Lepton Flavor Violation

II. The New Physics Flavor Puzzle

SSI$_{2010}$: Neutrinos – Nature's mysterious messengers
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Plan of Lectures

1. The (extended) Standard Model flavor puzzle
2. The New Physics flavor puzzle
    - The NP flavor puzzle
    - The SUSY flavor puzzle
    - LFV at ATLAS/CMS
3. Leptogenesis

The NP Flavor Puzzle

The SM = Low energy effective theory

1. Gravity $\Longrightarrow \Lambda_{\rm Planck} \sim 10^{19}$ GeV
2. $m_\nu \neq 0 \Longrightarrow \Lambda_{\rm Seesaw} \leq 10^{15}$ GeV
3. m_H^2-fine tuning; Dark matter = WIMP $\Longrightarrow \Lambda_{\rm NP} \sim$ TeV

$$\Downarrow$$

- The SM = Low energy effective theory
- Must write non-renormalizable terms suppressed by $\Lambda_{\rm NP}^{d-4}$
- $\mathcal{L}_{d=5} = \frac{Z^\nu_{ij}}{\Lambda_{\rm seesaw}} L_i L_j \phi\phi$
- $\mathcal{L}_{d=6}$ contains many flavor changing operators

New Physics - I

- The effects of new physics at a high energy scale $\Lambda_{\rm NP}$ can be presented as higher dimension operators

- For example, we expect the following dimension-six operators: $\mathcal{L}_{d=6} \supset \sum_{i\neq j} \frac{z_{ij}^{ee}}{\Lambda_{\rm NP}^2}(\overline{\ell_{Lj}}\gamma_\mu \ell_{Li})(\overline{e_L}\gamma_\mu e_L)$

- New contribution to $\ell_i \to \ell_j e^+ e^-$

$$B_{\ell_i\to\ell_j e^+e^-} \equiv \frac{{\rm BR}(\ell_i\to\ell_j e^+e^-)}{{\rm BR}(\ell_i\to\ell_j\nu_i\bar\nu_j)} = \frac{(|z_{ij}^{ee}|/\Lambda_{\rm NP}^2)^2}{G_F^2/2}$$

- Given an upper bound on $B_{ij} \Longrightarrow$ an upper bound on $z_{ij}^{ee}/\Lambda_{\rm NP}^2$

- Generic flavor structure $\equiv z_{ij}^{ee} \sim 1$ or, perhaps, $\rm loop-factor$

New Physics - II

- Another example:

$$\mathcal{L}_{d=6} \supset \frac{evz^{\gamma M}_{\mu e}}{\Lambda^2_{\rm NP}}\ \overline{\ell_i}\sigma_{\mu\nu}F^{\mu\nu}P_M\ell_j$$

- New contribution to $\ell_i \to \ell_j\gamma$

$$B_{\ell_i\to\ell_j\gamma} \equiv \frac{{\rm BR}(\ell_i\to\ell_j\gamma)}{{\rm BR}(\ell_i\to\ell_j\nu_i\bar\nu_j)} = \frac{48\pi^3\alpha v^2}{G_F^2 m^2_{\ell_i}}\frac{|z^{\gamma L}_{ij}|^2+|z^{\gamma R}_{ij}|^2}{\Lambda^4_{\rm NP}}$$

- Given an upper bound on $B_{ij} \Longrightarrow$ an upper bound on $z^{\gamma M}_{ij}/\Lambda^2_{\rm NP}$

- Generic flavor structure $\equiv z^{\gamma}_{ij} \sim \frac{1}{16\pi^2}$

Some data

$B_{\mu^-\to e^-e^+e^-}$	$< 1.0\times 10^{-12}$
$B_{\tau^-\to e^-e^+e^-}$	$< 2.0\times 10^{-7}$
$B_{\tau^-\to \mu^-e^+e^-}$	$< 1.6\times 10^{-7}$
$B_{\mu^-\to e^-\gamma}$	$< 1.2\times 10^{-11}$
$B_{\tau^-\to e^-\gamma}$	$< 6.2\times 10^{-7}$
$B_{\tau^-\to \mu^-\gamma}$	$< 2.6\times 10^{-7}$

High Scale?

- For $z^{ee}_{ij} \sim 1$: $\Lambda_{\rm NP} \gtrsim B^{-1/4} \times 350$ GeV
- For $z^{\gamma M}_{ij} \sim 1/16\pi^2$: $\Lambda_{\rm NP} \gtrsim B^{-1/4}(m_\mu/m_{\ell_i})^{1/2} \times 1.7$ TeV

	$\Lambda_{\rm NP} \gtrsim$
$B_{\mu^-\to e^-e^+e^-}$	350 TeV
$B_{\tau^-\to e^-e^+e^-}$	17 TeV
$B_{\tau^-\to \mu^-e^+e^-}$	17 TeV
$B_{\mu^-\to e^-\gamma}$	900 TeV
$B_{\tau^-\to e^-\gamma}$	15 TeV
$B_{\tau^-\to \mu^-\gamma}$	19 TeV

High Scale

- For generic lepton flavor parameters, $\Lambda_{\rm NP} \gtrsim 10^3$ TeV
- For generic quark flavor parameters, $\Lambda_{\rm NP} \gtrsim 10^4$ TeV

$$\Downarrow$$

$$\boxed{\text{Did we misinterpret the Higgs fine tuning problem?}}$$

$$\boxed{\text{Did we misinterpret the dark matter puzzle (it is not WIMP)?}}$$

Small (hierarchical?) flavor parameters?

- For $\Lambda_{\rm NP} \sim 1$ TeV, $z_{ij}^{ee} \lesssim 10 B_{ij}^{1/2}$; $16\pi^2 z_{ij}^{\gamma M} \lesssim 0.3 B_{ij}^{1/2}(m_{\ell_i}/m_\mu)$

ij	Observable	$z_{ij}^{ee} \lesssim$
μe	$B_{\mu^- \to e^- e^+ e^-}$	8.2×10^{-6}
τe	$B_{\tau^- \to e^- e^+ e^-}$	3.7×10^{-3}
$\tau \mu$	$B_{\tau^- \to \mu^- e^+ e^-}$	3.3×10^{-3}
ij	Observable	$16\pi^2 z_{ij}^{\gamma M} \lesssim$
μe	$B_{\mu^- \to e^- \gamma}$	1.3×10^{-6}
τe	$B_{\tau^- \to e^- \gamma}$	4.4×10^{-3}
$\tau \mu$	$B_{\tau^- \to \mu^- \gamma}$	2.9×10^{-3}

Small (hierarchical?) flavor parameters

For $\Lambda_{\rm NP} \sim$ TeV,

- $z_{\mu e} < 10^{-5}$
- $z_{\tau\ell} < 10^{-2}$
- $z_{sd} < 10^{-7}$

$$\Downarrow$$

$$\boxed{\text{The flavor structure of NP@TeV must be highly non-generic}}$$

How? Why? = The NP flavor puzzle

How does the SM ($\Lambda_{\rm SM} \sim m_W$) do it?

		$z_{ij} \sim$	$z_{ij}^{\rm SM}$
$\Delta m_K/m_K$	7.0×10^{-15}	5×10^{-9}	$\alpha_2^2 y_c^2 \vert V_{cd}V_{cs}\vert^2$
$\Delta m_D/m_D$	8.7×10^{-15}	5×10^{-9}	Long Distance
$\Delta m_B/m_B$	6.3×10^{-14}	7×10^{-8}	$\alpha_2^2 y_t^2 \vert V_{td}V_{tb}\vert^2$
$\Delta m_{B_s}/m_{B_s}$	2.1×10^{-12}	2×10^{-6}	$\alpha_2^2 y_t^2 \vert V_{ts}V_{tb}\vert^2$
		$\frac{\mathcal{I}m(z_{ij})}{\vert z_{ij}\vert} \sim$	$\frac{\mathcal{I}m(z_{ij}^{\rm SM})}{\vert z_{ij}^{\rm SM}\vert}$
ϵ_K	2.3×10^{-3}	$\mathcal{O}(0.01)$	$\mathcal{I}m\frac{y_t^2(V_{td}^*V_{ts})^2}{y_c^2(V_{cd}^*V_{cs})^2} \sim 0.01$
A_Γ	≤ 0.004	≤ 0.2	0
$S_{\psi K_S}$	0.67 ± 0.02	$\mathcal{O}(1)$	$\mathcal{I}m\frac{V_{tb}V_{td}^*}{V_{tb}^*V_{td}}\frac{V_{cb}^*V_{cd}}{V_{cb}V_{cd}^*} \sim 0.7$
$S_{\psi\phi}$	≤ 1	≤ 1	$\mathcal{I}m\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}\frac{V_{cb}^*V_{cs}}{V_{cb}V_{cs}^*} \sim 0.02$

- Does the new physics know the SM Yukawa structure? (MFV)

What does the ESM do?

	$z_{ij}^{\mathrm{max}}(\Lambda \sim m_W)$	z_{ij}^{ESM}	With $U_{e3} \sim 0.1$
$z_{\mu e}^{ee}$	8×10^{-8}	$\frac{\alpha_2^2}{m_W^2}(U_{e2}U_{\mu 2}^* \Delta m_{21}^2 + U_{e3}U_{\mu 3}^* \Delta m_{32}^2)$	3×10^{-29}
$z_{\tau e}^{ee}$	4×10^{-5}	$\frac{\alpha_2^2}{m_W^2}(U_{e2}U_{\tau 2}^* \Delta m_{21}^2 + U_{e3}U_{\tau 3}^* \Delta m_{32}^2)$	3×10^{-29}
$z_{\tau \mu}^{ee}$	3×10^{-5}	$\frac{\alpha_2^2}{m_W^2}(U_{\mu 2}U_{\tau 2}^* \Delta m_{21}^2 + U_{\mu 3}U_{\tau 3}^* \Delta m_{32}^2)$	4×10^{-28}
$z_{\mu e}^{\gamma L}$	8×10^{-11}	$\frac{\alpha_2 y_e}{4\pi m_W^2}(U_{e2}U_{\mu 2}^* \Delta m_{21}^2 + U_{e3}U_{\mu 3}^* \Delta m_{32}^2)$	2×10^{-34}
$z_{\tau e}^{\gamma L}$	3×10^{-7}	$\frac{\alpha_2 y_e}{4\pi m_W^2}(U_{e2}U_{\tau 2}^* \Delta m_{21}^2 + U_{e3}U_{\tau 3}^* \Delta m_{32}^2)$	2×10^{-34}
$z_{\tau \mu}^{\gamma L}$	2×10^{-7}	$\frac{\alpha_2 y_\mu}{4\pi m_W^2}(U_{\mu 2}U_{\tau 2}^* \Delta m_{21}^2 + U_{\mu 3}U_{\tau 3}^* \Delta m_{32}^2)$	6×10^{-31}
$z_{\mu e}^{\gamma R}$	8×10^{-11}	$\frac{\alpha_2 y_\mu}{4\pi m_W^2}(U_{e2}U_{\mu 2}^* \Delta m_{21}^2 + U_{e3}U_{\mu 3}^* \Delta m_{32}^2)$	4×10^{-32}
$z_{\tau e}^{\gamma R}$	3×10^{-7}	$\frac{\alpha_2 y_\tau}{4\pi m_W^2}(U_{e2}U_{\tau 2}^* \Delta m_{21}^2 + U_{e3}U_{\tau 3}^* \Delta m_{32}^2)$	7×10^{-31}
$z_{\tau \mu}^{\gamma R}$	2×10^{-7}	$\frac{\alpha_2 y_\tau}{4\pi m_W^2}(U_{\mu 2}U_{\tau 2}^* \Delta m_{21}^2 + U_{\mu 3}U_{\tau 3}^* \Delta m_{32}^2)$	1×10^{-29}

- The ESM LFV rates are negligibly tiny

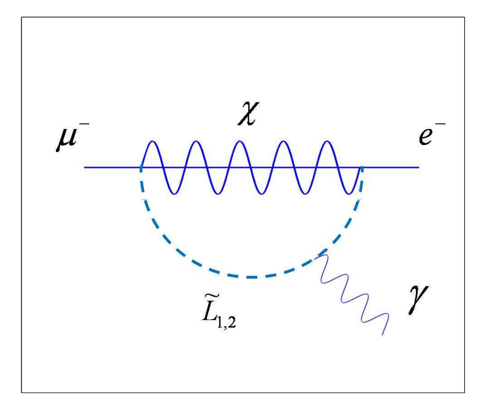
Intermediate summary

- The SM predicts no LFV
- The ESM predicts unobservably small LFV
- Any signal of LFV in charged lepton decays - an unambiguous signal of new physics beyond the ESM ($\Lambda_{\rm NP} \lesssim 10^3$ TeV)
- The flavor structure of new physics at the TeV scale must be highly non-generic ($\Longrightarrow$ The NP flavor puzzle)
- The NP flavor puzzle guarantees that such an LFV signal will provide important information about the NP

The Supersymmetric Flavor Puzzle

The $\mu \to e\gamma$ challenge

Take, for example, the contribution from the first two generations of slepton doublets to $\mu \to e\gamma$:



$$\Lambda_{\rm NP} = m_{\tilde L}; \quad z^{\gamma L}_{\mu e} \simeq \left(\frac{\alpha_2}{60\pi}\frac{m_\mu \tan\beta}{v}\right)\frac{\Delta m^2_{21}}{m^2_{\tilde L}} K^L_{e2} K^{L*}_{\mu 2}$$

$$\Longrightarrow \left(\frac{300\ \text{GeV}}{m_{\tilde L}}\right)^2 \times \frac{\Delta m^2_{21}}{m^2_{\tilde L}} \times \sin 2\theta \lesssim 10^{-3}$$

How can Supersymmetry do it?

$$\boxed{\frac{\mathrm{TeV}}{\tilde{m}} \times \frac{\Delta\tilde{m}^2_{ij}}{\tilde{m}^2} \times K_{ij} \ll 1}$$

Why? = The SUSY flavor puzzle

How can Supersymmetry do it?

$$\boxed{\frac{\text{TeV}}{\tilde{m}} \times \frac{\Delta\tilde{m}^2_{ij}}{\tilde{m}^2} \times K_{ij} \ll 1}$$

Why? = The SUSY flavor puzzle

- Solutions:
  - Heaviness: $\tilde{m} \gg 1$ TeV
  - Degeneracy: $\Delta\tilde{m}^2_{ij} \ll \tilde{m}^2$
  - Alignment: $K_{ij} \ll 1$
  - Split Supersymmetry
  - Gauge-mediation
  - Horizontal symmetries

Gauge Mediation – Squarks

- $\Delta m_K, \ \Delta m_D$:
  - The first two squark generations are quasi-degenerate
  - Could be the result of alignment ($\sim \sin\theta_C$) and RGE ($\frac{\Delta m^2}{m^2} \sim 0.1$)
  - Natural with gauge mediation ($\frac{\Delta m^2}{m^2} \sim y_c^2 \sim 10^{-4}$)
- Gauge mediation:
  - $\widetilde{M}^2_{\tilde{q}_L} = \tilde{m}^2\mathbf{1} + D_{q_L}\mathbf{1} + v_q^2 Y_q Y_q^\dagger$
  - RGE: $\tilde{m}^2_{\tilde{Q}_L}(m_Z) = \tilde{m}^2(r_3\mathbf{1} + c_u Y_u Y_u^\dagger + c_d Y_d Y_d^\dagger)$
  - The only source of flavor violation = The SM Yukawa couplings
  - An example of minimal flavor violation (MFV)
  - MFV solves all SUSY flavor problems

The seesaw mechanism - a reminder

- Add $N_i(1,1)_0$
- $\mathcal{L}_{\rm leptons} = Y^e_{ij}\overline{L_i}\phi_d E_j + Y^\nu_{ij}\overline{L_i}\phi_u N_j + M_j N_j N_j$
- Gives light neutrino masses $(m_\nu)_{ij} = \langle\phi_u\rangle^2 Y^\nu_{ik} Y^\nu_{jk} M_k^{-1}$
- Flavor: $SU(3)_L \times SU(3)_E \times SU(3)_N$ completely broken
- $15_R + 6_I$ lepton flavor parameters
  (compared to $9_R + 3_I$ in the ESM)

Gauge Mediation – Sleptons

- $\mu \to e\gamma,\ \mu \to eee$:
  - Suggestive: The first two slepton gen's – quasi-degenerate
  - Alignment of $\mathcal{O}(|U_{e2}|)$ and RGE do not help
  - Natural with gauge mediation
- Gauge mediation (GM) with $\Lambda_{\rm seesaw} < \Lambda_{\rm GM}$:
  - $\widetilde{M}^2_{\tilde{\ell}_L} = \tilde{m}^2 \mathbf{1} + D_{\ell_L} \mathbf{1} + v_d^2 Y^e Y^{e\dagger}$
  - LFV from RGE: $(\tilde{m}^2_{\tilde{L}_L})_{ij} \simeq -\frac{3\tilde{m}^2}{8\pi^2} Y^\nu_{ik} Y^{\nu *}_{jk} \ln\left(\frac{\Lambda_{\rm GM}}{M_k}\right)$
  - $SU(3)_L \times SU(3)_N$ broken by Y^e, Y^ν, M_N
  - Observable LFV effects – possible
  - Even with minimal lepton flavor violation (MLFV), we can obtain new information on flavor

MFV + SUSY

- Squarks:
  - Spectrum: $2+1$
  - Decays: $2 \longrightarrow u, d, s, c, \quad 1 \longrightarrow t, b$
- Sleptons, $\Lambda_{\rm seesaw} > \Lambda_{\rm mediation}$:
  - spectrum: 3
  - Decays: flavor diagonal
- Sleptons, $\Lambda_{\rm seesaw} < \Lambda_{\rm mediation}$:
  - $Y^\nu,\ M_N$ may leave a footprint on the slepton spectrum and flavor decomposition

LFV@ATLAS/CMS

Flavor Physics at the LHC era

- If ATLAS/CMS observe no NP...
- and flavor factories observe no NP...

Flavor Physics at the LHC era

- If ATLAS/CMS observe no NP...
- but flavor factories observe NP...
    - We may have misinterpreted the fine-tuning problem
    - We may have misinterpreted the dark matter puzzle

    - Flavor will provide the only clue for an accessible scale of NP

Flavor Physics at the LHC era

- ATLAS/CMS will, hopefully, observe NP at $\Lambda_{\rm NP} \lesssim$ TeV;
- If the NP couple to SM quarks and/or leptons –

There are new flavor parameters that can, in principle, be measured

- In combination with flavor factories, we may...
  - Understand how the NP flavor puzzle is (not) solved
  - Probe NP at $\Lambda_{\rm NP} \gg$ TeV
  - Get hints about the solution to the SM flavor puzzle

Gauge+Gravity Mediation

- Example: High (but not too high) scale gauge mediation
  - Gravity mediation sub-dominant but non-negligible
  - $r = \frac{\text{gravity}-\text{med}}{\text{gauge}-\text{med}} \sim \left(\frac{m_M}{m_P}\right)^2 \left(\frac{4\pi}{\alpha_2(m_M)}\right)^2 \frac{3}{8n_M}$
  - $\widetilde{M}^2_{\tilde{L}_L}(m_M) = \tilde{m}^2_{\tilde{L}_L}(\mathbf{1} + rX_{\tilde{L}_L})$
  - $\boxed{\text{Degeneracy depends on } r}$

Assume: The flavor structure of X determined by FN:

- $X_{\tilde{L}_L} \sim \begin{pmatrix} 1 & U_{e2} & U_{e3} \\ \cdot & 1 & U_{\mu3} \\ \cdot & \cdot & 1 \end{pmatrix}; \quad X_{\tilde{E}_R} \sim \begin{pmatrix} 1 & \frac{m_e/m_\mu}{U_{e2}} & \frac{m_e/m_\tau}{U_{e3}} \\ \cdot & 1 & \frac{m_\mu/m_\tau}{U_{\mu3}} \\ \cdot & \cdot & 1 \end{pmatrix}$
- $\boxed{\text{Mixing depends only on } X \text{ which is related to the SM flavor}}$

Solving the NP Flavor Puzzle

If ATLAS/CMS observe sleptons...

- Determine the slepton mass scale ($\tilde{m}$)
- Determine the slepton mass splitting ($m_{\tilde{\ell}_j} - m_{\tilde{\ell}_i}$)
- Determine the sfermion flavor decomposition (K^e_{ij})

$$\Downarrow$$

$$\boxed{\text{Learn how the SUSY flavor suppression is obtained}}$$

Physics at $\Lambda_{\text{NP}} \gg \Lambda_{\text{LHC}}$

If ATLAS/CMS determine slepton mass splittings...

- Find the ratio between gravity- and gauge-mediated contributions (r)
- Determine the messenger scale of gauge mediation (m_M)
- Find the hierarchy between the GMSB and see-saw scales

$$\Downarrow$$

$$\boxed{\text{Probe physics at } m_M \sim 10^{15}\ \text{GeV}}$$

Solving the SM Flavor Puzzle?

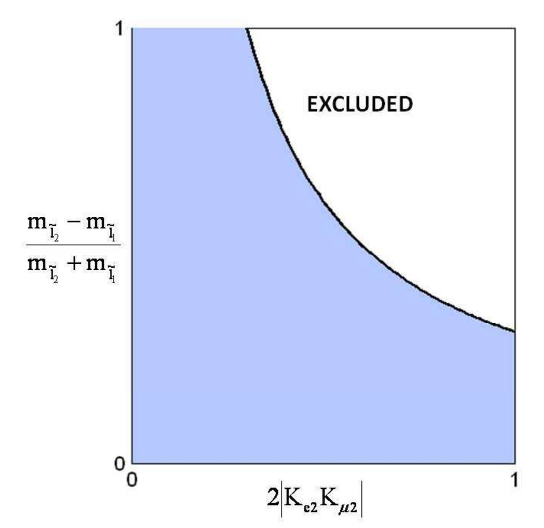
If ATLAS/CMS determine slepton flavor decomposition...

- Determine X of $\tilde{M}^2 = \tilde{m}^2(\mathbf{1} + rX)$
- Does X have the FN-predicted structure?

$$\Downarrow$$

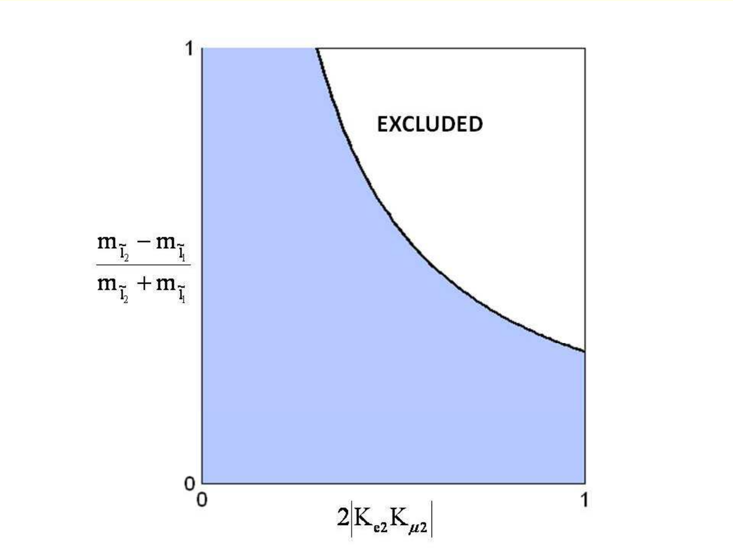
$$\boxed{\text{Test theories that explain the SM flavor structure}}$$

The SUSY flavor plane

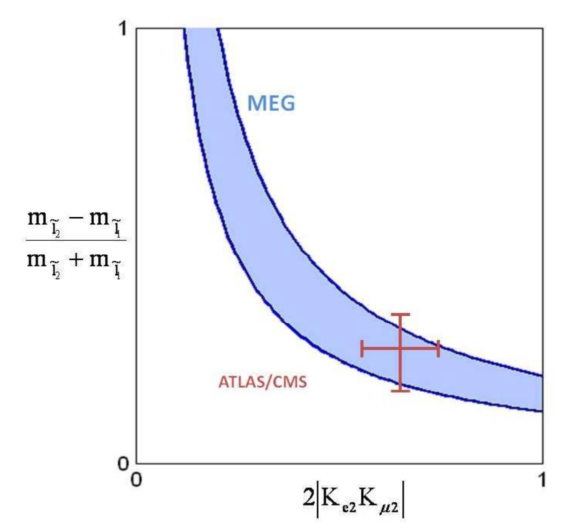


Flavor Factories

The SUSY flavor plane

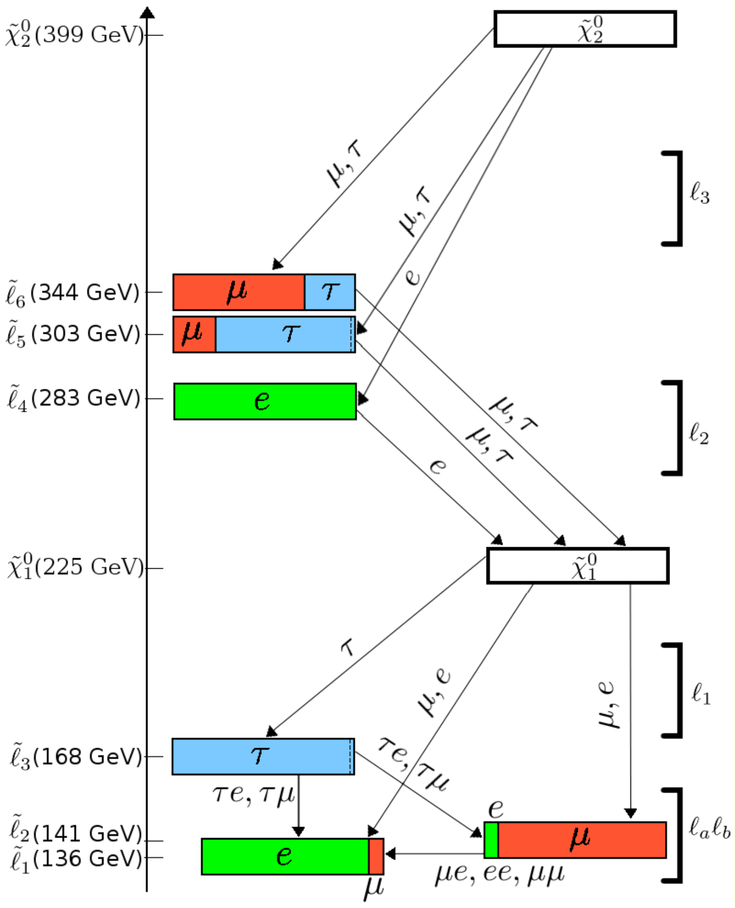


Flavor Factories



FF+ATLAS/CMS

Gauge+Gravity Mediation



$$\chi_1^0 \longrightarrow \tilde\ell_1^\pm \ell_1^\mp$$

$$\chi_1^0 \longrightarrow \tilde\ell_2^\pm \ell_2^\mp$$

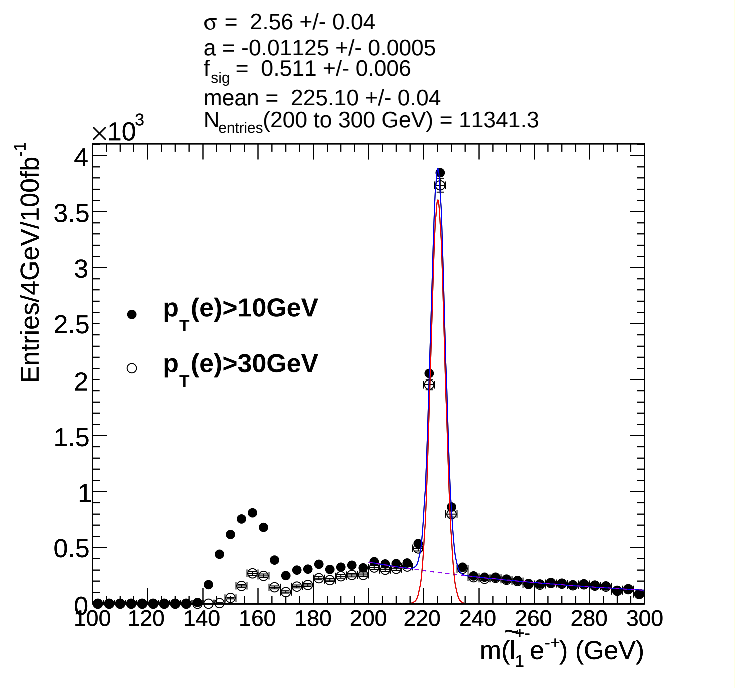
$$\tilde\ell_2^\pm \to \tilde\ell_1^\pm X^{\pm\mp}$$

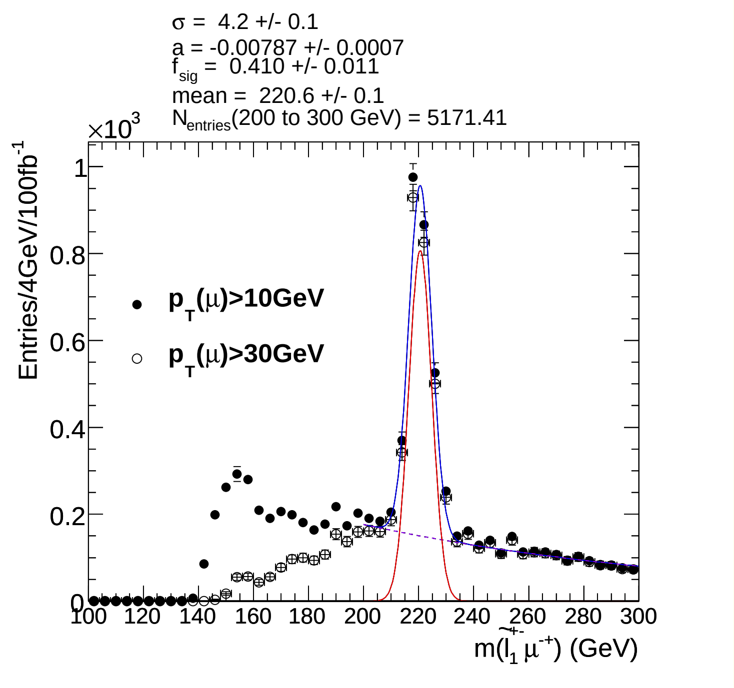
or

$$\tilde\ell_2^\pm \to \tilde\ell_1^\mp X^{\pm\pm}$$

$$m_{\tilde G} \ll m_{\tilde\ell_{1,2,3}} \ll m_{\chi_1^0}$$

Measuring slepton mass splitting



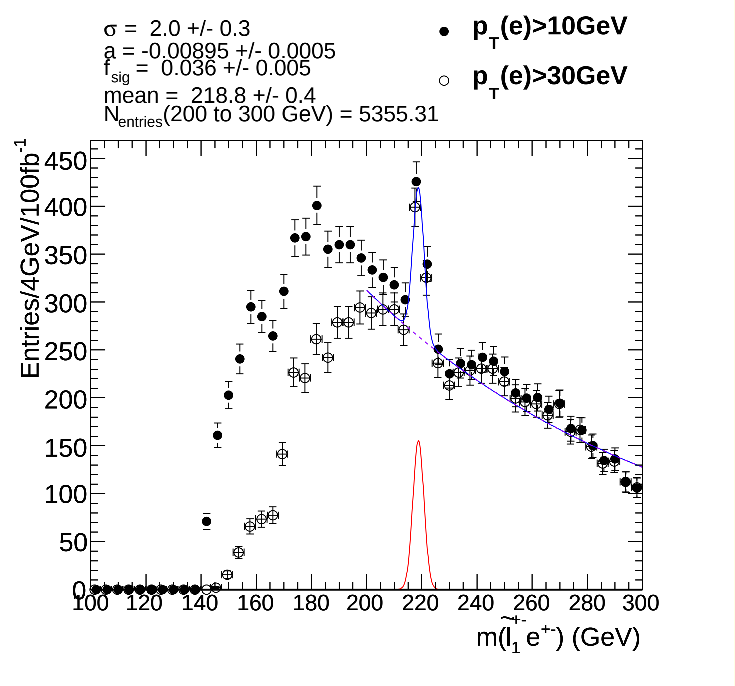


$$\sqrt{m^2_{\tilde{\ell}_1 e}} = M_{\chi^0_1}$$

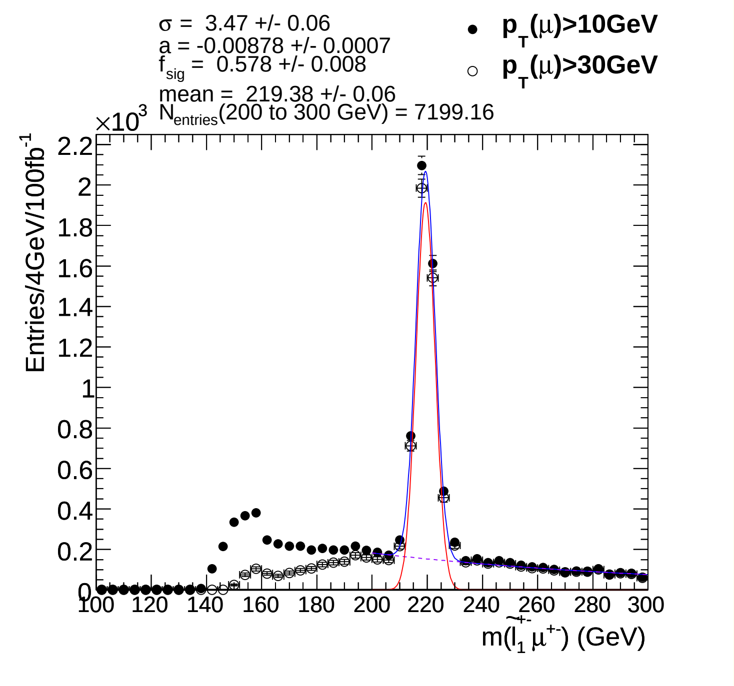
$$\sqrt{m^2_{\tilde{\ell}_1 \mu}} = M_{\chi^0_1} - E_{\rm shift}$$

$$\boxed{\Delta m_{21} = \frac{2m_{\chi^0_1} m_{\tilde{\ell}_1}}{m^2_{\chi^0_1}+m^2_{\tilde{\ell}_1}} E_{\rm shift}}$$

Measuring slepton flavor decomposition



$$\chi_1^0 \to \tilde{\ell}_1^\pm e^\pm X_{\rm invisible}$$



$$\chi_1^0 \to \tilde{\ell}_1^\pm \mu^\pm X_{\rm invisible}$$

$$\boxed{|K_{e2}/K_{\mu2}|^2 = N_{SSe}/N_{SS\mu}}$$

[Feng, Lester, Nir, Shadmi *et al.*, PRD77(2008)076002; PRD80(2009)114004; JHEP01(2010)047]

Lessons from $\tilde{\ell}_1, e, \mu$

- Determine Δm_{21} and $\sin 2\theta_{12}$:
  Is it consistent with $\mu \to e\gamma$?
  How the SUSY flavor problem is solved

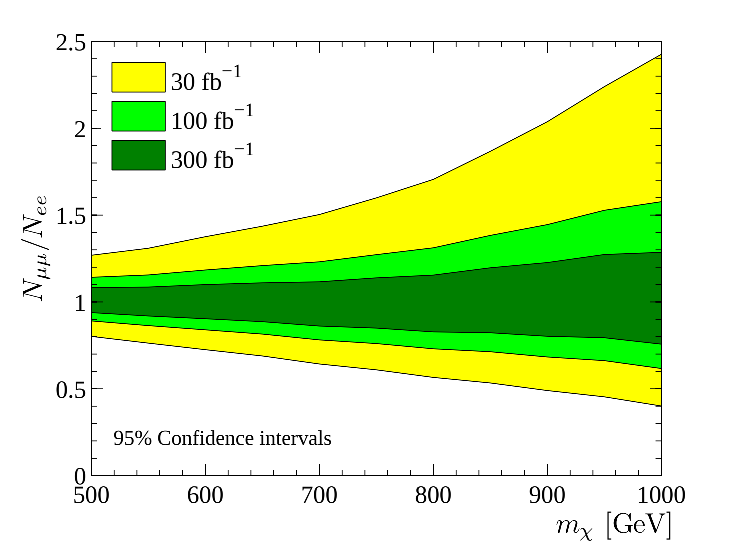
- Determine Δm_{21}, Δm_{54}, …:
  What is messenger scale of gauge mediation (M_m)?
  Probe physics at $M_m \sim 10^{15}$ GeV

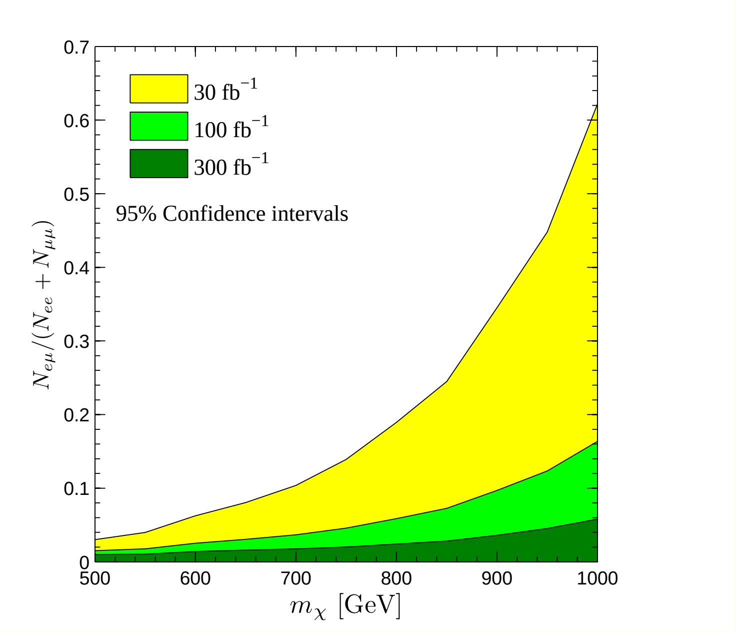
- Determine $|K_{e2}/K_{\mu 2}|$:
  Is the FN mechanism at work?
  How the SM flavor puzzle is solved

Vector-like leptons and MLFV

- Imagine: Vector-like lepton doublets with $m \lesssim TeV$
  - Avoid large FCNC by MLFV
  - The only LFV comes from $Y^E = \mathrm{diag}(y_e, y_\mu, y_\tau)$
    - The heavy mass spectrum:
      quasi-degeneracy or hierarchy $\propto Y^E$
    - The heavy-to-light couplings:
      universal or hierarchical (affects the lifetimes)
    - The heavy-to-light couplings:
      flavor-diagonal

Vector-like leptons and MLFV





- $N_{ee} \neq N_{\mu\mu}$ and/or $N_{e\mu} \neq 0$:
  Either MLFV with ν-related spurions or non-MLFV
- $N_{ee} = N_{\mu\mu}$ and $N_{e\mu} = 0$: Approximate $U(1)_e \times U(1)_\mu$
  Plus $m_{\chi_e} \approx m_{\chi_\mu}$: Approximate $U(2)_{e\mu}$

[Gross, Grossman, Nir, Vitells, PRD81(10)055013 [1001.2883]]

The role of flavor factories (FF)

ATLAS/CMS and flavor factories give complementary information

- In the absence of NP at ATLAS/CMS, flavor factories will be crucial to find $\Lambda_{\rm NP}$
- Consistency between ATLAS/CMS and FF is necessary to understand the NP flavor puzzle
- NP in $c \to u$? $s \to d$? $b \to d$? $b \to s$? $t \to c$? $t \to u$? $\mu \to e$? $\tau \to \mu$? $\tau \to e$?
  - MFV?
  - Structure related to SM?
  - Structure unrelated to SM?
  - Anarchy?

[Hiller, Hochberg, Nir, JHEP0903(09)115; JHEP1003(10)079 [1001.1513]]

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Yuval Grossman, YN, Jesse Thaler, Tomer Volansky, Jure Zupan
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Feng, French, Galon, Lester, YN, Shadmi, Sanford, Yu
JHEP 1001 (2010) 047 [arXiv:0910.1618]

Eilam Gross, Daniel Grossman, YN, Ofer Vitells
Phys. Rev. D81 (2010) 055013 [arXiv:1001.2883]

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