The University of Manchester

Charmless B meson decays $B_{(s)} \to p\bar{p}hh^{(\prime)}$ at LHCb

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on behalf of the LHCb collaboration

21 March 2016

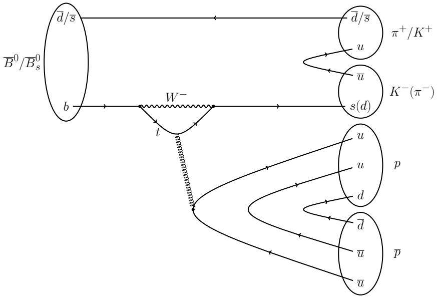
Overview

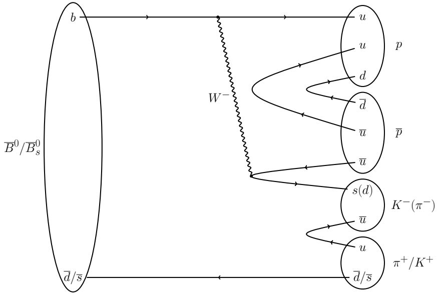
Introduction

- Very little is known about charmless baryonic B decays in general and $B_{(s)} \to p\bar{p}hh^{(\prime)}$ in particular
- In the PDG only:
  - $\mathcal{B}(B \to p\bar{p}K^{*0}(892)) = (1.24^{+0.28}_{-0.25}) \cdot 10^{-6}$
  - $\mathcal{B}(B \to p\bar{p}\pi\pi) < 2.5 \cdot 10^{-4} \quad \mathrm{CL} = 90\%$
- Little known also about baryonic B_s decays
  - Evidence for $\overline{B}{}^0_s \to \Lambda_c^+ \overline{\Lambda} \pi^-$ at Belle
- Aim is to measure the inclusive branching fractions of $B_{(s)} \to p\bar{p}hh^{(\prime)}$ excluding the charm resonances (η_c, J/ψ, $\psi(2S)$, D^0, Λ_c, ...)
- With the 3 fb^{-1} Run I LHCb dataset possible to measure branching fractions or to set World's best upper limits
- Analysis still ongoing

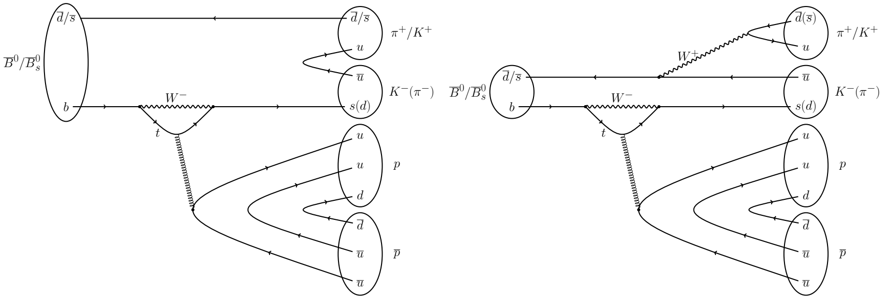
Theoretical overview

- Challenging to predict these branching fractions due to soft QCD
- No literature targeted these modes yet
- Possible to draw a few Feynman diagrams and do some naive considerations





Theoretical overview



Looking at CKM matrix elements can roughly expect the hierarchy:

$$\mathcal{B}(B \to p\overline{p}K^+\pi^-) > \mathcal{B}(B \to p\overline{p}\pi^+\pi^-) > \mathcal{B}(B \to p\overline{p}K^+K^-)$$

$$\mathcal{B}(B_s \to p\overline{p}K^+K^-) > \mathcal{B}(B_s \to p\overline{p}K^-\pi^+) > \mathcal{B}(B_s \to p\overline{p}\pi^+\pi^-)$$

LHCb

Acceptance: $2 < \eta < 5$
$\sim 1/4$ of produced $b\bar{b}$ pairs.

Decay time resolution ~ 45 fs

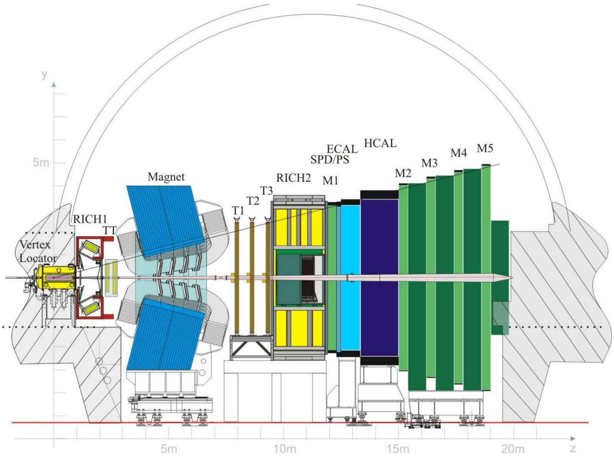
IP resolution $\sim 20\mu m$

Vertex resolution $\sim 13\ \mu$m in $x\ y$ (25 tracks)

$\Delta p/p \sim 0.5 - 1.0\%$

$\varepsilon(\mu) \sim 97\%$,
$misID(\pi \to \mu) \sim 1 - 3\%$

$\varepsilon(K) \sim 95\%$,
$misID(\pi \to K) \sim 5\%$



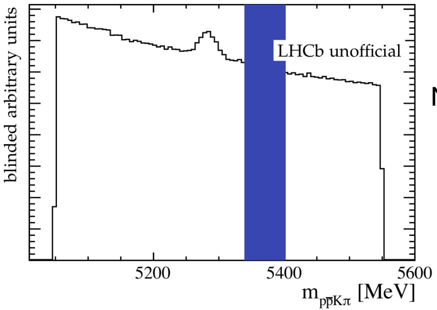
Analysis strategy

- Reconstruct and select $B^0_{(s)} \to p\bar{p}hh^{(\prime)}$ candidates
- Use as a normalisation mode $B \to (J/\Psi \to p\bar{p})(K^* \to K^+\pi^-)$
- Exclude charmonium and open charm mesons and baryons from the signal only as last step
- Same reconstruction and selection for signal and normalisation mode up to the charm vetoes to reduce systematic uncertainties
- Compute branching fractions as:

$$\frac{\mathcal{B}(B^0_{(s)} \to p\bar{p}hh^{(\prime)})}{\mathcal{B}_{\rm vis}(B \to J/\Psi K^*)} = \frac{N(B^0_{(s)} \to p\bar{p}hh^{(\prime)}) \cdot \varepsilon(B \to J/\Psi K^*)}{N(B \to J/\Psi K^*) \cdot \varepsilon(B^0_{(s)} \to p\bar{p}hh^{(\prime)})} \left(\times \frac{f_d}{f_s}\right)$$

Trigger and stripping

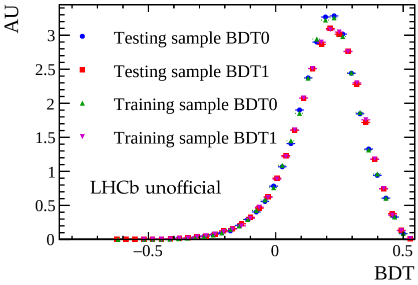
- Select candidates in the trigger exploiting presence of hadrons in the final state and the topology of the multibody decay
- In the first cut based selection (stripping):
  - Fiducial cuts on final state particles
  - Final state particles not coming from a primary vertex but all from the same secondary vertex
  - $B^0_{(s)}$ candidate in the right mass range

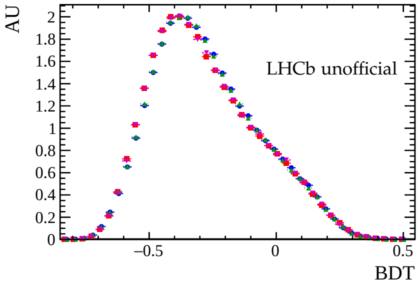


No charm veto applied
+
B_s region blinded

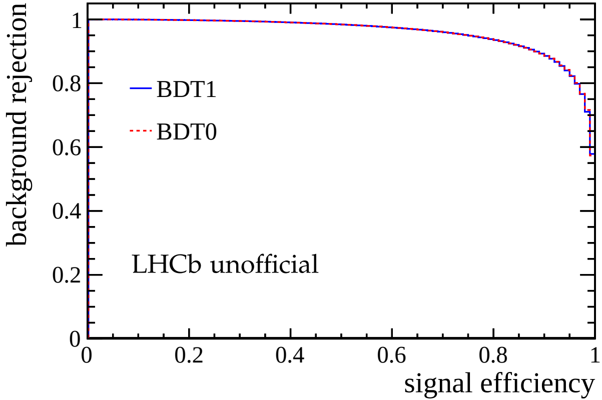
Multivariate selection

- BDT with topological and kinematical variables trained on signal MC (all $B^0_{(s)} \to p\bar{p}hh^{(\prime)}$ modes) and data upper sideband
- Signal and background divided in two independent samples
- Train BDT on one, test and apply on the other





Multivariate selection

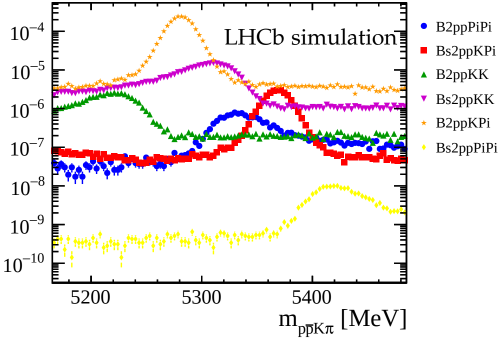


More than 85% background rejection with signal efficiency of 90%

Selection optimisation

- Maximize at the same time for cut on BDT output and Particle identification variables (to select protons and to distinguish between pions and kaons)
- Two kind of background to consider:
  - continuum combinatorial background
  - misID background (signal but in the wrong mass spectrum, peaks just under the signal peak)

Under the main peak there are both misID background and signal, its initial ratio (*f*) is an input of the procedure and a reasonable value can be guesstimated



Selection optimisation

- With very loose cuts, use simple fit (signal Gaussian + linear combinatorial background) to obtain g, initial ratio between background events under the peak and events in the peak
- Use MC to evaluate efficiencies of signal and misID background
- Fit sidebands to estimate efficiency background
- Use as significance:

$$Sig = \frac{\varepsilon_S}{\sqrt{\varepsilon_S + f \cdot \frac{\varepsilon_{M0}}{\varepsilon_{S0}} \cdot \varepsilon_M + g \cdot \frac{\varepsilon_{S0} + f \cdot \varepsilon_{M0}}{\varepsilon_{S0}} \cdot \varepsilon_B}}$$

Fit strategy

- From MC obtain shape of signal and misID background
- First fit before veto on charm components
- Simultaneous fit to the 3 final states, in each one:
  - B and B_s signal peaks,
  - misID component, yield constrained from efficiencies
  - Combinatorial background
- Subtract background (sPlots) to see charmonium resonances and open charms mesons and baryons
- Veto charm components and fit again

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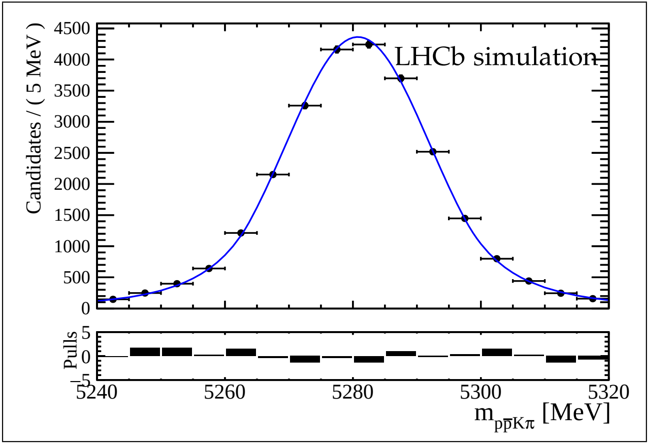

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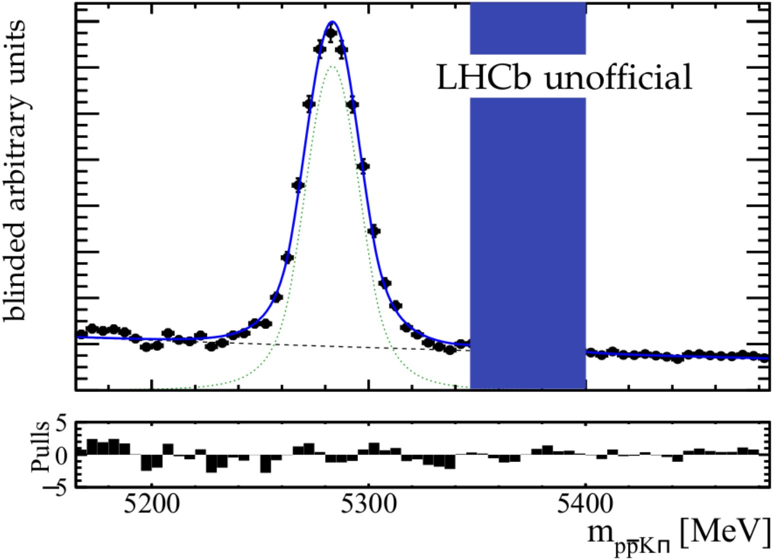

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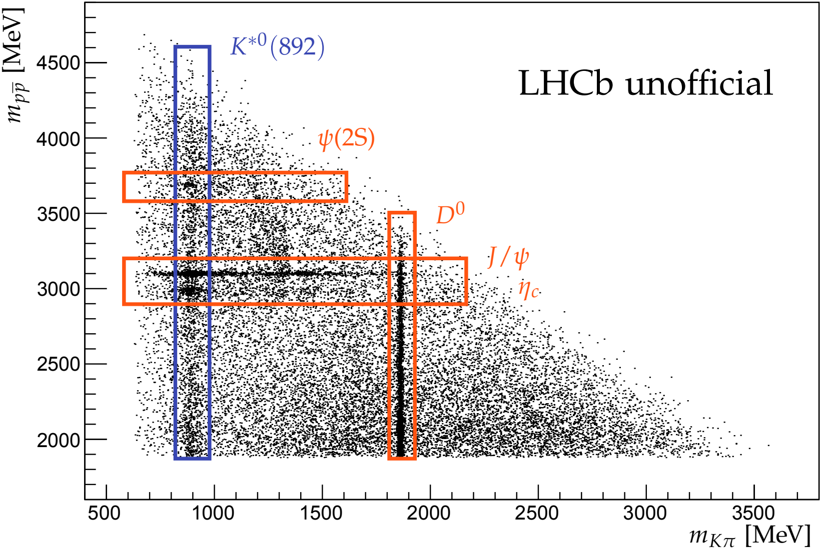

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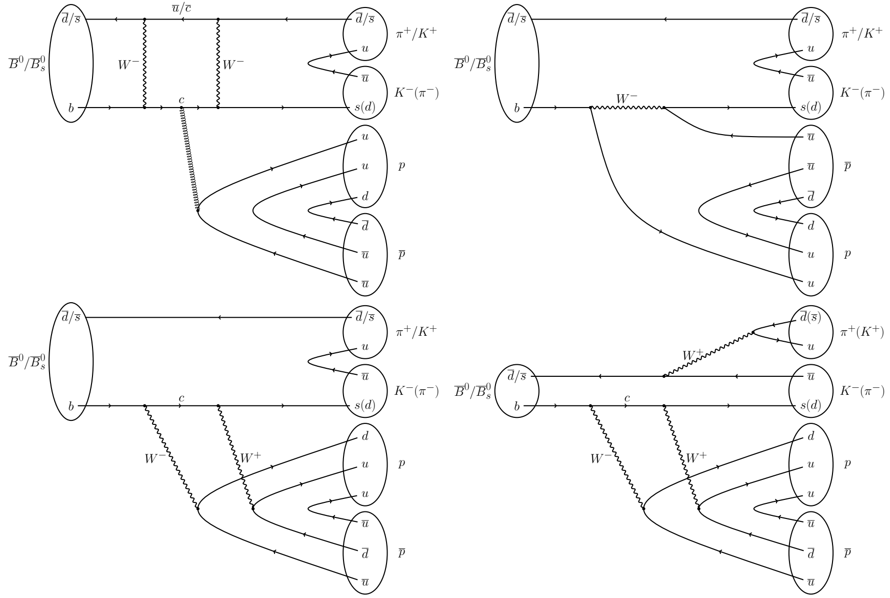
Conclusion

- Measurement of the branching fractions of the charmless baryonic decays $B_{(s)} \to p\bar{p}hh^{(\prime)}$ in advanced status
- In 6 decay modes either:
  - Make first observation
  - Set World's best upper limit
- Potential for first observation of a baryonic B_s decay

BACKUP

Feynman diagrams



Stripping selection

PION SELECTION	
Track fit χ^2/ndof	< 3
Has RICH informations	True
p	> 1500 MeV
p_T	> 300 MeV
Track impact parameter divided by its error	> 6
Track ghost probability	< 0.35
`ProbNNpi`	> 0.05

KAON SELECTION	
Track fit χ^2/ndof	< 3
Has RICH informations	True
p	> 1500 MeV
p_T	> 300 MeV
Track impact parameter divided by its error	> 4
Track ghost probability	< 0.35
`ProbNNk`	> 0.05

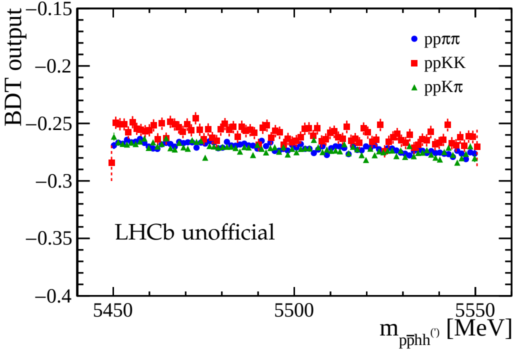
Stripping selection

PROTON SELECTION	
Track fit χ^2/ndof	< 3
Has RICH information	True
p	> 1500 MeV
p_T	> 300 MeV
Track impact parameter divided by its error	> 2
Track ghost probability	< 0.35
`ProbNNp`	> 0.05
$p\bar{p}$ SELECTION	
$m_{p\bar{p}}$	< 4700 MeV ($p\bar{p}KK$) < 5000 MeV ($p\bar{p}K\pi$) < 5350 MeV ($p\bar{p}\pi\pi$)
Sum p	> 7 GeV
Sum p_T	> 750 MeV
Max p	> 4 GeV
Max p_T	> 400 MeV
Product `ProbNNp`	> 0.05

Stripping selection

$B^0_{(s)}$ SELECTION	
Mass	$\in [5050, 5550]$ MeV
Vertex fit χ^2	< 30
Sum p_T of daughters	> 3000 MeV
p_T	> 1000 MeV
Particle trajectory minimum distance from a primary vertex	< 0.2 mm
Distance of closest approach between any two daughters divided by its error	< 20
Cosine of the angle between the particle momentum and its direction of flight	> 0.9999

Multivariate selection



No strong correlation between BDT output and mass

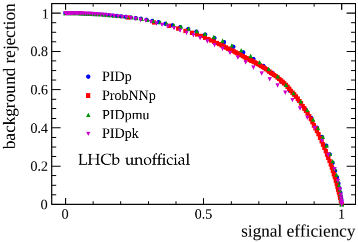
No significant benefit in having a different BDT per

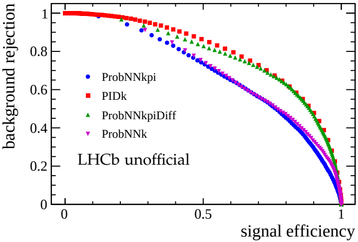
- year of data taking
- final state

Particle identification

In LHCb various variables can be used to discriminate between different particles

- Log likelihood difference between two different mass hypotheses for the same particle based on the RICH reconstruction (eg. `PIDk`)
- Neural network putting together information from RICH and the rest of the detector (tracker, muon chambers ...) (eg. `ProbNNp`)





Chosen

- `PIDk` to distinguish between pions and kaons, nice property that the same particle cannot be selected as kaon and pion at the same time
- `ProbNNp` to select protons

selection optimisation

Mode	Signal	misID	f	BDTCut	pCut	KCut	piCut
$p\bar{p}KK$	$B_s \to p\bar{p}KK$	$B \to p\bar{p}K\pi$	f_d/f_s	0.1	0.45	5	-
$p\bar{p}K\pi$	$B \to p\bar{p}K\pi$	$B_s \to p\bar{p}KK$	f_s/f_d	0.05	0.35	3	-0.5
$p\bar{p}\pi\pi$	$B \to p\bar{p}\pi\pi$	$B \to p\bar{p}K\pi$	$(\sin^2\theta_c)/5$	0.15	0.5	-	-0.5
Initial loose cuts				0	0.1	0.1	-0.1

$f_d/f_s = 3.86$ from LHCb-CONF-2013-011

$\sin^2(\theta_{\text{Cabibbo}}) \sim 0.05$

- `BDT > BDTCut`
- for p and $\bar{p}$ `ProbNNp > pCut`
- for K `PIDK > KCut`
- for π `PIDK < piCut`

Fit strategy

- First fit before veto on charm components
- Fit MC with double sided crystal ball function to get the shape for:
  - Signal (B and B_s)
  - Main mis-ID component
- Simultaneous fit to the 3 final states, in each one:
  - B and B_s signal peaks,
    - m_B free but common to all 3 final states, $m_{B_s} - m_B$ fixed at PDG value
    - Only one σ_B and one σ_{B_s} free, ratio between final states fixed from MC
    - Tail parameters fixed to MC values
  - Mis-ID component,
    - Shape fixed from MC
    - Yield fixed from efficiencies
  - Background parameterised with an exponential function
- Subtract background (sPlots) to see charmonium resonances and open charms mesons and baryons
- Veto charm components and fit again

Charm veto

- no Charmonium: $m_{p\bar{p}} < 2850$ MeV
- no D^0: veto ± 40 MeV from D^0 mass ($1825 < m_{K\pi} < 1905$ MeV)
- no Λ_c: veto ± 25 MeV from Λ_c mass ($2261 < m_{\bar{p}K\pi} < 2311$ MeV)