Hadron 2019
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Quarkonia production in heavy-ion collisions at LHCb

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Outline

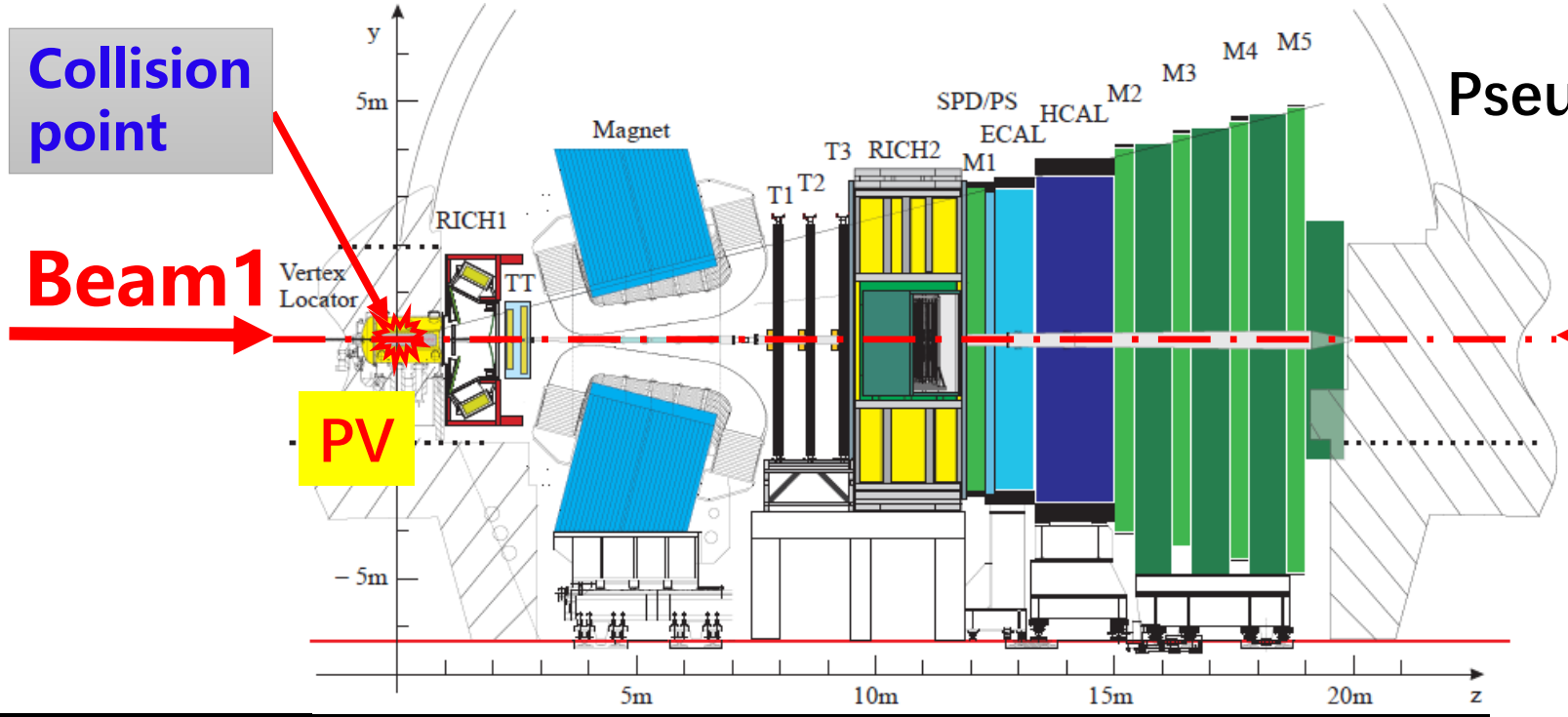
- Introduction
- Quarkonia production in pPb
- Quarkonia produciton in PbPb
- Summary

See talk by Shanzhen Chen at 9:55 of 20 August (Session 6):
Recent results and prospects on ultra-peripheral heavy-ion collisions at LHCb

See talk by Jiayin Sun at 9:15 of 21 August (Session 7):
Production of open heavy flavour hadrons in pPb and fixed-target collisions LHCb

The LHCb detector

JINST 3 (2008) S08005
Int. J. Mod. Phys. A 30 (2015) 1530022



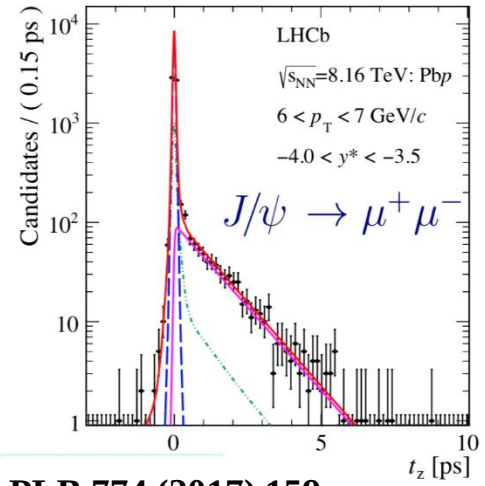
Pseudorapidity coverage
$2 < \eta < 5$

Vertex:	$\sigma_{IP} = 20\ \mu m$
Time:	$\sigma_\tau = 45\ fs$ for $B_s^0 \to J/\psi\phi$ or $D_s^+\pi^-$
Momentum:	$\Delta p/p = 0.4 \sim 0.6\%$ $(5 - 100\ GeV/c)$
Mass :	$\sigma_m = 8\ MeV/c^2$ for $B \to J/\psi X$ (constrainted $m_{J/\psi}$)
Hadron ID:	$\varepsilon(K \to K) \sim 95\%$ mis-ID $\varepsilon(\pi \to K) \sim 5\%$
Muon ID:	$\varepsilon(\mu \to \mu) \sim 97\%$ mis-ID $\varepsilon(\pi \to \mu) \sim 1 - 3\%$
ECAL:	$\Delta E/E = 1 \oplus 10\%/\sqrt{E\ (GeV)}$

Joined heavy-ion data taking since 2013

Key features for heavy-ion: performance + trigger

- Excellent detector performance, notably for heavy flavour hadrons
  - Precision vertexing and tracking
  - Excellent PID



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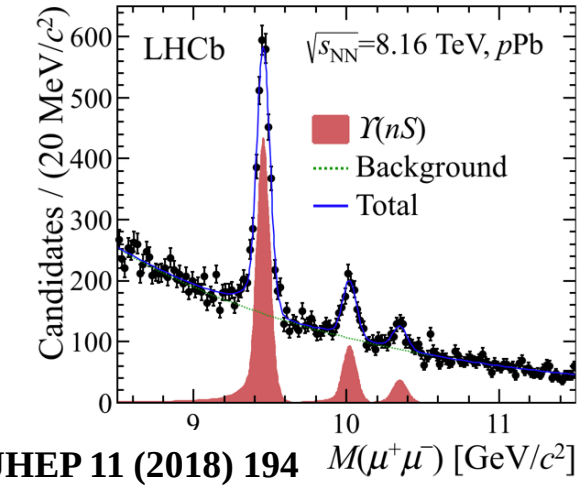
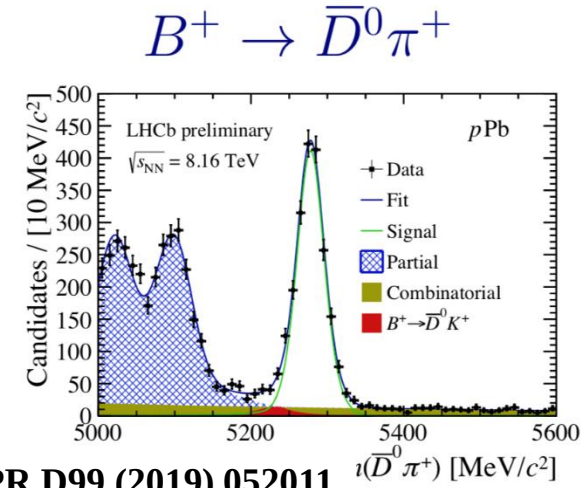


JHEP 11 (2018) 194

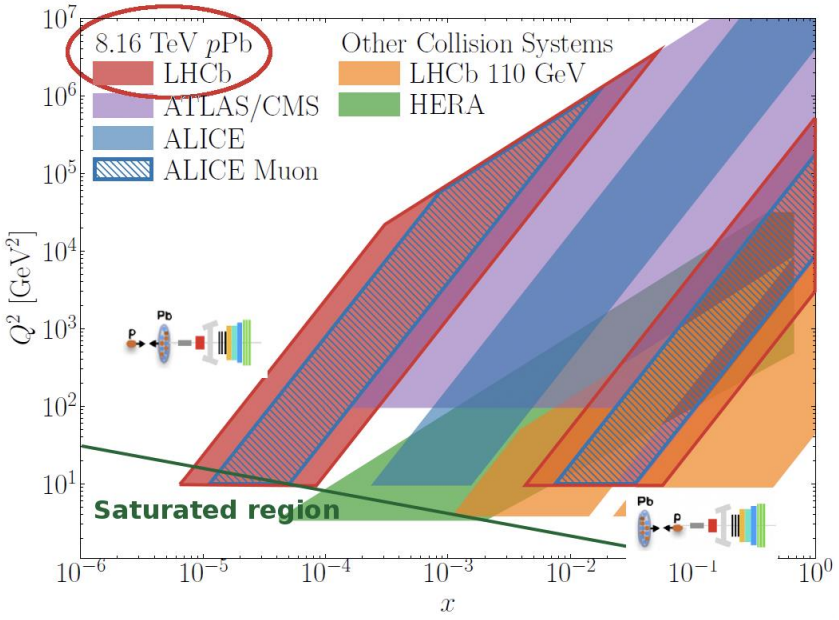


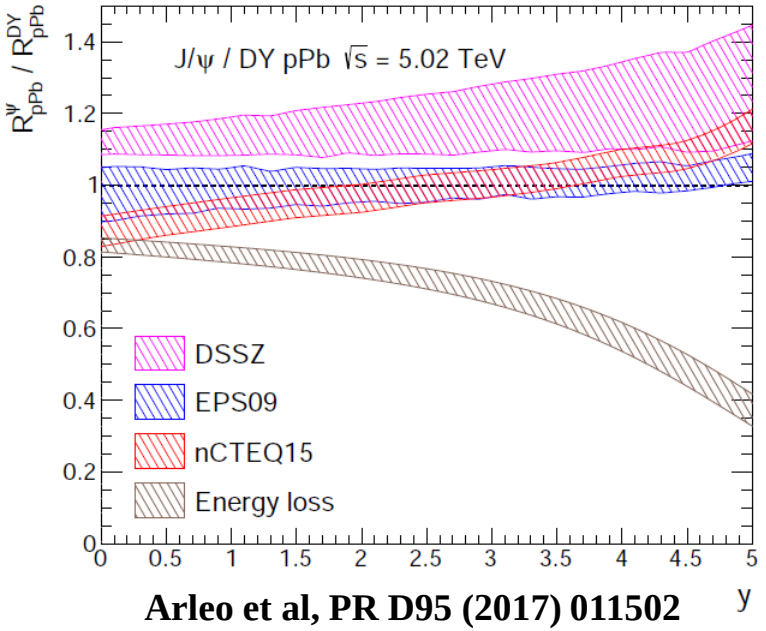
PR D99 (2019) 052011

- Efficient trigger: no rate limitation for heavy-ion runs
  - Can access heavy flavour hadrons with very low p_T

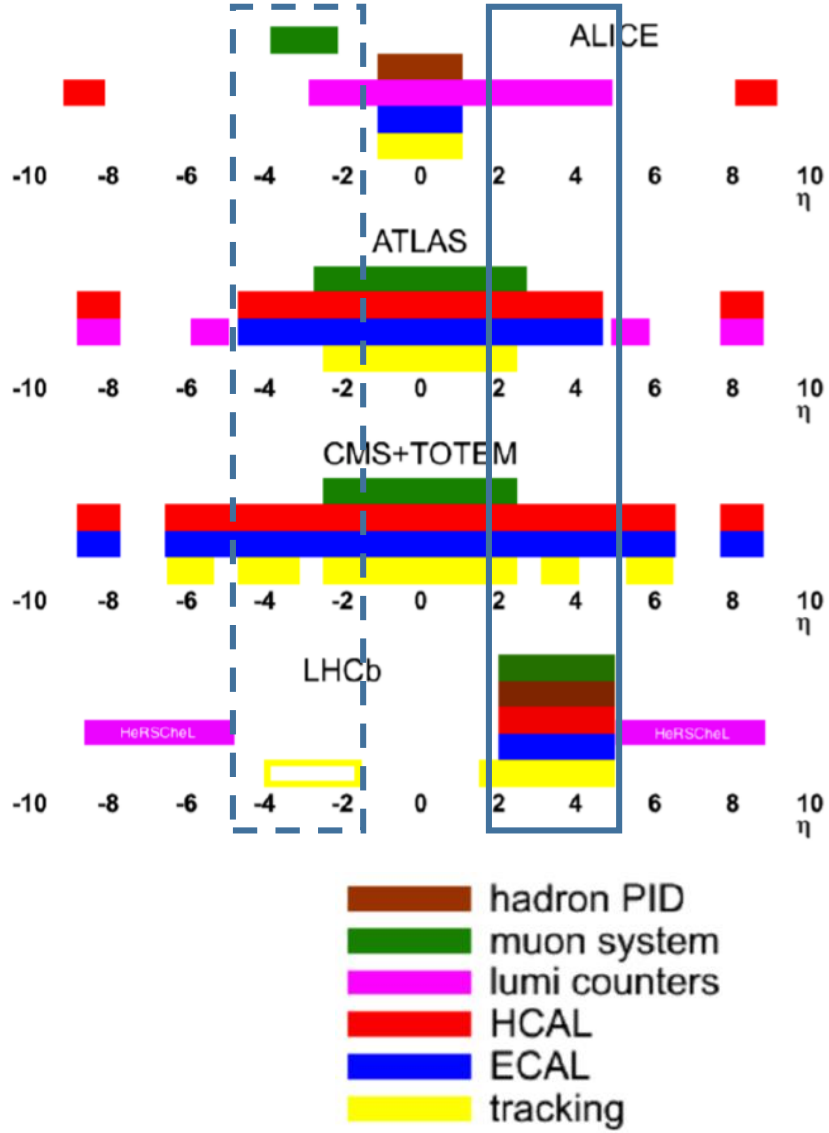
Key features for heavy-ion: forward acceptance

- Unique forward coverage at the LHC
  - Sensitive to small Bjorken-x
  - Rapidity dependence helps distinguishing nuclear effects



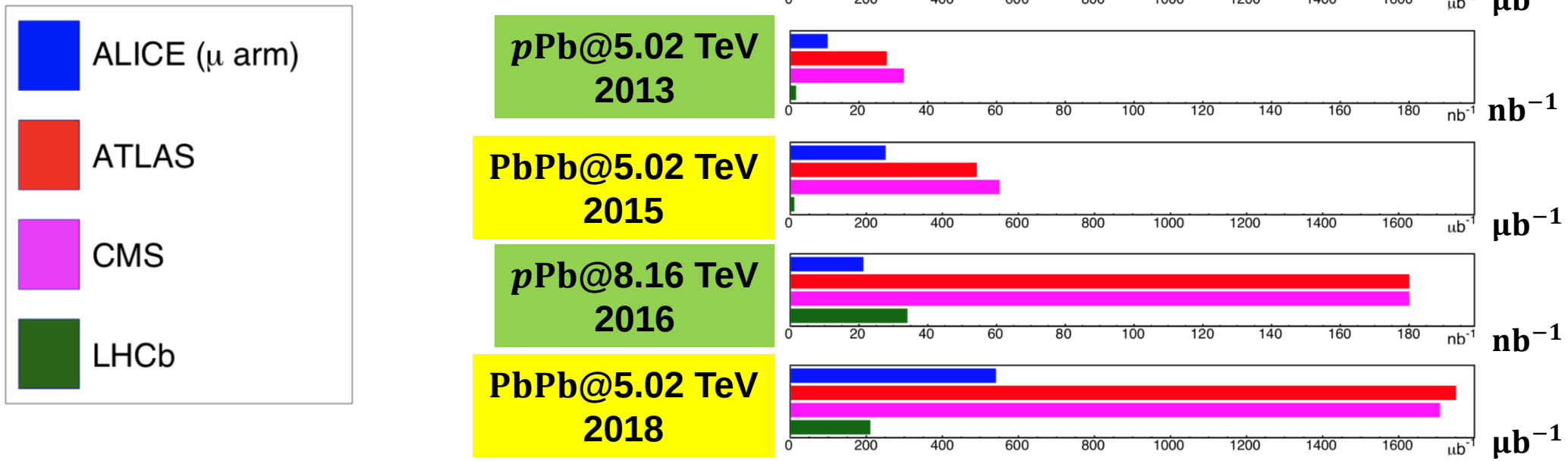


Arleo et al, PR D95 (2017) 011502



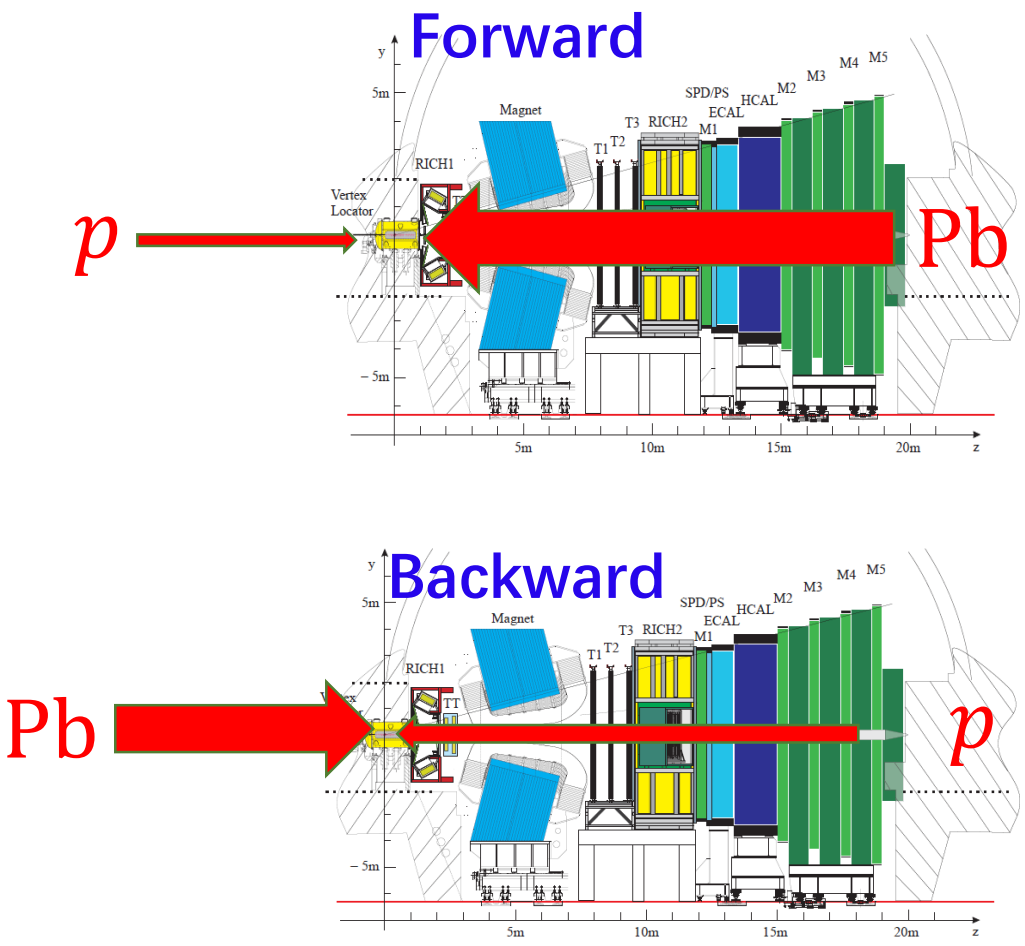
Heavy-ion samples at the LHC

- LHCb started pPb data taking in 2013 and PbPb in 2015
  - Very limited luminosity, but successful data taking and physics output
- Larger pPb samples in 2016 and PbPb samples in 2018, owing to larger share of the LHC luminosity



Quarkonia in pPb

Beam configuration



- Asymmetric beam energy due to different charge-mass ratios of proton and lead
  - ✓ rapidity shift $\Delta y = \pm 0.465$
- Rapidity coverage
  (in nucleon-nucleon centre-of-mass frame)
  - ✓ **Forward (pPb)**
    $\boldsymbol{y^* = y_{lab} - 0.465 \Rightarrow \quad 1.5 < y^* < 4.0}$
  - ✓ **Backward (Pbp)**
    $\boldsymbol{y^* = -(y_{lab} + 0.465) \Rightarrow \quad -5.0 < y^* < -2.5}$
- Common coverage
  - ✓ $2.5 < |y| < 4.0$

$\sqrt{s_{NN}}$	Lumi (Fwd)	Lumi (Bwd)
2013: $\sqrt{s_{NN}} = 5.02$ TeV	$1.1\ \mathrm{nb}^{-1}$	$0.5\ \mathrm{nb}^{-1}$
2016: $\sqrt{s_{NN}} = 8.16$ TeV	$13.6\ \mathrm{nb}^{-1}$	$20.8\ \mathrm{nb}^{-1}$

J/ψ in pPb at 8.16 TeV

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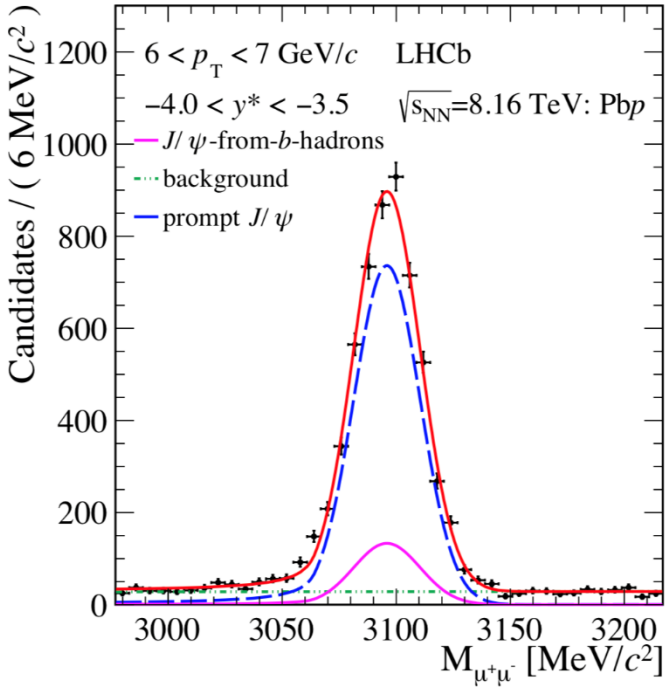
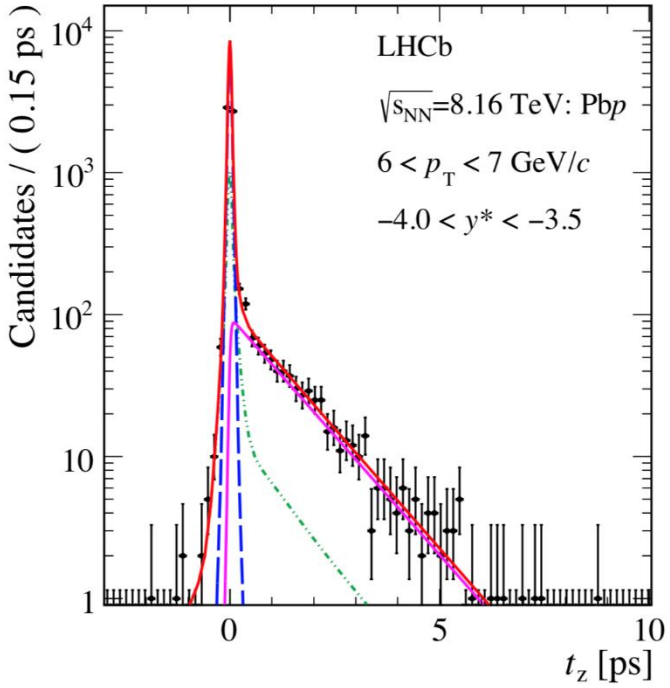
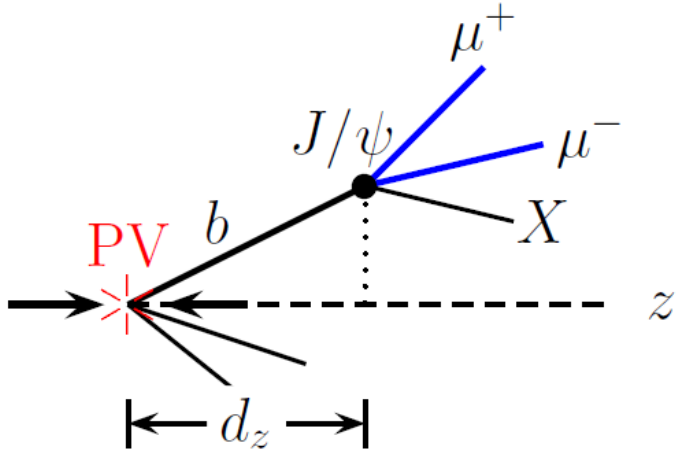
- Clean sample, number of signals much large than 2013 (5.02 TeV)
- Prompt and secondary J/ψ separated
- $\mathrm{d}^2\sigma/\mathrm{d}p_\mathrm{T}\mathrm{d}y$ measured down to zero p_T
- Sensitive probe of gluon PDF at low Bjorken-x







$$d_z = z_{J/\psi} - z_{\mathrm{PV}}$$

$$t_z \equiv d_z \times \frac{M_{J/\psi}}{p_{z,J/\psi}}$$

J/ψ in pPb at 8.16 TeV: cross-sections

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- Cross-sections measured in bins of p_{T} and y

Forward

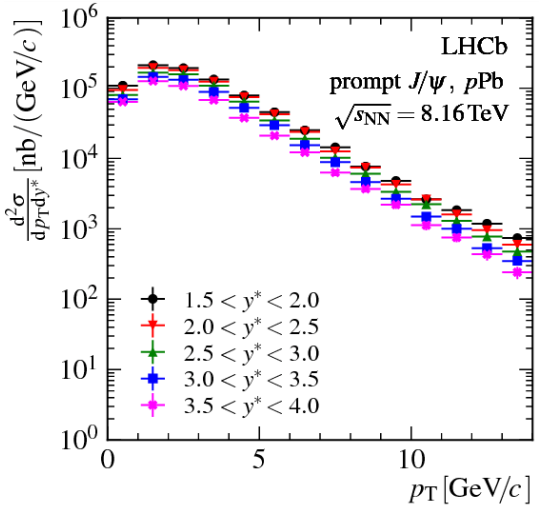
Forward

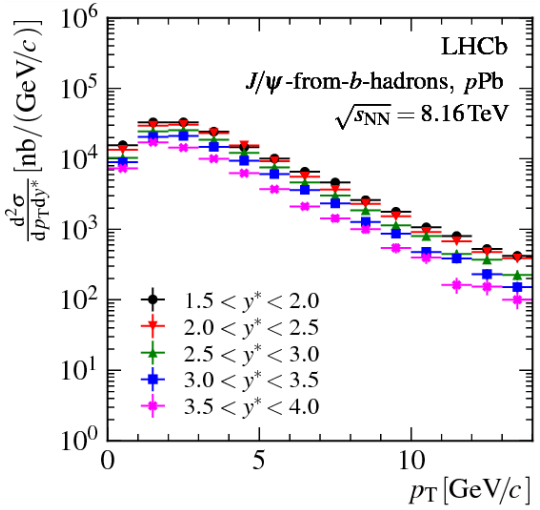
Prompt

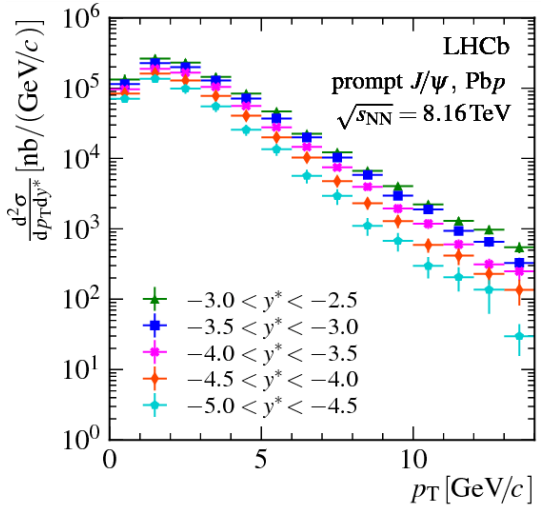
From-b

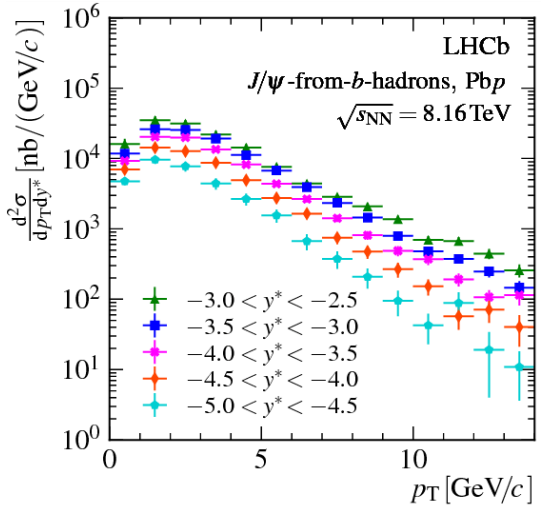
Backward

Backward

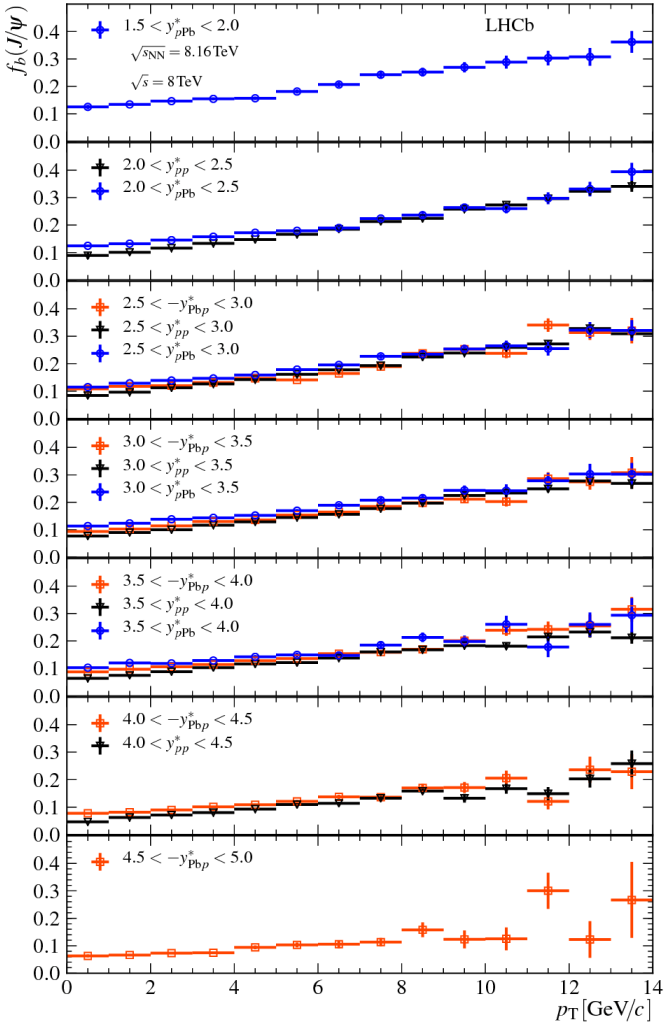








Fraction of from-b



J/ψ in pPb at 8.16 TeV: nuclear modification

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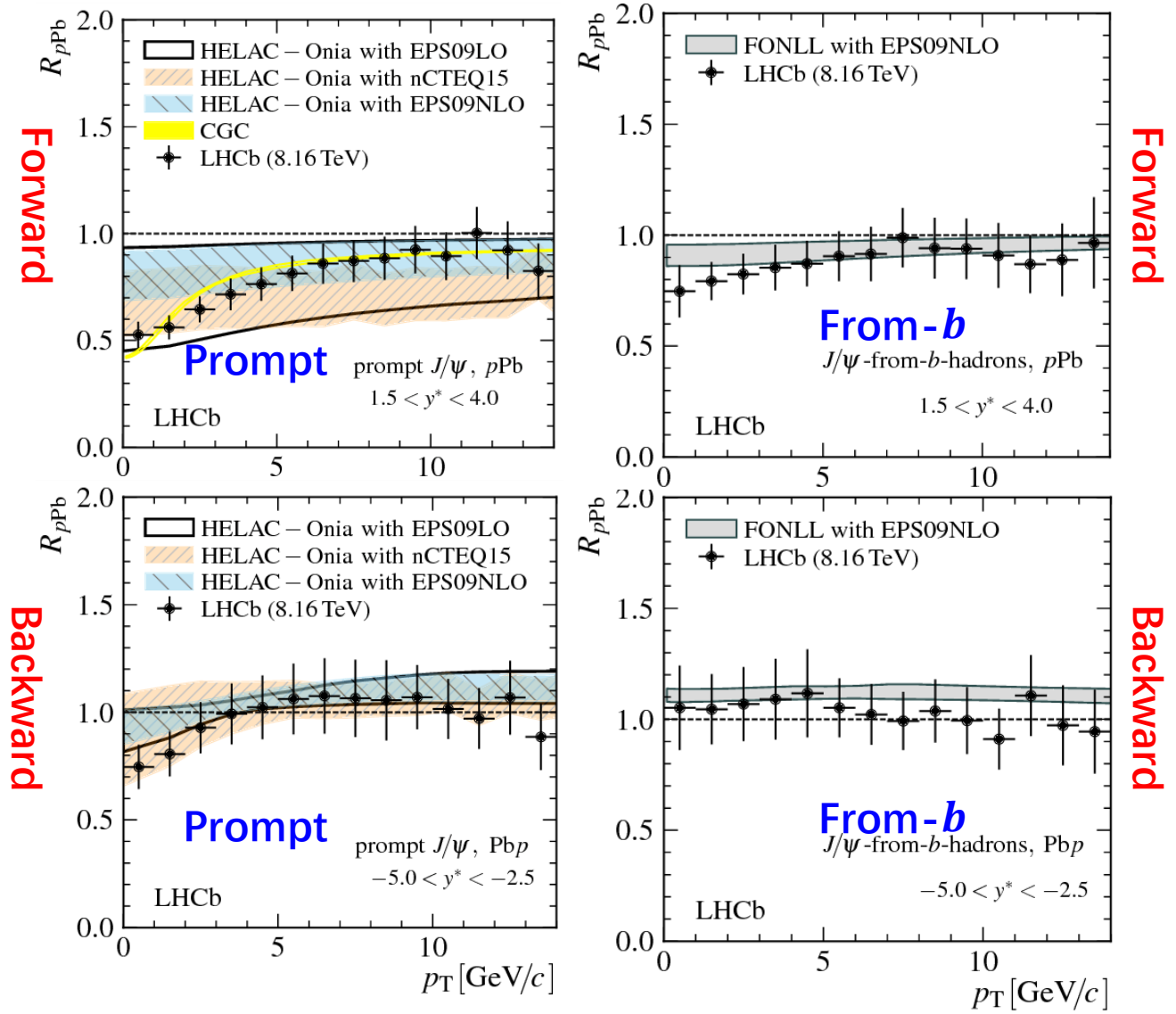
- Stronger suppression in forward than in backward
- Stronger suppression for prompt J/ψ
- Compatible with initial-state (nPDF) effects
  - Prompt: HELAC-onia 【Shao, CPC198 (2016) 238】 From-b: pQCD at FONLL 【Cacciari et al, JHEP05(1998)007】
- Good agreement with CGC calculation
  - Ducloue et al, 【PRD94(2016)074031】

Nuclear modification factor: $R_{pPb} \equiv \frac{1}{A}\frac{\sigma_{pPb}}{\sigma_{pp}}$



J/ψ in pPb at 8.16 TeV: nuclear modification

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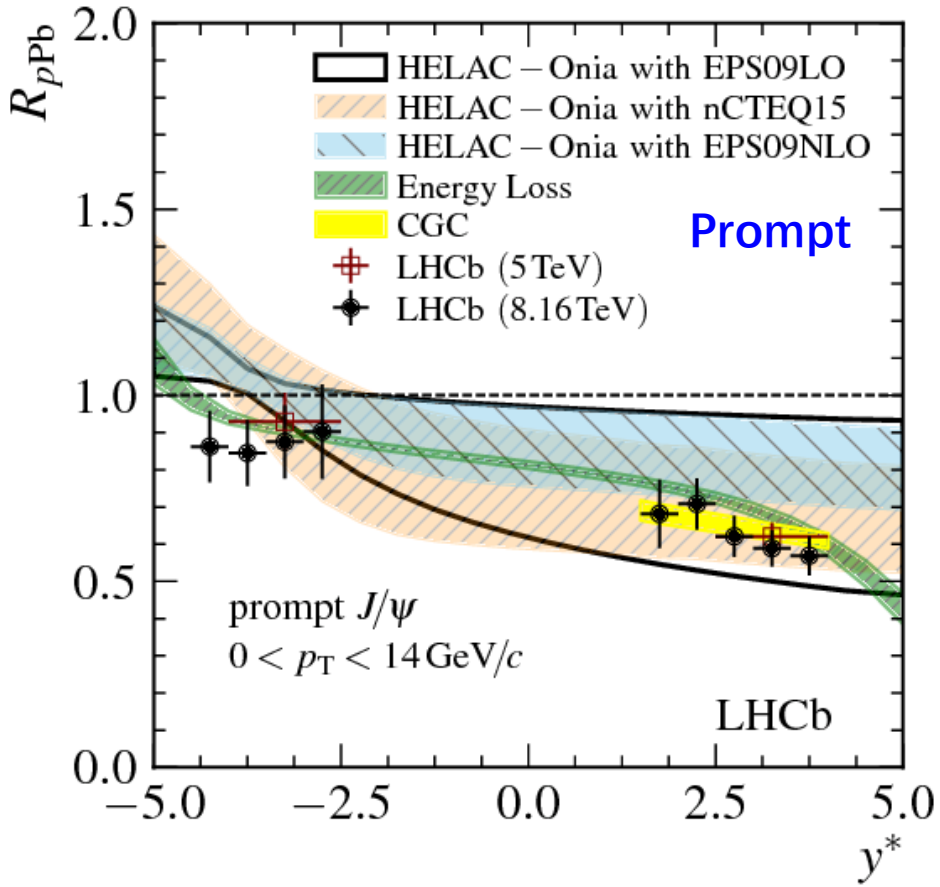
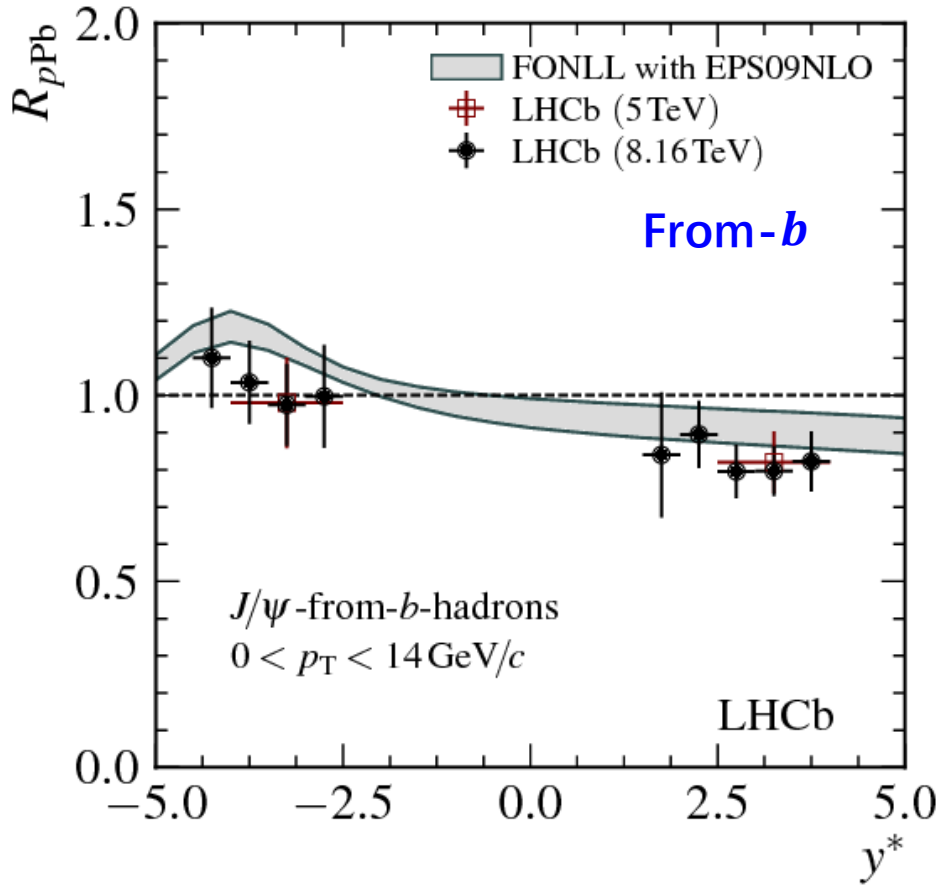
- Rapidity dependence of nuclear modification factor can be also described by coherent energy loss
  - Arleo and Peigne, JHEP03(2013)122

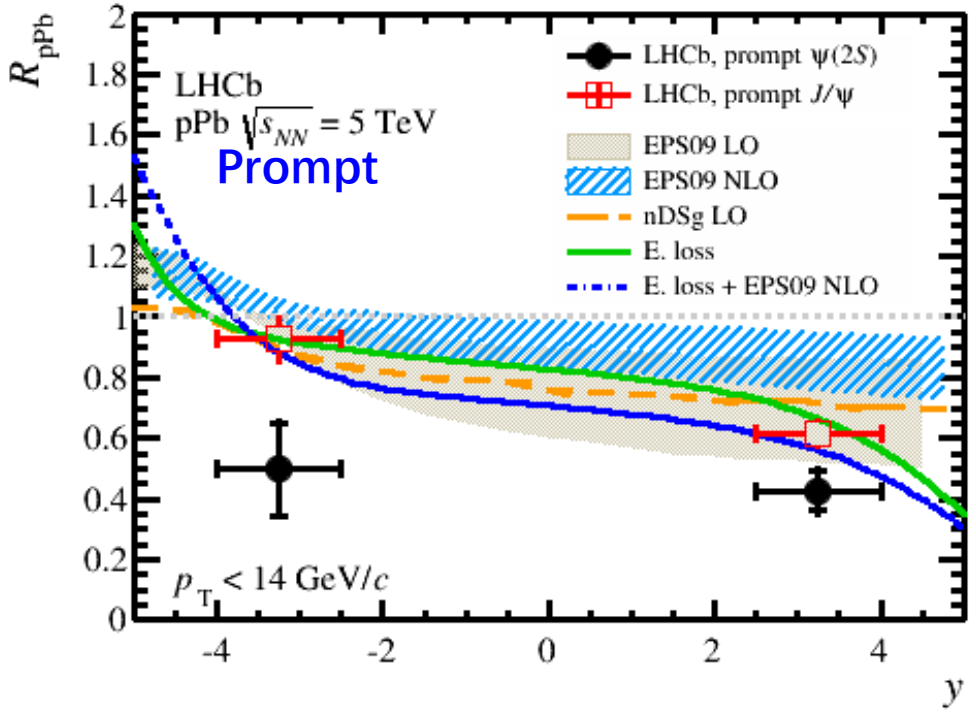


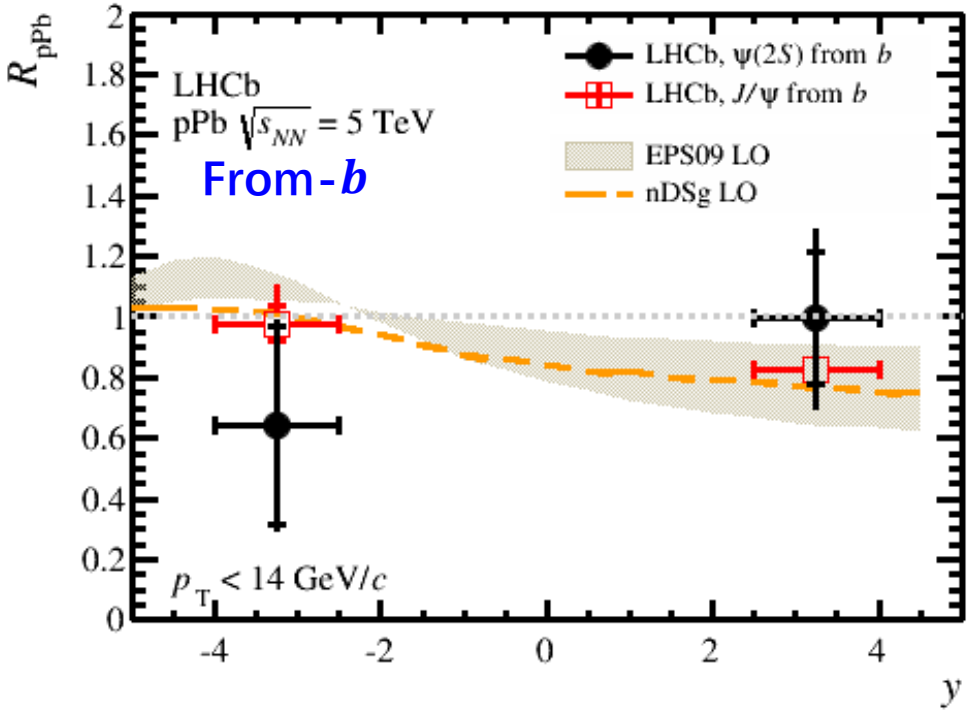


Comparison of J/ψ and $\psi(2S)$ in pPb

JHEP 03 (2016) 133

- $\psi(2S)$ in pPb at 8.16 TeV still under way
- Results from the 5 TeV sample show stronger suppression compared with prompt J/ψ
  - unexpected from initial-state effects or energy loss
  - Results of $\psi(2S)$ from b and J/ψ from b are compatible





$\Upsilon(nS)$ in pPb at 8.16 TeV

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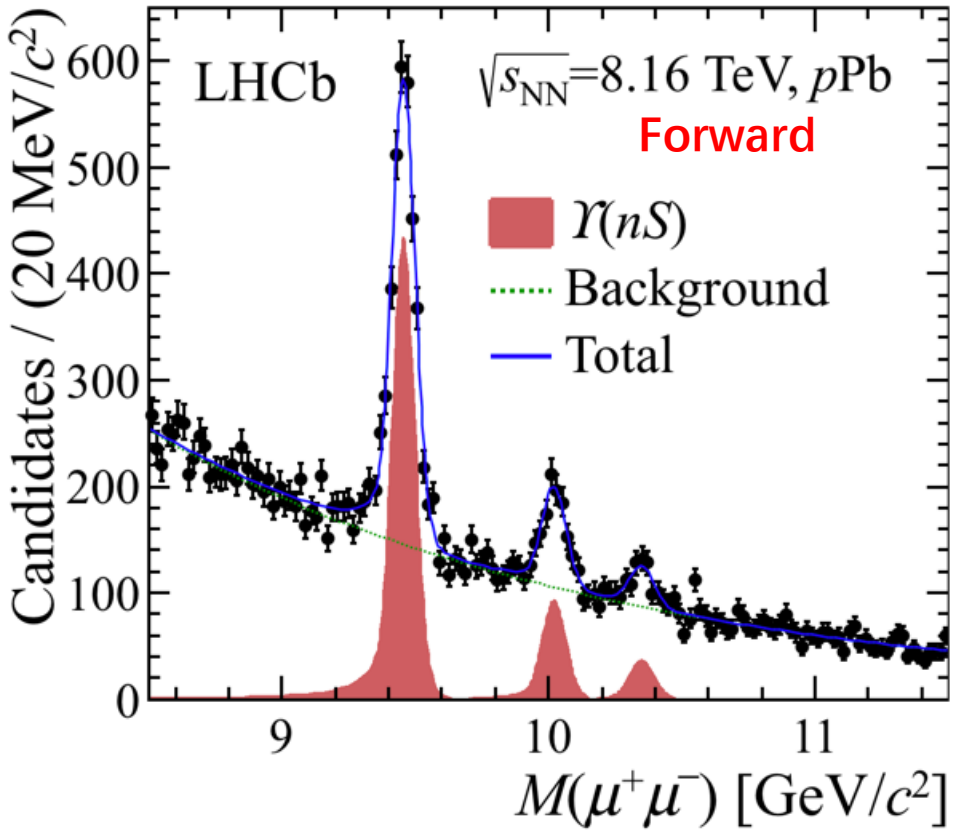
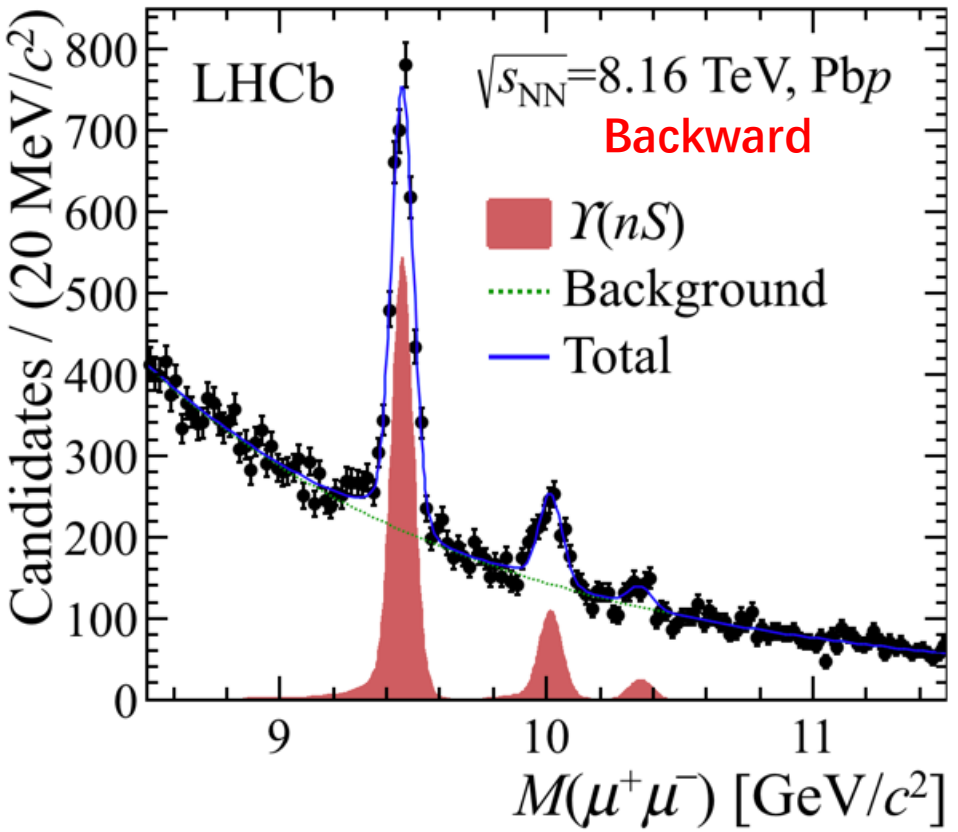
- Clearly distinguished the three $\Upsilon(nS)$ peaks
- Cross-sections measured and nuclear effects studied





$\Upsilon(nS)$ in pPb at 8.16 TeV: $R_{p\mathrm{Pb}}$

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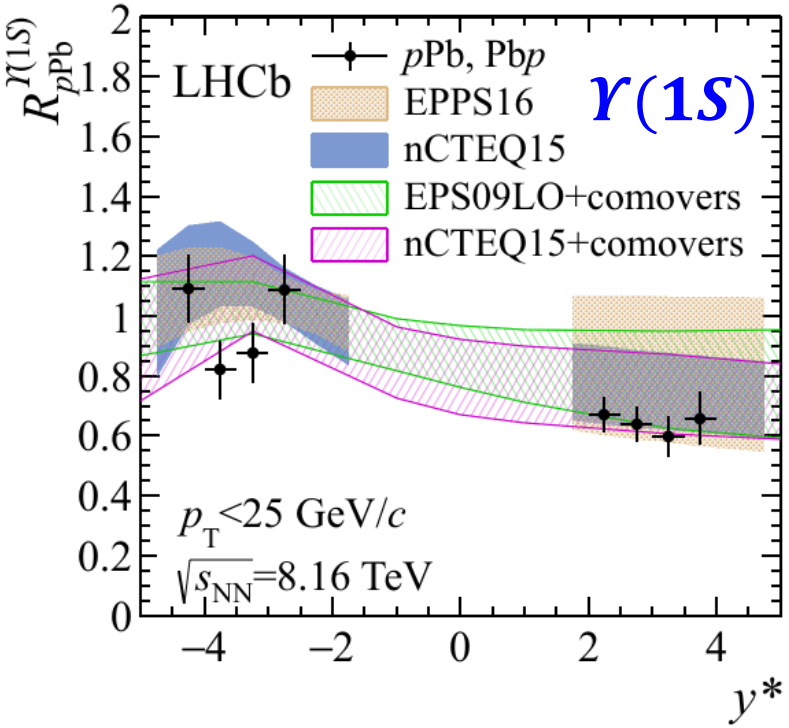
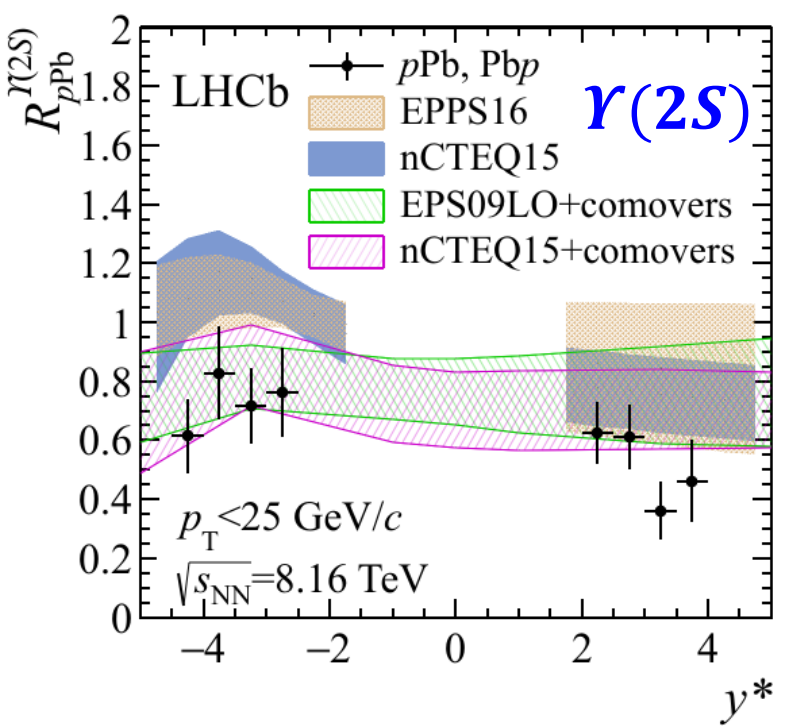
- Nuclear modification factor $R_{p\mathrm{Pb}}$ measured for $\Upsilon(1S)$ and $\Upsilon(2S)$
- Data favour prediction of comover model 【JHEP10(2018)094, PLB749(2015)98】
  - Larger suppression for excited states and in backward due to final-state effects





$\Upsilon(nS)$ in pPb at 8.16 TeV: double ratios

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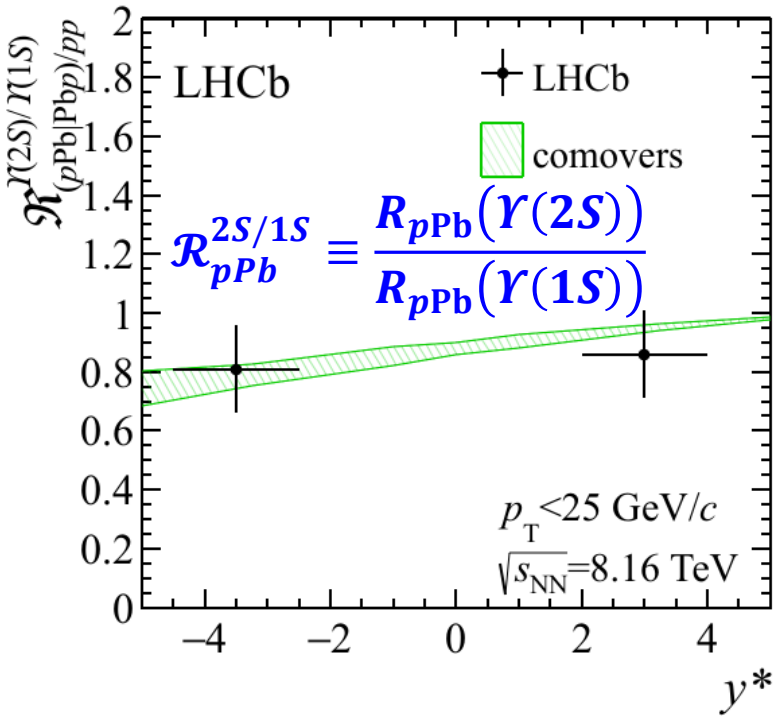
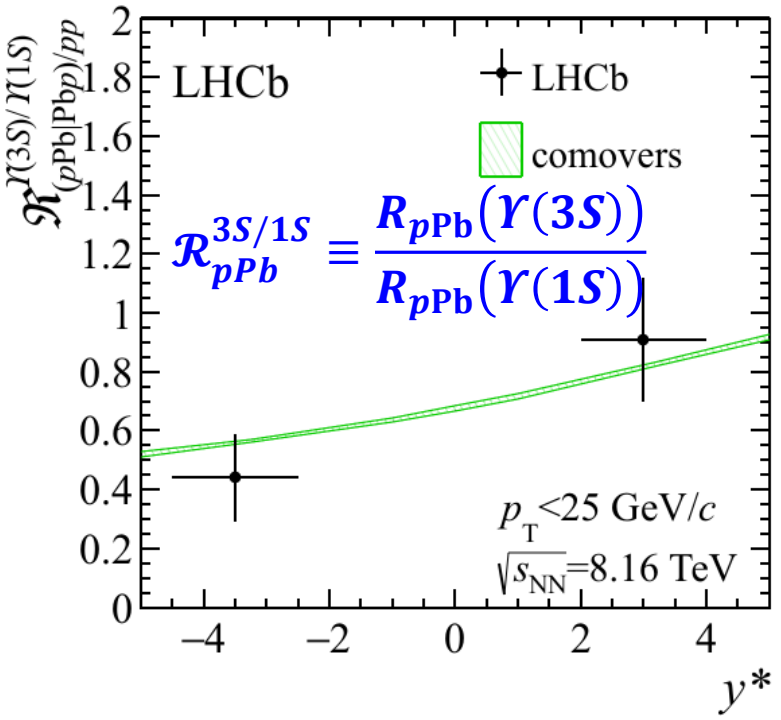
- Double ratios $\mathcal{R}_{p\mathrm{Pb}}^{2S/1S}$ and $\mathcal{R}_{p\mathrm{Pb}}^{3S/1S}$ show clear sequential suppression
  - Notable for $\Upsilon(3S)$, agree with comover model 【JHEP10(2018)094; PLB749(2015)98】
  - Crucial to get a correct interpretation of QGP-induced sequential suppression





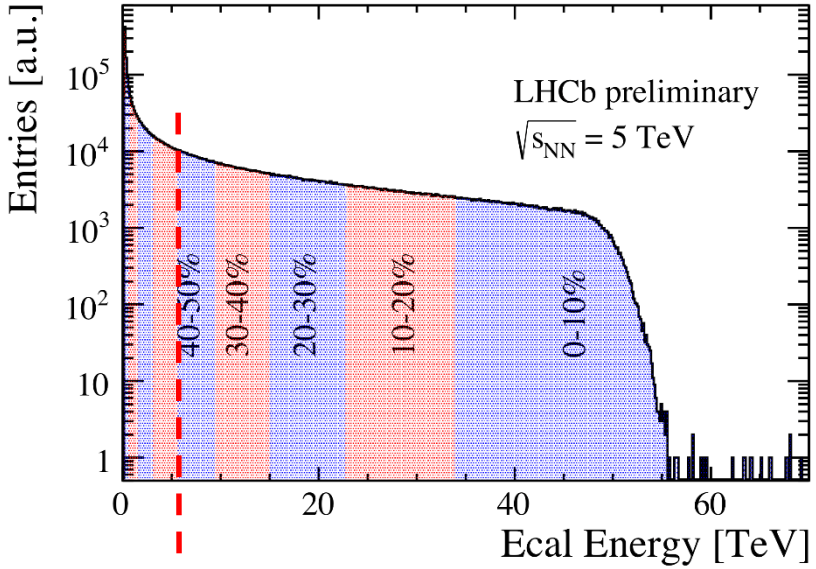
$$\mathfrak{R}^{\Upsilon(2S)/\Upsilon(1S)}_{p\mathrm{Pb}/pp} = 0.86 \pm 0.15,$$
$$\mathfrak{R}^{\Upsilon(3S)/\Upsilon(1S)}_{p\mathrm{Pb}/pp} = 0.81 \pm 0.15,$$
$$\mathfrak{R}^{\Upsilon(2S)/\Upsilon(1S)}_{\mathrm{Pb}p/pp} = 0.91 \pm 0.21,$$
$$\mathfrak{R}^{\Upsilon(3S)/\Upsilon(1S)}_{\mathrm{Pb}p/pp} = 0.44 \pm 0.15.$$

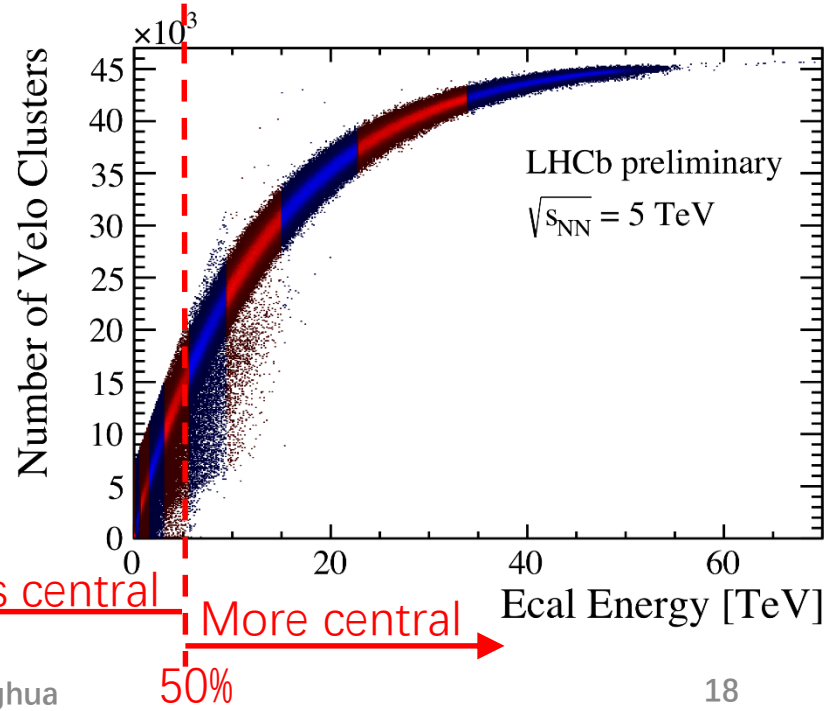
Quarkonia in PbPb collisions

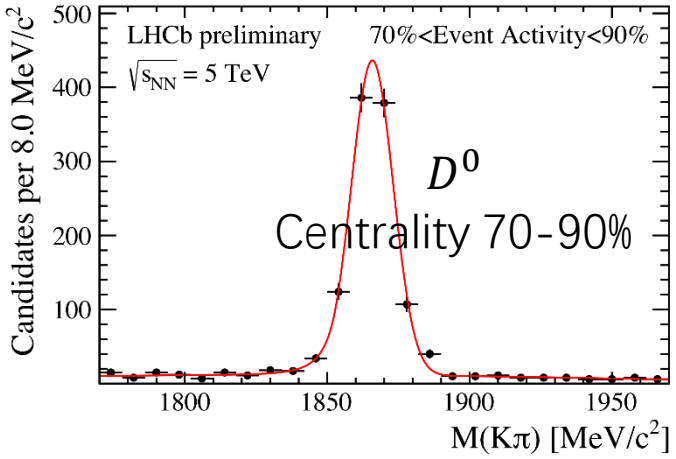
PbPb data at LHCb

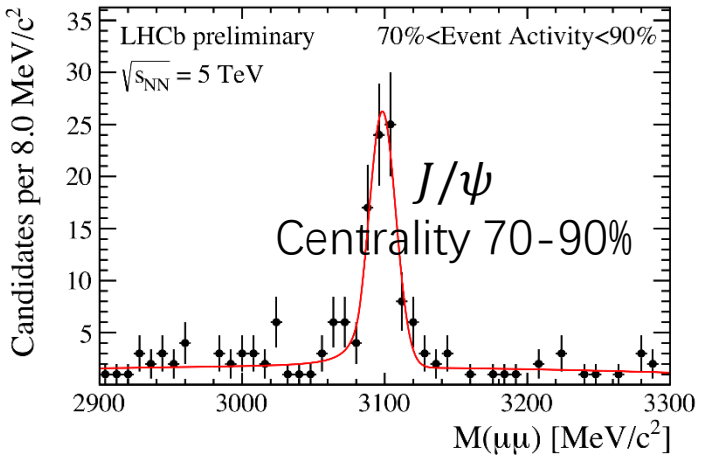
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

- PbPb data taking in 2015 (~10 μb) and 2018 (~210 μb)
- Centrality determined from total energy in ECAL
- Tracking performance good for centrality above 50%
- Interesting physics from peripheral collisions
  - J/ψ photoproduction
  - J/ψ and D^0 ratio, Υ vs centrality
  - Flow for D^0





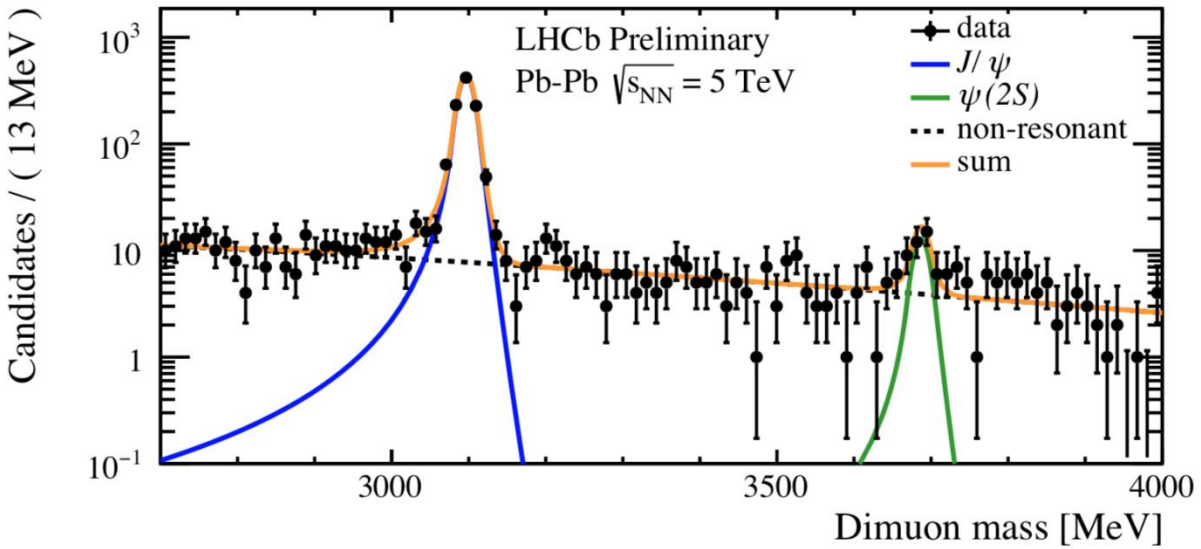


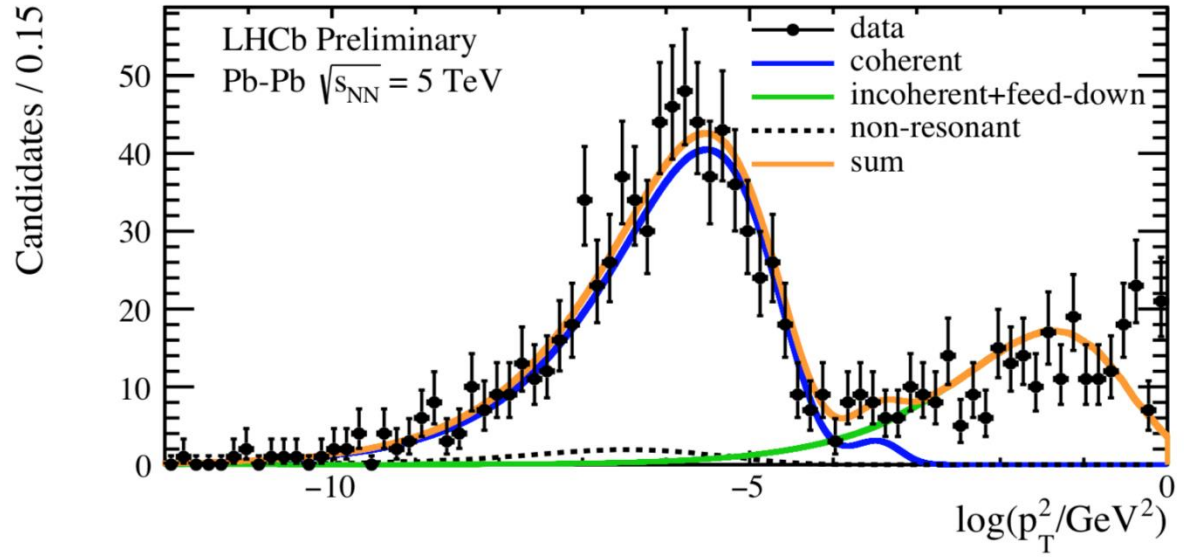


Ultra peripheral PbPb coliisions

LHCb-CONF-2018-003

- Photoproduction of hadrons enhanced by photon flux in PbPb
  - Proportional to $Z^2 = 82^2$
- Sentitive to gluon distribution at low Bjorken-x (down to 10^{-5}), the saturation region
- Signature is an exclusive dimuon with low p_{T} (< 1 GeV)
- Coherent and incoherent J/ψ photoproduction can be distinguished from p_{T} spectrum

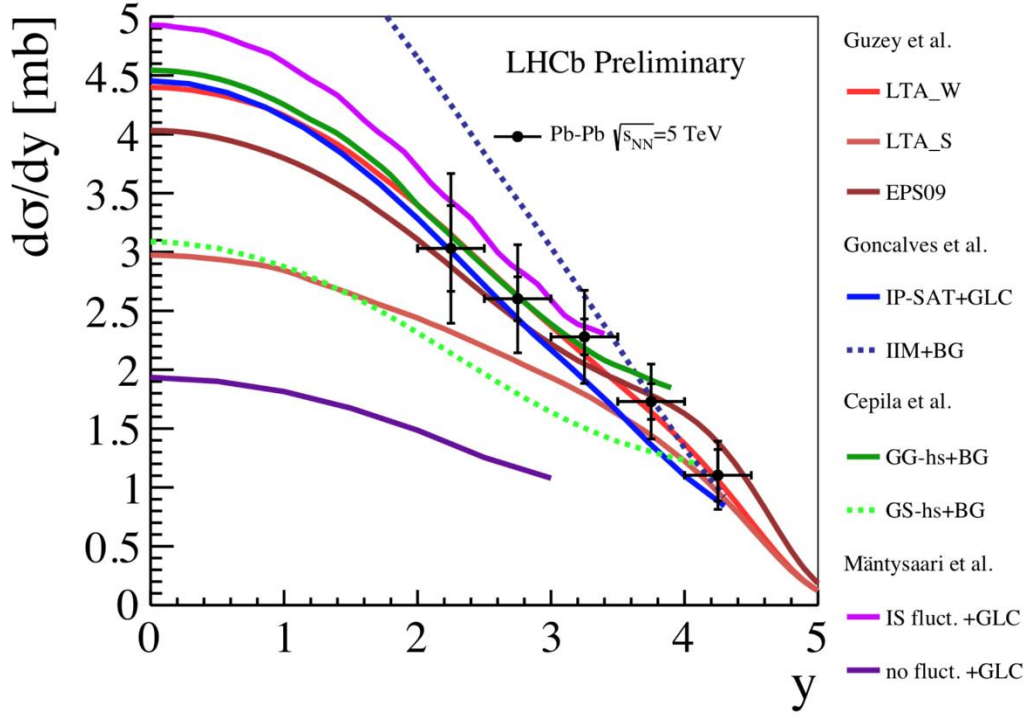




UPC result for coherent cross-section

LHCb-CONF-2018-003

- Results compared with different models
  - pQCD, Guzy et al, PRC93(2016)055206
  - Colour-Dipole model, Goncalves et al, PRD96(2017)094027
    Cepila et al, PRC97(2018)024901
    Mantysaari et al, PLB772(2017)832
- Good prospects with the larger sample collected in 2018
  - Better accuracy, including reduced systematic uncertainty through larger control sample
  - Access $\psi(2S)$ and possibly other quarkonia states



Summary

- Heavy-ion data collected by LHCb since 2013 have been providing unique results for heavy quarkonia

- More results with the Run 2 data are under way

- The ongoing Upgrade provide more opportunities in Run3 and 4
  - Larger data samples (at least 10 times)
  - Access more central PbPb collisions owing to the upgraded tracking system

Thank you