J/ψ production in proton-lead collisions at 8 TeV with the LHCb detector

arXiv:1706.07122; LHCB-PAPER-2017-014

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Motivation

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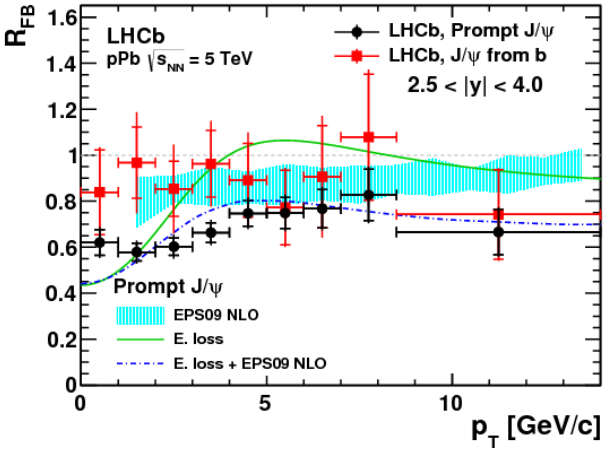
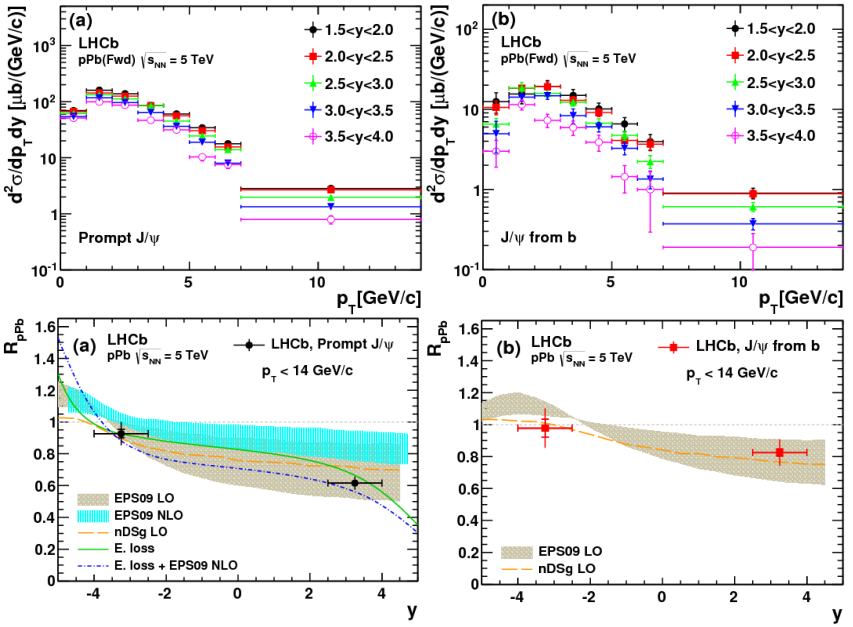
- Measurements of non-deconfinement effects in proton-nucleus collisions:
  - nuclear PDF,
  - saturation,
  - coherent energy loss.
- Important prerequisite for other measurements:
  - $\psi(2S)$ and χ_c: density effects on excited states?
  - Drell-Yan: disentangle shadowing to energy loss.
- Unique opportunity for precise measurements of J/ψ-from-b hadrons.
- In 2016 higher energy and larger statistics ($\sqrt{s}$ = 8.16 TeV, $\int \mathcal{L}dt \sim 35$ nb^{-1}) than in 2013 ($\sqrt{s}$ = 5.02 TeV, $\int \mathcal{L}dt \sim 2$ nb^{-1}) [1].

2013 data results [1]



Prompt J/ψ | J/ψ-from-b hadrons



[1]. JHEP 02 (2014) 072.

LHCb Experiment

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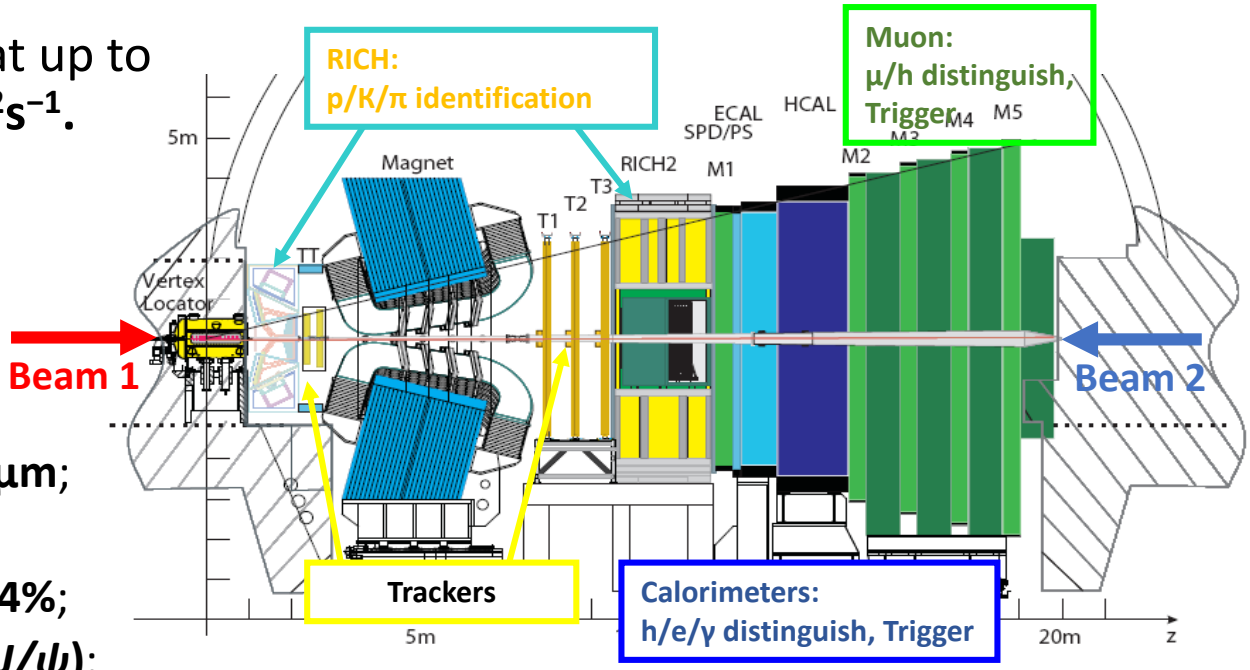
- **LHCb [1]** – forward spectrometer, located at LHC.
- Acceptance **$2 < \eta < 5$**
- Proton-proton interaction at up to **$\sqrt{s} = 13$ TeV, $\mathcal{L} = 4 \cdot 10^{32}$ cm^{-2}s^{-1}.**
- **Goal**: CP violation and rare decays of *B*-mesons.



- **Resolutions [2]:**
  - spatial (PV position): **~ 16 μm**;
  - decay time: **~ 50 fs**;
  - track's momentum: **0.5–0.4%**;
  - mass (FWHM): **~ 13 MeV (J/ψ)**;
  - particle identification: **~ 96%**.

[1]. JINST 3 (2008) S08005.
[2]. Int. J. Mod. Phys. A 30 (2015) 15300227.

Proton-Ion setup at LHCb

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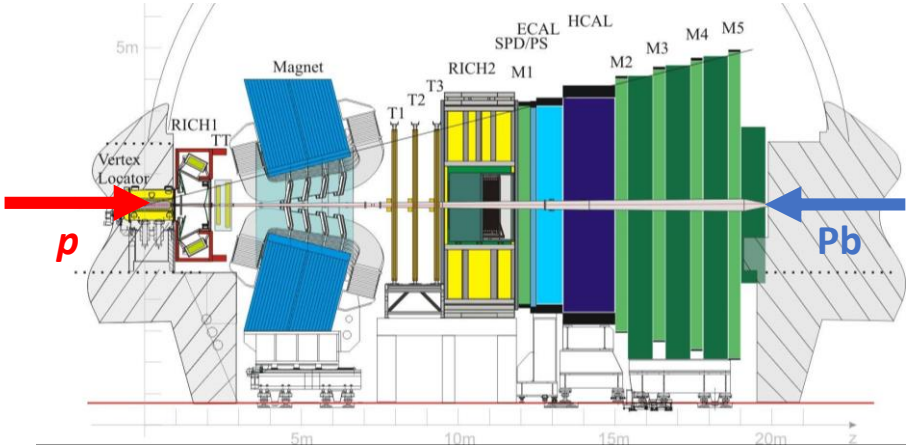
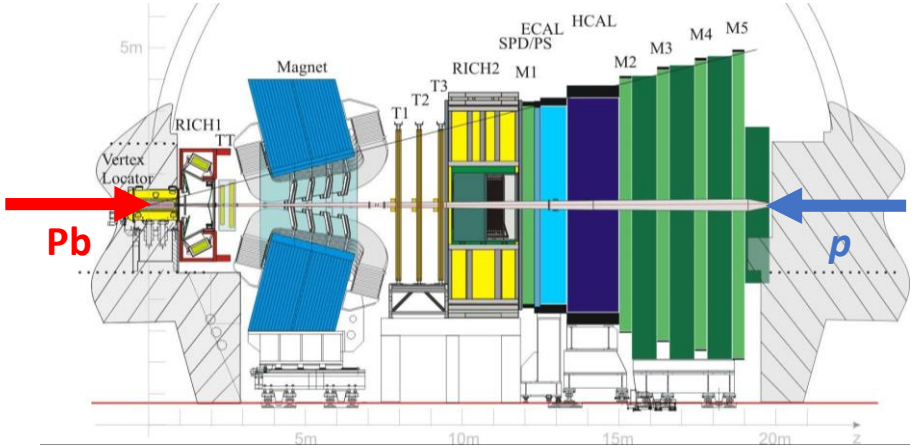
2016 heavy ion run:
Ion = ^{208}**Pb**, $\sqrt{s_{NN}}$ = **8.16** TeV, Integrated luminosity: **13.6** nb^{-1} (Fwd), **20.8** nb^{-1} (Bwd).

Forward (Fwd)



Backward (Bwd)



$1.5 < y^* < 4.0$ **$0 < p_T < 14$ GeV/c** **$-5.0 < y^* < -2.5$**

$y^* = y_{lab} - 0.465$ $y^* = -(y_{lab} + 0.465)$

Monte Carlo samples: **EPOS-LHC**. J/ψ from PYTHIA8 injected into each event [1].

[1]. Phys. Rev. C92 (2015) 034906; arXiv:1306.0121.

Signal Extraction

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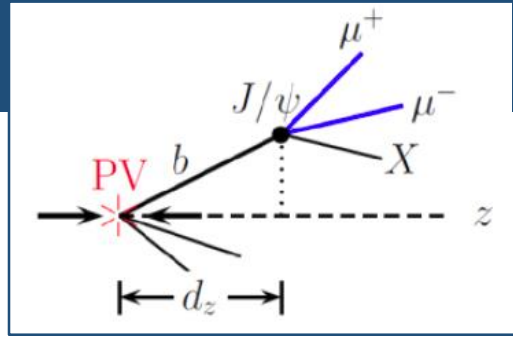
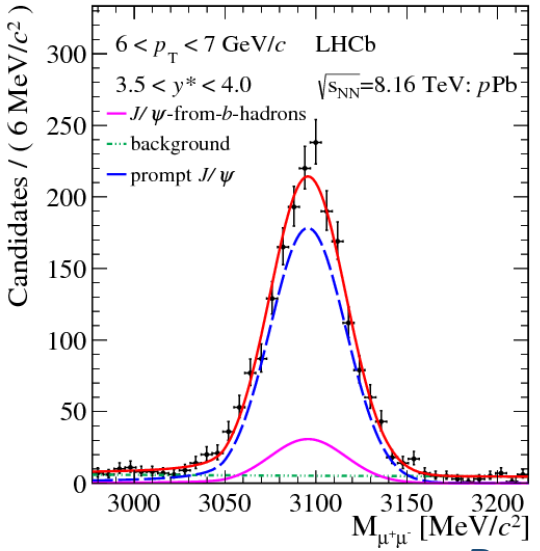
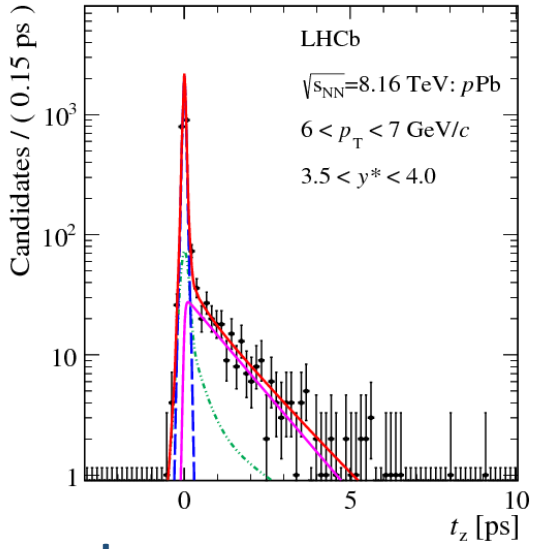
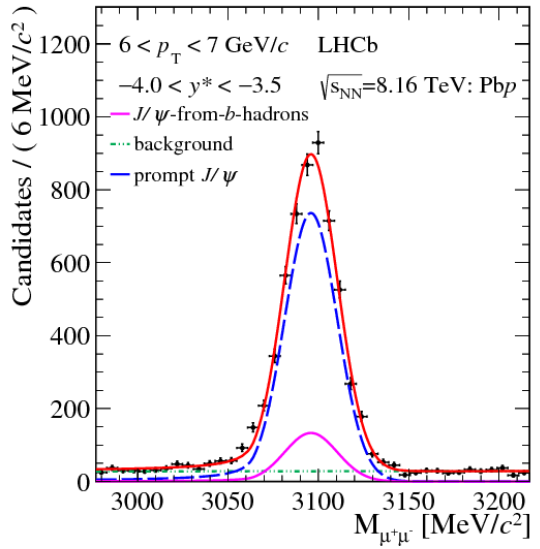


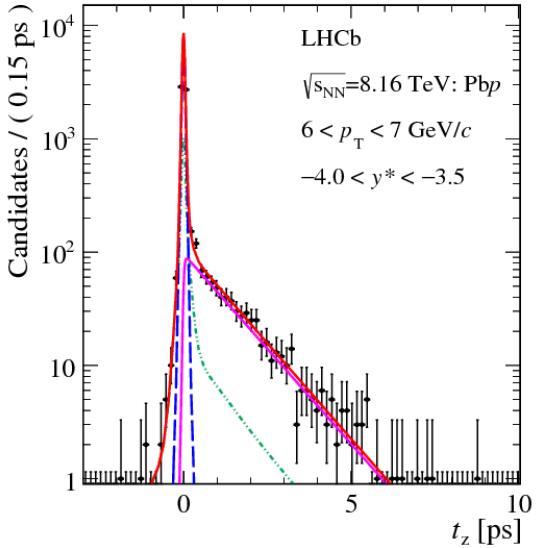
Forward





Backward





- $J/\psi \rightarrow \mu^+\mu^-$
- **Prompt J/ψ** and **J/ψ-from-b** hadrons are extracted by **simultaneous fit of mass** and pseudo-proper time: $t_z = (Z_{J/\psi} - Z_{PV}) \cdot M_{J/\psi}/p_z$
- **Mass** distributions:
  - Signal: **Crystal-Ball.**
  - Bkg: **exponential.**
- t_z distributions:
  - Signal: **$\delta(t_z)$ for prompt J/ψ; Exponential for J/ψ-from-b.**
  - Bkg: **empirical function** from sideband.
- **Total yields:**

	prompt	from-b
Forward:	**~ $3.8 \cdot 10^5$;**	**~ $6.7 \cdot 10^4$**
Backward:	**~ $5.6 \cdot 10^5$;**	**~ $7.1 \cdot 10^4$**

Results: Differential Production Cross-Sections

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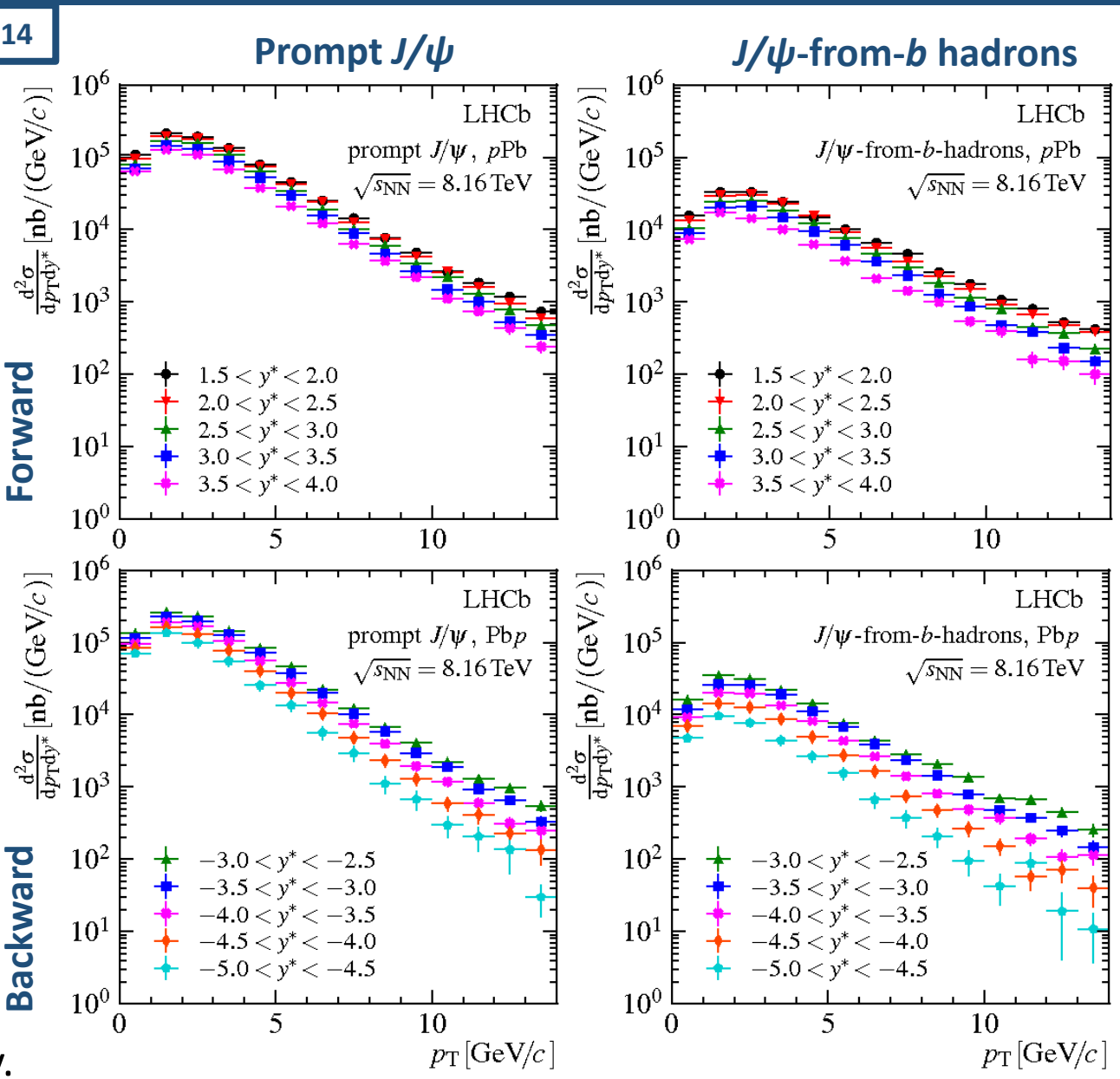
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*} = \frac{N}{\Delta p_\mathrm{T} \cdot \Delta y^* \cdot \epsilon \cdot \mathcal{B} \cdot \mathcal{L}}$$

- N – number of reconstructed prompt J/ψ or J/ψ-from-b;
- Δp_T = 1 GeV/c – transverse momentum bin widths;
- Δy = 0.5 – rapidity bin widths;
- ϵ – total efficiency;
- $\mathcal{B}$ – branching fraction of $J/\psi \to \mu^+\mu^-$ decay (~ 6%) [PDG];
- $\mathcal{L}$ – integrated luminosity.



Results: f_b

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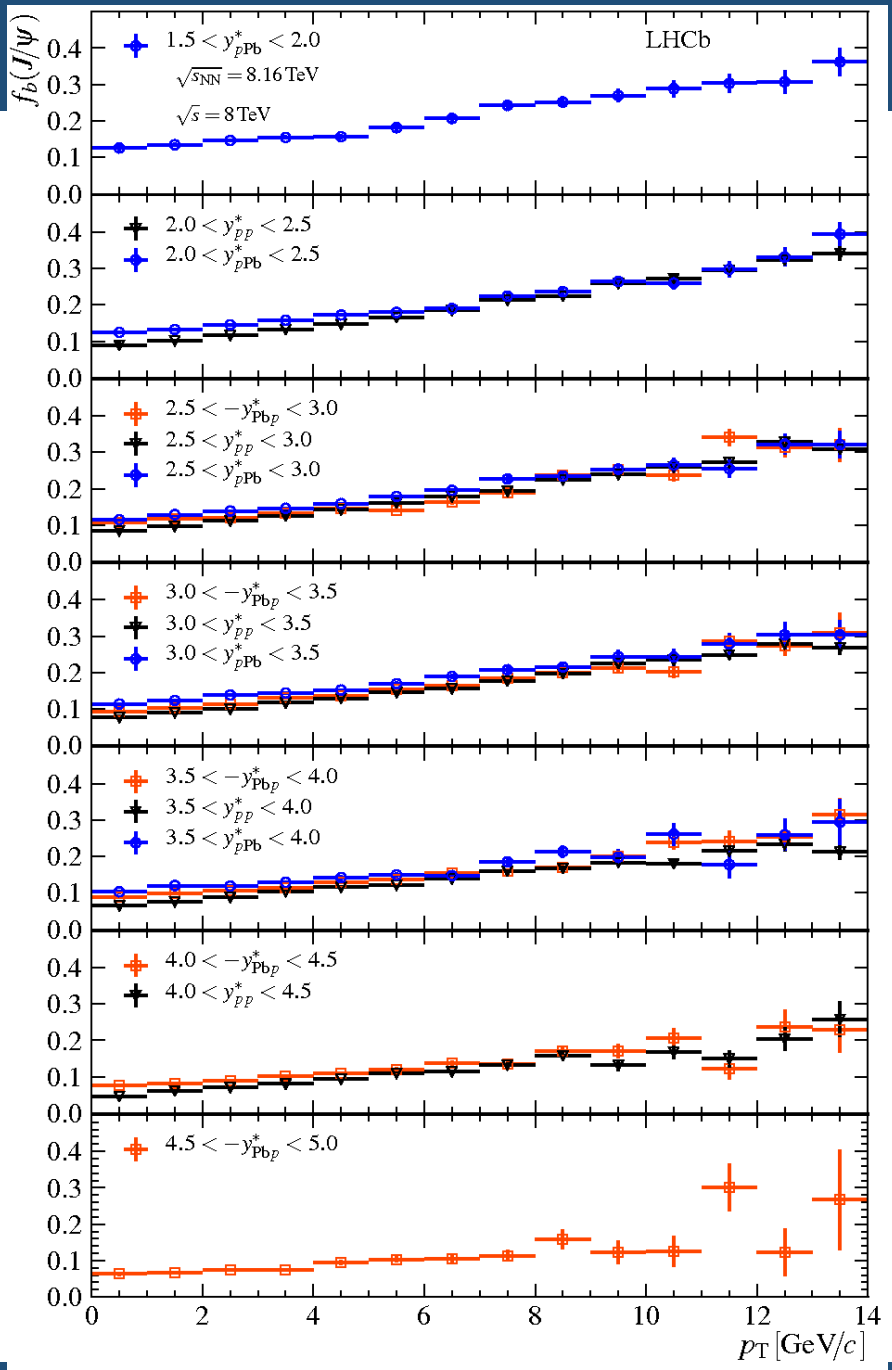
Fraction of *J/ψ*-from-*b* hadrons:

$$f_b = \frac{\frac{\mathrm{d}^2\sigma_{J/\psi\text{-from-}b}}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*}}{\frac{\mathrm{d}^2\sigma_{\mathrm{Prompt}\,J/\psi}}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*} + \frac{\mathrm{d}^2\sigma_{J/\psi\text{-from-}b}}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*}}.$$

- Comparing ***p-p*** (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.
- Advantage: most systematic uncertainties cancel.



Results: *p-p*@8.16TeV reference

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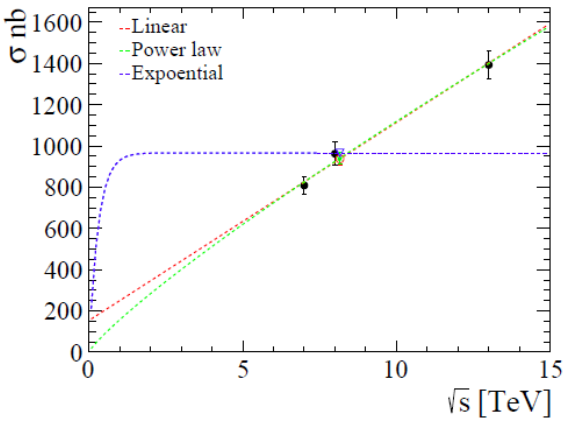
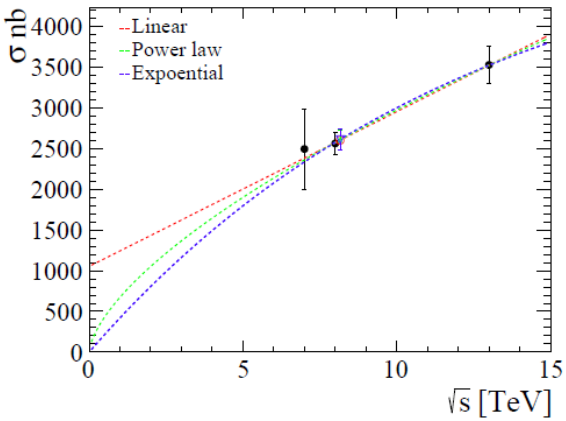
- *p-p* measurements at 8.16 TeV not available.
- Estimated based on interpolation (in energy), extrapolation (in rapidity outside *pp* coverage) of measurements at 7, 8 and 13 TeV.
- These methods were validated with ALICE and LHCb data [1]

Interpolation in energy

p_T bins

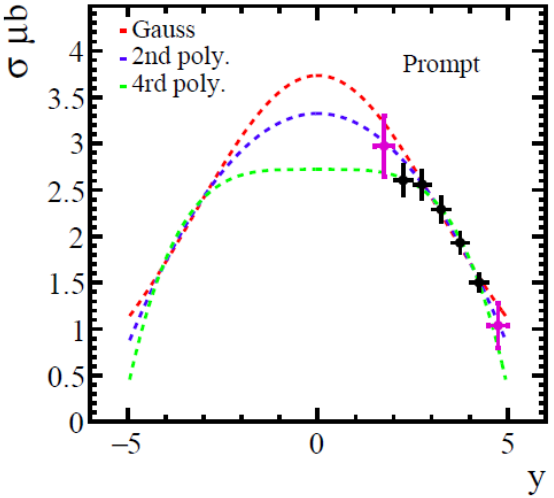


y^* bins

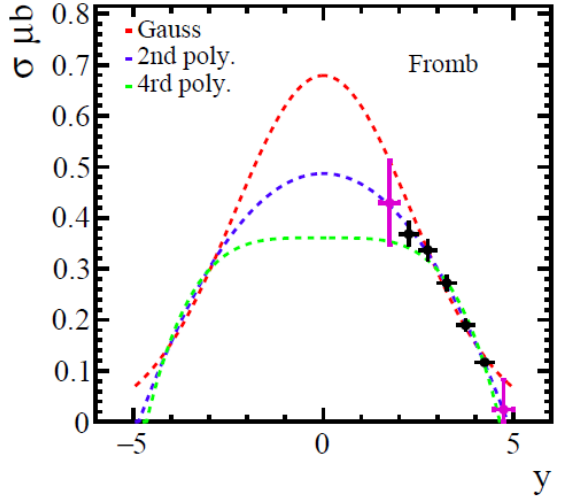


Extrapolation in rapidity

Prompt J/ψ



J/ψ-from-b hadrons



[1]. LHCb-CONF-2013-013; ALICE-PUBLIC-2013-002.

Results: Nuclear Modification Factors: Prompt J/ψ

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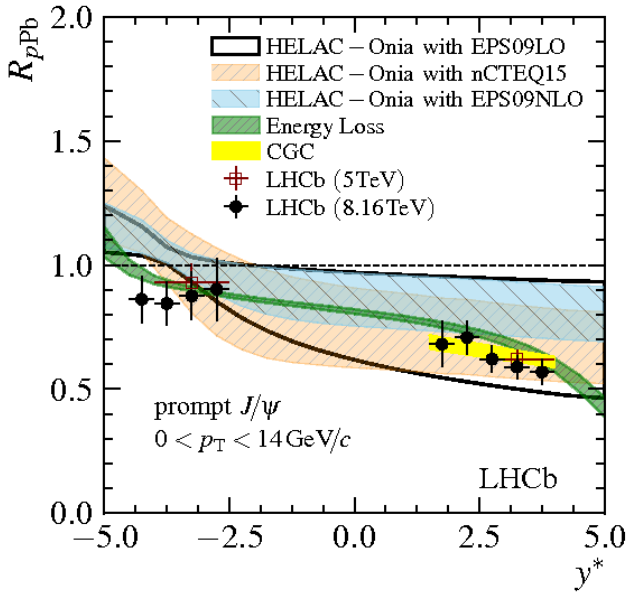
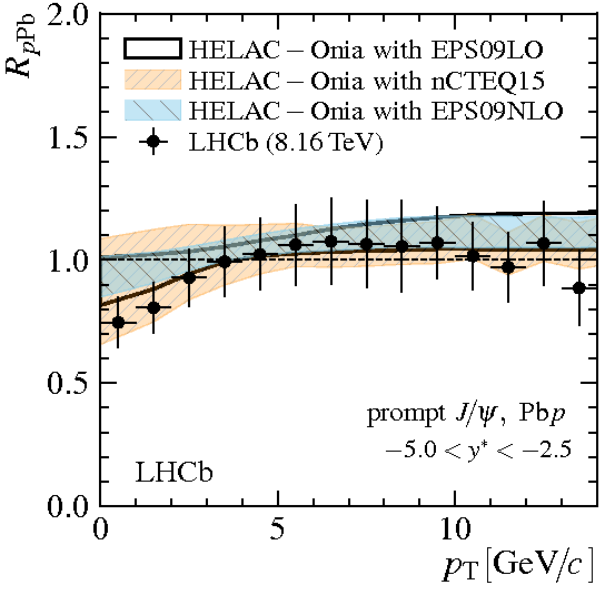
$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) = \frac{\left[\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*}\right]_{p\mathrm{Pb}}}{208 \cdot \left[\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*}\right]_{pp}}$$

- In Fwd: suppression at low p_T up to 50%, converging to unity at high p_T.
- In Bwd: $R_{p\mathrm{Pb}}$ closer to unity.
- Intriguing low values in Bwd at low p_T.
- Overall agreement with models:
  - Collinear factorization: nuclear PDF (HELAC) [1].
  - Color-Glass Condensate (CGC) [2].
  - Coherent energy loss [3].
- Compatible with p-Pb@5TeV results.

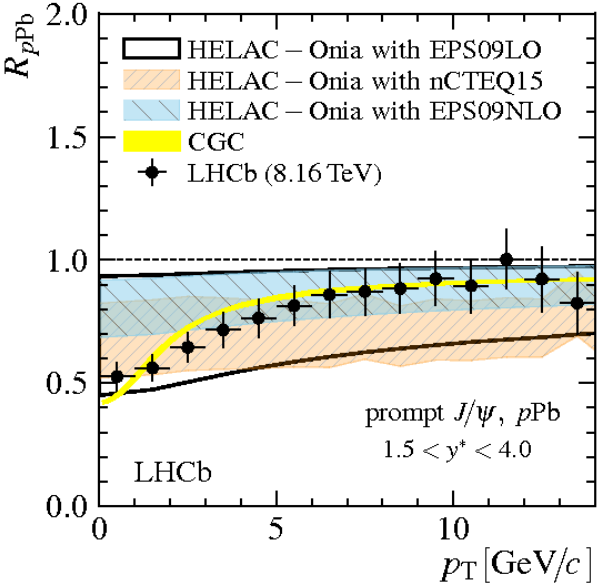


[1]. Comp. Phys. Com. 184 (2013) 2562, Comp. Phys. Com. 198 (2016) 238.
[2]. Phys. Rev. D91 (2015) 114005, Phys. Rev. D94 (2016) 074031.
[3]. JHEP 03 (2013) 122.

Backward



Forward



Results: Nuclear Modification Factors: J/ψ-from-b

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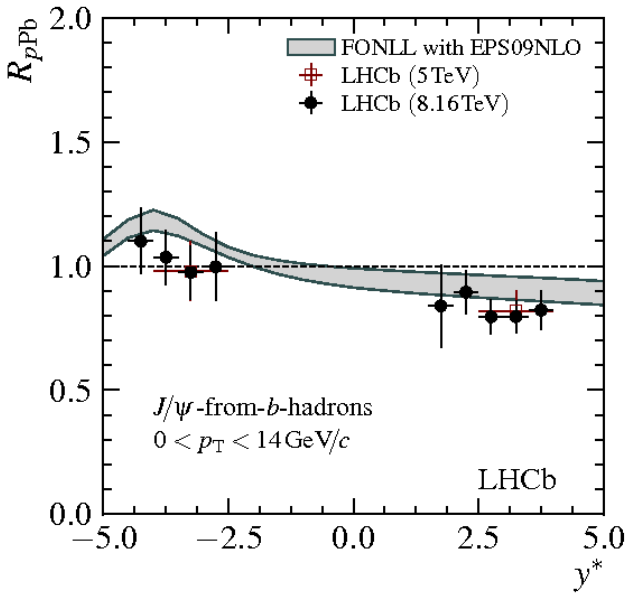
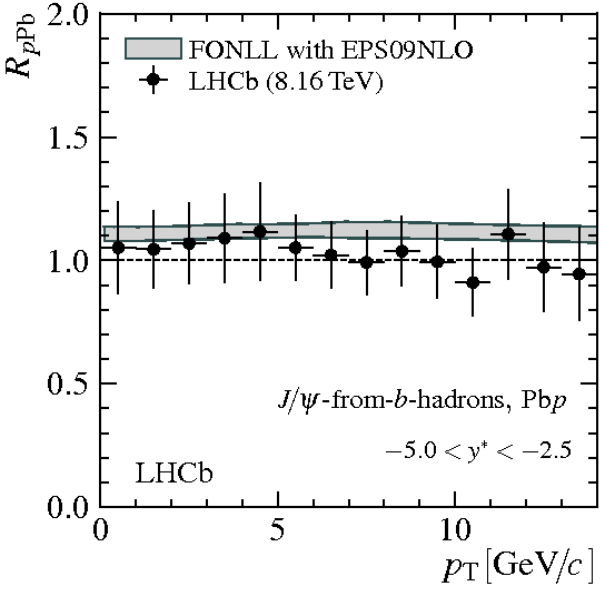
$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) = \frac{\left[\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*}\right]_{p\mathrm{Pb}}}{208 \cdot \left[\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y^*}\right]_{pp}}$$

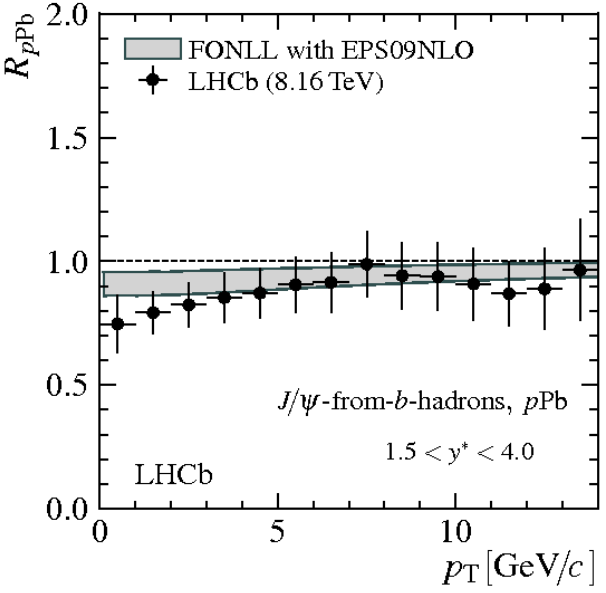
- In Fwd: suppression at low p_T up to 30%, converting to unity at high p_T.
- In Bwd: $R_{p\mathrm{Pb}}$ above unity, p_T dependence.
- Overall agreement with Model: FONLL with EPS09NLO [1].
- Compatible with p-Pb@5TeV results.
- Unprecedented precision.



Backward



Forward



[1]. JHEP 04 (2009) 065.

Results: Forward-Backward Asymmetry

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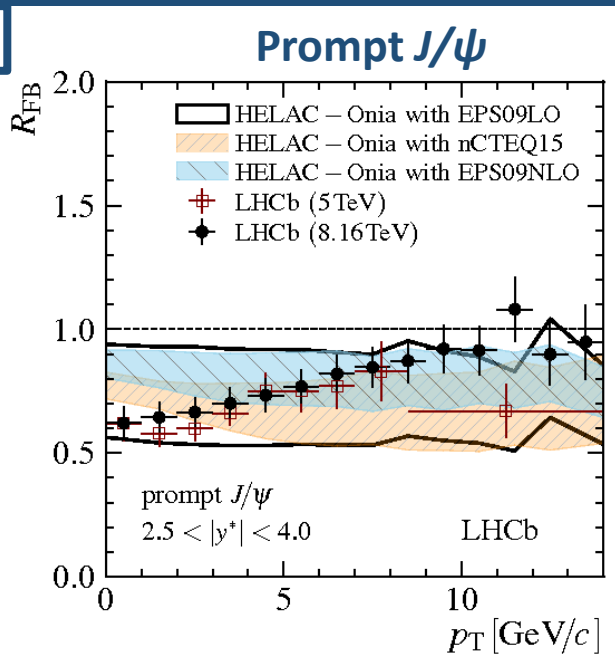
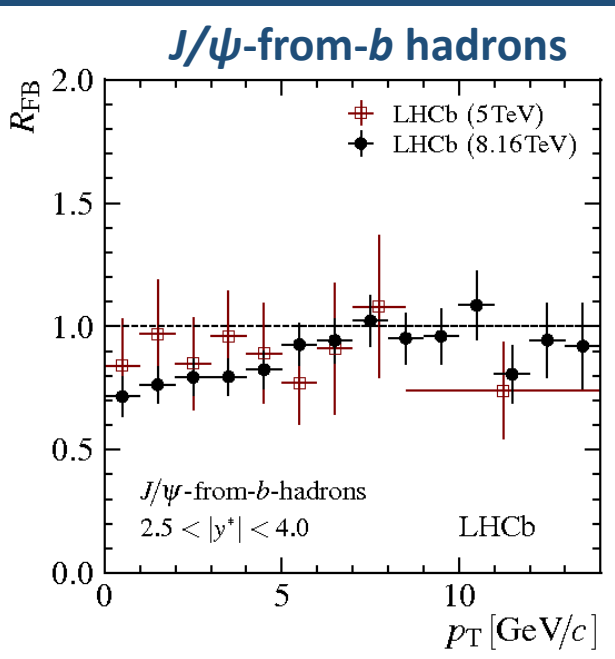
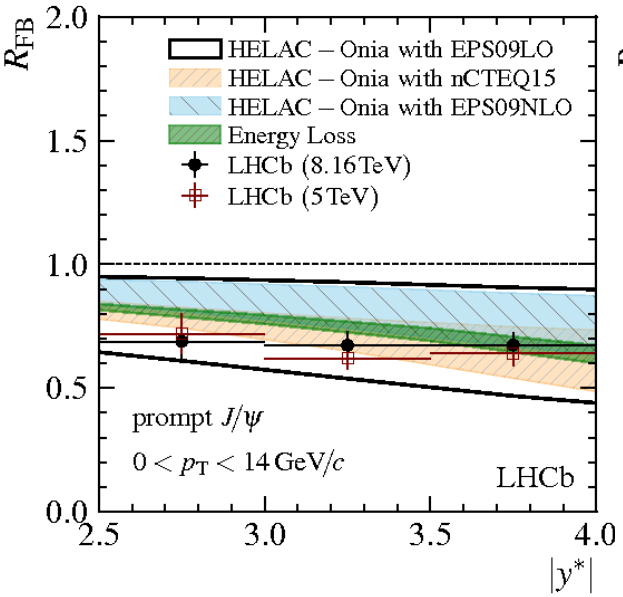
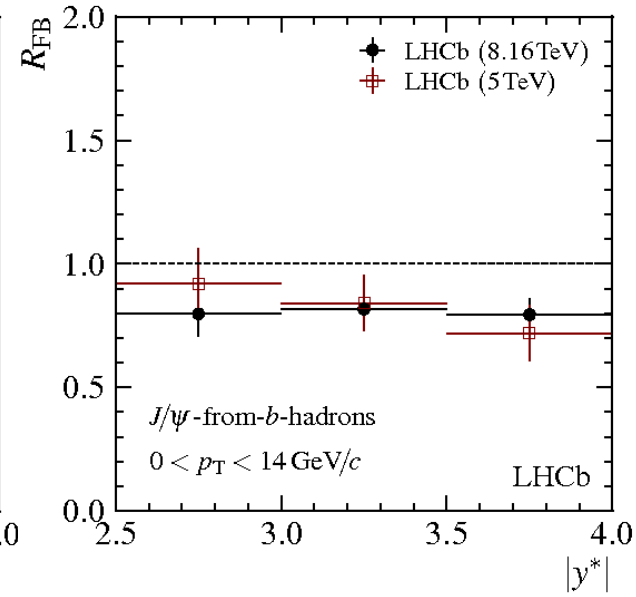
$$R_{FB}(p_T, |y^*|) = \frac{\frac{d^2\sigma}{dp_T\,dy^*}(p_T, y^*)}{\frac{d^2\sigma}{dp_T\,dy^*}(p_T, -y^*)}$$

- 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 p-Pb@5TeV data within uncertainties
- Total uncertainty ~ 10%
- Advantage: no pp-reference needed; many uncertainties cancel.









Conclusions

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- Prompt and non-prompt J/ψ production cross-sections as function of p_T and y^* are measured.
- Nuclear modification factors and Forward-backward asymmetry are measured as well.
- Unprecedented precision for prompt J/ψ and most significantly for J/ψ-from-b.
- These results can have an impact in constraining models for nuclear effects.
- These results will be the reference for the analysis of higher charmonium states.