A study of Lepton Flavor Violating process in $Z_0 \rightarrow \mu^+\tau^-$ Minimal Supersymmetric Standard Model

Martin Poláček

Katedra teoretickej fyziky a didaktiky fyziky
FMFI UK
Mlynská Dolina
842 48 Bratislava

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Standard Model and need for new theory

- Standard Model:The most precise theory mankind has ever had
- How do we know?
- A precise measurement of *Anomalous magnetic moment*
  A precise theoretical SM calculations
- discrepancy $\sim 10^{-8}$

Standard Model and need for new theory

- Standard Model is low energy approximation of some new and more complete theory
- Standard Model does not include gravity
- Neutrino masses, neutrino oscillation
- Hierarchy problem ?
- Gauge couplings never meet
- Standard Model requires 19 *ad-hoc* constants

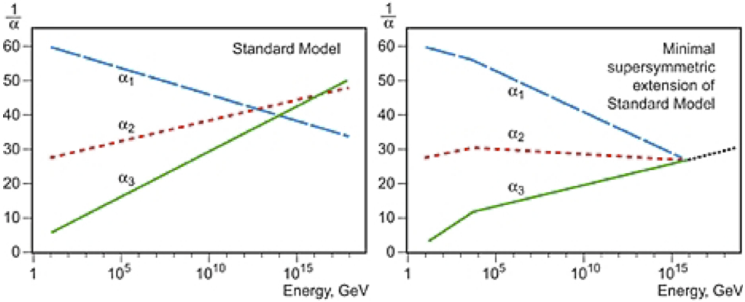
Standard Model and need for new theory

- Hierarchy problem ?
  Standard Model contains parameter with the dimension of energy: vacuum expectation value of Higgs field $v \approx 246\ GeV$
- v introduces scale
  all masses in the theory are proportional to v, for example:
  $M_W \approx \frac{g}{2} v \sim 80\ GeV$ or $M_H = v\sqrt{\frac{\lambda}{2}} \sim 100\ GeV$
- radiative corrections to Higgs mass are quadratically dependent on cutoff Λ
- radiative corrections to all the other SM particles are logarithmically dependent on cutoff Λ, they are protected by symmetries.
- We should expect that Higgs mass is also protected by some symmetry.

Supersymmetry

- There is such symmetry: **Supersymmetry**
  What it is?
- Symmetry between *fermions* and *bosons*
- Supersymmetry can protect Higgs mass
- Supersymmetry is possible non-trivial extension of *Poincaré* algebra
- In supersymmetry the gauge coupling constants meet at one point
- Has many other nice features: Dark matter candidate, Electroweak symmetry breaking,...
- Has also problems: μ problem, smalness of the CP violating phases, $\sim$ 100 free parameters,...

Supersymmetry



Why LFV process?

- Why lepton flavor violating process?
  There is no such process in the Standard Model with massless neutrinos
  SM with neutrino masses $Br(Z_0 \rightarrow \mu^+\tau^-) \sim 10^{-60}$ - can not be reached
- $Z_0 \rightarrow \mu^+\tau^-$ observation is clear signal of new physics.
- Present experimental limit obtained at LEP:
  $Br(Z_0 \rightarrow \mu^+\tau^-) \leq 10^{-5}$
- We give one-loop level prediction of $Br(Z_0 \rightarrow \mu^+\tau^-)$ in MSSM

Calculation

- Effective lagrangian calculation:

$$\begin{aligned}\mathcal{L}^{eff}_{Z_0\to\mu\,\tau} = & \quad g_Z\,[\,m_Z^2\,(\,F_L^Z\,\mu\,\bar\sigma^\epsilon\,\tau) + F_R^Z\,\mu^c\,\sigma^\epsilon\,\bar\tau)\,Z_\epsilon - \\ & - \quad 2\,m_\tau\,(\,D_L^Z\,\bar\mu\,\bar\sigma^{\epsilon\nu}\,\bar\tau^c + D_R^Z\,\mu^c\,\sigma^{\epsilon\nu}\,\tau\,)\,i\,\partial_\nu\,Z_\epsilon\,] + \\ & + \quad h.c.\end{aligned}$$

$$\begin{aligned}\mathcal{L}^{eff}_{Z_0\to\mu\,\tau} = & \quad g_Z\,[\,m_Z^2\,(\,F_L^Z\,\bar\psi_\mu\,\gamma^\epsilon\,P_L\,\psi_\tau + F_R^Z\,\bar\psi_\mu\,\gamma^\epsilon\,P_R\,\psi_\tau\,)\,Z_\epsilon - \\ & - \quad m_\tau\,(\,D_L^Z\,\bar\psi_\mu\,\sigma^{\epsilon\nu}\,P_R\,\psi_\tau + D_R^Z\,\bar\psi_\mu\,\sigma^{\epsilon\nu}\,P_L\,\psi_\tau\,)\,\partial_\nu\,Z_\epsilon] + \\ & + \quad h.c.\end{aligned}$$

Calculation

- Branching ratio (in c.m.s):

$$Br\,(\,Z_0 \to \mu^+\,\tau^-\,) = c\,m_{Z^0}^4 \left[\,|F_L^Z|^2 + |F_R^Z|^2 + \frac{1}{2}\left|\frac{m_\tau}{m_{Z^0}}\,D_L^Z\right|^2 + \frac{1}{2}\left|\frac{m_\tau}{m_{Z^0}}\,D_R^Z\right|^2\right] Br\,(\,Z^0 \to \bar{e}\,e)$$

where constants :
$c = (\,\frac{1}{4} - s_W^2 + 2\,s_W^4\,)^{-1}$
$Br\,(\,Z^0 \to \bar{e}\,e) \approx 3.4\,\%.$

What next?

- We need to calculate F_L^Z, F_R^Z, D_L^Z and D_R^Z in the MSSM.
- MSSM lagrangian

$$\mathcal{L}_{MSSM} = \mathcal{L}_{kinetic} - V_Y - V_F - V_D - V_{\tilde{\lambda}\,\psi\,\tilde{\phi}} + \mathcal{L}_{SOFT}$$

where :

$\mathcal{L}_{kinetic}$

$V_Y \propto W^{ij}\,\psi_i\,\psi_j + h.c.$ $\qquad W^{ij} = \frac{\delta^2}{\delta\,\phi_i\,\phi_j} W_{MSSM}$

$V_F \propto \sum_i \left| \frac{\delta}{\delta\,\phi_i} W_{MSSM} \right|^2$

$V_D \propto \sum g_G (\phi^*\, T^a\, \phi)^2$

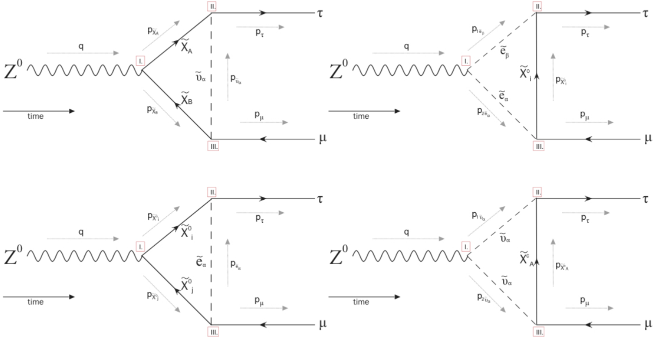
$V_{\tilde{\lambda}\,\psi\,\tilde{\phi}} = g\sqrt{2}\,(\phi^*\, T^a\, \psi)\,\lambda^a + h.c$

$$W_{MSSM} = \tilde{u}^c\, Y_u\, \tilde{Q}\, H_u - \tilde{d}^c\, Y_d\, \tilde{Q}\, H_d - \tilde{e}^c\, Y_e\, \tilde{L}\, H_d + \mu\, H_u\, H_d$$

$$
\begin{aligned}
\mathcal{L}_{\not{SOFT}} = & - \frac{1}{2}\left(M_{\tilde{g}}\, \tilde{g}^a\, \tilde{g}^a + M_{\tilde{W}}\, \tilde{W}^i\, \tilde{W}^i + M_{\tilde{B}}\, \tilde{B}\, \tilde{B} \right) + h.c. \\
& + \left(- \tilde{u}^c\, Z_u\, \tilde{Q}\, H_u + d^c\, Z_d\, \tilde{Q}\, H_d + \tilde{e}^c\, Z_e\, \tilde{L}\, H_d \right) + h.c. \\
& - \left(\tilde{Q}^\dagger\, m_Q^2\, \tilde{Q} + \tilde{L}^\dagger\, m_L^2\, \tilde{L} + \tilde{u}^{c\,*}\, m_{u^c}^2\, \tilde{u}^c + \right. \\
& + \left. \tilde{d}^{c\,*}\, m_{d^c}^2\, \tilde{d}^c + \tilde{e}^{c\,*}\, m_{e^c}^2\, \tilde{e}^c \right) - \\
& - m_{H_u}^2\, H_u^*\, H_u - m_{H_d}^2\, H_d^*\, H_d - b\, H_u\, H_d + h.c.
\end{aligned}
$$

What next?

- Four Feynman diagrams:



Results

- We obtained theoretical prediction of $Br(Z_0 \to \mu^+\tau^-) \sim 10^{-8}$
- Our result is of the typical range of LFV processes
- study of LFV processes is highly actual
- Study of this process is a part of bigger project

$\tan(\beta)$ vs $Br(Z_0 \rightarrow \mu^+\tau^-)$