B_c physics at LHCb.

Lucio Anderlini
on behalf of the LHCb collaboration.

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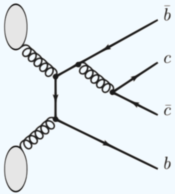
B_c physics at LHCb

Meson (sometime called quarkonium) with different heavy flavours $\Rightarrow$ Unique in the SM.

B_c production

Rare at e^+e^- colliders

At TeVatron and LHC: Production mechanism is mainly gg fusion



Theoretical α_s^4-calculation:

- $\sigma \sim 0.4\,\mu$b ($\sqrt{s} = 7$ TeV)
- $\frac{\sigma(B_c^+)_{\text{LHC}}}{\sigma(B_c^+)_{\text{TeVatron}}} \sim \mathcal{O}(10)$

B_c spectroscopy

Potential model prediction: analogous to quarkonium states

see Godfrey, PRD 70, 054017

To date: only ground state (B_c^+) observed.

Its mass:
Theory: $6.2 \div 6.4$ GeV$/c^2$ [CERN-2005-005]

PDG'12: 6277 ± 6 MeV$/c^2$
[CDF, PRL 100 182002]
[D0, PRL 101 012001]

B_c^+ decays

$\bar{b} \to \bar{c}$ transition

$B_c^+ \to J/\psi\, \ell^+ \nu_\ell$
$B_c^+ \to J/\psi\, \pi^+$

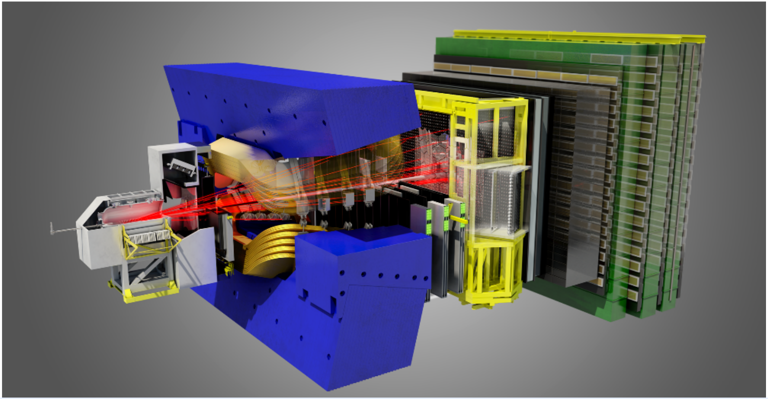
$c \to s$ transition

$B_c^+ \to B_s^0 \pi^+$
$B_c^+ \to B_s^0 \ell^+ \nu_\ell$

$c\bar{b} \to W^+$ transition

$B_c^+ \to \bar{K}^{*0} K^+$
$B_c^+ \to \phi K^+$
$B_c^+ \to \tau^+ \nu_\tau$

B_c physics at LHCb



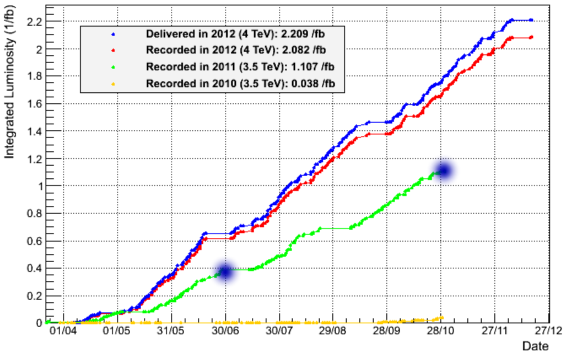
Already discussed by Zhenwei this afternoon!

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

Data taking

$1 + 2\ \mathrm{fb}^{-1}$

LHCb Integrated Luminosity pp collisions 2010-2012



Trigger

High efficiency trigger lines dedicated to single and dimuon.

Used to select J/ψ in B_c final states.

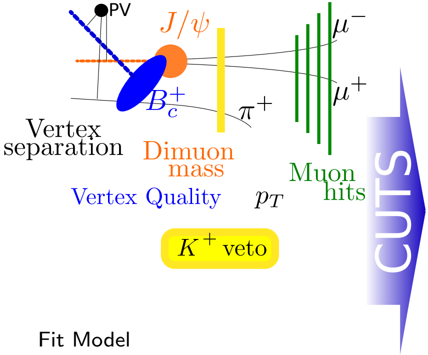
B_c^+ mass and production cross section

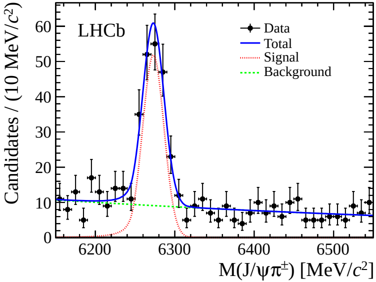
In 370 pb^{-1} of data LHCb selected

179 ± 17 $B_c^+ \to J/\psi\pi^+$ events

with $J/\psi \to \mu^+\mu^-$ (implicit hereafter)

$B^+ \to J/\psi K^+$ used as control channel





Fit Model

- Double sided crystal-ball signal
- Exponential background

Dominant systematics:

Background model:	0.32 MeV/c^2
Momentum scale:	1.4 MeV/c^2
Alignment:	0.6 MeV/c^2

More details in Raphael's talk

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

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

PDG'12 value:
$(6277 \pm 6)\mathrm{MeV}/c^2$

Based on $\sim 370\text{pb}^{-1}$ of 2011 data.

$B_c^+ \to J/\psi\ \pi^+$ 162 ± 18 Events

Use fully reconstructed

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

In the fiducial volume:

$p_T > 4$ GeV/c

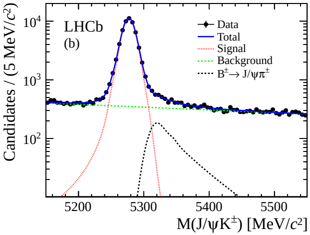
$2.5 < \eta < 4.5$

Large control sample available:

$$B^+ \to J/\psi\ K^+$$

Measure

$B^+ \to J/\psi\ K^+$ 56.2 ± 0.3 kEvents



$$\mathcal{R}_{c/u} = \frac{\sigma(B_c^+) \times Br(B_c^+ \to J/\psi\ \pi^+)}{\sigma(B^+) \times Br(B^+ \to J/\psi K^+)} = \epsilon_{\text{rel}} \times \frac{N(B_c^+)}{N(B^+)}$$

- Selection as similar as possible for B_c^+ and B^+.
- The efficiency ratio ϵ_{rel} is estimated with MC.

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

B_c^+ lifetime: 0.453 ± 0.041 ps

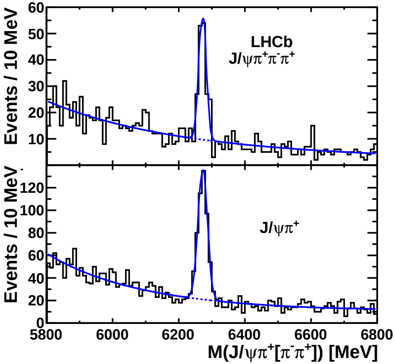
1^{st} observation of $B_c^+ \to J/\psi \pi^+ \pi^- \pi^+$

Theory: $Br(B_c^+ \to J/\psi\,\pi^+\pi^-\pi^+)/Br(B_c^+ \to J/\psi\,\pi^+)$ predictions

Rakitin and Koshkarev (no-recoil approximation)	~ 1.5	[PRD 81 014005]
Likhoded and Luchinsky (various approaches)	$\sim 1.9 - 2.3$	[PRD 81 014015]

Experiment: 2 more tracks $\Rightarrow$ lower (geometrical) efficiency $\Rightarrow$ never observed before.

Using $\sim$ 800 pb $^{-1}$ data collected in 2011



LHCb performed the **first observation** of the $B_c^+ \to J/\psi\,\pi^+\pi^-\pi^+$ decay.

Number of signal events: 135 ± 14

$B_c^+ \to J/\psi\pi^+$ used as control channel

414 ± 25 events.

After the efficiency correction, this leads to

$$\frac{Br(B_c^+ \to J/\psi\,\pi^+\pi^-\pi^+)}{Br(B_c^+ \to J/\psi\,\pi^+)} =$$

$$2.41 \pm 0.30(\text{stat}) \pm 0.33(\text{syst})$$

Systematics: B_c^+ lifetime uncertainty, tracker and trigger MC efficiency, kaon veto.

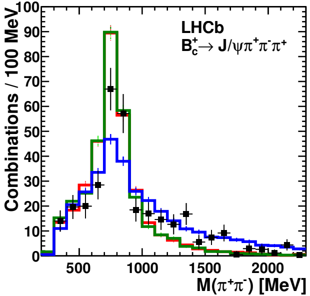
Selection efficiency estimated with MC. Ok, but with which model?

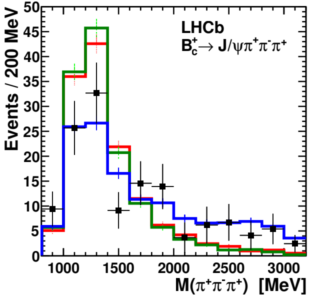
Available models:

Form-factor model by Berezhnoy, Likhoded and Luchinsky (BLL)
Based on amplitude factorization into hadronic and weak currents [PRD 81 014015]

Phase-space without polarization (PH)
Implementing the $B_c^+ \to J/\psi W^{+*}$ with $W^{+*} \to \pi^+\pi^-\pi^+$ without interference

Phase-space with polarization (PHPOL)
Helicity amplitudes: 0.46, 0.87 and 0.20 for +1, 0 and -1 J/ψ helicity [Rosner, PRD 42 3732]



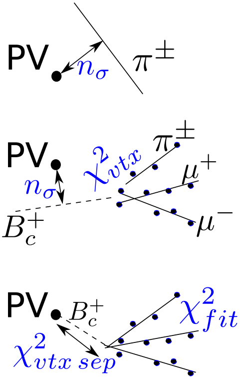


BLL model better agrees (in particular in the tails)

⇒ chosen as central value, systematic uncertainty assigned using the others.

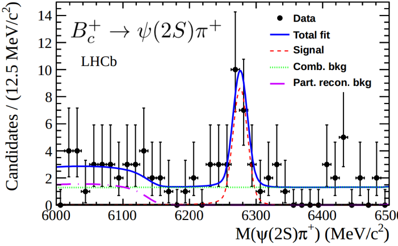
First observation of $B_c^+ \to \psi(2S)\pi^+$

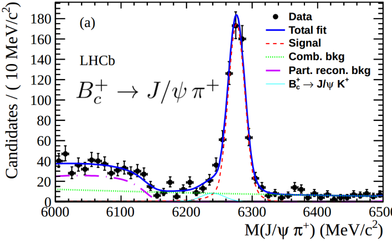
First observation of $B_c^+ \to \psi(2S)\pi^+$ decays at 5.2σ significance in 1.0 fb^{-1}! 20 ± 5 events



$p_T(B_c^+)$

$$\epsilon_{\psi(2S)} = 35.8\%$$
$$\epsilon_{J/\psi} = 37.2\%$$
$$\epsilon_{bkg} = 0.05\%$$





$B_c^+ \to J/\psi\pi^+$ used as control channel: same final state 595 ± 29 events

$$\mathcal{R}_{2S/1S} = \frac{Br(B_c^+ \to \psi(2S)\pi^+,\ \psi(2S) \to \mu^+\mu^-)}{Br(B_c^+ \to J/\psi\pi^+,\ J/\psi \to \mu^+\mu^-)} = \frac{\epsilon(B_c^+ \to J/\psi\pi^+)}{\epsilon(B_c^+ \to \psi(2S)\pi^+)} \cdot \frac{N(B_c^+ \to \psi(2S)\pi^+)}{N(B_c^+ \to J/\psi\pi^+)}$$

Efficiency ratio MC determination:

detector acceptance
$\times$ trigger efficiency
$\times$ reconstruction and selection efficiency.

$$\frac{\epsilon_{B_c^+ \to \psi(2S)\pi^+}}{\epsilon_{B_c^+ \to J/\psi\pi^+}} = 1.040 \pm 0.009$$

BDT systematic uncertainty assessment
Different cuts on the BDT response
$\Rightarrow$ slightly different $\mathcal{R}_{2S/1S}$.

The average of several tests differs from the nominal value by 4.5%.

Signal Model: double sided Crystal Ball.

Background Model:
Combinatorial bkg (exponential)
$+$ partial reconstructed bkg (resolved Argus function)

Component	Value
BDT selection	**4.5 %**
Signal shape	1.7 %
Background shape	2.9 %
Total	5.7%

$c\bar{c} \to \mu\mu$ branching fraction:

$$\frac{Br(\psi(2S) \to \mu^+\mu^-)}{Br(J/\psi \to \mu^+\mu^-)} = \frac{(0.773 \pm 0.017)\%}{(5.94 \pm 0.06)\%}$$

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

Prospects and Conclusion

Prospects

- Today, I have presented 2011 data analyses only.
  In 2012 we collected twice the luminosity
- Many $\bar{b} \to \bar{c}$ channels wait to be discovered,
- $c \to s$ transition are Cabibbo favored, but not yet observed,
- $\bar{b}c \to W^*$ transition physics have never been explored,
- B_c excited states have not yet been observed
- ...

Specific topics:

B_c^+ Lifetime w/ hadronic decays

Based on MC studies [CERN-LHCb-2008-077]:

- $B_c^+ \to J/\psi \pi^+$
- Statistical uncertainty below 30 fs with 1 fb^{-1}
- Will use data-based acceptance deterimination

B_c^+ Lifetime w/ semileptonic decays

$B_c^+ \to J/\psi \mu(\nu)$ compared to $B_c^+ \to J/\psi \pi^+$

Pro:

- Higher branching fraction: larger statistics;
- Very clean signature: 3μ
  $\Rightarrow$ No detachment cuts.

Cons:

- Neutrino missing energy: no mass peak
- Need excellent $h \to \mu$ misID control.
- Need MC to boost from the 3μ to the B_c rest frame

Conclusion

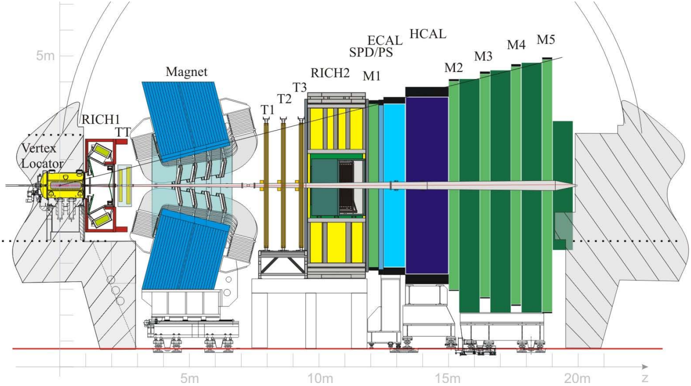
- The LHCb detector offers a great opportunity of studying B_c physics
  - **Mass** and **cross-section** measurement of B_c^+ using $B_c^+ \to J/\psi\pi^+$ decays with 2011 data;
  - **First observation** of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ decays and $\mathcal{B}$ measurement;
  - **First observation** of $B_c^+ \to \psi(2S)\pi^+$ decays and $\mathcal{B}$ measurement;
- **With these two new decay modes, the number of known B_c modes is doubled!**
- During the Long Technical Stop
  - Lifetime measurement
  - Studies on high yield semileptonic decays
  - Many more decay channels

Many things we can do about B_c:
Your suggestions on the most important points are always welcome!

Thank you!

Backup slides

B_c physics at LHCb



From Godfrey, PRD 70, 054017