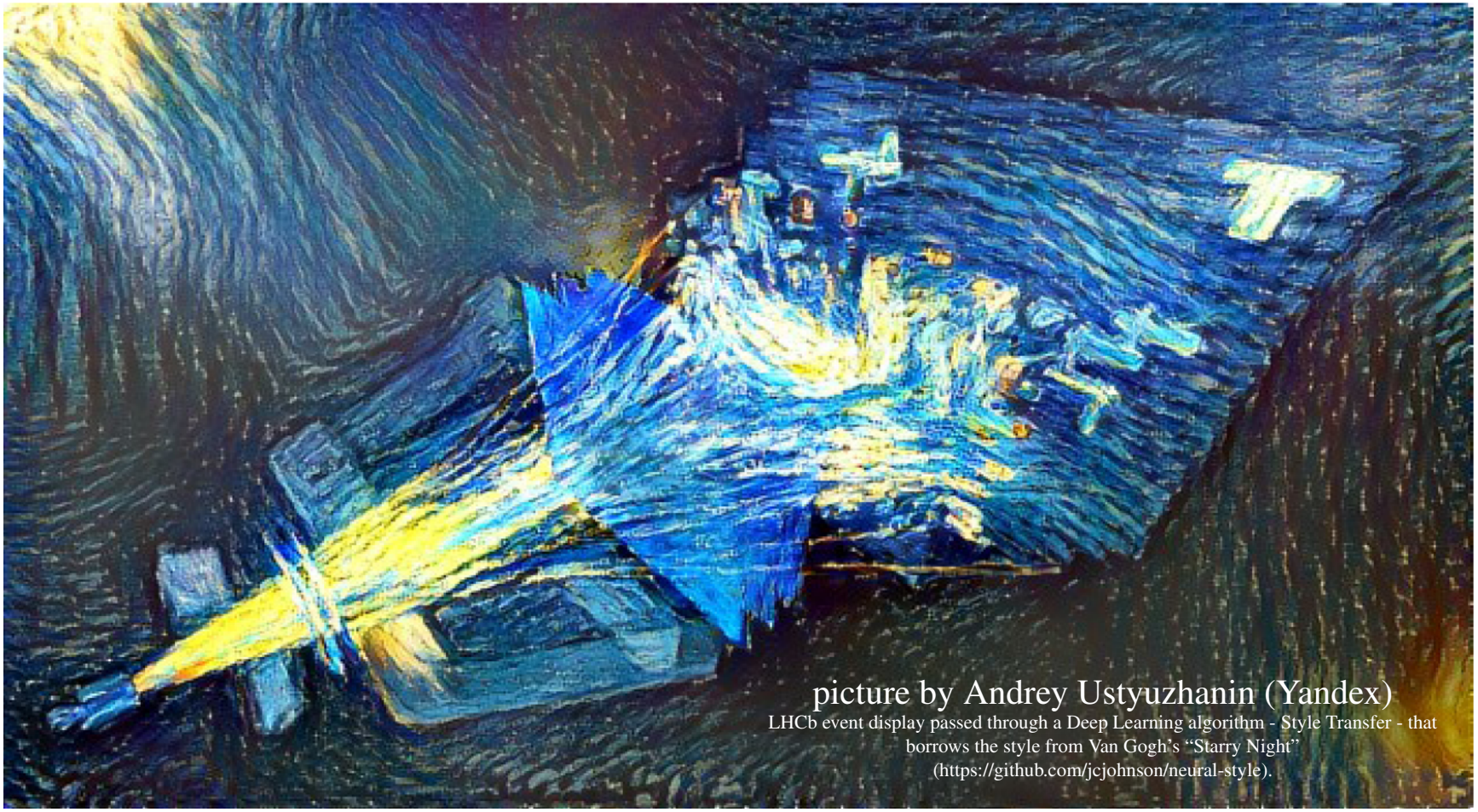
Quarkonia production in pPb and PbPb collisions at LHCb



Giacomo Graziani (INFN Firenze)
on behalf of the LHCb Collaboration

EPS-HEP Conference 2019
July 12, 2019

The LHCb experiment

LHCb is the experiment devoted to heavy flavours at the LHC

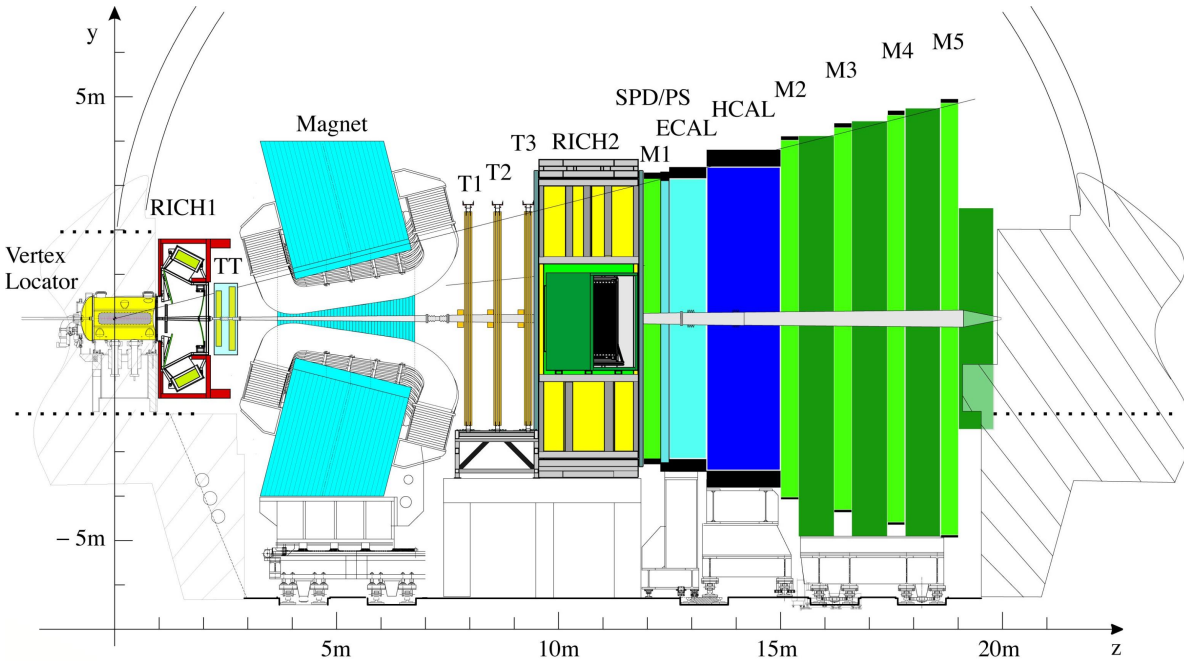
Detector requirements:

Forward geometry to optimize acceptance for $b\bar{b}$ pairs: $2 < \eta < 5$

Tracking : optimal resolution for proper time ($\sim$ 45 fs) and momentum ($<$ 1% for $p < 200$ GeV/c)

Particle ID : excellent capabilities to select exclusive decays

Trigger : high flexibility and bandwidth (1 MHz at hardware level, up to 15 kHz to disk)



JINST 3, (2008) S08005
Int.J.Mod.Phys.A30 (2015) 1530022

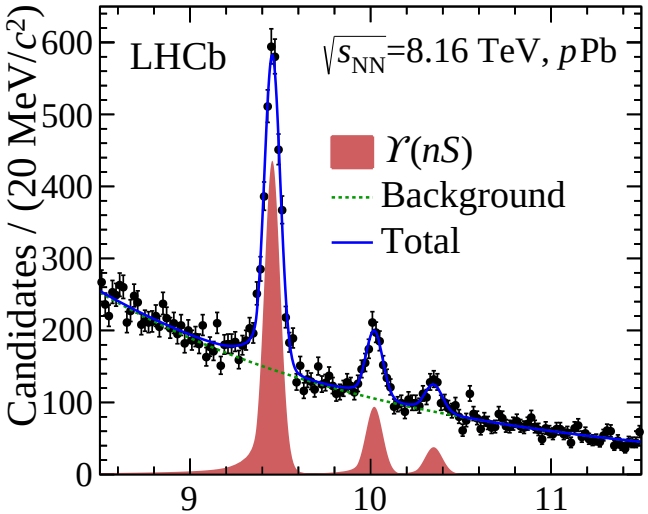
Some unique features are also attractive for heavy ion physics:

- excellent detector performance, notably for heavy flavours
- forward acceptance
- possibility to run in fixed-target mode

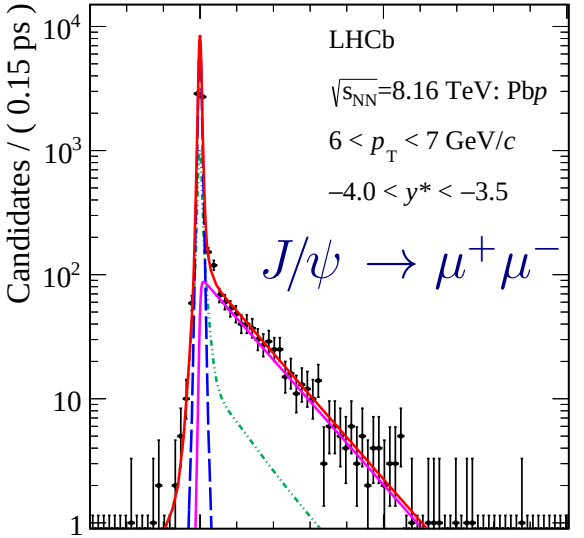
➡ see talk by Felipe Garcia later today

Key feature: detector performance and trigger

- Extreme vertexing performance and excellent PID: ideal to reconstruct heavy flavour states, disentangling charm and beauty components

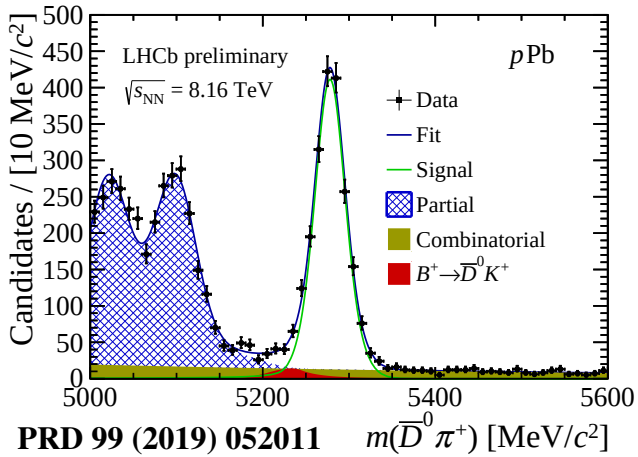


JHEP 11 (2018) 194



PLB 774 (2017) 159

$B^+ \to \overline{D}^0\pi^+$



PRD 99 (2019) 052011

- No rate limitations from trigger and DAQ for heavy ion runs:
  - large samples of Minimum Bias events
  - heavy flavour triggers with low p_T thresholds ($\sim$ 1 GeV)

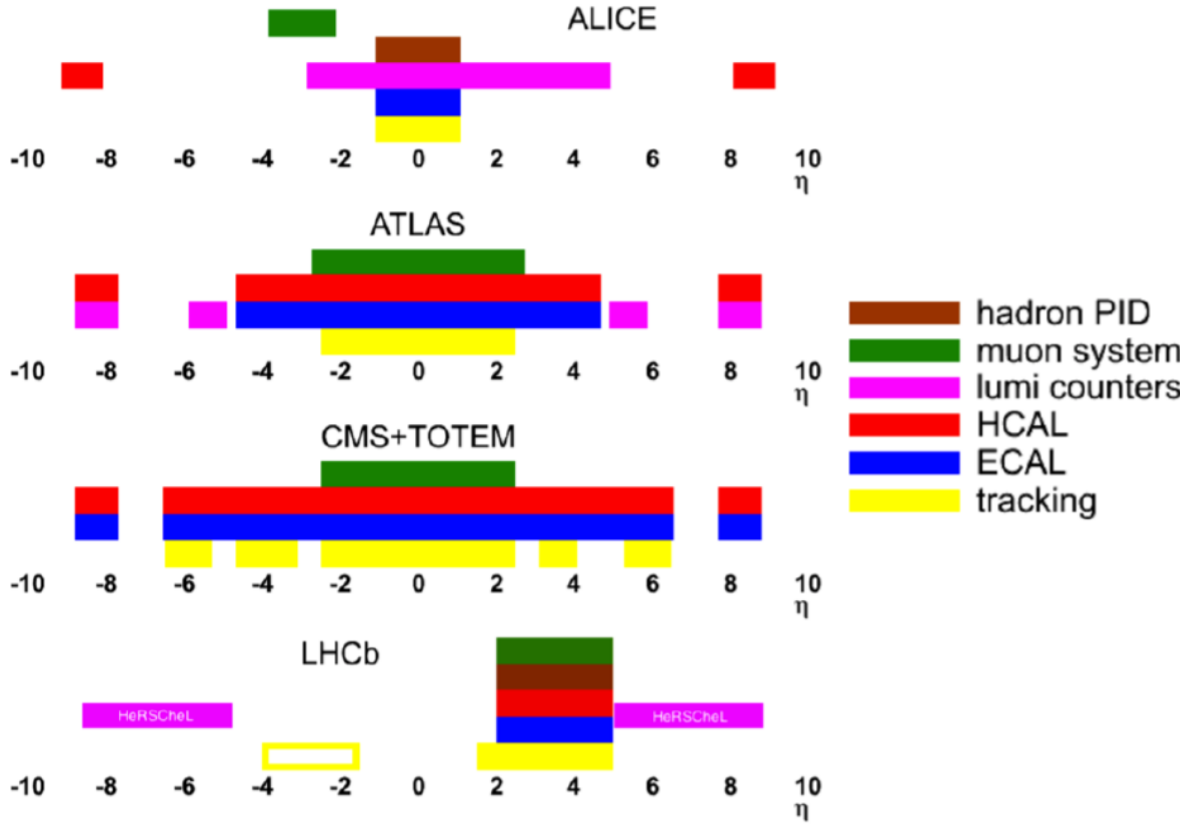
⚠ Tracking saturates for most central PbPb collisions

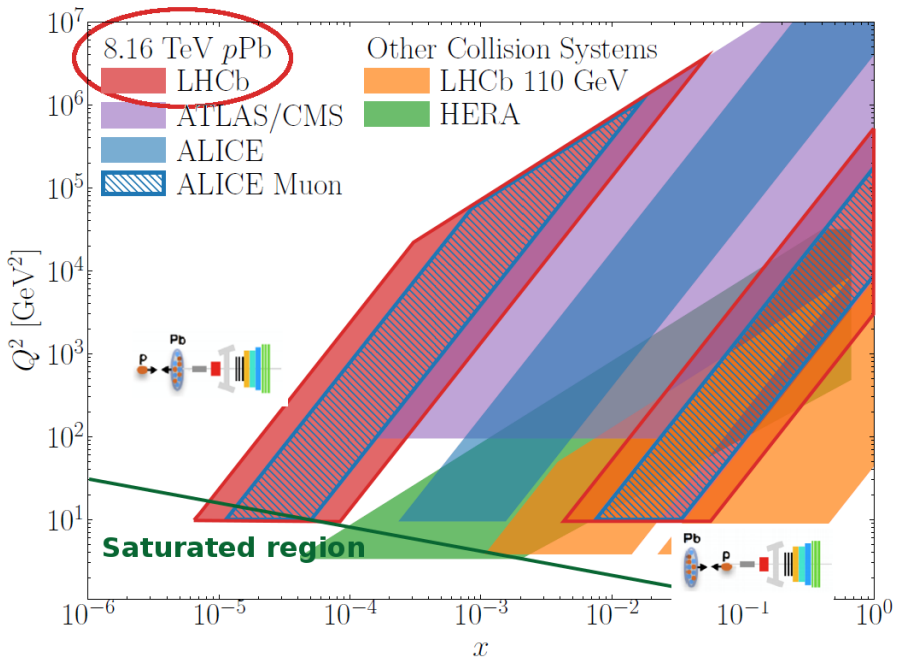
➡ LHCb more suited for small collision systems (pA collisions)

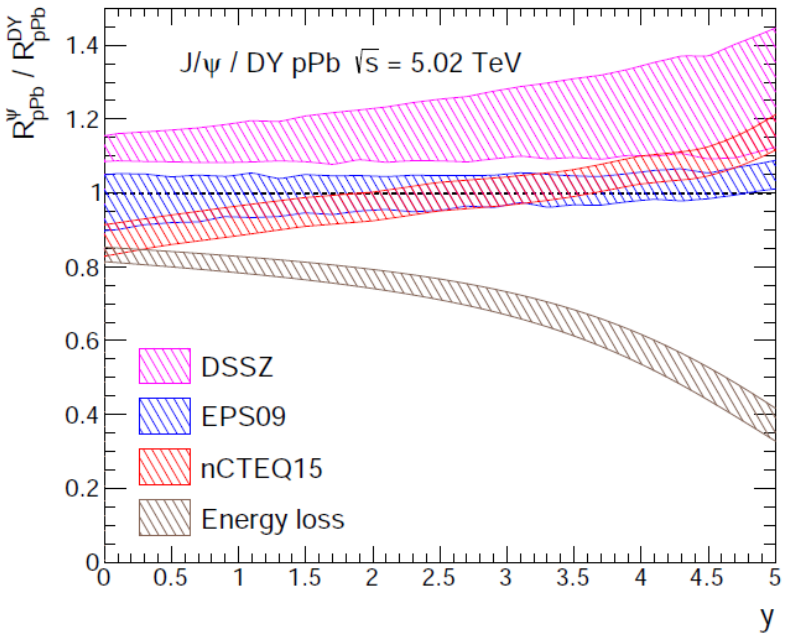
crucial environment to understand cold nuclear matter effects and collectivity in small systems

Key feature: forward acceptance

- Unique forward coverage at LHC





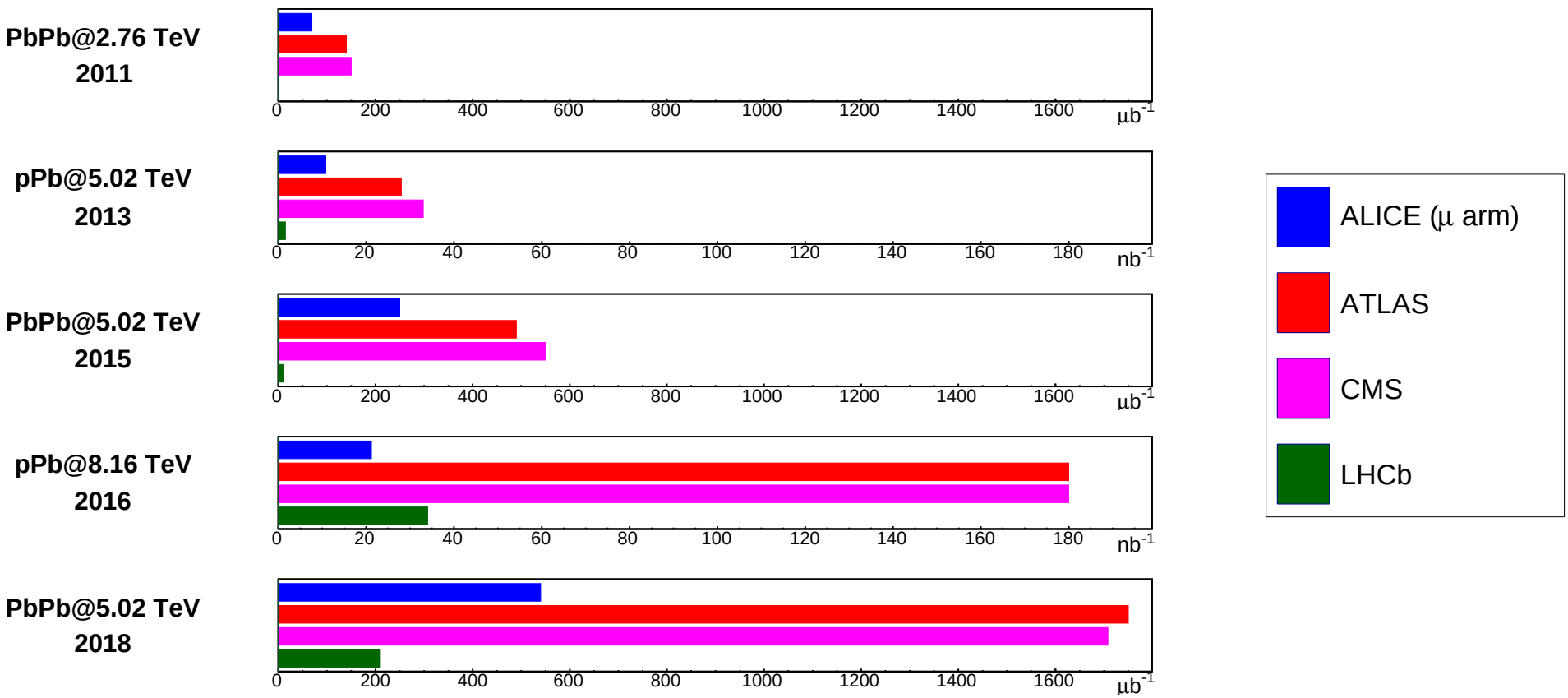


- Sensitivity to small Bjorken-x (down to $\sim 10^{-5}$)
  ➡ gluon saturation
- And to anti-shadowing region

- Rapidity dependence can disentangle nuclear effects (energy loss, comovers, . . .)
- Nicely complementing other LHC experiments

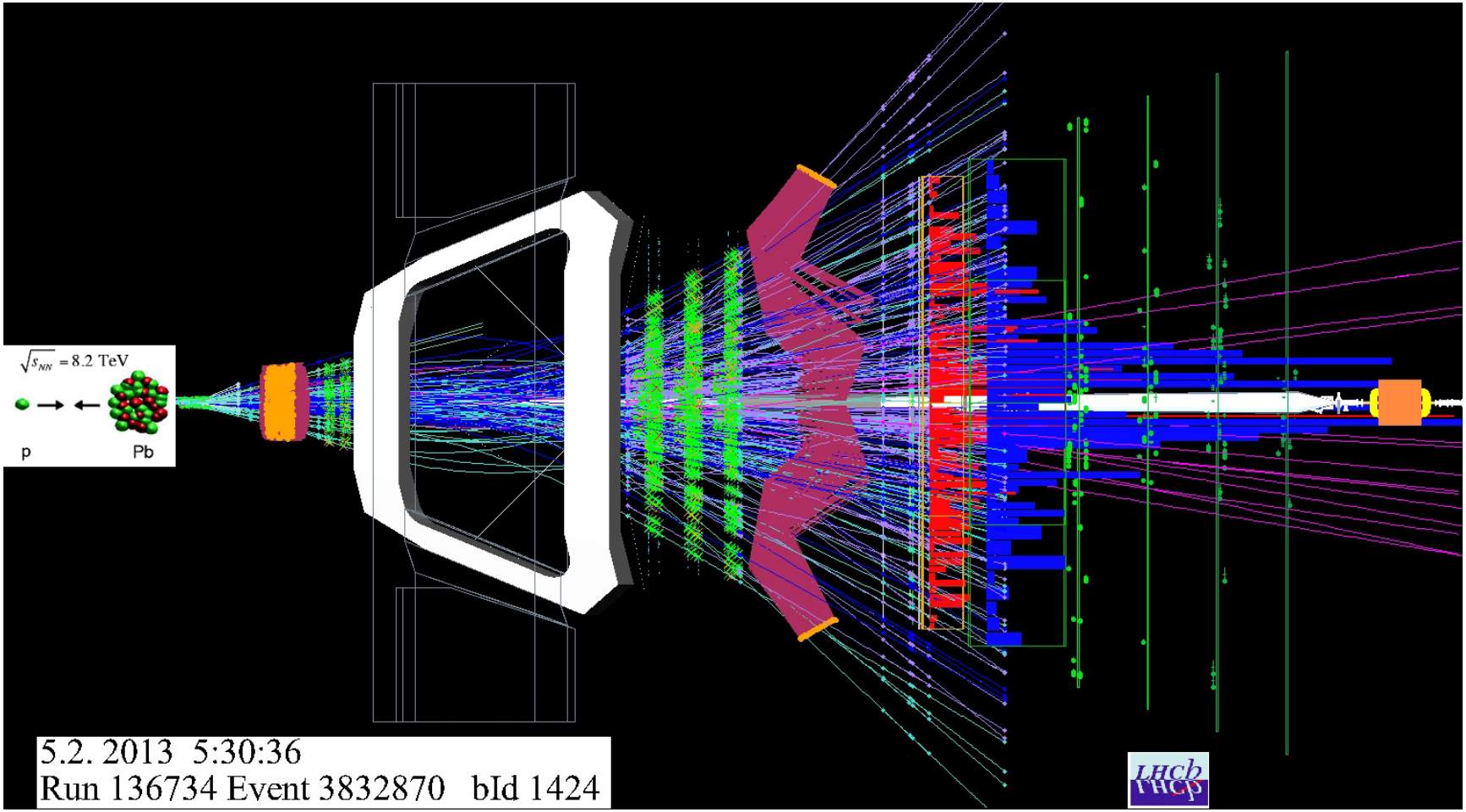
Arleo and Peigné, PRD 95 (2017) 011502

Heavy ion samples

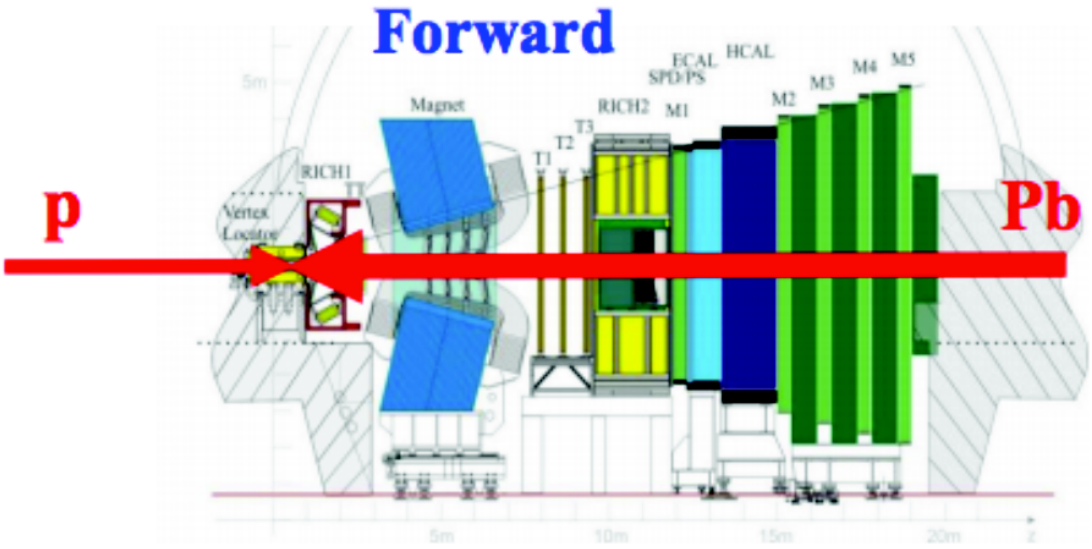


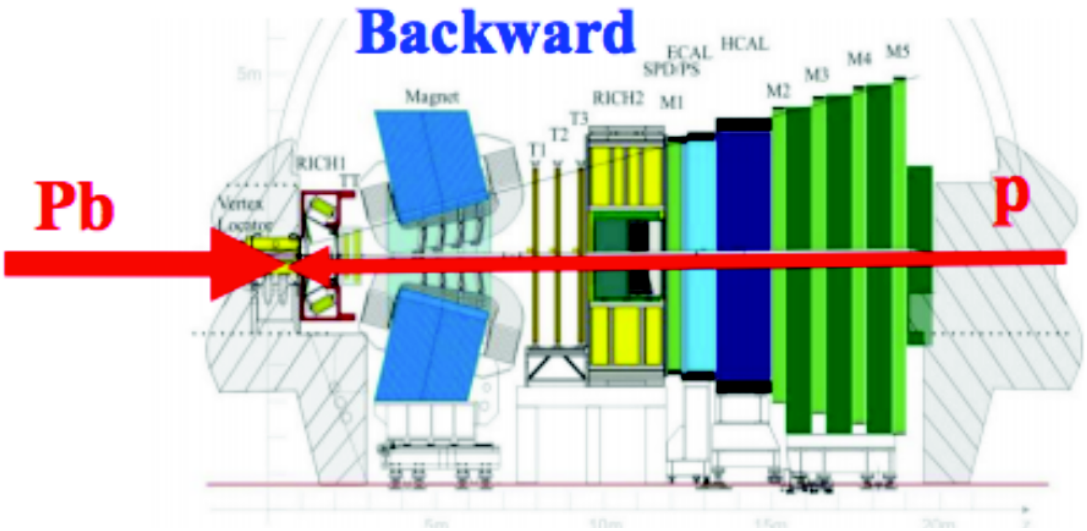
- First successful tests of heavy ion data taking in LHCb in 2013 (pPb) and 2015 (PbPb), with limited luminosity
- Larger samples acquired in 2016 (pPb) and 2018 (PbPb) with larger share of luminosity from LHC

Quarkonia from pPb collisions



pPb Data sets





Ion = $^{208}_{82}$Pb

Forward region:

- $y^* = y_{lab} - 0.465$
- *p*Pb: $1.5 < y < 4.0$

Backward region:

- $y^* = -(y_{lab} + 0.465)$
- Pb*p* : $-5.0 < y < -2.5$

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

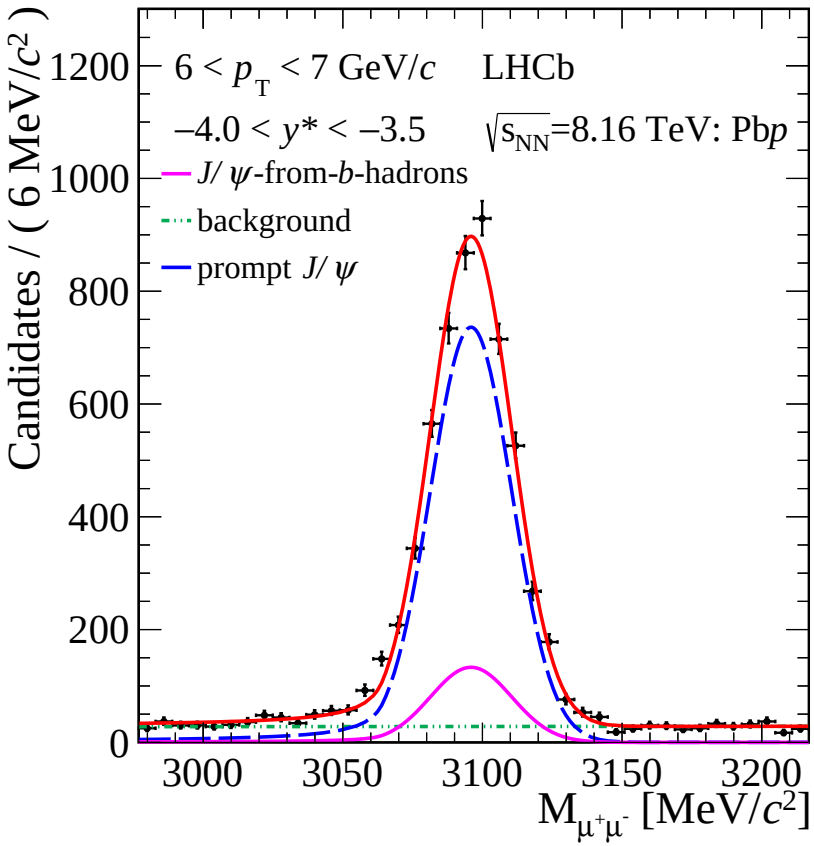
- **1.1 nb^{-1} (Fwd), 0.5 nb^{-1} (Bwd)**

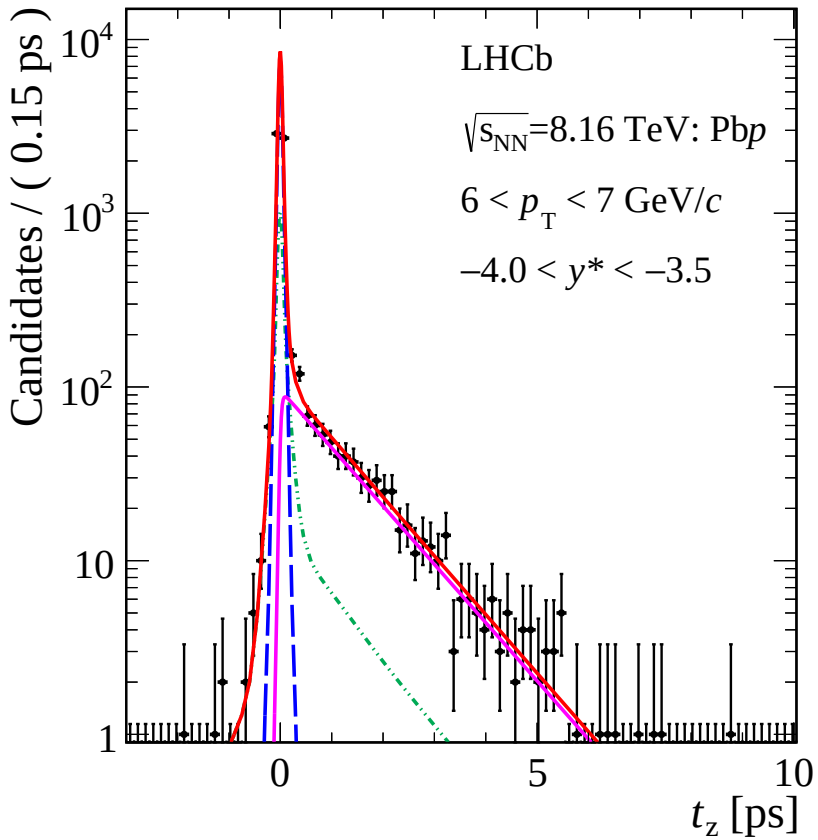
2016 data taking: $\sqrt{s_{NN}} = 8.16$ TeV

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

J/ψ in pPb@8 TeV

PLB 774 (2017) 159





- Very clean sample, down to 0 p_T
- Measurement double differential in p_T and rapidity
- Powerful probe of gluon PDF at low x
- **Separation of prompt and from-b components**, through pseudo-proper time

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

J/ψ in pPb: nuclear modification

PLB 774 (2017) 159

- Strong suppression in forward direction
- Clearly larger for prompt J/ψ

$$R_{pPb} \equiv \frac{1}{A}\frac{\sigma_{pPb}}{\sigma_{pp}}$$

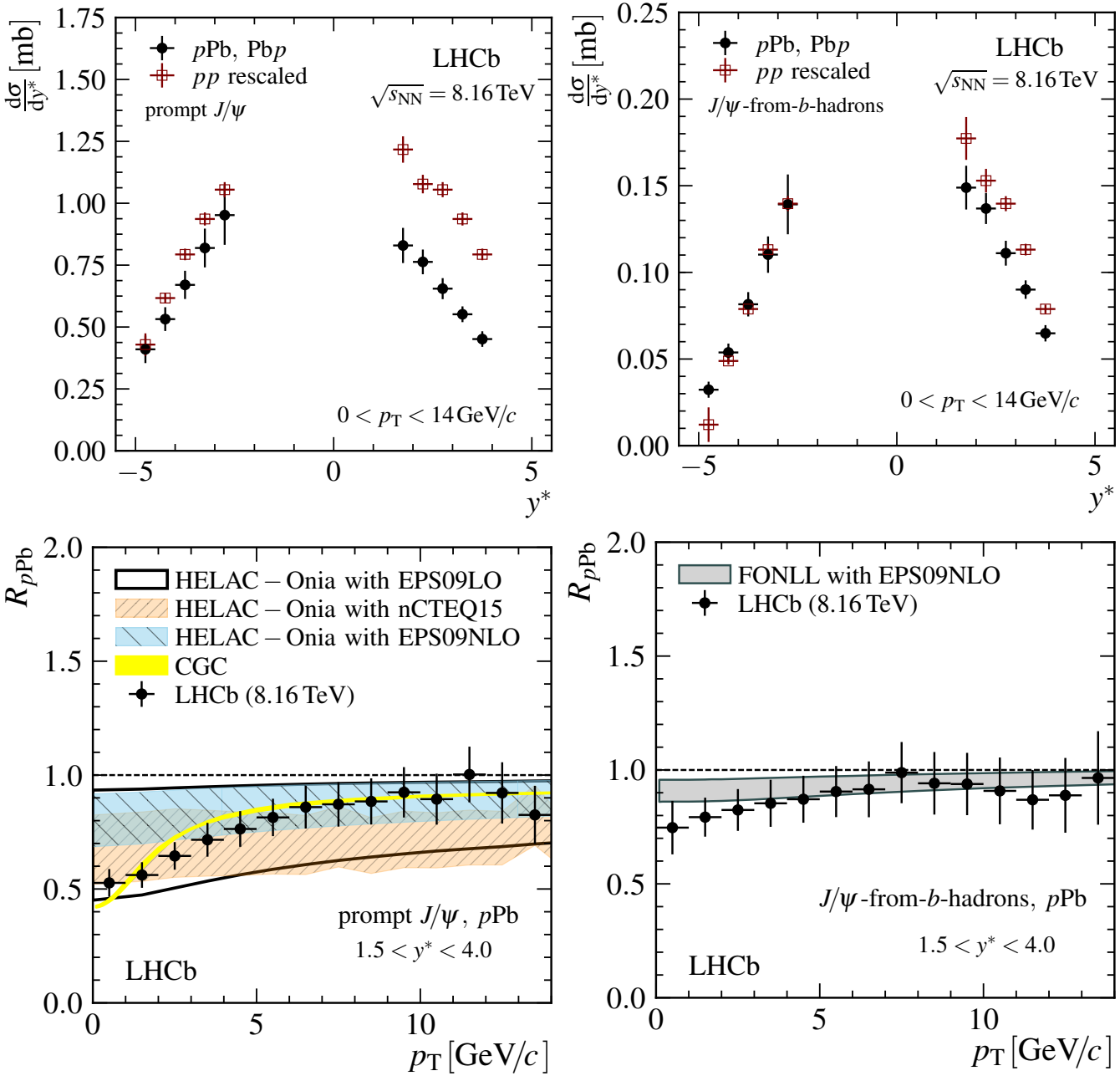
- Compatible with initial-state (nPDF) effects

prompt: HELAC-onia (collinear fact.)
Shao, Comp.Phys.Comm. 198 (2016) 238
from-b: pQCD at FONLL
Cacciari et al, JHEP 05 (1998) 007

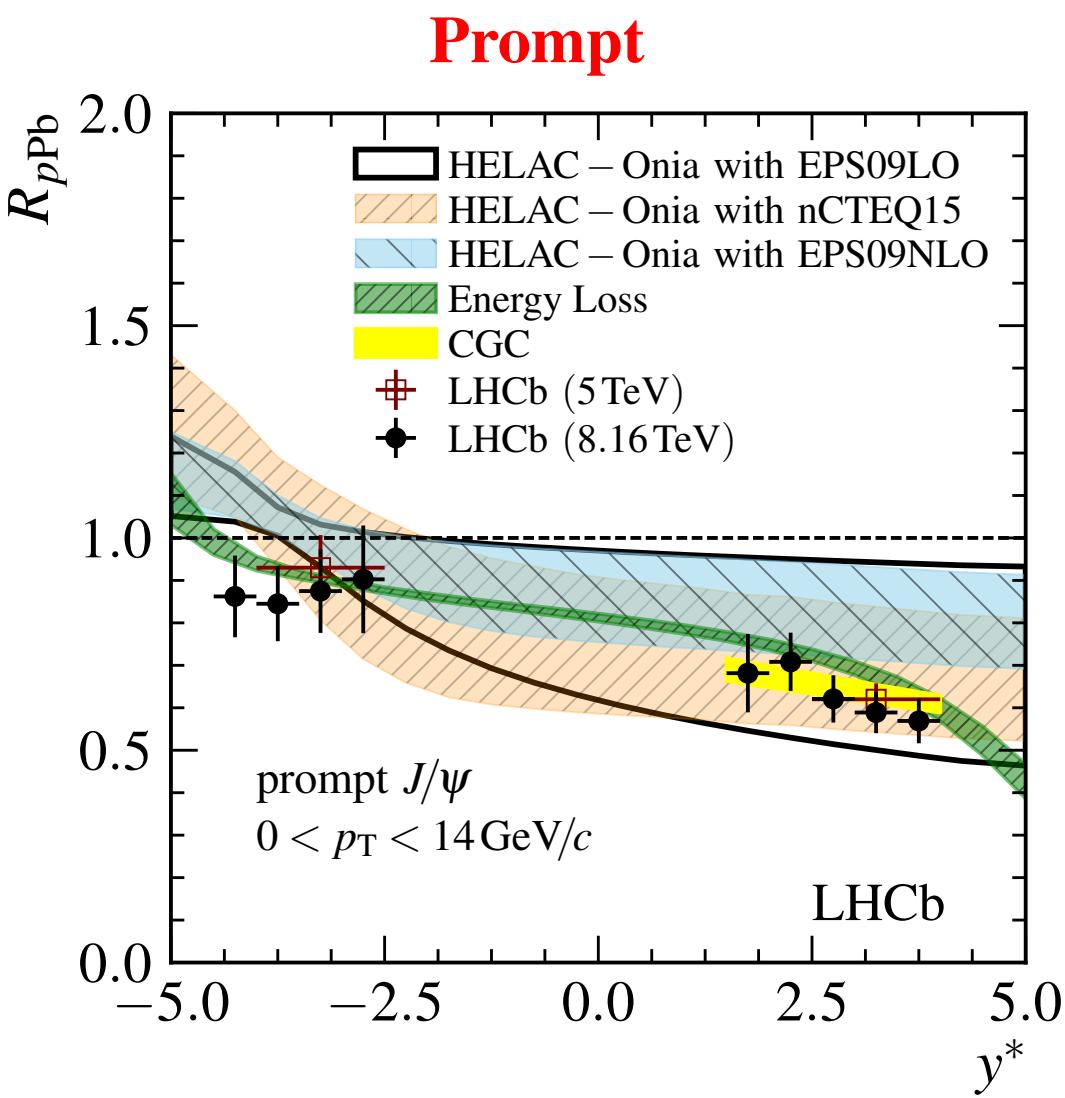
- Good agreement with (latest) CGC-model prediction

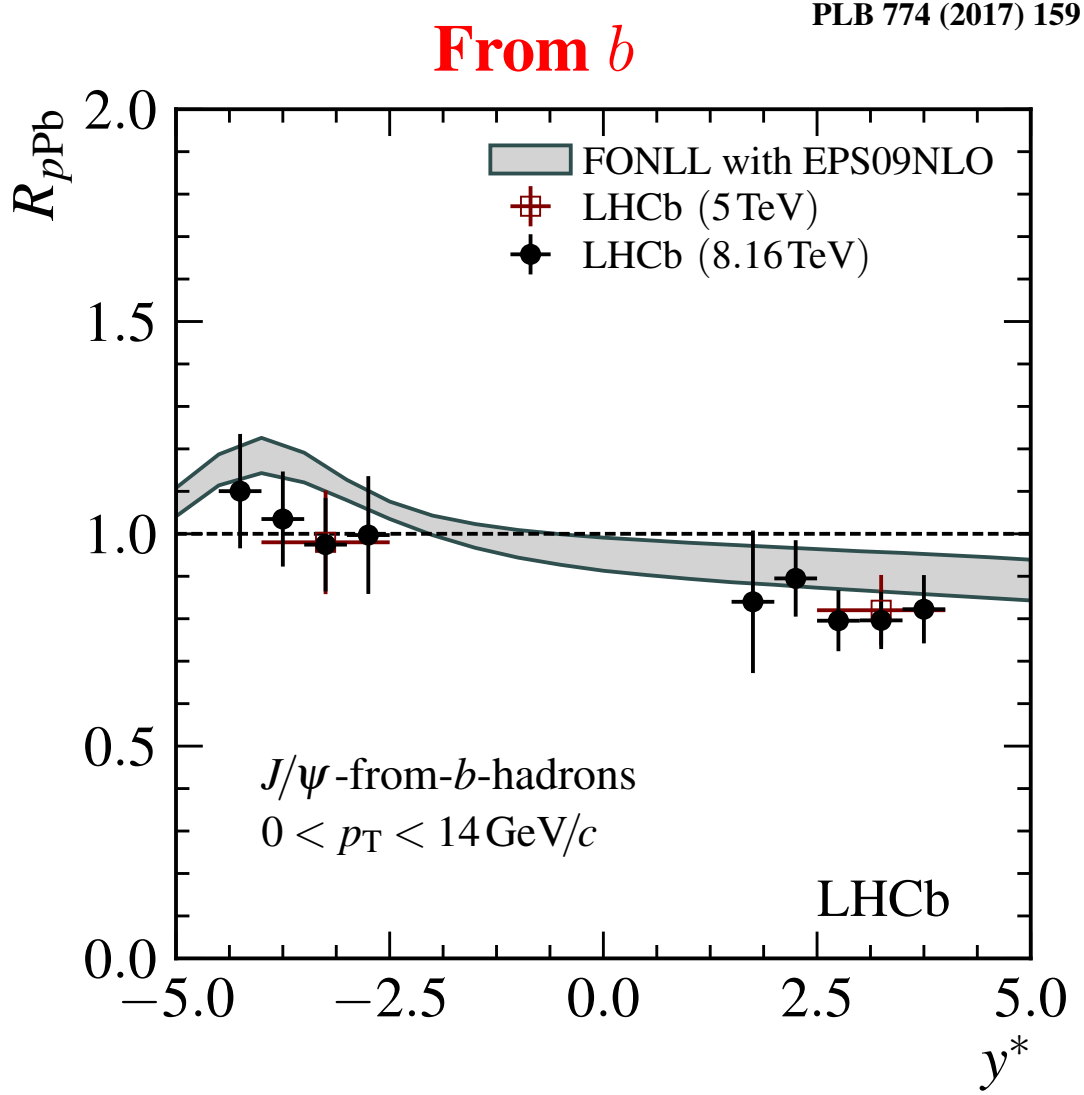
Ducloué et al, PRD94 (2016) 074031

Prompt **From b**



PLB 774 (2017) 159





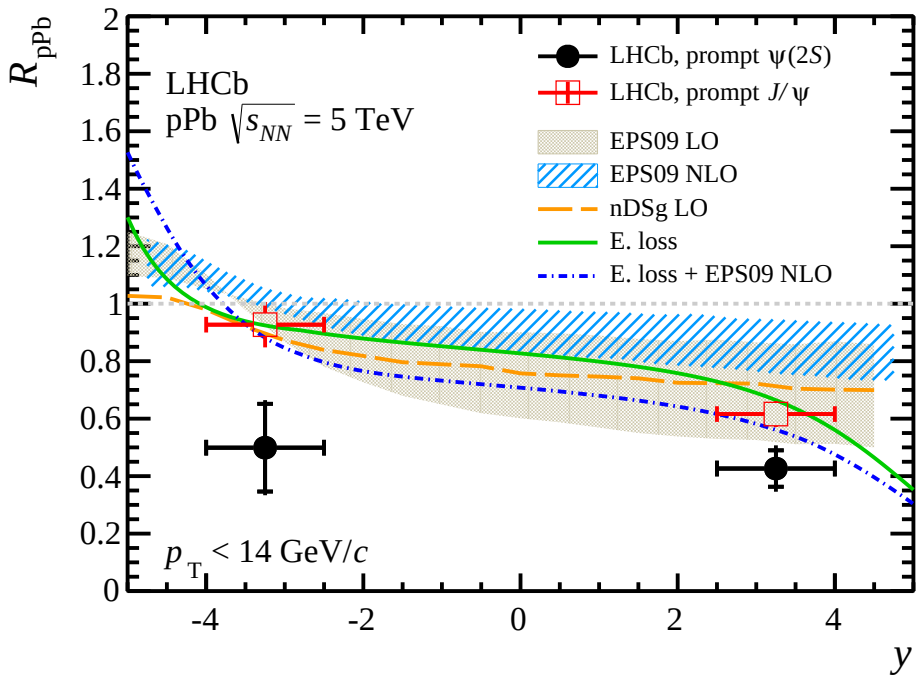
- Rapidity dependence can also be explained by coherent energy loss

Arleo and Peigné, JHEP 03 (2013) 122

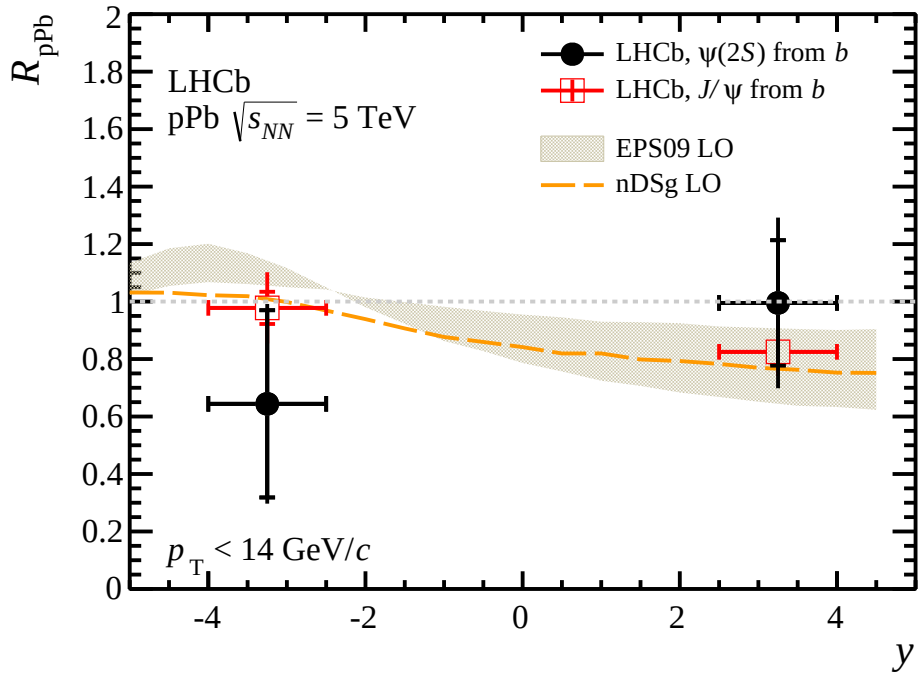
J/ψ and $\psi(2S)$ in pPb

JHEP 03 (2016) 133

Prompt



From b



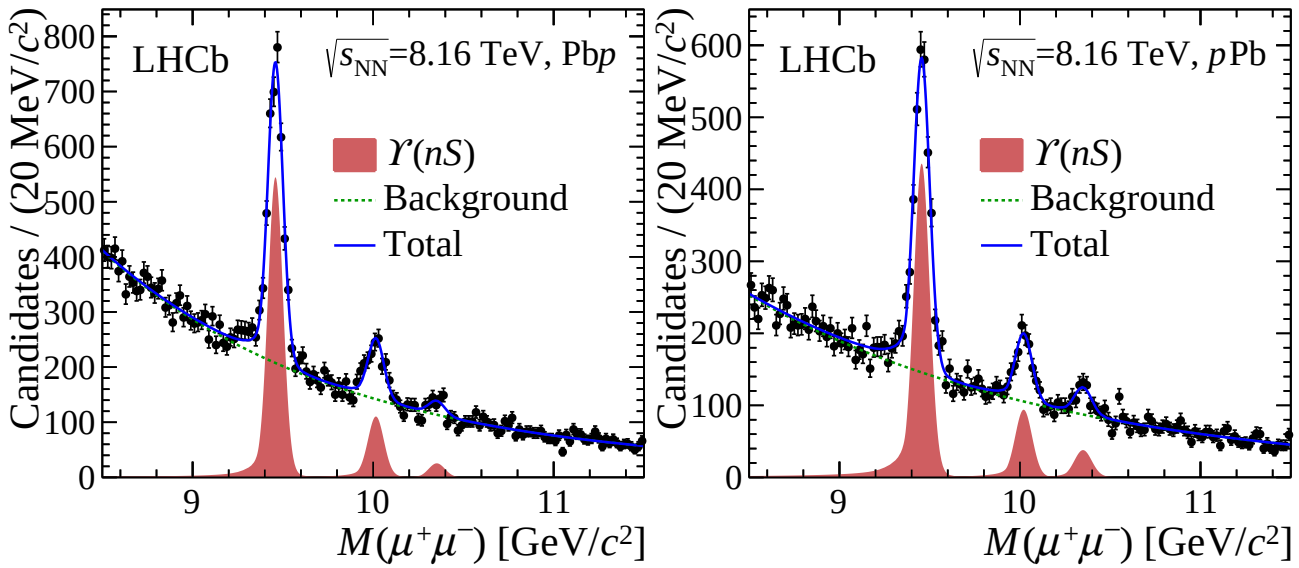
- Results from the smaller sample at 5 TeV show a stronger suppression for $\psi(2S)$, not expected from initial state effects or energy loss
- Confirming similar findings from PHENIX, ALICE, ATLAS/CMS
- Stay tuned for the update from 8 TeV data

Bottomonia in pPb@8 TeV

JHEP 11 (2018) 194

- Clean separation of three nS states

Backward **Forward**

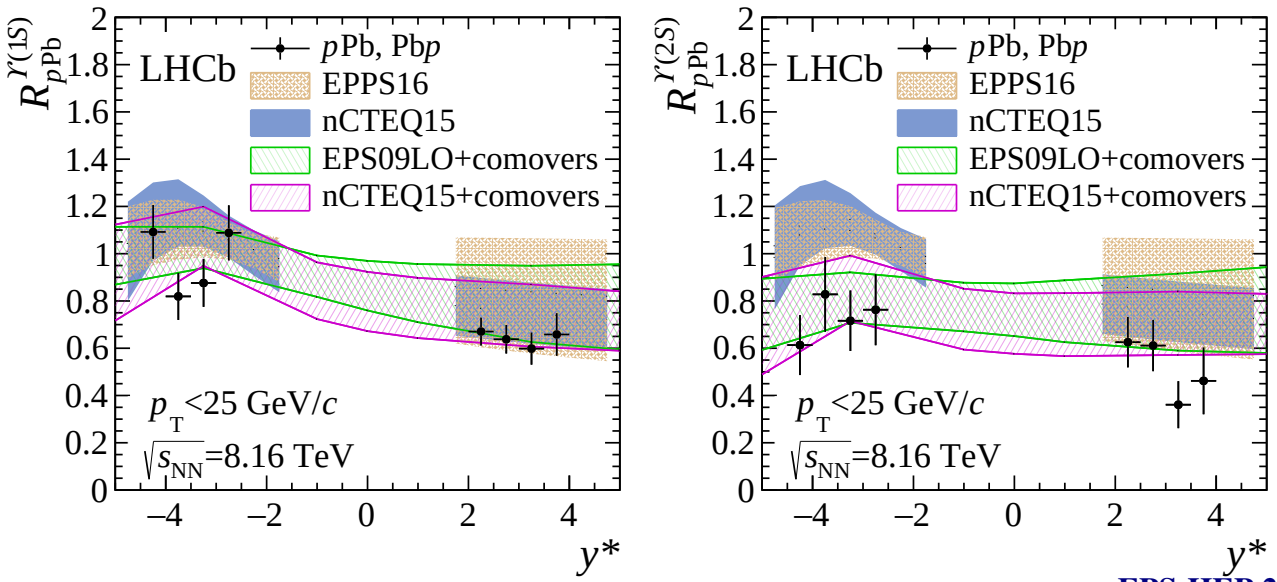


- "Comover" model predicts large final-state effects, larger for excited states and in backward direction

  Ferreiro and Lansberg, JHEP 10 (2018) 094

- Patterns observed in data support this picture

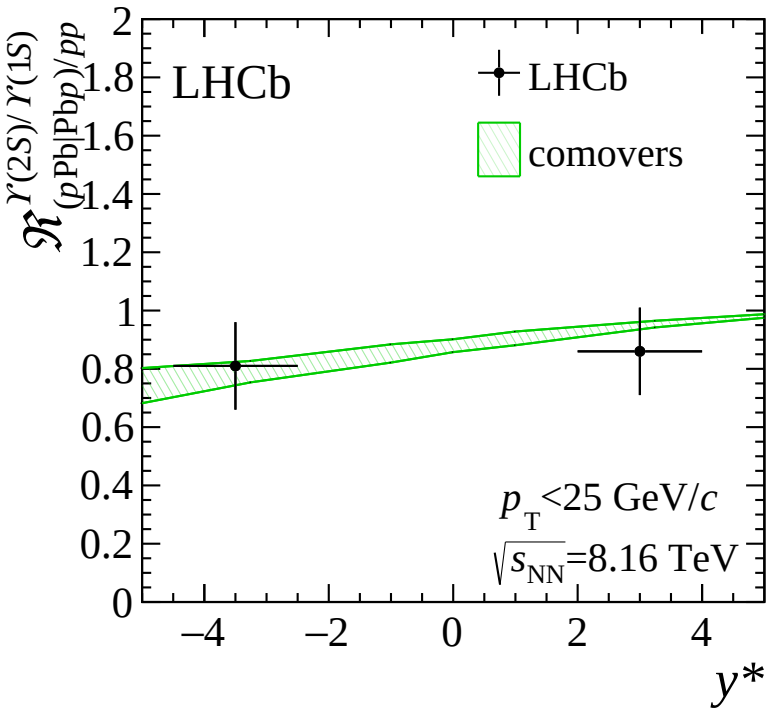
R for $\Upsilon(1S)$ **R for $\Upsilon(2S)$**

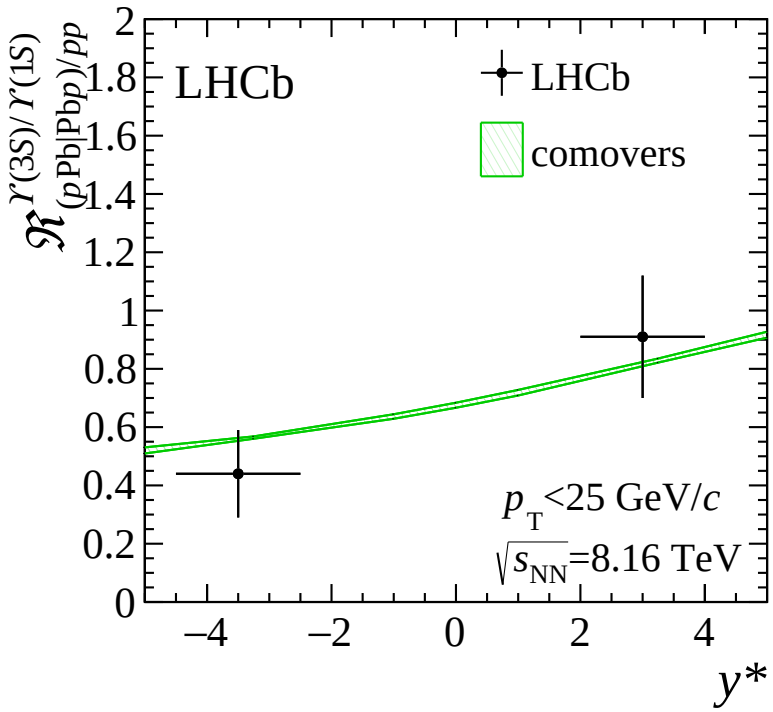


JHEP 11 (2018) 194

R($\Upsilon(2S)$)/R($\Upsilon(1S)$) **R($\Upsilon(3S)$)/R($\Upsilon(1S)$)**

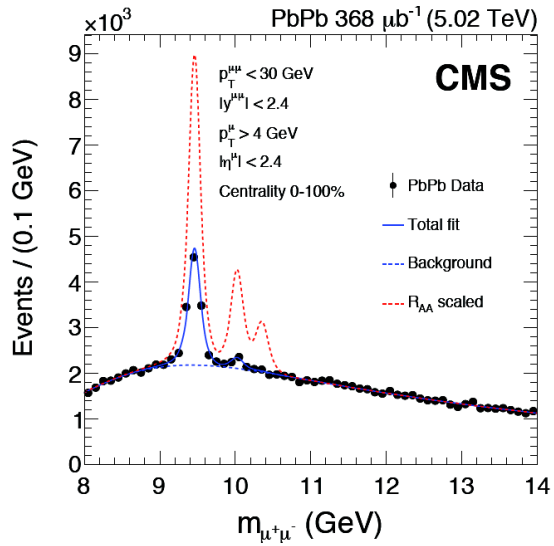
…notably for $\Upsilon(3S)$! Smoking gun for comovers?





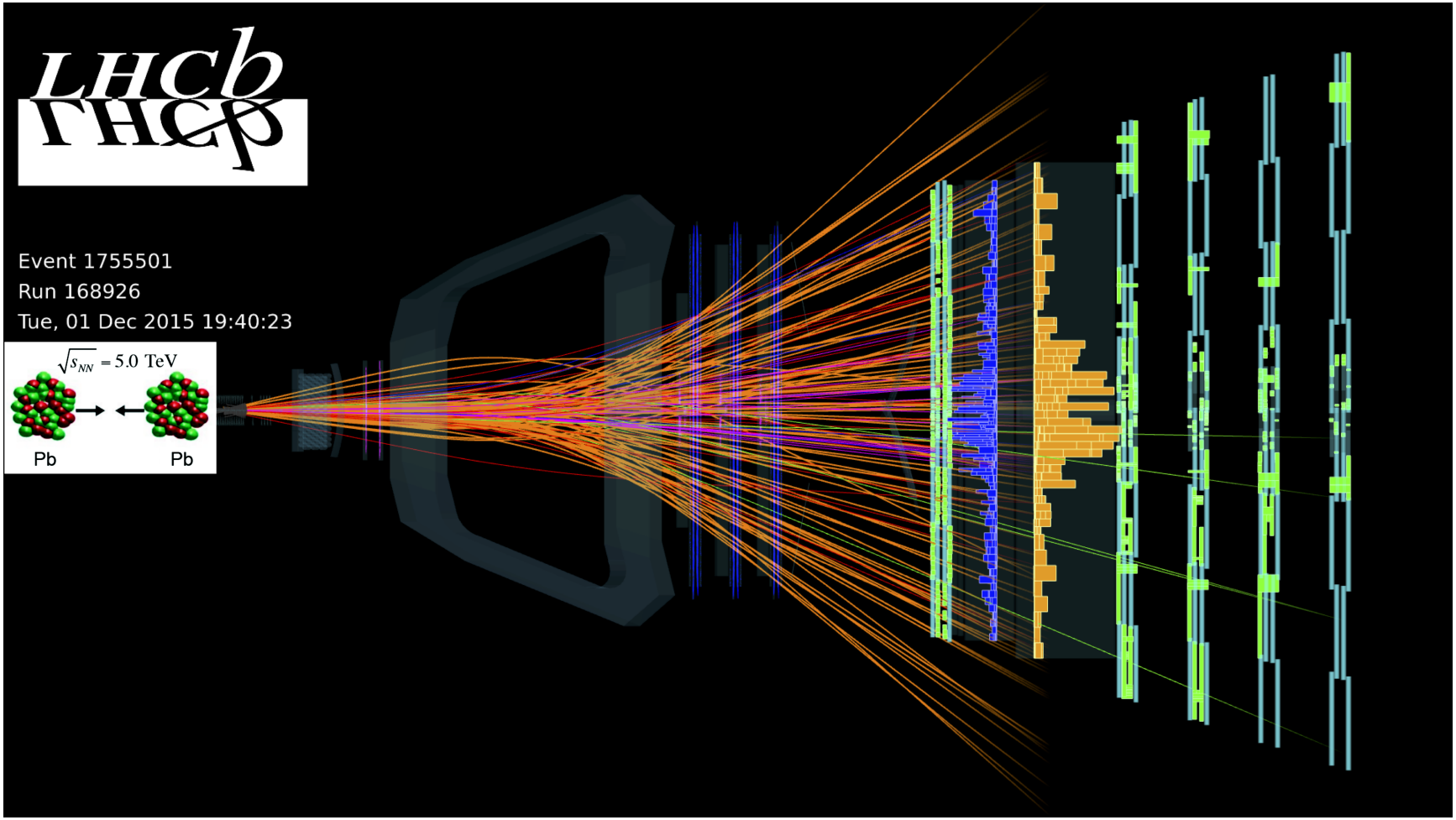
$$\Re^{\Upsilon(2S)/\Upsilon(1S)}_{p\mathrm{Pb}/pp} = 0.86 \pm 0.15,$$
$$\Re^{\Upsilon(3S)/\Upsilon(1S)}_{p\mathrm{Pb}/pp} = 0.81 \pm 0.15,$$
$$\Re^{\Upsilon(2S)/\Upsilon(1S)}_{\mathrm{Pb}p/pp} = 0.91 \pm 0.21,$$
$$\Re^{\Upsilon(3S)/\Upsilon(1S)}_{\mathrm{Pb}p/pp} = 0.44 \pm 0.15.$$

Understanding this effect is crucial to a correct interpretation of QGP-induced sequential quarkonia suppression observed in PbPb



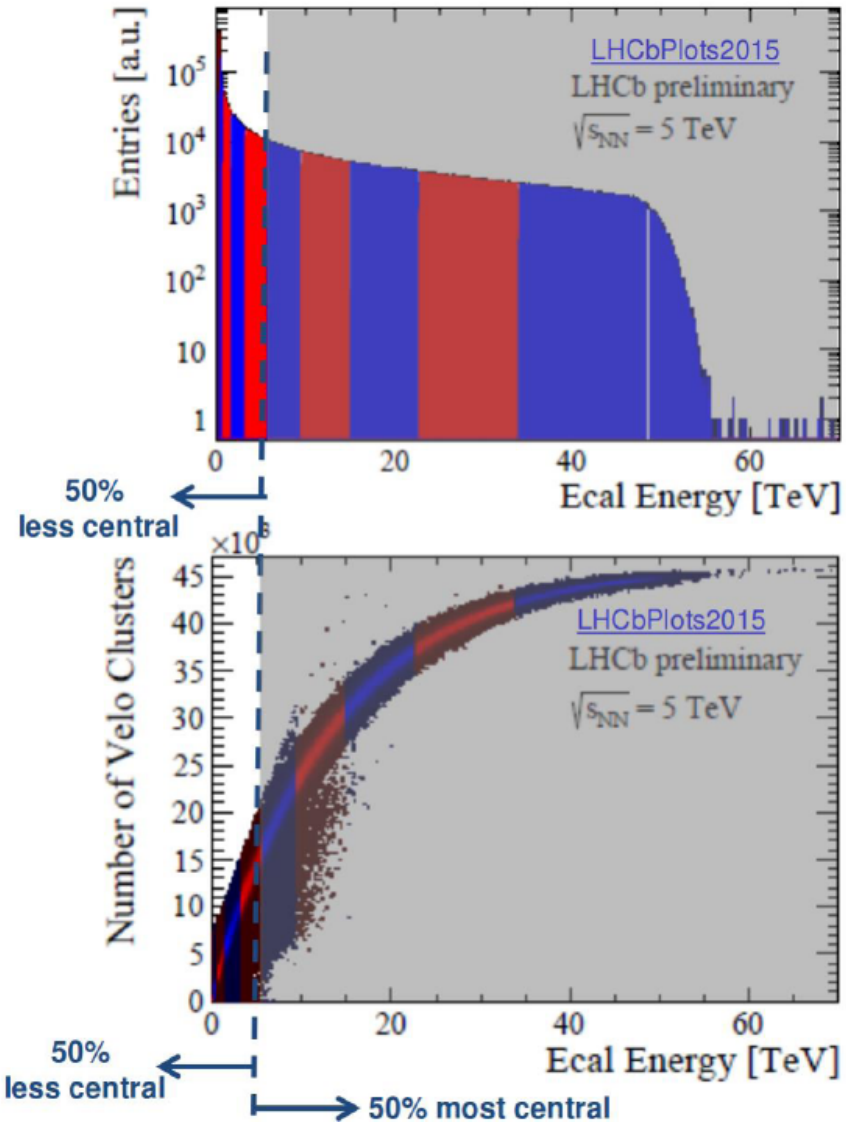
PLB 790 (2019) 270

PbPb collisions

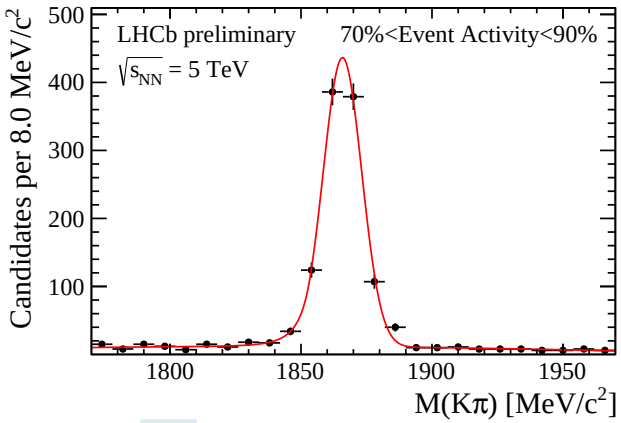


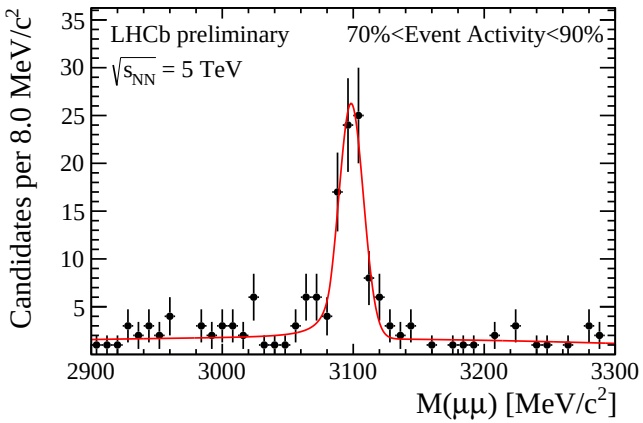
PbPb data and centrality reach

- LHCb entered PbPb data taking in **2015**.
  About 10 μb recorded by LHCb
- Centrality can be determined from the total energy in calorimeters (response is linear even for the most central events)
- Tracking performance is good for centrality above about 50%
- **2018** PbPb run: collected 210 μb



- Still interesting physics from peripheral collisions:
  - J/ψ photoproduction (low-p_T "excess")
  - $J/\psi/D^0$ ratio and Υ states vs centrality
  - flow for D^0

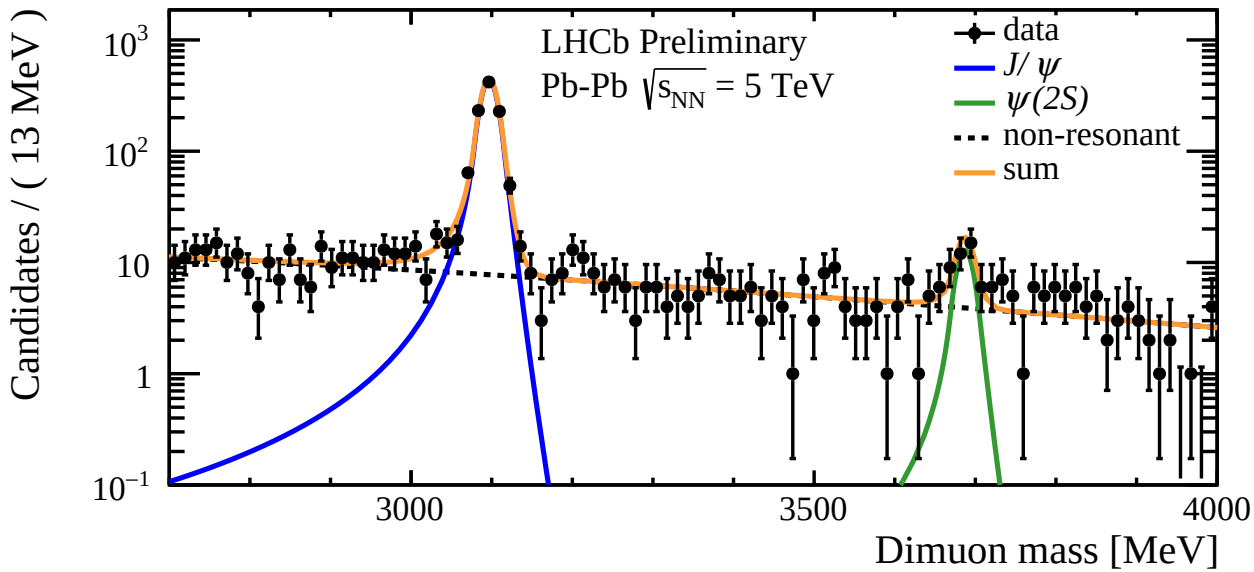


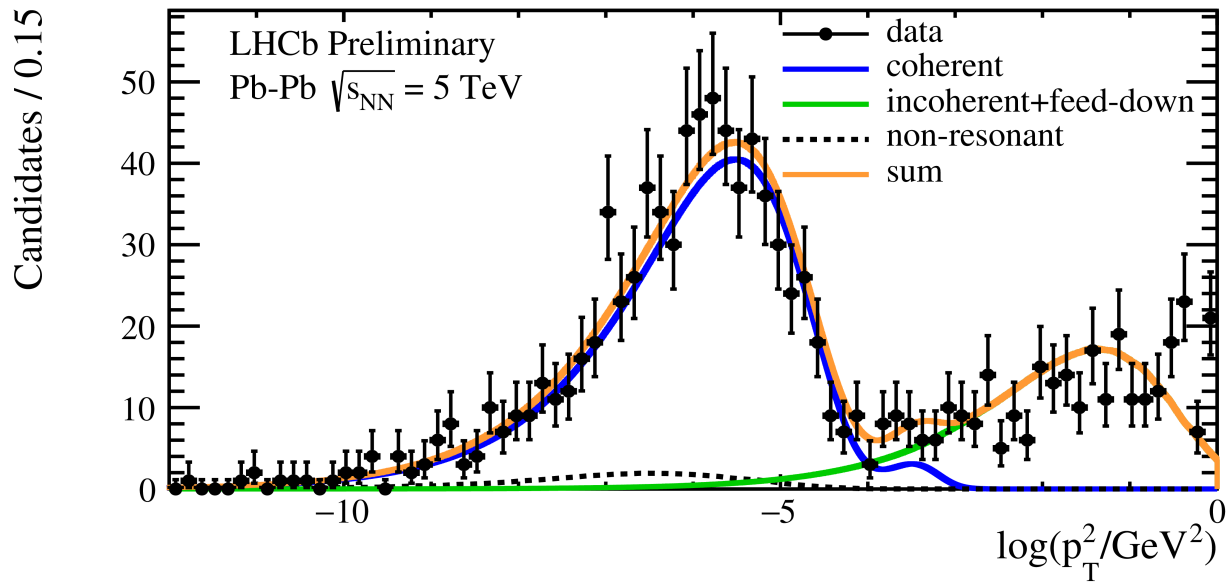


Ultra Peripheral Collisions

LHCb-CONF-2018-003

- Hadron photo-production enhanced by photon flux ($\propto Z^2$) in PbPb
- Sensitive to gluon distribution at x down to 10^{-5}, saturation region
- Signature is an exclusive dimuon with low p_T (< 1 GeV)
- Coherent and incoherent J/ψ photo-production can be distinguished from p_T shape
- Limited statistics, but precision of the measurement demonstrated





(templates from the STARLIGHT generator)

UPC result for coherent cross-section

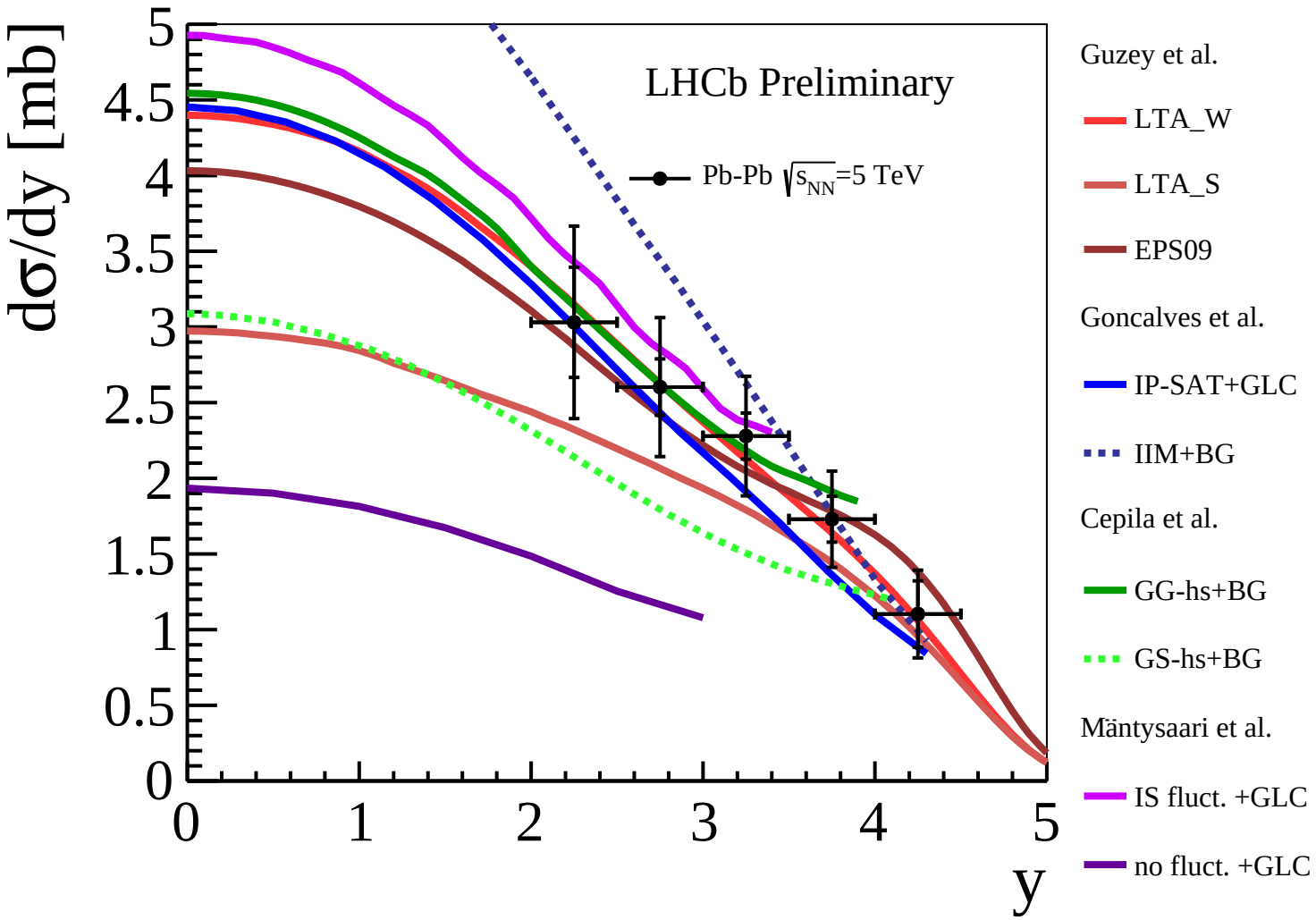
LHCb-CONF-2018-003

Results compared with different phenomenological models

pQCD
Guzey *et al.* PRC 93 055206 (2016),
Colour-Dipole model
Goncalves *et al.* PRD 96 094027 (2017),
Cepila *et al.* PRC 97 024901 (2018),
Mantysaari *et al.*, PLB 772(2017) 832

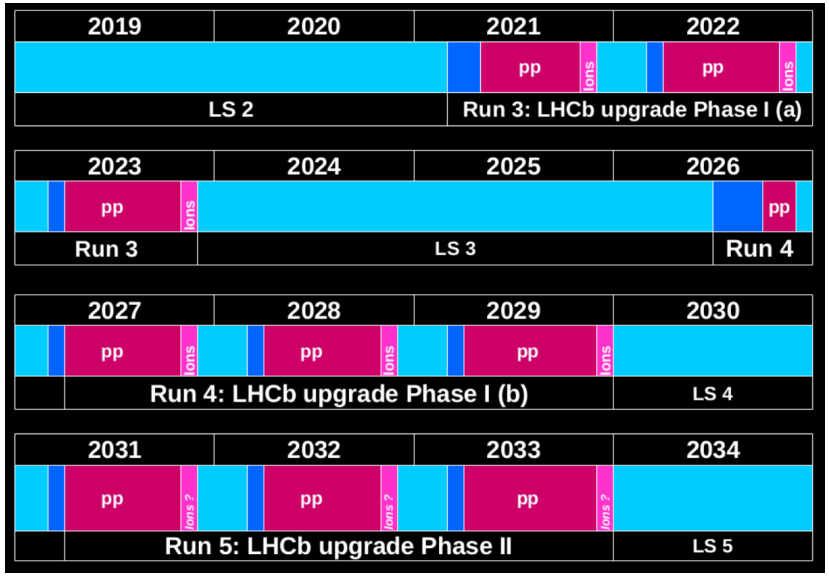
Very good prospects with the larger sample collected in 2018:

- better accuracy (including reduced systematic uncertainty through larger control samples)
- access $\psi(2S)$ and possibly other quarkonia states



Conclusions

- Quarkonium production in heavy ion collisions can be studied in unexpected place: LHCb has unique kinematic coverage and excellent reconstruction performance
- More to come with data from LHC Run 2: higher quarkonia states, Drell Yan production, flow studies ...



And substantial development of the program expected from LHC Run 3 and 4:

- Plans for larger integrated luminosities, at least factor 10, for pPb and PbPb in LHCb
- Upgraded detector, including vertex locator with finer granularity, being installed for Run 3 (2021)
- Phase II Upgrade in design phase LHCB-TDR-019 (2018): aim at 50 x Run 2 luminosity in pp
  ➡ dream detector for heavy-ion physics