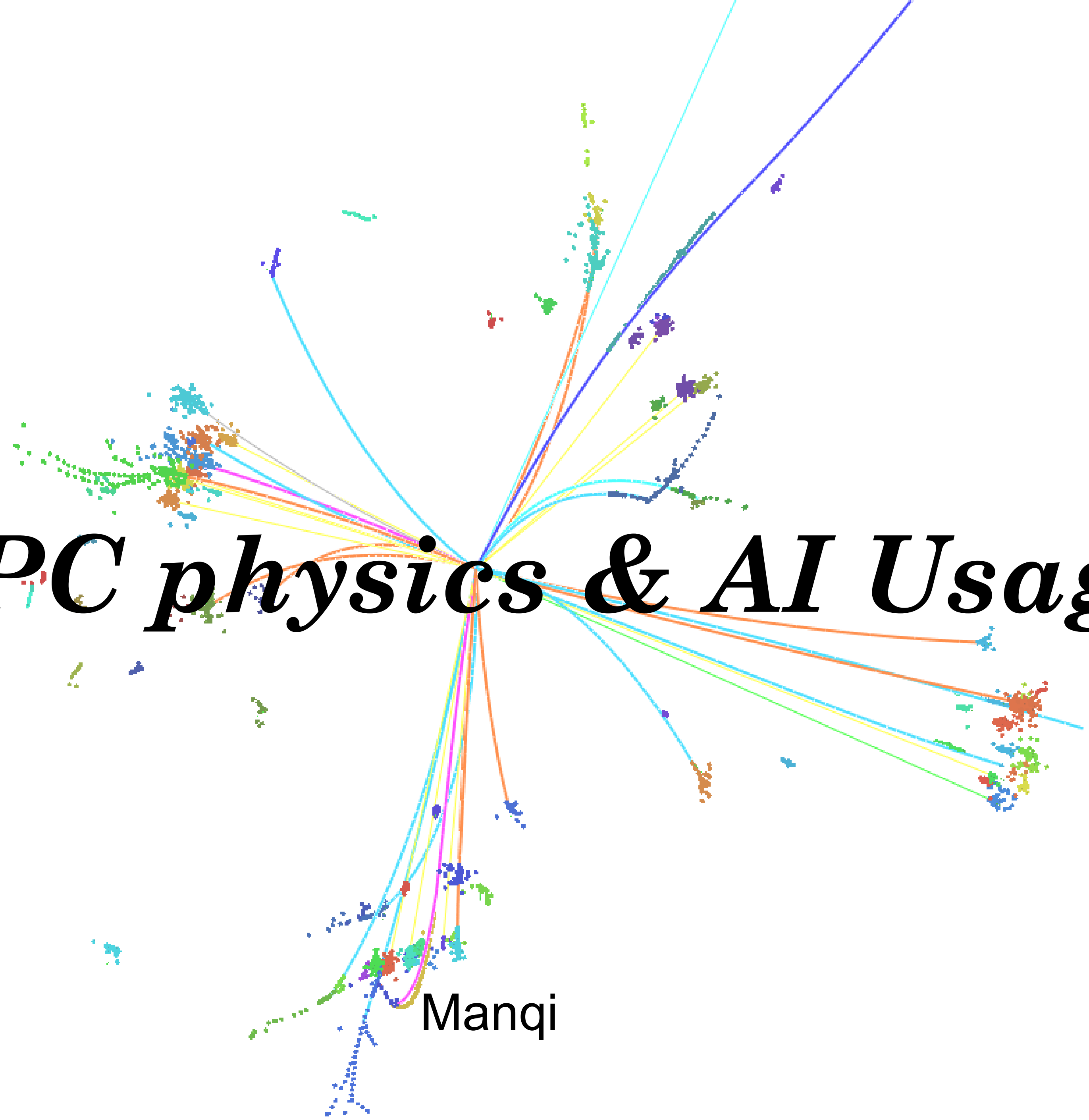
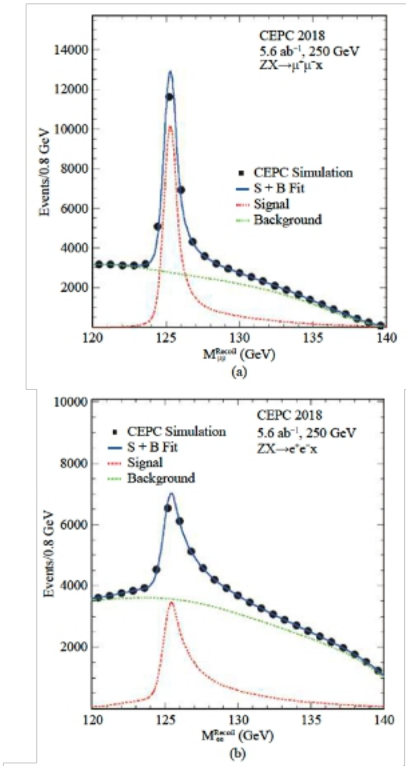
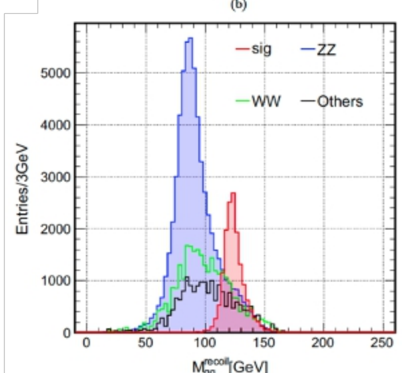
CEPC physics & AI Usage



Manqi

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





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

Precision Higgs physics at the CEPC*

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Haifeng Li(李海峰)[12] Liang Li(李亮)[10] Shu Li(李数)[11,10] Tong Li(李通)[12] Qiang Li(李强)[3] Hao Liang(梁浩)[4,6]
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Mila Pandurovic[16] Jianming Qian(钱剑明)[24;5)] Zhuoni Qian(钱卓妮)[19] Nikolaos Rompotis[22]
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Shufang Su(苏淑芳)[25] Dayong Wang(王大勇)[3] Jin Wang(王锦)[4] Liantao Wang(王连涛)[27;7)]
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Received 9 November 2018, Revised 21 January 2019, Published online 4 March 2019

* Supported by the National Key Program for S&T Research and Development (2016YFA0400400); CAS Center for Excellence in Particle Physics; Yifang Wang's Science Studio of the Ten Thousand Talents Project; the CAS/SAFEA International Partnership Program for Creative Research Teams (H751S018S5); IHEP Innovation Grant (Y4545170Y2); Key Research Program of Frontier Sciences, CAS (XQYZDY-SSW-SLH002); Chinese Academy of Science Special Grant for Large Scientific Project (113111KYSB20170005); the National Natural Science Foundation of China(11675202); the Hundred Talent Programs of Chinese Academy of Science (Y3515540U1); the National 1000 Talents Program of China; Fermi Research Alliance, LLC (DE-AC02-07CH11359); the NSF(PHY1620074) ; by the Maryland Center for Fundamental Physics (MCFP); Tsinghua University Initiative Scientific Research Program; and the Beijing Municipal Science and Technology Commission project(Z181100004218003)

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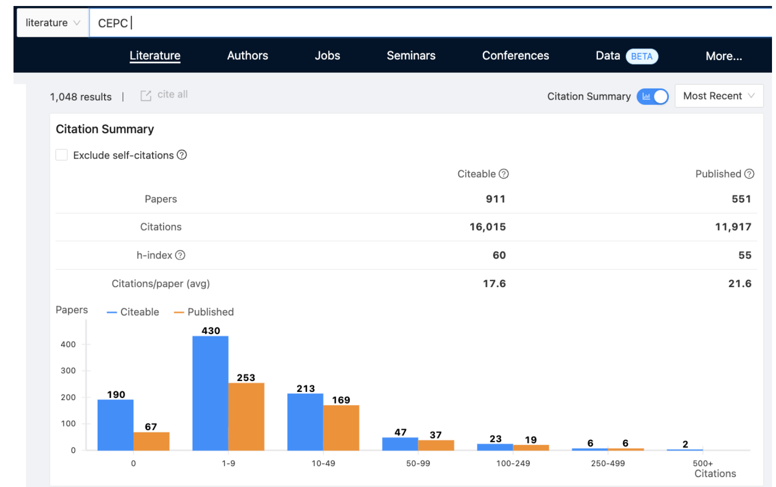


Subject

Phenomenology-HEP	455
Accelerators	346
Experiment-HEP	322
Instrumentation	208
Computing	21

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.
- …

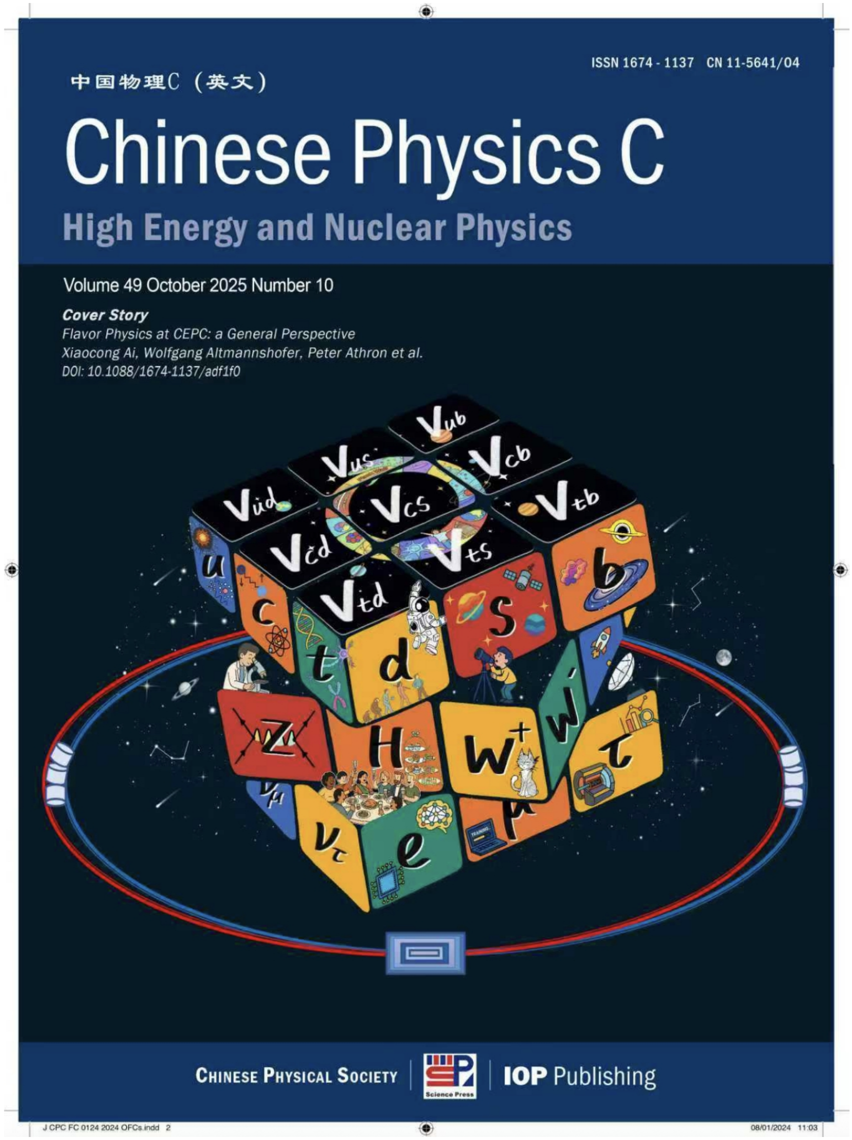
~ 500 Physics citables

White papers

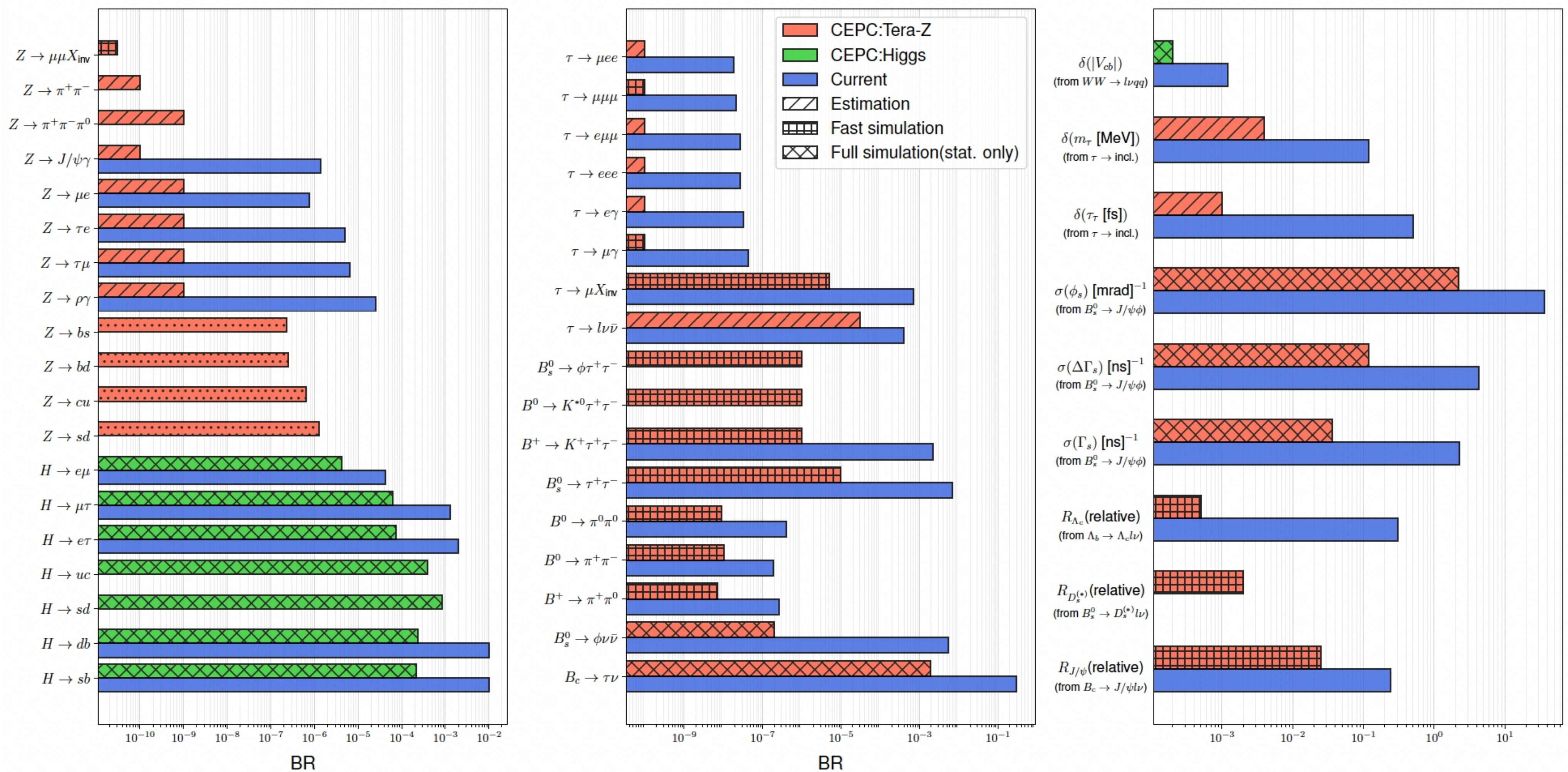
- Higgs: 2019, CPC
- ESPPU input: 2019 ArXiv
- Snowmass input: 2022 ArXiv

- **Flavor physics: 2025, CPC**
- **New physics: CPC, Accepted**

- **Current focus**
  - **EW White paper**
  - **QCD studies**
  - Reco & Det. Optimization
  - **...**



Flavor Physics



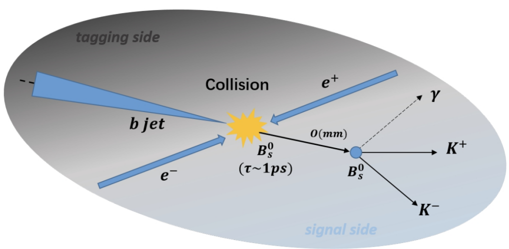
See the non-seen: i.e, Bc→tauv, Bs→Phivv

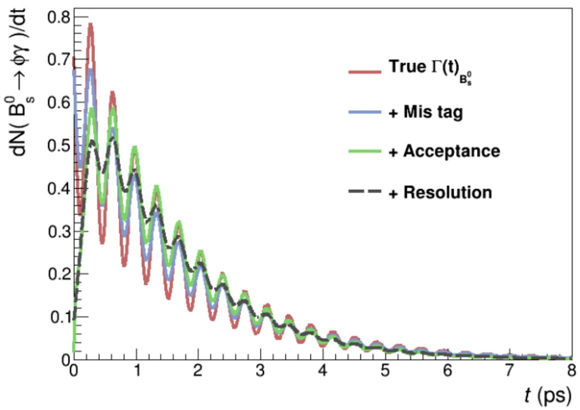
Orders of magnitudes improvements (1 – 2.5 orders...).

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

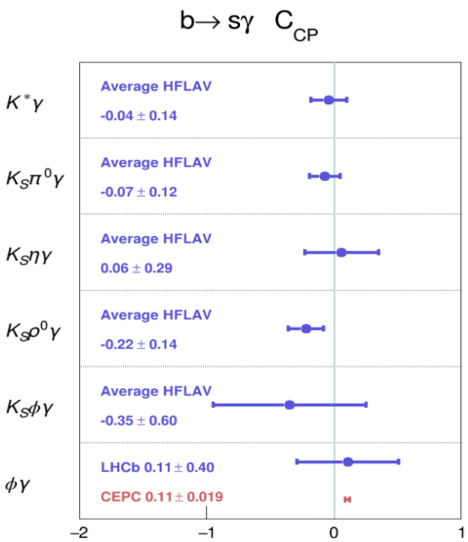
Flavor Physics

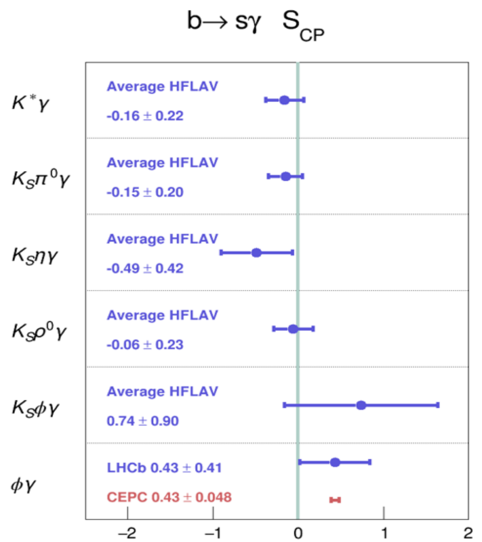
- A recent study: Time dependent CP measurements with Bs→Phi + Gamma
  - One order of magnitude improvement compared to LHCb
  - Dependence on ECAL & Pid quantified



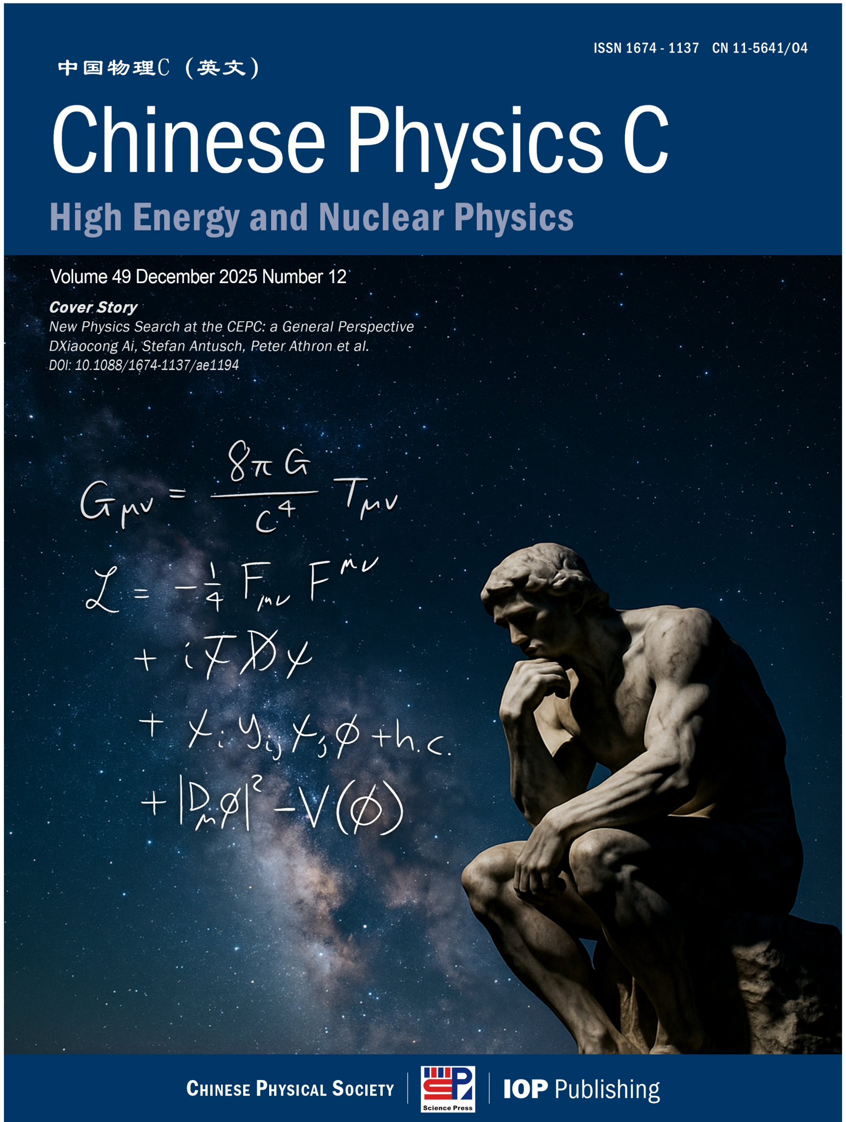


- A long wish list...
  - Matter origin
  - CKM measurements
  - CPV
  - Interplay between QCD & Flavor
  - ...



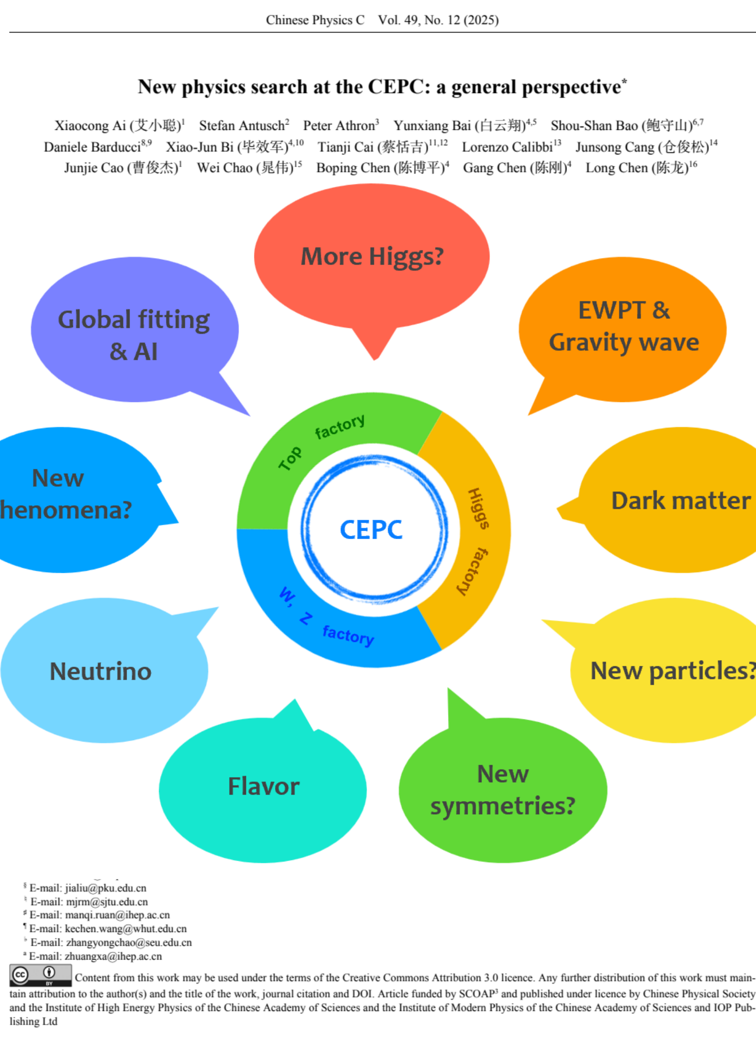


New Physics



https://arxiv.org/pdf/2505.24810

New Physics


Chinese Physics C Vol. 49, No. 12 (2025)

New physics search at the CEPC: a general perspective*

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Daniele Barducci[8,9] Xiao-Jun Bi (毕效军)[4,10] Tianji Cai (蔡恬吉)[11,12] Lorenzo Calibbi[13] Junsong Cang (仓俊松)[14]
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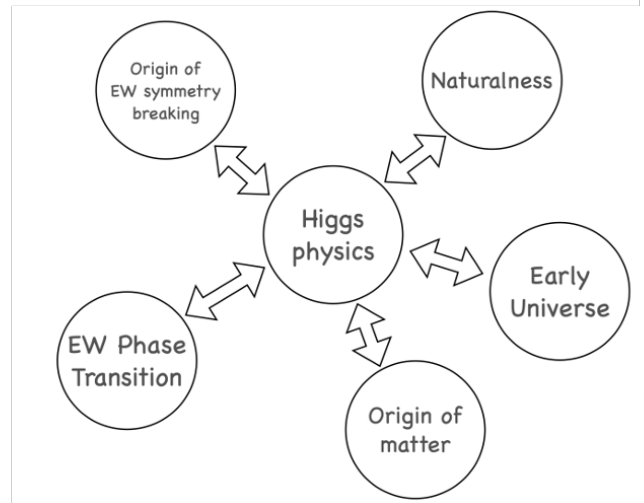
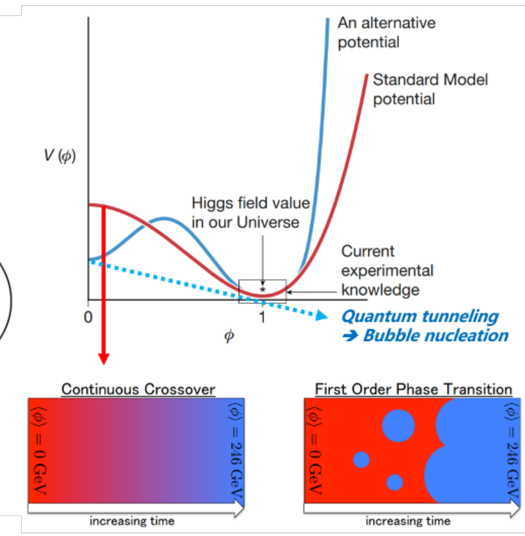
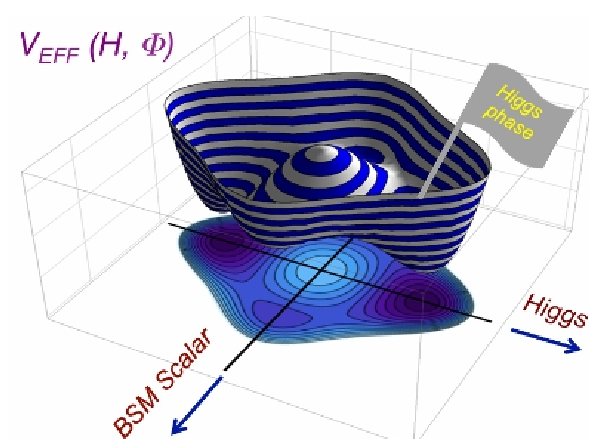
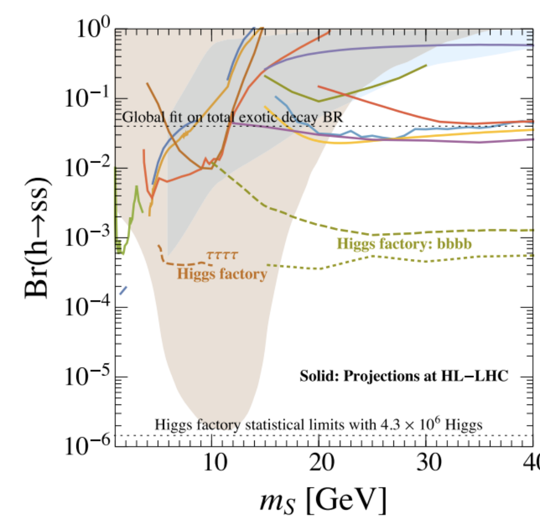


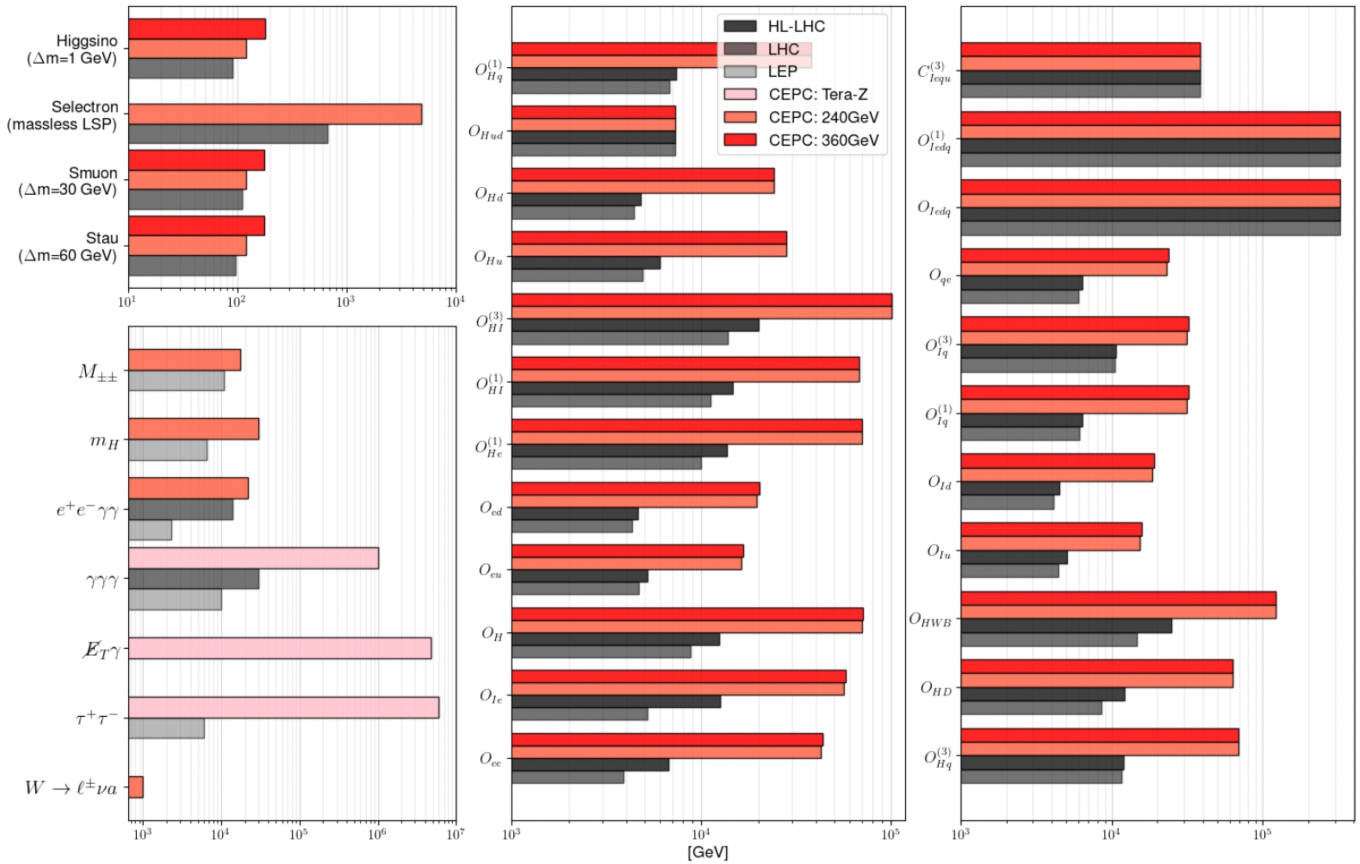


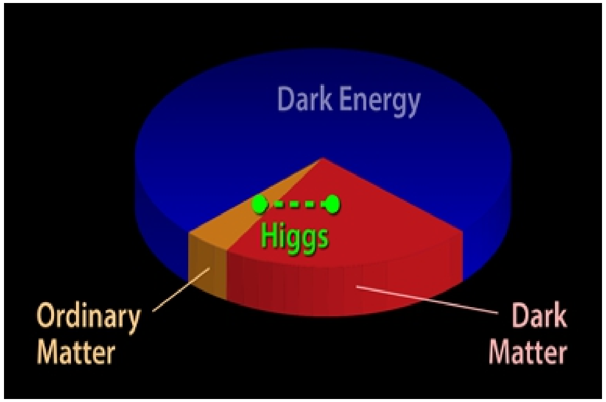


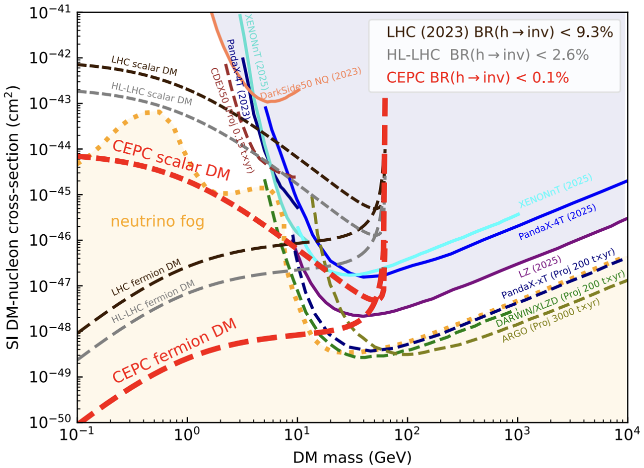


Decisive for 1st order EWPT detection in early Universe...

New Physics





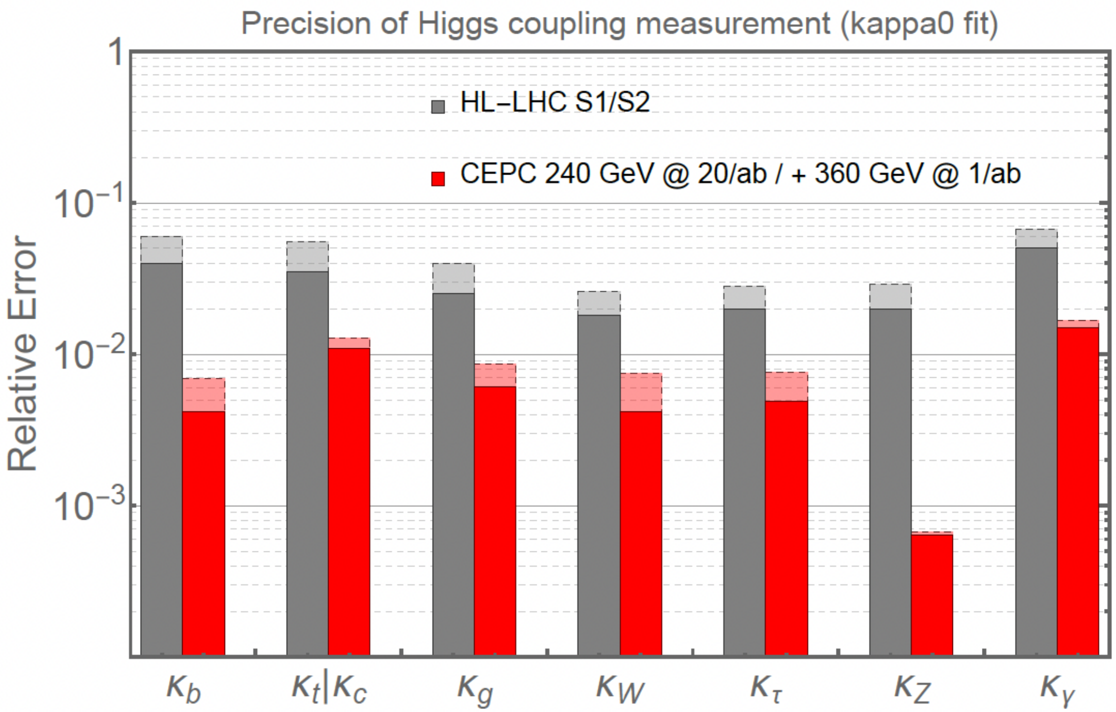


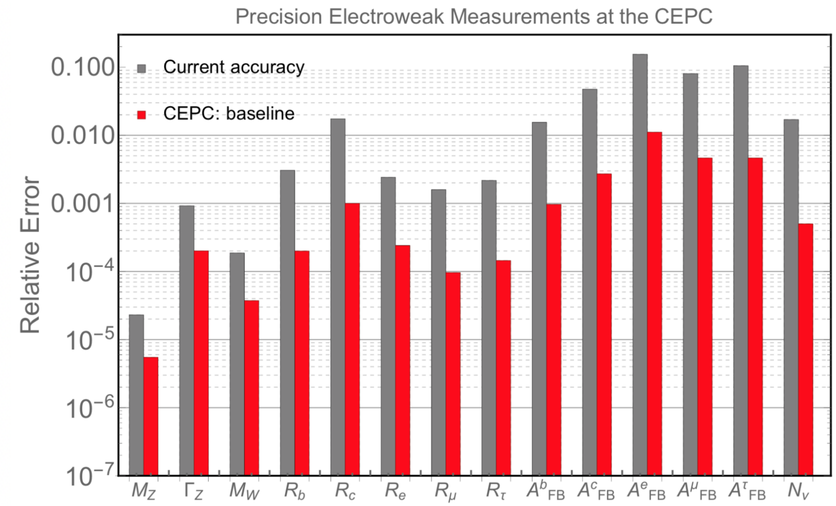
Dark matter: from Higgs & Z portals: orders of magnitudes improvements.

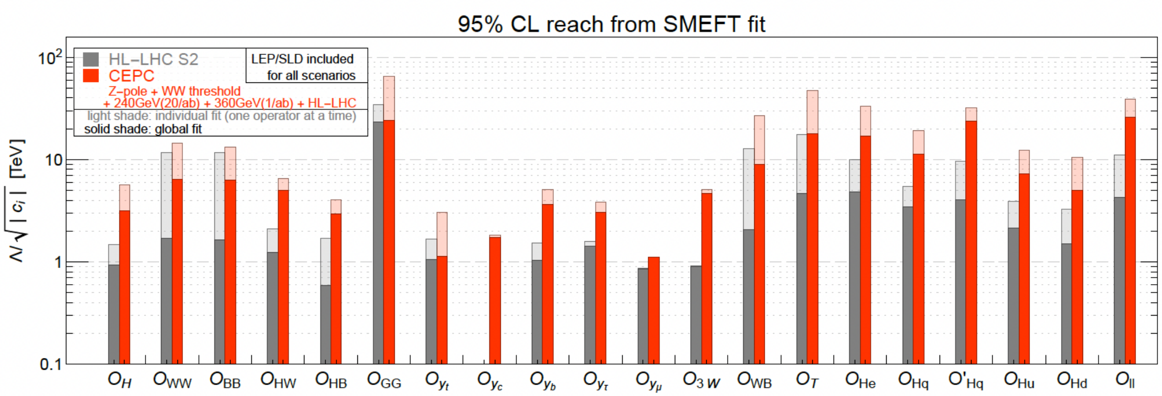
SMEFT etc, Access to NP ~ 100 TeV...

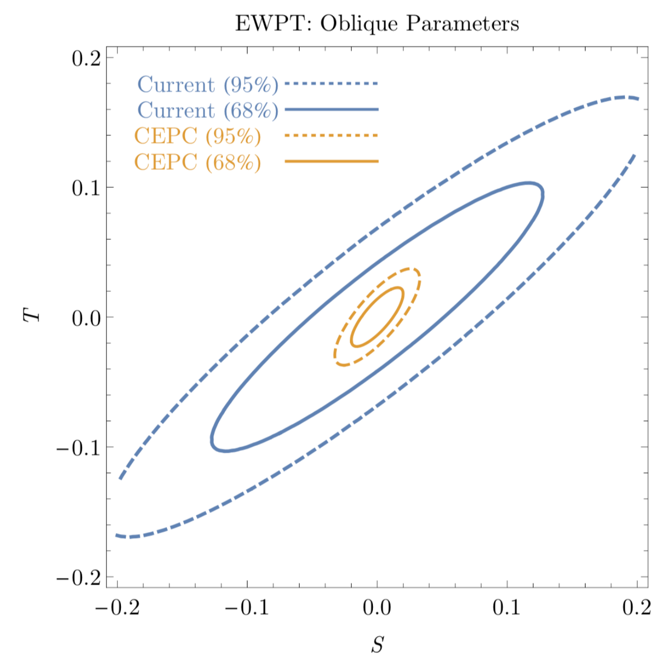
Leptongenesis, NP signature, like LLP & SUSY particles, are intensively discussed.

2022 Snowmass: Higgs, EW + SMEFT

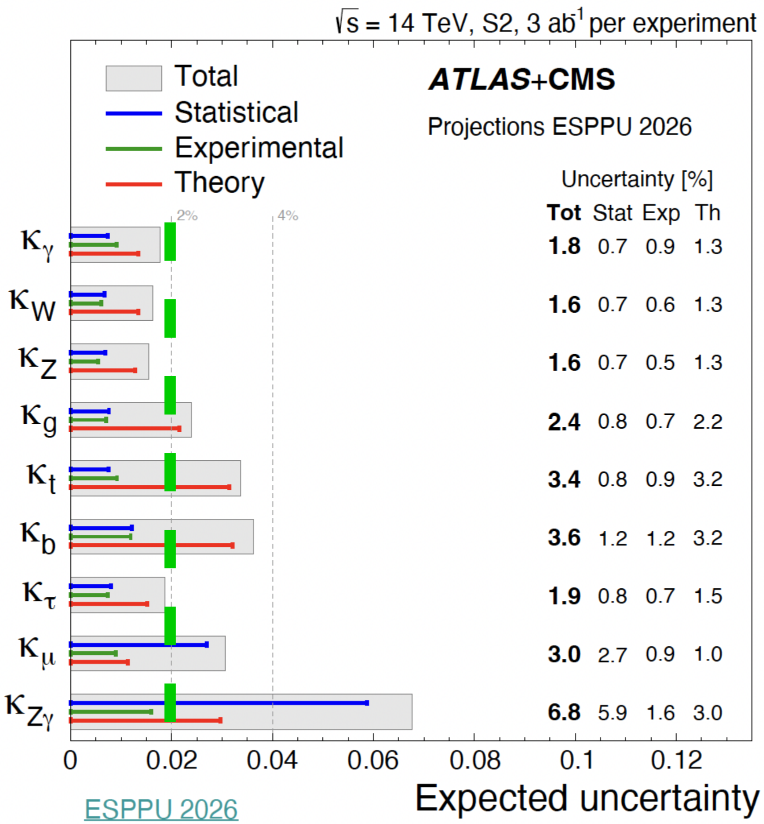




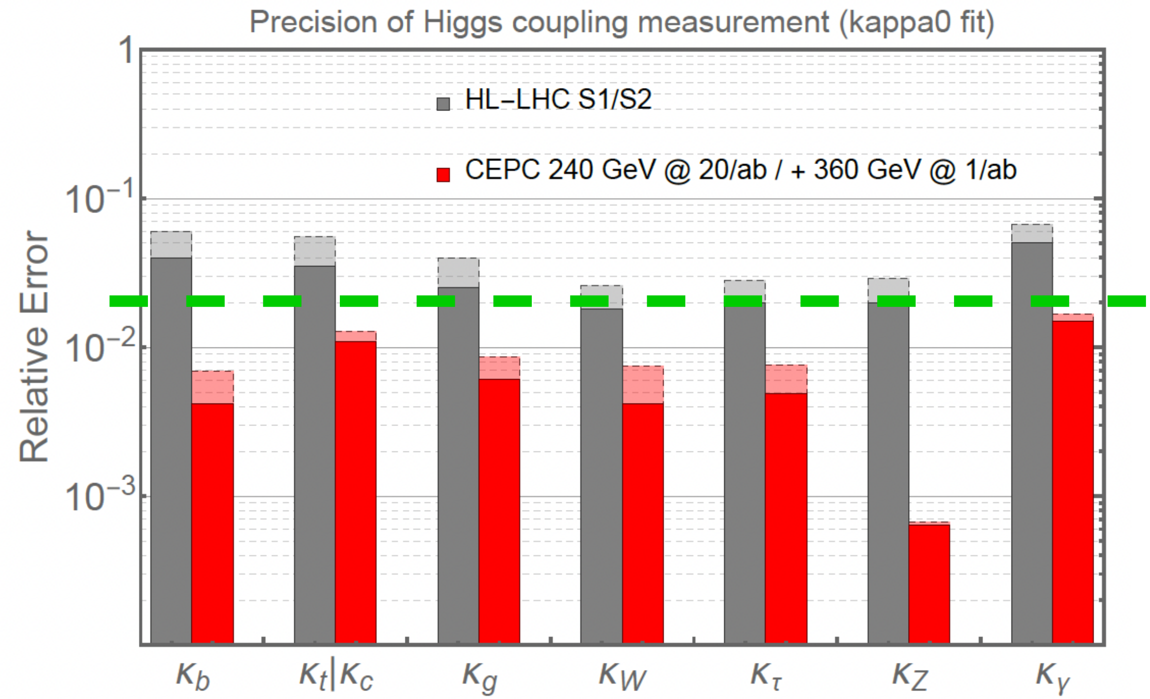




2026...



ESPPU 2026



- LHC doing well
  - Higgs yields of ~o(100M)...
  - Usage of AI tools
  - Trigger rate ~ 0.3%, Theoretical uncertainty dominant, might be further improved

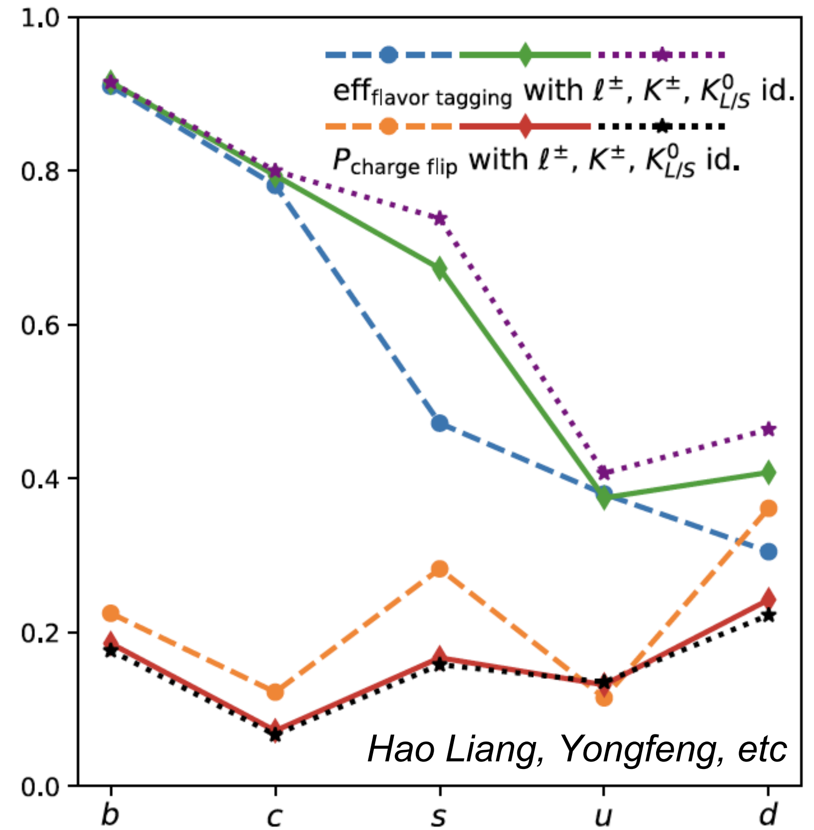
- Science merit of CEPC Higgs program
  - Absolute measurements; Higgs width; Exotic decays, i.e., H→inv; 2nd generation Yukawa, cc & ss;
  - Boost precision by 1 order of magnitude – **being challenged...**

Current focus: EW

- **Objective: A major update** since Snowmass (2022), cover Higgs + EW
  - Nominal Luminosity
  - AI usage...
    - Holistic approach
      - Jet origin id
      - Multi-heads event classification
    - Color singlet identification
    - *Supporting studies...*
  - Theoretical uncertainties

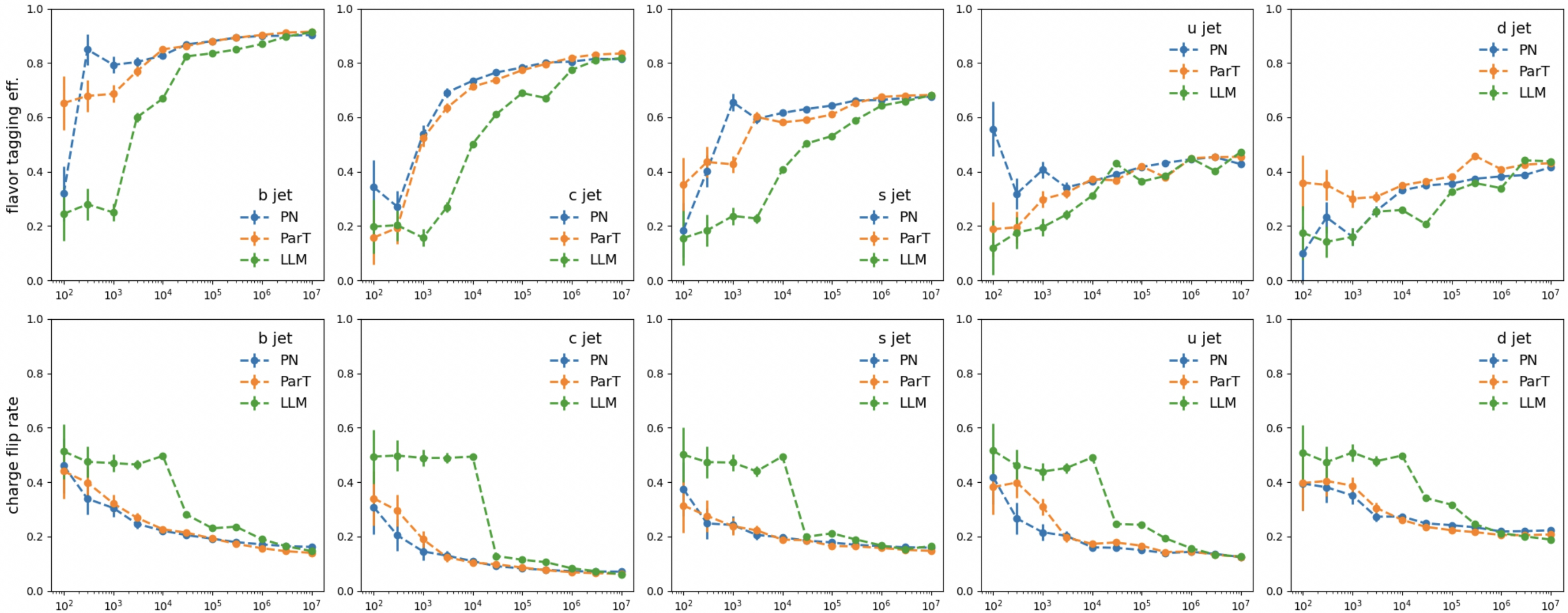
Holistic Reco: Jet origin id

True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.745	0.163	0.033	0.025	0.004	0.003	0.002	0.003	0.002	0.002	0.017
$\bar{b}$	0.170	0.737	0.026	0.033	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.014	0.743	0.055	0.036	0.031	0.025	0.009	0.009	0.018	0.043
$\bar{c}$	0.016	0.015	0.056	0.739	0.032	0.037	0.009	0.026	0.017	0.010	0.043
s	0.003	0.002	0.020	0.018	0.543	0.102	0.030	0.080	0.063	0.045	0.092
$\bar{s}$	0.003	0.003	0.018	0.020	0.102	0.542	0.084	0.028	0.045	0.062	0.094
u	0.002	0.003	0.020	0.011	0.044	0.131	0.367	0.055	0.080	0.174	0.111
$\bar{u}$	0.003	0.003	0.011	0.019	0.132	0.043	0.062	0.356	0.178	0.081	0.111
d	0.003	0.003	0.012	0.019	0.112	0.092	0.082	0.207	0.277	0.079	0.112
$\bar{d}$	0.003	0.003	0.020	0.012	0.092	0.112	0.219	0.076	0.079	0.272	0.113
G	0.015	0.014	0.024	0.024	0.052	0.052	0.043	0.041	0.034	0.034	0.667



- 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)*.
- Strong impact on all physics measurements with hadronic final states
- i.e., weak mixing angle measurements with ss final states, and verification of its RG behavior using months of data taking at c.m.s. slightly off Z mass peak: *EPJC (2025) 85:993*

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

Extend to speakable LLM...

arXiv > cs > arXiv:2510.00129

Search...
Help | Advar

Computer Science > Machine Learning

[Submitted on 30 Sep 2025]

BigBang-Proton Technical Report: Next-Word-Prediction is Scientific Multitask Learner

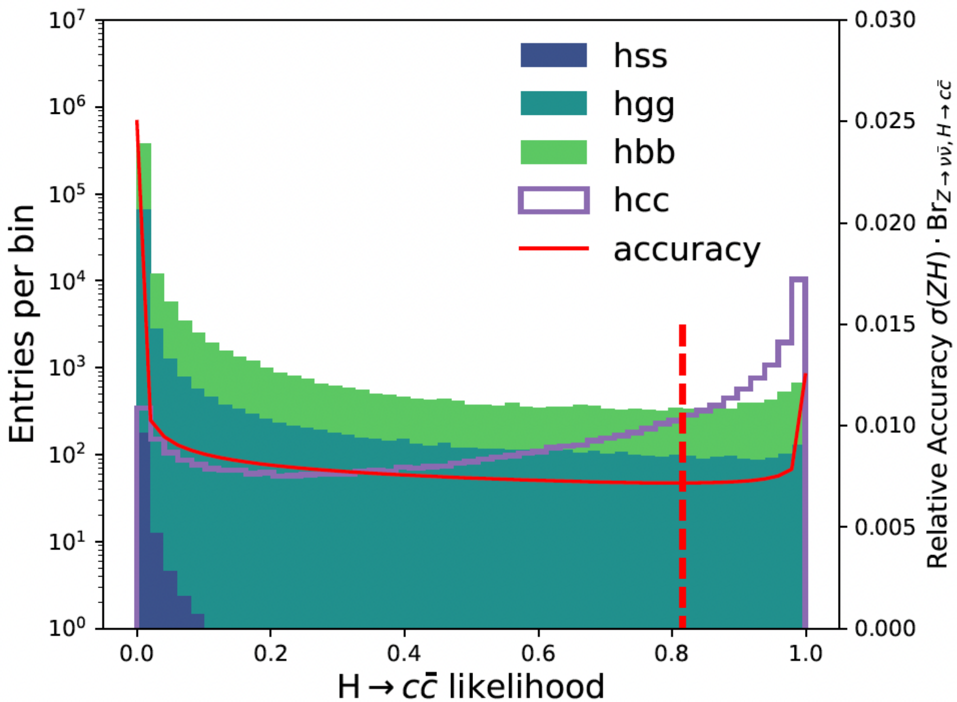
Hengkui Wu, Liujiang Liu, Jihua He, Qihao Wang, Keke Zhao, Shuyang Hu, Renle Fu, Dahao Liang, Lingyu Zeng, Bruce Liu, Yuan Liu, Jin Zhan, Jiaqiang Niu, Xinglong Jia, Yaqin Hu, Wenjun Ji, Panpan Chi, Ken Chen, Hengyuan Wu, Yingsi Xin, Yongfeng Zhu, Yuexin Wang, Manqi Ruan, Ningtao Bian, Xiaohua Wu, Weipeng Xu

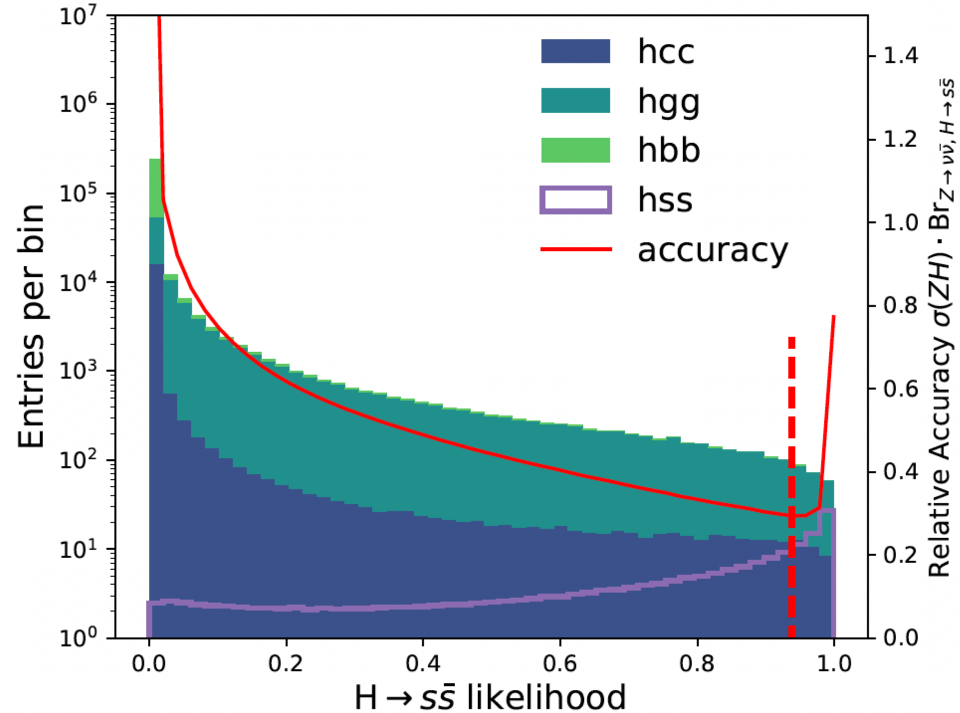
We introduce BigBang-Proton, a unified sequence-based architecture for auto-regressive language modeling pretrained on cross-scale, cross-structure, cross-discipline real-world scientific tasks to construct a scientific multi-task learner. BigBang-Proton incorporates three fundamental innovations compared to mainstream general-purpose LLMs: Theory-Experiment Learning paradigm aligns large-scale numerical experimental data with theoretical text corpora; Binary Patch Encoding replaces byte pair encoding(BPE) tokenization; Monte Carlo Attention substitutes traditional transformer architectures. Through next-word-prediction pretraining on cross-discipline scientific datasets of real-world problems mixed with general textual corpus, followed by fine-tuning and inference on downstream tasks, BigBang-Proton demonstrates 100\% accuracy in up to 50-digit arithmetic addition operations, performance on par with leading specialized models in particle physics jet tagging, matching MAE of specialized models in inter-atomic potential simulation, performance comparable to traditional spatiotemporal models in water quality prediction, and benchmark-exceeding performance in genome modeling. These results prove that language-guided scientific computing can match or exceed the performance of task-specific scientific models while maintaining multitask learning capabilities. We further hypothesize to scale the pretraining to the universe scale as a fundamental step toward developing material world foundational model.

Comments: 93 pages, 39 figures
Subjects: **Machine Learning (cs.LG)**; Materials Science (cond-mat.mtrl-sci); Artificial Intelligence (cs.AI); Computational Physics (physics.comp-ph)
MSC classes: 68T05, 68T50, 00A69, 94A99
ACM classes: I.2.6; I.2.7; J.2; I.6.3; K.4.1
Cite as: arXiv:2510.00129 **[cs.LG]**
(or arXiv:2510.00129v1 **[cs.LG]** for this version)
https://doi.org/10.48550/arXiv.2510.00129

https://arxiv.org/abs/2510.00129

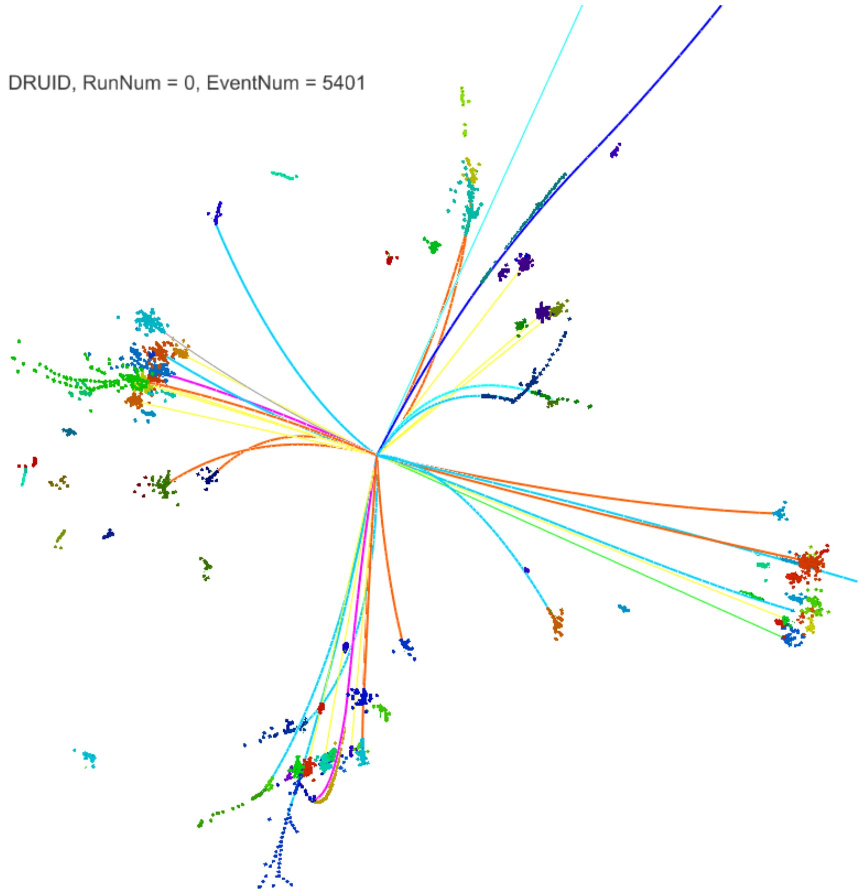
Holistic Analysis: vvH, H→2 jet

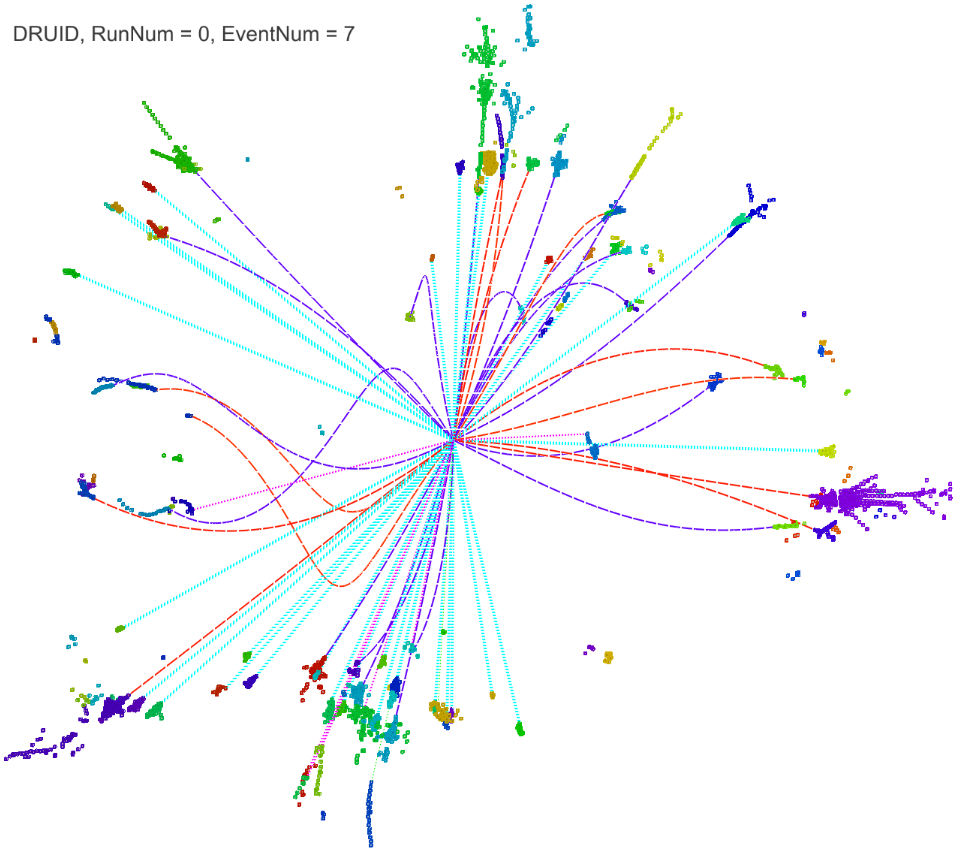




- vvH, H→bb/cc/gg/ss measurements: 4 kinds classification
- Simplified analysis with irreducible background...
- H→bb/cc/gg: close to the statistic limits - 2-6 times better than previous studies (include other bkgrd, BDT based, etc)
- H→ss: close to confirmation!

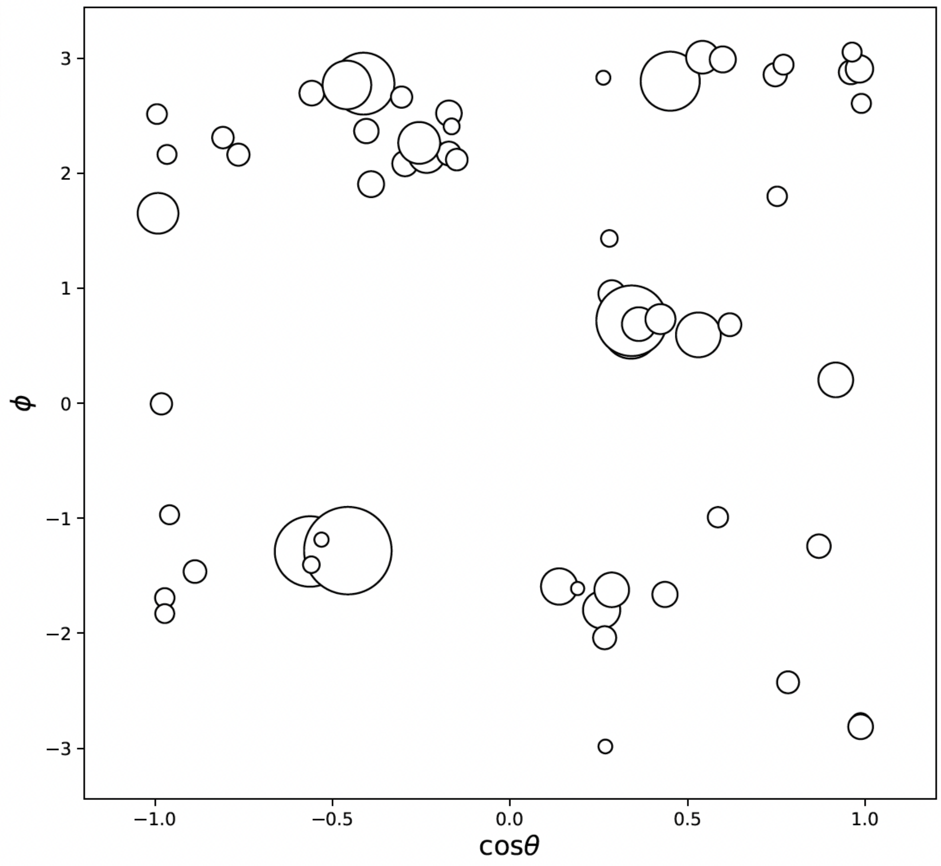
Color Singlet Identification

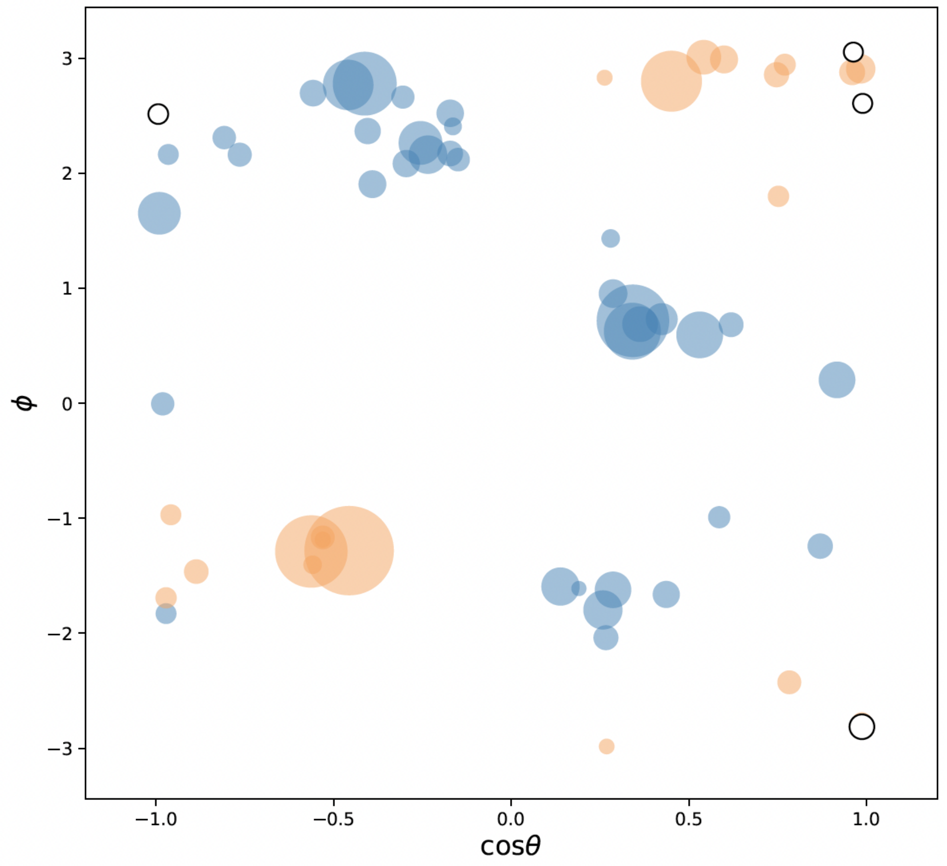




e.g. at full hadronic ZH event

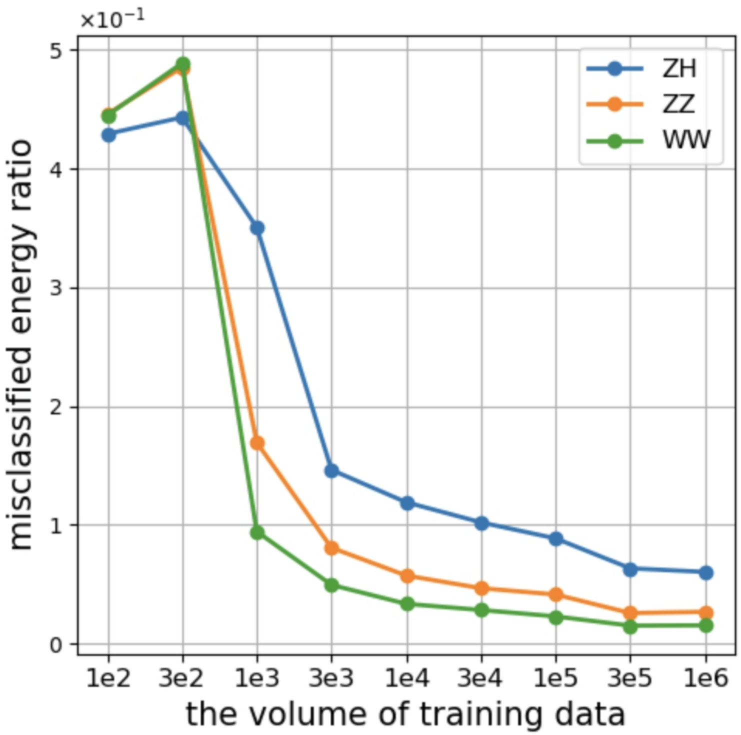
Advanced CSI using AI



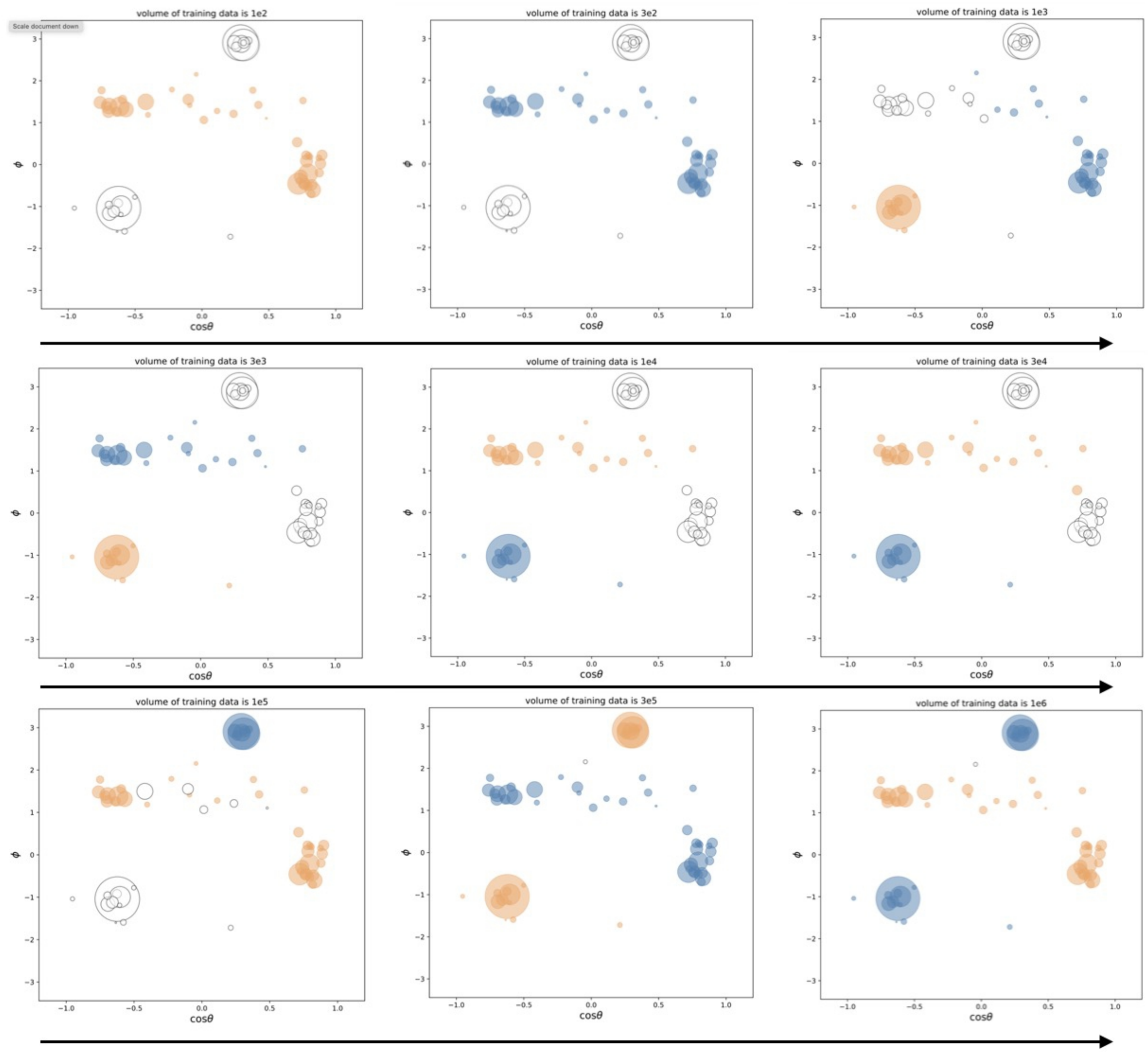


Yongfeng, Hao, Yuexin, etc

Scaling...

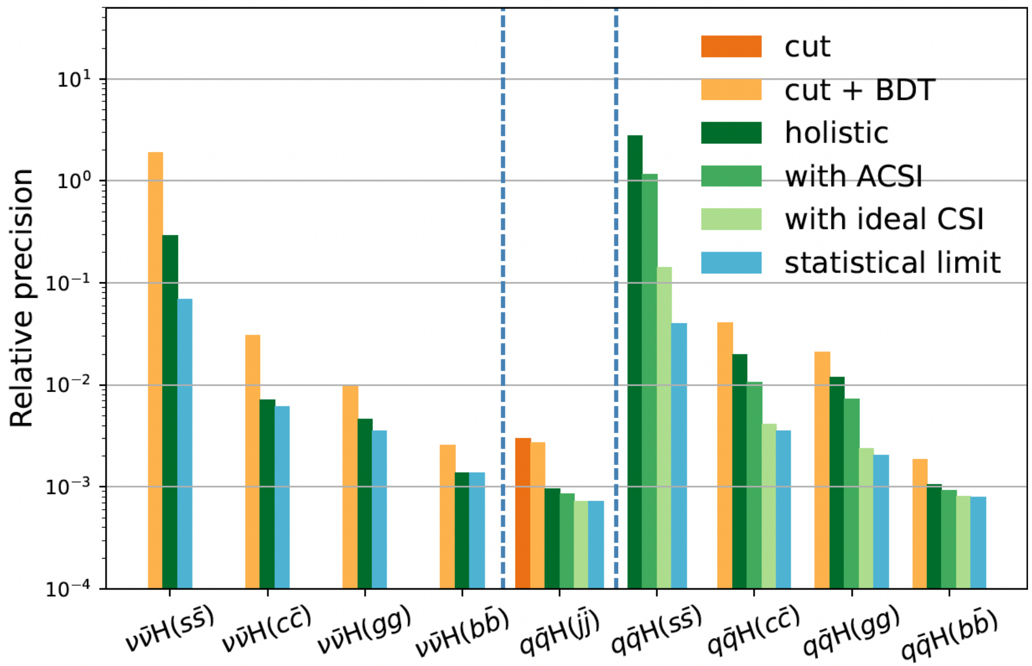


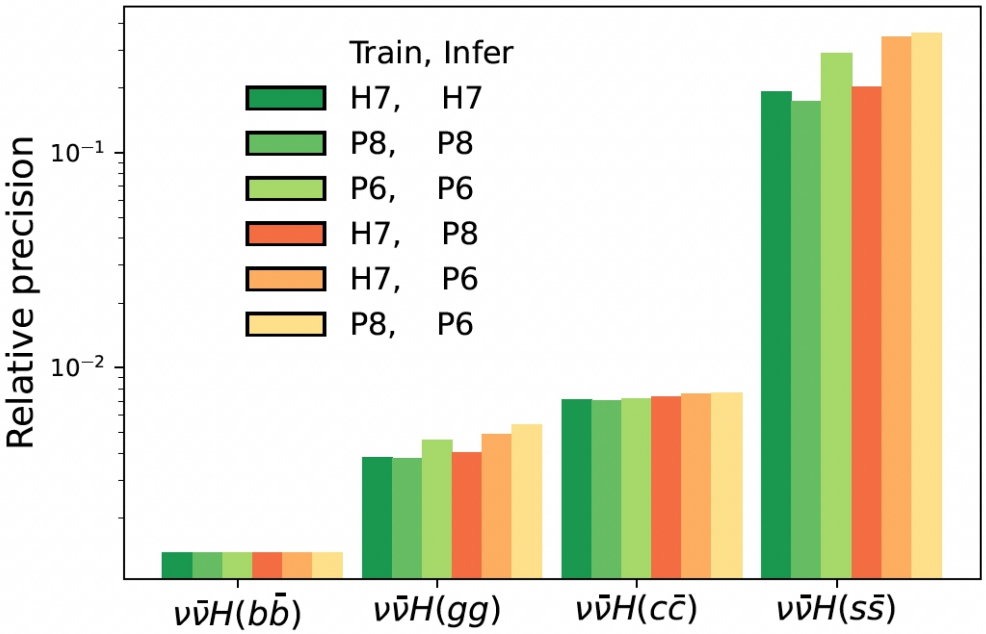
×10⁻¹
misclassified energy ratio
the volume of training data
ZH
ZZ
WW
0
1
2
3
4
5
1e2
3e2
1e3
3e3
1e4
3e4
1e5
3e5
1e6



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

Holistic approach + ACSI





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

in principle free from human intervene (if the simulation is good enough...)

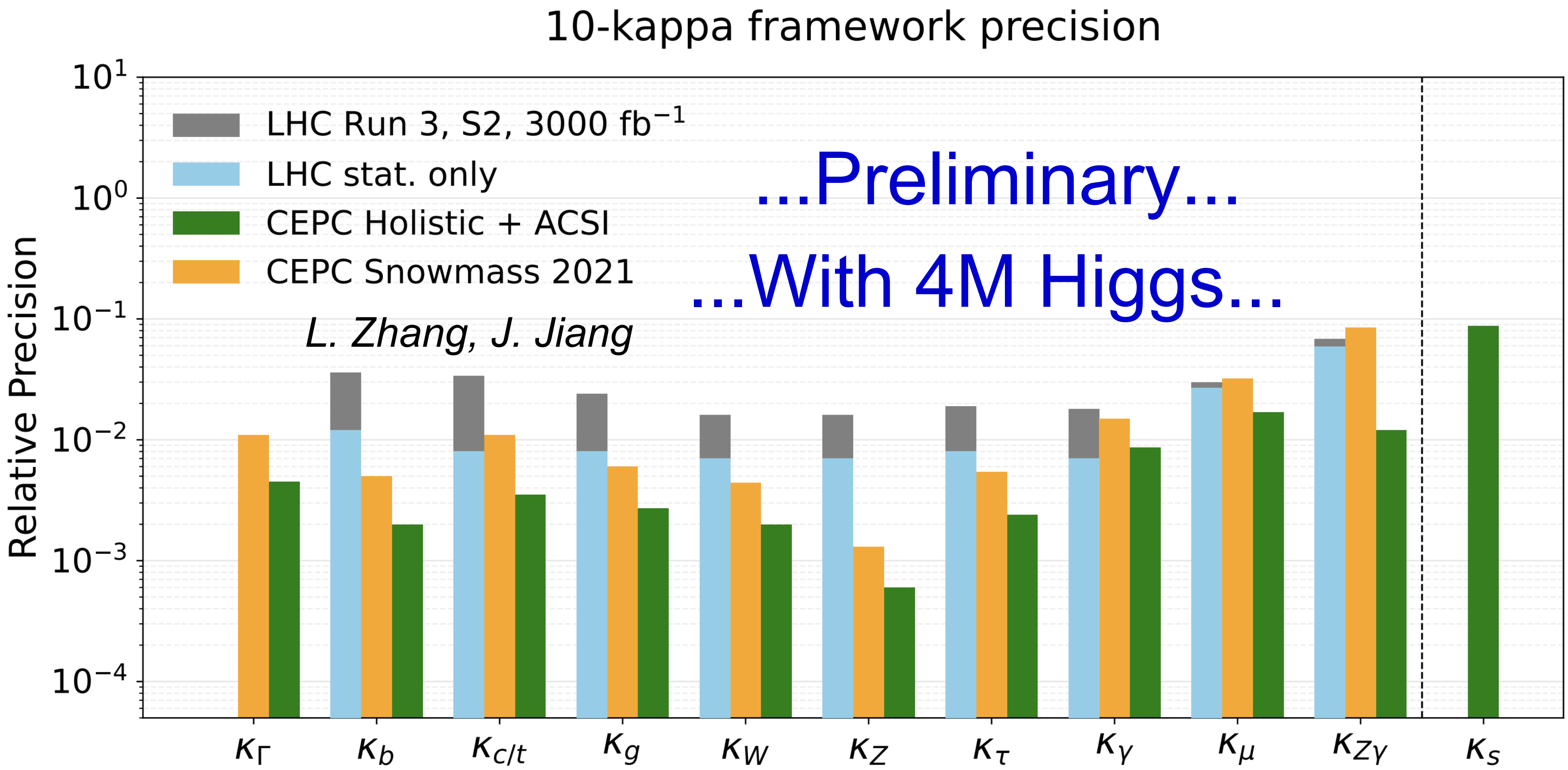
Strongly depends on Hadronization modes...

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

H→ss within the reach at toy analysis: clarify the conditions to confirm this decay mode.

https://arxiv.org/pdf/2506.11783

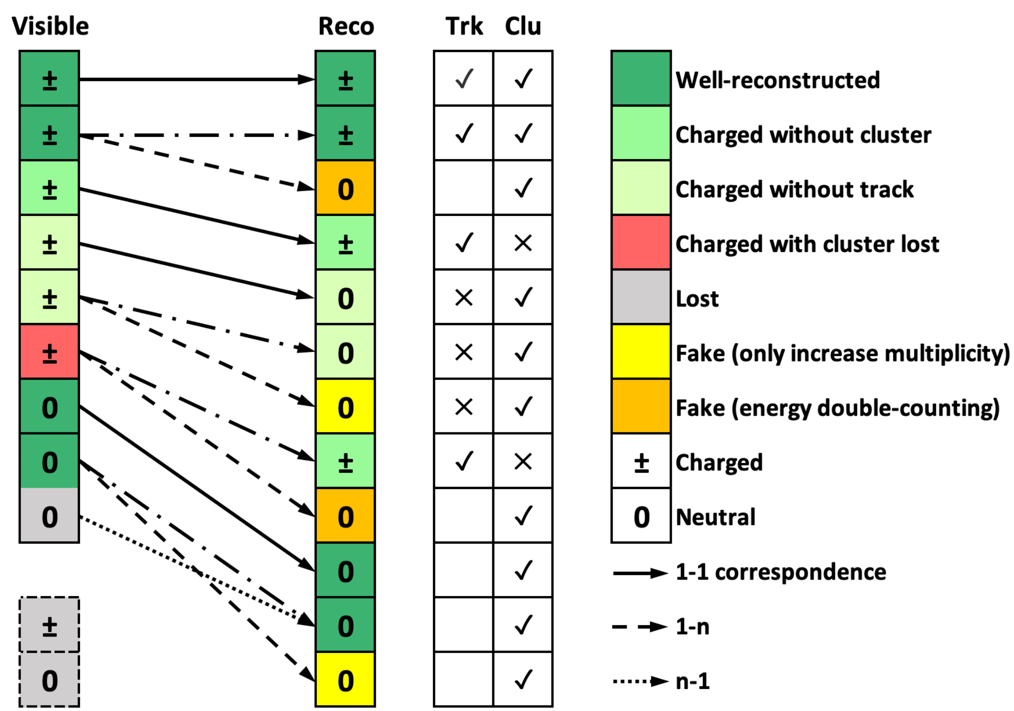
Updated comparison



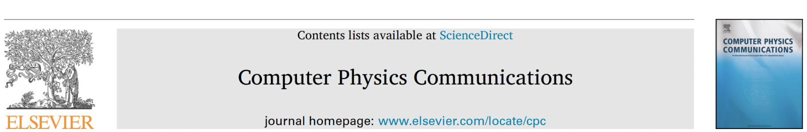
- LHC mainly dominated by theoretical/systematic...
- CEPC Holistic/ACSI approach the statistic limit – more luminosity is appreciated
- CEPC numbers not include theoretical uncertainties...
- CEPC numbers are based on fast simulation: modeling an 1-1 correspondence Detector.

1-1 correspondence reconstruction

Final state particles



https://arxiv.org/abs/2411.06939



Computer Physics Communications 314 (2025) 109661

Contents lists available at ScienceDirect

Computer Physics Communications

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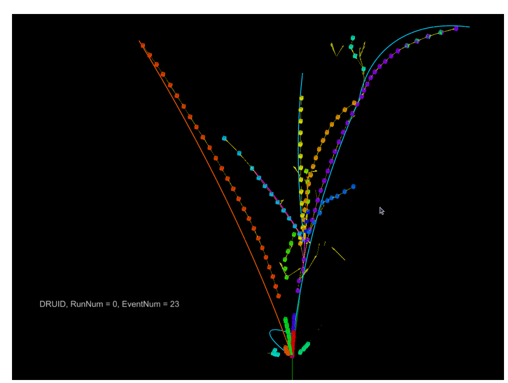
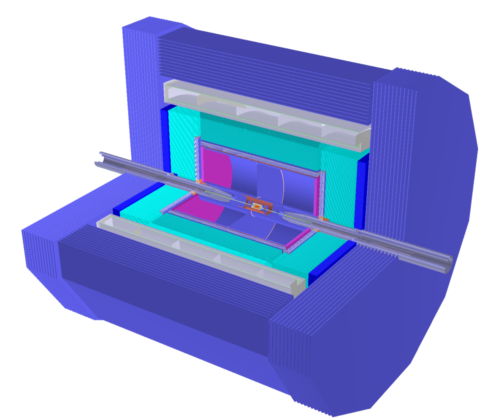
Computational Physics

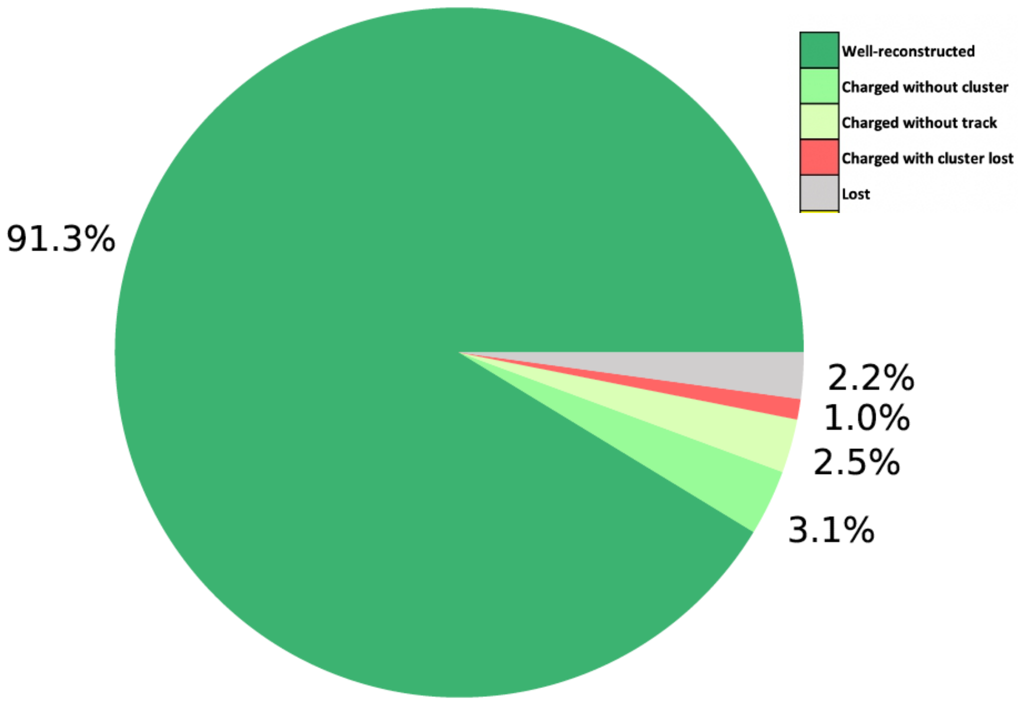
One-to-one correspondence reconstruction at the electron-positron Higgs factory

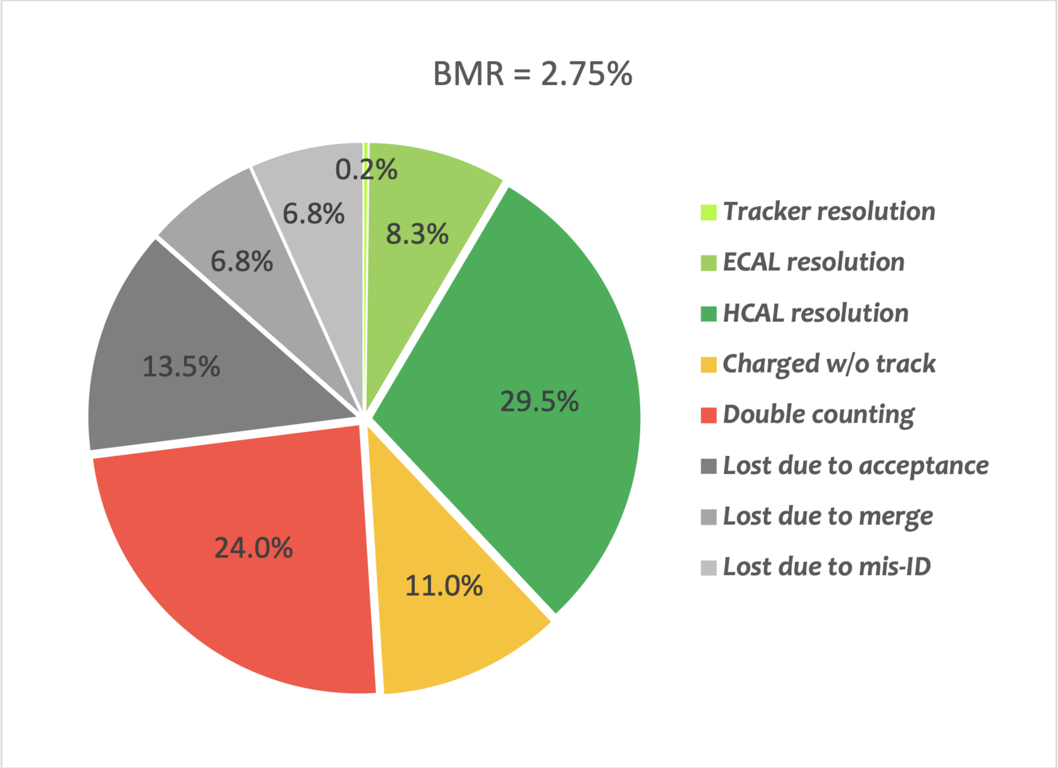
Yuexin Wang [a,b], Hao Liang [a,c,d], Yongfeng Zhu [e], Yuzhi Che [a,f], Xin Xia [a,c], Huilin Qu [g], Chen Zhou [e], Xuai Zhuang [a,c], Manqi Ruan [a,c,*]





BMR decomposition @ AURORA

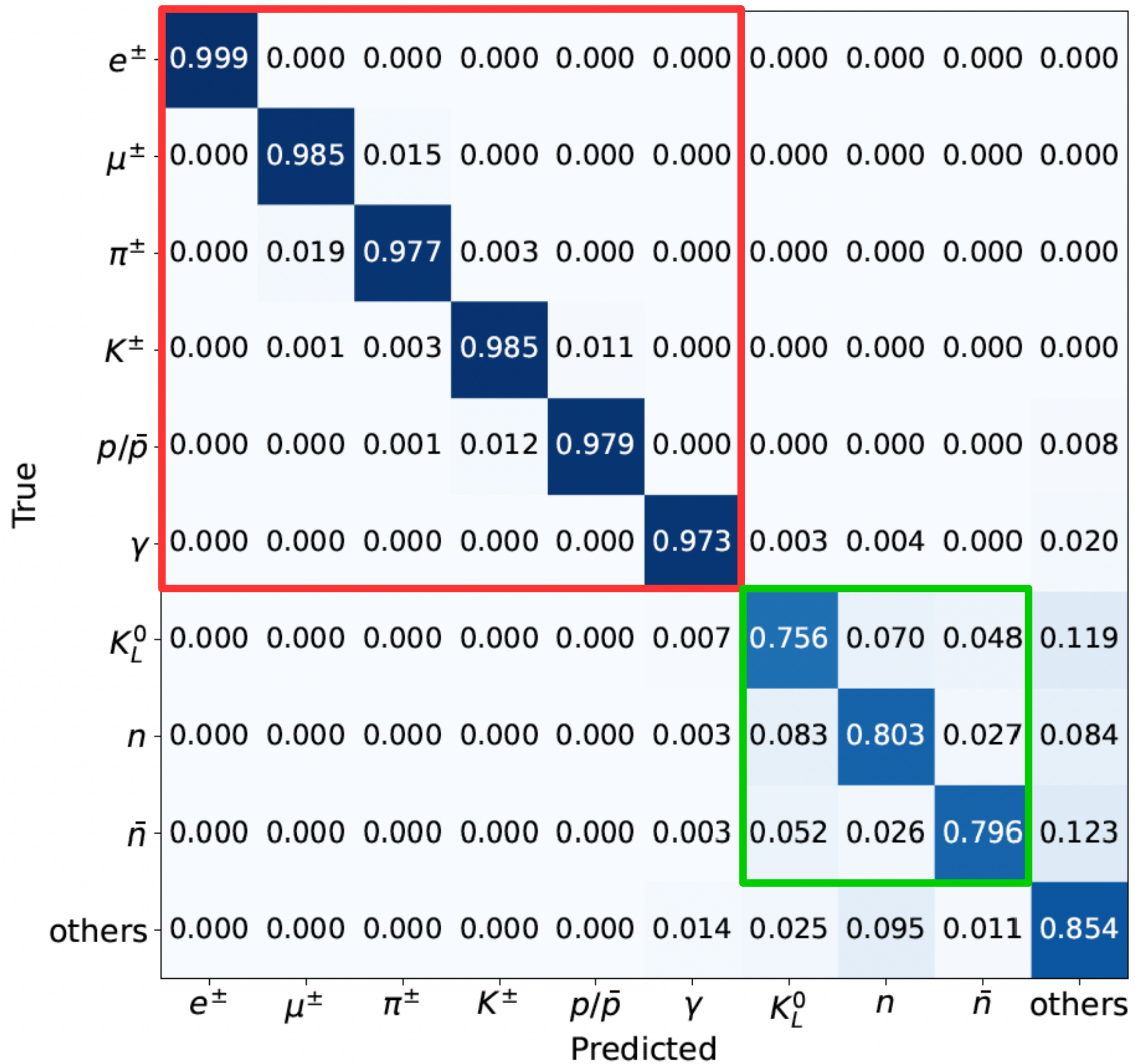


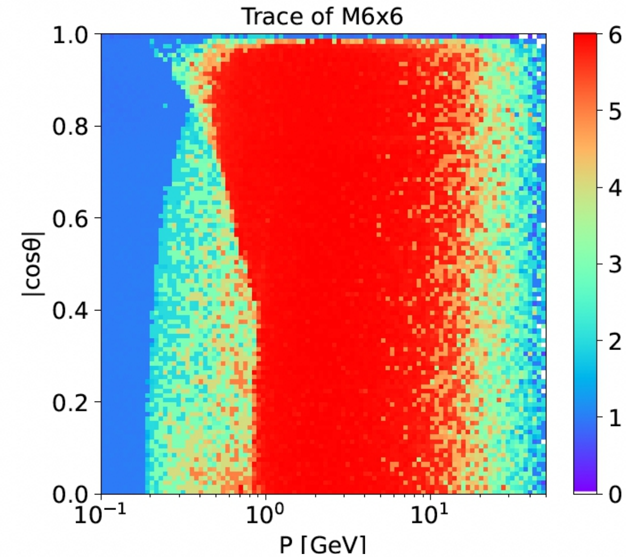


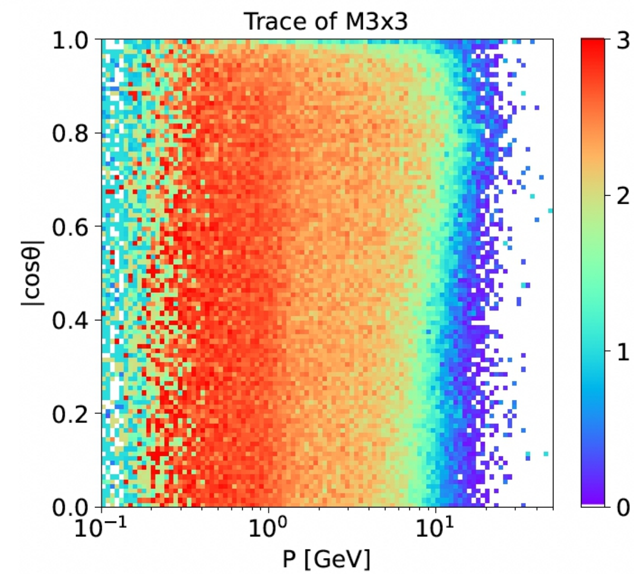
1-1 corresponding type: contributing to the BMR via resolution: ~o(0.1 – 0.001) of its mean value

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

Pid: differential performance

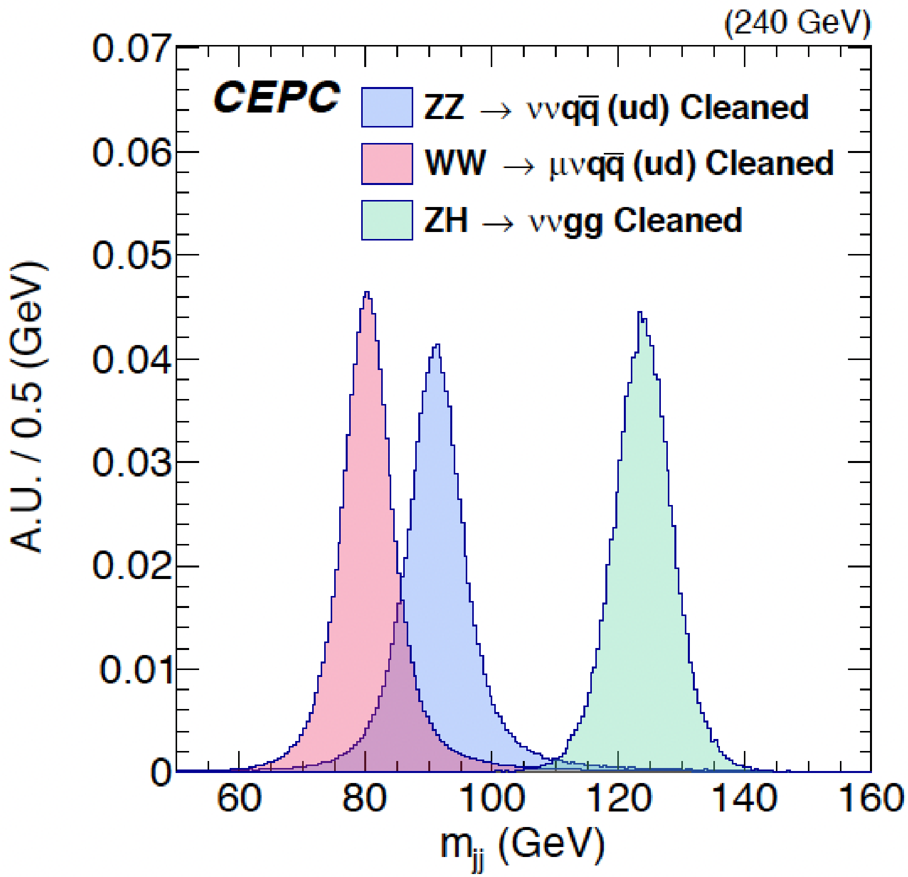


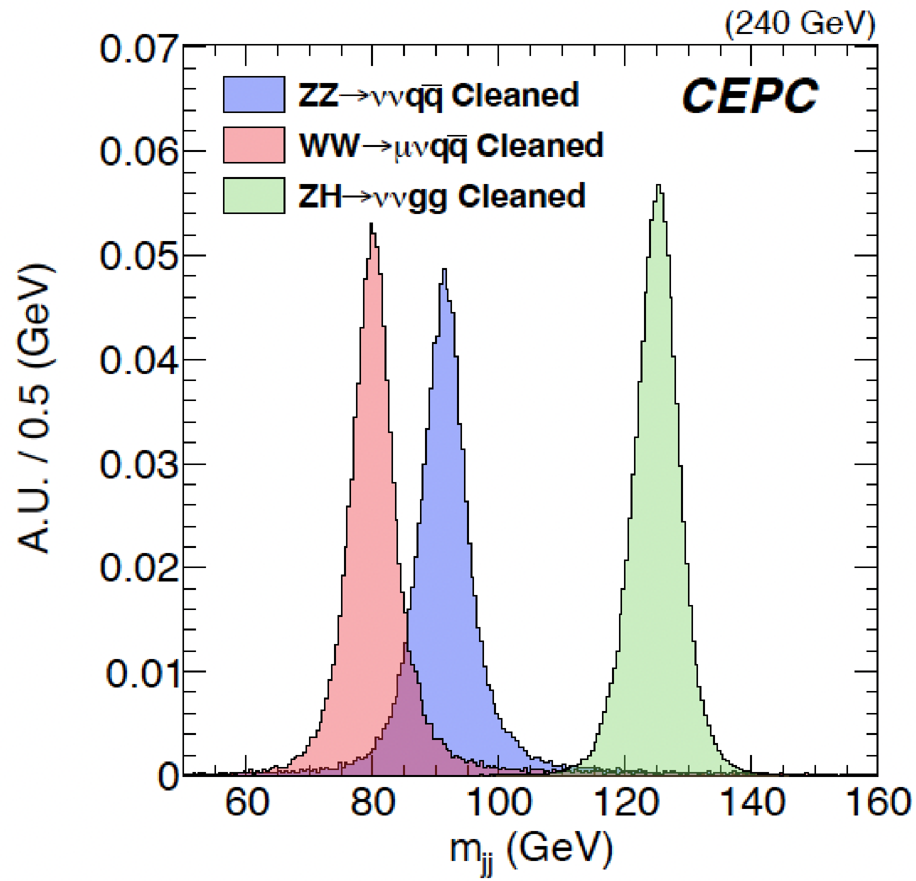




Neutral Hadron ID: 5d Calorimetry with ToF capability (δt~100 ps/hit)

BMR of 2.75% reached





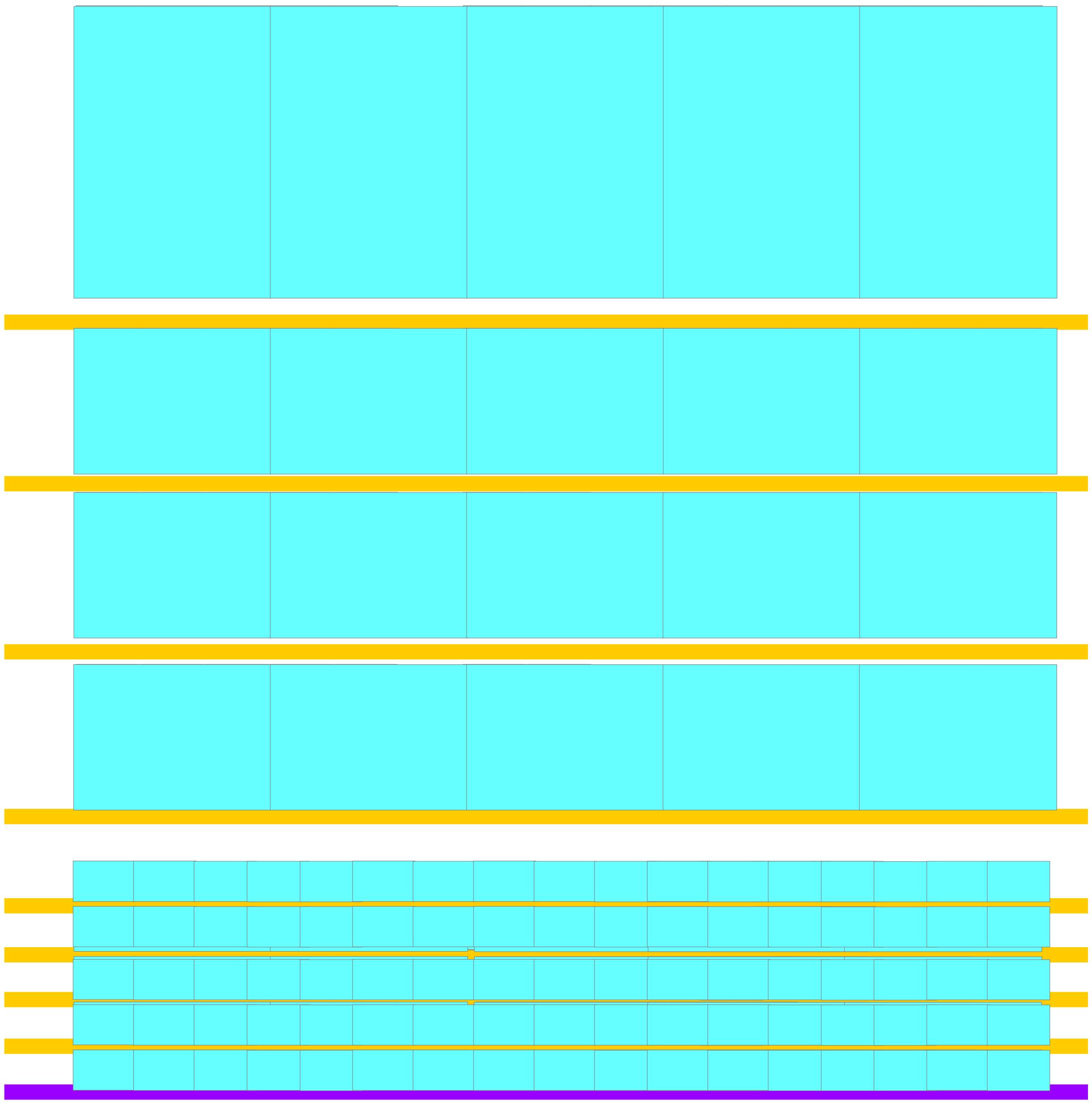
Detector change (usage of high density scintillating glass HCAL): BMR 3.7% → 3.4%;

AI enhanced reconstruction: 3.4% → 2.8%.

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

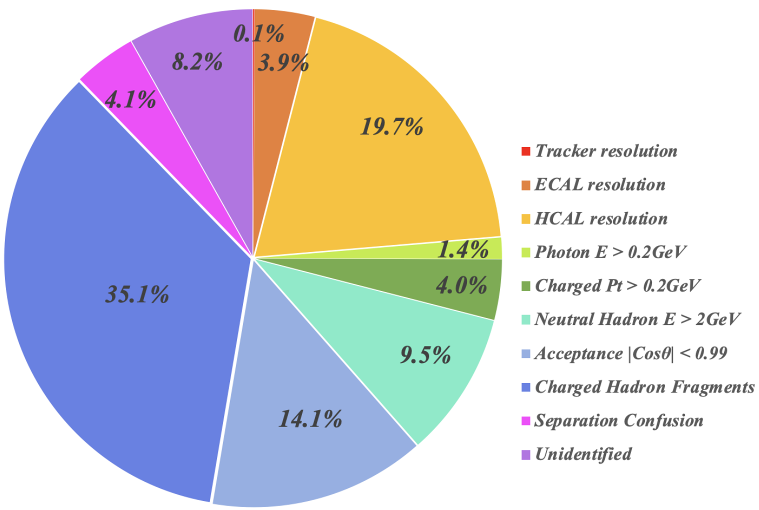
Design-4: Glass + Silicon

- Geometry
  - Glass provide Energy measurement, Glass portion close to 100%...
  - Silicon emphasize on Timing & Position
  - Optimized granularity at different location/depth
- Comments
  - Understand & verify the EM resolution of Glass...
  - Quantify the impact of Glass transparency
  - Mechanic & Cooling

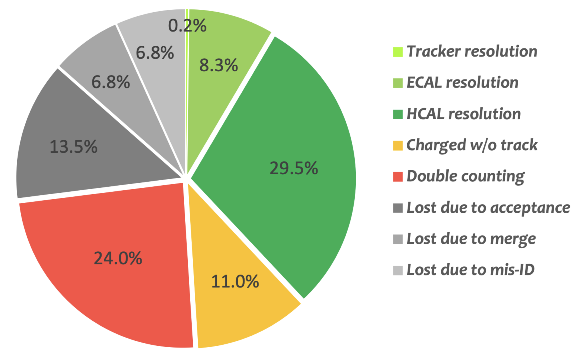


BMR: from CDR to possible future...

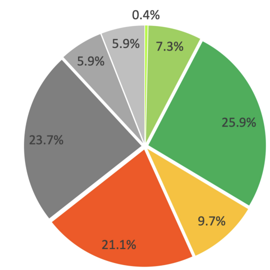
2016 - CDR: BMR ~ 4%

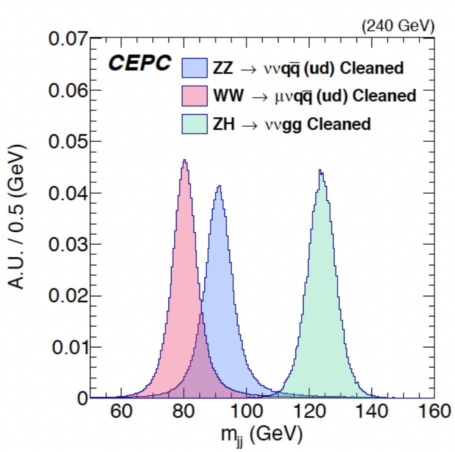


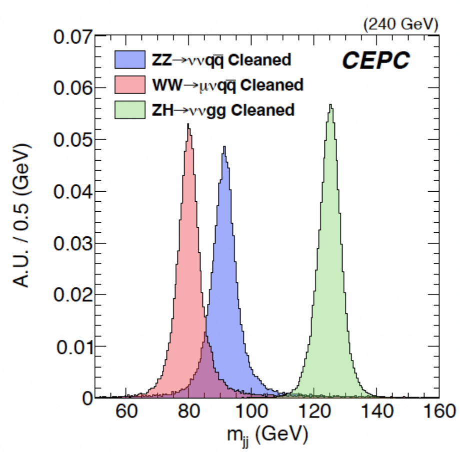
2024 - AURORA: BMR ~ 2.7%

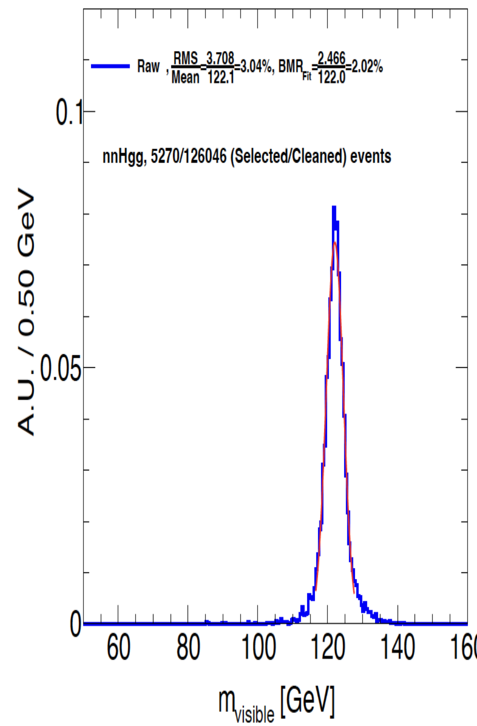


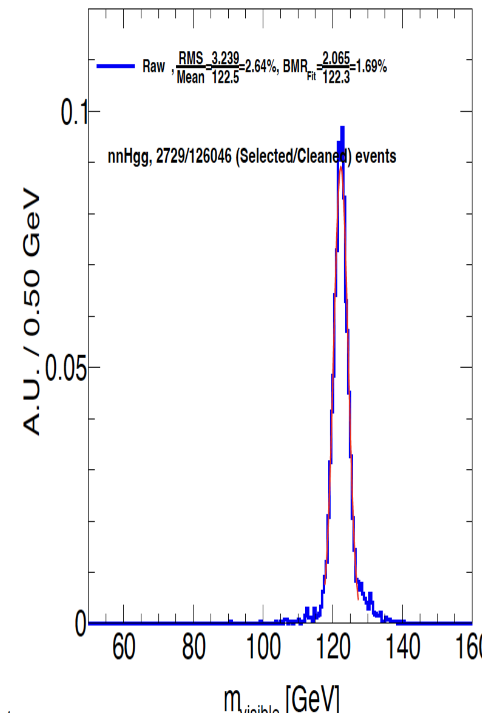
Future: BMR ~ 2.0%



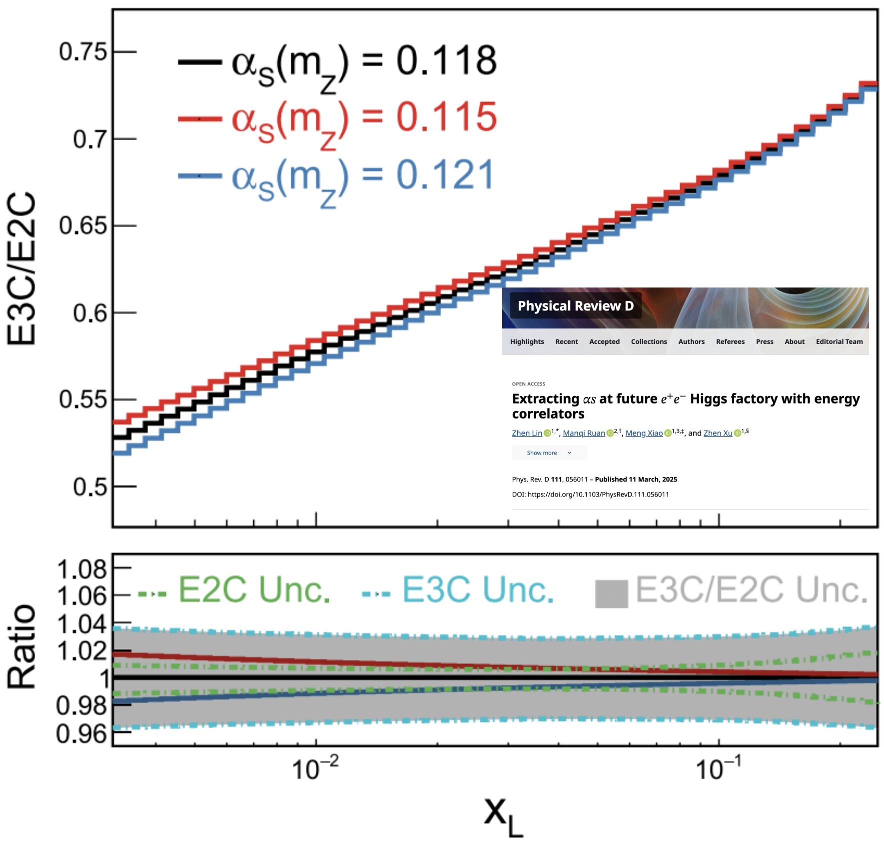


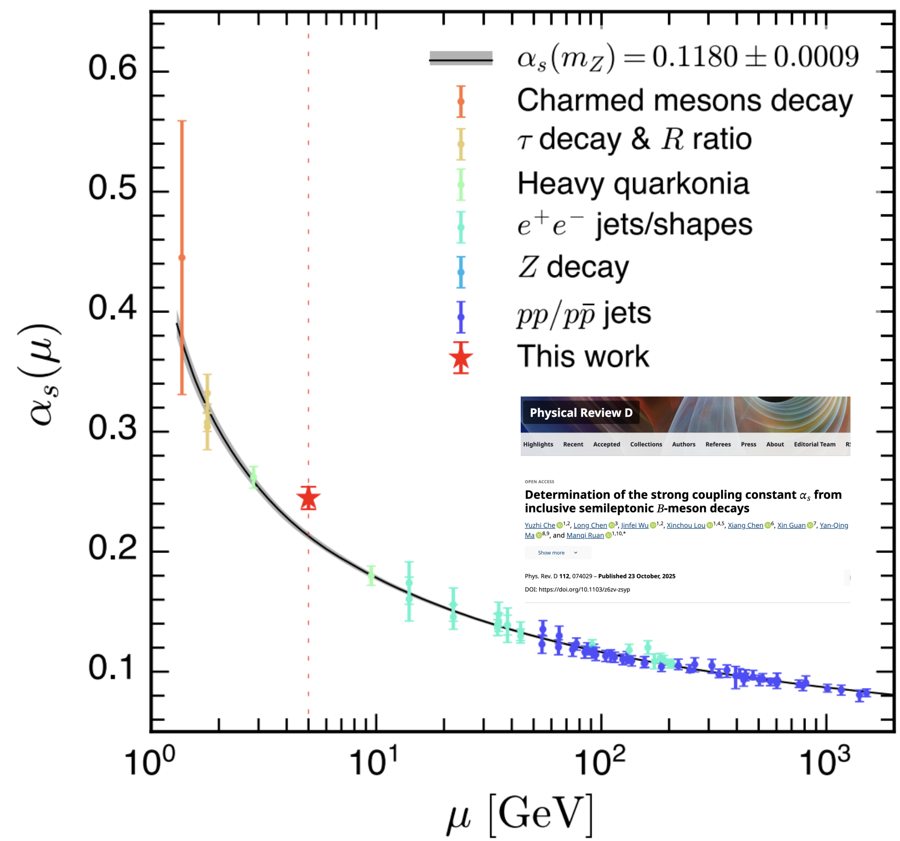






QCD relevant studies





- Strong coupling determination with EEC/b-decay: ***...theoretical uncertainty dominant...***
- Analyzing hadronic events, color singlet identification with AI tools, as well as Impact of hadronization
- Approach LEP data & bridge to b/c factories

To address the theoretical uncertainties: Precision calculation for electron positron collider

- Led by Michael (MJRM) with strong international participation
- Quantify the status... and maybe establish the roadmap to control the theoretical uncertainties...

AI: No free lunch! - Necessary studies...

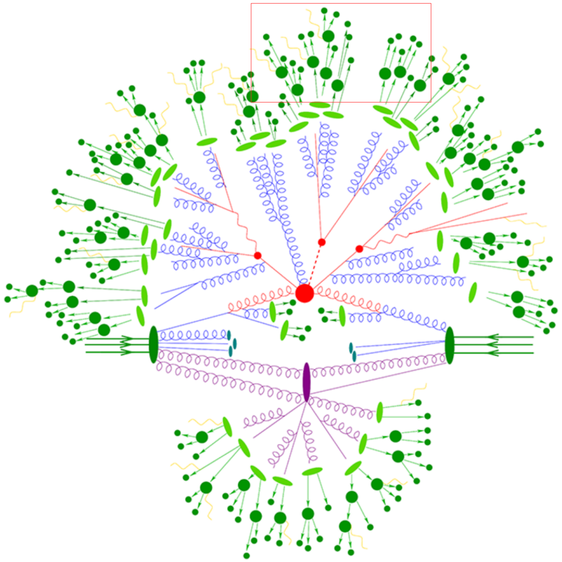
- Hadronization & impacts...
- Beam induced backgrounds & machine protection
- Event building with realistic detector time response, including electronic pulse shape & time sequence...
- TPC & Tracker:
  - Dependence of dE/dx or dN/dx performance on the shifting distance & readout threshold/Noise
  - 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...
- ...

- AI oriented systematics & mitigations... From supervised learning, to non/weakly-supervised, enhanced, LLM...

Targeted studies

- **Usage of Timing**, especially at 5d calorimetry
  - **Clustering with time**
  - **PFA of the Space Time**... to reconstruct all final state particles in the data stream continuum, and correctly associate them with different VTX & sources, including Beam Induced Background

- ***Holistic approach with sufficient categories (Multi-class identification)***
  - ~o(100) categories is sufficient... to identify almost all physics events at a Higgs factory
  - ~o(10) is probably sufficient for Z factory
  - Free of human intervene – in principle
- ***Color singlet identification & iteration with QCD studies***
- ***From leaves to the Tree:***
  - Id the parenting info of final state particles; i.e., *B→D→K→pi0→γ...*



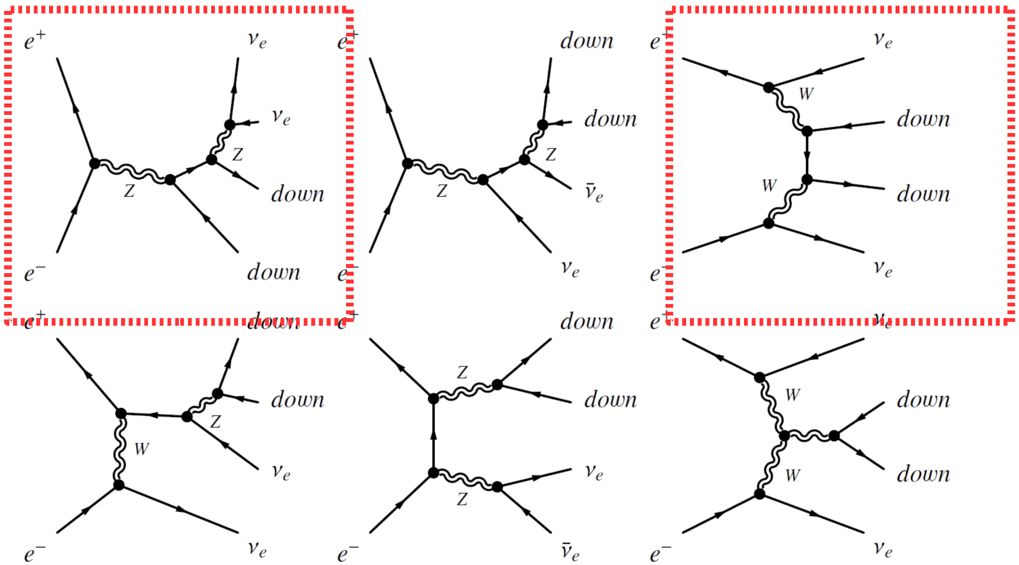
- *...*

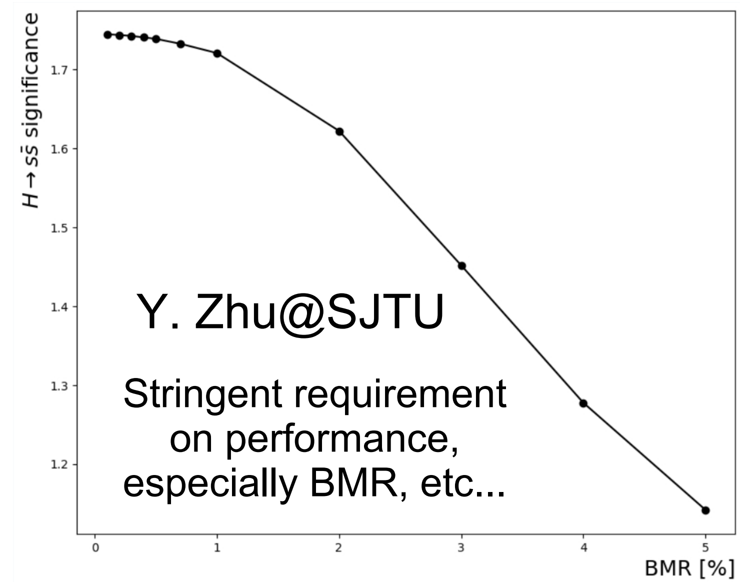
Summary

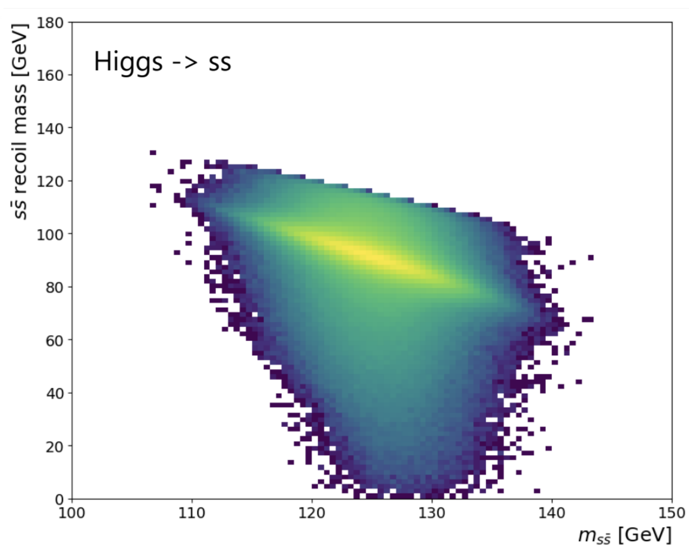
- **... CEPC has strong discovery power: leap of orders of magnitudes ...**
- **Flavor & NP White papers delivered in 2025**
  - Address the EWPT, DM, & multiple observation windows.
- **EW WP: a major update with strong engagement of AI technology, which roughly boost the discovery power by 3 folds at Higgs observables**
  - Holistic approach for classification + ACSI for grouping
    - Reco: Jet origin id, 'see' the quark & gluons...
    - Analysis: in principle free from Human intervene.
  - Multiple AI relevant challenges need to be addressed...
    - From supervised learning, to non/weakly-supervised, enhanced, LLM...
    - Rich interplay & synergies with AI studies...
  - 1-1 correspondence reconstruction: excellent PID + BMR of 2.7%, where 5-d calo is the key
  - **Theoretical uncertainty: hope to achieve much profound understanding via PCEPC & collective efforts**
- **AI: the trend, lots of interesting interplay anticipated...**

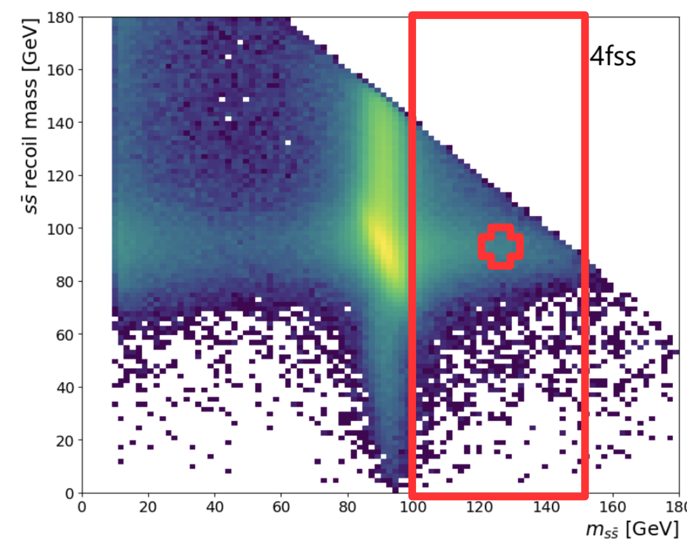
Back up

Performance requirements of H→ss measurements



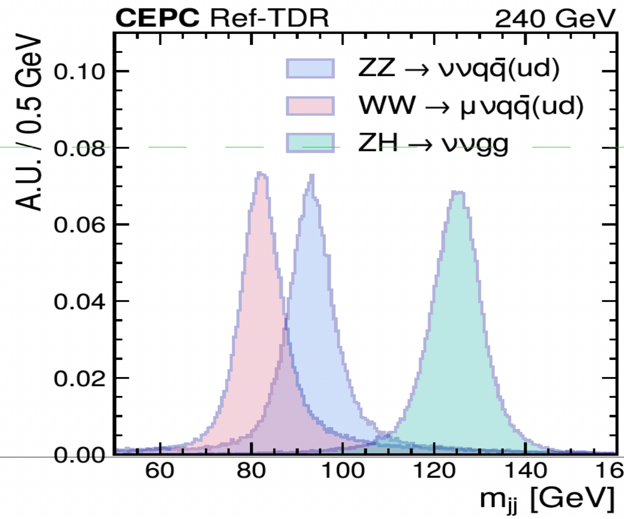


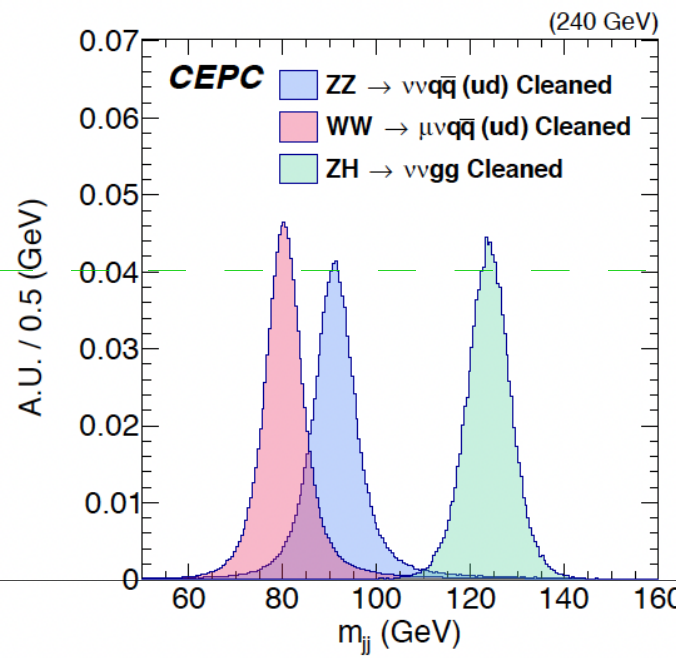


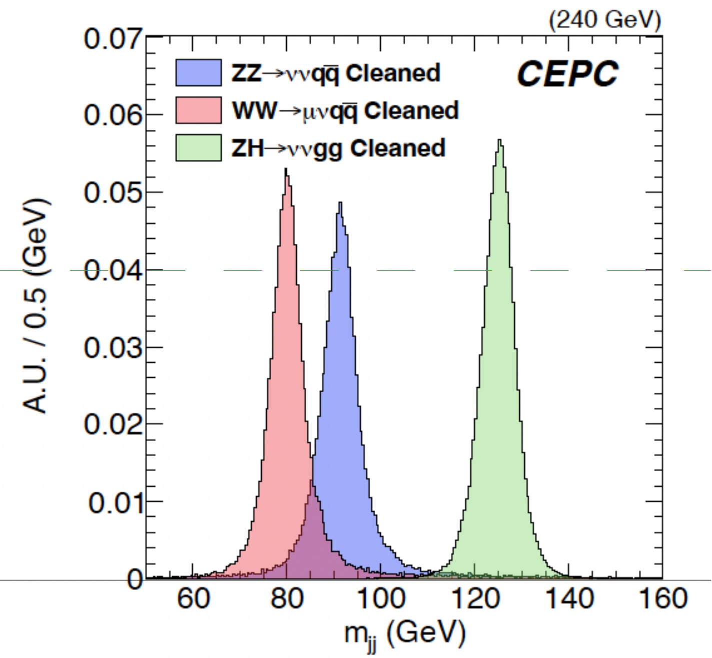


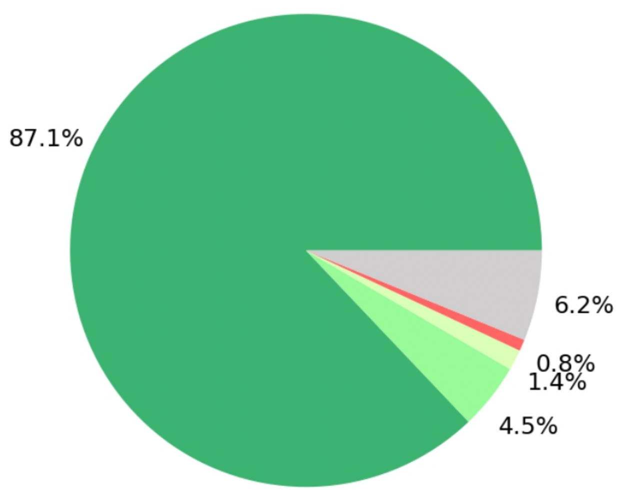
Comparison

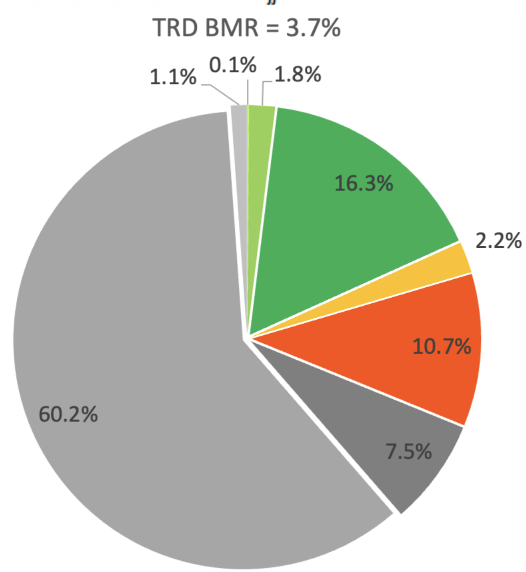
15*15*400

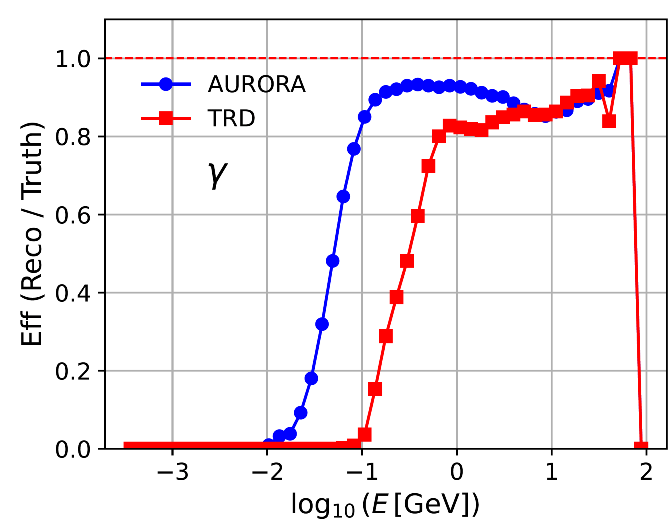






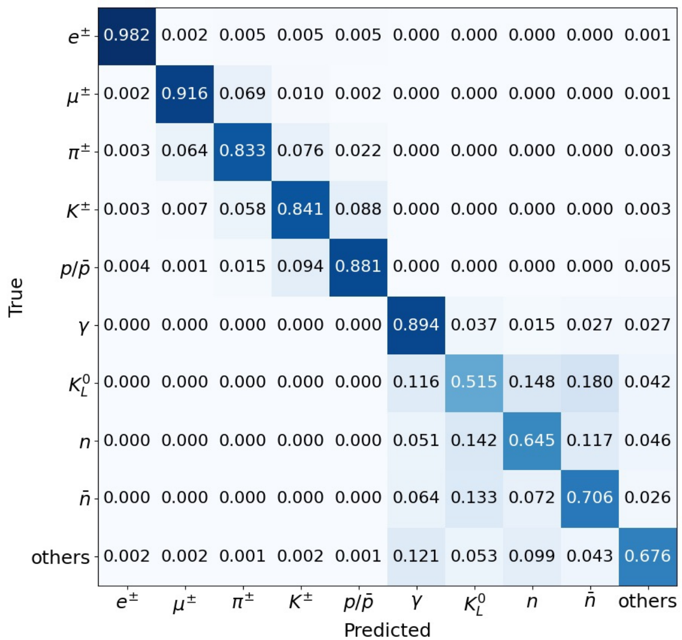


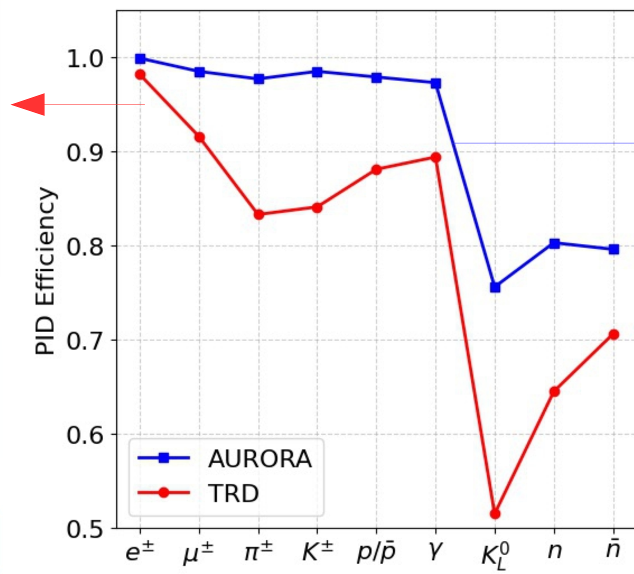


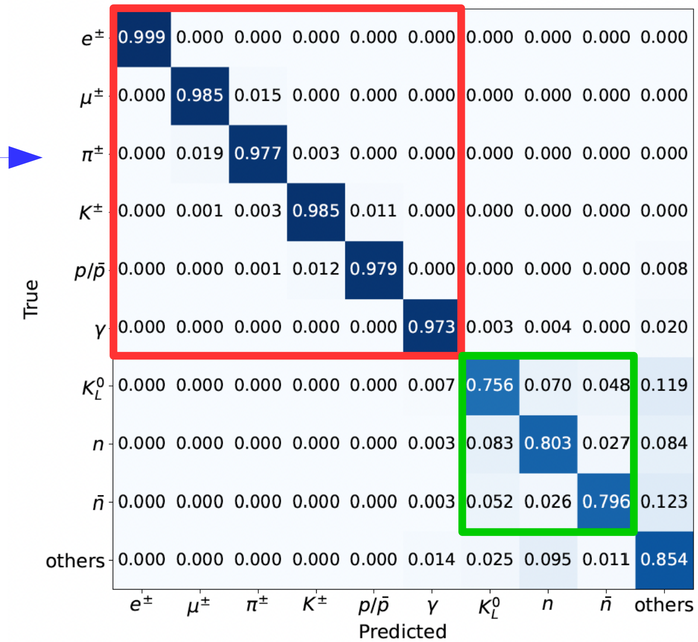


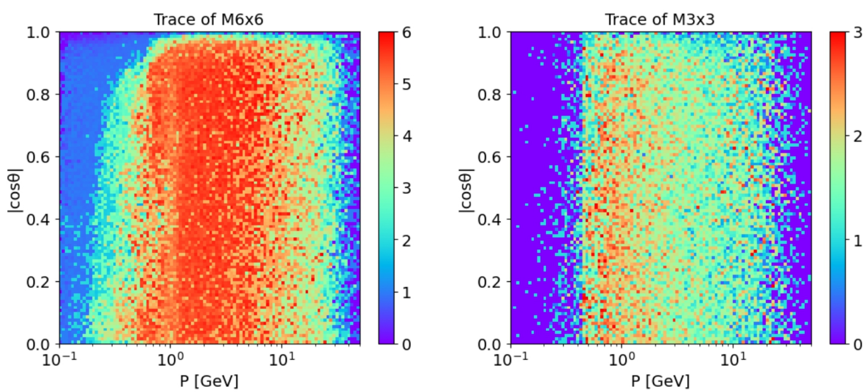
*From report in May CEPC day, using 10*10*400 xstal bar*

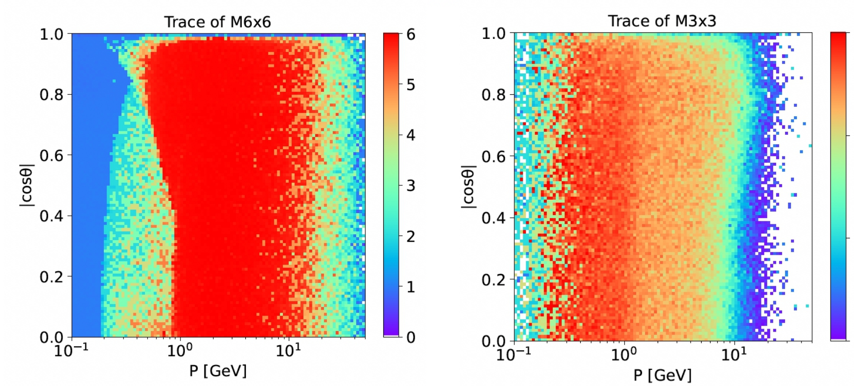
Pid









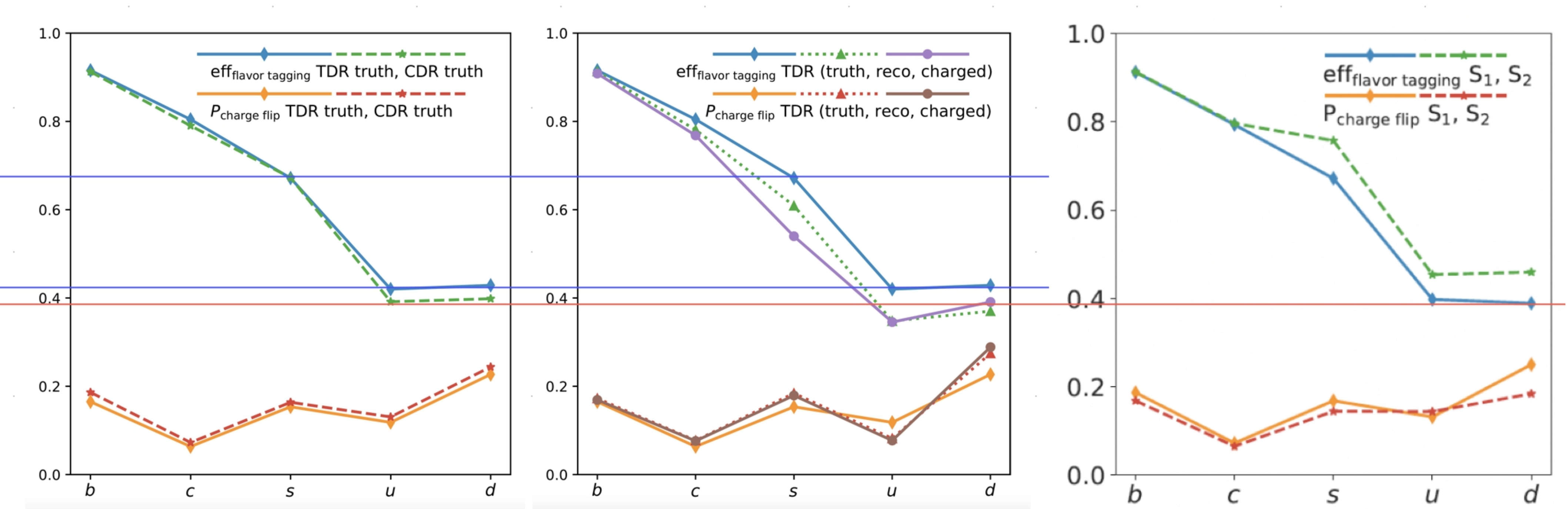


Kaon id: TDR has larger inner TPC radius. To be verified & confirmed quantitatively.

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

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

JoI at TRD, CDR & AURORA (ideal)



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

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

Neutral Hadron ID has strong impact on Light Quark ID: **Critical for in H→ss (to be quantified...)**

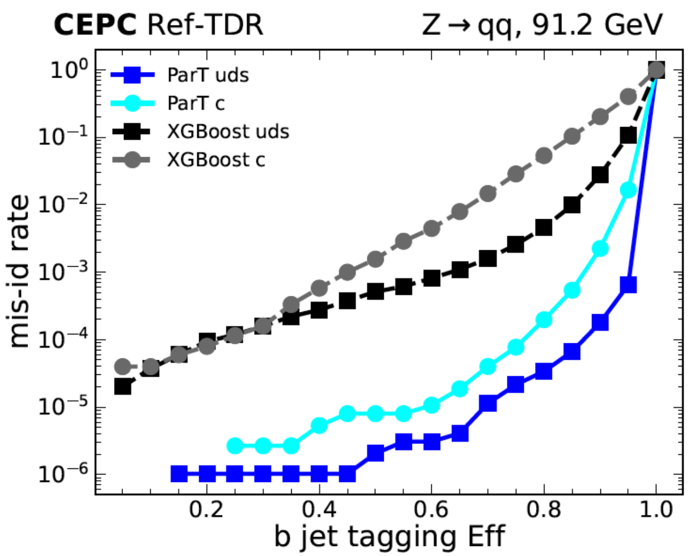
Performance changes

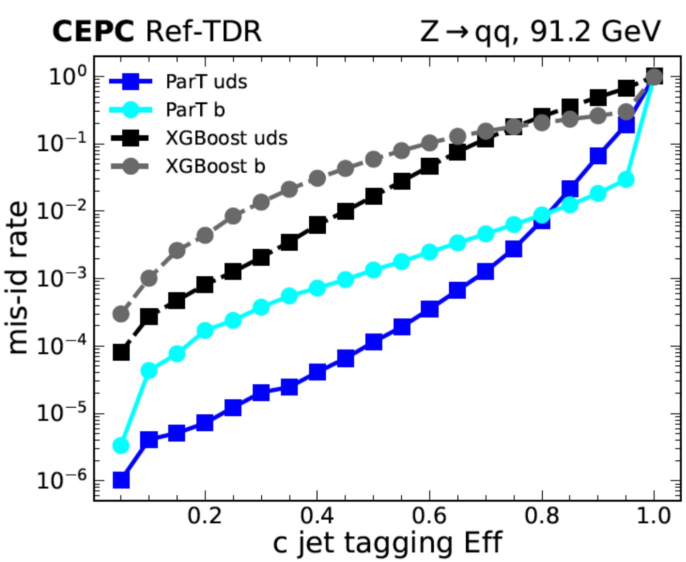
- From CDR to TRD
  - Stitching VTX
  - Glass HCAL
  - Larger inner radius of TPC
    - To be optimized especially in pace with BIB study
  - Xstal Bar ECAL (15*15*400 mm)
    - Hard to identify neutral particles, especially low energy ones, at busy super cell.
    - Timing information: used to determine the position, and not good enough to support Pid determination
    - Granularity & layout Need to be optimized
  - *TRD tracking algorithm is actually better than CDR*

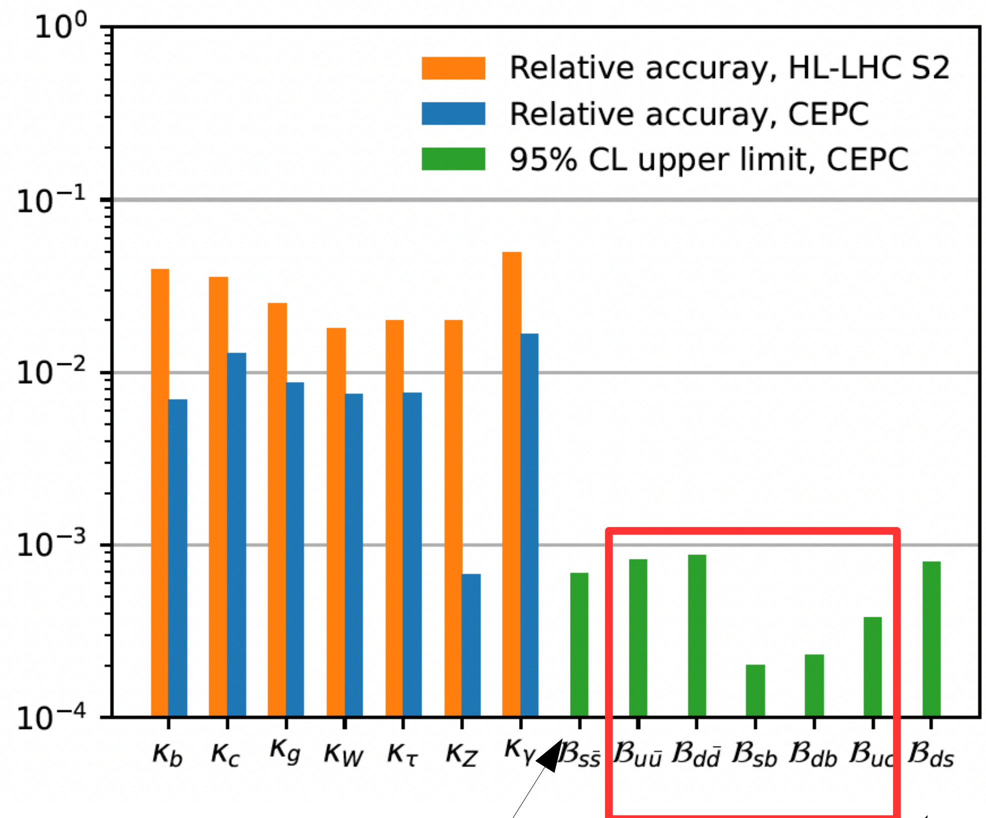
Summary

- ***LHC is expected to deliver percentage level Higgs measurements (ESPPU 2026), challenging the narration of 1 order of magnitude improvement at CEPC.***
  - ***LHC still has potential to improve... in pace with high precision theoretical calculation, AI usage especially in trigger, etc.***
- ***CEPC shines with Higgs width, invisible, etc. But we need to further develop the scientific merit***
  - ***Higgs to strange, 2nd generation Yukawa***
  - ***Higgs to NP (like H→4b for EWPT, etc)***
- ***Receipt to maintain this "1 order" advantageous of CEPC***
  - ***10 Million Higgs would be ideal.***
    - ***More detectors, higher instant luminosity, and maybe longer operation***
  - ***Holistic + ACSI, enhance the discovery power 3 times & identify H→ss decay, requiring***
    - ***1-1 correspondence...***
    - ***Lots of profound studies are needed...***
- ***Optimization suggestion for TRD***
  - ***TPC inner radius, and ECAL configuration especially granularity***

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 $\sin^2\theta^l_{eff}$ measurement

Table 2. Sensitivity S of different final state particles.

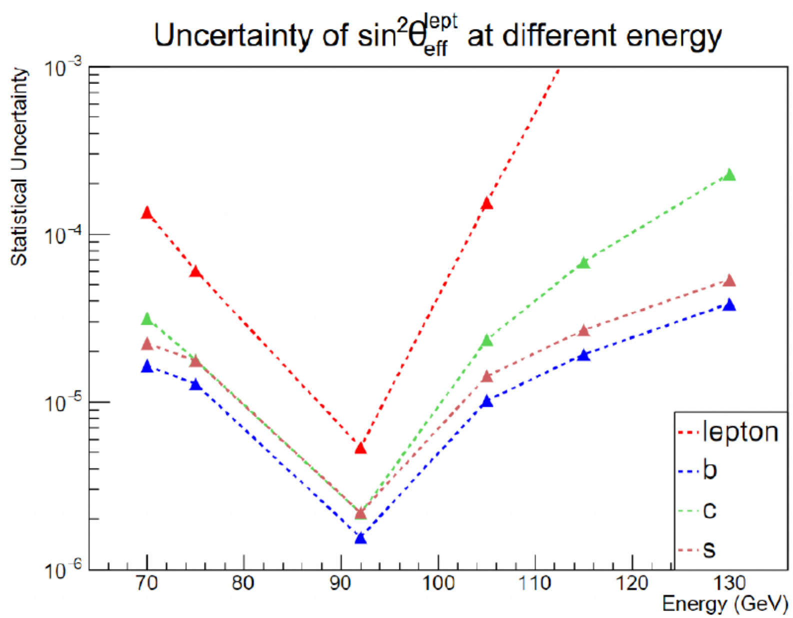
$\sqrt{s}$/GeV	S of $A^{e/\mu}_{FB}$	S of A^{d}_{FB}	S of A^{u}_{FB}	S of A^{s}_{FB}	S of A^{c}_{FB}	S of A^{b}_{FB}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958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

Chinese Physics C Vol. 47, No. 12 (2023) 123002

Measurement of the effective weak mixing angle at the CEPC*

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Abstract: We present a study of the measurement of the effective weak mixing angle parameter ($\sin^2\theta^\ell_{\rm eff}$) at the Circular Electron Positron Collider (CEPC). As a fundamental physics parameter, $\sin^2\theta^\ell_{\rm eff}$ plays a key role not only in the global test of the standard model electroweak sector, but also in constraining the potential beyond standard model new physics at the high energy frontier. CEPC proposes a two year running period around the Z boson mass pole at high instataneous luminosity, providing a large data sample with 4×10^{12} Z candidates generated in total. It allows a high precision measurement of $\sin^2\theta^\ell_{\rm eff}$ both in the lepton and quark final states, where the uncertainty can be one order of magnitude lower than any previous measurement at the LEP, SLC, Tevatron, and LHC. It will improve the overall precision of the $\sin^2\theta^\ell_{\rm eff}$ experimental determination to be comparable to the preicision of the theoretical calculation with two-loop radiative corrections, and it will also provide direct comparisons between different final states. In this paper, we also study the measurement of $\sin^2\theta^\ell_{\rm eff}$ in the high mass region. Taking data for one month, the precision of $\sin^2\theta^\ell_{\rm eff}$ measured at 130 GeV from b quark final state is 0.00010, which will be an important experimental observation on the energy-running effect of $\sin^2\theta^\ell_{\rm eff}$.

Keywords: effective weak mixing angle, Circular Electron Positron Collider (CEPC), electroweak

DOI: 10.1088/1674-1137/acf91f

Eur. Phys. J. C (2025) 85:993
https://doi.org/10.1140/epjc/s10052-025-14689-7

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Measurement of the effective weak mixing angle using $b\bar{b}$, $c\bar{c}$ and $s\bar{s}$ final states at the CEPC

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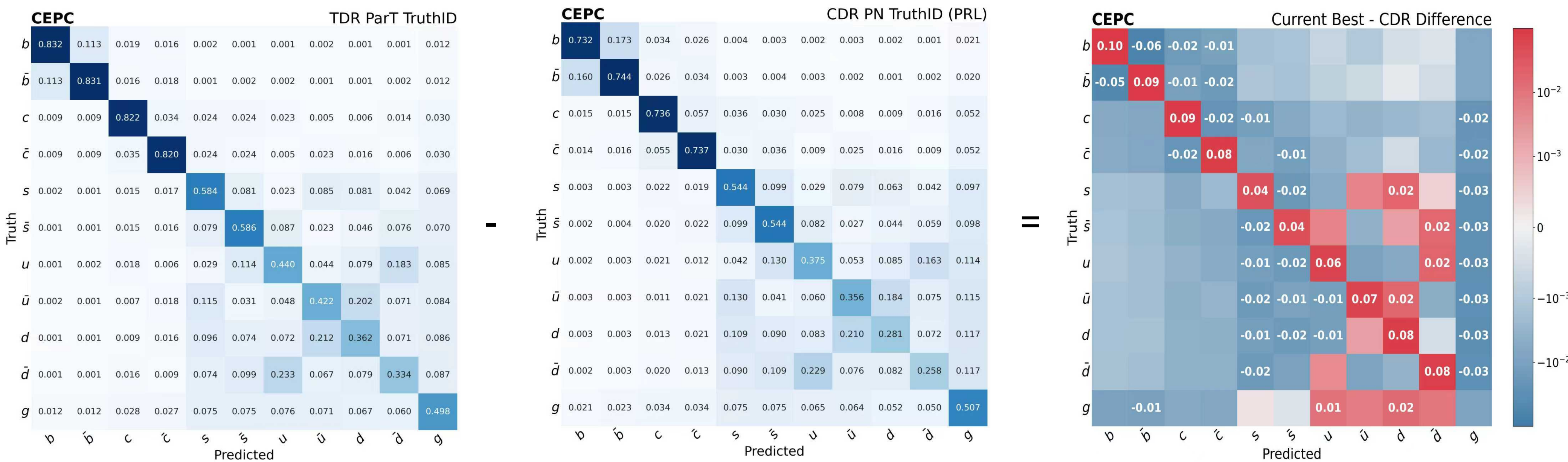
Received: 17 October 2024 / Accepted: 28 August 2025

Abstract The proposed Circular Electron Positron Collider (CEPC) is expected to provide adequate events around the Z boson mass pole, allowing high precision determination on the effective weak mixing angle. Specifically, one can acquire large data samples of the $Z\to b\bar{b}$, $Z\to c\bar{c}$ and $Z\to s\bar{s}$ events with high purity, even though the efficiencies of the jet tagging are limited to ensure a good separation between different flavors. According to recent studies of the detector and reconstruction algorithms, with the new jet tagging method at the CEPC detector which gives a purity of 99.9% for the $b\bar{b}$ and $c\bar{c}$ samples and 97% for the $s\bar{s}$ sample, the corresponding uncertainties on the effective weak mixing angle determined from those samples are better than 10^{-4} using data collected within 1 month. It allows high precision determinations of the effective weak mixing angle from different quark flavors especially for c and s quarks, which is essential to the standard model global test and potential new physics searches.

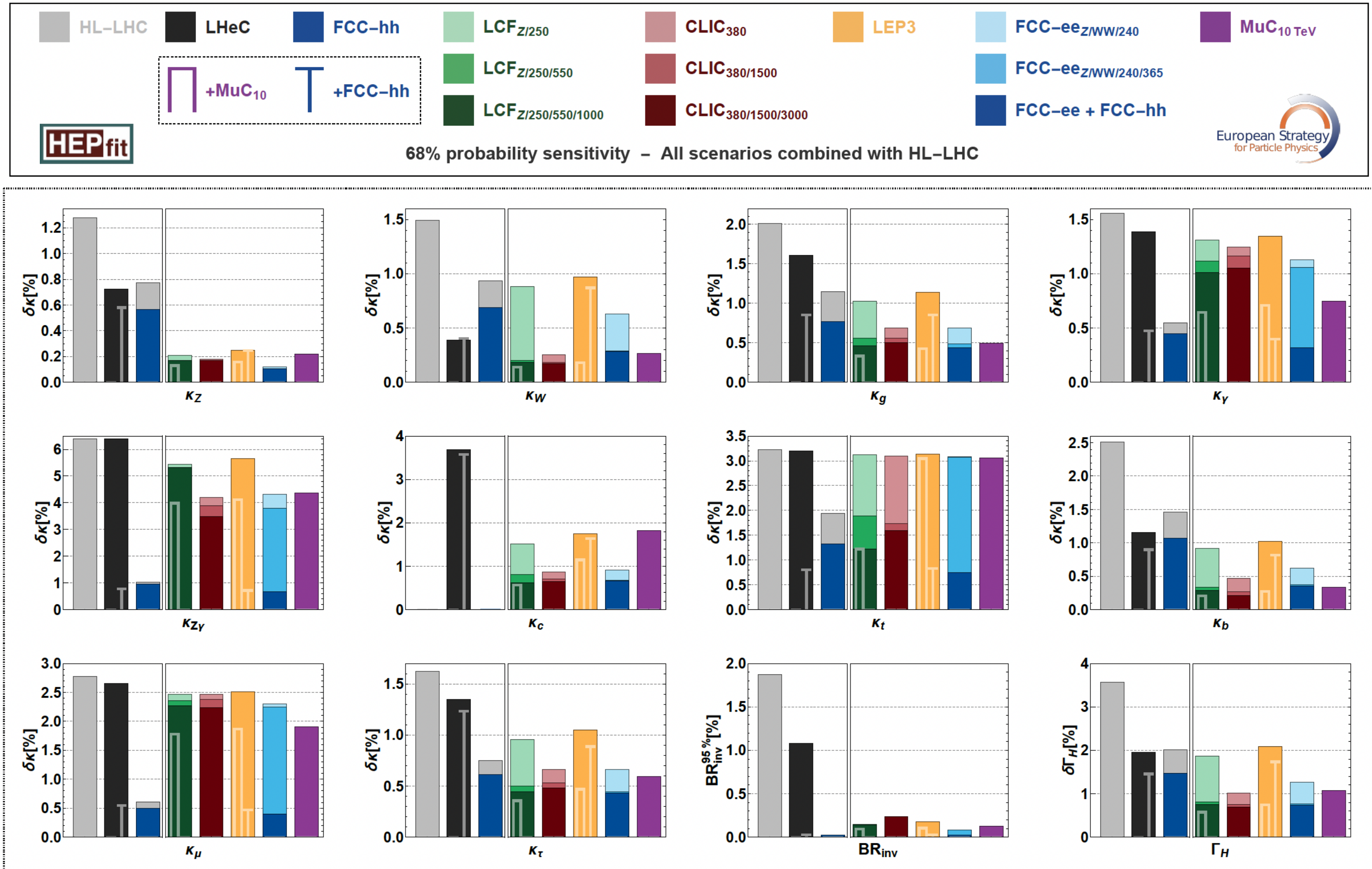
where κ_f is the flavor-dependent scale factor. In custom, the leptonic effective weak mixing angle ($\sin^2\theta^\ell_{\rm eff}$) is chosen as the experimental determined parameter, while the quark effective weak mixing angles are converted to the leptonic one accordingly. Since the higher order loop corrections are flavor-dependent, measuring the weak mixing angle from the Drell-Yan processes with different f is essential to both the SM global test and the beyond SM new physics search.

In the past two decades, $\sin^2\theta^\ell_{\rm eff}$ has been measured at the energy scale of the Z boson mass pole. The SLC $e^+e^-\to f\bar{f}$ measurement exploited the polarization of the electron beam, providing a pure leptonic determination, giving $\sin^2\theta^\ell_{\rm eff}$[SLC] $= 0.23098\pm0.00026$ [1]; The LEP $e^+e^-\to b\bar{b}$ measurement contains both Z-to-lepton and Z-to-heavy quark couplings, giving $\sin^2\theta^\ell_{\rm eff}$[LEP-b] $=0.23221\pm0.00029$ [1]. These two measurements achieve the best precision of the $\sin^2\theta^\ell_{\rm eff}$ determination, while their central value differ by 3.2 standard deviation. At the proton-antiproton collider Tevatron, $\sin^2\theta^\ell_{\rm eff}$ is measured in

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)...*



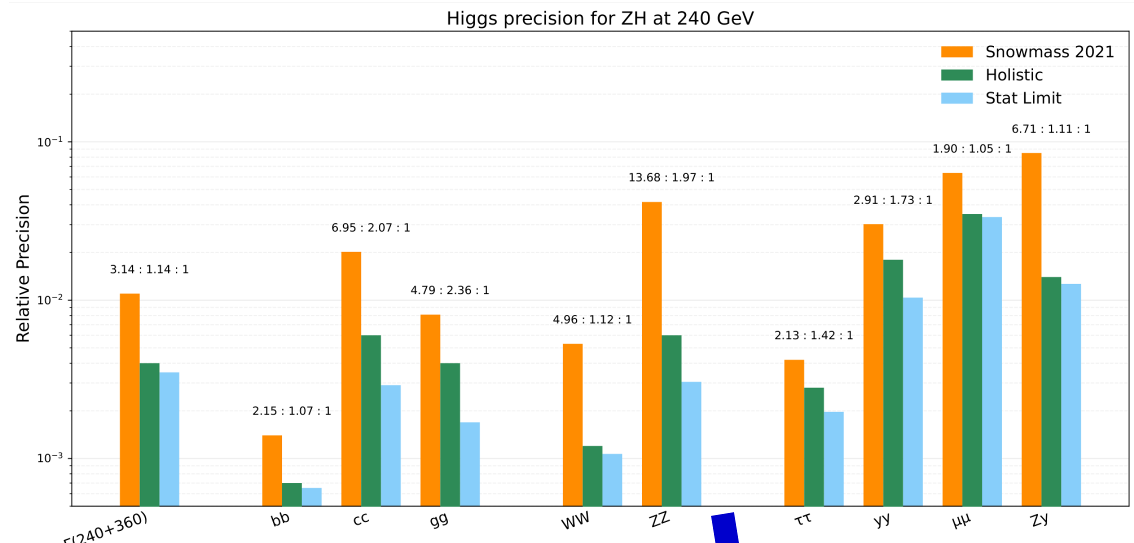
Observation consistent with Physics Briefing book of ESPPU 2026

FCC-ee 2.26 M @ 240 GeV + 0.46 M @ 360 GeV

Anticipated Higgs precisions... updates

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.

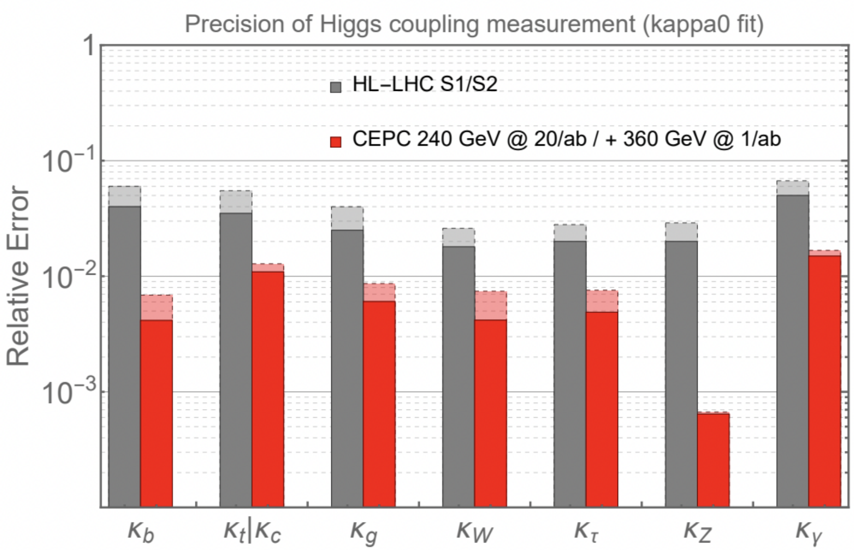
Channel	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}	
	Prec. (%)	Impr.	Prec. (%)	Impr.
ZH Production				
Inclusive	0.13	2.0	0.25	5.6
$H \to bb$	0.07	2.0	0.5	1.8
$H \to cc$	0.6	3.4	2.6	3.4
$H \to gg$	0.4	2.0	1.7	2.0
$H \to WW$	0.12	4.4	0.6	4.7
$H \to ZZ$	0.6	7.0	2.9	6.9
$H \to \tau\tau$	0.28	1.5	1.4	1.5
$H \to \gamma\gamma$	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	4.0
$H \to gg$	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	—	—

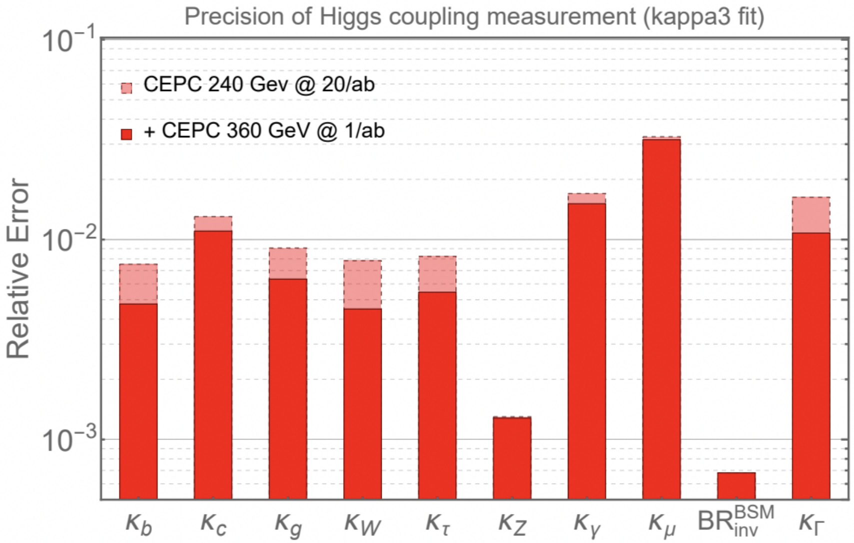


Preliminary!

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%**		
$\mathrm{Br}_{upper}(H \to inv.)$	**0.07%**				
Γ_H	**1.65%**		**1.10%**		





CSI: bottleneck for measurement at full hadronic events

PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: *March 11, 2022*
REVISED: *September 9, 2022*
ACCEPTED: *November 11, 2022*
PUBLISHED: *November 16, 2022*

JHEP11(2022)100

The Higgs$\to b\bar{b}, c\bar{c}, gg$ 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)

Updated result on $\sin^2 \theta^{l}_{eff}$ 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

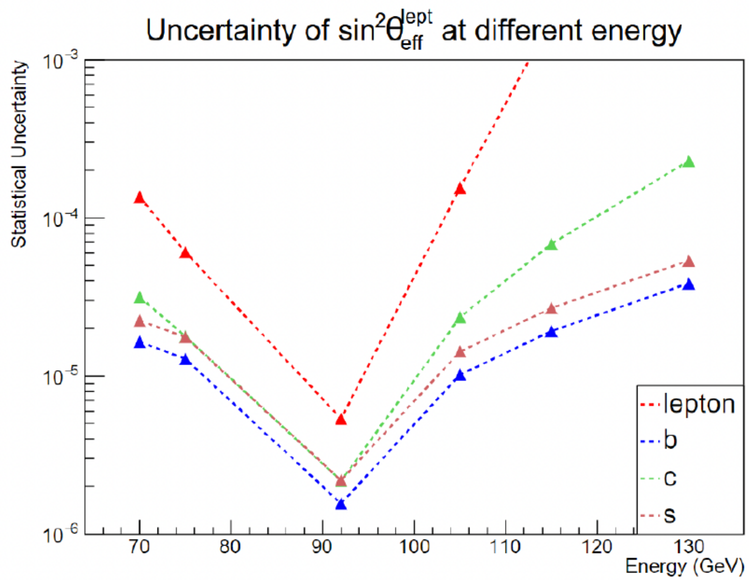
Table 3. Cross section of process $e^+e^- \to f\bar{f}$ calculated using the ZFITTER package. Values of the fundamental parameters are set as $m_Z = 91.1875$ GeV, $m_t = 173.2$ GeV, $m_H = 125$ GeV, $\alpha_s = 0.118$ and $m_W = 80.38$ GeV.

$\sqrt{s}$/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 $\sin^2 \theta^{l}_{eff}$ 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, i.e., those with Bs oscillation...

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Check for updates
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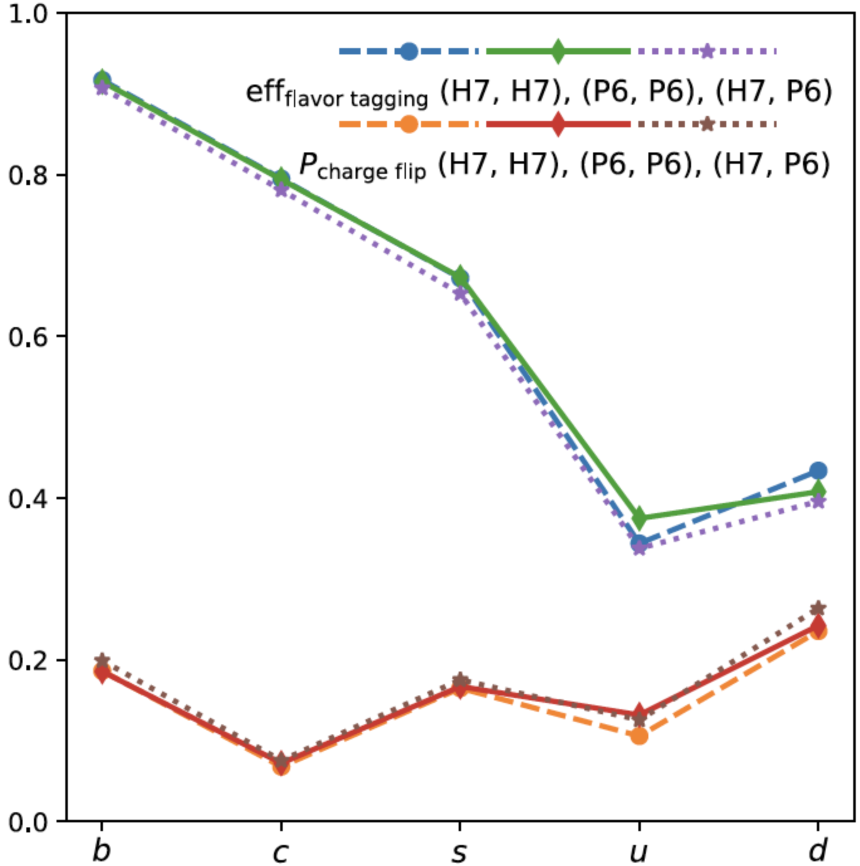
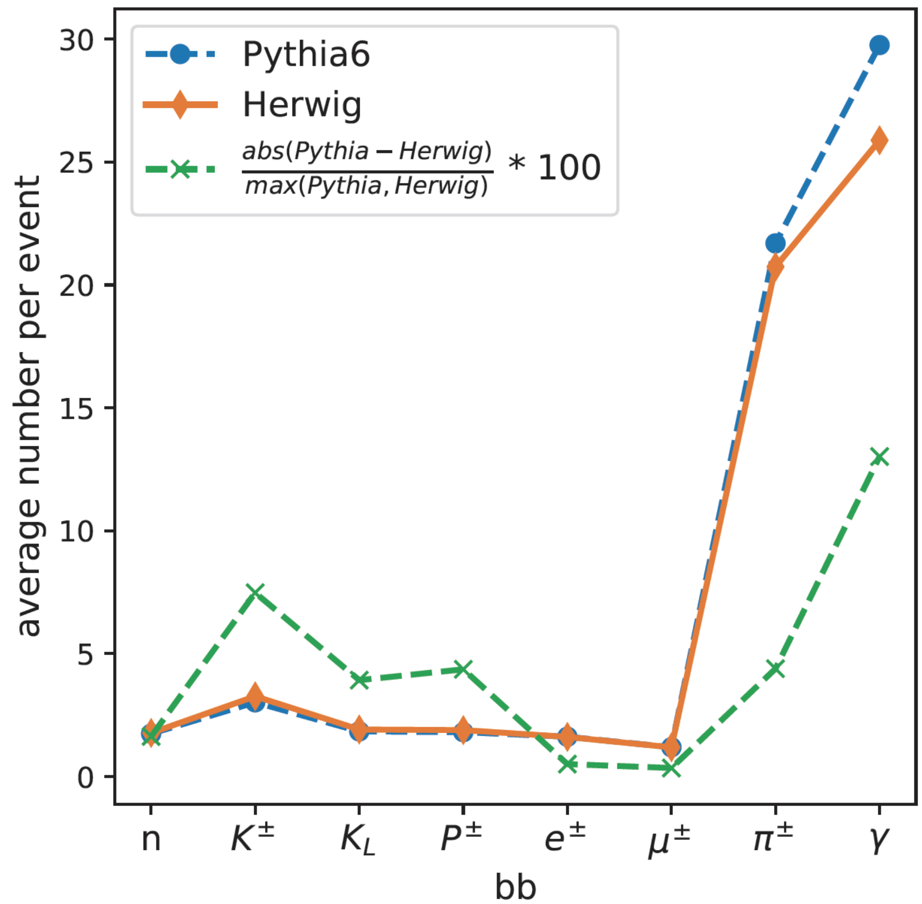
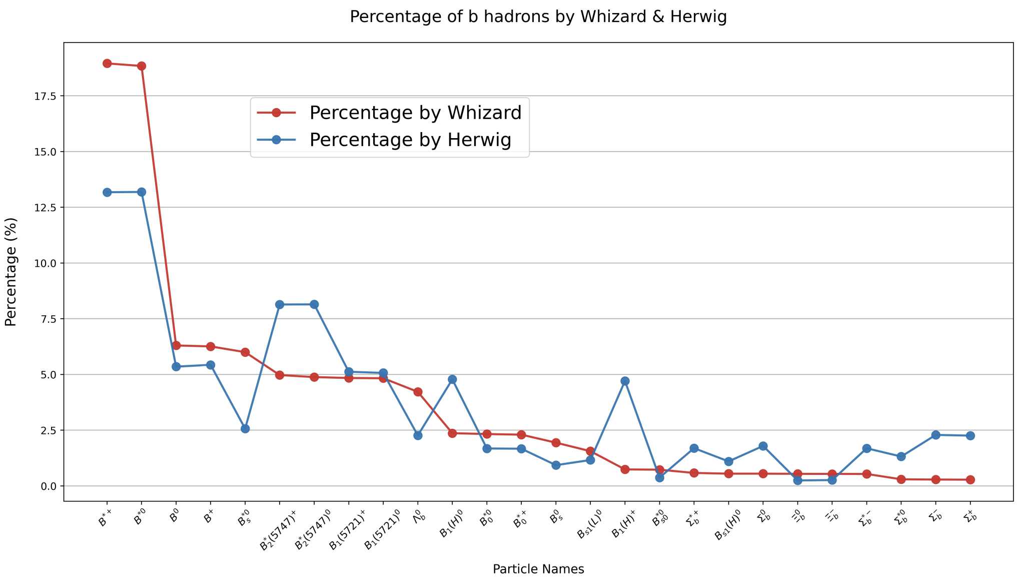
V.S. Hadronization models

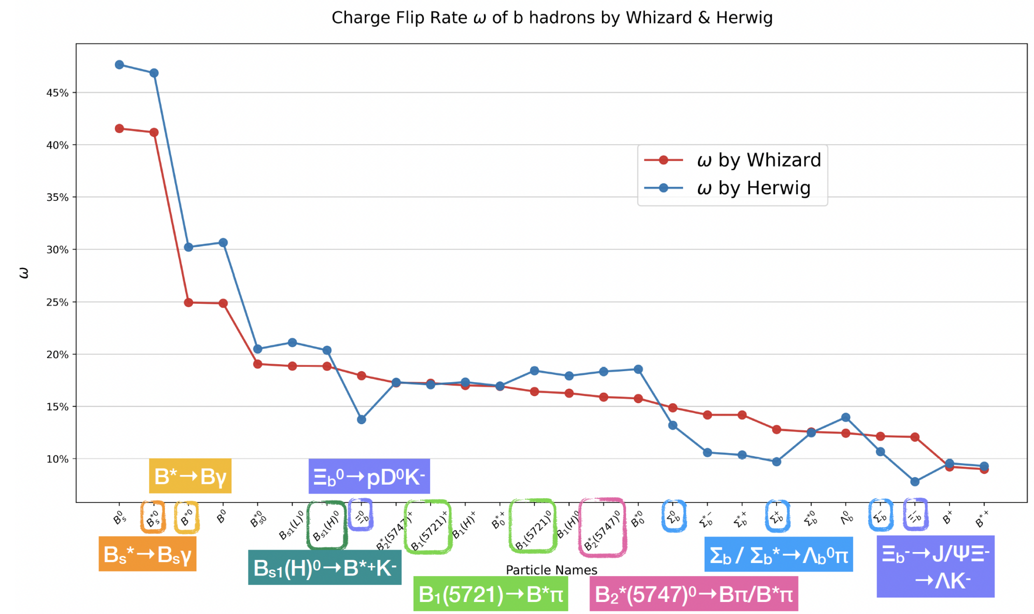


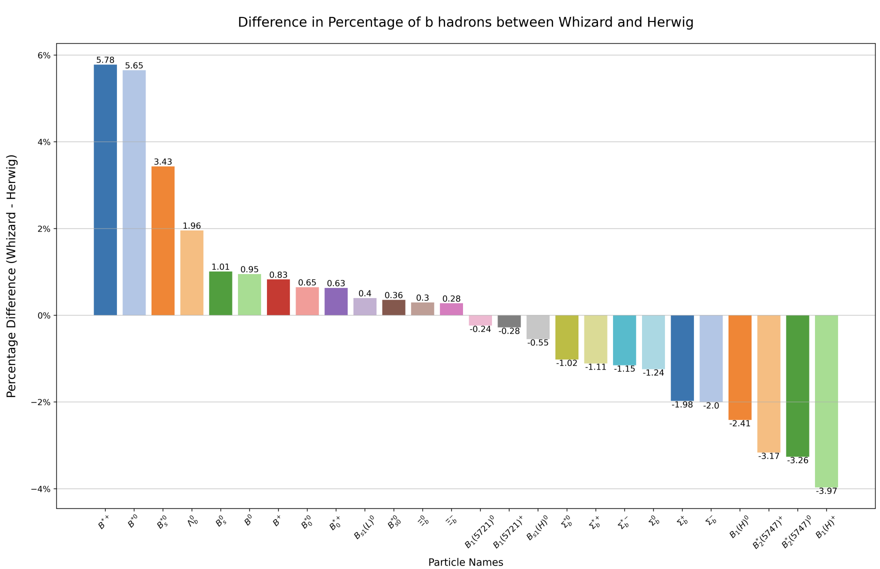


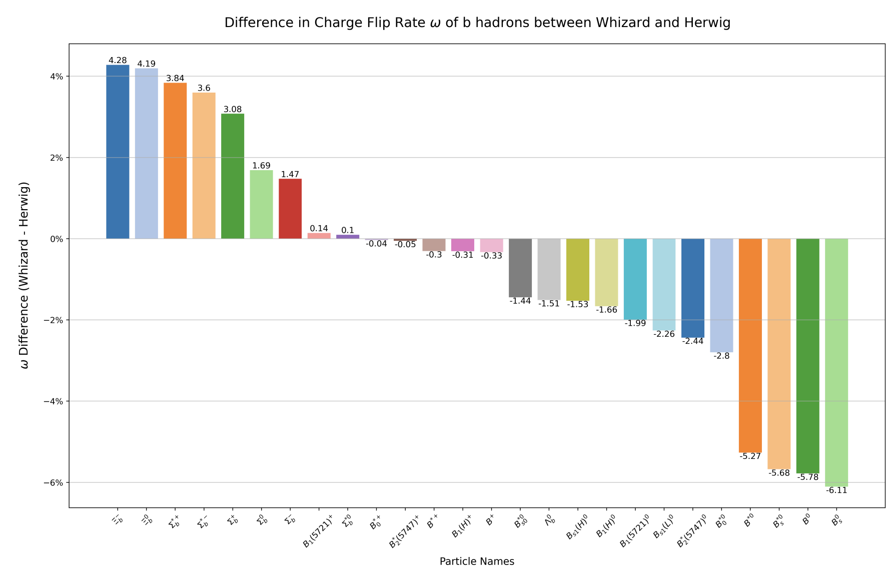
- Much severer descriptions.. in exclusive measurements (i.e., specific hadron generation, decay, etc)

b-jet: leading b-hadrons & flip rates

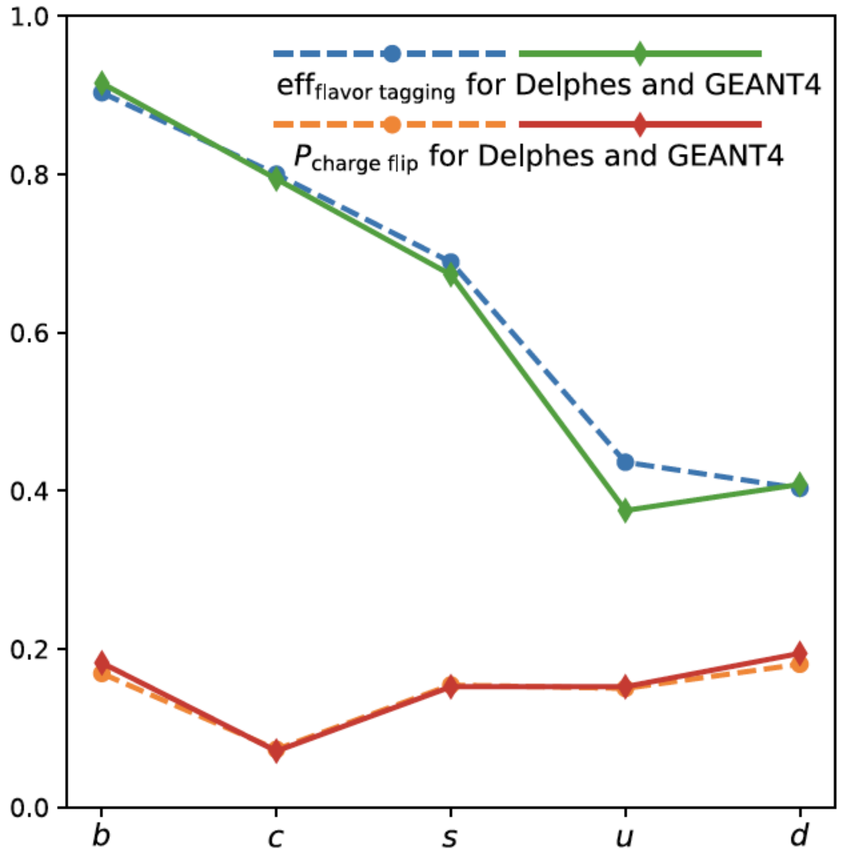




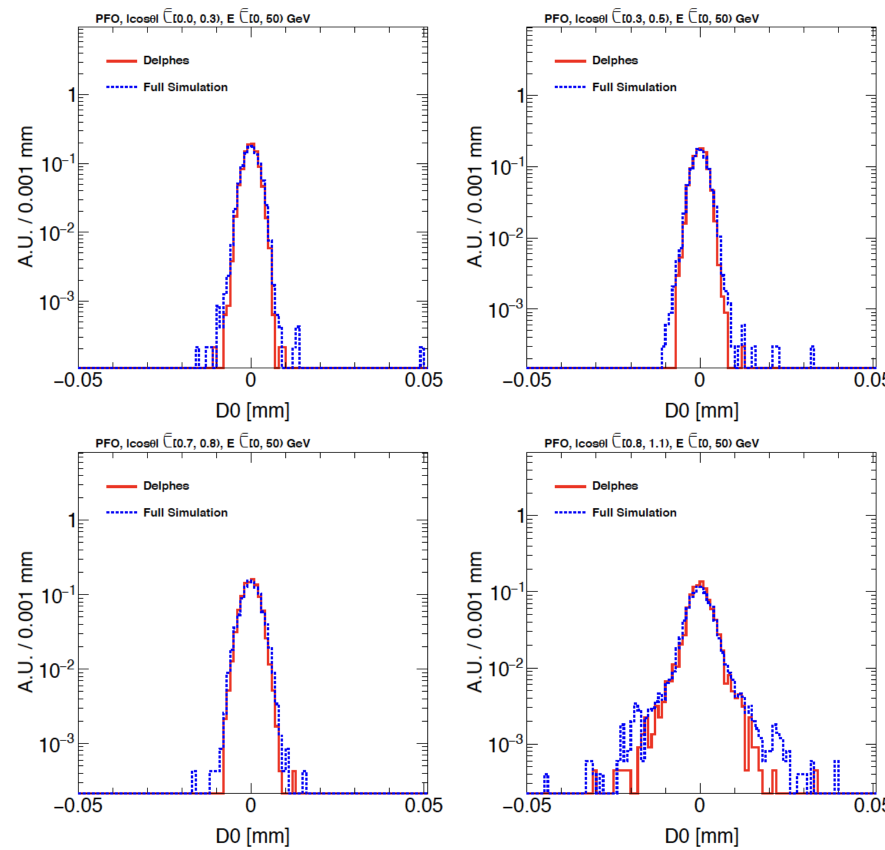




Fast/Full Simulation

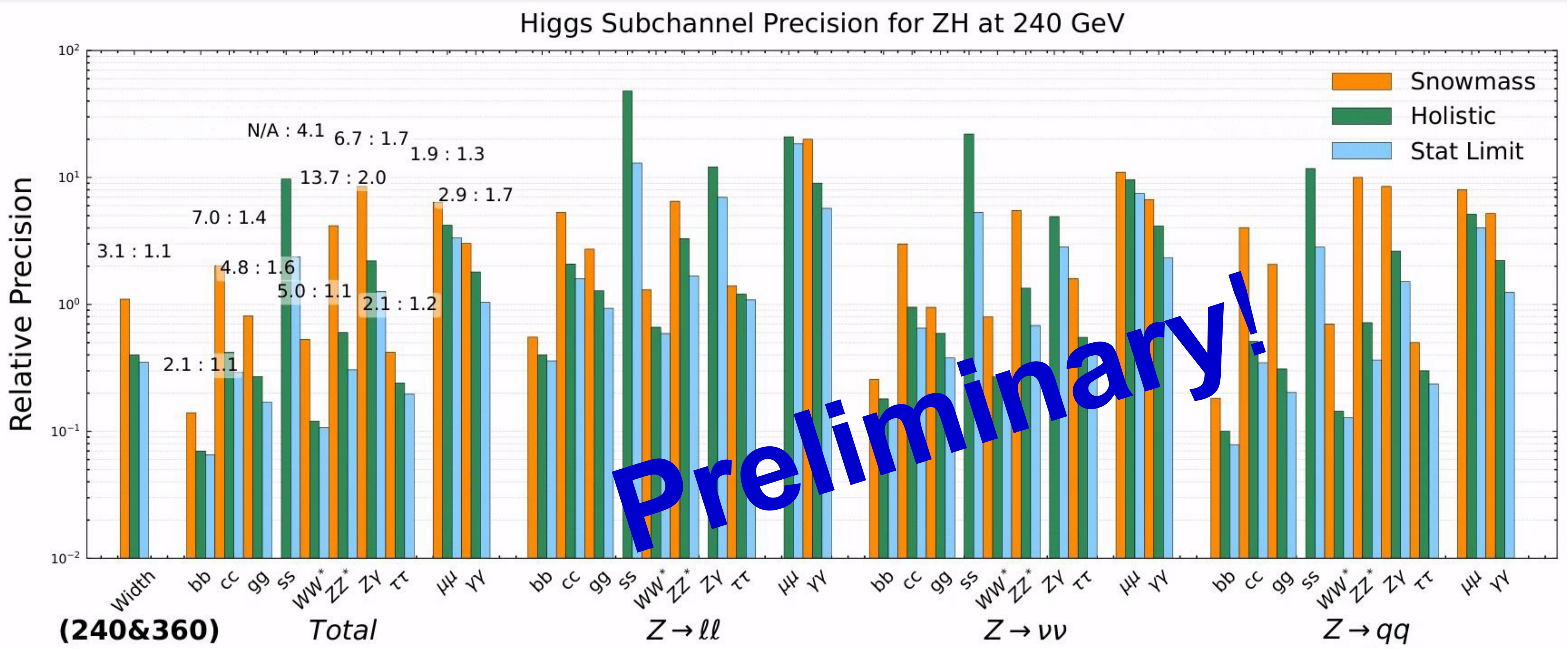


Z->μμ (91.2 GeV)



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

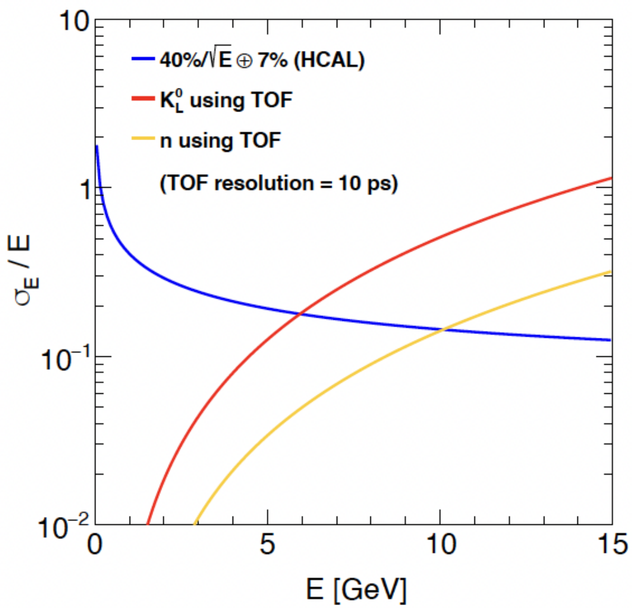
Anticipated Higgs measurements

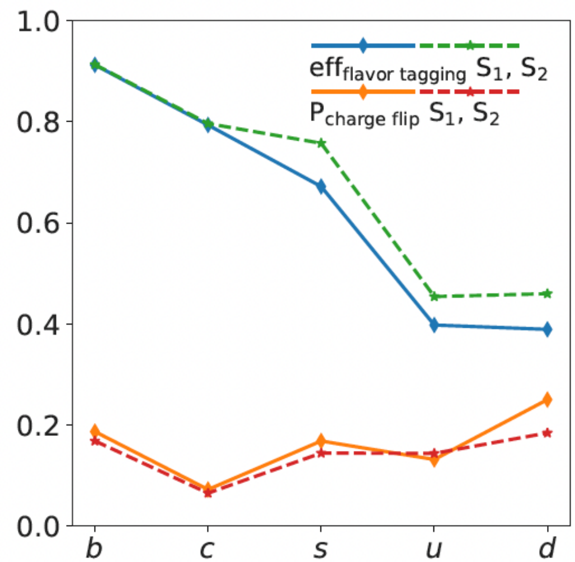


With Holistic approach..

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...