

Results on heavy ion and fixed target collisions at LHCb

Émilie Maurice on behalf of the LHCb collaboration

Hard Probes 2018, Aix-les-Bains, France

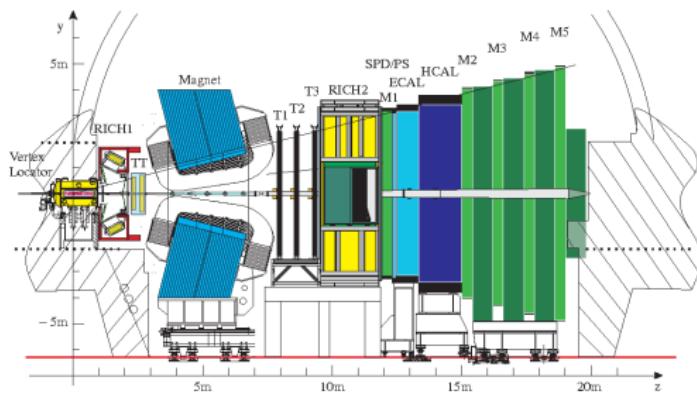


October 1st, 2018



The LHCb experiment [JINST 3 (2008) S08005]

LHCb was designed for heavy flavor physics but serves now as a general purpose detector



Fully instrumented in $2 < y < 5$

Excellent performance:

[Int. J. Mod. Phys. A 30 (2015) 1530022]

- ✓ Vertex, IP and decay time resolution
- ✓ Momentum resolution
- ✓ Particle identification
 $\epsilon_{K \rightarrow K} \approx 95\%$, $\epsilon_{\pi \rightarrow K} \approx 5\%$
 $\epsilon_{\mu \rightarrow \mu} \approx 97\%$, $\epsilon_{\pi \rightarrow \mu} \approx 1\text{--}3\%$
- ✓ Flexible trigger down to low- p_T

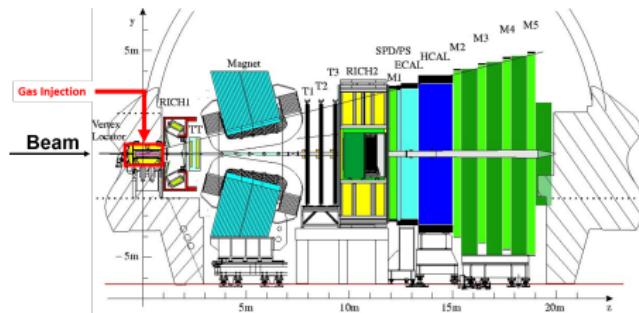
Unique forward kinematics in $p\text{Pb}$, PbPb collisions:

- ▶ 1.1 nb^{-1} $p\text{Pb}$, 0.5 nb^{-1} $\text{Pb}p$ at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ (2013)
- ▶ 13.6 nb^{-1} $p\text{Pb}$, 20.8 nb^{-1} $\text{Pb}p$ at $\sqrt{s_{NN}} = 8.16 \text{ TeV}$ (2016)
- ▶ Ion-Ion runs: $10 \mu\text{b}^{-1}$ PbPb at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ (2015) and $0.4 \mu\text{b}^{-1}$ XeXe
→ 2018 PbPb run aiming for a factor 10 more

The LHCb fixed-target experiment [JINST 9 (2014) P12005]

Unique fixed-target configuration at the LHC

Inject noble gases (He, Ne, Ar, ...) inside the Vertex Locator $\sim 10^{-7}$ mbar



Installed for beam-gas imaging

Parasitic to collider data taking

Fully benefit from LHCb excellent performance

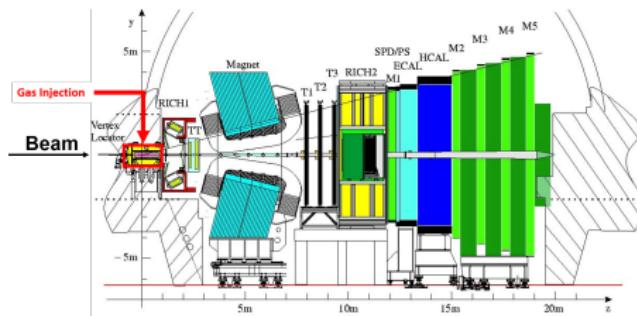
→ New physics opportunities
with p -nucleus and Pb-nucleus collisions

Heavy-ion and cosmic ray related physics

The LHCb fixed-target experiment [JINST 9 (2014) P12005]

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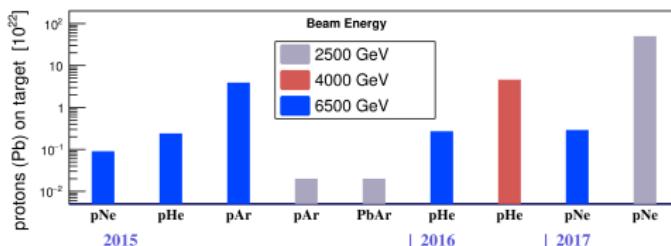
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Fixed-target kinematic region

$$\sqrt{s_{NN}} \in [69, 115] \text{ GeV}$$

backward rapidity region

LHCb heavy ions recent results

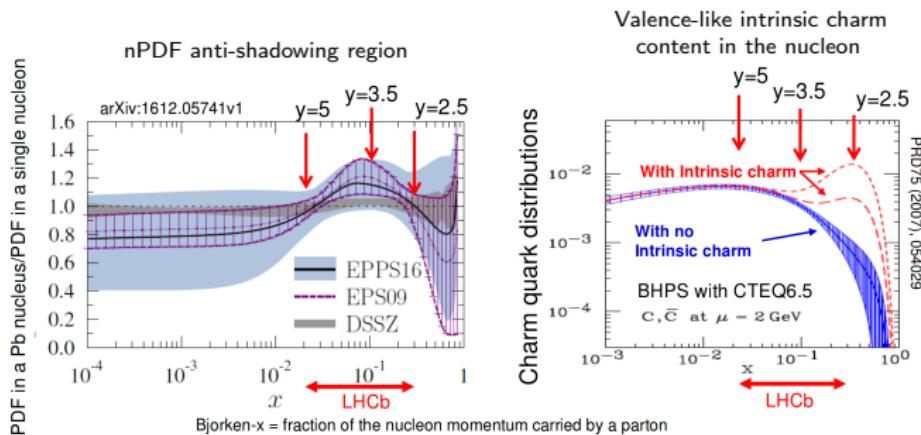
- ▶ **Charm production in fixed-target configuration**
LHCb-PAPER-2018-023
→ see Frédéric Fleuret's talk, Thursday at 9:40
- ▶ **Open charm and beauty production in $p\text{Pb}$ collisions**
 D^0 LHCb-PAPER-2017-015, JHEP10(2017)090
 Λ_c^+ LHCb-PAPER-2018-021, arXiv:1809.01404
 B^+, B^0, Λ_b LHCb-CONF-2018-004
→ see Yanxi Zhang's talk, Thursday at 9:00
- ▶ **Quarkonia production in $p\text{Pb}$ collisions**
 J/ψ LHCb-PAPER-2017-014, PLB774(2017)159
 $\Upsilon(nS)$ LHCb-PAPER-2018-035 in preparation
→ see Giulia Manca's talk, Wednesday at 10:00
- ▶ **Exclusive photonuclear J/ψ production in ultra-peripheral PbPb collisions**
LHCb-CONF-2018-003
→ see Samuel Belin's talk, Tuesday at 9:00

Charm production in fixed-target configuration

p -nucleus collisions with LHCb fixed-target:

- ▶ Baseline for future Pb-nucleus fixed-target studies for quark gluon plasma (QGP)
- ▶ Study of nuclear PDF (nPDF), nuclear absorption, ...

LHCb fixed-target collisions: large rapidity coverage at large Bjorken-x in the target

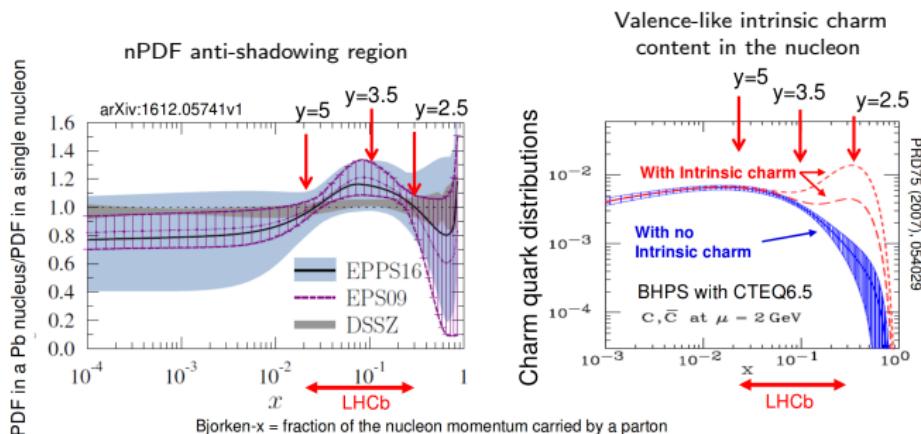


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Measurement of J/ψ and D^0 production using 2 data samples

System	$\sqrt{s_{NN}}$	Protons on target	Target A	\mathcal{L}_{int}
$p\text{Ar}$	110.4 GeV	4.10^{22}	40	not available
$p\text{He}$	86.6 GeV	5.10^{22}	4	$7.58 \pm 0.47 \text{ nb}^{-1}$

Charm production in fixed-target configuration

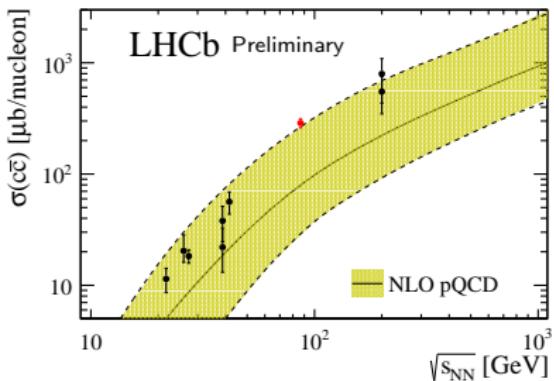
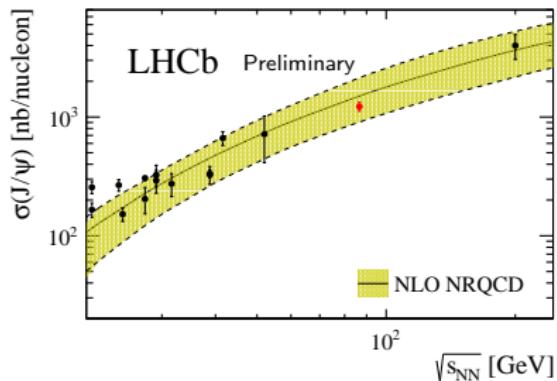
LHCb-PAPER-2018-023, in preparation

$$\sigma_{J/\psi} = 1225.6 \pm 62.0(\text{stat}) \pm 81.6(\text{syst}) \text{ nb/nucleon}$$

$$\sigma_{D^0} = 156.0 \pm 4.6(\text{stat}) \pm 12.3(\text{syst}) \mu\text{b/nucleon}$$

$$\text{with fraction } (c \rightarrow D^0) = 0.542 \pm 0.024$$

$$\sigma_{c\bar{c}} = 287.8 \pm 8.5(\text{stat}) \pm 25.7(\text{syst}) \mu\text{b/nucleon}$$

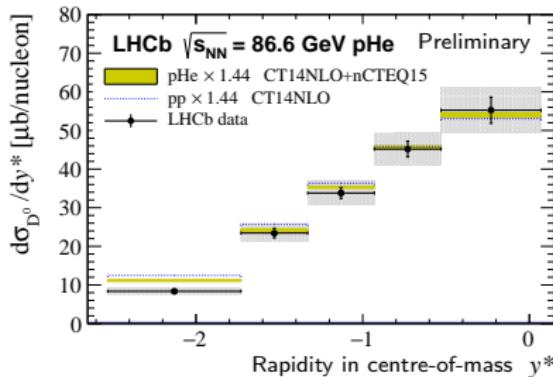
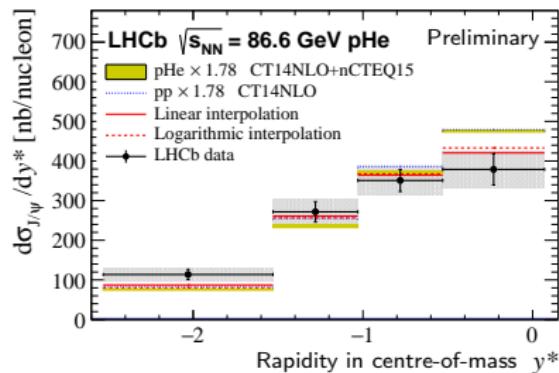


Cross-section measurements in agreement with previous experimental measurements and with theoretical predictions

→ see Frédéric Fleuret's talk

Charm production in fixed-target configuration

LHCb-PAPER-2018-023, in preparation



Cross-sections are compared with

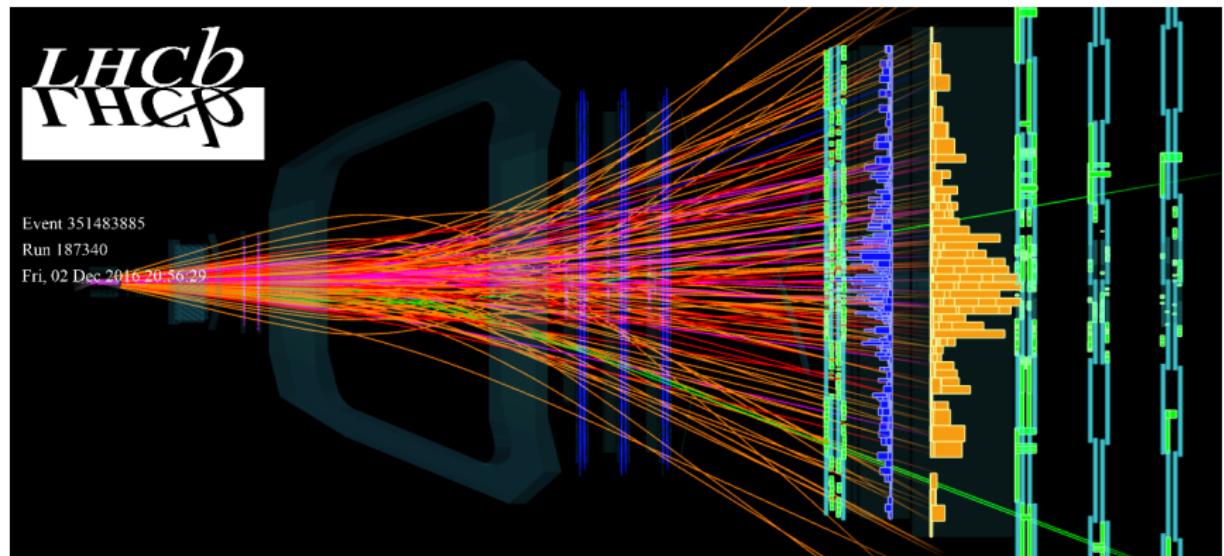
- ▶ Phenomenological parametrisations (JHEP 1303 (2013) 122) for J/ψ
→ Shape in agreement
- ▶ HELAC-onia model EPJC 77 (2017) designed and tuned for collider data
→ Reasonable agreement

No indication of visible valence-like intrinsic charm in rapidity distribution

Starting point for more detailed proton-Neon and future Lead-Neon collisions

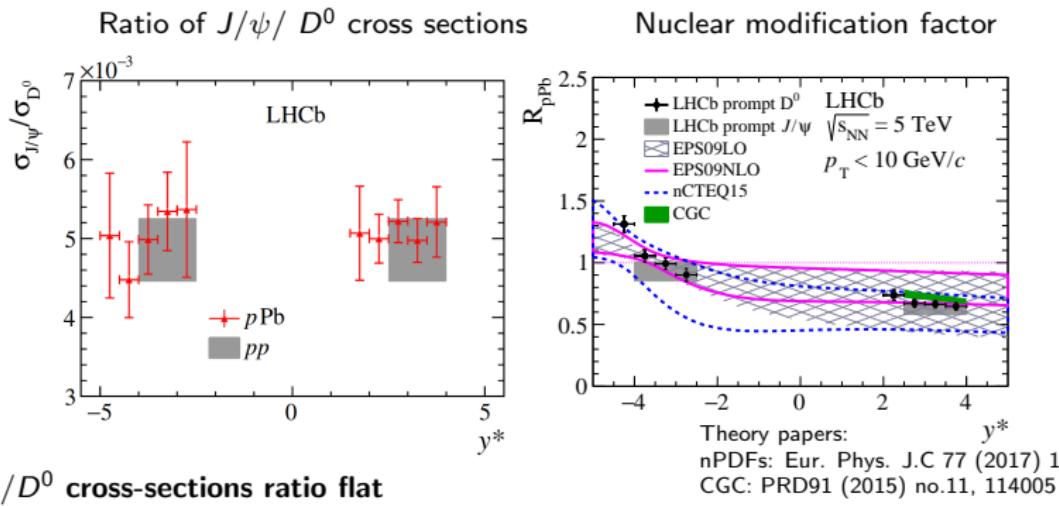
→ see Frédéric Fleuret's talk

$p\text{Pb}$, Ppb collisions



D^0 measurement in $p\text{Pb}$ 5.02 TeV

LHCb-PAPER-2017-015, JHEP 10 (2017) 090



Backward rapidity modification factor close to 1, increasing in most backward rapidity

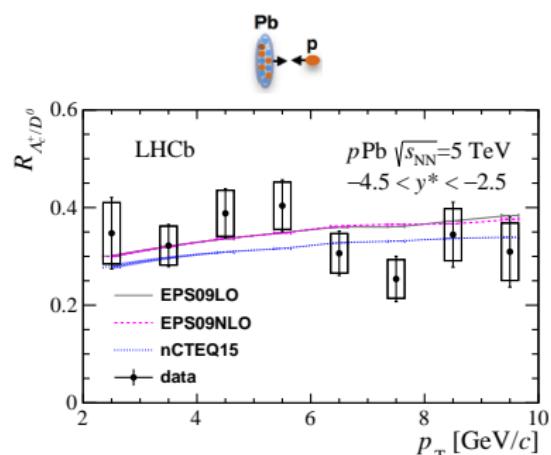
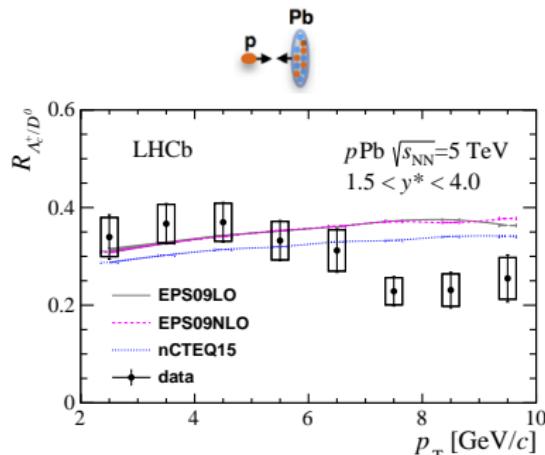
Forward rapidity significant suppression wrt pp yields, good agreement with the theoretical predictions (nuclear PDFs and color glass condensate)

→ see Yanxi Zhang's talk

Λ_c^+ measurements in $p\text{Pb}$ 5.02 TeV

Λ_c^+ cross-section measurements - LHCb-PAPER-2018-021 arXiv:1809.01404

Baryon-to-meson ratio $\Lambda_c^+/D^0 \rightarrow$ Sensitive to charm hadronisation mechanism



EPS09LO: Comput. Phys. Commun. 184 (2013) 2562, EPS09NLO: Comput. Phys. Commun. 198 (2016) 238,
nCTEQ15: Eur. Phys. J. C77 (2017) 1,

Forward rapidity: discrepancies at high- p_T between data and models tuned to pp

Backward rapidity: good agreement between data and model predictions

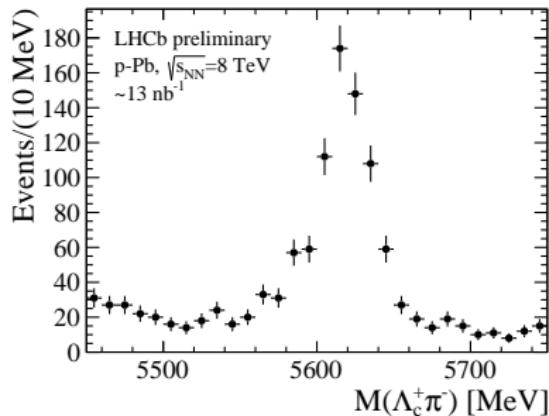
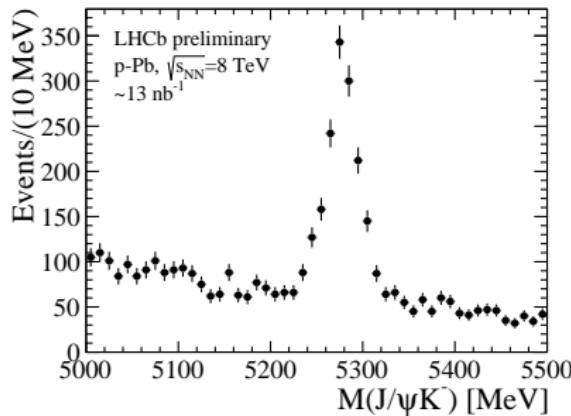
→ see Yanxi Zhang's talk

b-hadrons measurement in $p\text{Pb}$ 8.16 TeV

LHCb-CONF-2018-004 in preparation

$$B^- \rightarrow J/\psi K^-$$

$$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$$

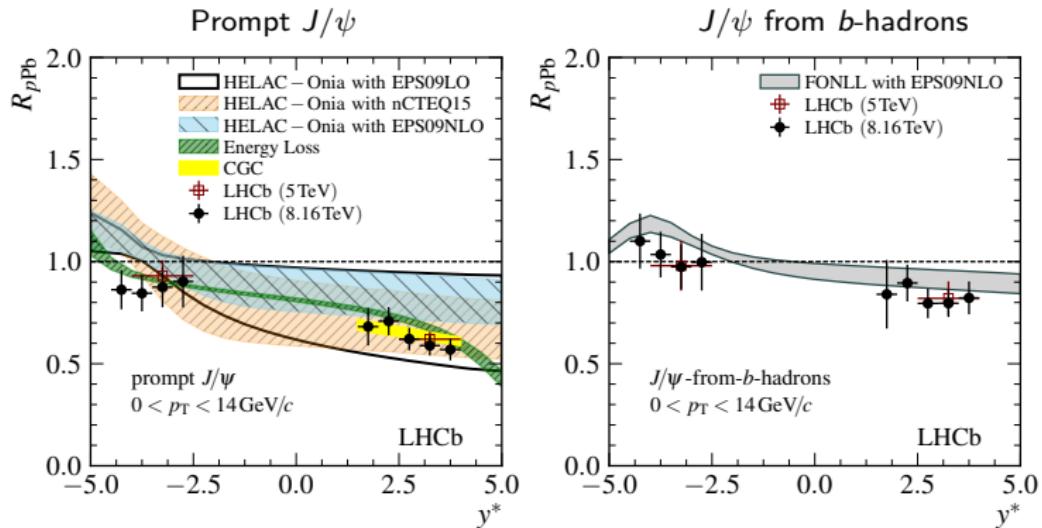


Soon: cross-section measurements at backward and forward rapidity,
comparison with pp and baryon / meson ratio

see Yanxi Zhang's talk

J/ψ measurement in $p\text{Pb}$ 8.16 TeV

LHCb-PAPER-2017-014, PLB 774 (2017) 159



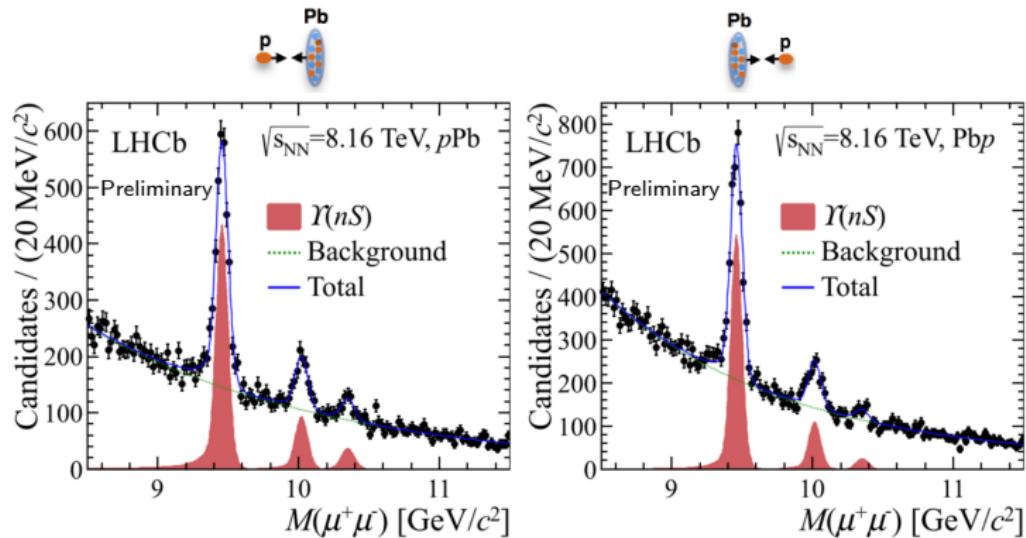
EPS09LO: Comput. Phys. Commun. 184 (2013) 2562, EPS09NLO: Comput. Phys. Commun. 198 (2016) 238,
nCTEQ15: Eur. Phys. J. C77 (2017) 1, Energy-loss: JHEP 03(2013)122, CGC: PRD91 (2015) no.11, 114005

Prompt and non prompt J/ψ results compatible with theoretical expectations and lower LHCb energy measurements

→ see Giulia Manca's talk

$\Upsilon(nS)$ measurement in $p\text{Pb}$ at 8.16 TeV

LHCb-PAPER-2018-035 in preparation



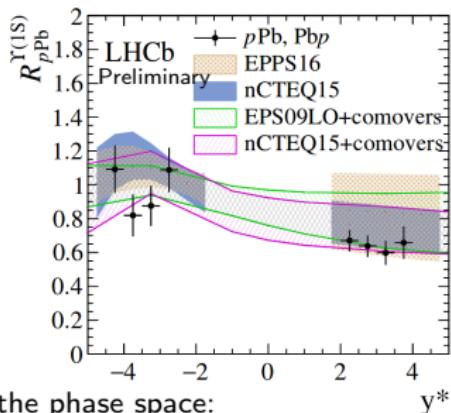
Study of $\Upsilon(nS)$ production with 20 times more luminosity than in Run 1

$\Upsilon(nS)$ measurement in $p\text{Pb}$ at 8.16 TeV

LHCb-PAPER-2018-035 in preparation

$\Upsilon(1S)$ nuclear modification factor:

- ▶ Backward rapidity: compatible with unity within uncertainties
- ▶ Forward rapidity: suppression



$\Upsilon(nS)$ nuclear modification factors integrated over the phase space:

$$R(p\text{Pb}/pp)[\Upsilon(2S)] = 0.86 \pm 0.15$$

$$R(p\text{Pb}/pp)[\Upsilon(3S)] = 0.81 \pm 0.15$$

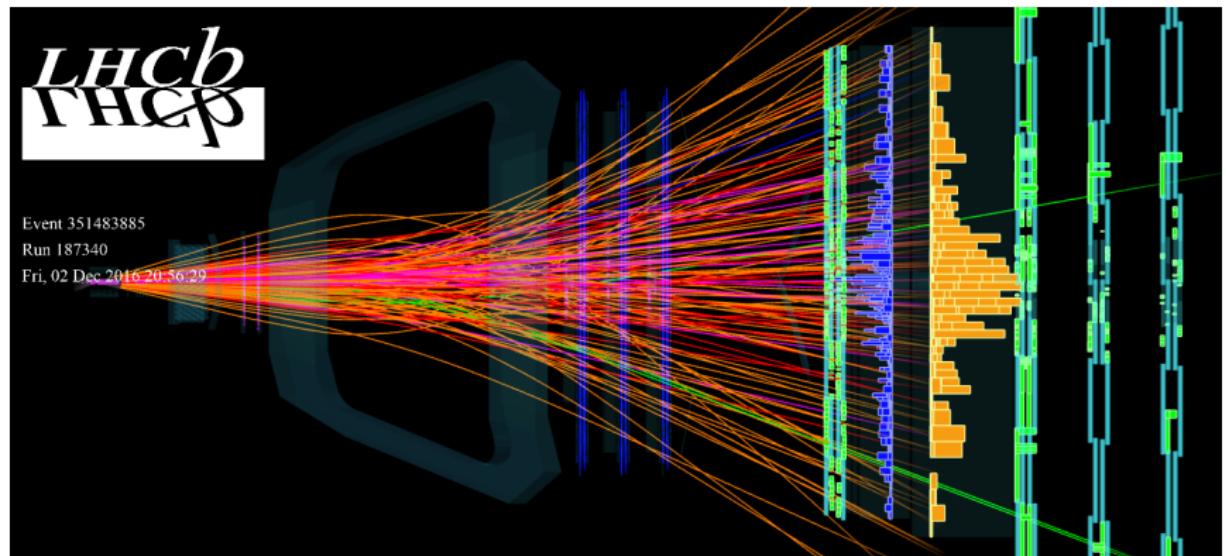
$$R(\text{Pb}p/pp)[\Upsilon(2S)] = 0.90 \pm 0.21$$

$$R(\text{Pb}p/pp)[\Upsilon(3S)] = 0.44 \pm 0.15$$

→ Additional suppression of excited states, significant for $\Upsilon(3S)$ in $\text{Pb}p$ collisions

→ see Giulia Manca's talk

PbPb collisions



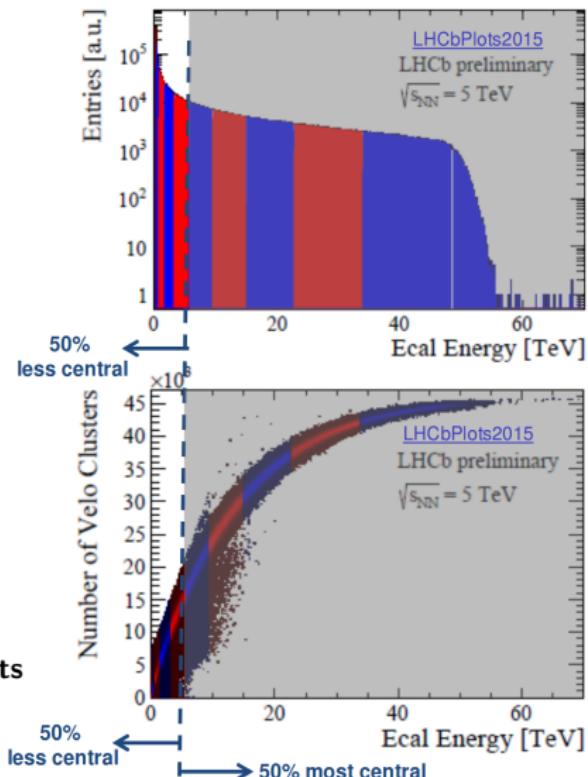
Centrality of PbPb collisions

LHCb centrality

- ▶ Measured by the calorimeter
- ▶ Reaches the detector limitation

→ Saturation in the Vertex Locator
for the most central PbPb collisions

LHCb current tracking algorithm efficient
up to 50% most central collisions



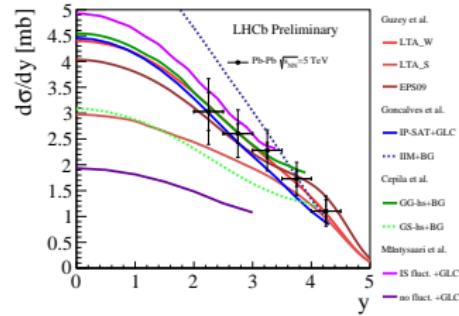
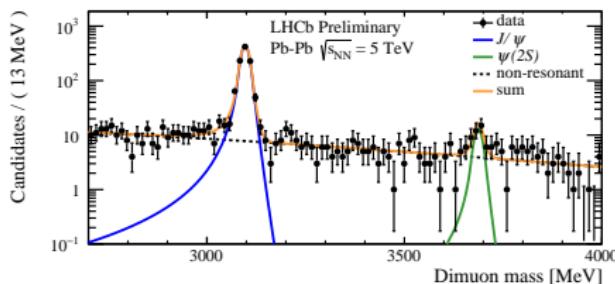
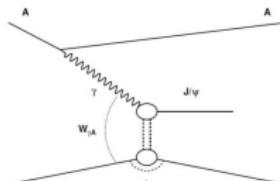
Physics studies limited to 50% less central events

J/ψ in PbPb ultra peripheral collisions

$J/\psi \rightarrow \mu^+ \mu^-$ in ultra peripheral collisions (UPC) - LHCb-CONF-2018-003

Interaction between the electromagnetic field of the ions
→ Coherent J/ψ photo-production, sensitive to nPDF, ...

No additional particle production



→ Constraint on model space

Cepila et al. PRC 97 024901 (2018), Goncalves et al. PRD 96, 094027 (2017), Guzey et al. PRC 93, 055206 (2016), Mäntysaari et al. PLB 772 (2017) 832-838 → Model without subnucleonic fluctuations disfavoured

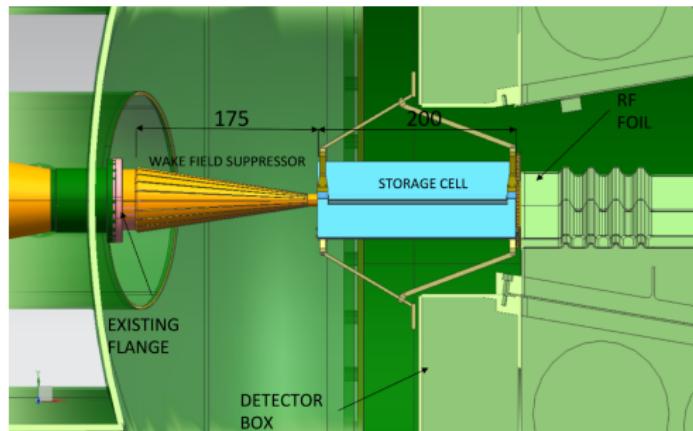
2018 PbPb run: expect 10 times more luminosity and include other final states in exclusive γ -induced reactions

→ see Samuel Belin's talk

Fixed-target upgrade

Current LHCb fixed-target setup will be upgraded for Run 3

Plan for a storage cell, placed upstream



- Injection of noble gases but also H₂, D₂ as references
- **10–100 times larger instantaneous luminosity per unit length**
- Other upgrades (crystal target, polarised target, wire target) under discussion

Conclusions

**The LHCb detector has unique capabilities for heavy flavor measurements at LHC
in collider and fixed-target modes**

Recent precision heavy flavour measurements

- ▶ Prompt and non-prompt charmonium, open charm (D^0, Λ_c^+), open beauty (B^0, B^+, Λ_b^+) and $\Upsilon(nS)$ production measurements in $p\text{Pb}$ collisions
- ▶ Demonstration of capabilities to run in PbPb collisions and exploitation with high-precision ultra-peripheral collisions
- ▶ First heavy flavour production measurement in fixed-target mode

More results to come

- ▶ 2016 $p\text{Pb}$ analyses ongoing
- ▶ 2018 PbPb collisions to be taken
- ▶ 2017 large $p\text{Ne}$ data sample to analyze and 2018 PbNe collisions to be taken

Rich heavy ion program with LHCb upgrade and the fixed-target upgrade !

Extra slides

Λ_c^+ invariant mass in $p\text{Pb}$ at 5.02 TeV

