# Inspecting the charm hadronization via measurements of charm baryon production in hadronic collisions with the ALICE experiment at the LHC

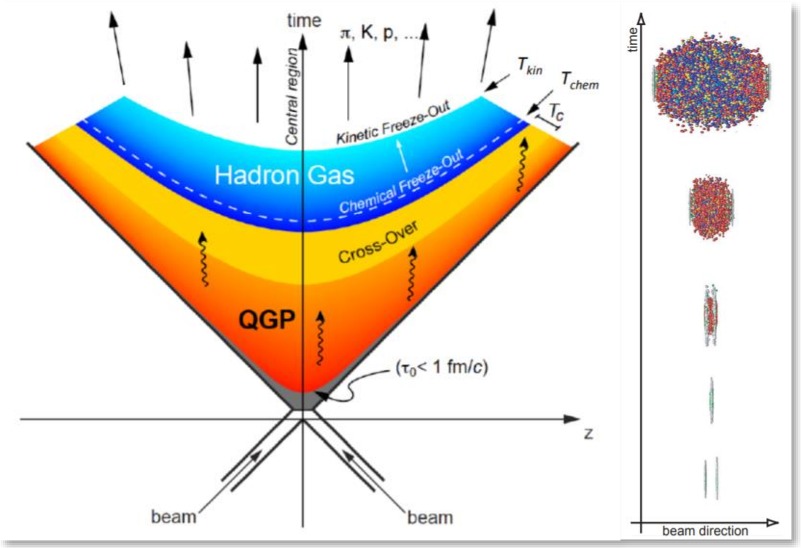

Assergi (L'Aquila) - Italy
10th May 2022

Mattia Faggin, University and INFN – Padova, Italy
On behalf of the ALICE collaboration

# Heavy quarks: a unique probe

- **Mass** of the order of **GeV/$c^2$** ⟶ **charm and beauty** mainly produced in **hard-scattering processes**

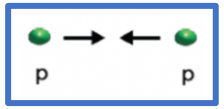
- **Pb–Pb** collisions: Phys. Rev. Lett. 116, 222302
  - quark-gluon plasma (**QGP**) produced ⟶ parton d.o.f.
  - **charm and beauty** produced **before** the **QGP** $\tau_{\rm QGP} \sim 1$ fm/$c$ (production timescale: $\Delta\tau \sim 1/Q \sim 1/2m$) ⟶ **Experience** the **full evolution** of the system



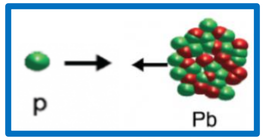

**CHARM**
- $m_{\rm c} \simeq 1.3$ GeV/$c^2$
- $\Delta\tau_{\rm c} \simeq 0.08$ fm/$c$

**BEAUTY**
- $m_{\rm b} \simeq 4.2$ GeV/$c^2$
- $\Delta\tau_{\rm b} \simeq 0.03$ fm/$c$

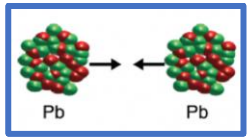
**Measurement of charm and beauty hadrons: access to charm and beauty quarks dynamics**




**pp collisions**
- Tests of pQCD calculations
- Reference for heavy-ion collisions



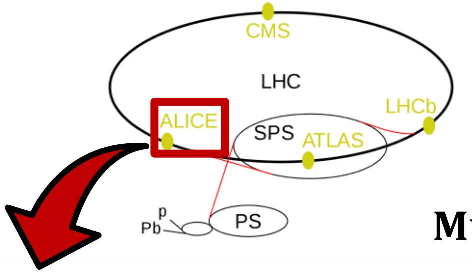

**p–Pb collisions**
- Cold nuclear matter effects
  ⟶ modification of parton distribution functions (PDF) in bound nucleons




**Pb–Pb collisions**
- Hot nuclear matter effects
  ⟶ Energy loss in the QGP
  ⟶ Collective motion of the system
  ⟶ Modification of hadronization mechanisms

ALICE

# The ALICE experiment



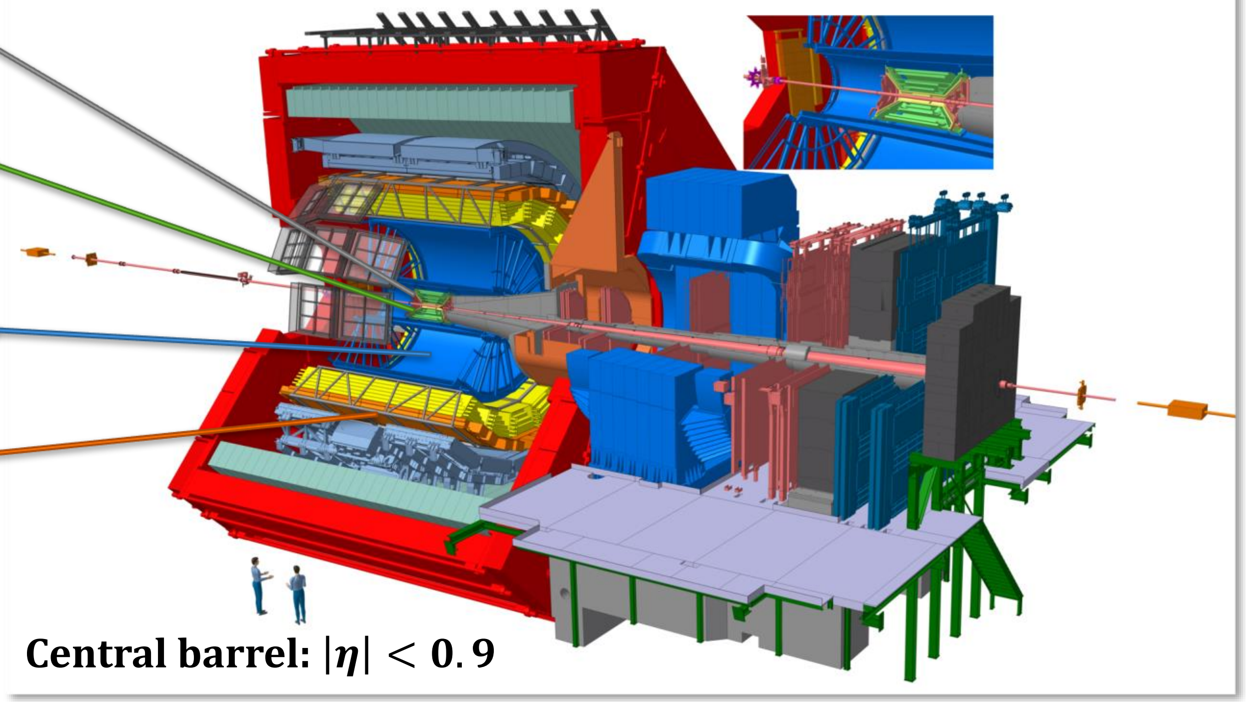

**V0**: trigger, centrality

**Inner Tracking System** (**ITS**): tracking, vertexing (primary, <u>HF decays</u>), PID via d$E$/dx, trigger

**Time Projection Chamber** (**TPC**): tracking, PID via d$E$/dx

**Time-Of-Flight (TOF)**: PID via time of flight

**Muon arm: $-4 < \eta < -2.5$**



**Central barrel: $|\eta| < 0.9$**

## Data samples

- **pp** (minimum-bias trigger)
  - $\sqrt{s} = 5.02$ TeV $\rightarrow$ $L_{\text{int}} \approx 19\ \text{nb}^{-1}$
  - $\sqrt{s} = 13$ TeV $\rightarrow$ $L_{\text{int}} \approx 32\ \text{nb}^{-1}$
- **p–Pb** (minimum-bias trigger)
  - $\sqrt{s_{\text{NN}}} = 5.02$ TeV $\rightarrow L_{\text{int}} \approx 287\ \mu\text{b}^{-1}$
- **Pb–Pb** (central 0-10%, semicentral 30-50%)
  - $\sqrt{s_{\text{NN}}} = 5.02$ TeV $\rightarrow L_{\text{int}} \approx 130\ \mu\text{b}^{-1}$ (0-10%)

    $L_{\text{int}} \approx 56\ \mu\text{b}^{-1}$ (30-50%)

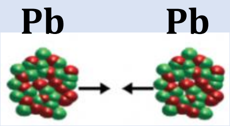
## Reconstructed charm-baryon decays

- $\Lambda_c^+$(udc) $\rightarrow \text{pK}^-\pi^+, \text{pK}_s^0$
- $\Sigma_c^{0,++}$(ddc, uuc) $\rightarrow \Lambda_c^+\pi^{-,+}$
- $\Xi_c^0$(dsc) $\rightarrow \Xi^-\text{e}^+\nu_\text{e}, \Xi^-\pi^+$
- $\Xi_c^+$(usc) $\rightarrow \Xi^-\pi^+\pi^+$
- $\Omega_c^0$(ssc) $\rightarrow \Omega^-\pi^+$

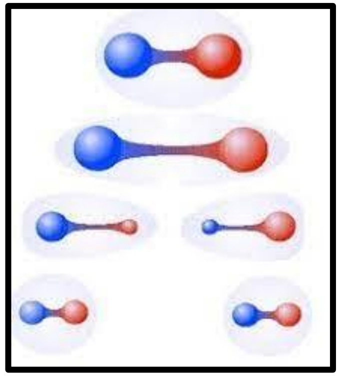
# Charm and beauty hadron formation in $e^+e^-$ and Pb-Pb collisions

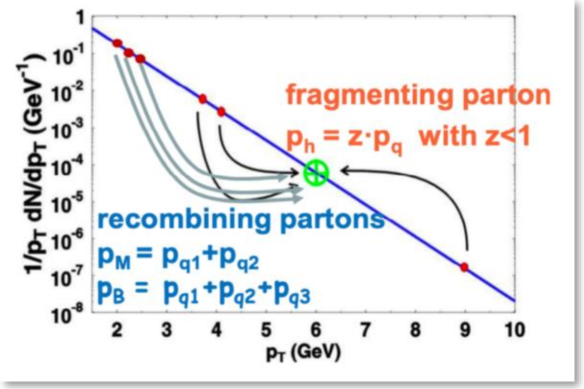
$e^+$ • ⟶ ⟵ • $e^-$

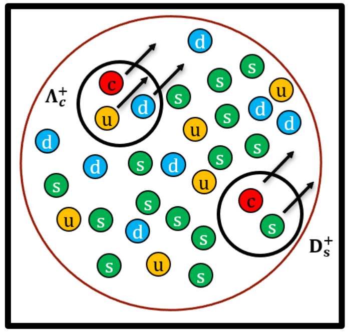
- "Point-like" object interaction
- Pure **fragmentation**




- QGP: complex large-size system
- Parton degrees of freedom
- **Modification of hadronization mechanisms**






**Fragmentation** Eur. Phys. J. C 78 no. 11, (2018) 983

- Hard scattering $e^+e^- \rightarrow q\bar{q}$
- Color-potential string between q and $\bar{q}$
- Hadronization via multiple string breaking and formation of quark-antiquark pairs

**Coalescence** PLB, Volume 68, Issue 5, 4 July 1977, Pages 459-462

- Charm quark produced in hard scattering coalesces with light (di-)quarks from the system
- Expected to increase baryon production at low-intermediate $p_T$
- QGP: interplay coalescence (low $p_T$) vs. fragmentation (high $p_T$)

# Charm and beauty hadron formation in pp collisions

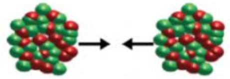
$e^+$ → ← $e^-$

- "Point-like" object interaction
- Pure fragmentation

p p

- Superimposition of many "$e^+e^-$" collisions?
- Colour charges from MPI modify hadronization?

Pb Pb



- QGP: complex large-size system
- Parton degrees of freedom
- Modification of hadronization mechanisms

Standard description of heavy-quark hadronization based on a factorization approach

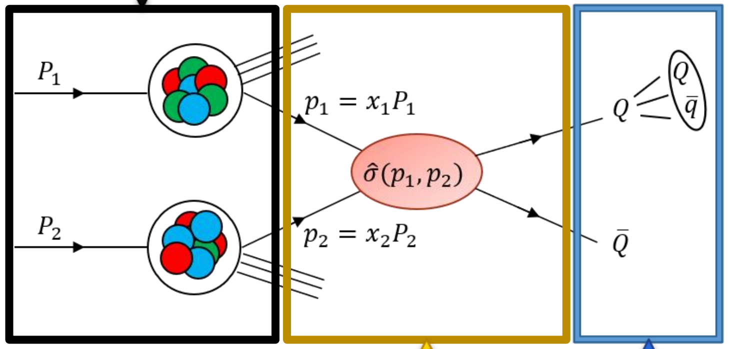
- ➢ Fragmentation functions assumed universal among collision systems and constrained from $e^+e^-$ and $e^-p$ measurements

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

Parton distribution functions (PDFs)

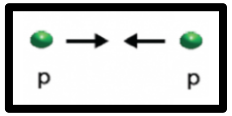
Hard scattering cross section (pQCD)

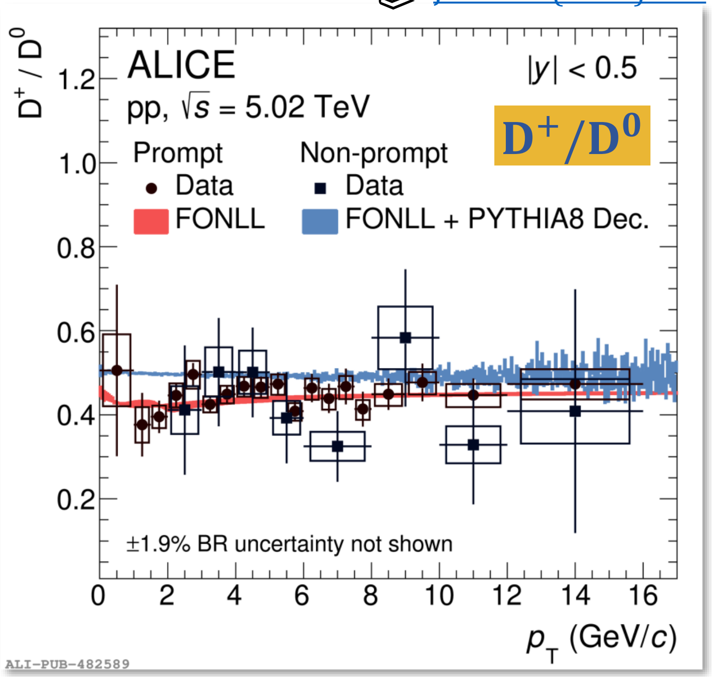
Fragmentation function (hadronization)

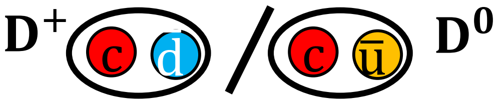


# Charm and beauty hadron formation in pp collisions

JHEP 05 (2021) 220





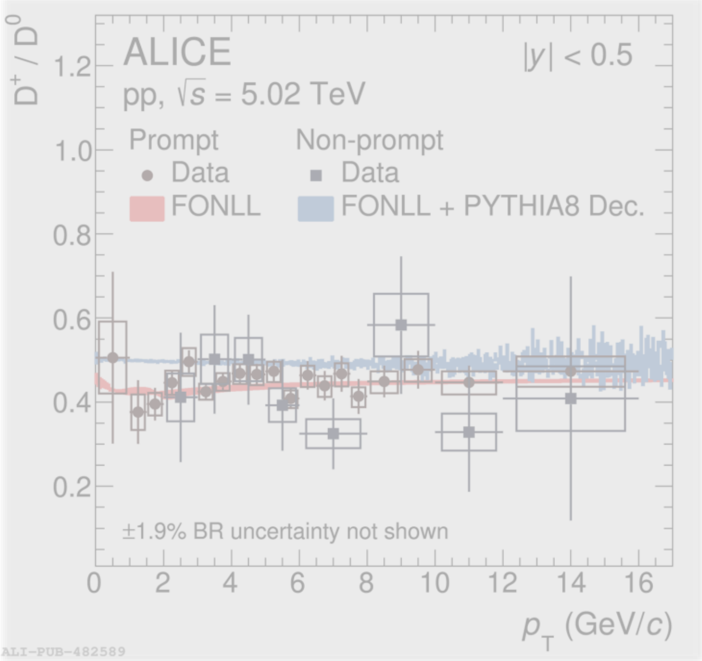
- Meson-to-meson ratios **independent** of meson $p_{\mathrm{T}}$ and **collision system**
- **Agreement** with **model calculations** (FONLL) based on a **factorization** approach and relying on **universal fragmentation functions** ($e^+e^-$, $e^-p$) and with **$e^+e^-$, $e^-p$ measurements**

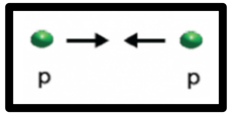
ALICE

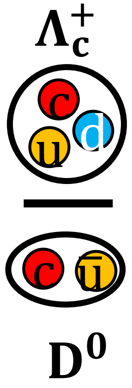
# Charm and beauty hadron formation in pp collisions

JHEP 05 (2021) 220

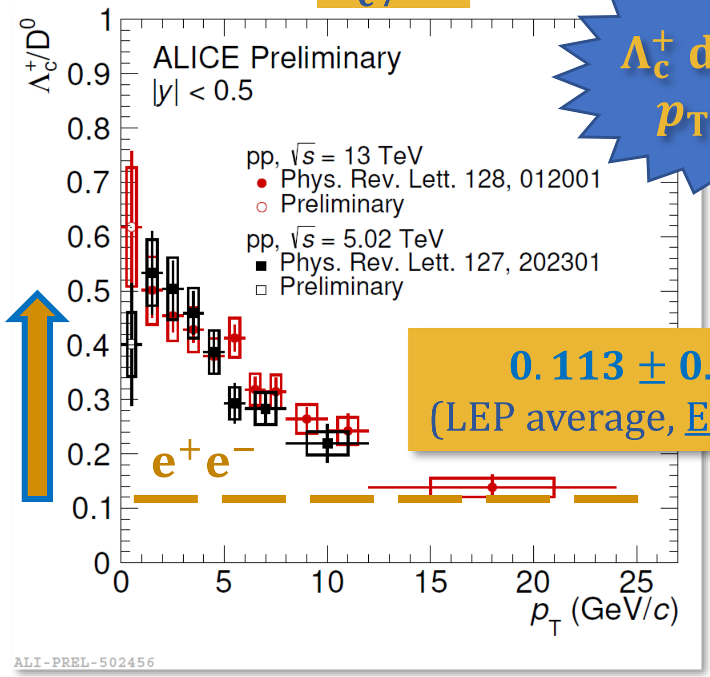
Phys. Rev. Lett. 127, 202301
Phys. Rev. Lett. 128, 012001




$\Lambda_c^+/D^0$




**$\Lambda_c^+$ down to $p_T = 0$ !**

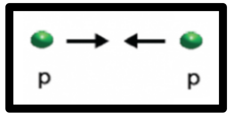
**$0.113 \pm 0.013 \pm 0.006$**
(LEP average, EPJC 75, 19 (2015))

- Meson-to-meson ratios **independent** of meson $p_T$ and **collision system**
- **Agreement** with **model calculations** (FONLL) based on a **factorization** approach and relying on **universal fragmentation functions** ($e^+e^-$, $e^-p$) and with **$e^+e^-$, $e^-p$ measurements**

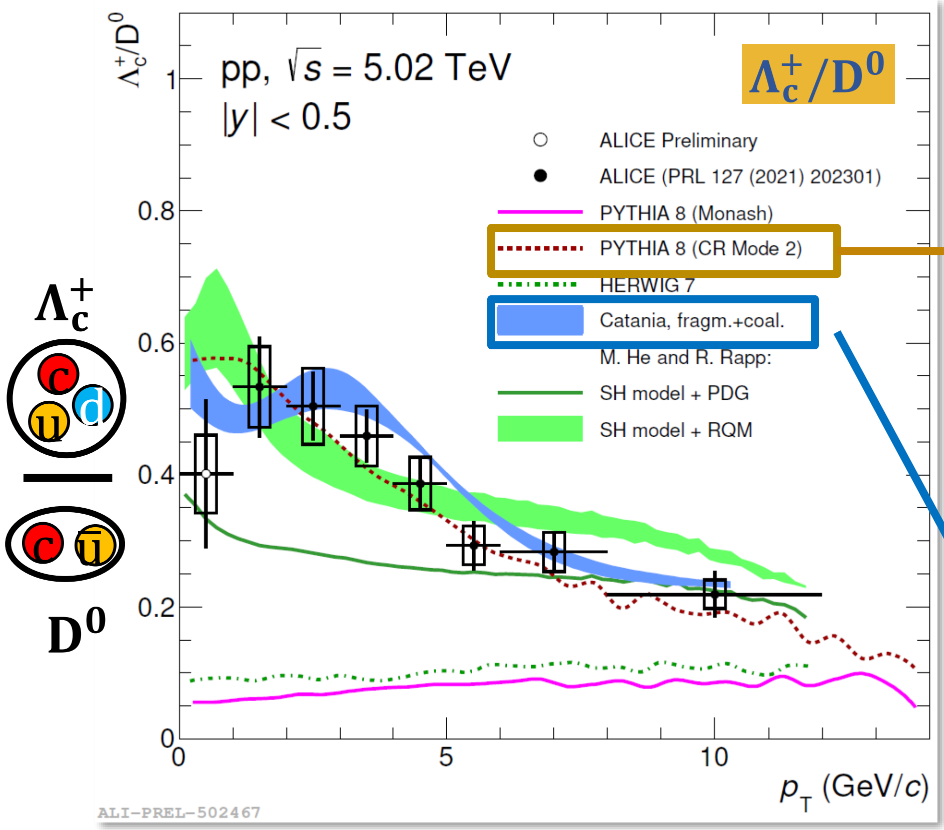
- **Baryon-to-meson** ratios **significantly higher** than $e^+e^-$ results
  → PYTHIA8 Monash ($e^+e^-$ charm fragmentation functions)
- Baryon-to-meson enhancement at low $p_T$ also observed in the beauty sector (LHCb: Phys. Rev. D 100, 031102(R))

- **Further hadronization mechanisms?**
- **Non-universal fragmentation functions?**

# $\Lambda_c^+/D^0$ in pp collisions - models

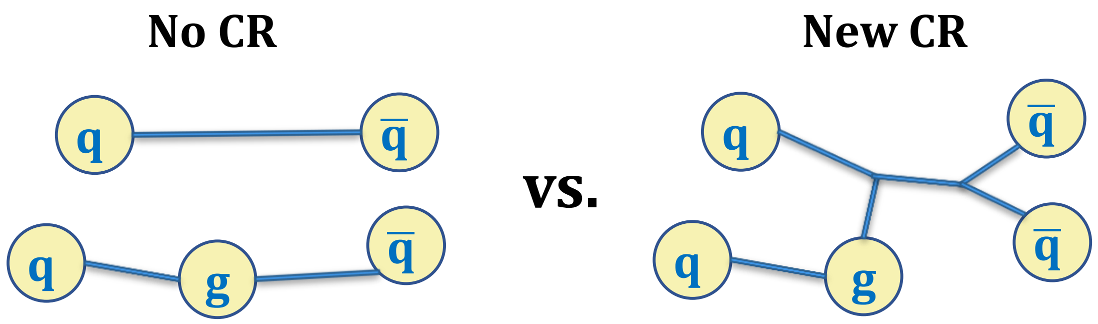


Phys. Rev. Lett. 127, 202301

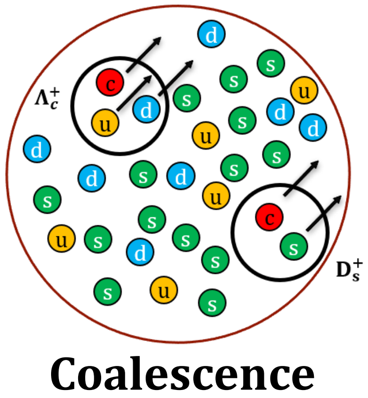



J.P. Christiansen, P. Z. Skands: JHEP 1508 (2015) 003

1. **PYTHIA 8 with updated Color Reconnection (CR-BLC) modeling**
   - CR with SU(3) weights and string length minimization
   - **"junction"** topology **enhances charm baryon production**

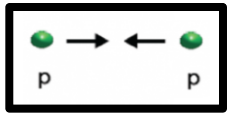



V. Minissale, S. Plumari, V. Greco: arXiv:2012.12001

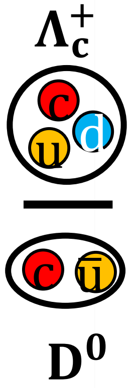


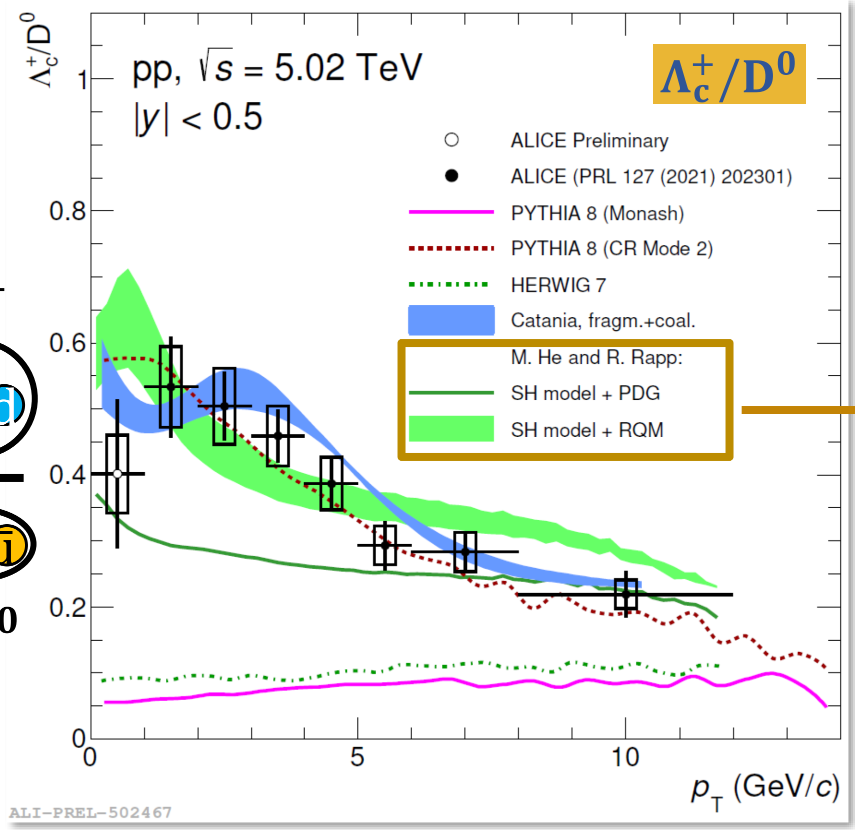

2. **Catania model**
   - **Thermalised system** of u,d,s and gluons assumed
   - Mixed hadron formation
     a. **Fragmentation**
     b. **Coalescence** → imposed to be the only mechanism for $p \to 0$

# $\Lambda_c^+/D^0$ in pp collisions - models




Phys. Rev. Lett. 127, 202301




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

3. **Statistical Hadronization Model and Relativistic Quark Model (SHM + RQM)**
   - **Hadronization** driven by statistical weights **governed by hadron masses** ($n_i \sim m_i^2 T_H K_2(m_i/T_H)$) at a hadronization temperature $T_H$
   - Strong **feed-down** from an **augmented set of excited charm baryons**
     - → PDG: 5 $\Lambda_c$, 3 $\Sigma_c$, 8 $\Xi_c$, 2 $\Omega_c$
     - → RQM: additional 18 $\Lambda_c$, 42 $\Sigma_c$, 62 $\Xi_c$, 34 $\Omega_c$ (not yet measured)

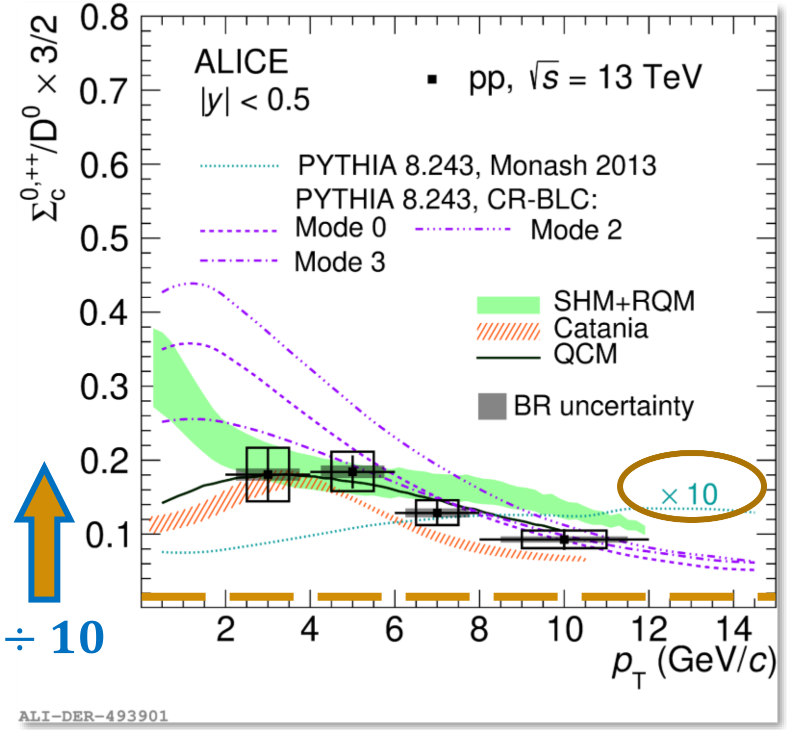
**Can further baryon measurements help understanding the mechanisms underlying the baryon enhancement?**

| $n_i[\cdot 10^{-4}\ \text{fm}^{-3}](T_H\ [\text{MeV}])$ | $D^0$ | $D^+$ | $D^{*+}$ | $D_s^+$ | $\Lambda_c^+$ | $\Xi_c^{0,+}$ | $\Omega_c^0$ |
|---|---|---|---|---|---|---|---|
| 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** |

# Heavier charm baryons: $\Sigma_c^{0,+,++}(2455)$

Phys. Rev. Lett. 128, 012001

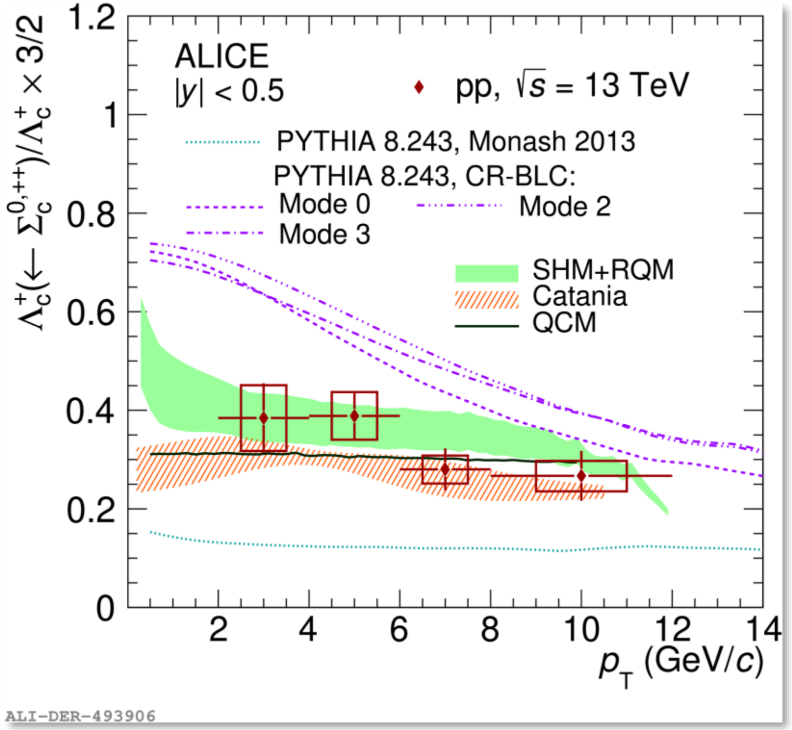
$\Lambda_c^+$ from $\Sigma_c^{0,+,++}$




× 5 ÷ 10

$\Sigma_c^{0,+,++}/D^0$

~ 0.02 ($e^+e^-$)
[Belle Collaboration, Phys. Rev. D 97, 072005]




$\Sigma_c^0$

$\Sigma_c^{++}$

- **Larger** than $e^+e^-$ and **Monash** (tuned on $e^+e^-$)
  → **larger relative enhancement than $\Lambda_c/D^0$**
- Well **described** by predictions from **SHM + RQM**, **Catania** and **QCM** (charm coalescence with equal-velocity light quarks, thermal weights for abundances)

- $\Sigma_c^{0,+,++}/D^0$ partially accounts for larger $\Lambda_c^+/D^0$
- Measurement of **$\Lambda_c$ feed-down from $\Sigma_c$**

$$\Lambda_c^+(\leftarrow \Sigma_c)/\Lambda_c^+ = 0.38 \pm 0.06(\text{stat.}) \pm 0.06(\text{syst.})$$

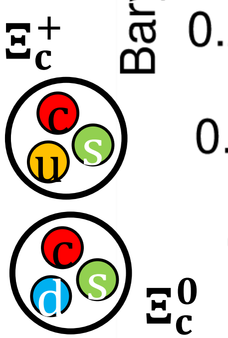
- **Overestimated** by **CR modes**

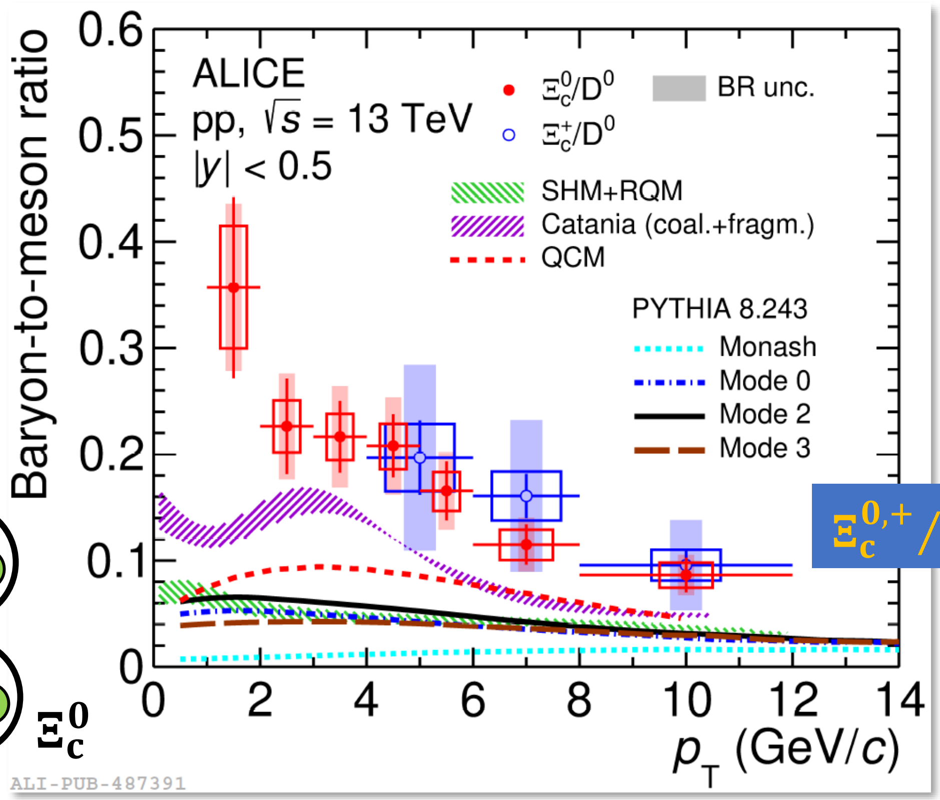
QCM: J. Song, H. Li, F. Shao: Eur. Phys. J. C (2018) 78: 344

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

ALICE: [PRL 127 (2021) 272001](#) | [Phys. Rev. Lett. 127, 272001](#)

ALICE: [JHEP 10 (2021) 159](#) | [JHEP 10 (2021) 159](#)

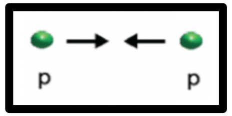


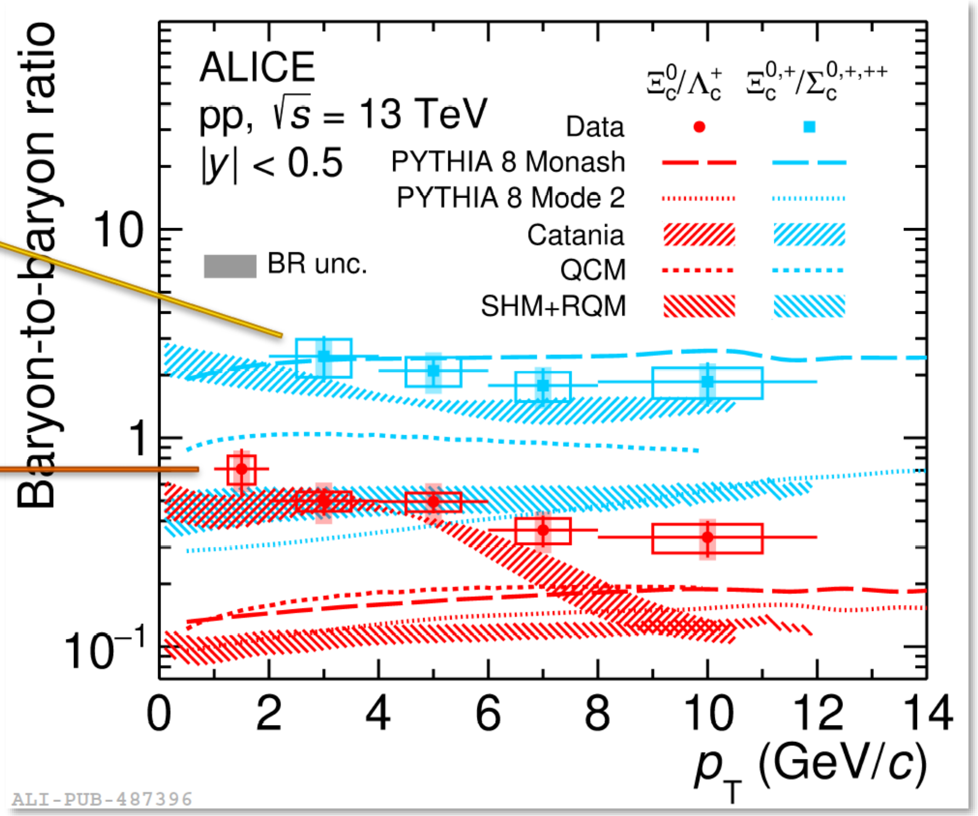




$\Xi_c^{0,+}/D^0$

$\Xi_c^{0,+}/\Sigma_c^{0,+,++}$

$\Xi_c^0/\Lambda_c^+$




- Clear $p_T$ dependence and **larger** than **Monash**
- **Significantly underestimated** by models
  - $D_s^+/(D^0+D^+)$ compatible with expectations from $e^+e^-$ ⟶ **baryons** are **'strange'**? [JHEP 05 (2021) 220](#)
- Catania (fragm. + coal.) gets close to the measurements

- $\Xi_c^0/\Sigma_c^{0,+,++}$ in **agreement** with **Monash**
  → similar suppression in $e^+e^-$ for $\Xi_c^{0,+}$ and $\Sigma_c^{0,+,++}$?
  → matter of similar (diquark) mass? $(m(\mathrm{uu,ud,dd})_1 \approx m(\mathrm{us})_0)$

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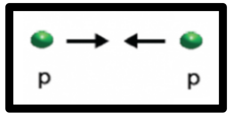
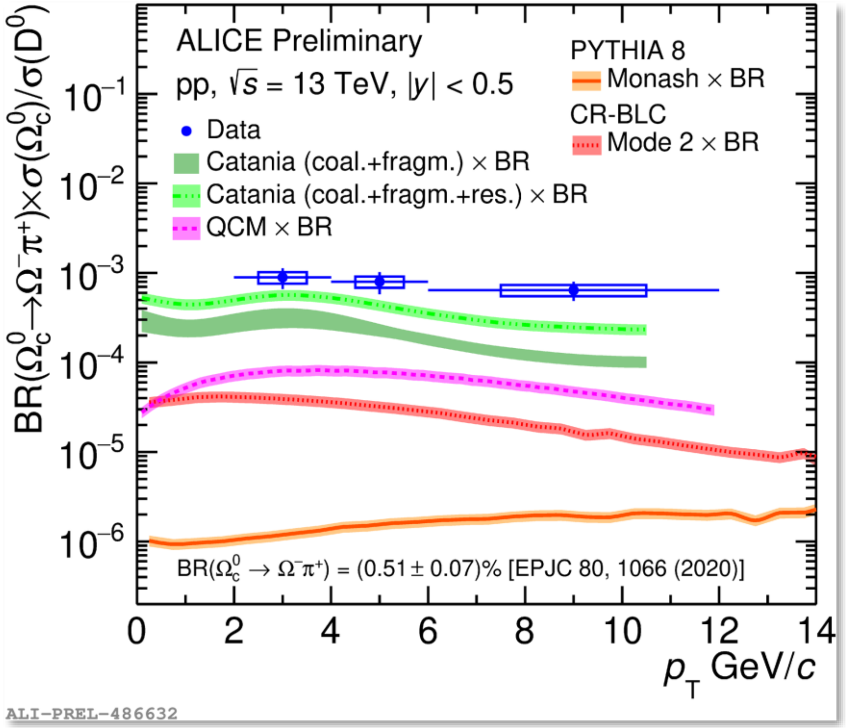
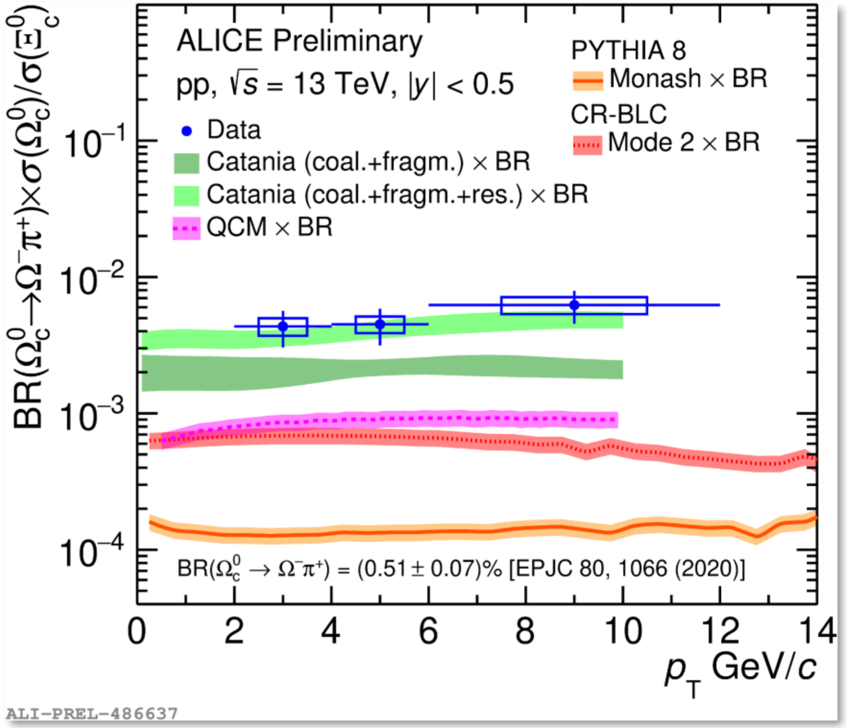
# Heavier charm baryons: $\Omega_c^0$




$\mathrm{BR}(\Omega_c^0 \to \Omega^-\pi^+) \times \Omega_c^0/D^0$




$\mathrm{BR}(\Omega_c^0 \to \Omega^-\pi^+) \times \Omega_c^0/\Xi_c^0$

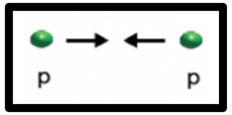
$\mathrm{BR}(\Omega_c^0 \to \Omega^-\pi^+) = (0.51 \pm 0.07)\%$ (Y. Hsiao et al. EPJC 80, 1066 (2020)) not measured → used to scale model predictions

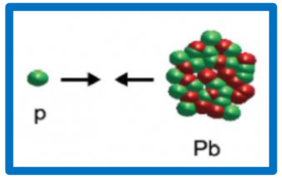
- **Pythia 8** with **CR-BLC underestimates** data
- **Coalescence models** get **closer** to the measurements
- $\Omega_c^0/\Xi_c^0$ described by **Catania** model (coalescence + fragmentation) including **higher-mass resonance** decays

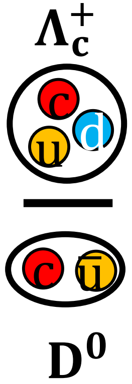
**$\Omega_c^0$ : sizeable contribution to charm production at LHC energies?**

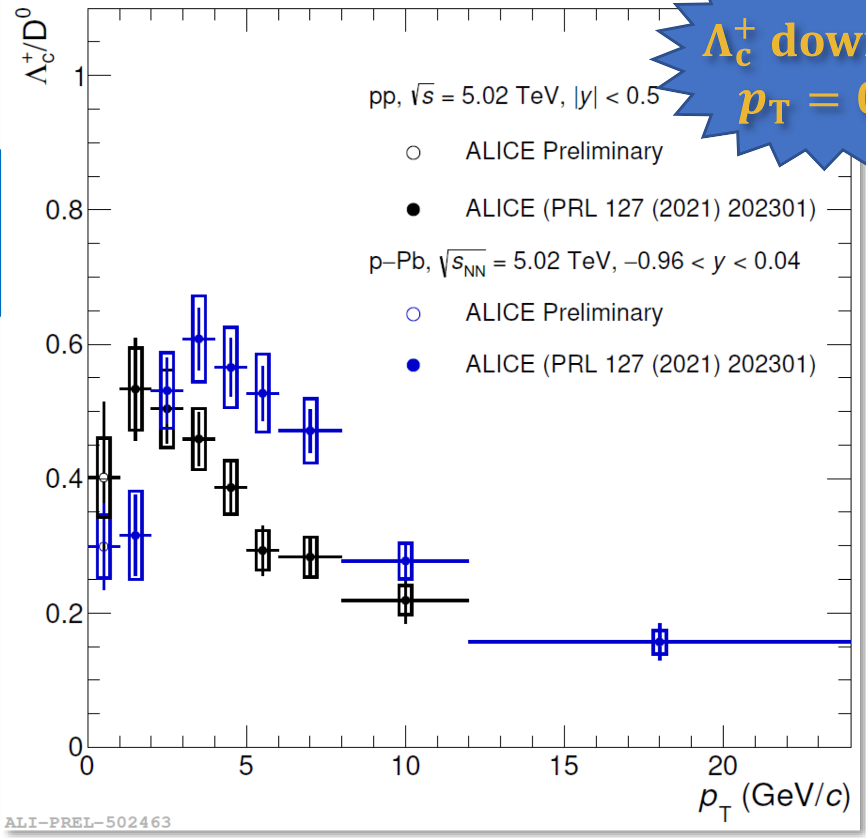
Phys. Rev. D 105, L011103 (2022) Phys. Rev. Lett. 127, 202301 JHEP 12(2019)092

# $\Lambda_c^+/D^0$ in p-Pb collisions and charm fragmentation fractions

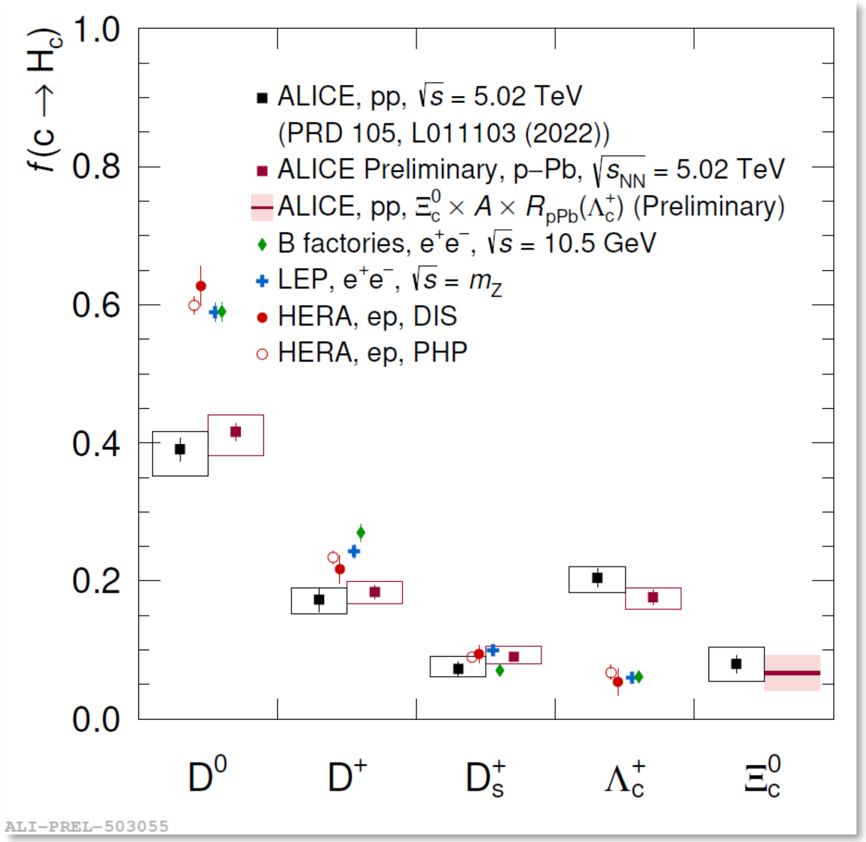


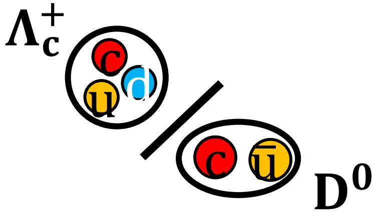




**$\Lambda_c^+$ down to $p_T = 0$ !**



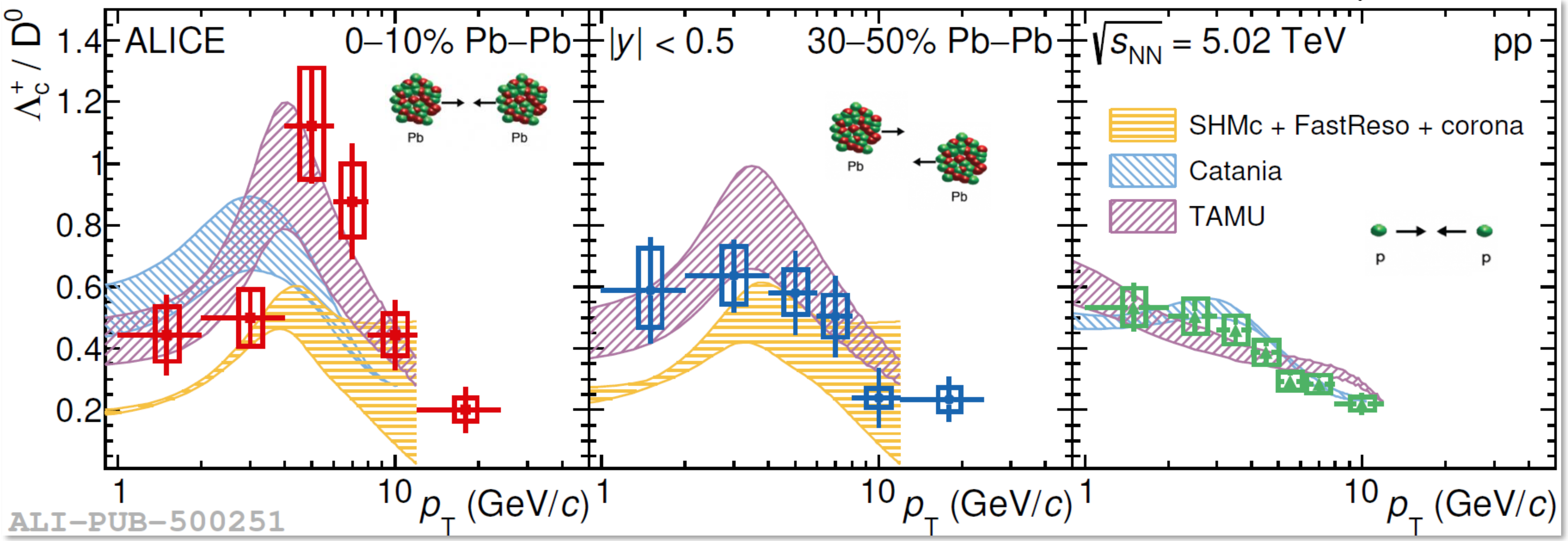

- **Compatible $p_T$-integrated $\Lambda_c^+/D^0$** ratio in **pp** and **p–Pb** collisions within uncertainties (next slides)
  $\longrightarrow$ **$\Lambda_c^+/D^0$ larger** in **p–Pb** collisions than in **pp** for **$p_T > 3$ GeV/$c$** given a harder $p_T(\Lambda_c^+)$ spectrum
- **Charm fragmentation fractions** in **pp** and **p–Pb** collisions at $\sqrt{s_{NN}} = 5.02$ TeV
  - No significant differences
  - Significant **baryon enhancement** with respect to **$e^+e^-$** and **$e^-p$** results

# $\Lambda_c^+/D^0$ in pp and Pb-Pb collisions




TAMU: PRL 124, 042301 (2020)
Catania: PRC 96, 044905 (2017)
SHMc: JHEP 07 (2021) 035

arXiv:2112.08156




- $\Lambda_c^+/D^0$ ratio in $4 \leq p_T < 8$ GeV/$c$ in **central** (0-10%) **Pb–Pb** collisions **larger** than **pp** (3.7σ)
- Shape qualitatively caught by SHMc (statistical hadronization + charm) and Catania model
- Data described by TAMU (hydro. + fragmentation + coalescence + extra c-baryons)

Baryon-to-meson **enhancement** due to an **interplay** of **radial flow** and **recombination**?

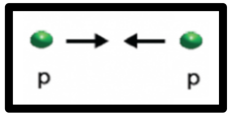
# $\Lambda_c^+/D^0$ in hadronic collisions vs. multiplicity

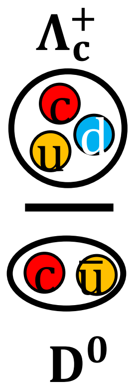

TAMU: PRL 124, 042301 (2020)
Catania: PRC 96, 044905 (2017)
SHMc: JHEP 07 (2021) 035

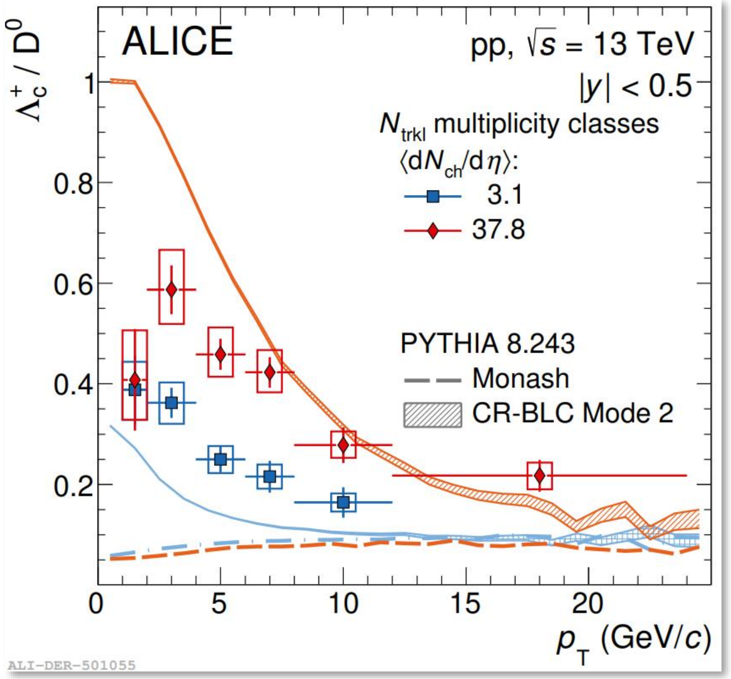


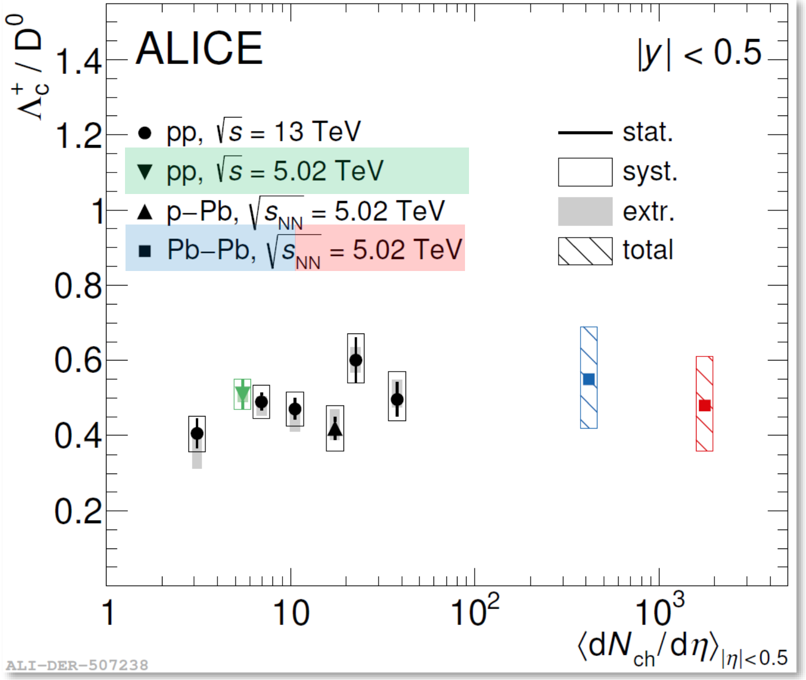
arXiv:2112.08156 PLB, Volume 829, 10 June 2022, 137065

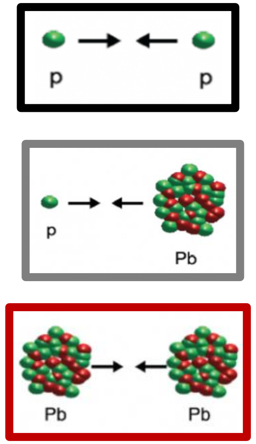

ALICE




- **$\Lambda_c^+/D^0$ vs. $p_T$** at **highest multiplicity larger** than that at **lowest multiplicity** ⟶ significance of **$5.3\sigma$** ($1 < p_T < 24$ GeV/$c$)
- **$p_T$ and multiplicity dependence** qualitatively **described** by **PYTHIA CR-BLC**
⟶ significantly underestimated by Monash tune
- **$p_T$-integrated $\Lambda_c^+/D^0$** ratio compatible with a **flat behaviour** versus event multiplicity

# $\Lambda_c^+/D^0$ in hadronic collisions vs. multiplicity

arXiv:2112.08156 PLB, Volume 829, 10 June 2022, 137065

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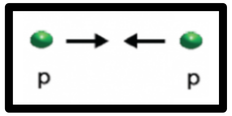
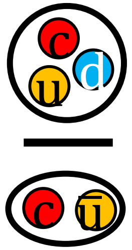
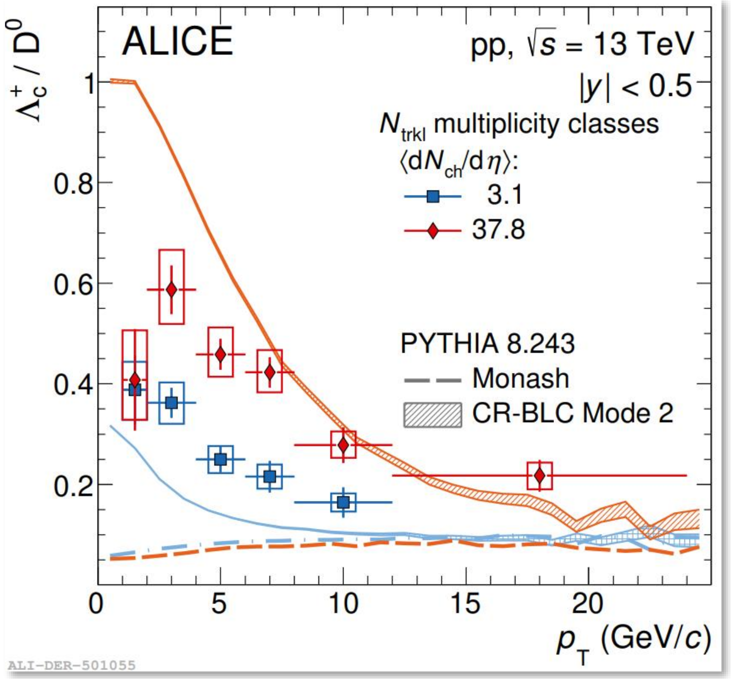
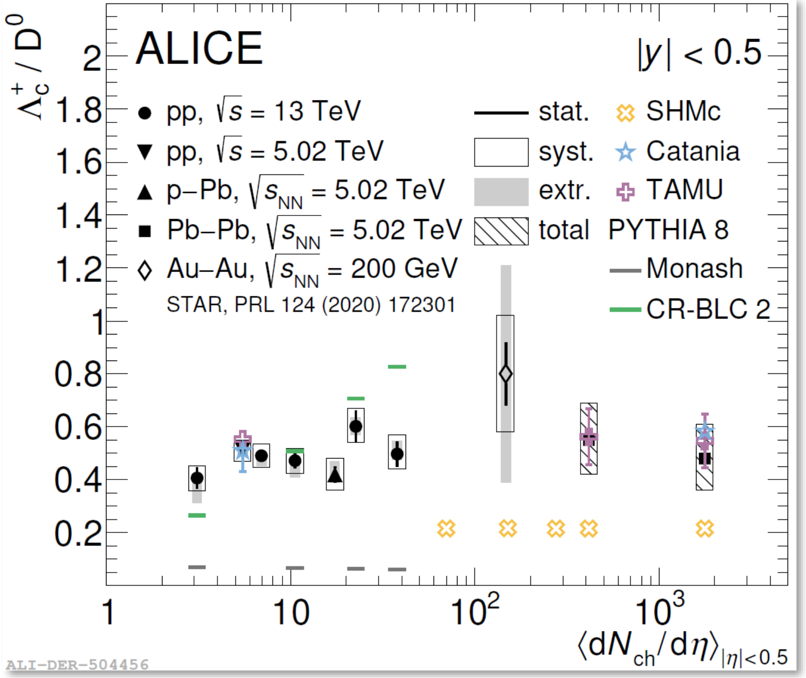


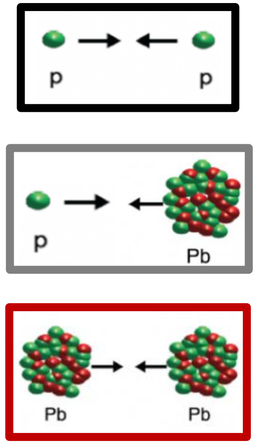

$\Lambda_c^+$



$D^0$

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  ⟶ significantly underestimated by Monash tune
- $p_T$**-integrated** $\Lambda_c^+/D^0$ ratio compatible with a **flat behaviour** versus event multiplicity
  ⟶ flat trend reproduced by models implementing fragmentation+coalescence and SHM predictions

Baryon-to-meson **enhancement at intermediate** $p_T$ due to an **interplay** of **radial flow** and **recombination** (different $p_T$ redistribution for baryons and mesons)?

ALICE

# Summary and outlook

- **pQCD models** based on **factorization approach** assuming **universal fragmentation functions** among collision systems **do not describe charm baryon production** in hadronic collisions **at the LHC**

  ⟶ $\Lambda_c^+/D^0$ and **fragmentation fractions** in pp **significantly different** from $e^+e^-$, $e^-p$

  ⟶ **Charm hadronization not** a **universal** process among collision systems

- **Further charm hadronization mechanisms** introduced by several models to describe the ALICE measurements

- **ALICE experiment ready for new data taking!**
  1. **Larger statistics**
  2. **Upgraded apparatus**

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ALICE-PUBLIC-2020-005

1.

**Target samples of ALICE high-energy pp programme**

- $L_{\text{int}} = 200\ \text{pb}^{-1}, \text{B} = 0.5\ \text{T}$ $\longrightarrow$ high-multiplicity, selection of rare signals
- $L_{\text{int}} = 3\ \text{pb}^{-1}, \text{B} = 0.2\ \text{T}$ $\longrightarrow$ continuous readout, all interactions kept

**Target sample of ALICE Pb–Pb programme (Run3 + Run4)**

- $L_{\text{int}} = 13\ \text{nb}^{-1}, \sqrt{s_{\text{NN}}} = 5.5\ \text{TeV}$ $\longrightarrow$ continuous readout , all interactions kept

ALICE

Mattia Faggin - University and INFN, Padova (Italy)

# Summary and outlook

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**Direct measurements of open-beauty hadrons!**

ALICE-PUBLIC-2020-005

1.

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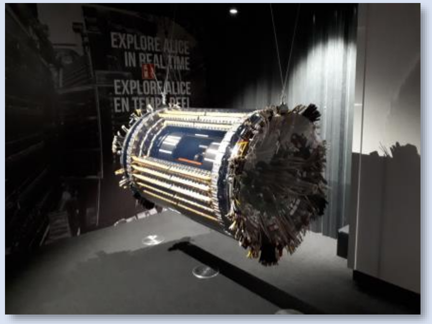
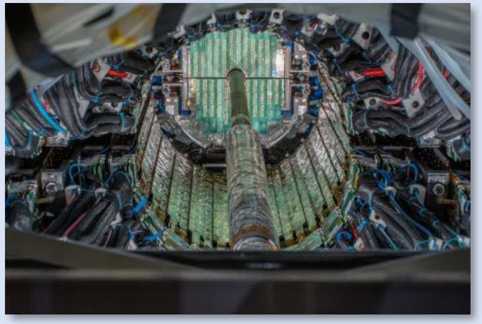
**ITS 1 (ALICE exhibition)**




**ITS 2**



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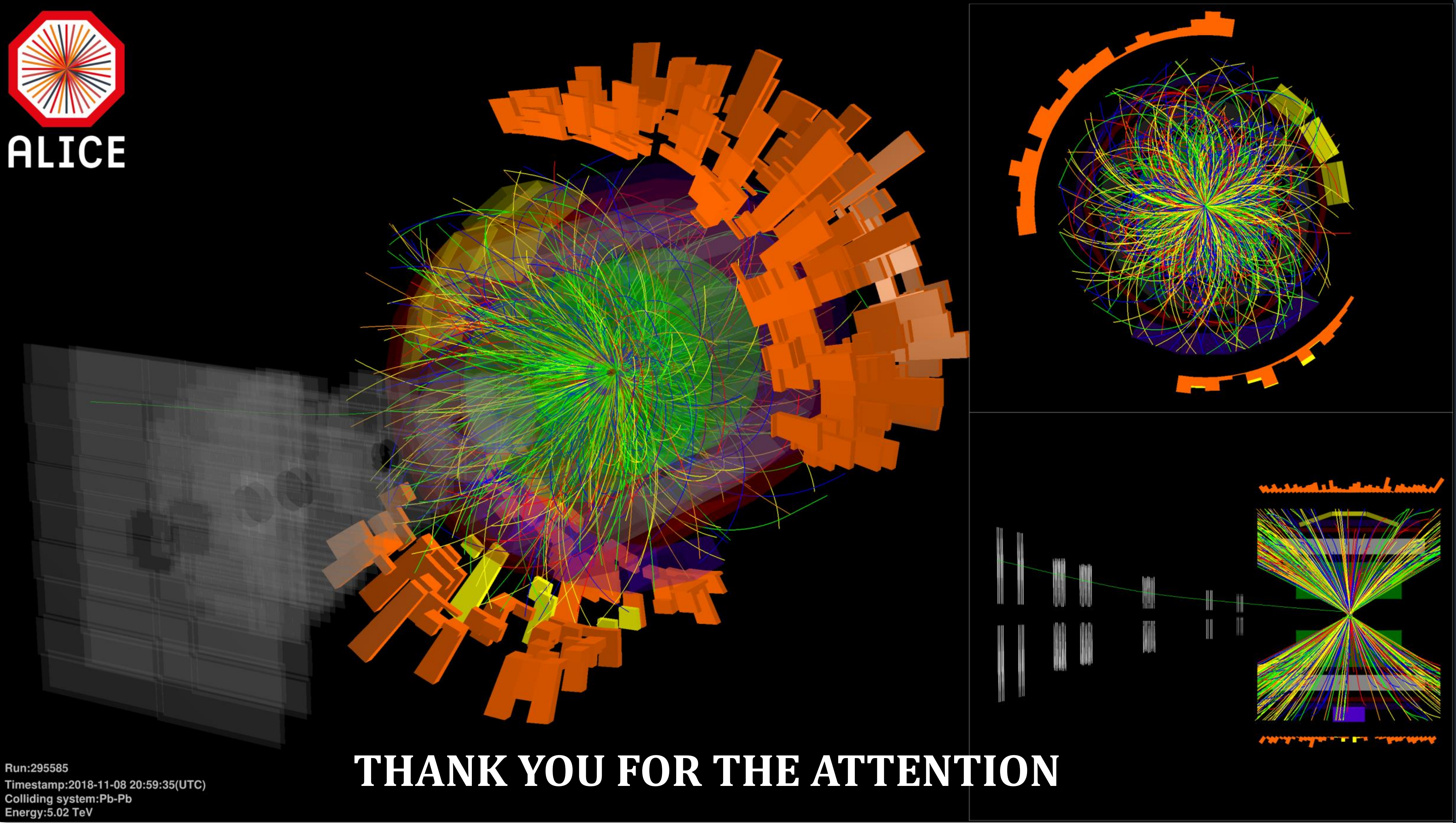
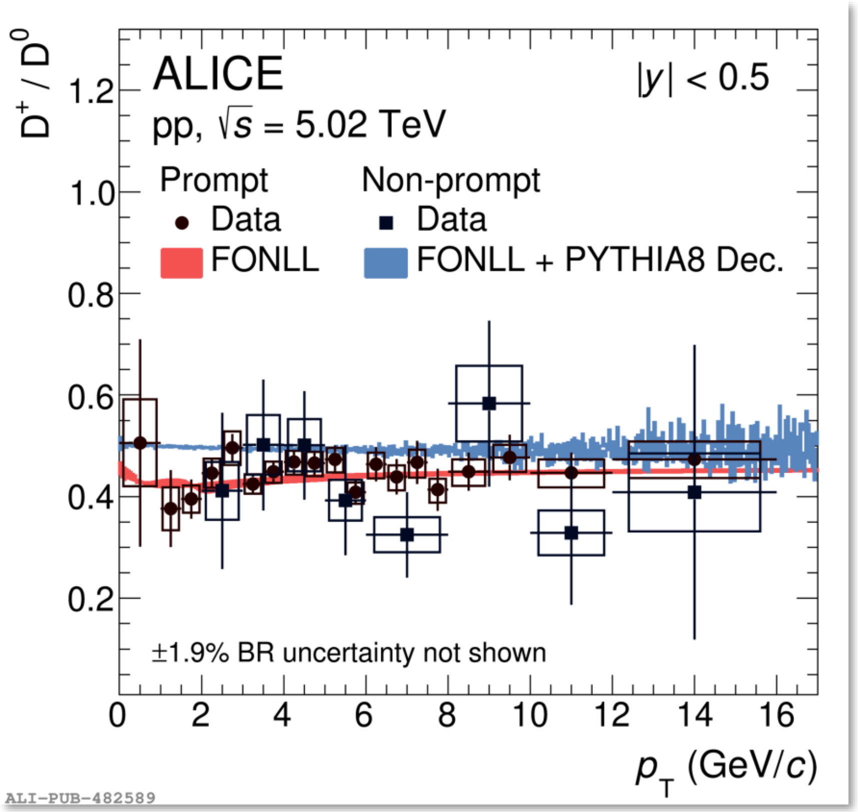
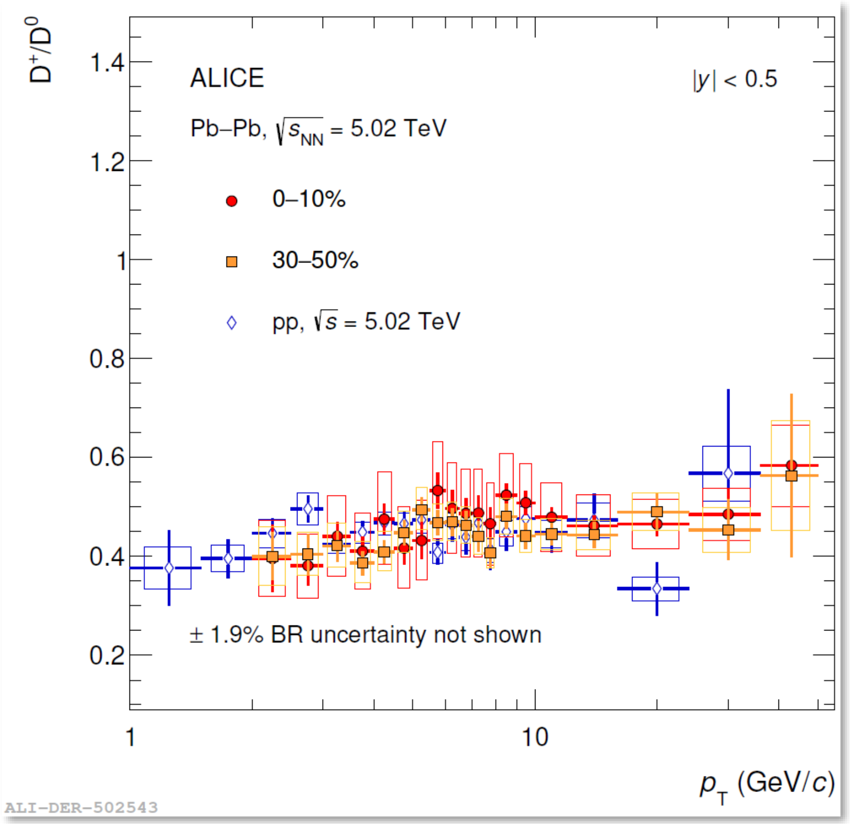



# THANK YOU FOR THE ATTENTION

# Backup

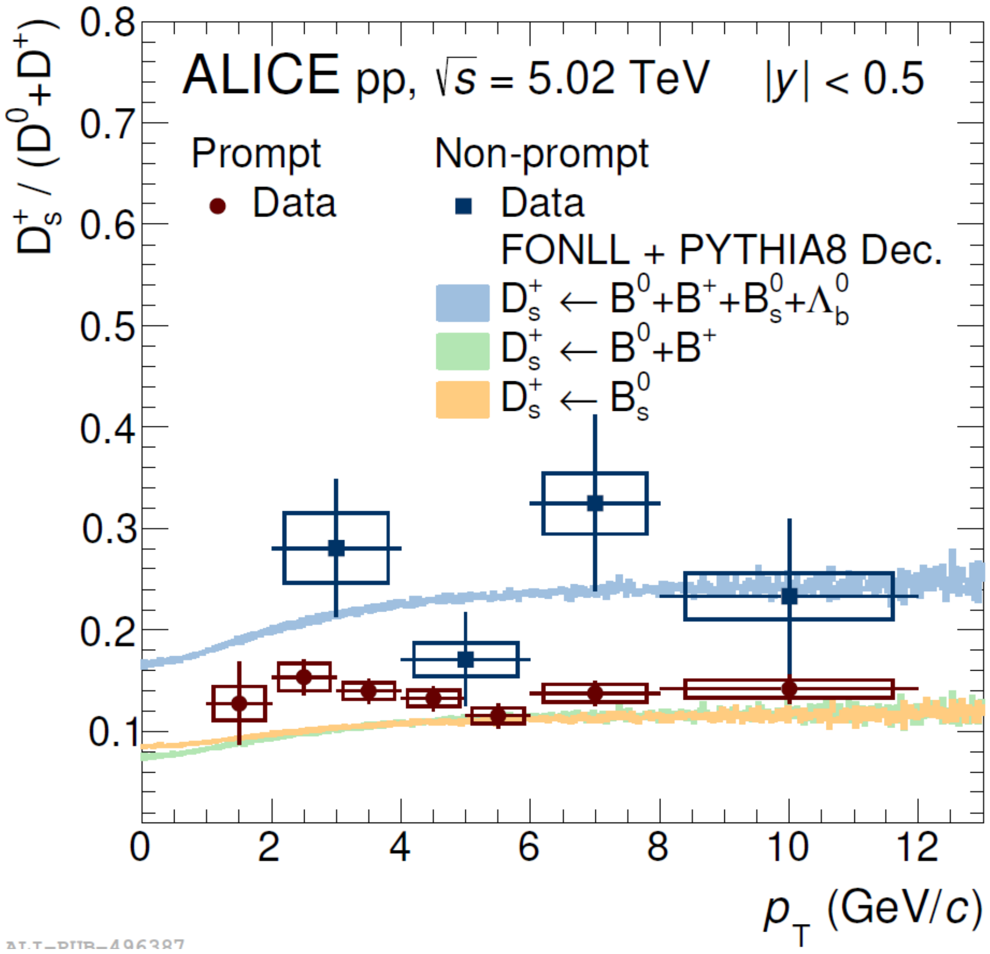
# Charm meson production in pp collisions




- Meson-to-meson ratios **independent** of meson $p_{\mathrm{T}}$ and **collision system**
- **In line** with model calculations based on a **factorization** approach and relying on **universal fragmentation functions** $(e^+e^-) \rightarrow$ FONLL

# Charm mesons: $D_s^+$




ALI-PUB-496387

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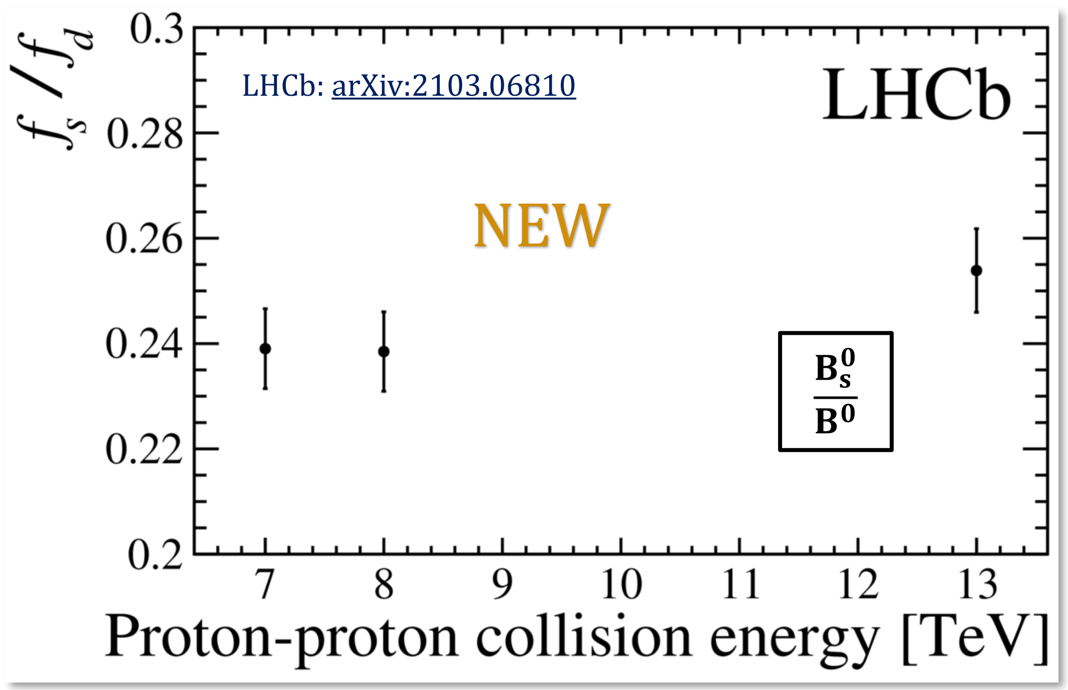
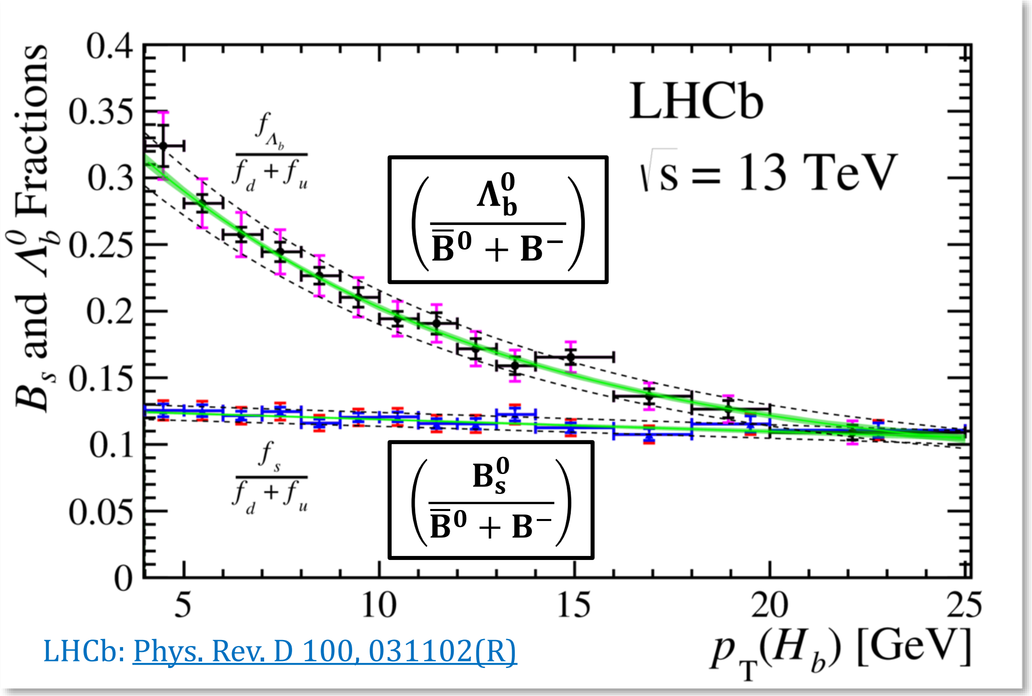
# Beauty meson fragmentation fraction ratios

$\sqrt{s} = 5.02, 7, 8, 13$ TeV

p → ← p




- 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 $\left(\frac{B_s^0}{\overline{B}^0 + B^-}\right)$

→ effect caused by the different masses?
$m_{\Lambda_b^0} (\sim 5.6\ \mathrm{GeV}/c^2) > m_B (\sim 5.3\ \mathrm{GeV}/c^2)$

→ non-universality of fragmentation fractions?

# The role of $\Lambda_c^+$ and $\Sigma_c^{0,+,++}$

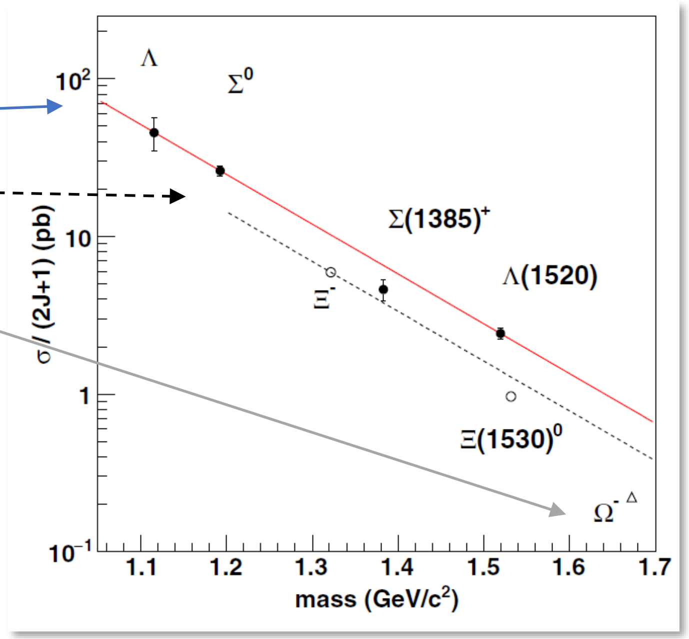
(PYTHIA 8)
$m(\mathrm{ud})_0 = 579\ \mathrm{MeV}/c^2$
$m(\mathrm{ud})_1 = 771\ \mathrm{MeV}/c^2$

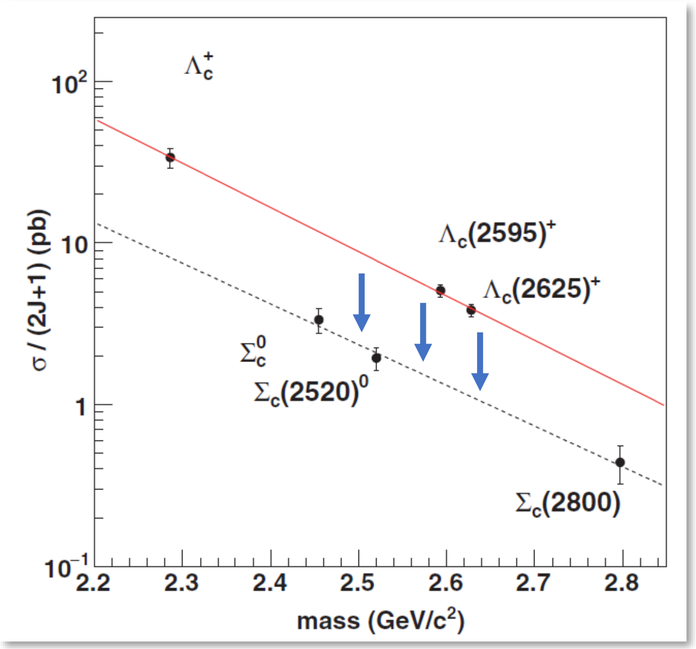
Belle, $e^+e^-$ $\sqrt{s} = 10.52$ GeV
(Phys. Rev. D 97, 072005)

$f(m) = a_0 \exp(a_1 m)$

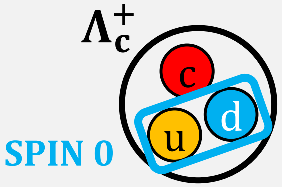
$S$ = -1
$S$ = -2
$S$ = -3

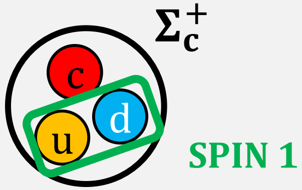
Hierarchy driven by $s\bar{s}$ pair creation




- In conventional fragmentation:
  - charm picks up a spin-0 $(\mathrm{ud})_0$ diquark $\rightarrow$ $\Lambda_c^+$ $(I = 0)$
  - charm picks up a spin-1 $(\mathrm{ud})_1$ diquark $\rightarrow$ $\Sigma_c^+$ $(I = 1)$



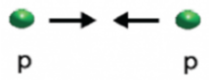




- $(\mathrm{ud})_1$ mass much larger than $(\mathrm{ud})_0$
  $\Rightarrow$ production of $\Sigma_c$ states expected to be suppressed compared to $\Lambda_c^+$

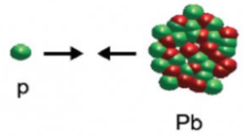
- $\Sigma_c$-state production suppressed by ~3-4 times that of excited $\Lambda_c^+$ states in $e^+e^-$ collisions at $\sqrt{s} = 10.52$ GeV

# Charm fragmentation functions in p-Pb collisions

| $H_c$ | $f(c \to H_c)$ (pp) | $f(c \to H_c)$ (p–Pb) ($R_{pPb}(\Xi_c) = R_{pPb}(\Lambda_c^+)$) |
|---|---|---|
| $D^0$ | $39.1 \pm 1.7(\text{stat})^{+2.5}_{-3.7}(\text{syst})$ | $41.6 \pm 1.24(\text{stat})^{+2.44}_{-3.44}(\text{syst})$ |
| $D^+$ | $17.3 \pm 1.8(\text{stat})^{+1.7}_{-2.1}(\text{syst})$ | $18.3 \pm 0.10(\text{stat})^{+1.52}_{-1.64}(\text{syst})$ |
| $D_s^+$ | $7.3 \pm 1.0(\text{stat})^{+1.9}_{-1.1}(\text{syst})$ | $9.0 \pm 0.48(\text{stat})^{+1.56}_{-1.04}(\text{syst})$ |
| $\Lambda_c^+$ | $20.4 \pm 1.3(\text{stat})^{+1.6}_{-2.2}(\text{syst})$ | $17.6 \pm 1.06(\text{stat})^{+1.34}_{-1.72}(\text{syst})$ |
| $\Xi_c^0$ | $8.0 \pm 1.2(\text{stat})^{+2.5}_{-2.4}(\text{syst})$ | $6.7 \pm 1.04(\text{stat})^{+2.35}_{-2.30}(\text{syst})$ |
| $D^{*+}$ | $15.5 \pm 1.2(\text{stat})^{+4.1}_{-1.9}(\text{syst})$ | $12.9 \pm 0.58(\text{stat})^{+3.32}_{-1.12}(\text{syst})$ |

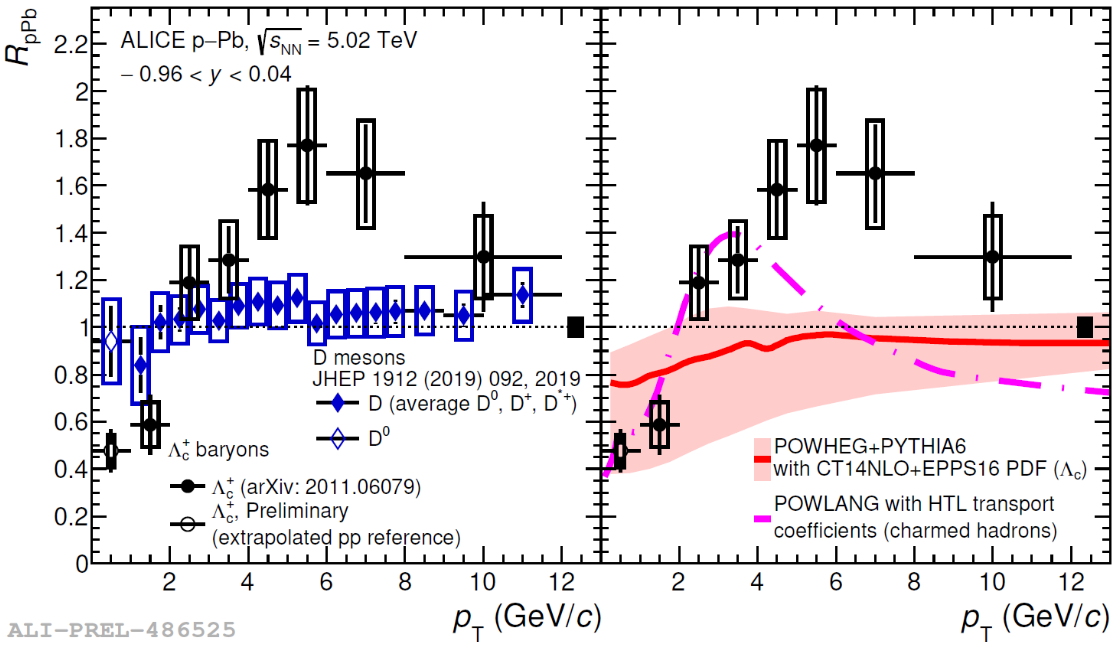


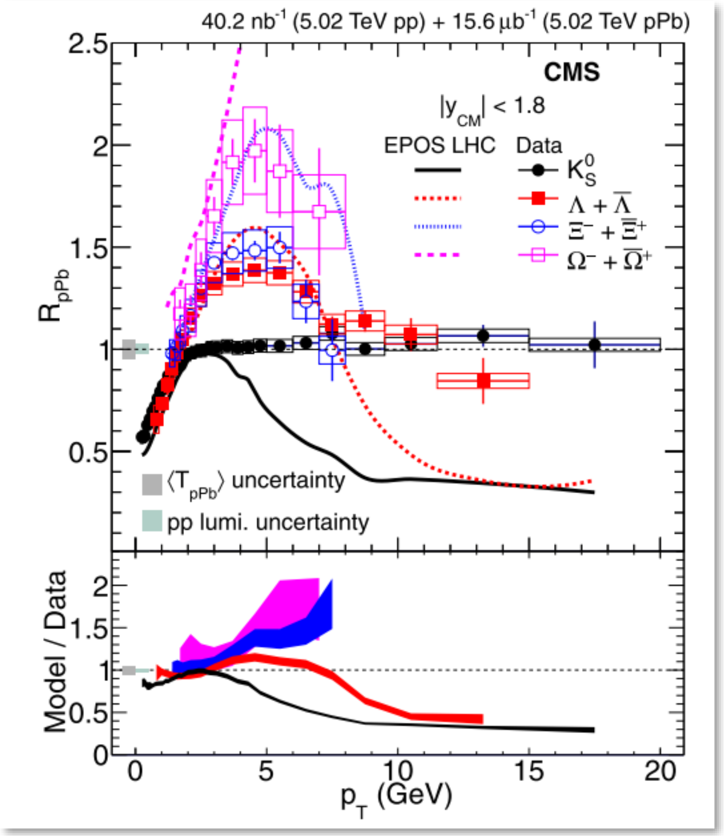

$\sqrt{s} = 5.02$ TeV




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

# Charm fragmentation functions in p-Pb collisions




$p_T$-integrated value for $\Lambda_c^+$ (preliminary):

$$R_{pPb} = 0.761 \pm 0.063(\text{stat.}) \pm 0.109(\text{syst.})^{+0.010}_{-0.013}\text{extrap.}$$

- Charm fragmentation fractions in hadronic collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - p-Pb:
    - i. $D^0$, $\Lambda_c^+$ (new): measured down to $p_T = 0$
    - ii. $D^+$, $D_s^+$: extrapolated down to $p_T = 0$ using POWHEG+PYTHIA
    - iii. $\Xi_c^0$ not measured $\longrightarrow$ $\sigma_{pp}(\Xi_c^0) \times 208 \times R_{pPb}(\Lambda_c^+)$

      $\longrightarrow$ assumption: $R_{pPb}(\Xi_c^+) = R_{pPb}(\Lambda_c^+)$ (support: CMS measurement for $\Xi^-$ and $\Lambda$, PHYSICAL REVIEW C 101, 064906 (2020))

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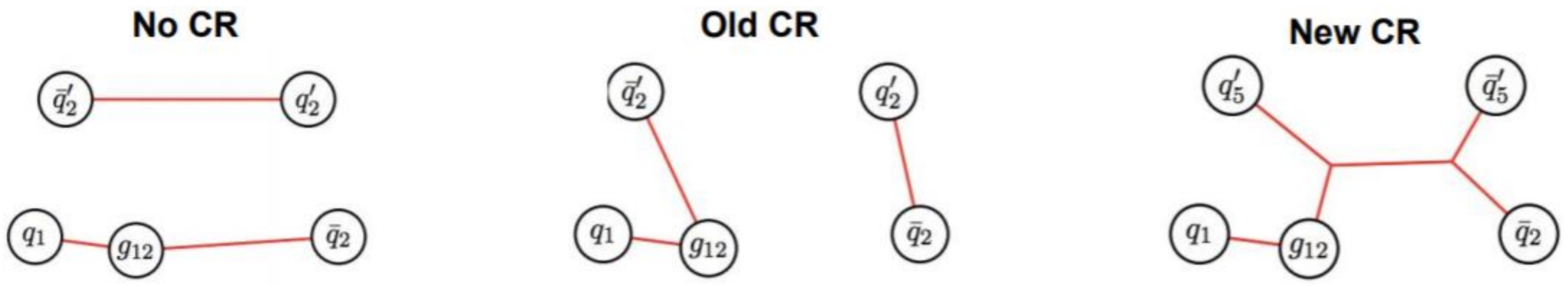
Mattia Faggin - University and INFN, Padova (Italy)

# 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?***



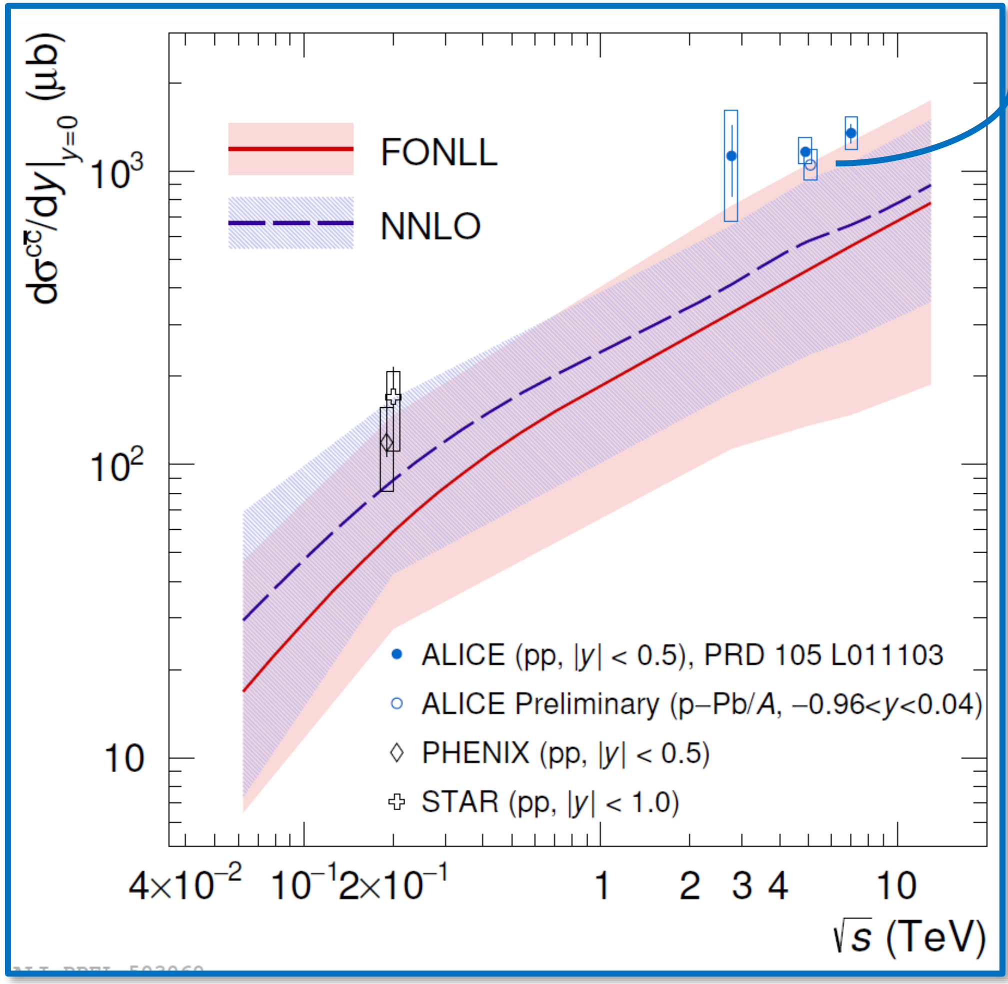

**No CR**
- Partons created in different MPIs do not interact

**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

Phys. Rev. D 105, L011103 (2022) JHEP 12(2019)092

# $c\bar{c}$ cross section in hadronic collisions




NEW

- **$c\bar{c}$ production cross section** at midrapidity in **pp** and **p-Pb (new)** collisions at $\sqrt{s_{NN}} = 5.02$ **TeV** measured as **sum of ground state hadron cross sections**

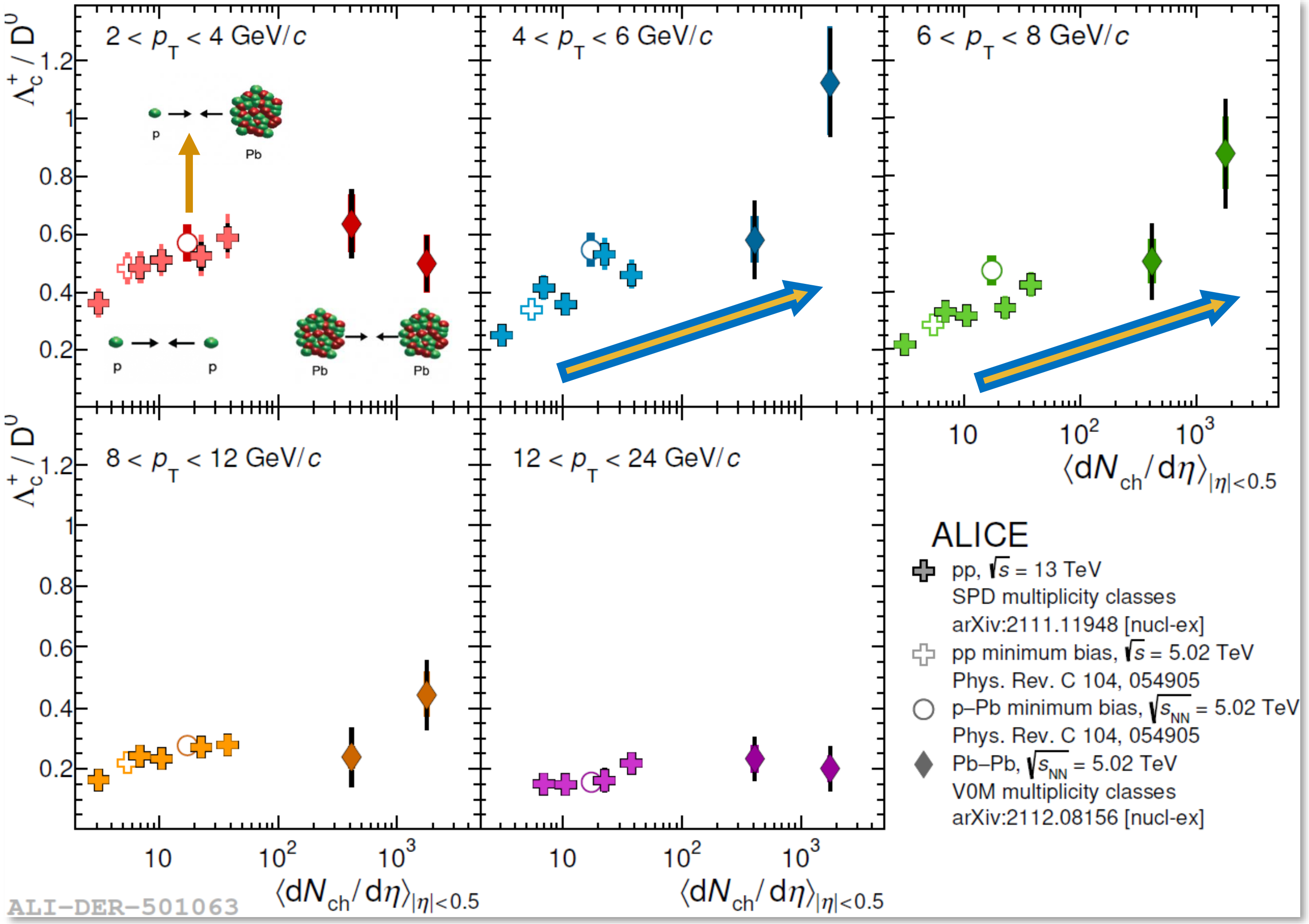
$$\left(\frac{d\sigma^{c\bar{c}}_{pp}}{dy}\right)_{|y|<0.5} = 1165 \pm 44(\text{stat.})^{+134}_{-101}(\text{syst.})\ \mu b$$

$$\frac{1}{A}\cdot\left(\frac{d\sigma^{c\bar{c}}_{p-Pb}}{dy}\right)_{-0.96<y<-0.04} = 1057.5 \pm 28.6(\text{stat.})^{+103.6}_{-76.0}(\text{syst.})\ \mu b$$

- Results **compatible** within systematic uncertainties
- **Results previously published** in **pp** at $\sqrt{s} = 2.76$ and **7 TeV** from D mesons **updated** with fragmentation fractions from $\sqrt{s} = 5.02$ TeV analysis
  → **~40% increase** driven by the observed **baryon enhancement**
- Results on **upper edge** of **FONLL and NNLO** calculations


FONLL: JHEP 1210 (2012) 137
NNLO: PRL 118 (2017) 122001, JHEP 03 (2021) 029
PHENIX: Phys. Rev. C 84 (2011) 044905
STAR: Phys. Rev. D 86 (2012) 072013

# Multiplicity dependence of $\Lambda_c^+/D^0$ in hadronic collisions



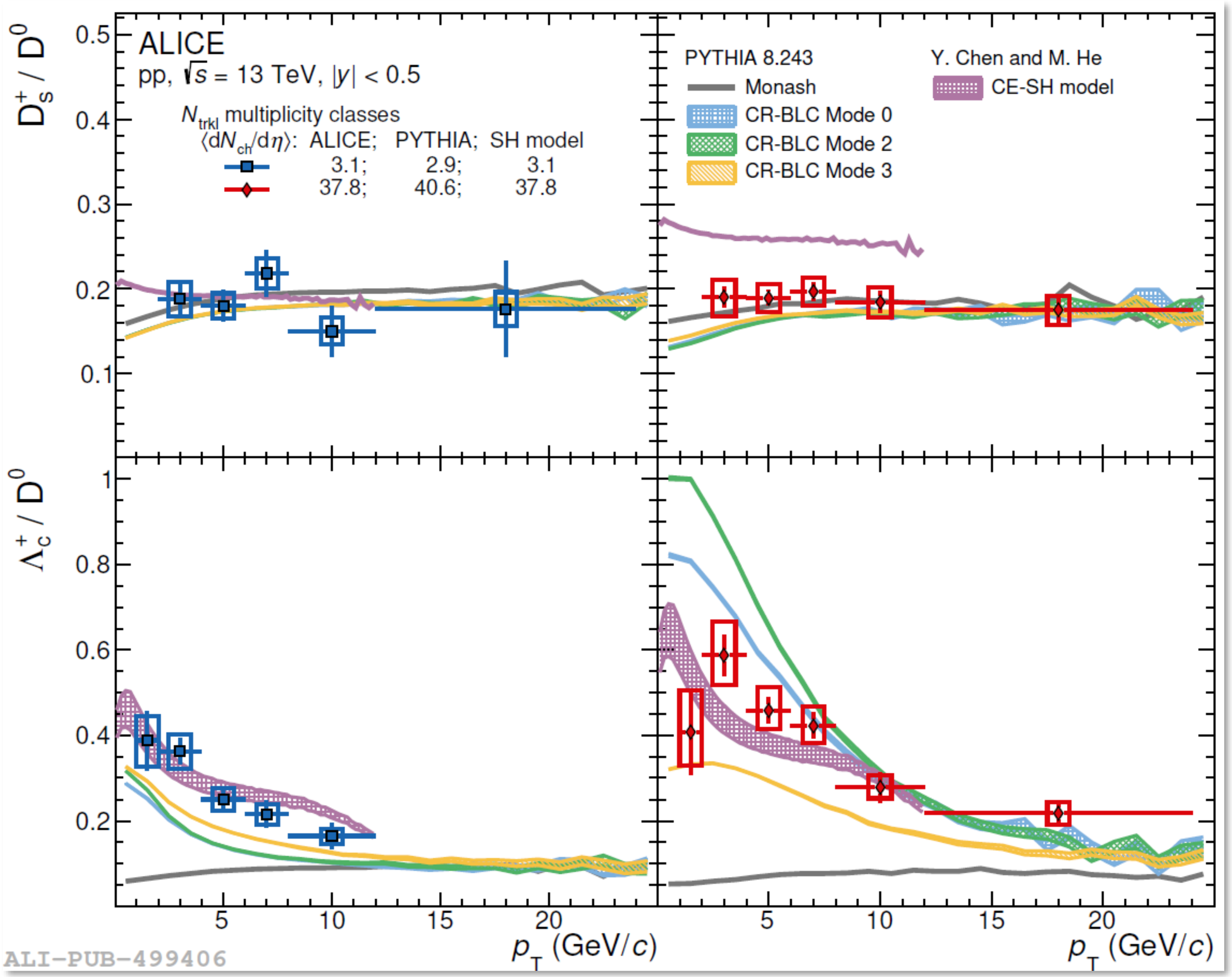

Increasing event multiplicity

- pp, p-Pb, Pb-Pb shown together as a function of event multiplicity
- **$p_T$-integrated $\Lambda_c^+/D^0$** ratio **not dependent on multiplicity** within uncertainties
- **$\Lambda_c^+/D^0$** ratio smoothly **increasing** at intermediate $p_T$ from pp to Pb-Pb

- **Similar heavy-flavour hadronization in different colliding systems?**
- Interplay with flow effects in Pb-Pb collisions?

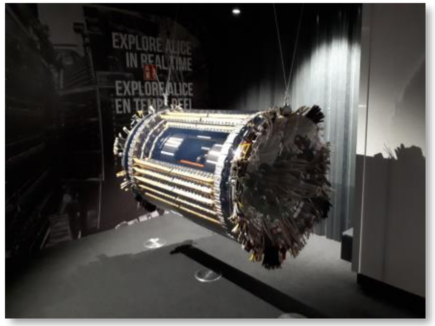
Lucas Anne Vermunt
**«Charm production: constraint to transport models and charm diffusion coefficient with ALICE»**
Thursday 7 April, 09:00

# Multiplicity dependence of $\Lambda_c^+/D^0$ in hadronic collisions

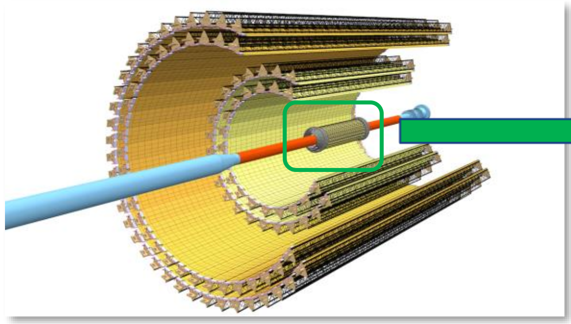


# ALICE ITS upgrades in Run 3 and 4

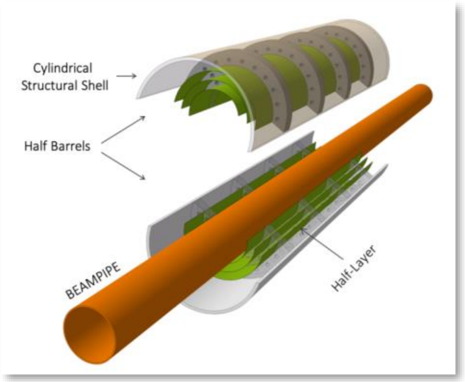
**ITS 1 (ALICE exhibition)**




**ITS 2**



**ITS 3**




6 layers:

- 2 layers of Silicon Pixel Detector (SPD)
- 2 layers of Silicon Drift Detectors (SDD)
- 2 layers of Silicon Strip Detectors (SSD)

7 layers of ALPIDE Monolitic Active Pixel Sensors
→ 10 $m^2$ active silicon area
→ $12.6 \times 10^9$ pixels

3 truly cylindrical Si pixel layers
→ ultra-thin wafer-sized curved sensors
→ no external connections air-flow cooling

| | ITS 1 | ITS 2 | ITS3 |
|---|---|---|---|
| Distance to interaction point (mm) | 39 | 22 | 18 |
| $X_0$ (innermost layer) (%) | ~1.14 | ~0.35 | 0.05 |
| Pixel pitch ($\mu m^2$) | $50 \times 425$ | $27 \times 29$ | $O(15 \times 15)$ |
| Readout rate (kHz) | 1 | 100 | |
| Spatial resolution ($r\varphi \times z$) ($\mu m^2$) | $11 \times 100$ | $5 \times 5$ | |

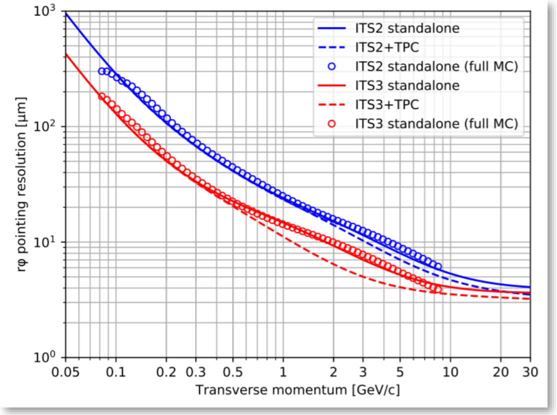
→ Closer to interaction point

→ Lower material budget

→ Improved granularity

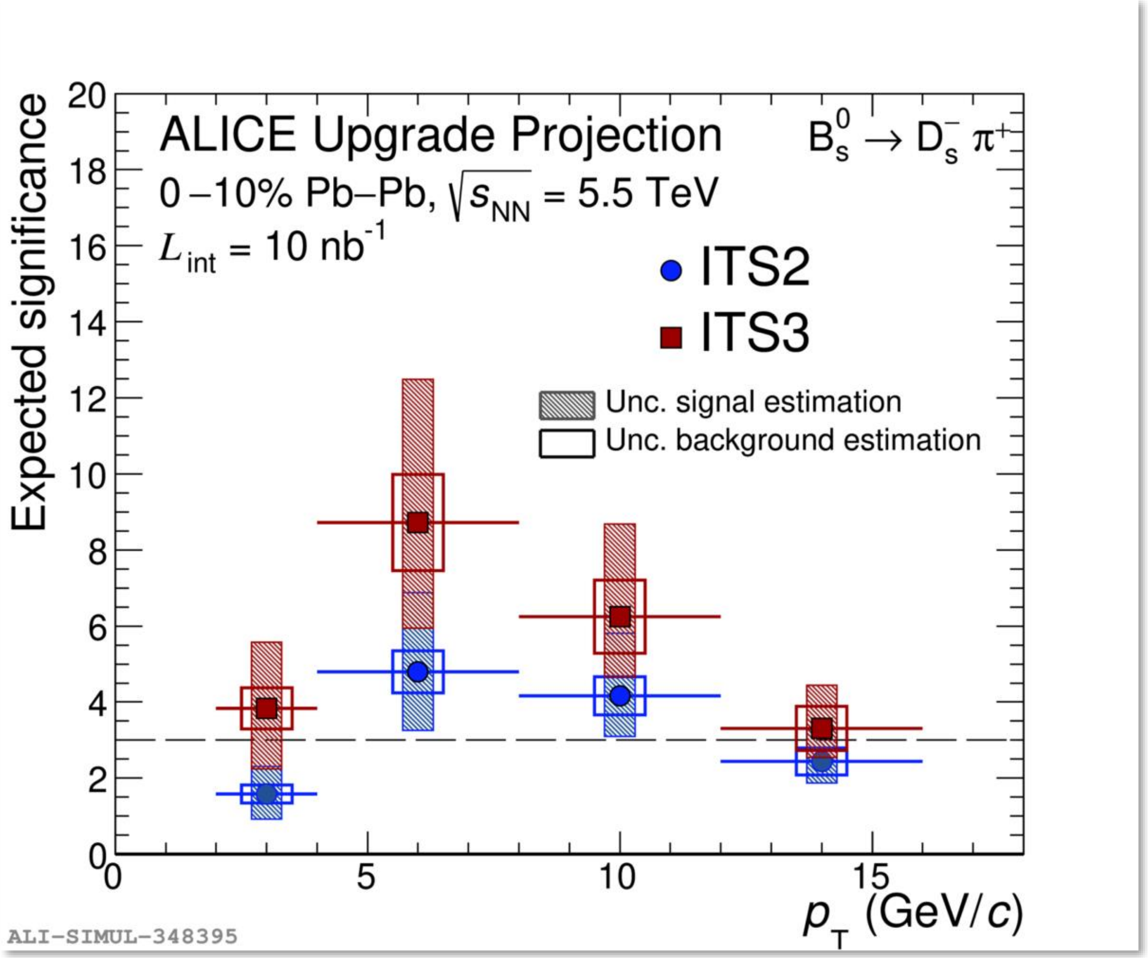
→ Faster readout

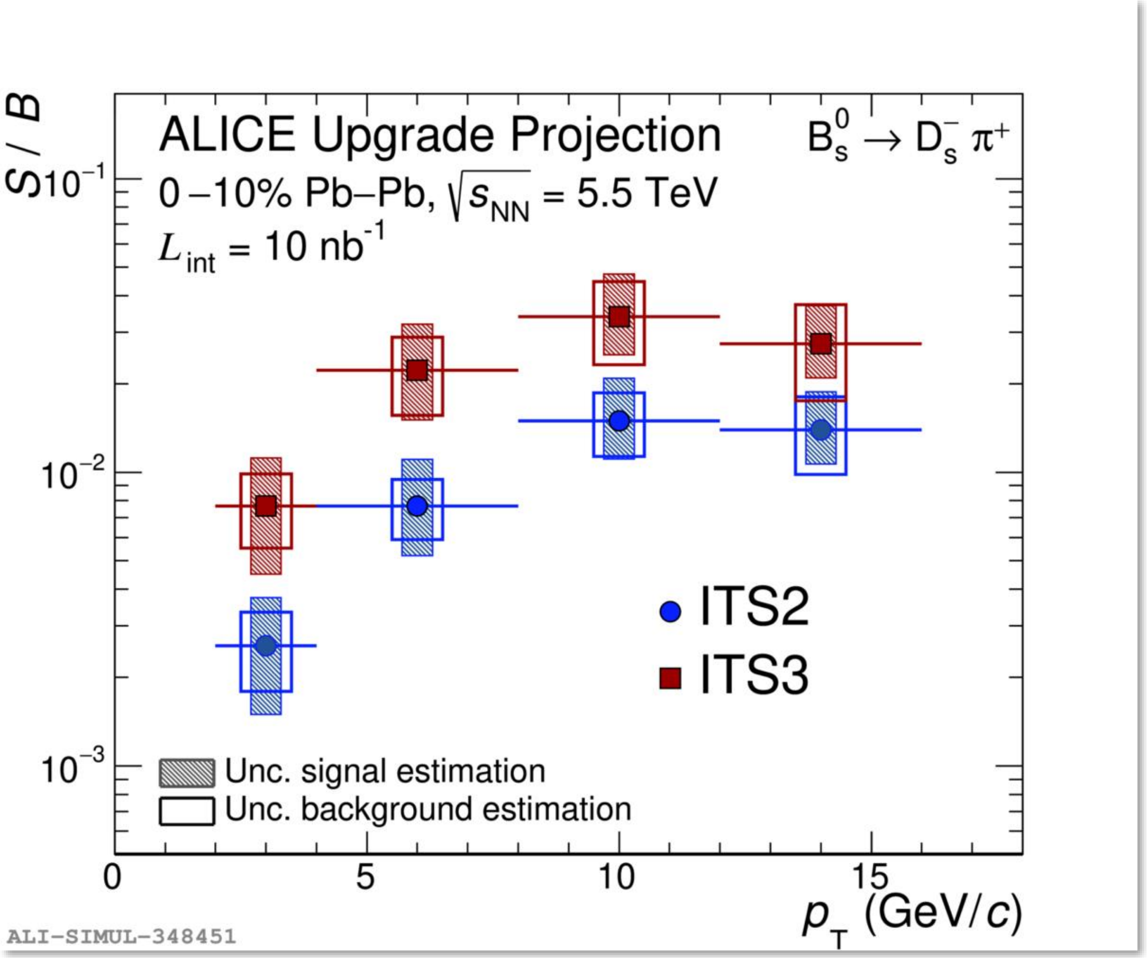
→ Improved resolution



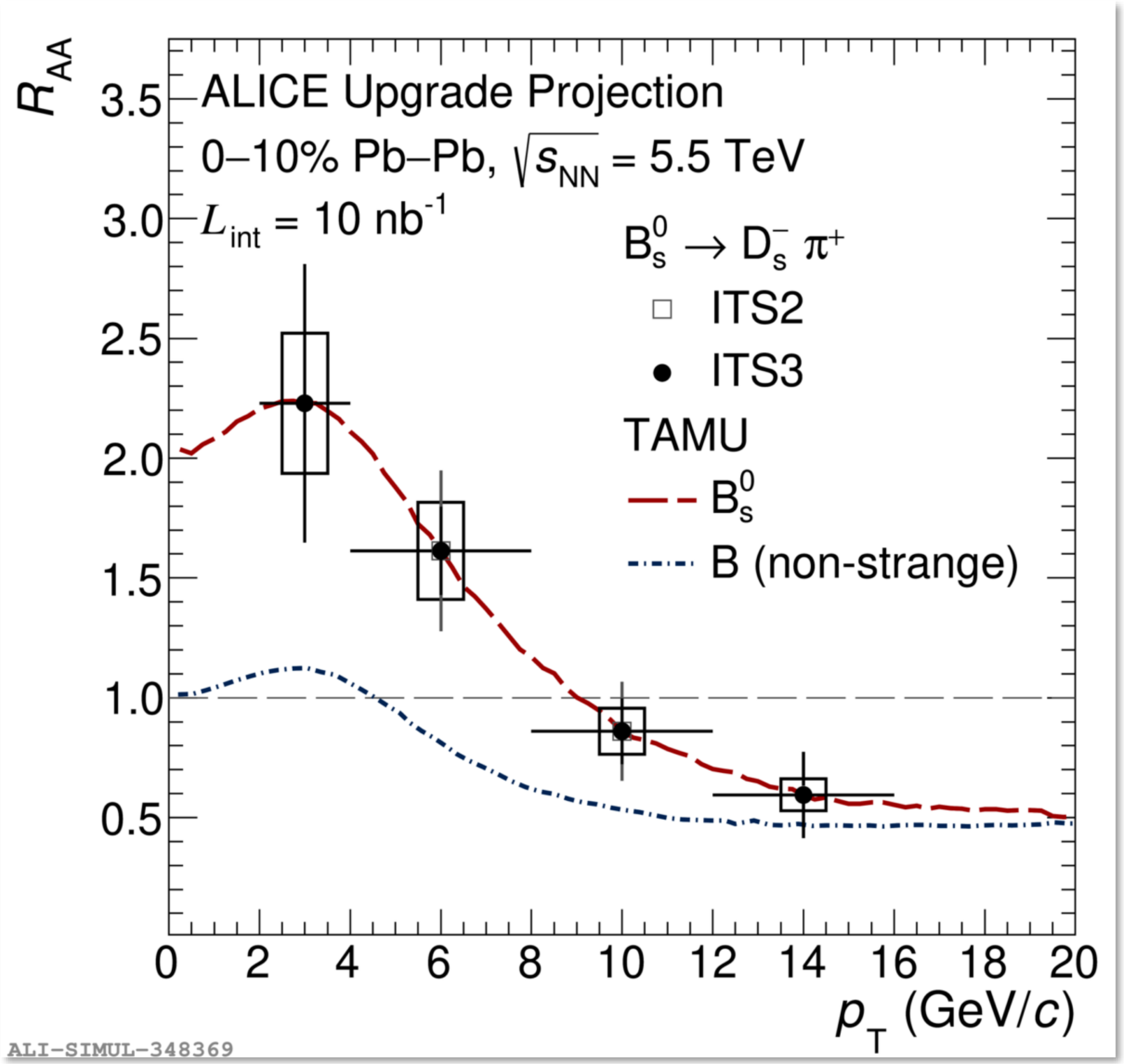

× ~2 improvement in pointing resolution (ITS2→ITS3)

# $B_s^0 \rightarrow D_s^- \pi^+$ measurement in Run 3 and 4 (1/2)



# $B_s^0 \to D_s^- \pi^+$ measurement in Run 3 and 4 (2/2)




ALICE

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# $\Lambda_b^0 \rightarrow \Lambda_c^+\pi^-$ measurement in Run 3 and 4