Lepton-flavor violation via four-Fermi contact interactions at e+e- linear collider

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arXiv:1803.10475 [hep-ph]

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Plan

(naive question)

μ (τ) $\rightarrow$3e exp. (high stat.) are known to be highly sensitive to LFV via 4-fermi contact interactions.

How about ILC (high E.) ?

- Introduction
- Set up
- Constraints on LFV couplings from low-energy exp.
- Analysis
- Summary

Introduction

Neutrino oscillation → finite neutrino mass (source of LFV)

→ too small to observe LFV processes

$$\mathrm{Br}(\mu \to e\gamma) = \frac{3}{32\pi}\alpha \left|U_{ei}^* U_{\mu i}\right|^2 \left(\frac{m_{\nu_i}}{m_W}\right)^4 < 10^{-48}\left(\frac{m_{\nu_i}}{1\ \mathrm{eV}}\right)^4$$

∵ LF symmetry is recovered at m(ν)→0

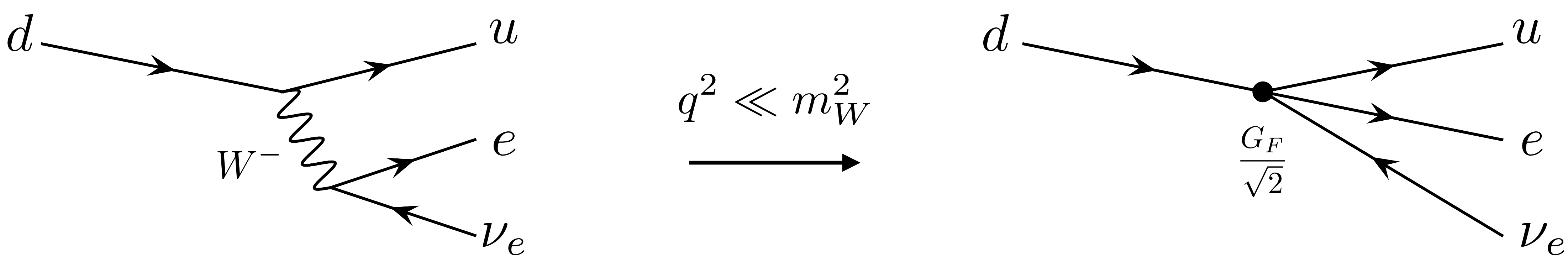
extra (sizable) LFV sources are expected in some new physics models

but no new particle has been found at LHC yet

Introduction

four Fermi contact interactions → describe (unknown) UV theory as a low-energy effective theory

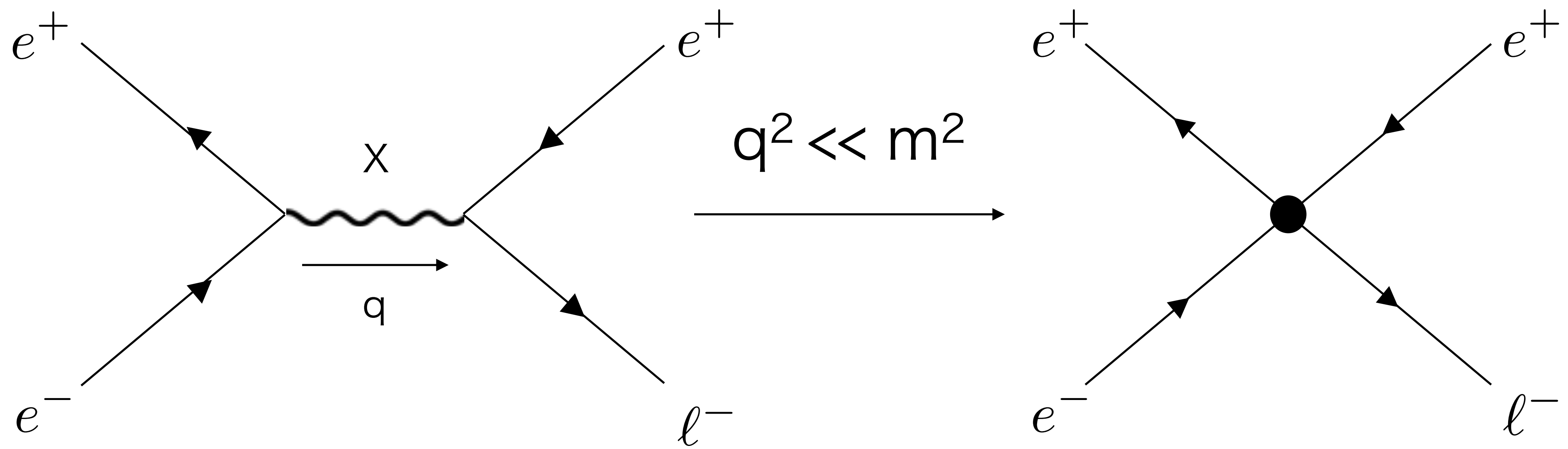
ex: Fermi theory



$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2}$$

Introduction

four Fermi contact interactions → describe (unknown) UV theory as a low-energy effective theory



LFV process $e^+e^- \to e^+\ell^- \quad (\ell = \mu,\ \tau)$ @ILC

compare sensitivity on LFV parameters w/ $\mu \to 3e$ and $\tau \to 3e$

effective Lagrangian

$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} \left\{ g_1^\ell \left(\overline{\ell_R} e_L\right) \left(\overline{e_R} e_L\right) + g_2^\ell \left(\overline{\ell_L} e_R\right) \left(\overline{e_L} e_R\right) \right.$$
$$+ g_3^\ell \left(\overline{\ell_R} \gamma^\mu e_R\right) \left(\overline{e_R} \gamma_\mu e_R\right) + g_4^\ell \left(\overline{\ell_L} \gamma^\mu e_L\right) \left(\overline{e_L} \gamma_\mu e_L\right)$$
$$\left. + g_5^\ell \left(\overline{\ell_R} \gamma^\mu e_R\right) \left(\overline{e_L} \gamma_\mu e_L\right) + g_6^\ell \left(\overline{\ell_L} \gamma^\mu e_L\right) \left(\overline{e_R} \gamma_\mu e_R\right) \right\} + \text{h.c.} \qquad (\ell = \mu,\ \tau)$$

Six operators (d=6)

$$\frac{d\sigma(e^+e^- \to e^+\ell^-)}{d\cos\theta} = \frac{G_F^2 s}{64\pi} \left[\left(G_{12}^\ell + 16 G_{34}^\ell\right)(1+\cos\theta)^2 + 4G_{56}^\ell \left\{4 + (1-\cos\theta)^2\right\} \right]$$

# of parameters: 6 → 3 (2) $\qquad G_{ij}^\ell \equiv |g_i^\ell|^2 + |g_j^\ell|^2$

LFV observables@low-energy

$$\mathrm{Br}(\mu \to 3e) = \frac{\Gamma(\mu \to 3e)}{\Gamma(\mu \to e\nu_\mu \bar{\nu}_e)} = \frac{1}{8}\left(G_{12}^{\mu} + 16 G_{34}^{\mu} + 8 G_{56}^{\mu}\right)$$

$$\mathrm{Br}(\mu^+ \to e^+ e^+ e^-) < 1.0 \times 10^{-12}$$

SINDRUM, NPB299,1(1988)

$$\mathrm{Br}(\tau \to 3e) = \frac{\tau_\tau}{\tau_\mu}\left(\frac{m_\tau}{m_\mu}\right)^5 \times \frac{1}{8}\left(G_{12}^{\tau} + 16 G_{34}^{\tau} + 8 G_{56}^{\tau}\right)$$

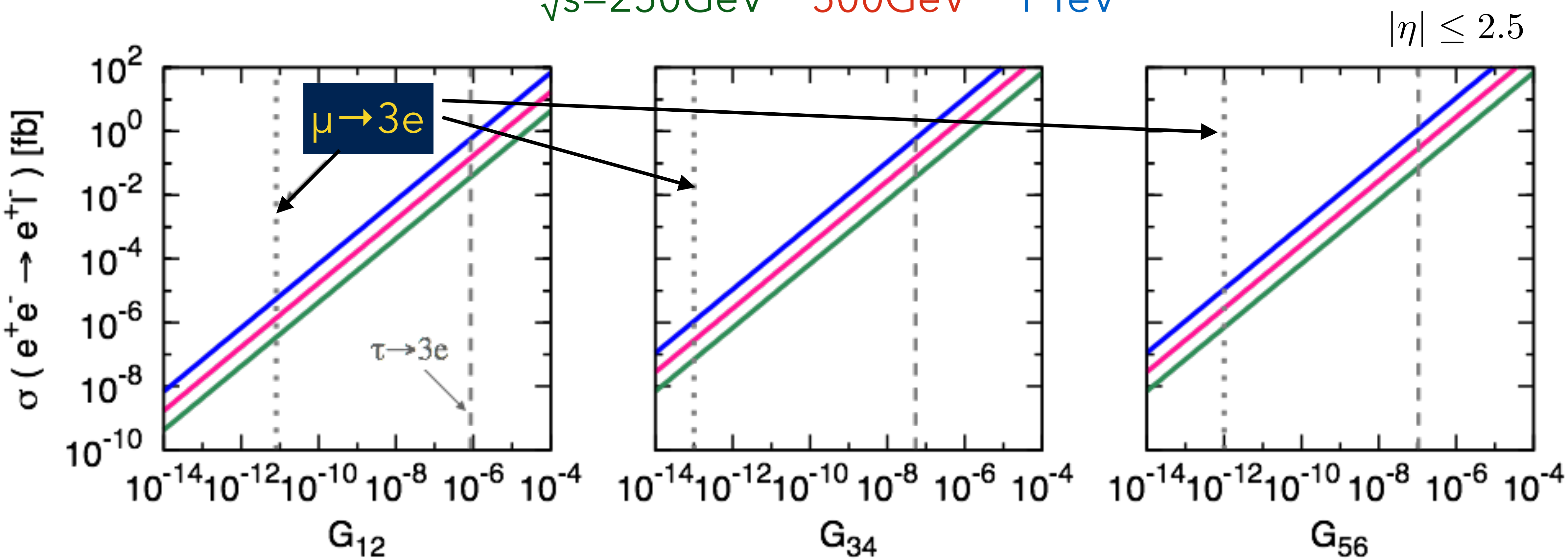
$$\approx 0.022 \times \left(G_{12}^{\tau} + 16 G_{34}^{\tau} + 8 G_{56}^{\tau}\right)$$

$$\mathrm{Br}(\tau^+ \to e^- e^+ e^-) < 2.7 \times 10^{-8}$$

Belle, PLB687,139(2010)

cross section vs. (μ, τ)→3e

√s=250GeV 500GeV 1 TeV



GCC, Shimo, arXiv:1612.07476

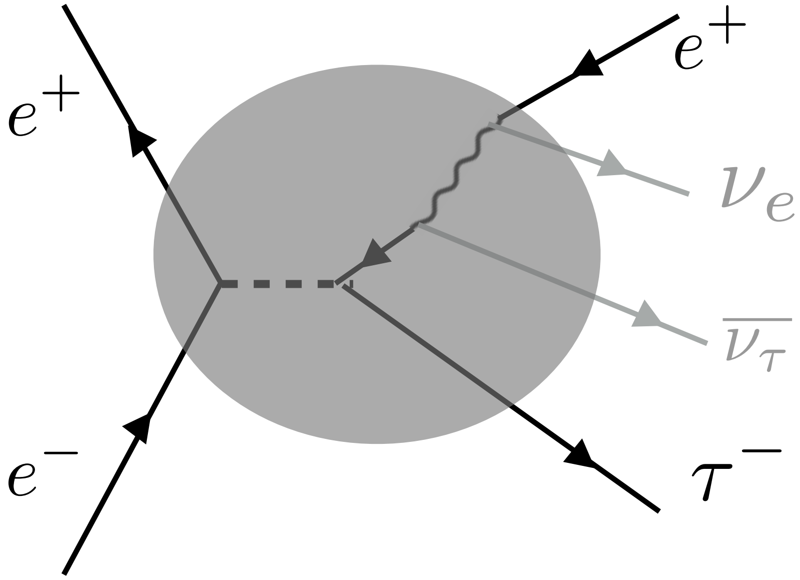
$$G^{\ell}_{ij} \equiv |g^{\ell}_i|^2 + |g^{\ell}_j|^2$$

μ-LFV couplings are severely constrained from Br(μ→3e)

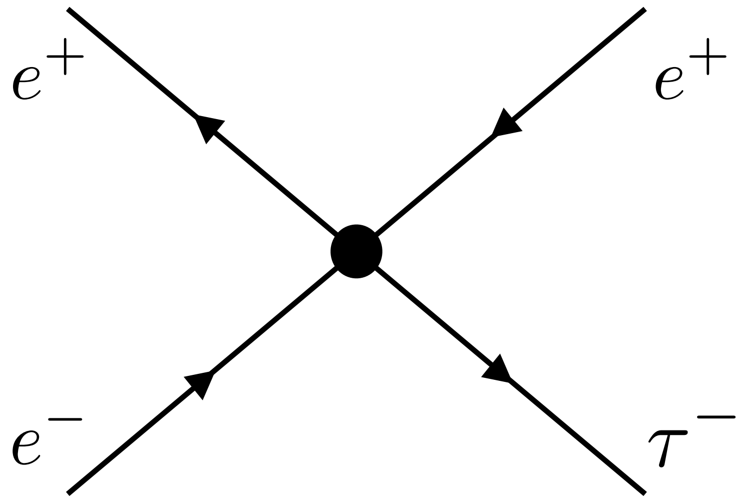
→ focus on τ-LFV

Background

$$e^+e^- \to e^+\nu_e\tau^-\overline{\nu_\tau}$$



[BG process]



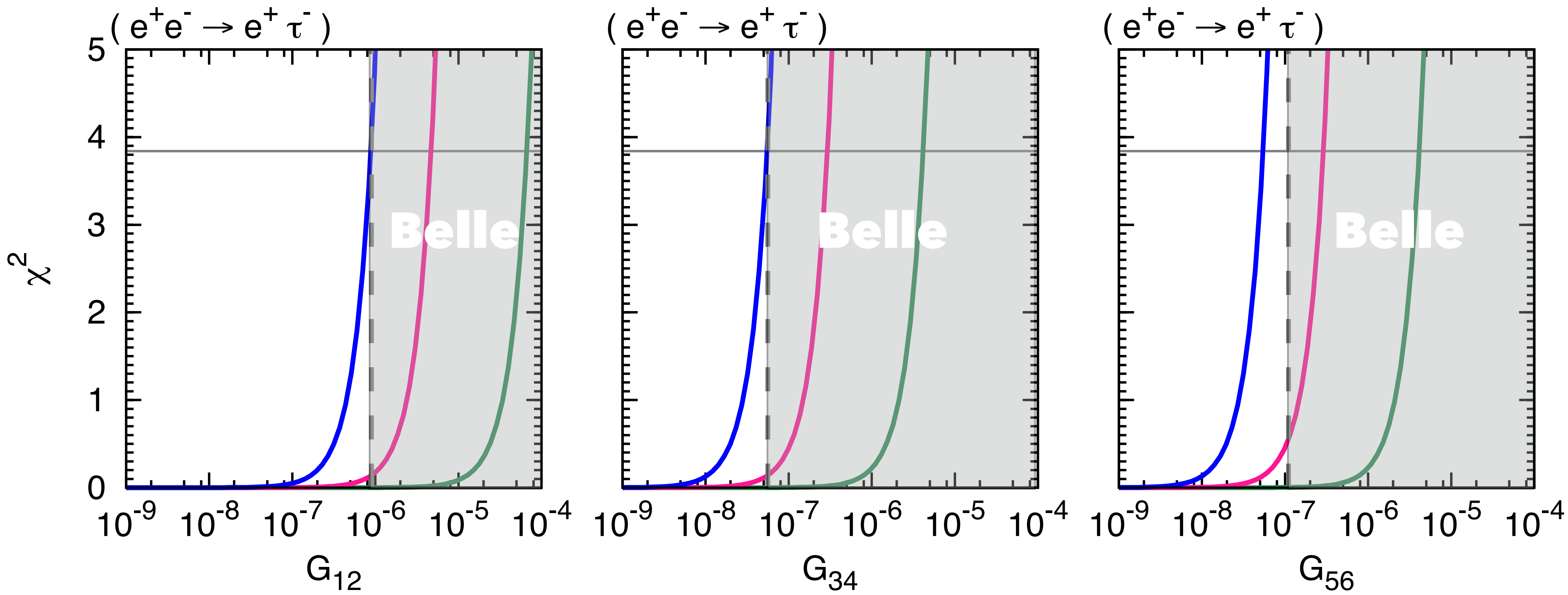
[signal process]

	$\sqrt{s} = 250$ GeV	500 GeV	1 TeV
$\sigma(e^+e^- \to e^+\nu_e\tau^-\overline{\nu_\tau})$ [fb]	203	113	85.5

MadGraph5_aMC@NLO

Bounds on LFV couplings (1)

$\sqrt{s}$=250GeV 500GeV 1 TeV



GCC, Shimo, arXiv:1612.07476

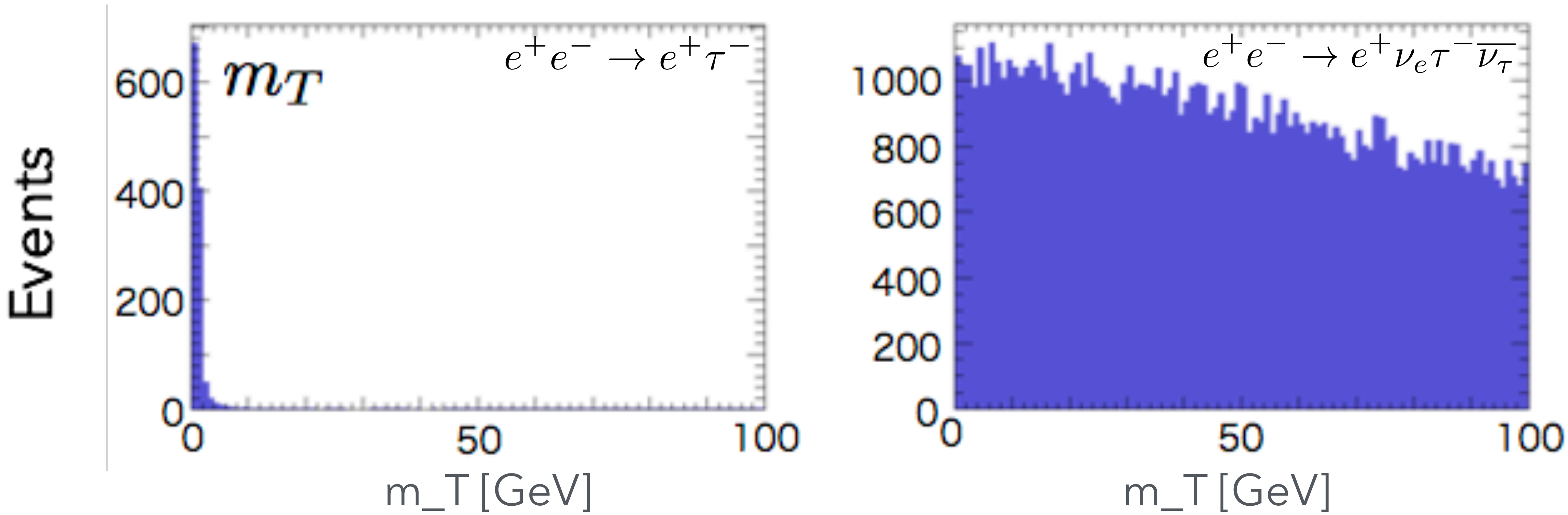
$$\chi^2 \equiv \frac{(N_{S+B} - N_S)^2}{N_B}$$

no improvement
→ reduce BG

	(i)	(ii)	(iii)
$\sqrt{s}$ (GeV)	250	500	1000
$\mathcal{L}$ (10^{34} cm^{-2} s^{-1})	0.75	3.6	3.6

signal vs. BG

(ex) $g_1 \neq 0,\ g_2 = \ldots = g_6 = 0$ $\sqrt{s} = 1\,\mathrm{TeV}$ $L_{int} = 1\,\mathrm{ab}^{-1}$

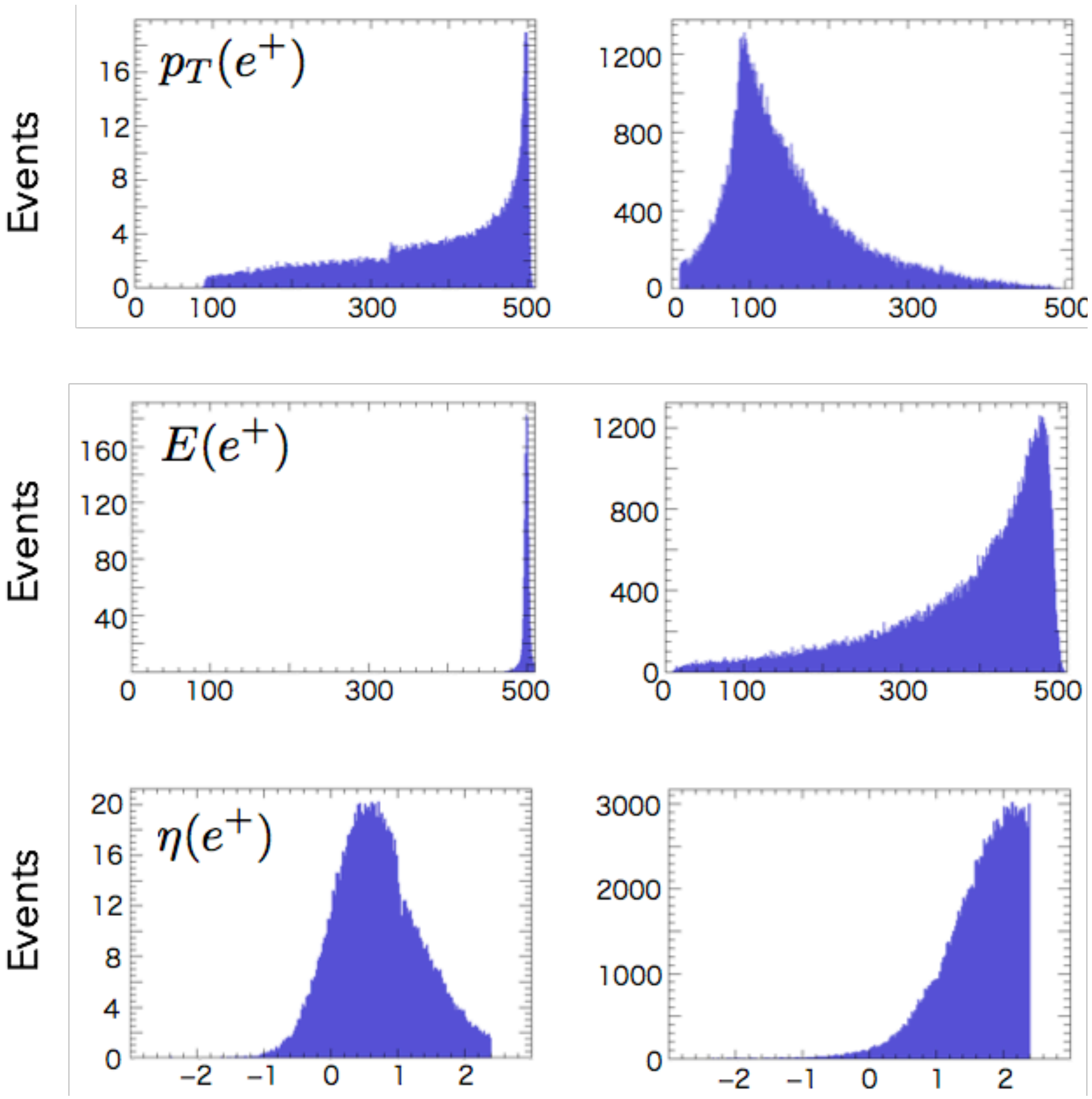


$$m_T^2 = (|\boldsymbol{p}_T^{\ell^-}| + |\not{\boldsymbol{p}}_T|)^2 - (\boldsymbol{p}_T^{\ell^-} + \not{\boldsymbol{p}}_T)^2$$

$\not{\boldsymbol{p}}_T$ from tau decay (in signal)

event generation: MadGraph5_aMC@NLO
hadronization: Pythia8
Detector sim. : Delphes

signal vs. BG



(ex) $g_1 \neq 0$, $g_2 = \ldots = g_6 = 0$ $\sqrt{s}$=1TeV L_{int} =1ab^{-1}

	signal	background
(i)	1368	171120
(ii)	1167	9976
(iii)	779	801

(i) no cut

(ii) $m_T \leq 10$ GeV

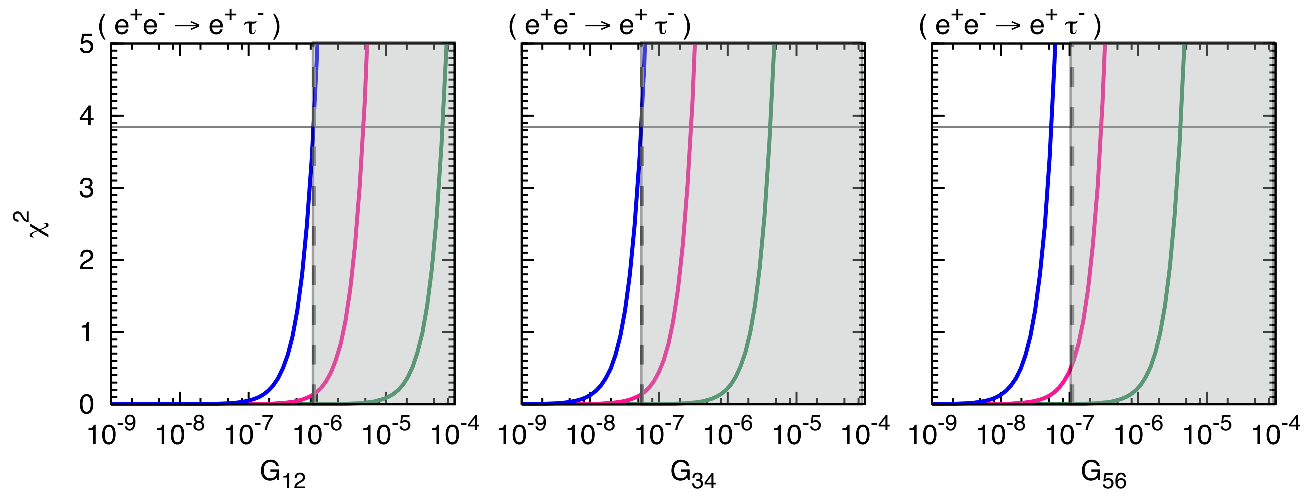
(iii) $p_T(e^+) \geq 300$ GeV

efficiency of τ-reconstruction @Delphes→90%

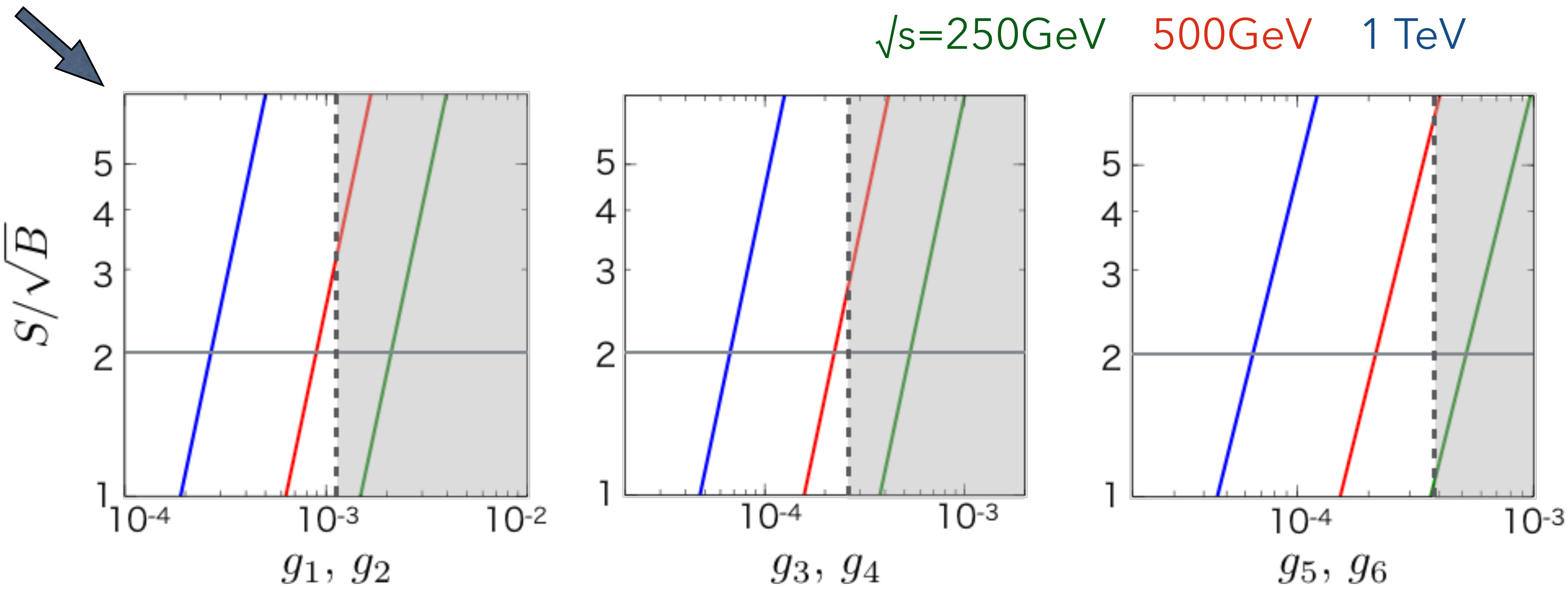
$\tau \to (\pi, \rho[2\pi], a_1[3\pi]) + \nu_\tau$

ILC TDR, 1306.6329
Tran et al., EPJC76 (2016)468

Bounds on LFV couplings (2)



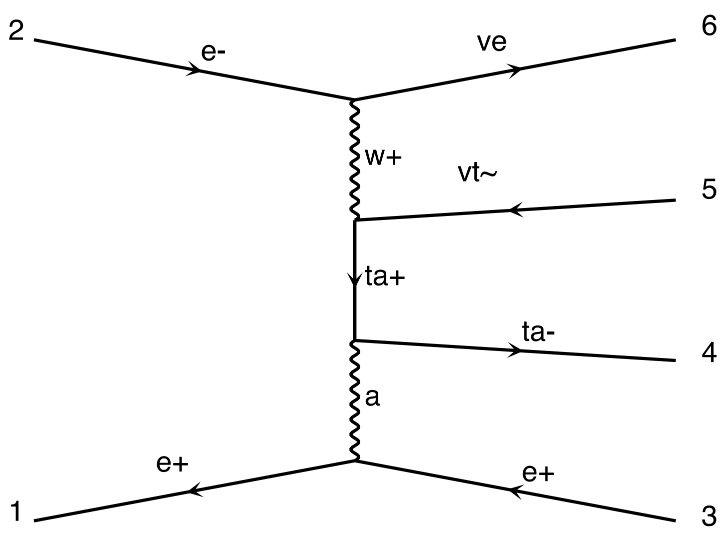
$\sqrt{s}$=250GeV 500GeV 1 TeV

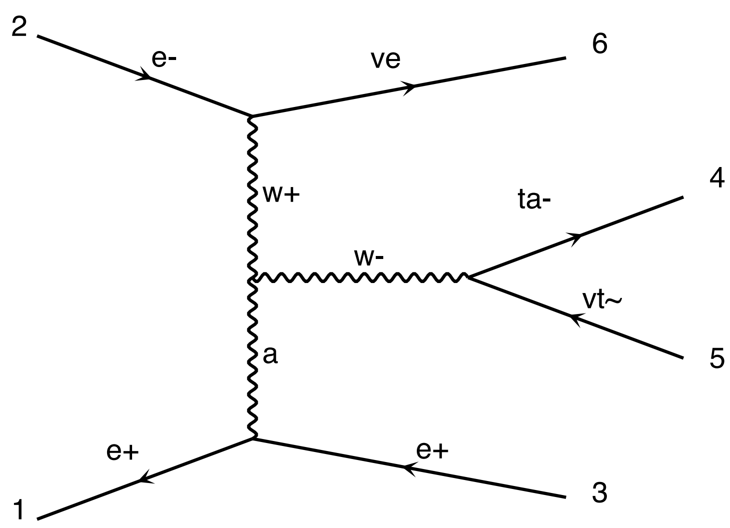


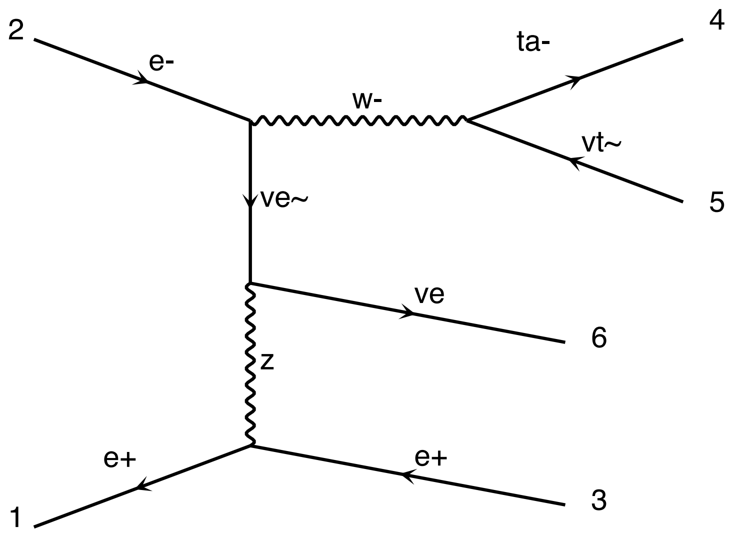
L_{int} =1ab^{-1}

polarized e-beam

some of BG diagrams are suppressed by polarized e- beam

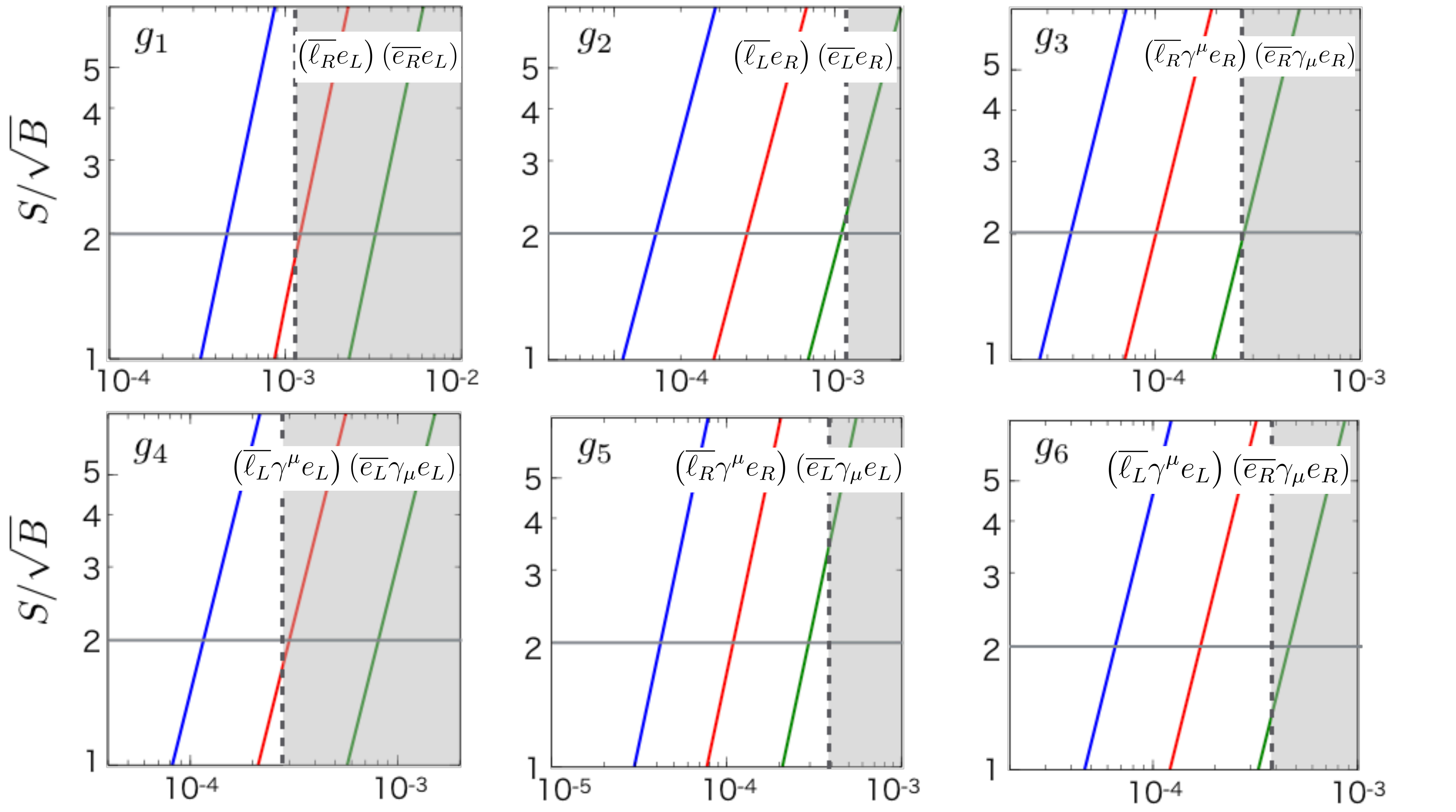






Bounds on LFV couplings (3)

Polarization [e⁻] = 0.8 $\sqrt{s}$=250GeV 500GeV 1 TeV

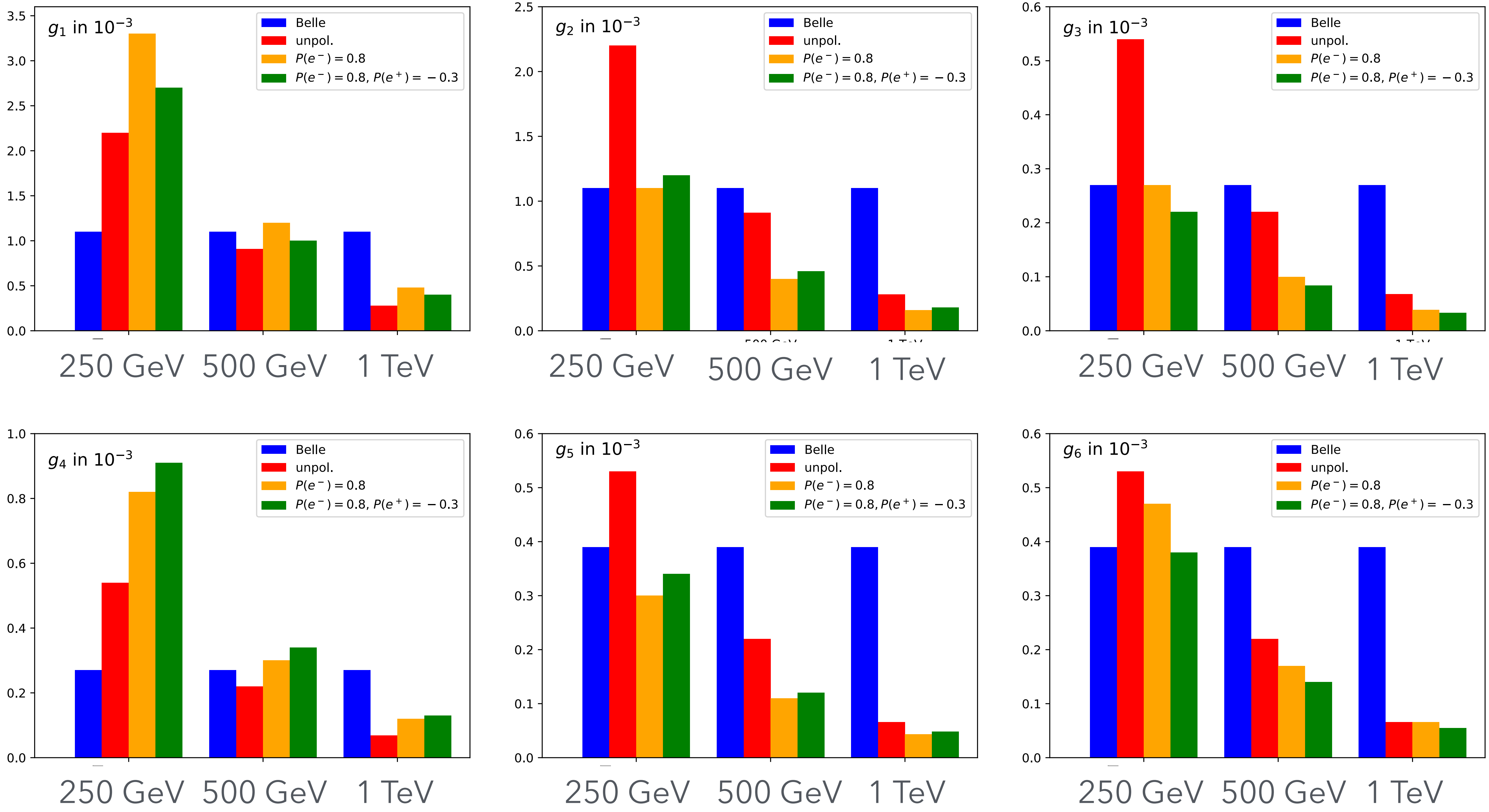


Bounds on LFV couplings (summary)

	g_1	g_2	g_3	g_4	g_5	g_6
	unpolarized					
$\sqrt{s} = 250$ GeV	2.2×10^{-3}		5.4×10^{-4}		5.3×10^{-4}	
500 GeV	9.1×10^{-4}		2.2×10^{-4}		2.2×10^{-4}	
1 TeV	2.8×10^{-4}		6.8×10^{-5}		6.6×10^{-5}	
	polarized $(P(e^-) = 0.8)$					
$\sqrt{s} = 250$ GeV	3.3×10^{-3}	1.1×10^{-3}	2.7×10^{-4}	8.2×10^{-4}	3.0×10^{-4}	4.7×10^{-4}
500 GeV	1.2×10^{-3}	4.0×10^{-4}	1.0×10^{-4}	3.0×10^{-4}	1.1×10^{-4}	1.7×10^{-4}
1 TeV	4.8×10^{-4}	1.6×10^{-4}	3.9×10^{-5}	1.2×10^{-4}	4.3×10^{-5}	6.6×10^{-5}
	polarized $(P(e^-) = 0.8,\ P(e^+) = -0.3)$					
$\sqrt{s} = 250$ GeV	2.7×10^{-3}	1.2×10^{-3}	2.2×10^{-4}	9.1×10^{-4}	3.4×10^{-4}	3.8×10^{-4}
500 GeV	1.0×10^{-3}	4.6×10^{-4}	8.4×10^{-5}	3.4×10^{-4}	1.2×10^{-4}	1.4×10^{-4}
1 TeV	4.0×10^{-4}	1.8×10^{-4}	3.3×10^{-5}	1.3×10^{-4}	4.8×10^{-5}	5.5×10^{-5}

Bounds on LFV couplings (summary)

Belle | unpol. | P(e–)=0.8 | +P(e+)=–0.3



Summary

sensitivity on LFV couplings@ILC w/pol. e-beam → better than Belle

limits on Br(τ→3e)@Belle-II →will be improved 2 order than current one: nearly one order improvement of LFV couplings

Bevan, etal. EPJC74,3026(2014)

1 TeV ILC w/ pol. beam may be competitive with Bell-II