Complementarity between Muon Colliders and Precision Experiments

Discovering lepton flavor violation within a SMEFT approach

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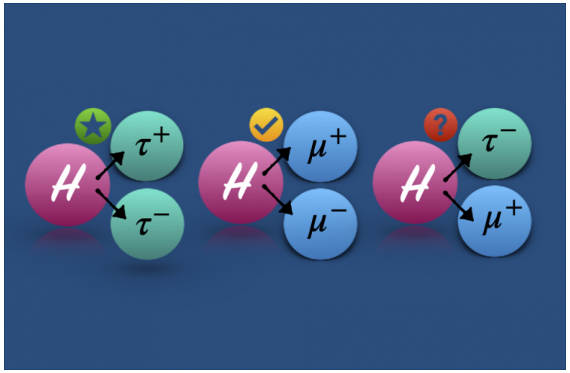
Early Career Researchers & Muon Colliders 2024

[Based on Work in Progress w/ P. Asadi, H. Bagherian, S. Homiller, and Q. Lu]

Why Lepton Flavor Violation?

- The Standard Model contains three flavors of charged leptons:e, μ, τ. Most **interactions within the Standard Model conserve lepton flavor** - the only exception is neutrino masses, but they are very small.
- **Measurable LFV** is a smoking gun **signal of new physics**, with several different potential new models/particles potentially leading to it.
- **Examples** where new physics generated LFV include **supersymmetry**, when SUSY breaking causes nondiagonal interactions between sleptons, and **leptoquark** models



[Image: CMS]

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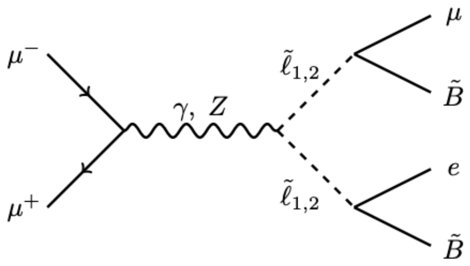
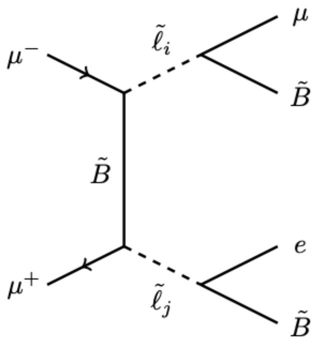
Types of Searches

- New physics searches can either by **model specific** or **model agnostic**.
- Model specific searches add potential new particles to the Standard Model, make a detailed hypothesis, and test this hypothesis. Most new physics searches that are performed in practice are model specific.
- Example: [Homiller et al: 2203.08825, 2103.14043] **studied LFV in Supersymmetric models** at a muon collider versus in low energy experiments.





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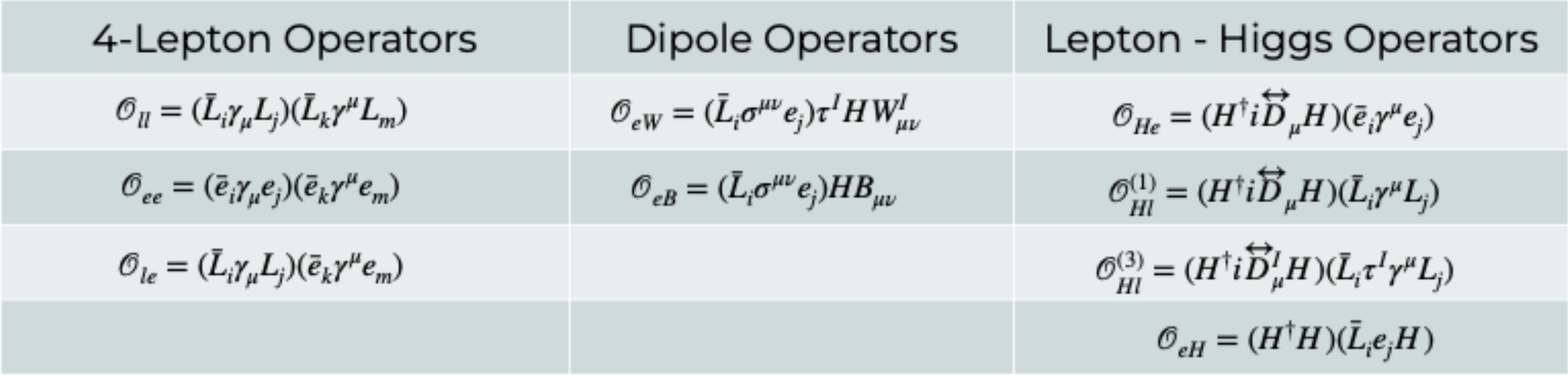
A SMEFT Approach

- In model agnostic searches, **new physics is parameterized in more general ways** that many different models can be matched on to. Model agnostic approaches often use **effective field theories**.
- **SMEFT** (Standard Model Effective Field Theory) is an example. In SMEFT, new physics is parameterized by **all higher dimensions operators which respect the SM symmetries**.
- We work to dimension 6, considering only operators with no quarks



4-Lepton Operators	Dipole Operators	Lepton - Higgs Operators
$\mathcal{O}_{ll} = (\bar{L}_i\gamma_\mu L_j)(\bar{L}_k\gamma^\mu L_m)$	$\mathcal{O}_{eW} = (\bar{L}_i\sigma^{\mu\nu}e_j)\tau^I H W^I_{\mu\nu}$	$\mathcal{O}_{He} = (H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_i\gamma^\mu e_j)$
$\mathcal{O}_{ee} = (\bar{e}_i\gamma_\mu e_j)(\bar{e}_k\gamma^\mu e_m)$	$\mathcal{O}_{eB} = (\bar{L}_i\sigma^{\mu\nu}e_j)HB_{\mu\nu}$	$\mathcal{O}^{(1)}_{Hl} = (H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{L}_i\gamma^\mu L_j)$
$\mathcal{O}_{le} = (\bar{L}_i\gamma_\mu L_j)(\bar{e}_k\gamma^\mu e_m)$		$\mathcal{O}^{(3)}_{Hl} = (H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{L}_i\tau^I\gamma^\mu L_j)$
		$\mathcal{O}_{eH} = (H^\dagger H)(\bar{L}_i e_j H)$

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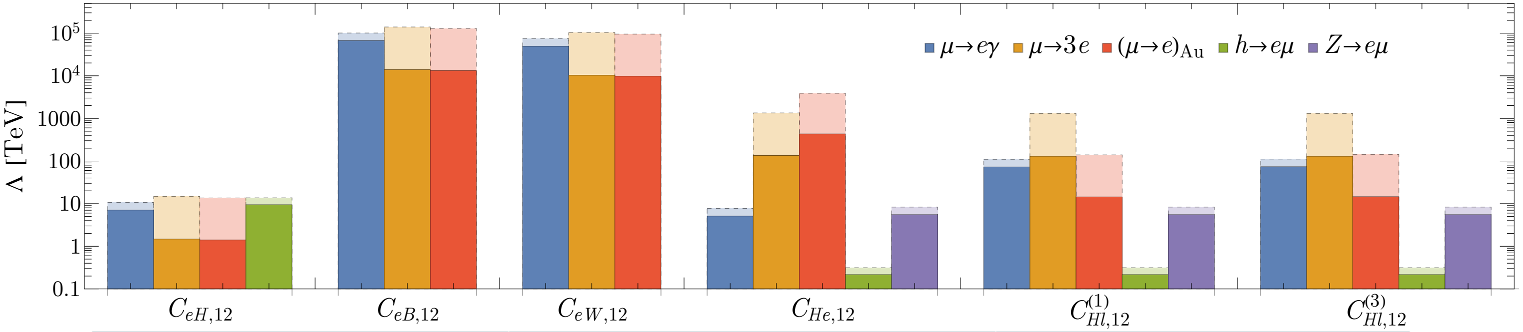
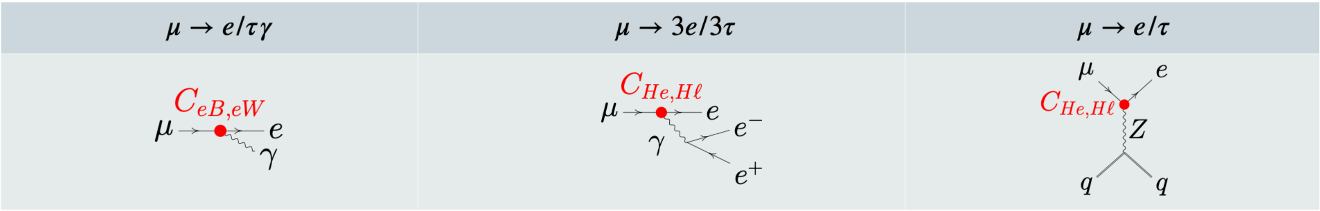
Low Energy Constraints vs. Muon Colliders

Precision experiments are currently our most sensitive probe of LFV. These experiments **look for the processes $\mu \to e\gamma$, $\mu \to 3e$, and $\mu \to e$**. Current constraints include BaBar, MEG, Belle, and SINDRUM; future ones include Mu3e, Mu2e, and MEG-II.





An advantage of **muon colliders** is that a **wider combination of operators can be probed**. For our study, we focus on $\mu \to \tau$ conversion because $\mu \to \tau$ conversion is more weakly constrained by precision experiments than $\mu \to e$.

[Images: S. Homiller, H. Bagherian]

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Muon Collider Studies

For **each operator**, we consider the full set of possible $\mu \to \tau$ processes and study **processes with the largest cross section** in more detail using MadGraph.

$$C_{eB} : \mu^- \gamma \to \tau^- h$$

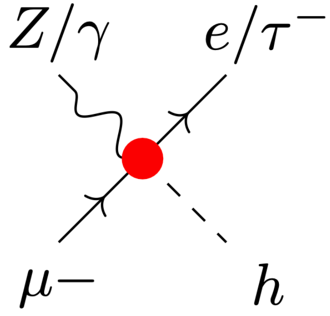
With 10 ab^{-1} of data:

1.2×10^4 Events

$$C_{He} : \mu^- Z \to \tau^- h$$

With 10 ab^{-1} of data:

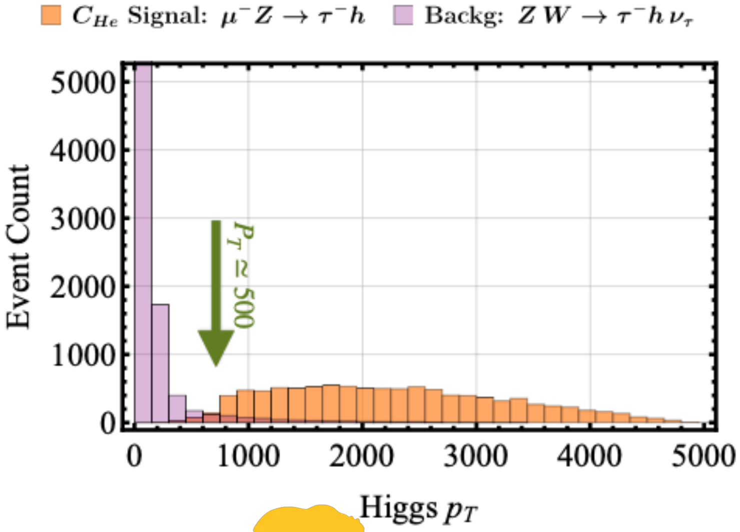
1.53×10^2 Events



For each of these, **consider the SM backgrounds**. An example:

$$Z/\gamma W \to h \tau \nu_\tau$$

This appears to have the same final states, but can be separated because of kinematic distributions.



[Image: H. Bagherian]

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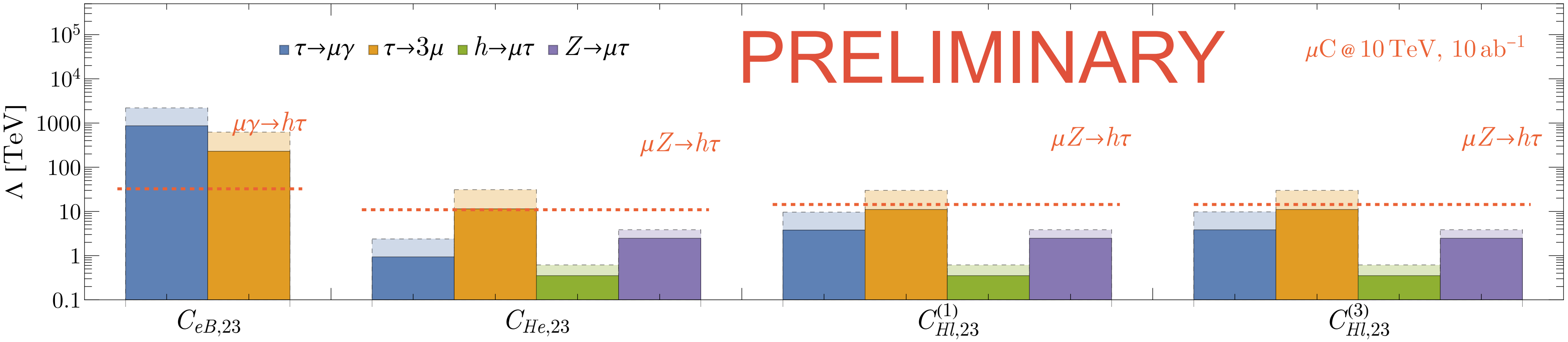
Results and Conclusions

A **muon collider** could explore **new physics beyond** the current reach of **low energy experiments**.



The **combination** of muon colliders and low energy experiments allows us to **probe specific flavor ansatz**, which can be studied using 2D plots.

Another advantage of muon colliders is that they can probe "**flat directions**" that low energy observables are insensitive to.

[Image: S. Homiller]

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