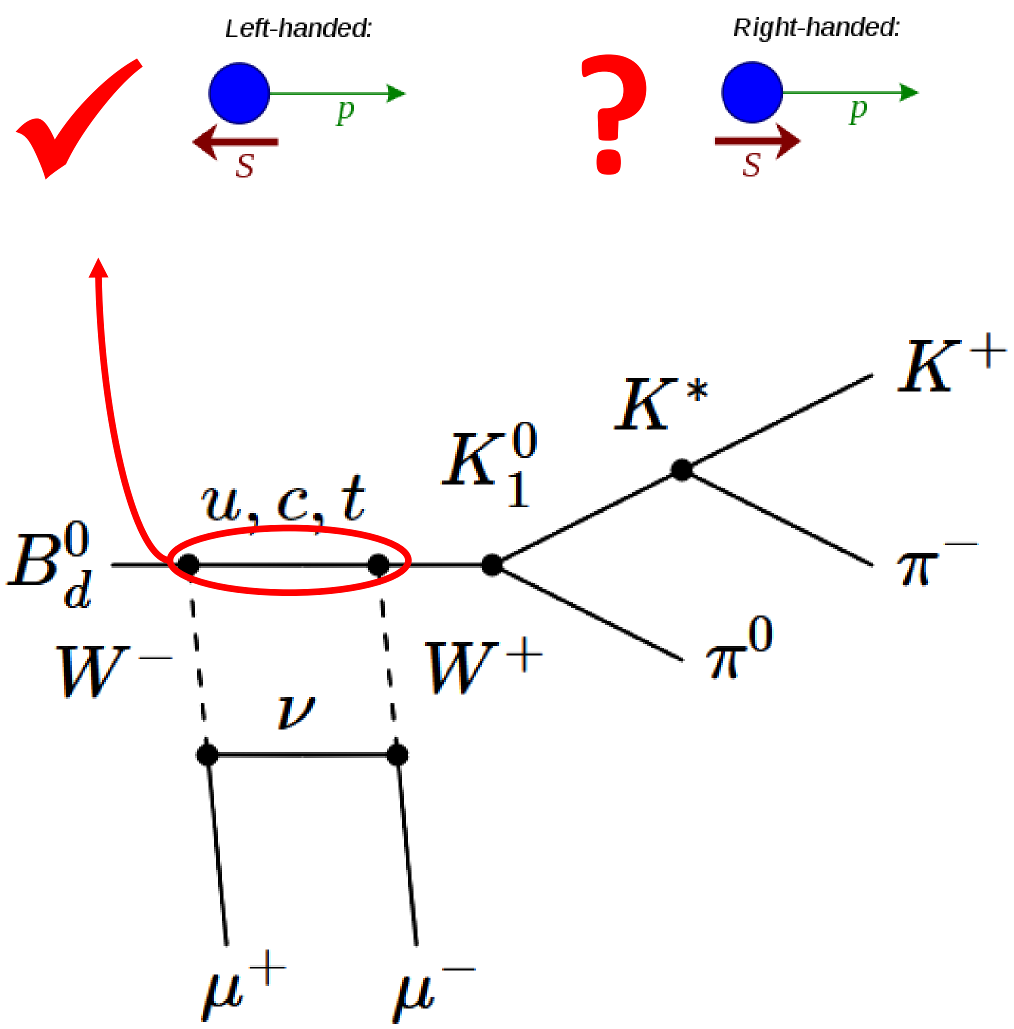
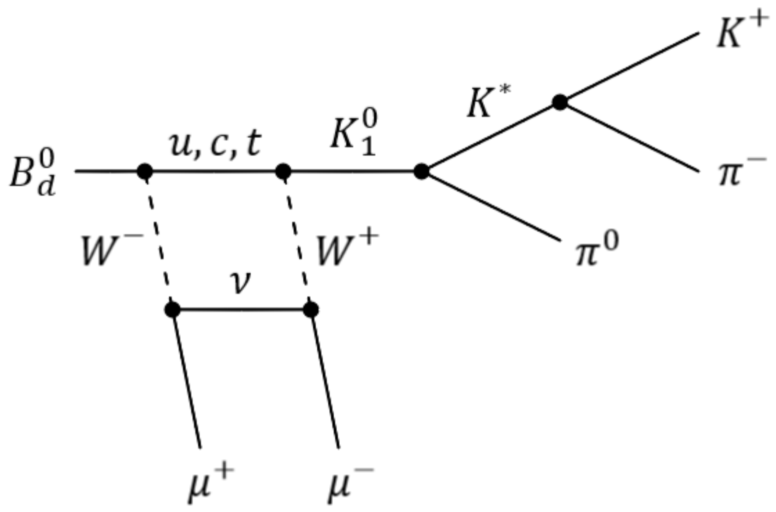
Search for Right-Handed Weak Decays with $B_d^0 \to K_1^0 \mu^+ \mu^-$

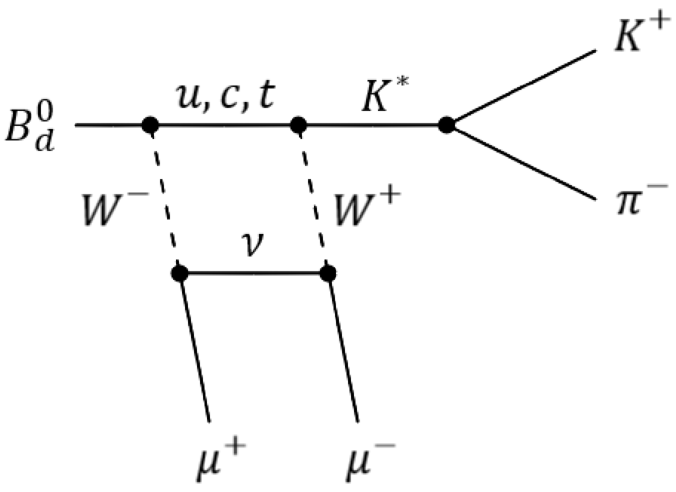
Motivation



- Standard Model Weak interactions only couple to left-handed particles (or right-handed antiparticles).
- No specific theoretical reason for this, falls out of surrounding theory and has agreed with observation.
- Right-handed weak decays may exist but are 'drowned out' by existing Standard Model left-handed decays.
- Past searches have limited sensitivity and set constraints.
- Parity Doubling - Comparing two decay channels with parity degenerate states, amplitudes come with a relative minus sign and effectively cancel out left-handed contributions.
- Very sensitive search for right-handed contributions.

Decay Channel & Aims



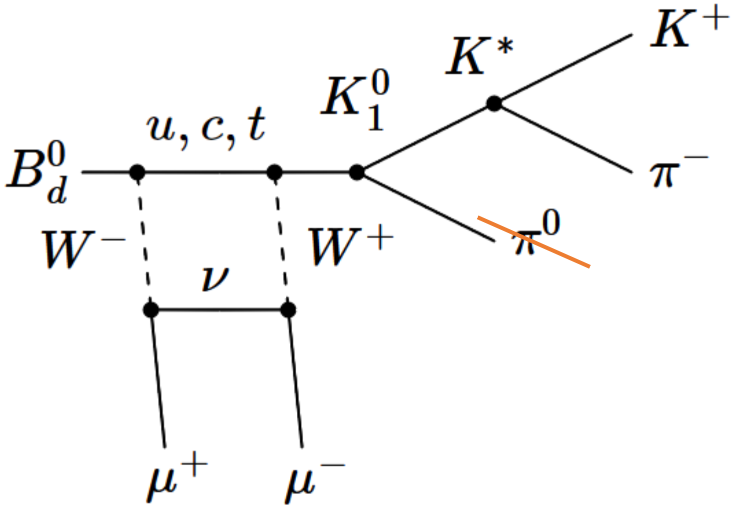


- Flavour changing neutral current (FCNC) - Standard Model rare interactions that are forbidden at tree level, proceed only through boxes & loops and highly suppressed by the GIM mechanism.
- FCNC Effective couplings are very well predicted, deviations from the Standard Model are easy to see.
- The primary aim is discovering the decay. Then making a measurement of its branching fraction via:

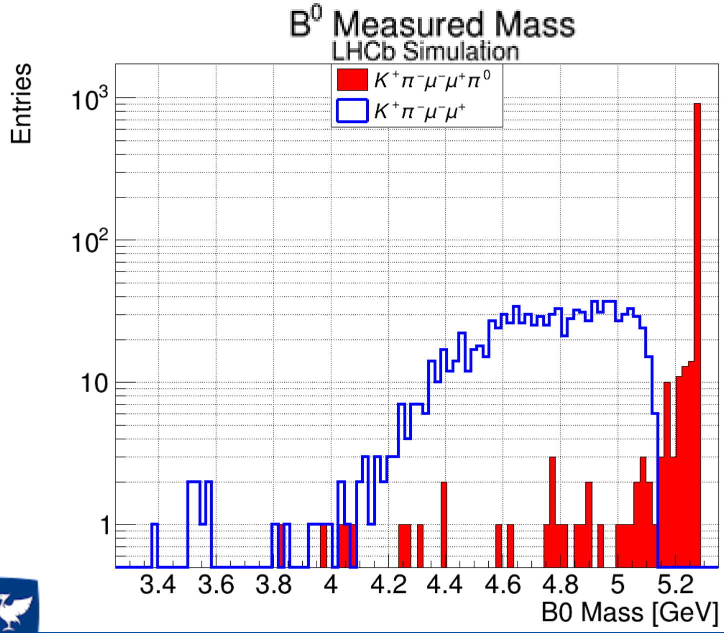
$$\boldsymbol{R} = \frac{\mathcal{B}_{B^0 \to J/\psi K_1^0}}{\mathcal{B}_{B^0 \to J/\psi K^*}}$$

- The K_1^0 and K^* states are (almost) parity-degenerate states, they have the same spin but opposite parity.
- Aim to use these channels to investigate the relative contributions of left- and right-handed weak currents in B decays.

Partial Reconstruction

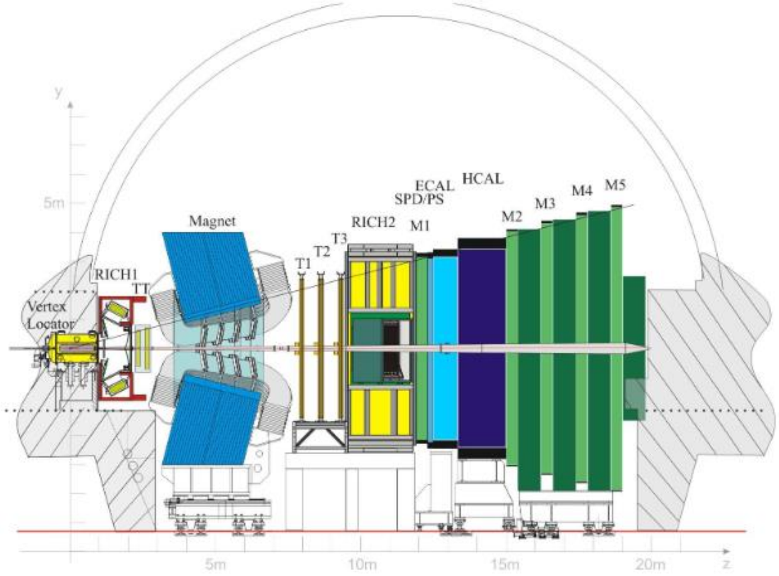


- Analysis of the first MC samples indicated a full reconstruction (including the π^0) was not viable for multiple reasons.
  - ➢ π^0 reconstruction efficiency is very low (average ~3.7 %) compared to charged tracks (average ~70+%).
  - ➢ Very busy hadronic event and limited π^0 reconstruction information produces a large combinatorial background.



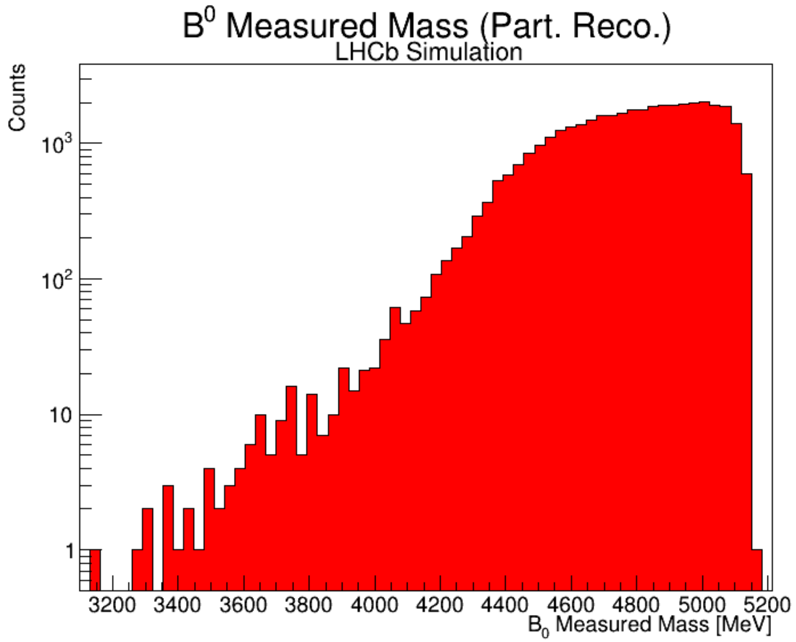
- Partial reconstruction results in:

➢ A significantly wider signal region.
➢ More than an order of magnitude increase in found signal events.
➢ Very few combinatoric background events.



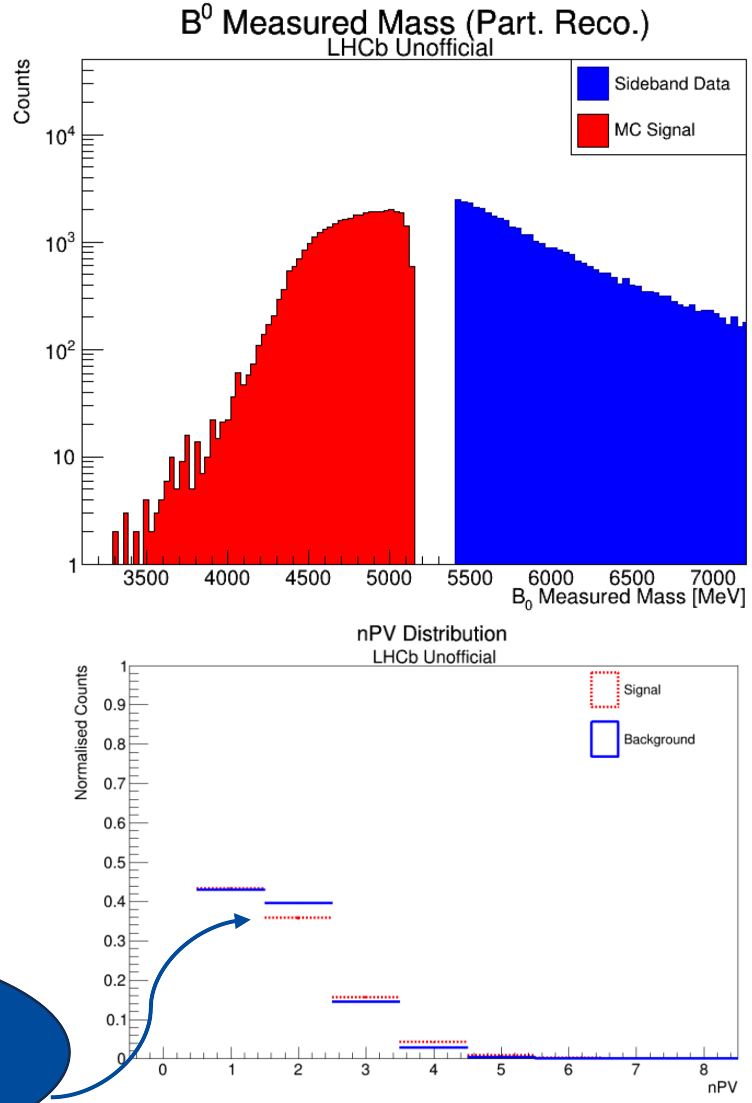
Triggers & Candidate Selection

- Analysis will use all Run 2 data, currently working with the 2016 data.
- Developed a trigger for the Run 2 software trigger which filters previous LHCb data (2016, 2017, 2018) for new channels/analyses.
- Also developed a trigger for Run-3 data collection this year and beyond, planning for data collection well beyond the current analysis.
- Both triggers were optimised using an MC generated signal sample and minimum bias for the best signal efficiency.
- Triggers feature tighter particle identification selections than similar analyses to reduce the increased rate from the required wider mass window.
- Events required to pass the Muon, Dimuon or Hadron hardware triggers.
- The analysis will be unblinded since the decay is partially reconstructed.



MVA - Overview

- An XGBoost Classifier is trained to reduce the combinatorial background.
- Inputs are sideband data (m_{B_0} > 5400 MeV) as a background proxy and truth matched MC signal events are used as a signal proxy.
- Weight corrections account for differences between data and simulation (e.g. number of primary vertices).
- Input variables are selected based on previous related analyses choices and visual separation.



Differences between simulation and background proxies.

MVA – Variable Selection

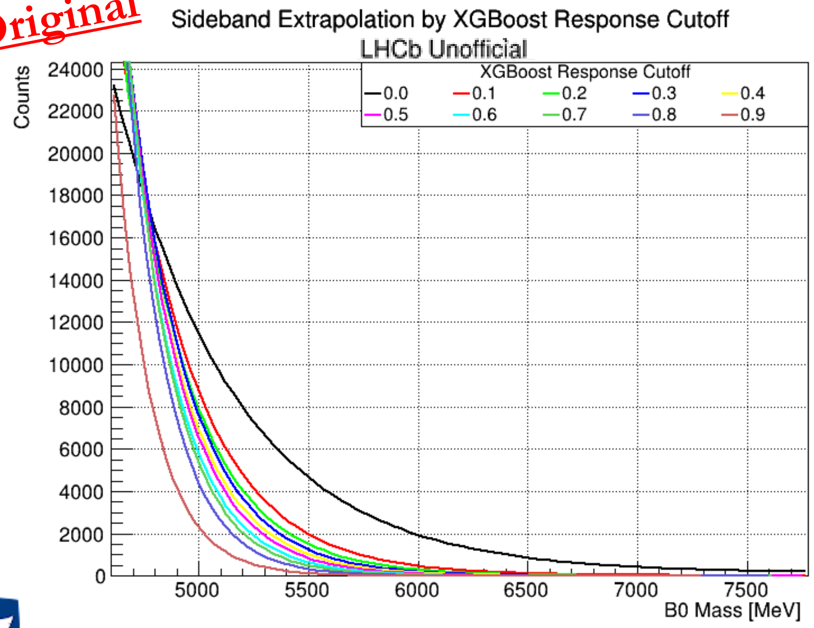
- Variables with high discriminating power that are used in similar analyses introduce a bias into the classifier that reduces the background rejection in the lower mass regions.

➢ Increased weighting on background events with a lower B^0 mass.
➢ Removing specific input B^0 variables (e.g. p_T, Vertex χ^2).

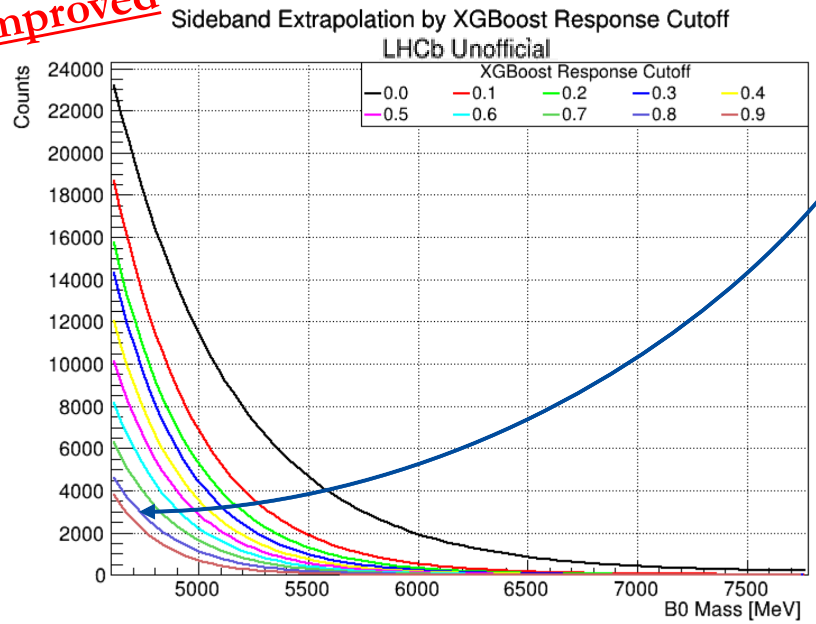
- Result is increased discrimination at lower masses. Needs more investigation.

Increased discrimination at lower mass.

Original

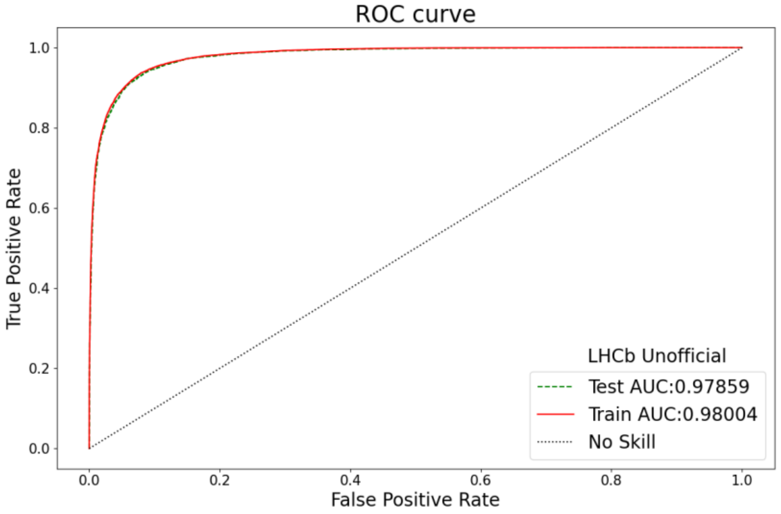


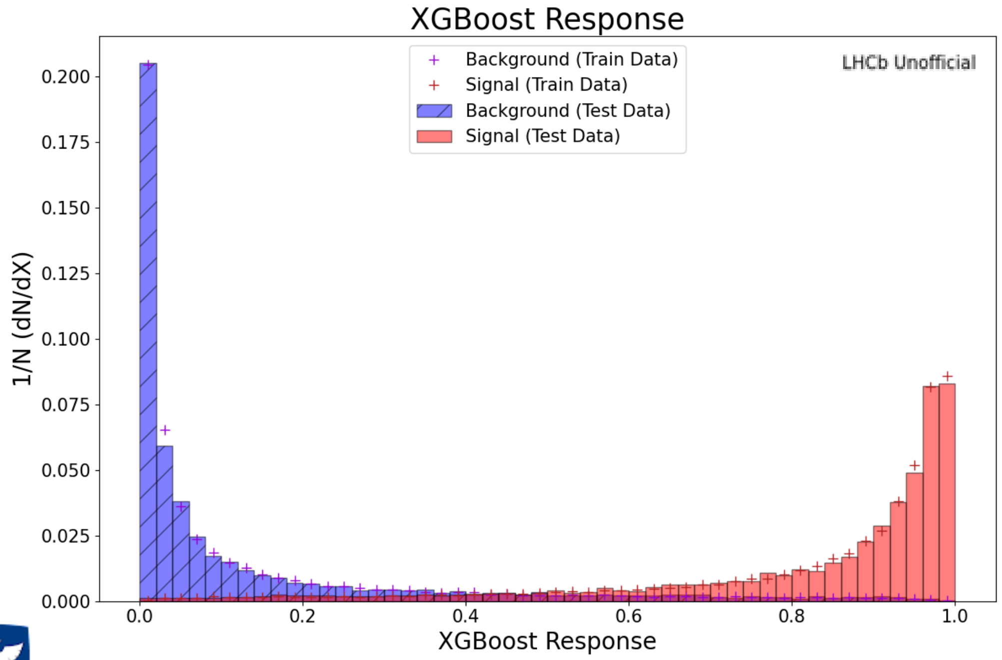
Improved

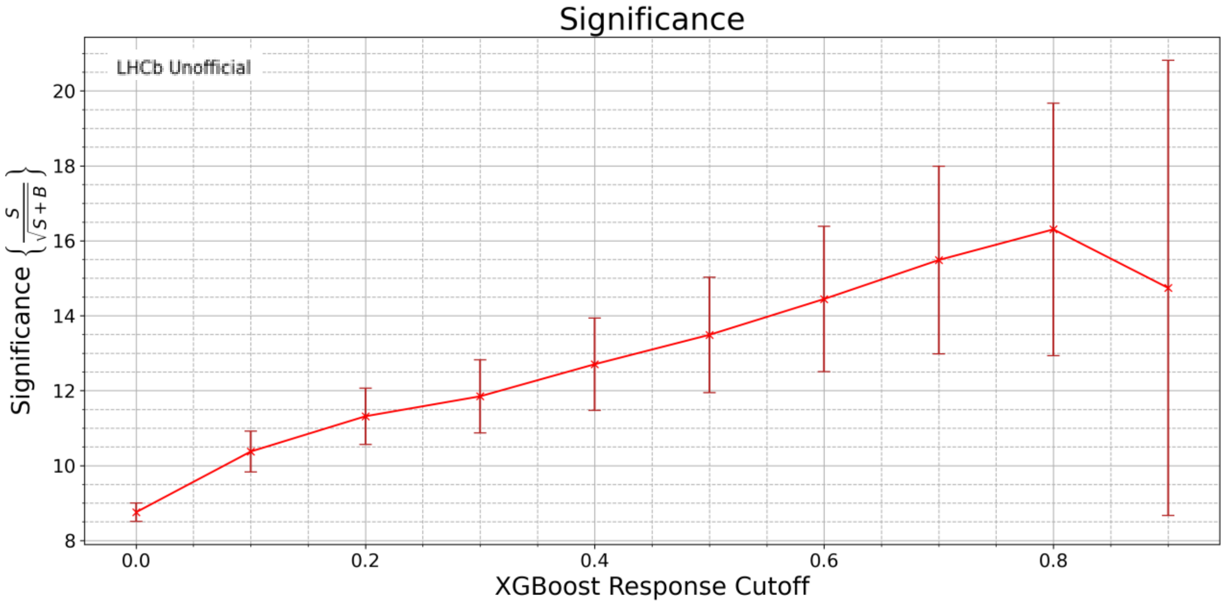


MVA – Current Status

- MVA is now successful in reducing combinatorics in the signal region.
- Current significance estimate at this stage is promising for next analysis steps.
- Investigating how to exploit powerful (but potentially biased) variables.







Outlook

- While partial reconstruction of the channel is required it introduces many challenges.
- Selections for data collection across Run 2 and Run 3 completed.
- Investigating the XGBoost mass bias and any further improvements that can be made.
- 2017 & 2018 data processing underway.
- Starting background sample generation and fitting.
- Signal region lies in the partially reconstructed shoulder of the B^0 peak, the variety of decay channels here will present a challenge in the fitting.
- Future analysis can benefit from the Run-3 trigger providing larger data samples.

Backups

Selections – Run 2 (Restrip)

- Optimised using a 10k MC sample and a ~250k minimum bias sample.
- Currently developing the analysis with the 2016 MU data.
- Selection Efficiency ~ 33% for signal with 100% background rejection on the (small) sample.

Candidate	$B^0 \to K^*\mu^+\mu^-$ (Stripping 2016)	$B^0 \to J/\psi\, K_1^0$ (Restripping)
B_d^0	IP χ2 < 16	IP χ2 < 100
	4800 MeV < M < 7100 MeV	2779.64 MeV < M < 7779.64 MeV
	Cos(θ_{DIRA}) > 0.9999	Cos(θ_{DIRA}) > 0.9995
	Flight Distance χ2 > 121	Flight Distance χ2 > 100
	Vertex χ2/ndf < 8	Vertex χ2/ndf < 9
Mu Mu / J/ψ	M(μ+μ−) < 7100 MeV	1000 MeV < M(J/ψ) < 9000 MeV
	Vertex χ2/ndf < 9	Vertex χ2/ndf < 9
K*(892)	M < 6200 MeV	700 MeV < M < 1100 MeV
	Vertex χ2/ndf < 8	Vertex χ2/ndf < 9
	Flight Distance χ2 > 16	
		${K^*}_{P_T}$ > 800 MeV

Candidate	$B^0 \to K^*\mu^+\mu^-$ (Stripping 2016)	$B^0 \to J/\psi\, K_1^0$ (Restripping)
All Tracks	Ghost Prob. < 0.5	Ghost Prob. < 0.4
		P_T > 300 MeV
		TRCHI2 < 4
Hadrons	Min IP χ2 > 6	Min IP χ2 > 4
		${K^+}_{ProbNN(K)}$ > 0.4
		${\pi^-}_{ProbNN(\pi)}$ > 0.4
Muons	Min IP χ2 > 9	Min IP χ2 > 4
	IsMuon	IsMuon & HasMuon
	DLLμπ > −3	${\mu^{+/-}}_{ProbNN(\mu)}$ > 0.4
		${\mu^{+/-}}_{ProbNN(\pi)}$ < 0.95
GEC	SPD Mult. < 600	SPD Mult. < 600

[All relevant values in MeV]

Selections – Run 3 Trigger

Candidate	$B^0 \to J/\psi\, K^*$ (Run 3)	$B^0 \to J/\psi\, K_1^0$ (Run 3)
B_d^0	4500 < M < 7000	3000 < M < 6500
	P_T > 0	P_T > 500
	Cos(θ_{DIRA}) > 0.9995	Cos(θ_{DIRA}) > 0.9995
	Flight Distance χ2 > 16	Flight Distance χ2 > 100
	Vertex χ2/ndf < 36	Vertex χ2/ndf < 7
	(BPV) IP χ2 < 36	(BPV) IP χ2 < 50
J/ψ	0 < M < 5500	210 < M < 4430
	P_T > 0	P_T > 0
	ADOCA χ2 < 36	ADOCA χ2 < 9
	Separation χ2 > 4	Separation χ2 > 100
	Vertex χ2/ndf < 25	Vertex χ2/ndf < 9
K*(892)	0 < M < 2600	800 < M < 1000
	${K^*}_{P_T}$ > 400	${K^*}_{P_T}$ > 500
	ADOCA χ2 < 36	ADOCA χ2 < 9
	(BPV) IP χ2 > 4	
	Vertex χ2/ndf < 25	Vertex χ2/ndf < 9

Candidate	$B^0 \to J/\psi\, K^*$ (Run 3)	$B^0 \to J/\psi\, K_1^0$ (Run 3)
Hadrons	${K^+}_P$ > 1000	P > 2000
	${\pi^-}_P$ > 2000	
	P_T > 250	${K^+}_{P_T}$ > 250
		${\pi^-}_{P_T}$ > 100
	Min IP χ2 > 4	Min IP χ2 > 10
	${\pi^-}_{PID(K)}$ < 4	${\pi^-}_{PID(K)}$ < 0
	${K^+}_{PID(K)}$ > -4	${K^+}_{PID(K)}$ > 0
Muons	P > 0	P > 4000
	P_T > 350	P_T > 400
	${\mu^{+/-}}_{PID(\mu)}$ > -4	${\mu^{+/-}}_{PID(\mu)}$ > -4
	Min IP χ2 > 4	Min IP χ2 > 12

- Implemented ready for data taking this year.
- Hoping to include some Run 3 data in this analysis.

[All relevant values in MeV]

MVA Input Variables Example