



XXVI International Workshop on
Deep Inelastic Scattering and
Related Subjects

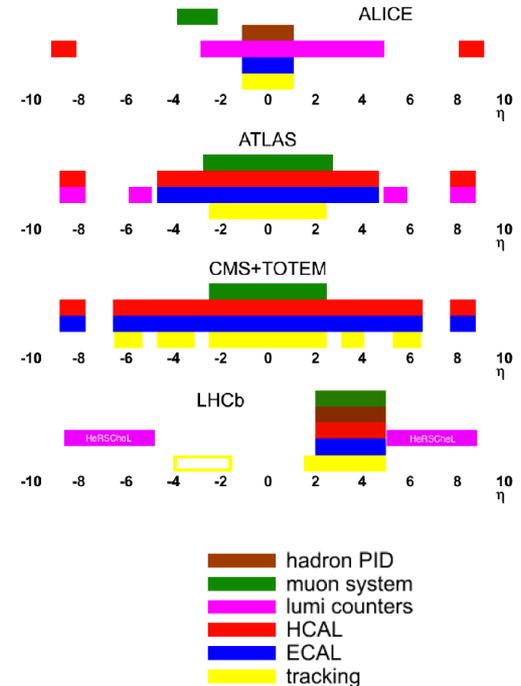
16-20 April 2018 Kobe, Japan



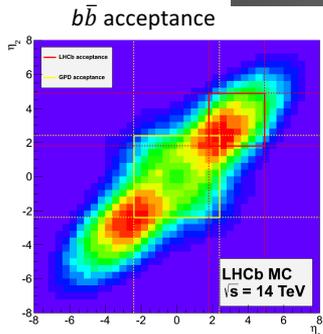
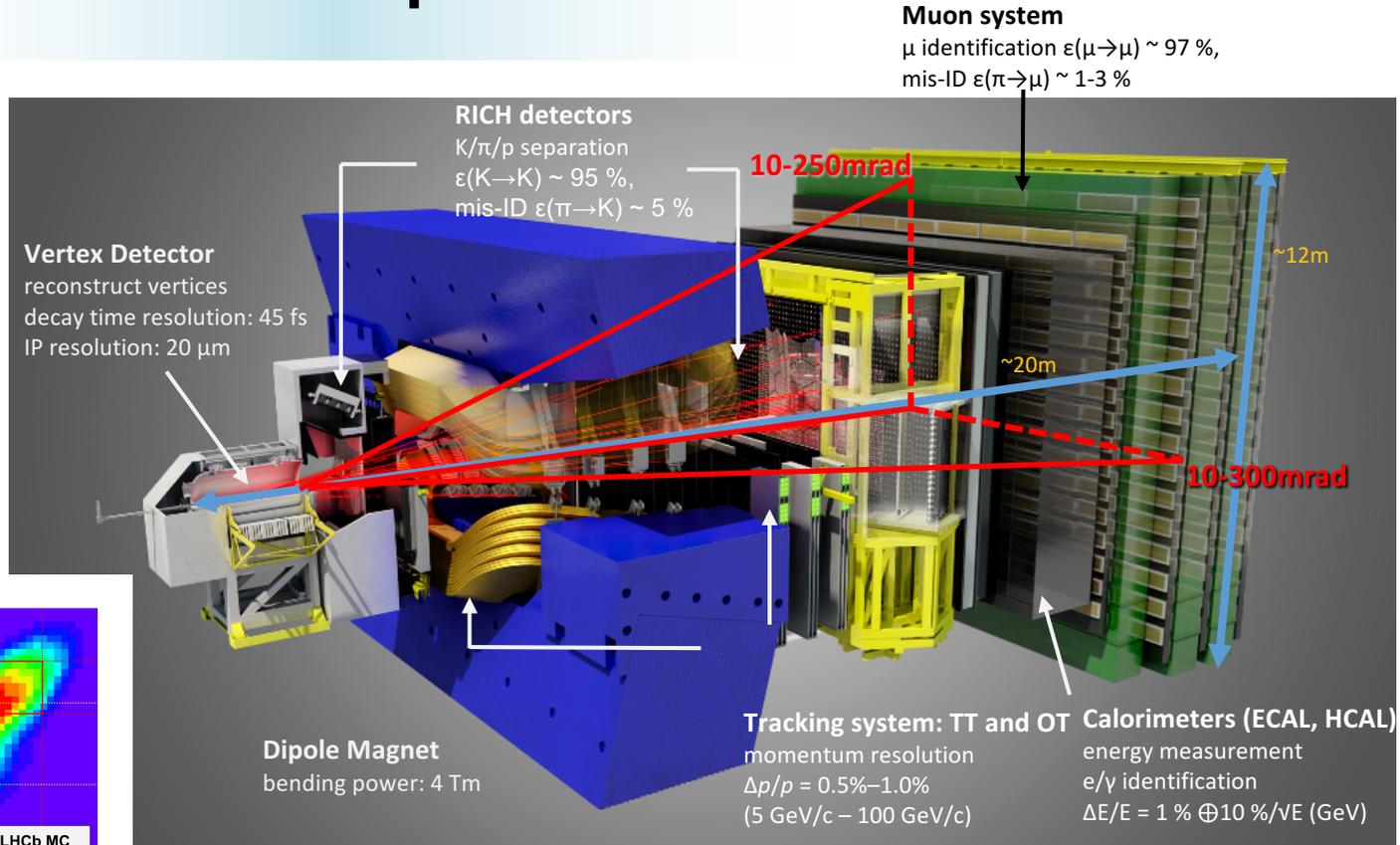
Heavy flavour production at LHCb

Why LHCb ?

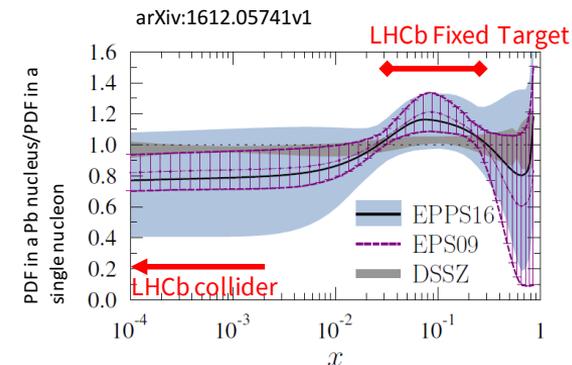
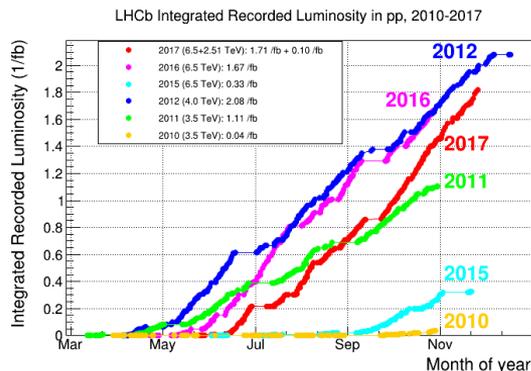
- LHCb is specialised in heavy flavour precision physics, beauty and charm:
 - Optimised for low pile-up collisions (*ie* low multiplicity):
 - Precise reconstruction of production and decay vertices: time dependent CP violation
 - Correlations between particles: flavour tagging
- Some characteristics of the experiment make it attractive for measurements of Heavy Flavour production:
 - Instruments fully the forward region: $2 < \eta < 5$
 - Precise vertexing: separation of prompt production from B decay products
 - Precise tracking: reconstruction down to $p_T=0$
 - Particle identification: full reconstruction of hadronic decays of charm or beauty, such as $D^0 \rightarrow K\pi$



The LHCb experiment



LHCb operation modes

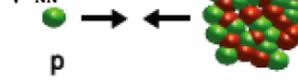


– Collider mode

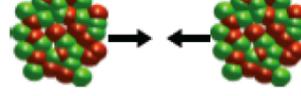
2.76 to 13 TeV



$\sqrt{s_{NN}} = 5$ to 8 TeV



$\sqrt{s_{NN}} = 5$ TeV



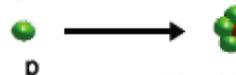
– Fixed-target mode

$\sqrt{s_{NN}^{SPS}} \sim 20$ GeV

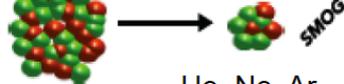
$\sqrt{s_{NN}^{RHIC}} = 200$ GeV

$\sqrt{s_{NN}^{LHC}} = 5$ TeV

$\sqrt{s_{NN}} = 90$ to 110 GeV



$\sqrt{s_{NN}} = 70$ GeV



Unique to LHCb

$$\text{LHCb rapidity } 2.5 < y_{\text{LHCb}} < 4.5 \Rightarrow \begin{cases} 7 \text{ TeV beam:} & -2.3 < y_{\text{LHCb}}^* < -0.3 \\ 2.75 \text{ TeV beam:} & -1.8 < y_{\text{LHCb}}^* < 0.2 \end{cases}$$

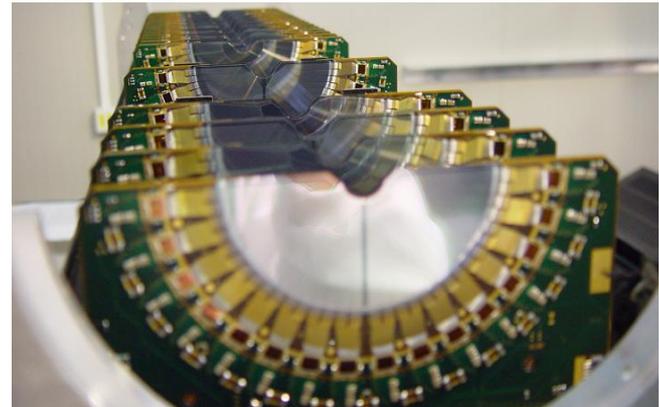
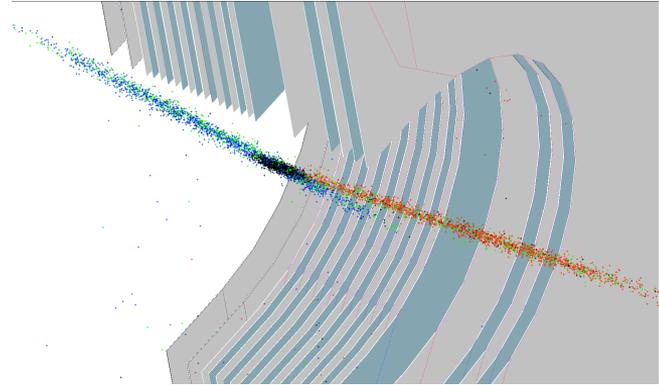
y_{LHCb}^* = rapidity in collision center of mass frame

Bjorken- x = fraction of the nucleon momentum carried by a parton

[arXiv:1612.05741]

Fixed target mode - SMOG

- Gas can be injected in the interaction region of LHCb, in the VELO vacuum (*ie* the LHC vacuum)
- Initially this was designed to measure the luminosity of LHCb, by measuring the beam images with beam-gas vertices: used during LHC van der Meer scan sessions: 1.2% precision on integrated luminosity
- Other use cases emerged:
 - Measure LHC ghost charge (proportion of particles outside the colliding buckets) for the ALICE, ATLAS and CMS luminosity
 - Fixed target physics



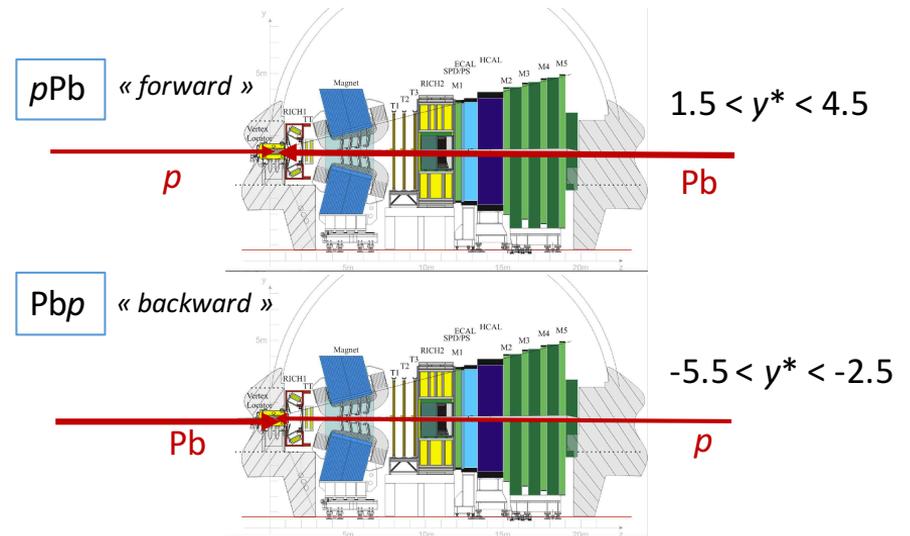
Collider mode: $p\text{Pb}$ collisions (2013, 2016)

- Due to geometry of detector: when swapping beams, two different coverages: statistics accumulated in both configurations in 2013 and 2016.
- Measurements of heavy flavour production compared to production in pp collisions at the same energy

$$R_{p\text{Pb}}(p_T, y^*) \equiv \frac{1}{A} \frac{d^2\sigma_{p\text{Pb}}(p_T, y^*)/dp_T dy^*}{d^2\sigma_{pp}(p_T, y^*)/dp_T dy^*}$$

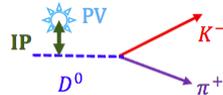
- Or comparing ratio of production in the forward and backward configuration in the same rapidity range

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



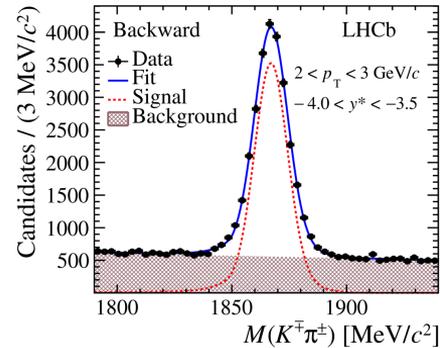
Open charm production

- Measured with hadronic decays, for example $D^0 \rightarrow K^- \pi^+$, in bins of p_T and y or y^* for various systems and energies: pp collisions at 5 TeV [JHEP 06 (2016) 147], 7 TeV [NPB 718 (2013) 902], 13 TeV [JHEP 05 (2017) 74], pPb collisions at 5 TeV [JHEP 10 (2017) 90] and pAr collisions at 110 GeV [LHCb CONF 2017-001]
- With tight requirements on particle identification
- Separate prompt D^0 from D^0 from B decays using the D^0 Impact Parameter to Primary Vertex:



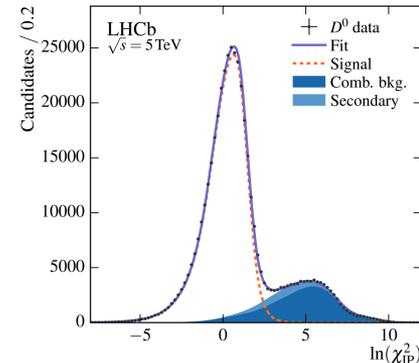
- The number of inclusive candidates is extracted from a fit to the mass distribution, then the number of prompt D^0 from the $\log(\chi_{IP}^2)$ distribution
- Efficiencies from simulation with data-driven corrections

$$\frac{d^2\sigma}{dp_T dy^*} = \frac{N(D^0 \rightarrow K^\pm \pi^\mp)}{\mathcal{L} \times \varepsilon_{\text{tot}} \times \mathcal{B}(D^0 \rightarrow K^\pm \pi^\mp) \times \Delta p_T \times \Delta y^*}$$



[JHEP 10 (2017) 90]

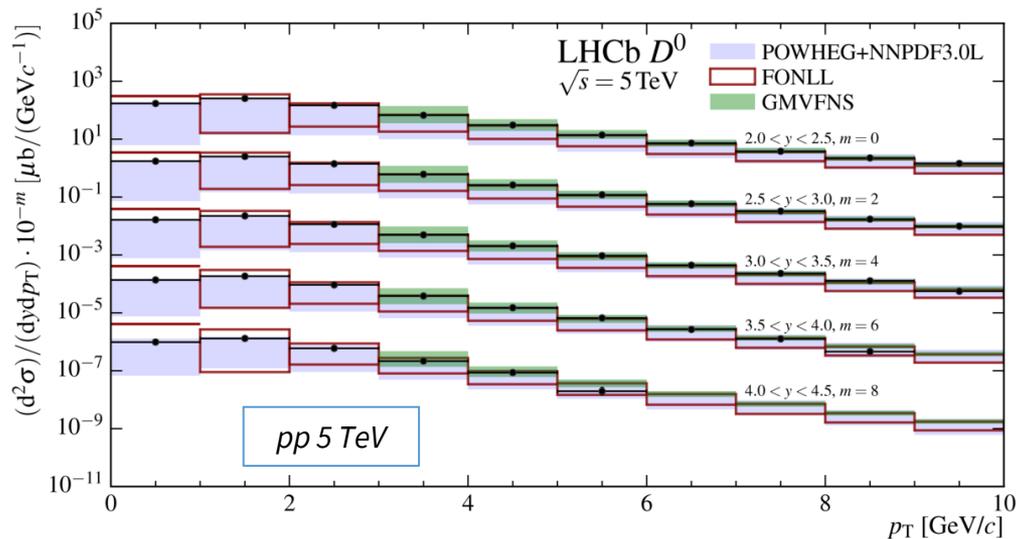
pPb 5 TeV



[JHEP 06 (2016) 147]

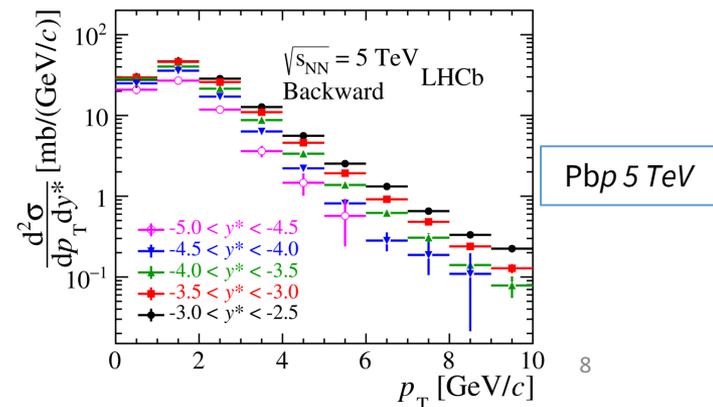
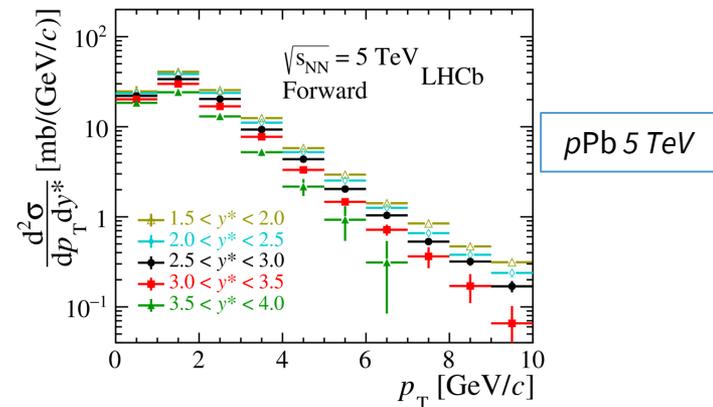
pp 5 TeV

Open charm cross-section at 5 TeV



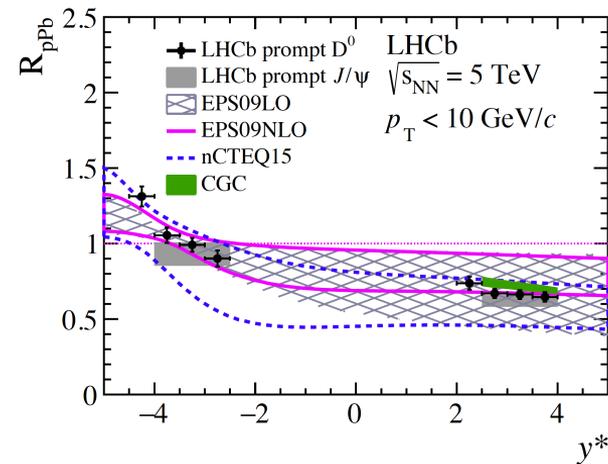
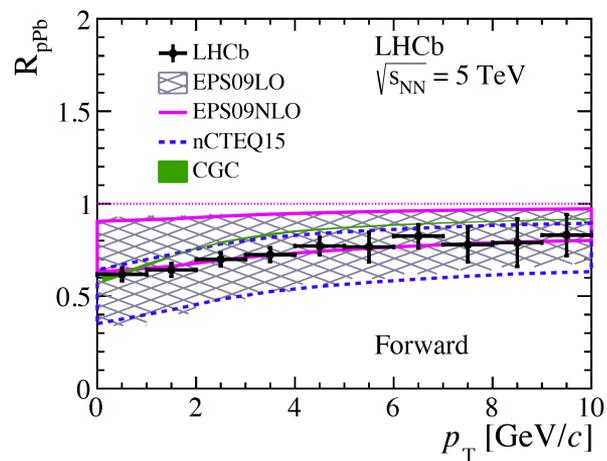
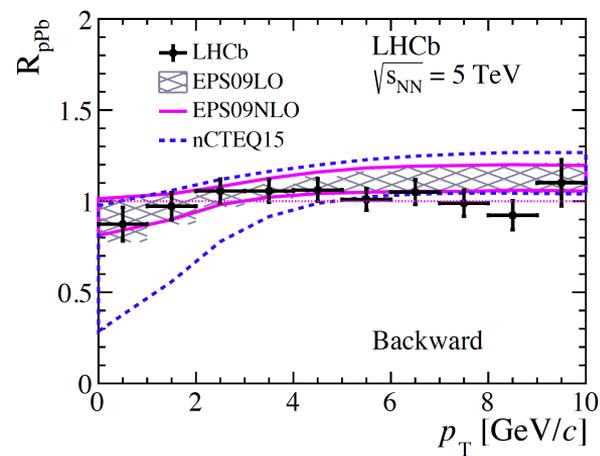
• Compared with

- POWHEG+NNPDF3L [R. Gauld, J. Rojo, L. Rottoli, J. Talbert, JHEP11 (2015) 009]
- FONLL [M. Cacciari, M.L. Mangano, P. Nason, EPJC75 (2015) 610]
- GMVFNS [B.A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger EPJC72 (2012) 2082]



Open charm cross-section at 5 TeV

- Computed in the kinematic range common to p Pb and pp or Pbp and pp , integrated over 1 dimension



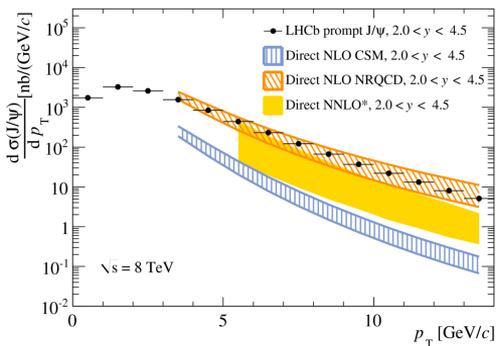
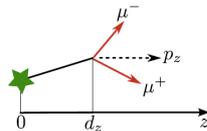
Compared with

- HELACOnia [J.-P. Lansberg, H.-S. Shao, EPJC77(2017)1] (tuned to reproduce pp data with the PDF set CT10NLO [H.-L. Lai et al, PRD82 (2010) 074024]) using nuclear PDFs:
 - EPS09LO or EPS09NLO [K.J. Eskola, H. Paukkunen, C.A. Salgado, JHEP04 (2009) 065]
 - nCTEQ15 [K. Kovarik et al, PRD93 (2016) 085037]
- CGC, Color Glass Condensate [B. Ducloué, T. Lappi, H. Mäntysaari, PRD91 (2015) 114005]
- Prompt J/ψ R_{ppb} measured at 5 TeV in LHCb [JHEP02 (2014) 072]

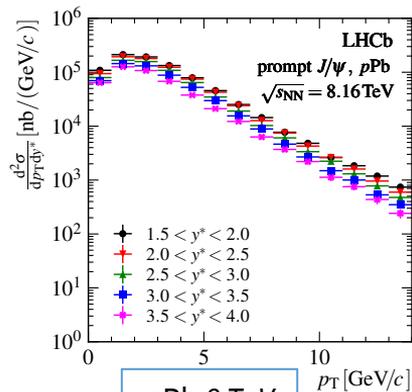
J/ψ production at 8 TeV

- Precise measurements of prompt J/ψ and J/ψ from B decays in pPb and pp collisions

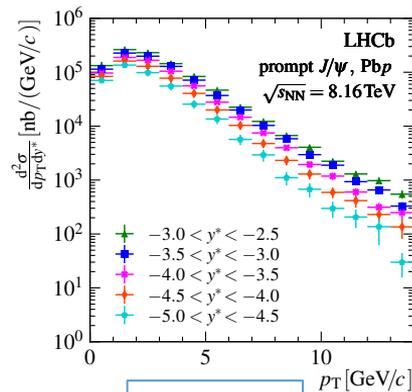
$$t_z(J/\psi) = \frac{d_z \times M_{J/\psi}}{p_z}$$



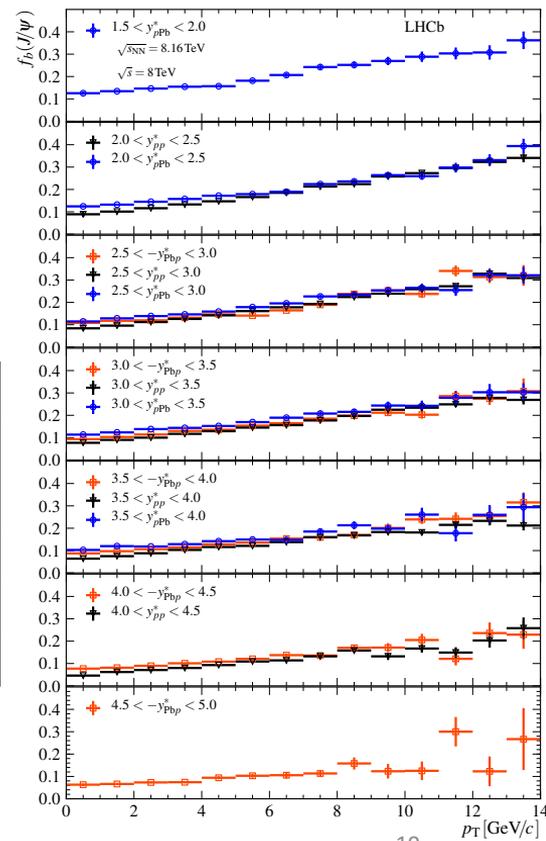
pp 8 TeV



pPb 8 TeV

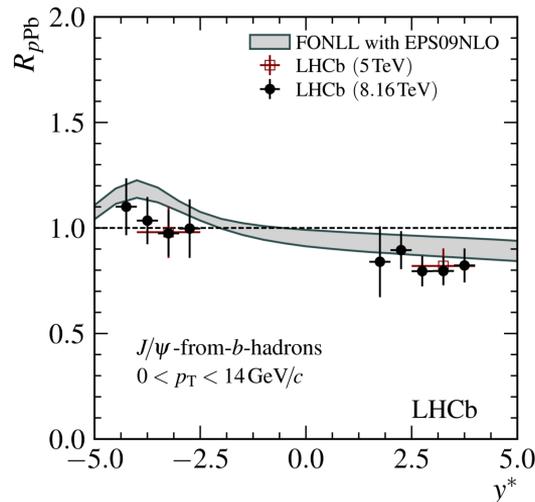
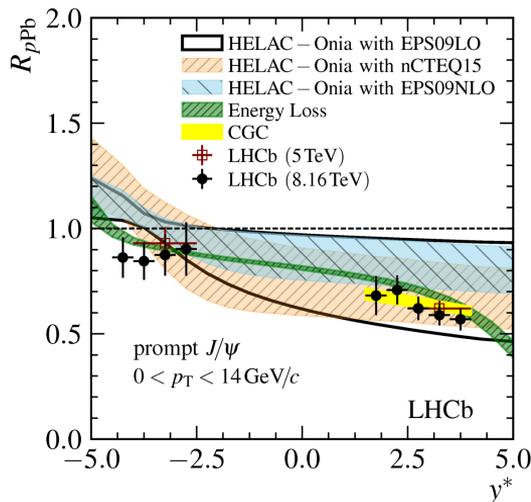


PbPb 8 TeV



J/ ψ production at 8 TeV

- Suppression of J/ ψ production in p Pb collisions compared to pp collisions for prompt and B decays

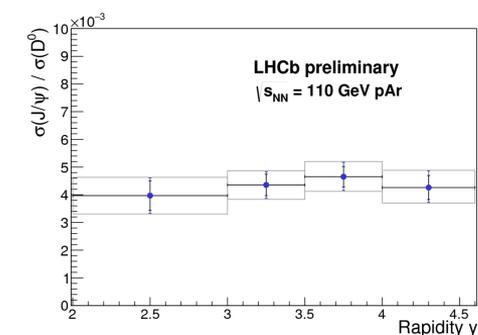
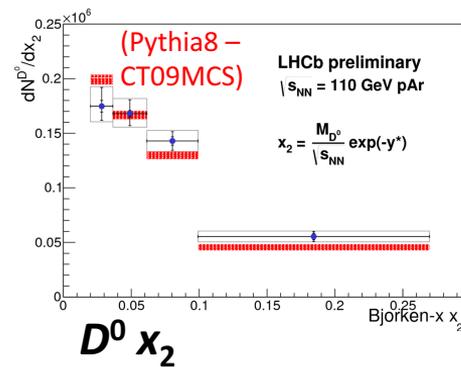
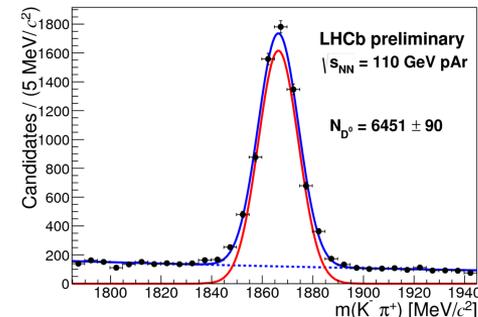
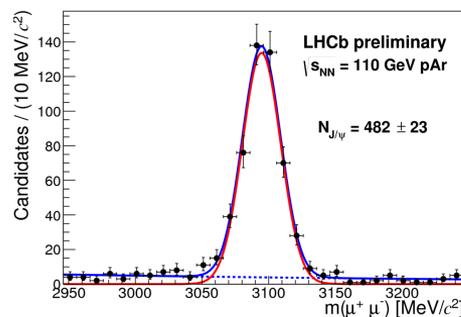


- Compared with

- HELACOnia [J.-P. Lansberg, H.-S. Shao, EPJC77(2017)1] or FONLL with different nPDF sets [K.J. Eskola, H. Paukkunen, C.A. Salgado, JHEP04 (2009) 065, K. Kovarik et al, PRD93 (2016) 085037]
- Color Glass Condensate [B. Ducloué, T. Lappi, H. Mäntysaari, PRD91 (2015) 114005]
- Energy Loss [F. Arleo, S. Peigne, JHEP03 (2013) 122]

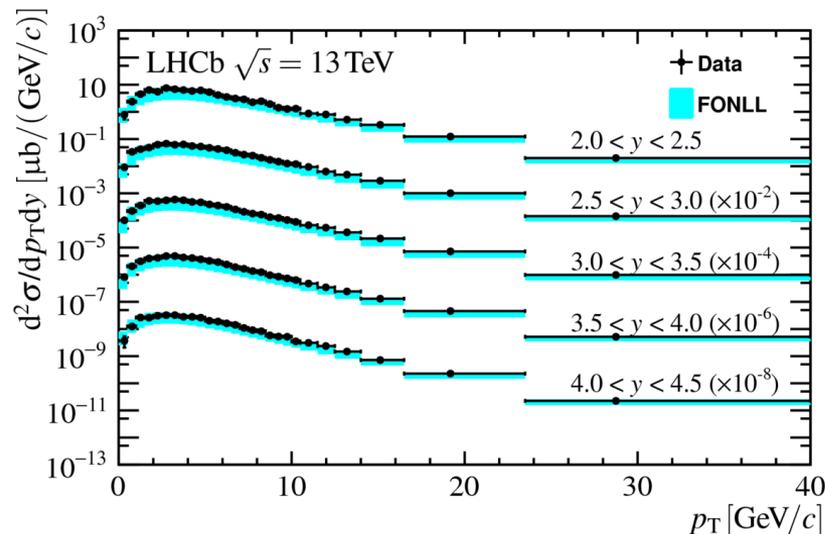
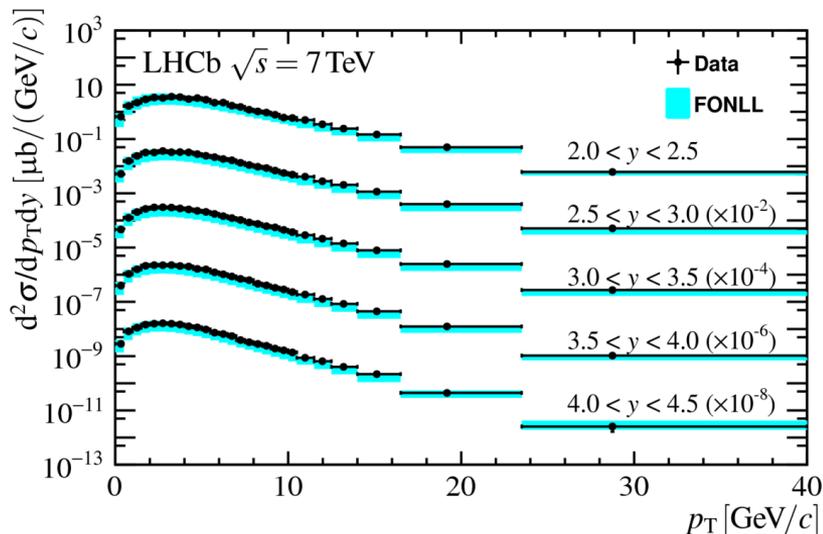
D^0 and J/ψ production in $p\text{Ar}$ at 110 GeV

- Overall data (17h) : $\sim 500 J/\psi$ $\sim 6500 D^0$
- Very clear signal, very small background
- Study $J/\psi/D^0$ as a baseline for Quark Gluon Plasma studies
- Bjorken- x range covered by the data
 - J/ψ $x_2 \in [0.03, 0.45]$
 - D^0 $x_2 \in [0.02, 0.27]$
 - Give access to intrinsic charm regime
- $p\text{He}$ @ 86.6 GeV analysis ongoing



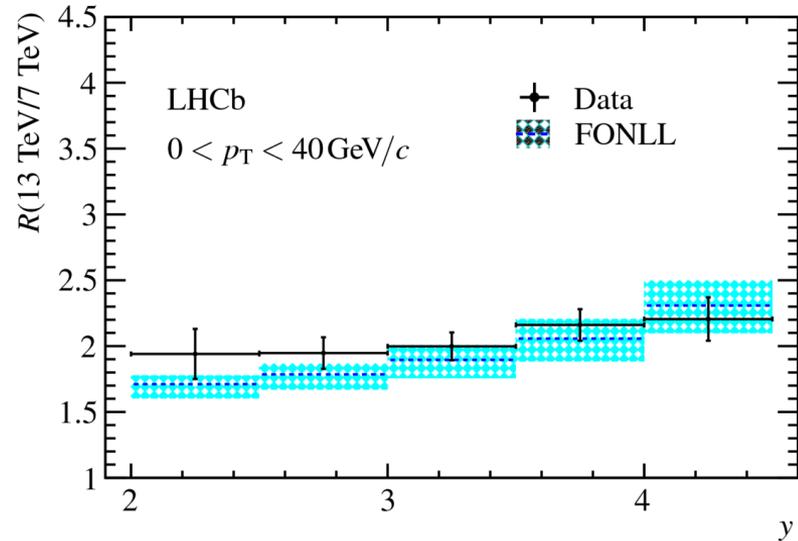
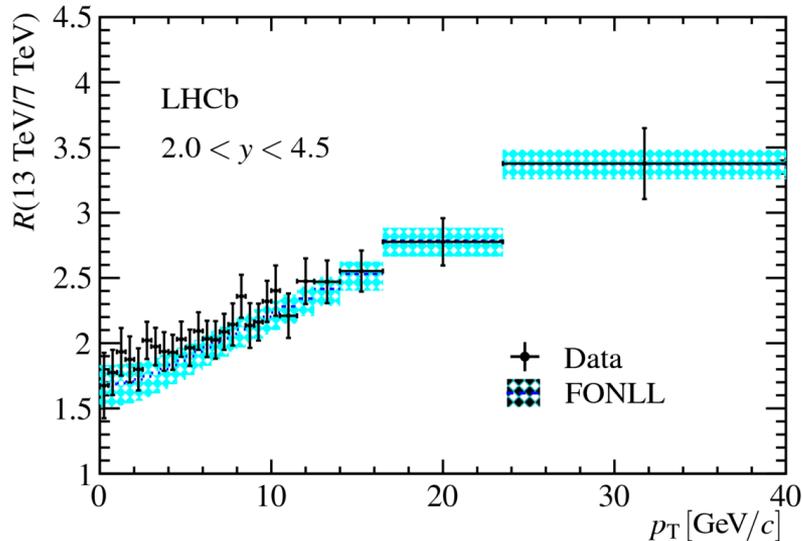
Open beauty production at 13 TeV

- New measurement of B^+ production in pp collisions, with 1 fb^{-1} of data at 7 TeV and 0.3 fb^{-1} of data at 13 TeV, in the decay mode $B^+ \rightarrow J/\psi K^+$
- Double differential in p_T ($0 < p_T < 40 \text{ GeV}$) and rapidity ($2.0 < y < 4.5$), in good agreement with FONLL based computations [M. Cacciari, M.L. Mangano, P. Nason, EPJC75 (2015) 610]



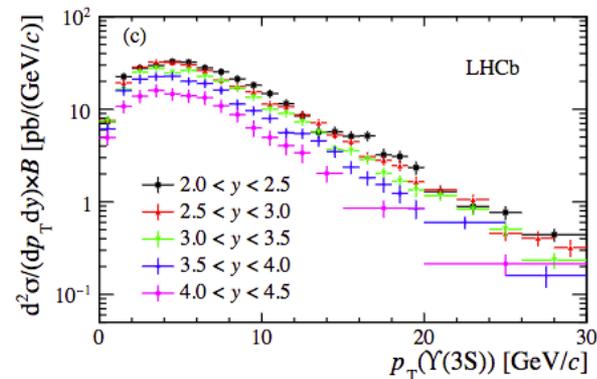
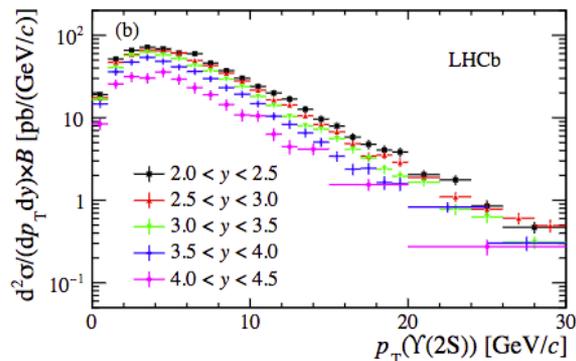
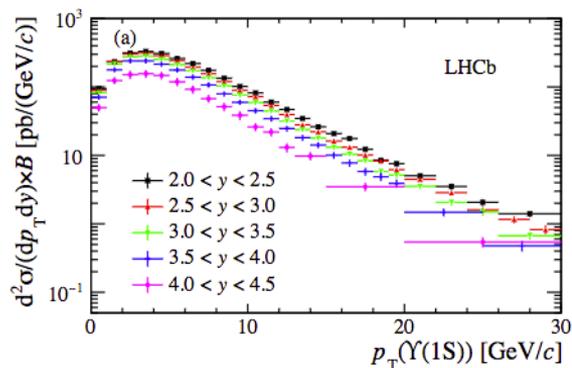
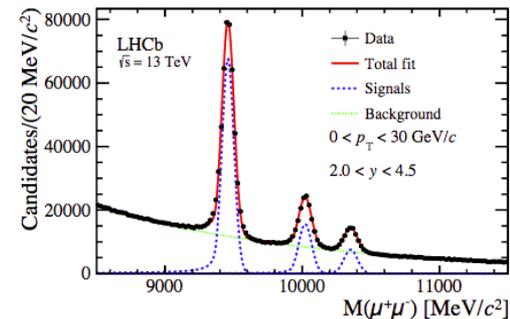
Open beauty production at 13 TeV

- Ratios of production cross-sections at 7 TeV and 13 TeV are also measured as functions of p_T and y and in good agreement with FONLL predictions, where many uncertainties cancel [M. Cacciari, M.L. Mangano, P. Nason, EPJC75 (2015) 610]



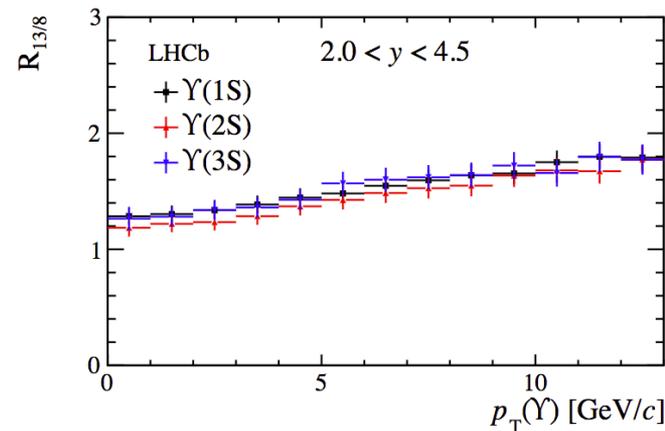
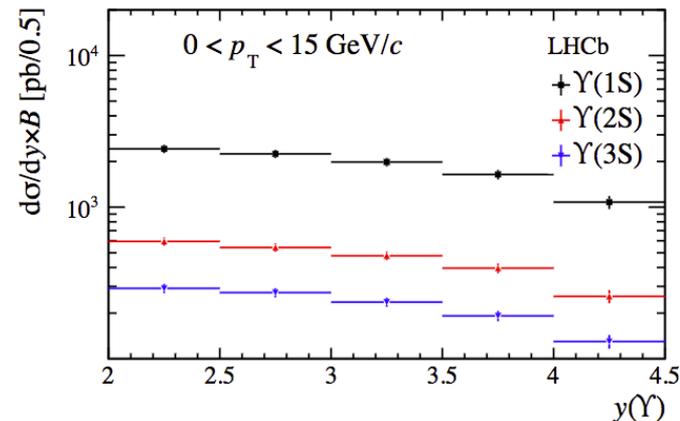
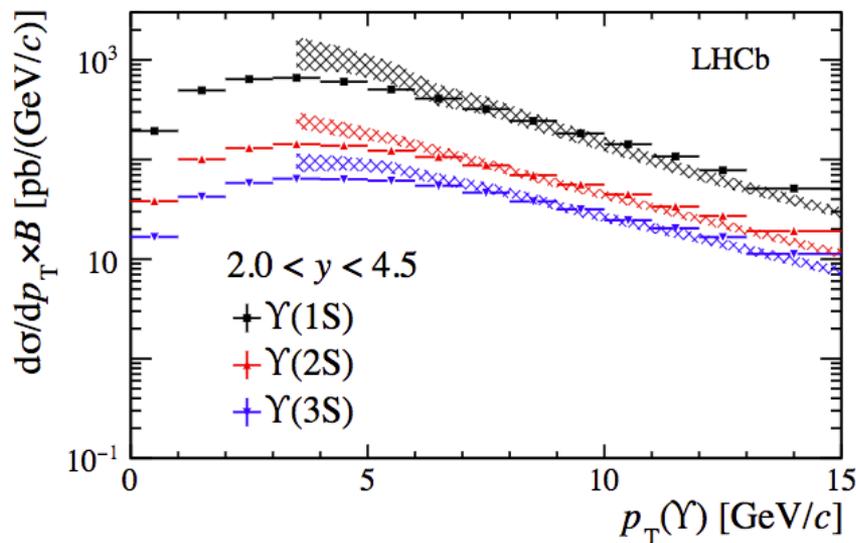
Bottomonium production at 13 TeV

- New measurement of $Y(1S)$, $Y(2S)$ and $Y(3S)$ production in pp collisions, with 0.3 fb^{-1} of data at 13 TeV, in the decay mode $Y(nS) \rightarrow \mu^+\mu^-$
- Double differential in p_T ($0 < p_T < 30 \text{ GeV}$) and rapidity ($2.0 < y < 4.5$)



Bottomonium production at 13 TeV

Comparison with recent theoretical computations based on NRQCD [Yu, Bin, Lu-Ping, Jian-Xiong CPC39 (2017) 12] shows good agreement.



Conclusions

- Production of heavy flavour, open charm and beauty or quarkonium, measured precisely in various systems accessible for the LHCb experiment
- Measurements in different systems will be obtained with the current data sets:
 - Other type of gases for the fixed target mode (Ne, He)
 - Open beauty in p Pb collisions
- With increased integrated luminosity from Run 2, access and update various quarkonium state cross-sections with different decay modes: $\eta_c(1S,2S) \rightarrow p\bar{p}$ or $\chi_c \rightarrow J/\psi\mu^+\mu^-$

