

Measurements of branching fractions and angular observables in B decays to VV final states

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(On behalf of **the LHCb collaboration**)

Rencontres de Moriond, EW Interactions and Unified Theories
March 2nd - 9th, 2013
La Thuile, Aosta valley, Italy



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decays to VV final
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$$B_s^0 \rightarrow J/\psi K^+ K^-$$

Amplitude analysis

$$B_s^0 \rightarrow J/\psi \bar{K}^{*0}$$

Angular parameters
Branching fraction

Summary

- 1 $B_s^0 \rightarrow J/\psi K^+ K^-$
 - Amplitude analysis

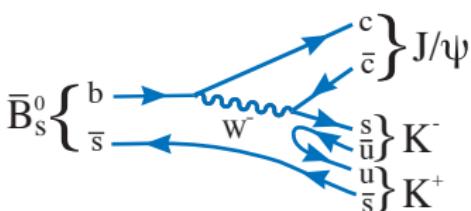
- 2 $B_s^0 \rightarrow J/\psi \bar{K}^{*0}$
 - Angular parameters
 - Branching fraction

- 3 Summary

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A large $\phi(1020)$ component is well known¹, and the $f_2'(1525)$ has recently been observed² and confirmed³, but the source of S-wave contributions has not been identified.

¹ Particle Data Group, J. Beringer *et al.*, *Review of particle physics*, Phys. Rev **D86** (2012) 010001

² The LHCb collaboration, R. Aaij *et al.*, *Observation of $B_s \rightarrow J/\psi f_2'(1525)$ in $J/\psi K^+ K^-$ final states*, Phys. Rev. Lett. **108** (2012) 151801, arXiv:1112.4695

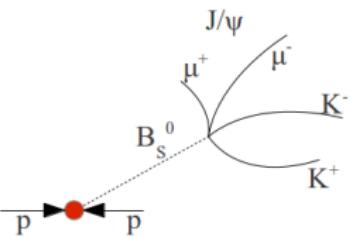
³ D0 Collaboration, V. M. Abazov *et al.*, *Study of the decay $B_s^0 \rightarrow J/\psi f_2'(1525)$ in $\mu^+ \mu^- K^+ K^-$ final states*, Phys. Rev. **D86** (2012) 092011, arXiv:1204.5723

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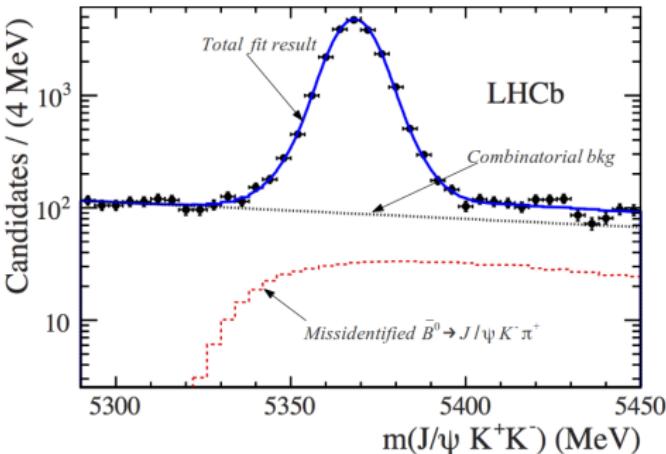


We found $(M(\bar{B}_s^0) \pm 20 \text{ MeV})$:

- $N_{B_s^0 \rightarrow J/\psi K^+ K^-} = 19195 \pm 150$
- $N_{Bkg} = 894 \pm 24$

arXiv:1302.1213(accepted in PRD)

- A set of selection cuts was applied, relying on the main strengths of LHCb (Vertex resolution, momentum, PID...)
- We also parametrized the misidentified $\bar{B}^0 \rightarrow J/\psi K^- \pi^+$



$B_s^0 \rightarrow J/\psi K^+ K^-$ Analysis

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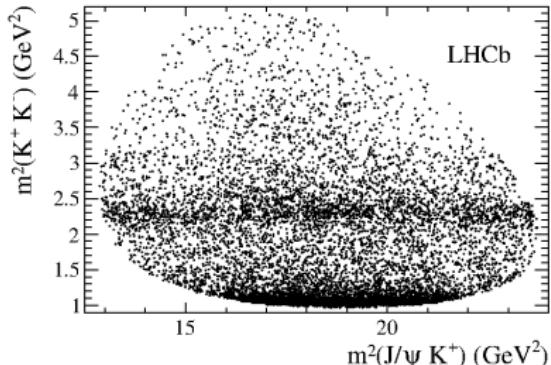
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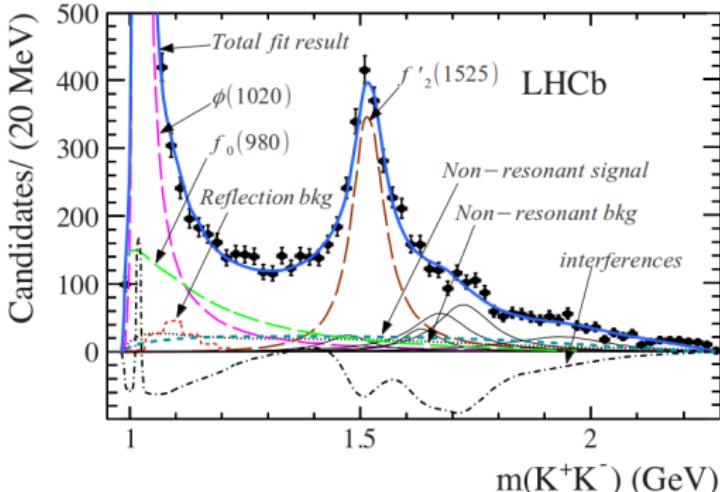
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- Dalitz plot generated with \bar{B}_s^0 candidates within $(M(\bar{B}_s^0) \pm 20 \text{ MeV})$
- Two clear horizontal bars from the $\phi(1020)$ and $f'_2(1525)$ resonances



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S-wave

We observe an S-wave $(1.1 \pm 0.1^{+0.2}_{-0.1})\%$ of the yield in $(M(\phi(1020)) \pm 12 \text{ MeV})$

Branching fractions

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi X) = \frac{N_{\bar{B}_s^0}/\epsilon_{\bar{B}_s^0}}{N_{B^-}/\epsilon_{B^-}} \times \mathcal{B}(B^- \rightarrow J/\psi K^-) \times \frac{1}{f_s/f_d}$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi K^+ K^-) = (7.70 \pm 0.08(stat) \pm 0.39(syst) \pm 0.60) \left(\frac{f_s}{f_d} \right) \times 10^{-4}$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \phi(1020)) = (10.50 \pm 0.13(stat) \pm 0.64(syst) \pm 0.82) \left(\frac{f_s}{f_d} \right) \times 10^{-4}$$

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f'_2(1525)) = (2.61 \pm 0.20(stat)_{-0.46}^{+0.52}(syst) \pm 0.20) \left(\frac{f_s}{f_d} \right) \times 10^{-4}$$

arXiv:1302.1213(accepted in PRD)

$\mathcal{B}(B^- \rightarrow J/\psi K^-) = (10.18 \pm 0.42) \times 10^{-4}$. Belle (arXiv:hep-ex/0211047) and BaBar (arXiv:hep-ex/0412062) average

$\frac{f_s}{f_d} = 0.256 \pm 0.020$ The LHCb collaboration, R. Aaij *et al.*, *Measurement of the fragmentation fraction ratio $\frac{f_s}{f_d}$ and its dependence on B meson kinematics*, arXiv:1301.5286; The LHCb collaboration, R. Aaij *et al.*, *Measurement of b-hadron production fractions in 7 TeV pp collisions*, Phys. Rev. D **85** 032008 (2012), arXiv:1111.2357

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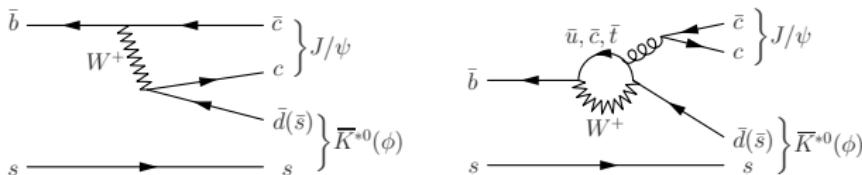
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Important to control the penguin effects in $B_s^0 \rightarrow J/\psi \phi$ and their impact on ϕ_s determination ^a

^aS. Faller, R. Fleisher and T. Mannel, PhysRevD.79.014005, arXiv:0810.4248



- Was first observed by CDF (Phys. Rev. D 83, 052012 (2011))

$$\mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0}) = (8.3 \pm 3.8) \times 10^{-5}$$

- LHCb reported a measurement of BR using $\sim 37 \text{ pb}^{-1}$ (LHCb-CONF-2011-025)

$$\mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0}) = (3.5_{-1.0}^{+1.1}(\text{stat}) \pm 0.9(\text{syst})) \times 10^{-5}$$

Under the assumption that the light quark (d,s) is an spectator of the decay of the b quark, the $\mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0})$ can be calculated as:

$$\mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0}) \sim \frac{|V_{cd}|^2}{|V_{cs}|^2} \times \mathcal{B}(B_d^0 \rightarrow J/\psi K^{*0}) = (6.5 \pm 1.0) \times 10^{-5}$$

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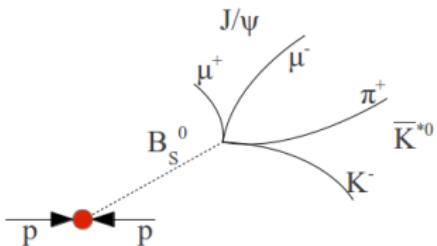
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⁴The number of B_s^0 and B^0 candidates found are:

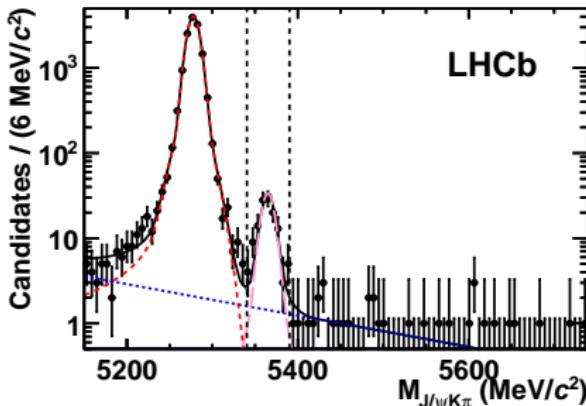
- $N_{B^0} = 13,365 \pm 116$
- $N_{B_s^0} = 114 \pm 11$

⁵ The LHCb collaboration, R. Aaij *et al.*, *Measurement of the $B \rightarrow J/\psi K^*$ branching fraction and angular amplitudes*, Phys. Rev. D **86** 071102(R) (2012), arXiv:1208.0738

The results presented here are based only on the analysis of **0.37 fb⁻¹** from the 2011 dataset

Data selection relies basically on:

- Vertex resolution, momentum and particle identification
 - A geometrical likelihood (GL) built from:
 - Impact Parameters of the B_s^0 candidate and its daughter tracks wrt PV
 - Decay time of the B_s^0 candidate
 - Distance of closest approach of the J/ψ and K^{*0}
- and trained with background from sidebands and signal from simulation



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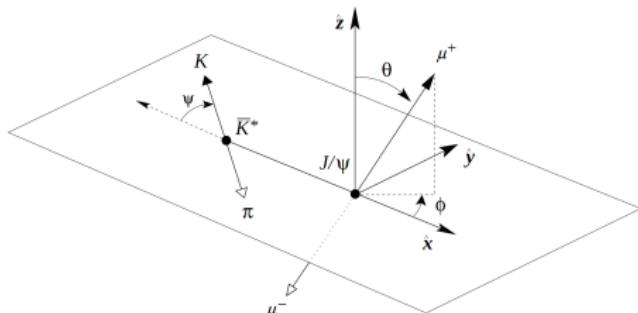
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Summary

Taking into account the $K\pi$ S-wave component and assuming no direct CP violation and insignificant $B_{(s)}^0 - \bar{B}_{(s)}^0$ production asymmetry:

$$\begin{aligned} \frac{d^3\Gamma}{d\Omega} &\propto 2|A_0|^2 \cos^2 \psi (1 - \sin^2 \theta \cos^2 \varphi) \\ &+ |A_{||}|^2 \sin^2 \psi (1 - \sin^2 \theta \sin^2 \varphi) \\ &+ |A_{\perp}|^2 \sin^2 \psi \sin^2 \theta \\ &+ \frac{1}{\sqrt{2}} |A_0| |A_{||}| \cos(\delta_{||} - \delta_0) \sin 2\psi \\ &+ \frac{2}{3} |A_S|^2 \left[1 - \sin^2 \theta \cos^2 \varphi \right] \\ &+ \frac{4\sqrt{3}}{3} |A_0| |A_S| \cos(\delta_S - \delta_0) \cos \psi \left[1 - \sin^2 \theta \cos^2 \varphi \right] \\ &+ \frac{\sqrt{6}}{3} |A_{||}| |A_S| \cos(\delta_{||} - \delta_S) \sin \psi \sin^2 \theta \sin 2\varphi \end{aligned}$$



$$f_{L,||,\perp} = \frac{|A_{0,||,\perp}|^2}{|A_0|^2 + |A_{||}|^2 + |A_{\perp}|^2}$$

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$B_s^0 \rightarrow J/\psi \bar{K}^{*0}$ angular parameters measured for the first time

$B_s^0 \rightarrow J/\psi \bar{K}^{*0}$ parameters ⁵	$ A_S ^2$	f_L	$f_{ }$
Value and statistical uncertainty	$0.07^{+0.15}_{-0.07}$	0.50 ± 0.08	$0.19^{+0.10}_{-0.08}$
Systematic uncertainties			
Angular acceptance	0.044	0.011	0.016
Background angular model	0.038	0.017	0.013
Assumption $\delta_S(M_{K\pi}) = \text{constant}$	0.026	0.005	0.002
B^0 contamination	0.036	0.004	0.007
Fit bias	—	—	0.005
Total systematic uncertainty	0.073	0.021	0.022

⁵The LHCb collaboration, R. Aaij *et al.*, *Measurement of the $B \rightarrow J/\psi K^*$ branching fraction and angular amplitudes*, Phys. Rev. **D** **86** 071102(R) (2012), arXiv:1208.0738

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Ratio of the two branching fractions

$$\frac{\mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0})}{\mathcal{B}(B_d^0 \rightarrow J/\psi K^{*0})} = \frac{f_d}{f_s} \frac{\varepsilon_{B_s^0}^{\text{tot}}}{\varepsilon_{B_d^0}^{\text{tot}}} \frac{\lambda_{B_s^0}}{\lambda_{B_d^0}} \frac{f_{K^{*0}}^{(d)}}{f_{K^{*0}}^{(s)}} \frac{N_{B_s^0}}{N_{B_d^0}}$$

Parameter	Name	Value
⁶ Hadronization fractions	f_d/f_s	3.75 ± 0.29
Efficiency ratio	$\varepsilon_{B_s^0}^{\text{tot}}/\varepsilon_{B_d^0}^{\text{tot}}$	0.97 ± 0.01
Angular corrections	$\lambda_{B_s^0}/\lambda_{B_d^0}$	1.01 ± 0.04
Ratio of K^{*0} fractions	$f_{K^{*0}}^{(s)}/f_{K^{*0}}^{(d)}$	1.09 ± 0.08
B signal yields	$N_{B_s^0}/N_{B_d^0}$	$(8.5^{+0.9}_{-0.8} \pm 0.8) \times 10^{-3}$
⁷ $B_d^0 \rightarrow J/\psi K^{*0}$ Branching fraction	$\mathcal{B}(B_d^0 \rightarrow J/\psi K^{*0})$	$(1.29 \pm 0.05 \pm 0.13) \times 10^{-3}$

$$^8 \mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0}) = (4.4^{+0.5}_{-0.4} \pm 0.8) \times 10^{-5}$$

⁶ The LHCb collaboration, R. Aaij *et al.*, *Measurement of b-hadron production fractions in 7 TeV pp collisions*, Phys. Rev. **D 85** 032008 (2012), arXiv:1111.2357

⁷ Belle collaboration, K. Abe *et al.*, *Measurements of branching fractions and decay amplitudes in $B \rightarrow J/\psi K^*$ decays*, Phys. Lett. **B538** (2002) 11, arXiv:hep-ex/0205021

⁸ The LHCb collaboration, R. Aaij *et al.*, *Measurement of the $B \rightarrow J/\psi K^*$ branching fraction and angular amplitudes*, Phys. Rev. **D 86** 071102(R) (2012), arXiv:1208.0738

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LHCb

In the first data taking period LHCb performed extremely well.

$$\bar{B}_s^0 \rightarrow J/\psi K^+ K^- \text{ (1.0 fb}^{-1} \text{ at } \sqrt{s} = 7 \text{ TeV)}$$

LHCb-PAPER-2012-040 (accepted in PRD)

- The S-wave measured is $(1.1 \pm 0.1^{+0.2}_{-0.1})\%$ of the yield in $(M(\phi(1020)) \pm 12 \text{ MeV})$
- we also measured the absolute branching fractions of:

$$\begin{aligned}\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi K^+ K^-) &= (7.70 \pm 0.08 \pm 0.39 \pm 0.60) \times 10^{-4} \\ \mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \phi(1020)) &= (10.50 \pm 0.13 \pm 0.64 \pm 0.82) \times 10^{-4} \\ \mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi f_2'(1525)) &= (2.61 \pm 0.20^{+0.52}_{-0.46} \pm 0.20) \times 10^{-4}\end{aligned}$$

$$B_s^0 \rightarrow J/\psi \bar{K}^{*0} \text{ (0.37 fb}^{-1} \text{ at } \sqrt{s} = 7 \text{ TeV)}$$

Phys. Rev. D **86** 071102(R) (2012), arXiv:1208.0738

- We have measured $\mathcal{B}(B_s^0 \rightarrow J/\psi \bar{K}^{*0}) = (4.4^{+0.5}_{-0.4} \pm 0.8) \times 10^{-5}$. Compatible with the previous CDF measurement and theoretical expectations.
- The first measurement of polarization fractions in this decay was also performed.

$$f_L = 0.50 \pm 0.08 \pm 0.02$$

$$f_{||} = 0.19^{+0.10}_{-0.08} \pm 0.02$$

$$|A_S|^2 = 0.07^{+0.15}_{-0.07}$$

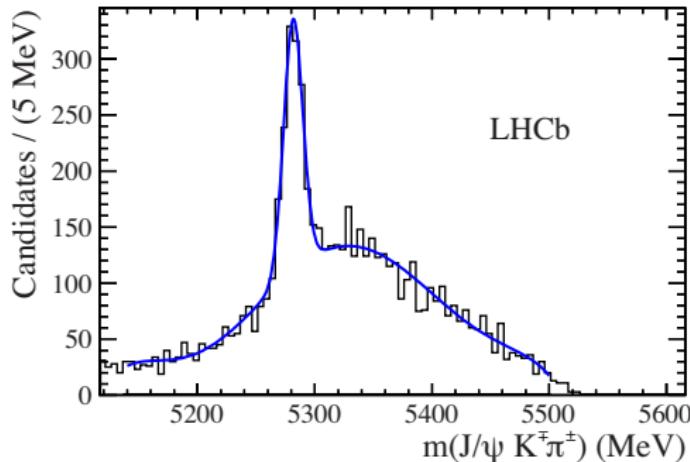
BACKUP SLIDES

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Invariant mass distribution for $J/\psi K^+ K^-$ candidates 25 – 200 MeV above the \bar{B}_s^0 mass, reinterpreted as $\bar{B}^0 \rightarrow J/\psi K^\mp \pi^\pm$ events. The fit is to a signal Gaussian whose mass and width are allowed to vary as well as the polynomial background.