LFU tests and other flavor physics opportunities at CEPC

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Apr. 15, Yangzhou
Joint Workshop of the CEPC Physics, Software and New Detector Concept

Lepton Flavor Universality (Violation)

Lepton flavor universality (LFU) demands that charged leptons have (almost) identical interactions, only differ by their Yukawa couplings and hence their masses.

However, in both flavor changing neutral current (FCNC) and flavor changing neutral current (FCCC) processes

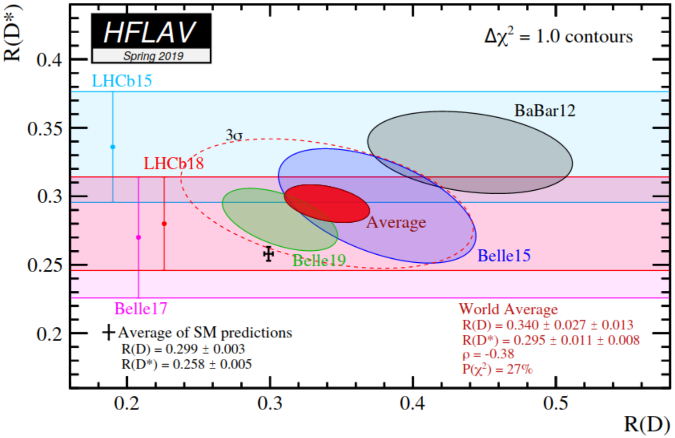
$$R_{K^{(*)}} \equiv \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)} \ , \tag{1}$$

$$R_{D^{(*)}} \equiv \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)} \ , \tag{2}$$

$$R_{J/\psi} \equiv \frac{\mathrm{BR}(B_c \to J/\psi\tau\nu)}{\mathrm{BR}(B_c \to J/\psi\ell\nu)} \ , \tag{3}$$

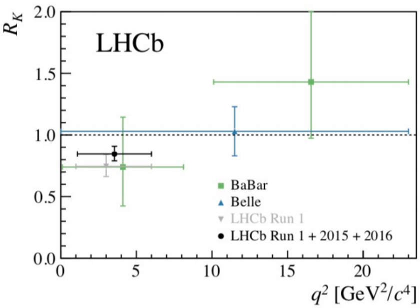
LFU is challenged.

FCCC B Anomalies

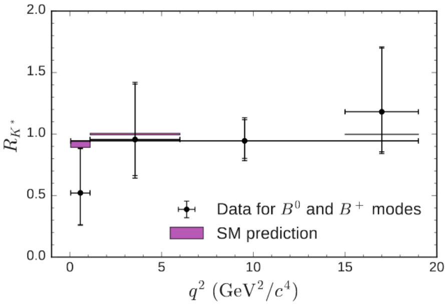


[Amhis et al., 2019]

FCNC Anomalies



R_K [Aaij et al., 2019].



R_{K^*} [Abdesselam et al., 2019].

Deviations in low-q^2 bins: robust against $c\bar{c}$ resonant/loop contributions (SM prediction ~ 1).

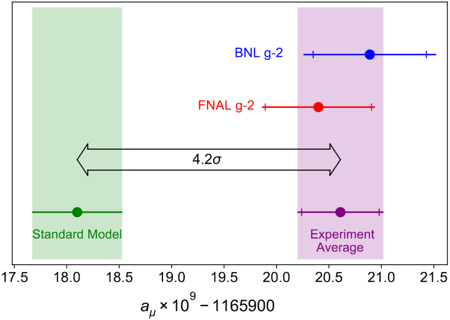
FCCC and FCNC B Anomalies

	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].

Also evidence for a BR($B_s \to \phi\mu\mu$), $m^2_{\mu\mu} \in [1, 6]$ GeV^2 below SM by $\sim 3\sigma$ [Aaij et al., 2015]

Muon $g-2$?



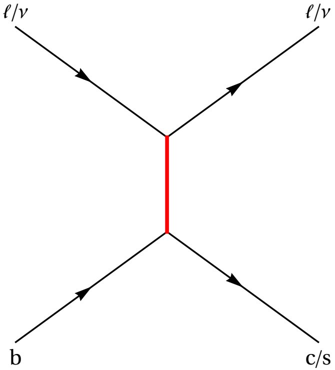
[Abi et al., 2021]

Such deviation is not observed in $g_e - 2$, a hint of LFUV?

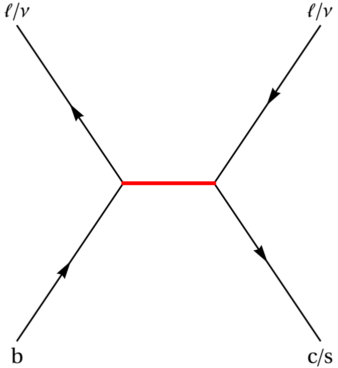
Lorenzo should have explained everything!

LFUV in BSM: Simplified Models (LO)

Induced by two types of heavy mediators:



Colorless Mediators



Colored Mediators (Leptoquarks)

LFUV in BSM: Simplified Models at Tree Level (II)

Model	Spin	SM charge	$b \to c\tau\nu$ operators
Scalars	0	$(1,2)_0$	O_S^τ, O_P^τ
V'	1	$(1,3)_0$	$O_V^\tau - O_A^\tau$
LQ S_1	0	$(\bar{3},1)_{\frac{1}{3}}$	$O_V^\tau - O_A^\tau$, $O_S^\tau - O_P^\tau - 4O_T^\tau$
LQ S_3	0	$(\bar{3},3)_{\frac{1}{3}}$	$O_V^\tau - O_A^\tau$
LQ R_2	0	$(3,2)_{\frac{7}{6}}$	$O_S^\tau - O_P^\tau + 4O_T^\tau$
LQ U_1	1	$(3,1)_{\frac{2}{3}}$	$O_V^\tau - O_A^\tau$, $O_S^\tau + O_P^\tau$
LQ U_3	1	$(3,3)_{\frac{2}{3}}$	$O_V^\tau - O_A^\tau$
LQ V_3	1	$(3,2)_{\frac{5}{6}}$	$O_S^\tau + O_P^\tau$

$b \to c\ell\nu$ (FCCC) Operators

$$H^{\text{eff}}_{b\to c\ell\nu} = \frac{4G_F V_{cb}}{\sqrt{2}} \sum_i C_i O_i \ , \tag{4}$$

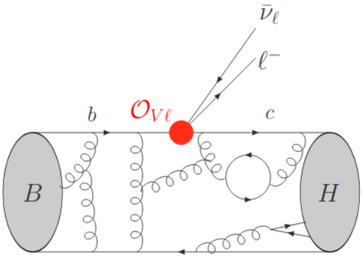
$$O^{cb\ell\nu}_{VL(R)} = [\bar{c}\gamma^\mu b][\bar{\ell}\gamma_\mu P_{L(R)}\nu] \ , \tag{5}$$

$$O^{cb\ell\nu}_{AL(R)} = [\bar{c}\gamma^\mu\gamma^5 b][\bar{\ell}\gamma_\mu P_{L(R)}\nu] \ , \tag{6}$$

$$O^{cb\ell\nu}_{SL(R)} = [\bar{c}b][\bar{\ell}P_{L(R)}\nu] \ , \tag{7}$$

$$O^{cb\ell\nu}_{PL(R)} = [\bar{c}\gamma^5 b][\bar{\ell}P_{L(R)}\nu] \ , \tag{8}$$

$$O^{cb\ell\nu}_{TL(R)} = [\bar{c}\sigma^{\mu\nu} b][\bar{\ell}\sigma_{\mu\nu}P_{L(R)}\nu] \ , \tag{9}$$



Only L operators survive w/o right-handed neutrinos.

$b \to s\ell\ell$ and $b \to s\nu\nu$ (FCNC) Operators

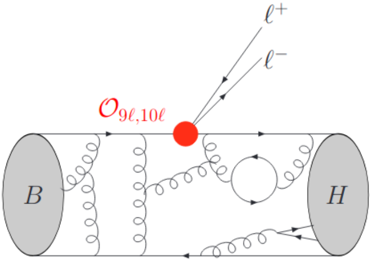
$b \to s\tau\tau$:

$$H^{\rm eff}_{b\to s\tau\tau} = H^{\rm SM}_{b\to s\tau\tau} + \frac{-4G_F V_{tb}V^*_{ts}}{\sqrt{2}} \times \qquad (10)$$

$$[C^{\rm NP}_9 O^\tau_9 + C^{\rm NP}_{10} O^\tau_{10} + C_{9'} O^\tau_{9'} + C_{10'} O^\tau_{10'}] \ .$$

$$O^\tau_{9(10)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_L b][\bar{\tau}\gamma_\mu(\gamma^5)\tau] \qquad (11)$$

$$O^\tau_{9'(10')} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_R b][\bar{\tau}\gamma_\mu(\gamma^5)\tau] \ ,$$



$b \to s\nu\nu$:

$$H^{\rm eff}_{b\to s\nu_i\nu_j} = \frac{-\alpha G_F V_{tb}V^*_{ts}}{2\sqrt{2}\pi}(C^{(ij)}_L[\bar{s}\gamma^\mu P_L b][\bar{\nu}_i\gamma_\mu P_L\nu_j] + C^{(ij)}_R[\bar{s}\gamma^\mu P_R b][\bar{\nu}_i\gamma_\mu P_L\nu_j]) \ . \qquad (12)$$

Strongly constrained by BR$(B \to K^{(*)}\nu\nu)$

Match with SMEFT

These operators are then closely related in SMEFT via gauge gauge invariance. Eg. dim-6 four-fermion operators [Grzadkowski et al., 2010, Azatov et al., 2018]:

$$\mathcal{L}^{\rm dim6} \supset \frac{1}{\Lambda^2} \sum \Big([C_{q\ell}^{(1)}][O_{q\ell}^{(1)}] + [C_{q\ell}^{(3)}][O_{q\ell}^{(3)}] + [C_{de}][O_{de}] + [C_{qe}][O_{qe}] + [C_{d\ell}][O_{d\ell}] + [C_{dq\ell e}][O_{dq\ell e}] + ... \Big) + \text{h.c.}\ , \quad (13)$$

$[O_{q\ell}^{(1)}]_{ijkl} = [\bar{Q}_i\gamma^\mu Q_j][\bar{L}_k\gamma_\mu L_l],\ [O_{q\ell}^{(3)}]_{ijkl} = [\bar{Q}_i\gamma^\mu\sigma^a Q_j][\bar{L}_k\gamma_\mu\sigma^a L_l]$
contribute to $b\to c\tau\nu, b\to s\tau\tau(\ell\ell)$ and $b\to s\nu\nu$.

$[O_{de}]_{ijkl} = [\bar{d}_i\gamma^\mu d_j][\bar{\ell}_k\gamma_\mu\ell_l]\ ,\ [O_{qe}]_{ijkl} = [\bar{Q}_i\gamma^\mu Q_j][\bar{\ell}_k\gamma_\mu\ell_l] \Rightarrow b\to s\tau\tau(\ell\ell)$

$[O_{d\ell}]_{ijkl} = [\bar{d}_i\gamma^\mu d_j][\bar{L}_k\gamma_\mu L_l] \Rightarrow b\to s\tau\tau(\ell\ell)$ and $b\to s\nu\nu$

$[O_{dq\ell e}]_{ijkl} = [\bar{d}_i Q_j^I][\bar{L}_k^I \ell_l] \Rightarrow b\to c\tau\nu$ and $b\to s\tau\tau(\ell\ell)$

...

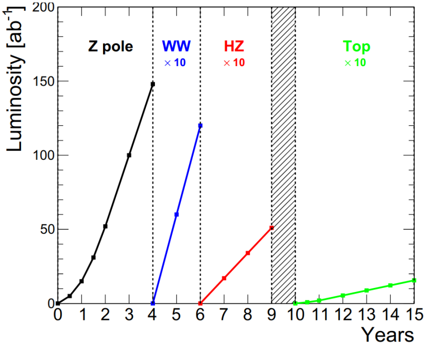
Unique Opportunities at Z pole

Giga-Z, Tera-Z and $10\times$Tera-Z: a phase of future linear/circular lepton colliders. [Fujii et al., 2019, Dong et al., 2018, Abada et al., 2019]

Flavor physics "for free"!

Operation mode	$\sqrt{s}$ (GeV)	L per IP (10^{34} cm^{-2}s^{-1})	Years	Total $\int L$ (ab^{-1}, 2 IPs)	Event yields
H	240	3	7	5.6	1×10^6
Z	91.2	32 (*)	2	16	7×10^{11}
W^+W^-	158–172	10	1	2.6	2×10^7 (†)

CEPC $\sim$ Tera-Z (CDR, still moving forward)



FCC-ee $\sim 10\times$ Tera-Z

Vs. B Factories and Hadron Colliders

Z factories are also $b(c/\tau)$ factories:

Channel	Belle II	LHCb	Giga-Z	Tera-Z	10×Tera-Z
B^0, $\bar{B}^0$	5.3×10^{10}	$\sim 6\times10^{13}$	1.2×10^{8}	1.2×10^{11}	1.2×10^{12}
$B^{\pm}$	5.6×10^{10}	$\sim 6\times10^{13}$	1.2×10^{8}	1.2×10^{11}	1.2×10^{12}
B_s, $\bar{B}_s$	5.7×10^{8}	$\sim 2\times10^{13}$	3.2×10^{7}	3.2×10^{10}	3.2×10^{11}
$B_c^{\pm}$	-	$\sim 4\times10^{11}$	2.2×10^{5}	2.2×10^{8}	2.2×10^{9}
Λ_b, $\bar{\Lambda}_b$	-	$\sim 2\times10^{13}$	1.0×10^{7}	1.0×10^{10}	1.0×10^{11}

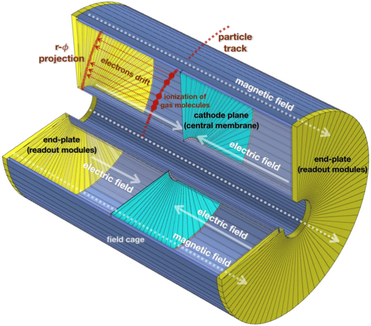
VS. B Factories

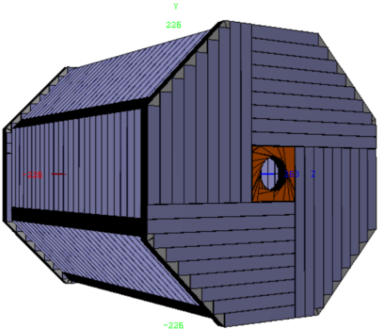
- Much higher b quark boost (by $\mathcal{O}(10)$)
- Better track momentum measurements
- Larger displacements with smaller uncertainty
- Abundant heavy b hadron

VS. Hadron Colliders

- Fixed E_{cm}
- Clean environment
- Direct missing momenta measurement
- Larger detector acceptance
- Better flavor tagging efficiency

Improvement of Detector Systems





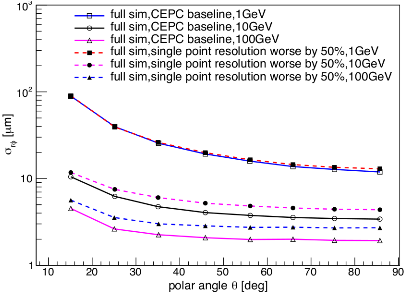
We are going to invest heavily in detector systems ($\gtrsim 10\%$ of the overall budget.)

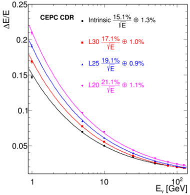
What shall we expect from them?

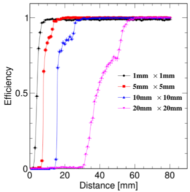
Improvement of Detector Systems (II)

Naively dream about/ask for: (Aggressive, more realistic with $N_{\text{detector}} > 1$?)

- $\pi/K \gtrsim 4\sigma,\ p/K \gtrsim 2\sigma$ @50 GeV
- $\pi/K \gtrsim 5\sigma,\ p/K \gtrsim 3\sigma$ @$\lesssim 2$ GeV
- $\mu/\pi \gtrsim 1(2)\sigma$ @$< (>) 4$GeV (in jets?)
- $e/\pi \gtrsim 3\sigma$, $e/\mu \gtrsim 5\sigma$ (in jets?)
- $\sigma_{p_T,\text{track}}/p_T^2 \lesssim 2\times 10^{-5}$ GeV^{-1}
- $\sigma_{\text{IP}} \lesssim 5 \bigoplus 10/p_T$ μm
- $\sigma_{E,\text{ECAL}}/E \lesssim 5\%/\sqrt{E} \bigoplus 0.5\%$
- $\sigma_{\theta,\text{ECAL}} \lesssim 5$ mrad
- $\sigma_{E,\text{HCAL}}/E \lesssim 50\%/\sqrt{E}$ @ 50 GeV
- $\gamma/K^0/n$ discrimination?

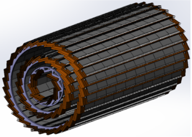


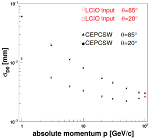




Key Detector Features for Flavor Physics

Materials from Zhijun, Chengdong, and Yunlong's talks



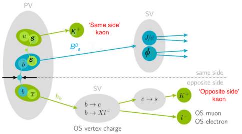


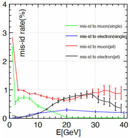
Tracking sys, grants $\mathcal{O}(10)$ fs sensitivity.

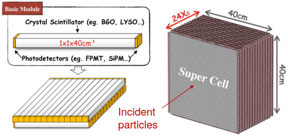
- High time precision for CPV measurements.
- Authentic c/τ reconstruction inside a jet.
- Greater acceptance for displaced signals.

Advanced PID coming from the combination of $dE(N)/dx$ method, time resolution and calorimetry:

- Flavor tagging for everything.
- Suppressing backgrounds in general.
- Clean leptonic/baryonic modes.
- ...







Calorimetry gives neutral energy and angular resolution.

- Better $\not{p}$ measurement for neutrinos.
- Excited states such as D_s^* and radiative decays.
- Distinguishing π^0/η..., allowing h^0X modes.
- ...

Vs. Proposed Experiments: How do Golden Modes Look Like?

Multiple charged tracks	Vs. Belle II, low track energy
Multiple time scale $\mathcal{O}(10)$ fs	Vs. Belle II, low track displacement
h^0 or γ (but no more than 1-2)	Vs. LHCb, large QCD noise
e instead of μ ?	Vs. LHCb, relying on MS
ν or other invisible fellas	Vs. LHCb, no sensitivity in principle
Λ or $K_S \to h^+h^-$	Vs. LHCb, low acceptance
Baryonic modes (p or $\Sigma^\pm$?)	Vs. both, advanced PID
Heavy hadrons ($B_s,\ B_c,\ \Lambda_b$, Ξ_b, ...)	Vs. Belle II, imited $\sqrt{s}$
Double heavy flavor (B_c, exotics...)	Vs. both, unique @ the Z pole
...	...

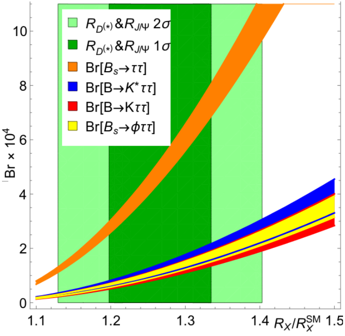
Sounds like ideal for LFU tests.

Other examples include: τ physics ($Z \to \tau\tau$ or τX, see Lorenzo's talk), $B_{d,s} \to \pi^0\pi^0$ (see Yuexin's talk)...

LFU Test with $b \to s\tau\tau$ Measurements

Current $b \to c\tau\nu$ anomalies indicate large enhancement of $b \to s\tau\tau$ rates. [Capdevila et al., 2018]

Current experiment constraint on BR $\sim 10^{-2.5}$



$$\delta C_9^\tau = -\delta C_{10}^\tau$$

$$= \frac{-2\pi V_{cb}}{\alpha V_{tb} V_{ts}^*}\left(\sqrt{\frac{R_X}{R_X^{\rm SM}}} - 1\right)$$

$$\sim \mathcal{O}(10) \times C_{9/10}^{\rm SM}$$

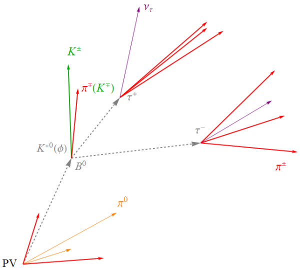
$$O_{9(10)}^\tau = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_L b][\bar{\tau}\gamma_\mu(\gamma^5)\tau]\,,$$

$$O_{9(10)}^{\prime\tau} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_R b][\bar{\tau}\gamma_\mu(\gamma^5)\tau]\,.$$

From SM ($\mathcal{O}(10^{-7})$) to $\mathcal{O}(10^{-4})$

LFU Test with $b \to s\tau\tau$ Measurements

More details in the published work (arXiv:2012.00665) [Li and Liu, 2020]



Use $\tau \to \pi^\pm\pi^\pm\pi^\mp\nu$ decay to locate each vertex

Dominant background from inclusive $D^\pm_{(s)}$ hadronic decays:

	Properties	Decay Mode	BR
$\tau^\pm$	$m = 1.777$ GeV $c\tau = 87.0\ \mu$m	$\pi^\pm\pi^\pm\pi^\mp\nu$ $\pi^\pm\pi^\pm\pi^\mp\pi^0\nu$	9.3% 4.6%
$D_s^\pm$	$m = 1.968$ GeV $c\tau = 151\ \mu$m	$\tau^\pm\nu$ $\pi^\pm\pi^\pm\pi^\mp\pi^0$ $\pi^\pm\pi^\pm\pi^\mp 2\pi^0$ $\pi^\pm\pi^\pm\pi^\mp K_S^0$ $\pi^\pm\pi^\pm\pi^\mp\phi$	5.5% 0.6% 4.6% 0.3% 1.2%
$D^\pm$	$m = 1.870$ GeV $c\tau = 311\ \mu$m	$\tau^\pm\nu$ $\pi^\pm\pi^\pm\pi^\mp\pi^0$ $\pi^\pm\pi^\pm\pi^\mp K_S^0$	$< 0.12\%$ 1.1% 3.0%

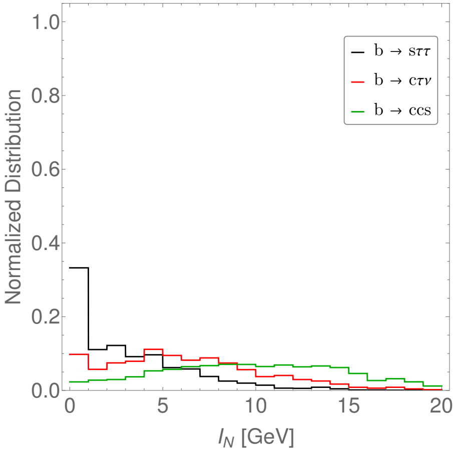
Overwhelmingly Large SM Backgrounds

Background overwhelming ($\mathcal{O}(10^5)$ larger before cuts) rather than background free!

Example	Typical BR
$b \to c\bar{c}s$ Type	
e.g. $B_s \to K^{*0} D_s^{(*)+} D^{(*)-}$	$\mathcal{O}(10^{-2} - 10^{-3})$
$b \to c\tau\nu$ Type	
e.g. $B^0 \to K^{*0} D_s^{(*)-} \tau^+ \nu$	$\mathcal{O}(10^{-3} - 10^{-5})$
$b \to c\bar{u}d$ Type	
e.g. $B^0 \to D^{(*)-} \pi^+ \pi^+ \pi^-$	$\mathcal{O}(10^{-2} - 10^{-3})$

No relevant background studies before!

Efforts to Remove Backgrounds

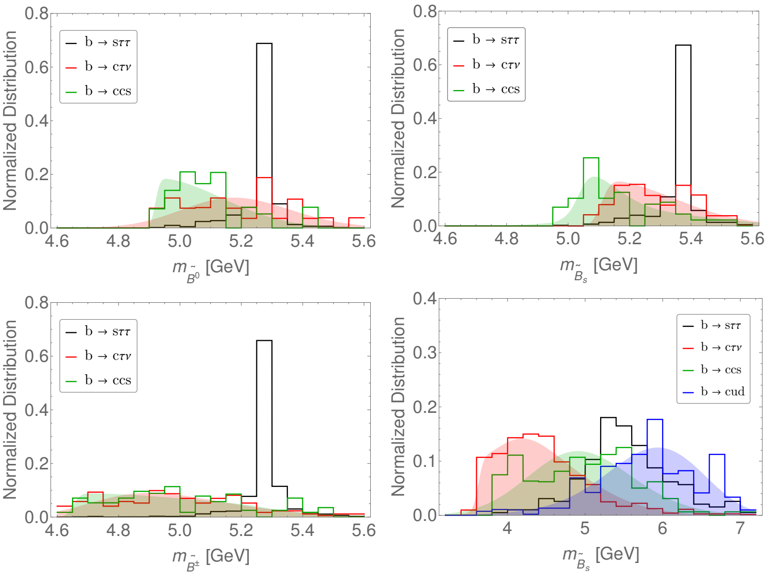


Good calorimetry saves the day!

Quite environment at the Z pole, using isolation variables to veto extra neutral particles (e.g. from $D_s \to \pi^\pm\pi^\pm\pi^\mp + n\pi^0$) and displaced K_S^0.

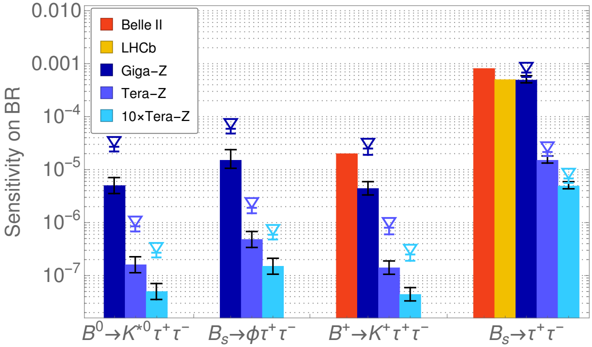
More advanced calorimetry: even better (e.g. π^0 reconstruction)?

Reconstructed Signals and Backgrounds



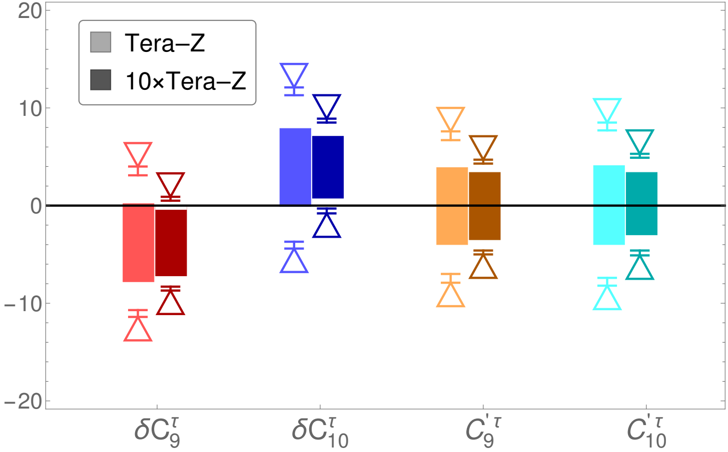
Projected Limits

More details in the published work (arXiv:2012.00665) [Li and Liu, 2020]



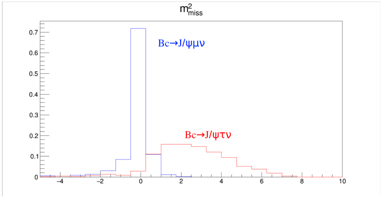
Traditional cut-based analysis: $\mathcal{O}(10^{-5} - 10^{-7})$ precision. Still affected by limited detector spacial resolution ("∇" symbols): Motivation for detector R&D!

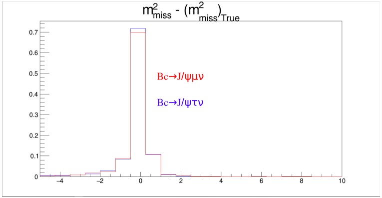
Constraints on EFT



Marginalized 1σ constraints on EFT operators. Current experimental constraint $\sim 10^3$.

LFU Test with FCCC (Prelim.)

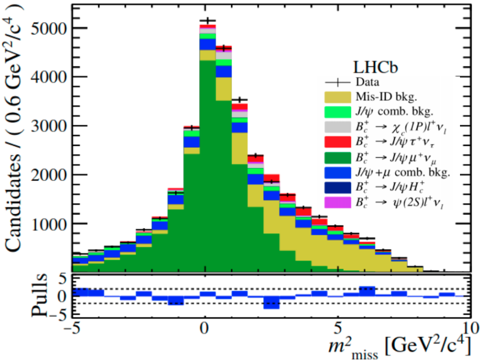




E.g. $R_{J\psi}$ measurement with

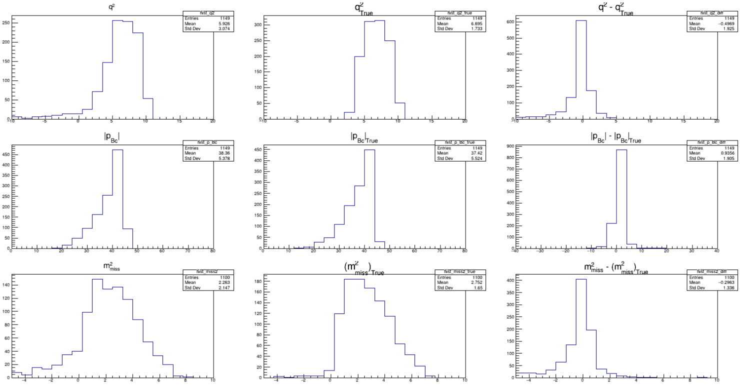
$\tau \to \mu\nu\nu,\ J/\psi \to \mu\mu$

Improved reconstruction quality, also expecting lower combinatoric bkg and mis-ID.



$R_{J/\psi}$ Measurement at Tera-Z (Prelim.)

More details on signal reconstruction (including vertex uncertainties):



Reconstruction quality is satisfying.

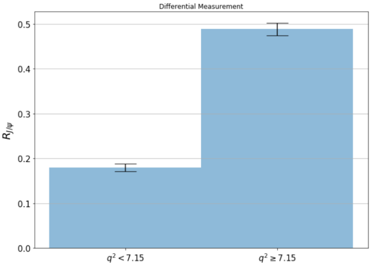
$R_{J/\psi}$ Measurement at Tera-Z (II) (Prelim.)

Cut flow and expected yields targeting $B_c^+ \to J/\psi\,\tau\,\nu_\tau$ mode at Tera-Z:

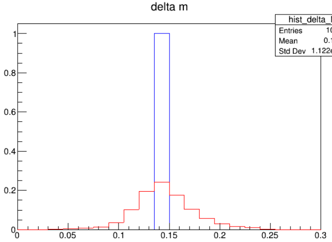
Preliminary!	# of B_c^+ at Tera-Z	$\epsilon_{3\mu}$	ϵ_{pre}	ϵ_{BDT}	Tera-Z yield
$B_c^+ \to J/\psi\,\tau\,\nu_\tau$	$\sim 2.2 \times 10^8$	5.5×10^{-5}	0.34	6.6×10^{-1}	$\sim 2.7 \times 10^3$
$B_c^+ \to J/\psi\,\mu\,\nu_\mu$	$\sim 2.2 \times 10^8$	1.3×10^{-3}	0.35	2.7×10^{-3}	$\sim 2.7 \times 10^2$
$B_c^+ \to \chi_c(1P)\,l^+\,\nu_l$	$\sim 2.2 \times 10^8$	–	–	2.1×10^{-2}	$\sim 8.1 \times 10^1$
$J/\psi + \mu$ comb. bkg.	–	–	0.069	1.6×10^{-2}	$\sim 1.4 \times 10^3$
Mis-ID bkg.	–	–	–	6.3×10^{-3}	$\sim \epsilon_{\mu\pi} \times 6.0 \times 10^3$
Fake-J/ψ bkg.	–	–	–	–	$< r_h \times 9.6 \times 10^0$

The expected precision is $\mathcal{O}(30)$ better, limited by the signal size.

Better result with luminosity$^+$ and using e instead of μ!



Further LFU Tests with FCCC (Prelim).



R_{D_s} and $R_{D_s^*}$:

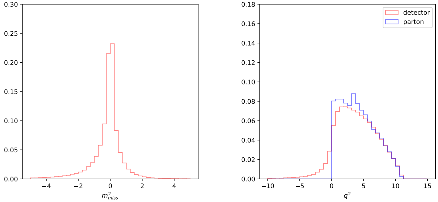
$$R_{D_s^{(*)}} \equiv \frac{\text{BR}(B_s \to D_s^{(*)-} \tau\nu)}{\text{BR}(B_s \to D_s^{(*)-} \ell\nu)} \,. \qquad (14)$$

The key is to separate D_s and D_s^*.
Challenging as BR($D_s^{*-} \to D_s^- +$ soft γ)$\simeq 94\%$.

R_{Λ_c}:

$$R_{\Lambda_c} \equiv \frac{\text{BR}(\Lambda_b \to \Lambda_c \tau\nu)}{\text{BR}(\Lambda_b \to \Lambda_c \ell\nu)} \,. \qquad (15)$$

using the $\Lambda_c \to pK\pi$ decay, clean vertex w/ low bkg.



Expecting $\lesssim \mathcal{O}(10^{-2})$ uncertainty for all channels with S/B $\gtrsim \mathcal{O}(1)$.

Further LFU Tests with FCCC (II) (Prelim).

Angles between theoretical sensitivity $\partial_{C_i}\Gamma(b \to c\tau\nu)$ in the 5-D theory space:

θ	$J(\psi)$	D	D^*	D_s	D_s^*	Λ_b	B_c
$J(\psi)$	-	$103°$	$3.01°$	$109°$	$1.96°$	$22.9°$	$81.8°$
D	$103°$	-	$102°$	$6.55°$	$102°$	$82.8°$	$90°$
D^*	$3.01°$	$102°$	-	$107°$	$4.45°$	$20.6°$	$81.2°$
D_s	$109°$	$6.55°$	$107°$	-	$108°$	$88°$	$90°$
D_s^*	$1.96°$	$102°$	$4.45°$	$108°$	-	$23.3°$	$82.8°$
Λ_b	$22.9°$	$82.8°$	$20.6°$	$88°$	$23.3°$	-	$79.6°$
B_c	$81.8°$	$90°$	$81.2°$	$90°$	$82.8°$	$79.6°$	-

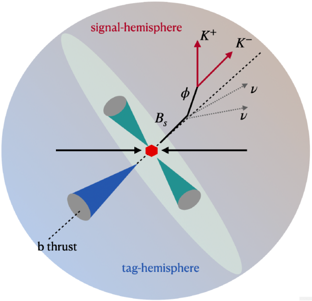
Vector (from $R_{J/\psi}$ and $R_{D^*_{(s)}}$), pseudoscalar (from $R_{D_{(s)}}$), baryonic (from R_{Λ_c}) and annihilation (from $B_c \to \tau\nu$, see also [Zheng et al., 2020]) decays are all necessary.

Rare FCNC Decays: $B_s \to \phi\nu\nu$ (Prelim.)

$b \to s\nu\nu$ transitions also important for B anomalies. Related with $b \to c\tau(\ell)\nu$ and $b \to s\tau\tau(\ell\ell)$ via gauge invariance.

	Experimental	SM Prediction
BR$(B^0 \to K^0\nu\bar{\nu})$	$< 2.6 \times 10^{-5}$	$(2.17 \pm 0.30) \times 10^{-6}$
BR$(B^0 \to K^{*0}\nu\bar{\nu})$	$< 1.8 \times 10^{-5}$	$(9.48 \pm 1.10) \times 10^{-6}$
BR$(B^\pm \to K^\pm\nu\bar{\nu})$	$< 1.6 \times 10^{-5}$	$(4.68 \pm 0.64) \times 10^{-6}$
BR$(B^\pm \to K^{*\pm}\nu\bar{\nu})$	$< 4.0 \times 10^{-5}$	$(10.22 \pm 1.19) \times 10^{-6}$
BR$(B_s \to \phi\nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$(11.84 \pm 0.19) \times 10^{-6}$

[Tanabashi et al., 2018, Straub, 2015, Geng and Liu, 2003]



Current limit of this channel still led by LEP: (limited production at B factories, $\vec{p}_\nu$ not achievable at hadron colliders).

Update of theoretical result ($\sim$ 16% smaller BR).

See Yudong's talk to get a more complete picture!

Summary

- Flavor physics is related to BSM, SM precision tests, pQCD, lattice, ... everything! Tera-Z is the bridge.
- Flavor studies at CEPC benefit from:
  1. Large luminosity (from accelerator physics)
  2. Clean environment and moderate energy (from m_Z)
  3. Good or even revolutionary detectors (from detector R&D)
- New collider/detector at the precision era: new challenges!
  1. LFUV, LFV, LNV, BNV...
  2. CKM and CPV measurements...
  3. Precision (τ) physics...
  4. Exotics, spectroscopy, double heavy flavor...

Aaij, R. et al. (2015).
Angular analysis and differential branching fraction of the decay $B_s^0 \to \phi\mu^+\mu^-$.
JHEP, 09:179.

Aaij, R. et al. (2019).
Search for lepton-universality violation in $B^+ \to K^+\ell^+\ell^-$ decays.
Phys. Rev. Lett., 122(19):191801.

Abada, A. et al. (2019).
Future Circular Collider.

Abdesselam, A. et al. (2019).
Test of lepton flavor universality in $B \to K^*\ell^+\ell^-$ decays at Belle.

Abi, B. et al. (2021).
Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm.

Phys. Rev. Lett., 126:141801.

Altmannshofer, W. et al. (2018).
The Belle II Physics Book.

Amhis, Y. S. et al. (2019).
Averages of b-hadron, c-hadron, and τ-lepton properties as of 2018.

Azatov, A., Bardhan, D., Ghosh, D., Sgarlata, F., and Venturini, E. (2018).
Anatomy of $b \to c\tau\nu$ anomalies.
JHEP, 11:187.

Capdevila, B., Crivellin, A., Descotes-Genon, S., Hofer, L., and Matias, J. (2018).
Searching for New Physics with $b \to s\tau^+\tau^-$ processes.
Phys. Rev. Lett., 120(18):181802.

Dong, M. et al. (2018).

CEPC Conceptual Design Report: Volume 2 - Physics & Detector.

Fujii, K. et al. (2019).
Tests of the Standard Model at the International Linear Collider.

Geng, C. and Liu, C. (2003).
Study of $B_s \to (\eta, \eta', \phi^) \ell\bar{\ell}$ decays.
J. Phys. G, 29:1103–1118.

Grzadkowski, B., Iskrzynski, M., Misiak, M., and Rosiek, J. (2010).
Dimension-Six Terms in the Standard Model Lagrangian.
JHEP, 10:085.

Li, L. and Liu, T. (2020).
$b \to s\tau^+\tau^-$ Physics at Future Z Factories.

Straub, D. M. (2015).
$b \to k^{(*)}\nu\bar{\nu}$ sm predictions.

Tanabashi, M. et al. (2018).
Review of Particle Physics.
Phys. Rev., D98(3):030001.

Zheng, T., Xu, J., Cao, L., Yu, D., Wang, W., Prell, S., Cheung, Y.-K. E., and Ruan, M. (2020).
Analysis of $B_c \to \tau \nu_\tau$ at CEPC.