Evidences for Lepton Flavour Universality Violation at LHCb

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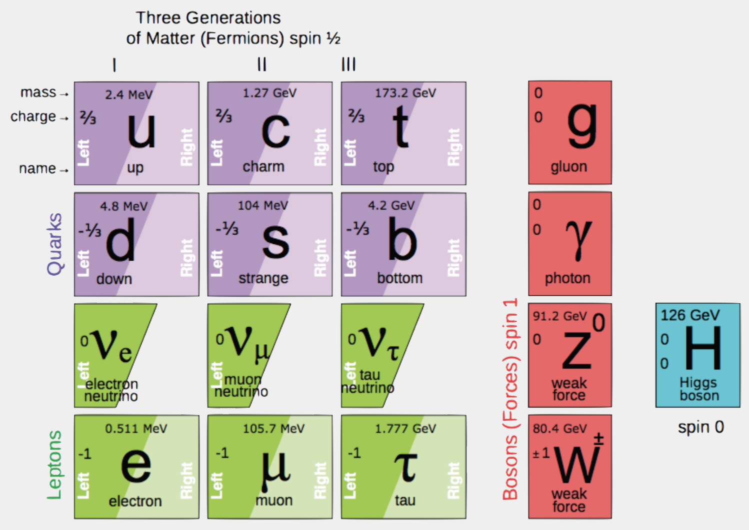
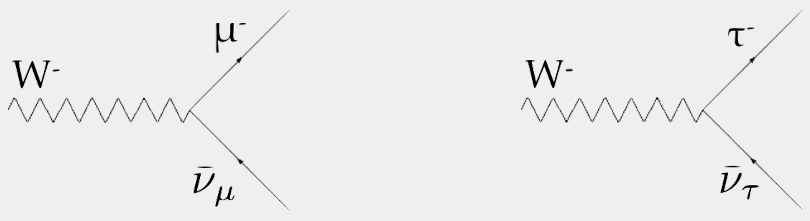
1) The Standard Model

- The Standard Model (SM) is a quantum field theory, self-consistent, weakly coupled up to 10^{10} GeV.
- Can explain (almost) all microscopic phenomena with great precision.
- Three main experimental problems still need to be explained:
  - Neutrino masses (seen from neutrino oscillations)
  - Baryon Asymmetry in the Universe (BAU)
  - Presence of Non-baryonic Dark Matter
- Quarks and leptons are divided in three families.
- The three generations of charged leptons are:
  - each paired with an electrically neutral lepton;
  - ordered by the mass of the charged lepton;



2) Lepton Flavour Universality

- In the SM, gauge bosons couple to leptons independently of their flavour $\longrightarrow$ Lepton Flavour Universality (LFU)



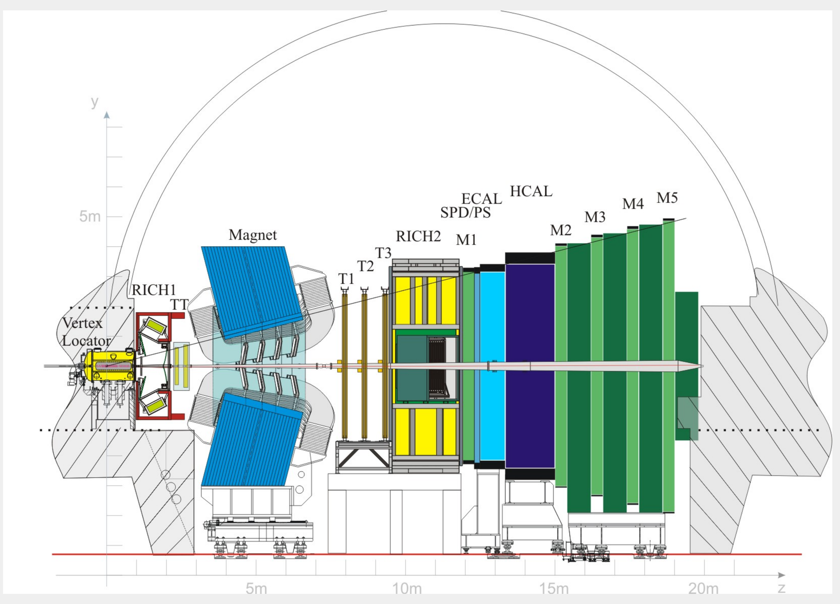
- Branching fractions of e, μ and τ differ only by phase space and helicity-suppressed contributions
- Violation of LFU $\longrightarrow$ hint for New Physics (NP) beyond the SM
- Precision tests of lepton universality performed over many years by many experiments.
- No definite violation of LFU observed up to now.

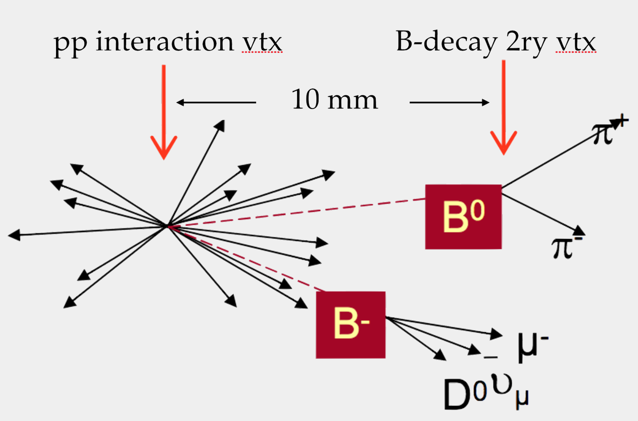
3) Why B-mesons?

- Several Beyond Standard Model (BSM) Theories predict stronger couplings of NP to the 3rd families
- Experimental constraints on 3rd generation of quarks and leptons much lower than the others

4) The LHCb experiment

- The LHCb detector is a single-arm forward spectrometer, covering the polar angle range of 3° - 23°.
- Main selection variables are the B-vertex displacement, the B-pointing to the vertex, relatively large p_T of the daughter particles

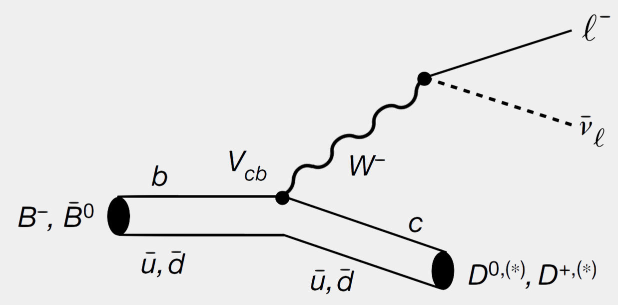




- B mesons produced forward in pp inelastic collisions at center of mass energies ranging from 7 $\longrightarrow$ 13 TeV
- So far produced more than $10^{12} b\bar{b}$ pairs
- Produced B mesons show small angle to beam and high momentum

5) Semileptonic B-decays

- In semileptonic B-decays the decay products are part leptons and part hadrons
- Charged Current decays mediated by vector boson W (tree level process)
- Total decay rate can be written as:



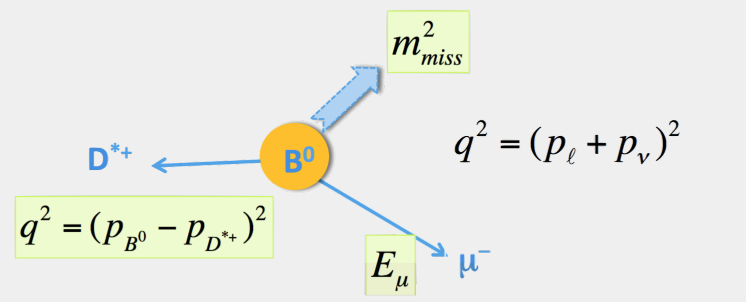
$$\frac{d\Gamma^{SM}(\bar{B} \to D^* l^- \nu^-)}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |p_{D^*}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_l^2}{q^2}\right) \times$$
$$\times \left[(|H_+|^2 + |H_-|^2 + |H_0|^2) \left(1 + \frac{m_l^2}{2q^2}\right) + \frac{3 m_l^2}{2q^2} |H_s|^2 \right]$$

- Measurement of semileptonic Branching Ratios ($\mathcal{B}$) allows to:
  - Remove dependence from quark mixing parameter
  - Reduce impact of experimental uncertainties
  - Partially cancel out theoretical hadronic uncertainties

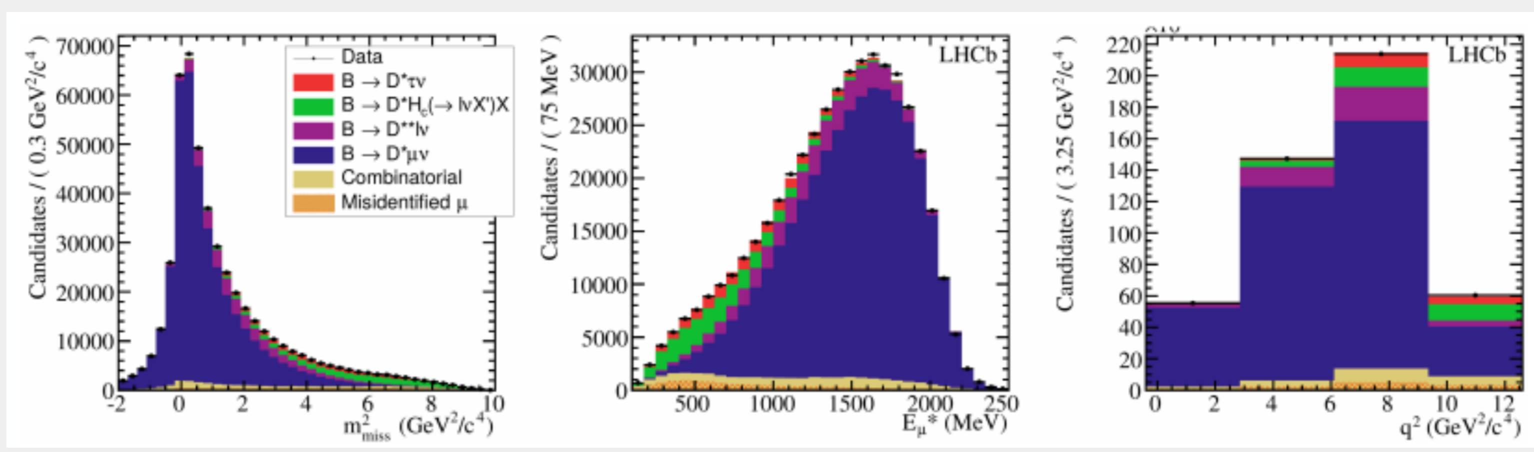
6) R_{D^*} Measurement at LHCb

$$R_{D^*} = \frac{\mathcal{B}(B \to D^* \tau \nu)}{\mathcal{B}(B \to D^* l \nu)} = \frac{\text{signal}}{\text{normalization}}$$

- LHCb uses only the muonic τ decay channel
- B-direction inferred from reconstructed pp collision point and secondary $D^* \mu$ reconstructed vertex

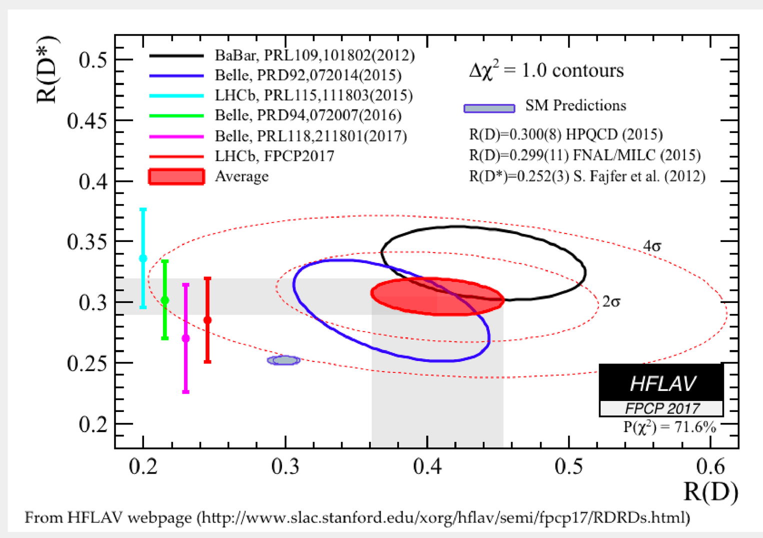


- Measured variables used to discriminate between signal, normalisation and backgrounds: m^2_{miss}, E_l^*, q^2



7) Conclusions and outlook

- $R_{D^*}(LHCb) = 0.336 \pm 0.027 \pm 0.030$ [1]
- $R_{D^*}(SM) = 0.252 \pm 0.003$ [2]
- Combination of results from LHCb, Belle and BaBar results in a discrepancy from SM of $\approx 4\,\sigma$.



- Result might be explained by unknown virtual particles interacting differently with leptons of higher mass (i.e. τ) such as:
  - W'^-: new vector boson (spin 1) similar to W^- but with $m_{W'} > m_W$ [3]
  - Leptoquarks: particles with electric and colour charges allowing transitions from quarks to leptons and vice versa [3]
  - Charged Higgs H^-: scalar (spin 0) which would affect also q^2 and angular distributions [4]
- So far q^2 spectrum and momentum distributions for $B \to D^* \tau \nu$ consistent with SM predictions
- Efforts to enlarge data samples and to reduce uncertainties in reconstruction efficiencies and background estimates.

References

[1] R. Aaij *et al.*, "Measurement of the ratio of branching fractions $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)$," *Phys. Rev. Lett.*, vol. 115, no. 11, p. 111803, 2015.

[2] S. Fajfer, J. F. Kamenik, and I. Nisandzic, "On the $B \to D^*\tau\bar{\nu}_\tau$ Sensitivity to New Physics," *Phys. Rev.*, vol. D85, p. 094025, 2012.

[3] D. Buttazzo, A. Greljo, G. Isidori, and D. Marzocca, "B-physics anomalies: a guide to combined explanations," *arXiv 1706.07808*, 2017.

[4] A. Crivellin, C. Greub, and A. Kokulu, "Explaining $B \to D\tau\nu$, $B \to D^*\tau\nu$ and $B \to \tau\nu$ in a 2HDM of type III," *Phys. Rev.*, vol. D86, p. 054014, 2012.