Open charm production in pp collisions at LHC

Sergey Barsuk, LAL Orsay
on behalf of Alice, Atlas, CMS and LHCb collaborations

Selected results since CHARM 2016

- In this talk: new results on
  open charm production in pp collisions

LHCb: Differential production cross-sections of D mesons at $\sqrt{s}$ = 5 and 13 TeV

ALICE: Differential production cross-sections of D mesons at $\sqrt{s}$ = 7 TeV

ALICE: First measurement of Ξ_c production at $\sqrt{s}$ = 7 TeV

LHCb: D_s production asymmetries at $\sqrt{s}$ = 7 and 8 TeV

Open charm and charmonium production @CHARM 2018: theory and experiment

- Open Charm production in pp collisions at LHC, SB
- Theory review of Charmonium production at LHC, Hong-Fei Zhang
- Charmonium production at LHC, Xiao-Rui Lyu
- Double Charmonium production in the LHC, Stanislav Poslavsky
- Multiple Charm and Charmonium production at LHC, Darren Price
- Soft gluon factorization, Yan-Qing Ma
- Experimental review of Open Charm in pA collisions, Alessandro Grelli
- Experimental review of Open Charm in AA collisions, Xiaoming Zhang
- Experimental review of Quarkonium production in pA collisions, Patrick Robbe
- Quarkonium production in AA collisions, Zebo Tang
- Theoretical overview of Charmonium evolutions in the hot medium, Baoyi Chen
- Open Charm in heavy-ion collisions, Magdalena Djordjevic
- Effective field theory calculations in Open Charm and Charmonium in media, Miguel Angel Escobedo Espinosa
- Charmonium suppression at finite temperature (lattice QCD), Hai-Tao Shu
- Measurement of multiplicity dependence of heavy-flavour hadron production in small systems and azimuthal correlations with charged particles with ALICE at the LHC, Marianna Mazzilli

Associate production

pp collisions

Heavy-ion collisions, pA and AA

❑ **Powerful QCD tests**, instead of using QCD to estimate observables, use production measurements to qualify QCD

❑ Essential to **consistently describe production/creation of heavy hadrons**

❑ New theory developments confronted to new experimental results

Impressive progress in both domains

from J.Effel, Création du Monde

❑ First clash to describe **« J/ψ production puzzle »**

❑ **« J/ψ production AND polarization puzzle »** boosted the progress

❑ Recently with the $\eta_c(1S)$ production measurement by LHCb more challenging **« J/ψ production AND polarization AND $\eta_c(1S)$ production puzzle »**

❑ **More precision** in conventional studies and **new sources of input**: quarkonium and **open charm** and beauty production, associate production, isolation, production in pPb and PbPb collisions, …

❑ A unique comprehensive model of **HF production** still missing

- Two scales of production:

  hard process of **$Q\bar{Q}$ formation** and **hadronization of $Q\bar{Q}$** at softer scales

- **Factorization**:

$$d\sigma_{A+B\to H+X} = \sum_n d\sigma_{A+B\to Q\bar{Q}(n)+X} \times \langle \mathcal{O}^H(n) \rangle$$

Short distance: perturbative cross-sections + pdf for the production of a $Q\bar{Q}$ pair

Long distance matrix elements (LDME), non-perturbative part

- Colour-singlet model: intermediate $Q\bar{Q}$ state is colourless and has the same J^{PC} quantum numbers as the final-state quarkonium

- NRQCD: all viable colours and J^{PC} allowed for the intermediate $Q\bar{Q}$ state, they are adjusted in the long-distance part with a given probability. LDME from experimental data

- **Universality**: *same LDME for prompt production and production in b-decays*

- Heavy-Quark **Spin-Symmetry**: links between colour-singlet and colour-octet LDME of different quarkonium states

- NEEDED: theory description and experimental verifications for many HF species at largest possible p_T and rapidity ranges

- **D-meson production to probe low scale distributions**, which are more sensitive to input gluon PDF: production of $c\bar{c}$ pair followed by fragmentation of c quark into D meson
- **Gluon fusion gg** dominates forward D meson production
- m_c is not large + large rapidity → probe gluon distribution $g(x,\mu_F^2)$ at small x

$$x \sim (m_T/\sqrt{s})e^{-y} \sim 10^{-5}$$

and at small factorization scale $\mu_F \sim m_T$

- Large uncertainties in **gluon PDF at low x**

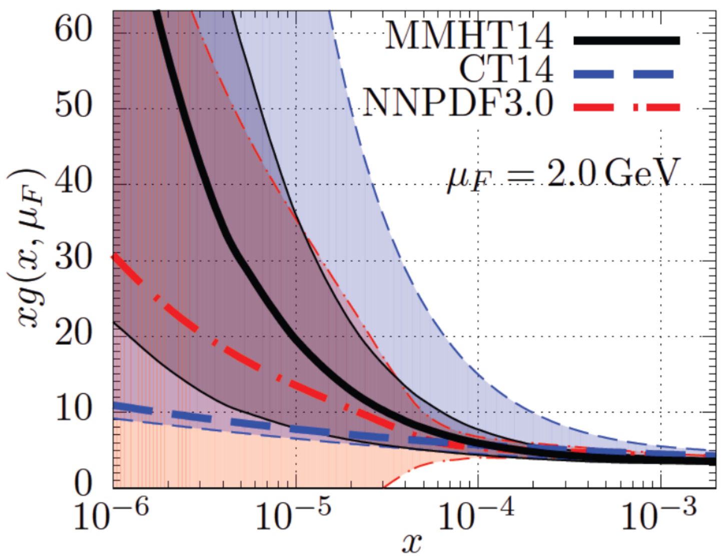
E.G.de Oliveira, A.D.Martin, M.G.Ryskin, arXiv:1712.06834

- Low x gluon density from NLO global parton analyses

R.D.Ball et al., JHEP 04 (2015) 040
L.A.Harland-Lang et al., EPJC 75 (2015) 204
S.Dulat et al., PRD 93 (2016) 033006

calculated using PDF interpolator LHAPDF

A.Buckley et al., EPJC 75 (2015) 132

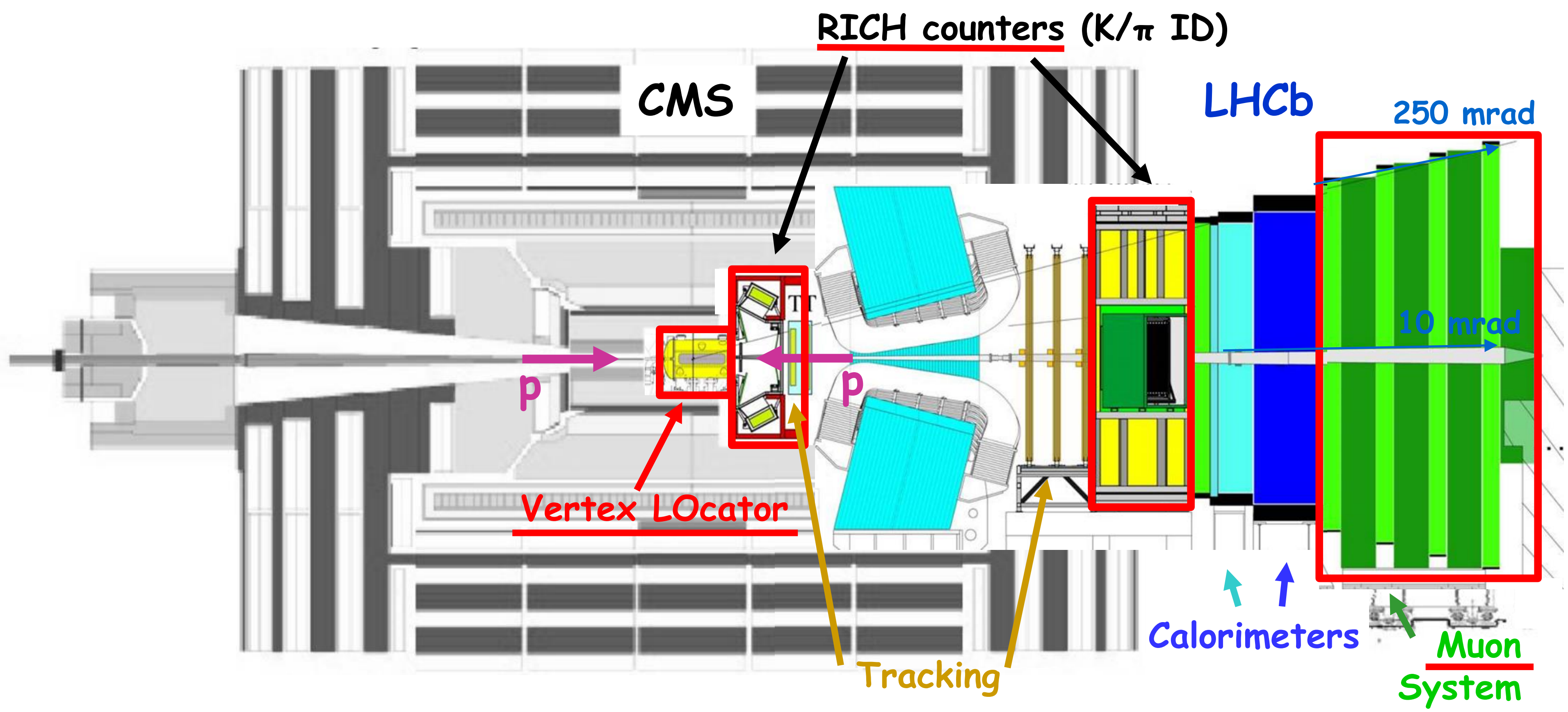


- Major problem: **choice of factorization and renormalization scales; less sensitive in ratios**, which do not however determine the normalization of gluon density

Production measurements by the LHC experiments

JINST 8 (2013) P08002, INT.J.MOD.PHYS.A30 (2015) 1530022

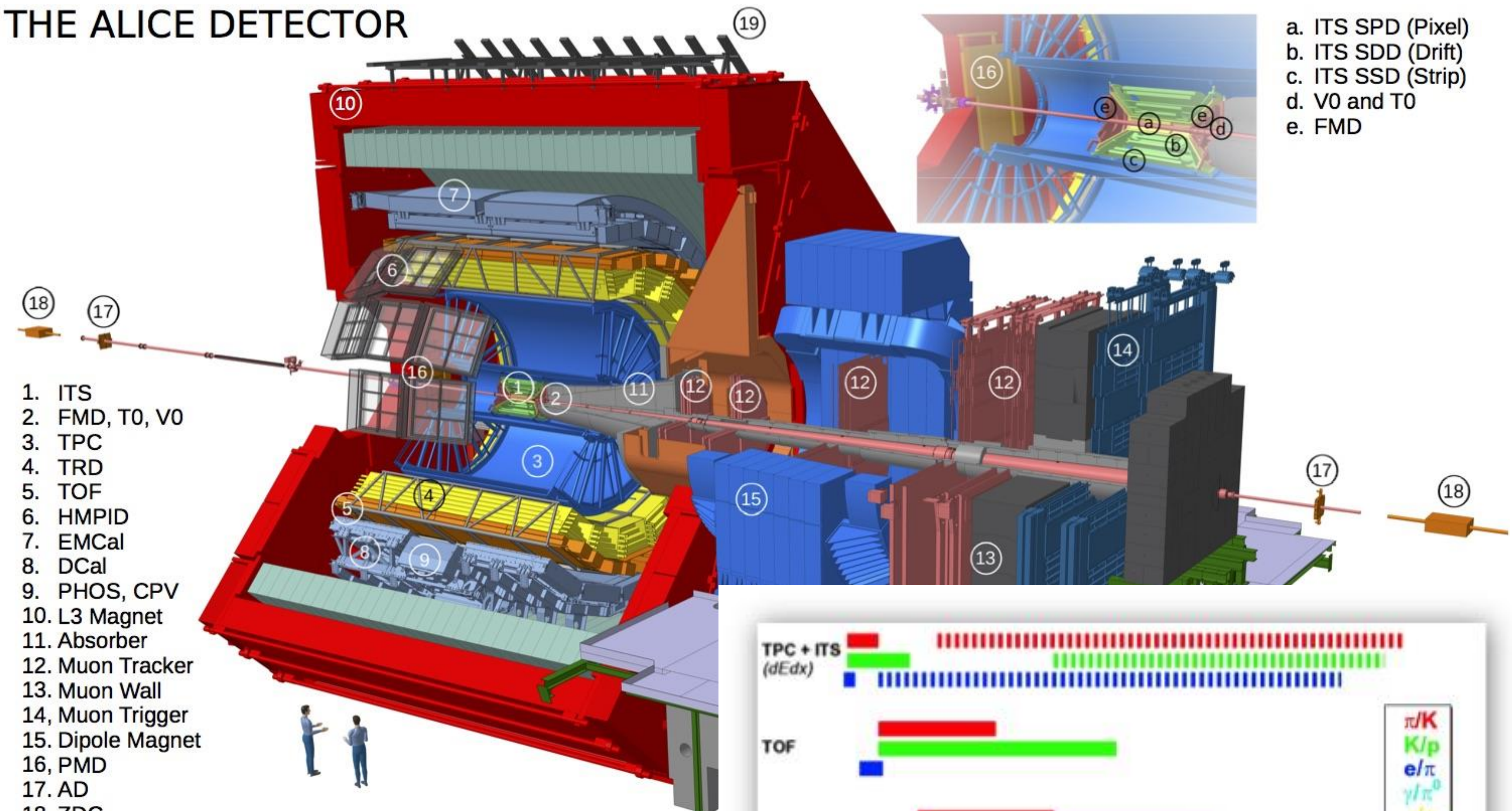
- **LHCb**: precision flavour physics, forward peaked HQ production
- Acceptance 1.9 < η < 4.9, **~4% of solid angle**, but **~40% of HQ production x-section**

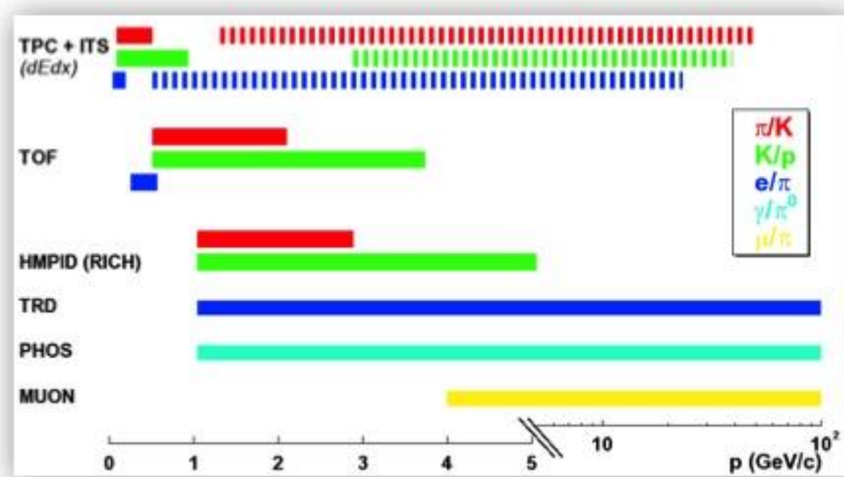


- **Complementary cross-section measurements** and overlap in terms of rapidity
- Key detector systems for production measurements: **vertex reconstruction (VELO), particle identification (Muon detector, RICHs), Trigger**

JINST 3 (2008) S08002, INT.J.MOD.PHYS.A29 (2014) 1430044

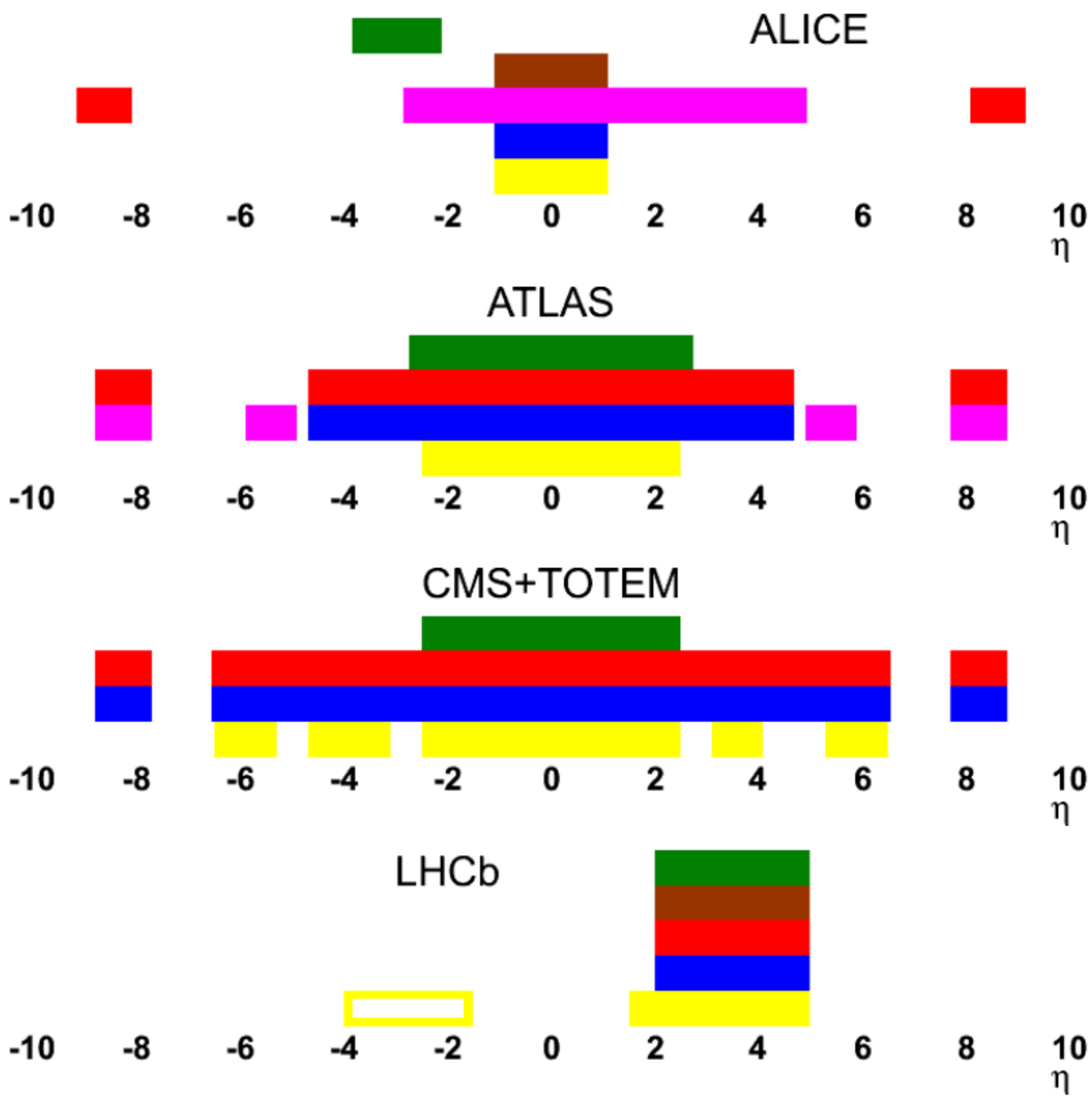
- **ALICE**: nuclei collisions at ultra-relativistic energies, QGP





- **Particle identification** (Tracker, TOF, HMPID, …)

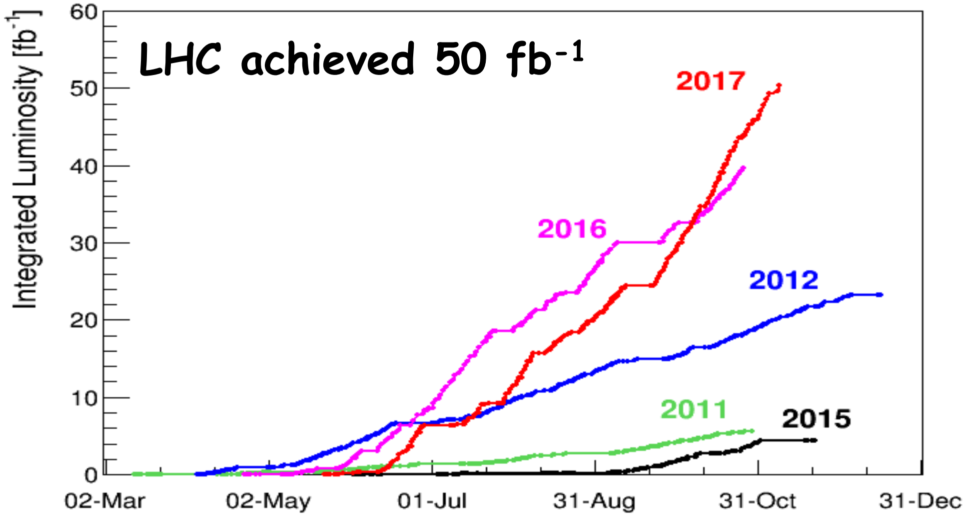
Production measurements by the LHC experiments



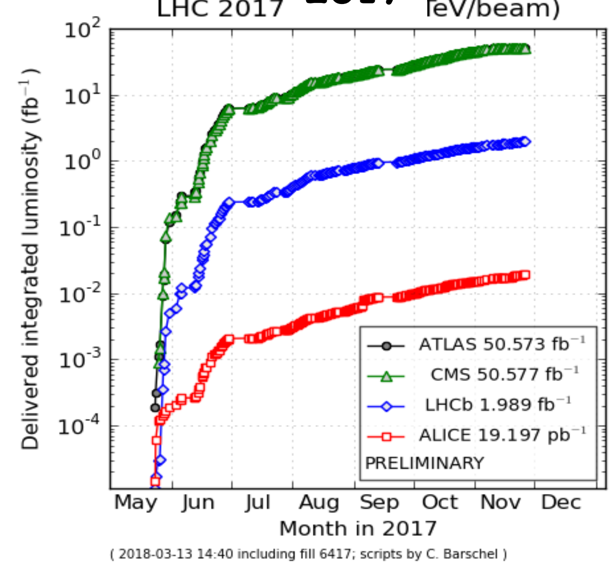
- ALICE
  - ➔ central
  - ➔ forward muon coverage
- ATLAS & CMS
  - ➔ central detectors
- LHCb
  - ➔ forward detector
  - ➔ tracking, particle-ID and calorimetry in full acceptance

Data samples

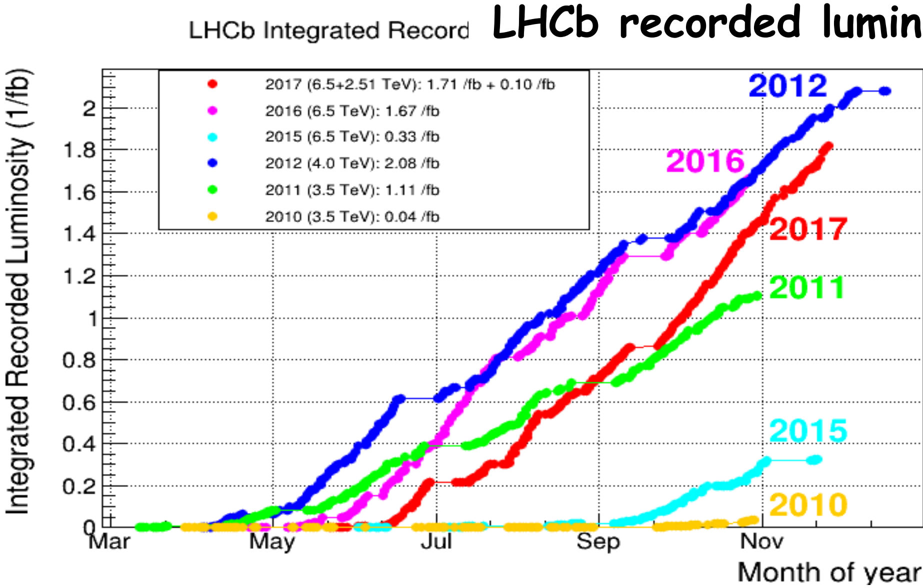
LHC delivered luminosity



2017



LHCb recorded luminosity in pp collisions



Run	Year	$\sqrt{s}$	$\mathcal{L}$
Run 1	2010	7 TeV	0.04 fb^{-1}
	2011	7 TeV	1.11 fb^{-1}
	2012	8 TeV	2.08 fb^{-1}
Run 2	2015	13 TeV	0.33 fb^{-1}
	2016	13 TeV	1.67 fb^{-1}
	2017	13 TeV	1.71 fb^{-1}
	2015	5 TeV	0.01 fb^{-1}
	2017	5 TeV	0.10 fb^{-1}

Open charm production in pp collisions

- Test of **pQCD and QCD-based models**
- **Sensitivity of precision SM tests** with CPV and rare decays
- **Normalization of backgrounds** for precision studies in HEP, cosmic-ray and neutrino astrophysics
- **Reference for heavy-ion program**

LHCb

ALICE

- Open charm prompt production at 7 TeV
  Nucl.Phys.B 871 (2013) 1
- Open charm prompt production at 7 TeV
  JHEP 01 (2012) 128
- Open charm prompt production at 13 TeV
  JHEP 1603 (2016) 159
  Err.: JHEP 1609 (2016) 013
  Err.: JHEP 1705 (2017) 074
- Open charm prompt production at 5 TeV
  JHEP 1706 (2017) 147
- Open charm prompt production at 7 TeV
  EPJC 77 (2017) 550

Open charm production at $\sqrt{s}$ = 5 and 13(*) TeV

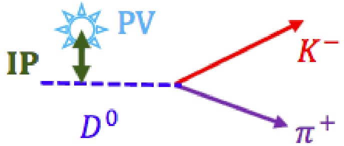
$\sqrt{s}$ = 5 TeV, $\int L dt \sim 8.6\ pb^{-1}$
$\sqrt{s}$ = 13 TeV, $\int L dt \sim 5.0\ pb^{-1}$

JHEP 1706 (2017) 147
JHEP 1705 (2017) 074
JHEP 1609 (2016) 013
JHEP 1603 (2016) 159

- Charmed mesons reconstructed with hadronic decays, e.g. $D^0 \to K^- \pi^+$ with tight requirements on particle identification
- Measurement of **integrated** and **differential production cross-sections** in bins of p_T and y or y*

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

- Separate prompt D^0 from D^0 from b-decays using the D^0 impact parameter to primary vertex



(*) *An issue was identified in the simulated samples used to calculate* ***track reconstruction efficiencies for some LHCb Run II production papers → UPDATES.***

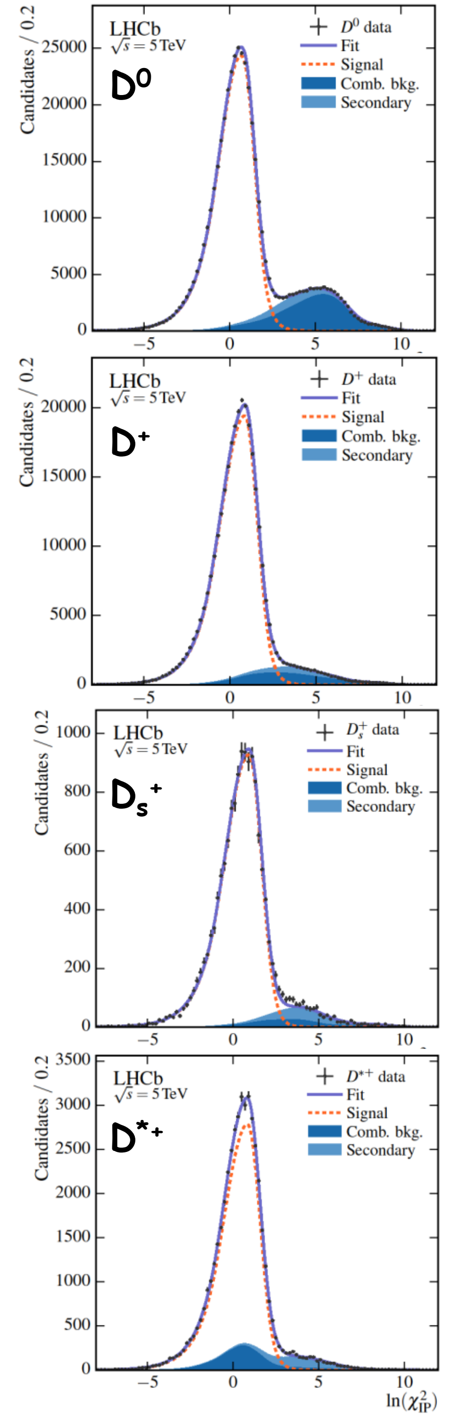
Reason: VELO simulation updated prior to Run II to account for radiation damage, but error in the parametric correction for the effect. Track efficiency calibration in data was unable to correct mis-modeling; track reconstruction efficiency underestimated in simulation; most affected: low pseudorapidity and low p_T.

Open charm production at $\sqrt{s}$ = 5 and 13 TeV

JHEP 1706 (2017) 147
JHEP 1705 (2017) 074
JHEP 1609 (2016) 013
JHEP 1603 (2016) 159

- Number of inclusive candidates from a fit to the mass distribution, then number of prompt D^0 fits to the ln χ^2 of the impact parameter with respect to the *pp* interaction vertex
- Efficiencies from simulation with data-driven corrections
- Also update of the measurement of **integrated** and **differential production cross-sections** of at $\sqrt{s}$ = **13 TeV**
- **Integrated inclusive cross-sections**
  (1 < p_T < 8 GeV/c, 2.0 < y < 4.5) :

	$\sqrt{s}$ = 5 TeV	$\sqrt{s}$ = 13 TeV
σ(pp → D^0 X)	1004 ± 3 ± 54 μb	2072 ± 2 ± 124 μb
σ(pp → D^+ X)	402 ± 2 ± 30 μb	834 ± 2 ± 78 μb
σ(pp → D_s^+ X)	170 ± 4 ± 16 μb	353 ± 9 ± 76 μb
σ(pp → D^{*+} X)	421 ± 5 ± 36 μb	784 ± 4 ± 87 μb

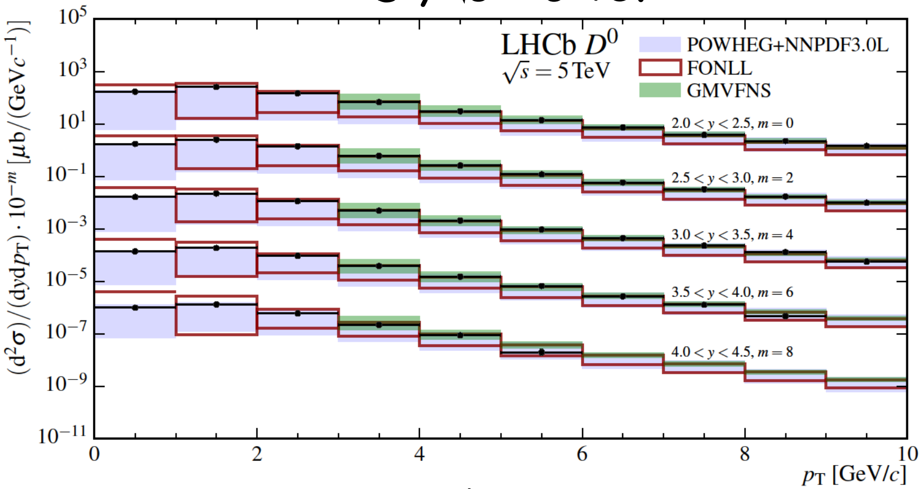


Open charm production at √s = 5 and 13 TeV

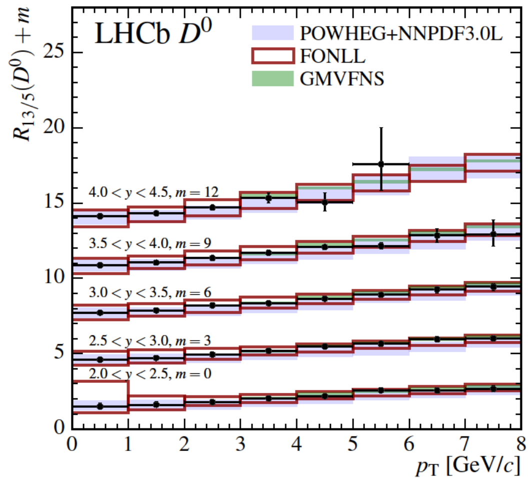
- Differential production cross-sections, *2.0 < y < 4.5*

JHEP 1706 (2017) 147
JHEP 1705 (2017) 074
JHEP 1609 (2016) 013
JHEP 1603 (2016) 159

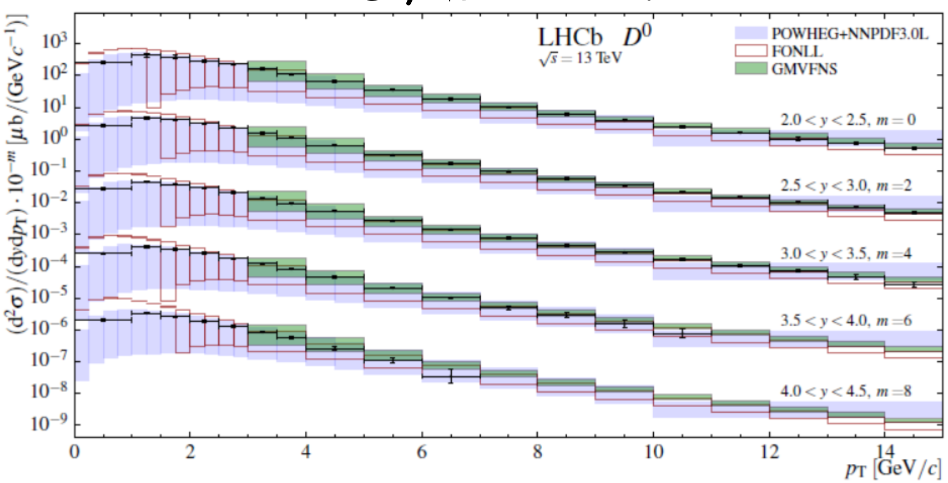
D^0, √s = 5 TeV



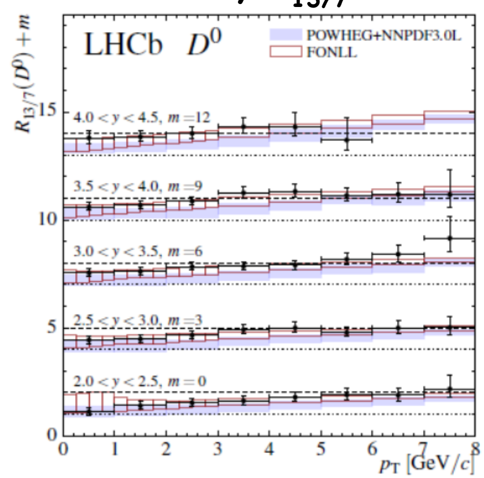
D^0, $R_{13/5}$



D^0, √s = 13 TeV



D^0, $R_{13/7}$

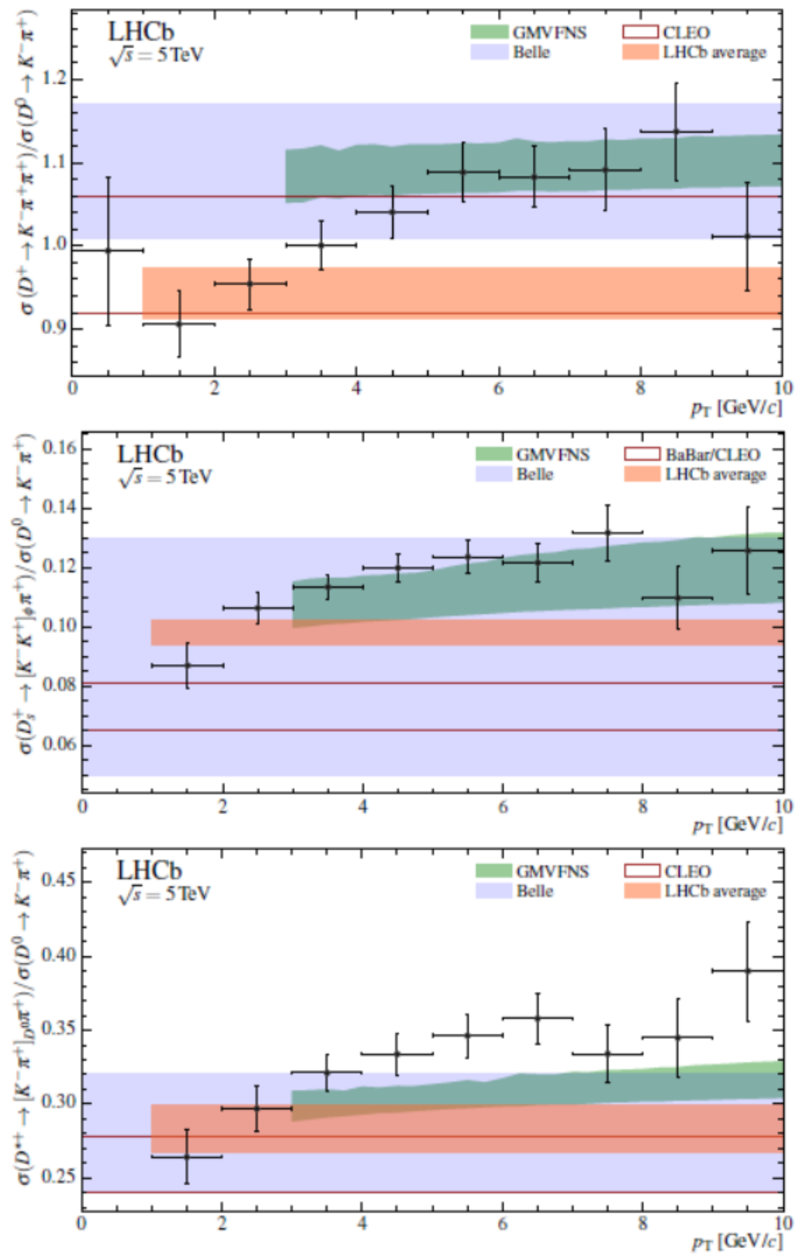


POWHEG+NNPDF3L: R.Gauld, J.Rojo, L.Rottoli, J.Talbert, JHEP11 (2015) 009
FONLL: M.Cacciari, M.L.Mangano, P.Nason, EPJC75 (2015) 610
GMVFNS: B.A.Kniehl, G.Kramer, I.Schienbein, H.Spiesberger EPJC72 (2012) 2082

- Reduced uncertainties in ratios
- General agreement with theory predictions

Open charm production at $\sqrt{s}$ = 5 and 13 TeV

JHEP 1706 (2017) 147
JHEP 1705 (2017) 074
JHEP 1609 (2016) 013
JHEP 1603 (2016) 159



- **Ratios of cross-section** times branching fraction of D^+, D^+_s and D^{*+} mesons with respect to the D^0 measurements.
- The ratios are given as a function of p_T integrated over y.

B.A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger
EPJC72 (2012) 2082

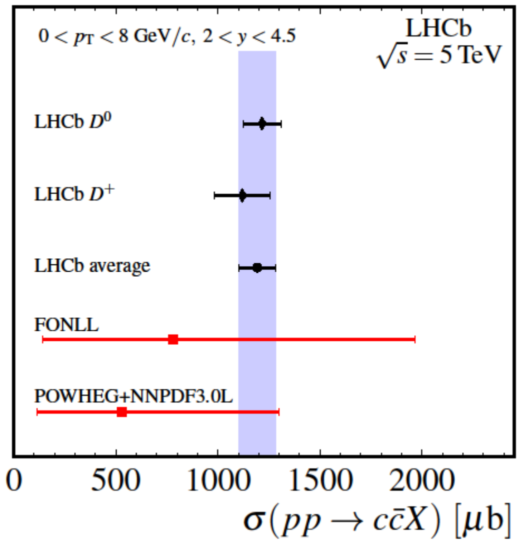
- Harder p_T spectrum of heavier mesons is observed.

- Cross-sections $pp \to c\bar{c}\,X$ from meson measurements (0 < p_T < 8 GeV/c, 2.0 < y < 4.5)

JHEP 1706 (2017) 147
JHEP 1705 (2017) 074
JHEP 1609 (2016) 013
JHEP 1603 (2016) 159

Lyons,Gibaut,Clifford, NIM A270 (1988) 110

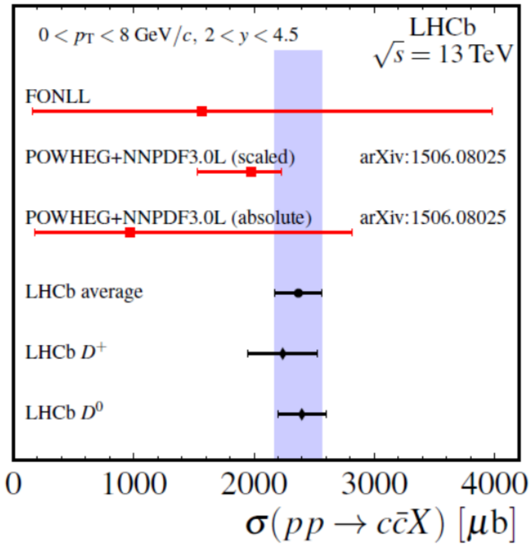
$$\boxed{\sigma(pp \to c\bar{c}X) = 1193 \pm 3 \pm 67 \pm 58\,\mu\mathrm{b}}$$



Cacciari, Mangano, Nason, Eur.Phys.J. C75 (2015) 610

Gauld et al., JHEP 1511 (2015) 009

$$\boxed{\sigma(pp \to c\bar{c}X) = 2369 \pm 3 \pm 152 \pm 118\,\mu\mathrm{b}}$$



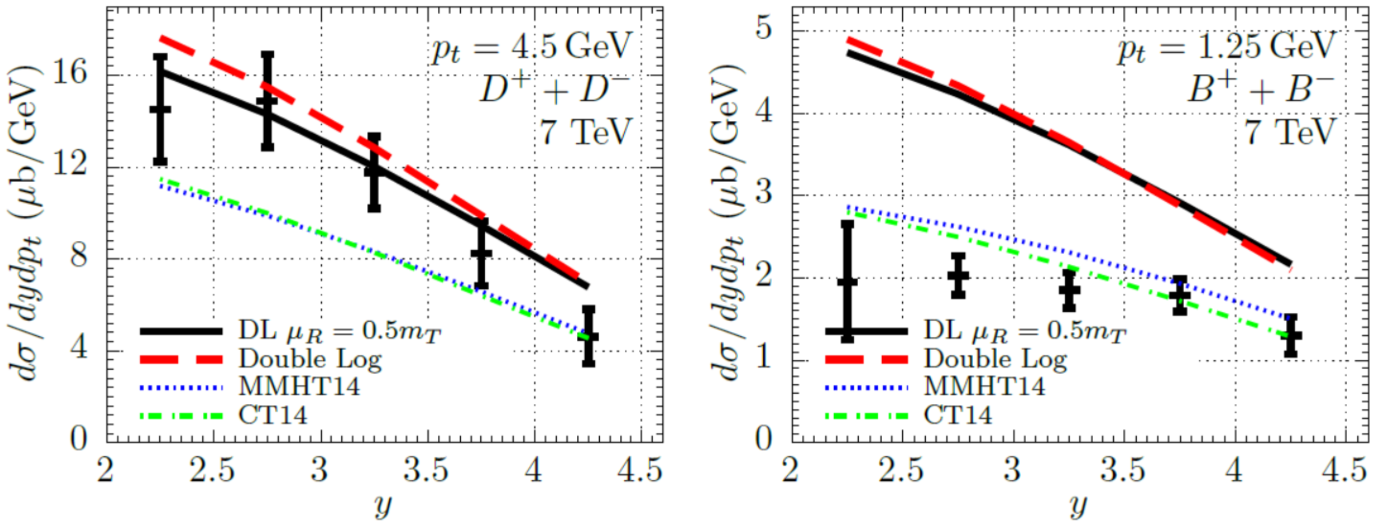
Cacciari, Mangano, Nason, Eur.Phys.J. C75 (2015) 610

Gauld et al., JHEP 1511 (2015) 009

- Check **consistency of the production description for heavy mesons**

E.G.de Oliveira, A.D.Martin, M.G.Ryskin, arXiv:1712.06834

- Same scale (same m_T) and same x interval:



- Gluons steeper than proposed by any models, are required to describe B production.
- Several **possible explanations**: inconsistency in data; non-perturbative effects in $c\bar{c}$ pair production or in $c \to D$ fragmentation; …

ALICE

- Improved production cross-section measurements of D mesons

EPJC 77 (2017) 550
$\sqrt{s}$ = 7 TeV, $\int L dt \sim 6.0\ \mathrm{nb}^{-1}$

- D mesons reconstructed via $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$, $D^{*+} \to D^0 \pi^+$, $D_s \to \varphi \pi^+$, $\to K^- K^+ \pi^+$ decays.
- **p_T-differential production cross-sections** determined for **$|y|<0.5$ and $0 < p_T < 36$ GeV/c (D^0), $1 < p_T < 24$ GeV/c (D^+ and D^{*+}), $2 < p_T < 12$ GeV/c (D_s)**

$$\frac{d^2\sigma^D}{dp_T dy} = \frac{1}{c_{\Delta y}\,\Delta p_T}\frac{1}{BR}\frac{\frac{1}{2}\,f_{\mathrm{prompt}}\cdot N^{D+\overline{D},\mathrm{raw}}\Big|_{|y|<y_{\mathrm{fid}}}}{(\mathrm{Acc}\times\varepsilon)_{\mathrm{prompt}}}\frac{1}{L_{\mathrm{int}}}$$

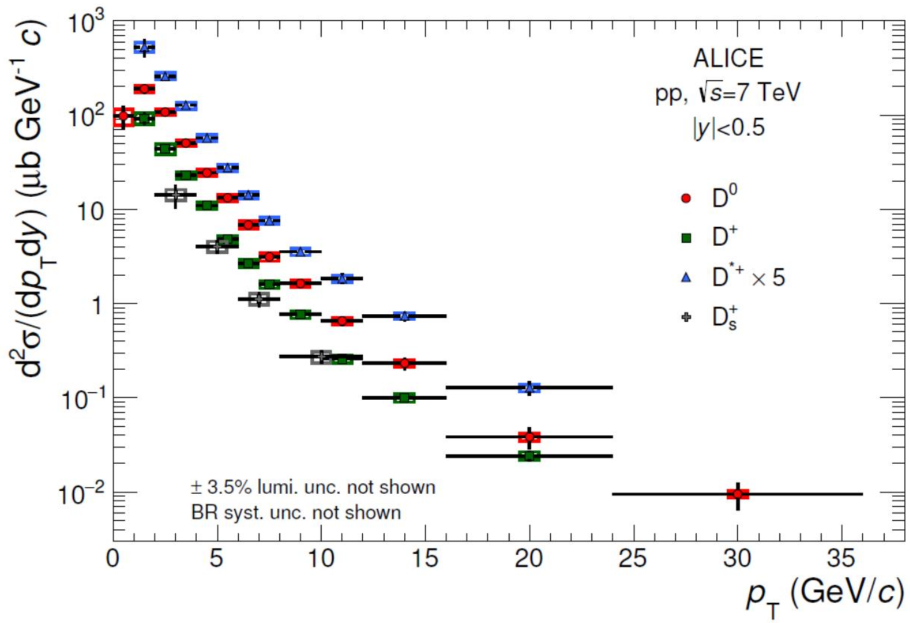
- f_{prompt} calculated using B-production cross sections from FONLL, $B \to DX$ kinematics from EvtGen and feed-down efficiencies

M.Cacciari, M.Greco, P.Nason, JHEP 05 (1998) 007
M.Cacciari, S.Frixione, P.Nason, JHEP 03 (2001) 006
D.J.Lange, NIMA 462 (2001) 152

EPJC 77 (2017) 550

- **p_T-differential inclusive production cross-section** of prompt D mesons
- In the lowest p_T bin, the D^0 cross section determined without decay vertex reconstruction

  Phys.Rev.C 94 (2016) 054908

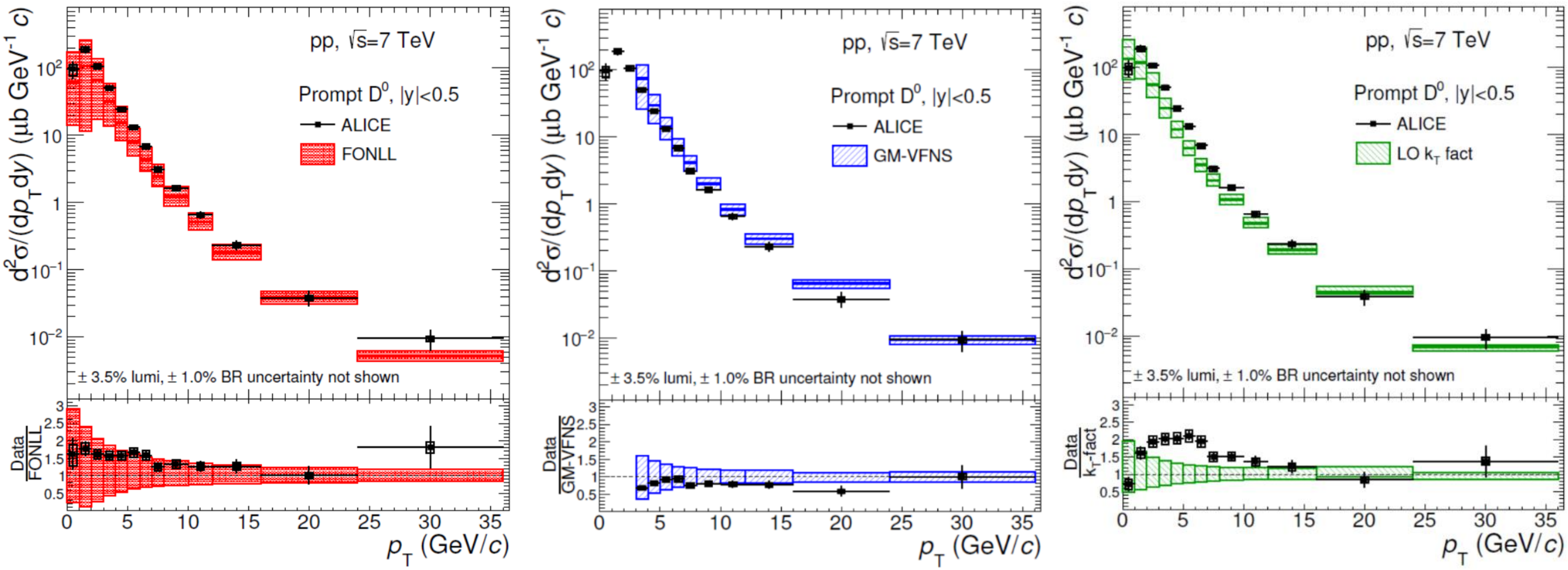


- **Visible production cross-section in p_T intervals**

	Kinematic range	Visible cross section (μb)
D^0	$0 < p_T < 36$ GeV/c	$500 \pm 36(\text{stat}) \pm 39(\text{syst}) \pm 18(\text{lumi}) \pm 5(\text{BR})$
	$1 < p_T < 24$ GeV/c	$402 \pm 24(\text{stat}) \pm 28(\text{syst}) \pm 14(\text{lumi}) \pm 4(\text{BR})$
	$2 < p_T < 12$ GeV/c	$210 \pm 7(\text{stat}) \pm 14(\text{syst}) \pm 7(\text{lumi}) \pm 2(\text{BR})$
D^+	$1 < p_T < 24$ GeV/c	$182 \pm 14(\text{stat}) \pm 20(\text{syst}) \pm 6(\text{lumi}) \pm 5(\text{BR})$
	$2 < p_T < 12$ GeV/c	$89 \pm 3(\text{stat}) \pm 9(\text{syst}) \pm 3(\text{lumi}) \pm 2(\text{BR})$
D^{*+}	$1 < p_T < 24$ GeV/c	$207 \pm 24(\text{stat}) \pm 20(\text{syst}) \pm 7(\text{lumi}) \pm 3(\text{BR})$
	$2 < p_T < 12$ GeV/c	$101 \pm 6(\text{stat}) \pm 8(\text{syst}) \pm 4(\text{lumi}) \pm 1(\text{BR})$
D_s^+	$2 < p_T < 12$ GeV/c	$40 \pm 8(\text{stat}) \pm 5(\text{syst}) \pm 1(\text{lumi}) \pm 1(\text{BR})$

- p_T-differential production cross-section of D^0 meson compared to pQCD calculations

EPJC 77 (2017) 550

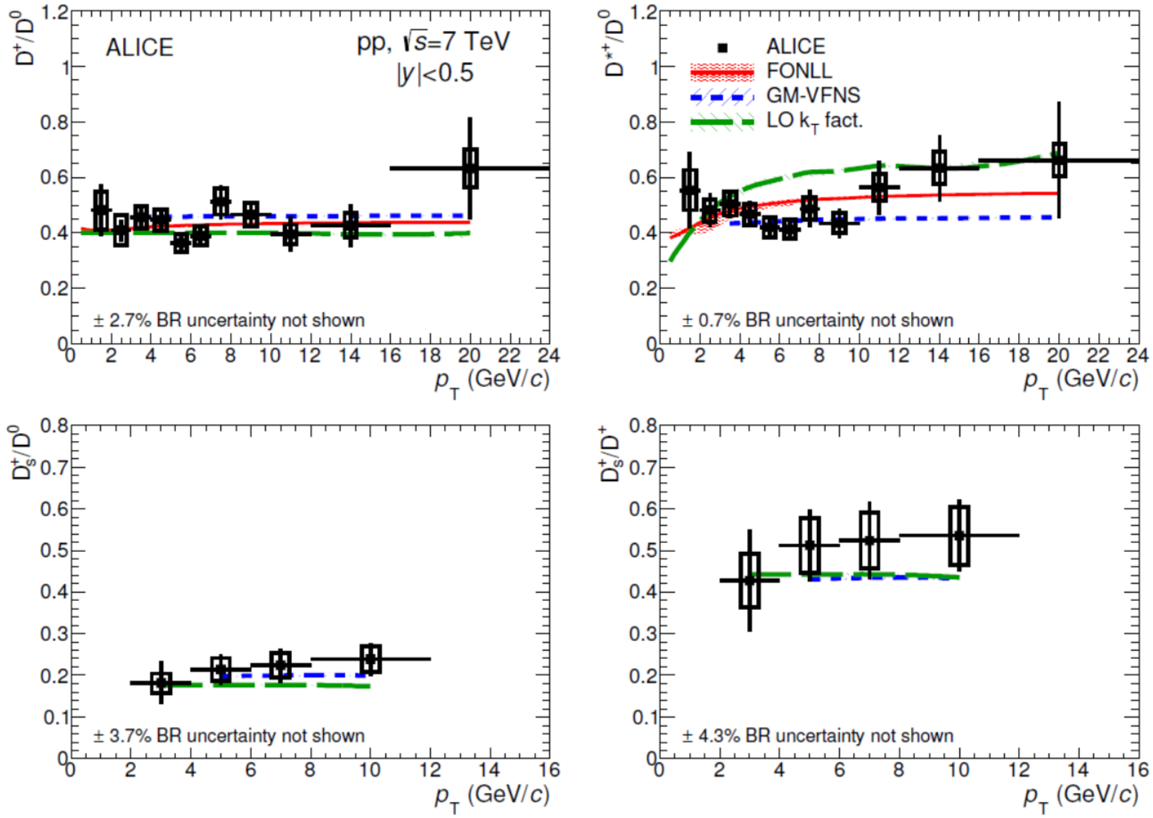


FONLL: M.Cacciari et al., JHEP 10 (2012) 137
GM-VFNS: B.A.Kniehl et al., EPJC 72 (2012) 2082
LO kT fact: R.Maciula and A.Szczurek, PRD 87 (2013) 094022

- **Uncertainties related to perturbative scale** reduced in ratios.

EPJC 77 (2017) 550

- **Ratios of D-meson production cross sections** compared to pQCD calculations



- **Ratios of measured p_T-integrated D-meson production cross sections** in |y|<0.5

	Kinematic range	Production cross section ratio
$\sigma(D^+)/\sigma(D^0)$	$1 < p_T < 24$ GeV/c	$0.45 \pm 0.04(\text{stat}) \pm 0.05(\text{syst}) \pm 0.01(\text{BR})$
$\sigma(D^{*+})/\sigma(D^0)$	$1 < p_T < 24$ GeV/c	$0.52 \pm 0.07(\text{stat}) \pm 0.05(\text{syst}) \pm 0.01(\text{BR})$
$\sigma(D_s^+)/\sigma(D^0)$	$2 < p_T < 12$ GeV/c	$0.19 \pm 0.04(\text{stat}) \pm 0.02(\text{syst}) \pm 0.01(\text{BR})$
$\sigma(D_s^+)/\sigma(D^+)$	$2 < p_T < 12$ GeV/c	$0.45 \pm 0.09(\text{stat}) \pm 0.06(\text{syst}) \pm 0.02(\text{BR})$

Open charm production at $\sqrt{s}$ = 7 TeV

EPJC 77 (2017) 550
$\sqrt{s}$ = 7 TeV, $\int Ldt$ ~ 6.0 nb^{-1}

- **Sensitivity to gluon PDF** down to Bjorken-x ~10^{-5}

- **Ratios of D^0 production cross section per unit of** rapidity at ALICE (|y| < 0.5) to that at LHCb in three rapidity ranges

Nucl.Phys. B871 (2013) 1

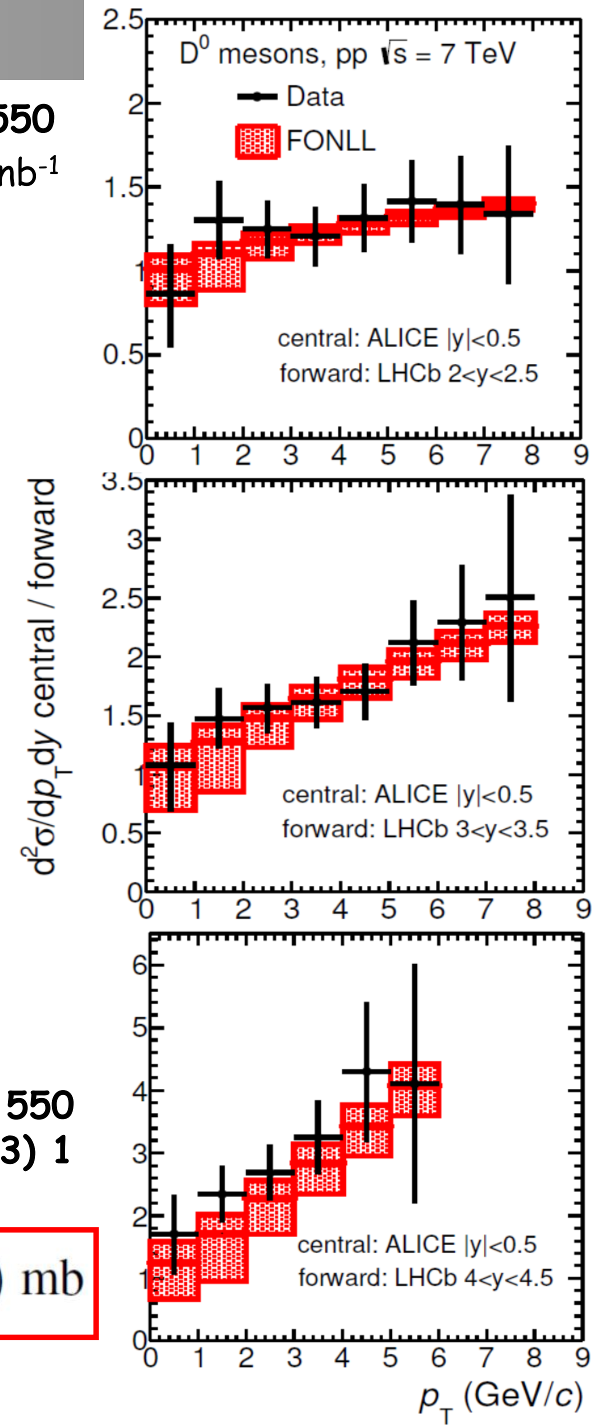
- **p_T-integrated $c\bar{c}$ production cross-section:**

$$d\sigma^{c\bar{c}}_{pp,\,7\,\mathrm{TeV}}/dy\,\Big|_{|y|<0.5} = 954 \pm 69\,(\mathrm{stat}) \pm 97\,(\mathrm{tot.\ syst.})\ \mu b$$

- **$c\bar{c}$ production cross-section in full phase space**, combining ALICE and LHCb measurements:

EPJC 77 (2017) 550
Nucl.Phys. B871 (2013) 1

$$\boxed{\sigma^{c\bar{c}}_{pp,\,7\,\mathrm{TeV}}(\mathrm{ALICE, LHCb}) = 7.44 \pm 0.14\,(\mathrm{stat.}) \pm 0.58\,(\mathrm{tot.\ syst.})\ \mathrm{mb}}$$



First measurement of Ξ_c production at $\sqrt{s}$ = 7 TeV

- Test of **pQCD and QCD-based models**
- Study of **charm quark fragmentation into baryonic states**

First measurement of Ξ_c production at 7 TeV **PLB 781 (2018) 8**

First measurement of Ξ_c production at $\sqrt{s}$ = 7 TeV

❑ Predictions for **heavy-baryon production** require knowledge about fragmentation function of charm quarks into baryonic states

PLB 781 (2018) 8

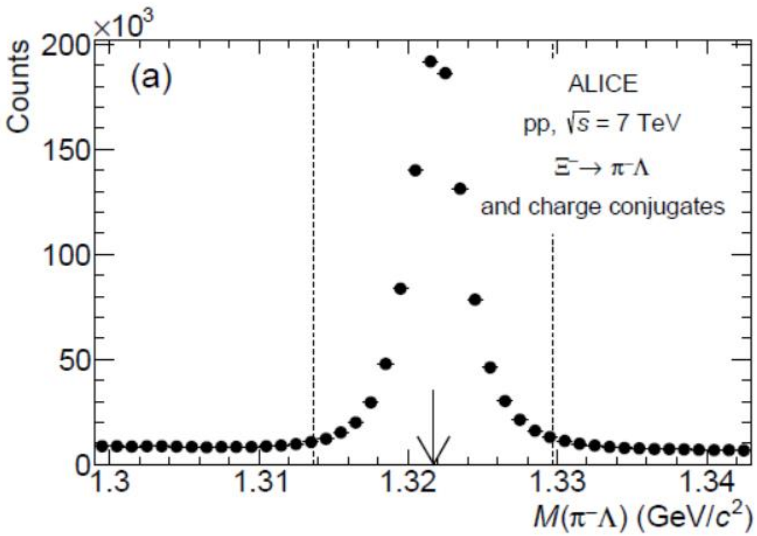
$\sqrt{s}$ = 7 TeV, $\int Ldt \sim 5.9\ nb^{-1}$

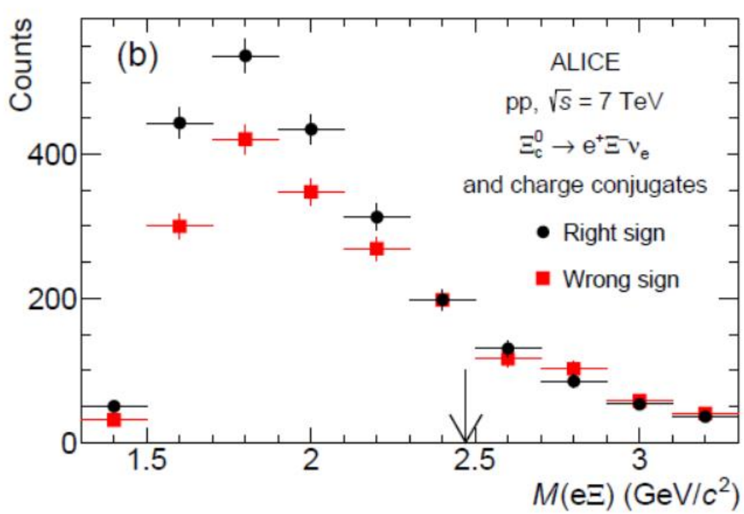
❑ Limited experimental data on heavy-baryon production at LHC, until recently only production of Λ_c

❑ Studies of Ξ_c at e^+e^- collisions so far. Ξ_c **production** at pp collisions expected to be different. Enhanced production of baryons relative to mesons expected

J.R.Christiansen,P.Z.Skands, arXiv:1505.01681

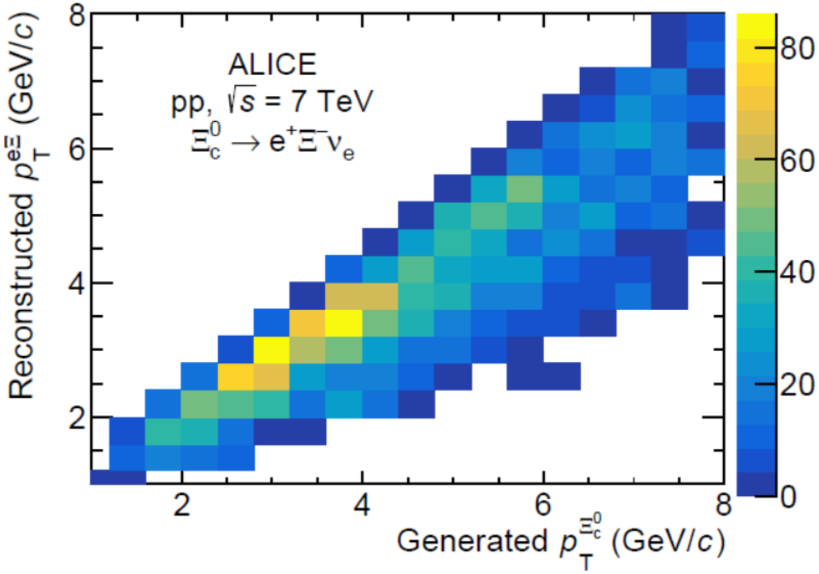
❑ Inclusive Ξ_c baryons reconstructed via decays $\boldsymbol{\Xi_c \to e^+ \Xi^- (\nu_e)}$ with $\boldsymbol{\Xi^- \to \pi^- \Lambda}$, $\boldsymbol{\Lambda \to p\, \pi^-}$





PLB 781 (2018) 8

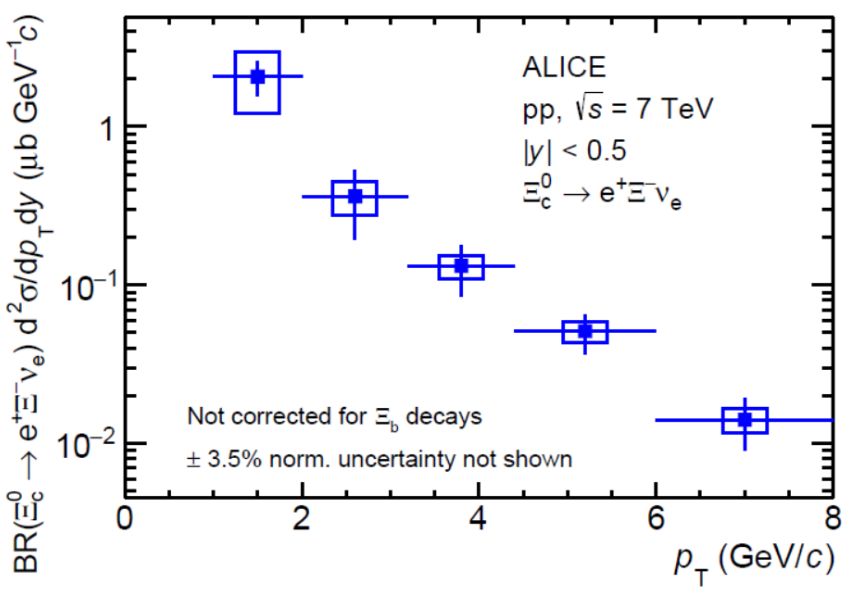
- **p_T-distribution of** $e^+ \Xi^-$ pairs is corrected for missing momentum of ν_e
  for $1<p_T<8$ GeV/c and $|y|<0.5$



- **Inclusive Ξ_c baryon p_T-differential production cross-section** × BR($\Xi_c \to e^+ \Xi^- \nu_e$) for $1<p_T<8$ GeV/c and $|y|<0.5$

$$\mathrm{BR}\cdot\frac{\mathrm{d}^2\sigma^{\Xi_c^0}}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} = \frac{N_{\Xi_c^0}}{2\cdot\Delta p_\mathrm{T}\Delta y\cdot(A\times\varepsilon)\cdot L_\mathrm{int}\cdot\mathrm{BR}_{\Xi^-}}$$

- Feed-down from Ξ_b baryon decays not subtracted

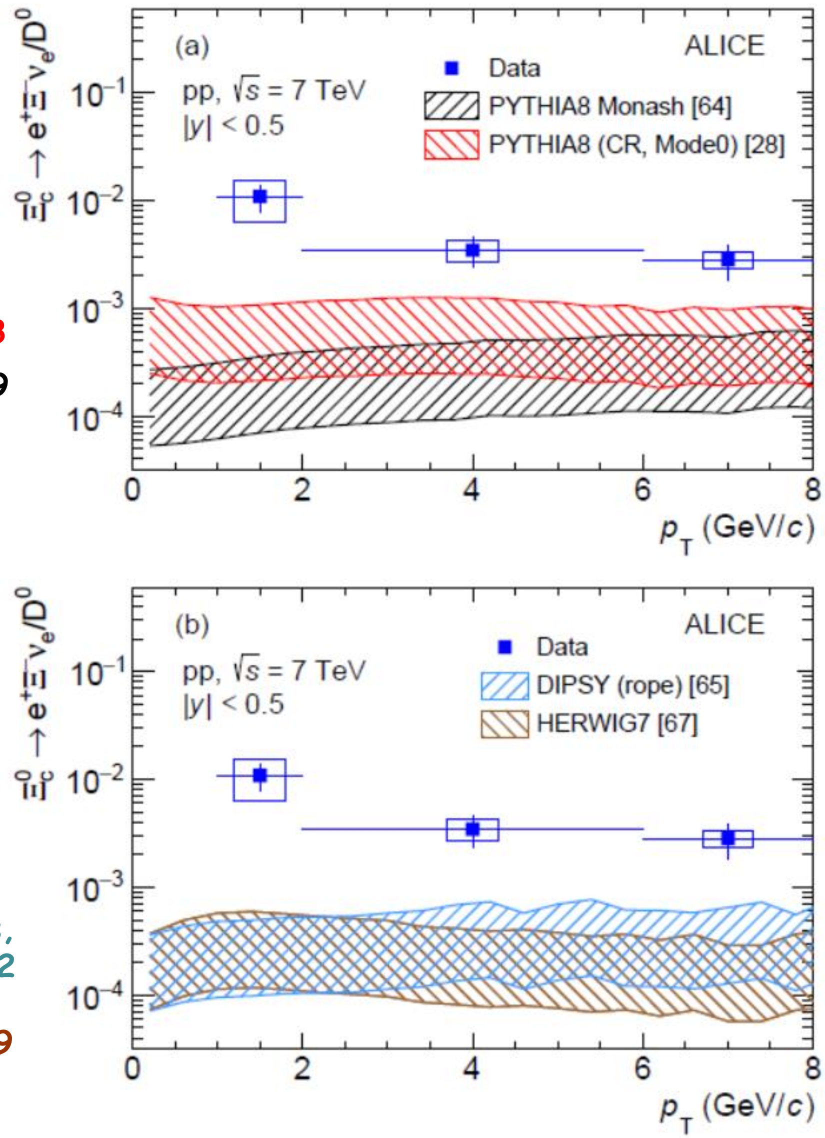


PLB 781 (2018) 8

- **Ratio of p_T-differential production cross-sections of Ξ_c (x BR($\Xi_c \rightarrow e^+ \Xi^- \nu_e$)) and D^0**

J.R.Christiansen,P.Z.Skands, JHEP 08 (2015) 003

M.Bahr et al., EPJC 58 (2008) 639



- Integrating over $1<p_T<8$ GeV/c and $|y|<0.5$:

$$\frac{\sigma(\Xi_c) \times BR(\Xi_c \rightarrow e^+ \Xi^- \nu_e)}{\sigma(D^0)} =$$

$$= (7.0 \pm 1.5(\mathrm{stat}) \pm 2.6(\mathrm{syst})) \times 10^{-3}$$

T.Sjostrand,S.Mrenna,P.Z.Skands, Comput.Phys.Commun. 178 (2008) 852

T.S.Biro,H.B.Nielsen,J.Knoll, NPB 245 (1984) 449

D_s production asymmetries at $\sqrt{s}$=7 and 8 TeV

Measurement of **hadron production asymmetries:**

- ❑ Understanding of **production mechanisms**
- ❑ **Input for CP-violation studies**

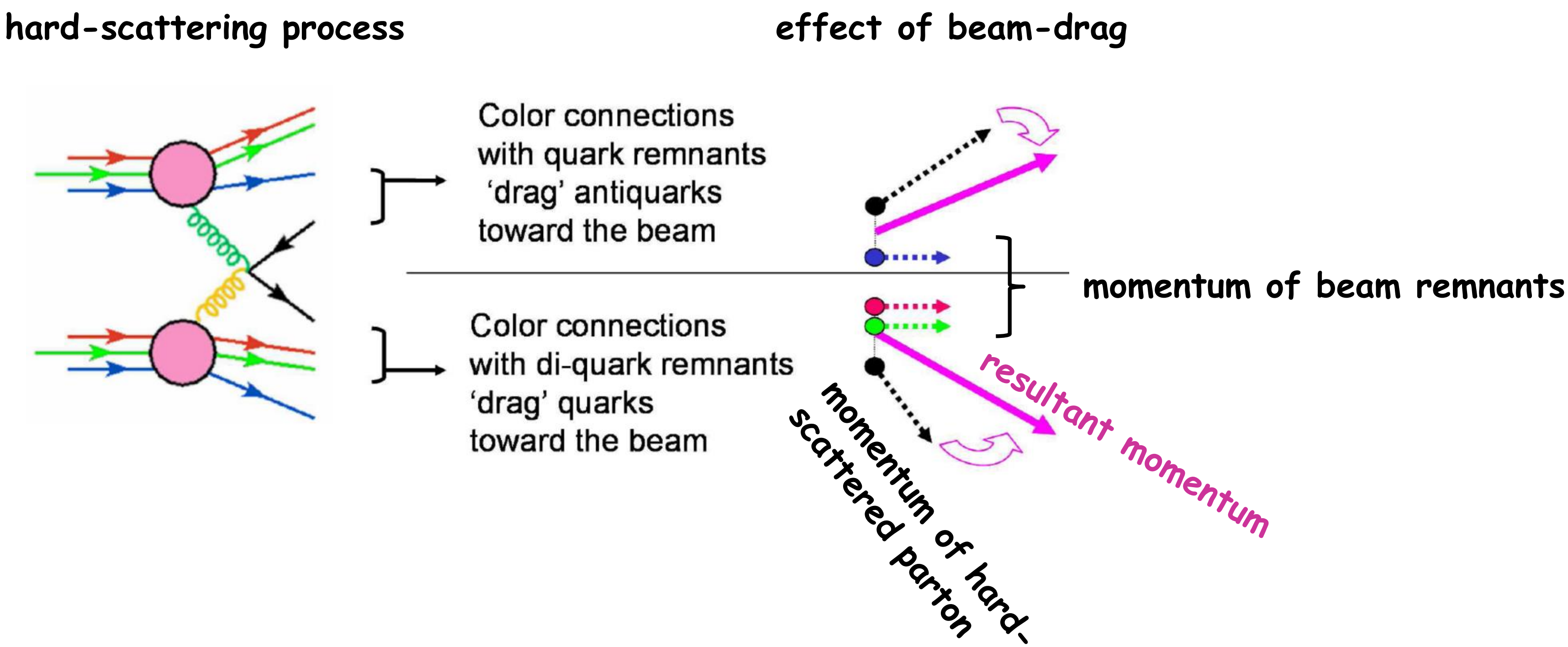
- ❑ Production asymmetries of D^+ and D_s at 7 TeV — **PLB 718 (2013) 902**, **PLB 713 (2012) 186**
- ❑ Production asymmetry of D_s at 7 and 8 TeV — **LHCb-PAPER-2018-010**

D_s production asymmetries at $\sqrt{s}$=7 and 8 *TeV*

- For the D_s system **production asymmetry** is not caused by valence quarks of the proton

LHCb-PAPER-2018-010
$\sqrt{s}$ = 7 TeV, $\int Ldt \sim 1\ fb^{-1}$
$\sqrt{s}$ = 8 TeV, $\int Ldt \sim 2\ fb^{-1}$

- Other possible effects, **beam drag**: beam remnants redistribute proportions of quarks and antiquarks in pseudo-rapidity and p_T, pulling them towards the beam
→ kinematic dependences



R.Lambert, CERN-THESIS-2009-001

- Reconstruct D_s candidates using decays $\mathbf{D_s \to KK\pi}$
- Different selection for each Dalitz region

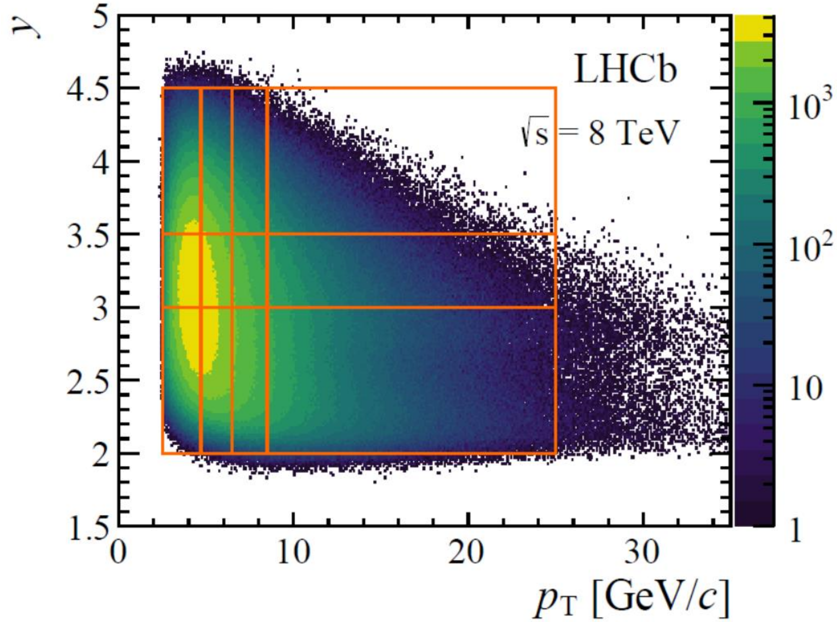
LHCb-PAPER-2018-010

- **Production asymmetry** $$A_P(D_s^+) = \frac{1}{1-f_{bkg}}\left(A_{raw} - A_D - f_{bkg}A_P(B)\right)$$

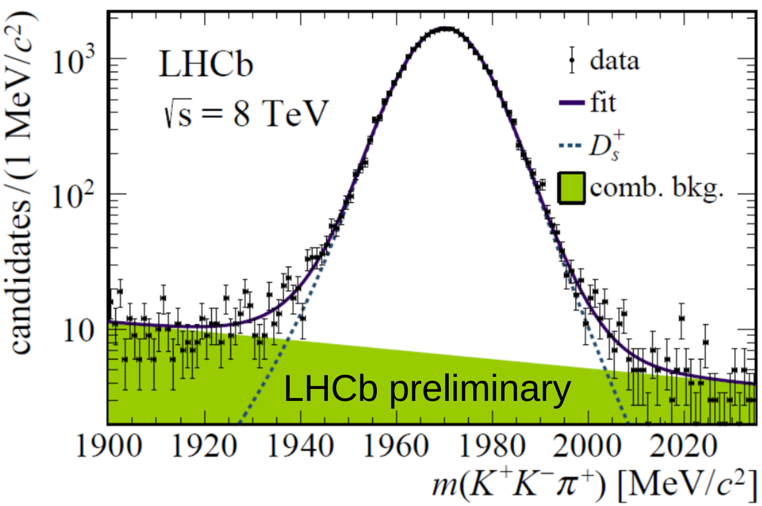
- Data set of 2.9×10^6 and 9.1×10^6 D_s candidates are selected in 7 and 8 TeV samples
- Production asymmetry studied **in bins of p_T and rapidity y**

$$y = \frac{1}{2}\ln\left(\frac{E+p_z c}{E-p_z c}\right)$$

LHCb preliminary



bin 3.5 < y < 4.5, 8.5 < p_T < 25.0 GeV



- **Raw asymmetry** from the number of observed D_s candidates

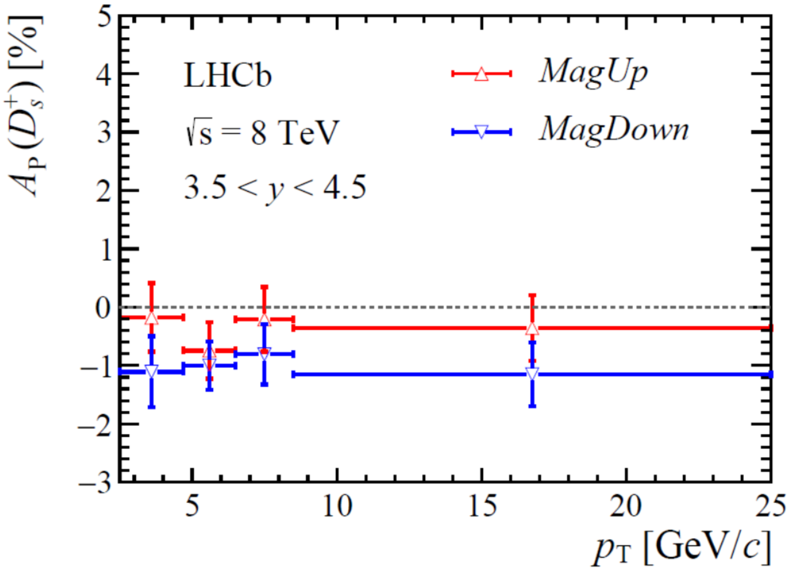
D_s production asymmetries at $\sqrt{s}$=7 and 8 TeV

LHCb-PAPER-2018-010

- **Production asymmetry** $$A_P(D_s^+) = \frac{1}{1-f_{bkg}}(A_{raw} - A_D - f_{bkg}A_P(B))$$

- **Detector asymmetry** determined using data-driven methods: $\mathbf{A_{track}(\pi)}$, $\mathbf{A_{track}(KK)}$, $\mathbf{A_{PID}}$, $\mathbf{A_{trigger}}$
- Consistency by comparing different magnet polarities

LHCb preliminary



- Correction for contributions from a fraction f_{bkg} = (4.12 ± 1.23)% of **D_s candidates originating from b-hadron decays**

JHEP 08 (2013) 117
JHEP 08 (2014) 143

- $A_P(B)$ – production asymmetry of b-hadrons

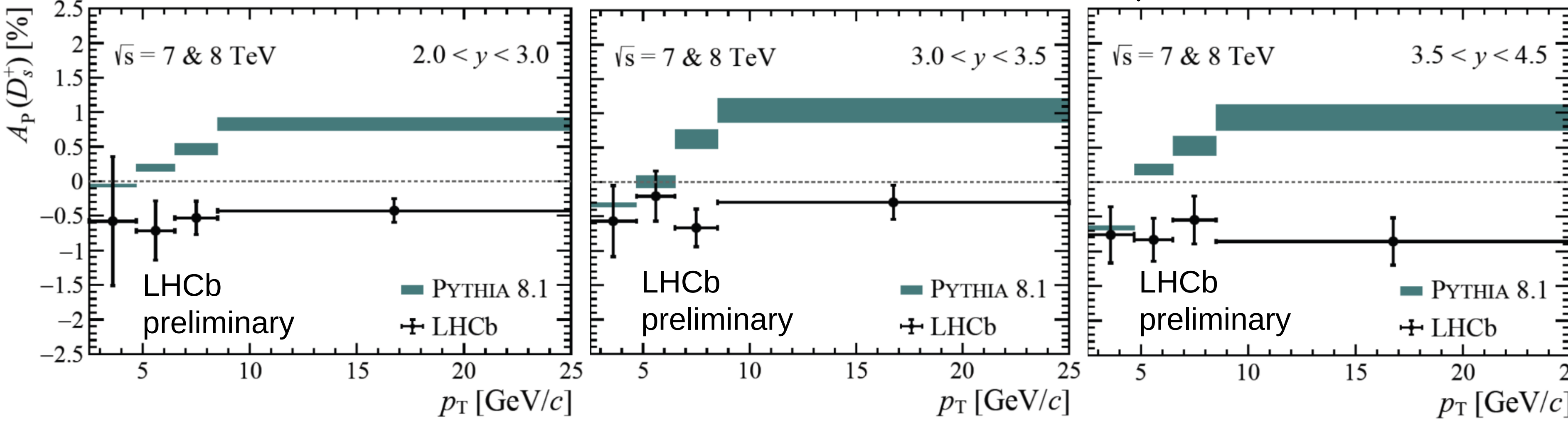
PRD 95 (2017) 052005
PLB 774 (2017) 139
PRL 114 (2015) 041601

D_s production asymmetries at $\sqrt{s}$=7 and 8 *TeV*

LHCb-PAPER-2018-010

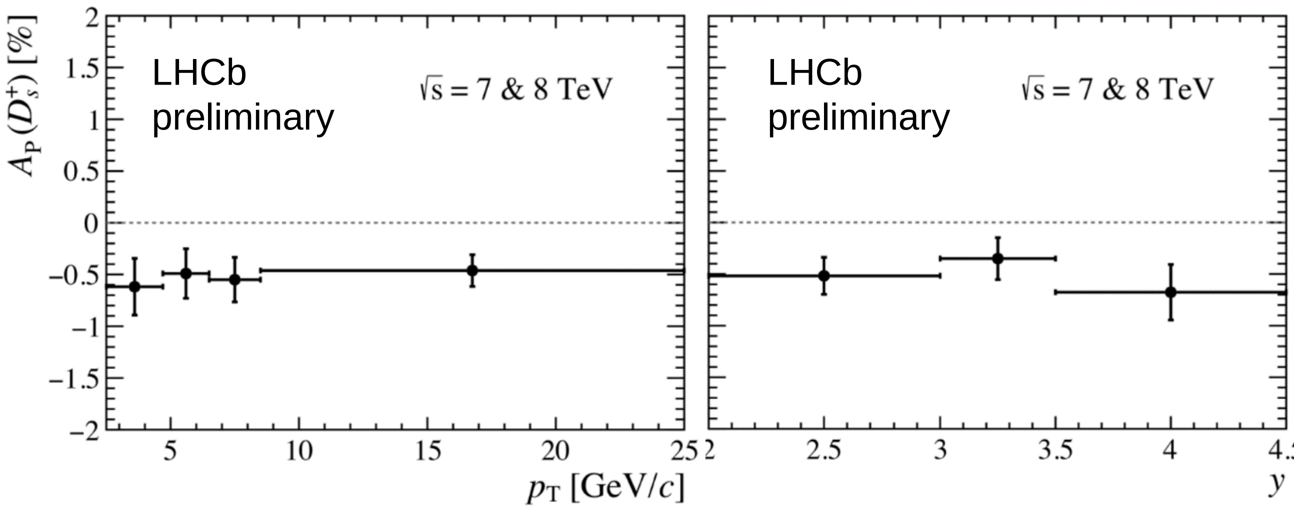
- **D_s production asymmetry** as a function of p_T for three bins of rapidity, compared to Pythia 8 with LHCb tune

Comput.Phys.Commun. 178 (2008) 852
JHEP 05 (2006) 026
J.Phys.Conf.Ser. 331 (2011) 032047



- No strong p_T dependence of production asymmetry → use these results to retune Pythia

- No kinematic dependence on p_T and y is observed

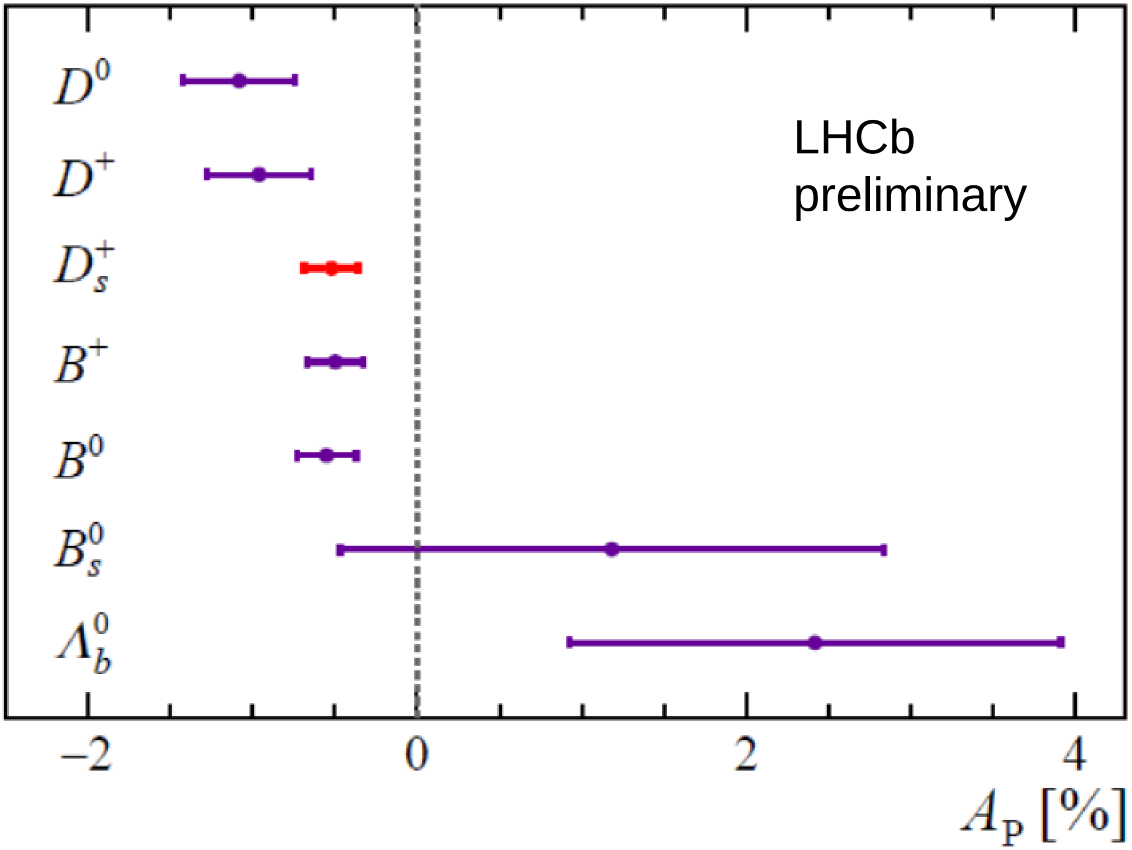


D_s production asymmetries at $\sqrt{s}$=7 and 8 TeV

LHCb-PAPER-2018-010

- Good agreement between 7 and 8 TeV data
- **Integrated production asymmetry** calculated assuming flat acceptance

- Overview of the **production asymmetry measurements at $\sqrt{s}$=7 and 8 TeV by LHCb**



LHCb-CONF-2011-023

PLB 718 (2013) 902

LHCb-PAPER-2018-010

PRD 95 (2017) 052005
PLB 774 (2017) 139

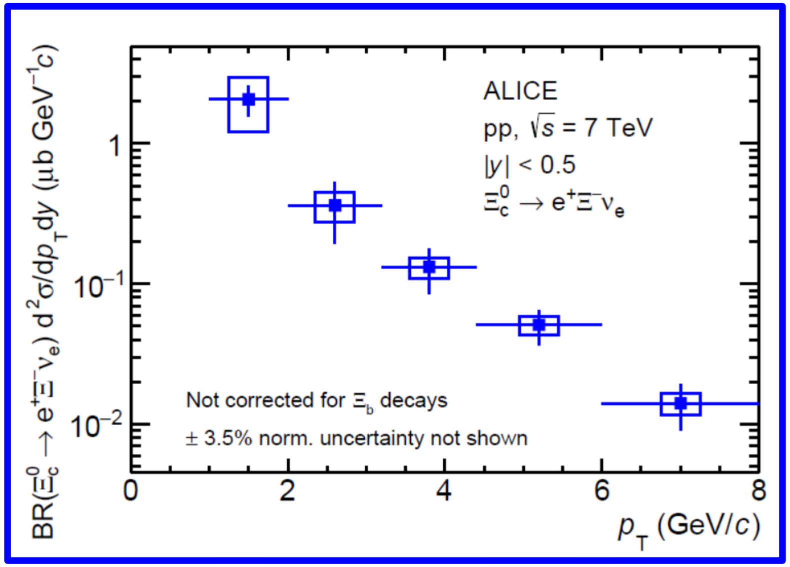
PRL 114 (2015) 041601
PLB 774 (2017) 139

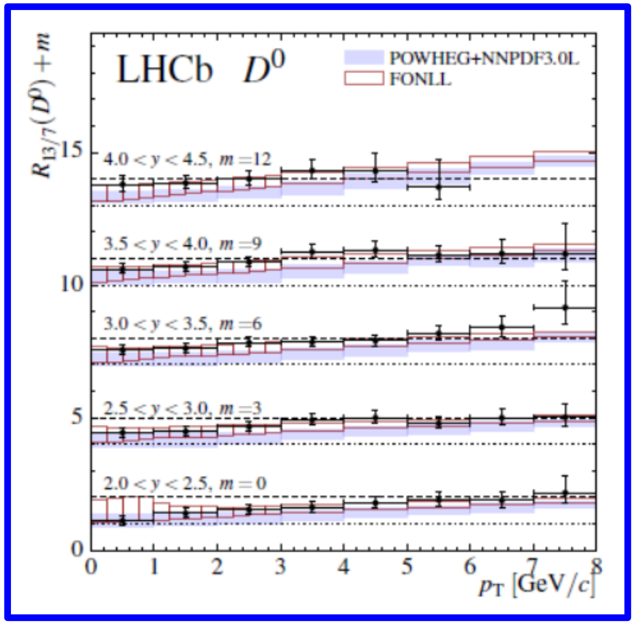
PLB 774 (2017) 139

PLB 774 (2017) 139

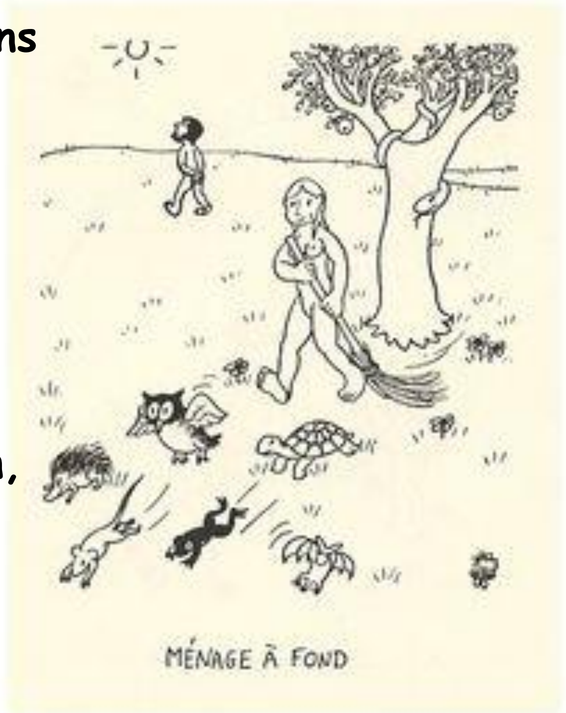
Summary

- Thanks to excellent operation of LHC machine and LHC experiments, **new precision tests** of our QCD comprehension using open charm production in pp collisions
- New results on **open charm production in pp collisions** at $\sqrt{s}$ = 5, 7, 8 and 13 TeV using Run I and Run II data from ALICE and LHCb experiments
- Bigger datasets, more precision, better sensitiveties, new observables, access to larger p_T range





- **Ratios between cross sections** for different species, for different energies, …
- **Simultaneous consideration of different observables** is crucial
- Also crucial to **quantify the assumptions of factorization, HQSS and universality**



- Yet another **effort needed in both theory and experiment to establish a consistent picture of HF production**