LEPTON-FLAVOR-UNIVERSALITY VIOLATION AND PROSPECTS AT BELLE II

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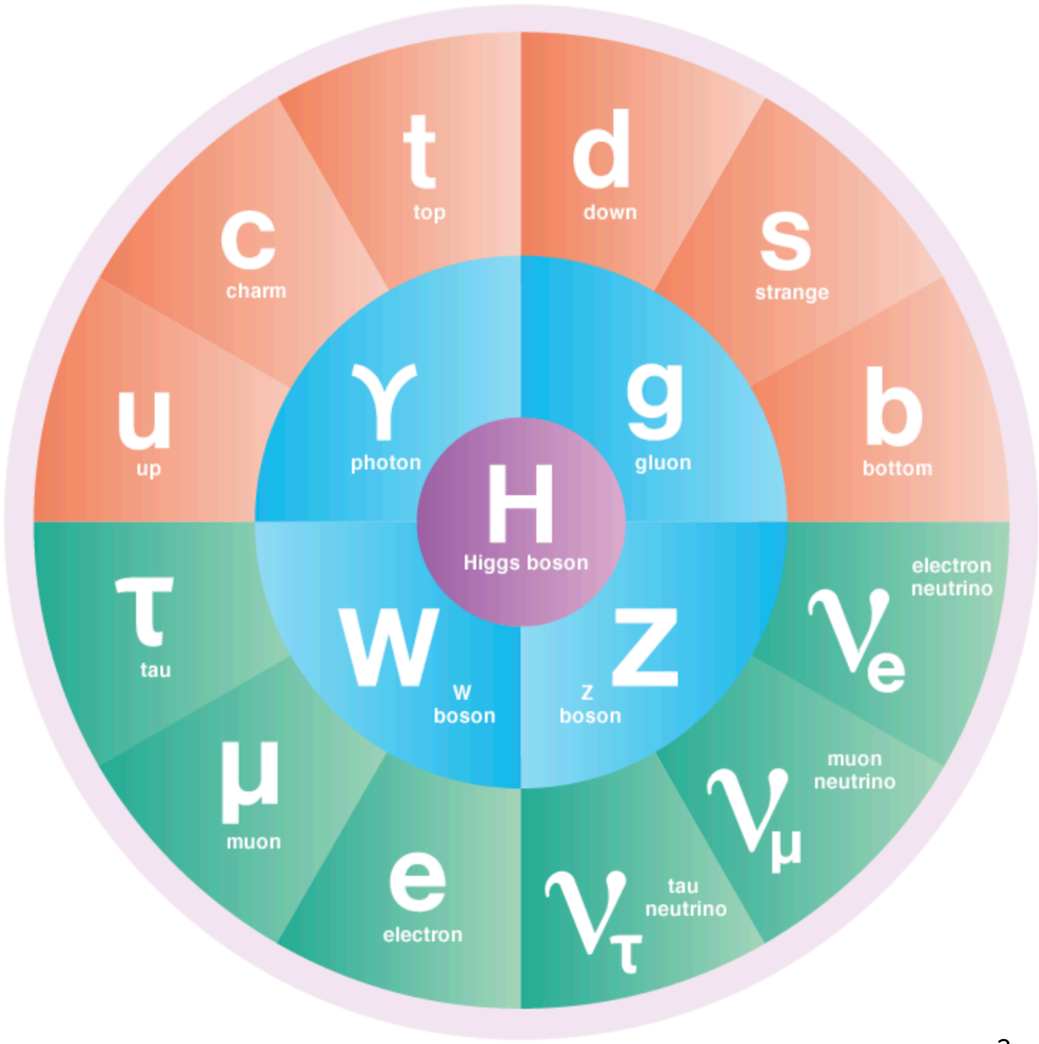
STANDARD MODEL OF PARTICLE PHYSICS

- Standard model (SM) describes three out of the four fundamental forces in nature
- Successful but incomplete, as it leaves open questions, such as dark matter, etc.

Determining the theory that completes the SM is the principal goal of today's particle physics

Two ways out:

- directly, in the high-energy collisions
- indirectly, with flavor physics



LEPTON-FLAVOR UNIVERSALITY

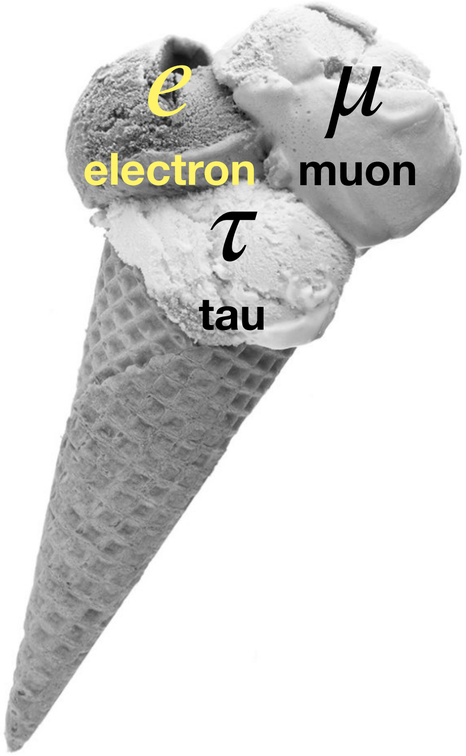
- Flavor is the property that distinguishes the various leptons in the SM
- Standard model: the flavors are “accidental”, universality of lepton flavor
- New physics: why we have 3 flavors, universality is not implied

=> Various ways to test the LFU, e.g.

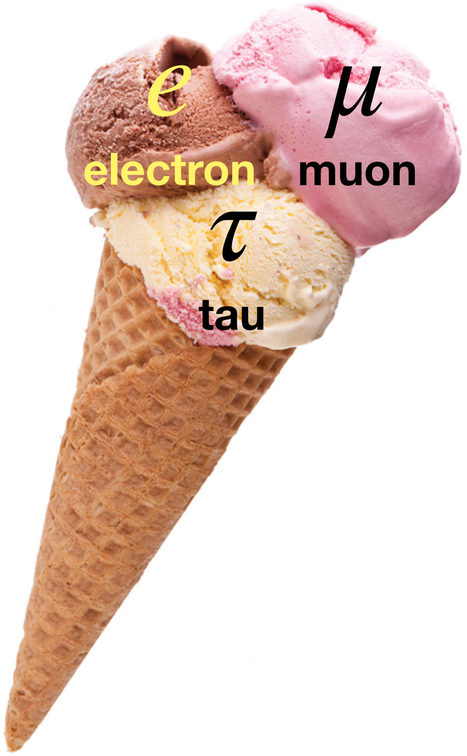
$$R^{B}_{\tau/\ell} = \frac{B \to X\tau}{B \to X\ell} \qquad \text{or} \qquad R^{\tau}_{\mu/e} = \frac{\tau \to X\mu}{\tau \to Xe}$$

Need to produce B- and τ-decay samples

Standard model



New physics

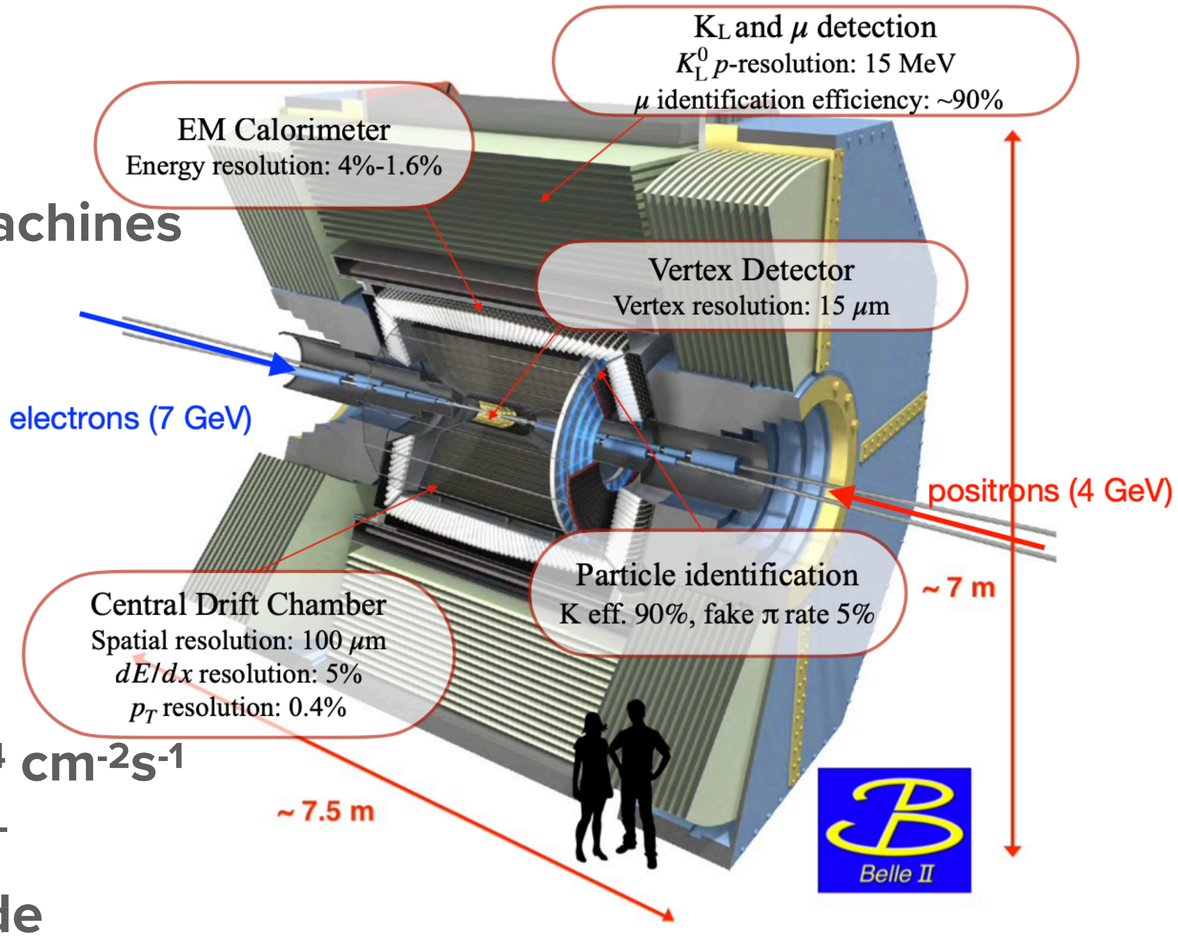


B meson: spin-0 bound state of a "b" quark with a lighter "u" or “d” partner. Massive (5 GeV) and long-lived (1.5 ps).

BELLE II EXPERIMENT @ SUPERKEKB

Energy-asymmetric e^+e^- collisions at 10.58 GeV corresponding to the $\Upsilon(4S)$-resonance mass

- **Clean experimental environment wrt hadron machines**
- **Similar performance for electrons and muons**
- **τ and B produced in pairs**
- **Well defined initial energy**
- **Nearly full 4π coverage**



Belle II status:

- **world-record luminosity by SuperKEKB 4.7×10^{34} cm^{-2}s^{-1}**
- **collected ~424 fb^{-1} of data: 450M $B\bar{B}$, 400M $\tau^+\tau^-$**
- **now starting ~one year stop for a partial upgrade**
- **expect O(10) ab^{-1} of data**

LFU TESTS IN SEMILEPTONIC B DECAYS

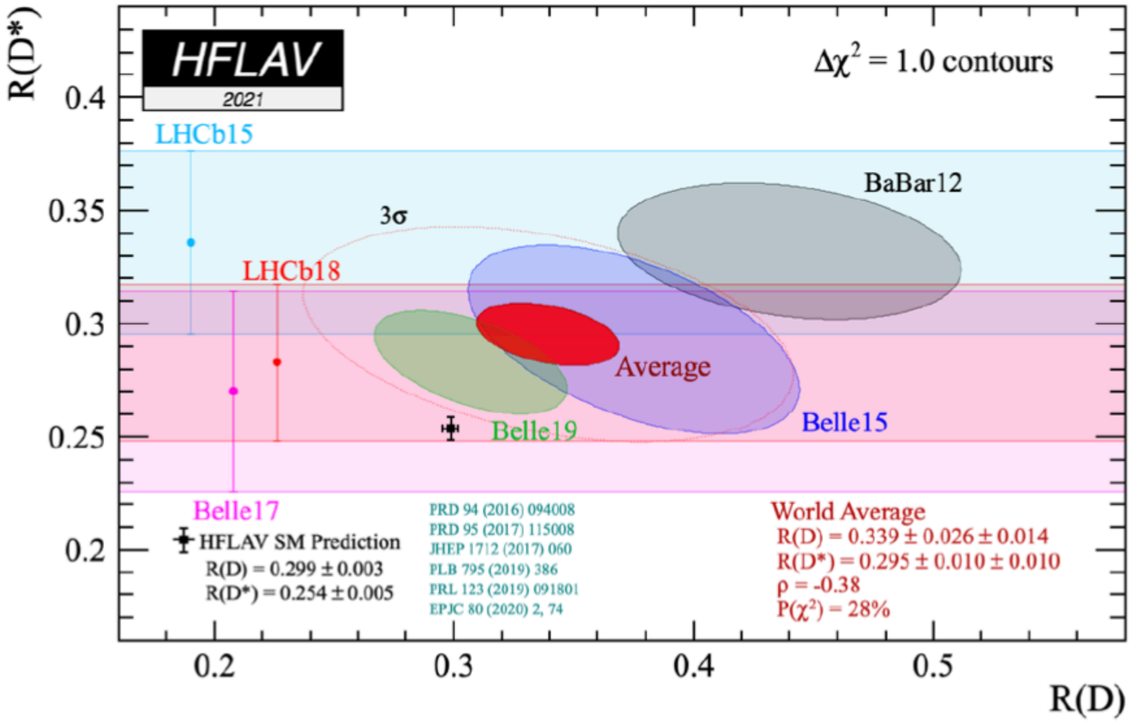
- **Semileptonic decays mediated by $b \to c\ell\nu$: large decay rates ~few %**

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)} \; (\ell = \mu, e)$$

- **Accessible via different sub-decay modes for taus and D mesons**

Belle II aim to provide the most precise experimental information to resolve the anomalies

State-of-the-art for $R(D^{(*)})$



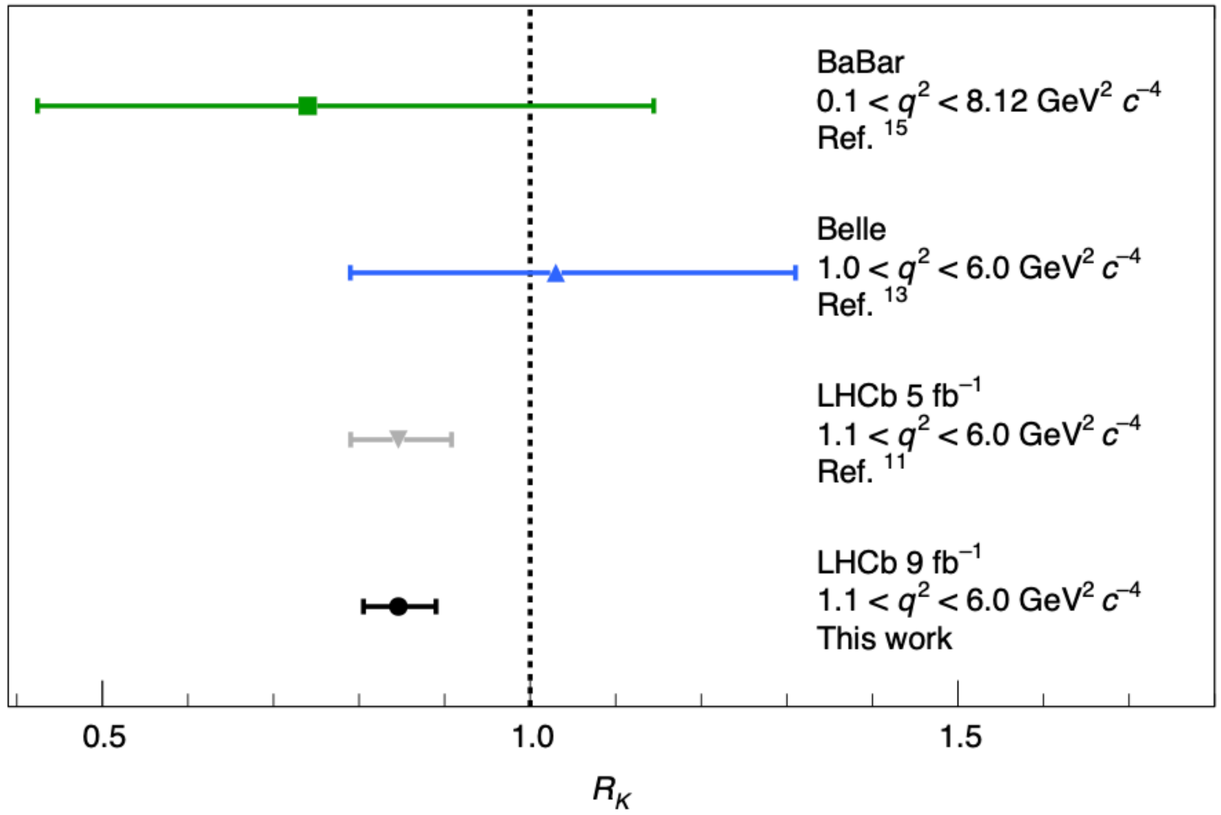
3.1σ tension wrt the SM

LFU TESTS IN RARE B DECAYS

- Rare decays mediated by $b \to s\ell\ell$: small decay rates ~10^{-7}—10^{-6}
- Non-SM particles can enhance the rates
- $$R(K) = \frac{\mathcal{B}(B \to K\mu\mu)}{\mathcal{B}(B \to Kee)}$$

Belle II should provide an independent test to confirm the tension with few ab^{-1}

State-of-the-art for $R(K)$

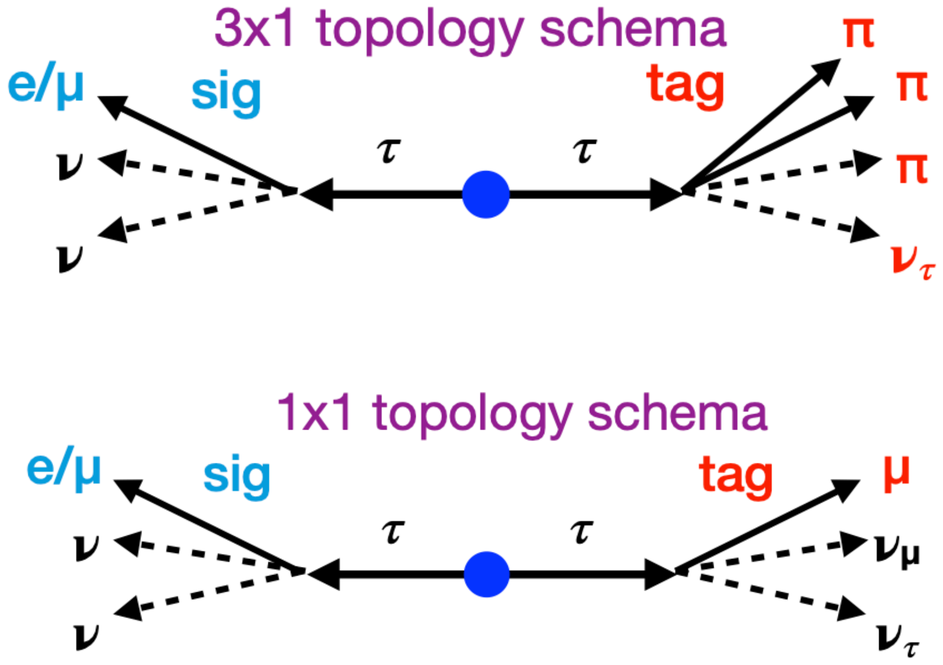


2—3σ tension wrt the SM

LFU TESTS IN TAU DECAYS

- Test LFU with light leptons in tau decays
  - $R^{\tau}_{\mu/e} = \dfrac{\tau \to \mu \bar{\nu}_{\mu} \nu_{\tau}}{\tau \to e \bar{\nu}_{e} \nu_{\tau}}$
- 3x1 topology:
  - Belle II simulation study achieves ~4x larger efficiency with better purity wrt world best
  - Systematic limited => more work to do
- 1x1 topology:
  - Belle II simulation study shows compatible statistical uncertainty

LFU tests in tau decays are unique for Belle II



SUMMARY

- Presence of flavor is a fundamental mystery of the nature
- Standard model can not distinguish flavor. Lepton flavor universality is implied
- New physics is potential to explain flavor
- State-of-art: several experimental measurements show hints of discrepancy wrt SM
- Belle II enjoys possibility to study all lepton-flavor combinations
  - can confirm (or not) the anomalies observed in the B decays
  - can probe the LFU in the tau lepton decays

BACKUP

SNOWMASS 2021 PROJECTIONS