Measurements of lepton flavor universality at LHCb

N. Skidmore

October 2019

1 Theoretical motivation

- Electroweak gauge bosons couple with equal strength to the three generations of leptons
- Lepton Flavor Universality (LFU) is an accidental symmetry i.e. not the consequence of a gauge symmetry
- LFU is broken only by Yukawa (Higgs) interactions in the SM - 3 generations differ only by mass

Lepton flavour violation is a similar concept to LFU violation and the observation of either is a sign of new physics. What physics result already suggests LFV?

- To search for new particles we can use direct or indirect searches
- Direct searches use the full energy of the collision to produce new particles
- Indirect searches compare SM predictions to experiment and have access to higher mass scales

What are the pros and cons for direct and indirect methods?

- At LHCb we use flavour changing charged currents (FCCC) like $b \to c l^+ \nu_l$ to search for LFU violation
- They occur at tree-level meaning they are theoretically clean but suffer from missing energy due to neutrinos

Why do neutrinos in the final state cause problems at a hadron collider but not at $e^+ - e^-$ colliders? Further, why can Atlas and CMS deal with neutrinos better than LHCb?

- Flavour changing neutral currents (FCNC) like $b \to sl^+l^-$ are even more interesting for LFU violation
- They occur only at loop level in the SM and are highly suppressed
- NP particles can enter these loops as virtual particles

What makes FCNC suppressed in the SM? Hint: CKM elements and GIM

- There are many beyond the SM (BSM) models that predict LFU violation
- They include the 2 Higgs doublet model, GUTs and SUSY

Draw Feynmann diagrams to show how a charged Higgs could cause LFU violation both at tree-level and loop level

2 Experimental challenges

- Reconstructing leptons is not a universal problem
- Muons are the easiest to reconstruct due to negligible Bremsstrahlung and a clean trigger signal
- Electrons suffer large Bremsstrahlung making reconstruction difficult and have lower trigger/PID/tracking efficiencies
- Taus are the hardest lepton to reconstruct as they decay to a final state containing one or more neutrinos

At LHCb we attempt to recover the energy lost by electrons due to Bremsstrahlung. Briefly explain how. Why can we not perfectly correct for Bremsstrahlung?

3 LFU measurements

- LHCb has a family of measurements called the $R(X)$ measurements that use FCCC and FCNC. They are $R(D^*)$, $R(J/\psi)$, $R(K)$, $R(K^{*0})$
- Tensions with the SM have been found in all of these results

Why do we measure ratios of branching fractions?