Flavour Physics of Leptons and Dipole Moments

arXiv:0801.1826 [hep-ph]

I. Bigi, M. Mangano, M. Raidal, A. van der Schaaf, Y. Semertzidis

Flavour in the Era of LHC, WG3

⇓

Flavour as a Window to New Physics at the LHC

Flavour program of LHC

- B, B_s decays
- $\tau \rightarrow 3\,l$ decays
- LFV in slepton decays

LHC

- EWSB
- Hierarchy problem(s)
- Dark Matter
- Neutrino masses, leptogenesis, LFV

Outline

- Previous study: flavour is a window to new physics

- Lepton Flavour physics at LHC

- Electric Dipole Moments

Scale of NP?

- EWSB ~ M_Z ~ 100 GeV
- Higgs mass $\Lambda_{NP} < 1$ TeV
- Precision physics, LEP2: $\Lambda_{NP} > 1$ TeV
- LFV: $\Lambda_{NP} > 10$ TeV
- EDMs, K-K mixing: $\Lambda_{NP} > 100$ TeV

Tension between our desire for 100 GeV NP and experimental results

N(F)P cannot be generic

- Flavour structure must be non-trivial
  - flavour symmetries: discrete, continuous, Abelian, non-Abelian, accidental, anarchy etc.

- SUSY breaking pattern must be non-trivial
  - extensive literature

- How to handle CP phases?
  - PQ symmetry?

Top down or bottom up approach for phenomenology?

- TD: Underlying “beautiful” physics predicts, up to corrections, low scale physics observables
  - GUTs, flavour models
- BU: Build low scale effective theories
  - MS+new particles + symmetries
  - MFV

Hierarchy vs. little hierarchy ?

- High scale and low scale physics live together
  - MSSM + seesaw + SUSY GUTs

- Nature has “onion” structure, NP scale after every loop factor
  - Technicolor, Little Higgs models + new particles

LFV: constraints

- $Br(\mu \rightarrow e\gamma) < 1.2 \; 10^{-11}$ (PSI: 10^{-13})
- MECO (expected 10^{-18}) cancelled ☹
- $Br(\tau \rightarrow \mu\gamma) < 4.5 \; 10^{-8}$ (S. b-factory)
- $Br(\tau \rightarrow e\gamma) < 1.1 \; 10^{-7}$

- $d_e < 1.6 \; 10^{-27}$ e cm (10^{-31-35} e cm)
- $d_\mu < 2.8 \; 10^{-19}$ e cm (NF: 10^{-24-25})

Low scale LF physics at LHC

- TeV scale seesaw I and flavoured resonant leptogenesis

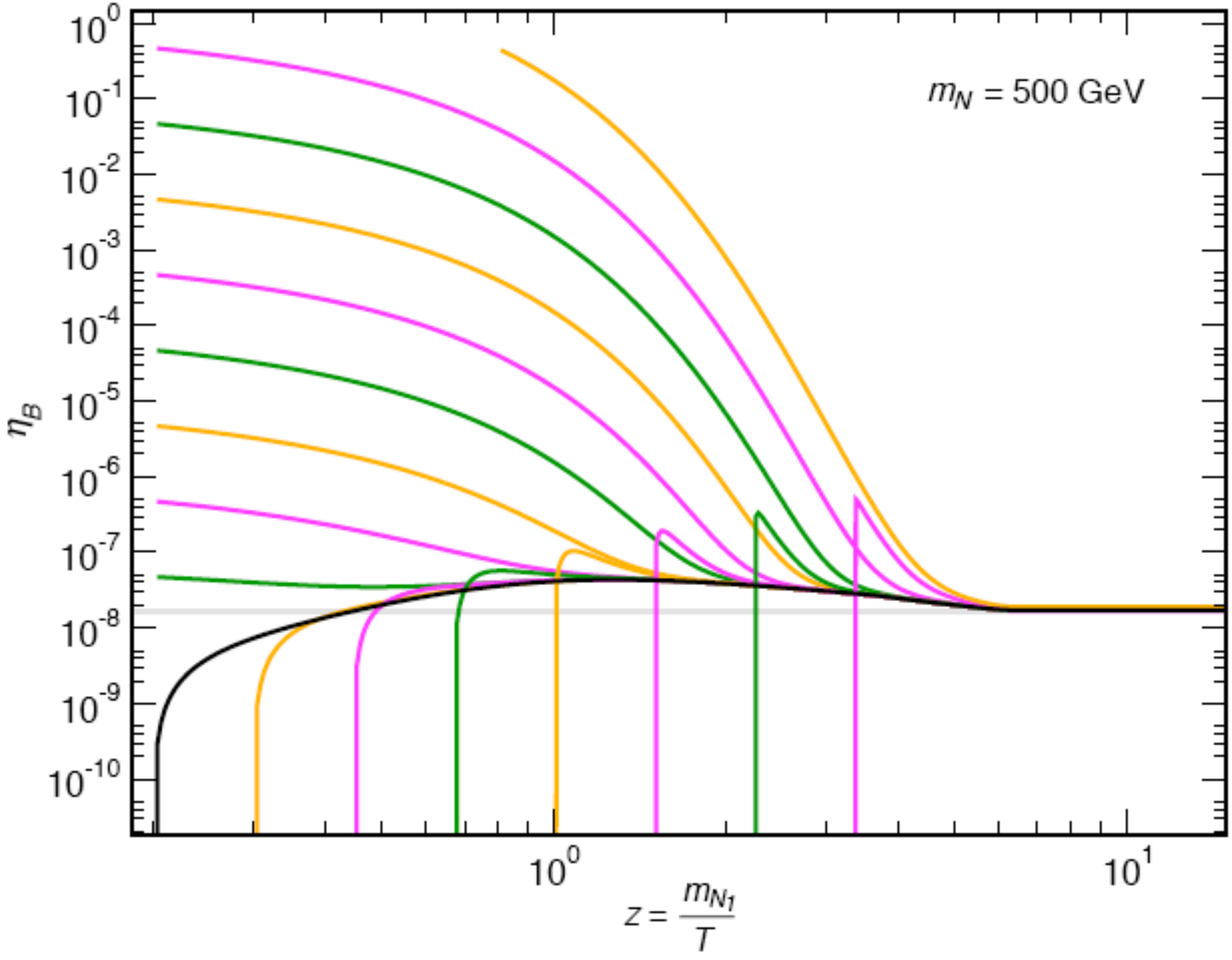
- TeV seesaw II and resonances of invariant mass in $T^{++} \rightarrow l^+ l^+$, one-to-one corresponcence between LFV Br and neutrino mass matrix
  - m_ν scale, hierarchy and Majorana phases from counting leptons at LHC

Flavoured resonant non-SUSY leptogenesis

$$-\mathcal{L}_Y^{\rm lepton} \;=\; \frac{m_N}{2}\,(\bar{\nu}_{iR})^C\nu_{iR} \;+\; h^l_{ii}\,\bar{L}_i\Phi l_{iR} \;+\; h^{\nu_R}_{ij}\,\bar{L}_i\widetilde{\Phi}\nu_{jR} \;+\; {\rm H.c.}$$

$$h^{\nu_R} \;=\; \begin{pmatrix} 0 & a\,e^{-i\pi/4} & a\,e^{i\pi/4} \\ 0 & b\,e^{-i\pi/4} & b\,e^{i\pi/4} \\ 0 & c\,e^{-i\pi/4} & c\,e^{i\pi/4} \end{pmatrix}$$

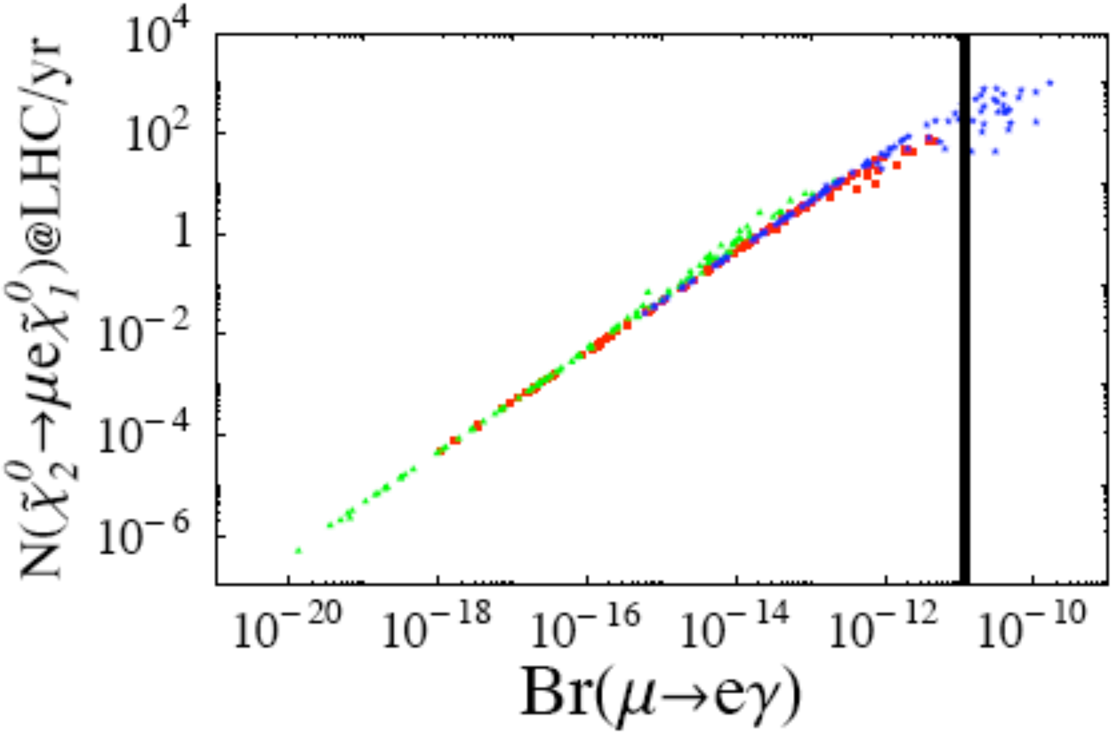
- Models with signatures at the observable level: $B(\mu \to e\gamma) \sim 10^{-13}$, $B(\mu \to eee) \sim 10^{-14}$, $B(\mu \to e) \sim 10^{-13}$, LNV/LFV at the ILC.
- Observation of an electron EDM $d_e \gtrsim 10^{-32}\ e \cdot {\rm cm}$ will rule out non-SUSY leptogenesis.



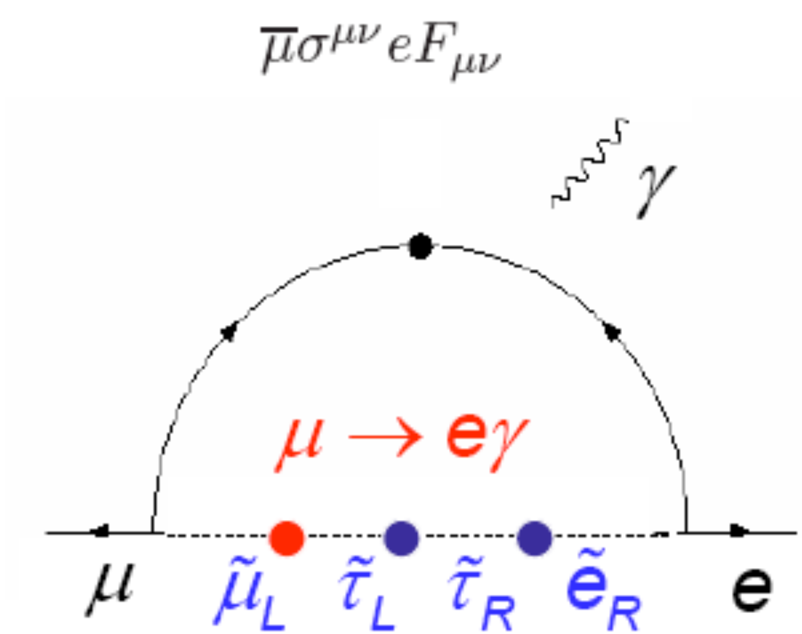
m_N = 500 GeV
η_B
$z = \frac{m_{N_1}}{T}$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^0
10^1

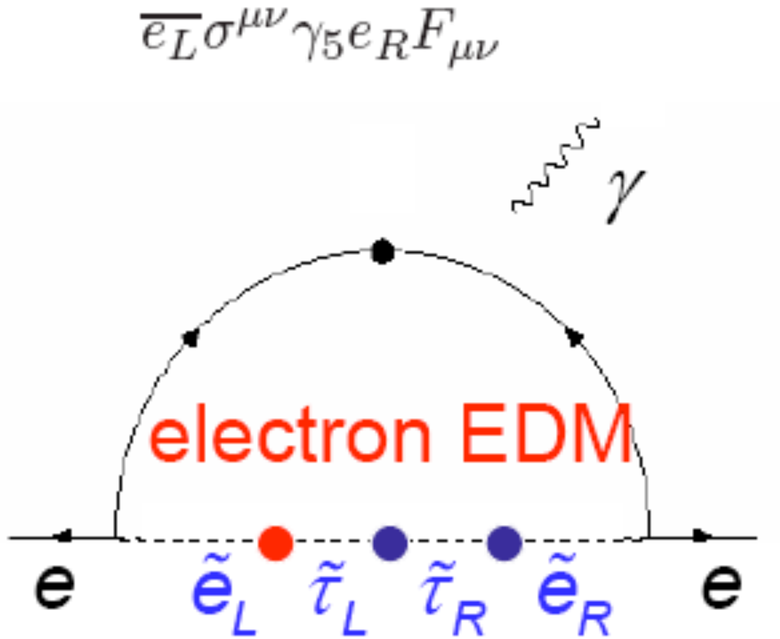
Br(μ→eγ) vs. LHC in mSUGRA

$$
\begin{aligned}
pp &\rightarrow \tilde{q}_a\tilde{q}_b, \tilde{g}\tilde{q}_a, \tilde{g}\tilde{g}, \\
\tilde{q}_a(\tilde{g}) &\rightarrow \tilde{\chi}_2^0 q_a(g), \\
\tilde{\chi}_2^0 &\rightarrow \tilde{l}_\alpha l_\beta, \\
\tilde{l}_\alpha &\rightarrow \tilde{\chi}_1^0 l_\beta,
\end{aligned}
$$



(g-2)$_\mu$, LFV decays and EDMs: NP correlations





EDMs are good probes of NP

SM:

$$d_e < 10^{-40} e\, cm$$
$$d_q \approx 10^{-(33-34)} e\, cm$$
$$d_n \approx 10^{-(31-32)} e\, cm$$

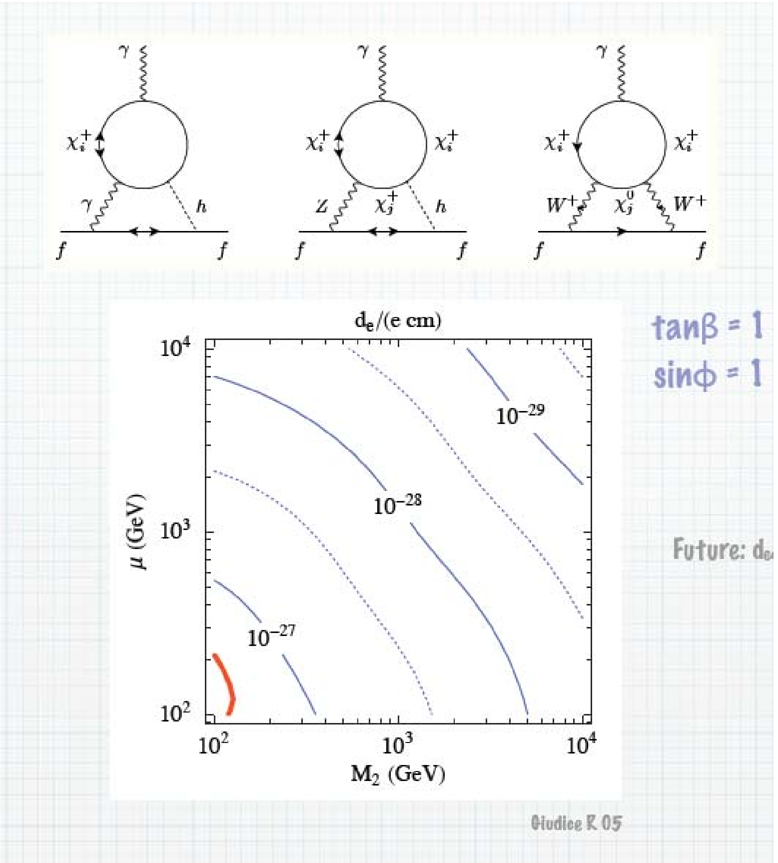
- Expected experimental improvement:

8 orders of magnitude at the amplitude level

$$d_e < 10^{-35}\ e\ cm$$

- LFV maximal in neutrino sector, SUSY seesaw implies 6 new phases
- $(g-2)_\mu$ shows 3σ deviation from the SM

SUSY CP problem can be bad



- Learn from the SM: CP is violated only in LFV, the Jarlskog invariants are suppressed

Estimating FV CPV in SUSY seesaw - ugly job

- Use mass insertion approximation
- Solve RGEs in powers of Log. LLog:

$$
\begin{aligned}
\left(m^2_{\tilde{L}}\right)_{ij} &\simeq -\frac{1}{8\pi^2}(3m_0^2 + A_0^2) Y^{\nu\,\dagger}_{ik} Y^{\nu}_{kj} \log\frac{M_X}{M_k} \,, \\
\left(m^2_{\tilde{e}_R}\right)_{ij} &\simeq 0 \,, \\
(A_e)_{ij} &\simeq -\frac{3}{8\pi^2} A_0 Y_e Y^{\nu\,\dagger}_{ik} Y^{\nu}_{kj} \log\frac{M_X}{M_k} \,,
\end{aligned}
$$

- EDMs occur beyond the LLog

Dominant contributions

- Small tan β regime: A_{ii}
- Large tan β regime: $(m_{LL}\ \mu \tan\beta\ m_{RR})_{ii}$
- Expected maximal values for EDMs:
    - $d_e < 10^{-28-29}$ e cm
    - $d_\mu < 10^{-26-27}$ e cm

SUSY GUTs

GUT effect, e.g. SU(5), if $M_X > M_{GUT}$

$$(\Delta_{RR})_{i\neq j} = -3 \cdot \frac{3m_0^2 + a_0^2}{16\pi^2} Y_t^2 V_{i3} V_{j3} \ln\left(\frac{M_X^2}{M_{GUT}^2}\right)$$

See-saw:

$$m_\nu = -Y_\nu \hat{M}_R^{-1} Y_\nu^T \langle H_u \rangle^2$$

$$(\Delta_{LL})_{i\neq j} = -\frac{3m_0^2 + A_0^2}{16\pi^2} Y_{\nu\, i3} Y_{\nu\, j3} \ln\left(\frac{M_X^2}{M_{R_3}^2}\right)$$

- Due to the presence m_{LL}, m_{RR}, d_e can easily exceed the present experimental bound $d_e < 1.6\ 10^{-27}$ e cm
- In those scenarios d_e is bounded by $Br(\tau \to e\gamma)$

Conclusions

- In some cases LHC is competitive in LFV with the dedicated flavour experiments
- Combining LHC results with the FP results may open window to NP (LFV, CPV, $(g\text{-}2)_\mu$, DM, leptogenesis, neutrino physics etc.)
- Running LHC will be a reality in 2 months
- Good luck!