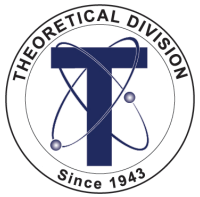
Search for lepton flavor violation at the EIC

Kaori Fuyuto

Los Alamos National Laboratory



V. Cirigliano, KF, C. Lee, E. Mereghetti, B. Yan
JHEP03(2021)256

May 20, 2021 at PPC 2021
LA-UR-21-24724

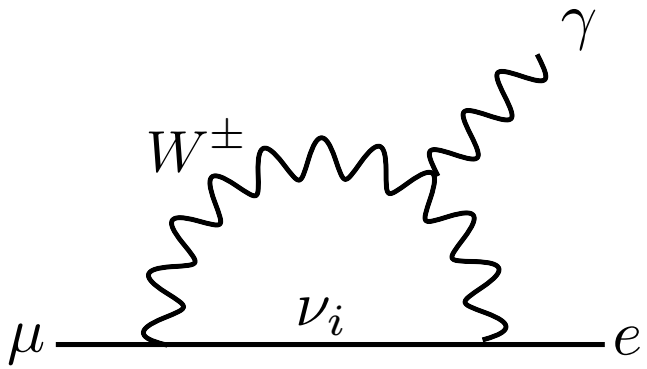
Charged Lepton Flavor Violation

Nonzero neutrino mass induces CLFV.

Ex) Minimal extension of the SM

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\nu-{\rm mass}}$$

Dirac or Majorana



Petcov '77, Marciano-Sanda '77 ....

$$\mathrm{Br}\,(\mu \to e\gamma) = \frac{3\alpha_{\rm em}}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{m^2_W}\right|^2 < 10^{-54}$$

Extremely small!

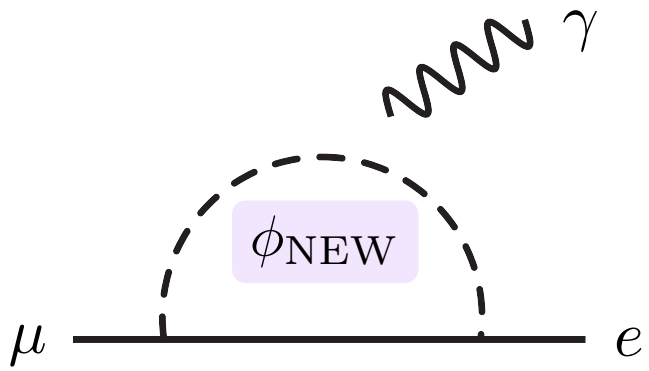
The predicted BR is too small to be observed.

Charged Lepton Flavor Violation

Nonzero neutrino mass induces CLFV.

Ex) Minimal extension of the SM

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\nu-{\rm mass}}$$



$$\mathrm{Br}\,(\mu \to e\gamma) = \frac{3\alpha_{\rm em}}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{m^2_W}\right|^2 < 10^{-54}$$

The observation of CLFV would imply another contribution.

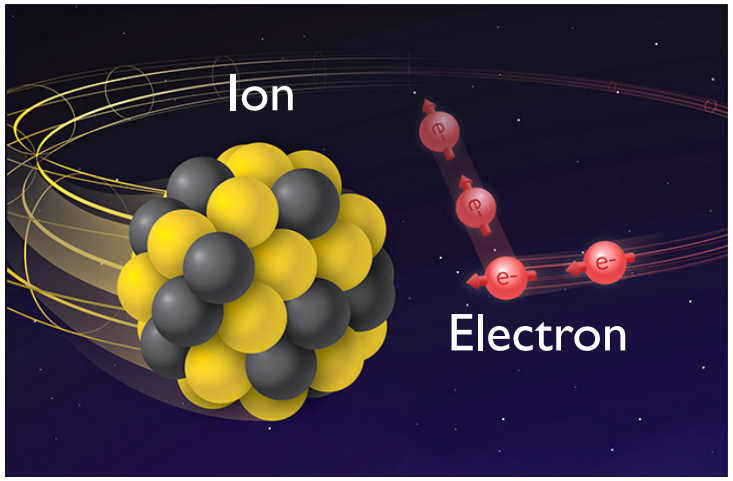
✔ BSM physics

Electron-Ion Collider

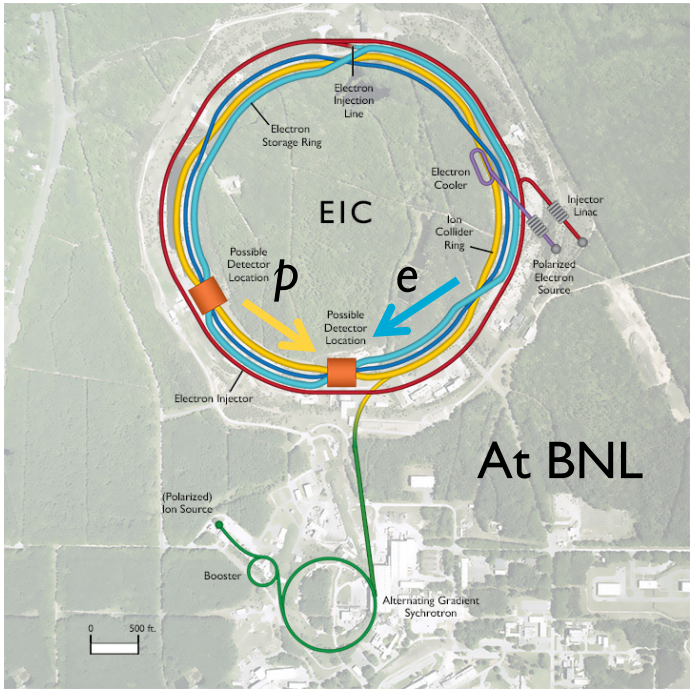
EIC Detector Requirements and R&D Handbook
EIC Yellow report, arXiv:2103.05419

- One potential probe : LFV search at the EIC

DOE granted CD-0 to the EIC on January 9, 2020.



Collide electrons and protons/heavy ions



Map the structure of the proton and nuclei

Electron-Ion Collider

EIC Detector Requirements and R&D Handbook
EIC Yellow report, arXiv:2103.05419

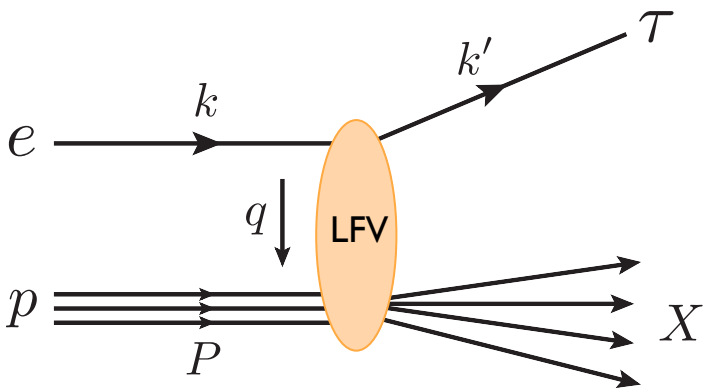
- Electrons - protons/heavy ions collisions

$$\sqrt{S} = 20 \sim 100 \text{ GeV} \quad (\text{Upgradable to } 140 \text{ GeV})$$

- High Luminosity

$$\mathcal{L} \sim 10^{33-34} \text{ cm}^{-2}\text{s}^{-1}$$

(10-100 fb^{-1} per year)



(e.g. HERA $\sqrt{S} = 318 \text{ GeV}, \ \mathcal{L} = 1.4 \times 10^{31} \text{ cm}^{-1}\text{s}^{-1}$)

✦ Opportunity to search for $ep \to \tau X$

Our study

V. Cirigliano, KF, C. Lee, E. Mereghetti, B. Yan
JHEP03(2021)256

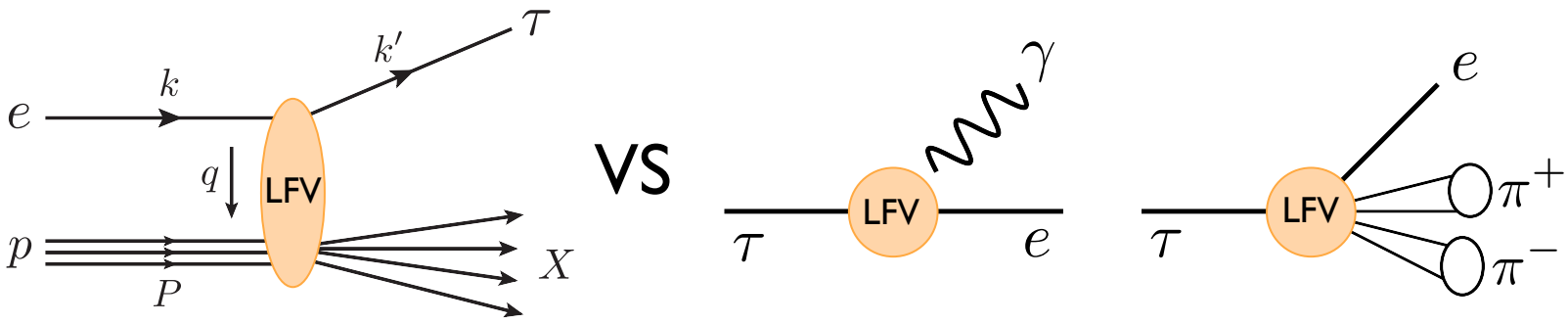
Study the possibility to probe e-tau LFV at the EIC

* Tau-e interactions in SMEFT (d = 6)

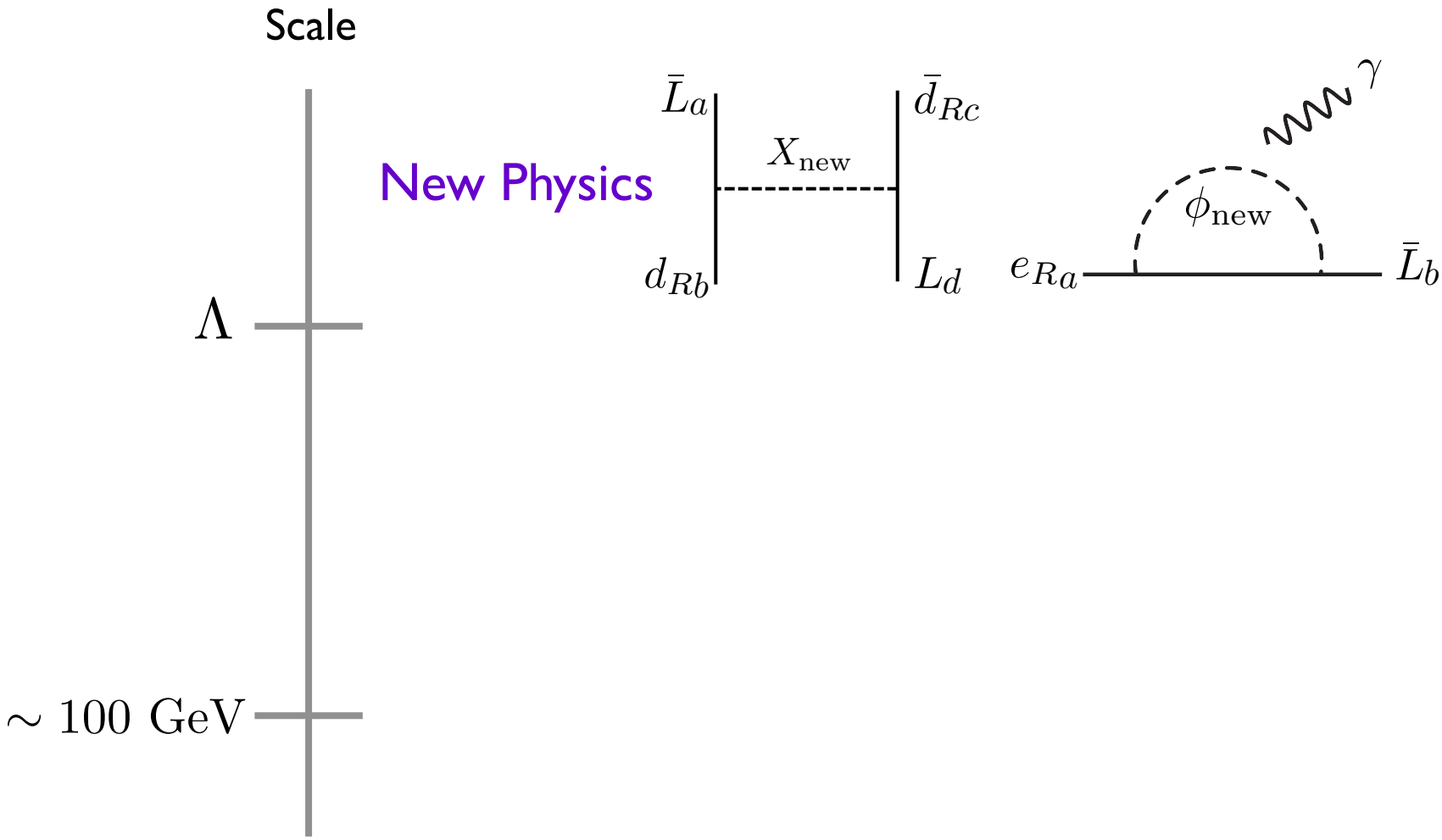
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2} C_{\tau e}^{(6)} \mathcal{O}^{(6)}$$

Tau-e LFV interaction

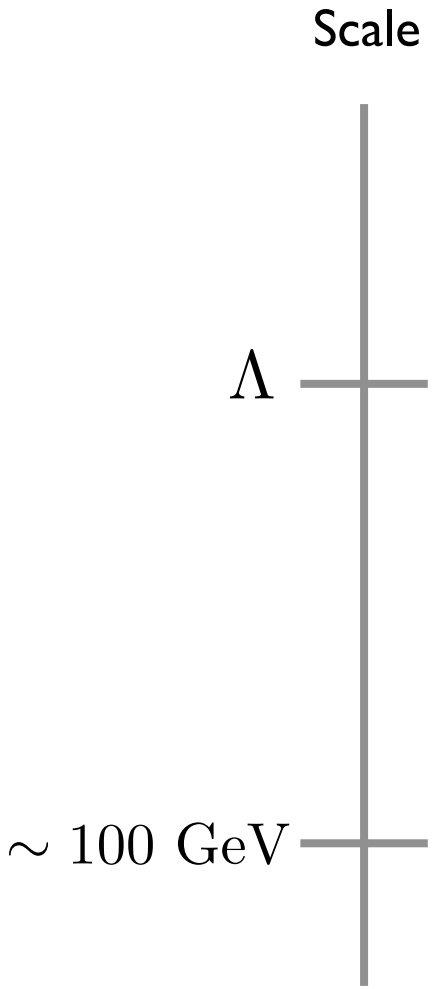
* Current limits e.g. $pp \to \tau e$ at LHC and tau decays



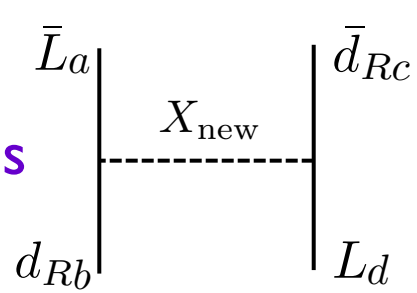
EFT approach

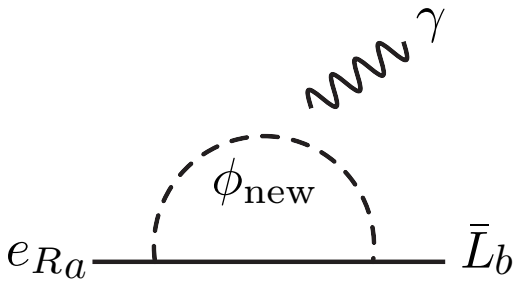


EFT approach



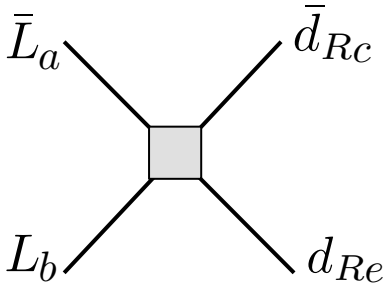
New Physics





SMEFT : $\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2} C^{(6)} \mathcal{O}^{(6)} + \cdots$

ex)



$\mathcal{O}^{(6)} = \bar{L}_a \gamma^\mu L_b \bar{d}_{Rc} \gamma_\mu d_{Re}$

* All the possible LFV dim 6 operators with general quark-flavor structure

LFV operators

Total : 16 different operators

Ex) dipole and four-fermion vector operator

$$\mathcal{L} \supset -\frac{e}{2v}\left(\Gamma^{e}_{\gamma}\right)_{\tau e}\bar{\tau}_L\sigma^{\mu\nu}e_R F_{\mu\nu} + \text{H.C}$$ Photon dipole

$$-\frac{4G_F}{\sqrt{2}}\left[C_{Ld}\right]_{\tau ebb}\bar{\tau}_L\gamma^{\mu}e_L\bar{b}_R\gamma_{\mu}b_R$$ VLR : bb element

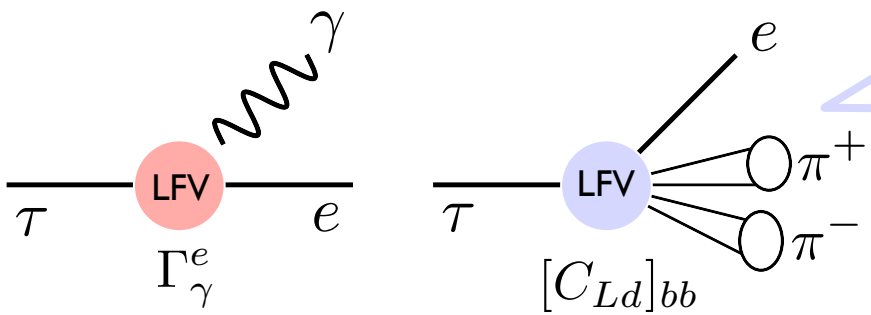
LFV operators

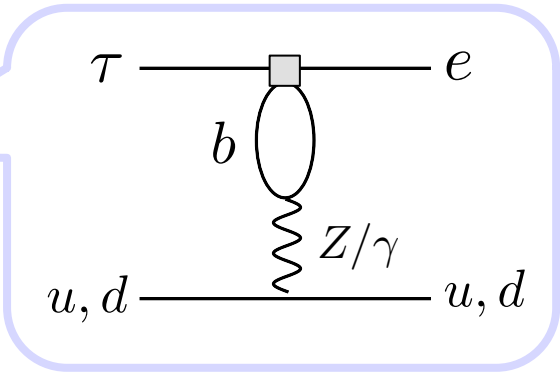
Total : 16 different operators

Ex) dipole and four-fermion vector operator

$$\mathcal{L} \supset -\frac{e}{2v}\left(\Gamma^e_\gamma\right)_{\tau e}\,\bar{\tau}_L\sigma^{\mu\nu}e_R F_{\mu\nu} + \text{H.C}$$ Photon dipole

$$-\frac{4G_F}{\sqrt{2}}\left[C_{Ld}\right]_{\tau ebb}\,\bar{\tau}_L\gamma^\mu e_L\bar{b}_R\gamma_\mu b_R$$ VLR : bb element

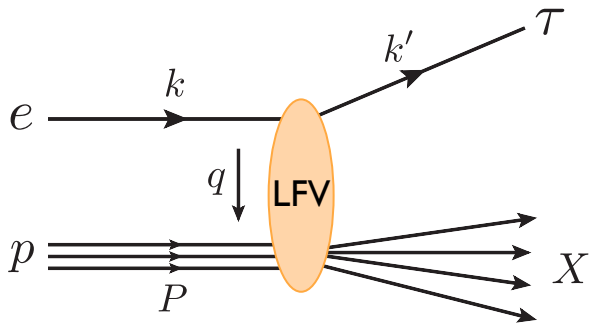




Loop effect $\sim 10^{-3}$

EIC analysis

- Cross sections : $\mathcal{O}(1-10)$ pb at $\sqrt{S} = 141$ GeV



- Major backgrounds

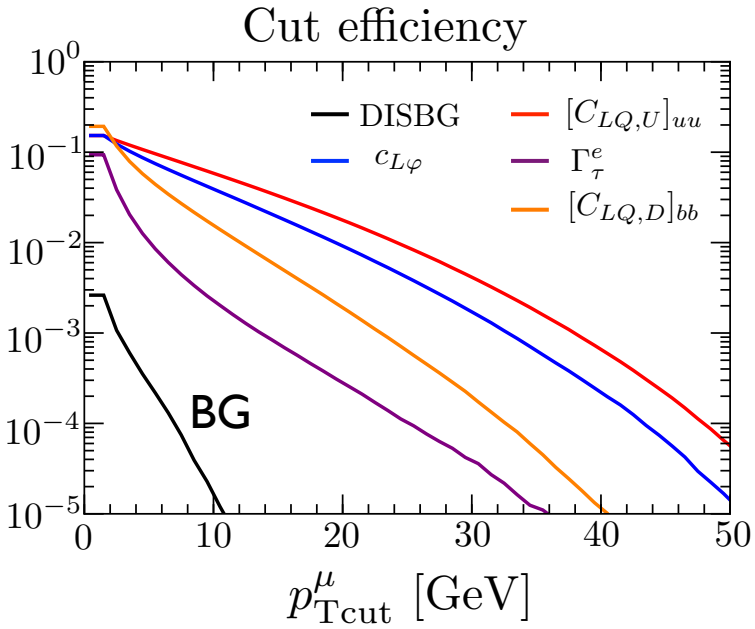
  1) Neutral Current : $ep \to ej$

  2) Charged Current : $ep \to \nu_e j$

- Promising channel

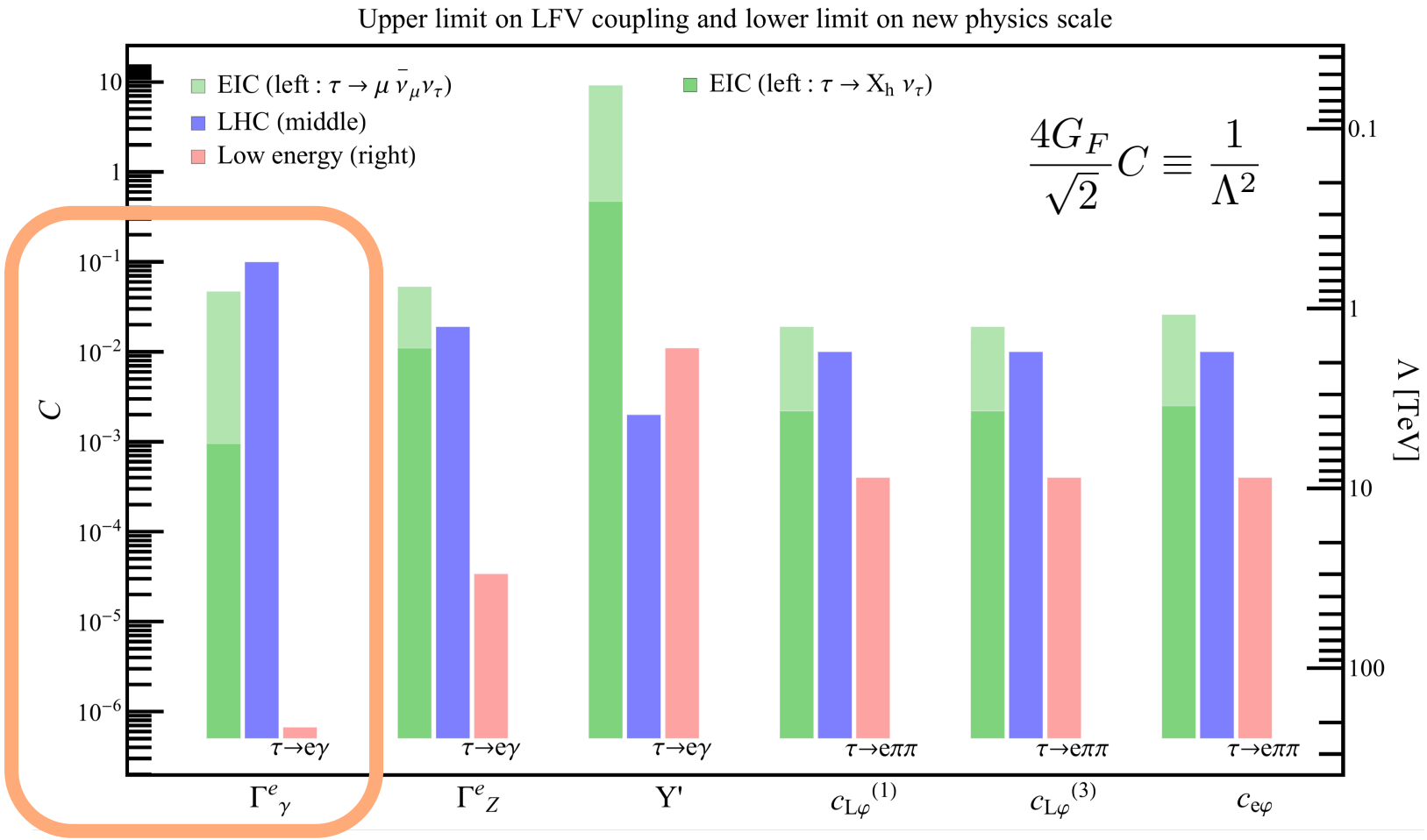
$$\mathrm{BR}\,(\tau \to \mu \bar{\nu}_\mu \nu_\tau) = 17.39\%$$

  * Moderate cuts enable to eliminate all SM background



Dipole operator

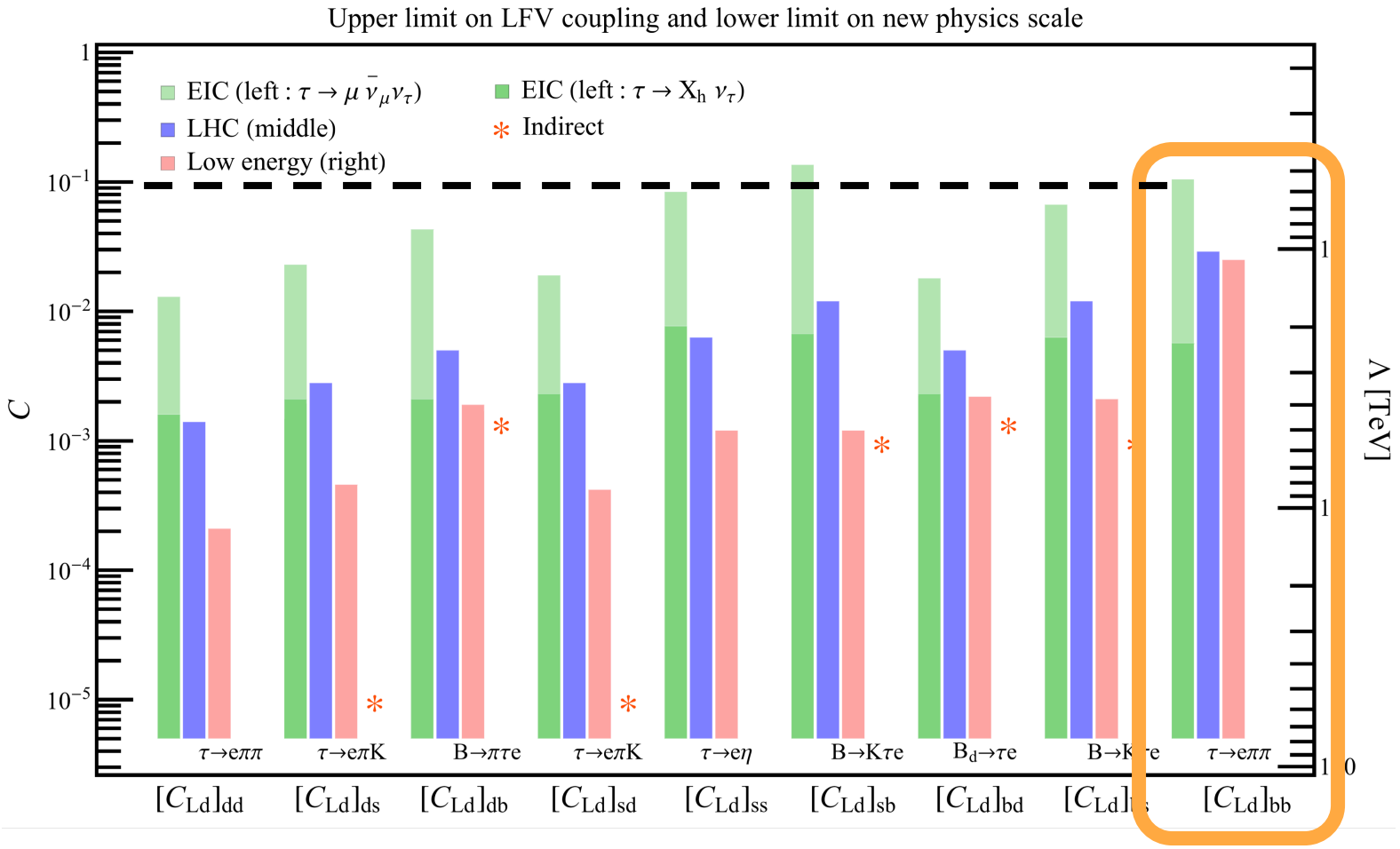
* single-operator analysis



EIC, LHC : $\Gamma^e_\gamma < O(10^{-(2-1)})$ Tau e gamma : $\Gamma^e_\gamma < 6.7 \times 10^{-7}$

Bottom operator

* single-operator analysis



EIC : $[C_{Ld}]_{bb} < 0.1$ LHC, Tau decay : $[C_{Ld}]_{bb} < O(10^{-2})$

Competitive!

Multi-operator scenario

See the situation where 8 operators are nonzero

* Z couplings + down-type 4F operators

$$\mathcal{L}_{\rm LFV} \supset -\frac{g_2}{c_W}\left(c^{(1)}_{L\varphi}+c^{(3)}_{L\varphi}\right)\bar{\tau}_L\gamma^\mu Z_\mu e_L$$

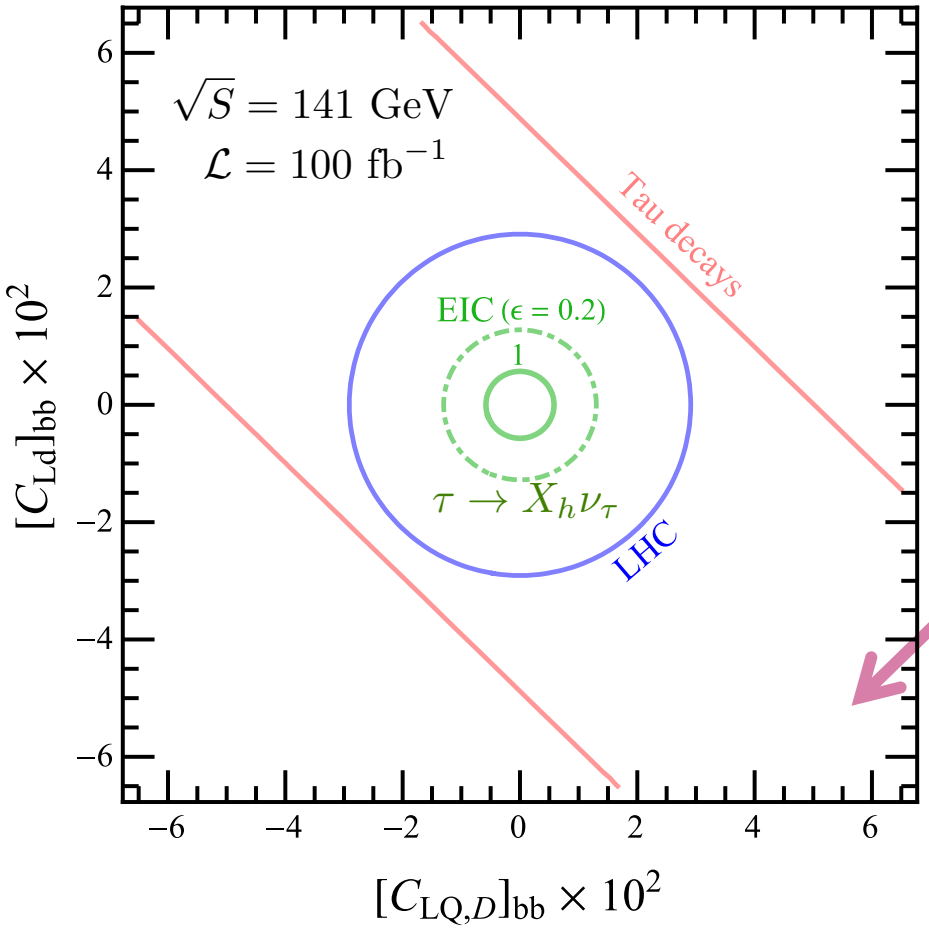
$$-\frac{4G_F}{\sqrt{2}}\sum_{a=d,s,b}[C_{Ld}]_{aa}\bar{\tau}_L\gamma^\mu e_L\bar{d}_{Ra}\gamma_\mu d_{Ra}$$

$$-\frac{4G_F}{\sqrt{2}}\sum_{a=d,s,b}[C_{LQ,D}]_{aa}\bar{\tau}_L\gamma^\mu e_L\bar{d}_{La}\gamma_\mu d_{La}$$

✔ Limits on $[C_{LQ,D}]_{bb}$ and $[C_{Ld}]_{bb}$ at 90% C.L.

The rest is marginalized.

Multi-operator scenario



Free direction appears.

$[C_{LQ,D}]_{bb} - [C_{Ld}]_{bb}$

Collider probes are necessary to close the free direction.

Summary

One key probe of new physics is search for CLFV.

Various searches for CLFV have been ongoing.

Ex) MEGII, COMET, Mu2e, Belle-II, LHC etc…

EIC provides a new high-energy search!

- SMEFT / Muonic channel
- Discovery potential in heavy-quark operators
- Complementary role in multi-operator case

Future direction ex) Reduce theoretical uncertainties
Detailed analysis in hadronic channel
Utilizing b/c tagging