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Belle II experiment reports the first direct measurement of tau-to-light-lepton ratio

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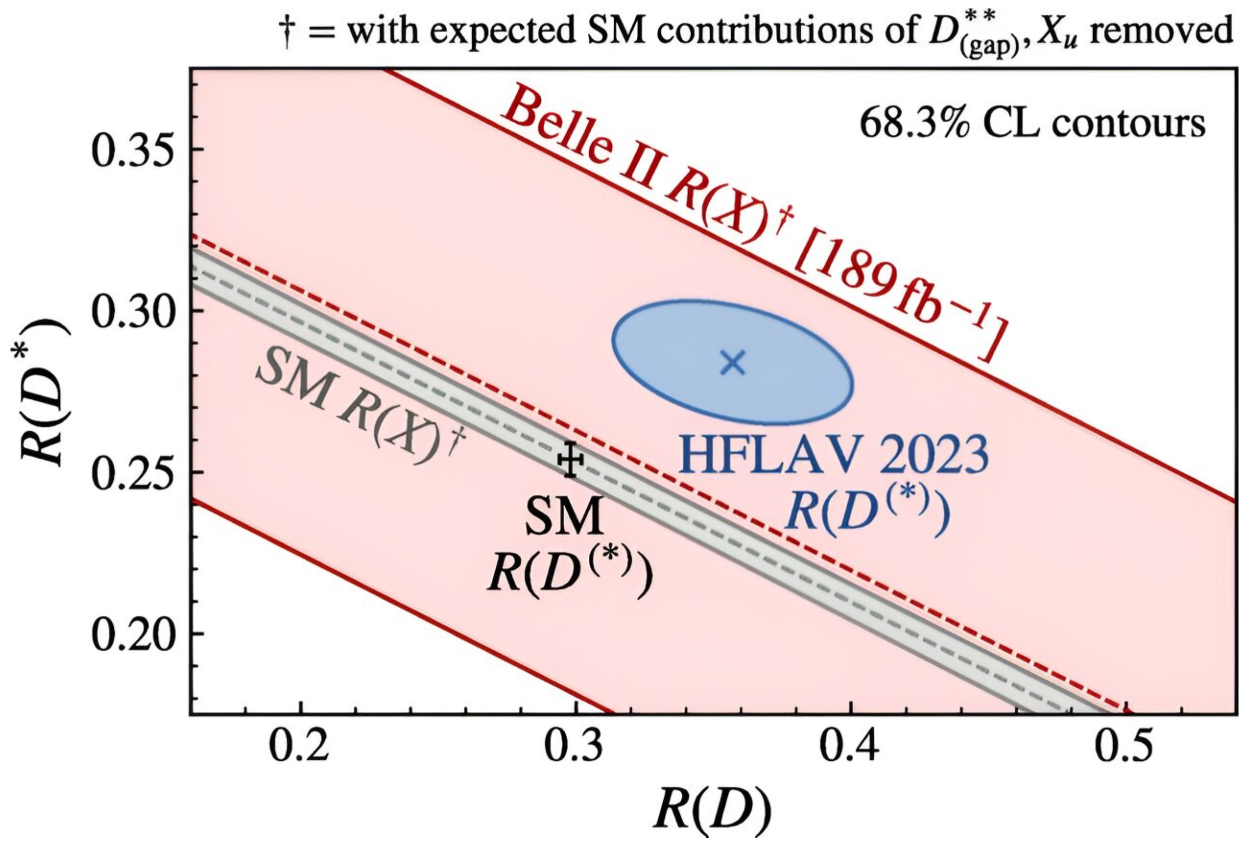

Constraints on $R(D^{(*)})$ from the measured $R(X_{\tau/\ell})$ value (red), compared to the world average of $R(D^{(*)})$ (blue) and the standard model expectation (gray and black). Credit: *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.211804

The Belle II experiment is a large research effort aimed at precisely measuring weak-interaction parameters, studying exotic hadrons (i.e., a class of subatomic particles) and searching for new physical phenomena. This effort primarily relies on the analysis of data collected by the Belle II detector (i.e., a general purpose spectrometer) and delivered by the SuperKEKB, a particle collider, both located at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan.

In a recent paper, published in *Physical Review Letters*, the Belle II Collaboration reported the first direct measurement of the tau-to-light-lepton ratio ??(????/ℓ) of inclusive B-meson branching fractions. With this measurement, the team was able to test the universality of charged-current weak interactions.

"Within our current best theory of particle physics, the standard model, charged leptons—electron, muon and tau—couple identically with weak and electromagnetic forces," Karim Trabelsi, spokesperson for the Belle II Collaboration, told Phys.org. "This phenomena is called lepton universality."

Notably, any sign of lepton universality being broken is an indication of non-standard model physics. As part of their recent paper, Trabelsi and his colleagues specifically set out to directly measure the ratio between tau and light leptons, as this could contribute to the search for and understanding of new physical phenomena (i.e., outside the standard model).

"The particular interest in comparing the tau to the lighter muon and electron arises from a tension between the average of existing measurements and the prediction from universality," Trabelsi said. "These measurements have only been done in decays where the lepton is accompanied by a single charmed meson (exclusive decays to D and D* mesons), whereas our study does not differentiate between the different types of hadrons or number of hadrons produced that accompany the lepton (inclusive decay)."

Theoretical predictions for exclusive and inclusive decay differ significantly, yet they are complementary when trying to probe any type of lepton universality. A comprehensive measurement considering both these decays, however, has so far only been performed using data collected by the Large Electron-Positron Collider (LEP), one of the largest particle accelerators located at CERN.

The key objective of the recent study by Belle II was to gather the first measurement for this specific quantity in over 20 years. To do this, they used the last sets of data collected by the Belle II detector.

"Our analysis relies on the production of pairs of B mesons, without any other accompanying particles that we have in electron positron collisions near threshold at Belle II," Trabelsi said. "We can fully reconstruct one B meson then search the rest of the event for a light lepton that may have come directly from the other B decay or from the decay of tau from the other B decay, that then decayed rapidly to a light lepton and two more neutrinos."

On average, the momentum of leptons resulting from tau decay is significantly lower than that of leptons promptly originating from a B meson. Moreover, additional neutrinos present during tau decays entail a lower energy and momentum compared to those present during events linked to prompt leptons.

"We thus used the distributions of lepton momentum and a variable related to the missing energy to separate the prompt and tau decays to determine the ratio," Trabelsi explained. "We calibrate the background distributions that can contaminate the measurement with subsidiary data samples enriched in the background processes."

The calibration performed by Belle II introduces systematic uncertainty into their measurement. Nonetheless, this uncertainty will decrease as the data collected and analyzed by the collaboration increases.

"Even though our measurement is compatible with both the standard model prediction and the anomalies seen in the exclusive decays, we have paved the way for a complementary probe of lepton universality once a larger data sample is available," Trabelsi said. "Such probes allow us to indirectly search for non-standard-model particles that would be inducing any observed lepton-flavor-universality violation."

This inclusive direct measurement of $R(X\tau/\ell)$ carried by Belle II could open new opportunities for searches aimed at observing and studying new physics outside the standard model. As the collaboration gathers more data in the future, the researchers plan to update this measurement and perform other precise measurements that could help to determine when lepton universality is broken.

"We are currently collecting more data and we will update this inclusive measurement, as well as the exclusive ones, in the near future," Trabelsi added. "Within a few years we should be able to definitively tell whether lepton-universality is being violated in these decays or not."

More information: I. Adachi et al, First Measurement of $R(X\tau/\ell)$ as an Inclusive Test of the $b \to c\tau\nu$ Anomaly, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.211804