New physics searches in Υ leptonic decays

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21 May 2010

New physics searches in Υ leptonic decays (*Outline*)

- ***Introduction***
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In collaboration with Hua-Sheng Shao and Kuang-Ta Chao.

1 Introduction

- The hunting of NP is one of the hottest topics for theorist and experimentalist.
- The B factories gave a very clear channel to test SM, just as $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon \to l^+l^-$ ($l = \tau, \mu$). Recent Babar measured the ratio [1, 2]

$$R_{\tau\mu} = \frac{Br[\Upsilon \to \tau^+\tau^-]}{Br[\Upsilon \to \mu^+\mu^-]} = 1.005 \pm 0.013 \pm 0.022, \quad (1)$$

- The Leading Order SM prediction of $R_{\tau\mu}$ is 0.992[3, 4] . It is consistent with experimental date within error bar.

- ★ The SM predictions should be compared with experimental data beyond tree level.
- ★ At the same time, $R_{\tau\mu}$ is sensitively on the coupling of $h(A_0)b\bar{b}$ and $h(A_0)l^+l^-$ within NP.
- ★ It is an excellent probe for the new Higgs interactions in some NP Model, where the coupling of Higgs $b\bar{b}$ and Higgs l^+l^- is enhanced [5].
- ★ Then we should calculate the ratio $R_{\tau\mu}$ and compare with the experimental data to test SM or hunt NP.

There are some theoretical and experimental works related with it.

- The QCD corrections of $\Upsilon \to l^+l^-$ have been calculated to two-loop [6].
- We have calculated Υ decay to charm jet[7].
- The CLEO got the ratio $R_{\tau\mu} = 1.02 \pm 0.02 \pm 0.05$ in 2006 [8].
- The MC simulation of $\Upsilon \to l^+l^-$ has been studied, where large logarithms have been resummed[9].
- The pseudoscalar Higgs A_0 is also introduced in decay and spectroscopy of bottomonium [10, 11].
- Babar has searched for a light Higgs boson A_0 in the radiative decay of $\Upsilon(nS) \to \gamma A_0$, $A_0 \to l^+l^-$ for $n = 1, 2, 3$. They found no evidence for such processes in the mass range$0.212GeV \leq M_{A0} \leq 9.3GeV$ and no narrow structure with $4.03GeV \leq M_{\tau^+\tau^-} \leq 10.10GeV$ [12].
- η_b leptonic decay is discussed too.[13, 14, 15].

2 Standard Model prediction

The LO QED Feynman diagrams of $\Upsilon \to l^+l^-$ are shown in Fig.1.

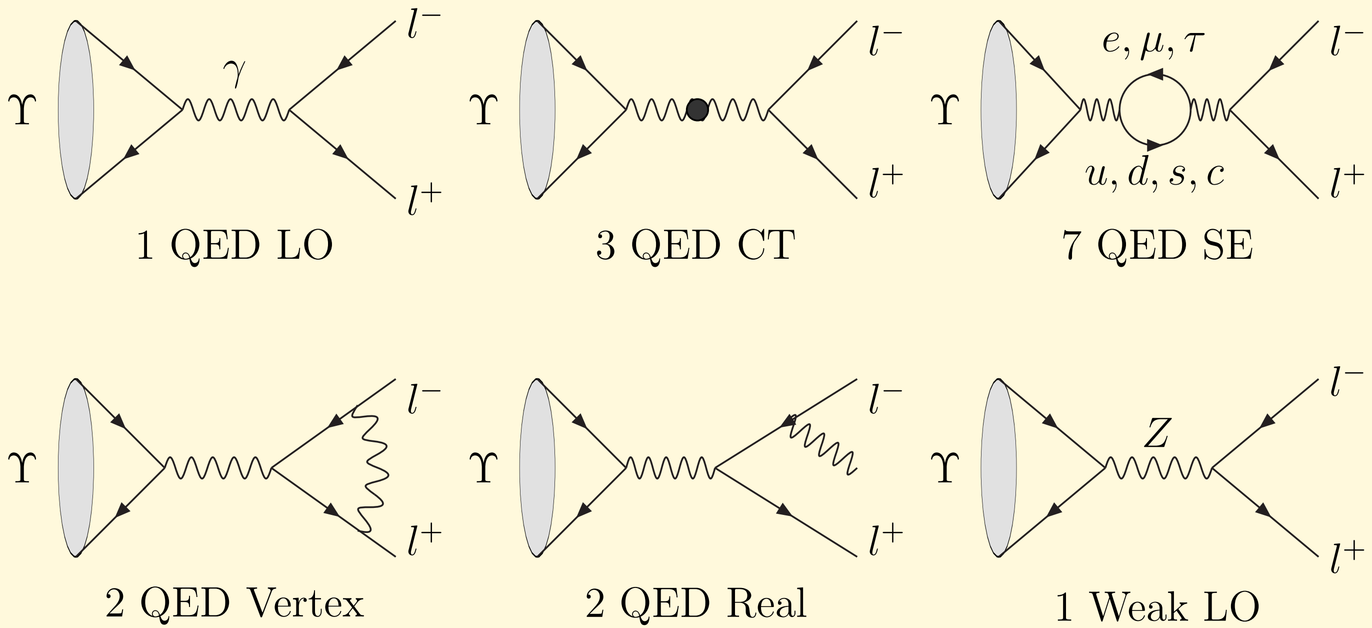


Fig.1 Part of the Feynman diagrams of $\Upsilon \to l^+l^-$ within SM.

Followed the process of $\Upsilon \to c\bar{c}$ in Ref.[7], we can get the LO amplitude and decay width of $\Upsilon \to l^+l^-$,

$$\begin{aligned} \mathcal{M}_{LO}[\Upsilon \to l^+l^-] &= \sqrt{\frac{16\pi}{3M_\Upsilon^3}}\,\alpha\,|R(0)|\,\bar{l}\,\not{\epsilon}\,l, \\ \Gamma_{LO}[\Upsilon \to l^+l^-] &= \frac{4|R(0)|^2\alpha^2\sqrt{1-4r_l}(1+2r_l)}{9M_\Upsilon^2}, \end{aligned} \tag{2}$$

where $r_l = M_l^2/M_\Upsilon^2$, $|R(0)|$ is the radial wave function of Υ at origin, ϵ is the polarization vector of Υ. If expanded with r_l, we can get

$$\Gamma_{LO}[\Upsilon \to l^+l^-] = \frac{4|R(0)|^2\alpha^2}{9M_\Upsilon^2}\left(1 - 6r_l^2 + \mathcal{O}\left(r_l^3\right)\right). \tag{3}$$

☆

$$R_{ll'}^{LO} = \frac{\sqrt{1-4M_l^2/M_\Upsilon^2}(1+2M_l^2/M_\Upsilon^2)}{\sqrt{1-4M_{l'}^2/M_\Upsilon^2}(1+2M_{l'}^2/M_\Upsilon^2)} = 1-6(M_l^4-M_{l'}^4)/M_\Upsilon^4+....,\qquad (4)$$

and

$$\frac{M_\mu^2}{M_\Upsilon^2} = 1.2\times 10^{-4}$$
$$\frac{M_\tau^2}{M_\Upsilon^2} = 3.5\times 10^{-2} \qquad (5)$$

☆ In experimental data, $R_{\tau\mu} = \frac{N_{sig\tau}}{\epsilon_{\tau\tau}}\cdot\frac{\epsilon_{\mu\mu}}{N_{sig\mu}}$, where $N_{sig\mu}$ ($N_{sig\tau}$) indicates the number of signal events. and $\epsilon_{\tau\tau}(\epsilon_{\mu\mu})$ is the efficiency.

☆ $R_{\tau\mu}$ is very clear in both theory and experiment.

- We take into account the NLO QED correction here.
- The renormalization of lepton and b quark wave function, and electron charge should appear.
- We use $D = 4 - 2\epsilon$ space-time dimension to regularize the divergence. On-mass-shell (OS) scheme is selected for $Z_{2b(l)}$ and modified minimal-subtraction ($\overline{\mathrm{MS}}$) scheme for Z_e:

$$
\begin{aligned}
\delta Z_{2f}^{\mathrm{OS}} &= -\frac{Q_f^2 \alpha}{4\pi}\left[\frac{1}{\epsilon_{\mathrm{UV}}} + \frac{2}{\epsilon_{\mathrm{IR}}} - 3\gamma_E + 3\ln\frac{4\pi\mu^2}{M_f^2} + 4\right], \\
\delta Z_e^{\overline{\mathrm{MS}}} &= \frac{\alpha}{6\pi}(3 + \frac{10}{3})\left(\frac{1}{\epsilon_{\mathrm{UV}}} - \gamma_E + \ln(4\pi)\right), \qquad (6)
\end{aligned}
$$

  where μ is the renormalization scale, γ_E is the Euler's constant, $f = b, l$, and Q_f is the charge of fermion f in unit of electron charge.
- If we ignore the self energy of photon and the renormalization of α, the NLO QED correction is just replaced $4\alpha_s/3$ with α from $\Upsilon \to c\bar{c}$[7].

In numerical calculation, the parameters are selected as:

$$\begin{aligned} M_e &= 0.5110 MeV, \quad M_d = 0.00 MeV, \quad M_u = 0.00 MeV, \\ M_\mu &= 0.1057 GeV, \quad M_s = 0.10 GeV, \quad M_c = 1.30 GeV, \\ M_\tau &= 1.7768 GeV, \quad M_b = 4.73 GeV, \quad \alpha = 1/132.33. \end{aligned} \tag{7}$$

Here $M_b = M_\Upsilon/2$. The renormalization scale μ is selected as $\mu = M_\Upsilon$.

Tab1 The numerical decay width of $\Upsilon \to l^+ l^- (l = \tau, \mu)$ and $R_{\tau\mu}$ within SM.

	$\Gamma[\tau]$	$\Gamma[\mu]$	$R_{\tau\mu}$
LO	$2.8221 \frac{\|R(0)\|^2}{10^7 GeV^2}$	$2.8444 \frac{\|R(0)\|^2}{10^7 GeV^2}$	0.9922
NLO QED	$2.7773 \frac{\|R(0)\|^2}{10^7 GeV^2}$	$2.7965 \frac{\|R(0)\|^2}{10^7 GeV^2}$	0.9932
Babar	-	-	1.005 ± 0.026

We should calculate the uncertainty for the theoretical prediction.

◎ For the NLO QED corrections have been taken into account, the uncertainty from higher order QED contributions is $\mathcal{O}(\alpha^2/\pi^2) \sim 6 \times 10^{-6}$

◈ The event is selected through four charge particle. So the uncertainty from QCD contributions are come from $\Upsilon \to l^+l^-gg \to l^+l^- + uncharged\ particles$. $\Gamma[\Upsilon \to l^+l^-gg]/\Gamma[\Upsilon \to l^+l^-]$ is about $2\%(0.2\%)$ for $\mu^+\mu^-(\tau^+\tau^-)$. As a naive estimate, the ratio of $gg \to uncharged\ particles$ should less than $1/3$. And uncertainty is less then 0.6%.

- Z can contribute to $\Upsilon \to l^+l^-$ at tree level. We can get

$$\frac{\mathcal{M}^Z_{LO}[\Upsilon \to l^+l^-]}{\mathcal{M}^\gamma_{LO}[\Upsilon \to l^+l^-]} = f_z \frac{\bar{l}\left[(4\sin^2\theta_W - 1)\not{\epsilon} + \not{\epsilon}\gamma^5\right] l}{\bar{l}\ \not{\epsilon}\, l}, \tag{8}$$

$$f_z = \frac{M^2_\Upsilon\left(3 - 4\sin^2\theta_W\right)}{16\left(M^2_\Upsilon - M^2_Z\right)\left(1 - \sin^2\theta_W\right)\sin^2\theta_W}. \tag{9}$$

Here $f_z \sim -M^2_\Upsilon/M^2_Z \sim -10^{-2}$. Then the uncertainty from vector current of Z on $R_{\tau\mu}$ should be $\mathcal{O}(f_z\left(1 - 4\sin^2\theta_W\right)(R^{QED}_{\tau\mu} - R^{LO}_{\tau\mu})) \sim \mathcal{O}(10^{-6})$. Here superscript QED means NLO QED has been taken into account. The axial vector current the ratio with a factor $\mathcal{O}(M^2_\Upsilon M^2_l/M^4_Z) \sim \mathcal{O}(10^{-5})$ only.

▲ Within SM, it should be considered that $\Upsilon \to \gamma\eta_b$, where $\eta_b \to l^+l^-$ is followed [11]. The energy of γ is about 70 MeV in $\Upsilon \to \gamma\eta_b$ and $Br[\eta_b \to l^+l^-(+\gamma_{soft})] \sim 10^{-8}$[13, 14]. For $\Upsilon \to \gamma\eta_b$ is a P wave process, we can estimate $Br[\Upsilon \to \gamma\eta_b]$ through

$$\frac{\Gamma[\Upsilon \to \gamma\eta_b]}{\Gamma[J/\psi \to \gamma\eta_c]} \sim \left(\frac{e_b}{e_c}\right)^2 \left(\frac{M_{J/\psi}(M_\Upsilon - M_{\eta_b})}{M_\Upsilon(M_{J/\psi} - M_{\eta_c})}\right)^3 . \tag{10}$$

Then $Br[\Upsilon \to \gamma\eta_b] \sim 10^{-5}$. So $Br[\Upsilon \to \gamma\eta_b] \times Br[\eta_b \to l^+l^-(+\gamma_{soft})] \sim 10^{-12}$. This can be ignored safely.

Tab.2 The uncertainties of $R_{\tau\mu}$ within SM.

	Order	Numerical
QED	α^2/π^2	6×10^{-6}
QCD	$< \alpha_s^2/\pi^2 \times \ln \frac{M_\mu^2}{M_b^2}/3 \times \frac{1}{3}$	$< 6 \times 10^{-3}$
$Z(W^\pm, H)$	$M_\Upsilon^2 M_l^2/M_Z^4$ or $\alpha M_l^2/(M_Z^2\pi)$	4×10^{-6}
η_b	$Br[\Upsilon \to \gamma\eta_b] \times Br[\eta_b \to l^+l^-]$	1×10^{-12}
Total	-	< 0.006
$R_{\tau\mu}^{SM}$	1	0.993 ± 0.006
$R_{\tau\mu}^{Babar}$	1	$1.005 \pm 0.013 \pm 0.022$

The uncertainties of $R_{\tau\mu}$ within SM are listed in Tab.2. Then SM prediction is

$$R_{\tau\mu} = 0.993 \pm 0.006. \tag{11}$$

Compared with Eq.(1), it is consistent with the experimental data in the error bar and a little less than the center value.

Most of the uncertainty come from the QCD contributions in Eq(11). It is difficult to measure. So we present a better approach to test the SM,

$$R_{\tau\mu}(E_{soft}) = \Gamma[\Upsilon \to \tau^+\tau^- + X]/\Gamma[\Upsilon \to \mu^+\mu^- + X]\Big|_{E_X<E_{soft}} \quad (12)$$

. If we select $E_{soft} \sim 5GeV$, $\Gamma[\Upsilon \to l^+l^- + gg]|_{M_X<E_{soft}}$ is less than $\Gamma[\Upsilon \to l^+l^-]/1000$, then the impact on $R_{\tau\mu}(E_{soft})$ is less than 2×10^{-5}, but the large logarithms appear

$$L = \ln \frac{4E_s^2}{M_\Upsilon^2} \ln \frac{4M_l^2}{M_\Upsilon^2}. \quad (13)$$

We resum the large logarithms with YFS resummation scheme[16, 9],

$$Y = \frac{-\alpha}{\pi}\left(2\left(\ln r_l + 1\right)\ln \frac{2E_s}{M_\Upsilon} + \frac{\ln r_l}{2} - \frac{\pi^2}{3} + 1\right). \quad (14)$$

The resumed results are

$$\begin{aligned} \Gamma_{LO}^{res} &= e^Y\,\Gamma_{LO}, \\ \Gamma_{NLO}^{res} &= \left(e^Y - 1 - Y\right)\Gamma_{LO} + \Gamma_{QED}. \end{aligned} \quad (15)$$

If we select $E_s = 0.2GeV$. Including the uncertainty, the ratio is

$$R_{\tau\mu}(0.2GeV) = 1.0628 \pm 0.0011. \tag{16}$$

The effect of QCD is very weak in this channel. $R_{\tau\mu}(E_{soft})$ can be compared with experimental data more precise.

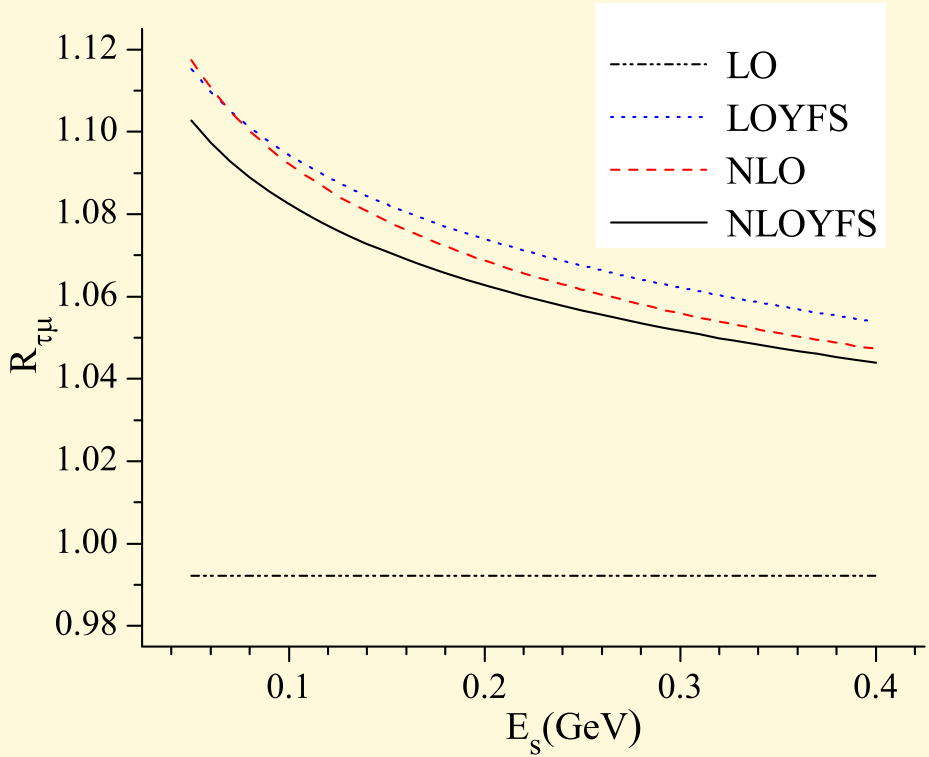


Fig.2 The dependence of $R_{\tau\mu}(E_{soft})$ on the soft cut E_s within SM.

Tab.3 The numerical decay width of processes $\Upsilon \to l^+l^-(l=\tau,\mu)$ in unit of $\frac{|R(0)|^2}{10^7 GeV^2}$ and $R_{\tau\mu}(E_{soft})$ within SM. $E_s=0.1$ means the soft cut is $0.1GeV$.

	$\Gamma[\tau]$	$\Gamma[\mu]$	$R_{\tau\mu}(E_{soft})$
LO	2.8221	2.8444	0.9922
LOYFS$\|_{E_s=0.10}$	2.7277	2.4925	1.0944
NLO$\|_{E_s=0.05}$	2.6744	2.3932	1.1174
NLOYFS$\|_{E_s=0.05}$	2.6768	2.4272	1.1028
NLO$\|_{E_s=0.10}$	2.6954	2.4678	1.0922
NLOYFS$\|_{E_s=0.10}$	2.6970	2.4916	1.0824
NLO$\|_{E_s=0.20}$	2.7158	2.5411	1.0688
NLOYFS$\|_{E_s=0.20}$	2.7168	2.5564	1.0628
NLO$\|_{E_s=0.45}$	2.7385	2.6236	1.0438
NLOYFS$\|_{E_s=0.45}$	2.7389	2.6312	1.0409

3 Impact from New Physics

NP may play a role in the discrepancy between theoretical prediction and experimental data of $R_{\tau\mu}$ in Eq.(11) and Eq.(1). We only consider the scheme of light Higgs h and pseudoscalar Higgs A_0 here.

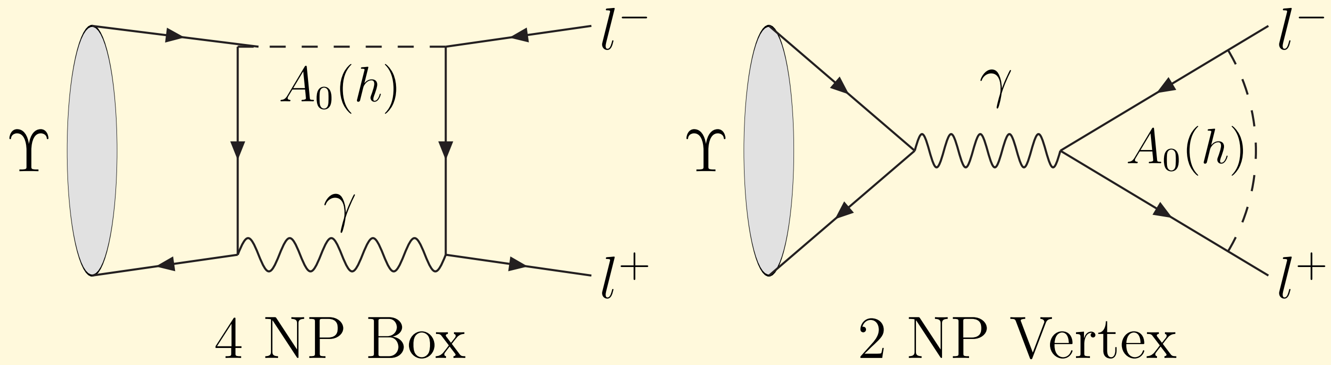


Fig.3 Part of the Feynman diagrams of $\Upsilon \to l^+ l^-$ which $A_0(h)$ involved. The Feynman diagrams which exchange $A_0(h)$ between $b\bar{b}$ are ignored for it should not change the ratio $R_{\tau\mu}$.

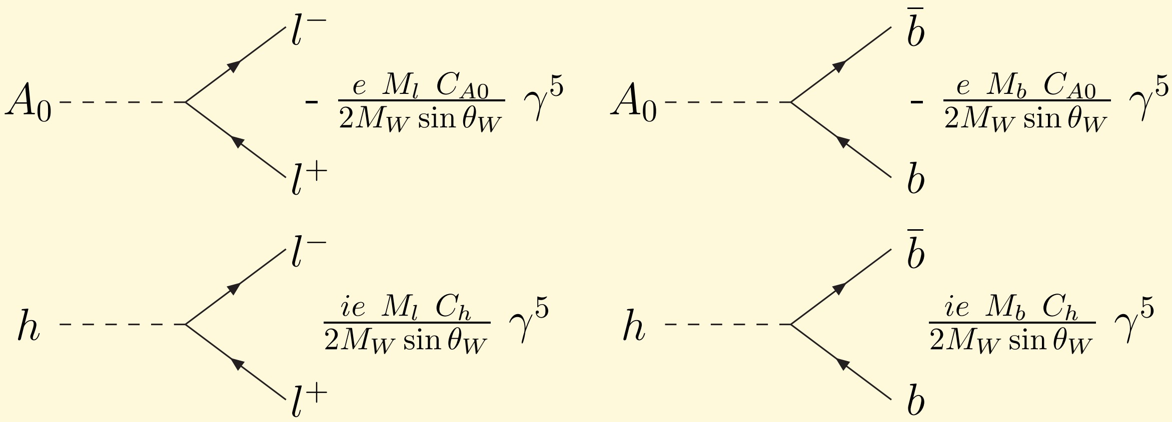
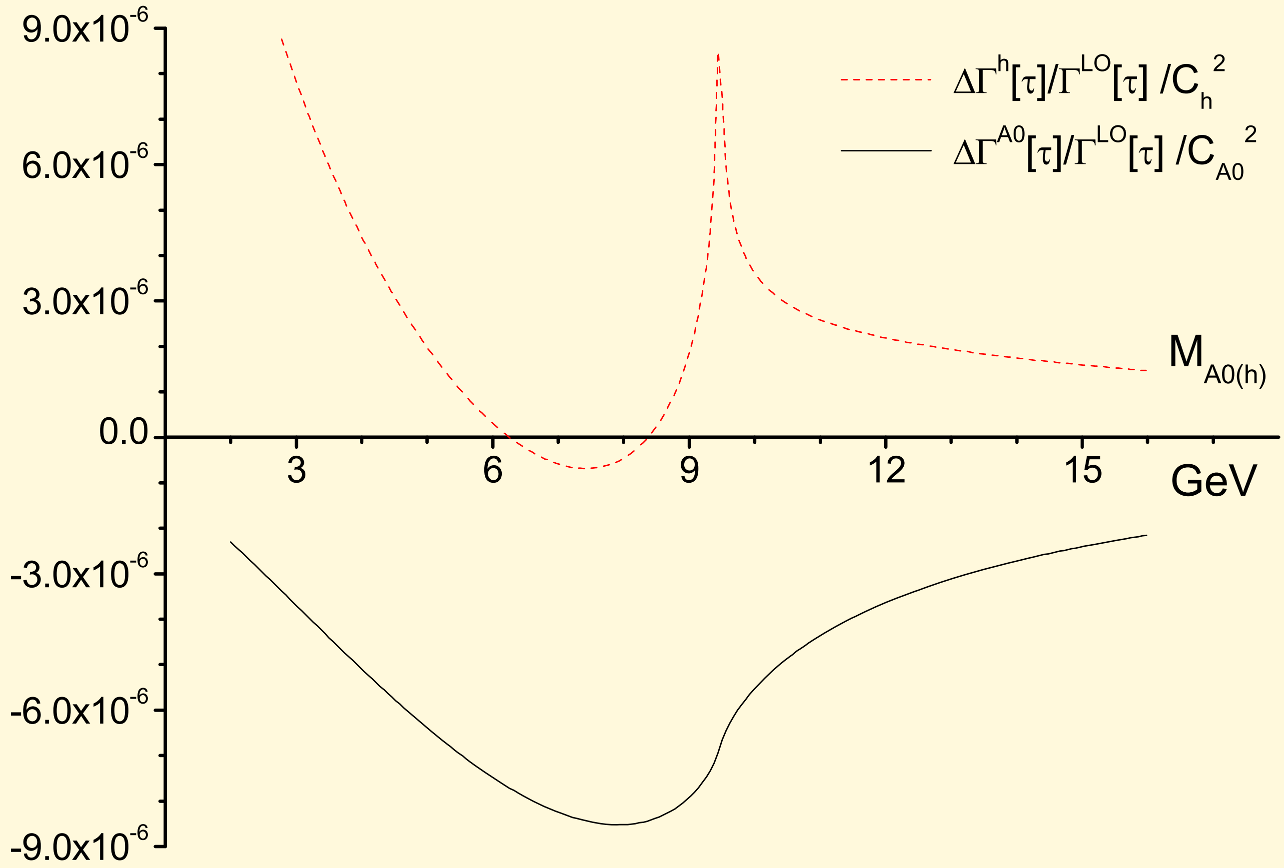


Fig.3 Feynman rule of $hf\bar{f}$ and $A_0 f\bar{f}$

- $C_{A0(h)}$ are different in the special model, we consider them as parameters.
- For it is IR finite which $A_0(h)$ involved in $\Upsilon \to \gamma_{soft} l^+ l^-$, so its contributions are suppressed by $E_s/M_b \sim 4 \times 10^{-2}$ when compared with virtual processes.
- So we ignored the real processes and included the virtual processes only when we considered the impact of $A_0(h)$ to $R_{\tau\mu}(E_{soft})$.

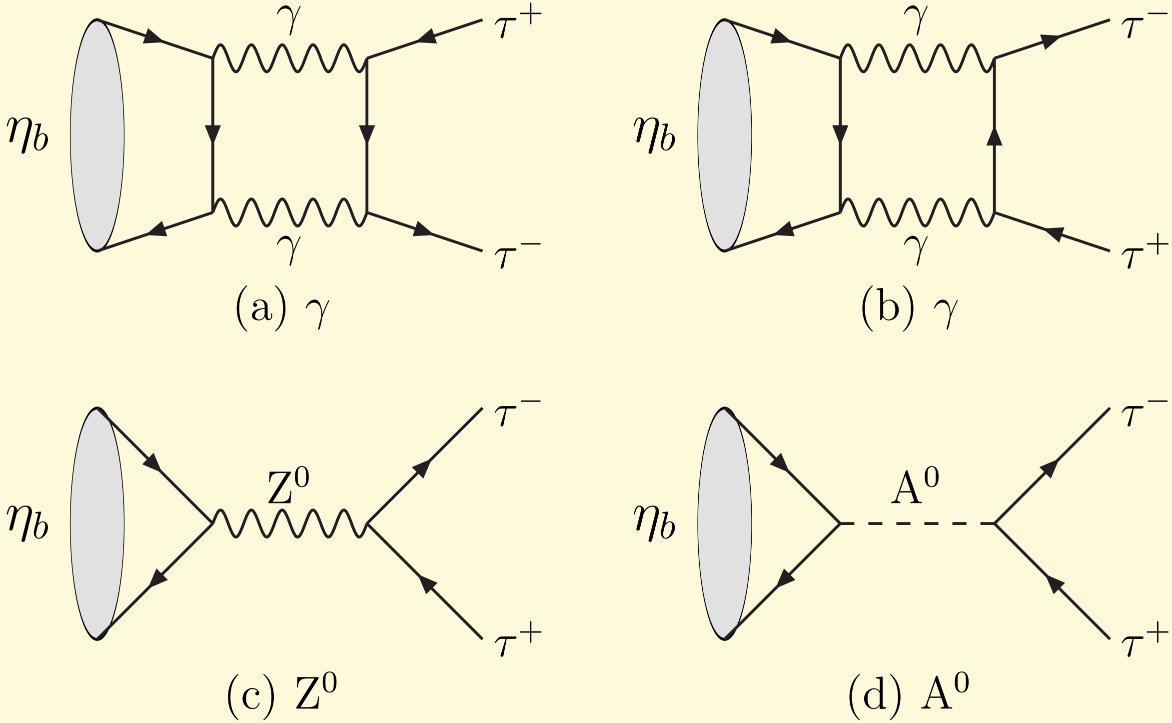


The $A_0(h)$ impact on $\Upsilon \to \tau^+\tau^-$ as a function of $M_{A0(h)}$. The $A_0(h)$ impact on real contributions ignored for it is suppressed by E_s/M_b and $\Upsilon \to \mu^+\mu^-$ is ignored for it is suppressed by M_μ^2/M_τ^2. The Feynman diagrams which exchange $A_0(h)$ between $b\bar{b}$ are ignored for it should not change the ratio $R_{\tau\mu}$.

- If we consider the $R_{\tau\mu}$, we should include the real correction too.
- If we select $10.3GeV < M_{A0(h)} < 10.6GeV$, $\Gamma^{A0}[\tau]/\Gamma^{LO}[\tau] \sim -4\times 10^{-6}C_{A0}^2 + 5\times 10^{-10}C_{A0}^4$, and $\Gamma^{h}[\tau]/\Gamma^{LO}[\tau] \sim 3\times 10^{-6}C_{h}^2 + 8\times 10^{-10}C_{h}^4$.
- The corresponding $R_{\tau\mu}(E_{soft})$ with $10.3GeV < M_{A0(h)} < 10.6GeV$, is $\Gamma^{A0}[\tau]/\Gamma^{LO}[\tau] \sim -5\times 10^{-6}C_{A0}^2$ and $\Gamma^{h}[\tau]/\Gamma^{LO}[\tau] \sim 3\times 10^{-6}C_{h}^2$.

4 Leptonic decay of η_b

It is also studied by Jia[14] within SM and by Rashed within NP[15].



Part of Feynman diagrams for $\eta_b \to \tau^+\tau^-$.

The amplitude

$$\mathcal{A}\Big(P(2p_1) \to l^-(p_2) + l^+(p_3)\Big) = -iC^P \frac{R_S(0)}{\sqrt{4\pi}} \frac{\sqrt{3}m_l}{4m_P^{5/2}} \bar{u}(p_2)\gamma^5 v(p_3). \tag{17}$$

Where m_l is mass of lepton, and m_P is mass if pseudoscalar heavy quarkonium. And there are three contribution for C^P:

$$C^P = C_A^P + C_Z^P + C_\gamma^P, \tag{18}$$

C_γ^P correspond to the contributions of γ at one-loop level. And C_Z^P correspond to the contributions of Z^0 at tree level. These two terms correspond standard model contribution. Within the new physics model, CP-odd Higgs A_0 is introduced, and it's contributions correspond C_A^P.
The decay width of $P \to l^+l^-$ can be get through Eq.(17)

$$\Gamma(P \to l^+l^-) = |C|^2 \frac{|R_S(0)|^2}{4\pi m_P^4} \frac{3m_l^2\sqrt{1 - 4m_l^2/m_P^2}}{128\pi} \tag{19}$$

Then C_A^P can be calculated directory:

$$\begin{aligned} C_A^{\eta_b} &= \frac{e^2 \csc^2\theta_W C_{A0}^2}{(r_A-1)r_W} \\ C_A^{\eta_c} &= \frac{e^2 \csc^2\theta_W}{(r_A-1)r_W} \end{aligned} \tag{20}$$

Where θ_W is weak mixing Weinberg angle, e is charge of electron, and r_i is m_i^2/m_P^2 for $i = Z, W, A^0, l$. The C_Z^P can be calculated directly too:

$$\begin{aligned} C_Z^{\eta_b} &= -\frac{e^2 \csc^2\theta_W \sec^2\theta_W}{r_Z} \\ C_Z^{\eta_c} &= \frac{e^2 \csc^2\theta_W \sec^2\theta_W}{r_Z} \end{aligned} \tag{21}$$

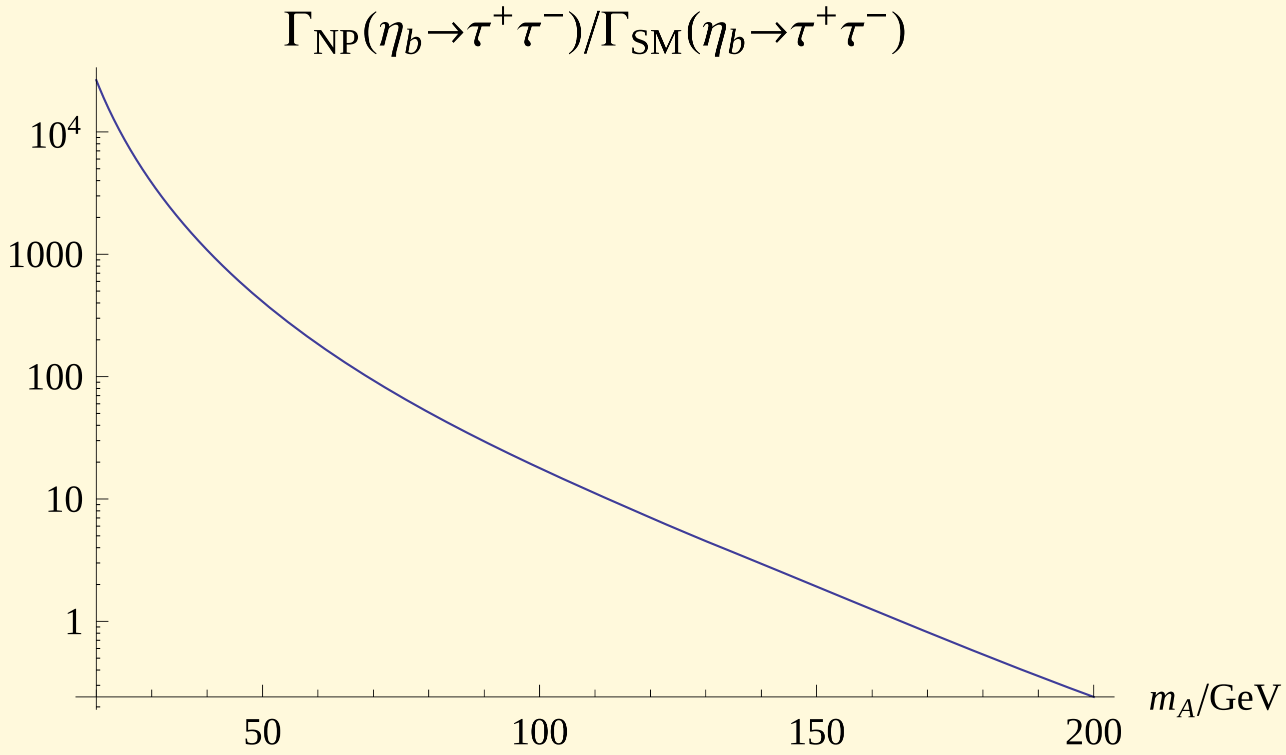
$$\begin{aligned} C_\gamma^{\eta_b} &= -\frac{e^4}{27\pi^2\sqrt{1-4r_l}}\left\{-24\tanh^{-1}\left(\sqrt{1-4r_l}\right) + 12\mathbf{Li}_2\left(\frac{\sqrt{1-4r_l}-1}{\sqrt{1-4r_l}+1}\right)\right. \\ &\left. +3\log\left(-\frac{2r_l+\sqrt{1-4r_l}-1}{2r_l}\right)\left[\log\left(-\frac{2r_l+\sqrt{1-4r_l}-1}{2r_l}\right)+2i\pi\right]+\pi^2\right\} \end{aligned}$$

The numerical decay width in units of keV within standard model. We use $|R_S^{\eta_b}(0)|^2 = 6.477$ GeV^3, $|R_S^{\eta_c(1S)}(0)|^2 = 0.810$ GeV^3, $|R_S^{\eta_c(2S)}(0)|^2 = 0.529$ GeV^3, $m_{\eta_b} = 9.4$ GeV, $m_{\eta_c(1S)} = 2.980$ GeV, and $m_{\eta_c(2S)} = 3.637$ GeV. Here 3.16E-16 means 3.16×10^{-16}. $\Gamma_{total}[\eta_b] \sim 10$MeV.

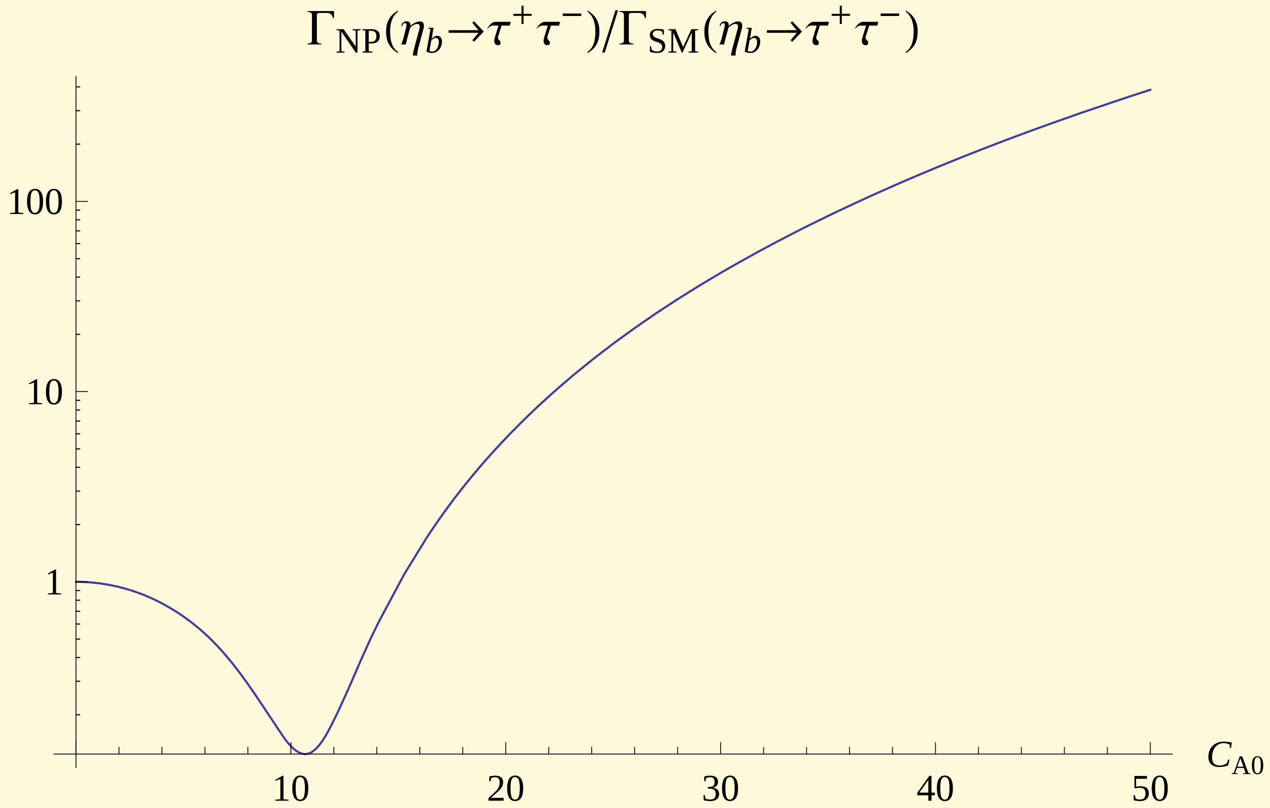
	η_b	$\eta_c(1S)$	$\eta_c(2S)$
$\Gamma_Z(e^+e^-)$	3.87E-12	4.84E-13	3.16E-13
$\Gamma_\gamma(e^+e^-)$	1.29E-10	1.53E-08	4.94E-09
$\Gamma_{SM}(e^+e^-)$	1.74E-10	1.51E-08	4.87E-09
$\Gamma_Z(\mu^+\mu^-)$	1.65E-07	2.04E-08	1.33E-08
$\Gamma_\gamma(\mu^+\mu^-)$	2.71E-07	2.15E-05	7.45E-06
$\Gamma_{SM}(\mu^+\mu^-)$	7.10E-07	2.09E-05	7.15E-06
$\Gamma_Z(\tau^+\tau^-)$	4.33E-05	-	8.11E-07
$\Gamma_\gamma(\tau^+\tau^-)$	6.32E-06	-	2.91E-05
$\Gamma_{SM}(\tau^+\tau^-)$	5.08E-05	-	3.18E-05

The numerical decay width of $\eta_b \to \tau^+\tau^-$ in units of keV. The unit of A^0 mass is GeV. $\Gamma_{SM}(\eta_b \to \tau^+\tau^-) = 5.08 \times 10^{-5}$ keV. $\Gamma_{total}[\eta_b] \sim 10$MeV.

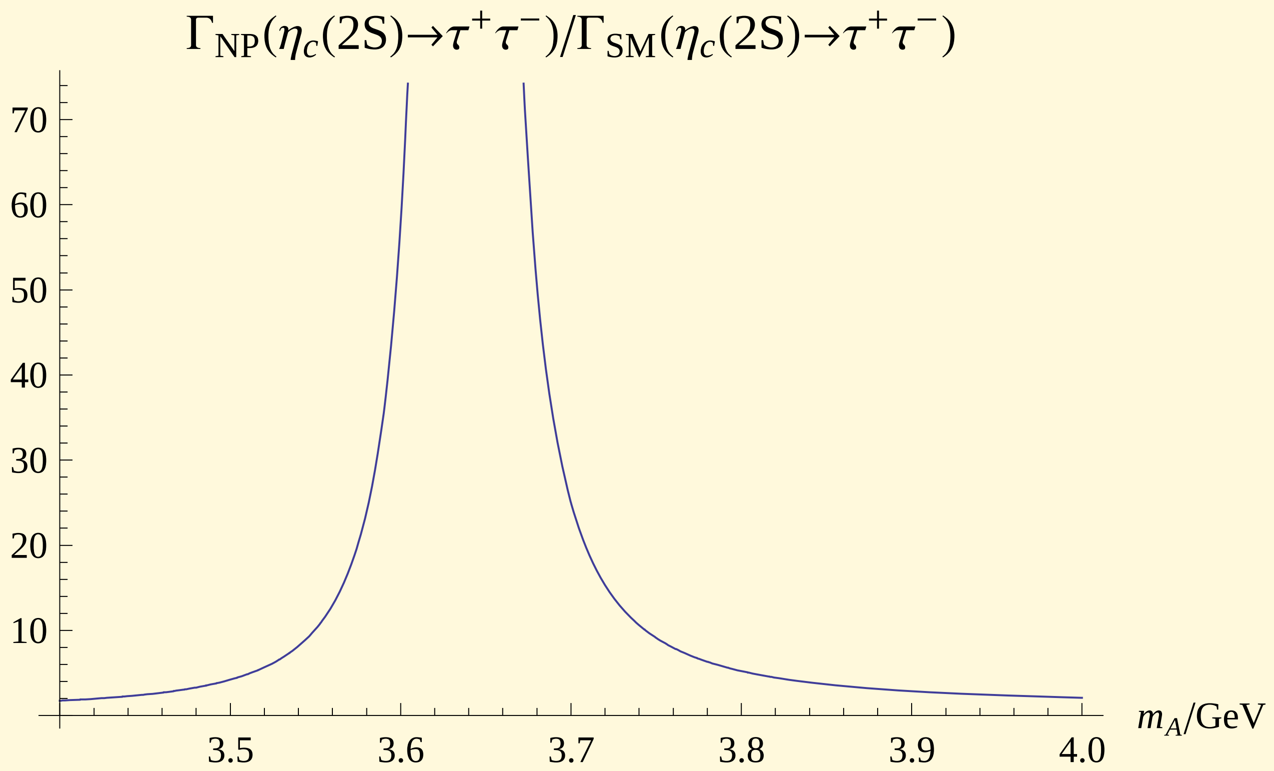
m_A \ C_{A0}	1	5	10	25	50
20	2.94E-5	1.60E-3	3.24E-2	1.34E+0	2.17E+1
50	4.76E-5	6.72E-6	3.10E-4	2.07E-2	3.55E-1
100	5.00E-5	3.36E-5	6.95E-6	9.06E-4	1.96E-2
150	5.04E-5	4.25E-5	2.29E-5	9.74E-5	3.39E-3
200	5.06E-5	4.60E-5	3.35E-5	1.22E-5	8.91E-4



$\Gamma_{NP}(\eta_b \to \tau^+\tau^-)/\Gamma_{SM}(\eta_b \to \tau^+\tau^-)$ as a function of CP-odd Higgs mass. Here $C_{A0} = 25$.



$\Gamma_{NP}(\eta_b \to \tau^+\tau^-)/\Gamma_{SM}(\eta_b \to \tau^+\tau^-)$ as a function of C_{A0}. Here $m_A = 100$ GeV.



$\Gamma_{NP}(\eta_c(2S) \to \tau^+\tau^-)/\Gamma_{SM}(\eta_c(2S) \to \tau^+\tau^-)$ as a function of m_A . Here the coupling $C^c_{A0} \times C^l_{A0} = 1$.

5 Summary

- Compared with the recent Babar's data $R_{\tau\mu} = 1.005 \pm 0.013 \pm 0.022$, we find that SM prediction $R_{\tau\mu} = 0.993 \pm 0.006$ is consistent with the experimental data and a little less than the center value.
- We present a better approach to test the SM in leptonic decay of Υ, $R_{\tau\mu}(E_{soft}) = \Gamma[\Upsilon \to \tau^+\tau^- + X]/\Gamma[\Upsilon \to \mu^+\mu^- + X]|_{E_X<E_{soft}}$. After resumming the large logarithms, we get $R_{\tau\mu}(E_{soft})$ with a soft cut at the precision level of 0.1%. The effect of QCD is very weak in this channel. It can be compared with experimental data more precise.
- We also consider the possible solution, light Higgs h and pseudo scalar Higgs A_0. To clarify the discrepancy, more work should be done by theorist and experimentalist.
- Leptonic decay of η_b within SM and NP is studied too.

References

[1] E. Guido and f. t. B. Collaboration, "Lepton Universality Test in $\Upsilon(1S)$ decays at BaBar," 0910.0423.

[2] **The BABAR** Collaboration, P. del Amo Sanchez *et al.*, "Test of lepton universality in Upsilon(1S) decays at BaBar," 1002.4358.

[3] M. A. Sanchis-Lozano, "Leptonic universality breaking in Υ decays as a probe of new physics," *Int. J. Mod. Phys.* **A19** (2004) 2183, hep-ph/0307313.

[4] M. A. Sanchis-Lozano, "Searching for new physics in leptonic decays of bottomonium," *Mod. Phys. Lett.* **A17** (2002) 2265–2276, hep-ph/0206156.

[5] E. Accomando *et al.*, "Workshop on CP Studies and Non-Standard Higgs Physics," hep-ph/0608079.

[6] M. Beneke, A. Signer, and V. A. Smirnov, "Two-loop Correction to the Leptonic Decay of Quarkonium," *Phys. Rev. lett.* **80** (1998) 2535–2538, hep-ph/9712302.

[7] Y.-J. Zhang and K.-T. Chao, "Υ decay to two-charm quark jets as a Probe of the Color Octet Mechanism," *Phys. Rev.* **D78** (2008) 094017, 0808.2985.

[8] **CLEO** Collaboration, D. Besson *et al.*, "First observation of $\Upsilon(3S) \to \tau^+\tau^-$ and tests of lepton universality in Υ decays," *Phys. Rev. Lett.* **98** (2007) 052002, hep-ex/0607019.

[9] K. Hamilton and P. Richardson, "Simulation of QED radiation in particle decays using the YFS formalism," *JHEP* **07** (2006) 010, hep-ph/0603034.

[10] F. Domingo, U. Ellwanger, and M.-A. Sanchis-Lozano, "Bottomoniom spectroscopy with mixing of η_b states and a light CP-odd Higgs," *Phys. Rev. Lett.* **103** (2009) 111802, 0907.0348.

[11] E. Fullana and M.-A. Sanchis-Lozano, "Hunting a light CP-odd non-standard Higgs boson through its tauonic decay at a (Super) B factory," *Phys. Lett.* **B653** (2007) 67–74, hep-ph/0702190.

[12] **BABAR** Collaboration, "Search for Dimuon Decays of a Light Scalar Boson in Radiative Transitions $\Upsilon \to \gamma A_0$," *Phys. Rev. Lett.* **103** (2009) 081803, 0905.4539. "Search for a low-mass Higgs boson in $\Upsilon(3S) \to \gamma A_0$, $A_0 \to \tau^+\tau^-$ at BABAR," *Phys. Rev. Lett.* **103** (2009) 181801, 0906.2219.

[13] Y.-J. Zhang and K.-T. Chao, " Leptonic decays of the pseudoscalar heavy quarkonium and CP-odd Higgs," *to be submited*.

[14] Y. Jia and W.-L. Sang, "Observation prospects of leptonic and Dalitz decays of pseudoscalar quarkonia," 0906.4782.

[15] A. Rashed, M. Duraisamy and A. Datta, "Probing light pseudoscalar, axial vector states through $\eta_b \to \tau^+\tau^-$," arXiv:1004.5419 [hep-ph].

[16] D. R. Yennie, S. C. Frautschi, and H. Suura, "The infrared divergence phenomena and high-energy processes," *Ann. Phys.* **13** (1961) 379–452.

Thanks!

Backup

The LO decay width

$$\Gamma_{LO}[\Upsilon \to l^+ l^-] \;=\; \frac{4|R(0)|^2\alpha^2\sqrt{1-4r_l}(1+2r_l)}{9M_\Upsilon^2}, \tag{22}$$

The NLO decay width piece is

$$\begin{aligned}
\Gamma_{NLO}[\Upsilon \to l^+ l^-)] = {} & \frac{4|R(0)|^2\alpha^2}{9M_\Upsilon^2}\sqrt{1-4r_l}\,(1+2r_l)\left\{1+\frac{\alpha}{4\pi\sqrt{1-4r_l}\,(1+2r_l)}\Bigg[\right. \\
& (32-32r_l^2)\mathrm{Li}_2(x_\beta)+(16-16r_l^2)\Big(\mathrm{Li}_2(-x_\beta)+\ln(x_\beta)\ln(1-x_\beta)\Big) \\
& +(2+4r_l)\sqrt{1-4r_l}\Big(6\ln(x_\beta)-8\ln(1-x_\beta)-4\ln(1+x_\beta)\Big) \\
& +(3+18r_l)\sqrt{1-4r_l}+(-12+8r_l+28r_l^2)\ln(x_\beta)+(8-32r_l^2)\ln(x_\beta)\ln(1+x_\beta)\Bigg] \\
& \left.+\text{Terms independent on } r_l\right\},
\end{aligned} \tag{23}$$

$x_\beta = (1-\sqrt{1-4r_l})/(1+\sqrt{1-4r_l})$