Tau polarization in SUSY cascade decays at LHC

Kentarou Mawatari
(馬渡 健太郎)
KIAS
KOREA INSTITUTE FOR ADVANCED STUDY

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  "Tau polarization in SUSY cascade decay"
  with S.Y.Choi (Chonbuk U.), K.Hagiwara (KEK), Y.G.Kim (Sejong U.), P.M.Zerwas (DESY/Aachen)

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  "Spin analysis of supersymmetric particles"
  with S.Y.Choi (Chonbuk U.), K.Hagiwara (KEK), H-U.Martyn, P.M.Zerwas (DESY/Aachen)

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1. Introduction: SUSY cascades

- Provide a rich source of information on SUSY particles and the structure of the underlying theory.
- The SPS1a cascade

$$\tilde{q} \underset{30\%}{\longrightarrow} q\tilde{\chi}_2^0 \underset{\substack{10\%\text{ for } e,\mu \\ 90\%\text{ for } \tau}}{\longrightarrow} q\ell\tilde{\ell} \underset{100\%}{\longrightarrow} q\ell\ell\tilde{\chi}_1^0$$

LSP (escape detection) ← $\tilde{\chi}_1^0$

- So far, the cascade have primarily been studied involving 1st and 2nd generation leptons/sleptons.
  - We focus on the 3rd generation.

1. Introduction: Tau polarization

- How the tau polarization can be exploited to study chirality and mixing effects in both the neutralino and stau sectors.

- As polarization analyzer, we use single pion decays of the tau's.

$z = E_\pi / E_\tau$

$$(\tau_R)^\pm \to \overset{(-)}{\nu}_\tau \, \pi^\pm \quad : \quad F_R = 2z \qquad \text{(hard fragment)}$$

$$(\tau_L)^\pm \to \overset{(-)}{\nu}_\tau \, \pi^\pm \quad : \quad F_L = 2(1-z) \qquad \text{(soft fragment)}$$

- For notational convenience we characterize the tau states by chirality (not helicity).
- The techniques can readily be applied to other decay modes, e.g., ρ and a_1.

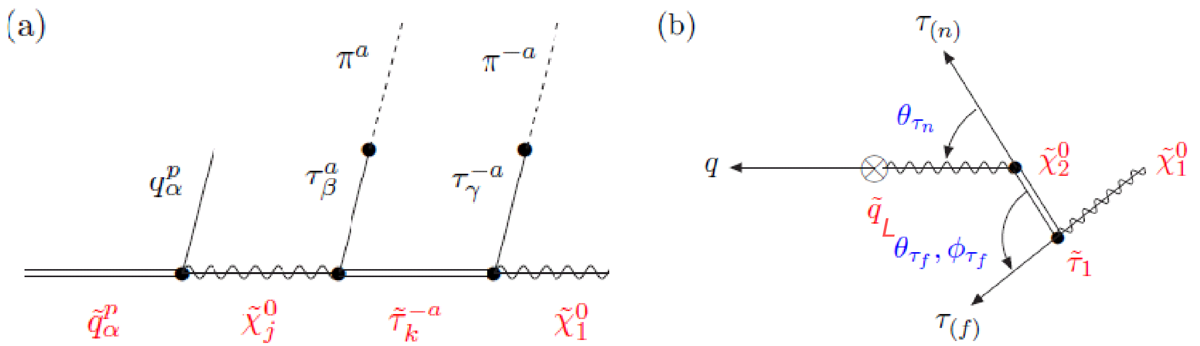
2. Invariant mass distributions

- tau-tau vs pi-pi invariant mass distribution

The distribution of the visible final state particles in the squark cascade

- $$\frac{1}{\Gamma_{\tilde{q}_\alpha}} \frac{d\Gamma^{pa;jk}_{\alpha\beta\gamma}}{d\cos\theta_{\tau_n} d\cos\theta_{\tau_f} d\phi_{\tau_f}} = \frac{1}{8\pi} \mathrm{B}(\tilde{q}_\alpha \to q_\alpha \tilde{\chi}^0_j)\, \mathrm{B}(\tilde{\chi}^0_j \to \tau_\beta \tilde{\tau}_k)\, \mathrm{B}(\tilde{\tau}_k \to \tau_\gamma \tilde{\chi}^0_1)\ [1 + (pa)(\alpha\beta)\cos\theta_{\tau_n}]$$

$p = \pm :$	particle/anti-particle	$\alpha = \pm :$	$\tilde{q}$ and q R/L chirality
$a = \pm :$	τ and π charge	$\beta = \pm :$	near τ_n R/L chirality
$j = 2, 3, 4 :$	neutralino mass index	$\gamma = \pm :$	far τ_f R/L chirality
$k = 1, 2 :$	$\tilde{\tau}$ mass index		



- The distribution **depends only on the near tau angle**.
  - The scalar character of the intermediate stau erases all angular correlations.

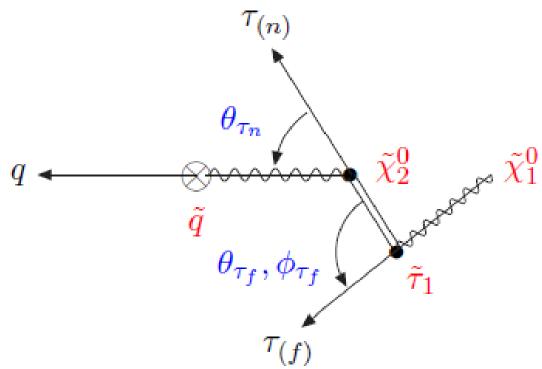
Invariant mass distribution

- The angles in the cascade are related to the invariant mass.

$$m_{\tau\tau}^2 = \frac{1}{2}(1-\cos\theta_{\tau_f}) \qquad max\, M_{\tau\tau}^2 = m_{\tilde{\chi}_j^0}^2(1-m_{\tilde{\tau}_k}^2/m_{\tilde{\chi}_j^0}^2)(1-m_{\tilde{\chi}_1^0}^2/m_{\tilde{\tau}_k}^2)$$

$$m_{q\tau_n}^2 = \frac{1}{2}(1-\cos\theta_{\tau_n}) \qquad max\, M_{q\tau_n}^2 = m_{\tilde{q}_\alpha}^2(1-m_{\tilde{\chi}_j^0}^2/m_{\tilde{q}_\alpha}^2)(1-m_{\tilde{\tau}_k}^2/m_{\tilde{\chi}_j^0}^2)$$

$$m_{q\tau_f}^2 = \frac{1}{4}(1+c_n)(1-c_f) - \frac{r_{jk}}{2}s_n s_f \cos\phi_{\tau_f} + \frac{r_{jk}^2}{4}(1-c_n)(1+c_f) \qquad max\, M_{q\tau_f}^2 = m_{\tilde{q}_\alpha}^2(1-m_{\tilde{\chi}_j^0}^2/m_{\tilde{q}_\alpha}^2)(1-m_{\tilde{\chi}_1^0}^2/m_{\tilde{\tau}_k}^2)$$



- Here, we define the invariant masses in units of their maximum values.

Pion invariant mass distribution

- Pion distributions

$$\frac{d\Gamma}{dm_{q\pi}^2} = \int_{m_{q\pi}^2}^1 \frac{dm_{q\tau}^2}{m_{q\tau}^2} \frac{d\Gamma_\beta}{dm_{q\tau}^2} F_\beta\left(\frac{m_{q\pi}^2}{m_{q\tau}^2}\right)$$

$$\frac{d\Gamma}{dm_{\pi\pi}^2} = \int_{m_{\pi\pi}^2}^1 \frac{dm_{\tau\tau}^2}{m_{\tau\tau}^2} \frac{d\Gamma_{\beta\gamma}}{dm_{\tau\tau}^2} F_{\beta\gamma}\left(\frac{m_{\pi\pi}^2}{m_{\tau\tau}^2}\right)$$

- $\tau_{L/R} \to \pi$ fragmentation func.

$$F_\beta(z) = 1 + \beta\,(2z - 1) \qquad z = m_{q\pi}^2/m_{q\tau}^2$$

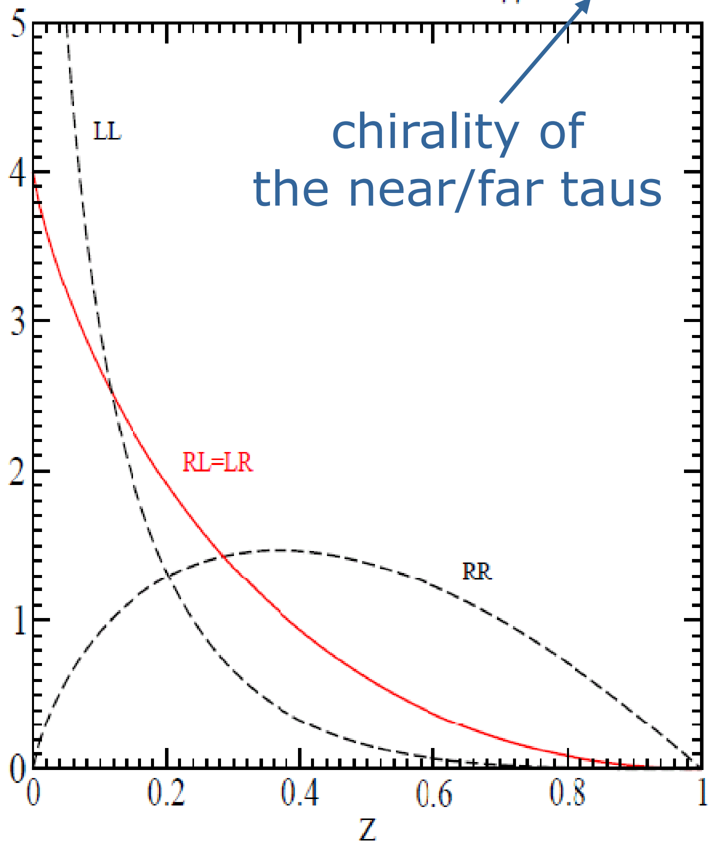
$$F_{RR}(z) = 4\,z\,\log\frac{1}{z} \qquad z = m_{\pi\pi}^2/m_{\tau\tau}^2$$

$$F_{RL}(z) = F_{LR}(z) = 4\left[1 - z - z\,\log\frac{1}{z}\right]$$

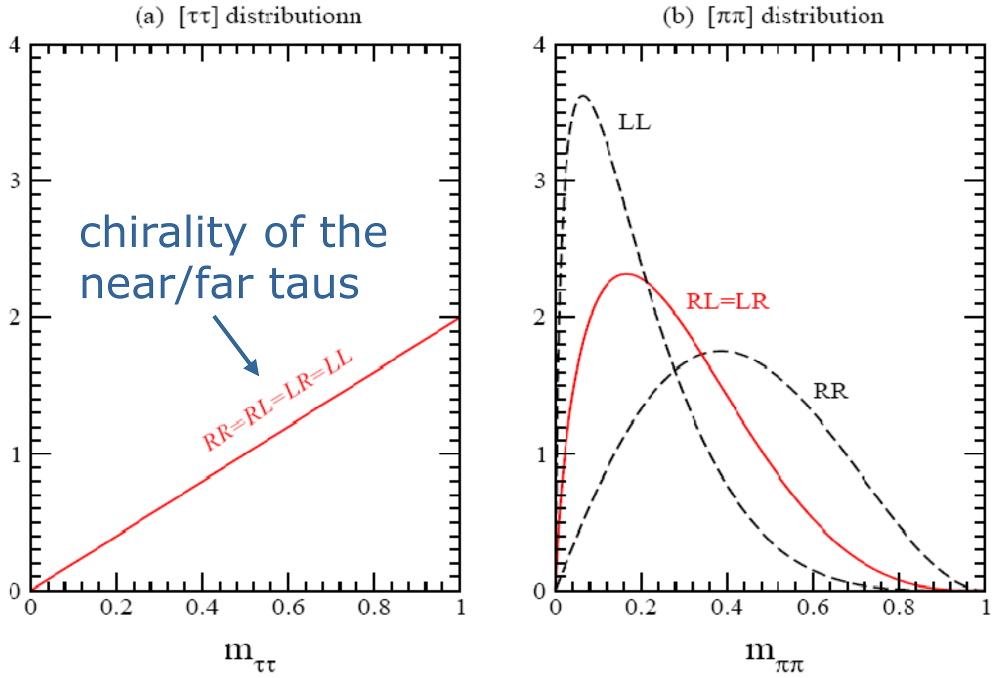
$$F_{LL}(z) = 4\left[(1+z)\,\log\frac{1}{z} + 2z - 2\right]$$

- The distributions do not require the experimental reconstruction of tau energy.

(c) Double Fragmentation Functions $F_{\beta\gamma}(z)$ [$\beta,\gamma = R,L$]



The tau-tau vs pi-pi invariant mass in the X_2 decays

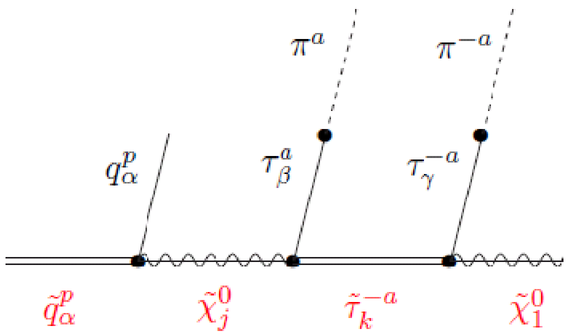


- The expectation value of the invariant mass

$$\langle m_{\pi\pi}\rangle = \begin{cases} 288/675 & \text{for } RR \\ 192/675 & \text{for } RL/LR \\ 128/675 & \text{for } LL \end{cases}$$

- The distributions do not depend on the X_2 polarization.
(∵ stau intermediate)

The tau polarization measurements has a great potential for determining the SUSY characters.

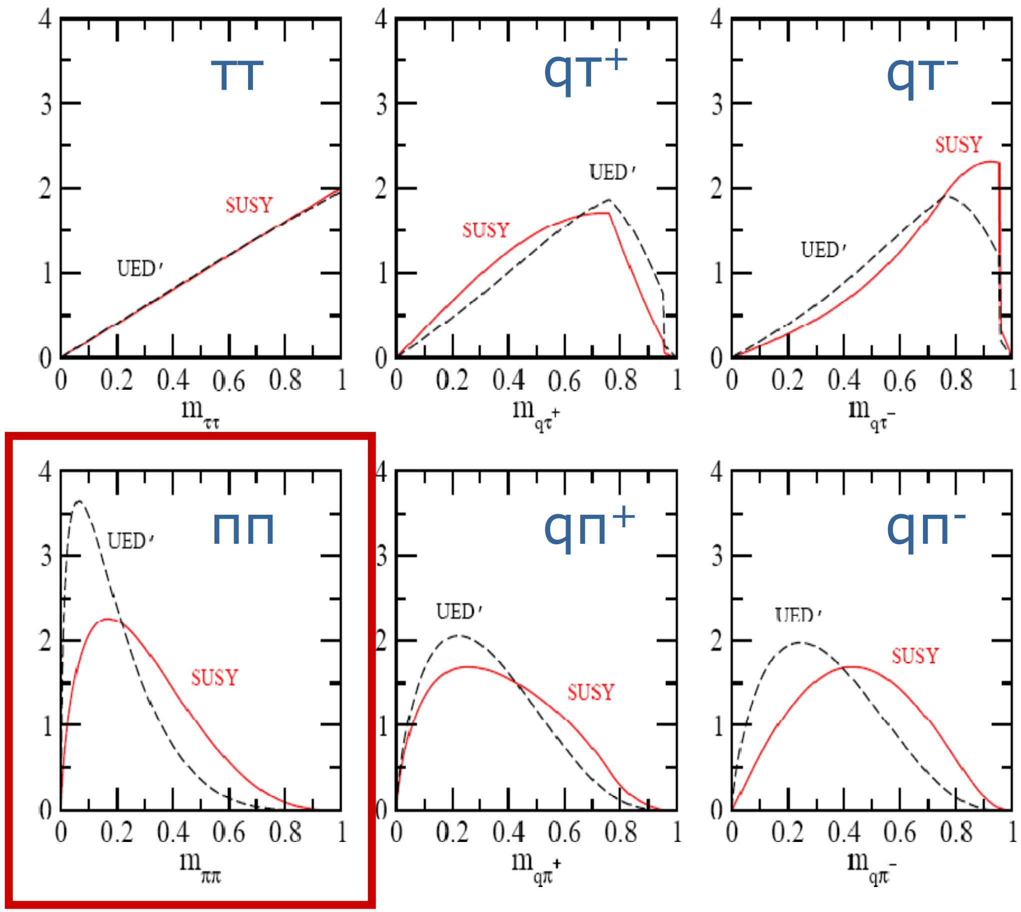


3. Numerical studies

- SUSY vs UED'
- Experimental effects
- Determination of the stau mixing

◆ SPS1a point: m_0=100 GeV, $m_{1/2}$=250 GeV, A_0=-100 GeV, tanβ=10, μ>0
m(squark)=570 GeV, m(neutralino2)=175 GeV,
m(stau1)=135 GeV, m(neutralino1)=100 GeV,
neutralino2～wino, stau1～stauR

SUSY vs UED’ (mass spectrum: SUSY SPS1a)



- The UED’ (universal extra dimension) cascade

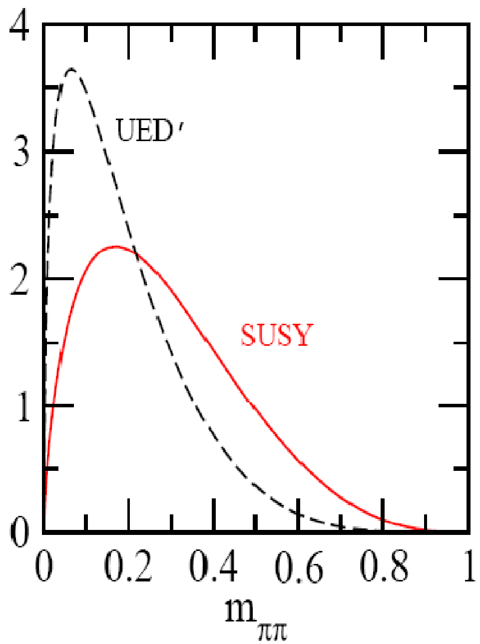
LKP

$$q_1 \to qZ_1 \to q\ell\ell_1 \to q\ell\ell\gamma_1$$

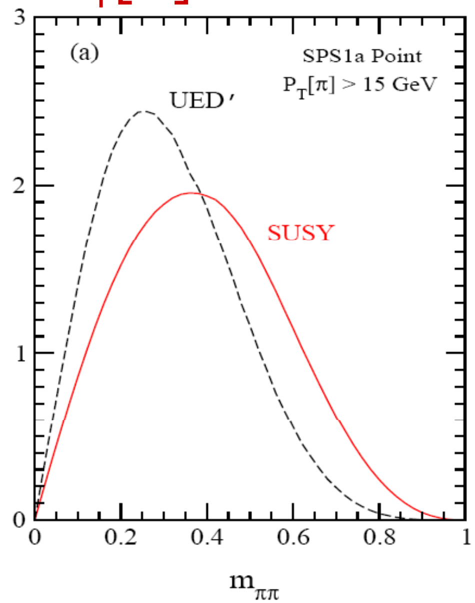
- SUSY: R-dominated ($\because$ $stau_1 \sim stau_R$)
- UED’: L-dominated ($\because$ $Z_1 \sim W_1^3$)
- The difference comes mainly from the chirality difference rather than the spin’s.

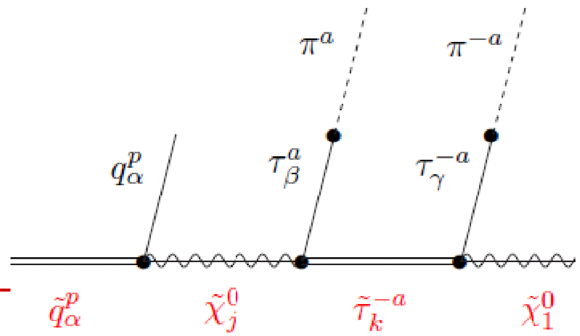
Transverse momentum cut for experimental analyses

- Experimental reconstruction of hadronic tau decays requires a cut of the low P_T region.
- Transverse momentum cut
  - increase the efficiencies
  - reduce the primary event number, and L/R sensitivity
- The SUSY R-dominated distribution is mildly affected.
- The UED' L-dominated distribution is shifted strongly.

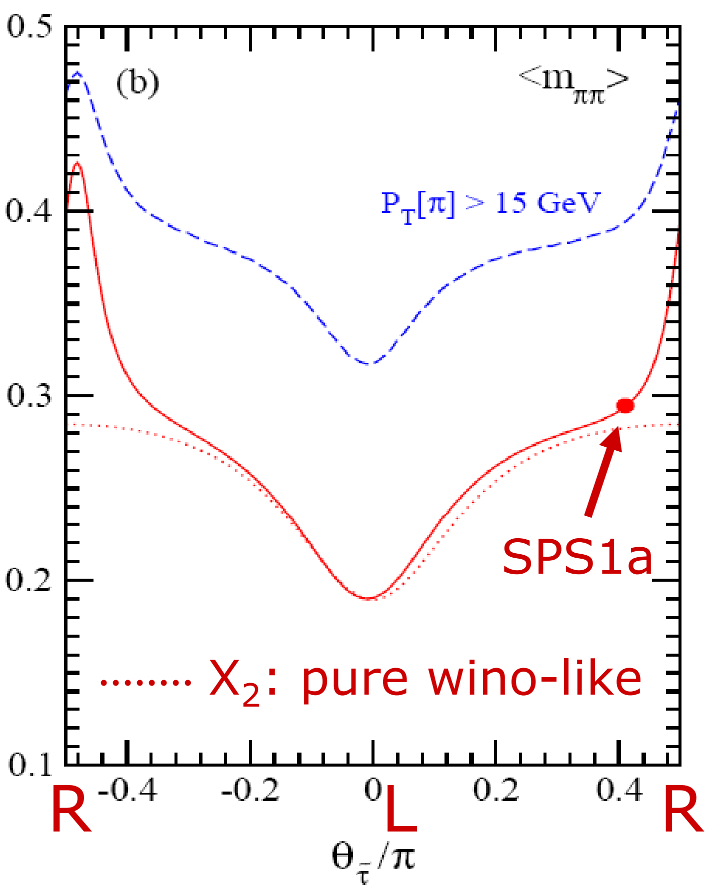


$P_T[\pi]>15$GeV





Determination of the stau mixing



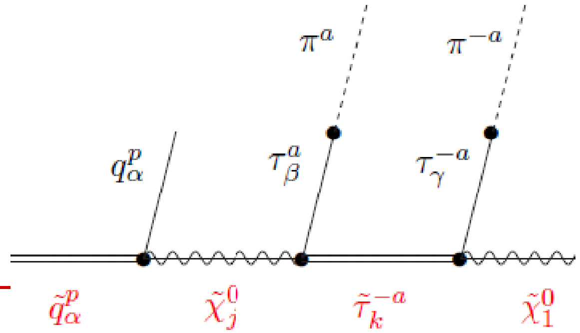
- The stau mixing

$$\tilde{\tau}_1 = \cos\theta_{\tilde{\tau}}\,\tilde{\tau}_L + \sin\theta_{\tilde{\tau}}\,\tilde{\tau}_R$$

$$\tilde{\tau}_2 = -\sin\theta_{\tilde{\tau}}\,\tilde{\tau}_L + \cos\theta_{\tilde{\tau}}\,\tilde{\tau}_R$$

- The large sensitivity near $|\theta|=\pi/2$ can be traced back to the fact that X_2 is *nearly* wino-like.
  - For $|\theta|=\pi/2$, $stau_1=stau_R$ couples to X_2 only through its small higgsino and U(1) gaugino components.
  - For $|\theta|<\pi/2$, the near tau coupling is L-dominated.

4. Summary



- The SUSY cascade decay

$$\tilde{q} \rightarrow q\tilde{\chi}^0_2 \rightarrow q\ell\tilde{\ell} \rightarrow q\ell\ell\tilde{\chi}^0_1$$

for the tau/stau case.

- The analysis of tau polarization in cascade decays, especially the $m_{\pi\pi}$ distribution, provides valuable information on chirality-type and mixing of SUSY particles.
  - The large size of the polarization effects was predicted and exemplified quantitatively by the pion channel on the theoretical basis.
  - The effects can be exploited experimentally in practice.

Tau-stau-neutralino coupling

$$\langle \tilde{\chi}^0_j | \tilde{\tau}_k | \tau_\beta \rangle = ig\, A^\tau_{\beta k j}$$

$$A^\tau_{Lkj} = -h_\tau N^*_{j3} U_{\tilde{\tau}_{k2}} + \frac{1}{\sqrt{2}} (N^*_{j2} + N^*_{j1} t_W) U_{\tilde{\tau}_{k1}}$$

$$A^\tau_{Rkj} = -h_\tau N_{j3} U_{\tilde{\tau}_{k1}} - \sqrt{2} N_{j1} t_W U_{\tilde{\tau}_{k2}}$$

$$h_\tau = m_\tau / \sqrt{2} m_W \cos\beta$$