21st International Conference on Supersymmetry and Unification of Fundamental Interactions
ICTP Trieste, Italy, 26—31 August 2013

The Abdus Salam International Centre for Theoretical Physics

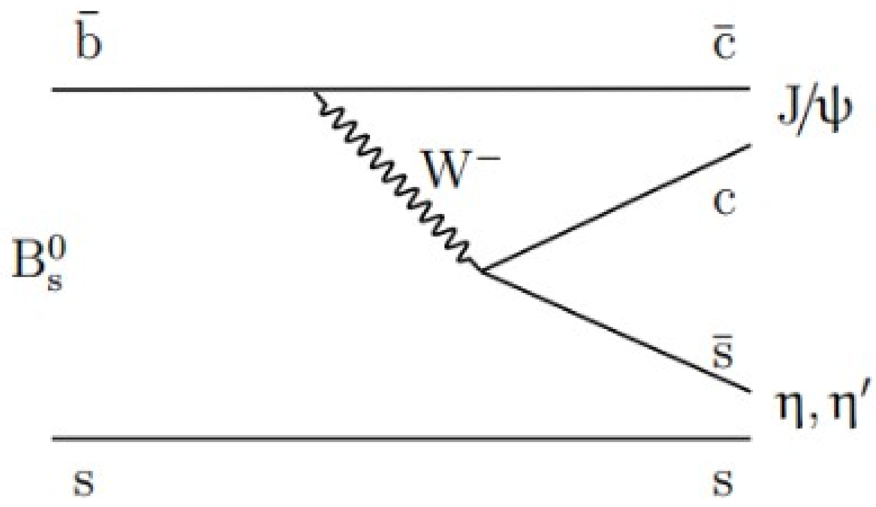
Study of $B_s \to J/\psi\eta$ and $B_s \to J/\psi\eta'$ decays at LHCb

D. Savrina
(ITEP&SINP MSU)

On behalf of the LHCb collaboration

$B_s \to J/\psi\eta^{(\prime)}$ decays

Dominated by the color-suppressed tree diagrams:



Physics motivation:

Measurement of the B-mesons effective lifetimes

[Eur.Phys.J. C71 (2011) 1798]

Measurement of the CP-violation and B_s- mesons mixing angle

[Eur.Phys.J. C71 (2011) 1798]

Measurement of the η-η' mixing angle and gluonic component contribution

[Eur.Phys.J. C71 (2011) 1798]

η-η' mixing

The η- and η'-mesons are the result of mixing between a singlet and octet states:

Phys.Rev. D85 (2012) 013016
Eur.Phys.J. C71 (2011) 1798

$$\begin{pmatrix} |\eta\rangle \\ |\eta'\rangle \end{pmatrix} = \begin{pmatrix} \cos\theta_P & -\sin\theta_P \\ \sin\theta_P & \cos\theta_P \end{pmatrix} \times \begin{pmatrix} |\eta_8\rangle \\ |\eta_1\rangle \end{pmatrix}$$

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In terms of isospin singlets:

$$|\eta\rangle = \cos\phi_P\,|\eta_q\rangle - \sin\phi_P\,|\eta_s\rangle\,,$$

$$|\eta'\rangle = \cos\phi_G \sin\phi_P\,|\eta_q\rangle + \cos\phi_G\cos\phi_P\,|\eta_s\rangle + \sin\phi_G\,|gg\rangle$$

$$|\eta_q\rangle = \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle\right)\,,\quad |\eta_s\rangle = |s\bar{s}\rangle$$

Mixing phases

Purely gluonic component

Global fit between previous measurements:

Not taking into account the gluonic component: $\phi_P = (41.4 \pm 0.5)^o$

Taking into account the gluonic component: $\phi_P = (39.7 \pm 0.7)^o$
$\phi_G = (22 \pm 3)^o$

[KLOE, Phys.Lett.B648 (2007) 267]

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Mixing phases

Purely gluonic component

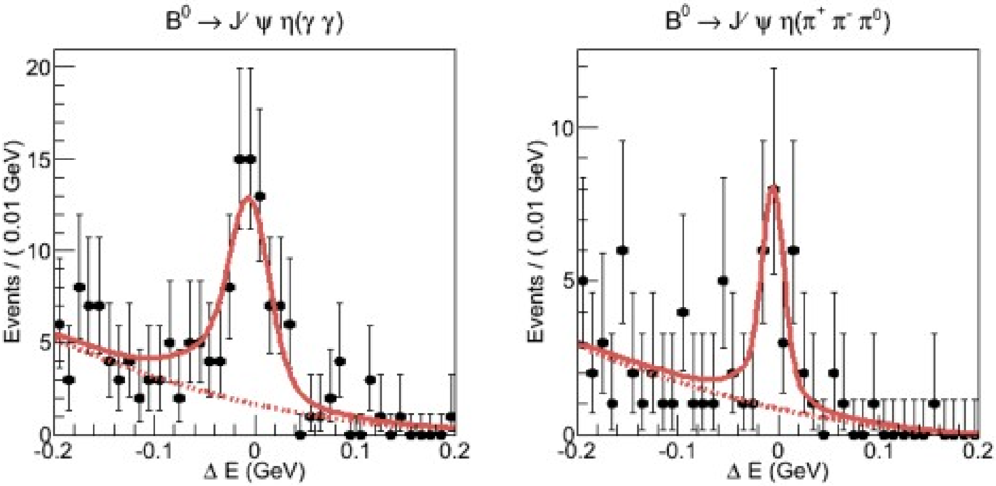
Ratio of branching fractions:

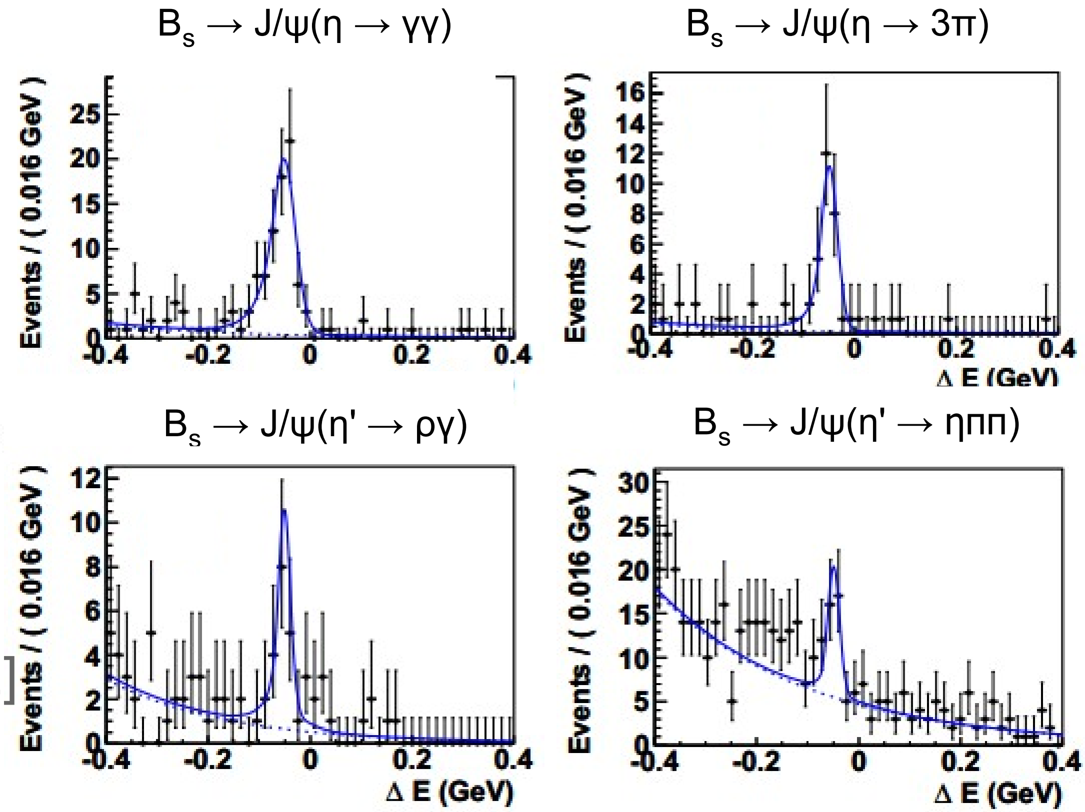
Not taking into account the gluonic component: $$\frac{\mathcal{B}(B_s^0\to J\psi\eta')}{\mathcal{B}(B_s^0\to J\psi\eta)}\cdot\frac{\mathcal{F}_s^{\eta}}{\mathcal{F}_s^{\eta'}} = \frac{\cos^2\phi_G}{\tan^2\phi_P}$$

Taking into account the gluonic component: $$\frac{\mathcal{B}(B_s^0\to J\psi\eta')}{\mathcal{B}(B_s^0\to J\psi\eta)}\cdot\frac{\mathcal{F}_s^{\eta}}{\mathcal{F}_s^{\eta'}} = \frac{1}{\tan^2\phi_P}$$

Previous studies

Belle, 2012





$BR(B^0 \to J/\psi\eta) = (12.3 \pm 1.8 \pm 0.7) \times 10^{-6}$

$BR(B^0 \to J/\psi\eta') < 7.4 \times 10^{-6}$ @90% CL

[Phys.Rev. D85 091102]

$BR(B_s \to J/\psi\eta) = (5.1 \pm 0.50 \pm 0.25) \times 10^{-4}$

$BR(B_s \to J/\psi\eta') = (3.71 \pm 0.60 \pm 0.18) \times 10^{-4}$

$$\frac{BR(B_s \to J/\psi\eta')}{BR(B_s \to J/\psi\eta)} = 0.73 \pm 0.14 \pm 0.02$$

[Phys. Rev. Lett. 108,181808]

Theoretical prediction

(no glueball contribution)

P. Colangelo, F. De Fazio, W. Wang

$BR(B_s \to J/\psi\eta) = (4.3 \pm 0.2) \times 10^{-4}$

$BR(B_s \to J/\psi\eta') = (4.4 \pm 0.2) \times 10^{-4}$

[Phys.Rev.D83:094027,2011]

The LHCb experiment

Experiment devoted to the studies of the heavy flavour physics

High b- and c-quarks production rates. At 7 TeV:

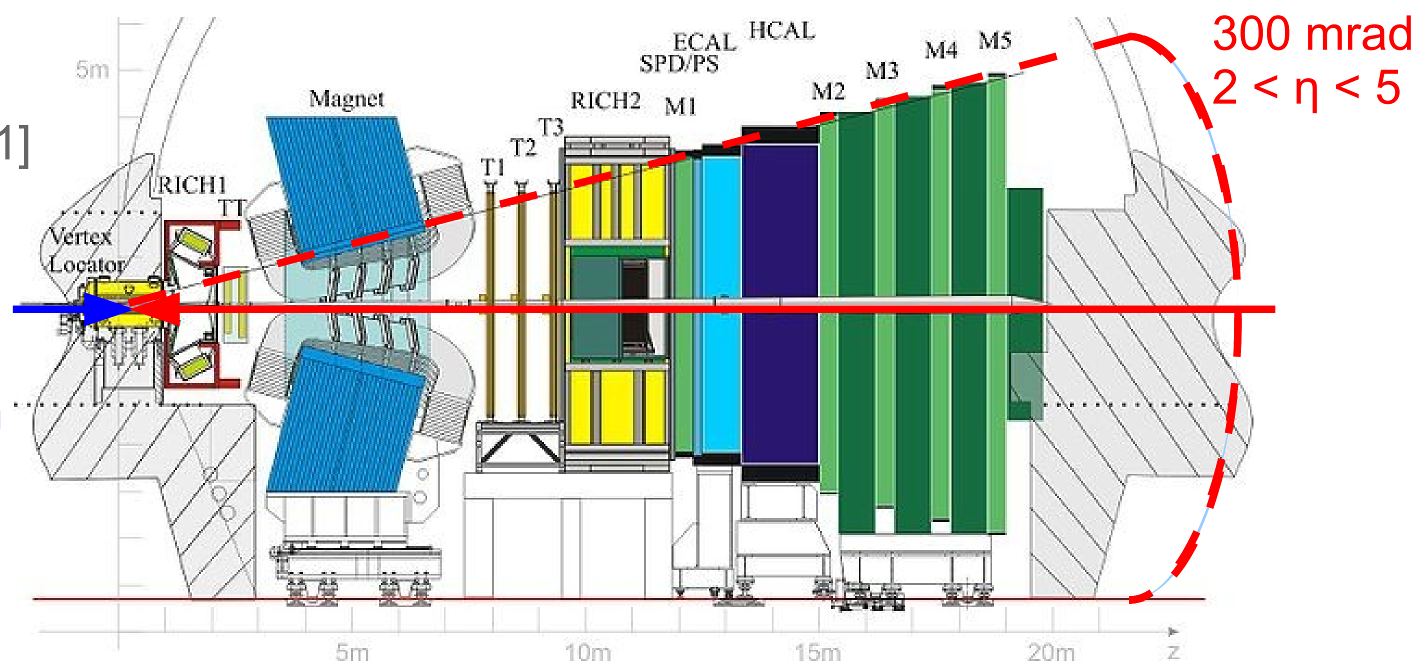
– σ(pp → ccX) = ~6 mb
[Nucl.Phys.B 871 (2013) 1]

– σ(pp → bbX) = ~0.3 mb
[PLB 694 (2010) 209]

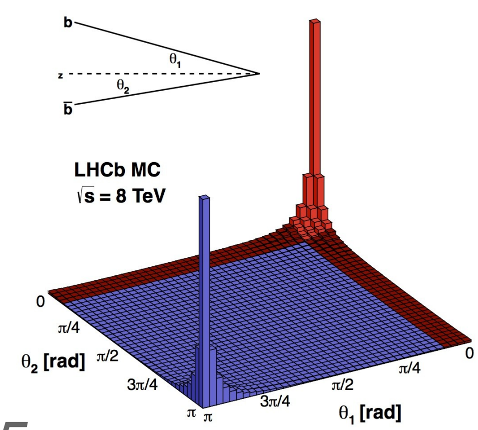
All possible beauty and charm species are produced

Cross-section in LHCb acceptance @7TeV

σ_{bb} = 75μb
[PLB 694 (2010) 209]



[JINST 3 (2008) S08005]

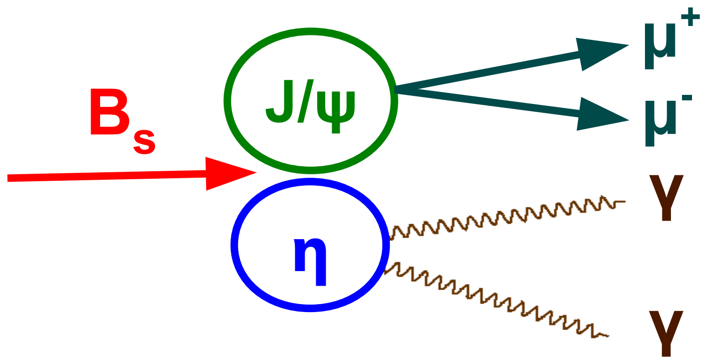


Propertime resolution: ~45 fs
Momentum resolution: ~0.4% for 5 GeV/c tracks
~0.6% for 100 GeV/c tracks

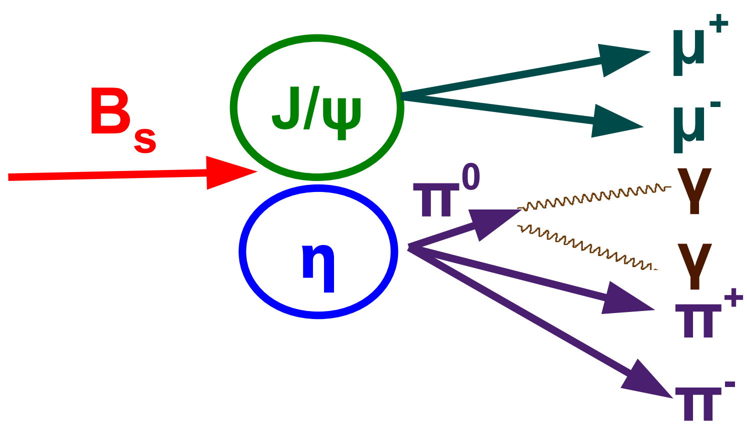
Charged pions
identification efficiency: ~95% are successfully identified
Photon energy resolution: ~1%
Muon identification efficiency: ~97% are successfully identified
Muon trigger efficiency: ~90%

Reconstructed decay modes

$B_s \rightarrow J/\psi\eta$ decays

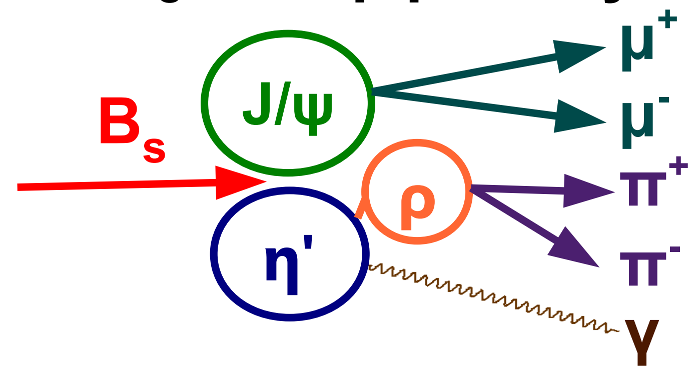


$BR(\eta \rightarrow \gamma\gamma) = (39.31 \pm 0.20)\%$

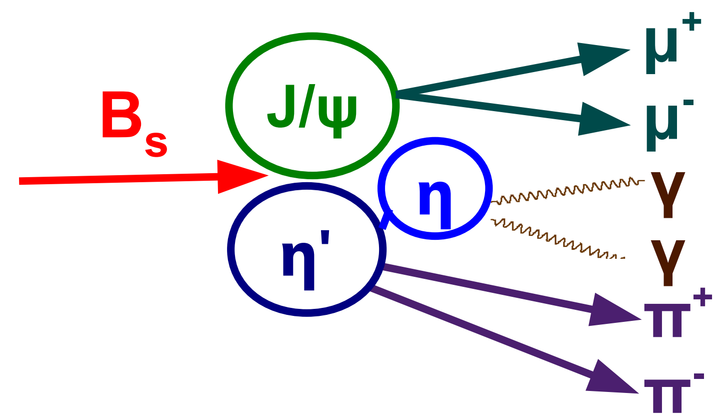


$BR(\eta \rightarrow \pi^+\pi^-(\pi^0 \rightarrow \gamma\gamma)) = (22.74 \pm 0.28)\%$

$B_s \rightarrow J/\psi\eta'$ decays

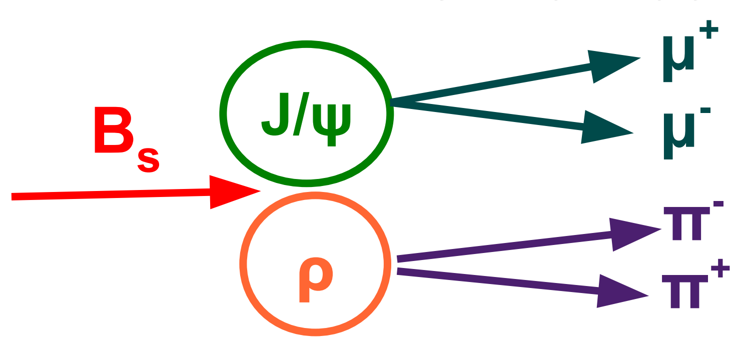


$BR(\eta' \rightarrow \rho\gamma) = (29.3 \pm 0.3)\%$



$BR(\eta' \rightarrow \pi^+\pi^-(\eta \rightarrow \gamma\gamma)) = (18.6 \pm 0.3)\%$

Normalization channel $B \rightarrow J/\psi\rho$



$BR(B^0 \rightarrow J/\psi\rho) = (2.7 \pm 0.4)\times 10^{-4}$

Cut-based analysis

Similar selections for all the signal and normalization channels

Branching fractions measurement

Data description

1.0 fb^{-1} of data collected in 2011
Proton-proton collisions
Center of mass energy 7 TeV

Particle data group 2012

Phys. Rev. D 85 032008
LHCb 2012

$$\frac{\mathcal{B}(B \to \psi X^0)}{\mathcal{B}(B \to \psi Y^0)} = \frac{N_{\psi X^0}}{N_{\psi Y^0}} \times \frac{\varepsilon^{tot}_{\psi Y^0}}{\varepsilon^{tot}_{\psi X^0}} \times \frac{\mathcal{B}(Y^0)}{\mathcal{B}(X^0)} \times \frac{f_y}{f_x}$$

$X^0, Y^0 = \eta, \eta', \rho$

Simulation
(cross-check with data, where possible)

$$\frac{\varepsilon^{tot}_{\psi Y^0}}{\varepsilon^{tot}_{\psi X^0}} = \frac{\varepsilon^{acc\&gen}_{\psi Y^0}}{\varepsilon^{acc\&gen}_{\psi X^0}} \times \frac{\varepsilon^{reco\&sel}_{\psi Y^0}}{\varepsilon^{reco\&sel}_{\psi X^0}} \times \frac{\varepsilon^{trig}_{\psi Y^0}}{\varepsilon^{trig}_{\psi X^0}} \times \eta^{corr}$$

The final result is obtained by averaging between the various η and η' modes

Photon correction

To compencate the difference between the simulation and the data

$$\eta^{corr}_{\pi^0} = \frac{N^{B^+ \to J/\psi (K^{*+} \to K^+ \pi^0)}}{N^{B^+ \to J/\psi K^+}} \times \frac{\varepsilon^{MC}_{B^+ \to J/\psi K^+}}{\varepsilon^{MC}_{B^+ \to J/\psi (K^{*+} \to K^+ \pi^0)}} \times \frac{\mathcal{B}(B^+ \to J/\psi K^+)}{\mathcal{B}(B^+ \to J/\psi (K^{*+} \to K^+ \pi^0))},$$

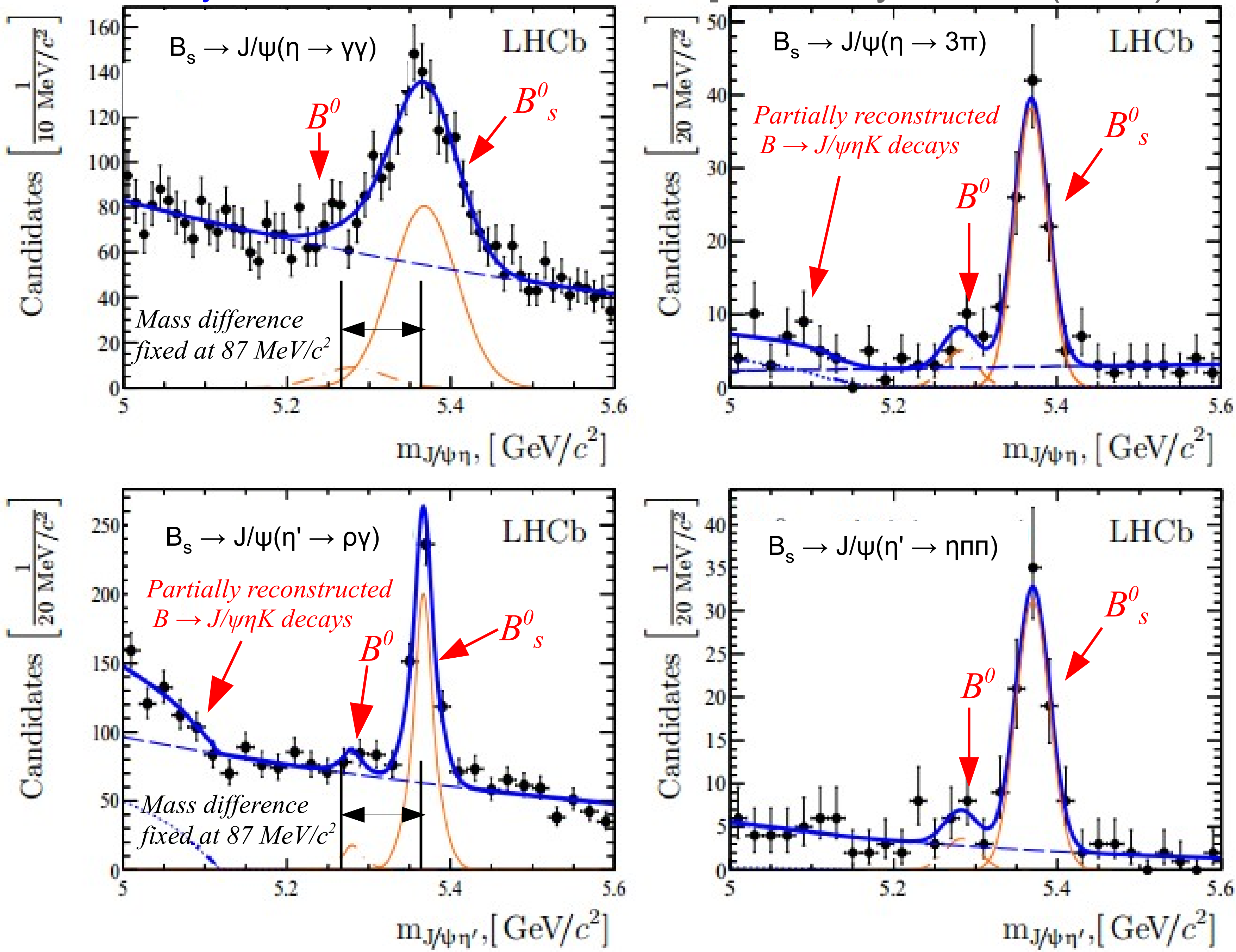
$B \to J/\psi\eta^{(\prime)}$ decays

[Nucl. Phys. B867 (2013) 547-566]

Signals observation

Integrated luminosity 1.0 fb^{-1}

[Nucl. Phys. B867 (2013) 547-566]



Fit results

For the B_s signals

Mode	$\mathcal{Y}_{B_s^0}$	$m_{B_s^0}$ [MeV/c^2]	$\sigma_{B_s^0}$ [MeV/c^2]	$\sigma_{B_s^0}^{MC}$ [MeV/c^2]	$\mathcal{S}_{B_s^0}$
$J/\psi\,\eta$, $\eta \to \gamma\gamma$	810 ± 65	5367 ± 4	40.1 ± 3.6	38.5 ± 0.6	15.7σ
$J/\psi\,\eta$, $\eta \to \pi^+\pi^-\pi^0$	94 ± 11	5368 ± 3	20.3 ± 2.3	17.6 ± 0.4	7.0σ
$J/\psi\,\eta'$, $\eta' \to \rho^0\gamma$	336 ± 30	5367 ± 1	8.0 ± 1.1	5.1 ± 0.6	12.2σ
$J/\psi\,\eta'$, $\eta' \to \pi^+\pi^-\eta$	79 ± 10	5369 ± 3	20.7 ± 2.3	16.4 ± 0.4	10.5σ

Signal positions
In agreement with the PDG value

Signal resolutions
In agreement with the expectation from the simulation

Signal significances

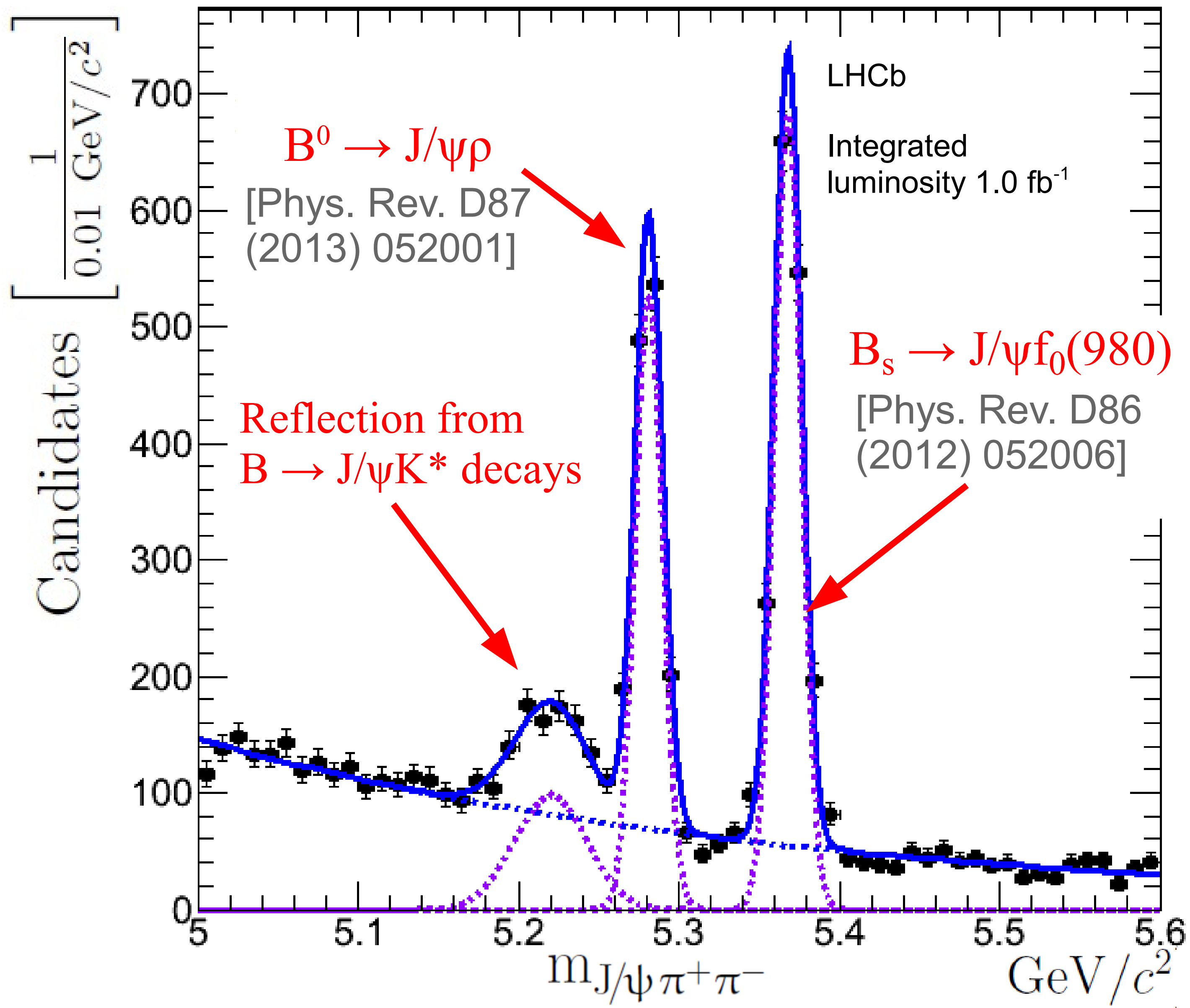
$$\mathcal{S} = \sqrt{-2 \times \ln \frac{\mathcal{L}_{\mathcal{B}}}{\mathcal{L}_{\mathcal{S}+\mathcal{B}}}},$$

The normalization channel
$B^0 \to J/\psi\rho^0$

[Nucl. Phys. B867 (2013) 547-566]

$B_{d,s} \to J/\psi\pi^+\pi^-$

Wide $\pi^+\pi^-$ invariant mass window [300; 1500] MeV/c^2



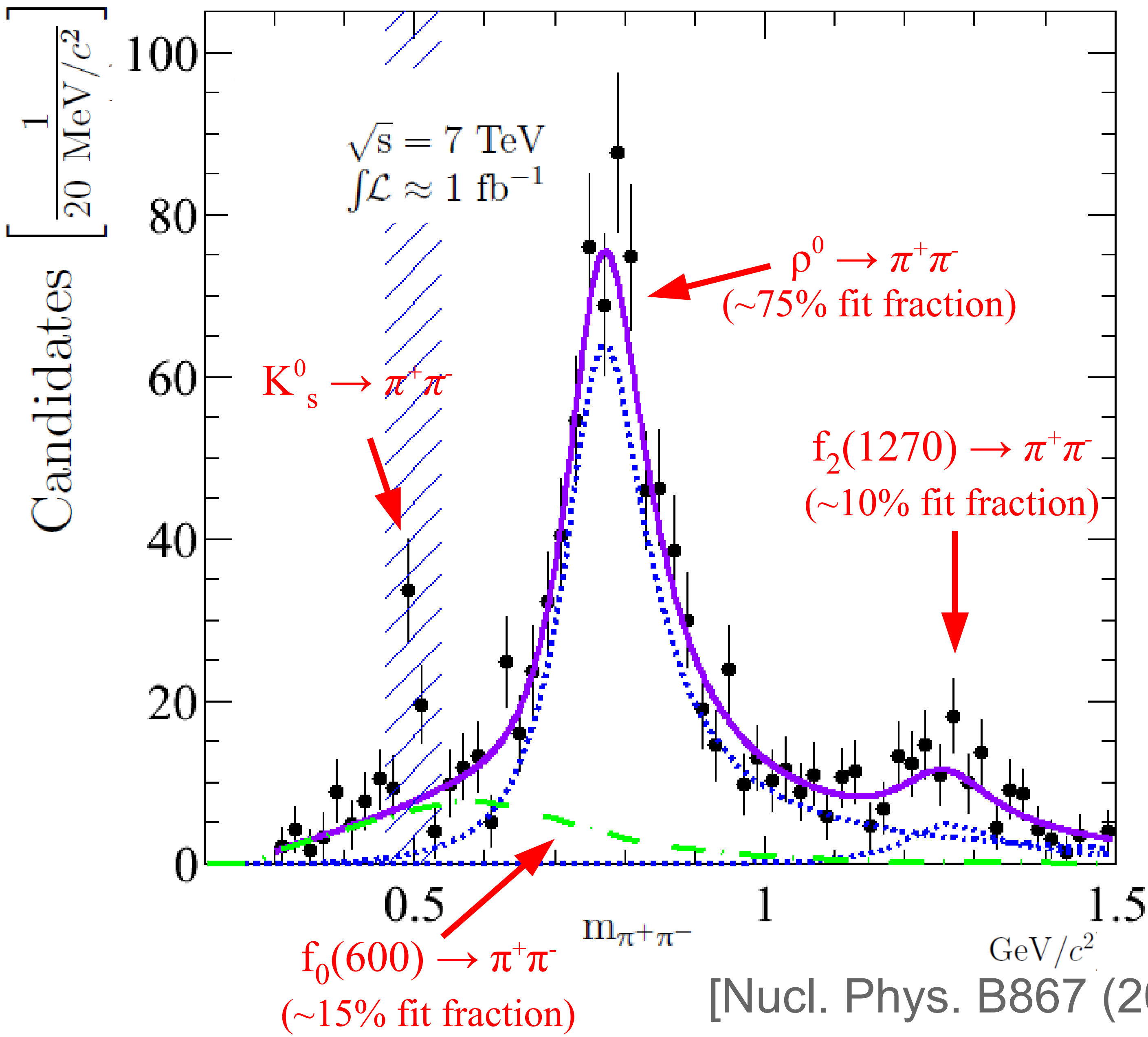
N_{Bs} = 1484 ± 43
M_{Bs} = 5368 ± 2
σ_{Bs} = 8.7 ± 0.2

N_{Bd} = 1143 ± 39
M_{Bd} = 5281 ± 2
σ_{Bd} = 8.7 ± 0.2

[Nucl. Phys. B867 (2013) 547-566]

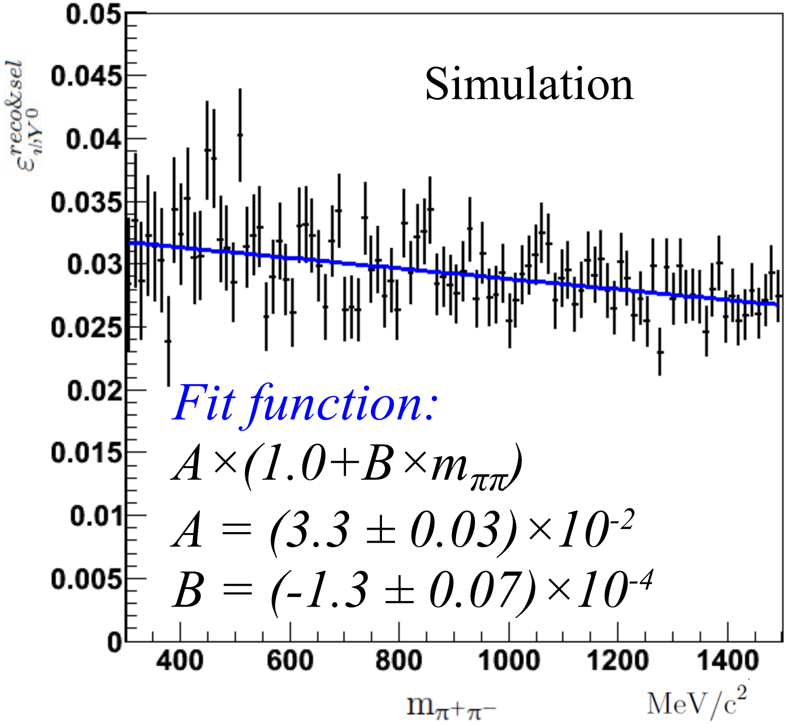
$B^0 \rightarrow J/\psi\pi^+\pi^-$: $\pi^+\pi^-$ invariant mass

The combinatorial background is subtracted (sPlot technique)

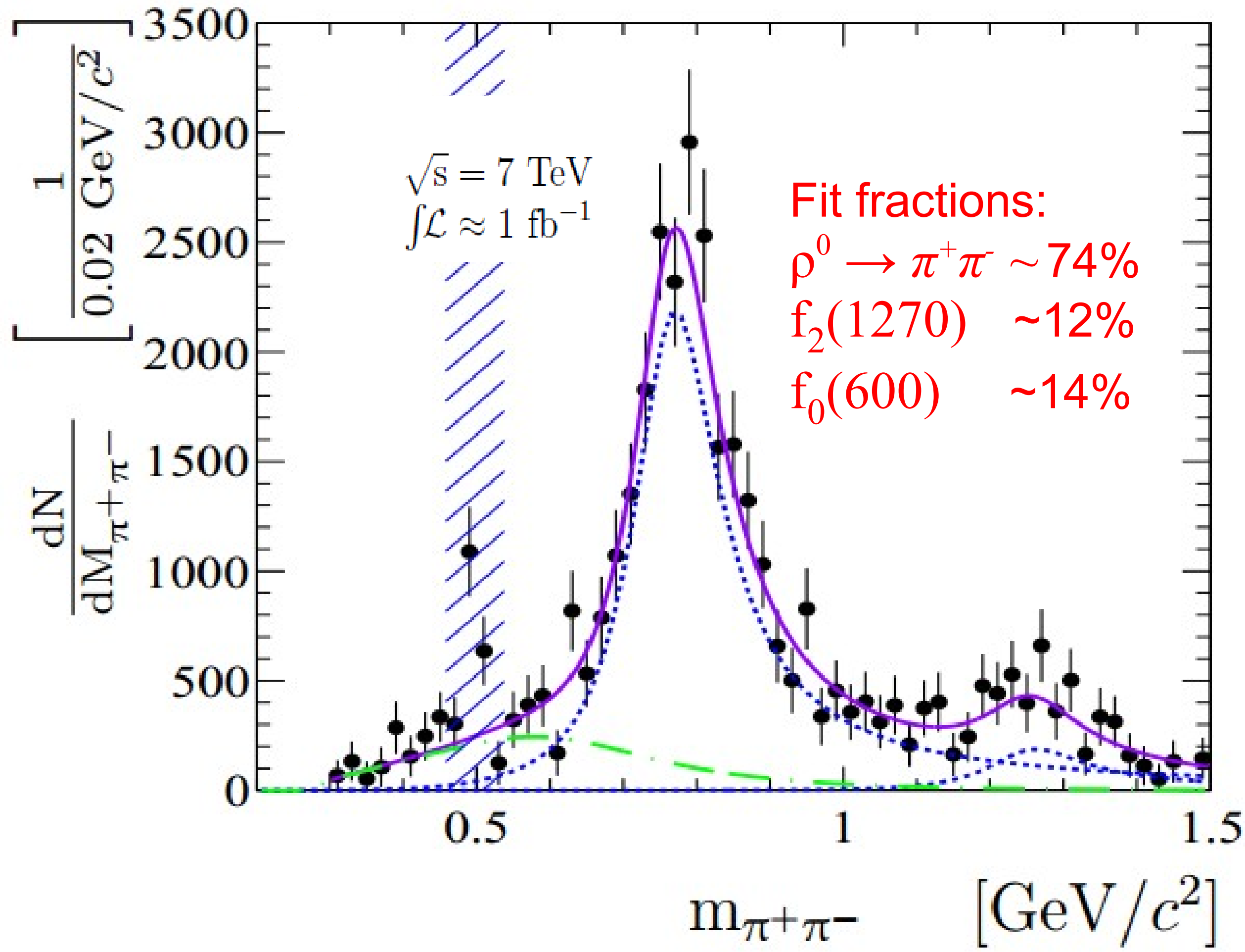


[Nucl. Phys. B867 (2013) 547-566]

Reconstruction and selection efficiency



Efficiency weighted distribution



[Nucl. Phys. B867 (2013) 547-566]

Branching fractions ratio

$$\frac{\mathcal{B}(B \to \psi X^0)}{\mathcal{B}(B \to \psi Y^0)} = \frac{N_{\psi X^0}}{N_{\psi Y^0}} \times \frac{\varepsilon^{tot}_{\psi Y^0}}{\varepsilon^{tot}_{\psi X^0}} \times \frac{\mathcal{B}(Y^0)}{\mathcal{B}(X^0)} \times \frac{f_y}{f_x}$$

$f_s/f_d = 0.267^{+0.021}_{-0.020}$

Mode	Yield	ε^{tot} [%]	η^{corr} [%]	$\mathcal{B}$ [%]
$B^0_s \to J/\psi\eta\,(\eta \to \gamma\gamma)$	810 ± 65	0.236 ± 0.006	98.0 ± 7.5	39.31 ± 0.20
$B^0_s \to J/\psi\eta\,(\eta \to \pi^+\pi^-\pi^0)$	94 ± 11	0.059 ± 0.002	94.1 ± 7.5	22.74 ± 0.28
$B^0_s \to J/\psi\eta'\,(\eta' \to \rho^0\gamma)$	336 ± 30	0.142 ± 0.004	98.0 ± 3.7	29.3 ± 0.6
$B^0_s \to J/\psi\eta'\,(\eta' \to \pi^+\pi^-\eta)$	79 ± 10	0.068 ± 0.003	96.0 ± 7.5	18.6 ± 0.3
Normalization channel				
$B^0 \to J/\psi\rho^0\,(\rho^0 \to \pi^+\pi^-)$	$(27.6 \pm 1.3) \times 10^3$	12.6 ± 0.5	–	98.90 ± 0.16

Reconstruction and selection efficiency is already taken into account

Only geometrical and trigger efficiencies are included

Branching fractions ratio

After averaging between various modes of η and η' modes

$$\mathcal{R}^{B_s^0,\eta'}_{B_s^0,\eta} = 0.90 \pm 0.09\,^{+0.06}_{-0.02},$$

$$\mathcal{R}^{B_s^0,\eta}_{B^0,\rho^0} = 3.75 \pm 0.31\,^{+0.30}_{-0.40} \times \left(\frac{f_d}{f_s}\right)$$

$$\mathcal{R}^{B_s^0,\eta'}_{B^0,\rho^0} = 3.38 \pm 0.30\,^{+0.14}_{-0.36} \times \left(\frac{f_d}{f_s}\right)$$

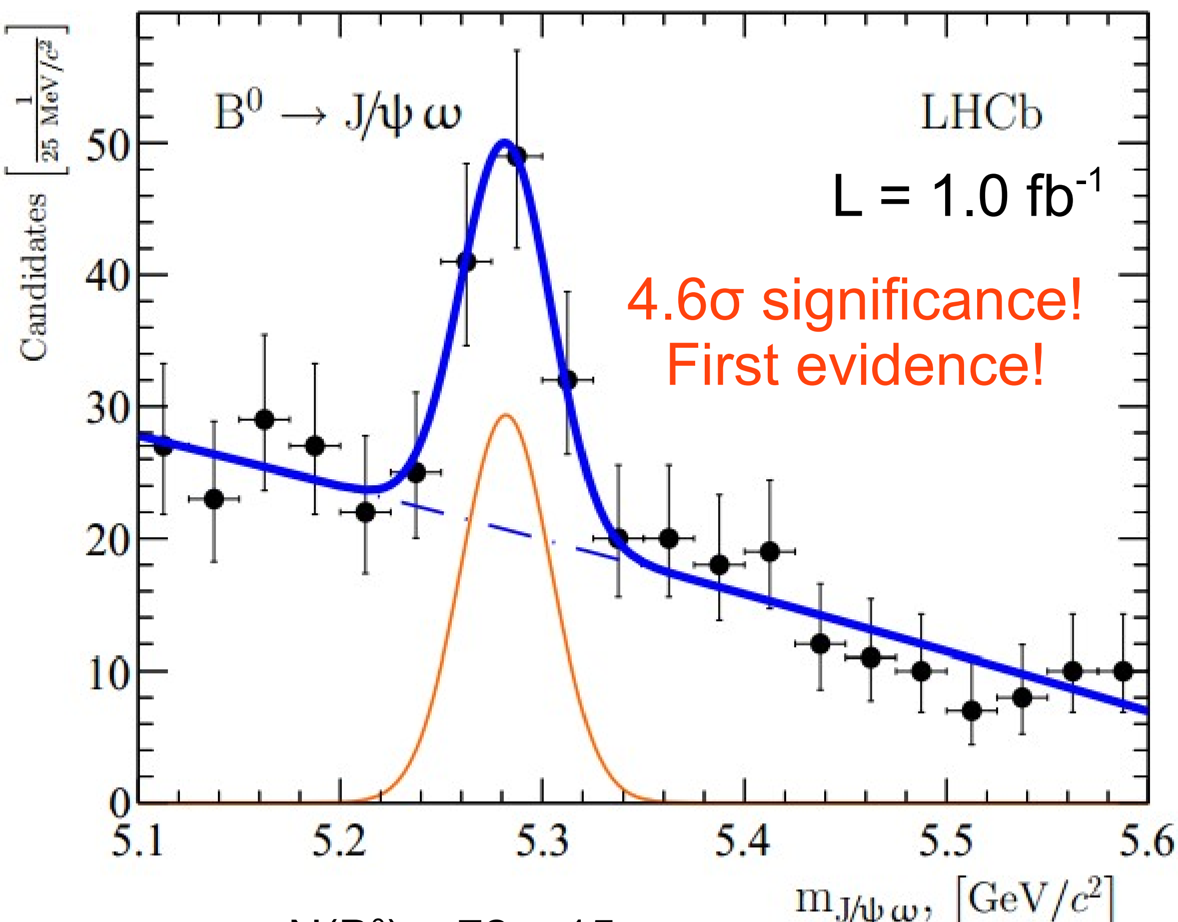
Systematical uncertainties include:

- uncertainty of the photon efficiency correction;
- charged pions reconstruction efficiency;
- trigger efficiency uncertainty;
- data fit uncertainty;
- intermediate resonances (η, η', π^0) decays branching fractions uncertainties.

[Nucl. Phys. B867 (2013) 547-566]

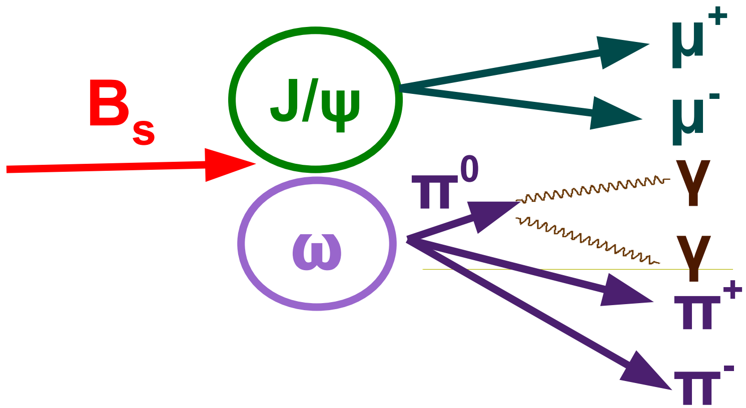
$B^0 \rightarrow J/\psi(\omega^0 \rightarrow \pi^0\pi^+\pi^-)$

Quite similar analysis strategy



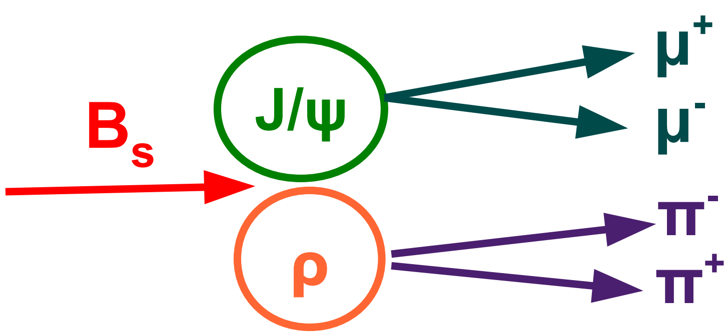
$N(B^0) = 72 \pm 15$
$M(B^0) = 5284 \pm 5$ (MeV/c^2)
$\sigma(B^0) = 23.7 \pm 4.8$ (MeV/c^2)

Reconstructed decay mode



BR($\omega \rightarrow \pi^+\pi^-(\pi^0 \rightarrow \gamma\gamma)$) = (89.2 ± 0.7)%

Normalization channel

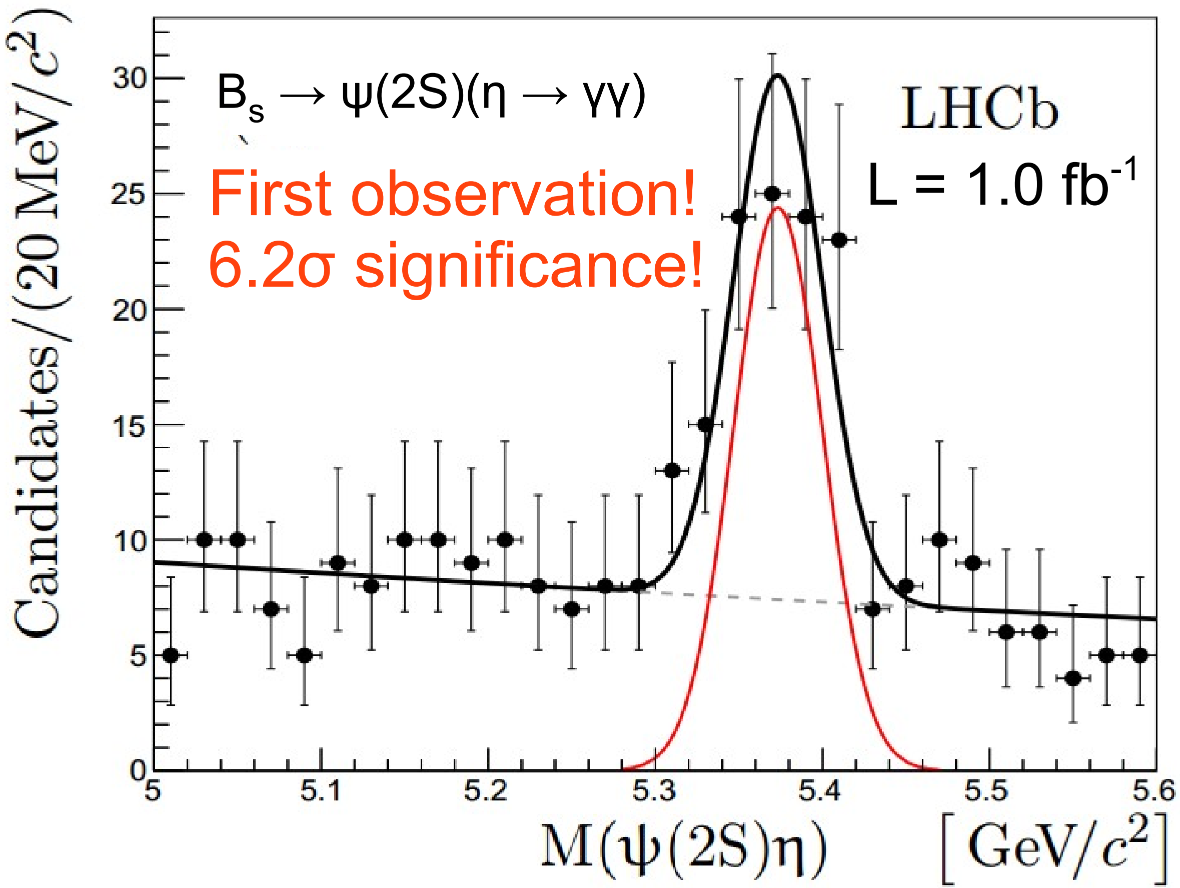


$$\mathcal{B}(B^0 \rightarrow J/\psi\,\omega) = (2.41 \pm 0.52(\mathrm{stat})\,^{+0.19}_{-0.35}(\mathrm{syst}) \pm 0.36(\mathcal{B}_{B^0\rightarrow J/\psi\,\rho^0})) \times 10^{-5}$$

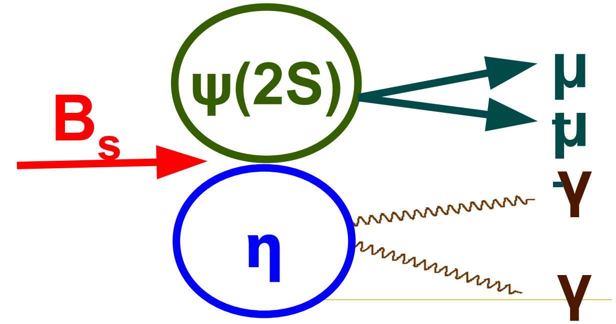
[Nucl. Phys. B867 (2013) 547-566]

The $B_s \to \psi(2S)\eta$ decay

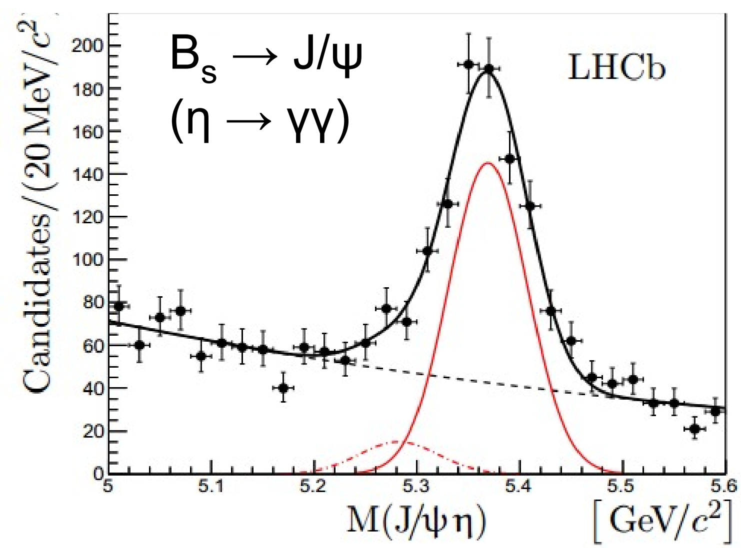
Quite similar analysis strategy



Reconstructed decay mode



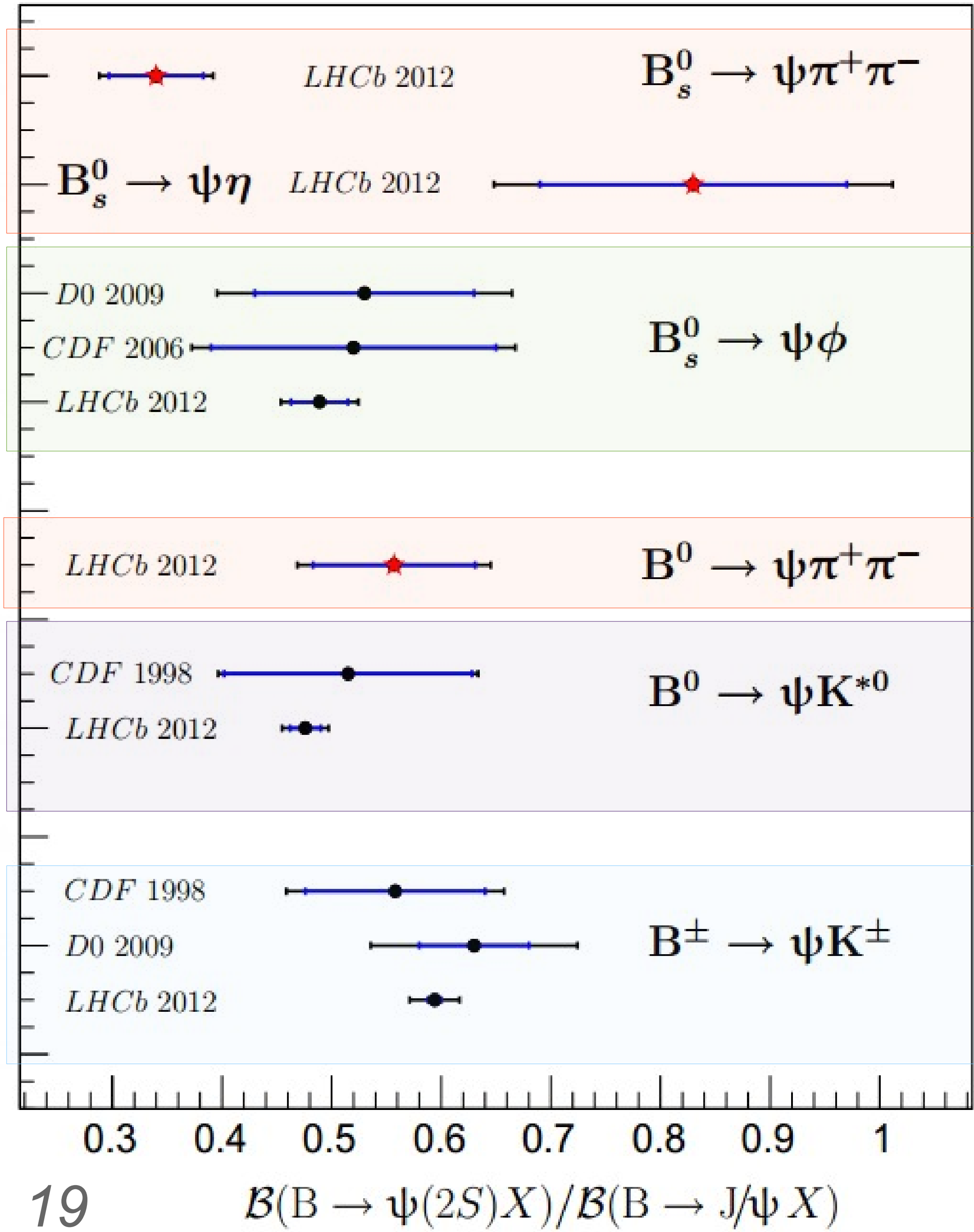
Normalization channel



[Nucl. Phys. B 871 (2013) 403-419]

Mode	N_B	M_B [MeV/c^2]	σ_B [MeV/c^2]
$B_s^0 \to J/\psi\,\eta$	863 ± 52	5370.9 ± 2.3	33.7 ± 2.3
$B_s^0 \to \psi(2S)\eta$	76 ± 12	5373.4 ± 5.0	26.6 fixed

Ratio of branching fractions



[Nucl. Phys. B 871 (2013) 403-419]

$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)\eta)}{\mathcal{B}(B_s^0 \to J/\psi\eta)} = 0.83 \pm 0.14\,(\text{stat}) \pm 0.12\,(\text{syst}) \pm 0.02\,(\mathcal{B})$$

D0: Phys. Rev. D 79, 111102
CDF: Phys. Rev. Lett. 96, 231801
LHCb: Eur. Phys. J. C72 2118

[Nucl. Phys. B 871 (2013) 403-419]

CDF: Phys. Rev. D 58, 072001
LHCb: Eur. Phys. J. C72 2118

CDF: Phys. Rev. D 58, 072001
D0: Phys. Rev. D 79, 111102
LHCb: Eur. Phys. J. C72 2118

Summary

With 1.0 fb^{-1} of data collected by the LHCb experiment in 2011

The $B_s \to J/\psi\eta$ and $B_s \to J/\psi\eta'$ decays are observed

and their branching fractions are measured

$$\mathcal{B}(B^0_s \to J/\psi\,\eta) = \left(3.79 \pm 0.31(\text{stat})\,^{+0.20}_{-0.41}(\text{syst}) \pm 0.56(\mathcal{B}_{B^0\to J/\psi\,\rho^0})\,^{+0.29}_{-0.27}\left(\frac{f_d}{f_s}\right)\right) \times 10^{-4}$$

$$\mathcal{B}(B^0_s \to J/\psi\,\eta') = \left(3.42 \pm 0.30(\text{stat})\,^{+0.14}_{-0.35}(\text{syst}) \pm 0.51(\mathcal{B}_{B^0\to J/\psi\,\rho^0})\,^{+0.26}_{-0.25}\left(\frac{f_d}{f_s}\right)\right) \times 10^{-4}$$

As well as the ratio of their branching fractions:

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

All the values are in a agreement with both Belle measurements and the theoretical prediction

First evidence of the $B^0 \to J/\psi\omega$ decay is found

and its branching fraction is measured

$$\mathcal{B}(B^0 \to J/\psi\,\omega) = (2.41 \pm 0.52(\text{stat})\,^{+0.19}_{-0.35}(\text{syst}) \pm 0.36(\mathcal{B}_{B^0\to J/\psi\,\rho^0})) \times 10^{-5}$$

[Nucl. Phys. B867 (2013) 547-566]

The $B_s \to \psi(2S)\eta$ decay is observed for the first time

and the ratio of branching fractions is measured:

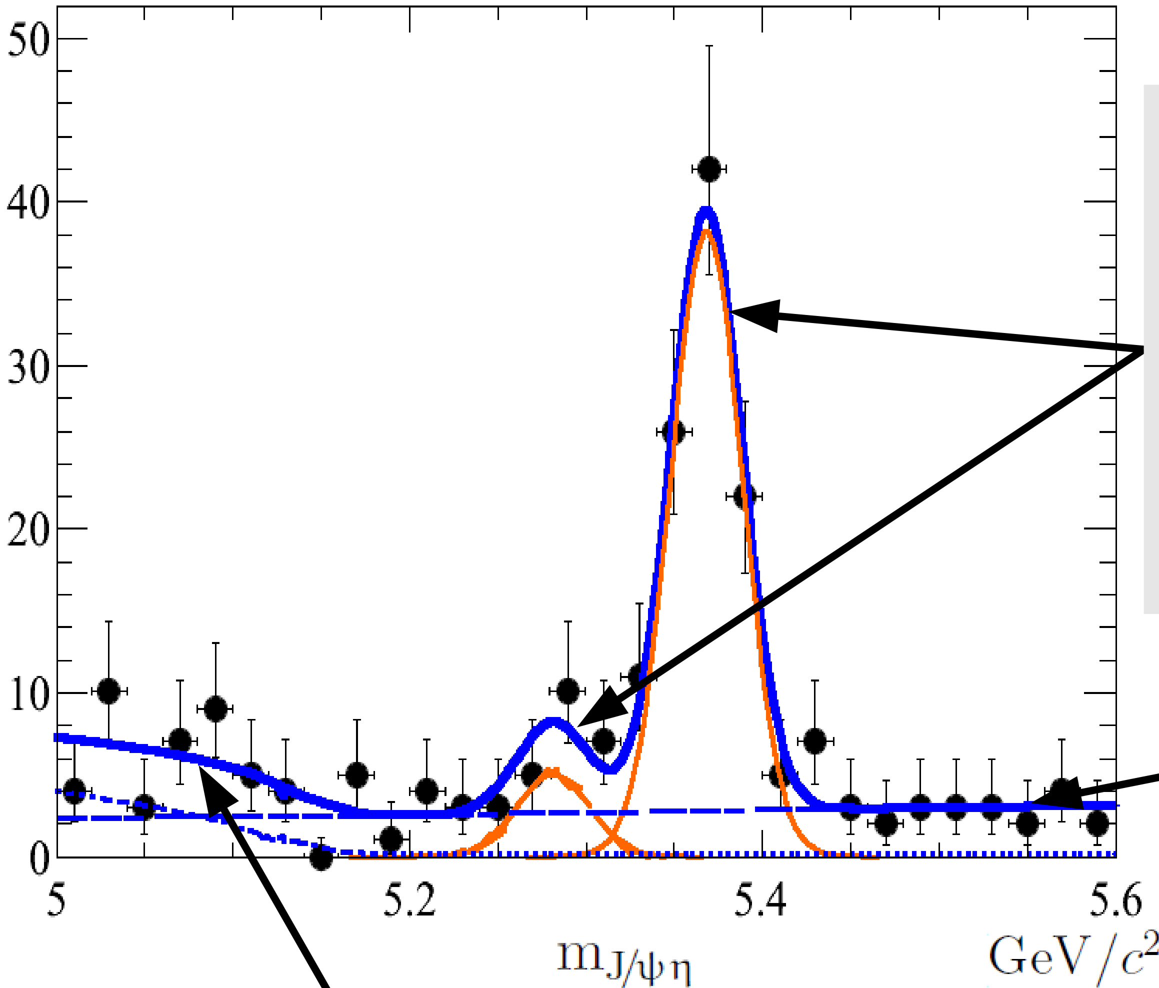
$$\frac{\mathcal{B}(B^0_s \to \psi(2S)\eta)}{\mathcal{B}(B^0_s \to J/\psi\,\eta)} = 0.83 \pm 0.14\,(\text{stat}) \pm 0.12\,(\text{syst}) \pm 0.02\,(\mathcal{B})$$

[Nucl. Phys. B 871 (2013) 403-419]

Backup

Fit strategy

$B_s \rightarrow J/\psi(\eta \rightarrow \pi^0\pi^+\pi^-)$



B_s and B^0 signals

- two Gauss functions with same resolutions
- difference between mean values is fixed (M_{Bs} — M_{Bd}) = 87 MeV/c^2;

- In the $J/\psi\eta'(\eta' \rightarrow \rho^0\gamma)$ case 2 Gaussian functions are used for each peak.

Exponential background

Partially reconstructed background is described with the phase space function under assumption of the $B \rightarrow J/\psi\eta K$ decay contribution, in case when kaon has escaped reconstruction.

$B^0 \to J/\psi\pi^+\pi^-$: $\pi^+\pi^-$ invariant mass

The combinatorial background is subtracted (sPlot technique)