Measurement of the $B^{\pm}$ production cross-section in pp collisions at $\sqrt{s}$ = 7 and 13 TeV

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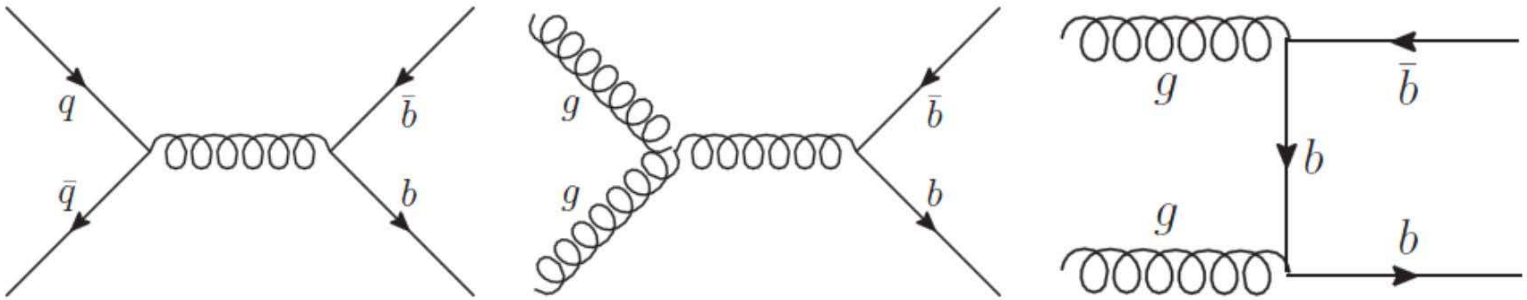
Outline

- Introduction
- Signal yield
- Efficiency
- Systematic uncertainties
- Results
- Summary

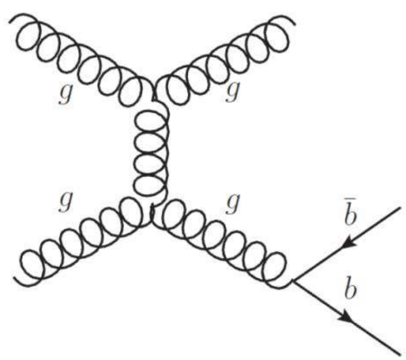
Beauty production

- Based on FONLL (fixed order next-to-leading logarithm) approach, the production cross-section is predictable

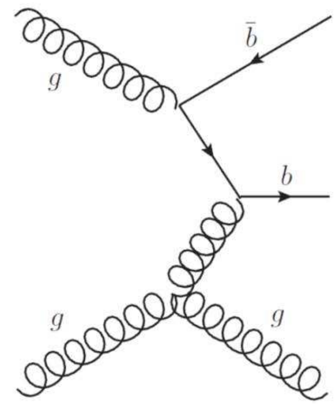
Leading Order



Next-to-Leading Order

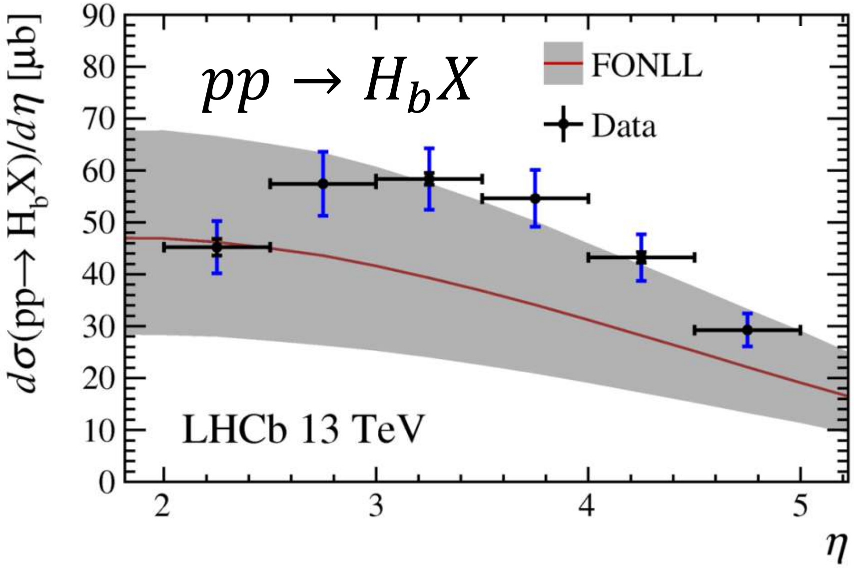


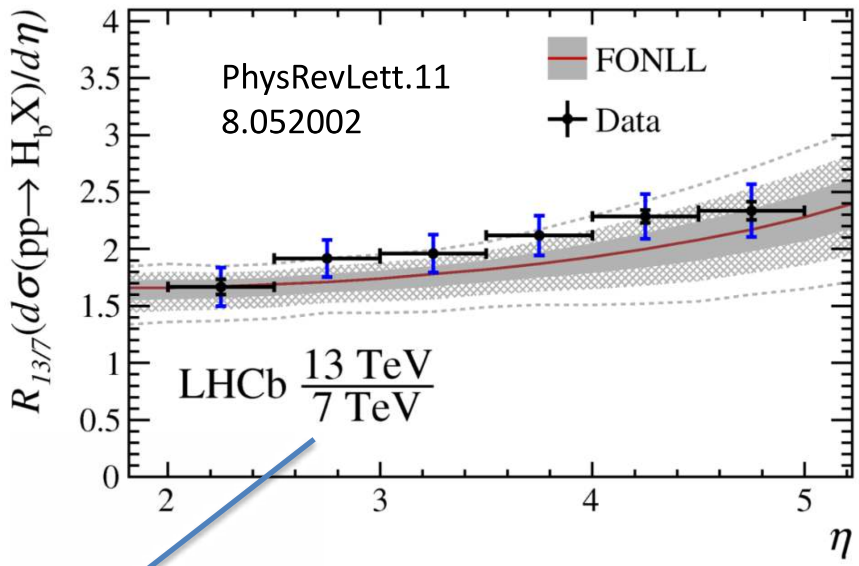
gluon splitting



flavour excitation

Beauty production cross-section

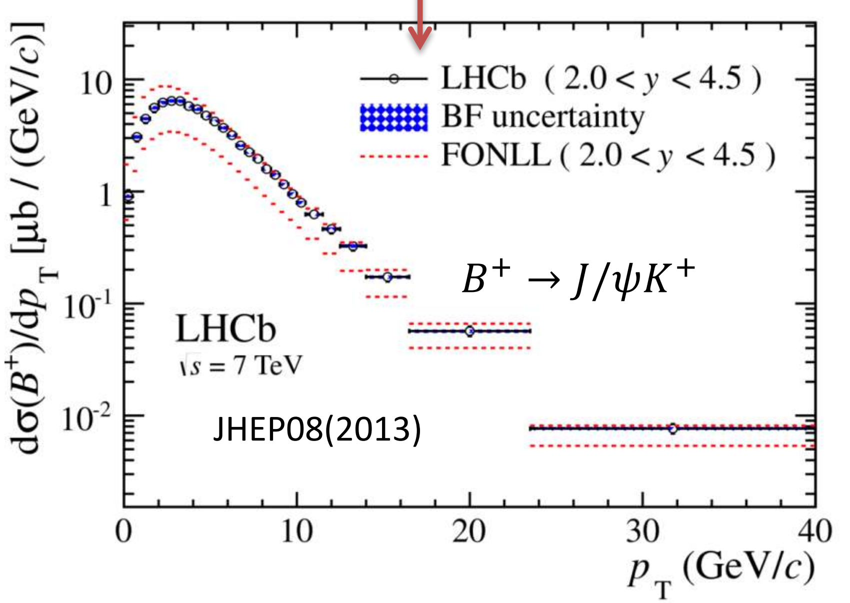




The measurement of the ratio can largely cancel some uncertainties.

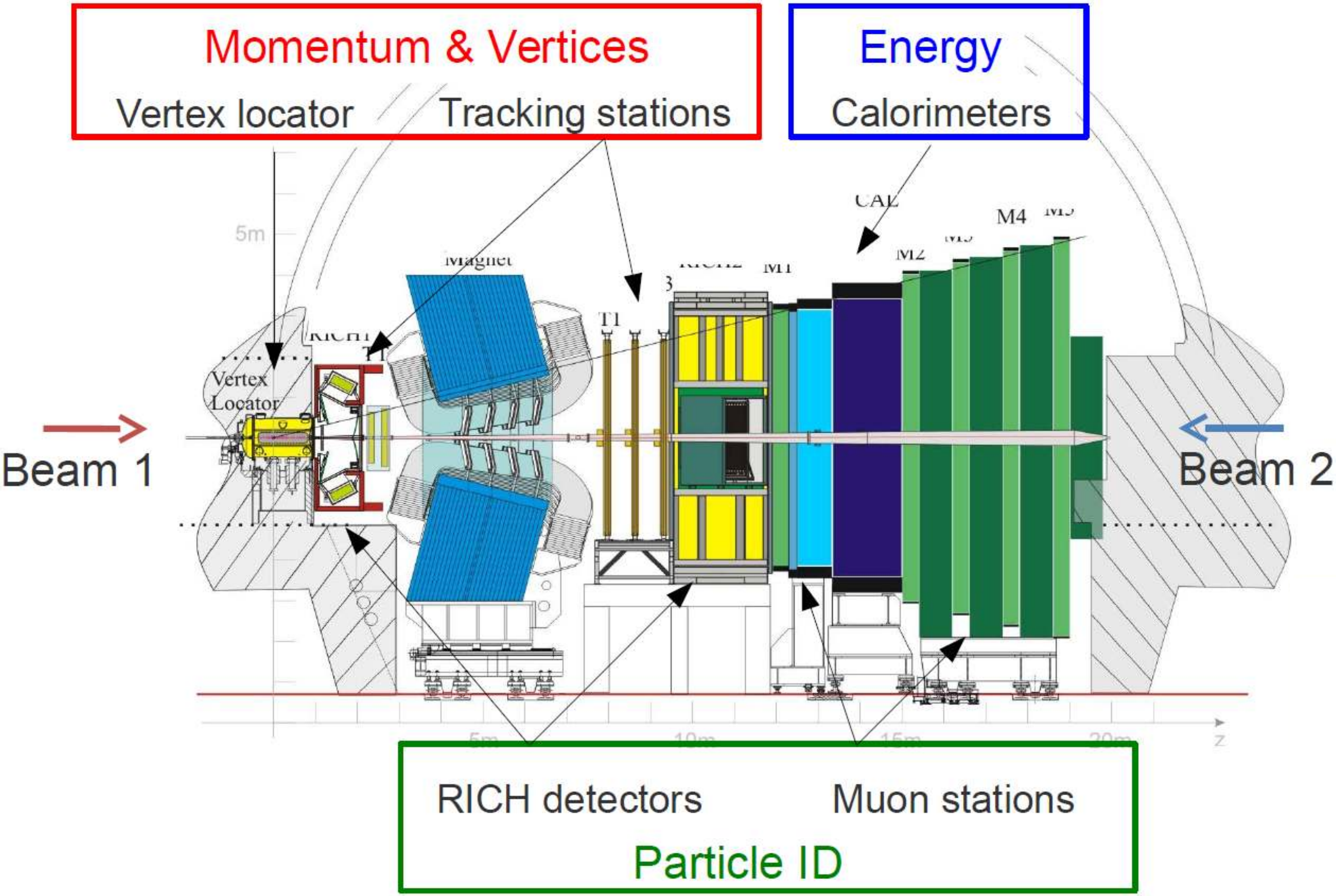
$B^{\pm}$ production cross-section in pp collisions

Experiment	Luminosity	$\sqrt{S}$ (TeV)	Range	Total Cross Section(μb)
CMS	48.1 pb^{-1}	13	$10\ (17) \leq p_T < 100\text{GeV}$, $\lvert y \rvert < 1.45\ (2.1)$	$15.3 \pm 0.4 \pm 2.1 \pm 0.4$
ATLAS	2.4 fb^{-1}	7	$0 < p_T < 120\text{GeV}$, $\lvert y \rvert < 2.25$	$10.6 \pm 0.3 \pm 0.7 \pm 0.2 \pm 0.4$
LHCb	362 pb^{-1}	7	$0 < p_T < 40\text{GeV}$, $2 < y < 4.5$	$38.9 \pm 0.3 \pm 2.8$

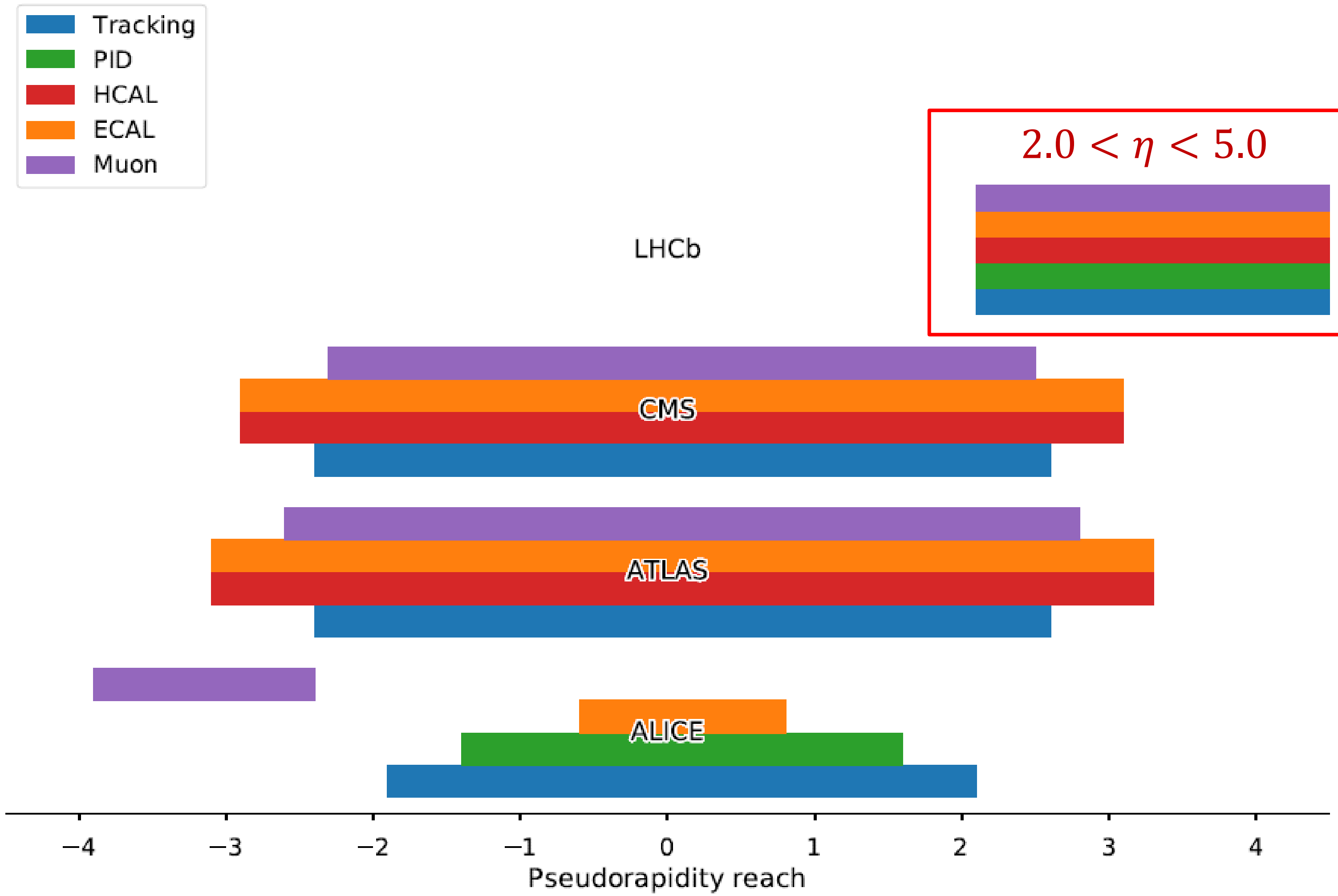


Measured at 7 TeV but no result at 13 TeV

LHCb detector



Pseudorapidity of LHCb detector



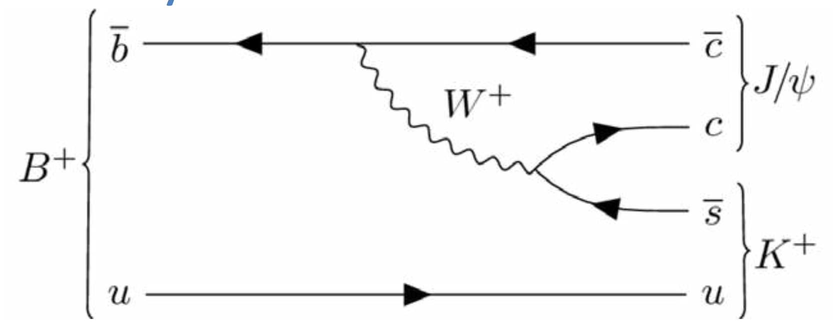
Cross-section determination

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}} = \frac{N_{B^\pm}}{\mathcal{L} \times \varepsilon_{\mathrm{tot}} \times \mathcal{B}\left(B^\pm \to J/\psi K^\pm\right) \times \mathcal{B}\left(J/\psi \to \mu^+\mu^-\right) \times \Delta y \times \Delta p_{\mathrm{T}}}$$

- N_{B^+} : number of B^+ signal events in each bin of $\Delta y \times \Delta p_T$
- ε_{tot} : total efficiency in each bin of $\Delta y \times \Delta p_T$
- $\mathcal{L}$: integrated luminosity
- $\mathcal{B}(B^+ \to J/\psi K^+)$: branch fraction, Bella[3] and BABAR[4]
- $\mathcal{B}(J/\psi \to \mu^+\mu^-)$: branch fraction, 2016 version of PDG[5]
- $\Delta y \times \Delta p_T$: bin width for p_T^B and y^B

Data sample and selection

- $B^+ \to J/\psi K^+$ decay



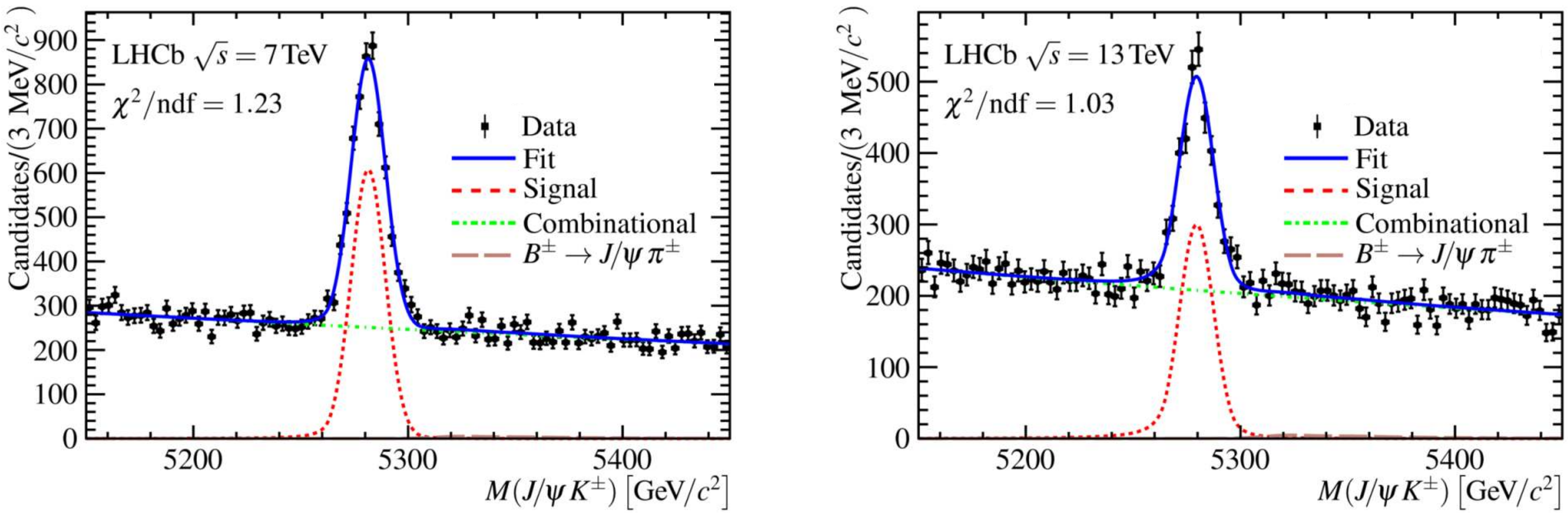
- Data sample and Selection

  - 1.0 fb^{-1} , 7 TeV , 2011; 0.3 fb^{-1} , 13 TeV, 2015

Description	$\mu^{\pm}$	K^+	J/ψ	B^+
P_T	> 0.7 GeV	> 0.5 GeV	-	[0, 40] GeV
PID	> 0	-	-	-
track $\chi^2/ndof$	< 3	< 3	-	-
vertex $\chi^2/ndof$	-	-	< 9	< 9
Mass	-	-	[3.04, 3.14] GeV	-
t	-	-	-	> 0.3 ps

Extract B^+ signal

- Fit data in each bin of $\Delta y \times \Delta p_T$
- Result of $3.5 < p_T < 4.0\ GeV$, $2.5 < y < 3.0$ as an example



black : data points
blue : fit results
red : signal (Double-sided Crystal Ball)
Green : combinatorial background (Exponential)
brown: Cabibbo suppressed background, $B^+ \to J/\psi\pi^+$ (Double Crystal Ball)

Efficiency

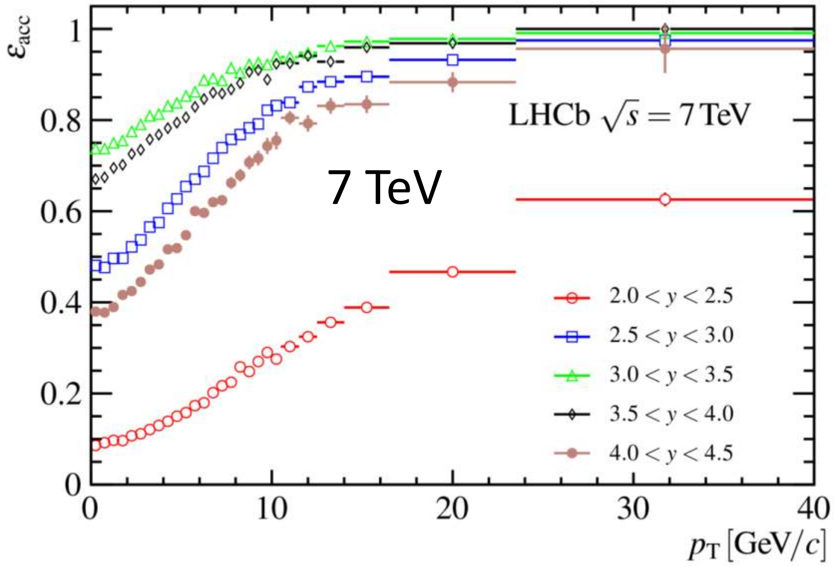
$$\varepsilon_{tot} = \varepsilon_{Acc} \times \varepsilon_{Reco\&Sel} \times \varepsilon_{Track} \times \varepsilon_{PID} \times \varepsilon_{Trig} \times \varepsilon_{GEC}$$

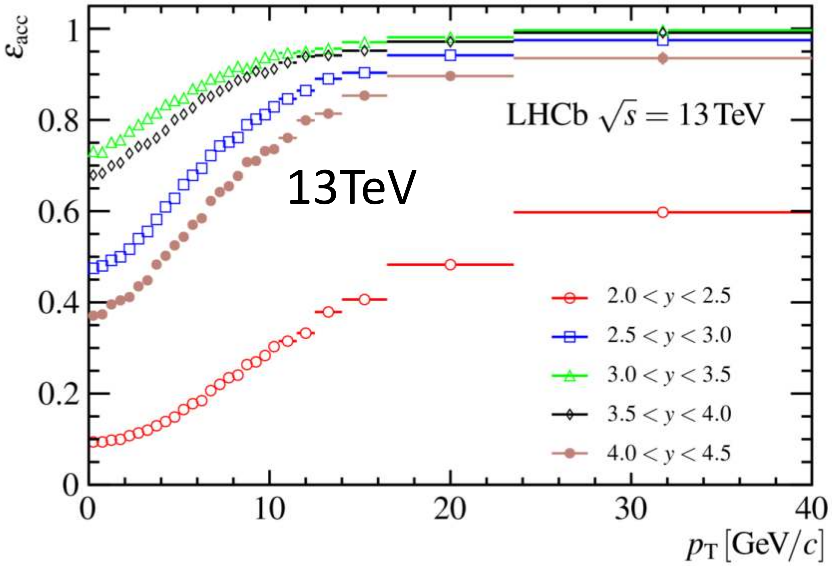
Efficiency	Description	Sample
ε_{Acc}	acceptance	Simulation
$\varepsilon_{Reco\&Sel}$	reconstruction and selection	Simulation
ε_{Track}	tracking	Data & Simulation
ε_{PID}	particle identity	J/Ψ data
ε_{Trig}	trigger	Data &Simulation
ε_{GEC}	global events cut	Data & Simulation

GEC : require nSPD hits < 900 to reject high-multiplicity events

Acceptance efficiency

$$\varepsilon_{Acc} = \frac{B^+ \text{ with } 2 < y < 4.5 \text{ and all tracks in LHCb}}{B^+ \text{ with } 2 < y < 4.5}$$



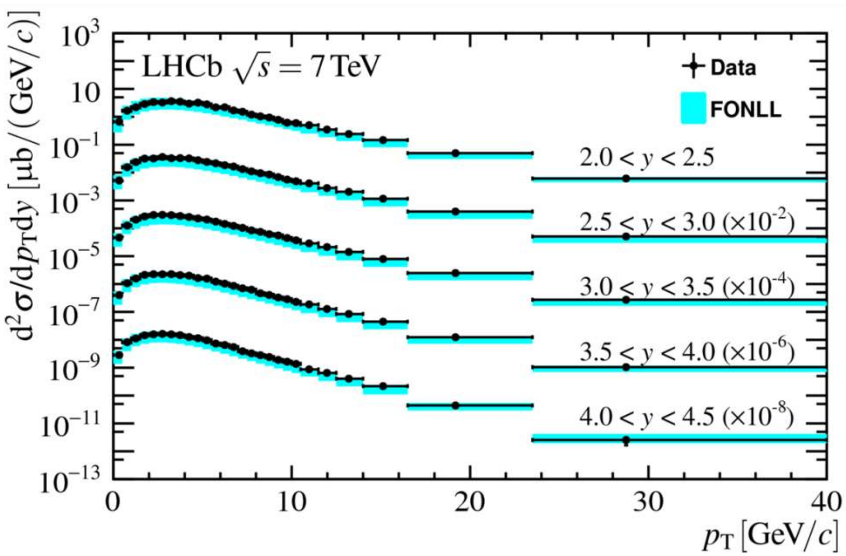


Relative systematic uncertainties

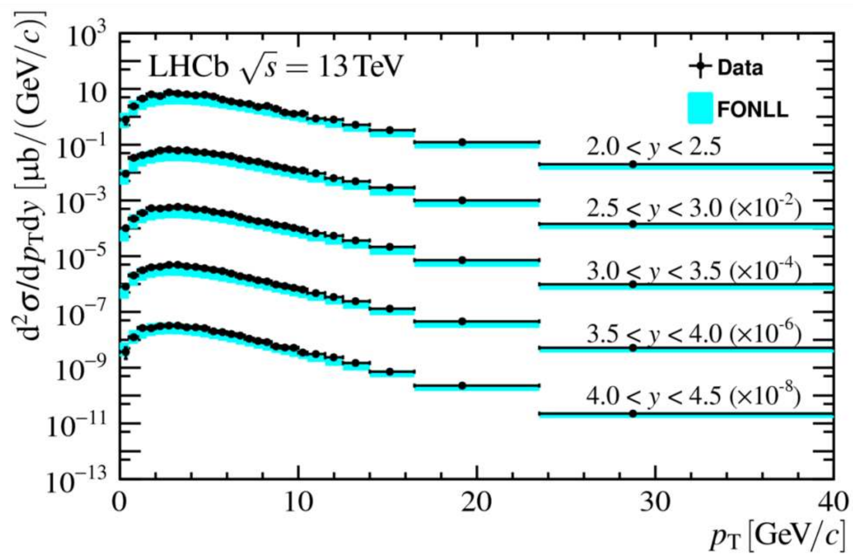
Sources	Uncertainty (%)		
	7 TeV	13 TeV	R(13 TeV/7 TeV)
Luminosity	1.7	3.9	3.4
Branching fractions	3.9	3.9	0.0
Binning	2.6	2.7	0.0
Mass fits	2.7	1.3	1.5
Acceptance	0.2	0.1	0.2
Reconstruction	0.1	0.1	0.2
Track	1.6	2.6	1.0
PID	0.4	0.1	0.4
Trigger	3.5	2.6	4.4
GEC	0.7	0.7	1.0
Selection	1.0	1.1	0.1
Weighting	0.2	0.2	0.3
Total	7.0	7.4	5.9

- Branching fractions → Limited knowledge of $\mathcal{B}(B^+ \to J/\psi K^+)$
- Binning, Mass fits → Bin size and fit model
- Acceptance, Reconstruction, Track, PID, GEC, Selection → Efficiency
- Trigger → Limited sample size

Double-differential production cross-section



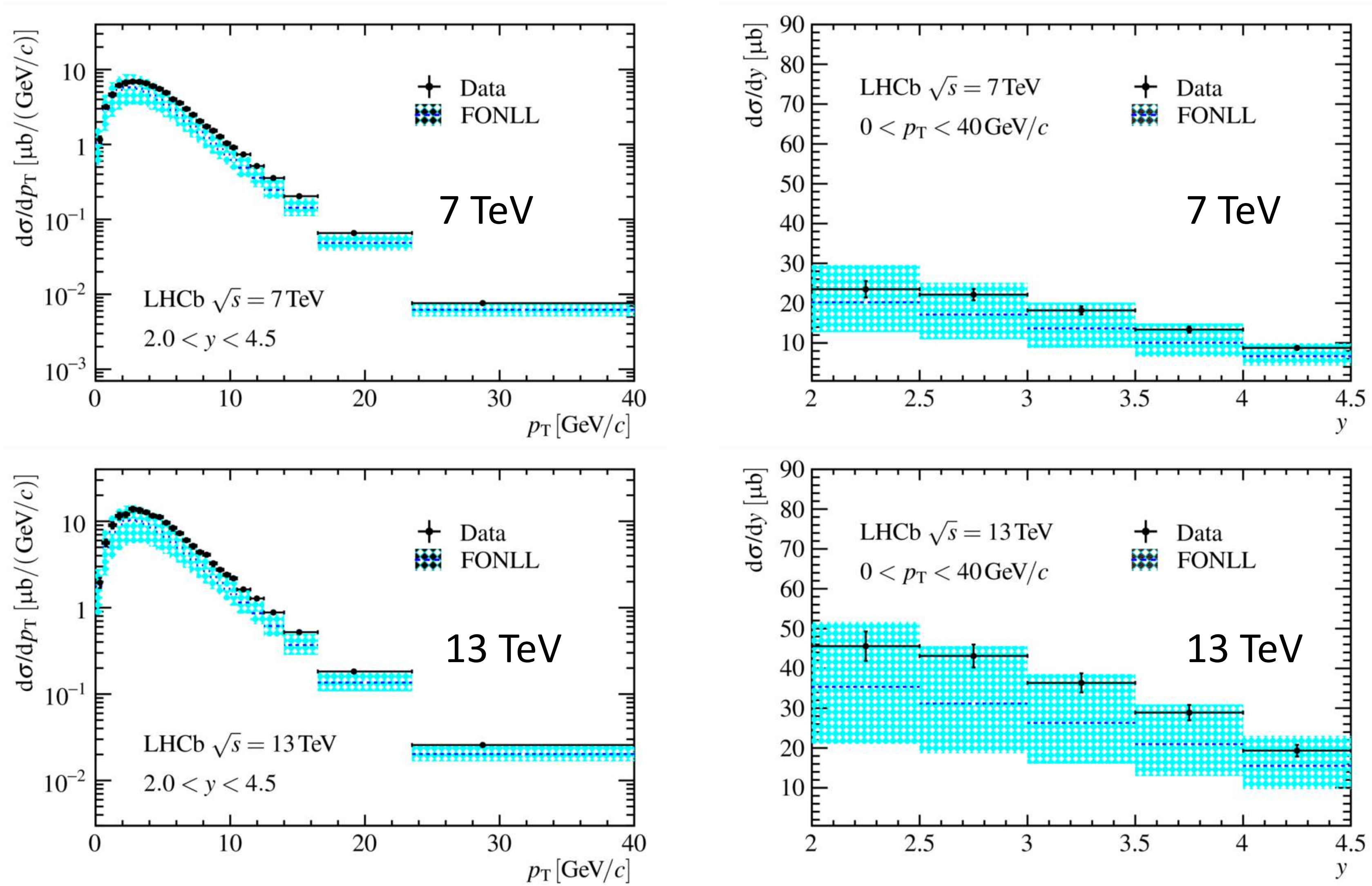
7 TeV



13 TeV

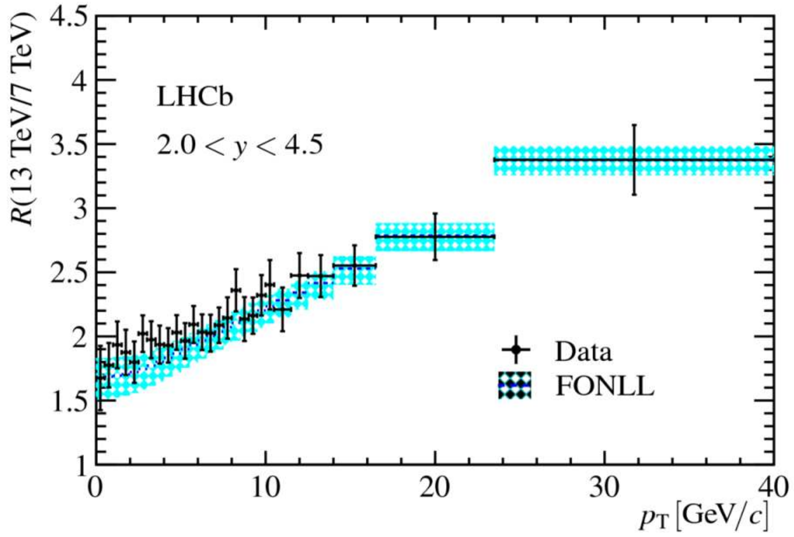
Good agreements between data points and theoretical predictions

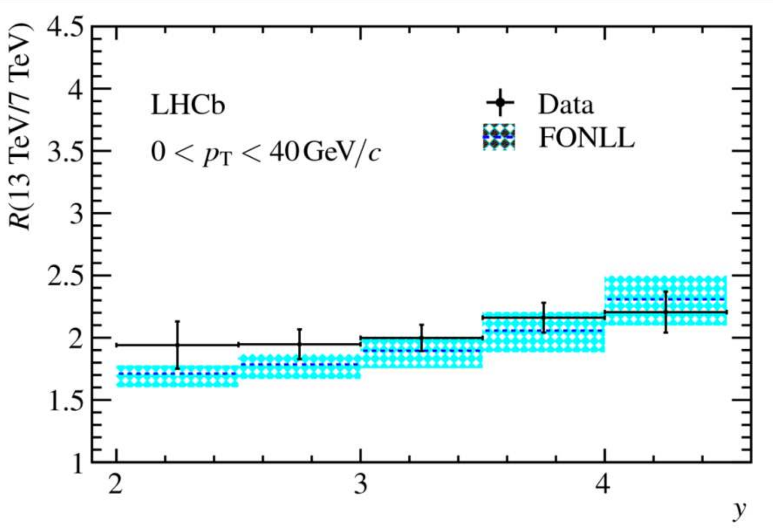
Single differential production cross-section



Ratio and total cross-section

- Ratio of cross-section, $R(13\text{ TeV}/7\text{ TeV})$





- Total cross-section $(2.0 < y < 4.5)$

$$\sigma(pp \to B^{\pm}X, \sqrt{s} = 7\text{ TeV}) = 43.0 \pm 0.2(stat) \pm 2.5(syst) \pm 1.7\ (Br)\ \mu b$$

$$\sigma(pp \to B^{\pm}X, \sqrt{s} = 13\text{ TeV}) = 86.6 \pm 0.5(stat) \pm 5.4(syst) \pm 3.4\ (Br)\ \mu b$$

$$R(13\text{ TeV} / 7\text{ TeV}) = 2.02 \pm 0.02(stat) \pm 0.12(syst)$$

Summary

- First precise measurement of the $B^{\pm}$ production cross-section at 13 TeV of LHCb.
- Result at 7 TeV is updated with 1.0 fb^{-1}.
- All measured results are in agreement with theoretical calculations based on the FONLL approach.

Backup

References

[1] M. Cacciari, M. L. Mangano, and P. Nason, Gluon PDF constraints from the ratioof forward heavy-quark production at the LHC at ps = 7 and 13 TeV, Eur. Phys. J.C75 (2015) 610, arXiv:1507.06197.

[2] LHCb collaboration, R. Aaij et al., Measurement of B meson production cross-sectionsin proton-proton collisions at ps = 7 TeV , JHEP 08 (2013) 117, arXiv:1306.3663

[3] Belle, K. Abe et al., Measurement of branching fractions and charge asymmetries for two-body B meson decays with charmonium, Phys. Rev. D67 (2003) 032003,arXiv:hep-ex/0211047.

[4] BaBar collaboration, B. Aubert et al., Measurement of branching fractions and charge asymmetries for exclusive B decays to charmonium, Phys. Rev. Lett. 94 (2005) 141801,arXiv:hep-ex/0412062.

[5] Particle Data Group, C. Patrignani et al., Review of Particle Physics, Chin. Phys.659 C40 (2016), no. 10 100001.

Fit model

$$PDF(x; M, \sigma, p, N_{sig}, N_{bkg}) =$$

$$N_{sig} F_{CB}^{ds}(x; M, \sigma) + N_{bkg} F_{EXP}^{bkg}(x; p) + \left(\frac{\mathcal{B}(B^+ \to J/\psi\pi^+)}{\mathcal{B}(B^+ \to J/\psi K^+)}\right) N_{sig} \frac{\varepsilon_{J/\psi\pi^+}}{\varepsilon_{J/\psi K^+}} F_{CB}^{Cabibbo}(x; M)$$

- double-sided CB function for signal
- exponential function for combinatorial background
- a combination of two single-sided CB functions for $B^+ \to J/\psi\pi^+$
- ignore other decay modes out of the fit region as $B^0 \to J/\psi K^0$, $B_s^0 \to J/\psi\phi$, $\lambda_b \to J/\psi pK$ and $\lambda_b \to J/\psi p\pi$