Probing R-Symmetric SUSY Lepton Flavor @Project X

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Outline

- *The SUSY lepton flavor problem*
- *The Minimal R-Symmetric Supersymmetric Model (MRSSM)* Phys.Rev.D78:055010,2008 Graham D. Kribs, Erich Poppitz, Neal Weiner
- *μ to e flavor constrains on the MRSSM* Phys.Rev.D82:035010,2010 Ricky Fok, Graham D. Kribs
- *Improving the current constrains at Project X*

The SUSY Lepton Flavor Problem

SUSY lepton flavor problem

In the MSSM

$$\begin{array}{c} \begin{array}{cccccc} \mathbf{m^2} & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 \\ m_{ij}^2 & \mathbf{m^2} & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 \\ m_{ij}^2 & m_{ij}^2 & \mathbf{m^2} & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 \\ m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & \mathbf{m^2} & m_{ij}^2 & m_{ij}^2 \\ m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & \mathbf{m^2} & m_{ij}^2 \\ m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & m_{ij}^2 & \mathbf{m^2} \end{array} \\ \begin{array}{cc} \mathrm{L} & \mathrm{R} \end{array} \end{array} \begin{array}{c} \\ \mathrm{L} \\ \\ \\ \mathrm{R} \\ \\ \end{array}$$

The m_{ij}^2 are tightly constrained!

Nucl.Phys.B783:112-142,2007
M. Ciuchini, A. Masiero, P. Paradisi, L. Silvestrini, S.K. Vempati, O. Vives

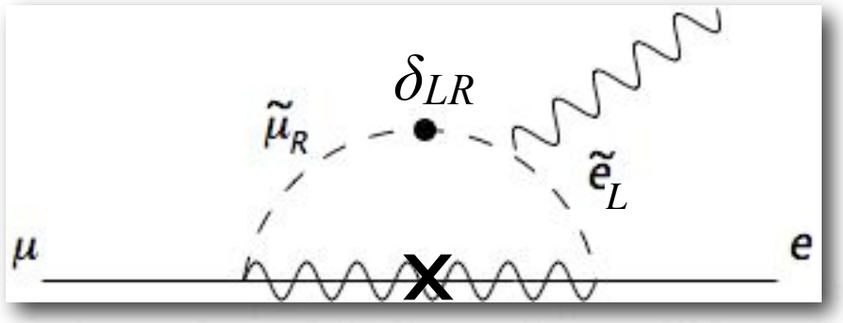
$$\delta_{ij} \equiv \frac{m_{ij}^2}{m^2} < 10^{-3} \text{ in mSUGRA}$$

WHY?? This is the SUSY lepton flavor problem

SUSY lepton flavor problem

In the MSSM, the most constraining process is

$\mu \rightarrow e\gamma$



$$\delta_{LR} \equiv \frac{m_{LR}^2}{m^2}$$

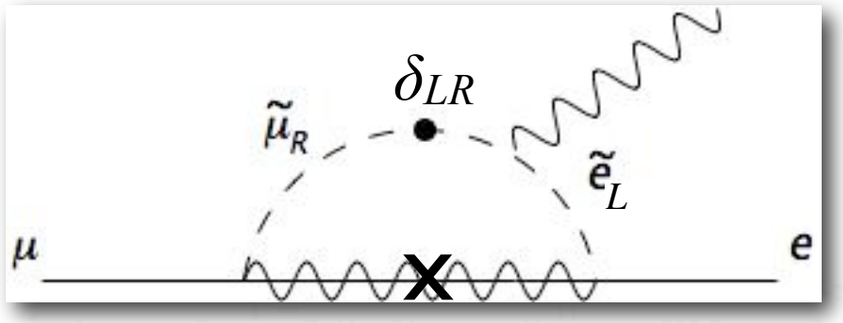
$\delta_{LR} < 3 \times 10^{-5}$, *mSUGRA*

It contains a left-right mixing of the sleptons and a chirality flip of the Gaugino/Higgsino

SUSY lepton flavor problem

In the MSSM, the most constraining process is

$\mu \rightarrow e\gamma$



$\delta_{LR} < 3 \times 10^{-5}$, *mSUGRA*

As we shall see, this is diagram NOT allowed in the MRSSM

Current limits on m_{ij}^2 *is much more relaxed, potentially solving the lepton flavor problem*

Project X will be able to determine whether the MRSSM is a solution

The Minimal R-Symmetric Supersymmetric Model (MRSSM)

Phys.Rev.D78:055010,2008
Graham D. Kribs, Erich Poppitz, Neal Weiner

Extending R-parity

Start with the MSSM with a Z_2 R-parity

SM fields	*R Parity*
Leptons (L,R)	Even
Gauge Bosons	Even
Higgs scalar	Even

SUSY fields	*R Parity*
Sleptons (L,R)	(Odd, Odd)
Gauginos	Odd
Higgsinos	Odd

Now Extend the R-parity to a U(1) continuous symmetry

i.e. conserved R-charges for each field

Extending R-parity

The MSSM with a U(1) R-Symmetry

SM fields	*R Charge*
Leptons (L,R)	0
Gauge Bosons	0
Higgs scalar	0

SUSY fields	*R Charge*
Sleptons (L,R)	(-1, 1)
Gauginos	1
Higgsinos	-1

Extending R-parity

The MSSM with a U(1) R-Symmetry

SM fields	*R Charge*
Leptons (L,R)	0
Gauge Bosons	0
Higgs scalar	0

SUSY fields	*R Charge*
Sleptons (L,R)	(-1, 1)
Gauginos	1
Higgsinos	-1

Consequences

a) Gaugino / Higgsino majorana masses terms violates R charge by 2.

Solution: Make gauginos and higgsinos Dirac.

b) Left-right slepton mixing also violates R charge by 2.

Gaugino and Higgsino masses

Introduce R-partners of Gauginos and Higgsinos

MRSSM fields	*R Charge*
R-Gauginos	-1
R-Higgsinos	1

SUSY fields	*R Charge*
Sleptons (L,R)	(-1, 1)
Gauginos	1
Higgsinos	-1

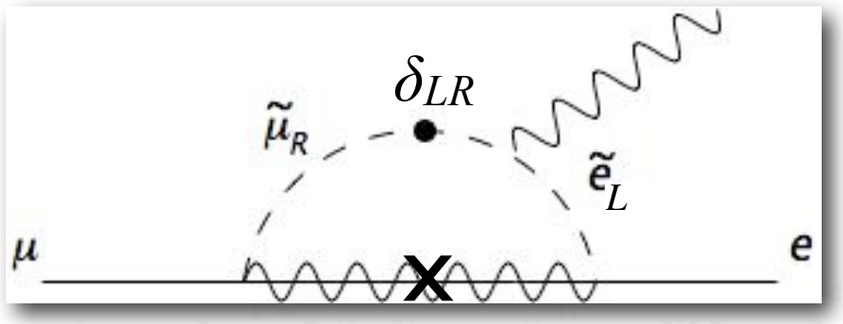
This allows for Dirac masses of inos.

The R-gaugino and gauginos are the right and left chiralities of the Dirac Gauginos

These new fields are not important in LFV processes and will not be considered further.

LFV in MRSSM

Recall the most constraining diagram in the MSSM is



This diagram vanishes in the MRSSM, two reasons:

a) no L-R mixing, $\delta_{LR} = 0$.

b) The chirality flip on the ino line flips the ino to its R-partner, which does not couple to leptons.

Question: What are the constrains on the slepton mixing in the MRSSM?? What is the dominant process?

μ to e flavor mixing constrains on the MRSSM

Phys.Rev.D82:035010,2010
Ricky Fok, Graham D. Kribs

The Sensitive Parameters

Bino mass M_1

H_d mass μ_d

Slepton masses m_1 m_2 $(m_2 = 1.5\, m_1)$

$\tilde{\mu}\tilde{e}$ mixing $\sin 2\theta_L$ $\sin 2\theta_R$

LR mixing forbidden in MRSSM

$$
\begin{array}{c}
\begin{pmatrix}
m^2 & m_{ij}^2 & 0 & 0 & 0 & 0 \\
m_{ij}^2 & m^2 & 0 & 0 & 0 & 0 \\
0 & 0 & m^2 & 0 & 0 & 0 \\
0 & 0 & 0 & m^2 & m_{ij}^2 & 0 \\
0 & 0 & 0 & m_{ij}^2 & m^2 & 0 \\
0 & 0 & 0 & 0 & 0 & m^2
\end{pmatrix}
\begin{array}{c} L \\ \\ \\ R \\ \\ \\ \end{array} \\
\begin{array}{cc} L & \qquad R \end{array}
\end{array}
$$

Analysis

We computed branching ratios of the following processes

$\mu \to e\gamma$ $\mu \to e$ conversion in gold $\mu \to eee$

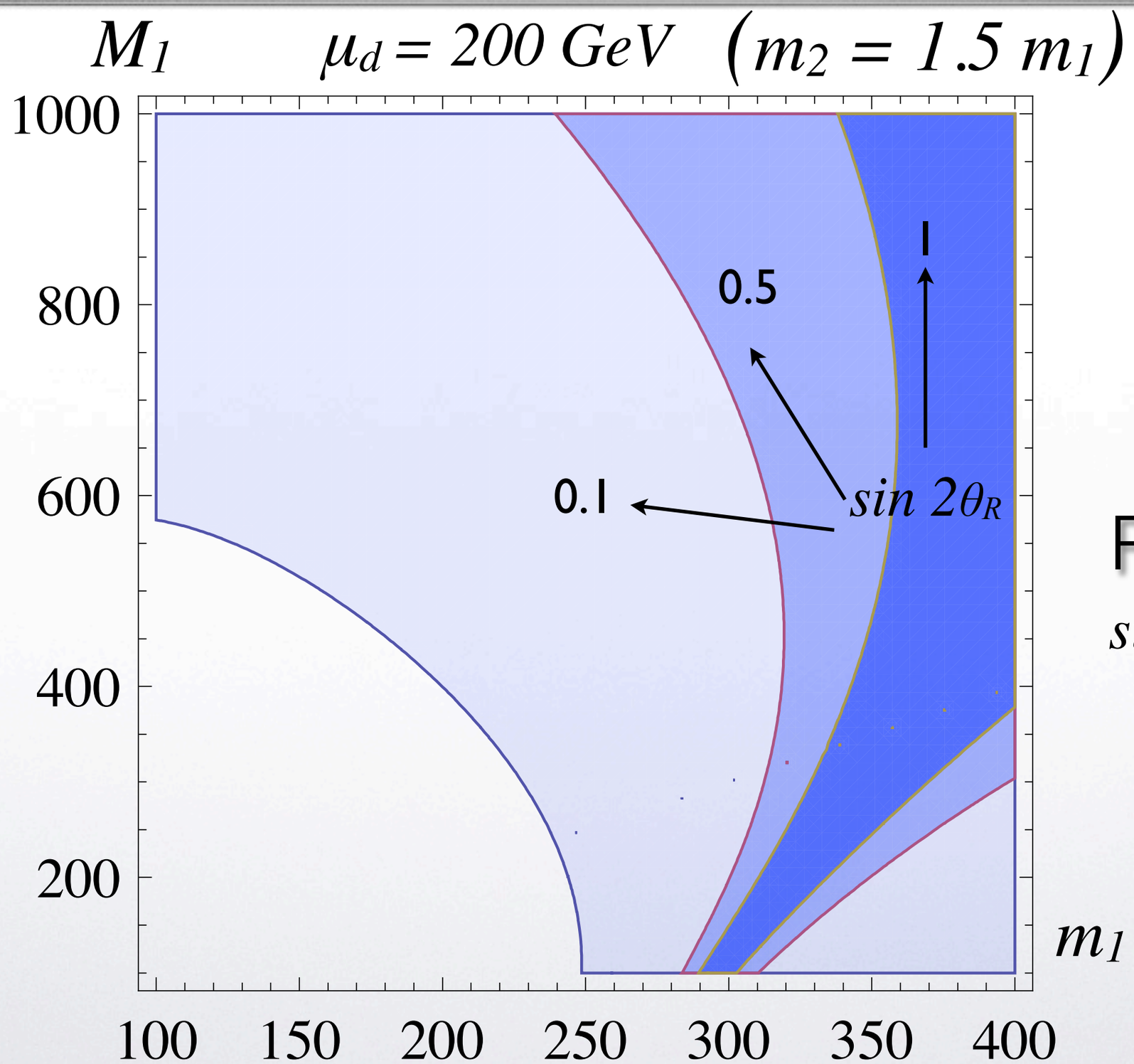
With only either one of θ_L or θ_R to be non-zero

Set $\tan\beta = 3$, and set the heavier slepton mass to be $m_2 = 1.5 m_1$

Then we set limits on the parameter space $(m_B, \mu_d, m_1, \sin 2\theta_{L,R})$ with current experimental bounds

$\mu \to e\gamma$

BR < 2.4 x 10^{-12}, MEG



RH

$\sin 2\theta_L = 0$

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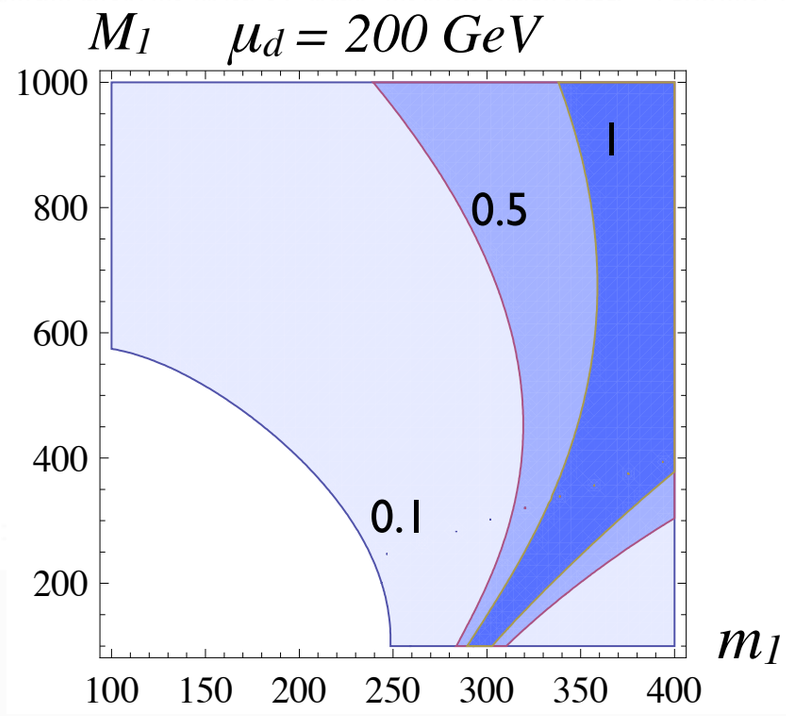
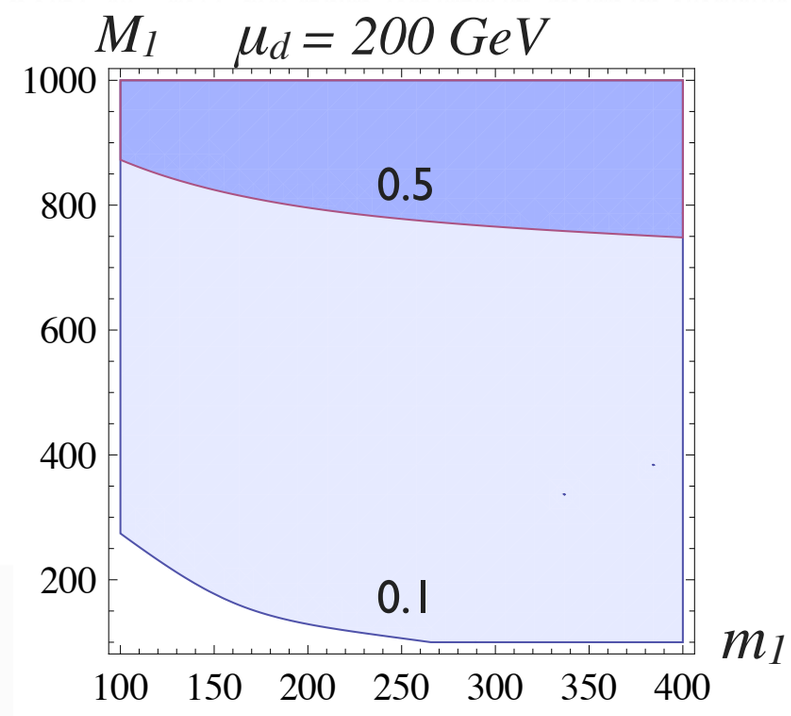
Right-handed mixing $\sin 2\theta_L = 0$

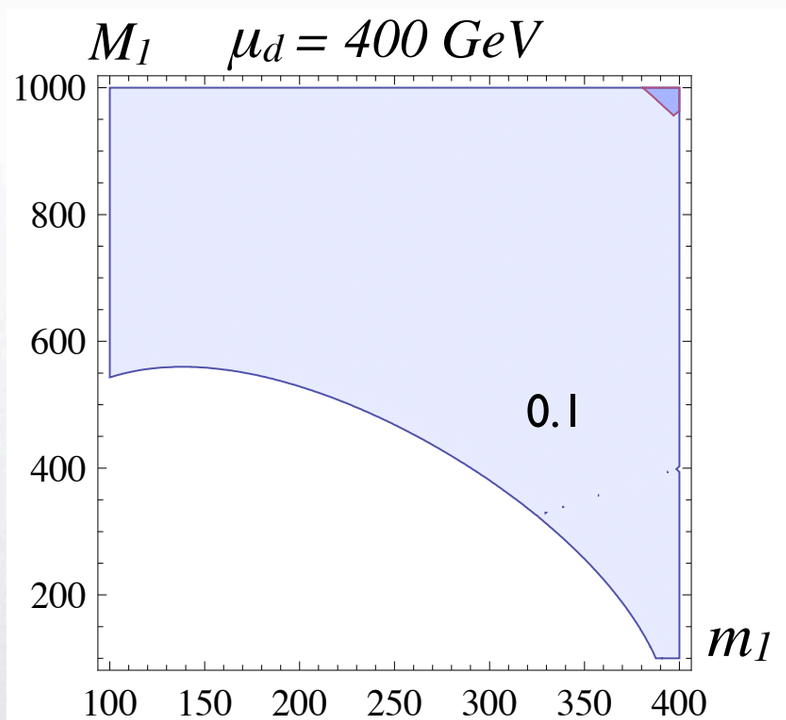
$\mu \to e\gamma$

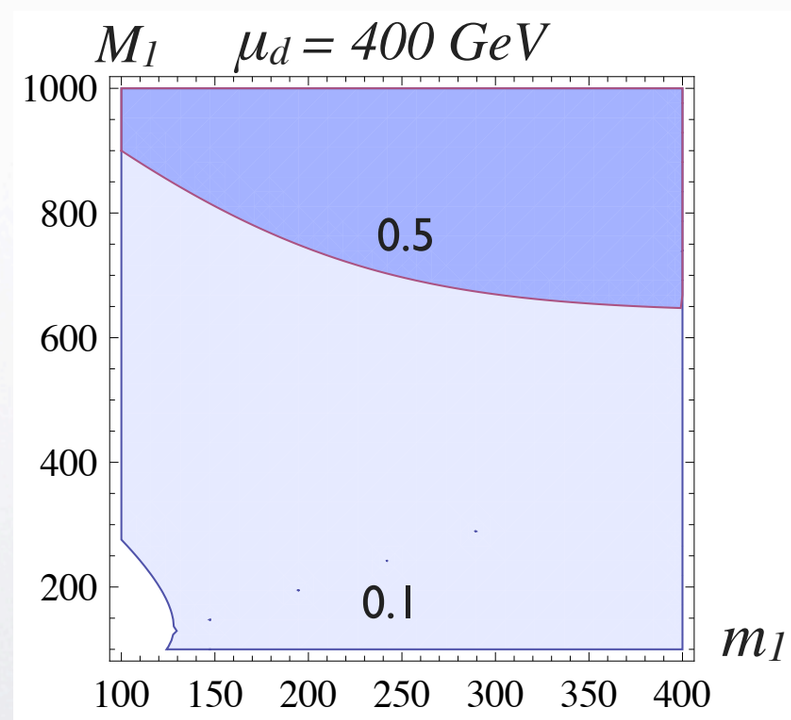




$(\mu \to e)_{\mathrm{Au}}$

$\mu \to e\gamma$





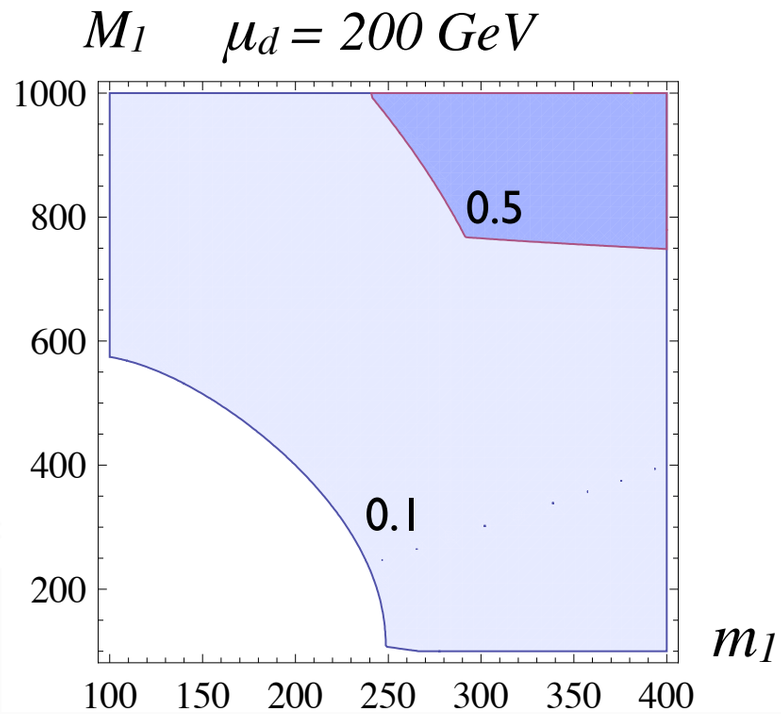
$(\mu \to e)_{\mathrm{Au}}$

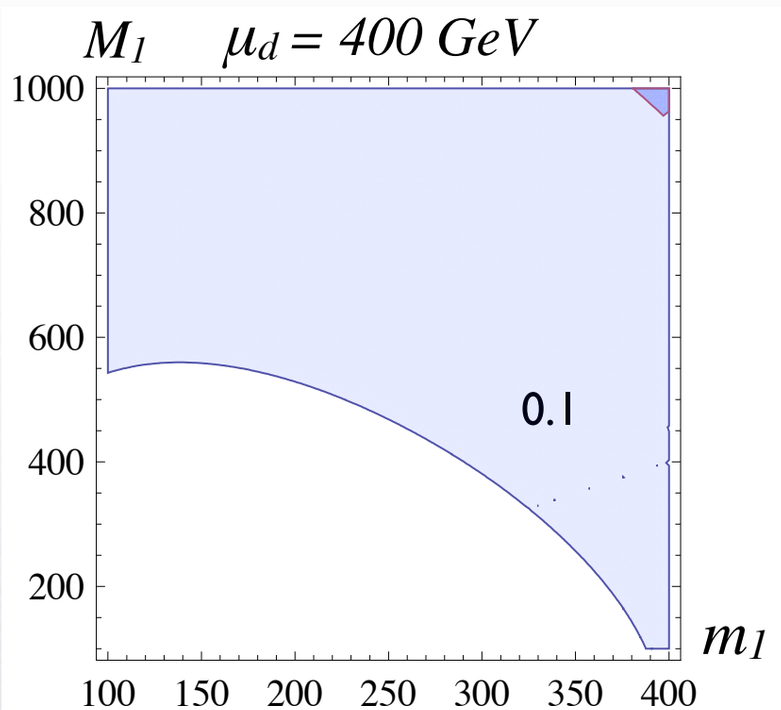
Fok, Kribs

BR < 2.4×10^{-12}, MEG

BR < 7.0×10^{-13} SINDRUM II

Combined Right handed mixing





O(0.1) mixing allowed

$\mu \to eee$ *gives looser bounds*

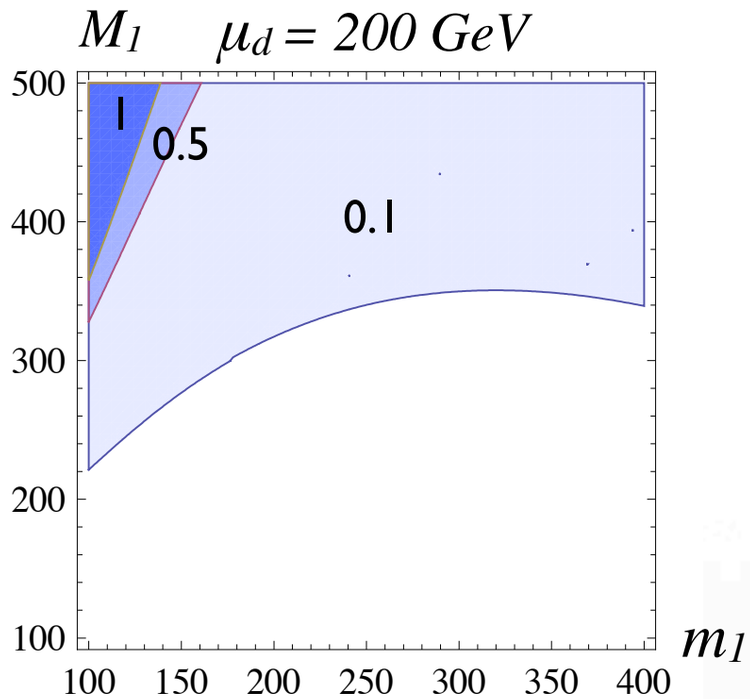
$\mu \to e\gamma$ *gives slightly better bounds*

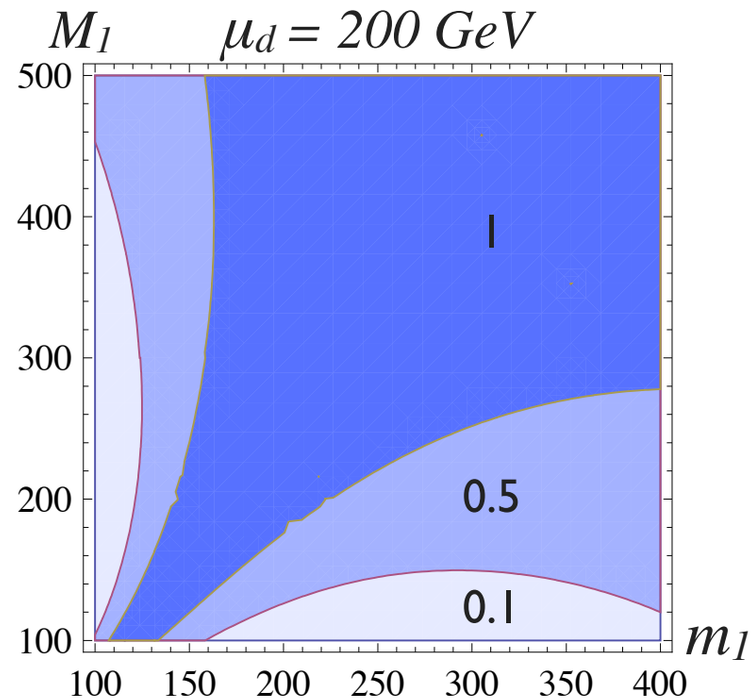
Fok, Kribs

Left-handed mixing

$\sin 2\theta_R = 0$

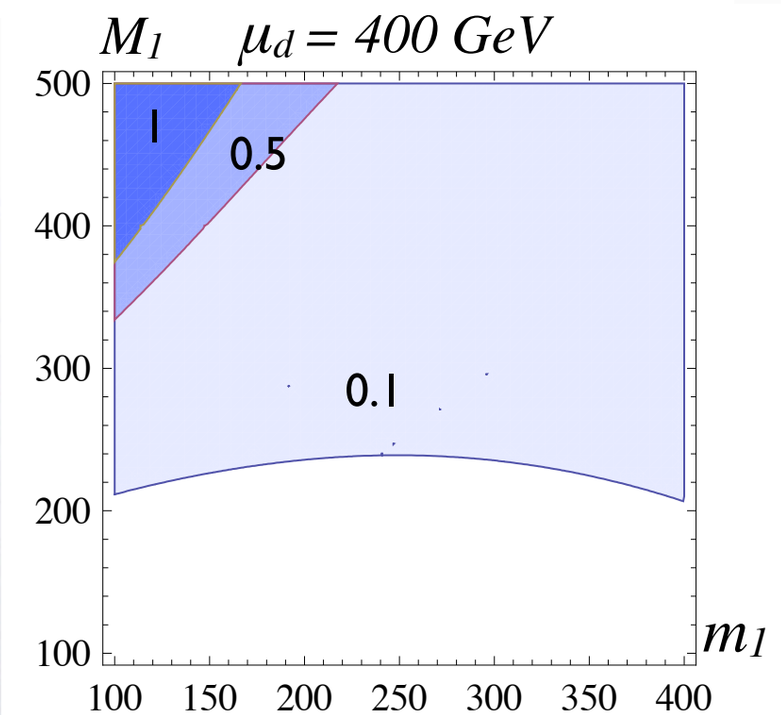
$\mu \to e\gamma$

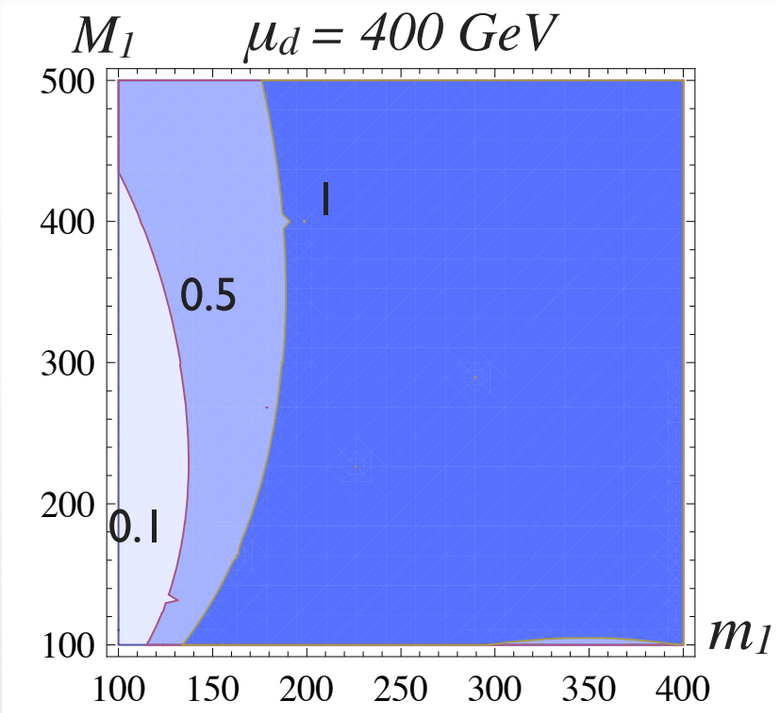




$(\mu \to e)_{\mathrm{Au}}$

$\mu \to e\gamma$





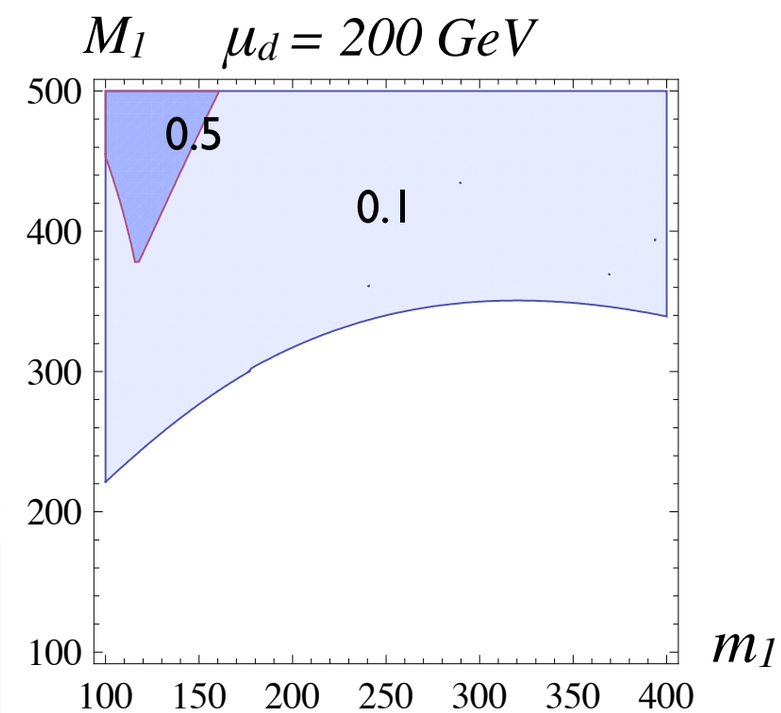
$(\mu \to e)_{\mathrm{Au}}$

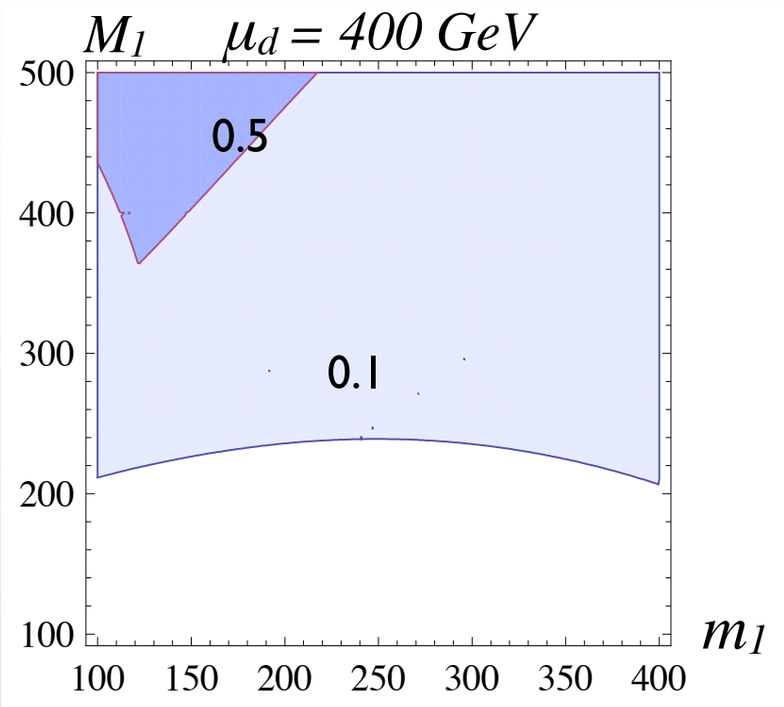
Fok, Kribs

BR < 2.4 x 10^{-12}, MEG

BR < 7.0 x 10^{-13} SINDRUM II

Combined Left handed mixing





O(0.1) mixing allowed

$\mu \to eee$ *gives looser bounds*

$\mu \to e\gamma$ *gives slightly better bounds*

Fok, Kribs

What does the plots mean?

$\mu \to e$ conversion from right handed mixing is coherent, can be used to constrain $sin2\theta_R$

Current bounds allow $sin2\theta_{L,R}$ of O(0.1) for most masses in the sub-TeV range

This does NOT say anything definite about the MRSSM as a solution for the lepton flavor problem

But Project X can!

Probing MRSSM LFV with Project X

Expected limits

Expected sensitivities at Project X

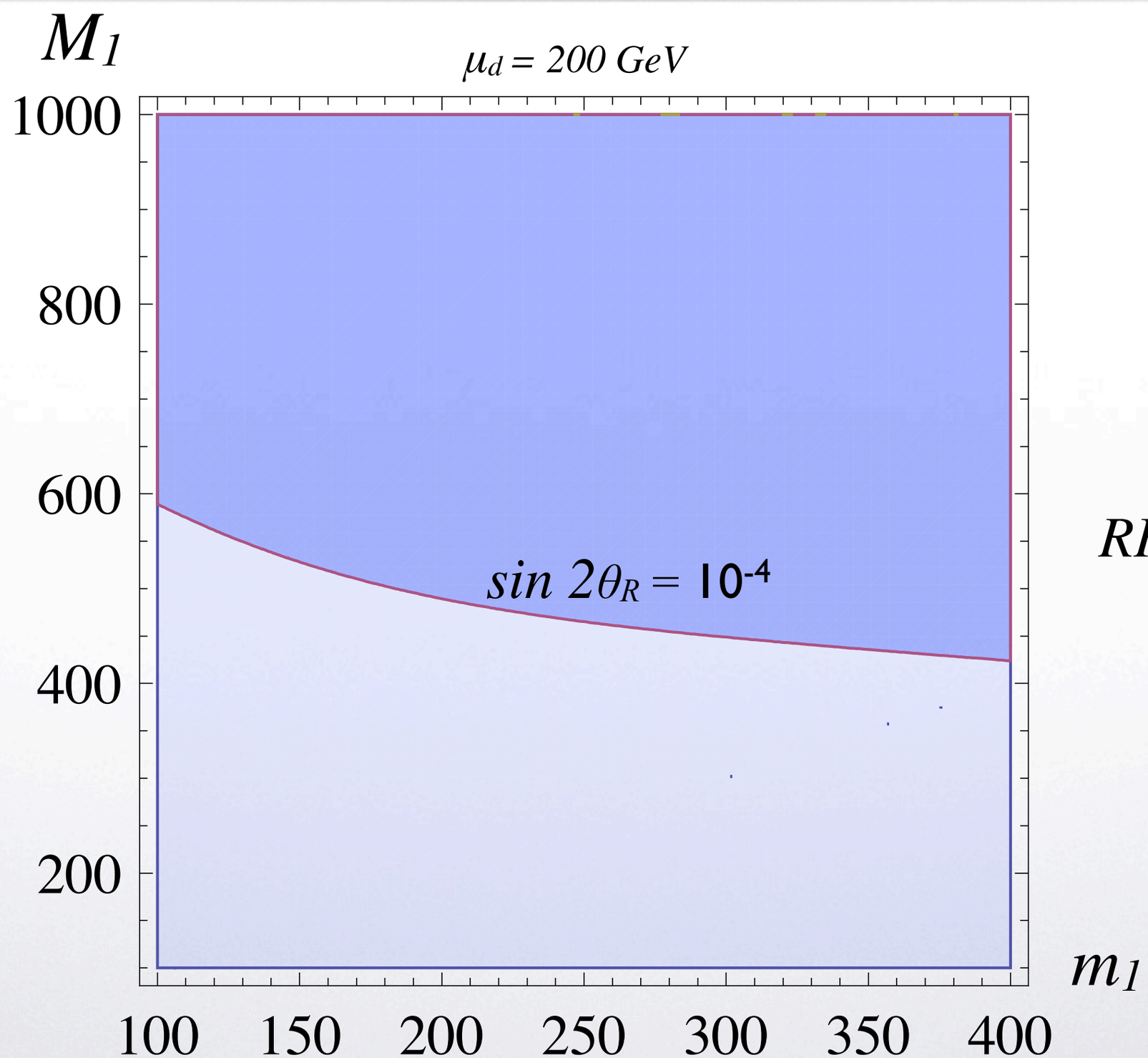
	Improvement in sensitivity	Expected limits on $\sin 2\theta$
$\mu \to e$ conversion	10^6	10^{-3} - 10^{-4}
$\mu \to eee$	10^3 - 10^4	10^{-3}
$\mu \to e\gamma$	???	???

Recall that $\mu \to e$ conversion due to RH slepton mixing is not affected by destructive interference

Checked numerically that $\mu \to eee$ does not change on the expected limits from $\mu \to e$ conversion significantly

Project X and the Science of the Intensity Frontier, white paper, Fermilab, 2010.
http://www.fnal.gov/pub/projectx/pdfs/ProjectXwhitepaperJan.v2.pdf

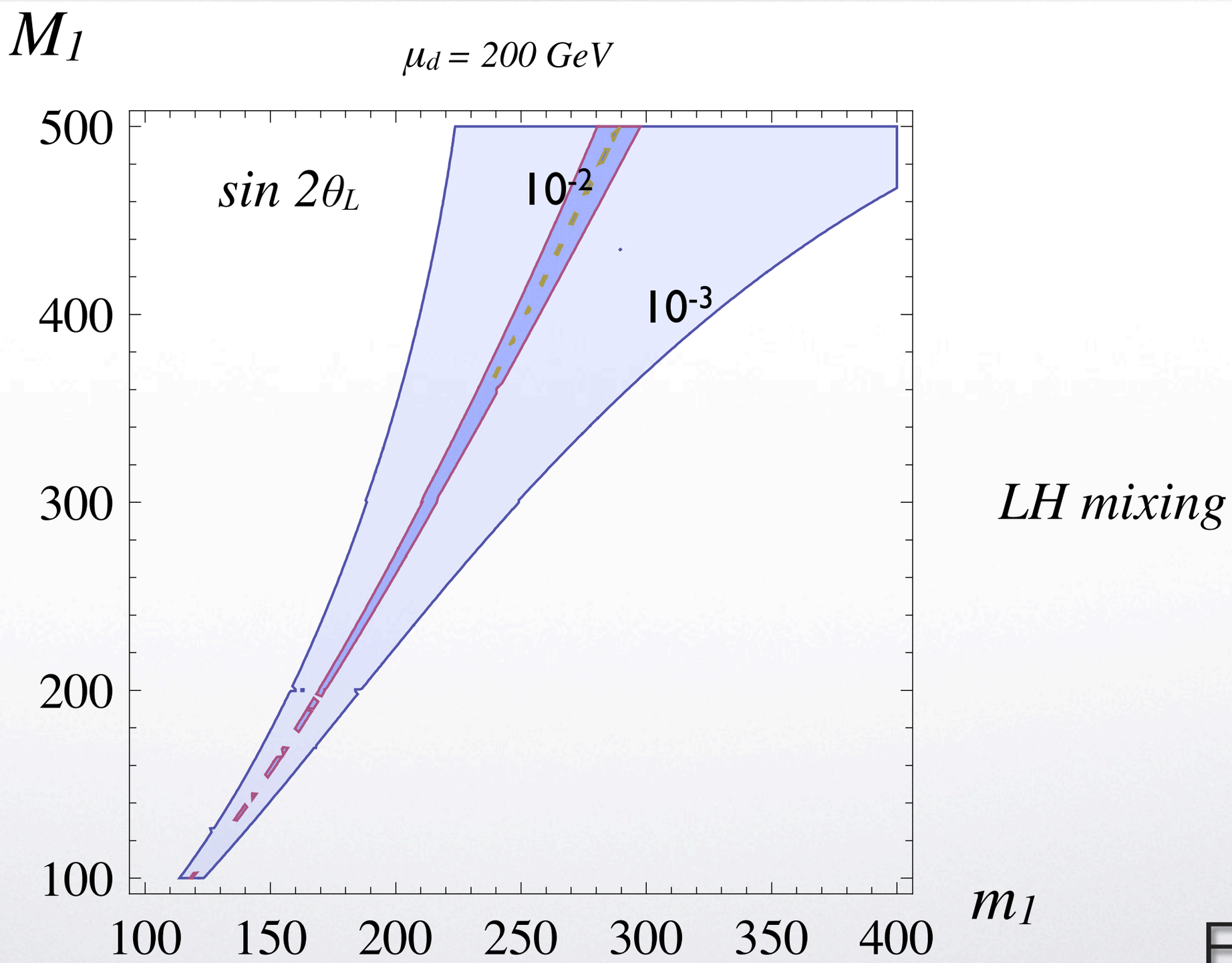
$\mu \rightarrow e$ BR < 10^{-19} Project X expected limit



RH mixing

Fok

$\mu \rightarrow e$ BR < 10^{-19} Project X expected limit



LH mixing

Fok

Expected limits

m^2	m_{ij}^2	0	0	0	0
m_{ij}^2	m^2	0	0	0	0
0	0	m^2	0	0	0
0	0	0	m^2	m_{ij}^2	0
0	0	0	m_{ij}^2	m^2	0
0	0	0	0	0	m^2

L

R

L R

Project X can constrain these elements down to 10^{-4}, assuming O(1) slepton mass splitting

Expected limits

m^2	m_{ij}^2	0	0	0	0
m_{ij}^2	m^2	0	0	0	0
0	0	m^2	0	0	0
0	0	0	m^2	m_{ij}^2	0
0	0	0	m_{ij}^2	m^2	0
0	0	0	0	0	m^2

L

R

L R

Project X can constrain these elements down to 10^{-3}, assuming O(1) slepton mass splitting

If Project X does not find any $\mu \to e$ conversion events, the flavor problem persists and cannot be explained by the MRSSM

Conclusion

Search for rare μ decays @ Project X can improve limits on LFV parameters by orders or magnitude

This is demonstrated in the μ_R-e_R mixing in the MRSSM, where the limit on their mixing angle can be improved by at least 10^3 from the current bound at SUNDRUM II.

Unless the two sleptons are degenerate, or they mostly mix with the stau. Project X can give a definite statement on whether the lepton flavor problem is solved by the MRSSM.

BACK UP

Insensitive Parameters

All parameters related to the stau:

- *stau masses, mixing with selectron and smuon*

Wino mass

- *Must be of O(TeV) to avoid excessive contribution to electroweak precision parametes.*

H_u masses

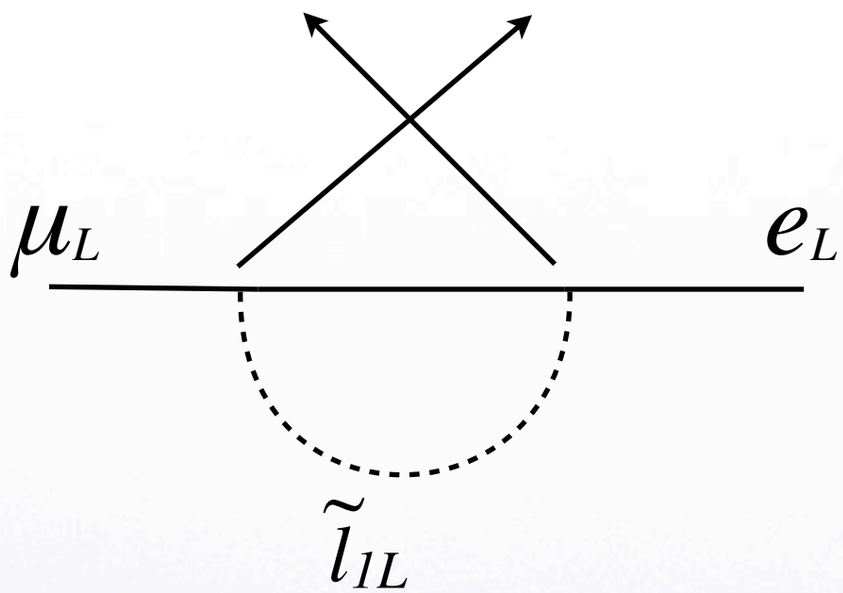
- *Charged leptons do not couple directly to H_u*

$\tan\beta$

- *Cancels between Yukawa and H_d - B mixing*

Mixing angles

$$\tilde{l}_{1L} = \cos\theta_L \, \tilde{e}_L + \sin\theta_L \, \tilde{\mu}_L$$

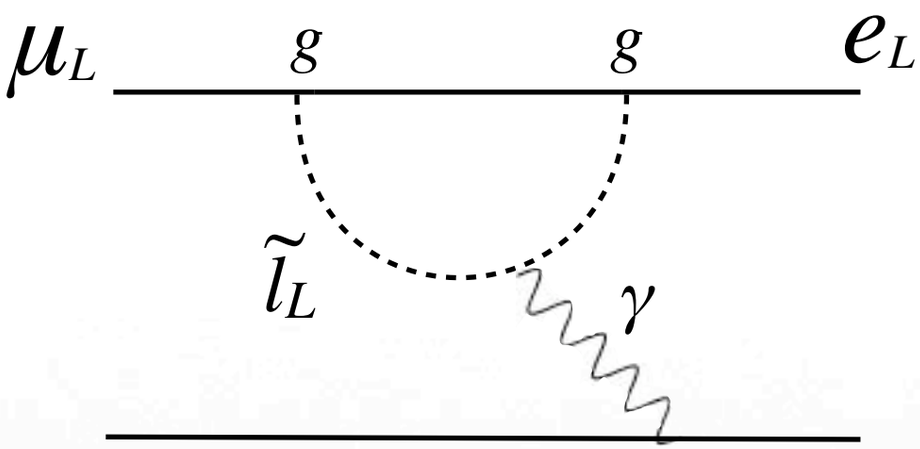


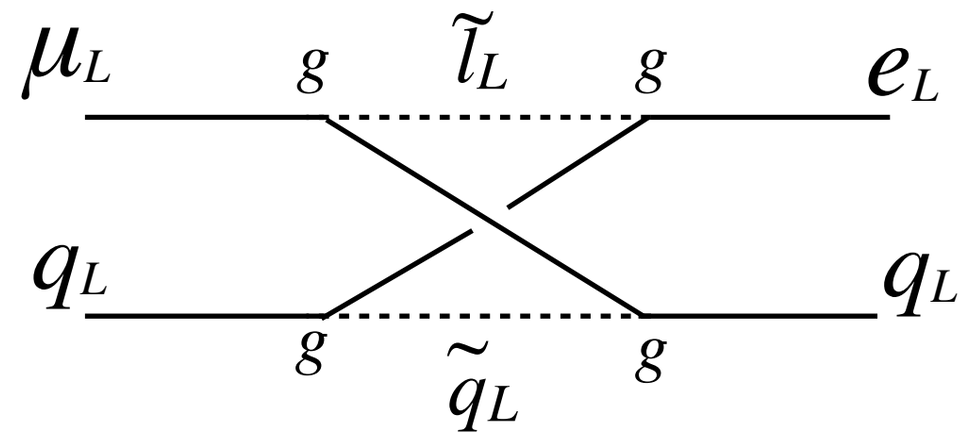
mixing parameter
$0 < \sin 2\theta_L < 1$

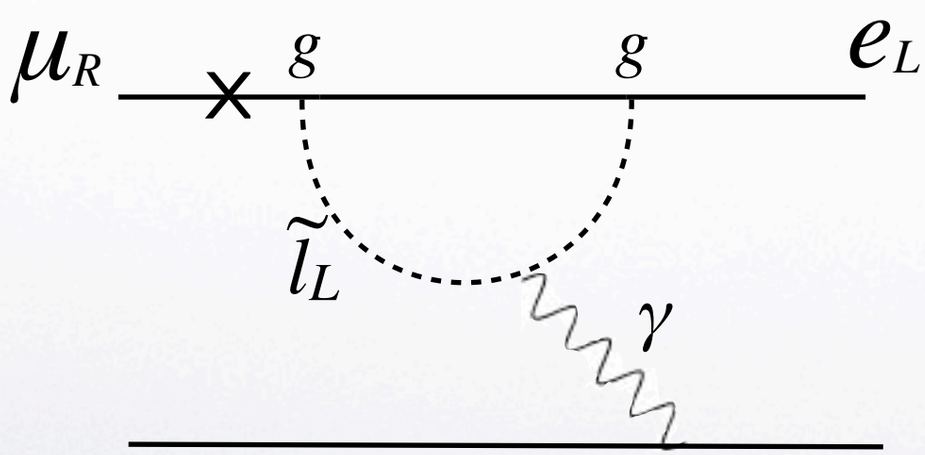
	$\tilde{e}_L$	$\tilde{\mu}_L$	$\tilde{\tau}_L$				
$\tilde{l}_{1L}$	c_L	s_L	0	0	0	0	
$\tilde{l}_{2L}$	$-s_L$	c_L	0	0	0	0	
	0	0	1	0	0	0	
	0	0	0	c_R	s_R	0	$\tilde{l}_{1R}$
	0	0	0	$-s_R$	c_R	0	$\tilde{l}_{2R}$
	0	0	0	0	0	1	
				$\tilde{e}_R$	$\tilde{\mu}_R$	$\tilde{\tau}_R$	

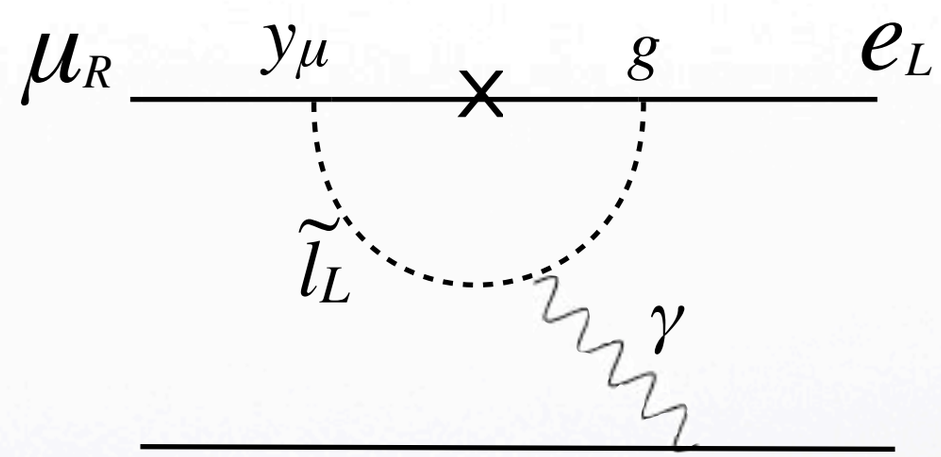
$\mu \rightarrow e$ conversion

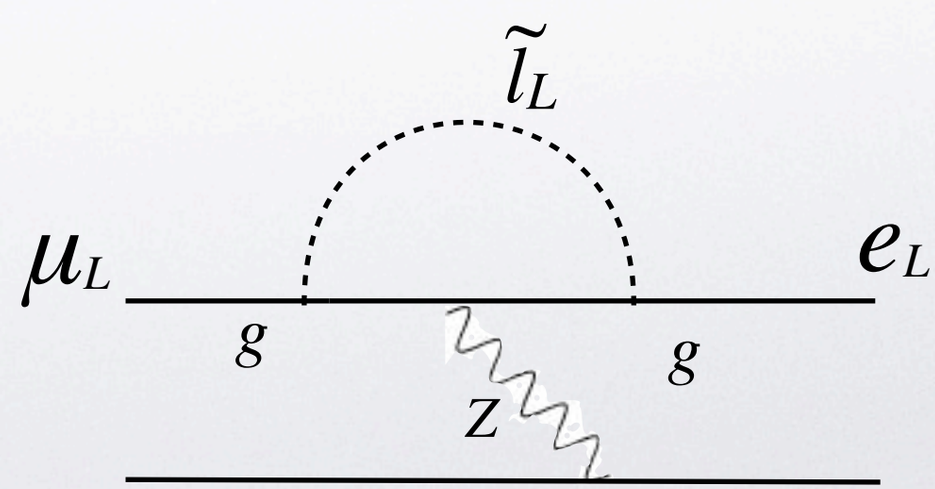
All the relevant diagrams are







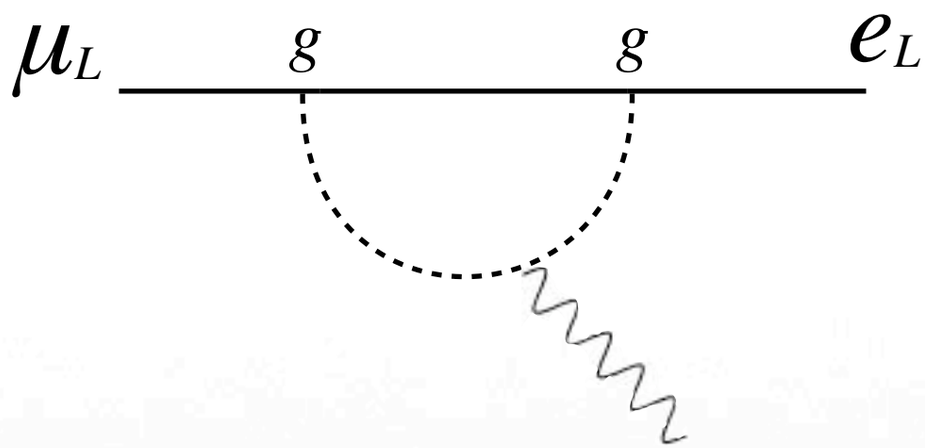


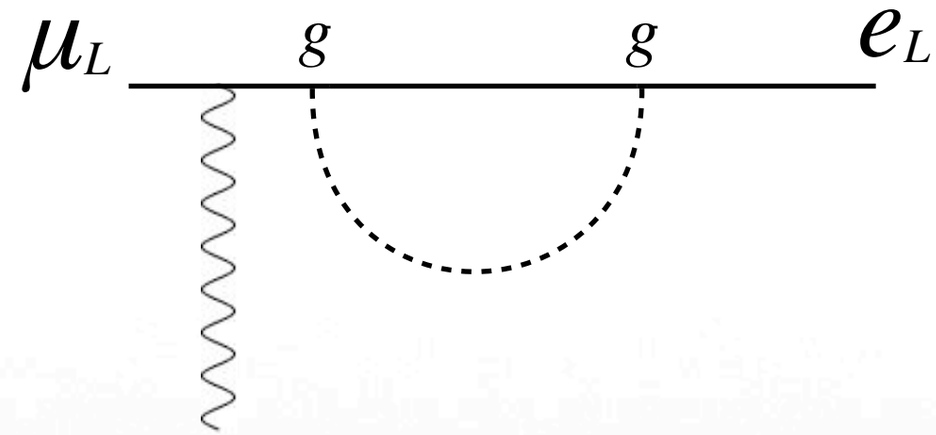


Why are chirality flips relevant?!

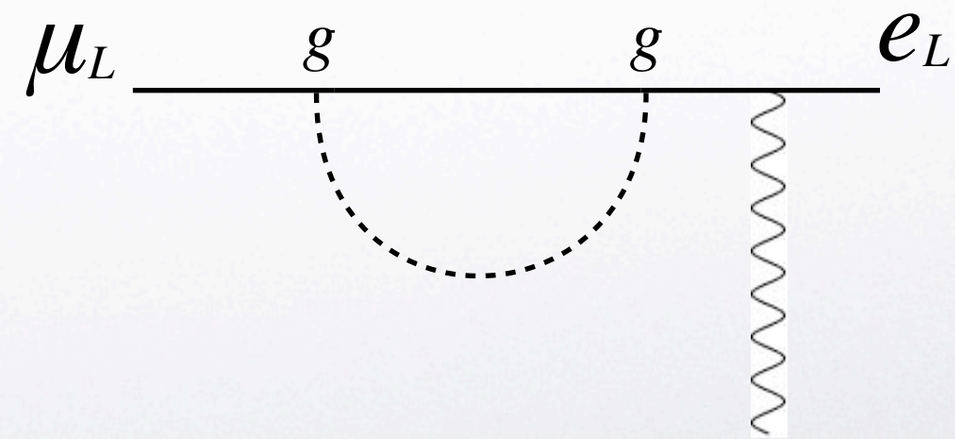
$\mu \rightarrow e$ conversion

γ Penguin





$\delta F_l(k^2) - \delta F_l(0)$, where $k^2 \sim -m_\mu^2$



$= \delta F_l'(0) k^2$

$\sim O(\delta F_l) \dfrac{m_\mu^2}{m_l^2}$, *dim 6!*

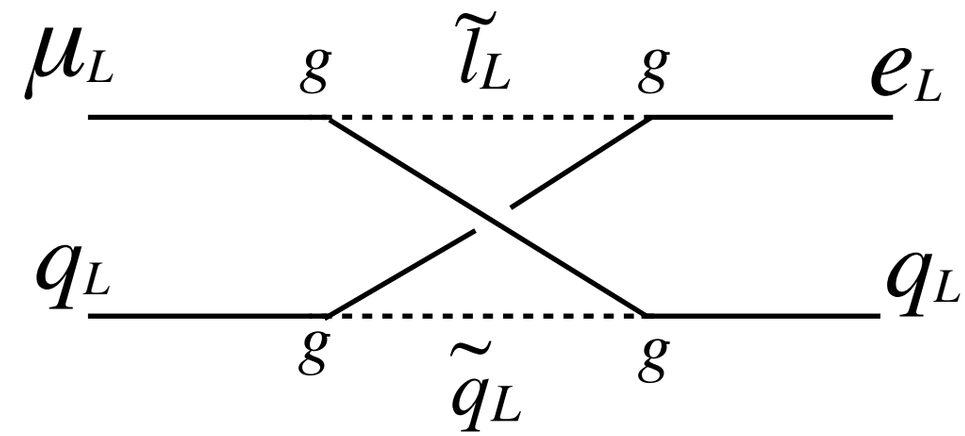
~ Same order as the chirality flipping diagram $m\bar{\psi}\sigma^{\mu\nu}\psi F_{\mu\nu}$

$\mu \rightarrow e$ conversion

Box

No chirality flip

$$\boxed{\overline{\psi}\gamma^{\mu}P_L\psi}$$



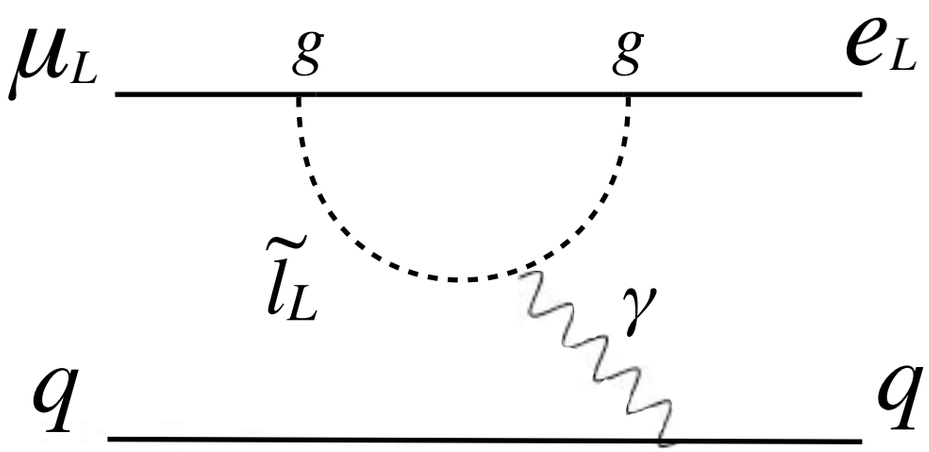
R-symmetry:

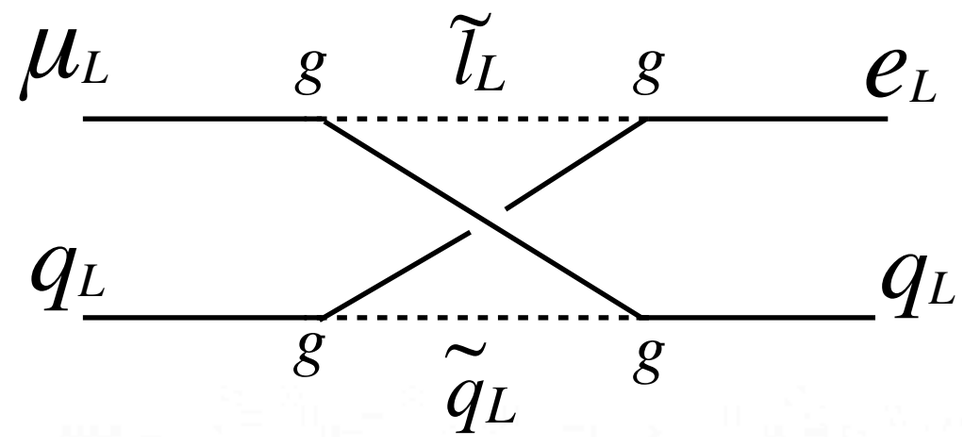
No L-R mixing between sleptons

The quark line must have the same chirality as the muon!!

$$\boxed{(\overline{\psi}\gamma^{\mu}P_L\psi)\,(\bar{q}\gamma_{\mu}P_L q)}$$

$\mu \rightarrow e$ conversion

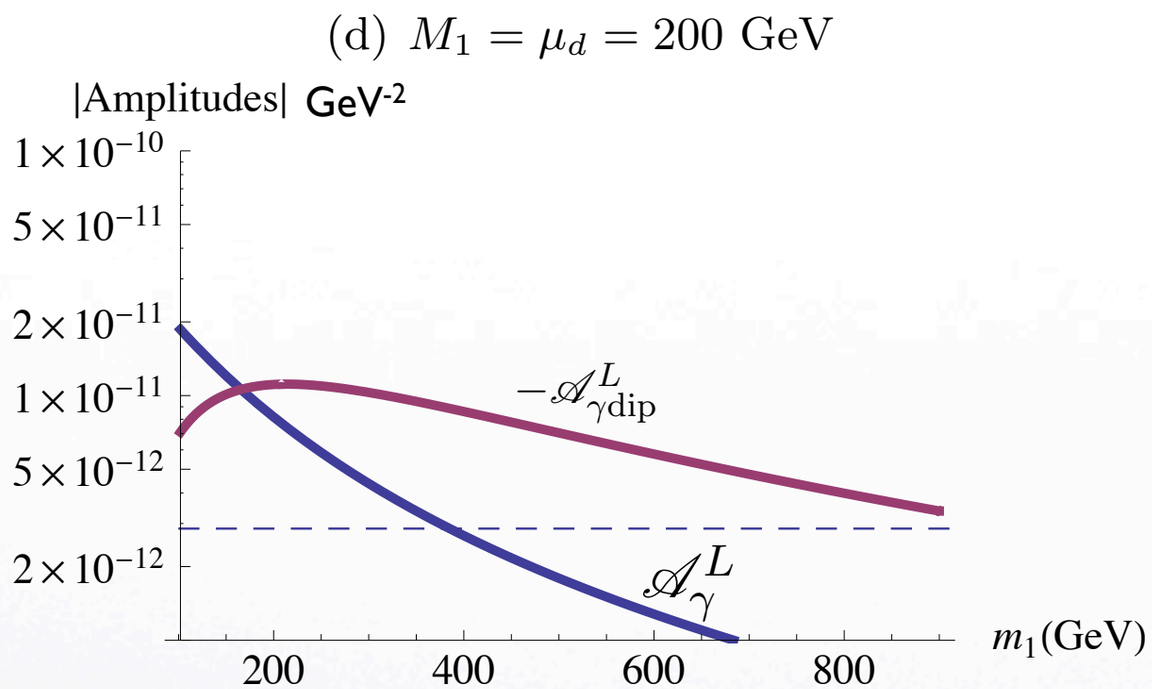




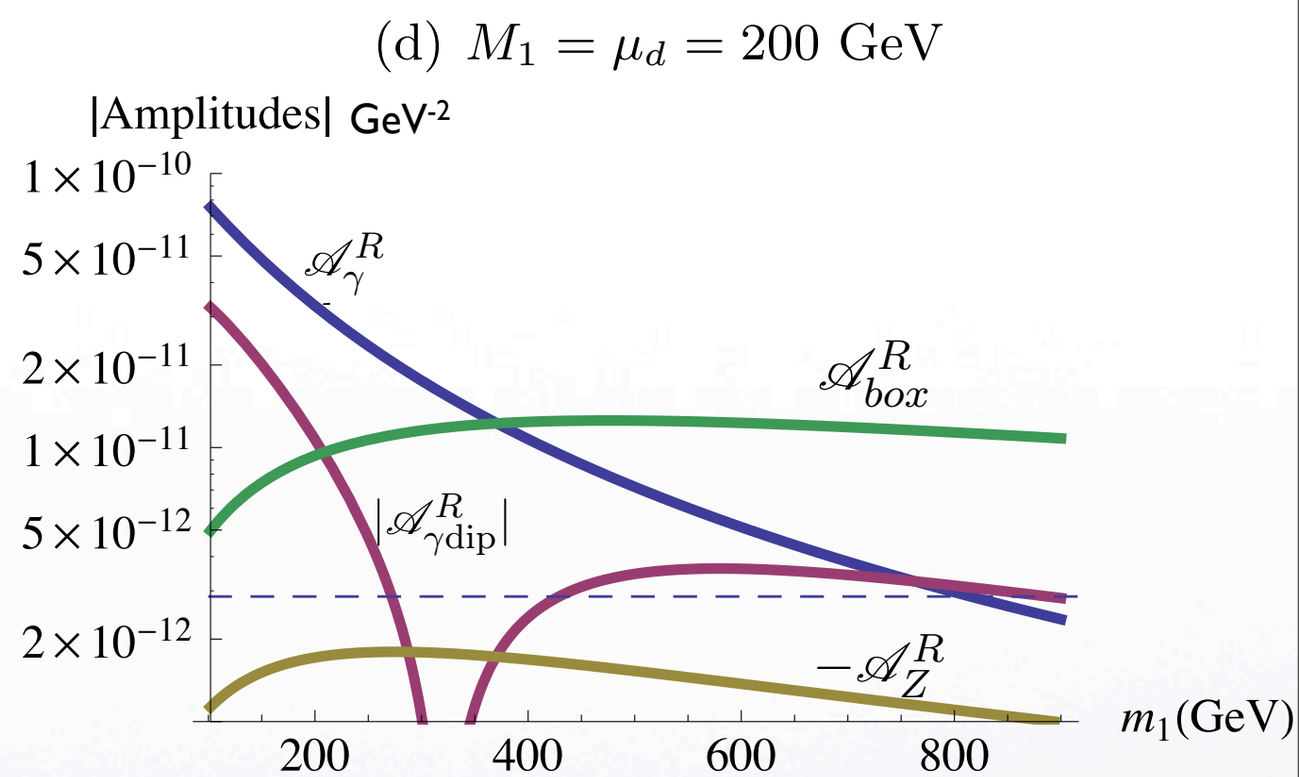
- No chirality flip on quark line, $\bar{q}\gamma^\mu q$, $\bar{q}\gamma^\mu\gamma^5 q$
- Considering only spin independent term, $\bar{q}\gamma^\mu q$ remains

$\Rightarrow$ No sea quark contributions, only u and d quarks

Maximal mixing



LH



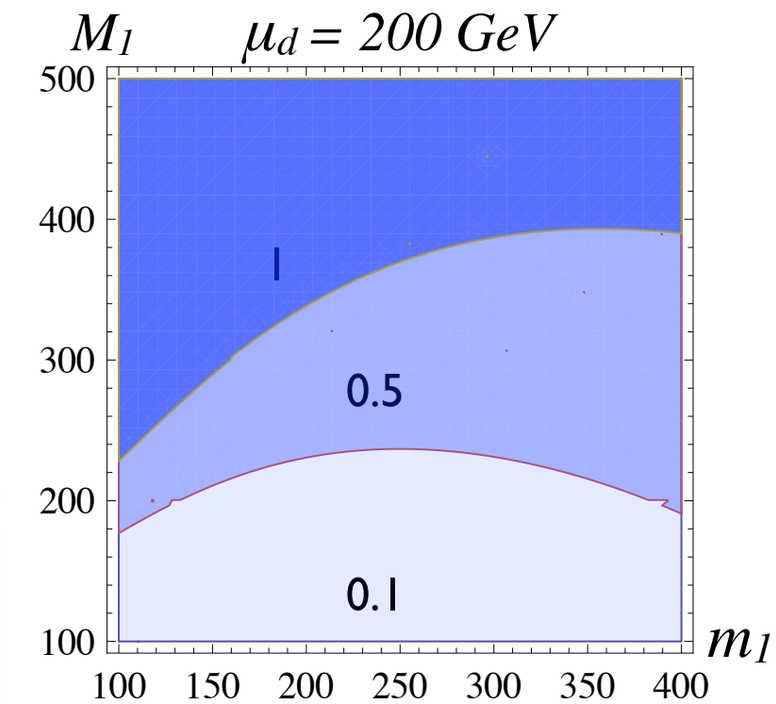
RH

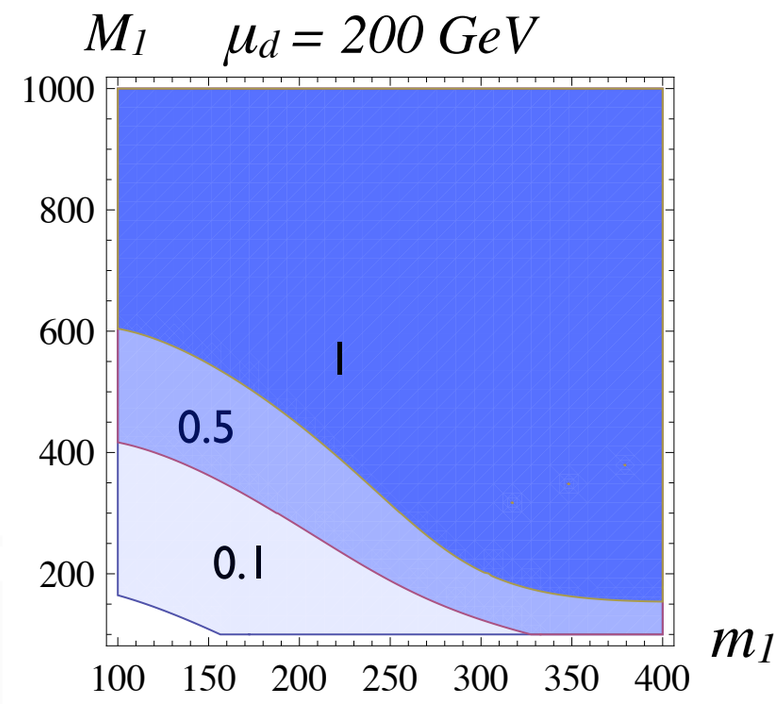
$$\Gamma_{\mu\to e} = 4m_\mu^5 e^4 |\mathscr{A}^L_{\gamma\mathrm{dip}} + \mathscr{A}^R_{\gamma} + \mathscr{A}^R_{box} + \mathscr{A}^R_{Z}|^2 + (L \leftrightarrow R)$$

$\mu \to 3e$

BR < 1.0 x 10^{-12} SINDRUM

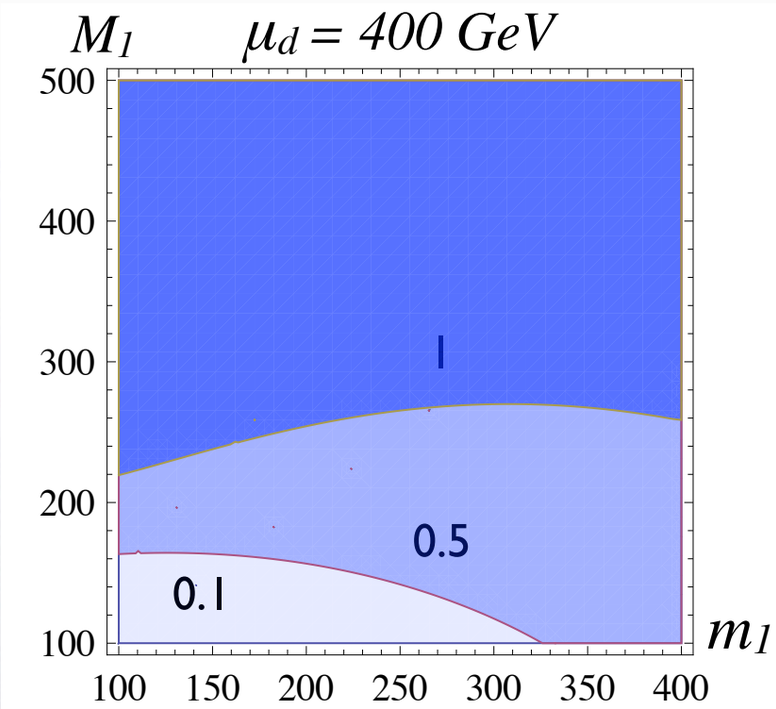
LH

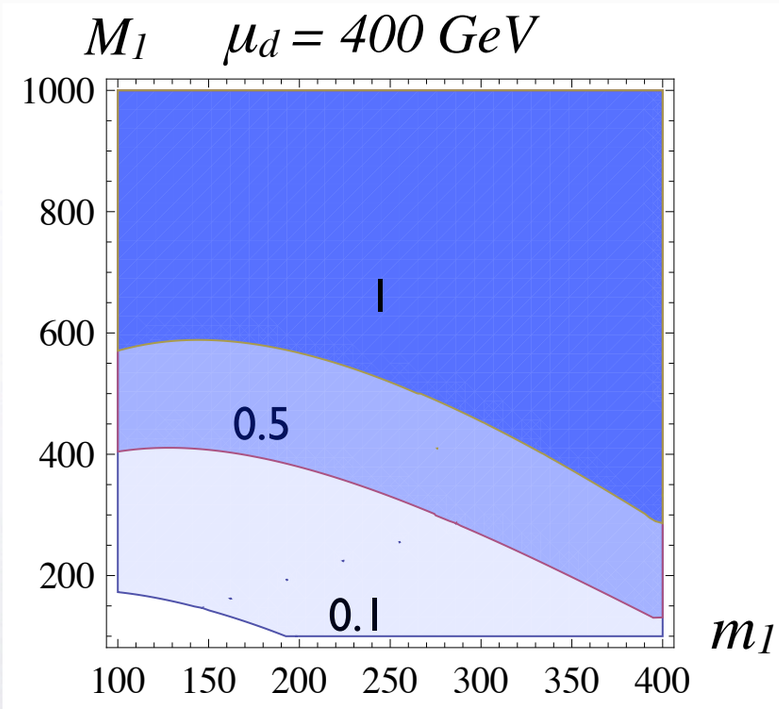




RH

LH



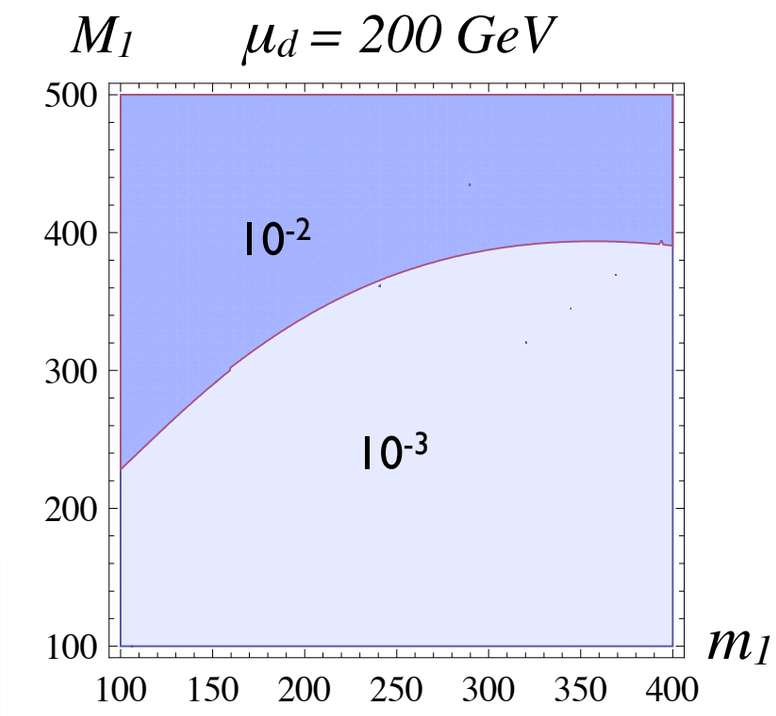


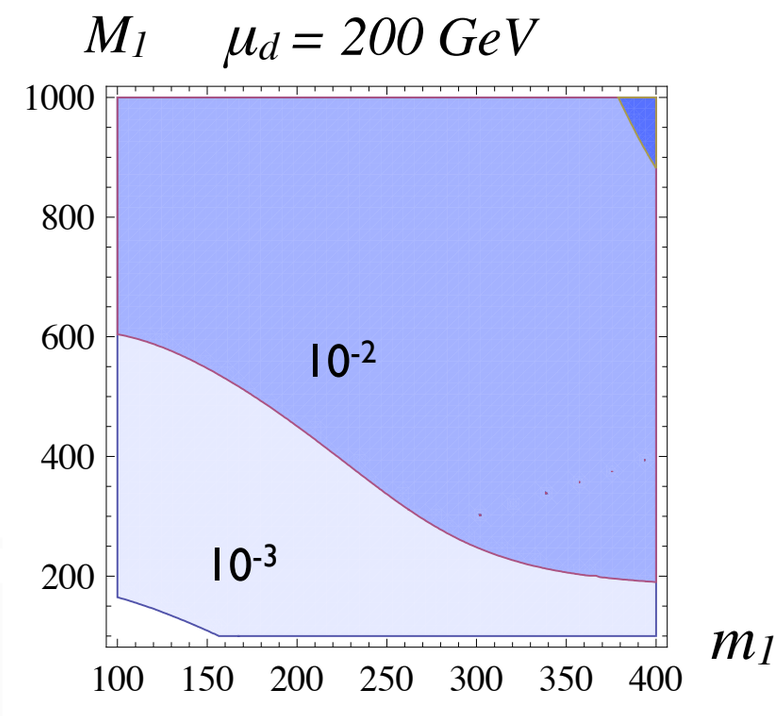
RH

Fok, Kribs

$\mu \to 3e$ BR < 10^{-16} Project X Expected Sensitivity

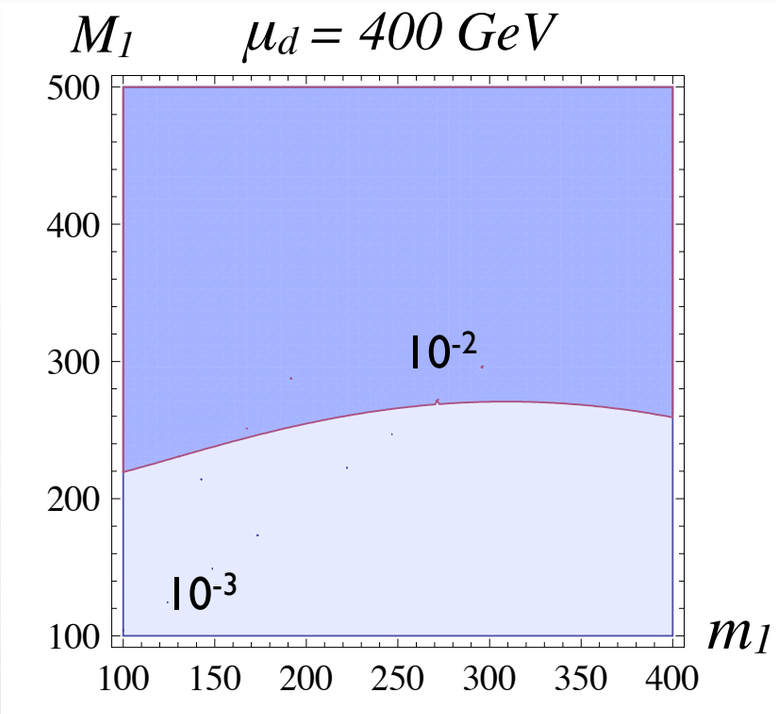
LH

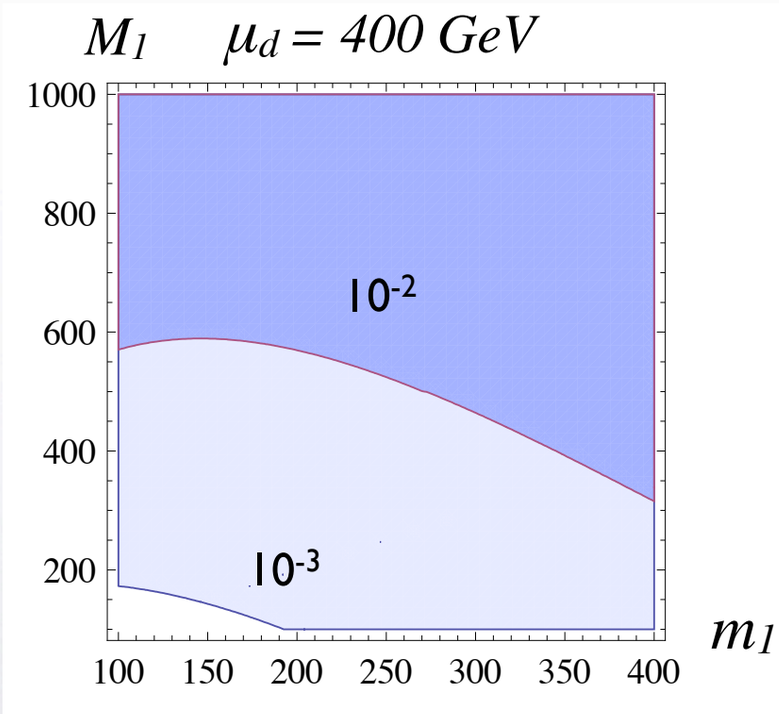




RH

LH





RH

Fok