LHCb results on 13 TeV *pp* collisions

Rencontres de Blois
France Blois
29 May - 3 June 2016

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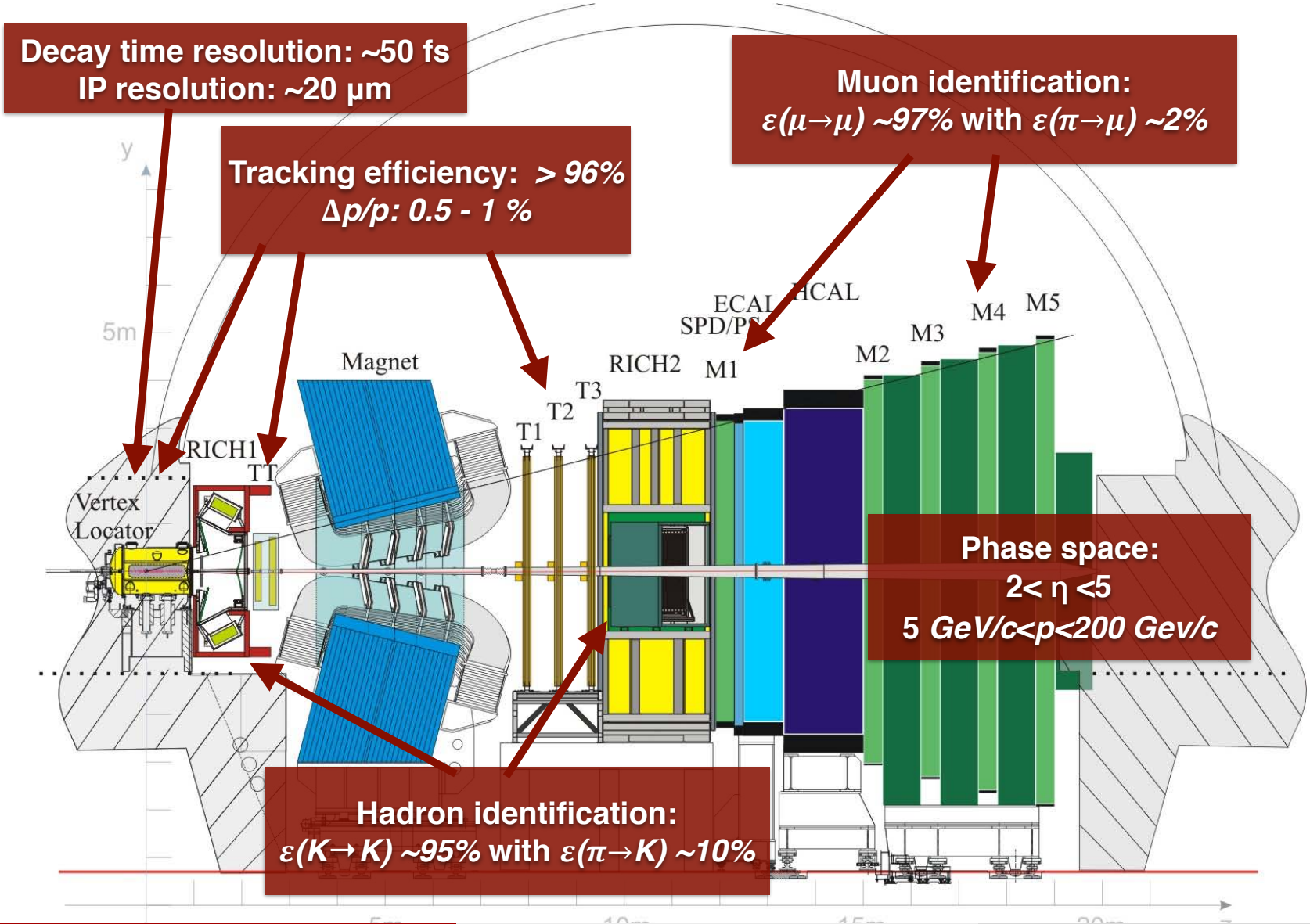
on behalf of the LHCb collaboration

The LHCb detector

Int.J.Mod.Phys. A30 (2015) 1530022



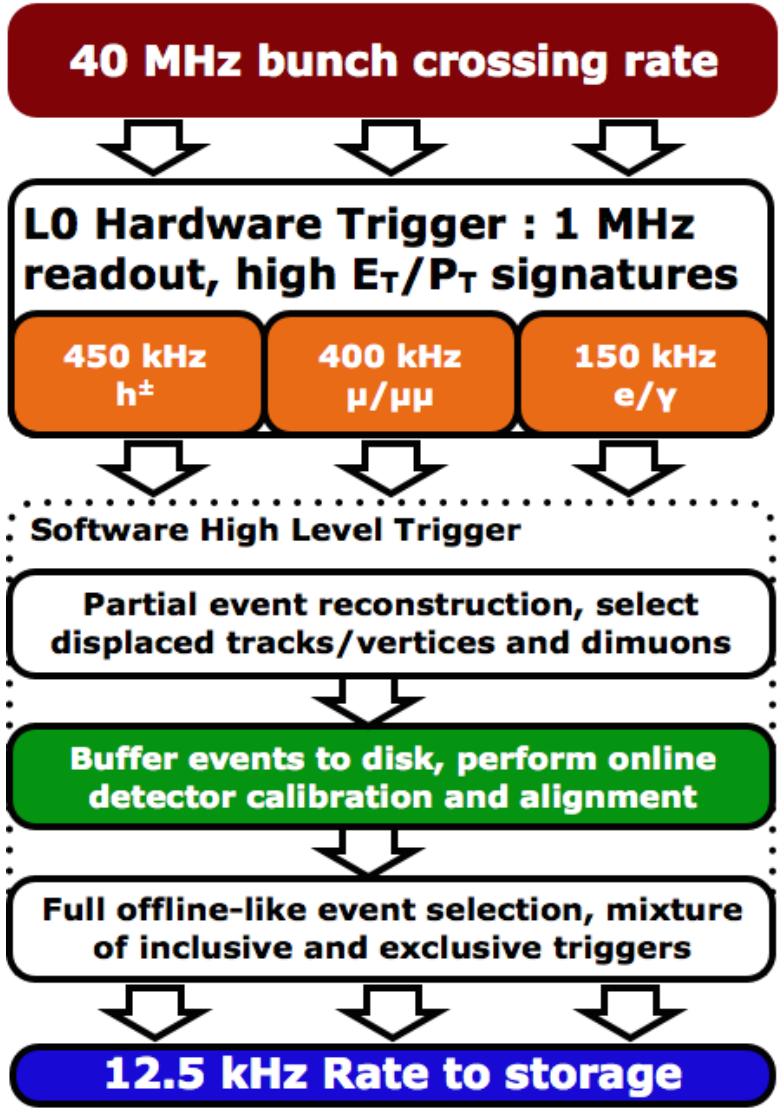
Novel data flow

arXiv:1604.05596

- **Deferred trigger**
  To finalize trigger selection, events are buffered to the disks, and are processed providing uniform load of the computer farm even in absence of data-taking.
- **Online calibration and alignment**
  In the beginning of every fill $\sim 200 \times 10^3$ events are used for tracker alignment and PID calibration
- **Tesla and Turbo stream**
  Novel software allows to perform analysis on candidates out of trigger.

Turbo stream:

Offline-quality reconstructed candidates out of trigger

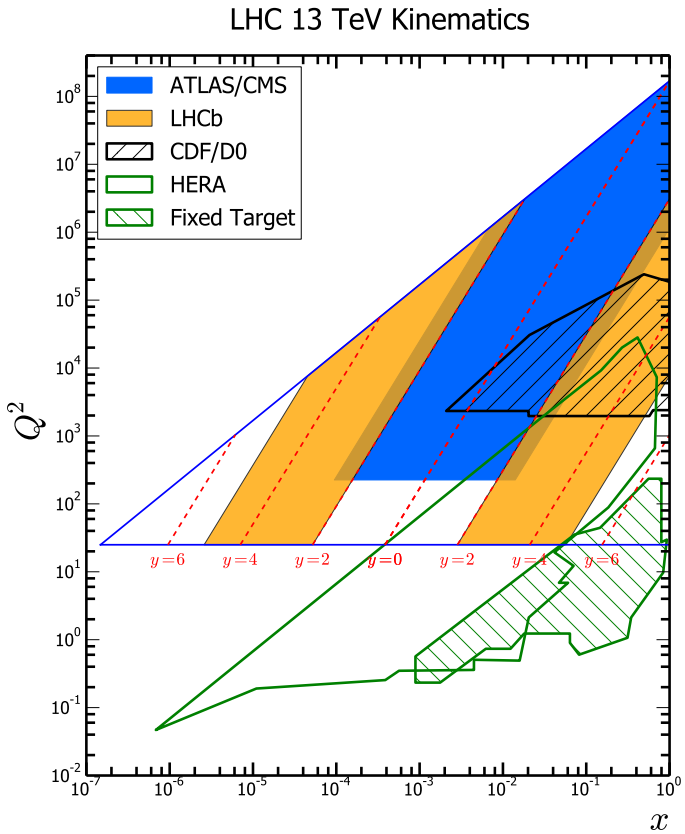


Schema of the LHCb trigger in RunII

Motivation for production measurements I

$$\sigma^{pp\to X} = \sum_{i,j=1}^{N_f} \int_0^1 dx_1 \int_0^1 dx_2 f_i(x_1, Q^2) f_j(x_2, Q^2) \sigma^{i,j\to X}$$

- Production cross-sections are sensitive to PDFs, $f(x, Q^2)$ (which can not be calculated perturbatively):
  - gluon PDFs from heavy flavour production
  - u, d PDFs from Z production
  - Unique LHCb acceptance gives access to the low-x regions
- Tests of different pQCD aproaches (FONLL[1], POWHEG[2], aMC@NLO[3])
- b-quark production cross-section
- Inputs for neutrino astronomy [arXiv:1506.08025]



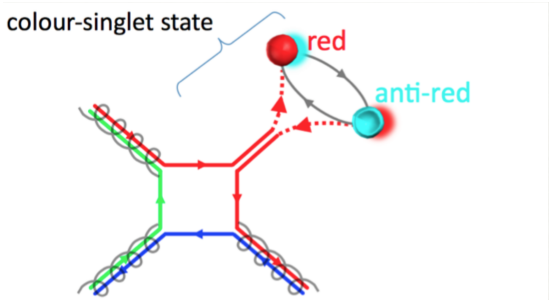
[1] *Eur.Phys.J.* C75.610 (2015)
[2] *JHEP* 1511 (2015) 009
[3] *JHEP* 1407 (2014) 079

Motivation for production measurements II

Charmonium production mechanism: long and not yet solved puzzle

First attempt to describe charmonium production:
Colour Singlet Model[1]

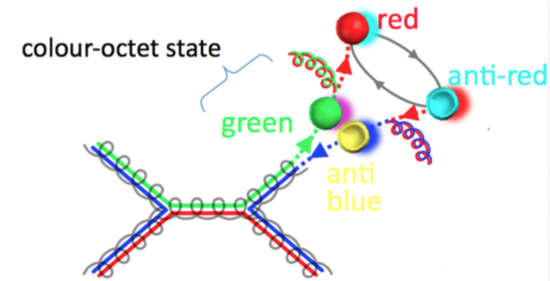
- Values of free parameters may be determined from experiment
- Predicts production at low (at LO) and high (at NLO) energies
- Large corrections at higher orders in α_s, not clear if it converges
- Inconsistent in predictions for high orbital momentum states

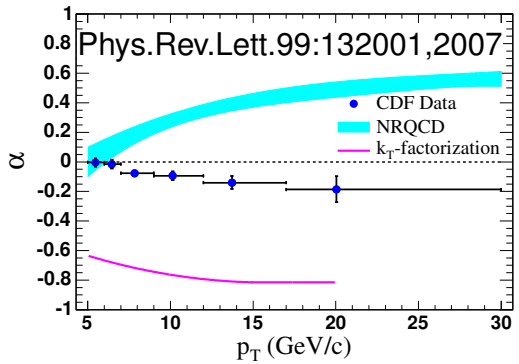


The most popular approach nowadays - NRQCD[2]

$$\sigma(H) = \sum_i \sigma_i(\Lambda)\,\langle \mathcal{O}_n^H(\Lambda)\rangle$$

- Summation over all possible $Q\bar{Q}$ states (colour octet and singlet)
- $\langle \mathcal{O}_n^H(\Lambda)\rangle$ are universal matrix elements defined experimentally
- Good agreement with production measurements
- Fails to describe polarisation at high p_{T}

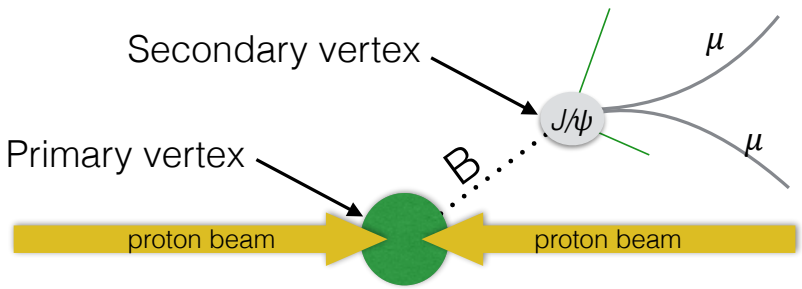




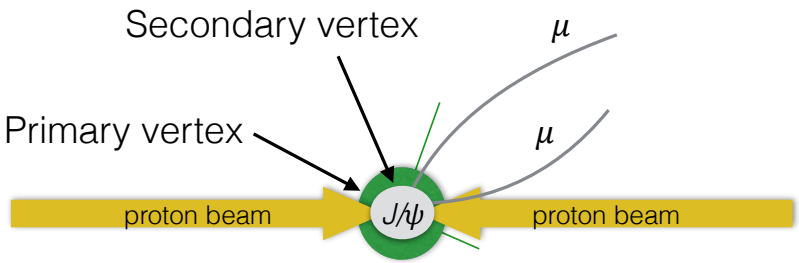
[1] *Phys.Rev.Lett.* 101:152001(2008) [2] *JHEP* 1505 (2015) 103
To find out more read, for instance, *Eur.Phys.J.* C71:1534 (2011)

Heavy flavour measurements. Analysis strategy.

- Select decay candidates (Turbo stream):
  - Efficiencies from simulation and data-driven techniques



J/ψ-from-b topology



Prompt J/ψ topology

Open charm analysis
JHEP 03(2016)159

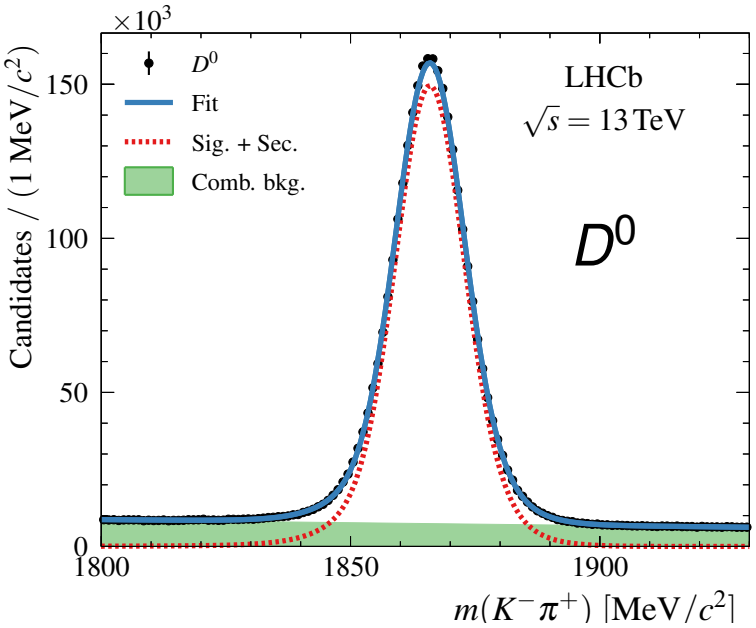
Production cross-section of prompt D^0, D^+, D_s^+ and D^{*+} mesons are measured in $\mathcal{L} = 4.98 \pm 0.19\ \text{pb}^{-1}$ of LHCb data.
$0 < p_{\text{T}} < 15\,\text{GeV}/c$, $2.0 < y < 4.5$

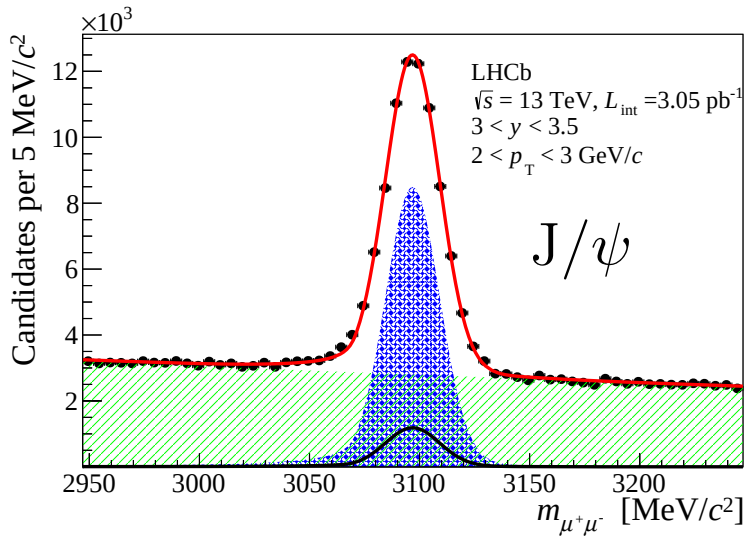
J/ψ analysis
JHEP 10(2015)172

Production cross-sections of prompt J/ψ and J/ψ-from-b mesons are measured in $\mathcal{L} = 3.05 \pm 0.12\ \text{pb}^{-1}$ of LHCb data.
$0 < p_{\text{T}} < 14\,\text{GeV}/c$, $2.0 < y < 4.5$

Heavy flavour measurements. Analysis strategy.

- Select decay candidates (Turbo stream):
  - Efficiencies from simulation and data-driven techniques
- Fit data in $p_{\mathrm{T}} - y$ bins
  - Mass fit to estimate yields





Open charm: *JHEP* 03(2016)159

J/ψ: *JHEP* 10(2015)172

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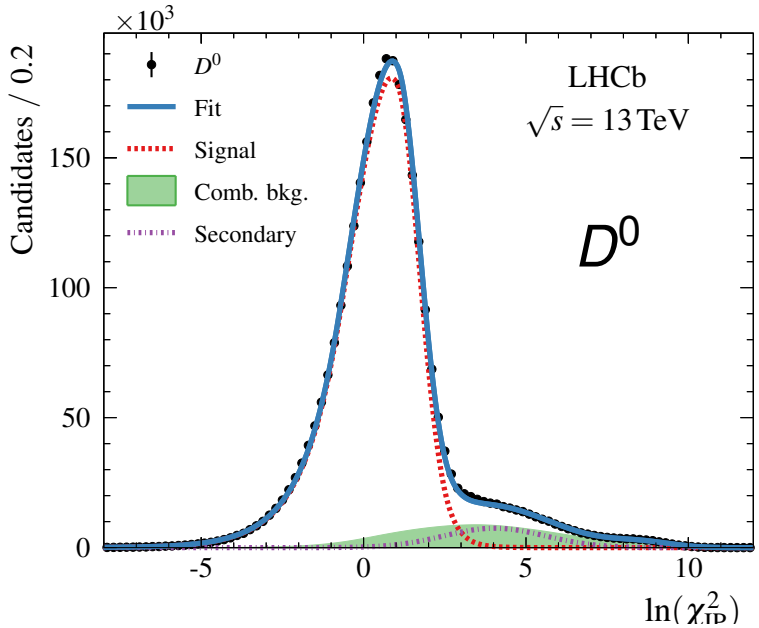
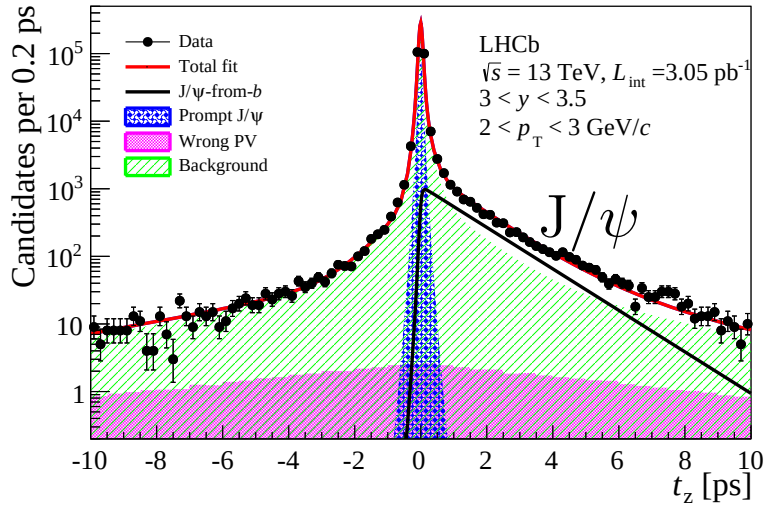
  - t_z or χ^2_{IP} fit to disentangle prompt and secondary contributions



χ^2_{IP}: variation of vertex fit χ^2 on association of tracks to the vertex.

$$t_z = \frac{(z_{\mathrm{J}/\psi} - z_{\mathrm{PV}}) \times M_{\mathrm{J}/\psi}}{p_z}$$



Open charm: *JHEP* 03(2016)159

J/ψ: *JHEP* 10(2015)172

Heavy flavour measurements. Analysis strategy.

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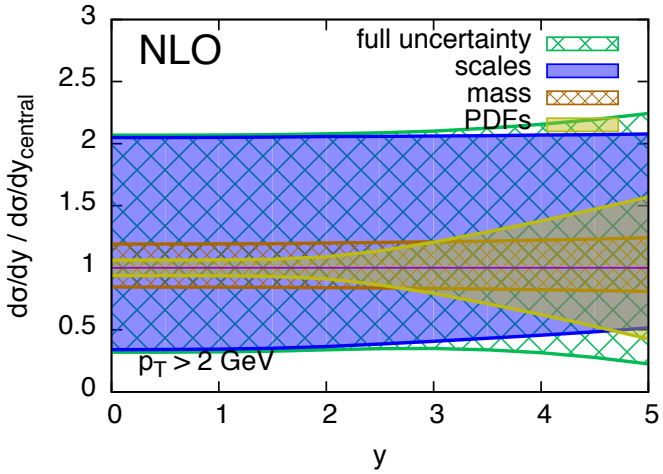
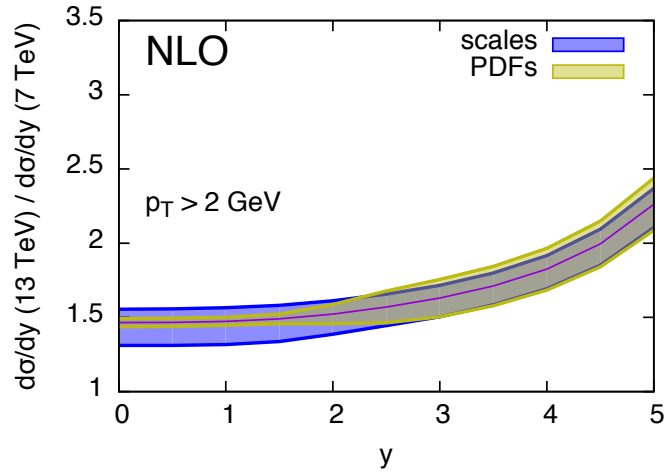
  - Mass fit to estimate yields
  - t_z or χ^2_{IP} fit to disentangle prompt and secondary contributions
- Define 13 TeV to 7(8) TeV cross-section ratios
  - Many of experimental and theoretical uncertainties cancel due to correlation

FONLL predictions for *c*-production at 13 TeV



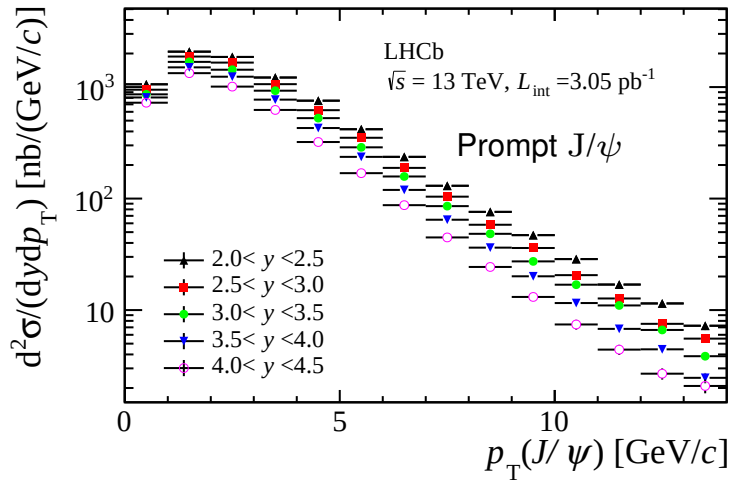
FONLL predictions for 13 TeV to 7 TeV *c*-production ratio



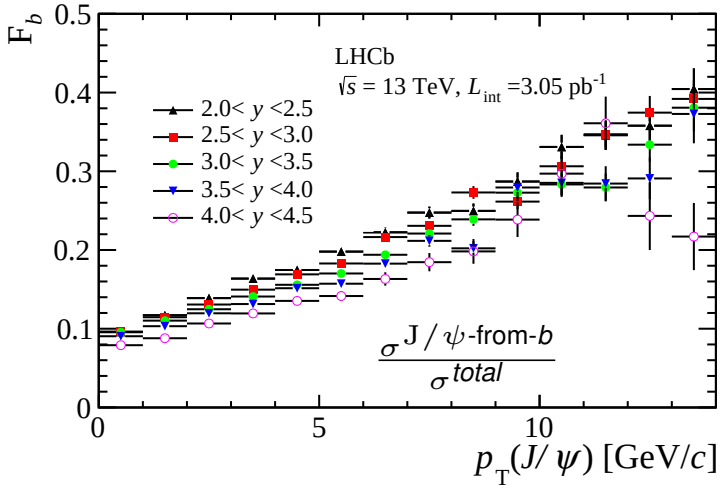
Figures are taken from *Eur.Phys.J.* C75.610 (2015)

Measured J/ψ production

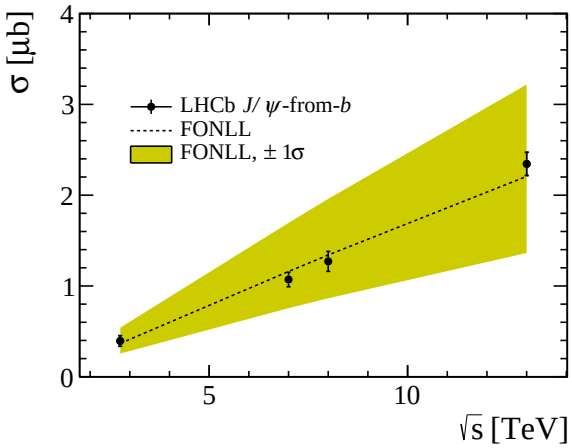
JHEP 10(2015)172



Differential cross-section for prompt J/ψ



Fractions of J/ψ-from-b



Integrated cross-section of J/ψ-from-b in fiducial region.

Integrated σ in LHCb acceptance:

$$\sigma_{prompt} = 15.35 \pm 0.03(stat) \pm 0.85(syst)\mu b$$

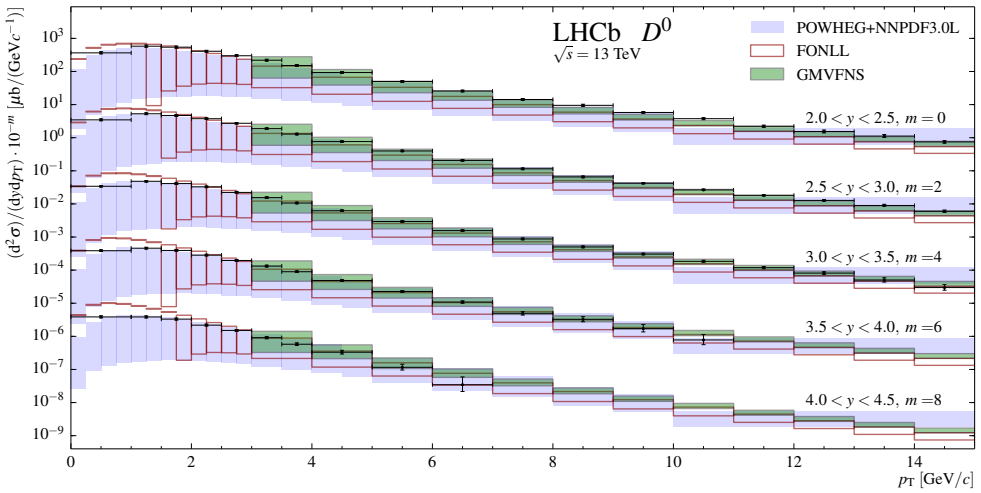
$$\sigma_{from\ b} = 2.36 \pm 0.01(stat) \pm 0.13(syst)\mu b$$

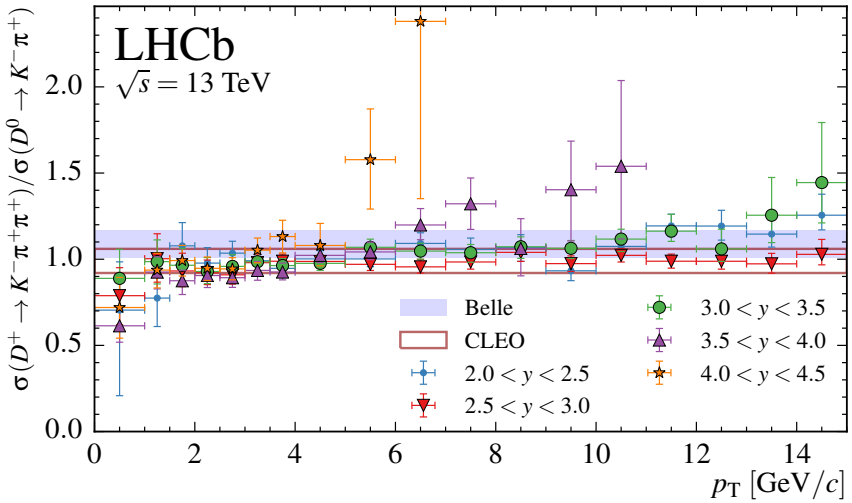
$$\sigma_{pp\to b\bar{b}X} = 512 \pm 2(stat) \pm 53(syst)\mu b^{*}$$

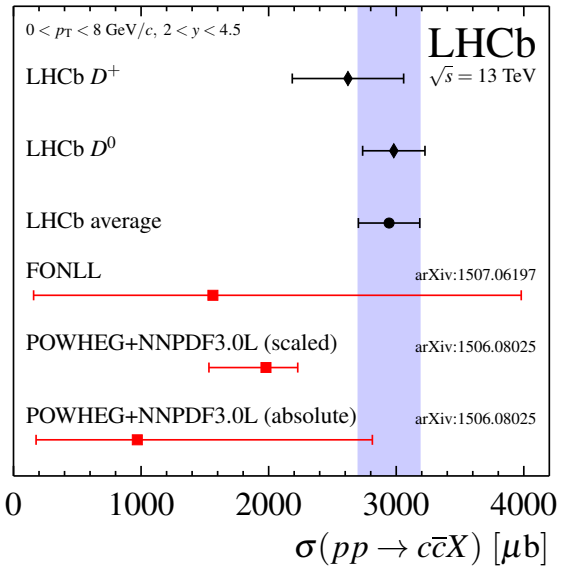
* Integrated $\sigma_{pp\to b\bar{b}X}$ for 4π with extrapolation factor from LHCb tuning of PYTHIA 6

Measured charm production

JHEP 03(2016)159





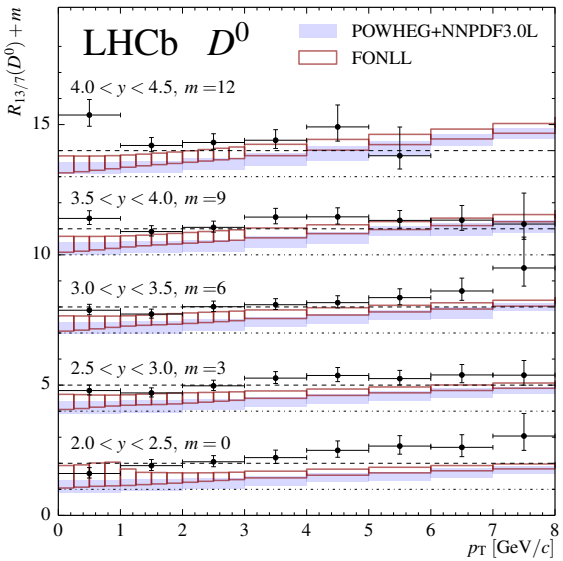


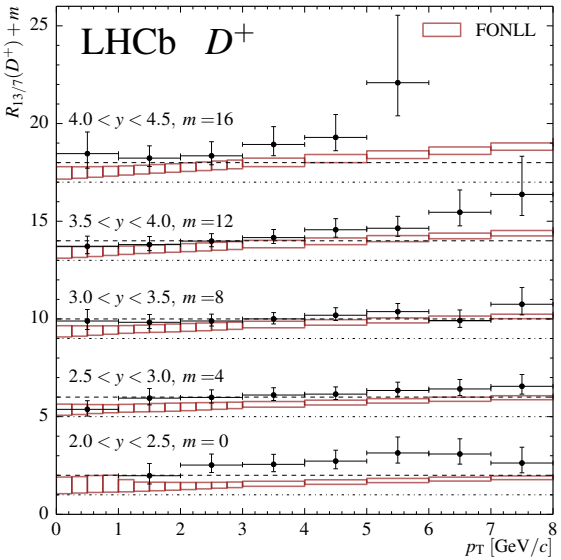
Integrated in $1 < p_T < 8\,\mathrm{GeV}/c$, $2 < y < 4.5$:

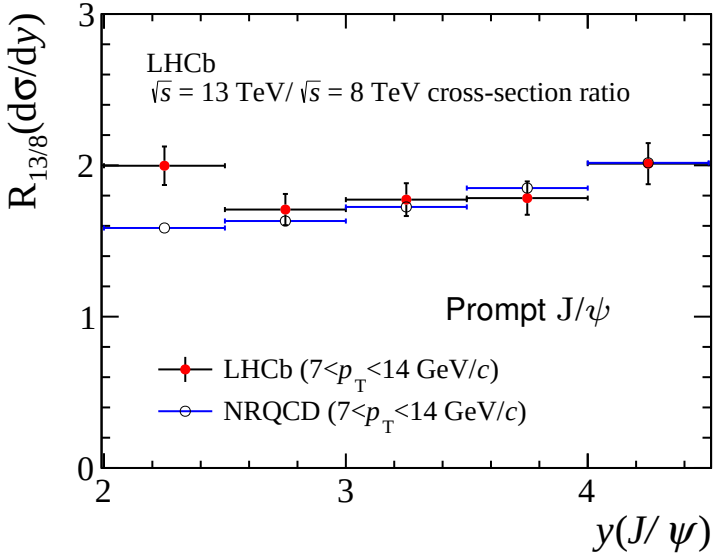
$$\sigma(pp \to D^0 X) = 2460 \pm 3(stat) \pm 130(syst)\mu b$$
$$\sigma(pp \to D^+ X) = 1000 \pm 3(stat) \pm 110(syst)\mu b$$
$$\sigma(pp \to D_s^+ X) = 460 \pm 13(stat) \pm 130(syst)\mu b$$
$$\sigma(pp \to D^{*+} X) = 880 \pm 5(stat) \pm 140(syst)\mu b$$

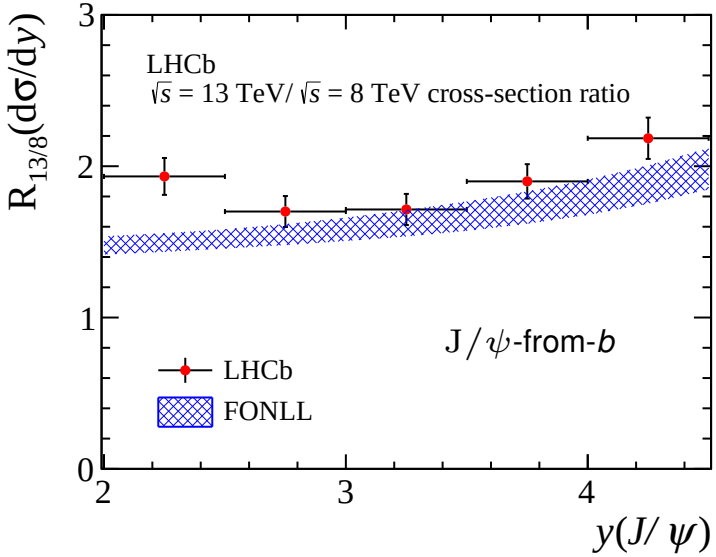
$$\sigma_{pp\to c\bar{c}X}^{p_T<8\,\mathrm{GeV}/c} = 2940 \pm 3(stat) \pm 180(stat) \pm 160(frag)\mu b$$

Comparison with lower energy results









J/ψ data:

13 TeV: *JHEP* 10(2015)172
8 TeV: *JHEP* 06(2013)064

Charm data:

13 TeV: *JHEP* 03 (2016) 159
7 TeV: *Nucl.Phys.B* 871 (2013) 1

Theory:

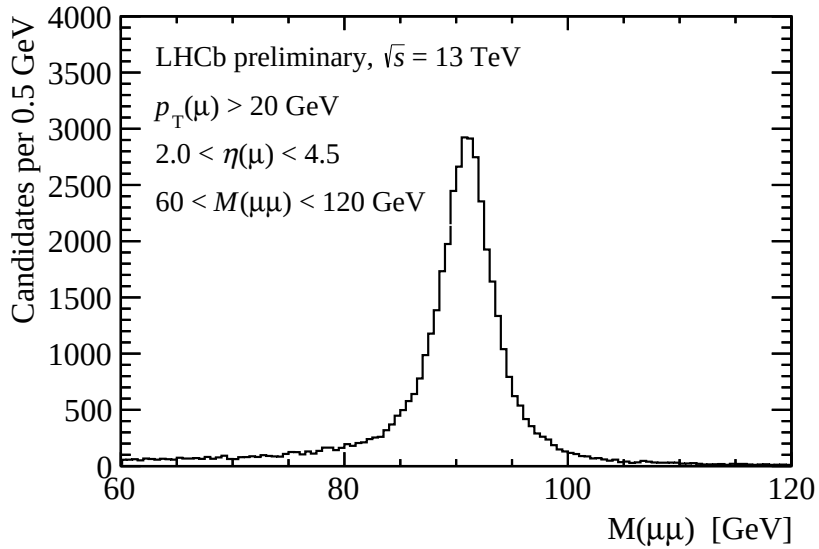
POWHEG: *JHEP* 1511 (2015) 009
FONLL: *Eur.Phys.J* C75.610(2015)
NRQCD: *JHEP* 1505 (2015) 103

Z-boson production. Analysis strategy

LHCb-CONF-2016-02

$$\sigma_{Z\to\mu\mu} = \frac{1}{\mathcal{L}} \times \rho \times f_{\text{FSR}} \times f_{\text{unf}} \times \sum_{j=1}^{N^Z} \frac{1}{\epsilon^j_{\text{REC}}}$$

- Cross-section is defined in $p_{\text{T}} - y - \phi^*_\eta$ bins of Z-boson
- Summation runs over candidates in given bin
- Efficiency ϵ and sample purity ρ are defined by data-driven techniques
- Final state radiation corrections f_{FSR} are estimated using HERWIG ++ and PYTHIA 8
- Possible bin-to-bin migrations are accounted by f_{unf}
- $\mathcal{L} = 294 \pm 11\ \text{pb}^{-1}$



ϕ^*_η [arXiv:1009.1580]

$\delta\phi$ - the azimuthal opening angle between the two leptons

$\cos\theta^*_\eta = \tanh((\eta^- - \eta^+)/2)$

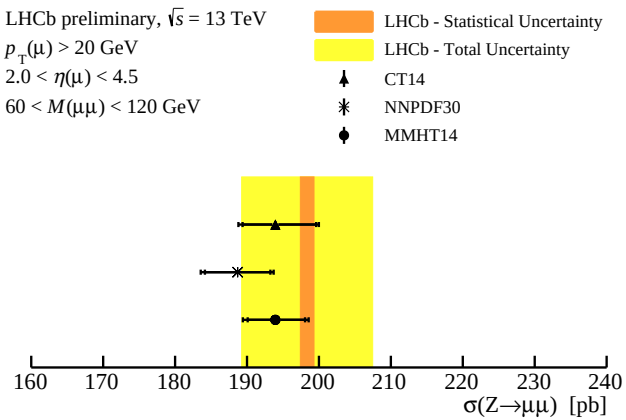
$\phi^*_\eta \equiv \tan((\pi - \delta\phi)/2)\sin\theta^*_\eta$

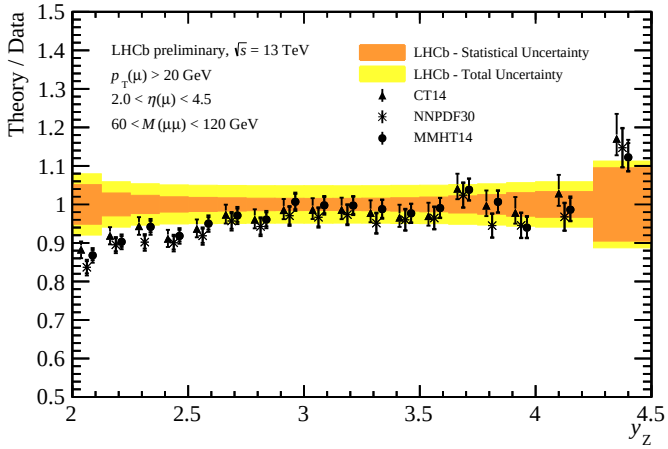
Measured Z-boson production

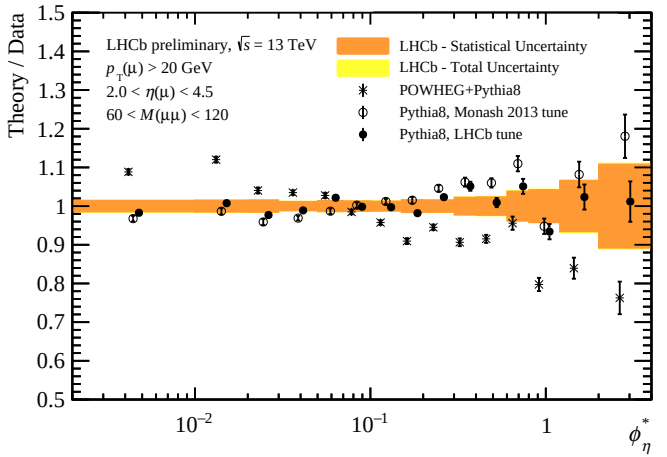
LHCb-CONF-2016-02

Integrated within LHCb acceptance (*preliminary*):

$$\sigma_{Z\to\mu\mu} = 198.4 \pm 1.0(stat) \pm 4.7(syst) \pm 7.7(lum)\ \text{pb}$$







- More data will constraint PDFs
- Data agree better with PYTHIA 8 than with POWHEG + PYTHIA 8
- LHCb tune of PYTHIA 8 does not perform significantly better than Monash 2013 tune

Conclusions

- Major update of the LHCb data-taking sequence is proven to be successful
- Three public measurements at new energy:
  - Measurement of forward J/ψ production cross-sections in *pp* collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ [*JHEP* 10(2015)172]
  - Measurement of prompt charm production cross-section in *pp* collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ [*JHEP* 03(2016)159]
  - Measurement of the $Z \to \mu^+\mu^-$ production cross-section at forward rapidities in pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ [LHCb-CONF-2016-02]
- New sensitivity for tests of QCD predictions

Thank you for attention!

Backup

CMS results on Z-production

CMS PAS SMP-15-011