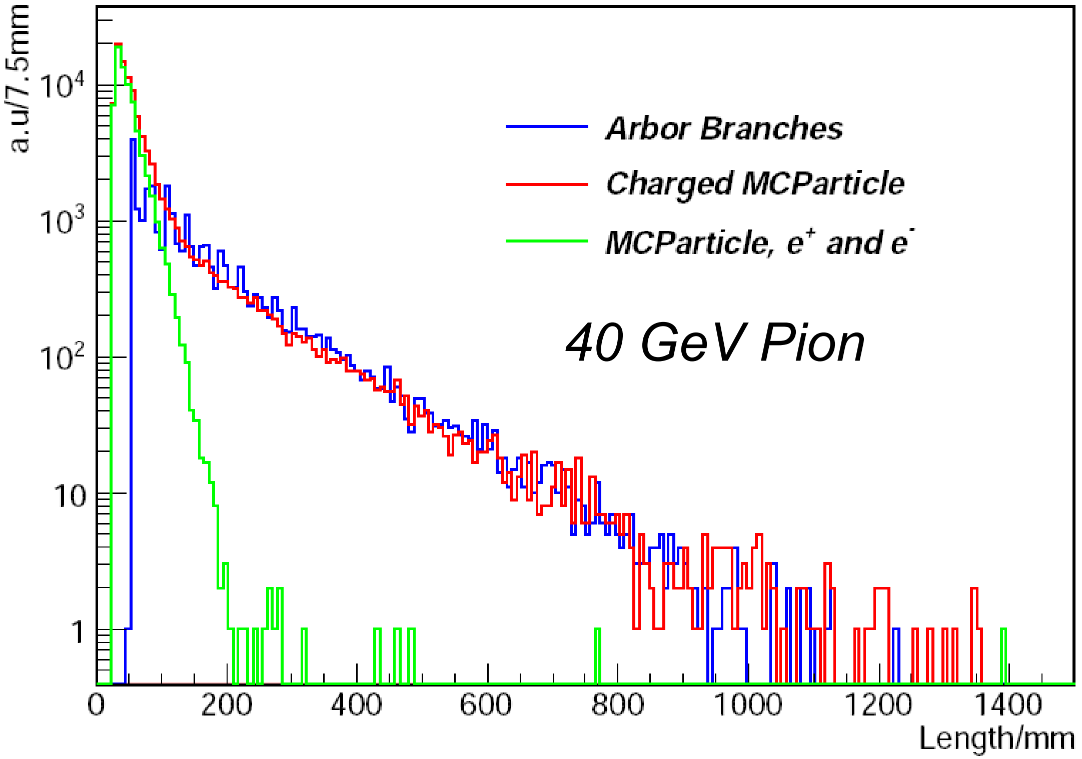
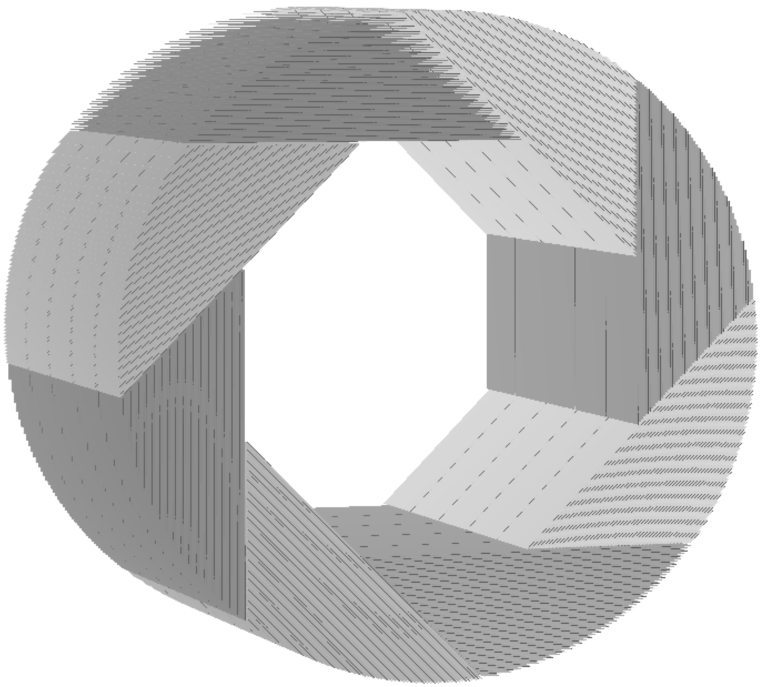
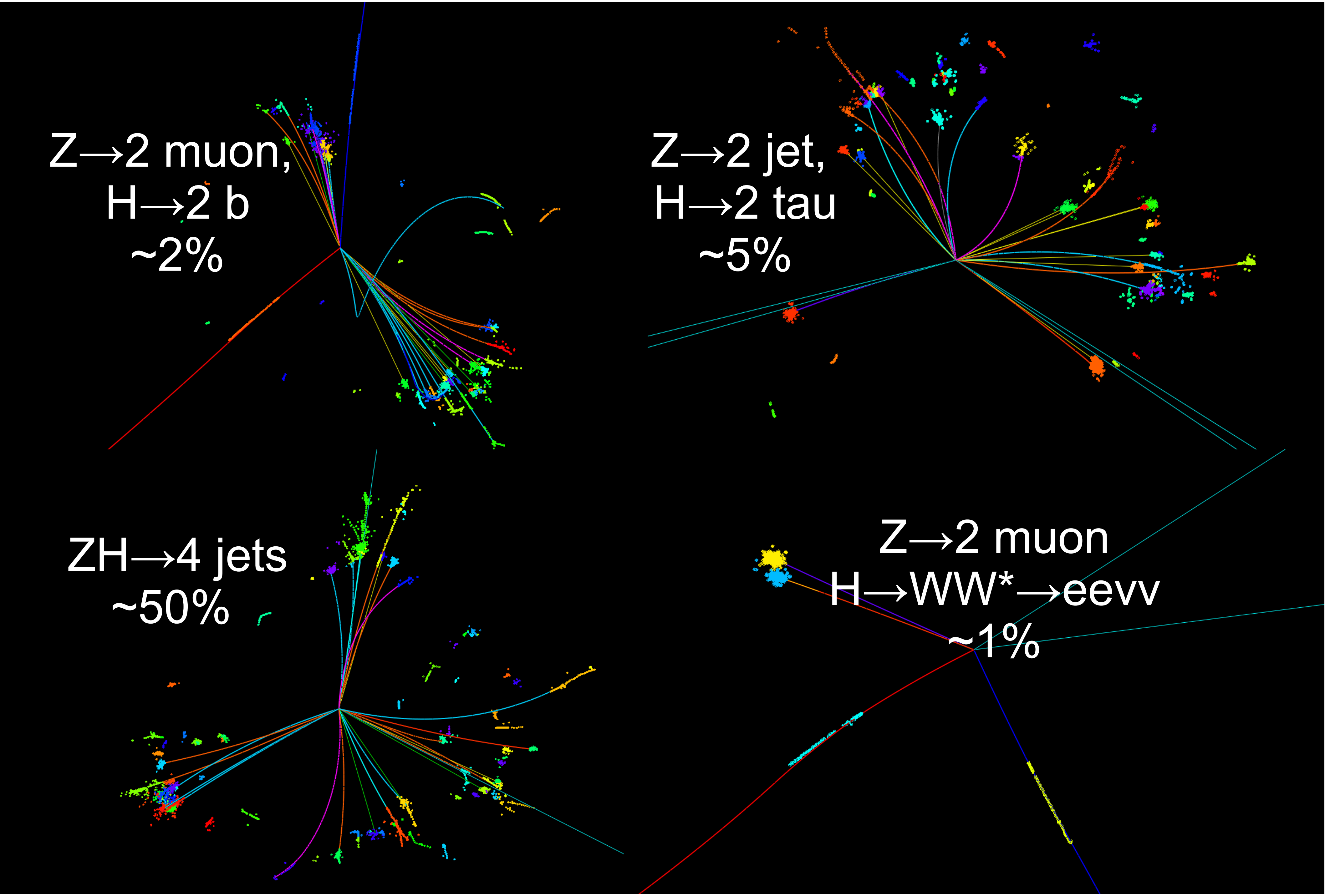
Validation: Arbor Branch Length Vs MC Truth



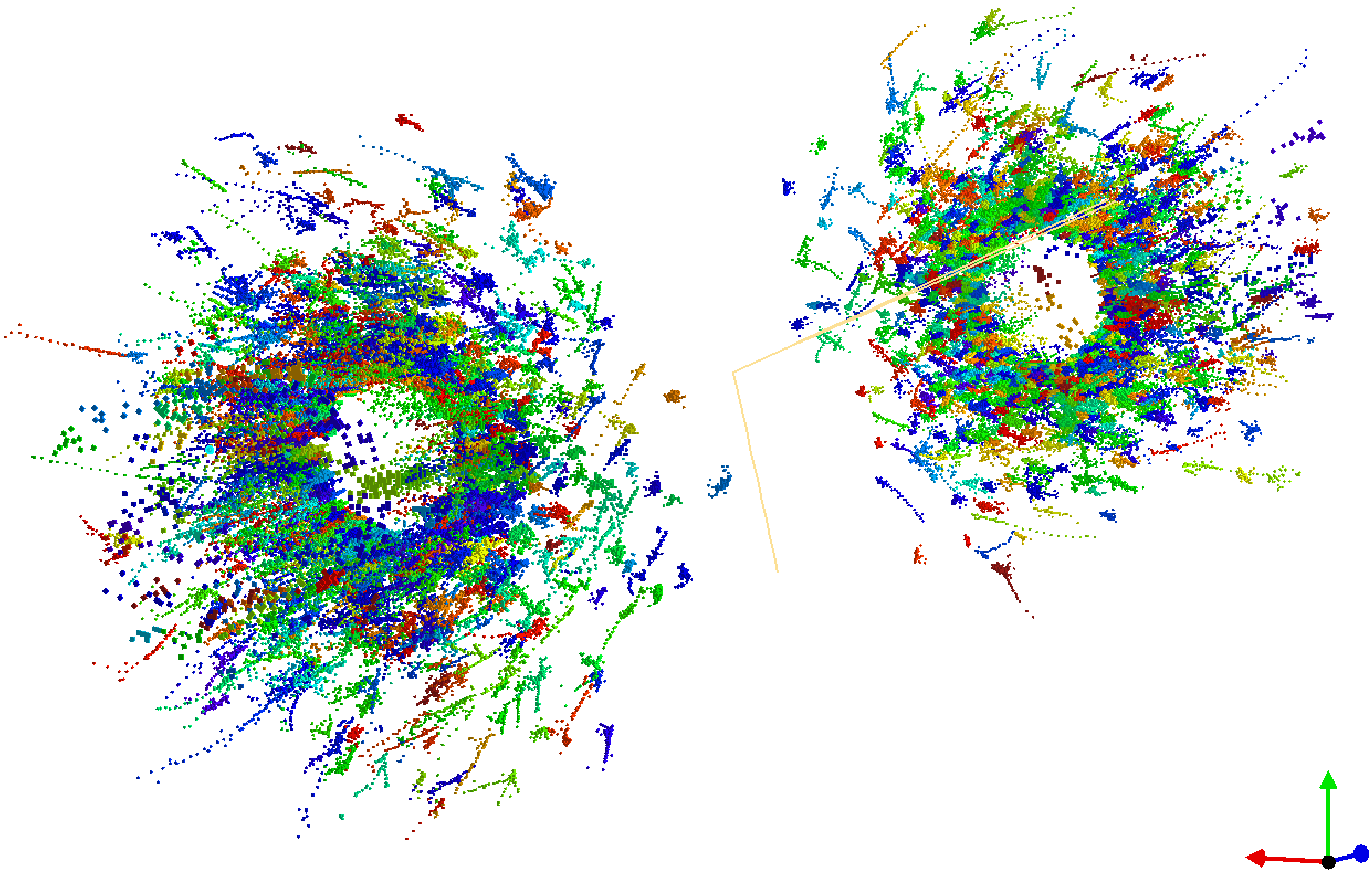


Arbor: successfully tag sub-shower structure

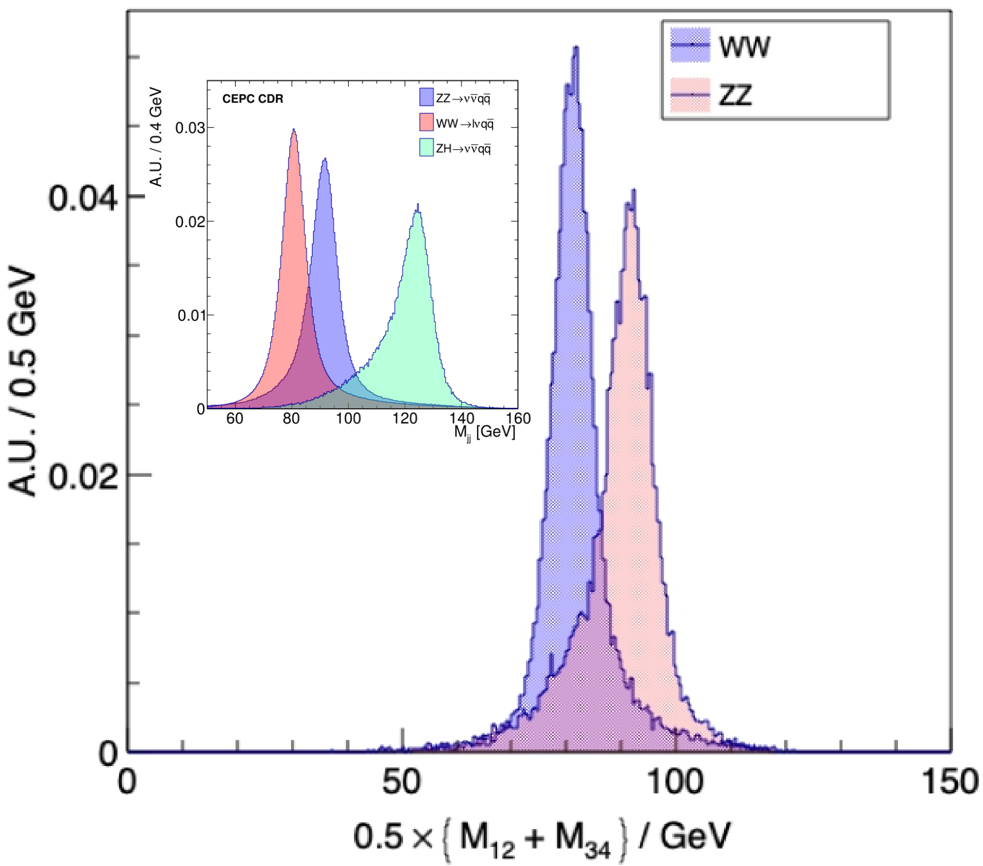
Samples: Particle gun event at ILD HCAL (readout granularity 1cm^2 & layer thickness 2.65cm)
Length:
Charged MCParticle: spatial distance between generation/end points
Arbor branch: sum of distance between neighboring cells

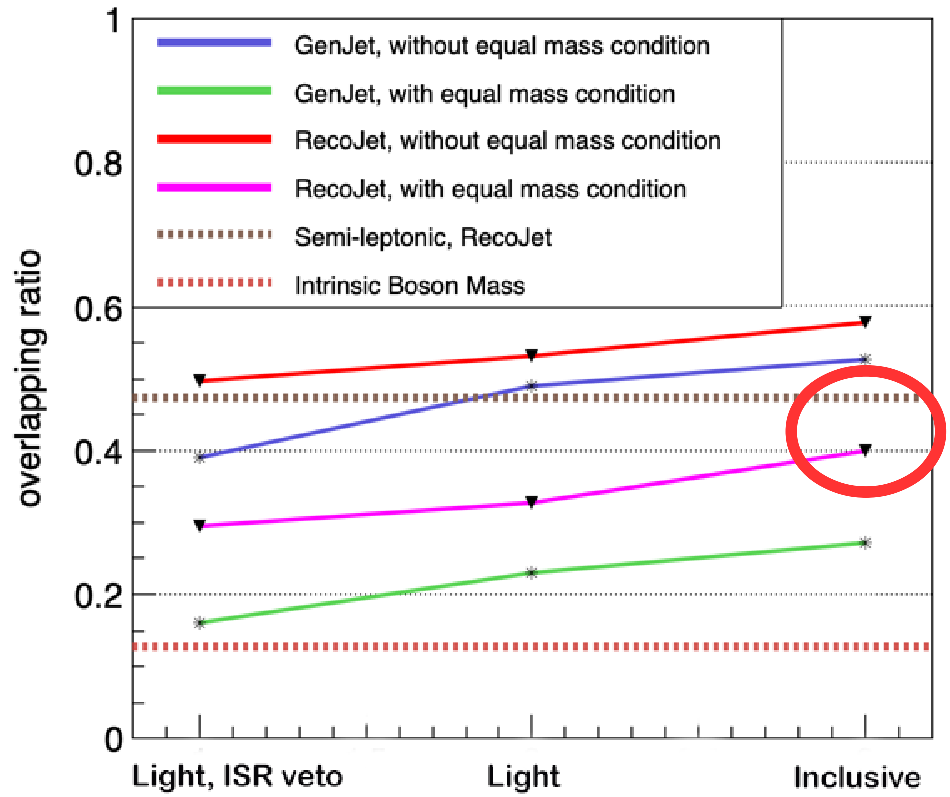

Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

CMS Experiment at LHC, CERN
Data recorded: Thu Jan 1 01:00:00 1970 CEST
Run/Event: 1 / 1201
Lumi section: 13



Separation of full hadronic WW-ZZ event





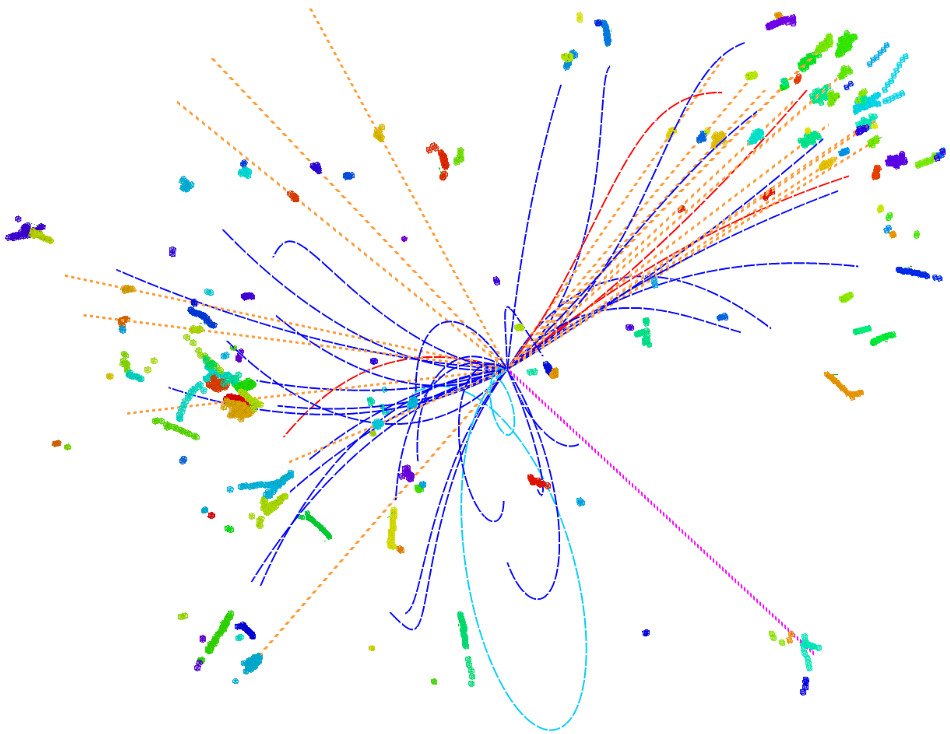
The CEPC Baseline could separate efficiently the WW-ZZ with full hadronic final state.

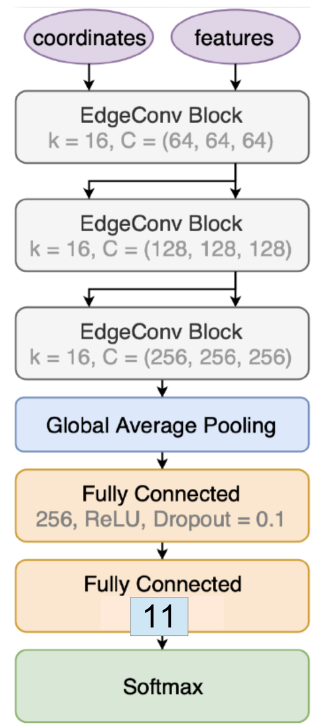
Critical to develop color singlet reconstruction: improve from the naive Jet clustering & pairing.

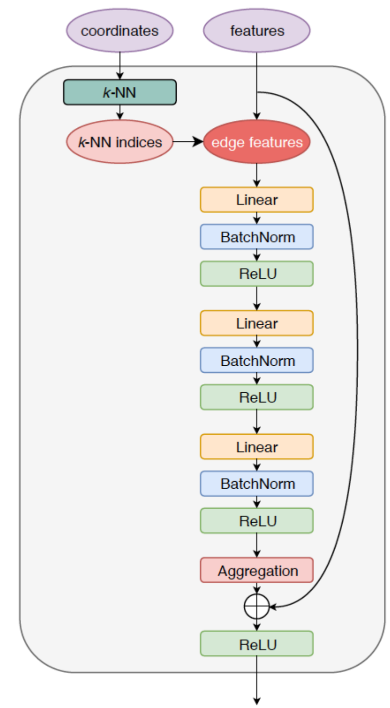
Quantified by differential overlapping ratio.

Control of ISR photon/neutrinos from heavy flavor jet is important.

Geo. & Tools

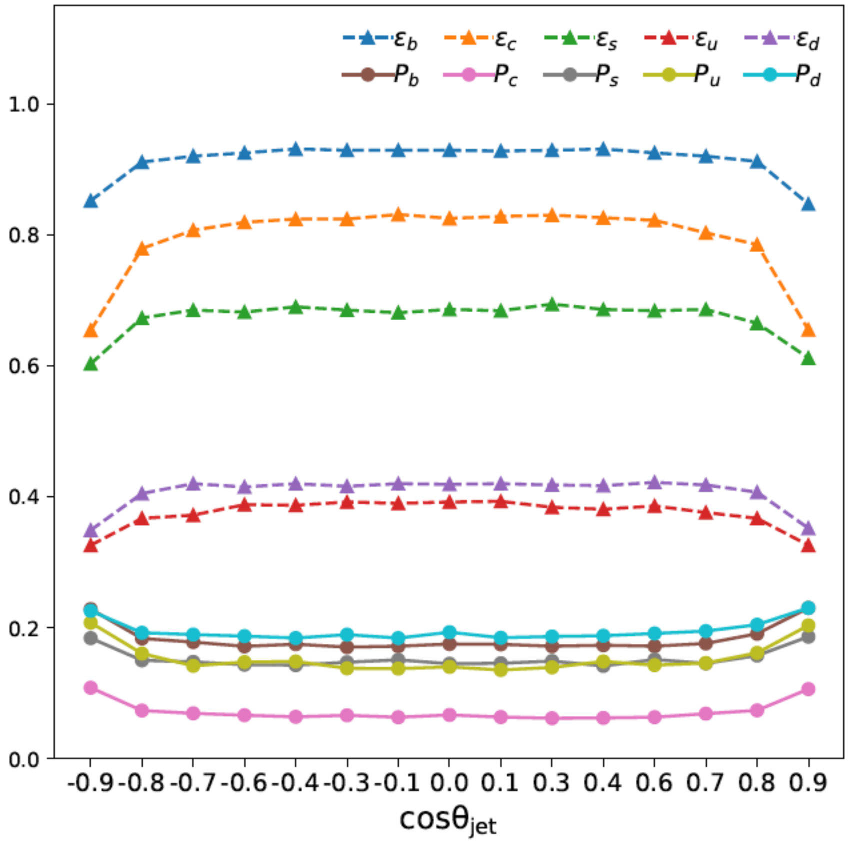


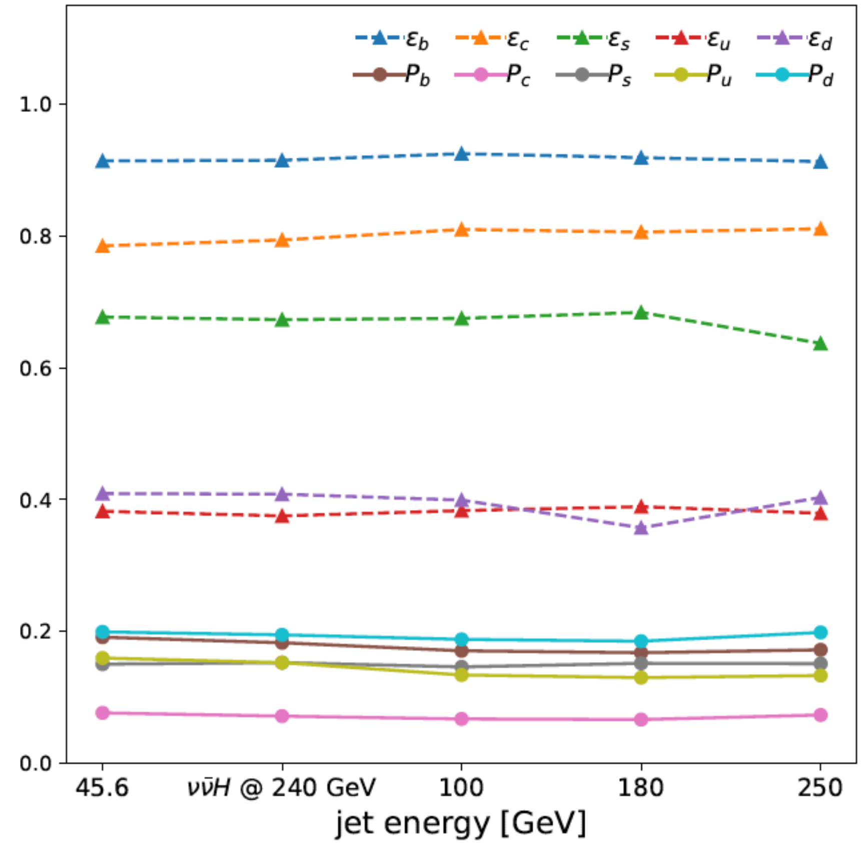




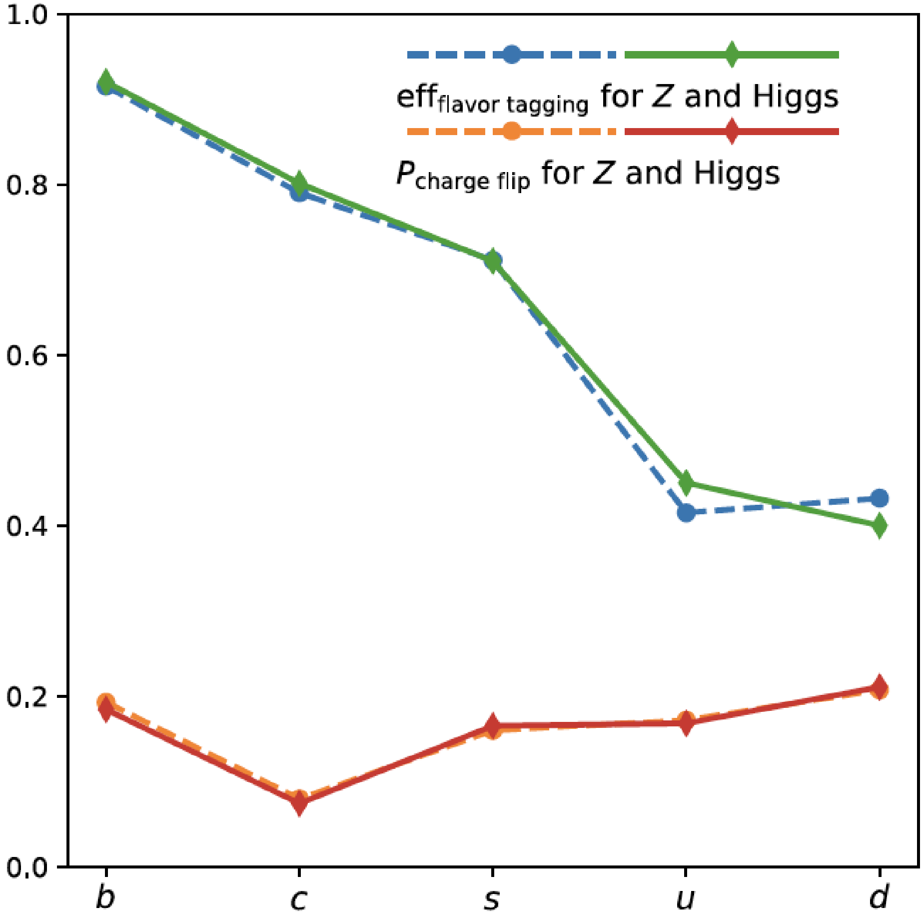
- **Jet origin identification: 11 categories (5 quarks + 5 anti quarks + gluon)**
- Full Simulated vvH, Higgs to two jets sample at CEPC baseline configuration: CEPC-v4 detector, reconstructed with **Arbor + ParticleNet (Deep Learning Tech.)**
  - Input: measurable information of all reconstructed jet particles (~ 10 float)
  - Output: 10(11)-likelihoods to different categories
- 1 Million samples each, 60/20/20% for training, validation & test

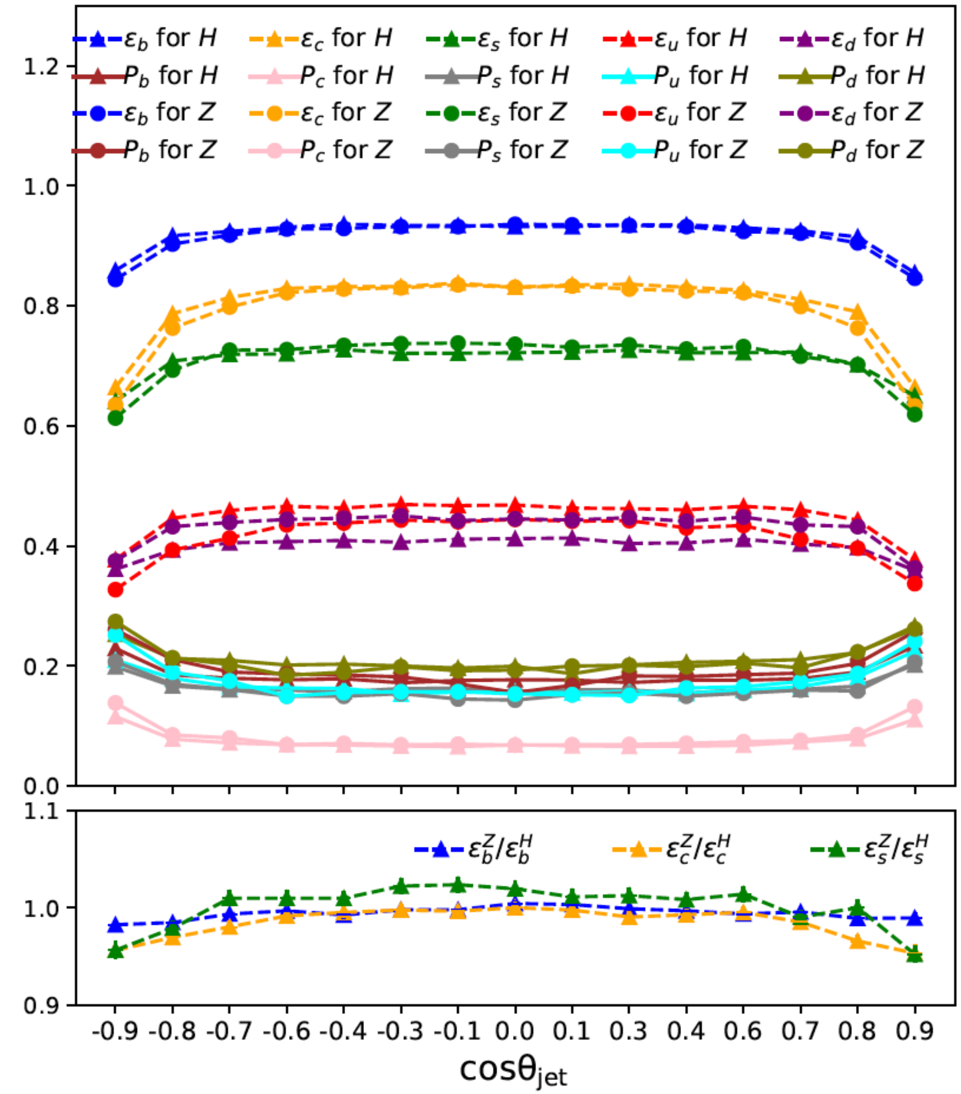
Performance V.S. Jet Kinematics





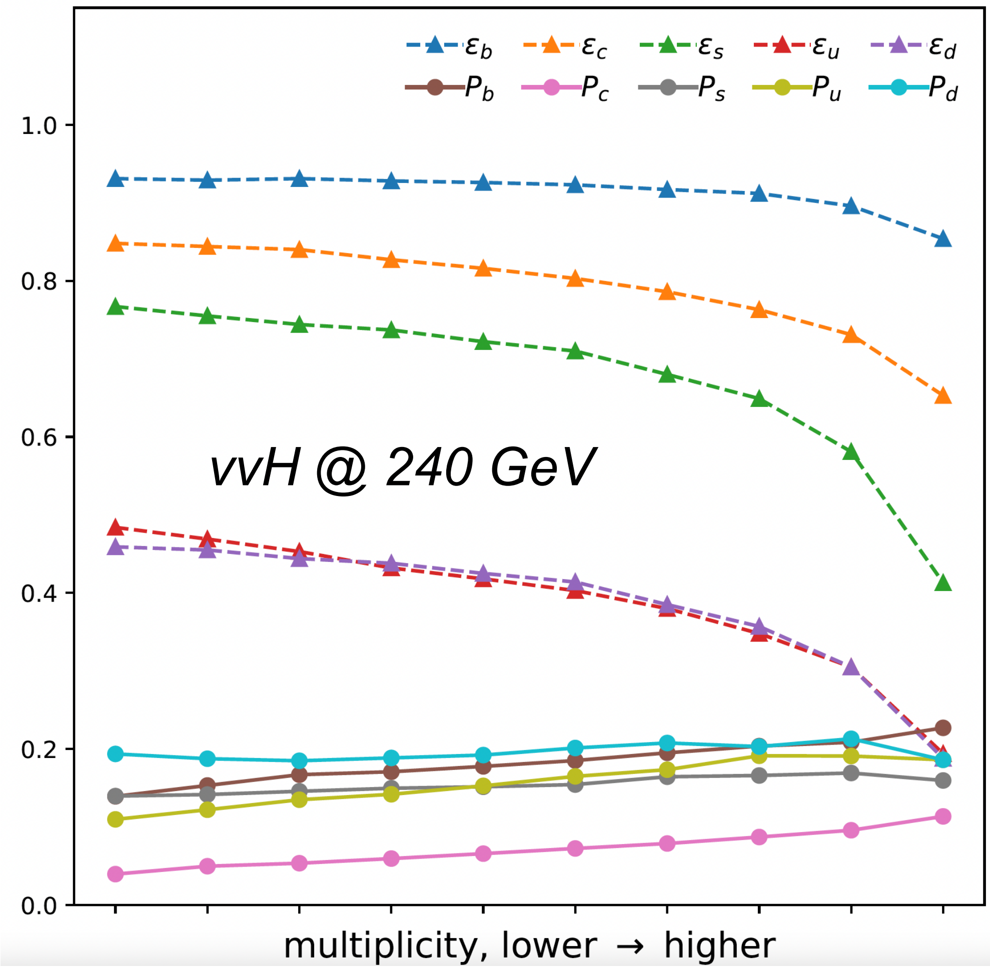
Performance @ Z and Higgs

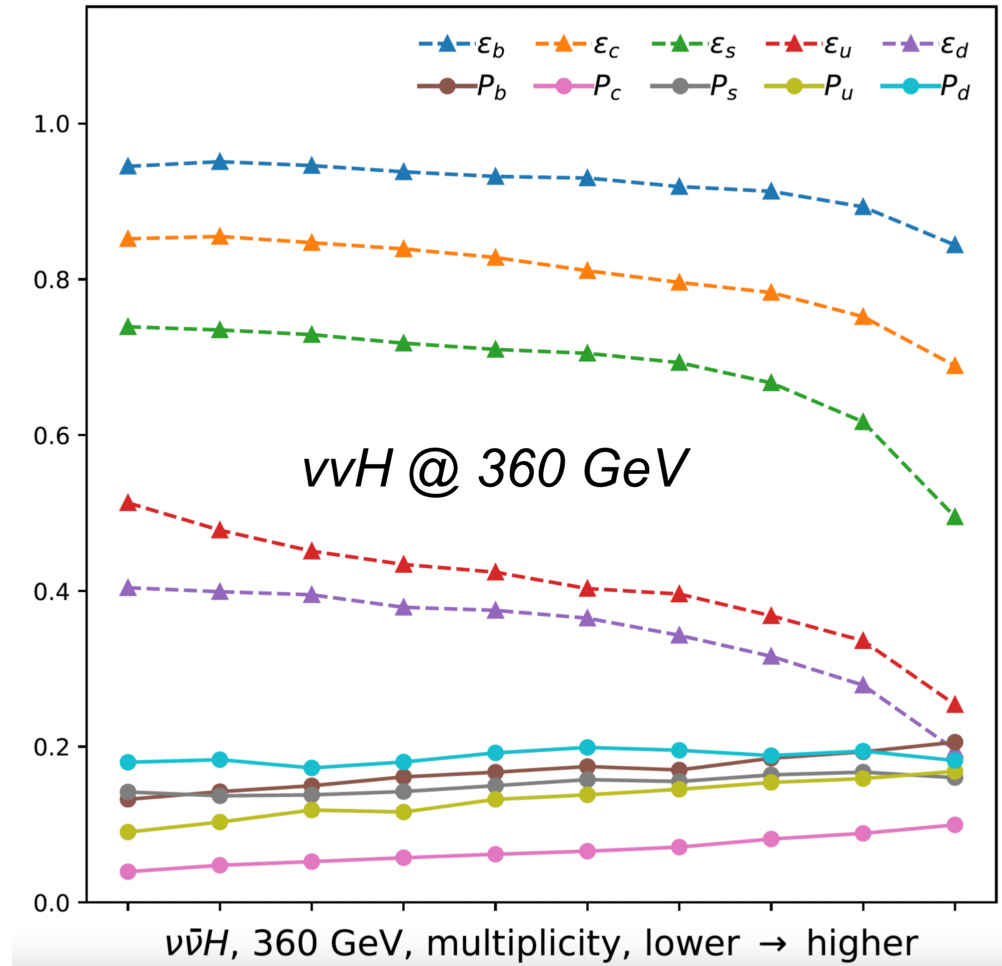




- *M10 instead of M11*

V.S. Multiplicity

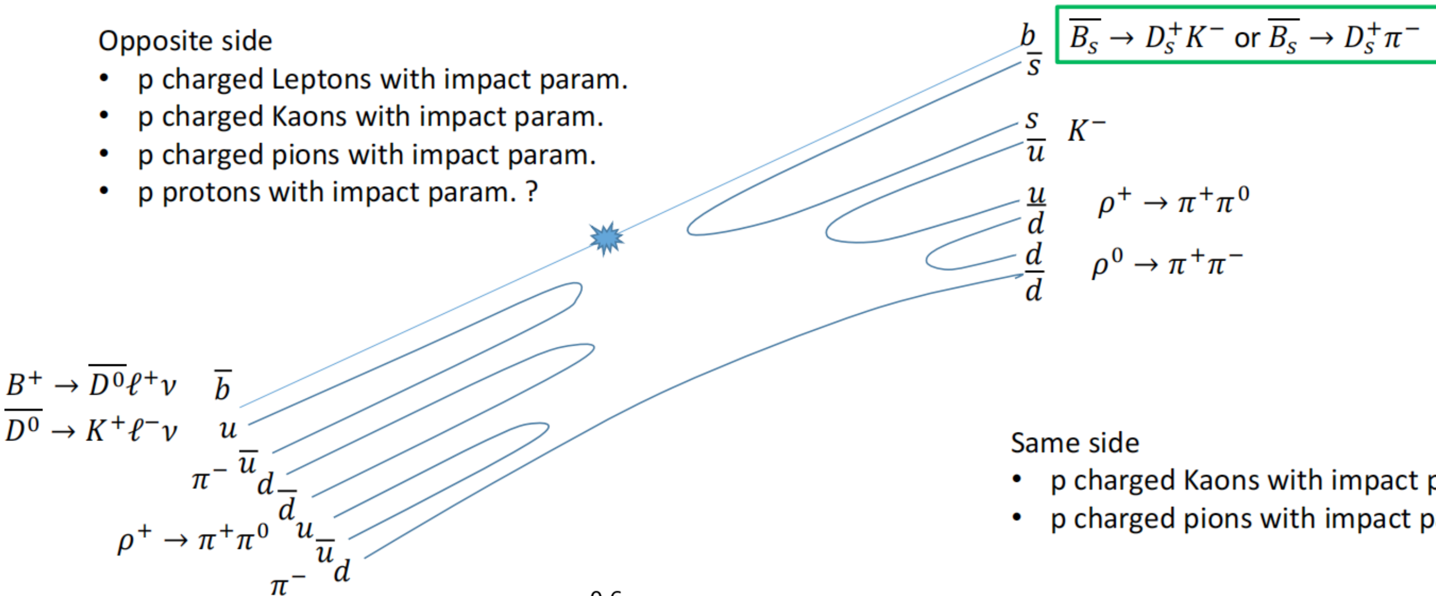




- *...many patterns need further understanding & towards further optimization...*

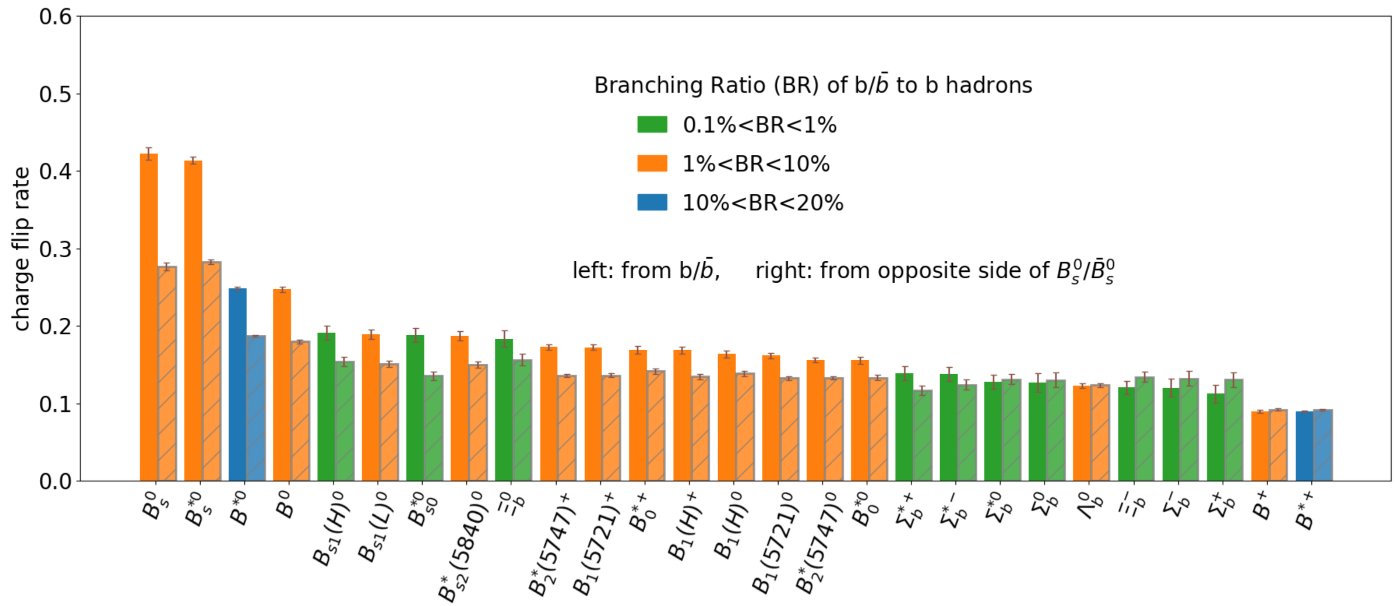
B-charge flip rate: Bs oscillations

Opposite side
- p charged Leptons with impact param.
- p charged Kaons with impact param.
- p charged pions with impact param.
- p protons with impact param. ?



- Using all reco P (exc. Bs decay final state):
- Flip rate ~ 15%, Eff. Tagging power > 40%

Same side
- p charged Kaons with impact param.
- p charged pions with impact param.



s-jets: dependency on Leading hadron