B_c physics at LHCb

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CERN

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B_c spectrum

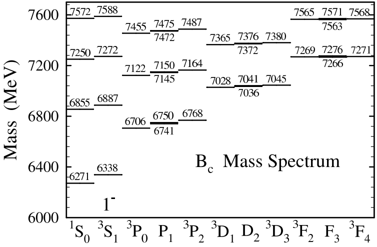
- B_c: Mesons formed by two different heavy flavour quarks, the $\bar{b}$ quark and the c quark *
  - Unique in the Standard Model because the top quark is too heavy and decays before forming any bound states

- B_c spectrum
  - Estimated using 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 (2000) 094019]
  - Lattice QCD: 6278(6)(4) MeV/c^2

    TWQCD, [arXiv:0704.3495]
  - PDG'12: 6277 ± 6 MeV/c^2



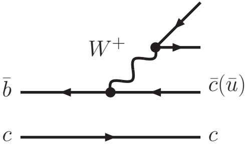
S.Godfrey, [PRD 70 (2004) 054017]

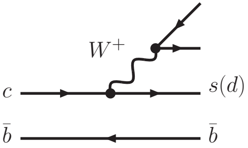
*Charge conjugates implied in this talk

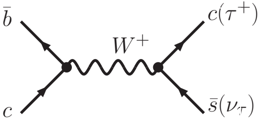
B_c decays

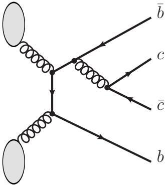
- B_c mesons' decays
  - Excited states (below BD threshold), decay through Strong or EM interactions into B_c^+
  - Ground state B_c^+: decay only weakly
- B_c^+ decay modes
  - $\bar{b} \to \bar{c}W^+$ ($\sim$20%), e.g., $J/\psi(3)\pi$, $J/\psi D_s^+$ $J/\psi \ell^+ \nu_\ell$
  - $c \to sW^+$ ($\sim$70%), e.g., $B_s^0 \pi^+$, $B_s^0 \ell^+ \nu_\ell$
  - $c\bar{b} \to W^+$ ($\sim$10%), e.g., $\bar{K}^{*0} K^+$, ϕK^+, $\tau^+ \nu_\tau$
- B_c^+ lifetime predictions
  - Inclusive rates or $\sum$(exclusive rates)
  - $\tau(B_c^+)_{\mathrm{SR}} = 0.48 \pm 0.05$ ps

    V. V. Kiselev, *et al.*, [NPB 585 (2000) 353]
  - PDG'12: 0.453 ± 0.041 ps









- B_c production
  - Difficult to generate at e^+e^- colliders
  - At hadron colliders, B_c generated mainly through $gg \to B_c + b + \bar{c}$
- B_c^+ production rate
  - Theoretical prediction (in nb) C.-H.Chang, *et al.*, [PRD 71 (2005) 074012]

-	$\|(^1S_0)_{\mathbf{1}}\rangle$	$\|(^3S_1)_{\mathbf{1}}\rangle$	$\|(^1S_0)_{\mathbf{8}}g\rangle$	$\|(^3S_1)_{\mathbf{8}}g\rangle$	$\|(^1P_1)_{\mathbf{1}}\rangle$	$\|(^3P_0)_{\mathbf{1}}\rangle$	$\|(^3P_1)_{\mathbf{1}}\rangle$	$\|(^3P_2)_{\mathbf{1}}\rangle$
LHC†	71.1	177.	(0.357, 3.21)	(1.58, 14.2)	9.12	3.29	7.38	20.4
TEVATRON	5.50	13.4	(0.0284, 0.256)	(0.129, 1.16)	0.655	0.256	0.560	1.35

  - ★ $\sigma(^3S_1)/\sigma(^1S_0) \sim 2.5$
  - ★ Colour octets and 1st P-wave contributions are small
  - ★ $\sigma(B_c^+)_{\rm LHC}/\sigma(B_c^+)_{\rm Tevatron} \sim$ O(10)
  - $\sigma(2S)/\sigma(1S)$ would be $|R_{2S}(0)/R_{1S}(0)|^2 \approx 0.6$
  - Including contributions of these states, $\sigma(B_c^+) \sim 0.9$ μb for $\sqrt{s} = 14$ TeV; or ~ 0.4 μb for $\sqrt{s} = 7$ TeV
    - ★ $\sim$ 10% from 1st P-wave states
    - ★ $\sim$ 1/3 from $2S$ states

† $\sqrt{s} = 14$ TeV

Experimental status, mass and lifetime

- Mass and lifetime

Collab.	$\mathcal{L}$ [fb^{-1}]	Mode	Signal yields	Mass [MeV/c^2]	Lifetime [ps]
CDF	0.11	$J/\psi\ell^+\nu$	$20.4^{+6.2}_{-5.5}$	$6400 \pm 390 \pm 130$	$0.46^{+0.18}_{-0.16} \pm 0.03$
D0	0.21	$J/\psi\mu^+X$	$95 \pm 12 \pm 11$	$5950^{+140}_{-130} \pm 340$	$0.45^{+0.12}_{-0.10} \pm 0.12$
CDF	0.36	$J/\psi\pi^+$	14.6 ± 4.6	$6285.7 \pm 5.3 \pm 1.2$	—
CDF	0.36	$J/\psi e^+\nu_e$	238	—	$0.463^{+0.073}_{-0.065} \pm 0.036$
CDF	2.4	$J/\psi\pi^+$	108 ± 15	$6275.6 \pm 2.9 \pm 2.5$	—
D0	1.3	$J/\psi\pi^+$	54 ± 12	$6300 \pm 14 \pm 5$	—
D0	1.3	$J/\psi\mu^+X$	881 ± 80	—	$0.448^{+0.038}_{-0.036} \pm 0.032$
CDF	1.0	$J/\psi\ell^+\nu$	—	—	$0.475^{+0.053}_{-0.049} \pm 0.018$
CDF	6.7	$J/\psi\pi^+$	308 ± 39	$(6274.6 \pm 2.9)^{\ddagger}$	$0.452 \pm 0.048 \pm 0.027$
LHCb	0.37	$J/\psi\pi^+$	179 ± 17	$6273.7 \pm 1.3 \pm 1.6$	—

‡fit value

Experimental status, production

- Production

Collab.	$\mathcal{L}$ [fb^{-1}]	Signal yields	Result
CDF	0.11	$20.4^{+6.2}_{-5.5}$	$\frac{\sigma(B_c^+)\times\mathcal{B}(B_c^+\to J/\psi\ell^+\nu)}{\sigma(B^+)\times\mathcal{B}(B^+\to J/\psi K^+)} = 0.132^{+0.041}_{-0.037}\,(\text{stat.}) \pm 0.031\,(\text{syst.})\,^{+0.032}_{-0.020}\,(\text{lifetime})$ for $p_\mathrm{T}(B) > 6$ GeV/c and $\lvert y\rvert < 1$
CDF†	1.0	—	$\frac{\sigma(B_c^+)\times\mathcal{B}(B_c^+\to J/\psi\mu^+\nu)}{\sigma(B^+)\times\mathcal{B}(B^+\to J/\psi K^+)} = 0.227 \pm 0.033(\text{stat.})^{+0.024}_{-0.017}(\text{syst.}) \pm 0.014(p_\mathrm{T}\ \text{spect.})$ for $p_\mathrm{T}(B) > 6$ GeV/c and $\lvert y\rvert < 1$
LHCb	0.37	162 ± 18	$\frac{\sigma(B_c^+)\times\mathcal{B}(B_c^+\to J/\psi\pi^+)}{\sigma(B^+)\times\mathcal{B}(B^+\to J/\psi K^+)} = (0.68 \pm 0.10\,(\text{stat.}) \pm 0.03\,(\text{syst.}) \pm 0.05(\text{lifetime}))\,\%$ for $p_\mathrm{T}(B) > 4$ GeV/c and $2.5 < \eta(B) < 4.5$

†: preliminary

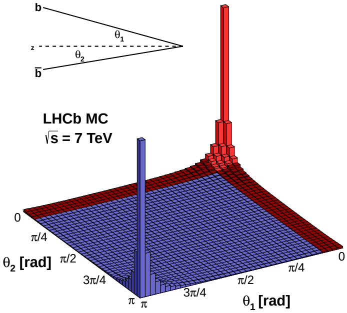
Experimental status, decay

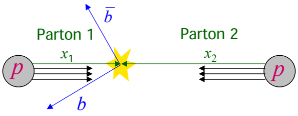
- Decay

Collab.	$\mathcal{L}$ [fb^{-1}]	Mode	Signal yields	Result
LHCb	0.8	$J/\psi\pi^+\pi^-\pi^+$	135 ± 14	$\frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 2.41 \pm 0.30\,(\text{stat.}) \pm 0.33\,(\text{syst.})$
LHCb	1.0			$f_c/f_u \cdot \mathcal{B}(B_c \to X)$ @ 90% CL
		$D_s^+\phi$	0	$< 0.8 \times 10^{-6}$
		D^+K^{*0}	1	$< 0.5 \times 10^{-6}$
		$D^+\overline{K}^{*0}$	0	$< 0.4 \times 10^{-6}$
		$D_s^+K^{*0}$	0	$< 0.7 \times 10^{-6}$
		$D_s^+\overline{K}^{*0}$	1	$< 1.1 \times 10^{-6}$

b and c production at LHC

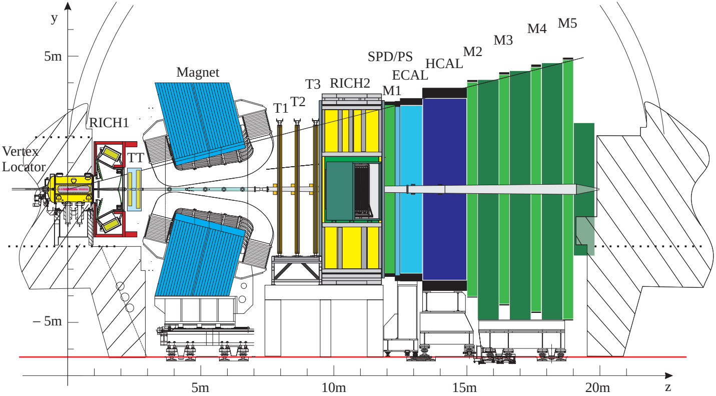
- Large production cross-sections @ $\sqrt{s} = 7$ TeV
  $\sigma_{pp}^{\text{inel}}$ ~ 60 mb [JINST 7 (2012) P01010]
  $\sigma(pp \to c\bar{c}X)$ ~ 6 mb [LHCb-CONF-2010-013]
  $\sigma(pp \to b\bar{b}X)$ ~ 0.3 mb [PLB 694 (2010) 209], c.f. $\sigma(e^+e^- \to b\bar{b}) \sim 1$ nb @ $\Upsilon(4S)$
- In high energy collisions, $b\bar{b}/c\bar{c}$ pairs are produced predominantly in forward or backward directions





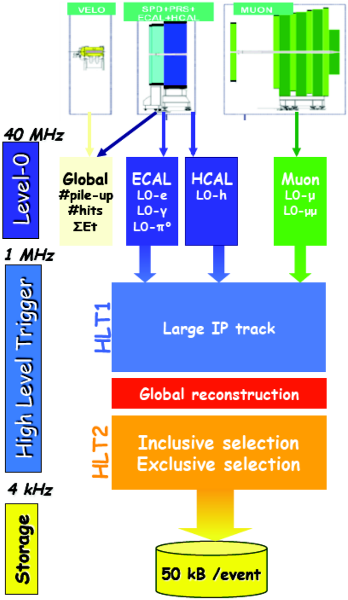
LHCb detector

- Forward spectrometer ($2 < \eta < 5$), dedicated to flavour physics



Vertex Locator	$\sigma_{\rm PV,x/y} \sim 10$ µm, $\sigma_{\rm PV,z} \sim 60$ µm
Tracking **(TT, T1-T3)**	$\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
RICHs	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system **(M1-M5)**	$\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1 - 3\%$
ECAL	$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

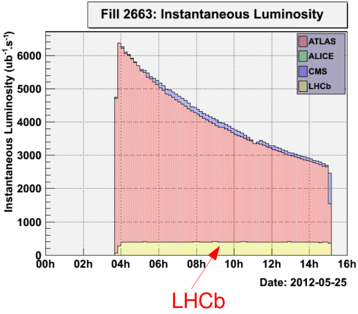
LHCb trigger system



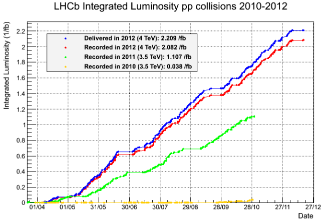
- Level-0, Hardware
  - Fully synchronous at 40 MHz
  - Selection of high p_{T} particles
    - $p_{\mathrm{T}}(\mu) >\sim 1.5$ GeV/c, $p_{\mathrm{T}}(\mu_1) \times p_{\mathrm{T}}(\mu_2) >\sim (1.5\,\mathrm{GeV}/c)^2$
    - $E_{\mathrm{T}}(h, e, \gamma) > 3-4$ GeV
- High Level Trigger (HLT), software
  - Runs $\sim$30 k processes
  - Stage 1, add tracking info, impact parameter cuts
  - Stage 2, full reconstruction + selections
- Global event cuts (GEC) applied on the hit multiplicity of sub-detectors to remove events with high occupancy.

LHCb data taking

- Luminosity levelling
  - $\mathcal{L} = 4 \times 10^{32}\ \text{cm}^{-2}\text{s}^{-1}$ (2×design)
  - Continuously adjust beam overlaps in collision region, luminosity kept flat at optimal level



- Integrated luminosity (recorded)
  - 2012: 2 fb^{-1} @ $\sqrt{s} = 8$ TeV
  - 2011: 1 fb^{-1} @ $\sqrt{s} = 7$ TeV
  - 2010: 37 pb^{-1} @ $\sqrt{s} = 7$ TeV



Measurement of B_c^+ production

[PRL 109 (2012) 232001]

Measurement of B_c^+ production

- Based on 0.37 fb^{-1} of data taken in 2011, we measured

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

for $p_{\rm T}(B) > 4$ GeV/c and $2.5 < \eta(B) < 4.5$

- We need to determine
  - Signal yields, $N\left(B_c^+ \to J/\psi\pi^+\right)$, $N(B^+ \to J/\psi K^+)$
  - Relative efficiency, $\varepsilon_{\rm tot}^{\rm rel}$

Events selections

- Based on “signatures” of *b*-hadrons
  - Long lifetime
  - Hard $p_{\rm T}$ distributions

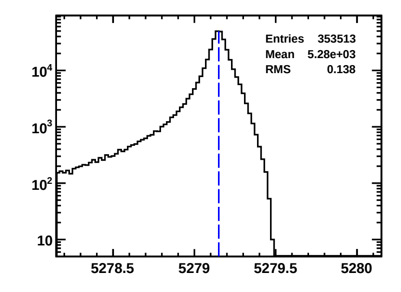
Quantity	Requirement
μ	
Track	Long track with muon detector hits (IsMuon)
$\Delta \mathrm{LL}_{\mu\pi}$	> 0
$p_{\rm T}$	$> 0.9\,\mathrm{GeV/c}$
Track fit quality χ^2/ndf	< 4
J/ψ	
Mass window	$3.04 < M_{\mu\mu} < 3.14$ GeV/c^2
Vertex fit χ^2/ndf	< 9
$\chi^2_{\rm IP}$	> 4 (only for B_c^+)
Bachelor hadron (π^+ for B_c^+ and K^+ for B^+)	
$p_{\rm T}$	$> 1.5\,\mathrm{GeV/c}$
Track fit quality χ^2/ndf	< 4
$\chi^2_{\rm IP}$	> 25 (only for B_c^+)
B_c^+ or B^+	
$p_{\rm T}$	$> 4\,\mathrm{GeV/c}$
Vertex fit χ^2/ndf	< 9
$\chi^2_{\rm IP}$	< 5 (only for B_c^+)
τ	$> 0.25\,\mathrm{ps}$
Pseudo-rapidity	$2.5 < \eta < 4.5$

Signal line shape

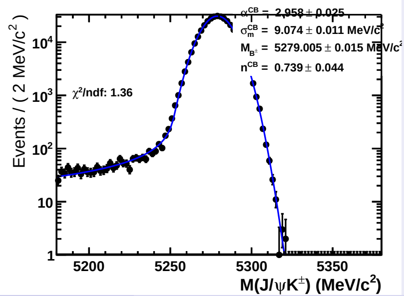
- Studied using $B^+ \to J/\psi K^+$ generator level events
- While ignoring the J/ψ FSR, i.e., take true J/ψ momentum, signal well described by Crystal ball function:

$$CB(m|M,\sigma,\alpha,n) = \begin{cases} e^{-\frac{(m-M)^2}{2\sigma^2}}, & \text{if } \alpha\frac{m-M}{\sigma} \geq -\alpha^2 \\ \frac{(\frac{n}{|\alpha|})^n e^{-\alpha^2/2}}{(\frac{n}{|\alpha|}-|\alpha|-\frac{\alpha}{|\alpha|}\cdot\frac{m-M}{\sigma})^n} & \text{for the other cases} \end{cases}$$

True $J/\psi K^+$ mass



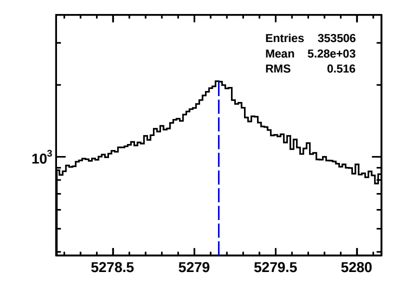
Smeared



Signal line shape (cont.)

- J/ψ FSR and mass constraint vertex fit cause tail on the right side

True $\mu^+\mu^-K^+$ mass



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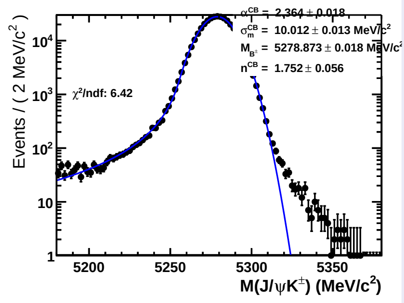
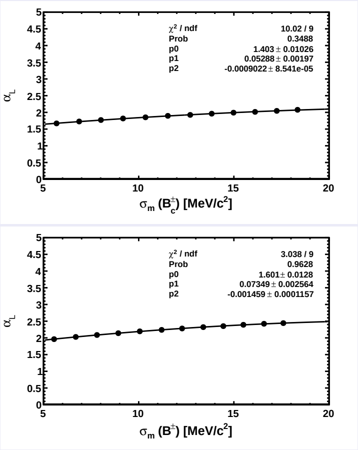


- A double-sided Crystal ball function used as signal line shape

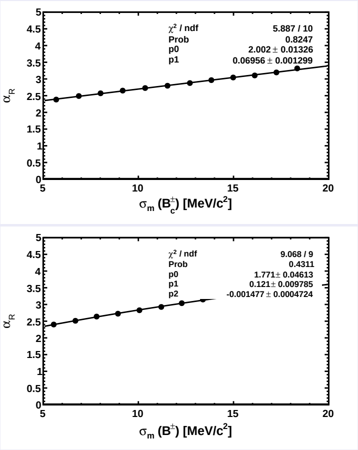
Parametrisation of double-sided CB

- n_L, n_R fixed to 2 and 4, α's parametrised as function of fitted mass resolutions.

α_L



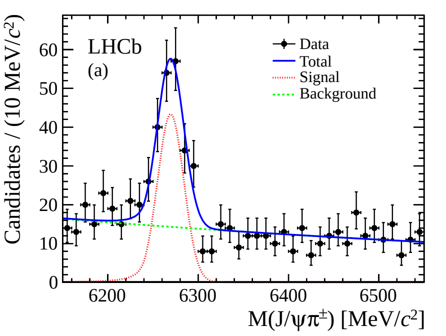
α_R



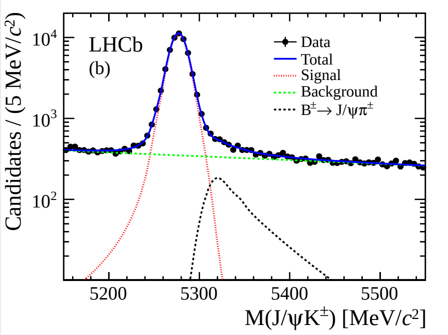
Signal yields

- B_c^+, a double-sided CB, $B_c^+ \to J/\psi K^+$ ignored
- B^+, two double-sided CB, $B^+ \to J/\psi\pi^+$ considered, and ratio to the number of signal fixed to 0.38%, as measured by LHCb [PRD 85 (2012) 091105]

B_c^+, 162 ± 18



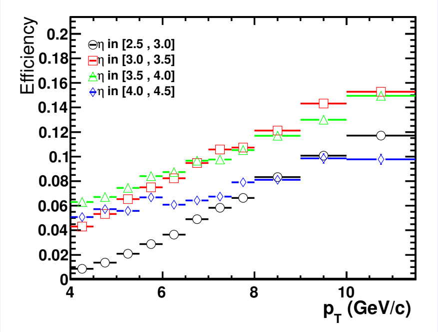
B^+, $56\,243 \pm 256$



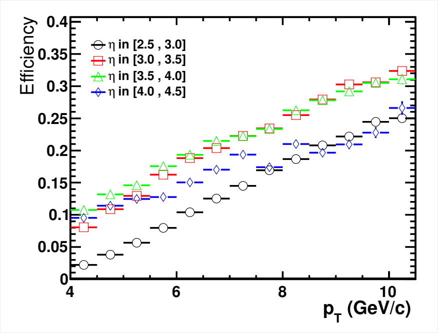
Efficiencies in bins of (p_{T}, η)

- $R_{c/u}$ would be biased if the predicted (p_{T}, η) distributions different from those in data while using the overall (relative) efficiency
- To reduce the dependence on theoretical predictions, efficiencies binned in (p_{T}, η), signal yields in each bin obtained using sPlot
- Model independent $R_{c/u} = (0.68 \pm 0.10)\%$

B_c^+



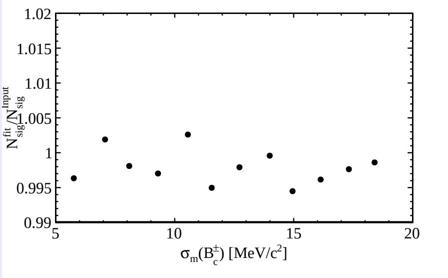
B^+



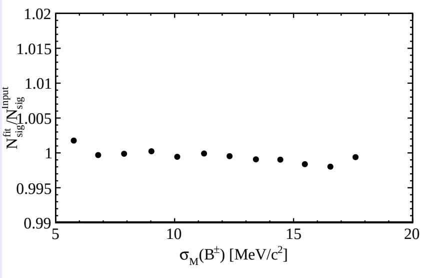
Systematic uncertainties, signal yields determination

- Fit model, difference between fitted number of signal and input ones, within 0.5%, conservatively, 1% assigned

B_c^+



B^+



- Cabbibo suppressed background, fit w/ or w/o, yields changed by $< 1\%$, ignored.

Systematic uncertainties, efficiencies determination

- Lifetime, $\tau(B_c) = (0.45 \pm 0.04)$ ps
  - Varied by $\pm\sigma$, relative efficiency changed by 7.3%.
- Trigger efficiency
  - With only lifetime unbiased (di)muon lines, ratio changed to (0.65 ± 0.10)%, i.e., 4.4%, taken as systematic uncertainty.
- Tracking efficiency
  - Toy MC done with 2011 tracking efficiency table, relative efficiency changed only by 0.2%, ignored
  - Assign 2% due to nuclear interaction

Systematic uncertainties, summary

Quantity	Systematic uncertainty (%)
Fit model	1.0
Cabbibo suppressed background	negligible
Selection	negligible
B_c^+ lifetime	7.3
GEC	negligible
Trigger	4.4
Tracking	negligible
Nuclear interaction	2.0
Weight procedure	negligible
Total	8.8

Results

- First measurement at 7 TeV, to guide B_c studies at LHC
  $R_{c/u} = (0.68 \pm 0.10\,(\text{stat.}) \pm 0.03\,(\text{syst.}) \pm 0.05(\text{lifetime}))\%$
  for $p_{\mathrm{T}}(B) > 4$ GeV/c and $2.5 < \eta(B) < 4.5$
- Comparison with theoretical prediction, taking
  - $\sigma(B_c^+) = 0.4\ \mu\text{b}$
  - $\mathcal{B}(B_c^+ \to J/\psi\pi^+) = 0.29\%$, C.-F. Qiao *et al.*, [arXiv:1209.5859]
  - $\sigma(B^+,\, p_{\mathrm{T}}(B) < 40\ \text{GeV}/c,\ 2.0 < y < 4.5) = 41.4 \pm 1.5 \pm 3.1\ \mu\text{b}$, measured by LHCb [JHEP 04 (2012) 093]
  - $\mathcal{B}(B^+ \to J/\psi K^+) = (0.1016 \pm 0.0033)\%$, PDG'12

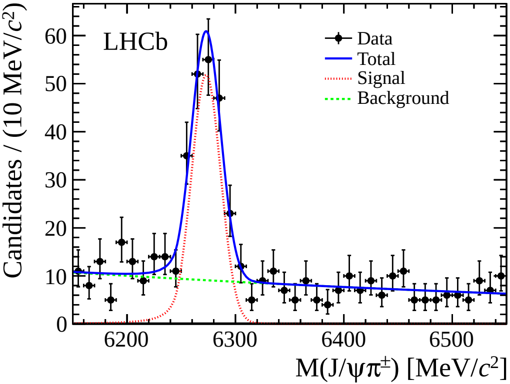
  and the efficiencies of acceptance from Monte Carlo, we obtain
  $R_{c/u}^{\text{Theo.}} = 0.56$
  before considering theoretical uncertainties.

Measurement of B_c^+ mass

[PRL 109 (2012) 232001]

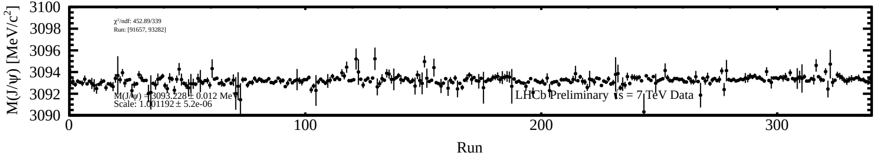
Measurement of $B_c^\pm$ mass

- Based on 0.37 fb^{-1} 2011 data
- Selection almost the same as that used for production measurement, except
  - Trigger and η requirements removed
  - $\Delta LL_{\pi K}(\pi) > -5$ added to reduce contamination of $B_c^+ \to J/\psi K^+$
  - $\sigma_m(B_c) < 20$ MeV/c^2



Calibration of momentum scale

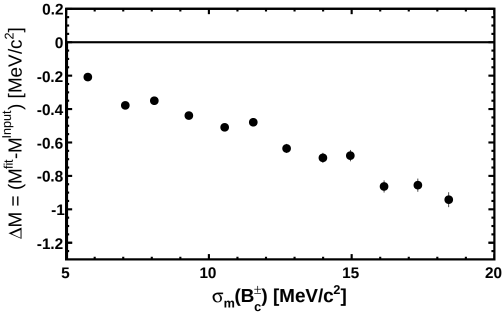
- Momentum scale calibrated with J/ψ run by run, split into 5 run periods, e.g.,



- Momentum scale verified with K_S^0, Υ, difference between J/ψ and Υ, 0.06% taken as systematic uncertainty

Systematic uncertainties, fit model

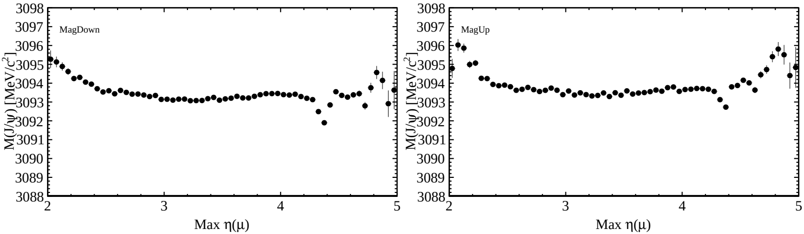
- Difference between fitted mass and input one: 0.7 ± 0.1 MeV/c^2 for $\sigma_M = 13$ MeV/c^2. B_c^+ mass corrected by 0.7 MeV/c^2, 0.1 MeV/c^2 taken as systematic uncertainty.



- Background line shape, using a flat line instead of exponential, changed by 0.3 MeV/c^2.

Systematic uncertainties, momentum scale

- Momentum scale, varied by $\pm 0.06\%$, B_c^+ mass changed by 1.4 MeV/c^2
- η dependence, momentum scale parametrized as function of η, the complete analysis repeated, variation of 0.3 MeV/c^2 seen.



- Energy loss, from 2010 measurement, 0.1 MeV/c^2
[PLB 708 (2012) 241]

Systematic uncertainties, momentum scale (cont.)

- Alignment, track slope varied by $\pm 0.1\%$, repeated the complete analysis, including momentum scale calibration, B_c^+ mass changed by 0.1 MeV/c^2
- Relative alignment of different sub-detectors, TT hits removed, repeated the complete analysis, including momentum scale calibration, B_c^+ mass changed by 0.6 MeV/c^2
- Charge and polarity, no obvious dependence for B_c^+ with the current statistics

Systematic uncertainties, summary

- Also measured the mass difference with respect to B^+, $\Delta M = M(B_c^+) - M(B^+)$, systematic uncertainties evaluated in the same way
- Summary of systematic uncertainties (in MeV/c^2)

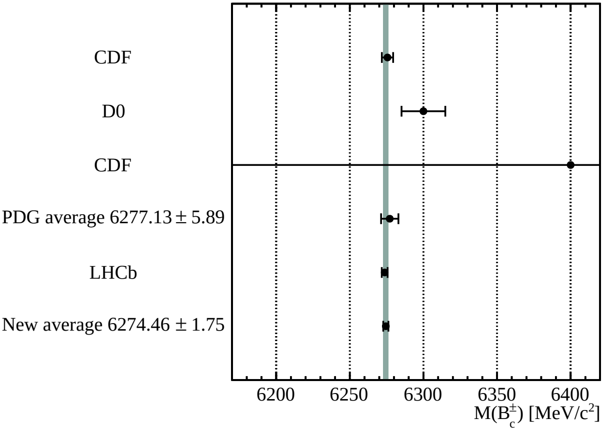
Source of uncertainty	$M(B_c^+)$	ΔM
Mass fitting:		
– Signal model	0.1	0.1
– Background model	0.3	0.2
Momentum scale:		
– Average momentum scale	1.4	0.5
– η dependence	0.3	0.1
Detector description:		
– Energy loss correction	0.1	-
Detector alignment:		
– Vertex detector (track slopes)	0.1	-
– Tracking stations	0.6	0.3
Quadratic sum	1.6	0.6

Results, world best to date

- Mass $M(B_c^+) = 6273.7 \pm 1.3\,(\mathrm{stat.}) \pm 1.6\,(\mathrm{syst.})\,\mathrm{MeV}/c^2$
- Mass difference $\Delta M = M(B_c^+) - M(B^+) = 994.6 \pm 1.3\,(\mathrm{stat.}) \pm 0.6\,(\mathrm{syst.})\,\mathrm{MeV}/c^2$.
  Taking the world average B^+ mass $(5279.25 \pm 0.17)\,\mathrm{MeV}/c^2$, we obtain,
  $M(B_c^+) = 6273.9 \pm 1.3\,(\mathrm{stat.}) \pm 0.6\,(\mathrm{syst.})\,\mathrm{MeV}/c^2$

New world average

- LHCb result in good agreement with previous measurements and theoretical prediction, 6278(6)(4) MeV/c^2 TWQCD, [arXiv:0704.3495]



First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$

[PRL 108 (2012) 251802]

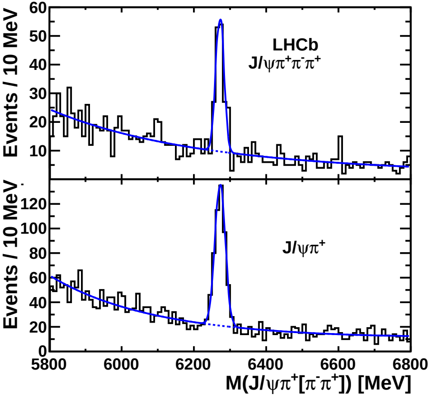
First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$

- Based on $\sim 0.8\ \text{fb}^{-1}$ data collected in 2011
- Cut based pre-selection + S/B likelihood-ratio discrimination
- Use $B^+ \to J/\psi\pi^+\pi^-K^+$ as control channel
- Measured

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = \frac{N(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{N(B_c^+ \to J/\psi\pi^+)} \times \varepsilon_{\text{tot}}^{\text{rel}}$$

Signal yields

- $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$, 135 ± 14, first observation
- $B_c^+ \to J/\psi\pi^+$, 414 ± 25



Ratio of branching fractions

- Total efficiencies computed from MC.
- Systematic uncertainties
  - Signal yields
    - Signal and background line shapes, 3%
  - Efficiencies
    - Decay model, 9%
    - Tracking efficiency, 5%
    - B_c^+ lifetime, 4%
    - Trigger efficiency, 4%
- Results

$$\frac{\mathcal{B}(B_c^+ \to J/\psi \pi^+ \pi^- \pi^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 2.41 \pm 0.30(\text{stat.}) \pm 0.33(\text{syst.})$$

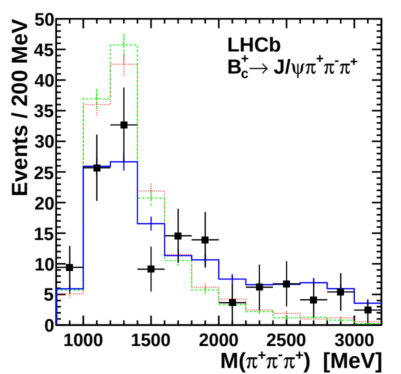
Theoretical predictions:

- ~ 1.5 by A. Rakitin & S. Koshkarev, [PRD 81 (2010) 014005]
- ~ 2.3 by A. K. Likhoded & A. V. Luchinsky, [PRD 81 (2010) 014015]

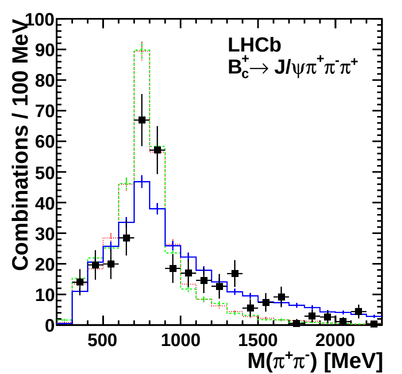
$M(\pi^+\pi^-\pi^+)$ & $M(\pi^+\pi^-)$ distributions of B_c^+ signal

- Background subtracted invariant mass distributions (points with error bars) of $M(\pi^+\pi^-\pi^+)$ & $M(\pi^+\pi^-)$ consistent with $B_c^+ \to J/\psi a_1^+(1260)$, with virtual $a_1^+(1260) \to \rho^0\pi^+$ decay model [PRD 81 (2010) 014015] [arXiv:1104.0808] used in MC (blue line)

$M(\pi^+\pi^-\pi^+)$

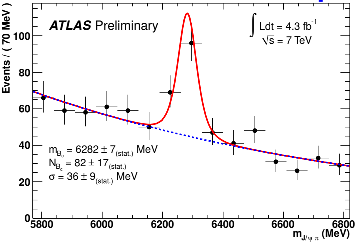


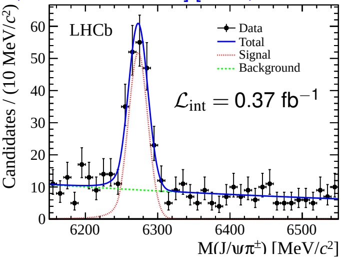
$M(\pi^+\pi^-)$

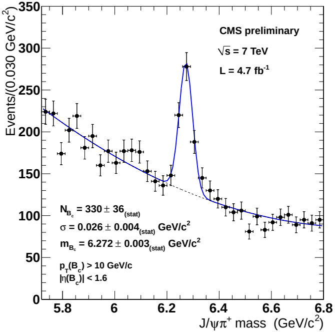


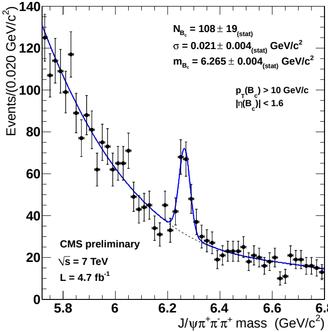
B_c^+ signals from other experiments at LHC

[ATLAS, CONF-2012-028] [CMS, PAS-BPH-11-003]





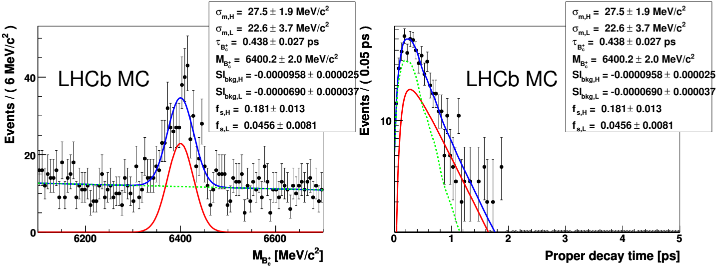




Prospects

Prospects: Lifetime measurement with $B_c^+ \to J/\psi\pi^+$

- Based on MC studies [CERN-LHCb-2008-077]
- Acceptance determined from MC, two $p_{\mathrm{T}}(B_c^+)$ bins (5-12, $>$ 12 GeV/c) to reduce dependence on $p_{\mathrm{T}}(B_c^+)$ distribution.
- Statistical uncertainty below 30 fs achievable with 1 fb^{-1} of data
- Plots in high p_{T} bin:



(a) Mass

(b) t in signal region

- Will also try data-driven method to determine acceptance [CERN-LHCb-2007-053]

Prospects Lifetime measurement with $B_c^+ \to J/\psi\mu^+ X$

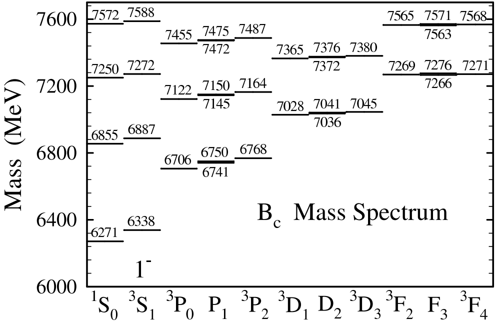
- $B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$, compared to $B_c^+ \to J/\psi\pi^+$
  - Pro
    - ★ Larger branching ratio, $\sim$1.9%
    - ★ 3 μ in the final states, easier (relatively) to reduce background
      Lifetime unbiased selection would be possible
  - Contra
    - ★ Missing energy caused by neutrino, partially reconstructed. Not easy to use MC-free method to estimate background.
    - ★ Need MC to correct the missing energy while calculating the lifetime
- Tight J/ψ selection, and a tight p_{T} cut on the bachelor μ.
- Expect $\sim$ 5 k reconstructed $B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$ from 1 fb^{-1} of data @ $\sqrt{s} = 7$ TeV, analysis ongoing to measure B_c^+ lifetime

Prospects More topics

- B_c^+ production
  - Measuring differential cross-section down to zero $p_{\mathrm{T}}(B)$, with 2012 data ($\sqrt{s} = 8$ TeV)
- B_c^+ mass,
  - Updating with all 2011+2012 data
  - Statistical uncertainty below 0.3 MeV/c^2, better understanding of momentum scale to control systematic uncertainty
- In the pipeline, $B_c^+ \to J/\psi K^+$, $B_c^+ \to \psi(2S)\pi^+$, $B_c^+ \to J/\psi D_s^+$
- $B_c^+ \to B_s^0 \pi^+$
  - Self-tagged channel
  - With $B_s^0 \to J/\psi\phi$ or $B_s^0 \to D_s\pi$
  - Analysis with 2011+2012 data ongoing
- Annihilation
  - Possible channel, e.g, $B_c^+ \to \bar{K}^{*0} K^+$, $\mathcal{B} \sim \mathrm{O}(10^{-6})$, c.f., S. Descotes-Genon, et al., [PRD 80, 114031 (2009)]

Prospects, search for excited states

- $B_c^{*+} \to B_c^+ \gamma$, very soft photon, difficult for LHCb
- 1st P-wave states, small cross-section, mass difference among four states are small, need more data
- $2S$ states, analysis with 2011+2012 data ongoing
  - $B_c(2^1S_0) \to B_c^+ \pi^+ \pi^-$
  - $B_c(2^3S_1) \to B_c^{*+}(B_c^+ \gamma)\pi^+\pi^-$, when photon is missing, invariant mass peak shifted down by $M(B_c^{*+}) - M(B_c^+)$ but not washed out



Summary

- LHCb performed the world-best measurements of B_c^+ production and mass, and observed $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ for the first time
- Lifetime measurements, observation of several new B_c^+ decay modes are in the pipeline
- Production and mass measurements are being updated, search for new decay modes and excited states are ongoing