USING MACHINE LEARNING TO EXPLORE THE B-ANOMOLIES AT THE LHCb EXPERIMENT

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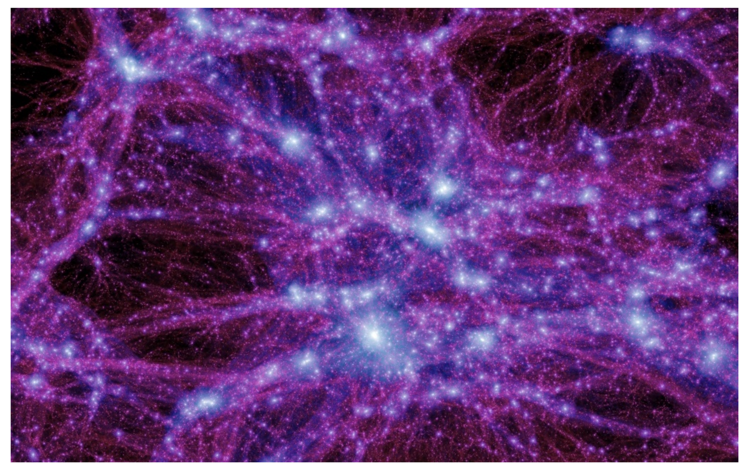
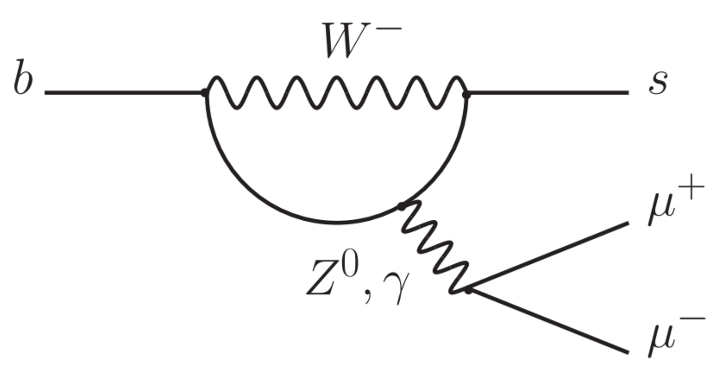
Background

- The standard model (SM) of particle physics is incomplete – unexplained phenomena such as Dark Matter (DM).
- Rare decays of B mesons indicate Lepton Flavour Universality violation (LFUV) and therefore are a good probe for New Physics (NP) [1].



This image shows DM responsible for a large scale structure [2].



'Penguin' diagram of the quark decay $b \to s\tau\tau$. Diagram is suppressed due to loop structure.

- LFUV is seen in observables such as *branching fractions* (the fraction of particles which decay via a particular process).
- Current measurements suggests the LFUV occurs in a hierarchical way – more massive leptons show greater deviation from the SM [3].
- Decays of τ particles are compelling to investigate. However, difficult to reconstruct in experiments.

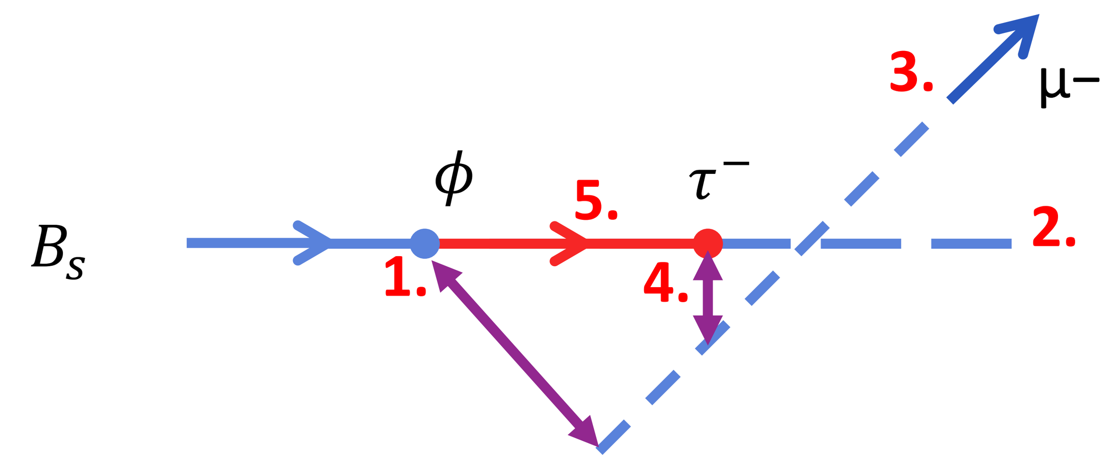
Theory

***Problem*: We want to identify events $B \to X\tau\tau$**

Decay Path : $B_s \to \phi \to K^+K^-$; $B_s \to \tau^+ \to \overline{\nu_\tau}\, \nu_\mu\, \mu^+$; $B_s \to \tau^- \to \overline{\nu_\mu}\, \nu_\tau\, \mu^-$

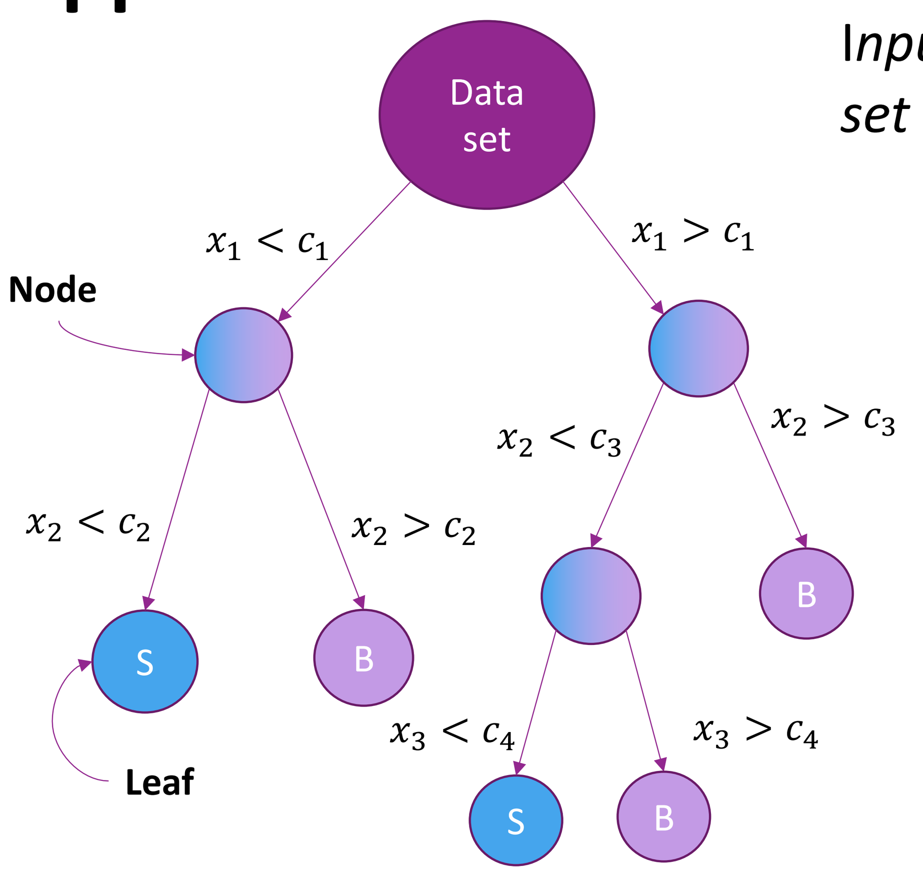
***Solution:* Constrain final system to reduce the degrees of freedom. Achieved by choosing the *X* meson to be of sufficient mass, leaving the minimal kinetic energy available to the τ. The τ then follow the B meson line of flight.**

We are testing the mass range of X for which this method is applicable.



1. Kaon flight paths used to identify ϕ_3 decay vertex.
2. Bs decay vertex = ϕ_3 vertex. Bs LOF extended.
3. Muon flight paths are reconstructed.
4. The point of closest distance between the μ and B_s LoF is the τ decay vertex.
5. Other variables, such as tau flight distance are then calculated.

Approach



An example of a single decision tree, Signal (S) and Background (B) events are split to maximise the measure of separation at each node.

Machine Learning - Boosted Decision Tree :

Input data is split sequentially based on a set of input features.

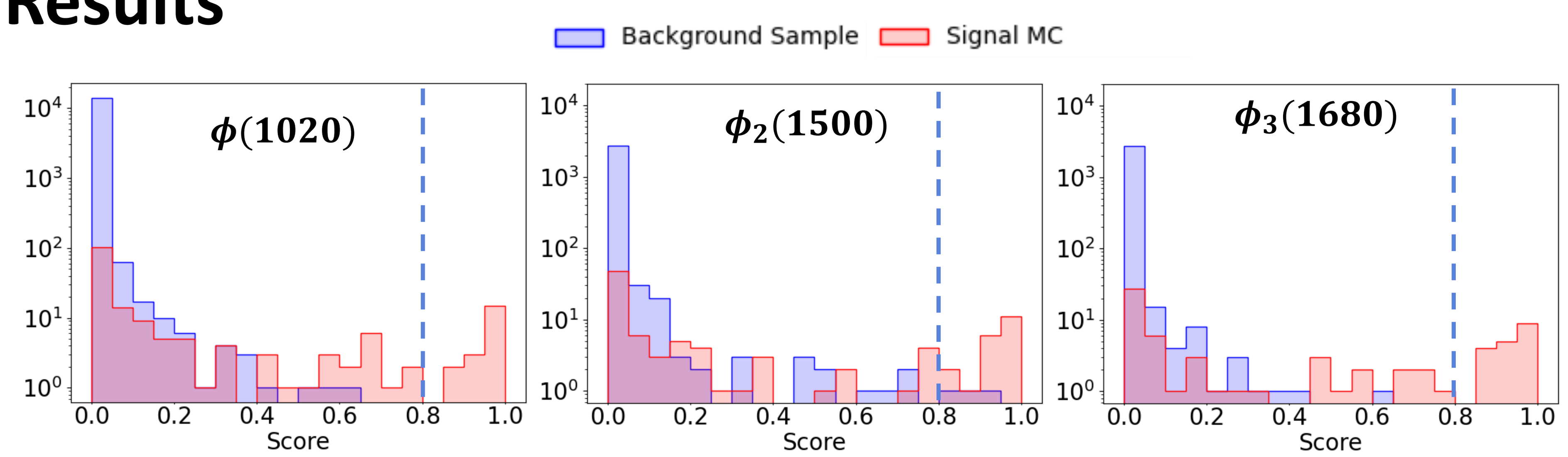
TRAINING

- Features – variables such as CDA and IP
- 'Signal' data – simulated Monte Carlo
- 'Background' data - competing processes selected from real LHCb data (e.g. $J/\Psi\ \phi \to \mu\mu KK$).

OUTPUTS

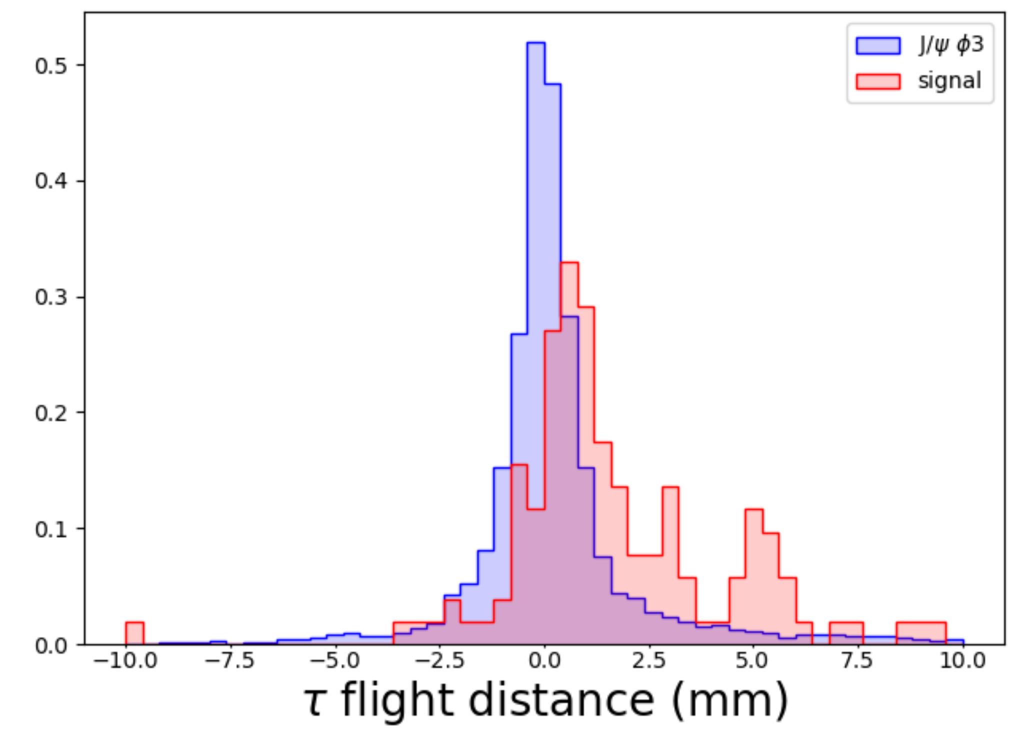
- Classifier that identifies signal and background candidates in a data set.

Results



- The plots suggest that a BDT trained at lower $\phi(1020)$ mass classifies signal and background just as well as that at $\phi_3(1680)$. It does seem to worsen for $\phi_2(1500)$.
- This is unexpected as we thought that the method would rely on the higher ϕ mass.

BDT SCORE	CANDIDATE
0	BACKGROUND
1	SIGNAL



This plot shows the tau flight distance for the signal MC and the $J/\Psi\ \phi_3$ competing decay for the $\phi_3(1680)$ BDT. This is one of the key features used to distinguish background and signal candidates.

Further work

If this method can be extended to lower masses it would be beneficial for the search to constrain the $b \to s\,\tau\,\tau$ branching fraction, as there are more available data in this region. In the high mass regime, making conclusions is difficult due to the limited statistics.

NEXT STEPS TO CONFIRM AND VALIDATE METHOD…

1. Using the classifier, calculate the known branching fraction $\mathcal{B}(B_s \to \phi\mu\mu)$ to ensure the BDT is working correctly.
2. Produce the new branching fractions for the lower mass ϕs and test whether the limit on the branching fraction is improved.

References:

[1] S. Descotes-Genonet al., "Implications from clean observables for the binned analysis of $B \to K^*\mu^+\mu^-$ at large recoil" JHEP, vol. 01, p. 048, 2013.doi:10.1007/JHEP01(2013)048. arXiv:1207.2753

[2] Boylan-Kolchin, Michael, et al. "Resolving cosmic structure formation with the Millennium-II Simulation." Monthly Notices of the Royal Astronomical Society 398.3 (2009): 1150-1164.

[3] B. Capdevila *et al.*, "Patterns of new physics in $b \to s\, l^+ l^-$ transitions in the light of recent data" JHEP,vol. 01, p. 093, 2018. DOI:10.1007/JHEP01(2018)093. arXiv:1704.05340