B-anomalies at the LHCb detector hinting at New Physics?

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1. Background

Rare decays of b quarks have presented a challenge in reconciling experiment with theory. Several measurements made by the LHCb, BaBar, and Belle experiments indicate **deviations from the Standard model** (SM) predictions in observables (Fig. 1) involving these decays suggesting **Lepton Flavour Universality** (LFU) violation and therefore hinting towards **New Physics** beyond the SM [1, 2].

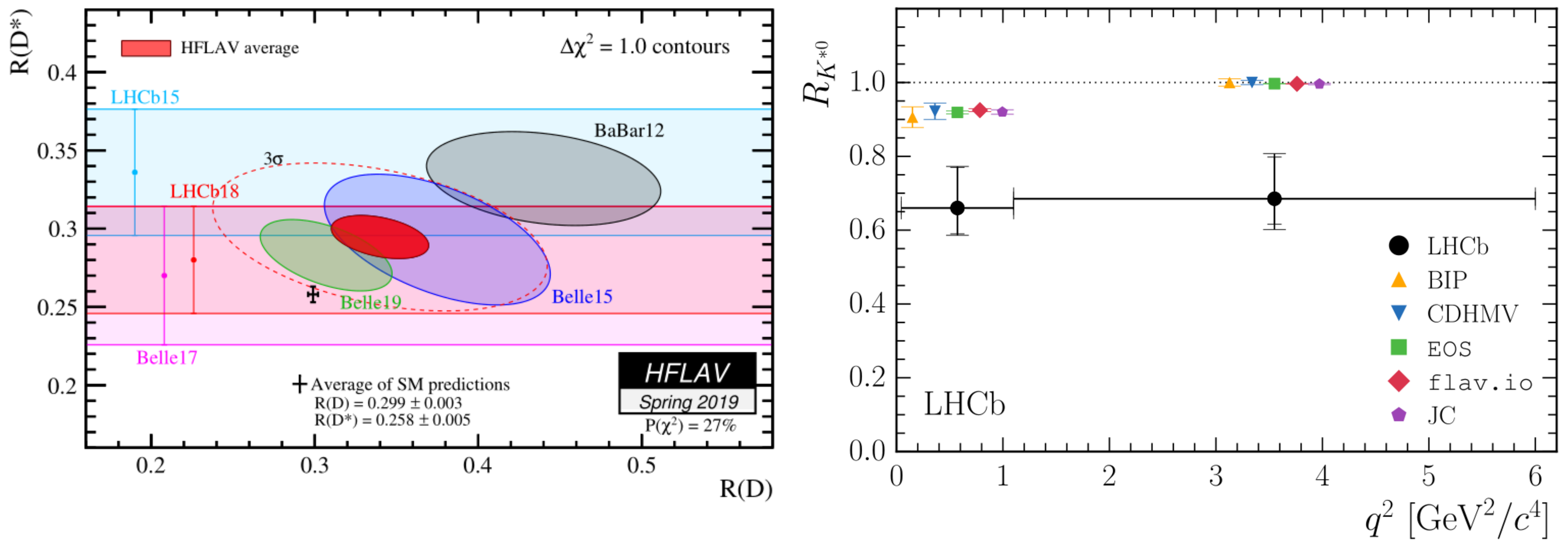


Fig. 1 *LFU violation hints in key observables $R(D)$ and $R(D^*)$ on the left [3], R_{K*} on the right [1].*

2. $B_s \to \Phi_3 \tau \tau$ decay

Beyond the SM theories suggest the **Leptoquark** as a possible explanation for these anomalies [4]. This new gauge boson would couple to quarks and leptons at a single vertex **hierarchically** and would imply significant LFU violating effects with b quark decays into τ's [5]. However, τ's decay at very short distances into muons and neutrinos and are hence **difficult to reconstruct**.

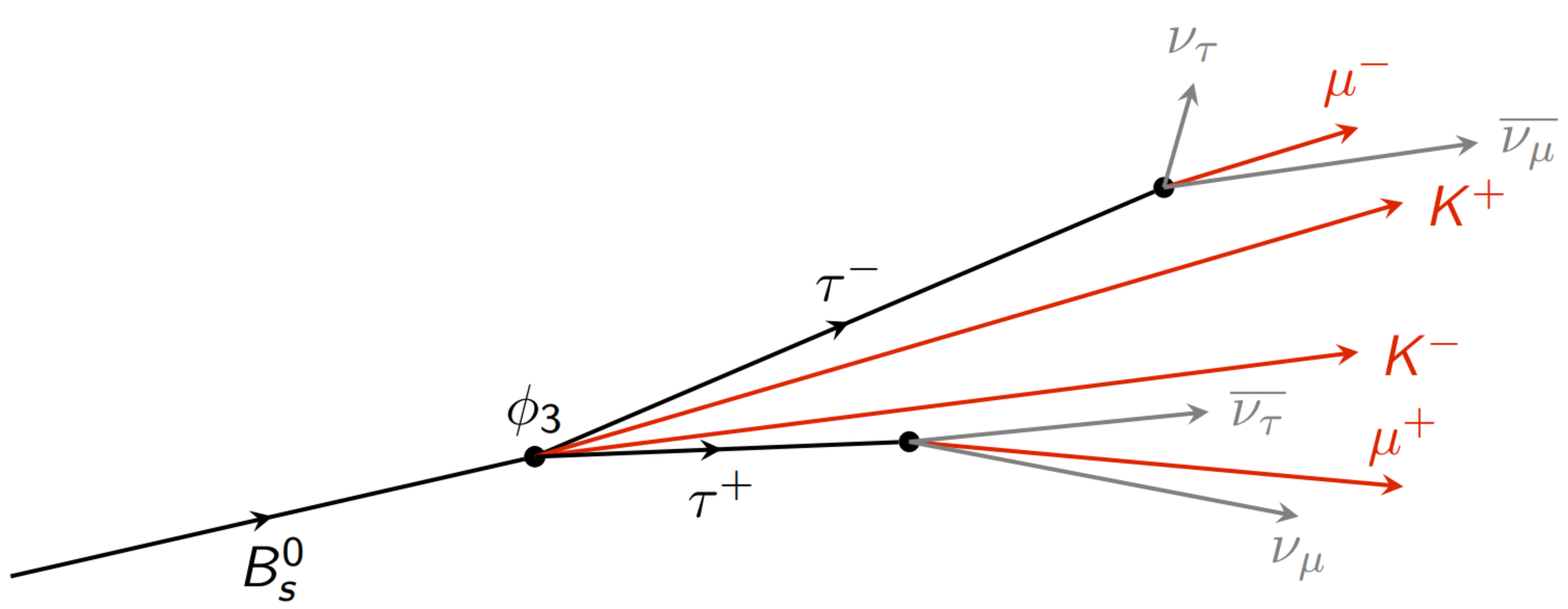


Fig. 2 *The B_s decay tree, key particles in black, particles shown in red (grey) are (not) detected [6].*

3. Aims

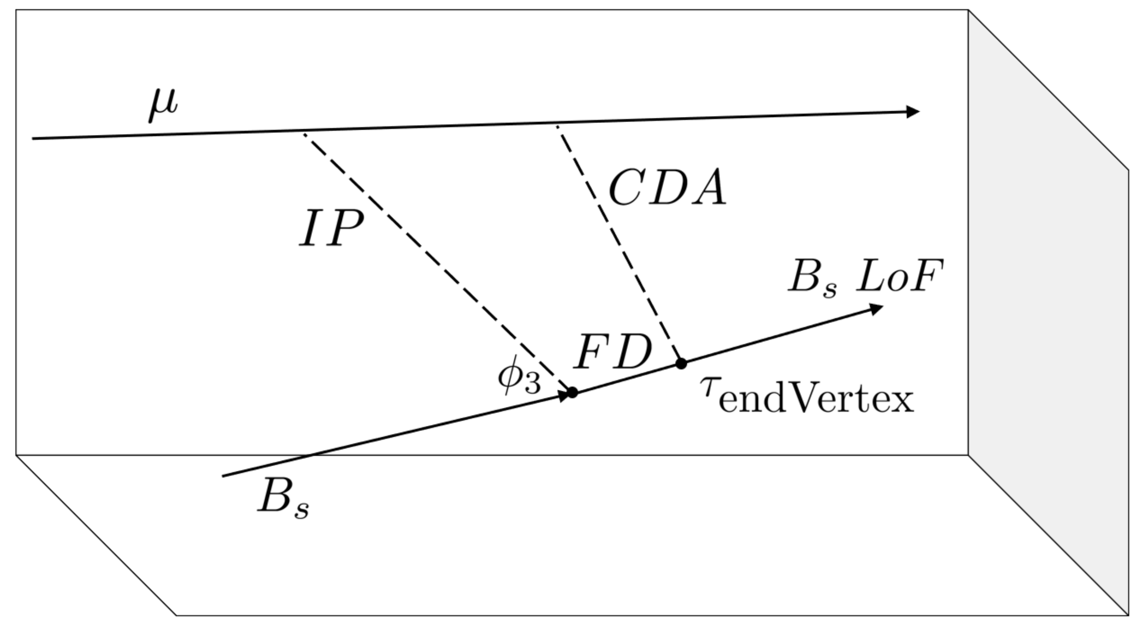
- Use **ensemble models** to identify τ decays through geometrical quantities with the key assumption that τ's are produced at rest
- Use LHCb reconstruction software to obtain **data χ^2 values** and get greater resolving power
- Obtain **better resolution** for Br($B_s \to \Phi_3 \tau \tau$)

4. Implementation

LHCb reconstruction software **Bender** is used to calculate the key distance quantities (Fig. 3);

- **Impact Parameter** (IP) between Φ_3 and μ
- **Flight Distance** (FD) of τ
- **Closest Distance of Approach** (CDA) between μ and τ – same as B_s line of flight (LoF)

Fig. 3 *Diagram of the key geometrical quantities in the decay.*



We then compare these Bender results to analytic calculations (Fig. 4) and the **data significance values χ^2** are extracted. These are the key descriptive features in boosted decision trees (BDTs).

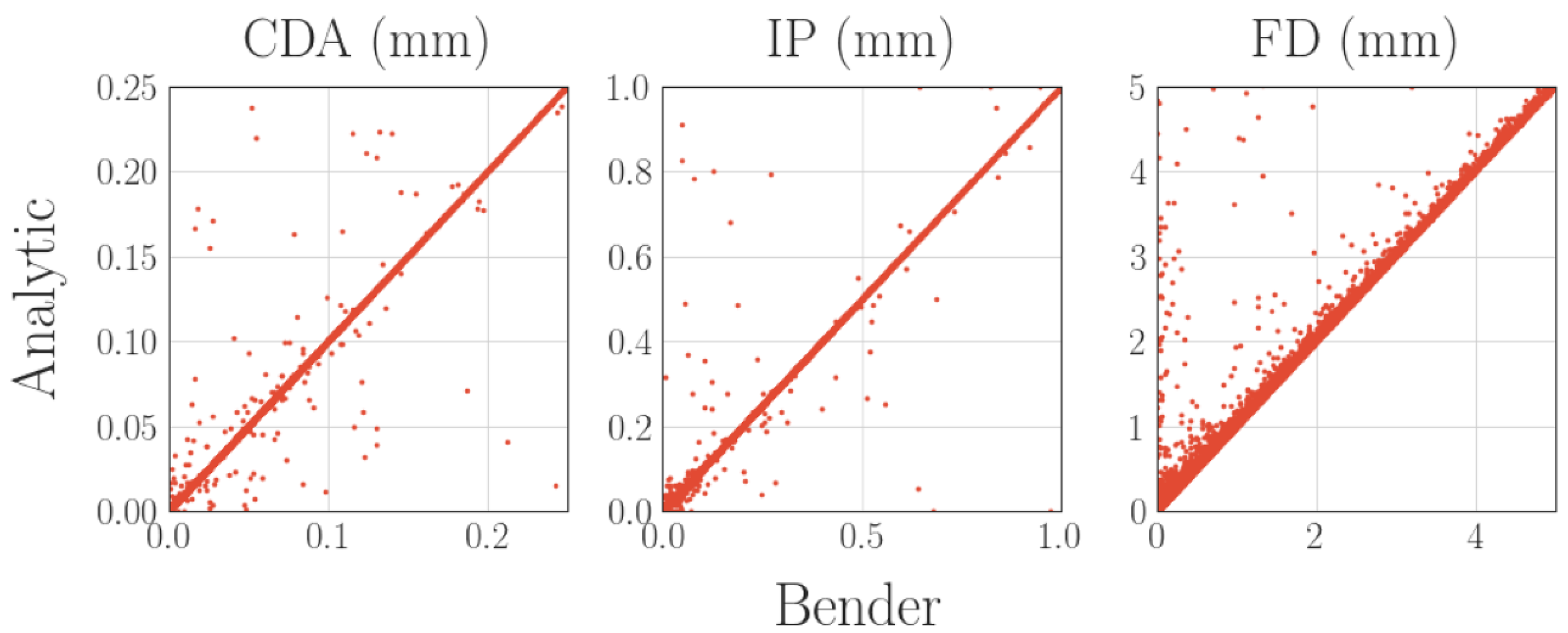


Fig. 4 *Plot of IP, FD, and CDA analytic and Bender values. The strong linearity indicates complete agreement.*

5. Analysis

After a selection on the data focusing on filtering out the J/ψ resonance, an **ensemble of decision trees** is trained with **extreme gradient boosting** to classify events of interest. The best classifier is chosen after repeated cross-validation (CV) and predictions are made. A previous study [6] clearly labels **CDA, IP, and FD as the most discerning features** (Fig. 5) and hence the inclusion of χ^2 allows for more informed predictions.

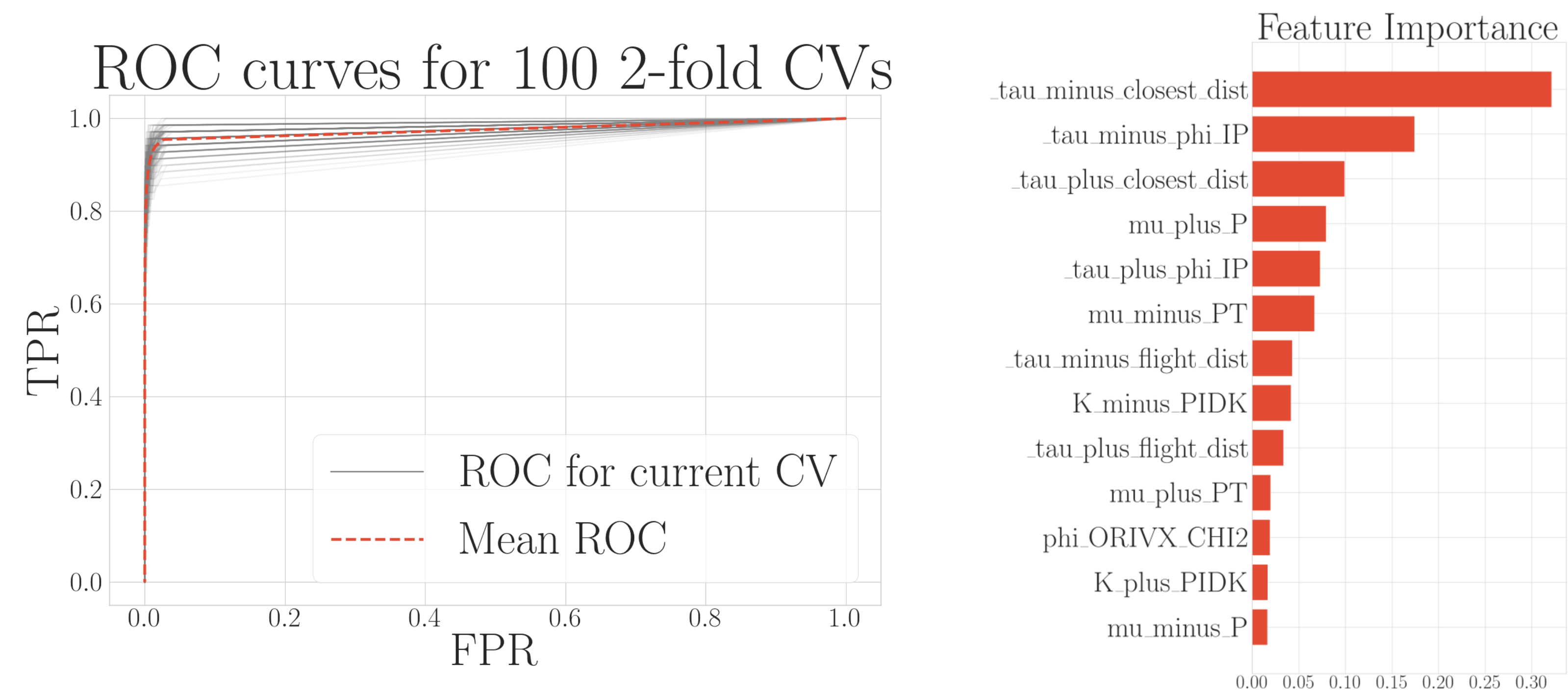


Fig. 5 *The ROC curves for repeated 2-fold CV together with the most discerning features of the ensemble [6].*

6. Future outlook

Eventually, an improvement in the estimate for the ratio Br($B_s \to \Phi_3 \tau\tau$)/Br($B_s \to \Phi_3 \mu\mu$) can be obtained. Possible extensions could be probing **higher Φ_3 masses** and pruning the decision trees to **prevent overfitting**.

References

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