Photon-hadron Collisions at LHCb

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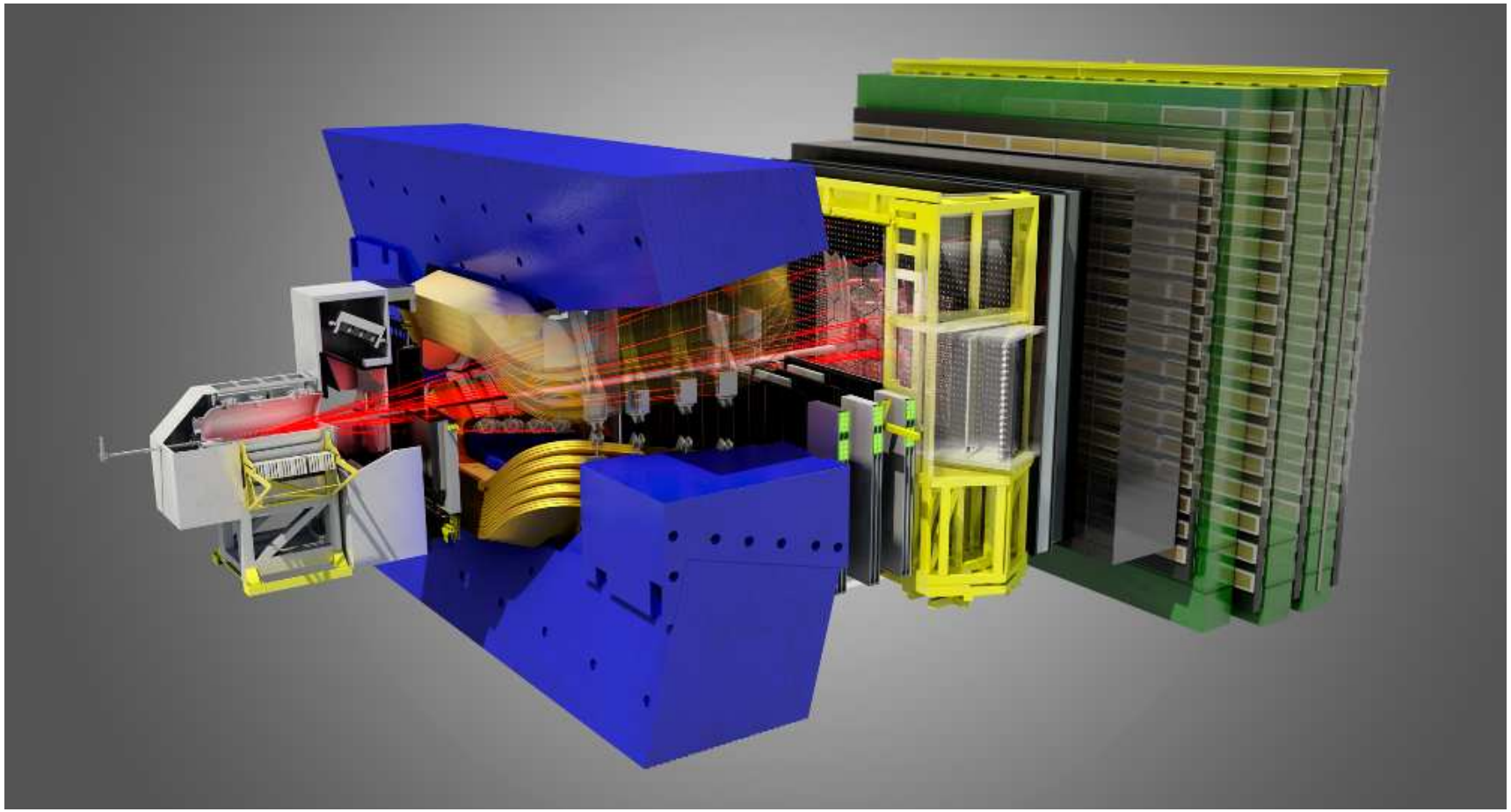
Outline

1. Experiment
2. Exclusive production of ψ
3. Exclusive production of Υ
4. Υ production in pPb collisions
5. Summary

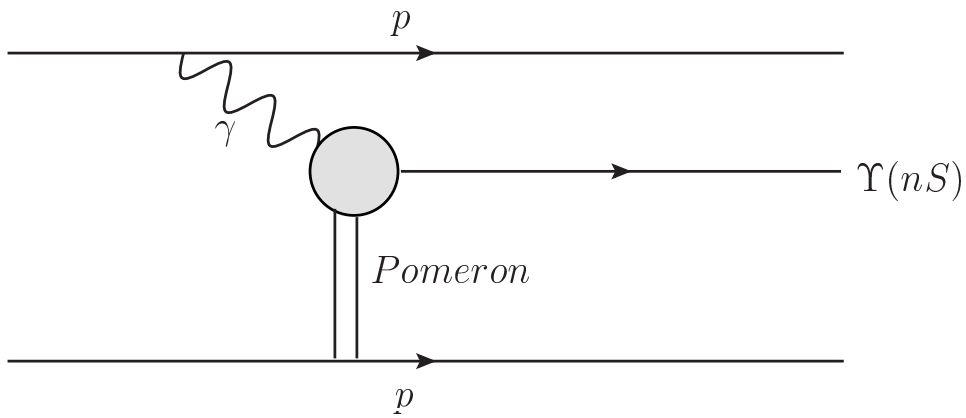
LHCb Experiment – I

- LHCb is a single-arm forward spectrometer at $2 < \eta < 5$ for a study of particles with b or c quarks
- 934 members, 65 Institutes from 17 countries
- 1.0 fb^{-1} at 7 TeV in 2010-2011, 2.0 fb^{-1} at 8 TeV in 2012
- High-precision tracking (silicon strip, straw drift tubes), dipole magnet 4Tm
- Excellent PID based on two RICH detectors
- Muon system (alternating layers of Fe and MWPC)
- Versatile trigger
- Detector described in A. Augusto Alves Jr. et al., JINST 3 (2008) S08005, its performance in R. Aaij et al., IJMPA 30 (2015) 1530022

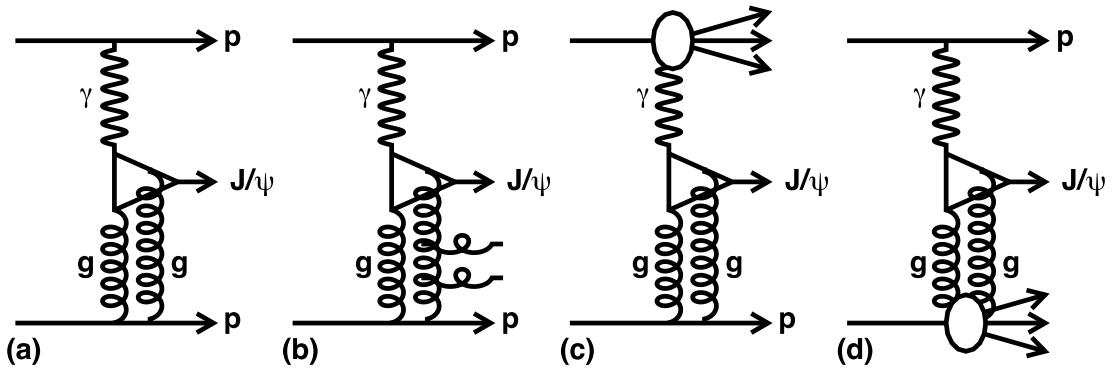
LHCb Experiment – II



Quarkonium Production in pp Collisions



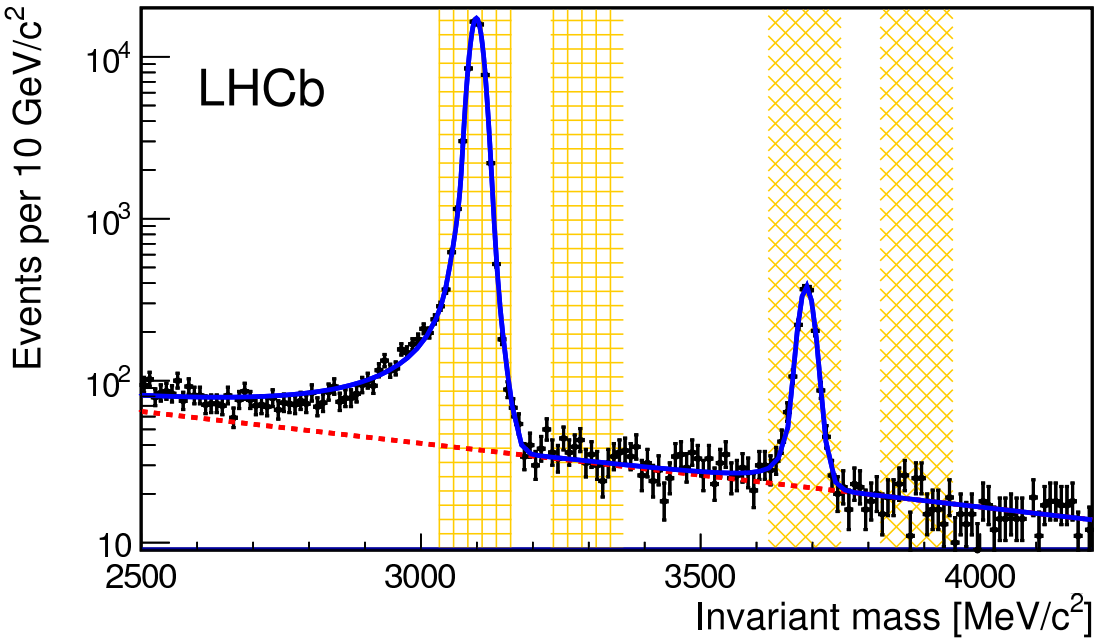
A pomeron (color-singlet system)



Exclusive (a) and inelastic (b,c,d) quarkonium production

Exclusive J/ψ and $\psi(2S)$ Production in pp Collisions at 7 TeV – I

930 pb^{-1} collected at $\sqrt{s}$=7 TeV in 2011, $J/\psi(\psi(2S)) \to \mu^+\mu^-$

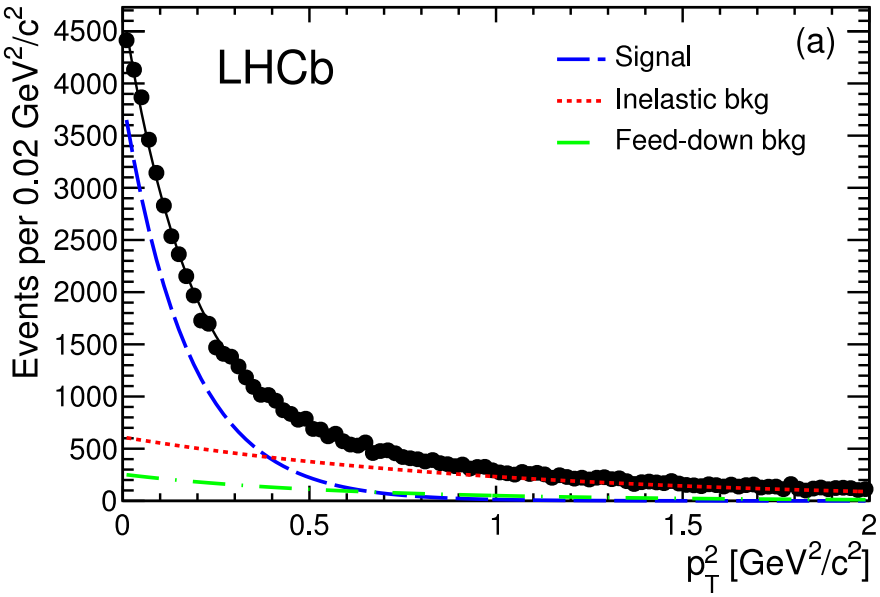


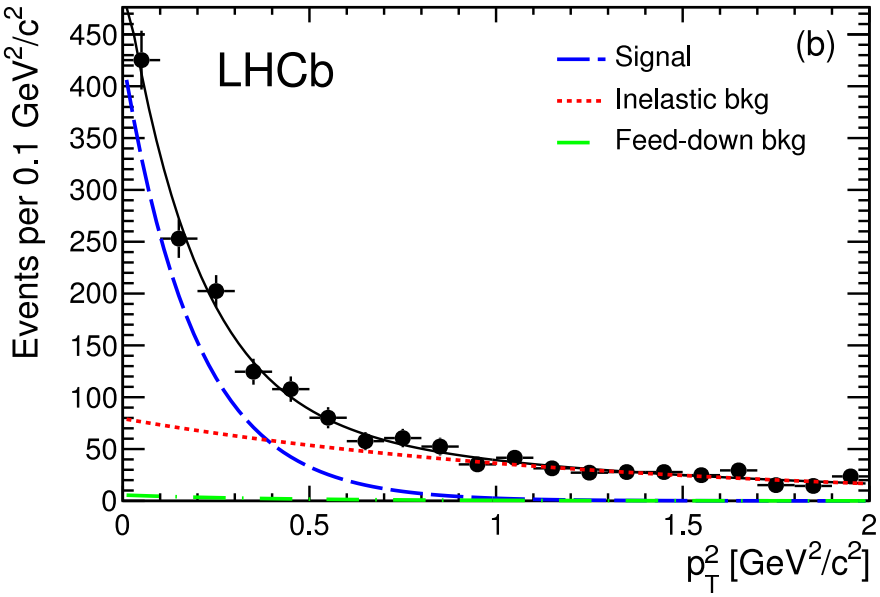
$p_{\rm T}^2 < 0.8$ GeV$^2/c^2$, $|M(\mu^+\mu^-) - M_{J/\psi(\psi(2S))}|$ <65 MeV/c^2,

55985 J/ψ and 1565 $\psi(2S)$ candidates found

R. Aaij et al., JPG 41 (2014) 055002

Exclusive J/ψ and $\psi(2S)$ Production in pp Collisions at 7 TeV – II

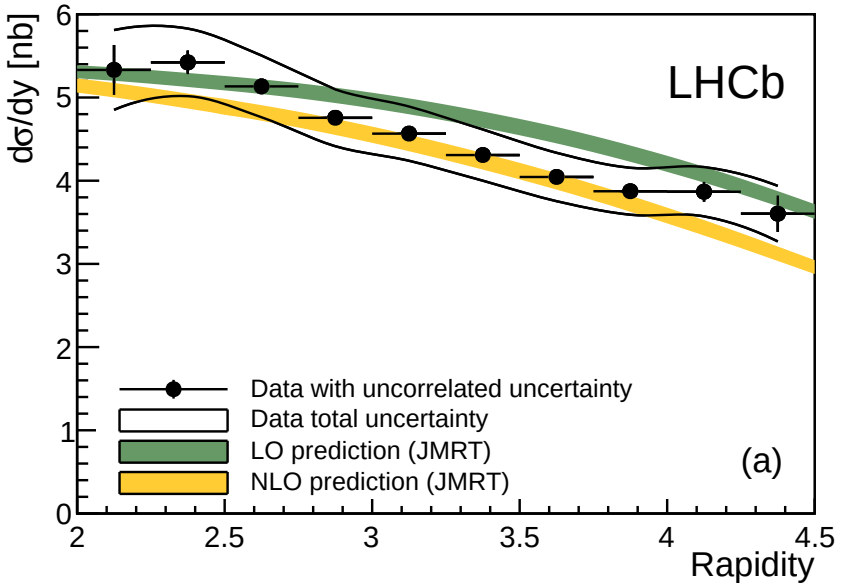




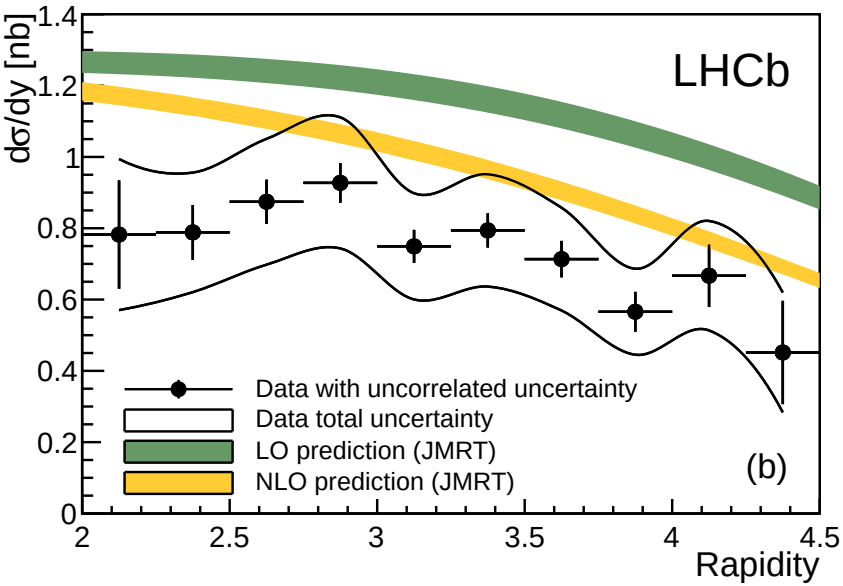
3 BG sources: non-resonant $\mu^+\mu^-$, feed-down from $\chi_c \to J/\psi\gamma$ and $\psi(2S)$, inelastic interactions (one or both protons dissociate)

R. Aaij et al., JPG 41 (2014) 055002

Exclusive J/ψ and $\psi(2S)$ Production in pp Collisions at 7 TeV – III



$(291 \pm 7 \pm 19)$ (282) pb

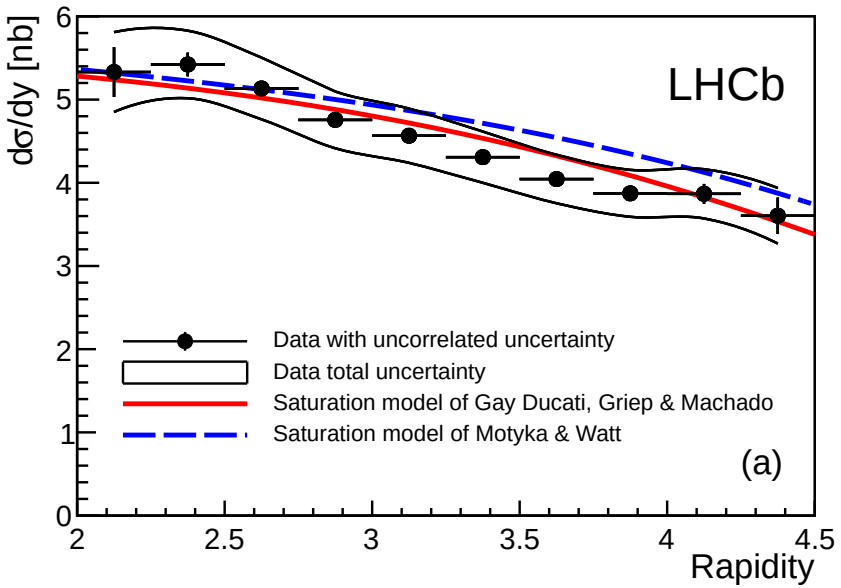


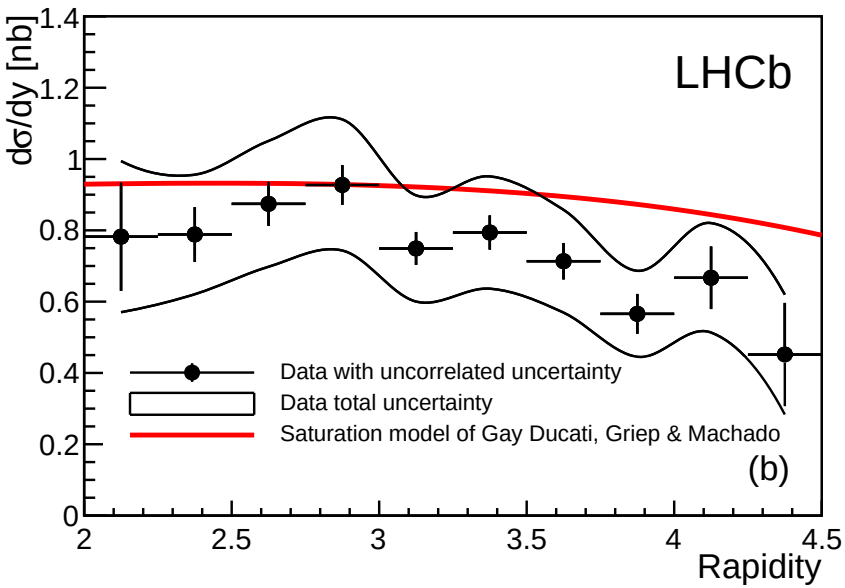
$(6.5 \pm 0.9 \pm 0.4)$ (8.3) pb

JMRT: S. Jones et al., JHEP 11 (2013) 085, extrapolated from HERA

LHCb: R. Aaij et al., JPG 41 (2014) 055002

Exclusive J/ψ and $\psi(2S)$ Production in pp Collisions at 7 TeV – IV

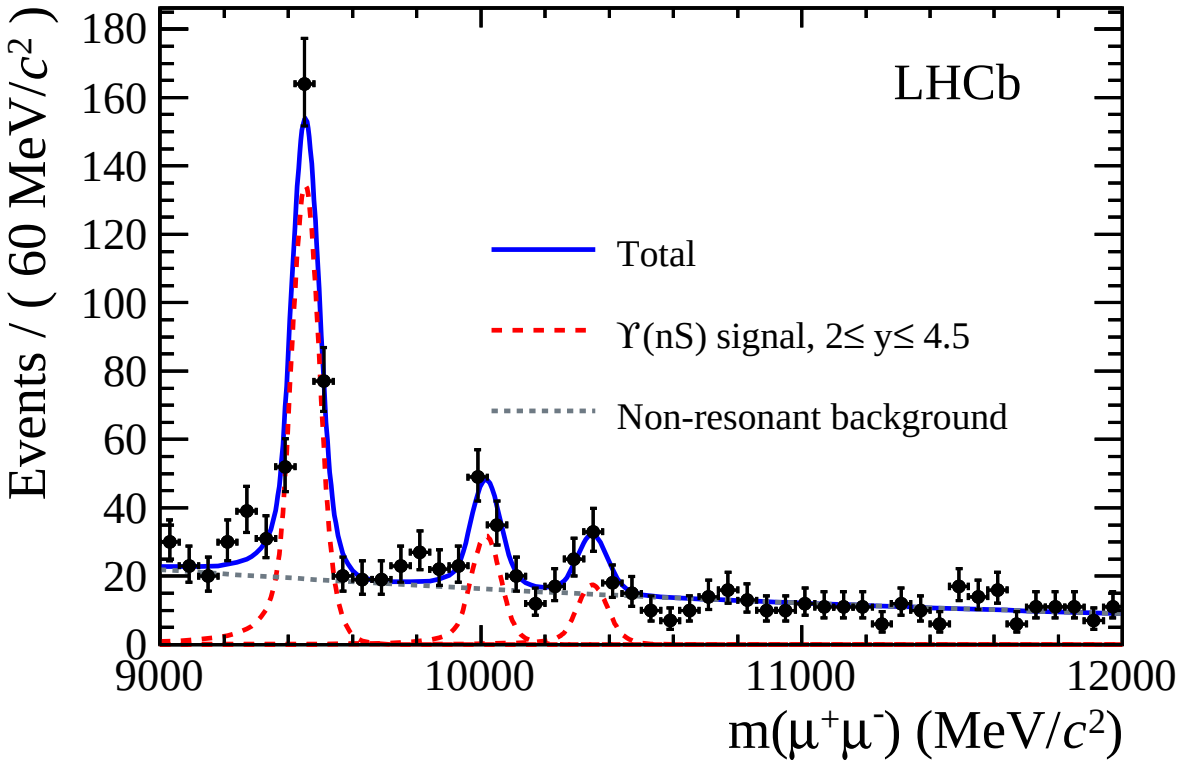




M.B. Gay Ducati et al., Phys. Rev. D 88 (2013) 017504

R. Aaij et al., JPG 41 (2014) 055002

Exclusive Υ Production in pp Collisions at 7 and 8 TeV – I



2.9 fb^{-1} at 7 and 8 TeV combined to increase statistics

$\Upsilon(nS) \to \mu^+\mu^-$ with $2 < \eta(\mu^\pm) < 4.5,\ 2 < y(\Upsilon(nS)) < 4.5$

R. Aaij et al., arXiv:1505.08139

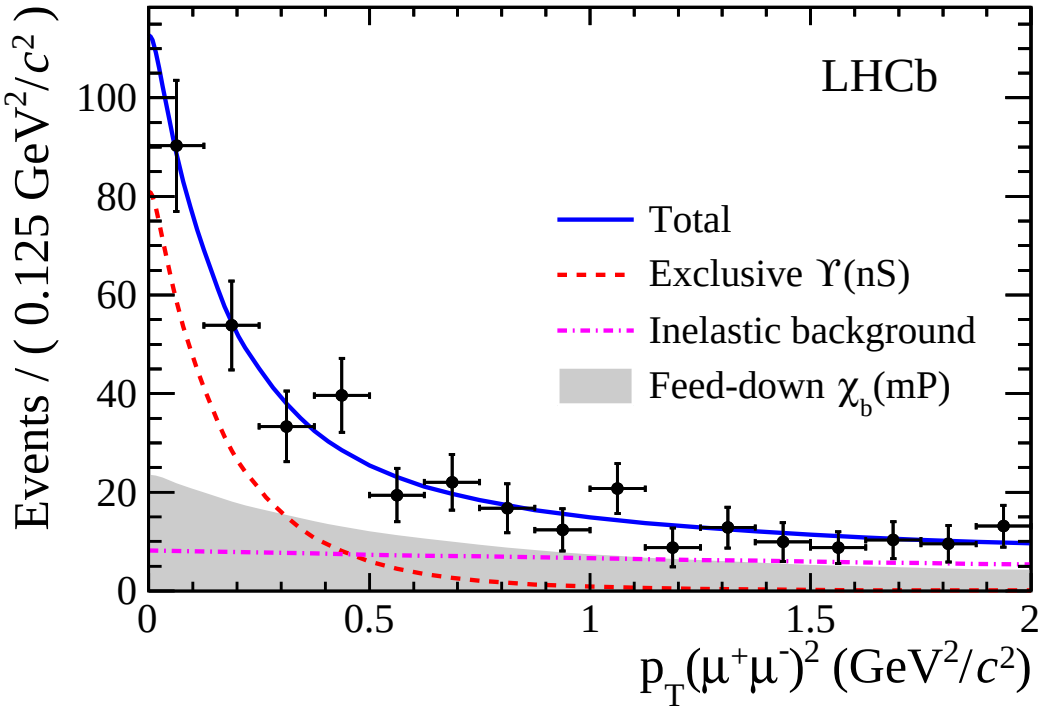
Exclusive Υ Production in pp Collisions at 7 and 8 TeV – II

Raw uncorrected yields

$y(\Upsilon)$	$2 < y < 4.5$	$2 < y < 3$	$3 < y < 3.5$	$3.5 < y < 4.5$
$N(\Upsilon(1S, 2S, 3S))$	382 ± 26	146 ± 16	133 ± 16	94 ± 14
$\Upsilon(1S)$ fraction	0.71 ± 0.03	0.74 ± 0.05	0.72 ± 0.06	0.68 ± 0.07
$\Upsilon(2S)$ fraction	0.18 ± 0.03	0.16 ± 0.04	0.15 ± 0.05	0.26 ± 0.06

R. Aaij et al., arXiv:1505.08139

Exclusive Υ Production in pp Collisions at 7 and 8 TeV – III



3 BG sources: non-resonant $\mu^+\mu^-$, feed-down from $\chi_b \to \Upsilon\gamma$, inelastic interactions

After feed-down subtraction inelastic BG from the $p_{\rm T}^2$

R. Aaij et al., arXiv:1505.08139

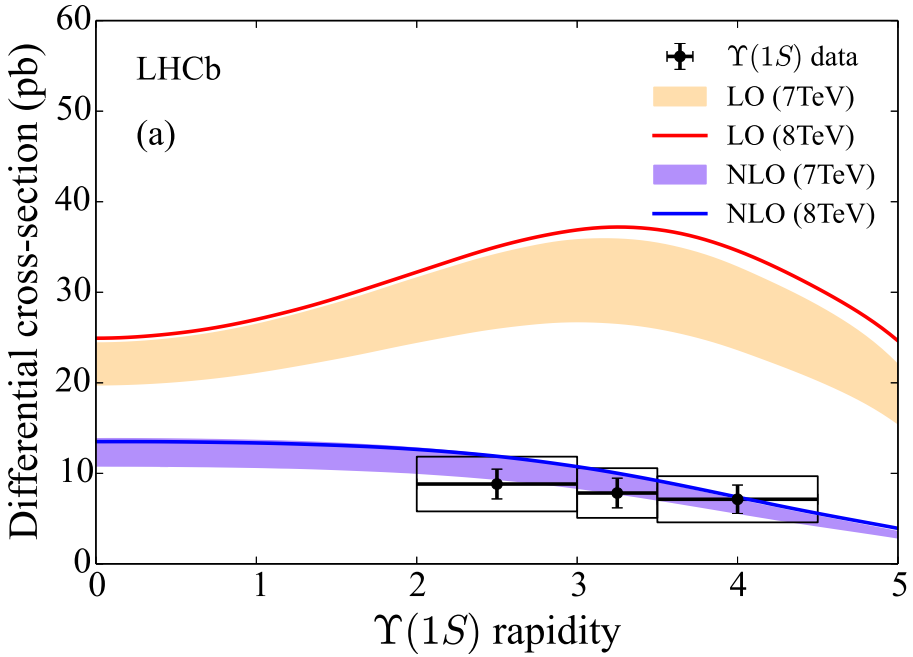
Exclusive Υ Production in pp Collisions at 7 and 8 TeV – IV

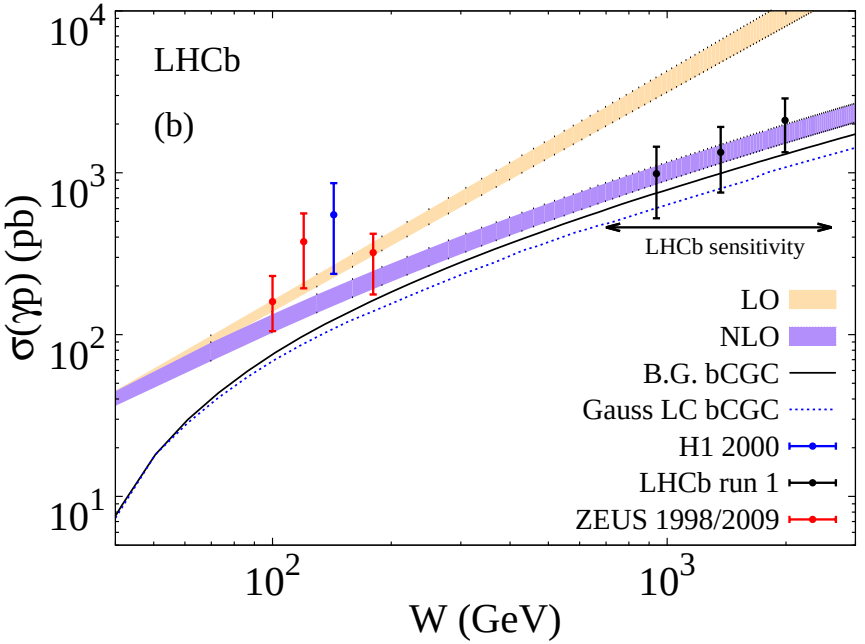
Process	σ, pb
$pp \to p\Upsilon(1S)p$	$9.0 \pm 2.1 \pm 1.7$
$pp \to p\Upsilon(2S)p$	$1.3 \pm 0.8 \pm 0.3$
$pp \to p\Upsilon(3S)p$	< 3.4 at 95%CL

The differential cross section (in y bins) is also obtained

R. Aaij et al., arXiv:1505.08139

Exclusive Υ Production in pp Collisions at 7 and 8 TeV – V



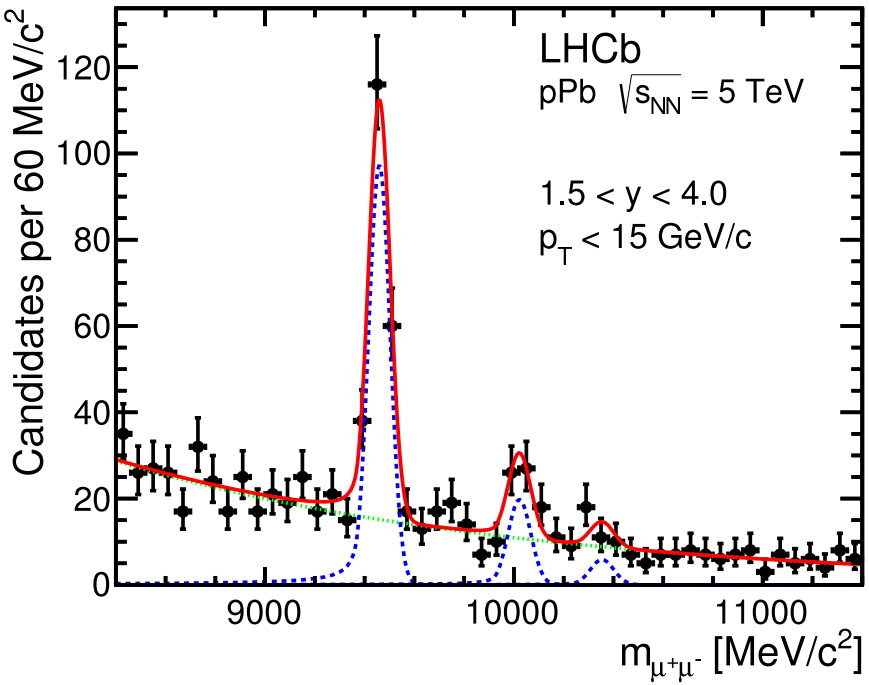


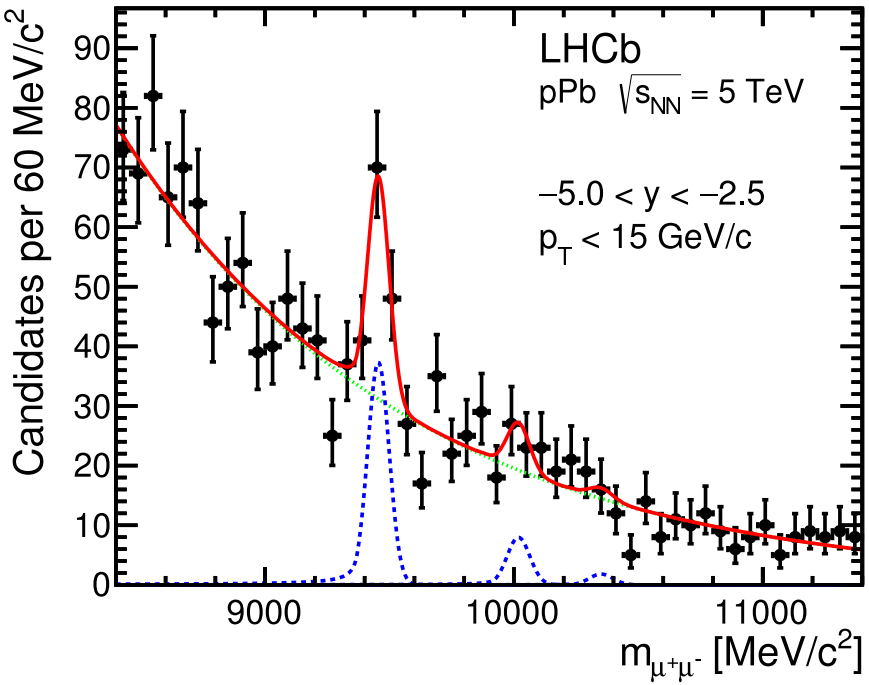
Good agreement of the differential σ with the NLO prediction

The photoproduction cross section discriminates between the LO and NLO, agrees with NLO and other models accounting for t dependence

R. Aaij et al., arXiv:1505.08139

Study of Υ Production in pPb Collisions at $\sqrt{s_{NN}}$ =5 TeV – I





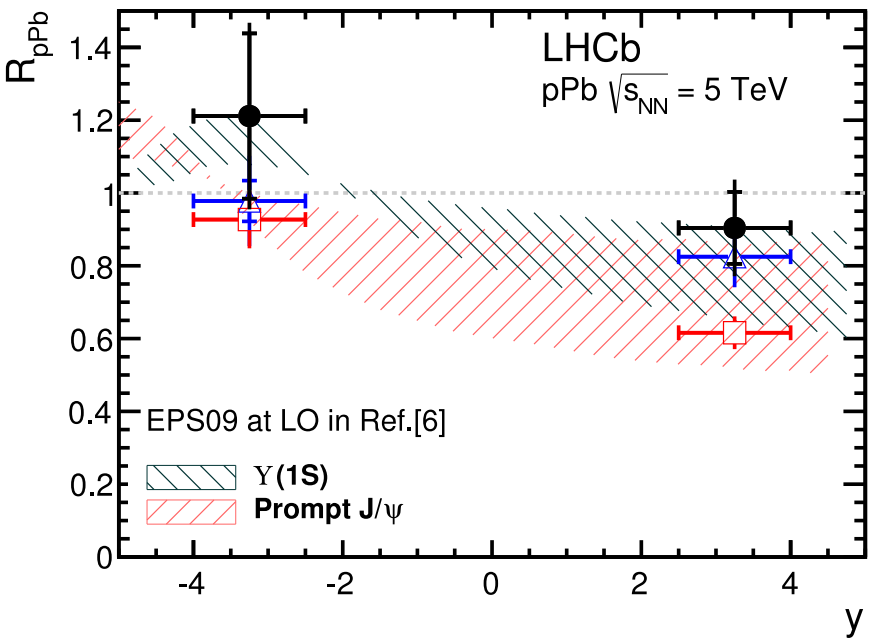
1.1 nb^{-1} (0.5 nb^{-1}) for forward (backward) collisions

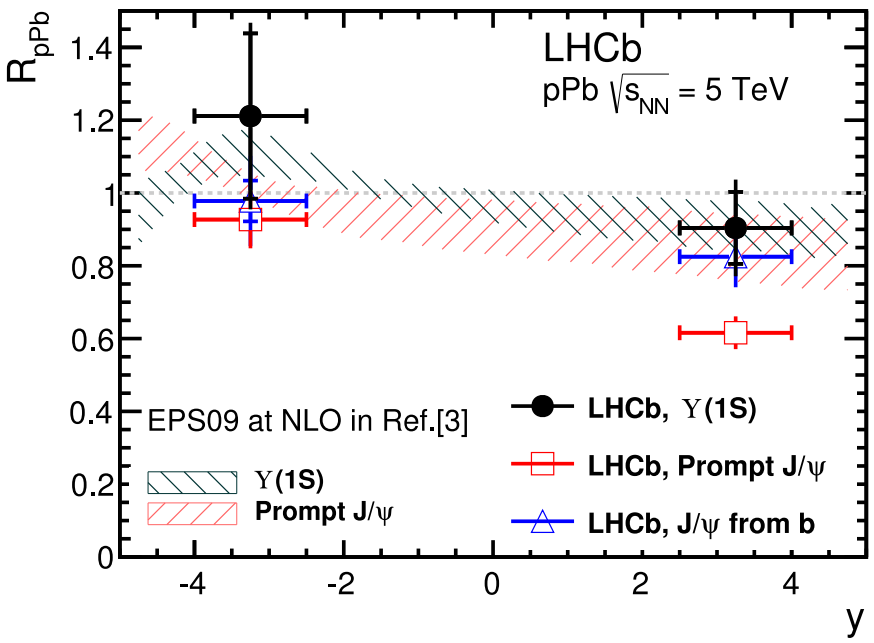
189 ± 16 (72 ± 14), 41 ± 9 (17 ± 10), 13 ± 7 (4 ± 8) for $\Upsilon(1,2,3S)$

Yield of $\Upsilon(1S)$ with $2.5 < |y| < 4.0$: 122 ± 13 (70 ± 13) for f(b) collisions

R. Aaij et al., JHEP 1407 (2014) 094

Study of Υ Production in pPb Collisions at $\sqrt{s_{NN}}$ =5 TeV – II





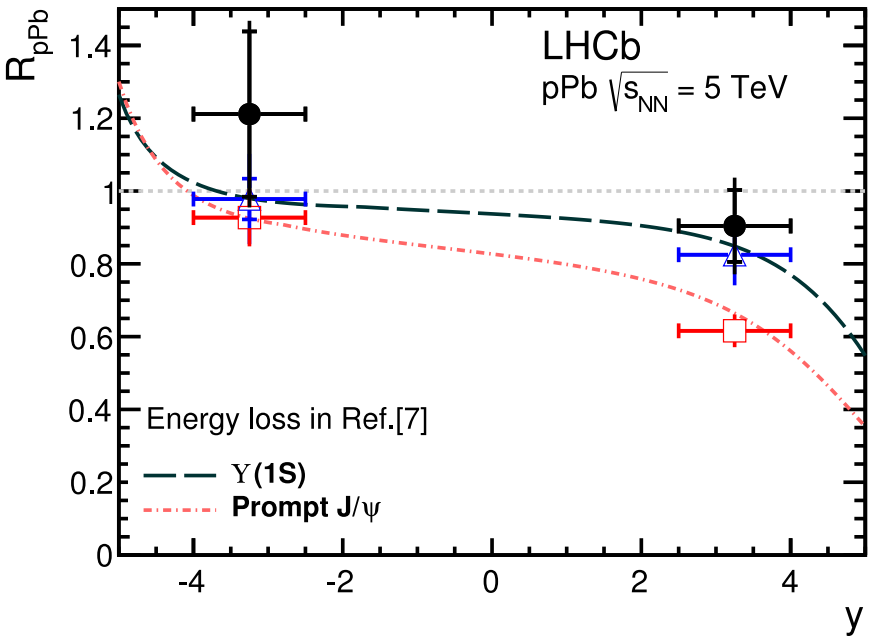
Nuclear modification factor $R_{p\mathrm{Pb}}(\sqrt{s_{NN}}) \equiv \sigma_{p\mathrm{Pb}}(\sqrt{s_{NN}})/(A \times \sigma_{pp}(\sqrt{s_{NN}}))$

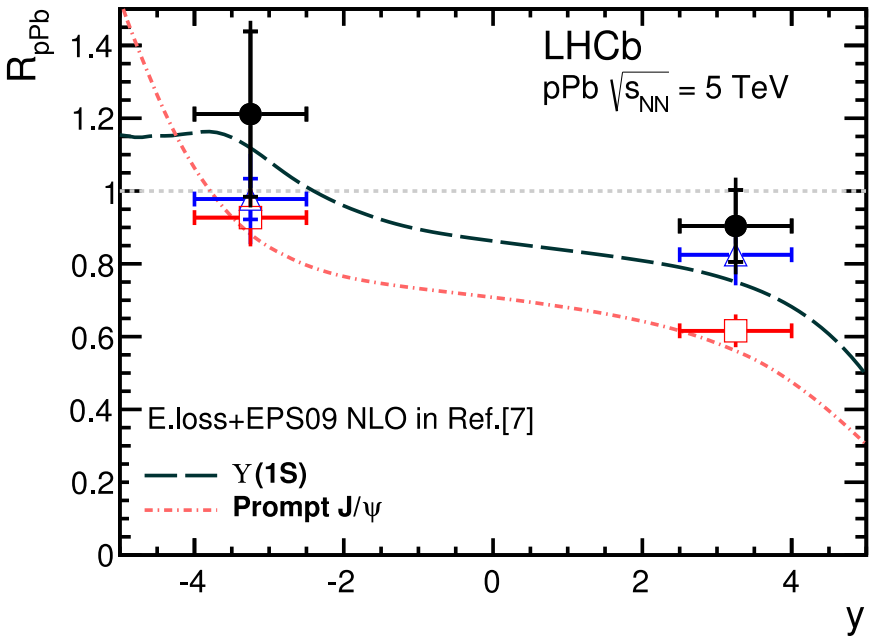
$R_{p\mathrm{Pb}}(\Upsilon(1S), -4.0 < |y| < -2.5) = 1.21 \pm 0.23 \pm 0.12,$

$R_{p\mathrm{Pb}}(\Upsilon(1S), 2.5 < |y| < 4.0) = 0.90 \pm 0.10 \pm 0.09,$

R. Aaij et al., JHEP 1407 (2014) 094

Study of Υ Production in pPb Collisions at $\sqrt{s_{NN}}$ =5 TeV – III

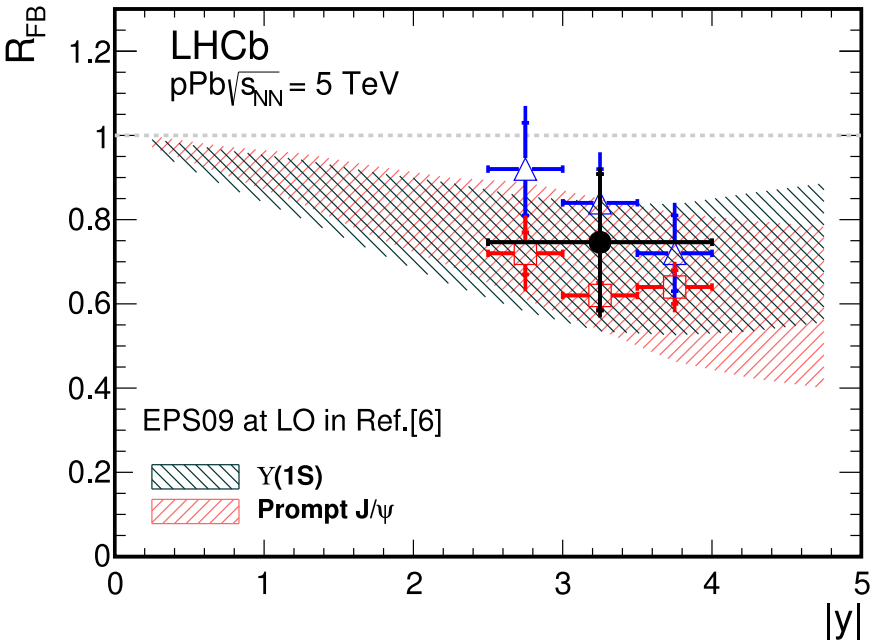


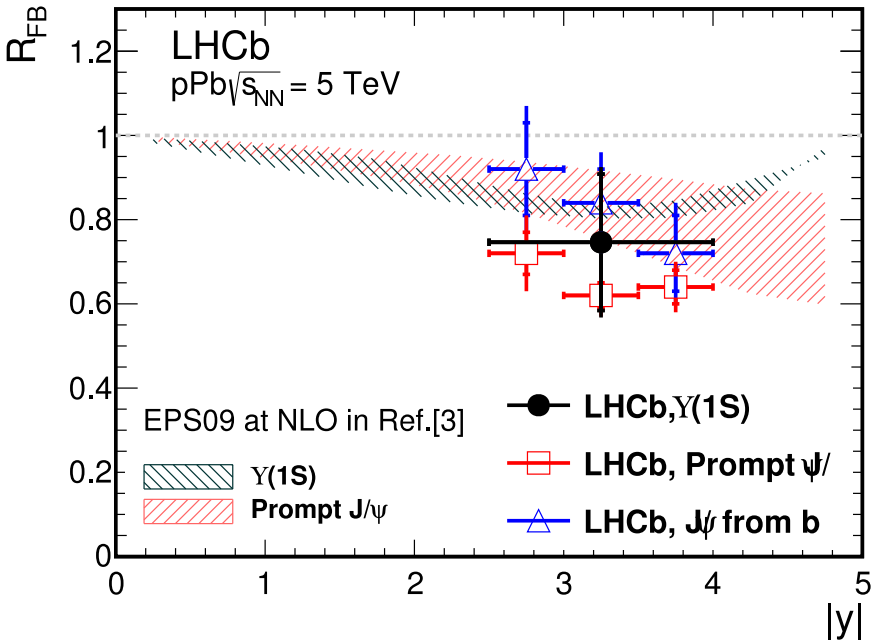


Suppression of $\Upsilon(1S)$ in the forward region smaller than J/ψ, enhancement in backward due to antishadowing

R. Aaij et al., JHEP 1407 (2014) 094

Study of Υ Production in pPb Collisions at $\sqrt{s_{NN}}$ =5 TeV – IV





F(B) production ratio: $R_{\rm FB}(\sqrt{s_{NN}},|y|) \equiv \sigma(\sqrt{s_{NN}},+|y|)/\sigma(\sqrt{s_{NN}},-|y|)$

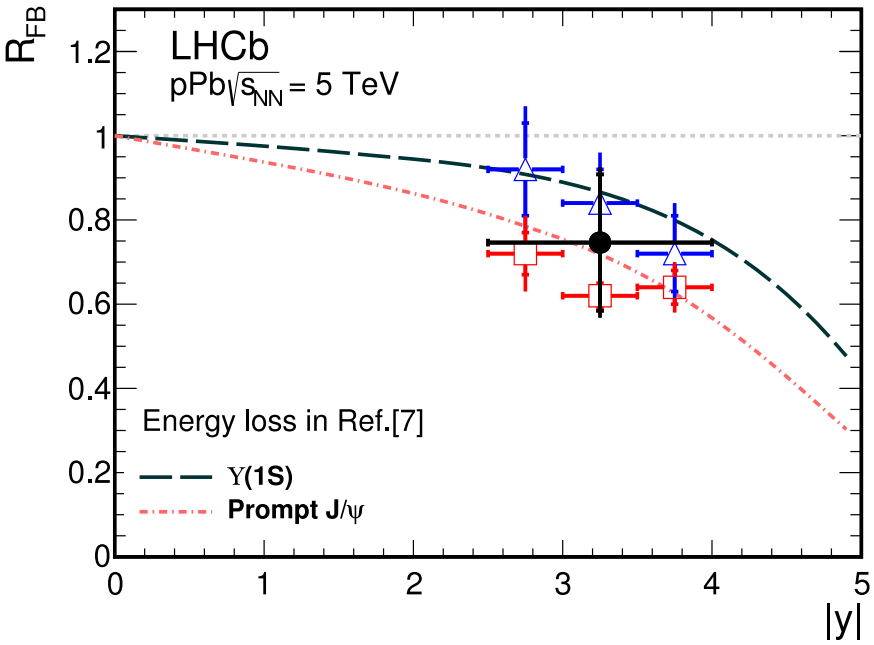
$R_{\rm FB}(2.5<|y|<4.0) = 0.75 \pm 0.16 \pm 0.08$

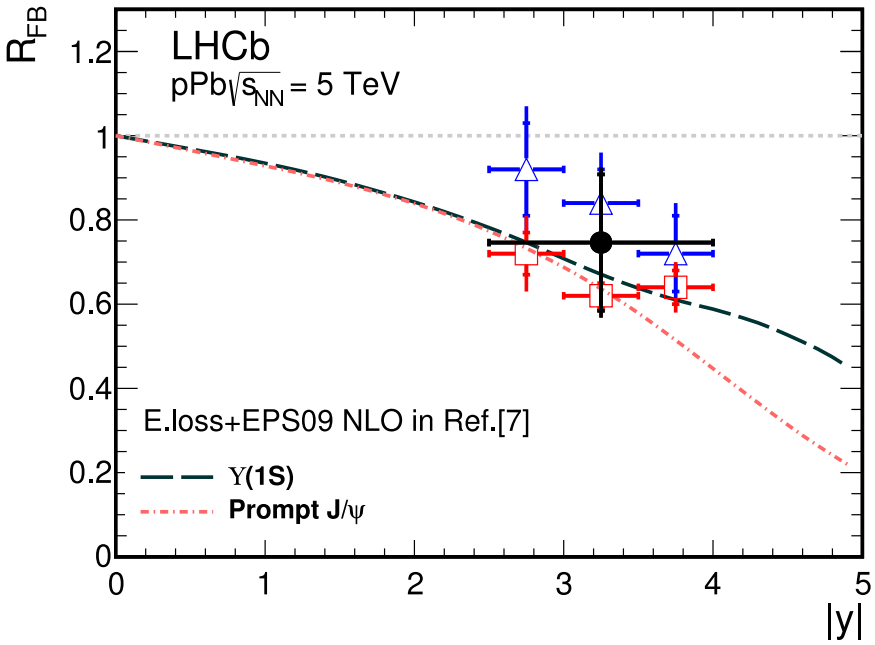
LO: G.A. Chirilli et al., Phys. Rev. D 86 (2012) 054005;

NLO: F. Arleo et al., JHEP 1303 (2013) 122

LHCb: R. Aaij et al., JHEP 1407 (2014) 094

Study of Υ Production in pPb Collisions at $\sqrt{s_{NN}}$ =5 TeV – V





Theory: G.A. Chirilli et al., 1209.1614

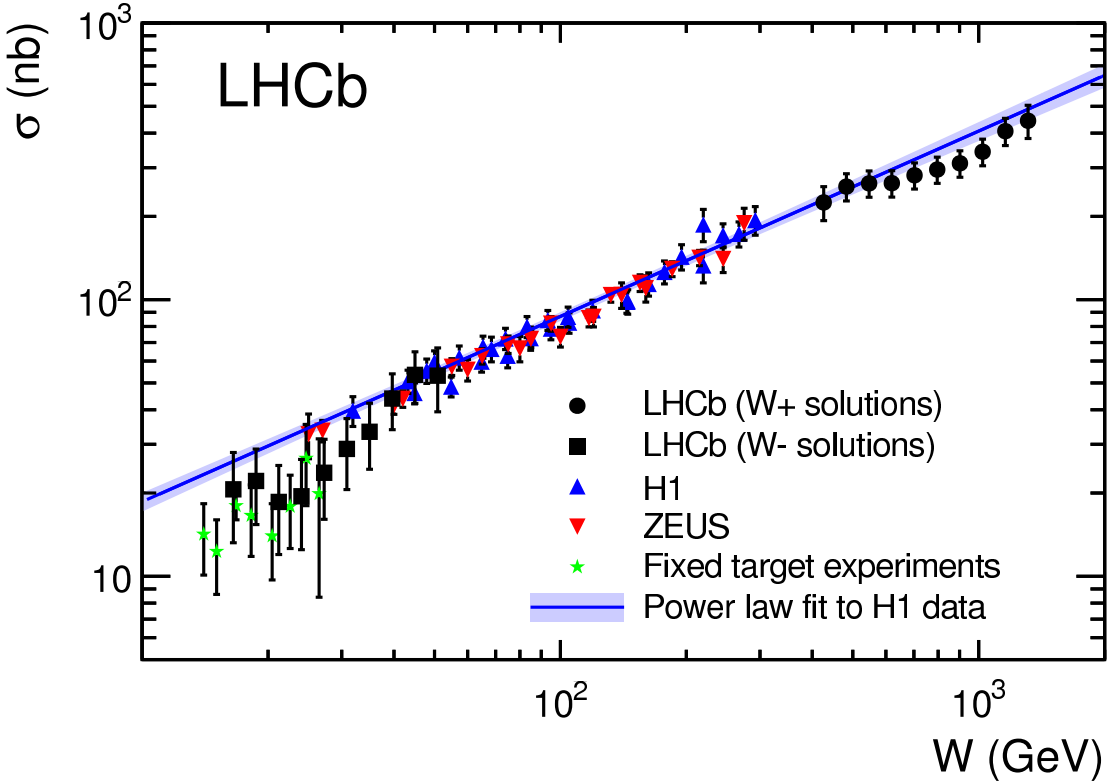
LHCb: R. Aaij et al., JHEP 1407 (2014) 094

Summary

- Exclusive J/ψ and $\psi(2S)$ production at 7 TeV studied, good agreement with the NLO predictions shown
- The first measurement of exclusive $\Upsilon(nS)$ production performed in a new kinematic region of pp collisions at 7 and 8 GeV, LO and NLO separated, agreement with NLO and refined models
- Production of Υ mesons was studied in pPb collisions at $\sqrt{s_{NN}}$= 5 TeV, nuclear modification factor and forward-backward asymmetry measured, first measurement of excited Υ's - $\Upsilon(2S)$ and $\Upsilon(3S)$ - performed, suppression of Υ in the forward region is smaller than for prompt J/ψ

Backup slides

Exclusive J/ψ and $\psi(2S)$ Production in pp Collisions at 7 TeV – IV



The power law: $\sigma_{\gamma p \to J/\psi p} = 81(W/90\text{GeV})^{0.67}$ nb,

H1: C. Alexa et al., Eur. Phys. J. C 73 (2013) 2466

LHCb: R. Aaij et al., JPG 41 (2014) 055002