

Recent history of B_c^+ mesons -- Experiments

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Outline

➤ Introduction

➤ (Selected) B_c^+ measurements

- Mass
- Lifetime
- Production
- Decays

➤ Summary

Introduction

➤ B_c meson family is unique in the Standard Model

- Formed by two open heavy flavor quarks: $\bar{b}c$
- Ground state weakly decay only → relatively long lifetime

➤ First observation by CDF in 1998

- Experimental studies limited

Phys.Rev.Lett. 81 (1998) 2432

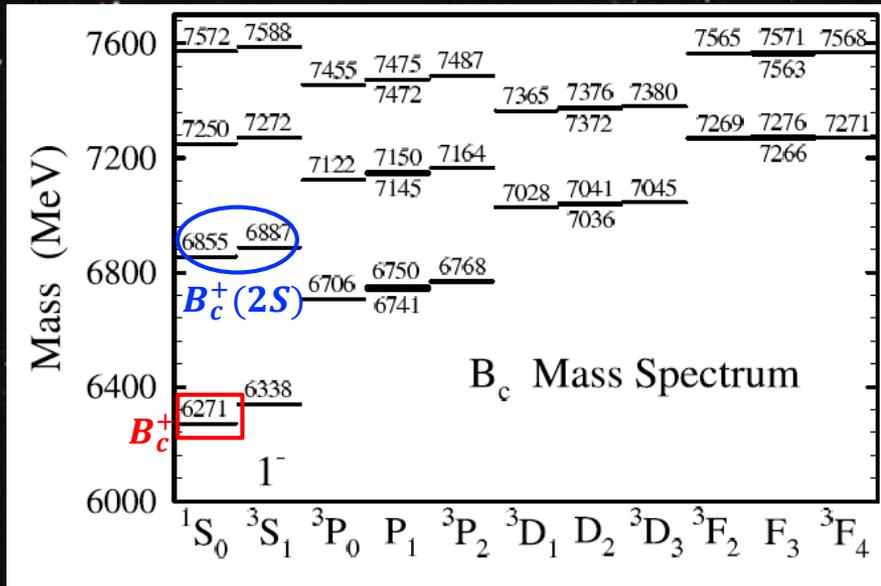
➤ Precise measurements helpful to test theoretical models

- Mass, lifetime, cross-section
- New decay modes and excited states
- $m_{B_c^+} = 6275.1 \pm 1.0 \text{ MeV}/c^2$
- $\tau_{B_c^+} = 0.507 \pm 0.009 \text{ ps}$

Chin. Phys. C, 38, 090001 (2014)
and 2015 update

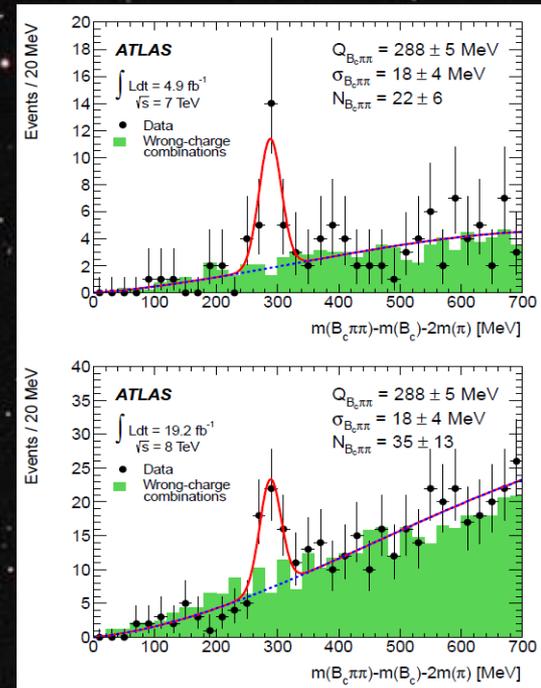
Introduction: spectrum

- Rich structures in the spectrum of $(\bar{b}c)$ system
 - Intermediate between charmonium and bottomonium
 - Can be calculated by potential model, NRQCD, Lattice QCD, ...
 - $B_c(2S)^+$ claimed by ATLAS, and confirmation is needed



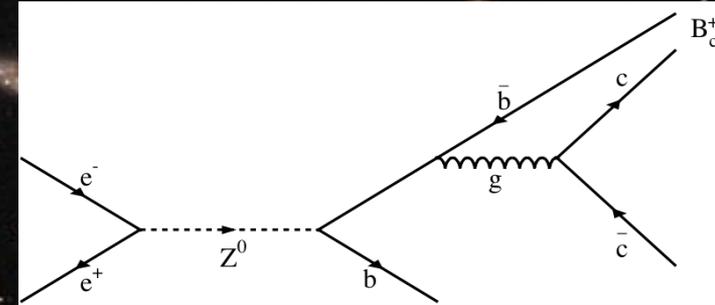
S. Godfrey, PRD 70, 054017 (2004)

PRL 113 (2014) 212004



Introduction: production

➤ Production at e^+e^- colliders is very difficult

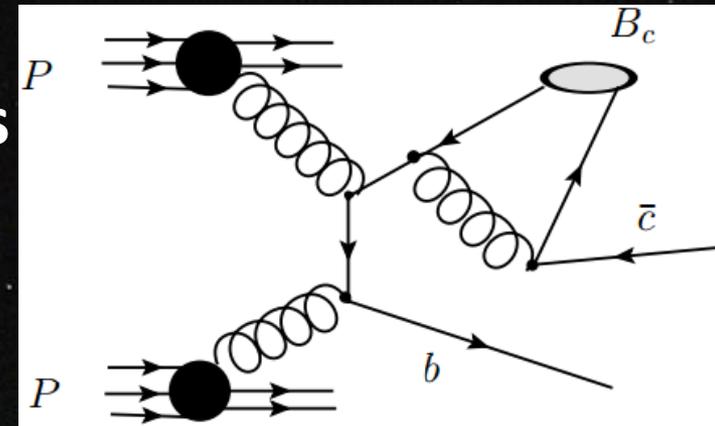


➤ At high energy hadron colliders, dominated by gluon-gluon fusions

- Large production cross-section at Tevatron & LHC

- $\sigma(B_c^+) \sim 0.47 \mu\text{b} @ 8 \text{ TeV}$

- $\sigma(B_c^+)_{\text{LHC}@14 \text{ TeV}} / \sigma(B_c^+)_{\text{Tevatron}@1.96 \text{ TeV}} \sim \mathcal{O}(10)$



PRD 71 (2005) 074012

➔ The LHC is a factory of B_c mesons

Introduction: decays

➤ Rich decay modes

- Either \bar{b} or c quark can decay with the other as spectator
- \bar{b} and c quarks can annihilate to a W^+ boson

✓ $\bar{b} \rightarrow \bar{c}$ transition

$$B_c^+ \rightarrow J/\psi l^+ \nu_l$$

$$B_c^+ \rightarrow J/\psi \pi^+$$

✓ $c \rightarrow s$ transition

$$B_c^+ \rightarrow B_s^0 l^+ \nu_l$$

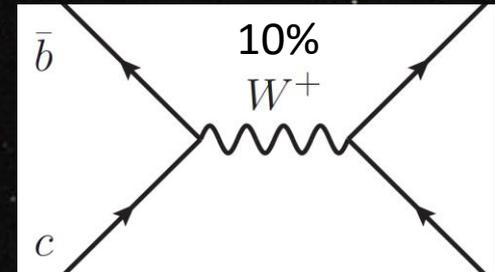
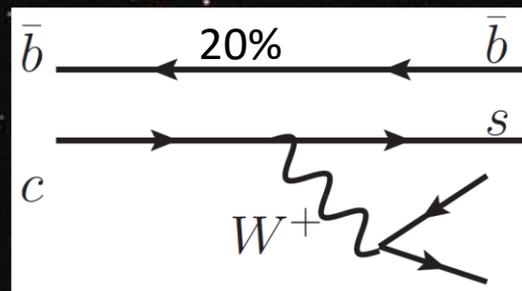
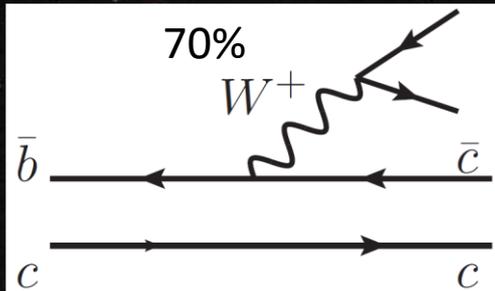
$$B_c^+ \rightarrow B_s^0 \pi^+$$

✓ $c\bar{b} \rightarrow W^+$ annihilation

$$B_c^+ \rightarrow \bar{K}^{*0} K^+$$

$$B_c^+ \rightarrow \phi K^+$$

$$B_c^+ \rightarrow \tau^+ \nu_\tau$$

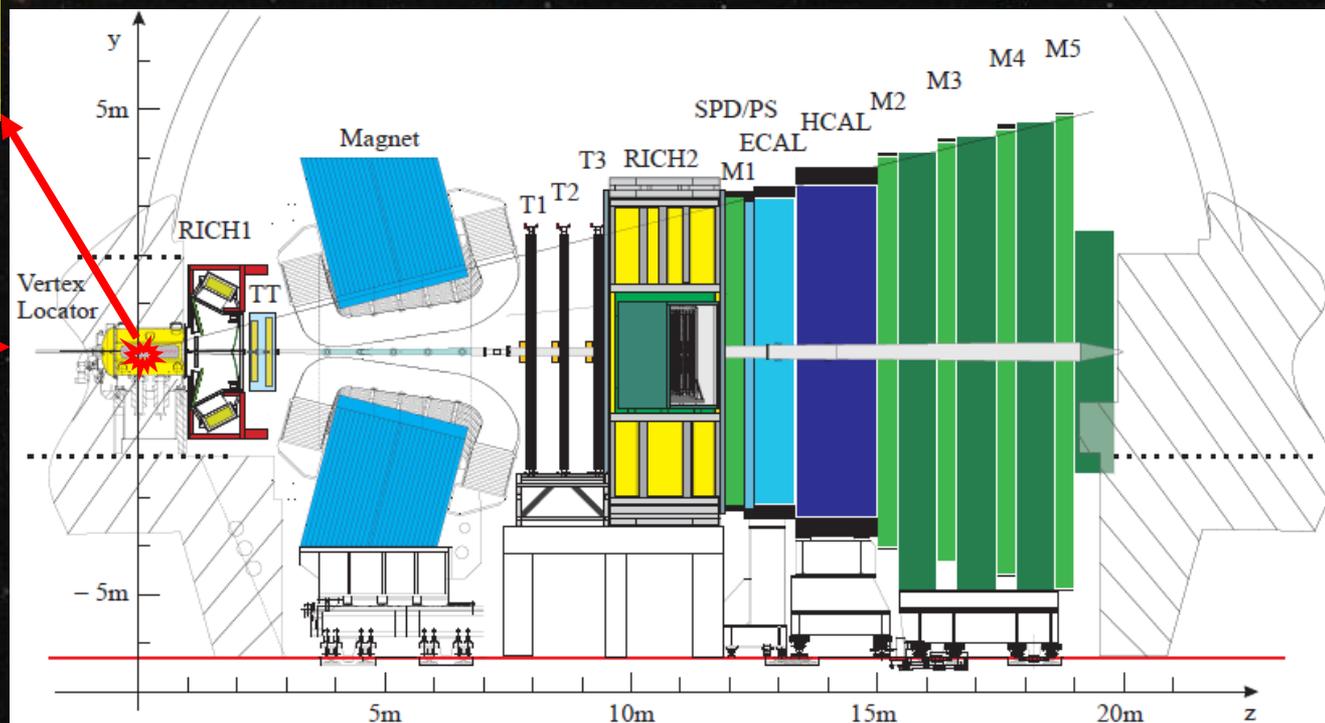


Spectator modes

annihilation modes

Phys.Atom.Nucl.67,1559

The LHCb detector



Int. J. Mod. Phys. A 30 (2015) 1530022

Impact parameter:

$$\sigma_{IP} = 20 \mu\text{m}$$

Proper time:

$$\sigma_{\tau} = 45 \text{ fs for } B_s^0 \rightarrow J/\psi\phi \text{ or } D_s^+ \pi^-$$

Momentum:

$$\Delta p/p = 0.4 \sim 0.6\% (5 - 100 \text{ GeV}/c)$$

Mass :

$$\sigma_m = 8 \text{ MeV}/c^2 \text{ for } B \rightarrow J/\psi X \text{ (constrained } m_{J/\psi})$$

RICH $K - \pi$ separation:

$$\epsilon(K \rightarrow K) \sim 95\% \quad \text{mis-ID } \epsilon(\pi \rightarrow K) \sim 5\%$$

Muon ID:

$$\epsilon(\mu \rightarrow \mu) \sim 97\% \quad \text{mis-ID } \epsilon(\pi \rightarrow \mu) \sim 1 - 3\%$$

ECAL:

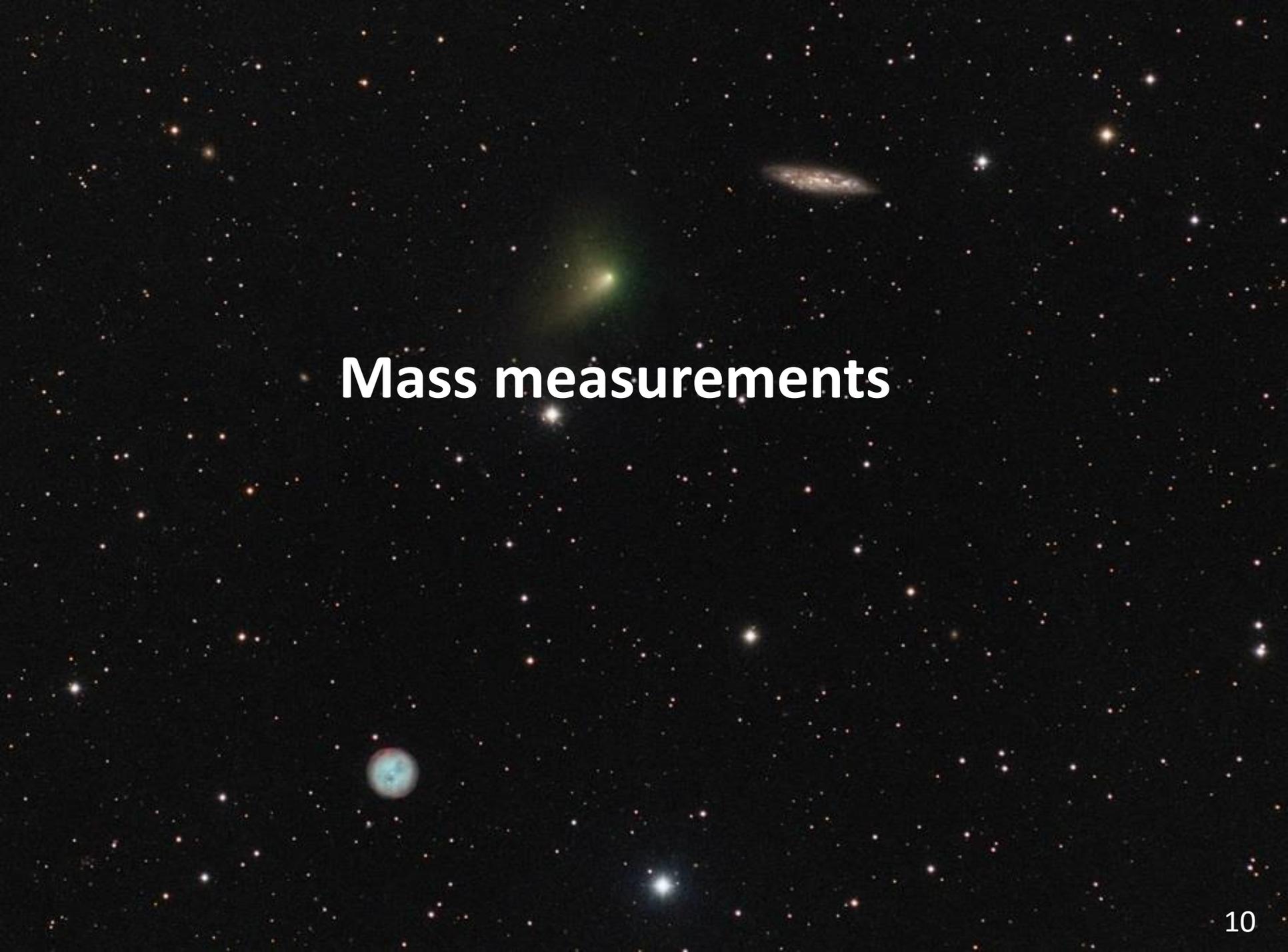
$$\Delta E/E = 1 \oplus 10\%/\sqrt{E(\text{GeV})}$$

B_c studies at LHC(b)

- 8 new decay channels observed by LHCb since 2012
- Measurements of mass, lifetime, branching fractions and differential cross-section (relative to B^+)
- $B_c(2S)^+$ states claimed by ATLAS

B_c^+ measurements at LHCb

Mass	$M(B_c^+ \rightarrow J/\psi\pi^+)$	[PRL 109 (2012) 232001]
	$M(B_c^+ \rightarrow J/\psi D_s^+)$	[PRD 87 (2013) 112012]
	$M(B_c^+ \rightarrow J/\psi p\bar{p}\pi^+)$	[PRL 113 (2014) 152003]
Production	$\frac{\sigma(B_c^+) \mathcal{B}(B_c^+ \rightarrow J/\psi\pi^+)}{\sigma(B^+) \mathcal{B}(B^+ \rightarrow J/\psi K^+)}$	[PRL 109 (2012) 232001] 7 TeV [PRL 114 (2015) 132001] 8 TeV
	$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \mathcal{B}(B_c^+ \rightarrow B_s^0\pi^+)$	[PRL 111 (2013) 181801]
Lifetime	$\tau(B_c^+ \rightarrow J/\psi\mu^+\nu_\mu X)$	[EPJC 74 (2014) 2839]
	$\tau(B_c^+ \rightarrow J/\psi\pi^+)$	[PLB 742 (2015) 29-37]
Decays/BF	$B_c^+ \rightarrow J/\psi\pi^+\pi^-\pi^+$	[PRL 108 (2012) 251802]
	$B_c^+ \rightarrow J/\psi K^+$	[JHEP 09 (2013) 075]
	$B_c^+ \rightarrow \psi(2S)\pi^+$	[PRD 87 (2013) 112012] 7 TeV [PRD 92 (2015) 072007] 7&8 TeV
	$B_c^+ \rightarrow J/\psi D_s^{(*)+}$	[PRD 87 (2013) 112012]
	$B_c^+ \rightarrow J/\psi K^+ K^- \pi^+$	[JHEP 1311 (2013) 094]
	$B_c^+ \rightarrow J/\psi 3\pi^+ 2\pi^-$ (evidence)	[JHEP 1405 (2014) 148]
	$\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi\pi^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi\mu^+\nu_\mu)}$	[PRD 90 (2014) 032009]
	$B_c^+ \rightarrow p\bar{p}\pi^+$ (upper limit)	[PLB 759 (2016) 313-321]

A deep space photograph showing a vast field of stars. A prominent green star is located in the upper-middle section, and a bright blue star is in the lower-left. A small, tilted galaxy is visible in the upper-right. The text "Mass measurements" is centered in white.

Mass measurements

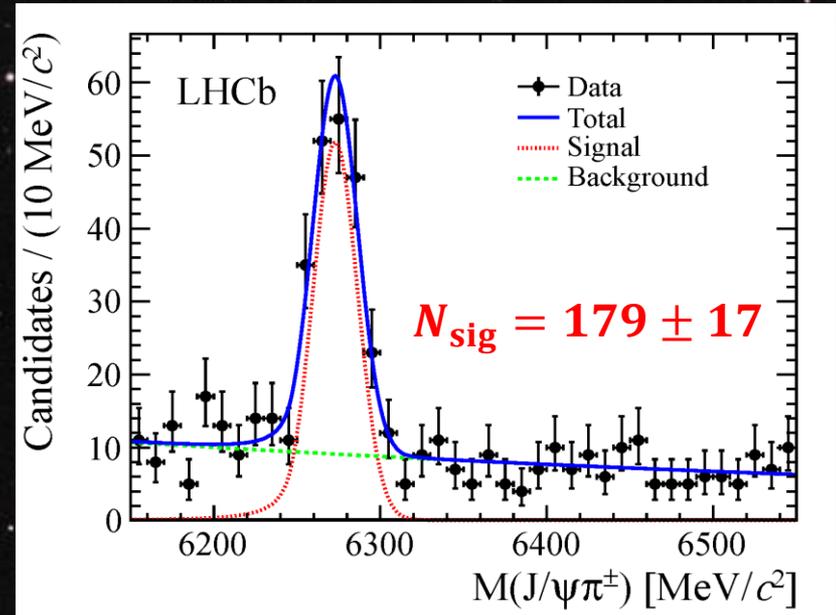
Mass measurement

➤ PDG 2012: $m_{B_c^+} = 6277 \pm 6 \text{ MeV}/c^2$ PRL109 (2012) 232001

➤ The first B_c^+ mass measurement at the LHC was done by LHCb

- 0.37 fb^{-1} @ 7 TeV
- $B_c^+ \rightarrow J/\psi \pi^+$

Signal: double-sided Crystal Ball
Background: exponential



$$m(B_c^+) = 6273.7 \pm 1.3_{\text{stat}} \pm 1.6_{\text{syst}} \text{ MeV}/c^2$$

$$m(B_c^+) - m(B^+) = 994.6 \pm 1.3_{\text{stat}} \pm 0.6_{\text{syst}} \text{ MeV}/c^2$$

Systematics dominated by momentum scale calibration ($1.4 \text{ MeV}/c^2$)

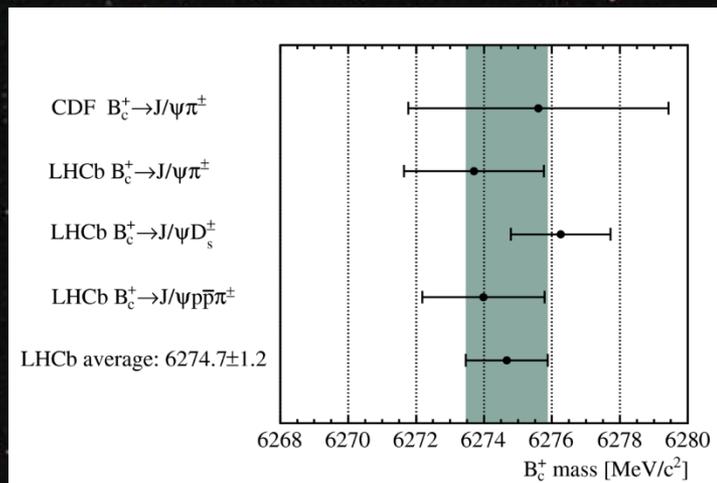
Mass measurement (cont.)

➤ B_c^+ mass was also measured using another two decays, whose Q -values are small

- $B_c^+ \rightarrow J/\psi D_s^+$: $m = 6276.28 \pm 1.44 \pm 0.36 \text{ MeV}/c^2$
- $B_c^+ \rightarrow J/\psi p \bar{p} \pi^+$: $m = 6274.0 \pm 1.8 \pm 0.4 \text{ MeV}/c^2$

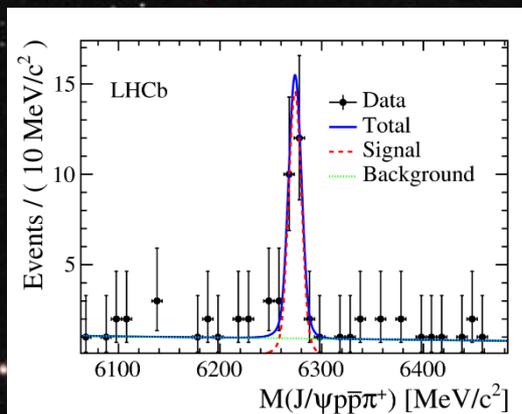
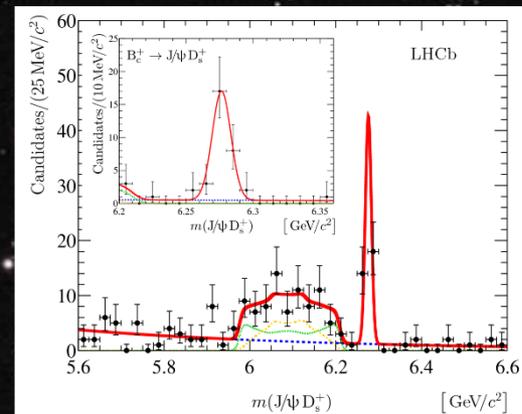
➤ LHCb combined results

- $m = 6274.7 \pm 1.2 \text{ MeV}/c^2$



PRD 87 (2013) 112012

PRL113 (2014) 152003



Lifetime measurements

- Semileptonic decay $B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu X$
- Hadronic decay $B_c^+ \rightarrow J/\psi \pi^+$

Lifetime

➤ Various theoretical predictions

- $[0.4, 0.7]$ ps PRD 53 (1996) 4991
- (0.59 ± 0.06) ps PLB 452 (1999) 129
- (0.48 ± 0.05) ps NPB 585 (2000) 353
- ~ 0.36 ps PRD 64 (2001) 014003

➤ PDG 2013: 0.453 ± 0.033 ps

➤ Precise measurement of B_c^+ lifetime provide important test of theoretical models, and

➤ Also helpful to reduce systematic uncertainty in many B_c^+ analyses

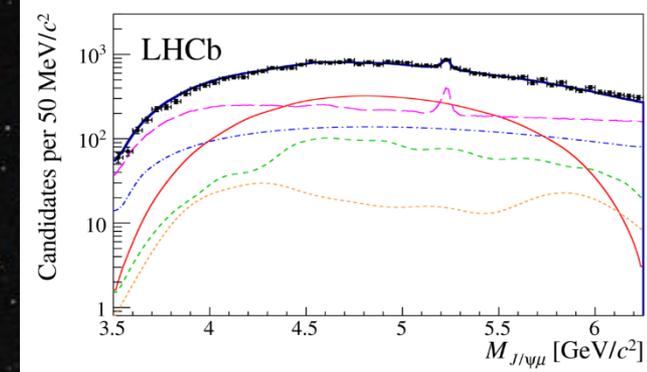
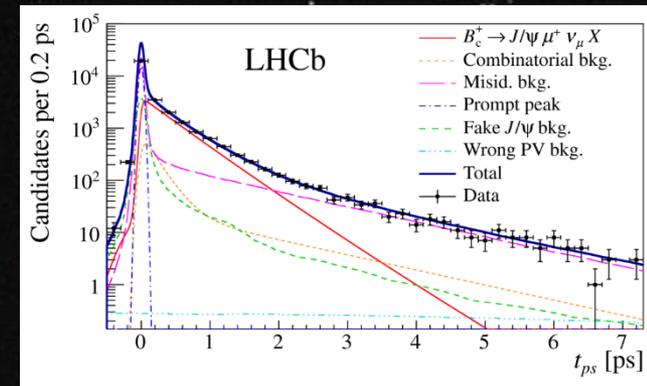
Lifetime: $B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu X$

- High statistics due to large branching fraction
- Missing energy due to partial reconstruction
 - Using a 2D ($m_{J/\psi\mu}$ and pseudo-proper time t_{ps}) model for data, to enhance S/B separation

- The lifetime determined from a 2D unbinned maximum likelihood fit using 2012 data (2 fb^{-1})

$$\tau = 509 \pm 8 \pm 12 \text{ fs}$$

Systematic uncertainties dominated by background model ($\pm 10 \text{ fs}$)



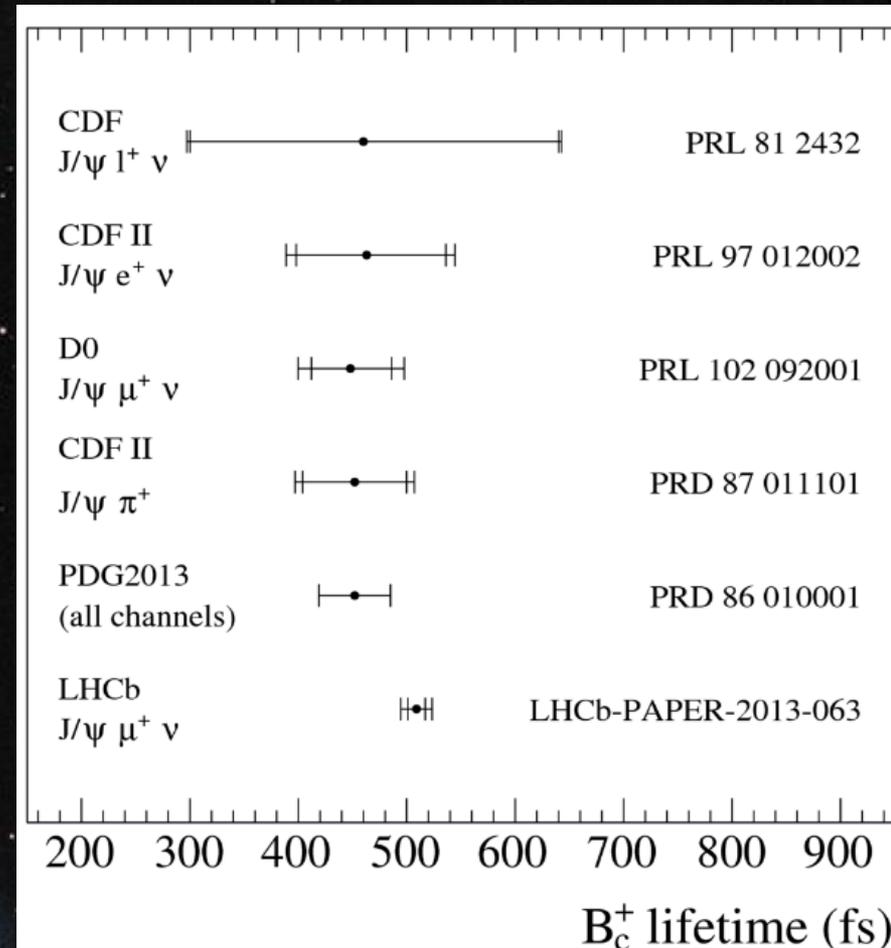
Lifetime: $B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu X$ (cont.)

➤ The most precise measurement

$$\tau = 509 \pm 8 \pm 12 \text{ fs}$$

➤ Consistent with results from other experiments

- Uncertainty much smaller



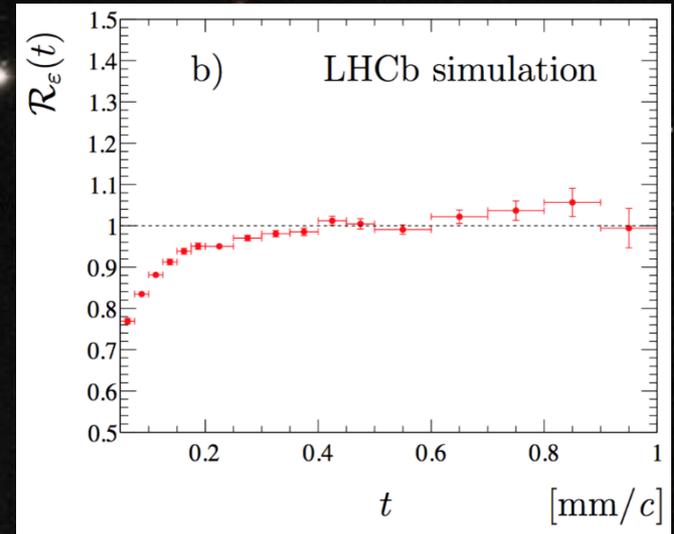
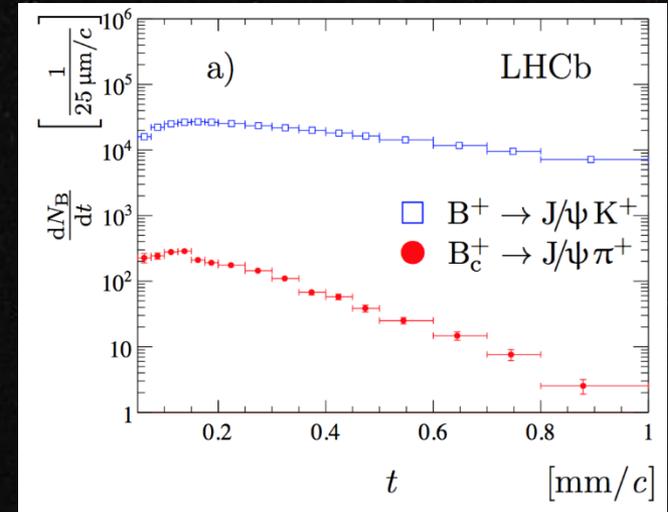
Lifetime: $B_c^+ \rightarrow J/\psi\pi^+$

➤ Fully reconstructed mode, but statistics smaller than semileptonic decay

➤ Measure $\Delta\Gamma \equiv \Gamma_{B_c^+} - \Gamma_{B^+}$
$$= \frac{1}{\tau_{B_c^+}} - \frac{1}{\tau_{B^+}}$$

using $\mathcal{R}(t) \propto \mathcal{R}_\varepsilon(t)e^{-\Delta\Gamma t}$

- $\mathcal{R}(t) \equiv N_{B_c^+}(t)/N_{B^+}(t)$
determined from fit to data
- $\mathcal{R}_\varepsilon(t) \equiv \varepsilon_{B_c^+}(t)/\varepsilon_{B^+}(t)$
determined from simulation



Lifetime: $B_c^+ \rightarrow J/\psi\pi^+$ (cont.)

PLB 742 (2015) 29

➤ $\Delta\Gamma$ determined from fit to $\mathcal{R}(t)/\mathcal{R}_\varepsilon(t)$

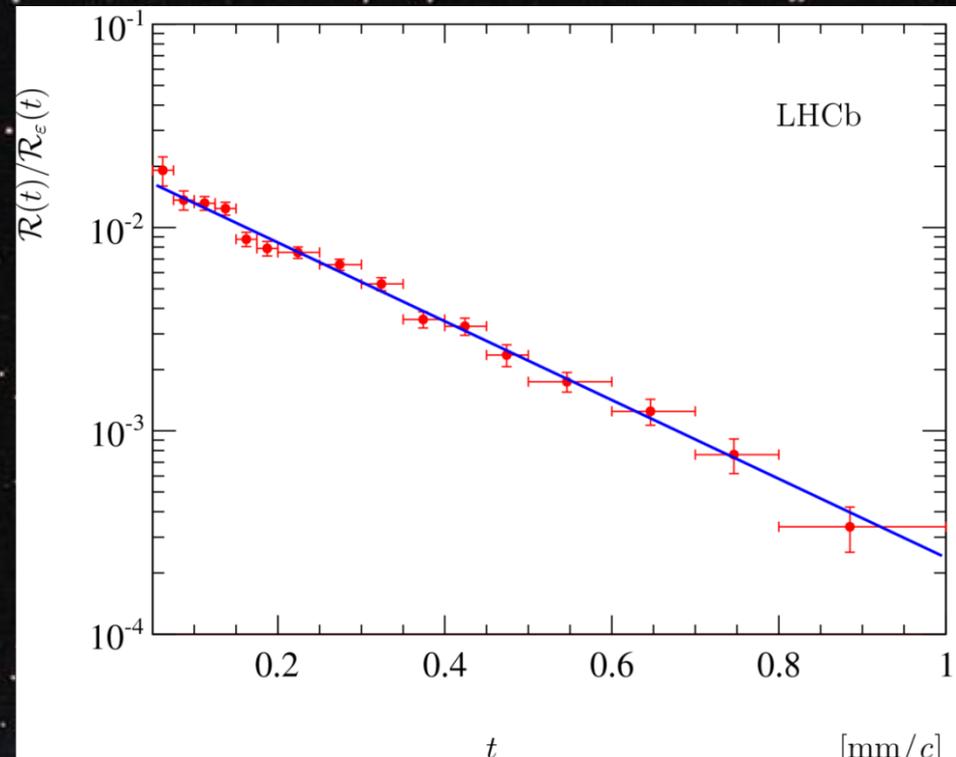
- $\Delta\Gamma = 4.46 \pm 0.14 \pm 0.07 \text{ c/mm}$

➤ $\tau_{B_c^+} = 513.4 \pm 11.0 \pm 5.7 \text{ fs}$

- In good agreement with result from semileptonic decay
- Dominated by statistical uncertainty

➤ Combined result

$$\tau_{B_c^+} = 511.4 \pm 9.3 \text{ fs}$$



Production measurements

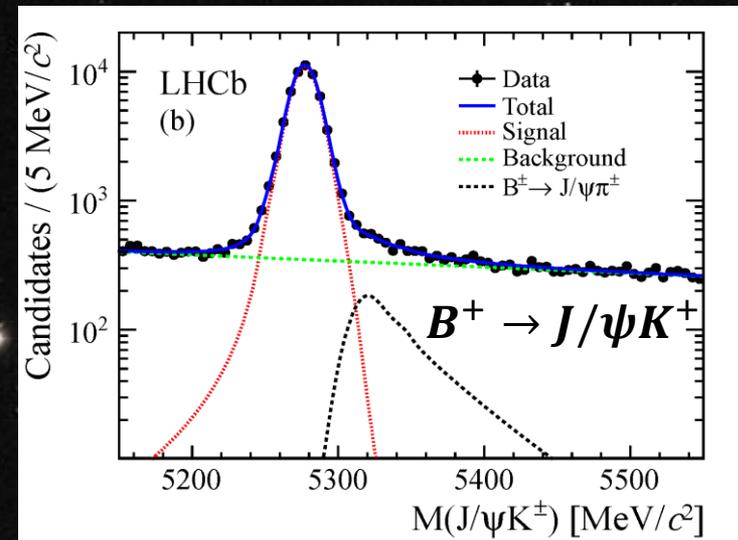
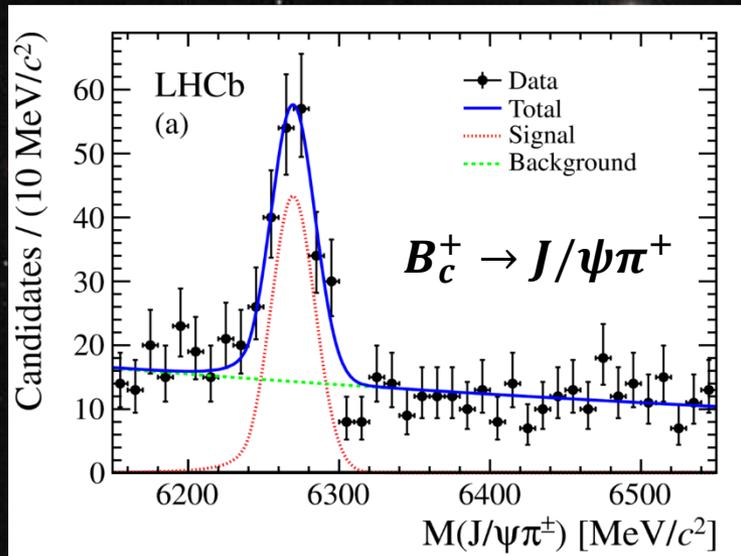
- For $B_c^+ \rightarrow J/\psi\pi^+$, relative to $B^+ \rightarrow J/\psi K^+$
- For other B_c^+ decays, (mostly) relative to $B_c^+ \rightarrow J/\psi\pi^+$

Production: $B_c^+ \rightarrow J/\psi\pi^+$

PRL109 (2012) 232001

- First measurement used data at 7 TeV (0.37 fb^{-1})
- Relative production measured

$$\mathcal{R} = \frac{\sigma(B_c^+) \times \mathcal{B}(B_c^+ \rightarrow J/\psi\pi^+)}{\sigma(B^+) \times \mathcal{B}(B^+ \rightarrow J/\psi K^+)}$$



$$\mathcal{R} = (0.68 \pm 0.10_{\text{stat}} \pm 0.03_{\text{syst}} \pm 0.05_{\text{lifetime}})\%$$

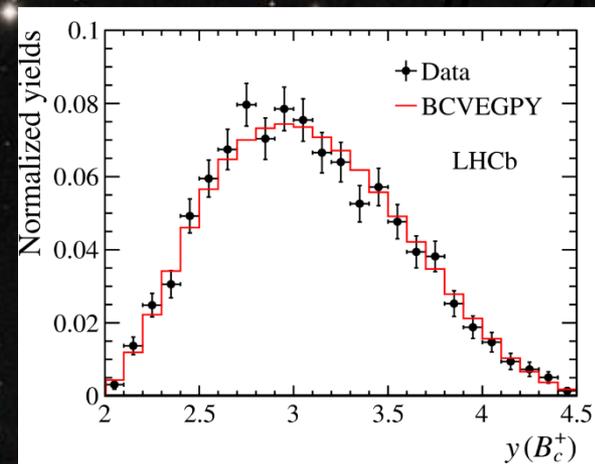
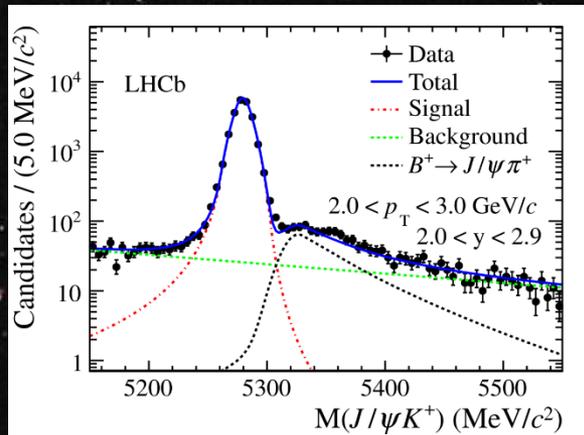
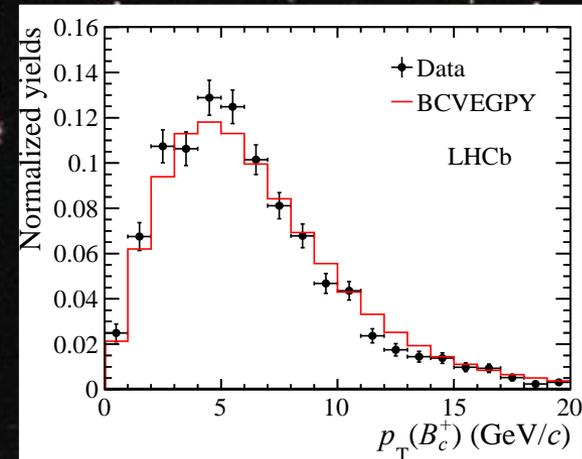
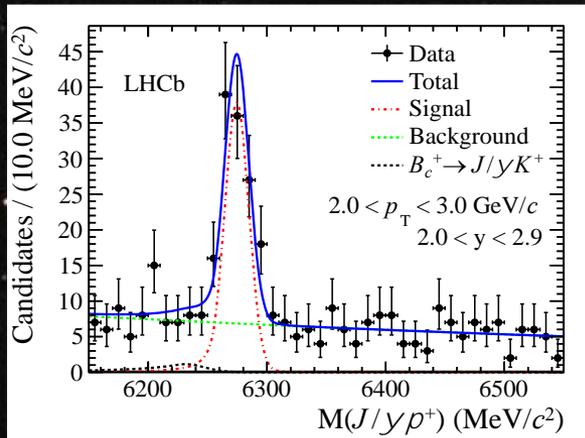
$$p_T(B) > 4 \text{ GeV}/c, \quad 2.5 < \eta < 4.5$$

Production: $B_c^+ \rightarrow J/\psi\pi^+$ (cont.)

PRL114 (2015) 132001

➤ Differential production measured at 8 TeV (2 fb^{-1})

- \mathcal{R} measured as a function of p_T and y for the first time



Production: $B_c^+ \rightarrow J/\psi\pi^+$ (cont.)

PRL114 (2015) 132001

➤ \mathcal{R} in bins of (p_T, y) well agree with BCVEGPY and FONLL

Compt. Phys. C174 (2006) 241

➤ Fiducial kinematic range:

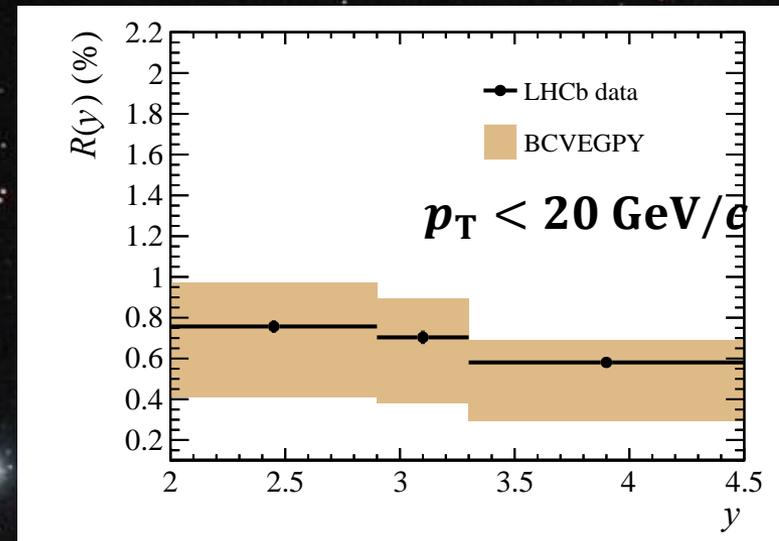
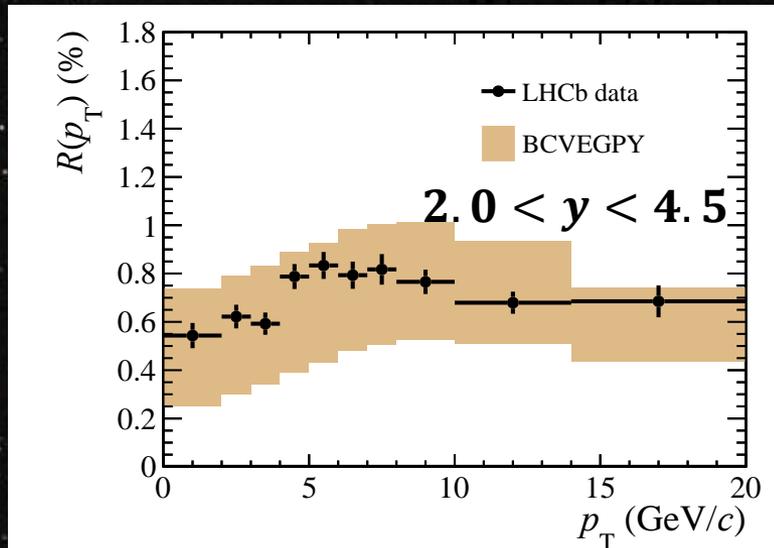
JHEP 10 (2012) 137

$$p_T < 20 \text{ GeV}/c, 2.0 < y < 4.5$$

➤ \mathcal{R} integrated over bins

$$\mathcal{R} = (0.683 \pm 0.018 \pm 0.009)\%$$

Normalization takes $\sigma(B_c^+) = 0.47 \text{ } \mu\text{b}$ and $\mathcal{B}(B_c^+ \rightarrow J/\psi\pi^+) = 0.33\%$



Decays and BF measurements

➤ 8 new decay modes observed by LHCb

- $B_c^+ \rightarrow B_s^0 \pi^+$: c quark as a spectator, the first weakly $B - B$ decay
- $B_c^+ \rightarrow J/\psi p \bar{p} \pi^+$: the first baryonic decay of B_c^+ meson
- $B_c^+ \rightarrow J/\psi D_s^{(*)+}$: the first charmonium+open charm decays
- $B_c^+ \rightarrow J/\psi K^+$: a Cabibbo-suppressed decay
- $B_c^+ \rightarrow \psi(2S) \pi^+$: a decay to excited charmonium
- $B_c^+ \rightarrow J/\psi \pi^+ \pi^- \pi^+$
- $B_c^+ \rightarrow J/\psi K^+ K^- \pi^+$

➤ Upper limits:

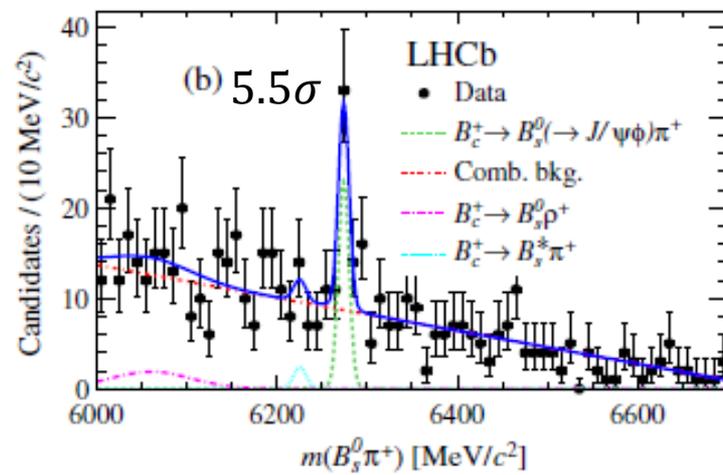
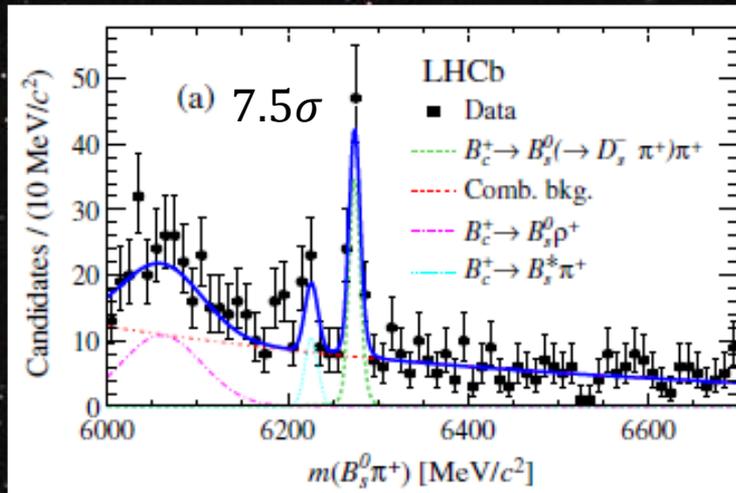
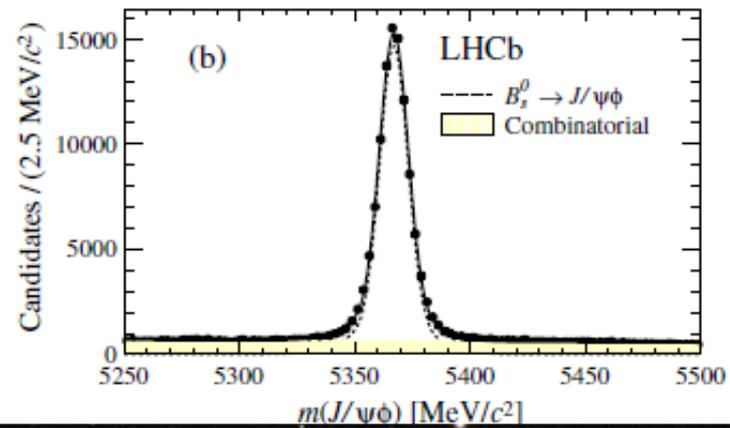
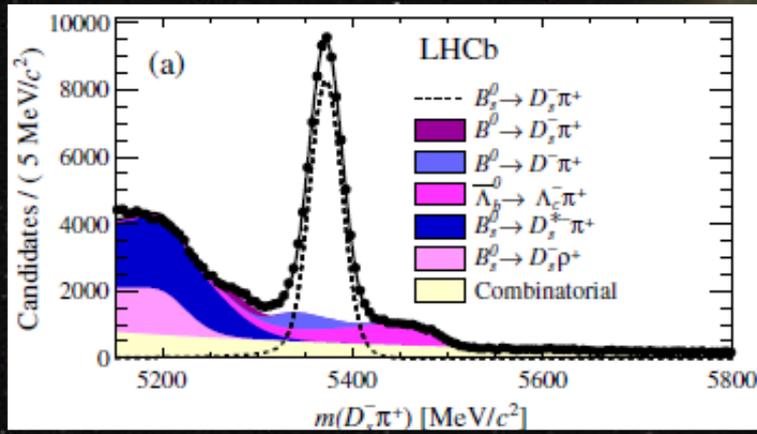
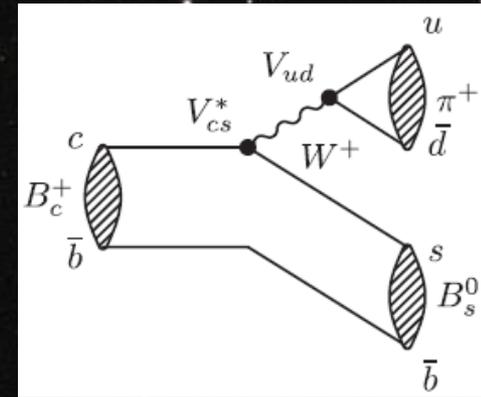
- $B_c^+ \rightarrow p \bar{p} \pi^+$
- $B_c^+ \rightarrow D_s^+ \phi, D_{(s)}^+ K^{*0}, D_{(s)}^+ \bar{K}^{*0}$

➤ An evidence of $B_c^+ \rightarrow J/\psi 3\pi^+ 2\pi^-$

$$B_c^+ \rightarrow B_s^0 \pi^+$$

- The bachelor π^+ allows self-tagging of B_s^0
- Both $B_s^0 \rightarrow D_s^- \pi^+$ and $B_s^0 \rightarrow J/\psi \phi$ used

PRL 111 (2013) 181801



$B_c^+ \rightarrow B_s^0 \pi^+$ (cont.)

PRL 111 (2013) 181801

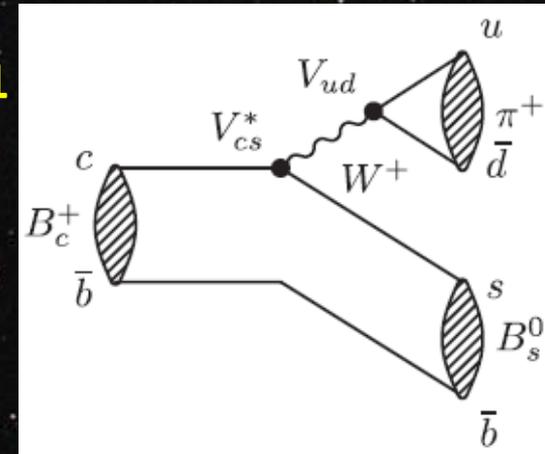
- The relative production measured

$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)} \times \mathcal{B}(B_c^+ \rightarrow B_s^0 \pi^+) = [2.37 \pm 0.31(\text{stat}) \pm 0.11(\text{syst})_{-0.13}^{+0.17}(\tau_{B_c})] \times 10^{-3}$$

- Assuming $\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+) \approx 0.15\%$

$$\Rightarrow \mathcal{B}(B_c^+ \rightarrow B_s^0 \pi^+) \approx 10\%$$

- The largest exclusive BF of any known weak B meson decay



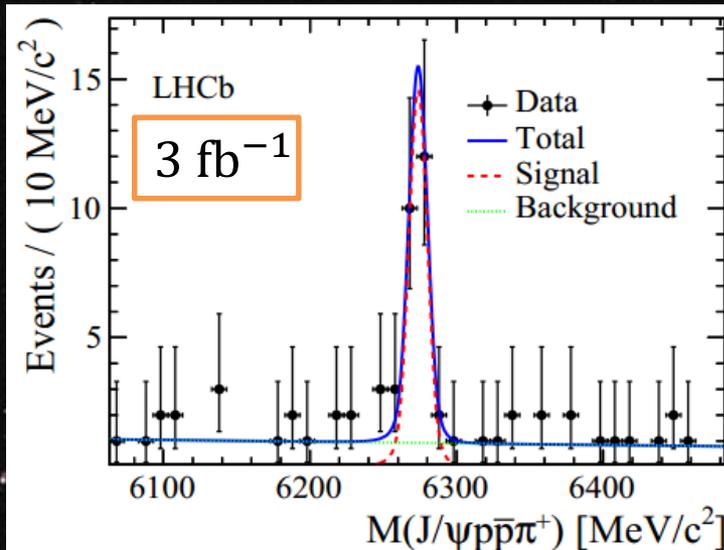
$B_c^+ \rightarrow J/\psi p \bar{p} \pi^+$

PRL 113 (2014) 152003

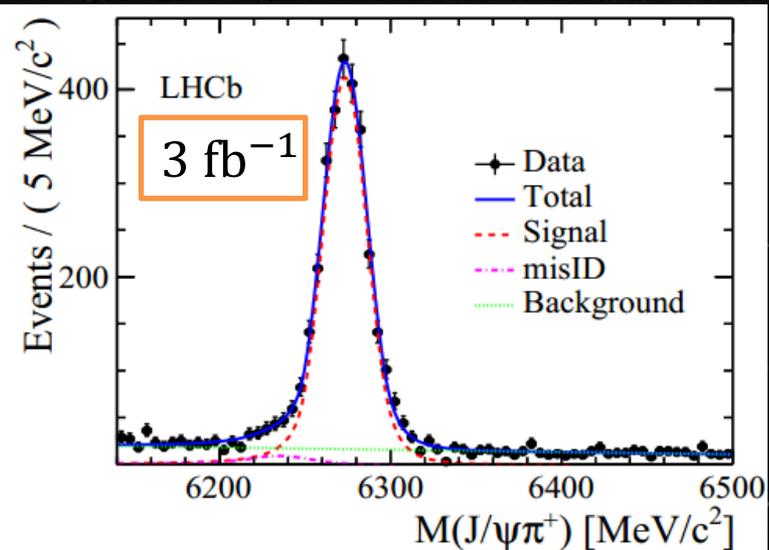
- Baryonic decay of b hadron is useful to understand baryon production mechanism, to search for new baryons/multiquarks
- Good hadron identification is essential for such analysis

➤ $\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi p \bar{p} \pi^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)} = 0.143^{+0.039}_{-0.034} \pm 0.013$, consistent with

$$\frac{\mathcal{B}(B^0 \rightarrow D^{*-} p \bar{p} \pi^+)}{\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+)} = 0.17 \pm 0.02$$



$$N_{\text{sig}} = 23.9 \pm 5.3 (7.3 \sigma)$$

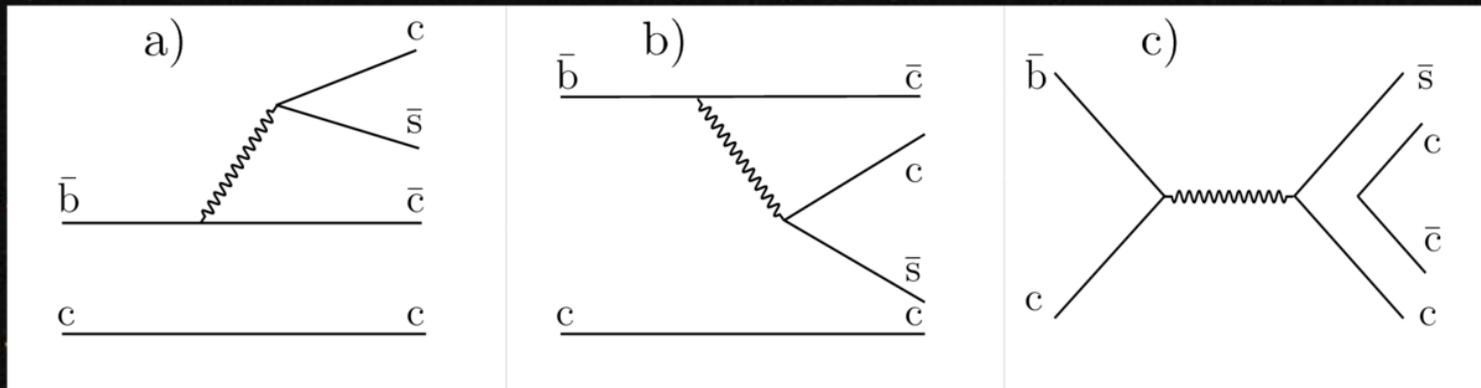


$$N_{\text{sig}} = 2835 \pm 58$$

$$B_c^+ \rightarrow J/\psi D_s^{(*)+}$$

PRD 87 (2013) 112012

- Expected Feynman diagrams of this process includes all three kind of decay modes: c -spectator, b -spectator, and annihilation
- $J/\psi D_s^+$ fully reconstructed
- $J/\psi D_s^{*+}$ partially reconstructed with missing γ/π^0 , and split for helicity
 - $\mathcal{A}_{\pm\pm} J/\psi: \pm 1; D_s^{*+}: \pm 1;$
 - $\mathcal{A}_{00} J/\psi: 0; D_s^{*+}: 0;$



$B_c^+ \rightarrow J/\psi D_s^{(*)+}$ (cont.)

PRD 87 (2013) 112012

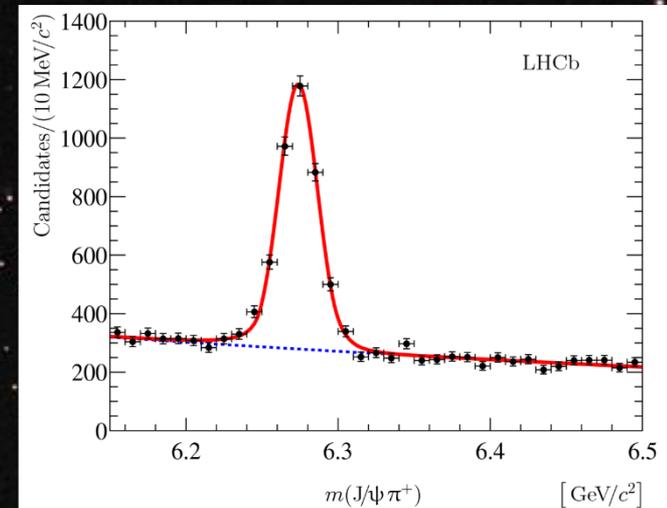
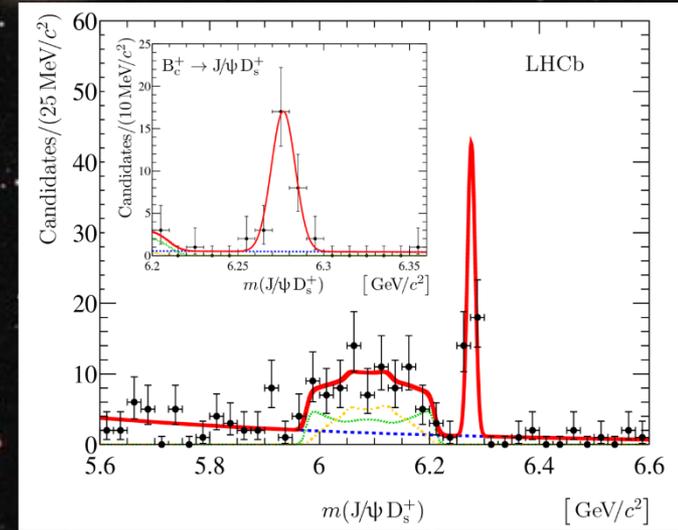
➤ $N_{sig} = 28.9 \pm 5.6$ for $J/\psi D_s^+$
in 2011+2012 data
significance $> 9\sigma$

➤ $\frac{N(J/\psi D_s^{*+})}{N(J/\psi D_s^+)} = 2.37 \pm 0.56$

➤ $\frac{\mathcal{A}_{\pm\pm}}{\mathcal{A}_{\pm\pm} + \mathcal{A}_{00}} = 0.52 \pm 0.20$

$\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \rightarrow J/\psi D_s^+)} = 2.37 \pm 0.56 \pm 0.10$

$\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi D_s^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)} = 2.90 \pm 0.57 \pm 0.24$



Search for $B_c^+ \rightarrow p\bar{p}\pi^+$

PLB 759 (2016) 313

➤ First search for B_c^+ annihilation decay mode using 3.0 fb^{-1} data at $\sqrt{s} = 7 \text{ TeV} \& 8 \text{ TeV}$

➤ Using $B^+ \rightarrow p\bar{p}\pi^+$ as control channel, measuring

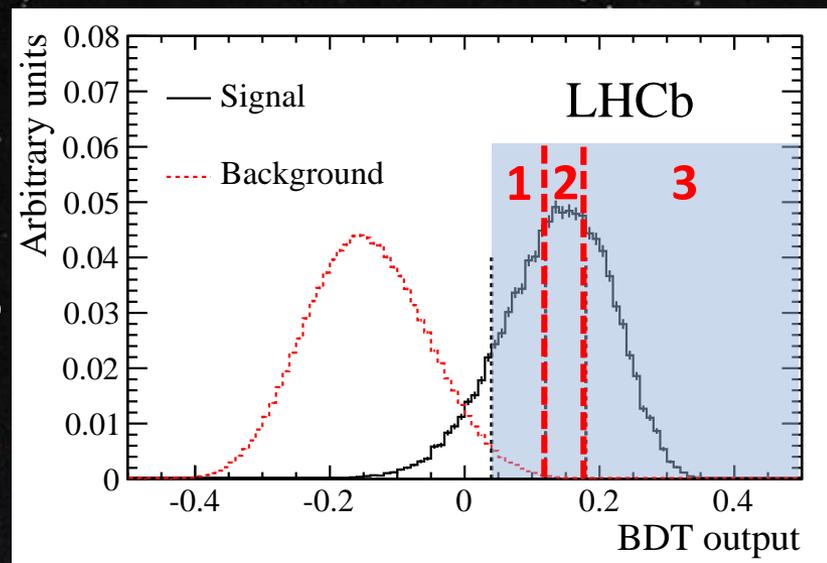
$$R_p \equiv \frac{f_c}{f_u} \times \mathcal{B}(B_c^+ \rightarrow p\bar{p}\pi^+)$$

• $m(p\bar{p}) < 2.85 \text{ GeV}/c^2$, to exclude $c\bar{c} \rightarrow p\bar{p}$

• $p_T(B) < 20 \text{ GeV}/c$

• $2.0 < y(B) < 4.5$

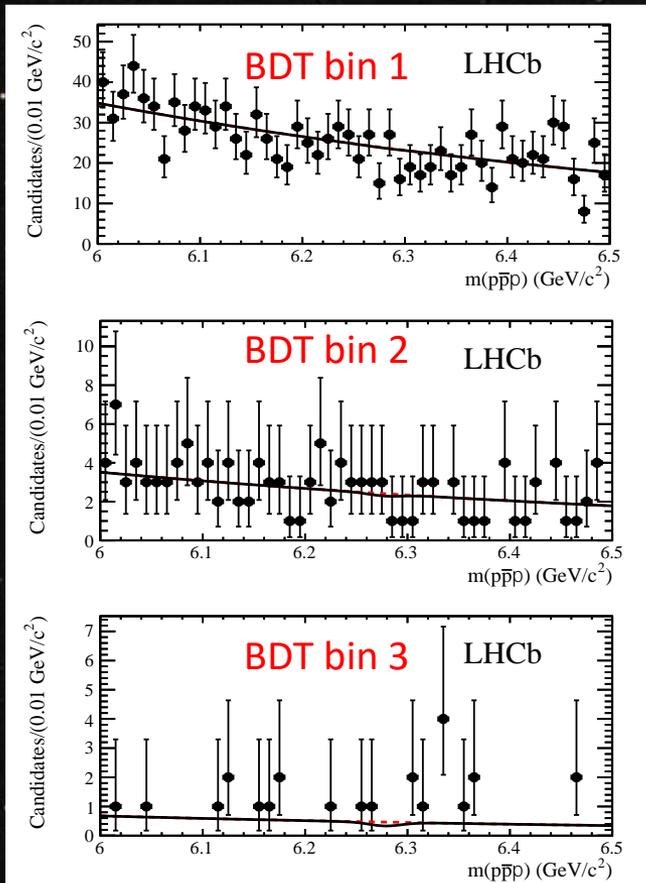
➤ Signal yield determined from simultaneous fit in 3 BDT bins to gain sensitivity



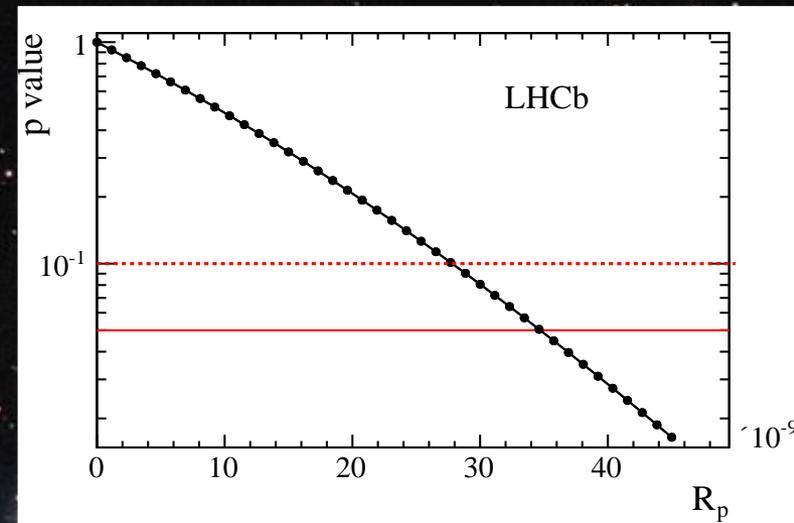
Search for $B_c^+ \rightarrow p\bar{p}\pi^+$ (cont.)

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- $N(B_c^+ \rightarrow p\bar{p}\pi^+) = -2.7 \pm 6.3$ (stat. uncertainty only)
- Upper limits estimated from p -value profile for R_p



- Upper limit: $R_p < 3.6 \times 10^{-8}$ at 95% confidence level





ATLAS measurements

ATLAS-CONF-2012-028

PRL 113 (2014) 212004

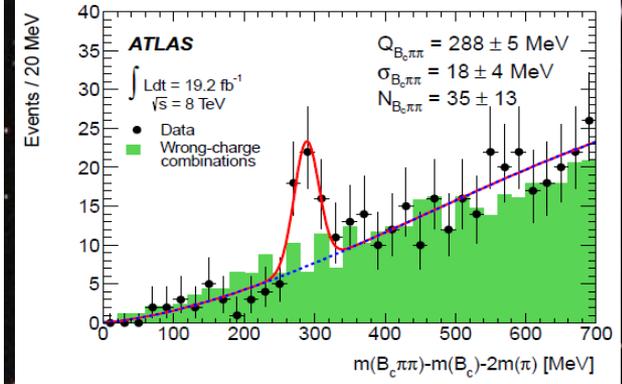
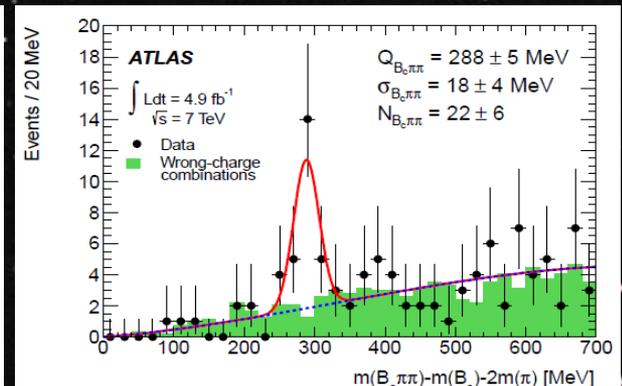
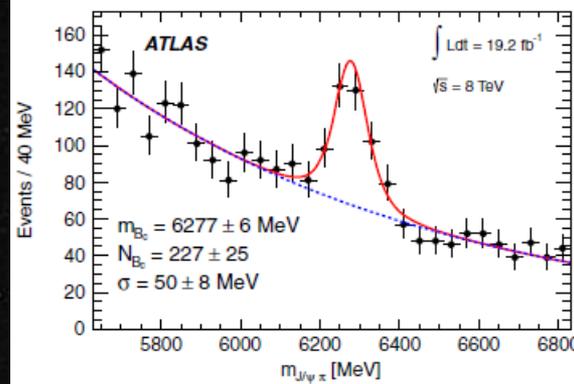
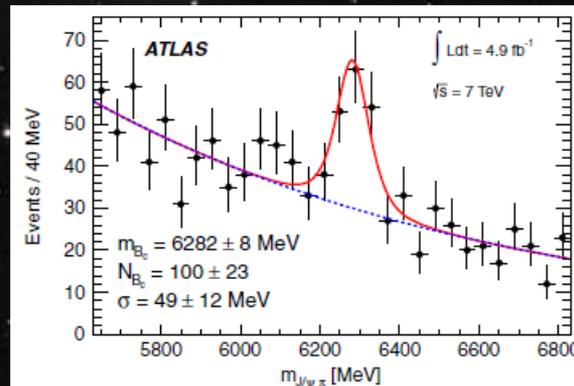
- $B_c^+ \rightarrow J/\psi\pi^+$ based on 4.3 fb^{-1} of data in 2011 (7 TeV)
 - $m = 6282 \pm 7 \text{ MeV}/c^2$; $\sigma = 32 \pm 9 \text{ MeV}/c^2$
- Observed $B_c(2S)^+$ states: $m = 6842 \pm 4 \pm 5 \text{ MeV}/c^2$

➤ Signal yield at 7 TeV

- $N(B_c) = 100 \pm 23$
- $N(2S) = 22 \pm 7$

➤ Signal yields at 8 TeV

- $N(B_c) = 227 \pm 25$
- $N(2S) = 35 \pm 13$





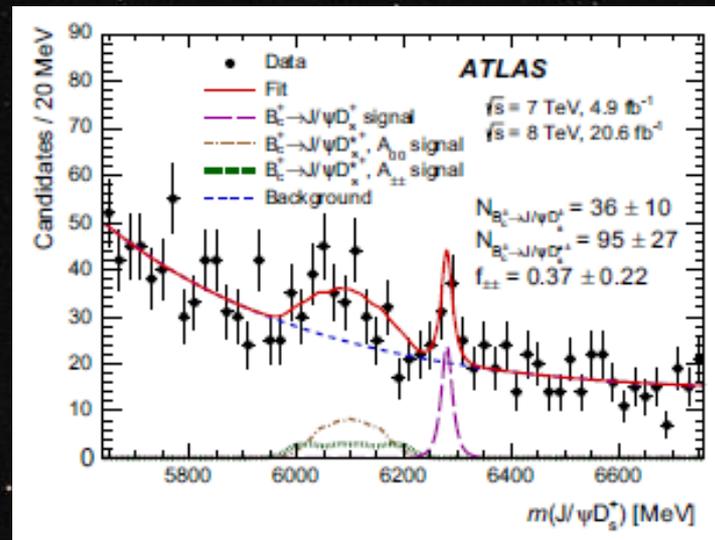
ATLAS measurements

EPJC 76(2016) 4

➤ $B_c^+ \rightarrow J/\psi D_s^{(*)+}$

- Based on ATLAS Run-I data

$$\begin{aligned} \mathcal{R}_{D_s^+/\pi^+} &= \frac{\mathcal{B}_{B_c^+ \rightarrow J/\psi D_s^+}}{\mathcal{B}_{B_c^+ \rightarrow J/\psi \pi^+}} \\ &= 3.8 \pm 1.1(\text{stat.}) \pm 0.4(\text{syst.}) \pm 0.2(\text{BF}), \\ \mathcal{R}_{D_s^{*+}/\pi^+} &= \frac{\mathcal{B}_{B_c^+ \rightarrow J/\psi D_s^{*+}}}{\mathcal{B}_{B_c^+ \rightarrow J/\psi \pi^+}} \\ &= 10.4 \pm 3.1(\text{stat.}) \pm 1.5(\text{syst.}) \pm 0.6(\text{BF}), \\ \mathcal{R}_{D_s^{*+}/D_s^+} &= \frac{\mathcal{B}_{B_c^+ \rightarrow J/\psi D_s^{*+}}}{\mathcal{B}_{B_c^+ \rightarrow J/\psi D_s^+}} \\ &= 2.8_{-0.8}^{+1.2}(\text{stat.}) \pm 0.3(\text{syst.}), \end{aligned}$$



$$\Gamma_{\pm\pm} / \Gamma = 0.38 \pm 0.23(\text{stat.}) \pm 0.07(\text{syst.})$$

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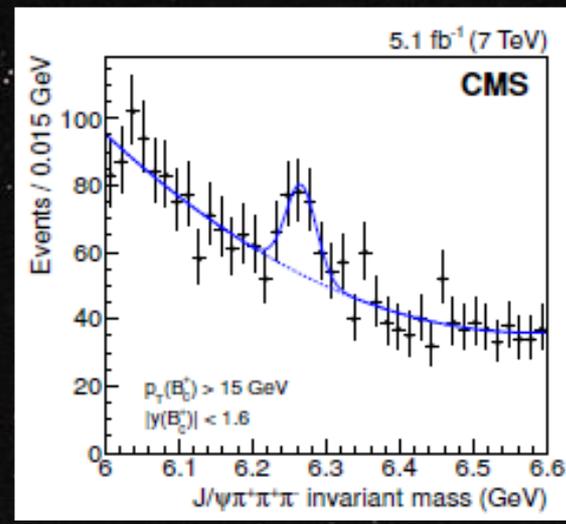
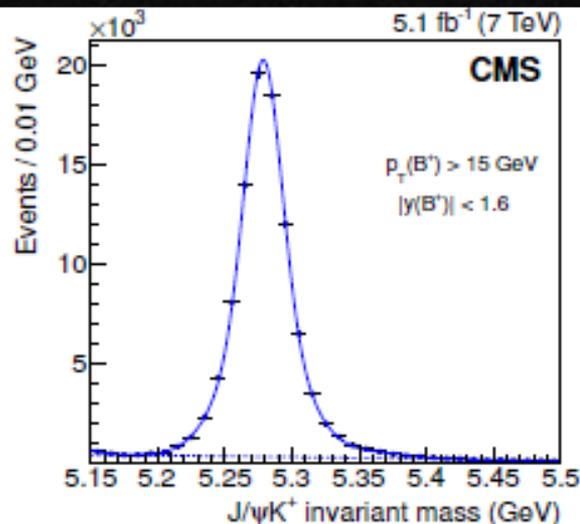
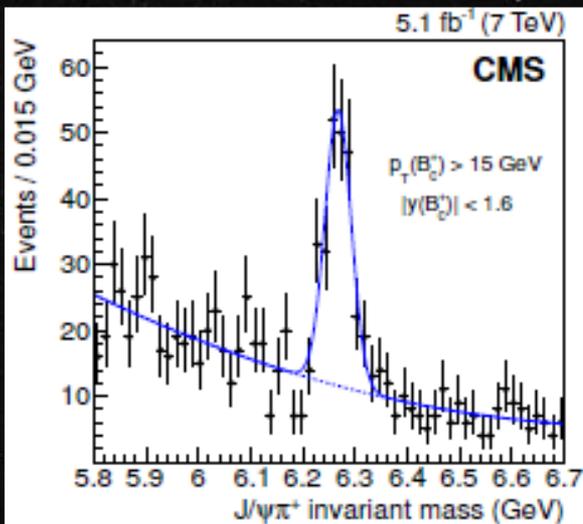
$N_{\text{sig}} = 108 \pm 19$



CMS measurements

CMS: JHEP 01 (2015) 063

- Relative production measured using 7 TeV data (5.1 fb^{-1})
- $R_{c/u} \equiv \frac{\sigma(B_c^+) \mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)}{\sigma(B^+) \mathcal{B}(B^+ \rightarrow J/\psi K^+)} = [0.48 \pm 0.05 \pm 0.03 \pm 0.05(\tau_{B_c})]\%$
 $p_T(B) > 15 \text{ GeV}/c, |y| < 1.6$
- $R_{B_c} \equiv \frac{\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+ \pi^- \pi^+)}{\sigma(B^+) \mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)} = 2.55 \pm 0.80 \pm 0.33_{-0.01}^{+0.04}(\tau_{B_c})$
 $p_T(B) > 15 \text{ GeV}/c, |y| < 1.6$



Summary

- The LHC provides a good opportunity of B_c studies
- Many results obtained using the Run-I data, and we know more and more about B_c^+ mesons
 - **Precisely measured mass and lifetime**
 - ✓ $m(B_c^+) = 6274.7 \pm 1.2 \text{ MeV}/c^2$
 - ✓ $\tau(B_c^+) = 511.4 \pm 9.3 \text{ fs}$
 - **Measurements of relative production cross-sections and branching fractions**
 - **8 new decay modes observed, including the b -spectator mode, the baryonic decay**
 - **Searching for annihilation decays**
 - **Excited states $B_c(2S)^+$ claimed by ATLAS**
- Data in Run-II will provide more opportunities

A deep space photograph of a starry night sky. The background is black, filled with numerous small, bright white stars. A prominent green star is located in the upper-middle section. A blue star is visible in the lower-left quadrant. A small, faint galaxy is visible in the upper-right quadrant. The text "Thanks !" is centered in the image in a bright yellow font.

Thanks !

A dark, starry night sky background. In the center, the text "Backup slides" is written in white. Surrounding the text are numerous stars of various colors and sizes. Notable features include a bright green star in the upper left, a bright blue star in the lower left, a bright red star in the lower right, and a small, faint galaxy in the upper right.

Backup slides

B_c results from Tevatron



- Experimental studies of B_c before 2011

dominated by Tevatron (CDF/D0)

- First observed by CDF in 1998 through $B_c^+ \rightarrow J/\psi l^+ \nu$

PRL 81 (1998) 2432

- Fully reconstructed channel $B_c^+ \rightarrow J/\psi \pi^+$ in 2005

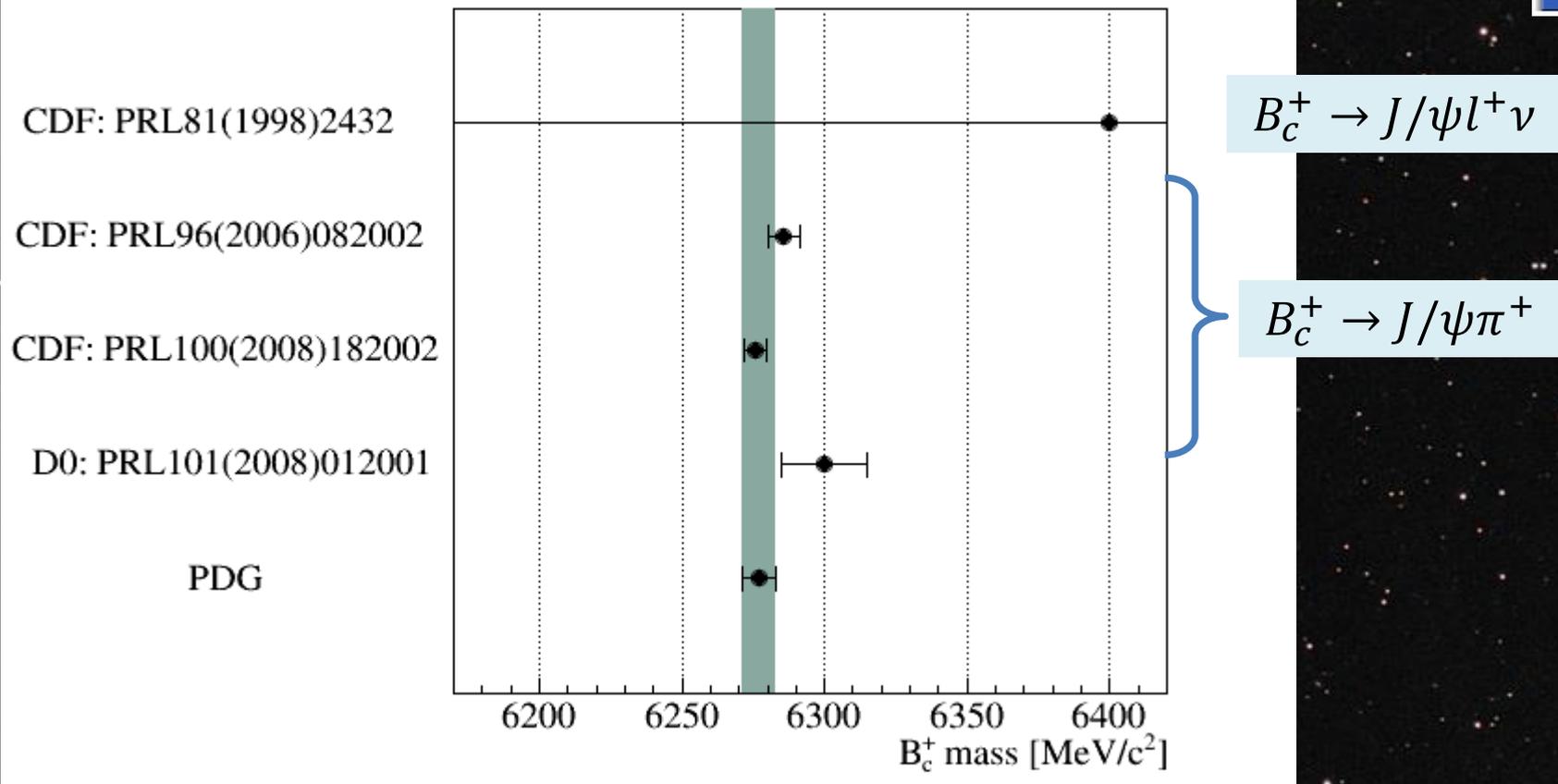
PRL 96 (2006) 082002

- Relative production of semileptonic decay measured

- $$\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi l^+ \nu)}{\mathcal{B}(B^+ \rightarrow J/\psi K^+)} = 0.132_{-0.037}^{+0.014} \pm 0.031_{-0.020}^{+0.032}$$

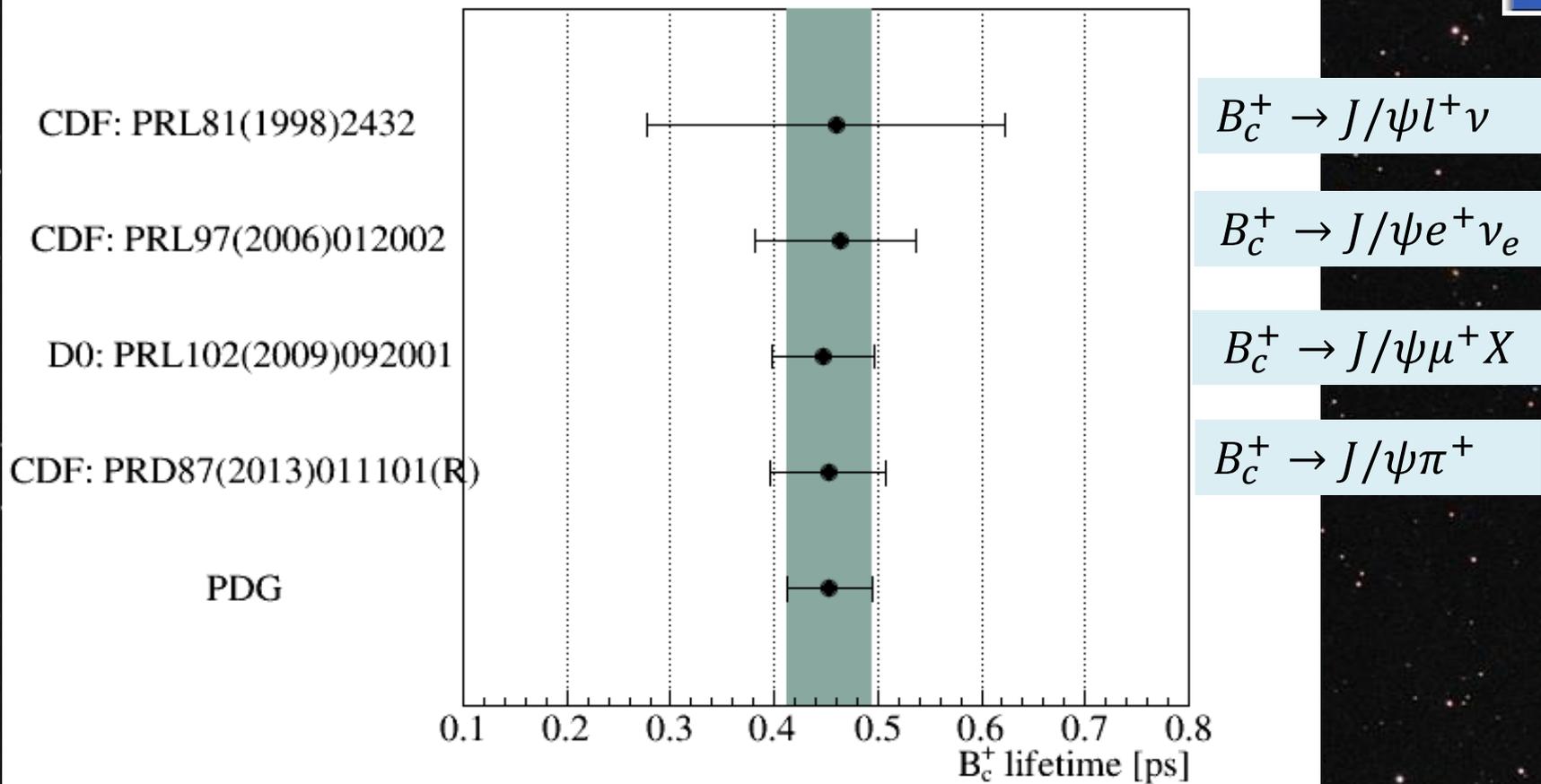
- Mass/lifetime measurements through both semileptonic and hadronic decays

Mass measurements from Tevatron



➤ PDG 2012: $m_{B_c} = 6277 \pm 6 \text{ MeV}/c^2$

Lifetime measurements from Tevatron



➤ Systematic uncertainties ~ 0.03 ps for all

➤ PDG 2012: $\tau_{B_c} = 0.453 \pm 0.041$ ps

➔ 9% uncertainty