LAL-Tsinghua activities in LHCb

Jibo HE
(for the LAL-Tsinghua Collaboration)

LAL, Orsay

3rd FCPPL Workshop @ IPNL (Lyon), 08/04/2010

LAL-Tsinghua Collaboration

- Collaboration between the LHCb groups of LAL (Orsay) and Tsinghua University (Beijing) started end of 2004, support from FCPPL in 2007.
- Collaboration members
  - LAL
    - ★ Marie-Hélène SCHUNE
    - ★ Patrick ROBBE
    - ★ Sergey BARSUK
    - ★ Jibo HE (Post-doc)
    - ★ Wenbin QIAN (Joint PhD student, embassy grant, about to finish)
  - Tsinghua
    - ★ Yuanning GAO
    - ★ ZhenWei YANG
    - ★ Wenbin QIAN (Joint PhD student, embassy grant, about to finish)
    - ★ Bo LIU (about to join)
- Supported / backed up by theorists from China and France.

Exchanges

- Visits
  - 12/2009 Y. Gao visited LAL
  - 05/2009 M-H Schune and P. Robbe visited Tsinghua
  - 10/2008 Y. Gao visited LAL
  - 10/2007 Y. Gao visited LAL
  - 05/2007 J. He visited LAL
  - 03/2006 P. Robbe visited Tsinghua
  - 12/2005 Y. Gao visited LAL
- Exchanges of PhD student and post-doc
  - 09/2008 J. He became a post-doc at LAL
  - 07/2007 W.Qian became a joint PhD student
- Regular phone/video meeting
- Discussions in the LHCb weeks

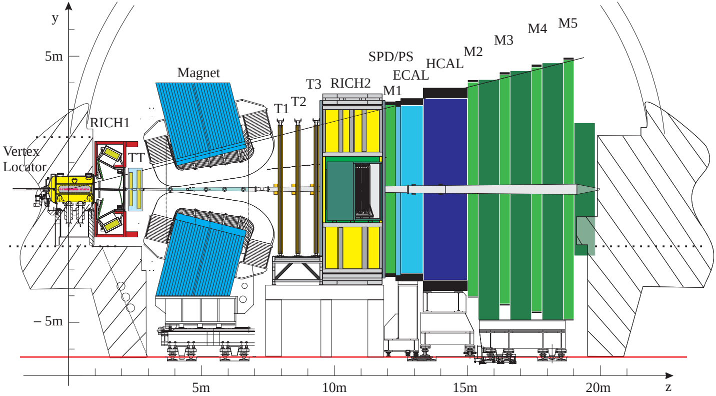
Topics and outputs

- Topics, focus on the (very) early physics at LHCb
  - J/ψ production
  - B_c physics
- Outputs
  - Journal papers
    - ★ Phys. Rev. D 80, 114031 (2009), in collaboration with S. Descotes-Genon (LPT, Orsay) and E. Kou (LAL).
  - Conference talks (on behalf of the LHCb collaboration)
    - ★ 02/2010, Prospects for quarkonium studies at LHCb, P. Robbe on Quarkonium Production at the LHC workshop.
    - ★ 02/2010, Heavy Quarkonia Studies at LHCb, J. He on ReteQuarkonii Thematic Day.
    - ★ 09/2009, LHCb Production: Onia, Cross Section, Correlations, Y. Gao on Beauty 2009.
    - ★ 07/2009, B_c mass and lifetime at LHCb, W. Qian on The 2009 Europhysics Conference on High Energy Physics (HEP 2009).
    - ★ 04/2009, Measurement of B_c mass and lifetime at LHCb, J. He on DIS 2009.

Topics and outputs (cont.)

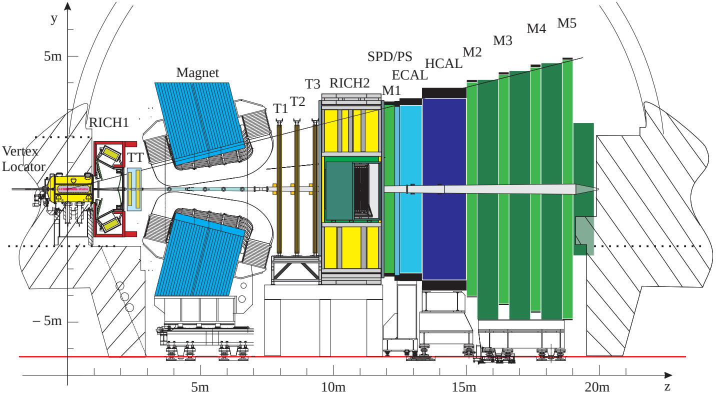
- Outputs (cont.)
  - LHCb public notes
    - One on J/ψ, LHCb-PUB-2010-011
    - Two on B_c, CERN-LHCb-2008-059, CERN-LHCb-2008-077
  - LHCb internal notes
    - One on B_c, CERN-LHCb-2009-017

The LHCb detector



Geometry acceptance	(15 - 300) mrad; $1.9 < \eta < 4.9$
Vertex Locator	$\sigma_{\mathrm{PV},x/y} \sim 10\ \mu$m, $\sigma_{\mathrm{PV},z} \sim 60\ \mu$m; $\sigma_L \sim 250\ \mu$m
Magnet	Warm magnet, ~ 4 Tm.
Tracking system (TT, T1-T3)	$\Delta p/p$: 0.35%-0.55%, σ_m:12-25 MeV/c^2

The LHCb detector (cont.)



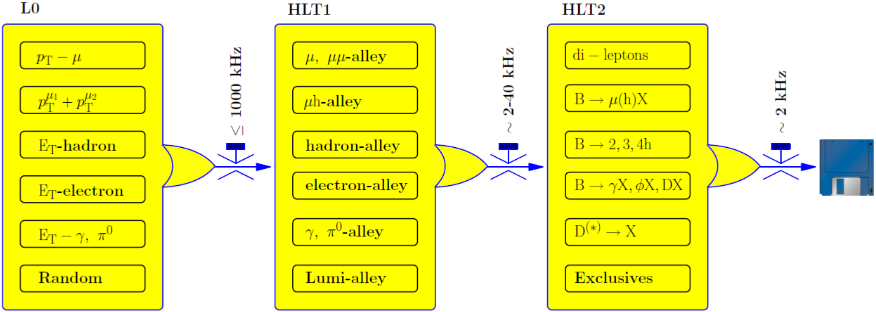
RICH1 & RICH2	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system (M1-M5)	$\varepsilon(\mu \to \mu) \sim 94\%$, mis-ID rate $(\pi \to \mu) \sim 3\%$
ECAL	$\sigma_E/E = 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E = (69 \pm 5)\%/\sqrt{E} \oplus (9 \pm 2)\%$ (E in GeV)

The LHCb trigger system

- Level-0 Trigger (Hardware)
  - High p_T μ, e, γ, hadron candidates

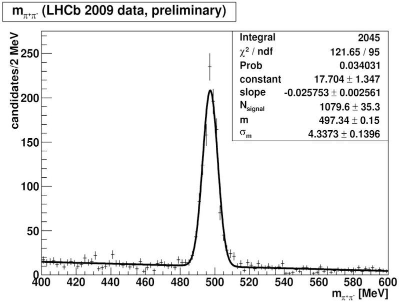
	had	μ	$\mu\mu$	$e^{\pm}$	γ	π^0
p_T>(GeV)	3.5	1	$\sum > 1.5$	2.6	2.3	4.5

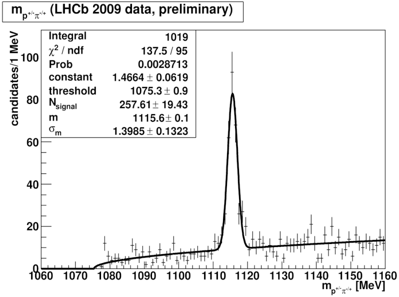
  - Efficiency: Muon (90%), Electromagnetic (70%), Hadronic (50%)
- High Level Trigger (Software)
  - HLT1: Check L0 candidate with more complete info, add impact parameters and lifetime cuts
  - HLT2: Global event reconstruction + selections (inclusive or exclusive)
  - Efficiency: Muon (80%), Electromagnetic (60%), Hadronic (80%)



The LHCb status

- The LHCb detector is fully installed. First data at $\sqrt{s}$ =900 GeV recorded, analysis ongoing.
- Very preliminary K_S^0 and Λ mass distributions, real data!





$$M_{K_S^0} = 497.3 \pm 0.2(\text{stat.})\ \text{MeV}/c^2$$
$$\sigma_m = 4.3 \pm 0.1(\text{stat.})\ \text{MeV}/c^2$$
$$M_{K_S^0}^{\text{PDG}} = 497.7\ \text{MeV}/c^2$$

$$M_\Lambda = 1115.6 \pm 0.1(\text{stat.})\ \text{MeV}/c^2$$
$$\sigma_m = 1.4 \pm 0.1(\text{stat.})\ \text{MeV}/c^2$$
$$M_\Lambda^{\text{PDG}} = 1115.7\ \text{MeV}/c^2$$

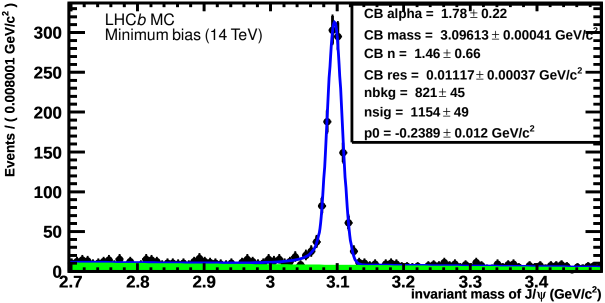
- Accumulating data at $\sqrt{s} = 7$ TeV, analysis started.

J/ψ production: motivation

- Underlying production mechanism of J/ψ not understood yet.
  - LO color octet mechanism (COM) can describe the p_{T} spectrum and cross section of the J/ψ produced at Tevatron, but can not explain the polarization, NLO doesn't help.
  - The other models, e.g., color evaporation model, k_{T} factorization, soft color interaction model can not describe the cross section and polarization simultaneously, either.
  - New measurements at the LHCb experiment (higher energy, special η coverage) will help resolve this issue.
- Large cross section and clear $J/\psi \to \mu^+\mu^-$ signal
  - J/ψ crucial for detector alignment, calibration, μ-ID and tracking efficiencies measurements, and so on.
  - The measurements of the cross sections of the prompt J/ψ and the J/ψ from b decays are important for later analysis in LHCb, e.g., absolute branching fraction measurements, assess event yields.

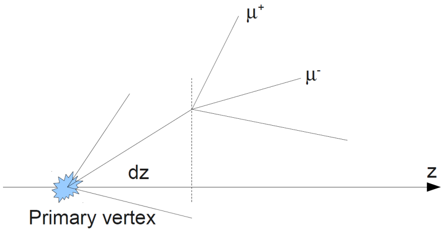
J/ψ selection

- Selection studied with the simulated minimum bias events (including all backgrounds)
  - Loose μ ID selection, loose cuts on $p_{\mathrm{T}}(\mu^{\pm})$, μ^{+} and μ^{-} coming from a common vertex, at least one reconstructed primary vertex
- Very good mass resolution: $\sim$11 MeV/c^2.
- Expect about 1.3 M reconstructed J/ψ from 1 pb^{-1} of data at $\sqrt{s} = 14$ TeV, $S/B = 17.3 \pm 2.3$ in $\pm 3\sigma$ mass window.
- Or about 0.56 M /pb^{-1} reconstructed J/ψ at $\sqrt{s} = 7$ TeV.

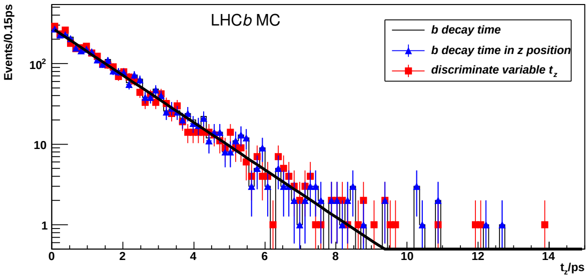


- Pseudo-lifetime t_z

$$t_z = \frac{dz}{p_z^{J/\psi}} m^{J/\psi}$$

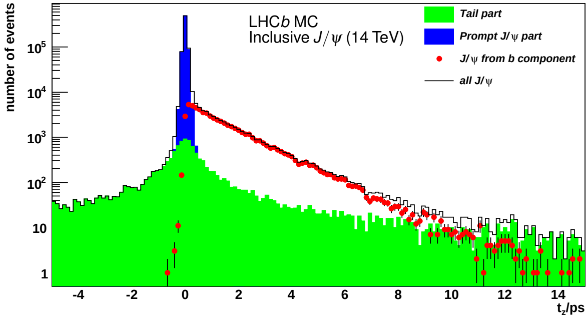


- Simple approximation of b lifetime



t_z distribution

- t_z distribution has four components
  - Prompt J/ψ, peak at 0, Gaussian
  - J/ψ from b decays, Exponential convoluted with Gaussian
  - Background distribution, estimated from mass sidebands
  - Long tail due to association to wrong primary vertex, measured using the J/ψ vertex and the PV in different event

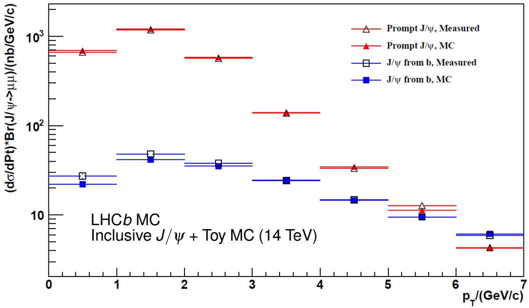


J/ψ cross section measurement

- Measurement in bins of p_{T} and η
  - 7 bins for p_{T} 0-7 GeV/c, 4 bins for η 3-5
- Combined mass and lifetime fit used to extract number of prompt J/ψ and J/ψ from b decays
- Reconstruction, selection and trigger efficiencies estimated using Monte Carlo
- Full procedure tested on a Monte Carlo sample corresponding to 0.8 pb^{-1} @ 14 TeV Only binning in p_{T}, because of small Monte Carlo statistics
  - Signal: inclusive J/ψ MC sample
  - Background: toy Monte Carlo reproducing behavior (mass and pseudo-lifetime) seen on MC Minimum bias sample.

J/ψ cross section measurement (cont.)

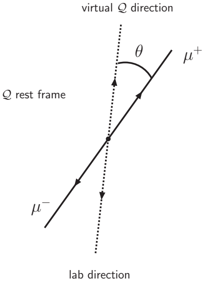
- Results (p_{T} in range 0-7 GeV, two μ in LHCb acceptance)
  - $\sigma(\text{prompt } J/\psi) \times \mathscr{B}(J/\psi \to \mu^+\mu^-) =$ $2597 \pm 12(\text{stat.}) \pm 24(\text{efficiency})$ nb (input: 2667 nb)
  - $\sigma(J/\psi \text{ from } b) \times \mathscr{B}(J/\psi \to \mu^+\mu^-) =$ $161 \pm 4(\text{stat.}) \pm 2(\text{efficiency})$ nb (input: 153 nb)

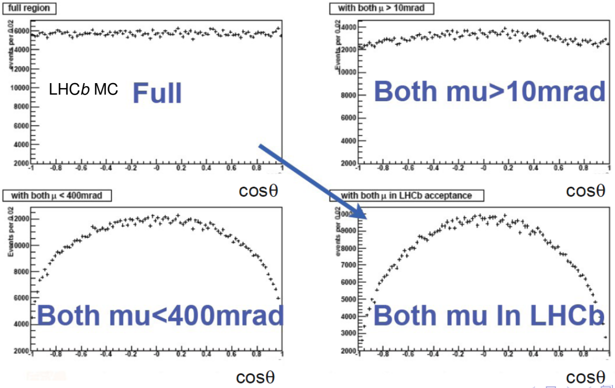


- Statistical error $< 10\%$ in each (p_{T}, η) bin, for 5 pb^{-1} of data at $\sqrt{s} = 7$ TeV.

Systematics by J/ψ polarization

- Polarization, using helicity frame. Will also use Gottfried-Jackson (GJ) and Collins-Soper (CS) frames, as suggested.
  - $\frac{dN}{d\cos\theta} \propto 1 + \alpha\cos^2\theta$; ($\alpha = 1$, Transverse; $\alpha = -1$, Longitudinal)
- LHCb acceptance generates an artificial polarization





Systematics by J/ψ polarization (cont.)

- Tevatron measurements disagree with theoretical predictions
- Systematic error up to 22% if ignoring polarization

Input α	Input σ [nb]	Measured σ [nb] assuming $\alpha = 0$	Discrepancy
0	2820	2758 ± 27	—
+1 (T)	3190	2738 ± 27	-14%
-1 (L)	2286	2787 ± 28	+22%

- Work done on measuring polarization and cross section simultaneously, finalizing...

Other systematics

- Other systematics (partial list)
  - Dominated by the integrated luminosity.

Source	Approximate value
Integrated luminosity	$\sim 10\%$
$\mathscr{B}(J/\psi \to \mu^+\mu^-)$	1%
Fit function (prompt J/ψ only)	2%
Event loss outside the mass window	2%
Monte Carlo matching	1%
Magnetic field effects	1%

Charmonium $\to p\bar{p}$

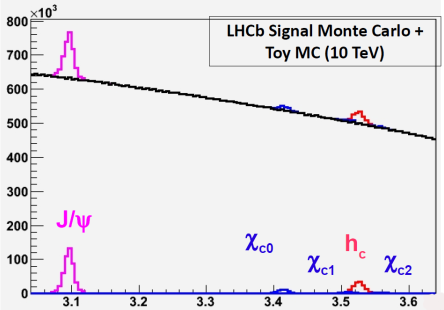
- This work is done in collaboration with B. Viaud and E. Kou.
- Simultaneous studies of Charmonium $\to p\bar{p}$

$c\bar{c}$ mesons	Mass [MeV/c^2]	$\mathcal{B}(c\bar{c}\to p\bar{p})$
$\eta_c(1S)$	2980.3 ± 1.2	$(1.3\pm0.4)\times10^{-3}$
$J/\psi(1S)$	3096.916 ± 0.011	$(2.17\pm0.07)\times10^{-3}$
$\chi_{c0}(1P)$	3414.75 ± 0.31	$(2.15\pm0.19)\times10^{-4}$
$\chi_{c1}(1P)$	3510.66 ± 0.07	$(6.6\pm0.5)\times10^{-5}$
$h_c(1P)$	3525.93 ± 0.27	not seen
$\chi_{c2}(1P)$	3556.20 ± 0.09	$(6.7\pm0.5)\times10^{-5}$
$\eta_c(2S)$	3637 ± 4	not seen
$\psi(2S)$	3686.09 ± 0.04	$(2.74\pm0.02)\times10^{-4}$

- Possible to observe $h_c(1P)\to p\bar{p}$ with 2010 data
  - $\mathcal{B}(h_c(1P)\to p\bar{p}) = (1.20\pm0.25)\times10^{-3}$, estimated by E. Kou, consistent with [arXiv:1004.0496]: $(1.52-1.93)\times10^{-3}$.
- Then measure $\frac{\sigma(c\bar{c})\times\mathcal{B}(c\bar{c}\to p\bar{p})}{\sigma(J/\psi)\times\mathcal{B}(J/\psi\to p\bar{p})}$, etc.
  - Theoretically interesting. E.g., $R_{\chi_c}=\sigma(\chi_{c2})/\sigma(\chi_{c1})$, $0.75_{\pm0.03(\mathrm{stat})\pm0.03(\mathrm{syst})\pm0.04(\mathrm{BF})}$ measured by CDF [PRL 98,232001(2007)] while heavy quark spin symmetry predicts 5/3, new NLO calculation [arXiv:1002.3987].

Charmonium $\to p\bar{p}$ (cont.)

- Event selections developed, mass resolutions about 10 MeV/c^2.
  - Mass distribution for 100 pb^{-1} at $\sqrt{s}$ =10 TeV, assuming $\sigma(h_c(1P))$ similar to $\sigma(J/\psi)$, $\mathscr{B}(h_c(1P) \to p\bar{p}) \sim 0.12\%$

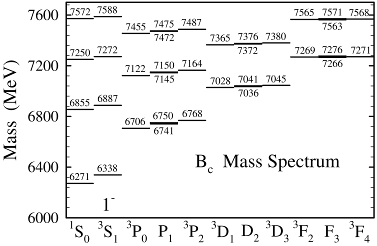


$M(p\bar{p})$ [GeV/c^2]

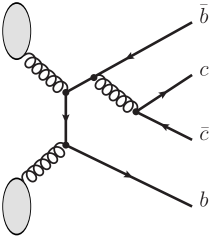
- Trigger efficiencies being improved
  - L0, $\varepsilon_{\mathrm{L0/Sel}} = (99.7 \pm 0.07)\%$.
  - Hlt1, $\varepsilon_{\mathrm{Hlt1/(Sel\&L0)}} = (11.4 \pm 0.5)\%$.
  - Hlt2, $\varepsilon_{\mathrm{Hlt2/(Sel\&L0\&Hlt1)}} = (17.1 \pm 1.6)\% \to (89.4 \pm 1.3)\%$ after implementing a dedicated Hlt2 line for these channels.

B_c spectrum and decays

- B_c spectrum
  - Estimated using potential models
- B_c^+ mass
  - Potential models: 6.2-6.4 GeV/c^2
  - pQCD: 6326^{+29}_{-9} MeV/c^2
  - Lattice QCD: 6278(6)(4) MeV/c^2
- B_c mesons' decays
  - Excited states (below *BD* threshold), decay through the Strong or EM interactions into B_c^+
  - Ground state B_c^+: decay only weakly
- 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., $\bar{K}^{*0}K^+$, ϕK^+, $\tau^+\nu_\tau$
- B_c^+ lifetime predictions
  - Inclusive rates or $\sum$(exclusive rates)
  - $\tau(B_c^+)_{\rm SR} = 0.48 \pm 0.05$ ps



B_c production



- B_c production
  - At hadron colliders, B_c generated mainly through $gg \to B_c + b + \bar{c}$
- B_c^+ production rate
  - Theoretical prediction [Phys. Rev. D 71, 074012 (2005)]

-	$\|(^1S_0)_\mathbf{1}\rangle$	$\|(^3S_1)_\mathbf{1}\rangle$	$\|(^1S_0)_\mathbf{8}g\rangle$	$\|(^3S_1)_\mathbf{8}g\rangle$	$\|(^1P_1)_\mathbf{1}\rangle$	$\|(^3P_0)_\mathbf{1}\rangle$	$\|(^3P_1)_\mathbf{1}\rangle$	$\|(^3P_2)_\mathbf{1}\rangle$
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

    - ★ $\sigma(^3S_1)/\sigma(^1S_0) \sim 2.5$
    - ★ Color octets and 1st P-wave contributions are small
    - ★ $\sigma(B_c^+)_{\mathrm{LHC}}/\sigma(B_c^+)_{\mathrm{Tevatron}} \sim$ O(10)
  - $\sigma(2S)/\sigma(1S)$ would be $|R_{2S}(0)/R_{1S}(0)|^2 \approx 0.6$
  - Considering the contributions of the decays of these states, $\sigma(B_c^+) \sim 0.9\ \mu\mathrm{b}$ for $\sqrt{s} = 14$ TeV, or $0.4\ \mu\mathrm{b}$ for $\sqrt{s} = 7$ TeV.

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	$J/\psi\ell^+\nu$	—	—	$0.475^{+0.053}_{-0.049} \pm 0.018$

- Only production cross section times branching ratio of $B_c^+ \to J/\psi\mu^+\nu_\mu$ relative to $B^+ \to J/\psi K^+$ measured by CDF (1 fb^{-1})

$$\mathscr{R}_\mu = \frac{\sigma(B_c^+) \times \mathscr{B}(B_c^+ \to J/\psi\mu^+\nu)}{\sigma(B^+) \times \mathscr{B}(B^+ \to J/\psi K^+)} \tag{1}$$
$$= 0.227 \pm 0.033(\text{stat.})^{+0.024}_{-0.017}(\text{syst.}) \pm 0.014(p_{\text{T}} \text{ spectrum})$$

for $p_{\text{T}}(B_c^+) > 6$ GeV/c and $|y| < 1$.

More on production rate

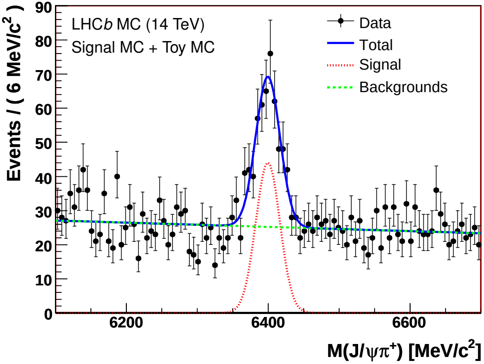
- From experimental measurements
  - For the positive charge B^+, CDF measured:
    $\sigma_{B^+}(p_{\mathrm{T}} \geq 6.0\ \mathrm{GeV}/c,\ |\mathrm{y}| < 1) = 2.78 \pm 0.24\ \mu$b
    $\Rightarrow \sigma_{B^+}(p_{\mathrm{T}} \geq 6.0\ \mathrm{GeV}/c,\ |\mathrm{y}| < 1) \times \mathscr{B}(B^+ \to J/\psi K^+) =$
    $(2.80 \pm 0.22) \times 10^{-3}\ \mu$b
  - For the positive charge B_c^+:
    $\left[\sigma(B_c^+) \times \mathscr{B}(B_c^+ \to J/\psi\mu^+\nu_\mu)\right]_{\mathrm{exp}} = (0.63 \pm 0.13) \times 10^{-3}\ \mu\mathrm{b}$
- Theoretical predictions
  - $\sigma(B_c^+) = 0.073\ \mu$b at $\sqrt{s} = 1.96$ TeV
    $\mathscr{B}(B_c^+ \to J/\psi\mu^+\nu_\mu) = 1.9\%$
    Fast simulation, $\varepsilon(p_{\mathrm{T}} \geq 6.0\ \mathrm{GeV}/c,\ |\mathrm{y}| < 1) \sim 23\%$
  - For the positive charge B_c^+:
    $\left[\sigma(B_c^+) \times \mathscr{B}(B_c^+ \to J/\psi\mu^+\nu_\mu)\right]_{\mathrm{theory}} = 0.16 \times 10^{-3}\ \mu\mathrm{b}$
  - 3.6σ smaller than experimental value before considering theoretical uncertainties Eur. Phys. J. C 38, 267 (2004).
- Would be interesting to measure production cross section to clarify whether theoretical prediction can describe experimental measurements.

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

- Main issue: large background (reminder: $\sigma(B_c^\pm) \sim 0.4\ \mu$b @ 7 TeV)
  - Real $J/\psi + \pi$ from fragmentation or from b decays
    - ★ Prompt J/ψ (cross section: $\sim 100\ \mu$b)
    - ★ $b \to J/\psi X$ (cross section: O(10) μb)
  - Combinatorial $J/\psi + \pi$ from fragmentation or from b decays
    - ★ Inclusive $b\bar{b}$ (cross section: $\sim 460\ \mu$b)
- Besides a tighter J/ψ selection, $p_{\mathrm{T}}(\pi)$ and lifetime cuts applied to suppress prompt backgrounds.
- Expect about 310 reconstructed $B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$ signal events from 1 fb^{-1} of data at $\sqrt{s} = 7$ TeV, with $B/S \sim [1,2]$ @ 90% CL, assuming $\sigma_{\mathrm{tot}}(B_c^\pm) = 0.4\ \mu$b and $\mathscr{B}(B_c^\pm \to J/\psi\pi^\pm) = 0.13\%$.

B_c^+ mass and lifetime measurement

- Mass measurement
  - Statistical uncertainty: ± 1.7 (stat.) MeV/c^2 (CDF: 2.9 (stat.) $\pm$ 2.5 (syst.) MeV/c^2)



- Lifetime measurement
  - Statistical uncertainty: ± 27 (stat.) fs. (D0: 38 (stat.) $\pm$ 32 (syst.) fs)

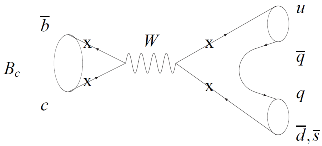
$B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$ event selection

- $B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$, compared to $B_c^+ \to J/\psi\pi^+$
  - Pro
    - ★ Larger branching ratio, ~1.9%. Possible to measure lifetime and production cross section with early data.
    - ★ 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.
- Besides a tighter J/ψ selection, a tight p_{T} cut ($>$ 3 GeV/c) applied on the bachelor μ.
- Expect about 4.7 K reconstructed $B_c^+ \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$ from 1 fb^{-1} of data @ $\sqrt{s} = 7$ TeV, with $B/S \sim$ $[6, 11]$ @ 90% CL.

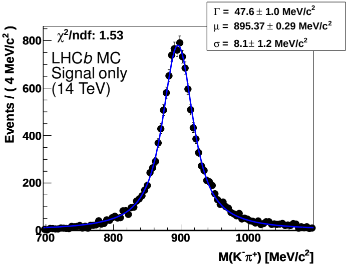
Background components determination

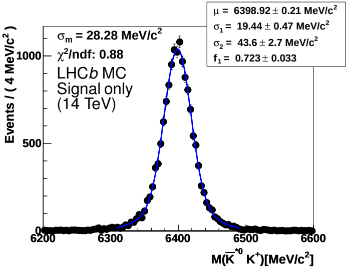
- $J/\psi\mu$ combination, four possibilities:
  11, 10, 01, 00 (1: real, 0: fake) [CDF note 9294]
- Fake J/ψ (01,00)
  - Data Driven, estimated from J/ψ sidebands.
  - After removing this kind of background, we have real J/ψ + track identified as μ (using PID$_\mu$).
- Fake lepton (10)
  - Data Driven, estimated from J/ψ + track sample (PID$_\mu$ requirements removed).
    - ★ $D^{*+} \to D^0(\pi^+K^-)\pi_s^+$, $\Lambda \to p^+\pi^-$, $K_S^0 \to \pi^+\pi^-$ studied to measure the mis-ID rates of $(\pi, K, p) \to \mu$, as a function of (p, η).
  - After removing this background further, we have real J/ψ + real μ.
- $b\bar{b}$ (11)
  - Monte Carlo
- Prompt J/ψ (11)
  - Data Driven, fraction floating in the lifetime fit
- Almost finished, finalizing...

Nonleptonic charmless B_c decays



- This study is done in collaboration with S. Descotes-Genon and E. Kou.
- One possible channel is $B_c^+ \to \bar{K}^{*0} K^+$, with branching ratio of O(10^{-6}).
- Mass resolutions





- Expect a few reconstructed events, Multi-variate analysis will be used to search these channels.

Other ongoing studies

- Hlt2 line implemented for $B_c^+ \to J/\psi\pi^+, J/\psi\mu^+X$, keep tuning with real data.
- $B^+ \to J/\psi K^+$
  - Control channel for $B_c^+ \to J/\psi\pi^+, J/\psi\mu^+X$, and other hot channels like $B_s^0 \to \mu^+\mu^-$, $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$.
  - Studying B^+ mass, lifetime and production cross section measurements using this channel.
- $B_c^+ \to B_s^0\pi^+$ with $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$
  - Expect about 100 reconstructed signal events from 1 fb^{-1} of data at $\sqrt{s} = 14$ TeV.
- B_c excited states
  - $B_c^{*+} \to B_c^+\gamma$ is difficult, $\Delta M = M(B_c^{*+}) - M(B_c^+)$ only 60-70 MeVc^2, γ is too soft to observe.
  - $B_c(2^1S_0) \to B_c^+\pi^+\pi^-$, and $B_c(2^3S_1) \to B_c^{*+}\pi^+\pi^- \to (B_c^+\gamma)\pi^+\pi^-$.

Summary

- The project is healthy and productive.
- Ready for the first measurements of the prompt J/ψ and $b\bar{b}$ production cross sections.
- Then the measurements of Charmonium $\rightarrow p\bar{p}$, $B_c^+ \rightarrow J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$ and $B_c^+ \rightarrow J/\psi(\mu^+\mu^-)\pi^+$ will be performed.
- Other studies, e.g., nonleptonic charmless B_c decays, $B_c^+ \rightarrow B_s^0\pi^+$ with $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$, and B_c excited states will follow.
- Supports from FCPPL very helpful and highly acknowledged!