Lepton Flavor Violation at a High-Energy Muon Collider

[arXiv:2203.08825]

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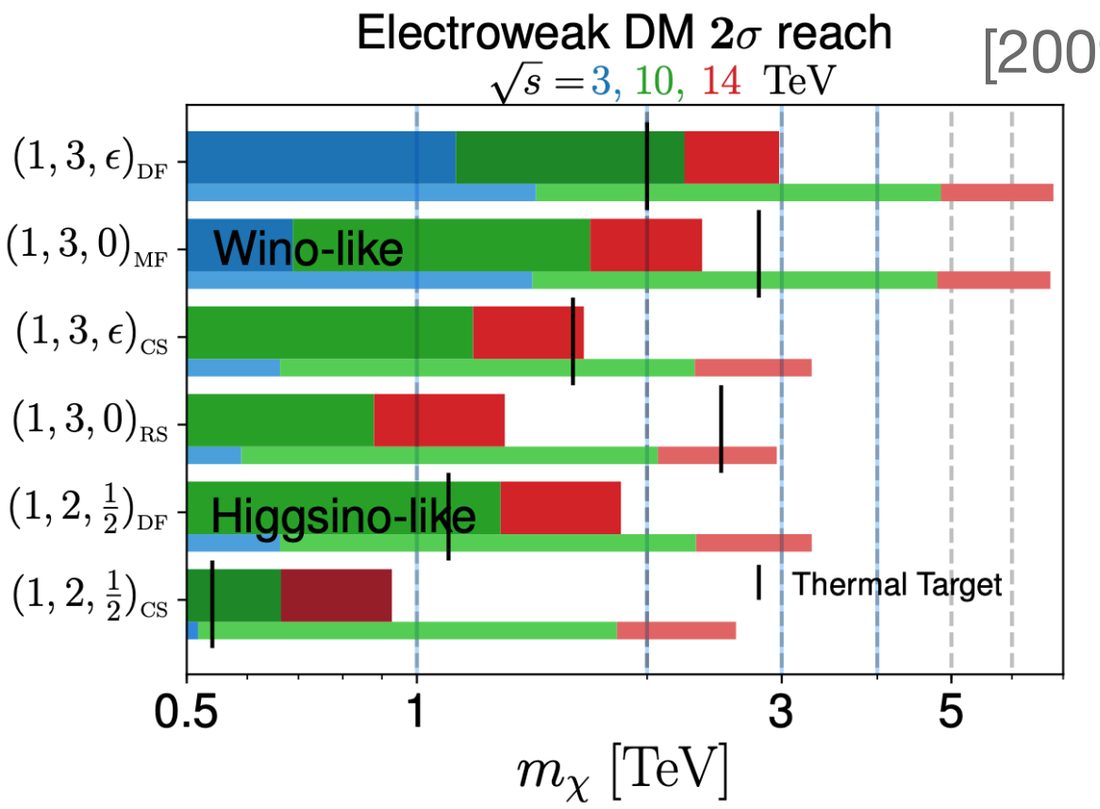
In collaboration with Qianshu Lu and Matthew Reece

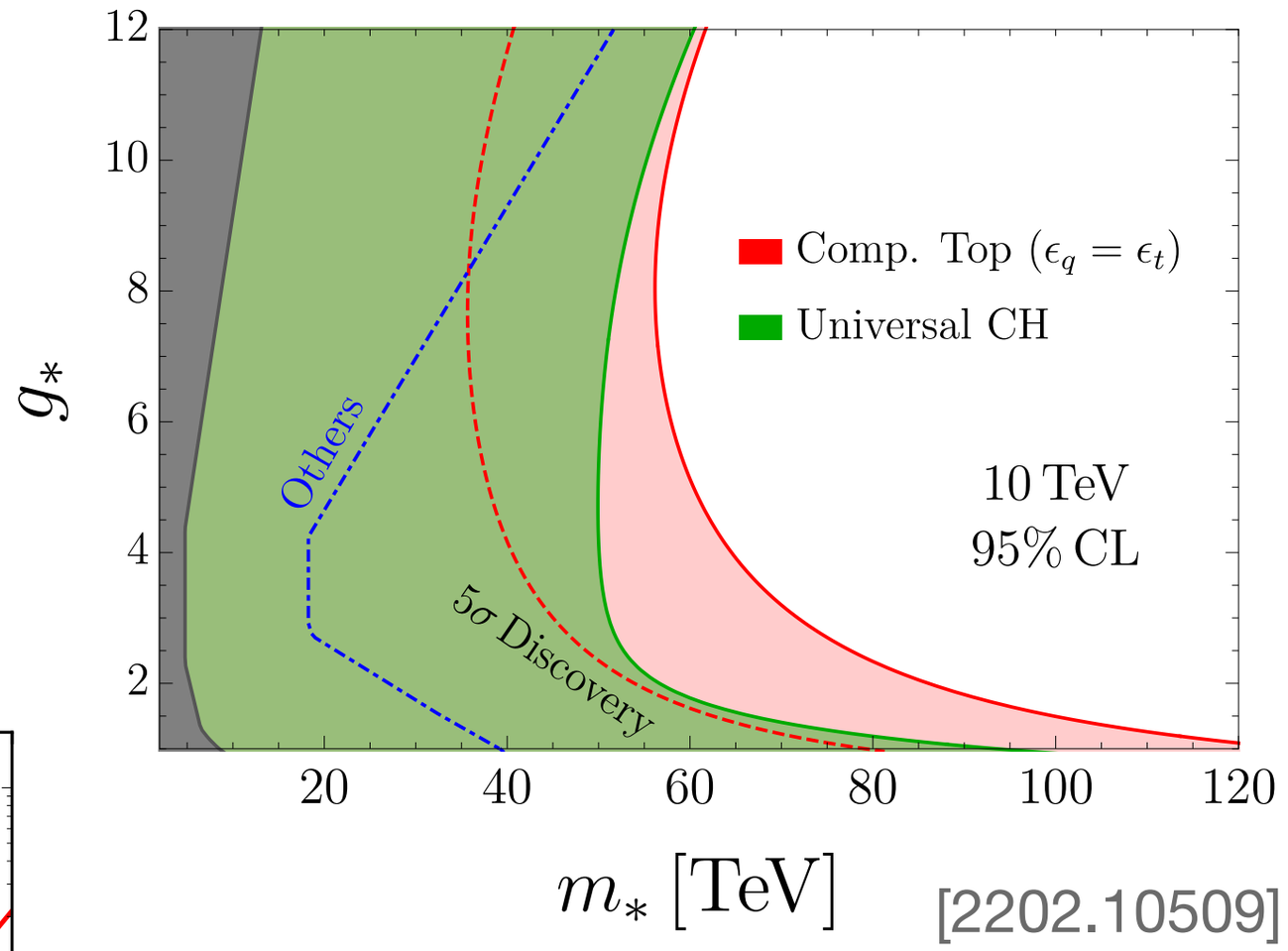
PITT PACC Seminar, April 6, 2022

Pushing the Energy Frontier is Essential

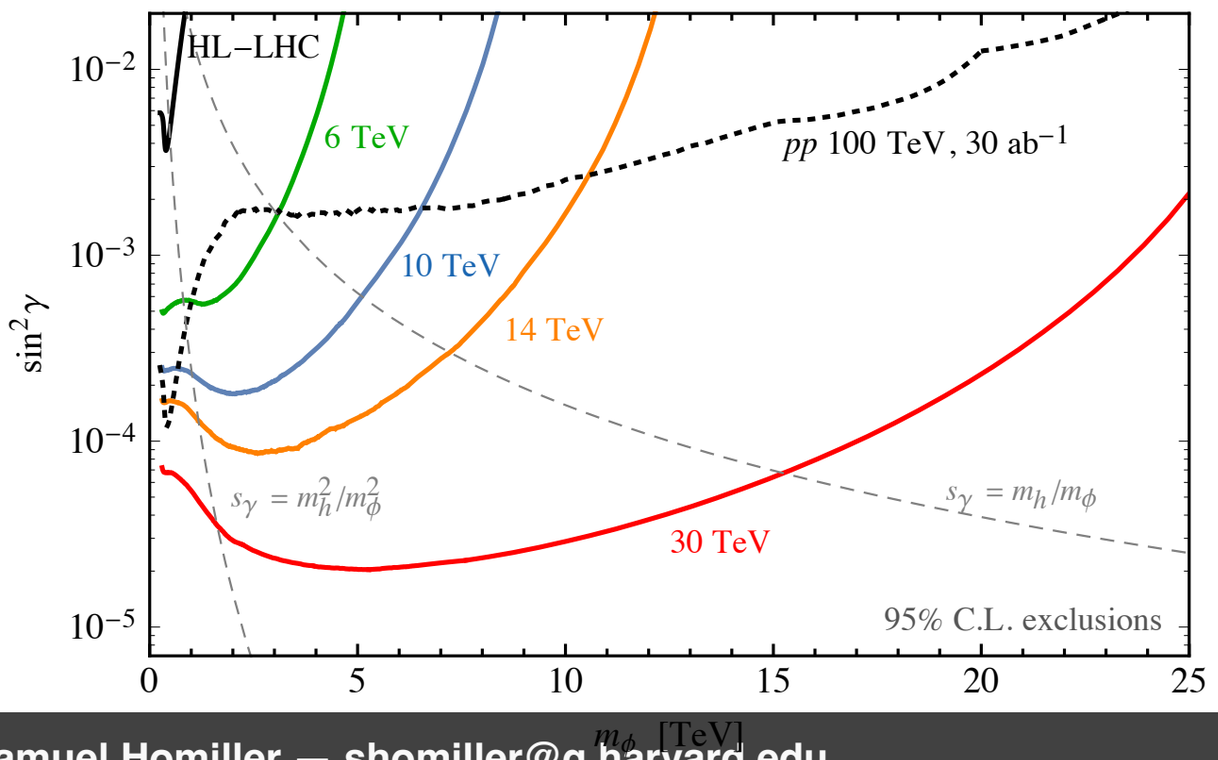
Muon Colliders Can Extend Our Reach



[2009.11287, 2203.07531]



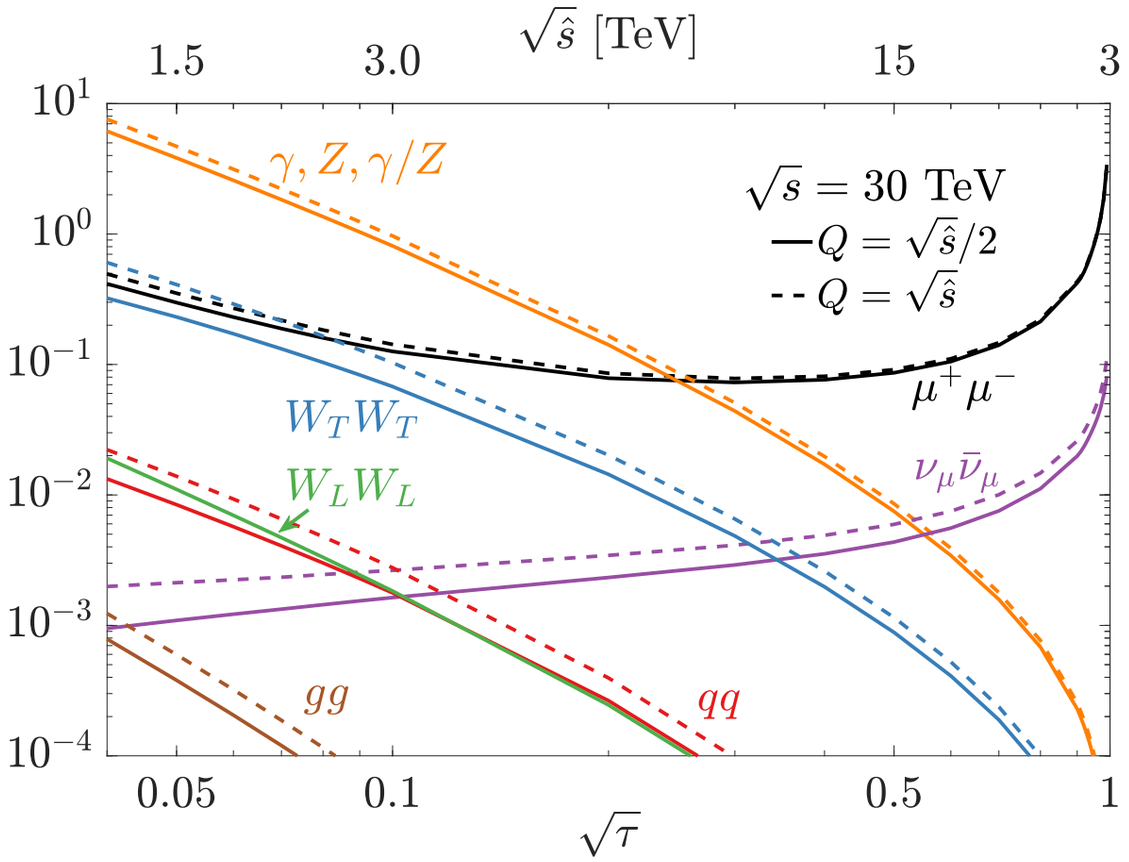
[2202.10509]

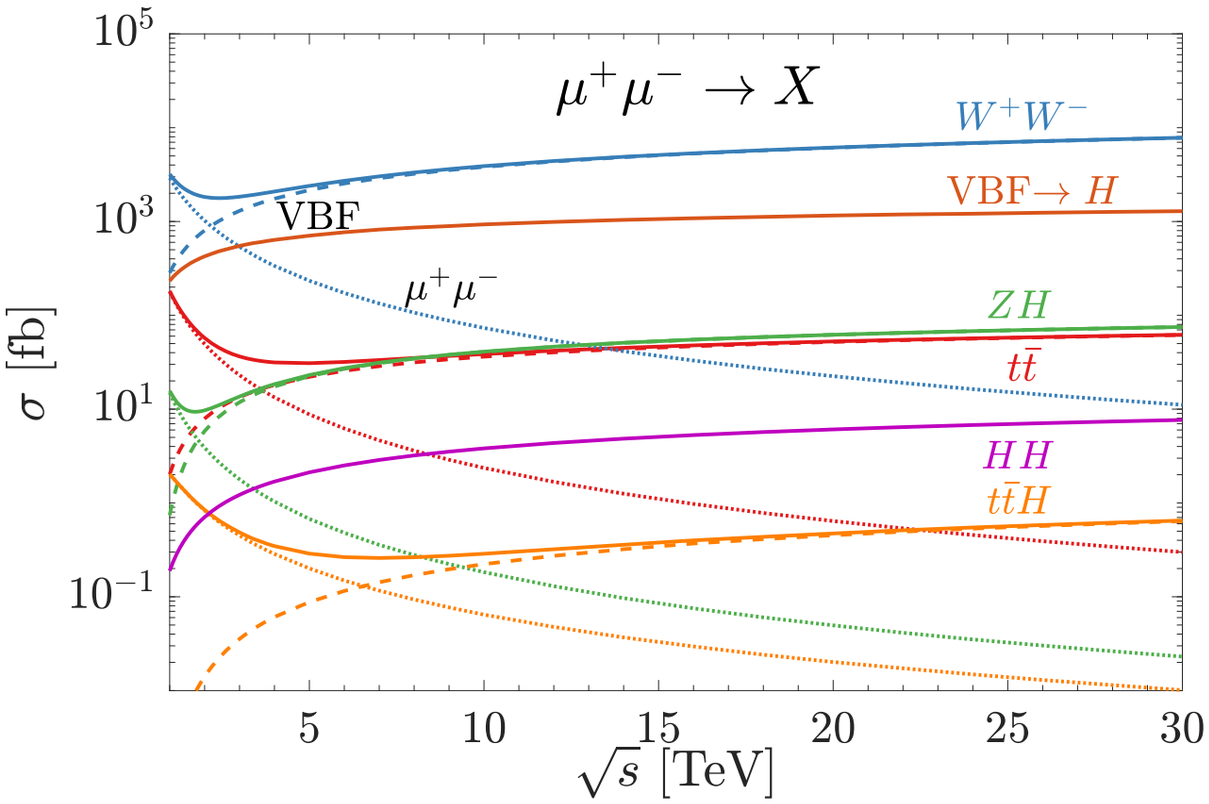


[2103.14043]

Muon Colliders Can Study the Higgs

Han, Ma, Xie [2007.14300]

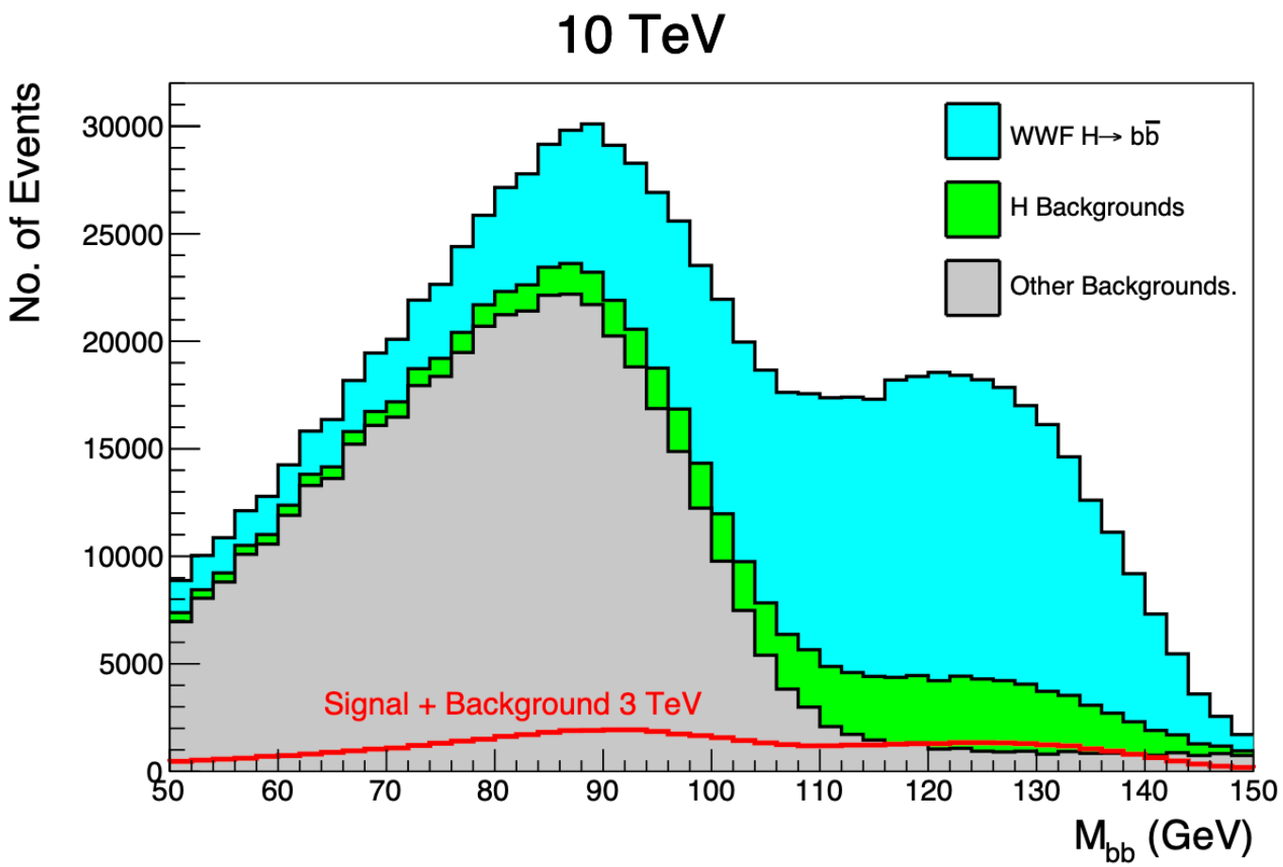




Large Higgs production rates from VBF in clean backgrounds

$\Longrightarrow$ precision measurements of the Higgs

Muon Colliders Can Study the Higgs

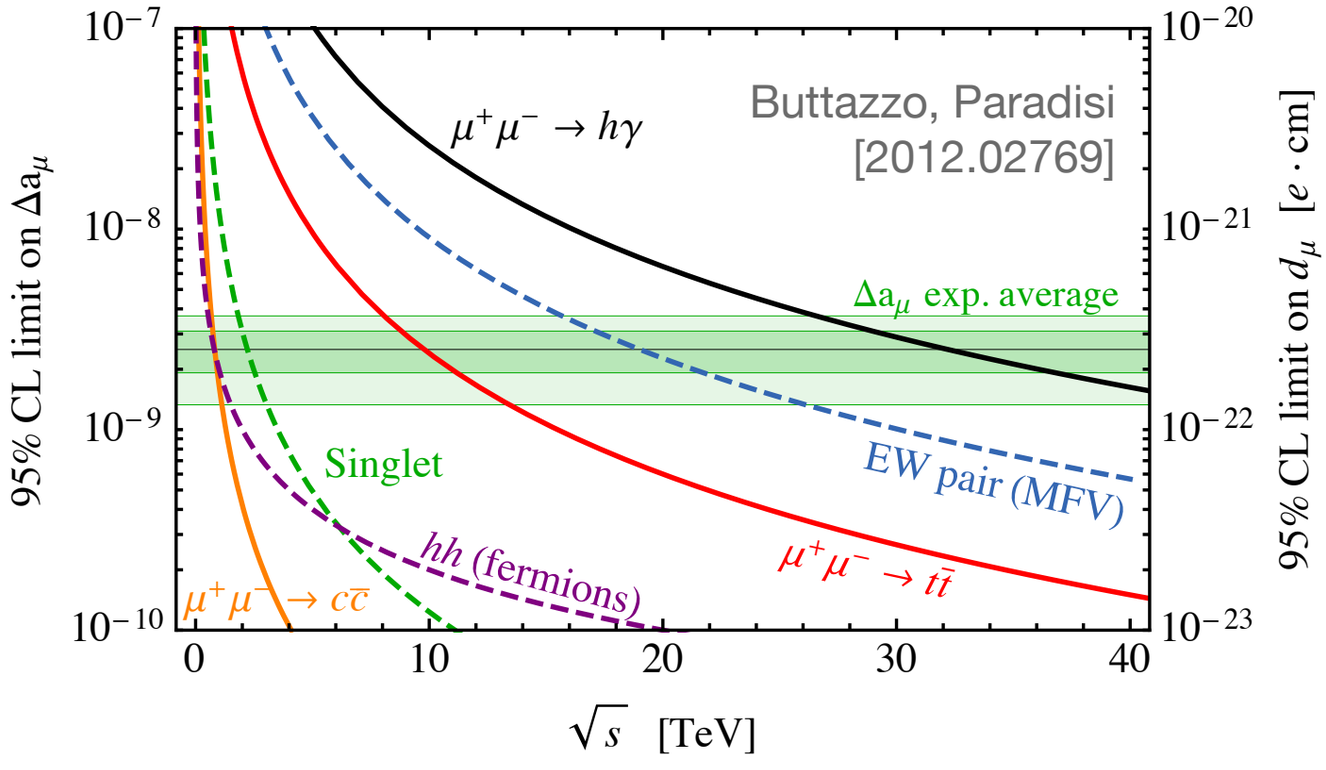


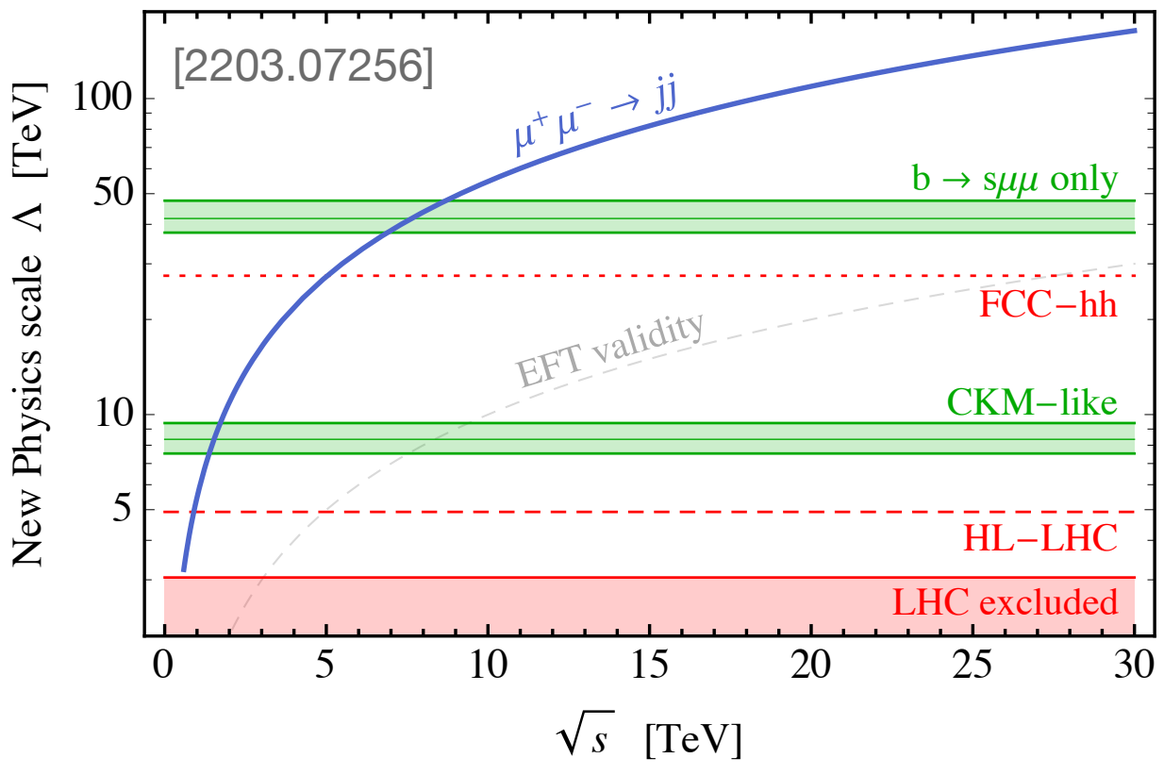
Forslund, Meade [2203.09425]

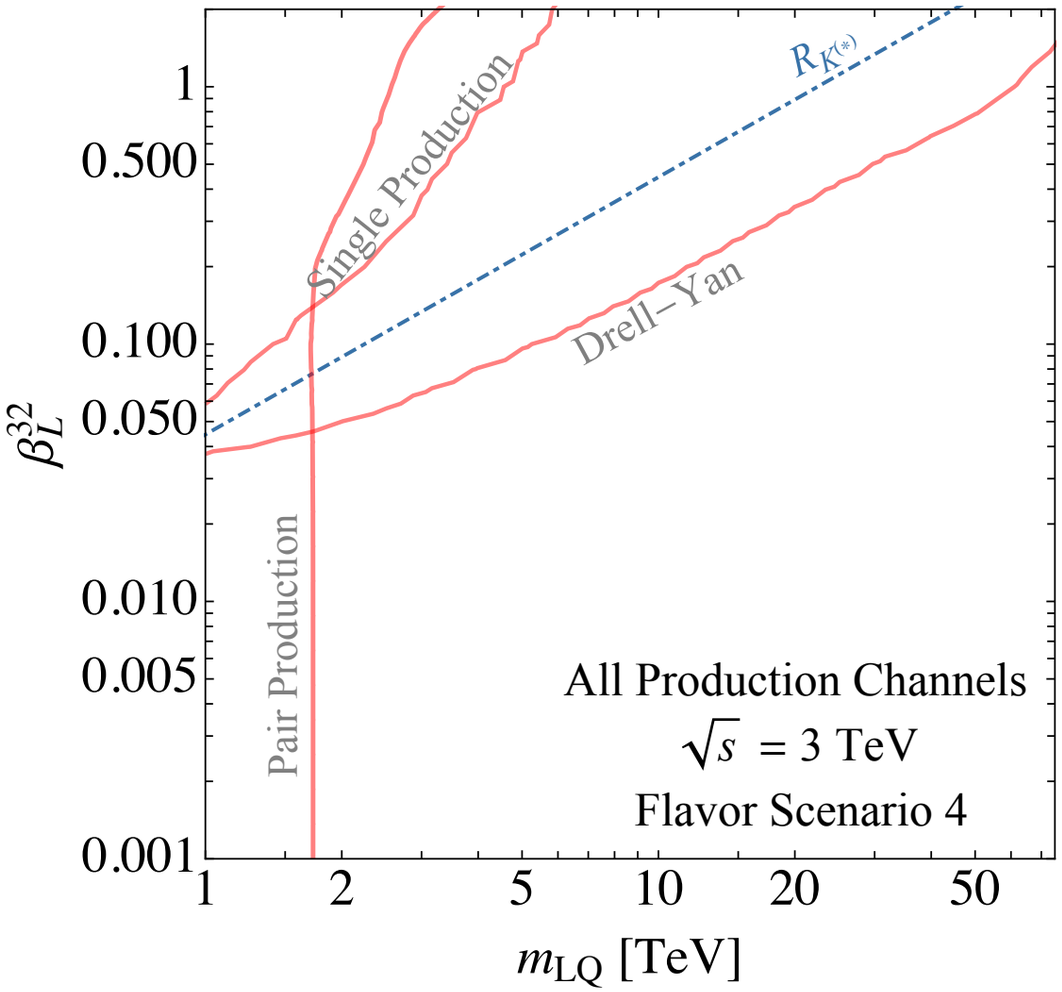
See also 2112.12507, 2203.04324, 2203.08874, …

	$\mu^+\mu^-$	
	3 TeV	10 TeV
κ_W	0.44	0.13
κ_Z	1.3	0.40
κ_g	2.4	0.67
κ_γ	3.9	1.1
$\kappa_{Z\gamma}$	37	10
κ_c	7.5	2.3
κ_t	35	52
κ_b	0.96	0.27
κ_μ	22	5.4
κ_τ	2.5	0.71

Muon Colliders Have Unique Probes

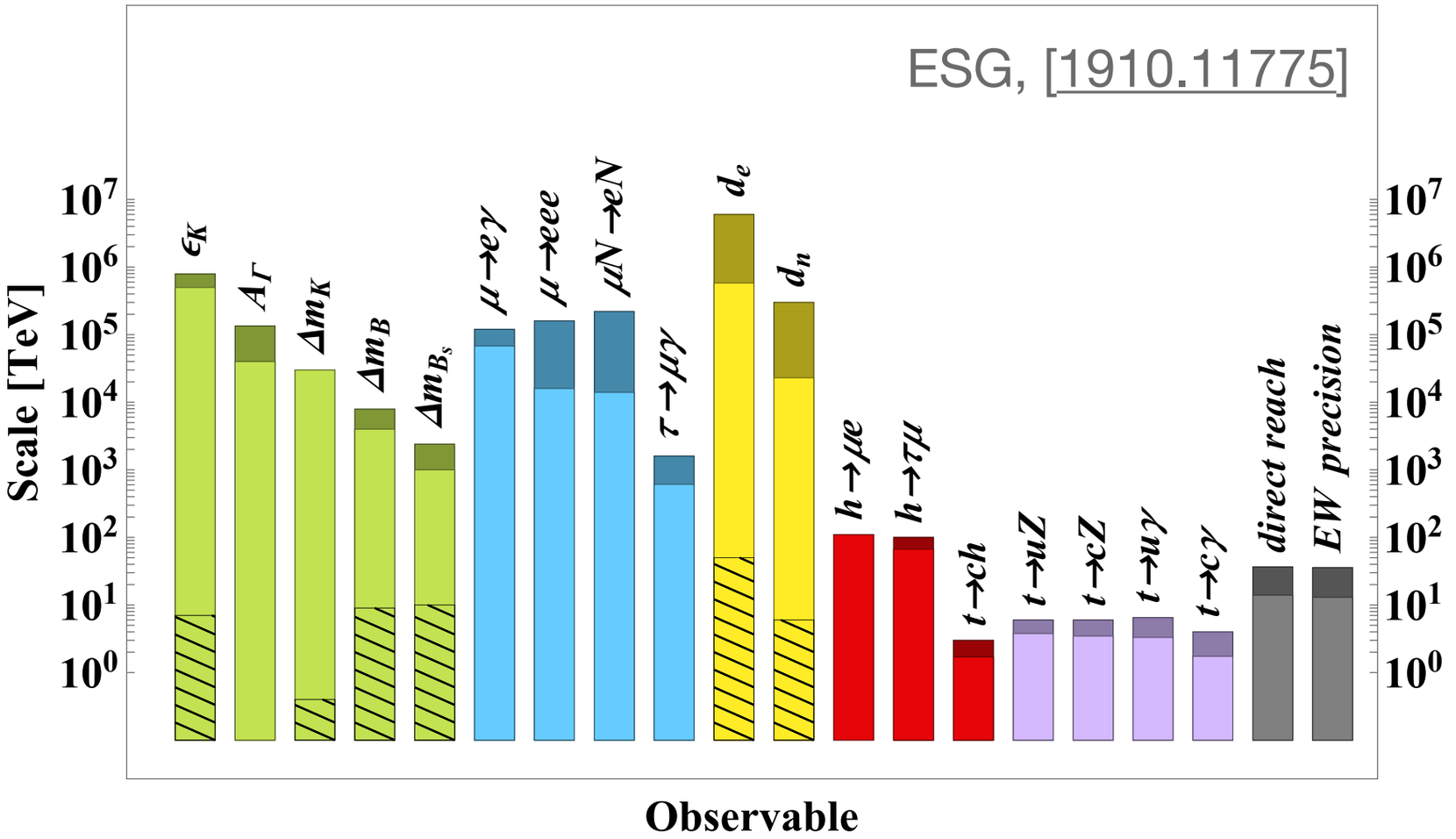






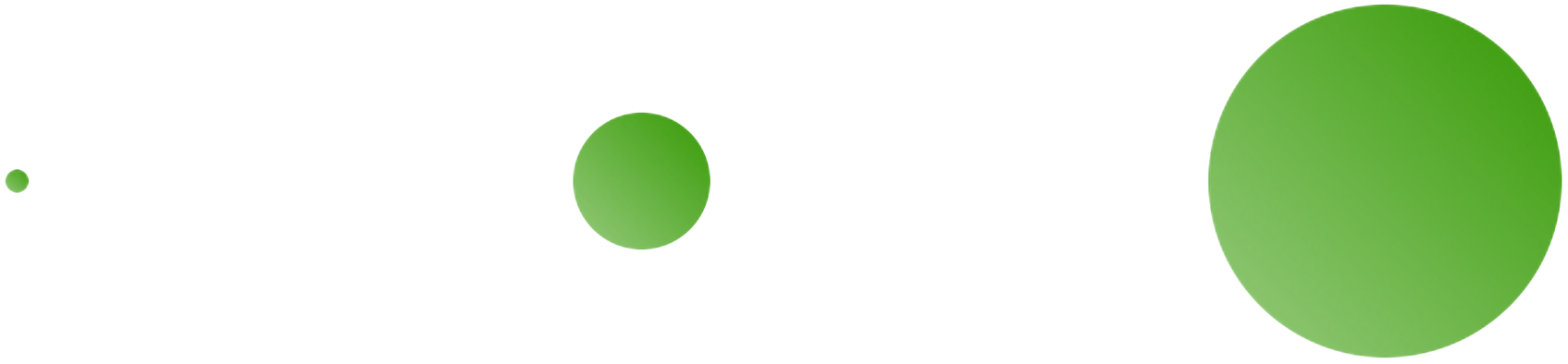
Asadi, Capdevilla, Cesarotti, SH
[2104.05720]

Can (Flavorful) New Physics Be Nearby?



Flavor Anarchy is Too Pessimistic!

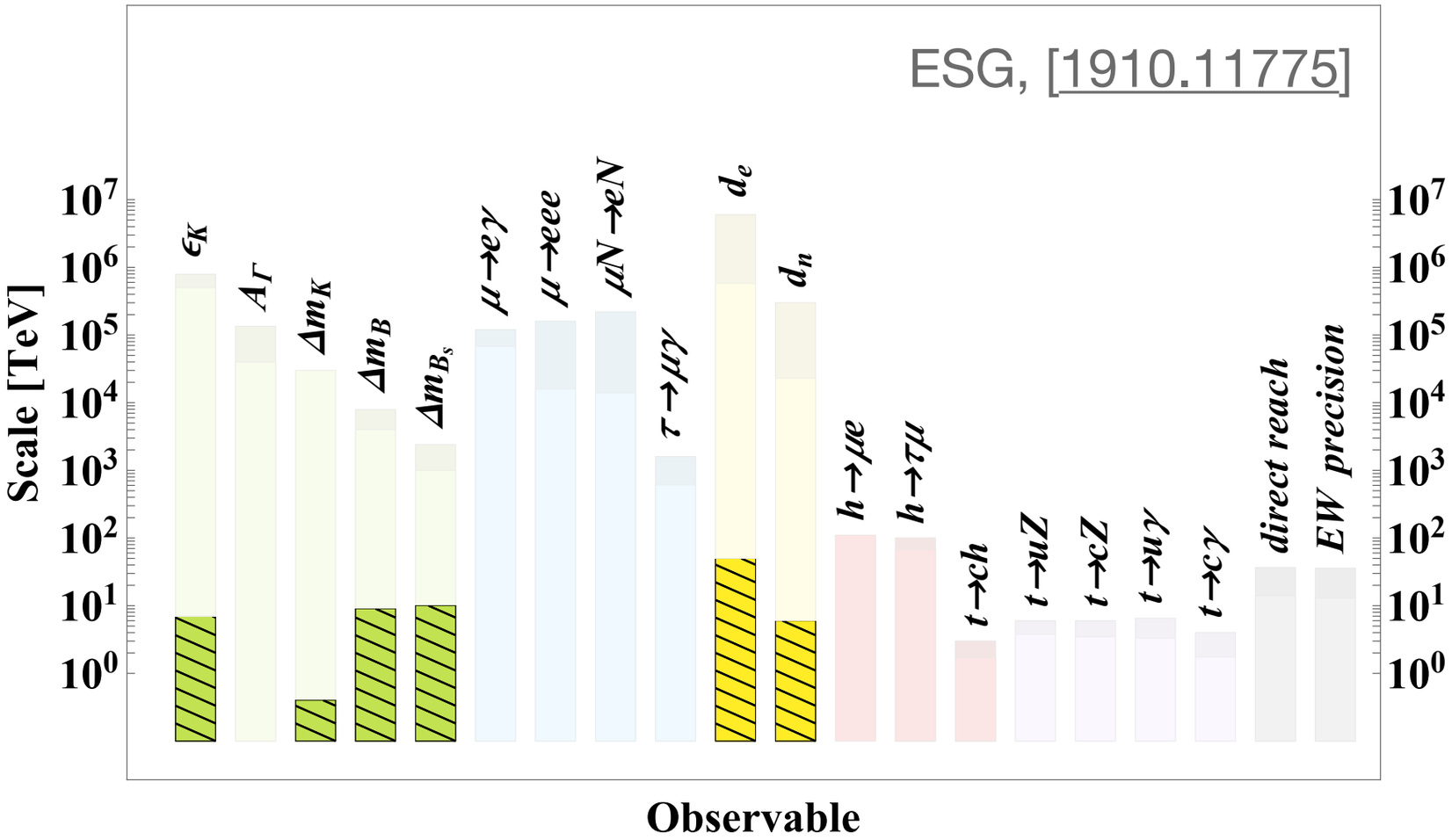
The only theory we've observed certainly doesn't look anarchic:



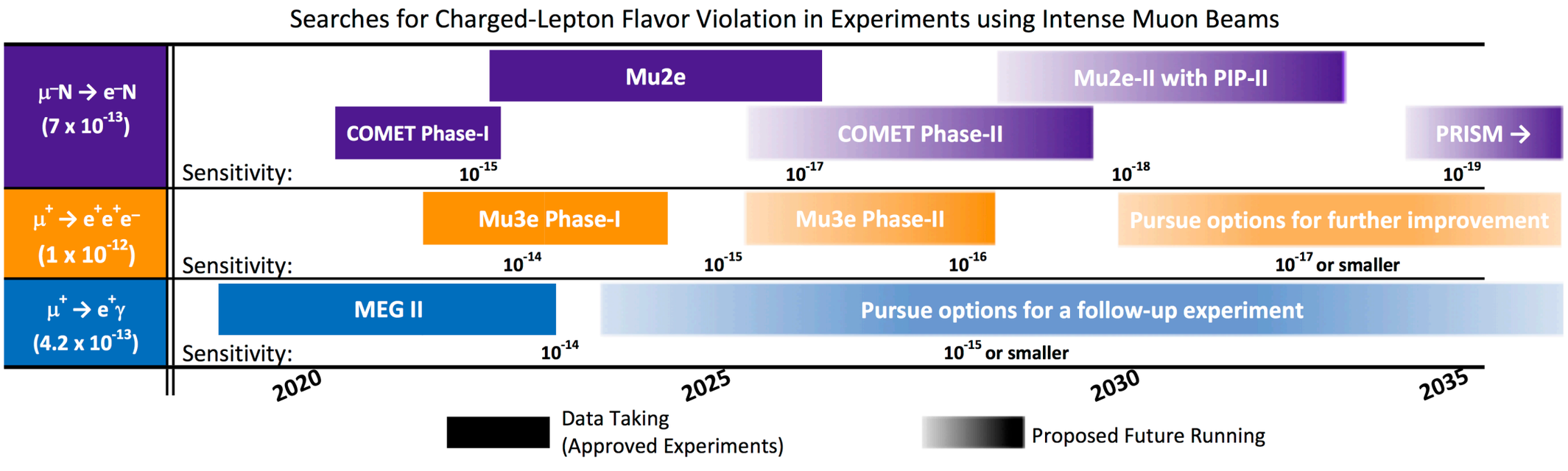
$m_e = 0.511\,\mathrm{MeV}$ $m_\mu = 105.7\,\mathrm{MeV}$ $m_\tau = 1776.9\,\mathrm{MeV}$

$$|V_{\mathrm{CKM}}| = \begin{pmatrix} 0.974 & 0.225 & 0.0037 \\ -0.225 & 0.973 & 0.042 \\ 0.0087 & -0.041 & 0.999 \end{pmatrix} \sim \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & \lambda^3 \\ -\lambda & 1-\frac{1}{2}\lambda^2 & \lambda^2 \\ \lambda^3 & -\lambda^2 & 1 \end{pmatrix}$$

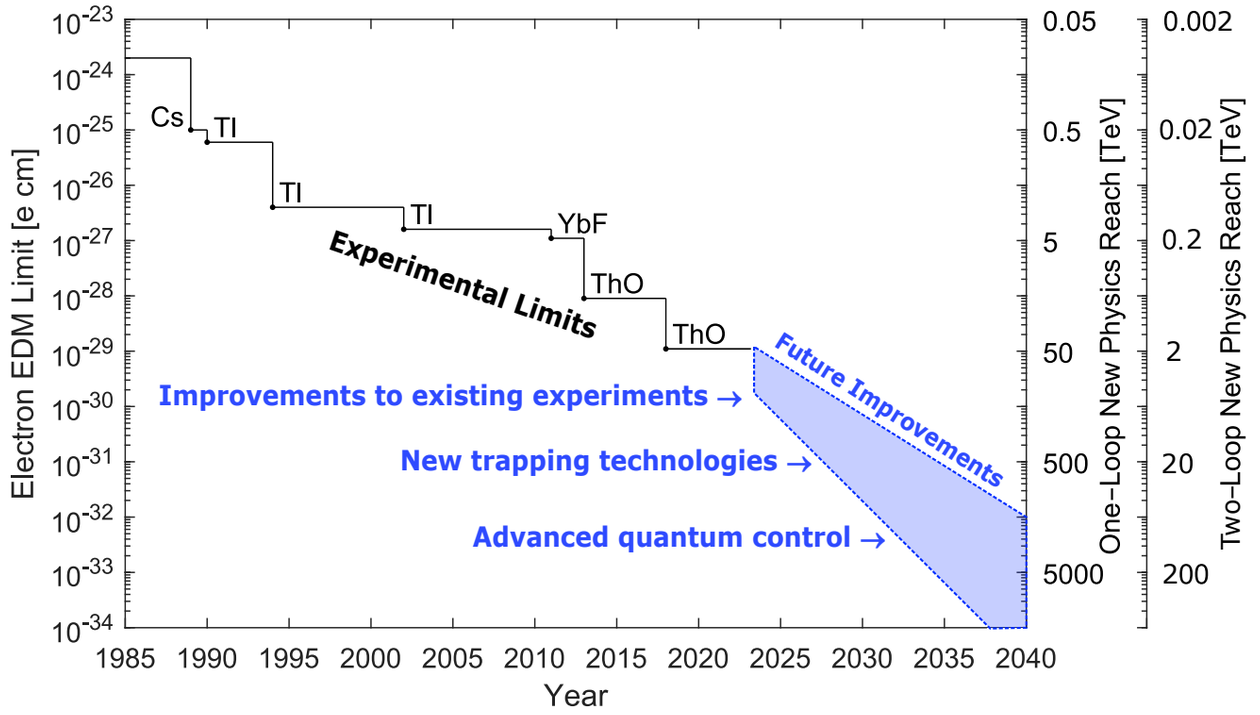
Flavor Anarchy is Too Pessimistic!



A Promising Decade of Precision Experiments



Put differently: precision probes have a fantastic chance at discovering signals of new physics in the coming decade, *and that physics could very well be near the TeV scale!*

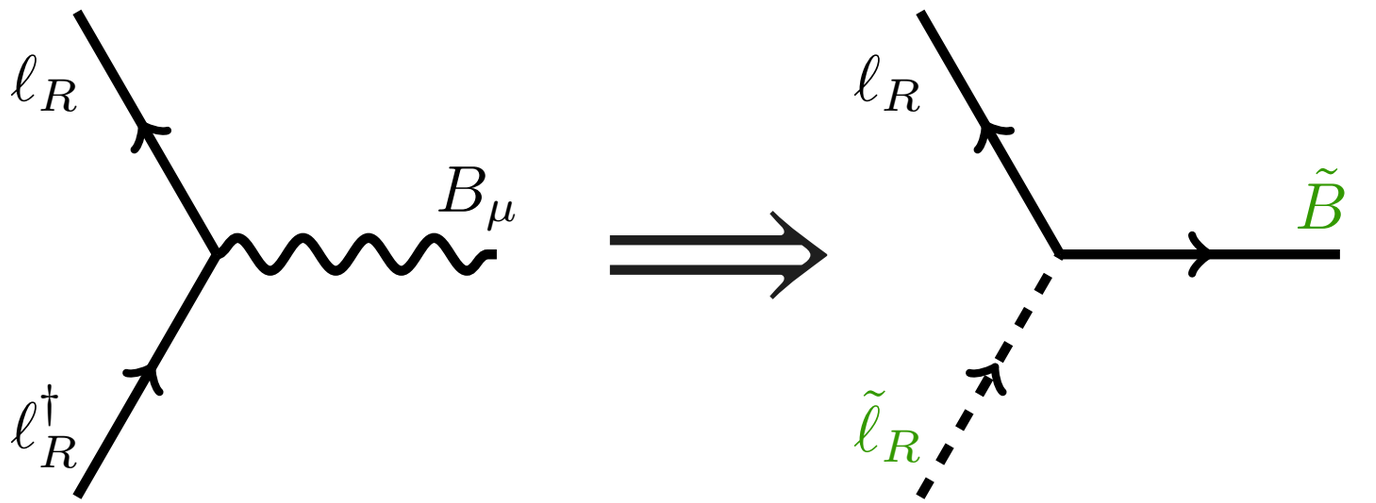


High-Energy Muon Colliders Uniquely Complementary to Precision Flavor Probes

Goal Today: demonstrate this in context of lepton flavor violation in an explicit scenario

Lepton Flavor Violation in the MSSM

Supersymmetry introduces scalar partners of LH, RH leptons



Lightest neutralino assumed to be pure Bino, mass M_1

$$\begin{pmatrix} \tilde{e}_R & \tilde{\mu}_R \end{pmatrix}$$

In what follows, we'll assume all the LH, color-charged superpartners are parametrically heavier, and can be ignored

For now, we'll also ignore $\tilde{\tau}_L, \tilde{\tau}_R$

Lepton Flavor Violation in the MSSM

We're left with a 2×2 mixing problem:

$$\begin{pmatrix} \tilde{e}_R^\dagger & \tilde{\mu}_R^\dagger \end{pmatrix} \begin{pmatrix} m_R^2 + \Delta_{ee}^{RR} & \Delta_{e\mu}^{RR} \\ \left(\Delta_{e\mu}^{RR}\right)^* & m_R^2 + \Delta_{\mu\mu}^{RR} \end{pmatrix} \begin{pmatrix} \tilde{e}_R \\ \tilde{\mu}_R \end{pmatrix}$$

Universal terms dictated by SUSY, gauge invariance

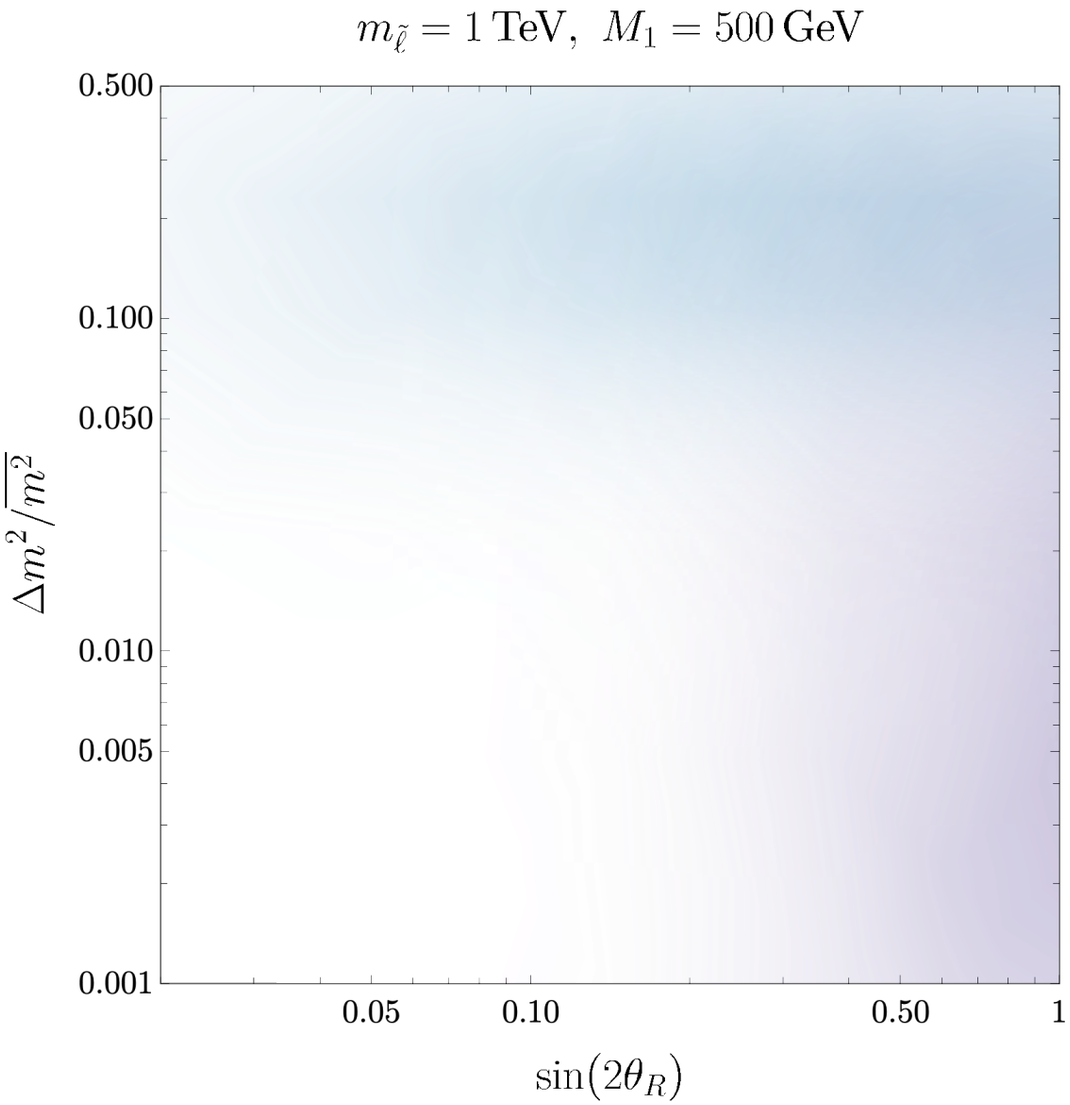
Flavor-violating, soft supersymmetry breaking terms

$\Longrightarrow$ flavor-violation a window into theory of SUSY-breaking

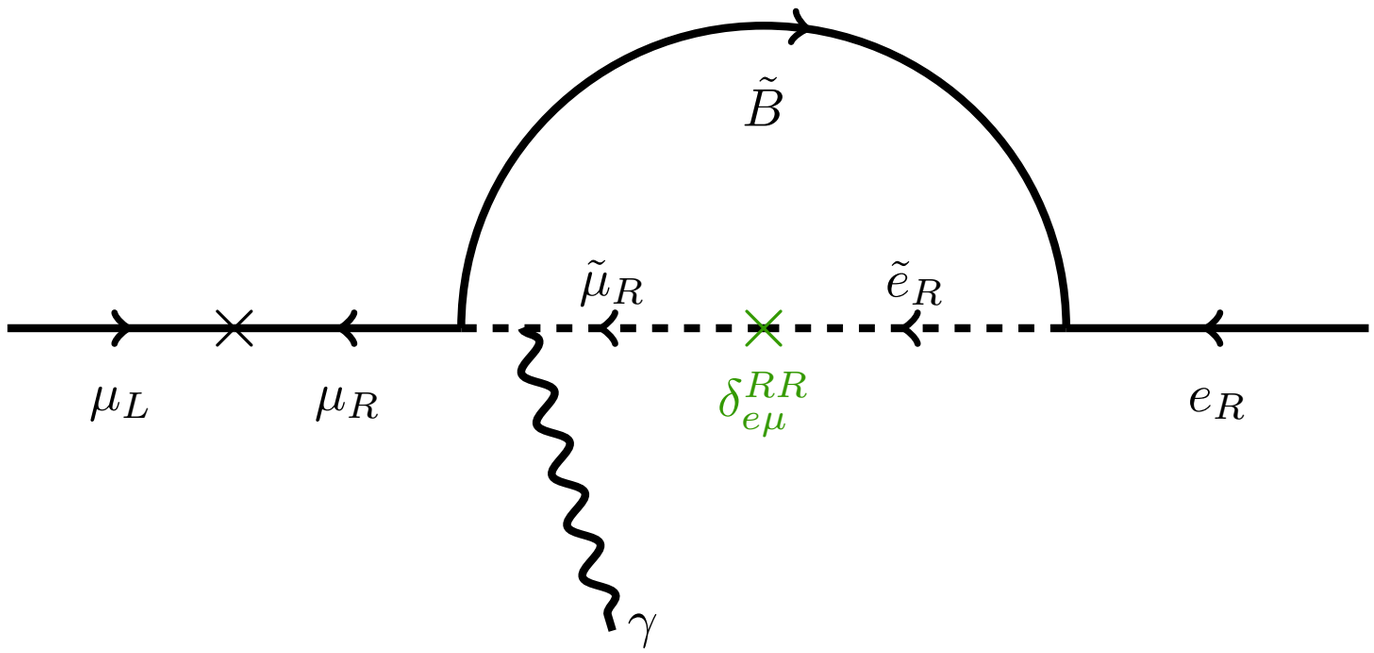
Diagonalize via unitarity matrix with mixing angle θ_R

Phenomenology described by $\sin 2\theta_R$, Δm^2, $\overline{m^2}$, and M_1

Expectations in Models of ~~SUSY~~

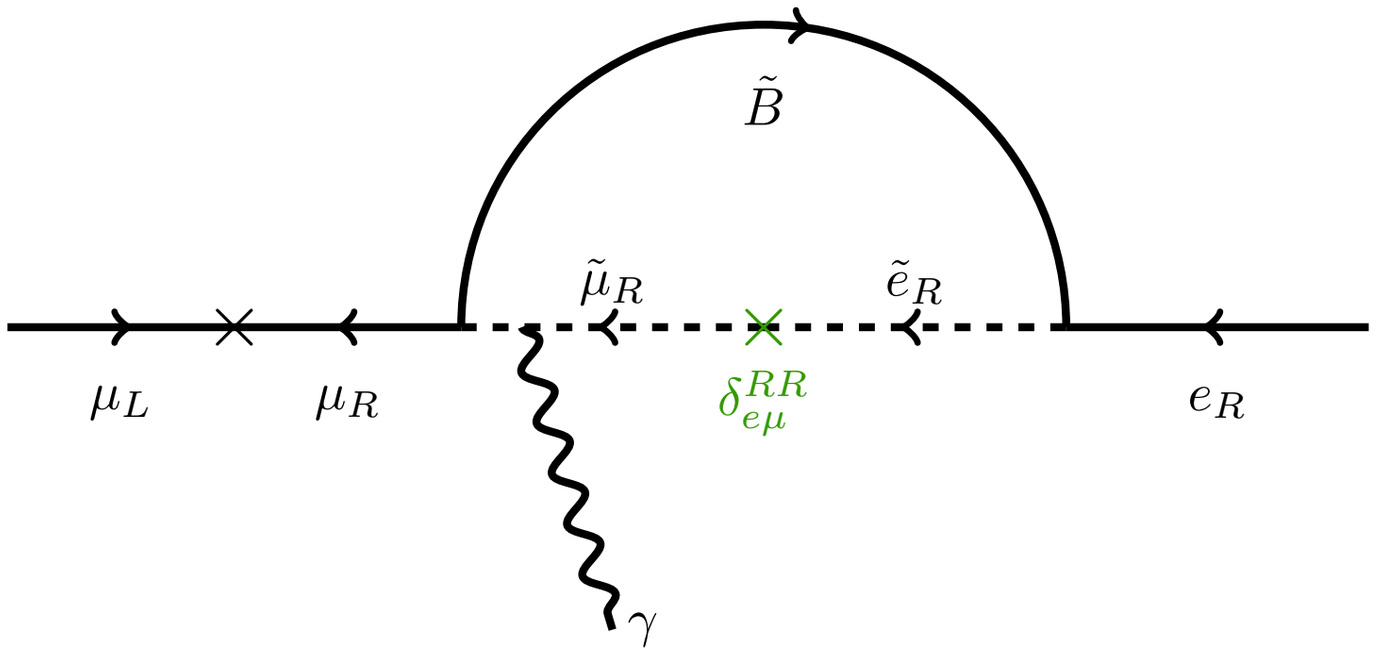


$\mu \to e\gamma$ Decays



$$\mathcal{A}^R_{\mu e} = m_\mu \frac{\alpha_Y}{8\pi} \sin(2\theta_R) \left[\frac{1}{m^2_{\tilde{\ell}_1}} \bar{A}\left(\frac{|M_1|^2}{m^2_{\tilde{\ell}_1}} \right) - \frac{1}{m^2_{\tilde{\ell}_2}} \bar{A}\left(\frac{|M_1|^2}{m^2_{\tilde{\ell}_2}} \right) \right]$$

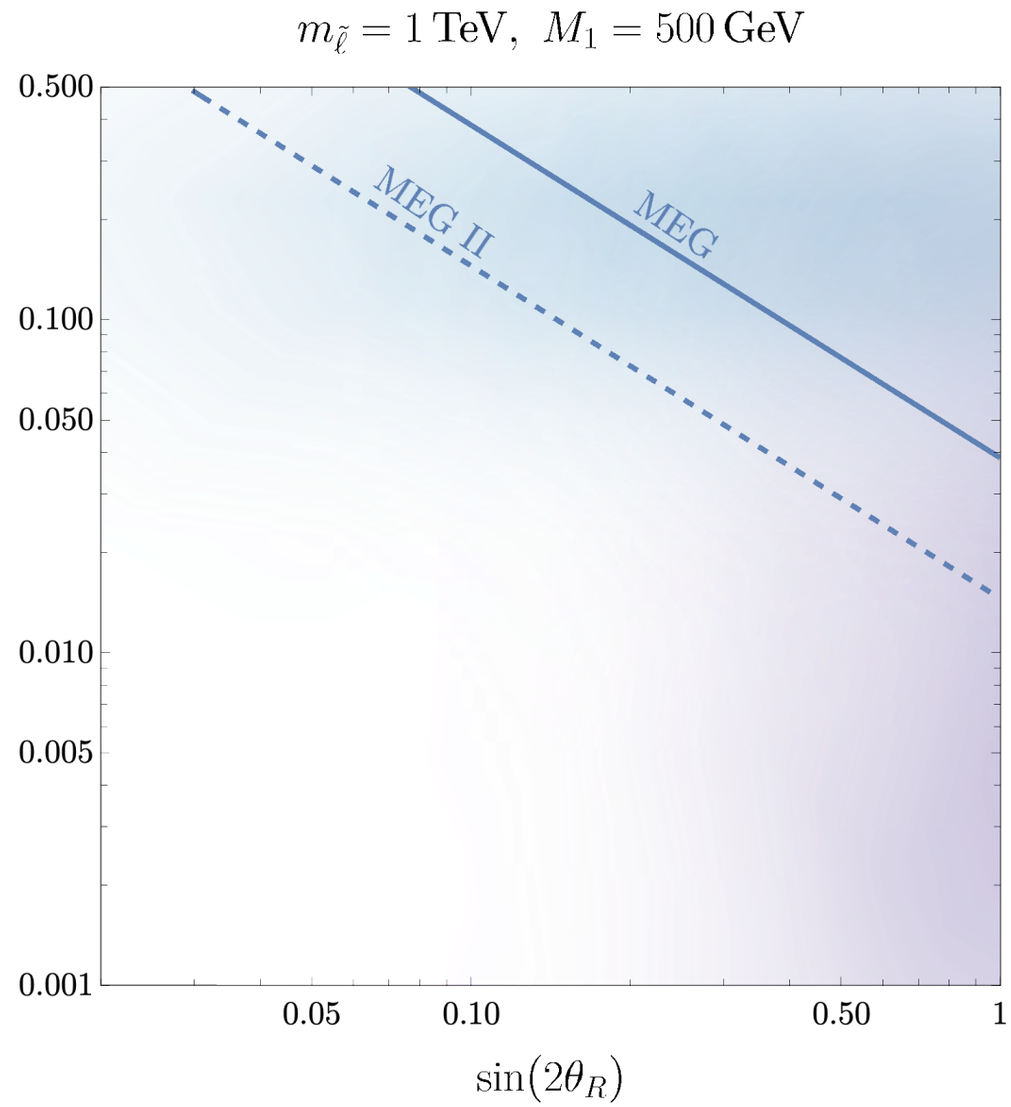
$\mu \to e\gamma$ Decays



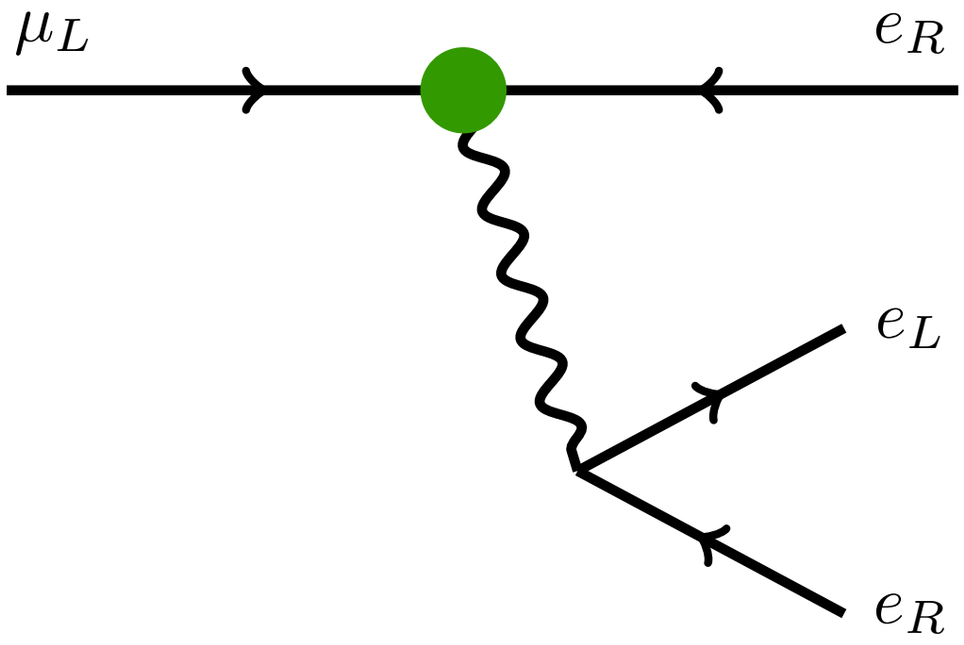
$$\mathcal{A}^R_{\mu e} = m_\mu \frac{\alpha_Y}{\pi} \delta^{RR}_{\mu e} \frac{1}{\overline{m^2}} f_{1n}\left(\frac{|M_1|^2}{\overline{m^2}}\right)$$

$$\delta^{RR}_{\mu e} = \frac{1}{2}\frac{\Delta m^2}{\overline{m^2}} \sin(2\theta_R)$$

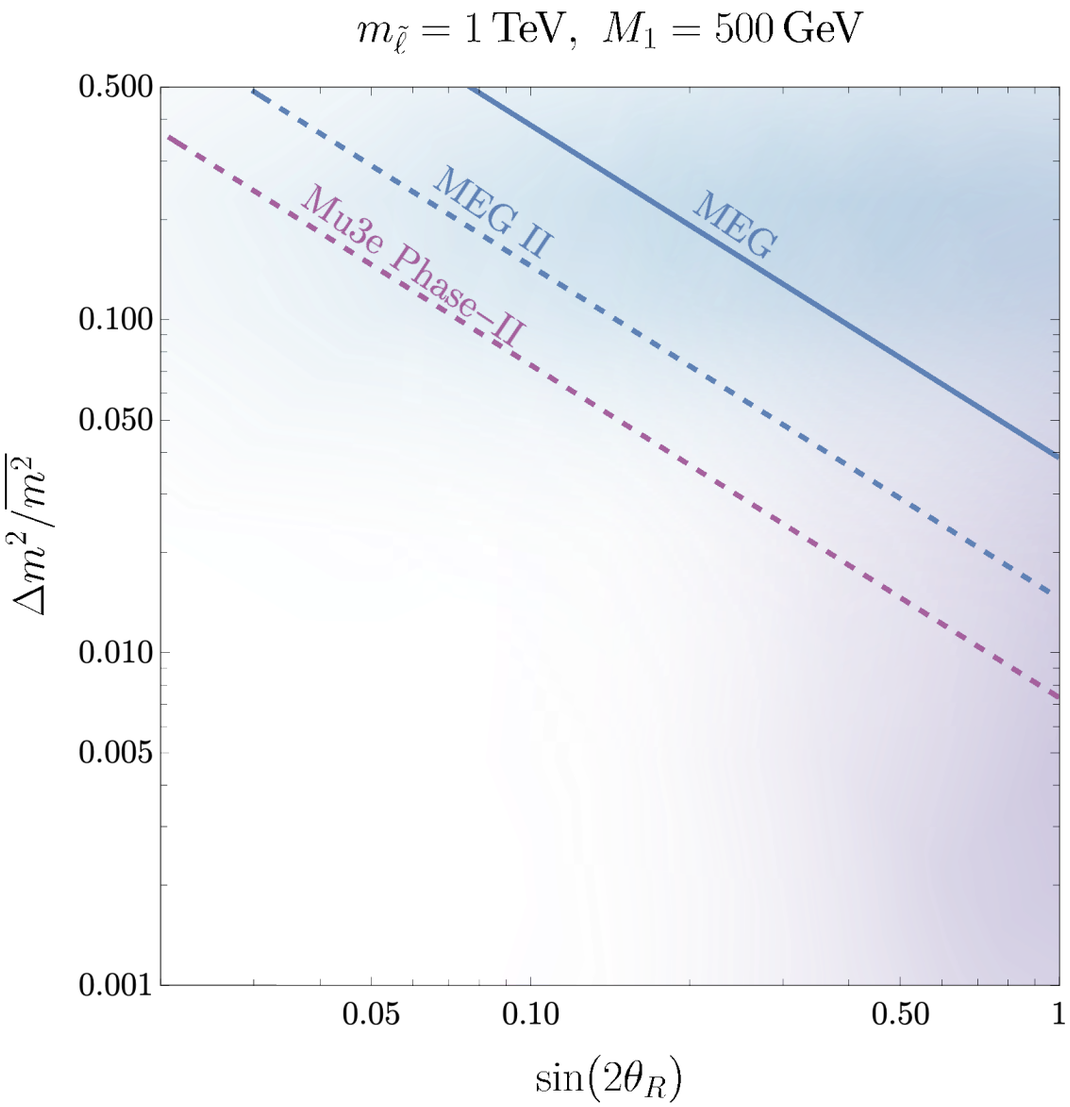
Mass-insertion parameter governing flavor violation



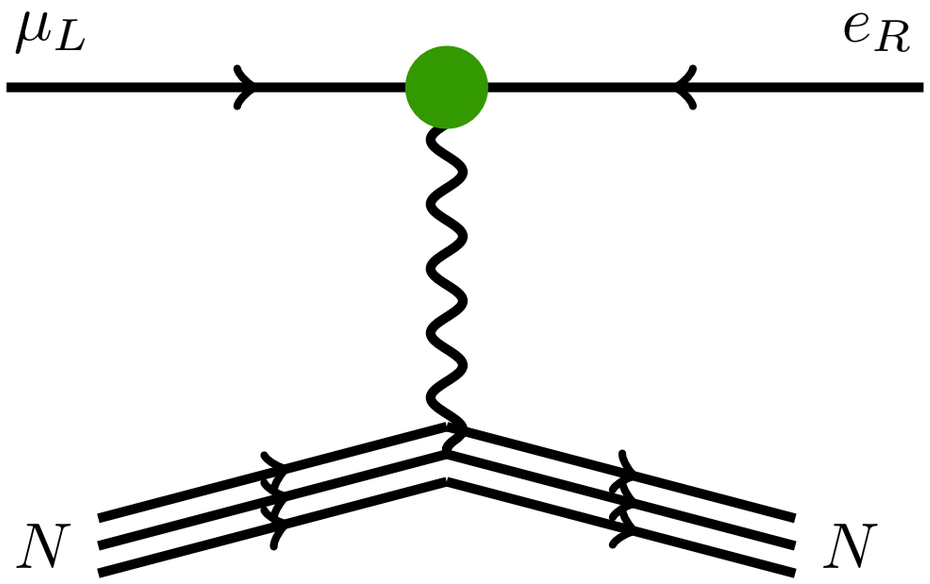
$\mu \to 3e$ Decays



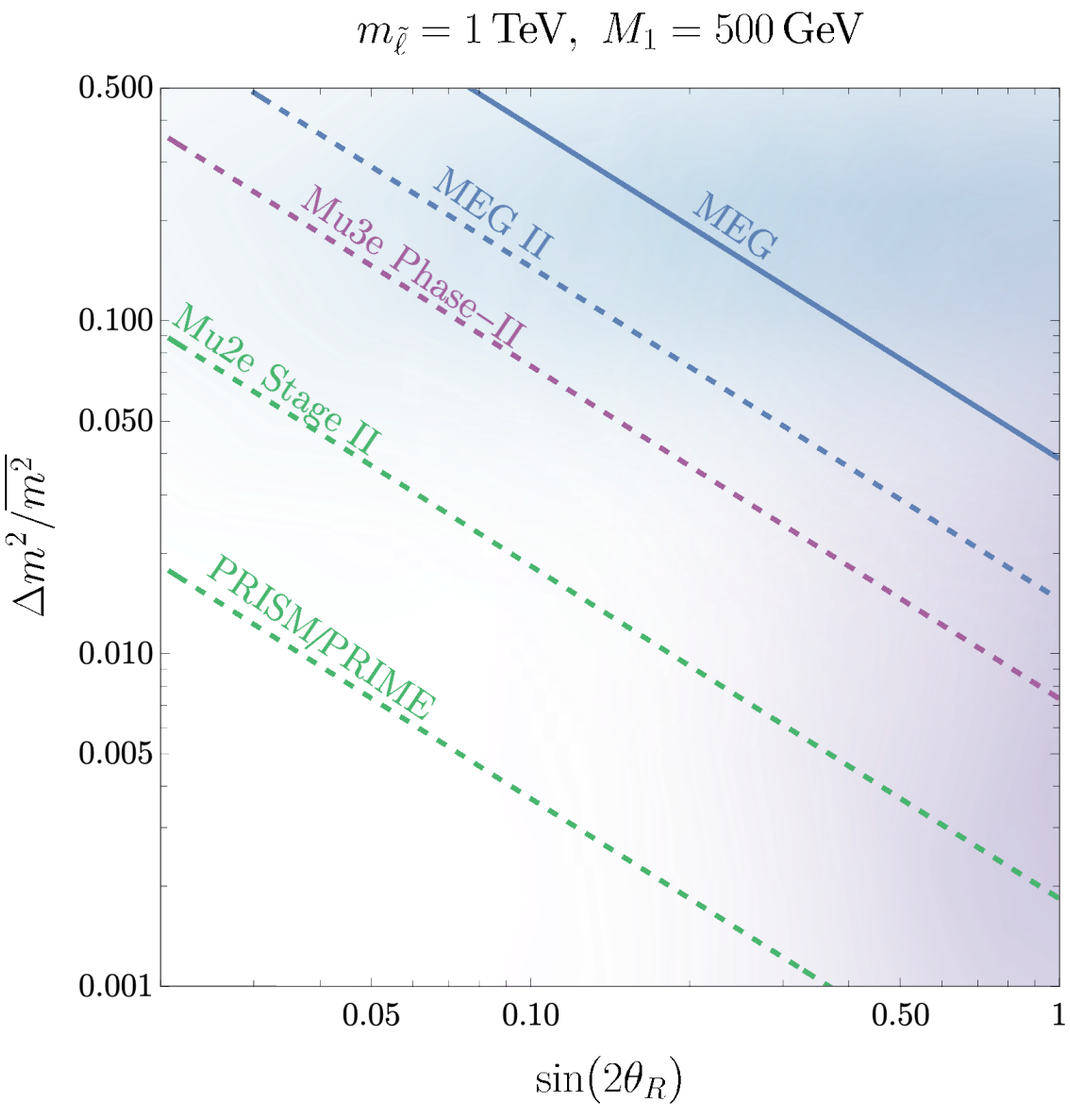
$$\mathrm{BR}(\mu \to 3e) = \frac{\alpha}{3\pi}\left(\log\frac{m_\mu^2}{m_e^2} - \frac{11}{4}\right)\mathrm{BR}(\mu \to e\gamma)$$



$\mu N \to eN$ Conversions



$$\mathrm{CR}(\mu \to e)_N = C_N \alpha \, \mathrm{BR}(\mu \to e\gamma)$$



Superpartners at a Muon Collider

Subtitle

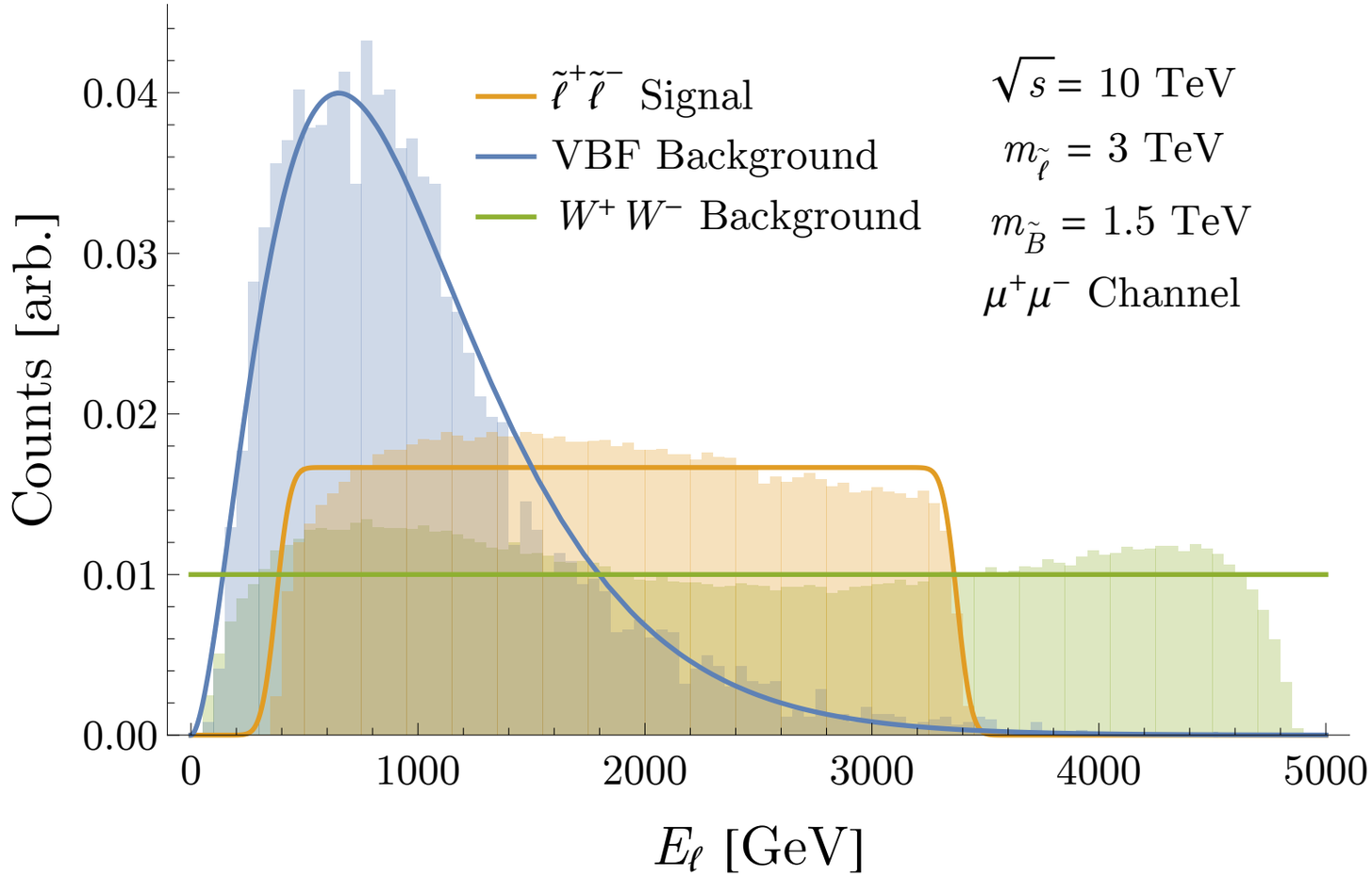
Measuring the Slepton/Neutralino Masses

Subtitle

$$E_\ell = \frac{\sqrt{s}}{4}\left(1 - \frac{M_1^2}{m_{\tilde{\ell}}^2}\right)(1 + \beta\cos\theta_0)$$

$$m_{\tilde{\ell}}^2 = s\frac{E_{\min}E_{\max}}{(E_{\min}+E_{\max})^2}$$

$$M_1^2 = m_{\tilde{\ell}}^2\left(1 - \frac{2(E_{\min}+E_{\max})}{\sqrt{s}}\right)$$



Measuring the Slepton/Neutralino Masses

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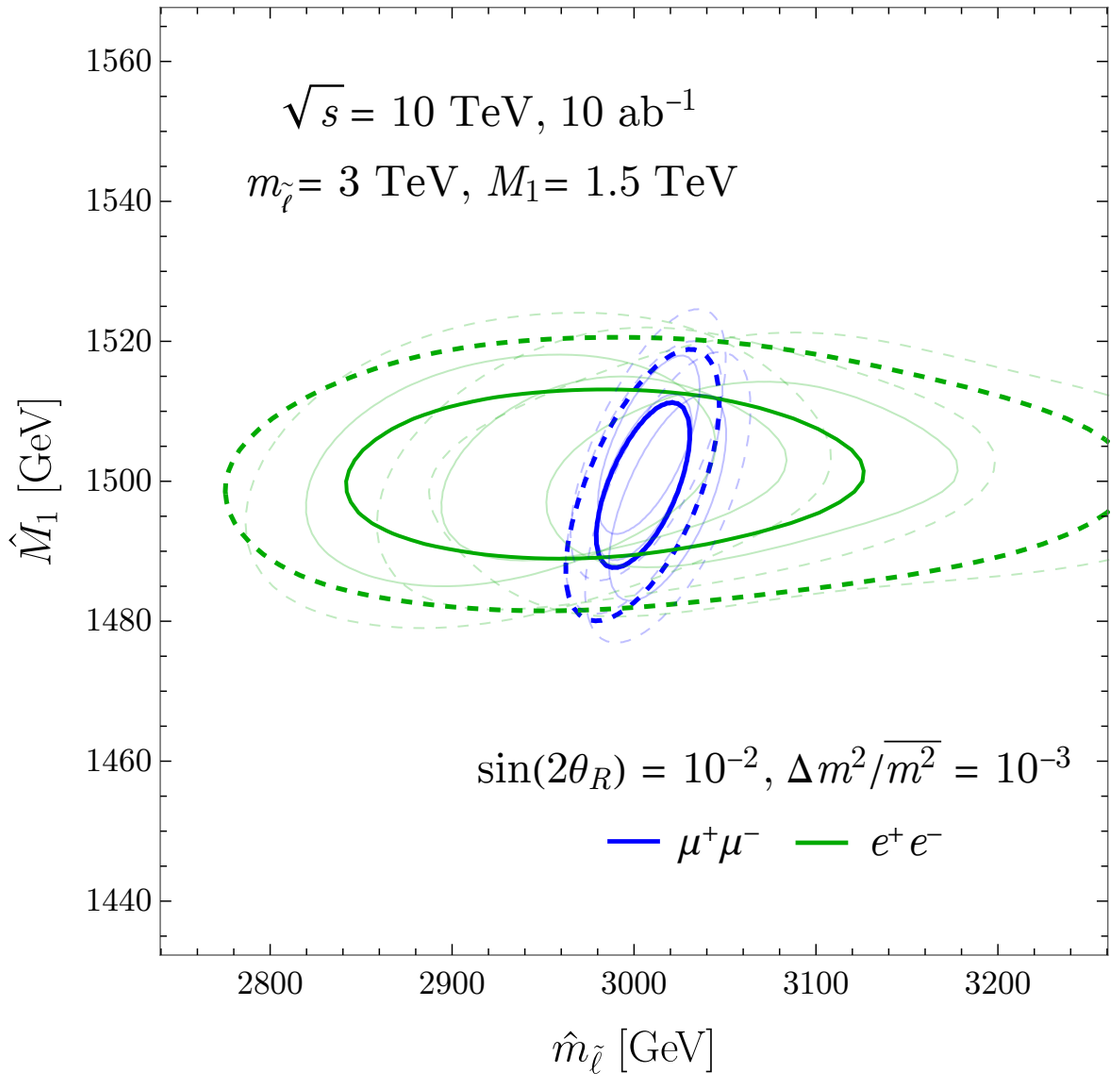

Measuring the Slepton/Neutralino Masses

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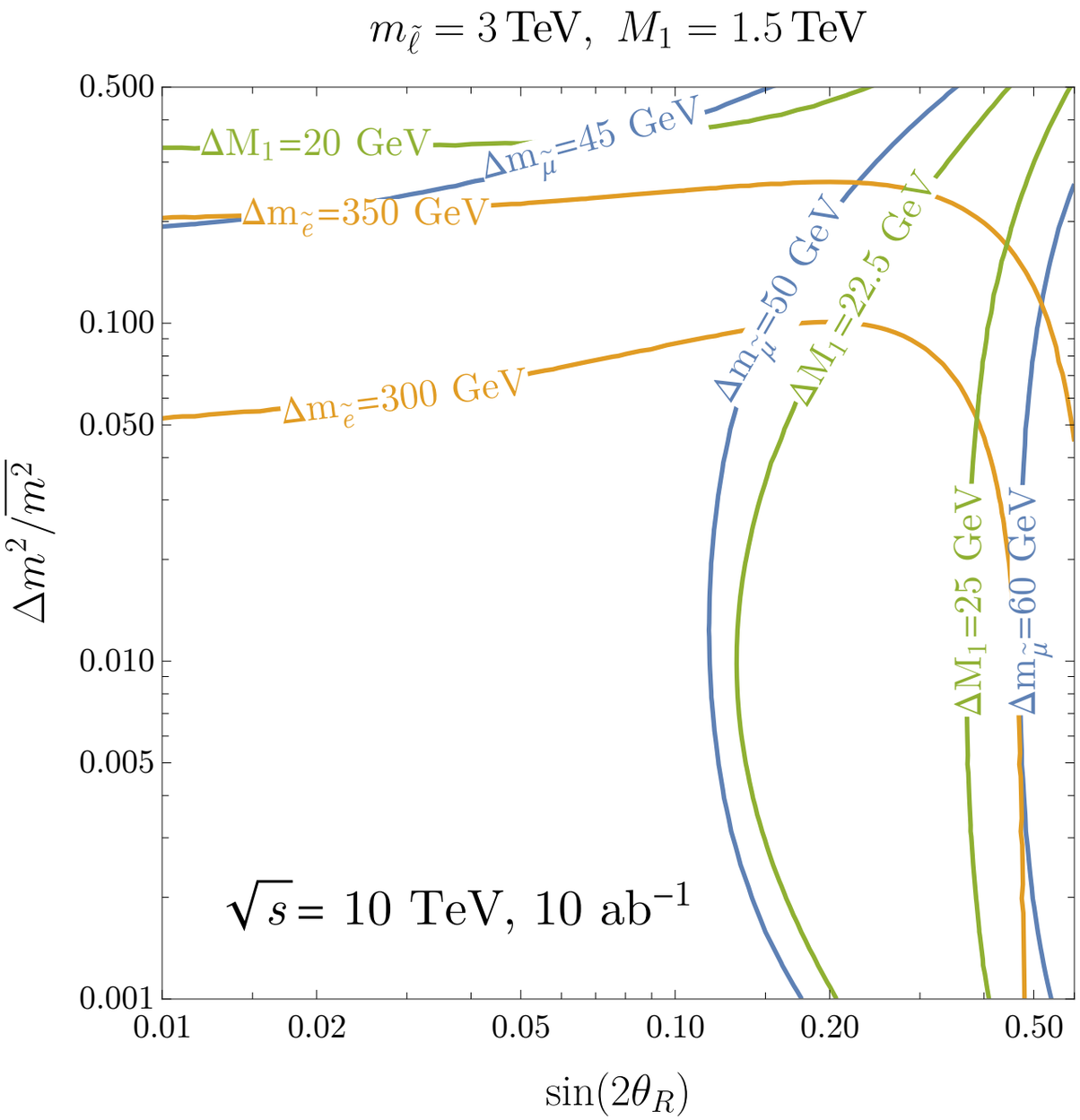
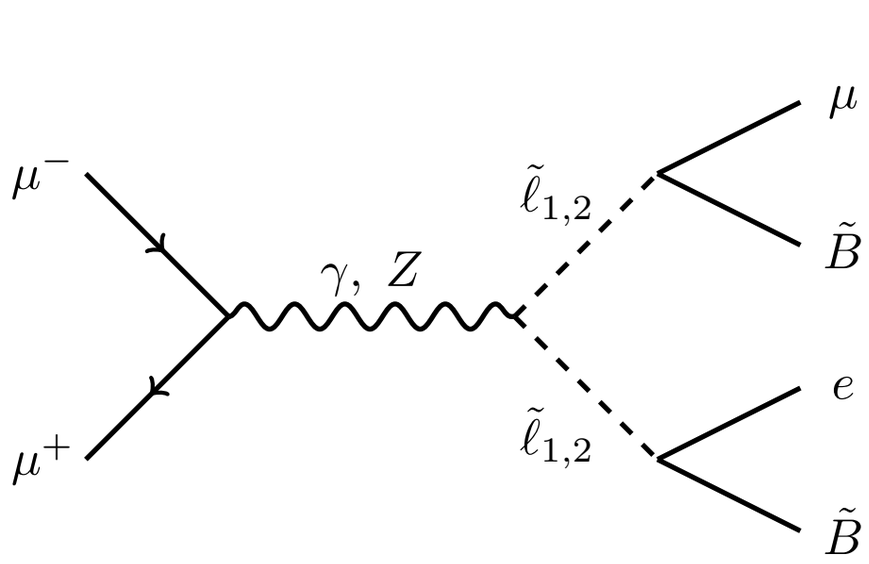
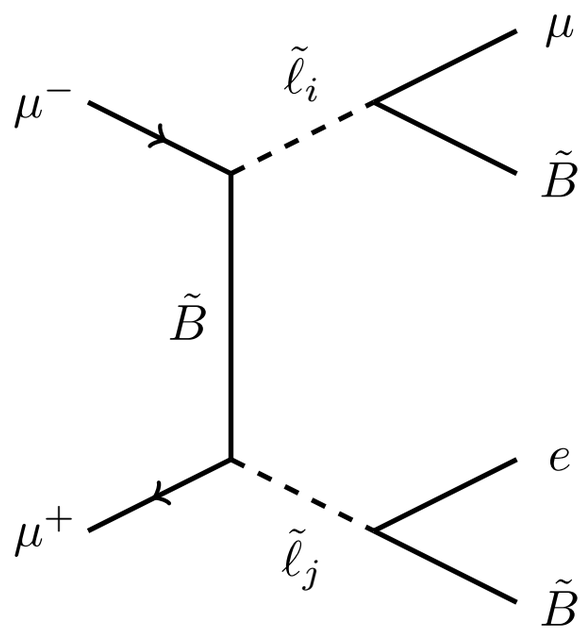


LFV Signals at a Muon Collider

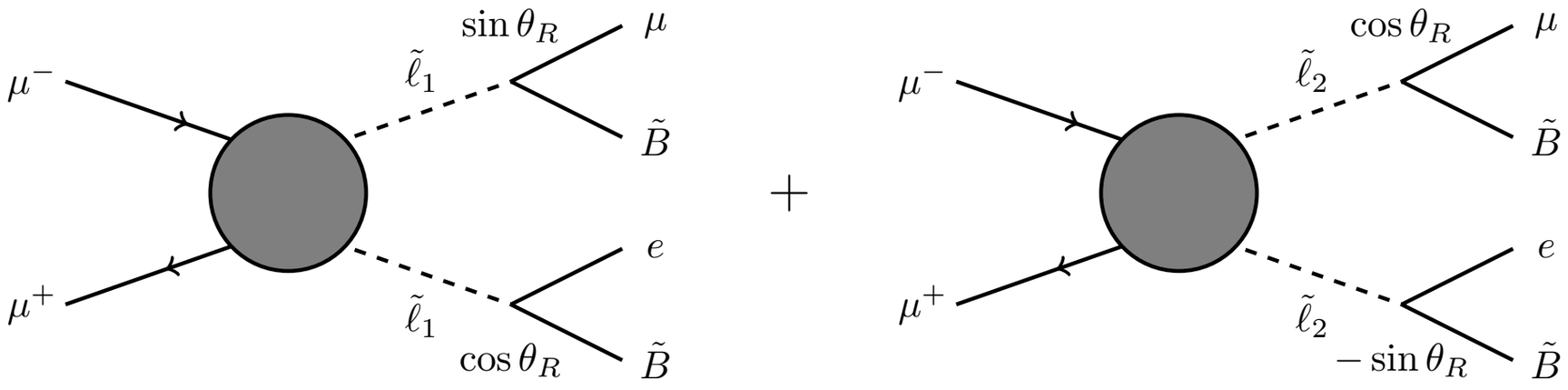
Subtitle



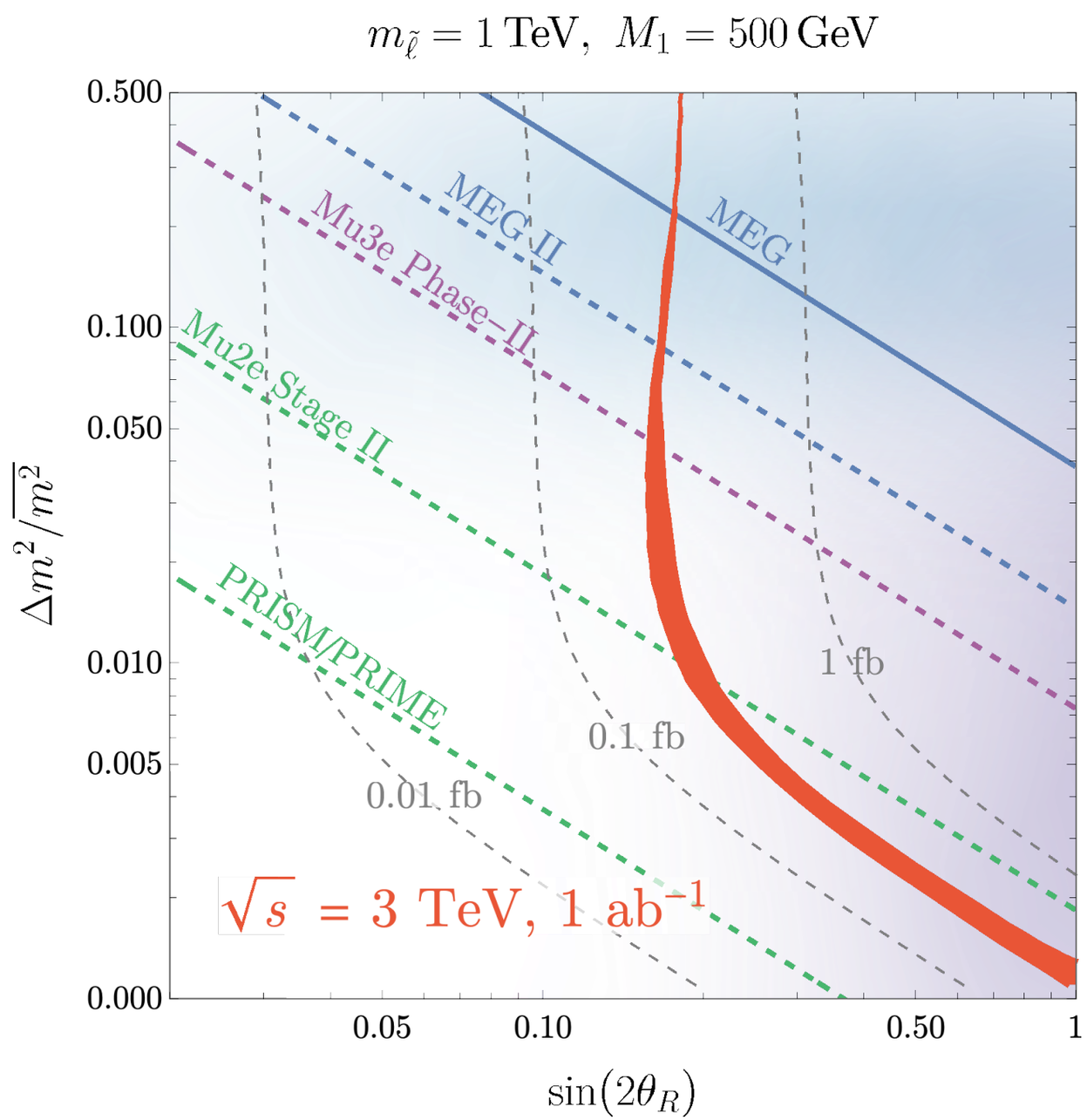


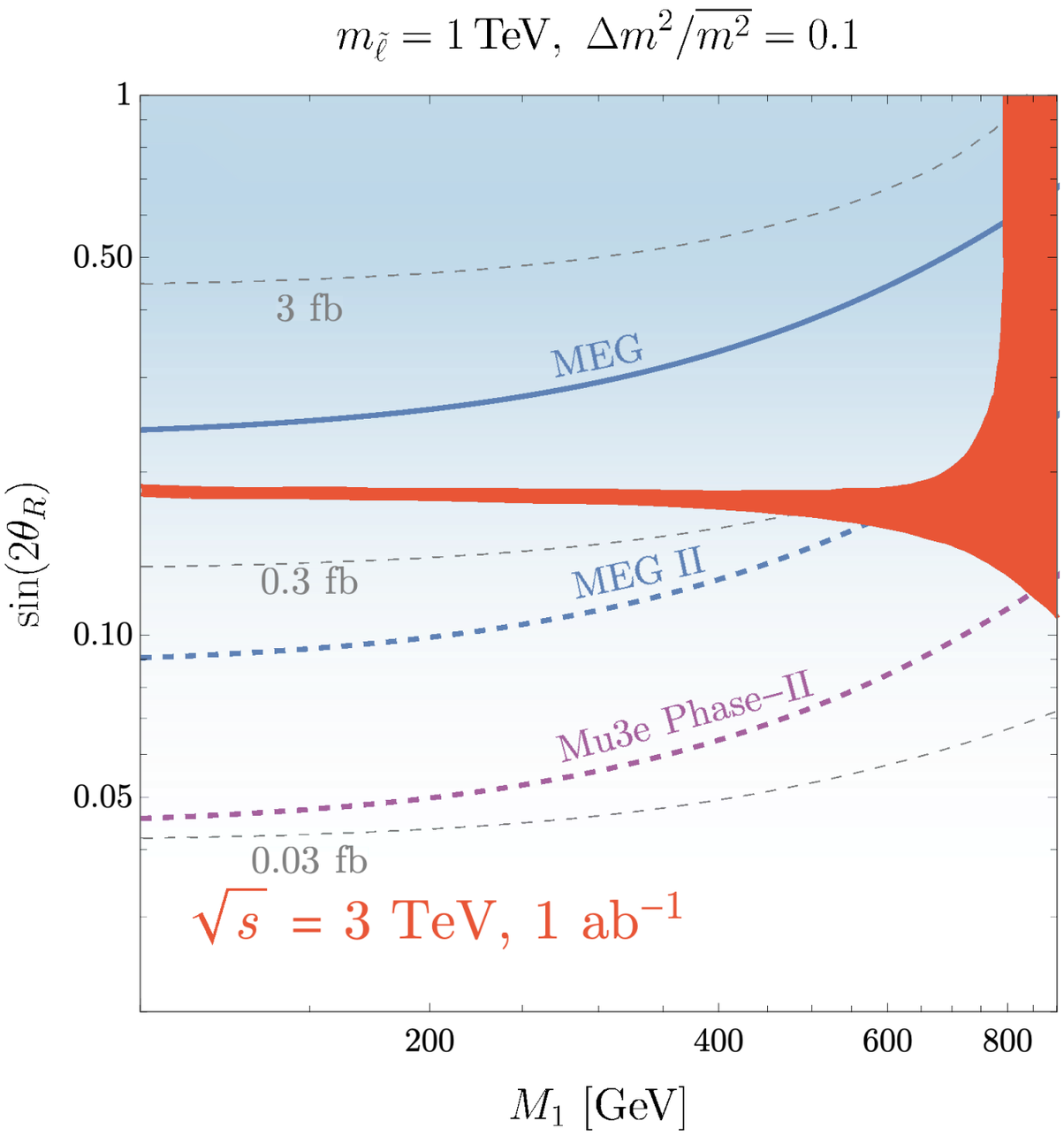
Interference is Important!

Subtitle

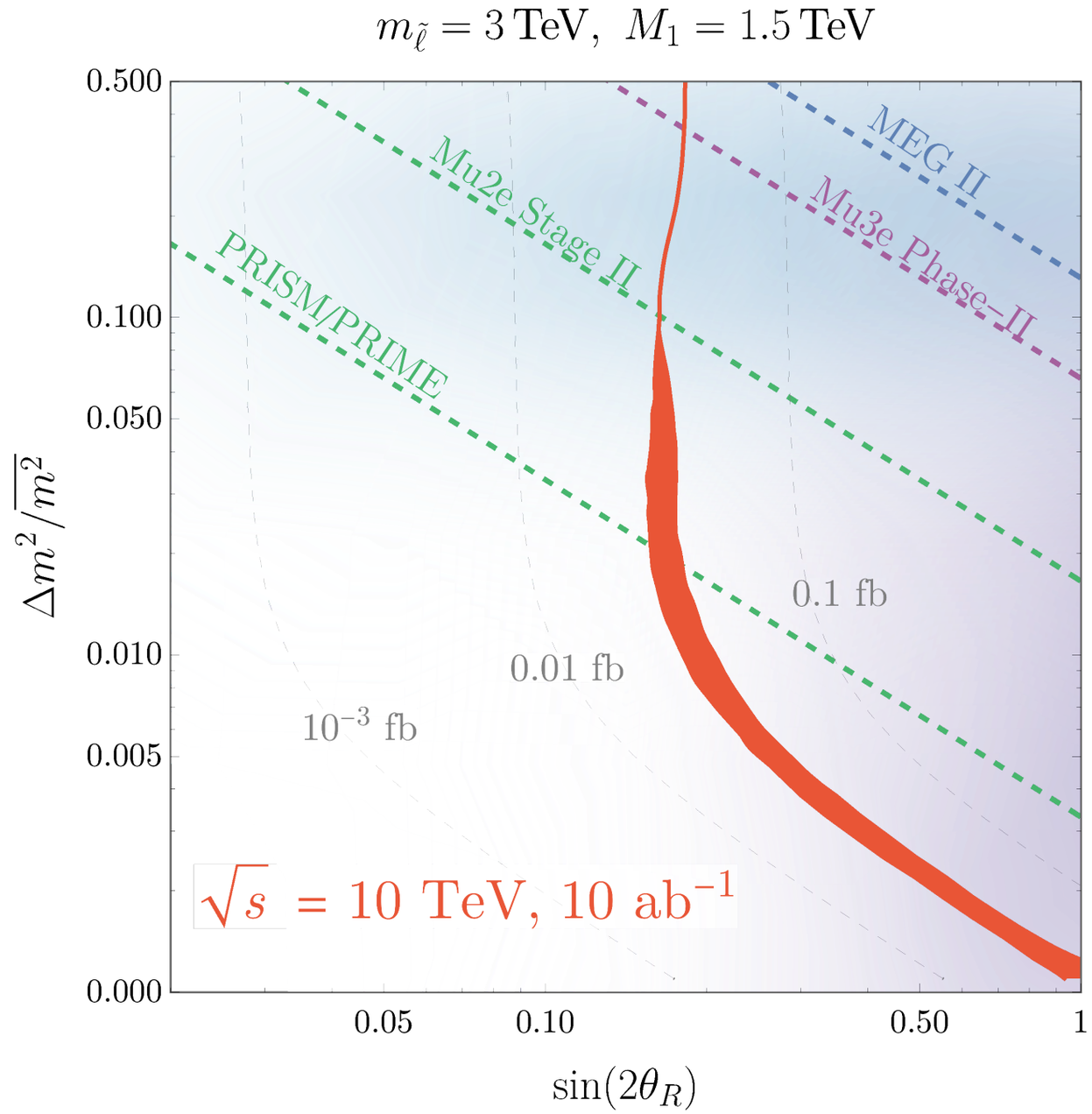


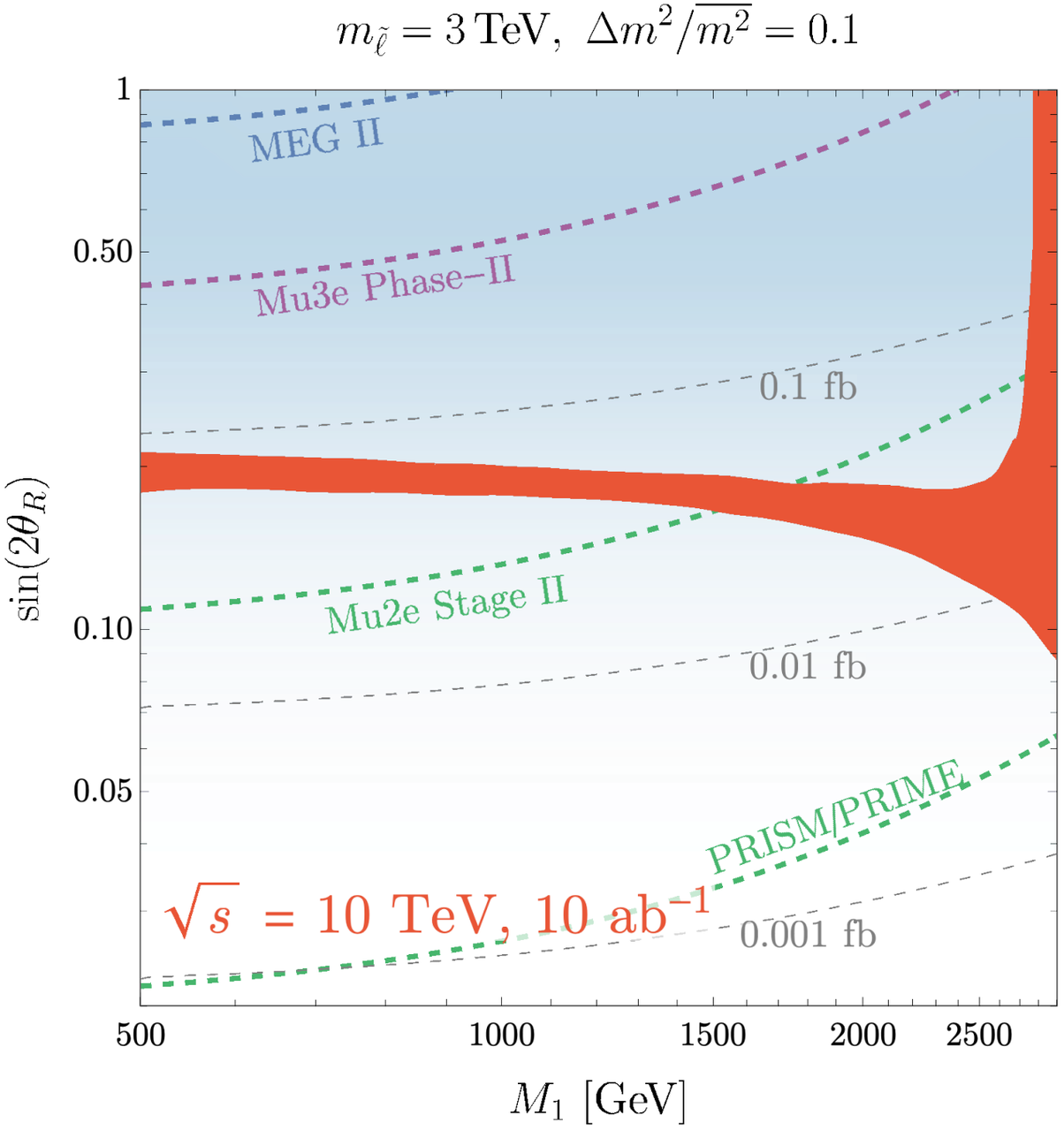
Discovery Reach for LFV Signals



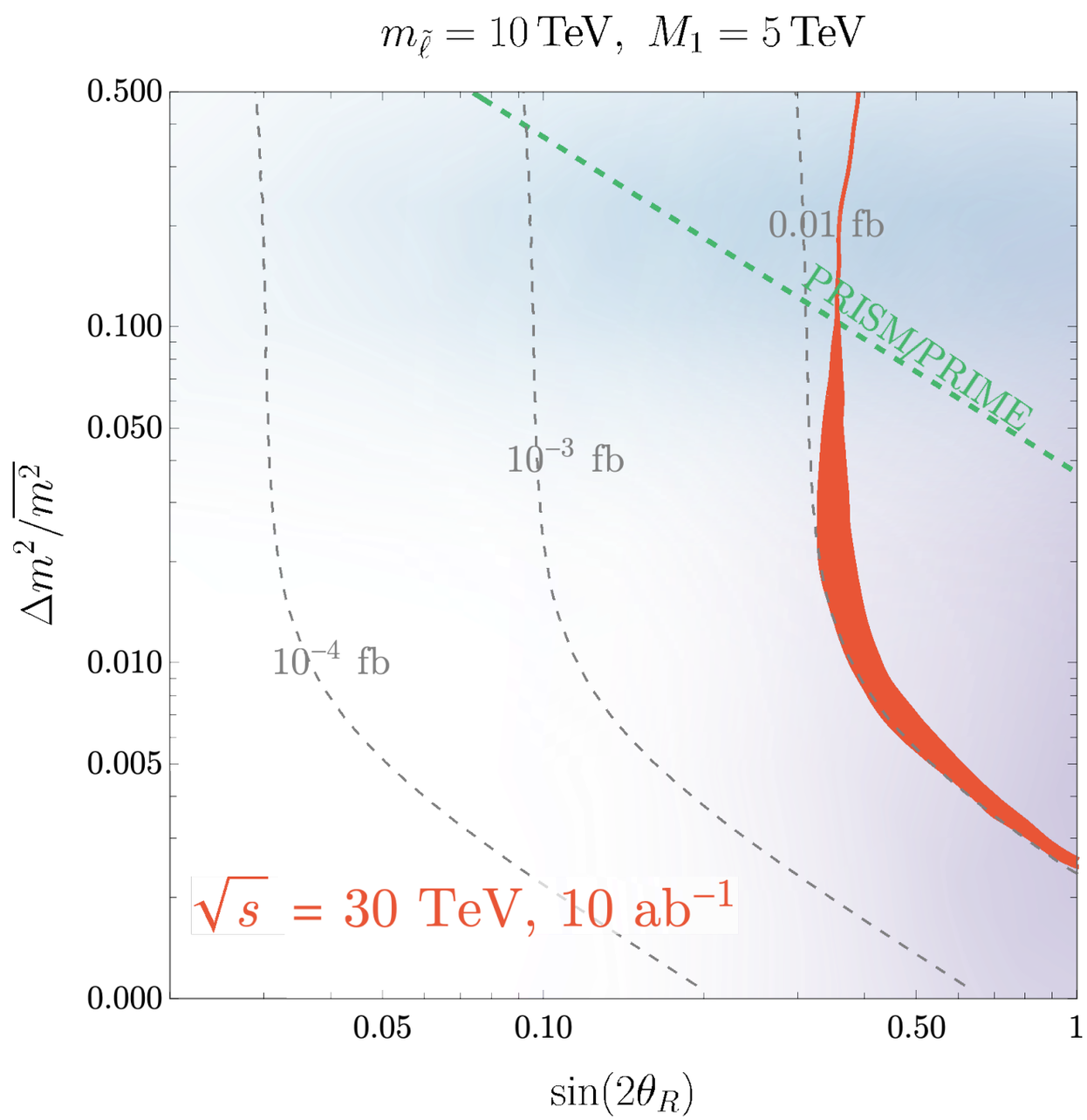


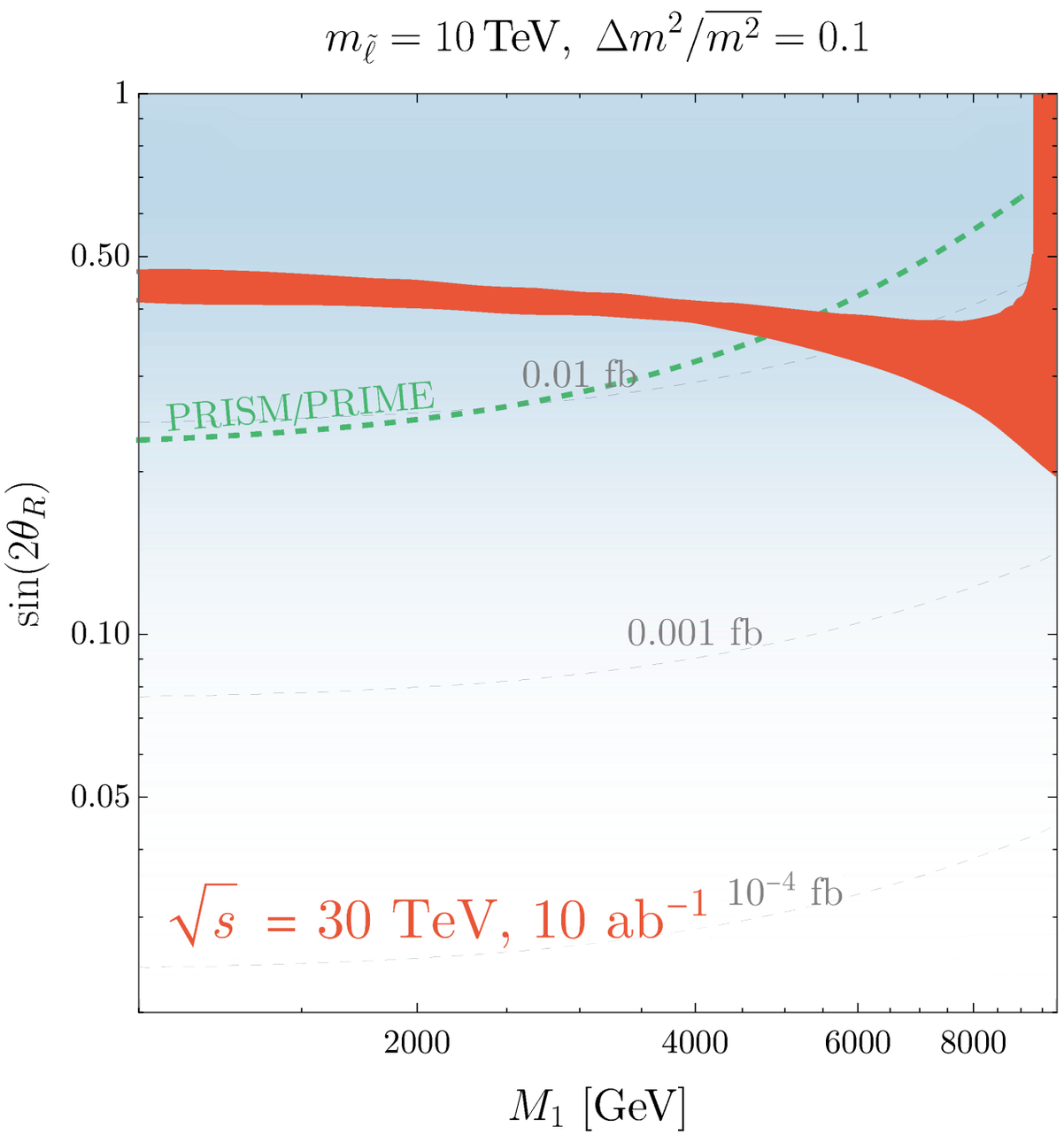
Discovery Reach for LFV Signals





Discovery Reach for LFV Signals





Beyond the Minimal Scenario

Subtitle

Complementarity with eEDM: MFV

Subtitle

Complementarity with eEDM: $\tilde{\tau}$ Mixing

Subtitle

Summary