B_c production at LHCb

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Outline

1. Introduction
2. B_c mass measurement
3. B_c cross section measurement
4. $B_c^{\pm} \to J/\psi(3\pi)^{\pm}$ measurements
5. Nearest future and conclusions

B_c mass and states

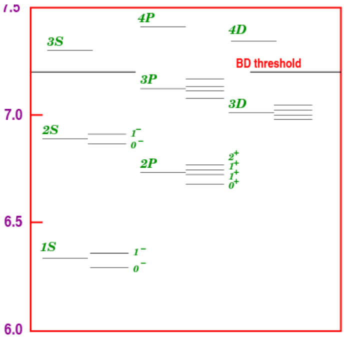
- B_c: unique state in SM formed by two heavy quarks of different flavors

  - B_c spectrum – potential models
  - B_c mass
  - Potential models: 6.2-6.4 GeV/c^2

    CERN-2005-005 and refs. therein
  - pQCD: 6326^{+29}_{-9} MeV/c^2

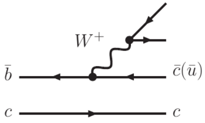
    N.Brambilla & A.Vairo PRD 62, 094019 (2000)
  - pQCD: Lattice QCD: 6278(6) MeV/c^2

    TWQCD, arXiv:0704.3495
  - PDG: 6277 ± 6 MeV/c^2

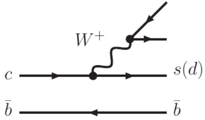


B_c decays

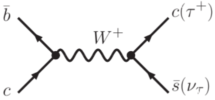
- Excited states (below BD threshold) – strong or EM decays
- Ground state – only weak decays:



$b \to cW$:
$J/\psi\pi$, $J/\psi 3pi$, $J/\psi l \nu_l$



$c \to sW$:
$B_s^0\pi$, $B_s^0 l\nu_l$

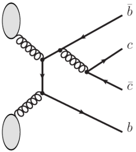


$cb \to W$:
$\bar{K}^{*0}K^{\pm}$, $\phi K^{\pm}$, $\tau\nu_\tau$

- B_c life-time:
  - $\tau(B_c) = 0.48 \pm 0.05$ ps – V.V.Kiselev et al, NP B585, 353 (2000)
  - PDG: 0.45 ± 0.04 ps

B_c production

- Very low production rate at e^+e^-, γe^- and *ep* colliders
- Produced via gluon fusion at hadron colliders
- B_c is produced via its excited states



- Total production rate at LHC ($\sqrt{s} = 14$ TeV) is about 1 μb.
- Contribution of different states:

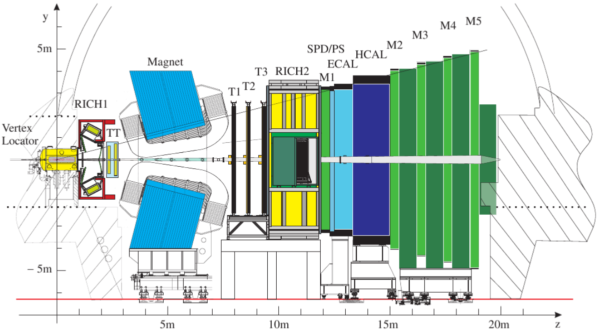
$1S_0$	$1S_1$	$2S_0$	$2S_1$	
0.19	0.47	0.05	0.11	[μb]

- With contribution of P-states as of $\sim$ 7% of S-states

A.V.Berezhnoj, A.K.Likhoded, M.V.Shevlyagin, Phys.Atom.Nucl. 58, 672 (1994)

I.P.Gouz et al., Phys.Atom.Nucl. 67, 1559 (2004)

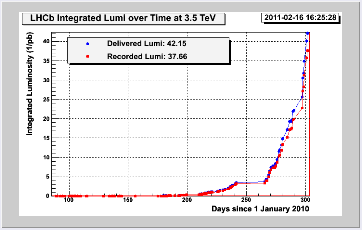
LHCb Detector



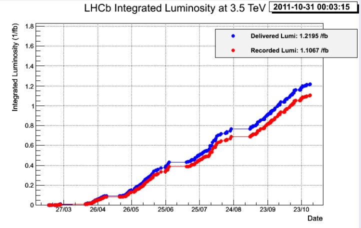
Geometry acceptance	$1.9 < \eta < 4.9$, unique in forward region
PV precision	$\sigma_{X,Y} \sim 10\ \mu$m, $\sigma_Z \sim 60\ \mu$m
Tracking	$\Delta p/p$: 0.35%-0.55%
Muon system	trueID$(\mu \to \mu) \sim 97\%$, misID $(h \to \mu) \sim 2\%$

LHCb data-taking

2010 – 37 pb^{-1} recorded



2011 – 1100 pb^{-1} recorded



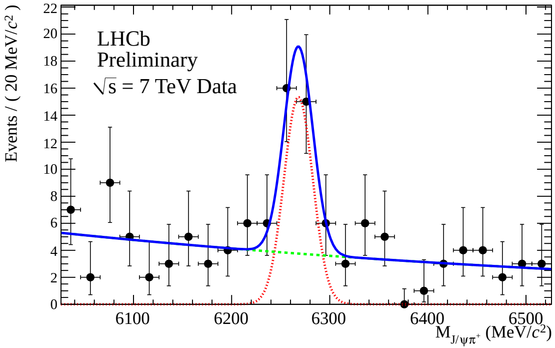
- 2010 data

  B_c mass measurement
  B_c production measurement

- 2011 data

  Observation of $B_c \to J/\psi 3\pi$
  Other preliminary studies

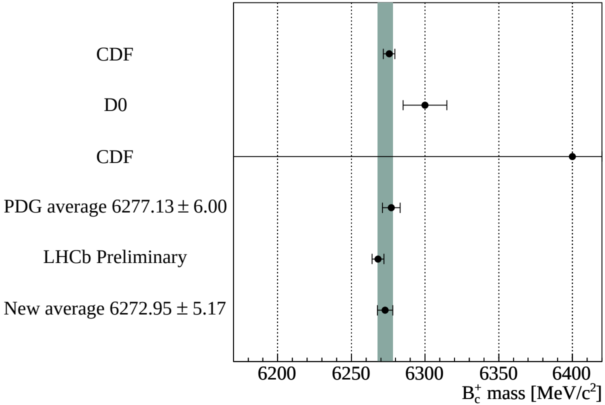
B_c mass measurement CERN-LHCb-CONF-2011-027



- Based on $\sim$ **35 pb^{-1}** data collected in 2010
- Signal events: **28 $\pm$ 7**
- Fit with:
  - Signal: Gaussian
  - Background: Exponential

Mass result (preliminary):

$$M(B_c^+) = 6268.0 \pm 4.0(\text{stat}) \pm 0.6(\text{syst})\ \text{MeV}/c^2$$



B_c mass measurement. Systematics.

Source	Value (MeV/c^2)
Mass Fitting:	
Background model	0.32
Signal model	0.07
Momentum calibration:	
Average momentum scale	0.23
η dependence	0.44
Detector description:	
Energy loss corrections	0.11
Alignment:	
Vertex detector	0.06
Total	0.61

Momentum scale calibrated with large $J/\psi \to \mu^+\mu^-$ sample

B_c cross section   CERN-LHCb-CONF-2011-017

- Based on $\sim 33\text{pb}^{-1}$ data sample collected in 2010
- Fully reconstructed $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$
- Use large sample $B^{\pm} \to J/\psi K^{\pm}$
- Measurement based on

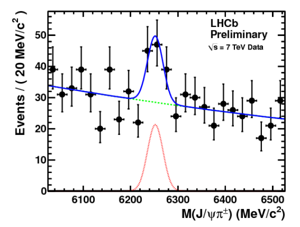
$$\frac{\sigma(B_c^{\pm}) \times \text{BR}(B_c^{\pm} \to J/\psi\pi^{\pm})}{\sigma(B^{\pm}) \times \text{BR}(B^{\pm} \to J/\psi K^{\pm})} = \epsilon_{\text{rel}} \times \frac{N(B_c^{\pm})}{N(B^{\pm})}$$

for $P_T(B) > 4$ GeV/c and $2.5 < \eta < 3.4$

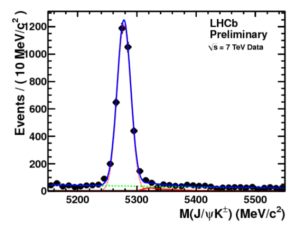
B_c cross section

- Life-time unbiased event selection
- Cabbibo suppressed background $B^{\pm} \to J/\psi\pi^{\pm}$ for $B^{\pm} \to J/\psi K^{\pm}$ taken into account
- Signal events ($B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$): **$43 \pm 13$**
- Normalization events ($B^{\pm} \to J/\psi(\mu^+\mu^-)K\pm$): **$3476 \pm 62$**

$B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$



$B^{\pm} \to J/\psi(\mu^+\mu^-)K\pm$



B_c cross section

- All efficiencies computed from MC
- Efficiencies are binned in (P_T, η)
- Systematics dominated by B_c life-time – will be reduced after direct life-time measurements
- Preliminary:

$$\frac{\sigma(B_c^\pm) \times \mathrm{BR}(B_c^\pm \to J/\psi\pi^\pm)}{\sigma(B^\pm) \times \mathrm{BR}(B^\pm \to J/\psi K^\pm)} = (2.2 \pm 0.8_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}})\%$$

- Analysis of 2011 data will come soon with a factor of ~ 25 in statistics

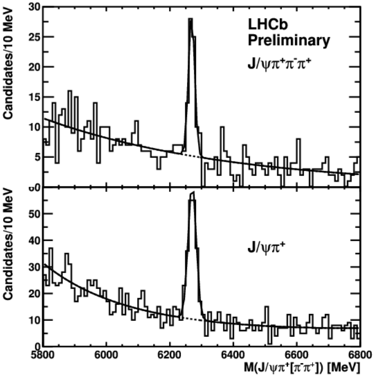
$B_c^{\pm} \longrightarrow J/\psi(3\pi)^{\pm}$ CERN-LHCb-CONF-2011-040

- Based on $\sim 300\text{pb}^{-1}$ data collected in 2011
- Use $B^{\pm} \to J/\psi(2\pi K)^{\pm}$ as control sample
- Measurement of

$$\frac{\text{BR}(B_c \to J/\psi 3\pi)}{\text{BR}(B_c \to J/\psi\pi)} = \epsilon_{\text{rel}} \frac{N(B_c \to J/\psi 3\pi)}{N(B_c \to J/\psi\pi)}$$

is performed

$B_c^{\pm} \rightarrow J/\psi(3\pi)^{\pm}$



- Number of signal events after fit:
  - $B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$ – **163 ± 16**
  - $B_c^{\pm} \rightarrow J/\psi(3\pi)^{\pm}$ – **58 ± 10, 6.8σ**

$B_c^{\pm} \to J/\psi(3\pi)^{\pm}$, Branching ratios

- All efficiencies computed from MC
- Systematic sources:
  - $P_T(B_c)$ spectrum – 9%
  - Trigger simulation – 4%
  - B_c life-time – 3%
  - Background shape – 2.2%
- Result (preliminary):

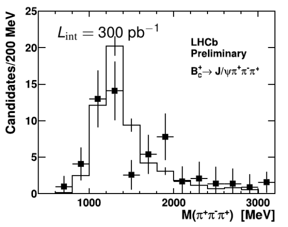
$$\frac{\text{BR}(B_c \to J/\psi 3\pi)}{\text{BR}(B_c \to J/\psi \pi)} = (3.0 \pm 0.6_{\text{stat}} \pm 0.4_{\text{syst}})\%$$

- To be compared with theoretical prediction:
  $\sim$ **2.3** by A.K.Likhoded, A.V.Luchinsky, (PRD 81, 014015 (2010))

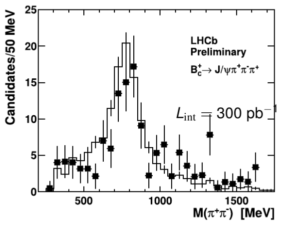
$B_c^{\pm} \longrightarrow J/\psi(3\pi)^{\pm}$

- Background-subtracted invariant masses of pion systems: $(3\pi)^{\pm}$ and $\pi^+\pi^-$
- Consistent with $B_c \to J/\psi a_1^{\pm}(1260)$ and $a_1^{\pm}(1260) \to \rho^0\pi^{\pm}$ (solid histograms – MC)

$(3\pi)^{\pm}$

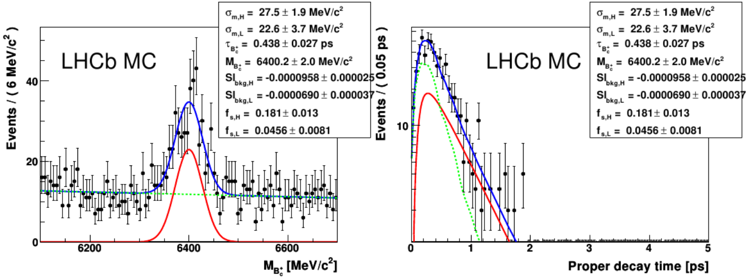


$\pi^+\pi^-$



Nearest future

- Full statistics of 2011 ($\sim$ **25** scale factor with respect to 2010 data)
- Improved mass measurements
- Life-time measurements
  - Based on MC studies (CERN-LHCb-2008-077)
  - Acceptance extracted from MC, two $P_T(B_c)$ bins are considered (5-12, >12 GeV/c)
  - Statistical uncertainty below 30 fs can be achieved with 1 fb^{-1} of data
  - For high P_T bin:



Nearest future

- Life-time measurements based on decay $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\mu^{\pm}\nu$
  - Advantages
    - Larger branching fraction $\sim$ **1.9%**
    - 3μ in the final state: **nice signature**
    - better possibilities to reduce background
    - It is possible to perform life-time unbiased selections
  - Disadvantages
    - Missing energy carried out by neutrino
    - Very difficult to use MC-free background estimations
    - Strongly depends on MC when missing energy corrections are needed
- $\sim$ **4.7 K** reconstructed $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\mu^{\pm}\nu$ events expected from 1 fb^{-1} of data at $\sqrt{s} = 7$ TeV.

Nearest future

Intensive searches for other decays and excited B_c states:

- b- and c-quark decay channels:
  - $B_c^\pm \to J/\psi K^\pm$, $B_c^\pm \to \psi(2S)\pi^\pm$
  - $B_c^\pm \to B_s^0 \pi^\pm$
    - Very clean channel with $B_s^0 \to J/\psi\phi$
    - Need high statistics. Can be done with 2011/2012 data
- Annihilation channel
  - One possibility: $B_c^\pm \to K^{*0} K^\pm$ with Br $\sim$ O(10^{-6})
  - Also requires high statistics
- Excited states
  - $B_c^* \to B_c\gamma$, $B_c^* \to B_c 2\gamma$, $B_c^* \to B_c 2\pi$
  - Very soft γs and pions (100-200 MeV/c in B_c^* rest frame)
  - Can be done for tight-boosted B_c states

Conclusions

- Clear signal in the channel $B_c^\pm \to J/\psi(\mu^+\mu^-)\pi^\pm$ was observed
- Mass and cross section measurements were performed with 2010 data collected by LHCb
- First observation of the decay $B_c^\pm \to J/\psi(\mu^+\mu^-)(3\pi)^\pm$ with the statistical significance **6.8σ**
- Prospects with 2011 data (~ 1 fb^{-1}):
  - We expect ~ 600 $B_c^\pm \to J/\psi(\mu^+\mu^-)\pi^\pm$ reconstructed events. Mass and production measurements will be improved. Life-time will be measured.
  - ~ 200 $B_c^\pm \to J/\psi(\mu^+\mu^-)(3\pi)^\pm$ signal events are expected. Will be combined with $B_c^\pm \to J/\psi(\mu^+\mu^-)\pi^\pm$ to improve mass, production and life-time measurements.
  - $B_c^\pm \to J/\psi(\mu^+\mu^-)\mu^\pm\nu$ will provide an order of magnitude higher yield. Can be used for life-time measurements
  - Other decay channels
  - Excited states

Conclusions

LHCb can do a lot of things about B_c

Any suggestions about important items are warmly welcomed

Thanks a lot