

Open and hidden beauty production in $p\text{Pb}$ collisions at LHCb

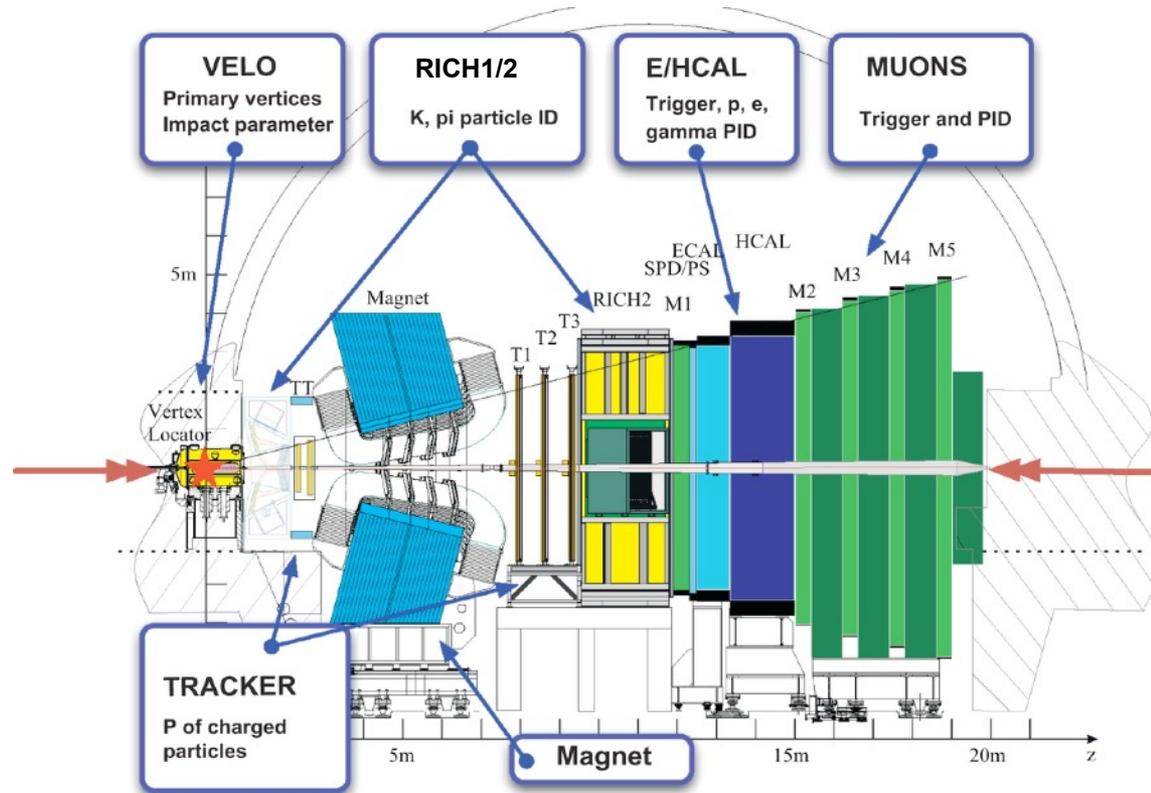
Shanzhen Chen, on behalf of the LHCb collaboration
Universita e INFN, Cagliari

6th November 2019



LHCb detector

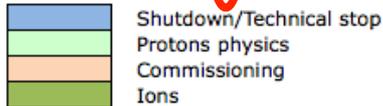
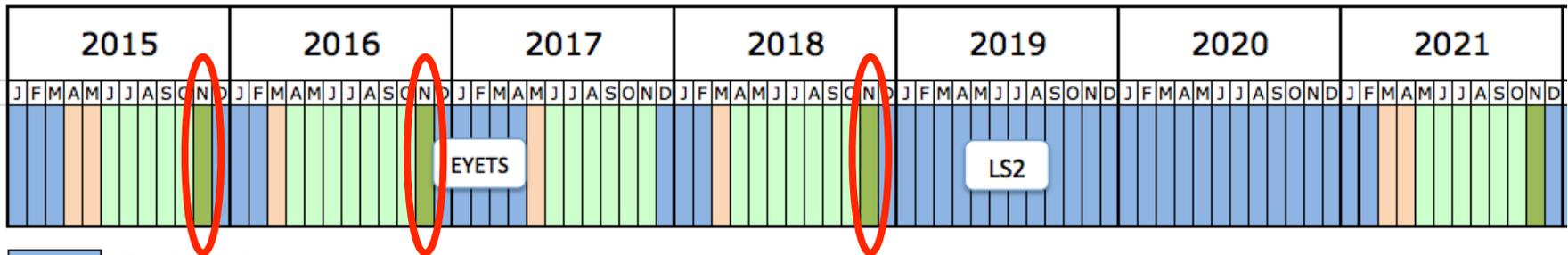
- LHCb - single armed forward spectrometer, located at LHC
- Fully instrumentally $2 < \eta < 5$
- Proton-proton interaction at up to $\sqrt{s} = 13$ TeV
- Physics goals:
 - Designed for: CP violation in b and c sectors
 - Today: also general purpose physics in forward region



[IJMPA 30, 1530022 (2015)] [2008 JINST 3 S08005]

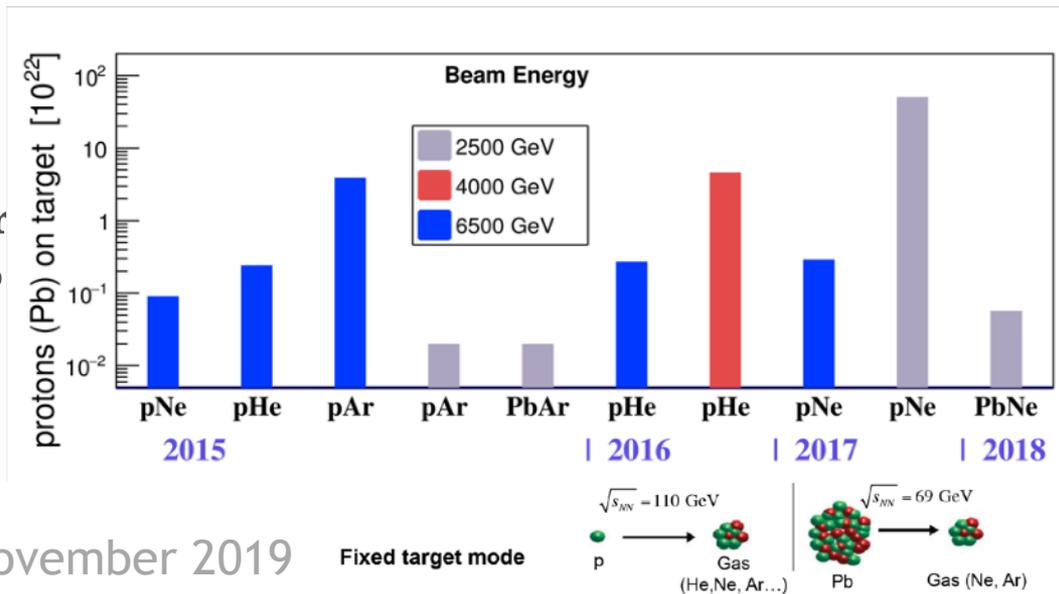
LHCb recorded data

- *pp* collider: 2010-2018, $\sqrt{s_{NN}} = 2.76, 5, 7, 8, 13$ TeV, $L \approx 9$ fb⁻¹
- *pPb* collider: 2013 and 2016, $\sqrt{s_{NN}} = 5.02$ & 8.16 TeV, $L \approx 2$ & 34 nb⁻¹
- *PbPb* collider: 2015 and 2018, $\sqrt{s_{NN}} = 5$ TeV, $L \approx 10$ μ b⁻¹ & 210 μ b⁻¹

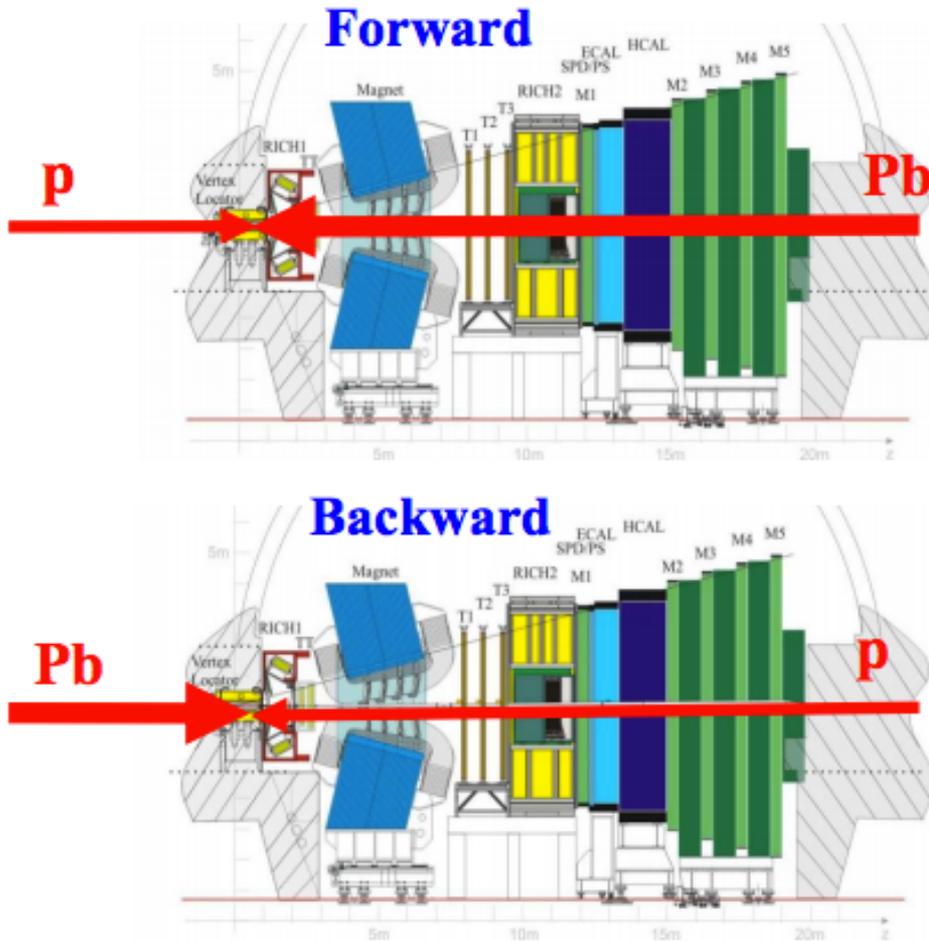


- **Fixed-target mode:**

Complementary to collider mode, inject noble gas into VELO, use non-colliding bunches



Proton-lead modes setups at LHCb



Ion = $^{208}_{82}\text{Pb}$

Forward region:

- $y^* = y_{\text{lab}} - 0.465$
- $p\text{Pb}: 1.5 < y^* < 4.0$

Backward region:

- $y^* = -(y_{\text{lab}} + 0.465)$
- $\text{Pbp} : -5.0 < y^* < -2.5$

2013 data taking: $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$

- 1.1 nb^{-1} (Fwd), 0.5 nb^{-1} (Bwd)

2016 data taking: $\sqrt{s_{\text{NN}}} = 8.16 \text{ TeV}$

- 13.6 nb^{-1} (Fwd), 20.8 nb^{-1} (Bwd)

Proton-lead collisions

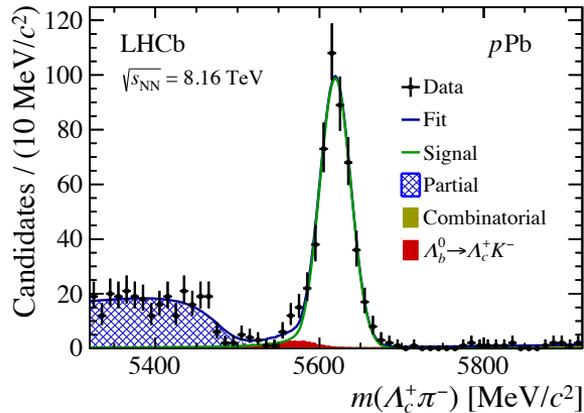
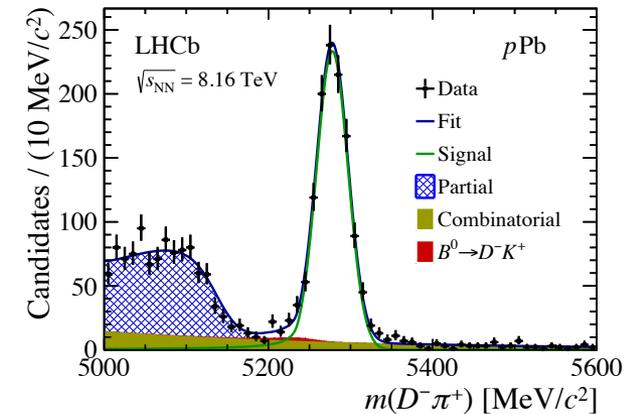
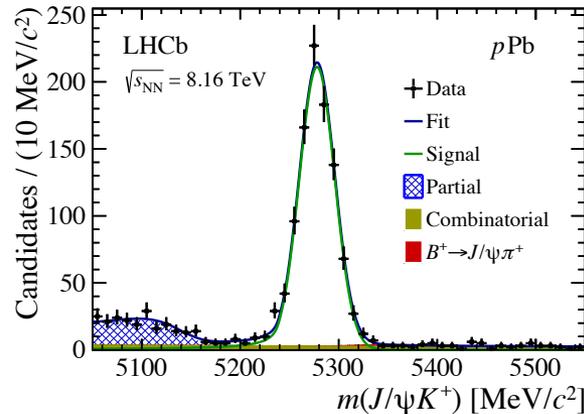
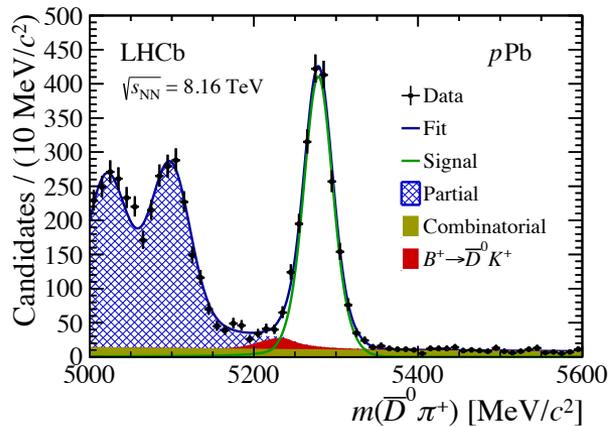
- **Study of cold nuclear matter effects and their disentangling from QGP effects**
- **Nuclear effects quantified by nuclear modification factor:**

$$R_{p\text{Pb}}(p_T, y^*) \equiv \frac{1}{A} \frac{d^2\sigma_{p\text{Pb}}(p_T, y^*)/dp_T dy^*}{d^2\sigma_{pp}(p_T, y^*)/dp_T dy^*}, A = 208$$

where reference σ_{pp} at 8.16 TeV can be taken from interpolations with pp 2.76, 5, 7, 8, 13 TeV data

b -hadron production in $p\text{Pb}$ at 8.16 TeV

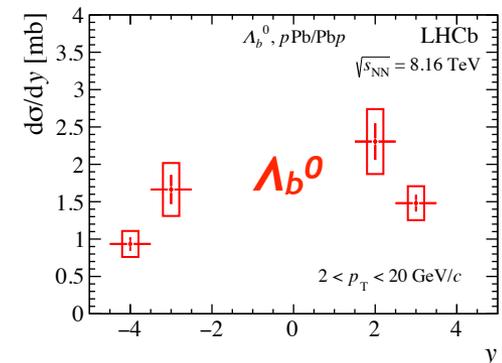
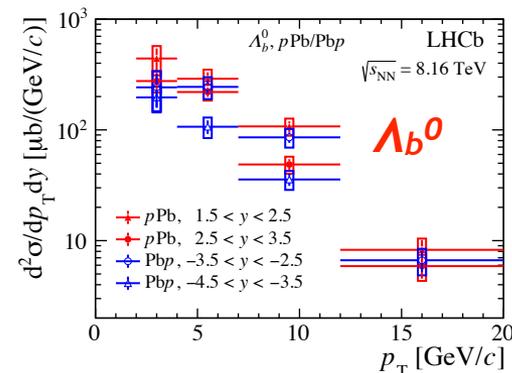
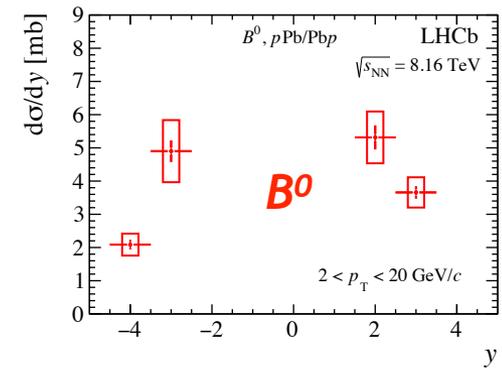
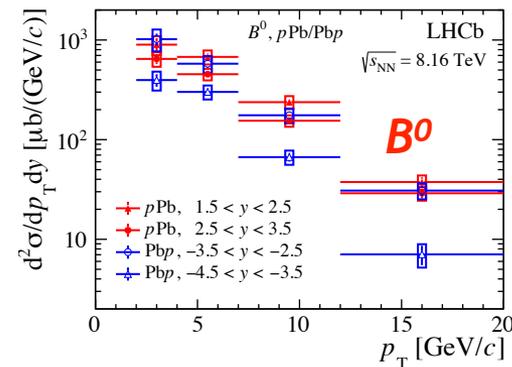
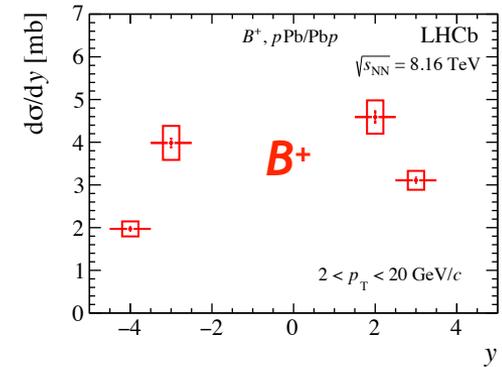
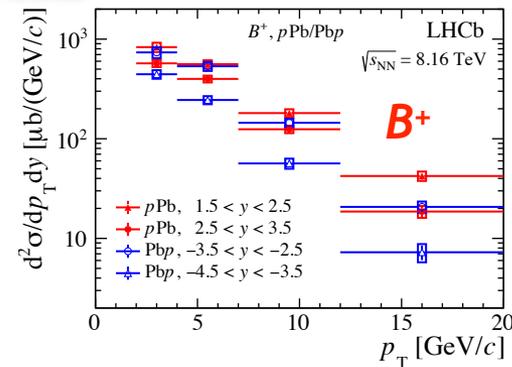
- Exclusive decay modes: $B^+ \rightarrow J/\psi K^+$, $B^+ \rightarrow D^0 \pi^+$, $B^0 \rightarrow D^- \pi^+$, $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$



Decay	$p\text{Pb}$	PbPb
$B^+ \rightarrow \bar{D}^0 \pi^+$	1943 ± 58	1824 ± 64
$B^+ \rightarrow J/\psi K^+$	883 ± 32	905 ± 33
$B^0 \rightarrow D^- \pi^+$	1155 ± 39	886 ± 34
$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$	484 ± 24	397 ± 23

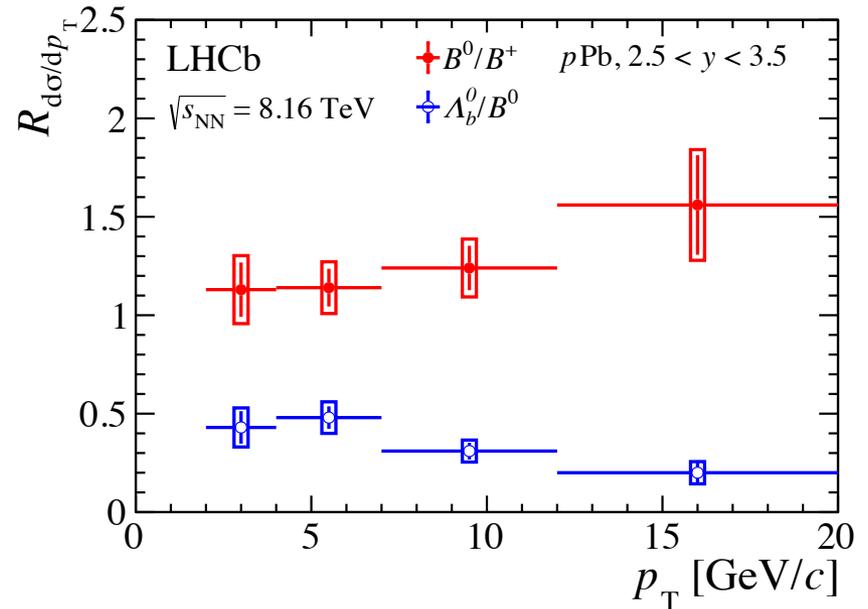
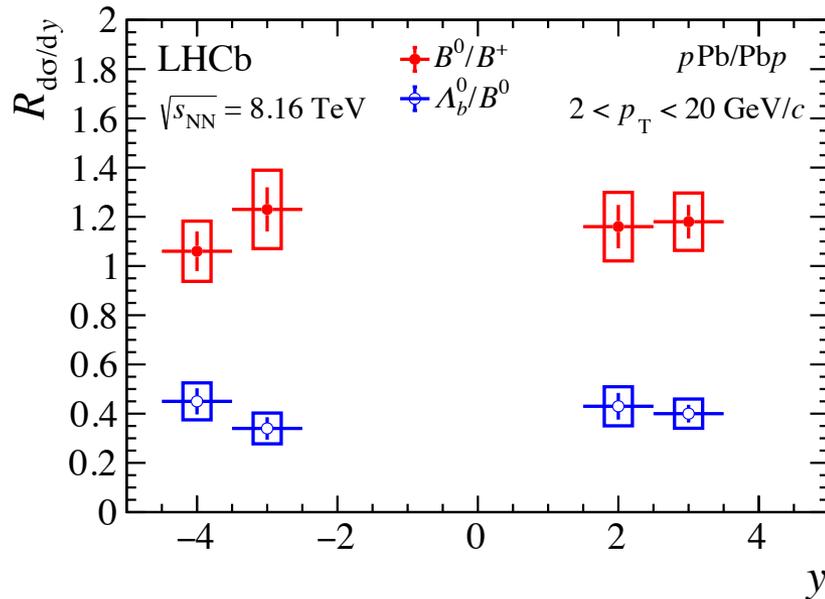
b-hadron cross-sections

- B^+ cross-section studied in $J/\psi K^+$ and $D^0 \pi^+$ modes. Both modes consistent. Weighted average shown here
- Similar p_T and y distributions for B^+, B^0 and Λ_b^0 hadrons



b -hadron cross-section ratios

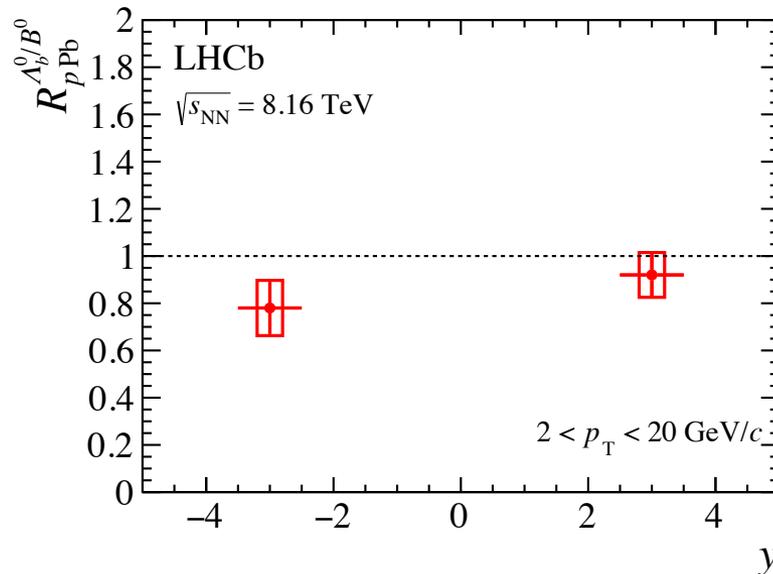
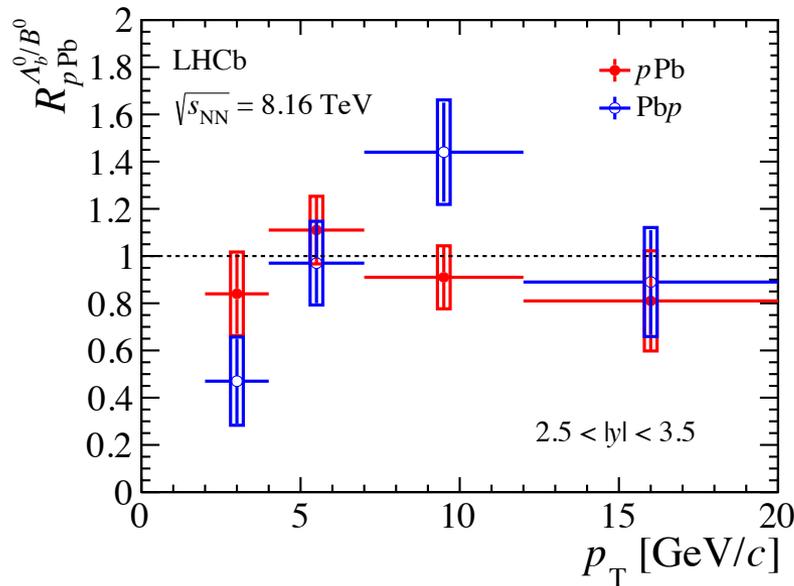
- Probing relative b -quark fragmentation into different b -hadrons



- B^0/B^+ ratio independent of y and p_T , slightly above unity (isospin symmetry)
- $\Lambda_b^0/B^0 \approx 40\%$, decreasing with p_T , no hint of strong rapidity dependence. similar to results in LHCb pp data [[JHEP 08 \(2014\) 143](#)]
- Λ_b^0/B^0 ratio reaches LEP data at high p_T , 0.20 ± 0.02 [[arXiv:1612.07233](#)]

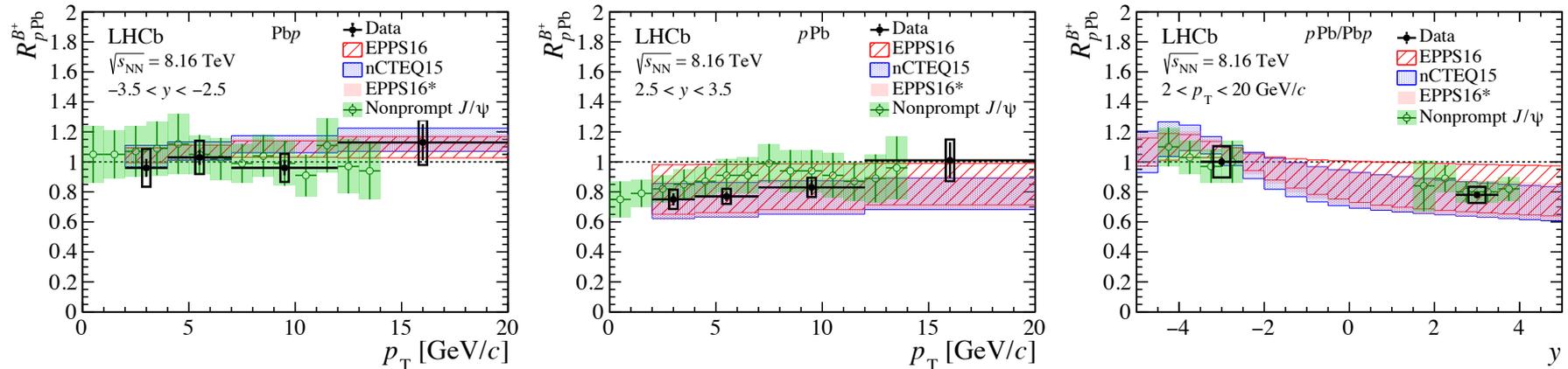
Λ_b^0 and B^0 relative modification

- Ratio of R_{pA} between Λ_b^0 and B^0 hadrons

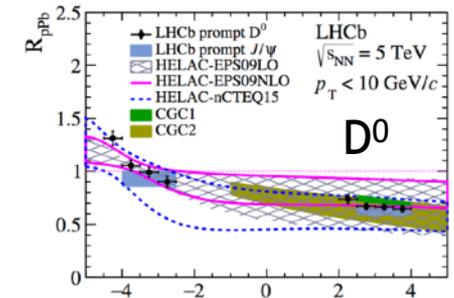


- **Forward rapidity: consistent with unity in all kinematic bins** \rightarrow b -quark fragmentation function at forward rapidity similar to pp
- **Backward rapidity: hint of stronger suppression for Λ_b^0 compared with B^0 . Demanding more statistics for a firm conclusion.**

B^+ nuclear modification factors

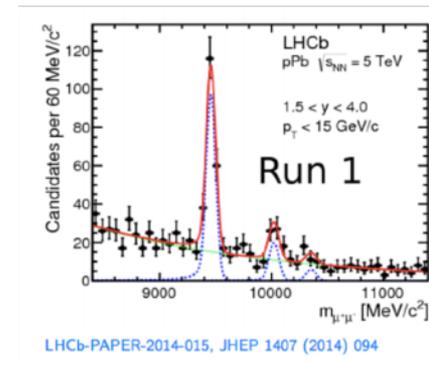
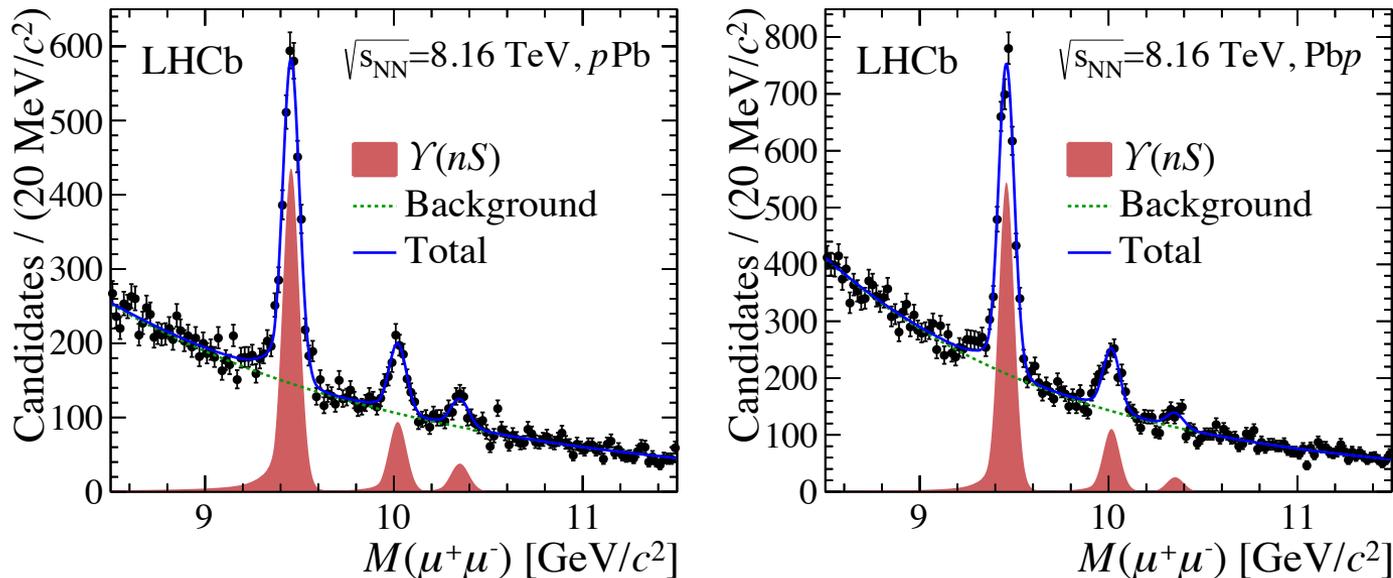


- Pattern consistent with R_{pA} of D^0 hadron
- Significant suppression ($\approx 25\%$) in forward rapidity, suppression decreased at large p_T
- Consistent with unity at backward rapidity
- Measurements in good agreement with J/ψ -from- b decay data and calculations using nPDF sets [[JHEP 04 \(2009\) 065](#), [EPJ C77 \(2017\) 1](#), [Comput. Phys. Commun. 198 \(2016\) 238](#)]



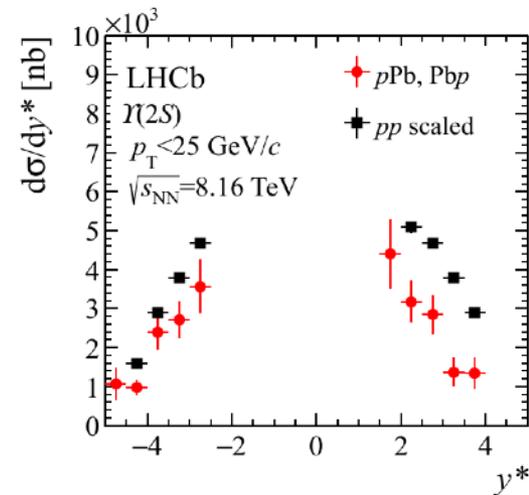
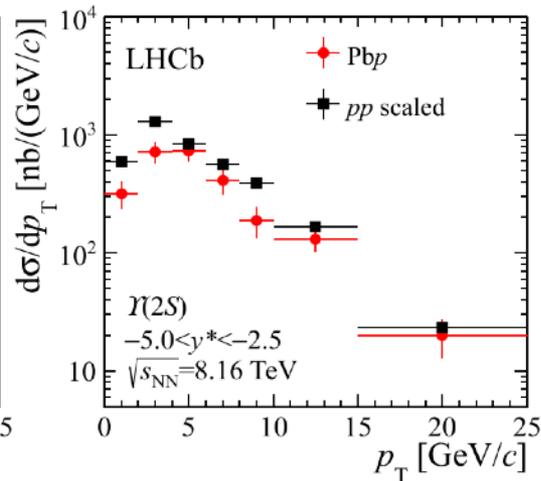
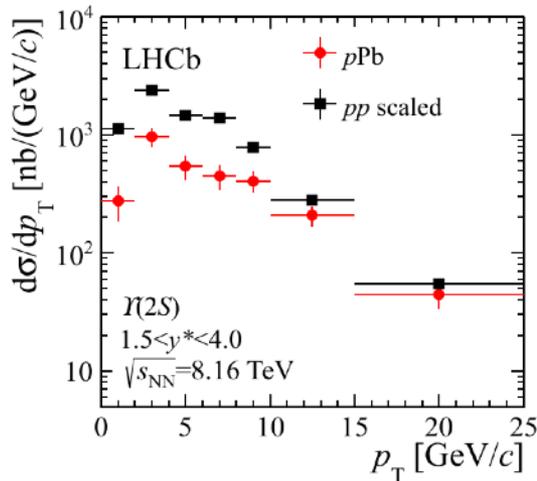
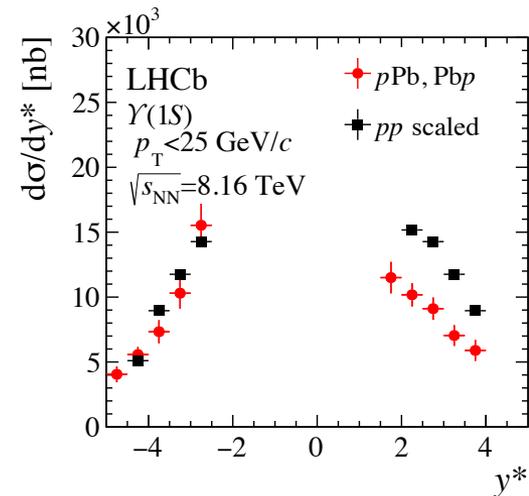
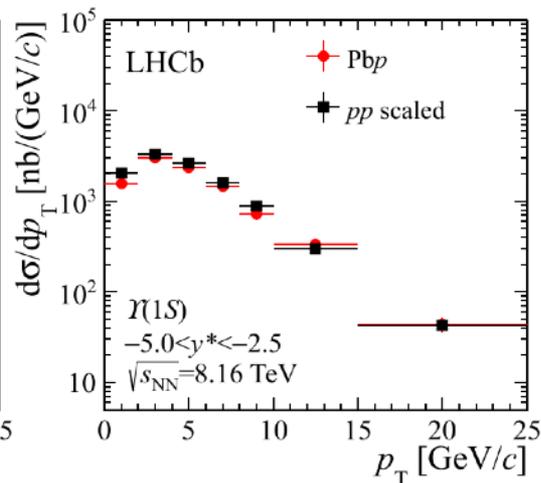
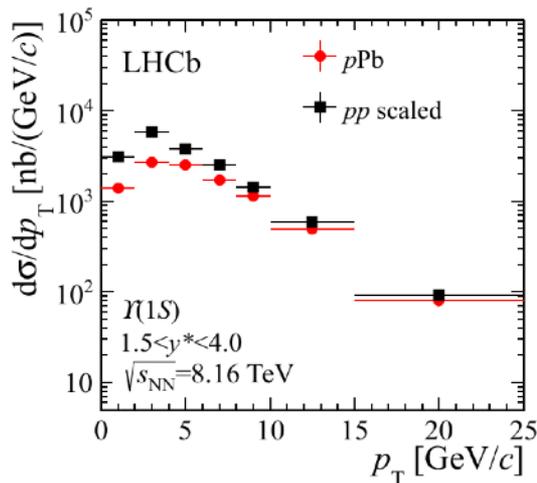
$\Upsilon(nS)$ production in $p\text{Pb}$ at 8.16 TeV

- **Quarkonium: QCD hydrogen atom \rightarrow probe deconfinement in PbPb**
- **J/ψ , $\Upsilon(nS)$ suppression observed in PbPb by CMS and ALICE**
- **Observed additional suppression of $\Upsilon(2S,3S)$ at low- p_T in $p\text{Pb}/\text{Pb}p$ by LHCb collaborations in Run-I, but statistics limited**



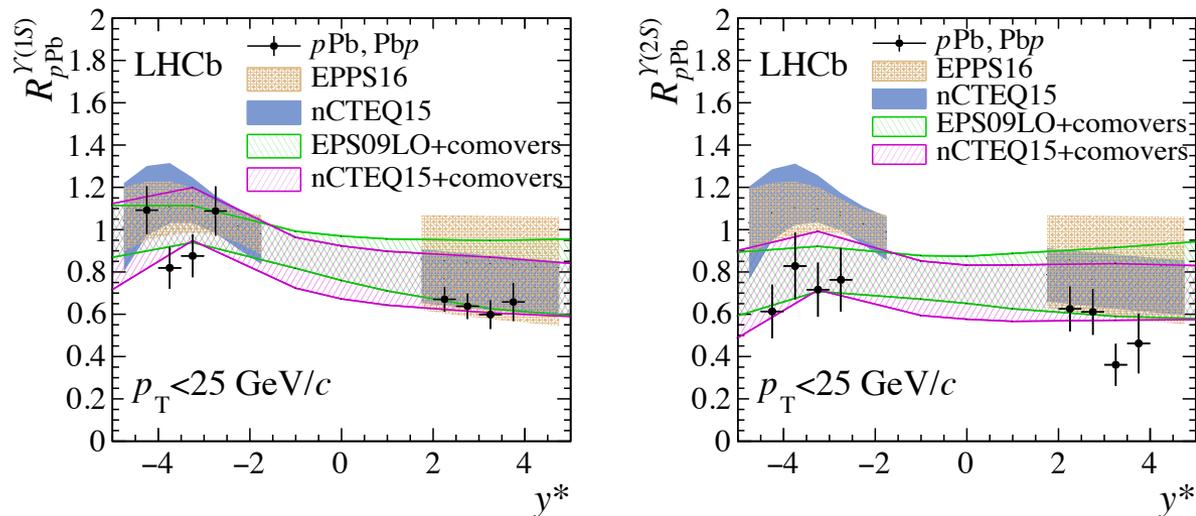
- **LHCb Run-II: Factor 20 more luminosity in 2016 than in Run-I**
- **Mass spectra are fitted with double crystal ball functions**
- **Clear $\Upsilon(3S)$ signal in both forward and backward rapidity**

$\Upsilon(nS)$ cross-sections



- $\Upsilon(1S)$ and $\Upsilon(2S)$ cross-sections are measured integrated in p_T and y^*

$\Upsilon(nS)$ nuclear modification factor



- $\Upsilon(1S)$: forward: suppressed by $\sim 30\%$
- $\Upsilon(1S)$: backward: compatible with unity within nPDF uncertainties
- $\Upsilon(2S)$: additional suppression confirmed
- Similar behaviour for $\psi(2S)$
- Consistent with comovers model

MODELS:

EPPS16: Eur. Phys. J. C (2017) 77: 163

EPS09: JHEP 04 (2009) 065, arXiv:0902.4154.

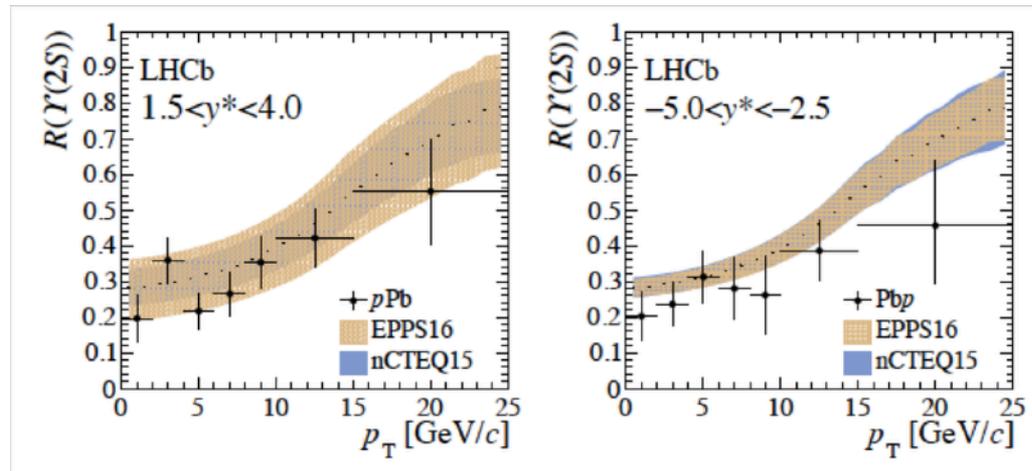
nCTEQ15: Phys. Rev. D93 (2016) 085037.

Comovers: arXiv:1804.04474; Phys. Lett. B749 (2015) 98, arXiv:1411.0549

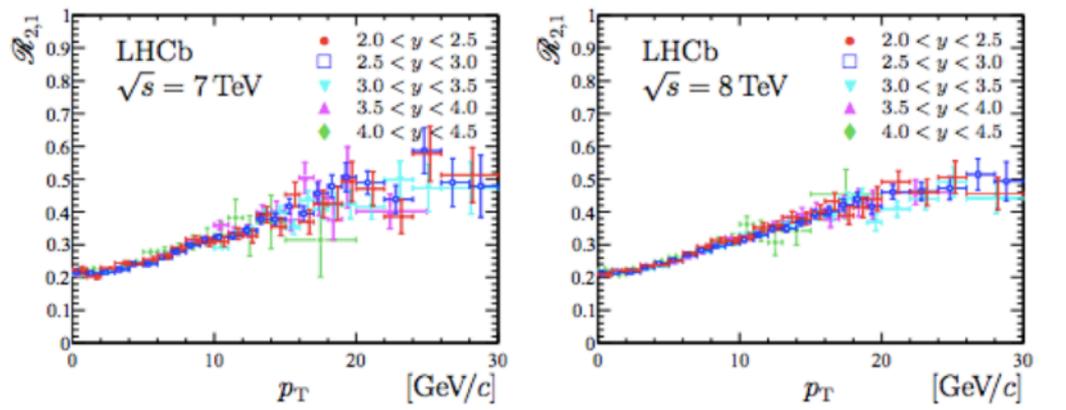
$\Upsilon(nS)$ ratios

- Ratio of $\Upsilon(2S)$ over $\Upsilon(1S)$
 - Differential in p_T

$$R(\Upsilon(nS)) = \frac{[d^2\sigma/dp_T dy^*](\Upsilon(nS))}{[d^2\sigma/dp_T dy^*](\Upsilon(1S))}$$



- pp results @8TeV



- Integrated Double Ratios

$$\mathcal{R}_{(pPb|Pbp)/pp}^{\Upsilon(nS)/\Upsilon(1S)} = \frac{R(\Upsilon(nS))_{pPb|Pbp}}{R(\Upsilon(nS))_{pp}}$$

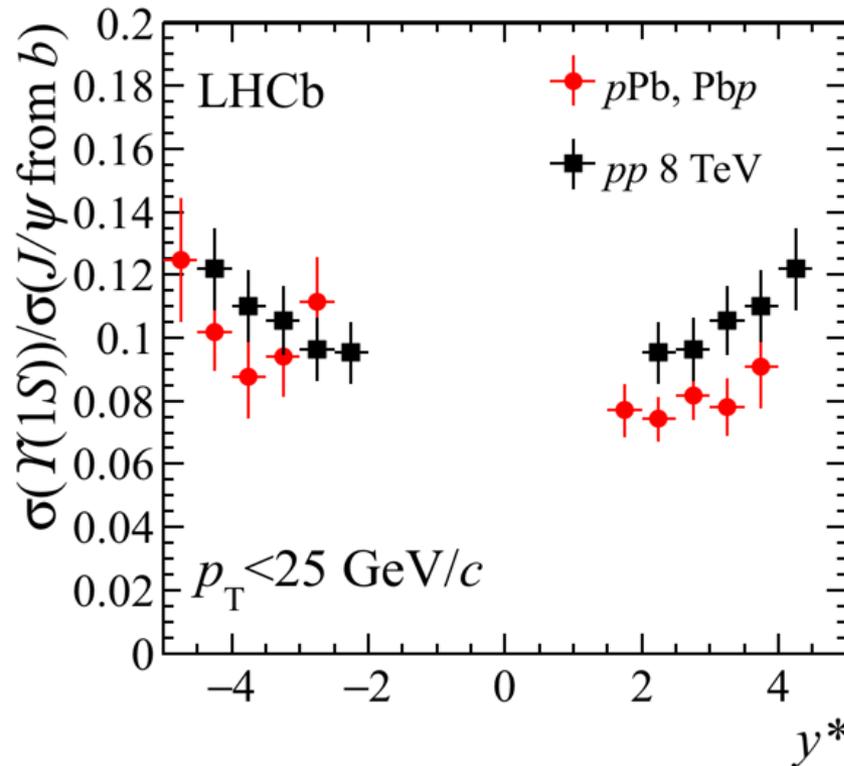
$$\mathcal{R}_{pPb/pp}^{\Upsilon(2S)/\Upsilon(1S)} = 0.86 \pm 0.15,$$

$$\mathcal{R}_{pPb/pp}^{\Upsilon(3S)/\Upsilon(1S)} = 0.81 \pm 0.15,$$

$$\mathcal{R}_{Pbp/pp}^{\Upsilon(2S)/\Upsilon(1S)} = 0.91 \pm 0.21,$$

$$\mathcal{R}_{Pbp/pp}^{\Upsilon(3S)/\Upsilon(1S)} = 0.44 \pm 0.15.$$

$\Upsilon(1S)$ to J/ψ -from- b ratio



- p_T -integrated $\Upsilon(1S)$ to J/ψ -from- b similar in pp & in $p\text{Pb}/\text{Pb}p$:
- Small suppression indicate different suppression mechanism for quarkonia with different binding energies

Conclusions

- **LHCb has strong capabilities to study heavy flavor in heavy ion collisions**
- **Open and hidden beauty production in p Pb collisions**
 - **Tested heavy-flavour bound state hadronisation & fragmentation down to low- p_T**
 - **Tested different suppression mechanism for quarkonia with different binding energies**
 - **Nuclear suppressions in p Pb forward: up to 20-30% for beauty**

Backups