Improved analysis for CLFV processes $\mu N(eN) \to \tau X$ with gluon operators

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M. Takeuchi, Y. Uesaka, M.Y., Phys. Lett. B772 (2017)

Analysis on CLFV scattering $\mu N(eN) \to \tau X$ including

(1) new subprocess $\ell g \to \tau g \quad (\ell \ni e, \mu)$

(2) quark number conserving subprocess $\ell g \to \tau q \bar{q}$

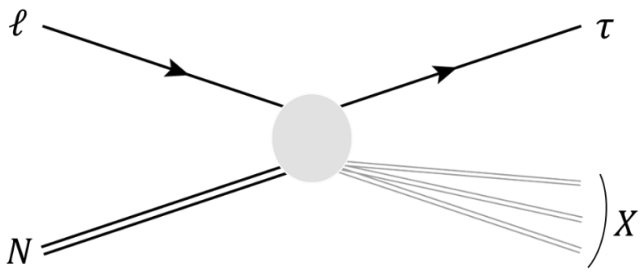
Search for LFV through $eN(\mu N)$ scattering

Focus : LFV via mediators which mainly interacts with heavy fermions

e.g., Higgs, KK gauge boson, flavon, leptoquark, ...

A promising way to search for tau LFV

$\ell + N \to \tau + X \quad (N: \text{Nucleus})$



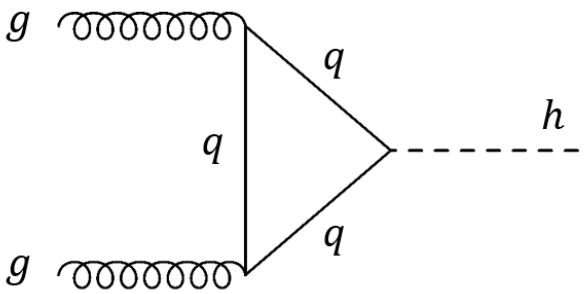
- Many exp. launch, e.g., ILC, LHeC, etc.
- Can reach high sensitivity beyond the Belle-II sensitivity limit for tau LFV

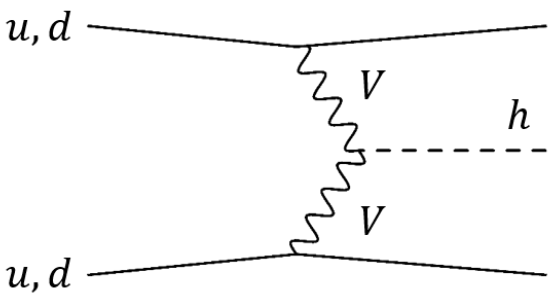
Precisely relate the LFV parameter and the event rate of $\ell N \to \tau X$!!

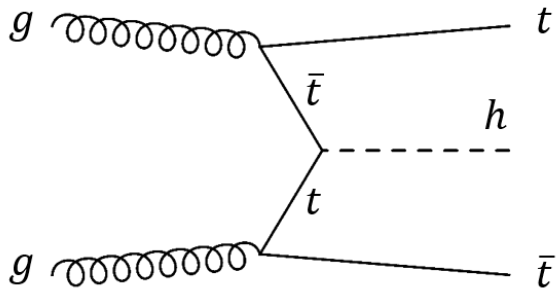
Which is correct sub-process for
LFV lepton-nucleus scattering $\ell N \to \tau X$?

Higgs production@LHC

Which is dominant sub-process?

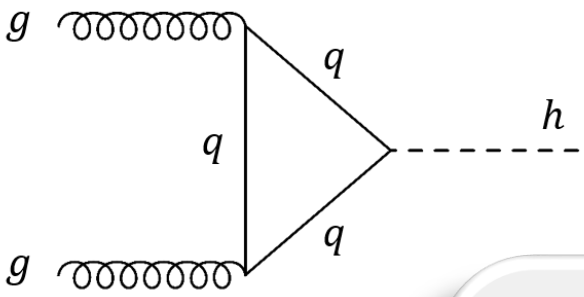


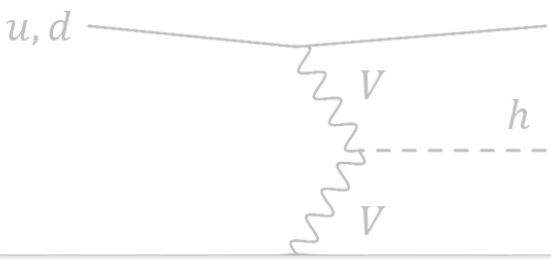


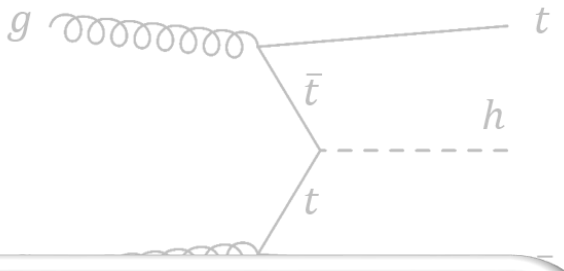


New sub-process for ℓN scattering

Which is dominant sub-process?

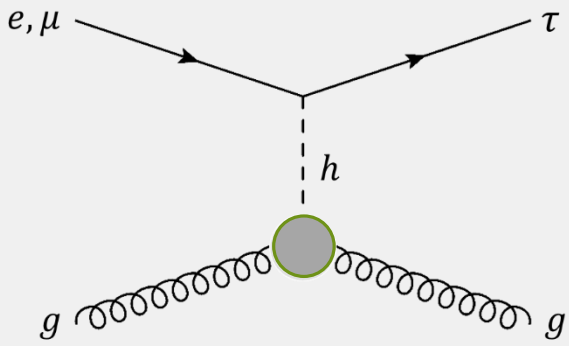






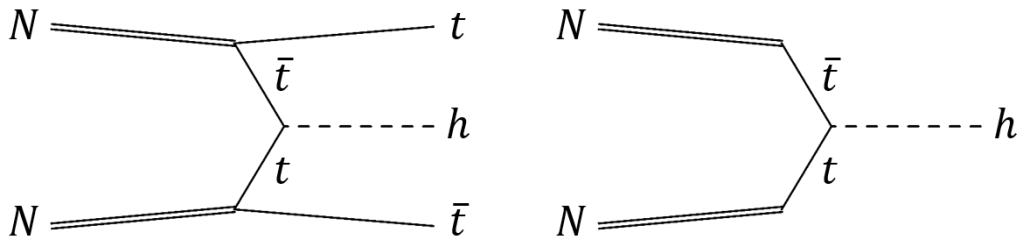
New sub-process for
$eN\ (\mu N) \to \tau X$

Dominant sub-process
for fixed target exp.



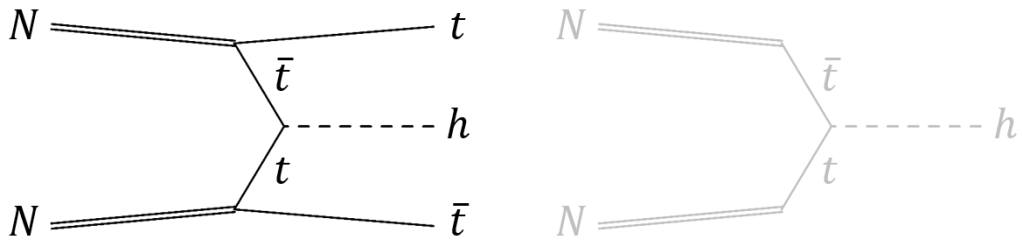
Higgs production@LHC

Which is correct sub-process?



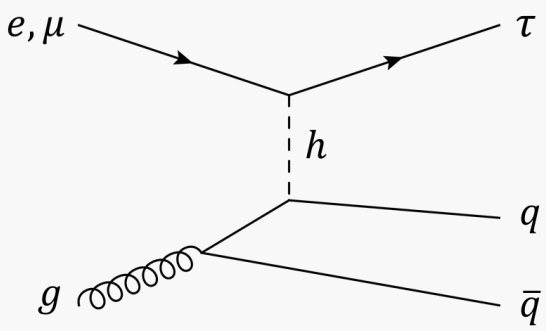
Correct sub-process for ℓN scattering

Which is correct sub-process?



Correct quark final state sub-process with quark-number conservation

Not $\ell q \to \tau q$!



Threshold and cross section are corrected

e.g., $E_{e(\mu)}^{\text{beam}} > 19\,\text{GeV}$ for $\ell b \to \tau b$

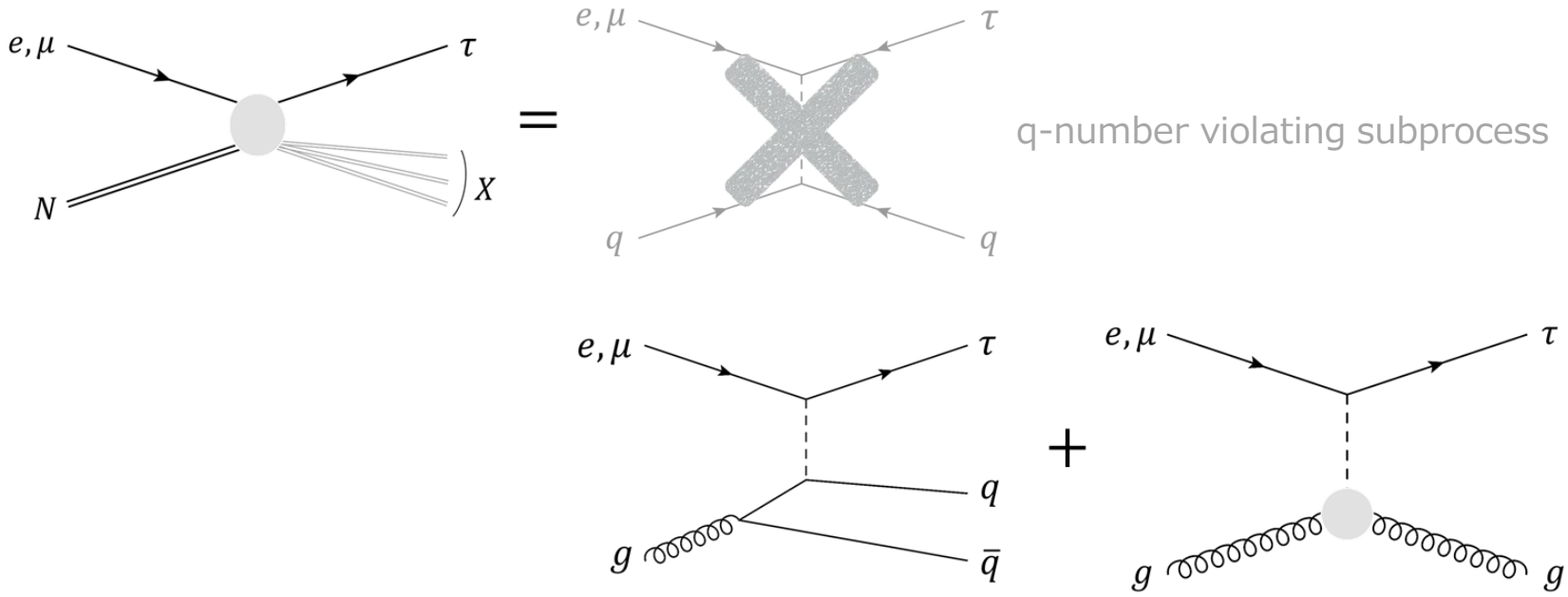
$E_{e(\mu)}^{\text{beam}} > 55\,\text{GeV}$ for $\ell g \to \tau b \bar{b}$

Aim of this work and outline

Reformulation of LFV lepton-nucleus scattering taking into account

(1) new sub-process $\ell g \to \tau g$

(2) quark-number conservation sub-process $\ell g \to \tau q \bar{q}$



Reformulation of $\sigma(\ell N \rightarrow \tau X)$

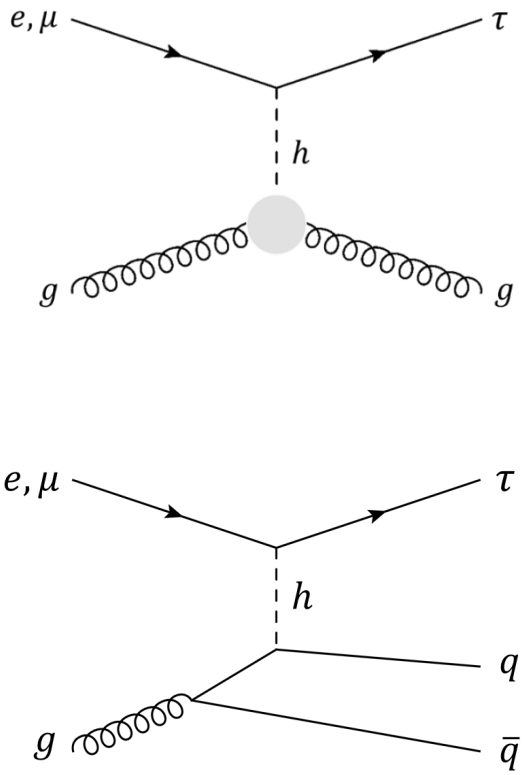
Lagrangian for $\ell g \to \tau g$ and $\ell g \to \tau q \bar{q}$

Important : momentum transfer dependence of hgg effective coupling

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm CLFV},$$

$$\mathcal{L}_{\rm SM} = -\sum_q y_q h \bar{q} q + g_{hgg} h G^a_{\mu\nu} G^{a\mu\nu},$$

$$\mathcal{L}_{\rm CLFV} = -\rho_{ij} \bar{\ell}_j P_L \ell_i h - \rho_{ji} \bar{\ell}_j P_R \ell_i h$$



ρ_{ij}, ρ_{ji} : LFV parameter (i, j : flavor index)

Current bound $\sqrt{|\rho_{\ell\tau}|^2 + |\rho_{\tau\ell}|^2} = 2.4 \times 10^{-3}$

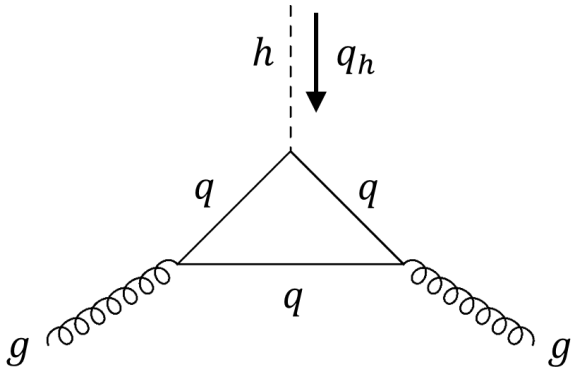
Note: stronger than the Belle-II sensitivity for tau CLFV search

Higgs-gluon-gluon coupling

hgg effective coupling

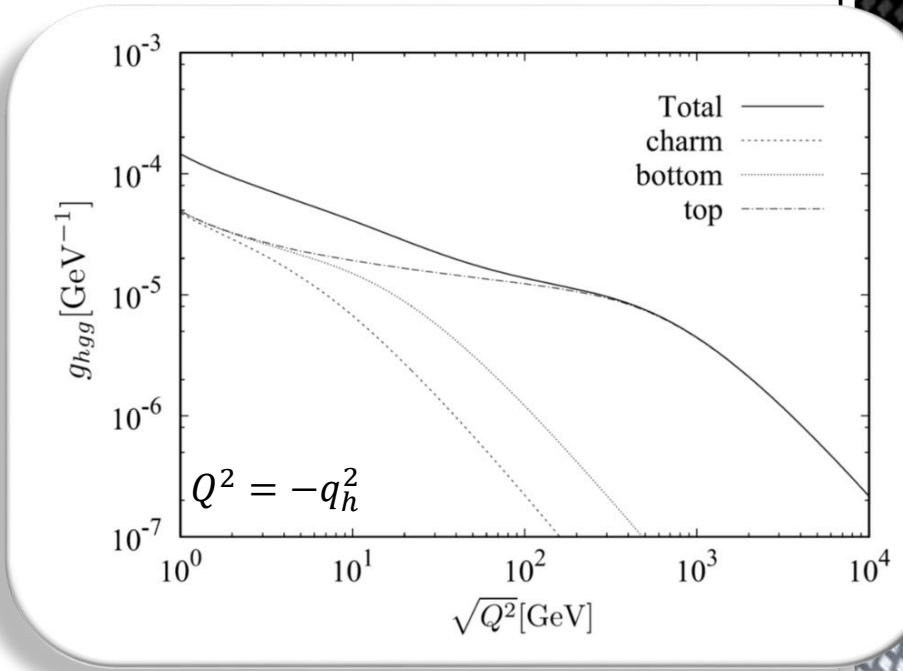
$$g_{hgg} = \sum_{q=c,b,t} \frac{\alpha_s}{8\pi v} \frac{4m_q^2}{q_h^2} \left[1 + \left(1 - \frac{4m_q^2}{q_h^2} \right) f\left(\frac{4m_q^2}{q_h^2} \right) \right]$$

$$f(r) = -\frac{1}{4} \log^2 \left[-\frac{1+\sqrt{1-r}}{1-\sqrt{1-r}} \right] \qquad (r < 0)$$



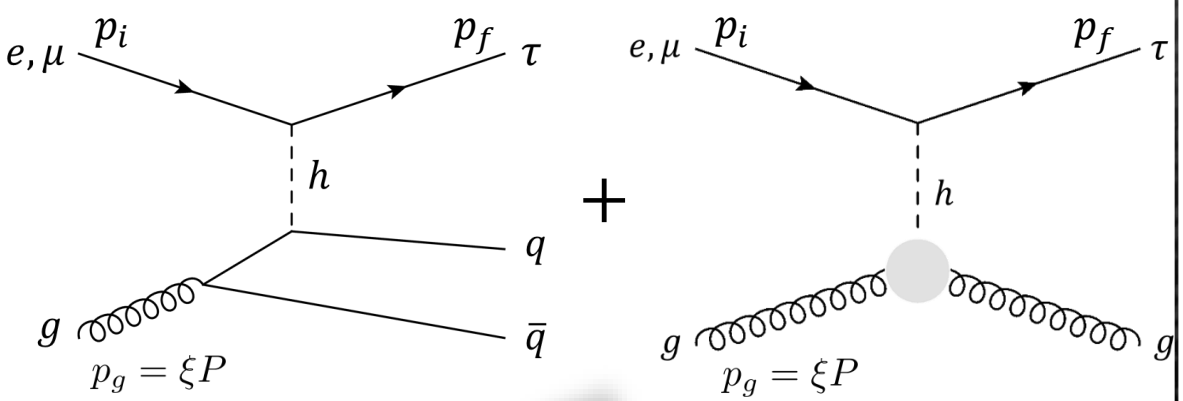
Sizable contributions from c-quark and b-quark, in addition to t-quark

Carefully include the scale dependence of hgg effective coupling



Cross section

H. Georgi, H. Politzer, PRL36 (1976)



$$\sigma_{\ell_i N \to \tau X} = \sum_{\hat{X}=g,q\bar{q}} \int dxdy \int_0^1 d\xi \frac{d^2\hat{\sigma}_{\ell_i g \to \tau \hat{X}}}{dxdy} f_g(\xi, Q^2)$$

Gluon PDF

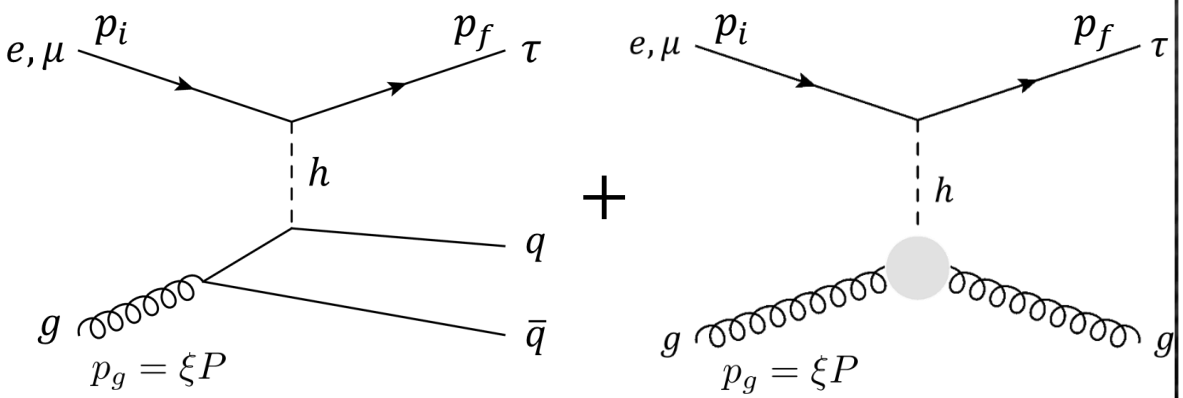
- Momentum fraction : $\xi = \dfrac{Q^2 + w^2}{Q^2} x$
- Invariant mass of $q\bar{q}$: $w^2 = (p_q + p_{q'})^2$
- Momentum transfer : $Q^2 = -(p_i - p_f)^2$

x : Bjorken variable

y : measure of inelasticy

Cross section

H. Georgi, H. Politzer, PRL36 (1976)



$$\sigma_{\ell_i N \to \tau X} = \sum_{\hat{X}=g,q\bar{q}} \int dxdy \int_0^1 d\xi \frac{d^2\hat{\sigma}_{\ell_i g \to \tau \hat{X}}}{dxdy} f_g(\xi, Q^2)$$

- Momentum fraction : $\xi = \dfrac{Q^2 + w^2}{Q^2} x$

x : Bjorken variable

Different quantities!

Calculate with taking into account $x \neq \xi$!!

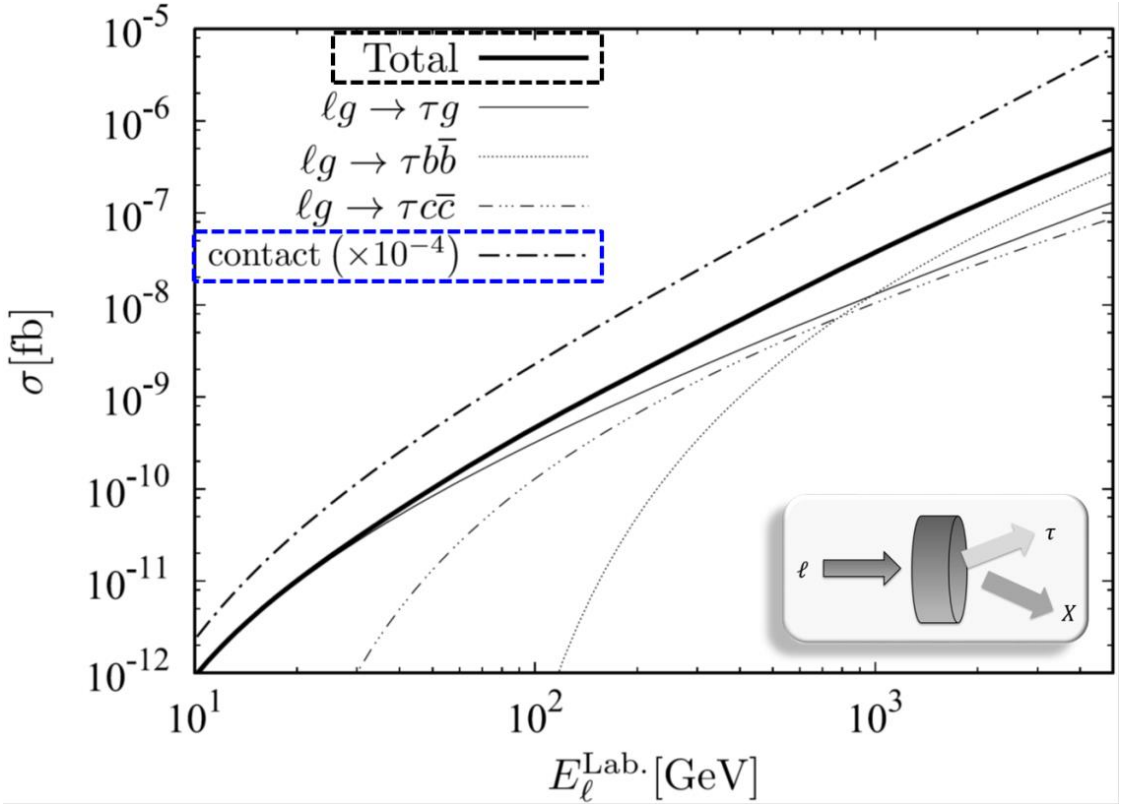
Numerical analysis

- ☑ For Higgs CLFV@fixed target exp.
- ☑ For general CLFV mediator@fixed target exp.
- ☑ For Higgs CLFV@beam collision exp.

CLFV coupling is taken to be current bound:

$$\sqrt{|\rho_{\ell\tau}|^2 + |\rho_{\tau\ell}|^2} = 2.4 \times 10^{-3}$$

Cross section vs beam energy for fixed target exp.



Large enhancement by new sub-process $\ell g \to \tau g$

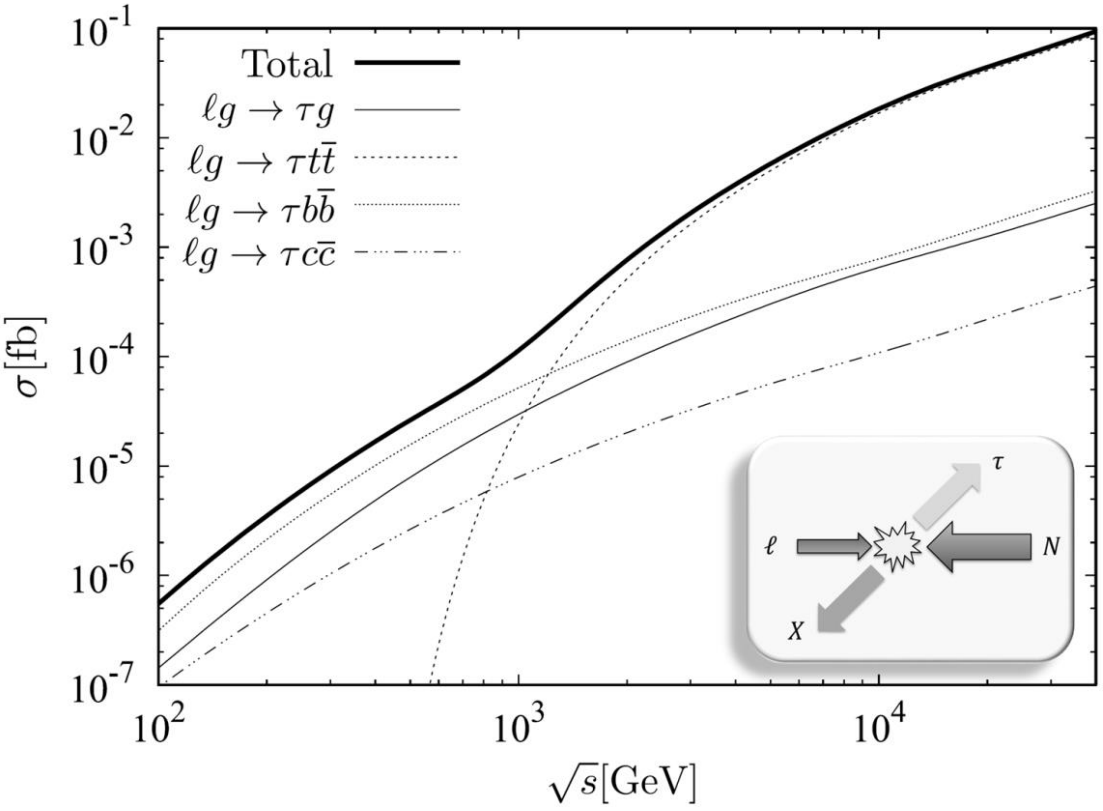
Large correction of σ arises from q-number conservation

$\tau b\bar{b}$ channel begins to be relevant at $E_\ell^{\rm Lab} \simeq 500\,{\rm GeV}$ (estimated in previous works as $E_\ell^{\rm Lab} \simeq 50\,{\rm GeV}$)

	ILC $(N_e \simeq 10^{22}/\text{year})$	ν factory $(N_\mu \simeq 10^{20}/\text{year})$
SM Higgs LFV	$O(10)$ event/year	$O(0.1)$ event/year
LFV via a heavy mediator	$O(10^5)$ event/year	$O(10^3)$ event/year

Cross section vs collision energy for collider exp.

(Higgs LFV)



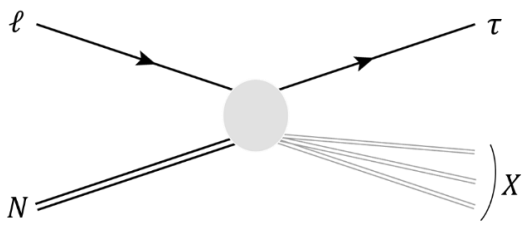
$\tau t\bar{t}$ channel dominates over others for $\sqrt{s} \gtrsim 1\,\mathrm{TeV}$

Important to understand the dominant channel with q-number conservation

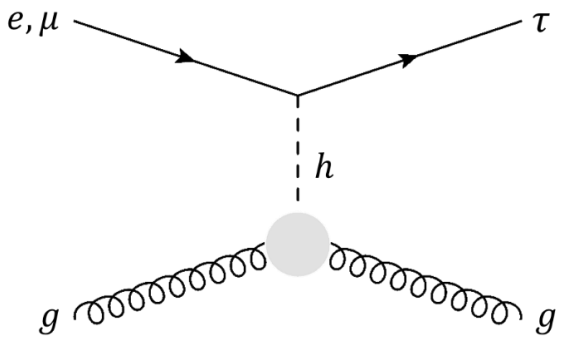
TLHeC ($\sqrt{s} = 1.3\mathrm{TeV}$)	FCC-eh ($\sqrt{s} = 3.5\mathrm{TeV}$)	FCC-eh ($\sqrt{s} = 5.9\mathrm{TeV}$)
$O(0.1)$ event/year	$O(1)$ event/year	$O(10)$ event/year

Summary

- ☑ We studied tau CLFV by mediators mainly interacting with heavy fermions



- ☑ It's necessary to precisely relate the CLFV parameters and event rate of ℓN scattering

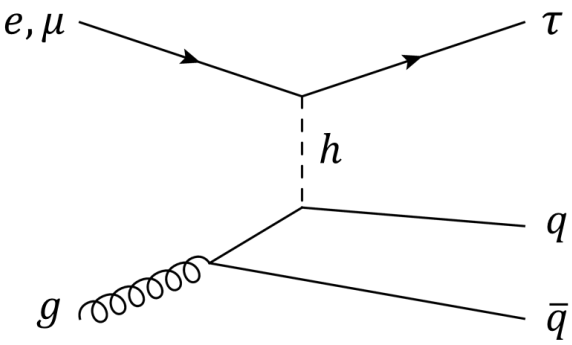


- ☑ **Reformulation of $\ell N \to \tau X$ taking into account important ingredients**

  (1) gluon contribution $\ell g \to \tau g$

  (2) q-number conservation $\ell g \to \tau q \bar{q}$

~~$\ell q \to \tau q$~~



- ☑ Future experiments (COMPASS, ILC, LHeC, ν factory, etc) could shed light on the tau CLFV

Thank you very much!

Backup slides

Cross sections for each PDF