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Double lepton polarization in $\Lambda_b \to \Lambda \ell^+ \ell^-$ decay in the Standard Model with fourth generations scenario

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Abstract

This study investigates the influence of the fourth generation quarks on the double lepton polarizations in $\Lambda_b \to \Lambda \ell^+ \ell^-$ decay by taking $|V_{t's}^* V_{t'b}| = 0.005, 0.01, 0.02, 0.03$ with phase $\{60°, 90°, 120°\}$. We will try to obtain a constrain on the mass of the 4th generation top like quark t', which is consistent with the $b \to s \ell^+ \ell^-$ rate. With the above mentioned parameters, we will try to show that the double lepton (μ, τ) polarizations are quite sensitive to the existence of fourth generation. It can serve as a good tool to search for new physics effects, precisely, to search for the fourth generation quarks (t', b') via its indirect manifestations in loop diagrams.

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1. Introduction

While the Standard Model (SM) provides a very good description of phenomena observed by experiments, it is still an incomplete theory. The problem is that the Standard Model cannot explain why some particles exist as they do. Another question concerns the fact that there are 3 pairs of quarks and 3 pairs of leptons. Each "set" of these particles is called a generation (a.k.a. family). Therefore, the up/down quarks are first generation quarks, while the electron

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and e-neutrino are first generation leptons. In the every-day world we observe only the first-generation particles (electrons, e-neutrinos, and up/down quarks). Why does the natural world, "need" the two other generations? Are there 3 generations or more? Nothing in the Standard Model itself fixes the number of quarks and leptons that can exist. Since the first three generations are full, any new quarks and leptons would be members of a "fourth generation". In this sense, SM may be treated as an effective theory of fundamental interactions rather than fundamental particles. There are many direct investigation for the 4th generation of fermions considering their manifestations in many areas of physics, i.e., gravitation, neutrino, Higgs physics and so on [1–5]. The democratic mass matrix approach [6], which is quite natural in the SM framework, may be considered as the interesting step in true direction. It is intriguing that flavors democracy favors the existence of the fourth SM family [7–9]. Any study related to the decay of the 4th generation quarks or indirect effects of those in FCNC requires the choice of the quark masses which are not free parameter, rather they are constrained by the experimental value of ρ and S parameters [9]. The ρ parameter, in terms of the transverse part of the W- and Z-boson self energies at zero momentum transfer, is given in [10],

$$\rho = \frac{1}{1-\Delta\rho}, \qquad \Delta\rho = \frac{\Pi_{ZZ}(0)}{M_Z^2} - \frac{\Pi_{WW}(0)}{M_W^2}, \tag{1}$$

the common mass of the fourth generation quarks ($m_{t'}$) lies between 320 GeV and 730 GeV considering the experimental value of $\rho = 1.0002^{+0.0007}_{-0.0004}$ [11]. The last value is close to upper limit on heavy quark mass, $m_q \leqslant 700~\text{GeV} \approx 4m_t$, which follows from partial-wave unitarity at high energies [12]. It should be noted that with preferable value $a \approx g_w$, flavor democracy predicts $m_{t'} \approx 8m_w \approx 640$ GeV. The above mentioned values for mass of $m_{t'}$ disfavor the fifth SM family both because in general we expect that $m_t \leqslant m_{t'} \leqslant m_t''$ and the experimental values of the ρ and S parameters [9] restrict the quark mass up to 700 GeV.

The study of production, decay channels and LHC signals of the 4th generation quarks have been continuing. But, one of the efficient ways to establish the existence of 4th generation is via their indirect manifestations in loop diagrams. Rare decays, induced by flavor changing neutral current (FCNC) $b \to s(d)$ transitions are at the forefront of our quest to understand flavor and the origins of CPV, offering one of the best probes for new physics (NP) beyond the Standard Model (SM). Several hints for NP have emerged in the past few years. For example, a large difference is seen in direct CP asymmetries in $B \to K\pi$ decays [13],

$$\begin{aligned} \mathcal{A}_{K\pi} &\equiv A_{\text{CP}}\big(B^0 \to K^+\pi^-\big) = -0.093 \pm 0.015, \\ \mathcal{A}_{K\pi^0} &\equiv A_{\text{CP}}\big(B^+ \to K^+\pi^0\big) = +0.047 \pm 0.026, \end{aligned} \tag{2}$$

or $\Delta\mathcal{A}_{K\pi} \equiv \mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi} = (14 \pm 3)\%$ [14]. As this percentage was not predicted when first measured in 2004, it has stimulated discussion on the potential mechanisms that it may have been missed in the SM calculations [15–17]. Better known is the mixing-induced CP asymmetry $\mathcal{S}_f$ measured in a multitude of CP eigenstates f. For penguin-dominated $b \to sq\bar{q}$ modes, within SM, $\mathcal{S}_{sq\bar{q}}$ should be close to that extracted from $b \to c\bar{c}s$ modes. The latter is now measured rather precisely, $\mathcal{S}_{c\bar{c}s} = \sin 2\phi_1 = 0.674 \pm 0.026$ [18], where ϕ_1 is the weak phase in V_{td}. However, for the past few years, data seem to indicate at 2.6σ significance,

$$\Delta\mathcal{S} \equiv \mathcal{S}_{sq\bar{q}} - \mathcal{S}_{c\bar{c}s} \leqslant 0, \tag{3}$$

which has stimulated even more discussions.

The $b \to s(d)\ell^+\ell^-$ decays have received considerable attention as a potential testing ground for the effective Hamiltonian describing FCNC in B and Λ_b decay. This Hamiltonian contains