第八届中国LHC物理研讨会

The 8th China LHC Physics Workshop

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Nov. 23-27, 2022, Nanjing Tangshan Yishang Hotel

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on behalf of the ALICE Collaboration

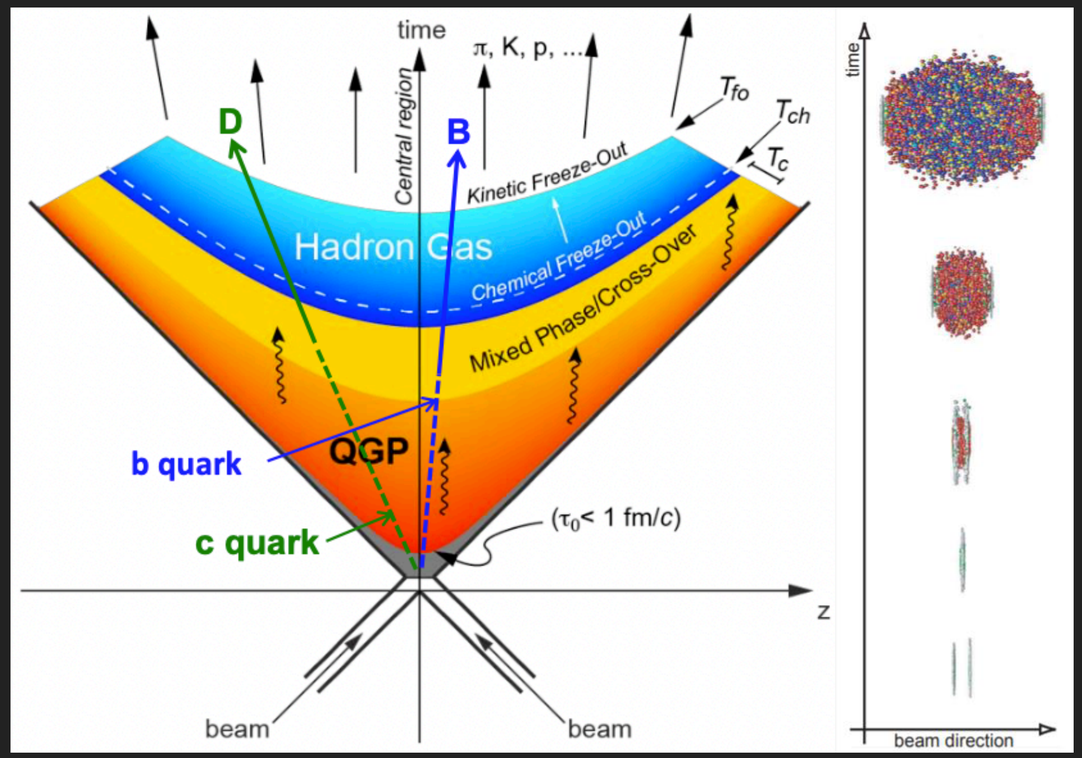
Charm-baryon production with ALICE

ALICE

CENTRAL CHINA NORMAL UNIVERSITY

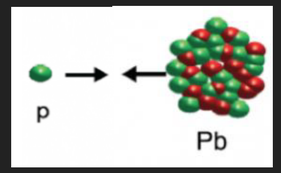
INFN PADOVA
Istituto Nazionale di Fisica Nucleare
Sezione di Padova

Heavy flavor: golden probe of the medium

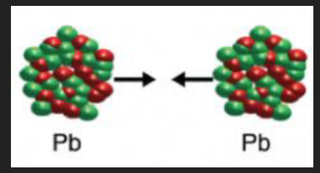


- Charm and beauty quarks: unique probes of the medium
  - $m_{\mathrm{Q}} \gg \Lambda_{\mathrm{QCD}}$
    - Enable the evaluation of their production cross sections within pQCD
  - $m_{\mathrm{Q}} \gg T_{\mathrm{QGP}}$
    - Produced mainly in initial hard scatterings (high Q^2) at early stage of heavy-ion collisions
  - $\tau_{\mathrm{prob}} \approx \frac{1}{2m_{\mathrm{q}}} \approx 0.1_{\mathrm{q=c}}(0.03)_{\mathrm{q=b}}\ \mathrm{fm}/c\ < \tau_{\mathrm{QGP}}(\approx 0.3-1.5\ \mathrm{fm}/c)$
    - Experience the full evolution of the QGP

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

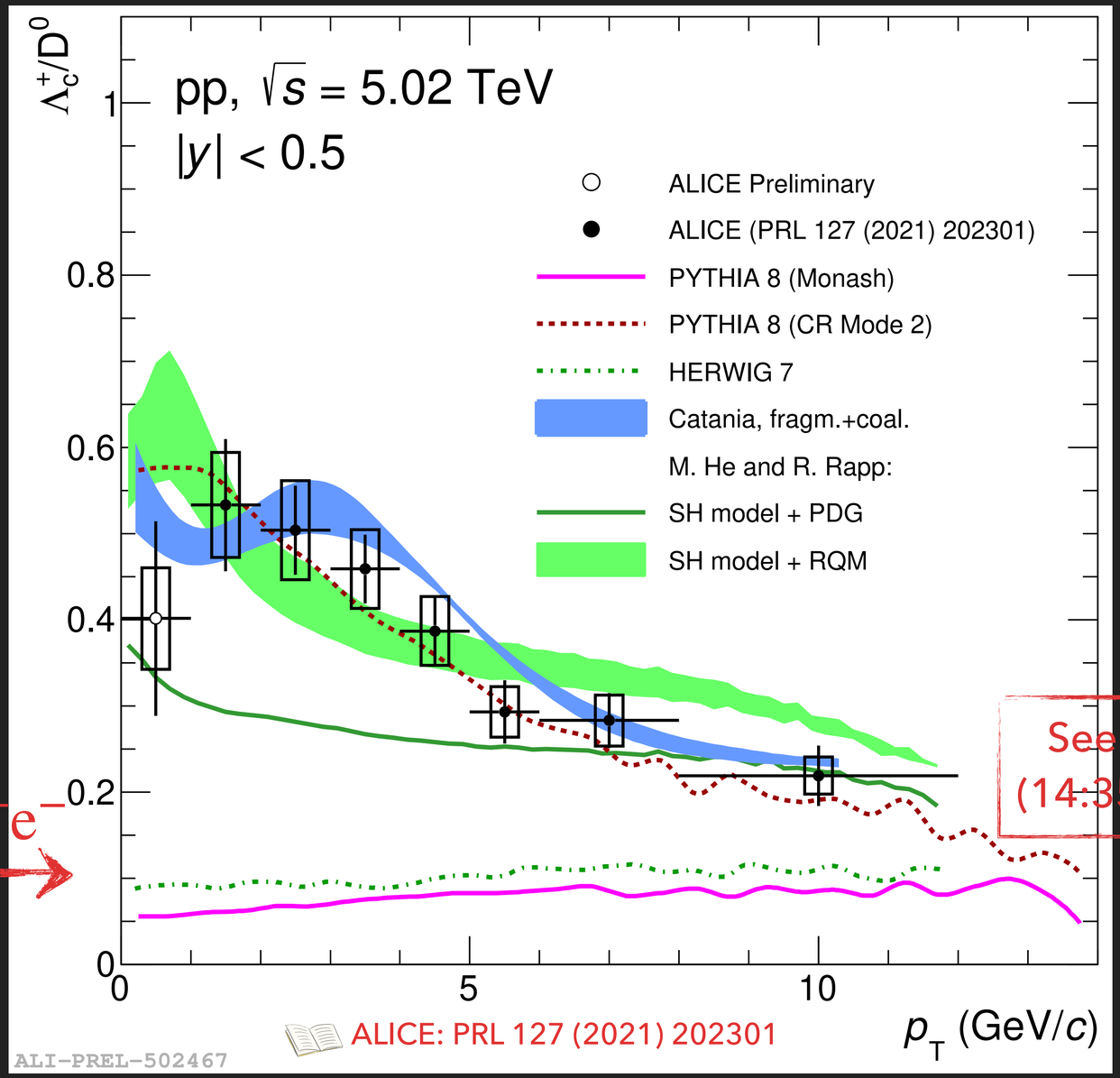


p-Pb collisions
- Cold nuclear matter effects
  - Modification of parton distribution functions (PDF) in bound nucleons



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

Prompt Λ_c^+ production in pp collisions



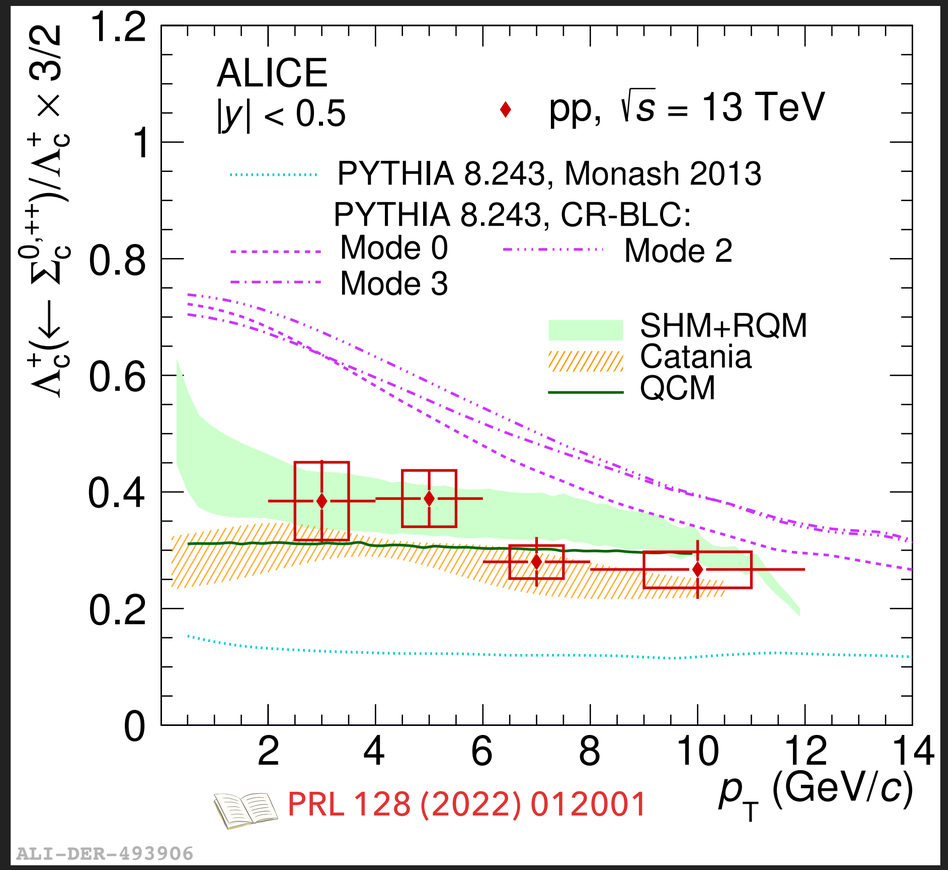
- Largely underestimated by PYTHIA 8 Monash[1]
  - PYTHIA 8 Monash: e^+e^- charm fragmentation functions
- Well described by PYTHIA 8 CR Mode2[2], SHM[3]+RQM[4], Catania[5]
  - PYTHIA 8 CR Mode2: color reconnection beyond leading color (CR-BLC) approximation
  - Catania: transport model with hadronization via coalescence+fragmentation
  - SHM+RQM: statistical hadronization model (SHM) with additional baryon states predicted by relativistic quark model (RQM)

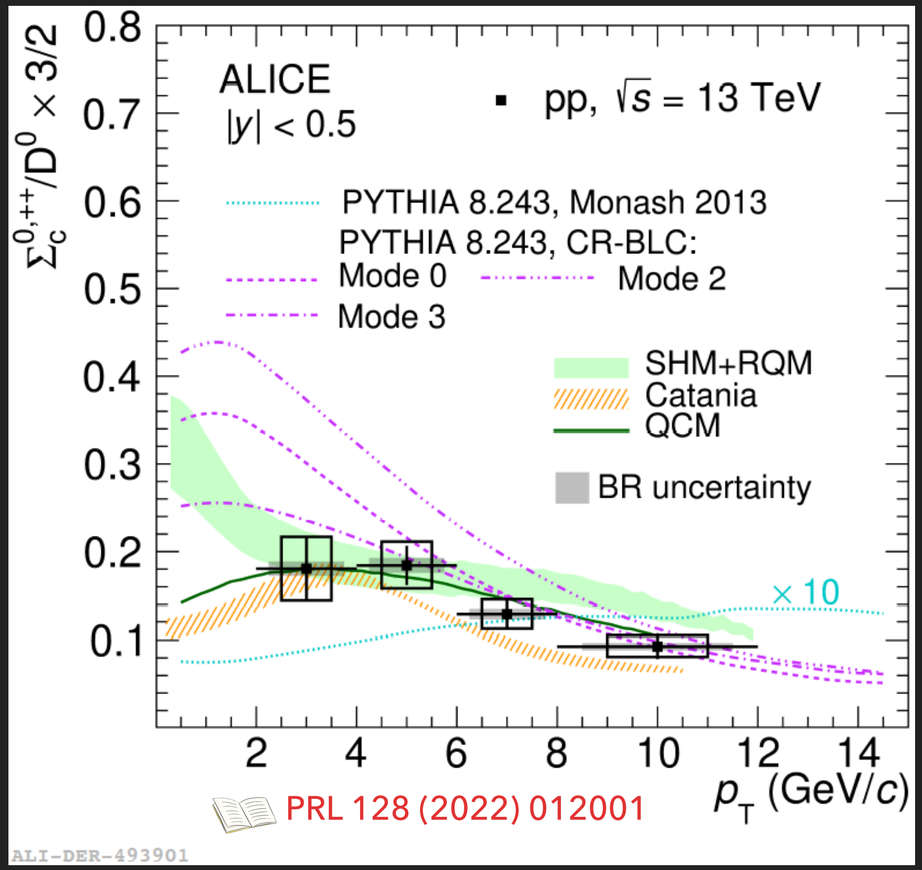
See Tiantian Cheng's talk
(14:35 25 Nov., HF/HI/QCD)

[1] P. Skands, et al., EPJC 74 (2014) 3024
[2] J. Christiansen, et al., JHEP 08 (2015) 003
[3] M. He and R. Rapp, PLB 795 (2019) 117-121
[4] D. Ebert, et al., PRD 84:014025, 2011
[5] V. Minissale, et al., PLB 821 (2021) 136622

Heavier charm baryons: $\Sigma_c^{0,+,++}$ production in pp collisions

- Feed-down from $\Sigma_c^{0,+,++}$ partially explains Λ_c^+/D^0 enhancement
  - $\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/\Lambda_c^+ = 0.38 \pm 0.06(\text{stat.}) \pm 0.06(\text{syst.})$
- $\Sigma_c^{0,+,++}/D^0$ enhancement in pp w.r.t. e^+e^-



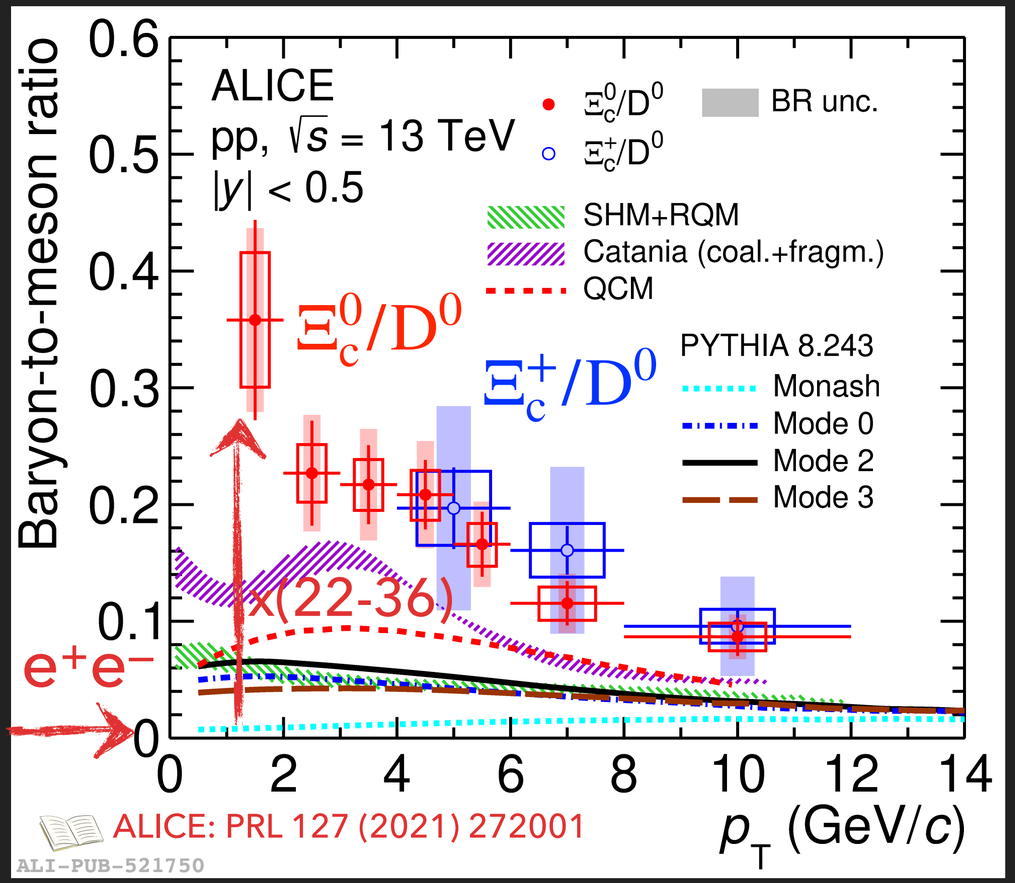


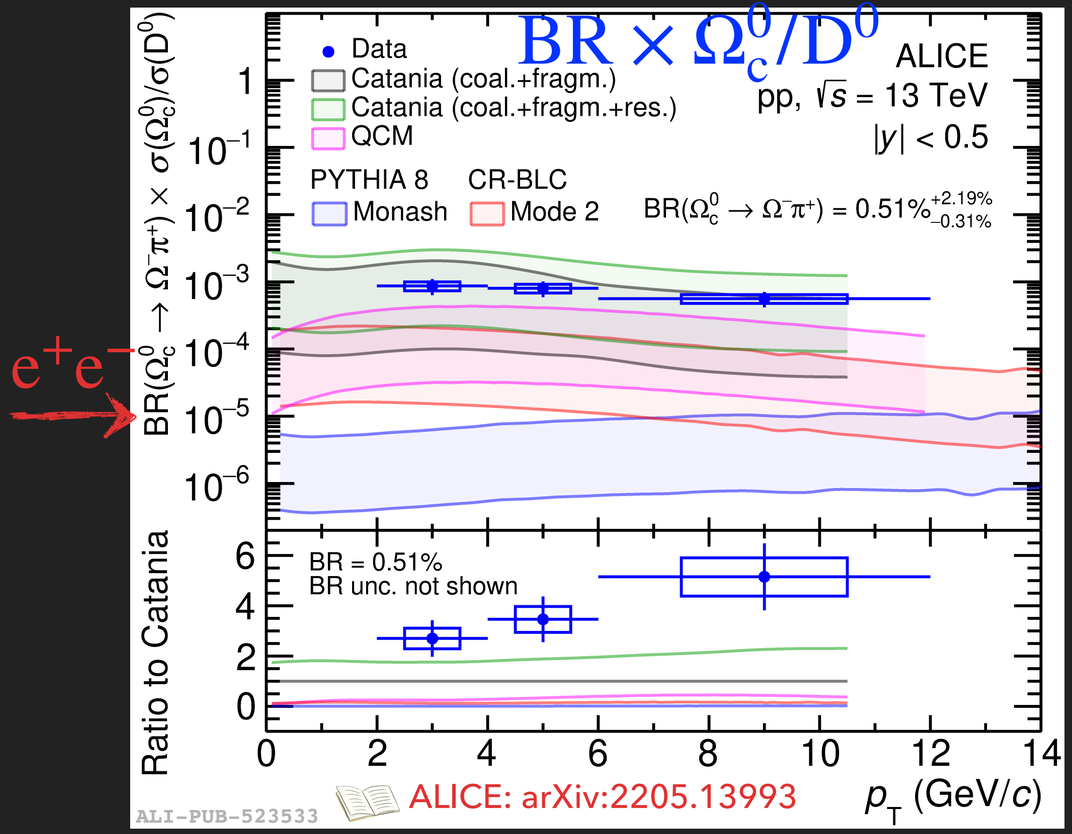
- PYTHIA 8 Monash[1] severely underestimates $\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/\Lambda_c^+$ and $\Sigma_c^{0,+,++}/D^0$
- PYTHIA 8 CR Modes[2] overestimate $\Lambda_c^+(\leftarrow \Sigma_c^{0,+,++})/\Lambda_c^+$, but describe $\Sigma_c^{0,+,++}/D^0$
- Well described by SHM[3]+RQM[4], Catania[5] and QCM[6]

[1] P. Skands, et al., EPJC 74 (2014) 3024
[2] J. Christiansen, et al., JHEP 08 (2015) 003
[3] M. He and R. Rapp, PLB 795 (2019) 117-121
[4] D. Ebert, et al., PRD 84:014025, 2011
[5] V. Minissale, et al., PLB 821 (2021) 136622
[6] J. Song, et al., EPJC (2018) 78: 344

Strange-charm baryons: $\Xi_c^{0,+}$ and Ω_c^0 production in pp collisions

- Ξ_c^0/D^0 in agreement with Ξ_c^+/D^0
- Significantly underestimated by models[1,2,3,4,5]
  - Different from $D_s^+/(D^0+D^+)$ ➡ baryons are "strange"?



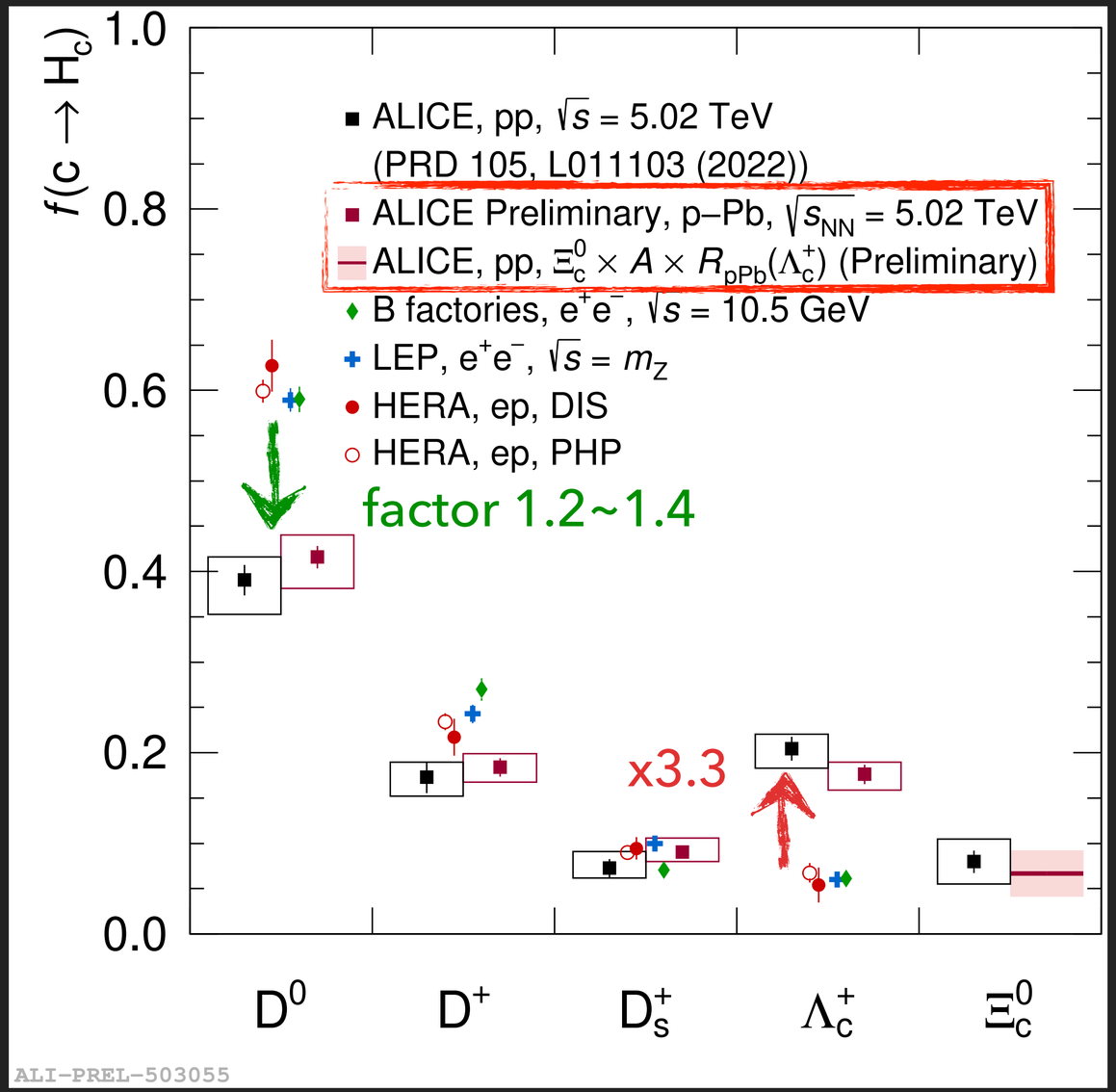


- $BR(\Omega_c^0 \to \pi^+\Omega^-)$ from theoretical calculations
- Large enhancement of Ω_c^0 than expected
  - Sizeable contribution to charm production?
- Catania[6] (additional resonances decay considered) closer to data points
  - Coalescence in pp?

[1] P. Skands, et al., EPJC 74 (2014) 3024
[2] J. Christiansen, et al., JHEP 08 (2015) 003
[3] M. He and R. Rapp, PLB 795 (2019) 117-121
[4] D. Ebert, et al., PRD 84 (2011) 014025
[5] J. Song, et al., EPJC 78 (2018) 344
[6] V. Minissale, et al., PLB 821 (2021) 136622
[7] Belle e^+e^-: PRD 97 (2018) 072005

Charm FF in small collision systems

ALICE: PRD 105 (2022) L011103



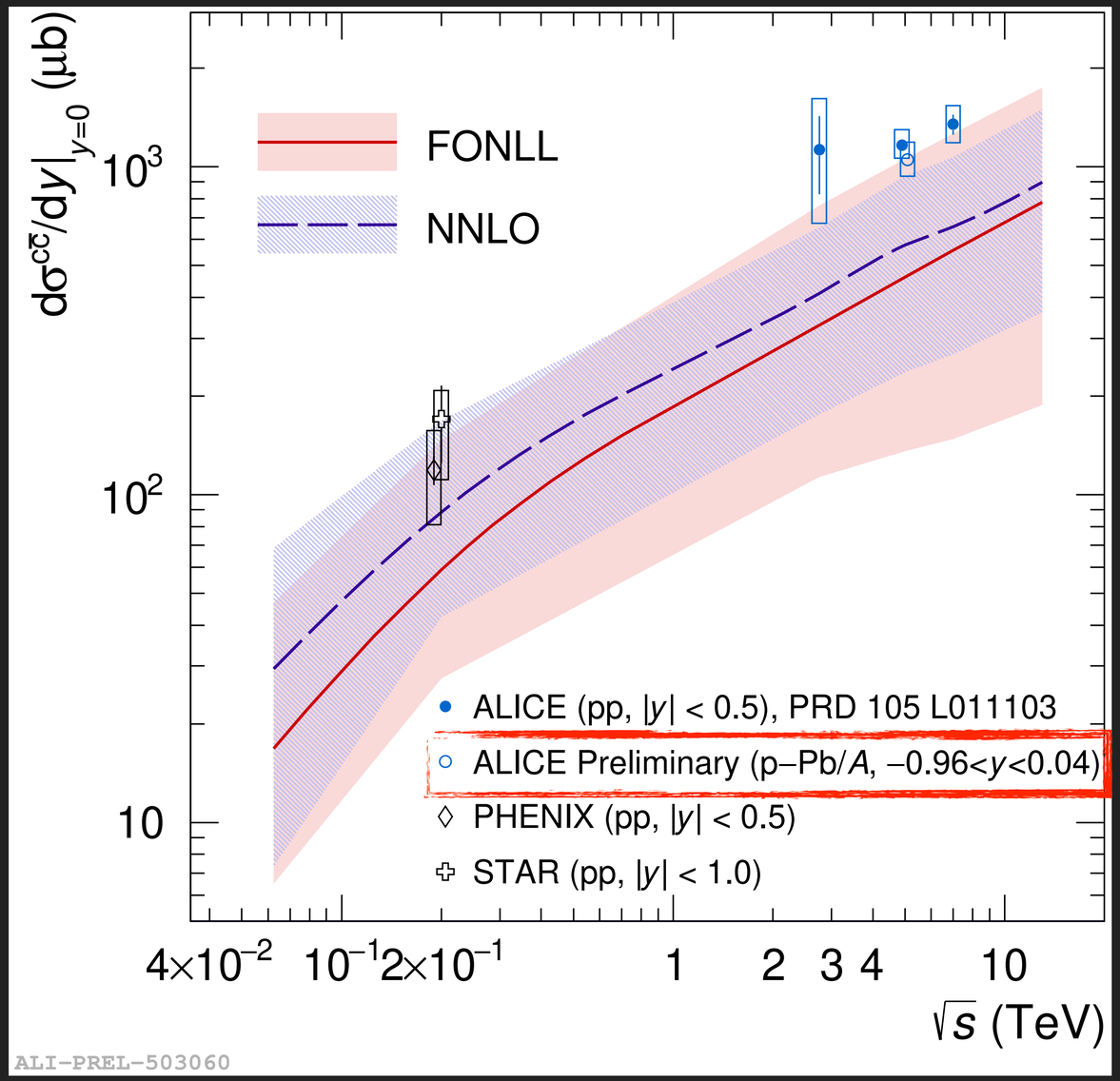
- Charm FF in hadronic collisions
  - pp@5.02 TeV: PRD 105 (2022) L011103
  - p-Pb@5.02 TeV:
    - D^0, Λ_c^+ : measured down to $p_T = 0$
    - D^+, D_s^+ : extrapolated to $p_T = 0$ using POWHEG+PYTHIA
    - Ξ_c^0 not measured yet → $\sigma_{pp}(\Xi_c^0) \times 208 \times R_{pPb}(\Lambda_c^+)$

- Charm FF compatible in pp and p-Pb collisions, but differ significantly from those in e^+e^- and e^-p collisions
  - Charm FF are not universal

[1] B factories: EPJC 76 (2016) 397
[2] LEP: EPJC 75 (2015) 19
[3] HERA: EPJC 76 (2016) 397

$c\bar{c}$ production cross section in small collision systems

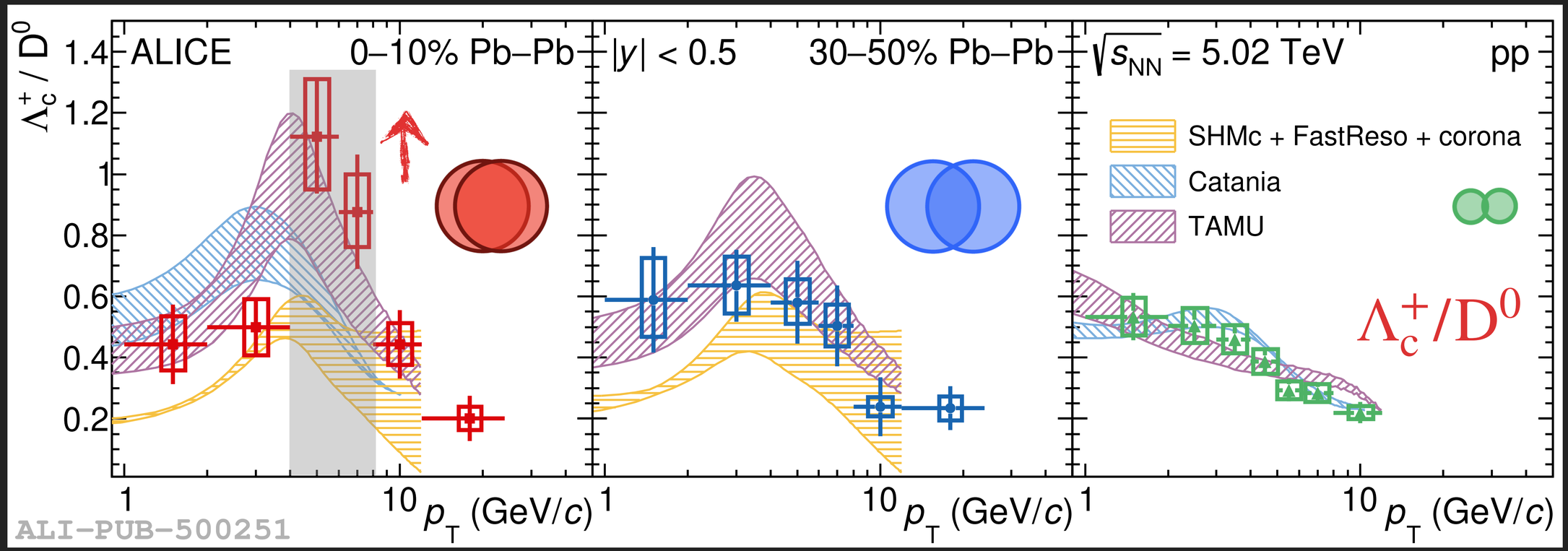
ALICE: PRD 105 (2022) L011103



- $c\bar{c}$ production cross section measured by summing all charm ground states
  - Updated results in pp@2.76 and 7 TeV based on new FF in pp@5.02 TeV, all points on upper edge of pQCD calculations

[1] STAR: PRD 86 (2012) 072013
[2] PHENIX: PRC 84 (2011) 044905
[3] FONLL: JHEP 10 (2012) 137
[4] Charm NNLO: PRL 118 (2017) 122001

Λ_c^+ production in Pb–Pb collisions

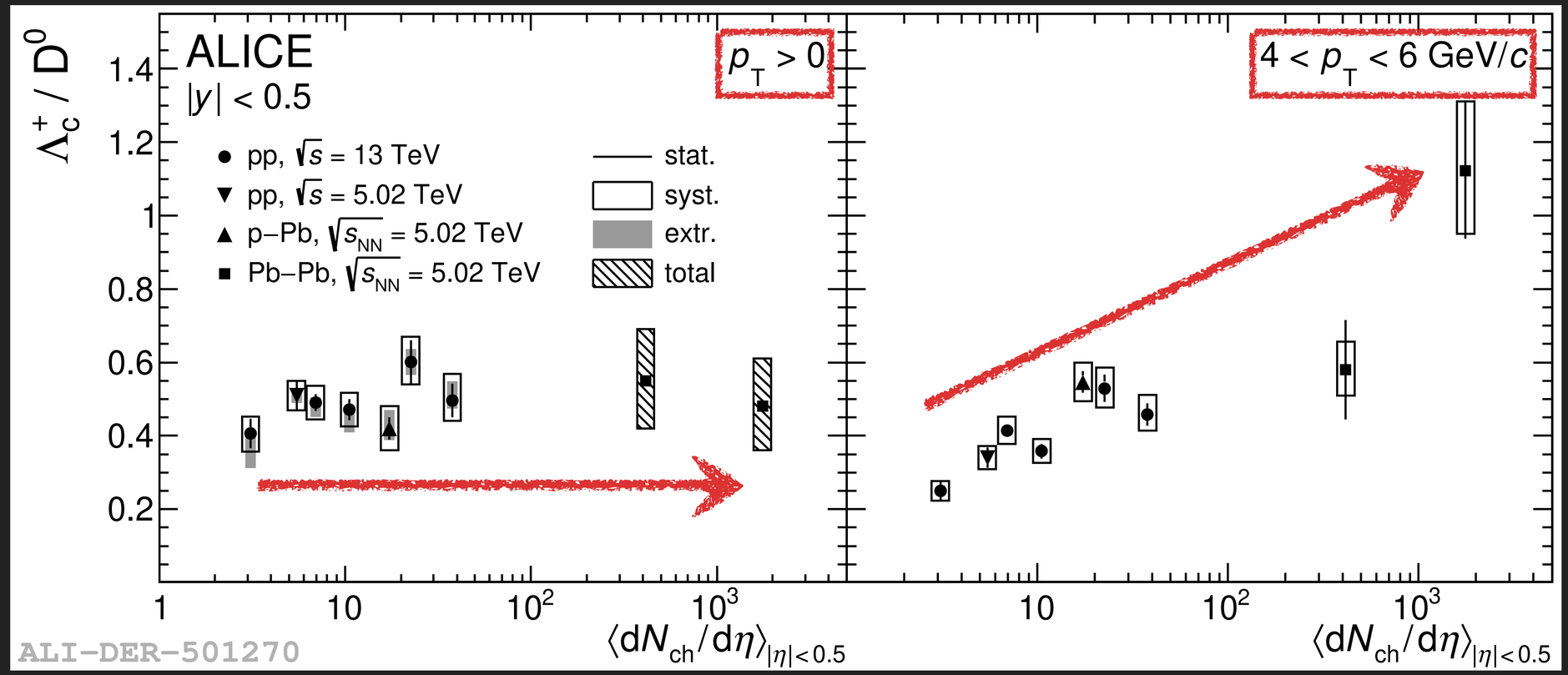


arXiv:2112.08156

- Λ_c^+/D^0: enhanced in $4 < p_T < 8$ GeV/c for central Pb-Pb w.r.t. pp by 3.7σ
  - Also seen for light-flavor baryon-to-meson ratios
  - Described by TAMU (coalescence with a Resonance Recombination Model)
  - The shapes of the Catania (coalescence with Wigner formalism) and SHMc predictions agree qualitatively

$\Xi_c^{0,+}/D^0$ and Ω_c^0/D^0 vs. p_T in Pb-Pb with Run 3 data to further constrain hadronization processes

Λ_c^+/D^0 vs. multiplicity for integrated and intermediate p_T

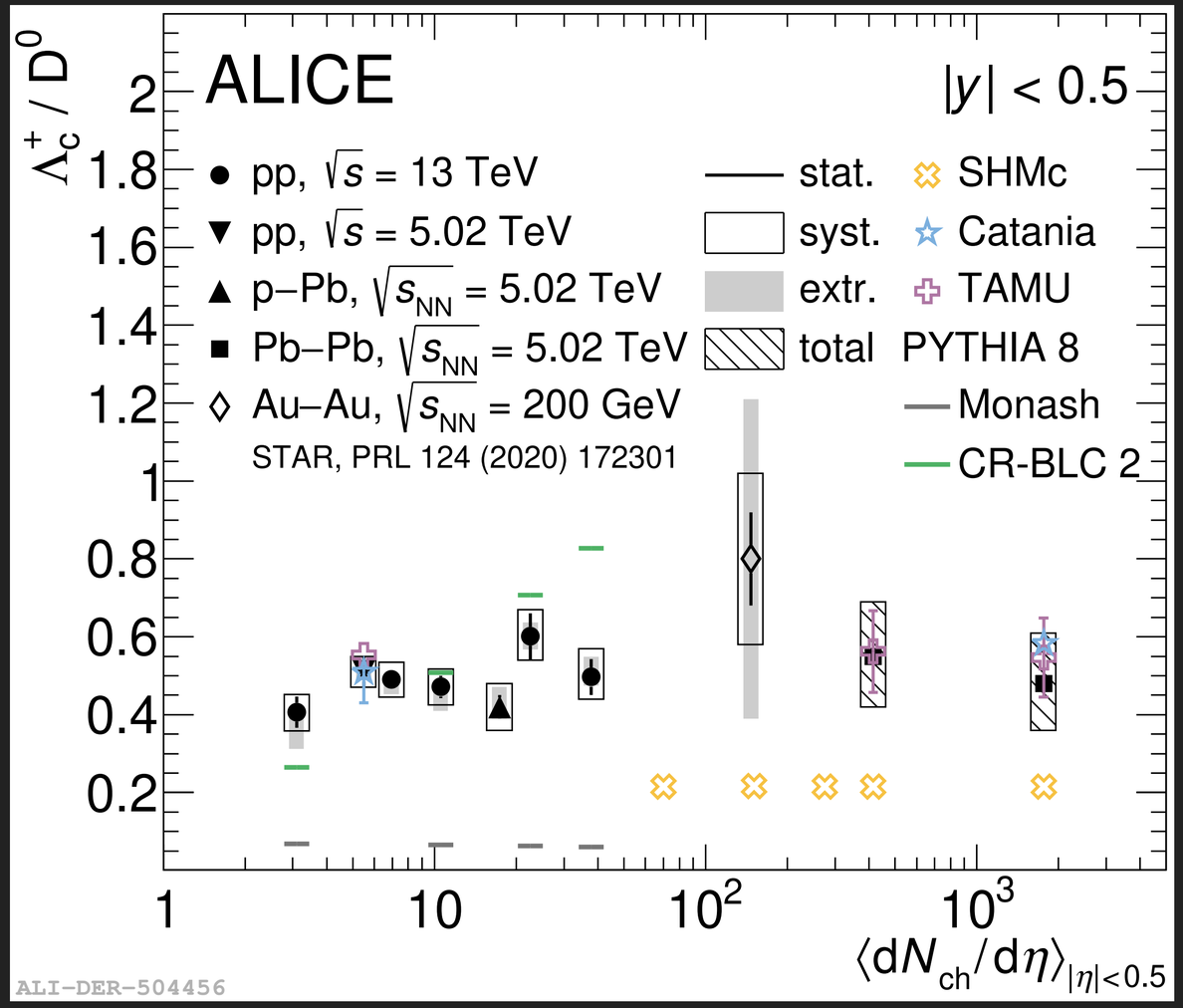


PRC 104 (2021) 054905
arXiv:2112.08156

- p_T-integrated Λ_c^+/D^0 ratio compatible with a flat behaviour versus event multiplicity, similar to Λ/K_s^0
- Re-distribution of p_T that acts differently for baryons and mesons, no modification of overall p_T-integrated yield
- ➡ Same mechanism in all collision systems? Modified hadronisation? Radial flow?

$\Xi_c^{0,+}/D^0$ and Ω_c^0/D^0 vs. multiplicity for integrated and intermediate p_T with Run 3 data to further constrain hadronisation processes

p_{T}-integrated $\Lambda_{\mathrm{c}}^{+}/\mathrm{D}^{0}$ vs. multiplicity comparing with models



PLB 829 (2022) 137065

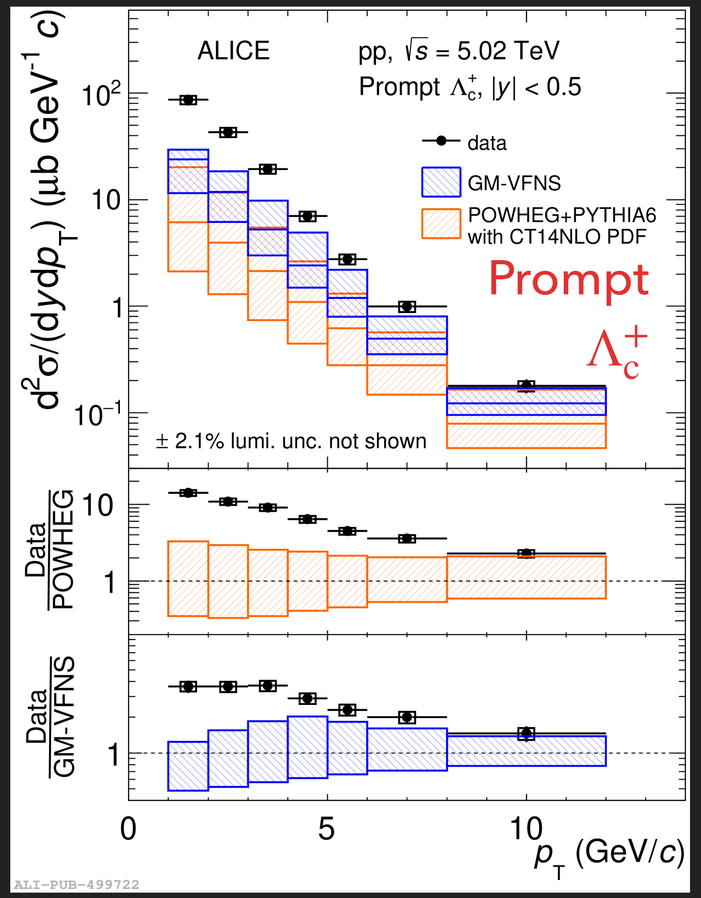
- Flat trend reproduced by models implementing fragmentation+coalescence and SHM predictions
- PYTHIA 8 CR-BLC 2 predicts enhancement with multiplicity

Summary

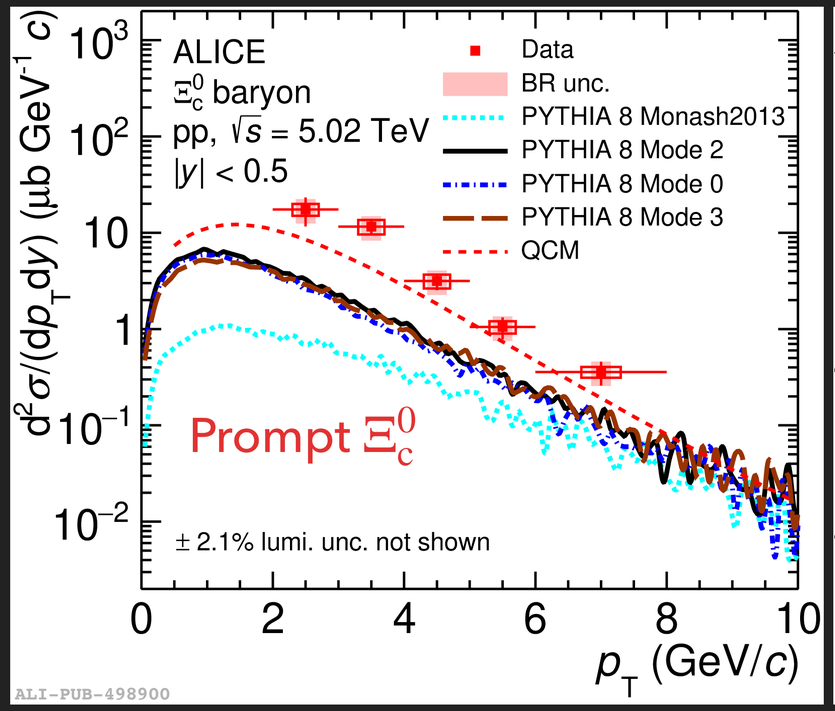
- Charm **baryon** production indicates that assumption of universal parton-to-hadron fragmentation fractions not valid at LHC energies
- Charm hadronisation mechanisms need further investigations
  - Coalescence in pp ?
- No modification of overall p_{T}-integrated yield in all collision systems
  - Same mechanism in all collision systems? Modified hadronization? Radial flow?
- We are looking forward to **Run 3** data

BACKUP

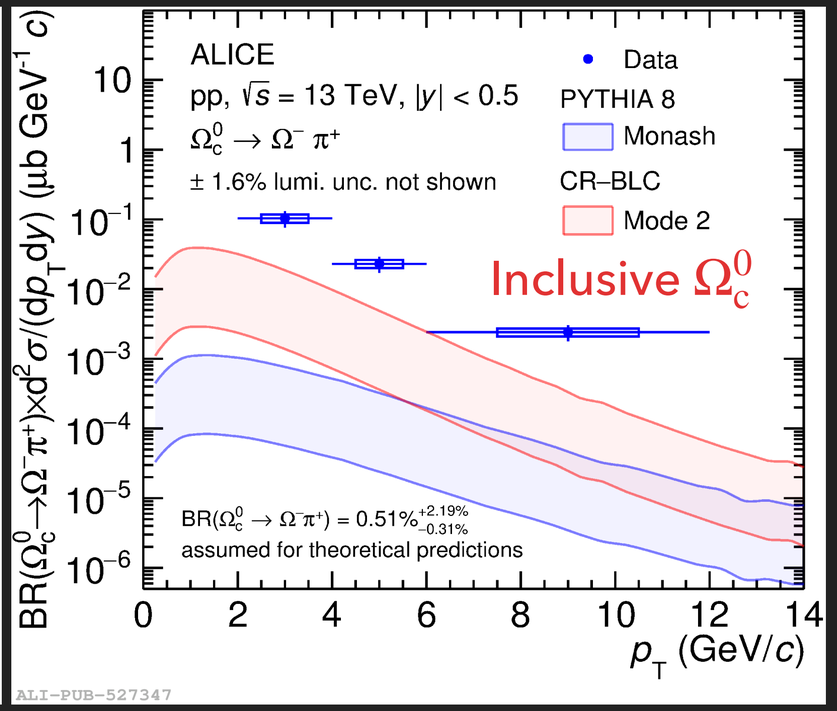
Charm baryon production in pp collisions at the LHC



ALICE: PRC 104 (2021) 054905



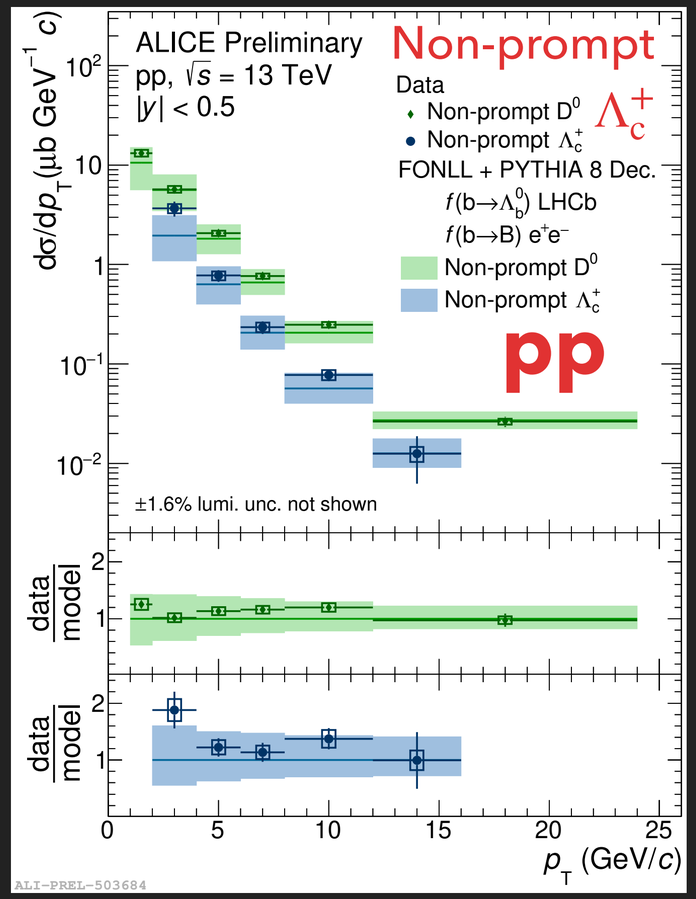
ALICE: JHEP 10 (2021) 159

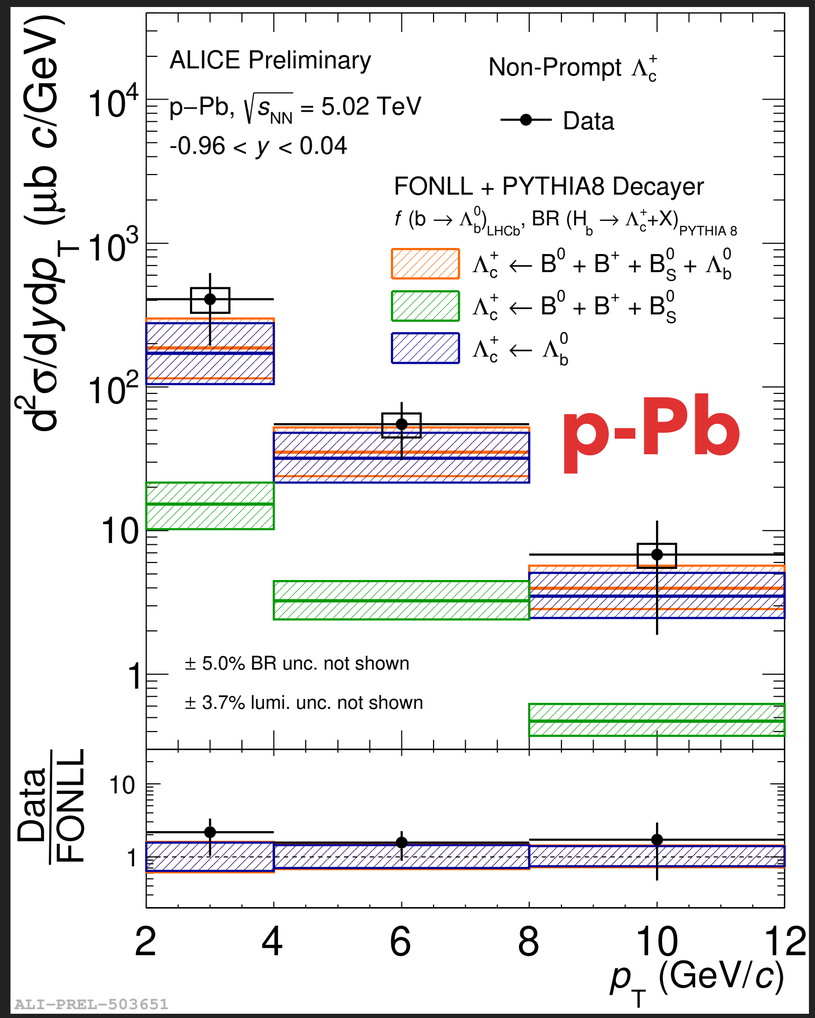


ALICE: arXiv:2205.13993

- pQCD calculations underestimate prompt Λ_c^+, especially at low p_T
- Models largely underestimate Ξ_c^0 and Ω_c^0

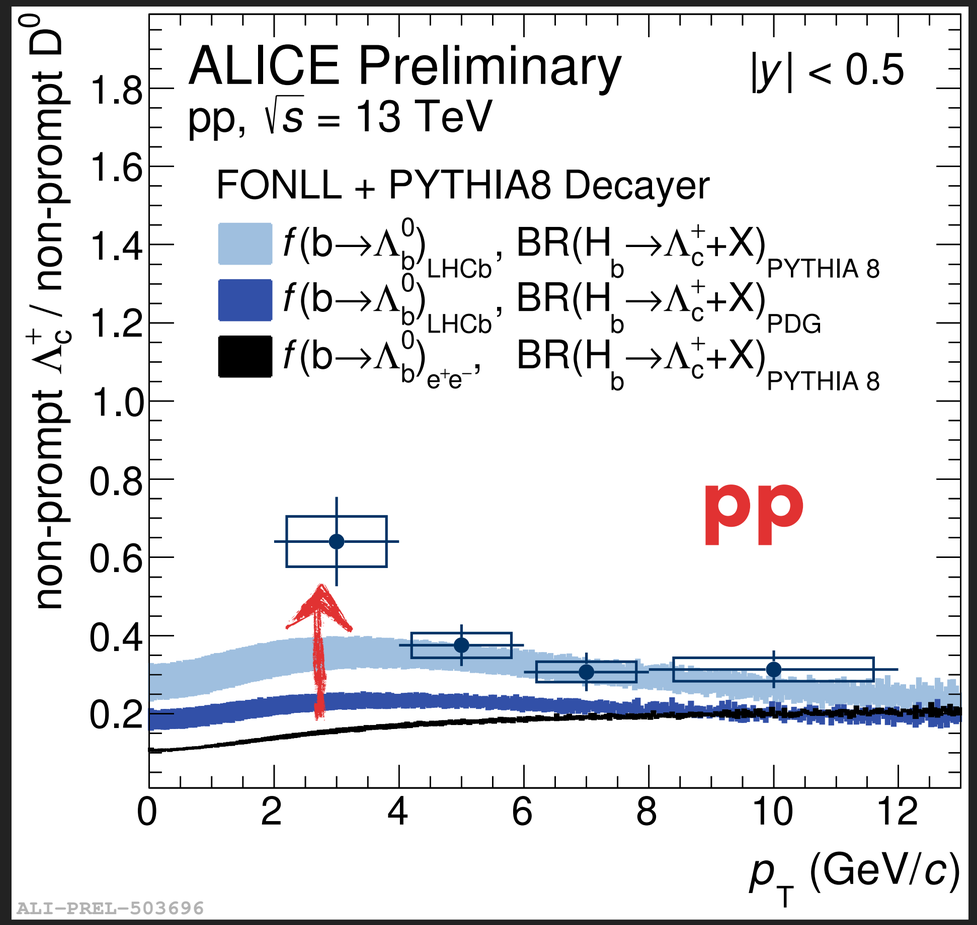
Non-prompt Λ_c^+ production in pp and p–Pb collisions (I)

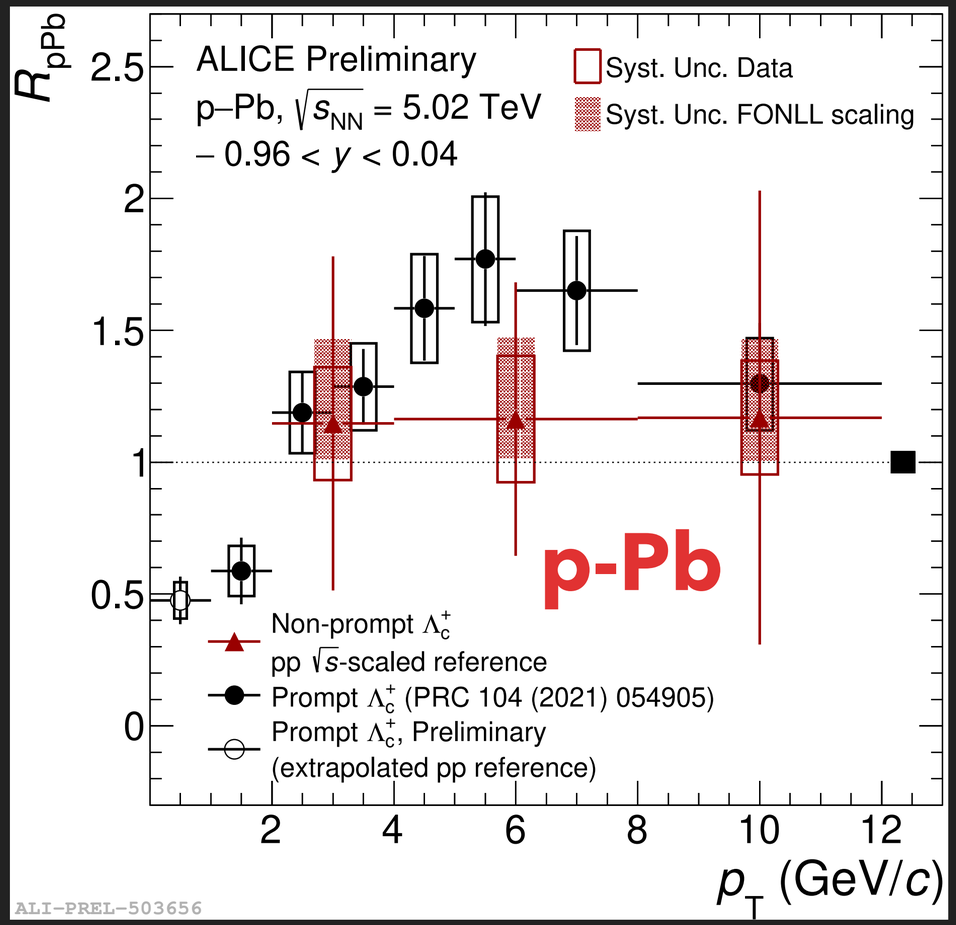




- Non-prompt Λ_c^+ p_T dependence well reproduced by theoretical calculations
  - Λ_b^0 FF measured by LHCb
  - Folding with $H_b \to \Lambda_c^+ + X$ decay from PYTHIA 8
- Non-prompt Λ_c^+
  - p_T dependence well reproduced by theoretical calculations, same as pp

Non-prompt Λ_c^+ production in pp and p–Pb collisions (II)





- Dominant contribution to non-prompt Λ_c^+ from Λ_b^0 decays
- Enhanced beauty-baryon production w.r.t. e^+e^- collisions ➡ suggests non-universality for beauty FF
  - Well reproduced by FONLL (LHCb FF) + PYTHIA 8 for $p_T > 4$ GeV/c