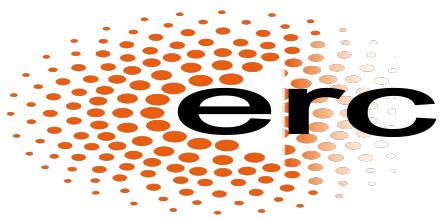
Recent results on heavy flavour production at LHCb

Michael Winn on behalf of the LHCb Collaboration

Laboratoire de l'Accélérateur Linéaire, Orsay

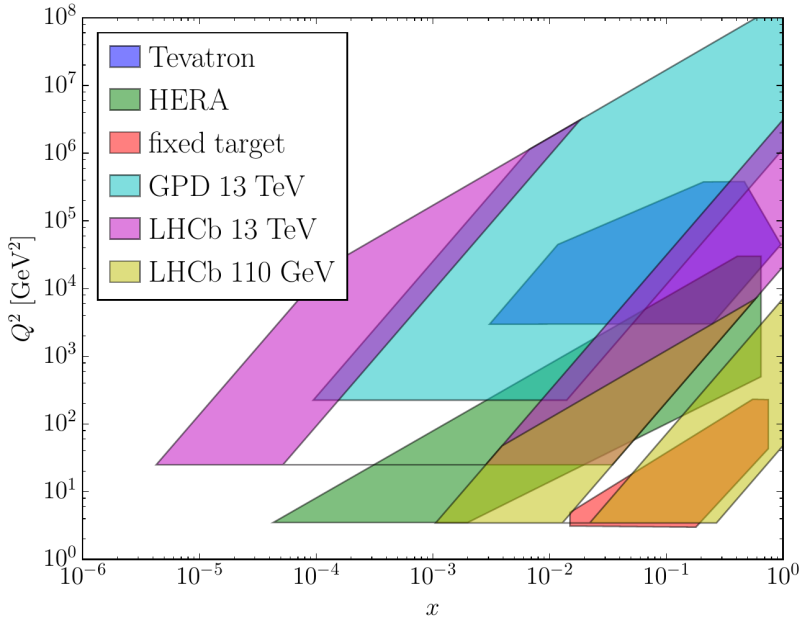


LHCb implications workshop, CERN, 08.11.2017

Outline

1. Heavy-flavour production in LHCb: exploring QCD
2. Open charm and charmonium production in pp, pPb and fixed-target pAr
3. Open beauty and bottomonium production in pp and pPb
4. Conclusions

Heavy-flavour production in LHCb



Measurement of the $\eta_c(1S)$ production cross-section in proton-proton collisions via the decay $\eta_c(1S) \to p\bar{p}$

by LHCb and the theory rebound:

η_c production at the LHC challenges nonrelativistic-QCD factorization

Mathias Butenschoen, Zhi-Guo He, Bernd A. Kniehl (Hamburg U., Inst. Theor. Phys. II)

Nov 19, 2014 - 5 pages

Phys.Rev.Lett. 114 (2015) no.9, 092004
(2015-03-06)
DOI: 10.1103/PhysRevLett.114.092004
DESY-14-219
e-Print: arXiv:1411.5287 [hep-ph] | PDF

η_c production at LHC and indications on the understanding of J/ψ production

Hao Han (Peking U. & Peking U., SKLNPT) , Yan-Qing Ma (Maryland U. & Peking U., CHEP) , Ce Meng (Peking U. & Peking U., SKLNPT) , Hua-Sheng Shao (CERN & Peking U. & Peking U., SKLNPT) , Kuang-Ta Chao (Unlisted, CN & Peking U., CHEP & Peking U., SKLNPT)

Nov 26, 2014 - 5 pages

Phys.Rev.Lett. 114 (2015) no.9, 092005
(2015-03-06)
DOI: 10.1103/PhysRevLett.114.092005
e-Print: arXiv:1411.7350 [hep-ph] | PDF

Impact of η_c hadroproduction data on charmonium production and polarization within NRQCD framework

Hong-Fei Zhang (Third Military Med. U., Chongqing) , Zhan Sun (Chongqing U.) , Wen-Long Sang (SWU, Chongqing & Beijing, Inst. Theor. Phys.) , Rong Li (Xian Jiaotong U.)

Dec 1, 2014 - 5 pages

Phys.Rev.Lett. 114 (2015) no.9, 092006
(2015-03-06)
DOI: 10.1103/PhysRevLett.114.092006
e-Print: arXiv:1412.0508 [hep-ph] | PDF

Left: courtesy of P. Ilten; right: title of Eur.Phys.J. C75 (2015) no.7, 311 and theory reactions.

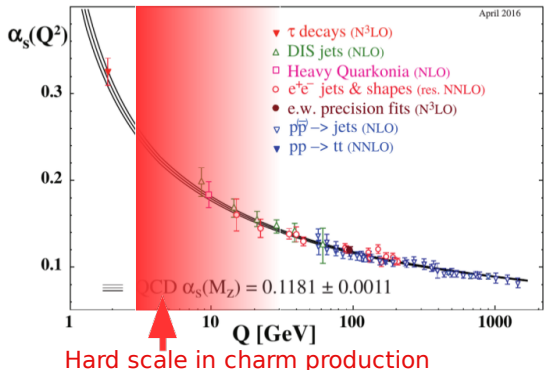
Heavy-flavour production:

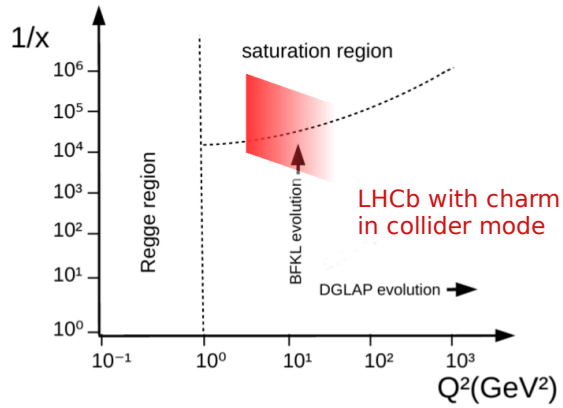
- test factorisation w.r.t. initial state/other diagrammatic approaches & factorisation w.r.t. final state as low as possible in Q^2
- test effective field theory for bound state production

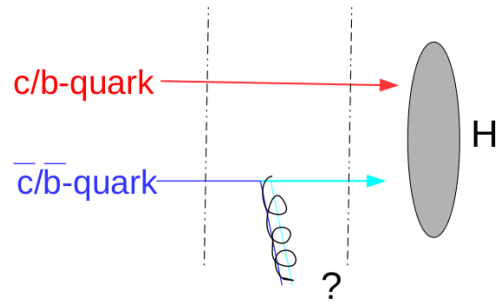
LHCb:

- forward acceptance: unique kinematics in $Q^2 - x$-plane
- flexible high-rate trigger down to low-Q^2, PID & precision vertexing
- only LHC fixed-target programme: unique kinematics

Open charm & charmonium production in pp and pPb





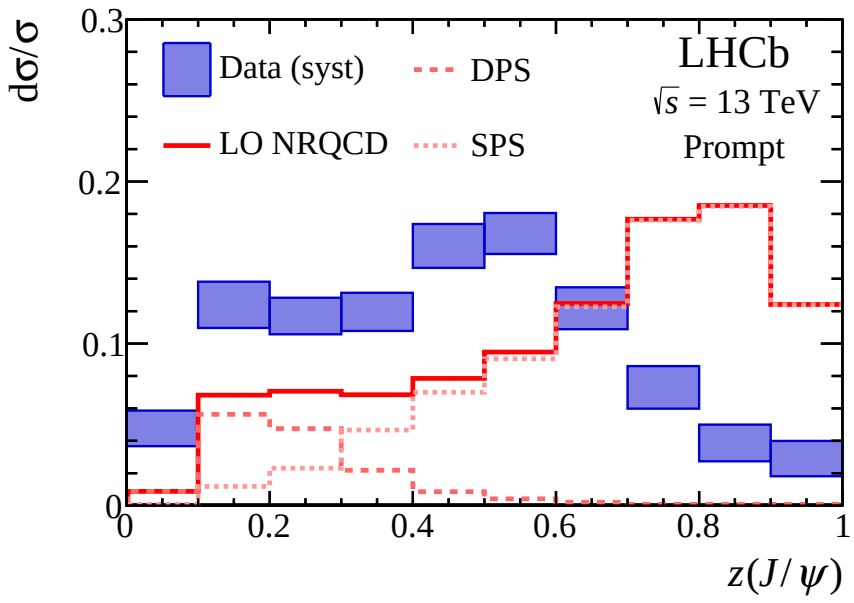


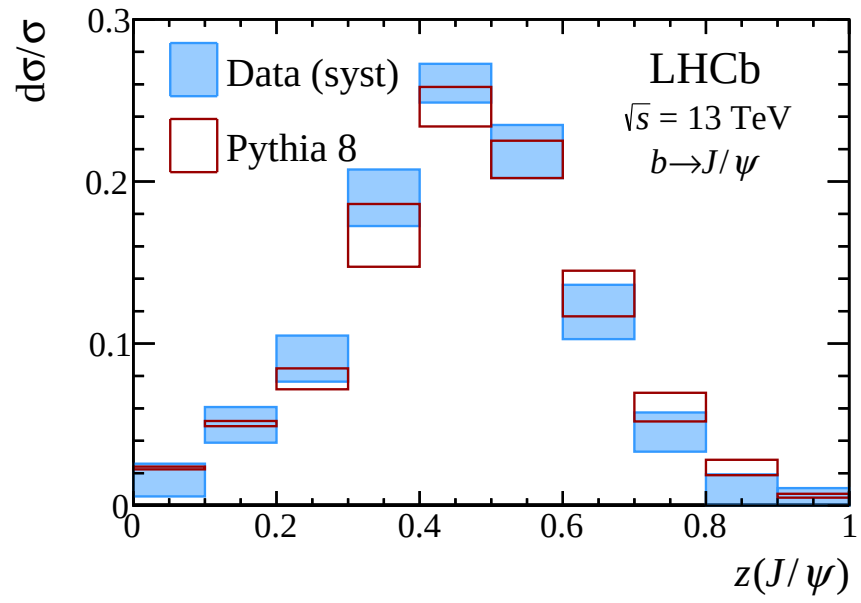
Left: adapted from PDG '16 QCD review; middle: adapted from R. Ellis, W. Stirling, and B. Webber. QCD and collider physics.

Charm production scale $Q \geq 2m_c = 3$ GeV$/c^2$

- a challenge for perturbative QCD
  $\rightarrow$ limits of perturbative convergence and factorisation schemes
- forward rapidity at the LHC: lowest-x values reached in any experiment
  $\rightarrow$ looking for end of linear parton evolution
- $c\bar{c}$-bound states below open charm threshold: corrections for relativistic quarks can be sizeable
- understanding crucial basis for heavy-ions: c, b best proxy of static colour charges within thermodynamic QCD system $\rightarrow$ probe deconfinement

J/ψ production in jets in pp at 13 TeV

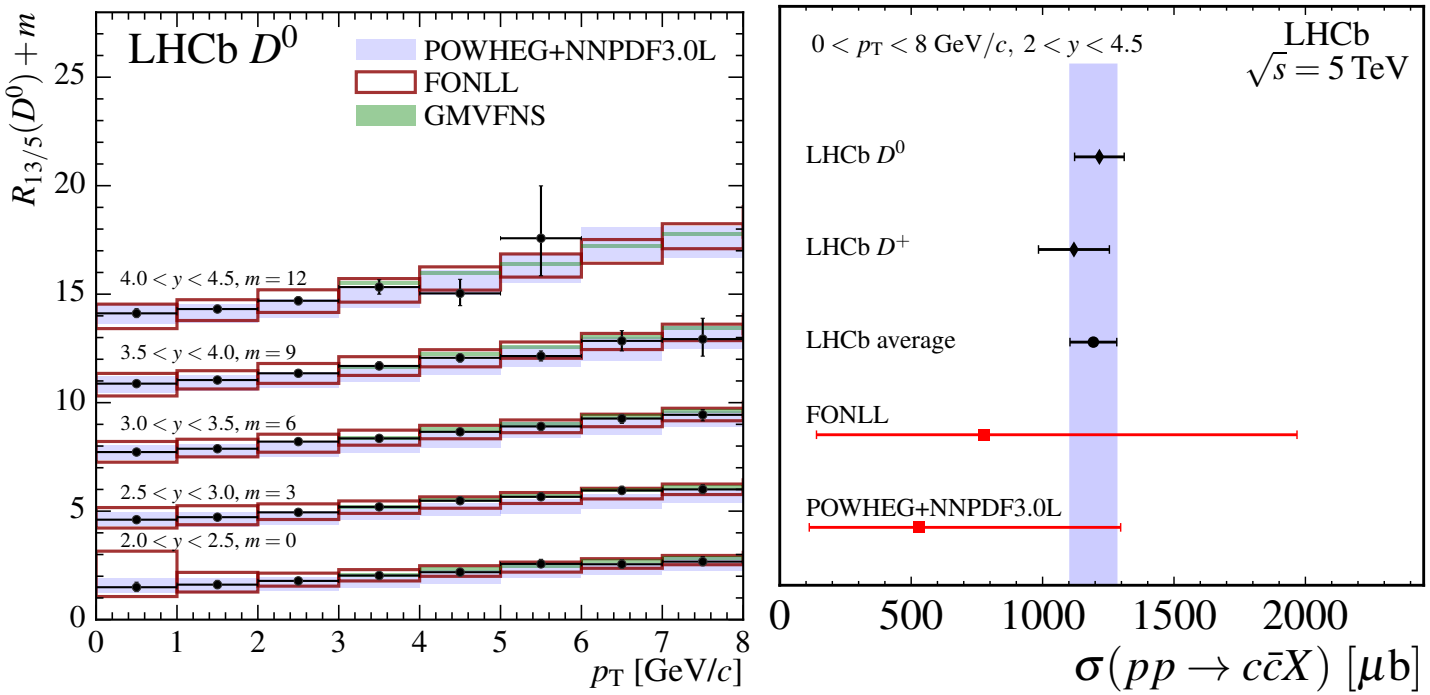




Phys. Rev. Lett. 118, 192001.

- jet fragmentation in prompt J/ψ not in accordance with NRQCD calculation using PYTHIA 8
- jet fragmentation in nonprompt J/ψ well reproduced by PYTHIA 8
- important input to understand quarkonium production

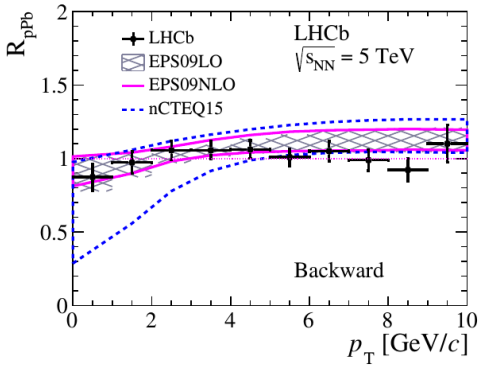
Open charm production at 5 and 13 TeV in pp collisions

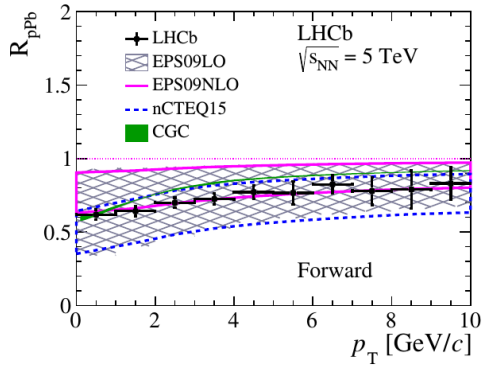


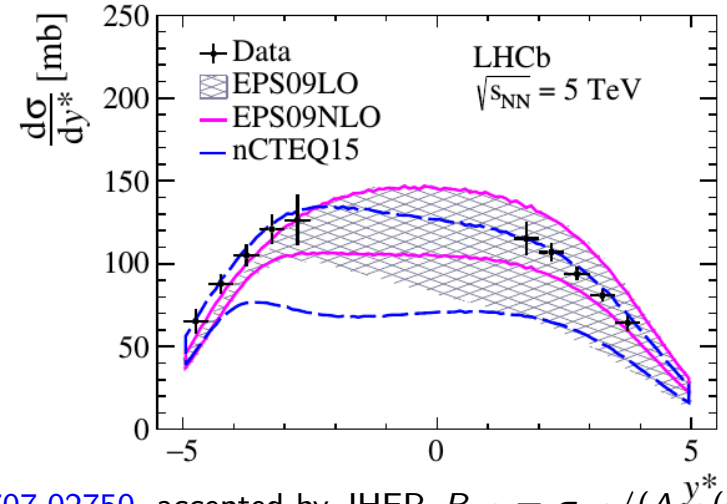
open charm production at 5 TeV JHEP06(2017)147 and at 13 TeV JHEP03(2016)159 JHEP09(2016)013 JHEP05(2017)074

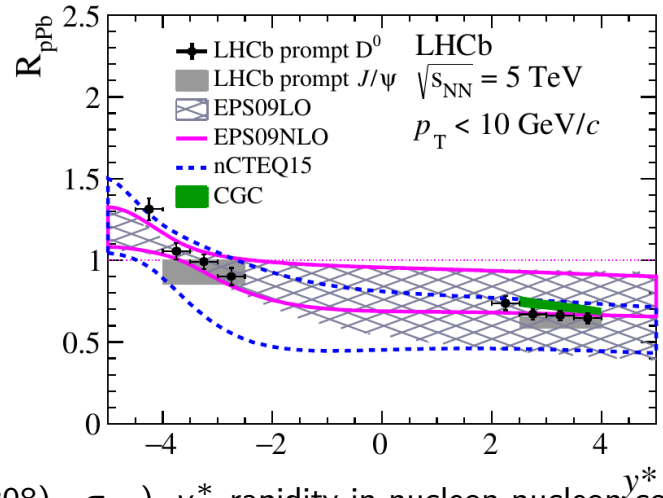
- fixed-order NLO combined with next-to-leading-log-resummation at high-p_T: successfully describing the absolute cross sections and their ratios between different energies
- no sign of break-down of collinear factorisation
- prerequisite to exploit data as PDF constraints beyond HERA-reach

D^0 in pPb: $\sqrt{s_{NN}} = 5$ TeV





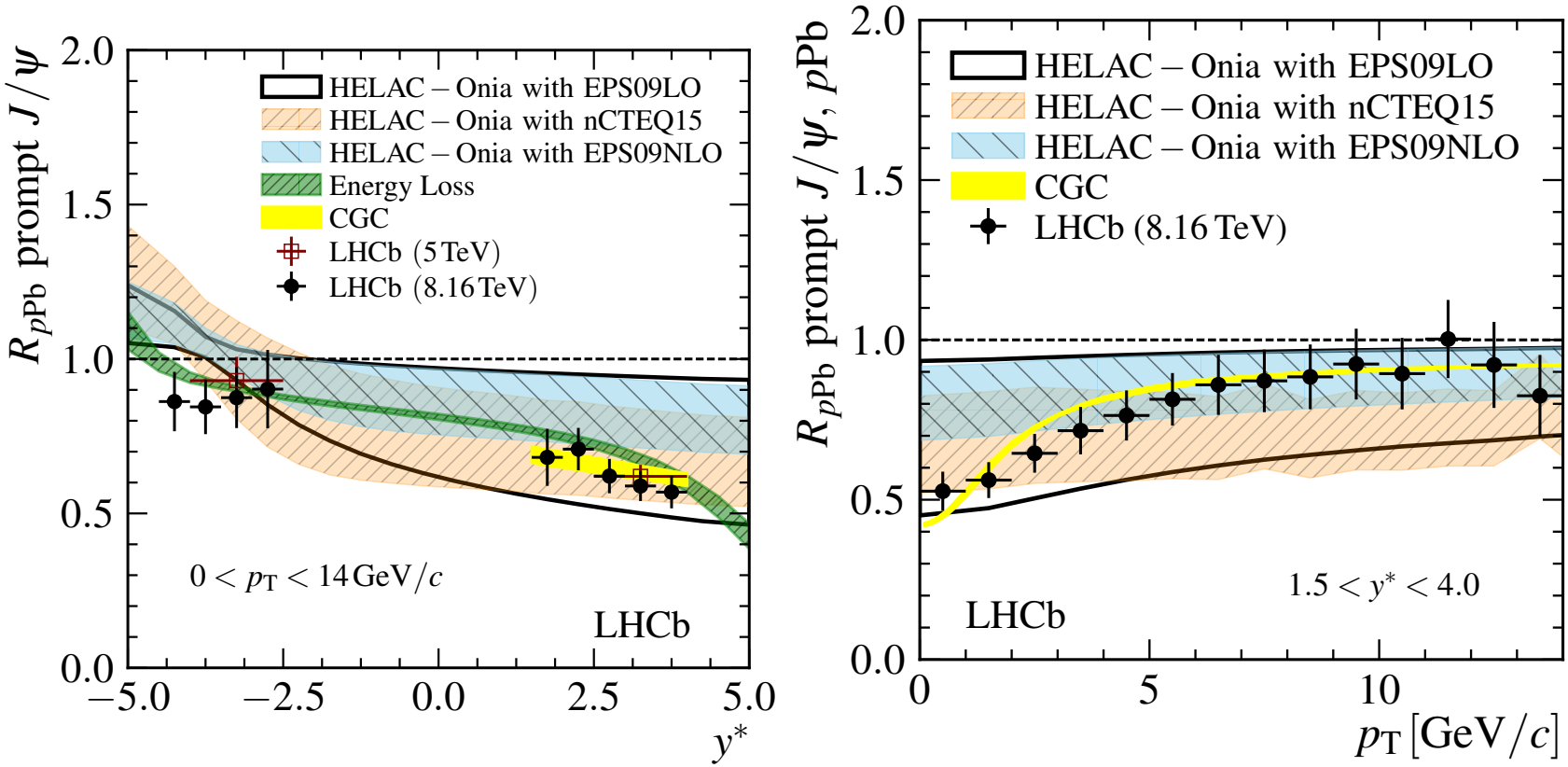




arXiv:1707.02750, accepted by JHEP, $R_{pA} = \sigma_{pA}/(A_{Pb}(= 208) \cdot \sigma_{pp})$, y^* rapidity in nucleon-nucleon collision frame, $y^* = y_{lab} - (+)0.465$ for forward (backward) configuration.

- sensitive to gluons down to $x = 10^{-6}$:
  best place to look for saturation, saturation scale $Q_S^2 \propto A^{1/3}$, $A_{Pb} = 208$
- Colour glass condensate and nuclear PDFs can describe data
- far more precise than nuclear PDF uncertainties since no HERA equivalent for nuclei
  $\rightarrow$ very important measurement for heavy-ion physics

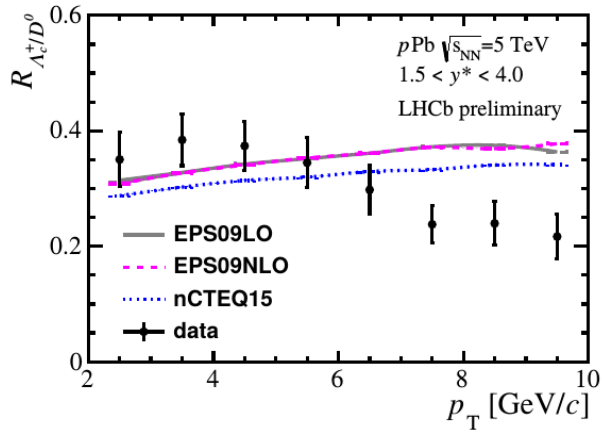
Prompt J/ψ in pPb at $\sqrt{s_{NN}} = 8.16$ TeV

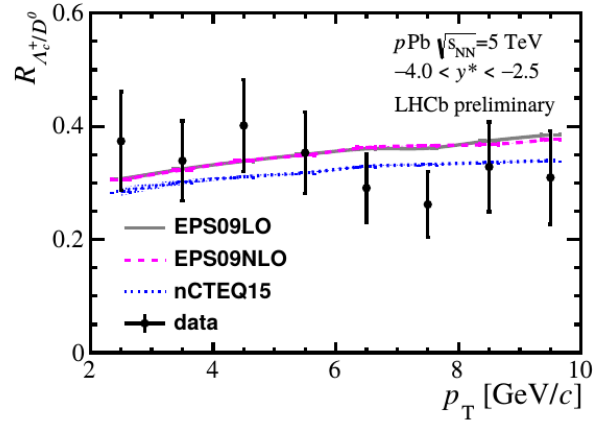


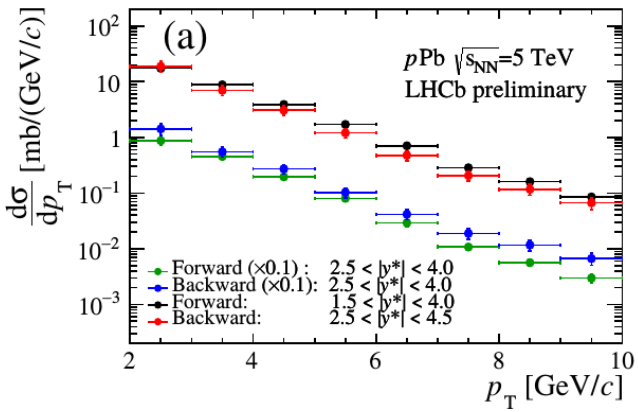
LHCB-PAPER-2017-014: accepted by PLB.

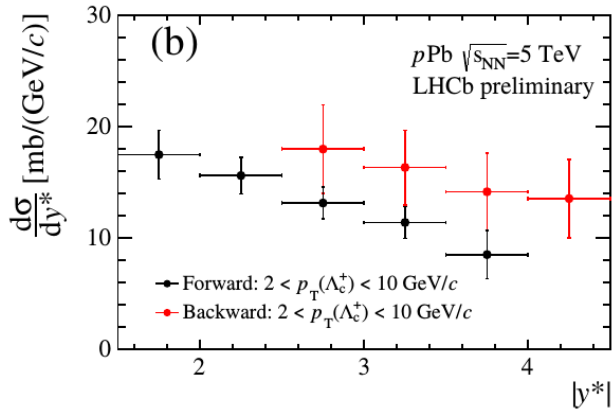
- collinear factorisation with HELAC-Onia arXiv:1610.05282, colour glass condensate arXiv:1503.02789, coherent energy loss arXiv:1212.0434
- remarkable: at very backward rapidity rise seen in D-meson data at 5 TeV not seen here in prompt J/ψ: D-measurement to be repeated at 8.16 TeV

Λ_C in pPb: $\sqrt{s_{NN}}$ =5 TeV





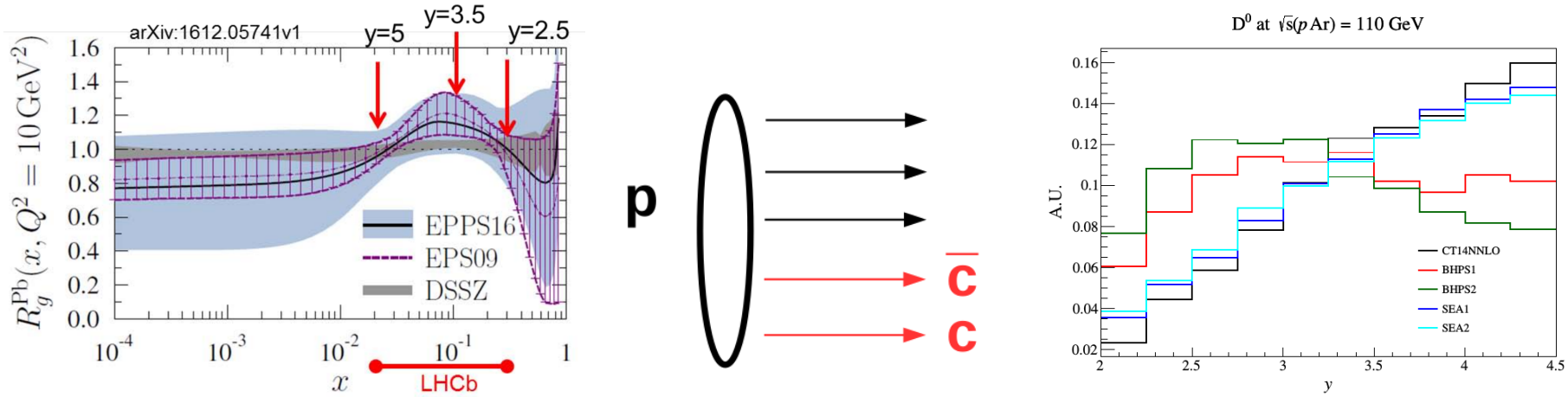




LHCb-CONF-2017–05.

- test of charm hadronisation universality in pPb: important input to understand behaviour observed in strangeness sector in pPb and high multiplicity events in pp/pPb related to the creation of a locally thermalised system
- to be complemented with a pp measurement at same $\sqrt{s_{NN}}$ for publication

Charm production in fixed-target collisions: unique constraints

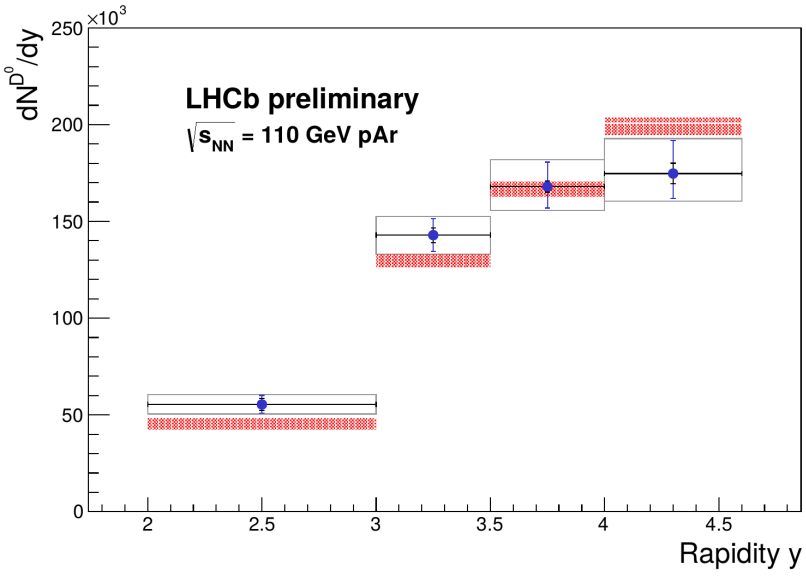


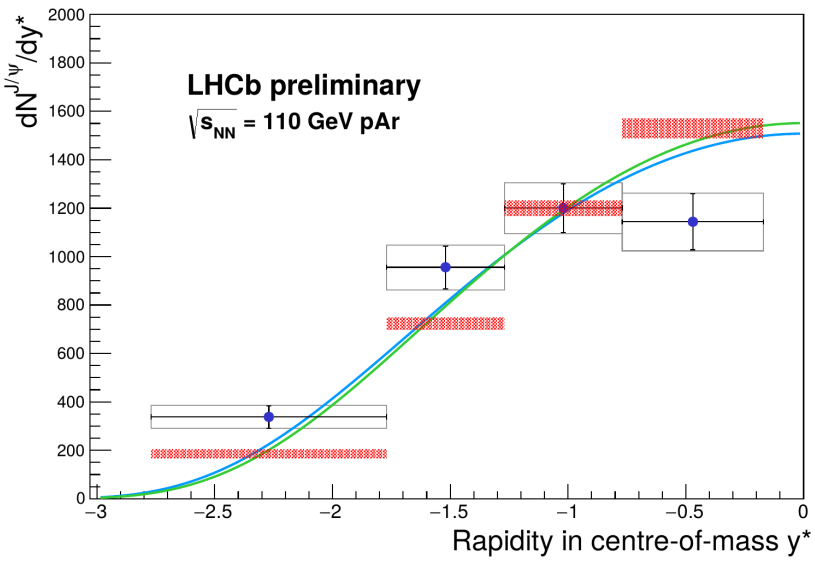
Left: figure from talk by E. Maurice at QM 2017; right: figure by P. Ilten link, considered pdf models based on CT14 from: Phys. Rev. D 93, 074008

- SMOG built for improved luminosity measured allowing for unique fixed-target programme with noble gas targets
- sensitive to nuclear modification of parton distribution function & intrinsic charm
- additional mechanisms can play a role: hadronisation time scale can be smaller than crossing time of proton through nucleus at this collision energy

Charm production in fixed target collisions: first results

Rapidity in cms: $y^* = y - 4.77$

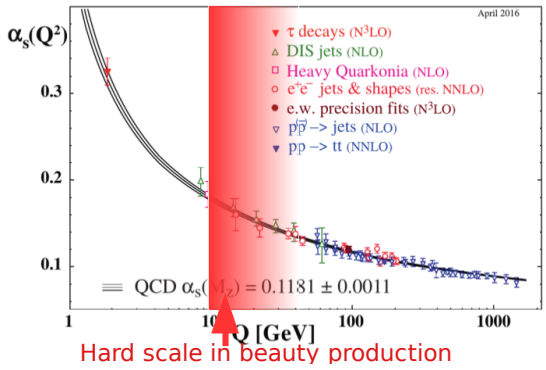


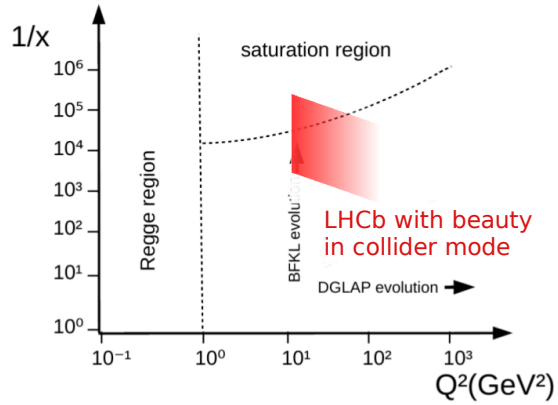


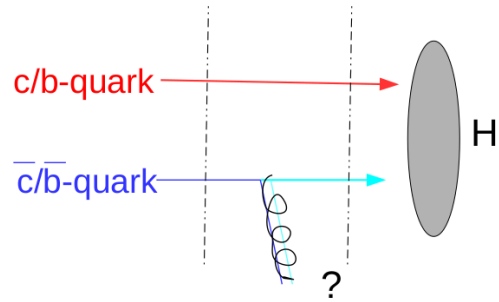
LHCb-CONF-2017-001

- normalised distributions compared with PYTHIA 8 with CT09MCS and with parameterisation of world-data by Arleo et al. for charmonium
- final analysis together with *p*He result

Open beauty & bottomonium production





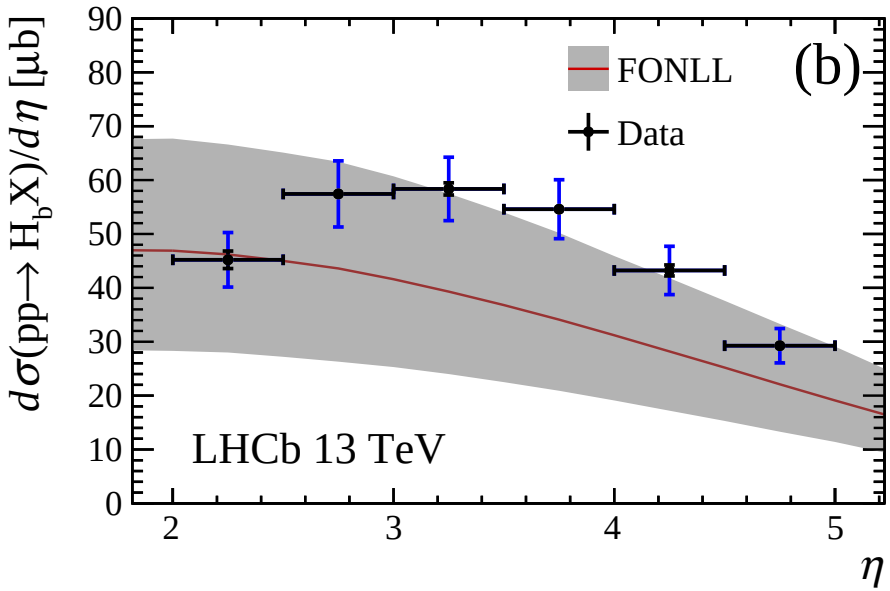


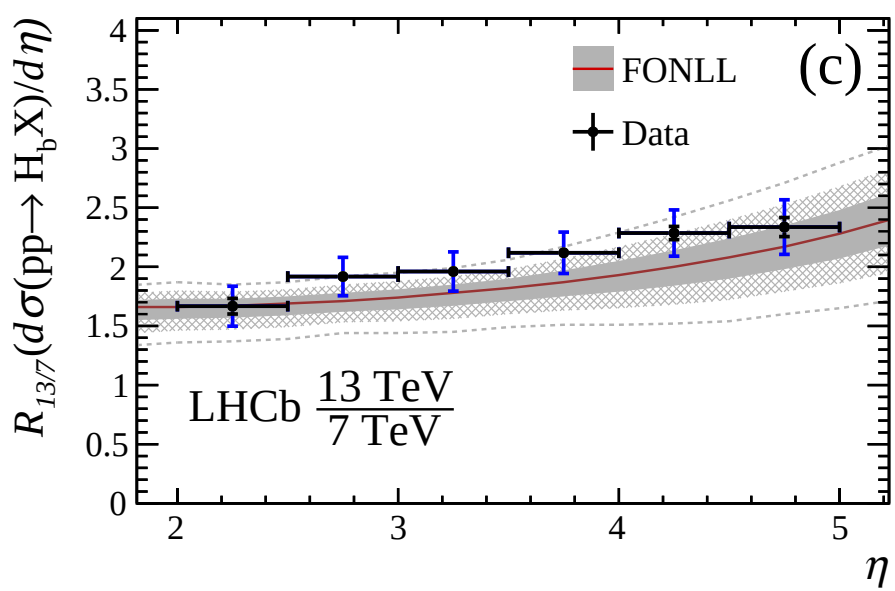
Left: adapted from PDG '16 QCD review; middle: adapted from R. Ellis, W. Stirling, and B. Webber. QCD and collider physics.

Beauty production scale $Q \geq 2m_b = 10\ \text{GeV}/c^2$

- better perturbative convergence as for charm, still low-x values reached
- relativistic corrections for bottomonium ground states smaller than for charmonium
- understanding relevant for heavy-flavour precision measurements: e.g. flavour tagging in presence of double parton scattering & factorisation assumptions intertwined between decay and production
- understanding crucial basis for heavy-ions: best proxy of static colour charges within thermodynamic QCD system $\rightarrow$ probe deconfinement

B-hadron production in *pp* collisions at 13 TeV and 8 TeV

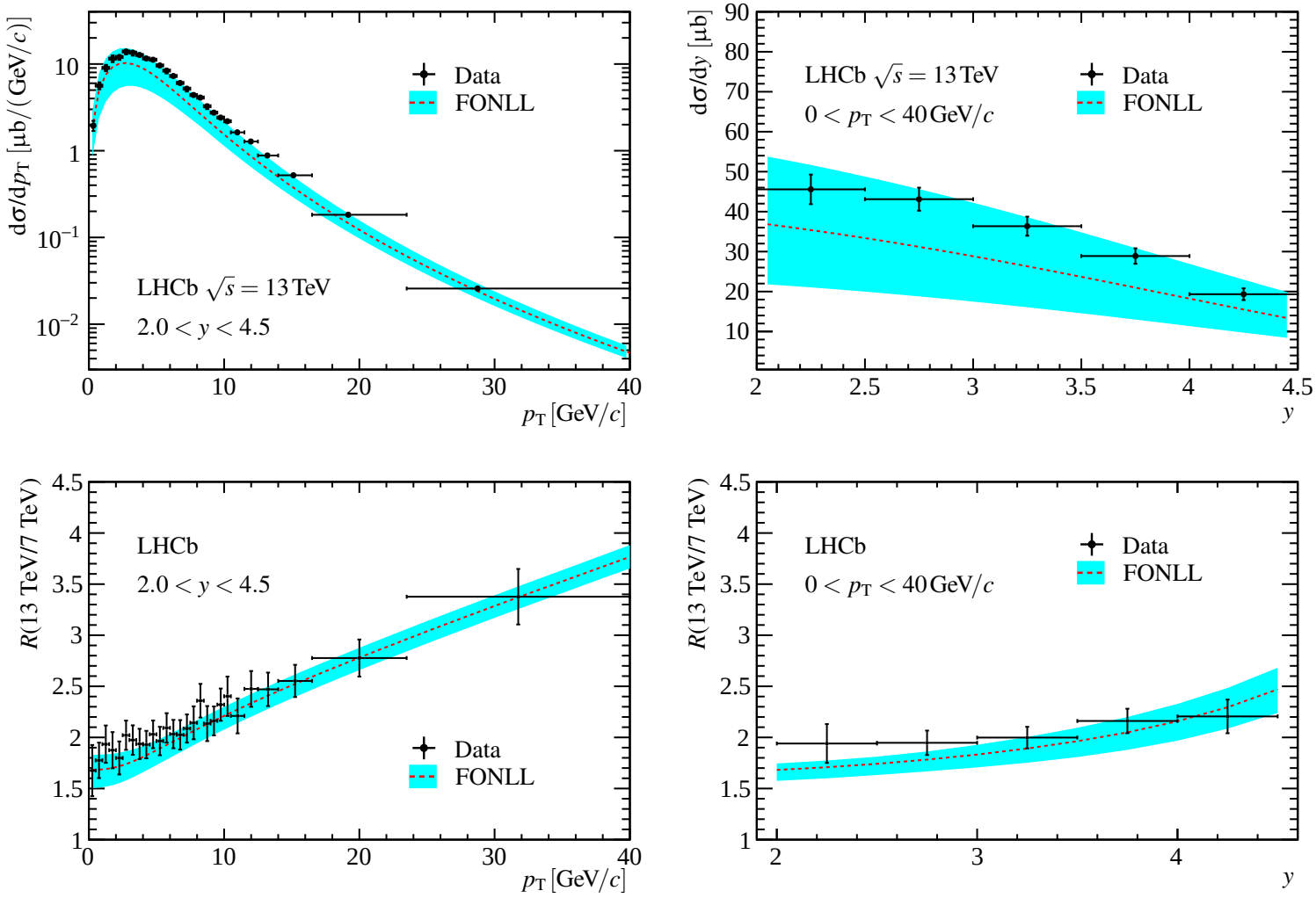




Phys. Rev. Lett. 118, 052002 (2017), arXiv:1612.0514

- precision measurement exploiting semileptontic decays: $b \to \mu$+charm hadron
- cross section and cross section ratio compatible with FONLL

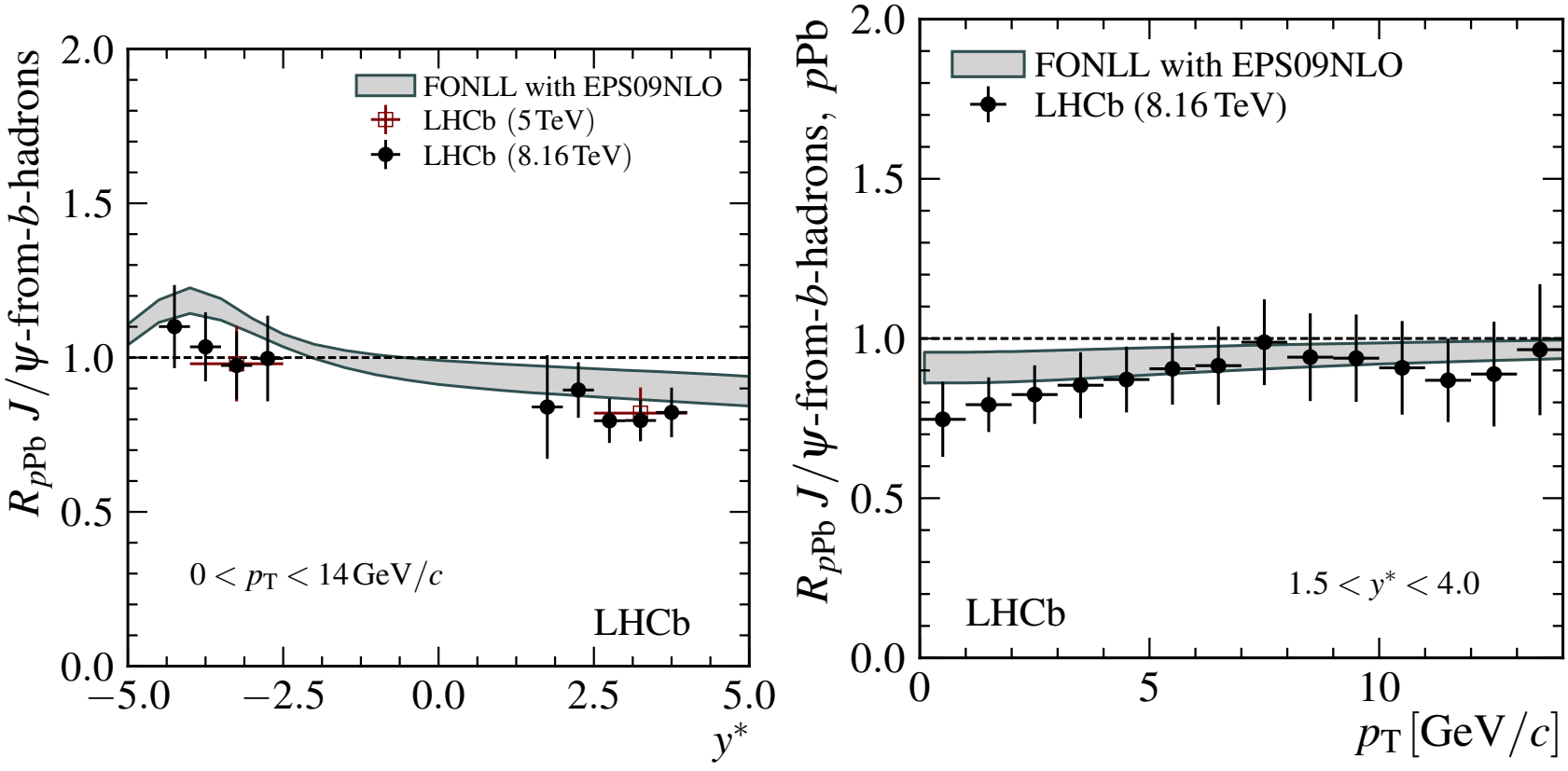
$B^{\pm}$ production at 7 and 13 TeV



arXiv:1710.04921

- $B^{\pm}$ production cross section via decay mode $J/\psi(\rightarrow \mu^+\mu^-) + K^{\pm}$ at 7 and 13 TeV and corresponding ratios described by state of art QCD calculation up to p_T =40 GeV/c

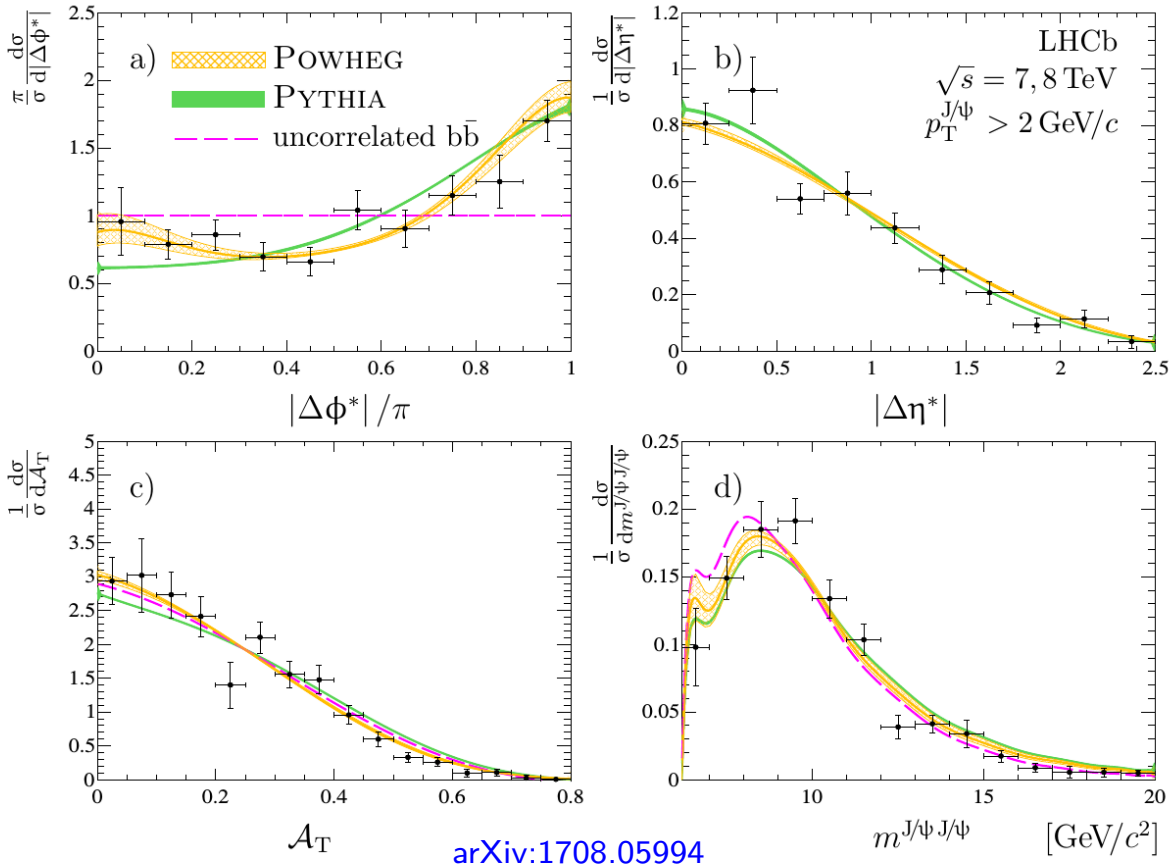
Nonprompt J/ψ in pPb at $\sqrt{s_{NN}} = 8.16$ TeV



LHCB-PAPER-2017-014: accepted by PLB, $R_{pPb} = \sigma_{pPb,J/\psi}/(208 \cdot \sigma_{pp,J/\psi})$

- first precise B-production measurement in pPb in general and down to low-p_T
- collinear factorisation with nuclear PDF EPS09 combined with FONLL describing data
- important input for the interpretation of nucleus-nucleus data on beauty production

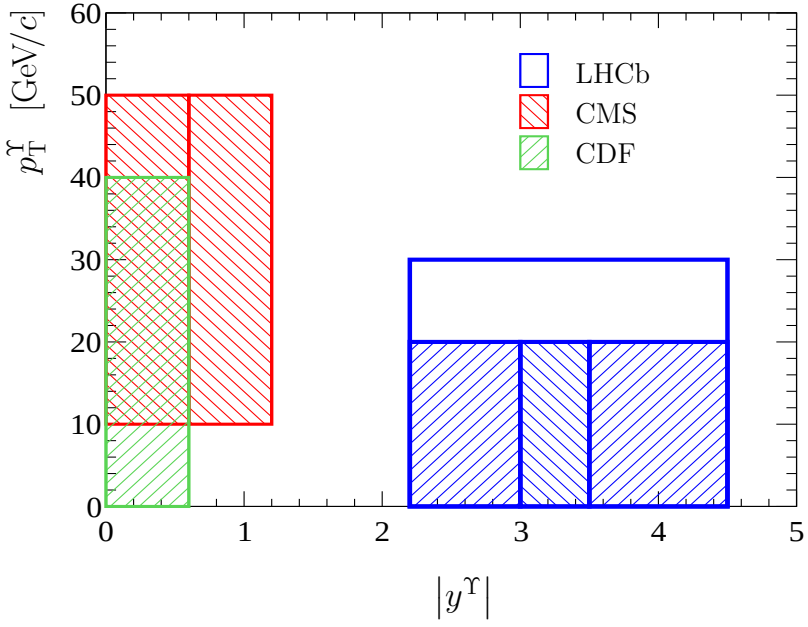
$b\bar{b}$-correlation via non-prompt J/ψ

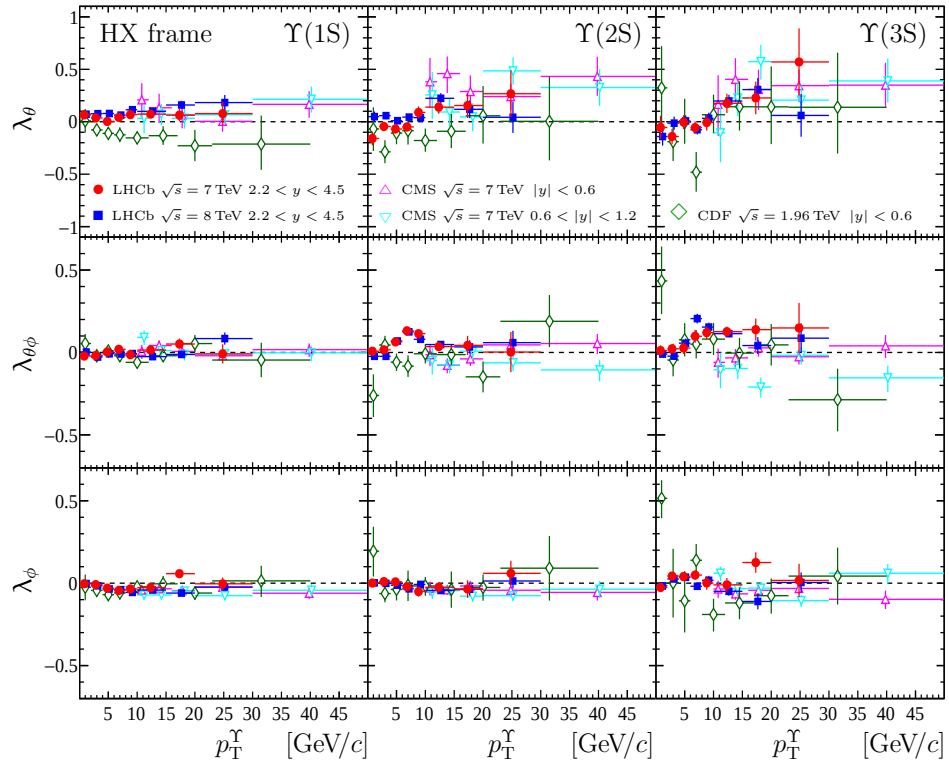


arXiv:1708.05994

- correlation decribed by Pythia (LO) and POWHEG (NLO)
- no large contribution from gluon splitting in contrast to $c\bar{c}$ measurement by LHCb J. High Energy Phys., 06 (2012) 141: no prominent peak at $\Delta\phi = 0$
- measurement based on 3 fb^{-1} at 7 and 8 TeV:
  future measurements for better discrimination power

Υ-polarisation in pp collisions

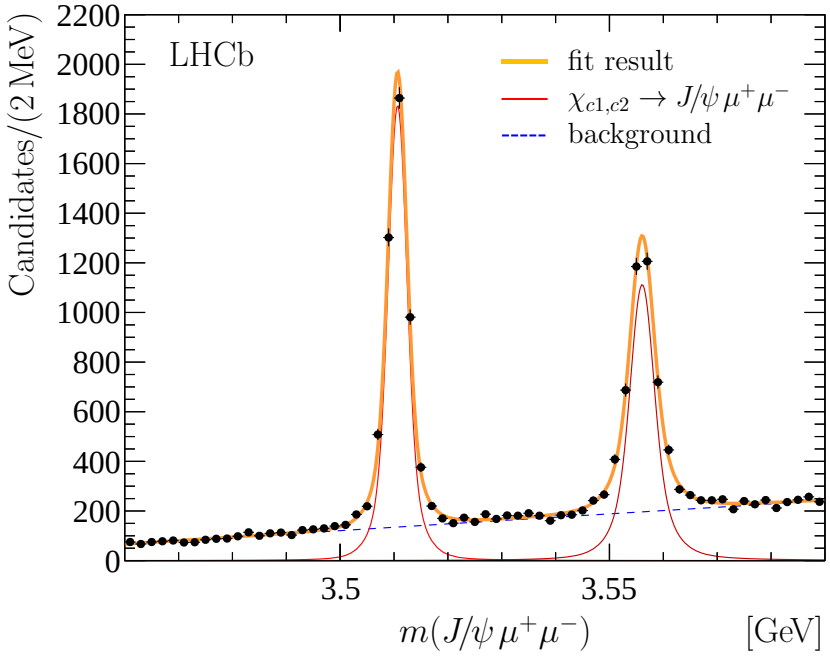


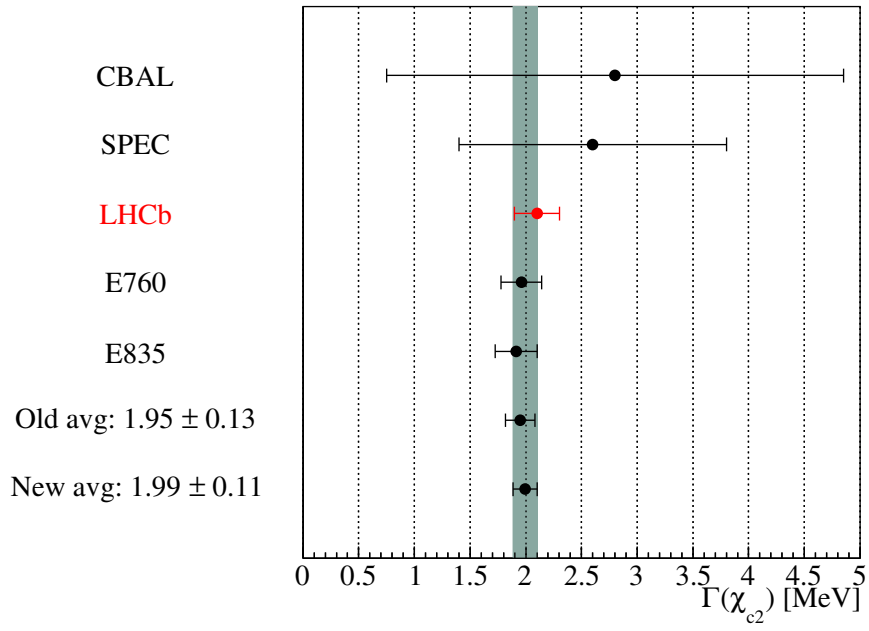


acceptance and example comparison for helicity frame from arXiv:1709.01301

- precision measurement of Υ polarisation down to 0 p_T
- statistically limited & different frames consistent w.r.t. each other
- agreement with CMS results at midrapidity
- important input to progress in the understanding of quarkonium hadroproduction

New roads for production studies





arXiv:1709.04247

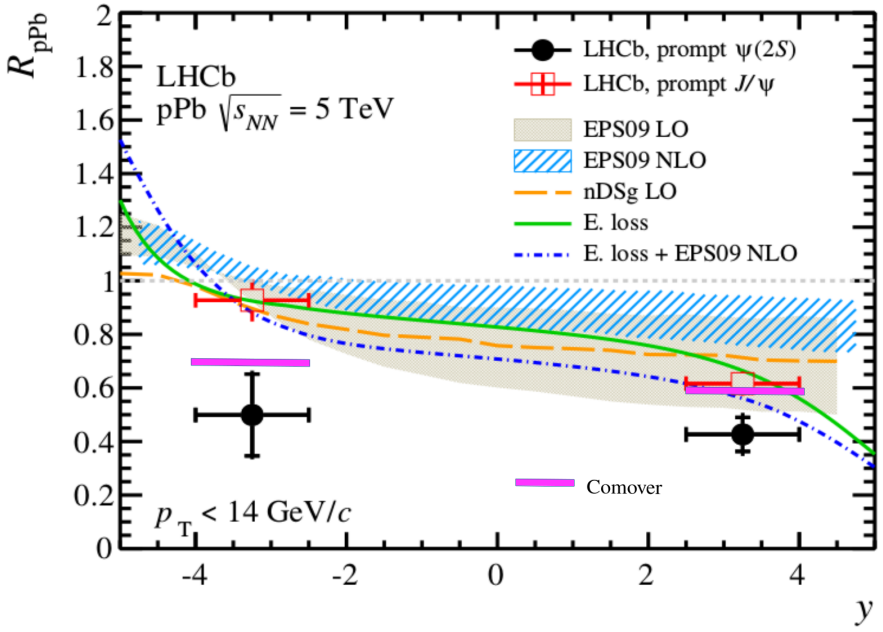
- one example: first observation of $\chi_{c1,c2} \to J/\psi(\to \mu^+\mu^-)\gamma^*(\to \mu^+\mu^-)$
- among the most precise single experiment determinations of χ_{c2}-width and masses with different systematic uncertainties
- starting point for production studies with large S/B and very good resolution

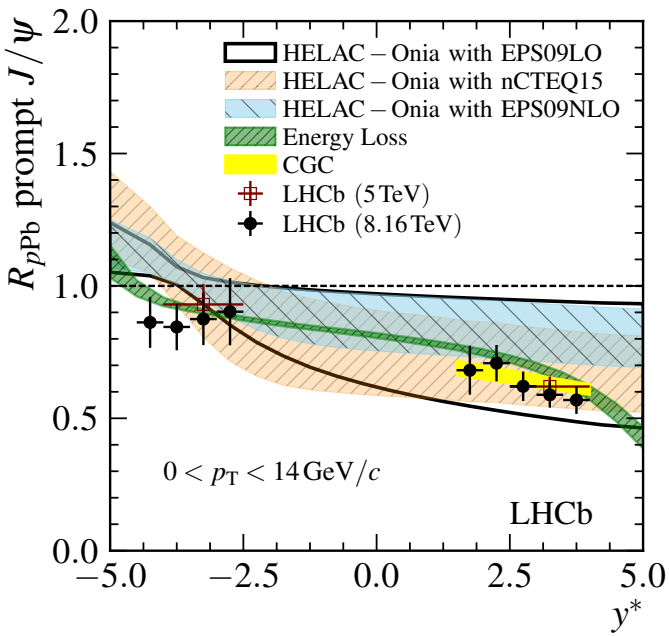
Conclusions

A variety of new heavy-flavour production measurements by LHCb available in pp and in nuclear collider and fixed-target collisions:

- constraining the partonic content of the proton and of nuclei
- probing the limits of collinear factorisation
- testing NRQCD factorisation in quarkonium production
- large potential with fixed-target collision studies:
  denser target in consideration for Run 3
- much more to come!

Back-up: Break-down of factorisation in nuclear collisions

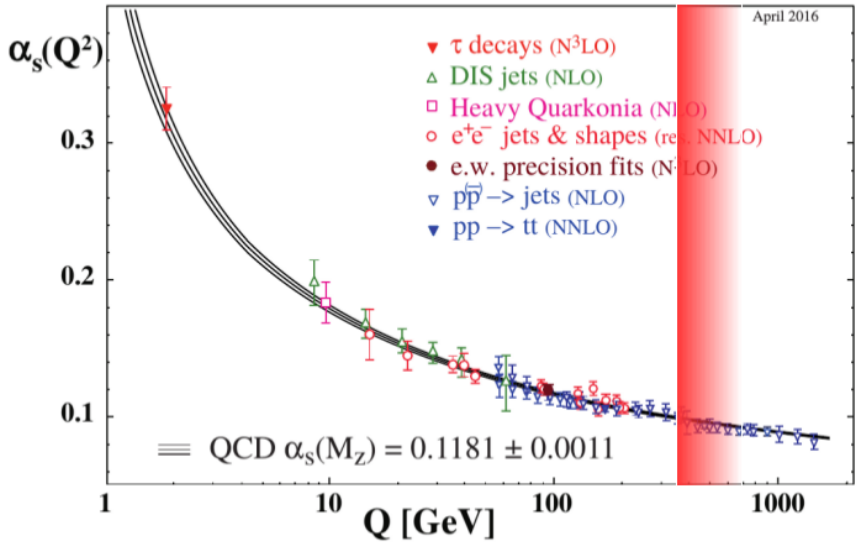




5 TeV: JHEP 02 (2014) 072, JHEP 1603 (2016) 133; 8.16 TeV arxiv:1706.07122, accepted by PLB.

- J/ψ result compatible with nuclear PDFs, coherent energy loss model, recent colour glass condensate calculations
- additional suppression for ψ(2S) not explained by nuclear PDFs nor by coherent energy loss
- 'comover' model with no precisely specified secondary interaction Phys.Lett. B749 (2015) 98-103: additional suppression also with hadron resonance gas + QGP ansatz by Du & Rapp Nucl.Phys. A 943 (2015)
- calculation from gluon-kicks estimated with Color Glass Condensate approach and colour evaporation model can explain the data arXiv:1707.07299

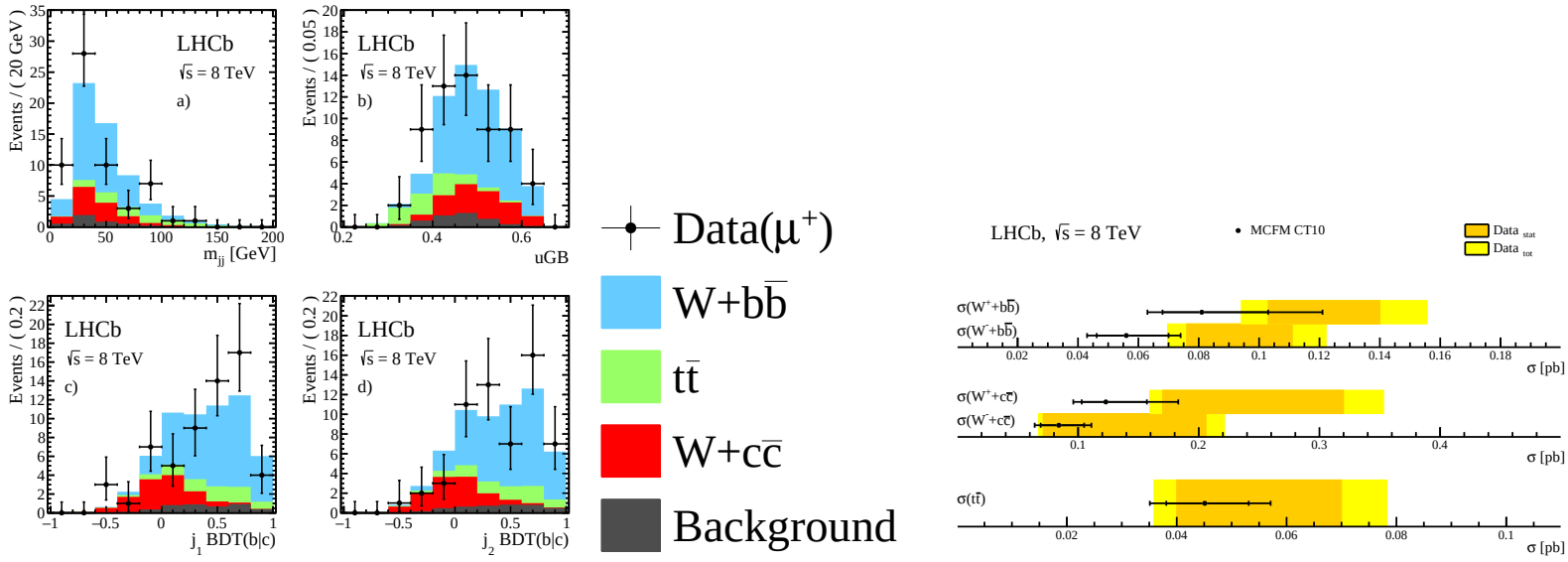
Back-up: top production in pp collisions



PDG '16 QCD review

- $m_{t\bar{t}} = 350$ GeV$/c^2$: large mass scale process
- well in the perturbative regime
- suited to probe gluon-PDFs at high-x

Back-up: $t\bar{t}$ production with lepton+2 jets in pp collisions at 8 TeV



Left: example for fit with μ^+ Phys. Lett. B767 (2017) 110.

- simultaneous 4D-fit for $\mu^{+/-}$ & $e^{+/-}$
- fiducial cross sections for $t\bar{t}$, $W + b\bar{b}$ $W + c\bar{c}$ in agreement with MCFM
- just the start of more to come with more statistics at higher collision energy