Exploring lepton flavor violation

at an e^-e^- linear collider

Brandon Murakami (Rhode Island College)
work in progress with Tim Tait (University of California, Irvine)
May 5, 2014

Charged

Lepton Flavor Violation

- Charged LFV is forbidden by the SM*.

e.g., $\mu^+ \not\to e^+\gamma$

$\tau^- \not\to \mu^+\mu^-\mu^-$

*with massless neutrinos

- Neutrinos always accompany lepton flavor changes.

e.g., $\mu^- \to e^-\bar{\nu}_e\nu_\mu(\gamma)$ BR = 100% - 0.0034%

$\mu^- \to e^-\bar{\nu}_e\nu_\mu + e^+e^-$ BR = 0.0034%

- If neutrino masses are included in the SM,

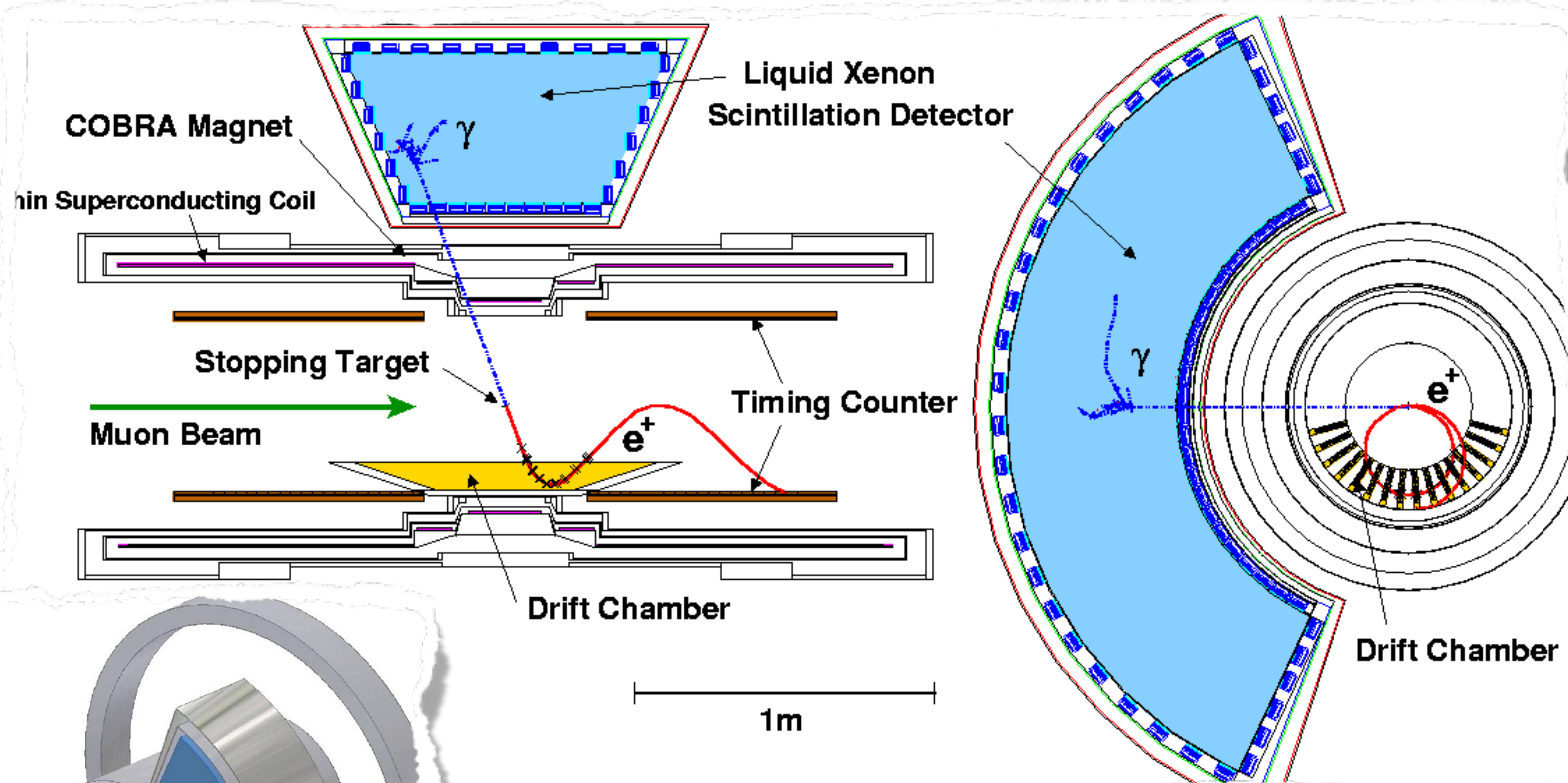
$$BR(\mu \to e\gamma) \sim \mathcal{O}\left(\frac{m_\nu^4}{m_W^4}\right).$$

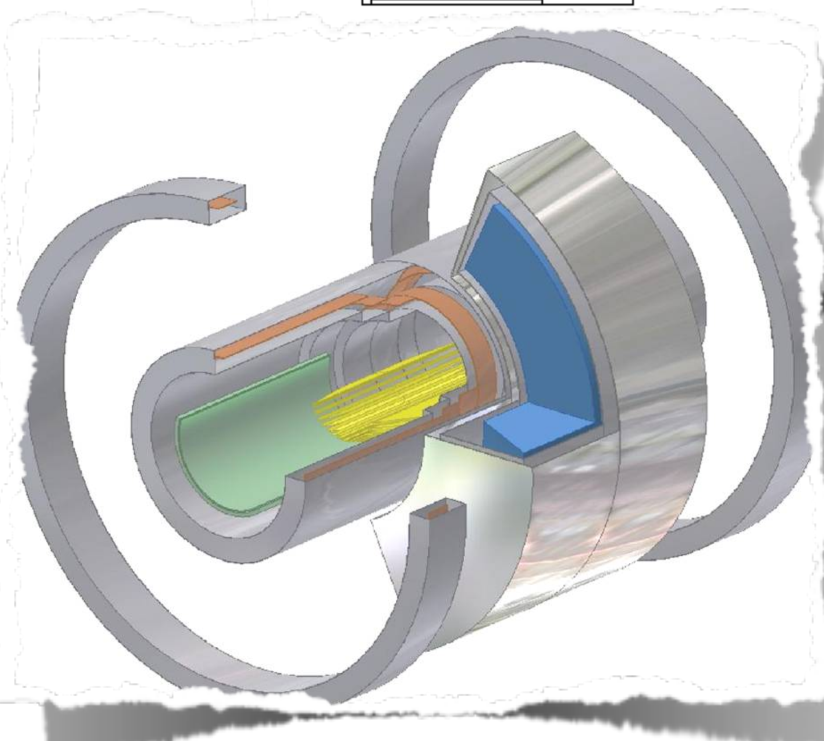
Observable LFV = new physics!

The MEG Experiment

Paul Scherrer Institut, Switzerland

Operating since 2008





~360 trillion muon decays observed.

No $\mu \rightarrow e\gamma$.

Keep looking.

…from a talk by Toshinori Mori (2013)

Low Energy Observables

...as a guide to collider observables

Observable	Limit	Future
$\mu^+ \to e^+\gamma$	5.7×10^{-13}	10^{-13} MEG [6]
$\tau^+ \to e^+\gamma$	3.3×10^{-8}	2.3×10^{-9} SuperB [9]
$\tau^+ \to \mu^+\gamma$	4.4×10^{-8}	3×10^{-9} Belle II [8], 1.8×10^{-9} [9]
$\mu \to eee$	1.0×10^{-12}	10^{-15} MUSIC [10], 10^{-16} Mu3e [11]
$\tau \to eee$	2.7×10^{-8}	2×10^{-10} [9]
$\tau \to \mu\mu\mu$	2.1×10^{-8}	1×10^{-9} [8], 2×10^{-10} [9]
μ^- SiC $\to e^-$ SiC	none	10^{-14} DeeMe
μ^- Al $\to e^-$ Al	none	10^{-16} COMET [13], Mu2e [14]
μ^- Ti $\to e^-$ Ti	4.3×10^{-12}	10^{-18} PRISM/PRIME [15]

Strong but not that strong.

$ee \to \tau e$ is observable at the ILC.

($ee \to \mu e$ is strongly constrained.)

$$\frac{em_\tau}{2}\bar{\tau}\sigma_{\mu\nu}F^{\mu\nu}(A_L P_L + A_R P_R)e + \text{h.c.}$$

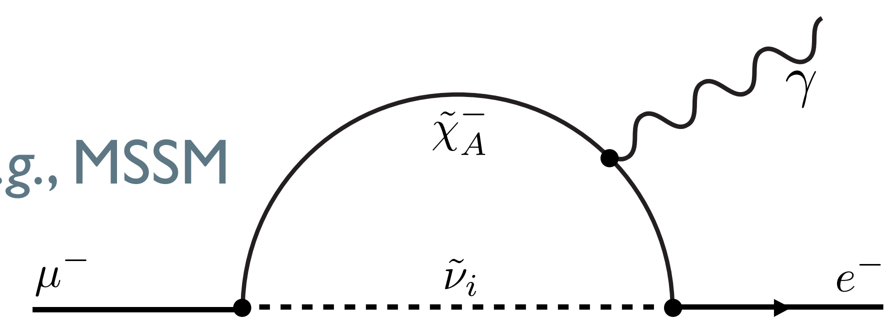
$\tau \to e\gamma$ ($\mu\gamma$) limits are too strict for ILC

$\Rightarrow$ We turn to 4-fermion contact operators for ILC studies.

Suppressing the Penguin

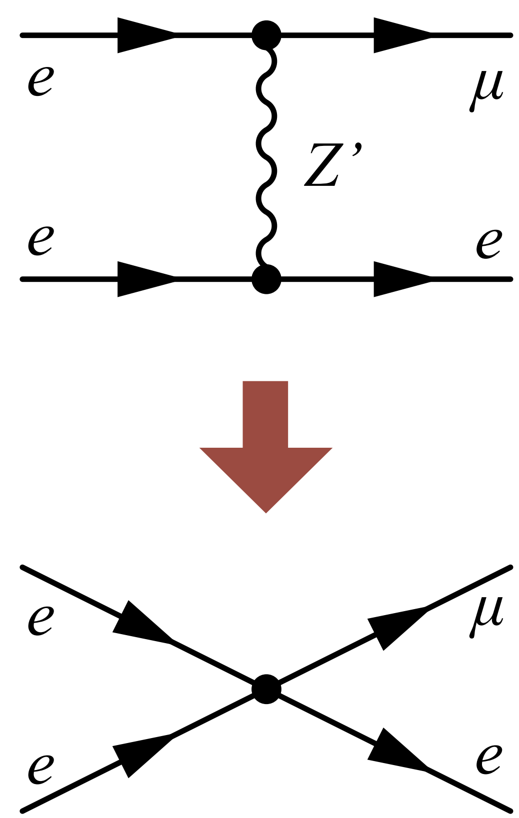
In large classes of popular models,

e.g., MSSM



the **photon penguin dominates LFV.**

Consider: contact operators via **tree-level LFV via bosons.**



e.g., Z'

Our EFT Model

Possible 4-fermion operators (10):

- (pseudo) scalar (4): $e.g., [\bar{e}\bar{e}][\bar{\tau}\bar{e}],\ [\bar{e}\gamma^5\bar{e}][\bar{\tau}\bar{e}], \ldots$
- (axial) vector (4): $e.g., [\bar{e}\gamma^\mu\bar{e}][\bar{\tau}\gamma_\mu\bar{e}], [\bar{e}\gamma^\mu\gamma^5\bar{e}][\bar{\tau}\gamma_\mu\bar{e}], \ldots$
- (anti-symmetric) tensor (2): $[\bar{e}\sigma^{\mu\nu}e][\bar{\tau}\sigma_{\mu\nu}e], \epsilon^{\mu\nu\rho\sigma}[\bar{e}\sigma_{\mu\nu}e][\bar{\tau}\sigma_{\rho\sigma}e]$

Fierz constraints (6). (Not shown.)

Our lagrangian choice:

$$
\begin{aligned}
-\mathcal{L} \supset\ & (v_{LL}[\bar{e}\gamma^\mu P_L e][\bar{\tau}\gamma_\mu P_L e] + v_{RR}[\bar{e}\gamma^\mu P_R e][\bar{\tau}\gamma_\mu P_R e] \\
& + v_{LR}[\bar{e}\gamma^\mu P_L e][\bar{\tau}\gamma_\mu P_R e] + v_{RL}[\bar{e}\gamma^\mu P_R e][\bar{\tau}\gamma_\mu P_L e]) + \text{h.c.}
\end{aligned}
$$

Why an e^-e^- collider?

Complimentary observables:

(unpolarized spins)

$$\Gamma(\tau^- \to e^+e^-e^-) = \frac{m_\tau^5}{1,536\pi^3}[2(|v_{LL}|^2 + |v_{RR}|^2) + (|v_{LR}|^2 + |v_{RL}|^2)]$$

$$\sigma(e^+e^- \to e^+\tau^-) = \frac{s}{12\pi}[(|v_{LL}|^2 + |v_{RR}|^2) + (|v_{LR}|^2 + |v_{RL}|^2)$$

↳ Studied by Ferriera, Guedes, Santos (2007)

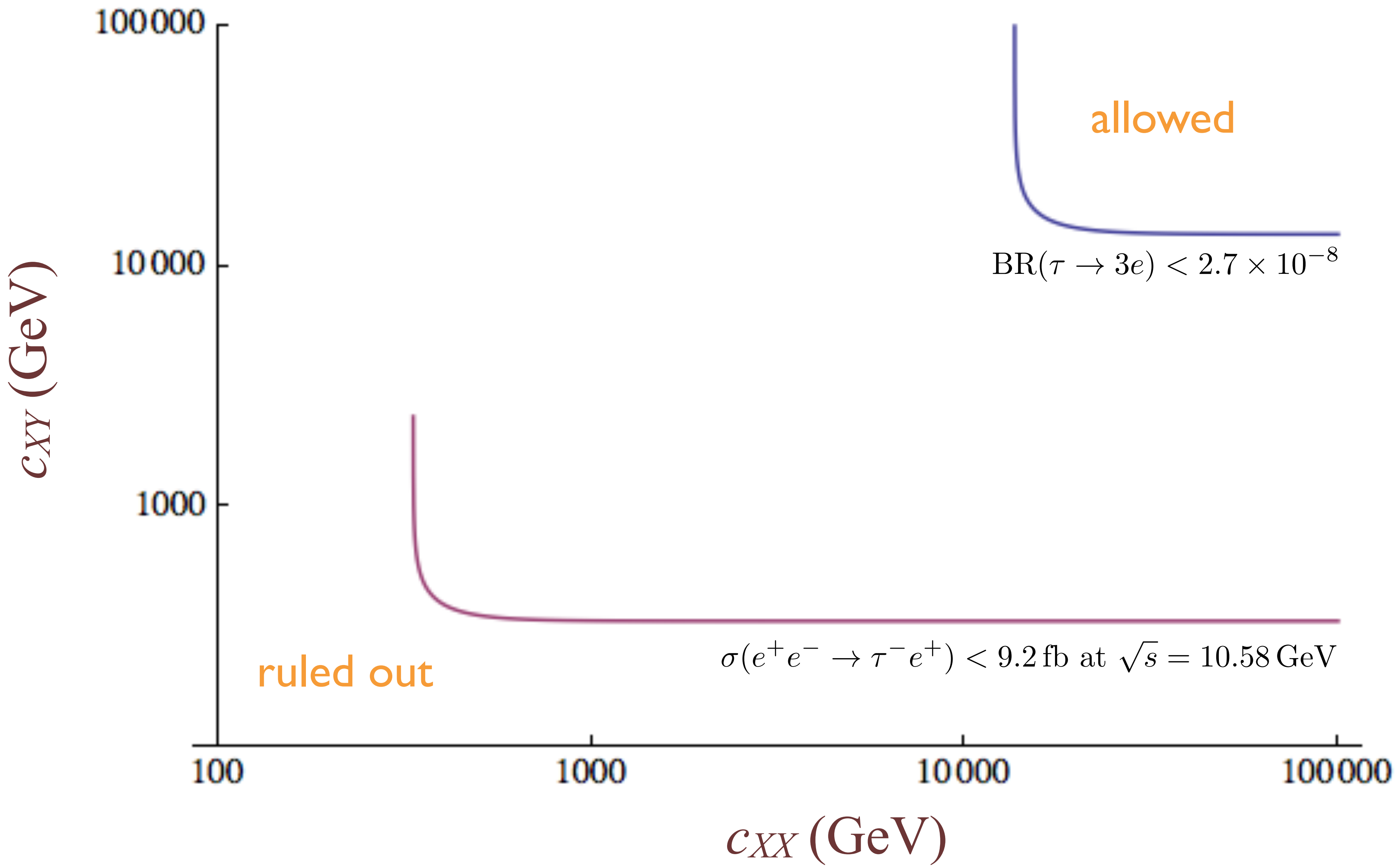
$$\sigma(e^-e^- \to e^-\tau^-) = \frac{s}{48\pi}[6(|v_{LL}|^2 + |v_{RR}|^2) + (|v_{LR}|^2 + |v_{RL}|^2)]$$

$$c_{XY}^{-4} \equiv |v_{LR}|^2 + |v_{RL}|^2$$

$$c_{XX}^{-4} \equiv |v_{LL}|^2 + |v_{RR}|^2$$

c's in GeV units

Coupling Limits

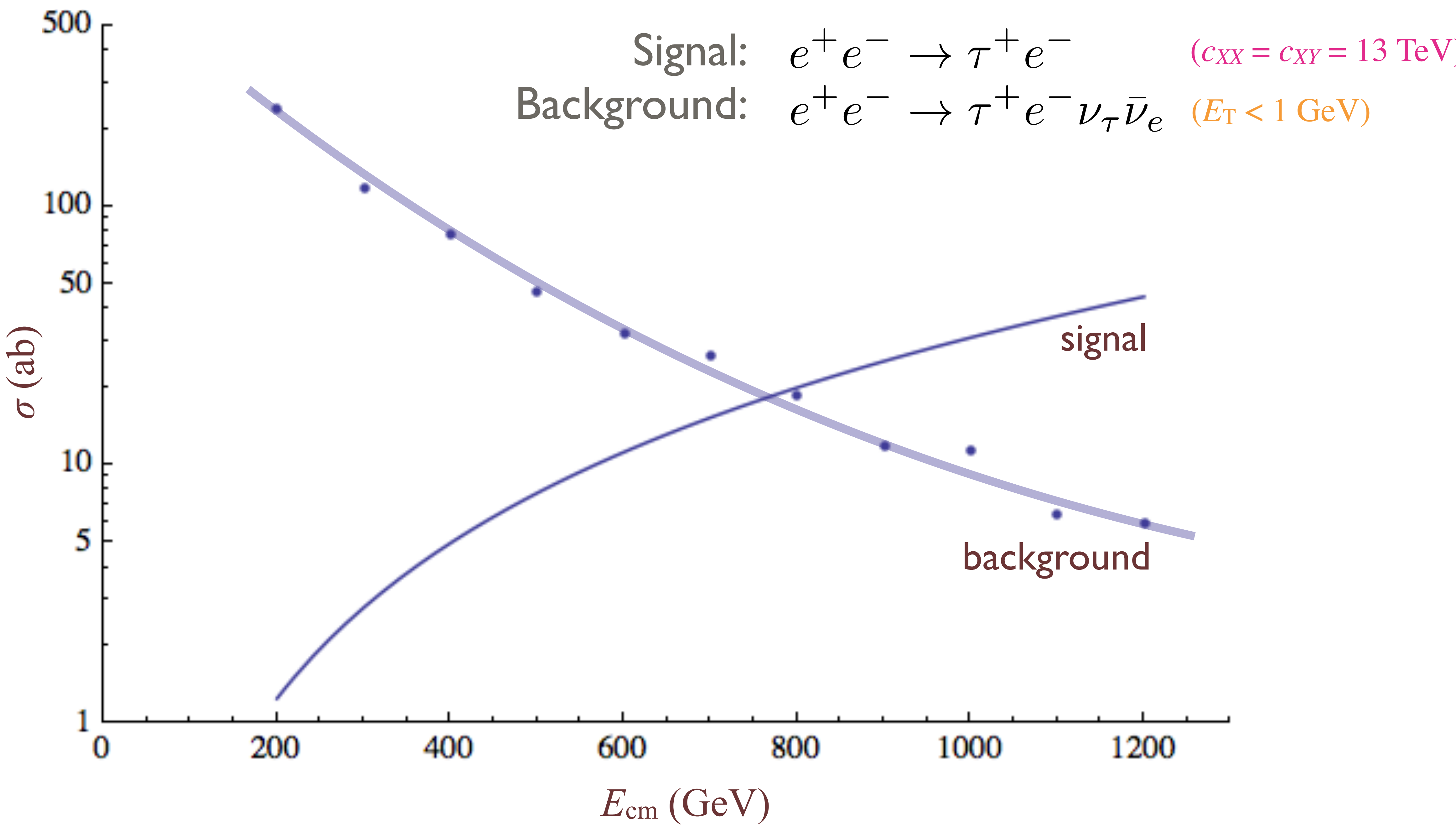


For $O(1)$ couplings, $\tau \longrightarrow 3e$ has probed beyond 10 TeV physics.

What can a linear collider do?

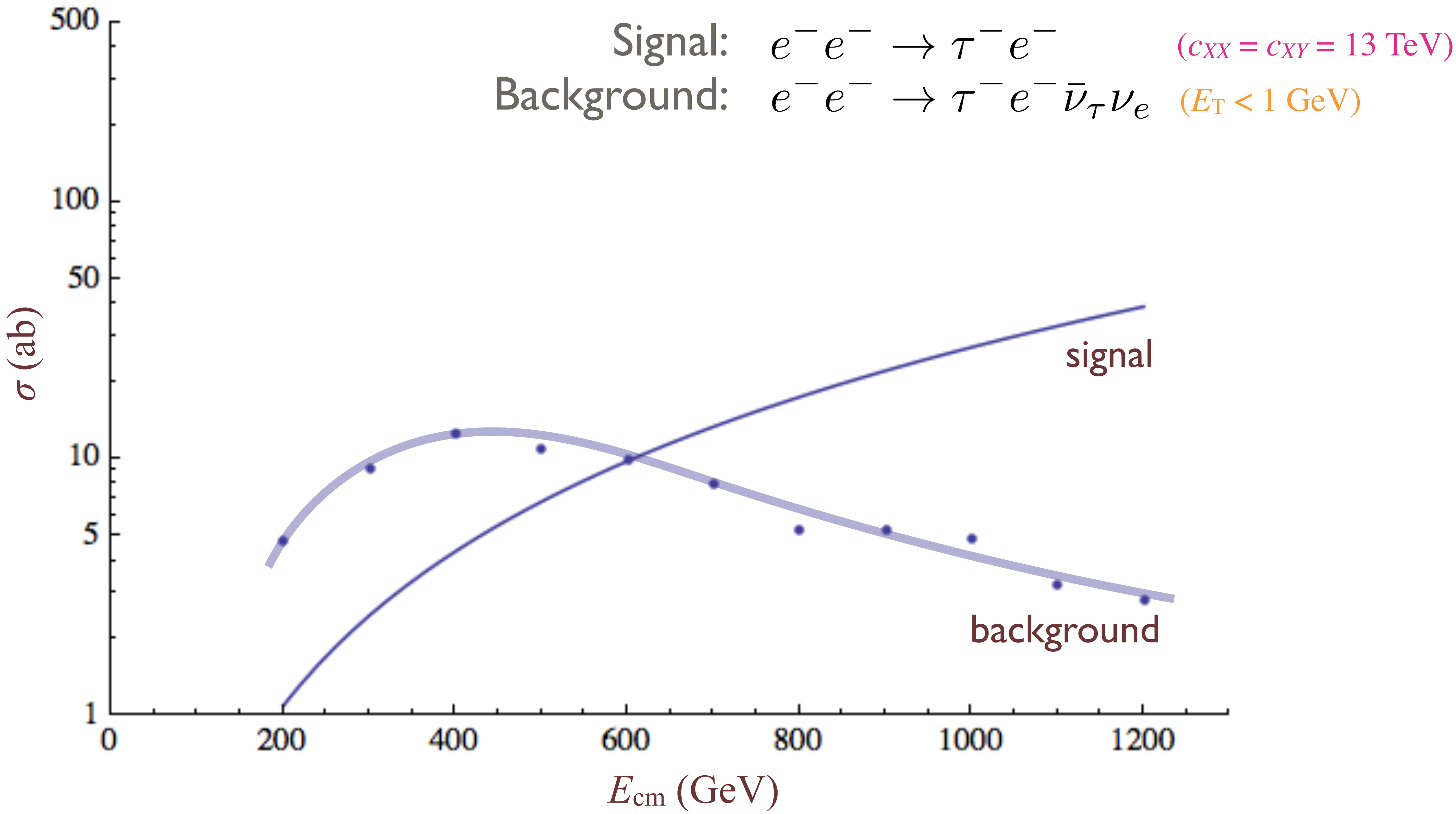
Signal and Background

...at an e^+e^- collider



Signal and Background

…at an $e^- e^-$ collider



Summary

- Observable charged LFV is unambiguously BSM physics.
- In an EFT with 4-fermion contact operators as the dominant LFV mechanism,

$$\tau \longrightarrow 3e$$
$$e^+e^- \longrightarrow \tau e$$
$$e^-e^- \longrightarrow \tau^-e^-$$

are complementary observables.

- $e^+e^- \longrightarrow \tau e$ is observable at the ILC.
- $e^-e^- \longrightarrow \tau^-e^-$ is observable at an e^-e^- collider or ILC option.
- These observables probe over 10 TeV physics with $O(1)$ couplings at a LC.