



ICHEP2018 SEOUL

XXXIX INTERNATIONAL CONFERENCE
ON *high Energy Physics*

JULY 4 - 11, 2018
COEX, SEOUL



Quarkonia production in $p\text{Pb}$ collisions with LHCb

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ICHEP
5th July 2018

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Istituto Nazionale di Fisica Nucleare





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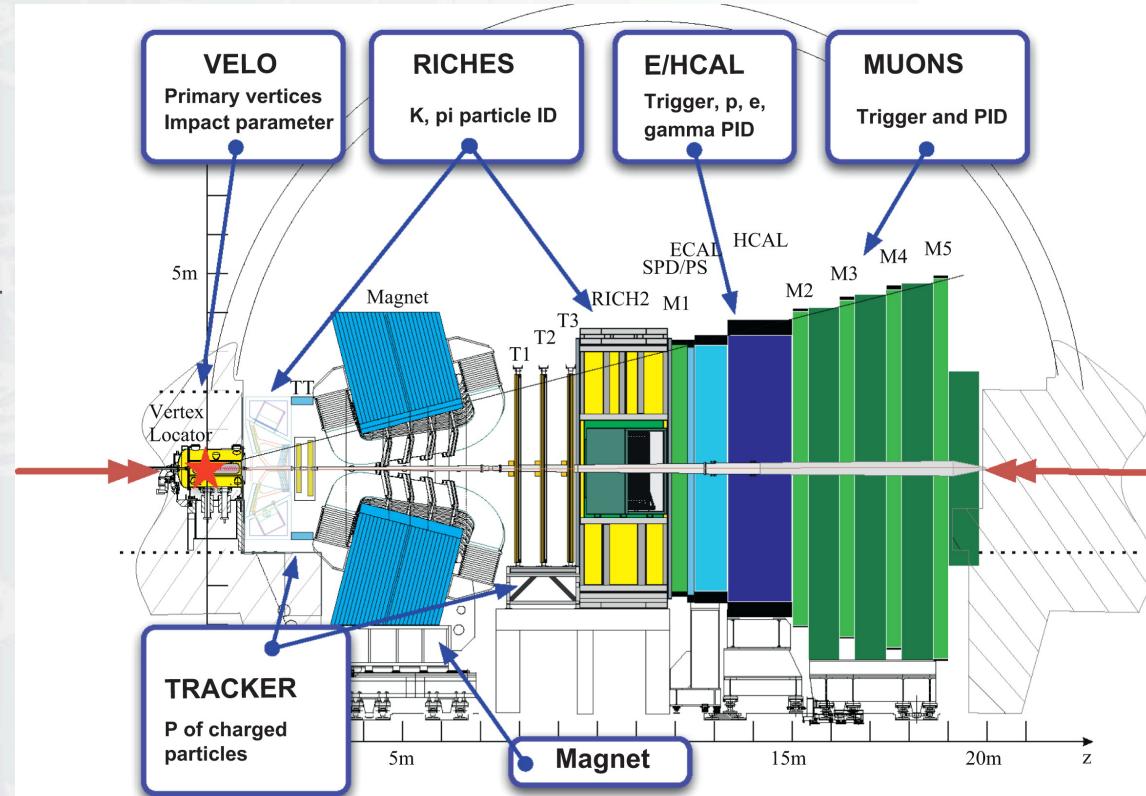
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LHCb detector and physics motivations

LHCb detector

- LHCb - single armed forward spectrometer, located at LHC
- Acceptance $2 < \eta < 5$
- 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]



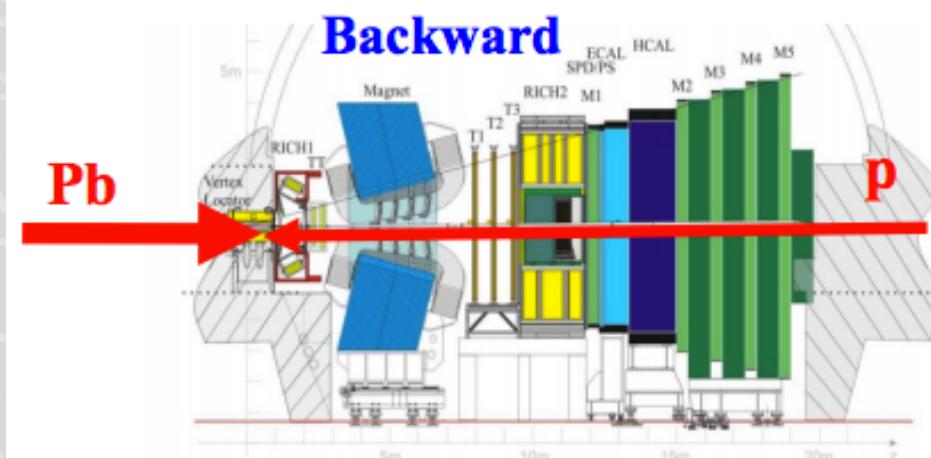
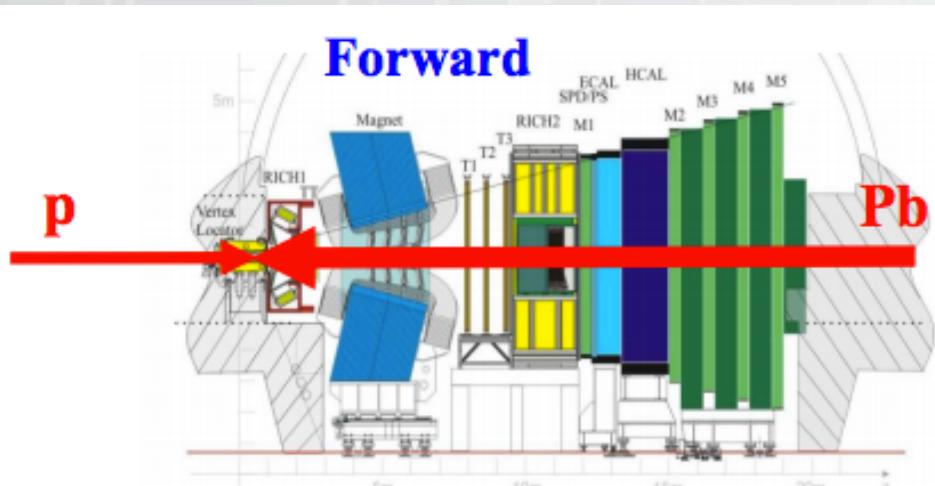
LHCb heavy ion collider mode

$E_{\text{beam}}(p)$	pp	p-SMOG	p-Pb/Pb-p	Pb-SMOG	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5. TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.02 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

(SMOG = System for Measuring the Overlap with Gas)

- **$p\text{Pb}/\text{Pbp}$ Quarkonium results - this talk**
- **$p\text{Pb}/\text{Pbp}$ open heavy flavour results - see Benjamin's talk later today**
- **Fixed target (SMOG) results - see Jihyun's talk on Saturday**

Proton-lead 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:

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

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

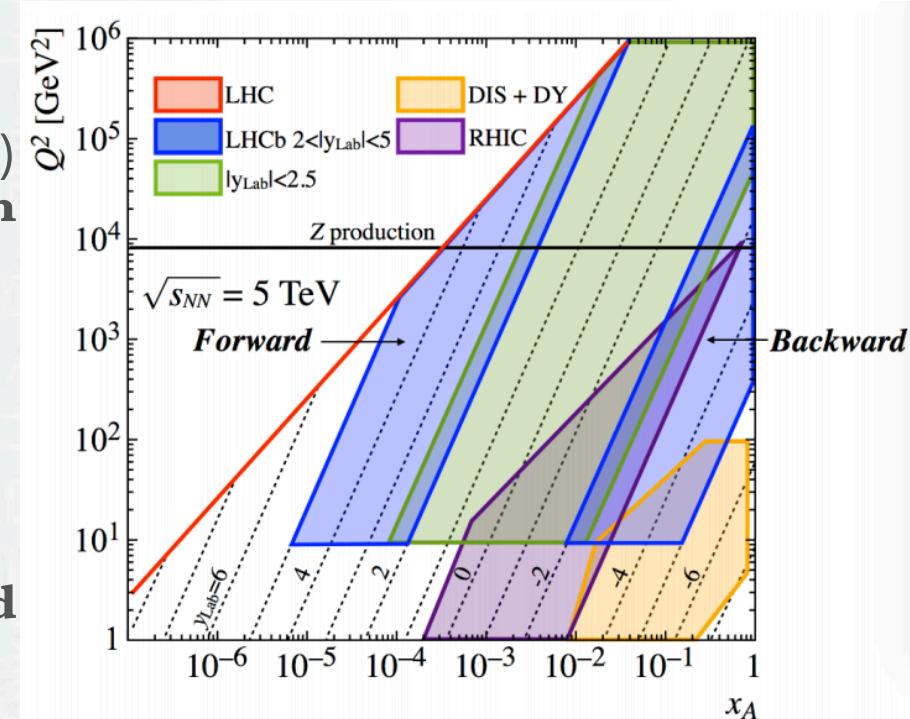
- 1.1 nb^{-1} (Fwd), 0.5 nb^{-1} (Bwd)

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

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

Physics motivation

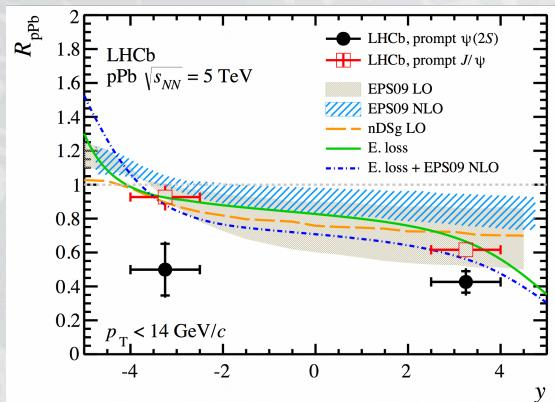
- Study of QCD in a yet barely explored regime
- Study of cold nuclear matter (CNM) effects and their disentangling from QGP effects
- Reference for nucleus-nucleus collisions
- Forward acceptance of LHCb allows to test unique phase space
 - x_A : momentum fraction carried by a parton inside the nucleon bound in the lead ion
 - sensitivity for very low as well as very high x_A -values



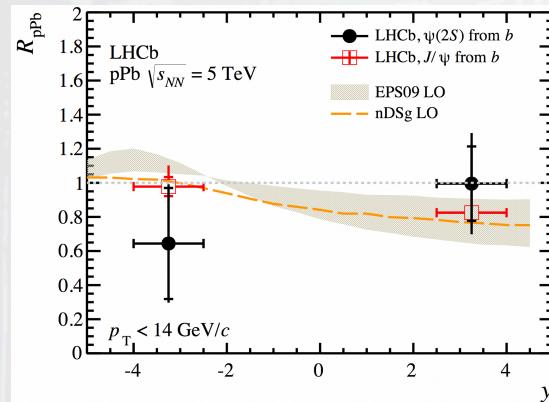
LHCb 5 TeV quarkonium results - J/ψ , $\psi(2S)$ and $\Upsilon(1S)$

- Candidates fully reconstructed from well identified muons
- Prompt J/ψ , $\psi(2S)$ and those from b decays separated using pseudo-proper decay time

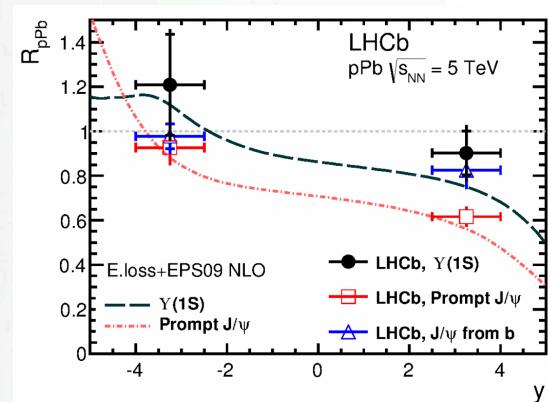
Prompt J/ψ , $\psi(2S)$



J/ψ , $\psi(2S)$ from b



$\Upsilon(1S)$



Forward rapidity

- Significant suppression for J/ψ , even larger for $\psi(2S)$
- Modest suppression for non-prompt J/ψ , similar to $\Upsilon(1S)$

Backward rapidity

- No suppression for J/ψ and $\Upsilon(1S)$
- Unexpected large suppression for $\psi(2S)$, not described by E.loss and shadowing



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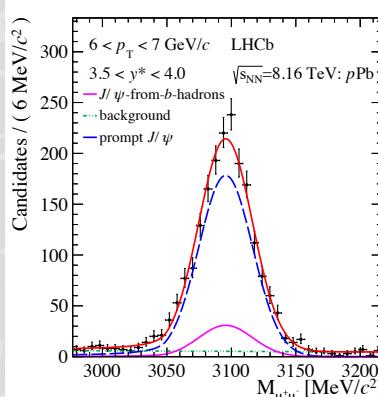
J/ ψ production in proton-lead collisions at 8.16 TeV

[[PLB 774\(2017\) 159-178](#)]

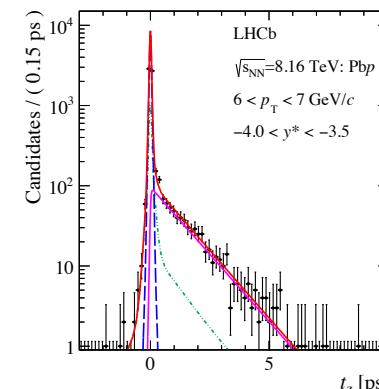
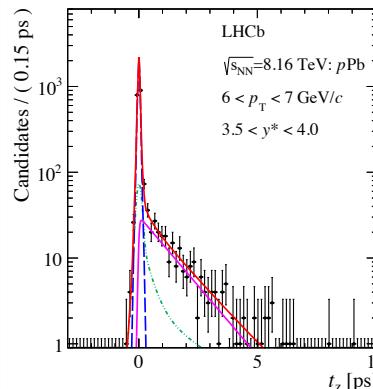
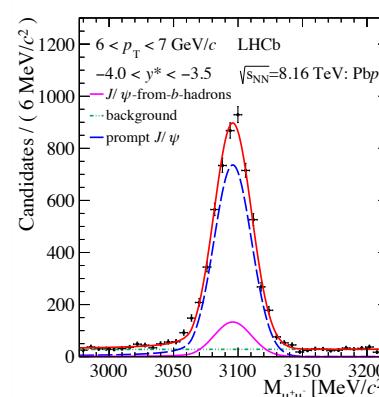
Signal extraction

- 2016 $p\text{Pb}$ collision data, 8.16 TeV
- Prompt J/ψ and J/ψ -from- b are extracted by simultaneous fit of mass and pseudo-proper time: $t_z = (\text{Z}_{\text{J}/\psi} - \text{Z}_{\text{PV}}) \times M_{\text{J}/\psi} / p_z$

Forward



Backward



Mass distribution:

Signal: Crystal Ball

Background: exponential

tz distribution:

Signal: $\delta(t_z)$ for prompt J/ψ ;
Exponential for J/ψ -from- b .

Background: empirical function from sideband

Total yields:

prompt	from-b
Forward: 3.8×10^5 ;	6.7×10^4
Backward: 5.6×10^5 ;	7.1×10^4



Results: J/ ψ total cross-sections in $p\text{Pb}$

- **Forward:**

$\sigma_{\text{prompt J}/\psi}(1.5 < y^* < 4.0, p_T < 14 \text{ GeV}/c) = 1625 \pm 4 \pm 117 \mu\text{b}$,

$\sigma_{\text{J}/\psi\text{-from-b-hadrons}}(1.5 < y^* < 4.0, p_T < 14 \text{ GeV}/c) = 276 \pm 2 \pm 20 \mu\text{b}$,

- **Backward:**

$\sigma_{\text{prompt J}/\psi}(-5.0 < y^* < -2.5, p_T < 14 \text{ GeV}/c) = 1692 \pm 4 \pm 182 \mu\text{b}$,

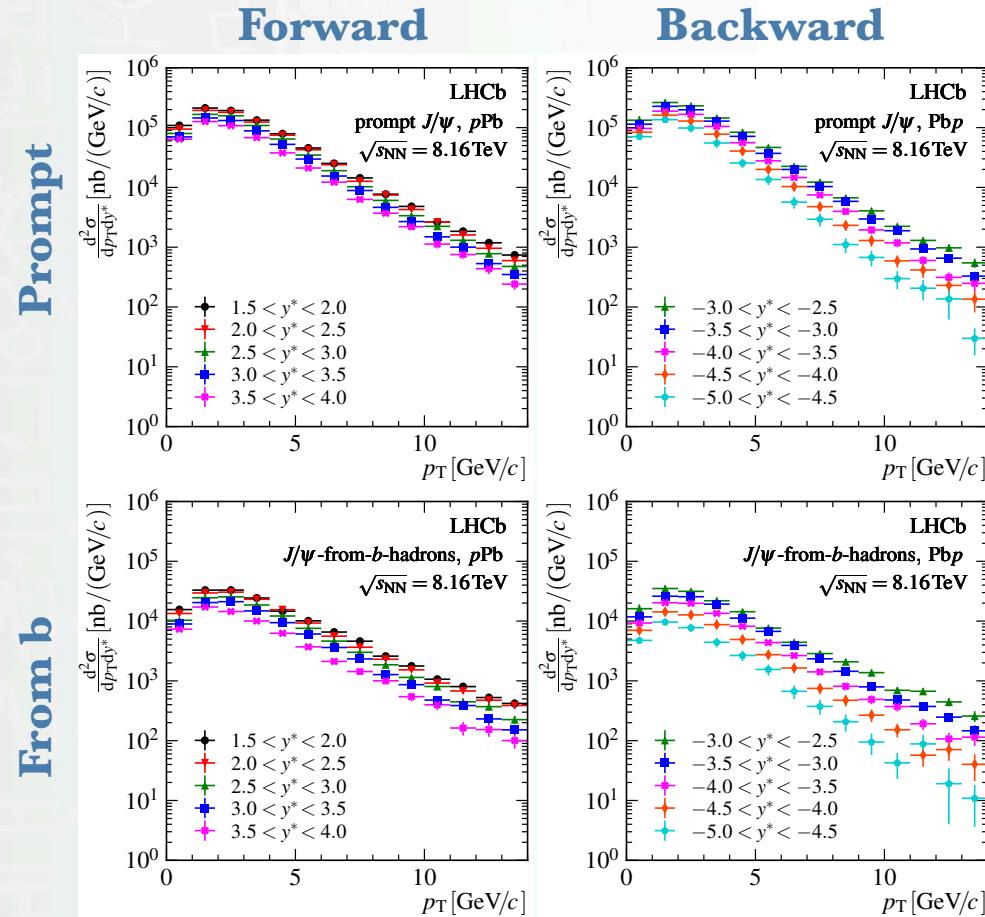
$\sigma_{\text{J}/\psi\text{-from-b-hadrons}}(-5.0 < y^* < -2.5, p_T < 14 \text{ GeV}/c) = 209 \pm 1 \pm 22 \mu\text{b}$,

Results: J/ ψ double differential cross-section

Double-differential cross-section is defined as:

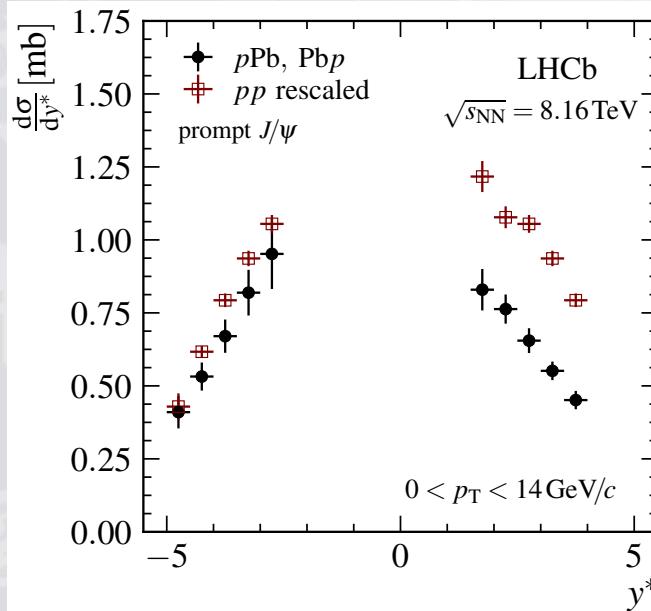
$$\frac{d^2\sigma}{dp_T dy^*} = \frac{N(J/\psi \rightarrow \mu^+ \mu^-)}{\mathcal{L} \cdot \epsilon_{tot} \cdot \mathcal{B} \cdot \Delta p_T \cdot \Delta y^*}$$

- **N: number of reconstructed prompt J/ ψ or J/ ψ -from-b;**
- **\mathcal{B} : branching fraction of J/ $\psi \rightarrow \mu^+ \mu^-$ decay ($\sim 6\%$) [PDG];**

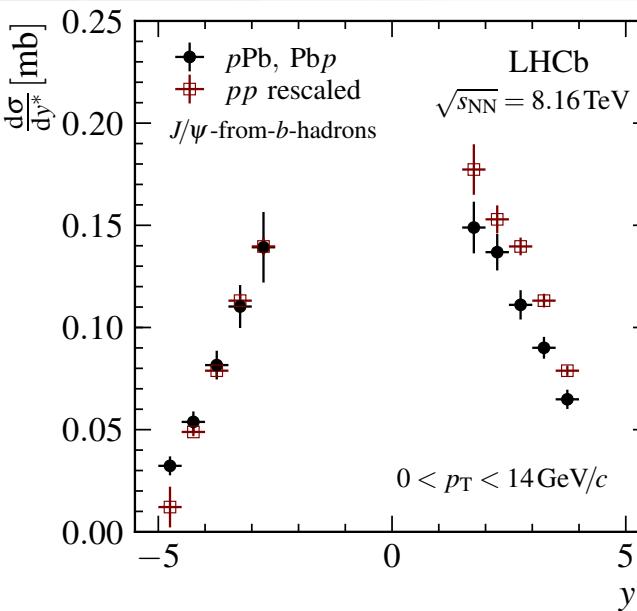


Results: J/ψ differential cross-section

Prompt



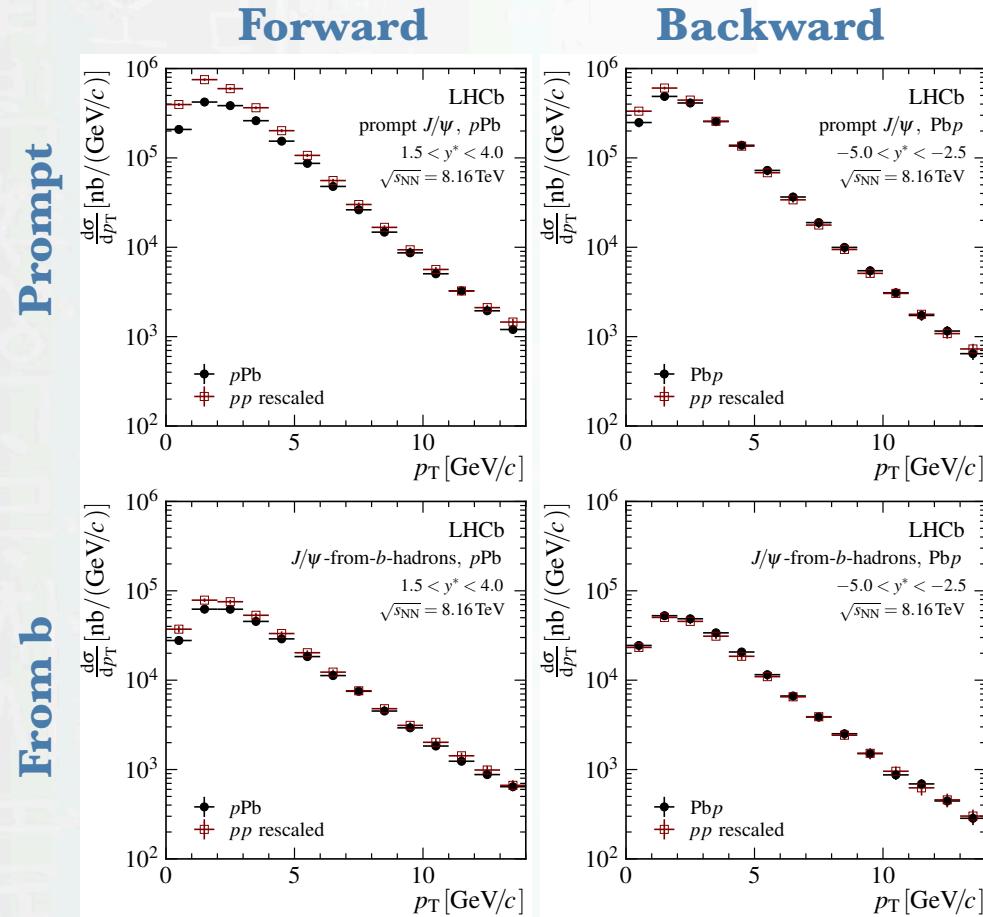
From b



- The cross-sections as a function of y^* , integrated over the p_T
- Sizeable forward-backward asymmetry
- Uncertainties are the quadratic sums of the statistical and systematic components

Results: J/ψ differential cross-section

- The cross-section is compared with the reference cross-section for prompt J/ψ and J/ψ -from-b-hadrons production in pp collisions at $\sqrt{s} = 8.16$ TeV, multiplied by the Pb mass number $A = 208$
- The cross-sections as a function of p_T , integrated over the range $1.5 < y^* < 4.0$ for $p\text{Pb}$ and $-5.0 < y^* < -2.5$ for $\text{Pb}p$

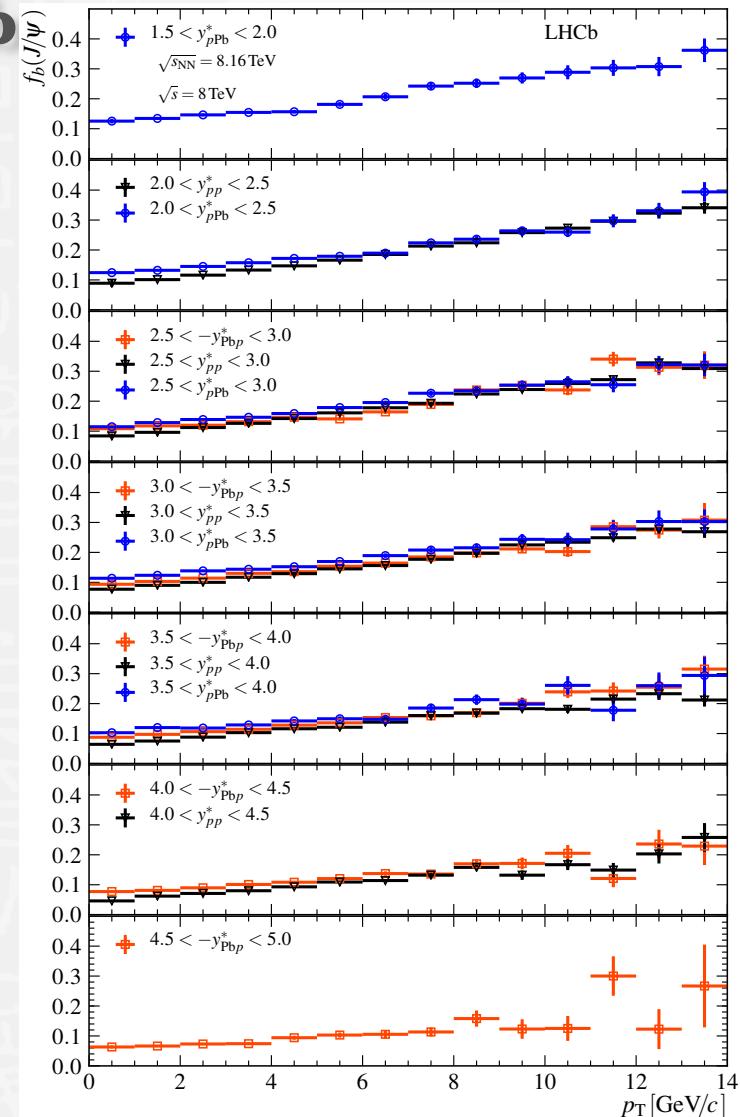


Results: fraction of J/ ψ -from-b

- Fraction of J/ ψ -from-b is defined as:

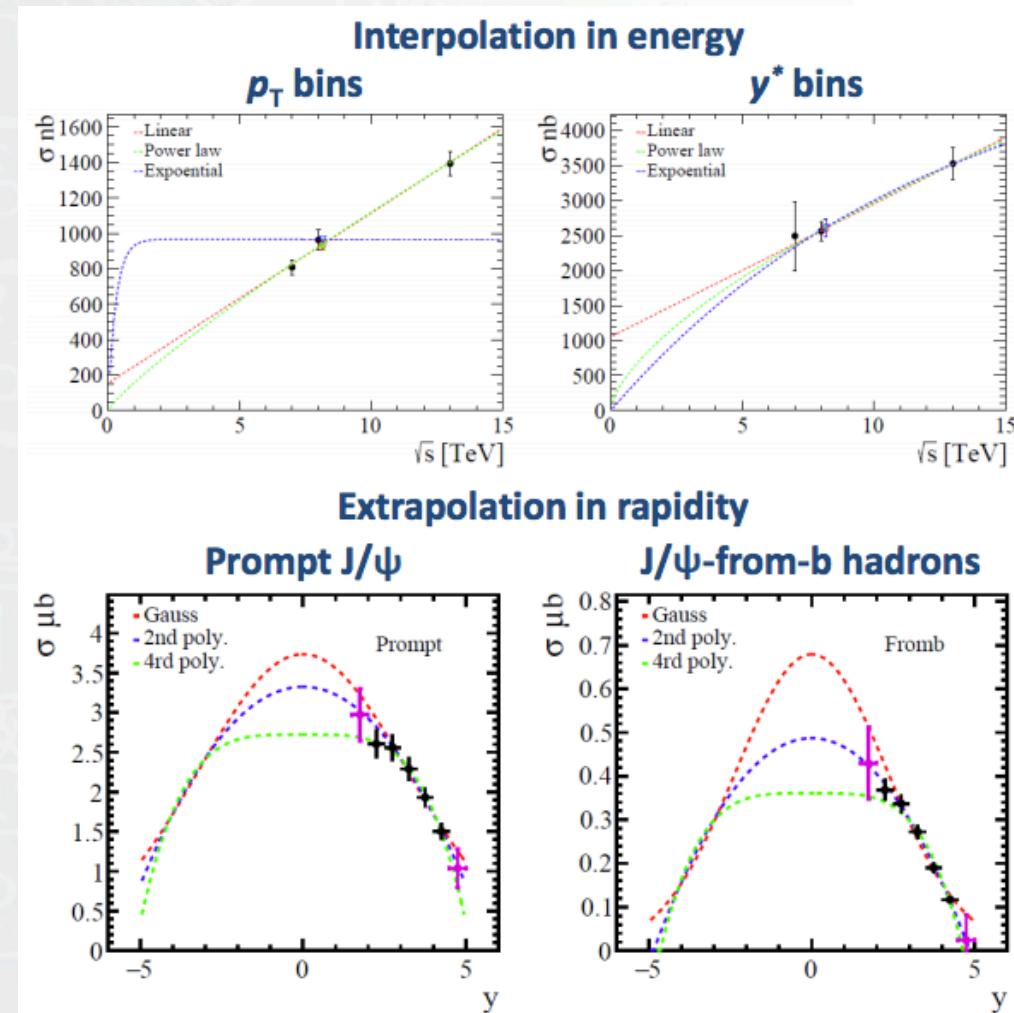
$$f_b \equiv \frac{\frac{d^2\sigma_{J/\psi\text{-from-}b\text{-hadrons}}}{dp_T dy^*}}{\frac{d^2\sigma_{\text{prompt } J/\psi}}{dp_T dy^*} + \frac{d^2\sigma_{J/\psi\text{-from-}b\text{-hadrons}}}{dp_T dy^*}}$$

- Comparing pp (black), forward (blue) and backward (red) configurations.
- Similar trends.
- But deviations at low p_T highlight the differences in the nuclear effects on prompt J/ ψ and J/ ψ -from-b hadrons.



Collision of pp at 8.16 TeV reference

- pp measurements at 8.16 TeV not available.
- Estimated based on interpolation (in energy), extrapolation (in rapidity outside pp coverage) of measurements at 7, 8 and 13 TeV.
- These methods were validated with ALICE and LHCb data [LHCb-CONF-2013-013; ALICE-PUBLIC-2013-002]



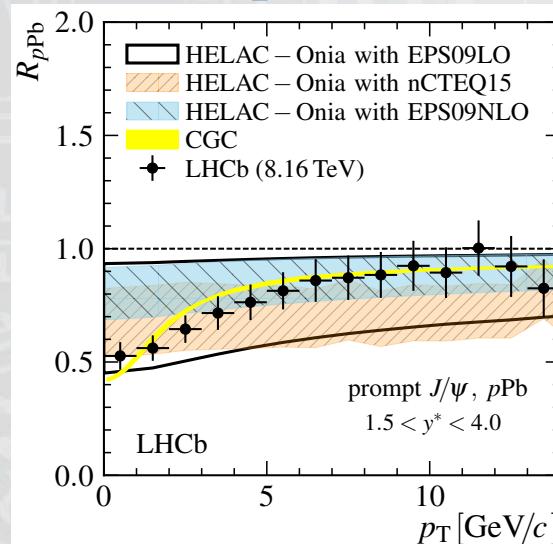
Results: prompt J/ ψ nuclear modification factor

- Nuclear modification factor is defined as:

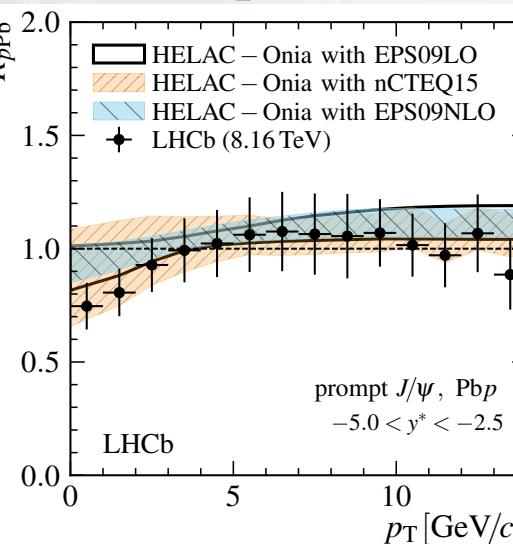
$$R_{p\text{Pb}}(p_T, y^*) \equiv \frac{1}{A} \frac{d^2\sigma_{p\text{Pb}}(p_T, y^*)/dp_T dy^*}{d^2\sigma_{pp}(p_T, y^*)/dp_T dy^*}, A = 208$$

- In Fwd: suppression at low p_T up to 50%, converging to unity at high p_T
- In Bwd: $R_{p\text{Pb}}$ closer to unity. Intriguing low values in Bwd at low p_T
- Overall agreement with theoretical models. Compatible with $p\text{Pb}$ 5 TeV results.

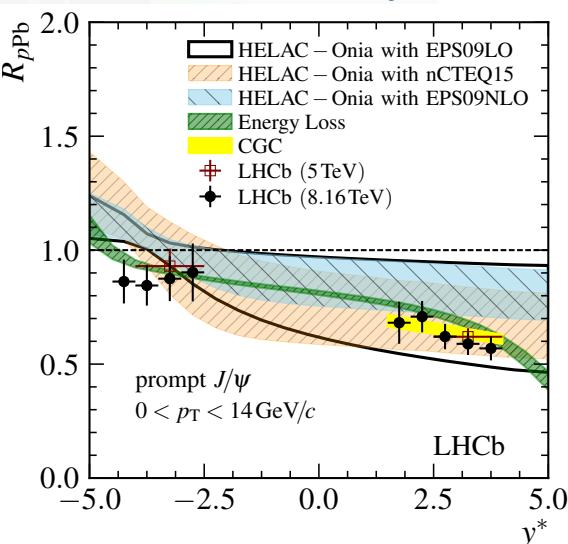
$R_{p\text{Pb}}$ vs. p_T , Forward



$R_{p\text{Pb}}$ vs. p_T , Backward



$R_{p\text{Pb}}$ vs. y^*



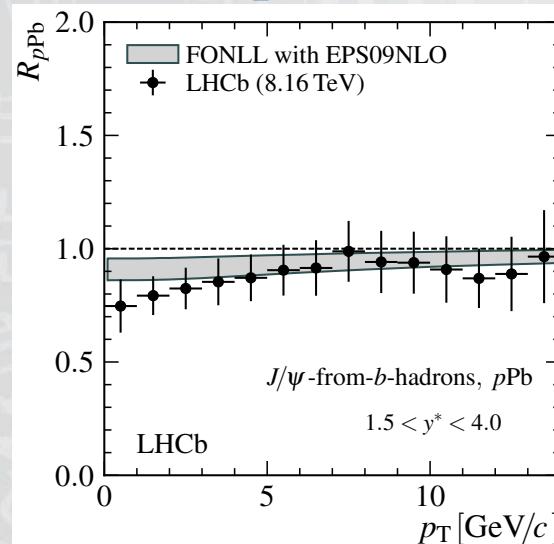
Results: J/ψ -from-b nuclear modification factor

- Nuclear modification factor is defined as:

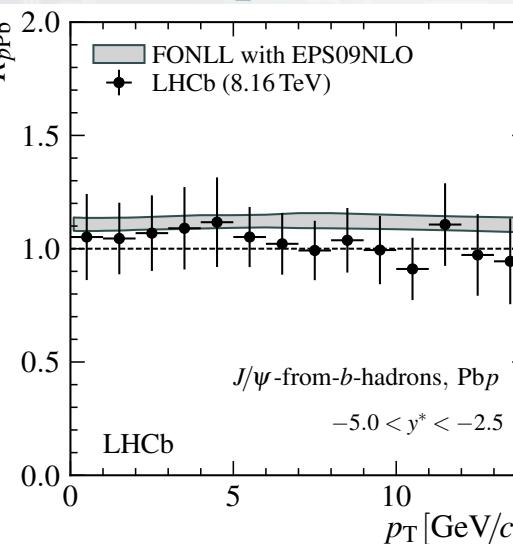
$$R_{p\text{Pb}}(p_T, y^*) \equiv \frac{1}{A} \frac{d^2\sigma_{p\text{Pb}}(p_T, y^*)/dp_T dy^*}{d^2\sigma_{pp}(p_T, y^*)/dp_T dy^*}, A = 208$$

- In Fwd: suppression at low p_T up to 30%, converging to unity at high p_T
- In Bwd: $R_{p\text{Pb}}$ slightly above unity
- Overall agreement with theoretical models. Compatible with $p\text{Pb}$ 5 TeV results.

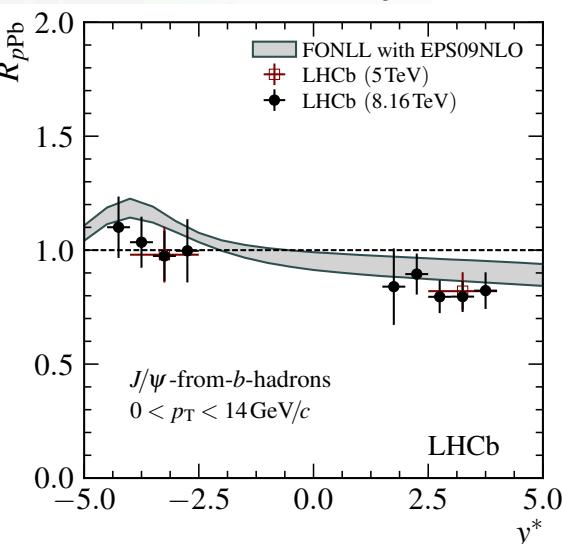
$R_{p\text{Pb}}$ vs. p_T , Forward



$R_{p\text{Pb}}$ vs. p_T , Backward



$R_{p\text{Pb}}$ vs. y^*

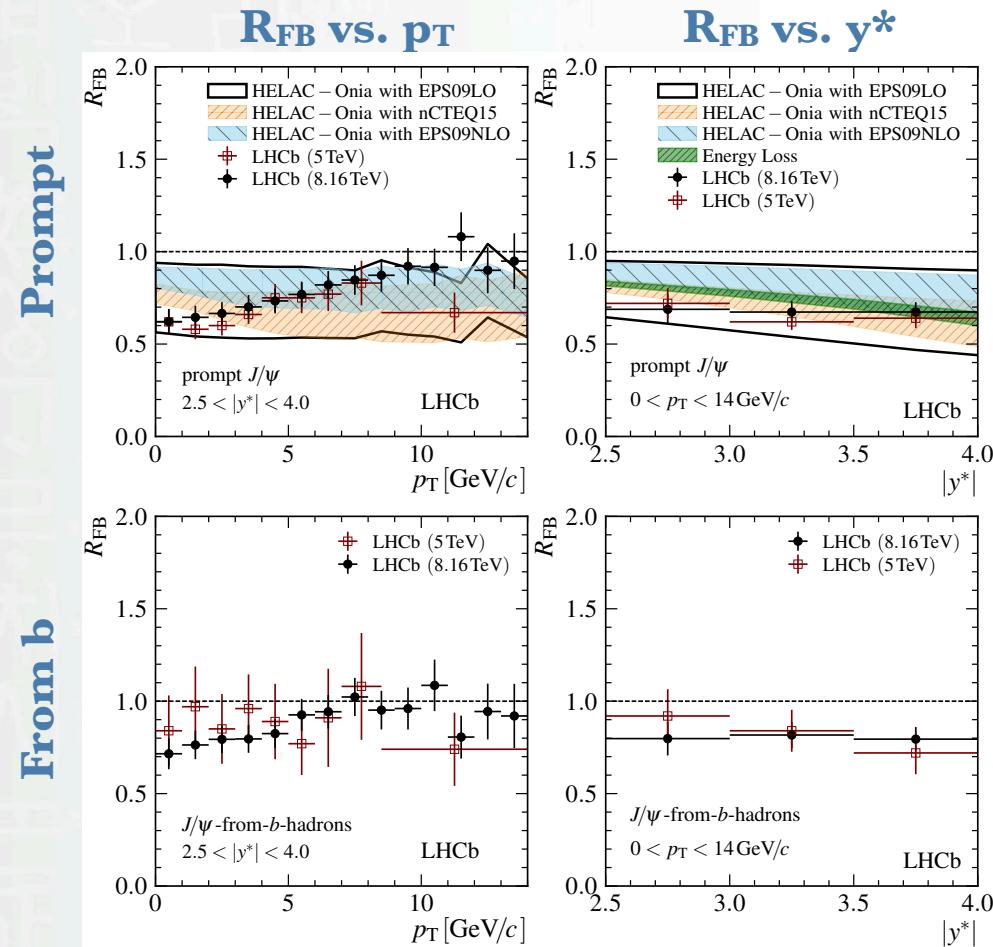


Results: J/ψ forward-backward asymmetry

- Forward-backward production ratio is defined as:**

$$R_{FB}(p_T, y^*) \equiv \frac{\frac{d^2\sigma_{pPb}(p_T, +|y^*|)}{dp_T dy^*}}{\frac{d^2\sigma_{pPb}(p_T, -|y^*|)}{dp_T dy^*}}$$

- Clear forward-backward asymmetry for prompt J/ψ , in particular at low p_T**
- For J/ψ -from-b: R_{FB} is closer to unity**
- Agreement with pPb 5 TeV data within uncertainties**





Outlooks and conclusions



Outlooks and conclusions

- Production cross-sections of prompt and non-prompt J/ψ in $\sqrt{s_{NN}} = 8.16 \text{ TeV}$ $p\text{Pb}$ collisions are measured as function of p_T and y^*
- Nuclear modification factors and forward-backward asymmetry are measured
- These results can have an impact in constrain models for nuclear effects
- These results will be the reference for the analyses of nucleus-nucleus collisions
- More measurements with $\sqrt{s_{NN}} = 8.16 \text{ TeV}$ are still yet to come ($\Psi(2S)$, $\Upsilon(nS)$, ...)

一令勿謝○戊辰○夜有○更客星在尾宿十度去極「百一十度形體」



Backups



LHCb heavy ion collider mode

	Year	$\sqrt{s_{\text{NN}}}$	Lumi
$p\text{Pb}/\text{Pbp}$	2013	5.02 TeV	1.6 nb^{-1}
PbPb	2015	5.02 TeV	$10 \mu\text{b}^{-1}$
$p\text{Pb}/\text{Pbp}$	2016	8.16 TeV	34 nb^{-1}
XeXe	2017	5.44 TeV	$0.4 \mu\text{b}^{-1}$
PbPb	2018	5.02 TeV	($\sim 10 \times 2015$)

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