Υ [and $\psi(2S)$] production in pp collsions at LHCb

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The LHCb experiment

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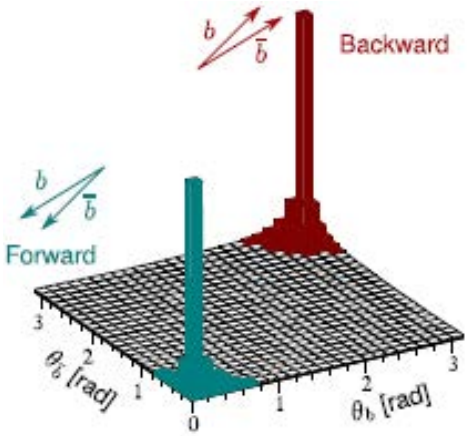
IJMP A30 (2015)1530022

LHC has record numbers of b (and c) hadrons:

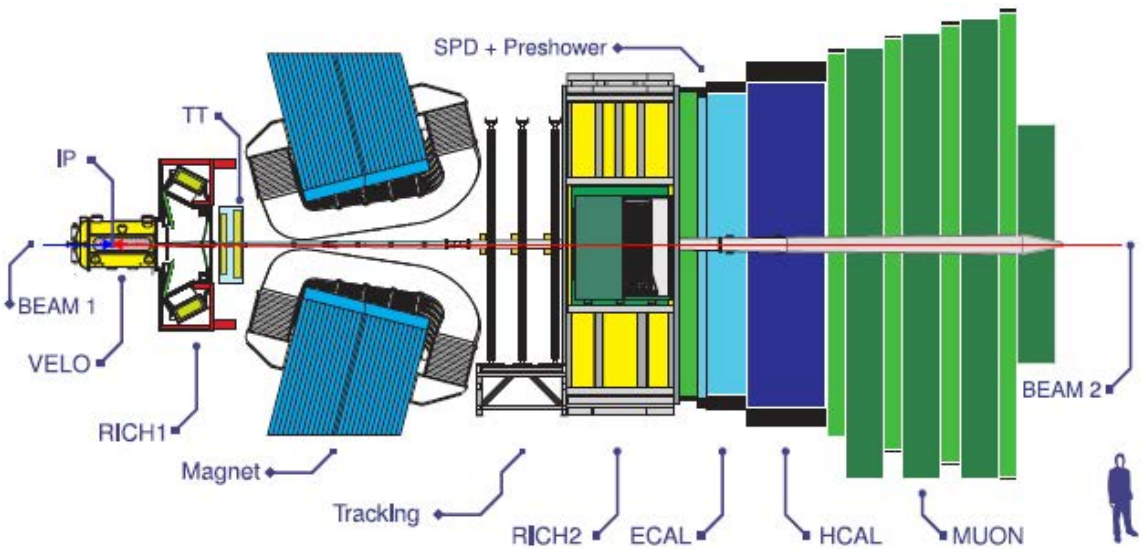
$\sigma_{b\bar{b}} \approx 250\ \mu$b @ 7 TeV $\sigma_{c\bar{c}} \approx 20 \times \sigma_{b\bar{b}}$

LHCb designed to study rare decays and CP violation in b-hadrons

ideal place also to study their properties and production



single-arm spectrometer covering the forward pseudorapidity region $2 < \eta < 5$



excellent performance:

- vertexing and tracking: good time of flight and invariant mass resolution
- PID for pions, kaons, protons and muons

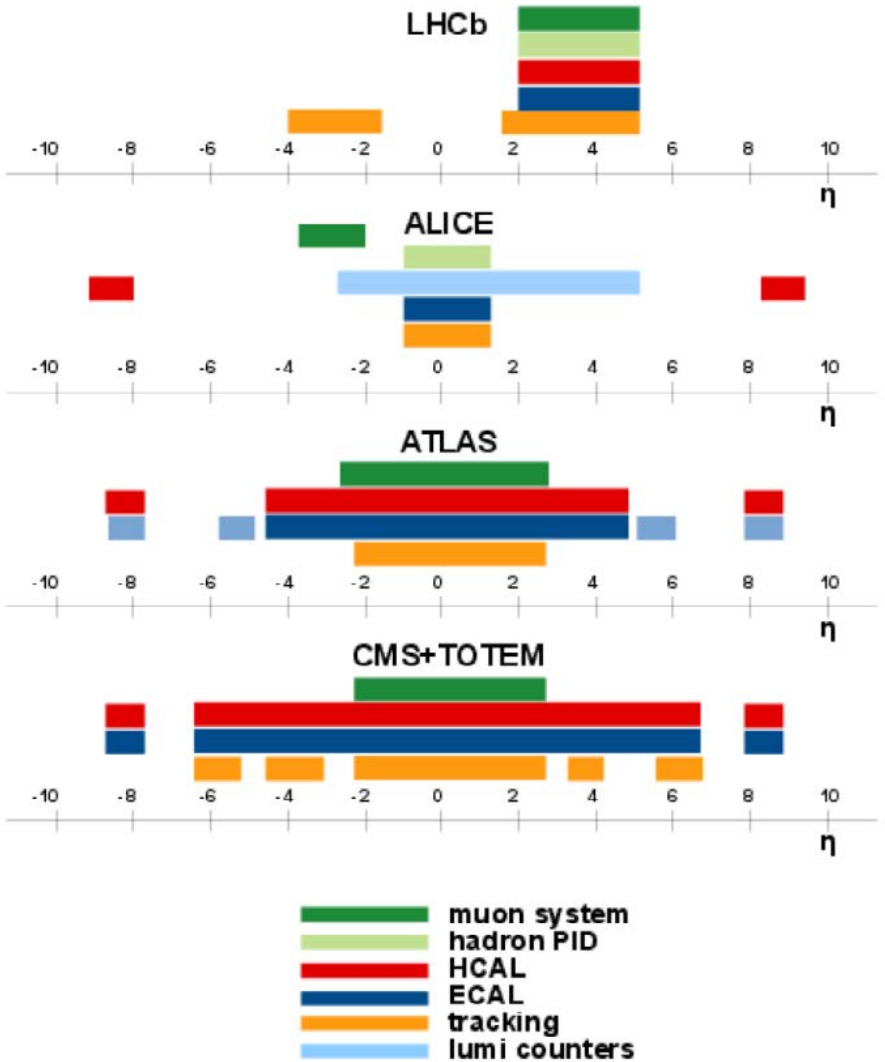
Trigger on high-p_t lepton or hadron from displaced vertexes

c and b-hadrons

LHCb detector coverage

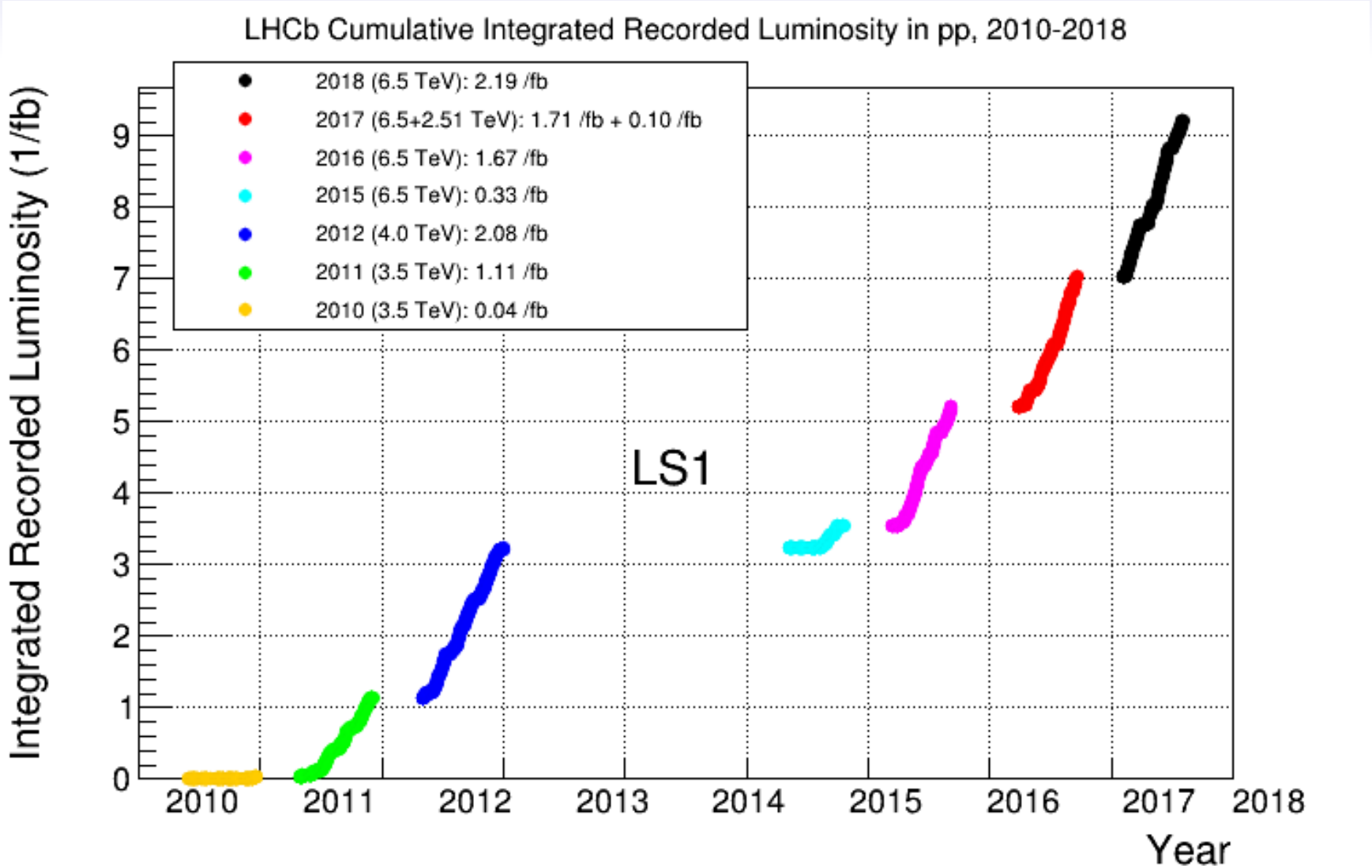
IJMP A30 (2015)1530022

μ and tracking coverage for $2 < \eta < 5$



Complementary to other LHC experiments

LHCb dataset in pp collisions



Total integrated luminosity in *pp* collisions exceeds 9 fb^{-1}

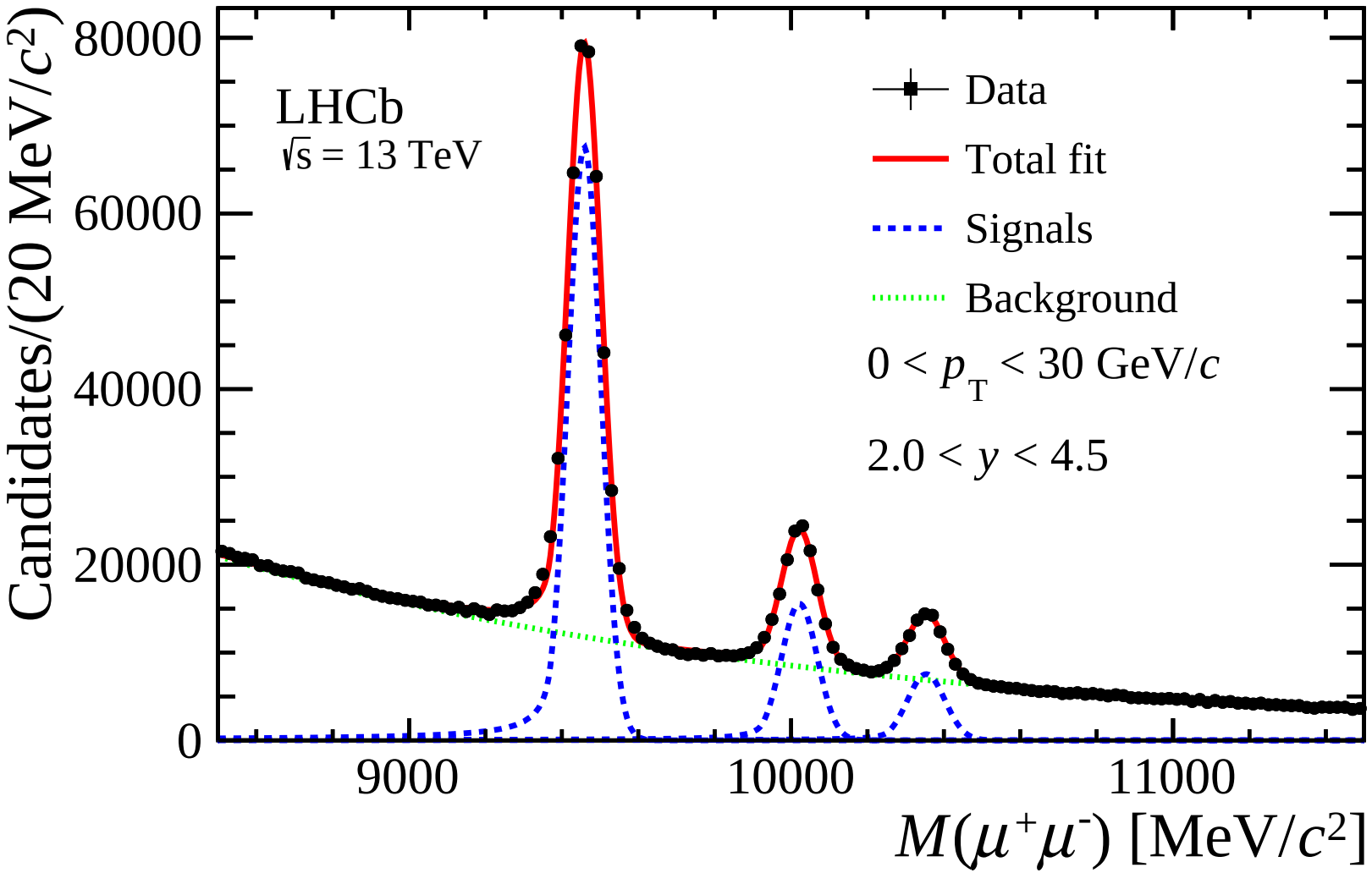
results presented here use a fraction of this..

Υ production in pp collisions at 13 TeV

JHEP 07 (2018) 134

$\Upsilon(nS) \to \mu^+\mu^-$

- muons must have momentum> 10 GeV, $p_t > 1$ GeV
- the pair must originate from a common vertex



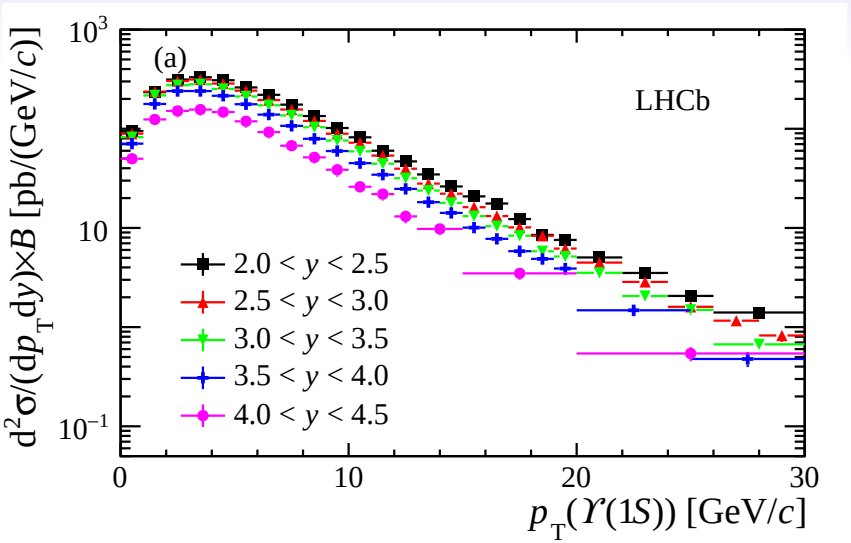
Doubly differential cross section

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} \times \mathcal{B}(\Upsilon \to \mu^+\mu^-) = \frac{N(p_\mathrm{T}, y)}{\mathcal{L} \times \varepsilon_\mathrm{tot}(p_\mathrm{T}, y) \times \Delta y \times \Delta p_\mathrm{T}}$$

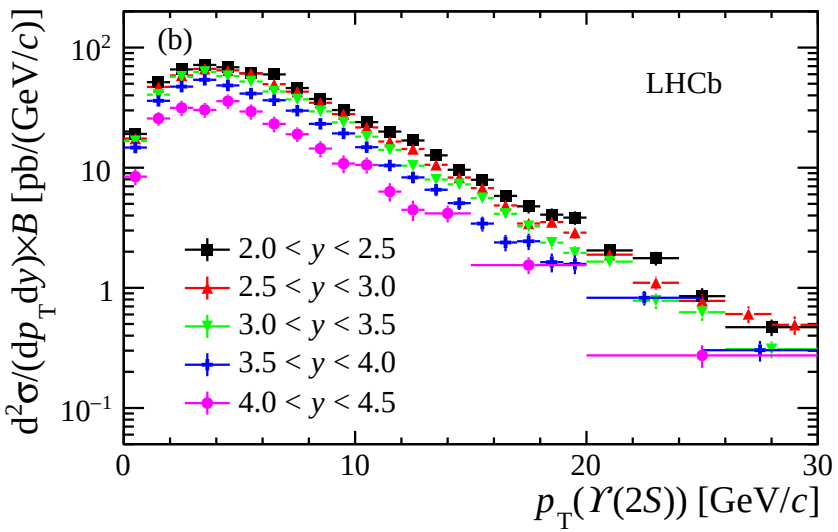
- $\Delta p_T; \Delta y$: p_T and y bin widths
- $N(p_T, y)$, $\epsilon(p_T, y)$ are the yields and efficiencies in each bin

Systematic errors (in part) correlated and/or depend on the bin (see backup)

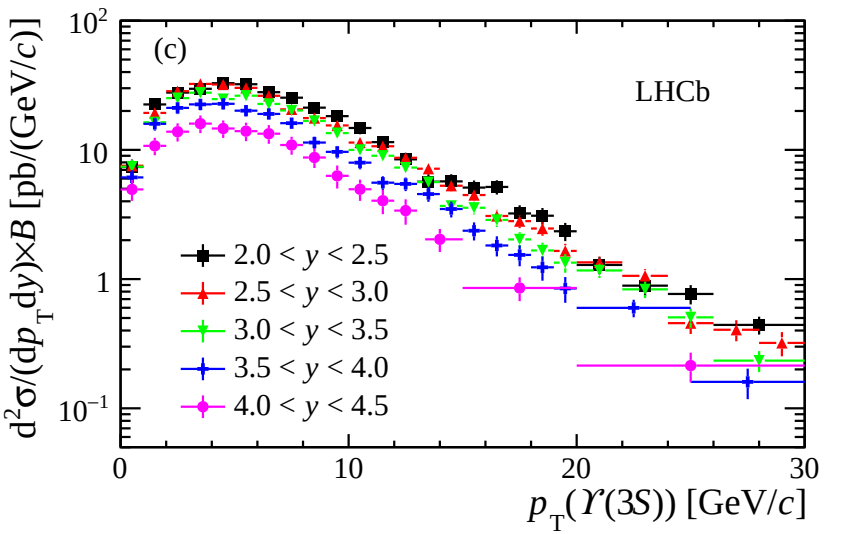
$\Upsilon(1S)$



$\Upsilon(2S)$



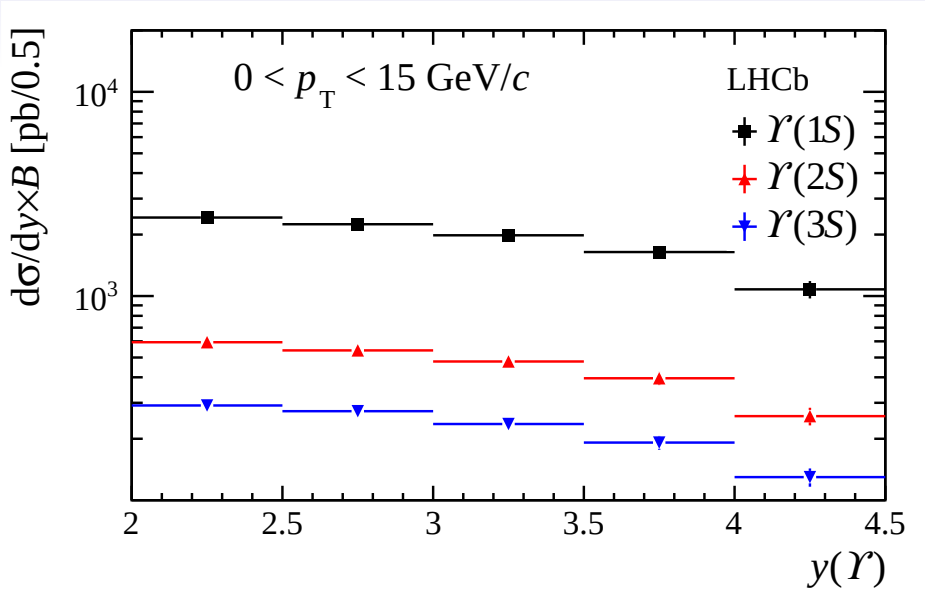
$\Upsilon(3S)$



Assume no polarization: compatible with our measurement JHEP 12 (2017) 110

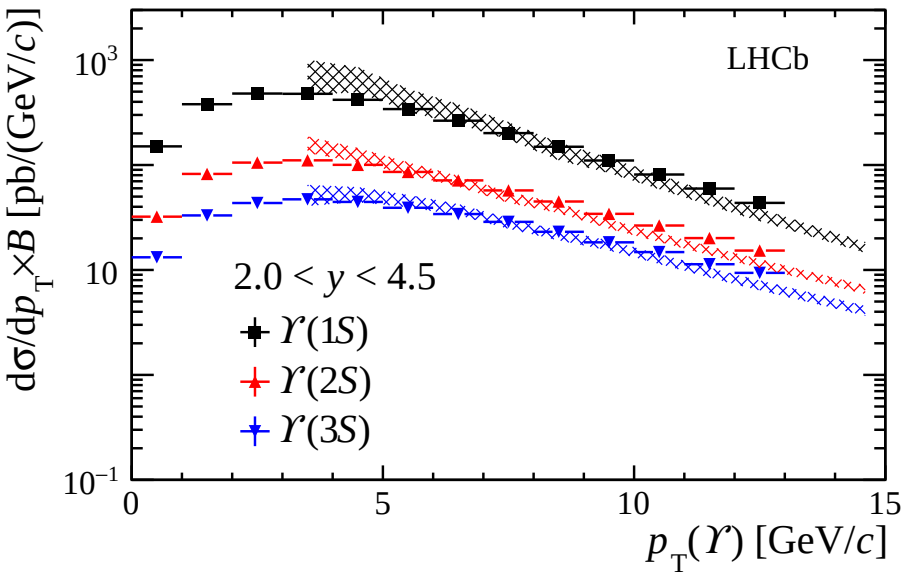
Differential cross sections vs p_T or y

Integrating over the p_T or y range we obtain the differential $\sigma \times \mathcal{B}$ as a function of the other variable for the three Υ's



The hatched area shows the NRQCD prediction for the differential cross section vs p_T

Feng et al.,Chin.Phys.C 39 (2015) 123102



good overall agreement

Cross sections ratios $\Upsilon(nS)/\Upsilon(1S)$

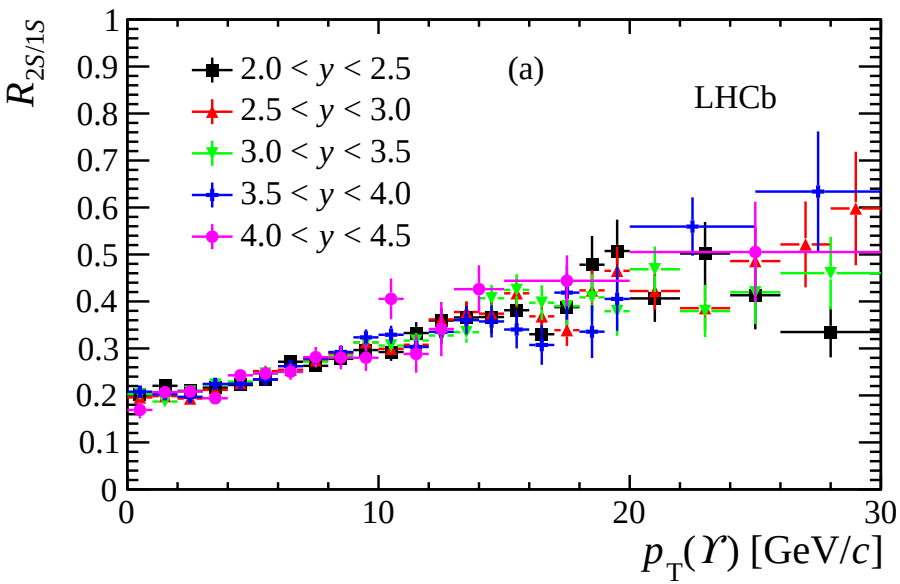
Most (ot at least a large part) of the systematic cancels in the ratio of cross sections

- both for experiment AND theory

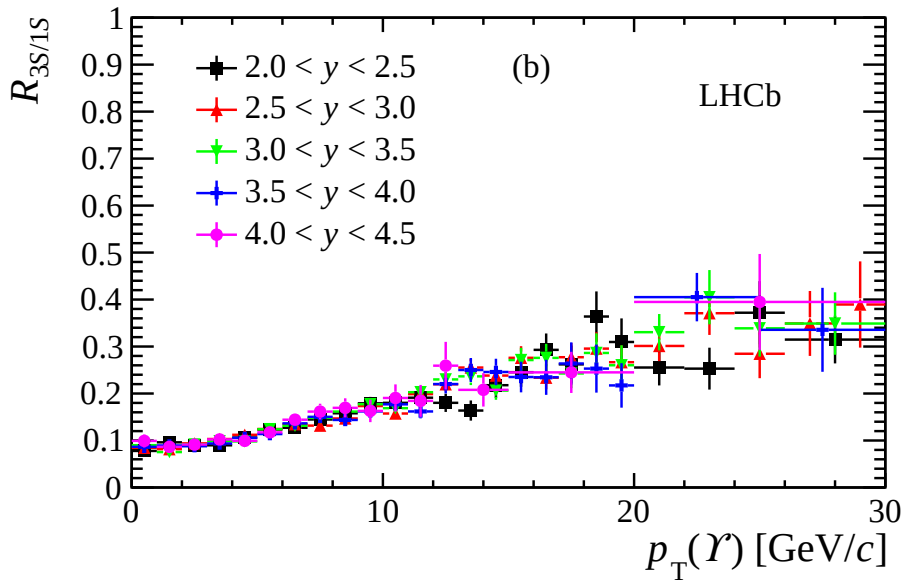
The ratios of the (double differential) $\sigma \times \mathcal{B}$ of the $\Upsilon(2S)/\Upsilon(1S)$ and $\Upsilon(3S)/\Upsilon(1S)$ indicate that $n > 1$ states are suppressed at low p_T

No trend visible in y

$R_{2/1}$

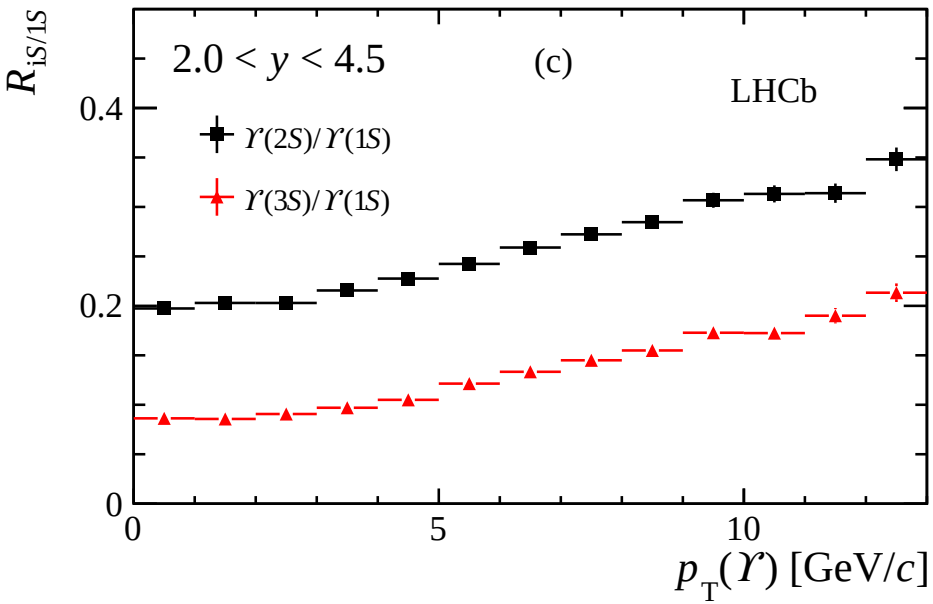


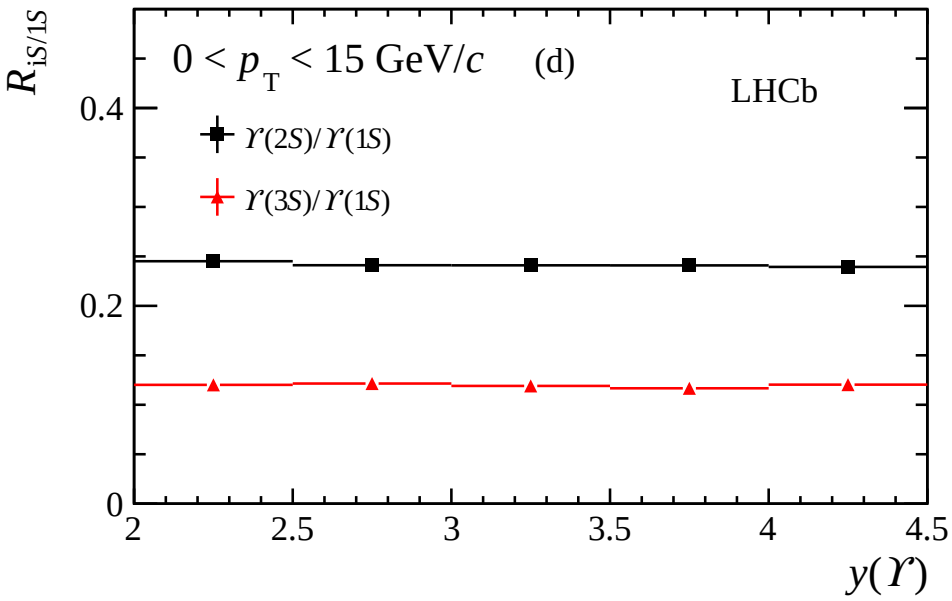
$R_{3,1}$



Cross sections ratios $\Upsilon(nS)/\Upsilon(1S)$

The trends are clearly visible when integrating the ratios over p_T or y





- indication of melting? in pp?

Cross sections vs $\sqrt{s}$

13 TeV JHEP 07 (2018) 134

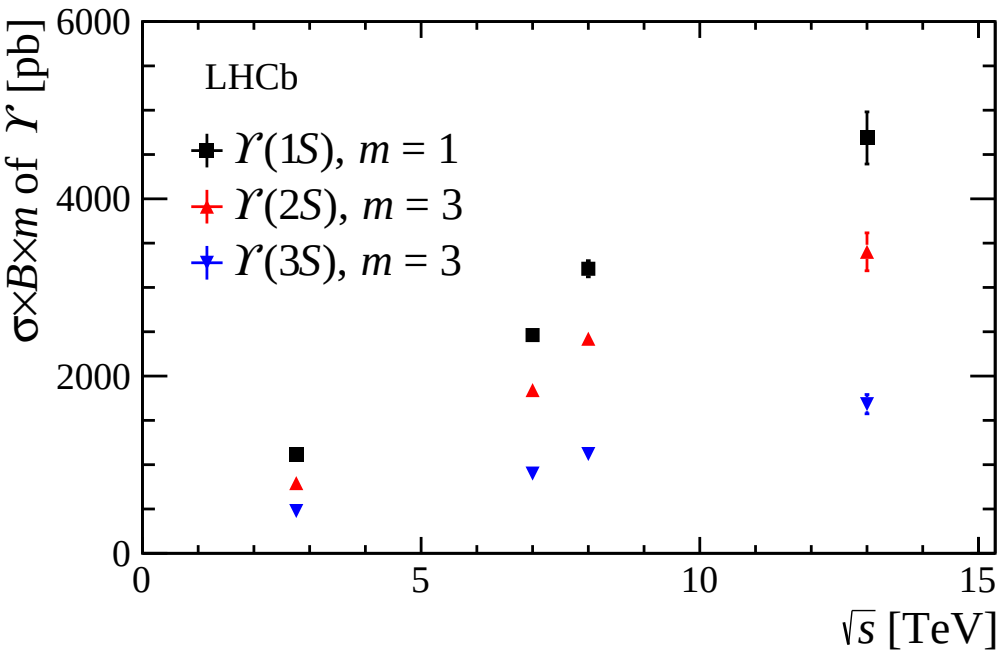
7,8 TeV JHEP 11 (2015) 103

2.76 TeV EPJ C 74 (2014):2835

$\sigma \times \mathcal{B}$ for the Υ narrow states in the kinematic region

$$0 < p_T < 15\,\mathrm{GeV} \qquad 2 < y < 4.5$$

has been measured by LHCb at 4 different $\sqrt{s}$

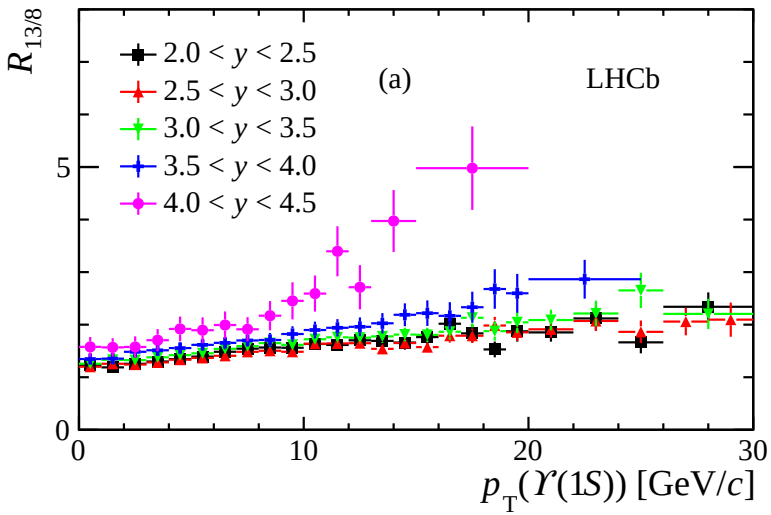


the values for $\Upsilon(2S)$ and $\Upsilon(3S)$ multiplied by m=3 for visibility

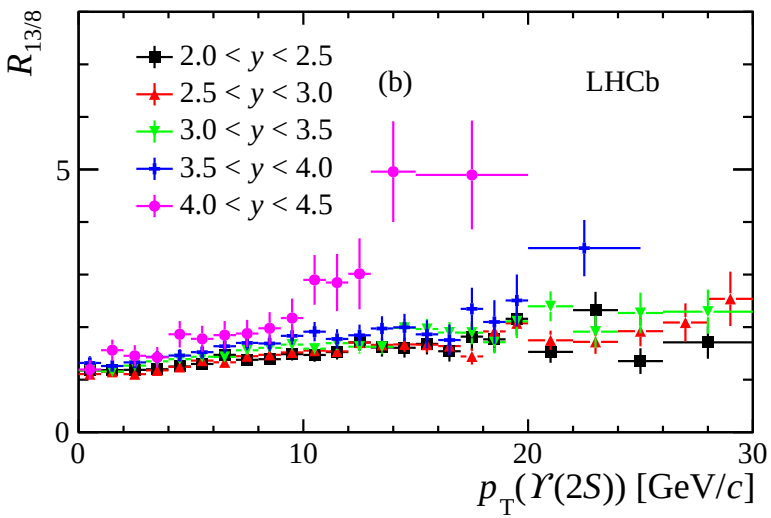
Cross sections ratios at different $\sqrt{s}$

The ratios of double differential cross sections measured at 13 TeV and 8 TeV for all three states increase with p_T and y

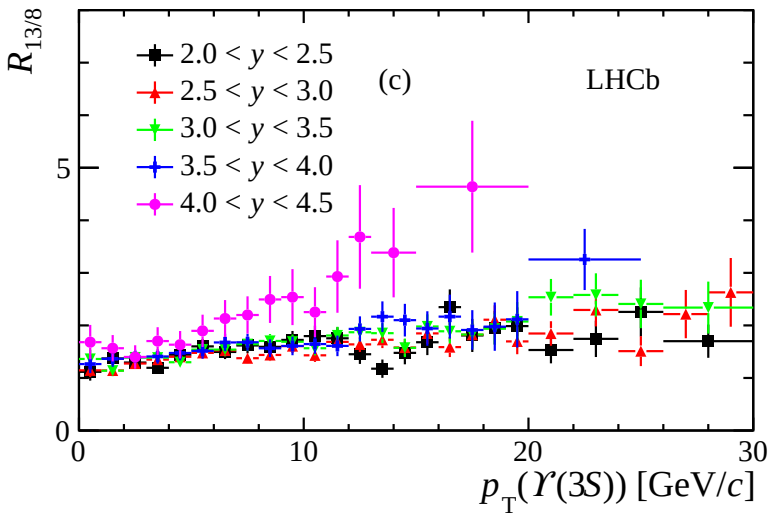
$\Upsilon(1S)$



$\Upsilon(2S)$

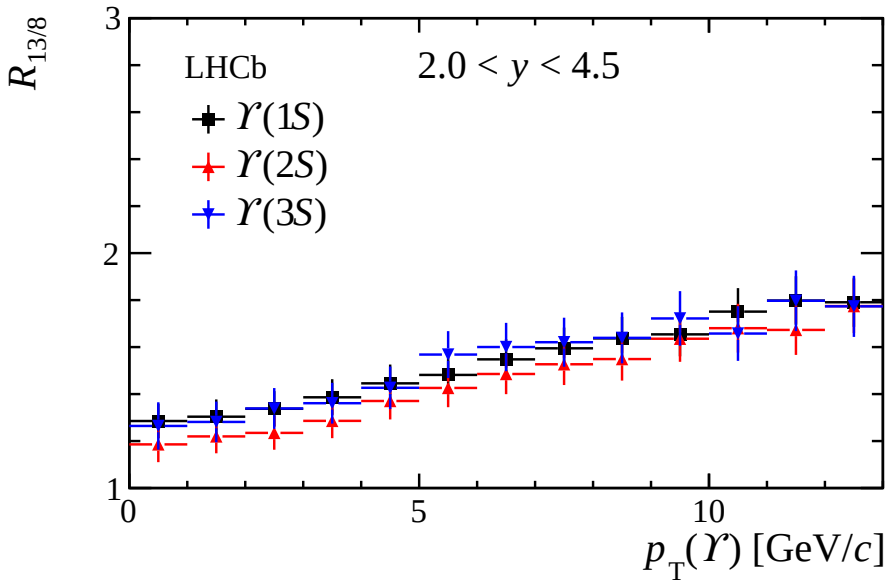


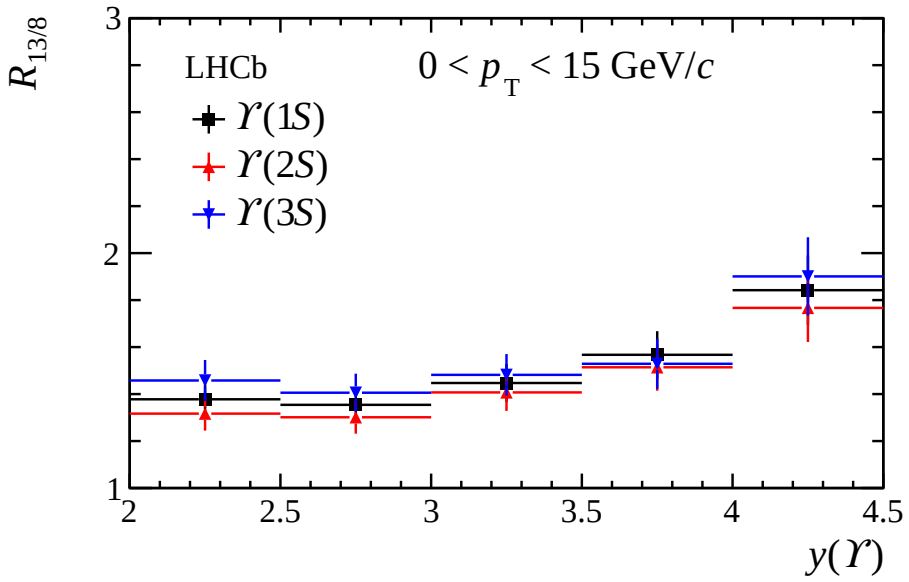
$\Upsilon(3S)$



Cross sections ratios at different $\sqrt{s}$

Again, the trends are clearly visible when integrating over p_T or y





$\psi(2S)$ production in pp collisions at 7 and 13 TeV

(preliminary)

LHCB-PAPER-2018-049 to be submitted to JHEP

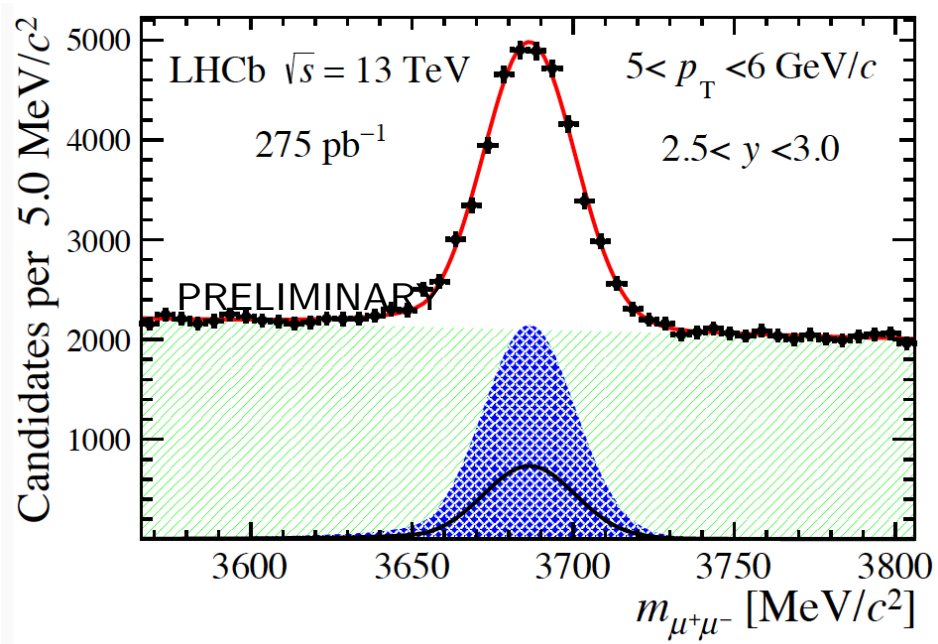
$\psi(2S) \to \mu^+\mu^-$

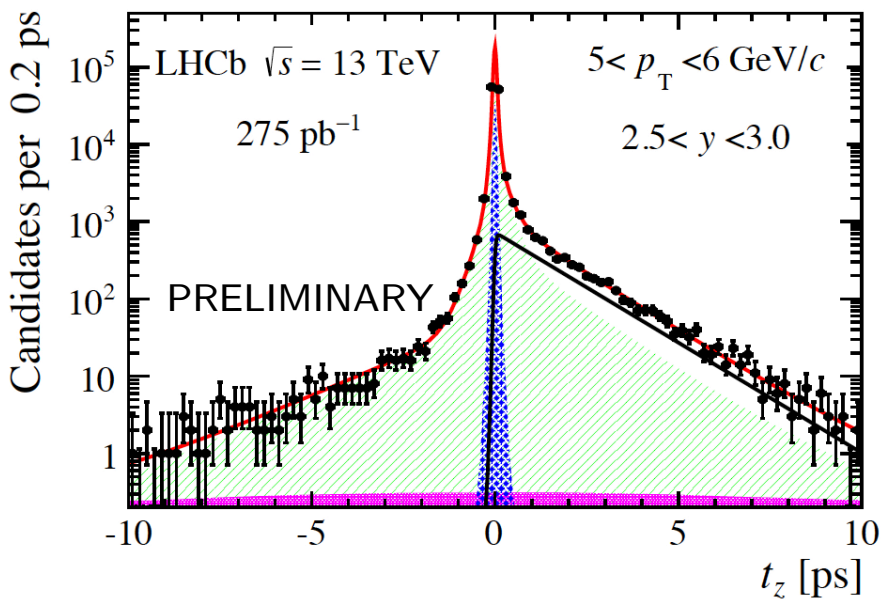
LHCB-PAPER-2018-049
to be submitted to JHEP

- Large yields for $\psi(2S) \to \mu^+\mu^-$
- "cleaner" interpretation wrt J/ψ: no feed-down from cascade decays
- ⋆ remain to account for feed-down from B's

$\Longrightarrow$ 2D fit to $\mu^+\mu^-$ invariant mass and pseudo decay time

$$t_z = \frac{\left(z_{\psi(2S)} - z_{\rm PV}\right) \times M_{\psi(2S)}}{p_z}$$





blue:prompt $\psi(2S)$ black:B decays

green:background

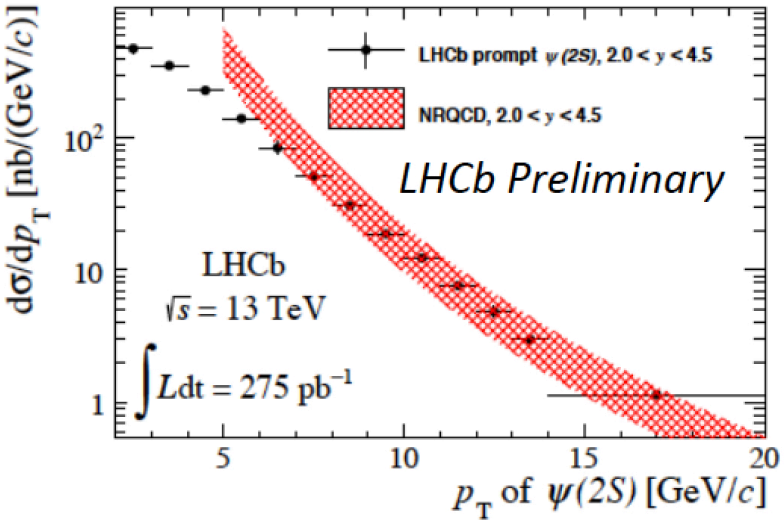
magenta:wrong PV

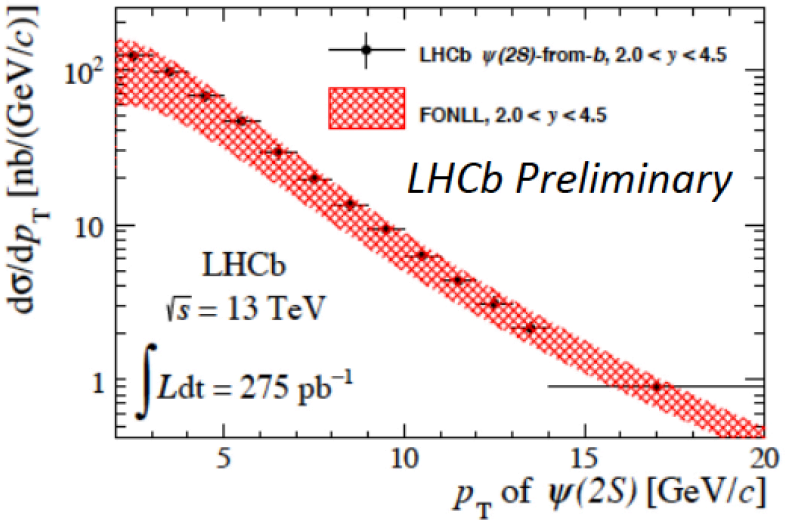
$\psi(2S)$ differential cross sections

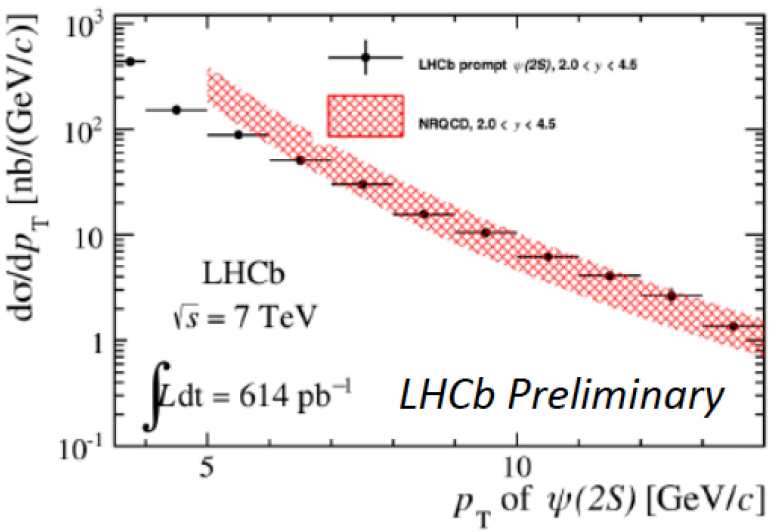
LHCB-PAPER-2018-049

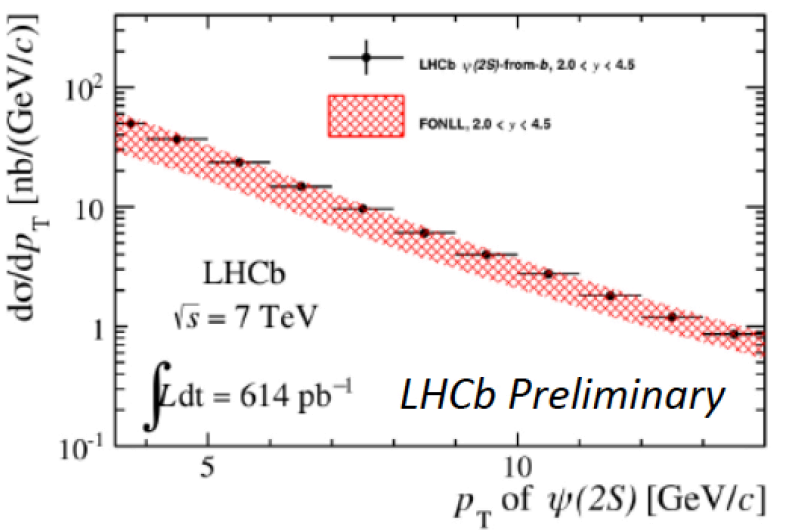
to be submitted to JHEP

Prompt









from B's

Overall good agreement with predictions, except for prompt at low p_T.
Measurement at 7 TeV supersedes earlier results based on smaller sample

Conclusions

- $\Upsilon(nS)$ doubly-differential cross section at 13 TeV

LHCB-PAPER-2018-049

$$0 < p_T < 30 \text{ GeV} \qquad 2 < y < 4.5$$

  - cross section ratios where systematics (both experiment and theory) partially cancel
    - $\Upsilon(nS)/\Upsilon(1S)$
    - 13 TeV and 8 TeV

- Preliminary results on $\psi(2S)$ production cross section at 7 and 13 TeV

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to be submitted to JHEP

Overall satisfactory comparisons with theory

Backup

Υ polarization

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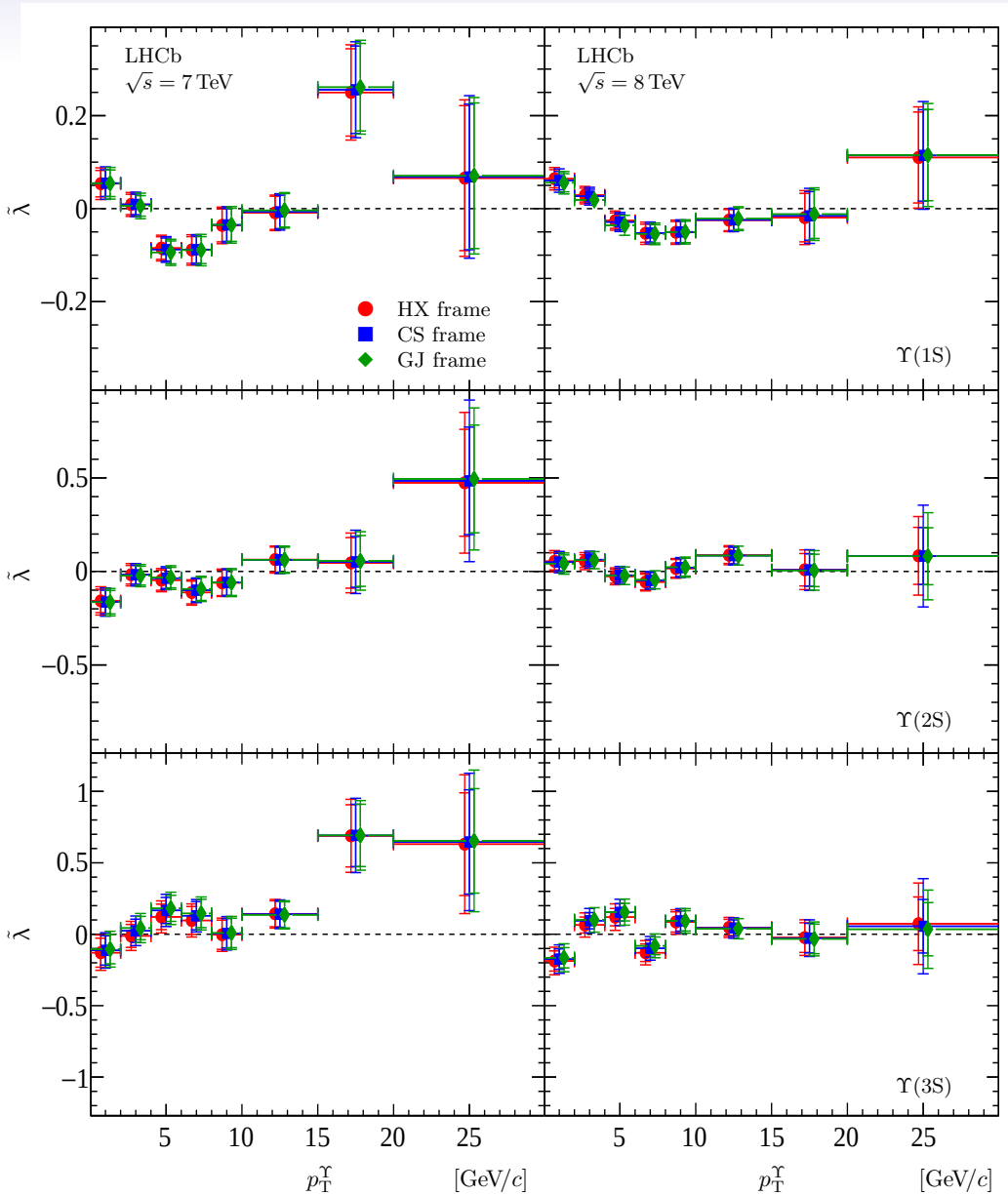
Frame-independent polarization parameter $\tilde{\lambda}$ as a function of p_T measured at 7 and 8 TeV

$$2.2 < y < 4.5$$



Systematic errors on Υ production

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