ALICE result QM preview

ALICE: total 30 parallel talks & 61 posters

MinJung Kweon
Inha University

Heavy Ion Meeting, 2023.8.25

Heavy flavour related talks/posters in ALICE for QM

Talks

Investigating the early magnetic field of QGP via heavy-flavour polarisation studies with ALICE	Luca Micheletti	**w/ DQ**
Probe parton propagation in heavy-ion collisions with ALICE heavy-flavour measurements	Ravindra Singh	
Latest ALICE results on charm and beauty hadronization mechanisms in hadronic collisions	Jianhui Zhu	
Heavy-flavor jet substructure for probing the flavour dependences of QCD parton showers with ALICE	Nima Zardoshti	**w/ JE**
First energy-energy correlators measurements for inclusive and heavy-flavour tagged jets	Wenqing Fan	**w/ JE**

Posters

Measurement of \ Ξ0c \ production as a function of multiplicity via hadron decay in pp collisions at s√ = 13 TeV with ALICE	Tao Fang
Azimuthal Correlations of Heavy-Flavor Decay Electrons and Charged Hadrons with the ALICE Detector	Amanda Flores
The measurement of Λ+c/D0 as a function of multiplicity at 5.02 TeV in pp and p-Pb collisions in ALICE experiment	Oveis Sheibani
Measurement of non-prompt D-mesons production in pp collisions at √s = 13 TeV using ML technique with ALICE	Renu Bala
Measurement of Xic0 via semileptonic decay in collisions of pp at 13 TeV and p-Pb at 5.02 TeV with ALICE	Chong Kim
Multiplicity dependency of Ξ+c production in pp collisions at s√ = 13 TeV with ALICE	Jaeyoon Cho
Ω0c production in pp collisions at s√ = 13 TeV with ALICE	Tiantian Cheng

Today, focus on the topic related to the heavy-flavour hadronization based on three most recent preprints

Charm production and fragmentation fractions in pp at $\sqrt{s}$ = 13 TeV [arXiv:2308.04877]

Study of flavor dependence of the baryon-to-meson ratio in pp at $\sqrt{s}$ = 13 TeV [arXiv:2308.04873]

Non-prompt D_s-meson Elliptic Flow in Pb–Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [arXiv:2307.14084]

Heavy flavour production in medium: what we see

$$\frac{\mathrm{d}N^{D}_{PbPb}}{\mathrm{d}p_T} = PDF(x_1)PDF(x_2) \otimes \frac{\mathrm{d}\hat{\sigma}^{c}}{\mathrm{d}p_T} \otimes P(\Delta E) \otimes D_{c\rightarrow D}(z)$$

Initial-state effects

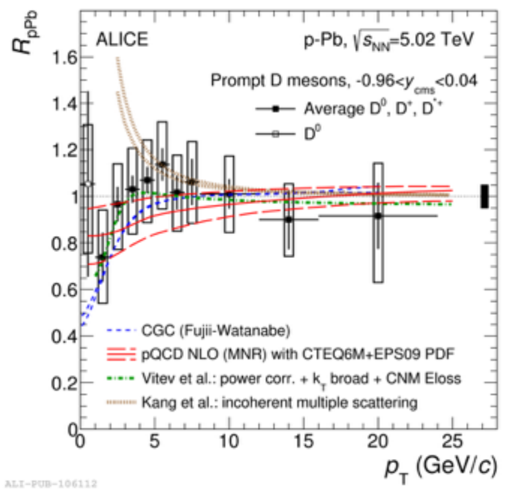
"Vacuum" parton spectra

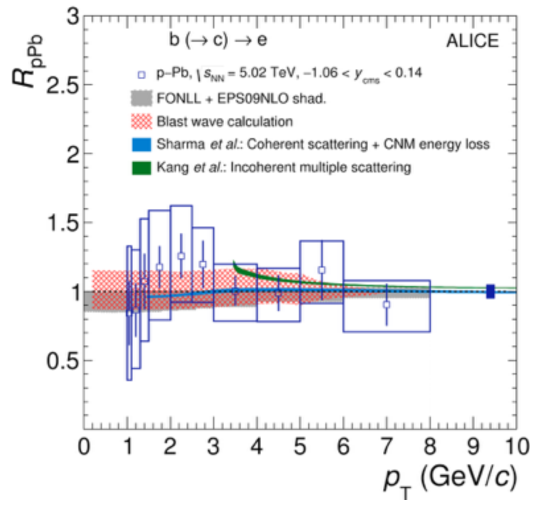
Parton interaction with the medium

(Modified?) hadronization

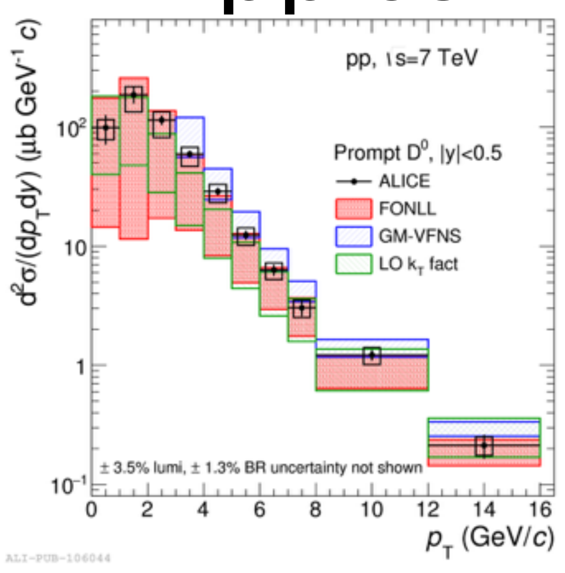
What we want to probe

Constrain models with measurements from p-Pb collisions





pp collisions



- Dynamics in QGP
  - energy loss via radiative ("gluon Bremsstrahlung") and collisional processes
    - color charge (Casimir factor)
    - quark mass (dead-cone effect)
    - path length and medium density

Heavy flavour production in medium: hadronization

$$\frac{dN^{D}_{PbPb}}{dp_T} = PDF(x_1)PDF(x_2) \otimes \frac{d\hat{\sigma}^c}{dp_T} \otimes P(\Delta E) \otimes D_{c\rightarrow D}(z)$$

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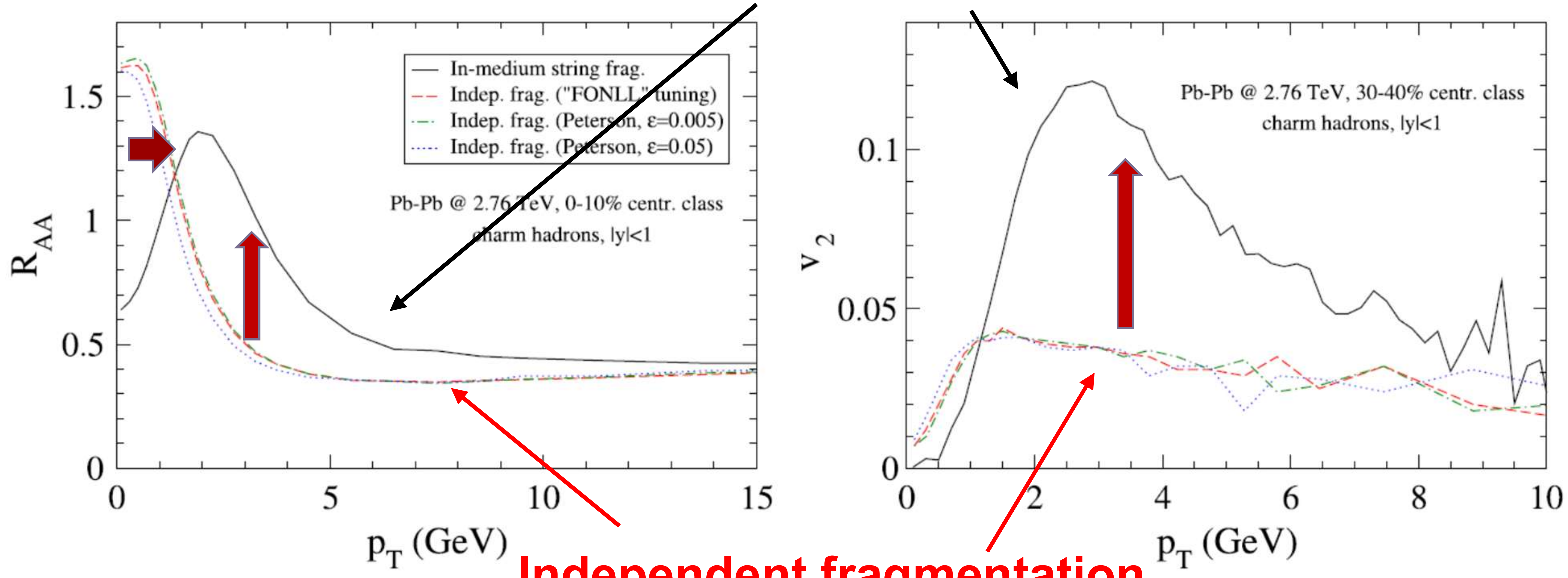
What we want to probe

In-medium hadronization



Independent fragmentation

Van Hees et al., PRC73 (2006) 034907

Rapp et al., NPA 979 (2018) 21

Heavy flavour production in medium: hadronization

Parton interaction with the medium

(Modified?) hadronization

$$\frac{\mathrm{d}N^{D}_{PbPb}}{\mathrm{d}p_T} = PDF(x_1)PDF(x_2) \otimes \frac{\mathrm{d}\hat{\sigma}^{c}}{\mathrm{d}p_T} \otimes P(\Delta E) \otimes D_{c\to D}(z)$$

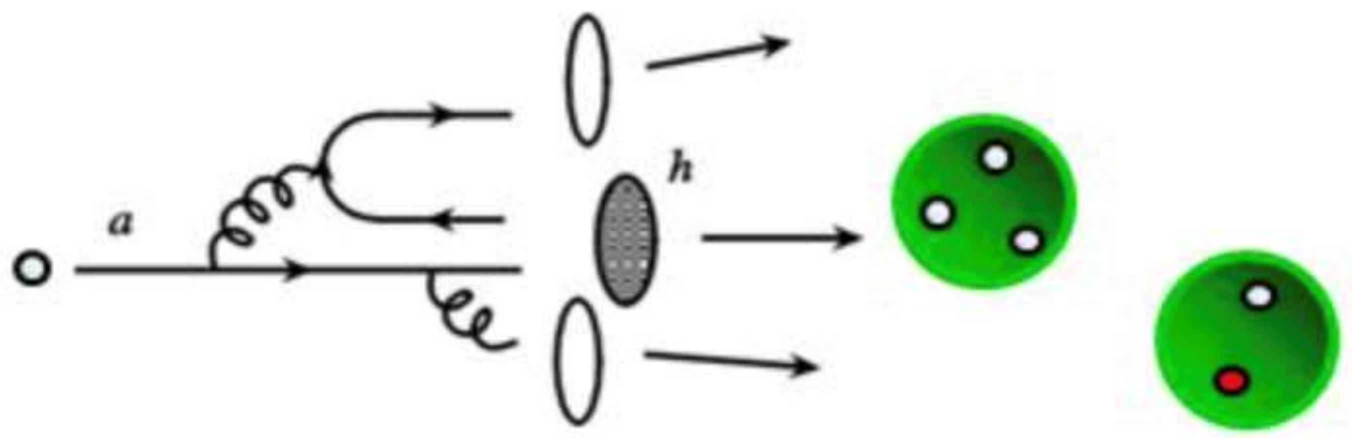
Initial-state effects

"Vacuum" parton spectra

What we want to probe

- Fragmentation functions D(z) are phenomenological functions to parameterize the non-perturbative parton-to-hadron transition
  - → z = fraction of the parton momentum taken by the hadron h
  - → Do not specify the hadronisation mechanism

- Parametrized on data and assumed to be "universal"



Question on the universality

Fragmentation Issues

Fragmentation Function (FF):
provides information about the energy fraction which is transfered from quark to a given meson (the larger m_Q the harder the fragmentation function)

Questions to be answered:

▷ what's the **proper parametrization** of non-perturbative frag. function?

- Peterson: $f(z) \propto 1/[z(1-\frac{1}{z}-\frac{\varepsilon}{(1-z)})^2]$
- Kartvelishvili: $f(z) \propto z^\alpha(1-z)$
- Lund symmetric: $f(z) \propto \frac{1}{z}(1-z)^a \exp(-\frac{bm_t^2}{z})$
- Bowler: $f(z) \propto \frac{1}{z^{1+r_b m_t^2}}(1-z)^a \exp(-\frac{bm_t^2}{z})$

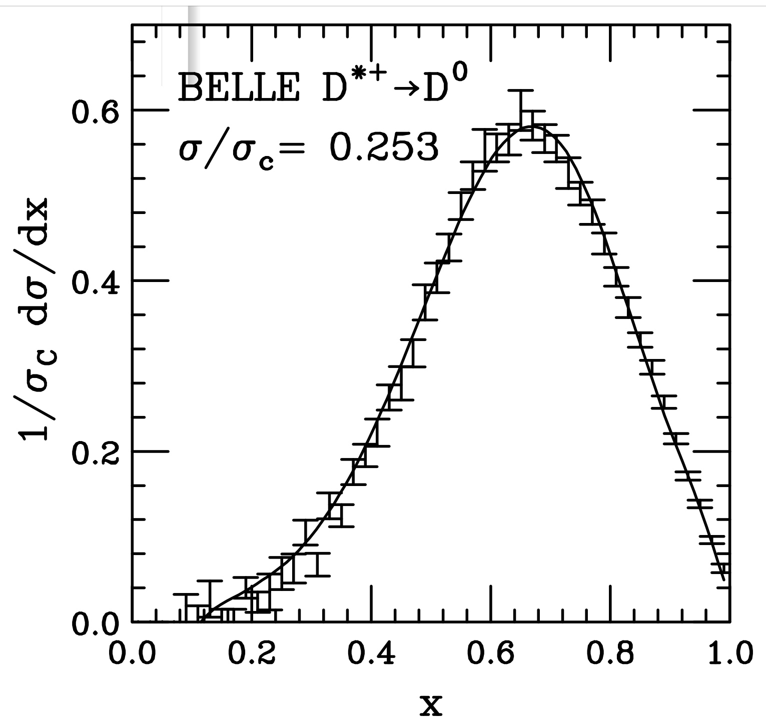
▷ is fragmentation function **universal**?
(i.e. are FF portable from e^+e^- to ep and pp?)

Zuzana Rúriková Charm Fragmentation Function June 7, 2006

▷ different observable definitions

▷ different center of mass energies, thus different pert. components as well

$\Longrightarrow$ **Direct shape comparison impossible!**



Fit to BELLE data
(Cacciari, Nason, Oleari)

▷ **Fitted parametrization:** $f(x) \propto \delta(1-x) + \frac{c}{N_{a,b}}(1-x)^a x^b$

▷ **ALEPH:** a= 2.4±1.2, b=13.9±5.7, c=5.9±1.7

▷ **CLEO/BELLE:** a= 1.8±0.2, b=11.3±0.6, c=2.46±0.07

Fits not in agreement! Does universality of $\mathrm{FF}_{\mathrm{np}}$ not hold?

Zuzana Rúriková Charm Fragmentation Function – June 7, 2006

Heavy flavour production in medium: hadronization

Parton interaction with the medium

(Modified?) hadronization

$$\frac{dN^{D}_{PbPb}}{dp_T} = PDF(x_1)PDF(x_2) \otimes \frac{d\hat{\sigma}^{c}}{dp_T} \otimes P(\Delta E) \otimes D_{c\to D}(z)$$

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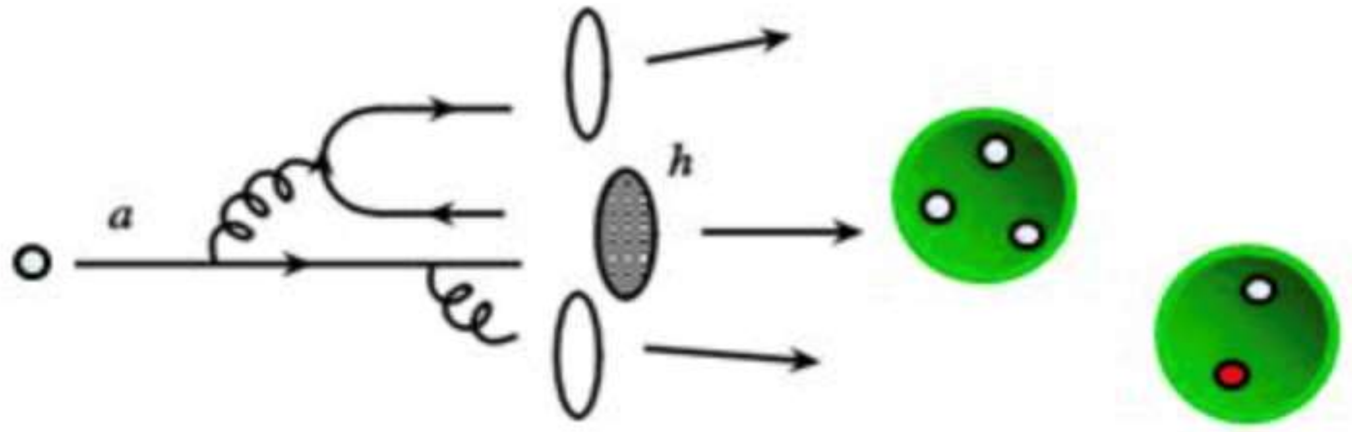
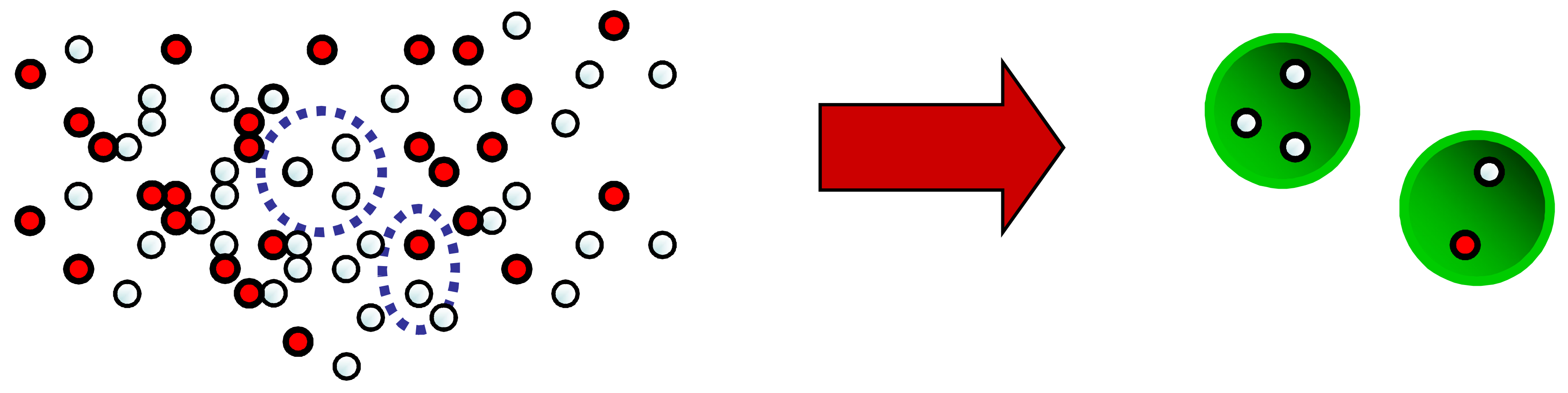


- In A-A collisions:
  - → Energy-loss of hard-scattered partons while traversing the QGP
  - → Modified fragmentation function D(z) by "rescaling" the variable z

Hadronization in medium

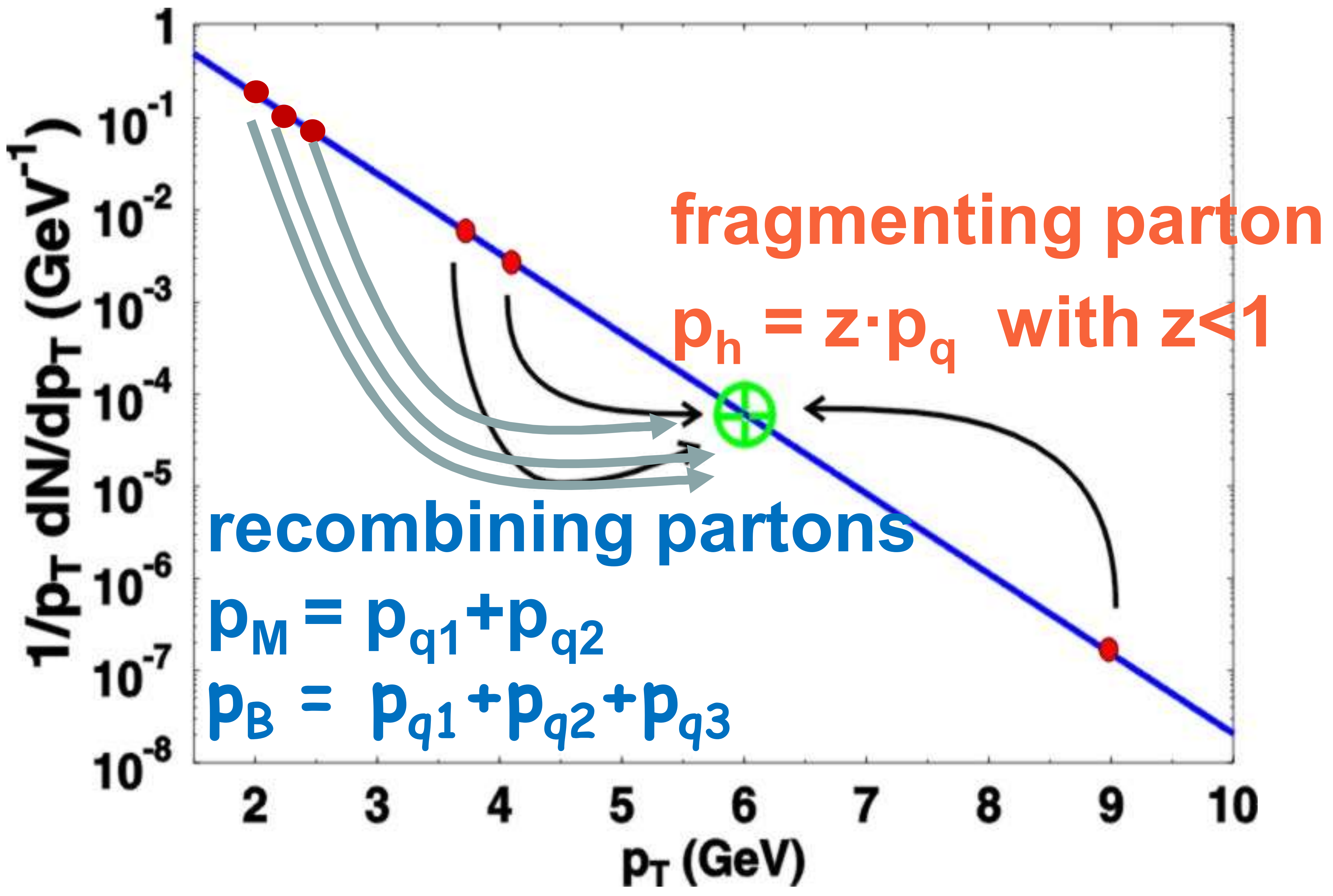
- Phase space at the hadronization is filled with partons
  - → Single parton description may not be valid anymore
  - → No need to create $q\bar{q}$ pairs via splitting / string breaking
  - → Partons that are “close” to each other in phase space (position and momentum) can simply recombine into hadrons



Greco et al., PRL 90 (2003) 202302

Fries et al., PRL 90 (2003) 202303

Hwa, Yang, PRC 67 (2003) 034902



- Recombination vs. fragmentation:
  - → Competing mechanisms
  - → Recombination naturally enhances baryon/meson ratios at intermediate p_T

Hadronization in vacuum

Parton interaction with the medium

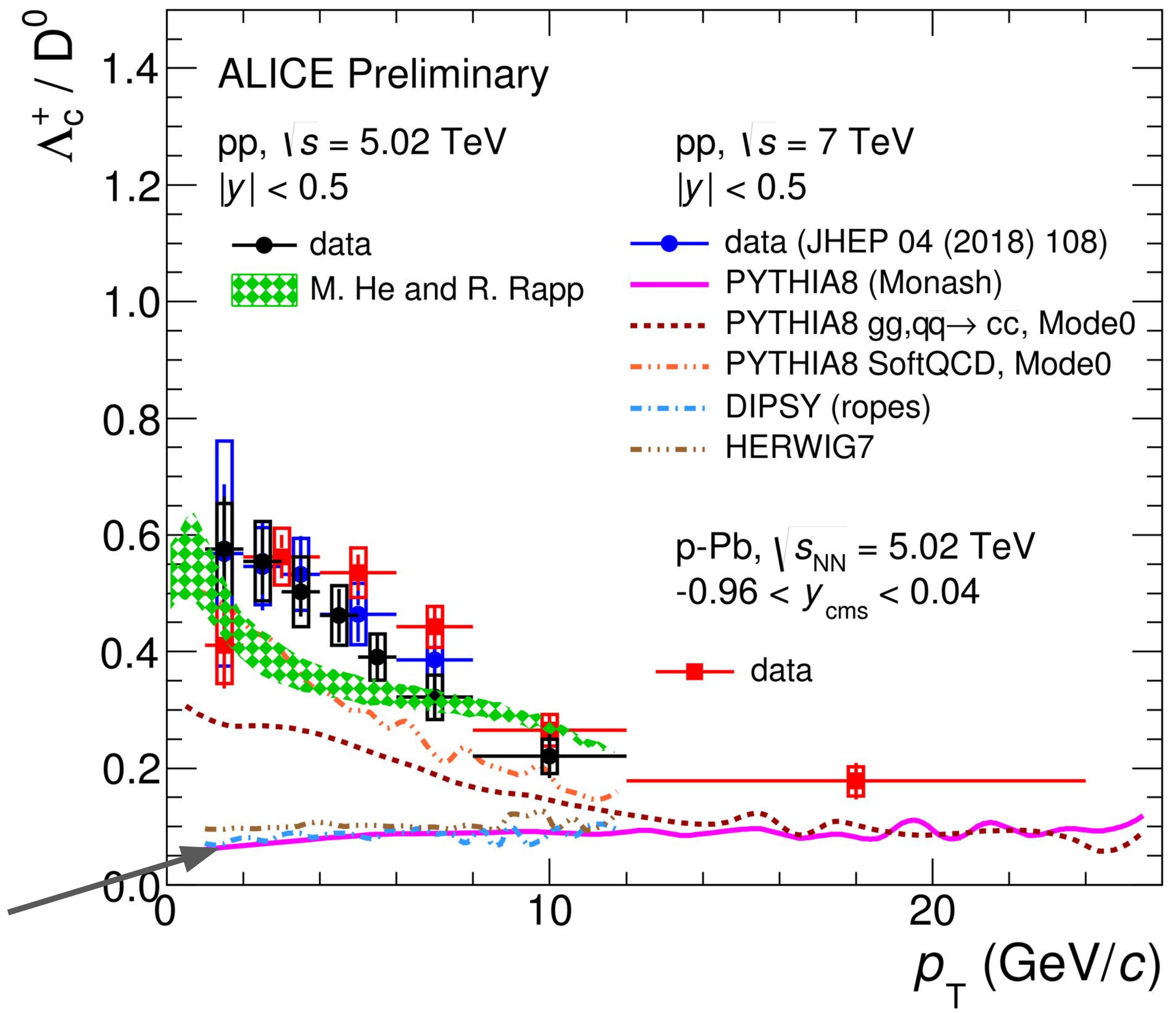
(Modified?) hadronization

$$\frac{\mathrm{d}N^D_{PbPb}}{\mathrm{d}p_T} = PDF(x_1)PDF(x_2) \otimes \frac{\mathrm{d}\hat{\sigma}^c}{\mathrm{d}p_T} \otimes P(\Delta E) \otimes D_{c\to D}(z)$$

Initial-state effects

"Vacuum" parton spectra

What we want to probe



e^+e^-

Not only in A-A, but also in pp?

Naïve expectation: ratios of particle-species yields independent from collision system

Unexpected findings in pp…

already since 2018…

Hadronization in vacuum

Parton interaction with the medium

(Modified?) hadronization

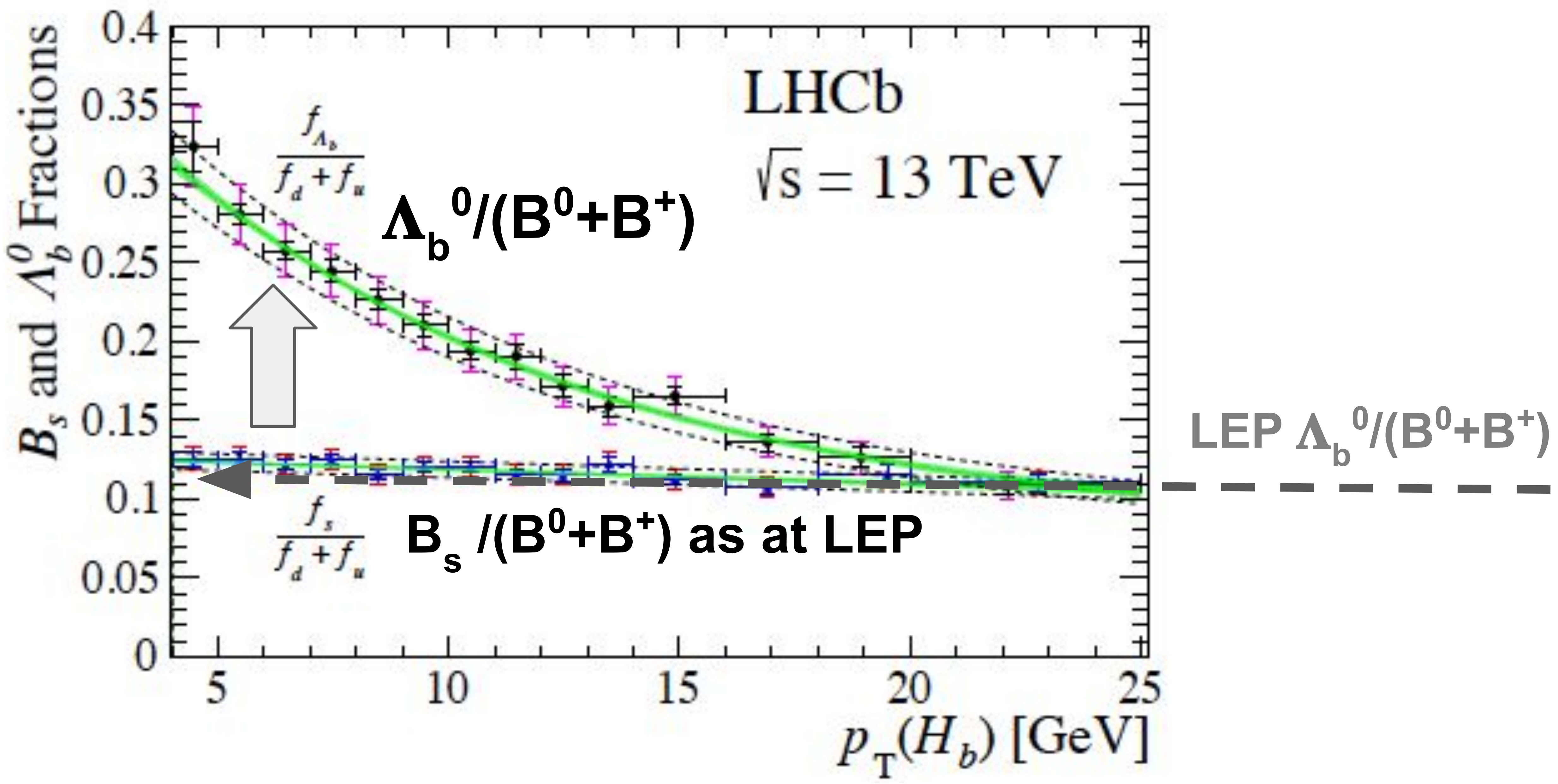
$$\frac{dN^{D}_{PbPb}}{dp_T} = PDF(x_1)PDF(x_2) \otimes \frac{d\hat{\sigma}^c}{dp_T} \otimes P(\Delta E) \otimes D_{c \to D}(z)$$

Initial-state effects

"Vacuum" parton spectra

What we want to probe

PRD100 (2019) no.3, 031102



Not only in A-A, but also in pp?

Naïve expectation: ratios of particle-species yields independent from collision system

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Similar trend in charm and beauty sectors

Hadronization in vacuum

Parton interaction with the medium

(Modified?) hadronization

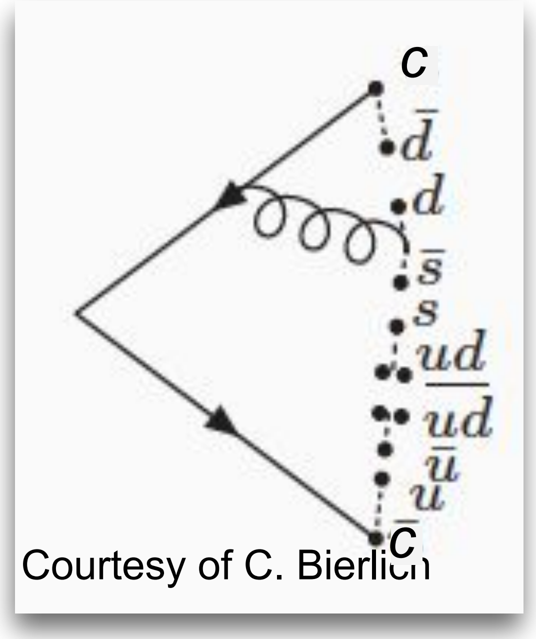
$$\frac{dN^{D}_{PbPb}}{dp_T} = PDF(x_1)PDF(x_2) \otimes \frac{d\hat{\sigma}^{c}}{dp_T} \otimes P(\Delta E) \otimes D_{c\to D}(z)$$

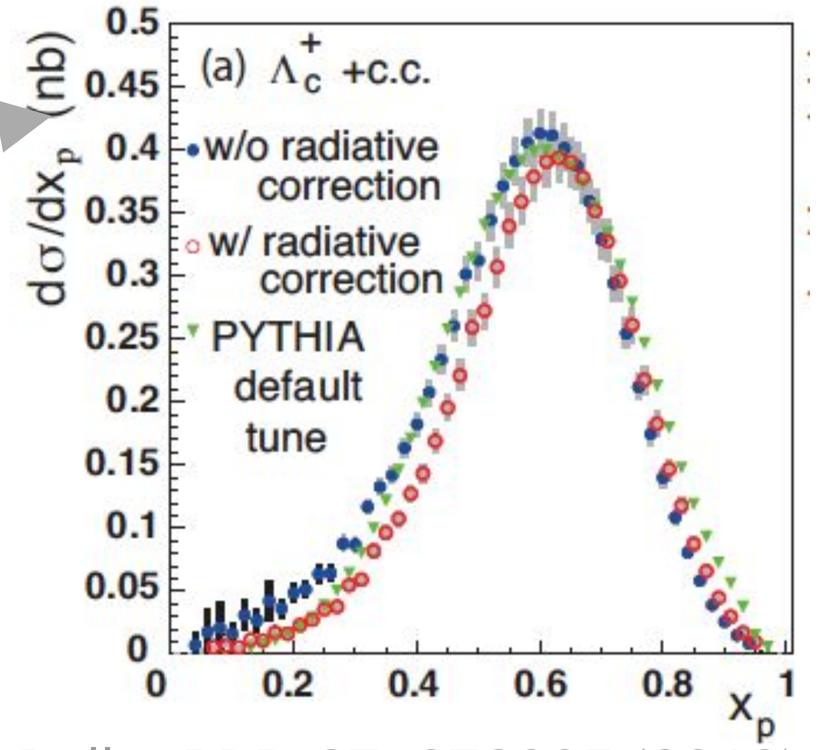
Initial-state effects

"Vacuum" parton spectra

What we want to probe

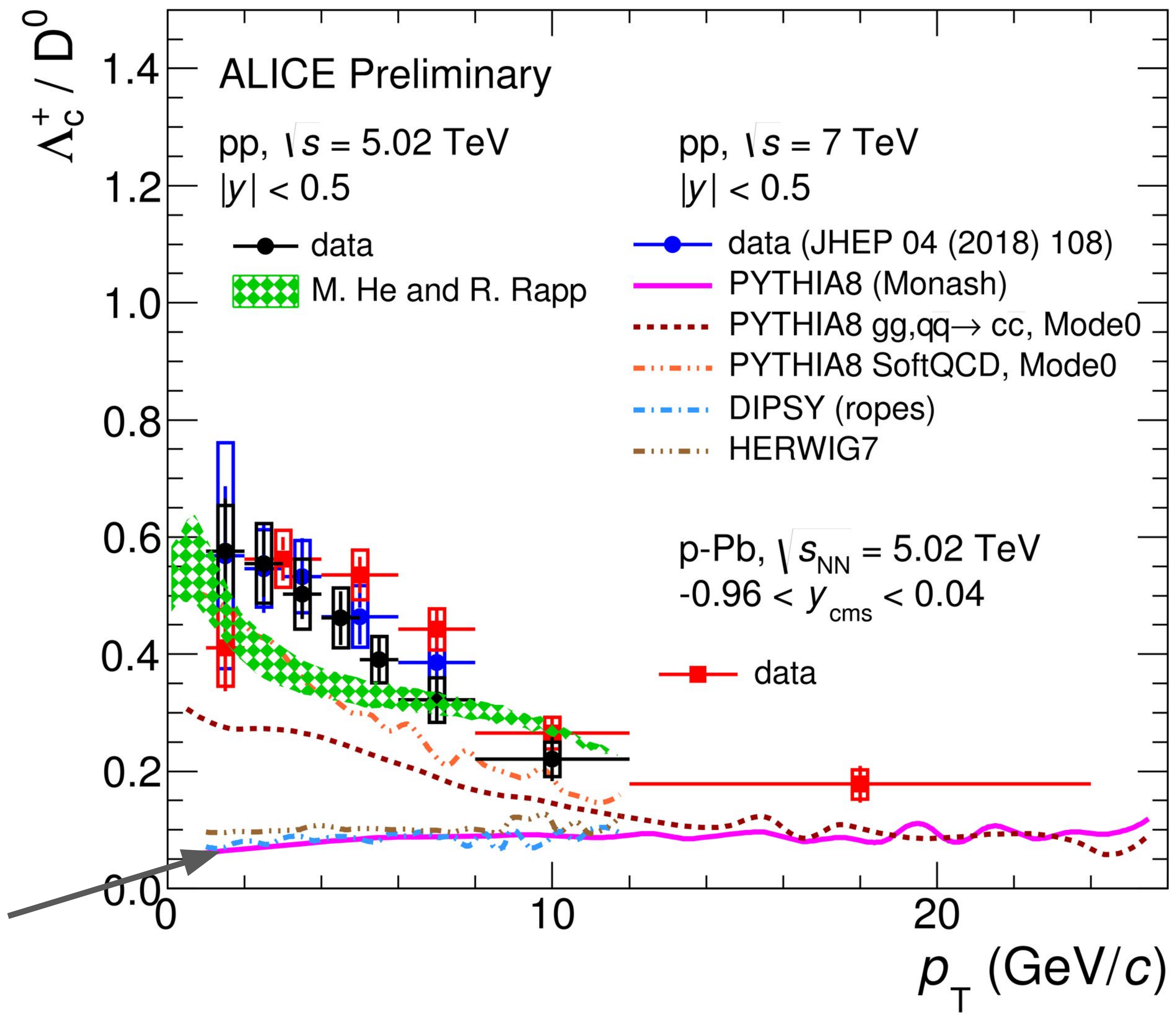
- Light quark/diquark pairs popping out from QCD color-confinement potential (← strings)
    - **Diquarks ↔ baryons**
- Hadronisation of different MPI products largely independent
- Reproduces e^+e^- data ~ fragmentation functions used in pQCD-based calculations





Belle, PRD 97, 072005 (2018)

e^+e^-



Way of heavy flavour hadronization, also in small systems?

- Fragmentation
  - → production from hard-scattering processes (PDF+pQCD)
  - → fragmentation functions: data parametrization, assumed universal

$$\sigma_{pp\to h} = PDF(x_a, Q^2)\, PDF(x_b, Q^2) \otimes \sigma_{ab\to q\bar{q}} \otimes D_{q\to h}(z, Q^2)$$

Parton shower: String fragmentation (Lund model - PYTHIA) + color reconnection (interaction from different scattering), Cluster decay (HERWIG)

Support need of abandoning independent hadronisation of different MPI
A hadronic environment matters

- Coalescence:
  - → recombination of partons in QGP close in phase space

$$\frac{dN_{Hadron}}{d^2 p_T} = g_H \int \prod_{i=1}^{n} p_i \cdot d\sigma_i \frac{d^3 p_i}{(2\pi)^3}\; f_q(x_i, p_i)\; f_W(x_1, \ldots, x_n; p_1, \ldots, p_n)\; \delta(p_T - \sum_i p_{iT})$$

Have described first AA observations in light sector for the enhanced baryon/meson ratio and elliptic flow splitting

- Statistical hadronization
  - → equilibrium + hadron-resonance gas + freeze-out temperature
  - → production depends on hadron masses and degeneracy, and on system properties

Require total charm cross section

ALICE will show…

Measuring all the way down to p_T, ….,
differentiating,
flavour dependences,
other characteristics to understand the behavior…

Charm production and fragmentation fractions in pp at $\sqrt{s}$ = 13 TeV [arXiv:2308.04877]

Study of flavor dependence of the baryon-to-meson ratio in pp at sqrt(s) = 13 TeV [arXiv:2308.04873]

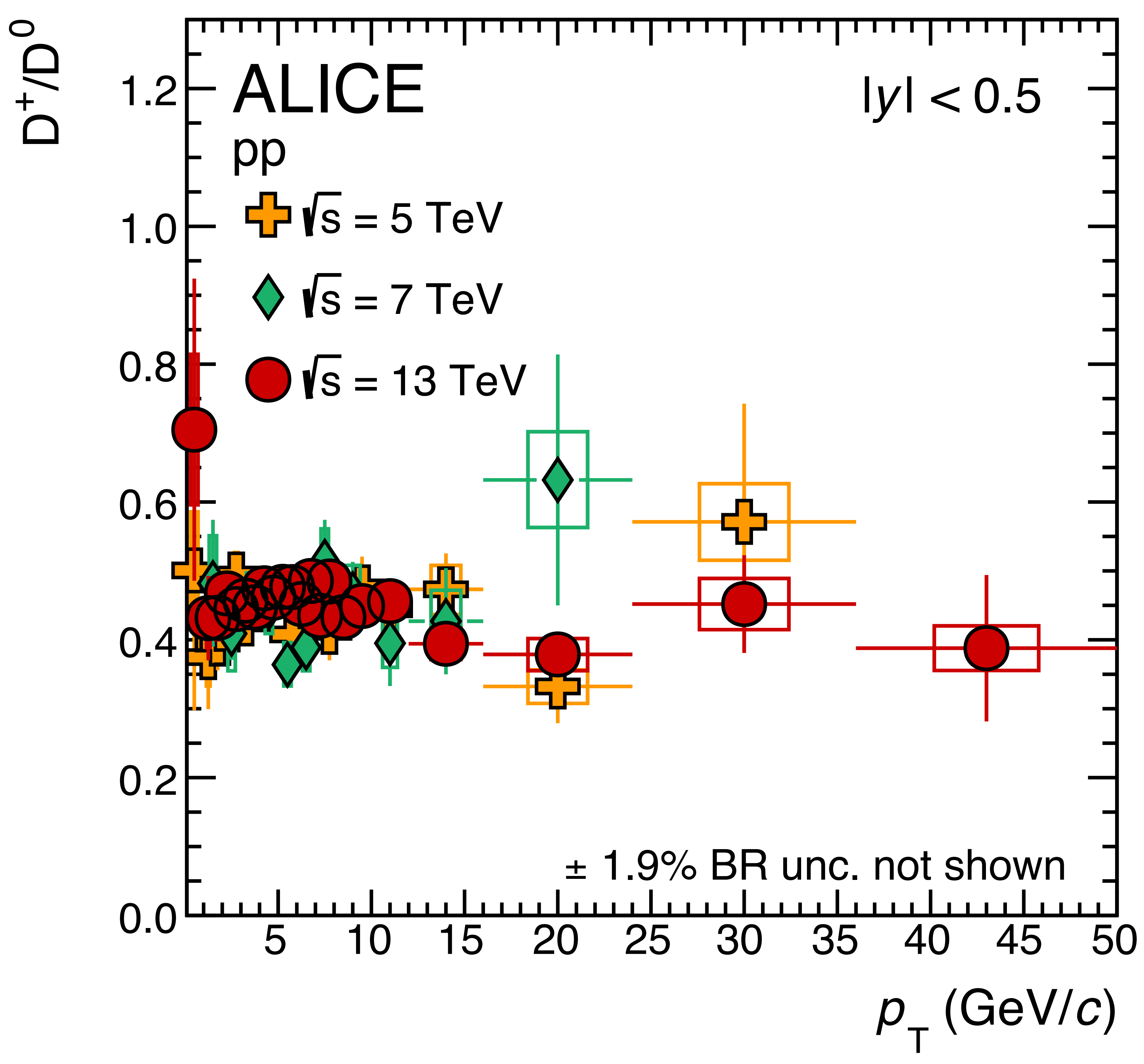
Non-prompt D_s-meson Elliptic Flow in Pb–Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [arXiv:2307.14084]

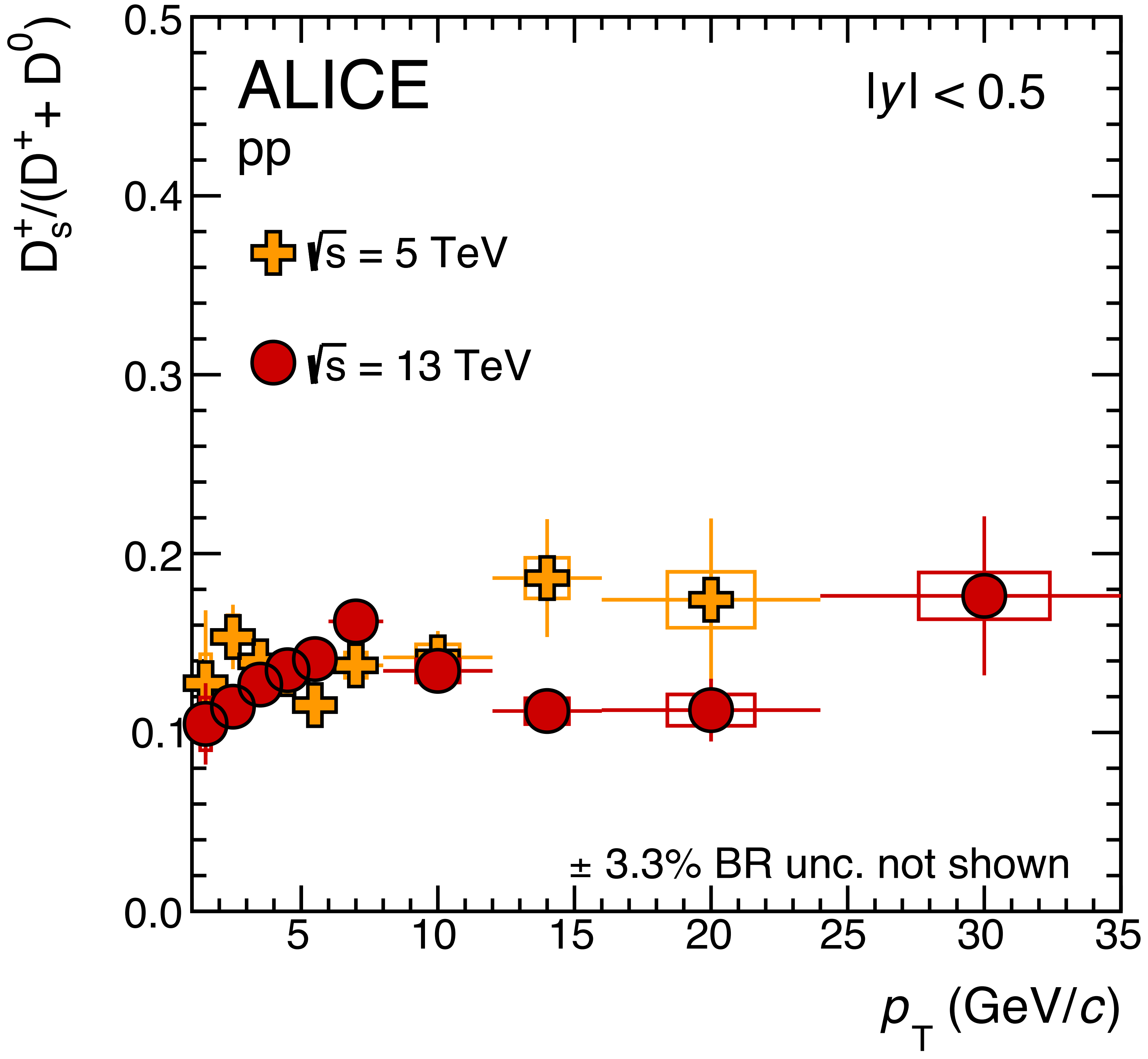
Charm production in pp

arXiv:2308.04877

Charm production and fragmentation fractions in pp at $\sqrt{s}$ = 13 TeV

Cross sections measurement of prompt D^0, D^+, D^{*+}, D_s^+, Λ_c^+, and Ξ_c^+ charm in pp at $\sqrt{s}$ = 13 TeV



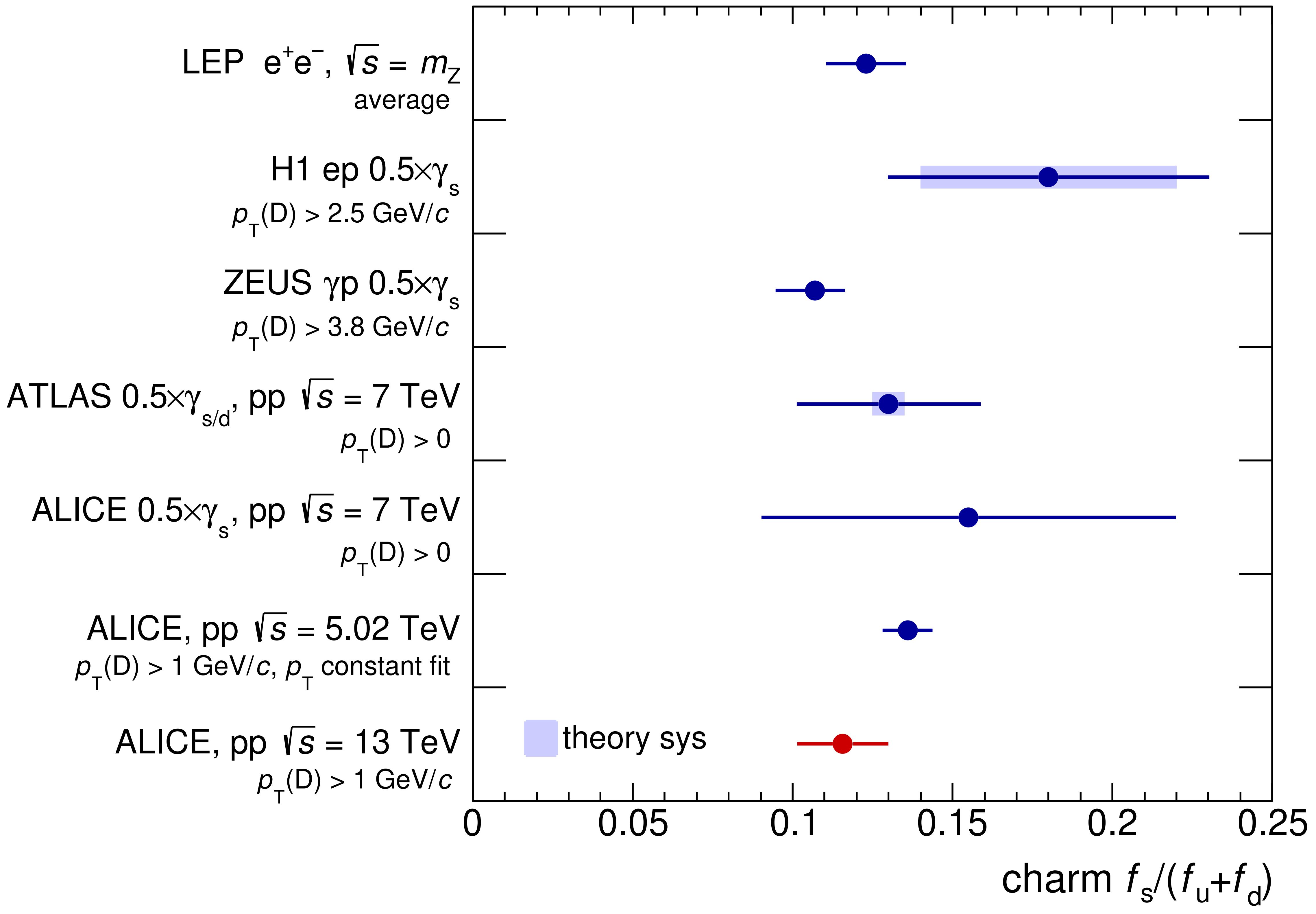


No significant dependence on the p_T

→common fragmentation functions of charm quarks to mesons at different LHC energies arXiv:2308.04877

Charm-quark fragmentation-fraction ratio

Strange to non-strange charm-meson production ratio



	$d\sigma/dy|_{|y|<0.5}$ (μb), $p_T > 0$
D^0	749 ± 27 (stat.) $^{+48}_{-50}$ (syst.) $\pm$ 12 (lumi.) $\pm$ 6 (BR)
D^+	375 ± 32 (stat.) $^{+35}_{-35}$ (syst.) $\pm$ 6 (lumi.) $\pm$ 6 (BR)
D_s^+	120 ± 11 (stat.) $^{+12}_{-13}$ (syst.) $^{+25}_{-10}$ (extrap.) $\pm$ 2 (lumi.) $\pm$ 3 (BR)
Λ_c^+	329 ± 15 (stat.) $^{+28}_{-29}$ (syst.) ± 5 (lumi.) ± 15 (BR)
Ξ_c^0 [52]	194 ± 27 (stat.) $^{+46}_{-46}$ (syst.) $^{+18}_{-12}$ (extrap.) $\pm$ 3 (lumi.)
Ξ_c^+	187 ± 25 (stat.) $^{+19}_{-19}$ (syst.) $^{+13}_{-59}$ (extrap.) $\pm$ 3 (lumi.) $\pm$ 82 (BR)
J/ψ [84]	7.29 ± 0.27 (stat.) $^{+0.52}_{-0.52}$ (syst.) $^{+0.04}_{-0.01}$ (extrap.)
D^{*+}	306 ± 26 (stat.) $^{+33}_{-34}$ (syst.) $^{+48}_{-17}$ (extrap.) $\pm$ 5 (lumi.) $\pm$ 3 (BR)
$\Sigma_c^{0,+,++}$	142 ± 22 (stat.) $^{+24}_{-24}$ (syst.) $^{+24}_{-32}$ (extrap.) $\pm$ 2 (lumi.) $\pm$ 6 (BR)

f_x: probability for a charm quark to hadronise with another quark of flavour x
⇨ D_s^+/D^0+D^+

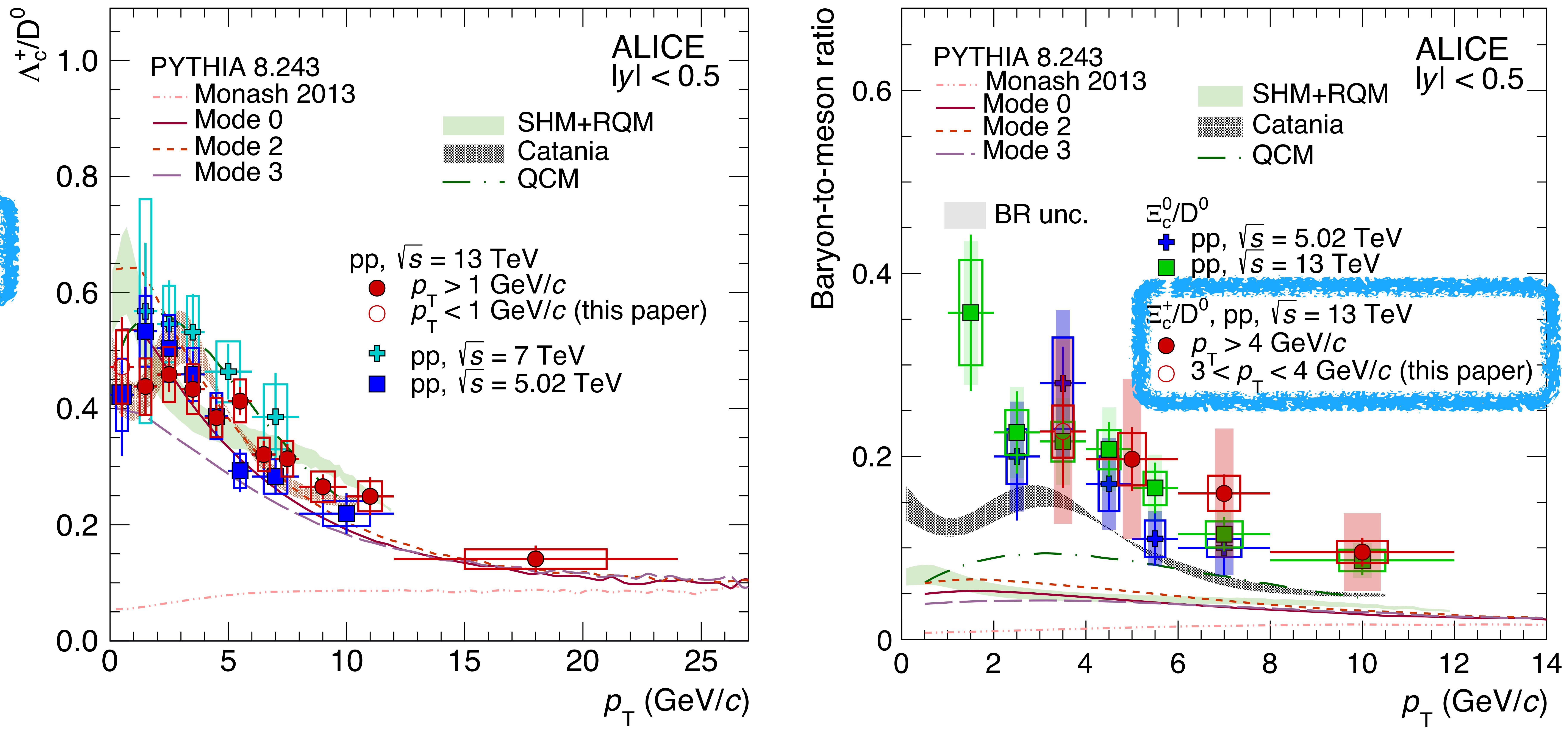
Production of prompt strange D mesons / prompt non-strange D mesons in e^+e^-, ep and pp collisions doesn't show any significant dependence of the collision system & energy!

Charm production in pp

arXiv:2308.04877

Cross sections measurement of prompt D^0, D^+, D^{*+}, D_s^+, Λ_c^+, and Ξ_c^+ charm in pp at $\sqrt{s}$ = 13 TeV

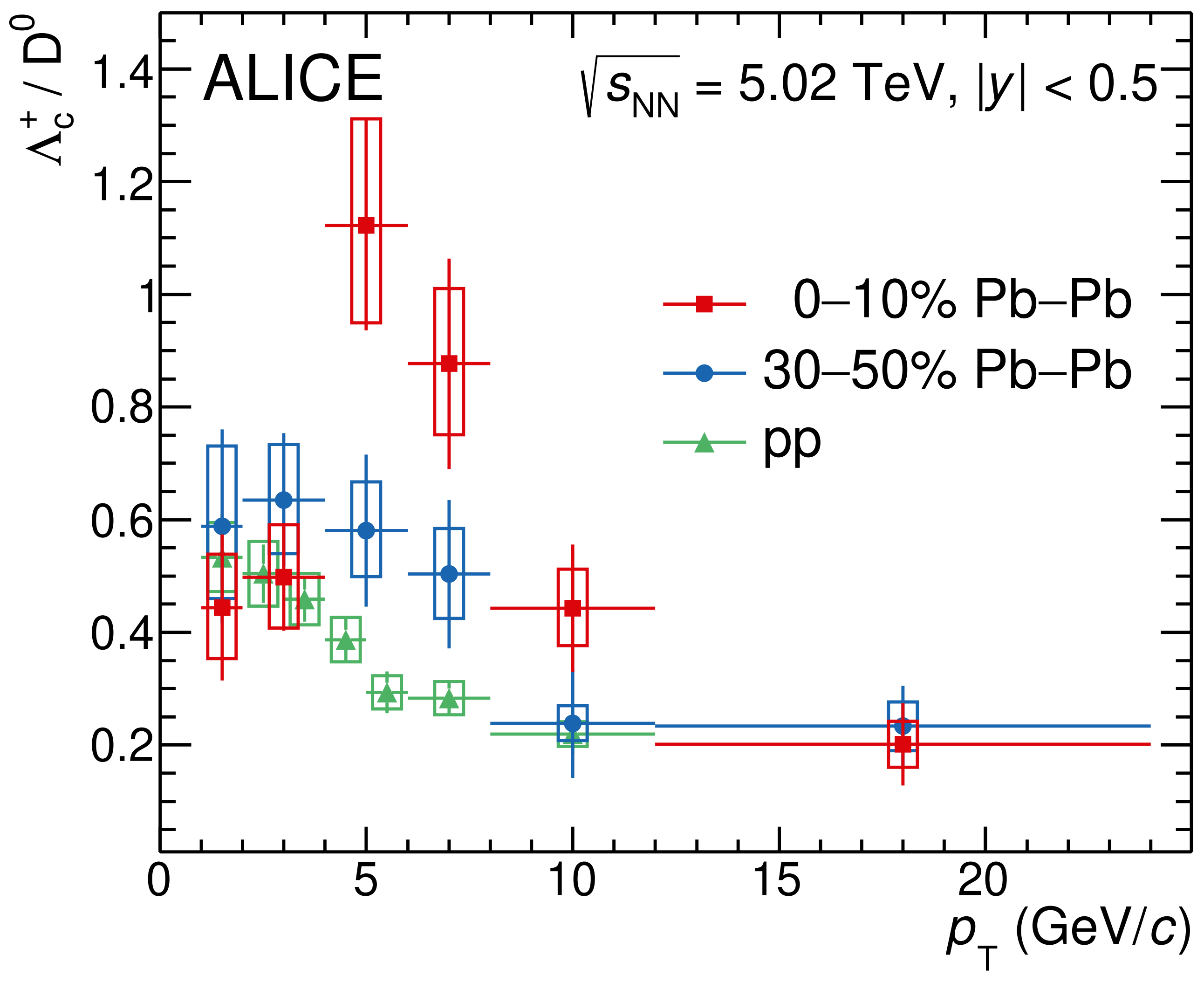
Down to p_T ~ 0

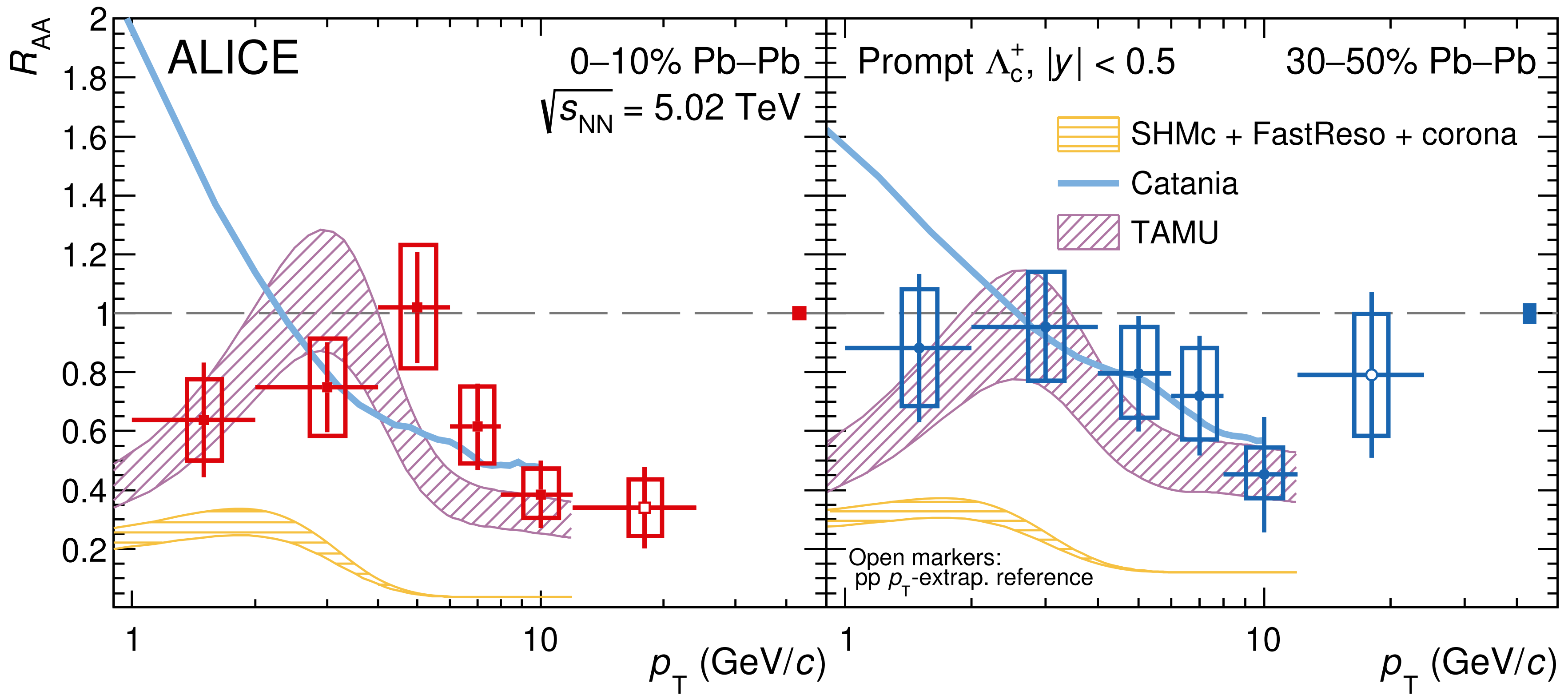


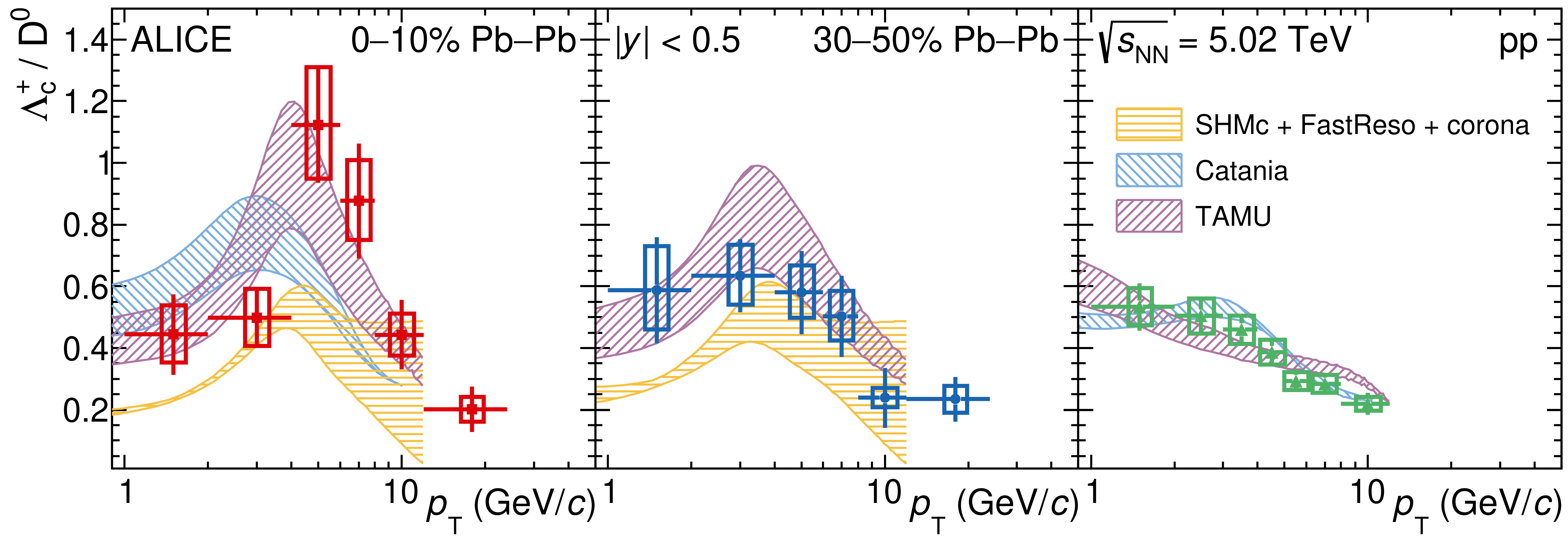
Significantly larger fraction of charm quarks hadronising to baryons is found compared to e^+e^-, ep collisions.

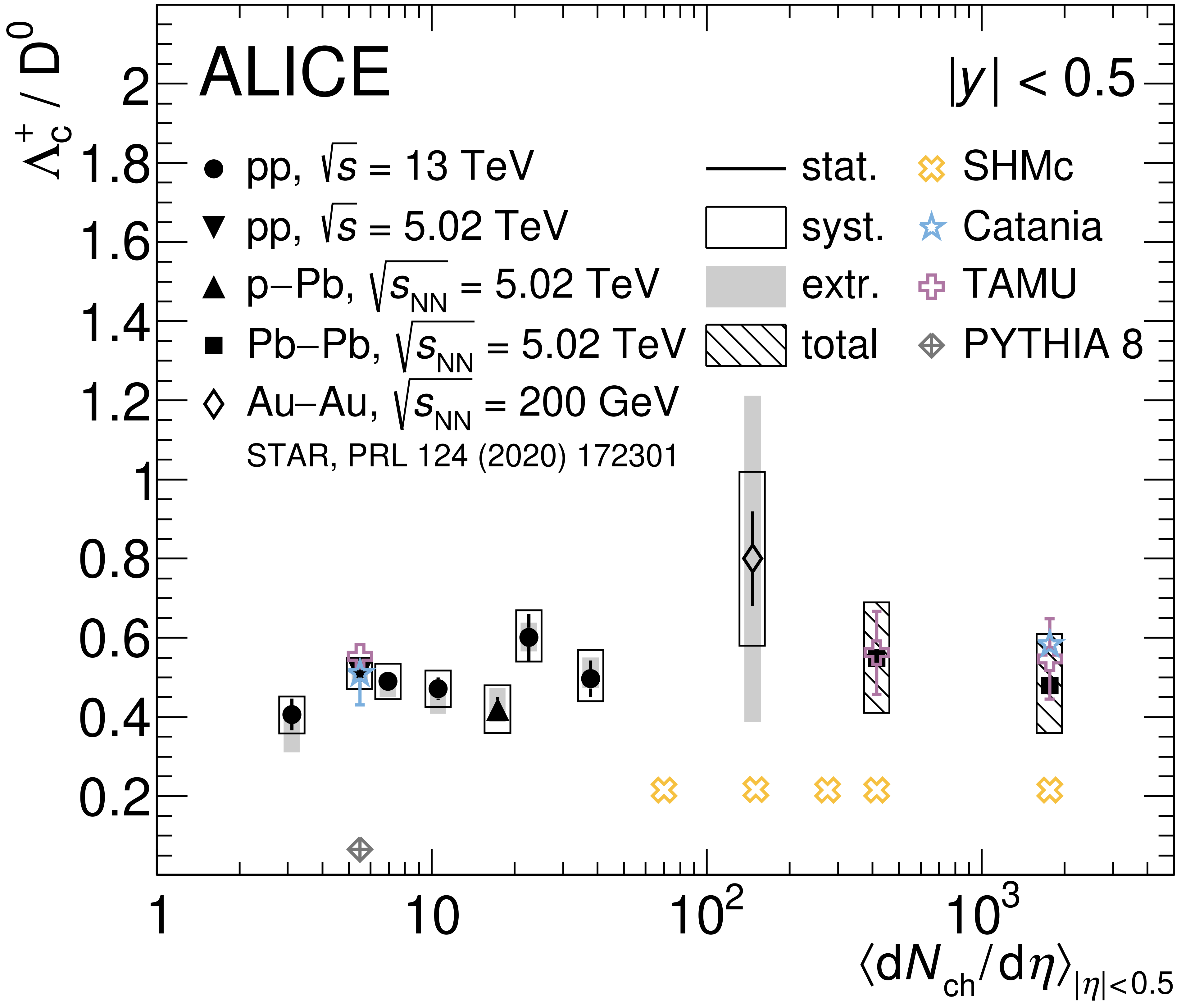
How about in Pb–Pb?

Physics Letters B 839 (2023) 137796





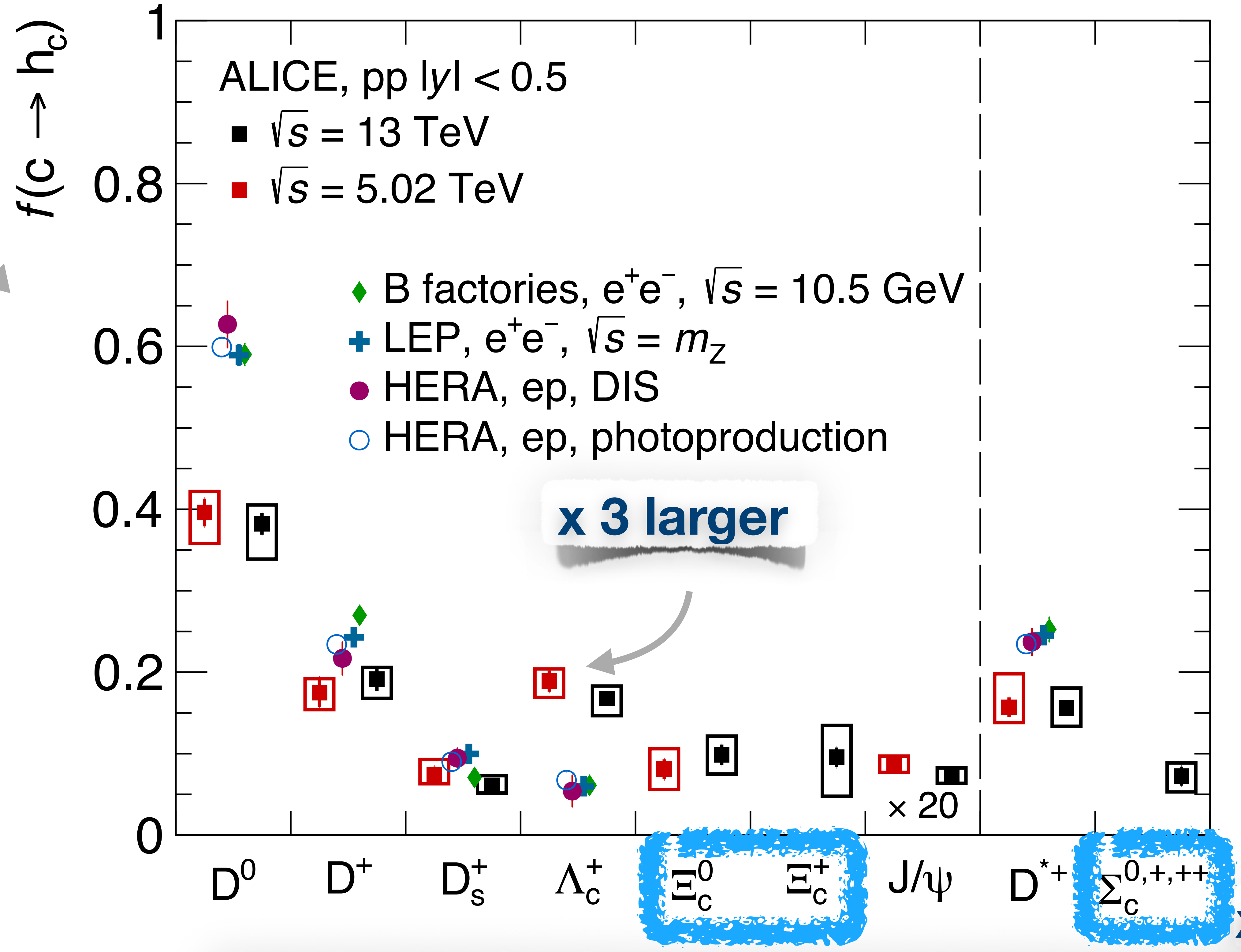


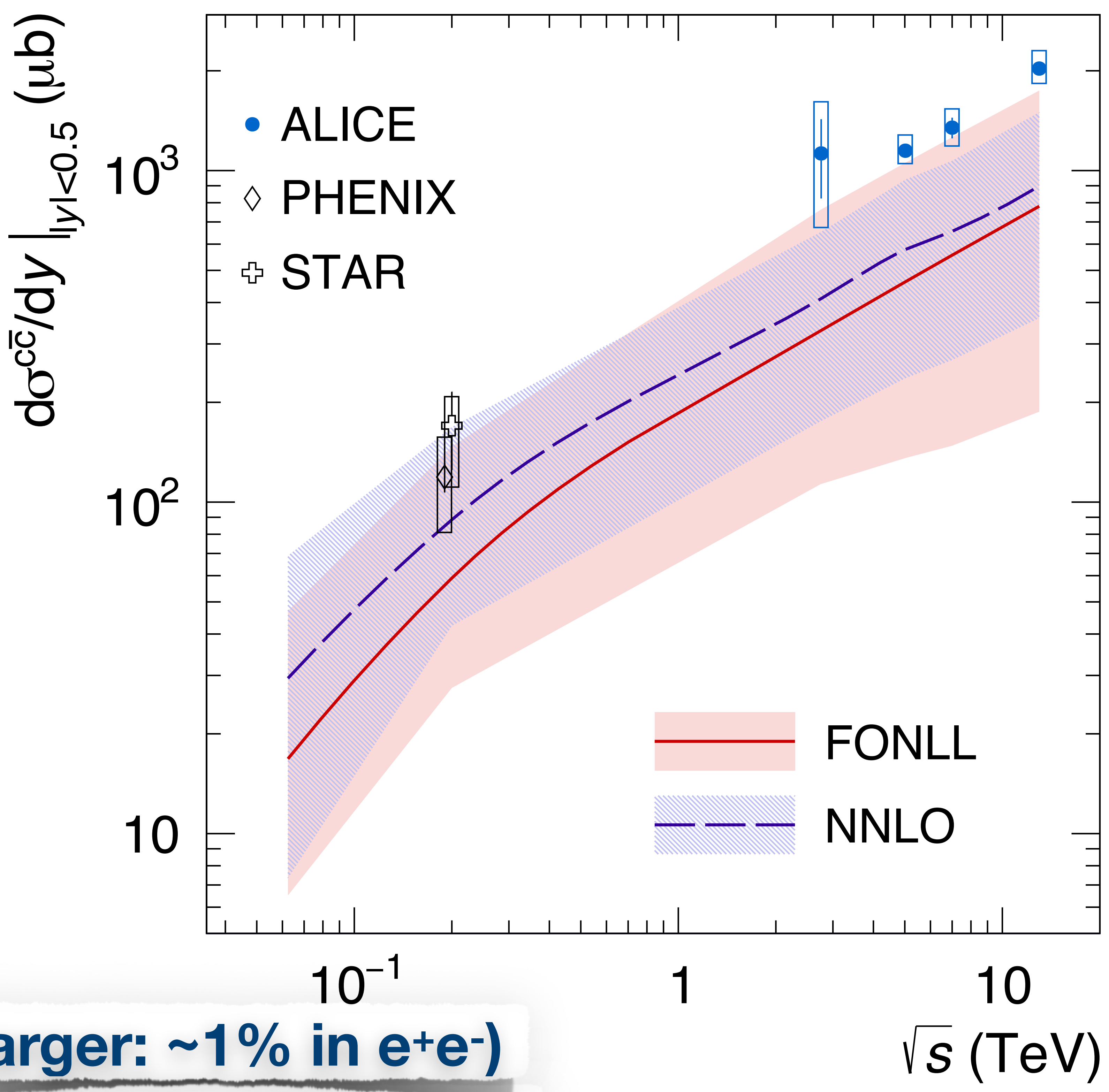


Modified mechanism of hadronization in all hadronic collision systems with respect to charm fragmentation tuned on e+e- and e-p measurements?

Charm-quark fragmentation fraction

arXiv:2308.04877





Used the sum of the p_T-integrated cross sections of D^0, D^+, D_s^+, J/ψ, Λ_c^+, Ξ_c^0, Ξ_c^+

x 3 larger

x 7 larger: ~1% in e^+e^-)

10% of total charm cross section (considered negligible in e^+e^-)

Σ_c^0: Larger feed-down to Λ_c^+ (40%, 17% in e^+e^-)

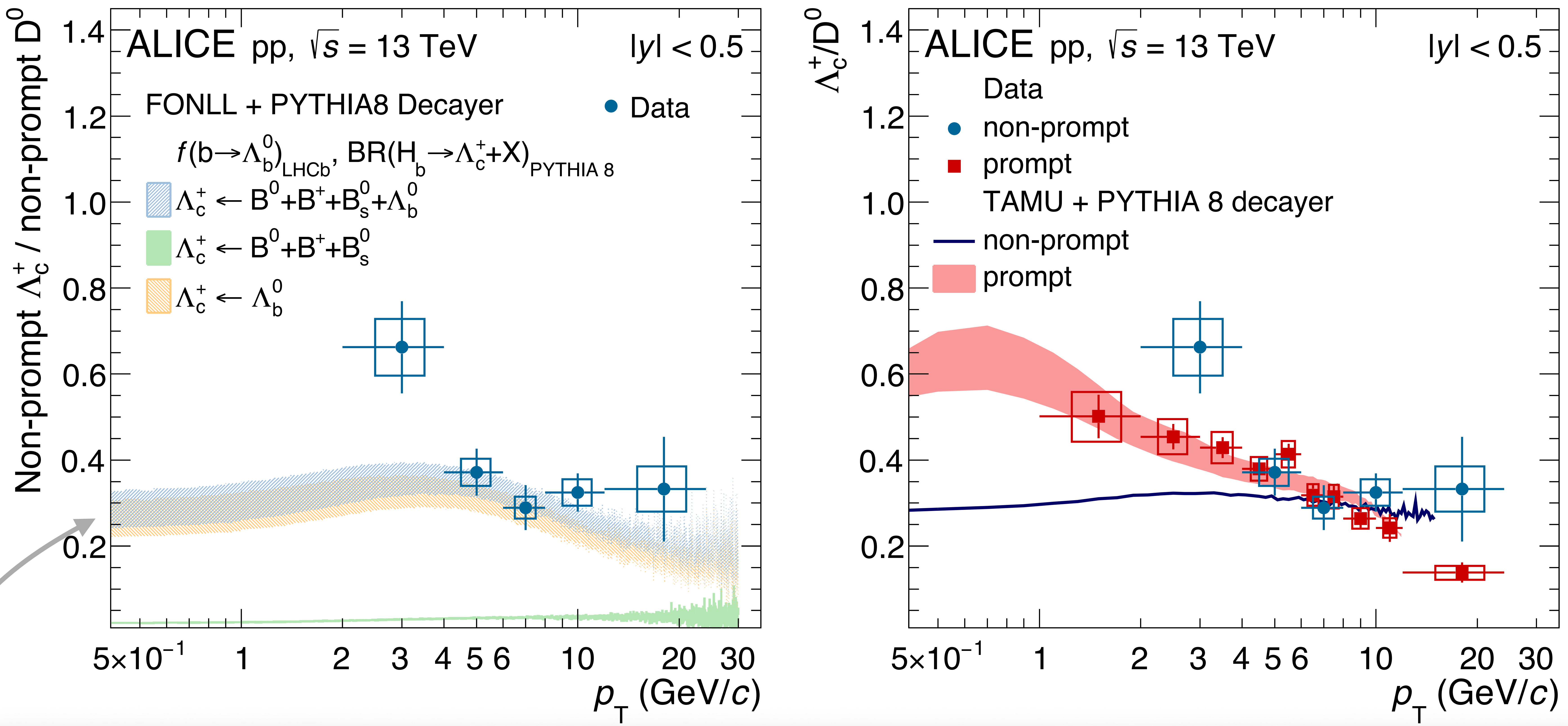
Normalized by the sum of the p_T-integrated cross sections of D^0, D^+, D_s^+, J/ψ, Λ_c^+, Ξ_c^0, Ξ_c^+

Conclusion: baryon enhancement at the LHC with respect to e^+e^- collisions is caused by different hadronisation mechanisms at play in the parton-rich environment produced in pp collisions

Moving to B sector

arXiv:2308.04873

Study of flavor dependence of the baryon-to-meson ratio in pp at $\sqrt{s}$ = 13 TeV



Note: should consider different decay kinematics → slightly modify p_T dependence

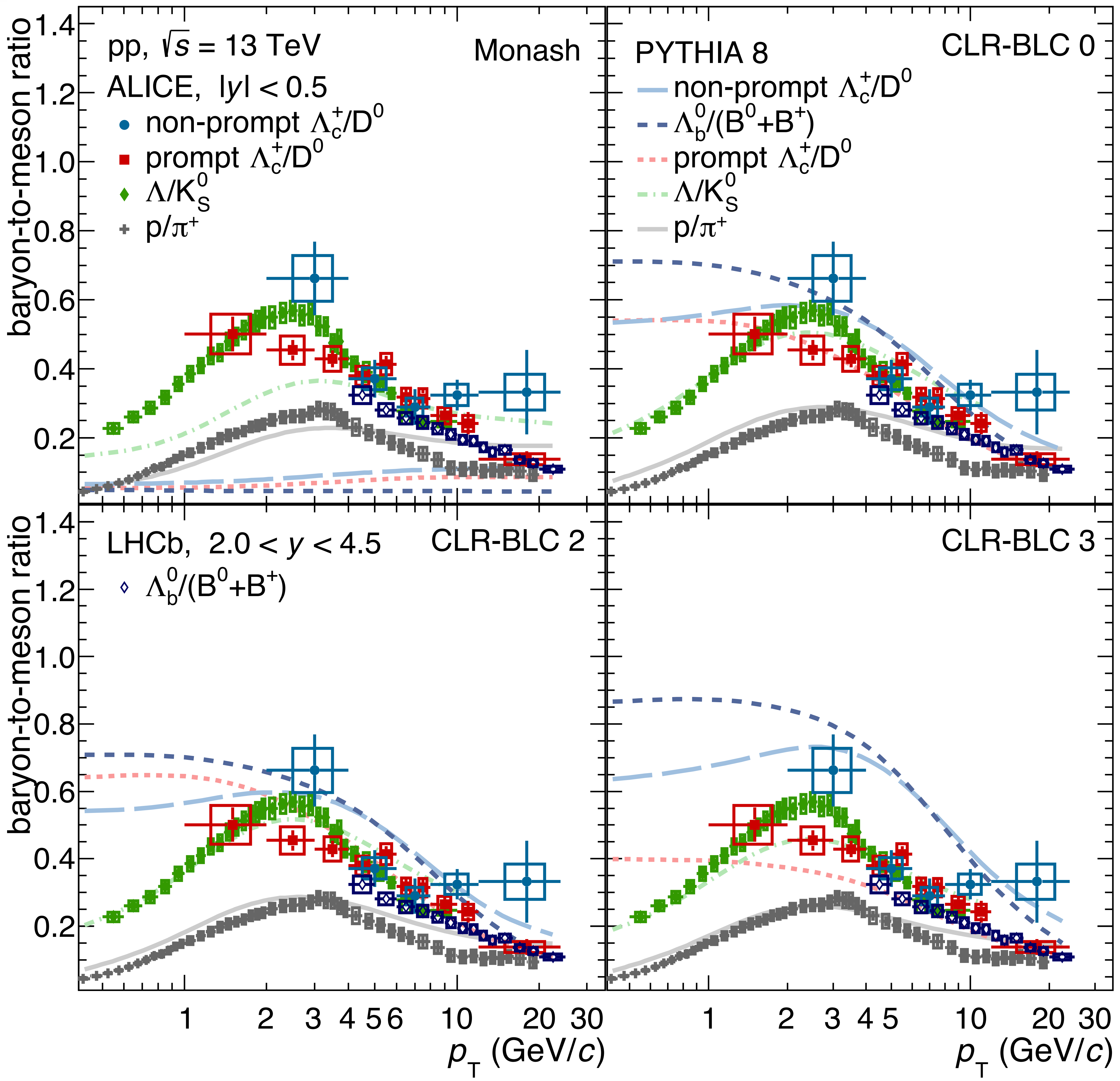
FONNL calculations based on using fragmentation fraction from e^+e^- and $f(b\rightarrow\Lambda_b^0)/f(b\rightarrow B)$ LHCb measurement

Non-prompt Λ_c^+ largely from the beauty baryons: good to investigate beauty baryon hadronization via non-prompt Λ_c^+

Similar trend to the prompt charm measurement!

Baryon to meson ratios of different flavors

arXiv:2308.04873



All the measurements for beauty, charm, and strange hadrons show a similar trend as a function of p_T and are compatible within the uncertainties

→ Similar baryon formation mechanism among light, strange, charm and beauty hadrons?

Note: for LHCb, different normalization & should consider decay kinematics (for the other case)
*** These three tunes are characterized by different constraints on the time dilation and causality**

Beauty-quark fragmentation fraction

arXiv:2308.04873

Table 2: p_T-integrated Λ_c^+/D^0 production ratio measured at midrapidity ($|y| < 0.5$) in pp collisions at $\sqrt{s} = 13$ TeV and in e^+e^- collisions at LEP [68] for prompt and non-prompt production.

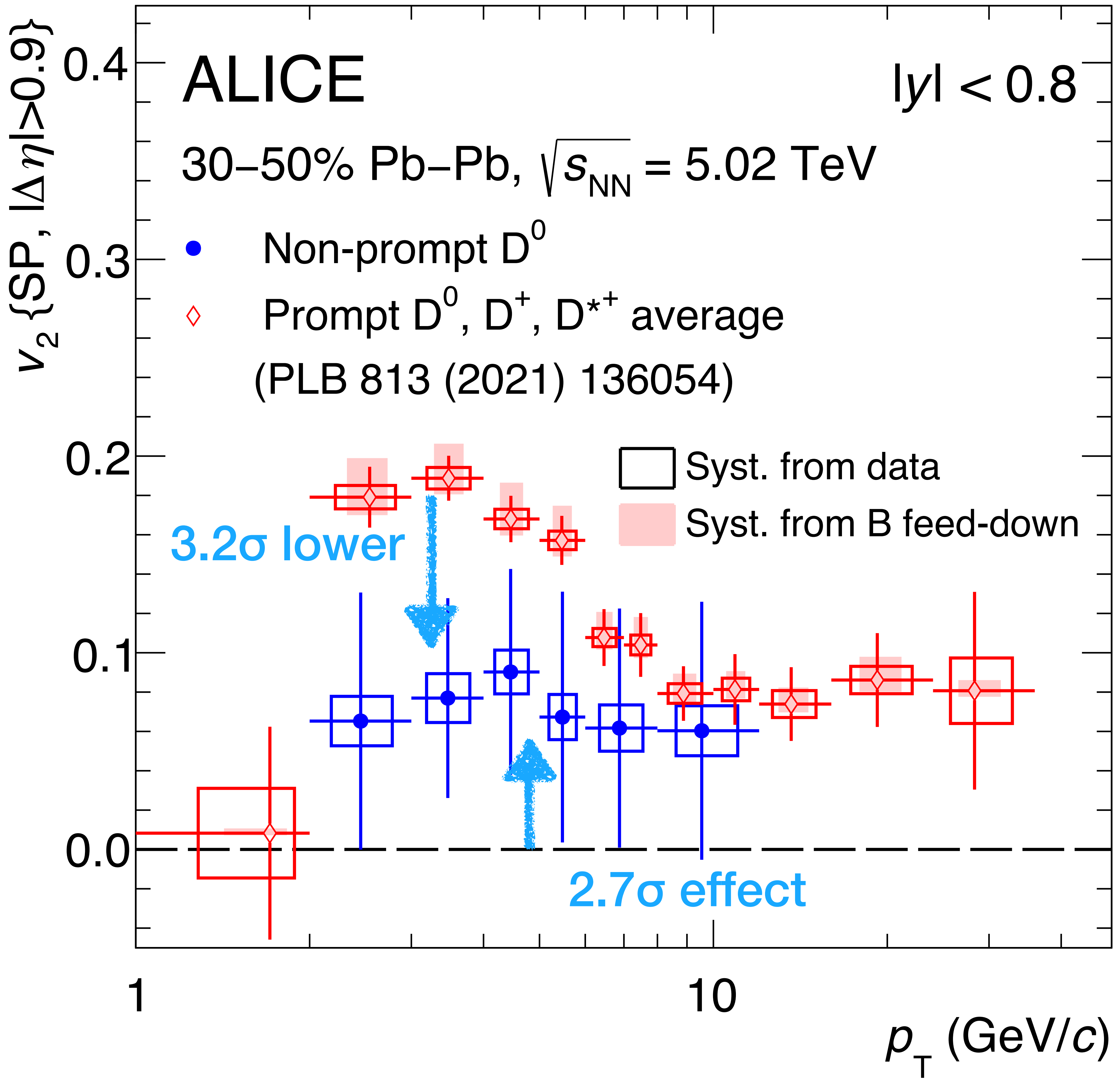
	ALICE	LEP average [68]
prompt Λ_c^+/D^0	$0.49 \pm 0.02(\text{stat})^{+0.05}_{-0.04}(\text{syst})^{+0.01}_{-0.03}(\text{syst})$ [60]	0.105 ± 0.013
non-prompt Λ_c^+/D^0	$0.47 \pm 0.06(\text{stat}) \pm 0.04(\text{syst})^{+0.03}_{-0.04}(\text{extrap})$	0.124 ± 0.016

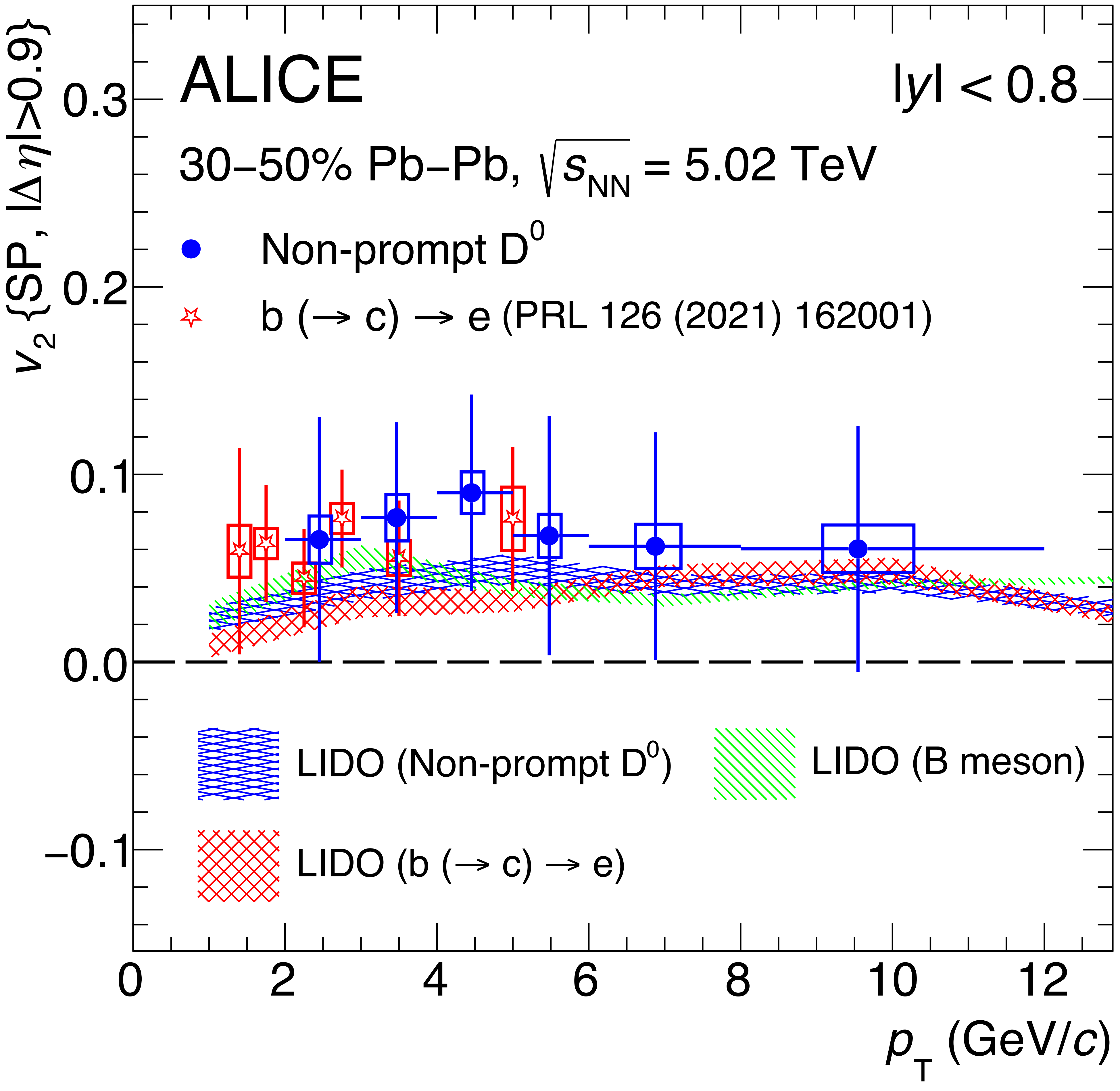
Significantly higher than that measured in e^+e^-

Beauty flow

arXiv:2307.14084

Non-prompt D_s-meson Elliptic Flow in Pb–Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

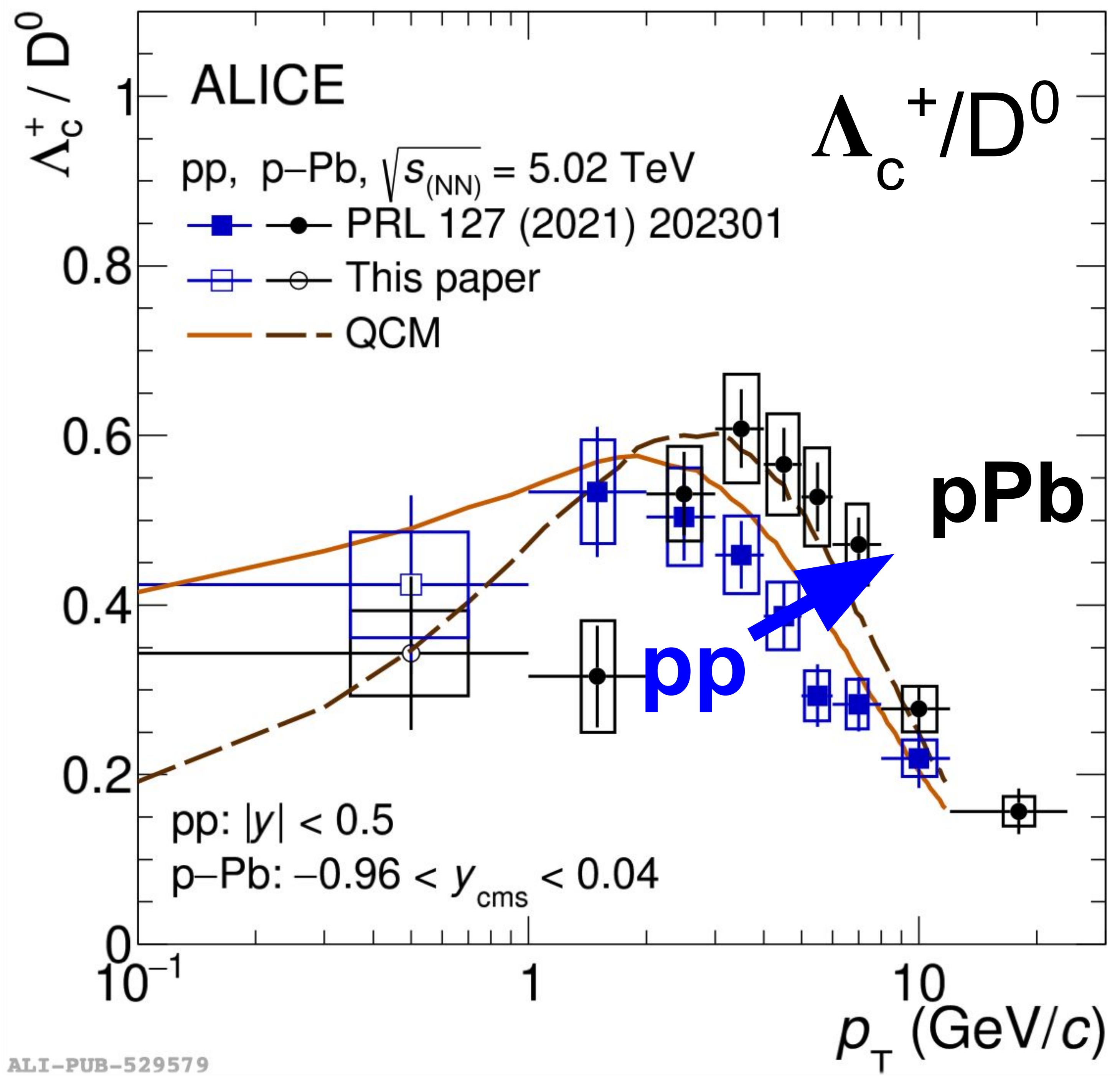




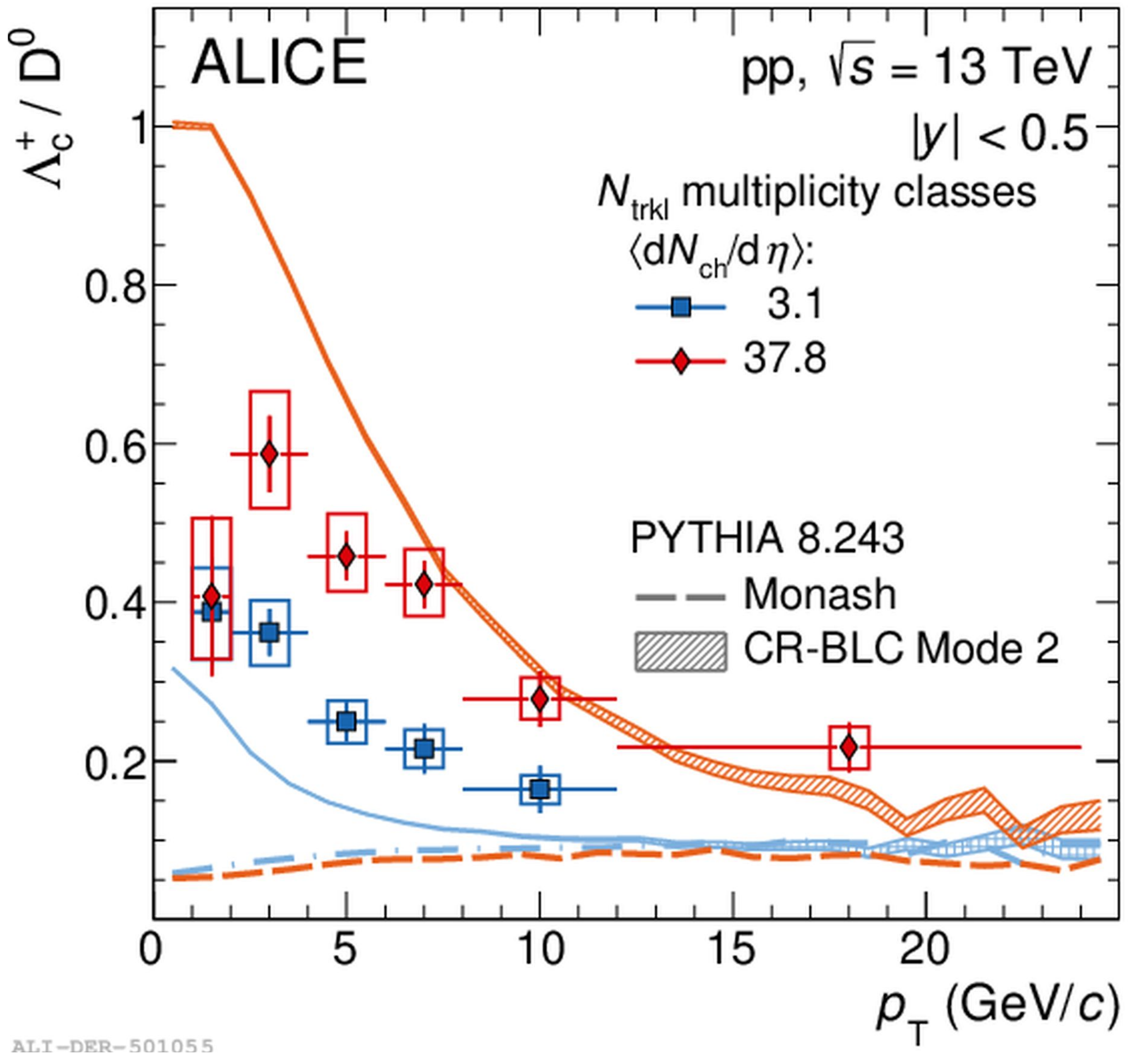
Weaker degree of thermalization for b

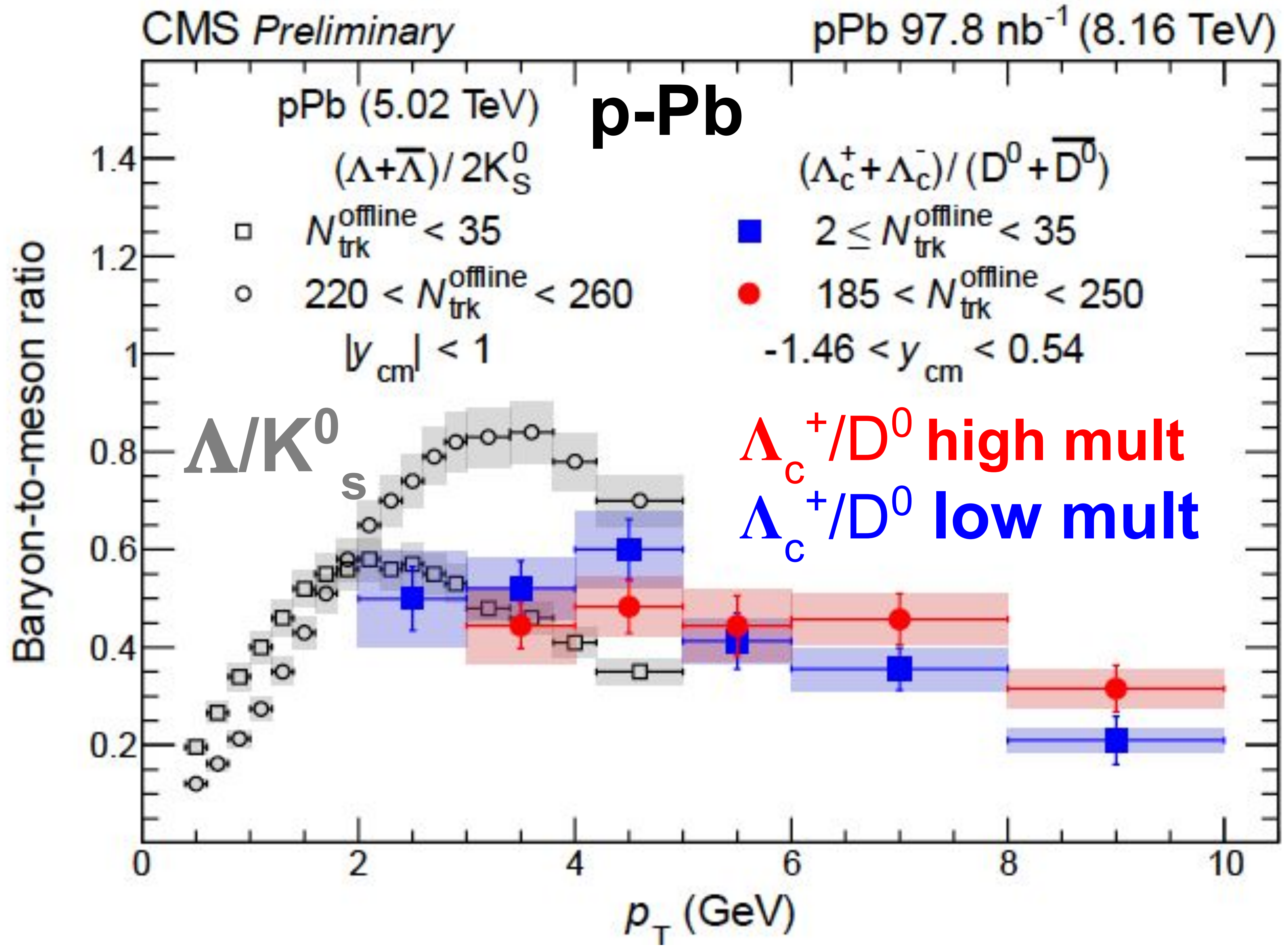
Extra Slides

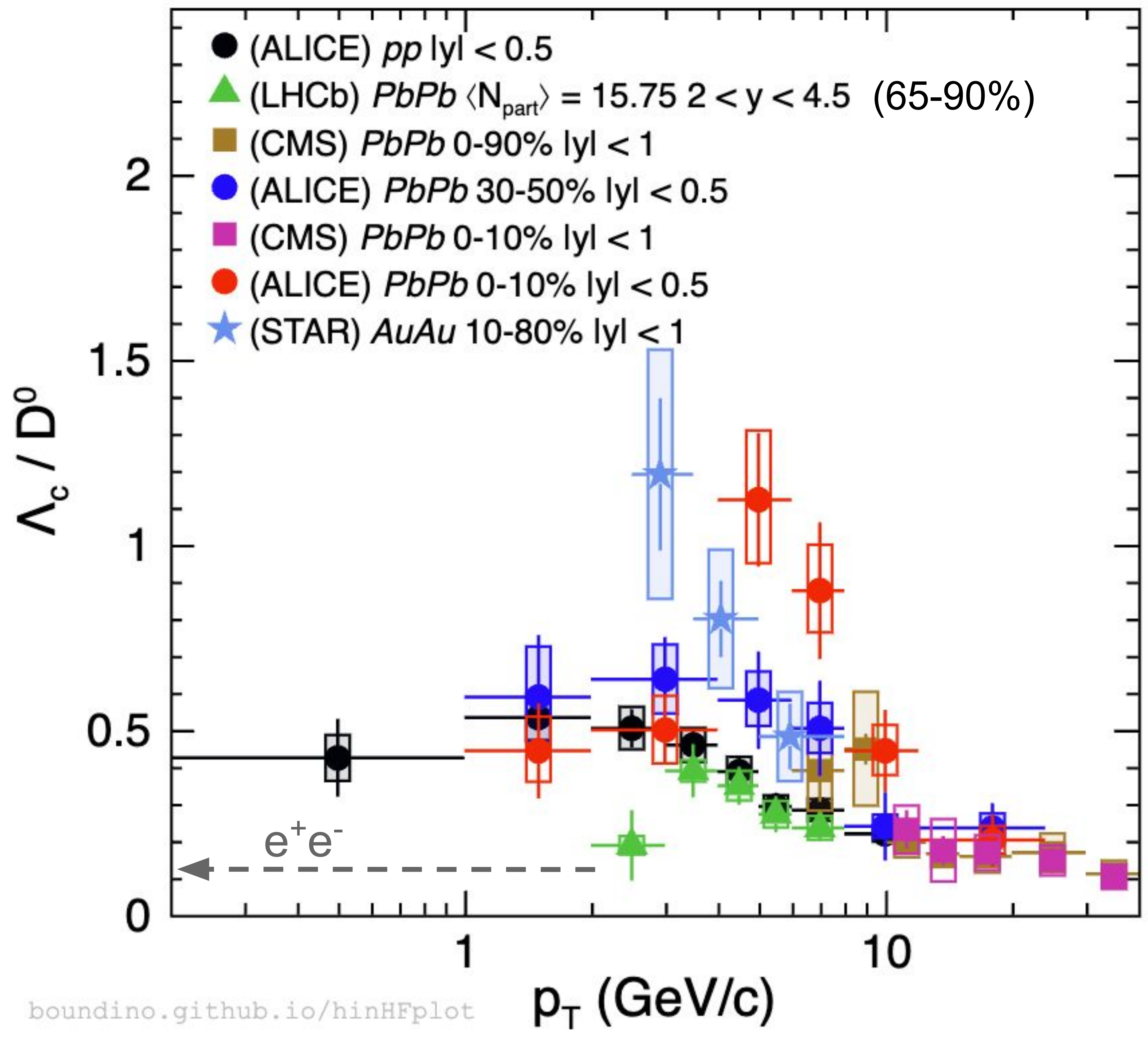
PRC 104 054905 (2021)



PLB 829 (2022) 137065

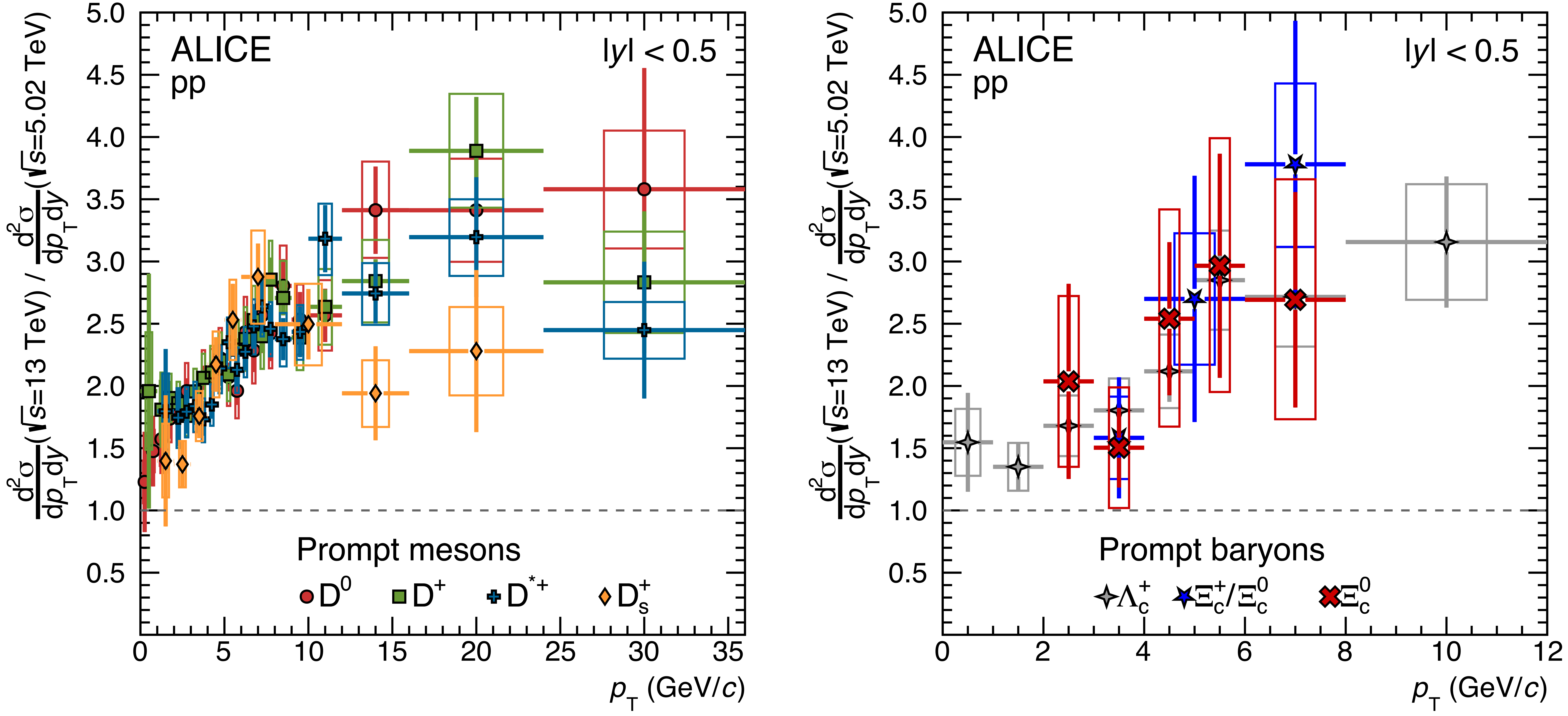





(ALICE) pp |y| < 0.5
(LHCb) PbPb ⟨N_part⟩ = 15.75 2 < y < 4.5 (65-90%)
(CMS) PbPb 0-90% |y| < 1
(ALICE) PbPb 30-50% |y| < 0.5
(CMS) PbPb 0-10% |y| < 1
(ALICE) PbPb 0-10% |y| < 0.5
(STAR) AuAu 10-80% |y| < 1
Λ_c / D^0
e^+e^-
p_T (GeV/c)
boundino.github.io/hinHFplot

arXiv:2308.04877

Charm production and fragmentation fractions in pp at sqrt(s) = 13 TeV



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