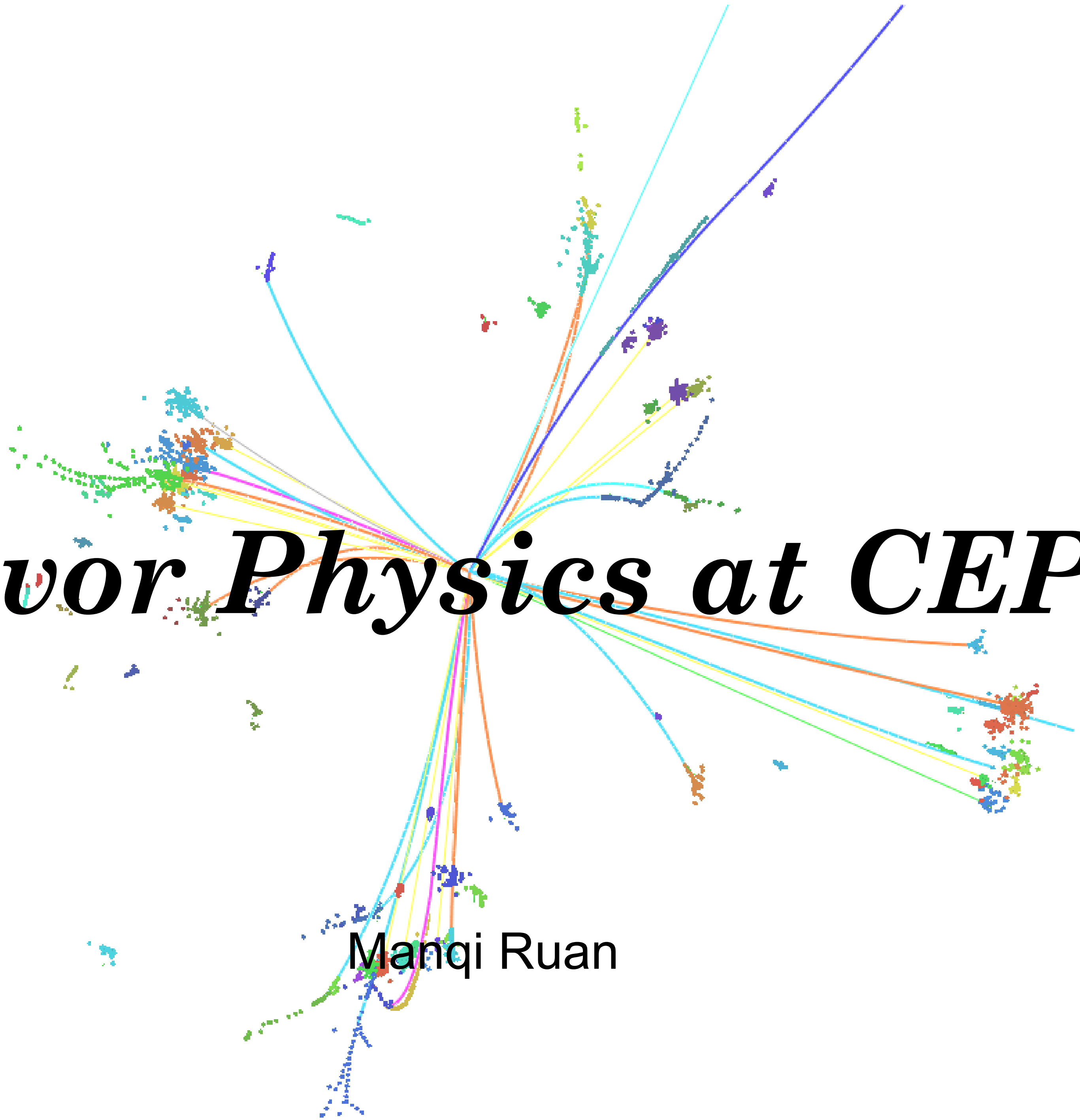
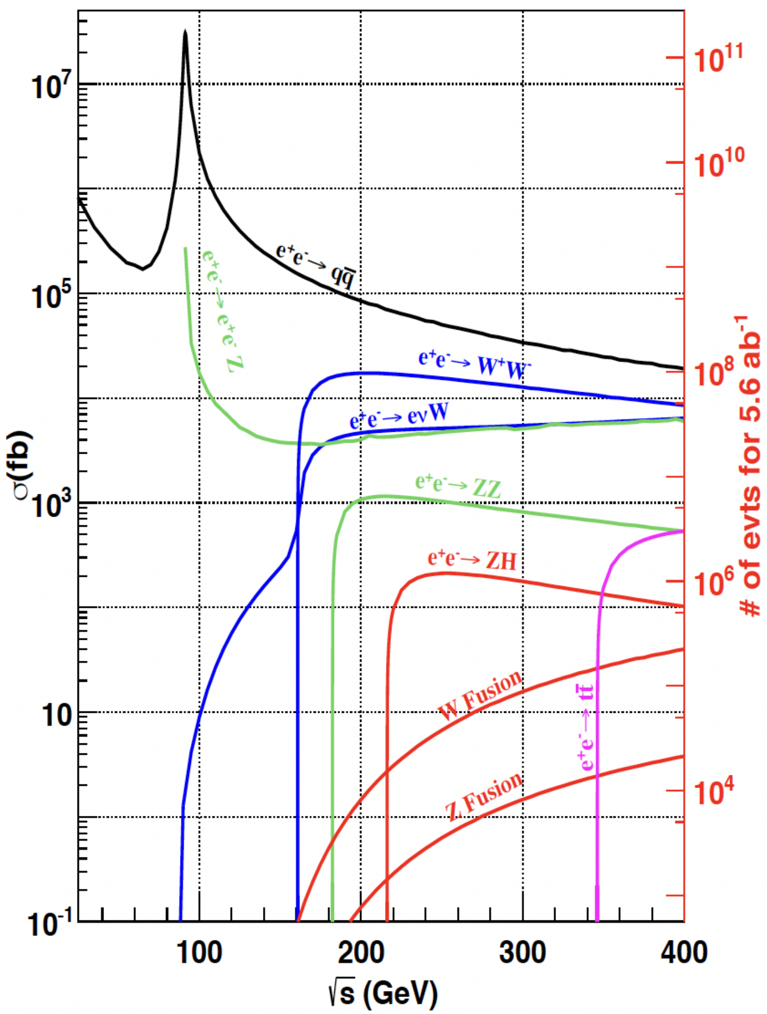
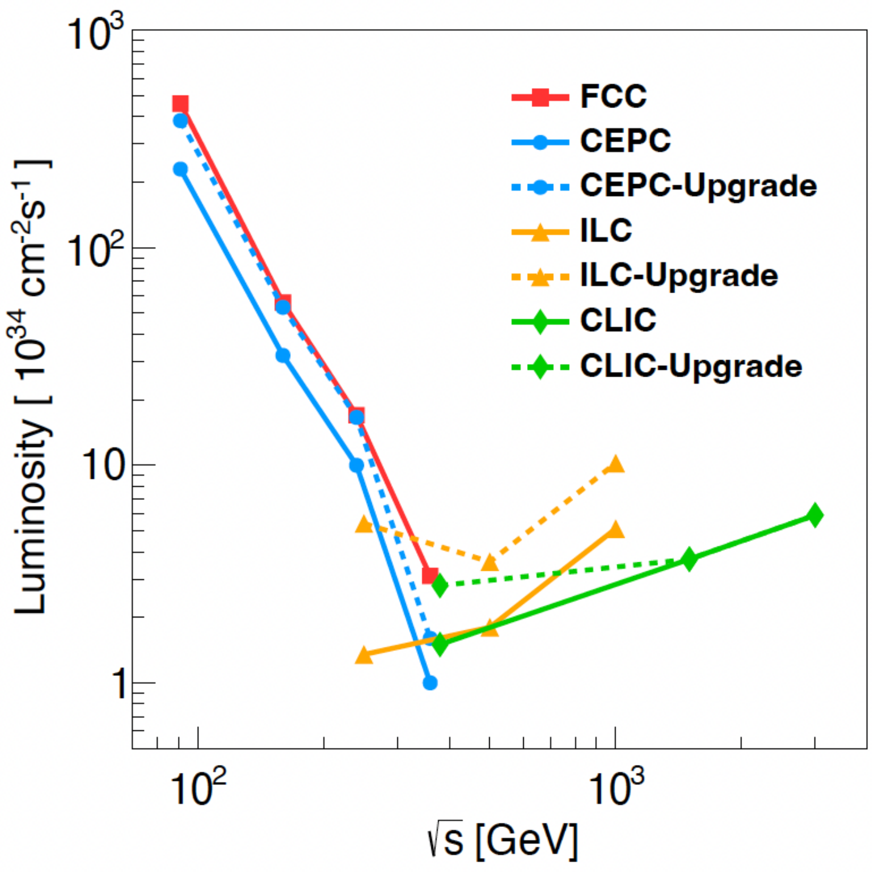
Flavor Physics at CEPC



Manqi Ruan

X sections & Luminosities

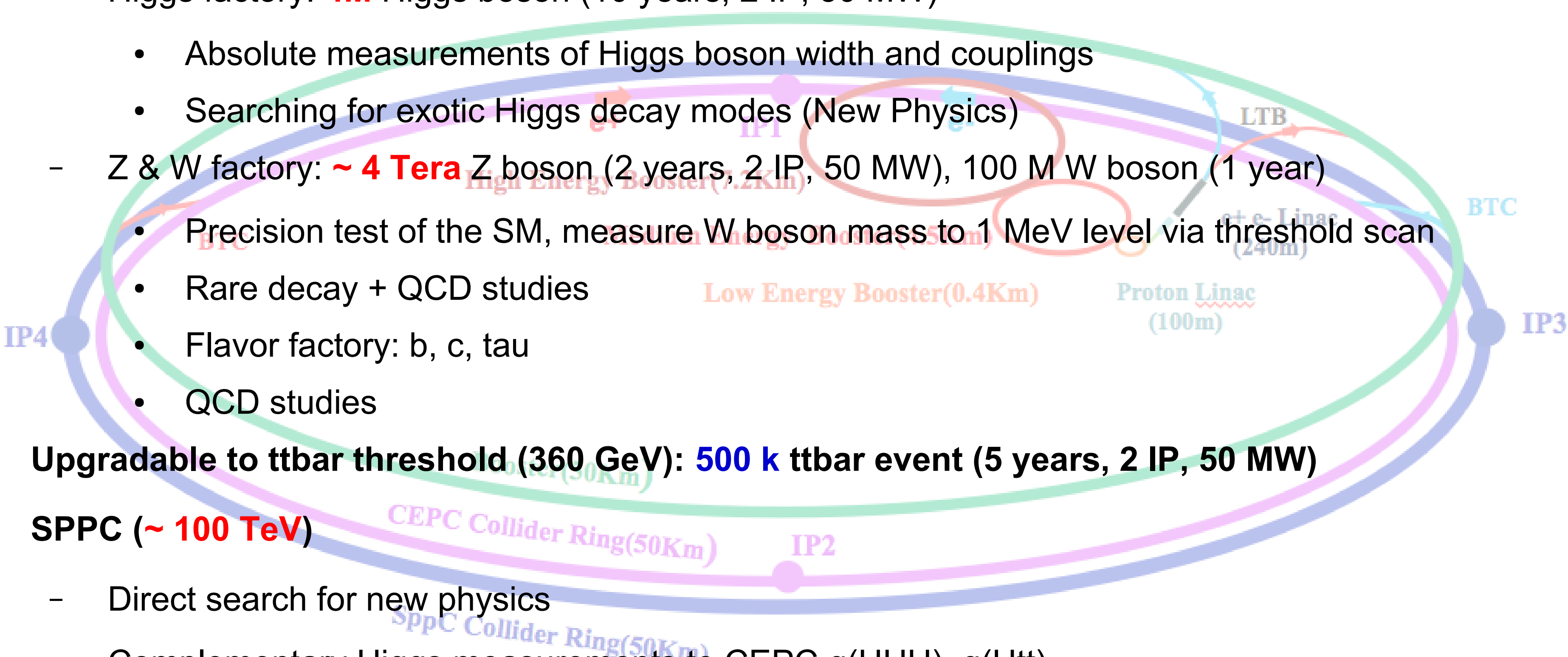




Yields of the CEPC

- **Tunnel ~ 100 km，** baseline SR Power/beam **30 MW**, upgradable to **50 MW**
- **CEPC (90 – 240 GeV)**
  - Higgs factory: **4M** Higgs boson (10 years, 2 IP, 50 MW)
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 4 Tera** Z boson (2 years, 2 IP, 50 MW), 100 M W boson (1 year)
    - Precision test of the SM, measure W boson mass to 1 MeV level via threshold scan
    - Rare decay + QCD studies
    - Flavor factory: b, c, tau
    - QCD studies
- **Upgradable to ttbar threshold (360 GeV): 500 k ttbar event (5 years, 2 IP, 50 MW)**
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

See also: 2205.08553



Comparative advantages of Flavor physics @ Tera-Z

- Compared to Belle II:
  - Higher yields;
  - Access to heavy hadrons like Bc, Lambda_b, exotics, etc
  - Larger boost
- Compared to LHCb:
  - Much lower yields
  - 4 pi detector with better measurements to neutral final states (photon, neutrinos)
  - Better time dependent measurements: better VTX & better Jet Charge Tagging

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 $\Upsilon(4S)$)	

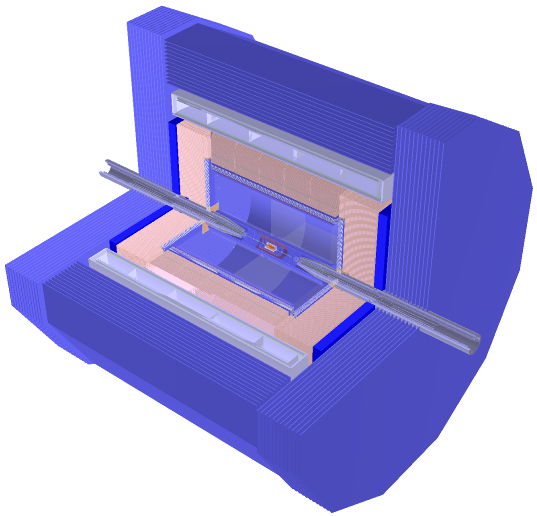
[Dong et al.(2018)]

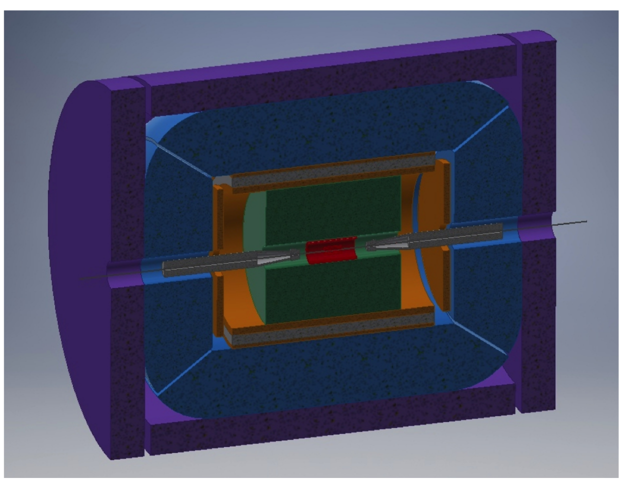
Flavor: Not only at Z pole, but also at Higher Energy...

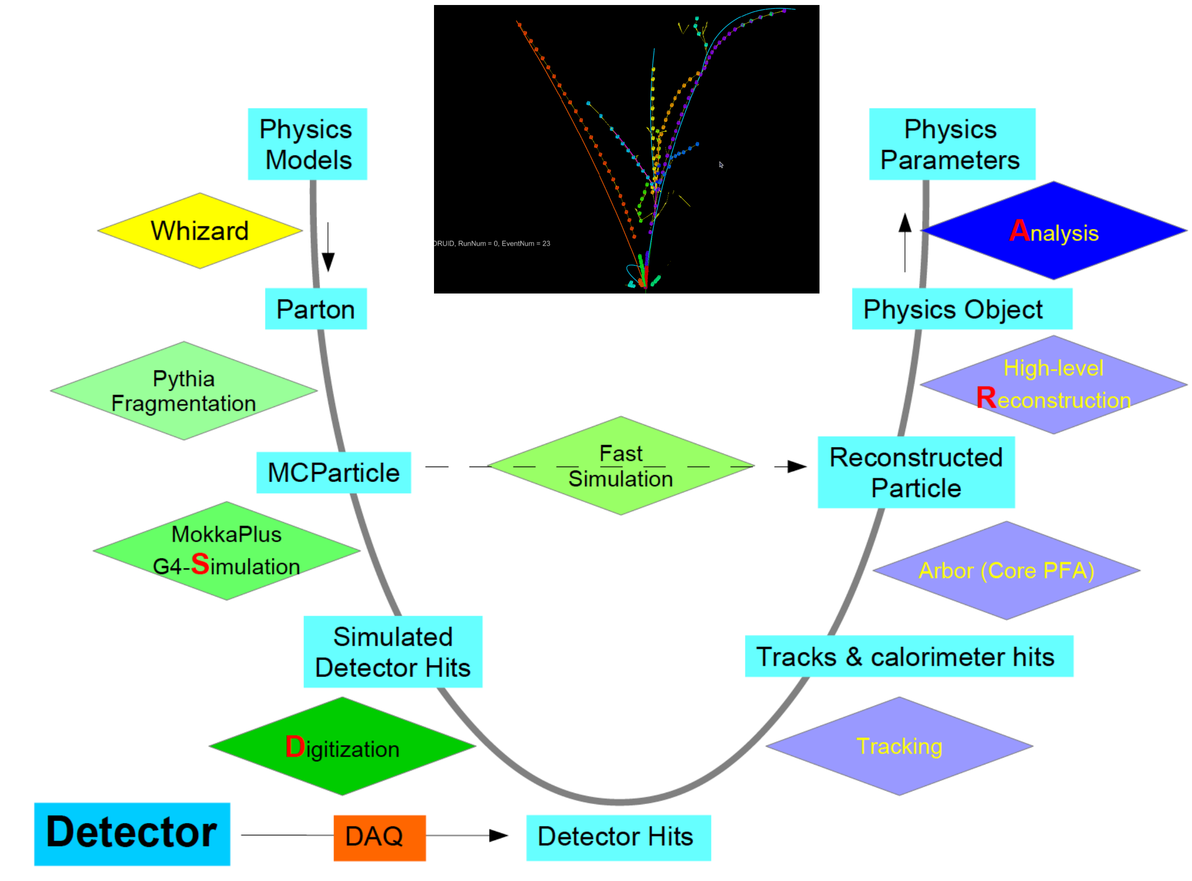
Performance requirements

- Detector Solenoid B-Field ~ 2 T, to be in cope with the High Luminosity Z pole operation
- A clear separation of the final state particles: Identification of Physics Objects, and Improving the E/P resolution for composited objects, especially jets
  - Leptons, especially these inside jets
  - Composited objects:
    - Two/three body objects: Pi-0, K-short, Lambda, Phi, Tau, D meson...
    - More bodies: Tau & Jets
  - PFA: pursuing 1-1 correspondence...
- BMR (Boson Mass Resolution): mass resolution of Hadronic decayed Higgs/Z/W
  - < 4% for Higgs measurements
  - Much demanding for Flavor Physics/New Physics Hunting
- Pid: Pion & Kaon separation > 3 σ (eff*purity of Kaon at Key processes > 60%...)
- Jet: Flavor Tagging & Charge Reconstruction, Color Singlet identification...
- Intrinsic accuracies: momentum, energy, VTX positions...

Detector concepts & Software



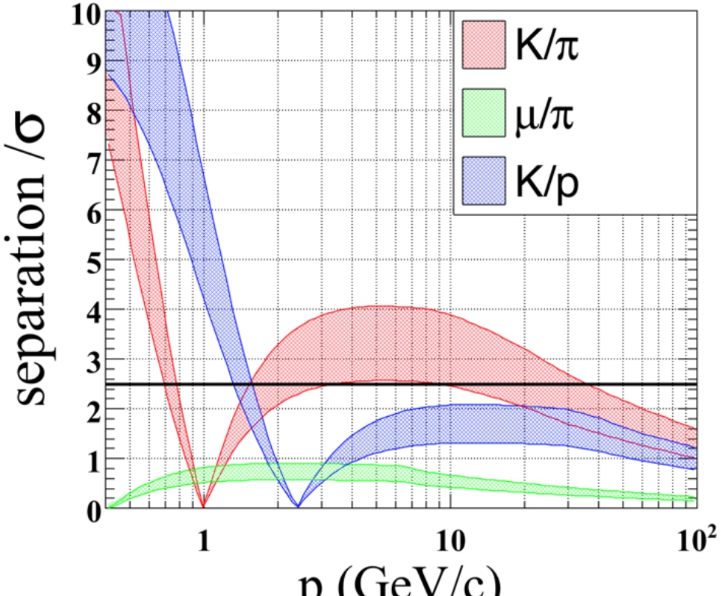


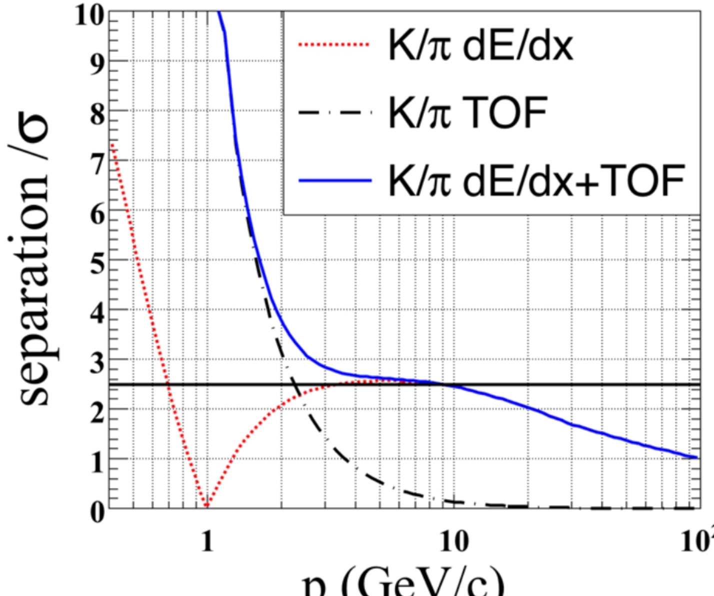


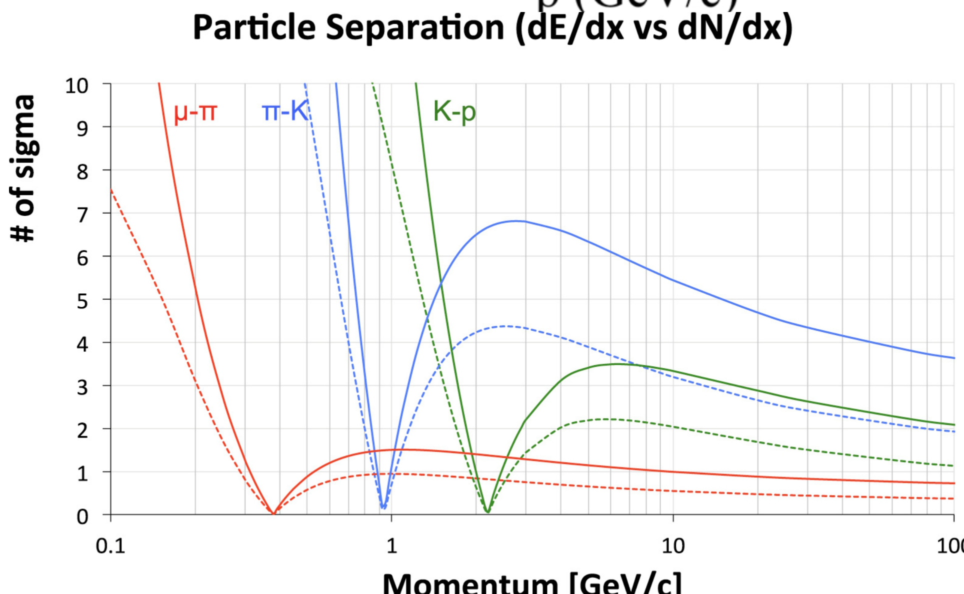
Multiple detector concepts, supported with intensive critical tech. R&D, and prototype test

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

Kaon identification: dE/dx or dN/dx + ToF



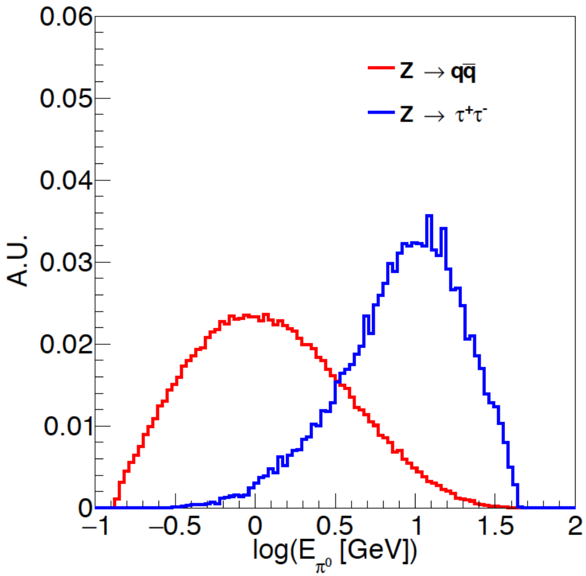


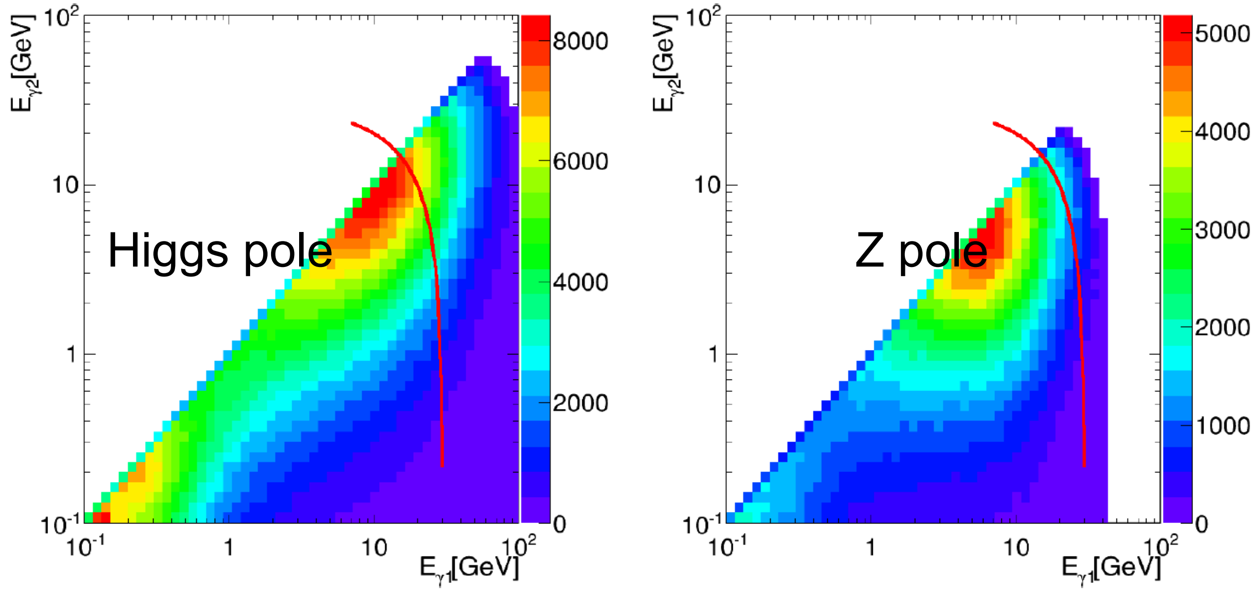


	factor	1.	1.2	1.5	2.
dE/dx	ε_K (%)	95.95	94.09	91.08	86.86
	$purity_K$ (%)	81.76	78.17	71.64	60.92
dE/dx & TOF	ε_K (%)	98.42	97.41	95.48	92.14
	$purity_K$ (%)	97.88	96.31	93.18	87.19

CEPC-DocDB-id: 172
https://arxiv.org/abs/1803.05134
Eur. Phys. J. C (2018) 78:464

π^0 reconstruction

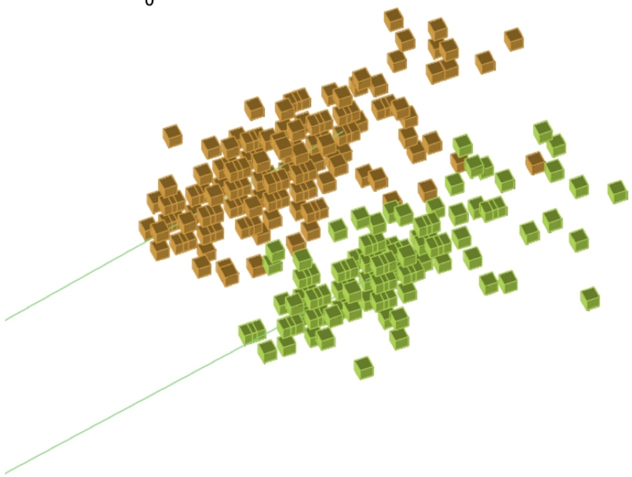




(a) (b)

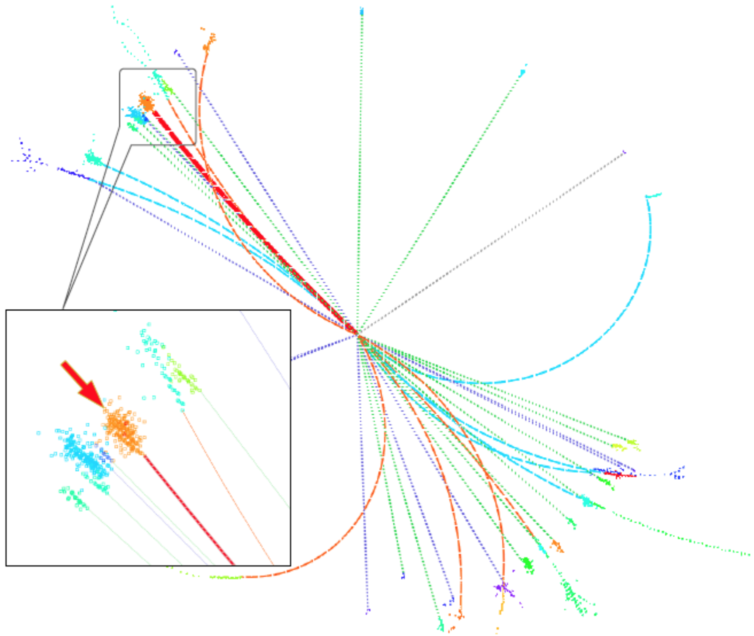
Fig. 14: The generated π^0 distribution as a function of the energies of di-photons from $\pi^0 \to \gamma\gamma$ in inclusive Higgs (a) and $Z \to \tau\tau$ samples (b). $E_{\gamma 1}$ is the energy of the leading photon. $E_{\gamma 2}$ is the energy of the sub-leading photon. The red line is the function of $E_{\gamma 1} + E_{\gamma 2} = 30$ GeV.

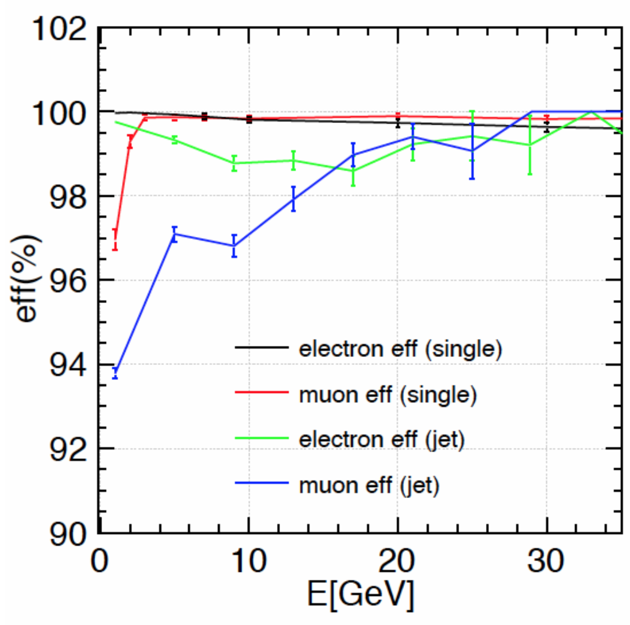
10 GeV π_0

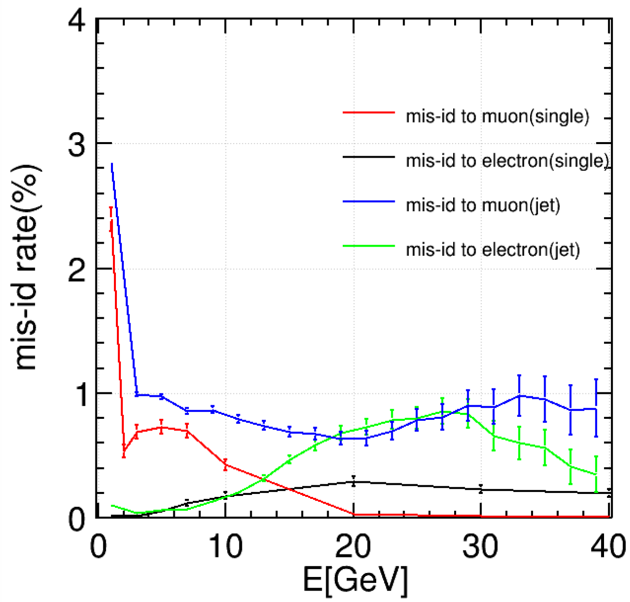


- photon threshold ~ o(100) MeV
- Can separate photons from Pi-0 decay, up to 30 GeV

Lepton: isolated & inside jet



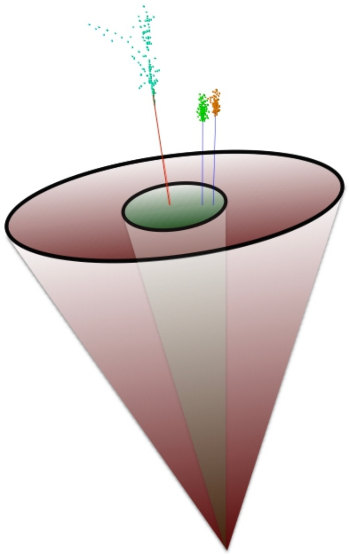


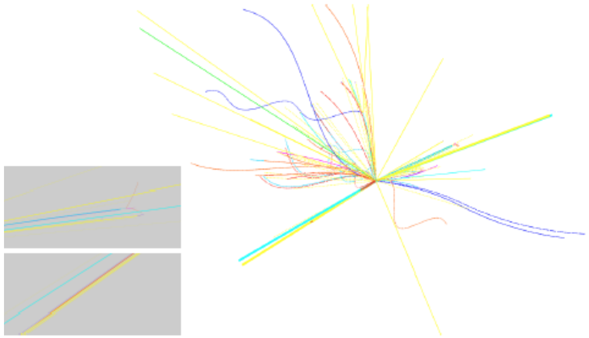


Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded – Due to the limited clustering performance (splitting & containimation).

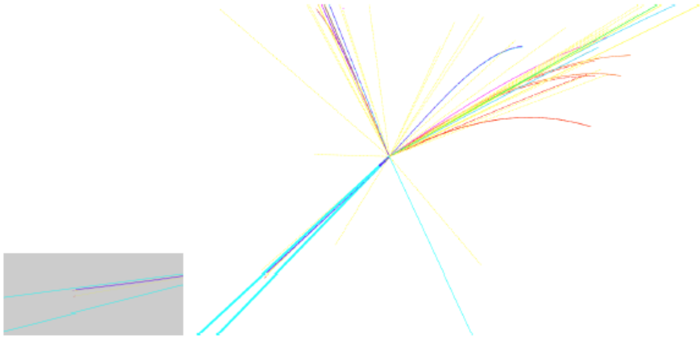
At the same working point, the efficiency can be reduced by up to 3%; while mis-id rate increases up to 1%. Marginal Impact on Flavor Physics measurements as Bc->tauv.

Taus: isolated or inside jets

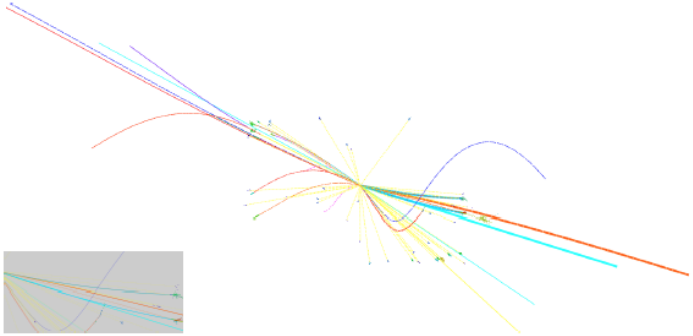




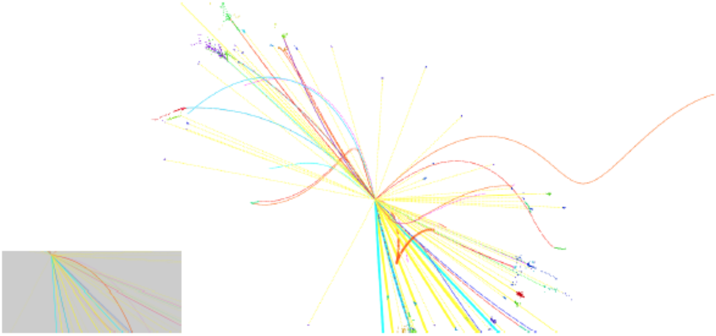
(a) $Z \to qq, H \to \tau\tau$ with two hadronic decay.



(b) $WW \to \tau\nu qq$ with one leptonic decay.

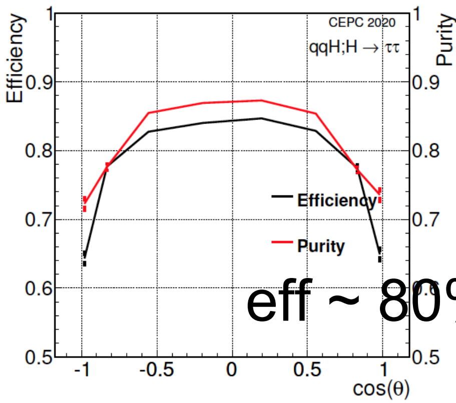


(c) $Z \to b\overline{b}, B_c \to \tau\nu$ with one hadronic dacay.

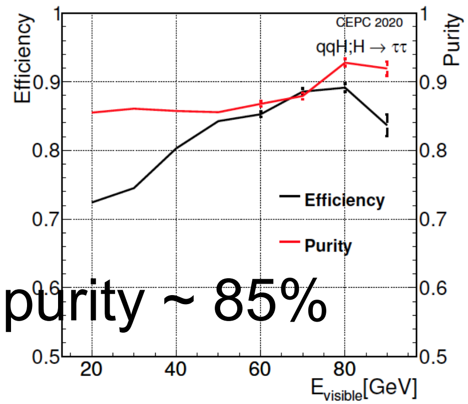


(d) $Z \to b\overline{b}, B_s \to \tau\tau$ with two hadronic decay mixed together.

Taus: isolated or inside jets

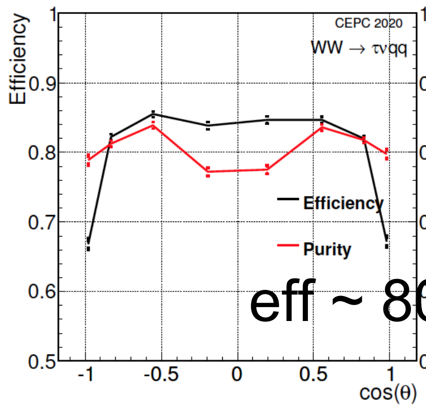


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

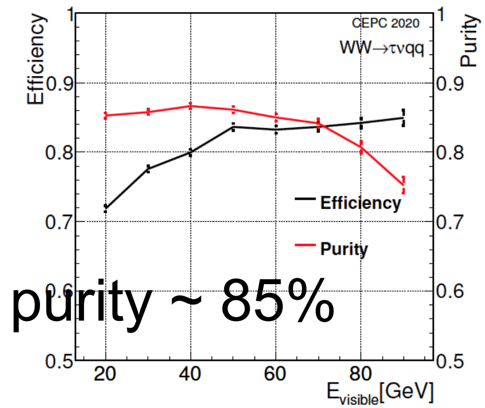


(b) Efficiency and purity performance along with visible energy. The performance above 80 GeV falls as a result of stringent cone selection.

eff ~ 80%, purity ~ 85%

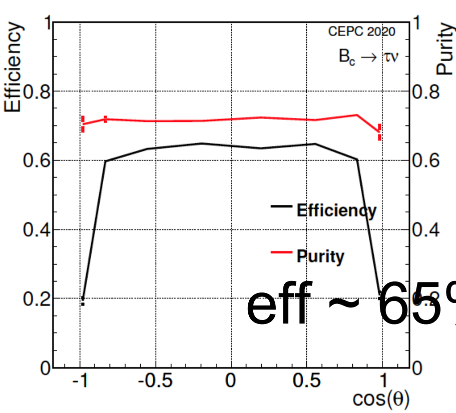


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

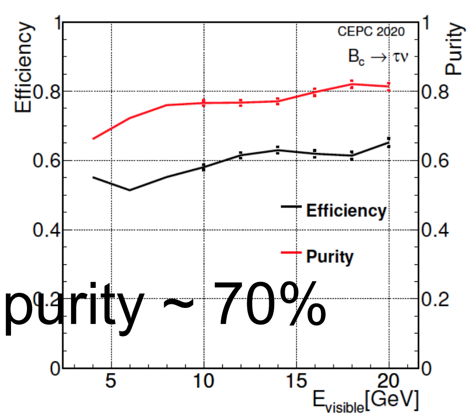


(b) Efficiency and purity performance along with visible energy

eff ~ 80%, purity ~ 85%

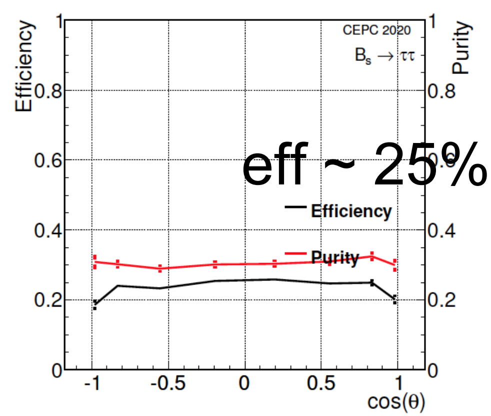


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

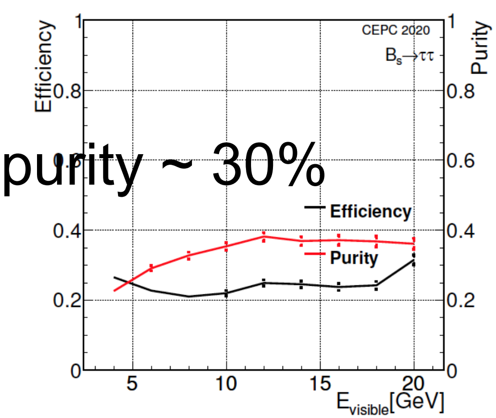


(b) Efficiency and purity performance along with visible energy

eff ~ 65%, purity ~ 70%



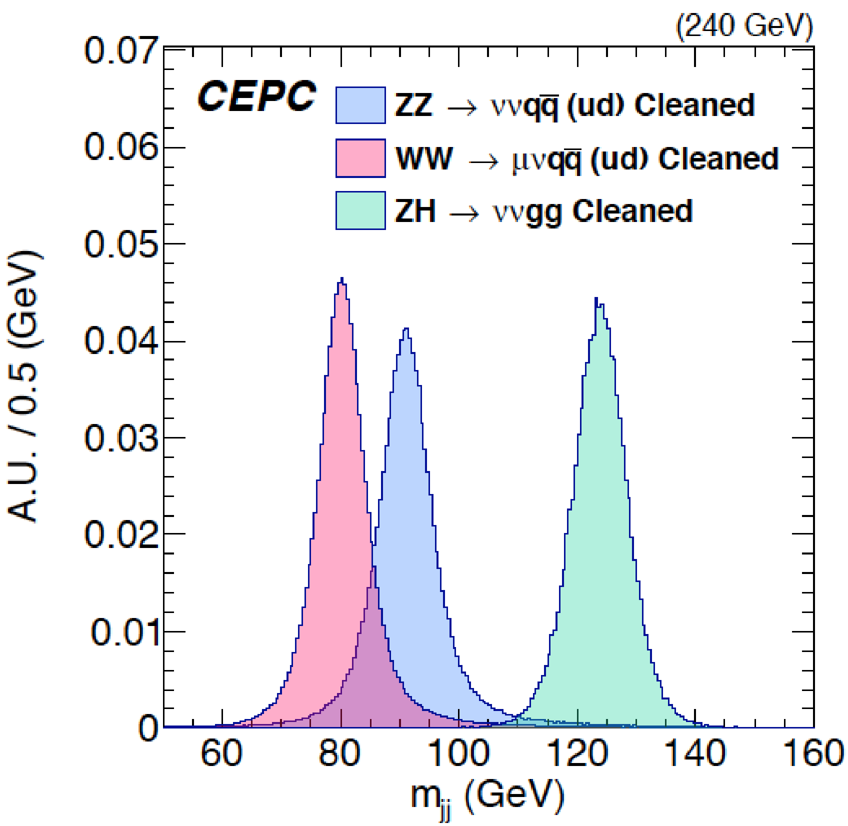
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

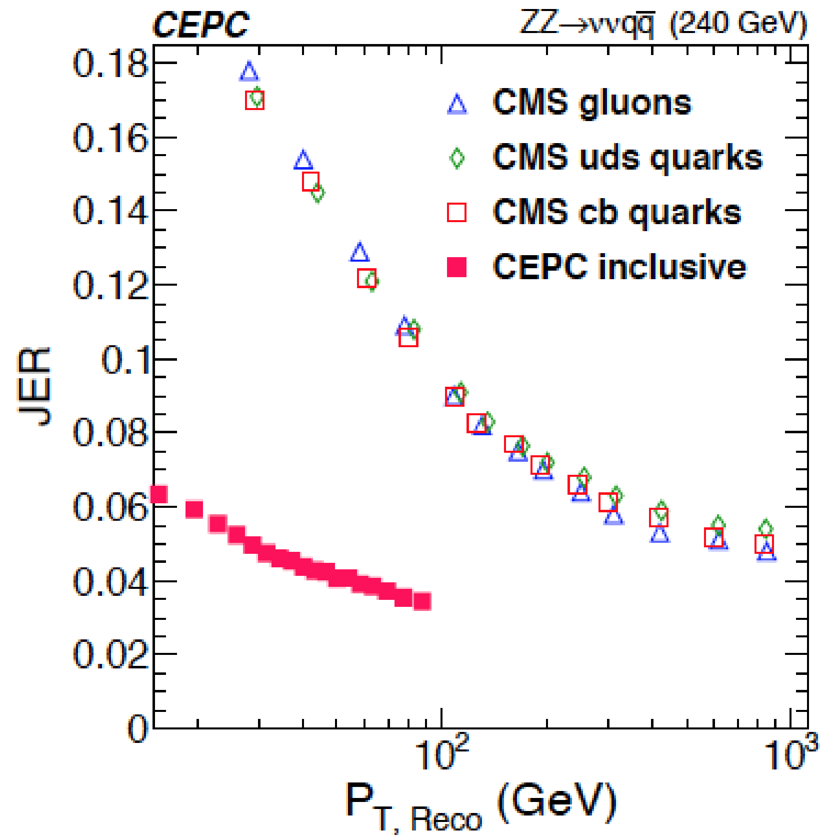


(b) Efficiency and purity performance along with visible energy

eff ~ 25%, purity ~ 30%

Hadronic system: BMR = 3.75%



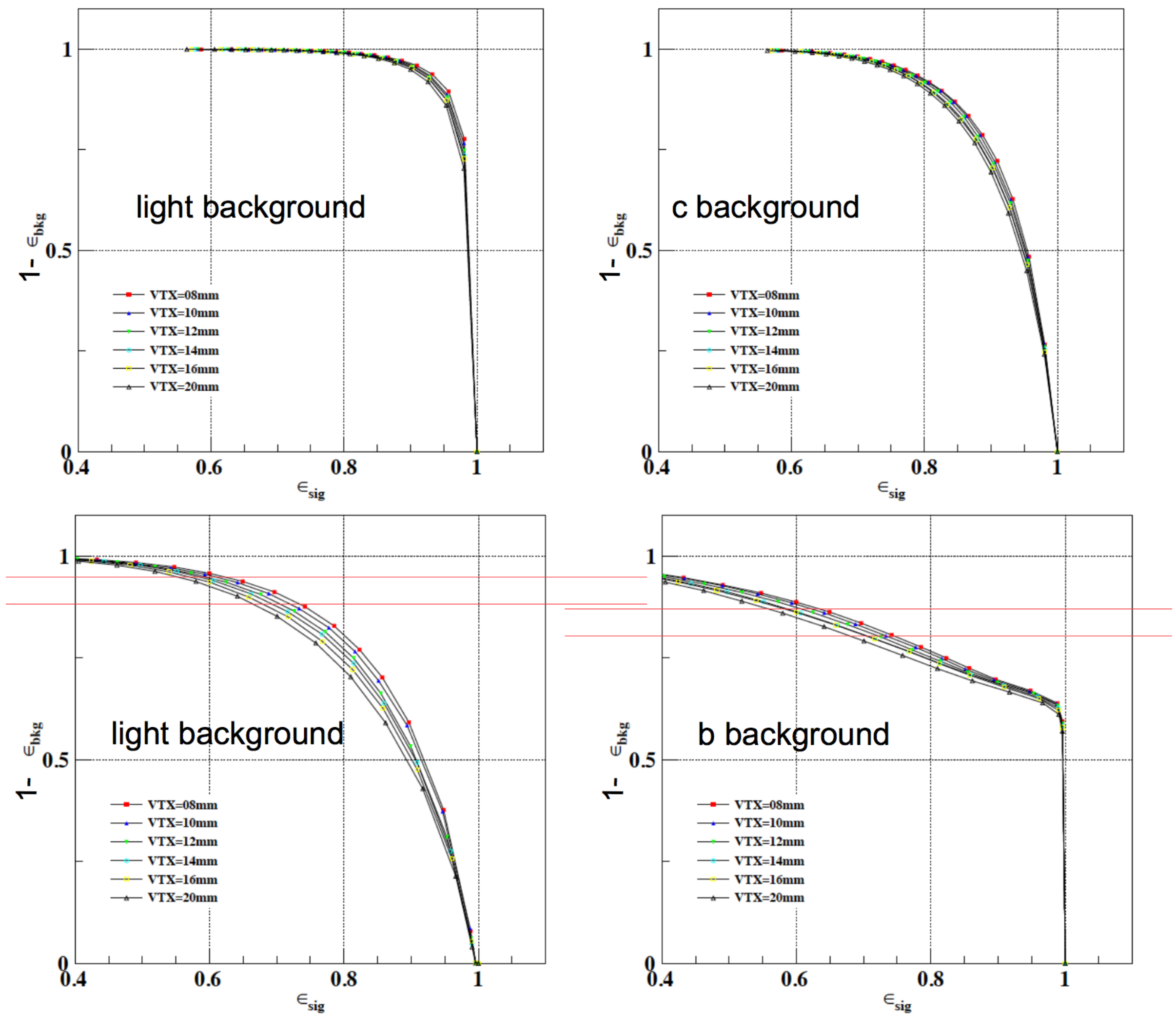


@ Hadronically decayed Higgs boson: not sensitive to different modes it decays into
BMR 3.6 – 3.8% for H->bb, cc, gg, WW*/ZZ*->4 jets

Jet Flavor Tagging

- Flavor Tagging (LCFIPlus), Typical Performance at Z pole sample:
  - *B-tagging:*
    eff/purity = 80%/90%
  - *C-tagging:*
    eff/purity = 60%/60%

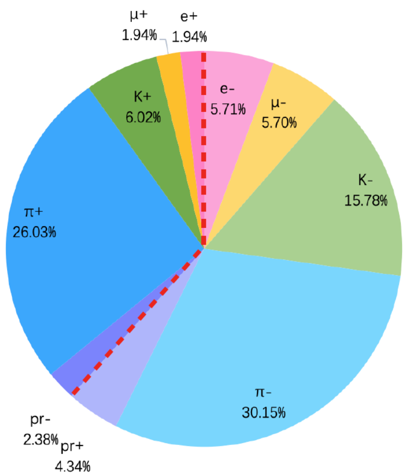
- Can be significantly improved via
  - Geometry optimization
    - Smaller inner radius
  - Better algorithm



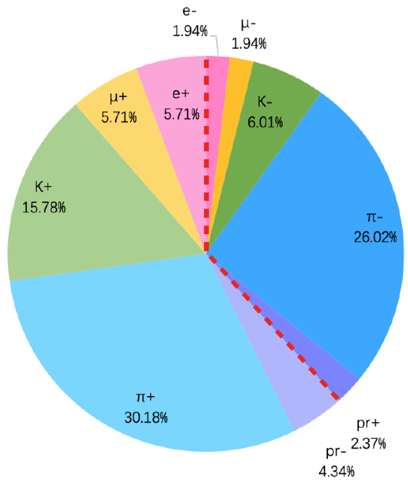
https://agenda.linearcollider.org/event/7645/contributions/40124/

Jet Charge reconstruction

$Z \to b\bar{b}$ **Percent of final charged leading particles of b jet and $\bar{b}$ jet**



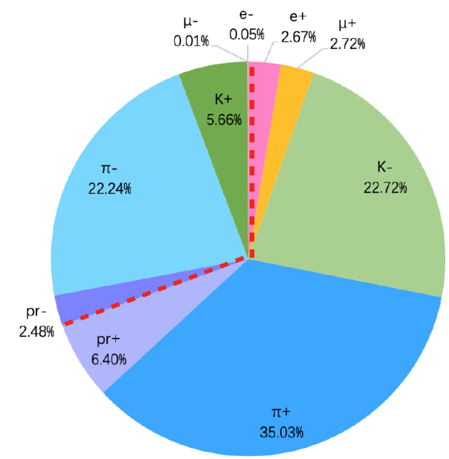
b jet



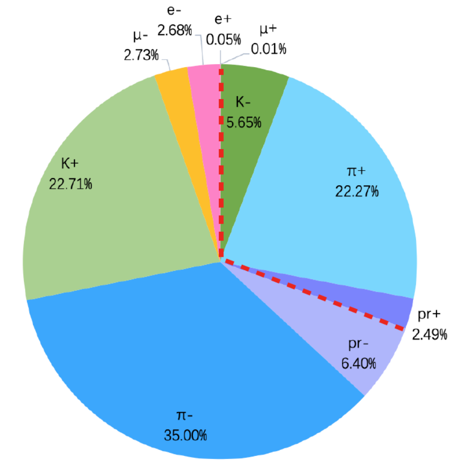
$\bar{b}$ jet

☞ *The distribution of each charged particle of two jets is asymmetry*

$Z \to c\bar{c}$ **Percent of final charged leading particles of c jet and $\bar{c}$ jet**



c jet



$\bar{c}$ jet

☞ *The distribution of each charged particle of two jets is asymmetry*

percent bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar	others	all
B^0bar	17.360%	17.350%	3.369%	0.022%	2.759%	0.688%	41.548%
B^-	17.350%	17.359%	3.364%	0.022%	2.765%	0.689%	41.550%
B_s^0bar	3.355%	3.362%	0.652%	0.004%	0.545%	0.144%	8.062%
B_c^-	0.022%	0.022%	0.004%	0.00003%	0.004%	0.001%	0.052%
Λ_b	2.762%	2.762%	0.543%	0.004%	0.451%	0.121%	6.644%
others	0.653%	0.655%	0.136%	0.001%	0.119%	0.579%	2.144%
all	41.503%	41.511%	8.068%	0.053%	6.641%	2.225%	100%

Effective tagging power:

A straight forward, leading particle based algorithm leads to effective tagging power of 10%/20% for b/c-jet
(... we understand how the jet charge information eventually incarnated into Leading final state particles...)

Can be significantly enhanced using Pt weighted, VTX charge, Kaon information, etc

Physics benchmarks

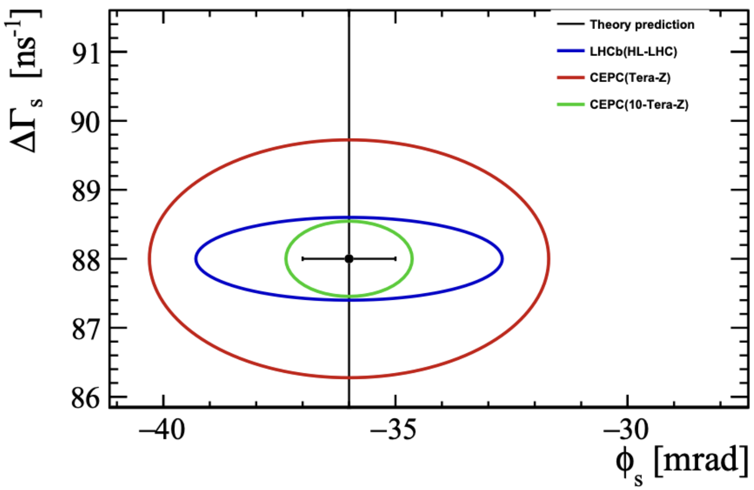
- CP measurement via Bs→Jpsi + Φ: detector acceptance, VTX, tracker momentum, Jet charge
  - Accuracy comparable to LHCb – strong motivation to go beyond Tera Z.
- Addressing Flavor Anomaly
  - Bs→Φvv: Pid, momentum and missing energy resolution
    - Percentage level accuracy anticipated
  - Bc→Tauv: Tau inside jet, missing energy
    - 1 order of magnitude better than current accuracy.
- CKM measurements
  - B0/Bs→2 pi0/eta; EM resolution, Pi0 reconstruction
    - 1 order of magnitude better than Belle II, or discovered for the first time, dependence on detector performance quantified.
    - Key input for alpha measurement -> need also Jet charge measurement
- Multiple studies on LFV, LFU, Tau related. Exotic...
- ...

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

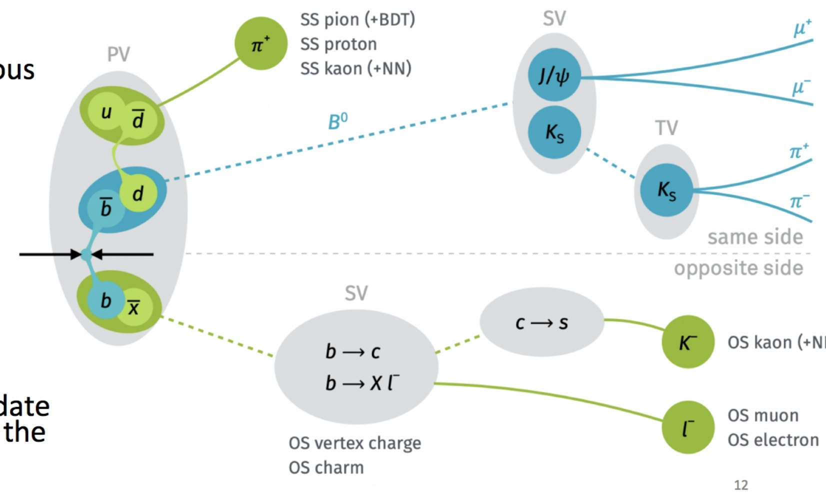
Contributions from physics beyond the SM could lead to much larger values of ϕ_s.

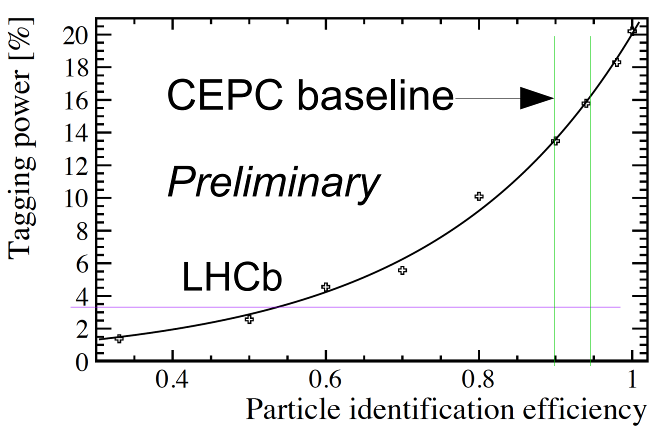


Flavour tagging power

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

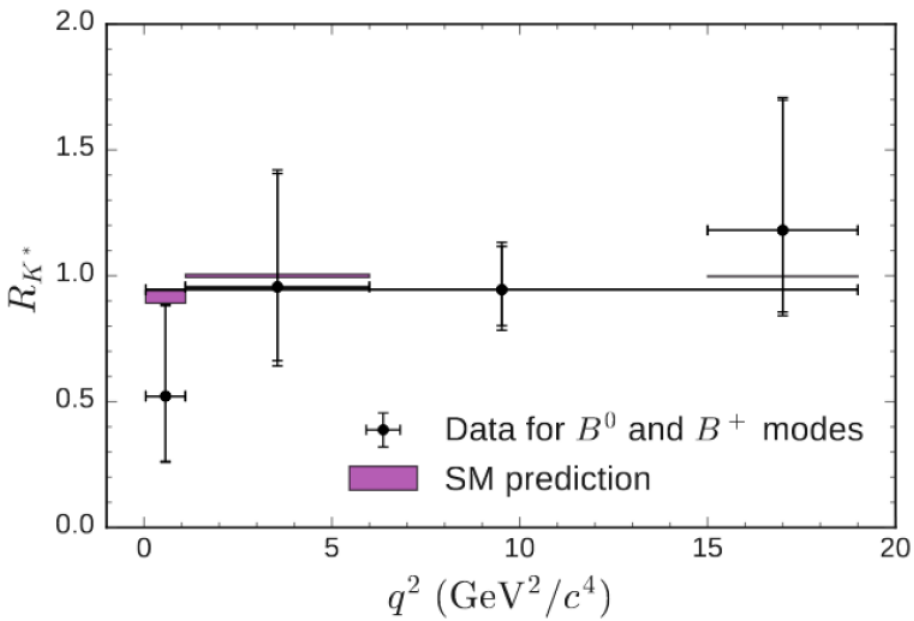
- For Bs:
  - OS lepton
  - OS kaon
  - SS kaon
- A naïve algorithm developed to validate the robustness of the estimation

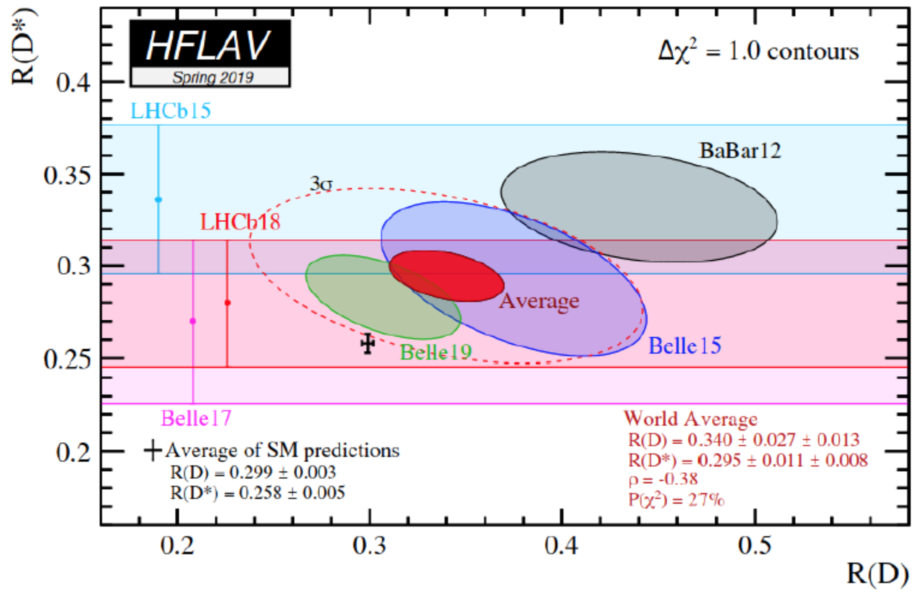




- With a decent Pid, the effective tagging power on jet Charge can be 5-6 times better than LHCb, which can compensate the statistic difference between LHCb & CEPC.
- Strong motivation to higher Luminosity at Z pole

B Anomalies Indicating LFUV

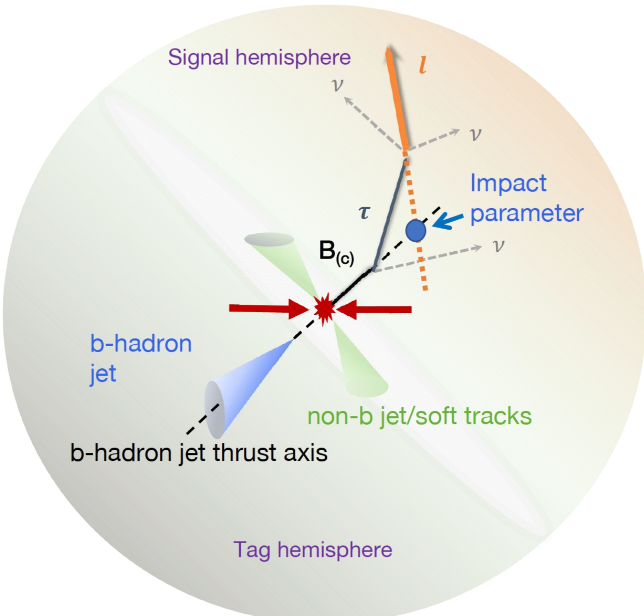


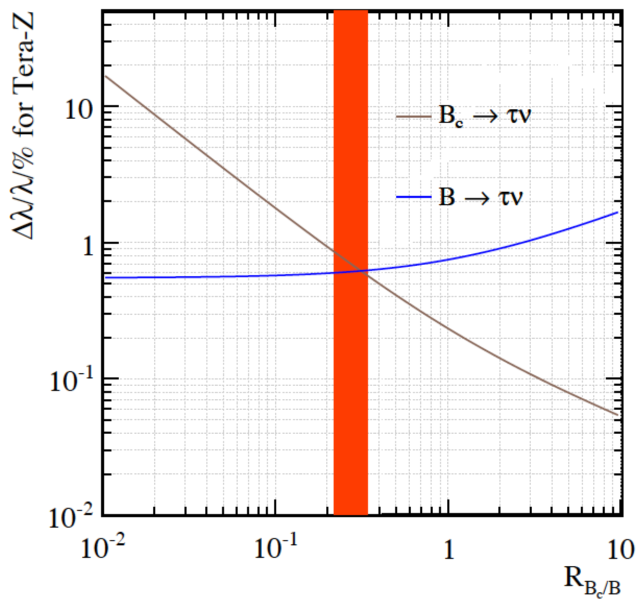


	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^\pm$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^\pm$ combined.
R_{D^*}	0.295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

Bc→Tauv





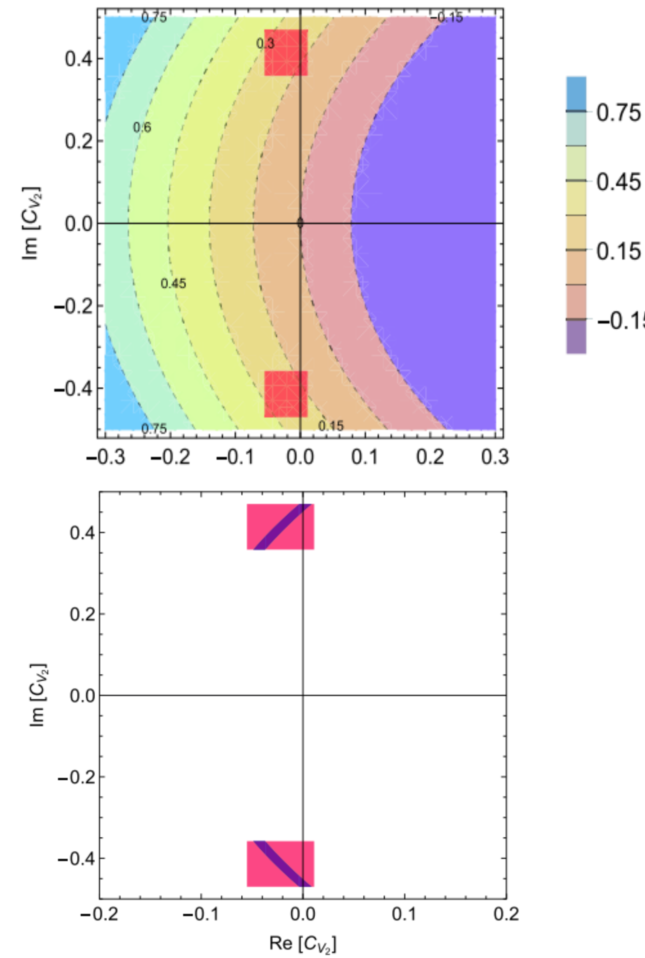


Fig. 10. (color online) Constraints on the real and imaginary parts of C_{V_2}. The red shaded area corresponds to the current constraints using available data on $b \to c\tau\nu$ decays. If the central values in Eq. (9) remain while the uncertainty in $\Gamma(B_c^+ \to \tau^+\nu_\tau)$ is reduced to 1%, the allowed region for C_{V_2} shrinks to the dark-blue regions.

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Analysis of $B_c \to \tau\nu_\tau$ at CEPC*

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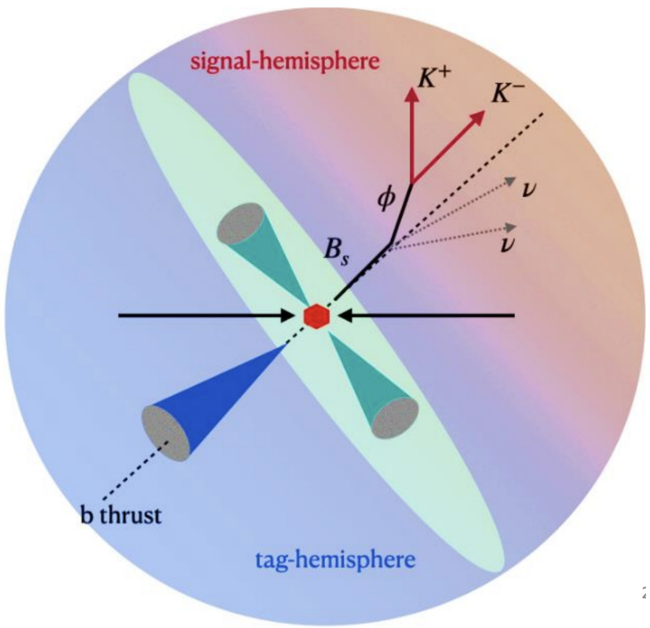
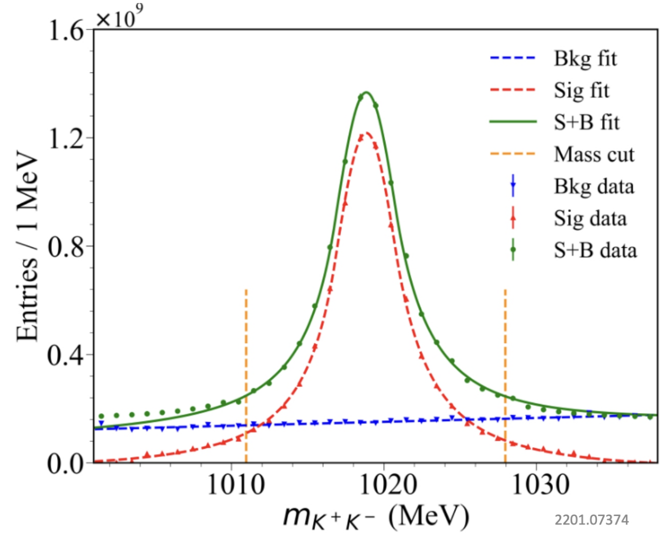
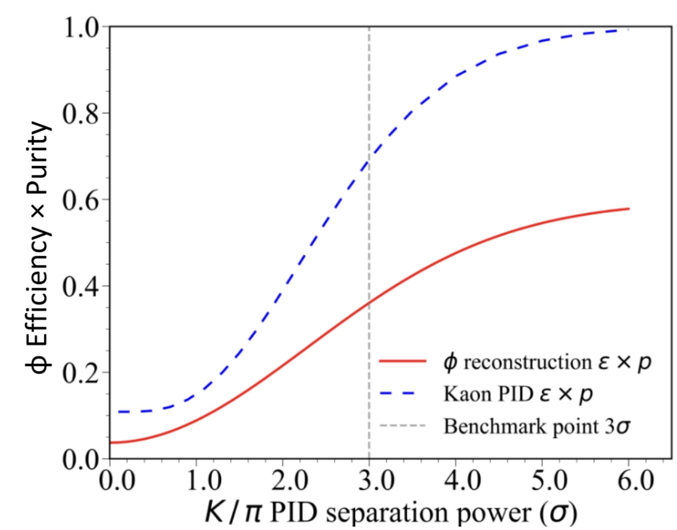
Abstract: Precise determination of the $B_c \to \tau\nu_\tau$ branching ratio provides an advantageous opportunity for understanding the electroweak structure of the Standard Model, measuring the CKM matrix element $|V_{cb}|$, and probing new physics models. In this paper, we discuss the potential of measuring the process $B_c \to \tau\nu_\tau$ with τ decaying leptonically at the proposed Circular Electron Positron Collider (CEPC). We conclude that during the Z pole operation, the channel signal can achieve five-σ significance with $\sim 10^9$ Z decays, and the signal strength accuracies for $B_c \to \tau\nu_\tau$ can reach around 1% level at the nominal CEPC Z pole statistics of one trillion Z decays, assuming the total $B_c \to \tau\nu_\tau$ yield is 3.6×10^6. Our theoretical analysis indicates the accuracy could provide a strong constraint on the general effective Hamiltonian for the $b \to c\tau\nu$ transition. If the total B_c yield can be determined to $O(1\%)$ level of accuracy in the future, these results also imply $|V_{cb}|$ could be measured up to $O(1\%)$ level of accuracy.

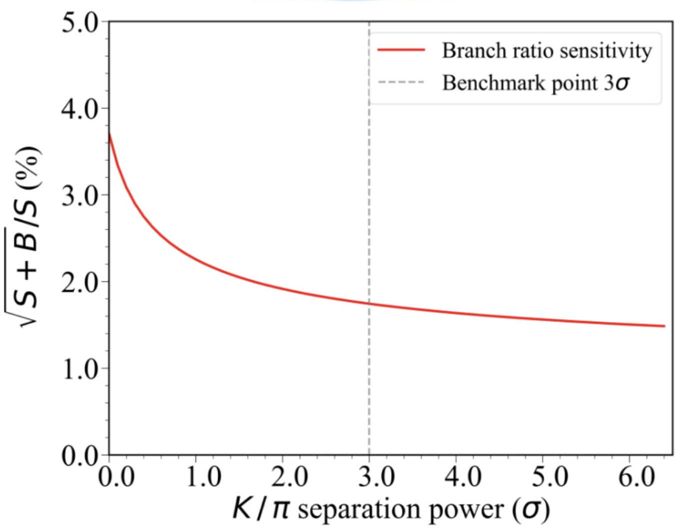
Taifan, etc, Published by CPC.
Collaborate with Wei Wang, et.al.

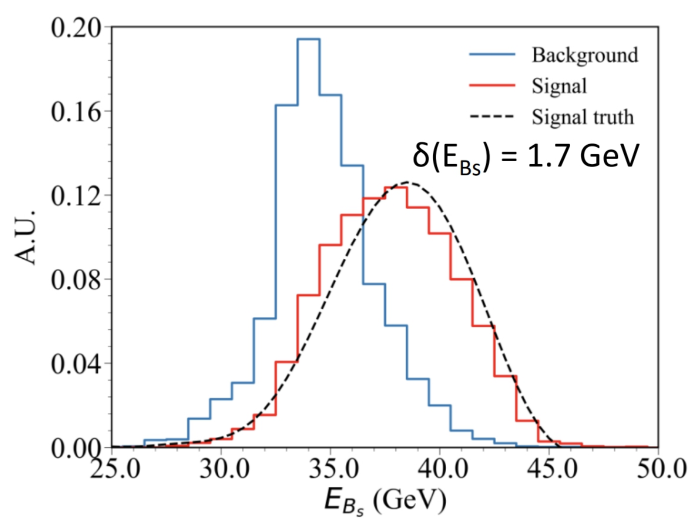
Bs→Phi νν

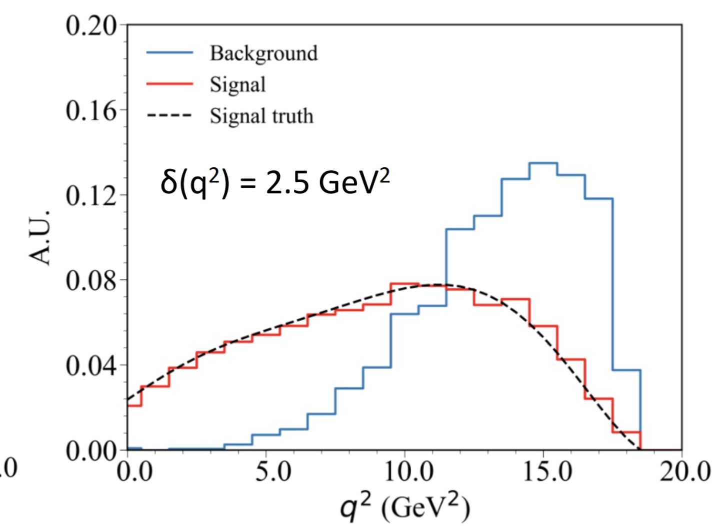












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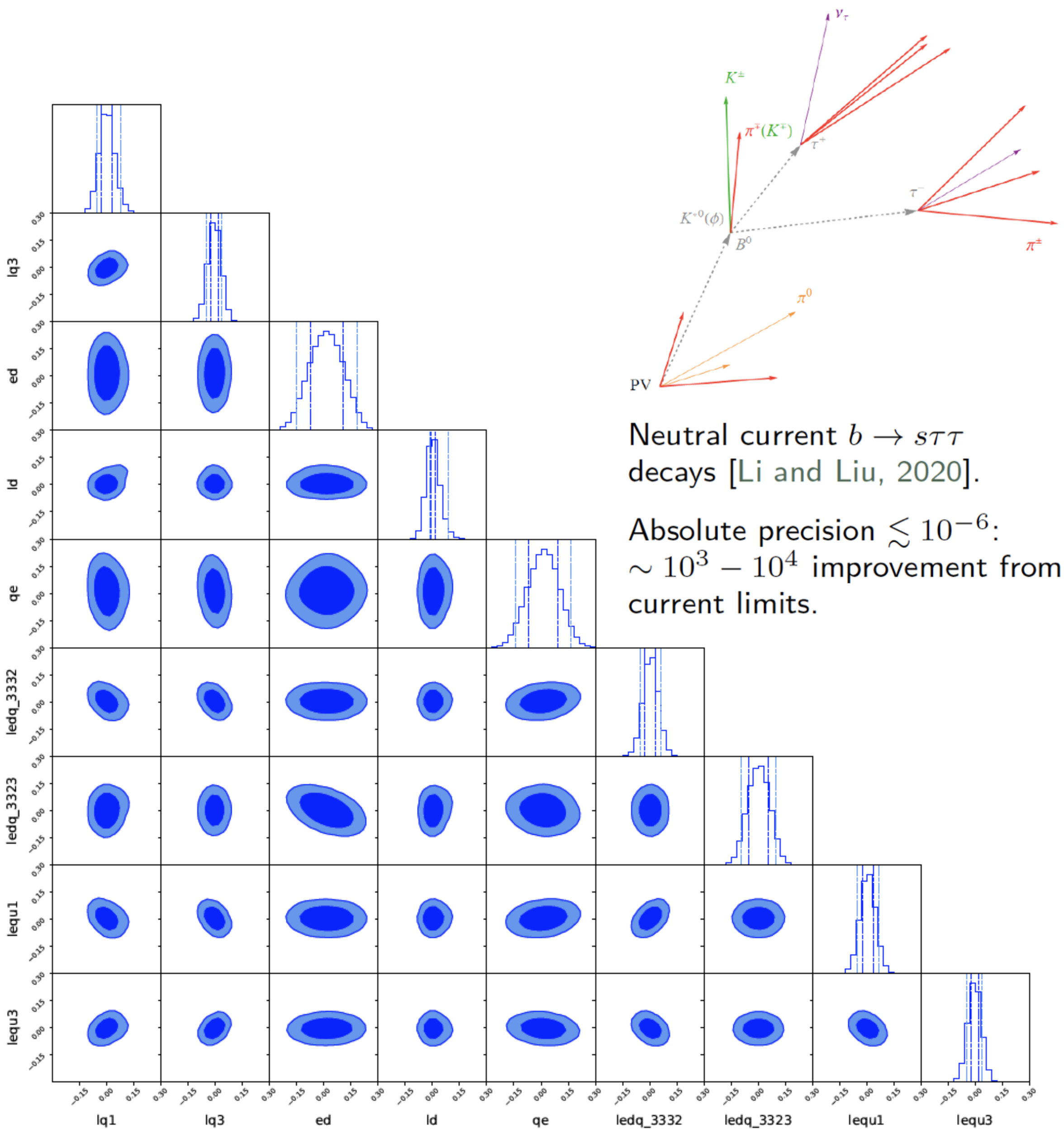
Current Progress in LFU Tests (II)



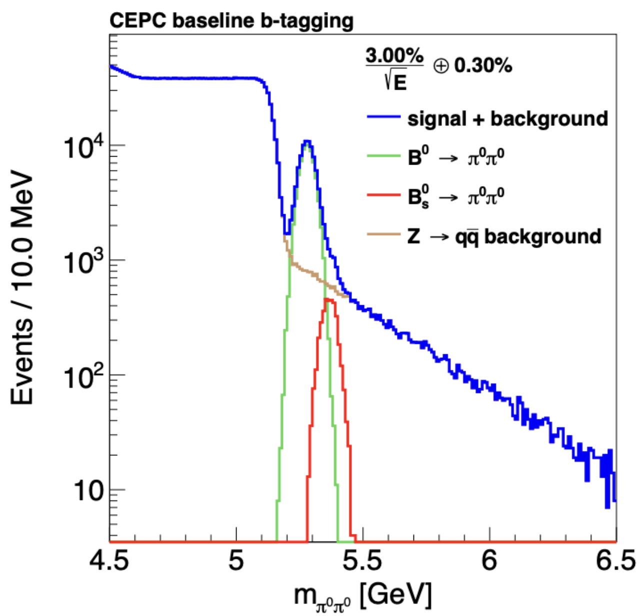
Neutral current $b \to s\tau\tau$ decays [Li and Liu, 2020].

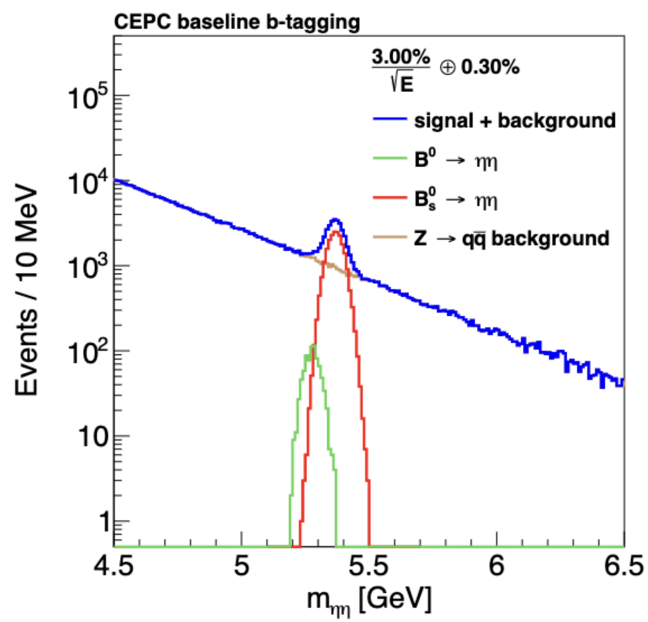
Absolute precision $\lesssim 10^{-6}$: $\sim 10^3 - 10^4$ improvement from current limits.

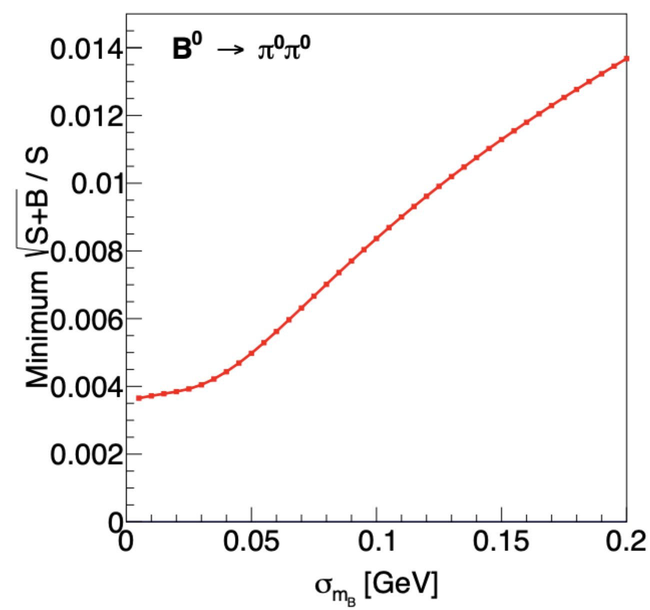
Preliminary: 9 effective channels:($R_{J/\psi}$, R_{D_s}, $R_{D_s^*}$, R_{Λ_c}, $B_c \to \tau\nu$, $B \to K\nu\bar{\nu}$, $B_s \to \phi\nu\bar{\nu}$, $B^0 \to K\tau\tau$, $B^+ \to K^+\tau\tau$, $B_s \to \tau\tau$...)

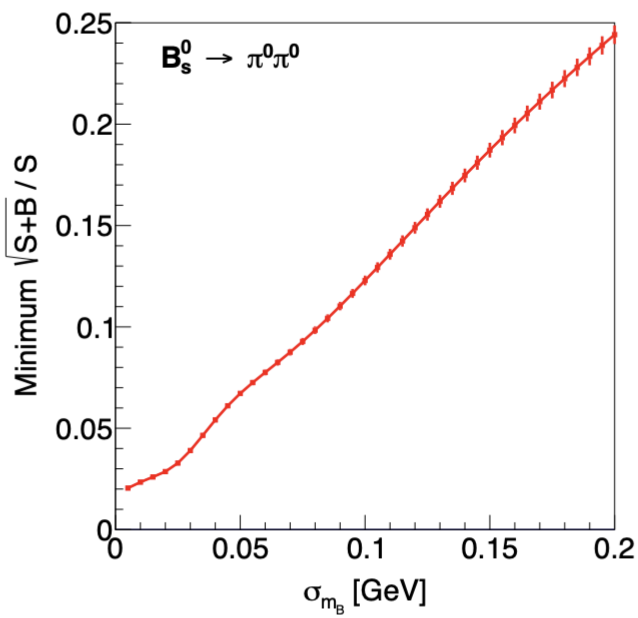
Dim-6 SMEFT basis at NP scale Λ=3 TeV.

B0/Bs→2 π^0/η





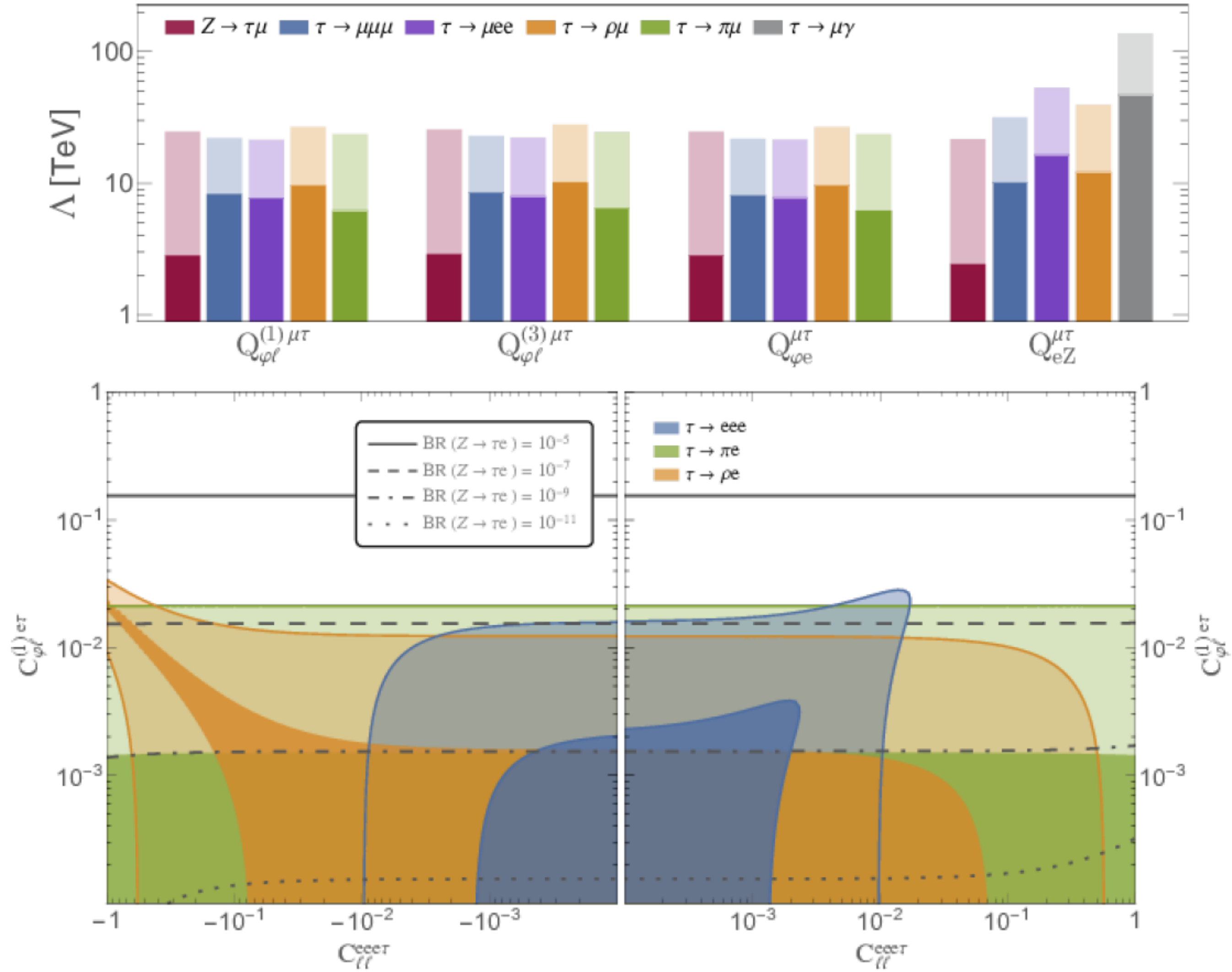




ECAL energy resolution	Channel	σ_{m_B} (MeV)	Signal	$q\bar{q}$ background	Background with false $\pi^0(\eta)$	$\sqrt{S+B}/S$ (%)
$\frac{3\%}{\sqrt{E}} \oplus 0.3\%$	$B^0 \to \pi^0\pi^0$	30.25	75859	15767	7.52%	0.40 ± 0.01
	$B_s^0 \to \pi^0\pi^0$	30.21	2545	5145	14.73%	4.03 ± 0.55
	$B^0 \to \eta\eta$	33.30	693	11034	52.86%	17 ± 2
	$B_s^0 \to \eta\eta$	33.26	19208	10586	65.25%	0.90 ± 0.05
$\frac{17\%}{\sqrt{E}} \oplus 1\%$	$B^0 \to \pi^0\pi^0$	166	57746	381331	4.04%	1.15 ± 0.03
	$B_s^0 \to \pi^0\pi^0$	165	2243	142716	5.74%	19.3 ± 0.6
	$B^0 \to \eta\eta$	170	324	68243	88.27%	85 ± 6
	$B_s^0 \to \eta\eta$	174	8300	49248	86.30%	2.90 ± 0.20

- Combining other relevant measurements at CEPC, the alpha angle can be determined to ~ 0.5 degree (Preliminary)

Lepton Flavor Violation (II)



[Calibbi et al., 2021]

Summary

- CEPC/Tera-Z: significant potential & comparative advantages on Flavor Physics

- Extremely rich physics program & extremely demanding detector requirements.
  - Separation power! Finding objects inside jets
  - Intrinsic sub detector resolutions...
  - Jets: BMR, Flavor, Charge...

- Precisions estimated at multiple physics benchmarks, many boost the current/estimated precisions by 1 order of magnitude

- A lot more to explore

Back up

Summary

- With intensive & continuous studies, flavor physics is much better understood now... well aligned with IAC recommendations.
- Good understanding on detector requirement & performance via Full simulation studies.
- Precisions estimated for ~ o(10) physics benchmarks, many boost the current/estimated precisions by 1 order of magnitude.
- First to explore the flavor physics measurement via Hadronic final states (B0/Bs->2 pi0, Bs->J/psi+Phi) at future Higgs/Z factories
- Talent Young people emerges during those activities
- A lot more to explore.

- However, the funding support is not ideal & need to be addressed

Baseline Detector-Reconstruction Performance

- Acceptance: |cos(θ)| < 099
- Tracks:
  - Pt threshold, ~ 100 MeV
  - δp/p ~ o(0.1%)
- Photons:
  - Energy threshold, ~ 100 MeV
  - δE/E: 3 – 15%/sqrt(E)
- Pi-Kaon separation requirement: 3-sigma
- Pi-0: rec. eff*purity @ Z→qq > 60 or 80% @ 5GeV, corresponding to EM resolution of 15%/sqrt(E) or 3%/sqrt(E)
- B-tagging: eff*purity @ Z→qq: 70%
- C-tagging: eff*purity @ Z→qq: 40%
- Jet charge: eff*$(1-2\omega)^2$ ~ 15%/30% @ Z→bb/cc
- Leptons:
  - Isolated: eff*purity @ ZH ~ 99% (E > 5 GeV)
  - Inside jet: eff*purity @ Z→qq ~ 90% (energy > 3 GeV)
- 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%
- BMR: 3.7%
- Missing Energy: Consistent with BMR.

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 –

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]

– 5 –

Facts & interpretation...

Many Thanks to Lingfeng & HKUST

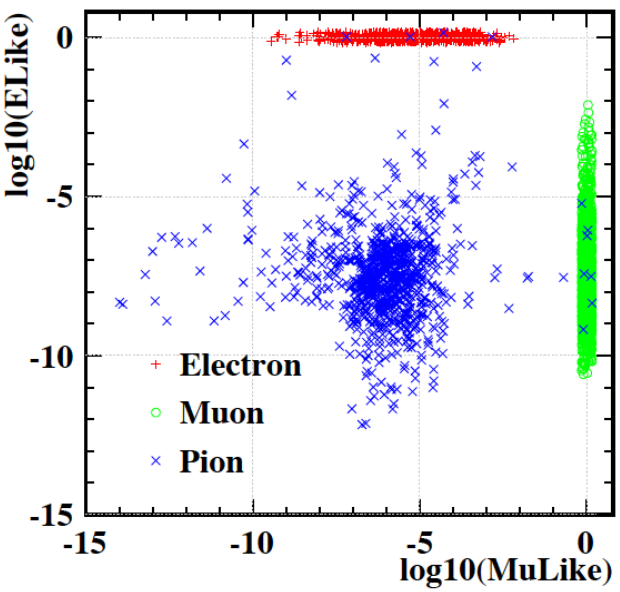
Collider requirements

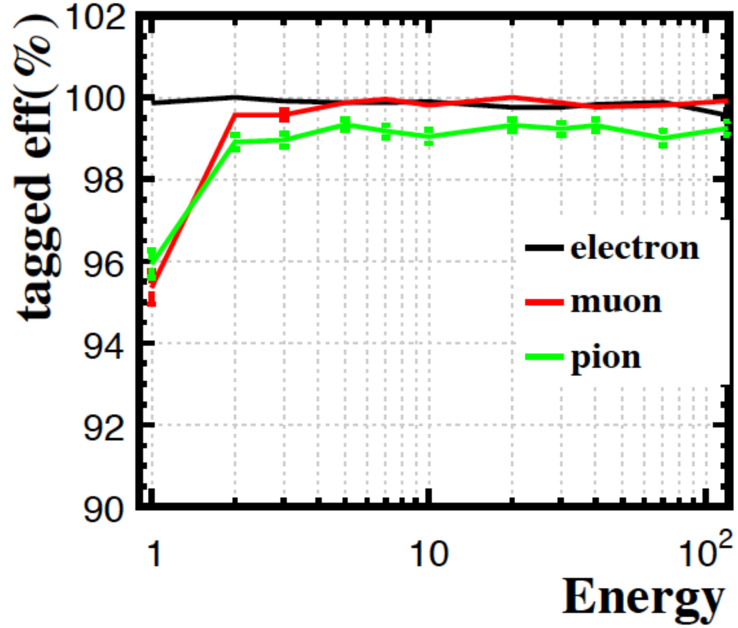
- Higher Yields
  - Goes beyond Tera-Z
  - Lower Solenoid B-Field (2-T) of the detector

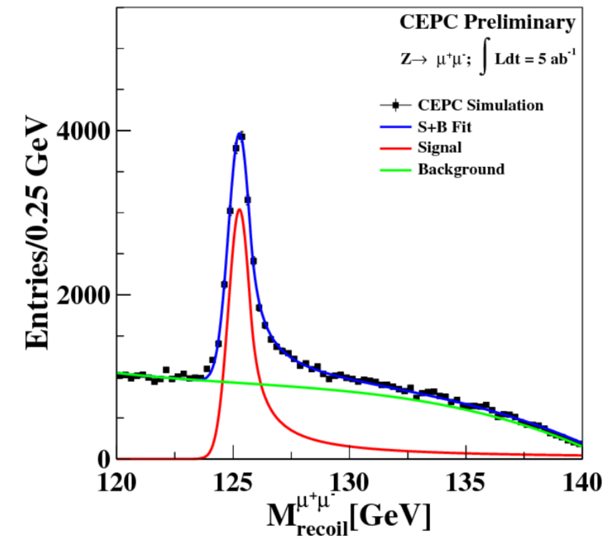
- Excellent stability & well understood collision environment
  - Luminosity monitoring ~ 1E-4
  - Beam energy spread ~ 1E-3
  - Beam energy calibration ~ sub MeV (towards EW measurements)
  - Beam polarization (??)

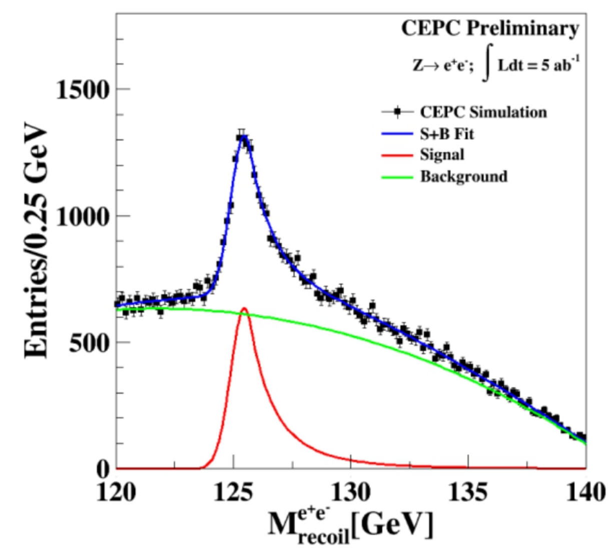
- Low Background
  - Beam induced background especially di-photon background
  - Off-time pile ups

Lepton: isolated





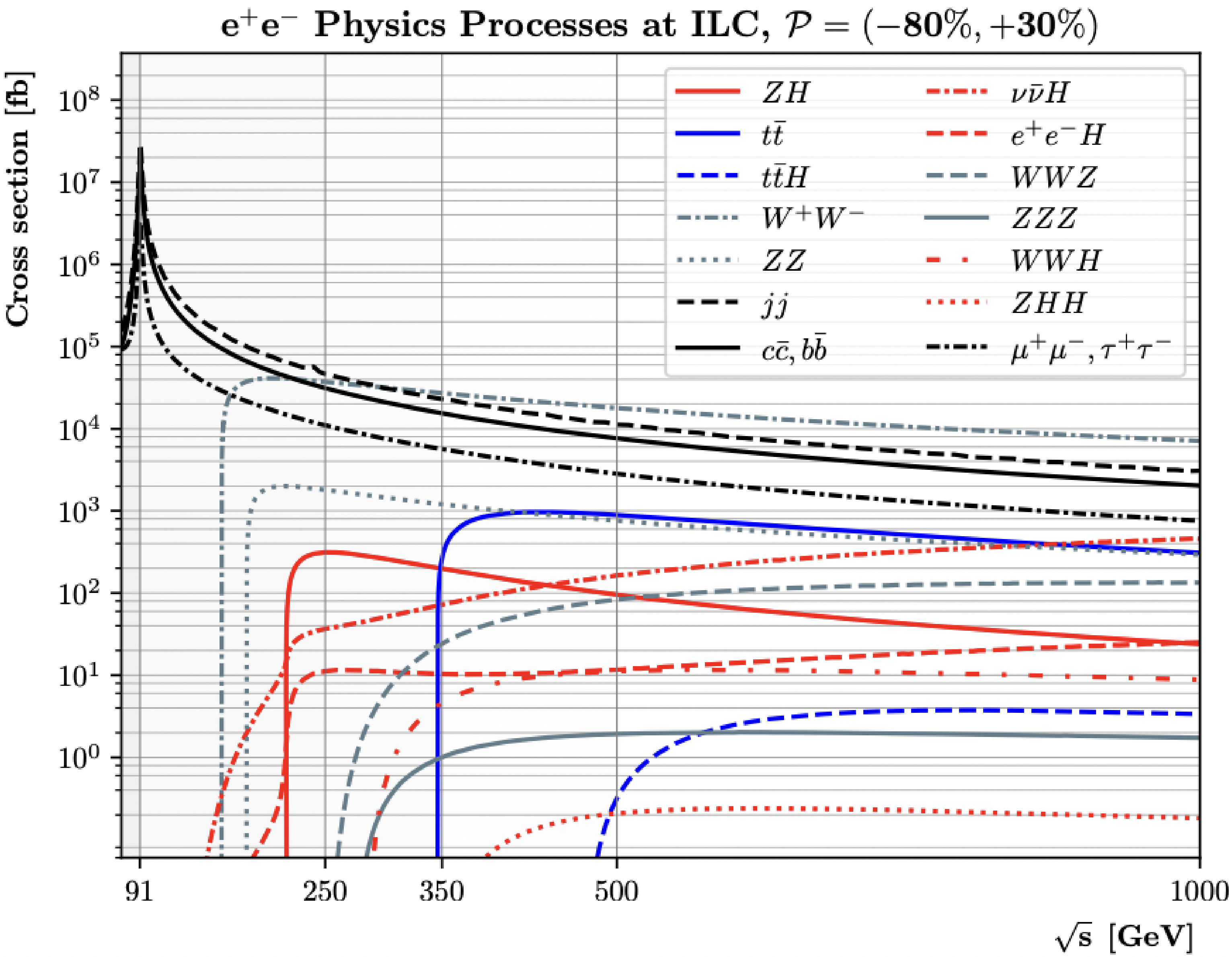




BDT method using 4 classes of 24 input discrimination variables.

Test performance at: Electron = E_likeness > 0.5 ;
Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5
CEPC-DocDB-id:148, Eur. Phys. J. C (2017) 77: 591



e+e− Physics Processes at ILC, 𝒫 = (−80%, +30%)
Cross section [fb]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
91
250
350
500
1000
√s [GeV]
ZH
tt̄
tt̄H
W+W−
ZZ
jj
cc̄, bb̄
νν̄H
e+e−H
WWZ
ZZZ
WWH
ZHH
μ+μ−, τ+τ−

Conclusion-2020

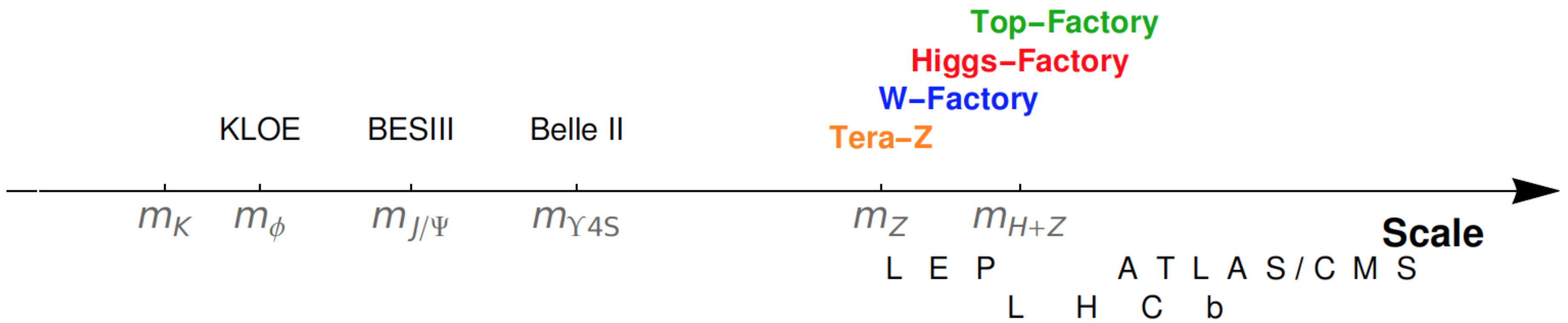
- The IAC recommendation is highly consistent with current CEPC simulation efforts: requirements, performance, analysis, and flavor physics
- Plan to address the IAC recommendation by the CEPC flavor physics white paper and corresponding documents. Performance – accuracy plots analogy to the BMR – Higgs accuracy plots shall be included.
- CEPC flavor simulation/analyses need to combine different methods:
  - Performance via Full Simulation and Analysis relies on Fast Simulation.
  - Proper modeling of the identification & reducible background contamination
- Significant progress on the flavor physics simulation
  - Good progress/coverage in Performance & object reconstruction
  - Multiple benchmark channels proposed, and half are covered by existing analysis

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}
Λ_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}
τ^+, τ^-	9×10^{10}	-	7.4×10^{7}	7.4×10^{10}



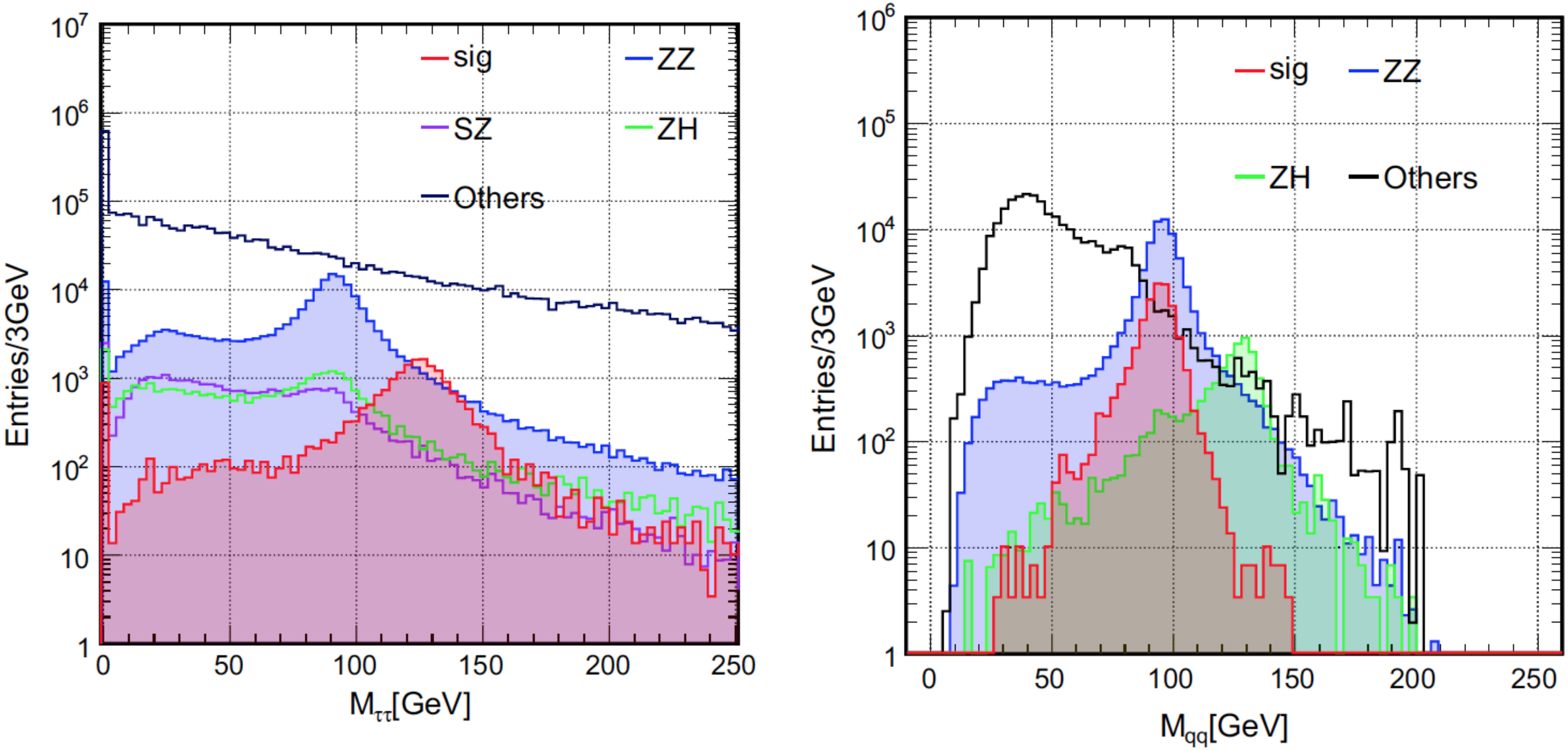
VS. B Factories

- Much higher b quark boost
- Abundant heavy b hadron

VS. Hadron Colliders

- Clean environment
- Direct missing momenta measurement

Signal strength measurement of qqH, $H\to\tau\tau$ @ 240 GeV



Invariant mass of di-tau: collinear approximation that assumes the neutrinos aligns with the direction of visible tau decay product

中國科學院高能物理研究所

IAC Report - Recommendations

Detector R&D and Physics Studies

***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).

Action Item: Continue to expand the team working on flavor physics and strong interactions

Promote engagement from university physicists

From IAC report 2019

Other recommended detector and physics studies:

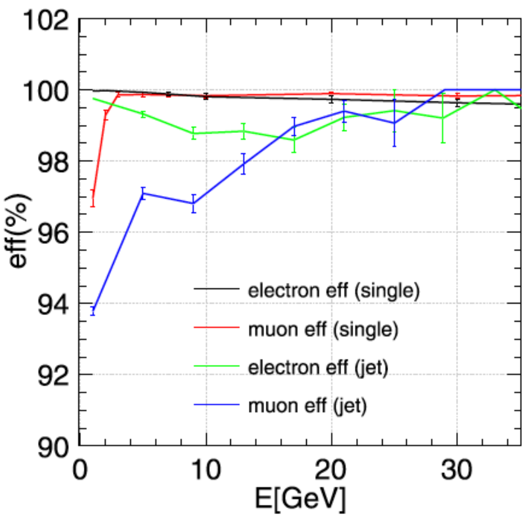
Recommendation 16:

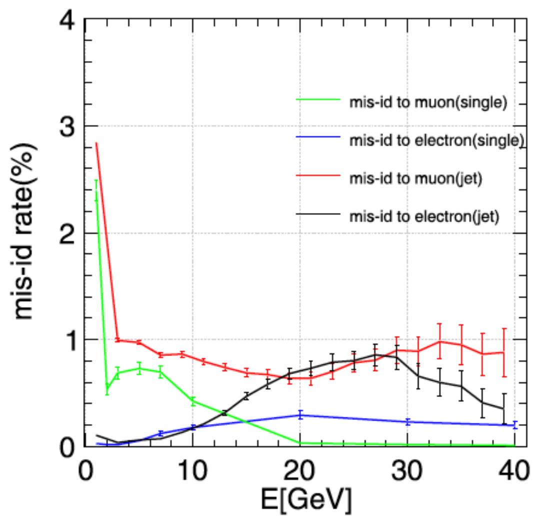
- *Perform detailed simulation studies to better understand the physics needs from the detector at the various CEPC energy stages; draw consequences about the corresponding detector performance requirements (e.g. photon resolution, jet resolution, added value of PID) and study how this influences the detector design.*
- *Study the physics case for performing flavor physics including the tau lepton at the Z-peak. Draw conclusions on a possible impact on the detector design.*
- *Given that time-of-flight detectors with a time resolution in the 30-50 ps are becoming available, study their potential added value for a CEPC detector by assessing a few key physics benchmarks.*
- *Assess the added value of dE/dx capabilities in the tracker.*
- *Assess the added value of the muon detector system. As a result, define the number of muon detection layers to include, together with their required performance.*

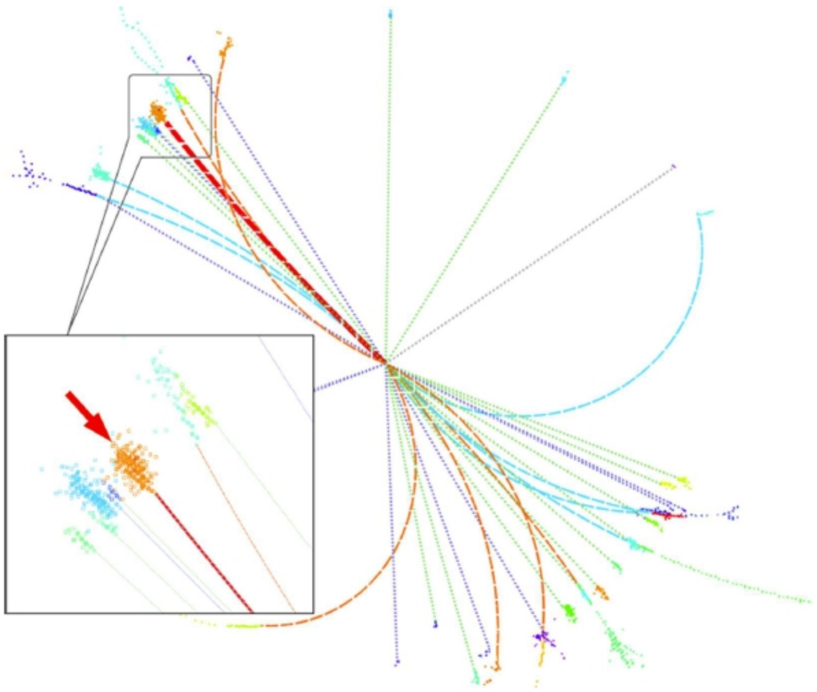
- Key words: Requirement, and Flavor

Physics objects

2021 JINST 16 P06013: Jet







Pi-0: CEPC Note 2021

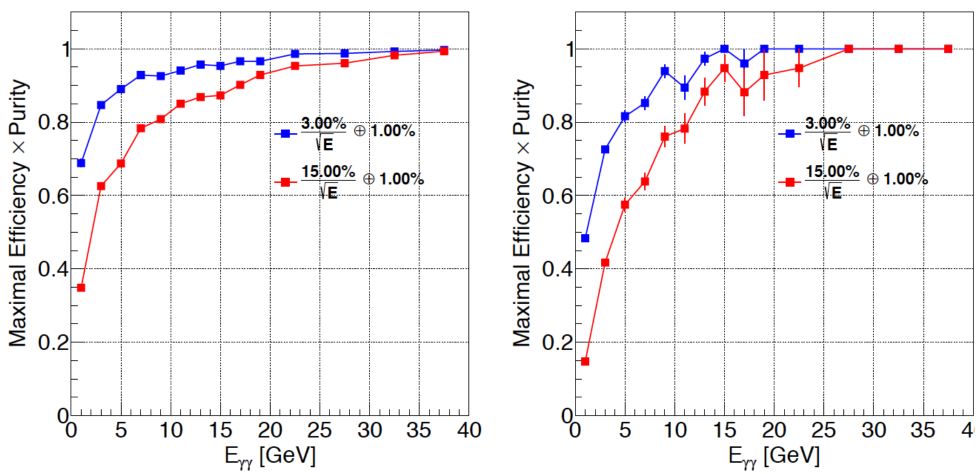
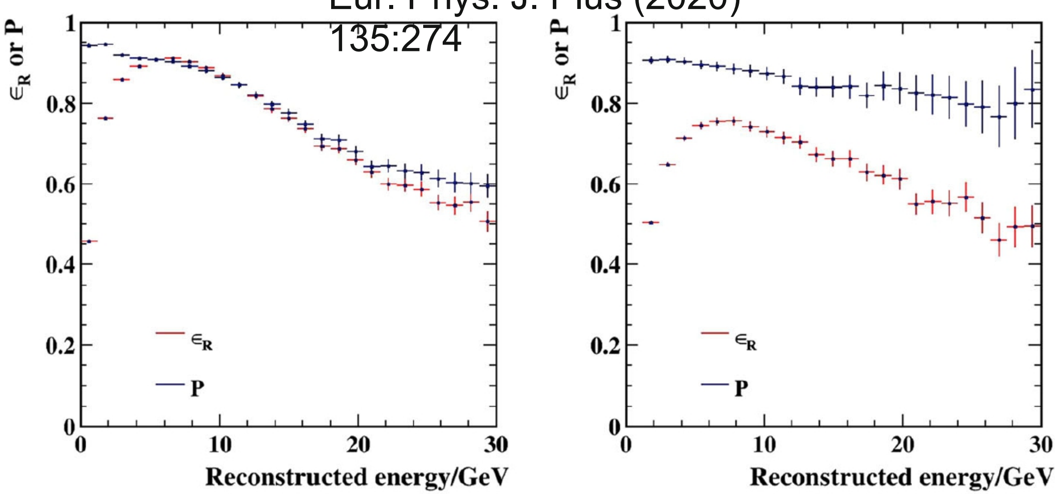


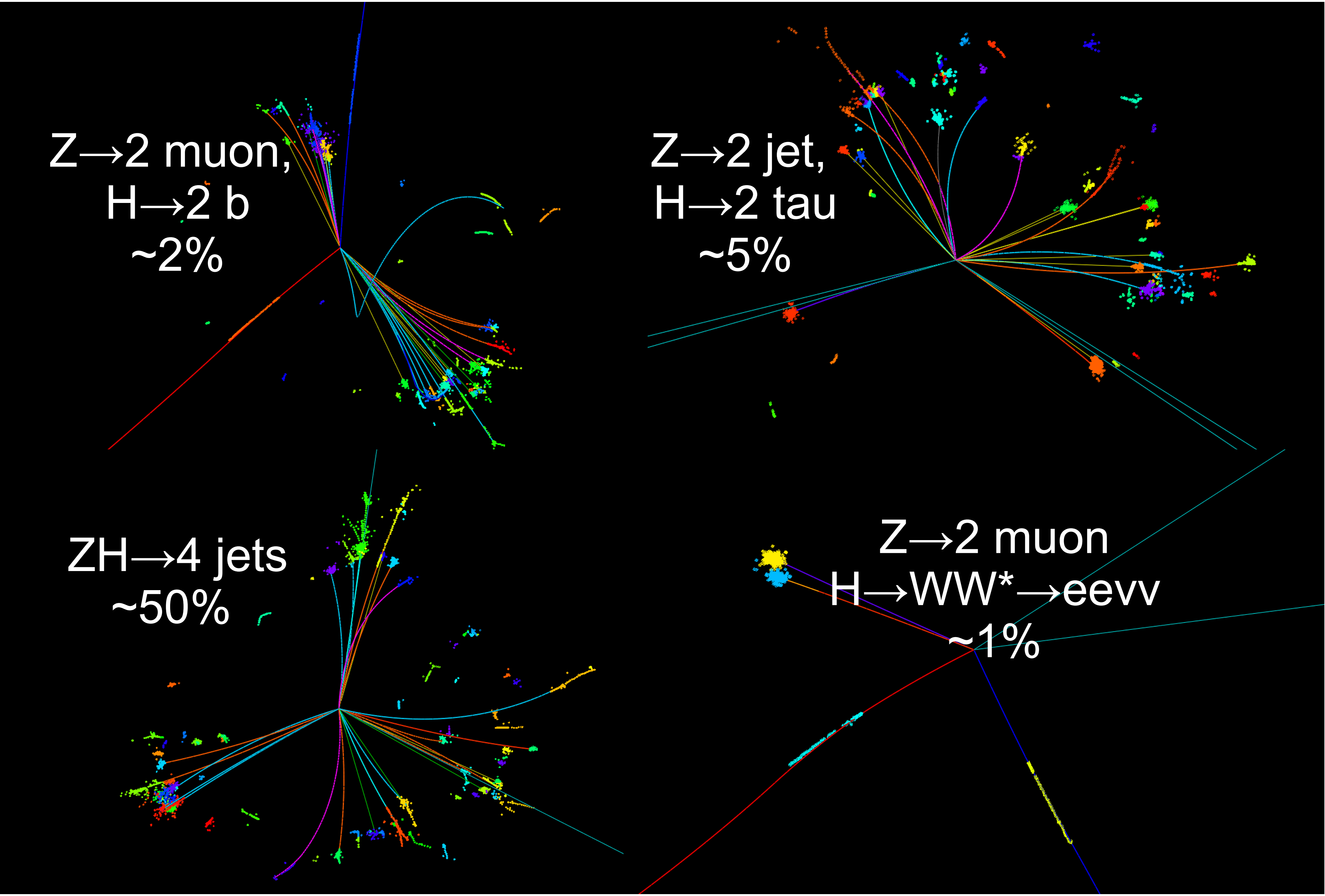
Figure 13: Energy differential maximal $\epsilon \times p$ for $Z \to \tau^+\tau^-$ (left) and $Z \to q\bar{q}$ (right).

Eur. Phys. J. Plus (2020) 135:274



(a) K_S^0 **(b)** Λ

Fig. 9 Energy dependence of ϵ_R and P


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%