Measurement of the $\Upsilon(nS)$ production cross-section at $\sqrt{s} = 13$ TeV at LHCb

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On behalf of the LHCb collaboration

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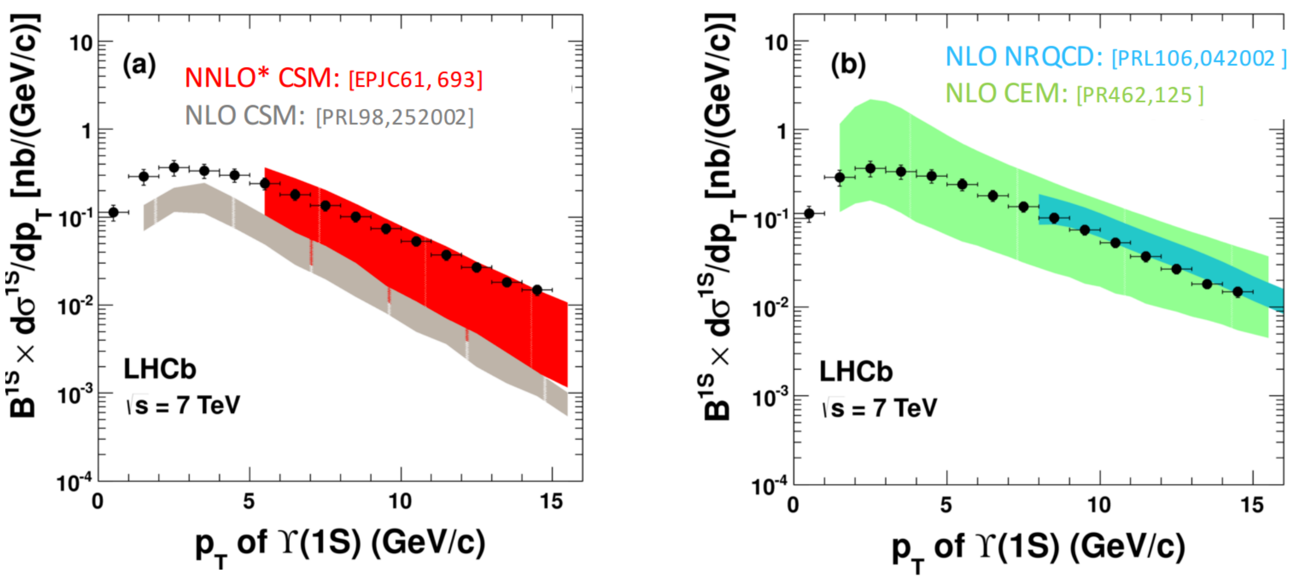
Outline

- Introduction
- LHCb detector
- Analysis strategy
- Results
- Summary

Introduction

- Heavy quarkonia production probing QCD.
- Sensitive to PDFs and fragmentation functions: non perturbative.
- Test models:
  - Colour evaporation model (CEM)
  - Colour-singlet model (CSM)
  - Non-relativistic QCD (NRQCD)

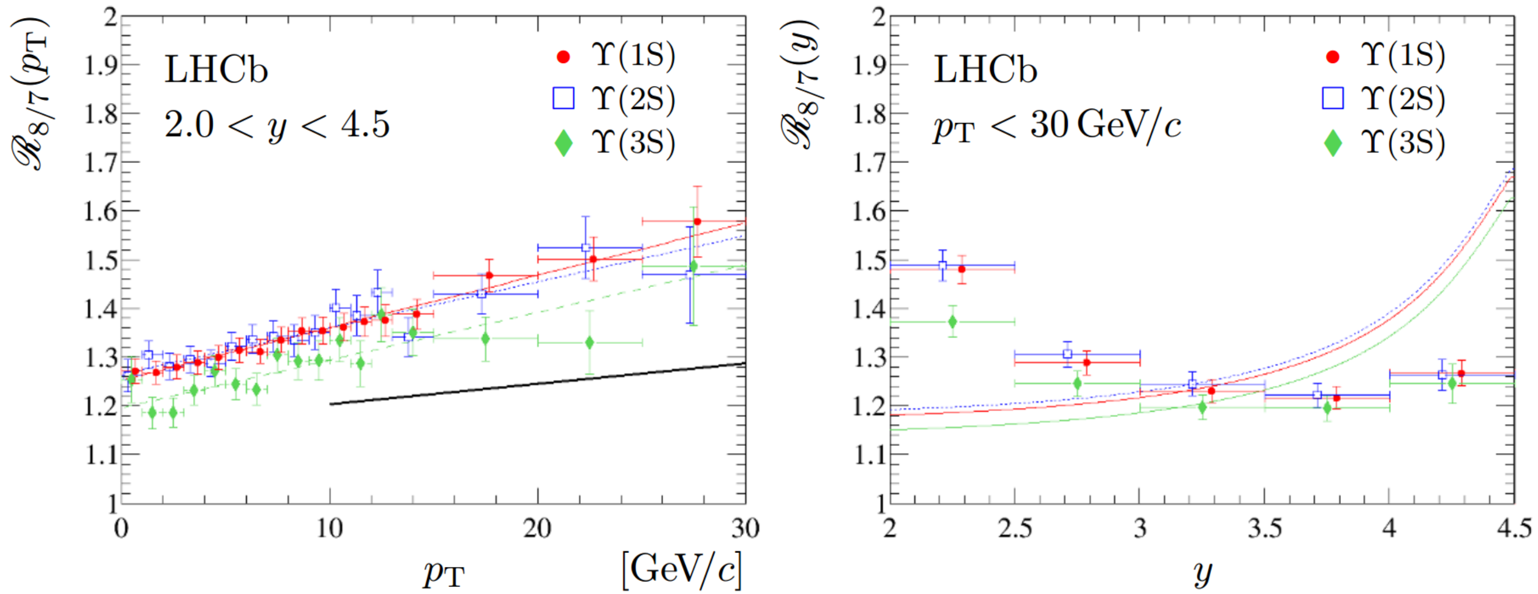
Eur. Phys. J. C72 (2012) 2025



Introduction

- The ratios, more precise, more constraints on theoretical models.

JHEP 11 (2015) 103



  - NRQCD underestimate the ratio with p_T
  - Different trends with y for CO mechanism only and data
- LHCb is a b/c factory with special acceptance, ideal place to study.

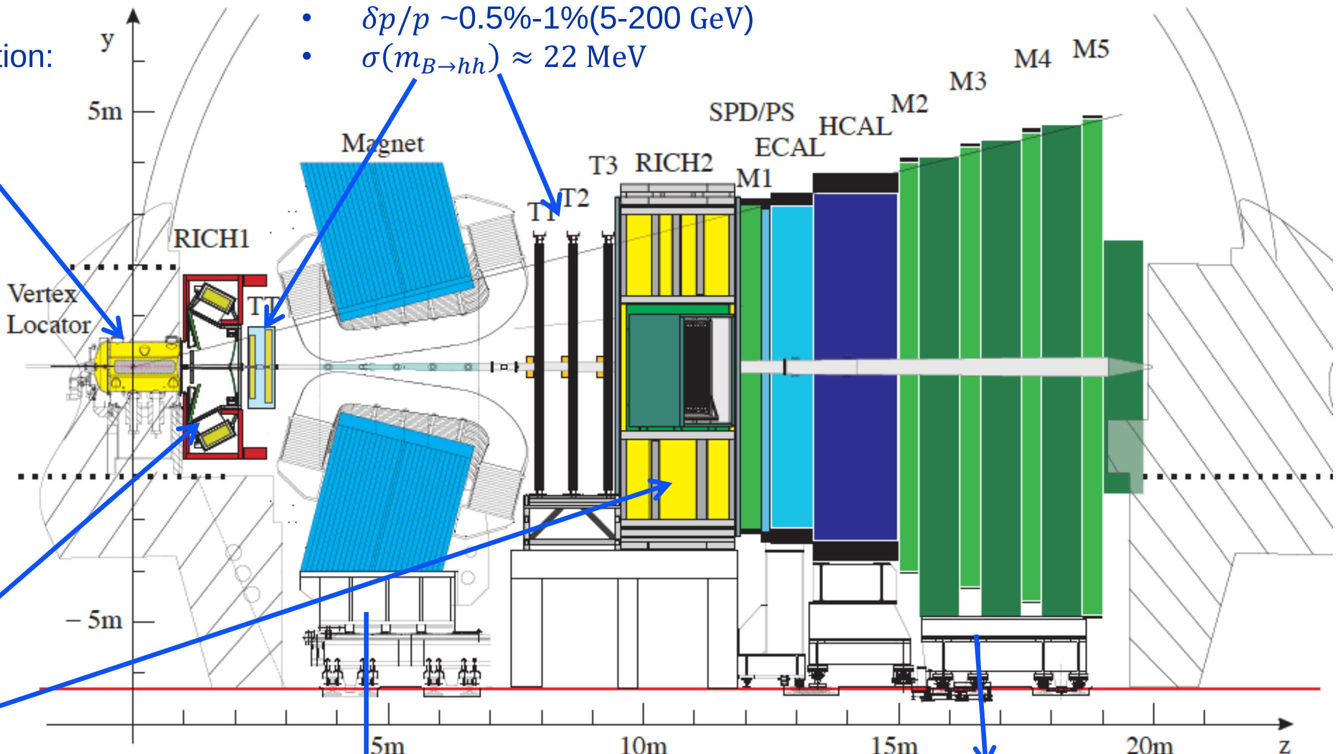
LHCb detector

- Aiming for precision measurements in b, c flavor sectors.
- Cover forward region $2 < \eta < 5$.

JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

Vertex Locator(vertex reconstruction)
- Impact parameter resolution: $20\ \mu\text{m}$
- Decay time resolution: 45 fs (τ_B~1.5 ps)

Tracking system(particle reconstruction)
- ϵ(Tracking) ~96%
- $\delta p/p$ ~0.5%-1%(5-200 GeV)
- $\sigma(m_{B\to hh}) \approx 22$ MeV



RICH: particle ID
- $\varepsilon(K \to K)$ ~95%
- Mis-ID: $\varepsilon(\pi \to K)$ ~5%

Magnet
Bending power: 4 Tm

Muon system
- μ ID: $\varepsilon(\mu \to \mu)$ ~97%
- Mis-ID: $\varepsilon(\pi \to \mu)$ ~1-3%

Analysis strategy

- With the 2015 pp collision data ($277 \pm 11\ \mathrm{pb}^{-1}$).
- Measure the production cross-sections of $\Upsilon(nS)$ (n=1,2,3) as a function of p_{T} ($0 < p_{\mathrm{T}} < 30\ \mathrm{GeV}/c$) and y ($2.0 < y < 4.5$).
- Double differential cross-sections:

$$\frac{\mathrm{d}^2\sigma_{\Upsilon}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \times \mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-) = \frac{N(\Upsilon(nS) \to \mu^+\mu^-)}{\mathcal{L} \cdot \varepsilon \cdot \Delta y \cdot \Delta p_{\mathrm{T}}}$$

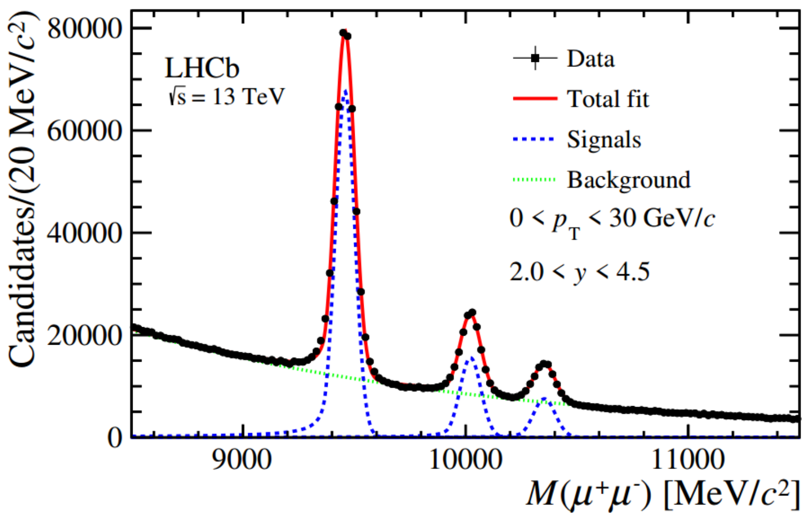
  - N: number of signals in a given bin.
  - $\mathcal{L}$: integrated luminosity.
  - ε: total efficiency in a given bin.
  - Δy, Δp_{T}: bin width (Δy=0.5, Δp_{T}=1 GeV/c).

- Measure the cross-section ratios between different states and between different energies.

Signal yields and efficiency

➢ Signal yields:

JHEP 07(2018) 134

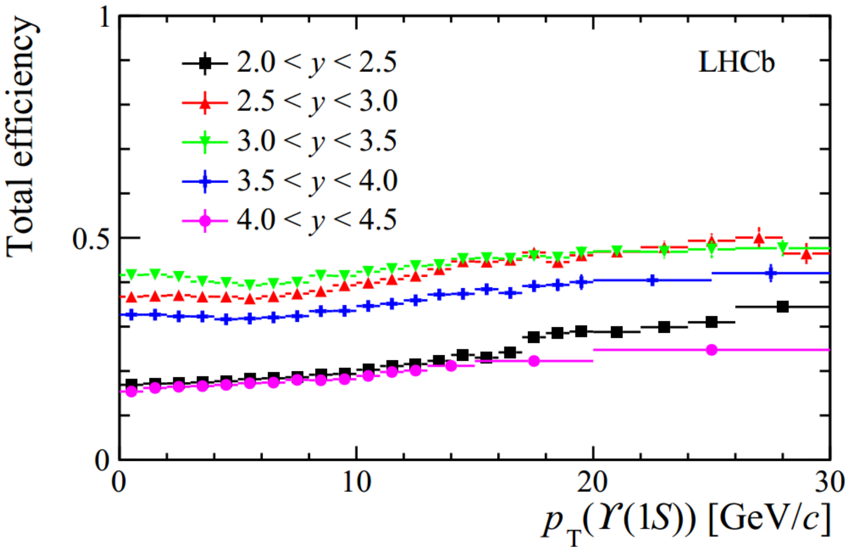


Unbinned maximum likelihood fit.

N($\Upsilon(1S)$): ~400k
N($\Upsilon(2S)$): ~100k
N($\Upsilon(3S)$): ~50k

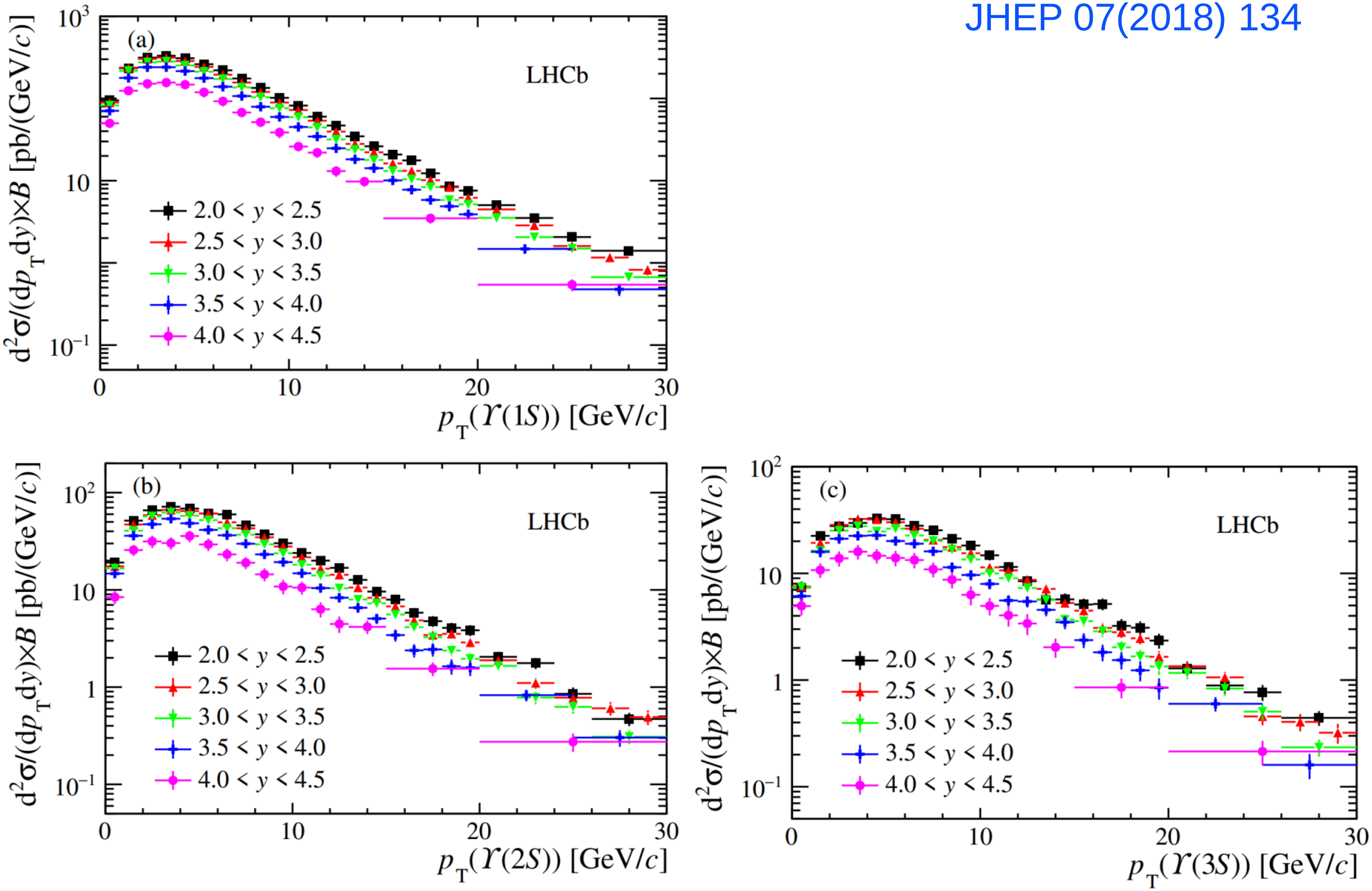
➢ Total efficiency:

Based on simulation and corrected with control data.



Double differential cross-sections (p_{T}, y)

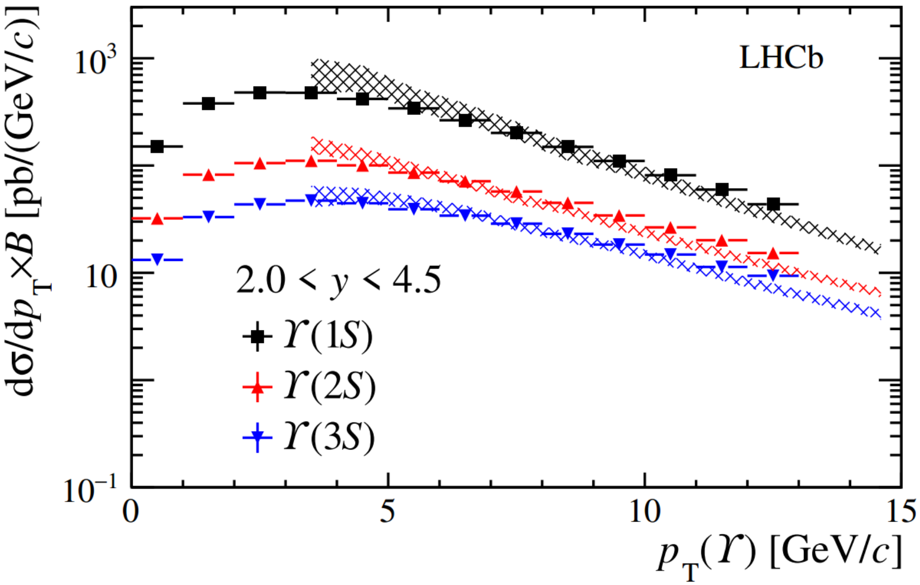
JHEP 07(2018) 134

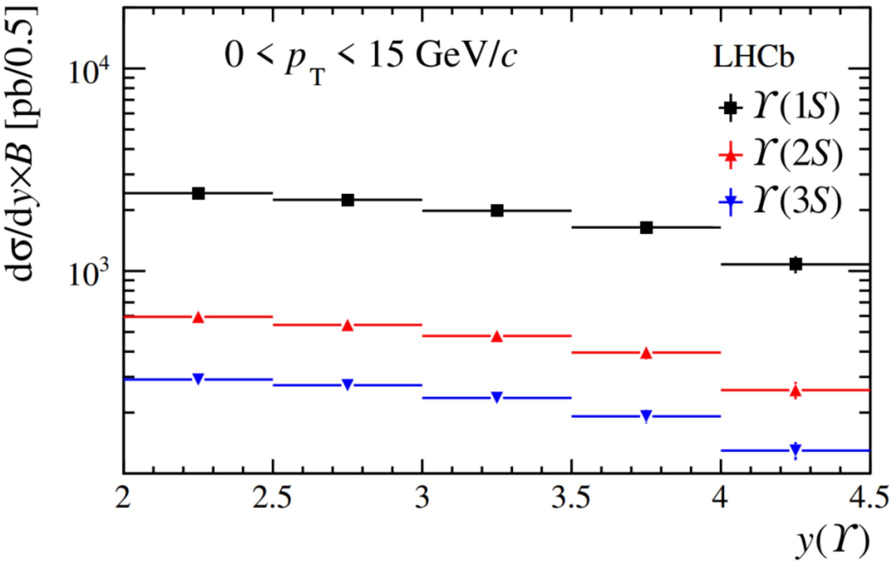


Single differential cross-sections

- ➢ Compare with NRQCD predictions. JHEP 07(2018) 134

Y. Feng, B. Gong, L.-P. Wan and J.-X. Wang， Chin. Phys. C 39(2015) 123102





Good agreement at high p_{T}.

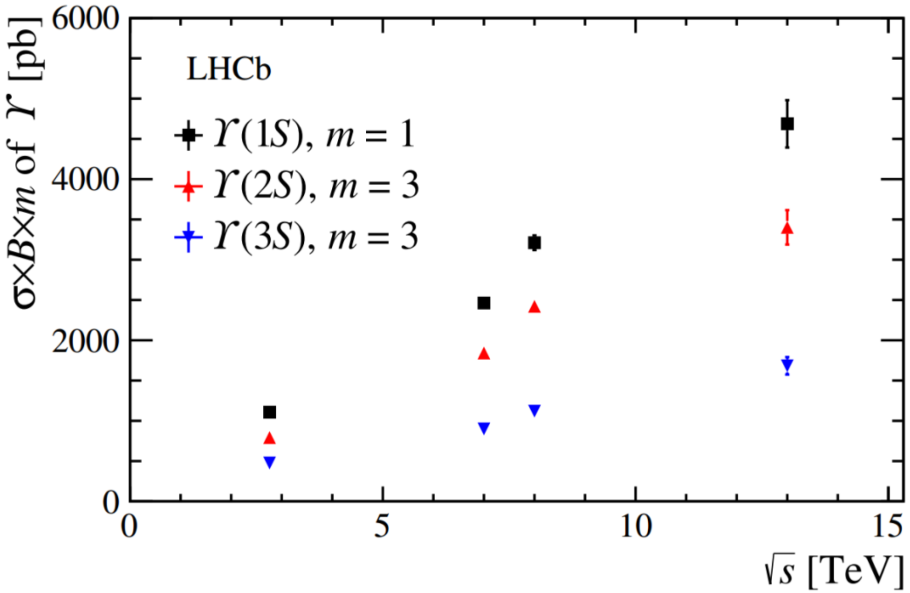
Integrated cross-sections

JHEP 07(2018) 134

- Over $0 < p_{\mathrm{T}} < 15\ \mathrm{GeV}/c$ and $2.0 < y < 4.5$:

$$\mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) \times \sigma(\Upsilon(1S), 0 < p_{\mathrm{T}} < 15\,\mathrm{GeV}/c, 2 < y < 4.5) = 4687 \pm 10 \pm 294\,\mathrm{pb},$$
$$\mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) \times \sigma(\Upsilon(2S), 0 < p_{\mathrm{T}} < 15\,\mathrm{GeV}/c, 2 < y < 4.5) = 1134 \pm 6 \pm 71\,\mathrm{pb},$$
$$\mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) \times \sigma(\Upsilon(3S), 0 < p_{\mathrm{T}} < 15\,\mathrm{GeV}/c, 2 < y < 4.5) = 561 \pm 4 \pm 36\,\mathrm{pb},$$

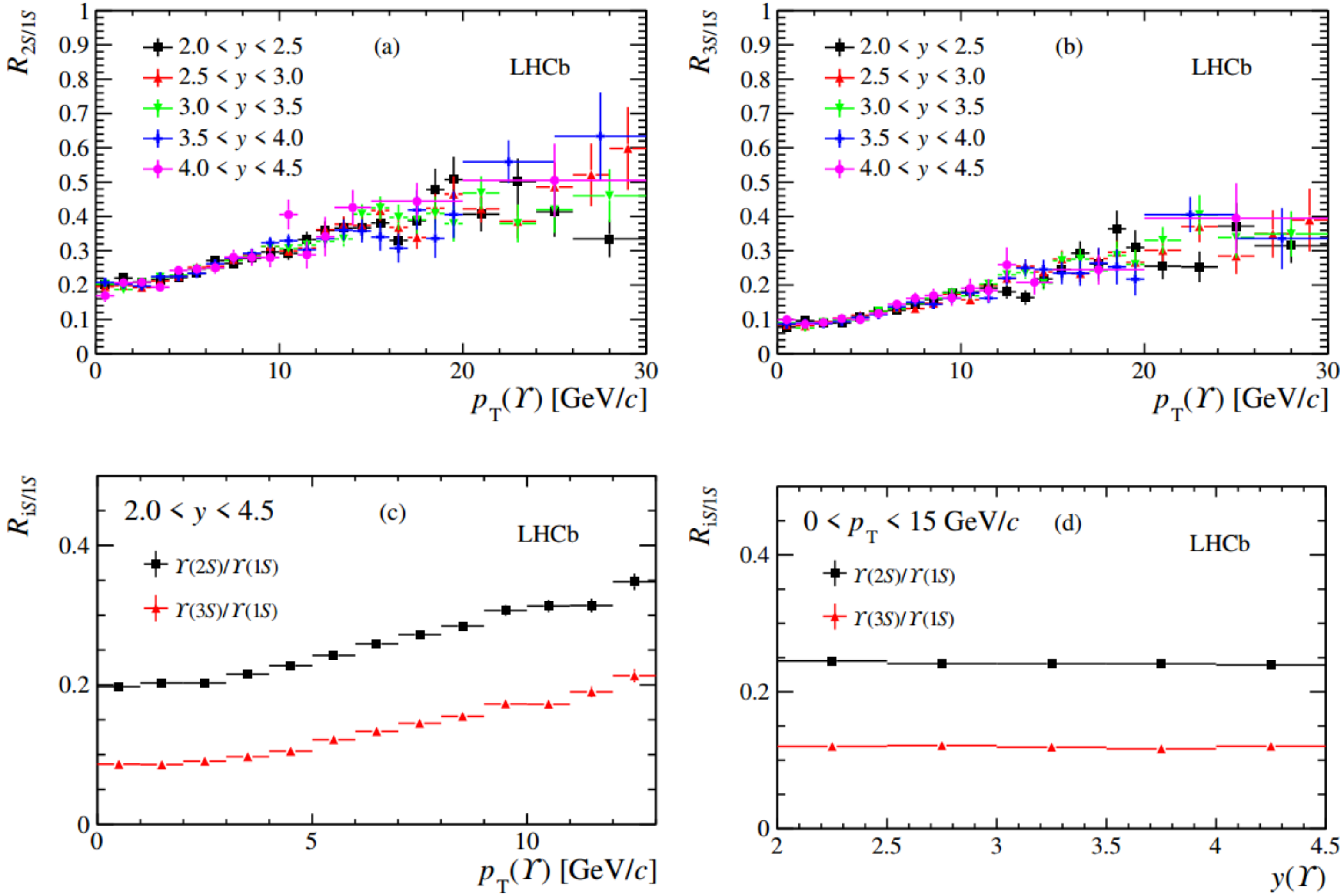
- Almost linear with energies:



Eur. Phys. J. C 74(2014) 2835
Eur. Phys. J. C 72(2012) 2025
JHEP 09(2015) 084

Cross-section ratios of $R_{\Upsilon(iS)/\Upsilon(1S)}$

JHEP 07(2018) 134



Cross-section ratios of $R_{13/8}$

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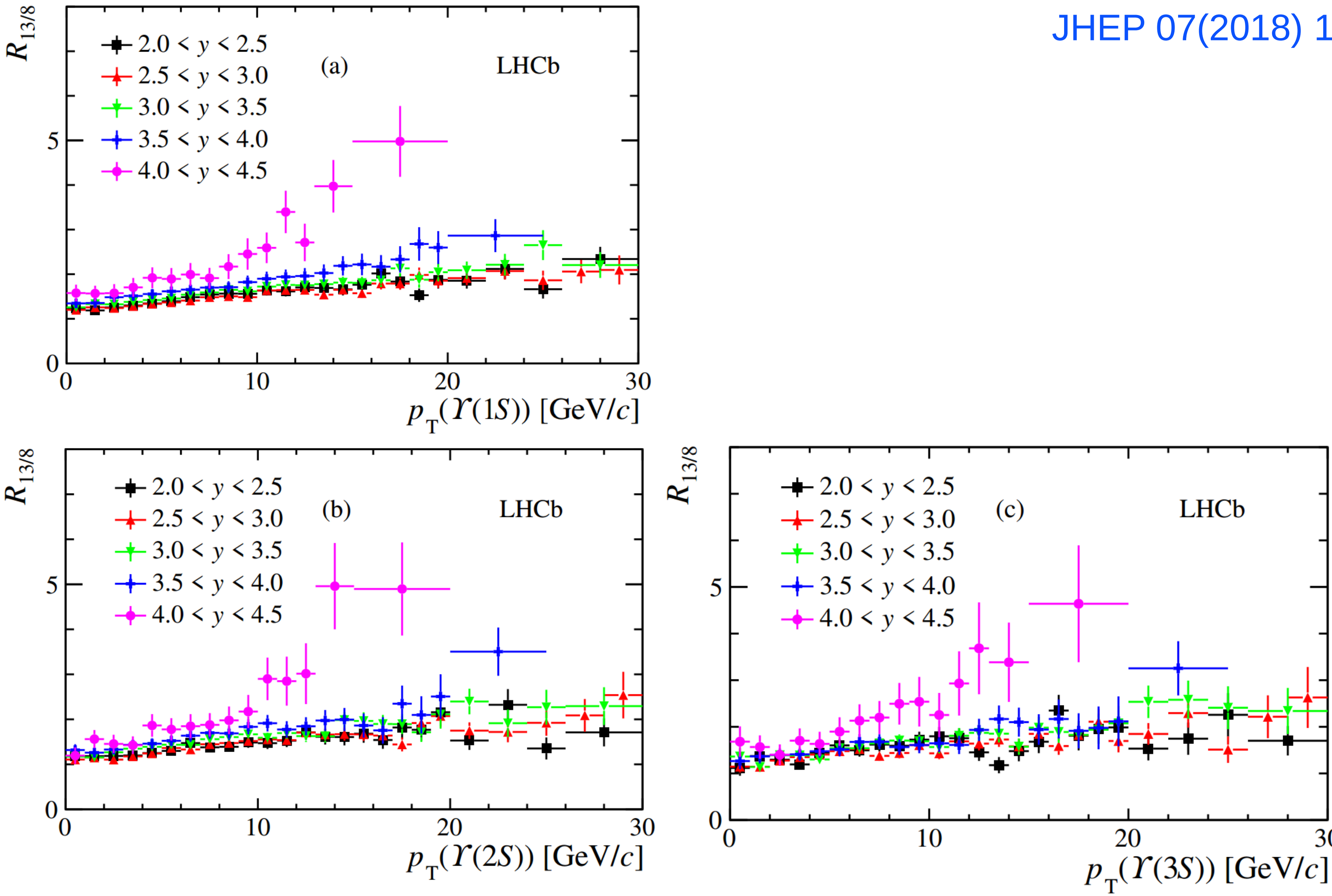

Cross-section ratios of $R_{13/8}$

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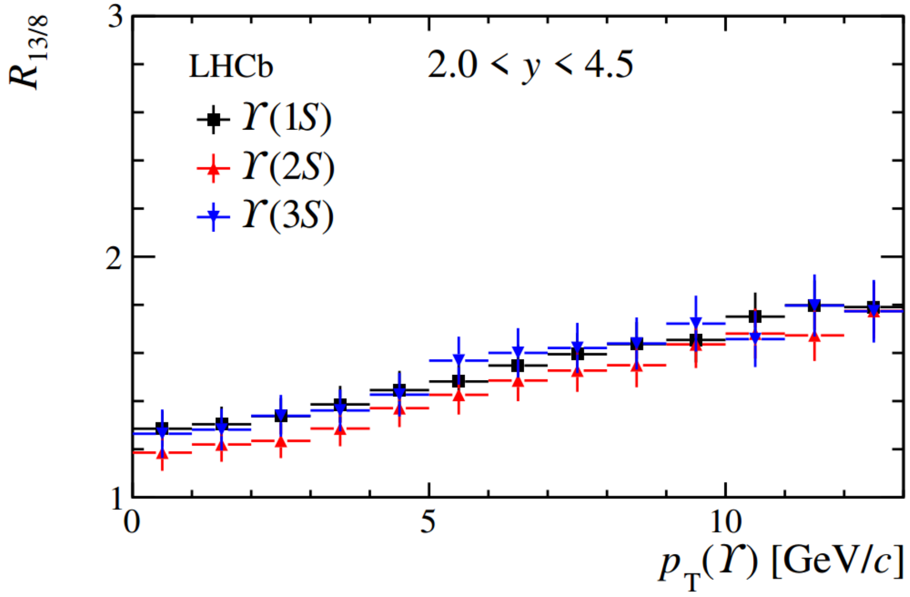
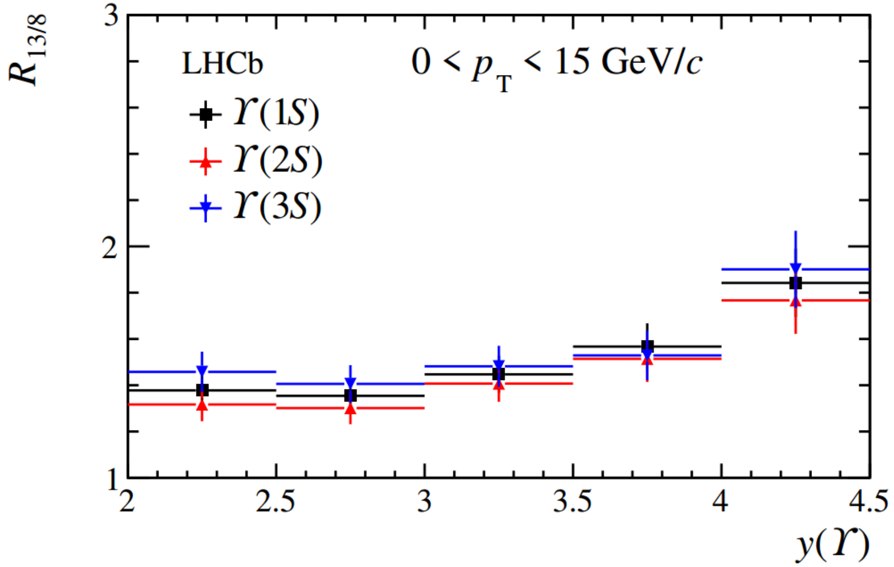




Summary

- $\Upsilon(\mathrm{n}S)$ $(n = 1,2,3)$ production in pp collisions at $\sqrt{s}$ =13 TeV are measured with 2015 data.

- Comparisons of production ratios between different states and between 13 TeV and 8 TeV are given.

- NRQCD predictions agree with our data well at high p_{T}.

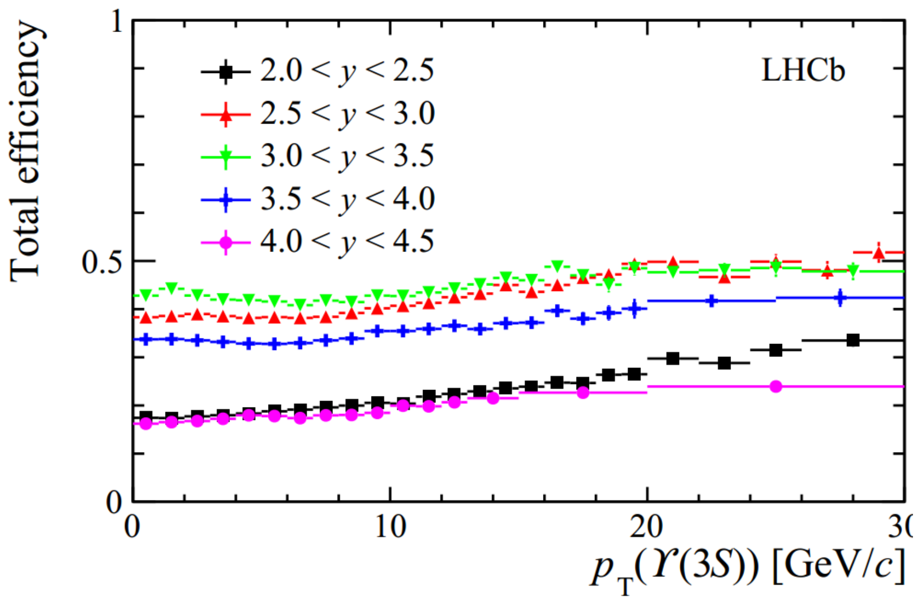
- LHCb has collected huge heavy quarkonia data, Run II ended, much more results come out soon.

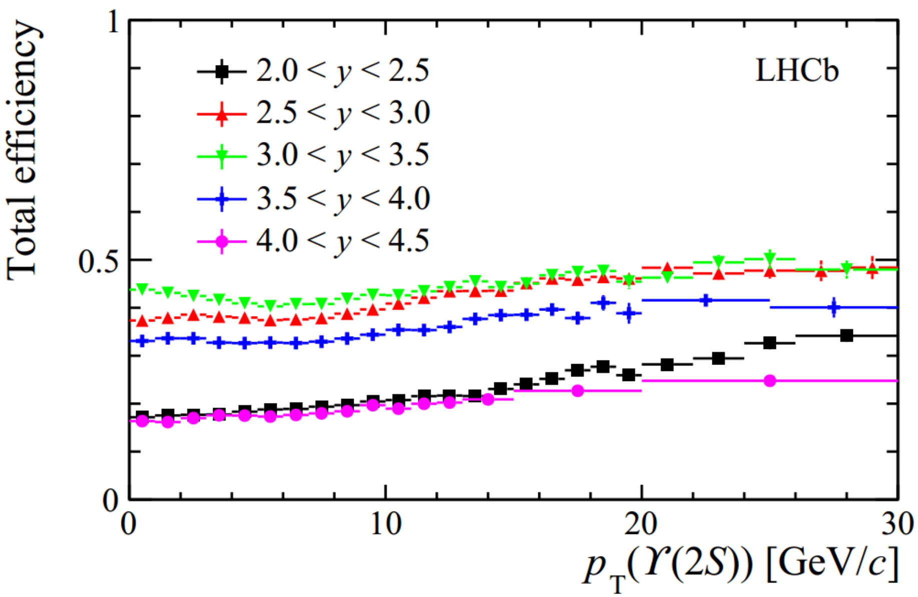
Thanks for your attention!

Backup

JHEP 07(2018) 134

Total efficiency:





Systematic uncertainties

JHEP 07(2018) 134

Source	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	Comment
Fit models	1.9	1.8	2.5	Correlated
Simulation statistics	0.4–4.6	0.5–5.1	0.5–4.4	Bin dependent
Global event requirements	0.6	0.6	0.6	Correlated
Trigger	3.9–9.8	3.9–9.8	3.9–9.8	Bin dependent
Tracking	(0.1–6.6) $\oplus(2 \times 0.8)$	(0.2–6.4) $\oplus(2 \times 0.8)$	(0.2–6.5) $\oplus(2 \times 0.8)$	Correlated
Muon identification	0.1–7.9	0.1–7.6	0.2–8.5	Correlated
Vertexing	0.2	0.2	0.2	Correlated
Kinematic spectrum	0.0–1.1	0.0–2.2	0.0–2.5	Bin dependent
Radiative tail	1.0	1.0	1.0	Correlated
Luminosity	3.9	3.9	3.9	Correlated
Total	6.2–14.3	6.2–14.6	6.4–14.9	Correlated

Dominated by the trigger and luminosity uncertainty.