# Lepton-Flavour Universality

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# What are Leptons?

- Leptons are elementary particles that are only affected by the electromagnetic, weak and gravitational forces.
- There are 6 leptons: 3 charged, and their 3 corresponding neutral particles (neutrinos).

| Electron | Muon | Tau |
|---|---|---|
| Completely stable<br>1/1836 the mass of a proton<br>Negatively Charged | Decays into an electron, and 2 neutrinos<br>207 times heavier than the electron<br>Relatively unstable (2.2 second lifetime) | Decays into either:<br>• A muon, a tau-neutrino and a muon-antineutrino<br>• An electron, a tau-neutrino and an electron-antineutrino<br>• Particles containing quarks and a tau-neutrino |

# What are Leptons?

| Name | Symbol | Lepton Number | Charge | Spin | Mass (MeVc$^{-2}$) |
|---|---|---|---|---|---|
| **Electron** | $e^-$ | +1 | -e | ½ | 0.511 |
| **Positron** | $e^+$ | -1 | +e | ½ | 0.511 |
| **Muon** | $\mu^-$ | +1 | -e | ½ | 105.66 |
| **Anti-muon** | $\mu^+$ | -1 | +e | ½ | 105.66 |
| **Tau** | $\tau^-$ | +1 | -e | ½ | 1.7768 |
| **Anti-tau** | $\tau^+$ | -1 | +e | ½ | 1.7768 |

| Name | Symbol | Lepton Number | Charge | Spin | Mass (MeVc$^{-2}$) |
|---|---|---|---|---|---|
| **Electron neutrino** | $\nu_e$ | +1 | 0 | ½ | <2.2x10*-6 |
| **Positron neutrino** | $\tilde{\nu}_e$ | -1 | 0 | ½ | <2.2x10*-6 |
| **Muon neutrino** | $\nu_\mu$ | +1 | 0 | ½ | <1.7 |
| **Muon antineutrino** | $\tilde{\nu}_\mu$ | -1 | 0 | ½ | <1.7 |
| **Tau neutrino** | $\nu_\tau$ | +1 | 0 | ½ | <15.5 |
| **Tau antineutrino** | $\tilde{\nu}_\tau$ | -1 | 0 | ½ | <15.5 |

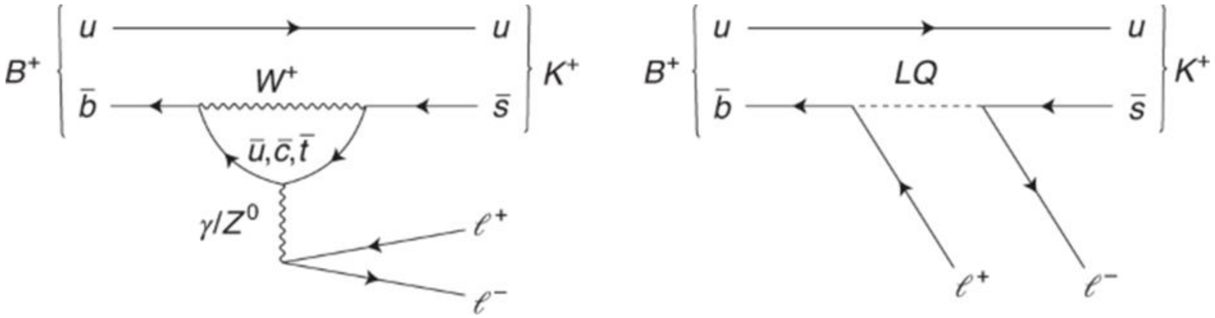
# What is Lepton-Flavour Universality?

One of the fundamental principles of the Standard Model (SM), this theory assumes that the interactions of W and Z electroweak gauge bosons and leptons are the same for all flavours.

However, this may not be true, as experiments have found deviations from the theory in the ratios of decay of B+ mesons into kaons, and either muons and anti-muons, or electrons and anti-electrons.

# What consequences would a violation of LFU have on the SM?

A violation of LFU would mean there are fundamental errors of the Standard Model and would require more details about the individual effect of W, Z bosons on each lepton flavor. It could mean that the Standard Model is incomplete and there could be a new fundamental particle, or law that would govern the decay of particles containing quarks into leptons.




(Left) The Standard Model of decay via electroweak bosons

(Right) A new theory suggesting a new hypothetical particle, the leptoquark, could interact with the different flavours of leptons in different ways, leading to varying interaction strengths.

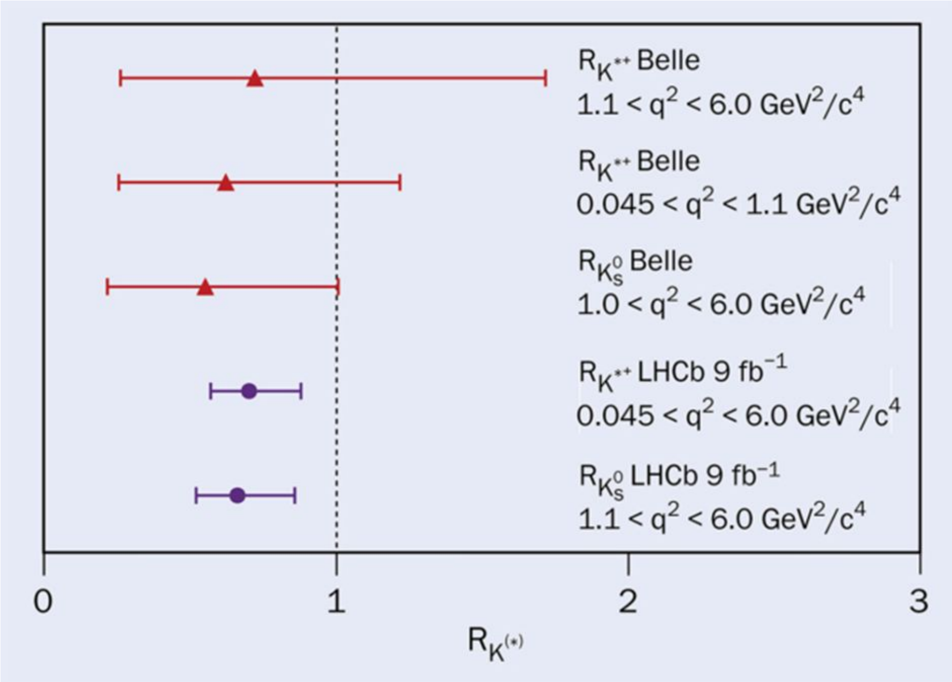
# What experiments are there currently?

CERN are currently measuring the relative frequencies of each lepton resulting from the decay of bottom quarks at the LHCb. These have given results that suggest that B+ mesons decay into muons up to 25% less often than into electrons, suggesting that leptons may not act in a similar, or universal, fashion. However, the infrequency of these decays means that there is massive structural fluctuation at 2.6 standard deviations, which means that statistical errors still dominate the probability. This makes the findings currently of little use.

The ratios of muon-electron decays are below the 1:1 ratio predicted by the Standard Model

Red: LHCb

Purple: Belle experiment



# What challenges are there in detecting it?

As research into the LFU symmetry in the SM is still relatively new, there is not enough data to clearly prove its violation with the largest deviation from SM predictions being 3.10σ measured by teams at LHCb.

Additionally, there are practical challenges that directly impede advancements in research. For example, since electrons react more with matter than muons and consequently emit more braking radiation (Bremsstrahlung photons), there are more uncertainties in the reconstruction efficiency and signal resolution of electrons which can degrade data precision and hinder analysis.

# Our experiment

Our experiment would measure the number of electron and anti-electrons, and muons and anti-muons produced from the decay of B+ mesons, to find a ratio between the different types of decay, to provide evidence for whether the Standard Model assumption is correct.

As cosmic rays can contain muons, which we are trying to detect in our experiment, we would want to conduct our experiment deep underground, so as to minimise any background detections of muons from cosmic rays.

B+ mesons are produced in proton-proton collisions, so we would need a proton beam to produce the mesons for decay.

# The Detectors

Innermost

- Central Drift Tracking Chamber
    - Detects charged particles
    - Measures the momentum and charge of particles passing through it
- Aerogel Cherenkov Detector
    - The patterns of light can be used to detect particles and help identify them
- Electromagnetic Calorimeter
    - This will stop any electrons passing through it, so we can detect how many electrons were produced in the decays

Outermost

- Muon Detector
    - This will identify how many muons were produced in the decays

# References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