Exploring Flavours with Quarkonia Candidates

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Scientists are inspecting early universe in two perspectives:
- One group is trying to probe the hot dense QGP medium as well as the particle dynamics passing through the medium [1, 2] and
- Other group is trying to probe new particles to explain various phenomena of early universe. Both the groups are motivated to build a fundamental and generalized theory about early universe.

The study of heavy ions are very crucial for these two approaches.

LFV Decays

Conservation laws for lepton flavour, baryons are gracefully maintained in the SM with the global symmetries of its Lagrangian.

The LFV decays have already been studied with the B mesons and bottom baryons theoretically, as well as in accelerators.

So, it is very interesting to study various resonance particles, which are formed at the very high energies, in terms of their LFV decays.

Attractiveness of Bottomonia Candidates

The quarkonium particle shows unique behaviour at high temperatures and densities.

We have chosen Bottomonium particles.

These particles are the bound states of bottom-antibottom and always lie below the threshold value of the open bottom system.

The Υ(ns) are the most important tools to probe High Energetic Medium theoretically and experimentally [2].

Introduction of BSM

We have studied the Lepton Flavour Violating Υ(ns) decays constraining the LFV NP couplings.

Why New Physics?

Though the standard model (SM) of particle physics is an outstandingly successful model, there are some sectors where it fails [1].
- The Lepton Flavour Violation is forbidden in SM but established in accelerators.
- The SM is unable to adopt some fundamental theory incorporating the gravity.
- It cannot explain dark matter, the dominance of matter; fails to prove the existence of massive neutrinos as well as neutrino oscillations.

Theoretical Framework:

We have structured the effective Hamiltonian for the LFV decays with the contribution of Z' in terms of Wilson coefficients:

$$H^{eff} = -\frac{(G_F \alpha)}{2\sqrt{2}\pi} V_{tb} V_{ts}^* \sum_{i=9,10} C_i^{Z'} O_r + h.c. \tag{1}$$

Where 9th and 10th semi-leptonic current operators are sensitive for semi-leptonic decays as well as for our BSM theory. Now we structure the Wilson coefficients in terms of NP quark couplings and NP leptonic couplings:

$$C_9^{Z'} = \frac{4\pi B_{sb}^L}{\alpha V_{tb} V_{ts}^*}(B_{ll'}^L + B_{ll'}^R), \quad C_{10}^{Z'} = \frac{4\pi B_{sb}^L}{\alpha V_{tb} V_{ts}^*}(B_{ll'}^L - B_{ll'}^R).$$

We have structured the branching ratios for lepton flavour violating Υ(ns) decays in terms of Wilson coefficients as:

$$Br(\Upsilon(ns) \to ll') = \frac{f_{\Upsilon(ns)}^2 m_{\Upsilon(ns)}^2 \tau_{\Upsilon(ns)}}{48\pi M_{Z'}^4}(2+r)(1-r)^2(|C_9|^2 + |C_{10}|^2). \tag{2}$$

Numerical Analysis (Constraints of NP couplings):

To constrain the quark Z' couplings, we have used the chi2 fitting technique. The figure shows **variation of NP couplings and the red point represents the minimised chi2 value.** In this technique, we have used the available experimental data of Table-1.

Taken from PDG

Various leptonic decays	Branching ratios [?]
$\Upsilon(1S) \to \mu\mu$	$(2.48 \pm 0.04) \times 10^{-2}$
$\Upsilon(1S) \to ee$	$(2.39 \pm 0.08) \times 10^{-2}$
$\Upsilon(1S) \to \tau\tau$	$(2.60 \pm 0.04) \times 10^{-2}$
$\Upsilon(2S) \to \mu\mu$	$(1.93 \pm 0.17) \times 10^{-2}$
$\Upsilon(2S) \to ee$	$(1.91 \pm 0.16) \times 10^{-2}$
$\Upsilon(2S) \to \tau\tau$	$(2.00 \pm 0.21) \times 10^{-2}$
$\Upsilon(3S) \to \mu\mu$	$(2.18 \pm 0.21) \times 10^{-2}$
$\Upsilon(3S) \to ee$	$(2.18 \pm 0.20) \times 10^{-2}$
$\Upsilon(3S) \to \tau\tau$	$(2.29 \pm 0.30) \times 10^{-2}$
$\Upsilon(1S) \to e\mu$	6.67×10^{-12}
$\Upsilon(2S) \to e\mu$	7.03×10^{-12}
$\Upsilon(3S) \to e\mu$	1.26×10^{-12}

Table 1: Experimental data of various observables used in analysis

$\chi^2_{min}/dof = 8.539/9$
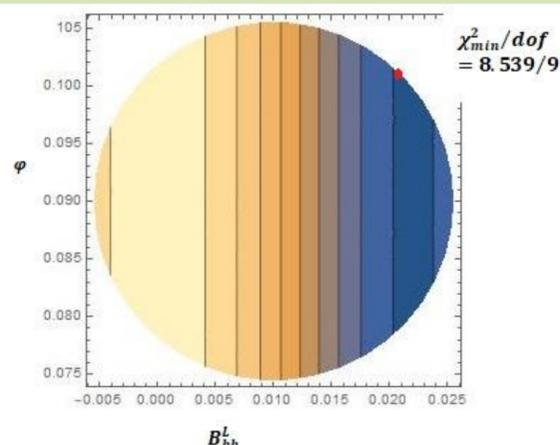
We have used the NP leptonic coupling as [3]:

Leptonic Couplings
$M_{\tau\mu} = 0.11, N_{\tau\mu} = -0.11$

Numerical Analysis (Calculation of Branching ratios):

Using all these NP couplings, we have calculated the branching ratios of lepton flavour violating Υ(ns) decays.

Decay modes	Branching ratios
$\Upsilon(1S) \to \mu\tau$	1.37×10^{-11}
$\Upsilon(2S) \to \mu\tau$	1.28×10^{-10}
$\Upsilon(3S) \to \mu\tau$	1.22×10^{-10}

Acknowledgement

Conclusion

➤ We have found b-b-Z' coupling using the chi2 fitting method with p-value 43% which is within the acceptable limits.

➤ The maximum allowed best-fit values of NP couplings are: Quark coupling = 2.21×10^{-2} and Phase Angle (φ) = 5.7°.

➤ The behaviour Υ(ns)s in the LFV framework is expected to provide very intriguing facts about the medium in which the particle is decaying into different flavored leptons with increased luminosity of LHC.

➤ It will help the colliders to probe the LFV decays in the search of NP.

References

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