



B decays to Charmonia at LHCb

Ivan Polyakov
ITEP

on behalf of the LHCb collaboration

LHC on the March, 20 November 2012

Outline



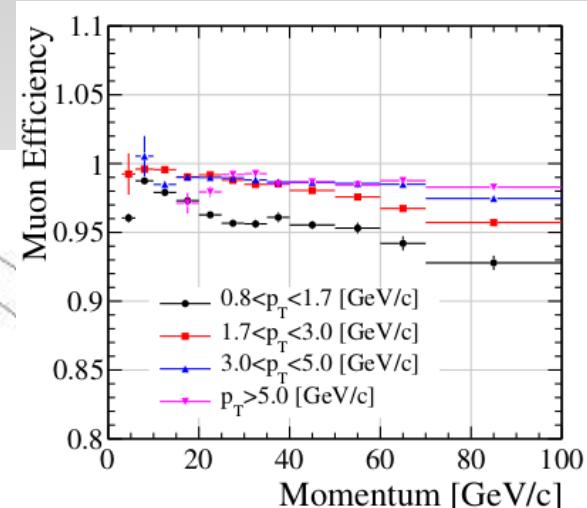
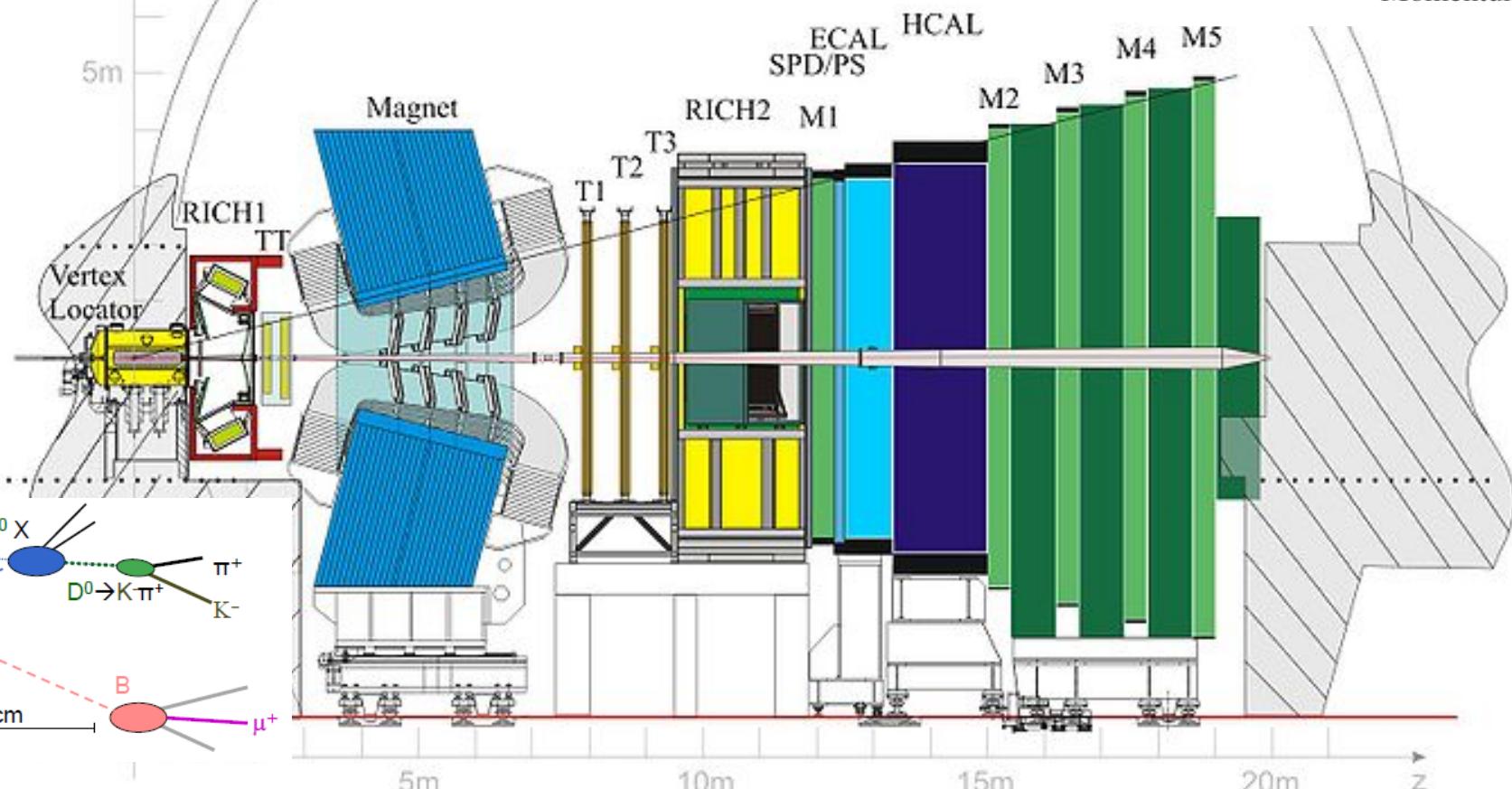
- LHCb detector
- $B \rightarrow \psi(2S)X$ and $B \rightarrow J/\psi X$
- $B_s \rightarrow J/\psi h^+ h^-$ important for CP violation studies
 - resonant structure in $B_s \rightarrow J/\psi \pi^+ \pi^-$
 - branching ratio of $B_s \rightarrow J/\psi K_s^0 (\rightarrow \pi^+ \pi^-)$
 - branching ratio & angular analysis of $B_s \rightarrow J/\psi K^* (\rightarrow K^+ \pi^-)$
- $B^0 \rightarrow J/\psi \omega$, $B_s \rightarrow J/\psi \eta(')$
- Summary

LHCb detector



Features relevant for $B \rightarrow J/\psi X$

- High efficiency single and di-muon trigger
- Good time resolution to select B candidates
- Good muon identification
- Good K/ π separation by RICH detectors





B \rightarrow $\Psi(2S)X$ and B \rightarrow J/ ψ X

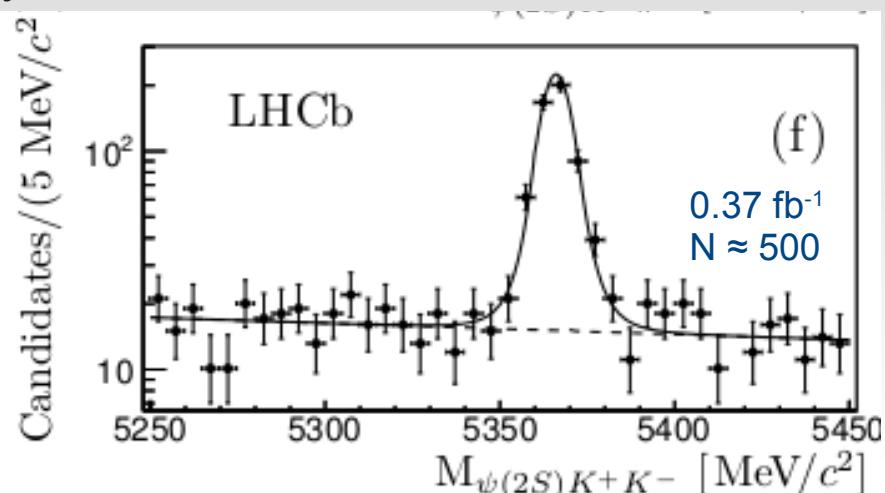
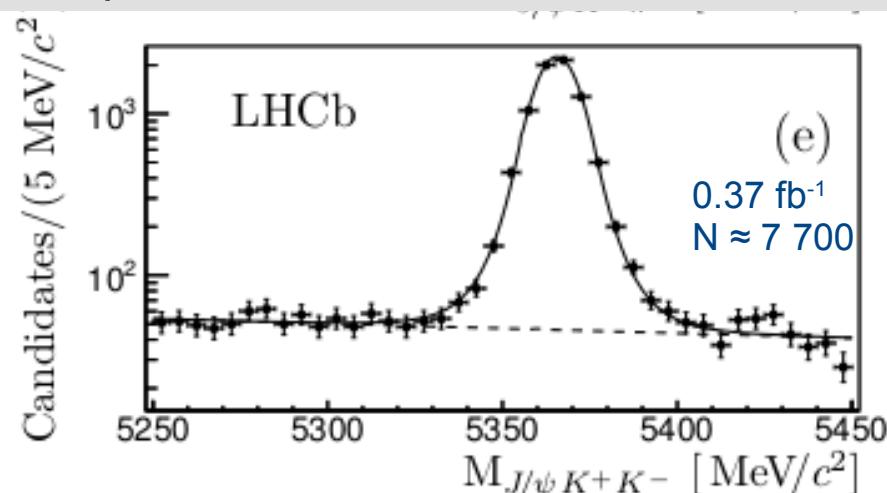
Relative BR's $B \rightarrow \psi(2S)X$ and $B \rightarrow J/\psi X$



where $X = K^+, K^{*0} \rightarrow K^+ \pi^-, \varphi \rightarrow K^+ K^-$

- Probe charmonium properties
- Explore new channels for CPV studies in B system

LHCb-PAPER-2012-010,
Eur. Phys. J. C (2012) 72:2118



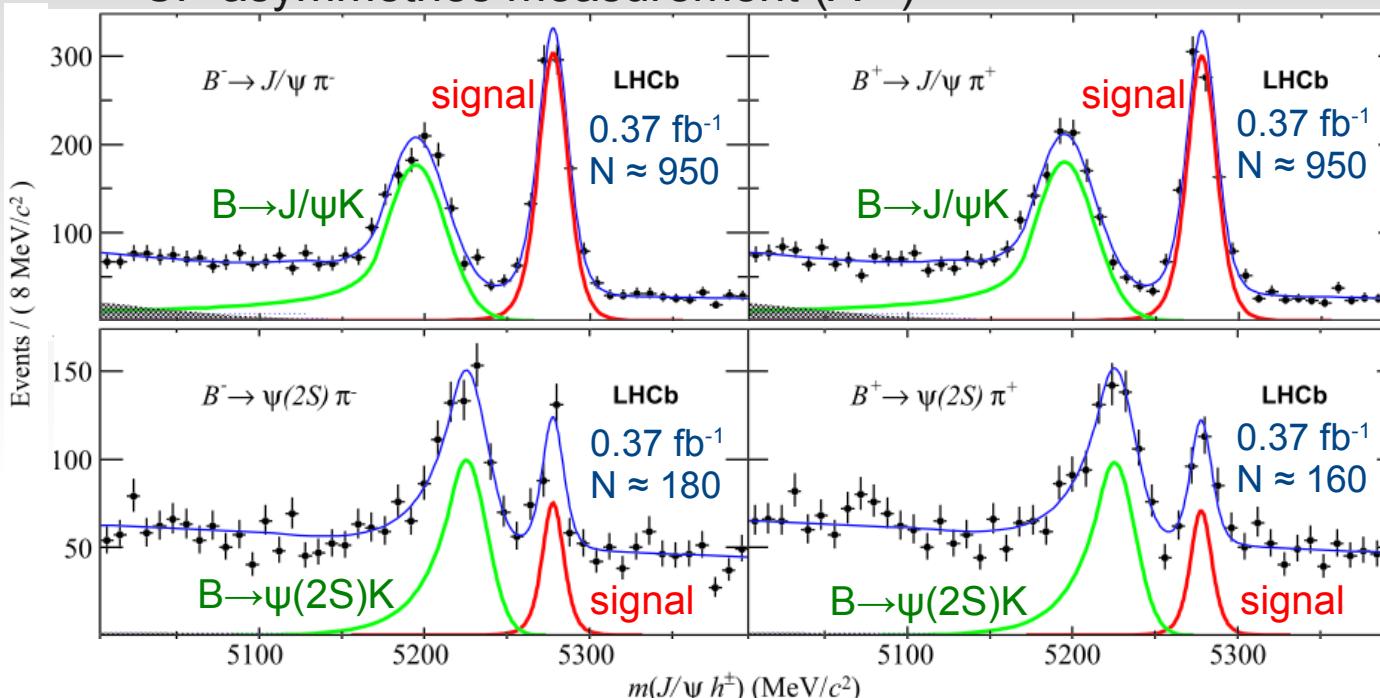
- Subtraction of non-resonant $B^0 \rightarrow \psi K^+ \pi^-$ and $B_s \rightarrow \psi K^+ K^-$ contribution
- Estimate efficiencies from simulation
- Most systematic uncertainties cancel in the ratio, the dominant are:
 - non-resonant contribution
 - data-simulation agreement
- Results are in the following...



$B^+ \rightarrow \Psi(2S)\pi^+$ and $B^+ \rightarrow J/\psi\pi^+$

- Cabibbo-suppressed decays
- Measure BR's relative to $B^+ \rightarrow \Psi K^+$ (R^Ψ)
- CP asymmetries measurement (A^{CP})

LHCb-PAPER-2011-024,
Phys. Rev. D 85, 091105(R) (2012)



- $A = A_{raw} - A_{prod} - A_{det}$
- Separate analysis for two magnet polarities
- Estimate efficiencies from simulation
- Detection and identification from data (on D mesons)
- production from $A_{J/\psi K}^{raw}$

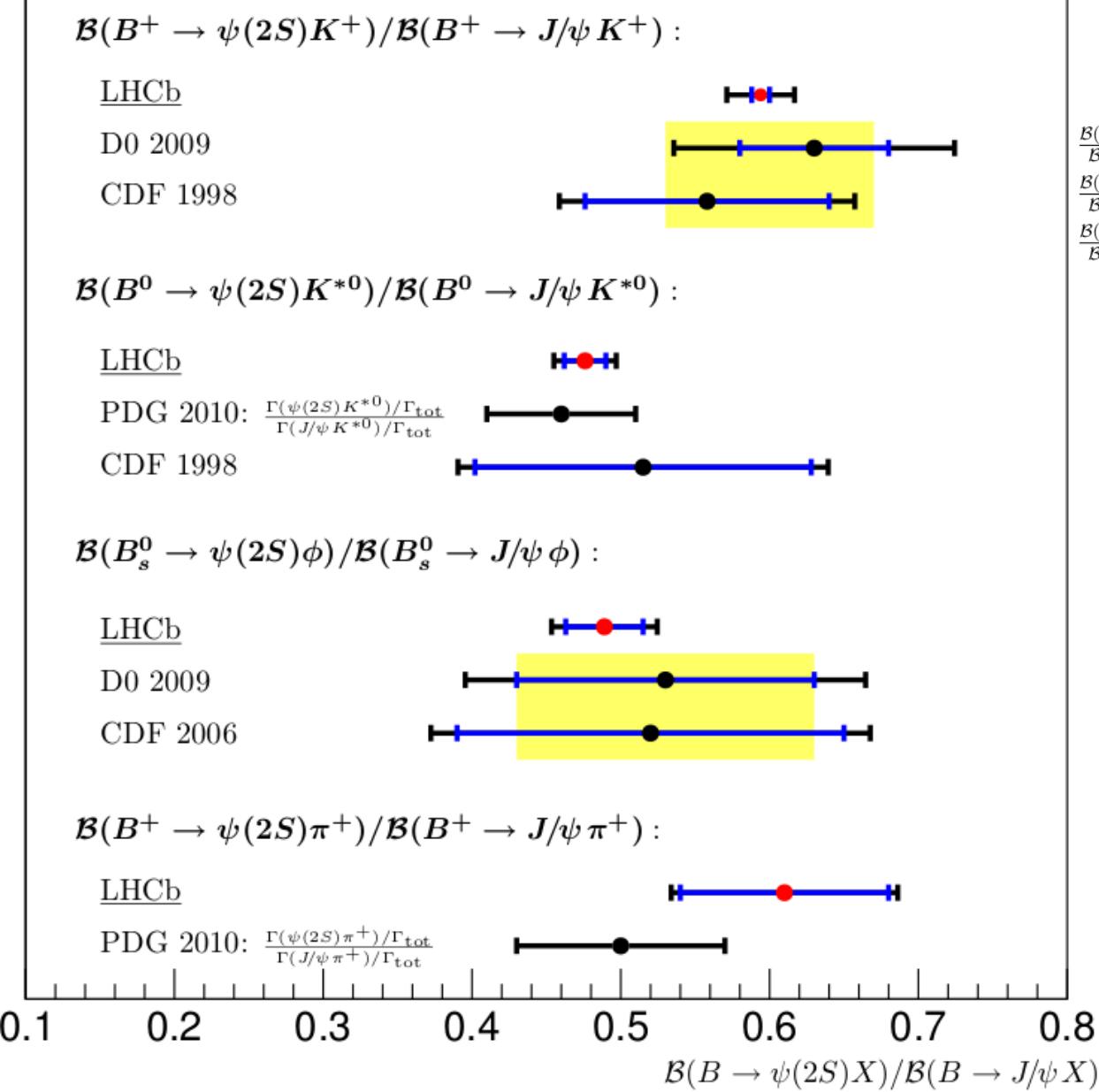
- Dominant systematic uncertainties
 - for R^Ψ : K/π identification, simulation, trigger
 - for A^{CP} : $A_{J/\psi K}^{raw}$ (PDG), $A_{J/\psi K}^{raw}$ (stat), detection, trigger
- Results:
 - For R see next slide
 - No evidence of CP asymmetry is seen

$$A_{CP}^{J/\psi\pi} = 0.005 \pm 0.027 \pm 0.011$$

$$A_{CP}^{\psi(2S)\pi} = 0.048 \pm 0.090 \pm 0.011$$

$$A_{CP}^{\psi(2S)K} = 0.024 \pm 0.014 \pm 0.008$$

Results for relative BR's



LHCb-PAPER-2012-010,
Eur. Phys. J. C (2012) 72:2118

$$\begin{aligned}\frac{\mathcal{B}(B^+ \rightarrow \psi(2S)K^+)}{\mathcal{B}(B^+ \rightarrow J/\psi K^+)} &= 0.594 \pm 0.006 \text{ (stat)} \pm 0.016 \text{ (syst)} \pm 0.015 (R_\psi), \\ \frac{\mathcal{B}(B^0 \rightarrow \psi(2S)K^{*0})}{\mathcal{B}(B^0 \rightarrow J/\psi K^{*0})} &= 0.476 \pm 0.014 \text{ (stat)} \pm 0.010 \text{ (syst)} \pm 0.012 (R_\psi), \\ \frac{\mathcal{B}(B_s^0 \rightarrow \psi(2S)\phi)}{\mathcal{B}(B_s^0 \rightarrow J/\psi \phi)} &= 0.489 \pm 0.026 \text{ (stat)} \pm 0.021 \text{ (syst)} \pm 0.012 (R_\psi),\end{aligned}$$

- The results are compatible with but significantly more precise than world averages (PDG)

LHCb-PAPER-2011-024,
Phys. Rev. D 85, 091105(R) (2012)

$$R^{J/\psi} = (3.83 \pm 0.11 \pm 0.07) \times 10^{-2}$$

$$R^{\psi(2S)} = (3.95 \pm 0.40 \pm 0.12) \times 10^{-2}$$

- $R^{\psi(2S)}$ is compatible with Belle
- $R^{J/\psi}$ is lower on 3.2σ than world average (PDG)

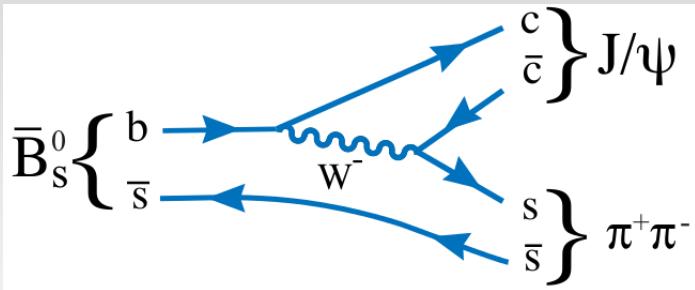


$B_s \rightarrow J/\psi \pi^+ \pi^-$
resonant structure

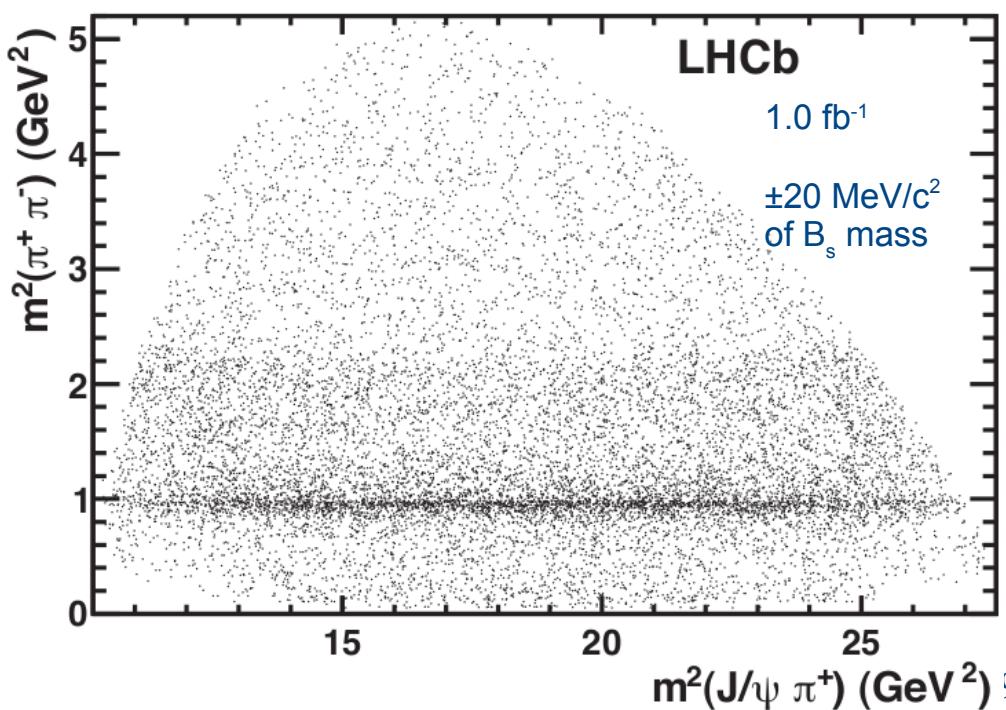
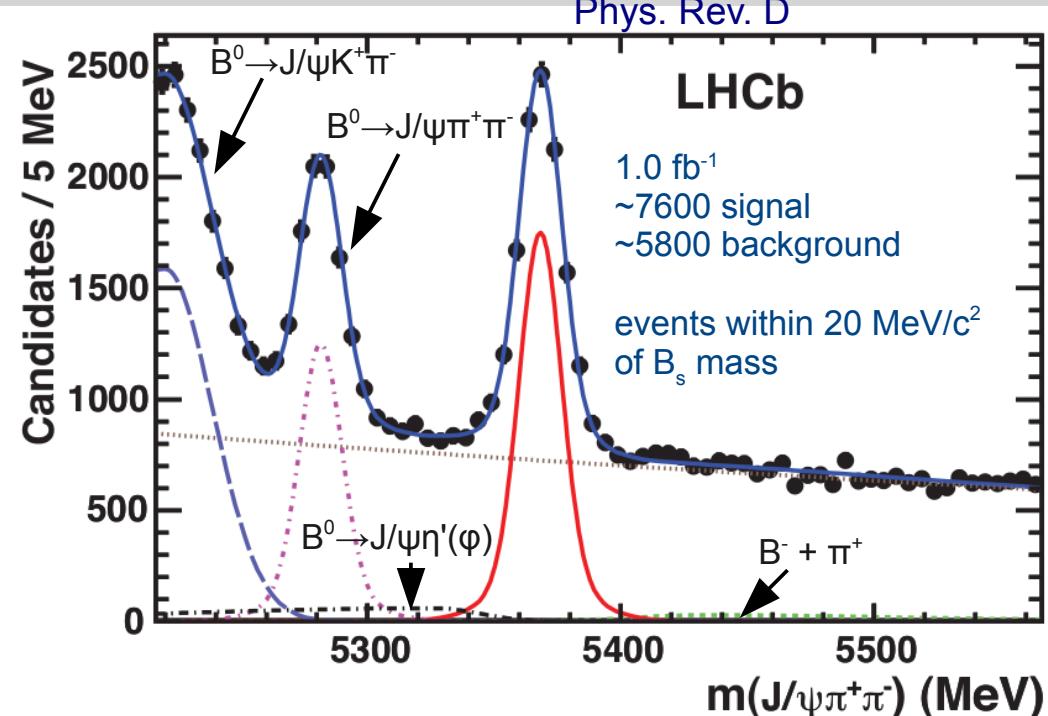
$B_s \rightarrow J/\psi \pi^+ \pi^-$ resonant structure



LHCb-PAPER-2012-005,
Phys. Rev. D



- Important for measurement of CPV
 - study $\pi^+ \pi^-$ mass range to determine its resonant structure and CP content
- Modified Dalitz-analysis:
 - $m^2(J/\psi \pi^+)$, $m^2(\pi^+ \pi^-)$ and $\theta(J/\psi)$
 - sum of $\pi^+ \pi^-$ resonances and S-wave non-resonant
 - Model background with $J/\psi \pi^+ \pi^+$ shape from data +4.5% $J/\psi \rho(770)$ modeled with MC
 - Obtain efficiencies from simulation



$B_s \rightarrow J/\psi \pi^+ \pi^-$ resonant structureLHCb-PAPER-2012-005,
Phys. Rev. D

- $I(ss) = 0 \rightarrow J(\pi^+ \pi^-) = 0.2$

Table 2: Models used in data fit.

Name	Components
Single R	$f_0(980)$
2R	$f_0(980) + f_0(1370)$
3R	$f_0(980) + f_0(1370) + f_2(1270)$
3R+NR	$f_0(980) + f_0(1370) + f_2(1270) + \text{non-resonant}$
3R+NR + $\rho(770)$	$f_0(980) + f_0(1370) + f_2(1270) + \text{non-resonant} + \rho(770)$
3R+NR + $f_0(1500)$	$f_0(980) + f_0(1370) + f_2(1270) + \text{non-resonant} + f_0(1500)$
3R+NR + $f_0(600)$	$f_0(980) + f_0(1370) + f_2(1270) + \text{non-resonant} + f_0(600)$

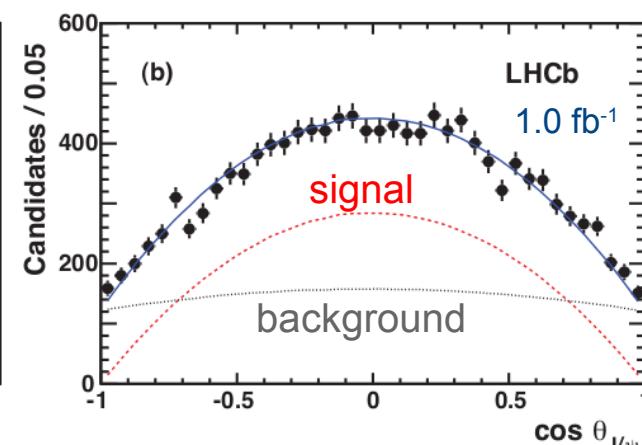
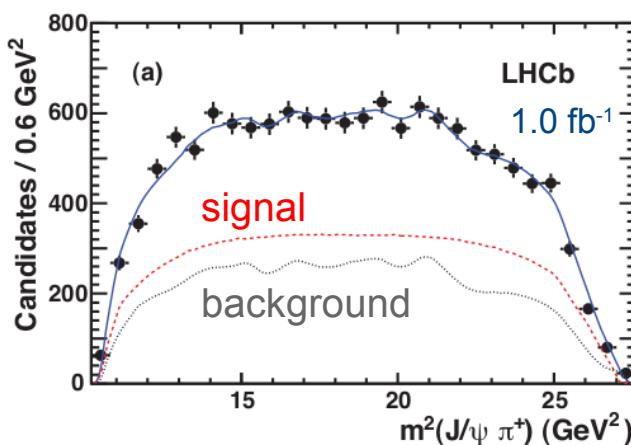
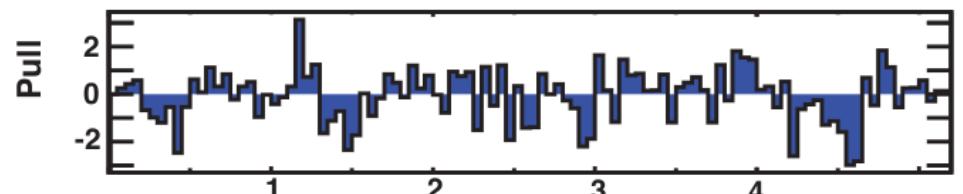
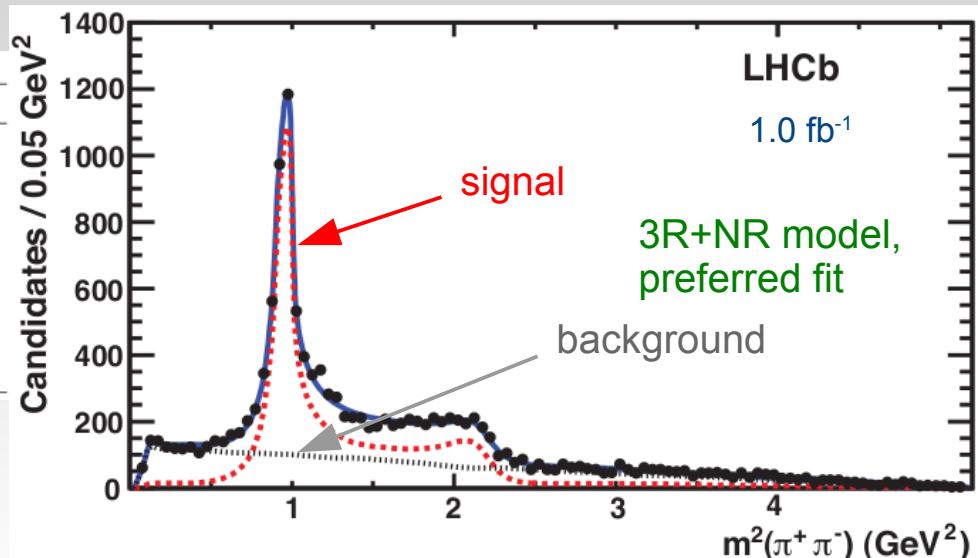
significance $< 3\sigma$

- Preferred-alternate fits,
resulted fractions, in %, for 3R+NR model:

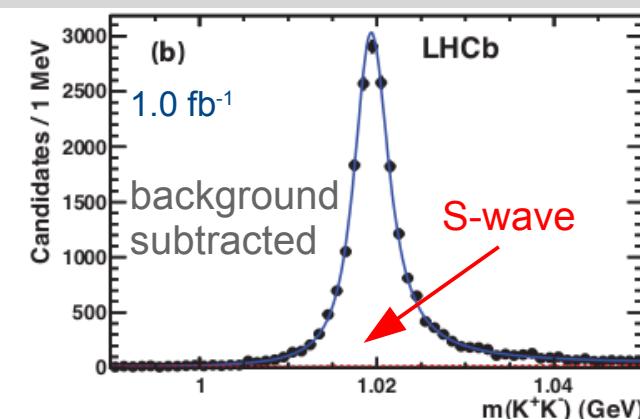
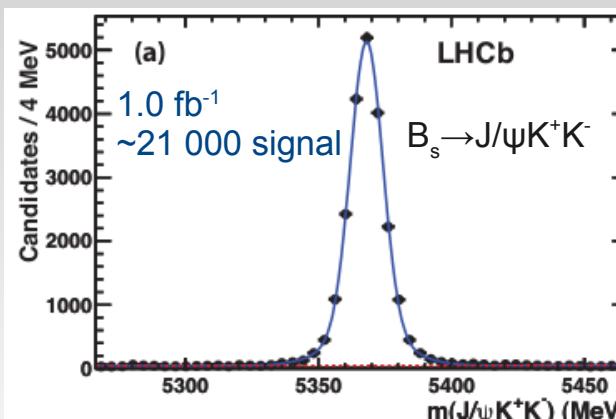
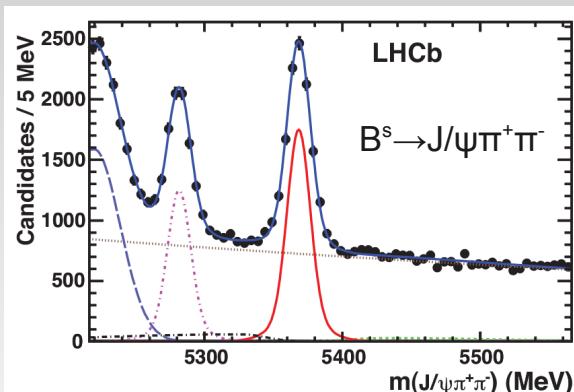
State	Preferred	Alternate
$f_0(980)$	69.7 ± 2.3	82.4 ± 2.3
$f_0(1370)$	21.2 ± 2.7	5.7 ± 0.7
NR	8.4 ± 1.5	11.3 ± 1.9
$f_2(1270)$	0.49 ± 0.16	0.42 ± 0.11

helicity = 0 only

- CP-even – $f_2(1270)$ with ± 1 helicity
and $\rho(770)$ modes

CP-odd fraction > 0.977 (95% C.L.)

$B_s \rightarrow J/\psi \pi^+ \pi^-$ resonant structure

LHCb-PAPER-2012-005,
Phys. Rev. D

- $B_s \rightarrow J/\psi K^+ K^-$
 - normalization channel, account for non-resonant background
- Dominant systematic uncertainty due to the fit:
 - Difference between two solutions
 - Including other resonances

Table 10: Relative systematic uncertainties on $R(\%)$.

Parameter	Total	$f_0(980)$	$f_0(1370)$	NR	$f_2(1270), \lambda = 0$
$m(\pi^+ \pi^-)$ dependent effic.	1.0	0.2	0.2	1.0	0.2
PID efficiency	2.0	2.0	2.0	2.0	2.0
$J/\psi \phi$ S-wave	0.7	0.7	0.7	0.7	0.7
$\bar{B}_s^0 p$ and p_T distributions	0.5	0.5	0.5	0.5	0.5
Acceptance function	0	0.1	1.3	1.4	3.9
$\mathcal{B}(\phi \rightarrow K^+ K^-)$	1.0	1.0	1.0	1.0	1.0
Background	0.6	0.6	0.6	0.6	0.6
Resonance fit	—	+18.2 -8.0	+0.8 -88.1	+57.6 -3.7	+3.0 -15.8
Total	± 2.7	+18.3 -8.4	+2.9 -88.2	+57.7 -4.8	+5.5 -16.4

$$\frac{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-)}{\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \phi)} = (19.79 \pm 0.47 \pm 0.52)\%,$$

$f_0(980)$	$13.9 \pm 0.6^{+2.5}_{-1.2}$
$f_0(1370)$	$4.19 \pm 0.53^{+0.12}_{-3.70}$
NR	$1.66 \pm 0.31^{+0.96}_{-0.08}$
$f_2(1270)$	$0.098 \pm 0.033^{+0.006}_{-0.015}$



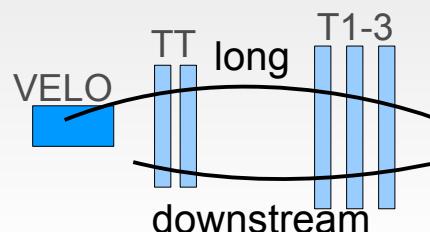
$B_s \rightarrow J/\psi K^0_s$
branching ratio

$B_s \rightarrow J/\psi K_s^0$ branching ratio



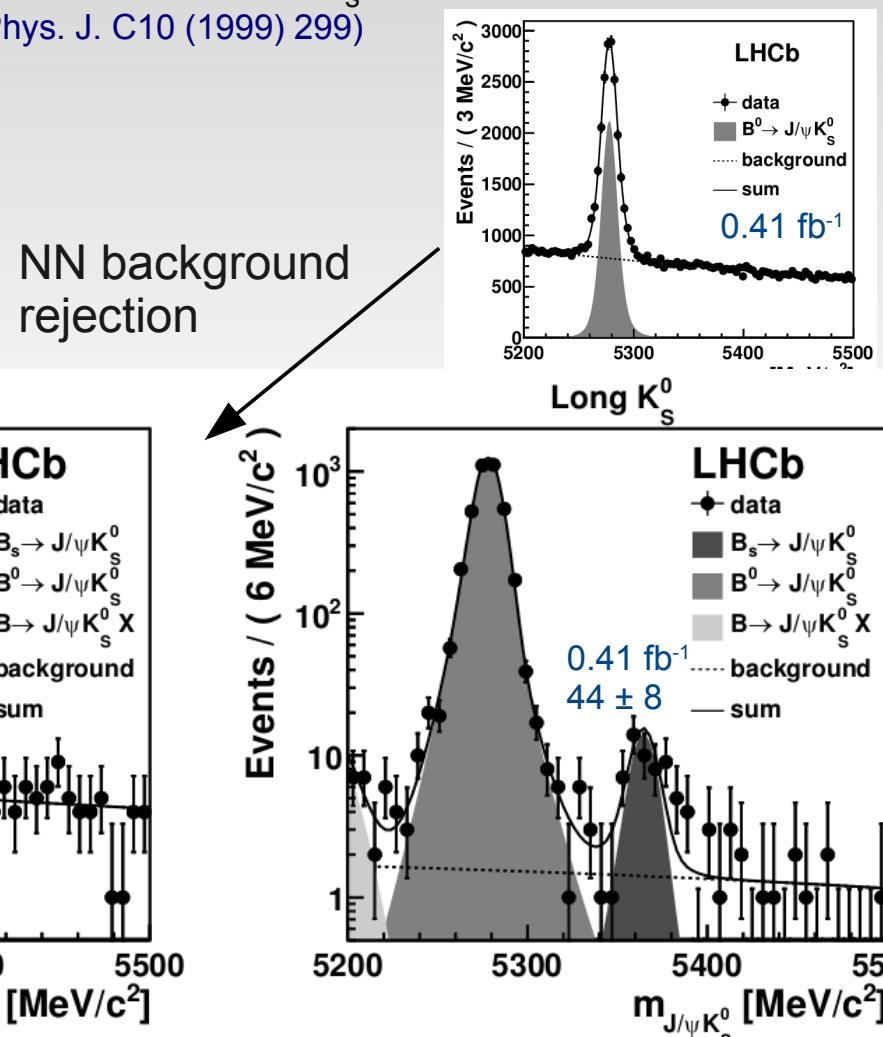
LHCb-PAPER-2011-041

- Motivation: to understand penguin contribution in $B^0 \rightarrow J/\psi K_s^0$
(R. Fleischer, Eur. Phys. J. C10 (1999) 299)
- Use NN trained on $B^0 \rightarrow J/\psi K_s^0$
- Separate Long and Downstream pions analysis



- f_s/f_d – LHCb result
[Phys. Rev. Lett. 107 (2011) 211801]
- Dominant systematics:
 - mass shape
 - acceptance

- Result: $\mathcal{B}(B_s^0 \rightarrow J/\psi K_s^0) = [1.83 \pm 0.21 \text{ (stat)} \pm 0.10 \text{ (syst)} \pm 0.14 \text{ } (f_s/f_d) \pm 0.07 \text{ } (\mathcal{B}(B^0 \rightarrow J/\psi K_s^0))] \times 10^{-5}$
- most precise measurement to date and compatible with expectations from SU(3)



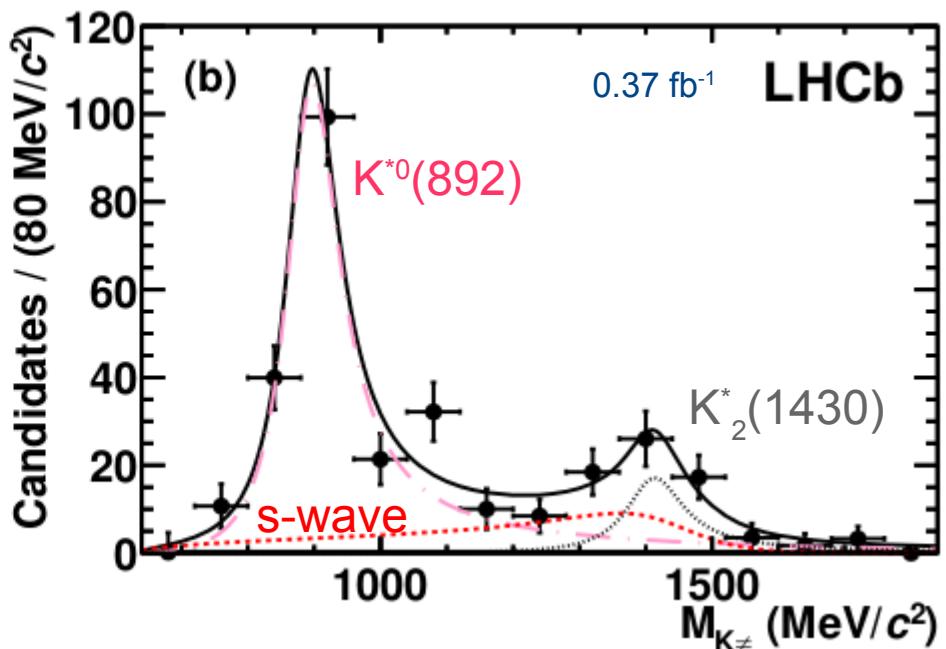
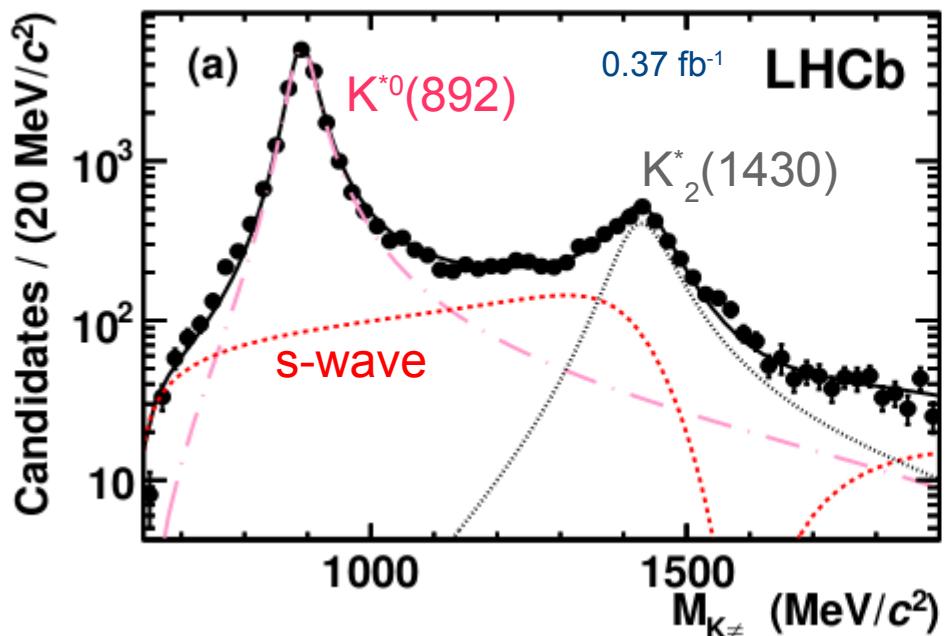
NN background rejection

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

branching ratio & angular amplitudes



- Motivation: to understand penguin contribution in $B_s \rightarrow J/\psi \varphi$
(Faller, Fleischer, Mannel, Phys. Rev. D79 (2009) 014005)
- Already preliminary LHCb BR measurement
→ improve the BR measurement
+ angular properties
- Use $B^0 \rightarrow J/\psi K^{*0}$ as normalization channel
- Resonant structure of $K\pi$

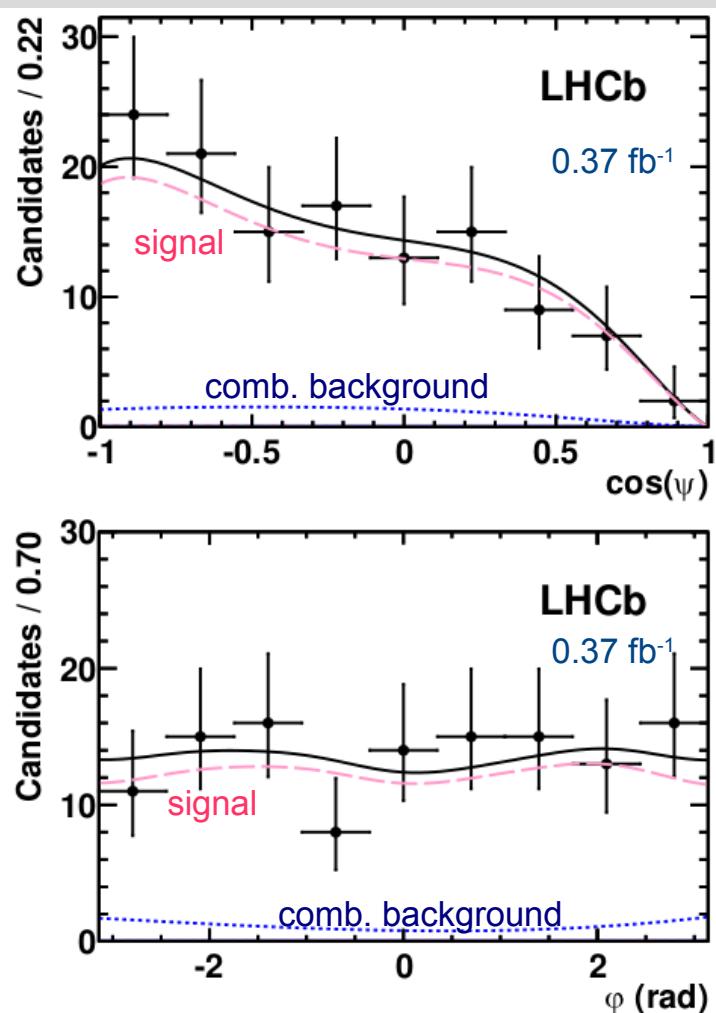
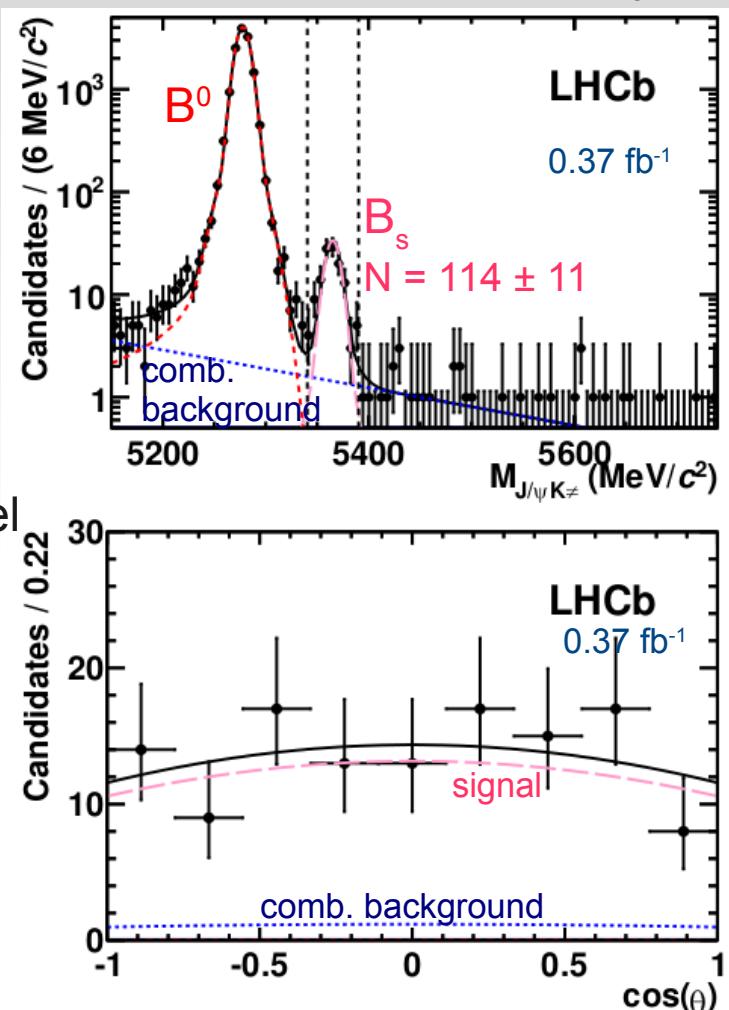


$B_s \rightarrow J/\psi K^{*0}$ BR & angular amplitudes



LHCb-PAPER-2012-014,
Phys. Rev. D 86 (2012) 071102

- Simultaneous fit of mass and angular distributions for B_s
- fit: signal($f_L, f_{||}, \delta_{||}$)
+ s-wave + comb. bkg
- B^0 as a cross-check
- Dominant systematics:
angular acceptance
background angular model



- Results:
- $BR(B_s \rightarrow J/\psi K^{*0}) = (4.4^{+0.5}_{-0.4} \pm 0.8) \times 10^{-5}$
 $f_L = 0.50 \pm 0.08 \pm 0.02$
 $f_{||} = 0.19^{+0.10}_{-0.08} \pm 0.02$
 $|A_s|^2 = 0.07^{+0.15}_{-0.07} (\text{within } \pm 40 \text{ MeV}/c^2)$

- BR is compatible with CDF result, but more precise
- the first measurement of the polarization fractions



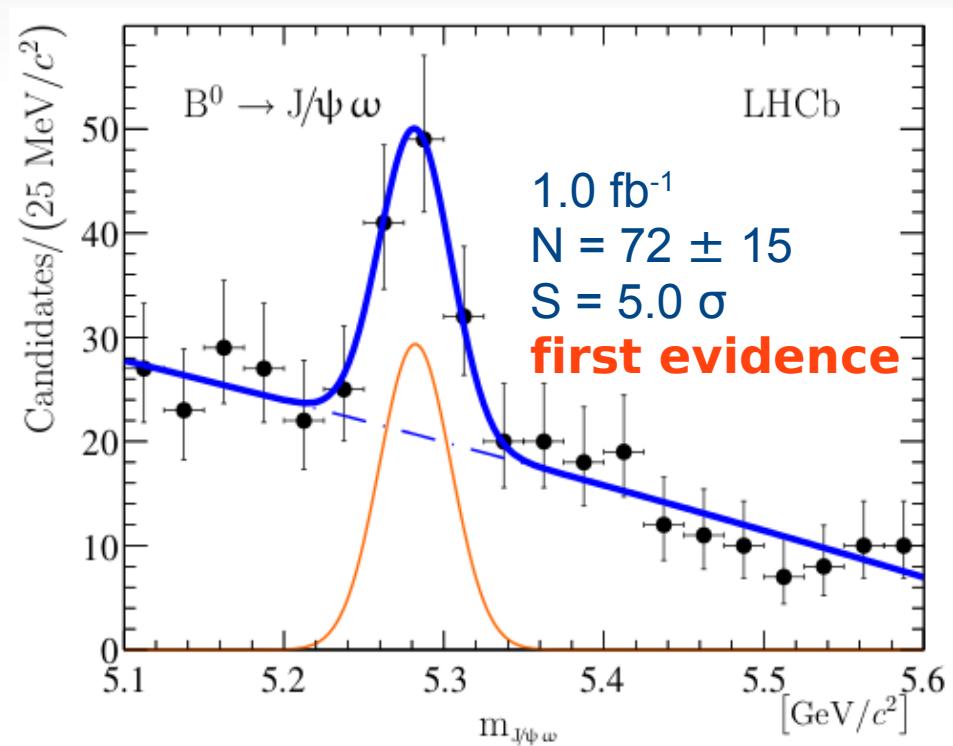
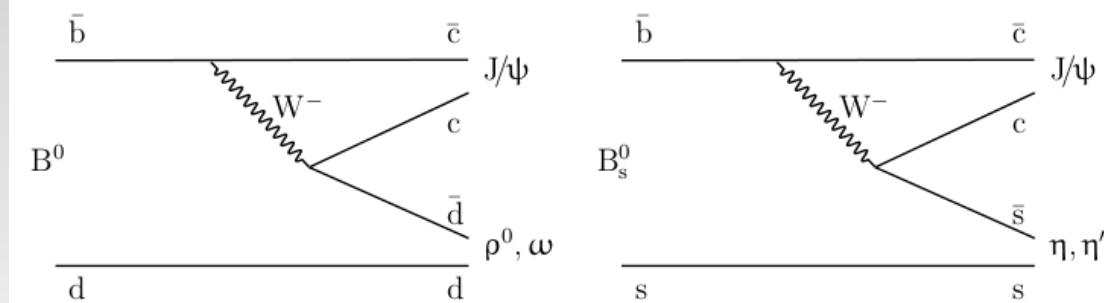
B⁰→J/ψω, B_s→J/ψη(')

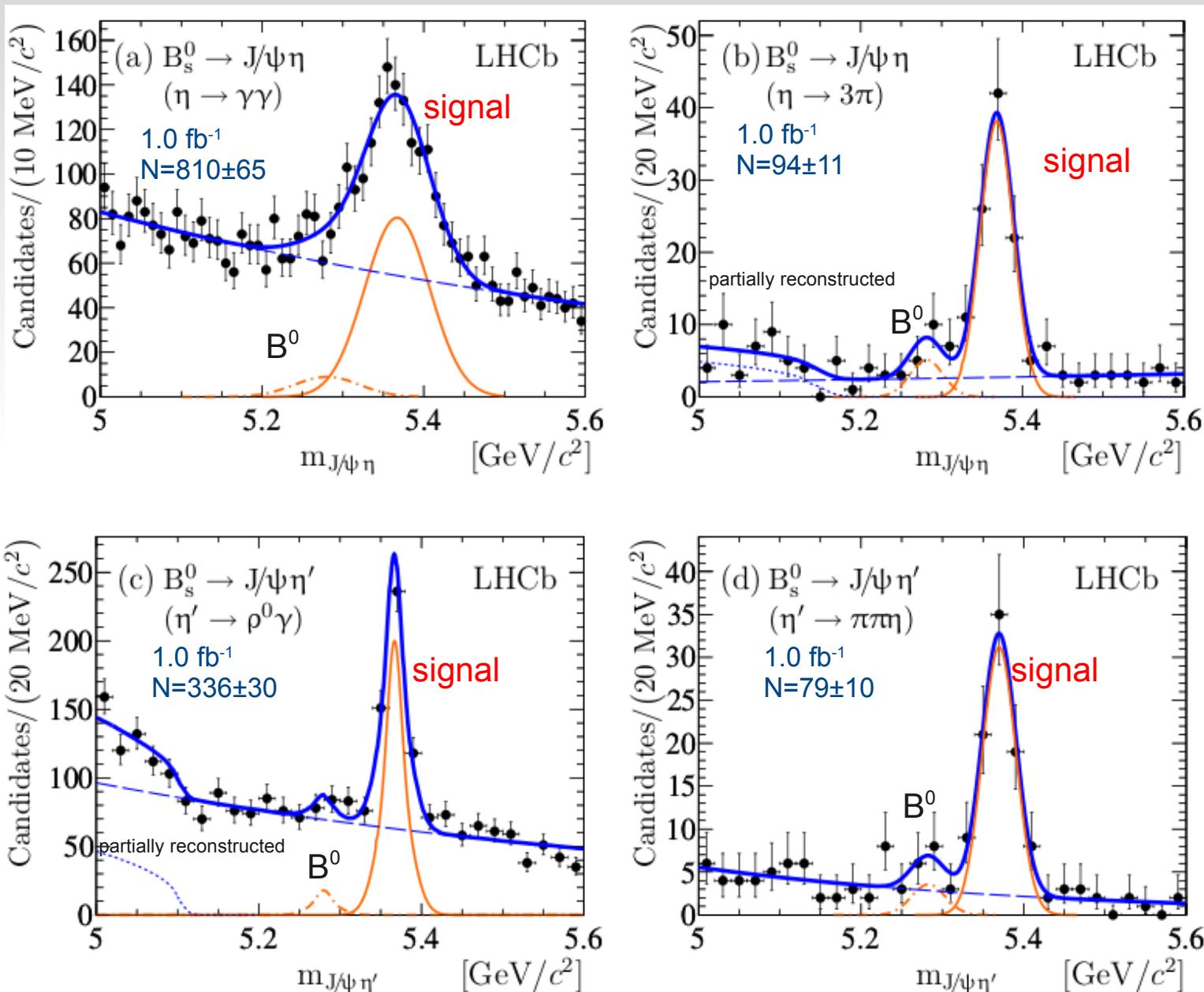


- Motivation:
 - Explore hadronic interactions
 - New channel for CPV studies
 - Estimation of gluonic component in η'

- Measure BR's relative to $B^0 \rightarrow J/\psi \rho^0 (\rightarrow \pi^+ \pi^-)$ and between $B_s \rightarrow J/\psi \eta$ and $B_s \rightarrow J/\psi \eta'$

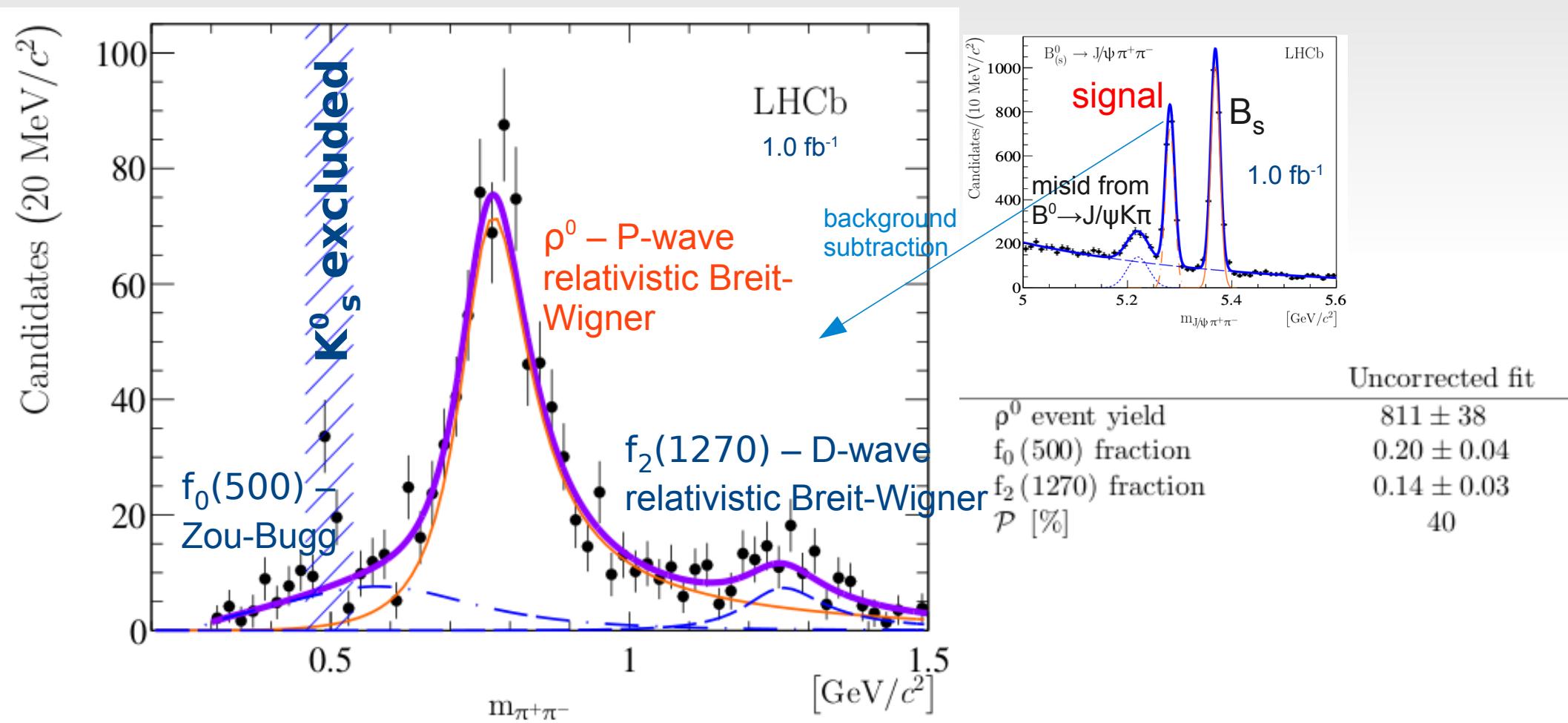
- Reconstruct $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \pi^+ \pi^- \pi^0$, $\eta' \rightarrow \rho^0 \gamma$,
 $\eta' \rightarrow \pi^+ \pi^- \eta$ and $\omega \rightarrow \pi^+ \pi^- \pi^0$







- The $B^0 \rightarrow J/\psi \rho^0 (\rightarrow \pi^+ \pi^-)$ decay were used for normalization





- Estimate efficiencies from simulation
- Systematic uncertainties:
 - photon or pion reconstruction efficiency
 - fit function
 - trigger
 - $BR(\eta, \eta', \omega)$
- Averaging BR's over different modes with simplified simulation

$$\frac{\mathcal{B}(B^0 \rightarrow J/\psi \omega)}{\mathcal{B}(B^0 \rightarrow J/\psi \rho^0)} = 0.89 \pm 0.19(\text{stat})^{+0.07}_{-0.13}(\text{syst})$$

- $B^0 \rightarrow J/\psi \omega$ – the first measurement
- $\eta-\eta'$: consistent with Belle, but more precise

$$\mathcal{R}_{B_s^0, \eta'}^{B_s^0, \eta'} = \frac{\mathcal{B}(B_s^0 \rightarrow J/\psi \eta')}{\mathcal{B}(B_s^0 \rightarrow J/\psi \eta)} = 0.90 \pm 0.09(\text{stat})^{+0.06}_{-0.02}(\text{syst})$$

$$\frac{\mathcal{B}(B_s^0 \rightarrow J/\psi \eta)}{\mathcal{B}(B^0 \rightarrow J/\psi \rho^0)} = 14.0 \pm 1.2(\text{stat})^{+1.1}_{-1.5}(\text{syst})^{+1.1}_{-1.0} \left(\frac{f_d}{f_s} \right)$$

$$\frac{\mathcal{B}(B_s^0 \rightarrow J/\psi \eta')}{\mathcal{B}(B^0 \rightarrow J/\psi \rho^0)} = 12.7 \pm 1.1(\text{stat})^{+0.5}_{-1.3}(\text{syst})^{+1.0}_{-0.9} \left(\frac{f_d}{f_s} \right)$$

Other measurements...



- Observation of $B_s^0 \rightarrow J/\psi f_2(1525)$ in $J/\psi K^+K^-$ final states, Phys. Rev. Lett. 108 (2012) 151801, LHCb-PAPER-2011-026
- First observation of $B_s^0 \rightarrow J/\psi f_0(980)$ decays, Phys. Lett. B 698 (2011) 115–122, LHCb-PAPER-2011-002

particularly CP violation

- Measurement of the time-dependent CP asymmetry in $B^0 \rightarrow J/\psi K_s^0$ decays, PAPER-2012-035
- Untagged angular analysis of $B^0 \rightarrow J/\psi K^{*0}$ and $B_s^0 \rightarrow J/\psi \phi$ decays, CONF-2011-002
- b-hadron lifetime measurements with exclusive $b \rightarrow J/\psi X$ decays reconstructed in the 2010 data, CERN-LHCb-CONF-2011-001
- Measurement of the $B^0 - \bar{B}^0$ oscillation frequency Δm_d with the decays $B^0 \rightarrow D^- \pi^+$ and $B^0 \rightarrow J/\psi K^{*0}$, Phys. Lett. B (), LHCb-PAPER-2012-032
- Measurement of the \bar{B}_s^0 effective lifetime in the $J/\psi f_0(980)$ final state, Phys. Rev. Lett. 109 (2012) 152002, LHCb-PAPER-2012-017
- Determination of the sign of the decay width difference in the B_s^0 system, Phys. Rev. Lett. 108 (2012) 241801, LHCb-PAPER-2011-028
- Measurement of the CP-violating phase ϕ_s in the decay $B_s^0 \rightarrow J/\psi \phi$, Phys. Rev. Lett. 108 (2012) 101803, LHCb-PAPER-2011-021
- Measurement of the CP violating phase ϕ_s in $B_s^0 \rightarrow J/\psi f_0(980)$, Phys. Lett. B 707 (2012) 497–505, LHCb-PAPER-2011-031

Conclusion



- LHCb shows excellent performance in measuring B decays to charmonia
- Most precise measurements of relative rates for $B \rightarrow \psi(2S)X$ and $B \rightarrow J/\psi X$,
+ BR's and A^{CP} for $B^+ \rightarrow \psi\pi^+$ are measured
- First investigation of resonance structure in $B_s \rightarrow J/\psi\pi^+\pi^-$ decays
→ provides new data sample for φ_s measurement
- Most precise branching ratio measurement of $B_s \rightarrow J/\psi K_s^0$
- First measurement of polarization fractions of $B_s \rightarrow J/\psi K^{*0}$
- First evidence for the $B^0 \rightarrow J/\psi\omega$,
most precise measurement of relative $B_s \rightarrow J/\psi\eta(')$ rates
- Many CPV studies with $B \rightarrow J/\psi X$
- LHCb has collected almost 2.0 fb^{-1} in 2012 → more results to come...