New results on heavy flavor in heavy ion collisions with LHCb

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On behalf of the LHCb collaboration

The fifth Annual Large Hadron Collider Physics conference

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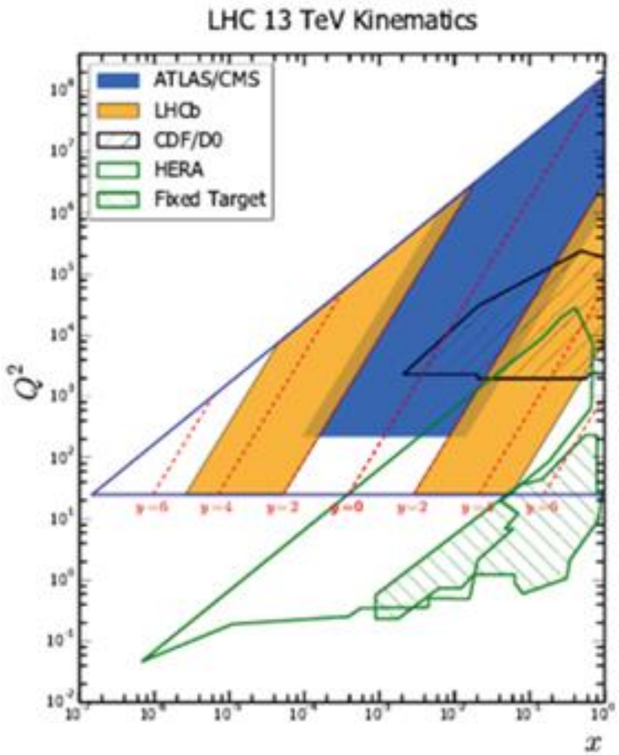
Outline

- Introduction
- LHCb detector
- Prompt $\boldsymbol{D^0}$ production in *p*Pb and Pb*p* collisions @5TeV
- J/ψ production in *p*Pb and Pb*p* collisions @8.16TeV
- Summary

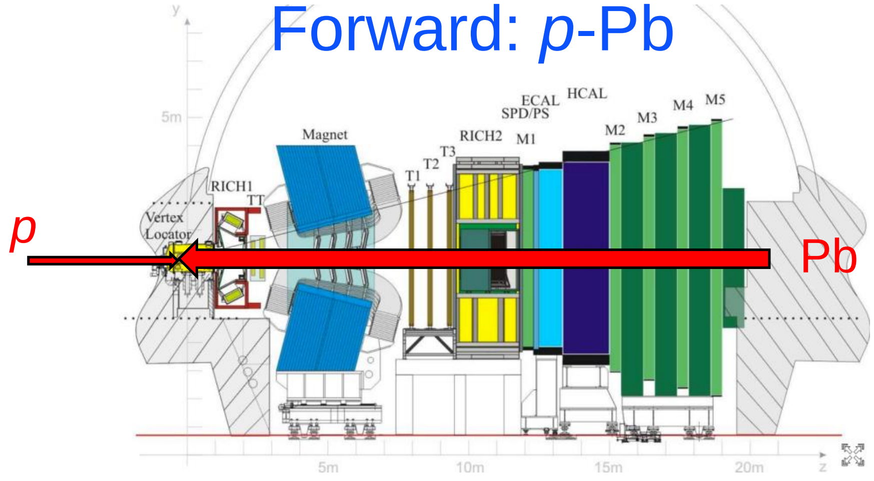
Introduction

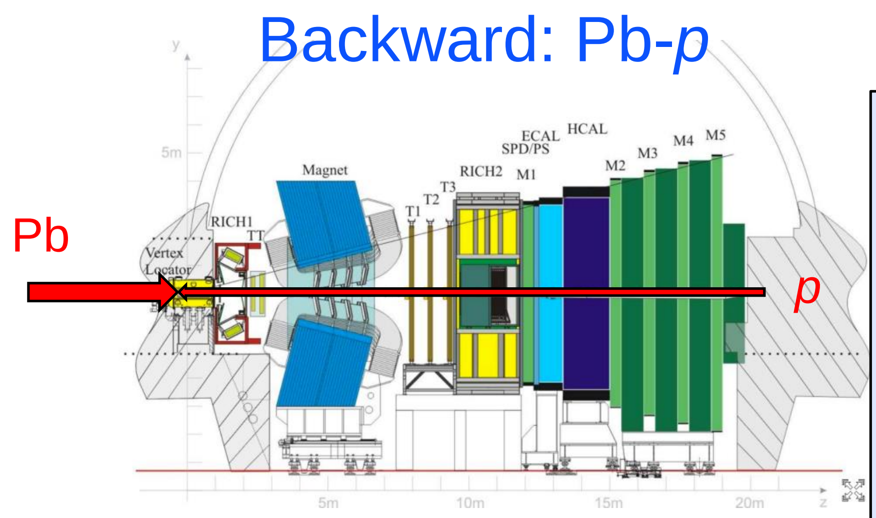
- LHCb is a heavy-flavor precision experiment both on *pp* collision and heavy-ion collision studies.
- Several collision modes exist: *pp*, *p*Pb, PbPb…
- Probe partons with low/high momentum fraction(Bjorken x).
- Heavy flavor measurements are important to probe Quark-Gluon Plasma(QGP) properties.
- Cold Nuclear Matter(CNM) effects could be accessed by *p*Pb collision.
  - nuclear PDFs
  - Color Glass Condensate(CGC)
  - Coherent energy loss



LHCb detector

LHCb, Int. J. Mod. Phys. A30 (2015) 1530022





Rapidity always defined w.r.t. proton direction.

y^*: rapidity defined in nucleon-nucleon rest frame.

Fwd: $1.5<y^*<4.0$

$y^* = y_{lab} - 0.465$

Bwd:

$-5.0<y^*<-2.5$

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

Properties：

Second vertex resolution：

$\sigma_{x,y} \sim 15\ \mu m$, $\sigma_z \sim 80\ \mu m$

$\Delta p/p$:

0.5% at 5 GeV/c to 1% at 1 GeV/c

K Identification：

~90% , mis-ID <5% ($p \in [2, 100]$ GeV/c)

μ Identification：

~97% , mis-ID <1% at high p_T

Prompt D^0 production in *p*Pb and Pb*p* @5TeV

Signal extraction from fitting Mass-χ^2_{IP}

Reconstructed from $D^0 \to K^-\pi^+$ using the 2013 pPb($\sim$1.1 nb^{-1}) and Pbp($\sim$0.5 nb^{-1}) data.

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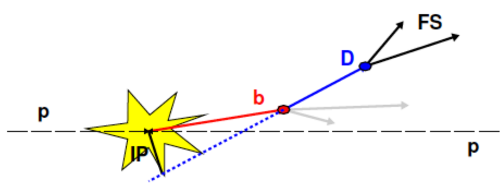
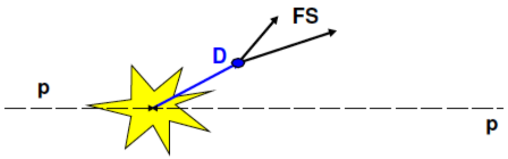
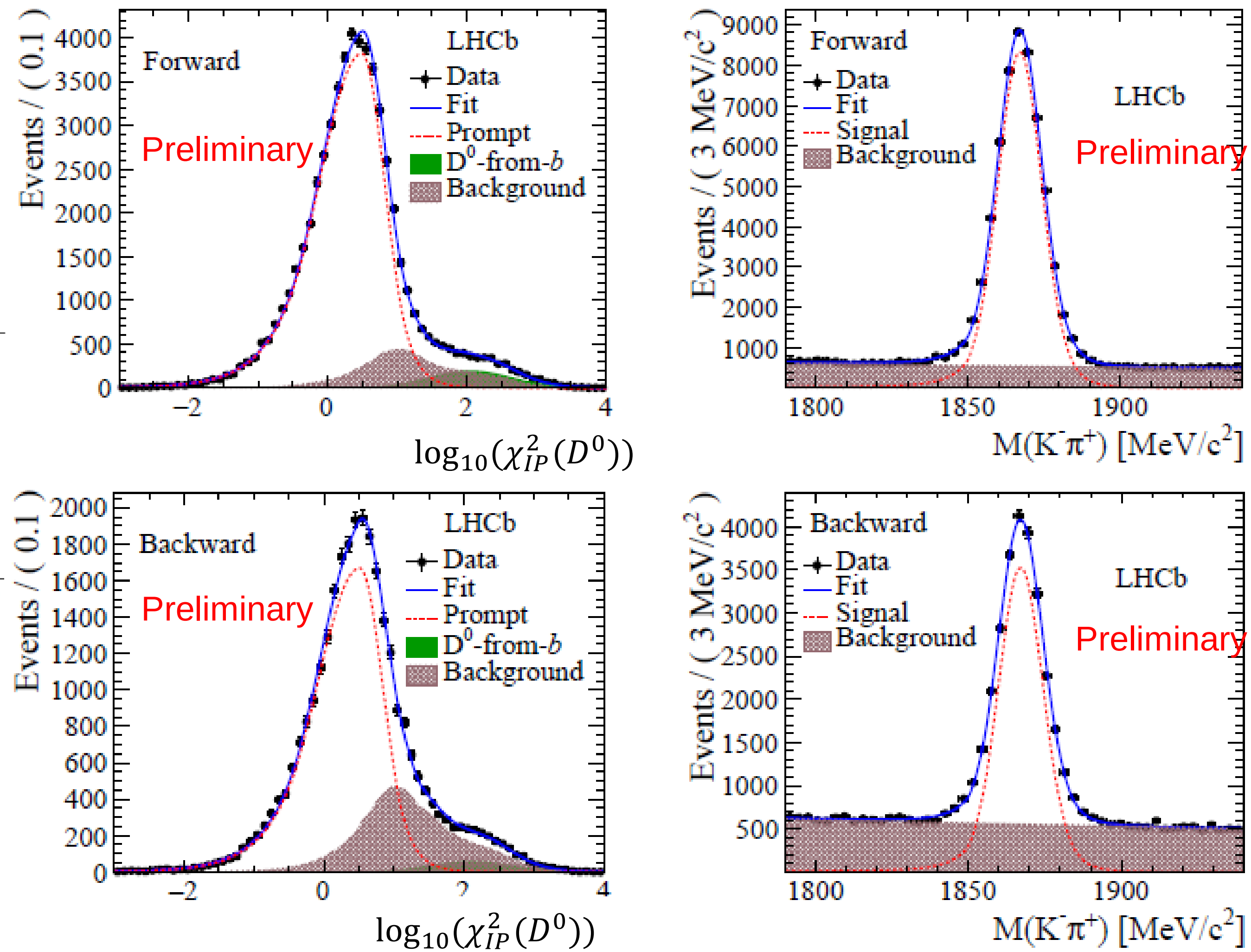
Fit in $p_\mathrm{T} \in (2,3)$ GeV/c $|y^*| \in (2.5,3.0)$ bin:







Double differential cross-section(p_{T}, y^*)

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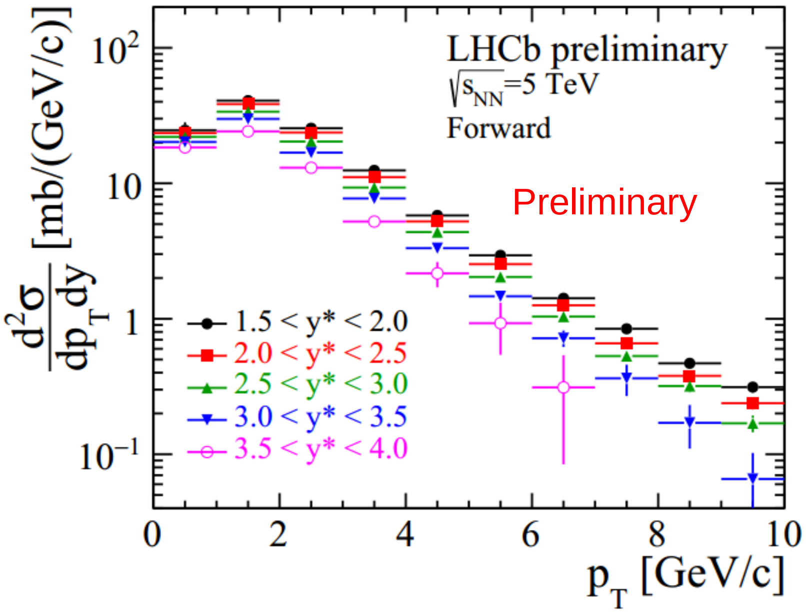
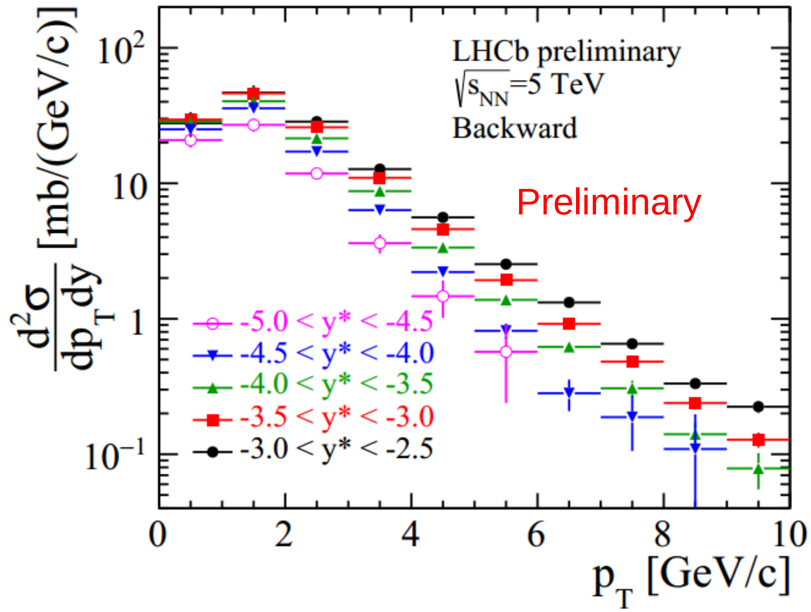




- The integrated cross-sections:

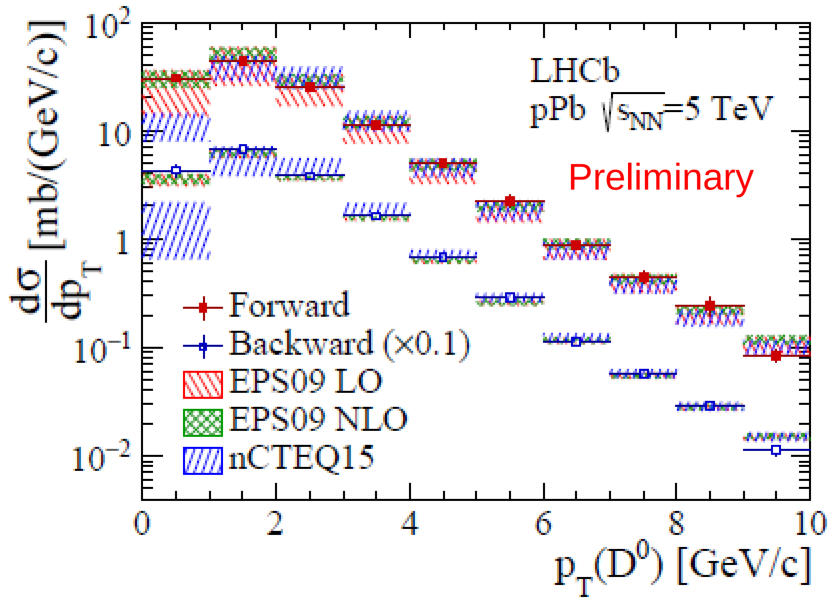
$$\sigma_{\text{forward}}(p_T < 10\ \text{GeV}/c,\ 1.5 < |y^*| < 4.0) = 230.6 \pm 0.5 \pm 13.0\ \text{mb},$$
$$\sigma_{\text{forward}}(p_T < 10\ \text{GeV}/c,\ 2.5 < |y^*| < 4.0) = 119.1 \pm 0.3 \pm 5.6\ \text{mb},$$

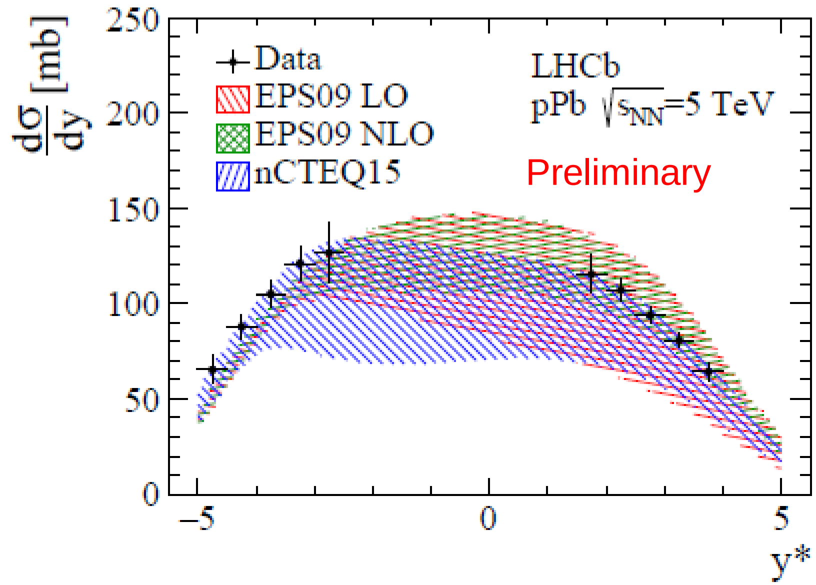
Preliminary

$$\sigma_{\text{backward}}(p_T < 10\ \text{GeV}/c,\ 2.5 < |y^*| < 5.0) = 252.7 \pm 1.0 \pm 20.0\ \text{mb},$$
$$\sigma_{\text{forward}}(p_T < 10\ \text{GeV}/c,\ 2.5 < |y^*| < 4.0) = 175.5 \pm 0.6 \pm 14.4\ \text{mb}.$$

Single differential cross sections

LHCb-PAPER-2017-015





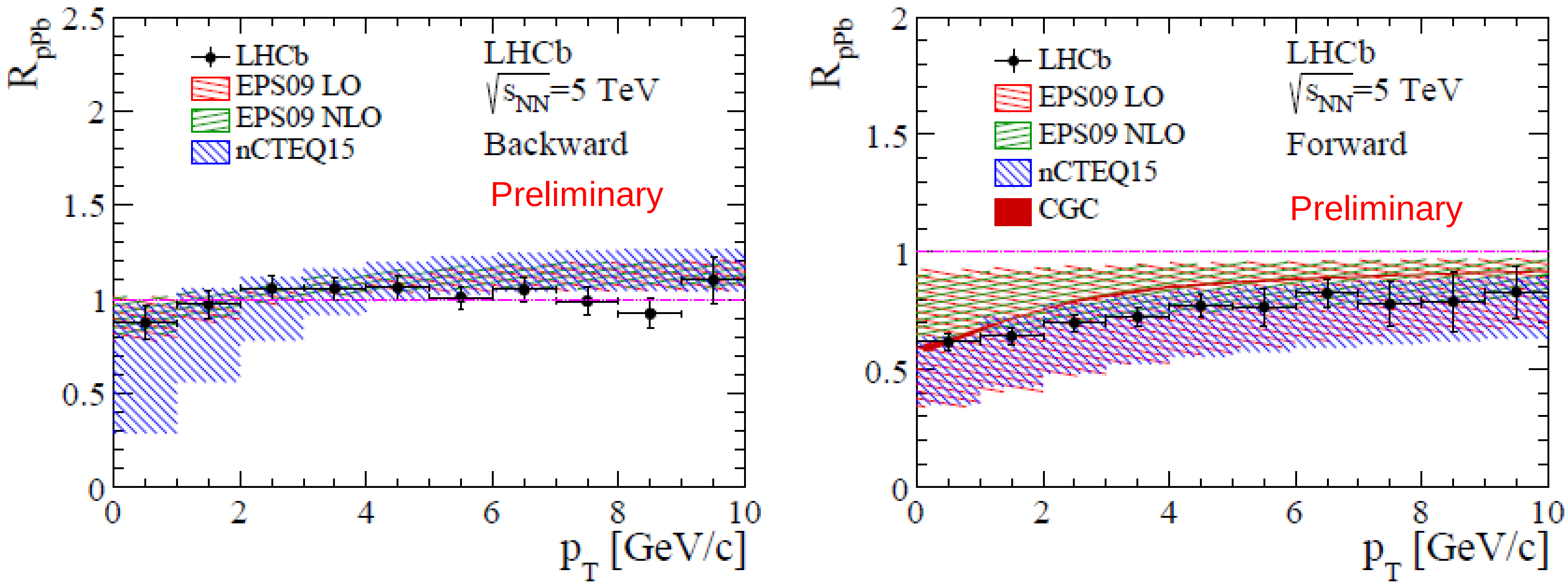
In general good agreement with EPS09 LO, EPS09 NLO, while nCTEQ15 underestimates data at low p_T.

[EPJC 77 (2017), Comput. Phys. Commun. 198 (2016), Comput. Phys. Commun -184 (2013)]

p_{T}-differential nuclear modification factors

$$R_{p\mathrm{Pb}}(y^*, p_{\mathrm{T}}, \sqrt{s_{NN}}) \equiv \frac{1}{A}\frac{d\sigma_{p\mathrm{Pb}}(y^*, p_{\mathrm{T}}, \sqrt{s_{NN}})/(dy^* dp_{\mathrm{T}})}{d\sigma_{pp}(y^*, p_{\mathrm{T}}, \sqrt{s_{NN}})/(dy^* dp_{\mathrm{T}})}$$

A=208 for *p*Pb



- $R_{p\mathrm{Pb}}$ slightly increases with p_{T} in both Fwd and Bwd.
- Calculations based on nPDFs or CGC are in good agreement with data.

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Phys. Rev. D91 (2015), no. 11 114005

Reference D^0 cross-section taken from LHCb-PAPER-2016-042*

y^*-differential nuclear modification factors

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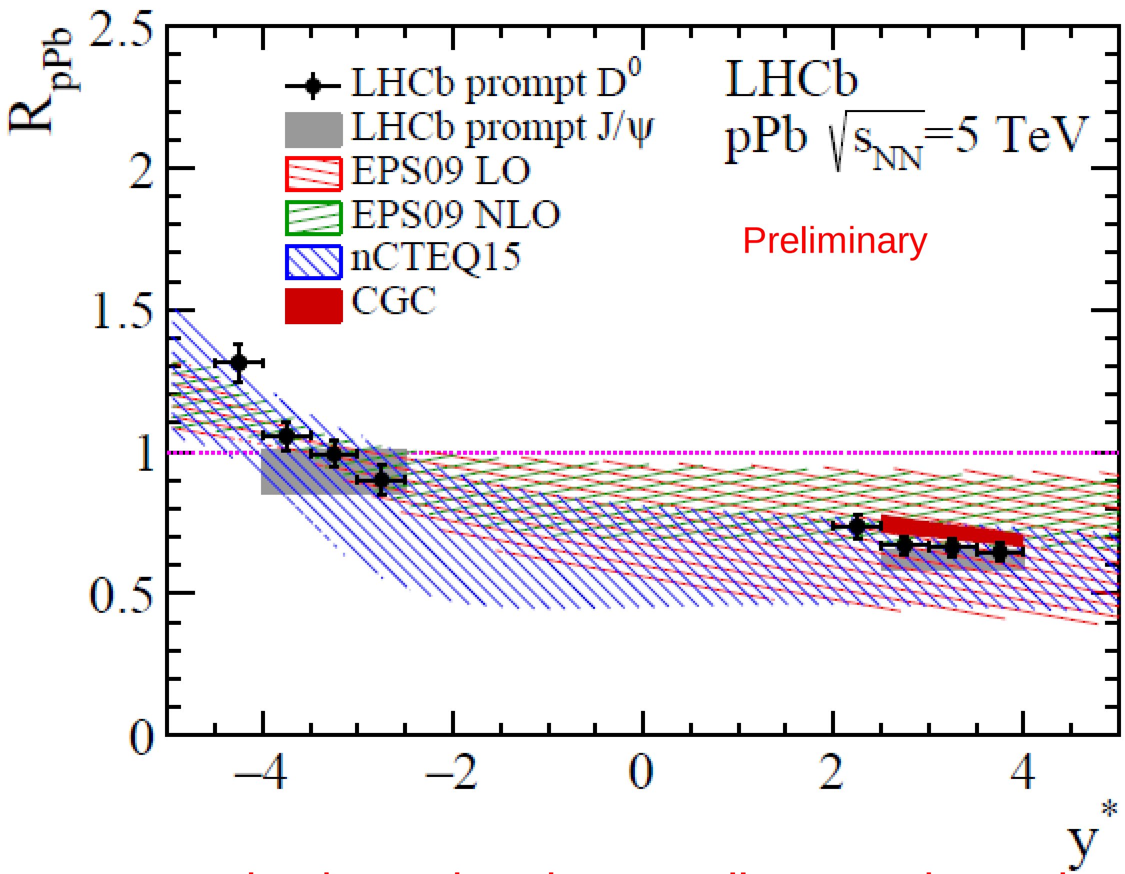


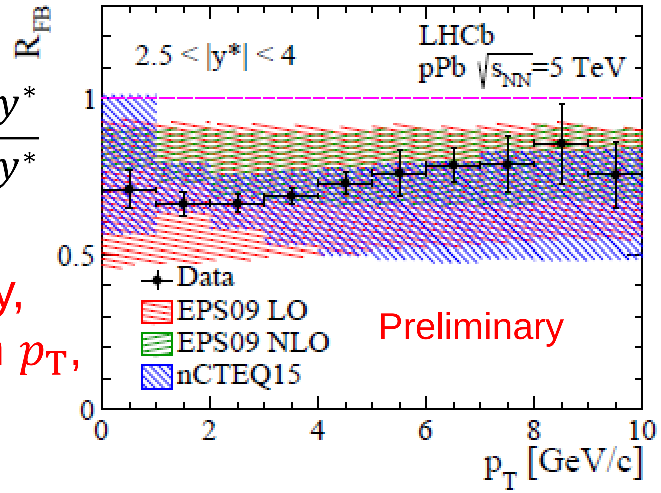
- Strong suppression in Fwd region, small excess in Bwd region.
- R_{pPb} decrease with increasing of rapidity.
- Calculations based on nPDFs or CGC are in good agreement with data.

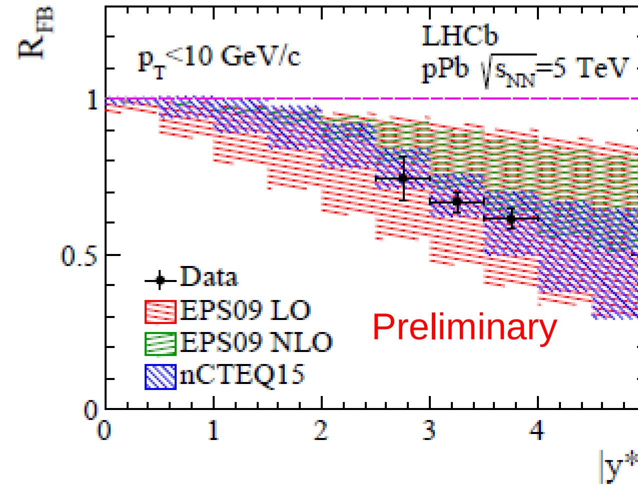
Forward-Backward production ratio

LHCb-PAPER-2017-015

$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) \equiv \frac{d^2\sigma_{p\mathrm{Pb}}(p_{\mathrm{T}}, +|y^*|)/dp_{\mathrm{T}}dy^*}{d^2\sigma_{\mathrm{Pb}p}(p_{\mathrm{T}}, -|y^*|)/dp_{\mathrm{T}}dy^*}$$

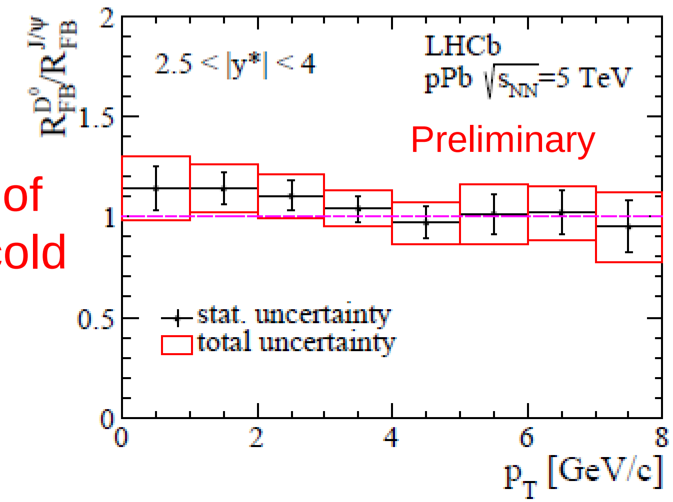
R_{FB}: Smaller than unity, slightly increasing with p_{T}, decreasing with $|y^*|$.

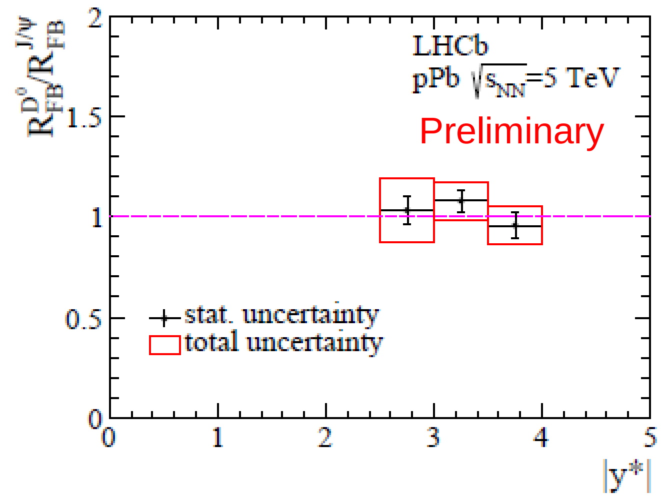




- Relative forward-backward production ratio:

Consistent with that of prompt J/ψ (similar cold nuclear effects).



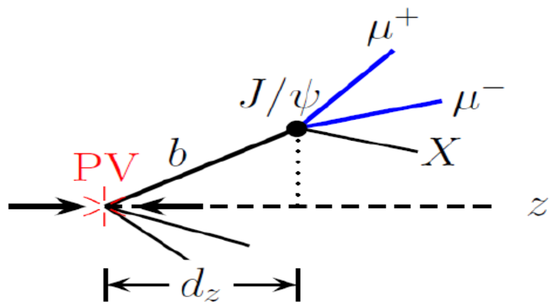


J/ψ: LHCb-PAPER-2013-052

J/ψ production in *p*Pb and Pb*p* @8.16TeV

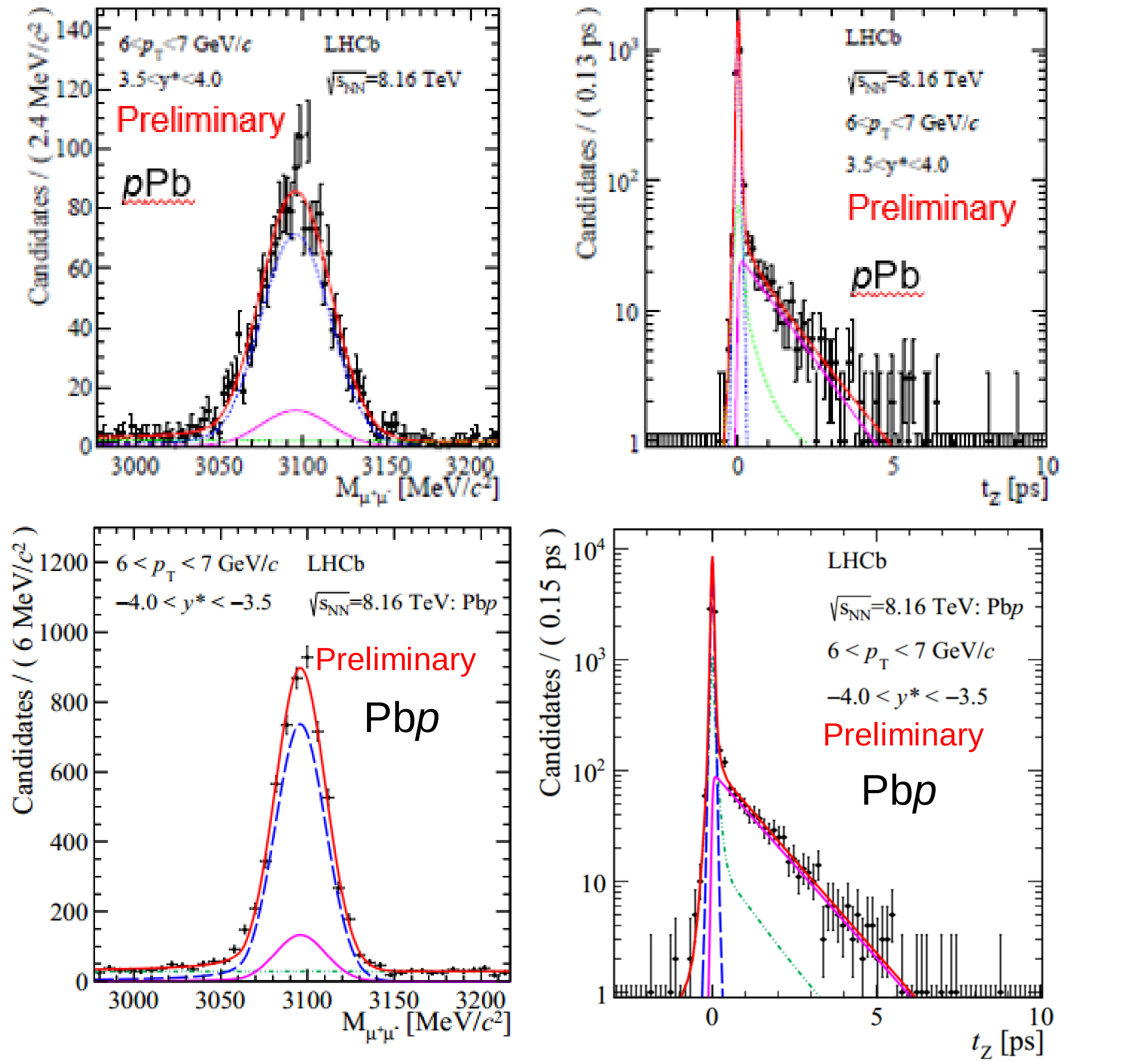
Signal extraction from fitting Mass-t_z

Two dimensional fit to mass and pseudo proper decay time on 2016 data(pPb ~14 nb^{-1} and Pbp ~21 nb^{-1}): LHCb-PAPER-2017-014



$$\left(t_z = \frac{(z_{J/\psi} - z_{\mathrm{PV}}) \times M_{J/\psi}}{p_z}, \right)$$

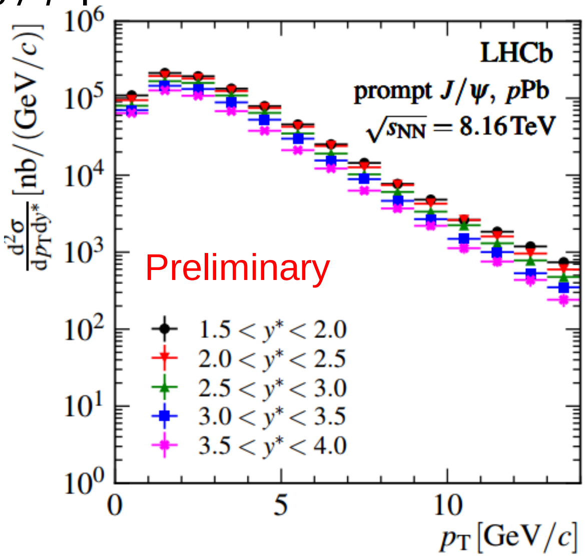
- Prompt and non-prompt components separated.
- pPb and Pbp results separated.

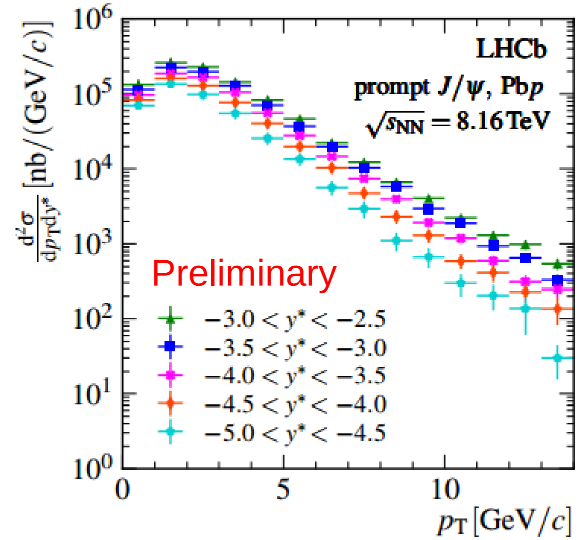


Double differential cross-section(p_{T}, y^*)

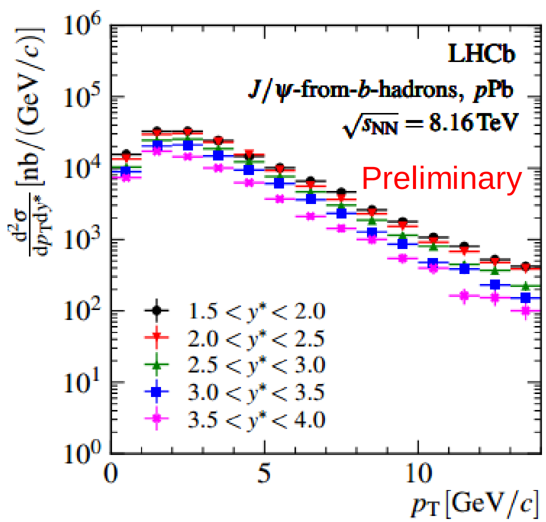
LHCb-PAPER-2017-014

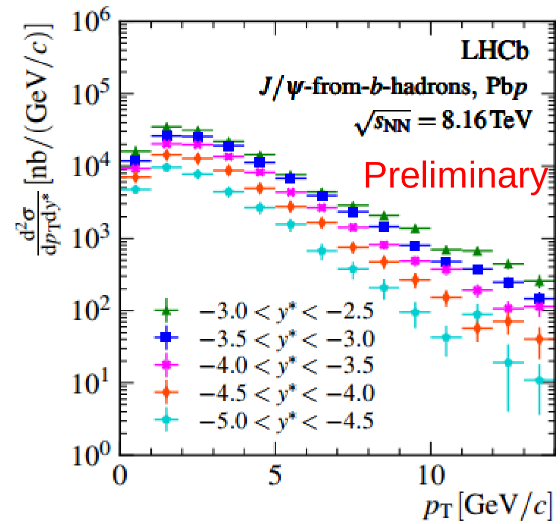
- Prompt J/ψ production cross sections:





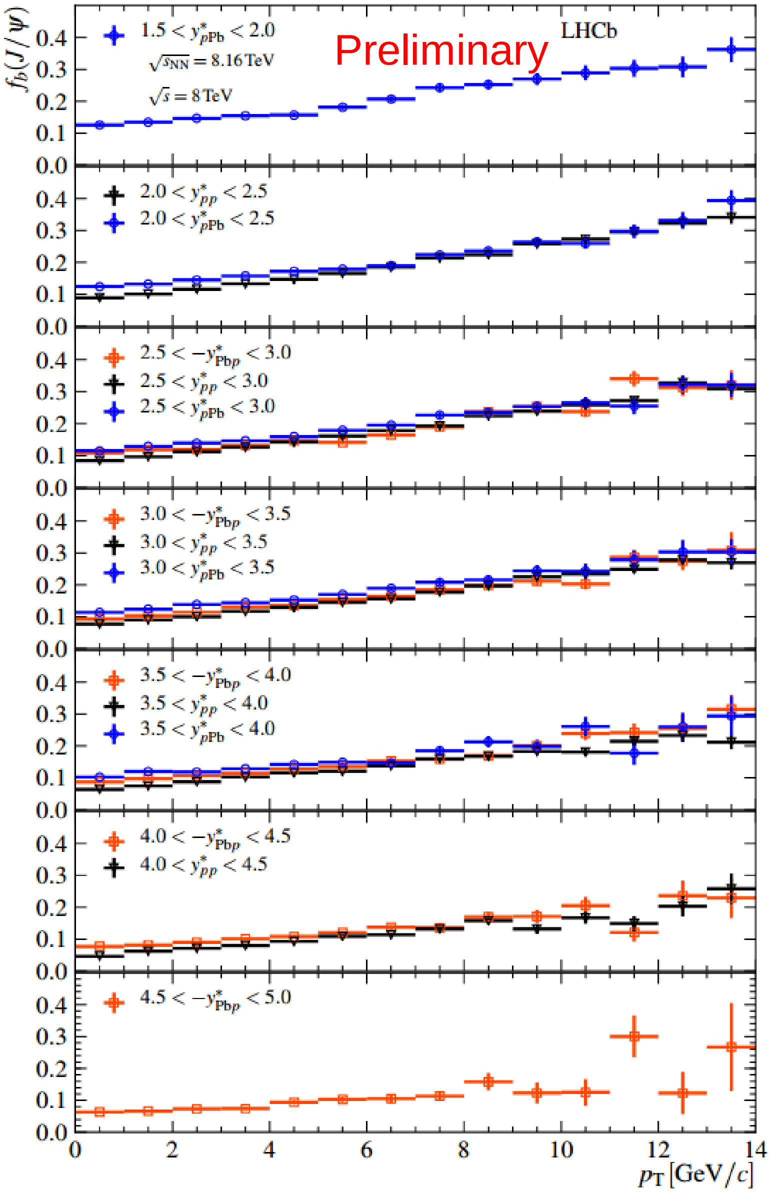
- Non-prompt J/ψ production cross sections:





Fraction of J/ψ from b decays

$$F_B = \frac{\sigma_{nonprompt\ J/\psi}}{\sigma_{prompt\ J/\psi} + \sigma_{nonprompt\ J/\psi}}$$



Comparing *pp*(8TeV), *p*Pb and Pb*p:*

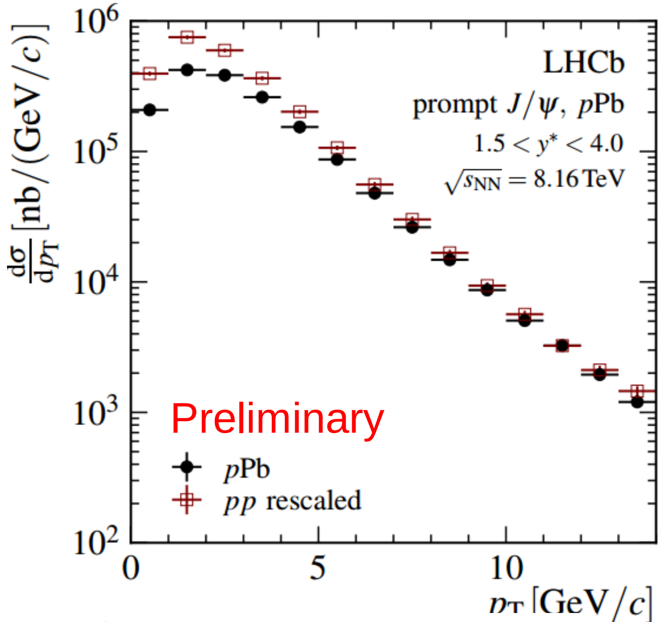
- Similar trends
- Deviations at low p_T highlight the differences in the nuclear effects on prompt and non-prompt.

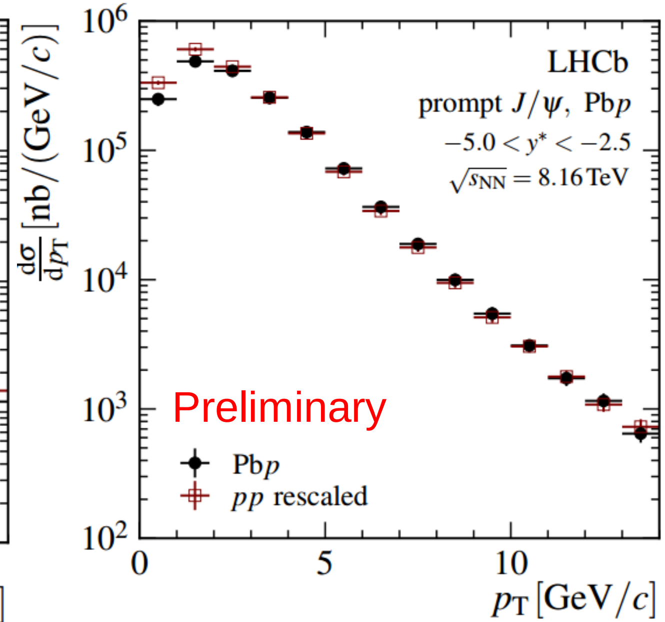
JHEP 06 (2013) 064

LHCb-PAPER-2017-014

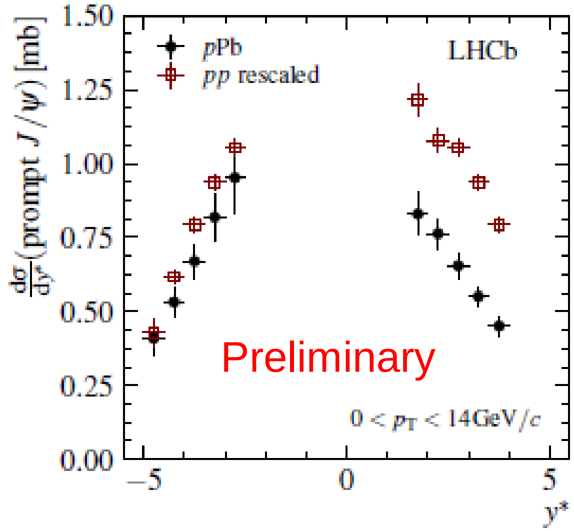
Single differential cross sections for prompt J/ψ

- As a function of p_T:





- As a function of y:



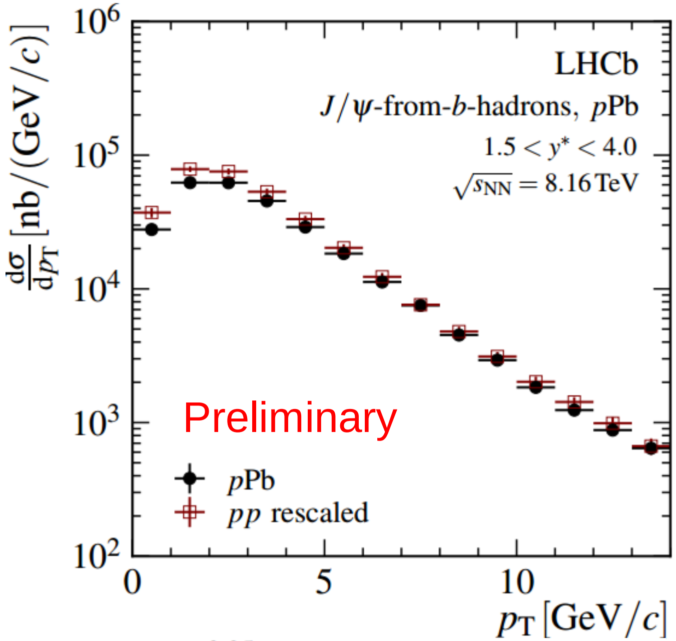
Comparison with the inter/extrapolated *pp* reference cross section re-scaled by A=208.

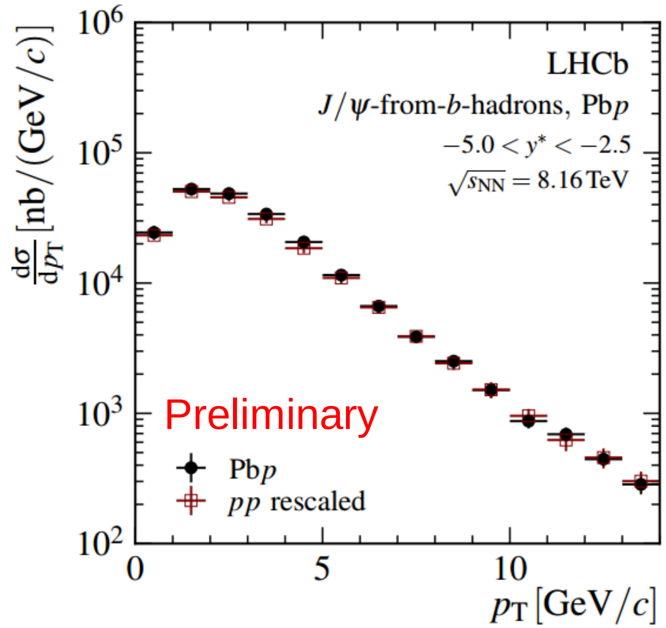
- Differences highlight the effect of the nuclear.

LHCb-CONF-2013-013
LHCb-PAPER-2017-014

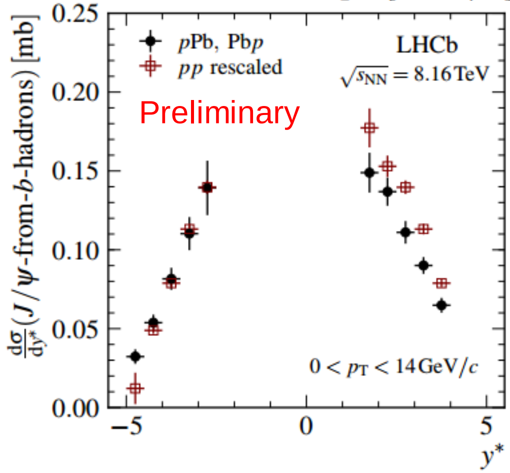
Single differential cross sections for non-prompt J/ψ

- As a function of p_T:





- As a function of y:



Comparison with the inter/extrapolated *pp* reference cross section re-scaled by A=208.

- Differences highlight the effect of the nuclear.

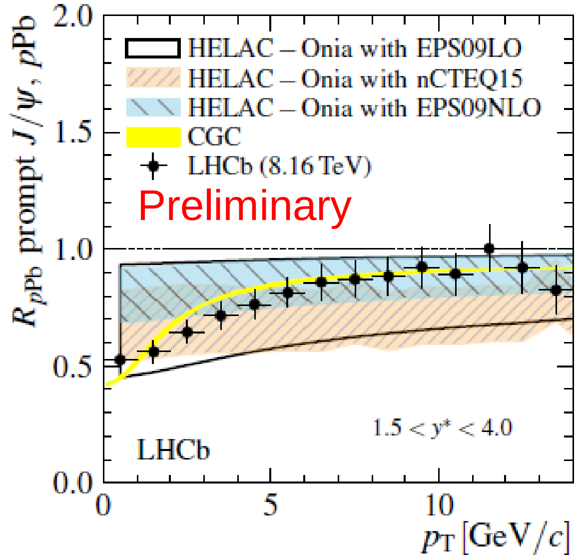
LHCb-CONF-2013-013

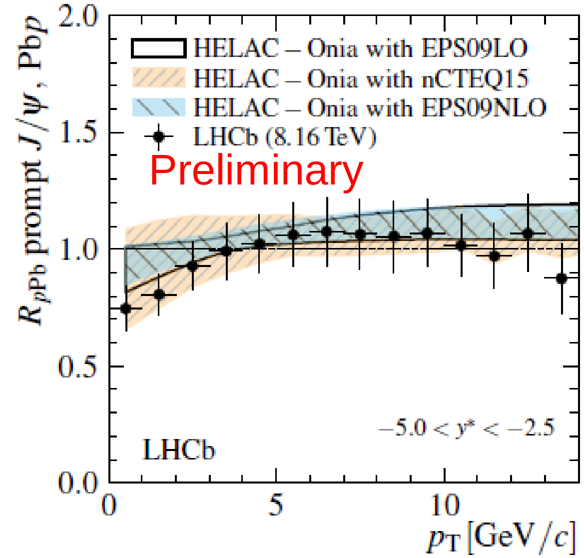
LHCb-PAPER-2017-014

Nuclear modification factors for prompt J/ψ

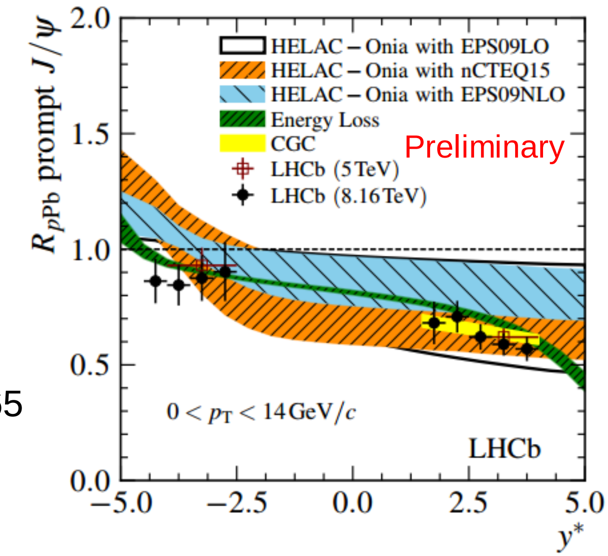
$$R_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_{NN}}) \equiv \frac{1}{A}\frac{d\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_{NN}})/(dy^* dp_\mathrm{T})}{d\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_{NN}})/(dy^* dp_\mathrm{T})}$$

A=208 for pPb





- In pPb: suppression at low p_T up to 50%
- In Pbp: closer to unity
- Overall agreement with the models presented.
- Compatible with pPb @5TeV results.



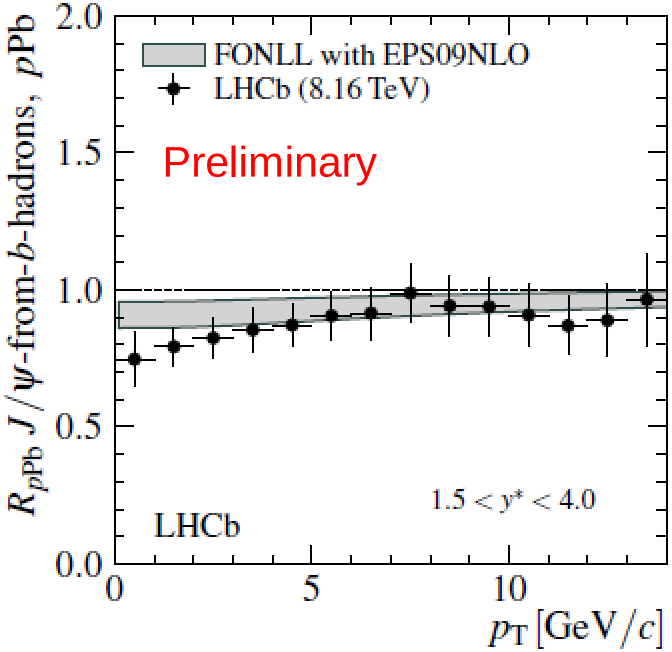
Comput. Phys. Commun. 184 (2013) 2562

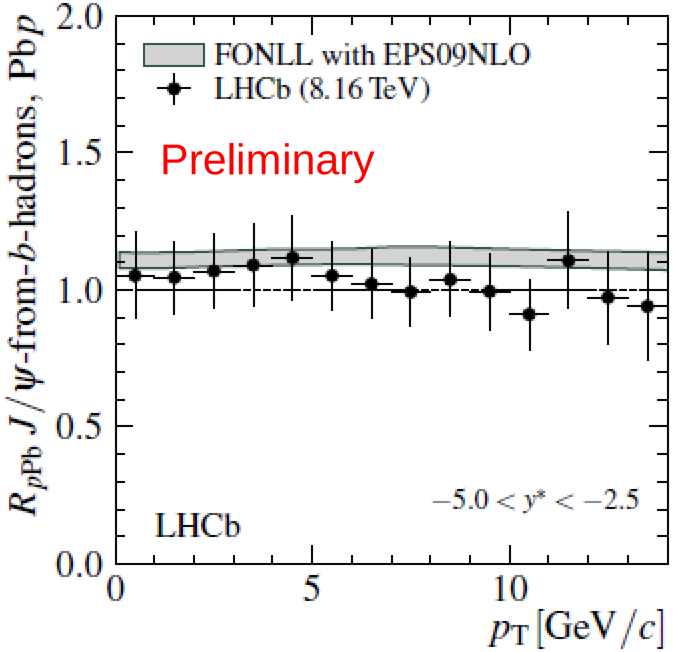
Comput. Phys. Commun. 198 (2016) 238 JHEP 04 (2009) 065

JHEP 03 (2013) 122 Phys. Rev. D91 (2015) 114005

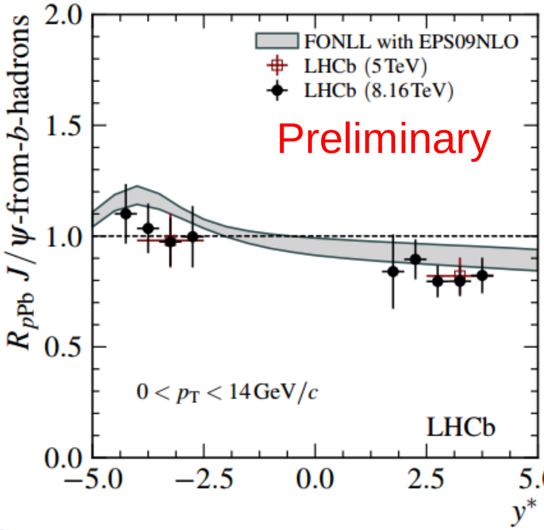
LHCb-PAPER-2017-014 Phys. Rev. D93 (2016) 085037

Nuclear modification factors for non-prompt J/ψ





- In pPb: suppression at low p_T up to 30%
- In Pbp: above unity, no p_T dependence
- Overall agreement with the FONLL predictions.
- Compatible with pPb @5TeV results.



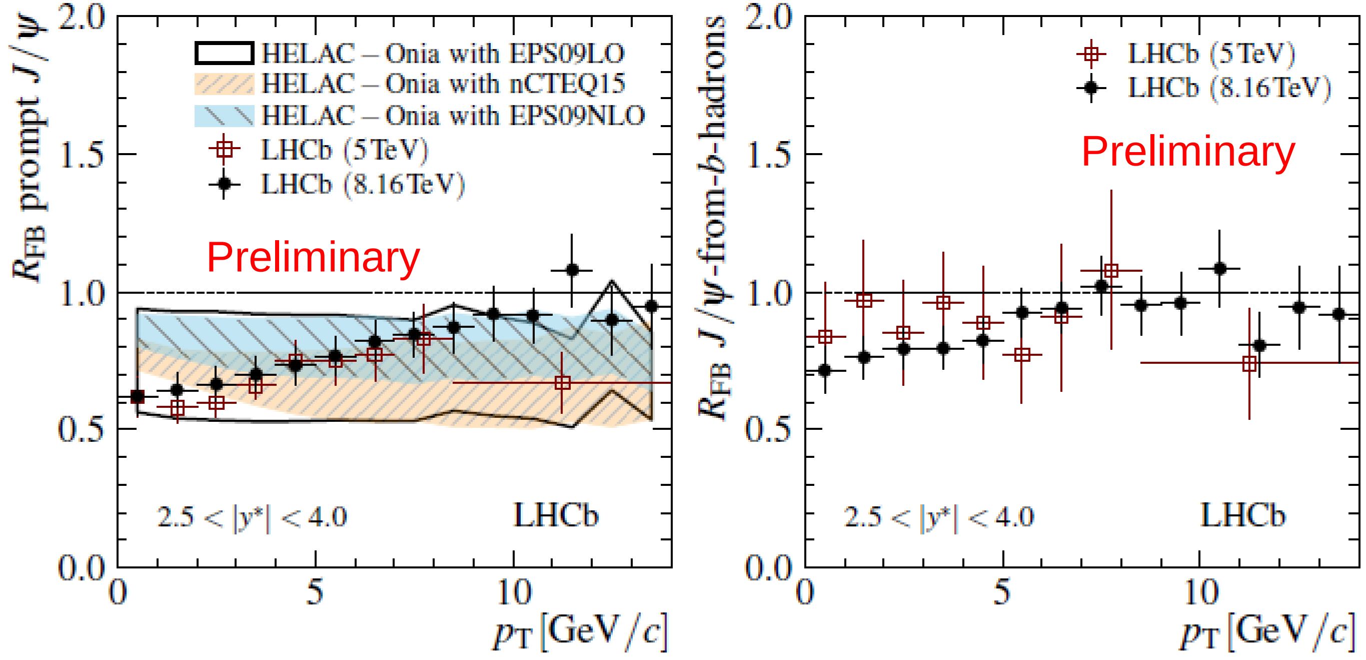
JHEP 05 (1998) 007 JHEP 03 (2001) 006

JHEP 04 (2009) 065 LHCb-PAPER-2017-014

Forward to backward ratio- p_T

LHCb-PAPER-2017-014

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



- Advantage: no *pp* cross section needed. Many uncertainties cancel.
- Agreement with 5TeV data within uncertainties.

Forward to backward ratio-y^*

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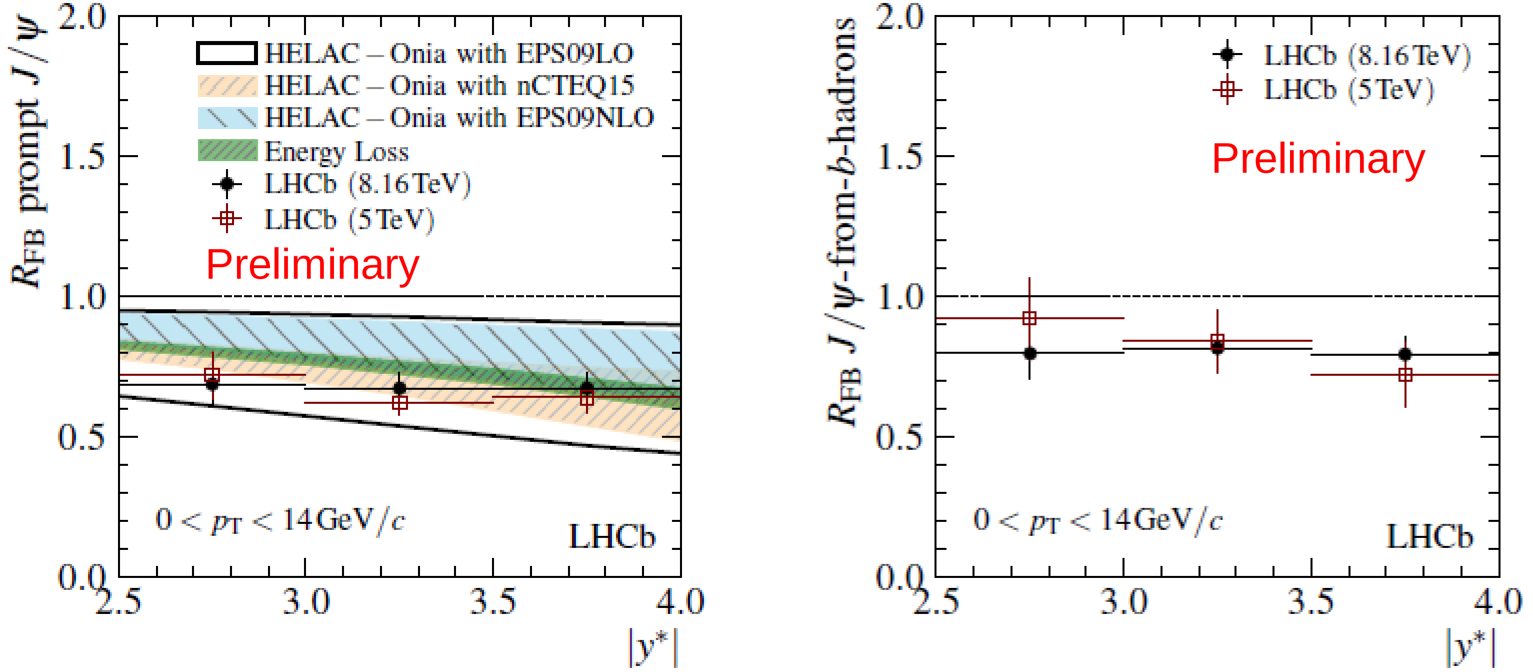

- Advantage: no *pp* cross section needed. Many uncertainties cancel.
- Agreement with predictions and 5TeV data within uncertainties.

Summary

- LHCb has collected large heavy ion collision data in *p*Pb and Pb*p*.
- Measurements of prompt D^0 production in *p*Pb and Pb*p* collisions at $\sqrt{s_{NN}} = 5\mathrm{TeV}$ show strong cold nuclear matter effects that are reproduced by calculations using nPDFs, CGC framework.
- Prompt and non-prompt J/ψ production in *p*Pb and Pb*p* collisions at $\sqrt{s_{NN}} = $ 8.16TeV help constraining models for nuclear effects.
- More results by LHCb under way…

Thanks for your attention!

BackUp

Fit functions in prompt D^0 production

- D^0 Mass: CB+Gaussian

- $\log_{10}(\chi^2_{IP}(D^0))$:

$$f(x;\mu,\sigma,\epsilon,\rho_{\rm L},\rho_{\rm R}) = \begin{cases} e^{\frac{\rho_{\rm L}^2}{2}+\rho_{\rm L}\frac{x-\mu}{(1-\epsilon)\sigma}} & x < \mu - (\rho_{\rm L}\sigma(1-\epsilon)), \\ e^{-\left(\frac{x-\mu}{\sqrt{2}\sigma(1-\epsilon)}\right)^2} & \mu - (\rho_{\rm L}\sigma(1-\epsilon)) \leq x < \mu, \\ e^{-\left(\frac{x-\mu}{\sqrt{2}\sigma(1+\epsilon)}\right)^2} & \mu \leq x < \mu + (\rho_{\rm R}\sigma(1+\epsilon)), \\ e^{\frac{\rho_{\rm R}^2}{2}-\rho_{\rm R}\frac{x-\mu}{(1+\epsilon)\sigma}} & x \geq \mu + (\rho_{\rm R}\sigma(1+\epsilon)), \end{cases}$$

Fit functions in J/ψ production

- Mass:
  - Signal: CB
  - Background: exponential

- t_z:
  - Signal:
    - Prompt: delta function
    - Non-prompt: single exponential
    - Resolution: sum of three Gaussian
  - Background: an empirical function derived from the upper mass sideband.

$$f_{\text{background}} = (1 - f_1 - f_2 - f_3 - f_4)\delta(t_z) + \theta(t_z)\left(f_1 \frac{e^{-t_z/\tau_1}}{\tau_1} + f_2 \frac{e^{-t_2/\tau_2}}{\tau_2}\right) + \theta(-t_z)\left(f_3 \frac{e^{t_z/\tau_3}}{\tau_3}\right) + f_4 \frac{e^{-|t_z|/\tau_4}}{2\tau_4},$$

Total efficiency for J/ψ production in *p*Pb and Pb*p* @8.16TeV