Higgs mediated CLFV processes $\mu N(eN) \to \tau X$ via 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 $\ell g \to \tau g$ $(\ell \ni e, \mu)$

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

Search for tau CLFV through $eN(\mu N)$ scattering

☑ Today's topic : tau CLFV via Higgs

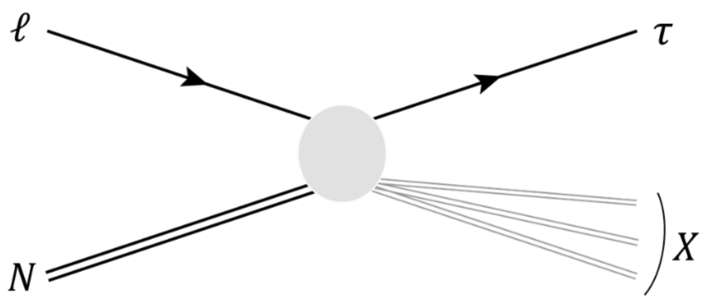
Results hold for any CLFV mediators mainly interacting with heavy fermions

e.g., heavy Higgs, flavon, leptoquark, ...

☑ A promising way to search for tau CLFV :

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

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

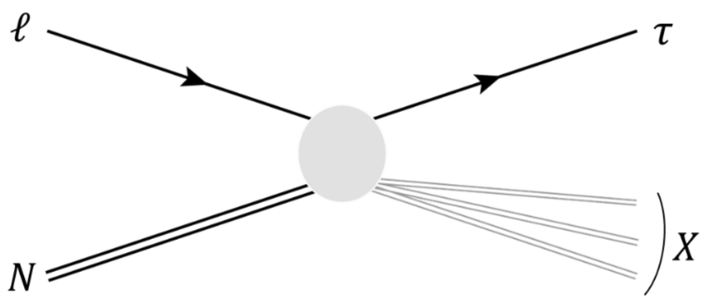


Search for tau CLFV through $eN(\mu N)$ scattering

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

- ☑ A promising way to search for tau CLFV :

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

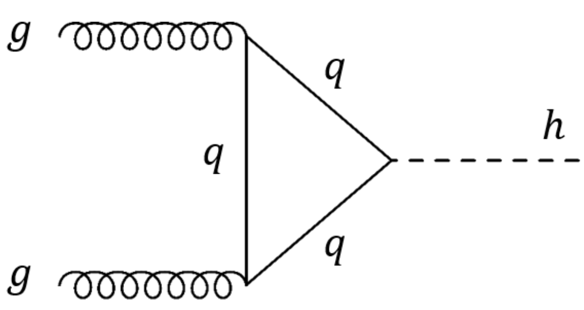


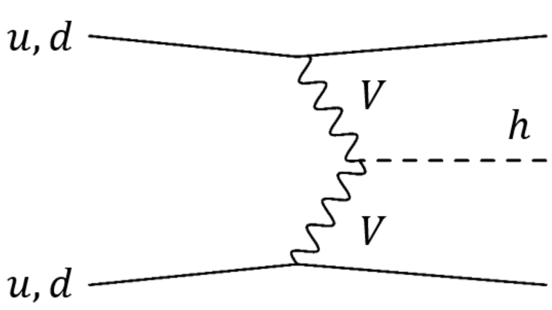
- Many exp. launch, e.g., ν-factory, ILC, LHeC, etc.
- Can reach high sensitivity beyond the Belle-II sensitivity limit for tau CLFV

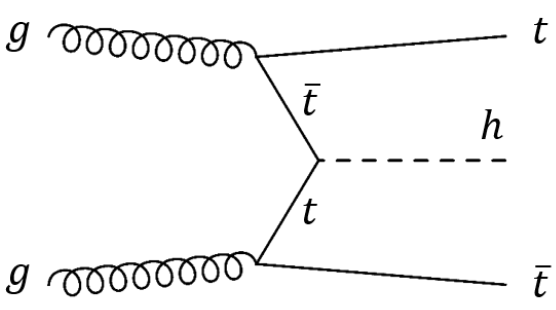
Prior to the analysis on $\ell N \to \tau X$,
answer easy quiz questions!

Higgs production@LHC

- ☑ Which is dominant sub-process?

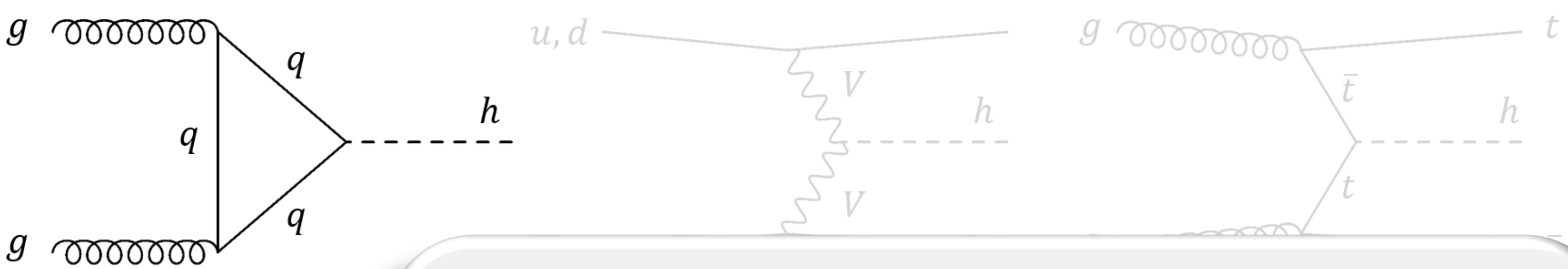






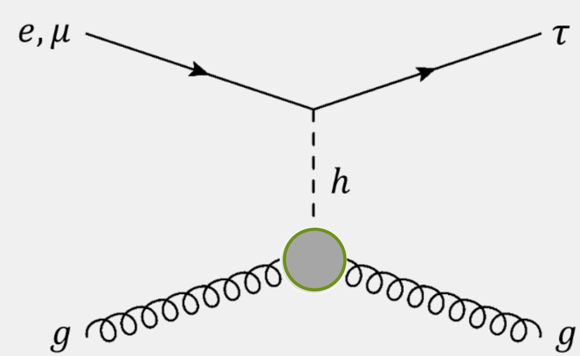
Higgs production@LHC

- ☑ Which is dominant sub-process?



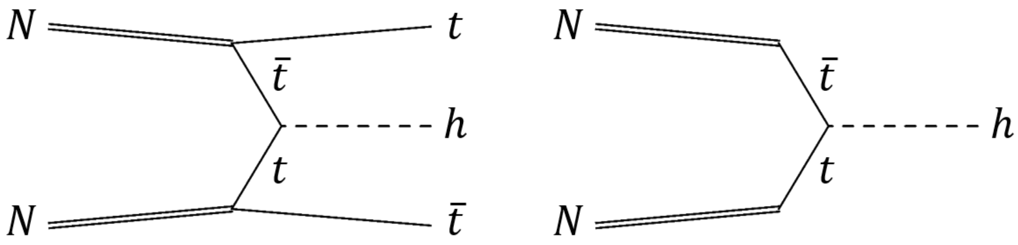
- ☑ New sub-process for $eN\ (\mu N) \to \tau X$

- ☑ Dominant sub-process for fixed target exp.



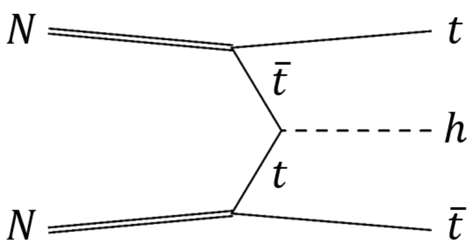
Higgs production@LHC

- ☑ Which is correct sub-process?



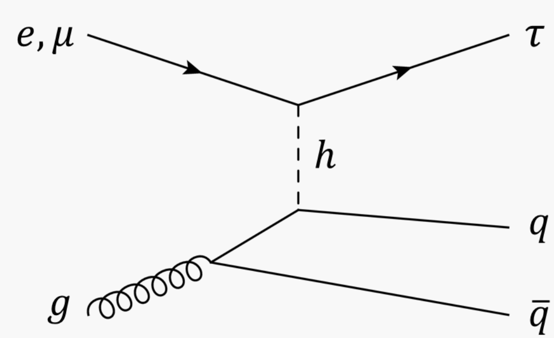
Higgs production@LHC

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

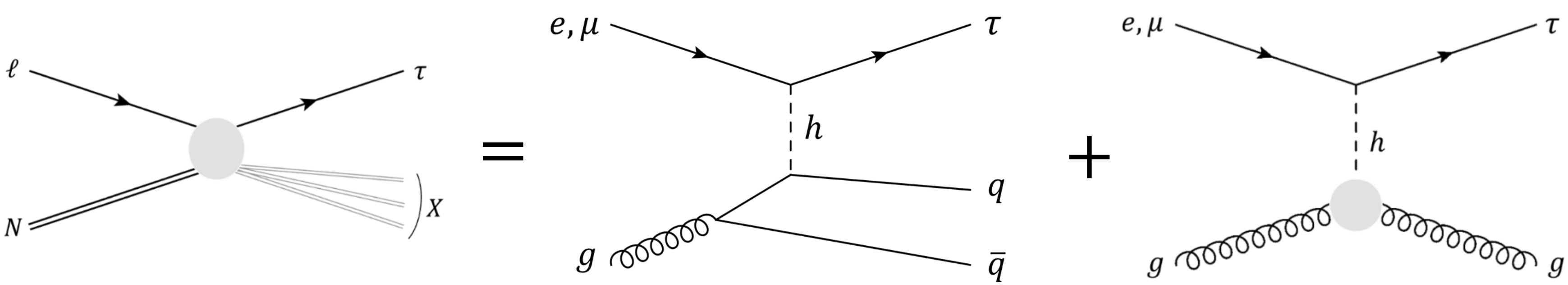
$E_{e(\mu)}^{\text{beam}} > 55$ GeV for $\ell g \to \tau b \bar{b}$

Aim of this work and outline

Reformulation of CLFV lepton-nucleus scattering taking into account

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

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



Outline

- Formulation of effective coupling and cross section
- Numerical analysis
- Summary

Formulation of effective coupling and cross section

- ☑ Lagrangian
- ☑ hgg effective coupling
- ☑ Cross section

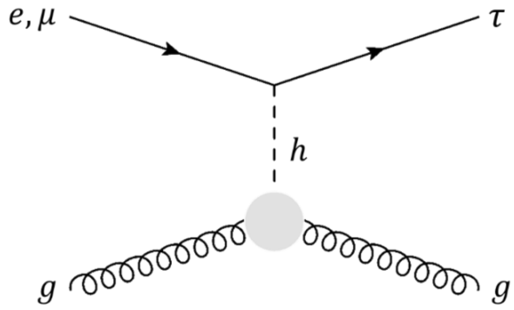
Lagrangian for $\ell g \to \tau g$ and $\ell g \to \tau q\bar{q}$

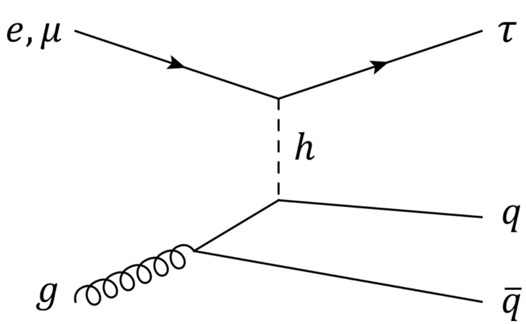
Important : momentum transfer dependence of hgg effective coupling

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

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

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





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

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

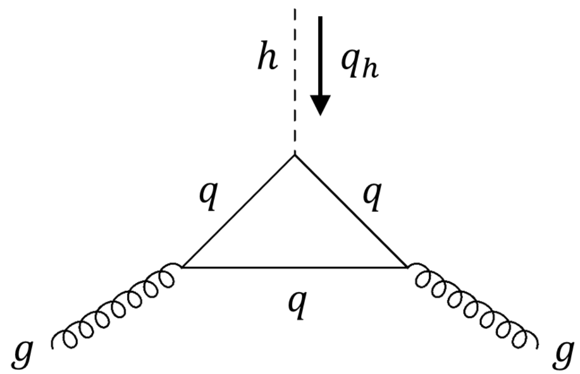
Note: stronger than the Belle-II sensitivity for tau CLFV search

Higgs-gluon-gluon coupling

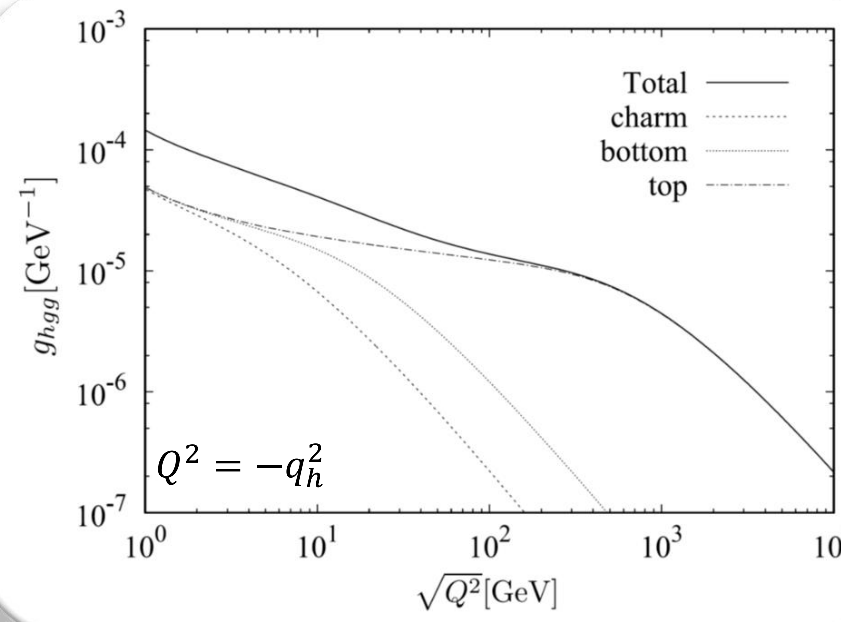
☑ hgg effective coupling

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

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

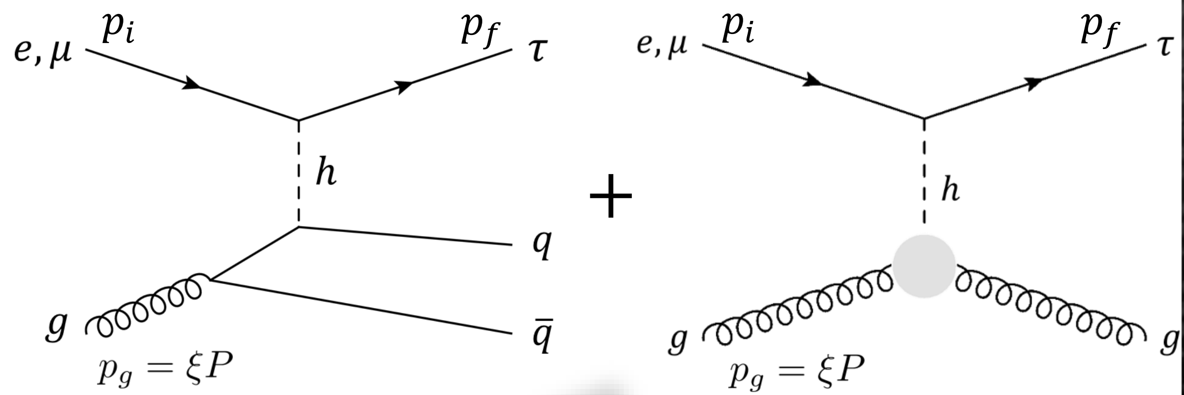


☑ In addition to t-quark, c-quark and b-quark also sizably contribute



Cross section

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



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

Gluon PDF

x : Bjorken variable

y : measure of inelasticy

- 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 : $Q^2 = -(p_i - p_f)^2$

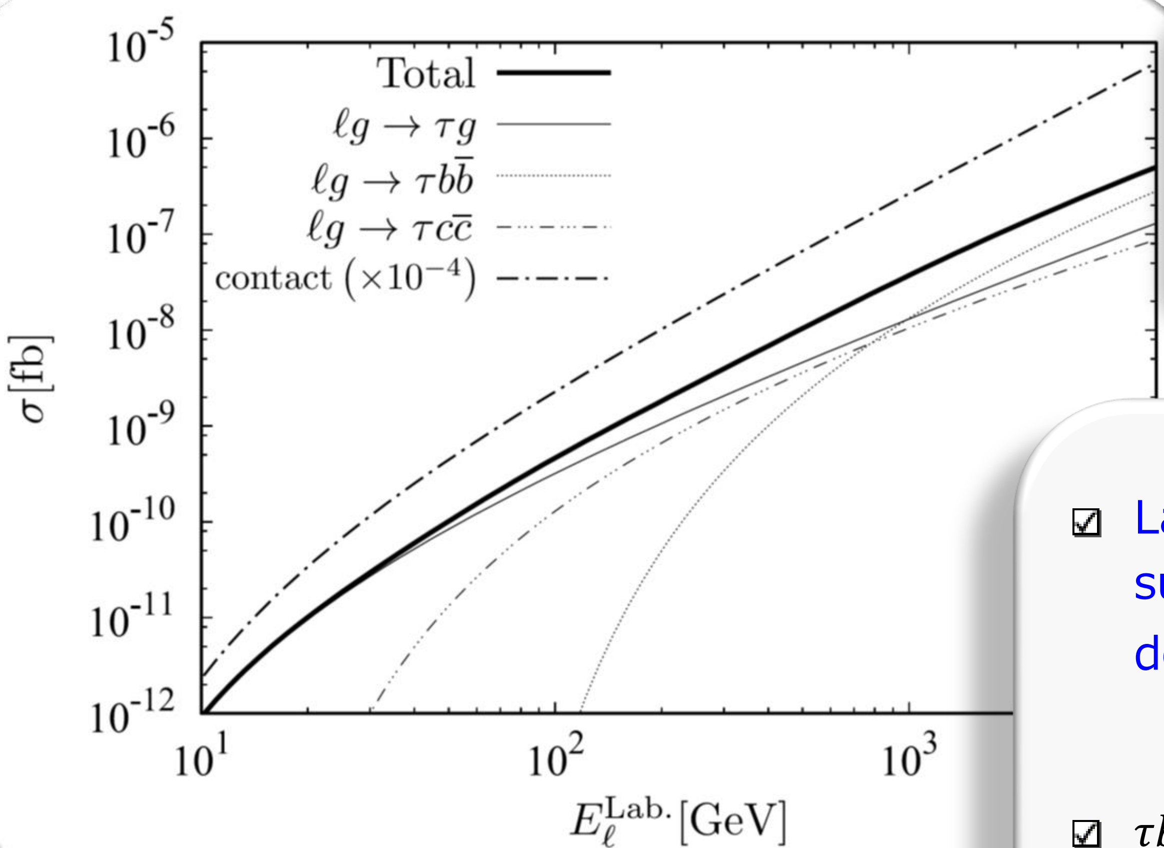
Numerical analysis

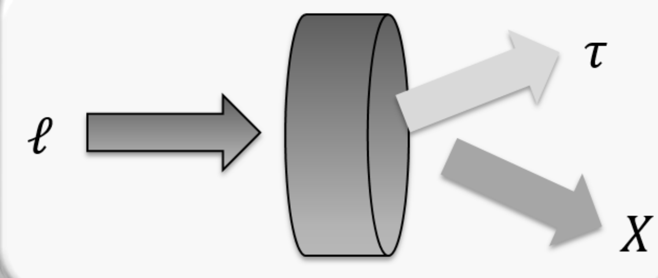
- ☑ For Higgs CLFV@fixed target experiments
- ☑ For general CLFV mediator@fixed target experiments
- ☑ For Higgs CLFV@beam collision experiments

CLFV effective coupling is taken to be current bound:

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

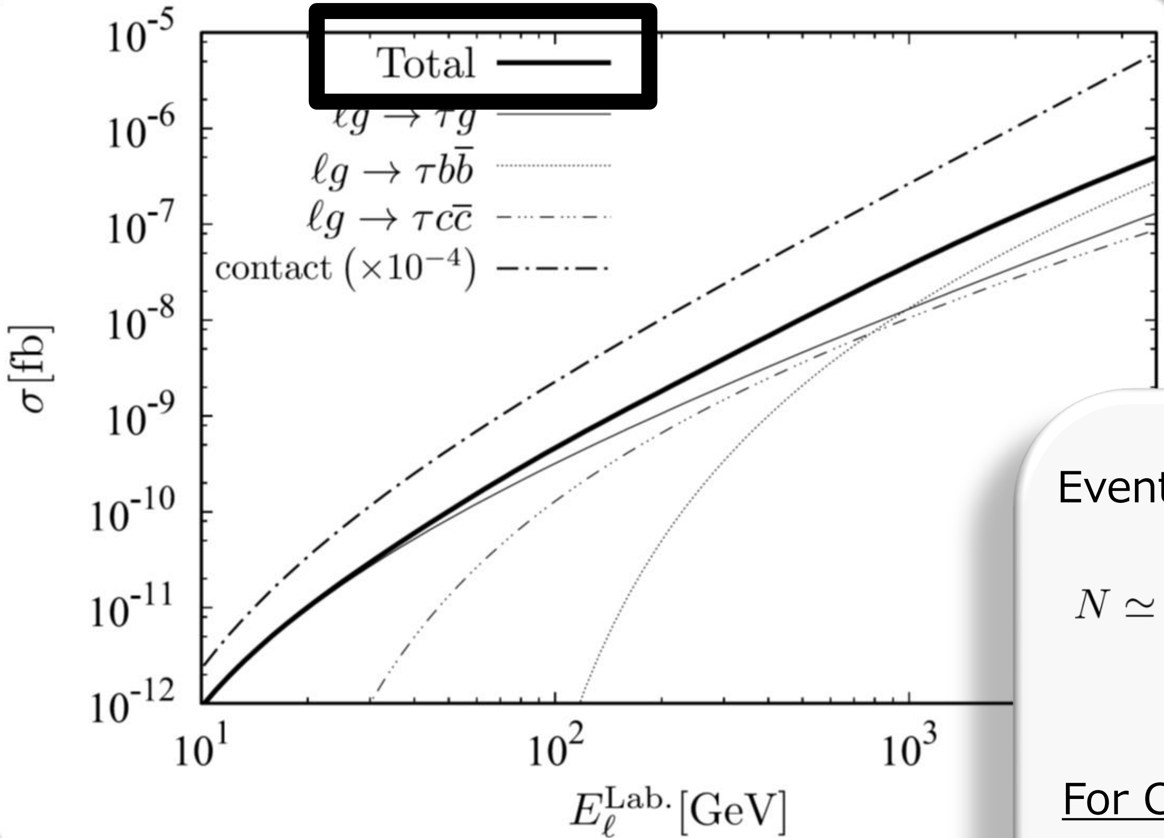
Cross section vs beam energy for fixed target exp.





- ☑ Large enhancement by the new sub-process $\ell g \to \tau g$, which is dominant for $E_\ell^{\mathrm{Lab}} \lesssim 1\ \mathrm{TeV}$
- ☑ $\tau b\bar{b}$ channel starts to be relevant at $E_\ell^{\mathrm{Lab}} \simeq 500\ \mathrm{GeV}$ (estimated in previous works as $E_\ell^{\mathrm{Lab}} \simeq 50\ \mathrm{GeV}$)

Cross section vs beam energy for fixed target exp.



Event rate/year (T_m: target mass)

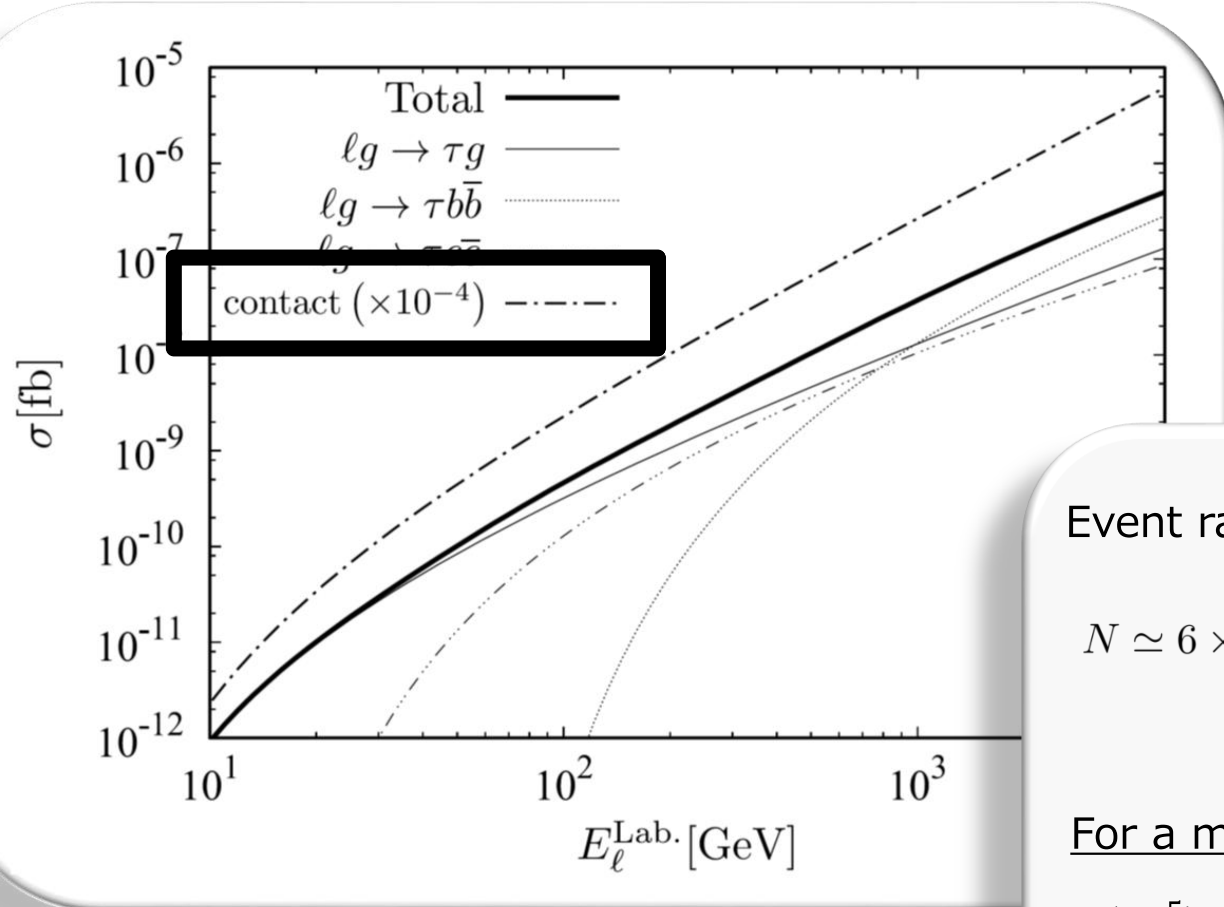
$$N \simeq 6 \times 10^{-16}\, N_{\ell_i} \left(\frac{\sigma_{\ell_i N \to \tau X}}{1\,\mathrm{fb}}\right) \left(\frac{T_m}{1\,\mathrm{g\,cm^{-2}}}\right)$$

<u>For CLFV mediator = Higgs</u>

$O(10)$ event@ILC ($N_e \simeq 10^{22}$/year)

$O(1)$ event@ν factory ($N_\mu \simeq 10^{20}$/year)

Cross section vs beam energy for fixed target exp.



Event rate/year (T_m: target mass)

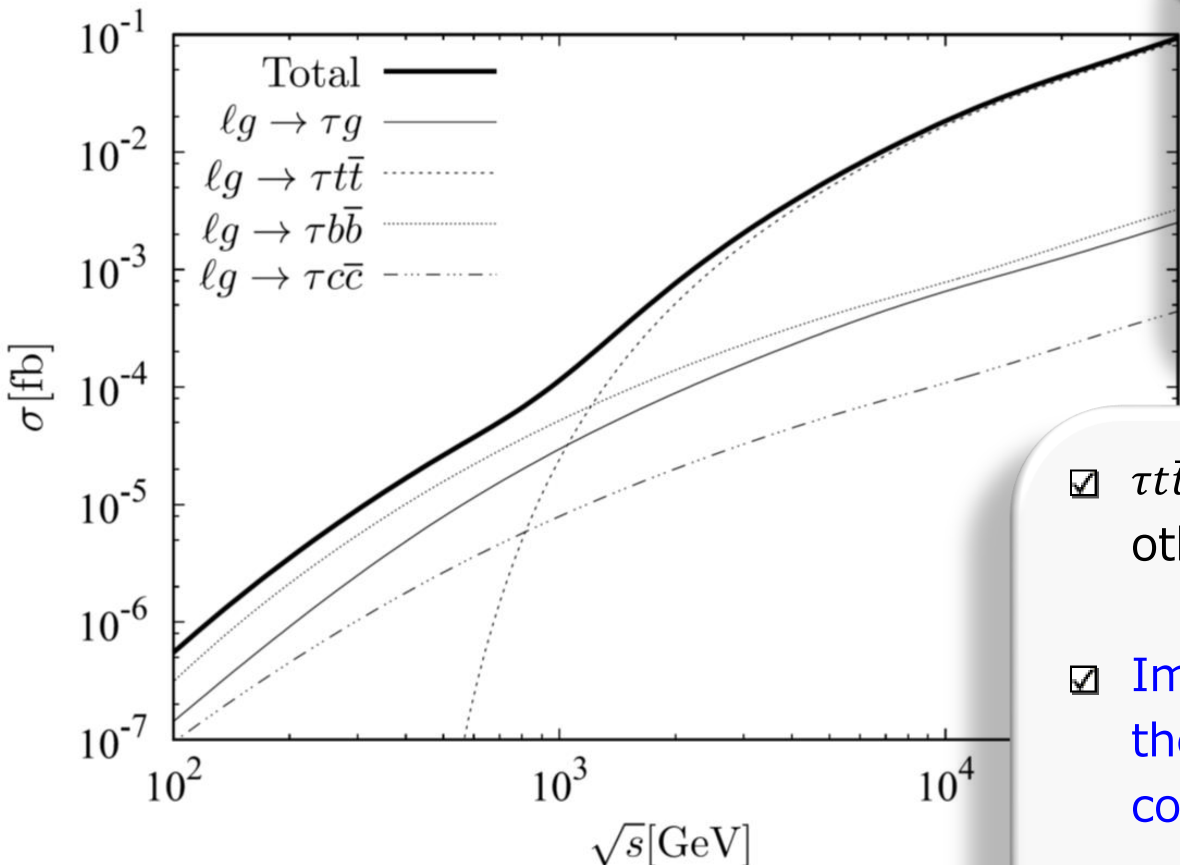
$$N \simeq 6 \times 10^{-16}\, N_{\ell_i} \left(\frac{\sigma_{\ell_i N \to \tau X}}{1\,\mathrm{fb}}\right) \left(\frac{T_m}{1\,\mathrm{g\,cm^{-2}}}\right)$$

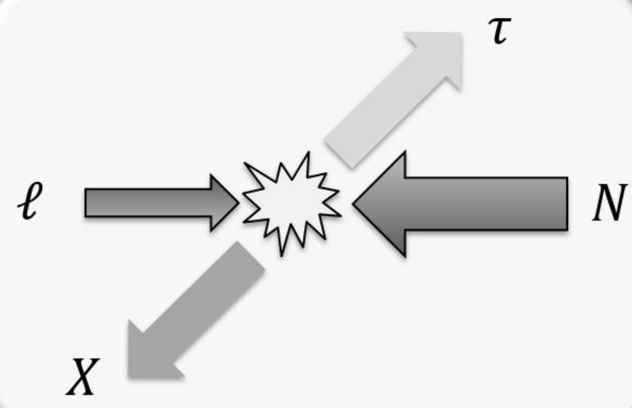
<u>For a mediator interacting with gluon</u>

$O(10^5)$ event@ILC ($N_e \simeq 10^{22}$/year)

$O(10^4)$ event@ν factory ($N_\mu \simeq 10^{20}$/year)

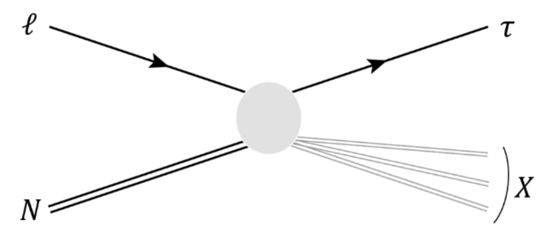
Cross section vs collision energy for collider exp.



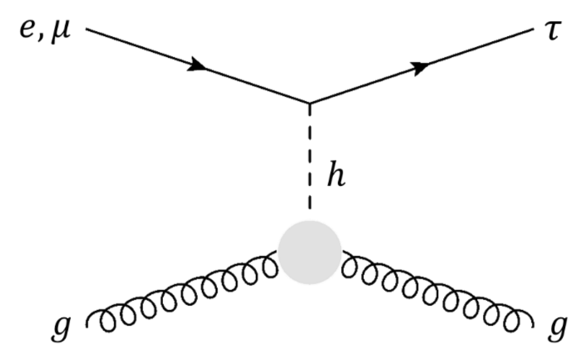


- ☑ $\tau t\bar{t}$ channel dominates over others for $\sqrt{s} \gtrsim 1\,\mathrm{TeV}$
- ☑ Important to correctly calculate the cross section with q-number conservation
- ☑ Assuming $O(1000)\ \mathrm{fb}^{-1}/\mathrm{year}$, $O(10)$ event/year@VLHeC

Summary



- ☑ Study tau LFV as it is relatively less constrained and sizable effects could be expected

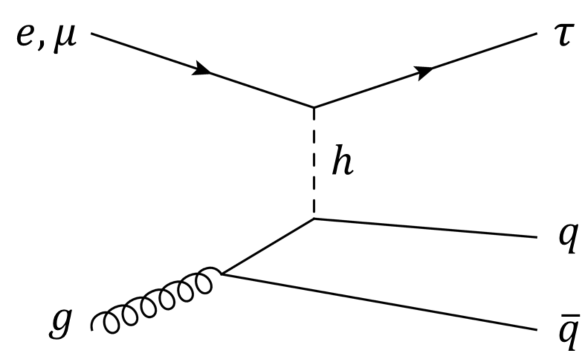


- ☑ Focusing on the tau LFV by mediators mainly interacting with heavy fermions

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

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

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



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

Thank you very much!

Backup slides

Cross sections for each PDF