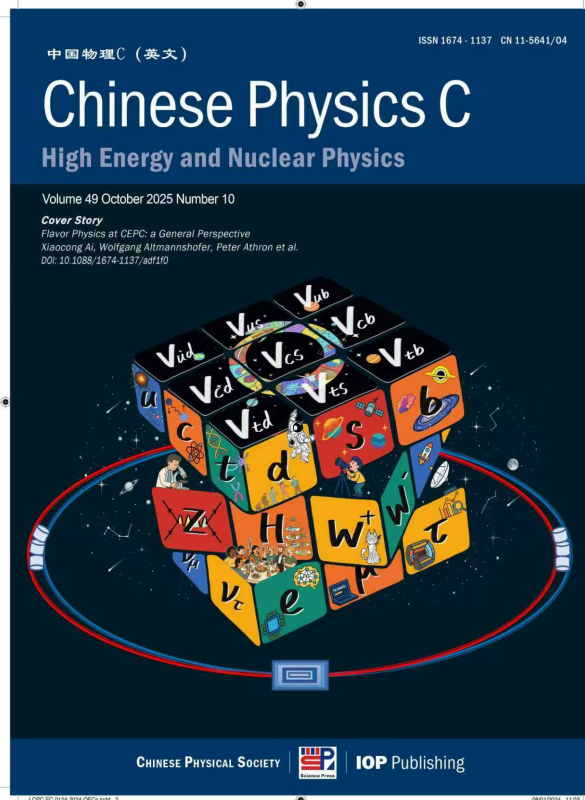


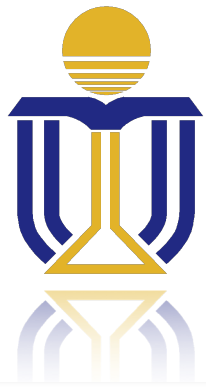


FLAVOR PHYSICS AT THE CEPC

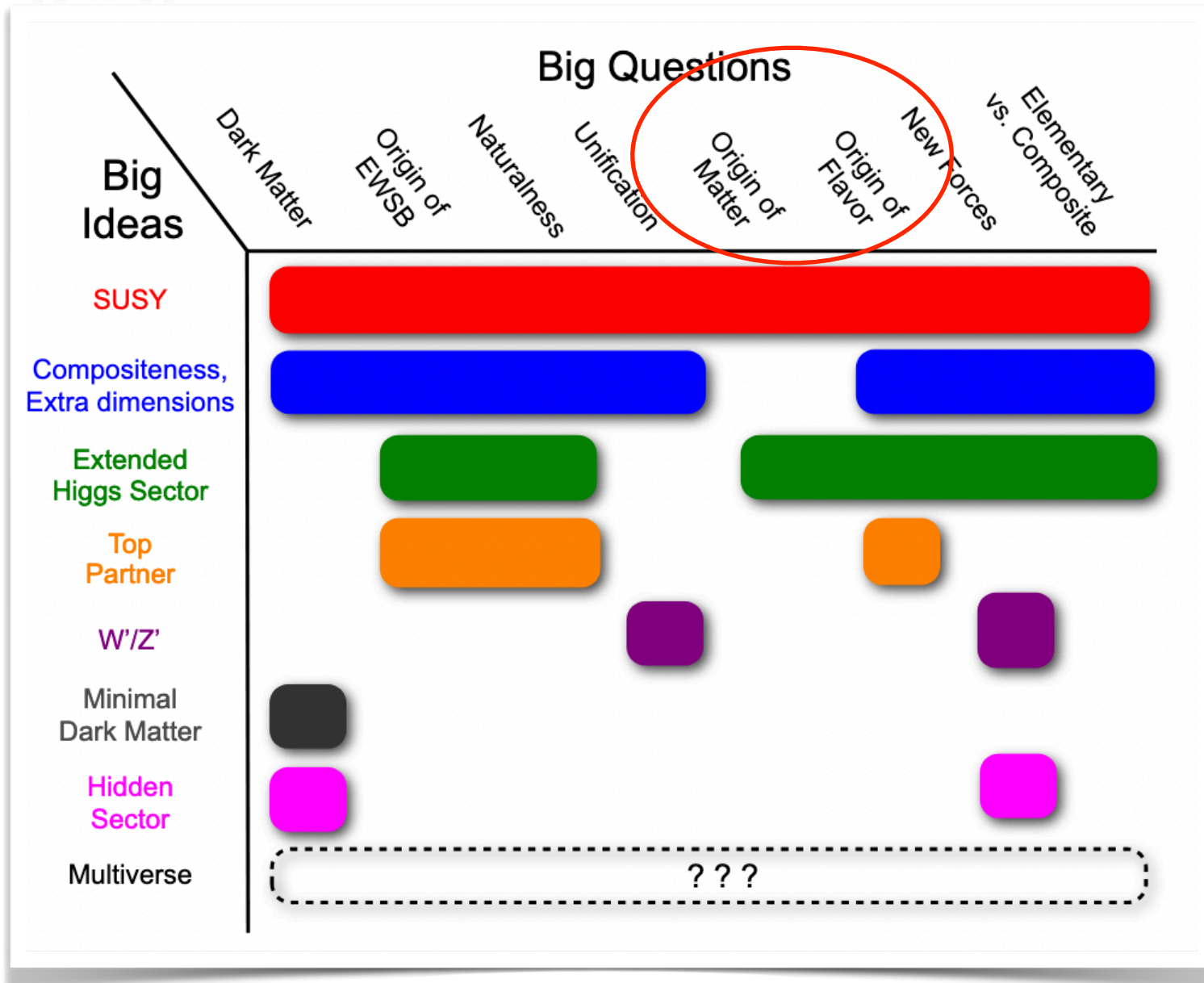
- A GENERAL PERSPECTIVE

Tao Liu

The Hong Kong University of Science and Technology



Flavor Physics



$$\mathcal{L}_{\text{SM}} \supset i\bar{\psi}\not{D}\psi + \bar{\psi}_i y_{ij} \psi_j \phi$$

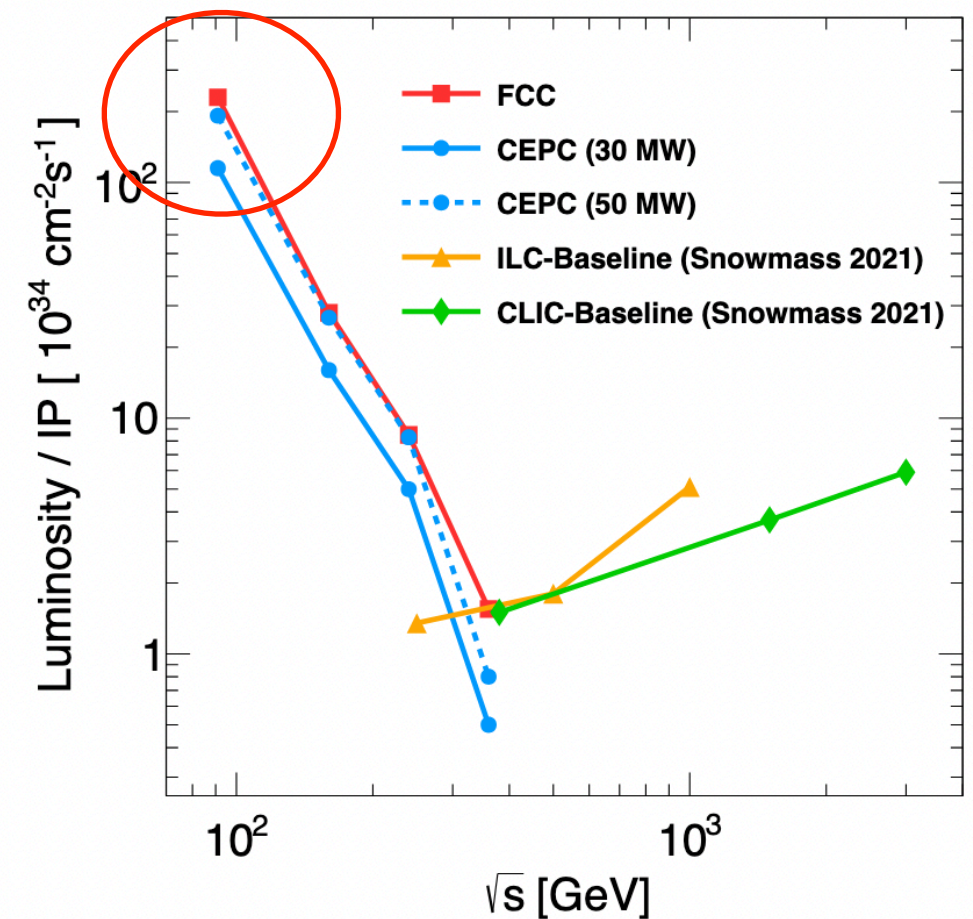
- How does flavor origin?
- What governs the structure of flavor couplings?
- Are there new sources for CP violation other than KM phase?
- Suppressed LFV, LFUV, etc: accidental or fundamental?
-

[Working group report for Snowmass 2013]



Precision Frontier of Next Decades

The new precision frontier in particle physics is expected to be defined by a new e^-e^+ collider.





Opportunities for Flavor Physics

CEPC Baseline

Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. /IP ($10^{34} \text{cm}^{-2} \text{s}^{-1}$)	Integrated Lumi. /yr (ab^{-1} , 2 IPs)	Total Integrated L (ab^{-1} , 2 IPs)	Total no. of events
H^*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30	0.5	0.13	0.65	0.4×10^6

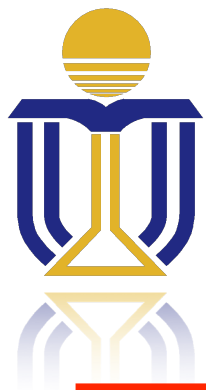


Opportunities for Flavor Physics

$$\text{BR}(Z \rightarrow b\bar{b}) \approx 15\%, \text{BR}(Z \rightarrow c\bar{c}) \approx 12\%, \text{BR}(Z \rightarrow \tau^+\tau^-) \approx 3\%$$

Particle	BESIII	STCF (1 ab ⁻¹)	Belle II (50 ab ⁻¹ on $\Upsilon(4S)$)	LHCb (300 fb ⁻¹)	CEPC (TDR)
$B^0, \bar{B}^0$	—	—	5.4×10^{10}	3×10^{13}	4.8×10^{11}
$B^\pm$	—	—	5.7×10^{10}	3×10^{13}	4.8×10^{11}
$B_s^0, \bar{B}_s^0$	—	—	6.0×10^8 (5 ab ⁻¹ on $\Upsilon(5S)$)	1×10^{13}	1.2×10^{11}
$B_c^\pm$	—	—	—	1×10^{11}	7.2×10^8
$\Lambda_b^0, \bar{\Lambda}_b^0$	—	—	—	2×10^{13}	1×10^{11}
$D^0, \bar{D}^0$	1.2×10^8	7.2×10^9	4.8×10^{10}	7×10^{14}	8.3×10^{11}
$D^\pm$	1.2×10^8	5.6×10^9	4.8×10^{10}	3×10^{14}	4.9×10^{11}
$D_s^\pm$	1×10^7	1.8×10^9	1.6×10^{10}	1×10^{14}	1.8×10^{11}
$\Lambda_c^\pm$	0.3×10^7	1.1×10^9	1.6×10^{10}	1×10^{14}	6.2×10^{10}
$\tau^+\tau^-$	3.6×10^8	3.6×10^9	4.5×10^{10}		1.2×10^{11}

- High production rate of relevant mesons, baryons, leptons, etc. at Z pole
 - Belle II has no statistics for heavy hadrons due to the limitation of energy threshold.
- Clean collider environment
 - Low QCD backgrounds
 - Negligible pile-ups
- Beam energy much larger than the quark and lepton masses
 - Boost kinematics
 - Higher precision of measuring momentum and efficiency for reconstructing vertex
 - Belle II: asymmetric beam energy has been taken to improve event reconstruction



White Paper on Flavor Physics at CEPC

- Present a picture of the CEPC potential, in exploring flavor physics
- Identify “golden” channels (machine operation mode, parent particle system, physical processes) for critical physics
 - High scientific value
 - Challenging or inaccessible for existing experiments: complex event topology or suppressed productions
- Develop new observables or methodologies, e.g., ML-based ones, for flavor physics
- As the technology roadmap is close for CEPC and FCC-ee, many of these studies can be directly applied to FCC-ee

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[Led by Lorenzo Calibbi, Lingfeng Li, TL, and Manqi Ruan]



$b \rightarrow c\tau\nu$ Transition

- FCCC-mediated beta decays have resulted in the discovery of weak interactions.
- Can be used to probe new physics and test LFU

$$\mathcal{H}_{b \rightarrow c\ell\nu}^{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{cb} \sum_i C_i O_i + \text{h.c.},$$

$$O_{S_{L(R)}} = (\bar{c} P_{L(R)} b) (\bar{\ell} P_L \nu),$$

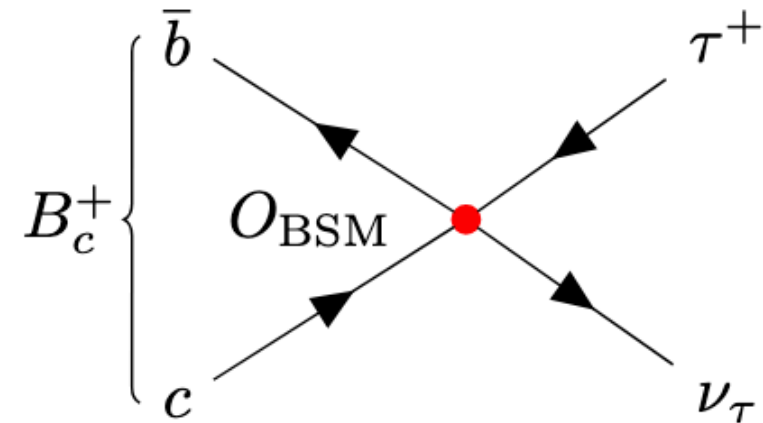
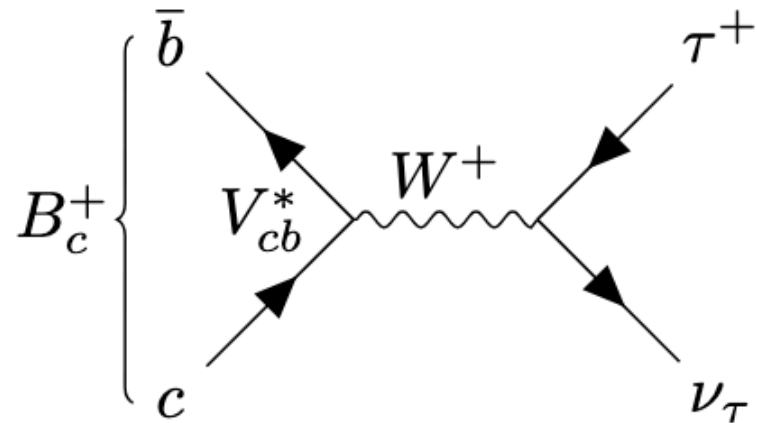
$$O_{V_{L(R)}} = (\bar{c} \gamma^\mu P_{L(R)} b) (\bar{\ell} \gamma_\mu P_L \nu),$$

$$O_T = (\bar{c} \sigma^{\mu\nu} b) (\bar{\ell} \sigma_{\mu\nu} P_L \nu),$$

$$\Lambda_{\text{NP}}^{\text{SL}} \sim (G_F |V_{cb}| \delta_{\text{SL}})^{-\frac{1}{2}} \sim (1.5 \text{ TeV}) \times \delta_{\text{SL}}^{-\frac{1}{2}}$$



$b \rightarrow c\tau\nu$ Transition - Leptonic B_c Decays



- SM prediction:

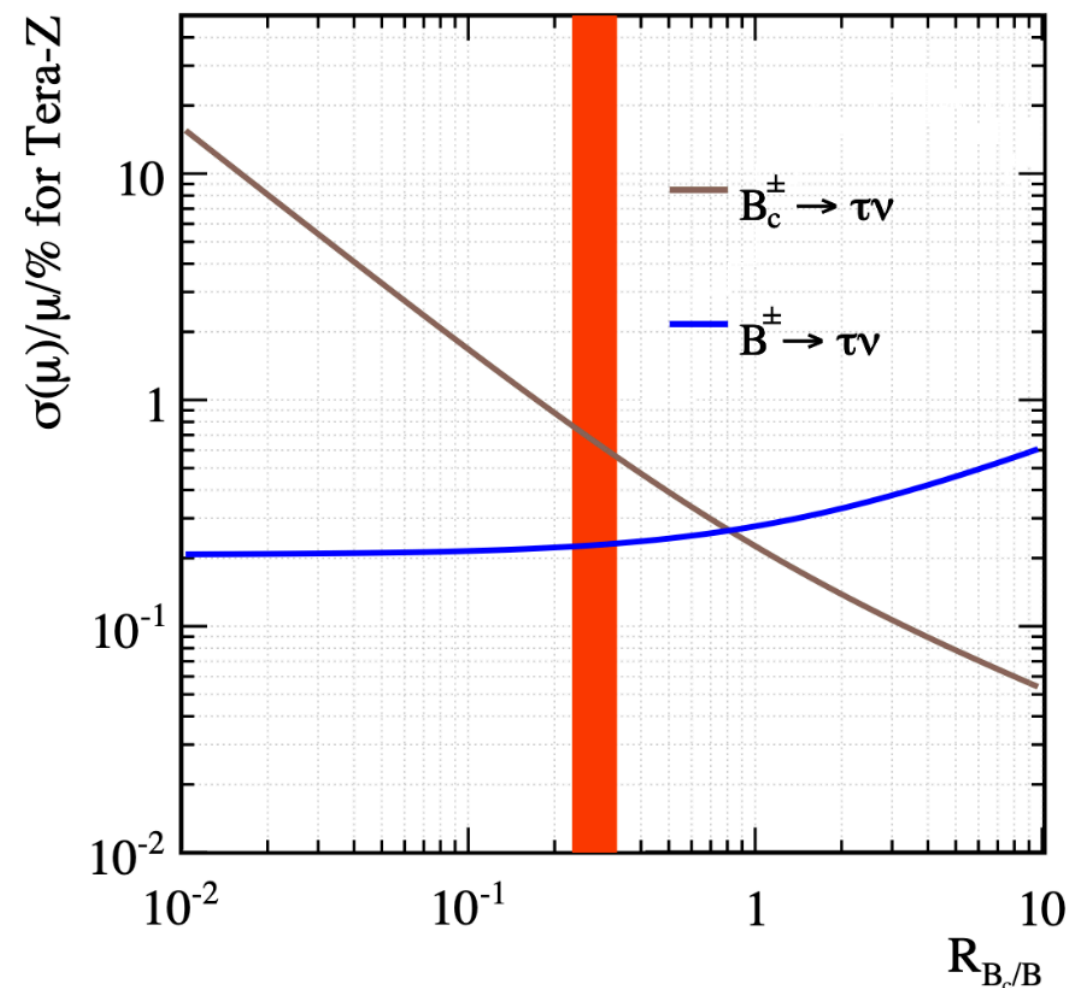
$$\text{BR}(B_c \rightarrow \tau\nu) \sim 2.3 \times 10^{-2}$$

- Current constraint:

$$\text{BR}(B_c \rightarrow \tau\nu) \lesssim 30\%$$

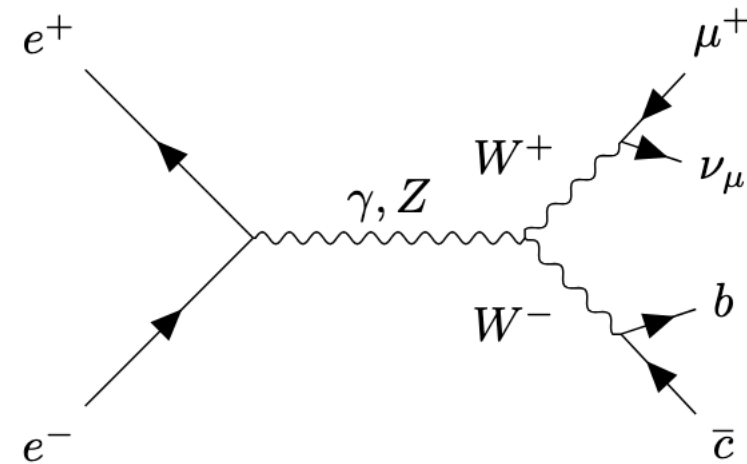
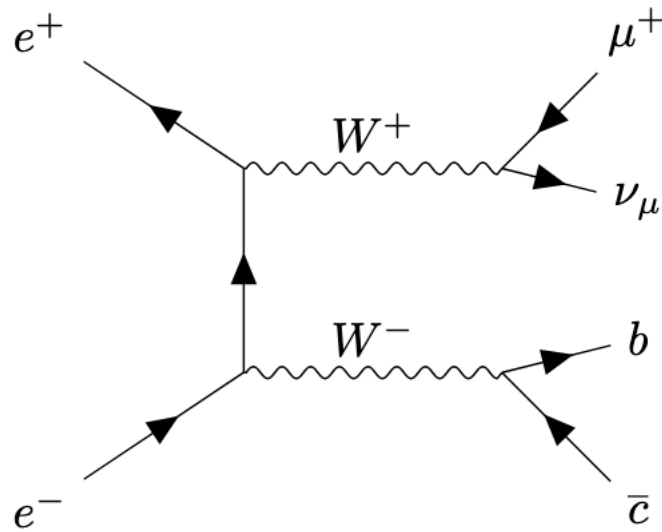
- Expected CEPC sensitivities: for both leptonic and three-prong tau decays

$$\sim \mathcal{O}(1\%)$$

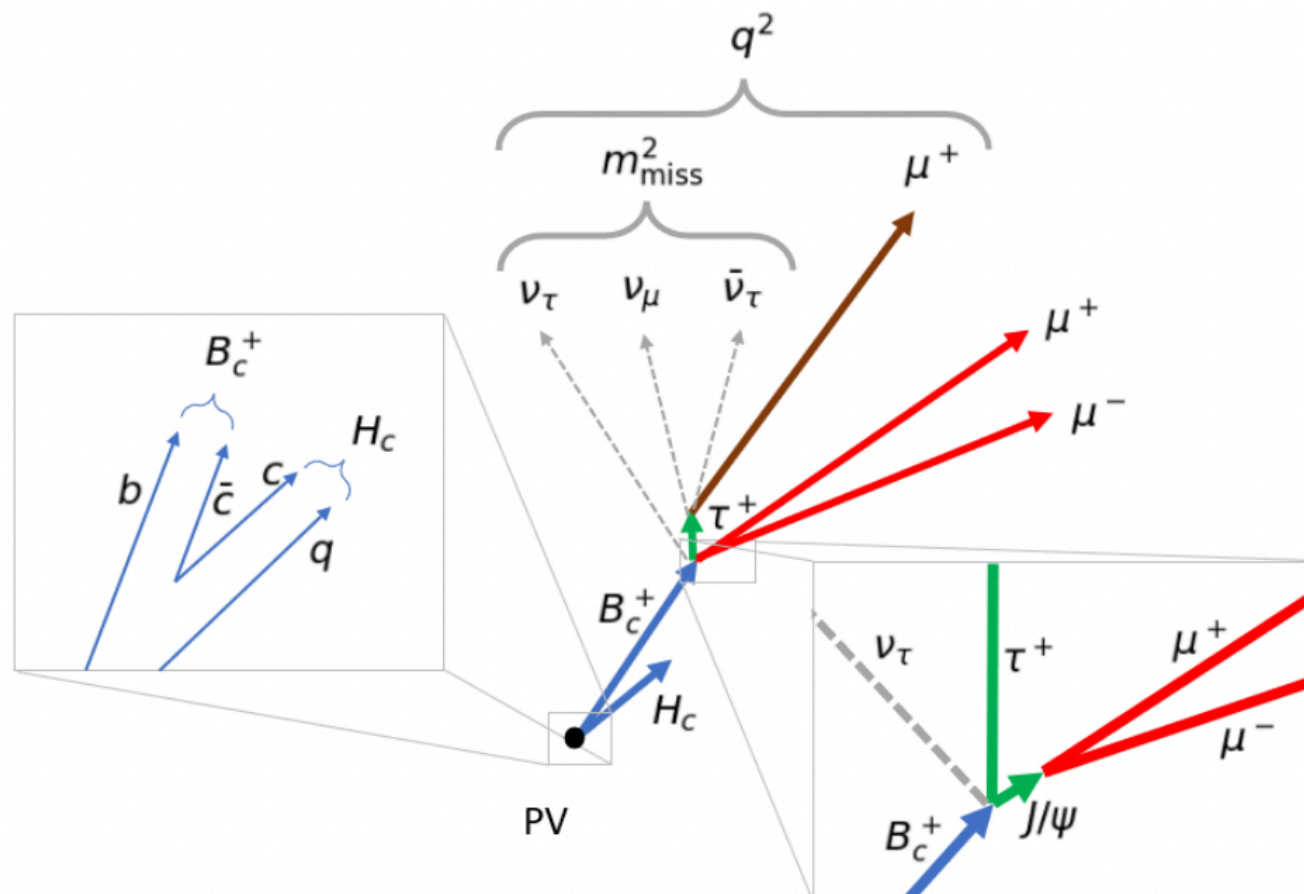




$b \rightarrow c\tau\nu$ Transition - Semileptonic H_b Decays



$$R_{H_c} \equiv \frac{\text{Br}(H_b \rightarrow H_c \tau \nu)}{\text{Br}(H_b \rightarrow H_c \ell \nu)}$$



Track-based strategy

R_{H_c}	SM Value	4 Tera-Z
$R_{J/\psi}$	0.289	2.1×10^{-2}
R_{D_s}	0.393	2.1×10^{-3}
$R_{D_s^*}$	0.303	1.6×10^{-3}
R_{Λ_c}	0.334	4.9×10^{-4}

Currently either no sensitivity or a precision $\sim 30\%$.



$b \rightarrow s$ Transition

- FCNC-mediated processes emerge at loop level in the SM
- Can be used to probe new physics and test LFU
 - Di-lepton (di-tau here) mode
 - Di-neutrino mode
 - Radiation mode

$$\mathcal{H}_{b \rightarrow s}^{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \sum_j (C_j O_j + C'_j O'_j) + (C_L O_L + C_R O_R) + \text{h.c.},$$

$$O_S^{(\prime)} = m_b (\bar{s} P_{R(L)} b) (\bar{\ell} \ell),$$

$$O_P^{(\prime)} = m_b (\bar{s} P_{R(L)} b) (\bar{\ell} \gamma^5 \ell),$$

$$O_9^{(\prime)} = (\bar{s} \gamma^\mu P_{L(R)} b) (\bar{\ell} \gamma_\mu \ell),$$

$$O_{10}^{(\prime)} = (\bar{s} \gamma^\mu P_{L(R)} b) (\bar{\ell} \gamma_\mu \gamma^5 \ell),$$

$$O_{T(T5)} = (\bar{s} \sigma_{\mu\nu} b) (\bar{\ell} \sigma^{\mu\nu} (\gamma^5) \ell),$$

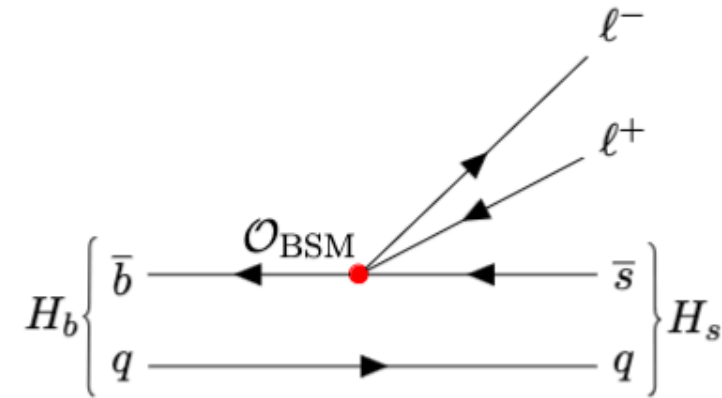
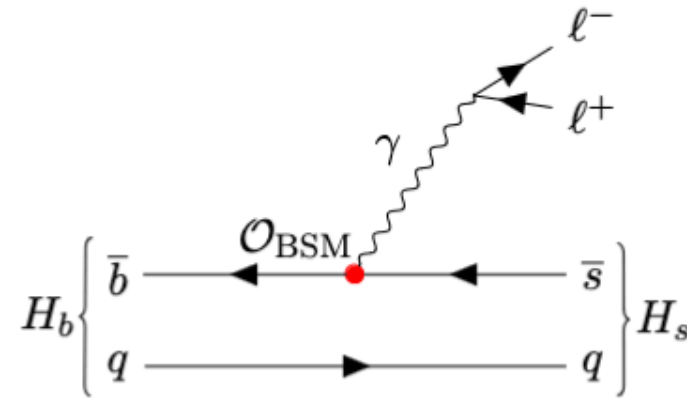
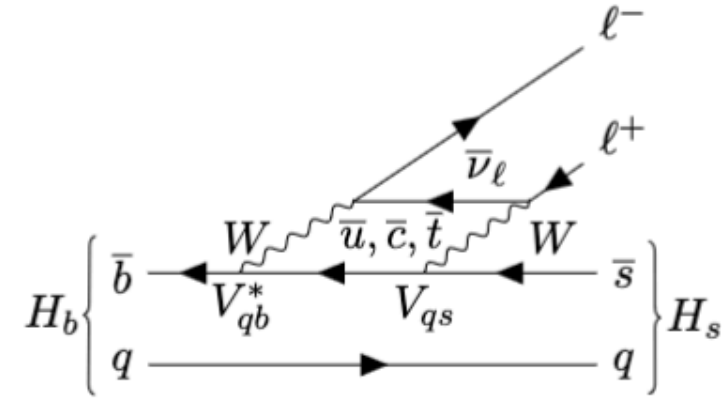
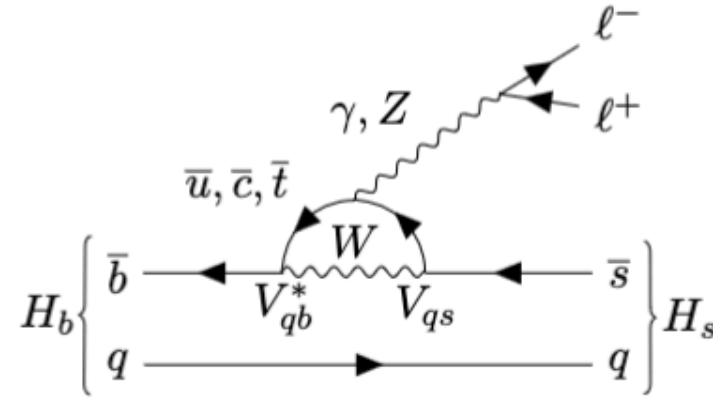
$$O_7^{(\prime)} = \frac{1}{e} m_b (\bar{s} \sigma^{\mu\nu} P_{R(L)} b) F_{\mu\nu},$$

$$O_{L(R)} = (\bar{s} \gamma^\mu P_{L(R)} b) (\bar{\nu} \gamma_\mu P_L \nu).$$

$$\Lambda_{\text{NP}}^{\text{rare}} \sim \left(\frac{\alpha}{4\pi} \frac{m_t^2}{m_W^2} G_F |V_{tb} V_{ts}^*| \delta_{\text{rare}} \right)^{-\frac{1}{2}} \sim (30 \text{ TeV}) \times \delta_{\text{rare}}^{-\frac{1}{2}}$$



$b \rightarrow s\tau\tau$ Transition

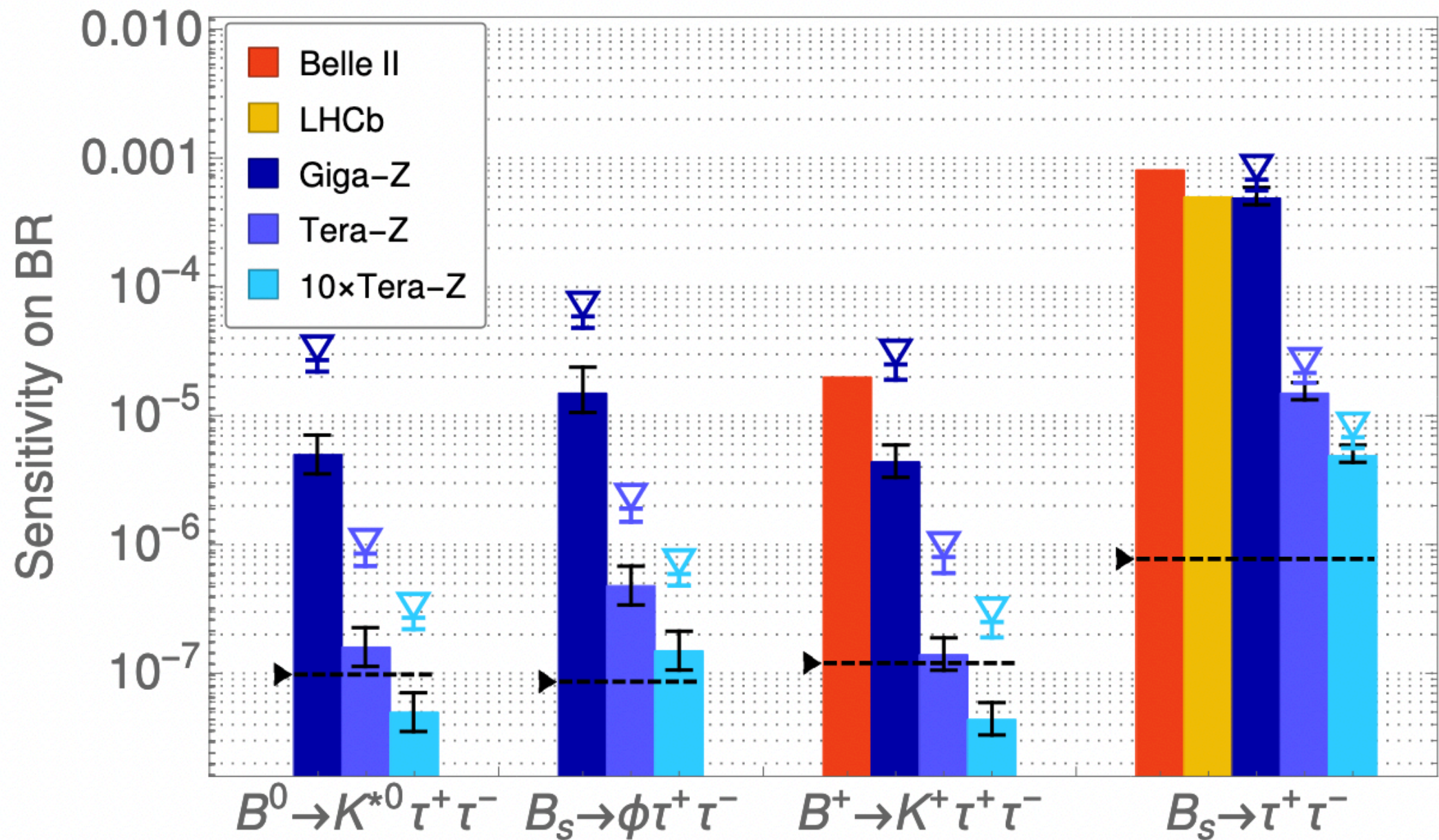


Channel	SM prediction for BR	$q^2 \equiv m_{\tau\tau}^2$ (GeV ²)
$B^0 \rightarrow K^{*0}\tau^+\tau^-$	$(0.98 \pm 0.10) \times 10^{-7}$ [11]	[15,19]
$B_s \rightarrow \phi\tau^+\tau^-$	$(0.86 \pm 0.06) \times 10^{-7}$ [11]	[15,18.8]
$B^+ \rightarrow K^+\tau^+\tau^-$	$(1.20 \pm 0.12) \times 10^{-7}$ [11]	[15,22]
$B_s \rightarrow \tau^+\tau^-$	$(7.73 \pm 0.49) \times 10^{-7}$ [12]	-

Current sensitivity is still far from the SM prediction.

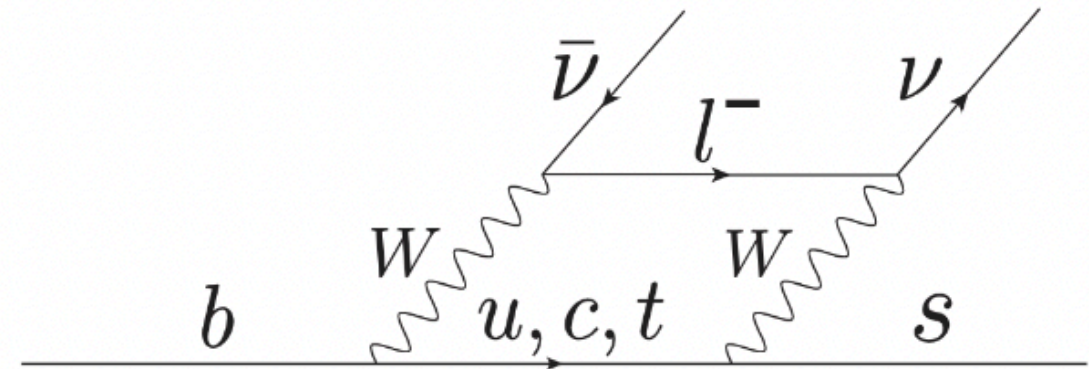
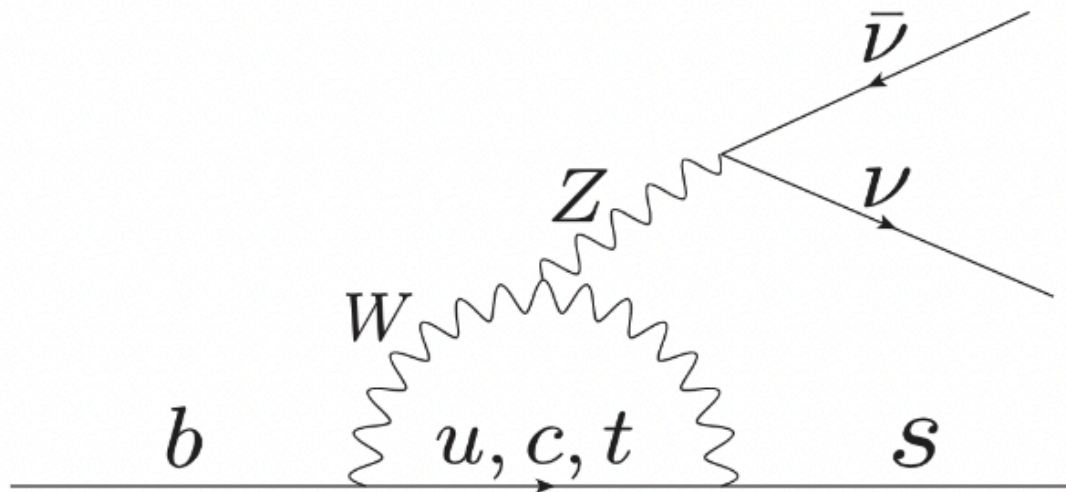


$b \rightarrow s\tau\tau$ Transition





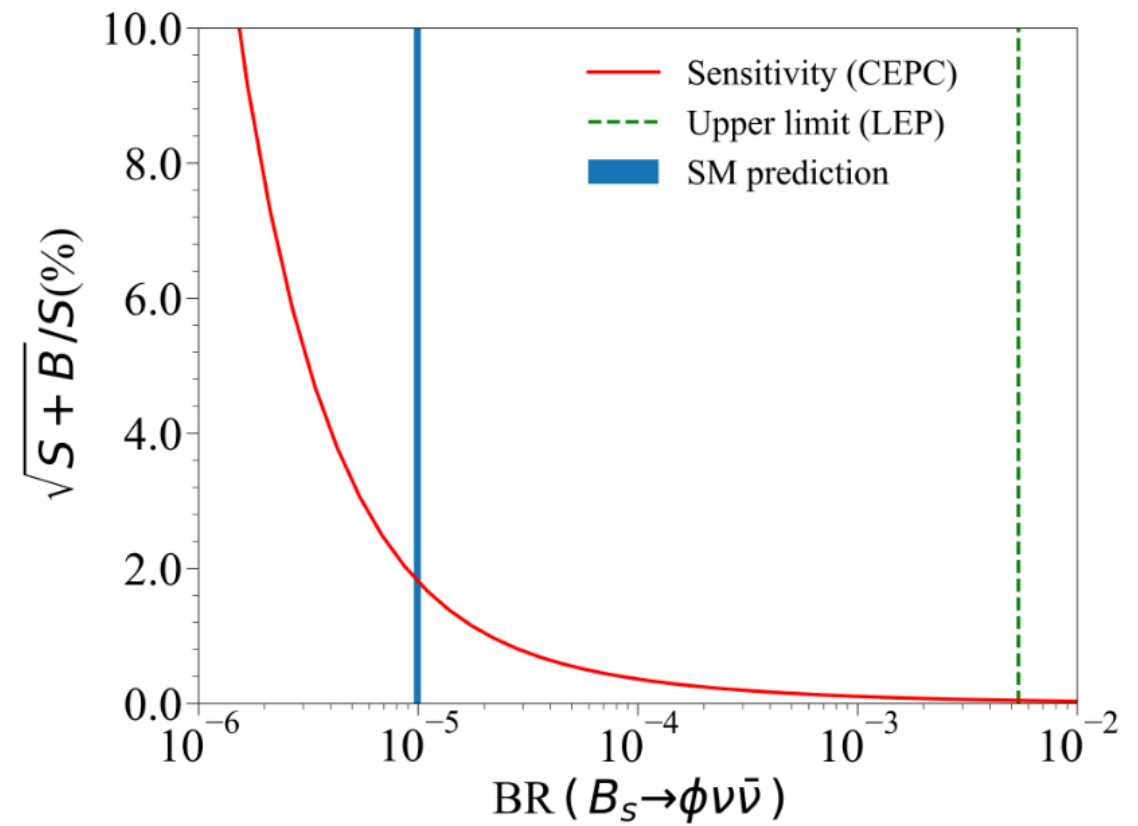
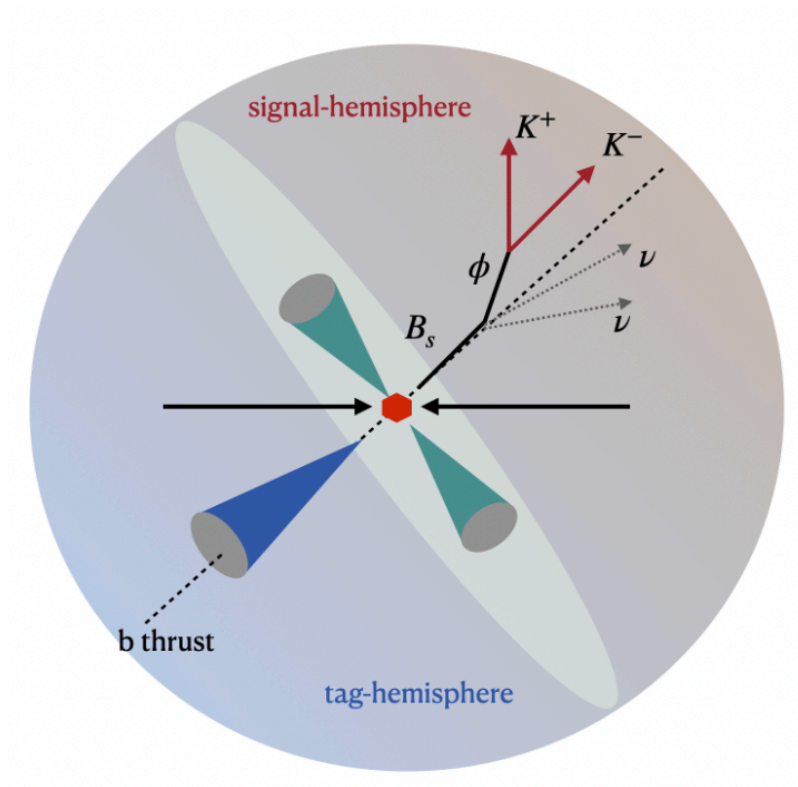
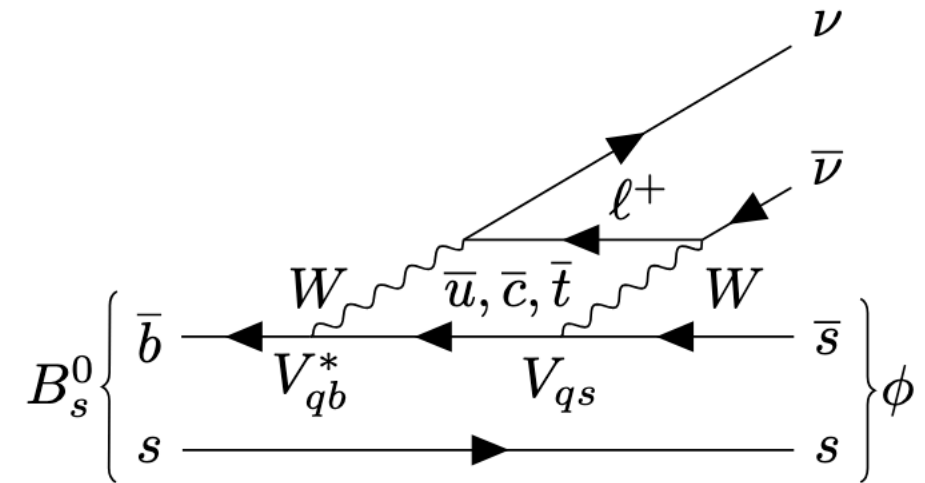
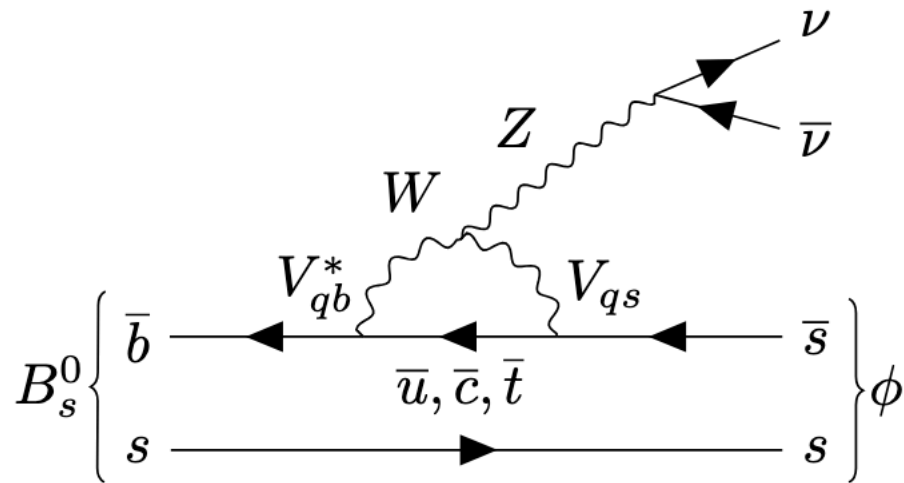
$b \rightarrow s\nu\nu$ Transition



	Current Limit	Detector	SM Prediction
$\text{BR}(B^0 \rightarrow K^0 \nu \bar{\nu})$	$< 2.6 \times 10^{-5}$ [3]	BELLE	$(3.69 \pm 0.44) \times 10^{-6}$ [1]
$\text{BR}(B^0 \rightarrow K^{*0} \nu \bar{\nu})$	$< 1.8 \times 10^{-5}$ [3]	BELLE	$(9.19 \pm 0.99) \times 10^{-6}$ [1]
$\text{BR}(B^\pm \rightarrow K^\pm \nu \bar{\nu})$	$< 1.6 \times 10^{-5}$ [4]	BABAR	$(3.98 \pm 0.47) \times 10^{-6}$ [1]
$\text{BR}(B^\pm \rightarrow K^{*\pm} \nu \bar{\nu})$	$< 4.0 \times 10^{-5}$ [5]	BELLE	$(9.83 \pm 1.06) \times 10^{-6}$ [1]
$\text{BR}(B_s \rightarrow \phi \nu \bar{\nu})$	$< 5.4 \times 10^{-3}$ [6]	DELPHI	$(9.93 \pm 0.72) \times 10^{-6}$

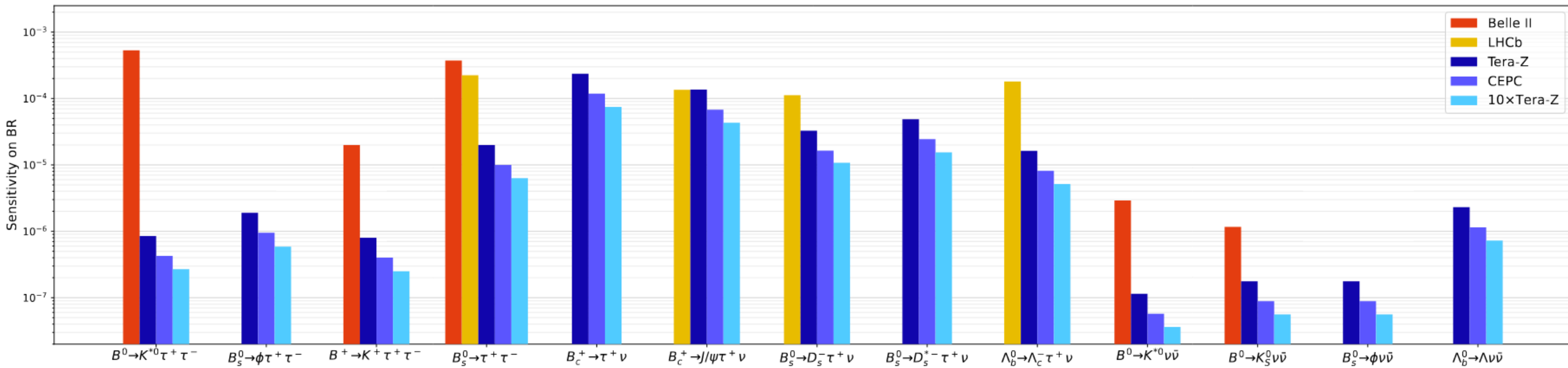


$b \rightarrow s\nu\nu$ Transition





An Overall Picture

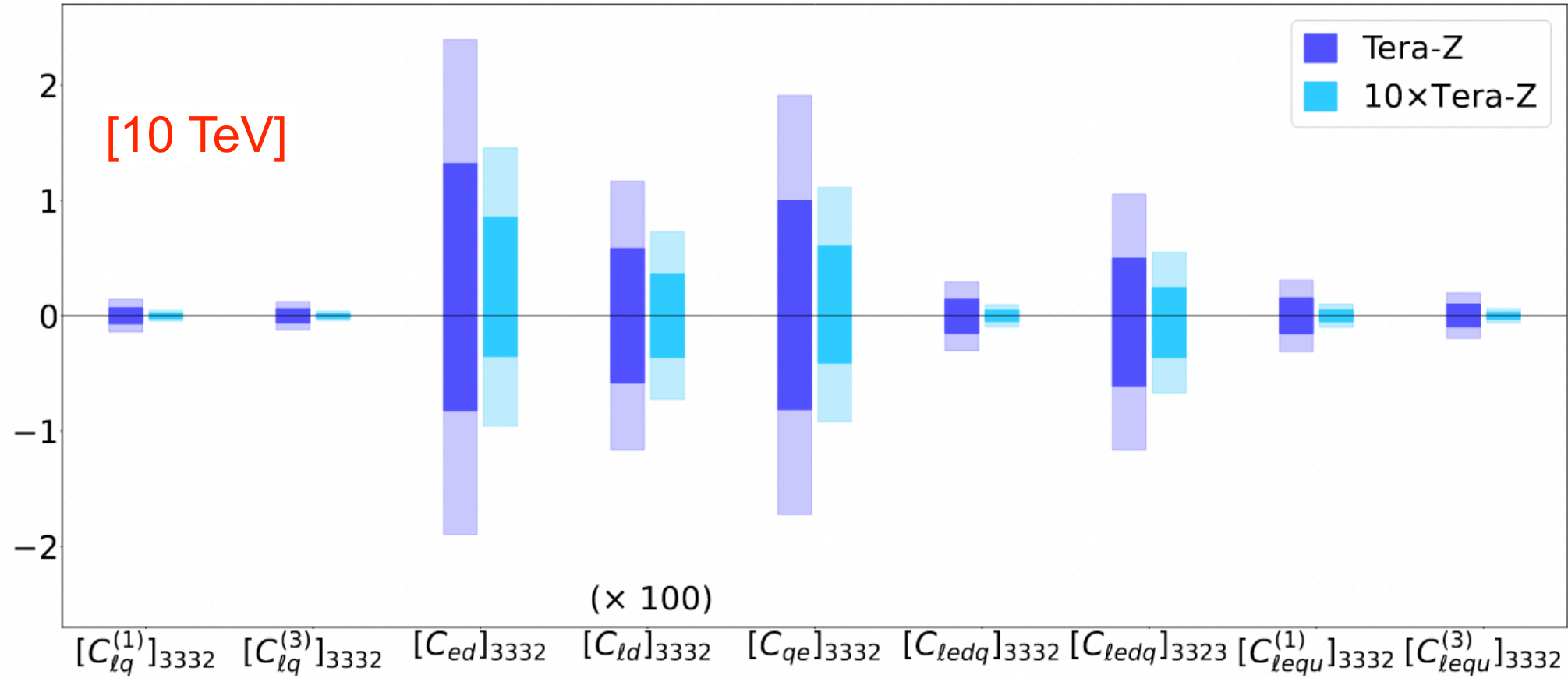


An all-three-family test of LFU in both charged and neutral currents becomes possible!



Interpretation in SMEFT

SMEFT operators	SMEFT operators (down basis)
$[O_{lq}^{(1)}]_{3332}$	$[\bar{\nu}\gamma^\mu P_L \nu + \bar{\tau}\gamma^\mu P_L \tau][\bar{b}\gamma_\mu P_L s]$
$[O_{lq}^{(3)}]_{3332}$	$2V_{cs}^*[\bar{\nu}\gamma^\mu P_L \tau][\bar{b}\gamma_\mu P_L c] - [\bar{\nu}\gamma^\mu P_L \nu - \bar{\tau}\gamma^\mu P_L \tau][\bar{b}\gamma_\mu P_L s]$
$[O_{ed}]_{3332}$	$[\bar{\tau}\gamma^\mu P_R \tau][\bar{b}\gamma_\mu P_R s]$
$[O_{ld}]_{3332}$	$[\bar{\nu}\gamma^\mu P_L \nu + \bar{\tau}\gamma^\mu P_L \tau][\bar{b}\gamma_\mu P_R s]$
$[O_{qe}]_{3332}$	$[\bar{\tau}\gamma^\mu P_R \tau][\bar{b}\gamma_\mu P_L s]$
$[O_{ledq}]_{3332}$	$V_{cs}^*[\bar{\nu}P_R \tau][\bar{b}P_L c] + [\bar{\tau}P_R \tau][\bar{b}P_L s]$
$[O_{ledq}]_{3323}$	$[\bar{\tau}P_R \tau][\bar{s}P_L b]$
$[O_{lequ}^{(1)}]_{3332}$	$V_{cs}^*[\bar{\nu}P_R \tau][\bar{b}P_R c]$
$[O_{lequ}^{(3)}]_{3332}$	$V_{cs}^*[\bar{\nu}\sigma^{\mu\nu} P_R \tau][\bar{b}\sigma_{\mu\nu} P_R c]$





CP-violation in B-Physics



The [Large Hadron Collider beauty](#) (LHCb) experiment specializes in investigating the slight differences between matter and antimatter by studying a type of particle called the "beauty quark", or "b quark".

A non-trivial task to bridge the potentially to-be-observed CP-violation and the origin of CBA.



Electroweak Beautygenesis: From $b \rightarrow s$ CP Violation to the Cosmic Baryon Asymmetry

[Tao Liu](#)¹, [Michael J. Ramsey-Musolf](#)², and [Jing Shu](#)³

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Phys. Rev. Lett. **108**, 221301 –
Published 29 May, 2012

DOI: <https://doi.org/10.1103/PhysRevLett.108.221301>

Cornell University

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High Energy Physics – Phenomenology

[Submitted on 1 Feb 2025]

Electroweak baryogenesis from charged current anomalies in B meson decays

[Peter Athron](#), [Michael J. Ramsey-Musolf](#), [Cristian Sierra](#),
[Yongcheng Wu](#)

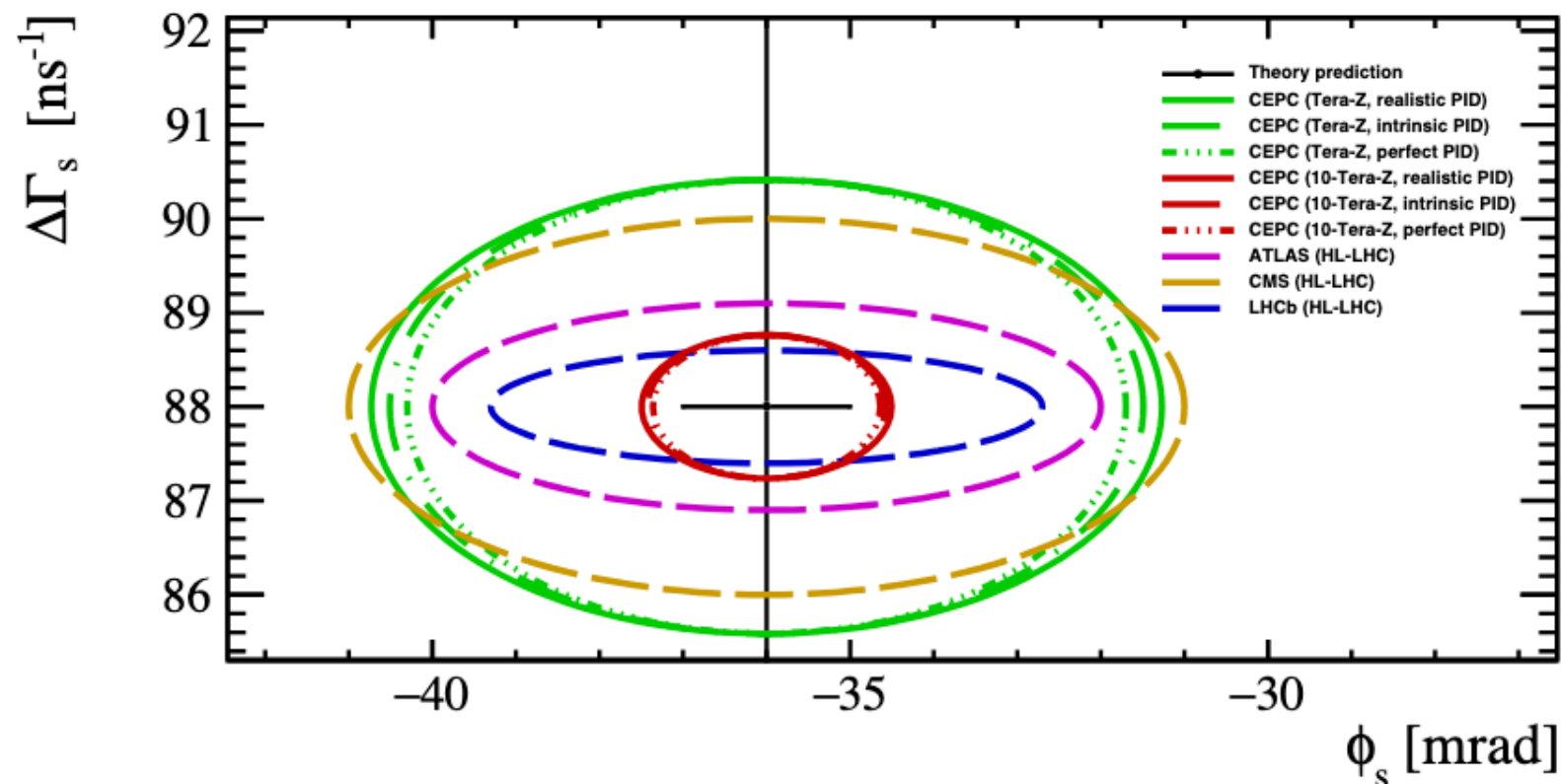
We demonstrate for the first time that new physics explaining the long standing charged B meson anomalies, $R(D^{(*)})$, can be the source of CP violation that explains the observed baryon asymmetry of the universe (BAU). We consider the general two Higgs doublet model with complex Yukawa couplings and compute the BAU in the semiclassical formalism, using a novel analytic approximation for the latter. After imposing constraints from both flavor observables and the electron electric dipole moment (eEDM), we find that a significant BAU can still be



CP-violation in B-Physics

- CP-violation in decay
 - time-integrated asymmetry
- CP-violation in mixing
 - time-integrated asymmetry and time-dependent asymmetry

$$B_s^0 \rightarrow J/\psi(\rightarrow \mu^+ \mu^-) \phi(\rightarrow K^+ K^-)$$





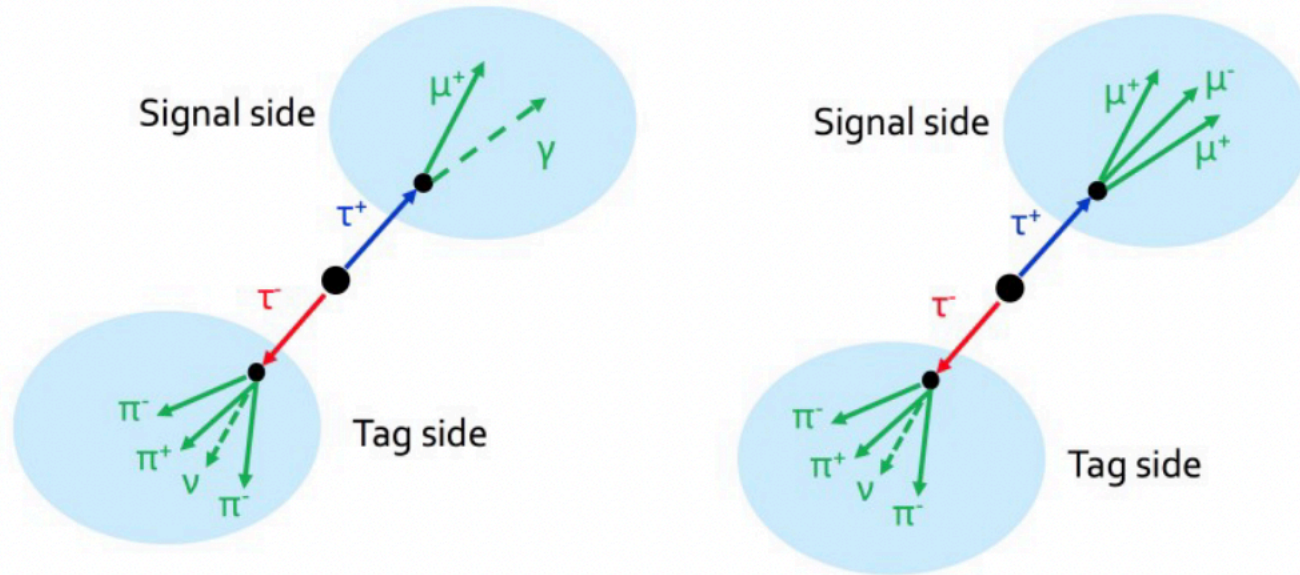
Tau Physics - General Comments

Particle	BESIII	STCF (1 ab ⁻¹)	Belle II (50 ab ⁻¹ on $\Upsilon(4S)$)	LHCb (300 fb ⁻¹)	CEPC (TDR)
$B^0, \bar{B}^0$	—	—	5.4×10^{10}	3×10^{13}	4.8×10^{11}
$B^\pm$	—	—	5.7×10^{10}	3×10^{13}	4.8×10^{11}
$B_s^0, \bar{B}_s^0$	—	—	6.0×10^8 (5 ab ⁻¹ on $\Upsilon(5S)$)	1×10^{13}	1.2×10^{11}
$B_c^\pm$	—	—	—	1×10^{11}	7.2×10^8
$\Lambda_b^0, \bar{\Lambda}_b^0$	—	—	—	2×10^{13}	1×10^{11}
$D^0, \bar{D}^0$	1.2×10^8	7.2×10^9	4.8×10^{10}	7×10^{14}	8.3×10^{11}
$D^\pm$	1.2×10^8	5.6×10^9	4.8×10^{10}	3×10^{14}	4.9×10^{11}
$D_s^\pm$	1×10^7	1.8×10^9	1.6×10^{10}	1×10^{14}	1.8×10^{11}
$\Lambda_c^\pm$	0.3×10^7	1.1×10^9	1.6×10^{10}	1×10^{14}	6.2×10^{10}
$\tau^+ \tau^-$	3.6×10^8	3.6×10^9	4.5×10^{10}		1.2×10^{11}

- Br (Z → tau pair) ~ 3% + L_CEPC ~ 100/ab
 - Yield at Z pole: 1.2×10^{11}
 - Five orders of magnitude more than the LEP yield
- LFV + LFUV



Tau Physics - LFV



- NP implications from CEPC:

$$\frac{1}{\Lambda^2} (\bar{\mu} \gamma^\mu P_{L,R} \tau) (\bar{\mu} \gamma_\mu P_{L,R} \mu)$$

$$\Lambda > 44 \text{ TeV}$$

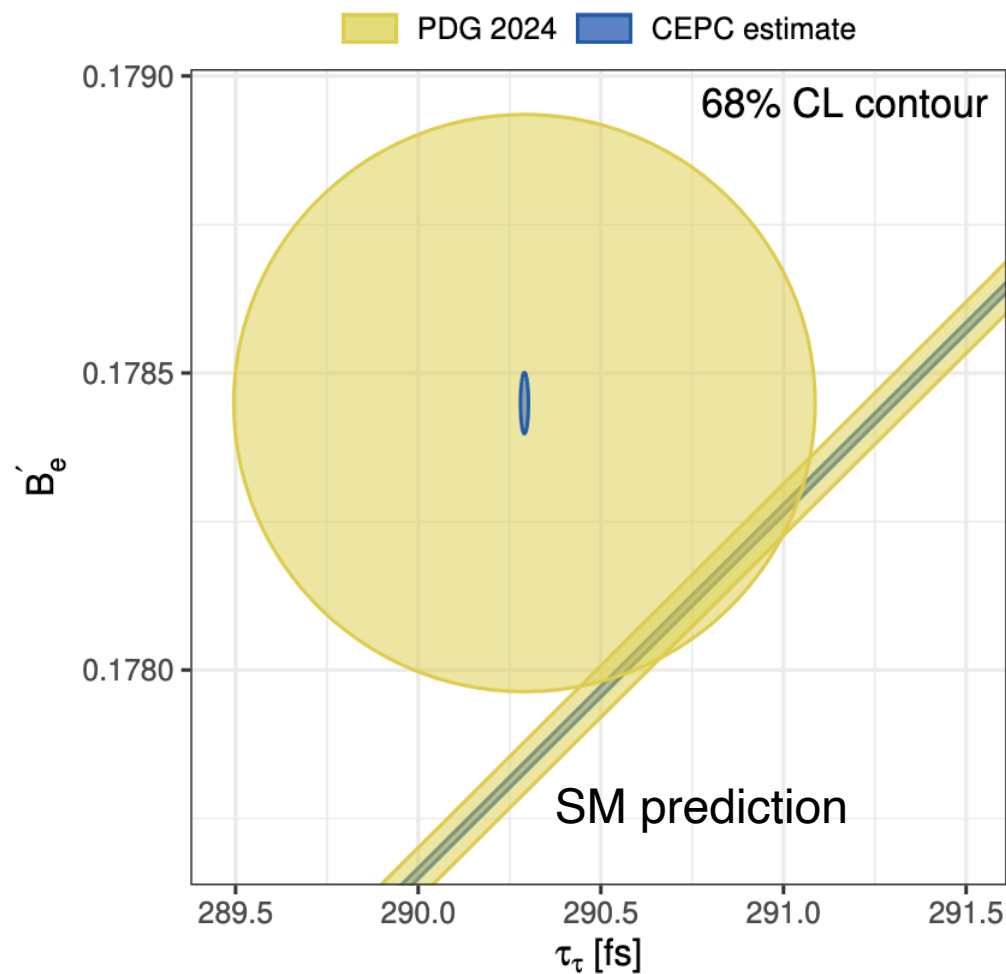
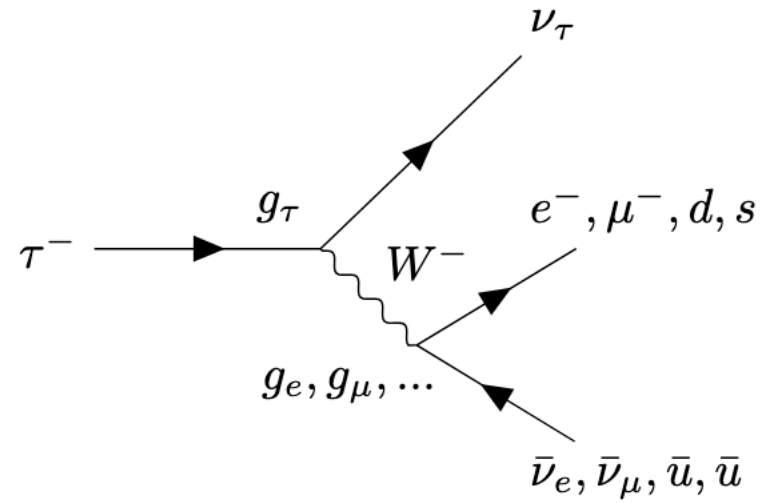
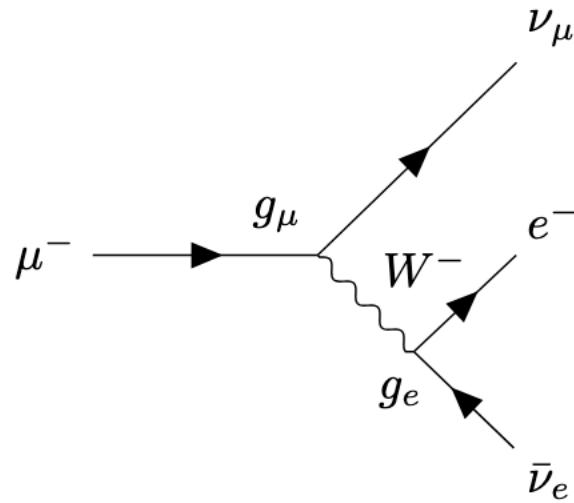
$$\frac{1}{\Lambda^2} (\bar{\mu} \sigma^{\mu\nu} P_{L,R} \tau) \Phi F_{\mu\nu}$$

$$\Lambda > 2800 \text{ TeV}$$

Measurement	Current	Belle II	FCC	CEPC prelim.
Lifetime [sec]	$(2903 \pm 5) \times 10^{-16}$		$\pm 6 \times 10^{-18}$	$\pm 7 \times 10^{-18}$
$\text{BR}(\tau \rightarrow e \nu \bar{\nu})$	$(17.82 \pm 0.04)\%$		$\pm 0.003\%$	$\pm 0.003\%$
$\text{BR}(\tau \rightarrow \mu \nu \bar{\nu})$	$(17.39 \pm 0.04)\%$		$\pm 0.003\%$	$\pm 0.003\%$
m_τ [MeV]	1776.93 ± 0.09		± 0.0016 (stat.) ± 0.018 (syst.)	
$\text{BR}(\tau \rightarrow \mu \mu \mu)$	$< 2.1 \times 10^{-8}$	3.6×10^{-10}	1.4×10^{-11}	10^{-10}
$\text{BR}(\tau \rightarrow \mu \gamma)$	$< 4.4 \times 10^{-8}$	6.9×10^{-9}	1.2×10^{-9}	10^{-10}



Tau Physics - LFUV



- SM prediction

$$g_e = g_\mu = g_\tau = g = e / \sin \theta_W$$

- Current precision

$$\frac{g_\tau}{g_e} = 1.0018 \pm 0.0014, \quad \frac{g_\tau}{g_\mu} = 1.0016 \pm 0.0014$$

- NP implications: $\sim 10^{-4} \Rightarrow$

$$\frac{1}{\Lambda^2} i(\Phi^\dagger \tau^I \overleftrightarrow{D}_\mu \Phi)(\bar{L}_3 \tau^I \gamma^\mu L_3)$$

$$\Lambda \approx 20 \text{ TeV.}$$



Flavor Physics on EW scales

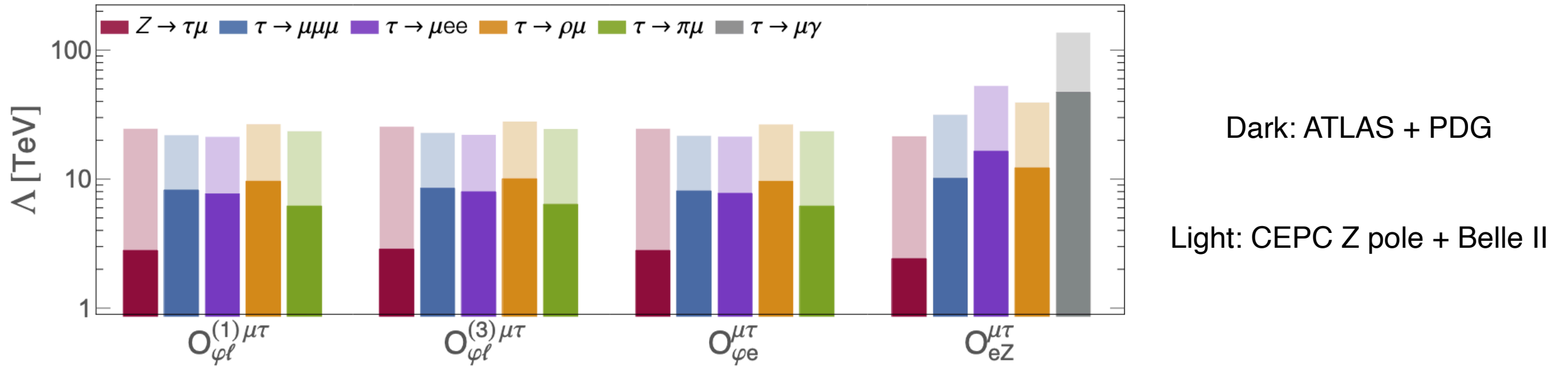
Operation mode	Z factory	WW threshold	Higgs factory	$t\bar{t}$
$\sqrt{s}$ (GeV)	91.2	160	240	360
Run time (year)	2	1	10	5
Instantaneous luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$, per IP)	191.7	26.7	8.3	0.83
Integrated luminosity (ab^{-1} , 2 IPs)	100	6.9	21.6	1
Event yields	4.1×10^{12}	2.1×10^8	4.3×10^6	0.6×10^6

- Flavor physics can be directly investigated at EW-scale
 - decays of Z boson, W boson, Higgs boson, top quark
- Well-complement heavy flavor physics (b , c , τ)
 - Different energy scales
 - Different physical effects (e.g., QCD)



Z Boson - LFV and LUV

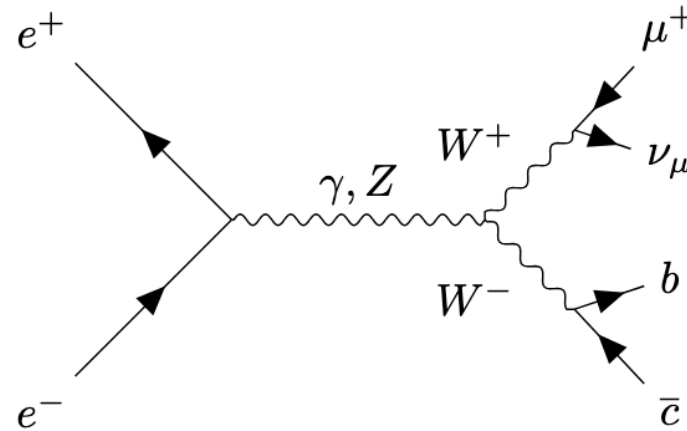
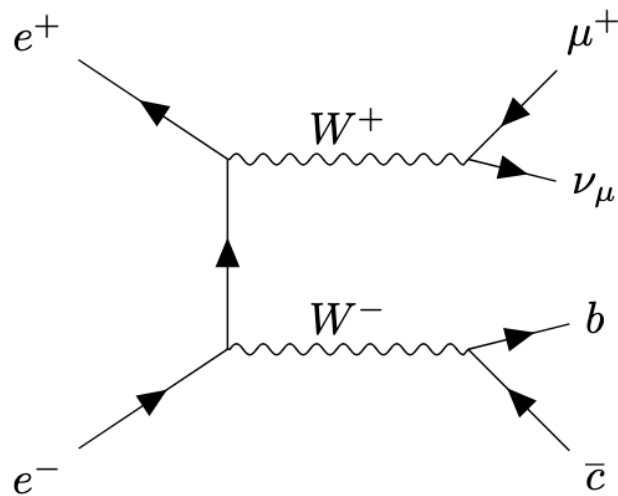
Measurement	Current	HL-LHC	FCC	CEPC prelim.
$\text{BR}(Z \rightarrow \tau\mu)$	$< 6.5 \times 10^{-6}$	1.4×10^{-6}	10^{-9}	10^{-9}
$\text{BR}(Z \rightarrow \tau e)$	$< 5.0 \times 10^{-6}$	1.1×10^{-6}	10^{-9}	
$\text{BR}(Z \rightarrow \mu e)$	$< 2.62 \times 10^{-7}$	5.7×10^{-8}	$10^{-8} - 10^{-10}$	10^{-9}



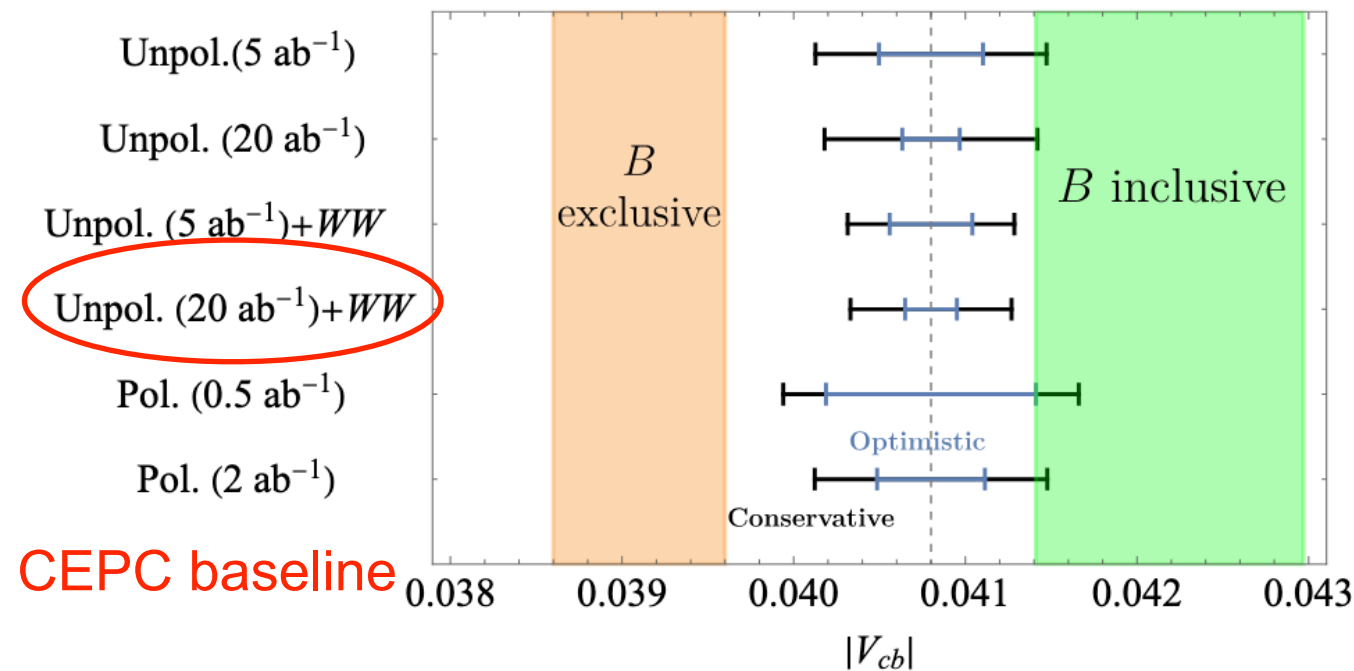
- Higgs current operators: $O_{\phi\ell}^{(1)} \equiv i(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi)(\bar{L}\gamma^\mu L)$, $O_{\phi\ell}^{(3)} \equiv i(\Phi^\dagger \tau^I \overleftrightarrow{D}_\mu \Phi)(\bar{L}\tau^I \gamma^\mu L)$, $O_{\phi e} \equiv i(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi)(\bar{E}\gamma^\mu E)$
- Dipole operators: $O_{eZ} \equiv (\sin\theta_w O_{eB} + \cos\theta_w O_{eW})$ with $O_{eB} \equiv (\bar{L}\sigma^{\mu\nu} E)\Phi B_{\mu\nu}$, $O_{eW} \equiv (\bar{L}\sigma^{\mu\nu} E)\tau^I \Phi W_{\mu\nu}^I$



W Boson - V_{cb} Measurement



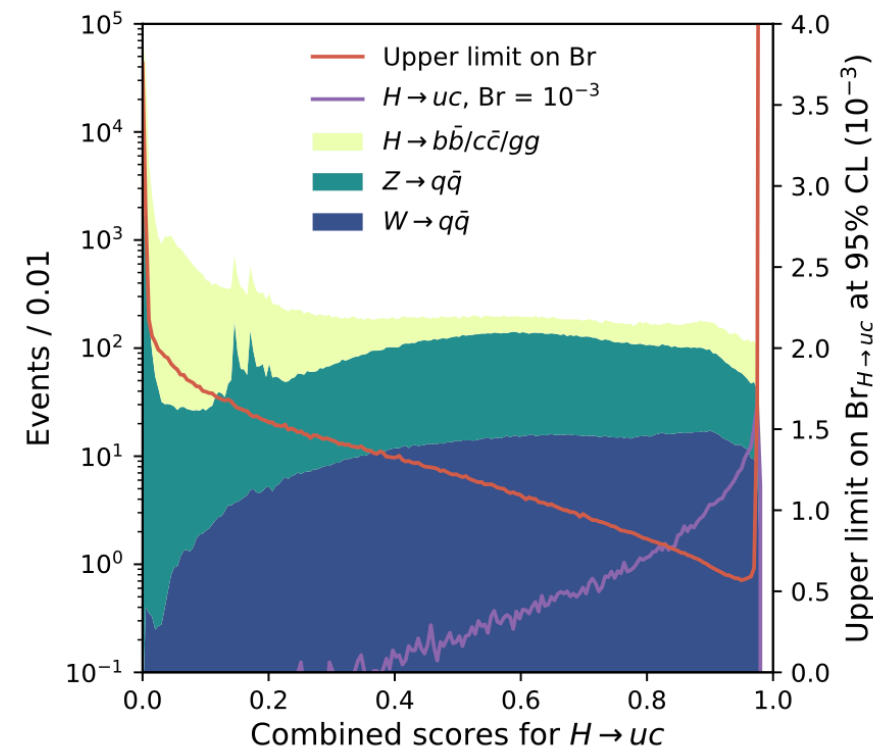
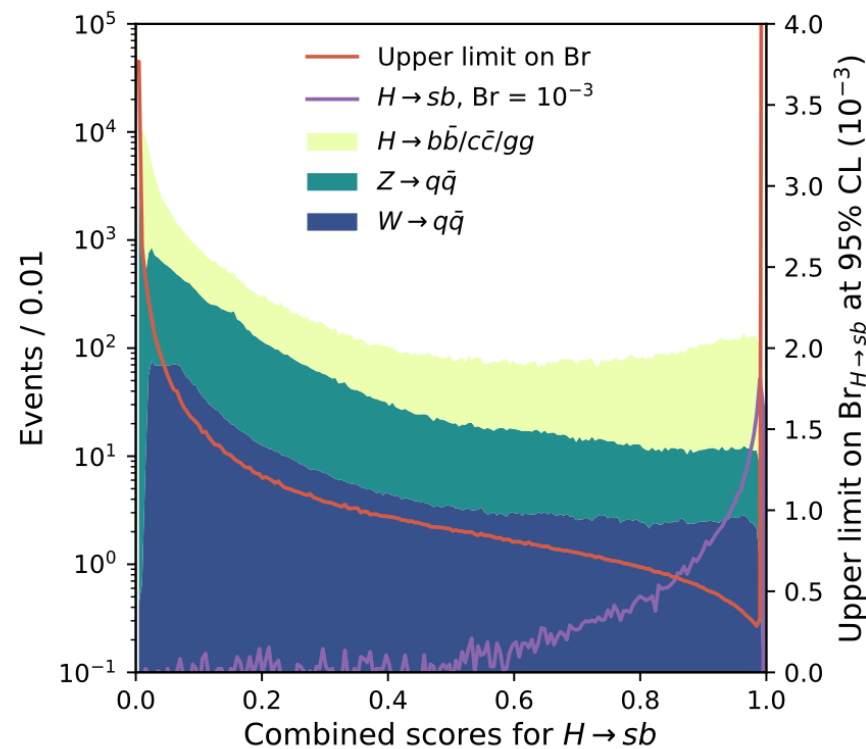
$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$



- Current precision is of percent level.
 - Discrepancy exists
- At CEPC, could be measured through
 - $b \rightarrow c$ transition at Z pole
 - $W \rightarrow bc$ at WW threshold
- Could be improved by one more order of magnitude at CEPC, potentially resolving the tension

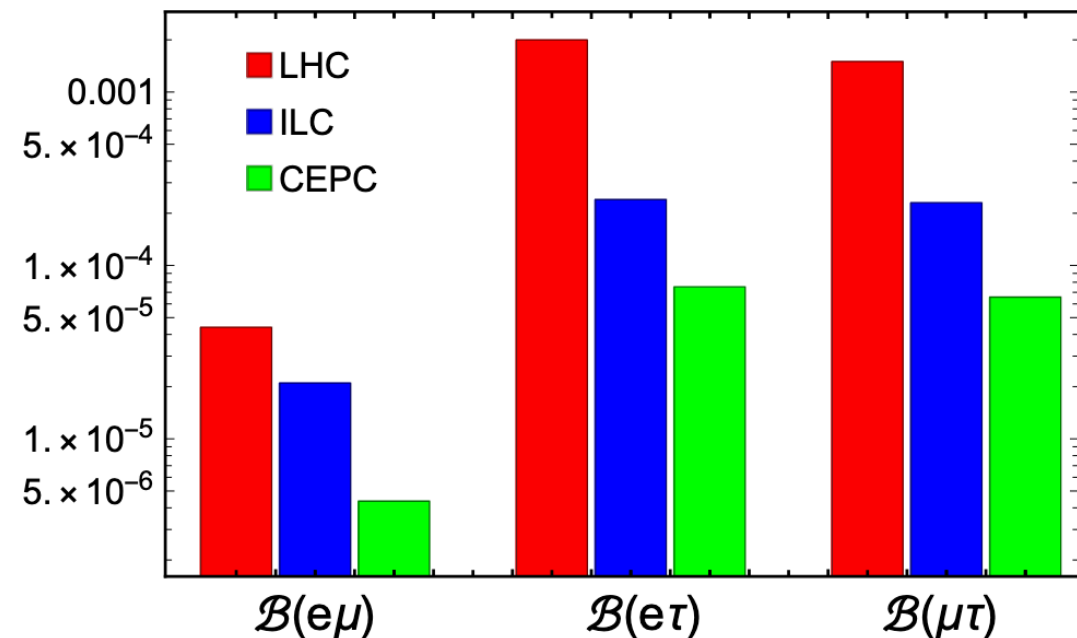


Higgs Boson - Flavor-violating Decays



$$O_{u\varphi}^{(ij)} = (\Phi^\dagger \Phi) \bar{Q}_i \tilde{\Phi} U_j, \quad O_{d\varphi}^{(ij)} = (\Phi^\dagger \Phi) \bar{Q}_i \Phi D_j$$

- 6D Yukawa operators: misaligned fermion mass matrix and Yukawa couplings $\Rightarrow$ Flavor off-diagonal effects.
- Contribute to both Higgs decays and heavy-flavor physics (mixing and decays)



[leptonic tau decays considered]



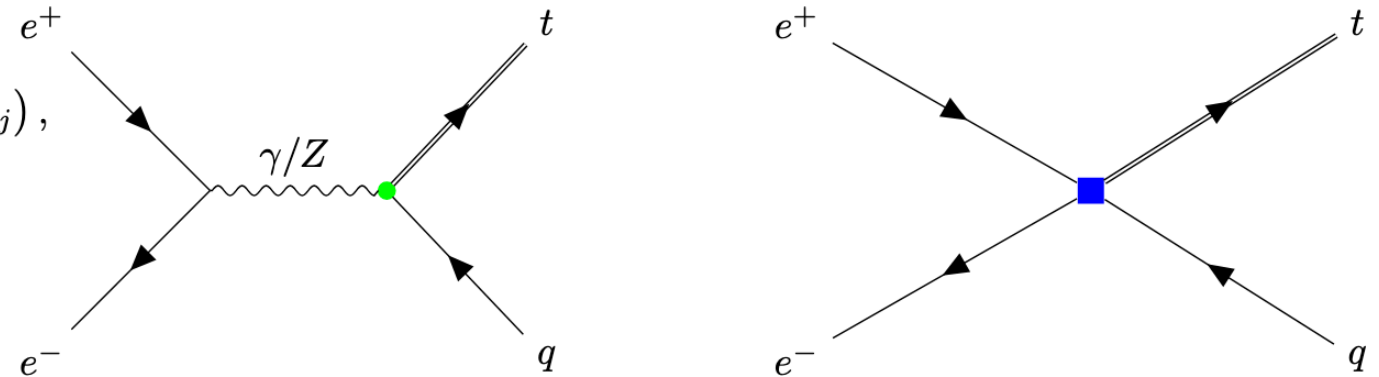
Top Quark

- Single top productions
 - Two-fermion FCNC operators (mainly constrained by LHC)

$$O_{\varphi q}^{1(ij)} = i \left(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi \right) (\bar{Q}_i \gamma^\mu Q_j), \quad O_{\varphi q}^{3(ij)} = i \left(\Phi^\dagger \tau^I \overleftrightarrow{D}_\mu \Phi \right) (\bar{Q}_i \gamma^\mu \tau^I Q_j),$$

$$O_{\varphi u}^{(ij)} = i \left(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi \right) (\bar{U}_i \gamma^\mu U_j),$$

$$O_{uW}^{(ij)} = (\bar{Q}_i \sigma^{\mu\nu} \tau^I U_j) \tilde{\Phi} W_{\mu\nu}^I, \quad O_{uB}^{(ij)} = (\bar{Q}_i \sigma^{\mu\nu} U_j) \tilde{\Phi} B_{\mu\nu},$$



- Four fermion contact operators (mainly constrained by LEP II)

$$O_{lq}^{1(ijkl)} = (\bar{L}_i \gamma_\mu L_j) (\bar{Q}_k \gamma^\mu Q_l), \quad O_{lq}^{3(ijkl)} = (\bar{L}_i \gamma_\mu \tau^I L_j) (\bar{Q}_k \gamma^\mu \tau^I Q_l),$$

$$O_{lu}^{(ijkl)} = (\bar{L}_i \gamma_\mu L_j) (\bar{U}_k \gamma^\mu U_l),$$

$$O_{eq}^{(ijkl)} = (\bar{E}_i \gamma_\mu E_j) (\bar{Q}_k \gamma^\mu Q_l), \quad O_{eu}^{(ijkl)} = (\bar{E}_i \gamma_\mu E_j) (\bar{U}_k \gamma^\mu U_l),$$

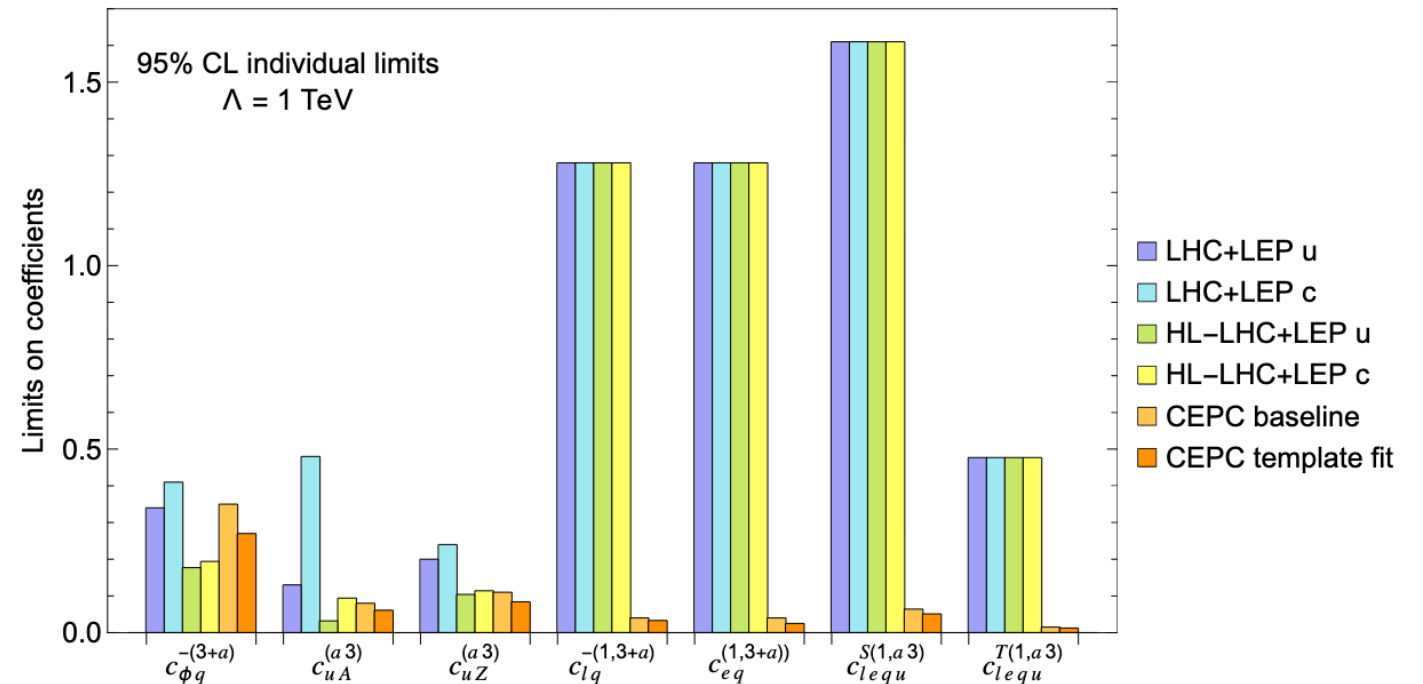
$$O_{lequ}^{1(ijkl)} = (\bar{L}_i E_j) \varepsilon (\bar{Q}_k U_l), \quad O_{lequ}^{3(ijkl)} = (\bar{L}_i \sigma_{\mu\nu} E_j) \varepsilon (\bar{Q}_k \sigma^{\mu\nu} U_l).$$

- Can be expanded to top pair events. E.g.,

- Current LHC bound:

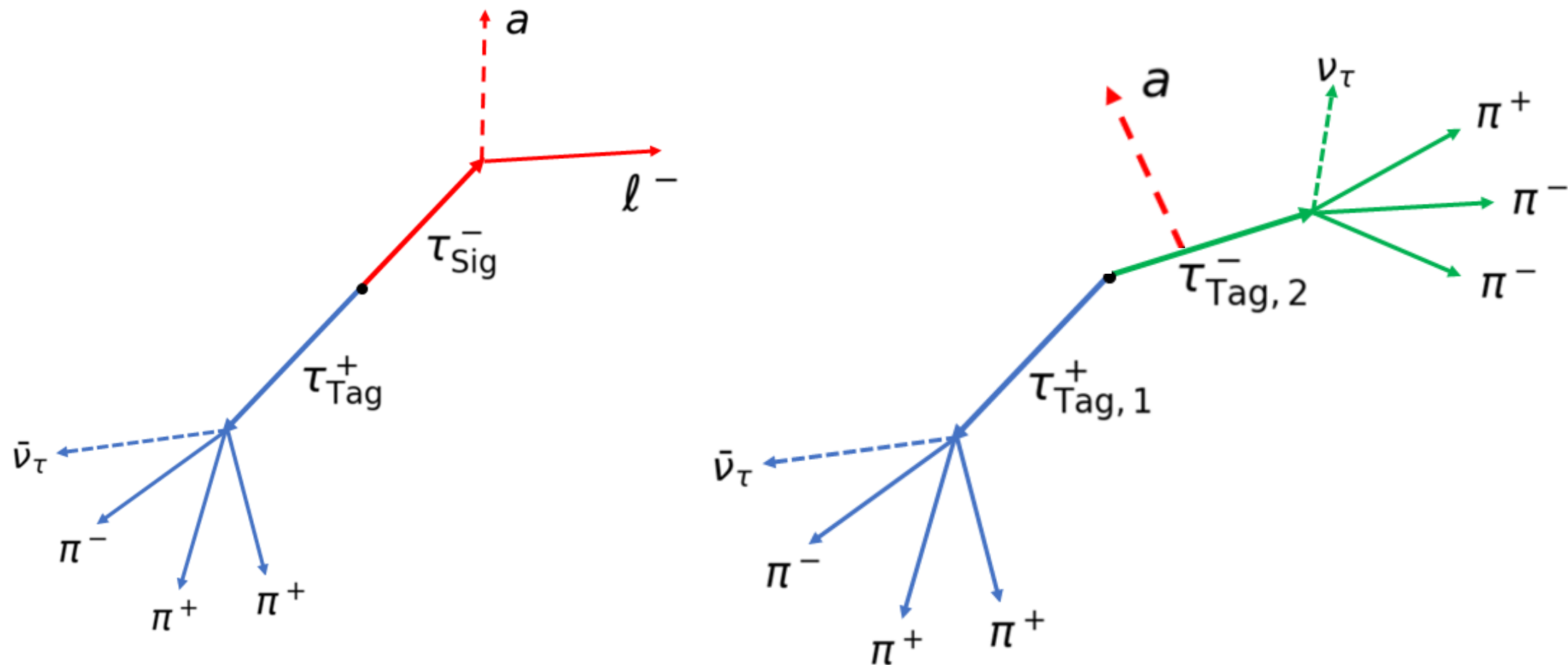
$$\text{BR}(t \rightarrow cH) < 4.3 \times 10^{-4} \text{ at 95\% C.L.}$$

- At CEPC: could be improved by one order of magnitude





Light Hidden Bosons - General Comments

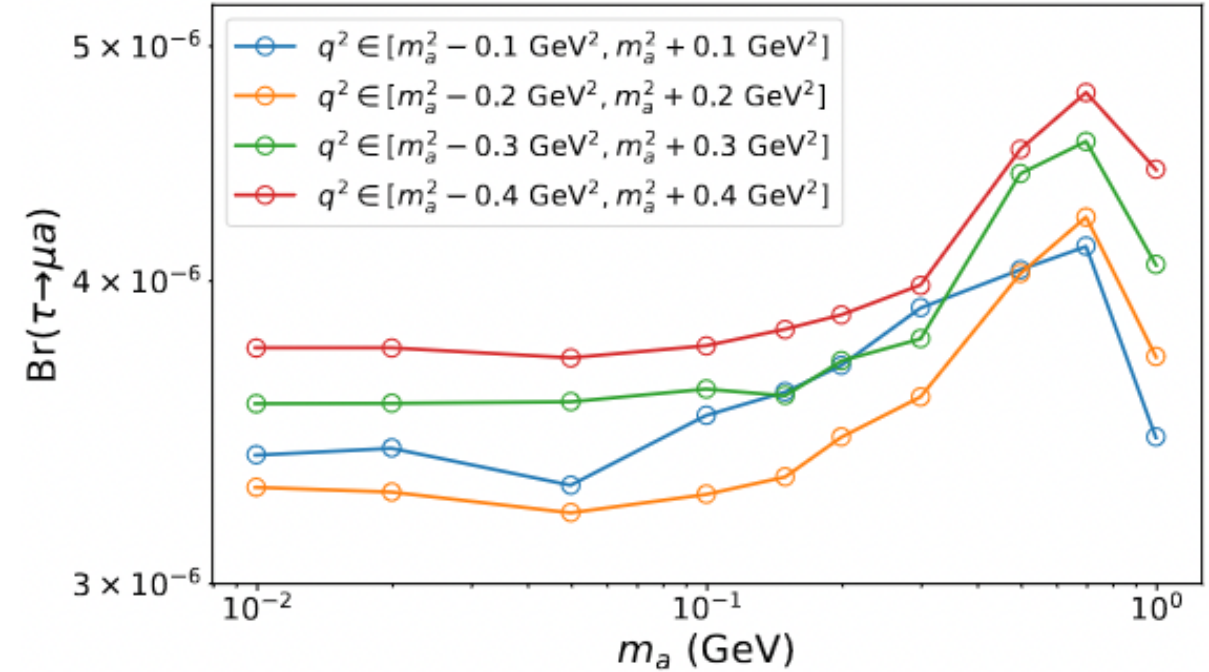
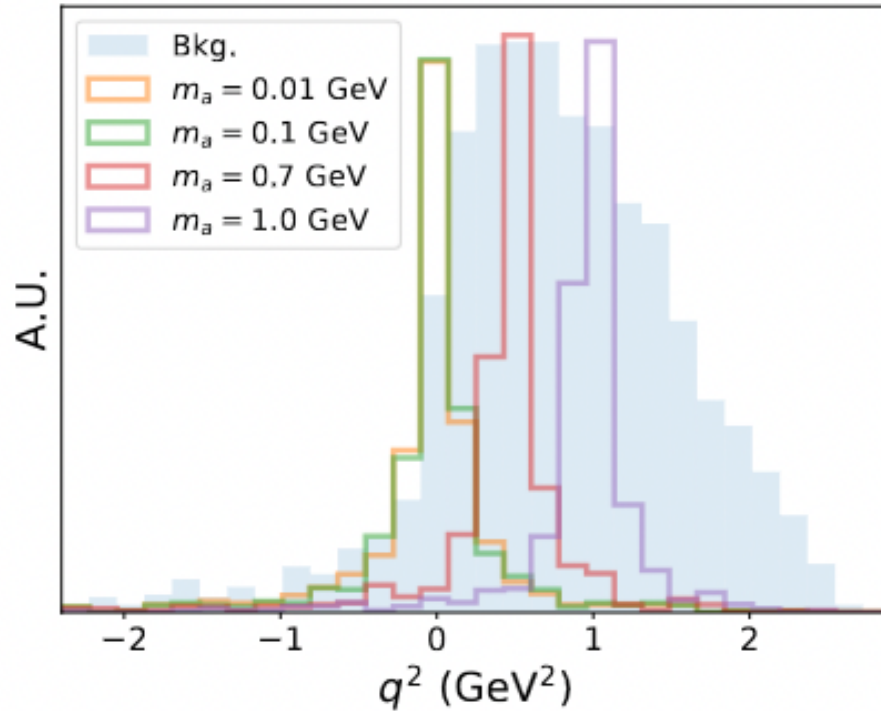


- Light bosons (axion, dark photon, dark pion, etc.) can couple to lepton and quark sectors, in a way either flavor-conserving or violating
- Thus could be radiated from initial or final state particles, or produced in lepton/quark decays, in flavor-physics experiments
- Yield a signature of missing energy, a long-lived particle or a visible resonance



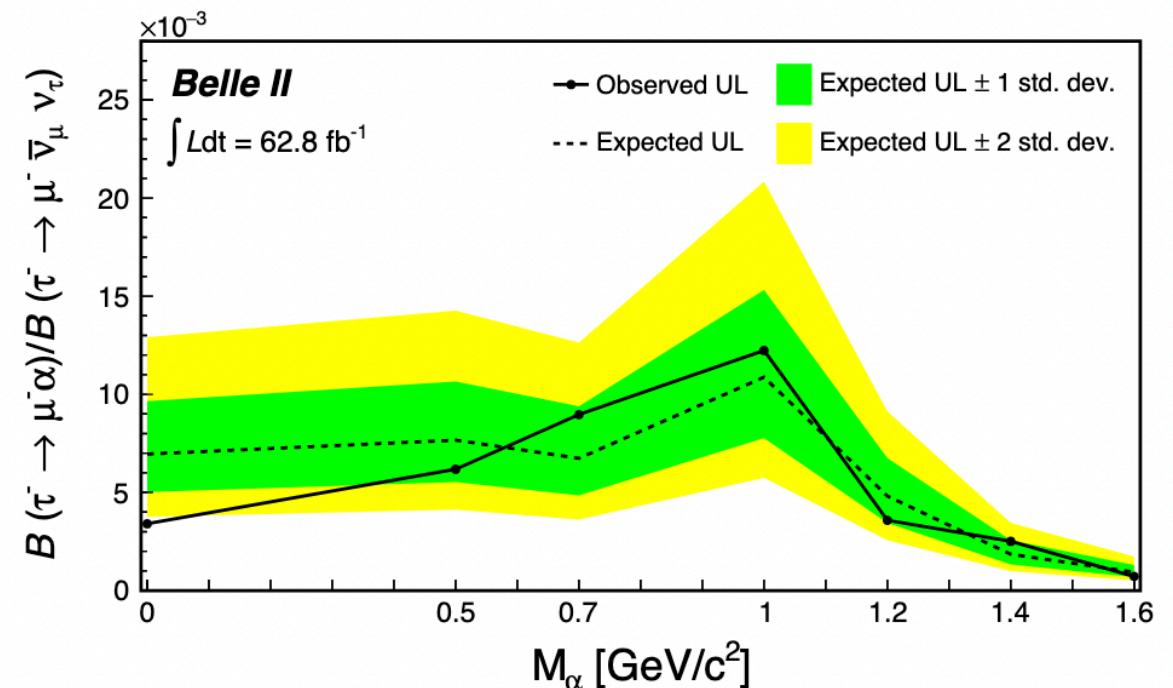
Light Hidden Bosons - Axions

$$Z \rightarrow \tau(\rightarrow \ell + \text{Missing})\tau(\rightarrow 3\pi\nu)$$



Translate to $\text{Br}(\tau \rightarrow \mu a) \sim O(10^{-5})$
for Belle II (50/ab)

[Belle II collaboration,
Phys.Rev.Lett (2023)]





Summary

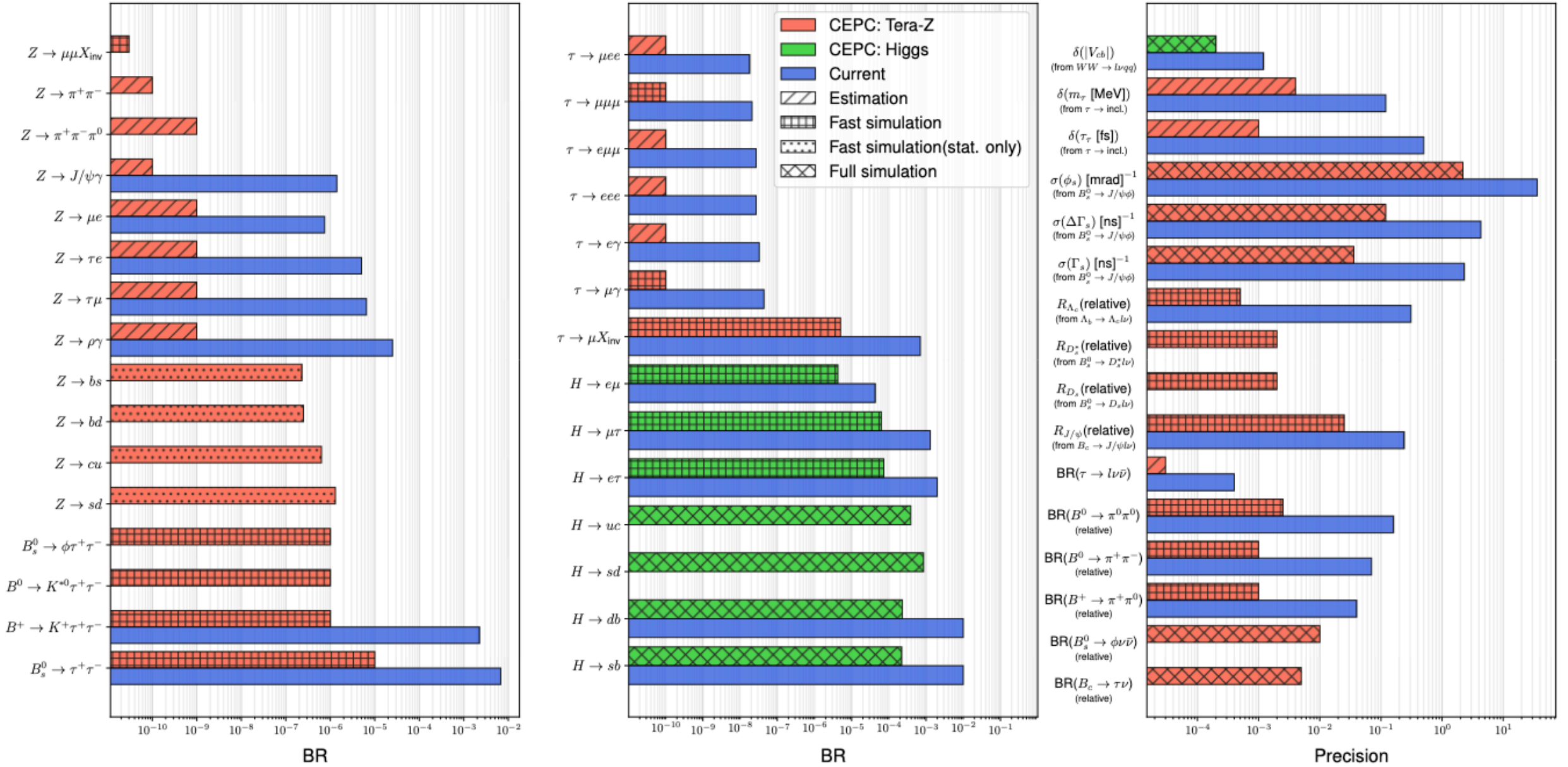
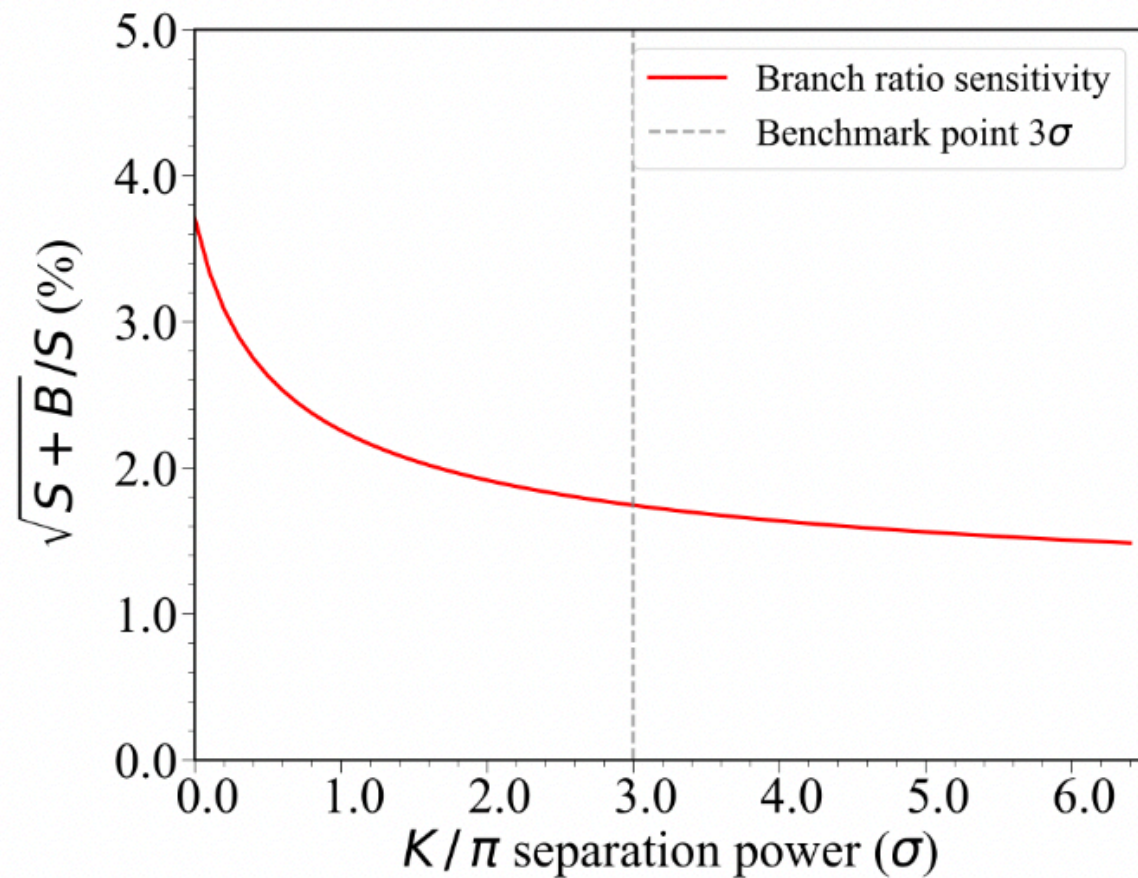


Figure 46: Anticipated upper limits or measurement precisions for the flavor physics benchmarks at the CEPC. It should be remarked that the limits of Z hadronic FCNC decays are statistic w.r.t. current performance of jet origin identification, whose calibration remains challenging. A breakthrough is thus needed to control the relevant systematic uncertainty to a level comparable to their statistic ones.

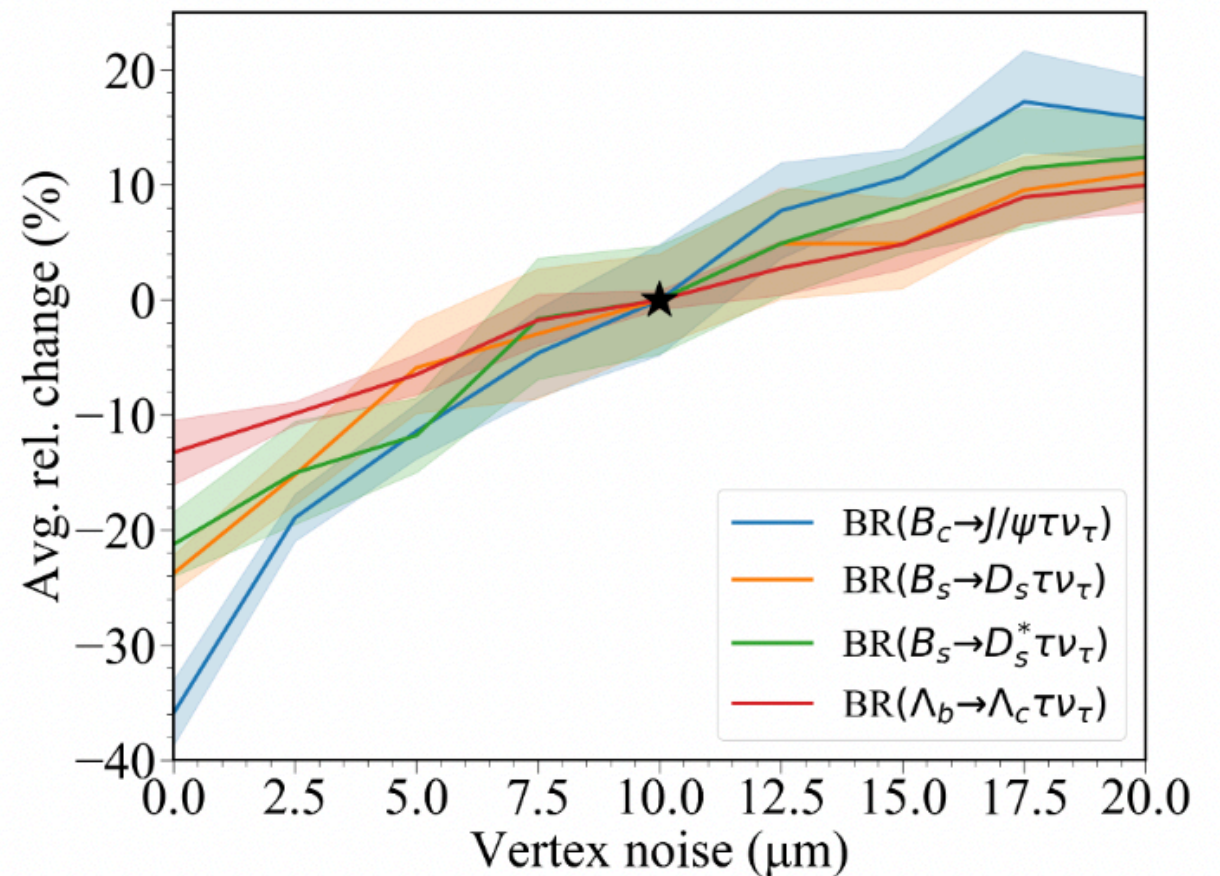


Comments - Detector Performance

- Baseline detector profile has been applied for most of these studies
- Study on the correlation between the sensitivities and detector performance can help to optimize both detector design and physics target precision



BR($B_s \rightarrow \phi \nu \bar{\nu}$) vs. PID performance

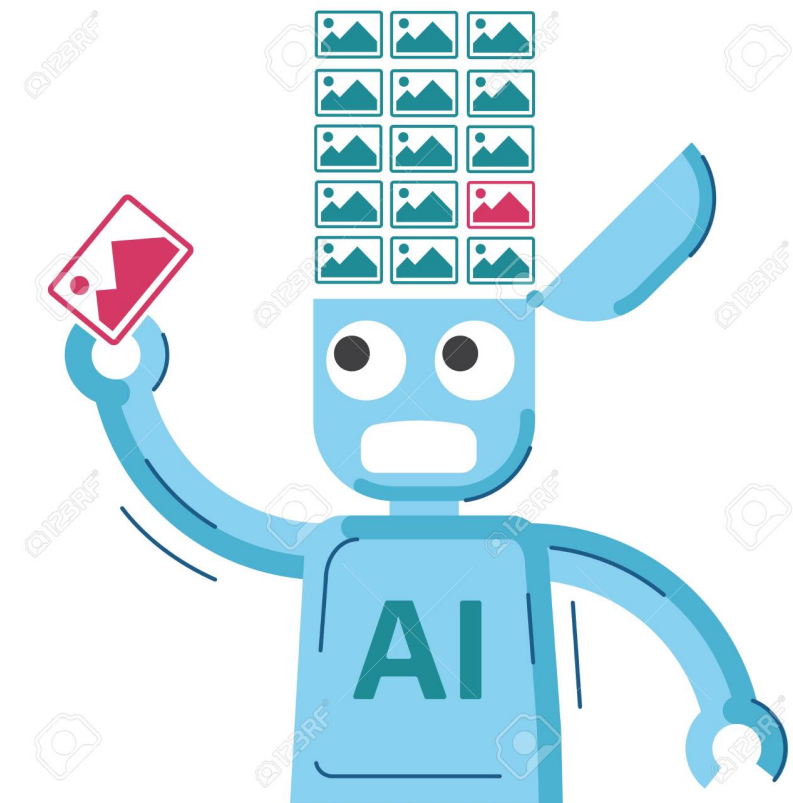


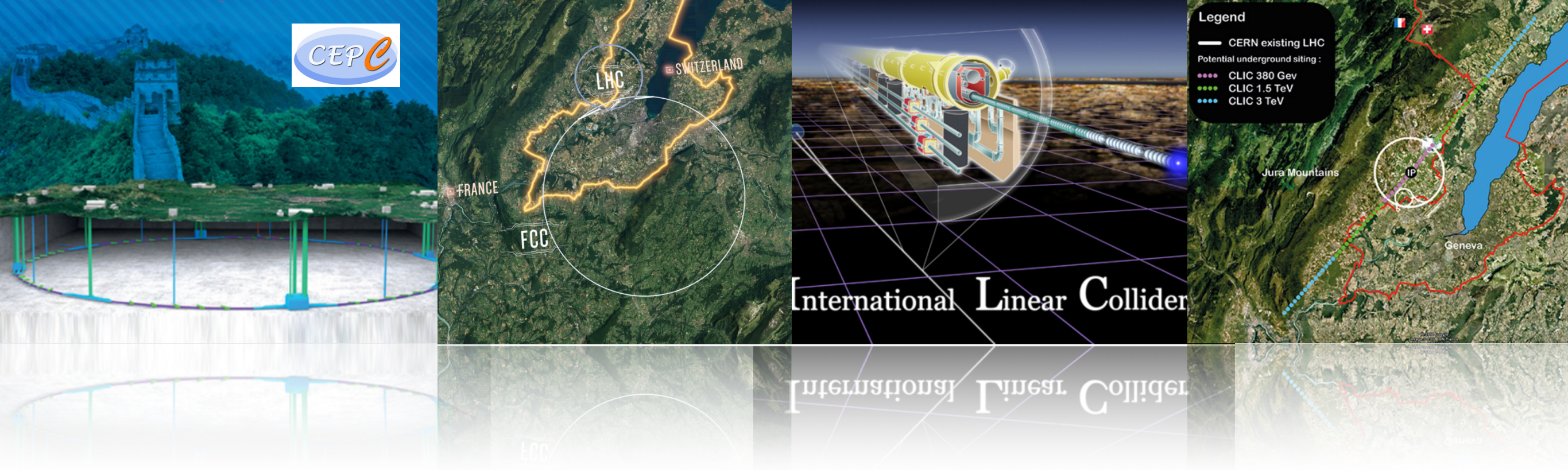
BR($H_b \rightarrow H_c \tau \nu_\tau$) vs. detector vertex noise



Comments - Systematics and AI

- Systematics understanding
 - Current discussions of sensitivities are essentially statistical
 - Can the experimental systematics be controlled to be below or comparable to the statistical ones?
 - Can theoretical accuracy for the background calculations and the signal predictions catch up with experiment progress by the time of CEPC data taking?
- Advanced AI tools
 - Most studies here are cut-based
 - ML tools can address complex event topology
 - AI agent may further boost the efficiency of data analysis and theory interpretation





Take-home Message

As a multi-functional machine, we would like to know the capability of the next-generation e^-e^+ colliders like CEPC, to push forward the relevant physics frontiers.

As part of its physics potential, Higgs physics, electroweak precision measurements and top physics at such an e^-e^+ collider have been broadly studied

Flavor physics is of high scientific value. The opportunities brought up by such a machine should be fully explored also.

This white paper aims to offer a perspective - a comprehensive survey is still needed.



大學教育資助委員會
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Thank you!