Quarkonium results in *p*Pb and PbPb collisions

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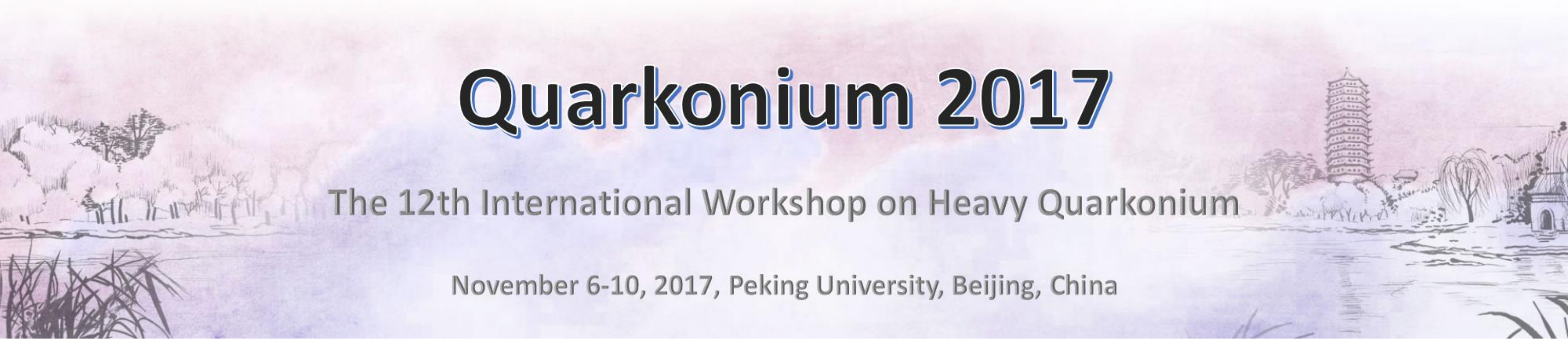
on behalf of the LHCb collaboration

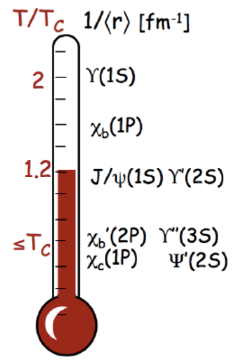


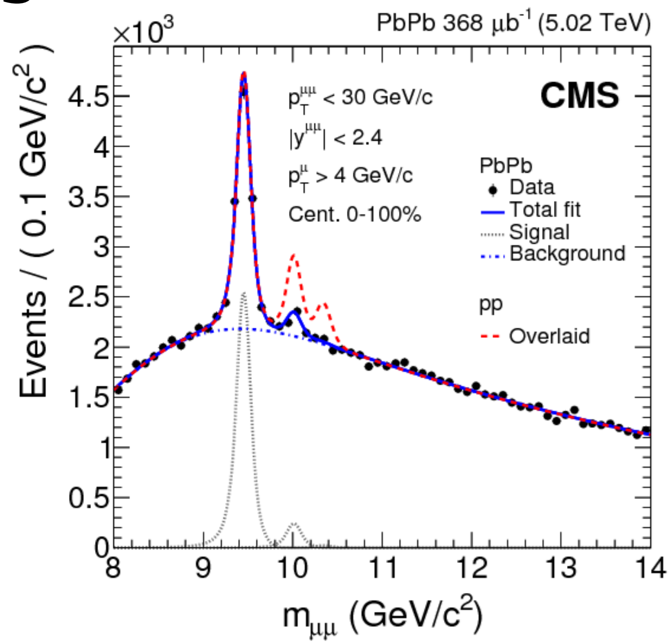
Outline

- Quarkonium in heavy-ion collisions
- The LHCb detector
- pPb collisions: recent results
  - J/ψ at 5.02, 8.16 TeV
  - $\psi(2S)$ at 5.02 TeV
  - Υ at 5.02 TeV
- PbPb collisions: work in progress

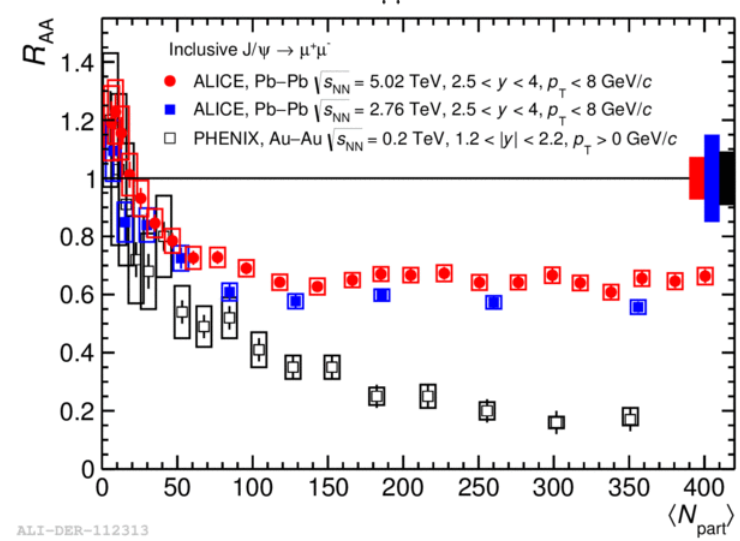
Quarkonia in PbPb Collisions

- Color screening: $Q\bar{Q}$ potential is screened by surrounding color charge, leading to dissociation
  - J/ψ suppression a signature of deconfinement
- Sequential melting: quarkonia states (e.g. Υ family) dissociate at different temperatures
  - QGP thermometer





- Hot medium effects:
  - Suppression by color screening
  - Regeneration via statistical recombination
  - Medium induced energy loss
- Cold nuclear matter (CNM) effects
  - Studied via proton-nucleus collisions
  - Crucial for the interpretation of AA results

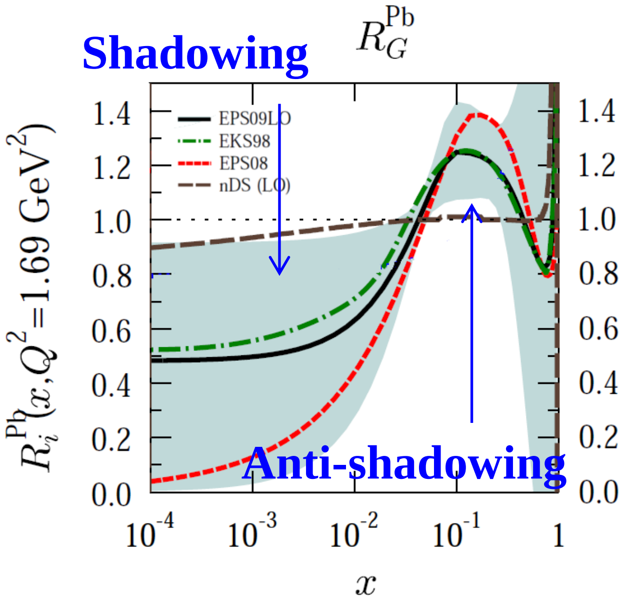


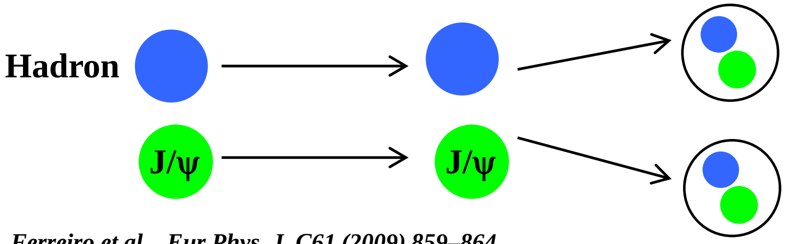
CMS arxiv:1706.05984
ALICE PLB766(2017) 212

Quarkonia in *p*Pb Collisions

Ferreiro et al., PRC 81(2010) 064911
Eskola et al., Eur.Phys.J. C9 (1999) 61-68
Eskola. et al., JHEP 0807 (2008) 102
Eskola et al., JHEP 0904 (2009) 065
De Florian et al., PRD69 (2004) 074028

- Cold Nuclear Matter effects
  - Initial state:
    - Modification of nuclear PDF
    - Gluon saturation
  - Multiple scattering of partons in the nucleus
  - Final state:
    - nuclear absorption (negligible at LHC energy)
    - Co-mover effect
      - Break-up of quarkonium by co-moving hadrons outside of nuclear remnant
      - study via $\psi(2S)$



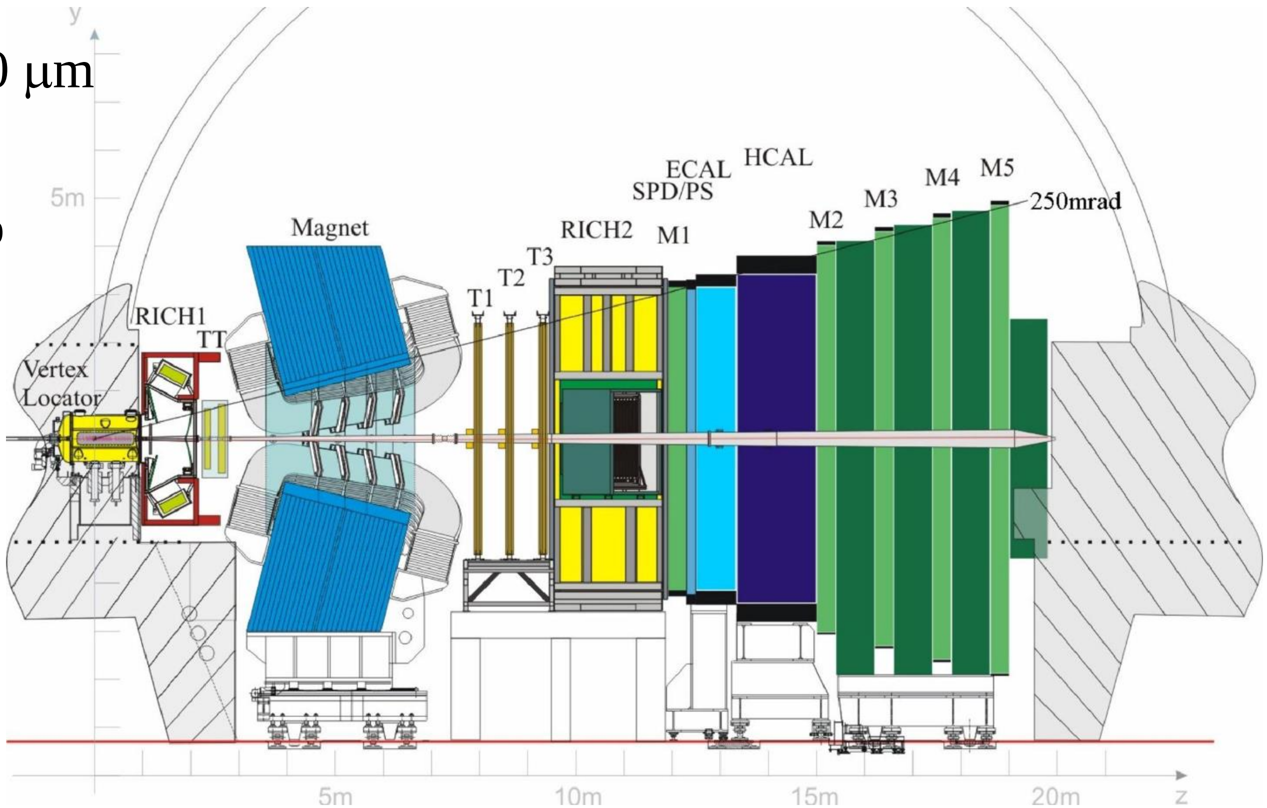


Ferreiro et al., Eur.Phys. J. C61 (2009) 859–864
Ferreiro et al., PLB680 (2009) 50–55
Ferreiro, et al., PRC81 (2010) 064911

Co-mover effect

LHCb detector

- A single arm forward spectrometer designed for the study of particles containing *c* or *b* quark.
- Acceptance: $2 < \eta < 5$
- Vertex detector
  - IP resolution ~ 20 μm
- Tracking system
  - $\frac{\Delta p}{p} = 0.5\% - 1\%$ (5-200 GeV/*c*)
- RICH
  - K/π/p separation
- Electromagnetic + hadronic Calorimeters
- Muon systems



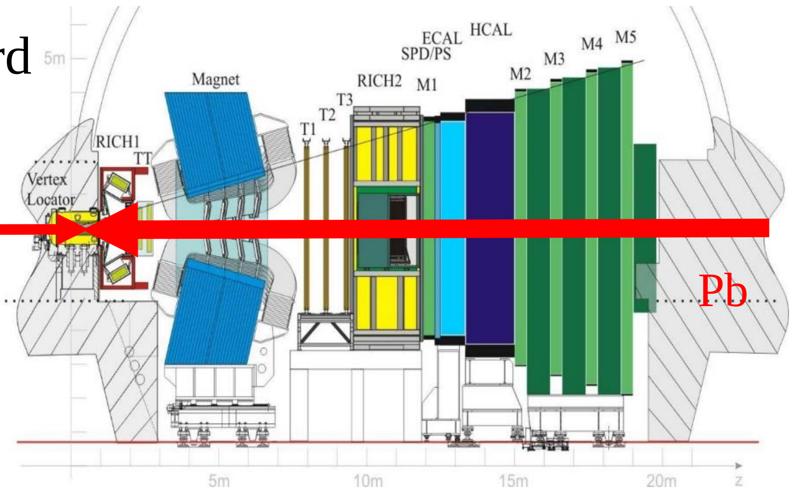
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

pPb datasets and recent results

Forward

pPb

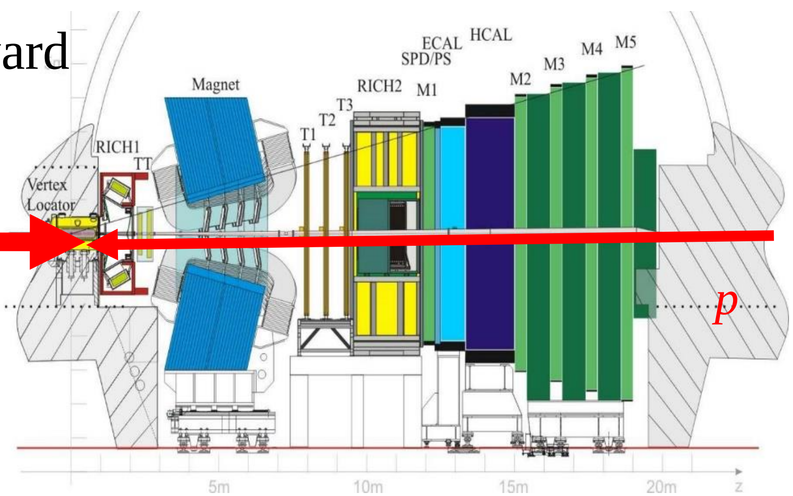
p



Backward

Pbp

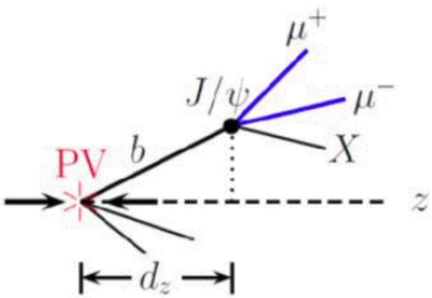
Pb



- Rapidity Coverage
  - y^*: rapidity in nucleon-nucleon cms
  - $y_{\text{cms}} = \pm 0.465$
  - Forward: $1.5 < y^* < 4.0$
  - Backward: $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$
- $\sqrt{s_{NN}} = 5$ TeV (2013)
  - pPb (1.06 nb^{-1}) + Pbp (0.52 nb^{-1})
  - J/ψ
  - $\psi(2S)$
  - Υ
- $\sqrt{s_{NN}} = 8$ TeV (2016)
  - pPb (13.6 nb^{-1}) + Pbp (21.8 nb^{-1})
  - J/ψ
- Separate prompt/from-b J/ψ and $\psi(2S)$

Prompt and nonprompt J/ψ in pPb at 8 TeV

- Sources
  - Prompt: direct production, feed down from heavier states $\psi(2S)$, χ_c
  - Nonprompt: from-b-hadrons decays

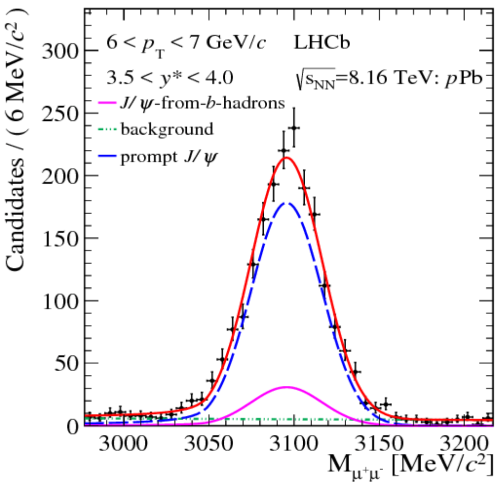


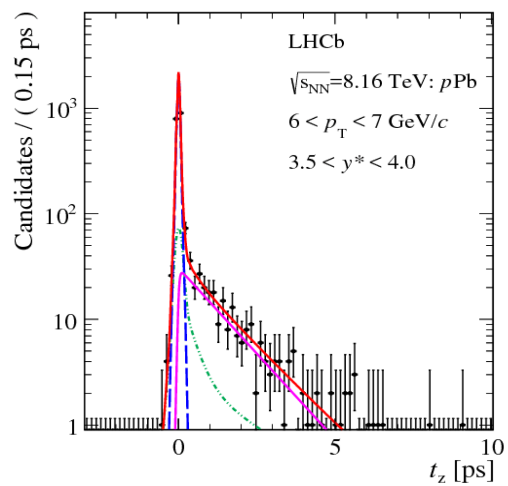
- First Run2 result in heavy ion collisions
- Reconstructed through $J/\psi \to \mu^+\mu^-$
- Prompt and nonprompt (from-b-hadrons) separated: the pseudo proper decay time

$$t_z \equiv \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z}$$

- Signal extraction with 2D simultaneous fit to mass and the pseudo proper decay time

LHCb arXiv:1706.07122





Prompt and nonprompt J/ψ in pPb at 8 TeV

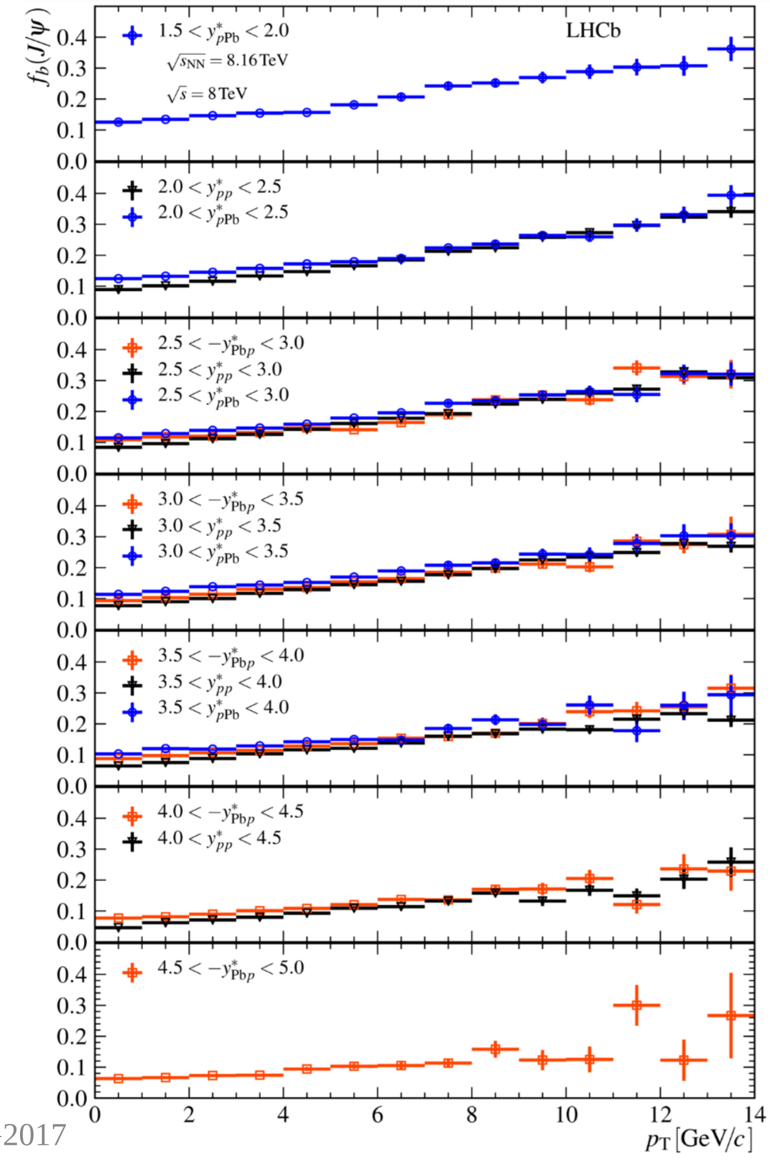
LHCb arXiv:1706.07122

- Separation of prompt and nonprompt J/ψ with p_{T} down to 0

- Fraction from b hadrons:

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

- *pp*, forward, backward compared:
  - similar trends
  - Increasing with p_{T}
  - Small differences at low p_{T}: cold nuclear matter effects different for the prompt and nonprompt

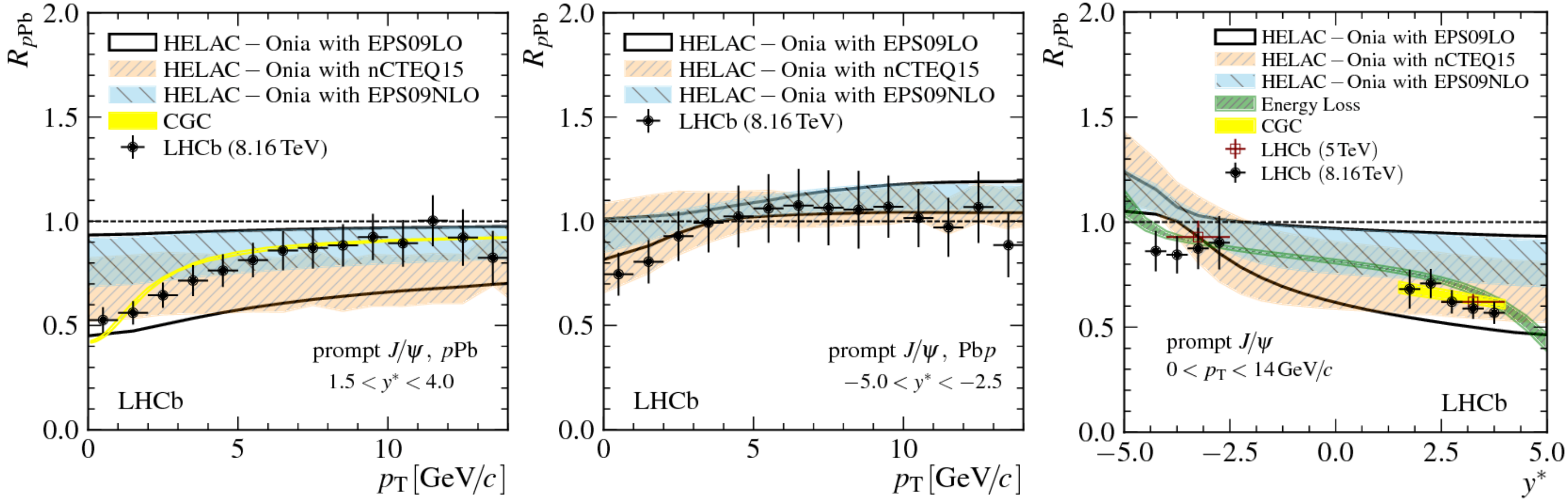


Prompt J/ψ at 8 TeV nuclear modification factor in pPb

$$R_{p\mathrm{Pb}}(y^*, p_T) = \frac{1}{A} \times \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_{NN}})/\mathrm{d}x}{\mathrm{d}\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_{NN}})/\mathrm{d}x}, \ A{=}208$$

- *pp* reference: interpolation of LHCb measurements at 7, 8 and 13 TeV
- Forward rapidity: suppression up to 50% at low p_T, decreasing with increasing p_T
- Backward rapidity: closer to unity
- Overall agreement with models with large uncertainties on the gluon PDFs at low x
- Compatible with 5 TeV results

LHCb arXiv:1706.07122

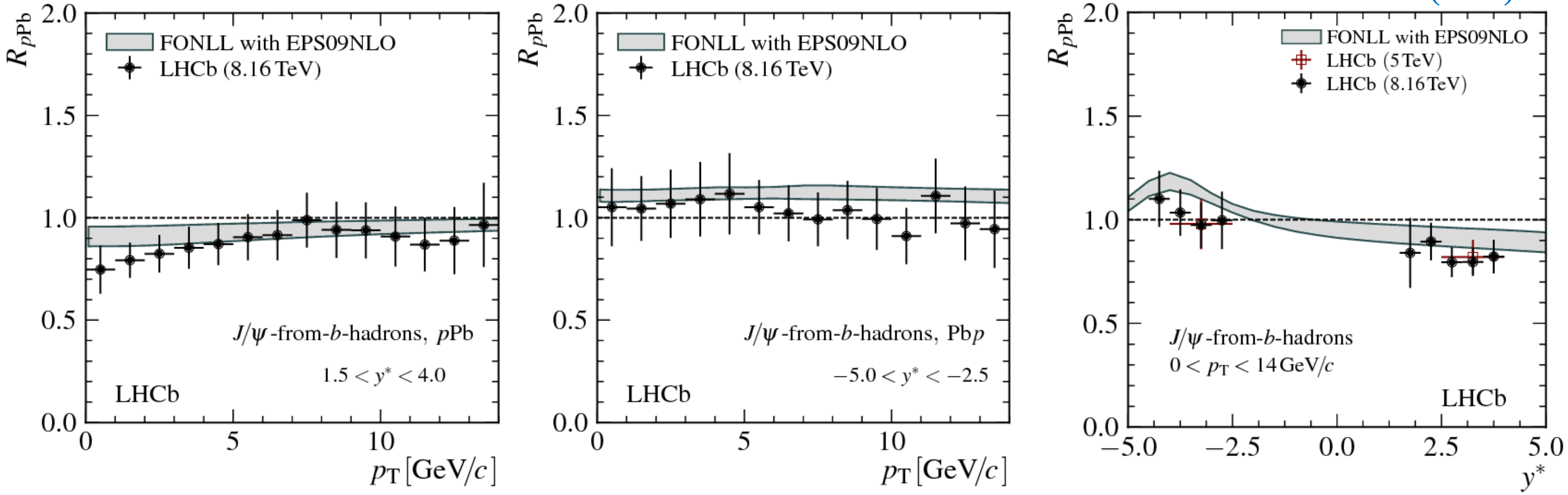


J/ψ-from-b-hadrons at 8 TeV nuclear modification factor in pPb

$$R_{p\mathrm{Pb}}(y^*, p_T) = \frac{1}{A} \times \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_{NN}})/\mathrm{d}x}{\mathrm{d}\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_{NN}})/\mathrm{d}x}, \; A{=}208$$

- *pp* reference: interpolation of LHCb measurements at 7, 8 and 13 TeV
- Forward rapidity: smaller suppression up to 30% at low p_T, reach unity at higher p_T
- Backward: compatible with unity
- FONLL with EPS09NLO consistent with data
- Compatible with 5 TeV results

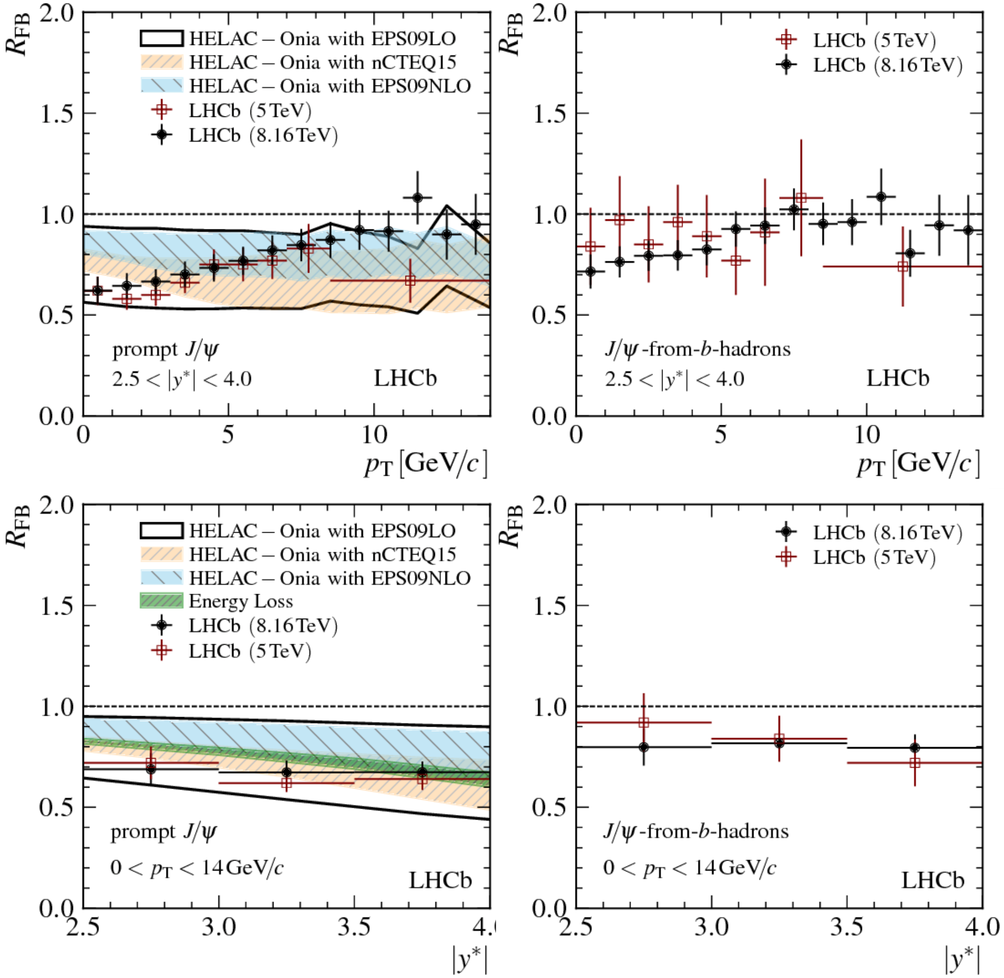
LHCb arXiv:1706.07122
EPS09 JHEP 04 (2009) 065



Prompt J/ψ at 8 TeV forward-backward production ratio

LHCb arXiv:1706.07122

- $R_{FB} = \frac{d\sigma(+|y^*|, p_T)/dx}{d\sigma(-|y^*|, p_T)/dx}$
- R_{FB} does not need inputs from pp collisions.
- Prompt J/ψ:
  - Clear forward-backward asymmetry
  - Increasing trend with increasing p_T
- Nonprompt J/ψ:
  - Closer to unity
- Models for prompt J/ψ only
- Consistent with 5 TeV results



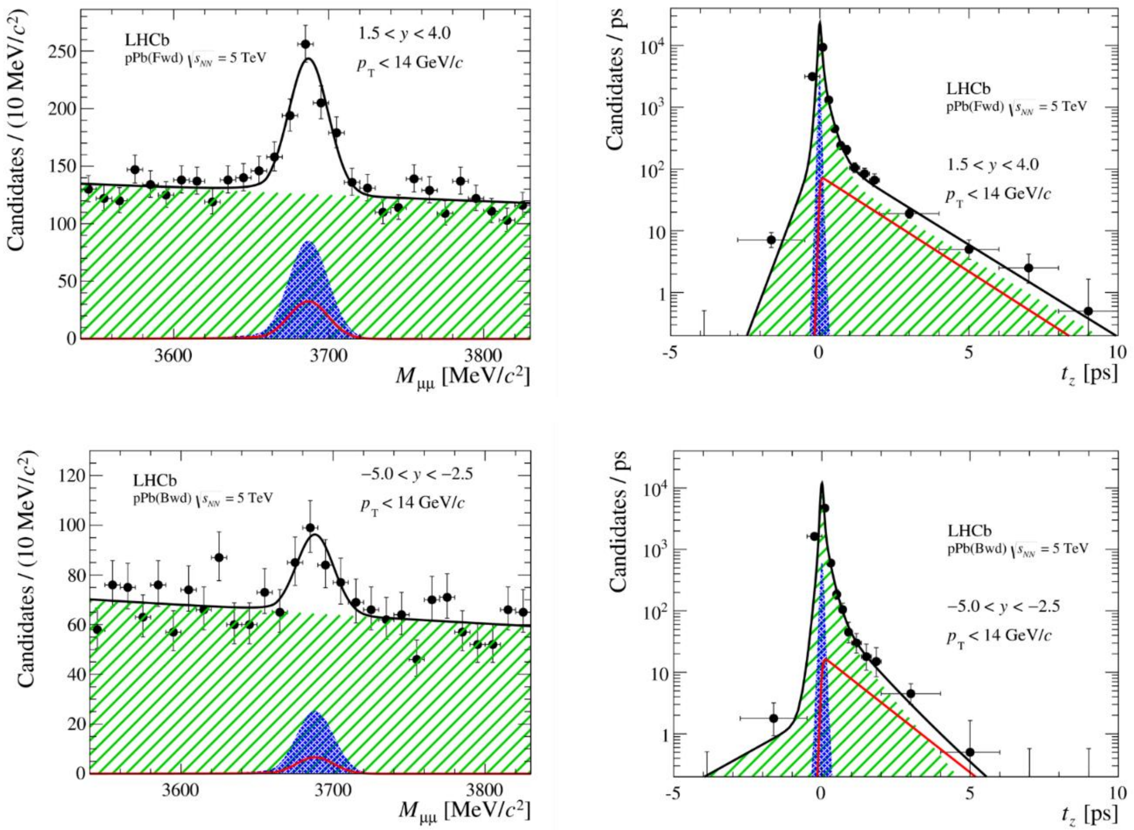
$\psi(2S)$ results at 5 TeV

- Very low binding energy
- Reconstructed through
  $\psi(2S) \to \mu^+\mu^-$
- Signal extraction with 2D simultaneous fit to mass and the pseudo proper decay time

$$t_z \equiv \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z}$$

- Prompt and nonprompt (from-*b*-hadrons) separated down to p_{T}~0

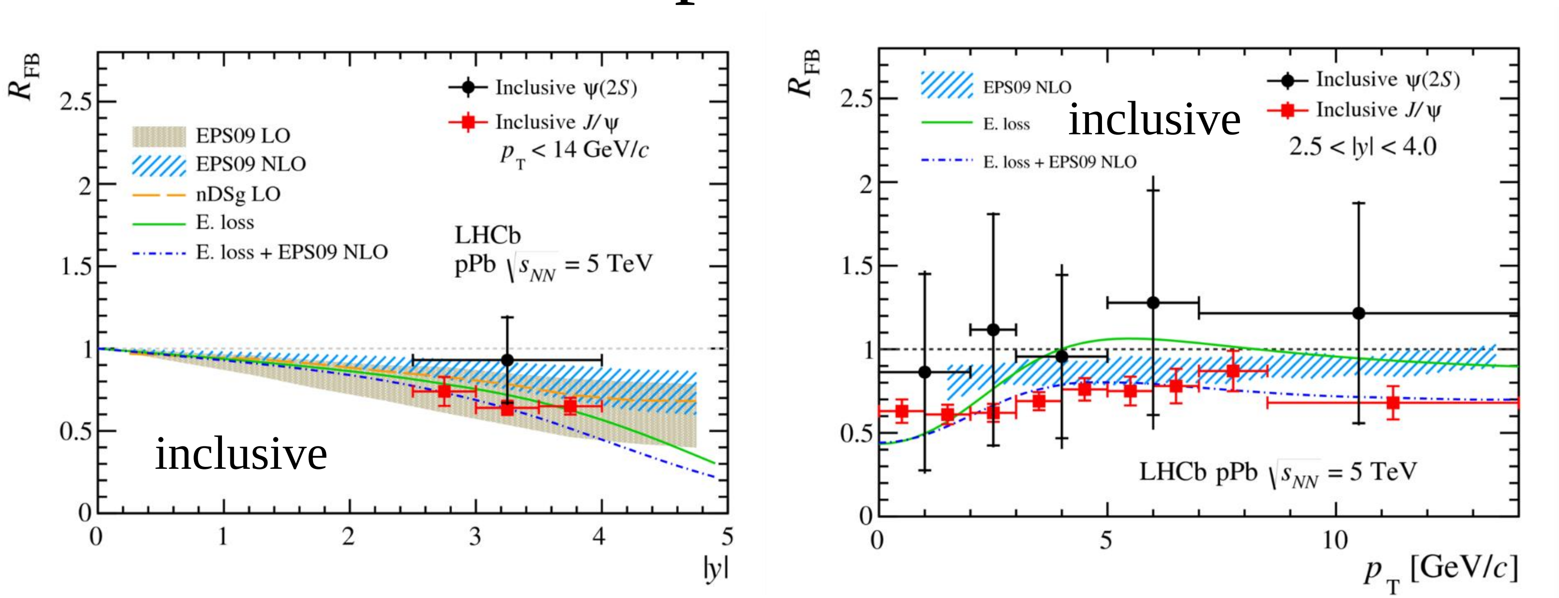
forward forward



backward backward

LHCb JHEP 03 (2016) 133

$\psi(2S)$ results at 5 TeV forward-backward production ratio



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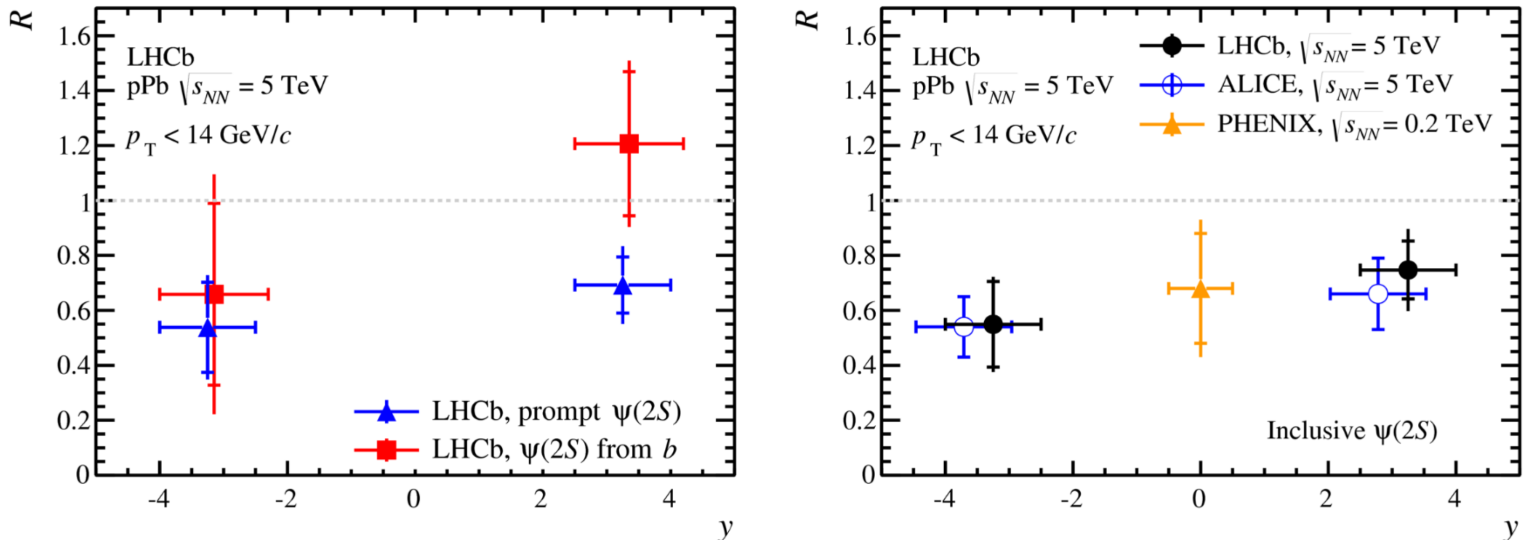
- *pp* reference not required
- Large experimental uncertainties
- Compatible with both unity and inclusive J/ψ R_{FB}
- Trend towards smaller asymmetry for $\psi(2S)$
- Expect to resolve with 2016 *p*Pb data (20x more than 2013)

$\psi(2S)$ results at 5 TeV
Relative suppression with respect to J/ψ



$$R \equiv \frac{R_{p\mathrm{Pb}}^{\psi(2S)}}{R_{p\mathrm{Pb}}^{J/\psi}} = \frac{\sigma_{p\mathrm{Pb}}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{p\mathrm{Pb}}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(5\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(5\,\mathrm{TeV})} = \frac{\sigma_{p\mathrm{Pb}}^{\psi(2S)}(5\,\mathrm{TeV})}{\sigma_{p\mathrm{Pb}}^{J/\psi}(5\,\mathrm{TeV})} \times \frac{\sigma_{pp}^{J/\psi}(7\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\,\mathrm{TeV})}$$

- Intriguing stronger suppression for prompt $\psi(2S)$ than for prompt J/ψ
- $\psi(2S)$ from b compatible with unity within large uncertainties
  - Expect similar suppression for $\psi(2S)$ from b and J/ψ from b
- Results for inclusive $\psi(2S)$ consistent with ALICE measurement

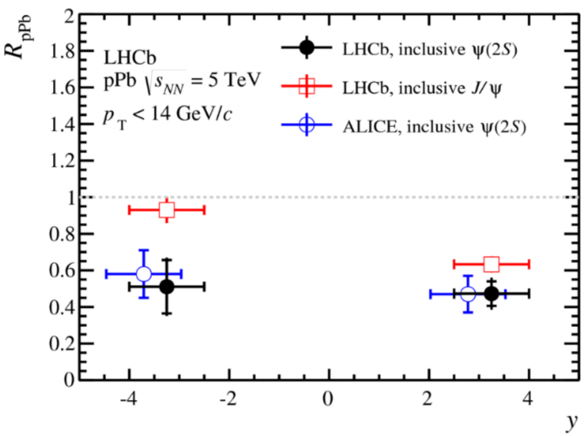
assuming:

$$\frac{\sigma_{pp}^{J/\psi}(5\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(5\,\mathrm{TeV})} = \frac{\sigma_{pp}^{J/\psi}(7\,\mathrm{TeV})}{\sigma_{pp}^{\psi(2S)}(7\,\mathrm{TeV})}$$

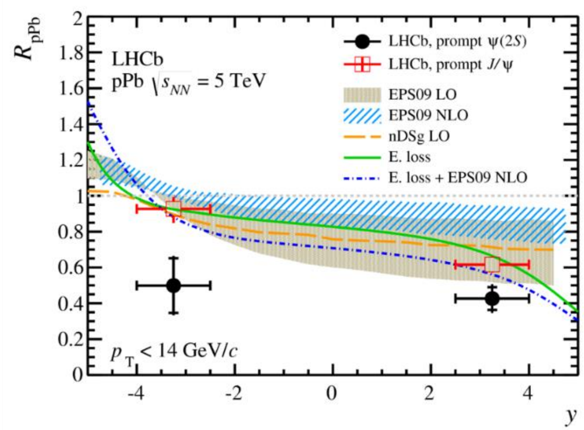
LHCb JHEP 1603 (2016) 133
ALICE JHEP 12 (2014) 073
PHENIX PRL 111 (2013) 202301

ψ(2S) results at 5 TeV nuclear modification factor in pPb

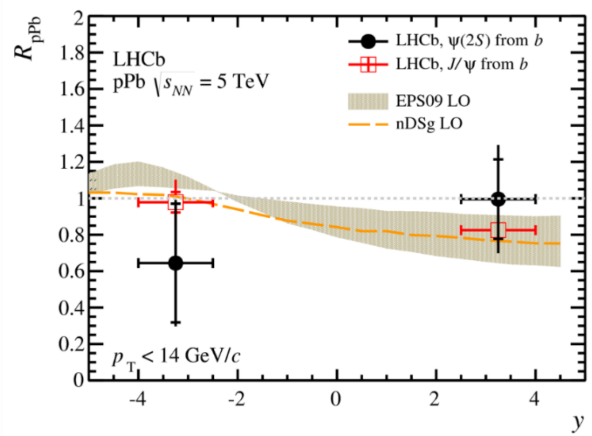
inclusive



prompt



from b



LHCb JHEP 03 (2016) 133

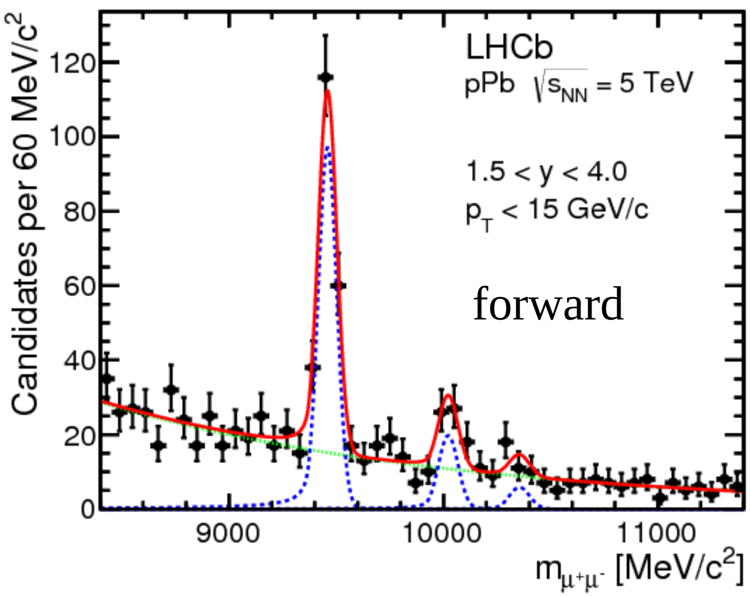
$$R_{p\mathrm{Pb}}^{\psi(2S)} = R_{p\mathrm{Pb}}^{J/\psi} \times R$$

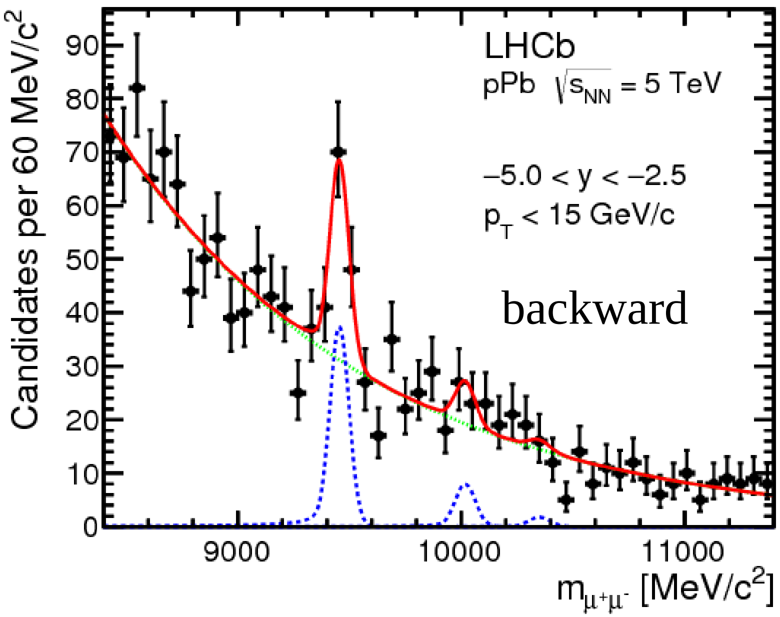
- $R_{p\mathrm{Pb}}(\psi(2S))$ calculated from $R_{p\mathrm{Pb}}(J/\psi)$
  - pp reference for J/ψ at 5 TeV is interpolated from measurements at 2.76, 7 and 8 TeV
- Inclusive ψ(2S): consistent with ALICE results
- Prompt ψ(2S): more suppressed than prompt J/ψ
  - E. loss + shadowing cannot explain prompt ψ(2S) suppression in the backward region
  - Other mechanism: comover effects?
- ψ(2S) from b: consistent with J/ψ from b

ϒ results at 5 TeV

- Reconstructed through dimuon decay channel
- Clear separation between ϒ states
- Statistics limited for
  - Differential measurement
  - Measurements of ϒ(2S) and ϒ(3S) states

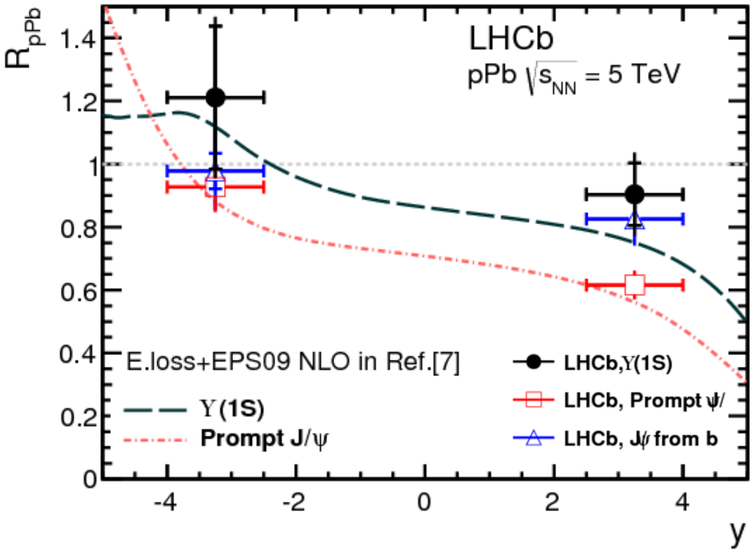
LHCb JHEP 07 (2014) 094

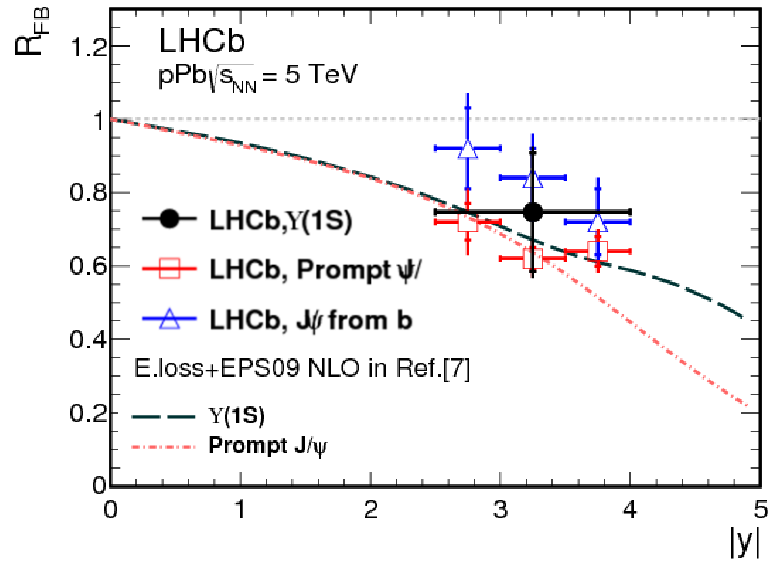




$\Upsilon(1S)$ results at 5 TeV
R_{FB} and R_{pPb} in pPb

LHCb JHEP 07 (2014) 094

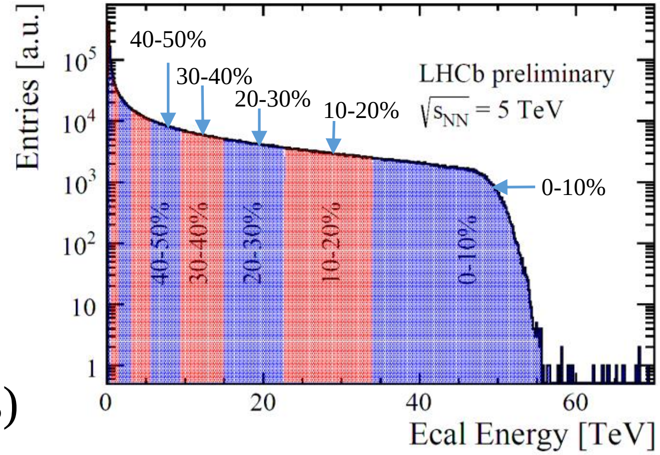




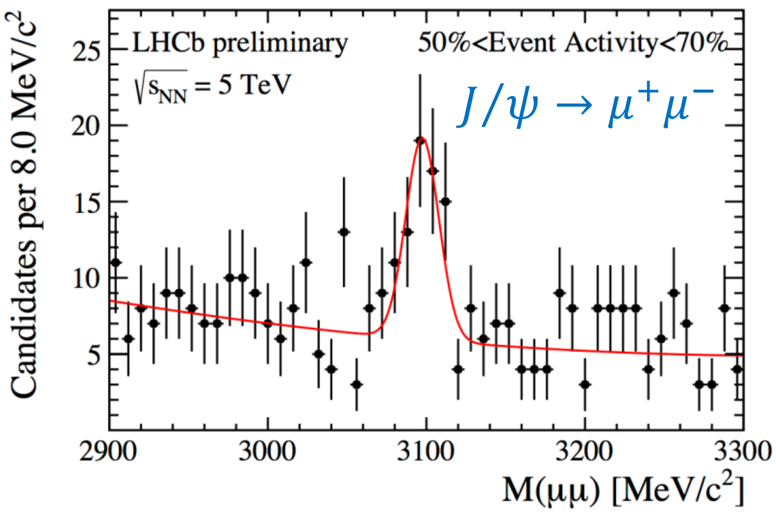
- Measurement of R_{FB} and R_{pPb} with $\Upsilon(1S)$ complementary to J/ψ
- Suppression in forward region smaller than J/ψ
- Suppression in forward region close to J/ψ from b (CNM effects on b hadrons)
- Possible enhancement in backward region due to anti-shadowing
- Energy loss + shadowing describes data well

PbPb collisions

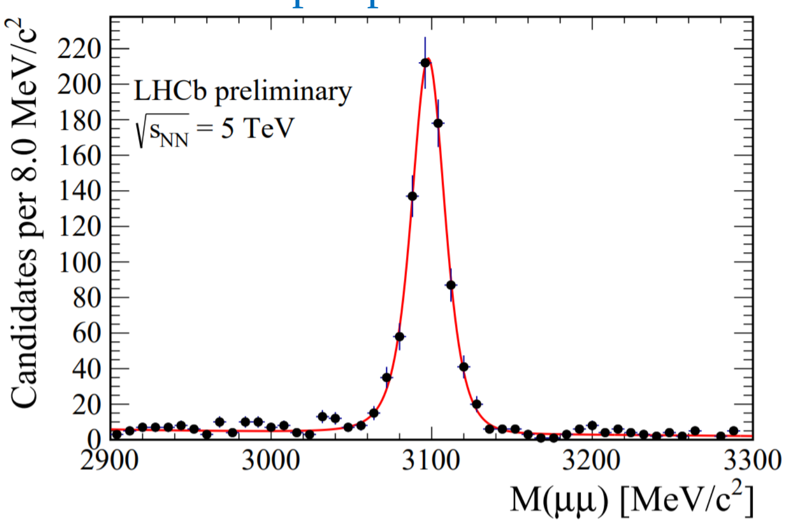
- December 2015: first LHCb PbPb data taken
- $\sqrt{s_{NN}} = 5$ TeV (3-5 μb^{-1})
- Event classification: total energy in the calorimeters (Ecal)
- Analyses limited by saturation in Vertex Locator (VELO)
- Track reconstruction: 50-100% event activity (~15k clusters)



Activity 50-70%



J/ψ photoproduction in ultraperipheral events

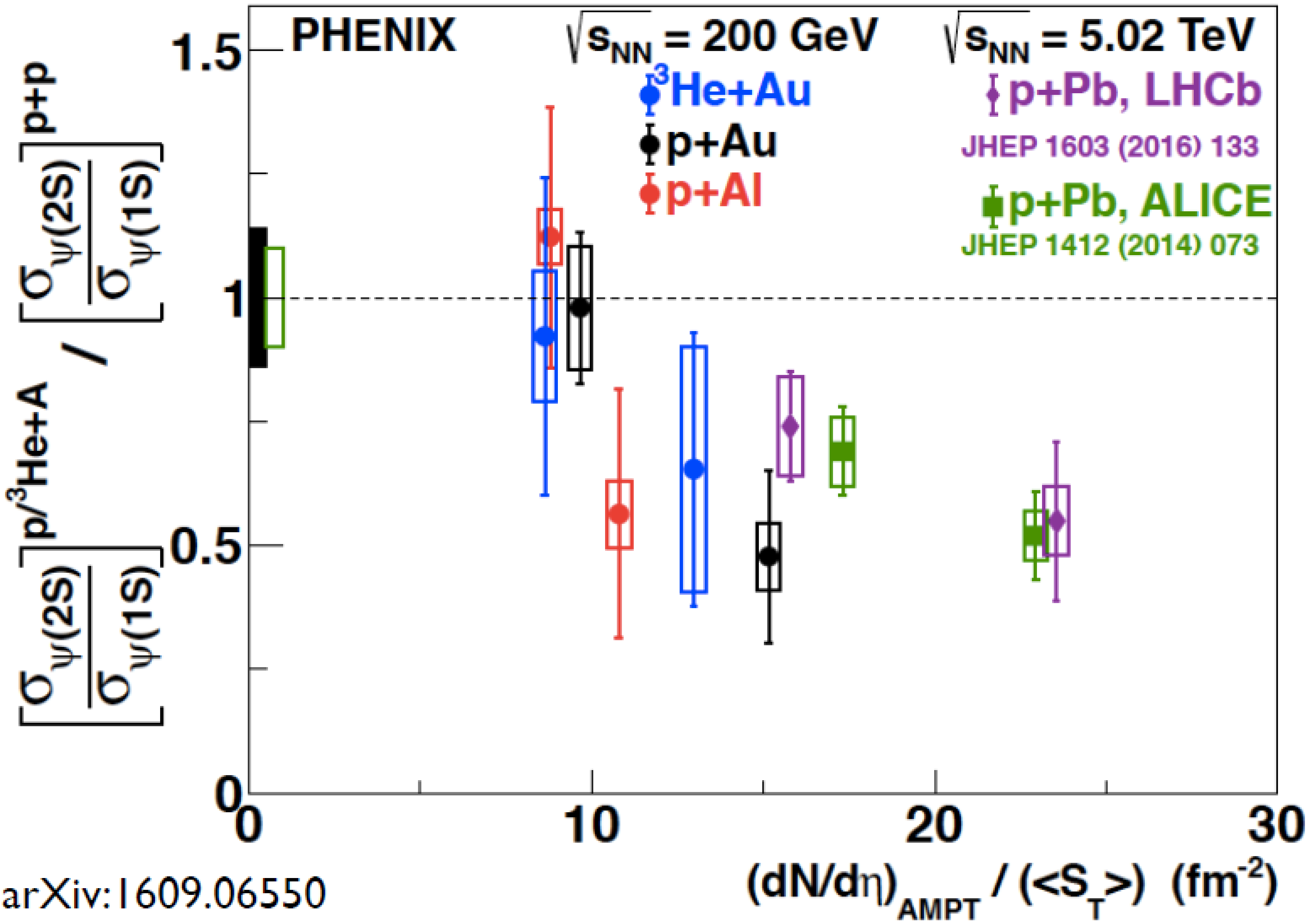


https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

Conclusion

- LHCb successfully participated in proton-lead data-taking in 2013 and 2016
  - Precision measurement of J/ψ performed with p_{T} down to 0
  - Measurements of $\psi(2S)$ and $\Upsilon(1S)$ show visible cold nuclear matter effects
    - Preferential suppression of prompt $\psi(2S)$ at backward rapidity
- 2016 pPb dataset with 20x more statistics expected to bring significant improvements
- A small sample of PbPb collisions collected in 2015
  - Ongoing analyses on semi-central to peripheral collisions

backup



arXiv:1609.06550