Lepton-nucleus CLFV scattering $\ell_i N \to l_j X$ by scalar interaction

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M. Takeuchi, Y. Uesaka, M.Y., arXiv:1903.XXXXX

$\ell_i N \to \ell_j X$ by mediators interacting with heavy quarks

(1) new subprocess $\ell_i g \to \ell_j g$

(2) effects of q-number conservation and of phase space

Charged Lepton Flavor Violation in ℓN scattering

Topic

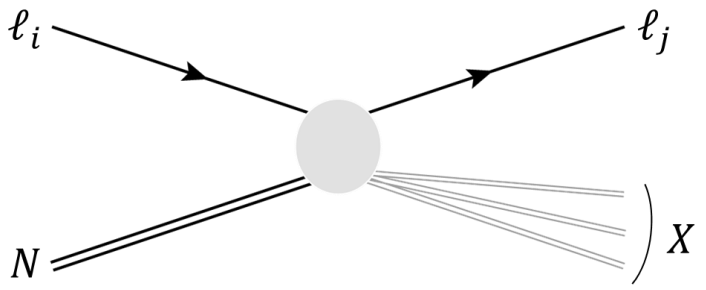
CLFV mediated by (pseudo-)scalar which mainly interacting with heavy quarks

Higgs, CP-odd Higgs, KK Higgs, Flavon, R-parity violating slepton, etc

Variety of applications!

A promising way to search for CLFV

$$\ell_i + N \to \ell_j + X \quad (N: \text{Nucleus})$$



- Many experiments launch (ILC, LHeC, etc.)
- Sensitivity comparable to other CLFV
- Unique probe to some CLFV ope.

Precisely relate the CLFV parameter and the observables of $\ell_i N \to \ell_j X$!!

CLFV scattering mediated by (pseudo-)scalar

A simplest extension for interactions of CLFV (pseudo-)scalar

$$\mathcal{L}_{\mathrm{CLFV}} = \sum_{X=S,A} \left(-\rho^X_{ij} \bar{\ell}_j P_L \ell_i \phi_X - \rho^X_{ji} \bar{\ell}_j P_R \ell_i \phi_X \right) + h.c.$$

$$\mathcal{L}_q = -\rho^S_{qq} \bar{q} q \phi_S - \rho^A_{qq} \bar{q} \gamma^5 q \phi_A + h.c.$$

ρ_{ij}, ρ_{ji} : CLFV parameter

(i, j : flavor index)

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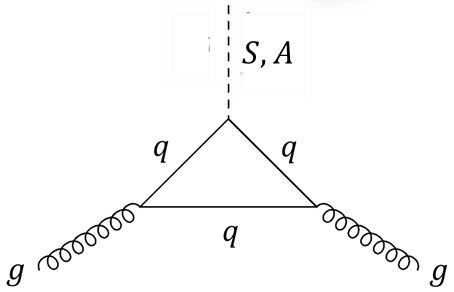
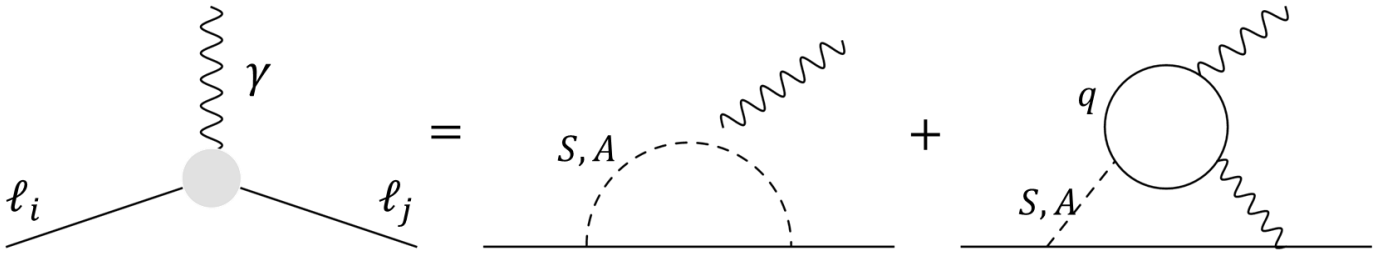
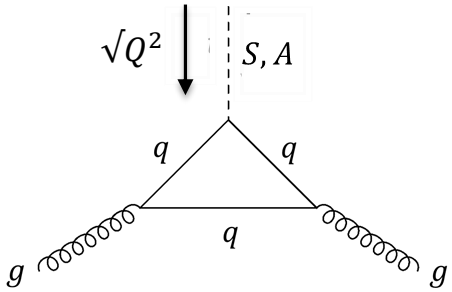




$\phi_{S(A)}gg$ effective coupling



$$\mathcal{L}_G = g_{Sgg}\phi_S G^a_{\mu\nu}G^{a\mu\nu} + g_{Agg}\phi_A G^a_{\mu\nu}\tilde{G}^{a\mu\nu}$$

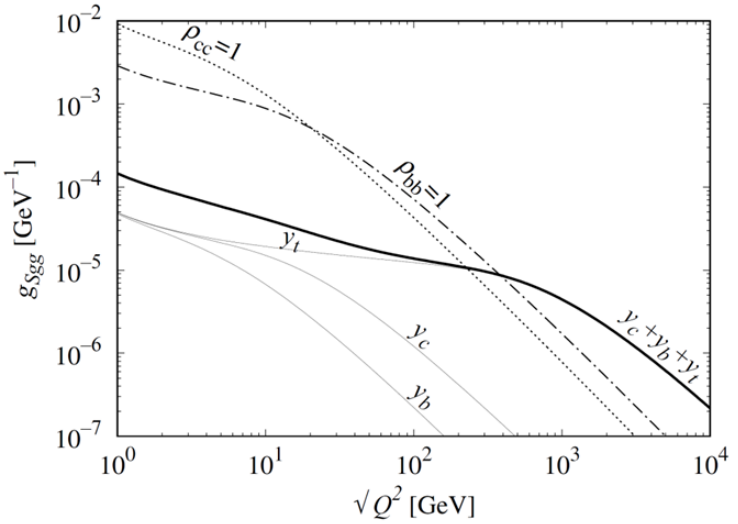
Carefully handle following issues to determine CLFV ope.

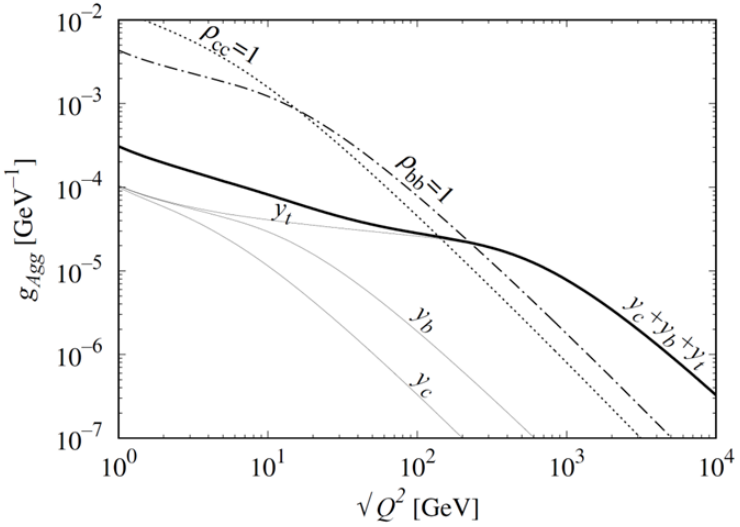
- Strong dependence of momentum transfer
- Pattern of mediator-quark interaction
- Sizable contributions of c- and b-quarks in addition to t-quark

$(a)\ \rho_{cc}^{S(A)} = 1,\ \rho_{bb}^{S(A)} = \rho_{tt}^{S(A)} = 0$

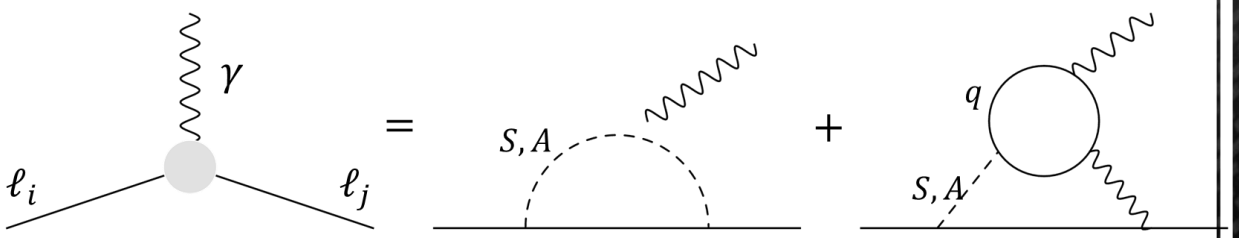
$(b)\ \rho_{bb}^{S(A)} = 1,\ \rho_{cc}^{S(A)} = \rho_{tt}^{S(A)} = 0$

$(c)\ \rho_{cc}^{S(A)} = y_c,\ \rho_{bb}^{S(A)} = y_b,\ \rho_{tt}^{S(A)} = y_t$





Photonic dipole



$$\mathcal{L}_{\text{dipole}} = -\frac{e}{2} m_j \sum_{X=S,A} \left(A_{ij}^X \bar{\ell}_j \sigma^{\mu\nu} P_L \ell_i F_{\mu\nu} + A_{ji}^X \bar{\ell}_j \sigma^{\mu\nu} P_R \ell_i F_{\mu\nu} \right)$$

$$A_{ij} = \frac{1}{16\pi^2 v^2} \left(A_1 + A_2^{t,b} + A_2^W \right)$$

Sensitive to models and mediator masses

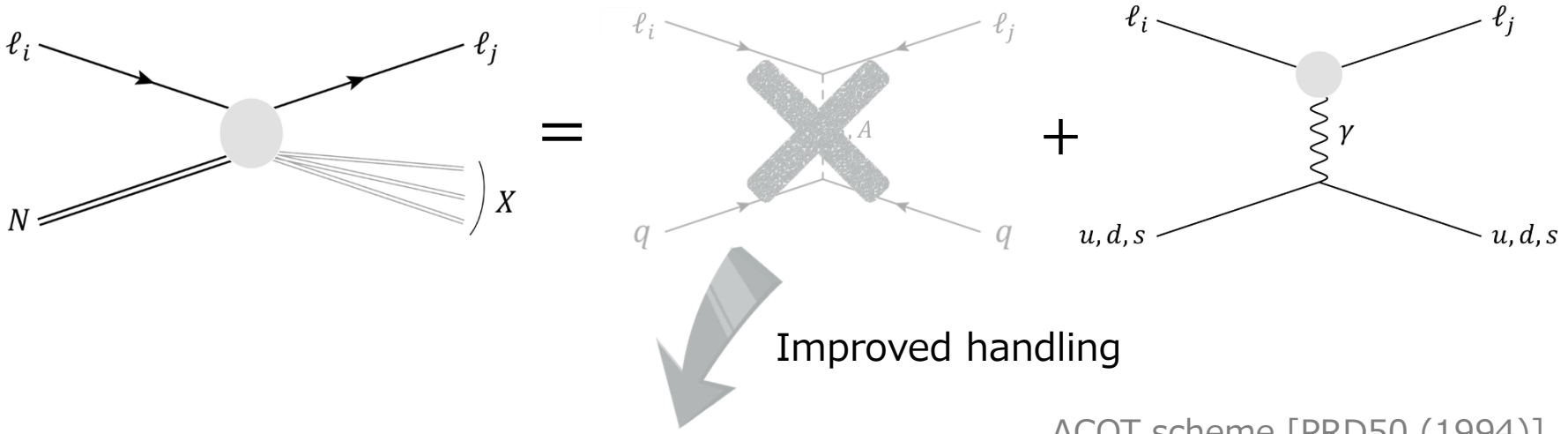
Event rate via the dipole operator is useful for model discrimination

e.g. coefficients in 2HDM as a function of scalar mass

m_ϕ [GeV]	125	200	300	400	500
$10^3 \times \tilde{A}_1^f(r_{\tau/\phi})$	2.0025	0.8872	0.4345	0.2605	0.1747
$10^3 \times \tilde{A}_2^{t,H}(r_{t/\phi})$	6.2431	4.6631	3.4720	2.7435	2.2504
$10^3 \times \tilde{A}_2^{t,A}(r_{t/\phi})$	8.9039	6.5746	4.8361	3.7840	3.0785
$10^3 \times \tilde{A}_2^{b,H}(r_{b/\phi})$	0.0407	0.0208	0.0114	0.0073	0.0052
$10^3 \times \tilde{A}_2^{b,A}(r_{b/\phi})$	0.0508	0.0255	0.0138	0.0088	0.0062
$10^3 \times \tilde{A}_{2,\phi}^W(r_{W/\phi})$	-14.0380	-8.8698	-5.1773	-2.9841	-1.5079

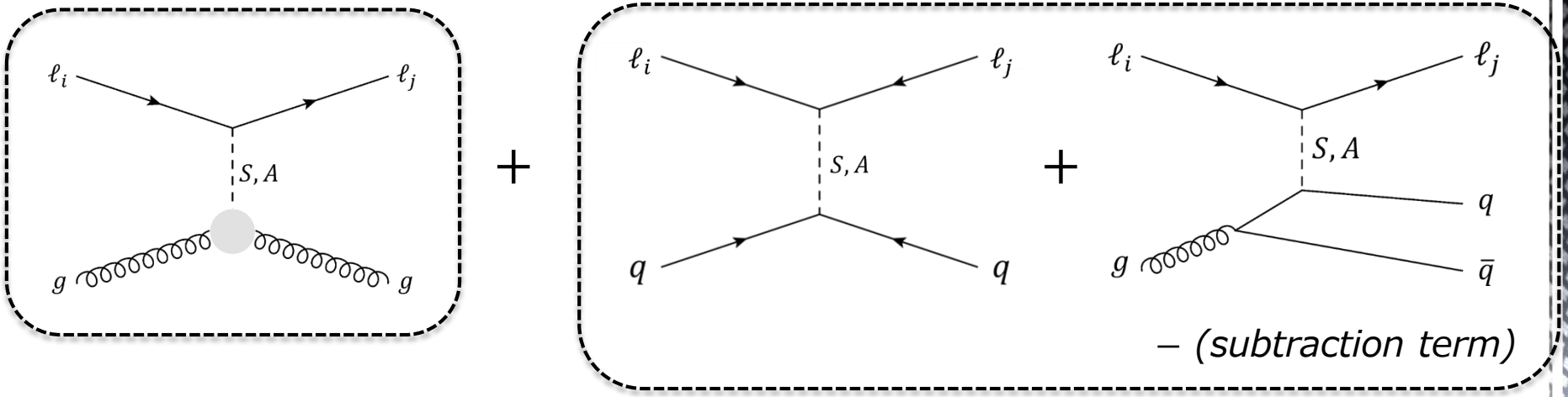
Subprocess of CLFV scattering $\ell_i N \to \ell_j X$

Take into account the ϕgg coupling and q-number conservation



Improved handling

ACOT scheme [PRD50 (1994)]



Cross section

See e.g. T. Stavreva, F. I. Olness, et al, (2012)
and M. Takeuchi, Y. Uesaka, M.Y., PLB772 (2017)

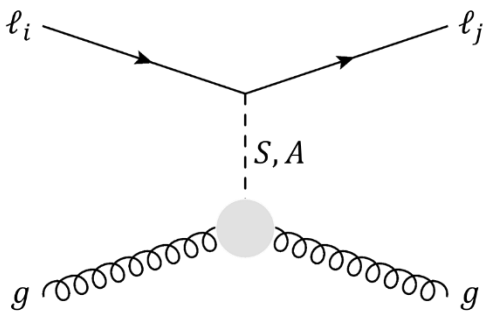
- Momentum fraction : $\xi = \dfrac{Q^2 + w^2}{Q^2} x$
- Invariant mass of $\hat{X}$: $w^2 = (p_q + p_{q'})^2$
- Momentum transfer : $Q^2 = -(p_i - p_f)^2$

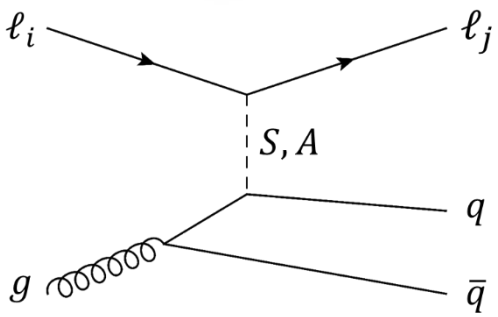
x : Bjorken variable

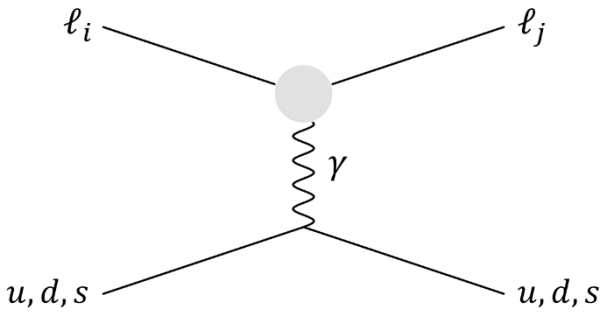
y : measure of inelasticy

$$\sigma_{\ell_i N \to \ell_i X} = \sum_{\hat{p}=g,q} \int dxdy \int_0^1 d\xi \frac{d^2\hat{\sigma}_{\ell_i \hat{p} \to \ell_j \hat{X}}}{dxdy} f_{\hat{p}}\left(\xi_{\hat{p}}, Q^2\right)$$

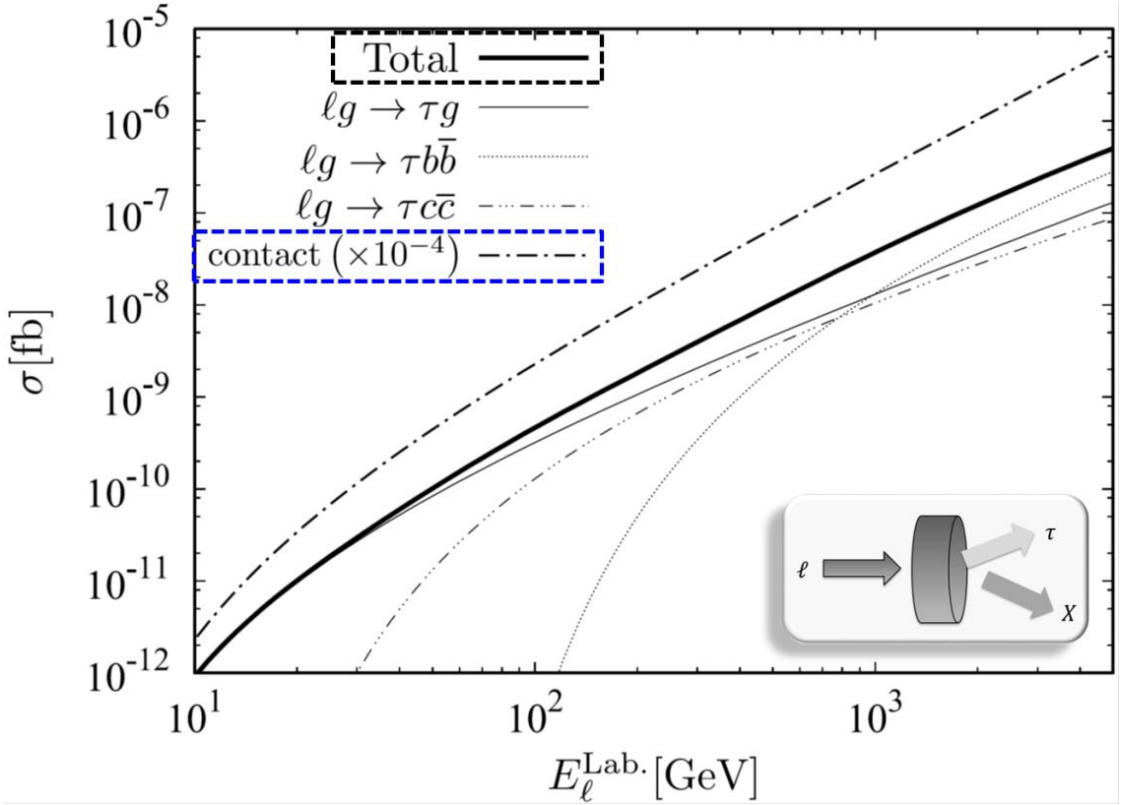
PDF (function of ξ, not x!)







Example: SM-Higgs and a heavy scalar



Large enhancement by new subprocess $\ell g \to \tau g$

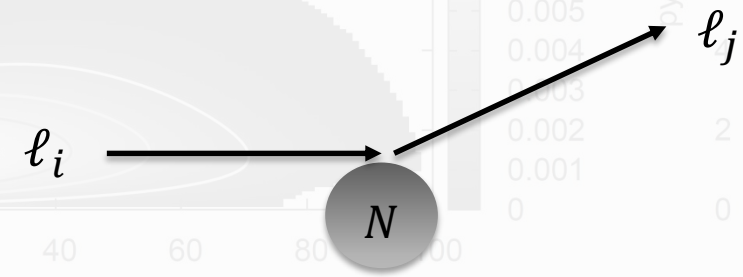
Large correction of σ arises from q-number conservation

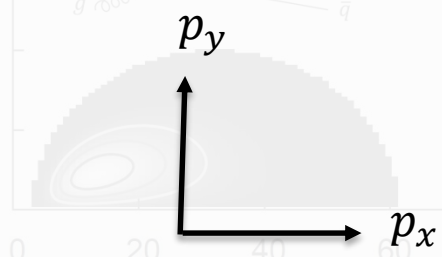
$\tau b \bar{b}$ channel begins to be relevant at $E_\ell^{\text{Lab}} \simeq 500\ \text{GeV}$ (estimated in previous works as $E_\ell^{\text{Lab}} \simeq 50\ \text{GeV}$)

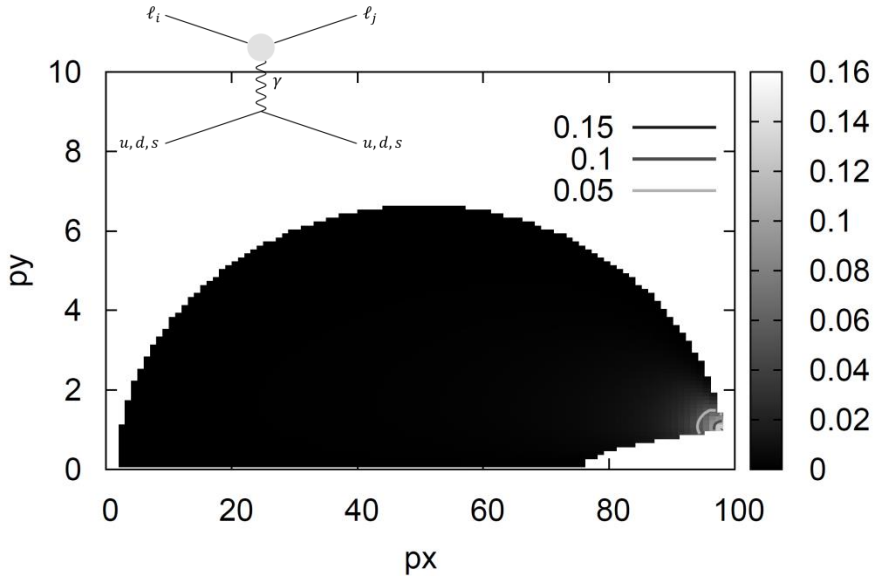
	ILC	ν factory
SM Higgs CLFV	$O(10)$ event/year	$O(0.1)$ event/year
CLFV via a heavy scalar	$O(10^5)$ event/year	$O(10^3)$ event/year

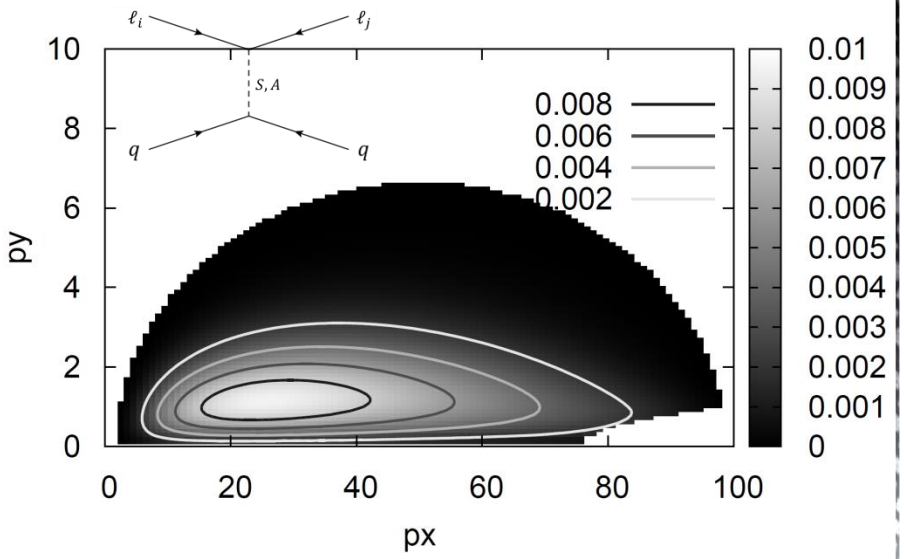
Momentum distribution of final lepton

Subprocesses and momentum distributions $d^2\sigma/dp_x dp_y$ in previous works









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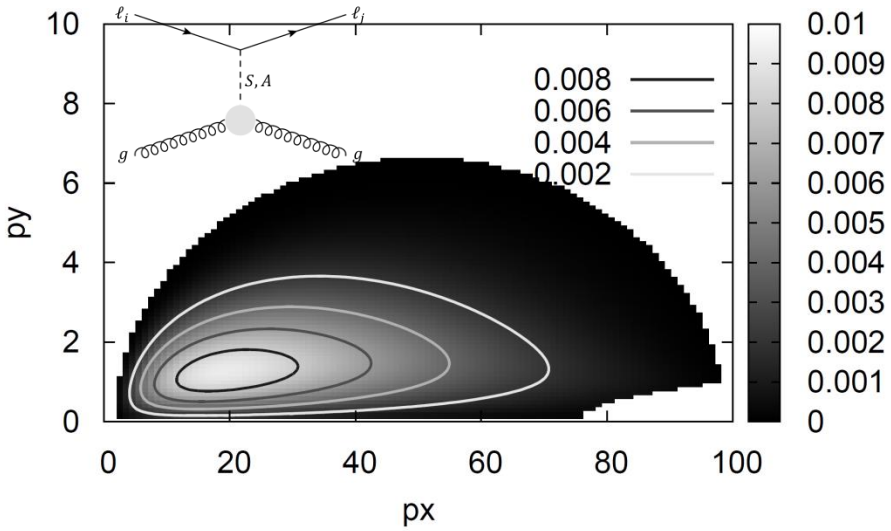
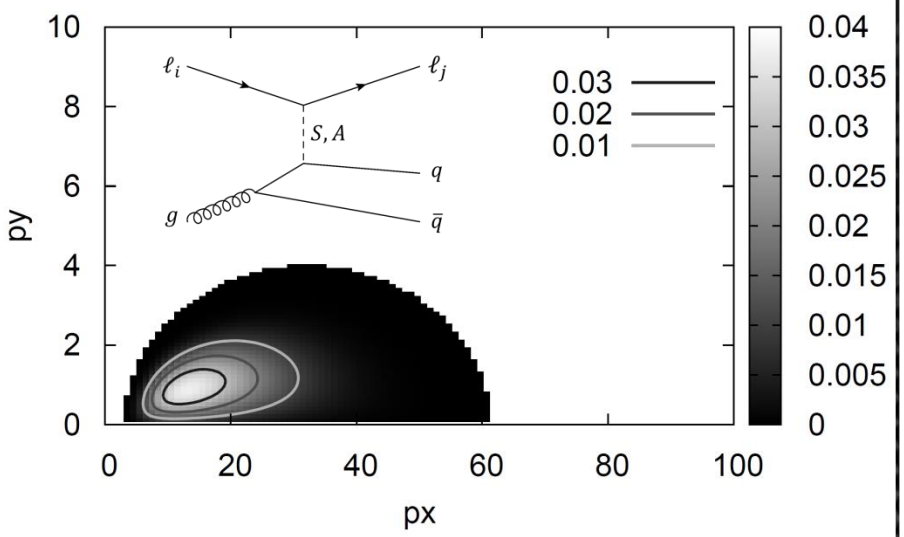
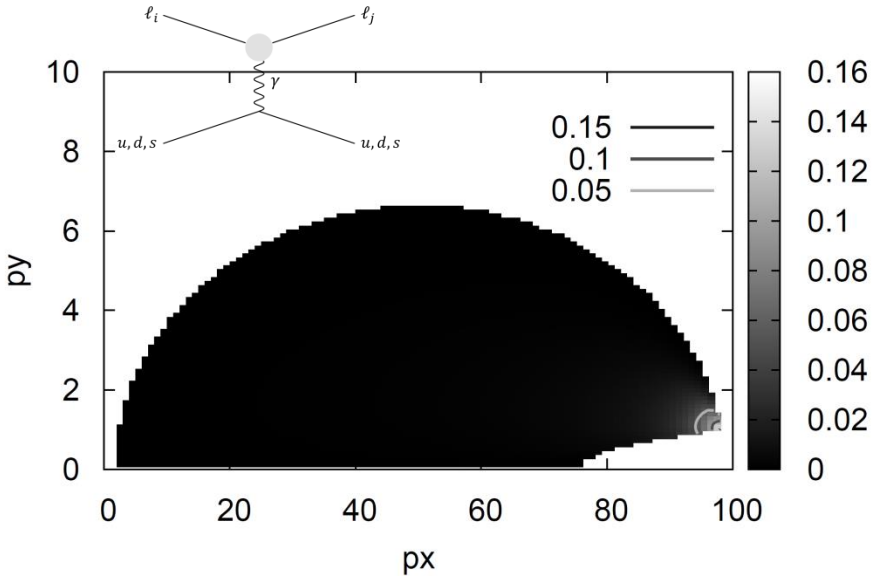




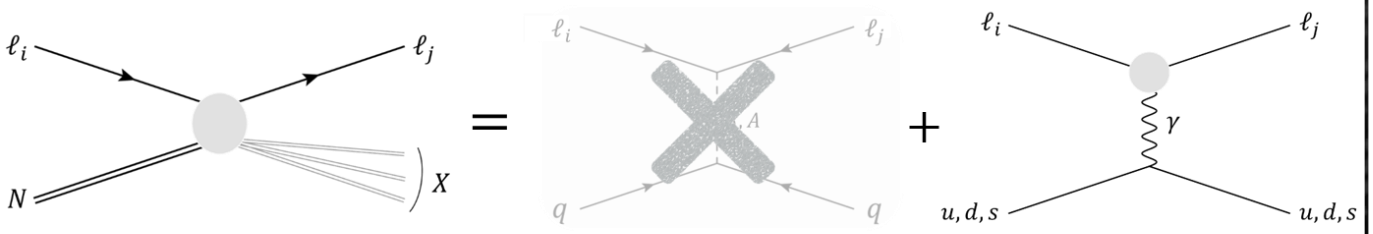


Improved subprocesses and distributions

Combining jet multiplicity, each one shows distinctive distribution

Important to analyze exp. data with improved ones to determine CLFV ope.

Summary



- ☑ Focusing on CLFV mediated by (pseudo-) scalars mainly interacting with heavy flavor

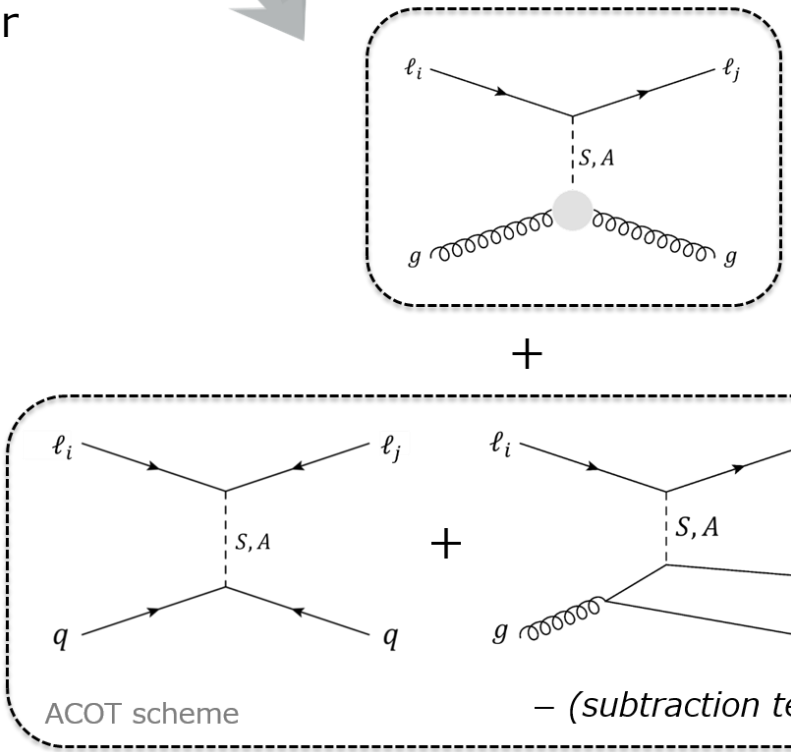
- ☑ **Reanalysis on $\ell_i N \to \ell_j X$ taking into account important ingredients**

  (1) gluon contribution $\ell_i g \to \ell_j g$

  (2) q-number conservation $\ell_i g \to \ell_j q\bar{q}$

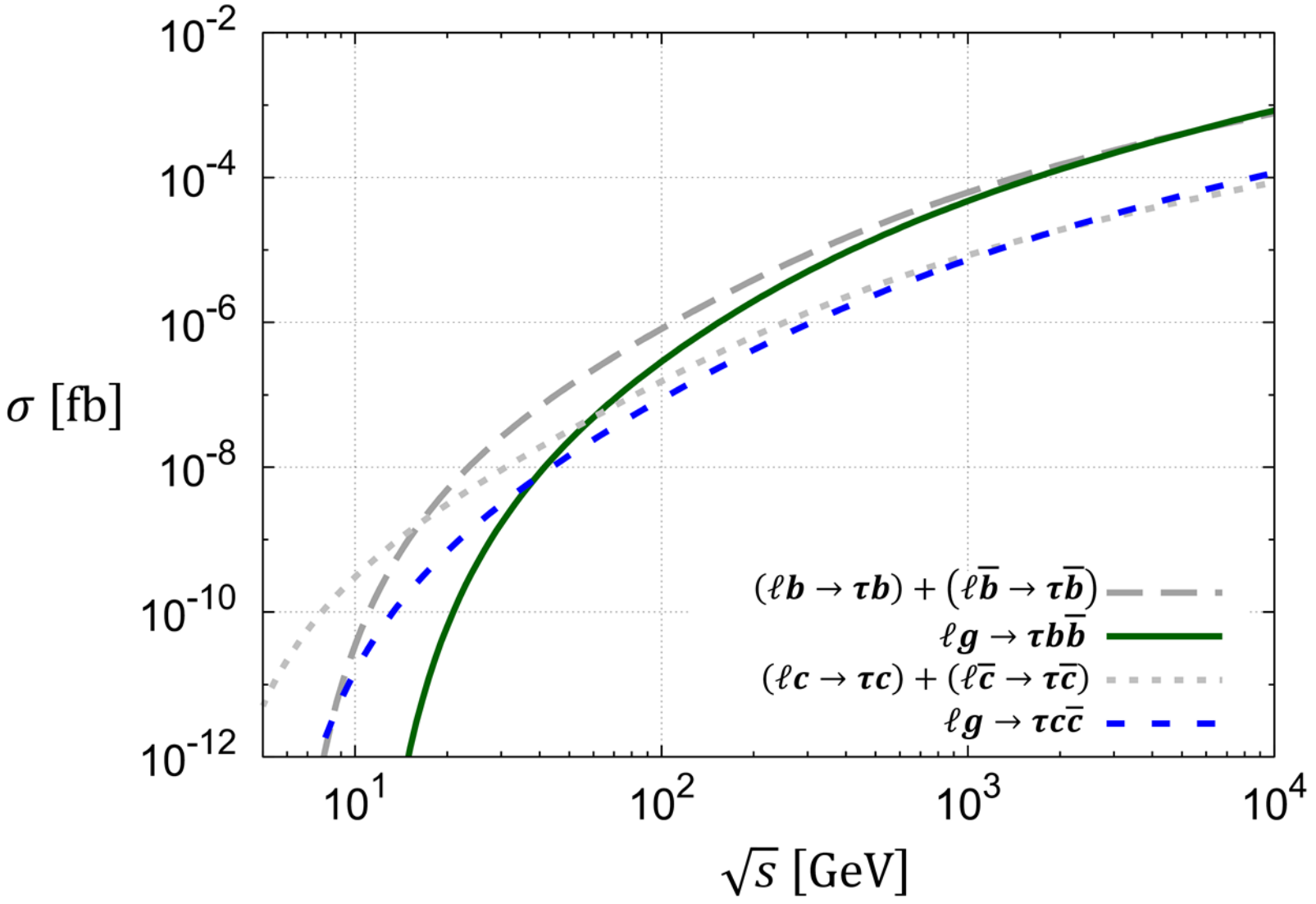
- ☑ Enhanced event rate and improved momentum distributions determine CLFV ope.

Improved handling



Thank you very much!

Backup slides


10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
σ [fb]
10^{1}
10^{2}
10^{3}
10^{4}
$\sqrt{s}$ [GeV]
$(\ell b \to \tau b) + (\ell \bar{b} \to \tau \bar{b})$
$\ell g \to \tau b \bar{b}$
$(\ell c \to \tau c) + (\ell \bar{c} \to \tau \bar{c})$
$\ell g \to \tau c \bar{c}$