

Heavy-flavour hadron production

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for the ALICE, ATLAS, CMS, LHCb Collaborations



Online

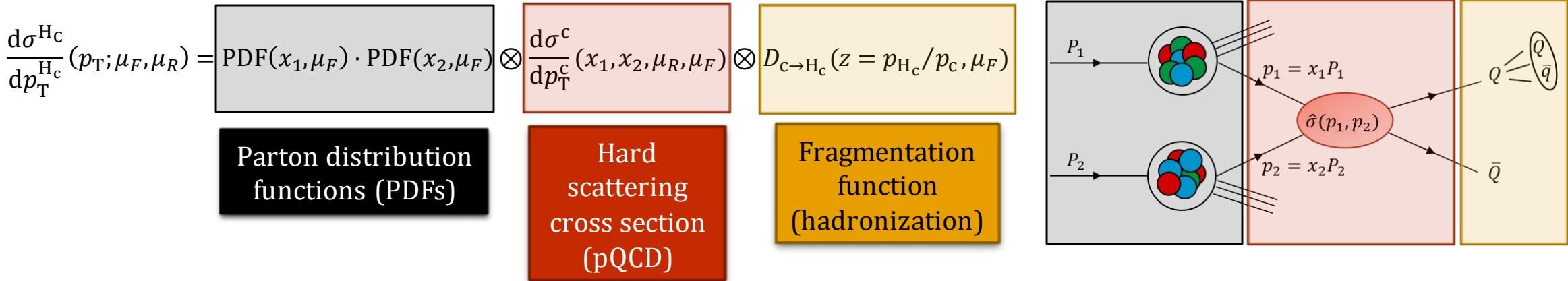
The Ninth Annual Conference on Large Hadron Collider Physics

LHCP2021

7-12 June 2021 Paris (France), Sorbonne Université (IN2P3/CNRS/IRFU/CEA)

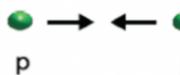
A graphic showing a silhouette of the Eiffel Tower and other Parisian landmarks, with a banner across it that says "Online".A graphic depicting a high-energy particle collision with many yellow lines representing particle tracks.

Heavy flavour (HF) production in pp collisions

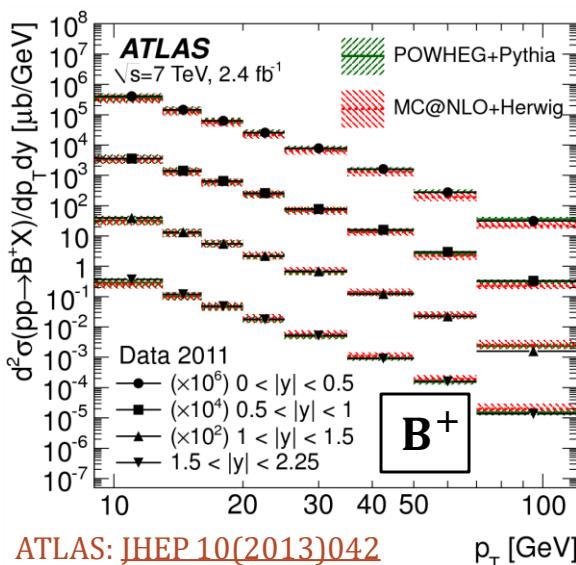
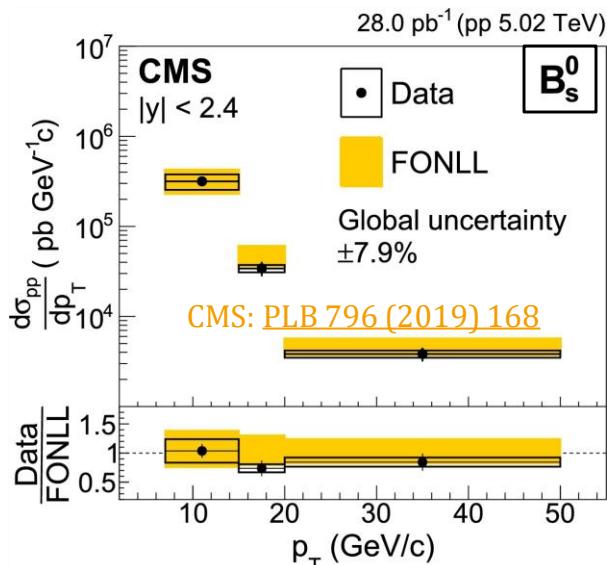
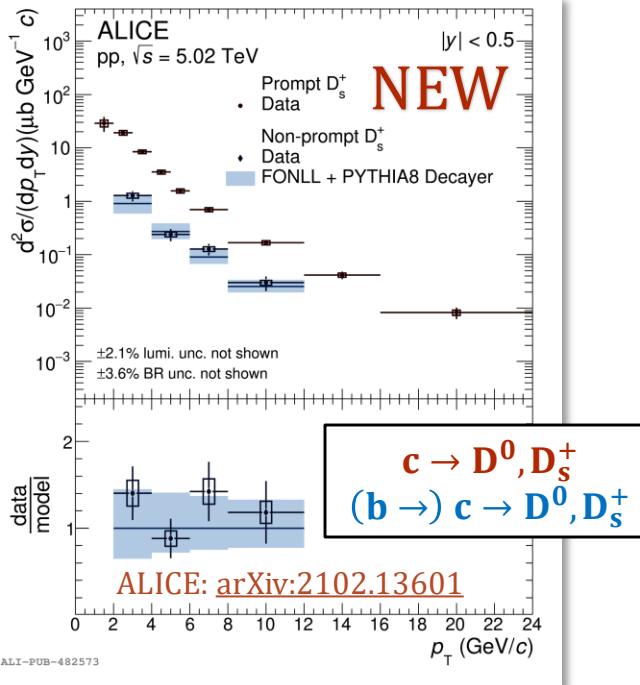
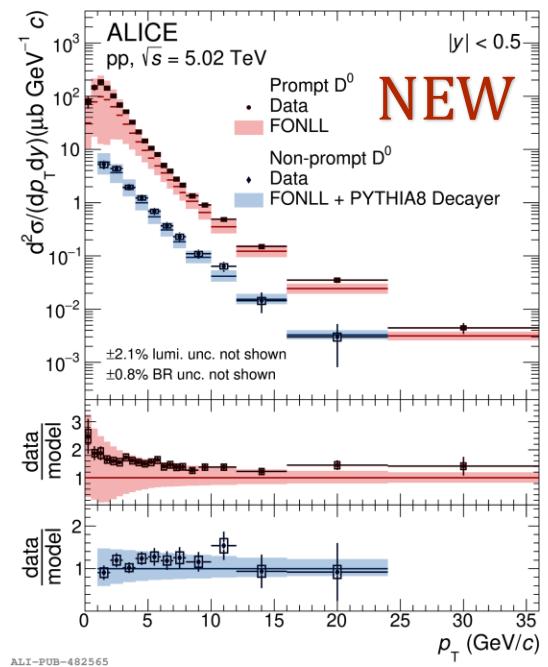


- The measurements of the **HF hadron production** are fundamental **tests** of **pQCD calculations**
- The standard description in pp collisions is based on the **factorization theorem**
→ **Fragmentation functions** assumed **universal** and constrained from e^+e^- and ep measurements
- **Ratios of particle species (Baryon-over-meson)** → ratios of fragmentation fractions, sensitive to HF quark hadronization

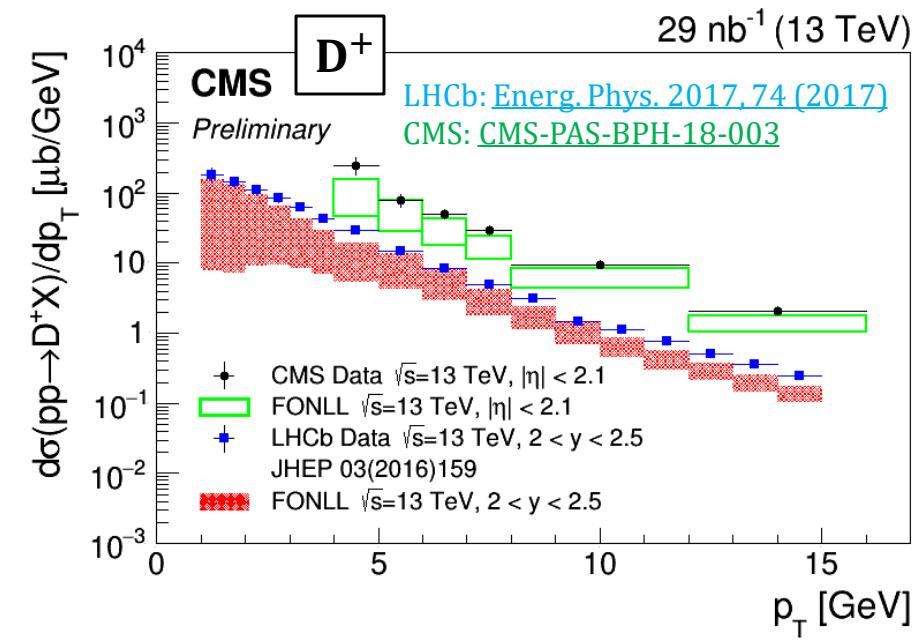
$$f(c \rightarrow H_c) = \sigma(H_c)/\sigma(c\bar{c})$$



Heavy flavour meson production



- **Charm and beauty meson production measurements** at LHC with **unprecedent precision** and **granularity**
- **Model** calculations based on factorization approach with universal fragmentation functions **describe the data** within uncertainties
→ **Success** in the **meson sector**





Meson-to-meson ratios

$$\frac{d\sigma^{H_c}}{dp_T^{H_c}}(p_T; \mu_F, \mu_R) = \text{PDF}(x_1, \mu_F) \cdot \text{PDF}(x_2, \mu_F) \otimes \frac{d\sigma^c}{dp_T^c}(x_1, x_2, \mu_R, \mu_F) \otimes D_{c \rightarrow H_c}(z = p_{H_c}/p_c, \mu_F)$$

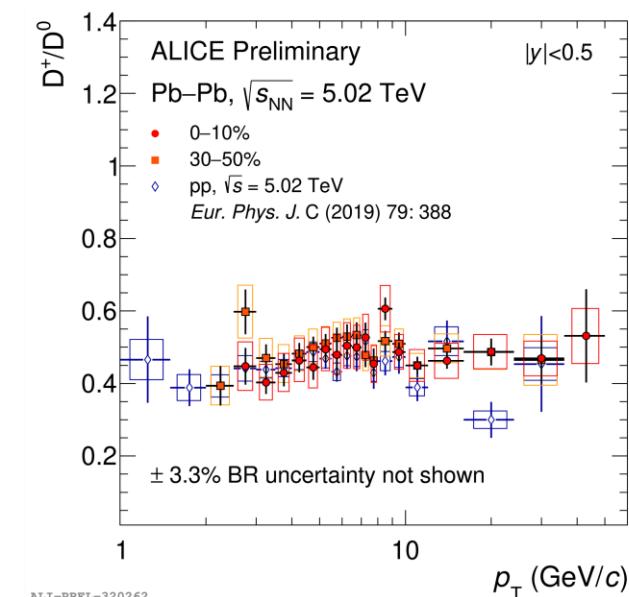
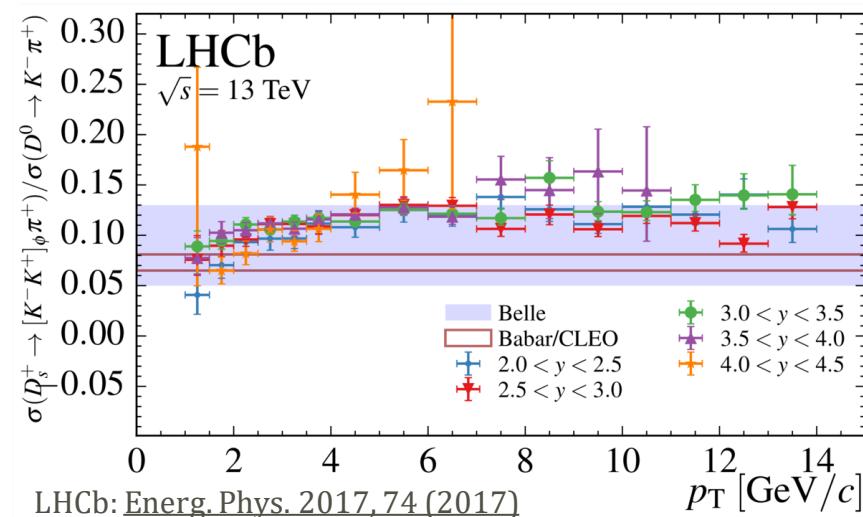
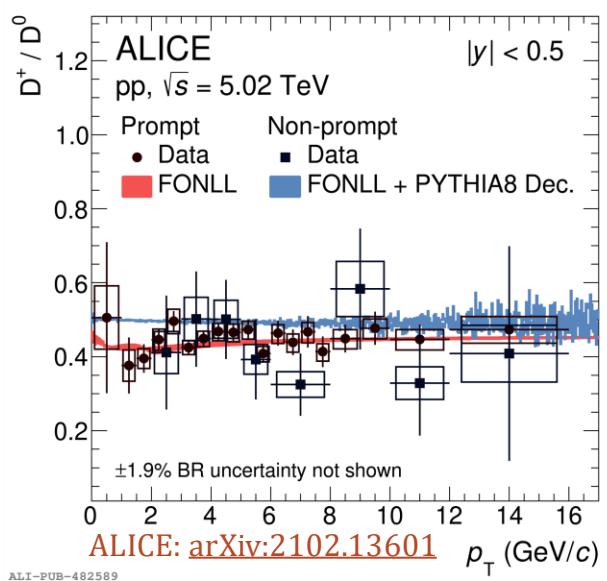
$D_{c \rightarrow H_c}(z = p_{H_c}/p_c, \mu_F)$

Heavy meson relative
abundances

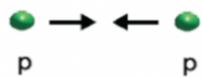
≡

fragmentation fraction ratios

NEW



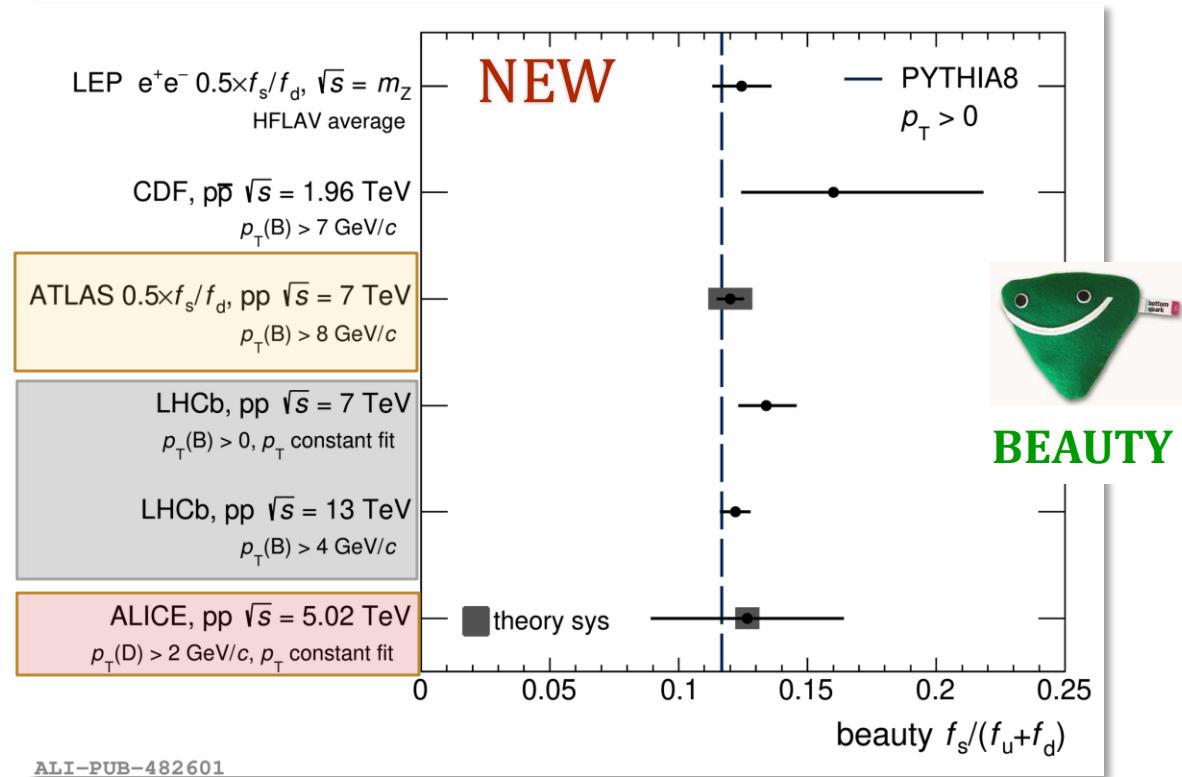
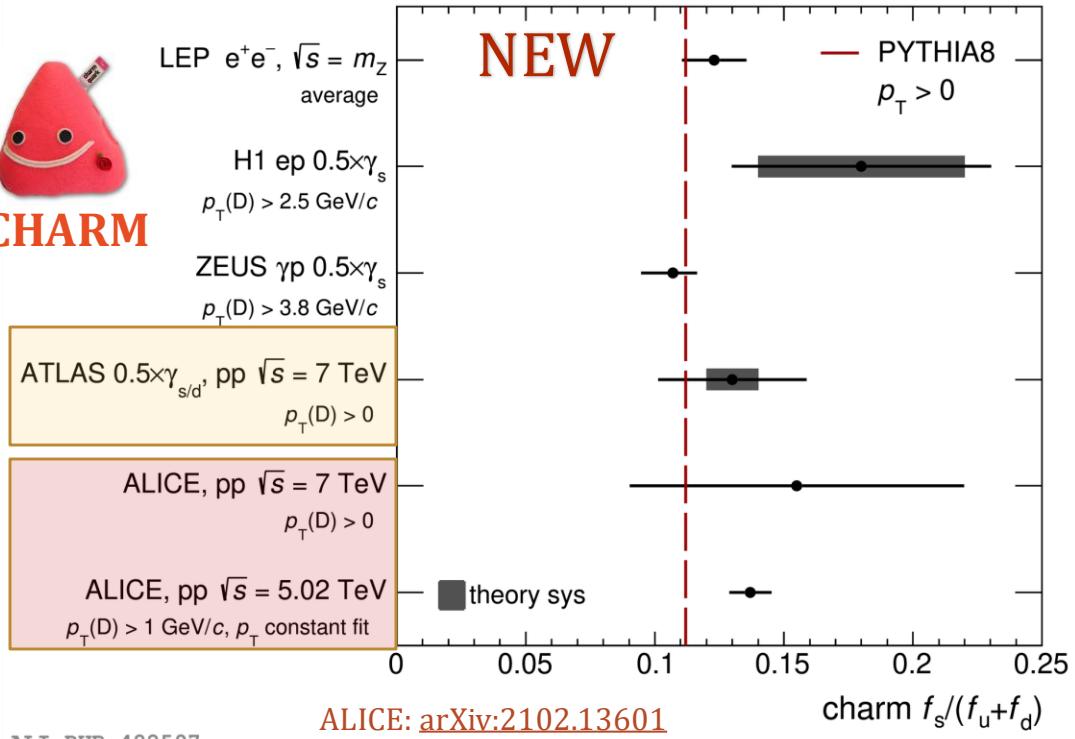
- Ratios almost **independent** from meson p_T
- In line with model **calculations** relying on universal fragmentation functions
- In line with **measurements** in e^+e^- collision
- Independent from the **collision system** and centrality (Pb-Pb)



HF meson fragmentation fraction ratios



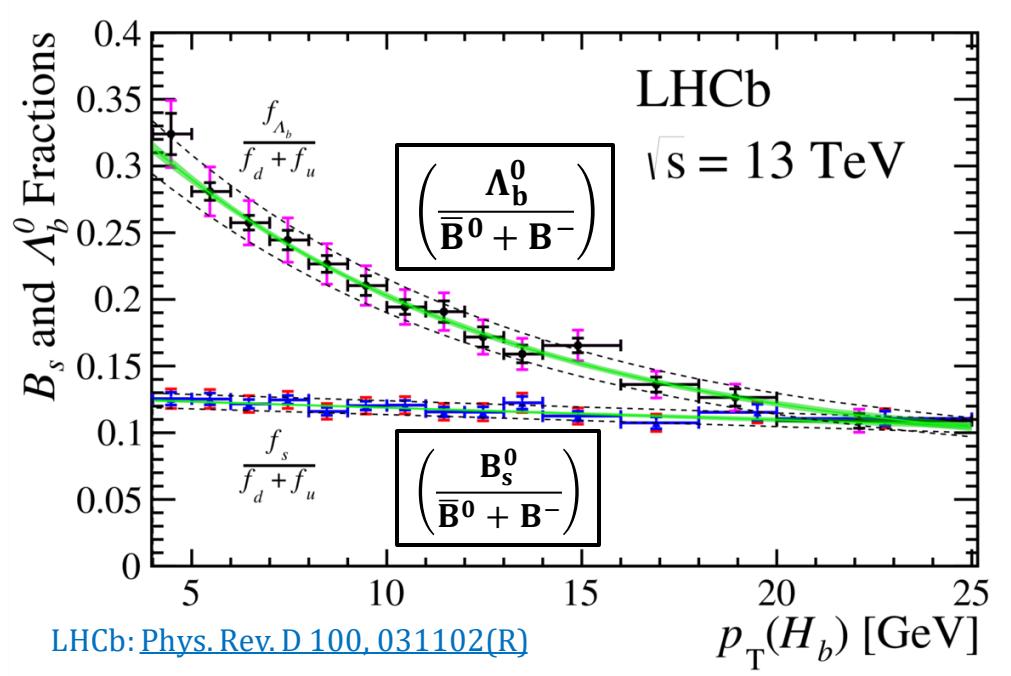
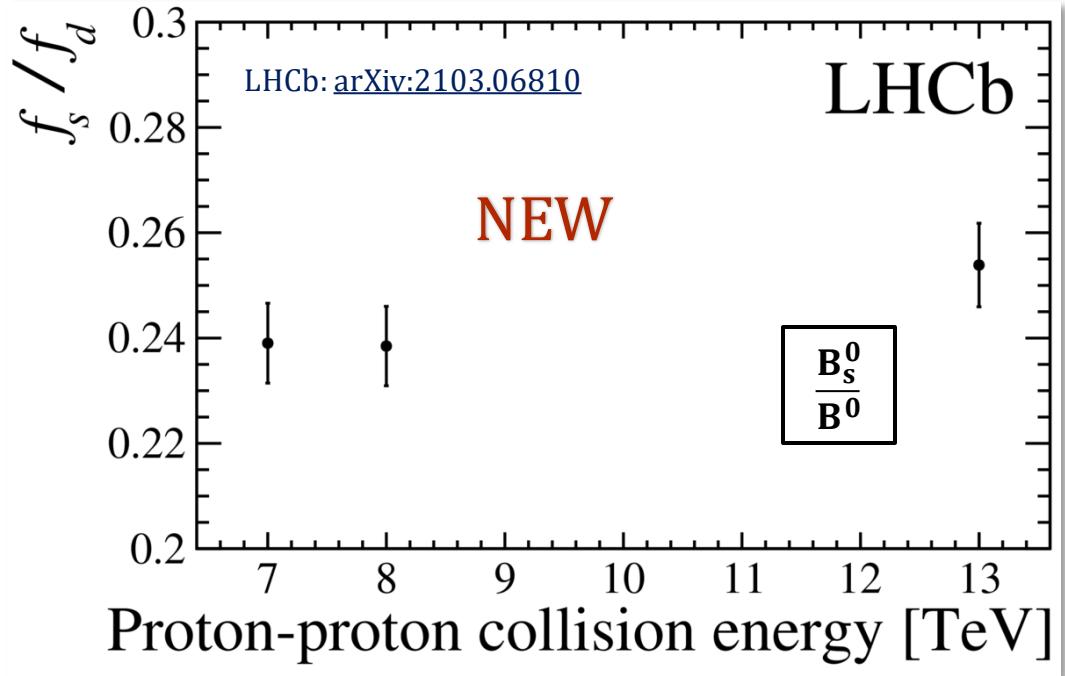
CHARM



- $\left(\frac{f_s}{f_u+f_d}\right)_{c(b)} \rightarrow \left(\frac{D_s^+}{D^0 + D^+}\right)_{\text{(non)prompt}}$ [ALICE, ATLAS] and $\left(\frac{B_s^0}{\bar{B}^0 + B^-}\right)$ [LHCb, ATLAS] in pp at $\sqrt{s} = 5.02, 7, 13 \text{ TeV}$
- Fragmentation fraction ratios for **charm** and **beauty** mesons **compatible** between the two flavours



Beauty meson fragmentation fraction ratios

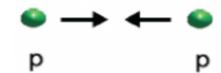


- Fragmentation fraction ratios **compatible** among **different** collision systems, **energies** and rapidity ranges
- Higher fraction at 13 TeV?

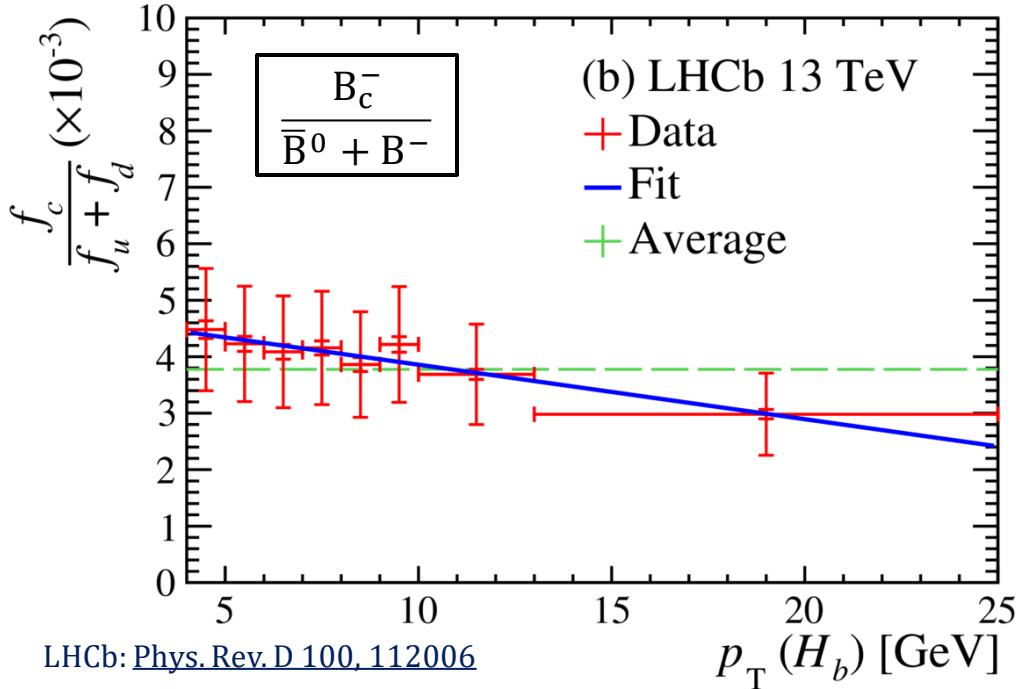
- **Baryon-over-meson** ratio
 - clear **decreasing** trend vs. p_T
 - significant **enhancement** at **low p_T** with respect to $\left(\frac{B_s^0}{\bar{B}^0 + B^-} \right)$
- effect caused by the different masses?
 $m_{\Lambda_b^0} (\sim 5.6 \text{ GeV}/c^2) > m_B (\sim 5.3 \text{ GeV}/c^2)$
- non-universality of fragmentation fractions?

$B_c^- (\bar{c}b)$ meson production

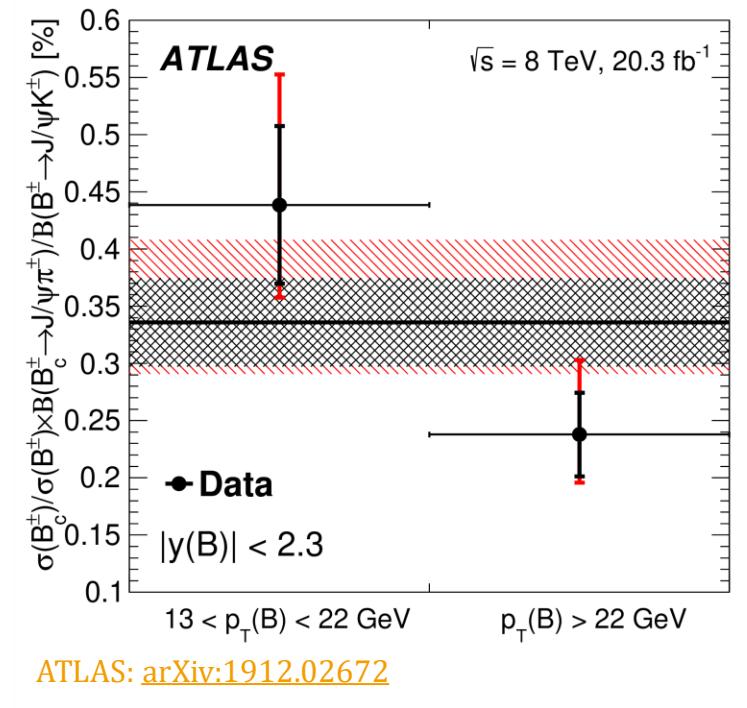
$\sqrt{s} = 8, 13 \text{ TeV}$



$\text{BR}(B_c^- \rightarrow J/\psi \mu^- \bar{\nu}) \in [1.4\%, 7.5\%]$ (theory)



$$\frac{\sigma(B_c^\pm)}{\sigma(B^\pm)} \times \frac{\text{BR}(B_c^\pm \rightarrow J/\psi \pi^\pm)}{\text{BR}(B^\pm \rightarrow J/\psi K^\pm)}$$



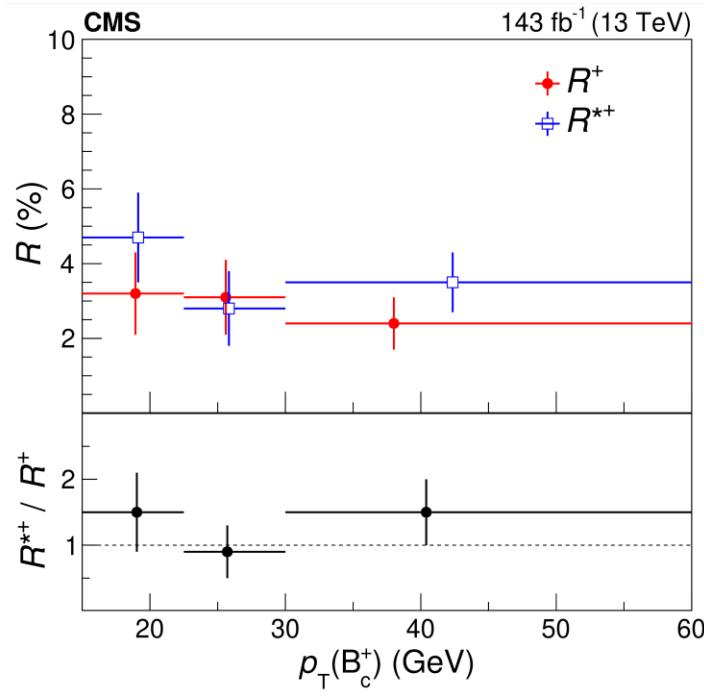
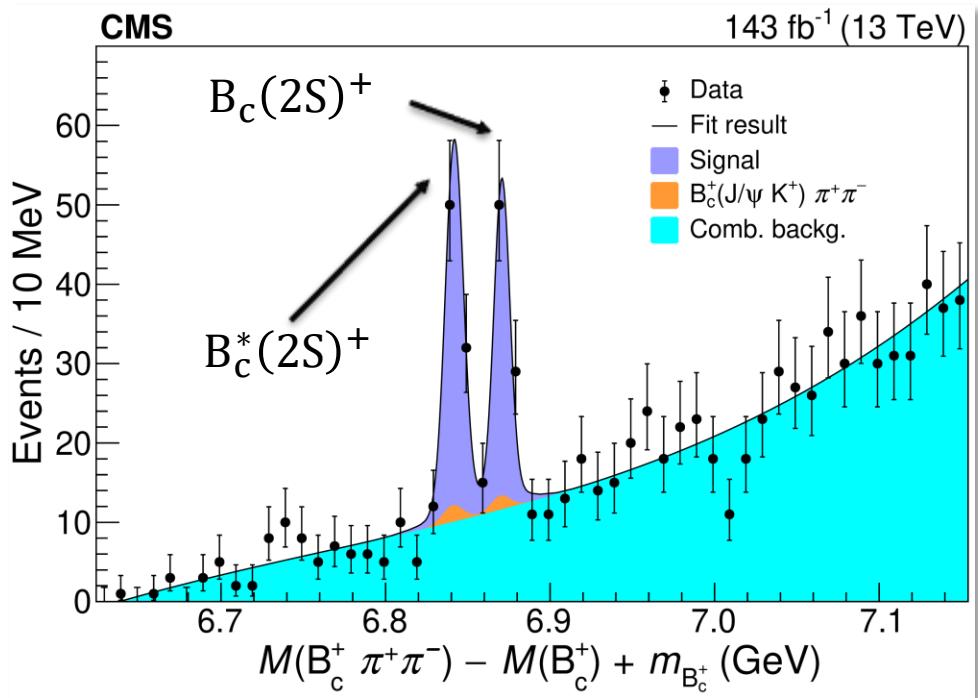
- Recent measurements B_c^\pm mesons
- $m_{B_c^-} (\sim 6.3 \text{ GeV}/c^2) > m_{\Lambda_b^0} (\sim 5.6 \text{ GeV}/c^2)$
- Milder p_T dependence for $B_c^- / (\bar{B}^0 + B^-)$ than $\Lambda_b^0 / (\bar{B}^0 + B^-)$

→ hypothesis of a pure mass-related effect (e.g. coalescence) disfavoured
 → Non-universality of fragmentation fractions?

... more on $B_c^- (\bar{c}b)$ meson production

CMS: Phys. Rev. D 102 (2020) 092007

NEW



$$R^+ \equiv \frac{\sigma(B_c(2S)^+)}{\sigma(B_c^+)} \text{BR}(B_c(2S)^+ \rightarrow B_c^+ \pi^+ \pi^-) = (3.47 \pm 0.63(\text{stat.}) \pm 0.33(\text{syst.}))\%$$

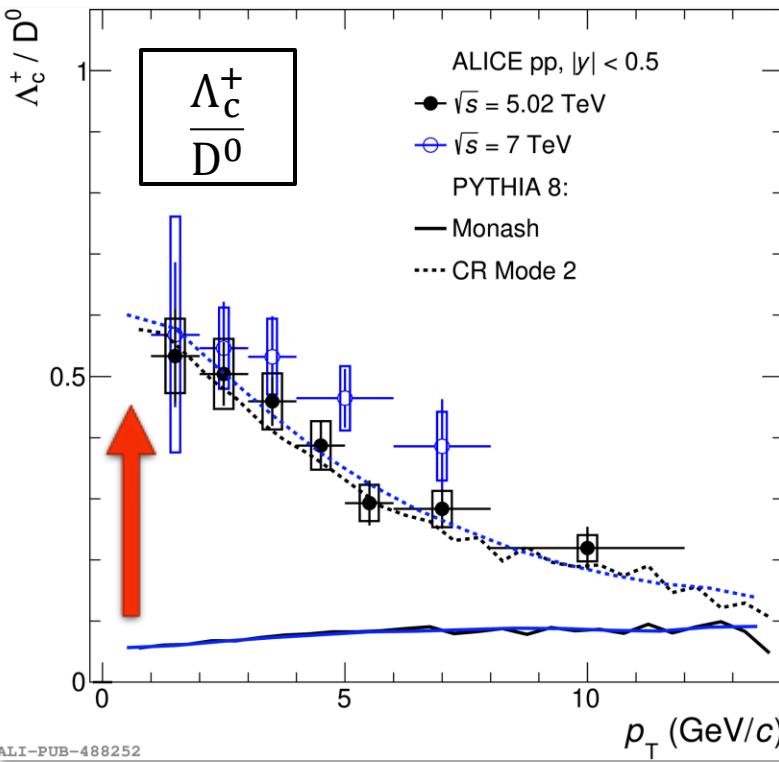
$$R^{*+} \equiv \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c^+)} \text{BR}(B_c^*(2S)^+ \rightarrow B_c^{*+} \pi^+ \pi^-) = (4.69 \pm 0.71(\text{stat.}) \pm 0.56(\text{syst.}))\%$$

- New measurements of $B(2S)^{\pm}$ and $B^*(2S)^{\pm}$ production
- Important step to further understand the production of these excited states and of B_c^-



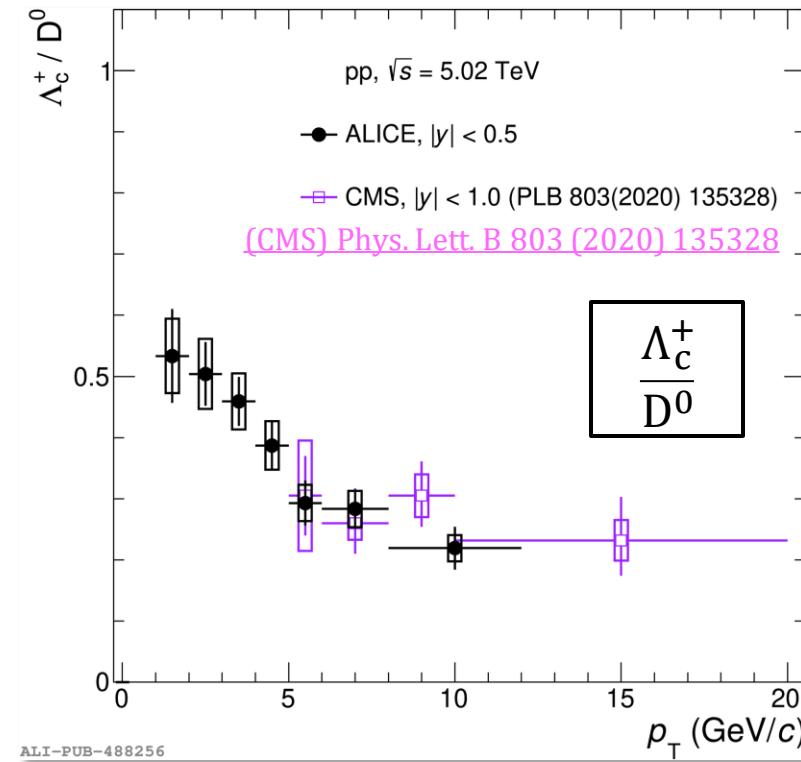
Baryon/meson ratios in the charm sector

ALICE: JHEP 04 (2018) 108



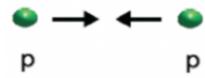
ALICE: arXiv:2011.06078

ALICE: arXiv:2011.06079

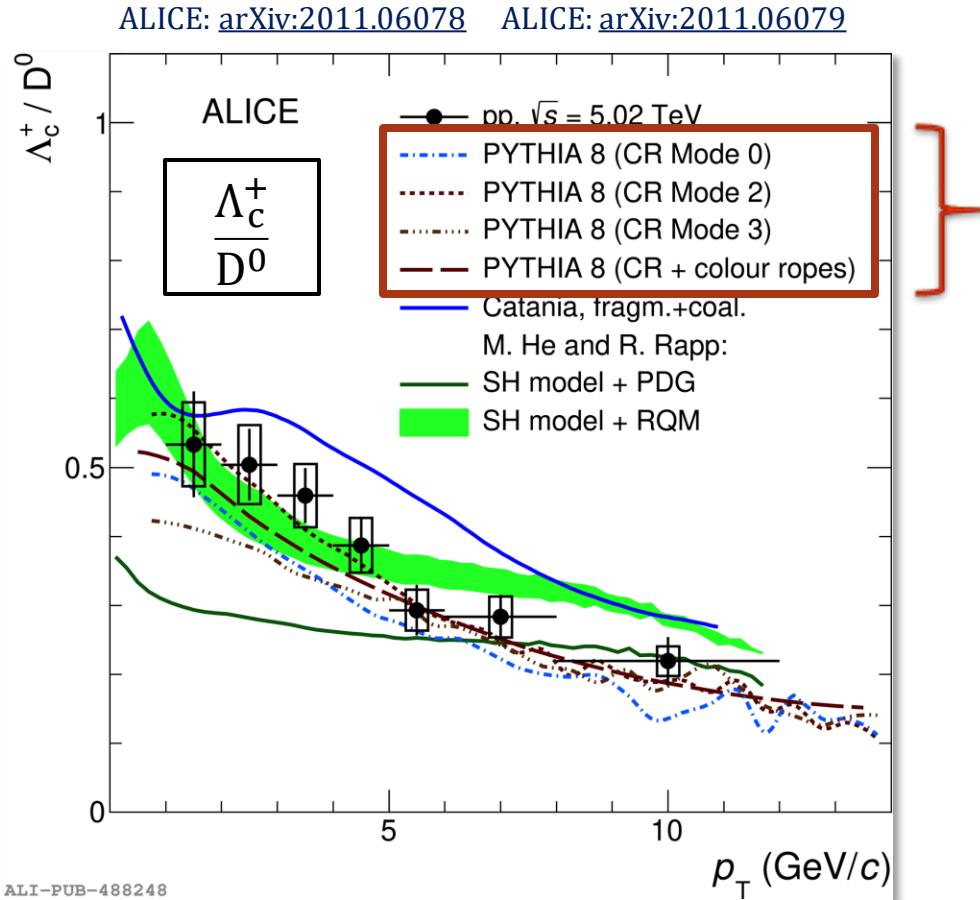


- **Strong p_T dependence** observed for Λ_c/D^0 ratio → same as b-sector (LHCb)
- Compatible results at midrapidity (ALICE vs. CMS)
- Ratio **significantly higher** than e^+e^- and ep collision results
→ factor $\times 2.5 \div 5$ enhancement in pp collisions

Do baryons point to non-universality of fragmentation functions?



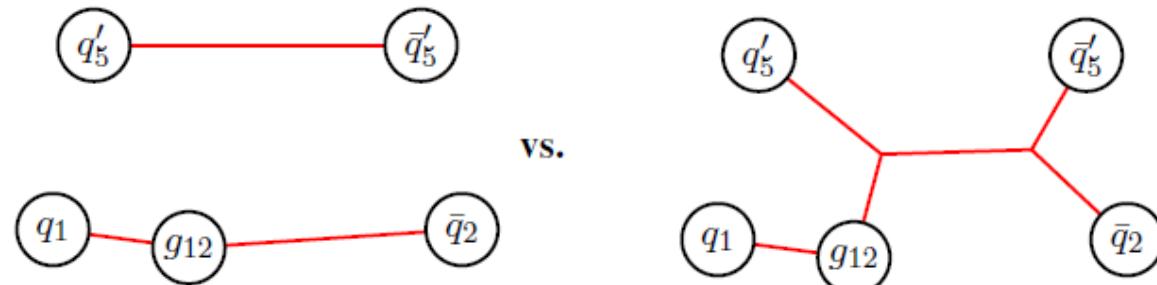
Baryon enhancement – models

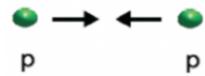


J.P. Christiansen, P. Z. Skands: JHEP 1508 (2015) 003

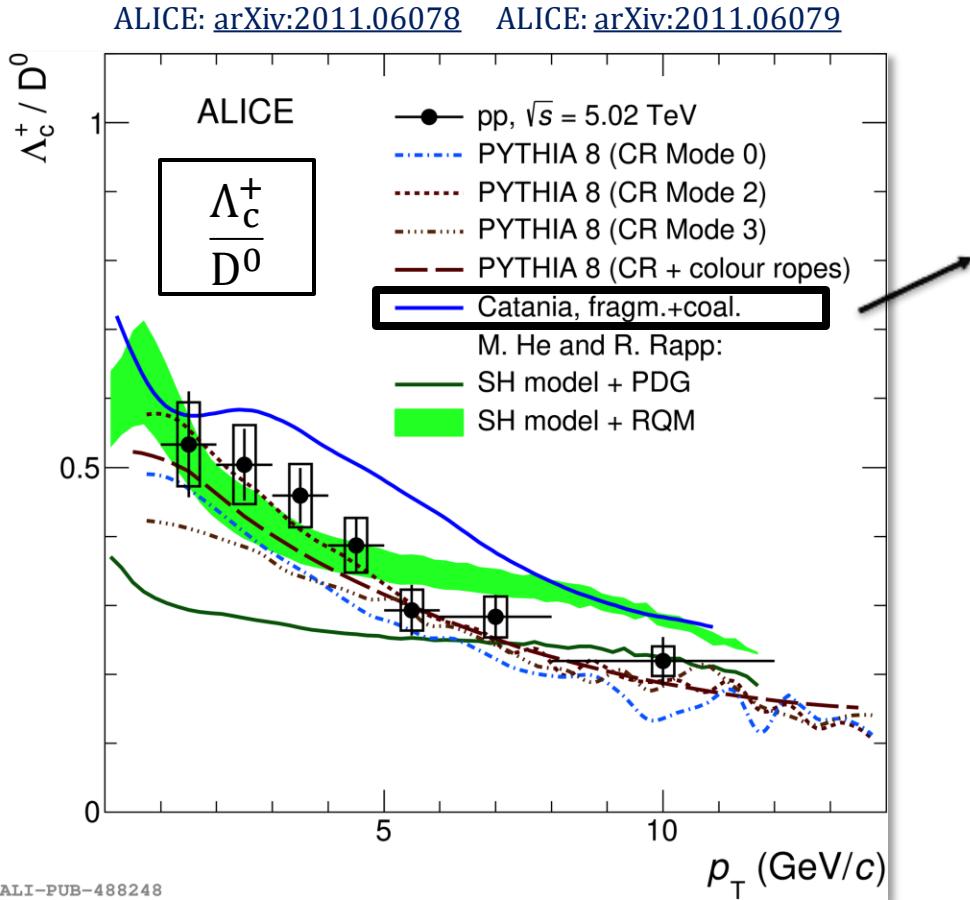
1. PYTHIA 8 with improved Colour Reconnection (CR)

- CR with SU(3) weights and string length minimization
- “junction” topology **enhances charm baryon production**





Baryon enhancement – models

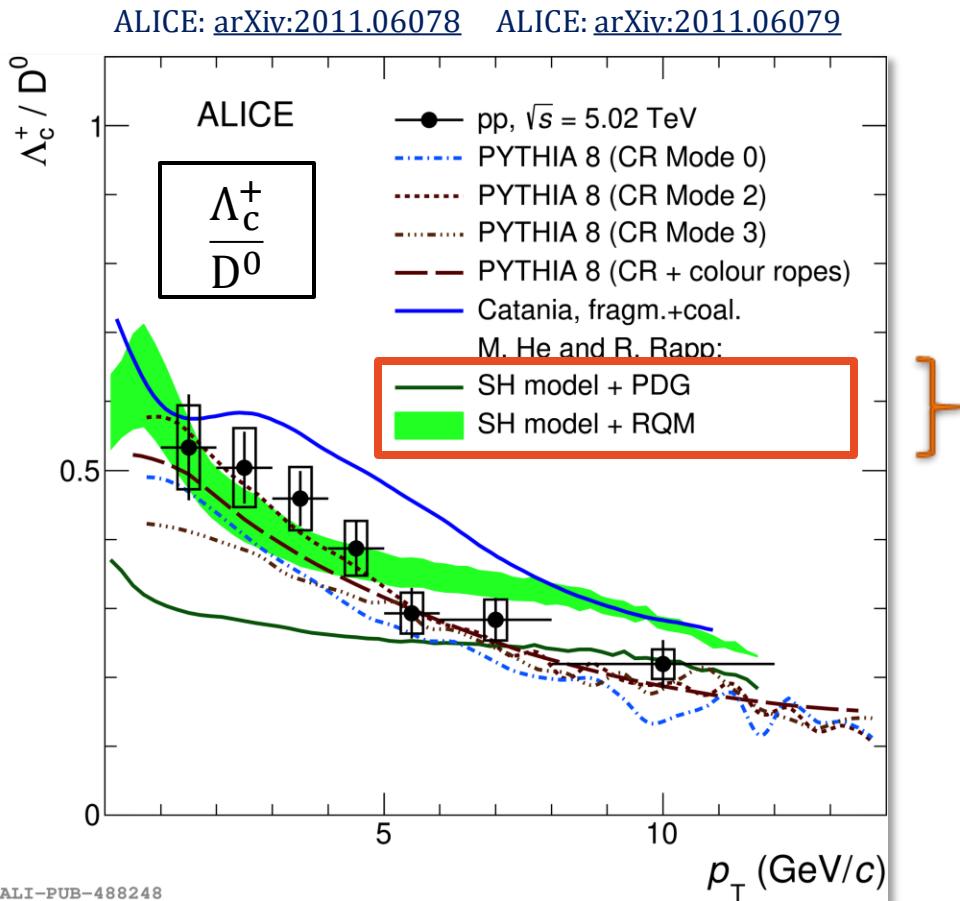
V. Minissale, S. Plumari, V. Greco: [arXiv:2012.12001](https://arxiv.org/abs/2012.12001)

2. Catania model

- **Thermalised system** of u,d,s and gluons assumed
 - Mixed hadron formation
 - a. **fragmentation**
 - b. **coalescence**
- imposed to be the only mechanism for $p \rightarrow 0$



Baryon enhancement – models



M. He, R. Rapp: PLB 795 (2019) 117-121

3. Statistical Hadronization Model and Relativistic Quark Model (SHM + RQM)

- Hadronization ruled by thermo-statistical weights governed by hadron masses ($n_i \sim m_i^2 T_H K_2(m_i/T_H)$) at a universal hadronization temperature T_H
- Strong feed-down from an augmented set of excited charm baryons
 - PDG: 5 Λ_c , 3 Σ_c , 8 Ξ_c , 2 Ω_c
 - RQM: additional 18 Λ_c , 42 Σ_c , 62 Ξ_c , 34 Ω_c

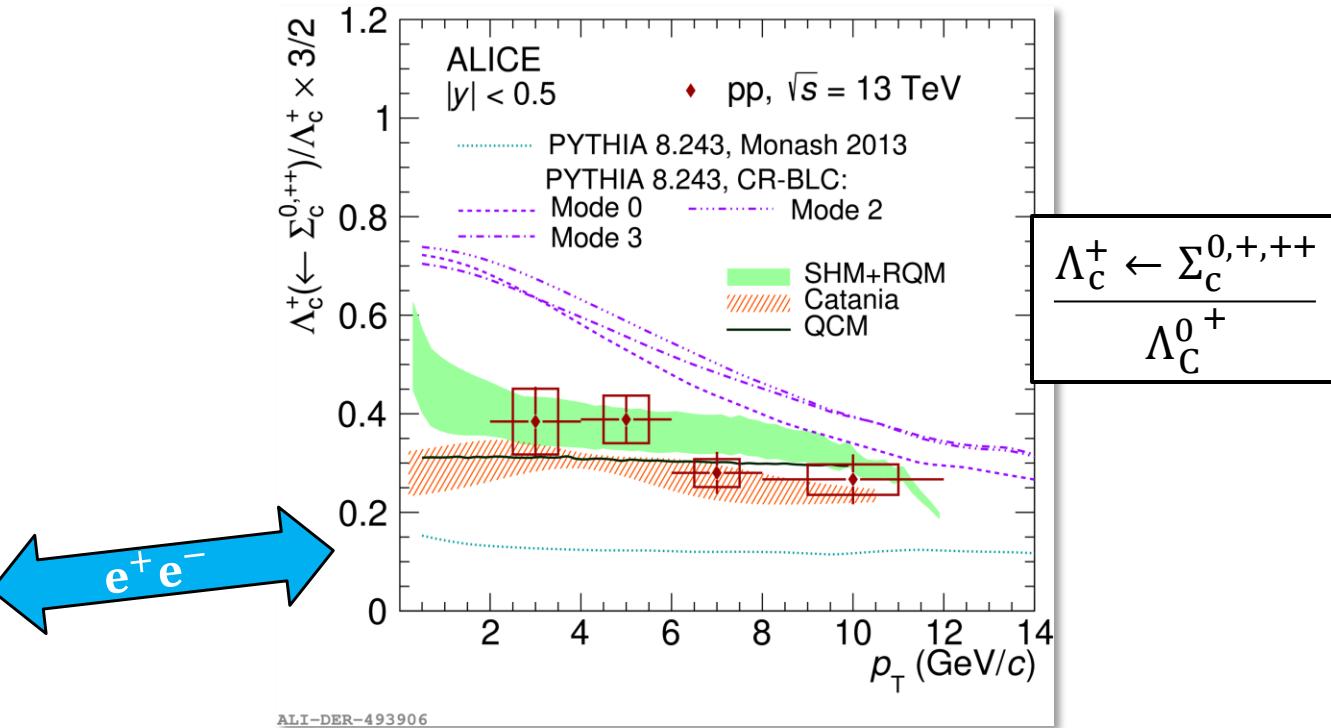
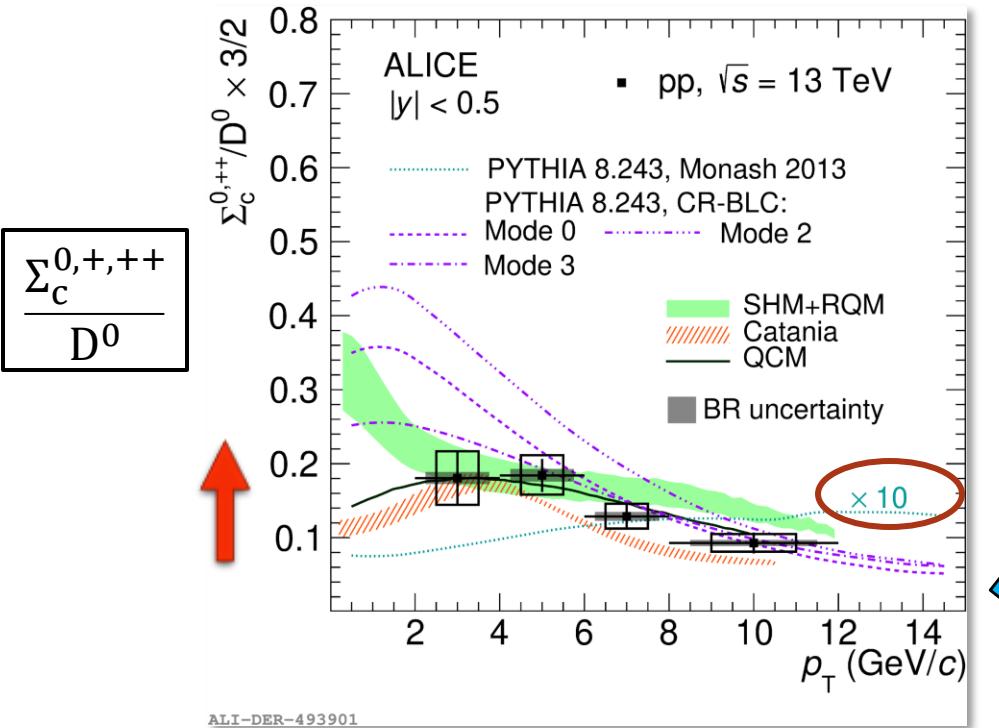
Can further baryon measurements help understanding the mechanisms underlying the baryon enhancement?

$n_i [\cdot 10^{-4} \text{ fm}^{-3}] (T_H [\text{MeV}])$	D^0	D^+	D^{*+}	D_s^+	Λ_c^+	$\Xi_c^{0,+}$	Ω_c^0
PDG (170)	1.161	0.5098	0.5010	0.3165	0.3310	0.0874	0.0064
RQM (170)	1.161	0.5098	0.5010	0.3165	0.6613	0.1173	0.0144

$\sqrt{s} = 13 \text{ TeV}$

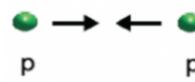
Heavier charmed baryons: $\Sigma_c^{0,+,++}$

ALICE: [arXiv:2106.08278 \[hep-ex\]](https://arxiv.org/abs/2106.08278)



- Larger than e^+e^- results (\leftrightarrow Monash)
→ larger relative enhancement than Λ_c/D^0
- $\Sigma_c^{0,+,++}/D^0$ partially accounts for larger Λ_c^+/D^0
- Well described by **SHM + RQM** and **QCM** (pure coalescence, J. Song, H. Li, F. Shao: *Eur. Phys. J. C* (2018) 78: 344) predictions

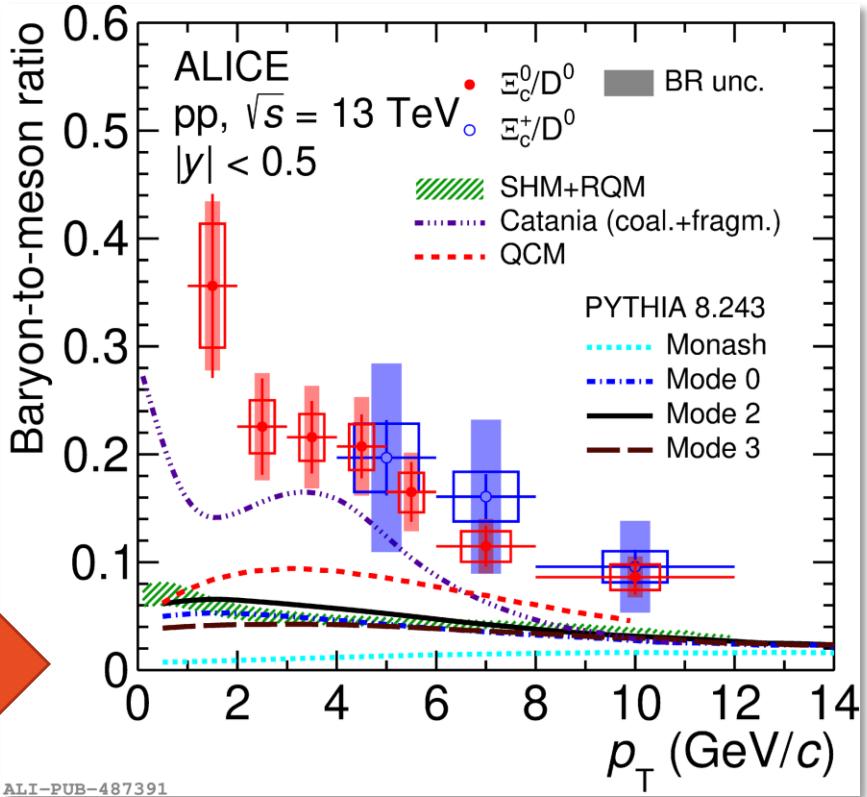
- Measurement of **Λ_c feed-down from Σ_c**
 $\Lambda_c^+ \leftarrow \Sigma_c / \Lambda_c^+ = 0.38 \pm 0.06(\text{stat.}) \pm 0.06(\text{syst.})$
- Overestimated by CR modes
→ something missing in the direct Λ_c description?
→ scenario with more baryons the most plausible?



Heavier charmed baryons: $\Xi_c^{0,+}$

NEW

$$\frac{\Xi_c^{0,+}}{D^0}$$

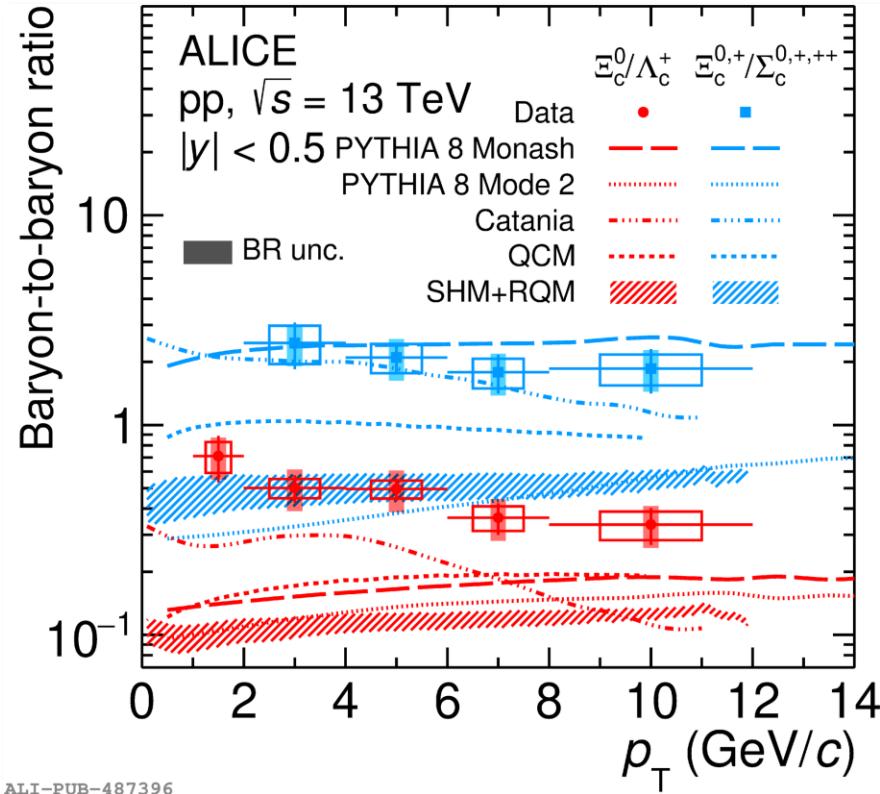


ALI-PUB-487391

NEW

$$\begin{array}{l} \Xi_c^{0,+} / \Sigma_c^{0,+,++} \\ \Xi_c^{0,+} / \Lambda_c^+ \end{array}$$

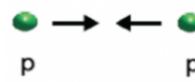
ALICE: arXiv:2105.05187
ALICE: arXiv:2105.05616



ALI-PUB-487396

- $\Xi_c^{0,+}/D^0$ shows clear p_T dependence and is **larger** than e^+e^-
- Significantly **underestimated** by:
 - Pythia CR → further strangeness enhancement needed?
 - SHM + RQM → more states needed?
 - QCM → coalescence alone not enough?
- Catania (fragm. + coal.) works better

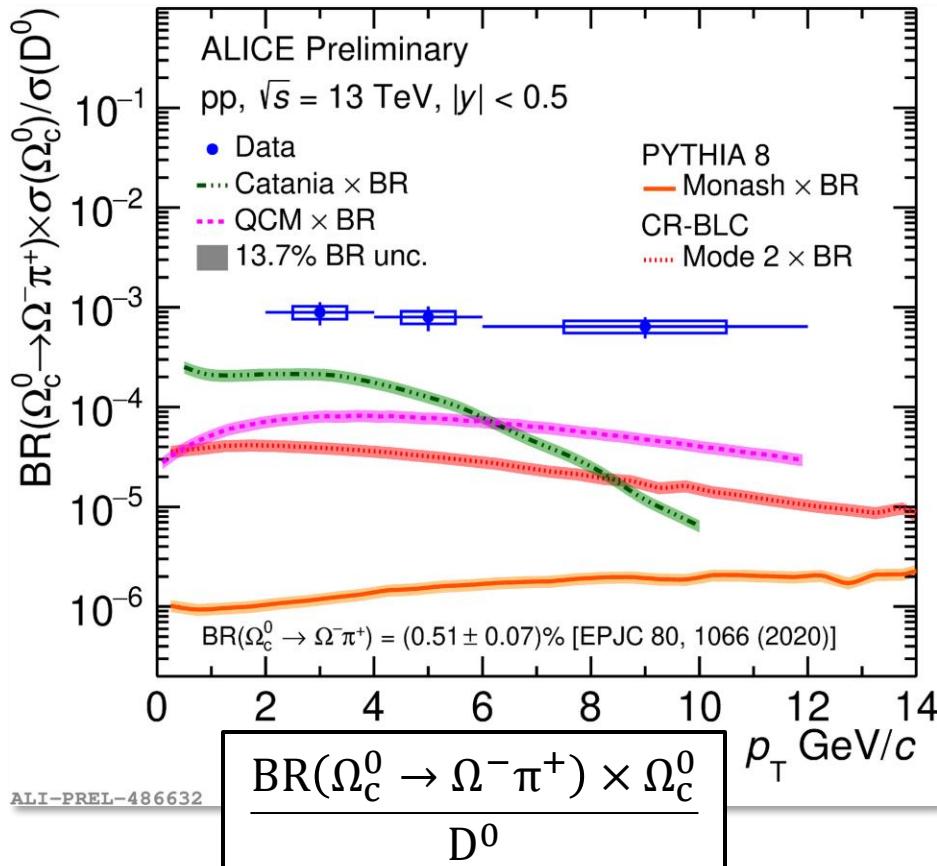
- $\Xi_c^0/\Sigma_c^{0,+,++}$ in **agreement** with **Monash**
 - similar enhancement for the two baryons w.r.t e^+e^- collisions?



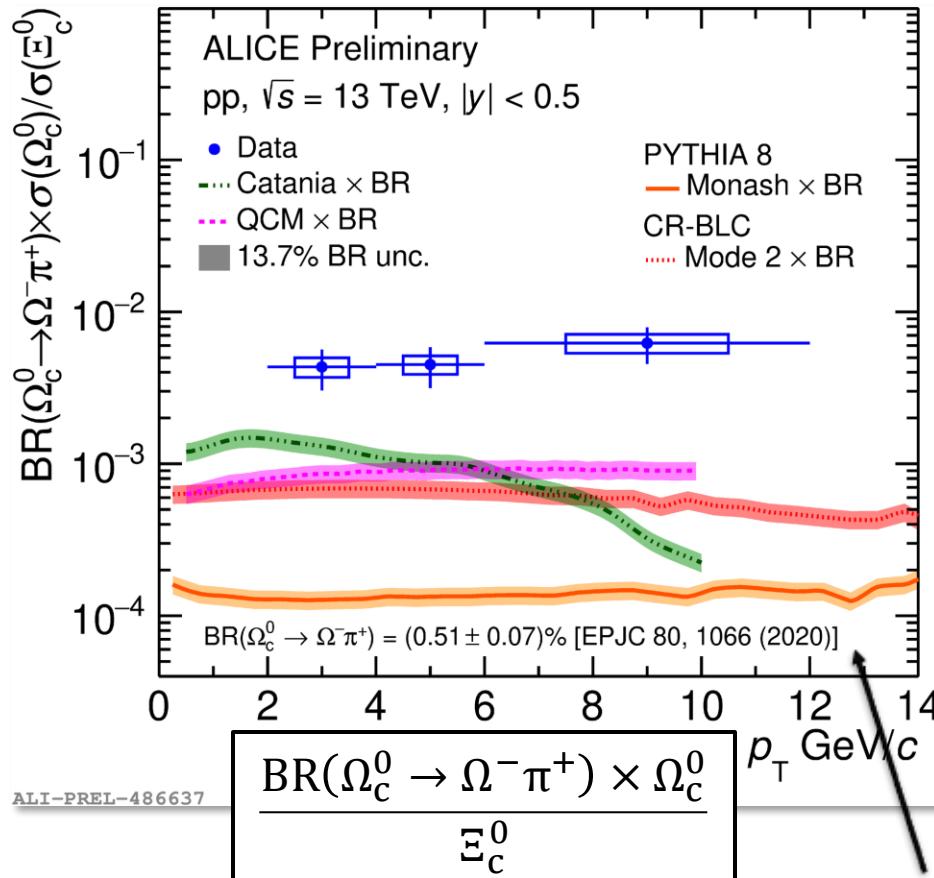
Heavier charmed baryons: Ω_c^0

09 June 2021

NEW



- Pythia 8 with CR underestimates data
- Coalescence models get closer, but still not enough



$\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) = (0.51 \pm 0.07)\%$
(Y. Hsiao et al. EPJC 80, 1066 (2020)) used to scale model predictions → not measured

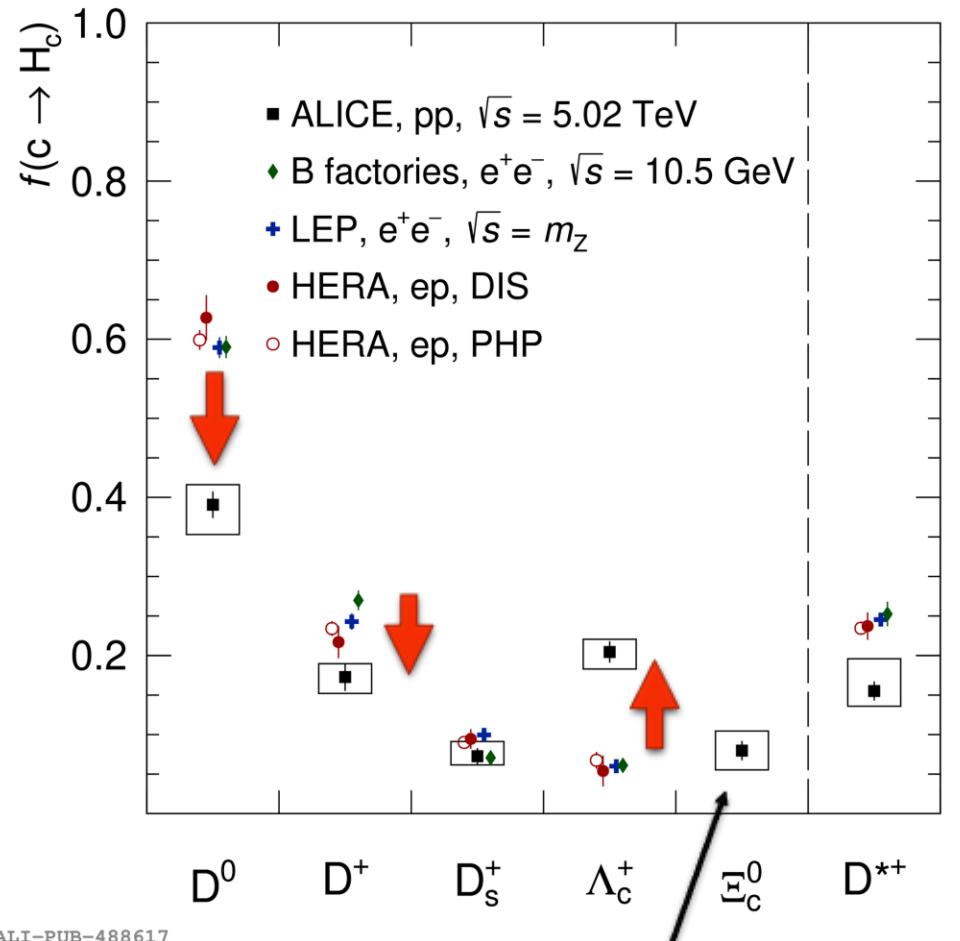
NEW

Charm fragmentation fractions in pp collisions

$\sqrt{s} = 5.02 \text{ TeV}$
 $p \rightarrow p$

NEW

ALICE: [arXiv:2105.06335](https://arxiv.org/abs/2105.06335)



First measurement of $f(c \rightarrow \Xi_c)$

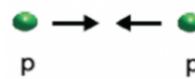
Single species cross section normalised by the sum of all ground states charm hadrons

Fragmentation fractions $f(c \rightarrow H_c)$ not universal

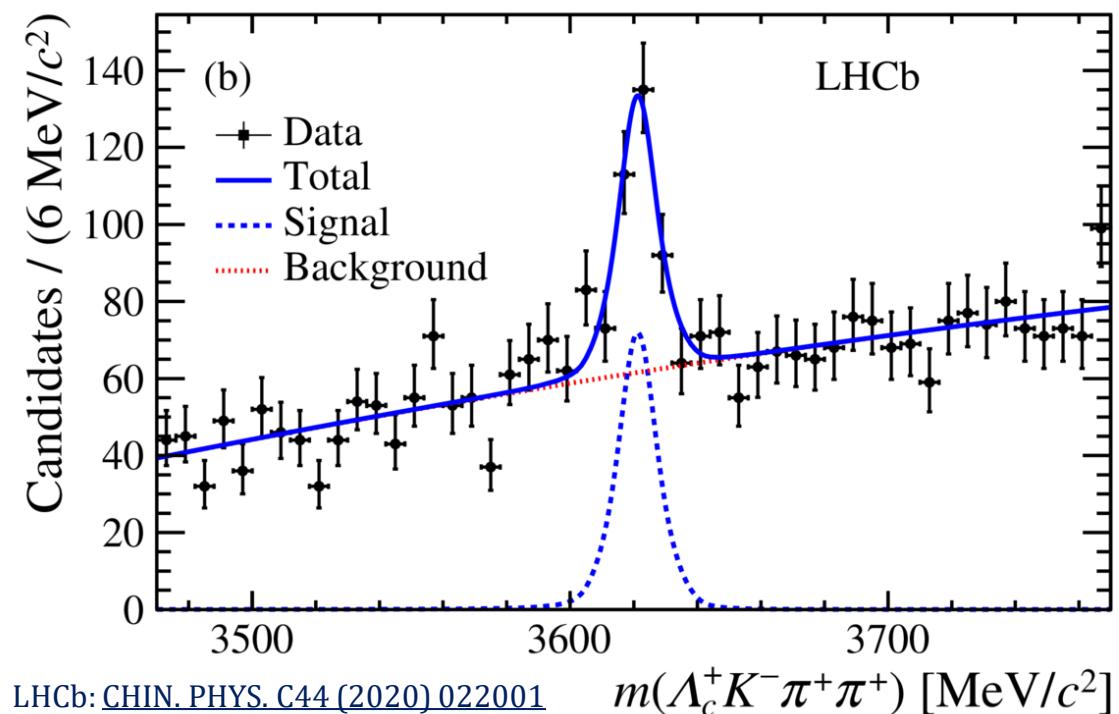
→ significant baryon enhancement in pp collisions

H_c	$f(c \rightarrow H_c)[\%]$
D^0	$39.1 \pm 1.7(\text{stat})^{+2.5}_{-3.7}(\text{syst})$
D^+	$17.3 \pm 1.8(\text{stat})^{+1.7}_{-2.1}(\text{syst})$
D_s^+	$7.3 \pm 1.0(\text{stat})^{+1.9}_{-1.1}(\text{syst})$
Λ_c^+	$20.4 \pm 1.3(\text{stat})^{+1.6}_{-2.2}(\text{syst})$
Ξ_c^0	$8.0 \pm 1.2(\text{stat})^{+2.5}_{-2.4}(\text{syst})$
D^{*+}	$15.5 \pm 1.2(\text{stat})^{+4.1}_{-1.9}(\text{syst})$

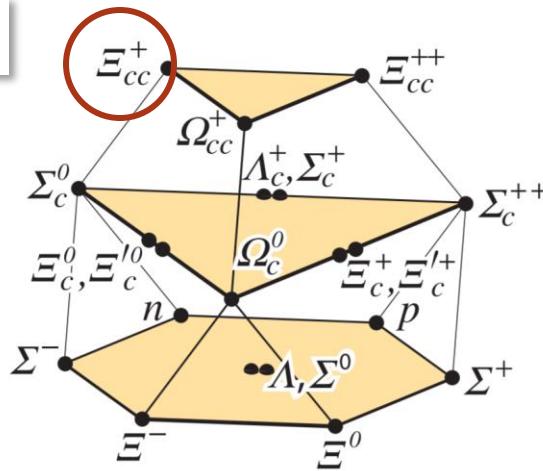
also
for Ξ_c^+



Doubly charmed baryons: Ξ_{cc}^{++}



Particle	Mass (GeV/ c^2)	Valence quarks
Λ_c^+	2.286	udc
Ξ_{cc}^{++}	3.621	ucc

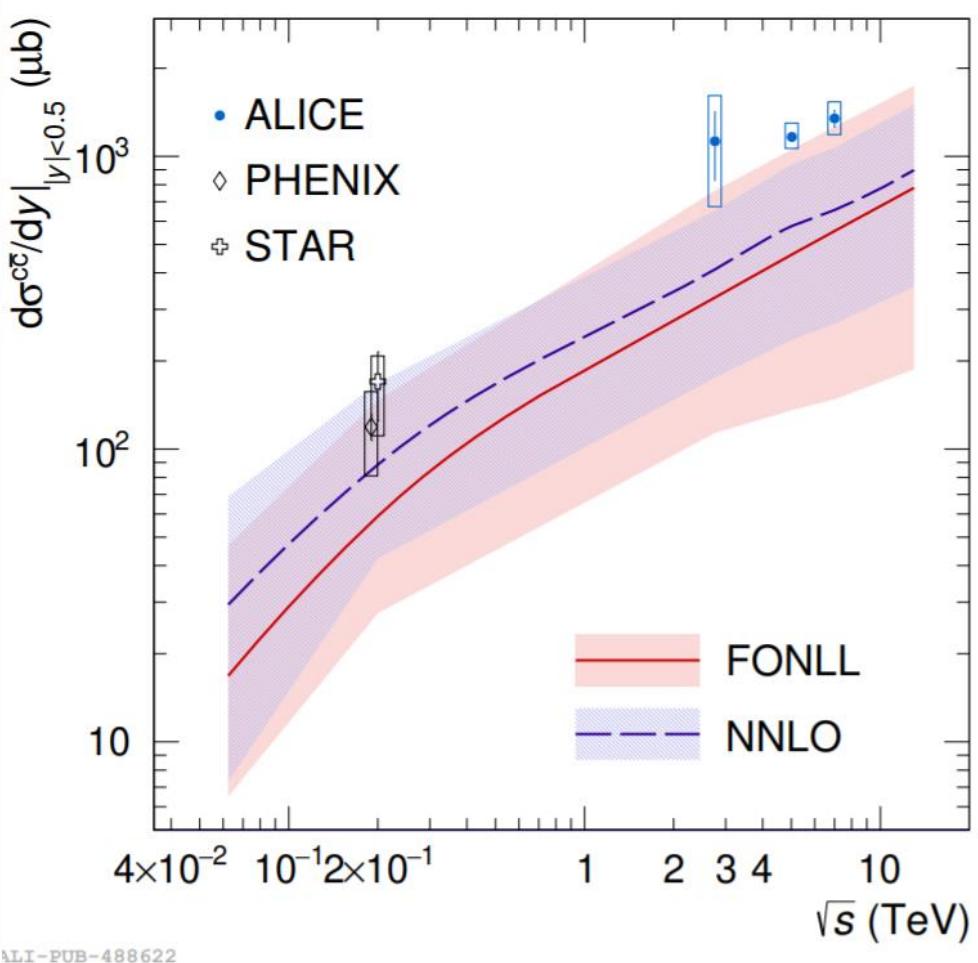


- Ξ_{cc}^{++} production compared with Λ_c^+ one
 - Double-over-single charmed baryon ratio
- $$[\text{BR}(\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+) \times \sigma(\Xi_{cc}^{++})]/[\sigma(\Lambda_c^+)] = (2.22 \pm 0.27(\text{stat.}) \pm 0.29(\text{syst.})) \times 10^{-4}$$
- More differential measurements and comparison with models: further insights in HF production

c \bar{c} cross section in pp collisions

NEW

ALICE: [arXiv:2105.06335](https://arxiv.org/abs/2105.06335)



FONLL: [JHEP 12 \(2012\) 137](https://doi.org/10.1007/JHEP12(2012)137)

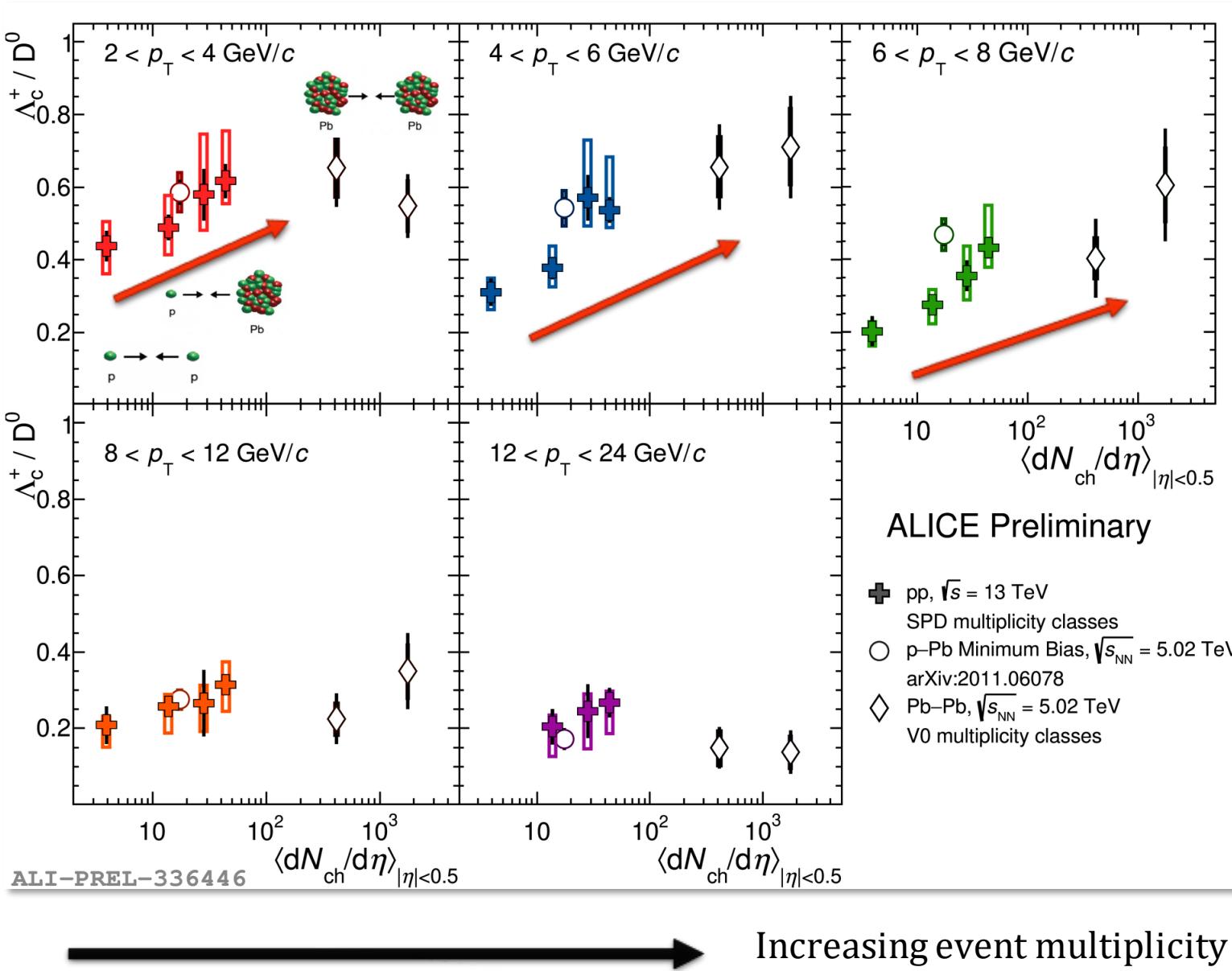
NNLO: [PRL 118 \(2017\) 122001](https://doi.org/10.1103/PhysRevLett.118.122001), [JHEP 03 \(2021\) 029](https://doi.org/10.1007/JHEP03(2021)029)

PHENIX: [Phys. Rev. C 84 \(2011\) 044905](https://doi.org/10.1103/PhysRevC.84.044905)

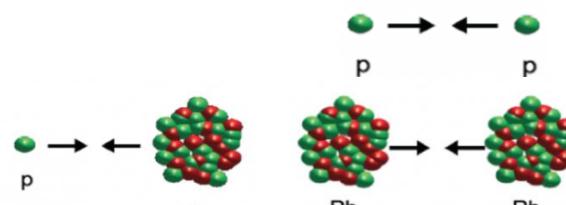
STAR: [Phys. Rev. D 86 \(2012\) 072013](https://doi.org/10.1103/PhysRevD.86.072013)

- **c \bar{c} production cross section** at midrapidity in **pp collisions** at $\sqrt{s} = 5.02 \text{ TeV}$ measured as sum of ground state hadron cross sections
 $(d\sigma^{c\bar{c}}/dy)|_{|y|<0.5} = 1165 \pm 44(\text{stat.})^{+134}_{-101}(\text{syst.}) \mu\text{b}$
- **Results previously published** at $\sqrt{s} = 2.76$ and 7 TeV from D mesons **updated** with fragmentation fractions from $\sqrt{s} = 5.02 \text{ TeV}$ analysis
 \rightarrow **40% increase**
- **Higher** values driven by the observed **baryon enhancement** in pp collisions
- Results on **upper edge of FONLL and NNLO** calculations

Charm production vs. multiplicity



$\sqrt{s_{NN}} = 5.02, 13$ TeV



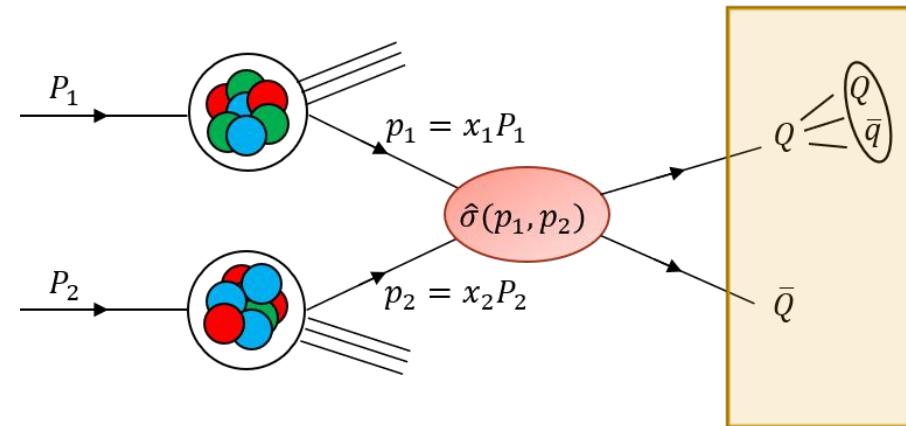
- pp, p-Pb, Pb-Pb colliding **systems** compared through **common multiplicity estimators**
- Λ_c^+ / D^0 ratio smoothly **increasing** at intermediate p_T from pp to Pb-Pb

- **Same underlying processes ruling the HF production in different colliding systems?**
- Interplay with flow effects in Pb-Pb collisions?

Summary

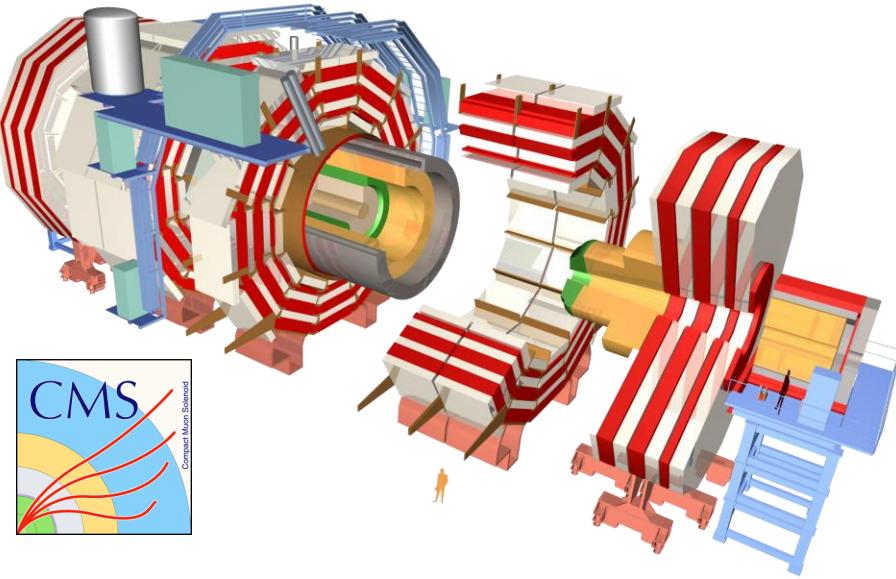
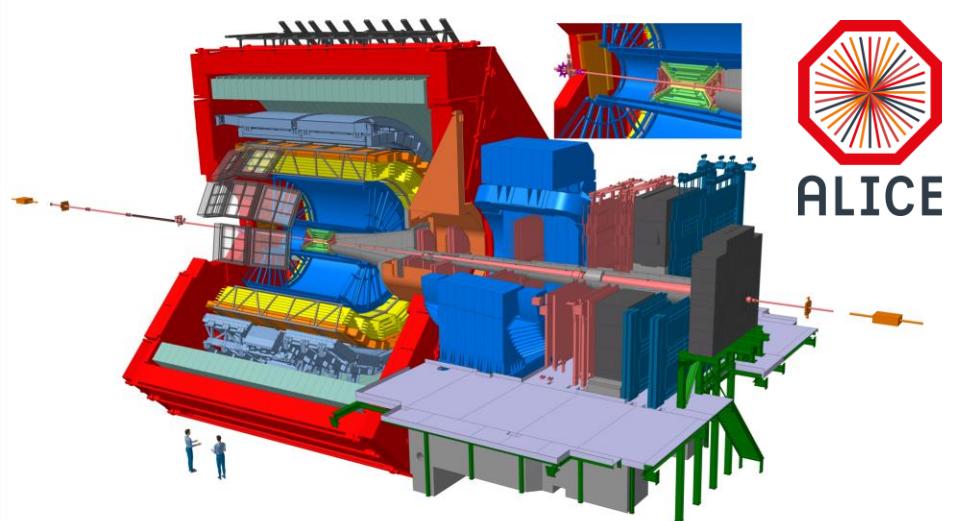
- Standard picture for the **heavy flavour production** in pp collisions based on the factorization approach, assuming **universal fragmentation functions**
- Recent results from **ALICE, ATLAS, CMS** and **LHCb** show that this **assumption** is **no more valid** in **hadronic collisions** at LHC
- Joint effort between theory and experiments to investigate the baryon enhancement in hadronic collisions
- Further QCD tests and insights on heavy flavour production from
 - **heavy flavour hadron spectroscopy**
 - **quarkonia** production

New measurement in the quarkonia sector
Valeriia Zhovkovska
Wednesday 9th June, 14:57

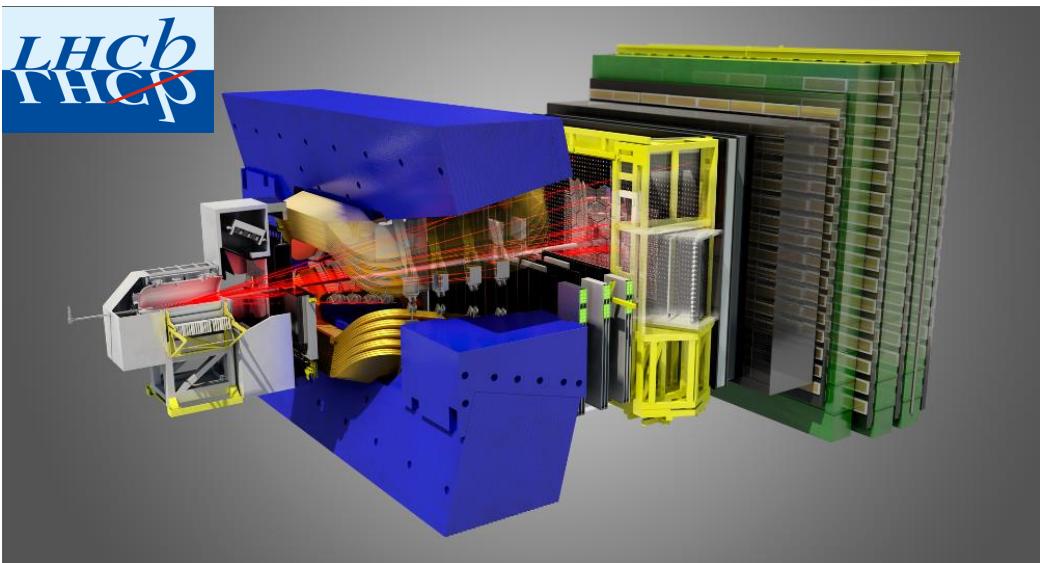
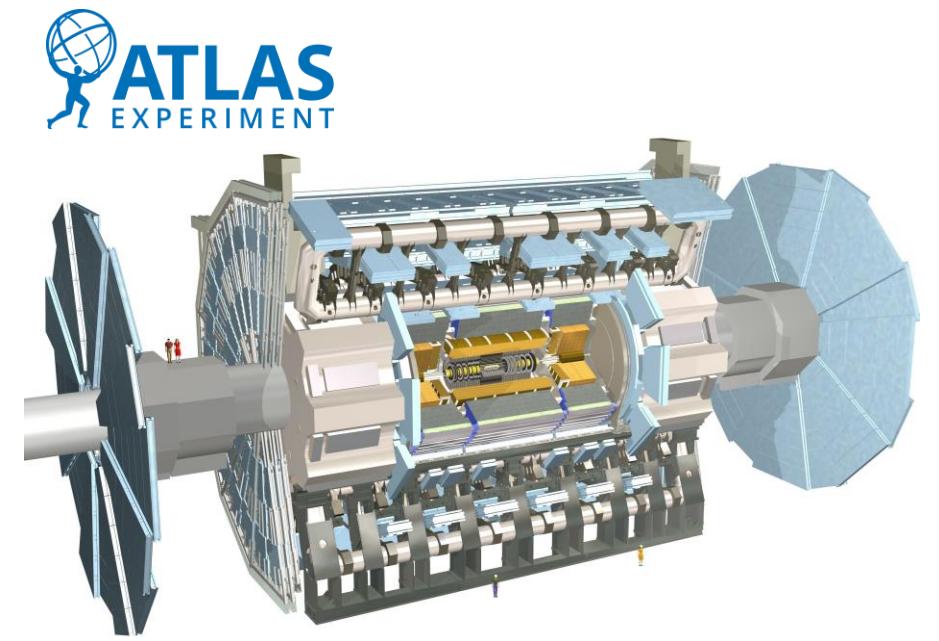


“Classical spectroscopy”
Valentina Mariani
Thursday 10th June, 14:15

“Tetra- and pentaquark spectroscopy”
Elisabetta Spadaro Norella
Thursday 10th June, 14:33



Thanks a lot for your attention!



Backup



The Ninth Annual Conference on Large Hadron Collider Physics

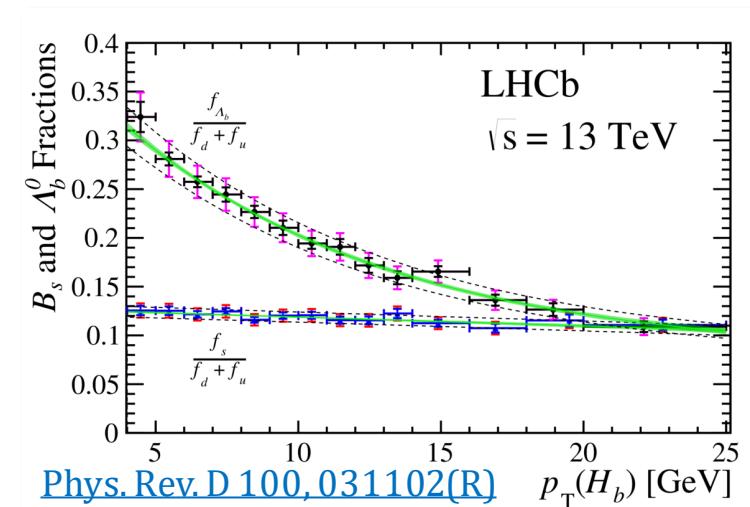
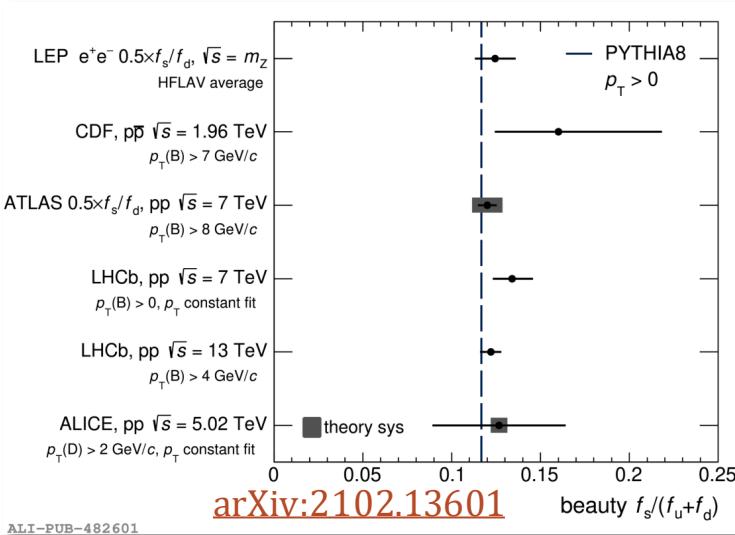
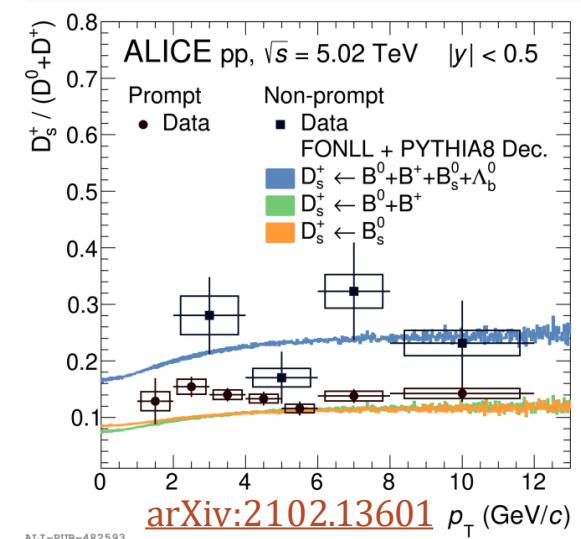
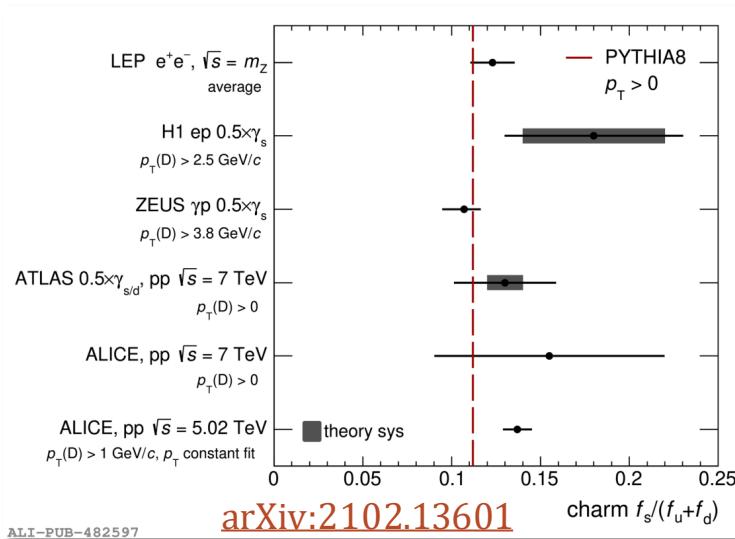
LHCP2021

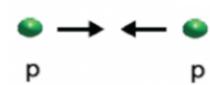
7-12 June 2021 ~~Paris (France), Sorbonne Université~~

~~(IN2P3/CNRS/IRFU/CEA)~~

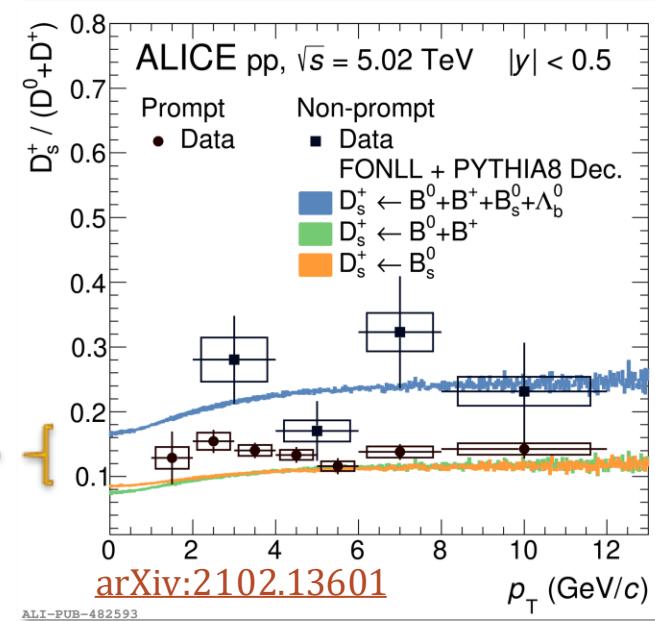
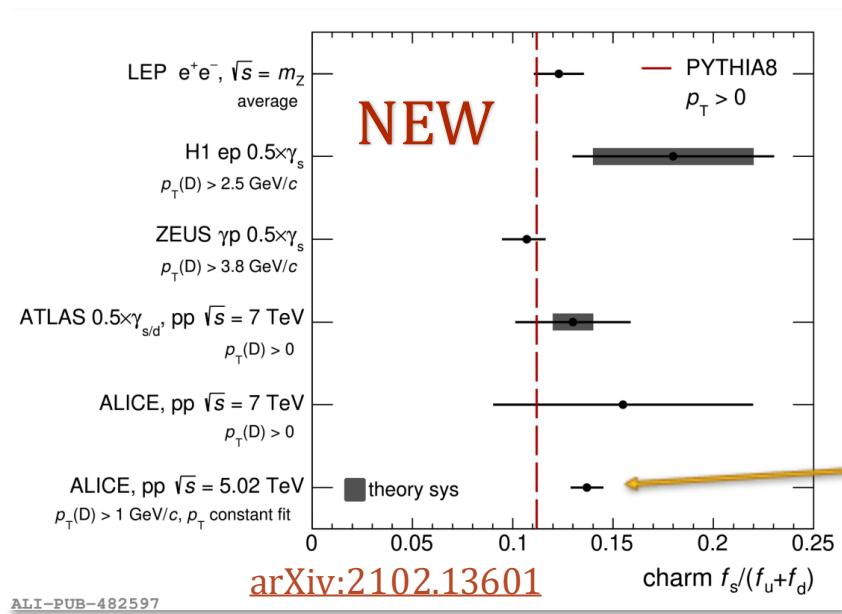


Heavy meson fragmentation fraction ratios





Charm meson fragmentation fraction ratios



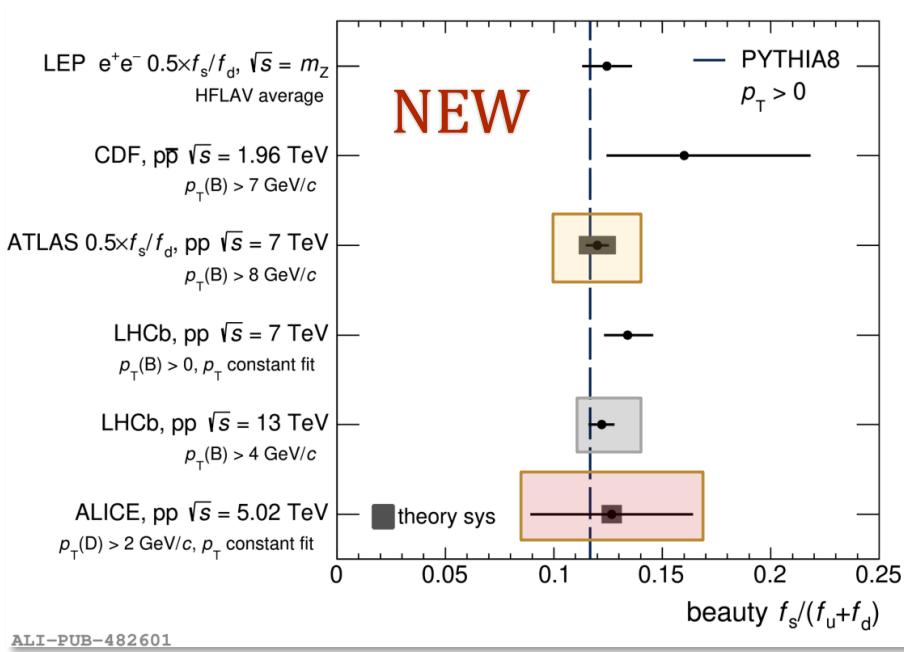
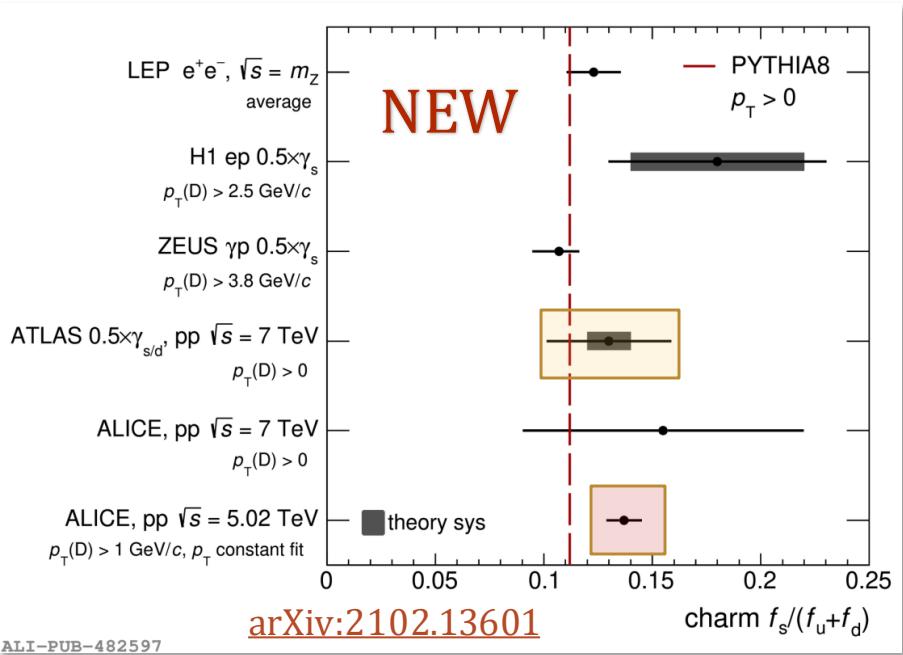
- $\left(\frac{f_s}{f_u+f_d}\right)_c$ recently **measured** at LHC as $\left(\frac{D_s^+}{D_s^0 + D_s^+}\right)$ **prompt**

$$\left(\frac{f_s}{f_u+f_d}\right)_c = 0.137 \pm 0.005 \text{ (stat)} \pm 0.006 \text{ (syst)} \pm 0.005 \text{ (BR)} [\text{ALICE}]$$

- Fragmentation fraction ratios **compatible** among **different** collision **systems** and **energies**


 $\sqrt{s} = 5.02, 13 \text{ TeV}$

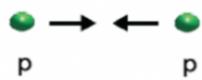
HF meson fragmentation fraction ratios


CHARM


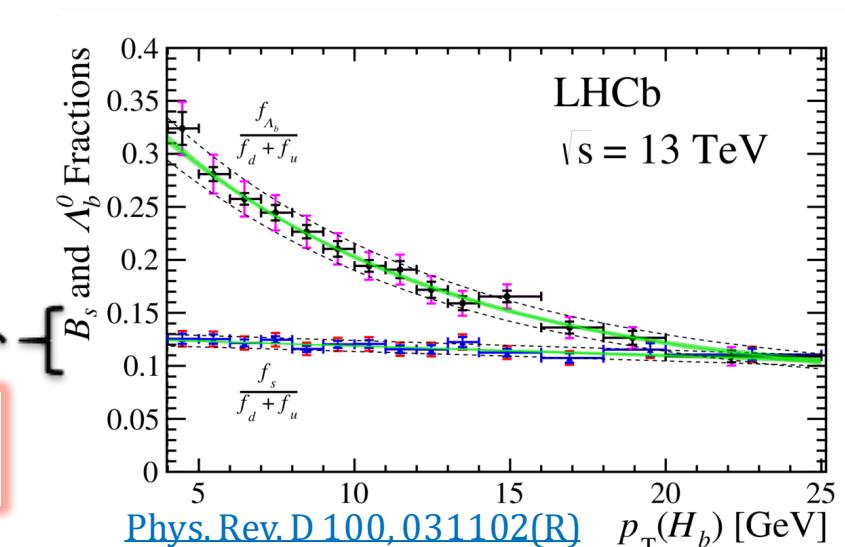
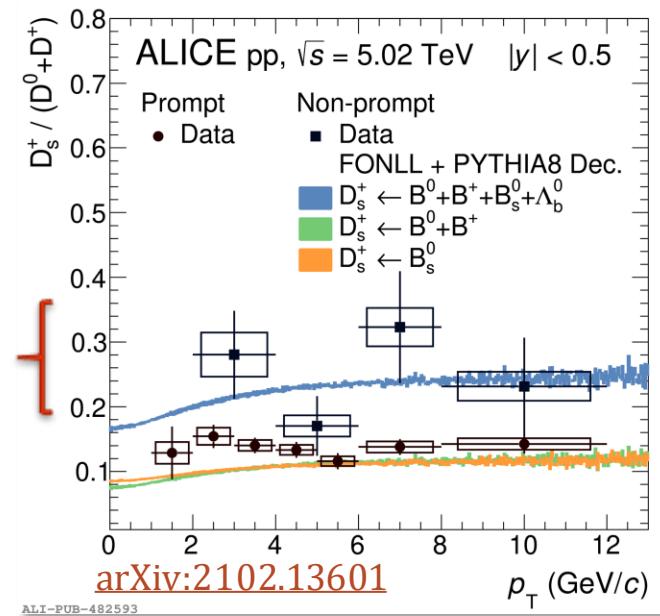
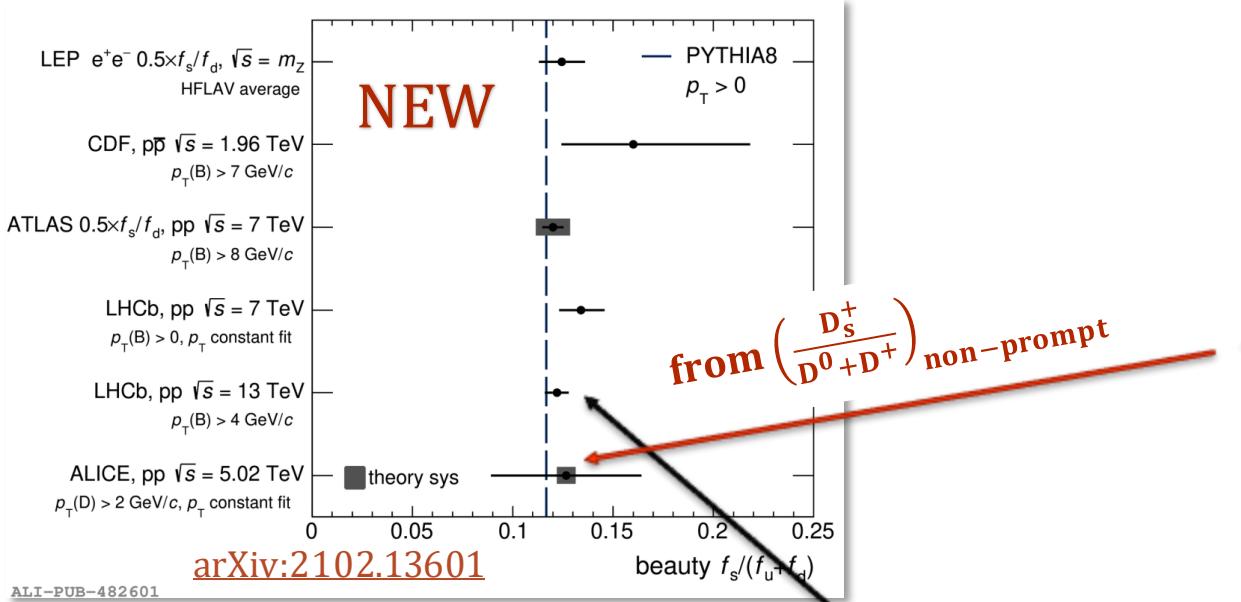
- $\left(\frac{f_s}{f_u+f_d}\right)_{c(b)} \rightarrow \left(\frac{D_s^+}{D^0 + D^+}\right)_{\text{(non)prompt}}$ [ALICE, ATLAS] and $\left(\frac{B_s^0}{B^0 + B^-}\right)$ [LHCb, ATLAS] in pp at $\sqrt{s} = 5.02, 7, 13 \text{ TeV}$
- Fragmentation fraction ratios for **charm** and **beauty** mesons **compatible** between the two flavours

$$\left(\frac{f_s}{f_u+f_d}\right)_c = \begin{cases} 0.137 \pm 0.005 \text{ (stat)} \pm 0.006 \text{ (syst)} \pm 0.005 \text{ (BR)} \quad \text{[ALICE]} \\ 0.5 \times (0.26 \pm 0.05 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \pm 0.02 \text{ (BR)} \pm 0.01 \text{ (extr.)}) \quad \text{[ATLAS]} \end{cases}$$

$$\left(\frac{f_s}{f_u+f_d}\right)_b = \begin{cases} 0.122 \pm 0.006 \quad \text{[LHCb]} \\ 0.127 \pm 0.036 \text{ (stat)} \pm 0.012 \text{ (syst)} \pm 0.005 \text{ (BR)} \pm 0.005 \text{ (th)} \quad \text{[ALICE]} \\ 0.5 \times (0.240 \pm 0.004 \text{ (stat.)} \pm 0.010 \text{ (syst.)} \pm 0.017 \text{ (th)}) \quad \text{[ATLAS]} \end{cases}$$

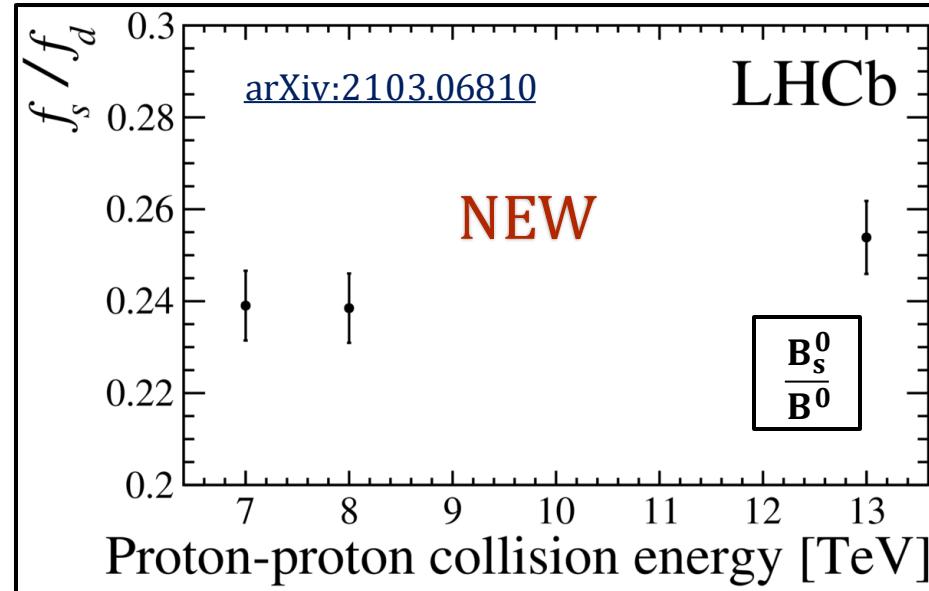
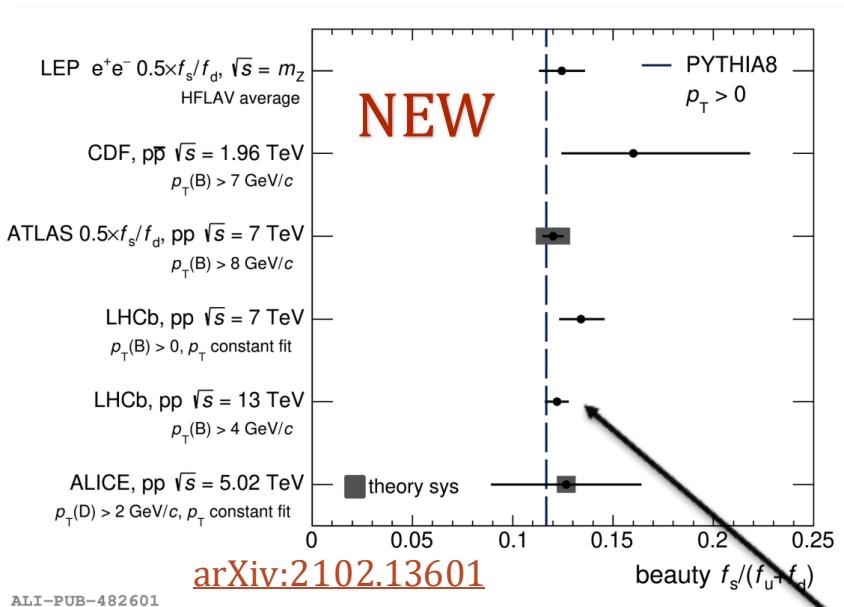
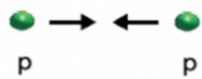


Beauty meson fragmentation fraction ratios



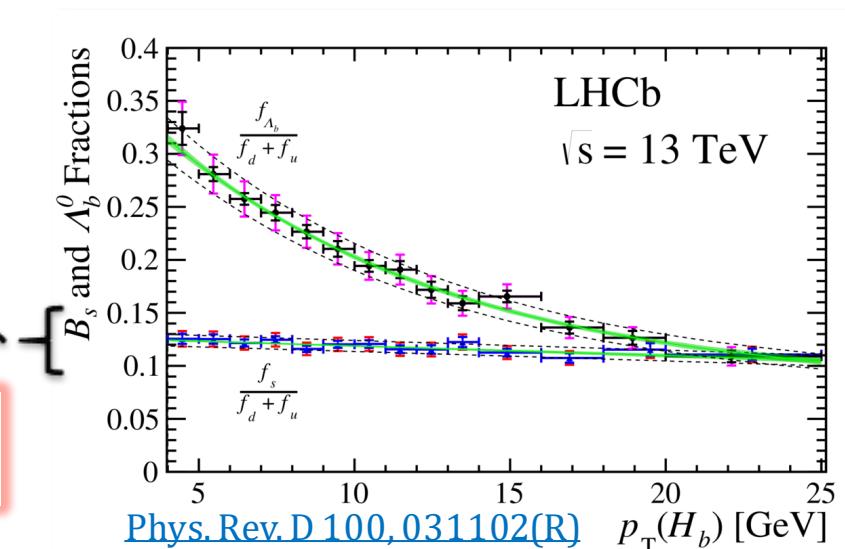
$$\left(\frac{f_s}{f_u + f_d} \right)_B = \begin{cases} 0.122 \pm 0.006 [\text{LHCb}] \\ 0.127 \pm 0.036(\text{stat}) \pm 0.012(\text{syst}) \pm 0.005(\text{BR}) \pm 0.005(\text{th}) [\text{ALICE}] \end{cases}$$

Beauty meson fragmentation fraction ratios



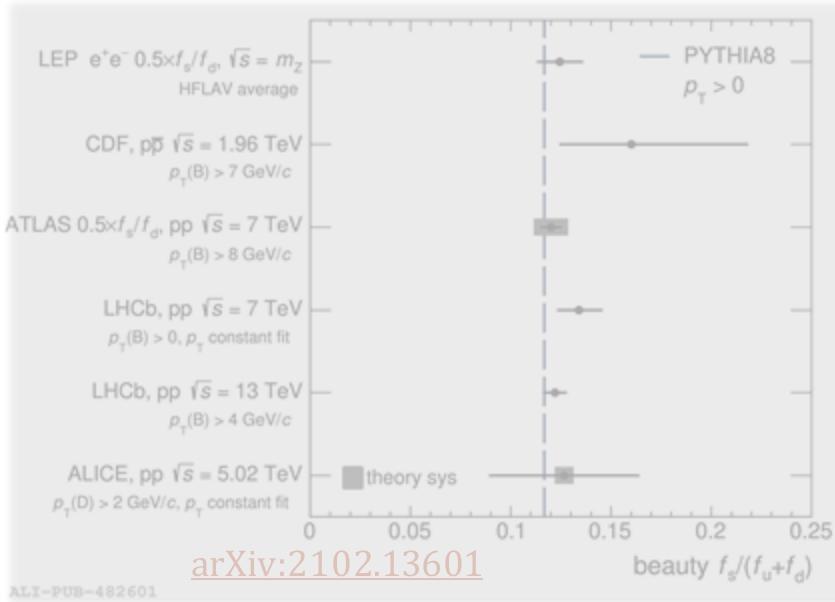
- Fragmentation fraction ratios **compatible** among **different** collision **systems**, **energies** and **rapidity** ranges

$$B_s^0 + B_{s0}^0$$



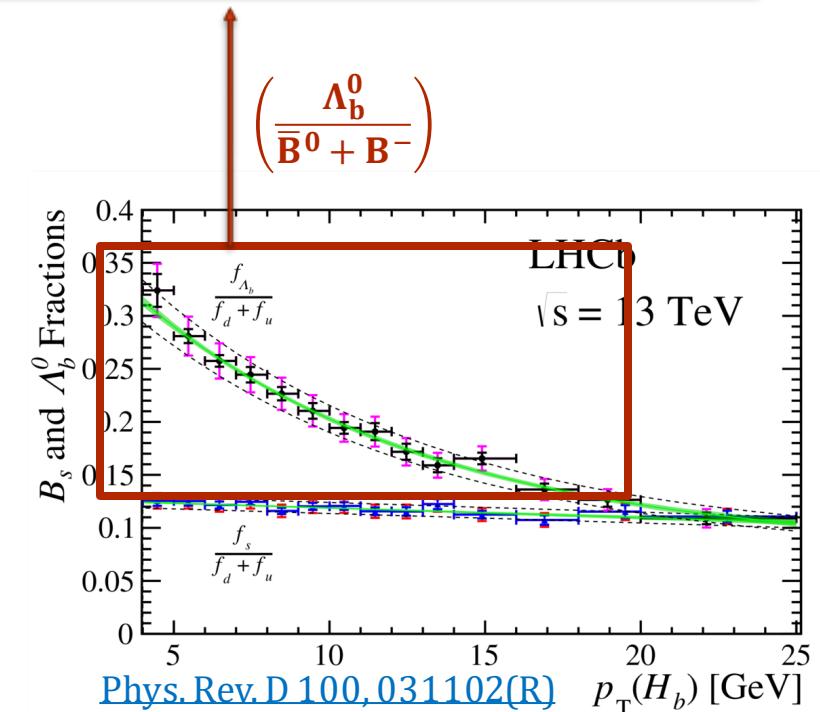
$$\left(\frac{f_s}{f_u + f_d} \right)_B = \begin{cases} \mathbf{0.122 \pm 0.006 \text{ [LHCb]}} \\ 0.127 \pm 0.036(\text{stat}) \pm 0.012(\text{syst}) \pm 0.005(\text{BR}) \pm 0.005(\text{th}) \text{ [ALICE]} \end{cases}$$

Beauty hadron fragmentation fraction ratios



- Fragmentation fraction ratios **compatible** among **different** collision **systems**, **energies** and **rapidity** ranges

- Baryon-over-meson ratio**
 - clear **decreasing** trend vs. p_T
 - significant **enhancement** at **low p_T**
- effect caused by the different masses?
 $m_{\Lambda_b^0} (\sim 5.6 \text{ GeV}/c^2) > m_B (\sim 5.3 \text{ GeV}/c^2)$
- fragmentation fraction universality violated?



$$\left(\frac{f_s}{f_u + f_d} \right)_B = \begin{cases} 0.122 \pm 0.006 & [\text{LHCb}] \\ 0.127 \pm 0.036(\text{stat}) \pm 0.012(\text{syst}) \pm 0.005(\text{BR}) \pm 0.005(\text{th}) & [\text{ALICE}] \end{cases}$$



Beauty meson fragmentation fraction ratios

respectively, with a standard deviation of about $2.8 \text{ GeV}/c$ at all energies. The following integrated f_s/f_d values for $p_T \in [0.5, 40] \text{ GeV}/c$ and $\eta \in [2, 6.4]$ are measured

$$f_s/f_d(7 \text{ TeV}) = 0.2390 \pm 0.0076 ,$$

$$f_s/f_d(8 \text{ TeV}) = 0.2385 \pm 0.0075 ,$$

$$f_s/f_d(13 \text{ TeV}) = 0.2539 \pm 0.0079 ,$$

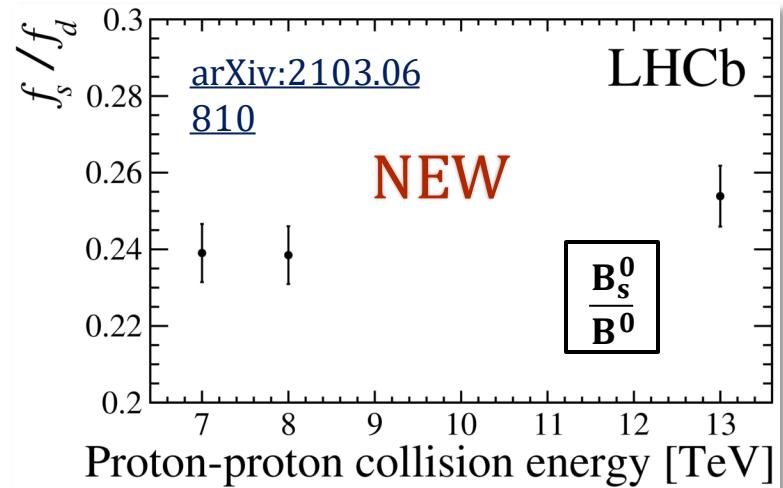
which are shown in Fig. 3. Ratios of the integrated values at different energies have also been calculated, incorporating correlations between the uncertainties, yielding

$$\frac{f_s/f_d(13 \text{ TeV})}{f_s/f_d(7 \text{ TeV})} = 1.064 \pm 0.008 ,$$

$$\frac{f_s/f_d(13 \text{ TeV})}{f_s/f_d(8 \text{ TeV})} = 1.065 \pm 0.007 ,$$

$$\frac{f_s/f_d(8 \text{ TeV})}{f_s/f_d(7 \text{ TeV})} = 0.998 \pm 0.008 ,$$

which can be used to correctly normalise future analyses using data at different energies.



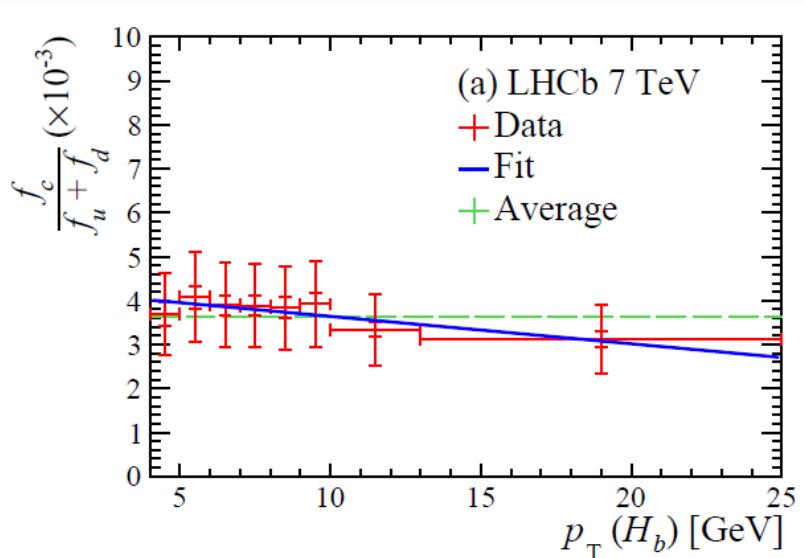
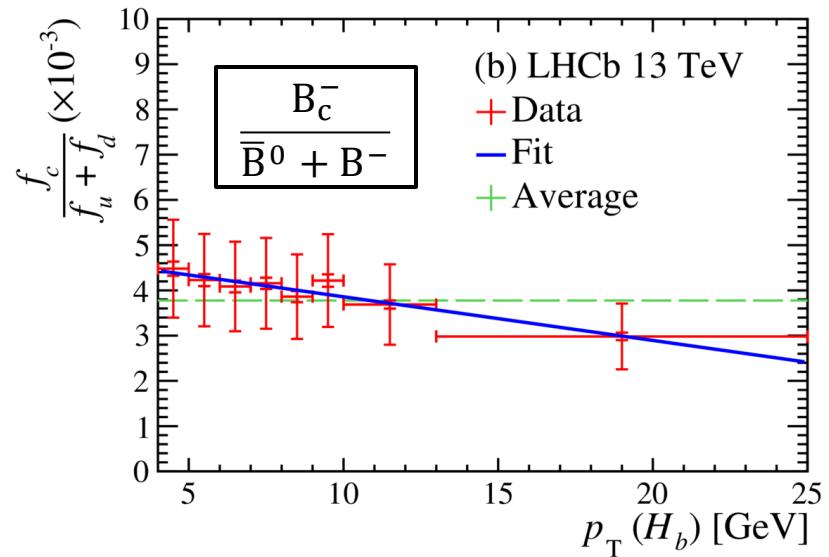
$B_c^- (\bar{c}b)$ meson production

$\sqrt{s} = 8, 13 \text{ TeV}$



$\text{BR}(B_c^- \rightarrow J/\psi \mu^- \bar{\nu}) \in [1.4\%, 7.5\%]$ (theory)

[Phys. Rev. D 100, 112006](#)

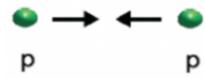


$$\frac{f_c}{f_u + f_d}(p_T) = A [p_1 + p_2 (p_T(H_b) - \langle p_T \rangle)]$$

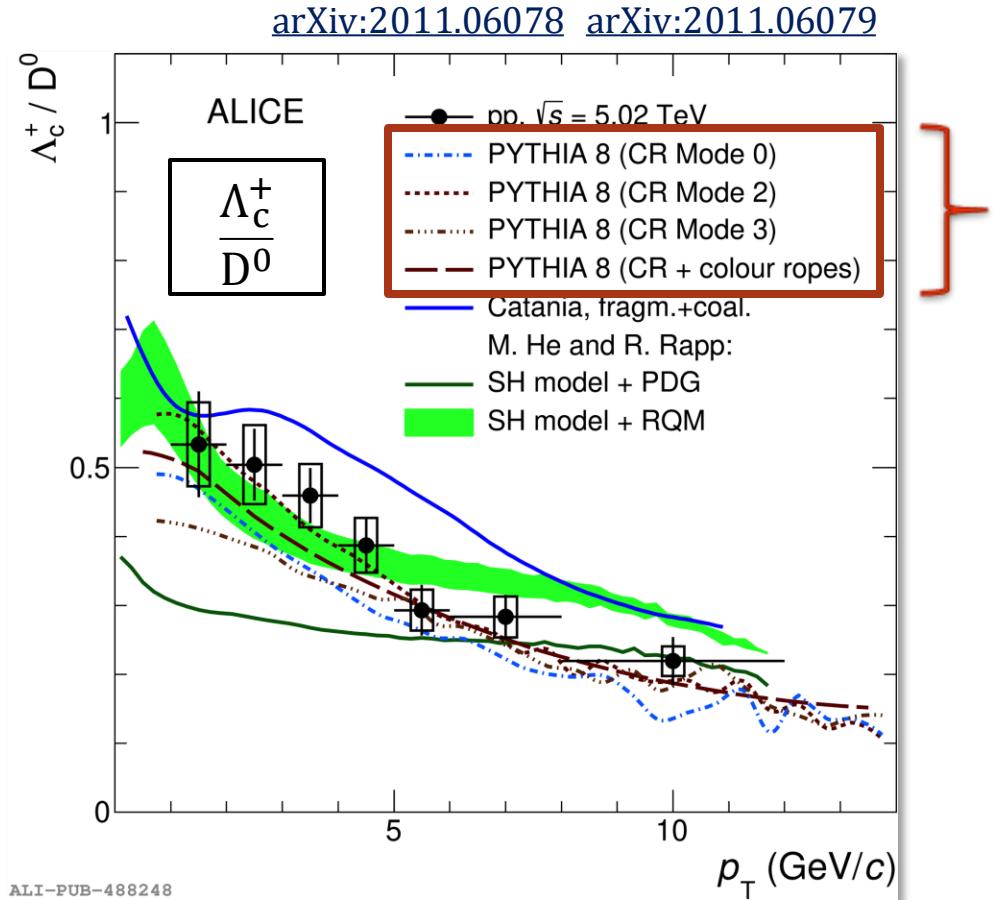
Energy	p_1	$p_2 \cdot 10^{-2} (\text{GeV}^{-1})$
7 TeV	$3.82 \pm 0.09 \pm 0.05$	$-6.2 \pm 1.7 \pm 1.1$
13 TeV	$4.13 \pm 0.05 \pm 0.04$	$-9.7 \pm 0.8 \pm 1.0$

$$\frac{f_c}{f_u + f_d} = (3.63 \pm 0.08 \pm 0.12 \pm 0.86) \cdot 10^{-3} \text{ for } 7 \text{ TeV},$$

$$\frac{f_c}{f_u + f_d} = (3.78 \pm 0.04 \pm 0.15 \pm 0.89) \cdot 10^{-3} \text{ for } 13 \text{ TeV},$$



Baryon enhancement – models



JHEP 1508 (2015) 003

1. PYTHIA 8 with improved Colour Reconnection (CR)

- CR with SU(3) weights and string length minimization
- “junction” topology enhances charm baryon production
- ropes: colour strings close in phase space allowed to recombine into higher multiplets
 - more probable in an environment with high string density (e.g. hadronic collisions at LHC)
 - increased production of baryons and strangeness
 - subleading effect w.r.t. junctions for charm baryons

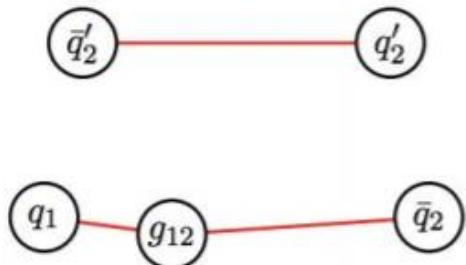
JHEP 03 (2015) 148

PYTHIA 8 CR modes

PYTHIA8 with String Formation beyond Leading Colour JHEP 1508 (2015) 003

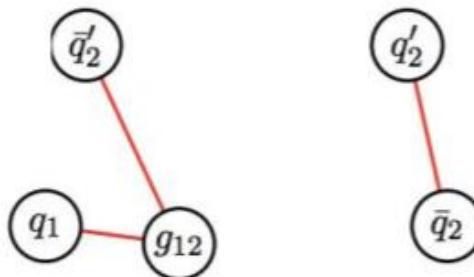
- Colour reconnection mode with SU(3) topology weights + string-length minimisation.
 - From junction reconnection → enhance baryons.
- A dynamical “QCD-inspired” way for coalescence?***

No CR



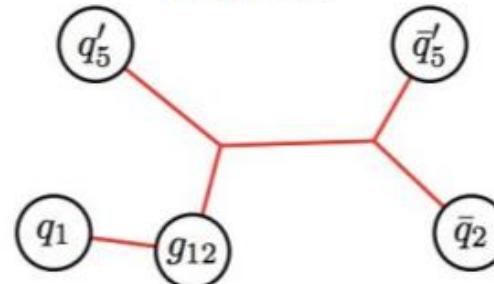
- Partons created in different MPIs do not interact

Old CR



- CR allowed between partons from different MPIs to minimize string length
- used in Monash tune

New CR



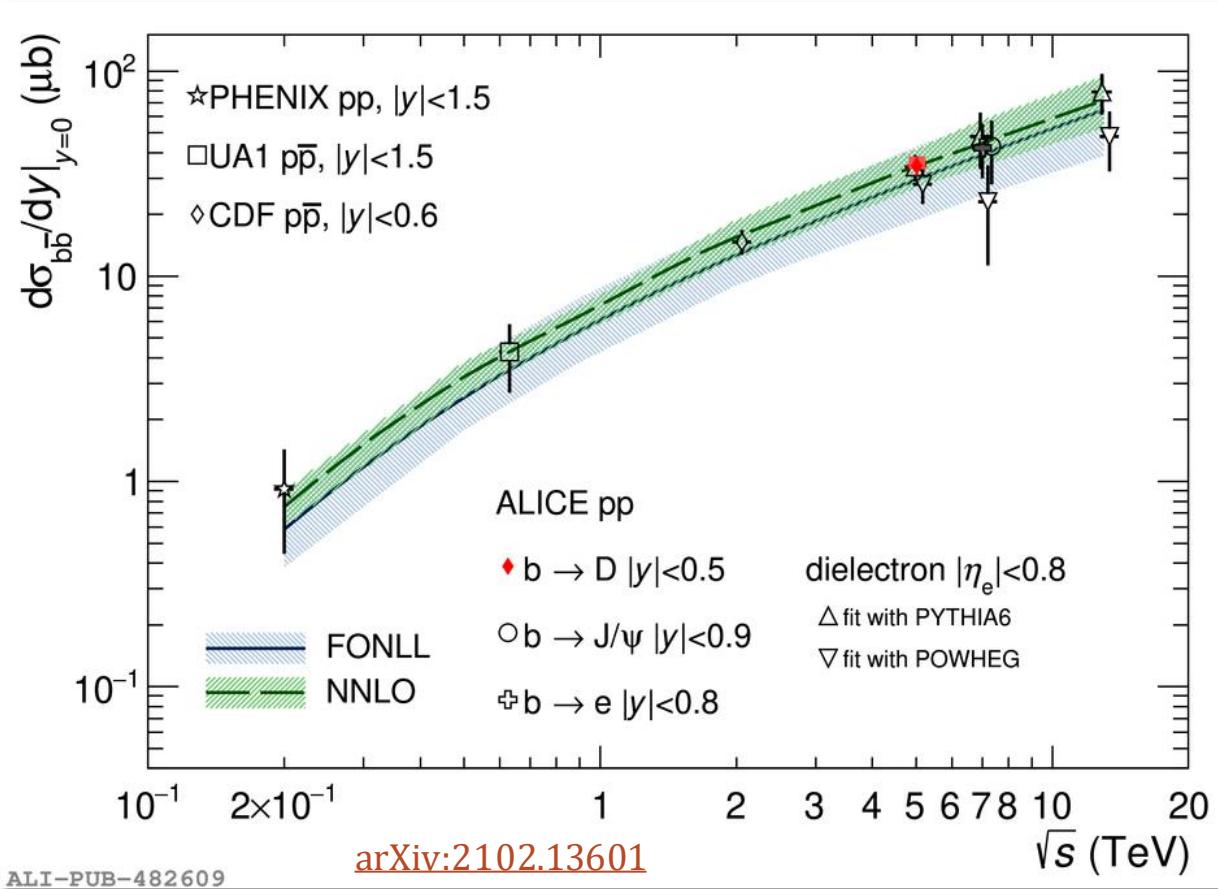
- Simple model of QCD colour rules to determine the formation of strings
- Minimization of the string length over all possible configurations
- Include CR with MPIs and with beam remnants

$b\bar{b}$ cross section in pp collisions

$\sqrt{s} = 5.02 \text{ TeV}$



NEW



- Updated measurement of $b\bar{b}$ cross section with non-prompt D-mesons
- Most precise results at midrapidity thanks to the usage of machine learning techniques
- Extrapolation down to 0 using PYTHIA and FONLL

$$(d\sigma^{b\bar{b}}/dy)|_{|y|<0.5} = 34.5 \pm 2.4(\text{stat.})^{+4.6}_{-2.9}(\text{syst.}) \mu\text{b}$$

Charmed baryons

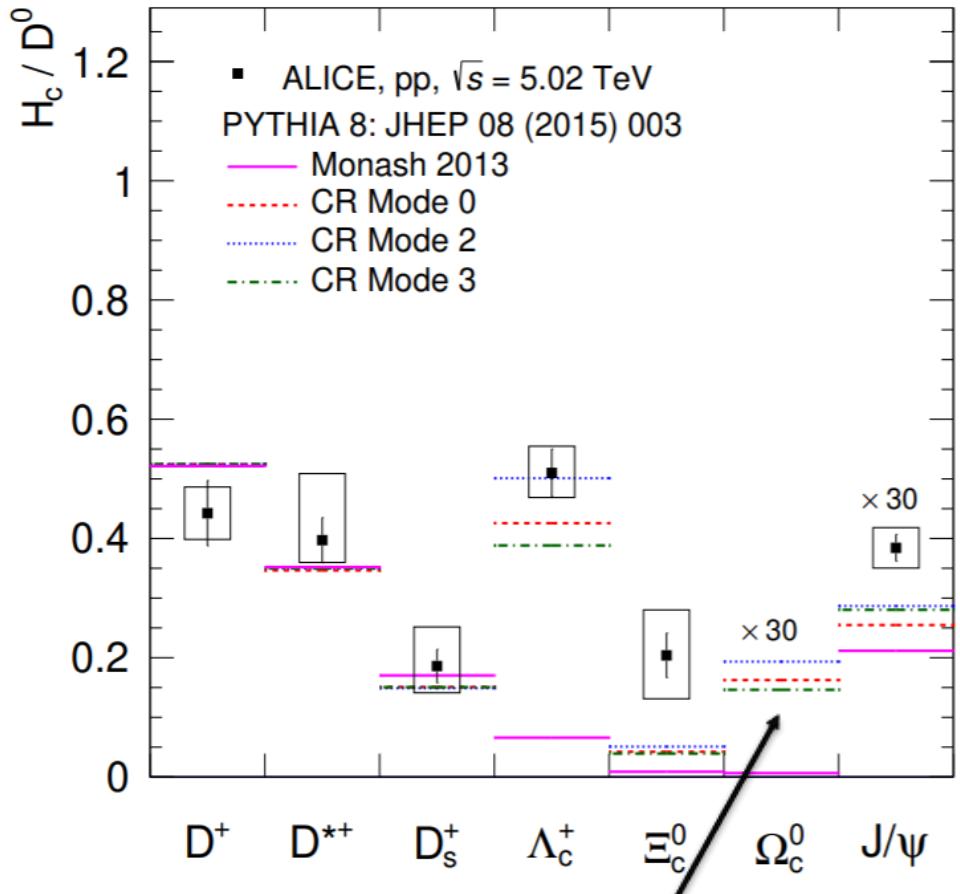
Particle	Mass (GeV/c ²)	Valence quarks
Λ_c^+	2.286	udc
$\Sigma_c^{0,++}$	2.455	ddc, uuc
Ξ_c^+	2.467	usc
Ξ_c^0	2.471	dsc
Ω_c^0	2.695	ssc
Ξ_{cc}^{++}	3.621	ucc

Charm fragmentation fractions in pp collisions

$\sqrt{s} = 5.02 \text{ TeV}$
 $p \rightarrow p$

NEW

[arXiv:2105.06335](https://arxiv.org/abs/2105.06335)



- Ω_c^0 neglected in the calculation of fragmentation fractions
- Asymmetric uncertainties to account for its possible influence

Single species cross section normalised by the sum of all ground states charm hadrons

Fragmentation fractions $f(c \rightarrow H_c)$ not universal
 → significant baryon enhancement in pp collisions

[arXiv:2105.06335](https://arxiv.org/abs/2105.06335)

H_c	$f(c \rightarrow H_c)[\%]$
D^0	$39.1 \pm 1.7(\text{stat})^{+2.5}_{-3.7}(\text{syst})$
D^+	$17.3 \pm 1.8(\text{stat})^{+1.7}_{-2.1}(\text{syst})$
D_s^+	$7.3 \pm 1.0(\text{stat})^{+1.9}_{-1.1}(\text{syst})$
Λ_c^+	$20.4 \pm 1.3(\text{stat})^{+1.6}_{-2.2}(\text{syst})$
Ξ_c^0	$8.0 \pm 1.2(\text{stat})^{+2.5}_{-2.4}(\text{syst})$
D^{*+}	$15.5 \pm 1.2(\text{stat})^{+4.1}_{-1.9}(\text{syst})$

also
for Ξ_c^+