B_c studies at LHC*b*

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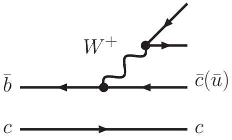
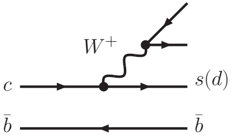
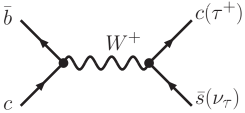
2nd FCPPL workshop

B_c decays

- B_c: Meson family formed by $\bar{b}$ and c [a]
- B_c meson's decays
  - Excited states: Strong or EM to B_c^+
  - Ground state B_c^+: Weak
- B_c^+ decay modes
  - $\bar{b} \to \bar{c}W^+$, e.g., $J/\psi\pi^+$, $J/\psi\ell^+\nu_\ell$
  - $c \to sW^+$, e.g., $B_s^0\pi^+$, $B_s^0\ell^+\nu_\ell$
  - $c\bar{b} \to W^+$, e.g., $c\bar{s}$, $\tau^+\nu_\tau$
- B_c^+ lifetime predictions
  - Inclusive rates or $\sum$(exclusive rates)
  - $\tau(B_c^+)_{\mathrm{SR}} = 0.48 \pm 0.05$ ps



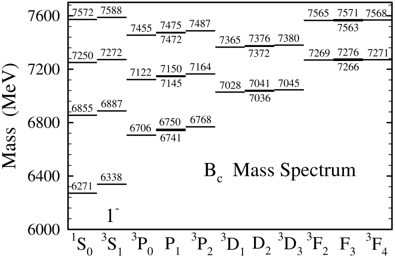




[a] Charge conjugates implied in this presentation

B_c spectrum and production

- B_c spectrum
  - Estimated using potential models
- B_c^+ mass
  - Potential: 6.2-6.4 GeV/c^2
  - pQCD: 6326^{+29}_{-9} MeV/c^2
  - Lattice QCD: 6278(6)(4) MeV/c^2



Taken from CERN-2005-005

- B_c production
  - At hadron collider: $gg \to B_c + b + \bar{c}$
- B_c^+ cross section
  - Considering the contributions of the decays of the excited states, $\sigma(B_c^+) \sim 0.4\ \mu$b
  - $\sigma(B_c^+)_{\mathrm{LHC}}/\sigma(B_c^+)_{\mathrm{Tevatron}} \sim$ O(10)

Experimental status

- Only $B_c^+ \to J/\psi(\mu^+\mu^-)X$ studied

Collab.	$\mathscr{L}_{\text{int}}$ [pb^{-1}]	Mode	Signal event	Mass [MeV/c^2]	Lifetime [ps]
CDF	110	$J/\psi\ell^+\nu$	$20.4^{+6.2}_{-5.5}$	$6400 \pm 390 \pm 130$	$0.46^{+0.18}_{-0.16} \pm 0.03$
D0	210	$J/\psi\mu^+X$	$95 \pm 12 \pm 11$	$5950^{+140}_{-130} \pm 340$	$0.45^{+0.12}_{-0.10} \pm 0.12$
CDF	360	$J/\psi\pi^+$	14.6 ± 4.6	$6285.7 \pm 5.3 \pm 1.2$	—
CDF	360	$J/\psi e^+\nu_e$	238	—	$0.463^{+0.073}_{-0.065} \pm 0.036$
CDF	2400	$J/\psi\pi^+$	108 ± 15	$6275.6 \pm 2.9 \pm 2.5$	—
D0	1300	$J/\psi\pi^+$	54 ± 12	$6300 \pm 14 \pm 5$	—
D0	1300	$J/\psi\mu^+X$	881 ± 80	—	$0.448^{+0.038}_{-0.036} \pm 0.032$
CDF	1000	$J/\psi\ell^+\nu$	—	—	$0.475^{+0.053}_{-0.049} \pm 0.018$
			Theoretical prediction	6278(6)(4)	0.48 ± 0.05
LHCb	1000	$J/\psi\pi^+$	450(?)	?	?
			$\approx 108 \times 10/2.4$		
LHCb	1000	$J/\psi\mu^+\nu_\mu$	6700(?)	—	?
			$\approx 881 \times 10/1.3$		

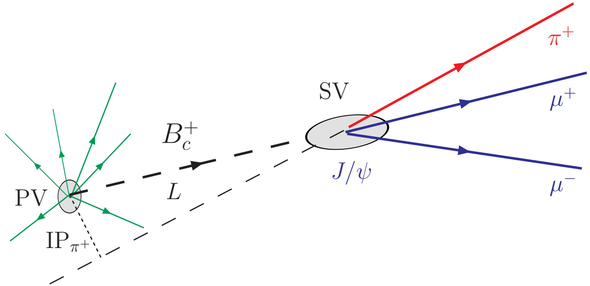
$$B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$$

$B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$ event selection

- Final states
  - Track $\chi^2/\mathrm{ndf} < 4$
  - $\Delta\ln L_{\mu\pi}(\mu) > -5$
  - $\Delta\ln L_{\pi K}(\pi) > -5$
  - $p_{\mathrm{T}}(\mu) > 1.0$ GeV/c
  - $p_{\mathrm{T}}(\pi) > 1.6$ GeV/c
  - IPS(π)>3.0 [a]

[a] IPS = $\sqrt{\chi^2_{\mathrm{IP}}} \sim \mathrm{IP}/\sigma_{\mathrm{IP}}$

- J/ψ selection
  - Mass: (3.04, 3.14) GeV/c^2
  - Vertex fit quality: $\chi^2/\mathrm{ndf} < 9$
  - IPS(J/ψ)>3.5
- B_c^+ selection
  - Vertex fit quality: $\chi^2/\mathrm{ndf} < 4$
  - $p_{\mathrm{T}}(B_c^+) > 5.0$ GeV/c
  - IPS(B_c^+)<3.0



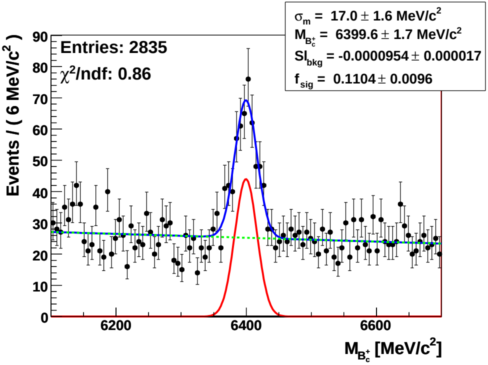
Signal yields and background level

- Assuming
  - Cross section $\sigma(B_c^+)$: 0.4 μb
  - BR($B_c^+ \to J/\psi\pi^+$)=1.3×10^{-3}
- Selection results in the B_c^+ $\pm 3\sigma$ mass window

Description	Result
Total efficiency $\varepsilon_{\rm tot}$	(1.013 ± 0.017) %
Signal yield (1 fb^{-1})	~ 310
B/S @ 90% CL	[1, 2]

B_c^+ mass measurement

- Signal events taken from the full Monte Carlo simulation, background events generated by the toy MC.
- Signal described by a Gaussian, background by 1st order polynomial.
- Un-binned maximum likelihood method, fitting result (1 fb^{-1}):
  - $M(B_c^+) = 6399.6 \pm 1.7$ MeV/c^2 (input: 6400 MeV/c^2).



Signal lifetime distribution

- Proper decay time t calculated as:

$$t = M_{B_c^+} \frac{L}{P_{B_c^+}}$$

- In theory, t follows $E(t|\tau)$. But the detector is not perfect, in practice, t can be described by

$$E(t|\tau) \otimes G(t|\sigma_t, S_t)$$

S_t is the scale factor of σ_t to account for the effects that the σ_t can be over- or under-estimated.

- Acceptance $\varepsilon(t)$ required to account for the effects caused by the lifetime biased cuts

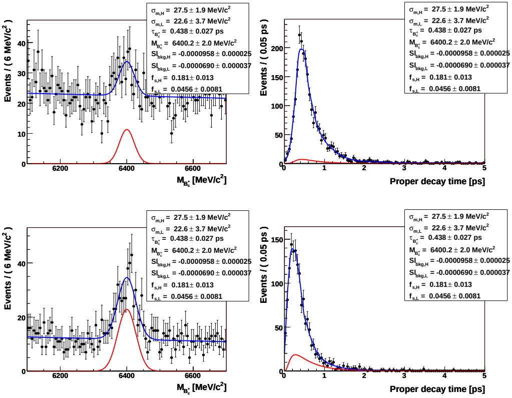
$$f(t, \sigma_t|\tau, S_t) = \varepsilon(t)\Big[E(t|\tau) \otimes G(t|\sigma_t, S_t)\Big]$$

B_c^+ lifetime fitting

- To reduce the dependence of the lifetime measurement on the B_c^+ p_{T} distribution (theoretical model), $p_{\mathrm{T}}(B_c^+)$ divided into two intervals, 5-12 GeV/c and > 12 GeV/c.
- Doing the mass lifetime combined fitting in the two p_{T} intervals simultaneously, $\tau(B_c^+) = 0.438 \pm 0.027$ ps (input: 0.46 ps).

p_{T}: 5-12 GeV/c

p_{T}: > 12 GeV/c

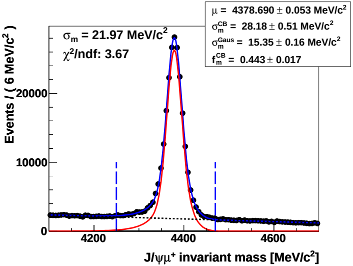


$$B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$$

$B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$ event selection

- Final states
  - Track $\chi^2/\text{ndf} < 4$
  - $p_\text{T}(\mu_{J/\psi}) > 1.5$ GeV/c
  - $\Delta\ln L_{\mu\pi}(\mu_{J/\psi}) > -5$
  - $p_\text{T}(\mu_{B_c^+}) > 3.0$ GeV/c
  - $\Delta\ln L_{\mu\pi}(\mu_{B_c^+}) > 0$
- J/ψ selection
  - Mass: (3.04, 3.14) GeV/c^2
  - Vertex fit quality: $\chi^2/\text{ndf} < 9$
- B_c^+ selection
  - Mass: $(3.2, 4.25)||(4.47, 6.4)$ GeV/c^2
    - ★ The hole (4.25, 4.47) is caused by the clone μ

      $M_{\mu_1\mu_2\mu_1} = \sqrt{2M^2_{J/\psi} + M^2_\mu} \approx 4379.5\text{MeV}/c^2$
  - Vertex fit quality: $\chi^2/\text{ndf} < 4$
  - $p_\text{T}(J/\psi\mu^+) > 6.0$ GeV/c



Signal yields and background level

- Assuming
  - Cross section $\sigma(B_c^+)$: 0.4 μb
  - BR($B_c^+ \to J/\psi\mu\nu_\mu$)=$1.9 \times 10^{-2}$
- Selection results

Description	Result
Total efficiency ε_{tot}	(1.092 ± 0.019) %
Signal yield (1 fb^{-1})	~ 4920
B/S @ 90% CL	$[4, 10]$

Pseudo lifetime

- Pseudo proper decay time t^* calculated as:

$$t^* = M_{\mathrm{J}/\psi\mu^+}\frac{L}{P_{\mathrm{J}/\psi\mu^+}}$$

- K factor needed to correct for the missing energy:

$$K = \frac{M'_{\mathrm{J}/\psi\mu}/P'_{\mathrm{J}/\psi\mu}}{M'_{\mathrm{B_c^+}}/P'_{\mathrm{B_c^+}}}$$

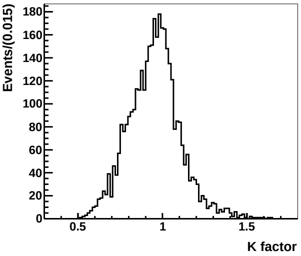
  Superscript "′" represents the Monte Carlo truth.

- Signal lifetime PDF written as:

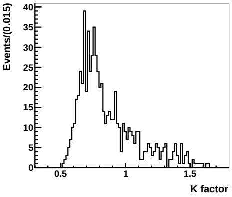
$$f(t^*,\sigma_{t^*}|\tau,S_{t^*}) = H(K)\otimes\left[E(t^*|\tau K)\otimes G(t|\sigma_{t^*},S_{t^*})\right]$$

  $H(K)$ is the K factor distribution.

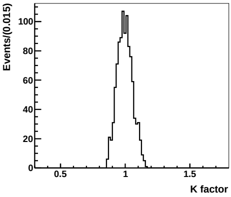
$H(K)$ in different $M_{J/\psi\mu^+}$ ranges



(a) $M_{J/\psi\mu^+}$: $(3.2, 4.25)||(4.47, 6.4)$ GeV/c^2

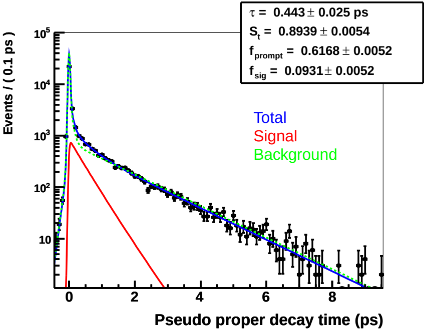


(b) $M_{J/\psi\mu^+}$: 3.2-4.25 GeV/c^2



(c) $M_{J/\psi\mu^+}$: 5.5-6.4 GeV/c^2

- $H(K)$ obtained from another sample (generator phase only), 100K events.
- τ, S_t, f_{prompt} and f_{sig} float, the other parameters are fixed.
- $\tau(B_c^+) = 0.441 \pm 0.025$ ps (input: 0.46 ps)



Comparison with former results

Collab.	$\mathscr{L}_{\text{int}}$ [pb^{-1}]	Mode	Signal event	Mass [MeV/c^2]	Lifetime [ps]
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CDF	1000	$J/\psi\ell^+\nu$	—	—	$0.475^{+0.053}_{-0.049} \pm 0.018$
LHCb	1000	$J/\psi\pi^+$	310	± 1.7(stat.)	± 0.027(stat.)
LHCb	1000	$J/\psi\mu^+\nu_\mu$	4920	—	± 0.025(stat.)

Summary

- $B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$ from the 1 fb^{-1} of data
  - Signal yield $\sim$ 310, B/S<2 @ 90% CL
  - Mass measurement precision: $\pm$1.7 (stat.) MeV/c^2
  - Lifetime measurement precision: $\pm$0.027(stat.) ps
- $B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$ from the 1 fb^{-1} of data
  - Signal yield $\sim$ 4920, B/S<10 @ 90% CL
  - Lifetime measurement precision: $\pm$0.025(stat.) ps
- More work will be done

Backup

Event selection in the two $p_{\mathrm{T}}(B_c^+)$ intervals

- Selection cuts re-optimized, lifetime cuts in the high p_{T} region loosened.

Description	Cut value	
p_{T} intervals of B_c^+	5-12 GeV/c	$\geq$ 12 GeV/c
$\mathrm{IPS}(\pi^+)$	> 3.0	> 2.0
$\mathrm{IPS}(J/\psi)$	> 3.5	> 2.5
$\mathrm{IPS}(B_c^+)$	< 3.0	< 4.0

- Selection results

p_{T} intervals of B_c^+	5-12 GeV/c	$\geq$ 12 GeV/c
Total efficiency $\varepsilon_{\mathrm{tot}}$	(0.337 ± 0.010) %	(0.856 ± 0.016) %
Signal yield	~ 100	~ 260
B/S @ 90% CL	[3.04, 5.82]	[0.55, 1.19]

Background t^* distribution

- Obtained from the inclusive J/ψ sample, as the first step.
- PDF

$$f^{t^*}_{\rm bkg}(t_i^*,\sigma_{t_i^*}|f_{\rm prompt},f_+,f_{++},\lambda_-,\lambda_+,\lambda_{++},S_{t^*})$$
$$=f_{\rm prompt}G(t_i^*,\sigma_{t_i^*}|S_{t^*})+(1-f_{\rm prompt})\big[(1-f_+-f_{++})\cdot E(t_i^*|\lambda_-)\otimes G(t_i^*|\sigma_{t_i^*},S_{t^*})$$
$$+f_+\cdot E(t_i^*|\lambda_+)\otimes G(t_i^*|\sigma_{t_i^*},S_{t^*})+f_{++}\cdot E(t_i^*|\lambda_{++})\otimes G(t_i^*|\sigma_{t_i^*},S_{t^*})\big]$$