J/ψ and $B_c^{\pm}$ production at LHCb

Jibo HE
(for the LHCb collaboration)

LAL, Orsay

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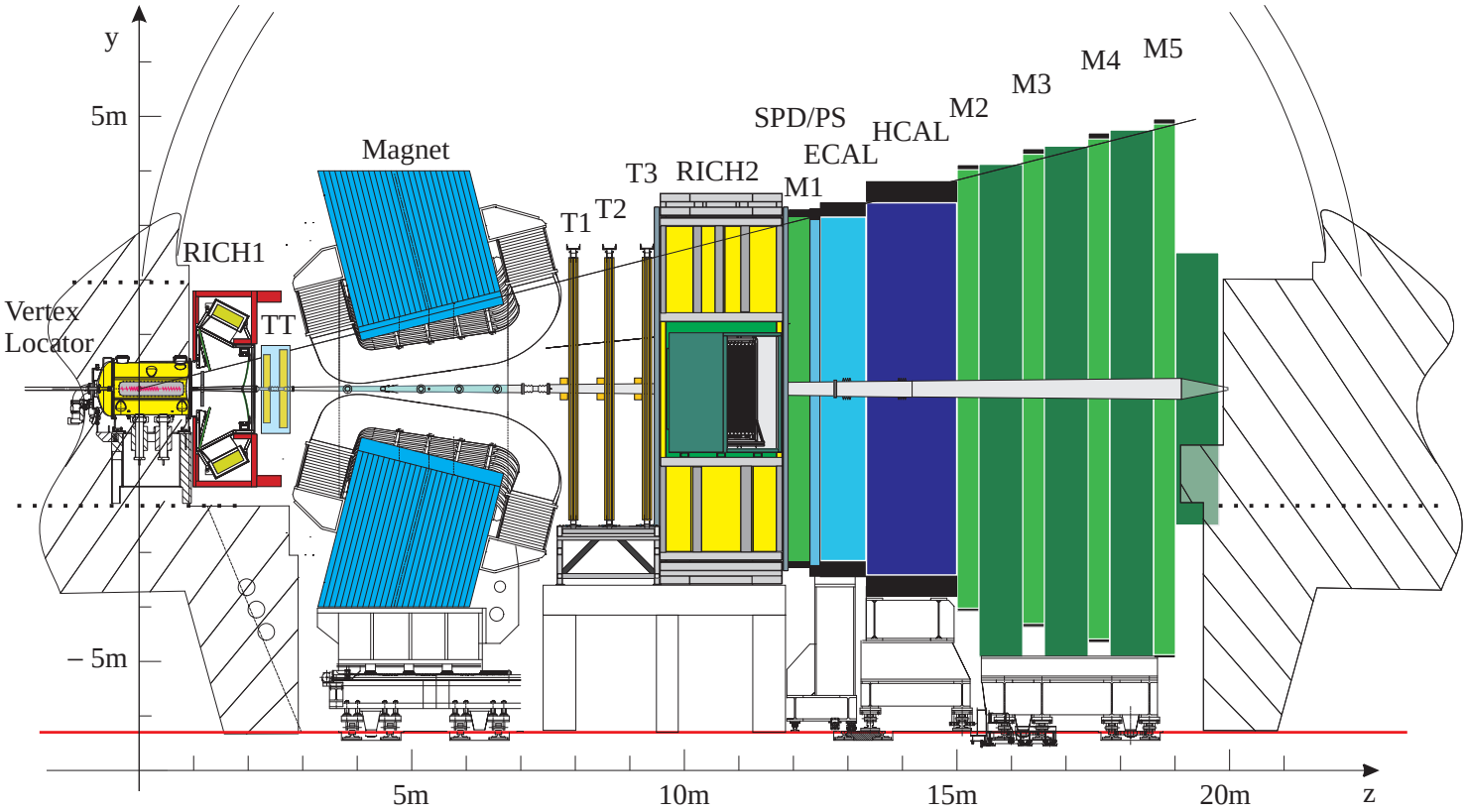
The LHCb detector see [N. HARNEW]'s talk for review



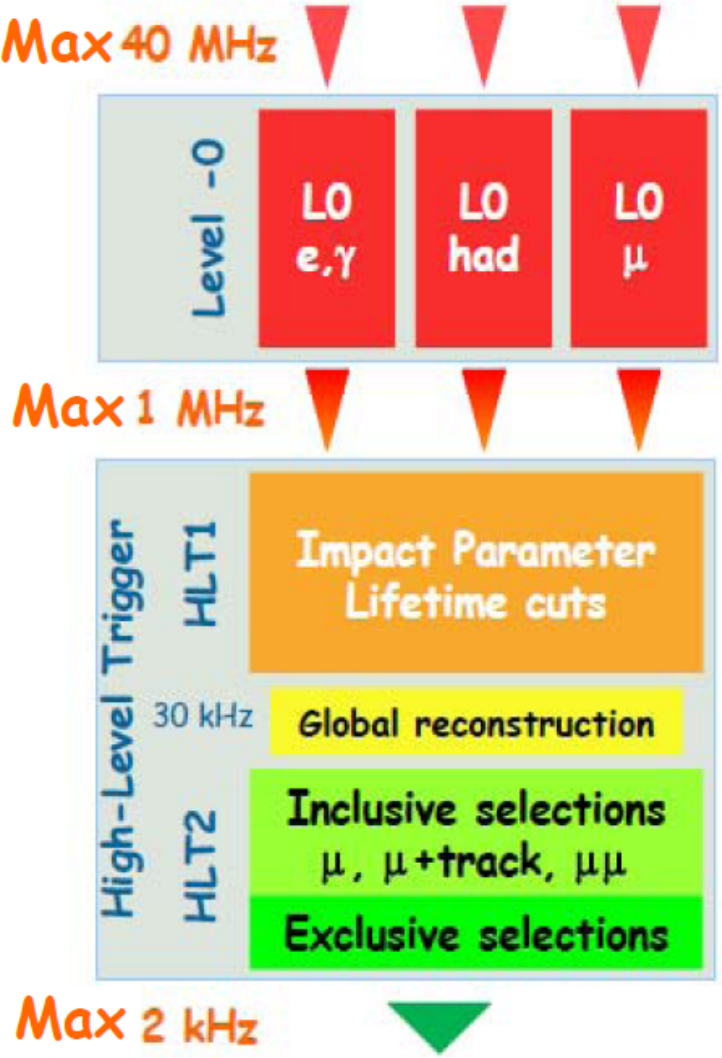
Geometry acceptance $1.9 < \eta < 4.9$, unique coverage

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

Tracking system (TT, T1-T3) $\Delta p/p$: 0.35%-0.55%, σ_m:12-25 MeV/c^2

Muon system (M1-M5) $\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(h \to \mu) \sim 2\%$

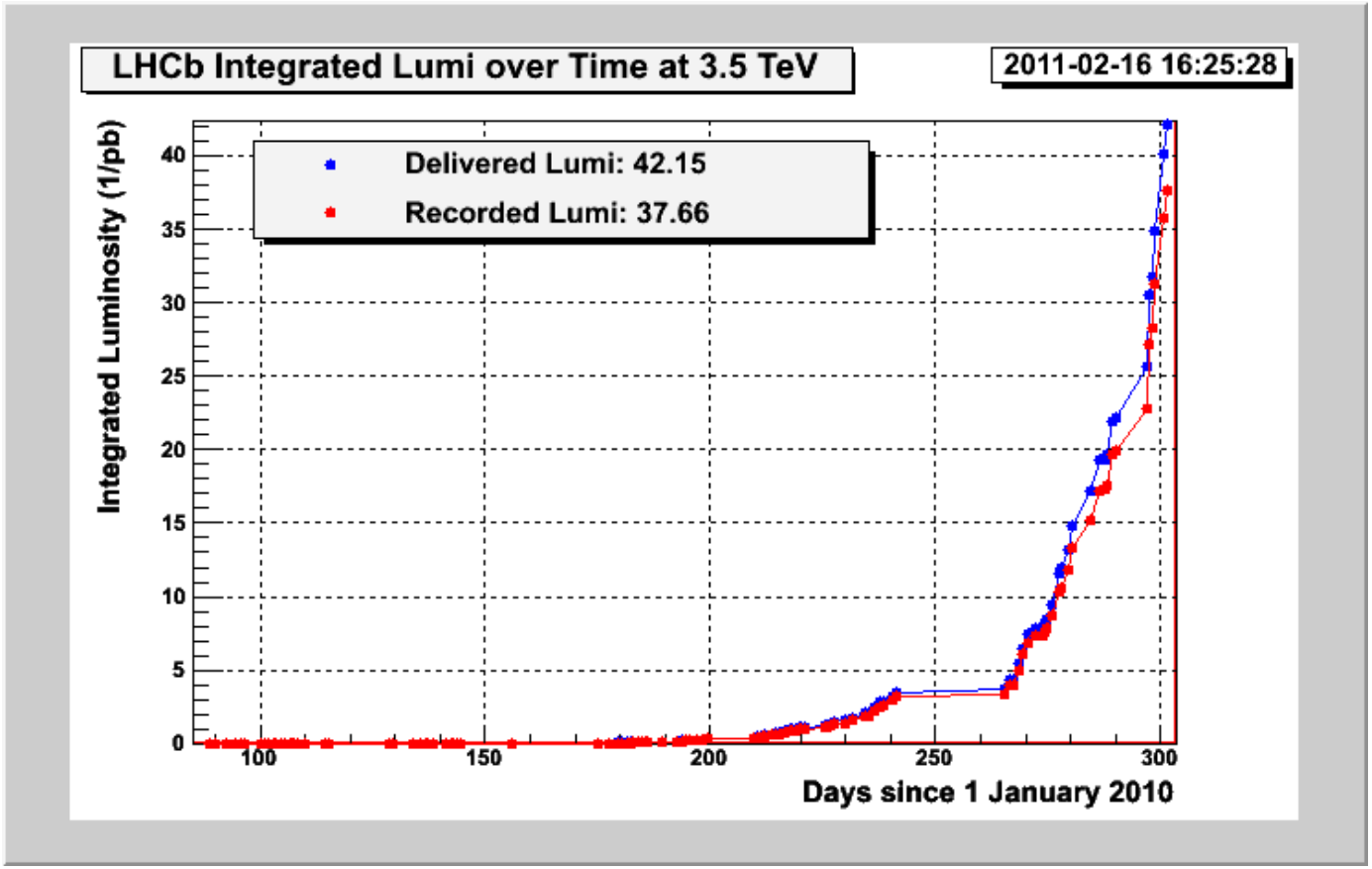
The LHCb trigger system



- Trigger used in J/ψ and $B_c^{\pm}$ production measurements, lifetime unbiased muon trigger, low p_{T} thresholds
  - L0 trigger
    - ★ Single muon: $p_{\mathrm{T}} > 1.4$ GeV/c
    - ★ Di-muon: $p_{\mathrm{T},1} > 0.56$ GeV/c, $p_{\mathrm{T},2} > 0.48$ GeV/c
  - Hlt1 trigger
    - ★ Single muon: confirm L0 single muon & require $p_{\mathrm{T}} > 1.8$ GeV/c
    - ★ Di-muon: confirm L0 Di-muon / single muon & require $m_{\mu\mu} > 2.5$ GeV/c^2
  - Hlt2 trigger
    - ★ Di-muon: $p_{\mathrm{T}}(\mu) > 0.5$ GeV/c & $m_{\mu\mu} > 2.9$ GeV/c^2
- Global event cuts (GEC) applied on the hit multiplicity of sub-detectors to remove events with high occupancy.

Data taking

- Run at $\sqrt{s} = 7$ TeV, and collected about ~ 37 pb^{-1} of data in 2010



J/ψ cross section measurement

- arXiv:1103.0423 [hep-ex], submitted to Eur. Phys. J. C
- Double differential cross section

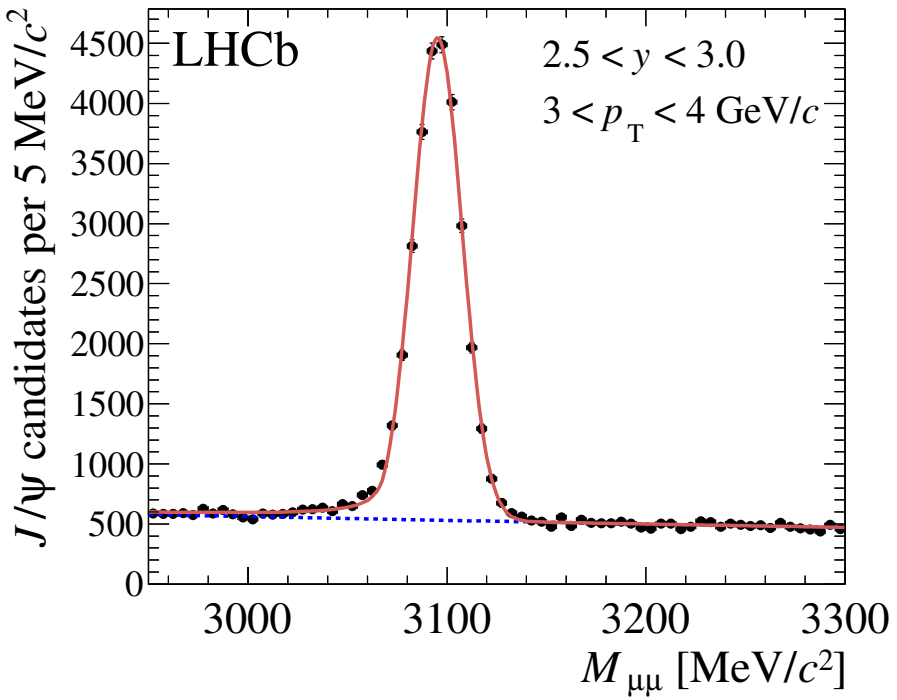
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\,\mathrm{d}p_{\mathrm{T}}} = \frac{N(J/\psi \to \mu^+\mu^-)}{\mathscr{L} \times \varepsilon_{\mathrm{tot}} \times \mathscr{B}(J/\psi \to \mu^+\mu^-) \times \Delta y \times \Delta p_{\mathrm{T}}}$$

  - 14 p_{T} bins, $p_{\mathrm{T}} < 14$ GeV/c
  - 5 y bins, 2<y<4.5
- Two categories of J/ψ
  - Prompt J/ψ: direct J/ψ, and J/ψ from feed down of heavier charmonium states
  - J/ψ from b decays
- Use (5.2 ± 0.5) pb^{-1} of data collected end of 09/2010 at LHCb, with pp collisions at $\sqrt{s} = 7$ TeV

J/ψ selection and mass fit

- Lifetime unbiased offline event selection, candidates triggered by lifetime unbiased muon trigger
  - Good tracks identified as μ by muon system, loose cuts on $p_{\mathrm{T}}(\mu^{\pm})$
  - μ^+, μ^- coming from a common vertex with good vertex fit quality
  - At least one reconstructed primary vertex
- Mass distribution

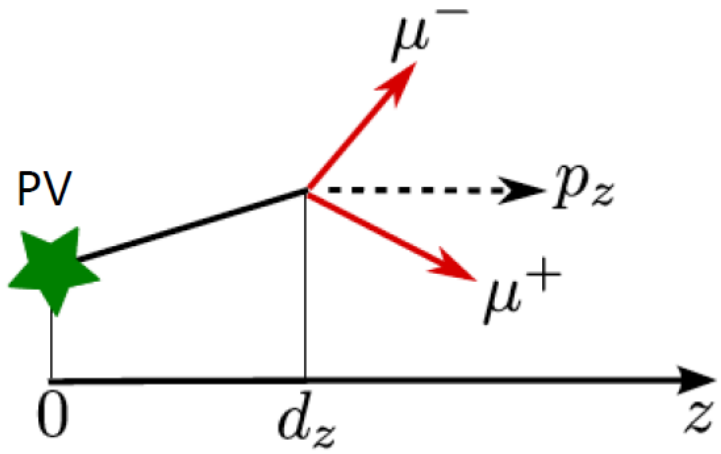
  - Signal, Crystal Ball
  - Background, Exponential
  - 70 bins fitted separately, fit results of one bin shown on the right, $\sigma_m \sim 12$ MeV/c^2
  - Summing over all bins, total number of J/ψ 565,000



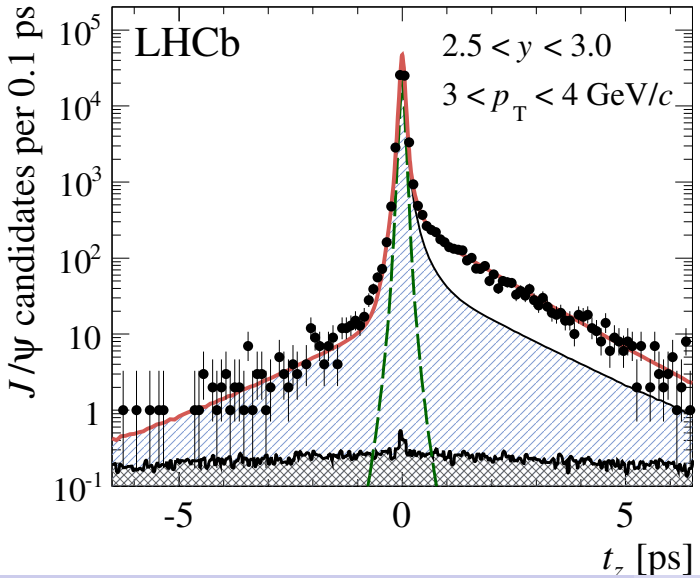
Separation of prompt J/ψ from J/ψ from b decays

- Pseudo-lifetime t_z

$$t_z = \frac{d_z \times M_{J/\psi}}{p_z}$$

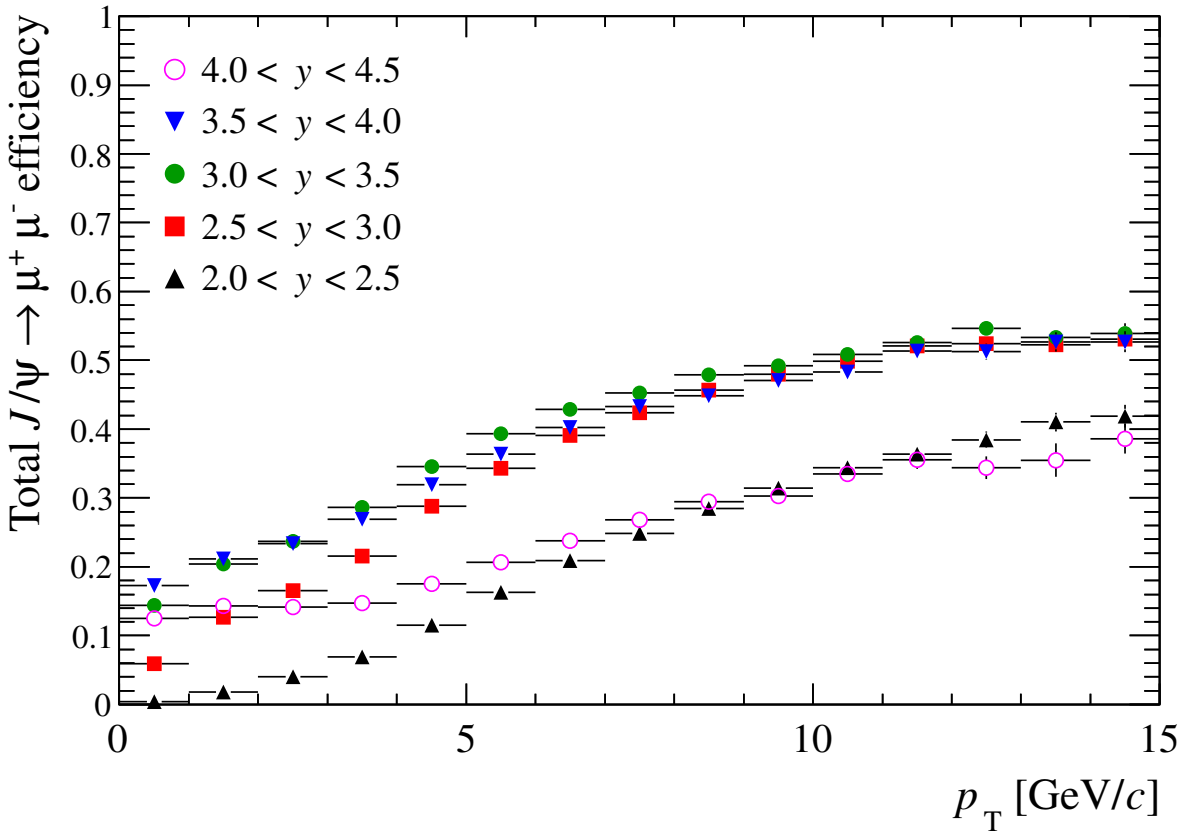


- t_z distribution
  - Prompt J/ψ
  - J/ψ from b decays
  - Background distribution, estimated from mass sidebands
  - Long tail due to association to wrong primary vertex, measured in data using the J/ψ vertex and the PV in "next" event



Efficiencies

- Efficiencies computed from Monte Carlo and extensively checked on data, with control samples.
- Efficiencies of prompt J/ψ and J/ψ from b decays almost equal. Small difference treated as systematics.



Systematics sources

Source	Systematic uncertainty (%)
Correlated between bins	
Inter-bin cross-feed	0.5
Mass fits	1.0
Radiative tail	1.0
Muon identification	1.1
Tracking efficiency	8.0[1]
Track χ^2	1.0
Vertexing	0.8
Global event cuts	2.0
$\mathscr{B}(J/\psi \to \mu^+\mu^-)$	1.0
Luminosity	10.0[2]

[1] 4% per track, improved recently

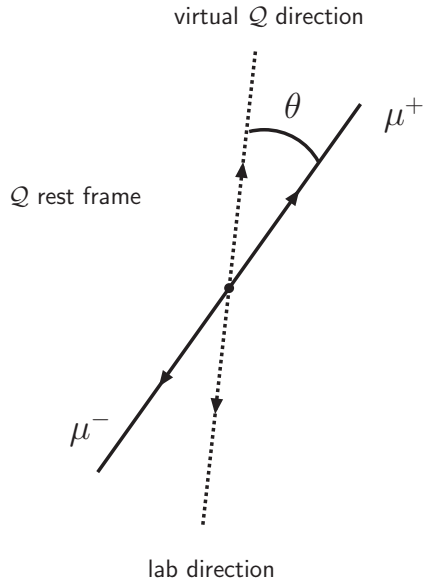
[2] dominated by uncertainty of the LHC proton beam currents, improved recently

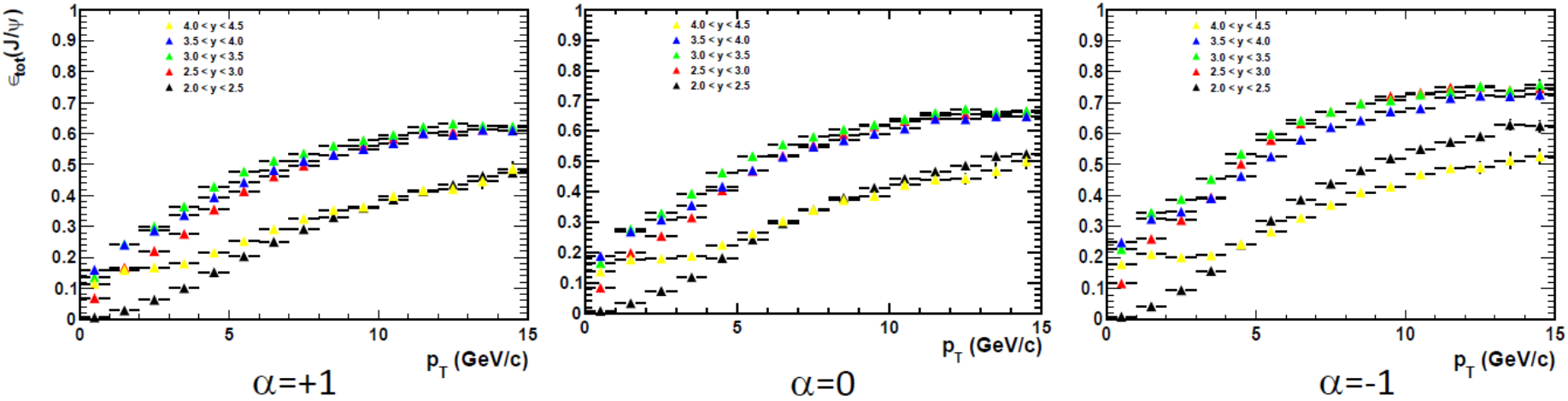
Systematics sources (cont.)

Source	Systematic uncertainty (%)
Uncorrelated between bins	
Bin size	0.1 to 15.0
Trigger	1.7 to 4.5
Applied only to J/ψ from b cross-sections, correlated between bins	
Global event cuts efficiency on B events	2.0
t_z fits	3.6
Applied only to the extrapolation of the $b\bar{b}$ cross-section	
b hadronisation fractions	2.0
$\mathscr{B}(b \to J/\psi X)$	9.0

Systematics due to J/ψ polarization

- Polarization, using helicity frame.
  - $\frac{dN}{d\cos\theta} \propto 1 + \alpha\cos^2\theta$; ($\alpha = 1$, Transverse; $\alpha = -1$, Longitudinal)
- Different polarization lead to very different efficiencies.
- Differences between 3% and 30% depending on the bin: quote 3 different results of the prompt J/ψ cross-section, one for each polarization case.
- Prompt J/ψ polarization measurement in pipeline. Systematics will be reduced.

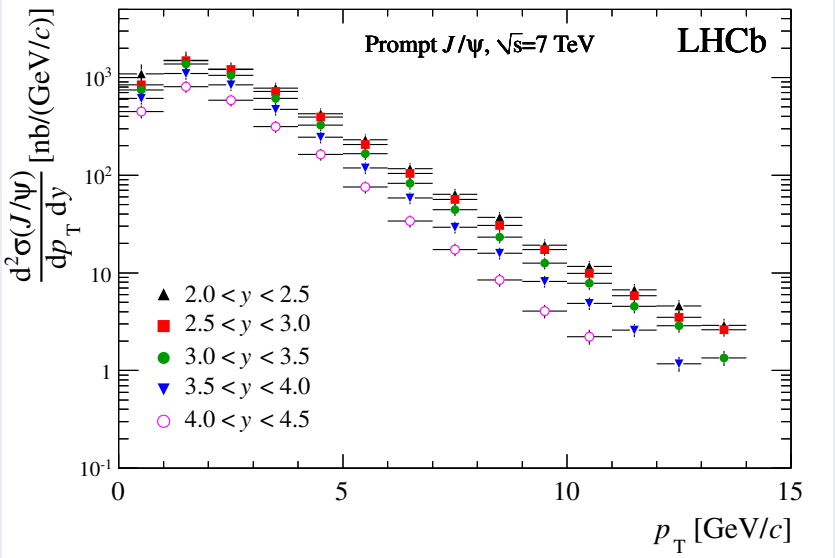




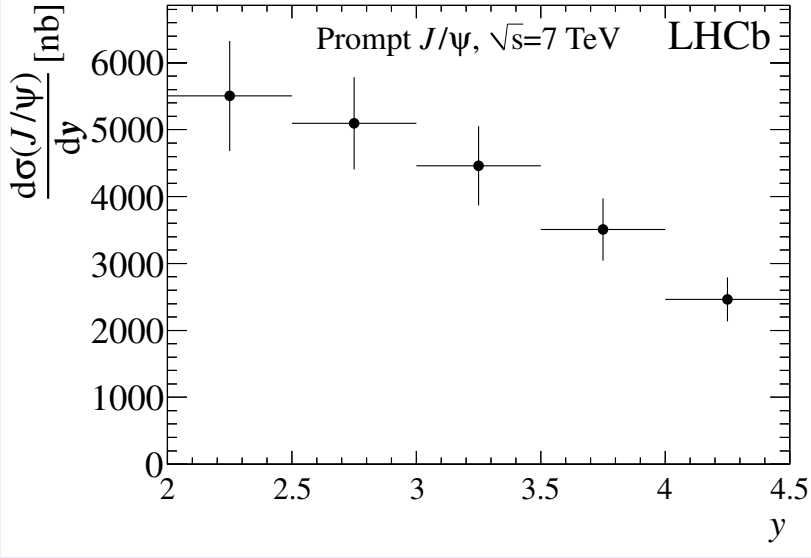
Results: prompt J/ψ cross sections assuming unpolarized

- Assuming J/ψ not polarized

$\frac{d^2\sigma(J/\psi)}{dp_T dy}$



$\frac{d\sigma(J/\psi)}{dy}$



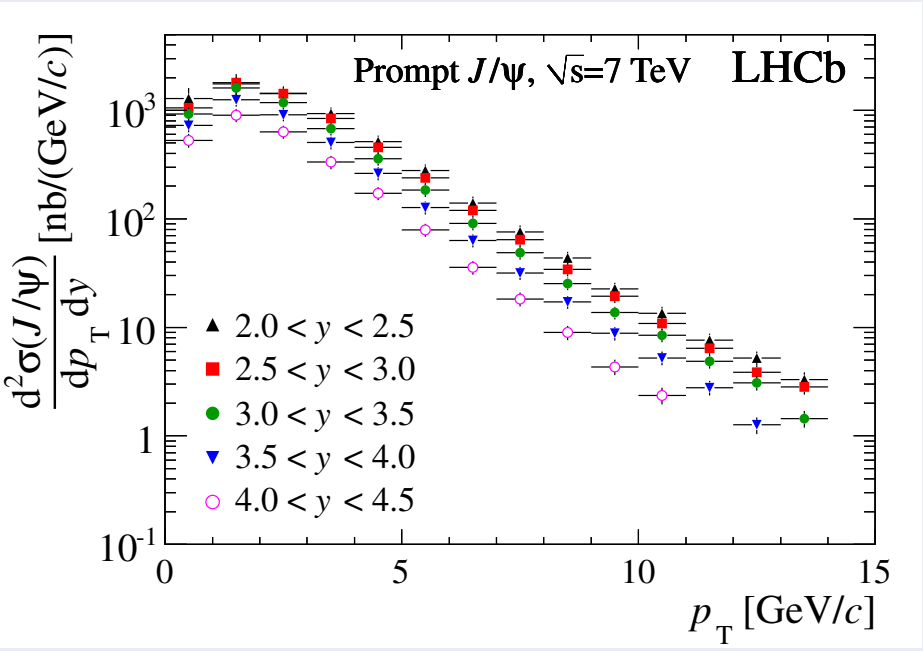
- Integrated over acceptance

$$\sigma(\text{prompt } J/\psi, p_T < 14\ \text{GeV}/c, 2.0 < y < 4.5)$$
$$= 10.52 \pm 0.04|_{\text{stat.}} \pm 1.40|_{\text{sys.}}{}^{+1.64}_{-2.20}|_{\text{polarization}}\ \mu\text{b}$$

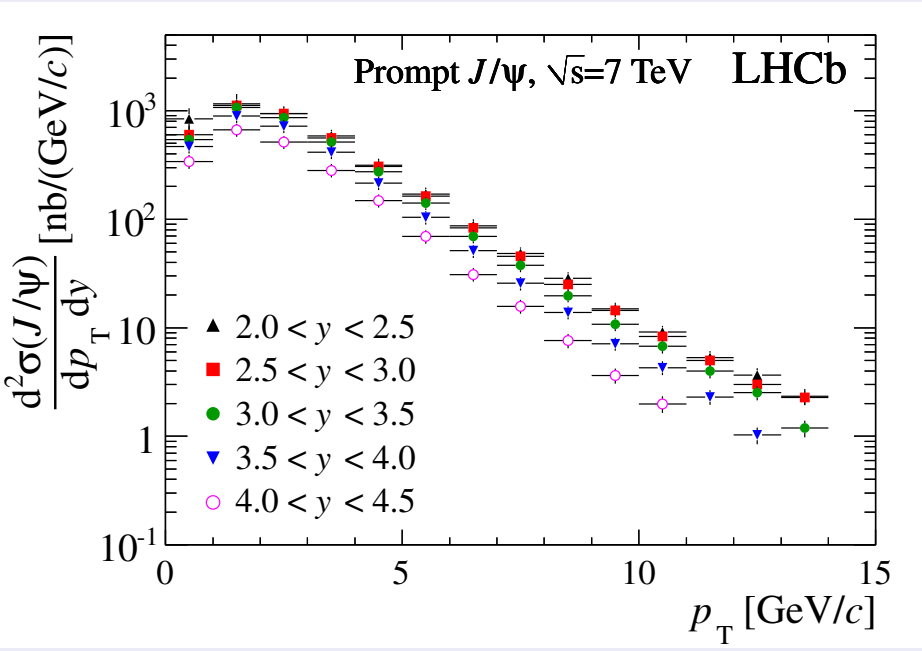
Results: prompt J/ψ cross sections two extreme polarizations

- Two extreme polarization

Full transverse ($\alpha = 1$)



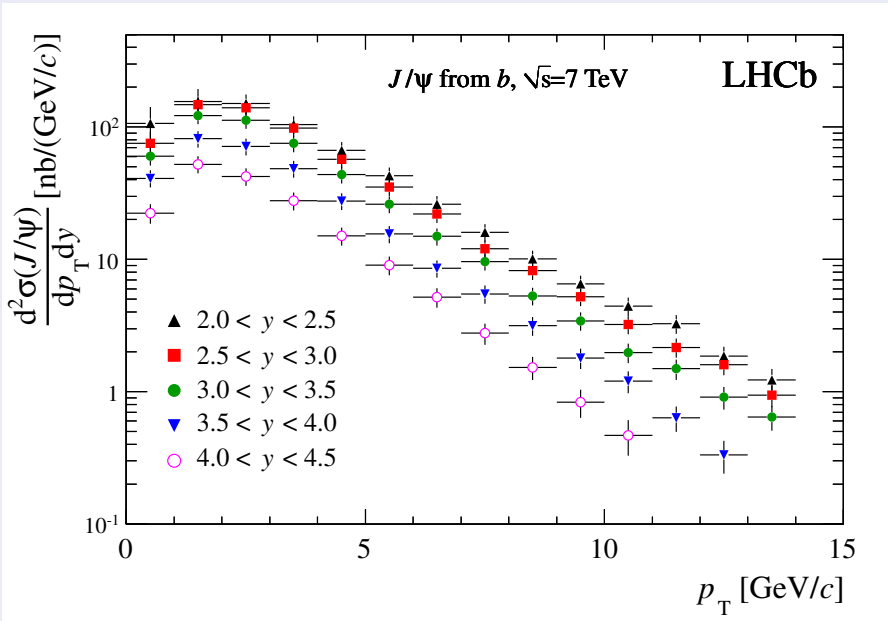
Full longitudinal ($\alpha = -1$)



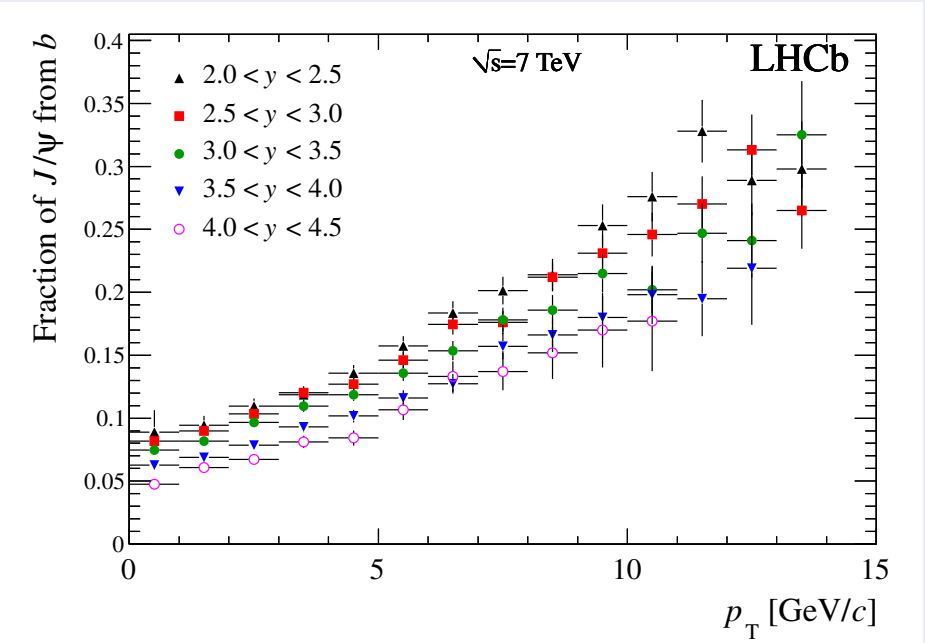
Results: J/ψ from b cross section

- b-hadrons produced more centrally than prompt J/ψ

$\frac{d^2\sigma(J/\psi)}{dp_T dy}$



Fraction of J/ψ from b



- Integrated over the acceptance

$$\sigma(J/\psi \text{ from } b, p_T < 14\,\text{GeV}/c, 2.0 < y < 4.5) = \boxed{1.14 \pm 0.01|_{\text{stat.}} \pm 0.16|_{\text{sys.}}\ \mu\text{b}}$$

$b\bar{b}$ cross section

- Extrapolation to full polar angle

$$\sigma(pp \to b\bar{b}X) = \alpha_{4\pi} \frac{\sigma\left(J/\psi \text{ from } b,\, p_{\mathrm{T}} < 14\,\mathrm{GeV}/c,\, 2.0 < y < 4.5\right)}{2 \times \mathscr{B}(b \to J/\psi X)}$$

  - $\alpha_{4\pi} = 5.88$ is the ratio of J/ψ from b events in the full range to the number of events in the region $2.0 < y < 4.5$, computed from simulation
  - $\mathscr{B}(b \to J/\psi X) = (1.16 \pm 0.10)\%$, measured at LEP DELPHI, Phys. Lett. B **341** (1994) 109; L3, Phys. Lett. B **317** (1993) 467; ALEPH, Phys. Lett. B **295** (1992) 396**,**
    2% systematics assigned due to different b fragmentation fractions measured at Tevatron CDF, Phys. Rev. D **77** (2008) 072003; HFAG, arXiv:1010.1589 [hep-ex]

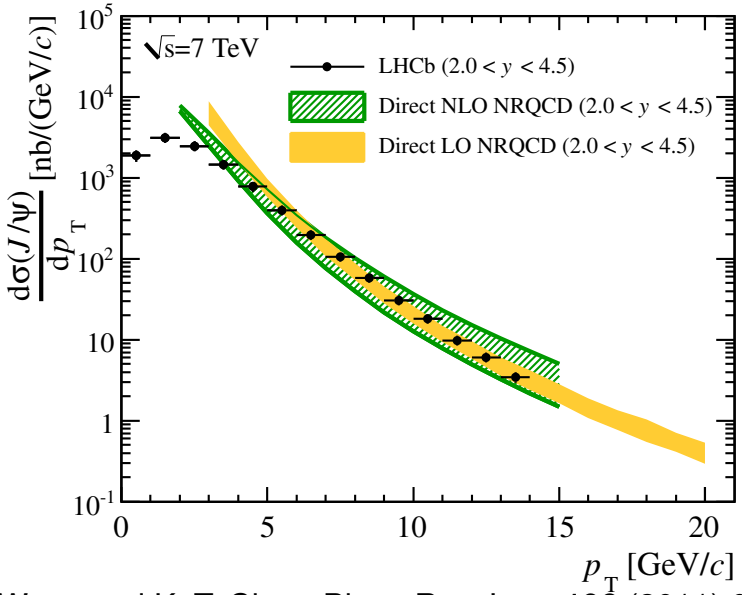
- Results

$$\sigma(pp \to b\bar{b}X) = \boxed{288 \pm 4|_{\text{stat.}} \pm 48|_{\text{sys.}}\ \mu\text{b}}$$

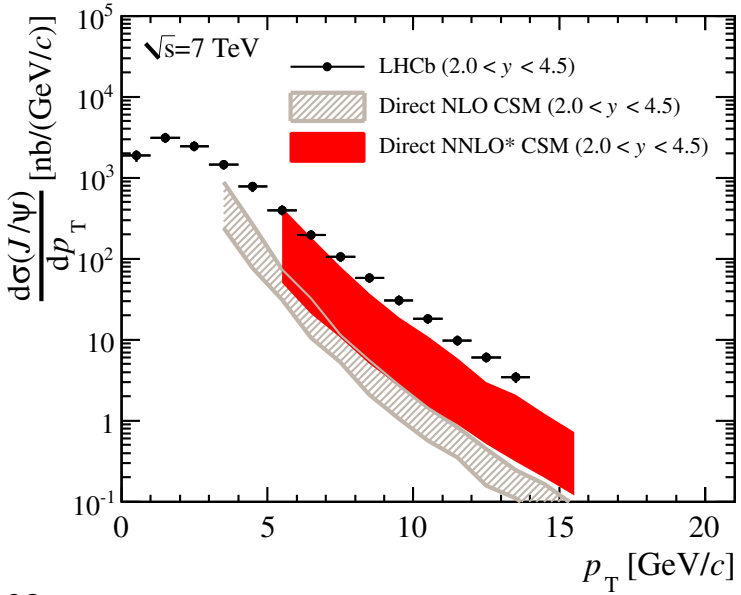
in excellent agreement with
$\sigma(pp \to b\bar{b}X) = 284 \pm 20|_{\text{stat.}} \pm 49|_{\text{sys.}}\ \mu\text{b}$ measured with
$b \to D^0 \mu \nu X$ at LHCb Phys. Lett. B **694** (2010) 209

Comparison with theoretical predictions prompt J/ψ

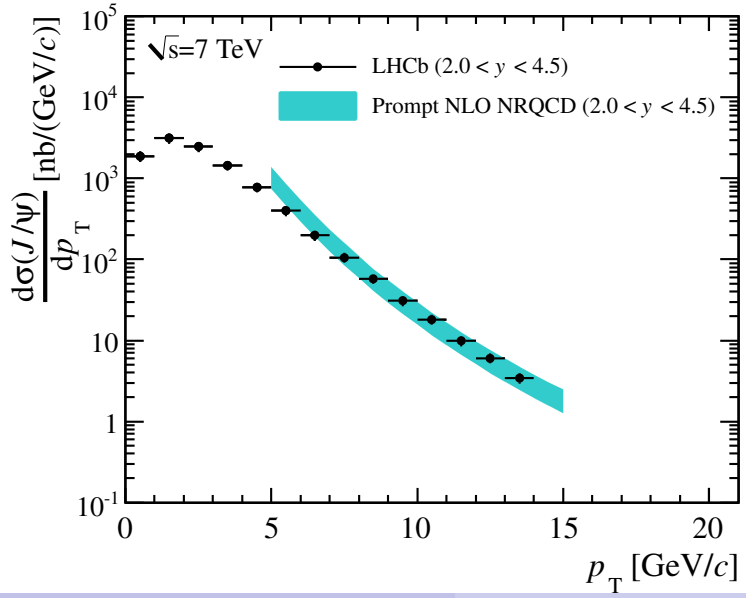
P. Artoisenet, Pos ICHEP 2010 (2010) 192
M. Butenschön and B. A. Kniehl, Phys. Rev. Lett. **106** (2011) 022301



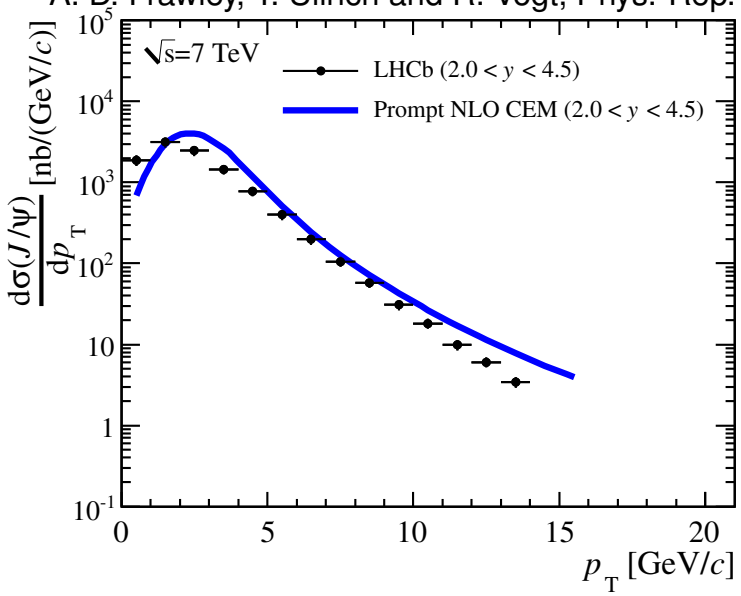
J.-P. Lansberg, Eur. Phys. J. C **61** (2009) 693



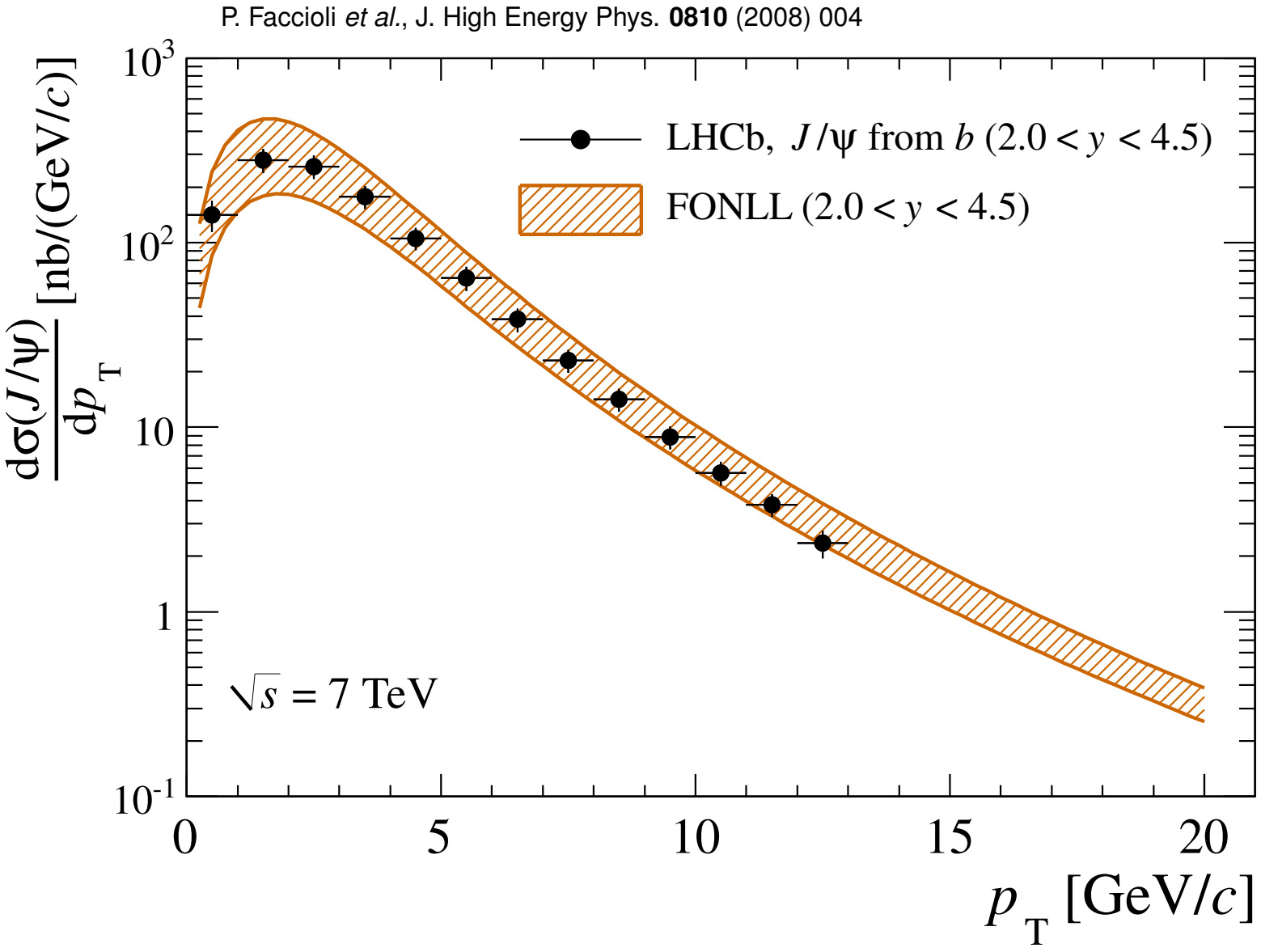
Y. Q. Ma, K. Wang and K. T. Chao, Phys. Rev. Lett. **106** (2011) 042002



A. D. Frawley, T. Ullrich and R. Vogt, Phys. Rep. **462** (2008) 125



Comparison with theoretical predictions J/ψ from b



$B_c^{\pm}$ cross section measurement

- LHCb-CONF-2011-017
- B_c: only meson family formed by two different heavy flavor quarks in SM.
- Use fully reconstructed $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$, relatively clean. Large control sample $B^{\pm} \to J/\psi K^{\pm}$ available.
- Measure

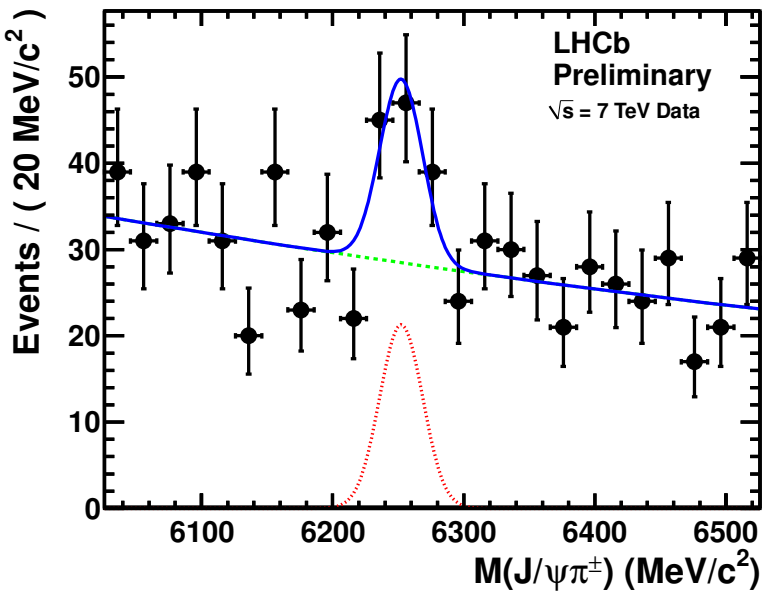
$$\mathscr{R}_{c+} = \frac{\sigma(B_c^{\pm}) \times BR(B_c^{\pm} \to J/\psi\pi^{\pm})}{\sigma(B^{\pm}) \times BR(B^{\pm} \to J/\psi K^{\pm})} = \varepsilon_{rel} \times \frac{N(B_c^{\pm})}{N(B_u^{\pm})}$$

  for $p_{\mathrm{T}}(B) > 4$ GeV/c and $\eta \in (2.5, 4.5)$
- Based on $\mathscr{L} = 32.5 \pm 3$ pb^{-1} data

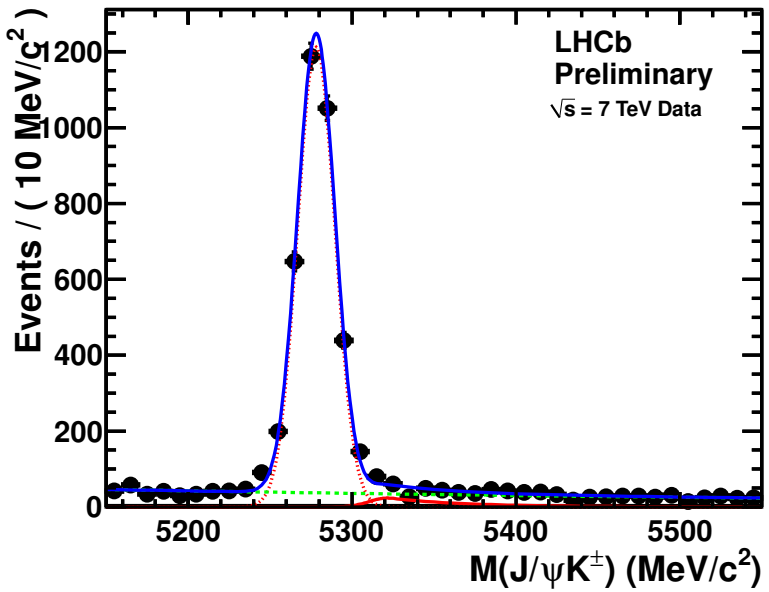
Extraction of $N(B_c^{\pm})$ and $N(B_u^{\pm})$

- Lifetime unbiased event selection (& trigger), as identical as possible between $B_c^{\pm} \to J/\psi\pi^{\pm}$ and $B^{\pm} \to J/\psi K^{\pm}$
- Cabibbo suppressed background $B^{\pm} \to J/\psi\pi^{\pm}$ considered for $B^{\pm} \to J/\psi K^{\pm}$
- 43 ± 13 $B_c^{\pm} \to J/\psi(\mu^+\mu^-)\pi^{\pm}$ signal, significance $\sim 4\sigma$

$B_c^{\pm} \to J/\psi\pi^{\pm}$
$N_{\rm sig} = 43 \pm 13$



$B^{\pm} \to J/\psi K^{\pm}$
$N_{\rm sig} = 3476 \pm 62$



Ratio of production cross section

- Total efficiencies computed from MC and checked on real data, binned in (p_{T}, η) to reduce the dependence on theoretical model
- Systematics dominated by $B_c^{\pm}$ lifetime (0.453 ± 0.041) ps, will be reduced after a better lifetime measurement
- Preliminary results

$$\begin{aligned}\mathscr{R}_{c+} &= \frac{\sigma(B_c^{\pm}) \times BR(B_c^{\pm} \to J/\psi\pi^{\pm})}{\sigma(B^{\pm}) \times BR(B^{\pm} \to J/\psi K^{\pm})} \\ &= (2.2 \pm 0.8|_{\mathrm{stat.}} \pm 0.2|_{\mathrm{sys.}})\%\end{aligned}$$

  for $p_{\mathrm{T}}(B) > 4$ GeV/c and $\eta \in (2.5, 4.5)$

- If using a model (BcVegPy C. Chang *et al.*, Comput. Phys. Commun. **159** (2004) 192; *ibid*, **175** (2006) 624) dependent total efficiency:

$$\mathscr{R}_{c+} = (1.4 \pm 0.4|_{\mathrm{stat.}} \pm 0.1|_{\mathrm{lifetime}})\%$$

Conclusion

- J/ψ production cross-section in pp collisions at $\sqrt{s} = 7$ TeV has been measured at LHCb with 5 pb^{-1} of data, as a function of (p_{T}, y).
- Large uncertainties due to unknown J/ψ polarization will be reduced by the prompt J/ψ polarization measurement in the pipeline
- $B_c^{\pm}$ production cross-section relative to that of $B^{\pm}$ measured, results sounds promising for B_c program at LHCb
- More $b \to J/\psi X$ production cross-section results coming soon.