Chapter 4

Decay \( h^0 \rightarrow \tau \mu \)

The goal of this chapter is to show the calculations of the possible branching ratio in the Minimal Supersymmetric Standard Model (MSSM) of the decay \( h^0 \rightarrow \tau \mu \). We have already shown the Ansatz for the extension of the MSSM and respectively how the MSSM extends the Standard Model. We proceed in the first subchapter to calculate the Branching Ratio of \( h^0 \rightarrow \tau \mu \) with this extension of the MSSM. We explain a generalized procedure of calculating the sixteen possibilities of decay with our Ansatz. In the second part of this chapter we show the plots of our calculation, making a random variation of all the free parameters of the branching ratio and make a comparison with the branching obtained with CMS paper. [10]

4.1 Decay \( h^0 \rightarrow \tau \mu \) in MSSM extended in FV

The quantum correction will be done by one-loop with s-leptons. In figure 4.1 a generalization of the possible decays is shown. In these diagrams the particle that interacts with the \( \tau \), will be labeled with the momentum \( q_1 \). Simultaneously the particle that interacts with the \( \mu \) particle will be labeled with the momentum \( q_3 \). The amplitudes of the different decays will have the labels \( j \) and \( k \), where \( j \) is assigned to the particle that interacts with the \( \mu \) particle and \( k \) to the particle that interacts with the \( \tau \) particle. The labels \( j \) and \( k \) take the integers 1, 2, 3, 4 and each number is related to a particle as follows.

\[
\begin{align*}
1 & \rightarrow \tilde{\mu}_1 \\
2 & \rightarrow \tilde{\mu}_2 \\
3 & \rightarrow \tilde{\tau}_1 \\
4 & \rightarrow \tilde{\tau}_2
\end{align*}
\]

(4.1)

As an example, the Feynman diagram with the decay \( \tau_2 \) with momentum \( q_1 \) and \( \mu_1 \) with momentum \( q_3 \), the amplitude will be represented by \( M_{14} \).

The Branching Ratio will be given by the sum of the different contributions

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of the possible Feynman diagrams, with one loop quantum correction.

\[
\text{BR}(h^0 \rightarrow \tau \mu) = \frac{\Gamma(h^0 \rightarrow \mu\tau)}{\Gamma_{\text{tot}}} \tag{4.2}
\]

where

\[
\Gamma(h^0 \rightarrow \mu\tau) = \sum_{j,k} \left\{ \frac{1}{8\pi m_{h^0}} \int_{(m_\tau + m_\mu)c^2} \delta(m_{j\sigma}c - E_T)c \frac{\rho}{E_T} dE_T \right\} \tag{4.3}
\]

And

\[
\rho = \frac{c\sqrt{m_{h^0}^4 + m_\mu^4 + m_\tau^4 - 2m_{h^0}^2 m_\mu^2 - 2m_{h^0}^2 m_\tau^2 - 2m_\mu^2 m_\tau^2}}{2m_{h^0}} \tag{4.4}
\]

Figure 4.1: Generalized Decay of $h^0 \rightarrow \tau \mu$, where $\mu_1, \mu_2, \tau_1, \tau_2$ are the s-leptons

We label as $p$ to the momentum of the higgs boson, $q_1, q_3$ to one of the s-partilces in the quantum correction loop and $q_2$ is the momentum of the Bino particle. We can express the momentums in terms of the others as follows.

\[
p = k_2 + k_1 \quad \text{Conservation of momentum}
\]

\[
q_2 = q_3 - k_1
\]

\[
q_3 = p + q_1
\]

(4.5)

In order to have all the expressions in one momentum of the loop, we isolate the expressions in terms of $q_1, k_2$ and $k_1$. We know the momentums $k_1, k_2$, since they are the momentums of the particles of the decay.
\[ q_2 = p + q_1 - k_1 \text{ We substitute } q_3 \]
\[ = k_2 + k_1 + q_1 - k_1 \text{ We substitute } p \]
\[ = k_2 + q_1 \]
\[ q_3 = k_2 + k_1 + q_1 \text{ We substitute } p \]

\[ (4.6) \]

We make the amplitude of probability over all the possibilities of momentum. Therefore we make the integral of the amplitude over all the 4-dimensionalspace, since we do not know the value of \( q \). The amplitudes will be calculated by an integral over the momentums in the loop as follows.

\[ M_{jk} = \int \frac{d^4q_1}{(2\pi)^4} \times \bar{v}_\mu \times g_{\bar{B}j_\mu} \times P_{\bar{B}}(q_2) \times g_{\bar{B}f_k} \times u_\tau(k_2) \times P_{f_k}(q_1) \times g_{h^{\circ}j_k} \times P_{f_j}(q_3) \]

\[ (4.7) \]

where \( g_{\bar{B}j_\mu} \) represent the interaction of the s-lepton with the particle \( \mu \) and \( g_{\bar{B}f_k} \) the interaction of the s-lepton with the \( \tau \) particle. \( P_{\bar{B}}(q_2) \) and \( P_{f_k}(q_3) \) are the propagators. The term \( g_{h^{\circ}j_k} \) represents the higgs interaction with the s-leptons. In Table 4.3 are shown the propagators that are of our interest, while the interactions are taken from Table 3.2 and Table 3.3.

As it is shown in Eq. 4.7 the integral will be done in terms of one of the internal momentums. We choose \( q_1 \), however it could be realized by any of the internal momentums \((q_1, q_2, q_3)\). Therefore we use the momentum equations in 4.6 and substitute in the propagators. And we have consequently an expression as follows

\[ M_{jk} = \int \frac{d^4q_1}{(2\pi)^4} \times \bar{v}_\mu(k_1) \times g_{\bar{B}j_\mu} \times P_{\bar{B}}(k_2 + q_1) \times g_{\bar{B}f_k} \times u_\tau(k_2) \times P_{f_k}(q_1) \times g_{h^{\circ}j_k} \times P_{f_j}(k_2 + k_1 + q_1) \]

\[ (4.8) \]

We will separate the integral in three expressions, in order to simplify all the calculations. The new expressions will be \( N_{jk}, D_{jk} \) and \( \alpha_{jk} \). The labels are given since \( N_{jk} \) will be a numerator, \( D_{jk} \) a denominator and \( \alpha_{jk} \) couplings to the fraction \( \frac{N_{jk}}{D_{jk}} \). We start with the following product, where we substitute the Progator of \( \bar{B} \) taken from Table 4.3 and we generalize the possible interactions from Table 3.3.

\[ \bar{v}_\mu g_{\bar{B}j_\mu} P_{\bar{B}}(k_2 + q_1) g_{\bar{B}f_k} u_\tau(k_2) = \bar{v}_\mu(k_1) \frac{g_4}{16} \tan^2 \theta_w (n_1 + n_2 \gamma_5) \frac{m_B}{(k_2 + q_1)^2} \frac{1}{m_B^2} \times \]
\[ \times \left( n_3 + n_4 \gamma_5 \right) u_\tau(k_2) \]
\[ = \bar{v}_\mu(k_1) \frac{g_4 a_1 a_2}{16} \tan^2 \theta_w (n_1 + n_2 \gamma_5) \frac{m_B}{(k_2 + q_1)^2} \times \]
\[ \times \left( n_3 + n_4 \gamma_5 \right) u_\tau(k_2) \]
\[ = \bar{v}_\mu(k_1) \frac{g_4 a_1 a_2}{16} \tan^2 \theta_w \frac{1}{(k_2 + q_1)^2} \times \frac{1}{m_B^2} \times N_{jk} \]

\[ (4.9) \]
If we label the following expressions as $\alpha_{jk}$ and $D_{jk}$

$$
\alpha_{jk} = \frac{ig h^{0} f_{j} f_{k} g^{2} a_{1} a_{2}}{16} \tan^{2} \theta_{w} \quad (4.13)
$$

$$
D_{jk} = [ (k_{2} + q_{1})^{2} - m_{B}^{2} ] [ q_{1}^{2} - m_{f_{j}}^{2} ] [ (k_{2} + k_{1} + q_{1})^{2} - m_{f_{k}}^{2} ] \quad (4.14)
$$

We can express $M_{jk}$ as

$$
M_{jk} = \alpha_{jk} \int \frac{d^{4} q_{1}}{(2\pi)^{4}} \frac{N_{jk}}{D_{jk}} \quad (4.15)
$$

where $n_{1}, n_{2}, n_{3}, n_{4}$ can take the integers 1, 3 and

$$
n_{1}(j) = \begin{cases} 
1 & \text{if } j = 2, 3 \\
3 & \text{if } j = 1, 4
\end{cases}
$$

$$
n_{2}(j) = \begin{cases} 
1 & \text{if } j = 1, 4 \\
3 & \text{if } j = 2, 3
\end{cases}
$$

$$
n_{3}(k) = \begin{cases} 
1 & \text{if } k = 2, 3 \\
3 & \text{if } k = 1, 4
\end{cases}
$$

$$
n_{4}(k) = \begin{cases} 
1 & \text{if } k = 1, 4 \\
3 & \text{if } k = 2, 3
\end{cases}
$$

$$
a_{1}(j) = \begin{cases} 
-c_{\varphi} & \text{if } j = 1, 2 \\
s_{\varphi} & \text{if } j = 3, 4
\end{cases}
$$

$$
a_{2}(k) = \begin{cases} 
-s_{\varphi} & \text{if } k = 1, 2 \\
c_{\varphi} & \text{if } k = 3, 4
\end{cases} \quad (4.10)
$$

We now substitute the propagators $P_{f_{j}}(q_{1})$, $P_{f_{j}}(k_{2} + k_{1} + q_{1})$ written generalized.

$$
M_{jk} = \frac{g^{2} a_{1} a_{2}}{16} \tan^{2} \theta_{w} \int \left( \frac{d^{4} q_{1}}{(2\pi)^{4}} \times \frac{1}{(k_{2} + q_{1})^{2} - m_{B}^{2}} \times N_{jk} \times P_{f_{j}}(q_{1}) \times g_{h^{0} f_{j} f_{k}} \times P_{f_{j}}(k_{2} + k_{1} + q_{1}) \right)
$$

$$
= \frac{g^{2} a_{1} a_{2}}{16} \tan^{2} \theta_{w} \int \left( \frac{d^{4} q_{1}}{(2\pi)^{4}} \times \frac{1}{(k_{2} + q_{1})^{2} - m_{B}^{2}} \times N_{jk} \times \right)
$$

$$
\times \left( \frac{i^{2}}{q_{1}^{2} - m_{f_{k}}^{2}} \times g_{h^{0} f_{j} f_{k}} \times \frac{i^{2}}{(k_{2} + k_{1} + q_{1})^{2} - m_{f_{j}}^{2}} \right)
$$

$$
\times \frac{1}{q_{1}^{2} - m_{f_{k}}^{2}} \times \frac{1}{(k_{2} + k_{1} + q_{1})^{2} - m_{f_{j}}^{2}} \quad (4.12)
$$

$$
\times \frac{1}{q_{1}^{2} - m_{f_{k}}^{2}} \times \frac{1}{(k_{2} + k_{1} + q_{1})^{2} - m_{f_{j}}^{2}} \quad (4.11)
$$

If we substitute Eq. [4.9] in Eq. [4.8] we obtain.

$$
M_{jk} = \frac{g^{2} a_{1} a_{2}}{16} \tan^{2} \theta_{w} \int \left( \frac{d^{4} q_{1}}{(2\pi)^{4}} \times \frac{1}{(k_{2} + q_{1})^{2} - m_{B}^{2}} \times N_{jk} \times P_{f_{j}}(q_{1}) \times g_{h^{0} f_{j} f_{k}} \times P_{f_{j}}(k_{2} + k_{1} + q_{1}) \right)
$$
We expand the products in the expression of $N_{jk}$

$$N_{jk} = \bar{\nu}_\mu(k_1)(n_1 + n_2 \gamma_5)(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})(n_3 + n_4 \gamma_5)u_\tau(k_2)$$

$$= \bar{\nu}_\mu(k_1) \{ n_1(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_3 + n_1(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_4 \gamma_5 + n_2 \gamma_5(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_3$$

$$+ n_2 \gamma_5(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_4 \gamma_5 \} u_\tau(k_2)$$

(4.16)

We substitute

$$\bar{g}_1 = \gamma^\nu q_{1\mu}, \bar{k}_2 = \gamma^\mu k_{2\mu}$$

And we use the following properties of the Dirac matrices

$$\gamma^2 = 1$$
$$\gamma^5 \gamma^\mu = -\gamma^\mu \gamma^5$$

(4.17)

$$N_{jk} = \bar{\nu}_\mu(k_1) \{ n_1(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_3 + n_1(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_4 \gamma_5 + n_2 \gamma_5(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_3$$

$$+ n_2 \gamma_5(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})n_4 \gamma_5 \} u_\tau(k_2)$$

$$= \bar{\nu}_\mu(k_1) \{ n_1 n_3(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}}) + n_1 n_4 \gamma_5(\bar{k}_2 - \bar{g}_1 + m_{\tilde{B}}) + n_2 n_3 \gamma_5(\bar{k}_2 + \bar{g}_1 + m_{\tilde{B}})$$

$$+ n_2 n_4(\bar{k}_2 - \bar{g}_1 + m_{\tilde{B}}) \} u_\tau(k_2)$$

$$= \bar{\nu}_\mu(k_1) \{ (n_1 n_3 - n_2 n_4)(\bar{k}_2 + \bar{g}_1) + (n_1 n_3 + n_2 n_4)m_{\tilde{B}}$$

$$+ \gamma_5((n_1 n_4 + n_2 n_3)m_{\tilde{B}} + (n_2 n_3 - n_1 n_4)(\bar{k}_2 + \bar{g}_1)) \} u_\tau(k_2)$$

(4.18)

We substitute $N_{jk}$ in $M_{jk}$

$$M_{jk} = \alpha_{jk} \int \frac{d^4q_1}{(2\pi)^2} \bar{\nu}_\mu(k_1) \left\{ (n_1 n_3 - n_2 n_4)(\bar{k}_2 + \bar{g}_1) + (n_1 n_3 + n_2 n_4)m_{\tilde{B}}$$

$$+ \gamma_5((n_1 n_4 + n_2 n_3)m_{\tilde{B}} + (n_2 n_3 - n_1 n_4)(\bar{k}_2 + \bar{g}_1)) \right\} u_\tau(k_2) \times \frac{1}{D_{jk}}$$

(4.19)
We take out from the integral the factors that does not depend of \( q_1 \)

\[
M_{jk} = \alpha_{jk} \bar{\nu}_\mu(k_1) \left\{ (n_1 n_3 - n_2 n_4) (\bar{k}_2 \int \frac{d^4 q_1}{(2\pi)^4 D_{jk}} + \int \frac{d^4 q_1 \bar{g}_1}{(2\pi)^4 D_{jk}}) ight. \\
+ (n_1 n_3 + n_2 n_4) m_\tilde{\tau} \int \frac{d^4 q_1}{(2\pi)^4 D_{jk}} + \gamma_5 \left\{ (n_1 n_4 + n_2 n_3) m_\tilde{\tau} \int \frac{d^4 q_1}{(2\pi)^4 D_{jk}} ight. \\
+ (n_2 n_3 - n_1 n_4) (\bar{k}_2 \int \frac{d^4 q_1}{(2\pi)^4 D_{jk}} + \int \frac{d^4 q_1 \bar{g}_1}{(2\pi)^4 D_{jk}}) \right\} u_\tau(k_2) \\
= \alpha_{jk} \bar{\nu}_\mu(k_1) \left\{ (n_1 n_3 - n_2 n_4) (\bar{k}_2 IC_1 + IC_2) + (n_1 n_3 + n_2 n_4) m_\tilde{\tau} IC_2 \\
+ \gamma_5 \left\{ (n_1 n_4 + n_2 n_3) m_\tilde{\tau} IC_2 + (n_2 n_3 - n_1 n_4) (\bar{k}_2 IC_1 + IC_1) \right\} \right\} u_\tau(k_2) \tag{4.20}
\]

where \( IC_1 \) and \( IC_2 \) are the two integral cases. \( IC_1 \) is the integral with \( q_1 \) and \( IC_2 \) is the integration of \( \frac{1}{D_{jk}} \). We use the tool \textit{FeynCalc} to calculate and evaluate these integrals. The result of integral \( IC_1 \) is in Ec. [4.25] and \( IC_2 \) is in Ec. [4.26].

Now we use the Dirac Ec. which states

\[
\bar{k}_2 u_\tau(k_2) = m_\tau u_\tau(k_2) \\
\bar{\nu}_\mu(k_1) \bar{k}_1 = -\bar{\nu}_\mu(k_1) m_\mu 
\]

\tag{4.21}

\[
M_{jk} = \alpha_{jk} \bar{\nu}_\mu(k_1) \left\{ (n_1 n_3 - n_2 n_4) (m_\tau IC_2 + IC_1) + (n_1 n_3 + n_2 n_4) m_\tilde{\tau} IC_2 \\
+ \gamma_5 \left\{ (n_1 n_4 + n_2 n_3) m_\tilde{\tau} IC_2 + (n_2 n_3 - n_1 n_4) (m_\tau IC_1 + IC_1) \right\} \right\} u_\tau(k_2) 	ag{4.22}
\]

We call as \( S_{jk} \) to the scalar part of \( M_{jk} \) and \( P_{jk} \) to the pseudoscalar part.

\[
S_{jk} = (n_1 n_3 - n_2 n_4) (m_\tau IC_2 + IC_1) + (n_1 n_3 + n_2 n_4) m_\tilde{\tau} IC_2 \\
P_{jk} = \gamma_5 \left\{ (n_1 n_4 + n_2 n_3) m_\tilde{\tau} IC_2 + (n_2 n_3 - n_1 n_4) (m_\tau IC_1 + IC_1) \right\} 
\]

\tag{4.23}

And therefore

\[
M_{jk} = \alpha_{jk} \bar{\nu}_\mu(k_1) \{ S_{jk} + P_{jk} \} u_\tau(k_2) \tag{4.24}
\]

We show in table [1.1] the sixteen scalar and pseudoscalar parts of the different \( M_{jk} \). The following expressions are the two possible integrals in \( M_{jk} \), where we
used FeynCalc for these results.

\[ IC_1 = \int d^4q_1 \frac{q_1}{(2\pi)^4((q_1 + k_2)^2 - m_{B_1}^2)(q_1 - m_{f_1}^2)((q_1 + k_2 + k_1)^2 - m_{f_1}^2))} \]

\[ = -i\pi^2 \frac{[m_{h_0}^2 - (m_\mu + m_\tau)^2][m_{h_0}^2 - (m_\mu - m_\tau)^2]}{[m_{h_0}^2 - (m_\mu + m_\tau)^2][m_{h_0}^2 - (m_\mu - m_\tau)^2]} \times \left\{ -[k_1(m_{h_0}^2 - m_\mu^2 + m_\tau^2) - k_2(m_{h_0}^2 + m_\mu^2 - m_\tau^2)]B_{0ijk} + [k_1(m_{h_0}^2 - m_\mu^2 - m_\tau^2) - 2m_{h_0}^2 B_{0kj}]B_{0mbj} + [2m_{h_0}^2 k_1 + k_2(-m_{h_0}^2 + m_\mu^2 + m_\tau^2)]B_{0kk} - \left[ k_2[m_{h_0}^2(m_{h_0}^2 + m_\mu^2 - m_\tau^2) + m_{h_0}^2(m_\mu^2 + m_\tau^2) + 2m_{h_0}^2 m_{f_1}^2 - 2m_{h_0}^2 m_{f_1}^2 - m_{f_1}^2 m_{f_2}^2 - m_{f_2}^2 m_{f_1}^2 - m_{f_1}^2 m_{f_2}^2 - m_{f_2}^2 m_{f_1}^2] + m_{f_1}^2 m_{f_2}^2 + m_{f_2}^2 m_{f_1}^2 \right] F_{c0} \right\} \]

\[ IC_2 = \int d^4q_1 \frac{q_1}{(2\pi)^4((q_1 + k_2)^2 - m_{B_2}^2)(q_1 - m_{f_1}^2)((q_1 + k_2 + k_1)^2 - m_{f_1}^2))} = i\pi^2 F_{c0} \]

where we labeled as \( m_{f_1} \) to the mass of the s-particle with the momentum \( q_1 \) and \( m_{f_2} \) to the s-particle with momentum \( q_3 \).

Furthermore

\[ B_{0kk} = B_0(m_{h_0}^2, m_{h_0}^2, m_{f_1}^2) \]
\[ B_{0kj} = B_0(m_{h_0}^2, m_{f_2}^2, m_{f_1}^2) \]
\[ B_{0mbj} = B_0(m_{h_0}^2, m_{h_0}^2, m_{f_1}^2) \]
\[ F_{c0} = C0(m_{h_0}^2, m_{h_0}^2, m_{f_1}^2, m_{f_2}^2, m_{f_2}^2, m_{f_1}^2) \]

Expression of Integal Case 1 \[ \text{(4.25)} \] has dependence of \( k_1 \) and \( k_2 \). We eliminate this dependence using the dirac equations in \[ \text{(4.21)} \] with the following operations. We start with equation \[ \text{(4.24)} \]

\[ M_{jk} = \alpha_j \bar{\nu}_\mu(k_1) \{ S_{jk} + P_{jk} \} u_\tau(k_2) = \alpha_j \{ \bar{\nu}_\mu(k_1)S_{jk}u_\tau(k_2) + \bar{\nu}_\mu(k_1)P_{jk}u_\tau(k_2) \} \]

where

\[ \bar{\nu}_\mu(k_1)S_{jk}u_\tau(k_2) = \bar{\nu}_\mu(k_1) \left\{ (n_1 n_3 - n_2 n_4)(m_\tau IC2 + IC1) + (n_1 n_3 + n_2 n_4)m_B IC2 \right\} u_\tau(k_2) = (n_1 n_3 - n_2 n_4)(m_\tau \bar{\nu}_\mu(k_1)IC2u_\tau(k_2) + \bar{\nu}_\mu(k_1)IC1u_\tau(k_2)) + (n_1 n_3 + n_2 n_4)m_B \bar{\nu}_\mu(k_1)IC2u_\tau(k_2) \]
We obtain in the equation above the multiplication $\bar{v}_\mu(k_1)IC_1u_\tau(k_2)$. We use the Dirac equation \(4.21\) and remove the momentum $k_1$ and $k_2$ dependence of the Integral Case $1$ \(4.23\)

\[
\bar{v}_\mu(k_1)IC_1u_\tau(k_2) = \frac{-i\pi^2}{[m^2_{\mu_0} - (m_\mu + m_\tau)^2][m^2_{\mu_0} - (m_\mu - m_\tau)^2]} \\
\times \bar{v}_\mu(k_1) \left\{ - [k_1(m^2_{\mu_0} - m_\mu^2 + m_\tau^2) - k_2(m^2_{\mu_0} + m_\mu^2 + m_\tau^2)]B_{\theta\hbar\kappa} \\
+ [k_1(m^2_{\mu_0} - m_\mu^2 - m_\tau^2) - 2m^2_{\mu_0}k_2]B_{0\mu\bar{b}\bar{d}} + [2m_\tau k_1 + k_2(-m^2_{\mu_0} + m_\mu^2 + m_\tau^2)]B_{\theta\tau\kappa} \\
- \left\{ k_1[m^2_B(m^2_{\mu_0} - m_\mu^2 + m_\tau^2) + m^2_{\mu_0}(m_\mu^2 - m_\tau^2)] + m^2_{\mu_0}m^2_{\tau_0} + m^2_\mu m^2_\tau - 2m^2_{\tau_0}m^2_{\mu_0} + 2m^2_{\mu_0}m^2_{\mu_0} - m^4_\tau \right\} \right\} \bar{u}_\tau(k_2) \\
= \frac{-i\pi^2}{[m^2_{\mu_0} - (m_\mu + m_\tau)^2][m^2_{\mu_0} - (m_\mu - m_\tau)^2]} \bar{v}_\mu(k_1) \left\{ - [-m_\mu(m^2_{\mu_0} - m_\mu^2 + m_\tau^2) \\
- m_\tau(m^2_{\mu_0} + m_\mu^2 - m_\tau^2)]B_{\theta\hbar\kappa} + [-m_\mu(m^2_{\mu_0} - m_\mu^2 - m_\tau^2) - 2m^2_\mu m_\tau]B_{0\mu\bar{b}\bar{d}} \\
+ [-2m^2_\mu m_\mu - m_\tau(-m^2_{\mu_0} + m_\mu^2 + m_\tau^2)]B_{\theta\tau\kappa} - (-m_\mu[m^2_B(m^2_{\mu_0} - m_\mu^2 + m_\tau^2) \\
+ m^2_{\mu_0}(m_\mu^2 - m_\tau^2) + m^2_{\mu_0}m^2_{\tau_0} + m^2_\mu m^2_\tau - 2m^2_{\tau_0}m^2_{\mu_0} + 2m^2_{\mu_0}m^2_{\mu_0} - m^4_\tau)] \right\} \bar{u}_\tau(k_2) \\
= \bar{v}_\mu(k_1)IC_1u_\tau(k_2)
\]

The expression above is general since we can introduce also the spinors in $P_{\mu}$.

From \(4.28\) we have $\bar{v}_\mu(k_1)P_{\mu\nu}u_\tau(k_2)$ which is expressed as

\[
\bar{v}_\mu(k_1)P_{\mu\nu}u_\tau(k_2) = \bar{v}_\mu(k_1)\gamma_5 \left\{ (n_1n_4 + n_2n_3)m_{\bar{b}\bar{d}}IC_2 + (n_2n_3 - n_1n_4)(n_1IC_2 + IC_1) \right\} u_\tau(k_2) \\
= (n_1n_4 + n_2n_3)m_{\bar{b}\bar{d}}\bar{v}_\mu(k_1)\gamma_5IC_2u_\tau(k_2) + (n_2n_3 - n_1n_4)(n_1\bar{v}_\mu(k_1)\gamma_5IC_2u_\tau(k_2) \\
+ \bar{v}_\mu(k_1)\gamma_5IC_1u_\tau(k_2))
\]

As it can be noticed that all terms of Integral Case $1$ \(4.23\) are multiplied by one of the slashed momentums($k_1$, $k_2$). Therefore all terms are multiplied by $\gamma^\mu$ since $k_1 = \gamma^\mu k_{1\mu}$ and $k_2 = \gamma^\mu k_{2\mu}$. Consequently $\gamma_5IC_1 = -IC_1\gamma_5$ because from eq. \(4.17\) we know that $\gamma_5\gamma^\mu = -\gamma^\mu\gamma_5$. We obtain

\[
\bar{v}_\mu(k_1)P_{\mu\nu}u_\tau(k_2) = (n_1n_4 + n_2n_3)m_{\bar{b}\bar{d}}\bar{v}_\mu(k_1)\gamma_5IC_2u_\tau(k_2) + (n_2n_3 - n_1n_4)(n_1\bar{v}_\mu(k_1)\gamma_5IC_2u_\tau(k_2) \\
- \bar{v}_\mu(k_1)IC_1\gamma_5u_\tau(k_2))
\]

In the equation above we would introduce the spinor $v_\mu(k_1)$ in $IC_1$ and eliminate the dependence of $k_1$. Then we factorize once again the spinor $v_\mu(k_1)$ and
rearrange as we have the expression in eq. [4.32]. Therefore the expression [4.30]
is applied to the IC in $S_{jk}$ and $P_{jk}$. Therefore the expression for IC1 is given by:

$$
IC_1 = \left\{ -m_\mu (m_{h^0}^2 - m_\mu^2 + m_\tau^2) \\
m_\tau (m_{h^0}^2 + m_\mu^2 - m_\tau^2) [B_{hjk} + m_\mu (m_{h^0}^2 - m_\mu^2 - m_\tau^2) - 2m_\mu^2 m_\tau] B_{bmbj} \\
+ [-2m_\mu^2 m_\mu + m_\tau (-m_{h^0}^2 + m_\mu^2 + m_\tau^2)] B_{btk} - \left\{ -m_\mu [m_{h^0}^2 (m_{h^0}^2 - m_\mu^2 + m_\tau^2) \\
+ m_{h^0}^2 (m_\mu^2 - m_\tau^2 + 2m_\mu^2 + m_\tau^2 - 2m_\mu^2 m_\tau - m_\mu^2 + m_\tau^2) - m_\tau [m_{h^0}^2 (m_{h^0}^2 + m_\mu^2 - m_\tau^2) \\
+ m_{h^0}^2 - m_\mu^2 (m_\mu^2 + m_\tau^2 + 2m_\mu^2 + m_\tau^2 - 2m_\mu^2 m_\tau - m_\mu^2 + m_\tau^2) + m_\mu^2 m_\tau + m_\mu^2 m_\tau + m_\tau^2] F_{c0} \right\} \right\} 
$$

(4.33)

We continue simplifying the expression of the Integral Case 1 in order to make more clear the calculations. We will make three new expressions labeled as $B_{jk}$ (expression with all the B0 functions), $C_{jk}$ and $C_{h^0\mu\tau}$. Firstly

$$
B_{jk} = -[m_\mu (m_{h^0}^2 - m_\mu^2 + m_\tau^2) - m_\tau (m_{h^0}^2 + m_\mu^2 - m_\tau^2) B_{hjk} + m_\mu (m_{h^0}^2 - m_\mu^2 - m_\tau^2) - 2m_\mu^2 m_\tau] B_{bmbj} \\
+ [-2m_\mu^2 m_\mu + m_\tau (-m_{h^0}^2 + m_\mu^2 + m_\tau^2)] B_{btk} 
$$

(4.34)

If we factorize the common products of the masses, we obtain

$$
B_{jk} = m_{h^0}^2 m_\mu [B_{hjk} - B_{bmbj}] + m_{h^0}^2 m_\tau [B_{hjk} - B_{btk}] \\
- m_\mu^2 [B_{hjk} - B_{bmbj}] - m_\mu^2 [B_{bjk} - B_{btk}] + m_\mu m_\tau^2 [B_{hjk} + B_{bmbj} - 2B_{btk}] \\
+ m_\mu^2 m_\tau^2 [B_{hjk} - 2B_{bmbj} + B_{btk}] 
$$

(4.35)

The result of the expression above is extremely important. The B0 function has a divergent term $\Delta_{UV}$ which needs to be eliminated in order to obtain a finite result. It is important to have the same number of B0 functions in the calculation expression with positive and negative sign in order to eliminate all the divergences. In equation (4.35), it is possible to verify that all divergences will be eliminated. It is an important and remarkable result since it means that our loop correction does not need more contributions in order to be finite. Similarly we label

$$
C_{h^0\mu\tau} = [m_{h^0}^2 - (m_\mu + m_\tau)^2] [m_{h^0}^2 - (m_\mu - m_\tau)^2] 
$$

(4.36)

And

$$
C_{jk} = -m_\mu [m_{h^0}^2 (m_{h^0}^2 - m_\mu^2 + m_\tau^2) + m_{h^0}^2 (m_\mu^2 - m_\tau^2)] + m_\mu^2 m_\tau^2 \\
+ m_{h^0}^2 m_\mu^2 - 2m_\mu^2 m_\tau^2 + m_\tau^2 m_\mu^2 - m_\tau^2] \\
- m_\tau [m_{h^0}^2 (m_{h^0}^2 + m_\mu^2 - m_\tau^2) + m_{h^0}^2 (m_\mu^2 + m_\tau^2)] + m_{h^0}^2 m_\tau^2 - 2m_\mu^2 m_\tau^2 - m_\mu^2 m_\tau^2 \\
+ m_\mu^2 m_\tau^2 + m_\tau^2] 
$$

(4.37)

The finite expression from any subtraction pair of B0 functions is given in Appendix.
Using Eqs. 4.35, 4.36, and 4.37 we can express the generalized and final result for $IC_1$ as

$$IC_1 = -\frac{i\pi^2}{C_{h\nu\mu\tau}} \{ B_{jk} - F_{c0} C_{jk} \}$$  

(4.38)

Now that we have the general expression for $M_{jk}$ and its respective terms we proceed to calculate $|M_{jk}|^2$ that is given by

$$|M_{jk}|^2 = M_{jk}M_{jk}^\dagger$$  

(4.39)

$$|M_{jk}|^2 = |\alpha_{jk}|^2 \{ \bar{v}_\mu(k_1)(S_{jk} + P_{jk})u_\tau(k_2) S_{jk}^\dagger - P_{jk}^\dagger \} v_\mu(k_1)$$  

(4.40)

$S_{jk}$ is composed of complex numbers multiplied by the unit matrix. Therefore we can commute $\gamma^0$. Furthermore, $P_{jk}$ has complex numbers and multiplied by the $\gamma_5$ matrix. The complex numbers are not affected by the commutation of $\gamma_0$, however $\gamma_5\gamma^0 = -\gamma^0\gamma_5$. Consequently we obtain

$$|M_{jk}|^2 = |\alpha_{jk}|^2 \{ \bar{v}_\mu(k_1)(S_{jk} + P_{jk}) u_\tau(k_2) (S_{jk}^\dagger - P_{jk}^\dagger) v_\mu(k_1) \}$$  

(4.41)

Since it is not known the final states of the spins of the particles $\mu$ and $\tau$, we make an average of the possible states. Proceeding firstly with the average of the final state of $\bar{u}_\tau(k_2)$ and $u_\tau(k_2)$

$$|M_{jk}|^2 = |\alpha_{jk}|^2 \{ \bar{v}_\mu(k_1)(S_{jk} + P_{jk}) \frac{1}{2} \sum_{\text{spin}=1,2} \{ u_\tau(k_2) * \bar{u}_\tau(k_2) \} (S_{jk}^\dagger - P_{jk}^\dagger) v_\mu(k_1) \}$$  

(4.42)

We label as $Q = (S_{jk} + P_{jk}) [k_2 + m_\tau] (S_{jk}^\dagger - P_{jk}^\dagger)$, to simplify and clarify the calculations.

We proceed to sum over the spins of $\bar{v}_\mu(k_1)$ and $v_\mu(k_1)$. Also, the multiplication
Consequently we obtain
\[
|M_{jk}|^2 = \frac{1}{2} |\alpha_{jk}|^2 \{ \bar{u}_\mu(k_1)Q_jk v_\mu(k_1) \}
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 \sum_{spin=1,2} \sum_{i,j=1}^4 \bar{v}_\mu(k_1)iQ_{i,j}v_\mu(k_1)j
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 \sum_{i,j=1}^4 Q_{ij} \{ v_\mu(k_1)\bar{v}_\mu(k_1) \}_{ji}
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 \sum_{i=1}^4 Q(k_1 - m_\mu)_{ji}
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 \sum_{i=1}^4 (Q(k_1 - m_\mu))_{ji}
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 Tr[Q(k_1 - m_\mu)]
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 Tr[(S_{jk} + P_{jk})(\bar{k}_2 + m_\tau)(S_{jk}^\dagger - P_{jk}^\dagger)(k_1 - m_\mu)]
\] (4.43)

Expanding the products
\[
|M_{jk}|^2 = \frac{1}{4} |\alpha_{jk}|^2 Tr\left[\left((S_{jk} + P_{jk})\bar{k}_2 S_{jk}^\dagger - (S_{jk} + P_{jk})\bar{k}_2 P_{jk}^\dagger\right)
\right.
\]
\[
+ (S_{jk} + P_{jk})m_\tau S_{jk}^\dagger - (S_{jk} + P_{jk})m_\tau P_{jk}^\dagger \left((k_1 - m_\mu)\right)
\]
\[
= \frac{1}{4} |\alpha_{jk}|^2 Tr\left[\left((S_{jk} + P_{jk})\bar{k}_2 S_{jk}^\dagger \bar{k}_1 - (S_{jk} + P_{jk})\bar{k}_2 P_{jk}^\dagger \bar{k}_1\right)
\right.
\]
\[
+ (S_{jk} + P_{jk})m_\tau S_{jk}^\dagger \bar{k}_1 - (S_{jk} + P_{jk})m_\tau P_{jk}^\dagger \bar{k}_1 \left((k_1 - m_\mu)\right)
\]
\[
- (S_{jk} + P_{jk})\bar{k}_2 S_{jk}^\dagger m_\mu + (S_{jk} + P_{jk})\bar{k}_2 P_{jk}^\dagger m_\mu 
\]
\[
- (S_{jk} + P_{jk})m_\tau S_{jk}^\dagger m_\mu + (S_{jk} + P_{jk})m_\tau P_{jk}^\dagger m_\mu \left((k_1 - m_\mu)\right)
\] (4.44)

If we consider the following properties of the dirac matrices, we can considerably simplify the \(|M|^2\) expression, since \(\bar{k}_1 = \gamma^\mu k_{1\mu}, \bar{k}_2 = \gamma^\nu k_{2\nu}\) and \(P_{jk} = factors\):

1) \(Tr[\gamma^\mu] = 0\)
2) \(Tr[\gamma^\nu\gamma_5] = 0\)
3) \(Tr[\gamma_5\gamma^\mu\gamma^\nu] = 0\)
4) \(\gamma_5^2 = I_{4x4}\)
5) \(\gamma_5\gamma^\mu = -\gamma^\mu\gamma_5\) \(\Rightarrow\) \(Tr[I_{4x4}] = 4\) (4.45)

Consequently we obtain
\[
|M_{jk}|^2 = \frac{1}{4} |\alpha_{jk}|^2 \left\{ \left|S_{jk}\right|^2 + \left|P_{jk}\right|^2 \right\} Tr[\bar{k}_2 \bar{k}_1] + 4 \left|P_{jk}\right|^2 - \left|S_{jk}\right|^2 m_\mu m_\mu \right\} \] (4.46)
where $P'_{jk}$ is the scalar part of $P_{jk}$.

In order to find the traces in the above expression, we use

$$Tr[k_2 \bar{k}_1] = \frac{g^{\mu\nu} k_{2\mu} k_{1\nu}}{4k_2 \cdot k_1} = \frac{4k_2^\mu k_{1\mu}}{} = 4\left(\frac{E_2}{c}, \bar{k}_2\right) \cdot \left(\frac{E_1}{c}, -\bar{k}_1\right)$$

(4.47)

If we take as our reference the particle $h^0$, the momentum conservation leads us to

$$p_{h^0} = \bar{k}_1 + \bar{k}_2 = 0$$
$$\bar{k}_1 = -\bar{k}_2$$

(4.48)

Then

$$Tr[k_2 \bar{k}_1] = 4\left\{\frac{E_2 E_1}{c^2} + |\bar{k}_2|^2\right\}$$

(4.49)

where we labeled $E_T$ as the total energy, and used the conservation of Energy. We re-express $|k_2|^2$

$$|k_2|^2 = |k_3|^2$$

$$\Rightarrow$$

$$\frac{E_2^2}{c^2} - m_2^2 c^2 = \frac{E_3^2}{c^2} - m_3^2 c^2$$

$$\Rightarrow$$

$$E_2^2 - E_3^2 = m_2^2 c^4 - m_3^2 c^4$$

$$(E_2 + E_3)(E_2 - E_3) = m_2^2 c^4 - m_3^2 c^4$$

(4.50)

If we use

$$E_T = m_{h^0} c^2 = E_2 + E_3$$

$\Rightarrow$

$$m_{h^0} c^2 - 2E_3 = E_2 - E_3$$

(4.51)

We obtain

$$m_{h^0} c^2 (m_{h^0} c^2 - 2E_3) = m_2^2 c^4 - m_3^2 c^4$$

(4.52)

Substituting $E_3$ and isolating $|k_2|$ we have

$$\rho = \frac{\sqrt{C_{h^0\mu\tau}}}{2m_{h^0}}$$

(4.53)

where we just renamed $|k_2|$ as $\rho$. For our special case, all the labeled momentums, masses and Energies with the number 2 will be referenced to the $\tau$ and with the number 1 to the $\mu$.
Taking $c = 1, \bar{h} = 1$, the expression $|M|^2$ is given by

$$|M_{jk}|^2 = |\alpha_{jk}|^2 \left\{ (|S_{jk}|^2 + |P_{jk}'|^2) (E_\tau E_\mu + \rho^2) + (|P_{jk}'|^2 - |S_{jk}|^2) m_\tau m_\mu \right\}$$

(4.54)

We have that

$$\Gamma(h^0 \rightarrow \tau \mu) = \sum_{jk} \frac{1}{8\pi \hbar m_{h^0}} \int_{(m_\tau+m_\mu)^2} |M_{jk}|^2 \frac{\delta(m_{h^0}c - \frac{E_T}{c})}{E_T} dE_T$$

(4.55)

Substituting $|M|^2$, we obtain.

$$\Gamma(h^0 \rightarrow \tau \mu) = \sum_{jk} \frac{c}{8\pi^2 \hbar m_{h^0}} |\alpha_{jk}|^2 \left\{ (|S_{jk}|^2 + |P_{jk}'|^2) (E_\tau E_\mu + \rho^2) + (|P_{jk}'|^2 - |S_{jk}|^2) m_\tau m_\mu \right\}$$

(4.56)

Using the function delta property

$$\int f(x) \delta(x - x') dx = f(x')$$

(4.57)

$$\Gamma(h^0 \rightarrow \tau \mu) = \sum_{jk} \frac{|\alpha_{jk}|^2 \rho}{8\pi^2 \hbar m_{h^0} c} \left\{ (|S_{jk}|^2 + |P_{jk}'|^2) (E_\tau E_\mu + \rho^2) + (|P_{jk}'|^2 - |S_{jk}|^2) m_\tau m_\mu \right\}$$

(4.58)

Once again taking $c = 1, \bar{h} = 1$.

$$\Gamma(h^0 \rightarrow \tau \mu) = \sum_{jk} \frac{|\alpha_{jk}|^2 \rho}{8\pi^2 m_{h^0} c} \left\{ |S_{jk}|^2 (E_\tau E_\mu + \rho^2 - m_\tau m_\mu) + |P_{jk}'|^2 (E_\tau E_\mu + \rho^2 + m_\tau m_\mu) \right\}$$

(4.59)

where

$$E_\mu = \sqrt{m_\mu^2 + \rho^2}$$

(4.60)

$$E_\tau = \sqrt{m_\tau^2 + \rho^2}$$

(4.61)

We divide the expression 4.59 by the total width. We used the value of 4 [MeV], which is between the range $6.1^{+7.7}_{-2.9}$[MeV] and in good accuracy with different papers where the total width is given 27, 28, 29, 30.
\[
\begin{array}{|c|c|c|}
\hline
\gamma \gamma & S_{jk} [1/\text{GeV}] & P_{jk} [1/\text{GeV}] \\
\hline
\tilde{\mu}_1 \tilde{\mu}_1 & -8 \frac{i \tau^2}{|\tau^2|} [B_{jk} - F_0] C_{jk} + C_{h^0\mu\tau}(\frac{10}{8} m_B + m_\tau)] & 6i\pi^2 m_B F_{\alpha\gamma} \gamma 5 \\
\hline
\tilde{\mu}_1 \tilde{\mu}_2 & 6i\pi^2 m_B F_{\mu \nu} & 8 \frac{i \tau^2}{|\tau^2|} [B_{jk} - F_0] C_{jk} + C_{h^0\mu\tau}(\frac{10}{8} m_B + m_\tau)] \gamma 5 \\
\hline
\tilde{\mu}_2 \tilde{\mu}_2 & 6i\pi^2 m_B F_{\mu \nu} & 8 \frac{i \tau^2}{|\tau^2|} [B_{jk} - F_0] C_{jk} + C_{h^0\mu\tau}(\frac{10}{8} m_B + m_\tau)] \gamma 5 \\
\hline
\end{array}
\]

Table 4.1: It is shown the Scalar and Pseudoscalar parts of \(M_{jk}\). Units in \(\frac{1}{\text{GeV}}\)
Table 4.2: The respective coupling $\alpha_{jk}$ for each of the possible loop corrections. Units in GeV

<table>
<thead>
<tr>
<th>$f \bar{f}$</th>
<th>$\alpha_{jk}$ [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{\mu}_1 \tilde{\mu}_1$</td>
<td>$-g_{h^0 \tilde{\mu}<em>1 \tilde{\mu}<em>1} \frac{i g^2 s</em>{\phi} c</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\mu}_1 \tilde{\mu}_2$</td>
<td>$-g_{h^0 \tilde{\mu}<em>1 \tilde{\mu}<em>2} \frac{i g^2 c</em>{\phi} s</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\mu}_1 \tilde{\tau}_1$</td>
<td>$0$</td>
</tr>
<tr>
<td>$\tilde{\mu}_2 \tilde{\mu}_1$</td>
<td>$-g_{h^0 \tilde{\mu}<em>2 \tilde{\mu}<em>1} \frac{i g^2 c</em>{\phi} s</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\mu}_2 \tilde{\mu}_2$</td>
<td>$-g_{h^0 \tilde{\mu}<em>2 \tilde{\mu}<em>2} \frac{i g^2 c</em>{\phi} s</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\mu}_2 \tilde{\tau}_1$</td>
<td>$-g_{h^0 \tilde{\mu}<em>2 \tilde{\tau}<em>1} \frac{i g^2 c</em>{\phi} s</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\tau}_1 \tilde{\mu}_1$</td>
<td>$0$</td>
</tr>
<tr>
<td>$\tilde{\tau}_1 \tilde{\tau}_2$</td>
<td>$0$</td>
</tr>
<tr>
<td>$\tilde{\tau}_2 \tilde{\mu}_1$</td>
<td>$g_{h^0 \tilde{\tau}<em>2 \tilde{\mu}<em>1} \frac{i g^2 s</em>{\phi} c</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\tau}_1 \tilde{\tau}_1$</td>
<td>$-g_{h^0 \tilde{\tau}<em>1 \tilde{\tau}<em>1} \frac{i g^2 c</em>{\phi} s</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
<tr>
<td>$\tilde{\tau}_2 \tilde{\tau}_2$</td>
<td>$-g_{h^0 \tilde{\tau}<em>2 \tilde{\tau}<em>2} \frac{i g^2 c</em>{\phi} s</em>{\phi}}{16} \tan^2 \theta_w$</td>
</tr>
</tbody>
</table>

Table 4.3: Expressions for the respective Propagators of the different particles, where $n$ is the label of the momentum and it depends on how the diagram is constructed. $j$ can be either 1 or 2 and are the different possible s-muons and s-taus.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Propagator</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{B}$</td>
<td>$\frac{i (q_2^2 + m_\tilde{B}^2)}{q_2^2 - m_\tilde{B}^2}$</td>
</tr>
<tr>
<td>$\tilde{\mu}_s$</td>
<td>$\frac{i}{q_1^2 s_\mu - m_\tilde{\mu}_s^2}$</td>
</tr>
<tr>
<td>$\tilde{\tau}_s$</td>
<td>$\frac{i}{q_{1,3}^2 s_{\tau} - m_\tilde{\tau}_s^2}$</td>
</tr>
</tbody>
</table>
4.1.1 Calculations and Computing the Branching Ratio

We used FORTRAN to calculate the branching ratio. Since we have five free parameters in our Branching Ratio expression, we made the analysis taking into account randomly all the possible values that could take the parameters in certain regions. These regions are constraints of the experiments or there would be no theoretical reason to extend the variables to bigger or lower regions. The regions are given by

- $\mu_{\text{susy}}$ is a parameter that experimentally must be bigger than $|500|$ GeV. Therefore we make plots variating this parameter randomly with positive values $\mu_{\text{susy}} > 500$ and negative values $\mu_{\text{susy}} < -500$. In figure 4.2($\mu_{\text{susy}} < 0$) and in figure 4.7($\mu_{\text{susy}} > 0$) are shown the randomly plotting of the Branching Ratio vs the free parameter $\mu_{\text{susy}}$.

- $m_0$ is the a parameter that comes from the trilinear term in our Ansatz for Flavour Violation. It is the parameter for all the masses and it must be $m_0 \gtrsim 500$ GeV. If the value of $m_0$ is lower than 500 GeV, the masses tend to be lower than 300 GeV, and if that were the case, the s-particle would have been already discovered. We take as a maximal value 5000 GeV for the same reason as the parameter $A_0$. In figure 4.3($\mu_{\text{susy}} > 0$) and in figure 4.8($\mu_{\text{susy}} < 0$)are shown the randomly ploting of the Branching Ratio vs the free parameter $m_0$.

- In figure 4.4($\mu_{\text{susy}} < 0$) and in figure 4.9($\mu_{\text{susy}} > 0$) are shown the randomly plotting of the Branching Ratio vs the free parameter $\tan(\beta)$. $1 \lesssim \tan(\beta) \lesssim 60$ since values lower to 1 tend to diverge to infinity. $\tan(\beta)$ Values of $\tan(\beta)$ can not be bigger than 60, since it is the ratio of the vacuum spectation values of the Higgs Boson.

- $A_0$ is measured in GeV and the value of the $A_0 \approx 1000$. Therefore we took randomly possible values in the range $800 < A_0 < 1200$ GeV. The value could be bigger. There is no experimental constraint. However, the value of the s-masses depend of $A_0$ and values can make the s-particle masses tend to infinity which would have no physical meaning. In figure 4.5($\mu_{\text{susy}} < 0$) and in figure 4.10($\mu_{\text{susy}} > 0$) are shown the randomly plotting of the Branching Ratio vs the free parameter $A_0$.

- $m_{\tilde{B}}$ can take any value greater than 500 GeV. It can not be lower since it would have been already discovered at experiments. We make the range of the bino mass from 500 to 5000 GeV. In figure 4.6($\mu_{\text{susy}} < 0$) and in figure 4.11($\mu_{\text{susy}} > 0$) are shown the randomly plotting of the Branching Ratio vs the free parameter $m_{\tilde{B}}$. 

Figure 4.2: Plot of Branching Ratio and $\mu_{\text{susy}}$, for $\mu_{\text{susy}} < 0$. All the values of $A_0, m_0, \tan(\beta), m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.

Figure 4.3: Plot of Branching Ratio and $m_0$ with $\mu_{\text{susy}} < 0$. All the values of $A_0, \mu_{\text{susy}}, \tan(\beta), m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.
Figure 4.4: Plot of Branching Ratio and $\tan(\beta)$ with $\mu_{\text{susy}} < 0$. All the values of $A_0, m_0, \mu_{\text{susy}}, m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.

Figure 4.5: Plot of Branching Ratio and $A_0$ with $\mu_{\text{susy}} < 0$. All the values of $\mu_{\text{susy}}, m_b, \tan(\beta), m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.
Figure 4.6: Plot of Branching Ratio and $m_b$ with $\mu_{\text{susy}} < 0$. All the values of $\mu_{\text{susy}}, m_0, \tan(\beta), A_0$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.

Figure 4.7: Plot of Branching Ratio and $\mu_{\text{susy}}$, for $\mu_{\text{susy}} > 0$. All the values of $A_0, m_b, \tan(\beta), m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.
Decay $h^0 \rightarrow \tau \mu$ in MSSM extended in FV

Figure 4.8: Plot of Branching Ratio and $\mu_0$ with $\mu_{\text{susy}} > 0$. All the values of $A_0, \mu_{\text{susy}}, \tan(\beta), m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.

Figure 4.9: Plot of Branching Ratio and $\tan(\beta)$ with $\mu_{\text{susy}} > 0$. All the values of $A_0, m_0, \mu_{\text{susy}}, m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.
Figure 4.10: Plot of Branching Ratio and $A_0$ with $\mu_{\text{susy}} > 0$. All the values of $\mu_{\text{susy}}, m_0, \tan(\beta), m_b$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.

Figure 4.11: Plot of Branching Ratio and $m_b$ with $\mu_{\text{susy}} > 0$. All the values of $\mu_{\text{susy}}, m_0, tan(\beta), A_0$ are varied. The three lines represent the value of the best fit of the Branching Ratio found by CMS and the lower and upper limits of error to the measure. The green region represents the solutions of our Ansatz to the region given by CMS.
Decay $h^0 \to \tau\mu$ in MSSM extended in FV