B_c Studies and B meson production at LHCb

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6th FCPPL @ Nanjing

Content

- Introduction
- LHCb detector
- Research highlights
- Prospects

LAL-Tsinghua collaboration

- The LHCb groups at LAL (Orsay) and Tsinghua (Beijing) are working closely since end 2004; supported by FCPPL
- Members:
  - LAL: 2 academics, 1 postdoc
  - Tsinghua: 2 academics, 2 postdocs, >2 students
- Supported by theorists from both countries
- Research interests:
  - $\boldsymbol{B_c}$ **physics**
  - $\boldsymbol{B}$ **meson production**
  - J/ψ production
  - pA collision study

A fruitful 2012 for the collaboration

- Thesis

Bo LIU, *Measurement of the B meson production cross-section at LHCb*

- Publications

Measurement of the $B^{\pm}$ production cross-section in pp collisions at $\sqrt{s} = 7$TeV. JHEP 04(2012)093
Measurements of B_c^+ production and mass with the $B_c^+ \to J/\psi\pi^+$ decay. PRL 109(2012) 232001
Observation of the decay $B_c^+ \to \psi(2S)\pi^+$. arXiv:1303.1737 submitted to PRL
Observation of the decay $B_c^+ \to J/\psi\, K^+$. LHCb-PAPER-2013-021, in preparation
Measurement of the B meson productions in pp collisions at $\sqrt{s} = 7$ TeV. LHCb-PAPER-2013-004, in preparation

- Event

New results on Charmonium production and decays. March 6-8, 2012, LAL(Orsay).
http://events.lal.in2p3.fr/workshop-charmonium/

- Conference talks on behalf of LHCb

Zhenwei Yang	Properties and decays of b hadrons	La Thuille, 2013
Xuhao Yuan	LHCb overview	LHC Era Physics, 2013
Jibo He	Heavy-flavour and quarkonium results in pp	SaporeGravis day meeting, 2012
Yiming Li	Bottomonia and Bc production	LHC on the march, 2012
Yuanning Gao	Highlights from the LHCb experiment	SUSY 2012
Yuanning Gao	Quarkonium production at LHC and Tevatron	FPCP 2012
Patrick Robbe	LHC results on open charm, double charm and X(3872) production	Charm 2012
Zhenwei Yang	Bc and b hadrons studies at LHCb	DIS 2012

LHCb experiment

A detector dedicated to studies of heavy flavour physics

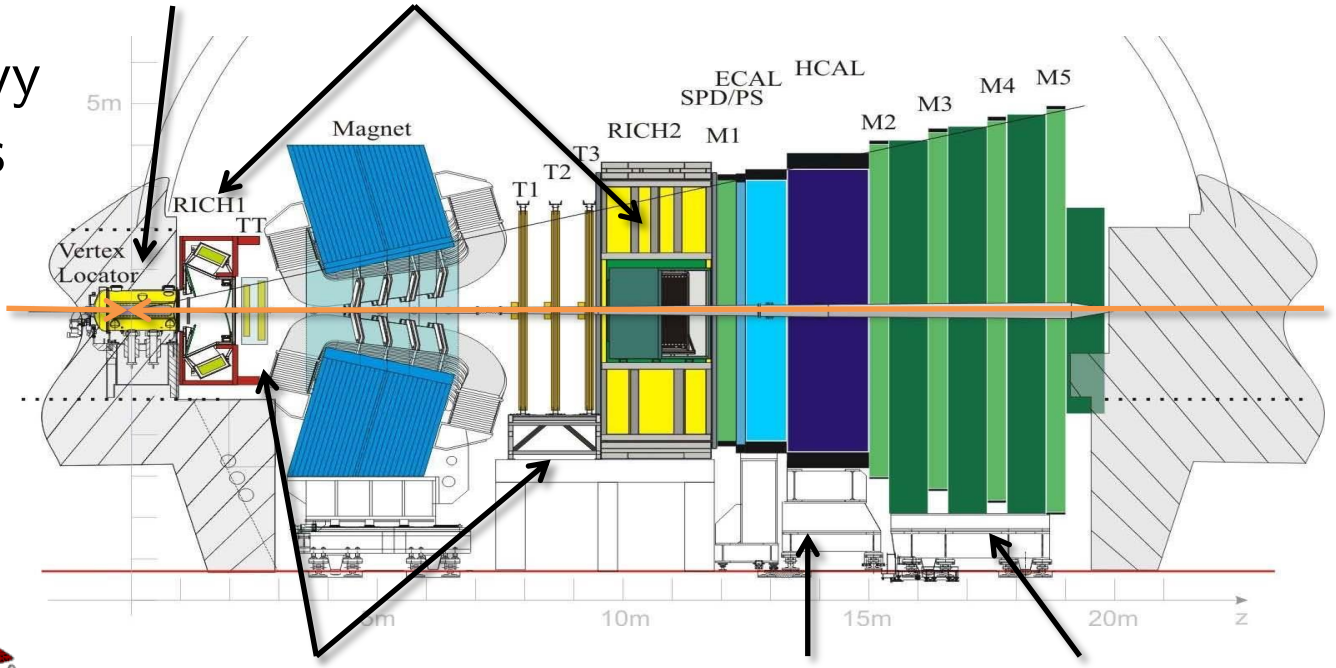
VELO

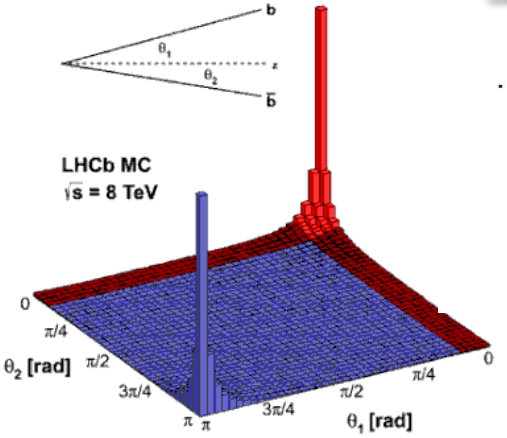
σ_{IP}~ 20μm for high p_T tracks

RICH

$\varepsilon(K \to K)$~95%

$\pi - K$ misID ~5%





$2 < \eta < 5$

Tracking

$\varepsilon(K \to K)$~95%

$\pi - K$ misID ~5%

CALO

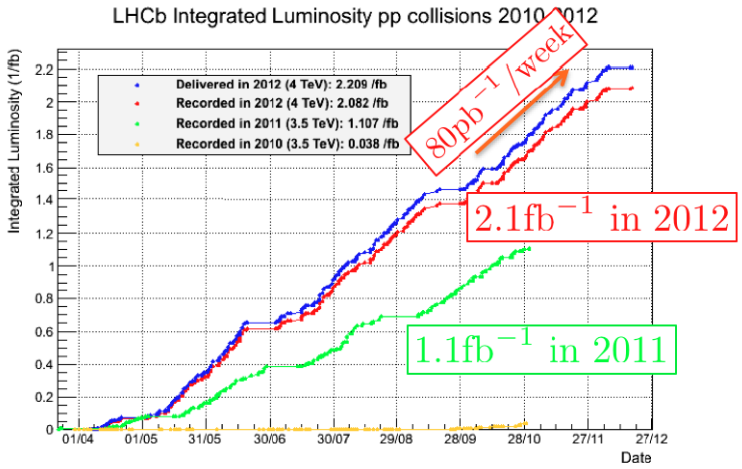
$\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\text{GeV}]}$

Muon system

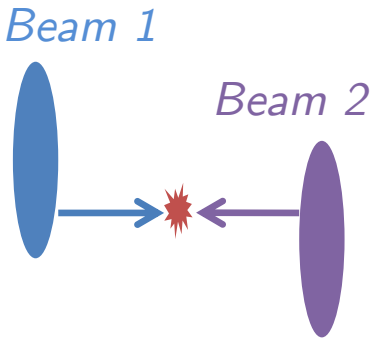
$\varepsilon(\mu \to \mu)$~95%

$\pi - \mu$ misID ~5%

LHCb operation



- Successful data collection since 2010
- Also in 2013 pA collisions: $L \sim 2$ nb^{-1}



"Lumi levelling"

- Luminosity levelling to reduce pileup
- Trigger system reduces the data rate from 40MHz to ~3kHz
  - 90% efficiency for dimuon channels
  - ~30% efficiency for hadronic final states

Recent highlights

- $B_{(s)}$ production measurement
- B_c physics
  - B_c production
  - B_c mass measurement
  - Observation of $B_c^+ \to \psi(2S)\,\pi^+$ decay
  - Observation of $B_c^+ \to J/\psi\,K^+$ decay

Results shown here are mostly based on 2011 data.

$B_u/B_d/B_s$ meson production

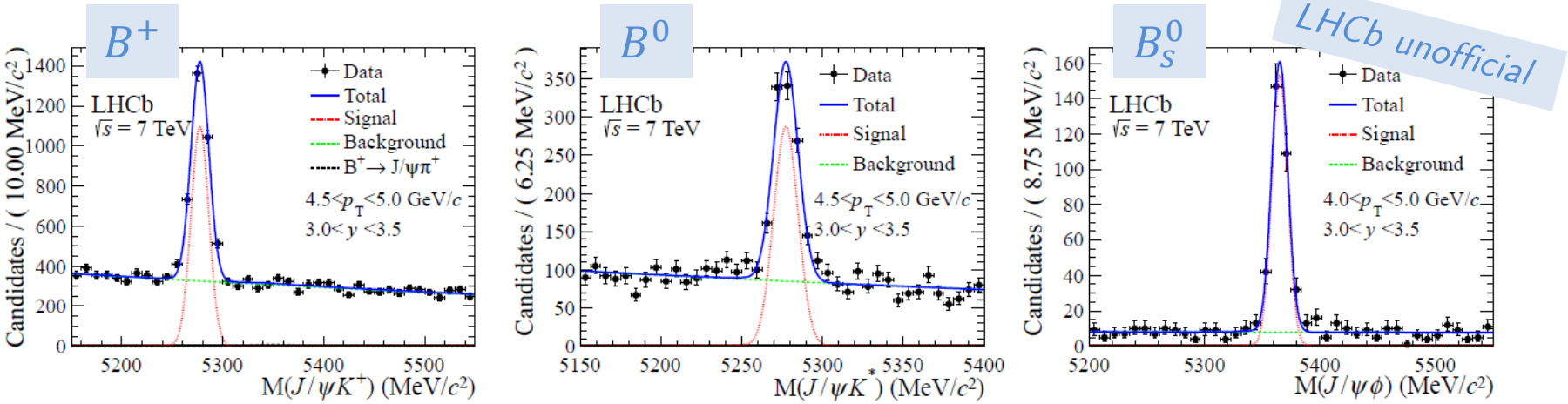
JHEP04(2012) 093

LHCb-PAPER-2013-004 in preparation

- Important tests for pQCD calculations
- B^+ production was measured using 35 pb^{-1} data
- The latest analysis uses 362 pb^{-1} data @ 7 TeV,

  $0 < p_T < 40$ GeV, $2.0 < y < 4.5$

$$\begin{cases} B^+ \to J/\psi\, K^+; \\ B^0 \to J/\psi\, K^{*+},\ K^{*+} \to K^+\pi^-; \\ B_s^0 \to J/\psi\, \phi,\ \phi \to K^+K^-. \end{cases} \qquad J/\psi \to \mu^+\mu^-$$



Integrated cross-sections

JHEP04(2012) 093

LHCb-PAPER-2013-004 in preparation

$0 < p_T < 40$ GeV, $2.0 < y < 4.5$

Result with 35pb^{-1} data:

41.4 ± 1.4(stat) ± 3.2(syst) μb

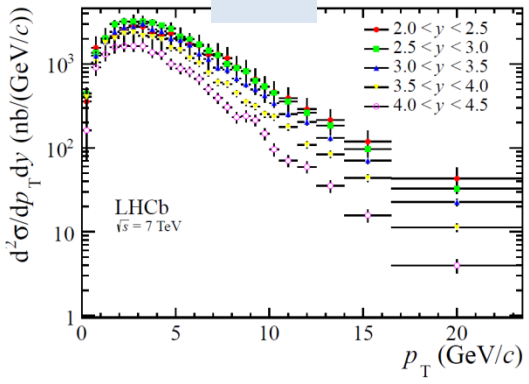
$$
\begin{aligned}
\sigma(pp \to B^+ X) &= 38.9 \pm 0.3\,(\text{stat.}) \pm 2.8\,(\text{syst.})\ \mu\text{b}, \\
\sigma(pp \to B^0 X) &= 38.9 \pm 0.6\,(\text{stat.}) \pm 3.6\,(\text{syst.}) \pm 4.8(\text{Br.})\ \mu\text{b}, \\
\sigma(pp \to B_s^0 X) &= 10.5 \pm 0.2\,(\text{stat.}) \pm 0.8\,(\text{syst.}) \pm 1.0\,(\text{Br.})\ \mu\text{b}.
\end{aligned}
$$

The main systematic uncertainties are from trigger efficiency and tracking efficiency.

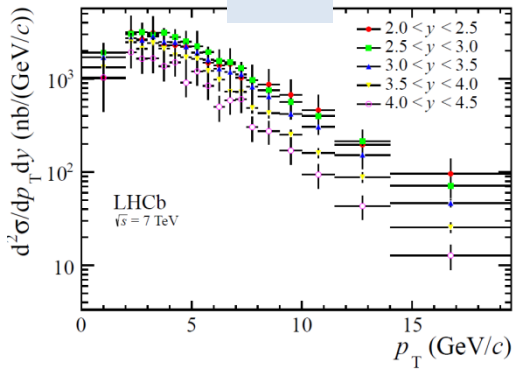
Differential cross-sections

LHCb-PAPER-2013-004 in preparation

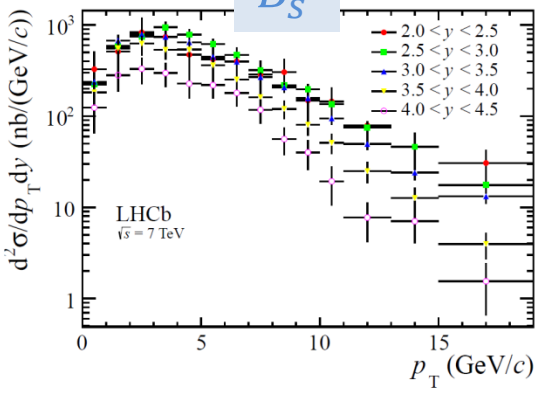
B^+



B^0



B_s^0



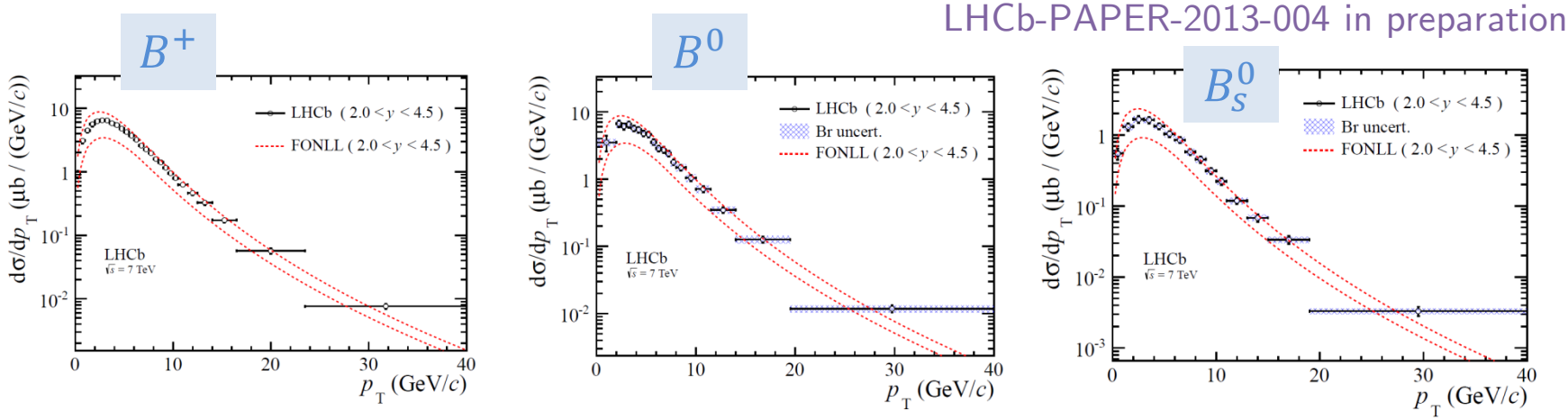
LHCb unofficial

- Differential cross-section in bins of p_T and y
- Unique rapidity range, complementary to ATLAS and CMS
- p_T range down to 0 GeV!

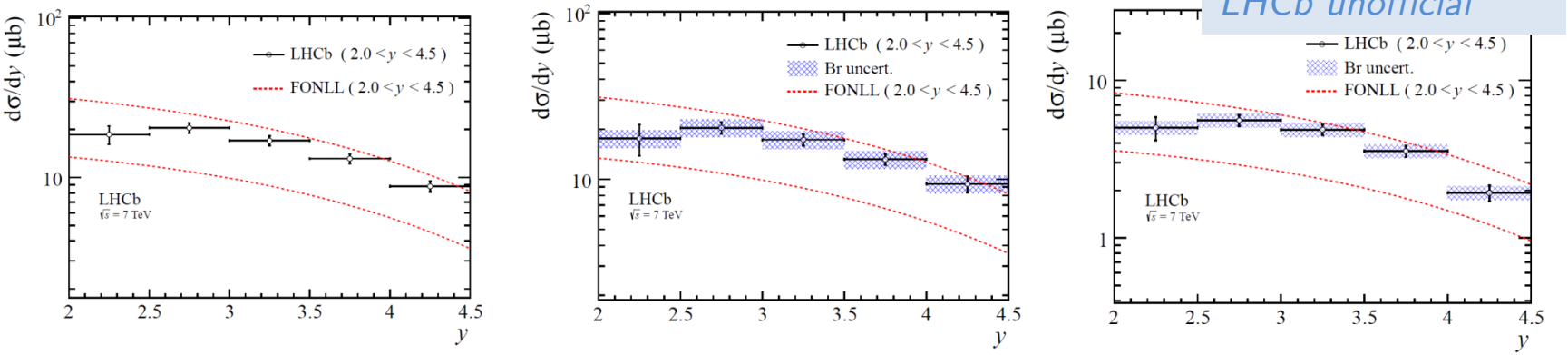
Comparison with theory

LHCb-PAPER-2013-004 in preparation

In bins of p_T



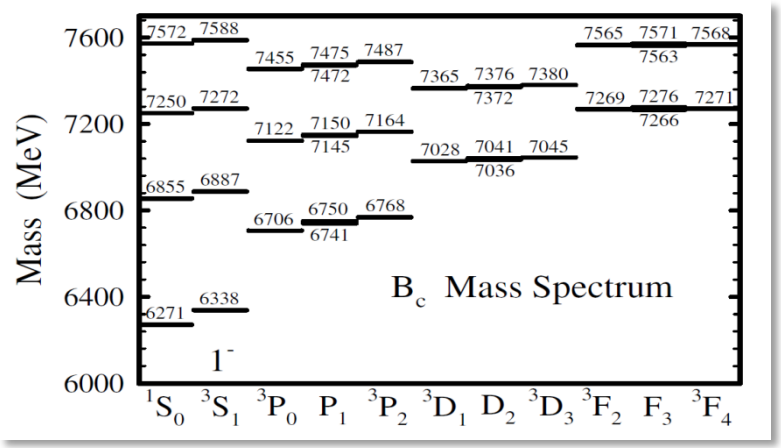
In bins of y



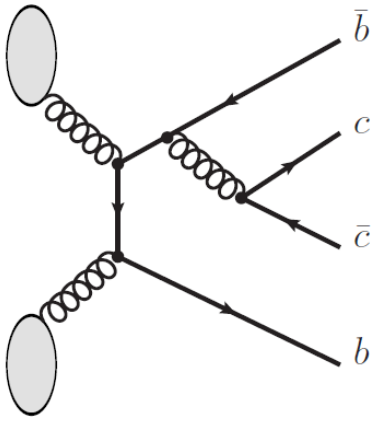
- Consistent with theoretical calculation: *Fixed-order plus next-to-leading order (FONLL):* Cacciari et al, JHEP 9805(1998) 007; JHEP 0103(2001) 006; JHEP 1210(2012) 137
- Overall scale fixed using hadronisation fractions $f_{b\to B_{u/d}}$, $f_{b\to B_s}$ measured by LHCb PRD 85(2012) 032008

B_c physics

- The only meson composed of different heavy flavour quarks ($\bar{b}c$)
- Mass spectrum similar to quarkonium states
- Production: mainly through gg fusion at hadron colliders
- Large production rate at LHC!
  - $\sigma(B_c^+)_{\mathrm{LHC}}/\sigma(B_c^+)_{\mathrm{Tevatron}} \sim O(10)$
  - $\sigma(B_c^+) \sim 0.4\,\mu b$ at $\sqrt{s} = 7$ TeV, $\sim 0.9\,\mu b$ at $\sqrt{s} = 14$ TeV



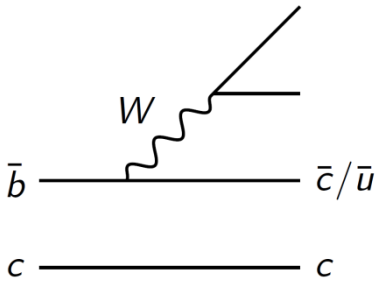
Godfrey, PRD.70(2004) 054017

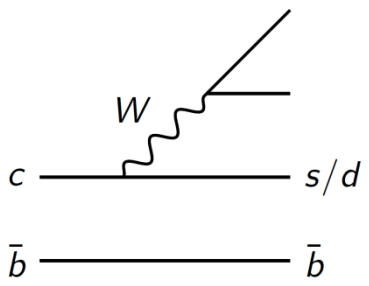


B_c decays

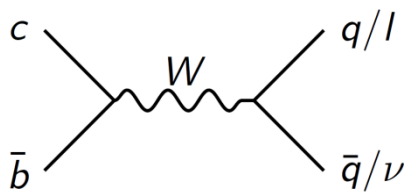
- Excited states decay to B_c^+ through strong/EM interaction
- Ground state only decays weakly

$\bar{b}/c$ decay with the other as spectator





annihilation



$B_c^+ \rightarrow$

~20%	~70%	~10%
$J/\psi l\nu$, $J/\psi\pi^+$	$B_s\pi$, $B_s l\nu$, ...	$\overline{K^*}K^+$, $\tau^+\nu$, ...
$J/\psi K^+$, $\psi(2S)\pi^+$,		
...		

Only ($\bar{b} \rightarrow \bar{c}W$) observed so far

- Rich decay modes $\Rightarrow \tau = 0.45 \pm 0.04$ ps PDG12

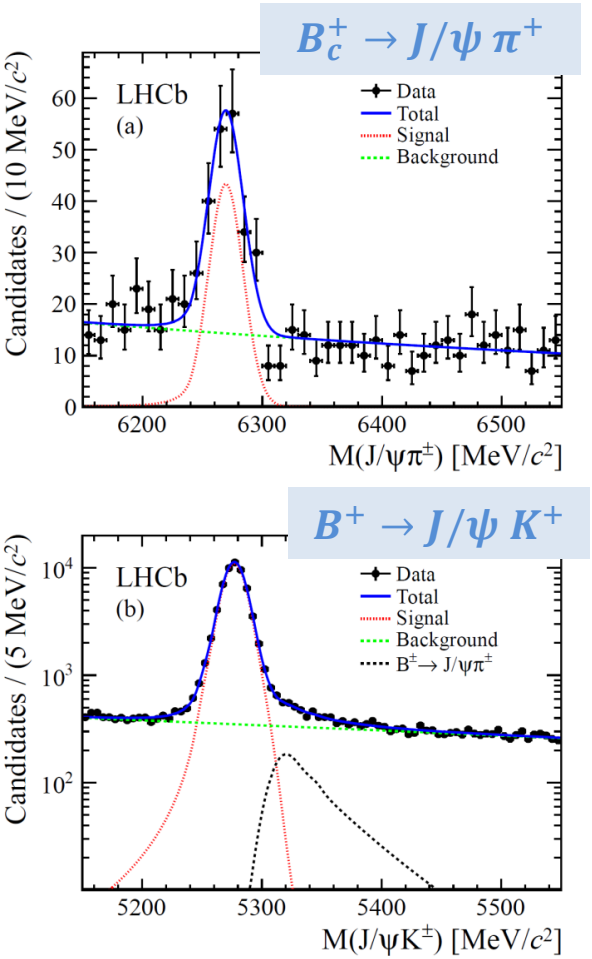
B_c production

PRL109(2012) 232001

- $B_c^+ \to J/\psi\,\pi^+$, $J/\psi \to \mu^+\mu^-$, normalisation channel $B^+ \to J/\psi\,K^+$
- Based on 0.37 fb^{-1} data @ 7 TeV, $p_T > 4$ GeV, $2.5 < \eta < 4.5$
  - Signal fitted with double-sided Crystall Ball function;
  - Cabibbo suppressed background for $B^+ \to J/\psi K^+$ is considered.

$$\frac{\sigma(pp \to B_c^+ X) \cdot \mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(pp \to B^+ X) \cdot \mathcal{B}(B^+ \to J/\psi K^+)} = (0.68 \pm 0.10(\text{stat.}) \pm 0.03(\text{syst.}) \pm 0.05(\text{lifetime}))\%$$

  - Efficiencies are calculated in individual (p_T, η) bins to avoid bias;
  - Systematic uncertainty is dominated by the contribution from B_c^+ lifetime: (0.453±0.041) ps



B_c mass measurement

PRL109(2012) 232001

- Measurement of mass difference $M(B_c^+) - M(B^+)$ is obtained by simultaneous fit of $J/\psi\pi^+$ and $J/\psi K^+$ invariant mass spectra
- The uncertainties due to detector description and alignment are cancelled in mass difference measurement
- The main systematic uncertainty comes from momentum scale calibration

$$M(B_c^+) = 6273.7 \pm 1.3(\text{stat.}) \pm 1.6(\text{syst.})\ \text{MeV}/c^2$$
$$M(B_c^+) - M(B^+) = 994.6 \pm 1.3(\text{stat.}) \pm 0.6(\text{syst.})\ \text{MeV}/c^2$$

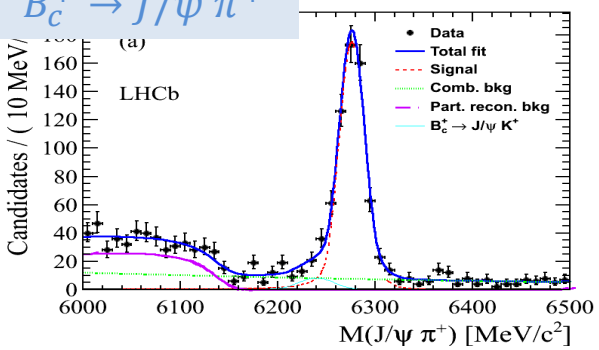
More precise than any previous results

Observation of $B_c^+ \to \psi(2S)\pi^+$

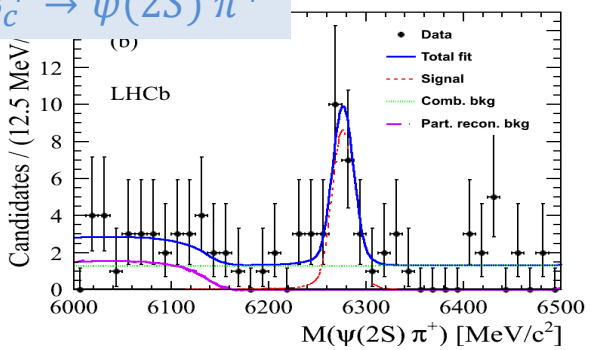
arXiv:1303.1737

- Search for the decay with 1 fb^{-1} data @ 7 TeV
- Event selected using boosted decision tree (BDT) trained on normalisation channel $B_c^+ \to J/\psi\,\pi^+$

$B_c^+ \to J/\psi\,\pi^+$



$B_c^+ \to \psi(2S)\,\pi^+$



First observation with a significance of 5.2 σ!

Background components: combinatorial; partially reconstructed (such as $B_c^+ \to J/\psi\,\rho^+$); Cabibbo suppressed $B_c^+ \to J/\psi\,K^+$.

$$\frac{\mathcal{B}(B_c^+ \to \psi(2S)\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 0.250 \pm 0.068\,(\text{stat}) \pm 0.014\,(\text{syst}) \pm 0.006\,(\mathcal{B}).$$

Uncertainty of $Br(J/\psi \to \mu\mu)/Br(\psi \to \mu\mu)$

Consistent with prediction made by relativistic quark model
PRD.68(2003) 094020

Observation of $B_c^+ \to J/\psi\, K^+$

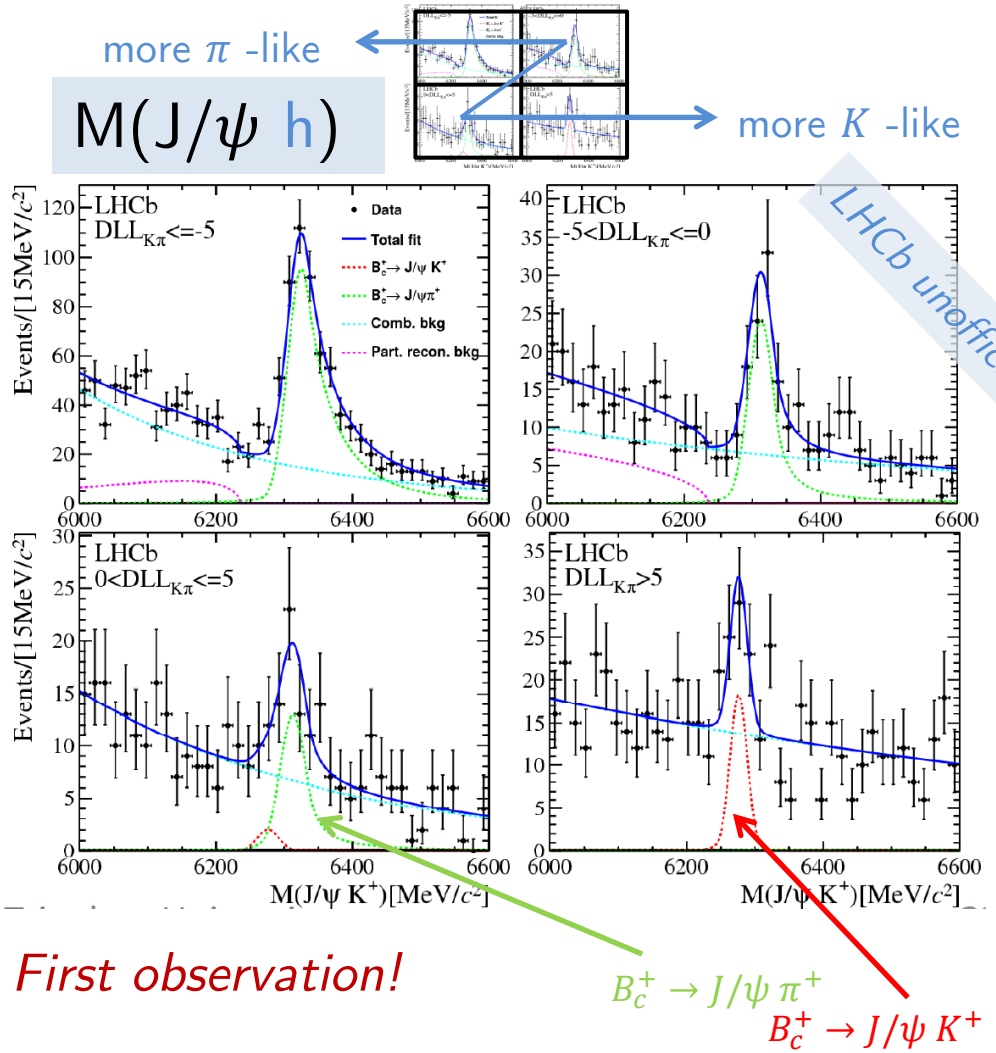
LHCb-PAPER-2013-021 in preparation

- 1 fb^{-1} data @7 TeV
- BDT based selection
- Fit for the mass spectra in various PID bins to minimise the uncertainty from particle identification

$$\frac{\mathcal{B}(B_c^+ \to J/\psi\, K^+)}{\mathcal{B}(B_c^+ \to J/\psi\, \pi^+)} = 0.068 \pm 0.019 \pm 0.005$$

BR dominated by statistical uncertainty;

Consistent with $\left|\frac{V_{us}}{V_{ud}}\right|^2$.



Prospects

- There are still 2 fb^{-1} data @ 8 TeV to be analysed!

  NB: $\sigma(\bar{b}b)$ also increases by ~8/7 ⇒ more than doubled with 2011
- Precision measurement of B_c lifetime
  - $B_c^+ \to J/\psi\,\pi^+$: using 1fb^{-1}, uncertainty below 30 fs is achievable (analysis under internal review)
  - $B_c^+ \to J/\psi\,\mu\nu$: large BR, clean signal, yet only partial reconstruction
- New decay modes:
  - More possibilities with $\bar{b} \to \bar{c}W$: $B_c \to J/\psi\,\rho^+$, ...
  - $B_c^+ \to B_s\pi^+$, with $B_s \to J/\psi\phi$ or $B_s \to D_s^-\pi^+$
  - Annihilation : $B_c^+ \to \bar{K}^{*0}K^+$
- Search for excited B_c states: $B_c(2S) \to B_c^+\pi^+\pi^-$
- B_c production can be measured more precisely, and with large statistics measurement of differential cross-section is possible

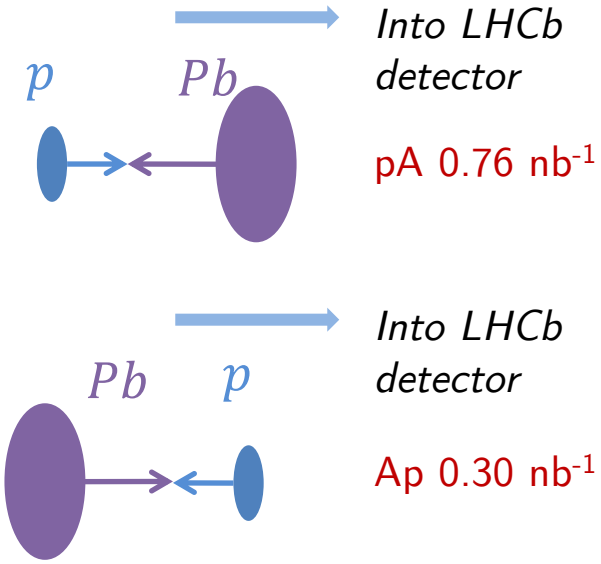
Summary

- A successful year for LAL-Tsinghua LHCb collaboration on the study of B_c and B meson production:
  - Precision measurement of B meson production in unique rapidity region
  - Measurement of B_c mass with high precision
  - First observation of $B_c \to \psi(2S)\pi$ decay
  - First observation of $B_c \to J/\psi\, K$ decay
- With the data LHCb collected in 2012, there will be more interesting results coming out in the future
- Support from FCPPL has been invaluable!

Backup

Study on pA collision

- Opportunity to study cold nuclear matter effects
- Unique contribution from LHCb:
  - Forward region
  - Excellent vertexing performance (separation of J/ψ from b decays)
- Aim:
  - $\overline{\Lambda}/\Lambda$, $\overline{\Lambda}/K_S$ wrt. rapidity
  - J/ψ cross-section in pA/Ap



pA pilot run (0.93 μb^{-1}), $\sqrt{s}$ = 5.02 TeV