$B_{(s)} \to J/\psi hh$ Decays

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Possible measurements of $B_{(s)} \to J/\psi hh$

- CP Violating weak phase ϕ_s
- Amplitude analyses: resonance structures
- Lifetime measurements: effective lifetime
- Branching fractions

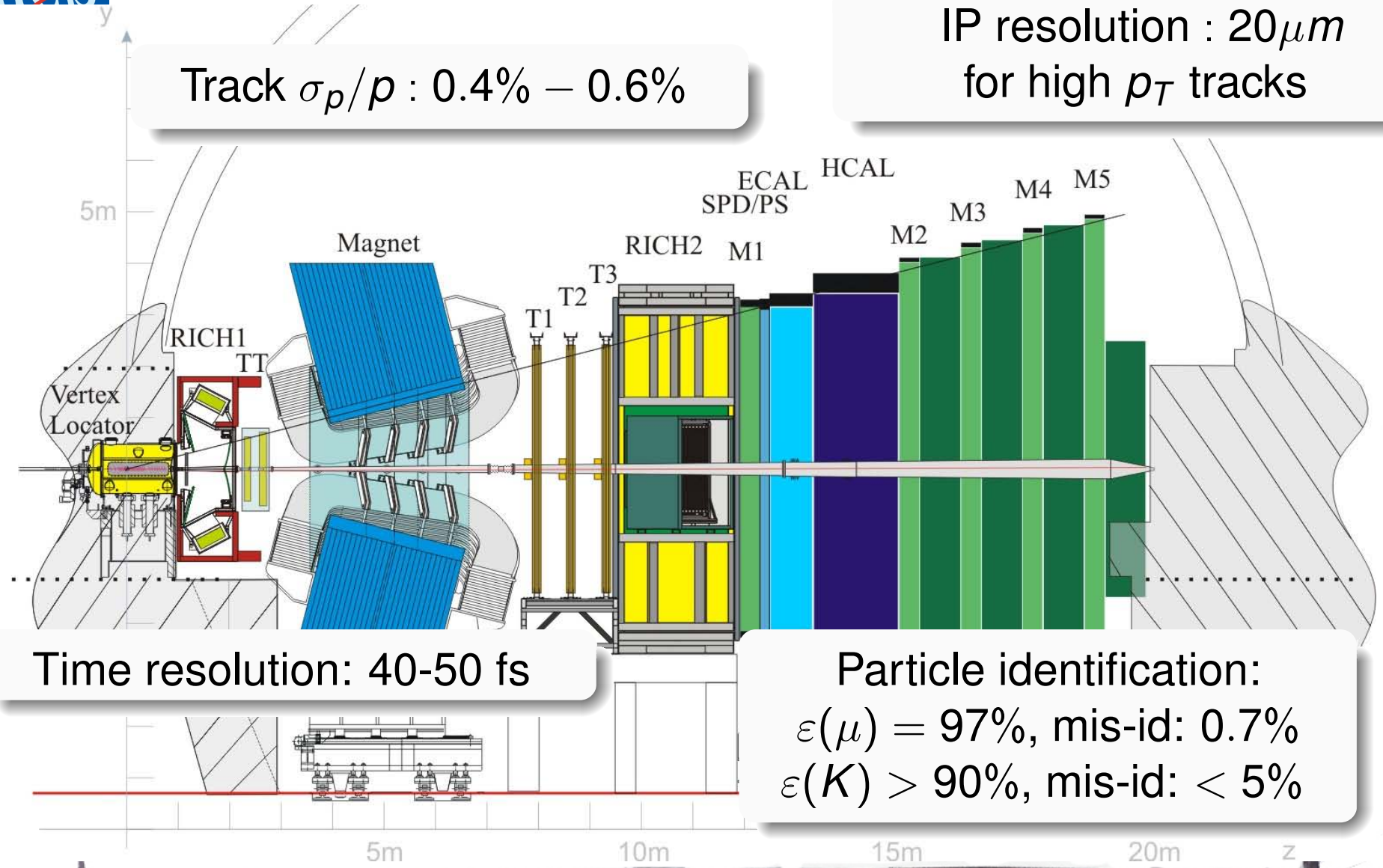
$J/\psi \to \mu^+\mu^-$ leaves clear signal in hadronic collider

- relatively low background
- easy to trigger
- large signal

LHCb data set:
1 fb^{-1} @$\sqrt{7}$ TeV
2 fb^{-1} @$\sqrt{8}$ TeV

Track σ_p/p : 0.4% – 0.6%

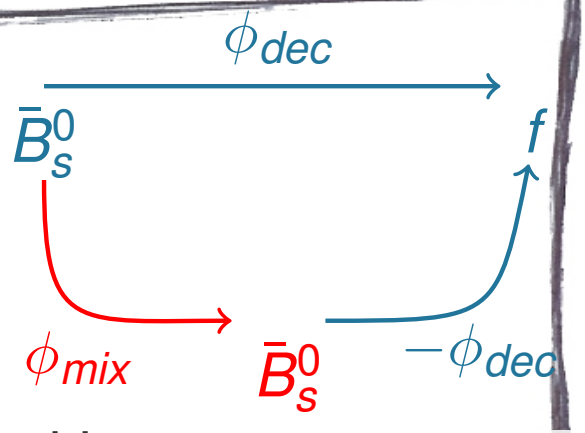
IP resolution : 20μm
for high p_T tracks



Time resolution: 40-50 fs

Particle identification:
$\varepsilon(\mu) = 97\%$, mis-id: 0.7%
$\varepsilon(K) > 90\%$, mis-id: $< 5\%$

- A weak phase ϕ_s arising from interference between B_s^0 decays w and w/o mixing to a final state CP eigenstates.



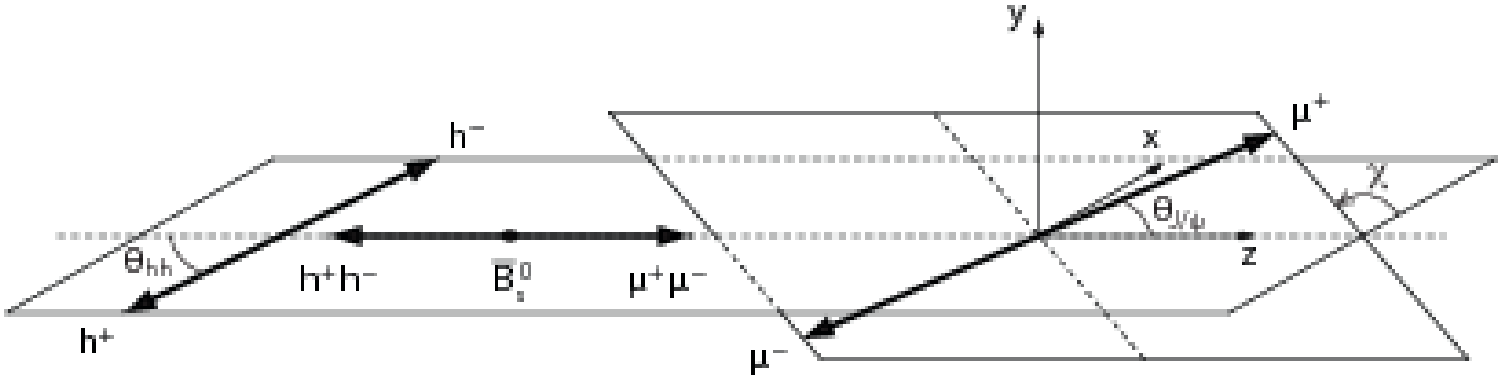
- Precise prediction in SM for $b \to c\bar{c}s$ transitions, e.g, (neglecting penguins contributions):

$$\phi_s^{SM} = \phi_{mix} - 2\phi_{dec} = -2arg(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}) \approx (-0.0363 \pm 0.0016)\text{rad}$$

CKMfitter PRD 84 (2011) 033005

- Expected $\phi_s = \phi_s^{SM} + \phi_s^{NP} \Rightarrow$ precise measurement of ϕ_s is sensitive test of NP in B_s^0 sector
- good candidates: $B_s^0 \to J/\psi K^+K^-$ and $J/\psi\pi^+\pi^-$

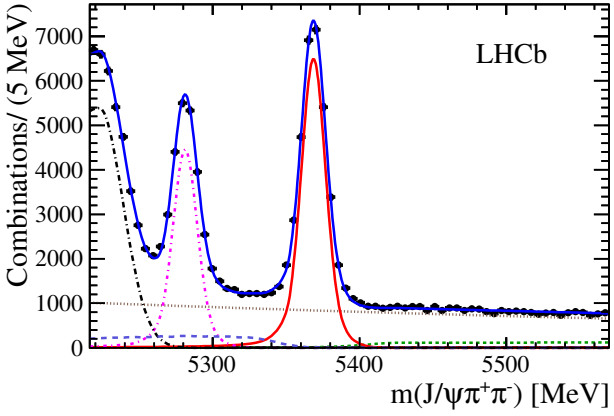
- *CP* even and *CP* odd components disentangled
  $\Rightarrow$ fit to B_s^0 proper time and 3 helicity angles

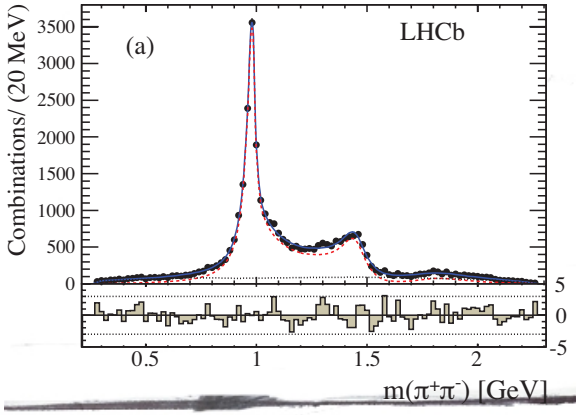


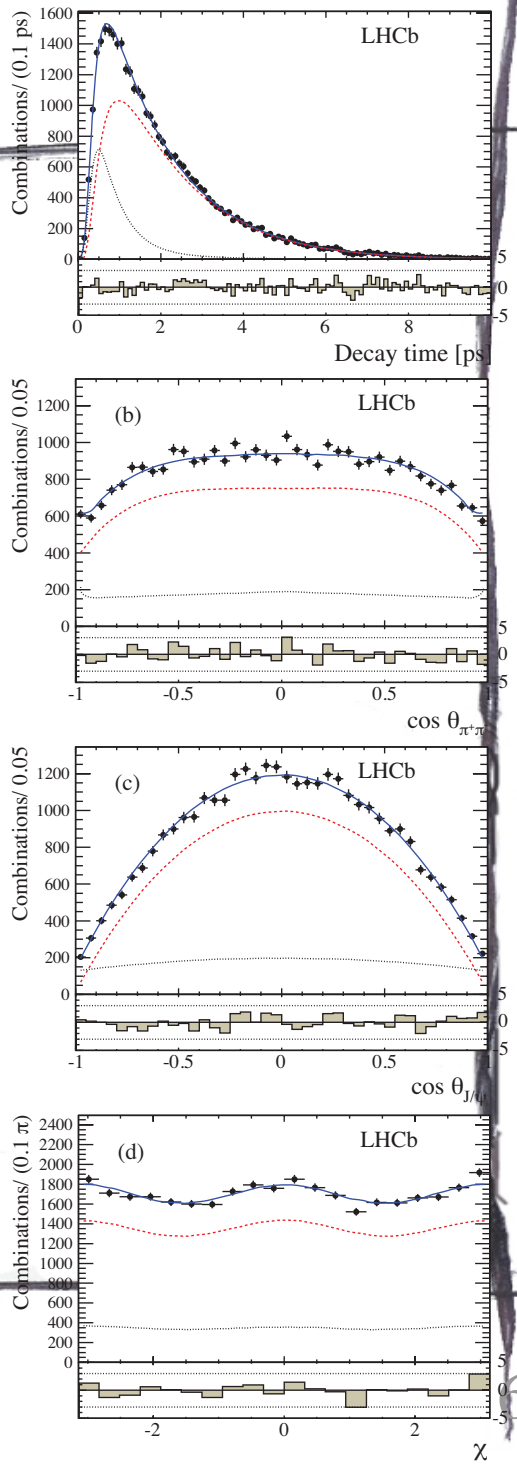
- B_s^0 or $\bar{B}_s^0$? $\Rightarrow$ need to know the production flavour
  Effective flavour tagging power: $\approx 4\%$
- Time and angular acceptance
  $\Rightarrow$ Either directly estimated or calibrated from data
- Resolution effects
  $\Rightarrow$ per-event decay time error estimate $\sim 40 - 50$ fs
  $\Rightarrow$ negligible angular resolution $\sim 2 - 20$ mrad

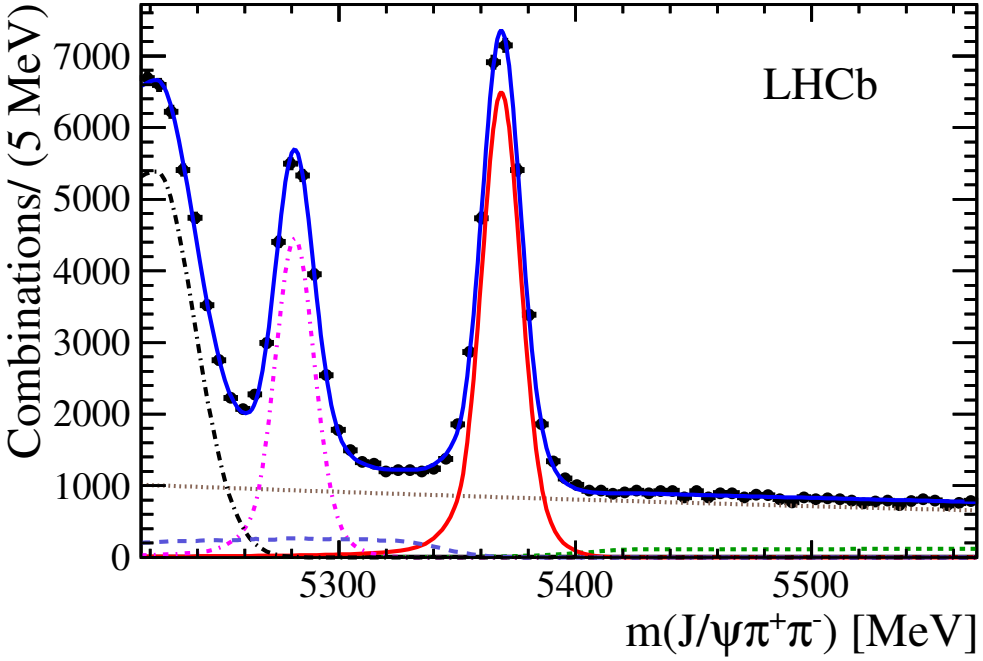
$B_s \to J/\psi\pi^+\pi^-$ with 3 fb^{-1} data

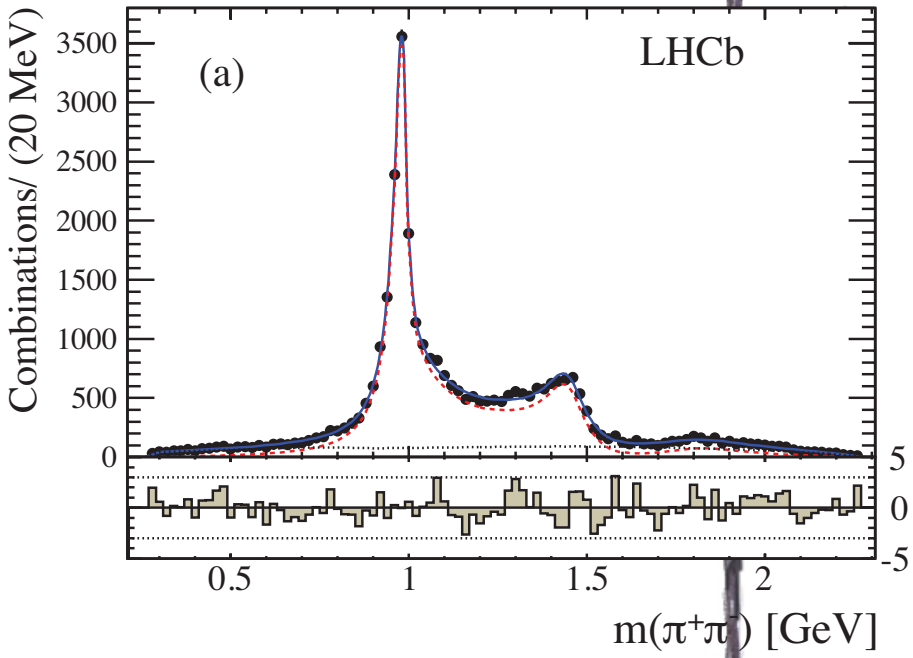
- 27100 $\pm$ 200 signal candidates
- time acceptance from $B^0 \to J/\psi K^{*0}$
- $\Delta\Gamma_s$ from $B_s^0 \to J/\psi\,\phi$
- largest systematic uncertainty: resonance model
- 6D maximum likelihood fit



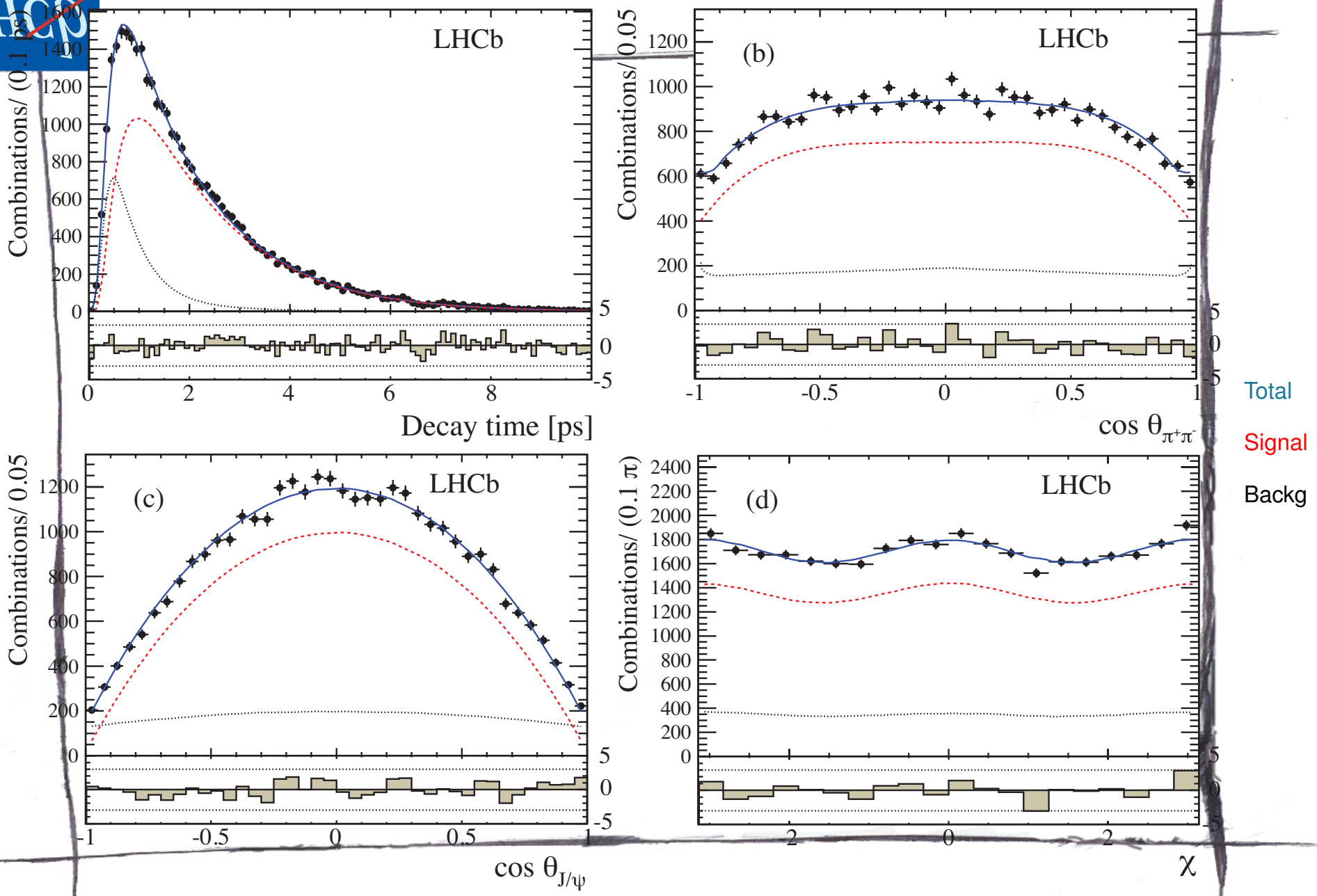








- initial fit to B_s^0 mass
- for ϕ_s measurement: events within ± 20 MeV of B_s^0 mass
- purity of 79.6%


LHCb
(a)
Combinations/ (0.1 ps)
Decay time [ps]
(b)
Combinations/ 0.05
cos θ$_{\pi^+\pi^-}$
(c)
Combinations/ 0.05
cos θ$_{J/\psi}$
(d)
Combinations/ (0.1 π)
χ
Total
Signal
Backg

$B_s \to J/\psi\pi^+\pi^-$ with 3 fb^{-1} data

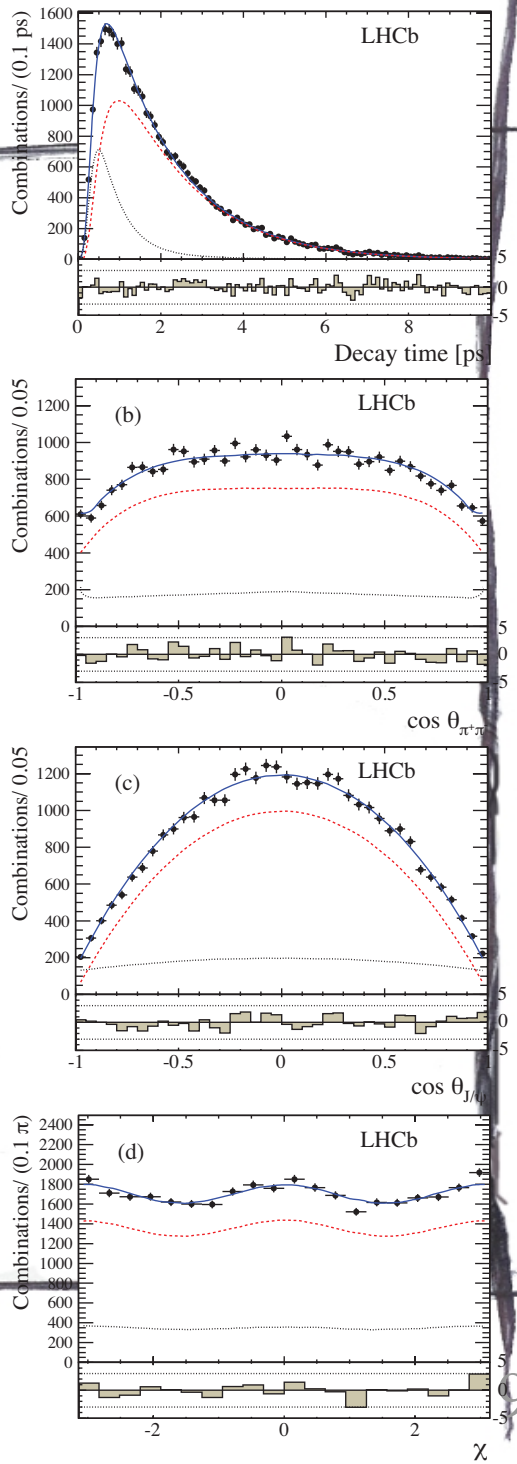
$$\phi_s = (0.075 \pm 0.067 \pm 0.008)\ \text{rad}$$

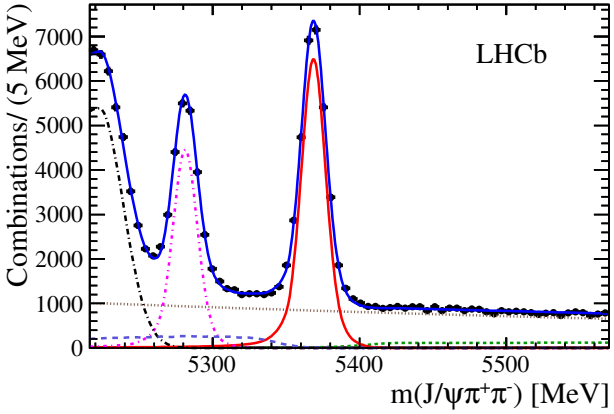
Allowing direct CPV:

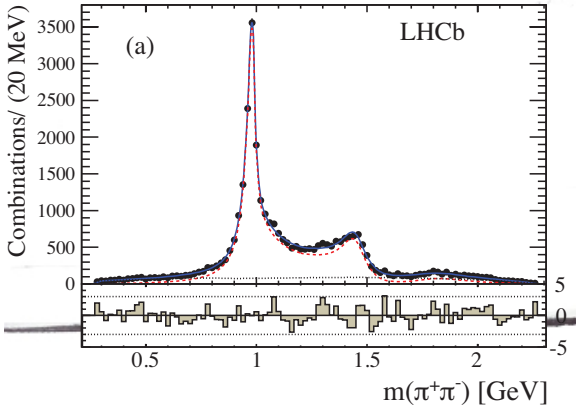
$$\phi_s = (0.070 \pm 0.068 \pm 0.008)\ \text{rad}$$
$$|\lambda| = (0.89 \pm 0.05 \pm 0.01)$$

consistent with SM

arXiv:1405.4140





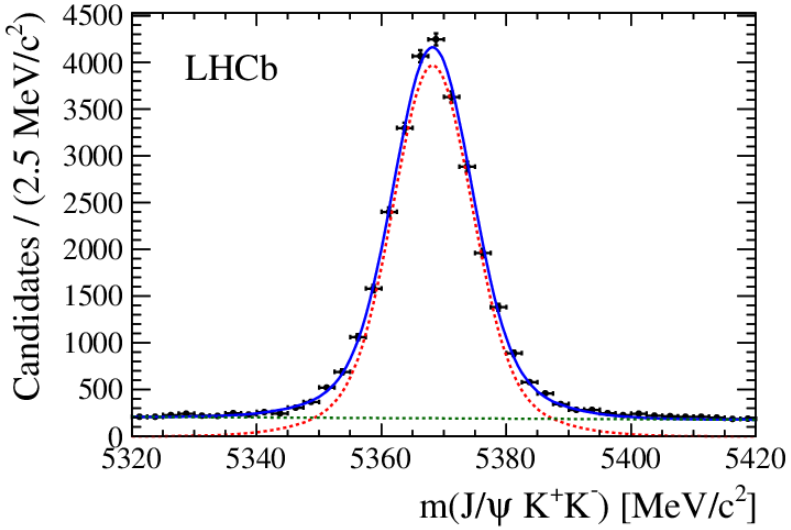


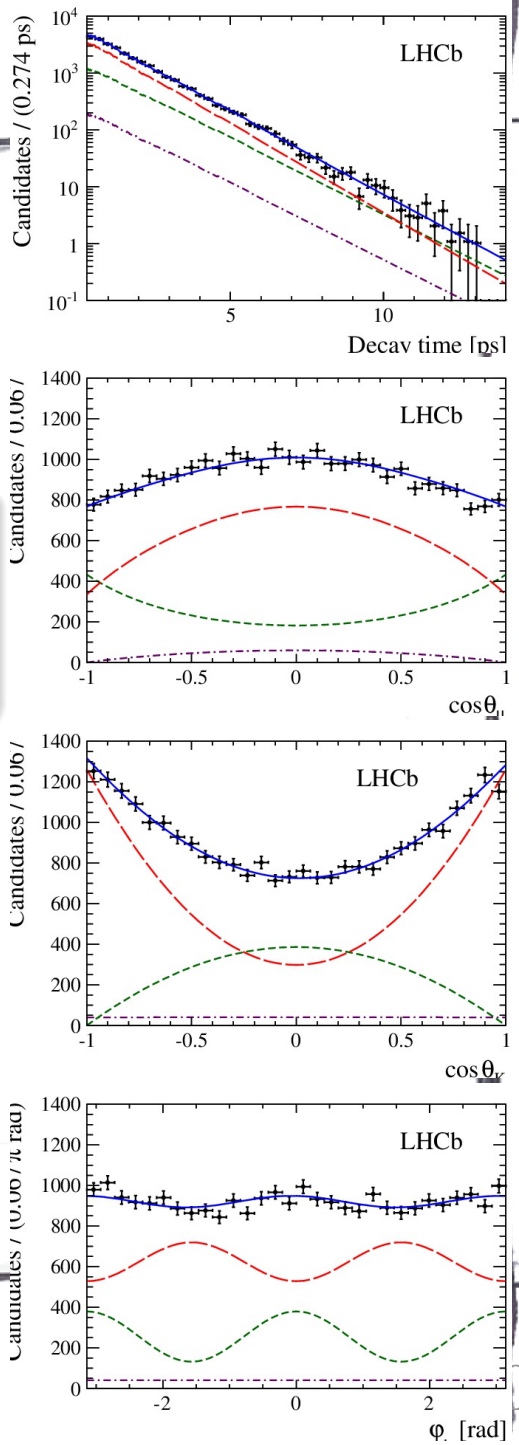
$B_s \to J/\psi K^+K^-$ with 1 fb^{-1} data

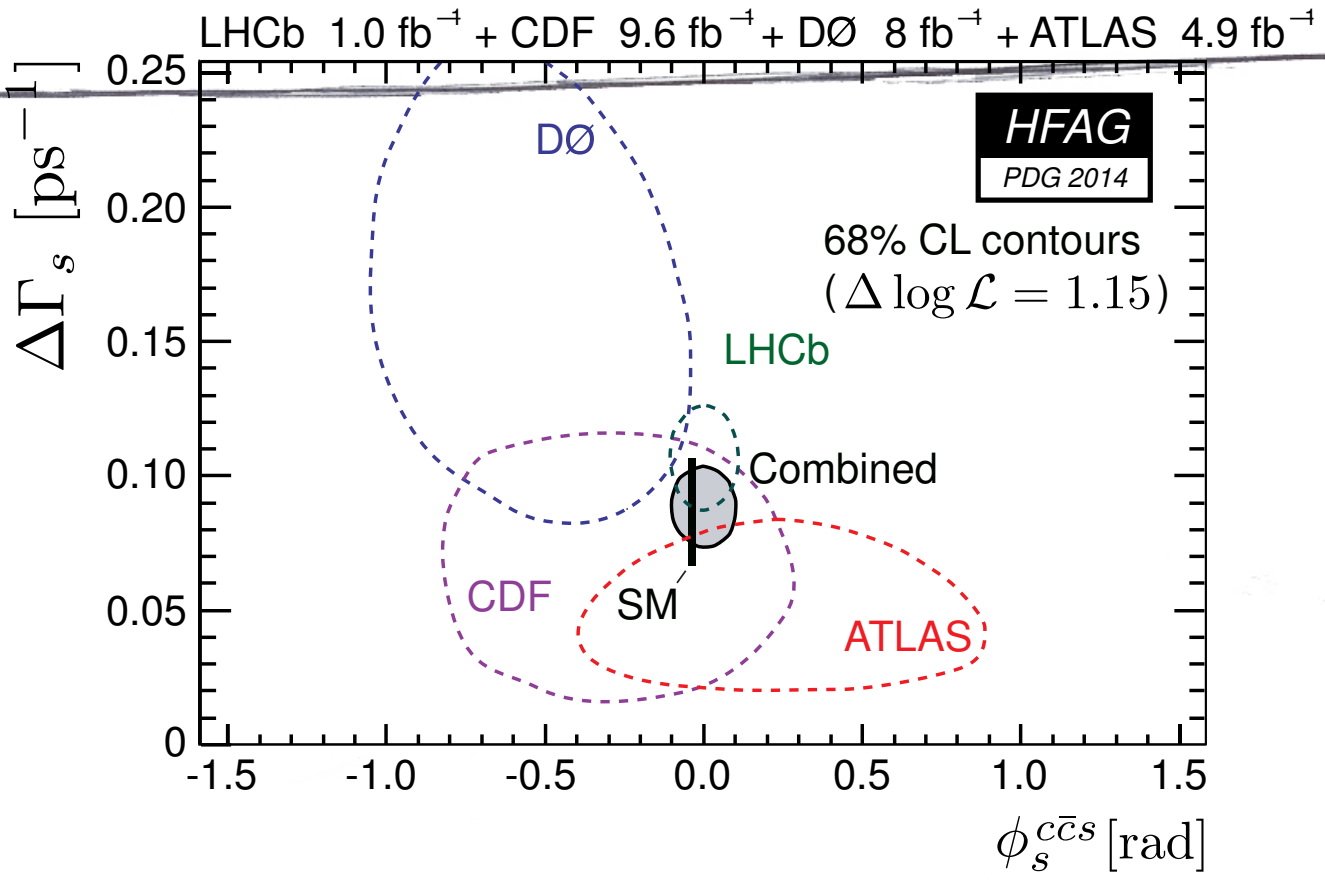
- 27600 signal candidates
- 4D maximum likelihood fit to background subtracted data

$$\phi_s = (0.07 \pm 0.09 \pm 0.01)\ \text{rad}$$
$$\Delta\Gamma_s = (0.100 \pm 0.016 \pm 0.003)\ \text{ps}^{-1}$$
to be updated...

PRD **87**, 112010 (2013)







LHCb $B_s \to J/\psi\pi^+\pi^-$ and $J/\psi K^+K^-$ combined [1 fb^{-1}]

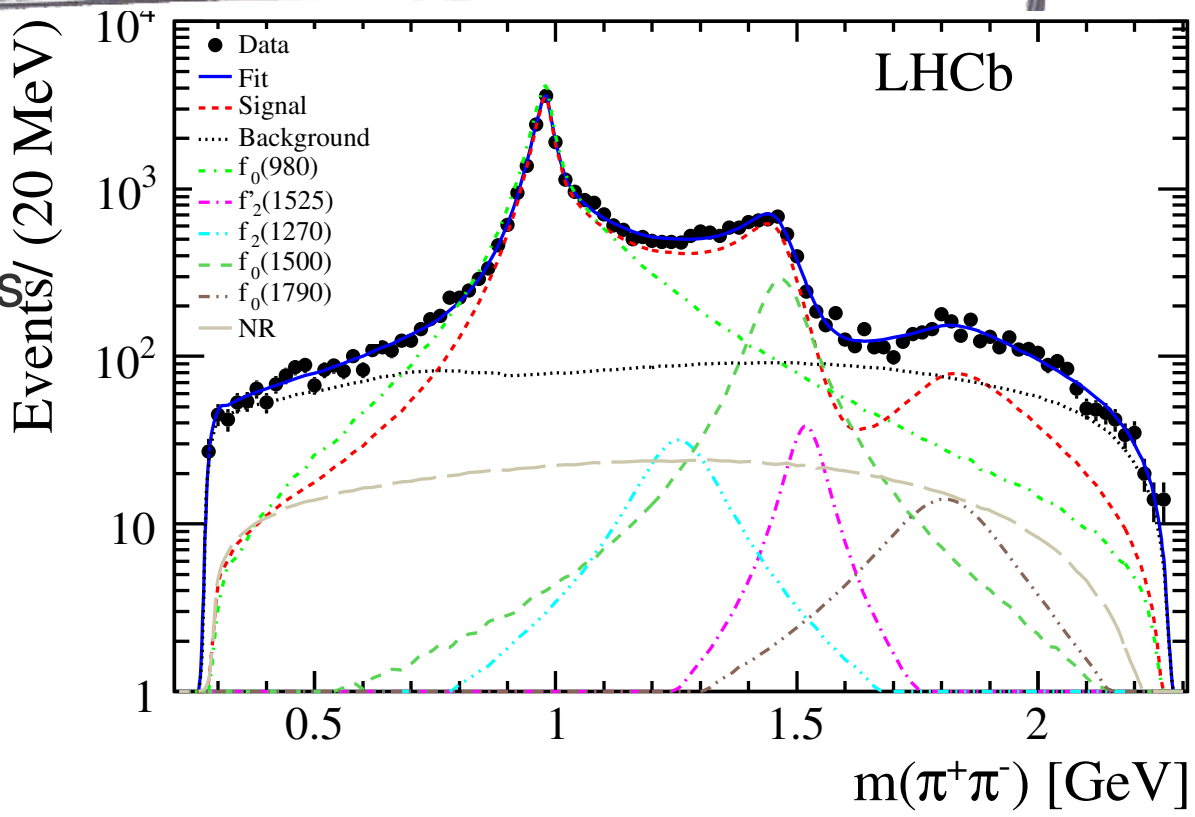
The most precise to date

$$\phi_s = (0.01 \pm 0.07 \pm 0.01)\ \text{rad}$$
$$\Delta\Gamma_s = (0.106 \pm 0.011 \pm 0.007)\ \text{ps}^{-1}$$
$$\Gamma_s = (0.661 \pm 0.004 \pm 0.006)\ \text{ps}^{-1}$$

PRD **87**, 112010 (2013)

$B_s^0 \to J/\psi\pi^+\pi^-$ Amplitude analysis

- Simultaneous fit to $m_{\pi^+\pi^-}$ spectrum and helicity angles
- Signal: 5 interfering resonances plus a non-resonant

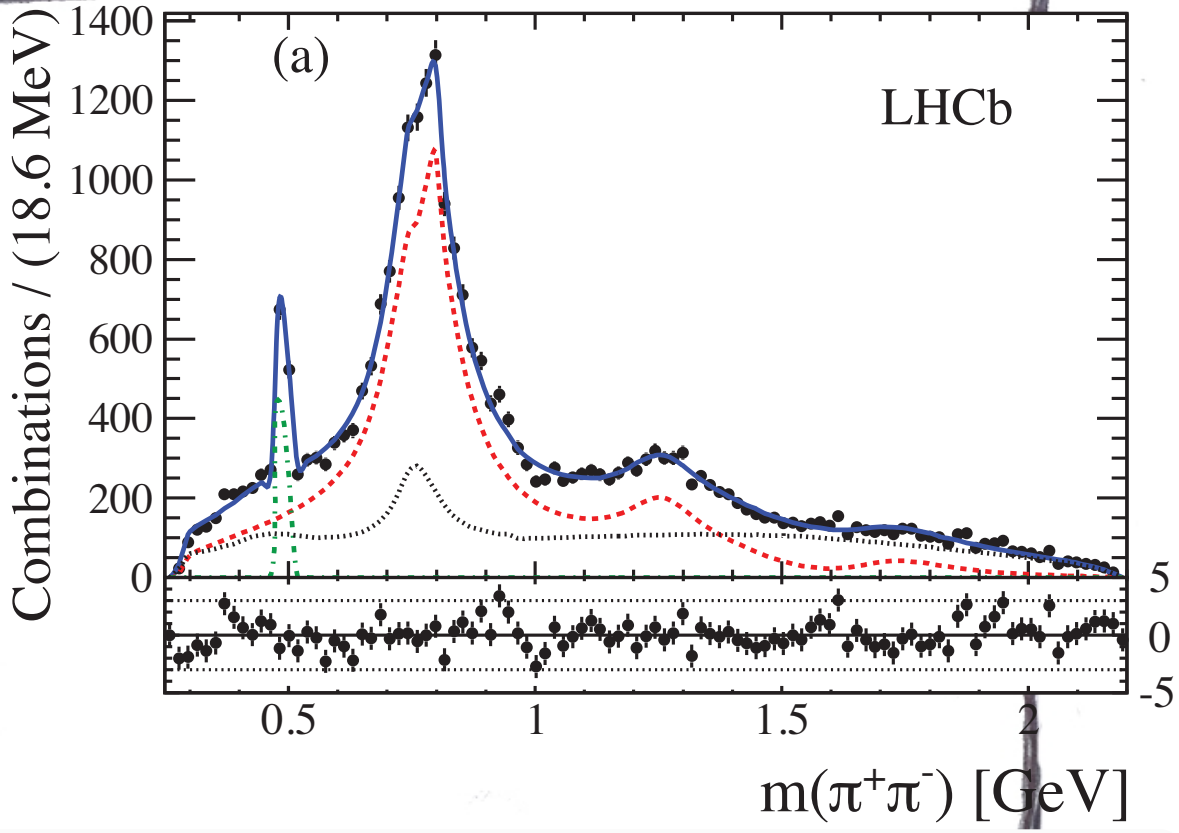


CP-odd > 97.7 confirmed @95% C.L.
$f_0(500)$ not observed
mixing angle between $f_0(500)$ and $f_0(980)$ resonances $< 7.7^\circ$ @90%

PRD **89**, 092006 (2014)

$B^0 \to J/\psi\pi^+\pi^-$ Amplitude analysis

- Simultaneous fit to $m_{\pi^+\pi^-}$ spectrum and helicity angles
- Signal: 6 interfering resonances



CP-even fraction $(56.0 \pm 1.4)\%$
no evidence for $f_0(980)$ resonance production
mixing angle between $f_0(500)$ and $f_0(980)$ resonances $< 17^\circ$ @90%
inconsistent with having a tetraquark substructure at the 8 sigma

arXiv: 1404.5673

B-Hadron Lifetime Measurements

- Useful fundamental information
- Measured the effective lifetimes of the exclusive decays:

  $B_s^0 \to J/\psi\phi$, $B^0 \to J/\psi K^{*0}$, $B^0 \to J/\psi K_S^0$,

  $B^+ \to J/\psi K^+$ and $\Lambda_b^0 \to J/\psi\Lambda$
- Lifetime ratios to test HQE theory

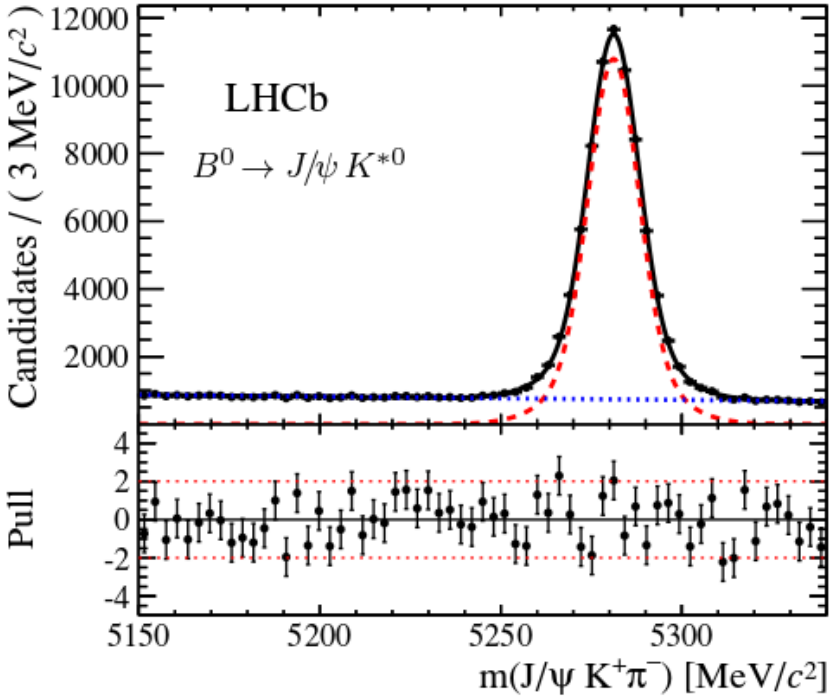
$\Rightarrow$ at lowest order the b-quark decay governs the lifetime

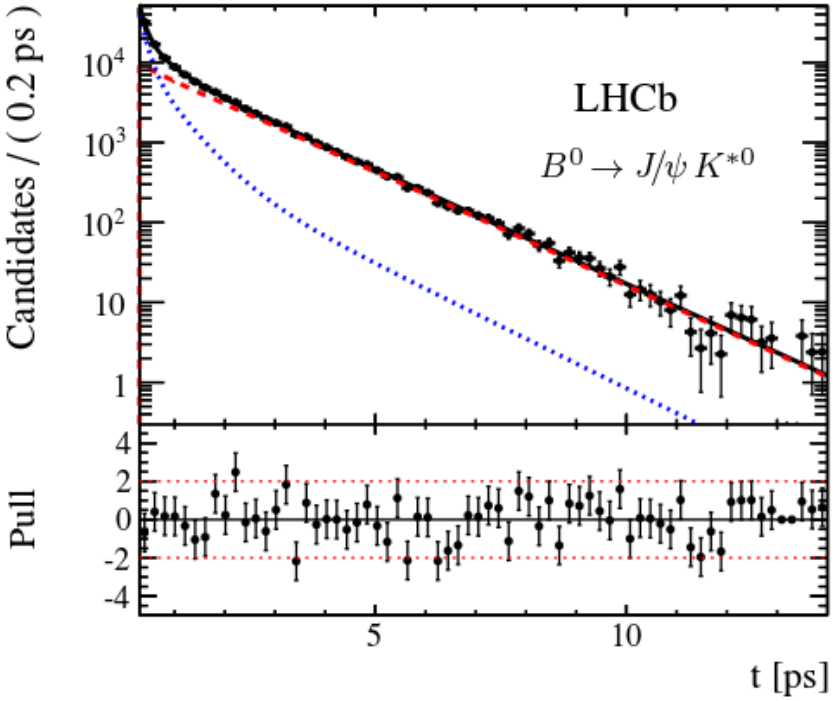
$\Rightarrow$ many systematics cancel

- Determination of $\Delta\Gamma_d/\Gamma_d$ from the effective lifetimes of

  $B^0 \to J/\psi K^{*0}$ and $B^0 \to J/\psi K_S^0$,

- Two-dimensional maximum likelihood fit to m($J/\psi X$) and time
- Main challenge: controlling detector acceptance, reconstruction and selection efficiencies.
- Decay time resolution 40-50 fs for fully reconstructed decays





Results JHEP 04 (2014) 114

$\tau_{B^+\to J/\psi K^+}$	$1.637 \pm 0.004 \pm 0.003$
$\tau_{B^0\to J/\psi K^{*0}}$	$1.524 \pm 0.006 \pm 0.004$
$\tau_{B^0\to J/\psi K^0_S}$	$1.499 \pm 0.013 \pm 0.005$
$\tau_{\Lambda^0_b\to J/\psi \Lambda}$	$1.415 \pm 0.027 \pm 0.006$
$\tau_{B^0_s\to J/\psi \phi}$	$1.480 \pm 0.011 \pm 0.005$
$\tau_{B^+}/\tau_{B^0\to J/\psi K^{*0}}$	$1.074 \pm 0.005 \pm 0.003$
$\tau_{B^0_s}/\tau_{B^0\to J/\psi K^{*0}}$	$0.971 \pm 0.009 \pm 0.004$
$\tau_{\Lambda^0_b}/\tau_{B^0\to J/\psi K^{*0}}$	$0.929 \pm 0.018 \pm 0.004$
τ_{B^+}/τ_{B^-}	$1.002 \pm 0.004 \pm 0.002$
$\tau_{\Lambda^0_b}/\tau_{\bar{\Lambda}^0_s}$	$0.940 \pm 0.035 \pm 0.006$
$\tau_{B^0\to J/\psi K^{*0}}/\tau_{\bar{B}^0\to J/\psi \bar{K}^{*0}}$	$1.000 \pm 0.008 \pm 0.009$

$\frac{\Delta\Gamma_d}{\Gamma_d} = -0.044 \pm 0.025 \pm 0.011$ Prediction: $(42 \pm 8) \times 10^{-4}$

arXiv:hep-ph/1102.4274

- Large variety of measurements in the B sector

only limited number of them can be shown in 15 minutes

- Improved constraints but still room for NP.
- Some measurements still on partial data sample, many still statistically dominated
- ϕ_s from $B_s^0 \to J/\psi\,\phi$ to be updated with 3fb^{-1}

Current Unofficial LHCb Average $= (70 \pm 54 \pm 8)$ mrad
($B_s^0 \to J/\psi\,\pi^+\pi^-$ w/ 3fb^{-1} + $B_s^0 \to J/\psi\,K^+K^-$ w/ 1fb^{-1})

All is consistent w/ SM; NP is hiding well...