

Search for rare baryonic decays of beauty hadrons at LHCb



Simon Akar
on behalf of the LHCb Collaboration





Physics landscape

- **Dynamics of B -meson baryonic decays are not well understood**
- **Interesting patterns in rates with or without $p\bar{p}$ pairs in final state**

$$- \mathcal{B}(B^0 \rightarrow \pi^+\pi^-) = (5.1 \pm 0.2) \times 10^{-6} \quad \sim \quad \mathcal{B}(B^0 \rightarrow p\bar{p} \pi^+\pi^-) = (2.9 \pm 0.2) \times 10^{-6}$$

$$- \mathcal{B}(B^0 \rightarrow K^+\pi^-) = (2.0 \pm 0.1) \times 10^{-5} \quad \sim \quad \mathcal{B}(B^0 \rightarrow p\bar{p} K^+\pi^-) = (6.3 \pm 0.5) \times 10^{-6}$$

$$- \mathcal{B}(B^0 \rightarrow K^+K^-) = (7.8 \pm 0.5) \times 10^{-8} \quad < \quad \mathcal{B}(B^0 \rightarrow p\bar{p} K^+K^-) = (1.2 \pm 0.3) \times 10^{-7}$$

$$- \mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.3 \pm 0.3) \times 10^{-8} \quad \sim (?) \quad \mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p}) < (2.0) \times 10^{-7}$$

[PRL 119 (2017) 23, 232001]

[PRD 98 (2018) 7, 071102]

Threshold enhancement effect at
 $m(p\bar{p}) = m(p) + m(\bar{p})$

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New measurements of purely baryonic B decays would provide new insight in the understanding of the non-trivial processes involved

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New measurements of purely baryonic B decays would provide new insight in the understanding of the non-trivial processes involved



**Search for the
rare baryonic decay $B_s^0 \rightarrow p\bar{p}$**

Full Run2 data: 6 fb⁻¹

arXiv:2206.06673
submitted to PRD

- **Two-body baryonic decays suppressed with respect to multibody decays**
- **LHCb observation of $B^0 \rightarrow p\bar{p}$ using Run1 data (3 fb^{-1})**

$$\mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}$$

$$\mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 1.5 \times 10^{-8}$$

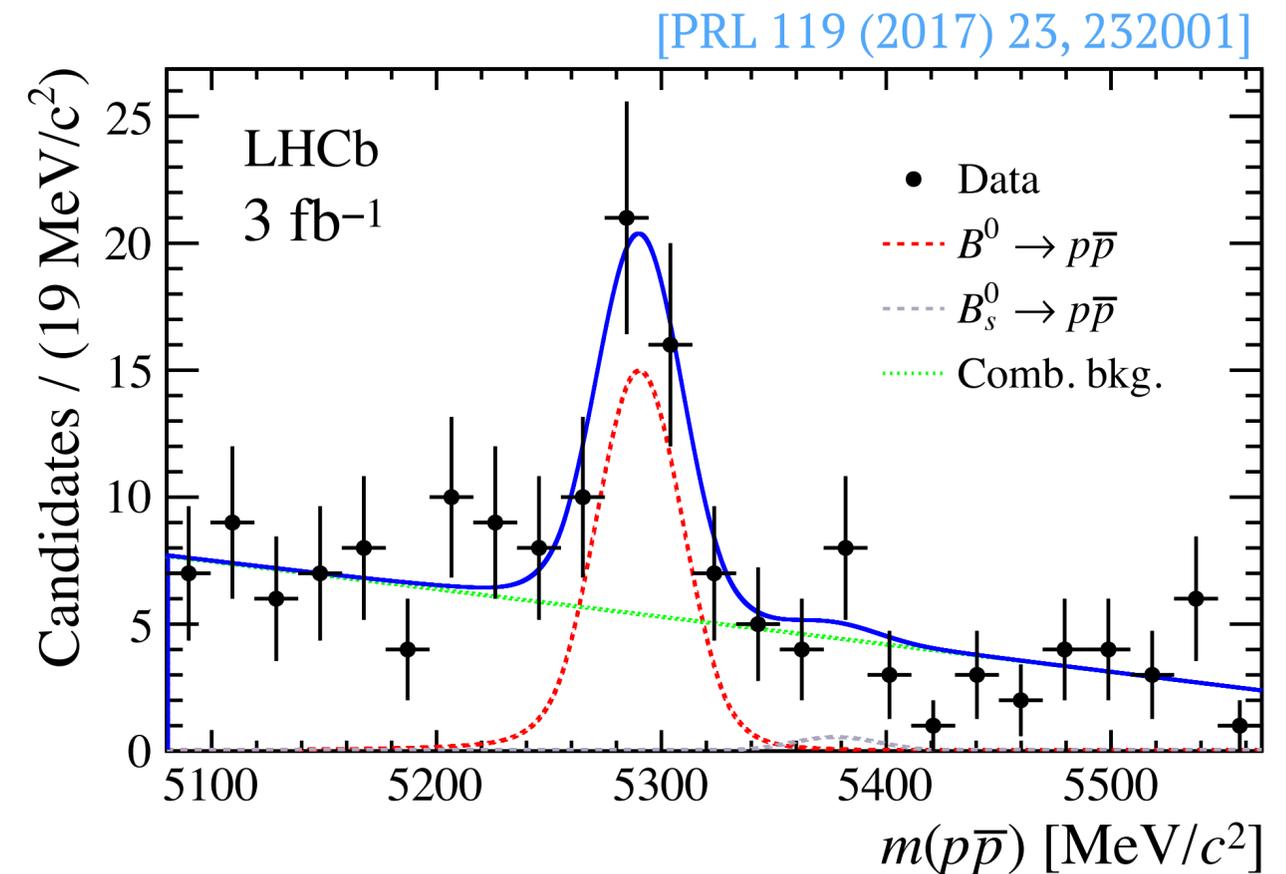
- Some predictions expect $B_s^0 \rightarrow p\bar{p}$ to be further suppressed (no penguin-level gluon-exchange and annihilation contributions)

[PRD 89, 056003 (2014), PRD 95, 096004 (2017)]

- Other predictions expect $B_s^0 \rightarrow p\bar{p}$ rates similar to that of $B^0 \rightarrow p\bar{p}$

[JHEP2004, 035 (2020)]

- **Using full Run2 (6 fb^{-1}) data, present updated search for $B_s^0 \rightarrow p\bar{p}$ decays**

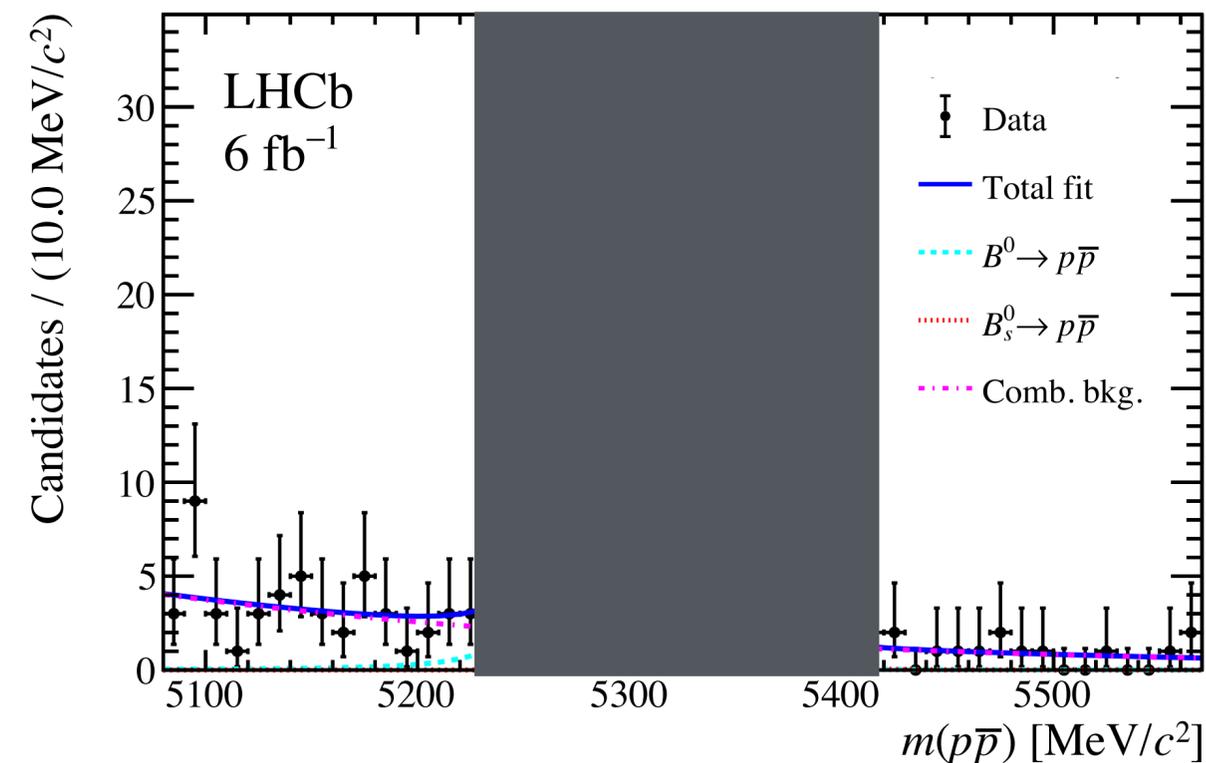


- **Similar strategy as analysis on Run1 data**

- Using full 6 fb^{-1} of Run2 data
- Blind analysis in the signal region:
 $m(p\bar{p}) \notin [5230, 5417] \text{ MeV}/c^2$
- $B^0 \rightarrow K^+\pi^-$ as normalisation channel
- Sig. and norm. yields from individual fits

- **Selection in a nutshell**

- Initial selection step (mostly) based on topological variables to reduce combinatorial background
- Intermediate selection based on PID variables to reduce candidates with mis-ID daughters
- Final selection using BDT (TMVA) to further reduce backgrounds while keeping high signal efficiency



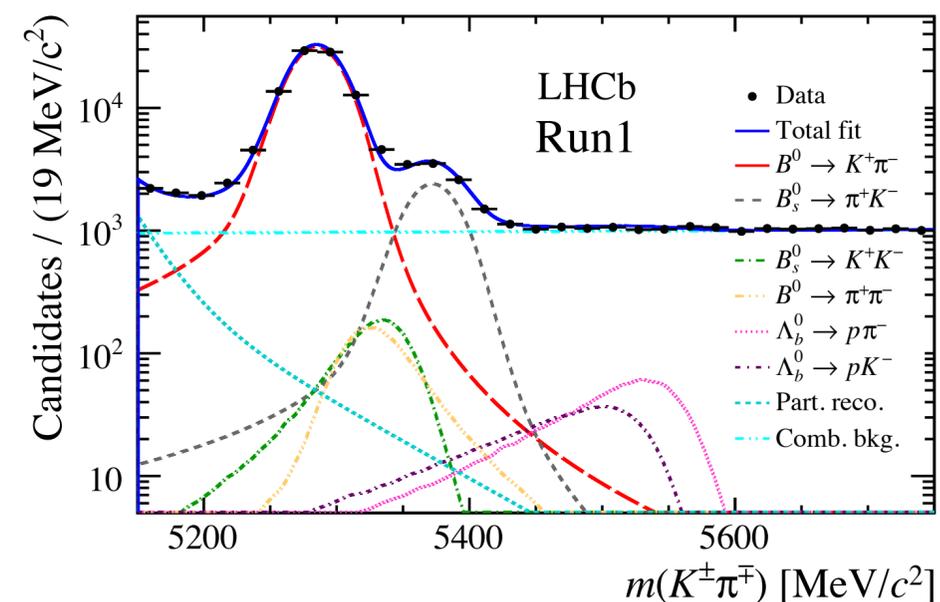
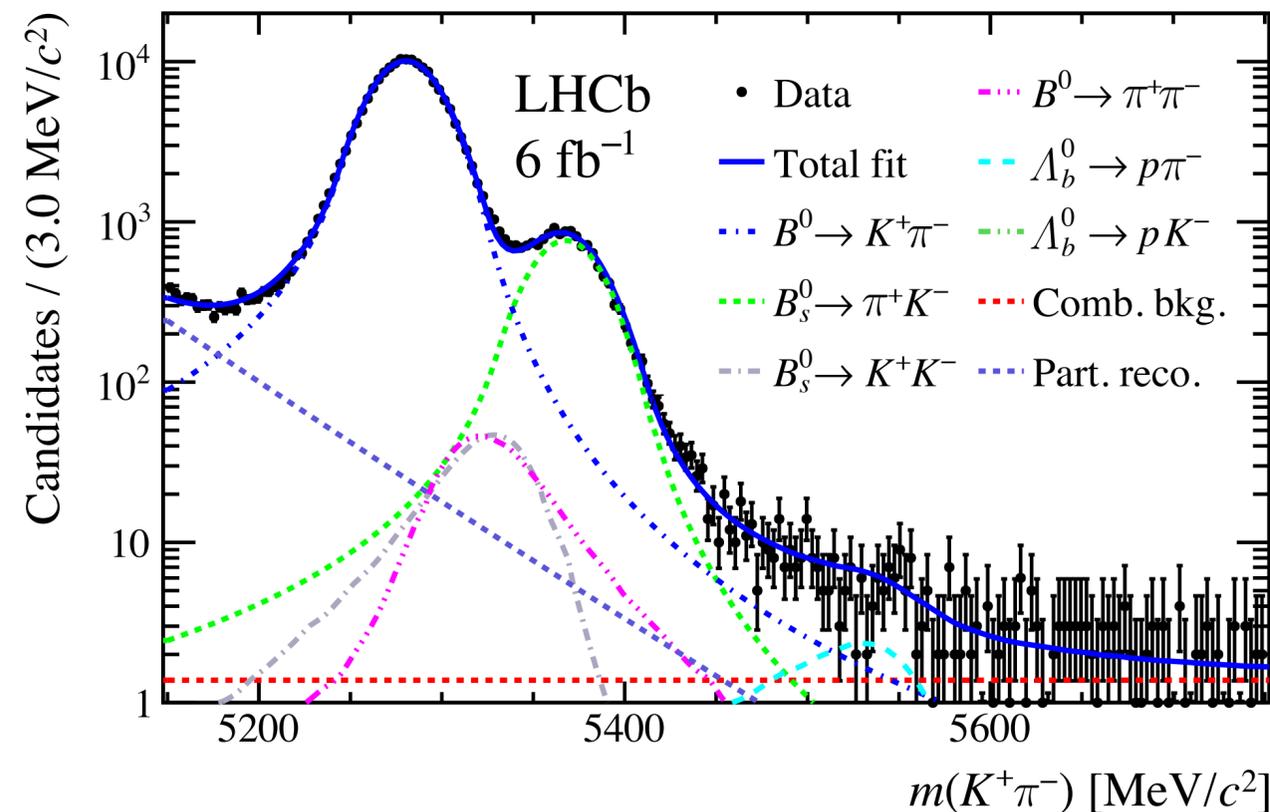
- **Fit to $m(K^+\pi^-)$**

- Several contributions included
 - $B^0 \rightarrow K^+\pi^-$; $B_s^0 \rightarrow \pi^+K^-$; $B_s^0 \rightarrow K^+K^-$
 - mis-ID bkg.
 - partially reco bkg.
 - comb bkg.

- **Signal yield result**

- $N(B^0 \rightarrow K^+\pi^-) = 179890 \pm 350$ (Run2)

Improved S/B with respect to Run1 analysis with
 $N(B^0 \rightarrow K^+\pi^-) = 88961 \pm 341$



[PRL 119 (2017) 23, 232001]

- **Fit to $m(p\bar{p})$: signal yields**

- $N(B^0 \rightarrow p\bar{p}) = 98 \pm 11$
- $N(B_s^0 \rightarrow p\bar{p}) = 4 \pm 5$

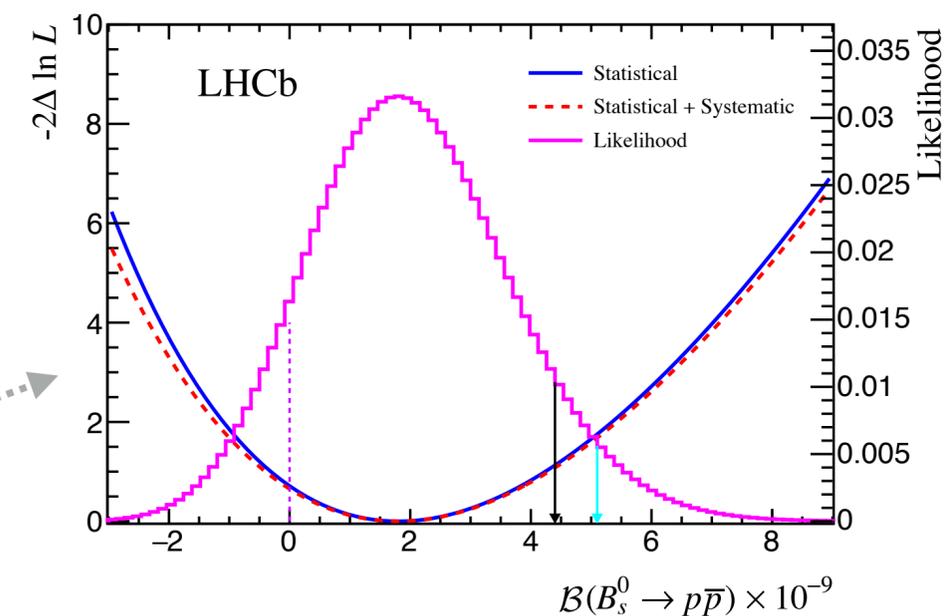
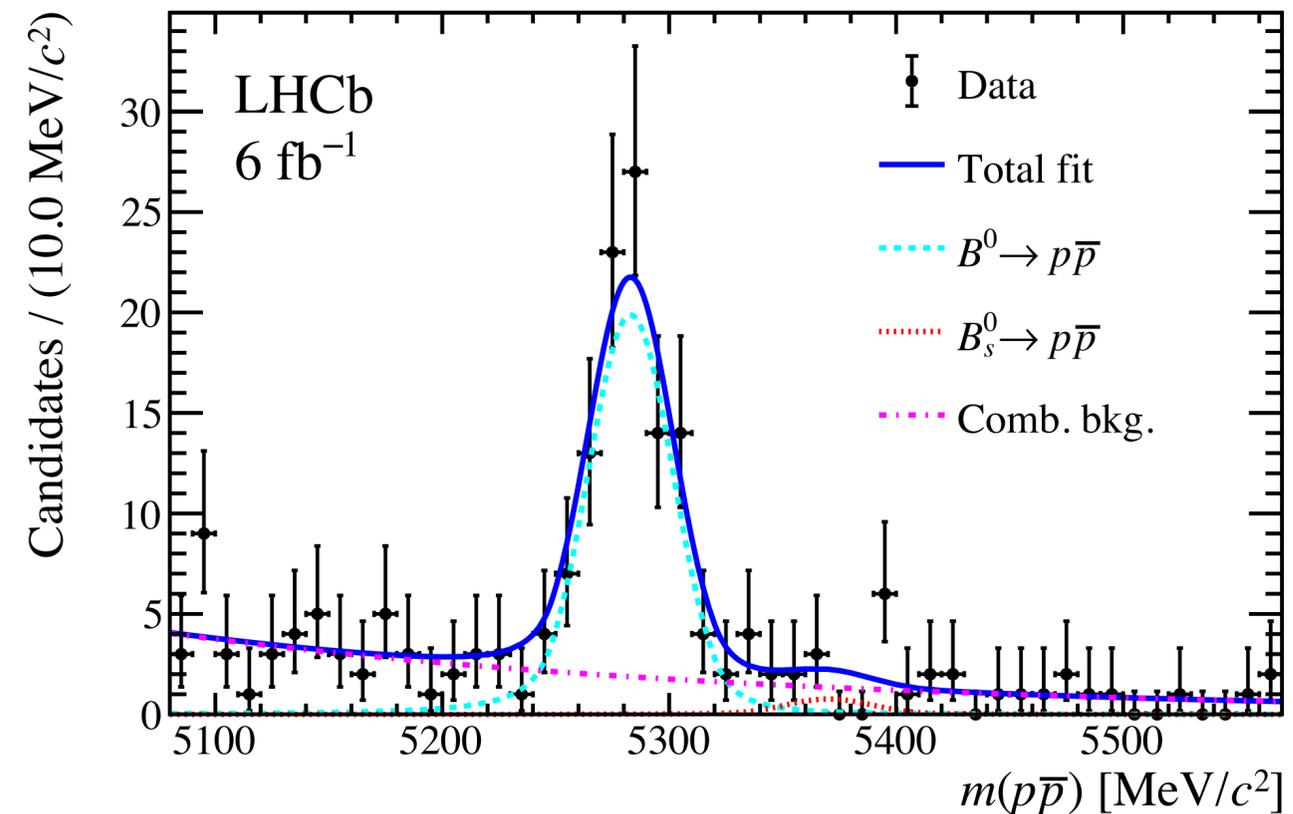
- **Branching fraction measurements**

- $B^0 \rightarrow p\bar{p}$ Run2 alone:
 $\mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8}$
- $B^0 \rightarrow p\bar{p}$ combination with Run1:

$$\mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.27 \pm 0.13 \pm 0.05 \pm 0.03) \times 10^{-8}$$

- **Improved UL on $B_s^0 \rightarrow p\bar{p}$ by factor 3**

$$\mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 4.4 \text{ (5.1)} \times 10^{-9} \text{ at 90\% (95\%) CL}$$





**Searches for the
rare baryonic decays
 $B^0 \rightarrow p\bar{p}p\bar{p}$ and $B_s^0 \rightarrow p\bar{p}p\bar{p}$**

Full Run1 & Run2 data: 9 fb⁻¹

Preliminary results
LHCb-PAPER-2022-032

- **Main goal: first observation of a purely baryonic 4-body decay**

$$\mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p}) < 2.0 \times 10^{-7} \text{ at 90\% confidence level } [\text{PRD 98 (2018) 7, 071102}]$$

- Very rare decay with clean expected experimental signature
↳ accessible if $\mathcal{B} \sim [10^{-8}, 10^{-7}]$
- $B_s^0 \rightarrow p\bar{p}p\bar{p}$ (no study reported) is expected to be further suppressed with respect to B^0
↳ hadronisation fraction $f_s/f_d \sim 25\%$, and $|V_{us}/V_{ud}|^2 \sim 5\%$
- An observation would constitute a first step toward an amplitude analysis to study the baryon-antibaryon subsystem and threshold effects with LHCb Upgrade

- The $p\bar{p}p\bar{p}$ data samples are **blinded** in the signal region: $[5240, 5407]$ MeV/ c^2
 - **Tighter selection** applied for B_s^0 search & branching fraction determination due to the lower expected yield wrt B^0 (tight PID for B^0 & very tight PID for B_s^0)
 - Charmonium contribution to $p\bar{p}p\bar{p}$ spectrum expected to be small to negligible
 - ↳ perform inclusive measurement and qualitative statement after $c\bar{c}$ vetoes
 - **Signal significances** measured from fits to $m(p\bar{p}p\bar{p})$ alone
 - **Branching fractions** measured from simultaneous fits to sig. and norm. channels
 - ↳ $B^0 \rightarrow J/\psi(p\bar{p})K^{*0}(K\pi)$ and $B_s^0 \rightarrow J/\psi(p\bar{p})\phi(KK)$:

$$\mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p}) = \mathcal{B}_{\text{vis}}(B^0 \rightarrow J/\psi K^{*0}) \times \frac{N(B^0 \rightarrow p\bar{p}p\bar{p})}{N(B^0 \rightarrow J/\psi K^{*0})} \times \frac{\epsilon(B^0 \rightarrow J/\psi K^{*0})}{\epsilon(B^0 \rightarrow p\bar{p}p\bar{p})}$$

similarly for B_s^0
with $J/\psi\phi$

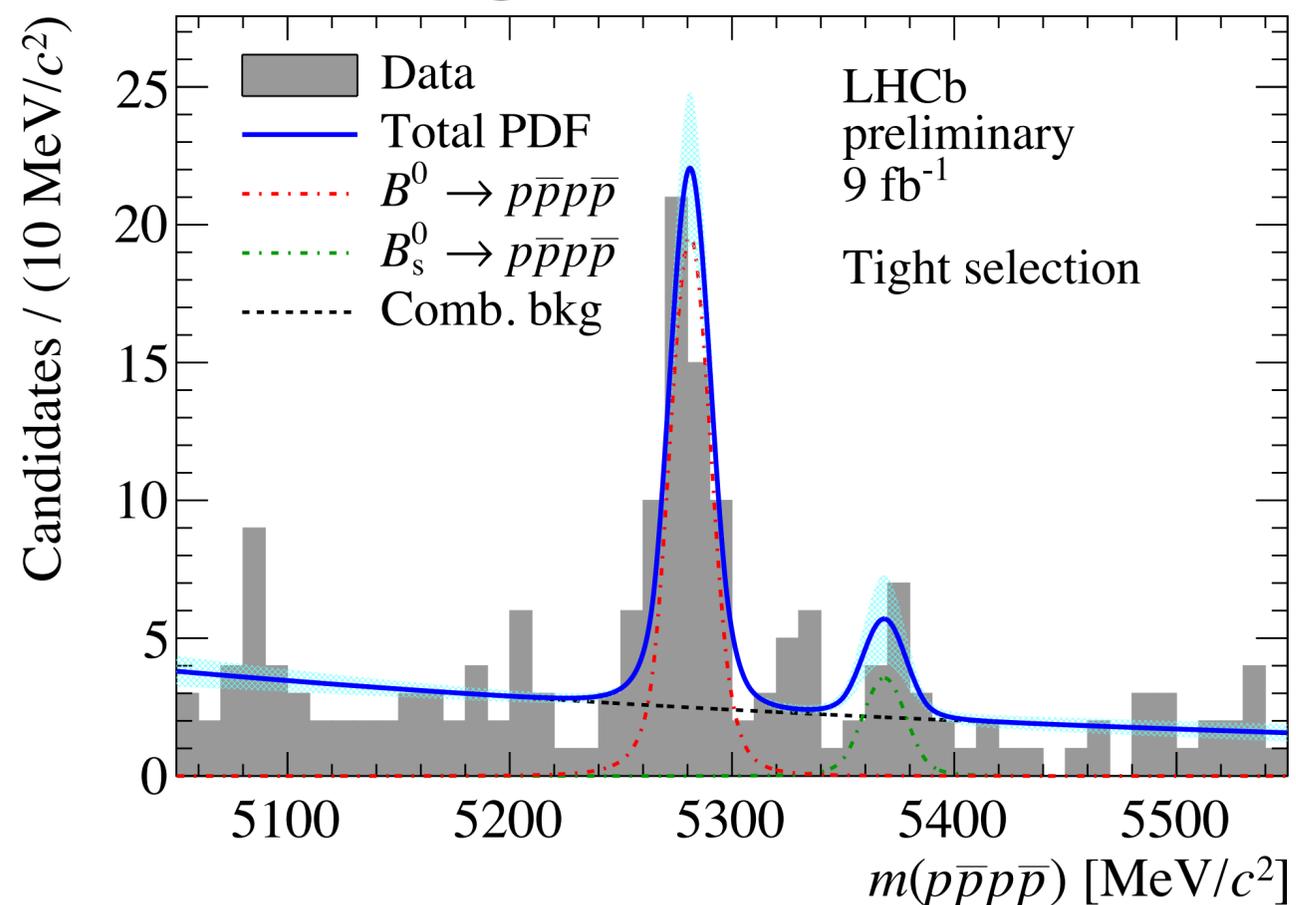
Taken from PDG

UML fit to data

From simulation
corrected with
norm. channels

- **Fit to $m(p\bar{p}p\bar{p})$:**

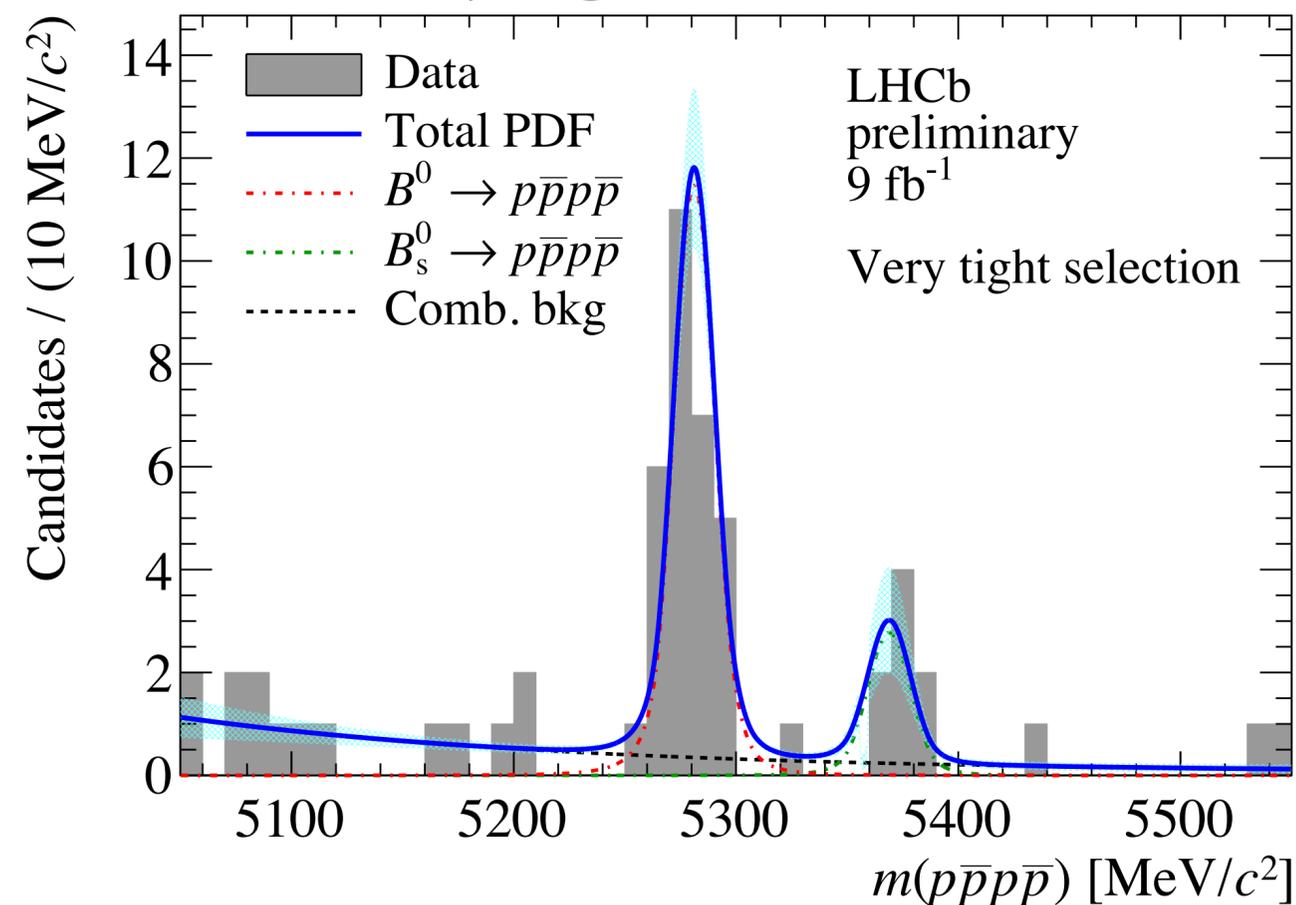
Tight selection



$$N(B^0 \rightarrow p\bar{p}p\bar{p}) = 48 \pm 8$$

Significance: $> 9\sigma$

Very tight selection

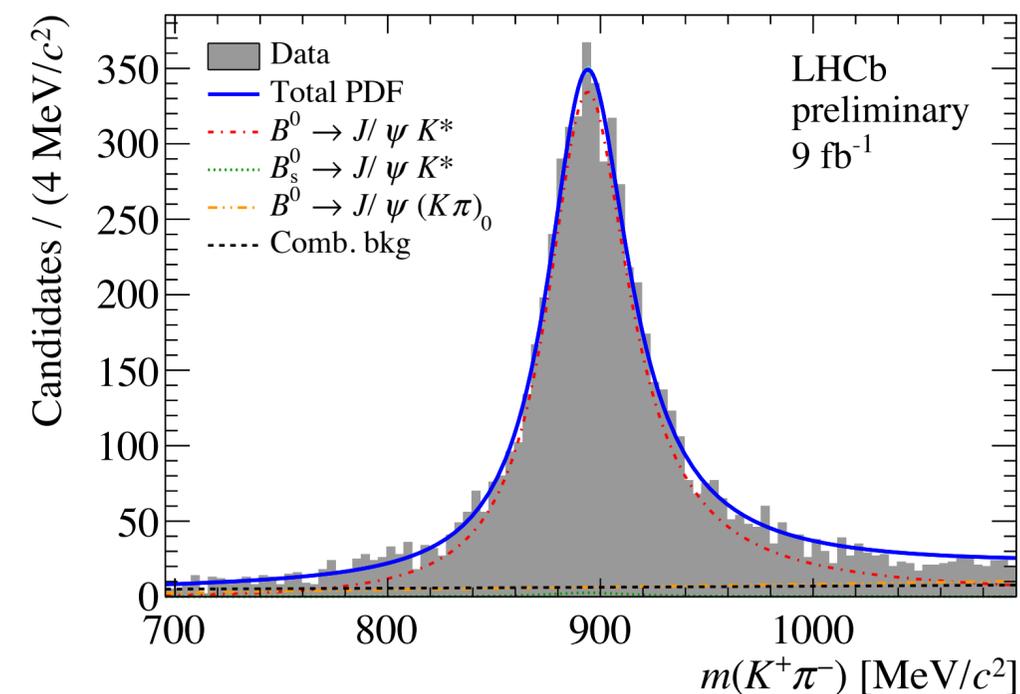
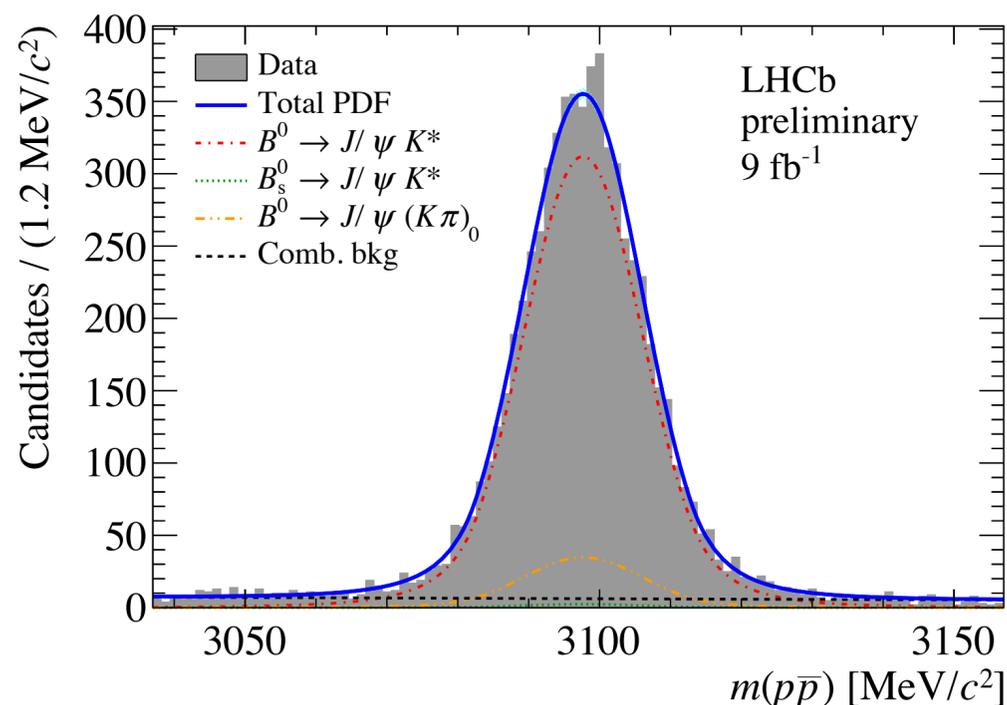
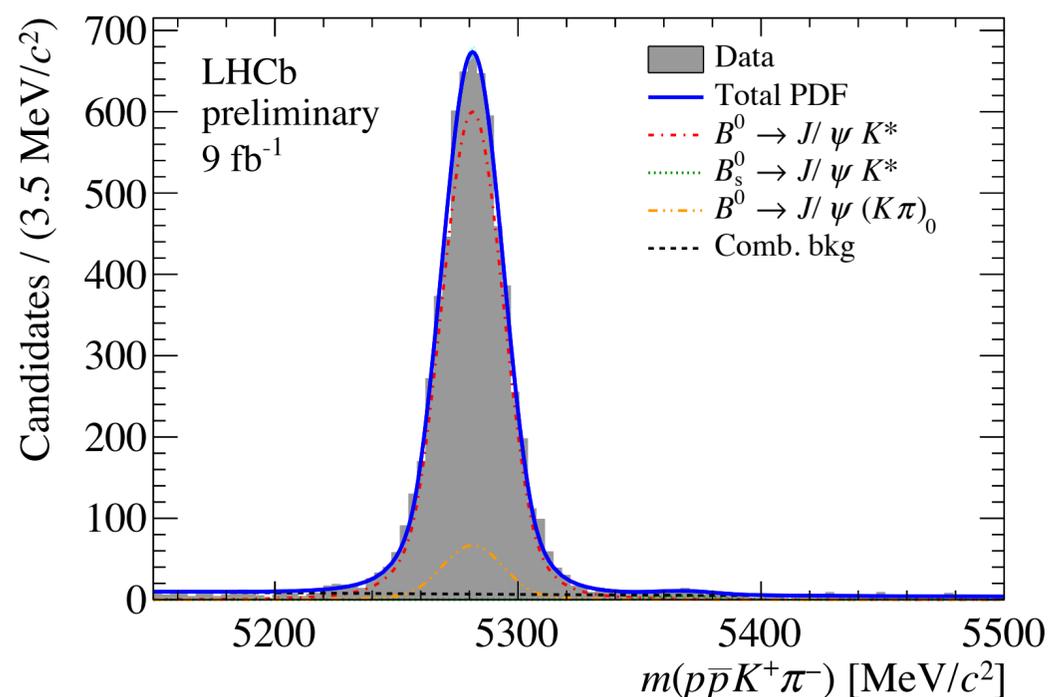


$$N(B_s^0 \rightarrow p\bar{p}p\bar{p}) = 7.1 \pm 2.9$$

Significance: 4σ

Including stat. and syst. uncertainties

- **Simultaneous fit to $m(p\bar{p}p\bar{p})$, $m(p\bar{p}K\pi)$, $m(p\bar{p}KK)$**
 - Normalisation modes described by 3D fit model
 - ↳ accounting for $(K\pi)$ S -wave component in $p\bar{p}K\pi$ data



Branching fractions: results

- **Inclusive branching fractions** (preliminary results)

$$\mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p}) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8}$$

Tight selection

$$\mathcal{B}(B_s^0 \rightarrow p\bar{p}p\bar{p}) = (2.3 \pm 1.0 \pm 0.2 \pm 0.1) \times 10^{-8}$$

Very tight selection

**First measurement of $\mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p})$
Unexpectedly large $\mathcal{B}(B_s^0 \rightarrow p\bar{p}p\bar{p})$**

- **Branching fractions with $c\bar{c}$ veto** (preliminary results)

- $m(p\bar{p}) < 2.85$ GeV for all four possible $p\bar{p}$ pairs

$$\mathcal{B}(B^0 \rightarrow p\bar{p}p\bar{p}) = (1.6 \pm 0.4) \times 10^{-8}$$

$$\mathcal{B}(B_s^0 \rightarrow p\bar{p}p\bar{p}) = (2.2 \pm 1.2) \times 10^{-8}$$

Data is consistent with decays proceeding primarily through charmless transitions

stat uncertainties only

- **Summary:**

- **Searched for $B_s^0 \rightarrow p\bar{p}$ decays**

- ↳ improved UL by factor 3 $\mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 4.4 (5.1) \times 10^{-9}$ at 90% (95%) CL

- ↳ improved $\mathcal{B}(B^0 \rightarrow p\bar{p})$ $\mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.27 \pm 0.13 \pm 0.05 \pm 0.03) \times 10^{-8}$

- **Searched for $B^0 \rightarrow p\bar{p}p\bar{p}$ & $B_s^0 \rightarrow p\bar{p}p\bar{p}$ decays**

- ↳ clear B^0 signal observed (9σ) with unexpectedly large B_s^0 signal (4σ):

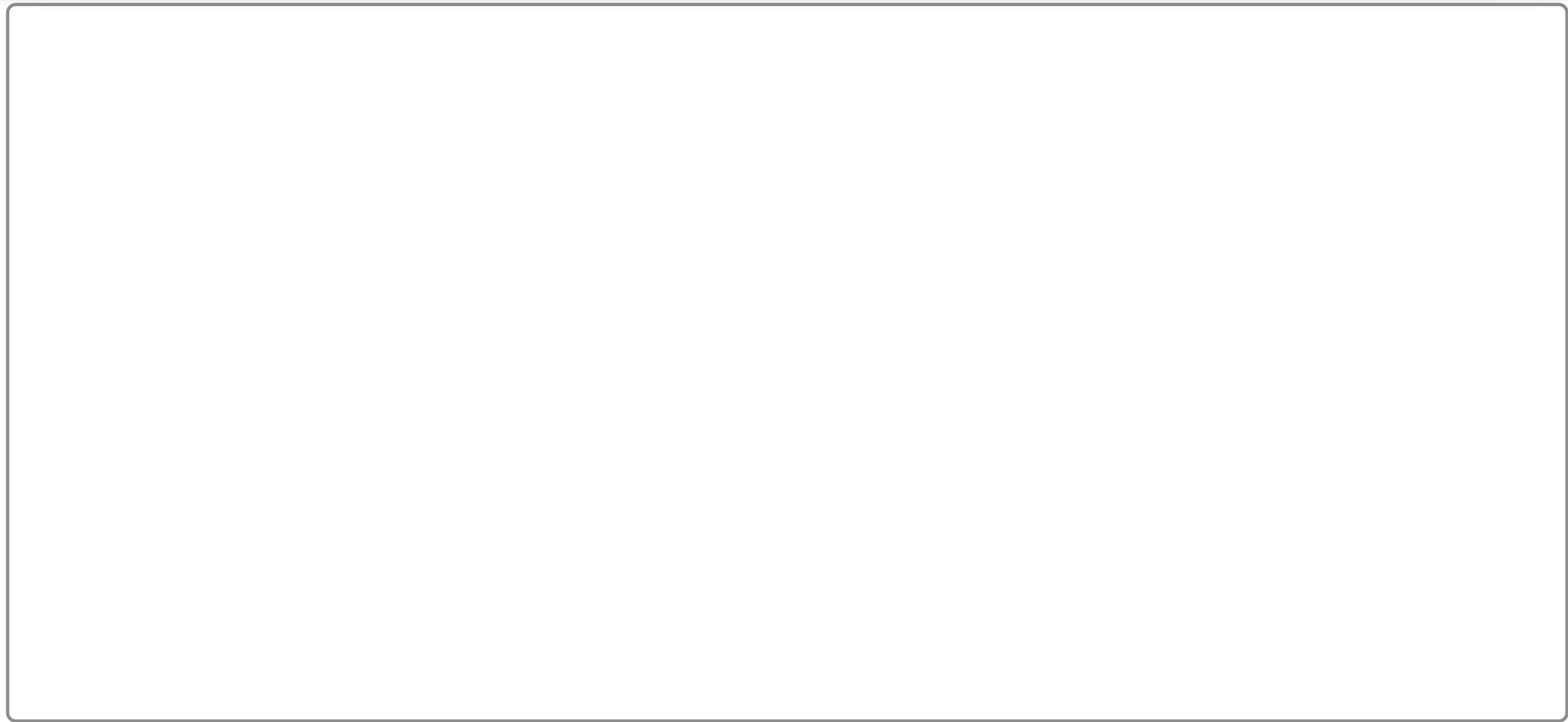
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- **Outlook:**

- Hadronic decays will greatly benefit from LHCb Upgrade (removal of hardware trigger)
- Very promising prospects regarding study of purely baryonic decays at LHCb
- Enable improving understanding of the non-trivial processes involved in the decays of B mesons to charmless hadronic multi-body final states



Source of systematic uncertainties	$B^0 \rightarrow p\bar{p}$	$B_s^0 \rightarrow p\bar{p}$
f_s/f_d	-	3.1
L0 trigger efficiency	1.0	1.0
Selection efficiency relative to $B^0 \rightarrow K^+\pi^-$	2.0	2.0
Tracking efficiency	1.9	1.9
PID efficiency	2.4	2.4
Fit model	1.0	22.0
Total	3.9	22.5

Uncertainties in %

Systematics $p\bar{p}p\bar{p}$

	$B^0 \rightarrow p\bar{p}p\bar{p}$	$B_s^0 \rightarrow p\bar{p}p\bar{p}$
Nominal $\mathcal{B}(B_{(s)}^0 \rightarrow p\bar{p}p\bar{p}) \times 10^{-8}$	2.21 ± 0.37	2.30 ± 0.96
Systematic source		
Efficiencies (MC stat)	0.02	0.03
Efficiencies (weights)	0.06	0.09
PID	0.03	0.03
Tracking	0.02	0.02
Fixed PDF parameters	0.02	0.02
Signal model	0.00	0.04
Background model	0.03	0.17
Quadratic sum	0.08	0.20
Normalisation \mathcal{B}	0.09	0.13

Uncertainties in absolute values