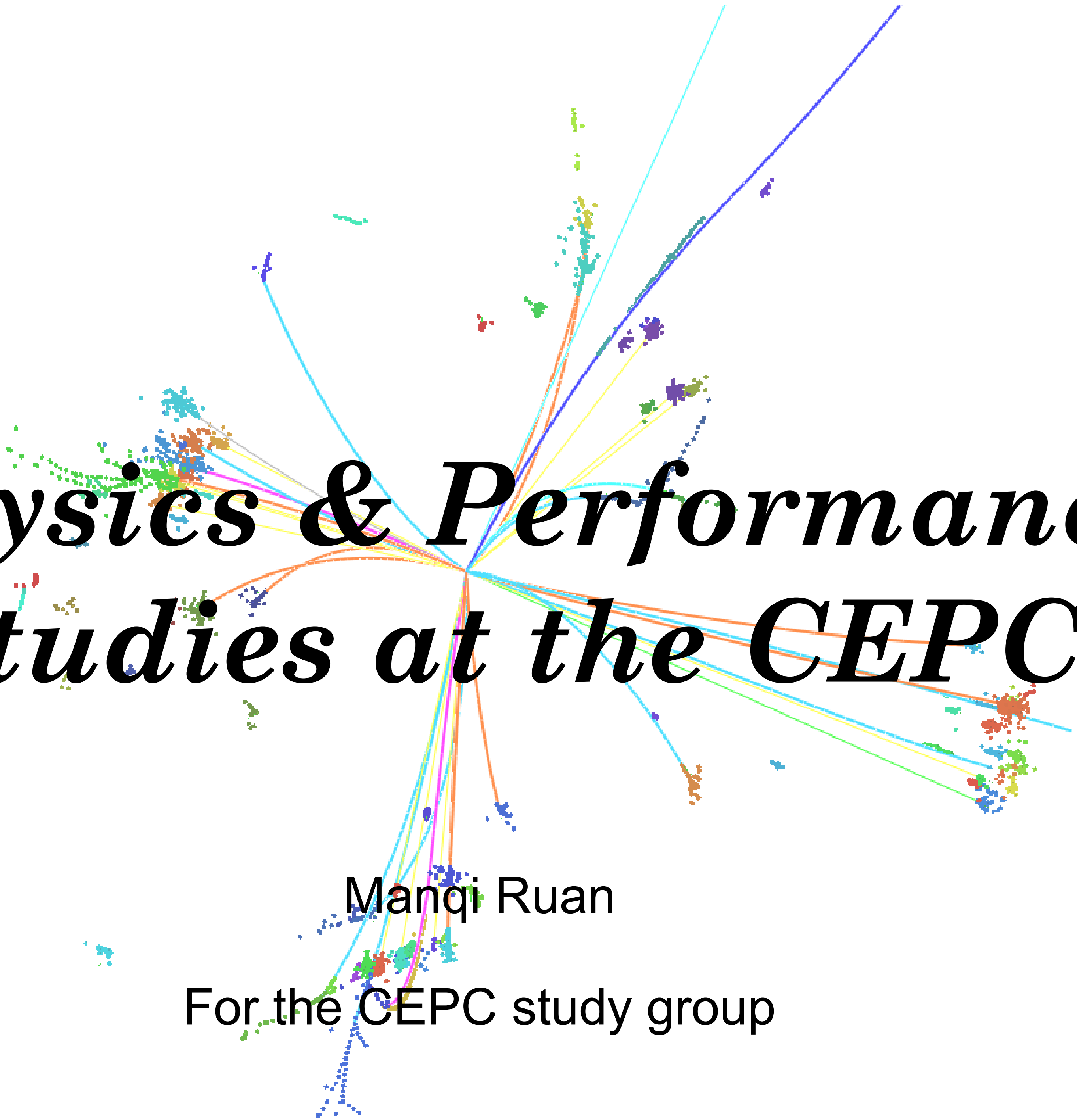


Physics & Performance studies at the CEPC

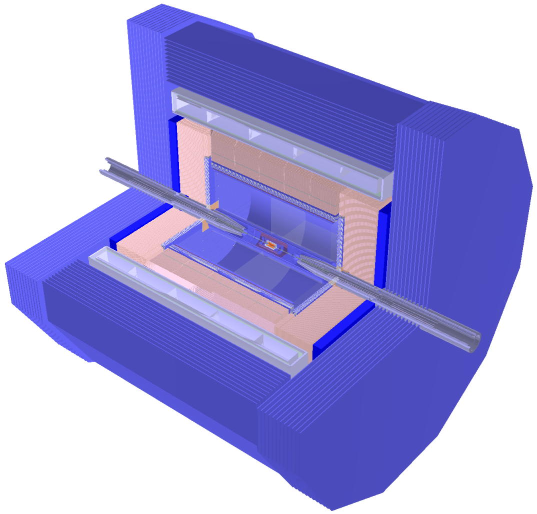
Manqi Ruan

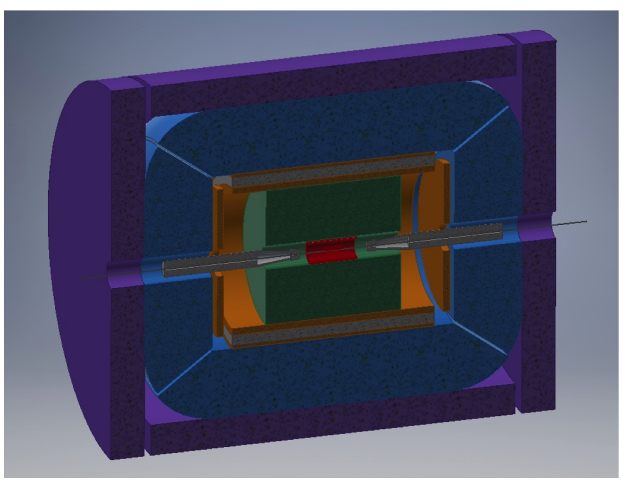
For the CEPC study group

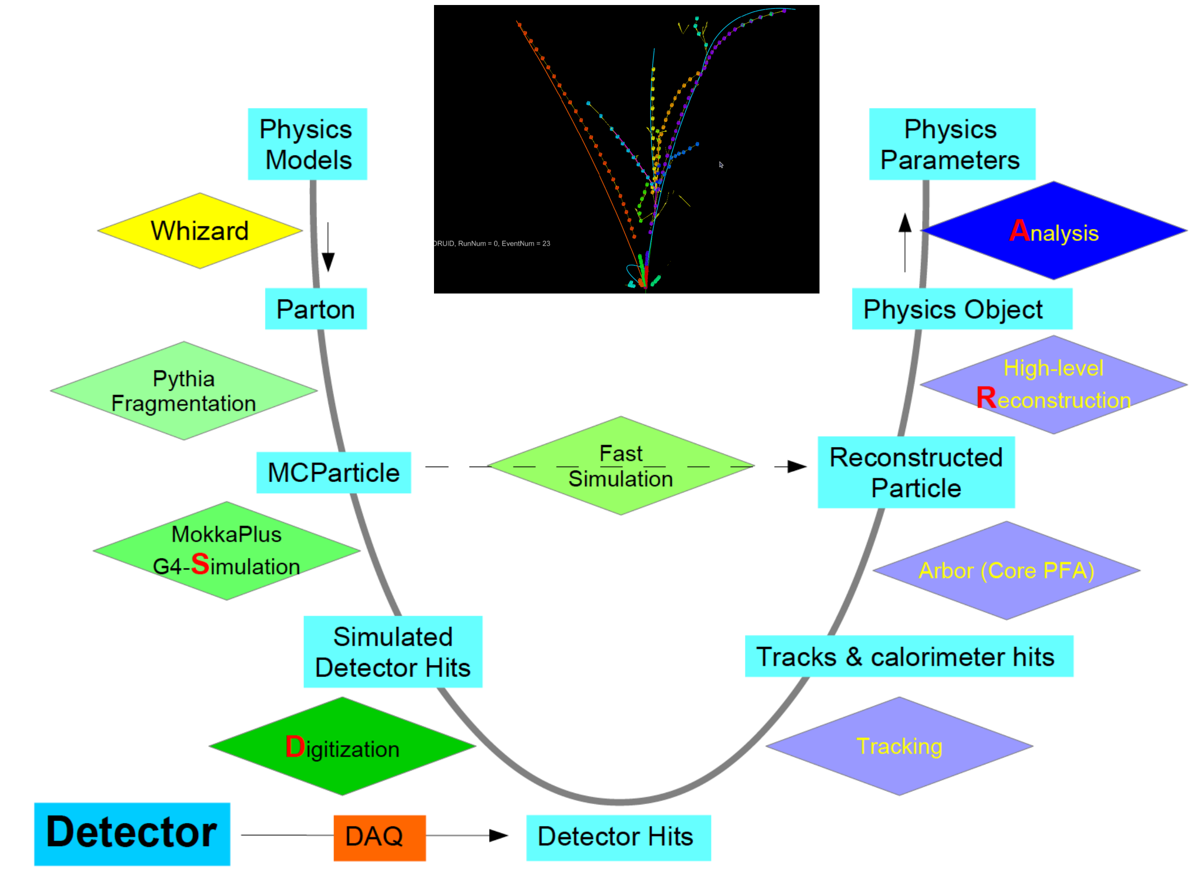
Outline

- Reminder of the Status at CDR & IAC Recommendation
- The updates: a duet
  - Physics:
    - White Paper & Snowmass
  - Performance:
    - Requirement studies
    - Algorithm development & quantification at Full-sim level
- Summary

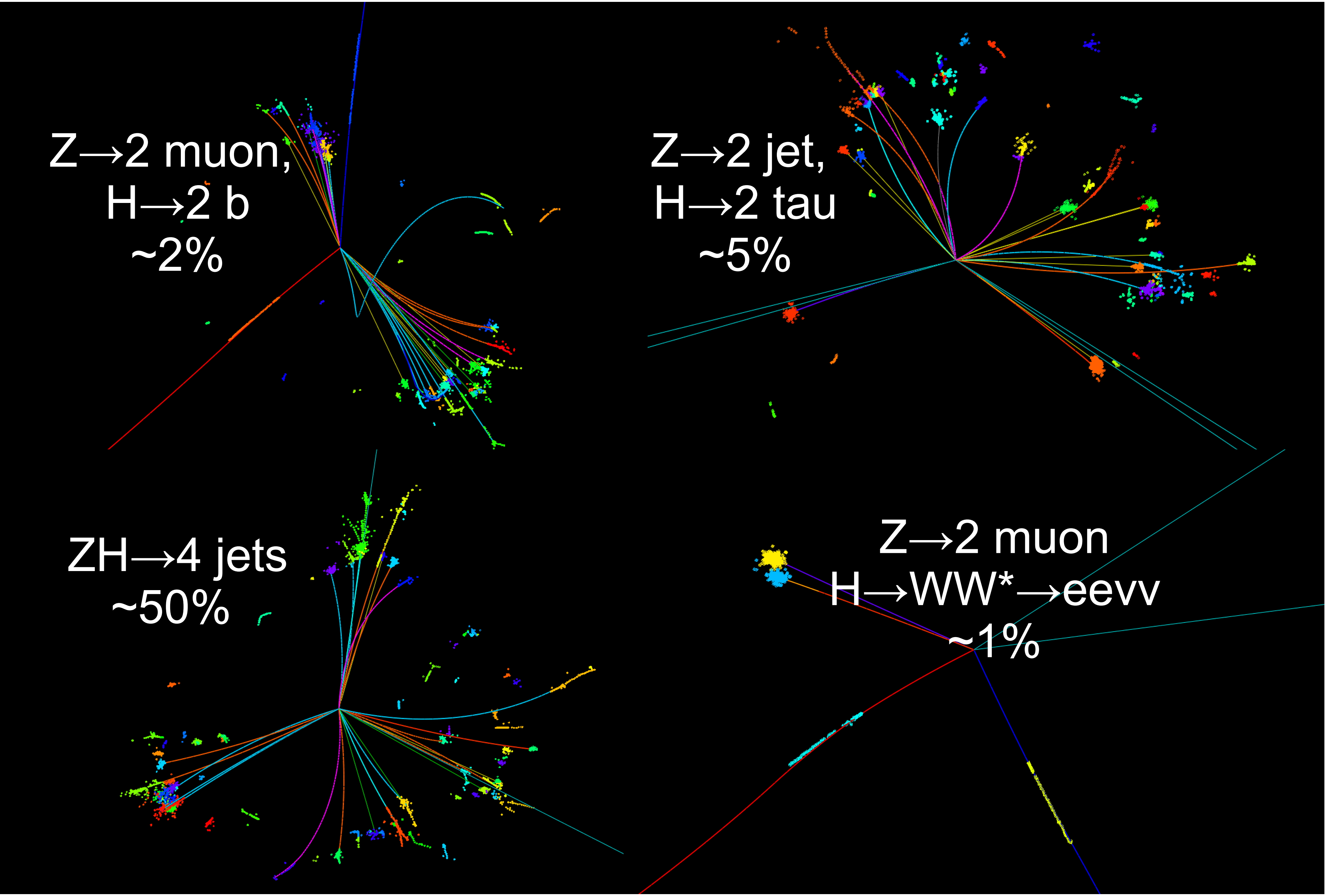
Detector & Software



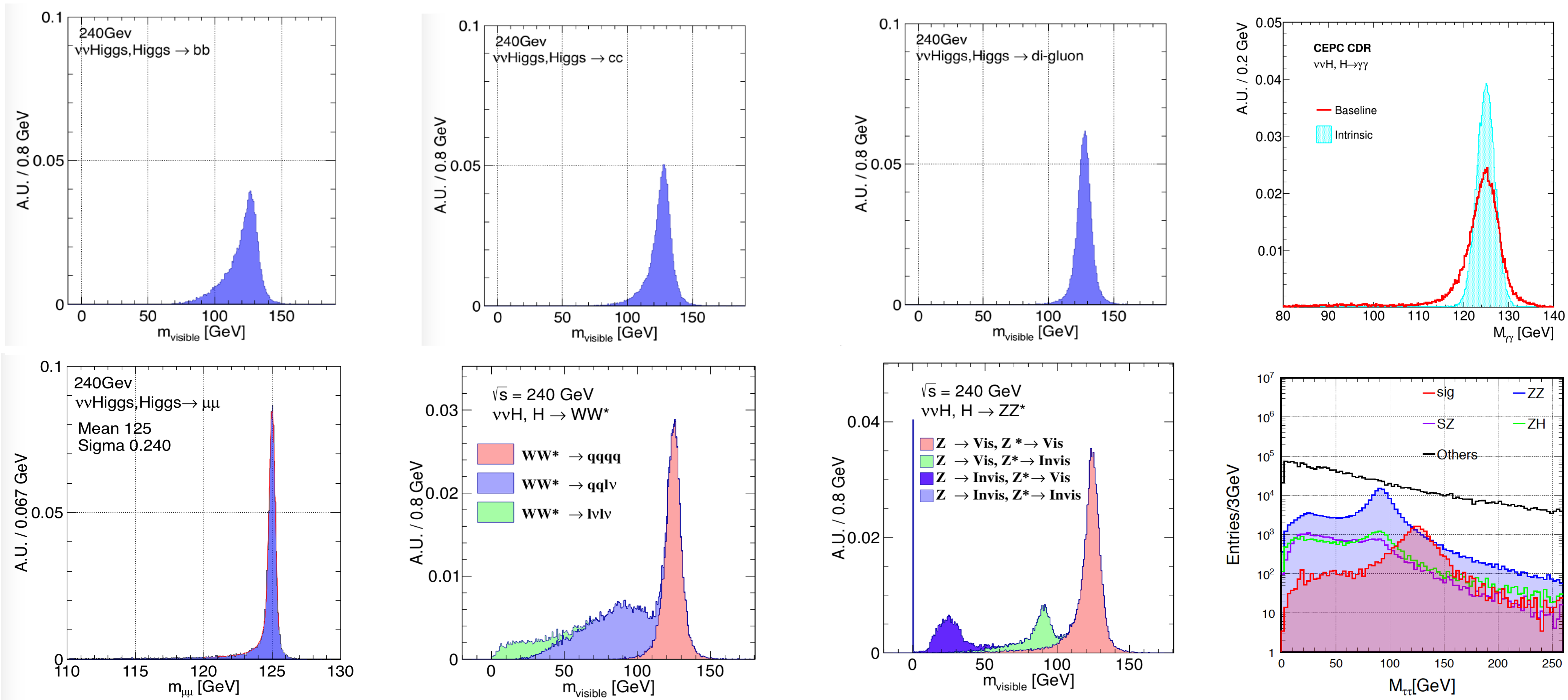




Full simulation reconstruction Chain functional, iterating/validation with hardware studies


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

Reconstructed Higgs Signatures

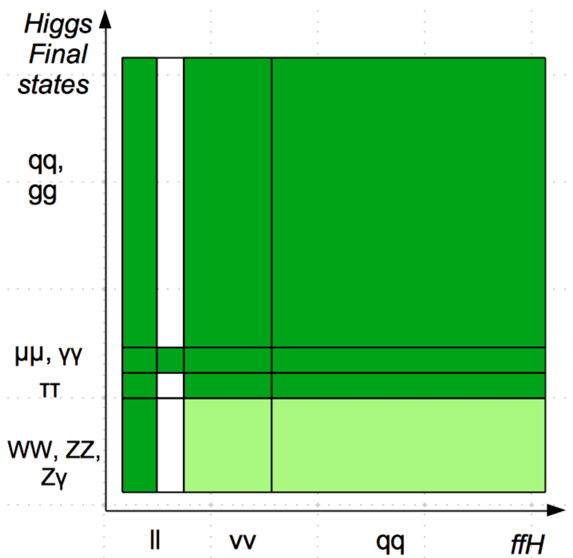


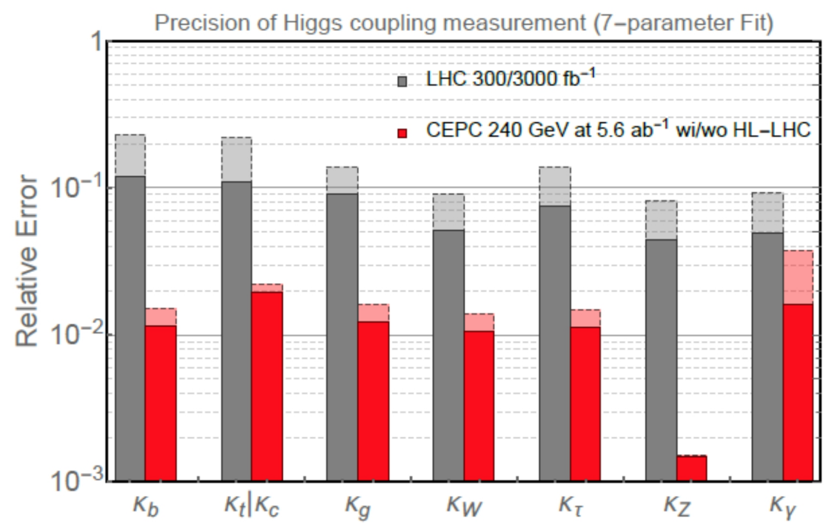
Clear Higgs Signature in all SM decay modes

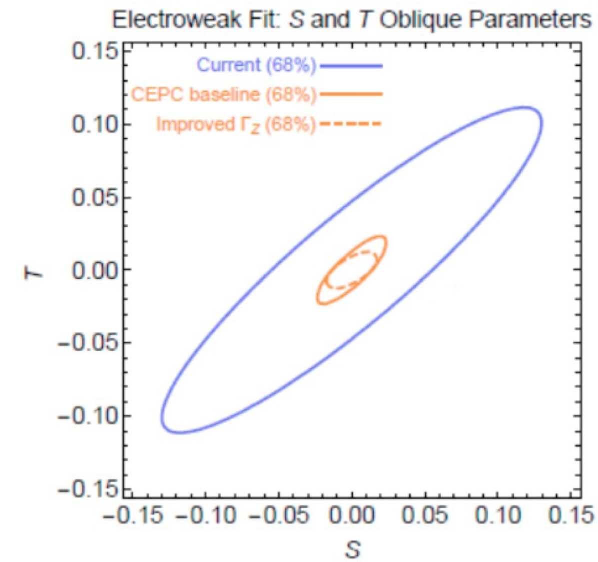
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

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

Physics potential







70 OVERVIEW OF THE PHYSICS CASE FOR CEPC

Particle	Tera-Z	Belle II	LHCb
b hadrons			
B^+	6×10^{10}	3×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8} (5 ab^{-1} on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}		1×10^{13}
Λ_b	1×10^{10}		1×10^{13}
c hadrons			
D^0	2×10^{11}		
D^+	6×10^{10}		
D_s^+	3×10^{10}		
Λ_c^+	2×10^{10}		
τ^+	3×10^{10}	5×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	

Observable	Current sensitivity	Future sensitivity	Tera-Z sensitivity
BR($B_s\to ee$)	2.8×10^{-7} (CDF) [438]	$\sim 7\times10^{-10}$ (LHCb) [435]	$\sim$ few $\times10^{-10}$
BR($B_s\to\mu\mu$)	0.7×10^{-9} (LHCb) [437]	$\sim 1.6\times10^{-10}$ (LHCb) [435]	$\sim$ few $\times10^{-10}$
BR($B_s\to\tau\tau$)	5.2×10^{-3} (LHCb) [441]	$\sim 5\times10^{-4}$ (LHCb) [435]	$\sim10^{-5}$
R_K, R_{K^*}	$\sim10\%$ (LHCb) [443, 444]	$\sim$few% (LHCb/Belle II) [435, 442]	$\sim$few %
BR($B\to K^*\tau\tau$)	–	$\sim10^{-5}$ (Belle II) [442]	$\sim10^{-8}$
BR($B\to K^*\nu\nu$)	4.0×10^{-5} (Belle) [449]	$\sim10^{-6}$ (Belle II) [442]	$\sim10^{-6}$
BR($B_s\to\phi\nu\bar\nu$)	1.0×10^{-3} (LEP) [452]	–	$\sim10^{-6}$
BR($\Lambda_b\to\Lambda\nu\bar\nu$)	–	–	$\sim10^{-6}$
BR($\tau\to\mu\gamma$)	4.4×10^{-8} (BaBar) [475]	$\sim10^{-9}$ (Belle II) [442]	$\sim10^{-9}$
BR($\tau\to3\mu$)	2.1×10^{-8} (Belle) [476]	$\sim$ few $\times10^{-10}$ (Belle II) [442]	$\sim$ few $\times10^{-10}$
$\frac{BR(\tau\to\mu\nu\bar\nu)}{BR(\tau\to e\nu\bar\nu)}$	3.9×10^{-3} (BaBar) [464]	$\sim10^{-3}$ (Belle II) [442]	$\sim10^{-4}$
BR($Z\to\mu e$)	7.5×10^{-7} (ATLAS) [471]	$\sim10^{-8}$ (ATLAS/CMS)	$\sim10^{-9}-10^{-11}$
BR($Z\to\tau e$)	9.8×10^{-6} (LEP) [469]	$\sim10^{-6}$ (ATLAS/CMS)	$\sim10^{-8}-10^{-11}$
BR($Z\to\tau\mu$)	1.2×10^{-5} (LEP) [470]	$\sim10^{-6}$ (ATLAS/CMS)	$\sim10^{-8}-10^{-10}$

Table 2.5: Order of magnitude estimates of the sensitivity to a number of key observables for which the tera-Z factory at CEPC might have interesting capabilities. The expected future sensitivities assume luminosities of 50 fb^{-1} at LHCb, 50 ab^{-1} at Belle II, and 3 ab^{-1} at ATLAS and CMS. For the tera-Z factory of CEPC we have assumed the production of 10^{12} Z bosons.

...From 1 M Higgs, 100 M W (10 M @ W threshold scan) & 1 T Z boson...

IAC Recommendation 2020

***Recommendation 13**: Assess the CEPC physics potential of the 360 GeV stage in full, including a demonstration that the accelerator design optimally fits the physics objectives at this stage.* Even if the 360 GeV stage is still far away in time, it is an important element to the attractiveness of CEPC as a whole. Not emphasizing it strongly in the presentation of the CEPC program may discourage potential partners.

***Recommendation 14**: Assess the CEPC physics potential for the high luminosity Z factory stage.* In particular it is important to fully develop the flavor physics program for this stage, from the perspective of weak interactions (e.g., precision measurements and rare and forbidden decays in the SM and in BSM scenarios), as well as from the perspective of strong interactions (e.g., in the area of exotic hadrons, where unique studies of doubly heavy or fully heavy tetraquarks, also including b quarks, would be possible).

Physics white papers

- CEPC is a Discovery machine!
  - Need to quantify CEPC physics potential at Higgs, EW, Flavor, QCD & BSM, with benchmark analyses, and Global interpretation
  - Guide the design/optimization of the facility & Maximize the physics output: to quantify the requirements on Luminosity, beam quality, & detector performance

- White paper activities:
  - 2019.3 Higgs White Paper delivered
  - 2019.7 WS @ PKU: EW, Flavor, QCD working group formed
  - 2020.1 WS @ HKIAS: Review progress & iterate. EW Draft Ready
  - 2021.4 WS @ Yangzhou: BSM working group formed

White paper Status

- CEPC Physics/Detector WS, April 2021 @ Yangzhou
  - ~ 45 Physics reports
  - ~ 10 Performance/Optimization study
  - Significant Fresh

- *Higgs: Impact of 360 GeV Runs*
- *EW: Draft ready*
- *QCD: intensive discussions...*
- *Flavor + BSM:*
  - *Many Performance & Benchmark analyses*

Higgs white paper delivered

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

Precision Higgs physics at the CEPC*

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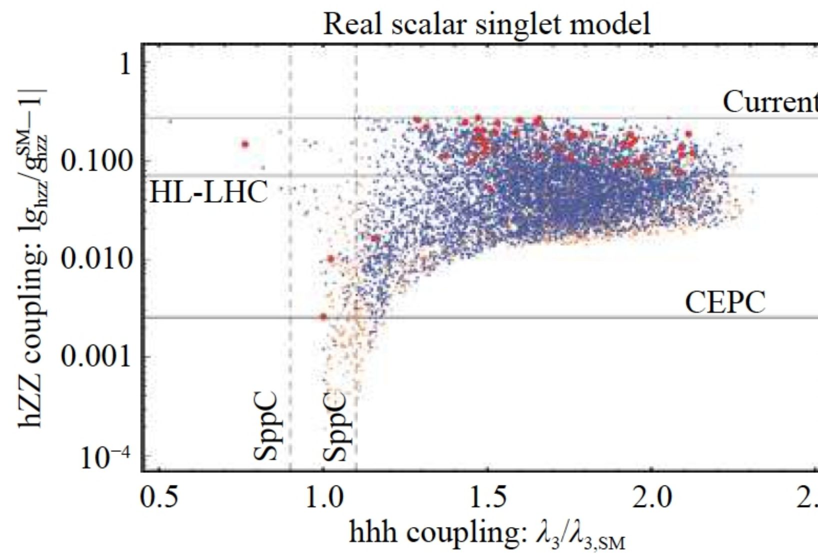
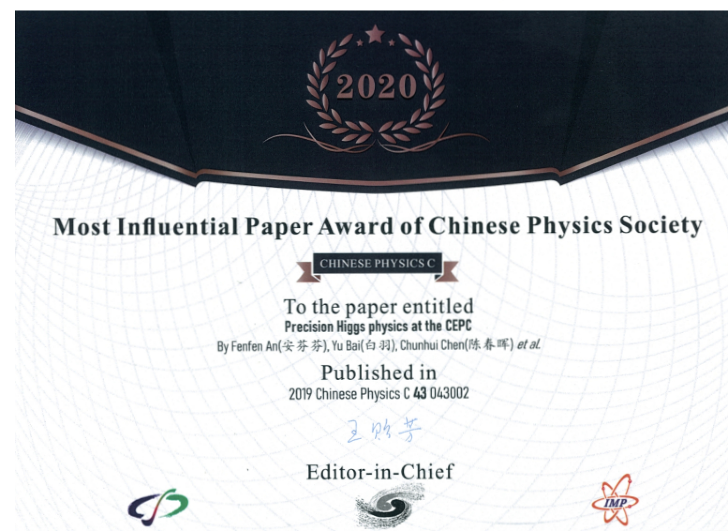
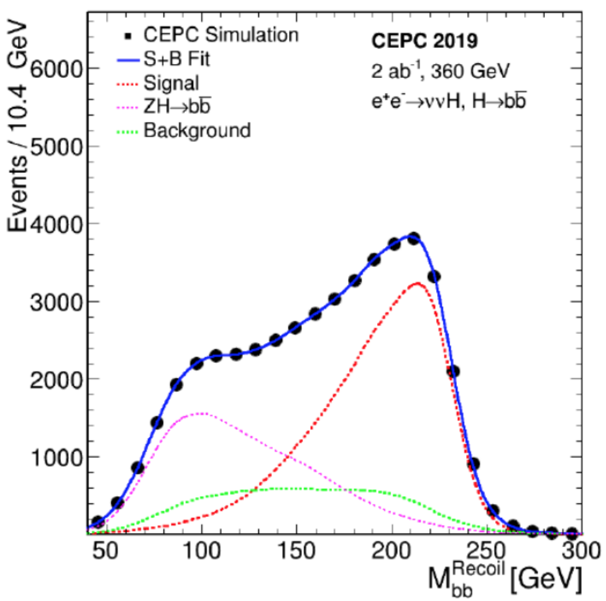
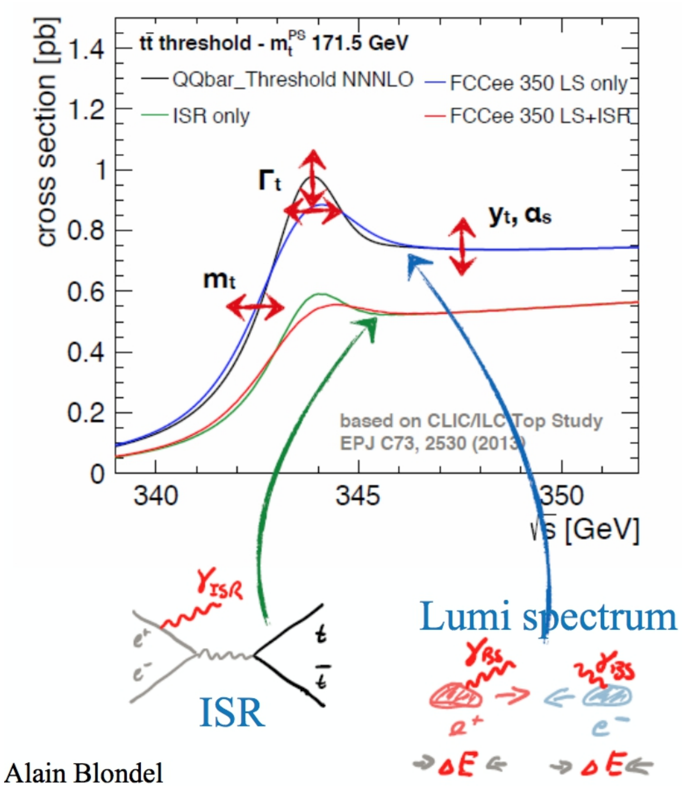




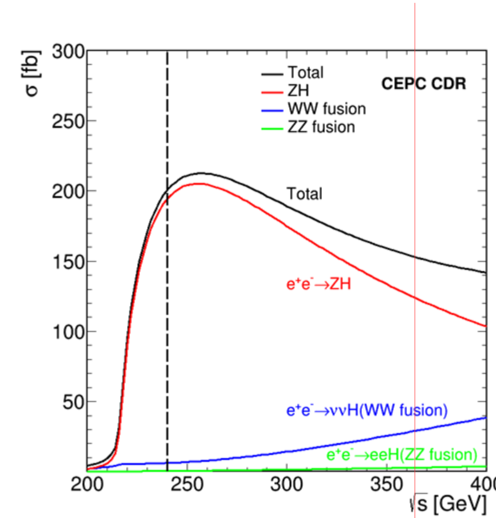
CEPC upgrading option: 360 GeV Run

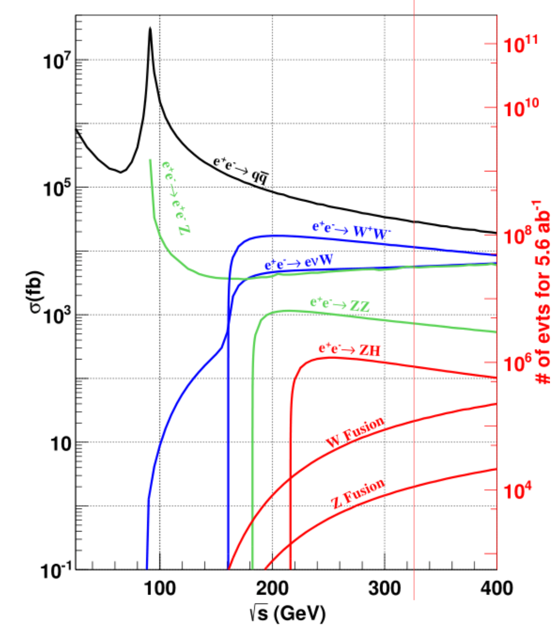
- 2 ab^{-1} @ 360 GeV
- For Higgs
  - 30% more Higgs events
  - Higgs width accuracy improves by 2 times (2.8%→1.4%)
  - ...
- For Top, For NP...



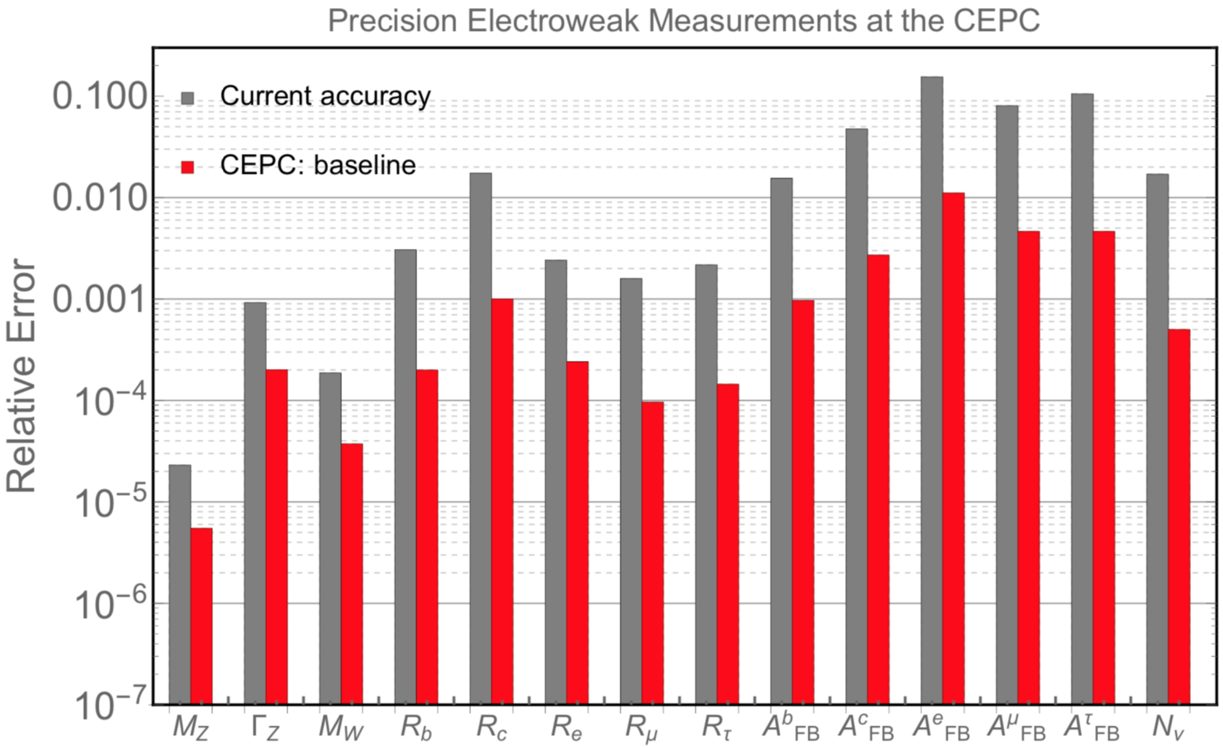


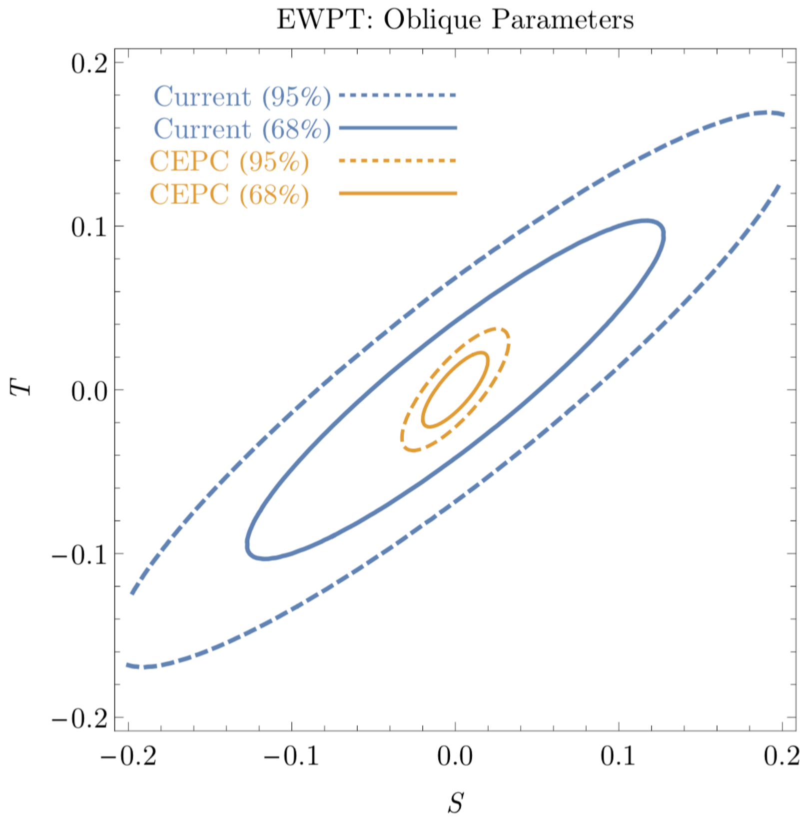
Alain Blondel





EW



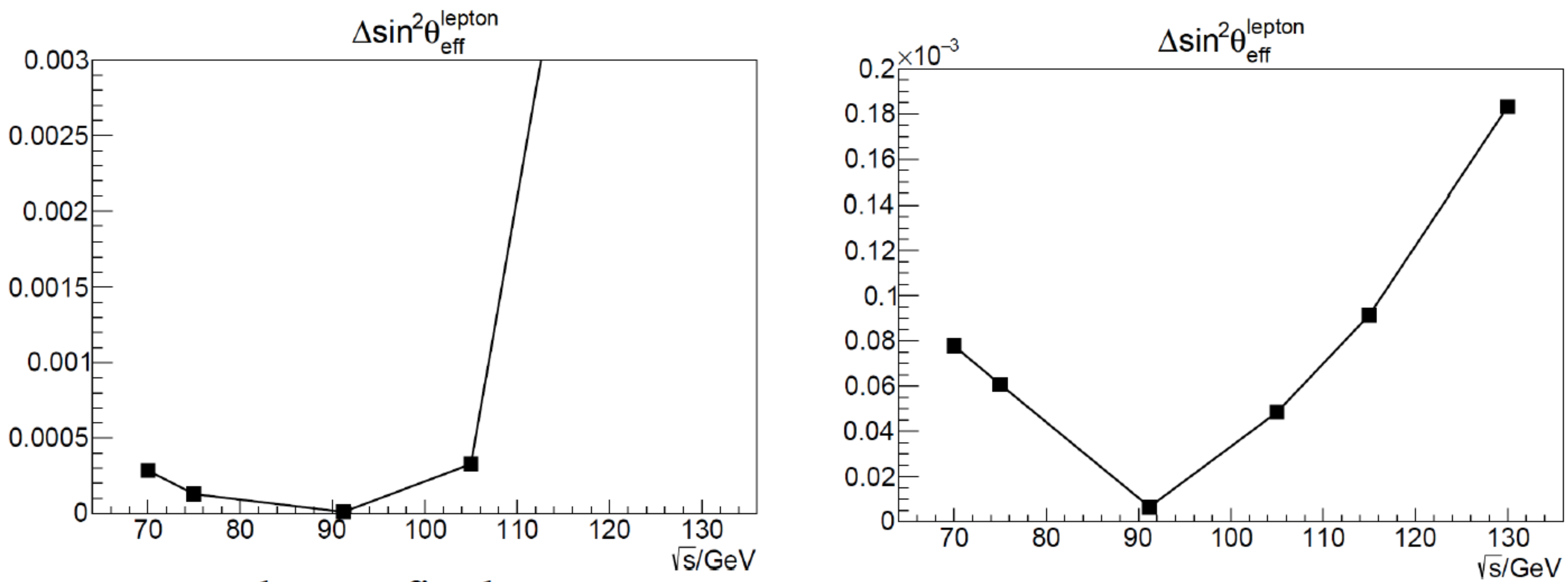


With 2 years of Z pole operation (~ 1 Tera Z) and 1 year of W mass scan (~1E7 W)

Results: A_{FB} measurement

Consider 1 month statistics at each energy point
($\sim 6e11/24\ Z\ events$ at Z pole)

Only statistical uncertainty considered



lepton final state
$(ee + \mu\mu + \tau\tau)$

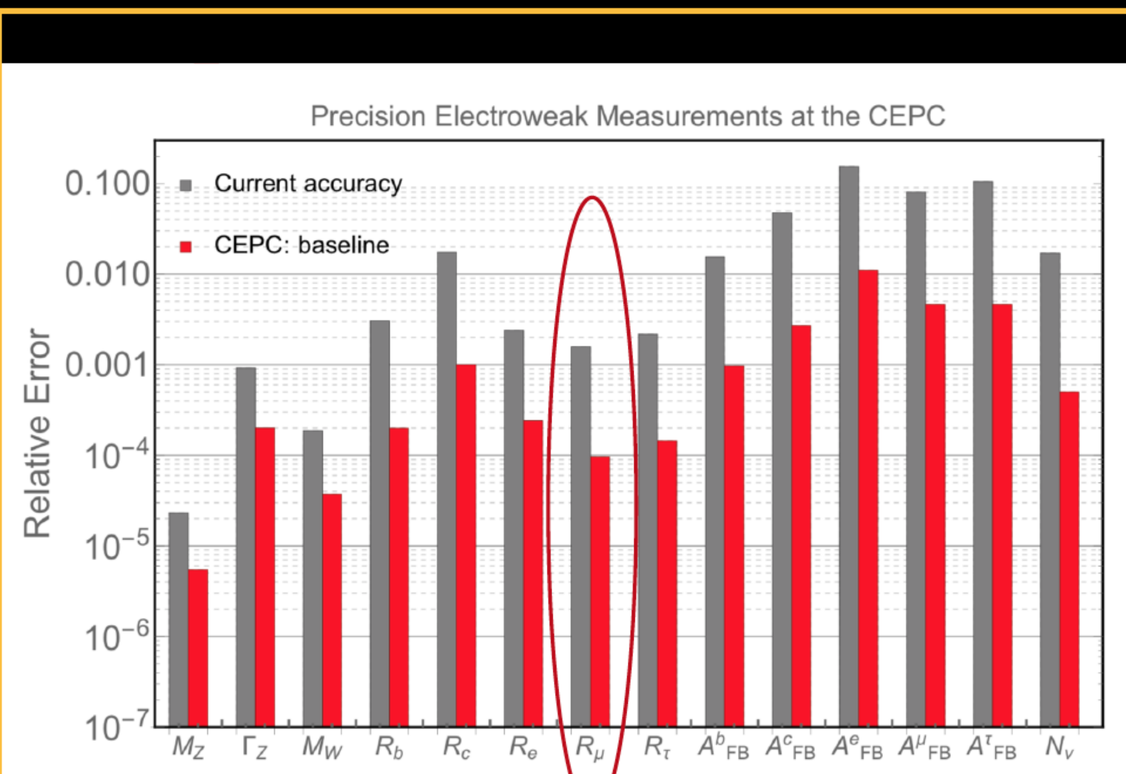
b quark final state

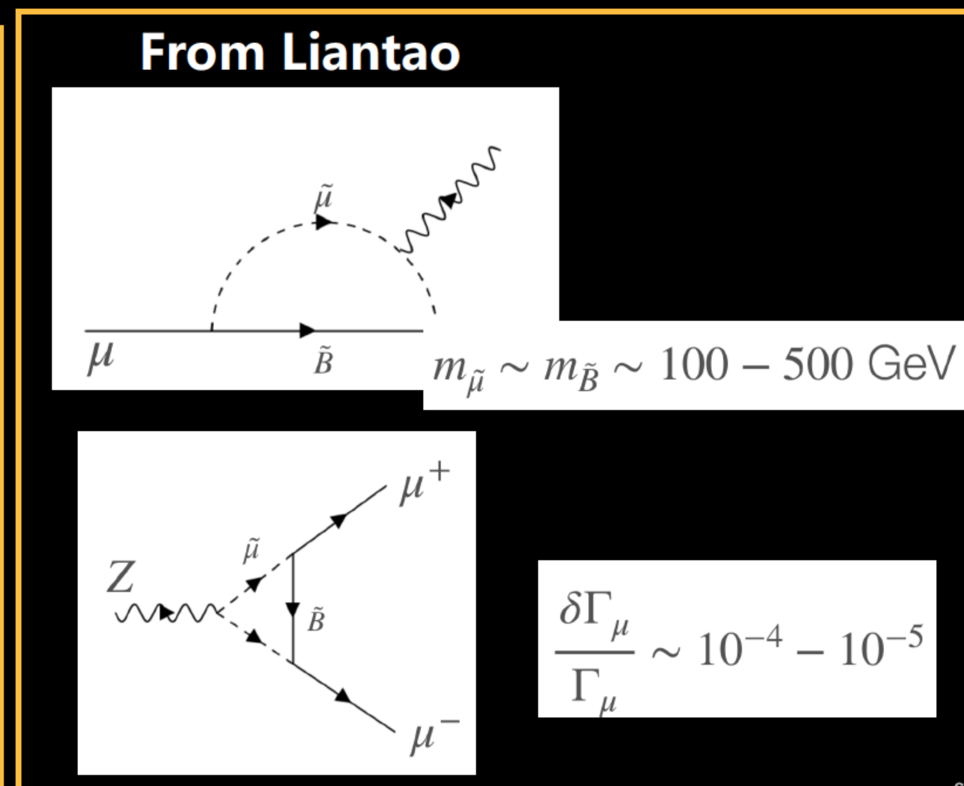
Energy scale	70 GeV	75 GeV	91.19 GeV	105 GeV	115 GeV	130 GeV
$\Delta\sin^2\theta_{eff}$ from lepton final state	0.00028	0.00013	0.00001	0.00033	0.00385	0.00766
$\Delta\sin^2\theta_{eff}$ from b quark final state	0.00008	0.00006	<0.00001	0.00005	0.00009	0.00018

EW

Probing new physics behind muon g-2 at CEPC

- From Liantao, if new physics behind muon g-2 @ one loop
- Expect to see disagreement with SM at Z->μ μ branching ratio at 10^{-4} to 10^{-5}
- Within the reach of CEPC Z pole physics



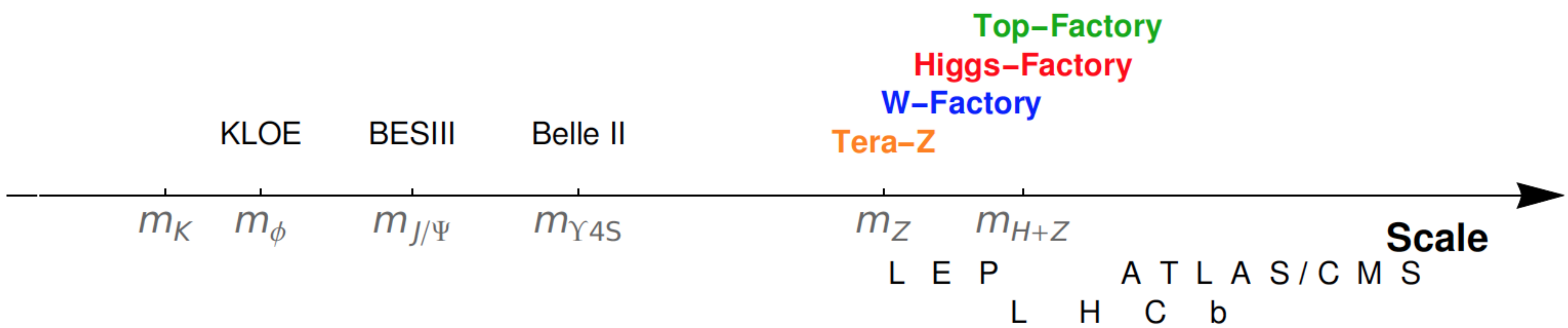


Flavor Physics at CEPC

Z Factory $\supseteq$ Flavor Factory

Particle-ID $\supseteq$ Flavor-ID!

Channel	Belle II	LHCb	Giga-Z	CEPC (Tera-Z)
$B^0,\ \bar{B}^0$	5.3×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^{8}	1.2×10^{11}
$B^\pm$	5.6×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^{8}	1.2×10^{11}
$B_s,\ \bar{B}_s$	5.7×10^{8}	$\sim 2 \times 10^{13}$	3.2×10^{7}	3.2×10^{10}
$B_c^\pm$	-	$\sim 4 \times 10^{11}$	2.2×10^{5}	2.2×10^{8}
$\Lambda_b,\ \bar{\Lambda}_b$	-	$\sim 2 \times 10^{13}$	1.0×10^{7}	1.0×10^{10}
$c,\ \bar{c}$	2.6×10^{11}	$\gtrsim 10^{14}$	2.4×10^{8}	2.4×10^{11}
$\tau^+,\ \tau^-$	9×10^{10}	-	7.4×10^{7}	7.4×10^{10}



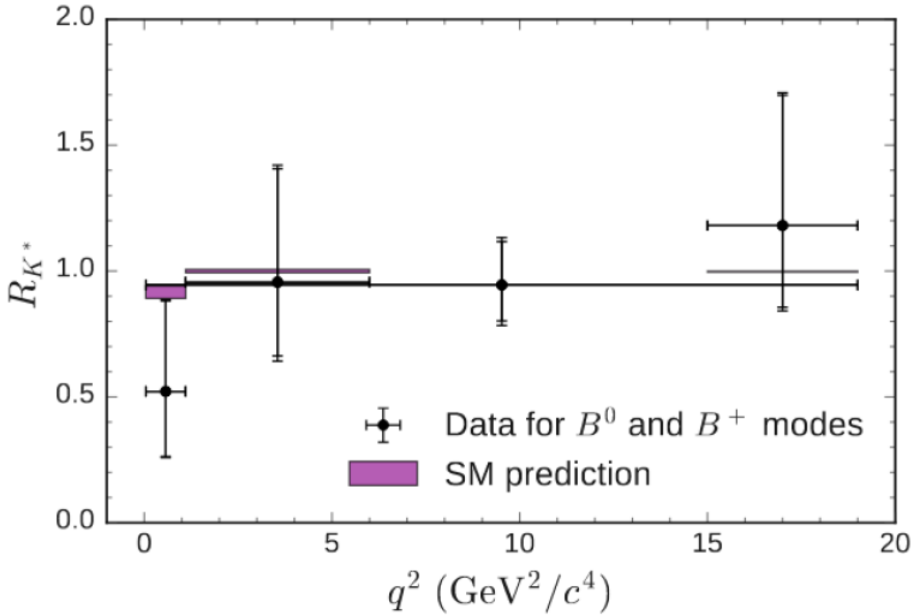
VS. B Factories

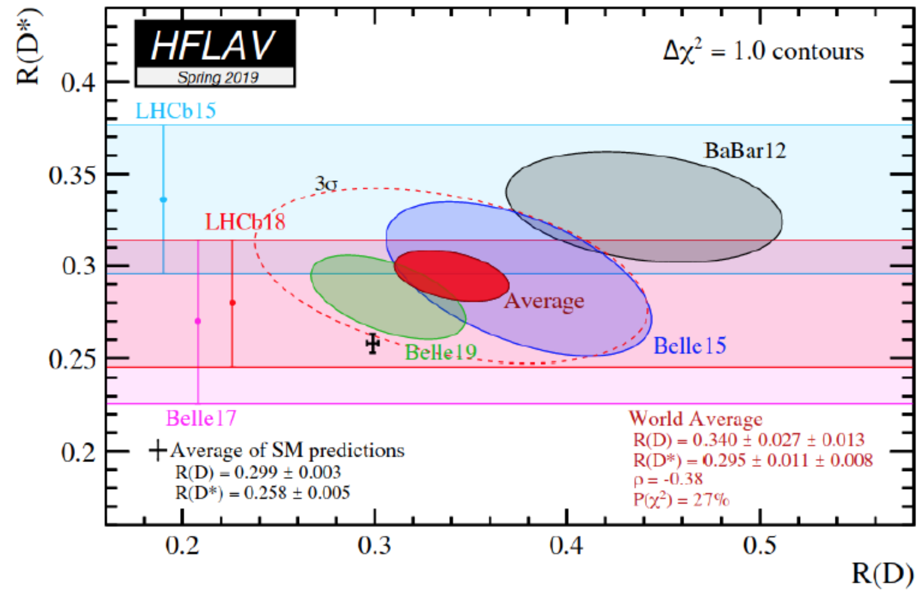
- Much higher b quark boost
- Abundant heavy b hadron

VS. Hadron Colliders

- Clean environment
- Direct missing momenta measurement

B Anomalies Indicating LFUV

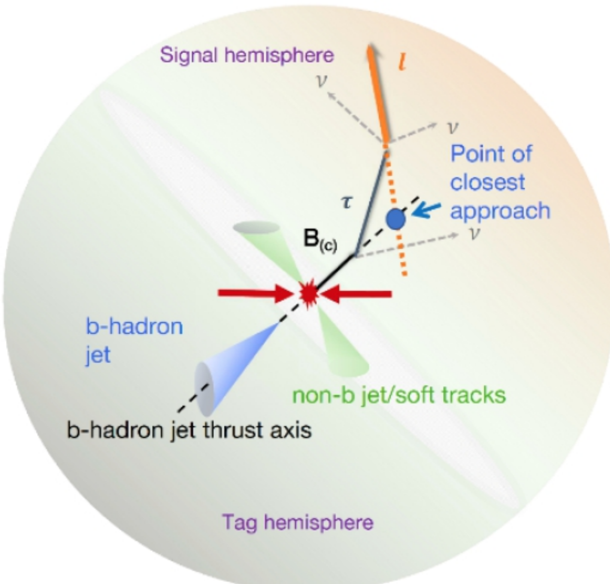




	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^\pm$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^\pm$ combined.
R_{D^*}	0.295 ± 0.014	0.258 ± 0.005	B^0 and $B^\pm$ combined.
$R_{J/\psi}$	$0.71 \pm 0.17 \pm 0.18$	0.25-0.28	

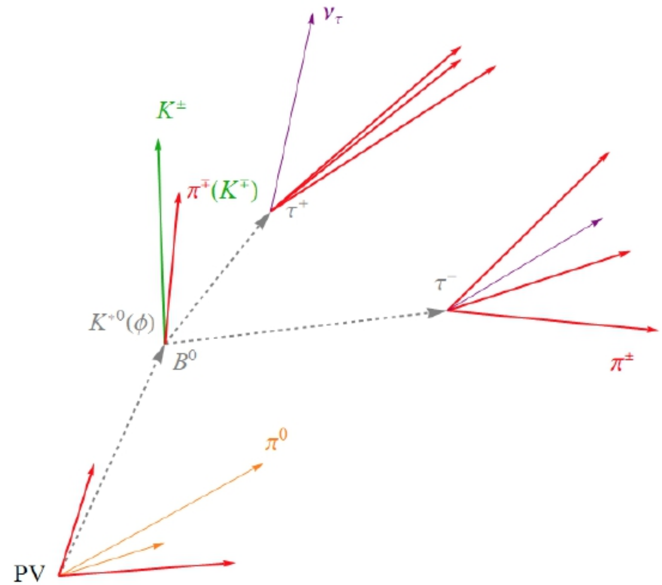
[Tanabashi et al., 2018][Altmannshofer et al., 2018].

Current Progress in LFU Tests



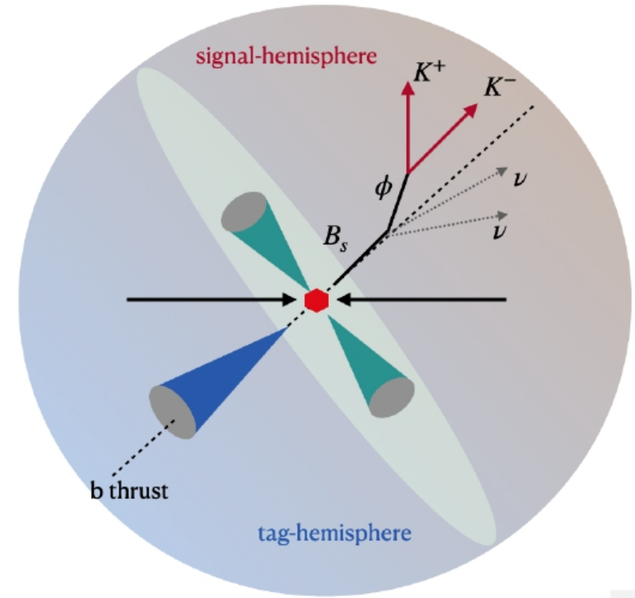
Charged current $B_c \to \tau\nu$ decays [Zheng et al., 2020b].

Absolute precision $\sim 10^{-4}$.



Neutral current $b \to s\tau\tau$ decays [Li and Liu, 2020].

Absolute precision $\lesssim 10^{-6}$: $\sim 10^3 - 10^4$ improvement from current limits.

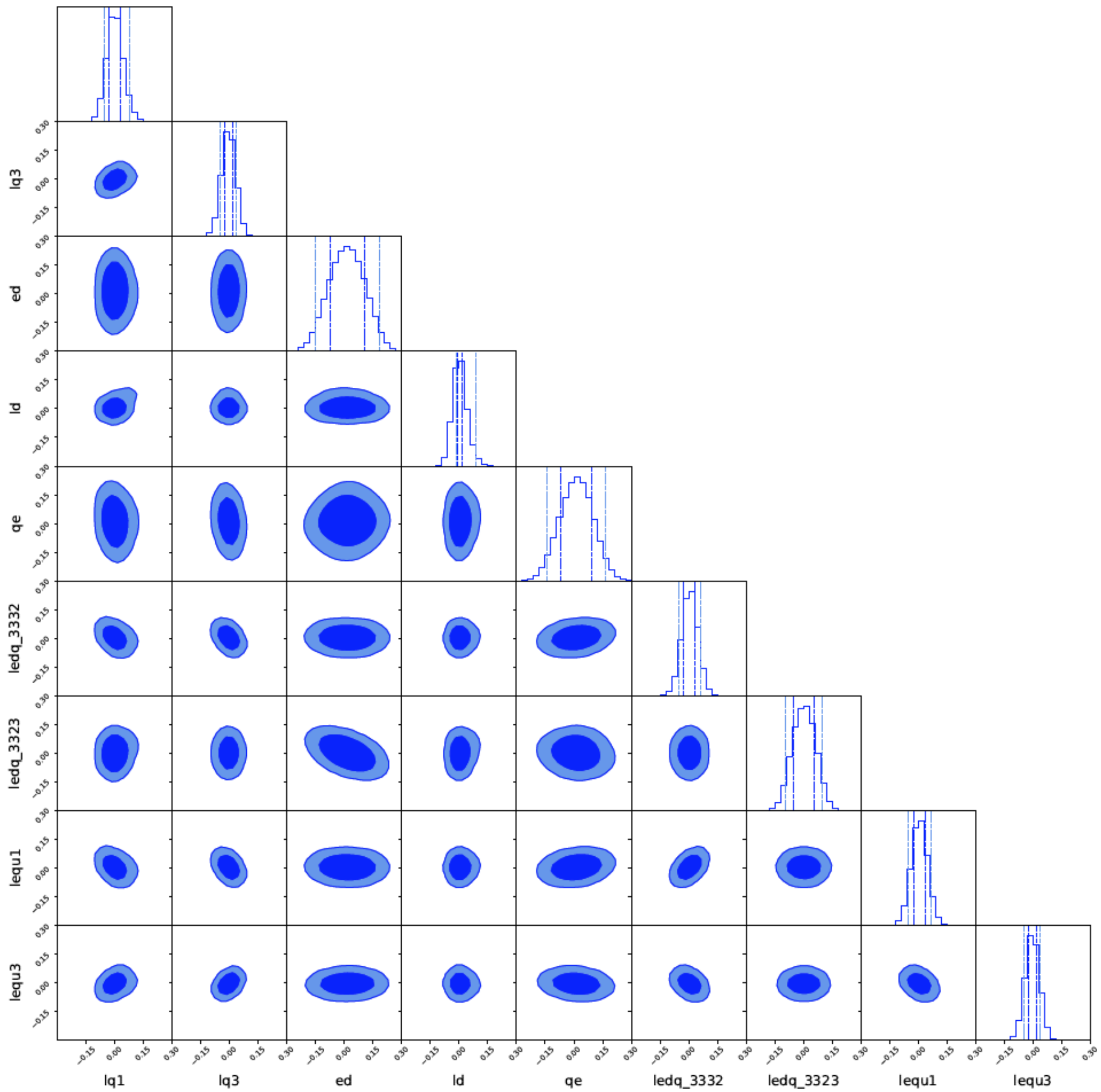


Neutral current $B_s \to \phi\nu\bar{\nu}$ decay [In preparation]

Absolute precision $\sim 10^{-7}$.

Unique opportunities at the Z-pole

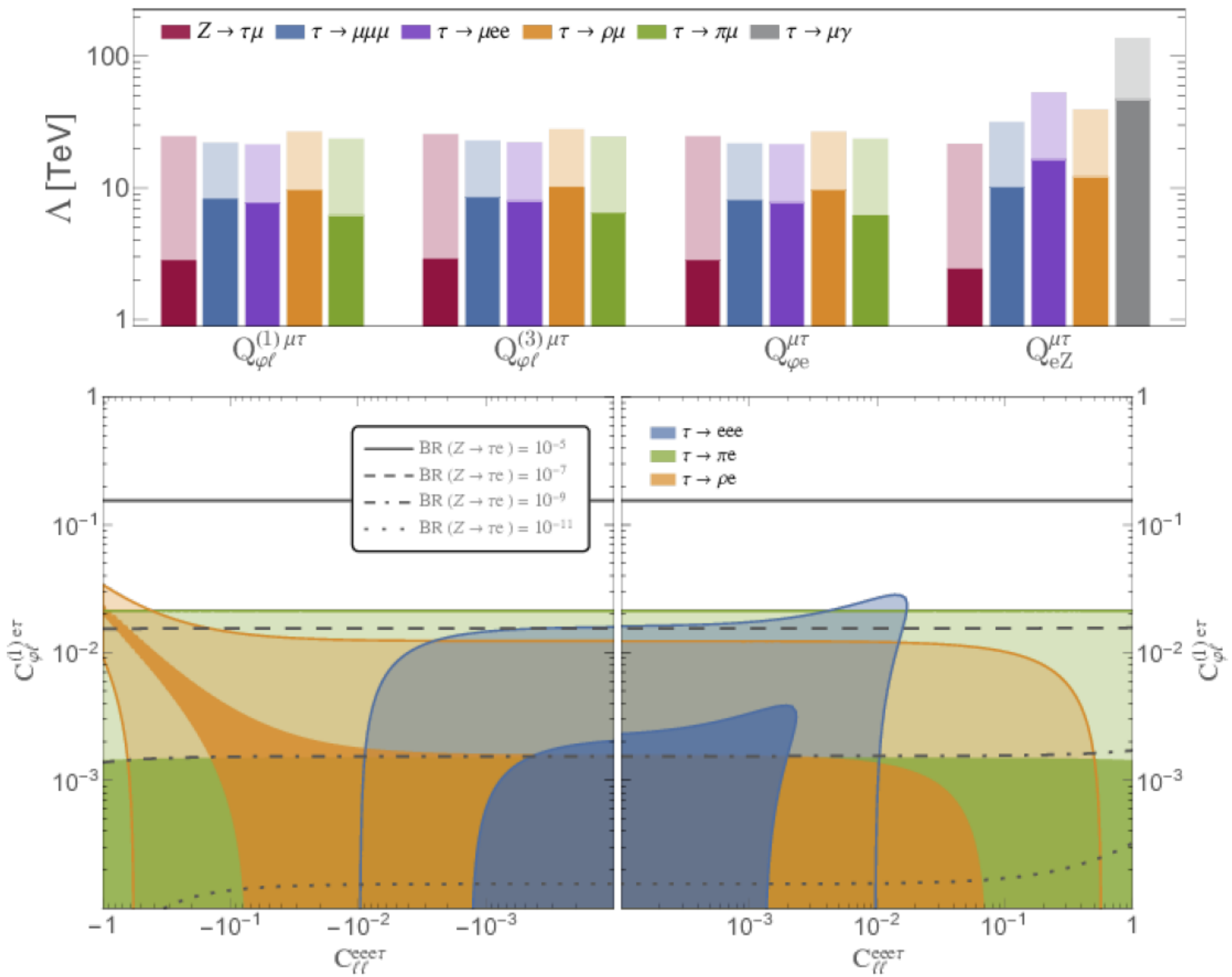
Current Progress in LFU Tests (II)



Preliminary: 9 effective channels:($R_{J/\psi}$, R_{D_s}, $R_{D_s^*}$, R_{Λ_c}, $B_c \to \tau\nu$, $B \to K\nu\bar{\nu}$, $B_s \to \phi\nu\bar{\nu}$, $B^0 \to K\tau\tau$, $B^+ \to K^+\tau\tau$, $B_s \to \tau\tau$...)

Dim-6 SMEFT basis at NP scale Λ=3 TeV.

Lepton Flavor Violation (II)



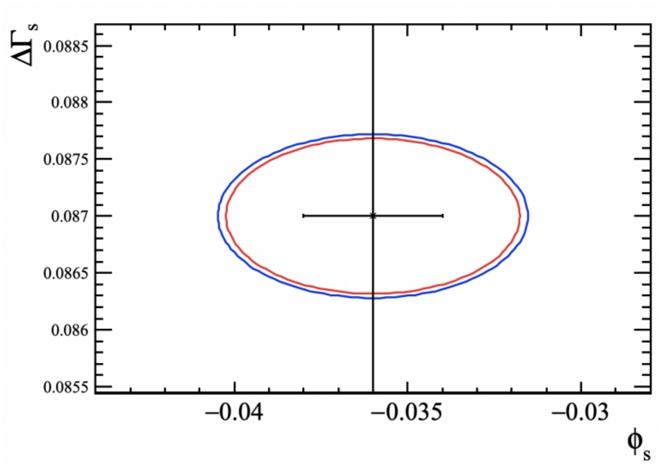
[Calibbi et al., 2021]

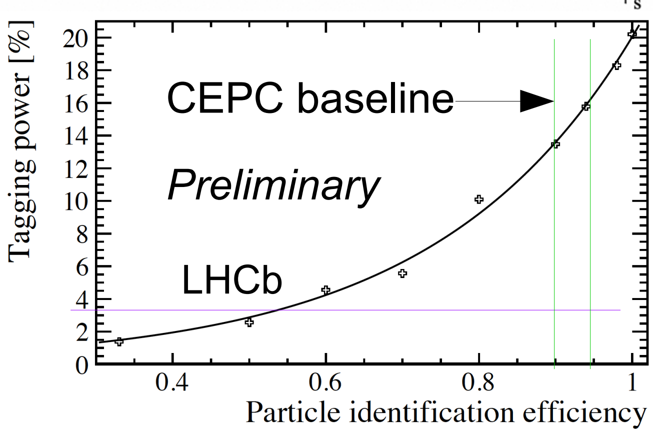
CP measurement with Bs->J/psi Phi

$\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H, \phi_s = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$

SM: small CPV phase ϕ_s

Contributions from physics beyond the SM could lead to much larger values of ϕ_s.

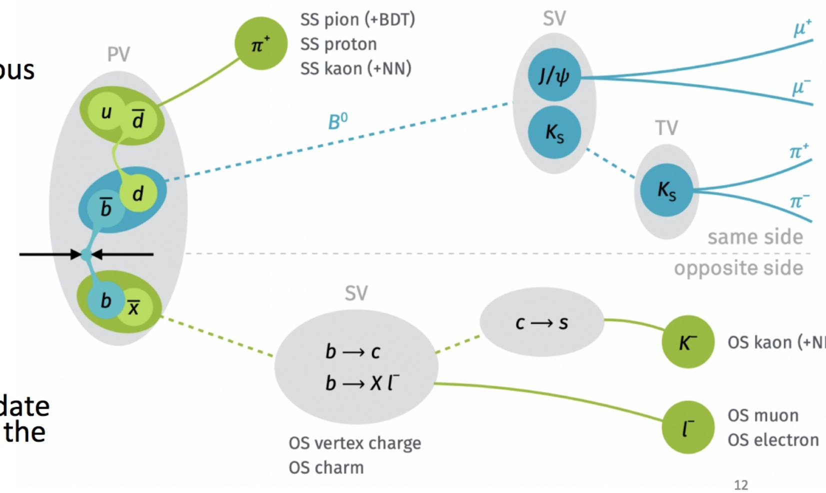




Flavour tagging power

- LHCb: 3~4%
- CEPC: 15% (Previous estimation)
- B factory: ~30%

- For Bs:
  - OS lepton
  - OS kaon
  - SS kaon
- A naïve algorithm developed to validate the robustness of the estimation



- With a decent Pid, the effective tagging power on jet Charge can be 5-6 times better than LHCb, which can compensate the statistic difference between LHCb & CEPC.
- Strong motivation to higher Luminosity at Z pole

White paper

Contents

1 Introduction

2 Description of CEPC facility

The Circular Electron Positron Collider (CEPC) is a double-ring e^+e^- collider with a 100 km circumference and two interaction points (IP) designed to precisely measure the Higgs boson and related particles. The CEPC Conceptual Design Report [1] includes exquisite details of the CEPC detector system. It operates at $\sqrt{s} \sim 240$ - 250 GeV for Higgs Factory,

factory mode can measure the BR with a $\mathcal{O}(10^{-4})$ precision. The CEPC study [23] uses full simulation and $\tau^\pm \to \ell^\pm \nu\bar{\nu}$ decay, while the FCC-ee based study [24] but uses fast simulation and $\tau^\pm \to \pi^\pm\pi^\pm\pi^\mp\nu$ decays. A work in preparation [cite] studies R_{D_s}, $R_{D_s^*}$, $R_{J/\psi}$, and R_{Λ_c} in the general Tera-Z context and the fast simulation template of the CEPC. The results from these studies are promising. The relative uncertainty (stat. only) of $R_{J/\psi}$ may reach $\lesssim 3\%$ with 10^{12} Z produced. The numbers are $\sim 0.5\%$ for $R_{D_s^{(*)}}$, and $\sim 0.2\%$ R_{Λ_c} [cite]. Their S/B are of $\gtrsim 1$, ensuring robustness against background uncertainties. Although complete projections of these semileptonic observables are yet available for Belle II and LHCb, we can still compare them with the projected $\sigma(R_{D^{(*)}}) \sim 2(1)\%$ (stat.) at Belle II [2], $\sigma(R_{J/\psi}) \gtrsim 3\%$ (stat.+syst), and $\sigma(R_{\Lambda_c}) \sim 2.5\%$ (stat.+syst) after LHCb upgrade II [25]. It is clear that the potential of semileptonic measurements at CEPC is stronger than other experiments.

However, there are still many open topics in this field to be explored. For example, R_D and R_{D^*} and relevant differential measurements seems necessary. It may need specific work using full simulation, as data from other experiments keeps accumulating at Belle II [26] and LHCb [27]. The competition will be inevitable. The measurement of higher D-meson resonances like $B \to D^{**}\ell(\tau)\nu$ decays [28], providing further new observables sensitive to new physics, complementary to the ones mentioned above. The multi-body decays of $D^{**} = D_0^*(2300), D_1(2420), D_1(2430)^0, D_2^*(2460)$ may limit the relevant sensitivities at Belle II. Additionally, the searches for remaining baryonic decays such as R_{Ξ_c} from Ξ_b decay are viable. R One may further extend the trend to search for the inclusive $b \to X_c\ell(\tau)\nu$ decay rates at CEPC, but it could be challenging. Moreover, the searches of exclusive $b \to u\ell\nu$ decays are viable at CEPC, as long as the hadronic u final state like $\pi^\pm$ and ρ^0 can be well reconstructed. Finally, if the systematic uncertainty from lepton mis-ID is under control, the LFU tests between the first two generations, *e.g.*, $\frac{\mathrm{BR}(b\to c+\mu\nu)}{\mathrm{BR}(b\to c+e\nu)}$ become relevant. We may soon deliver the estimated limit once the performance study is done. Finally, from the time-dependent asymmetry of semileptonic $B_{d,s}$ decays we can extract the valuable CPV from $B_{d,s} - \bar{B}_{d,s}$ mixing, namely $\mathcal{A}_{\mathrm{SL}}^{[}$ and $\mathcal{A}_{\mathrm{SL}}^{f}$, contributing to the global picture of the phase β and β_s [29]. The current experimental uncertainty $\sim \mathcal{O}(10^{-3})$ [30] is still far from the SM prediction ($\mathcal{O}(10^{-4})$ for $\mathcal{A}_{\mathrm{SL}}^{d}$ and $\mathcal{O}(10^{-5})$ for $\mathcal{A}_{\mathrm{SL}}^{s}$) [31]. It will be interesting to validate the suggested precision of $\mathcal{O}(10^{-5})$ at the FCC-ee [21] and $\mathcal{O}(10^{-4})$ at the future LHCb [25].

4 Rare/Penguin and Forbidden b Decays

FCNC $b \to s$ and $b \to d$ decays are forbidden at the tree-level in the SM. These decays are induced by EW penguin or box diagrams in the SM at the one-loop level, making them rare processes in general. Rich phenomena thus emerge as physics at the EW scale meets QCD, ideal for testing SM at high precision. Moreover, as the SM rates are suppressed by the off-diagonal CKM matrix elements and the loop factor, these FCNC modes are also sensitive to small new physics contributions. At the CEPC's Z-pole run, the high luminosity ensures large signal statistics even if the target mode has a typically small BR $\lesssim 10^{-5}$.

4.1 Dileptonic Modes

The CEPC full potential for dileptonic decays of b is still under evaluation. For light leptons, the event reconstruction is relatively straightforward, limited by statistics, lepton identification systematics, and the reconstruction of the hadronic decay products. In contrast, for di-τ modes, the missing momentum from neutrino makes the event reconstruction challenging. The background level also increases due to the large number of D mesons produced by Z and inclusive b-hadron decays. Fortunately, the advanced detector system and the clean environment make the di-τ mode one of the most valuable targets at the CEPC. The sensitivity and discovery potential will be orders of magnitude higher than those at other flavor physics experiments.

The sensitivity of several exclusive $b \to s\tau^+\tau^-$ decays are evaluated using $\tau^\pm \to \pi^\pm\pi^\pm\pi^\mp\nu$ decays [32, 33]. The sensitivity are estimated together with the typical background level, reaching $\mathcal{O}(10^{-5})$ for the two-body $B_s \to \tau^+\tau^-$ mode and $\mathcal{O}(10^{-7})$ for other three-body modes. For the baseline CEPC luminosity, such sensitivities can $O(1)$ deviations from the SM. The SM rates of $b \to s\tau^+\tau^-$ will be directly measured if the luminosity is comparable to that of FCC-ee. It is noteworthy that these CEPC upper limits are 1-2 orders of magnitude smaller than the Belle II and LHCb upgrade two ones [2, 25], making them one of the flagships of CEPC flavor physics. A further study using full simulation might be available in the future (see also [34]). For light dilepton decays, a fast simulation study on $B^0 \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ measurements (see [34] for more details). The preliminary result indicates the measurement of $\mathrm{BR}(B_s \to \mu^+\mu^-)$ is statistic limited, reaching $\mathcal{O}(10^{-10})$. On the other hand, $\mathrm{BR} B^0 \to \mu^+\mu^-$ measurement is strongly affected by the $B^0 \to \pi^+\pi^-$ background with $\pi - \mu$ mis-ID.

Other than above studies that are published or in preparation, several valuable analyses to be done. The evaluation of $R_{K^{(*)}}$ potential at the CEPC is yet done. There will be multiple final states like K^+ or $K^*(892)^0 \to K^\pm\pi^\mp$ available at the CEPC. The lepton-ID induced systematics will be the bottleneck of the projection. However, the excellent electron-ID from the future detector will provide some advantage against the LHCb. Other similar topics include R_{pK} [35], R_ϕ [36], $R_{f_2'}$ [36] (potentially large deviations from the SM!), and R_Λ coming from heavier b-hadron decays. The latter may require a new analysis framework as the Λ lifetime is large. In addition, $b \to u\ell^+\ell^-$ searches may share similar systematic uncertainty sources with $b \to s\ell^+\ell^-$ decays, complimentary to LHCb measurements[1]. For di-τ modes, it is worth probing the possibility of differential measurements like the forward-backward asymmetry and the τ polarimetry, which further improves the constraint on new physics [32]. Other channels such as $\Lambda_b \to \Lambda\tau^+\tau^-$ are also noteworthy.

4.2 Neutrino Modes

FCNC $b \to s/d\nu\bar{\nu}$ decays are similar to dileptonic modes. They are thus important for testing the SM. Also, they can provide the possibility of extracting the elements of the CKM matrix and search for the origin of the CP violations. Because they are not affected by the non-factorizable corrections and no photonic penguin contributions, there will be

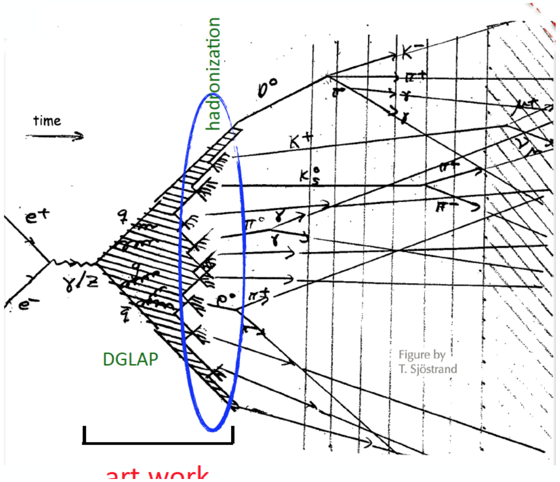
[1] There are ~ 900 LHCb events yields for $B^+ \to \pi^+e^+e^-$ at by the end of HL-LHC era [25]

Facts & interpretation...

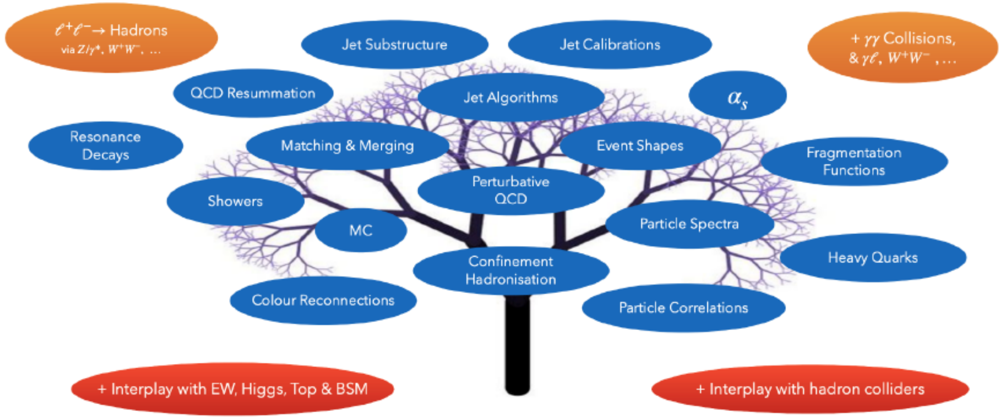
Many Thanks to Lingfeng & HKUST

QCD @ CEPC

- How to achieve the ultimate precision for alphaS at the CEPC ?
- Can we see gluon spin interference at the CEPC ??
- How to observe entanglement from non-global observables at the CEPC ???
- Can we quantitatively understand hadronization ????



- QCD at e+e- colliders remain exciting
- New potential for ultimate precision
- Novel QCD phenomena awaiting discovery
- Deep theory puzzle calls for new data

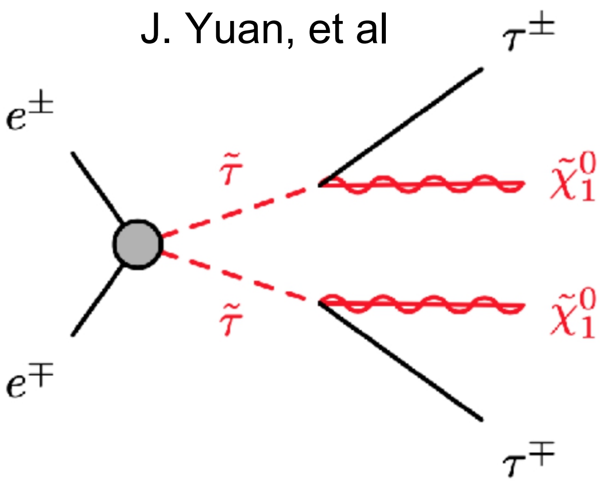


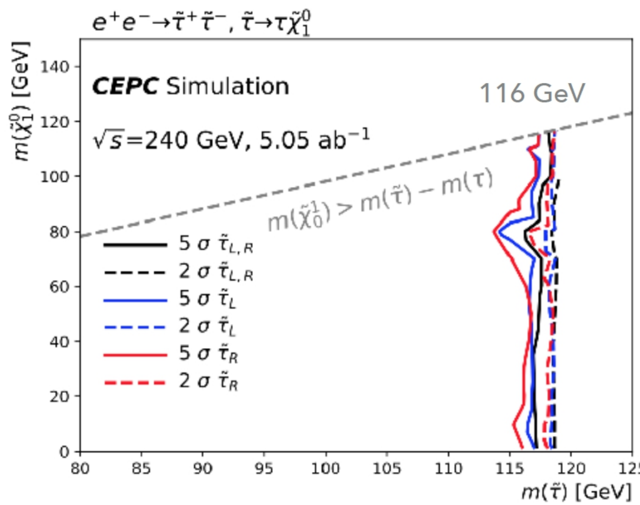
credit: Peter Skands

+ a lot of interest/questions from Performance studies... see later

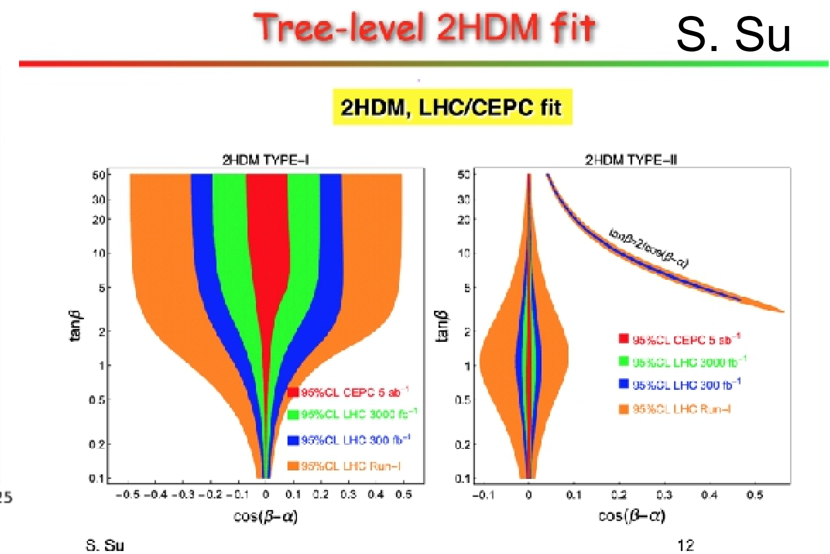
BSM

J. Yuan, et al

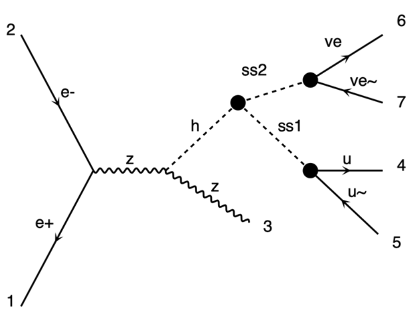


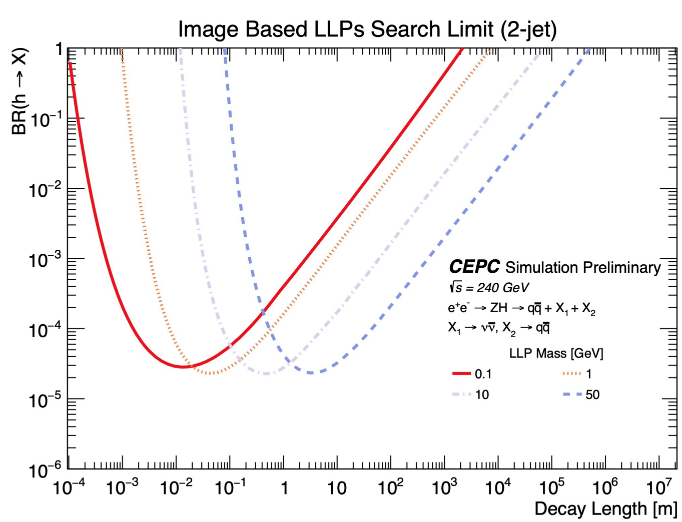


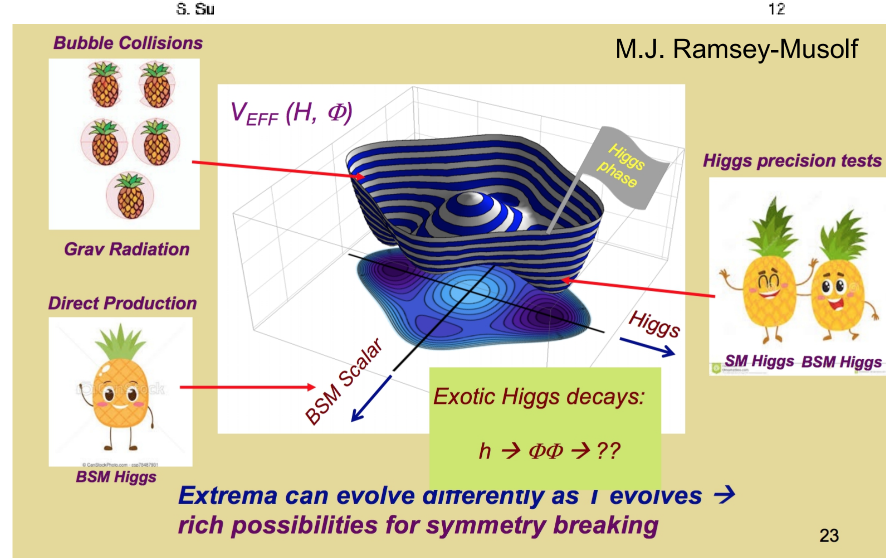
S. Su



Y. Zhang, et al

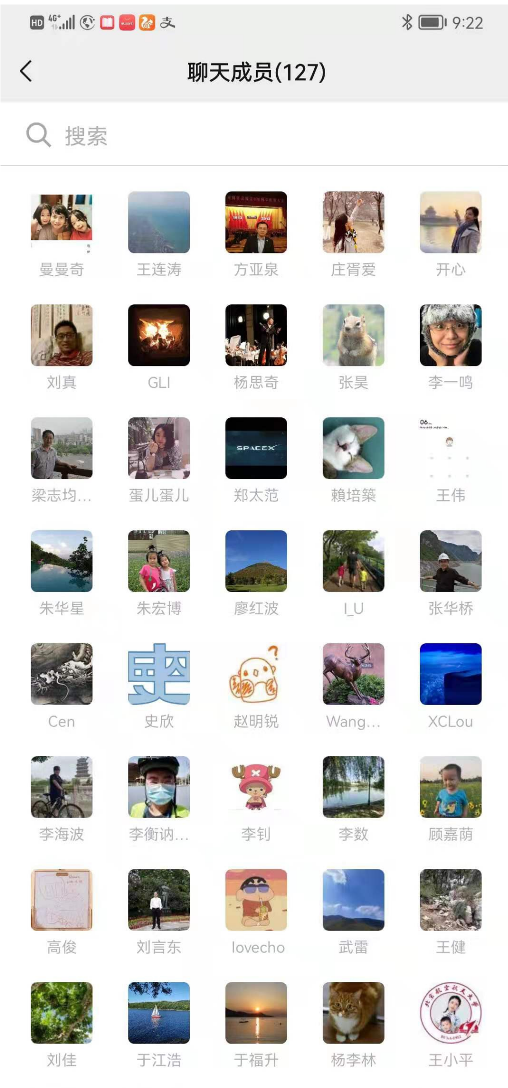






https://indico.ihep.ac.cn/event/13888/session/15

CEPC @ Snowmass

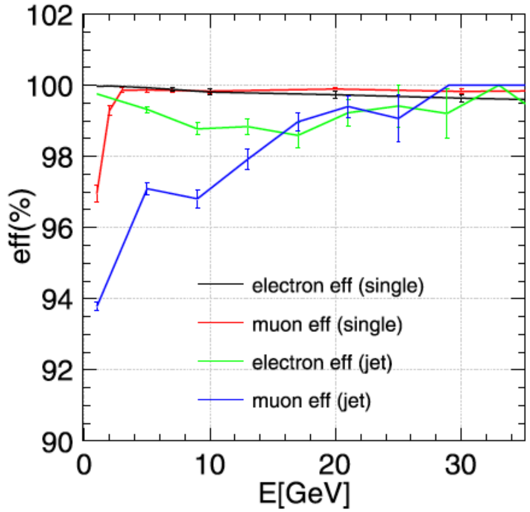


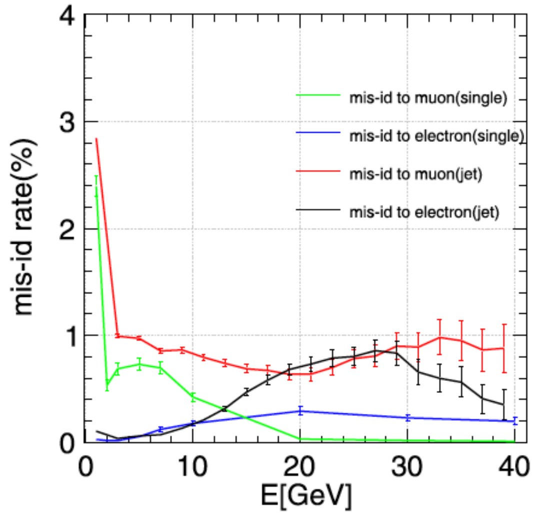
	Submitter	Title	Status
1	Xin	EF01 Higgs boson CP properties at CEPC	
2	Yanping	EF01 Measurement of branching fractions of Higgs hadronic decays	
3	MJRM & Shu	EF02 Study of EWPT in Exotic Higgs decays with CEPC detector simulation	
4	Mingrui Zhao	EF03 Feasibility study of CP violation phase Phi-s measurement via Bs->J/psi Phi at CEPC	About to submit
5	Peiwen Wu	EF03 Probing top quark FCNC couplings at future electron positron collider	
6	Lingfeng Li	EF03 Searching for Bs->Phivv and other b->svv processes at CEPC	About to submit
7	Siqi Yang	EF04 Measurement of leptonic effective weak mixing angle at CEPC	About to submit
8	Jiayin Gu	EF04 Probing new physics with measurement of ee->WW at CEPC with optimal observables	About to submit
9	Qin qin	EF05 Exclusive Z decay	ArXiv
10	Zhao Li	EF05 NNLO EW correction to Higgs and Z associated production at future Higgs factory	
11	Yang Zhang	EF08 SUSY Global fits with future colliders using GAMBIT	About to submit
12	Tianjun li	EF08 Probing SUSY and DM at CEPC, FCC & ILC	
13	Mengchao Zhang	EF09 Search for Asymmetric DM model at CEPC by displaced lepton jets	PRD accept https://link.aps.org/doi/10.1103/PhysRevD.104.055008
14	Peiwen Wu	EF09 Search for t+j+MET signals from DM models at future electron positron collider	
15	Xin Shi & Weiming	EF09 DM via Higgs portal at CEPC	
16	Kepan Xie	EF10 Lepton portal DM, Gravitational waves and collider phenomenology	JHEP 06 (2021) 149
17	Taifan Zheng	RF1 Exploring NP with Bc->Tauv	Chinese Phys. C 45 023001
18	Bo Li	EF04 Measurement of Rb in hadronic Z decays at the CEPC	About to submit
19	Zhao Li	EF04 NNLO electroweak correction to Higgs and Z associated production at future Higgs factory	
20	Shuang-Yong Zhou	EF04 Positivity bounds on quartic-gauge-boson couplings	

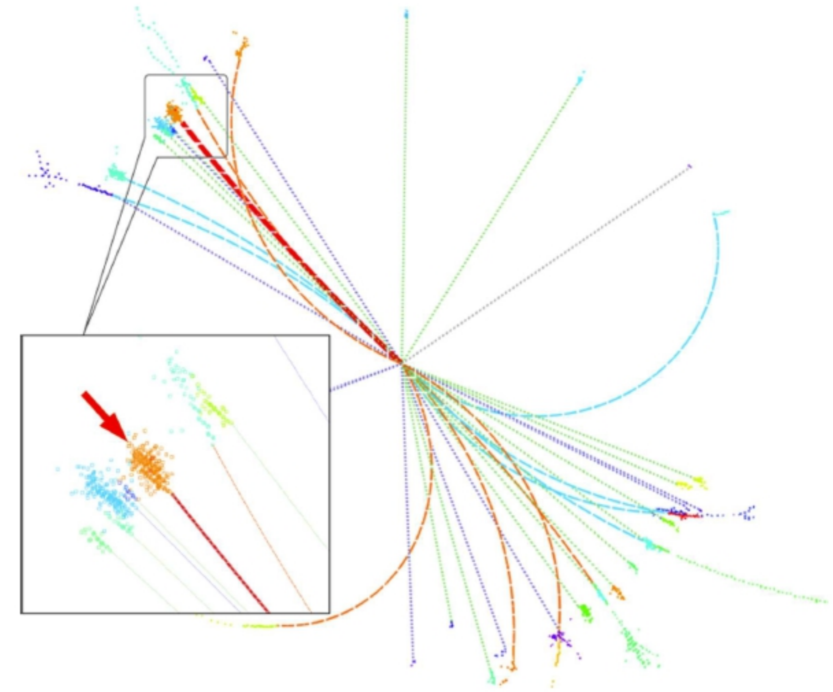
1/4 published
1/4 about to publish
1/2 keep on cultivating...

Lepton & Pi-0

2021 JINST 16 P06013: Jet

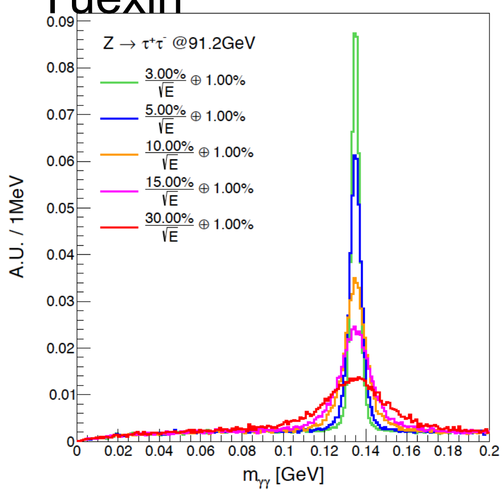


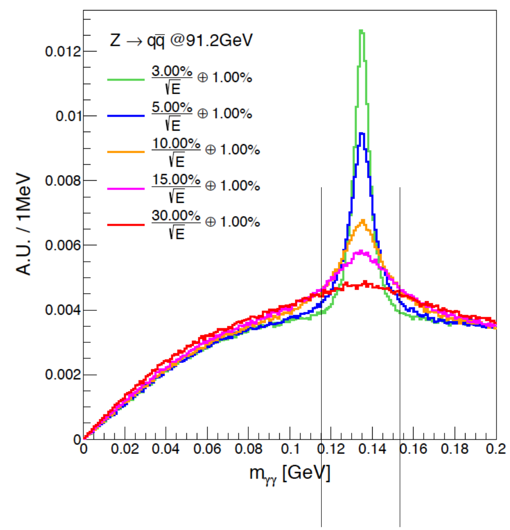




Yuexin

Pi-0: CEPC Note 2021





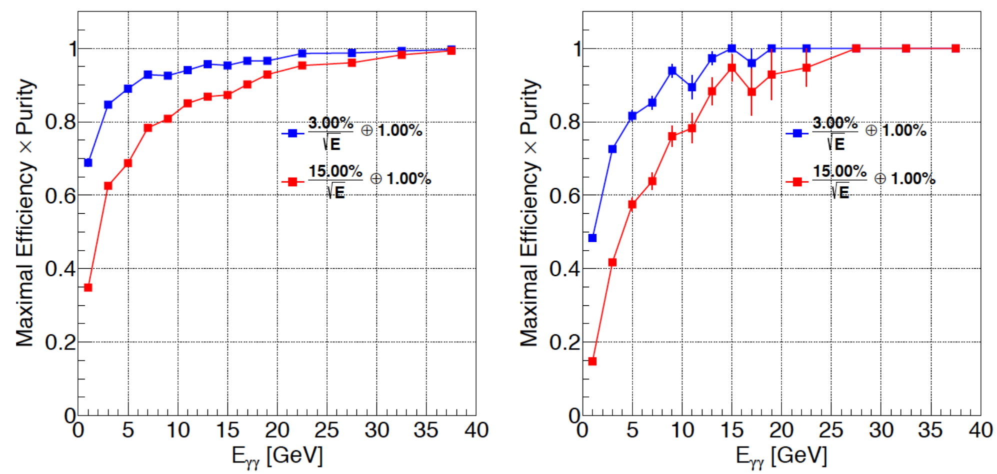


Figure 13: Energy differential maximal $\epsilon \times p$ for $Z \to \tau^+\tau^-$ (left) and $Z \to q\bar{q}$ (right).

Kshort, Lambda & Phi

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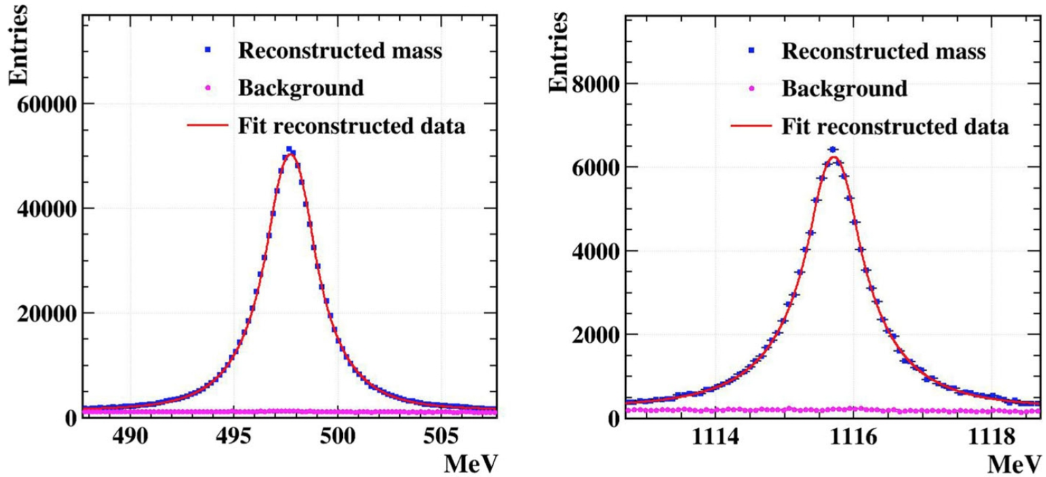
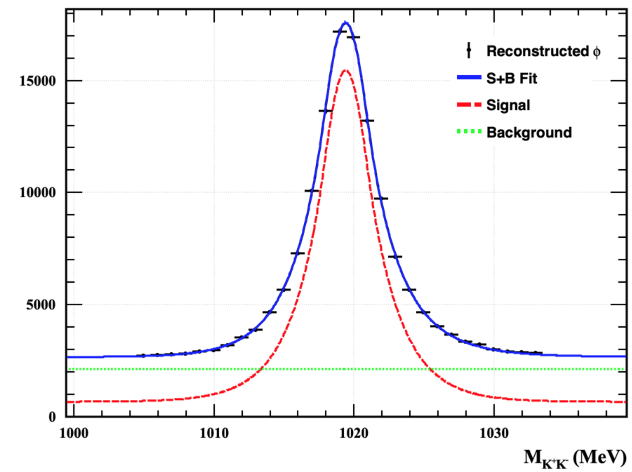


(a) K_S^0 **(b)** Λ

Fig. 7 All reconstructed mass distributions of K_S^0 and Λ. They are fitted with double-sided crystal ball functions



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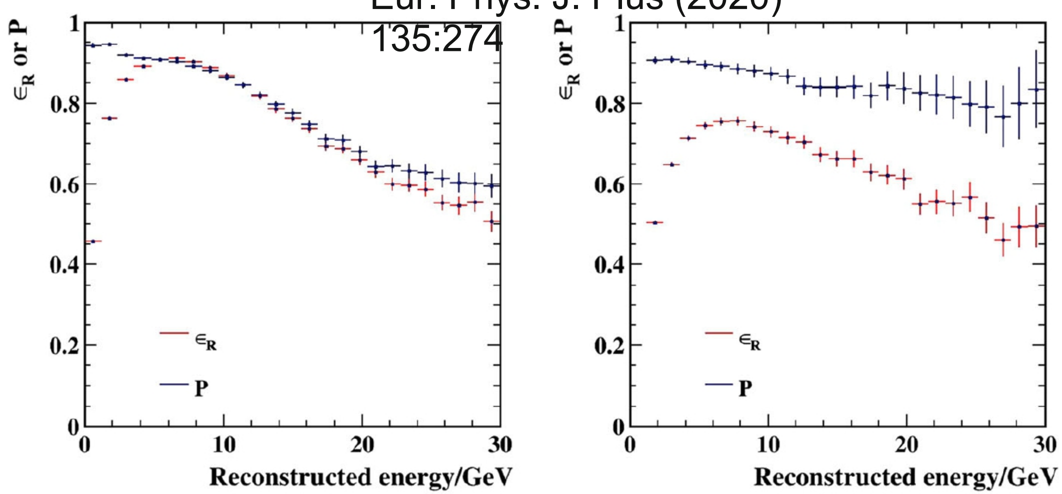
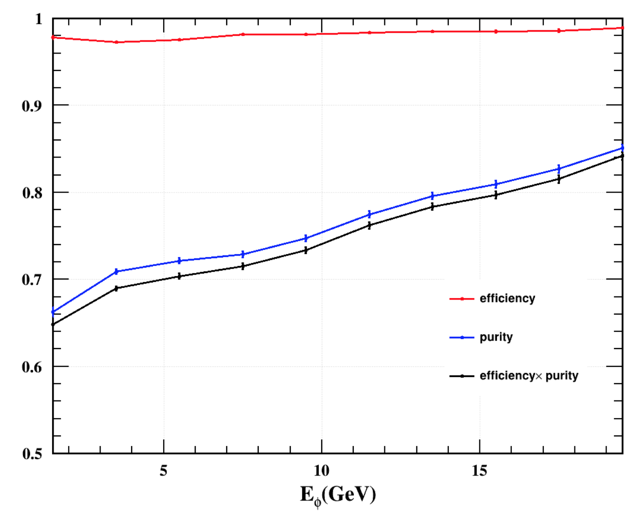
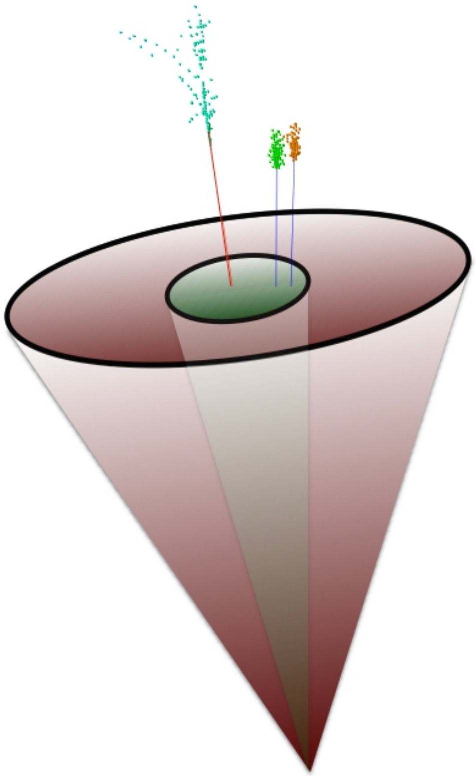


(a) K_S^0 **(b)** Λ

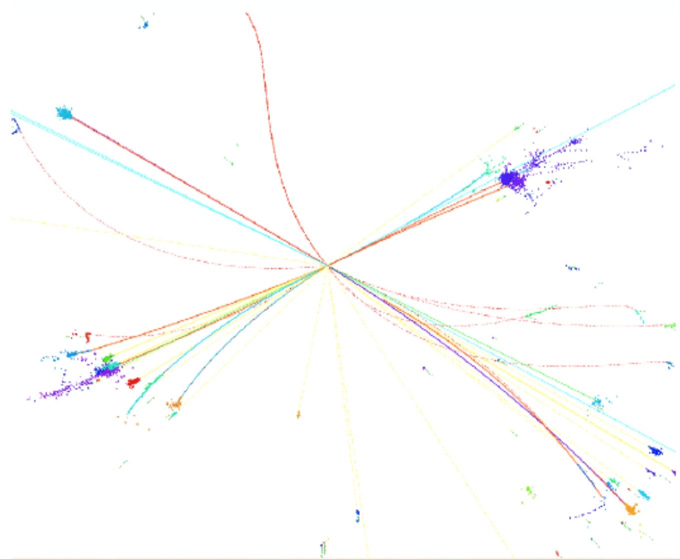
Fig. 9 Energy dependence of ϵ_R and P



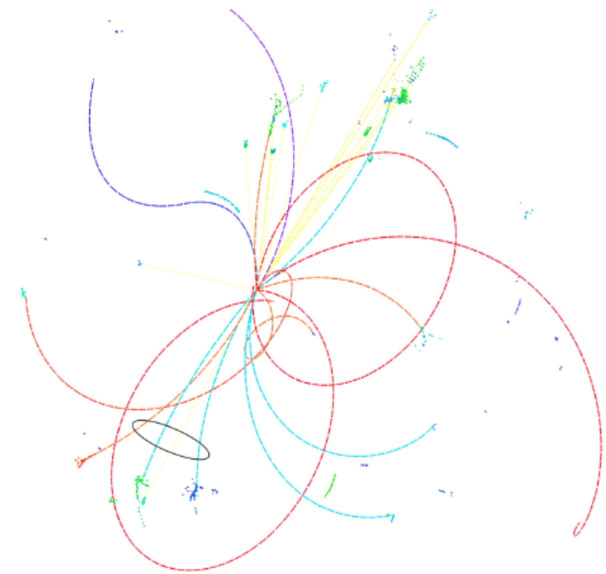
Taus



Semi-Leptonic:
ZH, $Z\to qq$, $H\to\tau\tau$
$WW\to\tau\nu qq$

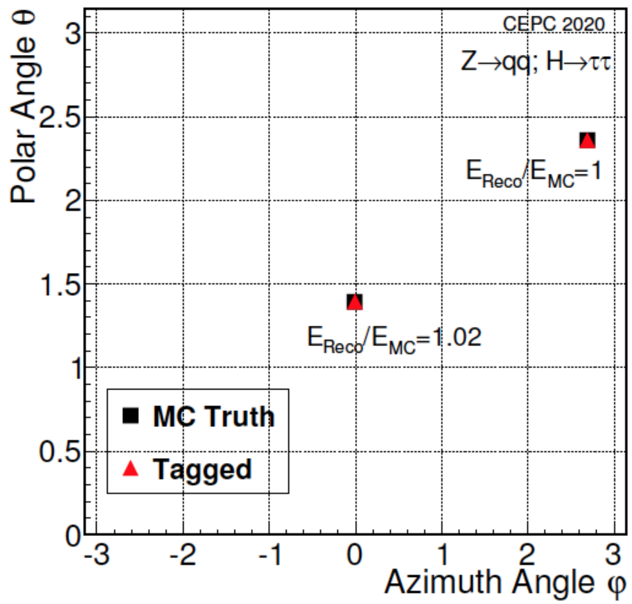


Full-Hadronic:
$Z\to qq\to\tau + X$

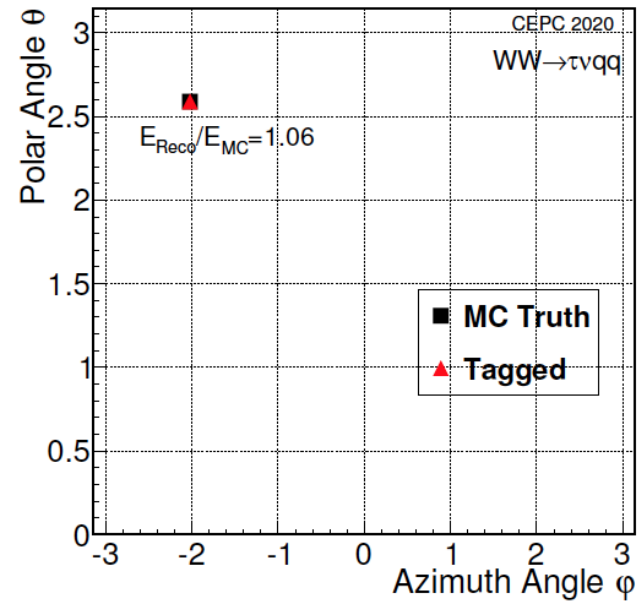


TAURUS (Tau ReconstrUction toolS):
an overall efficiency*purity higher than 70% is achieved for $qq\tau\tau$, and $qq\tau\nu$ events

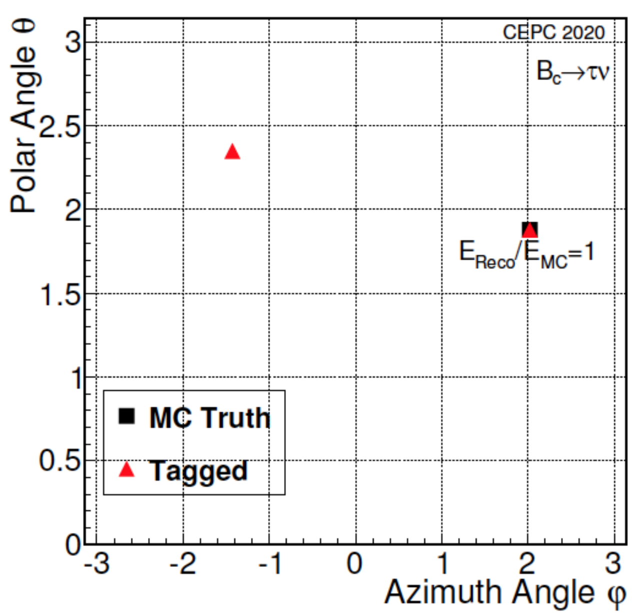
TAURUS/Specify Tau decay product



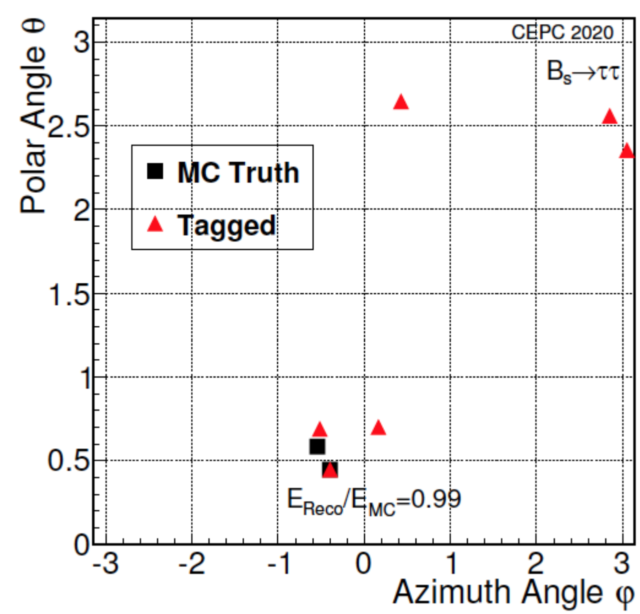
(a) $Z \to qq, H \to \tau\tau$, efficiency=1, purity=1



(b) $WW \to \tau\nu qq$, efficiency=1, purity=1

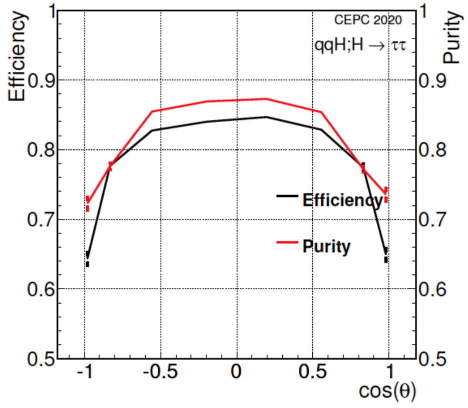


(c) $Z \to b\overline{b}, B_c \to \tau\nu$, efficiency=1, purity=0.5

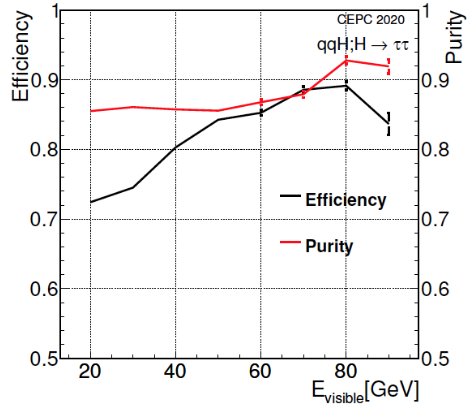


(d) $Z \to b\overline{b}, B_s \to \tau\tau$, efficiency=0.5, purity=0.167

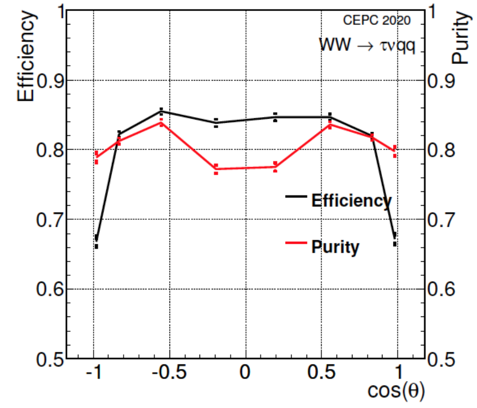
TAURUS: differential performance



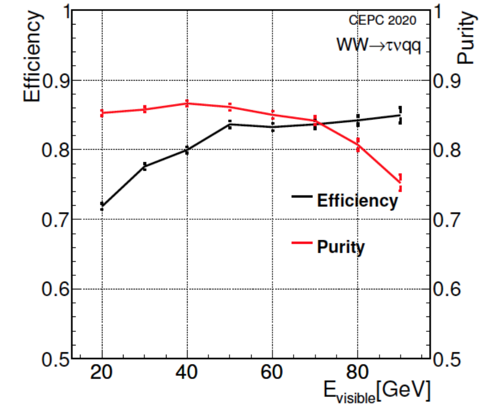
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.



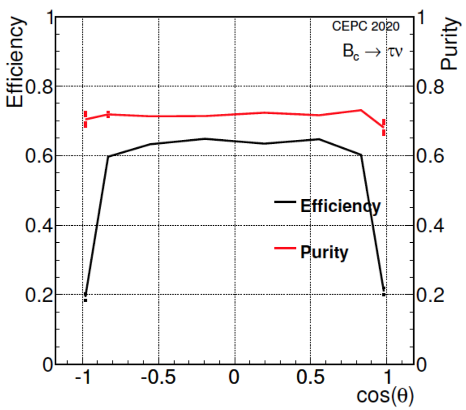
(b) Efficiency and purity performance along with visible energy. The performance above 80 GeV falls as a result of stringent cone selection.



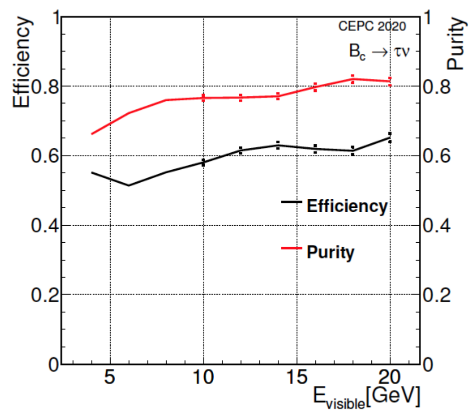
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.



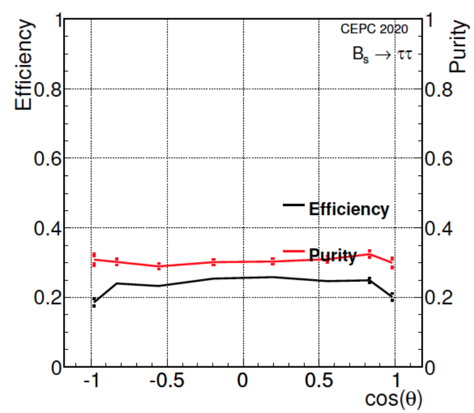
(b) Efficiency and purity performance along with visible energy



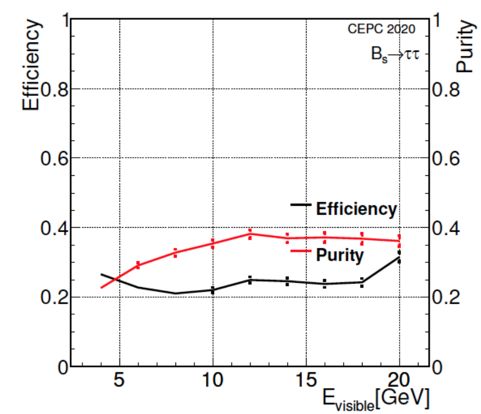
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.



(b) Efficiency and purity performance along with visible energy



(a) Efficiency and purity performance along with polar angle θ, parameters fixed.



(b) Efficiency and purity performance along with visible energy

Eur. Phys. J. C (2020) 80:7
https://doi.org/10.1140/epjc/s10052-019-7557-y

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

The measurement of the $H \rightarrow \tau\tau$ signal strength in the future e^+e^- Higgs factories

Dan Yu[1], **Manqi Ruan**[1,a], **Vincent Boudry**[2], **Henri Videau**[2], **Jean-Claude Brient**[2], **Zhigang Wu**[1], **Qun Ouyang**[1], **Yue Xu**[3], **Xin Chen**[3]

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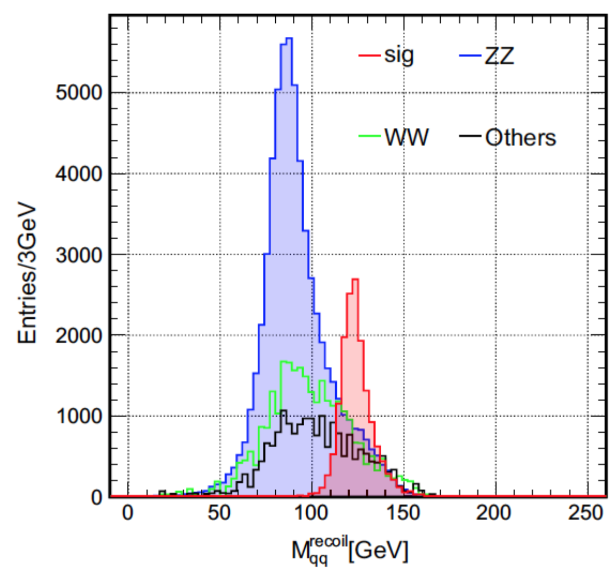
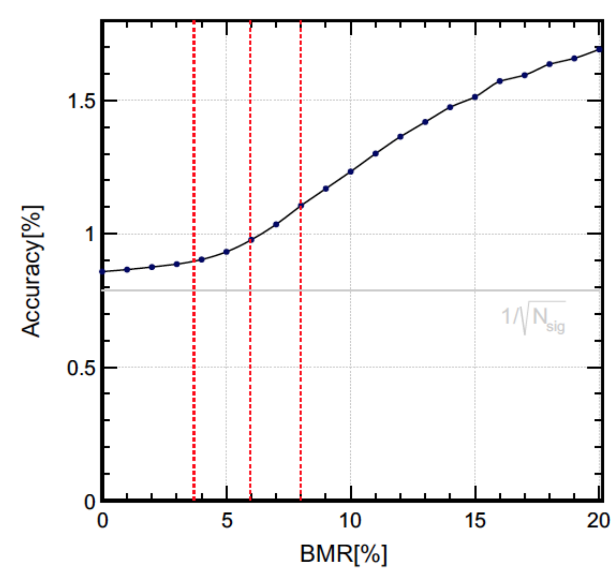
[2] LLR, Ecole Polytechnique, Palaiseau, France
[3] Tsinghua University, Beijing, China

Received: 22 July 2019 / Accepted: 12 December

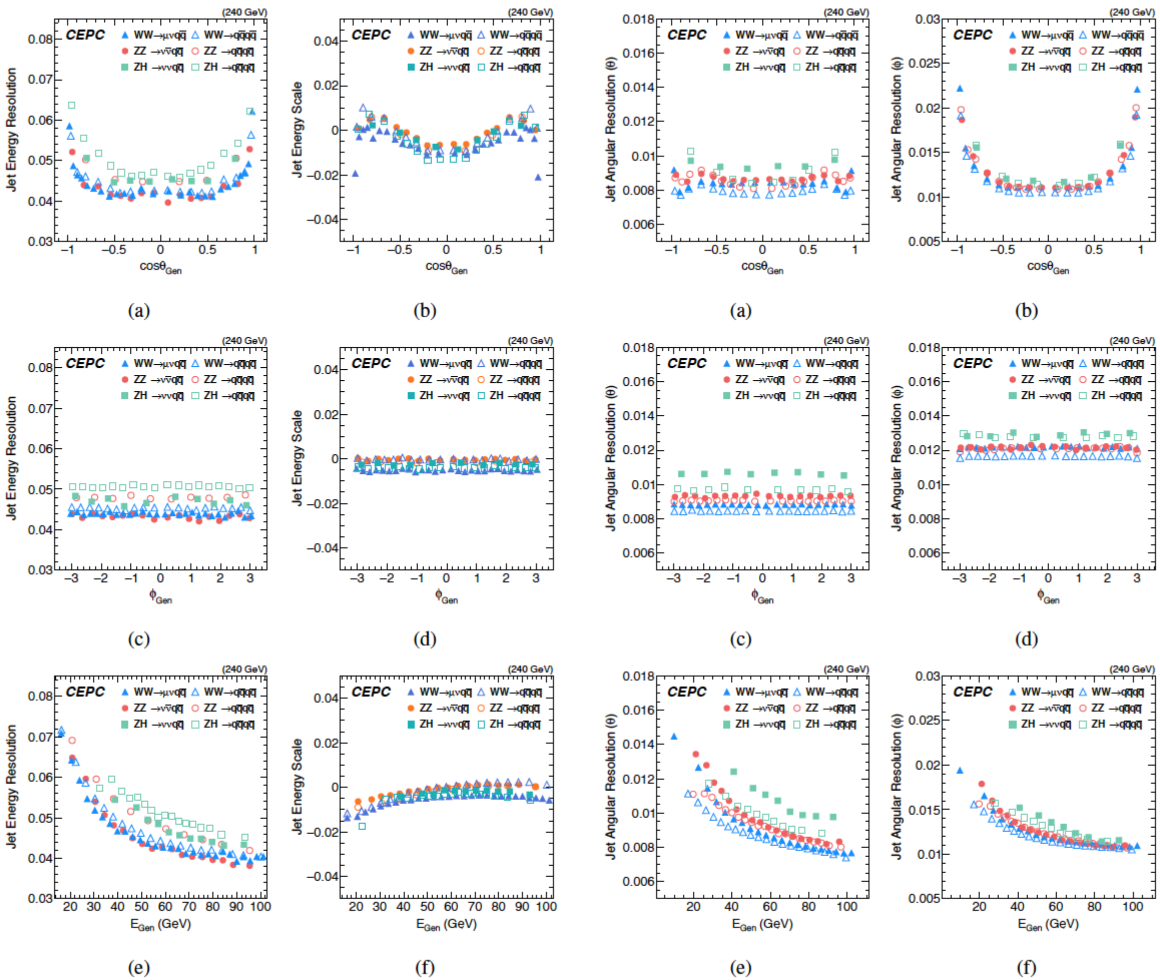
Table 9 Extrapolated accuracy $\delta(\sigma \times \mathrm{BR})/(\sigma \times \mathrm{BR})$ in the ILC 250 GeV (2000 fb^{-1})

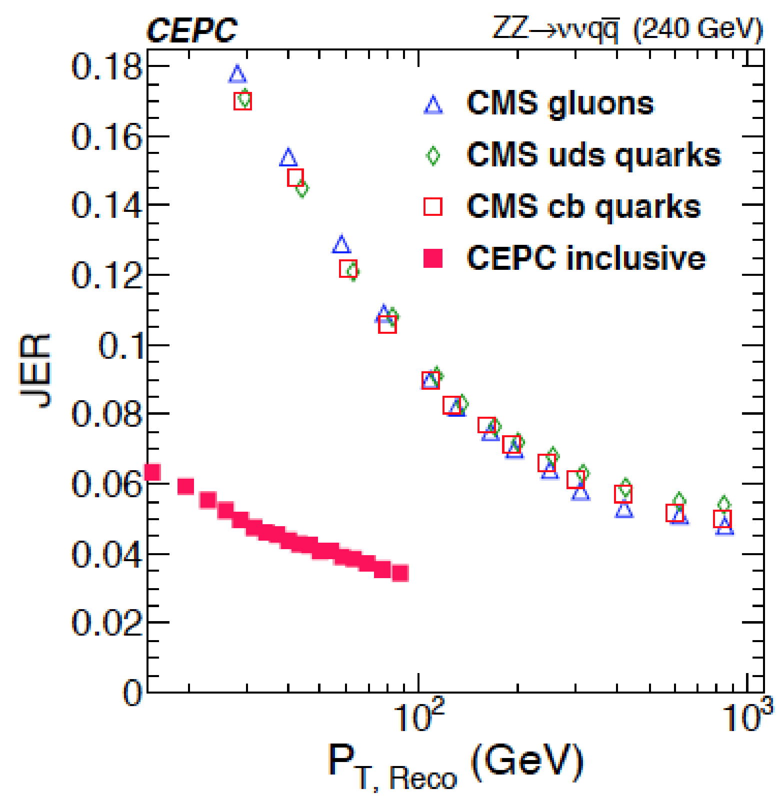
	CEPC	ILC(L)	ILC(R)
Luminosity (ab^{-1})	5.6	2	2
Polarization (e^-, e^+)	–	(0.8, −0.3)	(−0.8, 0.3)
Total Higgs	1.18 M	0.60 M	0.40 M
Accuracy (%)	0.8	1.09	1.21





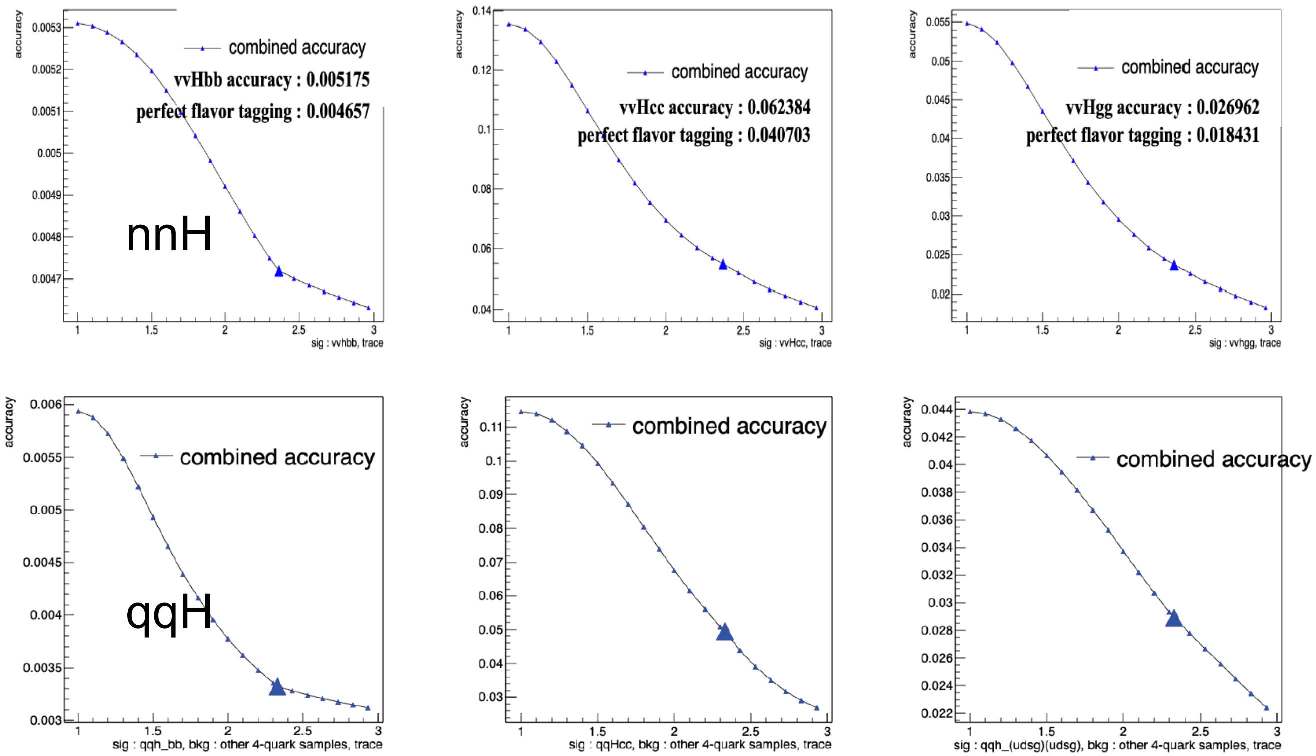
Individual Jet Responses

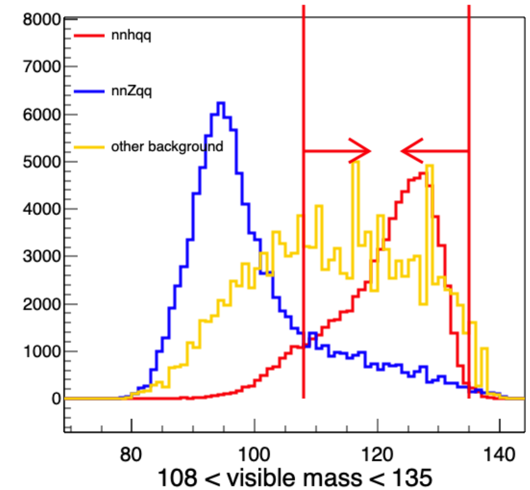


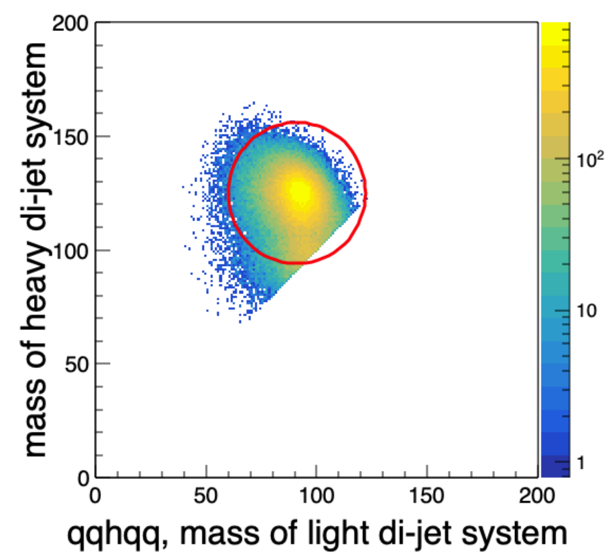


Jet Energy Response: 2.5 – 4 times better than LHC in the same Pt range,
Jet Energy Scale: 3 times better before sophisticated calibration

H→bb, cc, gg: BMR, Color Singlet id (CSI) & Flavor tagging (Preliminary)





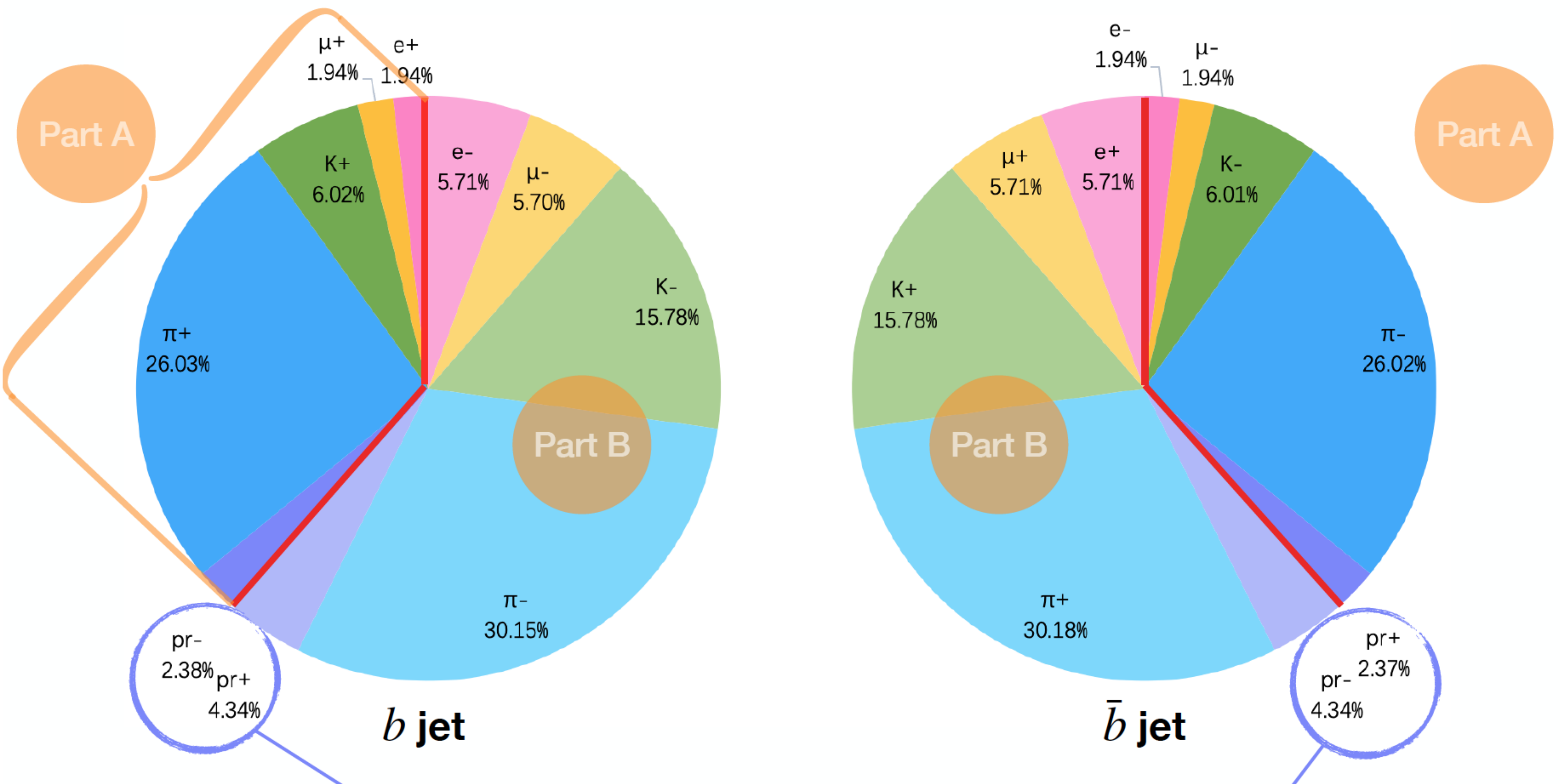


BMR is good enough... Huge penitential compared to Baseline FT + Naive CSI (ee-kt jet clustering & matching)

- Ideal CSI improves the accuracies by up to 2 times...
- Ideal Flavor tagging improves the accuracy of of Hcc by 2 times @ qqH, & 50% @ nnH

$Z \to b\bar{b}$

Percent of final charged leading particles



ω(using only charge) = 0.403

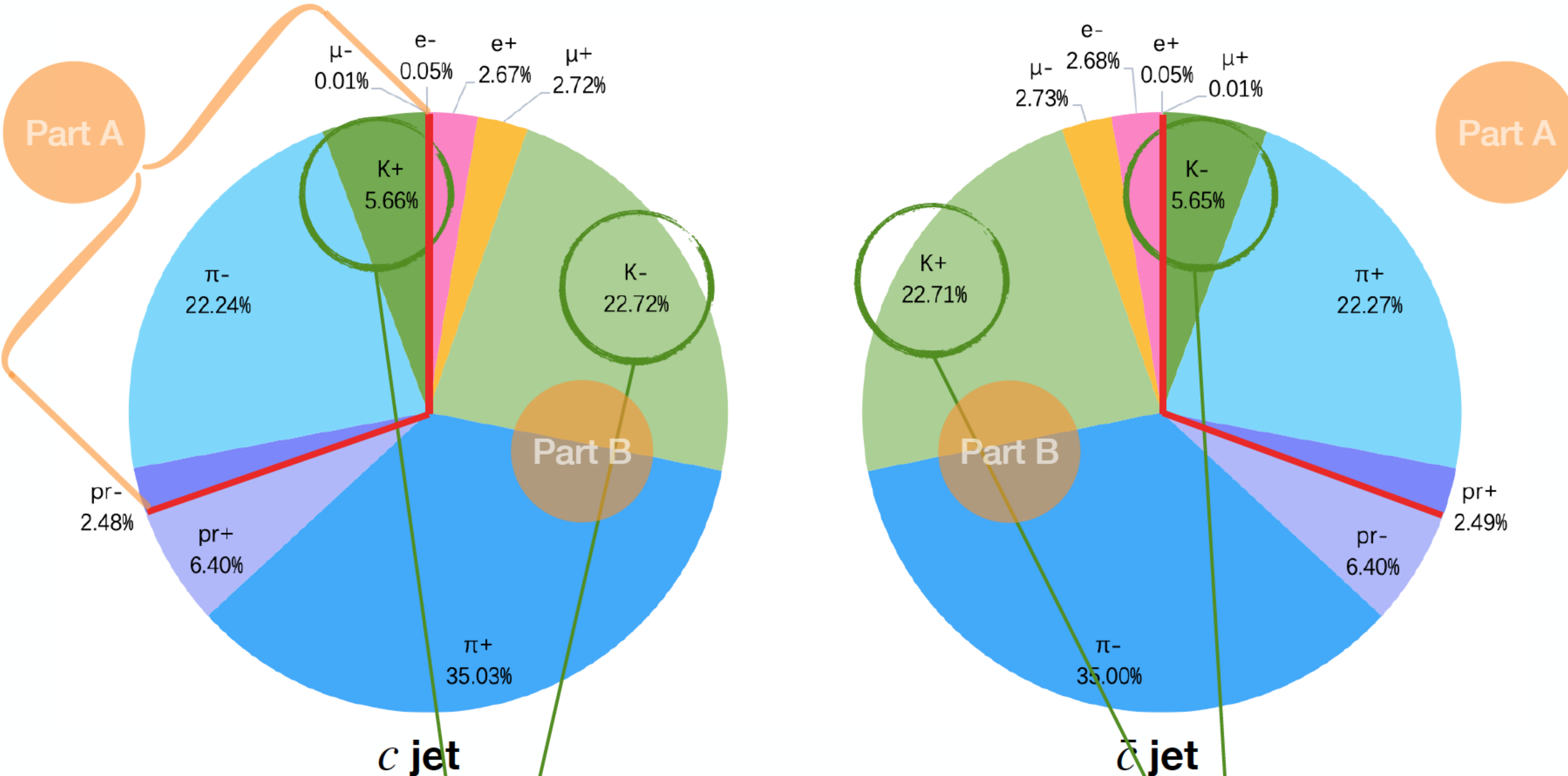
ω(using charge & PID) = 0.383

ω(using only charge) = 0.402

ω(using charge & PID) = 0.383

$Z \to c\bar{c}$

Percent of final charged leading particles

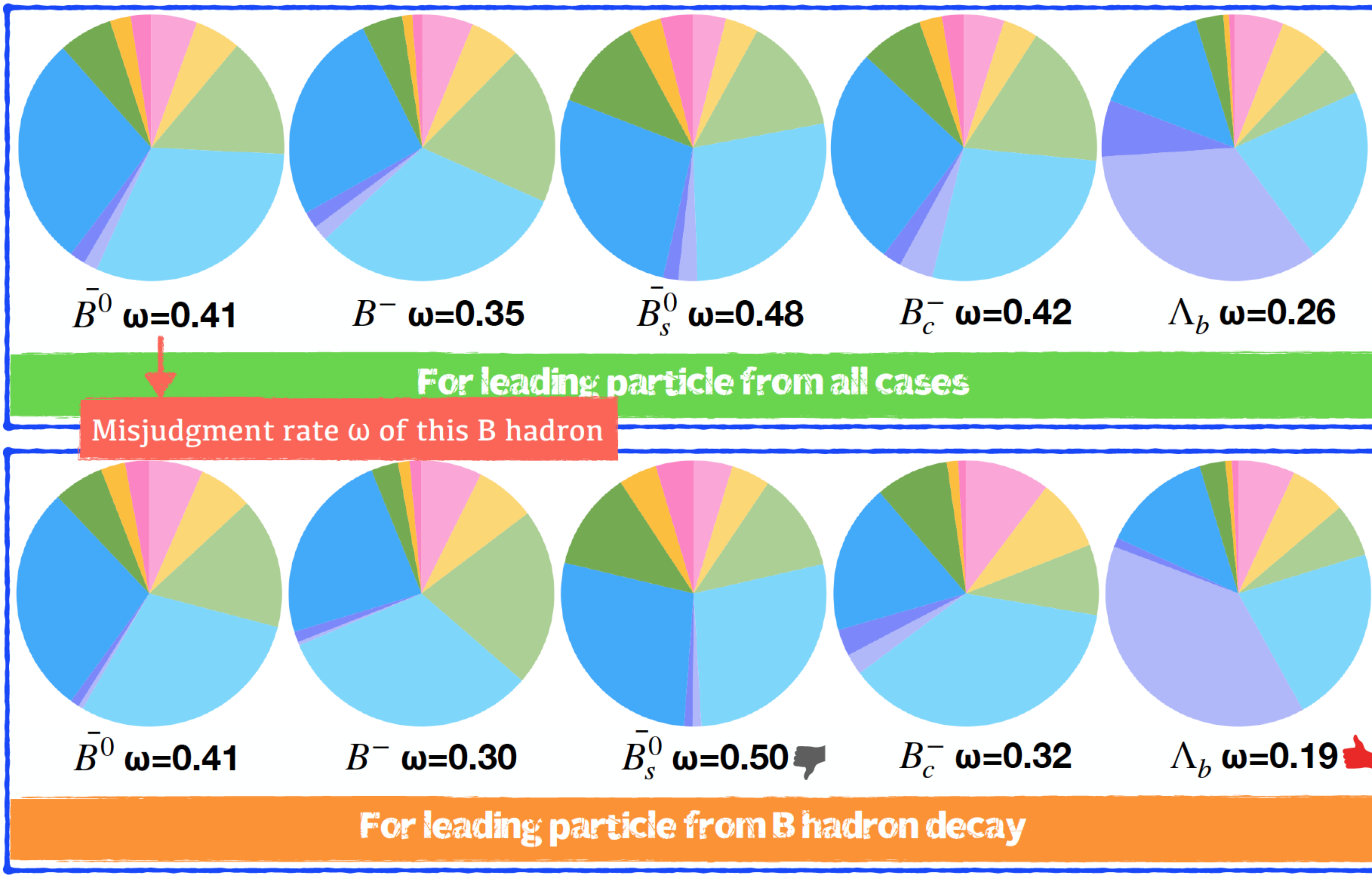


ω(using only charge) = 0.473 ω(using only charge) = 0.475

ω(using charge & PID) = 0.304 ω(using charge & PID) = 0.305

$Z \to b\bar{b}$

Percent of leading particles of each B hadron of b jet



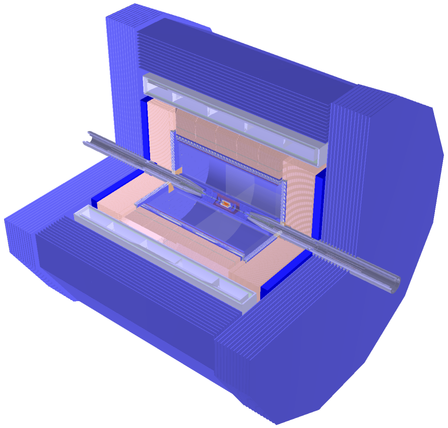
To QCD community:

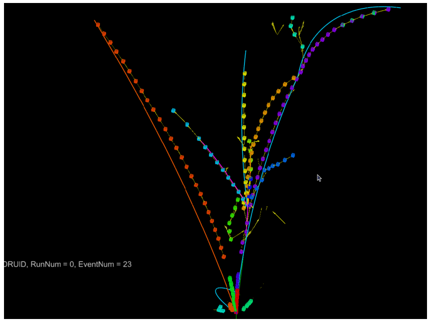
- What's the dependency on fragmentation method/tools?
- What's the ultimate CSI?

Better understood detector Performance

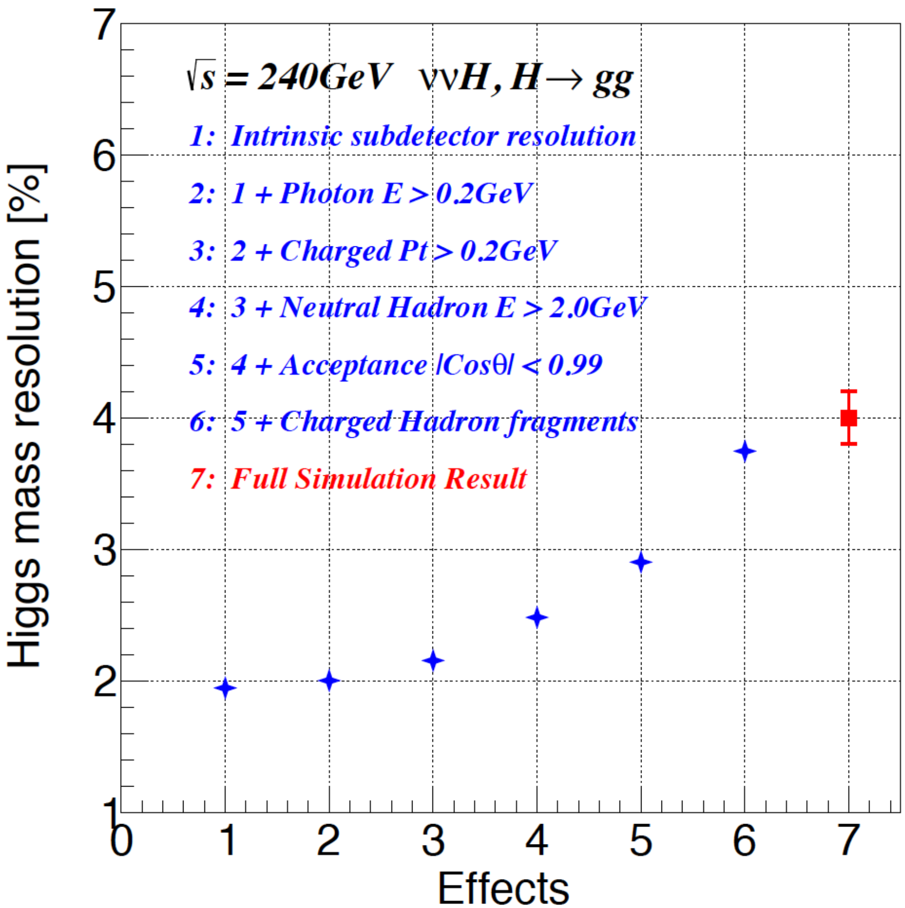
- Acceptance: |cos(θ)| < 0.99
- Tracks:
  - Pt threshold, ~ 100 MeV
  - δp/p ~ o(0.1%)
- Photons:
  - Energy threshold, ~ 100 MeV
  - δE/E: 3 – 15%/sqrt(E)
- BMR: 3.7%
- b-tagging: eff*purity @ Z→qq: 70%
- c-tagging: eff*purity @ Z→qq: 40%
- Pi-Kaon separation: 3-sigma (requirement)
- Pi-0: eff*purity @ Z→qq > 60% @ 5GeV
- Jet charge: eff*$(1-2\omega)^2$ ~ 15%/30% @ Z→bb/cc

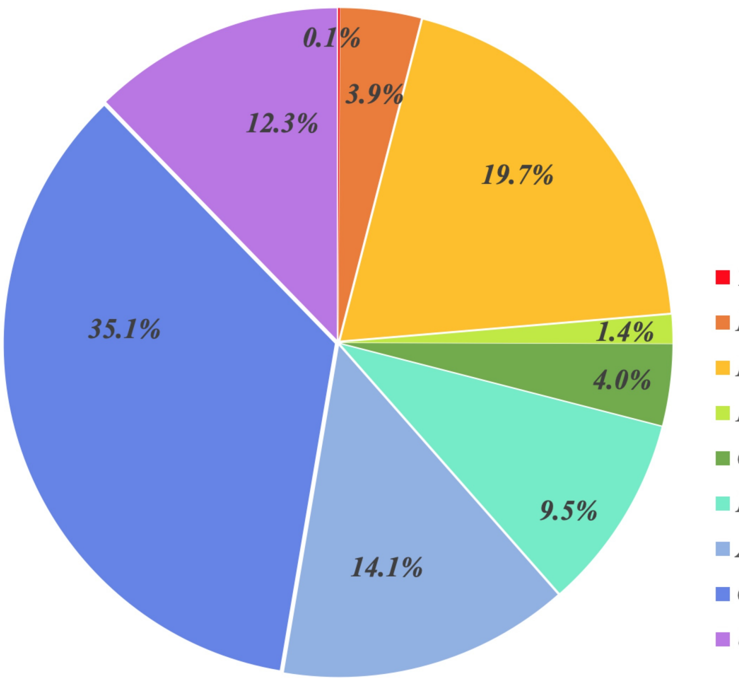
- Lepton inside jets: eff*purity @ Z→qq ~ 90% (energy > 3 GeV): slight degrading in jet
- Tau: eff*purity @ WW→tauvqq: 70%, mis id from jet fragments ~ o(1%)
- Reconstruction of simple combinations: Ks/Lambda/D with all tracks @ Z→qq: 60/75 – 80/85%
- Missing Energy: Consistent with BMR.





PFA Fast simulation (Preliminary)





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Fast simulation reproduces the full simulation results, factorize/quantifies different impacts

Remarks:

- Same cleaning condition as in the Full simulation applied
- Early phase of modeling/tuning

Summary

- CEPC CDR provides solid basis for physics & performance study
- The IAC recommendation is very helpful & implemented
  - Top & Z, flavor physics with strong interactions
  - Plan to cover: NP @ top, exotic hadron search at Z pole
- Physics: to quantify the discovery power of CEPC, and to optimize its physics output:
  - White paper in good shape
  - Enhanced community, especially from theorists
- Performance:
  - Much better understanding on baseline detector performance, especially those flavor physics oriented performance, etc.
  - Clearer Physics requirements, that guides the detector design & optimization
- Frequent & regular communications with other international projects & strategic discussion
- Intensive & Health iteration with Detector & theory community.