Multi-parameter approach to R-parity violating SUSY couplings

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PHENO 2009

05/11/2009

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R-parity in SUSY

In MSSM super-potential terms that violate B, L are allowed,

$$\hat{f}_T = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^c_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^c_k + \lambda''_{ijk}\hat{U}^c_i\hat{D}^c_j\hat{D}^c_k$$

$$\hat{f}_B = \mu'_i\hat{L}_i\hat{H}_u.$$

$SU(2) \to \lambda$ antisymmetric in ij. $SU(3) \to \lambda''$ antisymmetric in jk.

In order to have stable LSP one imposes R-parity conservation,

$$R = (-1)^{3(B-L)-2S}.$$

- Standard model particles $\to R = 1$
- Superpartners $\to R = -1$
  - Use experimental uncertainties to place bounds on

$$r_{ijk}(\tilde{f}_i) = \sum_i |\lambda_{ijk}|^2/(4\sqrt{2}G_F m^2_{\tilde{f}_i})$$

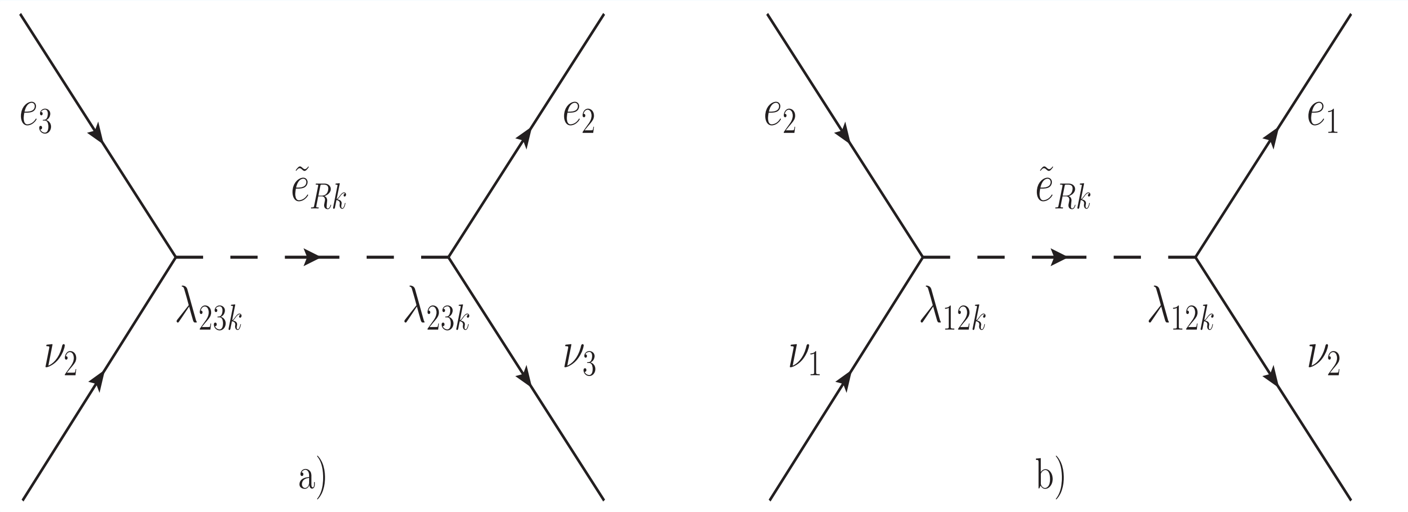
Our approach

- In the literature assumption that a single coupling dominates the R-parity contribution to a process (**SCD**)
- We adopt "multi-parameter" approach to explore new regions of parameter space
- Reduce the degeneracies by considering many experiments together
- Adopt new PDG2008 data
- Consider low energy process with SM particles in initial and final states.

Furthermore,

- $\lambda''_{ijk} = 0$, avoids proton decay
- Mass basis for the $SU(2)$ doublets
- $\mu' = 0$

An example: Muon and tau decays

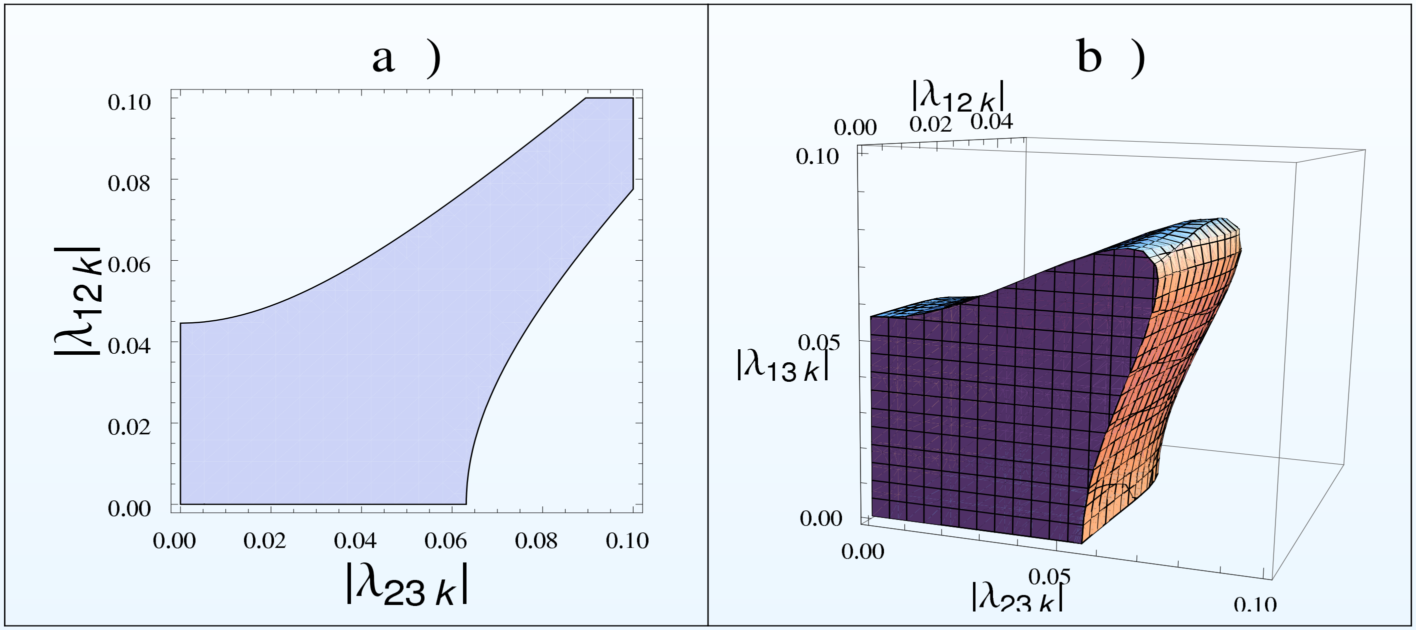


Let us consider the two following ratios:

$$R_{\tau\mu} = \frac{\Gamma(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\Gamma(\mu^- \to e^- \bar{\nu}_e \nu_\mu)} = R_{\tau\mu}^{SM} \left\{1 + 2\left[r_{23k}(\tilde{e}_{Rk}) - r_{12k}(\tilde{e}_{Rk})\right]\right\}$$

$$R_{\tau} = \frac{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}{\Gamma(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)} = R_{\tau}^{SM} \left\{1 + 2\left[r_{13k}(\tilde{e}_{Rk}) - r_{23k}(\tilde{e}_{Rk})\right]\right\}$$

Muon and tau decays



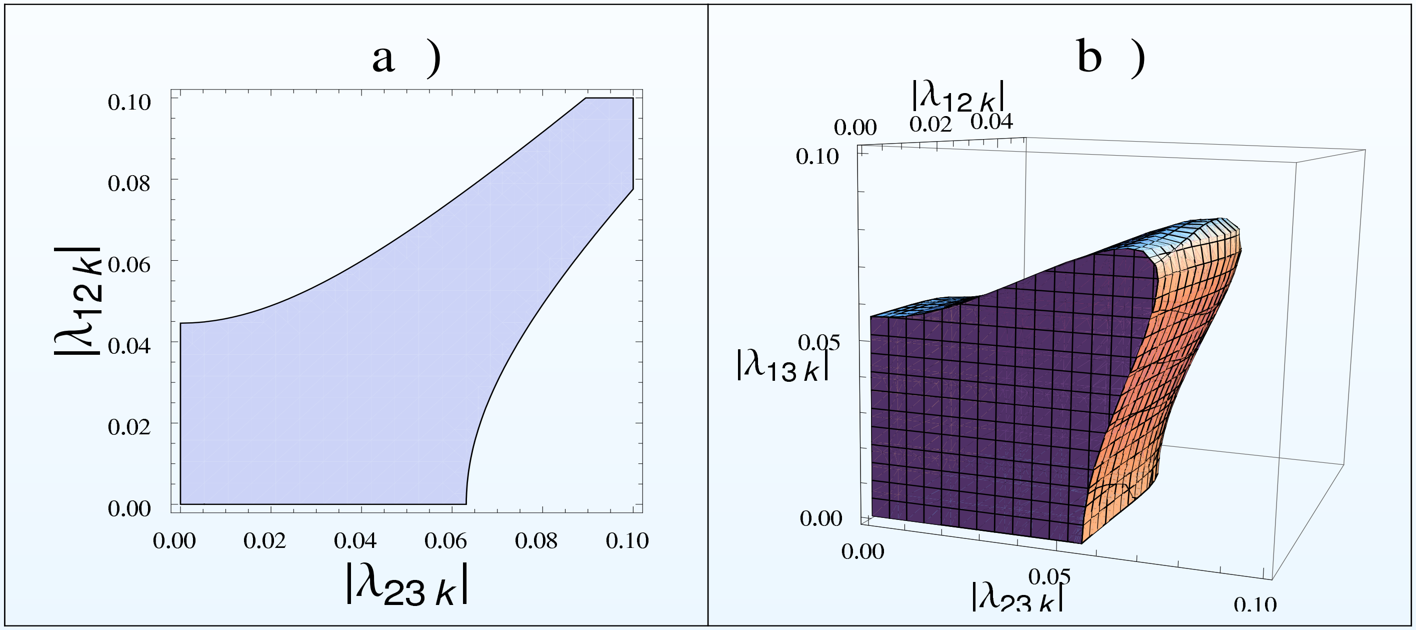
SCD bounds from $R_{\tau\mu}$ visible on the axes of Fig. (a):

- $|\lambda_{23k}| \leq 0.063\ (m_{\tilde{e}_{Rk}}/100\ \text{GeV})$, $|\lambda_{12k}| \leq 0.045\ (\tilde{e}_{Rk})$.

SCD bounds from R_τ:

- $|\lambda_{23k}| \leq 0.051\ (\tilde{e}_{Rk})$, $|\lambda_{13k}| \leq 0.048\ (\tilde{e}_{Rk})$.

Muon and tau decays



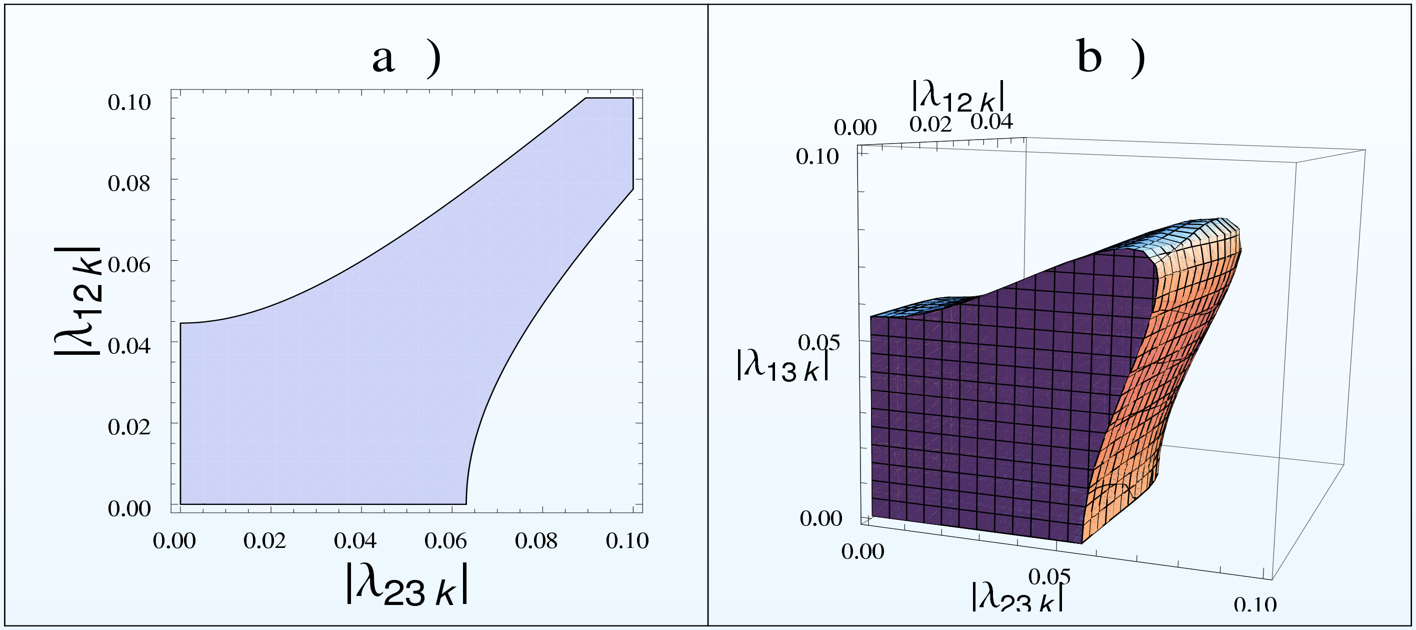
- G_F measured in muon decay $\Rightarrow$

  Lifetime gives bound on $|\lambda_{12k}| \leq 0.037\ (\tilde{e}_{Rk})$

- Combine this process with $R_{\tau\mu}$, R_τ $\Rightarrow$ 3D plot (Fig. b)

  The bulged area is the 2σ allowed region

Muon and tau decays



- Combined 2σ bound correlated parameters:
  (The k-indices in Fig. (b) are free to take any value or the sum)

$$|\lambda_{23k}| \leq 0.066 \; (\tilde{e}_{Rk})$$ SCD: 0.051

$$|\lambda_{13k}| \leq 0.071 \; (\tilde{e}_{Rk})$$ SCD: 0.048

List of processes we consider

Leptonic cases:

- Universality in muon and tau decay (previous case)
- $\nu_\mu - e$ ($\bar{\nu}_\mu - e$) scattering
- $\nu_e - e$ ($\bar{\nu}_e - e$) scattering

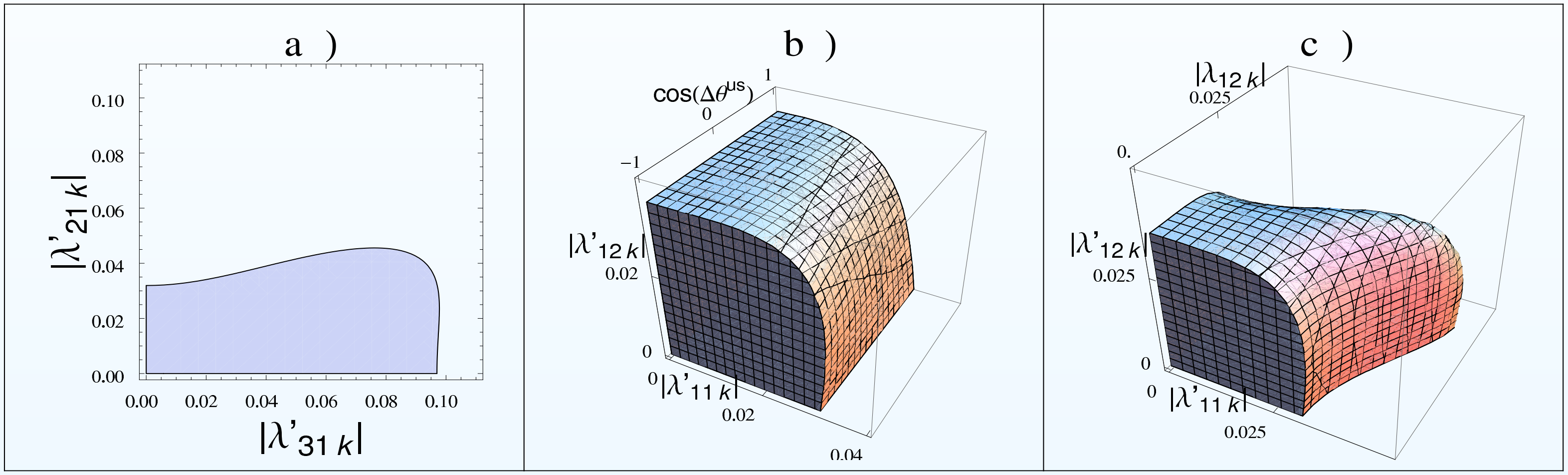
Semi-leptonic cases:

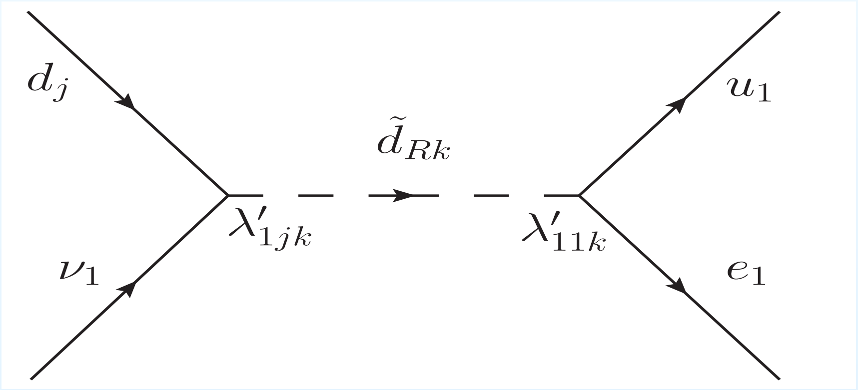
- Universality in pion and tau decay
- Unitarity of CKM matrix
- Forward-backward asymmetry in $e^+e^- \to c\bar{c}$
- Atomic parity violation
- D-meson semi-leptonic decays

Summary of bounds

λ(scale)	Experiment	Corr. λ	SCD Bound	Bound(2σ)
$\lambda_{12k}(m_{\tilde{e}_{Rk}})$	G_μ	none	NA	**0.037**
$\lambda_{121}(m_{\tilde{\mu}_L})$	$\nu_e(\overline{\nu}_e)e$	$\lambda_{131}(m_{\tilde{\tau}_L})$	0.33	**0.36**
$\lambda_{121}(m_{\tilde{e}_L})$	$\nu_\mu e$	$\lambda_{231}(m_{\tilde{\tau}_L})$	0.138	**0.118**
$\lambda_{13k}(m_{\tilde{e}_{Rk}})$	R_τ	$\lambda_{12k}(m_{\tilde{e}_{Rk}}), \lambda_{23k}(m_{\tilde{e}_{Rk}})$	0.048	**0.071**
$\lambda_{131}(m_{\tilde{\tau}_L})$	$\nu_e(\overline{\nu_e})e$	$\lambda_{121}(m_{\tilde{\mu}_L})$	0.33	**0.36**
$\lambda_{23k}(m_{\tilde{e}_{Rk}})$	R_τ	$\lambda_{12k}(m_{\tilde{e}_{Rk}}), \lambda_{13k}(m_{\tilde{e}_{Rk}})$	0.051	**0.066**
$\lambda_{231}(m_{\tilde{\tau}_L})$	$\nu_\mu e$	$\lambda_{121}(m_{\tilde{e}_L})$	0.138	**0.118**
$\lambda'_{11k}(m_{\tilde{d}_{Rk}})$	$CKM_{unitary}$	$\lambda_{12k}(m_{\tilde{e}_{Rk}}), \lambda'_{12k}(m_{\tilde{d}_{Rk}})$	0.027	**0.039**
$\lambda'_{12k}(m_{\tilde{d}_{Rk}})$	$A_{FB}(c\overline{c})$	none	NA	**0.027**
$\lambda'_{22k}(m_{\tilde{d}_{Rk}})$	D_0 decay	$\lambda'_{12k}(m_{\tilde{d}_{Rk}})$	0.10	**0.090**
$\lambda'_{21k}(m_{\tilde{d}_{Rk}})$	$(\pi/\tau)_{universal.}$	$\lambda'_{31k}(m_{\tilde{e}_{Rk}})$	0.032	**0.040**
$\lambda'_{31k}(m_{\tilde{d}_{Rk}})$	$(\pi/\tau)_{universal.}$	$\lambda'_{21k}(m_{\tilde{e}_{Rk}})$	0.092	**0.092**
$\lambda'_{1j1}(m_{\tilde{u}_{Lj}})$	APV	$\lambda_{12k}(m_{\tilde{e}_{Rk}}), \lambda'_{11k}(m_{\tilde{d}_{Rk}})$	0.024	**0.045**
$\lambda'_{32k}(m_{\tilde{d}_{Rk}})$	D_s decay	$\lambda'_{22k}(m_{\tilde{d}_{Rk}}), \lambda'_{12k}(m_{\tilde{d}_{Rk}})$	0.34	**0.29**

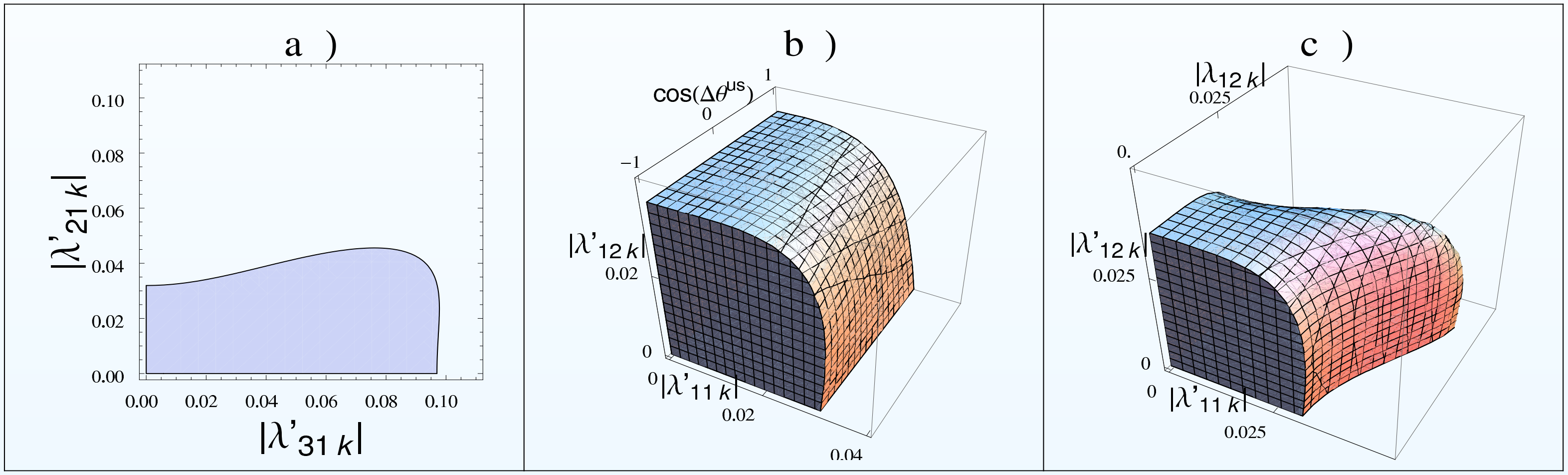
CKM Unitarity (Figs. b, c)





$$d \to ue\bar{\nu}_e \ (j=1) \mid s \to ue\bar{\nu}_e \ (j=2) \mid b \to ue\bar{\nu}_e \ (j=3)$$

CKM Unitarity (Figs. b, c)

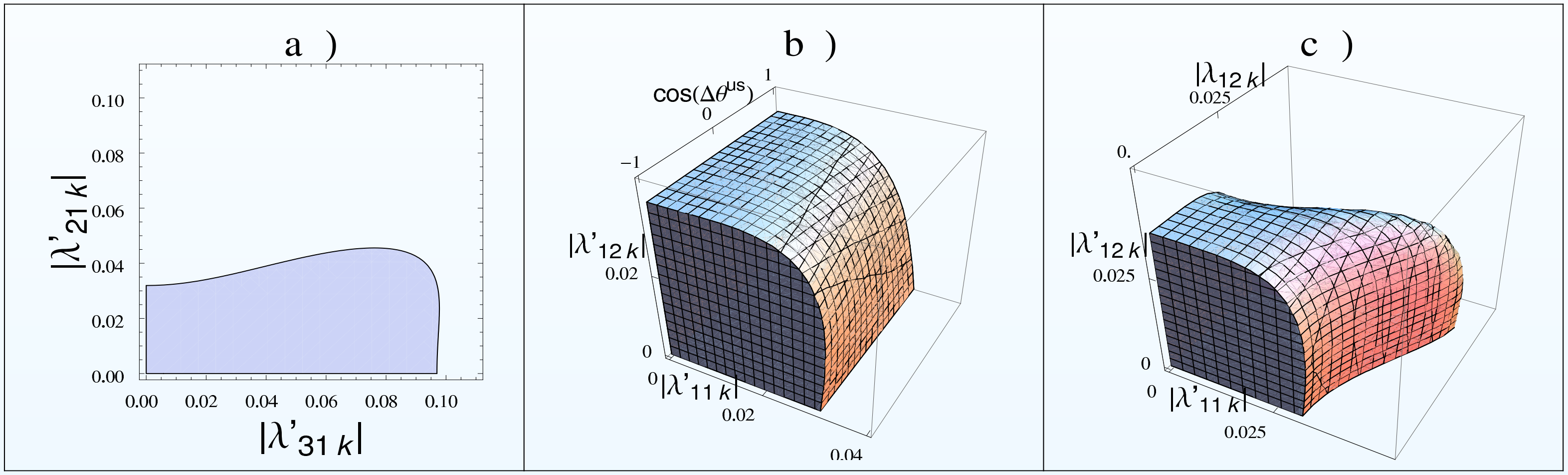


Imposing the unitarity constraint,

$$\sum_{i=1}^{3} |V_{ud_i}|^2 = 1 - 2r_{12k}(\tilde{e}_{Rk}) + 2r'_{11k}(\tilde{d}_{Rk})\,|V_{ud}|$$

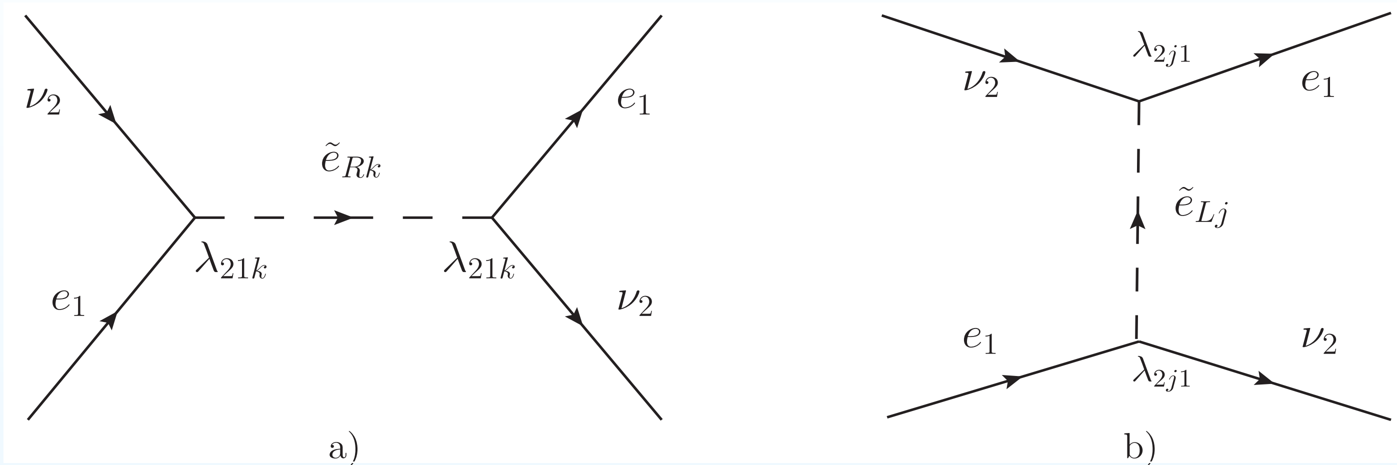
$$+2\left(\sum_k \frac{|\lambda'_{11k}||\lambda'_{12k}|\cos(\Delta\theta_k^{us})}{4\sqrt{2}G_F m^2_{\tilde{d}_{Rk}}}\right)|V_{us}|$$

CKM Unitarity (Figs. b, c)



- Dependence on $\cos(\Delta\theta_k^{us}) \equiv \cos(\theta_{us} + \theta_{12k} - \theta_{11k})$ (b)
  (Here, k-index common to xyz-axes)
- The FB asymmetry in $e^- e^+ \to c\bar{c}$ only involves $\lambda'_{12k} \leq 0.027\ (\tilde{d}_{Rk})$.
- Correction to G_F from μ-decay only involves λ_{12k}.
- Combined 2σ gives (c) $\to |\lambda'_{11k}| \leq 0.039\ (\tilde{d}_{Rk})$ SCD: 0.027.

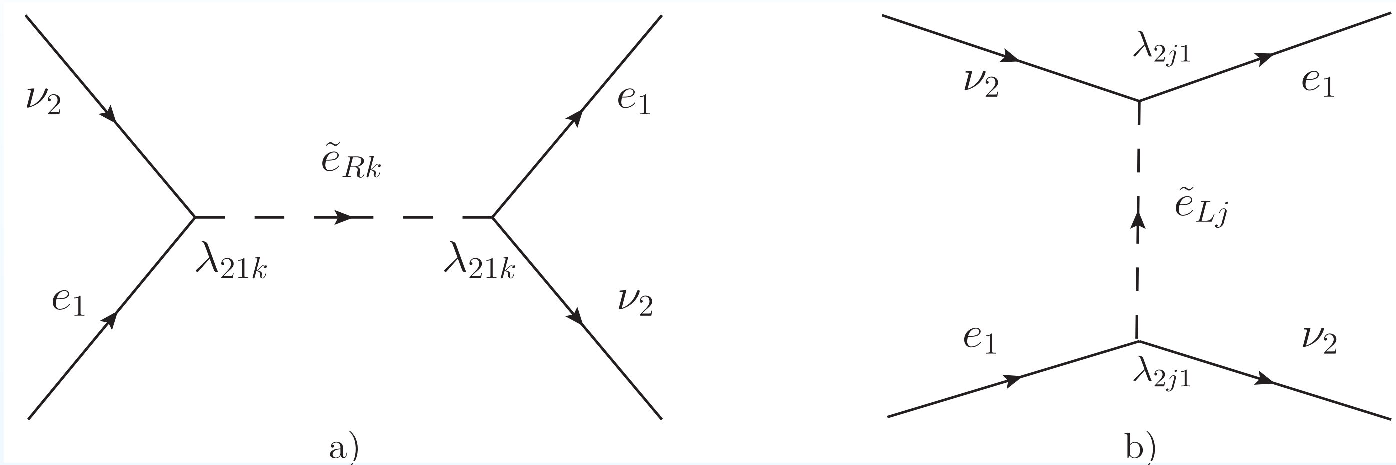
$\nu_\mu - e$ scattering



- CHARM II has extracted g_L, g_R individually from $\sigma_{\text{tot}}(\nu_\mu e)$
- Antisymmetry in i, j allows bounds on individual couplings
- One can use new PDG2008 data for g_A, g_V to get the 2σ bound

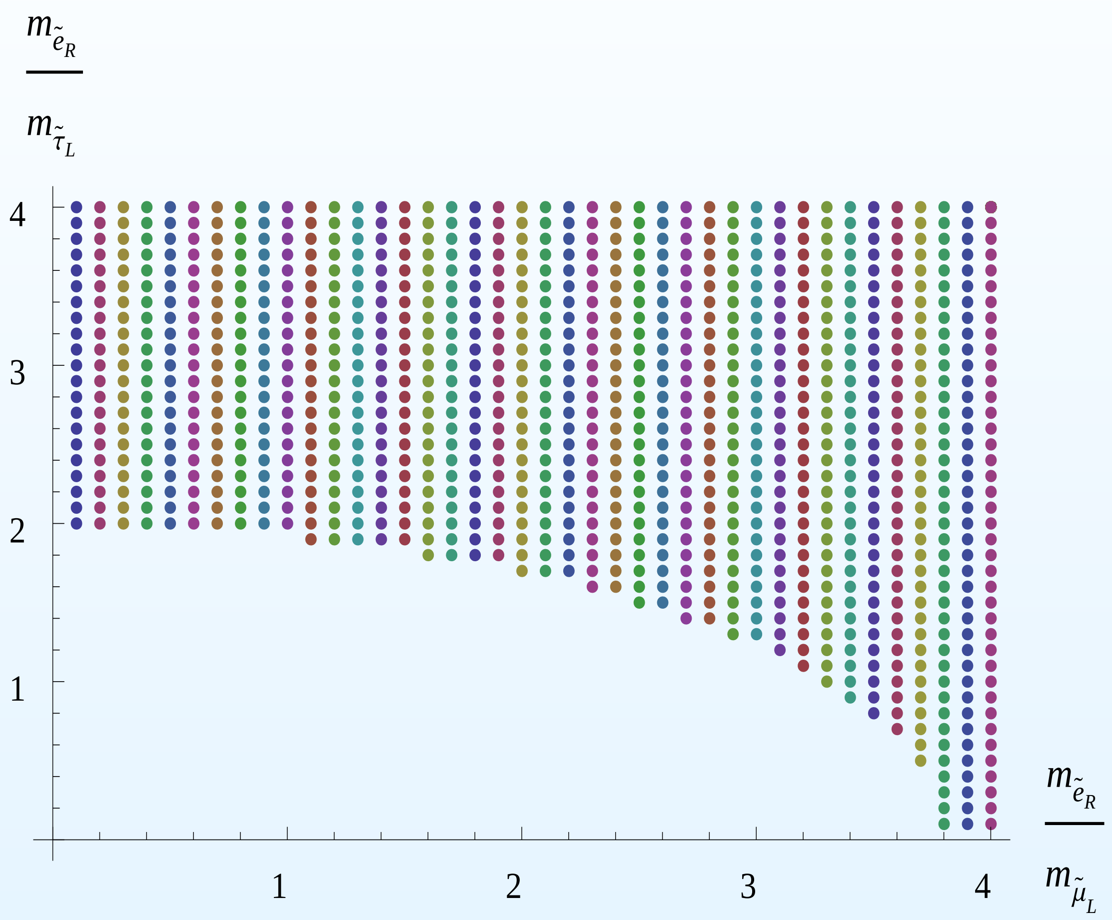
$$\sqrt{[|\lambda_{121}|(m_{\tilde{e}_L})^{-1}]^2 + [|\lambda_{231}|(m_{\tilde{\tau}_L})^{-1}]^2} \leq 0.130$$

$\nu_e - e$ ($\bar{\nu}_e - e$) scattering



- LSND: σ_{tot} from flavor-diag elastic $\nu_e e$ accelerator data ~ 10 MeV
  - $\sqrt{[|\lambda_{121}|(m_{\tilde{\mu}_L})^{-1}]^2 + [|\lambda_{131}|(m_{\tilde{\tau}_L})^{-1}]^2} \leq 0.66$
- Combine the previous result with elastic $\bar{\nu}_e e$ reactor data ~ 1 MeV (Reines, Gurr and Sobel, '76)
  - $\sqrt{[|\lambda_{121}|(m_{\tilde{\mu}_L})^{-1}]^2 + [|\lambda_{131}|(m_{\tilde{\tau}_L})^{-1}]^2} \leq 0.38$
- Additional resolving power due to term $\propto m_e g_L g_R$ (low energy)

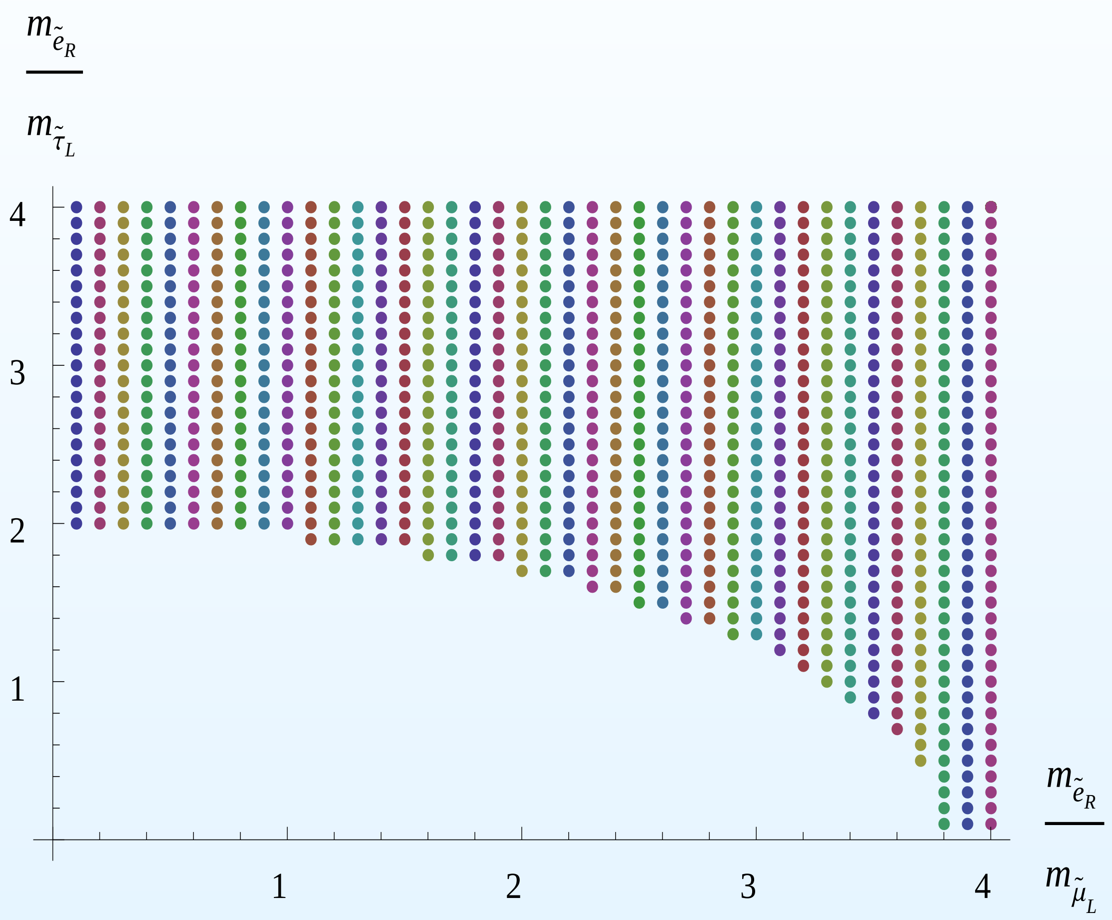
Condition on the masses



Previous bound gives at 1σ:

$$0.14 \leq \sqrt{[|\lambda_{121}|(m_{\tilde{\mu}_L})^{-1}]^2 + [|\lambda_{131}|(m_{\tilde{\tau}_L})^{-1}]^2} \leq 0.34$$

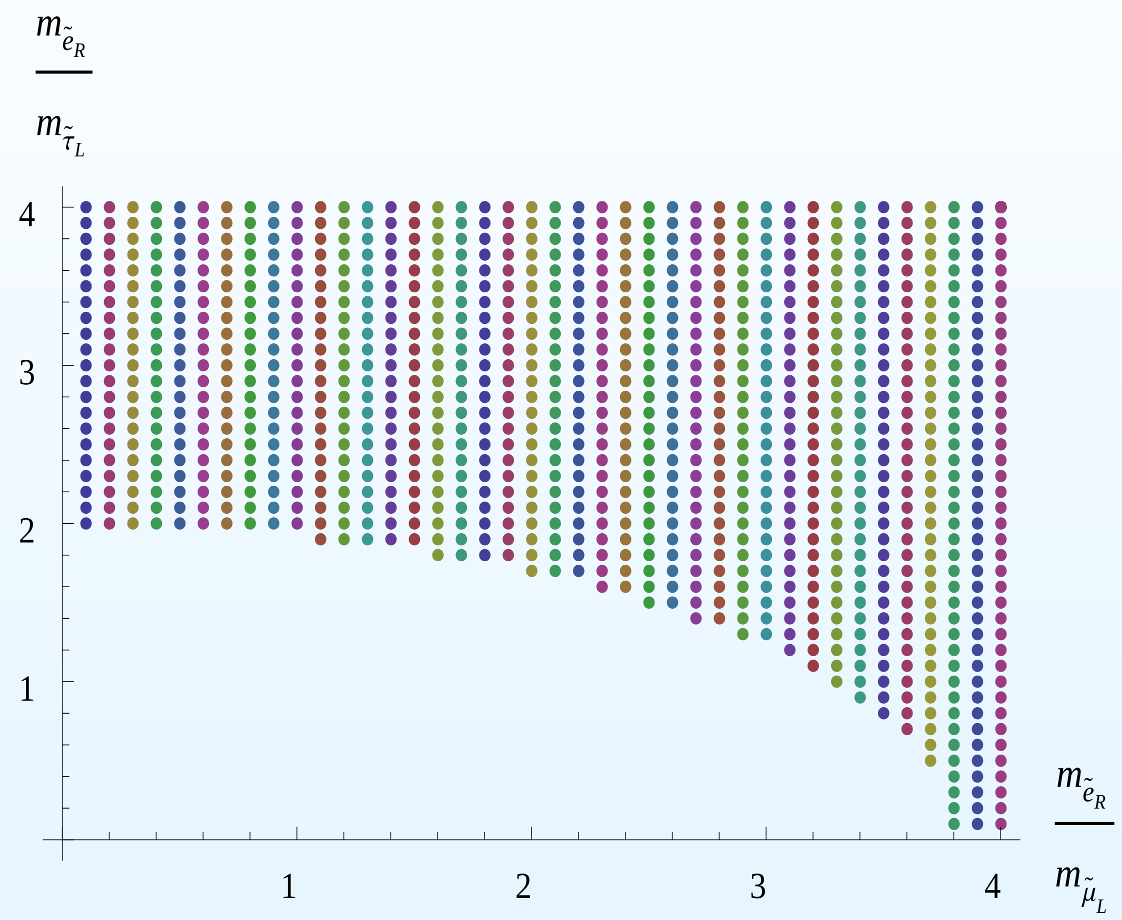
Condition on the masses



Seek consistency with

- G_F correction from μ-decay, $|\lambda_{121}|(100\text{ GeV})/m_{\tilde{e}_R} \leq 0.037$

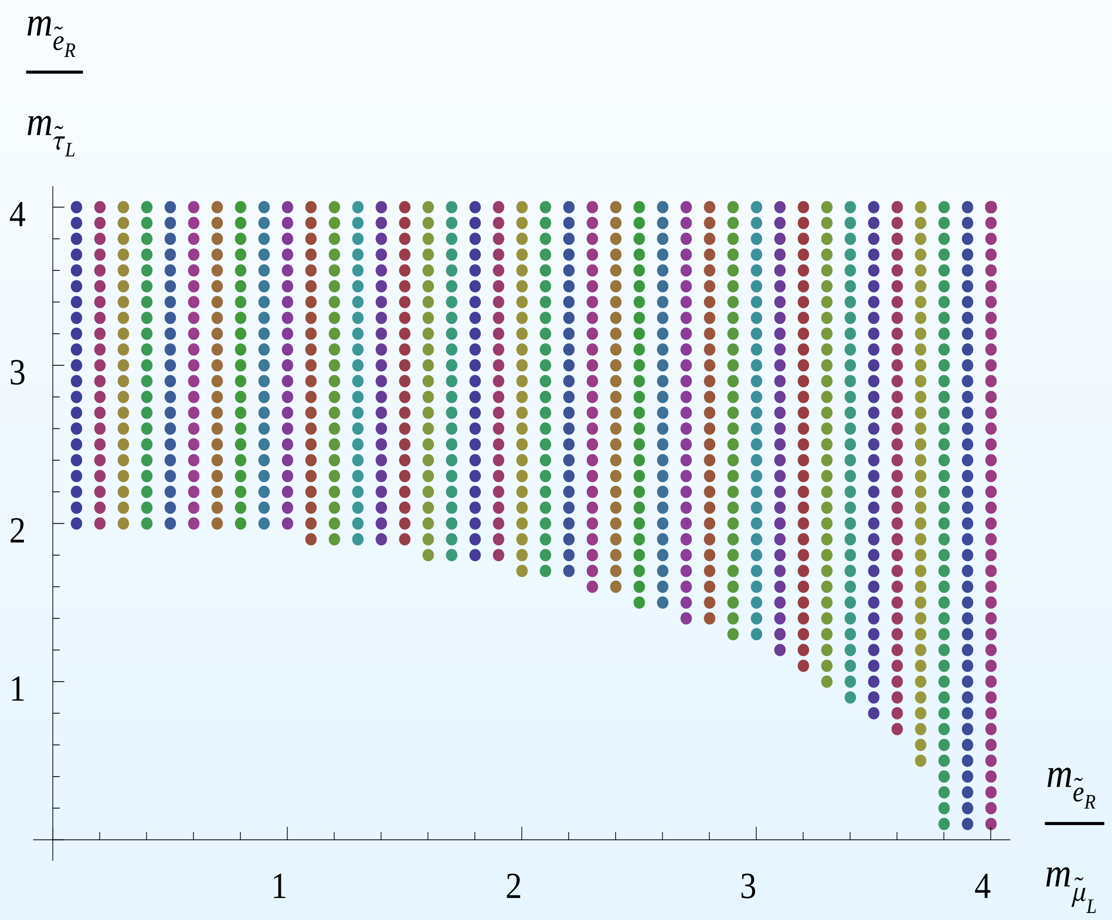
Condition on the masses



And

- τ-decay, $|\lambda_{131}|(\text{100 GeV})/m_{\tilde{e}_R} \leq 0.071$

Condition on the masses



We get a relation between sparticle masses!

The darkened region is allowed.

Summary and Conclusions

- Joint analysis of different experiments involving the same subset of couplings can explore new regions of parameter space
- The new 2σ bounds on individual couplings are generally different from those obtained by SCD
- In the $\bar{\nu}_e e$ case we could extract hierarchical relationships among sfermion masses
- Allowed ranges of parameters were larger by at most factor 2 $\Rightarrow$ Order of magnitude estimate reliable in SCD