IL NUOVO CIMENTO Vol. 33 C, N. 6 Novembre-Dicembre 2010
DOI 10.1393/ncc/i2011-10769-1

Colloquia: IFAE 2010

Test of lepton universality in $\Upsilon(1S)$ decays at BaBar

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(ricevuto l' 8 Ottobre 2010; pubblicato online il 2 Febbraio 2011)

Summary. — The ratio $R_{\tau\mu}(\Upsilon(1S)) = \Gamma_{\Upsilon(1S)\to\tau^+\tau^-}/\Gamma_{\Upsilon(1S)\to\mu^+\mu^-}$ is measured using a sample of $\sim 122\times 10^6\Upsilon(3S)$ events recorded by the BaBar detector. In the standard model (SM) this ratio is expected to be close to 1. Any significant deviations could be introduced by the coupling to a light pseudoscalar Higgs boson. The result obtained is: $R_{\tau\mu}(\Upsilon(1S)) = 1.005\pm 0.013(\text{stat.})\pm 0.022(\text{syst.})$.

PACS 13.20.Gd – Decays of J/Ψ, Υ, and other quarkonia.
PACS 14.80.Ec – Other neutral Higgs bosons.
PACS 12.60.Fr – Extensions of electroweak Higgs sector.

In the Standard Model (SM), the couplings of the gauge bosons to leptons are independent of the lepton flavor. The quantity $R_{\tau\mu}(\Upsilon(1S)) = \frac{\Gamma_{\Upsilon(1S)\to\tau^+\tau^-}}{\Gamma_{\Upsilon(1S)\to\mu^+\mu^-}}$ is expected to be ~ 0.992 [1], the discrepancy from one being due to small lepton-mass effects.

In the next-to-minimal extension of the SM [2], deviations of $R_{\tau\mu}$ from the SM expectation may arise due to a light CP-odd Higgs boson, A^0. The present data [3] do not exclude the existence of such a boson with a mass below $10\,\text{GeV}/c^2$. A^0 may mediate the following processes [4]:

$$\Upsilon(1S)\to A^0\gamma\to l^+l^-\gamma \qquad \text{or} \qquad \Upsilon(1S)\to\eta_b(1S)\gamma,\quad \eta_b(1S)\to A^0\to l^+l^-,$$

where $l=\tau,\mu$. If the photon remained undetected, the lepton pair would be ascribed to the $\Upsilon(1S)$ and the proportionality of the coupling of the Higgs to the lepton mass would lead to an apparent violation of lepton universality.

This analysis focuses on the measurement of $R_{\tau\mu}(\Upsilon(1S))$ in the decays $\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-$, with $\Upsilon(1S)\to l^+l^-$ and $l=\mu,\tau$. Only τ decays to a single charged particle (plus neutrinos) are considered, resulting in final states of exactly four detected particles for both the $\mu^+\mu^-$ and $\tau^+\tau^-$ samples. The data collected at the $\Upsilon(3S)$ resonance by the BaBar detector (which is described in detail elsewhere [5]) correspond to $28\,\text{fb}^{-1}$.

The event selection is optimized using Monte Carlo (MC) simulated events. Different selection criteria are used for the $\Upsilon(1S)\to\mu^+\mu^-$ (D_μ) and the $\Upsilon(1S)\to\tau^+\tau^-$ (D_τ) decays because the presence of neutrinos in the final state in the latter leads to a larger contamination from the background (mainly non-leptonic $\Upsilon(1S)$ decays and $e^+e^-\to$

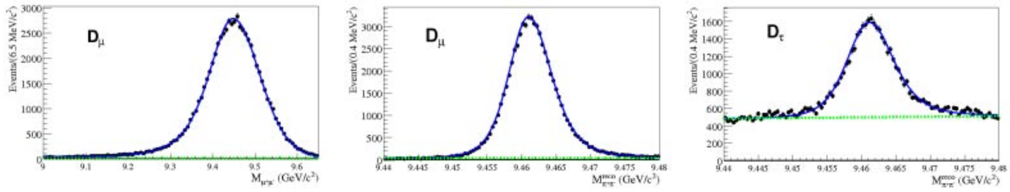

Fig. 1. – One-dimensional fit projections for $M_{\mu^+\mu^-}$ (left) and for $M^{reco}_{\pi^+\pi^-}$ (center) in the D_μ sample, and for $M^{reco}_{\pi^+\pi^-}$ (right) in the D_τ sample. In each plot the dashed line represents the background shape, while the solid line is the sum of signal and background contributions to the fit, and the points are the data.

$\tau^+\tau^-$ events). The final selection efficiencies for the reconstructed decay chains are $\epsilon_{\mu\mu} \sim 45\%$ and $\epsilon_{\tau\tau} \sim 17\%$ for the $\mu^+\mu^-$ and the $\tau^+\tau^-$ final states, respectively.

An extended unbinned maximum-likelihood fit, applied simultaneously to the two disjoint datasets D_μ and D_τ, is used to extract $R_{\tau\mu} = \frac{N_{sig\tau}}{\epsilon_{\tau\tau}} \cdot \frac{\epsilon_{\mu\mu}}{N_{sig\mu}}$, where $N_{sig\mu}$ ($N_{sig\tau}$) indicates the number of signal events in the D_μ (D_τ) sample. For the D_μ sample, a two-dimensional probability density function (PDF) is used, based on the invariant dimuon mass, $M_{\mu^+\mu^-}$, and $M^{reco}_{\pi^+\pi^-} = \sqrt{s + M^2_{\pi\pi} - 2 \cdot \sqrt{s} \cdot E^*_{\pi\pi}}$, the invariant mass of the system recoiling against the pion pair, where $\sqrt{s}$ is the e^+e^- center-of-mass (CM) energy and $E^*_{\pi\pi}$ indicates the $\pi^+\pi^-$ pair energy calculated in the e^+e^- CM frame. For the D_τ sample, a one-dimensional PDF is used, based on $M^{reco}_{\pi^+\pi^-}$. The result of the simultaneous fit is $R_{\tau\mu} = 1.006 \pm 0.013$, where the quoted error is statistical only. Figure 1 shows the projections of the fit results for the three variables.

Several systematic errors cancel in the ratio. The residual systematic uncertainties are related to the differences between data and simulation in the efficiency of event selection, the muon identification, and the trigger and background filters. There is also a systematic uncertainty on the signal and background yields due to the imperfect knowledge of the PDFs used in the fit. The total systematic uncertainty, obtained by summing all of the contributions in quadrature, is estimated to be 2.2%.

Including all the systematic corrections, the ratio $R_{\tau\mu}$ is found to be [6]

$$R_{\tau\mu}(\Upsilon(1S)) = 1.005 \pm 0.013(\text{stat.}) \pm 0.022(\text{syst.}).$$

No significant deviation of the ratio $R_{\tau\mu}$ from the SM expectation is observed. This result improves both the statistical and systematic precision with respect to the previous measurement [7].

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