CELEBRATING
10 YEARS

$B^0_{s,d} \to \pi^+\pi^-\mu^+\mu^-$ Angular Analysis

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Recap

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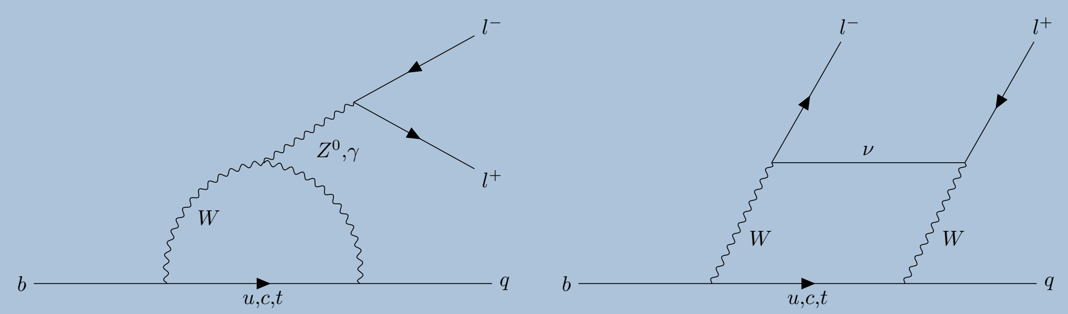
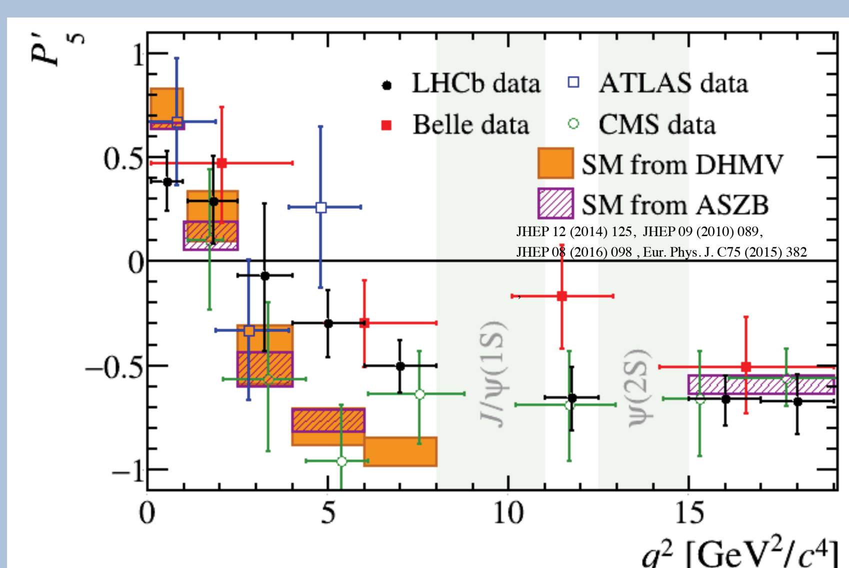
Motivations

Feynman Diagrams

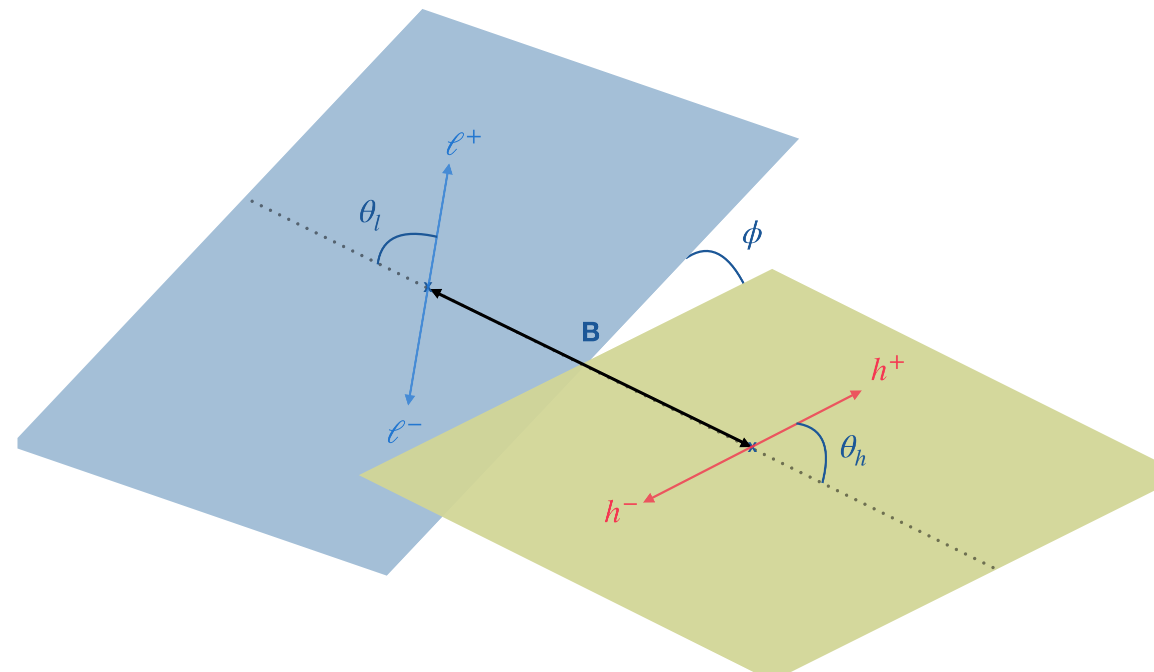


- First angular analysis of decay modes, following branching fraction measurements
- Wilson coefficients measured through angular observables, sensitive to NP
- Tensions with SM found (eg P_5' measured with a 3.5σ deviation from SM prediction)



ATLAS JHEP 10 (2018) 047
Belle PRL118, 111801 (2017)
CMS PLB 781 (2018) 517541
LHCb JHEP 02 (2016) 104

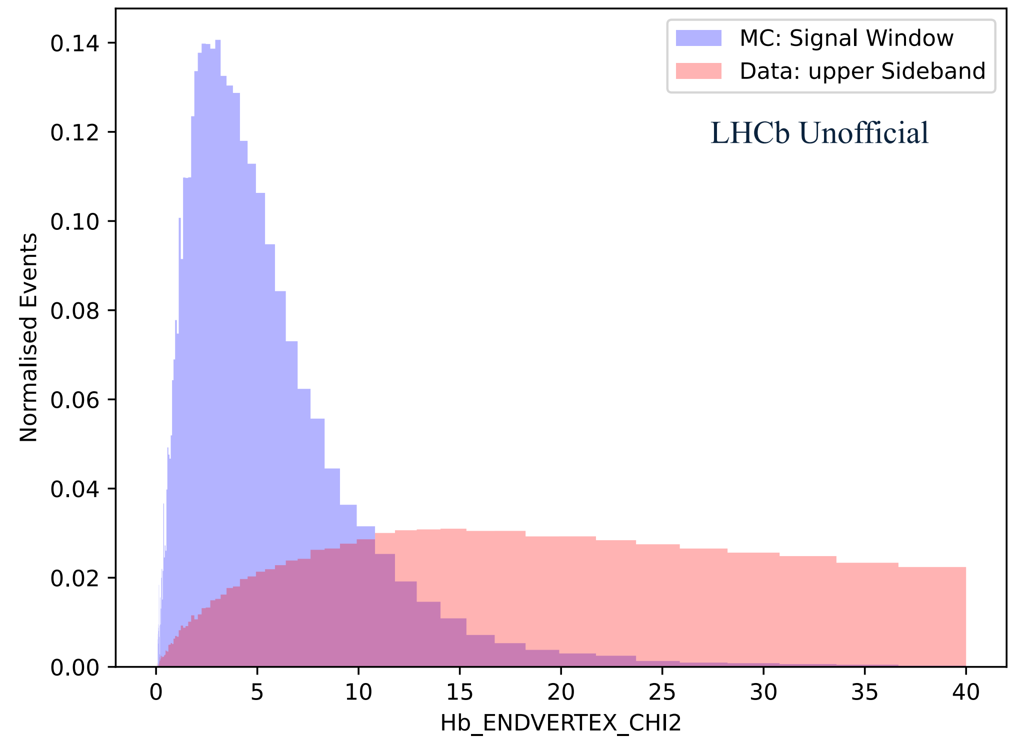
- Rare decays
- $b \to sll$ transitions (loop diagrams)
- Three angles (θ_K *or* θ_h, θ_l, ϕ) and q^2 describe the complete kinematics of the decay
- Angular observables (coefficients) are connected to Wilson coefficients, sensitivity to C7 C9, C10

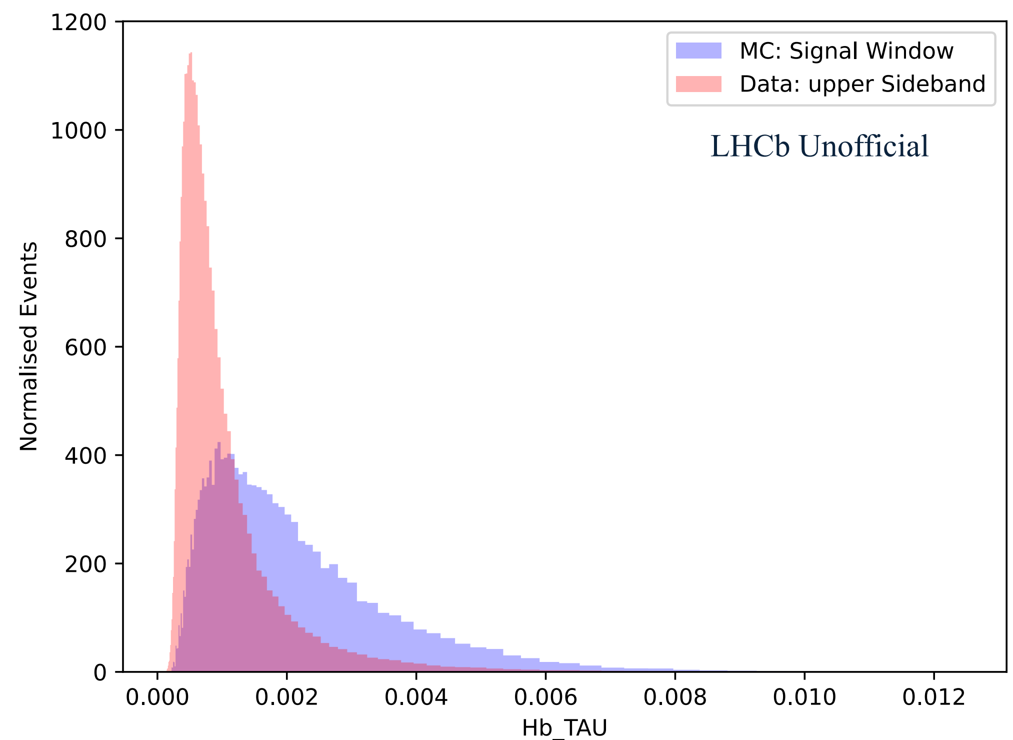


$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell\mathrm{d}\cos\theta_K\mathrm{d}\Phi} = \frac{9}{32\pi}\big[S_1^s\sin^2\theta_K + S_1^c\cos^2\theta_K$$
$$+ S_2^s\sin^2\theta_K\cos 2\theta_\ell + S_2^c\cos^2\theta_K\cos 2\theta_\ell$$
$$+ S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\Phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\Phi$$
$$+ A_5\sin 2\theta_K\sin\theta_\ell\cos\Phi + A_6\sin^2\theta_K\cos\theta_\ell$$
$$+ S_7\sin 2\theta_K\sin\theta_\ell\sin\Phi + A_8\sin 2\theta_K\sin 2\theta_\ell\sin\Phi$$
$$+ A_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\Phi\big]$$

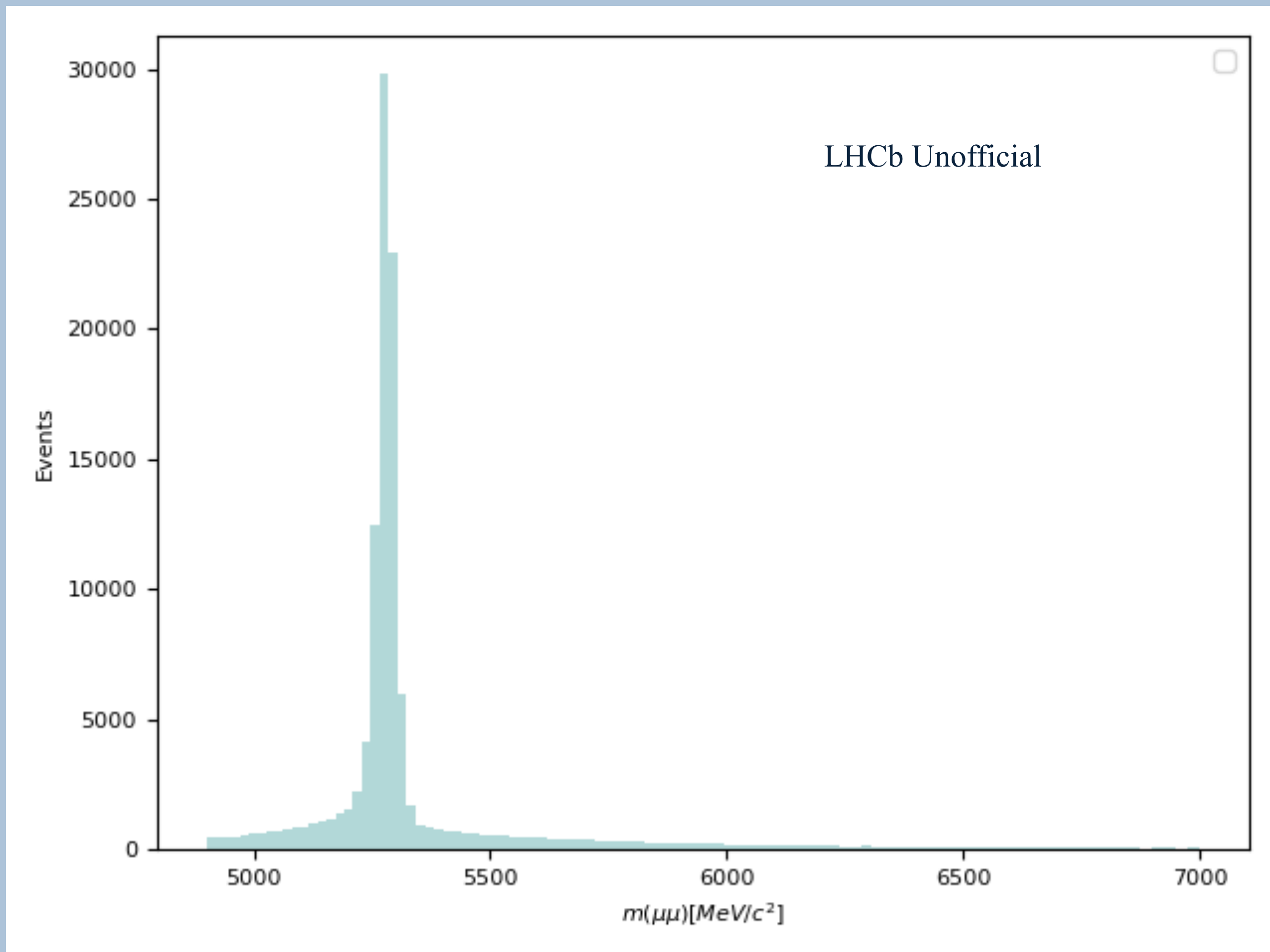
Progress

- Stripping lines
- Pre-selection:
  - J/ψ and $\psi(2s)$ removal
  - Loose requirements on kinematic and topological variables
  - PID requirements



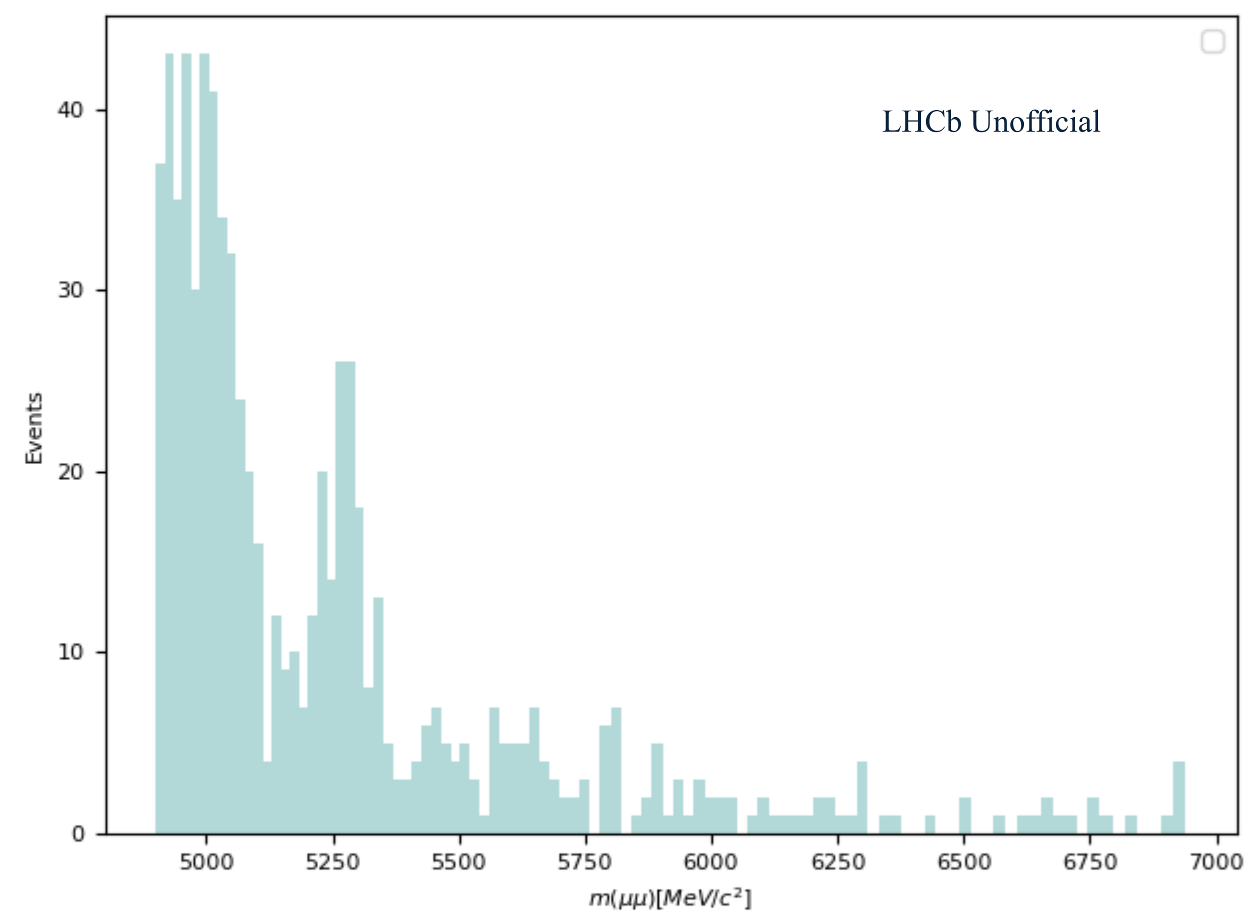


Kinematic and topological variables after pre-selection, plots show discrimination between the MC simulated data and the background, upper sideband, of the LHCb data



Raw Invariant mass distribution of 2018 MC simulated data for control mode,
$B^0(B_s^0) \to \pi\pi\ J/\psi$

Invariant mass distribution of 2018 MC simulated data for control mode,
$B^0(B_s^0) \to \pi\pi\ J/\psi$,
with pre-selection requirements applied

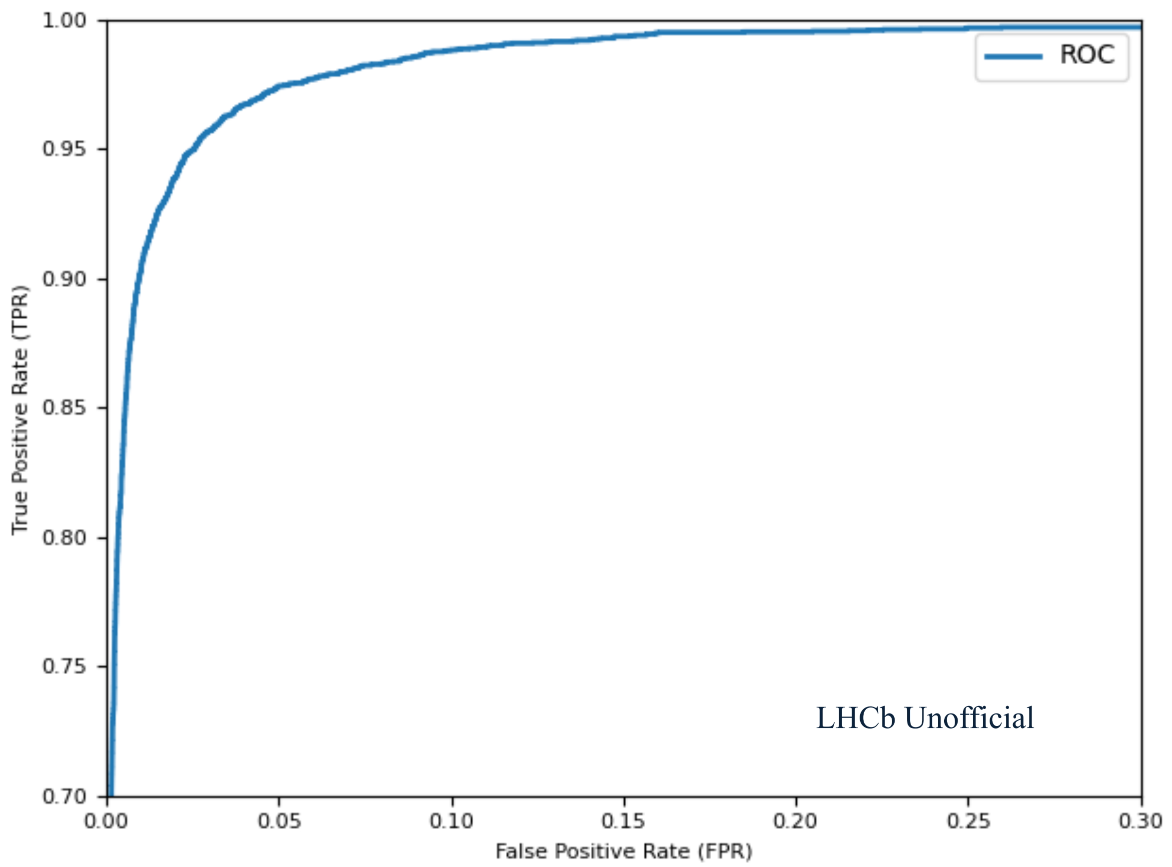


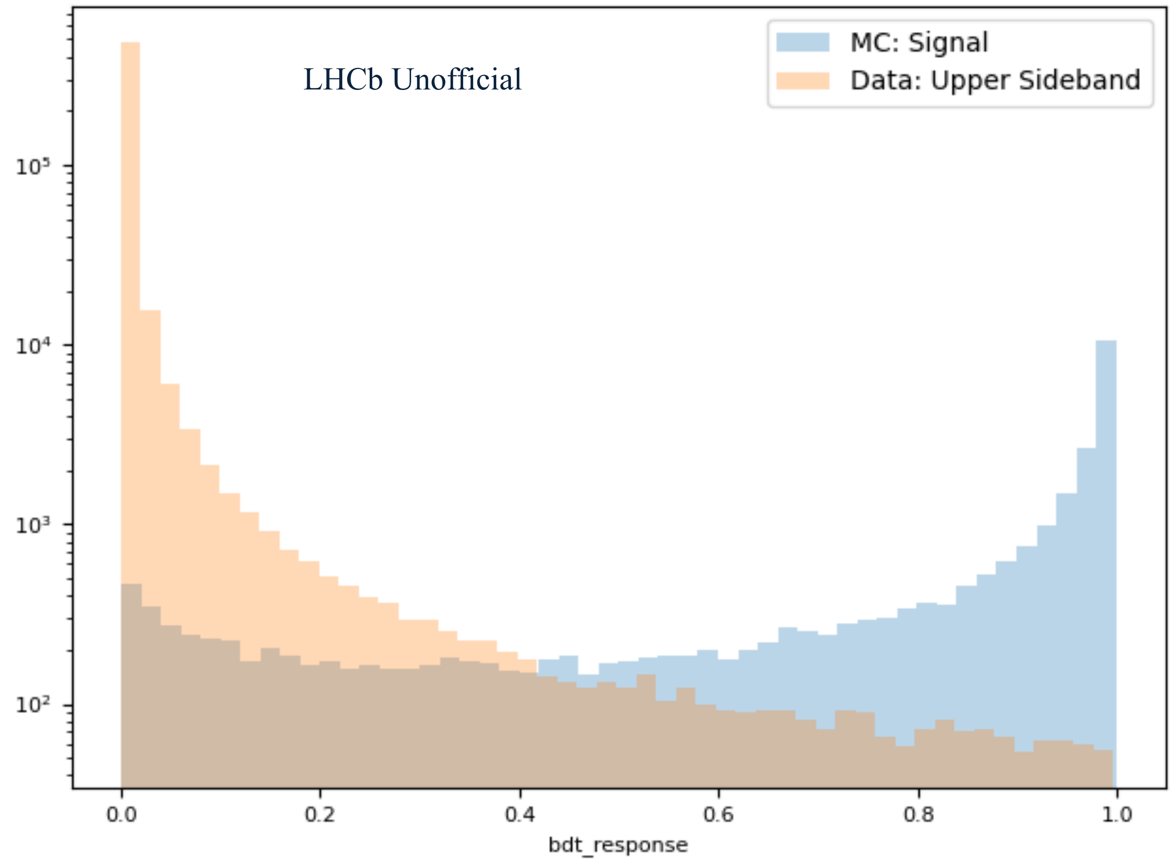
- MVA (XGBoost):
  - MC simulated data as signal
  - LHCb data as background, selecting only upper sideband mass
- K-Folding:
  - The MVA is split into k folds to reduce biasing

Future Steps

- Complete MVA training
- Reweigh MC to match data
- Calculate PID efficiency
- Optimise MVA and selection

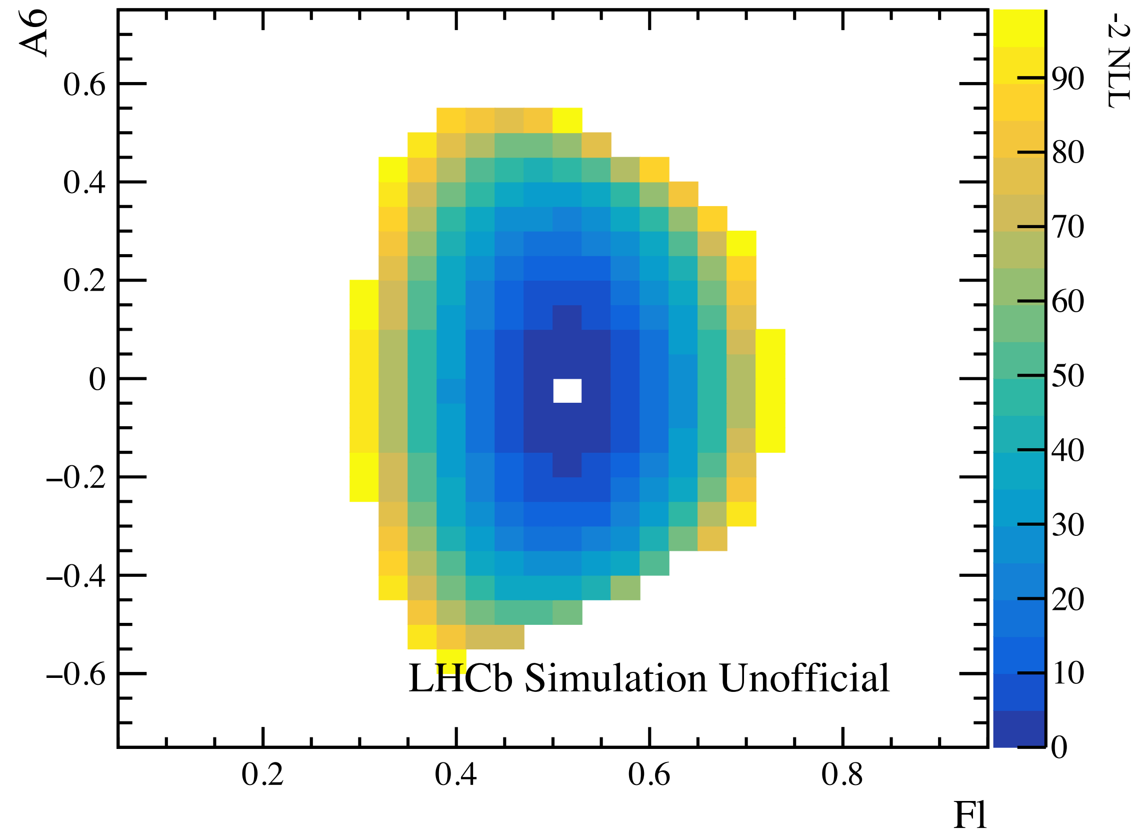
ROC curve produced by the MVA, multiple sets of variables are tested, the set with the highest AUC is chosen





Probability predictions of the MVA which determines the likelihood of an event being signal or background

- Three angles (θ_h, θ_l, ϕ) and invariant mass
- Fitting model pre-determined using toy pseudo-studies
- Perform fit in bins of q^2



2D negative-log likelihood correlation between F_l and A_6 , using simulated, 1000e event, pseudo-studies

Future Steps

- Investigate issues: bugs or is the model too complex?
- Apply to data post-selection

- Pseudo-studies performed using data generated from 3D, P and S wave, angular distribution
- Included mass distribution
- Added backgrounds for each of the four dimensions
- Issues with results (poor performance with low number of events, ~50)

Thanks for listening

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Backup

3D Distribution

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell\mathrm{d}\cos\theta_K\mathrm{d}\Phi} = \frac{9}{32\pi}\Big[S_1^s\sin^2\theta_K + S_1^c\cos^2\theta_K + S_2^s\sin^2\theta_K\cos 2\theta_\ell + S_2^c\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\Phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\Phi + A_5\sin 2\theta_K\sin\theta_\ell\cos\Phi + A_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\Phi + A_8\sin 2\theta_K\sin 2\theta_\ell\sin\Phi + A_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\Phi\Big], \quad (1)$$

1D Projections:

Integrate 3D over two angles

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_K} = \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) + \frac{3}{2}F_\mathrm{L}\cos^2\theta_K$$

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell} = \frac{3}{8}(1-F_\mathrm{L})(1+\cos^2\theta_\ell) + \frac{3}{4}F_\mathrm{L}(1-\cos^2\theta_\ell) + \frac{3}{4}A_6\cos\theta_\ell$$

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\Phi} = \frac{1}{2\pi} + \frac{1}{2\pi}S_3\cos 2\Phi + \frac{1}{2\pi}A_9\sin 2\Phi$$

S-Wave

$$\frac{1}{\mathrm{d}(\Gamma+\bar\Gamma)/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar\Gamma)}{\mathrm{d}q^2\,\mathrm{d}\vec\Omega}\Bigg|_{\mathrm{S+P}} = (1-F_\mathrm{S})\frac{1}{\mathrm{d}(\Gamma+\bar\Gamma)/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar\Gamma)}{\mathrm{d}q^2\,\mathrm{d}\vec\Omega}\Bigg|_{\mathrm{P}} + \frac{3}{16\pi}F_\mathrm{S}\sin^2\theta_l + \frac{9}{32\pi}(S_{11}+S_{13}\cos 2\theta_l)\cos\theta_K + \frac{9}{32\pi}(S_{14}\sin 2\theta_l + S_{15}\sin\theta_l)\sin\theta_K\cos\phi + \frac{9}{32\pi}(S_{16}\sin\theta_l + S_{17}\sin 2\theta_l)\sin\theta_K\sin\phi\,,$$

Obtained from LHCB-PAPER-2013-037, there may be differences in S's and A's naming.

2.1 Measuring P'_4

Applying the transformations:

$$\begin{aligned}\phi &\rightarrow -\phi \text{ (for } \phi < 0)\\ \phi &\rightarrow \pi - \phi \text{ (for } \theta_l > \pi/2)\\ \theta_l &\rightarrow \pi - \theta_l \text{ (for } \theta_l > \pi/2)\end{aligned}$$

These angular transformations ('foldings') are chosen to simplify the pdfs as much as possible, reducing the free parameters in the fit without losing any experimental sensitivity.

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\Big]$$

2.2 Measuring P'_5

Applying the following set of transformations:

$$\begin{aligned}\phi &\rightarrow -\phi \text{ (for } \phi < 0)\\ \theta_l &\rightarrow \pi - \theta_l \text{ (for } \theta_l > \pi/2)\end{aligned}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi\Big]$$

2.3 Measuring P'_7

Starting from Eq. 1 and applying the following set of transformations:

$$\begin{aligned}\phi &\rightarrow \pi - \phi(\phi > \pi/2)\\ \phi &\rightarrow -\pi - \phi(\phi < -\pi/2)\\ \theta_l &\rightarrow \pi - \theta_l(\theta_l > \pi/2)\end{aligned}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi\Big]$$

All include 'nuisance' parameters Fl , S3

2.4 Measuring P'_8

Applying the following transformations:

$$\begin{aligned}\phi &\rightarrow \pi - \phi(\phi > \pi/2)\\ \phi &\rightarrow -\pi - \phi(\phi < -\pi/2)\\ \theta_l &\rightarrow \pi - \theta_l(\theta_l > \pi/2)\\ \theta_K &\rightarrow \pi - \theta_K(\theta_l > \pi/2)\end{aligned}$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{8\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi\Big]$$

$$P_1 = \frac{S_3}{1-F_L}$$
$$P_2 = \frac{S_6}{1-F_L}$$
$$P_3 = \frac{S_9}{1-F_L}$$
$$P'_4 = \frac{S_4}{\sqrt{F_L(1-F_L)}}$$
$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$
$$P'_6 = \frac{S_7}{\sqrt{F_L(1-F_L)}}$$
$$P'_8 = \frac{S_8}{\sqrt{F_L(1-F_L)}}$$

LHCb-ANA-2013-006

$$P'_4,\ S_4: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \phi \to \pi - \phi & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad (3)$$

$$P'_5,\ S_5: \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad (4)$$

$$P'_6,\ S_7: \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2, \end{cases} \quad (5)$$

$$P'_8,\ S_8: \begin{cases} \phi \to \pi - \phi & \text{for } \phi > \pi/2 \\ \phi \to -\pi - \phi & \text{for } \phi < -\pi/2 \\ \theta_K \to \pi - \theta_K & \text{for } \theta_\ell > \pi/2 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2. \end{cases} \quad (6)$$

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Common terms, only P' value differs between 3D P' observable projections

$$\frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \right.$$

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\right].$$

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_5\sin 2\theta_K\sin\theta_\ell\cos\phi\right].$$

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_6\sin 2\theta_K\sin\theta_\ell\sin\phi\right].$$

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \sqrt{F_L(1-F_L)}P'_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi\right].$$

$$\mathcal{P}_{\text{tot}} = f_{\text{sig}}\mathcal{P}_{\text{sig}}(\vec{\Omega}, m) + (1 - f_{\text{sig}})\mathcal{P}_{\text{bkg}}(\vec{\Omega}, m).$$

$$\mathcal{P}_{\text{sig}}(\vec{\Omega}, m) = \mathcal{P}_{\text{sig}}(\vec{\Omega}) \times \mathcal{P}_{\text{sig}}(m)$$
$$\mathcal{P}_{\text{bkg}}(\vec{\Omega}, m) = \mathcal{P}_{\text{bkg}}(\vec{\Omega}) \times \mathcal{P}_{\text{bkg}}(m).$$

$$\mathcal{P}_{\text{bkg}}(\cos\theta_l, \cos\theta_K, \phi) = \left[\sum_{i=0}^{2} c_i T_i(\cos\theta_l)\right] \times \left[\sum_{j=0}^{2} c_j T_j(\cos\theta_K)\right] \times \left[\sum_{k=0}^{2} c_k T_k(\phi)\right]$$

i	I_i	f_i
$1s$	$\frac{3}{4}\left[\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm L}\rvert^2+\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2\right]$	$\sin^2\theta_K$
$1c$	$\lvert\mathcal{A}_0^{\rm L}\rvert^2+\lvert\mathcal{A}_0^{\rm R}\rvert^2$	$\cos^2\theta_K$
$2s$	$\frac{1}{4}\left[\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm L}\rvert^2+\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2\right]$	$\sin^2\theta_K\cos 2\theta_l$
$2c$	$-\lvert\mathcal{A}_0^{\rm L}\rvert^2-\lvert\mathcal{A}_0^{\rm R}\rvert^2$	$\cos^2\theta_K\cos 2\theta_l$
3	$\frac{1}{2}\left[\lvert\mathcal{A}_\perp^{\rm L}\rvert^2-\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2-\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2\right]$	$\sin^2\theta_K\sin^2\theta_l\cos 2\phi$
4	$\sqrt{\frac{1}{2}}\mathrm{Re}(\mathcal{A}_0^{\rm L}\mathcal{A}_\parallel^{\rm L*}+\mathcal{A}_0^{\rm R}\mathcal{A}_\parallel^{\rm R*})$	$\sin 2\theta_K\sin 2\theta_l\cos\phi$
5	$\sqrt{2}\mathrm{Re}(\mathcal{A}_0^{\rm L}\mathcal{A}_\perp^{\rm L*}-\mathcal{A}_0^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin 2\theta_K\sin\theta_l\cos\phi$
$6s$	$2\mathrm{Re}(\mathcal{A}_\parallel^{\rm L}\mathcal{A}_\perp^{\rm L*}-\mathcal{A}_\parallel^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin^2\theta_K\cos\theta_l$
7	$\sqrt{2}\mathrm{Im}(\mathcal{A}_0^{\rm L}\mathcal{A}_\parallel^{\rm L*}-\mathcal{A}_0^{\rm R}\mathcal{A}_\parallel^{\rm R*})$	$\sin 2\theta_K\sin\theta_l\sin\phi$
8	$\sqrt{\frac{1}{2}}\mathrm{Im}(\mathcal{A}_0^{\rm L}\mathcal{A}_\perp^{\rm L*}+\mathcal{A}_0^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin 2\theta_K\sin 2\theta_l\sin\phi$
9	$\mathrm{Im}(\mathcal{A}_\parallel^{\rm L*}\mathcal{A}_\perp^{\rm L}+\mathcal{A}_\parallel^{\rm R*}\mathcal{A}_\perp^{\rm R})$	$\sin^2\theta_K\sin^2\theta_l\sin 2\phi$

10	$\frac{1}{3}\left[\lvert\mathcal{A}_{\rm S}^{\rm L}\rvert^2+\lvert\mathcal{A}_{\rm S}^{\rm R}\rvert^2\right]$	1
11	$\sqrt{\frac{4}{3}}\mathrm{Re}(\mathcal{A}_{\rm S}^{\rm L}\mathcal{A}_0^{\rm L*}+\mathcal{A}_{\rm S}^{\rm R}\mathcal{A}_0^{\rm R*})$	$\cos\theta_K$
12	$-\frac{1}{3}\left[\lvert\mathcal{A}_{\rm S}^{\rm L}\rvert^2+\lvert\mathcal{A}_{\rm S}^{\rm R}\rvert^2\right]$	$\cos 2\theta_l$
13	$-\sqrt{\frac{4}{3}}\mathrm{Re}(\mathcal{A}_{\rm S}^{\rm L}\mathcal{A}_0^{\rm L*}+\mathcal{A}_{\rm S}^{\rm R}\mathcal{A}_0^{\rm R*})$	$\cos\theta_K\cos 2\theta_l$
14	$\sqrt{\frac{2}{3}}\mathrm{Re}(\mathcal{A}_{\rm S}^{\rm L}\mathcal{A}_\parallel^{\rm L*}+\mathcal{A}_{\rm S}^{\rm R}\mathcal{A}_\parallel^{\rm R*})$	$\sin\theta_K\sin 2\theta_l\cos\phi$
15	$\sqrt{\frac{8}{3}}\mathrm{Re}(\mathcal{A}_{\rm S}^{\rm L}\mathcal{A}_\perp^{\rm L*}-\mathcal{A}_{\rm S}^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin\theta_K\sin\theta_l\cos\phi$
16	$\sqrt{\frac{8}{3}}\mathrm{Im}(\mathcal{A}_{\rm S}^{\rm L}\mathcal{A}_\parallel^{\rm L*}-\mathcal{A}_{\rm S}^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin\theta_K\sin\theta_l\sin\phi$
17	$\sqrt{\frac{2}{3}}\mathrm{Im}(\mathcal{A}_{\rm S}^{\rm L}\mathcal{A}_\perp^{\rm L*}+\mathcal{A}_{\rm S}^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin\theta_K\sin 2\theta_l\sin\phi$

$$S_i=(I_i+\bar{I}_i)\Big/\left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}+\frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2}\right)\quad\text{and}$$
$$A_i=(I_i-\bar{I}_i)\Big/\left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}+\frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2}\right).$$

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}=\lvert A_{0,\rm L}\rvert^2+\lvert A_{\parallel,\rm L}\rvert^2+\lvert A_{\perp,\rm L}\rvert^2+\lvert A_{0,\rm R}\rvert^2+\lvert A_{\parallel,\rm R}\rvert^2+\lvert A_{\perp,\rm R}\rvert^2$$

$$F_{\rm S}=\frac{\lvert\mathcal{A}_{\rm S}^{\rm L}\rvert^2+\lvert\mathcal{A}_{\rm S}^{\rm R}\rvert^2}{\lvert\mathcal{A}_{\rm S}^{\rm L}\rvert^2+\lvert\mathcal{A}_{\rm S}^{\rm R}\rvert^2+\lvert\mathcal{A}_0^{\rm L}\rvert^2+\lvert\mathcal{A}_0^{\rm R}\rvert^2+\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2+\lvert\mathcal{A}_\perp^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2}$$

	i	S	A
P	3		✓
	4	✓	
	5		✓
	6		✓
	7	✓	
	8		✓
	9		✓
S	10	✓	
	11		✓
	12	✓	
	13		✓
	14		✓
	15	✓	
	16		✓
	17	✓	

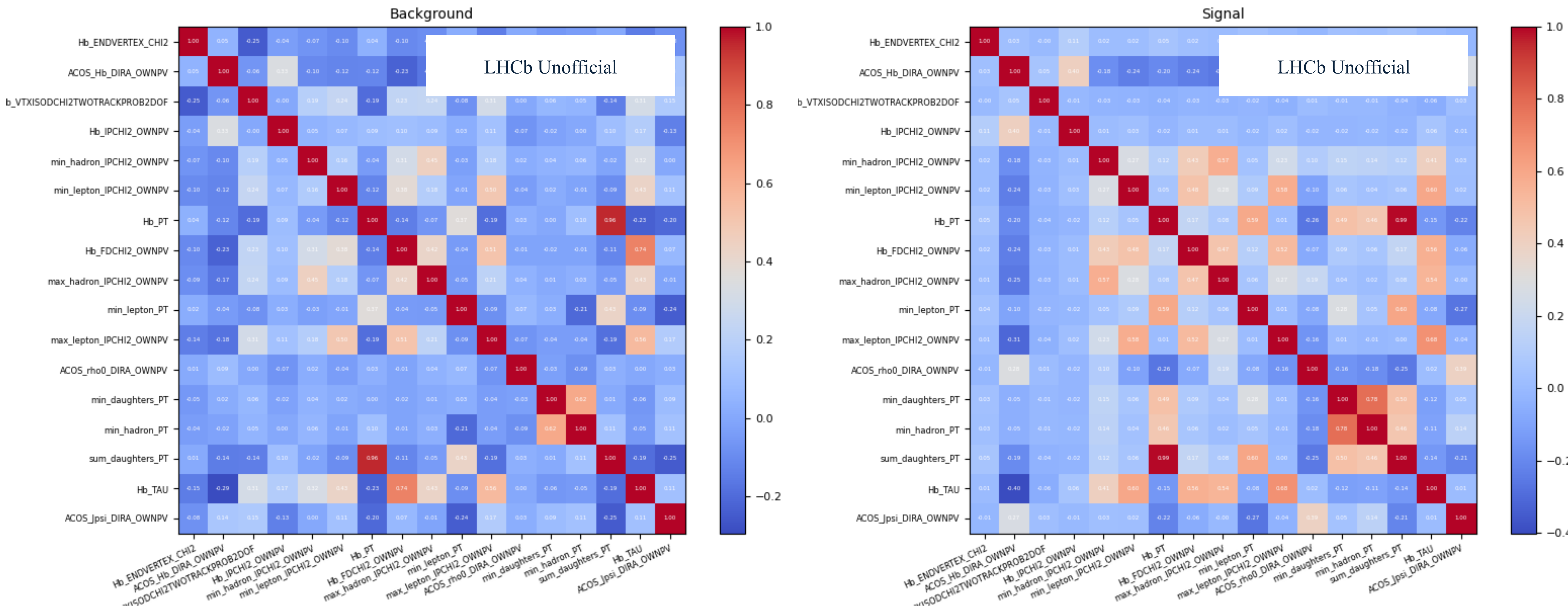
$$A_{\perp}^{L} = a e^{i\delta_{strong}} e^{i\delta_{weak}}$$

$$\bar{A}_{\perp}^{L} = a e^{i\delta_{strong}} e^{-i\delta_{weak}}$$

$$S_i = (I_i + \bar{I}_i) \Big/ \left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} + \frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2} \right) \quad \text{and}$$

$$A_i = (I_i - \bar{I}_i) \Big/ \left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} + \frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2} \right) .$$

28/07/2021



Correlations of the variables used to train the MVA. (a) LHCb data used as the background sample, (b) MC simulated data used as signal

Data / MC Sets

Decay	Physics / Phase-Space	Event Type	Sim Year (Version - Num Evt)					
			2011	2012	2015	2016	2017	2018
$B^0 \to \rho^0\mu^+\mu^-$	Physics	11114022	09b - 2M	09b - 2M	09c - 0.5M	09c - 0.5M	09e - 2M	09h - 0.5M
$B_s^0 \to f_0(980)\mu^+\mu^-$	Phys	13114011	09b - 2M	09b - 2M	09c - 0.5M	09c - 0.5M	09e - 2M	09h - 0.6M
$B^0 \to K^{*0}\mu^+\mu^-$	Phys	11114001	08e - 1M	08b - 0.5M	09c - 1M	09b - 1.4M		
$B^0 \to K^{*0}\mu^+\mu^-$	Phys	11114002	09i - 2M	09i - 4M	09i - 2M	09i - 4M	09i - 4M	09i - 4M
$B^0 \to J/\psi\,\rho^0$	Phys	11144008	08e - 1M	08a - 0.5M	09c - 0.5M	09d - 2.1M	09h - 0.5M	09h - 0.6M
$B_s^0 \to J/\psi\, f_0(980)$	Phys	13144014	09c - 0.5M	08a - 0.5M	09c - 0.5M	09c - 0.5M	09h - 0.5M	09h - 0.5M
$B^0 \to J/\psi K^{*0}$	Phys	11144001	08f - 6M	08f - 8M	09c - 2M	09c - 15.5M	09i - 5M	09i - 5M
$B^0 \to J/\psi K \pi$	Phase Space	11144050	08c - 1.4M	08c - 3M		09h - 1M	09h - 1M	
$B_s^0 \to J/\psi\, \eta'$	Phys	13144201		08a - 1M	09h - 1M	09h - 1M	09h - 5M	09h - 5.4M
$B_s^0 \to J/\psi\, \phi$	Phys	13244410	08i - 1.3M	08i - 1.5M		09d - 2M	09h - 4M	09h - 4M
$B^0 \to \rho^0\mu^+\mu^-$	Phase Space	11114025	09k - 2M	09k - 2M	09k - 2M	09k - 2M	09k - 2M	09k - 2M
$B_s^0 \to f_0(980)\mu^+\mu^-$	Phase Space	13114012	09k - 2M	09k - 2M	09k - 2M	09k - 2M	09k - 2M	09k - 2M