Constraints on R-parity Violating Couplings from Precision Electroweak Measurements

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R-parity violation

MSSM

$$+\frac{1}{2}\lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k$$

$$+\frac{1}{2}\lambda''_{ijk} U_i D_j D_k$$

λ_{ijk} are already constrained to be small $O(10^{-2})$

$\because$ violates lepton universality in lepton decays at tree level.

Try to constrain λ'_{ijk} and λ''_{ijk}.

⇒ Look at Z-pole or W-pole observables only.

- ☆ Sensitive to Vertex Corrections
- ☆ Blind to Oblique Corrections
- ☆ No condition on the new physics scale.
- ☆ Can accommodate mixing with extra gauge bosons.
  (treat as vertex correction)
- ☆ No need to specify the model completely
- ☆ Can lead to strong constraints

Z pole observables :

m_Z , $\cancel{\Gamma_Z}$

$$\sigma^0_{had} = \frac{12\pi}{m_Z^2} \frac{\Gamma_{e^+e^-}\Gamma_{had}}{\Gamma_Z^2}$$

$$R_\ell = \frac{\Gamma_{had}}{\Gamma_{\ell^+\ell^-}} \qquad (\ell = e, \mu, \tau)$$

$$A_f = \frac{(g_L^f)^2 - (g_R^f)^2}{(g_L^f)^2 + (g_R^f)^2} \qquad (f = e, \mu, \tau, s, c, b)$$

$$A_{FB}(f) = \frac{3}{4} A_e A_f \qquad (f = e, \mu, \tau, u, s, c, b)$$

$$R_b = \frac{\Gamma_b}{\Gamma_{had}}, \quad R_c = \frac{\Gamma_c}{\Gamma_{had}}$$

$$R_s' = \frac{\Gamma_s}{\Gamma_u + \Gamma_d + \Gamma_s}$$

Ratios of coupling constants

$\Rightarrow$ Depends on Oblique Corrections only through $\underline{\sin^2\theta_W}$.

Simplifying Approximations :

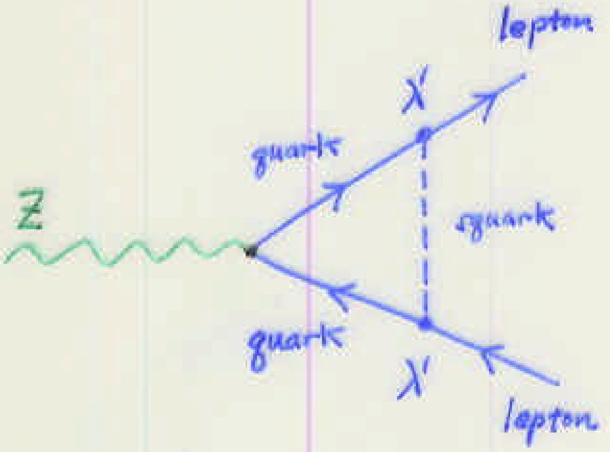
- ★ Take all quarks and leptons to be massless except the top.
- ★ Take all slepton masses to be degenerate.
- ★ Take all squark masses to be degenerate.

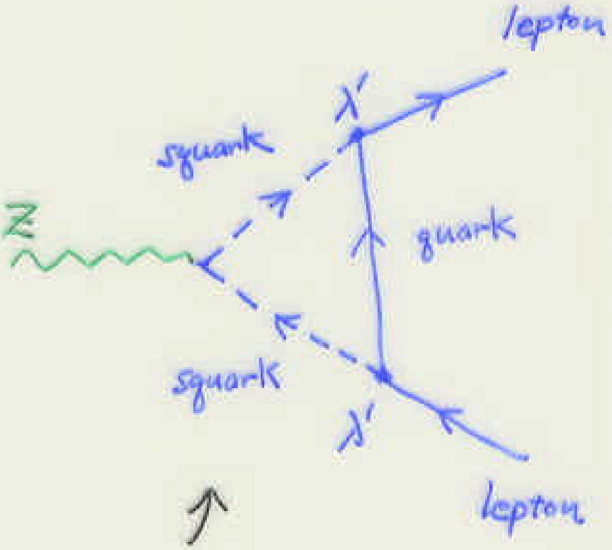
of W and Z couplings

⇒ flavor dependence only from
R-parity violating couplings and
Higgs coupling to the left-handed bottom.

$\lambda'_{ijk} L_i Q_j D_k$

↳ corrects W and Z coupling to i-th generation left handed lepton.

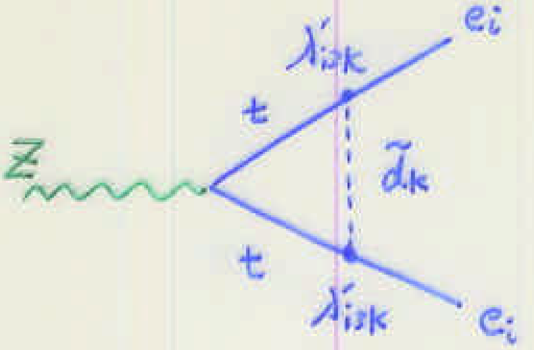


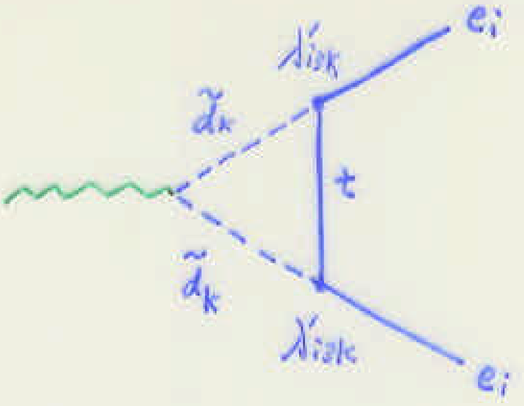


depend on quark and squark masses

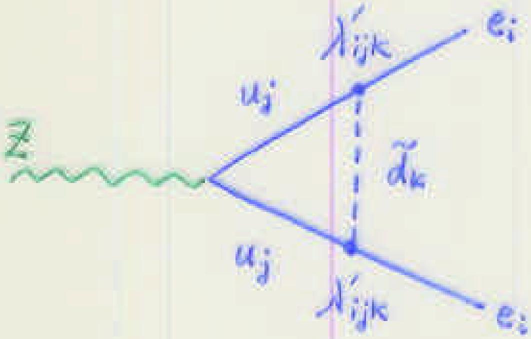
$\Downarrow$

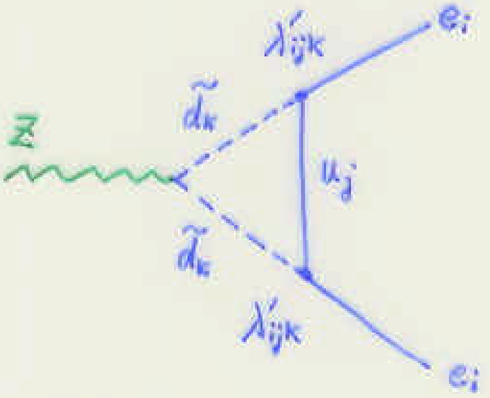
Must consider the diagrams with the top $(j=3)$ separately.





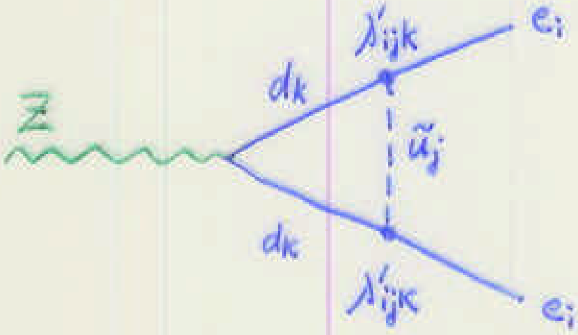
$$\delta h^{(u)}_{i3k} = +0.63\% \, |\lambda'_{i3k}|^2$$ ← squark mass = 100 GeV

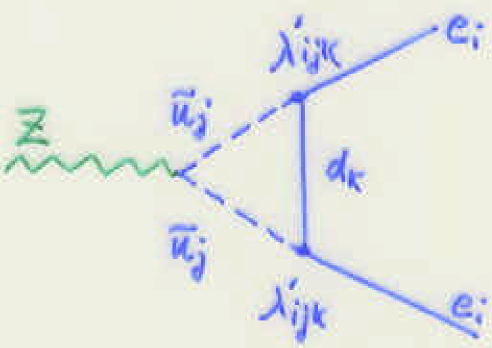




$(j \neq 3)$

$$\delta h^{(u)}_{ijk} = -0.02\% \, |\lambda'_{ijk}|^2$$





$$\delta h^{(d)}_{ijk} = -0.06\% \, |\lambda'_{ijk}|^2$$

☆ Keep only top-quark diagrams.

$$\delta h_i^{\not{R}} \approx \sum_k \delta h_{i3k}^{(u)} = +0.63\% \sum_k |\lambda'_{i3k}|^2$$

Shift in left handed coupling of i-th lepton

$$R_\ell = \frac{\Gamma_{had}}{\Gamma_{\ell\bar{\ell}}} = \frac{N_c \sum_q (h_{qL}^2 + h_{qR}^2)}{h_{\ell L}^2 + h_{\ell R}^2} \quad (\ell = e, \mu, \tau)$$

$$\frac{\delta R_\ell}{R_\ell} = \Delta_R + 4.3\, \delta h_\ell^{\not{R}}$$

$$A_\ell = \frac{h_{\ell L}^2 - h_{\ell R}^2}{h_{\ell L}^2 + h_{\ell R}^2}, \quad A_{FB}(\ell) = \frac{3}{4} A_e A_\ell$$

$$\frac{\delta A_\ell}{A_\ell} = \Delta_A - 25\, \delta h_\ell^{\not{R}}$$

$$\frac{\delta A_{FB}(\ell)}{A_{FB}(\ell)} = 2\Delta_A - 25\, \delta h_e^{\not{R}} - 25\, \delta h_\ell^{\not{R}}$$

5 parameters : Δ_R, Δ_A, $\delta h_e^{\not{R}}$, $\delta h_\mu^{\not{R}}$, $\delta h_\tau^{\not{R}}$

$$
\left\{
\begin{aligned}
\Delta_{Re} &\equiv \Delta_R + 4.3\,\delta h_e^{\pi} \\
\Delta_{Ae} &\equiv \Delta_A - 25\,\delta h_e^{\pi} \\
\delta_{\mu e} &\equiv \delta h_\mu^{\pi} - \delta h_e^{\pi} \\
\delta_{\tau e} &\equiv \delta h_\tau^{\pi} - \delta h_e^{\pi}
\end{aligned}
\right.
$$

$$\downarrow$$

$$
\left\{
\begin{aligned}
\Delta_{Re} &= 0.0007 \pm 0.0020 \\
\Delta_{Ae} &= 0.052 \pm 0.012 \\
\delta_{\mu e} &= 0.00038 \pm 0.00056 \\
\delta_{\tau e} &= -0.00013 \pm 0.00061
\end{aligned}
\right.
$$

$$\downarrow$$

$$
\left\{
\begin{aligned}
\sum_k |\lambda'_{23k}|^2 - \sum_k |\lambda'_{13k}|^2 &= 0.062 \pm 0.093 \\
\sum_k |\lambda'_{33k}|^2 - \sum_k |\lambda'_{13k}|^2 &= -0.02 \pm 0.10
\end{aligned}
\right.
$$

Neglect λ'_{13k} (already well constrained)

$$\begin{cases} \sum_k |\lambda'_{23k}|^2 \le 0.16 \ (0.25) \\ \sum_k |\lambda'_{33k}|^2 \le 0.08 \ (0.18) \end{cases}$$

$$\downarrow$$

$$\begin{cases} |\lambda'_{23k}| \le 0.40 \ (0.50) \\ |\lambda'_{33k}| \le 0.28 \ (0.42) \end{cases}$$

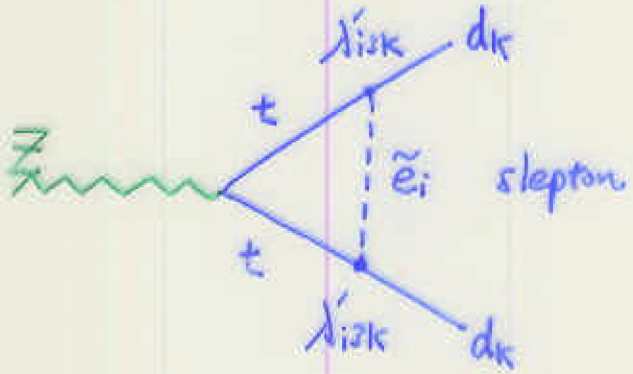
Limit from W-decay

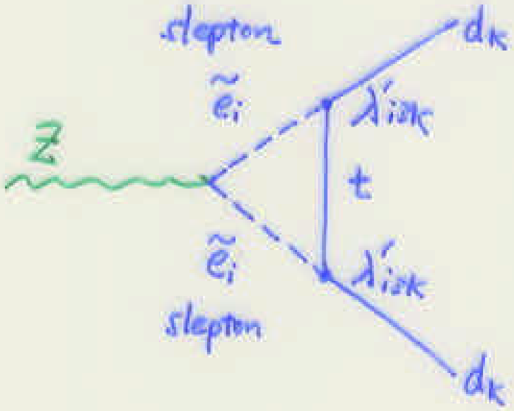
$$|\lambda'_{33k}| \le 1.7 \ (2.4)$$

$\lambda'_{ijk} L_i Q_j D_k$

only top

corrects right-handed down-type quark couplings.



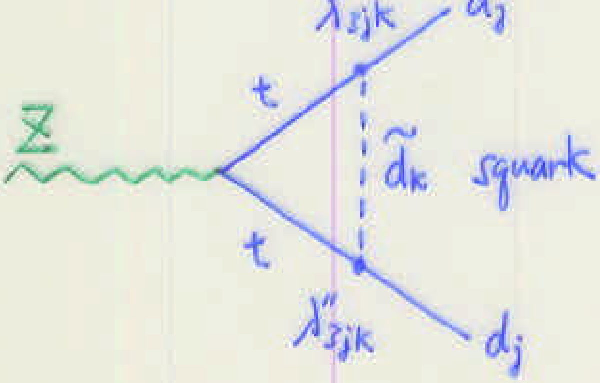


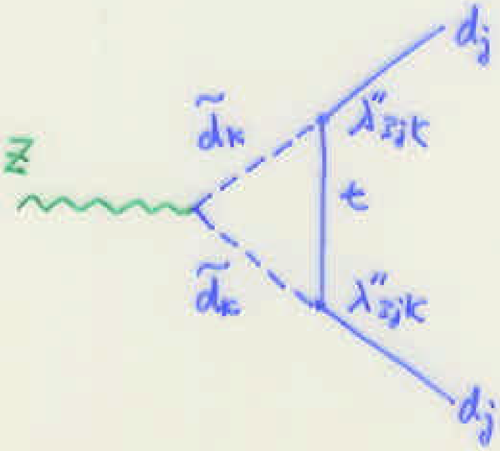
$\frac{1}{2} \lambda''_{ijk} U_i D_j D_k$

top

antisymmetric

corrects right-handed down-type quark couplings





Flavor Dependent shifts :

$$\delta h_d^{R} \,,\ \delta h_s^{R} \,,\ \delta h_b^{R} \,,\ \delta h_b^{Higgs}$$

shift to left-handed coupling of the b.

Flavor Independent shifts :

$$\delta s^2$$

shift in effective value of $\sin^2\theta_W$.

5 parameter fit

$$\left\{ \begin{aligned} \delta s^2 &= -0.00092 \pm 0.00022 \\ \delta h_d^{R} &= 0.081 \pm 0.077 \\ \delta h_s^{R} &= 0.055 \pm 0.043 \\ \delta h_b^{R} &= 0.026 \pm 0.010 \\ \delta h_b^{Higgs} &= -0.0031 \pm 0.0042 \end{aligned} \right.$$

$$\delta h^{*}_{d_k} = -\,0.215\% \sum_i |\lambda'_{i3k}|^2$$

$$= -\,0.43\% \sum_j |\lambda''_{3jk}|^2$$

$$\left\{\begin{array}{l} \sum_i |\lambda'_{i31}|^2 \le -2\ (34)\,[70] \\ \sum_i |\lambda'_{i32}|^2 \le -6\ (14)\,[34] \\ \sum_i |\lambda'_{i33}|^2 \le -7.4\ (-2.8)\,[1.9] \end{array}\right. \rightarrow \left\{\begin{array}{l} |\lambda'_{i31}| \le (5.8)\,[8.4] \\ |\lambda'_{i32}| \le (3.8)\,[5.9] \\ |\lambda'_{i33}| \le (-)\,[1.4] \end{array}\right.$$

$$\left\{\begin{array}{l} \sum_k |\lambda''_{31k}|^2 \le -1\ (17)\,[35] \\ \sum_k |\lambda''_{32k}|^2 \le -3\ (7)\,[17] \\ \sum_k |\lambda''_{33k}|^2 \le -3.7\ (-1.4)\,[0.9] \end{array}\right. \rightarrow \left\{\begin{array}{l} |\lambda''_{321}| \le (2.7)\,[4.1] \\ |\lambda''_{33i}| \le (-)\,[0.96] \end{array}\right.$$

Conclusions

☆ To go beyond the standard STU analysis, look at vertex corrections at the Z and W poles.

☆ Application of the technique places strong constraints on R-parity violating couplings.