B_c Properties and Decays

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slides prepared by Michele Veltri[(2)].

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Introduction

A unique system in the standard model

- Made of two heavy quarks, of different flavour: $(\bar{b}c)$
- Non relativistic system: mass spectrum similar to quarkonium
- Can decay only weakly ➜ Longer lifetimes than quarkonia

A great "laboratory" for testing potential models
and weak decay mechanism of heavy–quark bound states.

History

LEP (1990-1995)	- Hint(?) of two events by OPAL
Tevatron (1998)	- B_c discovery by CDF
Tevatron Run II (2008)	- Signal significance $> 5\sigma$. Mass and lifetime measurements by CDF and D0
B-Factories	- e^+e^- colliders operate at the $\Upsilon(4S)$ mass B_c production under threshold.

Introduction

Information about this particle before LHC (CDF and D0 experiments):

- Few decays observed: $B_c^+ \to J/\psi\ \ell^+\nu_\ell$, and $B_c^+ \to J/\psi\ \pi^+$
- 6 MeV/c^2 mass uncertainty ($< 0.3\,\mathrm{MeV}/c^2$ for other B mesons)
- 7% uncertainty on the lifetime ($< 0.7\%$ for other B mesons)

With LHC entering a new era (also) for B_c physics

Large progress in the exp knowledge (...and theory also!) of this particle

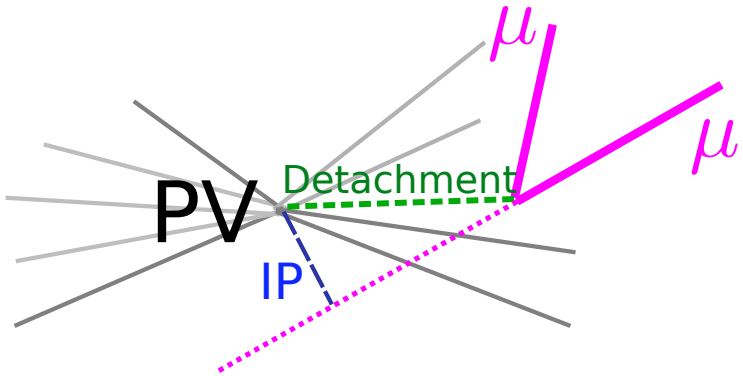
- Many new modes observed
- High precision measurement of mass and lifetime by ATLAS, CMS and LHCb

Outline

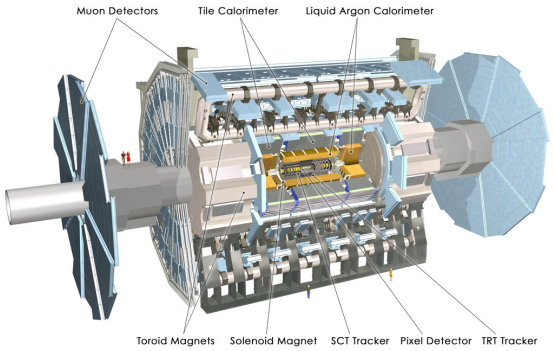
- Production
- Mass
- Lifetime
- Decays

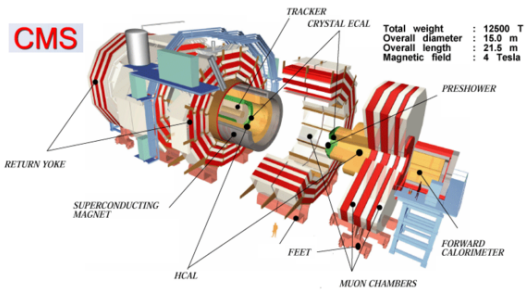
Typical Analysis Strategy for $B_c \to J/\psi\ (\mu\mu) + X$

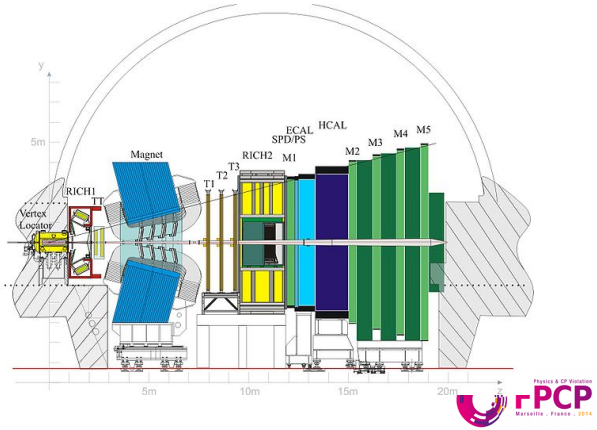
$$B_c^+ \to J/\psi X$$
$$\hookrightarrow \mu^+\mu^-$$



- Trigger and offline selection relying on high p_T muon or dimuon candidates
- Detachment and impact parameter requirements reject most of the background
- When needed, simulation is used to correct for **efficiency** and **acceptance**
- Normalization channel (when needed): $B_c^+ \to J/\psi\ \pi^+$

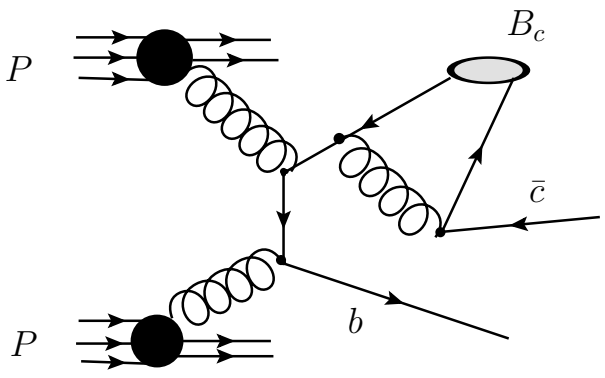






B_c Production

- B mesons production:
  $b\bar{b}$ pair production & fragmentation
- The $q\bar{q}$ ratio in fragmentation is
  $u{:}d{:}s{:}c \approx 1{:}1{:}0.3{:}10^{-11}$ [PRD48 (1993) 4086]
  ➜ Almost negligible for B_c at hadronic collider
- B_c production is mainly due to gg fusion
- pQCD α_s^4 calculations:
  $\sigma(B_c) \sim 0.4 \div 0.9\ \mu\text{b}$ (at $\sqrt{s} = 7 \div 14\ TeV$)
- $\sigma(B_c)/\sigma(B) \sim 10^{-3}$
- $\sigma(B_c)_{\text{LHC}}/\sigma(B_c)_{Tevatron} \sim \mathcal{O}(10)$ [P. Atom. Nucl. 64 (2004)]
- $gg \to B_c$ implemented in Monte Carlo generator BCVEGPY [Comput. Phys. Comm. 159 (2004) 192-224]
- No absolute branching ratio measured up to date



gg fusion mechanism
36 diagrams in total

B_c Production

Two production measurements by CMS and LHCb

CMS [preliminary CMS–PAS–BPH–12–011] LHCb [PRL 109 (2012) 232001]

- Use fully reconstructed decay $B_c^+ \to J/\psi\ \pi^+$
- Production relative to that of $B^+ \to J/\psi\ K^+$

$$R_{c/u} = \frac{\sigma(B_c)\,\mathcal{B}(B_c^+ \to J/\psi\,\pi^+)}{\sigma(B^+)\,\mathcal{B}(B^+ \to J/\psi\,K^+)} = \frac{N\left(B_c^+ \to J/\psi\,\pi^+\right)}{\epsilon^c_{\rm tot}}\,\frac{\epsilon^u_{\rm tot}}{N(B^+ \to J/\psi\,K^+)}$$

- Decays with identical topologies
- The two experiments provide results in complementary η regions

CMS

$$R_{c/u} = \left(0.48 \pm 0.05(stat) \pm 0.04(syst)^{+0.05}_{-0.03}(\tau_{B_c})\right) \times 10^{-2}$$

$N_{B_c^+ \to J/\psi\,\pi^+} = 176 \pm 19$, $p_T(B_c) > 15$ GeV, $|y| < 1.6$, $\sqrt{s}$ =7 Tev, $\mathcal{L}$ =5.1 fb^{-1}

LHCb

$$R_{c/u} = (0.68 \pm 0.10(stat) \pm 0.03(syst) \pm 0.05(\tau_{B_c})) \times 10^{-2}$$

$N_{B_c^+ \to J/\psi\,\pi^+} = 162 \pm 18$, $p_T(B_c) > 4$ GeV, $2.5 < \eta < 4.5$, $\sqrt{s}$ =7 Tev, $\mathcal{L}$ =0.37 fb^{-1}

B_c Mass

Measurements by ATLAS, CMS and LHCb using $B_c^+ \to J/\psi\ \pi^+$ decay

CDF and D0 combination: $M(B_c) = 6277 \pm 6\ \mathrm{MeV}/c^2$

[PDG 2012]

$M(B_c) = 6282 \pm 7(\mathrm{stat})\ \mathrm{MeV}/c^2$

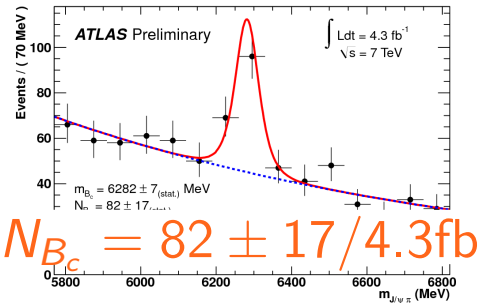
[preliminary ATLAS–CONF–2012–028]

$M(B_c) = 6272 \pm 3(\mathrm{stat})\ \mathrm{MeV}/c^2$

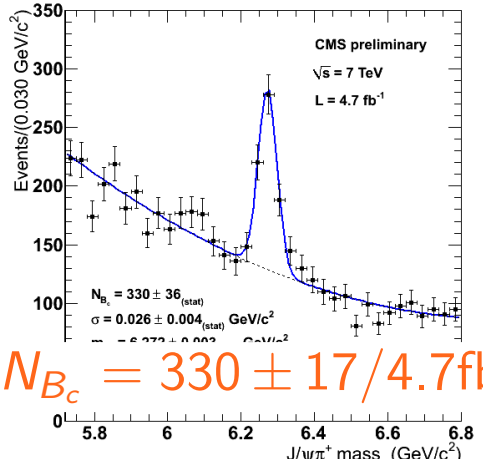
[preliminary CMS–PAS–BPH–11–003]

$M(B_c) = 6273.7 \pm 1.3(\mathrm{stat}) \pm 1.6(\mathrm{syst})\ \mathrm{MeV}/c^2$

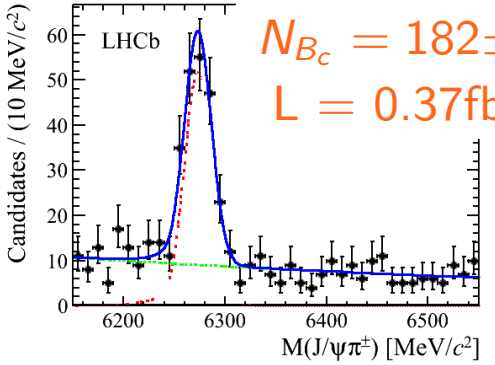
[PRL 109 (2012) 232001]



$N_{B_c} = 82 \pm 17/4.3\mathrm{fb}^{-1}$



$N_{B_c} = 330 \pm 17/4.7\mathrm{fb}^{-1}$



$N_{B_c} = 182 \pm 18$

$L = 0.37\mathrm{fb}^{-1}$

- Decay with large Q–value: M(B_c) - M(J/ψ) - M(π^+)
  ➜ The syst uncertainty is completely dominated by the uncertainty on the momentum scale
- LHCb further improved the B_c mass knowledge by using the decay $B_c^+ \to J/\psi\ D_s^+$

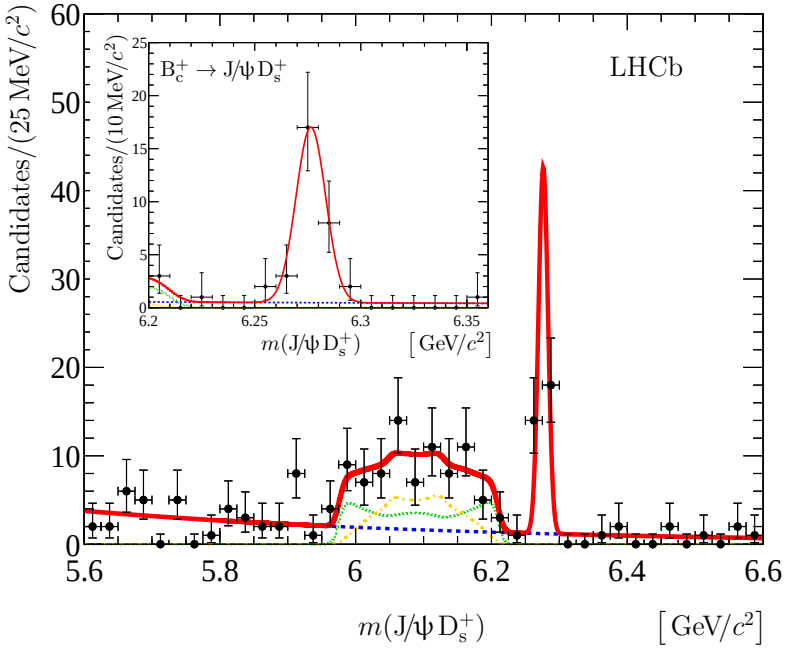
B_c mass using the $B_c^+ \to J/\psi\ D_s^+$ decay

[PRD 87 (2013) 112012]

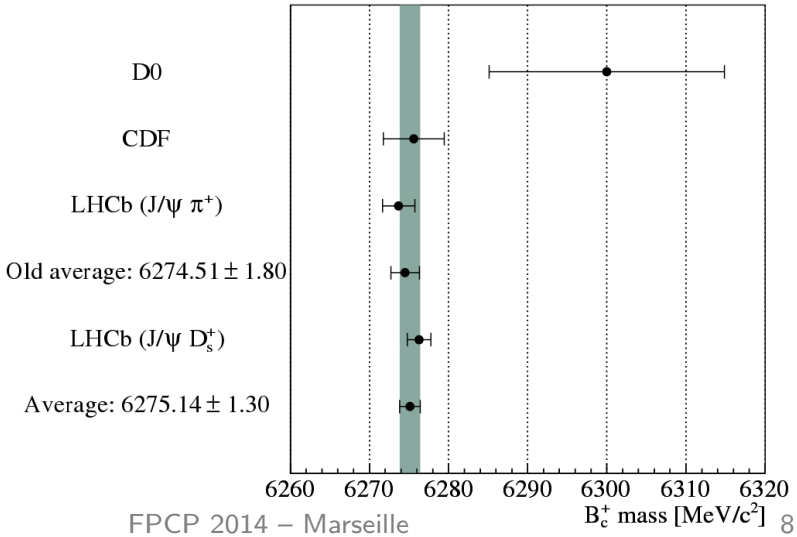
- Low Q–value ➜ Small systematic uncertainty on the momentum
  Accuracy in the momentum scale: 3×10^{-4} ➜ 0.30 MeV/c^2
- Use D_s^+ mass value: 1968.29 ± 0.18 MeV/c^2 [LHCb, JHEP06 (2013) 065]
  Effect of uncertainty on D_s^+ mass ➜ 0.16 MeV/c^2

$$\mathrm{M}(B_c) = 6276.28 \pm 1.44(\mathrm{stat}) \pm 0.36(\mathrm{syst})\ \mathrm{MeV}/c^2$$

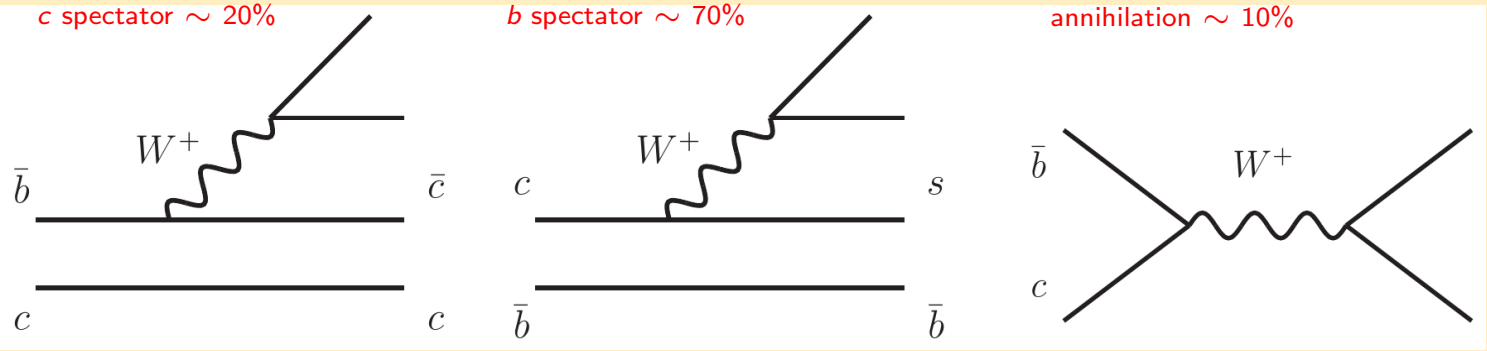
Most precise single measurement, uncertainty dominated by statistical errror.



New world average:
$6275.14 \pm 1.30\,\mathrm{MeV}/c^2$



B_c Lifetime



1. $B_c^+ \to J/\psi\ \ell^+\ \nu_\ell$
   $B_c^+ \to J/\psi\ \pi^+$
2. $B_c^+ \to B_s^0\ \pi^+$
   $B_c^+ \to B_s^0\ \ell^+\ \nu_\ell$
3. $B_c^+ \to \tau^+\ \nu_\tau$
   $B_c^+ \to \bar{K}^{*0}\ K^+$

Estimate Γ summing the contributions of the dominating decay process

$$\Gamma = \Gamma_{\bar{b}} + \Gamma_c - \Gamma_{PI} + \Gamma_{anni}$$

[P. Atom. Nucl. 64 (2004)]

$\bar{b} \to \bar{c} + c\ \bar{s}$: account for Pauli interference with c of initial state

- Decay mechanism dominated by c decay ➜ $\tau_{B_c} \approx \tau_{charm}$
- Theory predictions are in the range: $\tau_{B_c} = (0.3 \div 0.7)$ ps
- PDG 2013: $\tau_{B_c} = 0.452 \pm 0.033$ ps
- B_c lifetime affected by sizeable uncertainty
  ➜ Source of systematic uncertainty for most B_c measurements

B_c Lifetime using $B_c \to J/\psi\, \mu^+ X$ decays

[EPJC 74 (2014) 2839]

Partially reconstructed, semileptonic B_c decays

Clear experimental signature:
a μ^+ and a J/ψ from a common vertex.

Large branching fraction

➜ **Lifetime unbiased** trigger and selection.

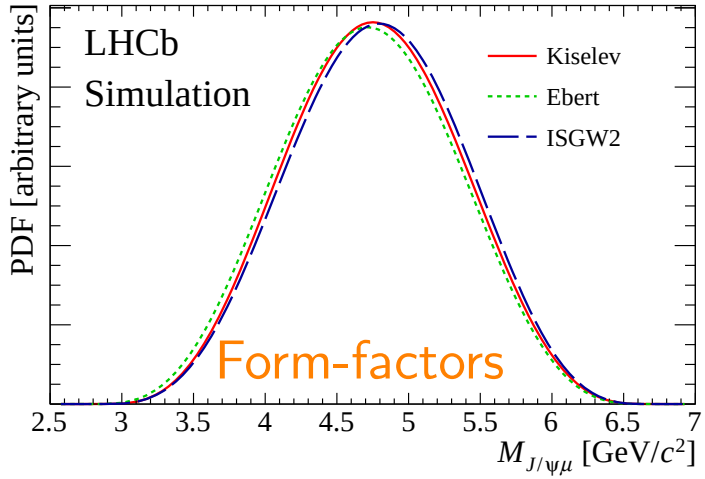
Partial reconstruction (missing neutrino): cannot reconstruct B_c proper decay time t.

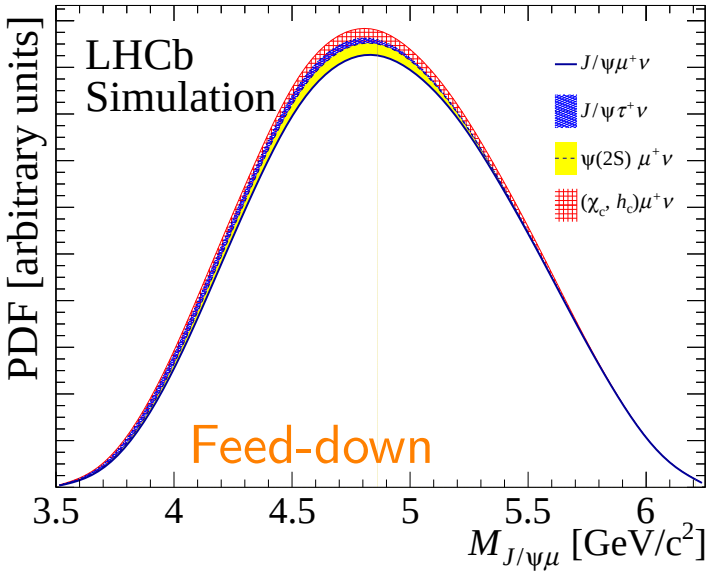
Use **pseudo-proper decay time** t_{ps}, instead.
$t_{ps} \equiv$ decay time in $J/\psi\ \mu^+$ rest frame

The correction between t_{ps} and t ($k = t_{ps}/t$)
is obtained from simulation.

It accounts for

- kinematics
- dynamics (decay form-factors)
- feed-down modes (higher $c\bar{c}$ states)





2012 dataset: 2 fb^{-1}

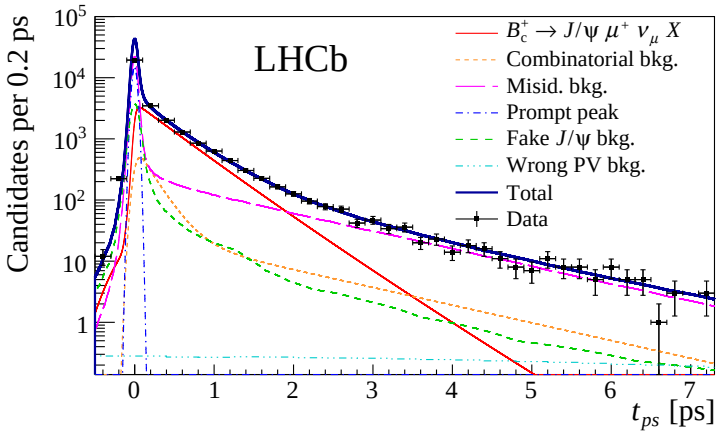
B_c Lifetime using $B_c \to J/\psi\,\mu^+ X$ decays

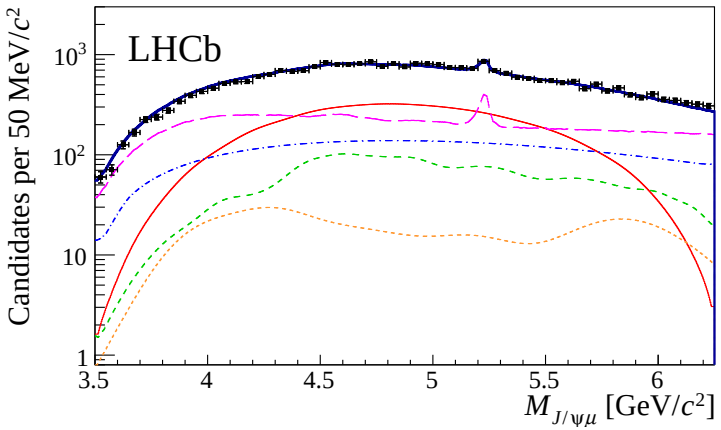
[EPJC 74 (2014) 2839]

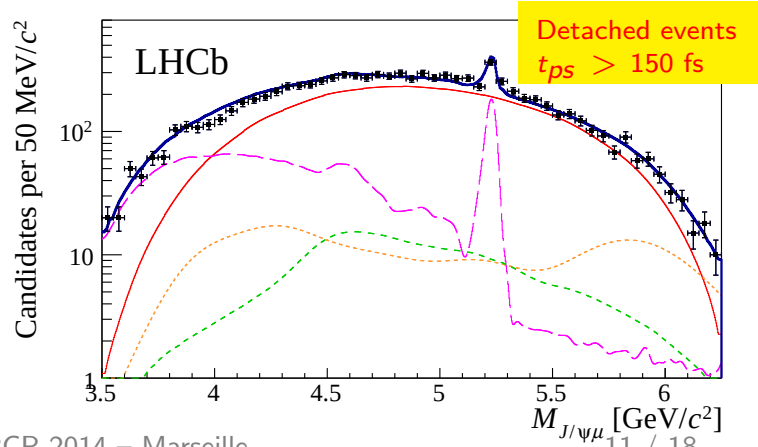
- Decay-time signal model in $M_{J/\psi\,\mu}$ mass bins:
  $exp(t) \otimes h^m(k) \otimes$ 3–Gaussian (for resolution)
- Background model
  Include the PV region to constrain the tails of background distribution in the signal region

1. J/ψ + hadron misidentified as a μ
   ➜ Dominant source
2. Fake J/ψ + real μ
3. Combinatorial: J/ψ + μ not coming from a B_c
   ➜ Prompt and detached
   - Prompt relevant for decays close to PV
   - Detached from MC sample of
     $H_b \to J/\psi$ X $\qquad H_b \equiv B_d, B_u, B_s, \Lambda_b$

All background sources modelled on data
(except for detached combinatorial)







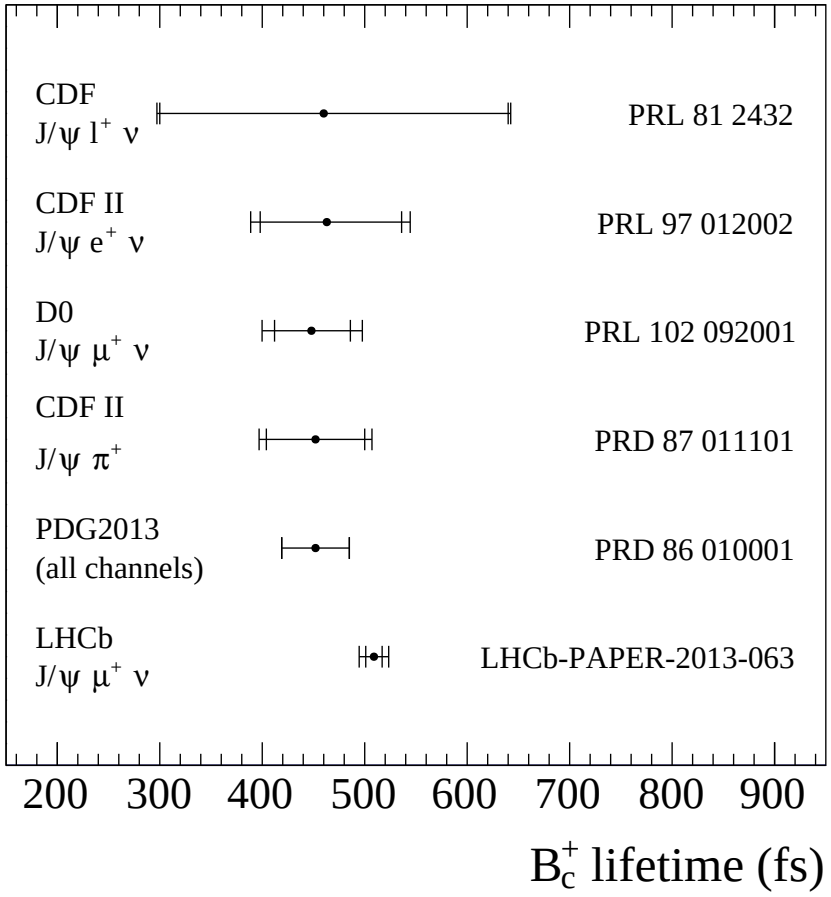
B_c Lifetime using $B_c \to J/\psi\,\mu^+ X$ decays

[EPJC 74 (2014) 2839]

- τ_{B_c} is determined from a maximum unbinned likelihood fit to the $(t_{ps}, M_{J/\psi\,\mu})$ distribution

$\tau_{B_c} = 509 \pm 8(stat) \pm 12(syst)$ fs

- Dominating systematic uncertainty:
  Background model ($\pm$ 10 fs)
  Signal model ($\pm$ 5 fs)



- This is the most precise measurement of τ_{B_c} to date
- With less than half the uncertainty wrt. PDG 2013

B_c Decays

Only two B_c decay modes were observed before LHC by CDF and D0:

$$B_c \to J/\psi\, \ell^+ \nu_\ell \qquad \text{and} \qquad B_c \to J/\psi\, \pi^+$$

Many new decay modes observed by the LHC experiments:

Observation of $B_c^+ \to \psi(2S)\pi^+$ [LHCb, PRD 87 (2013) 071103]

Observation of $B_c^+ \to J/\psi\, D_s^+$ and $B_c^+ \to J/\psi\, D_s^{*+}$ decays [LHCb, PRD 87 (2013) 112012]

First observation of the decay $B_c^+ \to J/\psi\, K^+$ [LHCb, JHEP 09 (2013) 075]

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Decay modes $B_c \to J/\psi + \text{multi} - \text{hadrons}$

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B_c Decays: $B_c^+ \to B_s^0\ \pi^+$

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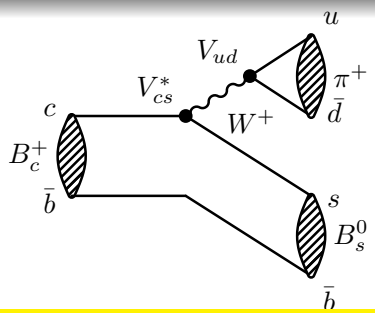
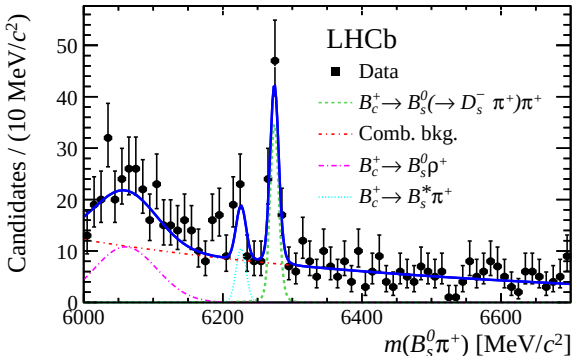
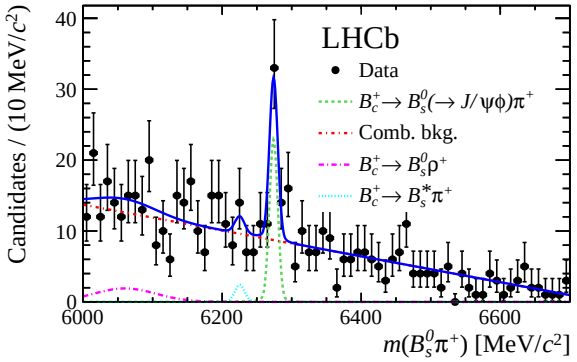


- b–spectator type favoured decay ➜ $\Gamma_c \approx 70\%$
- Wide range of theory predictions for $\mathcal{B}$: 2 $\to$ 20%
- Search performed with 3 fb^{-1} at $\sqrt{s}$ =7+8 TeV
- Two channels used: $B_s^0 \to D_s^-\ (K^+\ K^-\ \pi^-)\ \pi^+$ and $B_s^0 \to J/\psi\,(\mu^+\mu^-)\phi(K^+K^-)$

$N_{B_c^+ \to B_s^0(D_s^-\ \pi^+)\pi^+} = 64 \pm 10$
$N_{B_c^+ \to B_s^0(J/\psi\ \phi)\pi^+} = 35 \pm 8$
(both $> 5\sigma$ significance)



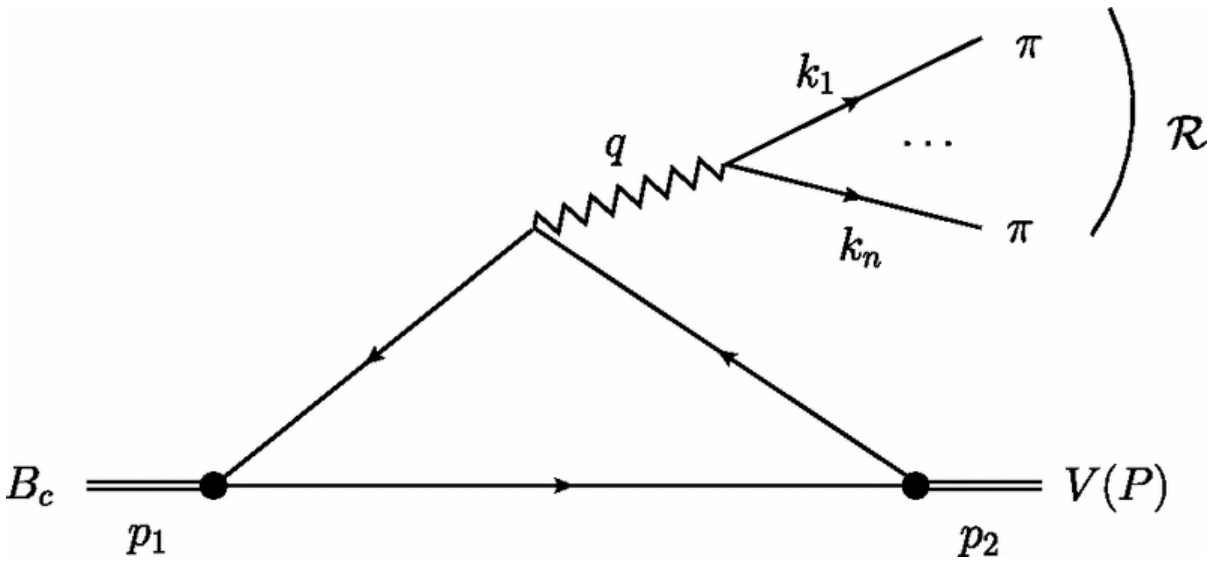


$$\frac{\sigma(B_c)}{\sigma(B_s^0)} \times \mathcal{B}(B_c \to B_s^0\pi^+) = \left[2.37 \pm 0.31(\text{stat}) \pm 0.11(\text{syst})^{+0.17}_{-0.13}(\tau_{B_c})\right] \times 10^{-3}$$

- First weak $B \to B$ decay observed
- With additional theory/exp input $\mathcal{B}(B_c \to B_s^0\pi^+) \approx 10\%$ can be obtained

Largest branching fraction of any known weak B meson decay

B_c decays to J/ψ + multi-hadron



Factorization Approximation

Factorize the decay amplitude into two independent parts
$B_c^+ \to J/\psi \; W^{+*}$

Use form factors from semi–leptonic decays

W^{+*} hadronization via decays of virtual resonances

Use experimental info from other decays like $\tau \to n\pi$

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B_c Decays: $B_c \to J/\psi\,\pi^+\pi^-\pi^+$

Measure $R_{3\pi} \equiv \frac{\mathcal{B}(B_c \to J/\psi\,\pi^+\pi^-\pi^+)}{\mathcal{B}(B_c \to J/\psi\,\pi^+}$)

$$R_{3\pi} = 2.43 \pm 0.76(stat)^{+0.46}_{-0.44}(syst)$$

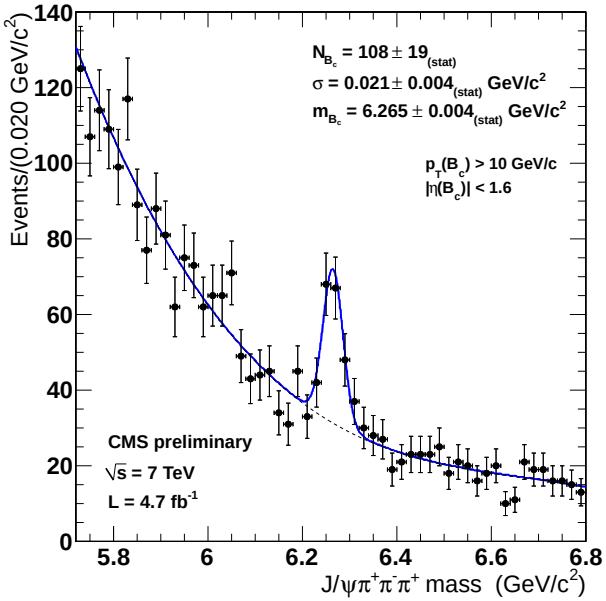
[preliminary CMS–PAS–BPH–12–011]

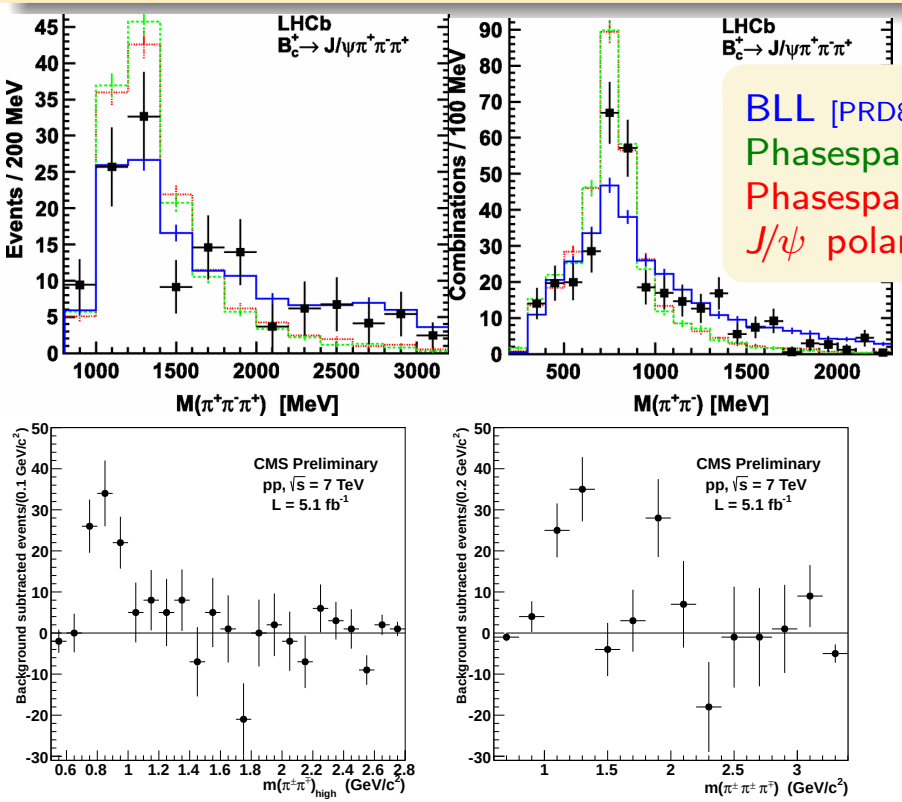
$$R_{3\pi} = 2.41 \pm 0.30(stat) \pm 0.33(syst)$$

[PRL 108 (2012) 251802]

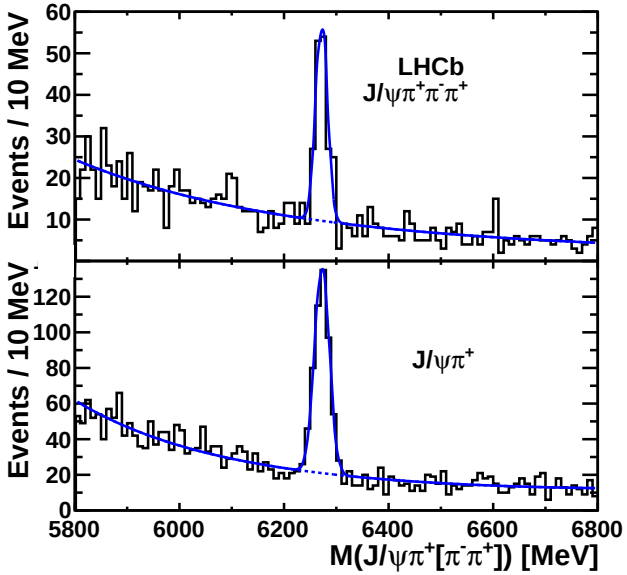
Consistent with prediction of: $R_{3\pi} = 2.3$

[PRD81 (2012) 014015]





BLL [PRD81014015]
Phasespace
Phasespace with J/ψ polarization



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Observation of $B_c^+ \to J/\psi\, D_s^+$ and $B_c^+ \to J/\psi\, D_s^{*+}$ decays [LHCb, PRD 87 (2013) 112012]

First observation of the decay $B_c^+ \to J/\psi\, K^+$ [LHCb, JHEP 09 (2013) 075]

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Decay modes $B_c \to J/\psi + \text{multi} - \text{hadrons}$

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Evidence for the decay $B_c^+ \to J/\psi\, 3\pi^+\, 2\pi^-$ [LHCb, arXiv:1404.0287]

Observation of the decay $B_c^+ \to J/\psi\, K^+K^-\pi^+$ [LHCb, JHEP 1311 (2013) 094]

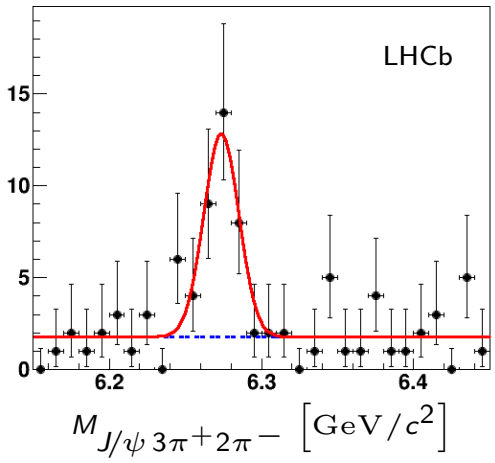
B_c Decays: $B_c^+ \to J/\psi\ 3\pi^+\ 2\pi^-$

Evidence for the decay $B_c^+ \to J/\psi\ 3\pi^+\ 2\pi^-$

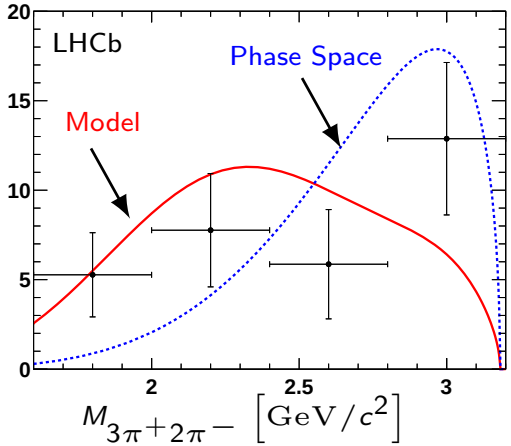
[LHCb-PAPER-2014-009, accepted in JHEP]

- Search performed with 3 fb^{-1} at $\sqrt{s}$ =7+8 TeV
- $N_{B_c^+ \to J/\psi\, 3\pi^+ 2\pi^-} = 32 \pm 8$ (4.5σ significance)
- No resonant stuctures found in the combinations of final state particles
- Low efficiency w.r.t to normalization channel

➜ Need to reconstruct four additional π



$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, 3\pi^+ 2\pi^-)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 1.74 \pm 0.44(stat) \pm 0.24(syst)$$



- Dominant syst uncertainty: Fit and decay model
- Consistent with analogous measurements in B^+ and B^0

$$\frac{\mathcal{B}\left(B^0 \to D^{*-} 3\pi^+ 2\pi^-\right)}{\mathcal{B}\left(B^0 \to D^{*-} \pi^+\right)} = 1.70 \pm 0.34 \qquad \frac{\mathcal{B}\left(B^+ \to \bar{D}^{*0} 3\pi^+ 2\pi^-\right)}{\mathcal{B}\left(B^+ \to \bar{D}^{*0} \pi^+\right)} = 1.10 \pm 0.24$$

In good agreement with theory predictions of 0.95 and 1.1 [PRD86 (2012) 074024]

B_c Decays

Only two B_c decay modes were observed before LHC by CDF and D0:

$$B_c \to J/\psi\, \ell^+ \nu_\ell \qquad \text{and} \qquad B_c \to J/\psi\, \pi^+$$

Many new decay modes observed by the LHC experiments:

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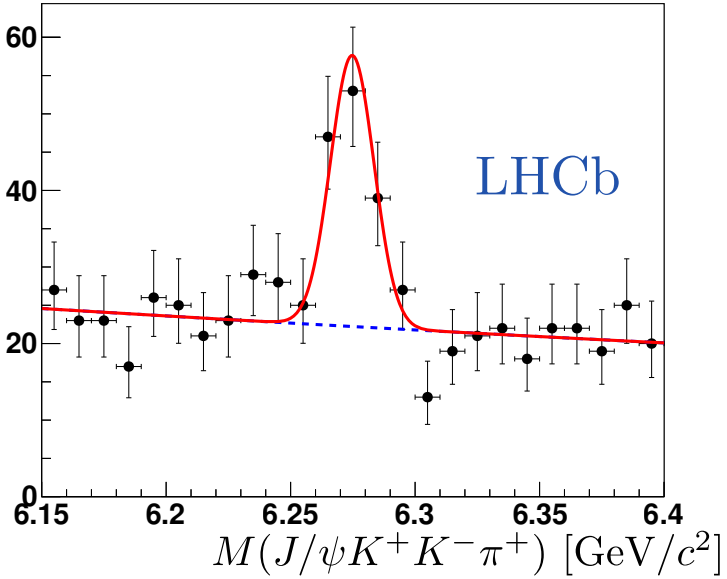
B_c Decays: $B_c^+ \to J/\psi\ K^+\ K^-\ \pi^+$

[JHEP11 (2013) 094]

$B_c^+ \to J/\psi\ K^+\ K^-\ \pi^+$

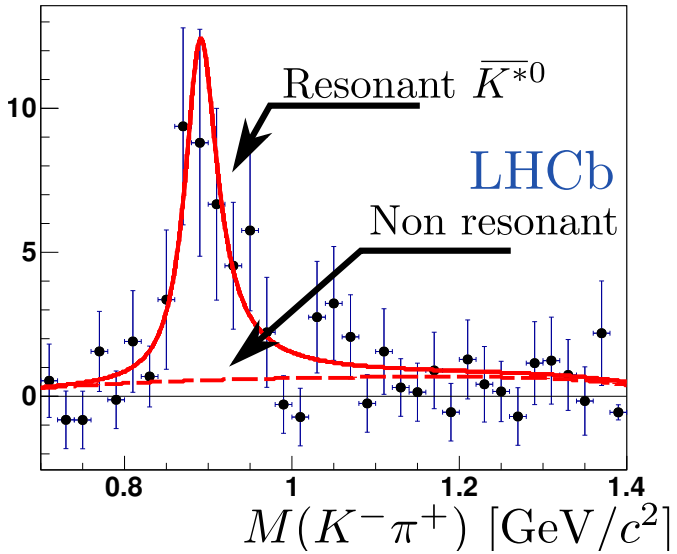
- Search performed with 3 fb^{-1} at $\sqrt{s}$ =7+8 TeV
- $D_s^+ \to K^+\ K^-\ \pi^+$ and $B_s^0 \to J/\psi\ K^+\ K^-$ invariant mass regions are excluded
- $N_{B_c^+ \to J/\psi\, K^+ K^- \pi^+} = 78 \pm 14$ (6.3σ significance)
- Found a resonant structure in the $K^+\pi^+$ system. The largest contribution to the decay is due to

$$B_c \to J/\psi\, K^+ \bar{K}^{*0}$$



$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+ K^- \pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.53 \pm 0.10(stat) \pm 0.05(syst)$$

- Largest syst uncertainty:
  Fit model and track reconstruction



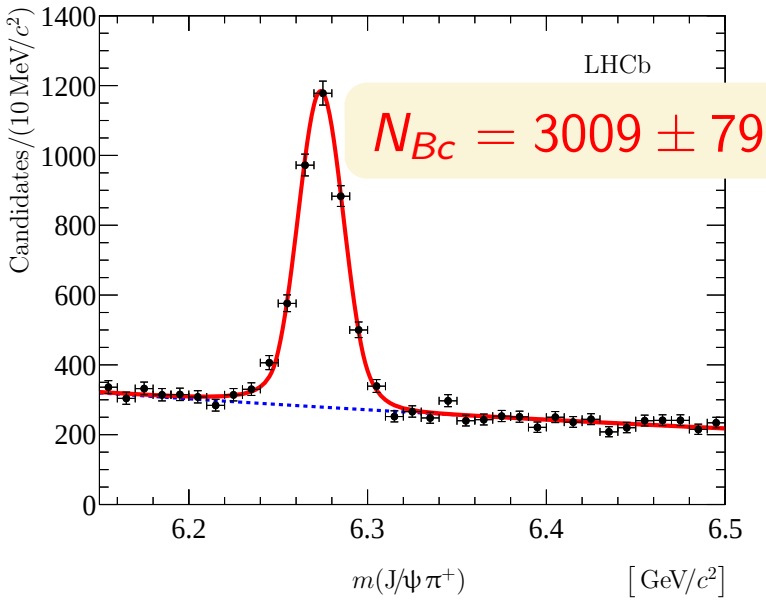
In good agreement with theory predictions of 0.49 and 0.47 [arXiv:1307.0953]

Summary

LHC has taken over Tevatron legacy of B_c physics

The B_c meson is abundantly produced at LHC

In the last two years there was an impressive progress in this field



[LHCB – PRD 87 (2013) 112012]

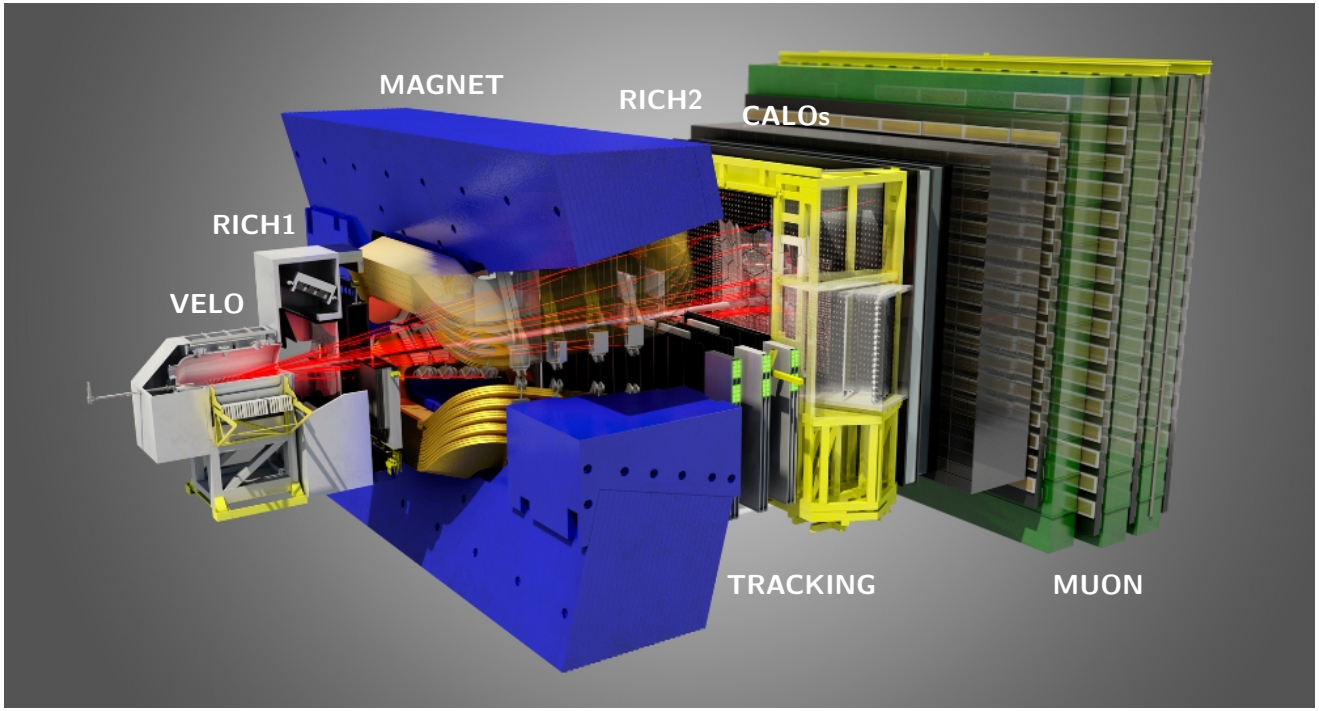
Many results provided by the LHC experiments:

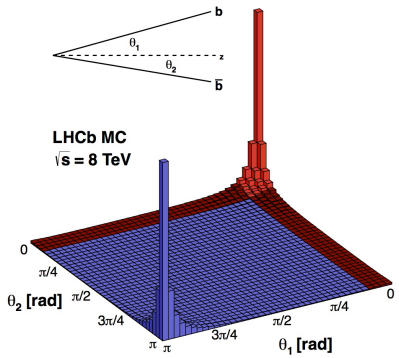
- Mass measurement with 1.5 MeV/c^2 total uncertainty [ATLAS, CMS, LHCb]
- Lifetime measurement with 2.8% uncertainty [CMS, LHCb]
- Observation of eight new decay modes [LHCb]

More results to come, many analyses are in progress right now!

Additional Material

The LHCb Detector



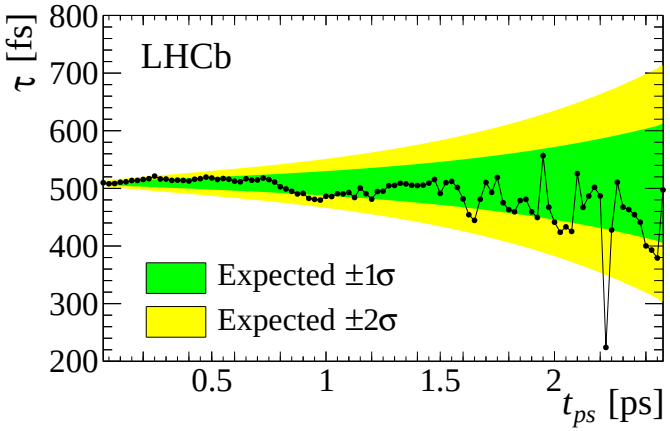


- Unique geometrical acceptance: $2 < \eta < 5$ coverage
- Excellent vertex locator (VELO): $\sigma_{PV,xy} \sim 10\ \mu$m, $\sigma_{PV,z} \sim 60\ \mu$m
- Tracking system: $\Delta p/p = 0.35\% \div 0.55\%$
- Muon system: $\epsilon(\mu \to \mu) \sim 97\%$, MisID rate$(h \to \mu) \sim \mathcal{O}(1\%)$

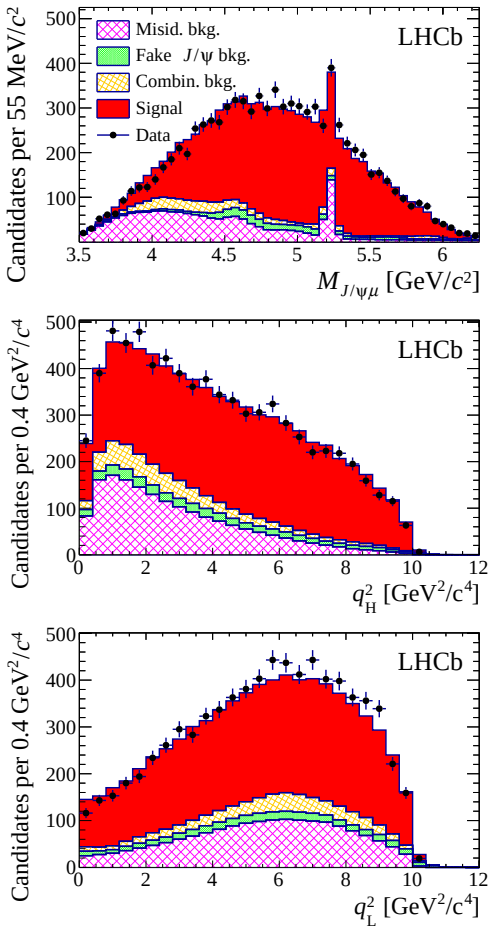
B_c Lifetime using $B_c^+ \to J/\psi\ \mu^+ X$

Source	Assigned systematic [fs]
B_c production model	1.0
B_c decay model	5.0
Signal resolution model	1.3
Prompt background model	6.4
Fake J/ψ background yield	0.4
Fake J/ψ background shape	2.3
Combinatorial background yield	3.4
Combinatorial background shape	7.3
Misidentification background yield	0.8
Misidentification background shape	1.2
Length scale calibration	1.3
Momentum scale calibration	0.2
Efficiency function	2.6
Incorrect association to PV	1.8
Multiple candidates	1.0
Fit validation	0.5
Quadratic sum	12.4

- Prompt Background model:
  Perform the fit applying a minimum t_{ps} cut



- B_c decay model: form–Factors and feed–down
- Deform the Dalitz plot with a linear deformation
  $\text{Dalitz}(M^2_{J/\psi\ \mu}, M^2_{\mu\nu}), \quad M^2_{\mu\nu} \equiv q^2$
- Study the agreement between the deformed model and data using the distributions of $M^2_{J/\psi\ \mu}$, q^2_L, q^2_H



B_c Lifetime

Hadronic ($B_c^+ \to J/\psi\ \pi^+$) or semileptonic ($B_c^+ \to J/\psi\ \ell\nu_\ell$ X) channel ?

Semileptonic channel - The pros

- ✓ High statistics: 20× hadronic mode
- ✓ Clean experimental signature: 3μ
- ✓ Lifetime unbiased acceptance

Hadronic channel - The cons

- ✗ Low statistics: Helicity suppressed
- ✗ Huge π background from PV
  ➜ Detachment from PV
- ✗ Lifetime biased acceptance

Semileptonic channel - The cons

- ✗ Partial reconstruction: ν undetected
- ✗ Dependence on form–factor model
- ✗ Unavoidable feed–down contributions

Hadronic channel - The cons

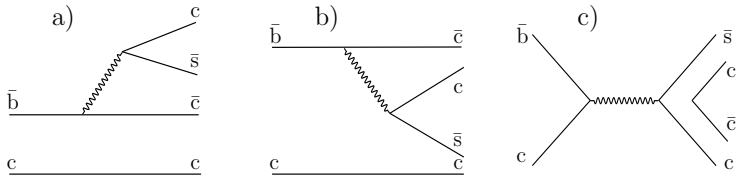
- ✓ Full event reconstruction
- ✓ Simpler data model
- ✓ No feed–down contributions

- Early measurements by CDF and D0 used the semileptonic channel
- CDF has recently measured τ_{B_c} with the $B_c^+ \to J/\psi\ \pi^+$ channel

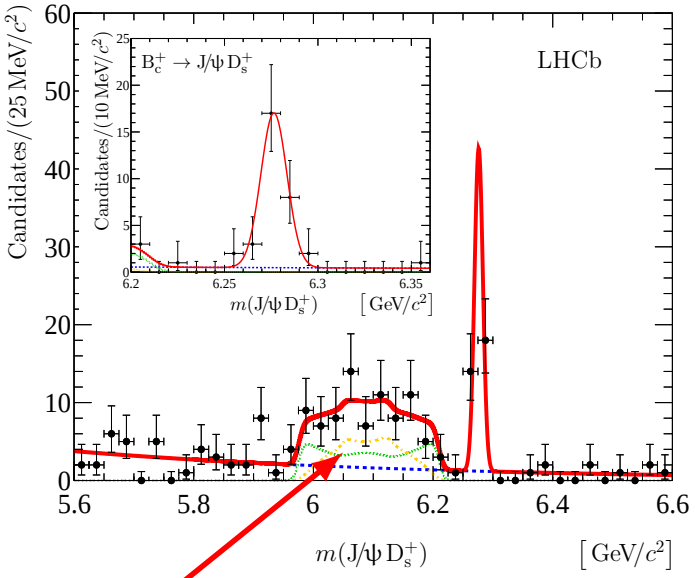
B_c Decays: $B_c^+ \to J/\psi\ D_s^+$

First observation of $B_c^+ \to J/\psi\ D_s^+$ and $B_c^+ \to J/\psi\ D_s^{*+}$ modes

[PRD 87 (2013) 112012]



Contributions also from color suppressed spectator and annihilation diagrams



The wide structure is $B_c^+ \to J/\psi\ D_s^{*+}$ followed by $D_s^{*+} \to D_s^+\ \gamma$ or $D_s^{*+} \to D_s^+\ \pi^0$ with neutral particle undetected

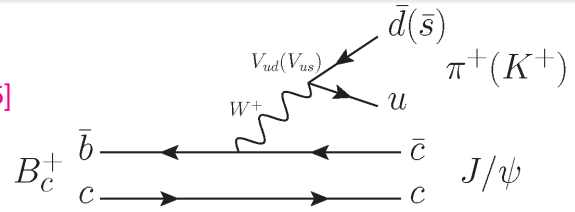
- Search performed with 3 fb^{-1} collected in 2011+2012 at $\sqrt{s}$ =7 and 8 TeV
- Very clean signal: $J/\psi \to \mu^+\mu^-$
  $D_s^{*+} \to \gamma/\pi^0\ D_s^+$; $D_s^+ \to \phi\ (K^+\ K^-)\ \pi^+$
- $B_c^+ \to J/\psi\ D_s^{*+}$ is a P→VV decay
  Three helicity amplitudes: A_{++}, A_{00}, A_{--}
- Mass model: Gaussian signal, exponential for combinatorial bkg, two shapes from MC for $A_{\pm\pm}$ and A_{00}
- $N_{B_c^+ \to J/\psi\, D_s^+} = 28.9 \pm 5.6$
  ($> 9\sigma$ significance)

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

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

B_c Decays: $B_c^+ \to J/\psi\ K^+$

First observation of $B_c^+ \to J/\psi\ K^+$ decay [JHEP 09 (2013) 075]



- Search performed with 1 fb^{-1} at $\sqrt{s}$ =7 TeV
- Event selection with MVA techniques
- Separation π/K provided by the RICH system:
  $\mathrm{DLL}_{K\pi} = \ln \mathcal{L}(K) - \ln \mathcal{L}(\pi)$

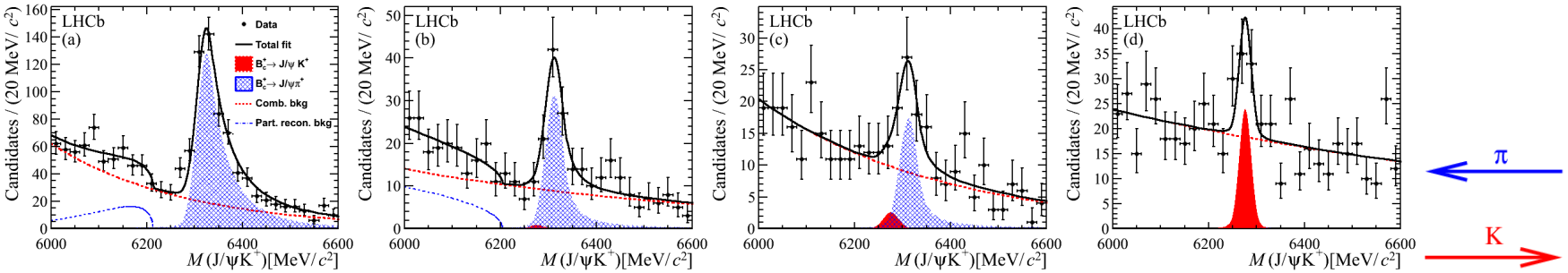
Measurement of: $\dfrac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)}$

Dominated by the ratio of CKM elements:

$|V_{us}/V_{ud}|^2 \approx 0.05$

Theory predictions in the range: $0.054 \div 0.088$

- Unbinned max likelihood fit with K mass hypothesis in four bins of $\mathrm{DLL}_{K\pi}$



- Total $B_c^+ \to J/\psi\ K^+$ yield of 46±12 events (5σ significance)

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.069 \pm 0.019(stat) \pm 0.005(syst)$$

Results in agreement with theory and naive factorization

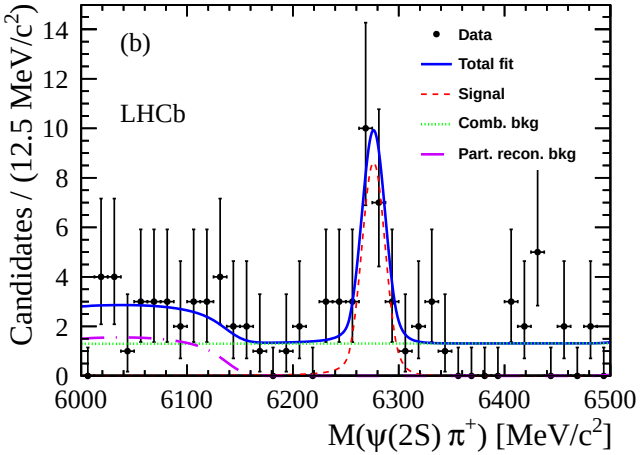
B_c Decays: $B_c^+ \to \psi(2S)\,\pi^+$

Observation of the Decay $B_c^+ \to \psi(2S)\,\pi^+$ [PRD 87 (2013) 071103]

- Search performed with 1 fb^{-1} at $\sqrt{s}$ =7 TeV

$$R_{1S/2S} = \frac{\mathcal{B}(B_c \to \psi(2S), \psi(2S) \to \mu^+\mu^-)}{\mathcal{B}(B_c \to J/\psi\,\pi^+, J/\psi \to \mu^+\mu^-)} = \frac{N\left(B_c^+ \to \psi(2S)\right)}{\epsilon_{(B_c^+ \to \psi(2S))}} \frac{\epsilon_{B_c^+ \to J/\psi\,\pi^+}}{N\left(B_c^+ \to J/\psi\,\pi^+\right)}$$

- Mass model: double sided Crystal Ball for signal exp for combinatorial bkg and resolved ARGUS for partially reconstructed bkg
- Total $B_c^+ \to \psi(2S)\,\pi^+$ yield of 20±5 events (5σ significance)
- Largest syst uncertainty: BDT selection and bkg/signal shape
- $R_{1S/2S}$ is corrected for $\mathcal{B}(c\bar{c} \to \mu^+\,\mu^-)$ using the more precise $\mathcal{B}(c\bar{c} \to e^+e^-)$ and assuming universality of weak interactions



$$\frac{\mathcal{B}(B_c^+ \to \psi(2S)\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\,\pi^+)} = 0.250 \pm 0.068(stat) \pm 0.014(syst) \pm 0.006(\mathcal{B})$$

This result favours the prediction of PRD68 (2003) 094020