Overview of experimental results on open heavy-flavour hadronization

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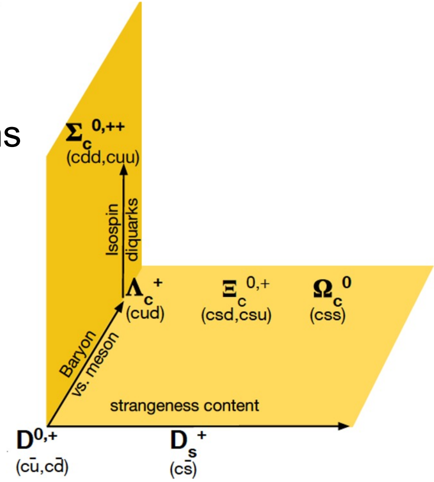
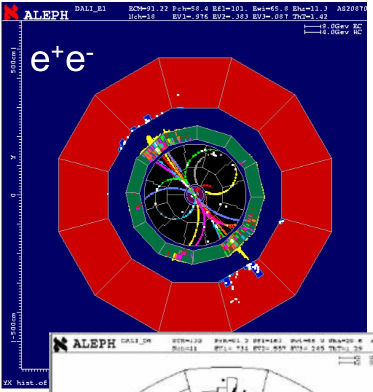
Introduction

Heavy quarks are formed in initial hard scatterings, before hadronization
with cross sections that can be calculated with pQCD
→ "calibrated probes" of final-state effects, including hadronization, in all collision systems



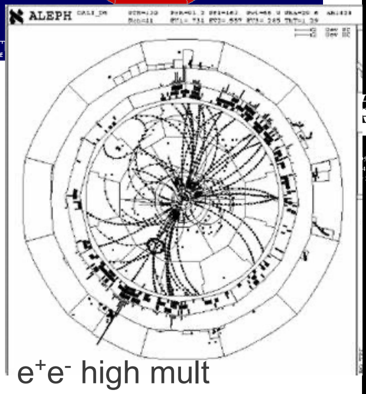
LHC: heavy-flavour baryon formation not understood in hadronic collisions

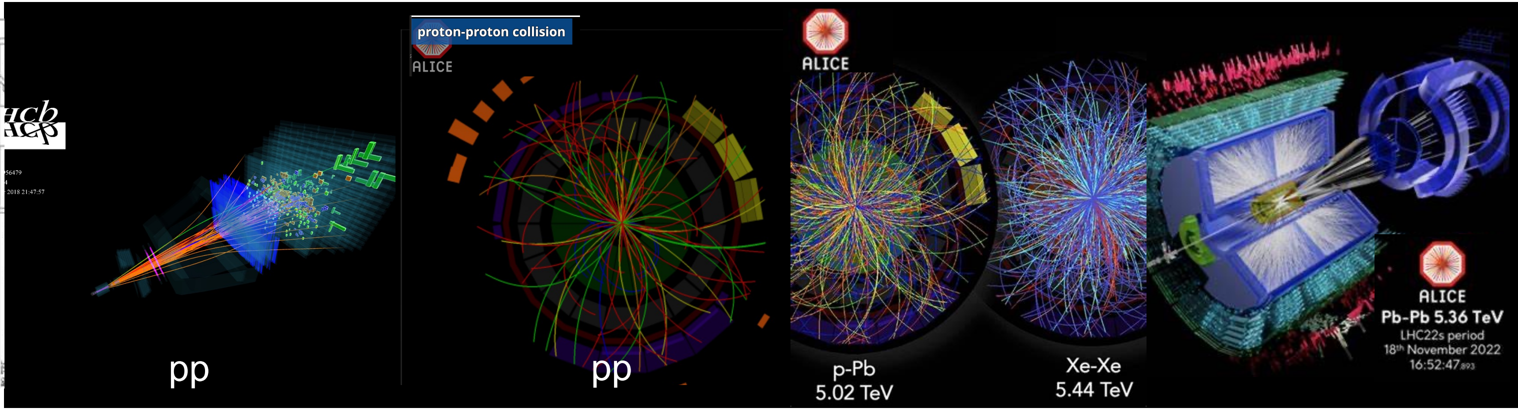


Experimentally:
- event multiplicity, different collision systems
- different hadron species

⇨ lever arm to investigate hadronisation mechanisms

Recent review on the topic: Altmann, Dubla, Greco, AR, Skands arxiv 2405.19137





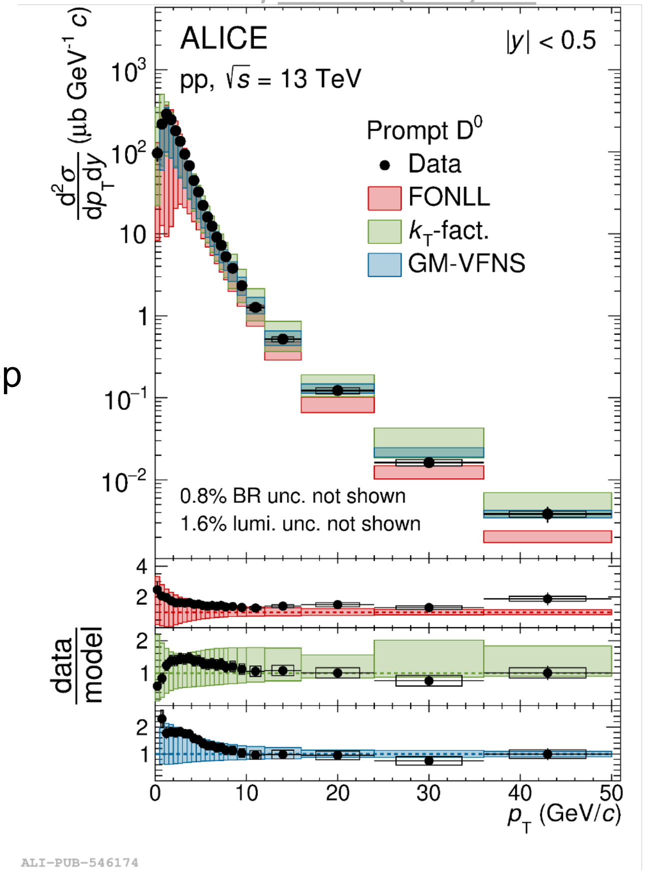
D- and B-meson cross sections and ratios

Precise measurements of prompt HF-meson cross sections

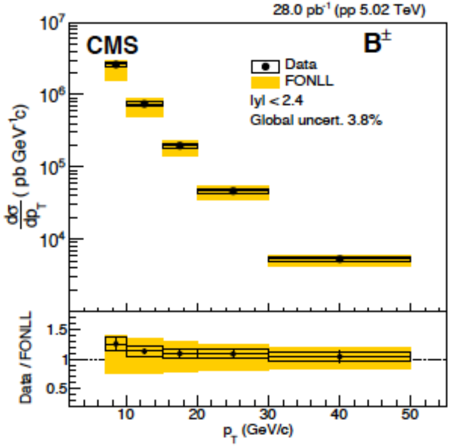
Test pQCD calculations of charm production relying on **factorisation** approach and assumption that **fragmentation functions** determined in e^+e^- can be used in pp (“**universality**”)

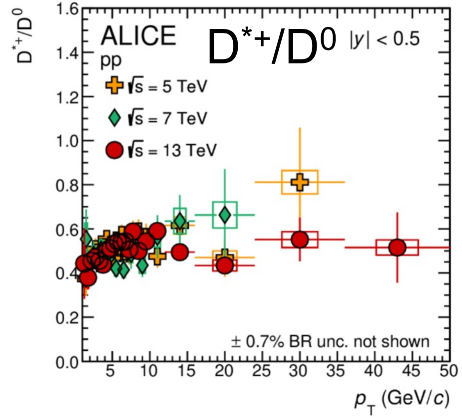
Yield-meson ratios compatible with e^+e^- values

ALICE, JHEP 12 (2023) 086



CMS, PRL, 119 152301 (2017)





FONLL: JHEP 05 (1998) 007
GM-VFNS: PRD 101 (2020) 114021
k_T-fact: PRD 104 (2021) 094038

D- and B-meson cross sections and ratios

ALICE, JHEP 12 (2023) 086

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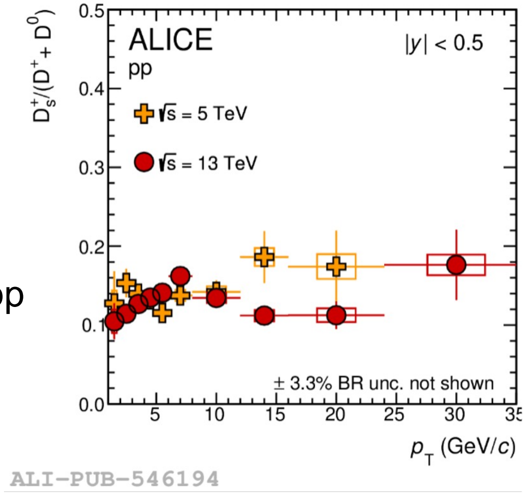
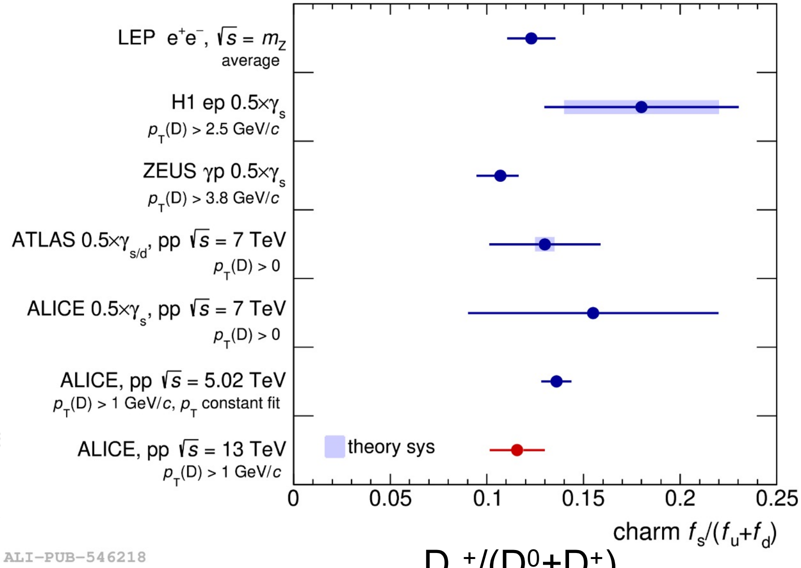
Including D_s^+

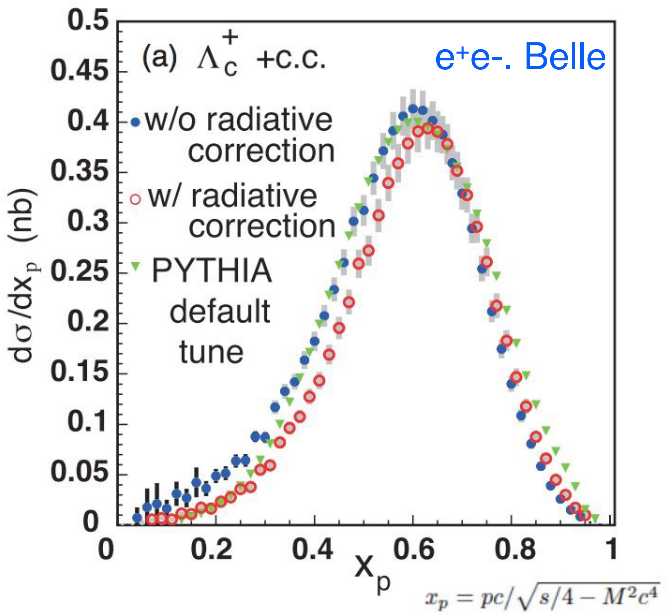




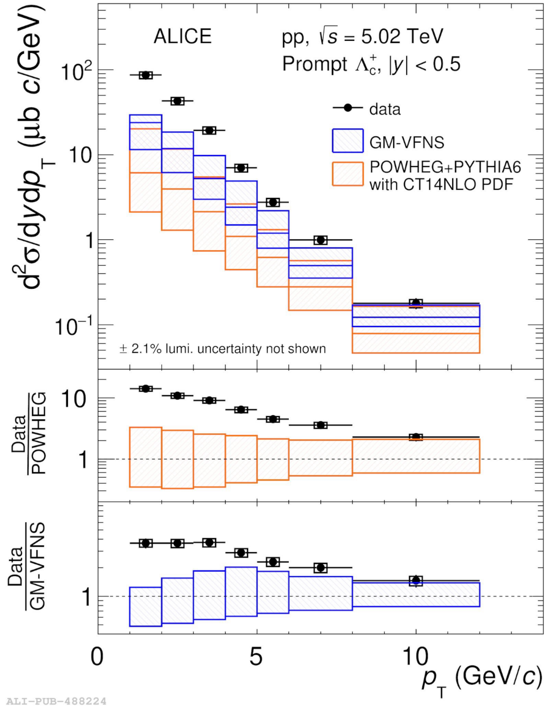
$D_s^+/(D^0+D^+)$

FONLL: JHEP 05 (1998) 007
GM-VFNS: PRD 101 (2020) 114021
k_T-fact: PRD 104 (2021) 094038

Heavy-flavour baryons



Belle: PRD 97, 072005 (2018)



ALICE
PRC 104 054905 (2021)
PRL 127 202301 (2021)

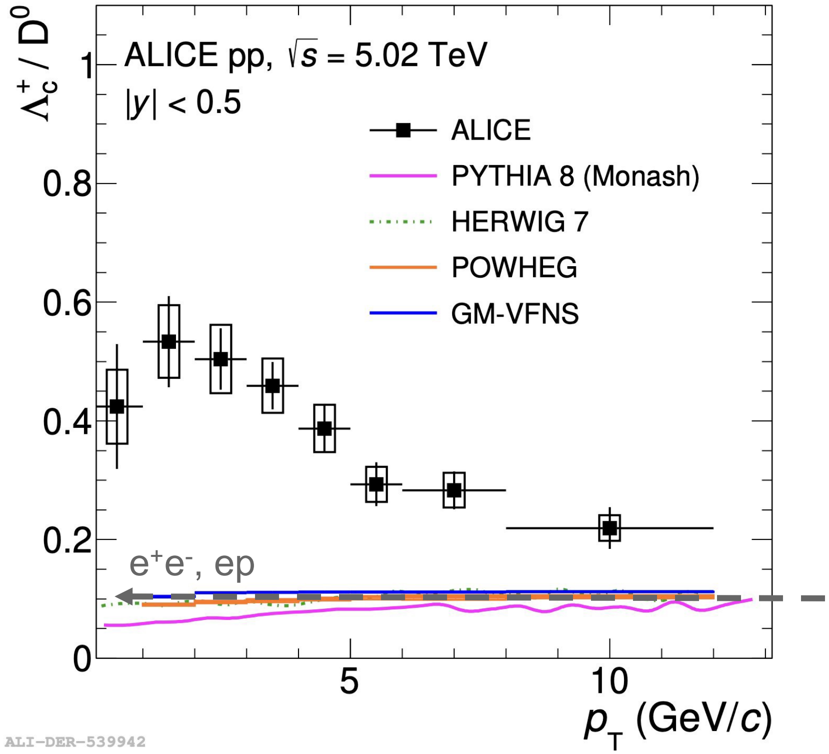
GM-VFNS: PRD 101 (2020) 114021
POWHEG: JHEP 09 (2007) 126
PYTHIA6: JHEP 05 (2006) 026
CT14 NLO: Phys. Rev. D 93, 033006 (2016)

PYTHIA with Lund string-fragmentation reproduces c → Λ_c^+ “fragmentation fuction” in e^+e^-

pQCD-based models (GM-VFNS, POWHEG+PYTHIA6) **strongly underestimate Λ_c^+** cross section

Λ_c^+/D^0 baryon-to-meson cross-section ratio

ALICE,PRC 104 054905 (2021)
ALICE, PRL 127 202301 (2021)
ALICE, PRC 107 (2023) 6, 064901



Λ_c^+/D^0 ratio higher (x4-5) values at low p_T than e^+e^-, ep

Significantly decreasing with p_T , approaching e^+e^- at high p_T

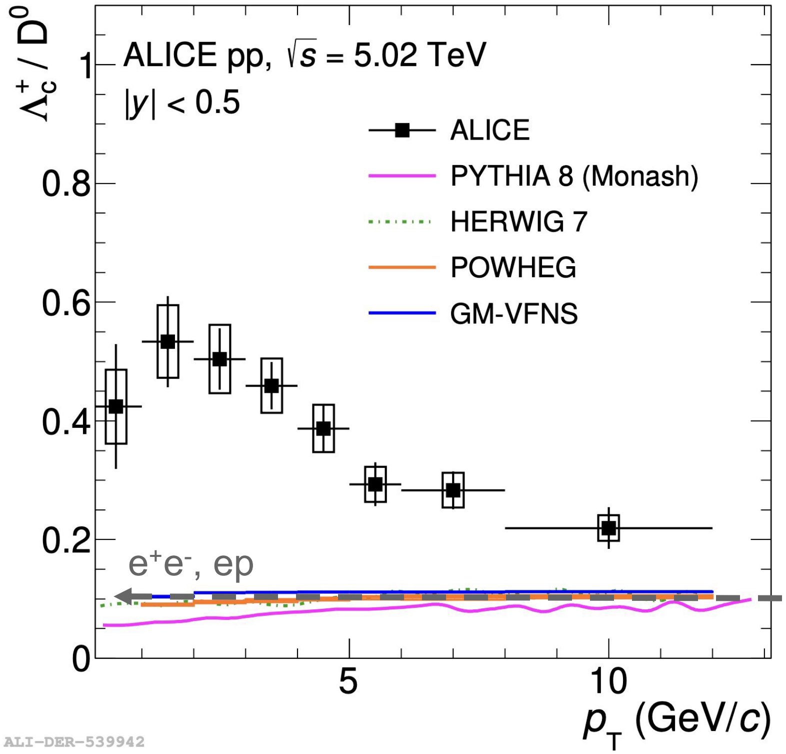
Recently extended down to p_T = 0 at 5 and 13 TeV

	$\Lambda_c^+/D^0 \pm$ stat. $\pm$ syst.	System	$\sqrt{s}$ (GeV)	Notes
ALICE	$0.51 \pm 0.04 \pm 0.04\,^{+0.01}_{-0.02}$	pp	5020	$p_T > 0, \lvert y \rvert < 0.5$
ALICE	$0.43 \pm 0.03 \pm 0.05\,^{+0.05}_{-0.03}$	p–Pb	5020	$p_T > 0, -0.96 < y < 0.04$
CLEO [16]	$0.119 \pm 0.021 \pm 0.019$	e^+e^-	10.55	
ARGUS [15, 17]	0.127 ± 0.031	e^+e^-	10.55	
LEP average [18]	$0.113 \pm 0.013 \pm 0.006$	e^+e^-	91.2	
ZEUS DIS [21]	$0.124 \pm 0.034\,^{+0.025}_{-0.022}$	e^-p	320	$1 < Q^2 < 1000$ GeV^2, $0 < p_T < 10$ GeV/c, $0.02 < y < 0.7$
ZEUS γp, HERA I [19]	$0.220 \pm 0.035\,^{+0.027}_{-0.037}$	e^-p	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert \eta \rvert < 1.6$
ZEUS γp, HERA II [20]	$0.107 \pm 0.018\,^{+0.009}_{-0.014}$	e^-p	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert \eta \rvert < 1.6$

Similar values at LEP, B-factories, and ep: different $c\bar{c}$ production processes, very different jet energies

Λ_c^+/D^0 baryon-to-meson cross-section ratio

ALICE,PRC 104 054905 (2021)
ALICE, PRL 127 202301 (2021)
ALICE, PRC 107 (2023) 6, 064901



Not described by

- **PYTHIA 8 Monash**
- **pQCD-based calculations**

relying on **factorisation** approach and **universality** of fragmentation functions, which work well for mesons

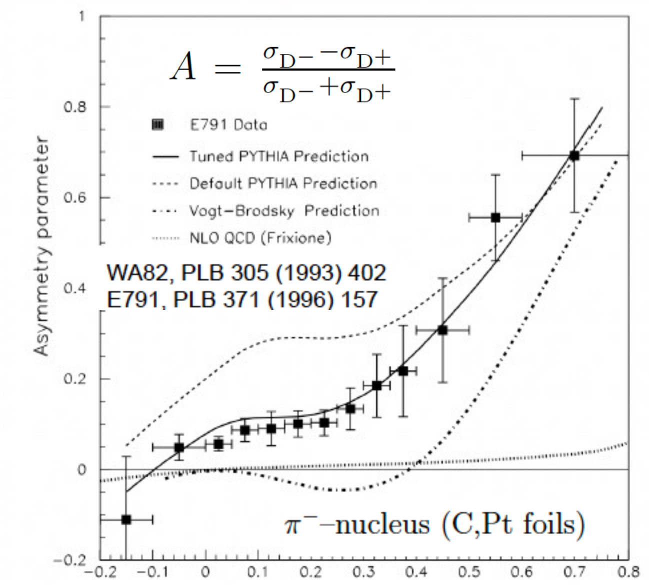
Hadronisation not a universal process

Fragmentation:
either fragmentation (functions) not universal or not enough, other mechanisms needed

Is it surprising?

… it surprised us, especially the size of the effect.   But we did not expect fragmentation to always hold…

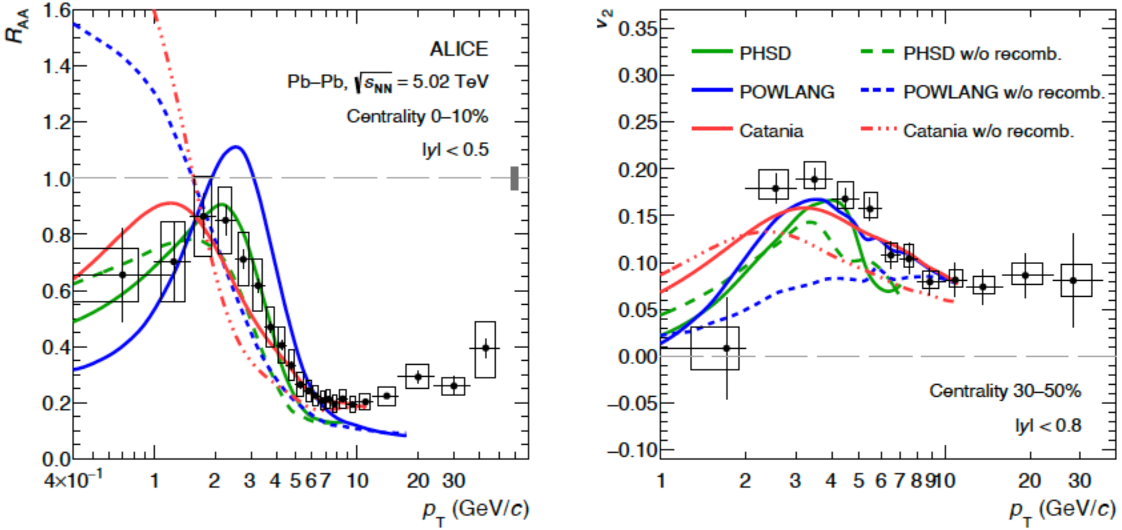
Beam remnants, quantum-number conservation, kinematic limitations



$x_F = p_Z/p_{Zmax}$

Leading–particle effect: c quarks can combine with pion valence quark
→ Slightly more D^- than D+ with harder x_F

Nucleus-nucleus: recombination expected, needed to explain D meson data in Pb-Pb collisions expected to also alter particles abundances



ALICE, JHEP 01 (2022) 174

Fig. from Altmann, Dubla, Greco, AR, Skands arxiv 2405.19137

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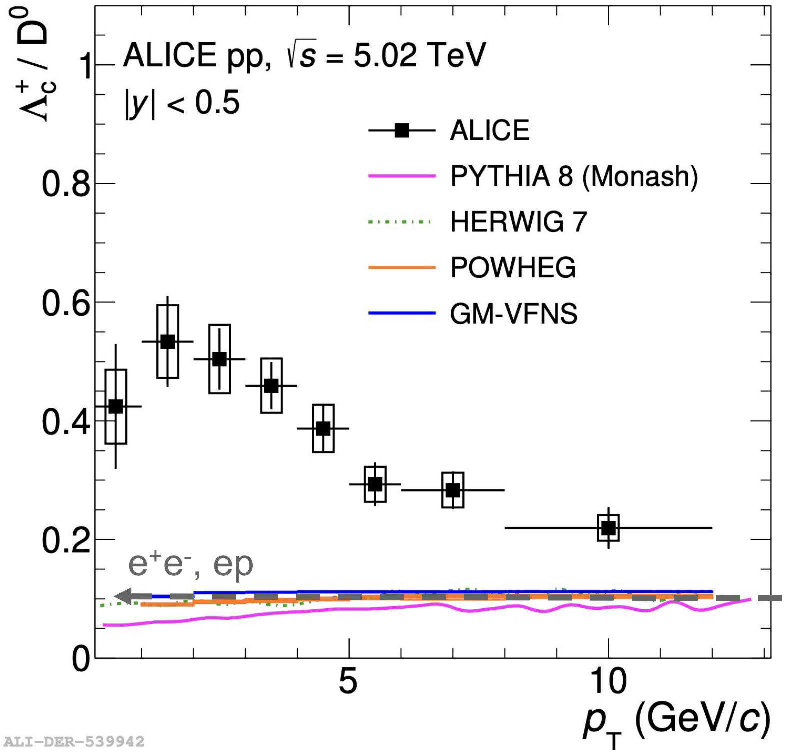
ALICE, PRL 127 202301 (2021)
ALICE, PRC 107 (2023) 6, 064901



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Hadronisation not a universal process
already in pp, with large and not understood differences w.r.t. e^+e^-

Fragmentation:
either fragmentation (functions) not universal or not enough, other mechanisms needed

How does it evolve across systems from e^+e^- to AA?
What does regulate its modification?
In which regimes does fragmentation dominate?
Which models/mechanisms can better describe the data?

Λ_c^+/D^0 baryon-to-meson cross-section ratio

ALICE,PRC 104 054905 (2021)
ALICE, PRL 127 202301 (2021)
ALICE, PRC 107 (2023) 6, 064901
CMS, JHEP 01 (2024) 128

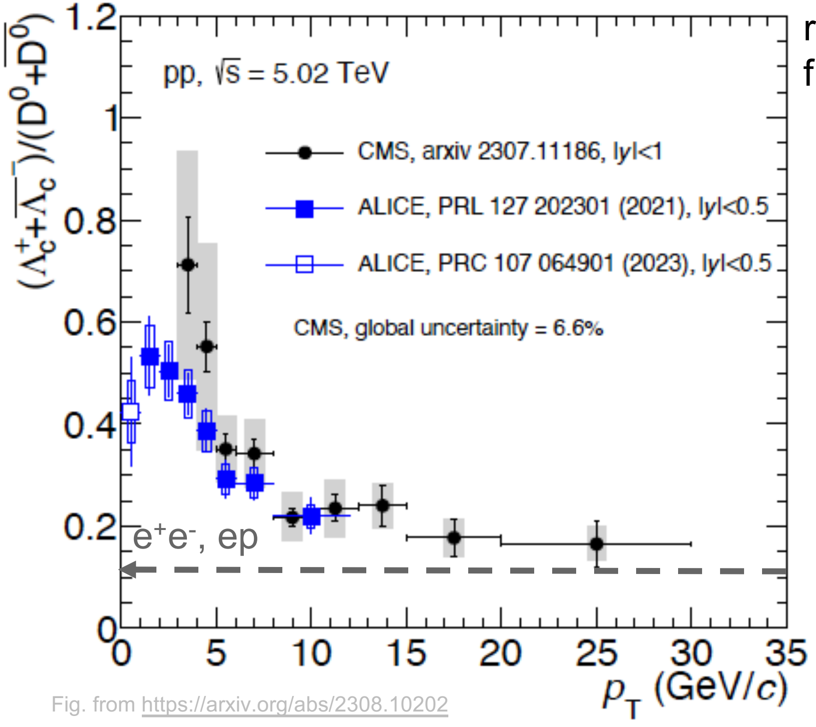

Fig. from https://arxiv.org/abs/2308.10202

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ALICE, JHEP 12 (2023) 086

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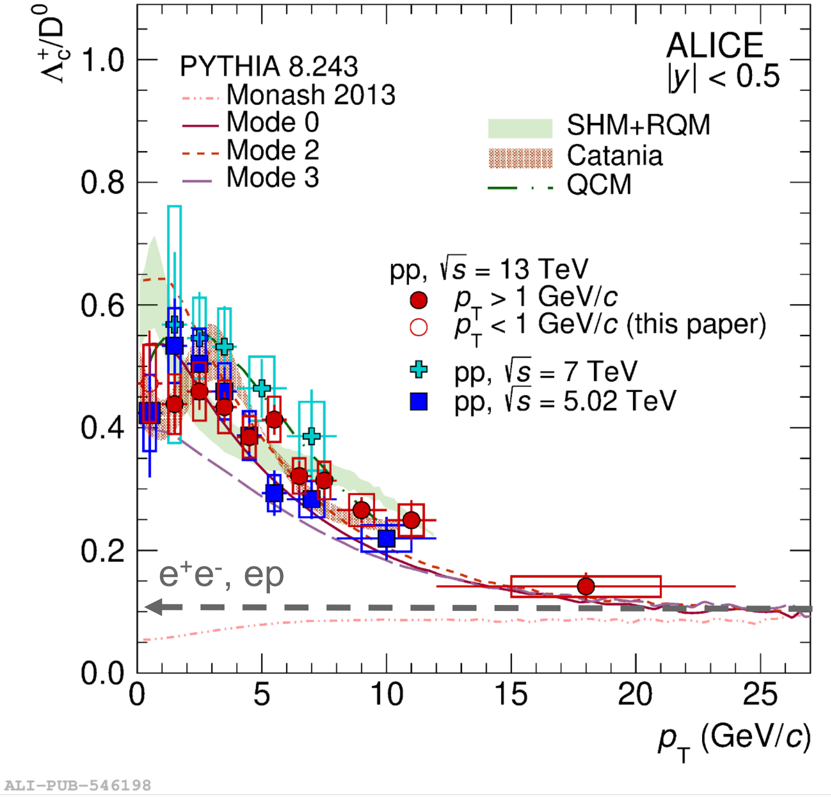
ALICE, PRC 107 (2023) 6, 064901



No evidence of dependence on collision energy

Λ_c^+/D^0 baryon-to-meson cross-section ratio

ALICE, JHEP 12 (2023) 086

ALICE,PRC 104 054905 (2021)
ALICE, PRL 127 202301 (2021)
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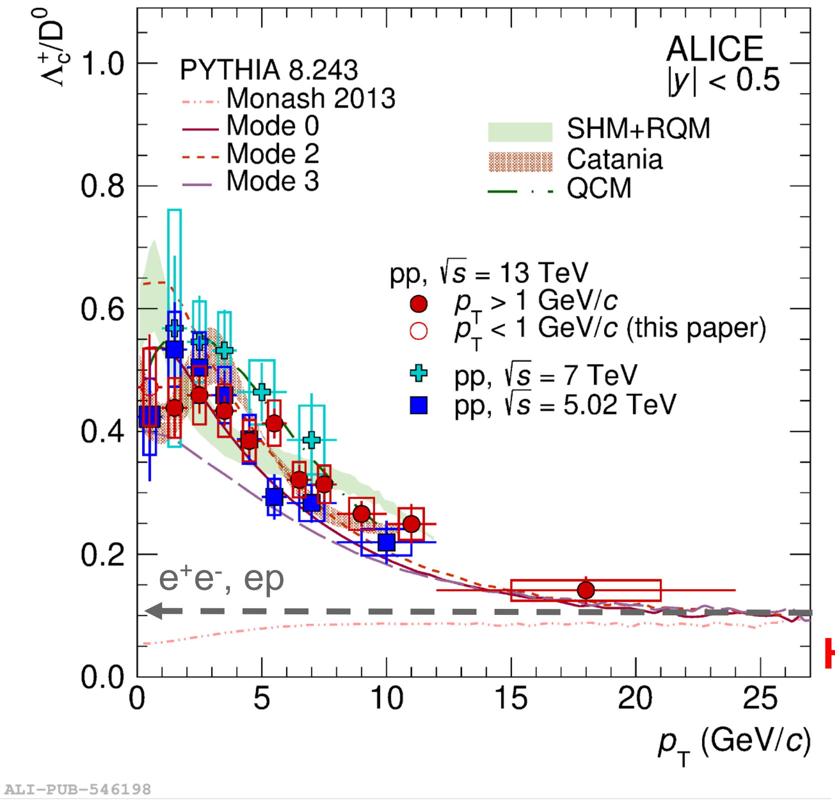


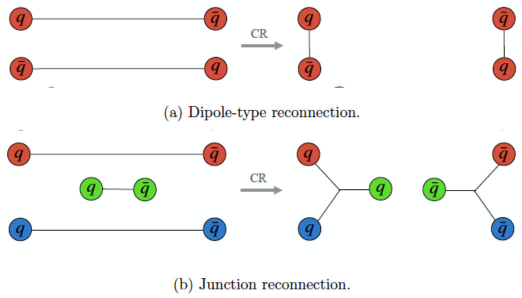
Data described by:

PYTHIA 8 with String Formation beyond Leading Colour (JHEP 1508 (2015) 003)

More complete and realistic (=closer to QCD) scheme of colour-reconnection (CR)

- "***...between which partons do confining potentials arise?***"

Junction reconnection topologies → enhance baryons.



Hadronisation of quarks from different MPI correlated
→ A hadronic environment matters

Λ_c^+/D^0 baryon-to-meson cross-section ratio

ALICE, JHEP 12 (2023) 086

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ALICE, PRL 127 202301 (2021)
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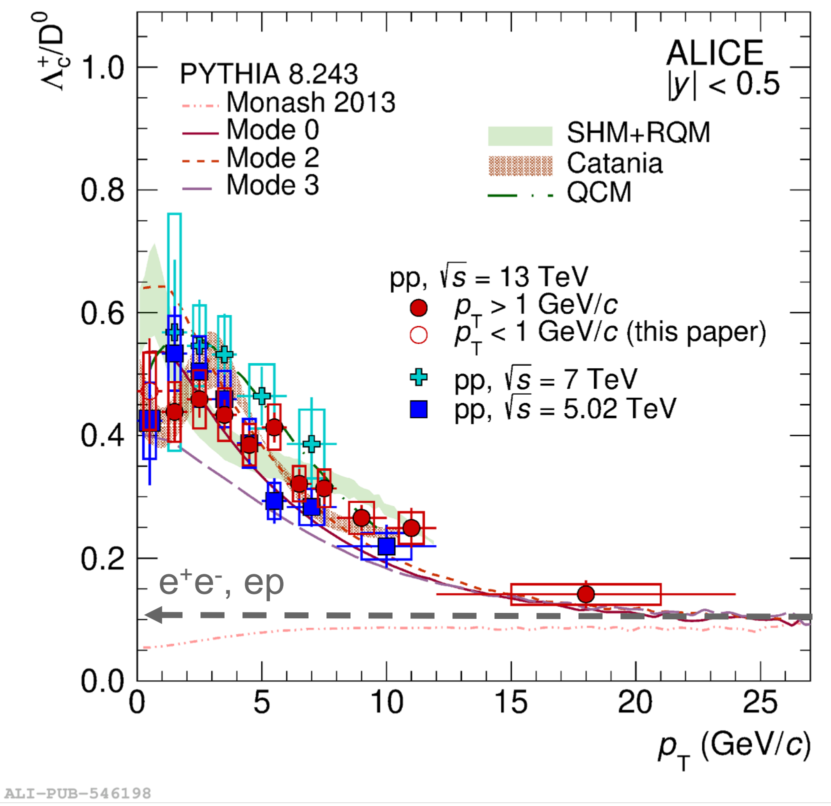

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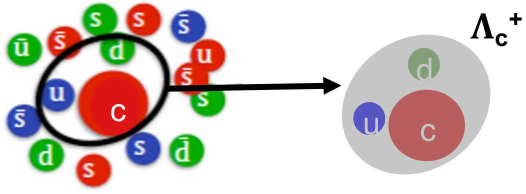
Catania model: "sudden" **coalescence** (Wigner function) + "vacuum" fragmentation (PLB 821 (2021) 136622)

f_q = phase-space distributions of quarks in the system

$$\frac{dN_H}{dyd^2P_T} = g_H \int \prod_{i=1}^{N_q} \frac{d^3p_i}{(2\pi)^3E_i} p_i \cdot d\sigma_i \, f_{q_i}(x_i, p_i) \times f_H(x_1...x_{N_q}, p_1...p_{N_q}) \, \delta^{(2)}\left(P_T - \sum_{i=1}^{n} p_{T,i}\right)$$

f_H= phase-space distributions of quarks within hadron

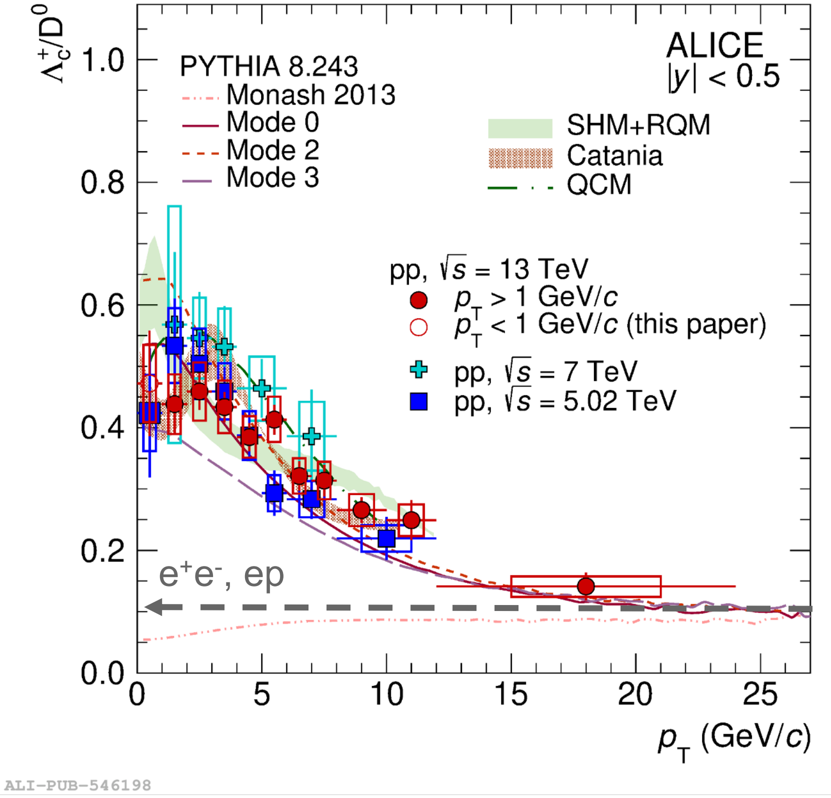
For LF: "small" QGP in pp, but "bulk" of quarks is likely enough



Λ_c^+/D^0 baryon-to-meson cross-section ratio

ALICE, JHEP 12 (2023) 086

ALICE,PRC 104 054905 (2021)
ALICE, PRL 127 202301 (2021)
ALICE, PRC 107 (2023) 6, 064901



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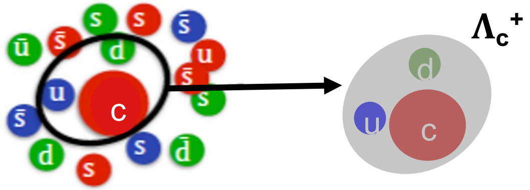
QCM: quark **recombination** model based on “equal quark-velocity” coalescence (EPJC 78, 2018 4, 344)



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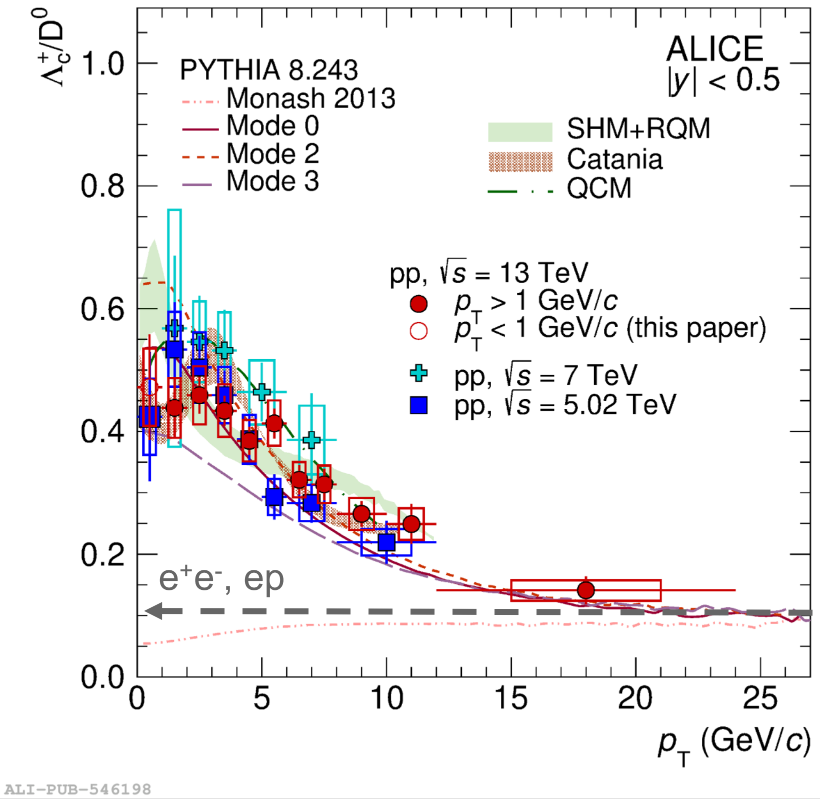

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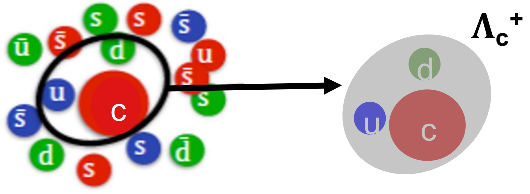
SHM+RQM, PLB 795 117-121 (2019): no info on partonic phase
Hadron abundances ← **Statistical Hadronisation Model** + feed-down from **augmented set of charm-baryon states** (from Relativistic Quark Model)

→ 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



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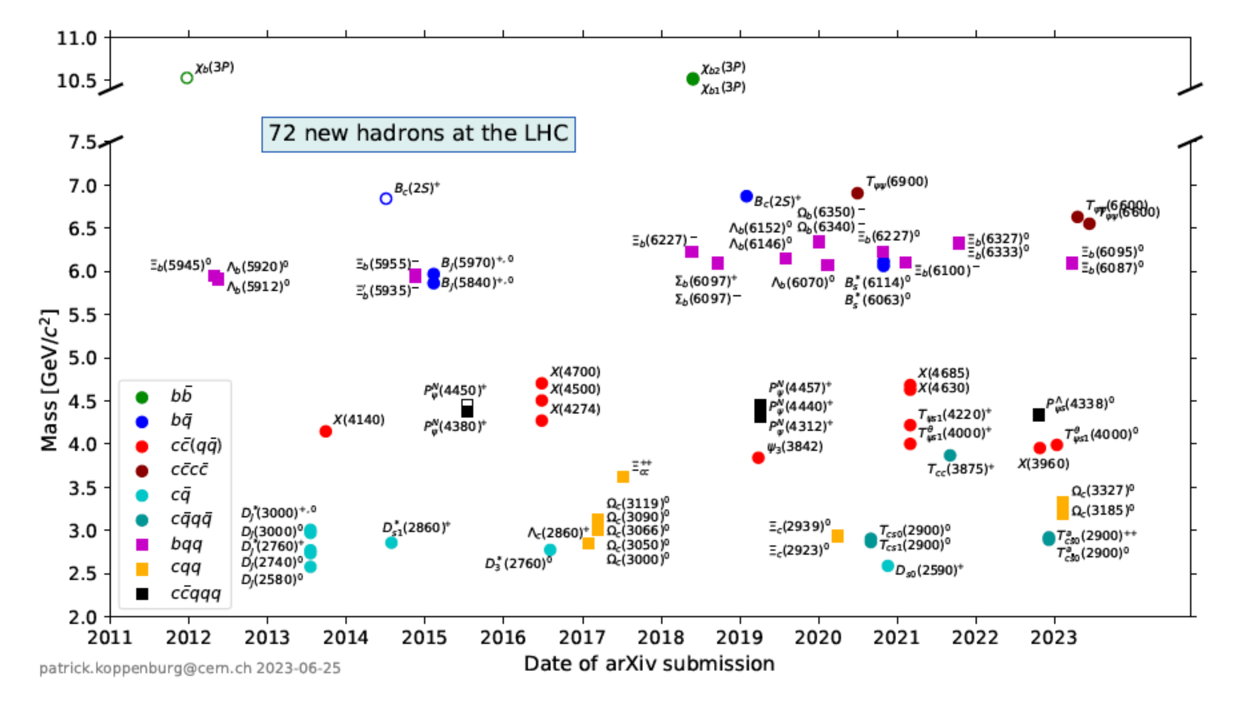


Many new states (being) discovered at the LHC

.. but not hundreds so far

om

ALI-PUB-546198

Beauty baryons in pp collisions: LHCb results

LHCb PRL 132 (2024) 8, 081901

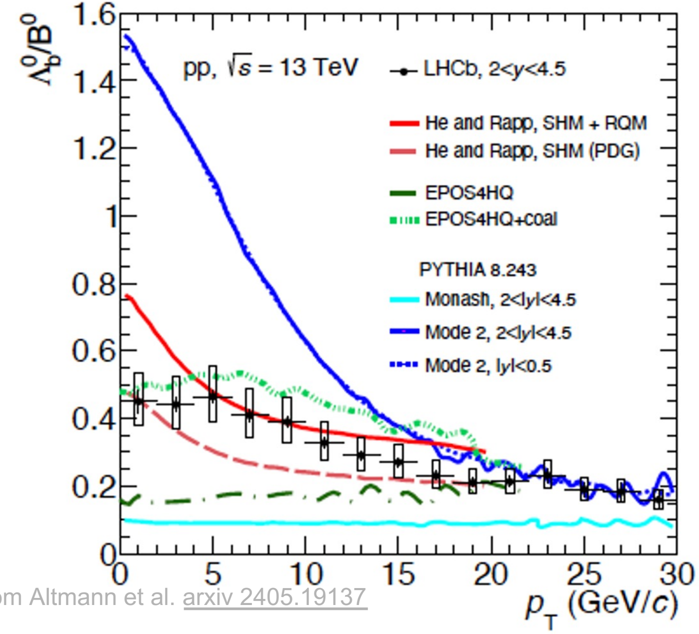
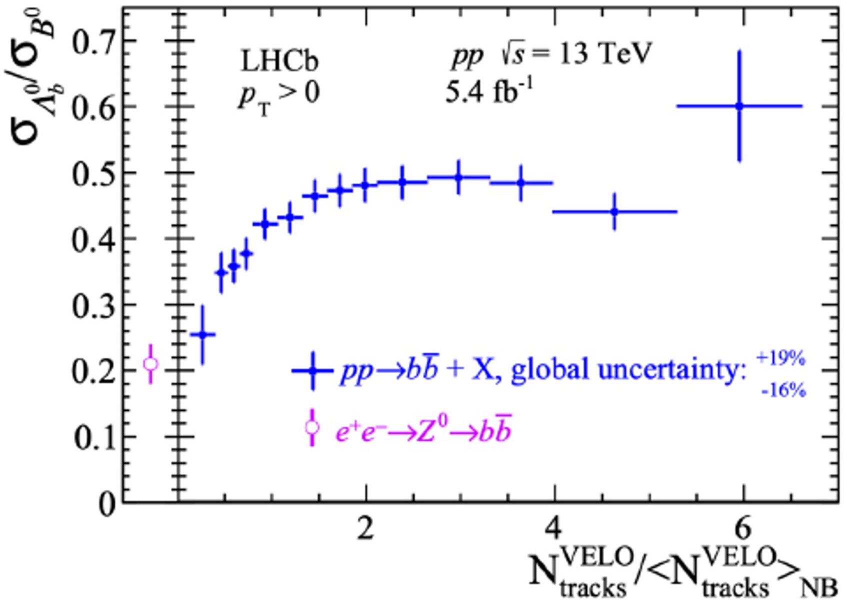


Fig. from Altmann et al. arxiv 2405.19137

LHCb, PRL 132, 081901



Similar trend in beauty and charm sector, discovered even earlier for beauty
- LHCB: PRD 85, 032008 (2012), PRD100 (2019) no.3, 031102, also observed by CDF (see backup)

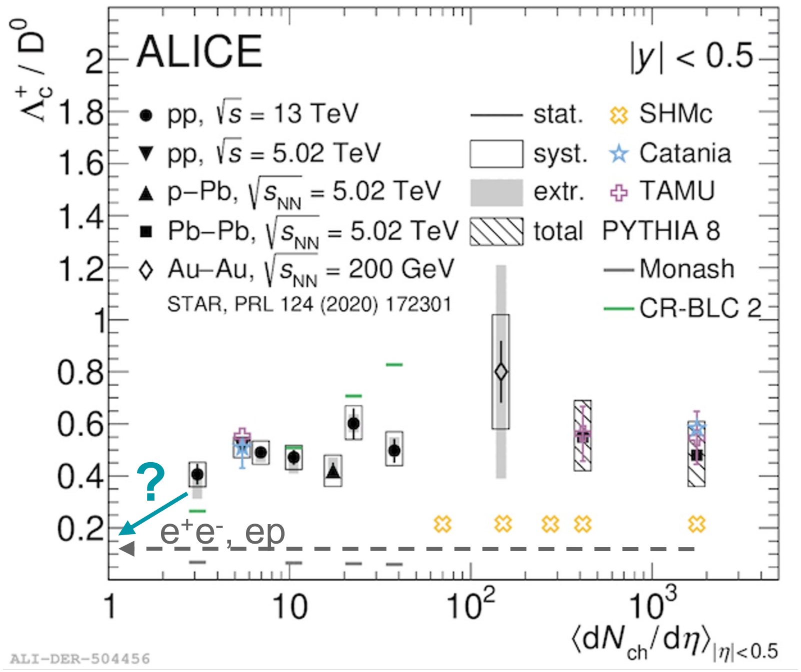
Ratio of p_T-integrated yields: **"turn-on" curve at low multiplicity than flat trend**

LEP values recovered at **hight p_T and at low multiplicity**: **region of fragmentation dominance**?

SHM+RQM and EPOS4HQ+coal better describe the data

Λ_c^+/D^0 from pp to central AA: p_T-integrated

ALICE, PRC 104 054905 (2021) , PRL 127 202301 (2021), PLB 829 (2022) 137065, PLB 839 (2023) 137796



No evidence of evolution of p_T-integrated Λ_c^+/D^0 ratio despite strong modification of p_T-differential trend (see later)

Data uncertainty large

Significantly higher values than e^+e^-

STAR Au-Au data compatible with ALICE

PYTHIA 8 CR-BLC expects increase with multiplicity

SHMc (Pb–Pb): flat trend **below data** SHMc, JHEP 07 035 (2021

Note: no additional RQM high-mass baryons

TAMU, Catania: similar values in pp and Pb–Pb

TAMU, PRL 124, 4 (2020) 042301; Catania, EPJC 78 4 (2018) 348

Lowest multiplicity still to be covered: will recover e^+e^- as in beauty case?

→ more precise measurements from LHC new runs awaited

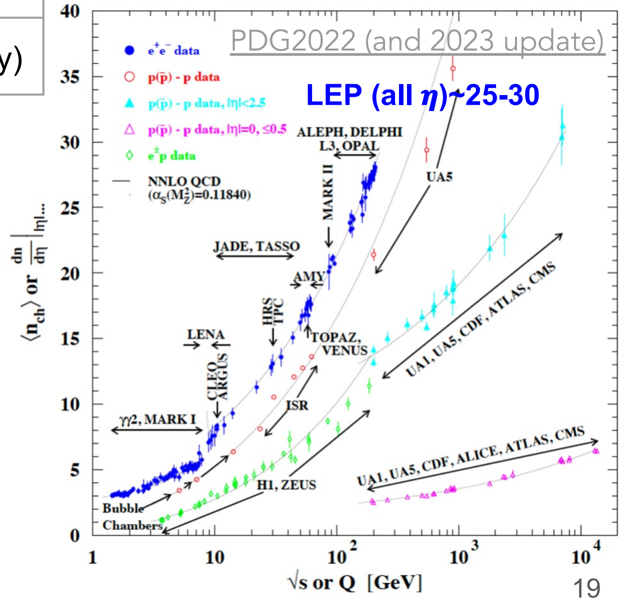
Not just a matter of how many particles

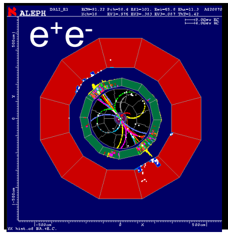
Typical charged particle multiplicities probed, $\langle dN_{ch}/d\eta \rangle (\eta=0)$:

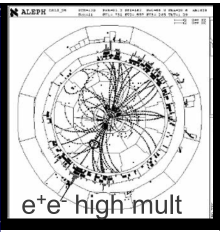
	Low mult.	Min. bias	High mult.
pp (13 TeV)	~4.5	~7 (INEL>0)	~32 (~0.5% of events)
p–Pb (5.02 TeV)	~7	~17 (NSD)	~42 (~5% of events)
Pb–Pb (5.02 TeV)		~415 (30-50% centrality)	~1760 (0-10% centrality)

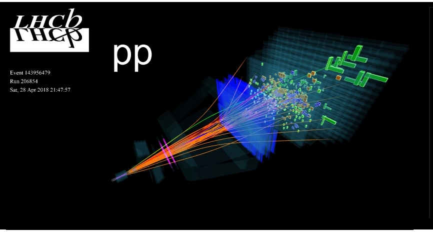
Multiplicities in e^+e^- at LEP not that low (high-energy jets)
Can overlap with pp ones

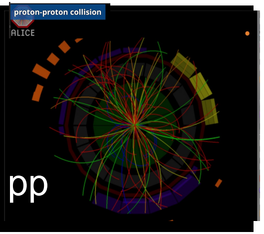
Intrinsic difference: MPI in pp, only 1 scattering in e^+e^-
→ comparison of min. bias pp vs. e^+e^- very sensitive to MPI



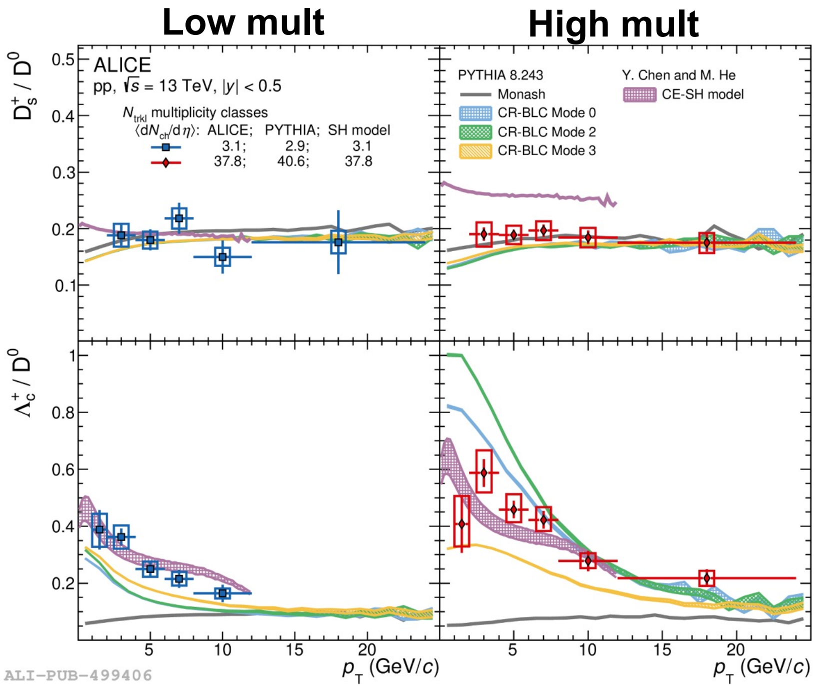








Evolution with event activity: Λ_c^+/D^0 and D_s^+/D^0 vs. p_T in pp



D_s^+/D^0 independent on charged-particle multiplicity

Λ_c^+/D^0 increases with multiplicity at midrapidity

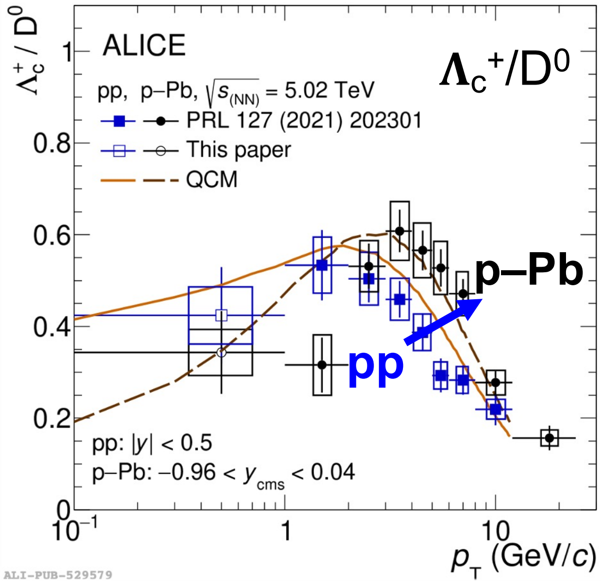
Trends qualitatively reproduced by **PYTHIA 8 with CR-BLC**
→ interplay of Color Reconnection (CR) and MPI

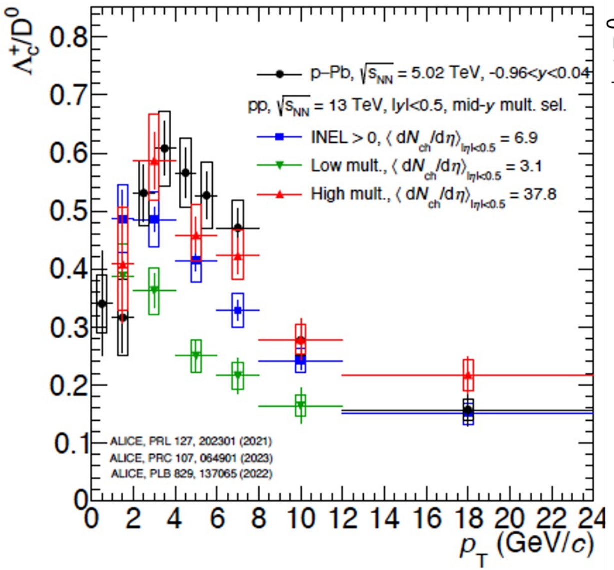
Canonical Ensemble-SH (+ RQM baryons) catches Λ_c^+/D^0 but not D_s^+/D^0 : ratios decrease at low multiplicity from baryon and strangeness number conservation in smaller volume

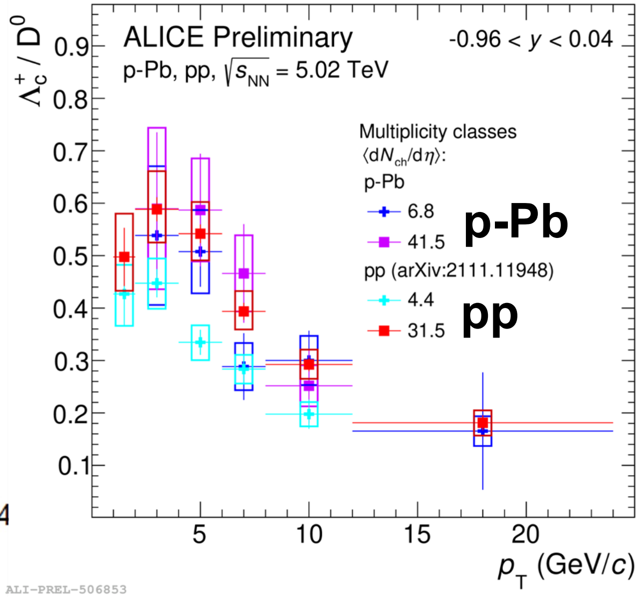
ALICE, PLB 829 (2022) 137065
PYTHIA8: Monash, EPJ C74 (2014) 3024,
CR-BLC JHEP 1508 (2015) 003
CE-SH, PLB 815 (2021) 136144

Λ_c^+/D^0 vs. p_T in pp, p–Pb, Pb–Pb

ALICE, PRC 104 054905 (2021) , PRL 127 202301 (2021), PRC 107 (2023) 064901





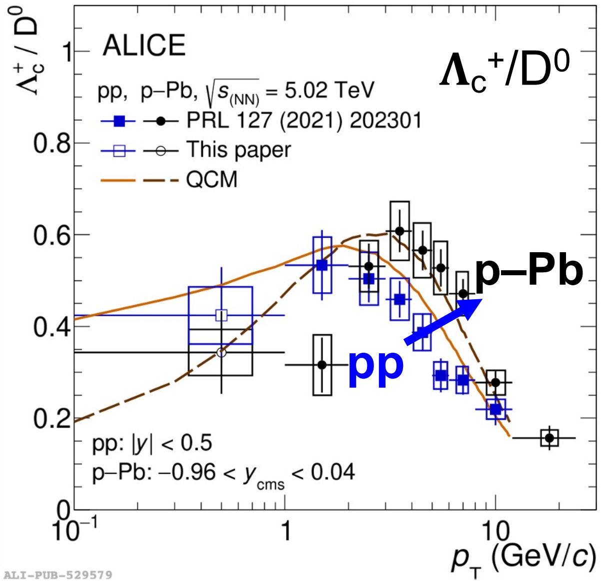


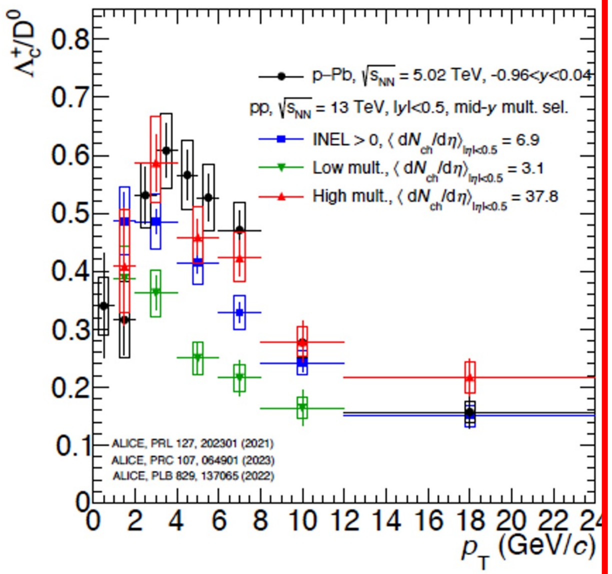
- **Push (flow?) towards higher p_T of Λ_c^+/D^0** from (min bias) pp to p–Pb, described by QCM PRC 97 064915 (2018)
- Similar values in high-mult. pp, low- and high-mult p–Pb

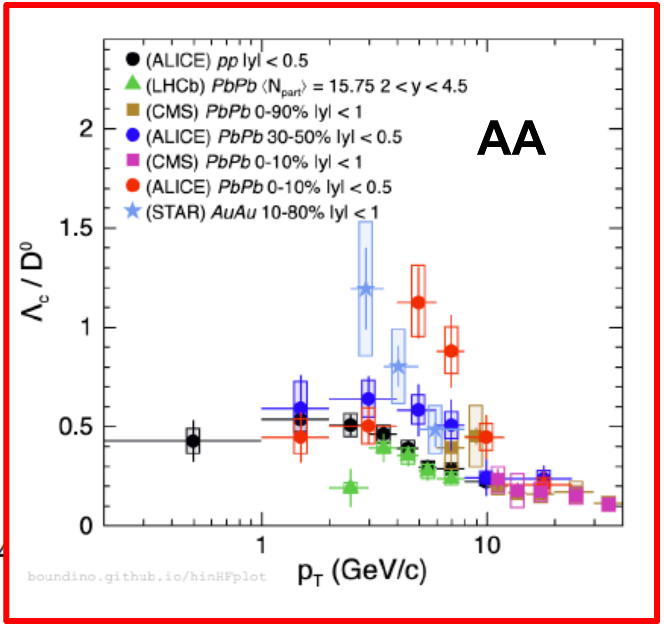
  → **very low multiplicity pp "isolated", ~threshold effect?**

Λ_c^+/D^0 vs. p_T in pp, p–Pb, Pb–Pb

ALICE, PRC 104 054905 (2021) , PRL 127 202301 (2021), PRC 107 (2023) 064901





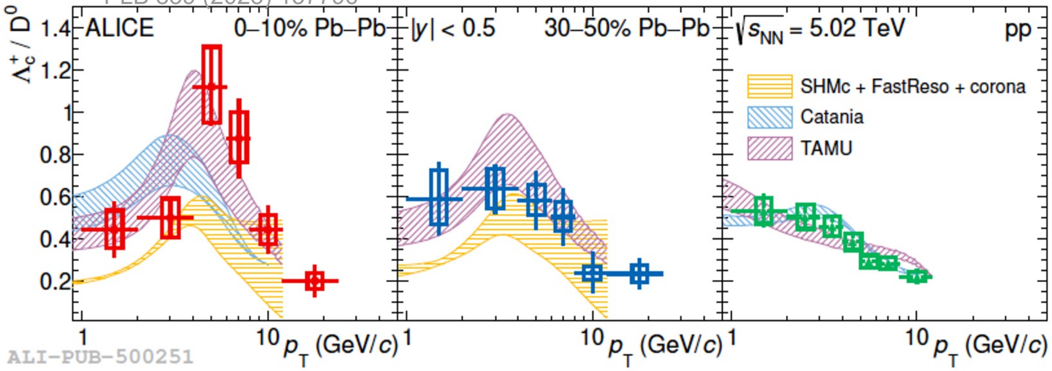


- **Push (flow?) towards higher p_T of Λ_c^+/D^0** from (min bias) pp to p–Pb, described by QCM PRC 97 064915 (2018)
- Similar values in high-mult. pp, low- and high-mult p–Pb, *peripheral and semicentral Pb–Pb*
  → **very low multiplicity pp "isolated", ~threshold effect?**
- ***Central Pb–Pb: "radial-flow"-like peak*** appearing at intermediate p_T, which could be caused by recombination of charm with flowing light quarks

Constraining hadronization in the medium

Λ_c^+/ D^0 evolution with p_T and centrality **described by models with recombination**
Partly also by SHM

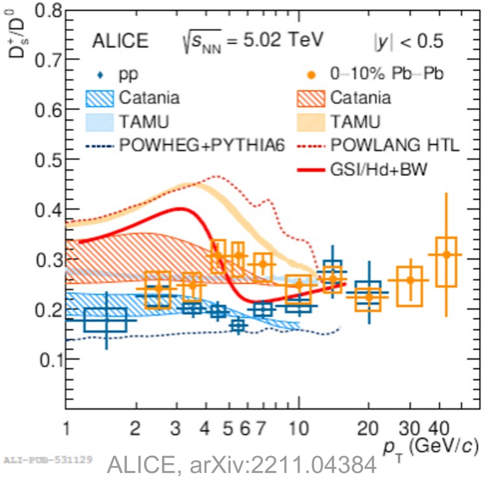
PLB 839 (2023) 137796



Indication higher prompt D_s^+/D^0 in central Pb-Pb than in pp collisions **at intermediate p_T**

Non-prompt D_s^+ (ALICE), **B_s^0** (CMS): **limited precision and momentum coverage** though already telling

→ **look forward to Run 3 measurements**



ALICE, arXiv:2211.04384
PLB 846 (2023) 137561

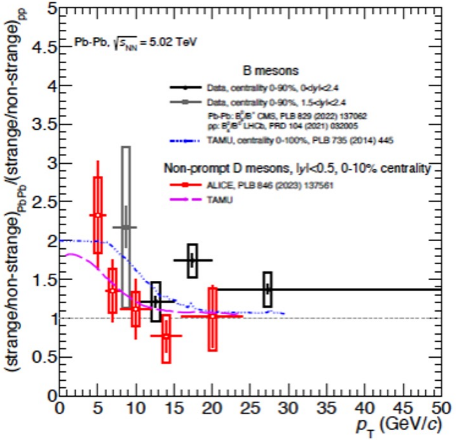
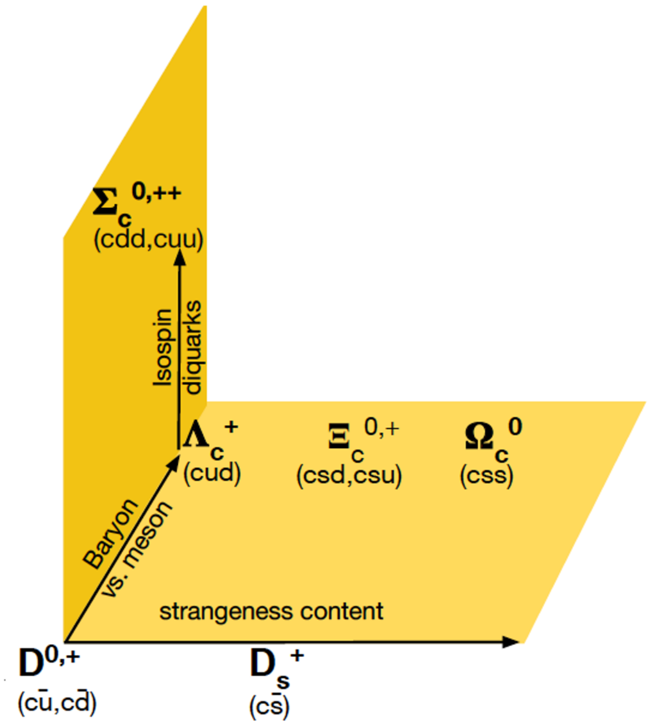


Fig. from arxiv 2405.19137

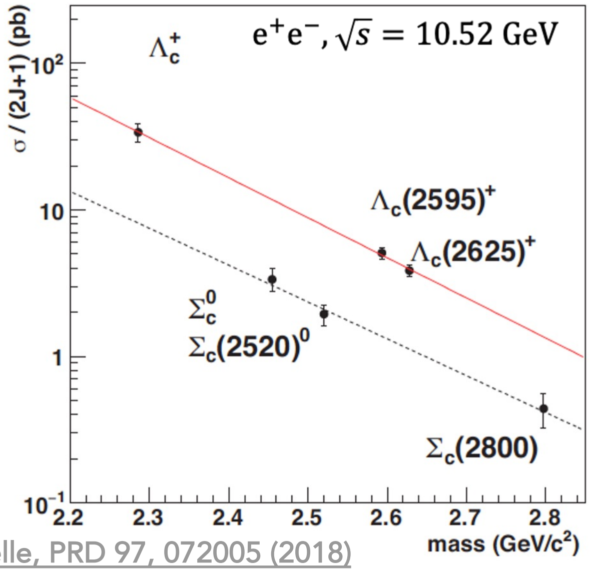
Different baryon species



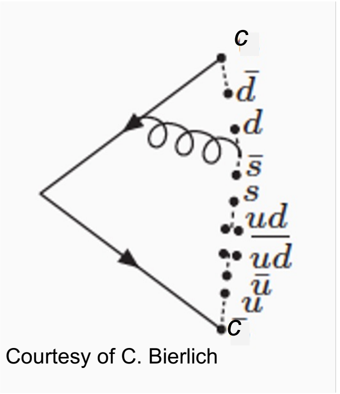
Particle	Mass (GeV/c^2)
D^0	1.865
D^+	1.870
D_s^+	1.968
Λ_c^+	2.286
$\Sigma_c^{0,++}$	2.454
Ξ_c^0	2.470
Ξ_c^+	2.468
Ω_c^0	2.695

$\Sigma_c^{0,++}$ production and $\Lambda_c^+ \leftarrow \Sigma_c^{0,++}$ feedown

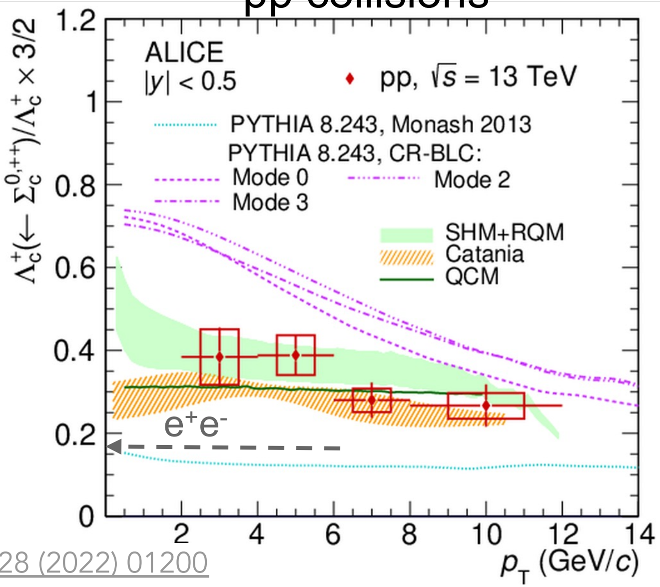
e⁺e⁻ collisions



Belle, PRD 97, 072005 (2018)



pp collisions



PRL 128 (2022) 01200

Σ_c states suppressed w.r.t. Λ_c states

In string fragmentation: from heavier diquark-antidiquark pair from vacuum

Λ_c (isospin = 0) needs spin = 0 diquark $(ud)_0$

Σ_c (isospin = 1) needs spin = 1 diquark $(ud,dd,uu)_1$, which is heavier than $(ud)_0$

$\Lambda_c^+ \leftarrow \Sigma_c^{0,+,++}$ feed-down about twice larger than in e⁺e⁻

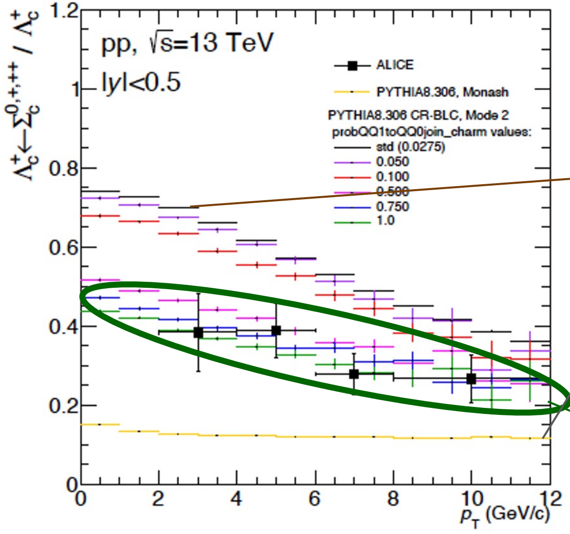
→ $\Sigma_c^{0,+,++}$ "enhancement" larger than Λ_c^+ one

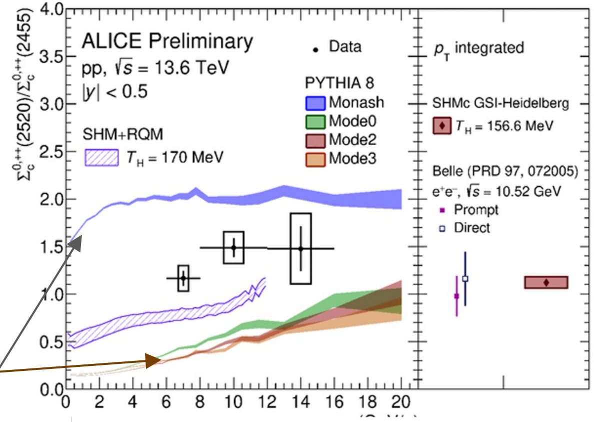
→ **$\Sigma_c^{0,+,++}$ produced differently in pp than e⁺e⁻**

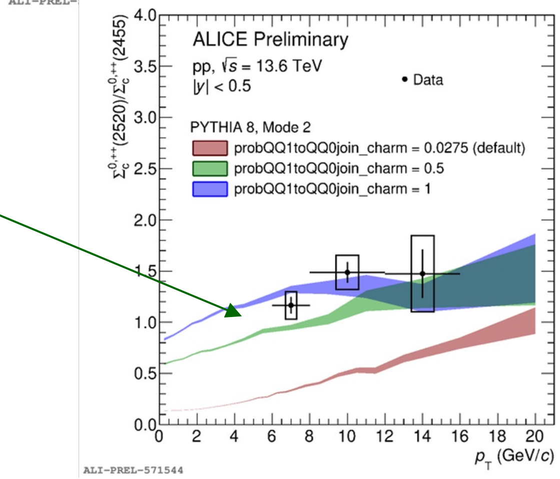
→ **suppression from $(ud,dd,uu)_1$ diquark creation reduced/absent**, as comparison to models suggests

Constraining higher-mass states: $\Sigma_c^{0,++}(2520)/\Sigma_c^{0,++}(2455)$

Tuning of parameter determining the probability to form in junctions a $(cq)_1$ diquark relative to that of $(cq)_0$ diquarks





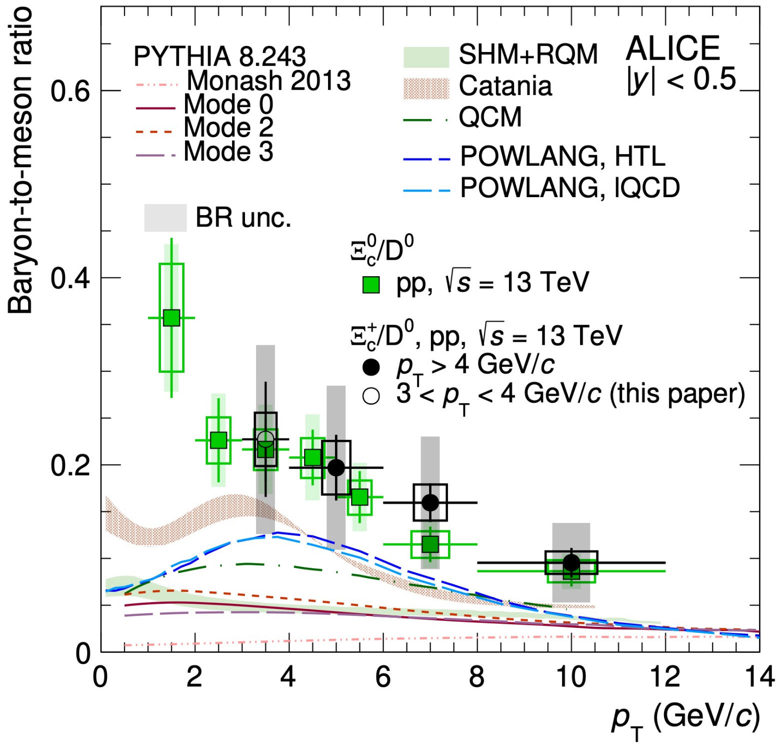


Reasonably, values assuming similar probabilities allow PYTHIA8 to better reproduce the Λ_c^+, $\Sigma_c^{0,++}(2455)$, and $\Sigma_c^{0,++}(2520)$ data

Altmann, Dubla, Greco, AR, Skands arxiv 2405.19137

$\Xi_c^{0,+}/D^0$ baryon-to-meson cross-section ratio

PRL 127 (2021) 272001



Similar trend than Λ_c^+/D^0

Even **larger increase** w.r.t. PYTHIA 8 Monash and e^+e^-

PYTHIA 8 with CR-BLC and **SHM+RQM** expect significant larger values than e^+e^- but underestimate the data

Catania, POWLANG and **QCM** expectation close to data

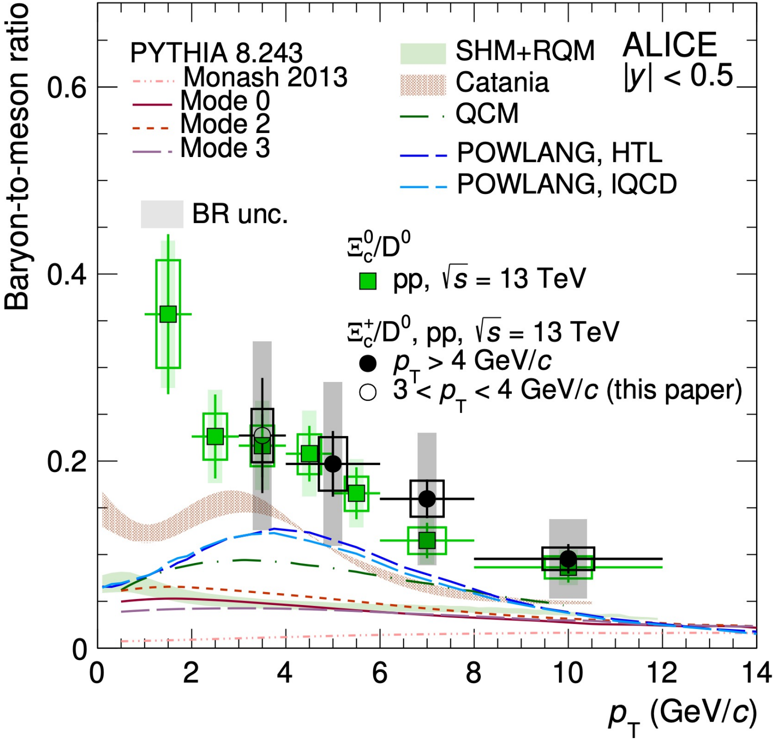
POWLANG (PRD **109**, L011501): local colour-neutralization mechanism
1) HQ recombined with light quark/diquarks from thermal source
2) Cluster decay or string fragmentation of the pair, depending on the pair mass

Large branching ratio (BR) uncertainty

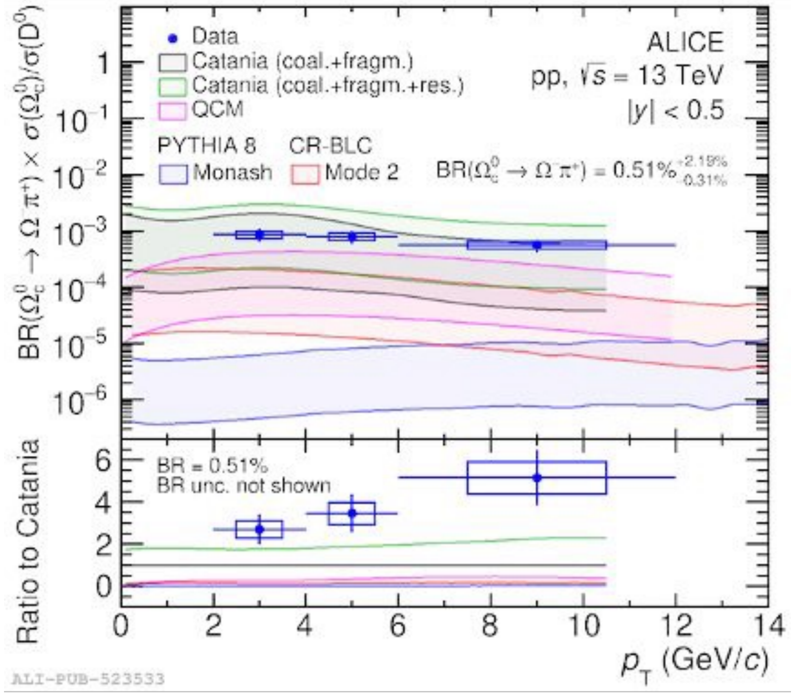
Run 3 data will allow to reduce experimental uncertainty

$\Xi_c^{0,+}/D^0$ and Ω_c^0/D^0 baryon-to-meson ratios

PRL 127 (2021) 272001

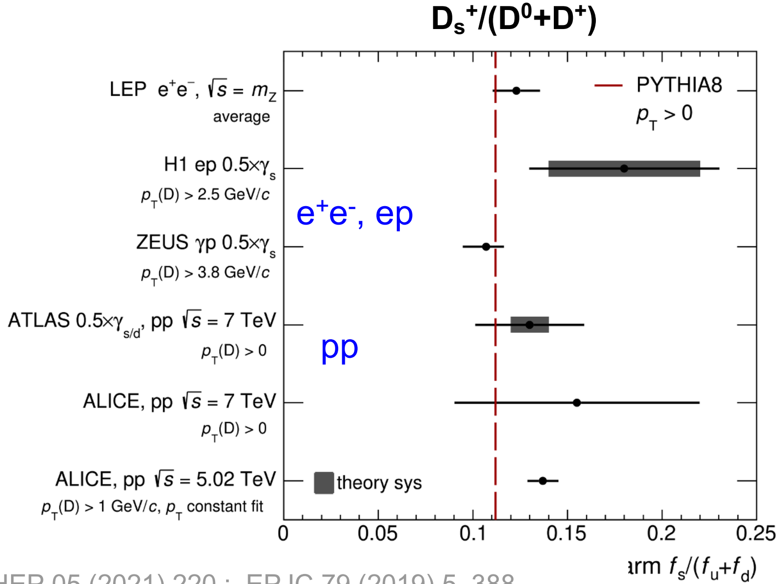


PLB 846 (2023) 137625

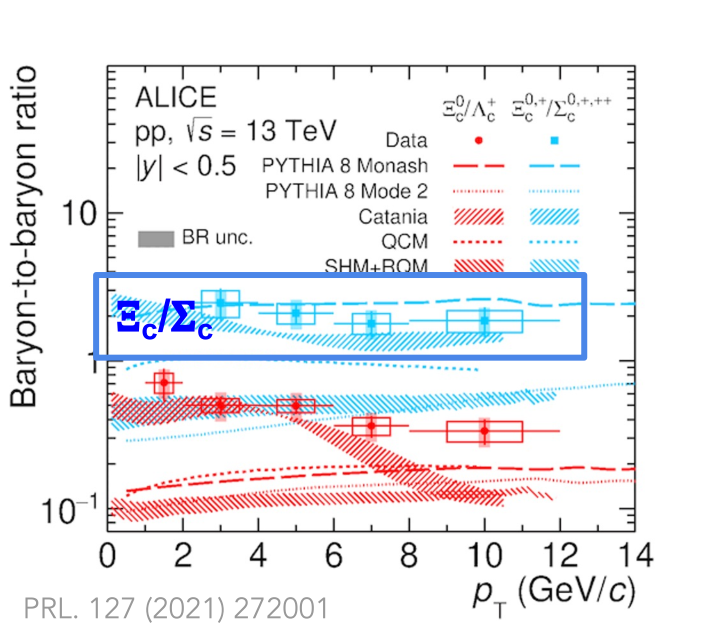


Unknown BR prevents from concluded
High sensitivity to model details

Baryon-to-baryon: $\Xi_c^{0,+}$ and $\Sigma_c^{0,++}$



JHEP 05 (2021) 220 ; EPJC 79 (2019) 5, 388



PRL. 127 (2021) 272001

Differently to Ξ_c/D^0, $D_s^+/(D^0+D^+)$ (prompt and non-prompt) compatible with expectations from e^+e^-

$\Xi_c^{0,+}/\Sigma_c^{0,+,++}$ ratio close to default PYTHIA8, which strongly underestimates their production

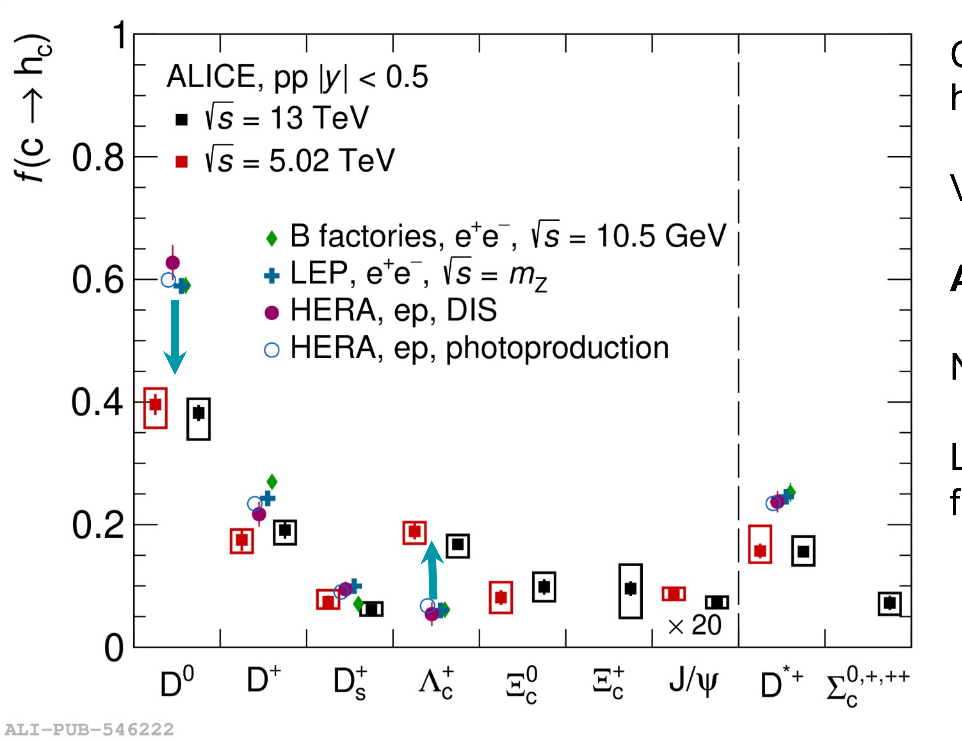
→ **similar suppression in e^+e^-? Related to diquark rather than quarks?**

(note mass of spin-1 $(dd,ud,uu)_1$ diquarks might be similar to spin-0 $(us,ds)_0$ diquarks)

Fragmentation fractions: pp vs. e^+e^- collisions

ALICE, ALICE, JHEP 12 (2023) 086

→ C. Terrevoli's talk



Calculated from sum of cross sections of weakly decaying hadrons

Values for mesons significantly lower than in e^+e^-

About 30-40% of charm quarks hadronise to baryons

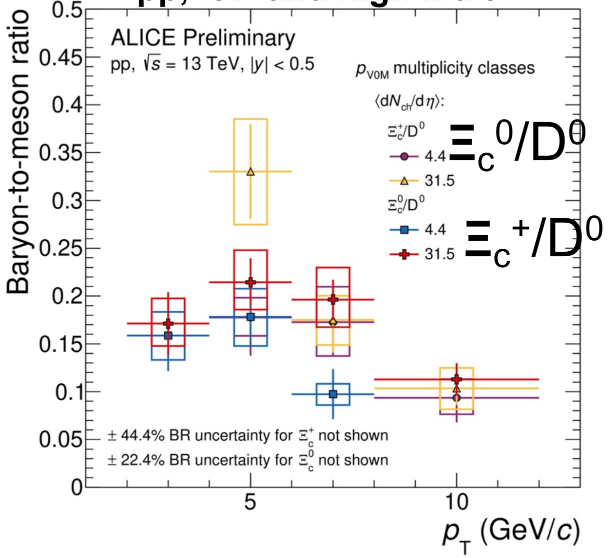
No evidence of energy dependence

Lower p_T reach expected with Run 3 data will allow to further reduce extrapolation uncertainties

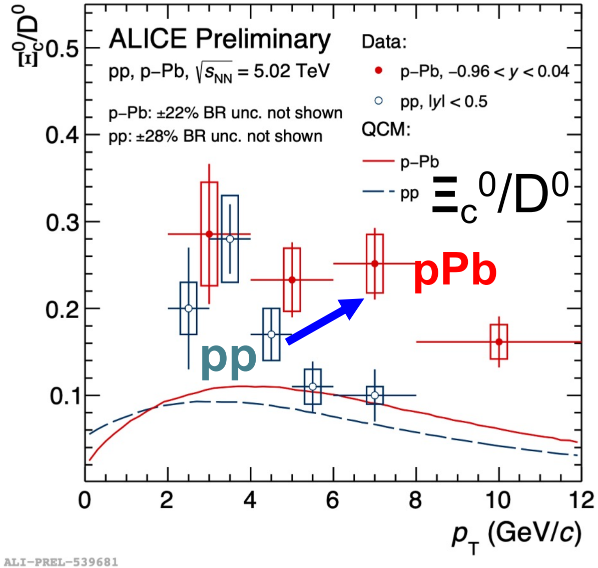
Evolution with event activity in pp and p–Pb: $\Xi_c^{0,+}$

ALICE, PRC 104 054905 (2021) , PRL 127 202301 (2021), PRC 107 (2023) 064901

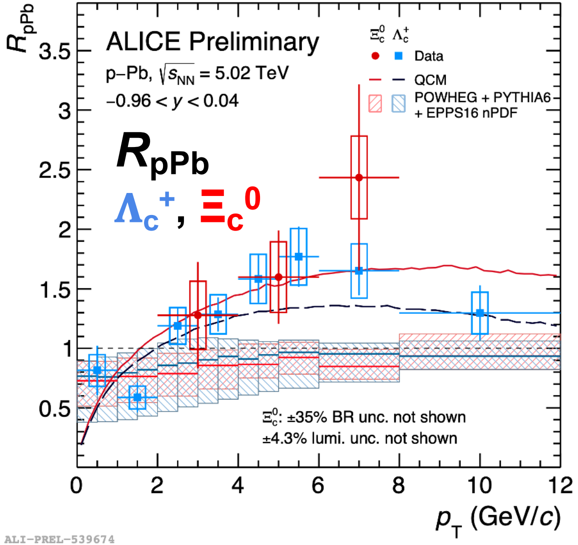
pp, low and high mult



ALI-PREL-548915



ALI-PREL-539681



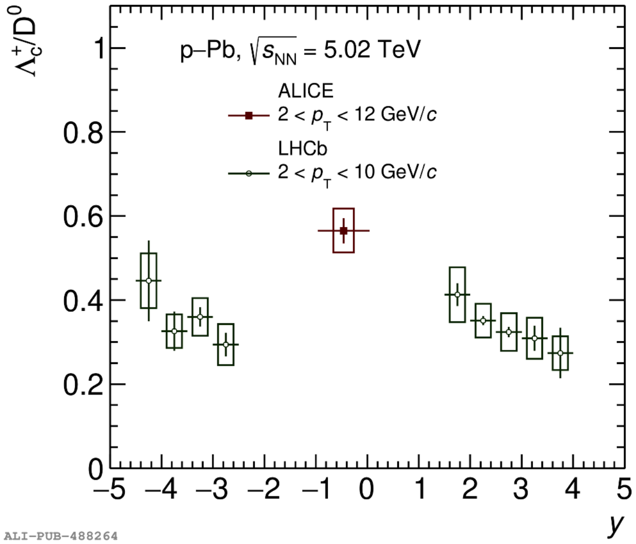
ALI-PREL-539674

- Precision not enough to conclude about multiplicity trend of $\Xi_c^{0,+}/D^0$ in pp → Run 3 data needed
- **p–Pb: similar push towards higher p_T observed for Λ_c^+/D^0 and $\Xi_c^{0,+}/D^0$ ratios**
    - Similar nuclear modification factor (R_{pPb})
    - Described by QCM within uncertainties QCM: PRC 97 064915 (2018)

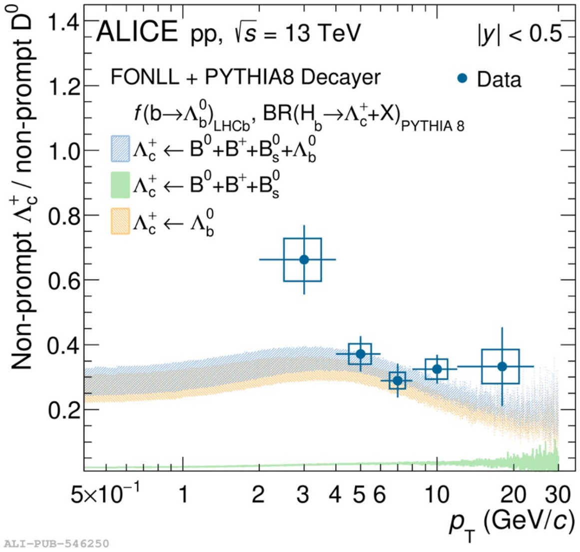
Rapidity dependence

Rapidity dependence

charm, p–Pb



beauty, pp



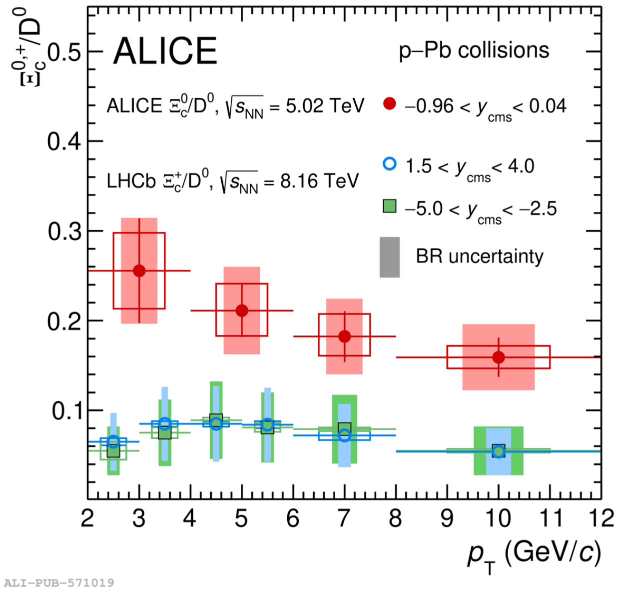
Possible dependence on rapidity of Λ_c^+/D^0? To be revisited with run 3 data (also in pp)

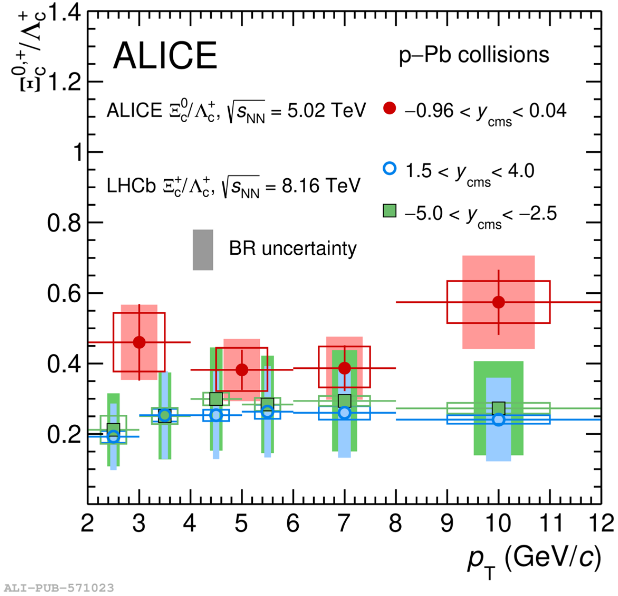
Beauty: non-prompt Λ_c^+ ALICE data consistent with LHCb Λ_b^0 data
→ low p_T region to be explored with run 3 data

What should we expect in coalescence models and SHM?

ALICE, JHEP 04 (2018) 108
ALICE, PRC 104 054905 (2021)
LHCb (p-Pb), JHEP 02 102 (2019)
ALICE, beauty: arxiv 2308.04873
LHCb, beauty: PRD100 (2019) no.3, 031102

Rapidity dependence





arxiv 2405.14538

Possible dependence on rapidity of Λ_c^+/D^0? To be revisited with run 3 data (also in pp)

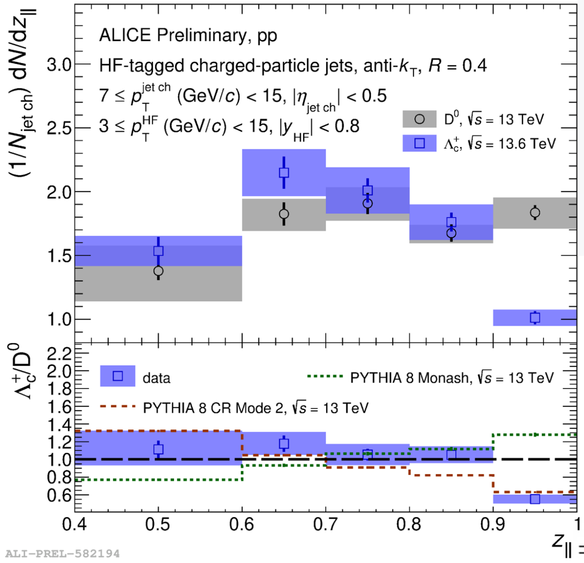
- May apply also to $\Xi_c^{0,+}/D^0$

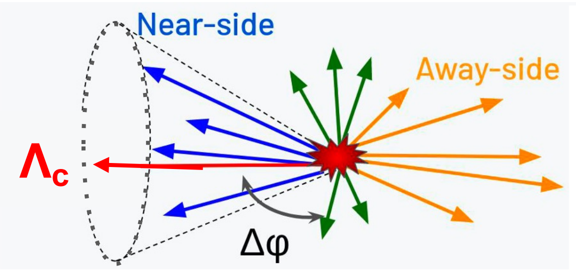
Beauty: non-prompt Λ_c^+ ALICE data consistent with LHCb Λ_b^0 data
→ low p_T region to be explored with run 3 data

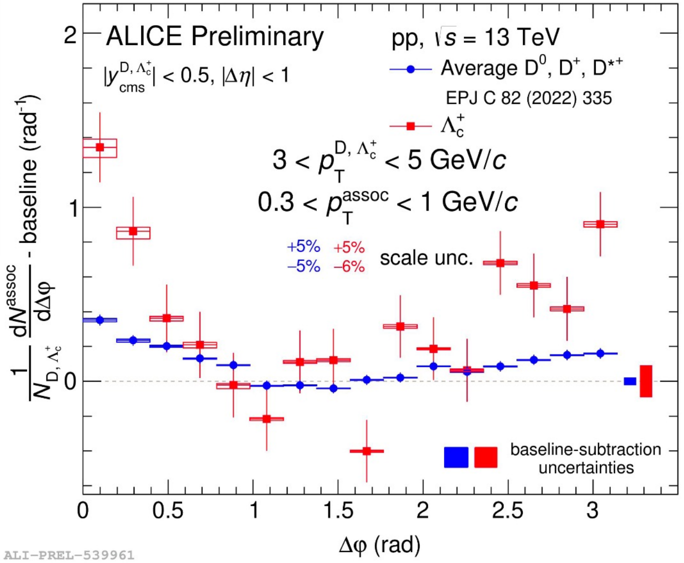
What should we expect in coalescence models and SHM?

ALICE, JHEP 04 (2018) 108
ALICE, PRC 104 054905 (2021)
LHCb (p-Pb), JHEP 02 102 (2019)
ALICE, beauty: arxiv 2308.04873
LHCb, beauty: PRD100 (2019) no.3, 031102

Jets and correlations







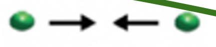
$$z_{\parallel} = \frac{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{HF}}}{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{ch\ jet}}}$$

- Jets: indication of **softer fragmentation c→Λ_c than c→D**
- Coherent with higher associated yield in the nearside of Λ_c^+ - hadron azimuthal correlations w.r.t. D-hadron
  … away side surprisingly high!!! No straightforward explanation
  Higher-mass states + decay kinematics? Production process? Do Λ_c^+ come on average from higher-p_T jets?

Summary: HF hadronisation in our QCD laboratories

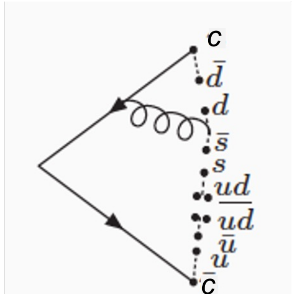
Hadronization universality violated already in pp collisions
Multiple parton interactions in pp build a system rich of quarks or gluons, dense enough to alter hadronisation w.r.t. e^+e^-

e^+e^- = "vacuum"



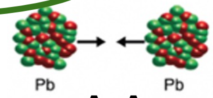
pp
~~not far from vacuum ~ many independent scatterings~~
(for HF at least)

Dynamical model
"Local" dynamical constraints
(e.g. Lund string fragmentation, quarks and diquarks popping out from QCD potential)

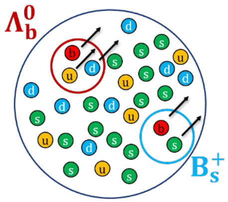


Courtesy of C. Bierlich

MPI, system size



A-A
Dense, extended-size system
Equilibrium
Flow



(Semi)phenomenological models sufficient to describe relative particle abundances *once ingredients are tuned*?

Summary: HF hadronisation in our QCD laboratories

From experimental side, quite clear picture emerged, **general trends established**

Main open points:

- Explain $\Xi_c^{0,+}$, $\Omega_c^{0,+}$ **baryons and** D_s^+ **mesons** in a coherent picture
- **Rapidity** puzzle
- HF **jets and correlations** (to be revisited with improved experimental precision)

Consolidation of emerging picture to better constrain models

- More precise and p_T - differential measurements **down to** $p_T = 0$
- Especially for $\Xi_c^{0,+}$, $\Omega_c^{0,+}$ and $\Sigma_c^{0,++}$
- Cover **low multiplicity** for charm

Spectroscopy: measure production of **higher-mass states** and search for new ones

Understand role of **diquarks**

Further information expected from **B_c, tetra and pentaquark-candidate states, and multi-charm**

谢谢！

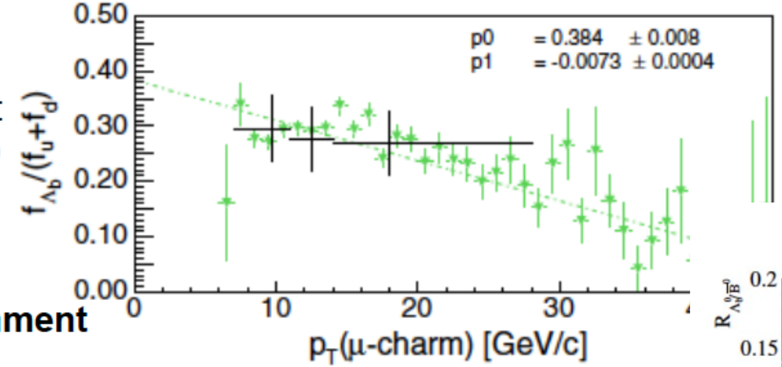
Λ_b^0 from LEP to Tevatron

Before CDF measurement in ppbar collisions, the world average of the ratio Λ_b to (B^- + anti-B^0) ratio was dominated by LEP data (DELPHI, Z. Phys. C **68**, 375 (1995), Eur. Phys. J. C **2**, 197 (1998)) in Z-boson hadronic decays

$$\frac{f_{\Lambda_b}}{f_u + f_d} \sim 0.125 \pm 0.042$$

S. Eidelman et al, PDG, PLB 592 1 (2004)

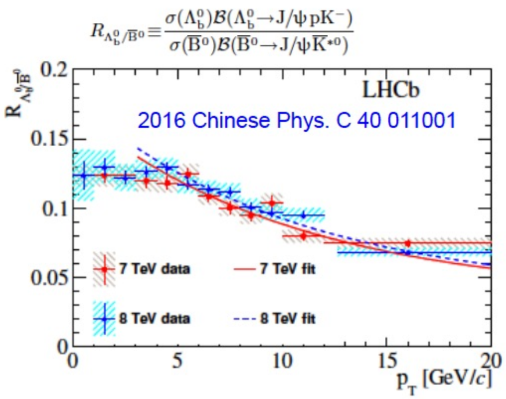
CDF found a higher value (~0.28, 2.3σ higher) in ppbar collisions at √s=1.96 TeV (PRD 77 072003 (2008))



Possible explanations mentioned:

- **Dependence on bottom-hadron p_T:** <p_T (b)>~ 15 (45) GeV/c at Tevatron (LEP)
  - Supported by different Λ_b and B p_T spectrum shapes and dedicated studies
- **Different hadro-production environment**

Compare to LHCb trend

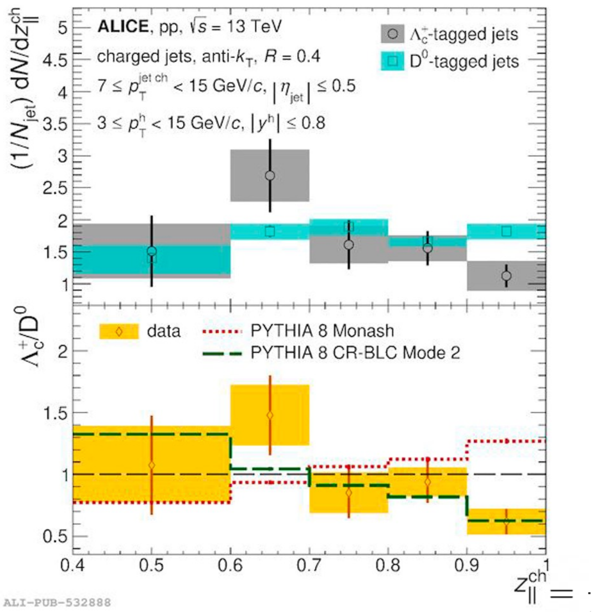


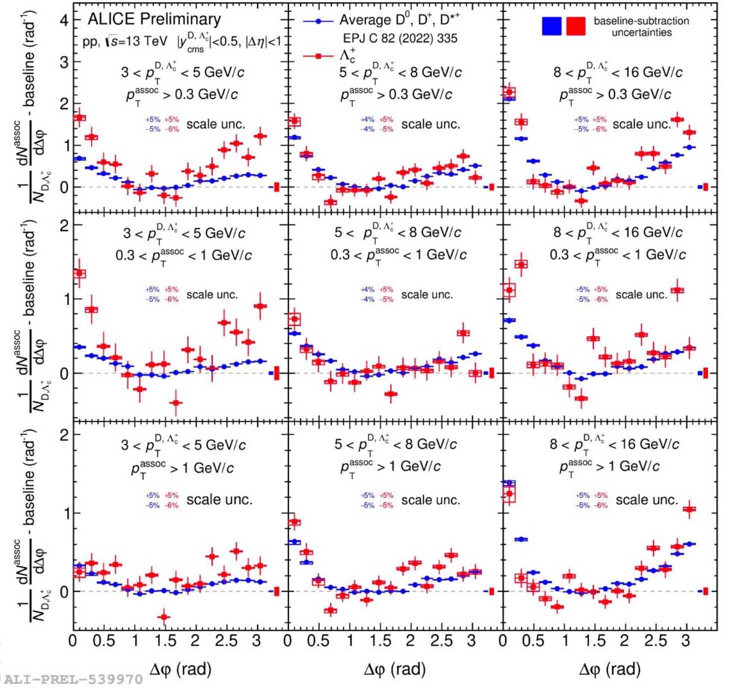
b hadron	Fraction at Z[%]	Fraction at $\bar{p}p$ [%]
B^+, B^0	41.2 ± 0.8	34.0 ± 2.1
B_s^0	8.8 ± 1.3	10.1 ± 1.5
b baryons	8.9 ± 1.2	21.8 ± 4.7

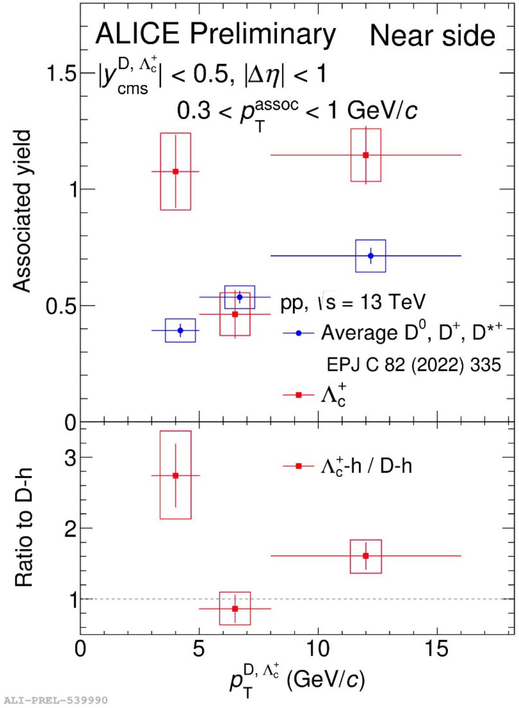
HFLAAV, EPJC 77 (2017) 895

Jets and correlations

ALICE, PRD 109 (2024) 072005







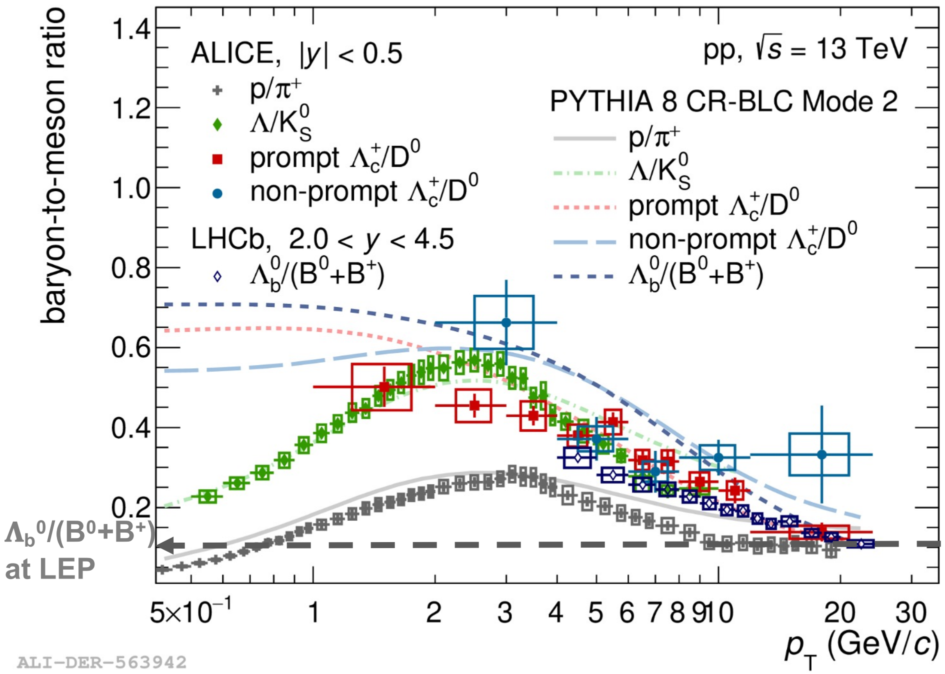
Large Near Side… Large Away Side!

suggests that the $z_{//}$ distribution (and NS) are not altered because of local effect coming with hadronisation

→ The most natural, straightforward conclusion we have is that a large fraction of low-p_T Λ_c^+ comes from moderate-high-p_T jets!

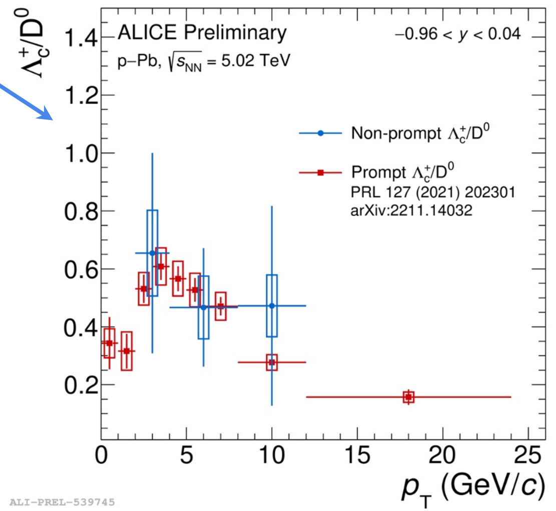
Beauty vs. charm (and light flavour)

ALICE, PRD 108 (2023) 11, 112003
LHCb, PRD100 (2019) no.3, 031102



Non-prompt Λ_c^+ / non-prompt D^0 similar to Λ_c^+/D^0

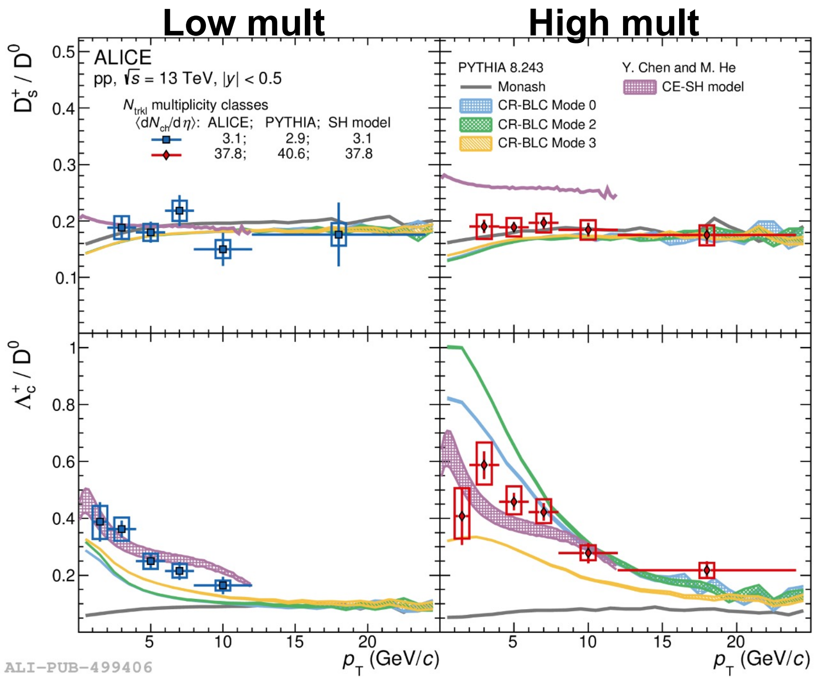
- also in p–Pb collisions (large uncertainties)

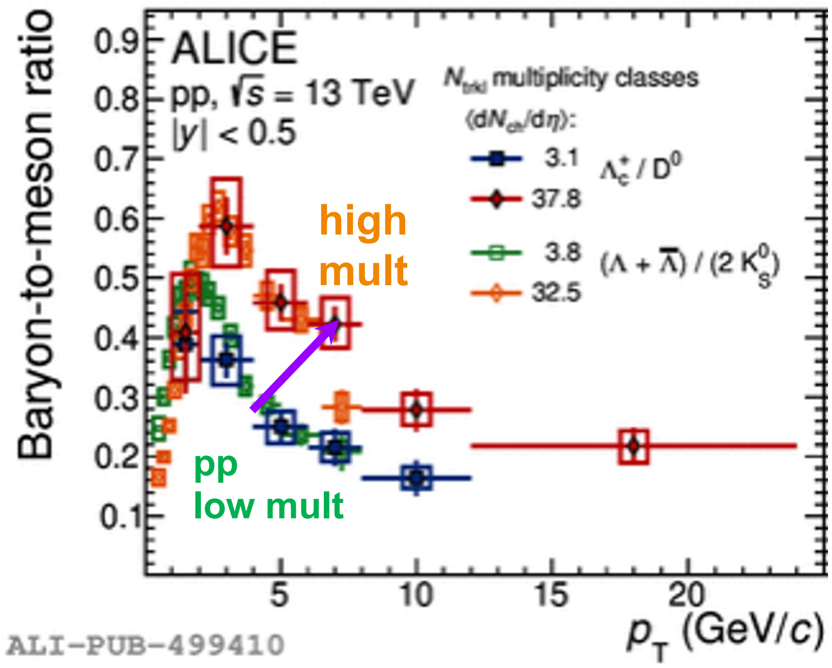


Similar p_T trend for charm, beauty, and light-flavour baryon-to-meson ratios for p_T>2 GeV/c

PYTHIA8 CR-BLC JHEP 1508 (2015) 003

Evolution with event activity: Λ_c^+/D^0 and D_s^+/D^0 vs. p_T in pp





ALICE, PLB 829 (2022) 137065
PYTHIA8: Monash, EPJ C74 (2014) 3024,
CR-BLC JHEP 1508 (2015) 003
CE-SH, PLB 815 (2021) 136144

Similar trend than Λ/K_s^0

D_s^+/D^+ from ALICE with run 3 data