Model-independent analysis of charge leptonic flavor violation processes at CEPC

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Outline

- Flavor physics at Z pole
- Charge leptonic flavor violation processes
- Results (?)
- Summary

$b\bar{b}$ are assumed to be produced in equal amount at Z pole with Belle II

- cross section

Fermion Pair	$\sqrt{s} = 91$ GeV	$\sqrt{s}$=250 GeV
$\nu\bar{\nu}$	2913	4.7
e^+e^-	1476	4.3
$\mu^+\mu^-$	1477	4.3
$\tau^+\tau^-$	1474	4.3
$u\bar{u}$	5238	10.7
$d\bar{d}$	6668	11.2
$c\bar{c}$	5237	10.7
$s\bar{s}$	6668	11.2
$b\bar{b}$	6549	10.8
hadron	30360	54.4

- The Z^0 factory with the high luminosity will produce about 10^{11} $b\bar{b}$. we assume instantaneous luminosity of $8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and an integrated luminosity of $40ab^{-1}$ will be collected at CEPC with two-year running on Z pole at two collision points.

Providing unique opportunity for "extreme" heavy flavor experiments

- Low background compared to LHCb
- The b-pair flying with large momentum at a Z^0 factory will help significantly in the competition with Belle II.

1. The B_s decay and *CP* violation, $B_s \to \mu^+\mu^-$,$B_s - \bar{B}_s$ mixing
2. baryons decays, Ξ_b
3. B_c
4. τ physics

B_c meson Decays

- B_c meson can not produced at Belle.
- For B_c meson, although CDF、D0 and LHCb had collected some data, many results have large uncertainties because of the large background.
- At CEPC, B_c meson will be produced in equal amount with with B_u, B_d and B_s.

1. The spectrums of Bc mesons
2. The life time and decay width
3. The weak decays of Bc meson with Charm
4. The weak decays of Bc meson without Charm
5. Looking for the Bc decays with neutral objects in the final states which cannot be reached by the LHCb. Especially interesting is to look for pure leptonic decays of $B_c \to \mu\nu$ and $B_c \to \tau\nu$ (V_{cb}).

τ physics-the τ-pair with large momentum and strongly boost

Charge leptonic flavor violation processes

- Charged Lepton Flavor Violation (cLFV) processes are very interesting to study because if they are observed, that would be a clear indication of physics beyond the Standard Model. discriminating between different new physics scenarios with high sensitive data.
- LHC、Belle、Babar reported cLFV in semileptonic decays of B mesons deviations from the SM of 2-3σ significance
  - The angular observable P_5' in $B \to K^* \mu^+ \mu^-$;
  - $B_s \to \phi \mu^+ \mu^-$;
  - $R(K)$

$$R(K) = \frac{Br[B \to K \mu^+ \mu^-]}{Br[B \to K e^+ e^-]} = 0.745^{+0.090}_{-0.074} \pm 0.036.$$

  - and the SM-forbidden decay $h \to \mu\tau$ of the Higgs boson

- Contrary to LHCb and Belle II, CEPC will have more advantages in processes involving τ:
  - $\tau \to 3\mu$.....
  - $Z \to \tau^+\mu^-$
  - $H \to \tau^+\mu^-$
  - $B_d, B_s \to \tau^+\mu^-$
  - $\mathrm{Br}(B \to K\tau^+\tau^-)/\mathrm{Br}(B \to K\mu^+\mu^-)$
  - ......

The CPEC will allow us to study cLFV in τ, Z^0 and H^0 decays in different landscapes, the first two with a run of two years at Z^0 peak and the third one in five (or more) years at Z^0+ Higgs production.

Charge lepton flavour violating (cLFV) τ Decays

- The lepton τ is heavy enough to decay into hadrons, together with radiative $\tau \to \ell\gamma$ and leptonic $\tau \to \ell\ell'\bar{\ell}''$ decays, semileptonic decays $(\tau \to \ell\,(\pi, \eta^{(\prime)}, \pi\pi, \ldots))$ offer an interesting window to probe the underlying LFV mechanism, being particularly sensitive to different kinds of NP or effective operators in the couplings between quarks and leptons.

- Effective Lagrangian at low energy for LFV τ decays
  LFV $\tau - \mu$ transitions can be organized according to the type of operators present:

$$\mathcal{L}_{eff} = \mathcal{L}_{eff}^{(D)} + \mathcal{L}_{eff}^{(\ell q)} + \mathcal{L}_{eff}^{(G)} + \mathcal{L}_{eff}^{(4\ell)} + \cdots\ ,$$

  where the dots stands for operators of higher dimension.

1. The effective dipole operators of dimension five $\mathcal{L}_{eff}^{(D)}$,

$$\mathcal{L}_{eff}^{(D)} = -\frac{m_\tau}{\Lambda^2} \left\{ \left(\mathrm{C_{DR}}\, \bar{\mu}\, \sigma^{\rho\nu}\, P_L\, \tau + \mathrm{C_{DL}}\, \bar{\mu}\, \sigma^{\rho\nu}\, P_R\, \tau\right) F_{\rho\nu} + \mathrm{h.c.} \right\}, \tag{1}$$

2. dimension-six four-fermion operators $\mathcal{L}_{eff}^{(\ell q)}$,

$$\begin{aligned}\mathcal{L}_{eff}^{(\ell q)} = -\frac{1}{\Lambda^2} \sum_{q=u,d,s} \Big\{ & \left(\mathrm{C^q_{VR}}\, \bar{\mu}\, \gamma^\rho\, P_R\, \tau + \mathrm{C^q_{VL}}\, \bar{\mu}\, \gamma^\rho\, P_L\, \tau\right) \bar{q}\, \gamma_\rho\, q \\ & + \left(\mathrm{C^q_{AR}}\, \bar{\mu}\, \gamma^\rho\, P_R\, \tau + \mathrm{C^q_{AL}}\, \bar{\mu}\, \gamma^\rho\, P_L\, \tau\right) \bar{q}\, \gamma_\rho \gamma_5\, q \\ & + m_\tau m_q G_F \left(\mathrm{C^q_{SR}}\, \bar{\mu}\, P_L\, \tau + \mathrm{C^q_{SL}} \bar{\mu}\, P_R\, \tau\right) \bar{q}\, q \\ & + m_\tau m_q G_F \left(\mathrm{C^q_{PR}}\, \bar{\mu}\, P_L\, \tau + \mathrm{C^q_{PL}}\, \bar{\mu}\, P_R\, \tau\right) \bar{q}\, \gamma_5\, q \\ & + m_\tau m_q G_F \left(\mathrm{C^q_{TR}}\, \bar{\mu}\, \sigma^{\rho\nu} P_L\, \tau + \mathrm{C^q_{TL}}\, \bar{\mu}\, \sigma^{\rho\nu}\, P_R\, \tau\right) \bar{q}\, \sigma_{\rho\nu}\, q + \mathrm{h.c.} \Big\},\end{aligned} \tag{2}$$

3. The effective gluonic operators of dimension-seven $\mathcal{L}_{eff}^{(G)}$,

$$\mathcal{L}_{eff}^{(G)} = -\frac{m_\tau G_F}{\Lambda^2}\frac{\beta_L}{4\alpha_s}\Big\{ (\mathrm{C_{GR}}\,\bar\mu\,P_L\,\tau + \mathrm{C_{GL}}\,\bar\mu\,P_R\,\tau)\; G^a_{\rho\nu}G^{\rho\nu}_a + \left(\mathrm{C_{\widetilde{G}R}}\,\bar\mu\,P_L\,\tau + \mathrm{C_{\widetilde{G}L}}\,\bar\mu\,P_R\,\tau\right)\; G^a_{\mu\nu}\widetilde{G}^{\mu\nu}_a + \mathrm{h.c.}\Big\}, \tag{3}$$

with $\beta_L/(4\alpha_s) = -9\alpha_s/(8\pi)$. The dual tensor of the gluon field strength is defined by $\widetilde{G}^a_{\rho\nu} = \frac{1}{2}\,\epsilon_{\rho\nu\alpha\beta}\,G^{a,\,\alpha\beta}$.

4. The effective four-lepton operators (taking $\tau \to 3\mu$ for example),

$$\mathcal{L}_{eff}^{(4\ell)} = -\frac{1}{\Lambda^2}\Big\{\mathrm{C_{SLL}}\;(\bar\mu\,P_L\,\tau)\,(\bar\mu\,P_L\,\mu) + \mathrm{C_{SRR}}\;(\bar\mu\,P_R\,\tau)\,(\bar\mu\,P_R\,\mu) + \mathrm{C_{VLL}}\;(\bar\mu\gamma^\mu\,P_L\,\tau)\,(\bar\mu\,\gamma_\mu\,P_L\,\mu) + \mathrm{C_{VRR}}\;(\bar\mu\,\gamma^\mu\,P_R\,\tau)\,(\bar\mu\,\gamma_\mu\,P_R\,\mu) + \mathrm{C_{VLR}}\;(\bar\mu\,\gamma^\mu\,P_L\,\tau)\,(\bar\mu\,\gamma_\mu\,P_R\,\mu) + \mathrm{C_{VRL}}\;(\bar\mu\,\gamma^\mu P_R\,\tau)\,(\bar\mu\,\gamma_\mu\,P_L\,\mu) + \mathrm{h.c.}\Big\}. \tag{4}$$

Table: *Sensitivity of LFV τ decays to the different effective operators at tree-level. The symbol ✓ ($-$) denotes that the operator does (not) contribute at tree-level to a given process. For operators involving quark bilinears, the relevant isospin structure ($I = 0, 1$) probed by a given decay is also specified.*

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$\mathrm{C_{SLL,RR}}$	✓	–	–	–	–	–
$\mathrm{C_{VLL,RR}}$	✓	–	–	–	–	–
$\mathrm{C_{VLR,RL}}$	✓	–	–	–	–	–
$\mathrm{C_{DL,R}}$	✓	✓	✓	✓	–	–
$\mathrm{C^q_{VL,R}}$	–	–	✓ (I=1)	✓(I=0,1)	–	–
$\mathrm{C^q_{SL,R}}$	–	–	✓ (I=0)	✓(I=0,1)	–	–
$\mathrm{C_{GL,R}}$	–	–	✓	✓	–	–
$\mathrm{C^q_{AL,R}}$	–	–	–	–	✓ (I=1)	✓ (I=0)
$\mathrm{C^q_{PL,R}}$	–	–	–	–	✓ (I=1)	✓ (I=0)
$\mathrm{C_{\tilde{G}L,R}}$	–	–	–	–	–	✓

- Current bounds on LFV τ decay rates have been set by the Belle II, BaBar and LHCb collaborations.

τ^- decay mode	Upper bound on BR	Upper bound at CEPC
$\mu\,\gamma$	4.4×10^{-8}	10^{-9}
$\mu^-\,\mu^+\mu^-$	2.1×10^{-8}	
$\mu\,\pi^0$	1.1×10^{-7}	
$\mu\,\eta$	6.5×10^{-8}	
$\mu\,\eta'$	1.3×10^{-7}	
$\mu\,\pi^+\pi^-$	2.1×10^{-8}	
$\mu\,\rho$	1.2×10^{-8}	
$\mu\,f_0$	3.4×10^{-8}	

- CEPC offers very interesting prospects in improving the current bounds especially for the process $\tau \to \mu\gamma$ where one expects to reach a sensitivity on the branching ratio of 10^{-9}, two orders of magnitude better than the current bound.

cLFV Higgs Decays

- 2015 CMS excess

$$\mathcal{B}_{exp}(H \to \mu^{\pm}\tau^{\mp}) = 0.84^{+0.39}_{-0.37}\%,$$

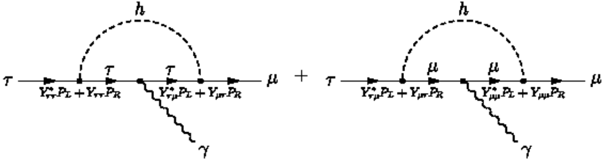
- LFV Higgs decays will be studied at the CEPC in $e^+e^- \to Z^0 H$. With Z^0 tagging, about 1 million Higgs boson can be produced in a five-year running at the center-of-mass of 240-250 GeV.We expect to obtain a sensitivity of 10^{-4}.

- $h \to e\mu, e\tau, \mu\tau$ arise at tree level from the assumed flavor violating Yukawa interactions,

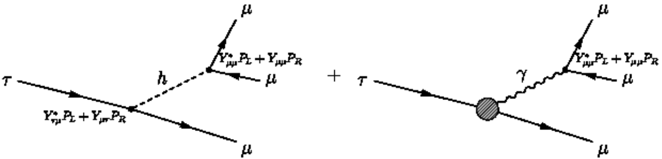
$$\begin{aligned}\mathcal{L}_Y \supset & - Y_{e\mu}\bar{e}_L\mu_R h - Y_{\mu e}\bar{\mu}_L e_R h - Y_{e\tau}\bar{e}_L\tau_R h - Y_{\tau e}\bar{\tau}_L e_R h \\ & - Y_{\mu\tau}\bar{\mu}_L\tau_R h - Y_{\tau\mu}\bar{\tau}_L\mu_R h + h.c.\end{aligned} \quad (5)$$

Indirect constraints

1. Constraints from $\tau \to \mu\gamma$, $\tau \to e\gamma$.



2. Constraints from $\tau \to 3\mu$, $\tau \to 3e$



3. .....

Table: Present upper bounds and future expected sensitivities for cLFV

LFV Observable	Present Bound $(90\% CL)$	Future Sensitivity	CEPC
BR$(\mu \to e\gamma)$	4.2×10^{-13} (MEG 2016)	4×10^{-14} (MEG-II)	
BR$(\tau \to e\gamma)$	3.3×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)	
BR$(\tau \to \mu\gamma)$	4.4×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)	
BR$(\mu \to eee)$	1.0×10^{-12} (SINDRUM 1988)	10^{-16} Mu3E (PSI)	
BR$(\tau \to eee)$	2.7×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)	
BR$(\tau \to \mu\mu\mu)$	2.1×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)	
BR$(\tau \to \mu\eta)$	2.3×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)	
CR$(\mu - e, \mathrm{Au})$	7.0×10^{-13} (SINDRUM II 2006)		
CR$(\mu - e, \mathrm{Ti})$	4.3×10^{-12} (SINDRUM II 2004)	10^{-18} PRISM (J-PARC)	
CR$(\mu - e, \mathrm{Al})$		3.1×10^{-15} COMET-I (J-PARC)	
		2.6×10^{-17} COMET-II (J-PARC)	
		2.5×10^{-17} Mu2E (Fermilab)	

LFV Observable	Present Bound $(95\% CL)$	CEPC
BR$(H \to \mu e)$	3.6×10^{-3} (CMS 2015)	
BR$(H \to \tau e)$	1.04×10^{-2} (ATLAS 2016), 0.7×10^{-2} (CMS 2015)	
BR$(H \to \tau\mu)$	1.43×10^{-2} (ATLAS 2016), 1.51×10^{-2} (CMS 2015)	10^{-4}
BR$(Z \to \mu e)$	1.7×10^{-6} (LEP 1995), 7.5×10^{-7} (ATLAS 2014)	
BR$(Z \to \tau e)$	9.8×10^{-6} (LEP 1995)	
BR$(Z \to \tau\mu)$	1.2×10^{-5} (LEP 1995), 1.69×10^{-5} (ATLAS 2014)	

cLFV Z decays

- ATLAS Collaboration improved the upper limit of the $Z \to e^{\pm}\mu^{\mp}$ to be 7.5×10^{-7}
- At the CEPC a few times of 10^{11} Z^0 would be produced, and the sensitivities would be reached to 10^{-11}

$$\mathcal{L}_Z \supset g_{e\mu}\bar{e}_L \not{Z}\mu_L + g_{\mu e}\bar{\mu}_R \not{Z}e_R + g_{e\tau}\bar{e}_L \not{Z}\tau_L + g_{\tau e}\bar{\tau}_R \not{Z}e_R + g_{\mu\tau}\bar{\mu}_L \not{Z}\tau_R + g_{\tau\mu}\bar{\tau}_L \not{Z}\mu_R h + h.c. \quad (6)$$

- Indirect constraints on the Z coupling with e μ, τ are the same for those on higgs.

Summary

- The fermion pairs could be produced with large cross sections at Z-pole.
- For B, B_s, and τ lepton, CEPC offer us a good place for crosschecking the results of LHCb and B factory.
- For B_c, the measurement results are expected to be precise due to the low background.
- High sensitivity constraints on cLFV (τ, higgs, Z) at CEPC.

THANK YOU