$B_c$ Properties and Decays

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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.

Lucio Anderlini – Properties and decays of the \( B_c \) meson
Introduction

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

- Few decays observed: \( B_c^+ \rightarrow J/\psi \ell^+ \nu \ell \), and \( B_c^+ \rightarrow J/\psi \pi^+ \)
- 6 MeV/c\(^2\) mass uncertainty (< 0.3 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 $B_c \rightarrow J/\psi (\mu\mu) + X$

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

- $B$ mesons production:
  - $b$ bar $b$ pair production & fragmentation

- The $q\bar{q}$ ratio in fragmentation is
  \[ u:d:s:c \approx 1:1:0.3:10^{-11} \]
  → Almost negligible for $B_c$ at hadronic collider

- $B_c$ production is mainly due to $gg$ fusion

- pQCD $\alpha_s^4$ calculations:
  \[ \sigma(B_c) \sim 0.4 \div 0.9 \ \mu b \text{ (at } \sqrt{s} = 7 \div 14 \ \text{TeV)} \]
  \[ \sigma(B_c)/\sigma(B) \sim 10^{-3} \]
  \[ \sigma(B_c)_{\text{LHC}}/\sigma(B_c)_{\text{Tevatron}} \sim O(10) \]
  [P. Atom. Nucl. 64 (2004)]

- $gg \rightarrow B_c$ implemented in Monte Carlo generator $Bcvegpy$

- No absolute branching ratio measured up to date
Two production measurements by CMS and LHCb

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

$$R_{c/u} = \frac{\sigma(B_c) B(B_c^+ \rightarrow J/\psi \pi^+)}{\sigma(B^+) B(B^+ \rightarrow J/\psi K^+)} = \frac{N(B_c^+ \rightarrow J/\psi \pi^+)}{\epsilon_{c} \epsilon_{u} \ N(B^+ \rightarrow J/\psi K^+)}$$

- Decays with identical topologies
- The two experiments provide results in complementary $\eta$ regions


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

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

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

$N_{B_c^+ \rightarrow J/\psi \pi^+} = 162 \pm 18$, $p_T(B_c) > 4 \text{ GeV}$, $2.5 < \eta < 4.5$, $\sqrt{s} = 7 \text{ TeV}$, $\mathcal{L} = 0.37 \text{ fb}^{-1}$
Measurements by ATLAS, CMS and LHCb using $B_c^+ \rightarrow J/\psi \, \pi^+$ decay

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

$M(B_c) = 6282 \pm 7\,(\text{stat})$ MeV/c$^2$  
[preliminary ATLAS–CONF–2012–028]

$M(B_c) = 6272 \pm 3\,(\text{stat})$ MeV/c$^2$  
[preliminary CMS–PAS–BPH–11–003]

$M(B_c) = 6273.7 \pm 1.3\,(\text{stat}) \pm 1.6\,(\text{syst})$ MeV/c$^2$  
[PRL 109 (2012) 232001]

- Decay with large $Q$–value: $M(B_c) - M(J/\psi) - M(\pi^+)$  
  - 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 $B_c^+ \rightarrow J/\psi \, D_s^+$

$L_{B_c} = 82 \pm 17/4.3\,fb^{-1}$

$L_{B_c} = 330 \pm 17/4.7\,fb^{-1}$

$L_{B_c} = 182 \pm 18\,fb^{-1}$

$L = 0.37\,fb^{-1}$
$B_c$ mass using the $B_c^+ \rightarrow J/\psi \ D_s^+$ decay

- Low Q–value $\rightarrow$ Small systematic uncertainty on the momentum
  Accuracy in the momentum scale: $3 \times 10^{-4} \rightarrow 0.30$ MeV/$c^2$

- Use $D_s^+$ mass value: $1968.29 \pm 0.18$ MeV/$c^2$ [LHCb, JHEP06 (2013) 065]
  Effect of uncertainty on $D_s^+$ mass $\rightarrow 0.16$ MeV/$c^2$

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

Most precise single measurement, uncertainty dominated by statistical error.

New world average:
$$6275.14 \pm 1.30 \text{ MeV}/c^2$$
**$B_c$ Lifetime**

Estimate $\Gamma$ summing the contributions of the dominating decay process

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

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

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

- $b$ spectator $\sim 20\%$
- $c$ spectator $\sim 70\%$
- Annihilation $\sim 10\%$

1. $B_c^+ \rightarrow J/\psi \ell^+ \nu_\ell$
2. $B_c^+ \rightarrow B_s^0 \pi^+$
3. $B_c^+ \rightarrow \tau^+ \nu_\tau$

$B_c$ lifetime affected by sizeable uncertainty

- Source of systematic uncertainty for most $B_c$ measurements
**B_c Lifetime using B_c \rightarrow J/\psi \mu^+ X**

covers

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**Partially reconstructed, semileptonic B_c decays**

Clear experimental signature:

- a $\mu^+$ and a $J/\psi$ 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)

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Lucio Anderlini – Properties and decays of the $B_c$ meson

FPCP 2014 – Marseille
**B_c Lifetime using B_c → J/ψ μ⁺X decays**

- Decay-time signal model in \( M_{J/ψμ} \) mass bins: 
  \( \exp(t) \otimes h^m(k) \otimes 3\text{–Gaussian} \) (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 
  \( H_b \to J/ψ \ X \quad H_b \equiv B_d, B_u, B_s, Λ_b \)

**All background sources modelled on data**
(except for detached combinatorial)
$B_c$ Lifetime using $B_c \rightarrow J/\psi \mu^+ X$ decays

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

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

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

- This is the most precise measurement of $\tau_{B_c}$ to date
- With less than half the uncertainty wrt. PDG 2013
Only two $B_c$ decay modes were observed before LHC by CDF and D0:

$$B_c \rightarrow J/\psi \ell^+ \nu_\ell \quad \text{and} \quad B_c \rightarrow J/\psi \pi^+$$

Many new decay modes observed by the LHC experiments:

- Observation of $B_c^+ \rightarrow \psi(2S)\pi^+$
- Observation of $B_c^+ \rightarrow J/\psi D_s^+$ and $B_c^+ \rightarrow J/\psi D_s^{*+}$ decays
- First observation of the decay $B_c^+ \rightarrow J/\psi K^+$
- Observation of the decay $B_c^+ \rightarrow B_s^0 \pi^+$

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

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- Evidence for the decay $B_c^+ \rightarrow J/\psi 3\pi^+ 2\pi^-$
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[LDCHb, PRD 87 (2013) 071103]
[LDCHb, PRD 87 (2013) 112012]
[LDCHb, JHEP 09 (2013) 075]
[LDCHb, PRL 111 (2013) 181801]
[LDCHb, PRL 108 (2012) 251802]
[CMS–PAS–BPH–11–003]
[LHCb, arXiv:1404.0287]
[LHCb, JHEP 1311 (2013) 094]
**B_c Decays: \( B^+_c \rightarrow B^0_s \pi^+ \)**

Observation of the decay \( B^+_c \rightarrow B^0_s \pi^+ \)

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

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

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

**Largest branching fraction of any known weak \( B \) meson decay**
Factorization Approximation

Factorize the decay amplitude into two independent parts

\[ B_c^+ \rightarrow J/\psi \ W^{++} \]

Use form factors from semi–leptonic decays

\[ W^{++} \] hadronization via decays of virtual resonances

Use experimental info from other decays like \( \tau \rightarrow n\pi \)
Only two $B_c$ decay modes were observed before LHC by CDF and D0:

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- Observation of the decay $B_c^+ \to J/\psi K^+ K^- \pi^+$
**B_c Decays:** \( B_c \to J/\psi \pi^+ \pi^- \pi^+ \)

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

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

[preliminary CMS–PAS–BPH–12–011]

\[ R_{3\pi} = 2.41 \pm 0.30 (\text{stat}) \pm 0.33 (\text{syst}) \]

[PRL 108 (2012) 251802]

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

[PRD81 (2012) 014015]

**BLL [PRD81014015]**

**Phasespace**

**Phasespace with** \( J/\psi \) **polarization**

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**B_c Decays**

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- Observation of the decay $B_c^+ \rightarrow J/\psi K^+K^-\pi^+$
Evidence for the decay $B_c^+ \rightarrow J/\psi\ 3\pi^+\ 2\pi^-$

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

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

- Dominant syst uncertainty: Fit and decay model
- Consistent with analogous measurements in $B^+$ and $B^0$
  $$\frac{\mathcal{B}(B^0 \rightarrow D^{*-} 3\pi^+\ 2\pi^-)}{\mathcal{B}(B^0 \rightarrow D^{*-}\ \pi^+)} = 1.70 \pm 0.34$$
  $$\frac{\mathcal{B}(B^+ \rightarrow D^{*0} 3\pi^+\ 2\pi^-)}{\mathcal{B}(B^+ \rightarrow D^{*0}\ \pi^+)} = 1.10 \pm 0.24$$

In good agreement with theory predictions of 0.95 and 1.1 [PRD86 (2012) 074024]
Only two $B_c$ decay modes were observed before LHC by CDF and D0:

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

Many new decay modes observed by the LHC experiments:

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

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

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

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

- 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

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!

$L_{B_c} = 3009 \pm 79$
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: $\epsilon(\mu \rightarrow \mu) \sim 97\%$, MisID rate($h \rightarrow \mu$) $\sim O(1\%)$
$B_c$ Lifetime using $B_c^+ \rightarrow J/\psi \mu^+ X$

<table>
<thead>
<tr>
<th>Source</th>
<th>Assigned systematic [fs]</th>
</tr>
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<tbody>
<tr>
<td>$B_c$ production model</td>
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<tr>
<td>$B_c$ decay model</td>
<td>5.0</td>
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<tr>
<td>Signal resolution model</td>
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<td>Prompt background model</td>
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<td>Fake $J/\psi$ background yield</td>
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<tr>
<td>Fake $J/\psi$ background shape</td>
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<tr>
<td>Combinatorial background yield</td>
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<td>Combinatorial background shape</td>
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<td>Misidentification background yield</td>
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<td>Incorrect association to PV</td>
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<td>Fit validation</td>
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<tr>
<td>Quadratic sum</td>
<td>12.4</td>
</tr>
</tbody>
</table>

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

- $B_c$ decay model: form–Factors and feed–down
  \[ \text{Dalitz}(M_{J/\psi \mu}^2, M_{\mu \nu}^2), \quad M_{\mu \nu}^2 \equiv q^2 \]

- Deform the Dalitz plot with a linear deformation

- Study the agreement between the deformed model and data using the distributions of $M_{J/\psi \mu}^2, q_L^2, q_H^2$
**$B_c$ Lifetime**

<table>
<thead>
<tr>
<th><strong>Semileptonic channel - The pros</strong></th>
<th><strong>Hadronic channel - The cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ High statistics: $2\times$ hadronic mode</td>
<td>✓ Full event reconstruction</td>
</tr>
<tr>
<td>✓ Clean experimental signature: $3\mu$</td>
<td>✓ Simpler data model</td>
</tr>
<tr>
<td>✓ Lifetime unbiased acceptance</td>
<td>✓ No feed–down contributions</td>
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</tbody>
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<tr>
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<tr>
<td>✗ Partial reconstruction: $\nu$ undetected</td>
<td>✓ Low statistics: Helicity suppressed</td>
</tr>
<tr>
<td>✗ Dependence on form–factor model</td>
<td>✗ Huge $\pi$ background from PV</td>
</tr>
<tr>
<td>✗ Unavoidable feed–down contributions</td>
<td>➔ Detachment from PV</td>
</tr>
<tr>
<td></td>
<td>✗ Lifetime biased acceptance</td>
</tr>
</tbody>
</table>

- Early measurements by CDF and D0 used the semileptonic channel
- CDF has recently measured $\tau_{B_c}$ with the $B_c^+ \rightarrow J/\psi \pi^+$ channel
**B_c Decays: \( B_c^+ \rightarrow J/\psi \ D_s^+ \)**

**First observation of \( B_c^+ \rightarrow J/\psi \ D_s^+ \) and \( B_c^+ \rightarrow J/\psi \ D_{s^*}^+ \) modes**

- Search performed with 3 fb\(^{-1}\) collected in 2011+2012 at \( \sqrt{s} = 7 \) and 8 TeV
- Very clean signal: \( J/\psi \rightarrow \mu^+ \mu^- \)
  \( D_{s^*}^+ \rightarrow \gamma/\pi^0 \ D_s^+ \); \( D_s^+ \rightarrow \phi \ (K^+ \ K^-) \ \pi^+ \)
- \( B_c^+ \rightarrow J/\psi \ D_{s^*}^+ \) 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 \( A_{00} \)
- \( N_{B_c^+ \rightarrow J/\psi \ D_s^+} = 28.9 \pm 5.6 \) (> 9σ significance)

**Contributions also from color suppressed spectator and annihilation diagrams**

**The wide structure is \( B_c^+ \rightarrow J/\psi \ D_{s^*}^+ \) followed by \( D_{s^*}^+ \rightarrow D_s^+ \gamma \) or \( D_{s^*}^+ \rightarrow D_s^+ \pi^0 \) with neutral particle undetected**

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

\[
\frac{\mathcal{B}(B_c^+ \rightarrow J/\psi \ D_{s^*}^+)}{\mathcal{B}(B_c^+ \rightarrow J/\psi \ D_s^+)} = 2.37 \pm 0.56\ (stat) \pm 0.10\ (syst)
\]
**B_c Decays: \( B_c^+ \rightarrow J/\psi \) \( K^+ \)**

First observation of \( B_c^+ \rightarrow J/\psi \) \( K^+ \) decay

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

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

- Total \( B_c^+ \rightarrow J/\psi \) \( K^+ \) yield of 46\(\pm\)12 events (5\(\sigma\) significance)

**Results in agreement with theory and naive factorization**
**Observation of the Decay \( B_c^+ \rightarrow \psi(2S) \pi^+ \)**

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

\[
R_{1S/2S} = \frac{B(B_c \rightarrow \psi(2S), \psi(2S) \rightarrow \mu^+ \mu^-)}{B(B_c \rightarrow J/\psi \pi^+, J/\psi \rightarrow \mu^+ \mu^-)} = \frac{N(B_c \rightarrow \psi(2S))}{e_{(B_c \rightarrow \psi(2S))}} \frac{e_{B_c^+ \rightarrow J/\psi \pi^+}}{N(B_c^+ \rightarrow J/\psi \pi^+)}
\]

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

\[
\frac{B(B_c^+ \rightarrow \psi(2S) \pi^+)}{B(B_c^+ \rightarrow J/\psi \pi^+)} = 0.250 \pm 0.068(\text{stat}) \pm 0.014(\text{syst}) \pm 0.006(\mathcal{B})
\]

This result favours the prediction of PRD68 (2003) 094020