Study of $B^0_{(s)} \to \rho^0 K^{*0}$ decays at the LHCb experiment

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The $B^0_{(s)} \to \rho^0 K^{*0}$ analysis motivation

B-meson to two spin-1 vectors

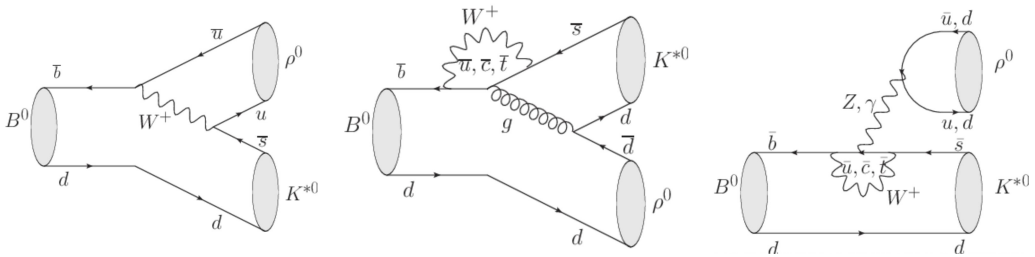
- Decay amplitude is described by a basis of three amplitudes $f_{L,\|,\perp} = \frac{|A_{0,\|,\perp}|^2}{|A_0|^2 + |A_\||^2 + |A_\perp|^2}$

Expectation of predominant longitudinal polarisation (QCDf) violated in measurements of penguin B->VV decays

- LHCb Run 1 analysis: $f_L^{\rho^0 K^{*0}} = 0.164 \pm 0.015(\text{stat.}) \pm 0.022(\text{syst.})$

$B^0_{(s)} \to \rho^0 K^{*0}$ is self-tagging, charge of the kaon tags flavour of the *B*-meson at decay

- Doubly-Cabbibo suppressed tree, also via gluonic, and electroweak penguins
- Penguin-tree interference causes *CP*-violation in the decay



Run 1 analysis: LHCb-PAPER-2018-042

Analysis aims

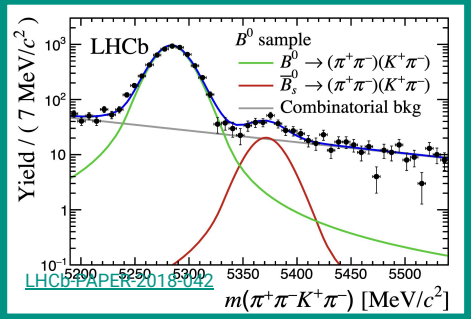
Full Run 1 & Run 2 analysis using LHCb data

Branching fraction measurements

Best measurement on $B^0 \to \rho^0 K^{*0}$ branching fraction: $3.9 \pm 1.3 \times 10^{-6}$ (PDG)

First observation of $B_s^0 \to \rho^0 \bar{K}^{*0}$

Run 1 LHCb analysis focussed purely on the angular analysis - **no previous LHCb measurement** on the branching fractions

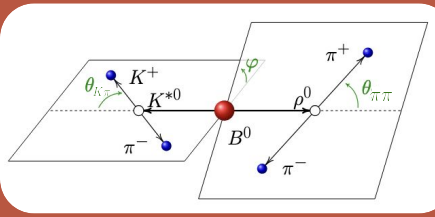


Amplitude Analysis

Perform **5-dimensional amplitude analysis** of $B^0 \to (\pi^+\pi^-)(K^+\pi^-)$

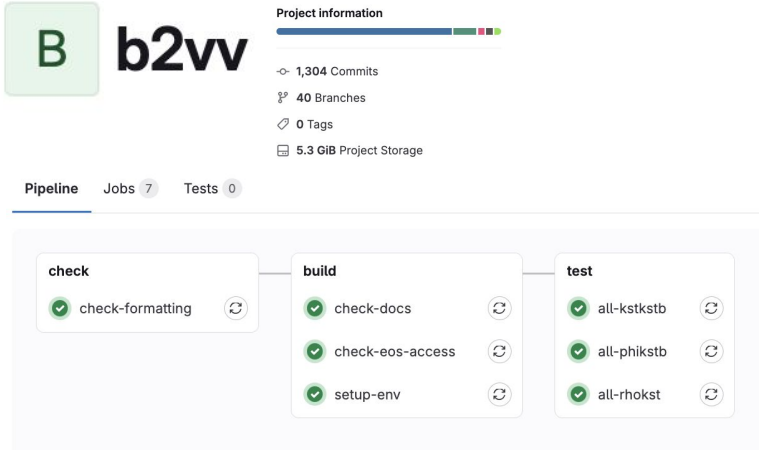
Measure ***CP* averages** and **asymmetries** of the **magnitudes and phase differences** for contributing **amplitudes**

An update on the LHCb Run 1 analysis result



Analysis software developments

- Analysis supported by **python package** designed for **full selection of events** & **efficiencies computation**
- Full analysis pipeline is **mode-independent** across Charmless B->VV decays
    - **CI-tested** across multiple decay modes



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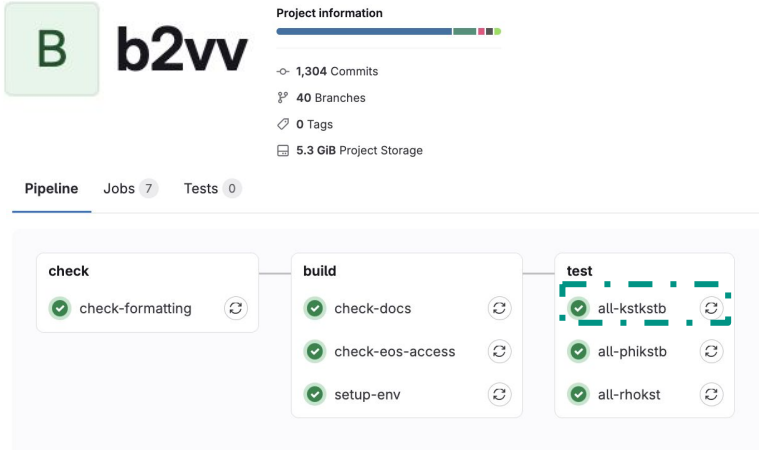

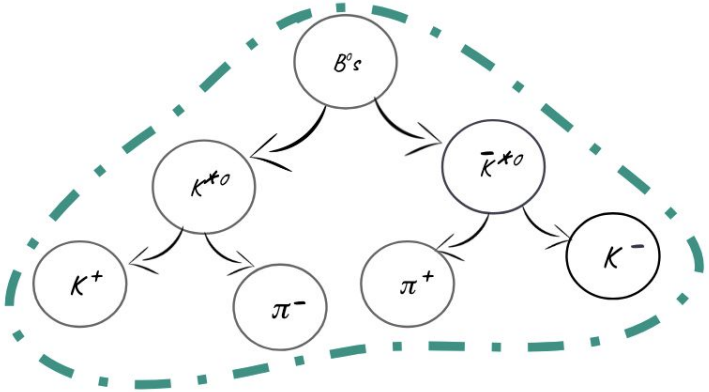

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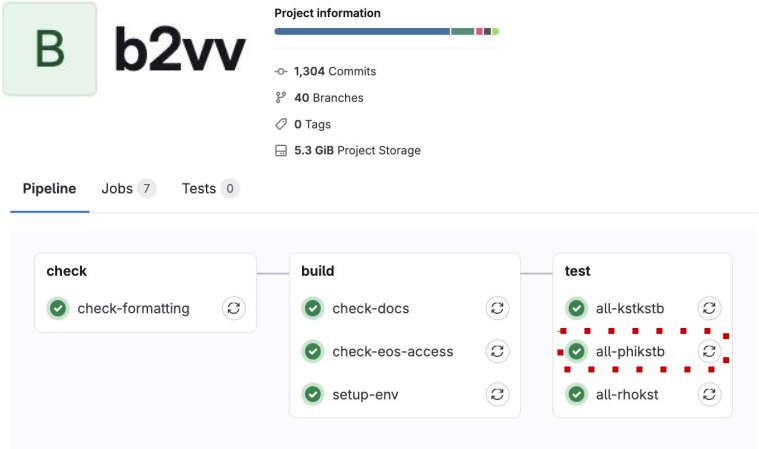

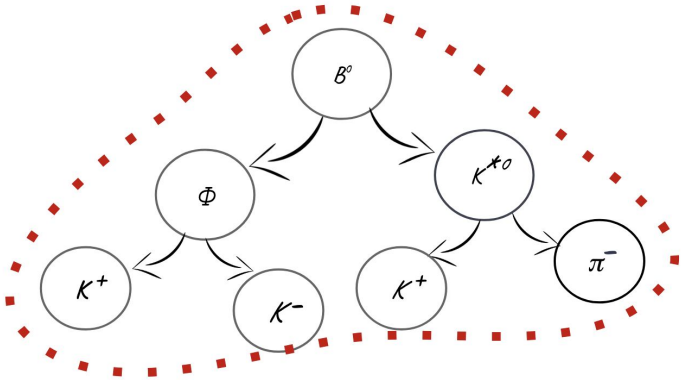

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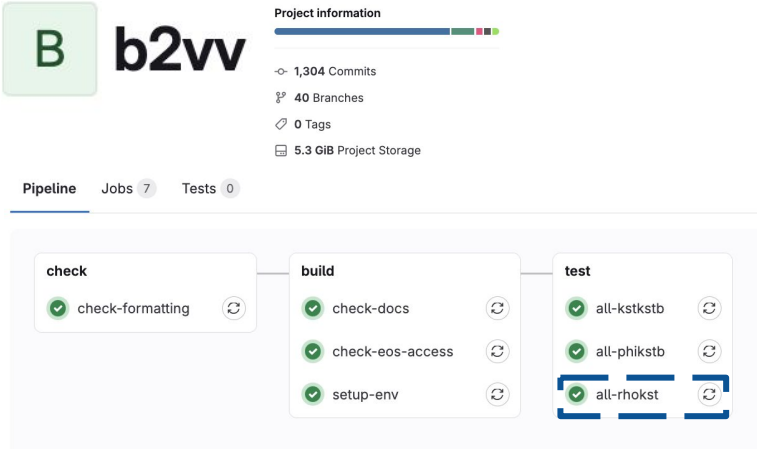
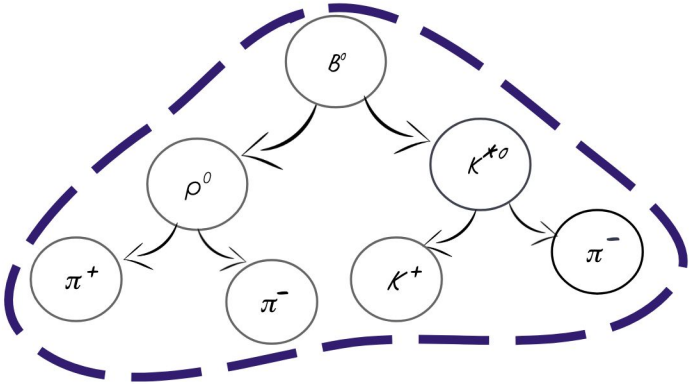
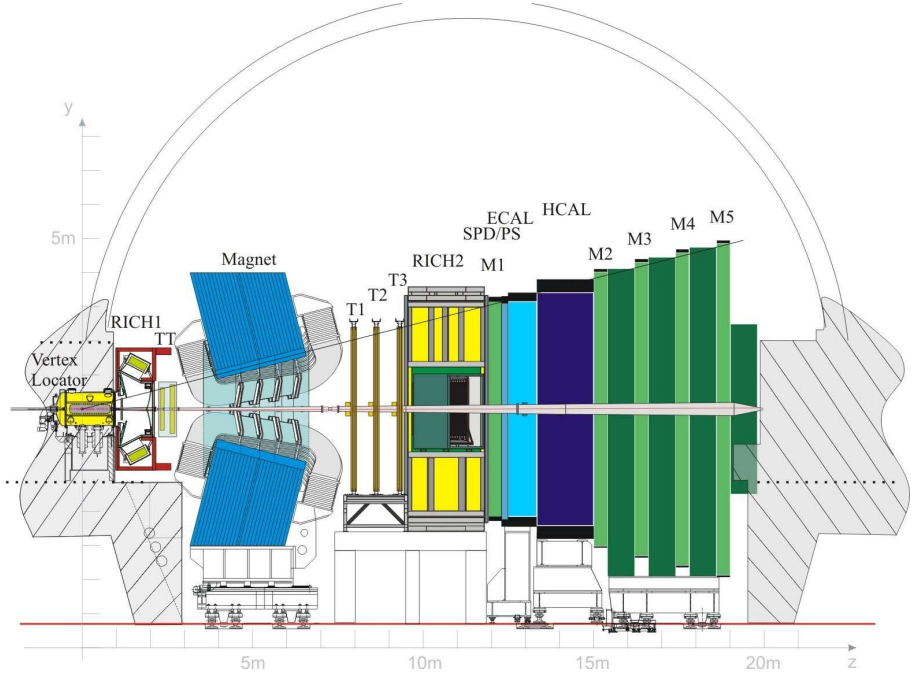




The LHCb experiment

- Full LHCb **Run 1 & Run 2 dataset**, totals an integrated luminosity of 9 fb^{-1} of *pp* collisions
  - Abundance of B^0 and B_s^0 mesons
- **Vertexing information** allows identification of **displaced vertices** from *B*-meson decays
- **Excellent particle identification** (PID) information from RICH systems - easily separate **charged final state hadrons, p-K-pi**
- **Good momentum resolution** from tracking allows to distinguish B^0 and B_s^0 peaks in invariant mass



Candidate selection & simulation corrections

Trigger

Separate categories at **hardware trigger stage**:
Trigger on signal (TOS)
vs
Trigger independent of signal (TIS)
High level trigger requirements on decay topology

Pre-selections

$m_{\pi\pi}$: 300 - 1200 MeV

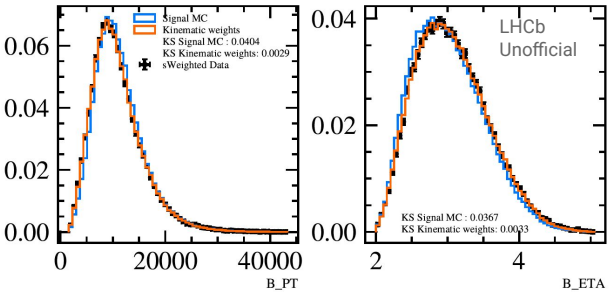
$m_{K\pi}$: ± 300 MeV K*(892)

Requires **displaced secondary vertex** & **high p_T tracks**

Kinematic corrections

Kinematics of *B*-meson in simulation corrected using **sWeighted data** as target

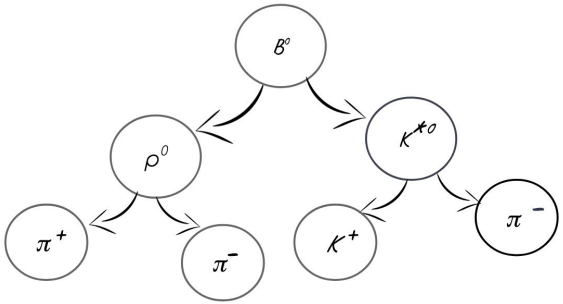
Separate weights derived for exclusive trigger categories



PID corrections

PID variables in simulation **poorly modelled**

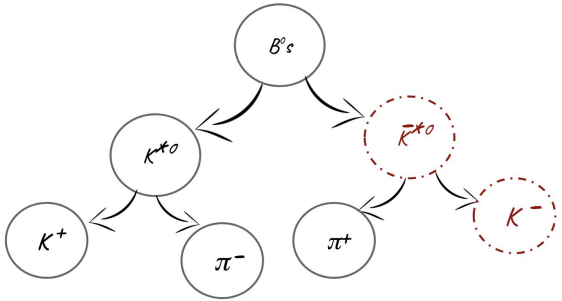
PID variables corrected using dedicated samples of calibration data



Control over backgrounds

Mis-identified background

Mis-identified final state hadrons from p/K/pi swaps are controlled with **PID requirements**



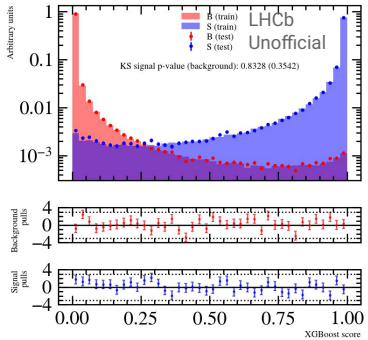
Key background : $B^0_s \to K^{*0}\overline{K}^{*0}$

From pi-K swap

Occupies invariant mass region between signal decay modes

Combinatorial background

Controlled by **BDT** trained on decay topology, kinematics and isolation information



XGBoost BDT

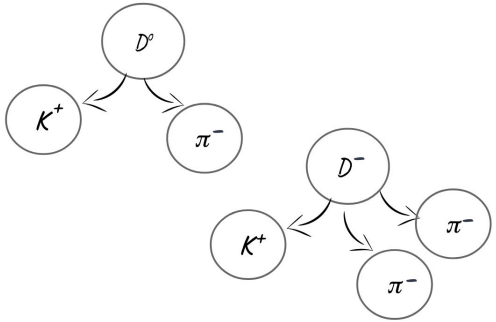
5 k-folds

Hyper-parameters optimised using optuna package

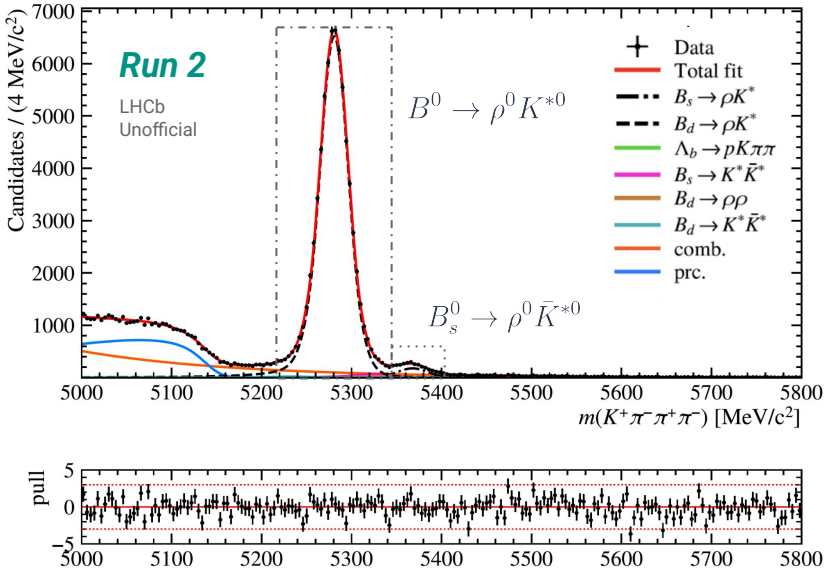
Charm contaminations

Dedicated **vetoes in the invariant mass** of 2/3 body combinations

Acceptance effects of these cuts needs to be carefully modelled



Candidate selected fits



Total yield

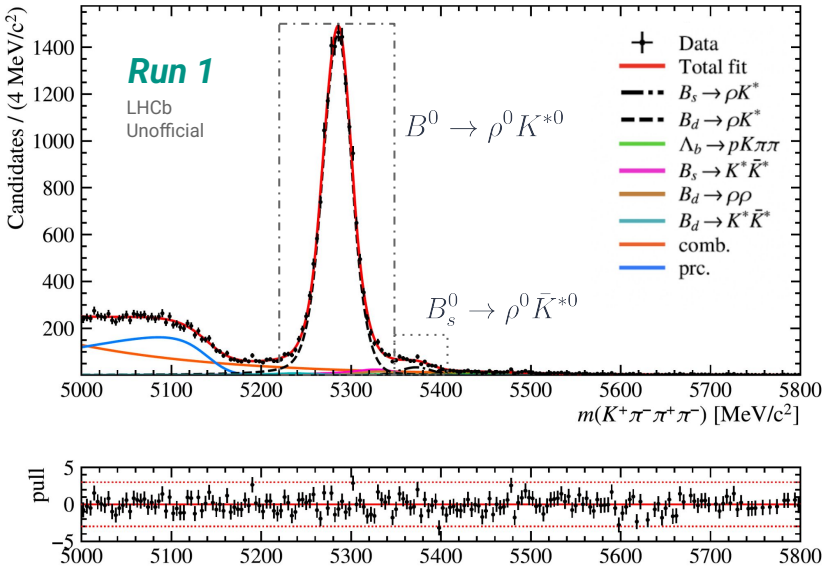
$B^0 \to \rho^0 K^{*0}$	$B_s^0 \to \rho^0 \bar{K}^{*0}$
~85,000	~2,000

Signal significance

$B^0 \to \rho^0 K^{*0}$	$B_s^0 \to \rho^0 \bar{K}^{*0}$
Run 1: 119	Run 1: 9
Run 2 : 250	Run 2 : 25

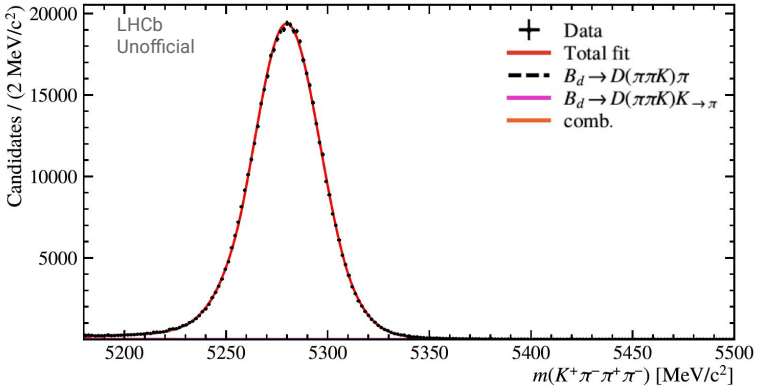
- BDT score & PID selection cuts optimised simultaneously for signal significance

$$significance = \frac{S}{\sqrt{S+B}}$$



Branching fraction measurements

- Use as **normalisation mode** $B^0_{(s)} \to D^-_{(s)}\pi^+$
  - $D_{(s)} \to \pi\pi K$ **same final state** to limit systematic uncertainties
  - Clean high stats mode - allow for precise measurement of the signal branching fractions
  - **Dedicated BDT and corrections** owing to differing kinematics

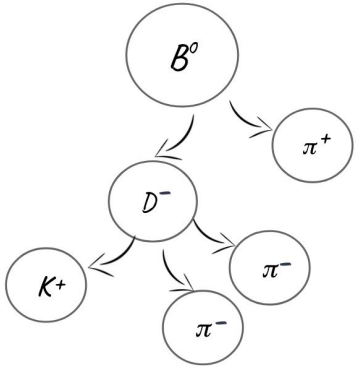


Signal candidates from mass fit needs to consider f_{VV} from amplitude fit

$$\mathcal{B}(sig) = \frac{N_{sig}}{N_{norm}} \frac{\epsilon_{norm}}{\epsilon_{sig}} \mathcal{B}(norm)$$

Well measured branching fraction

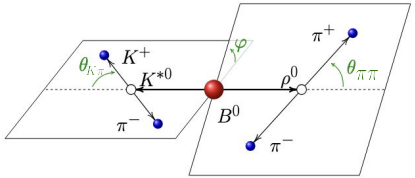
Efficiencies derived from corrected simulation



Amplitude fits of $B^0 \to (\pi^+\pi^-)(K^+\pi^-)$

- Fits to selected data samples in the signal region
- Combinatorial background modelled using the *B* mass sidebands

Angular fits to the variables
$m(V_1), m(V_2), \cos(\theta_1), \cos(\theta_2), \phi$

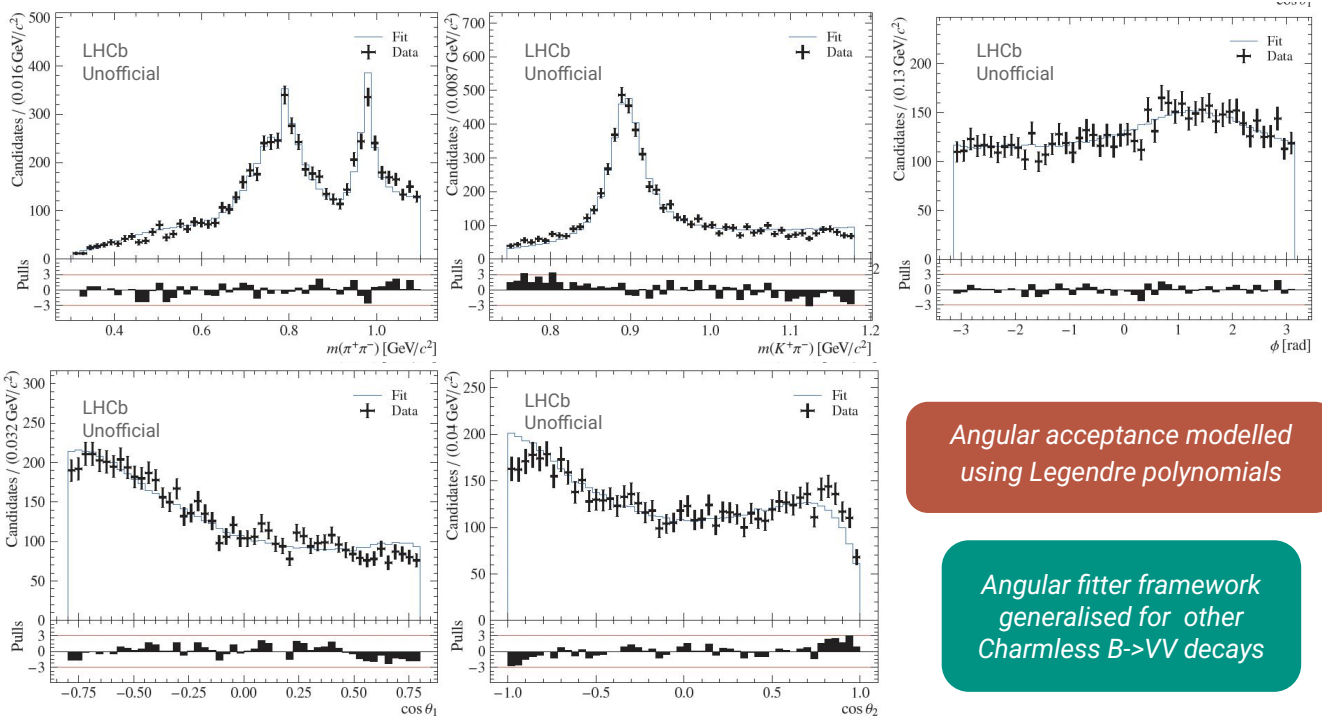


$\pi^+\pi^-$
$\rho(770)$
ω
$f_0(500)$
$f_0(980)$
$f_0(1370)$

$K^+\pi^-$
$K*(892)$
$K^+\pi^-_{S-wave}$

14 contributing terms

Run 1, B^0



Angular acceptance modelled using Legendre polynomials

Angular fitter framework generalised for other Charmless B->VV decays

Summary

- Event selection is well advanced with abundant yield of signal candidates
- Branching fraction measurements are progressing and inclusive measurements will be finalised soon
- Development of angular fitter is ongoing
  - Preliminary amplitude fits show promise
  - Collaboration with Peking university on developing amplitude fits
- Software packages developed for this analysis provide useful generalisation and support for other ongoing (and future planned) analyses of Charmless B->VV decays

Thanks for listening!

Backup

Detailed summary of the selection for $B^0_{(s)} \to \rho^0 K^{*0}$

Full Run 1 & Run 2 dataset

- B2KsthhLine used for stripping
  - $m_{\pi\pi}$ mass range of 300-1200 MeV

MC is re-stripped to remove any PID cuts & PID variables are corrected using PIDGen2 (equivalent to PIDCorr)

Mass vetoes for *D* meson decays

4D optimisation of the chosen FOM for the combinatorial BDT cut & PID selection working point

- Separate selection for exclusive hTOS & TIS samples

Trigger

	Trigger lines
L0	L0_HadronDecision_TOS or L0HadronDecision_TIS or L0MuonDecision_TIS or L0DiMuonDecision_TIS or L0ElectronDecision_TIS or L0PhotonDecision_TIS
HLT1	and Hlt1TrackAllL0Decision_TOS or Hlt1TrackMVADecision_TOS or Hlt1TwoTrackMVADecision_TOS
HLT2	and Hlt2Topo2BodyBBDTDecision_TOS or Hlt2Topo3BodyBBDTDecision_TOS or Hlt2Topo4BodyBBDTDecision_TOS or Hlt2Topo2BodyDecision_TOS or Hlt2Topo3BodyDecision_TOS or Hlt2Topo4BodyDecision_TOS

Pre-selection

Variable	Cut
allTracks_p	< 100 GeV
allTracks_isMuon	$== 0$
allTracks_GhostProb	< 0.3
B_IPCHI2_OWNPV	> 0
B_IP_OWNPV	< 0.2 mm
B_FDCHI2_OWNPV	> 0
B_FD_OWNPV	< 100 mm
Kst_IPCHI2_OWNPV	> 0
Rho_IPCHI2_OWNPV	> 0
nLongTracks	< 250
CosThetaClone	< 0.9999998
k1_PIDK	> -5
$\lvert M(K^\pm\pi^\mp_\rho) - M_{D^0,\mathrm{PDG}}\rvert$	> 30 MeV
$\lvert M(K^\pm\pi^\mp\pi^\mp_\rho) - M_{D^\mp,\mathrm{PDG}}\rvert$	> 40 MeV

PID & BDT selection

$B^0 \to (p_1^+p_2^-)(k_1^+p_3^-)$	
Variable	Definition
min_pi_ProbNN	Min(πs ProbNNpi*(1-ProbNNk))
k1_ProbNN	Min(Ks ProbNNk*(1-ProbNNpi))
max_ProbNNp	Max($p2, p3$s ProbNNp))
optimBDT	Optimised combinatorial BDT score