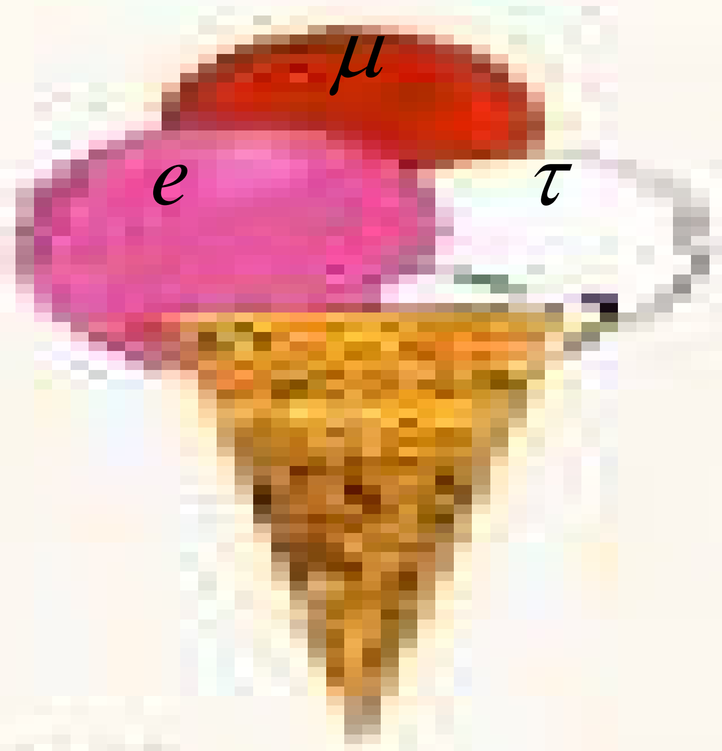
Lepton Flavor Violation at the LHC



why flavor?

flavor is a fundamental puzzle in the SM:

quark sector: small (vastly different) parameters

lepton sector: small parameters in charged lepton masses

$$(m_e, m_\mu, m_\tau) \sim 100\ \mathrm{GeV}\ (10^{-6}, 10^{-3}, 10^{-2})$$

large mixings: much less mysterious on their own
but why so different from quark mixings?

LHC:

flavor not center-stage

focus on new physics behind EWSB

Large Hierarchy Collider

flavor – secondary role: constraints on new physics indeed: FV new physics (if there) is doing a great job of hiding itself:

$$\mathrm{Br}(\mu \to \mathrm{e}\gamma) < 1.2 \cdot 10^{-11} \quad \text{MEGA}$$

$$\mathrm{Br}(\tau \to \mathrm{e}\gamma) < 1.1 \cdot 10^{-7} \quad \text{BABAR}$$

$$\mathrm{Br}(\tau \to \mu\gamma) < 4.5 \cdot 10^{-8} \quad \text{BELLE}$$

...

Ciuchini Masiero Paradisi Silvestrini Vempati Vives 07

also non-FV processes: g-2, EDMs   Feng Matchv YS 01

this talk: CP=0

spreading belief: new physics is flavor blind

flavor blindeness (universality) has become holy grail of new physics

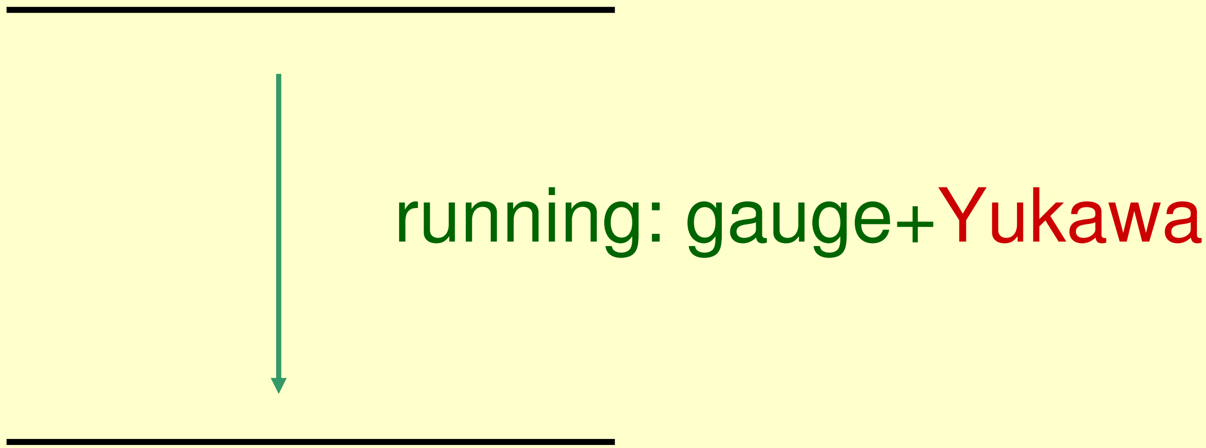
Take SUSY as an example:

- GMSB: by construction:

  superpartner masses determined by gauge interactions
- AMSB: automatically: superpartner masses largely determined by SU(3)xSU(2)xU(1) representations
- Gravity mediation: by “wishful thinking”:

  start with common scalar masses at high scale (mSUGRA)

of course, SM Yukawas are there:



spectrum of new particles sensitive to Yukawas

but Yukawas are only source of flavor violation:

all these models are Minimally Flavor Violating

DAmbrosio,Giudice, Isidori, Strumia

will see:

- this is overkill:

  natural SUSY models that are non-MFV
  (contain new sources of FV in lepton sector)
  and still < current bounds on FV

- If new physics is there and is non-MFV:

1. affects searches for new physics
2. can teach us about flavor

Feng Lester Nir YS 0712.064

why (charged) leptons?

experiment: easy first step:

- "self-tagging": e, μ, τ
  flavor tagging much harder with quarks
- cleaner: energy determination, QCD backgnd

experiment (theory motivated):

sleptons often lightest

GMSB: $\tilde{m}_l^2 \propto \alpha_2^2, \alpha_1^2$

$\tilde{m}_q^2 \propto \alpha_3^2$

mSUGRA: $\tilde{m}_l^2 \supset$ running $\propto \alpha_2^2, \alpha_1^2$

$\tilde{m}_q^2 \supset$ running $\propto \alpha_3^2$

AMSB: sleptons even tachyonic..

$\rightarrow$ sleptons appear at the end of decay chains

measuring their masses should be easier

theory:

neutrinos: mixing is large in the lepton sector

can affect slepton sector

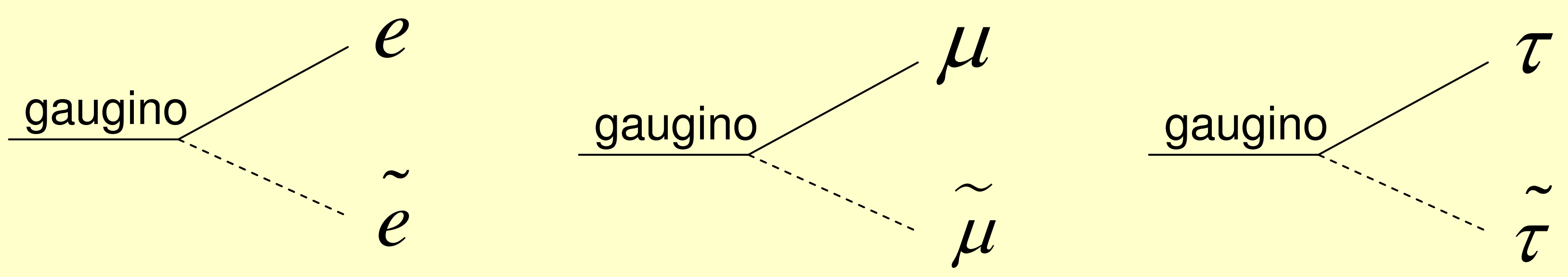
Feng Nir YS

Masina Savoy

Paradisi

....

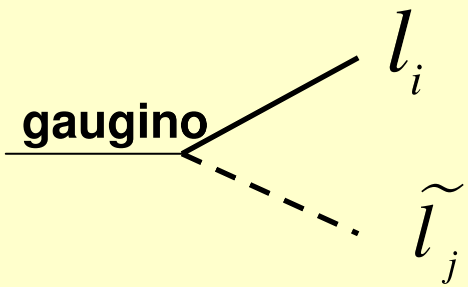
lepton flavor violation in SUSY:



consider $m^2_{slepton}$ in $(\tilde{e},\tilde{\mu},\tilde{\tau})$ basis diagonalize it to form slepton mass eigenstates:

$$\tilde{l}_1, \tilde{l}_2, \tilde{l}_3 \quad m_1, m_2, m_3$$

so: mixings:



$$\propto K_{ij}$$

LFV @ LHC

- if interested in flavor:

1. detecting LFV? LFV signatures?
2. measuring LFV?
    1. slepton mass splittings
    2. slepton mixings
3. lessons about theory of SUSY breaking?

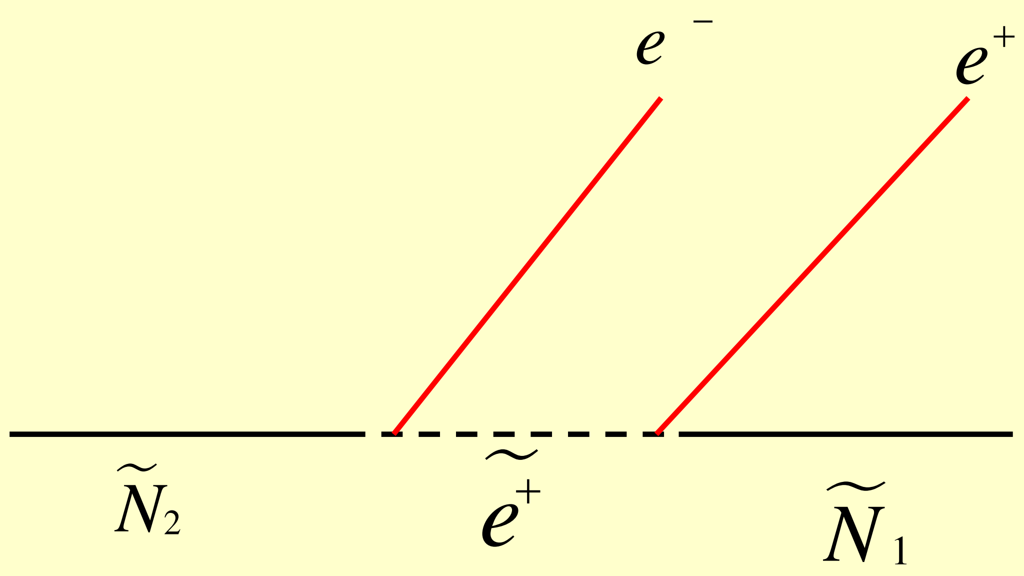
    theory of flavor?

- if not interested in flavor:

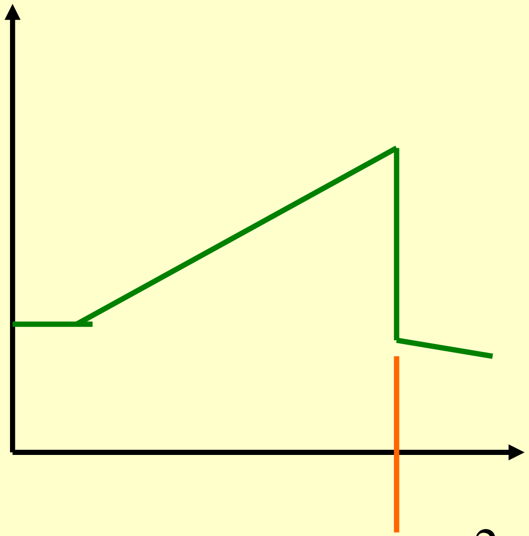
    should we still worry about it?

start with last question:

common tool for measuring superpartner masses (differences): kinematic edges



e+ e- invariant mass has sharp endpoint

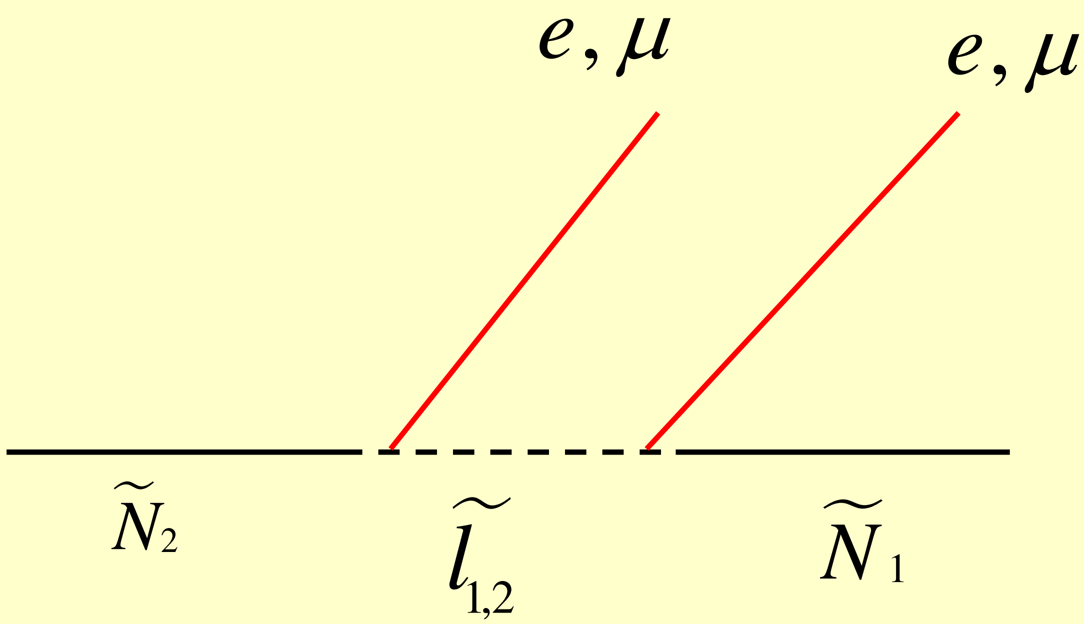


$$m^2_{e+e-}\Big| = (m^2_{N2} - m^2_{\tilde{e}})(m^2_{\tilde{e}} - m^2_{N1})$$

background: uncorrelated leptons:

$$e^+e^- + \mu^+\mu^- - (e^+\mu^- + e^-\mu^+)$$

but what if:



$$\tilde{l}_1 = \cos\theta\ \tilde{e} - \sin\theta\ \tilde{\mu}$$

$$\tilde{l}_2 = \sin\theta\ \tilde{e} + \cos\theta\ \tilde{\mu}$$

with small Δm

→ edge smeared
signal degraded upon subtracting OF

should keep LFV in mind!

but we ARE interested in flavor:

detecting LFV:

Arkani-Hamed Cheng Feng Hall

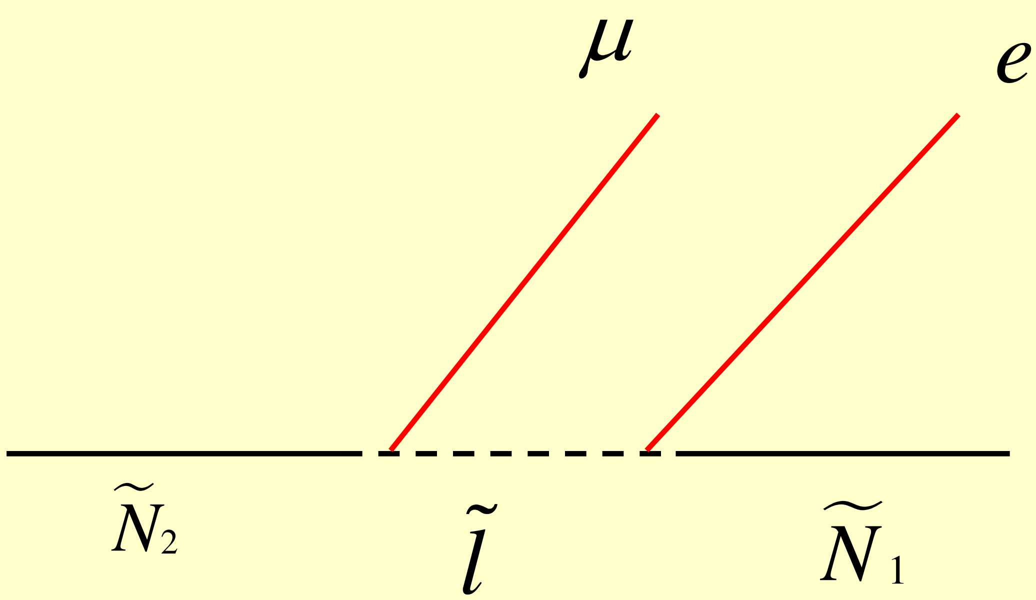
most studies assume mSUGRA-like model:

$$+\ \Delta m^2_{e\mu},\ \ \Delta m^2_{\mu\tau},\ \ \Delta m^2_{e\tau}$$

$$+\ Y_\nu^{\mathrm{Dirac}}$$

Bityukov Krasnikov
Agashe Graesser
Hinchliffe Paige
Hisano Kitano Nojiri
Bartl Hidaka Hohenwarter-Sodek Kernreiter Majerotto Porod
Carvalho Ellis Gomez Lola Roamo
Carquin Ellis Gomez Lola Rodriguez-Quintero
….

- LSP=neutralino, missing energy
- main signature: from neutralino decay:



main bgnd: uncorrelated leptons: SM + SUSY
again: kinematic edges

- in purely MFV models:

  FV below LHC sensitivity

- e mu experimentally easier but

1. most models predict larger effects involving taus
   - stau mass splitting larger because of Yukawa (especially for large tan(beta))

     usually lightest
   - larger mu-tau neutrino mixing
2. constraints on FV in e-mu stronger

backgrounds challenging:

can`t rely on flavor subtraction

$$e^+e^- + \mu^+\mu^- - (e^+\mu^- + e^-\mu^+)$$

• QCD + misidentifications: jets → leptons (taus)

• beyond discovery:
must determine mixings statistically:
no information on event-by-event basis

our models:

Feng Lester Nir YS 0712.0674

+ (in progress) Engelhard French Galon Sanford Yu

main theory difference: non-MFV

Flavor-Violating effects can be substantial

Other examples:

Nomura Papucci Stolarsky

Kribs Poppitz Weiner

- main experimental difference: (first stage!)

  "look for lost coin under lamp"

meta-stable slepton NLSP

everything visible:
no missing energy
reconstruct full event

[eliminate SM bgnd]

models:

$$m^2_{slepton} = \text{GMSB} + \text{gravity mediation}$$

always there (gravity mediation)

$$x \equiv \frac{\text{gravity mediation}}{\text{GMSB}} \leq 1$$

can vary x by dialing messenger scale

can get large mixings even with

GMSB >> gravity mediation

because

identity matrix

arbitrary texture

rare decays?

to suppress rare decays:

flavor symmetry [U(1)xU(1)]

- broken by small parameter λ
- two roles:

1. explains fermion masses:

   small numbers in fermion masses =

   powers of small parameter

2. suppresses FV in slepton sector (alignment):

Nir Seiberg

off diagonal elements in both lepton and slepton mass-matrices are suppressed by powers of small parameter:

$$m_{lepton} \propto \begin{pmatrix} \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & 1 \end{pmatrix} \qquad "\bullet" = O(\lambda^{\#})$$

$$m^2_{slepton} \propto \begin{pmatrix} A & \bullet & \bullet \\ \bullet & B & \bullet \\ \bullet & \bullet & C \end{pmatrix} \qquad A, B, C = O(1)$$

in fermion mass basis:

slepton matrix approximately diagonal

mixings can be small: $O(\lambda^{\#})$

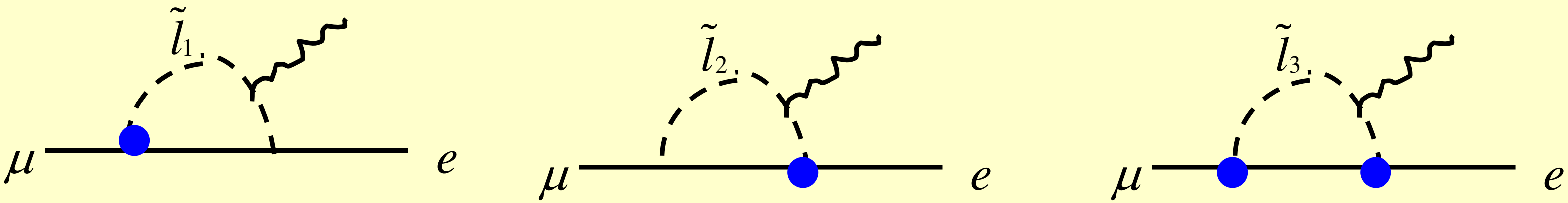
GMSB $\propto$ identity

gravity mediation: small
close to diagonal
(thanks to flavor symmetry)

so flavor constraints taken care of by a combination of:

degeneracy $(\rightarrow \text{ small } \Delta m^2)$

and alignment $(\rightarrow \text{ small } K_{ij})$



R-sector:

$$\frac{(\Delta\widetilde{m}_R)_{21}}{\widetilde{m}_R} \leq 1 \qquad \frac{(\Delta\widetilde{m}_R)_{23}}{\widetilde{m}_R} \leq 1$$

mixings: 1-2 ~ 0.01
1-3 ~ 0.001
2-3 ~ 0.1

MFV models:

$$\frac{(\Delta\widetilde{m})_{21}}{\widetilde{m}} \sim 10^{-6}\tan^2\beta \qquad \frac{(\Delta\widetilde{m})_{23}}{\widetilde{m}} \sim 10^{-4}\tan^2\beta$$

$$\text{for } \tan\beta \sim 10, \quad m \sim 100\text{GeV}:$$

$$(\Delta\widetilde{m})_{21} \sim 10\text{MeV} \quad (\Delta\widetilde{m})_{23} \sim \text{GeV}$$

mixings ~ 0

L-sector:

our models (quite model dependent):

mass splittings: 0.2-20GeV
mixings as high as 0.04

- can we detect this sort of LFV?

[zeroth order: can LHC distinguish between MFV and non-MFV in leptons?]

- can we measure such mass splittings, mixings?

(in progress)

first stage: meta-stable slepton LSP:

- being dominantly GMSB models:

  LSP can be gravitino

  with slepton NLSP

  (selectron, smuon OR stau)

but also possible in SUGRA

- NLSP decays to gravitino outside detector so its track is observed in the muon detector

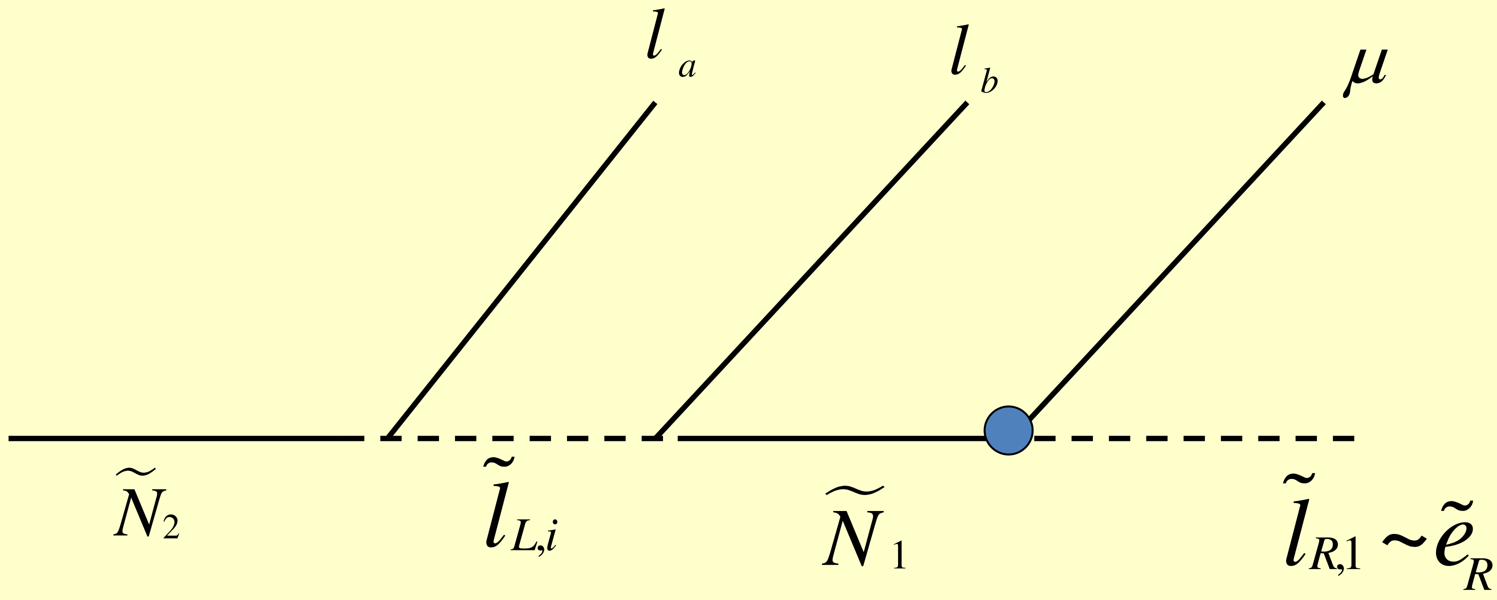
  "slow muon"

EVENT FULLY RECONSTRUCTIBLE

in principle: can measure all masses

observe mixings on event-by event basis

for example:



l_a
l_b
μ
$\widetilde{N}_2$
$\tilde{l}_{L,i}$
$\widetilde{N}_1$
$\tilde{l}_{R,1} \sim \tilde{e}_R$

meta-stable slepton:

- beta<1: must modify trigger, reconstruction

ATLAS: Tarem et al

earlier work: Ambrosanio Mele Petrarca Polesello Rimoldi

Ellis Oye Raklev

- can measure mass

  momentum (probably betas between 0.7-0.9 best)

- no SM background

to conclude:

- new physics need not be flavor blind or MFV

→ flavor could play interesting role at the LHC

- in example today:

hierarchy problem, EWSB: SUSY

SM flavor (masses, mixings): flavor symmetry

(lepton, slepton)$_i$: same charge q_i
under flavor symmetry

lepton masses, slepton masses determined by different combinations of q_i's

measuring slepton masses, mixings: more inputs

(on top of lepton masses) to determine q_i

not only lepton flavor constraining SUSY:

SUSY could answer SM lepton flavor questions