Margaret Island Symposium 2022

The role of the underlying event in the charmed-baryon enhancement in high-energy pp collisions

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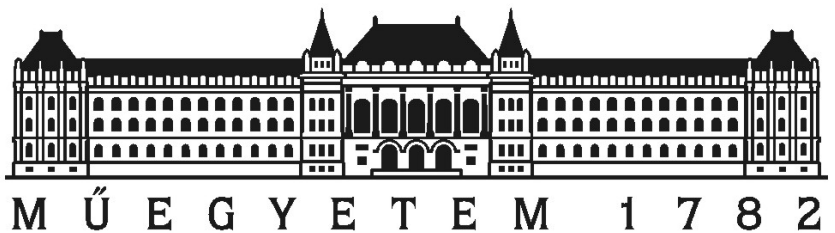
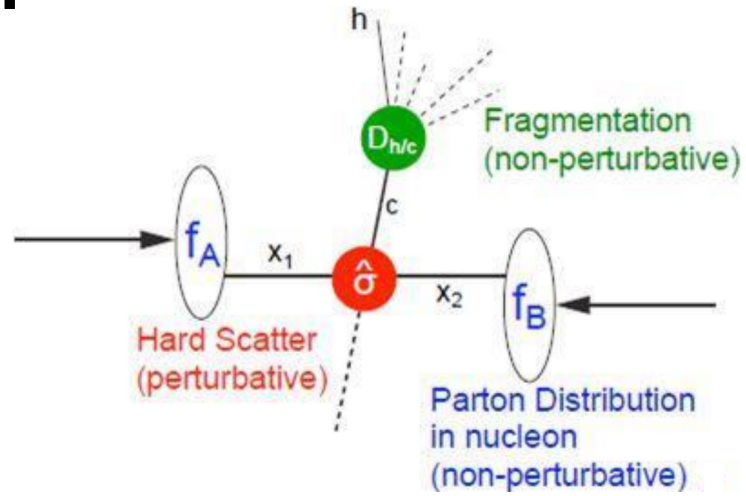


Motivation

- Heavy-flavor hadrons are created through the fragmentation of heavy quarks into mesons and baryons.
  - pQCD has been succesful at several energies at the LHC to describe the production of HF mesons
- Description relies on the **factorization approach**, in which the production cross section of the heavy-flavor particles factorizes into **3 independent contributions:** PDFs of colliding hadrons, the parton-parton scattering cross-section and the fragmentation function:



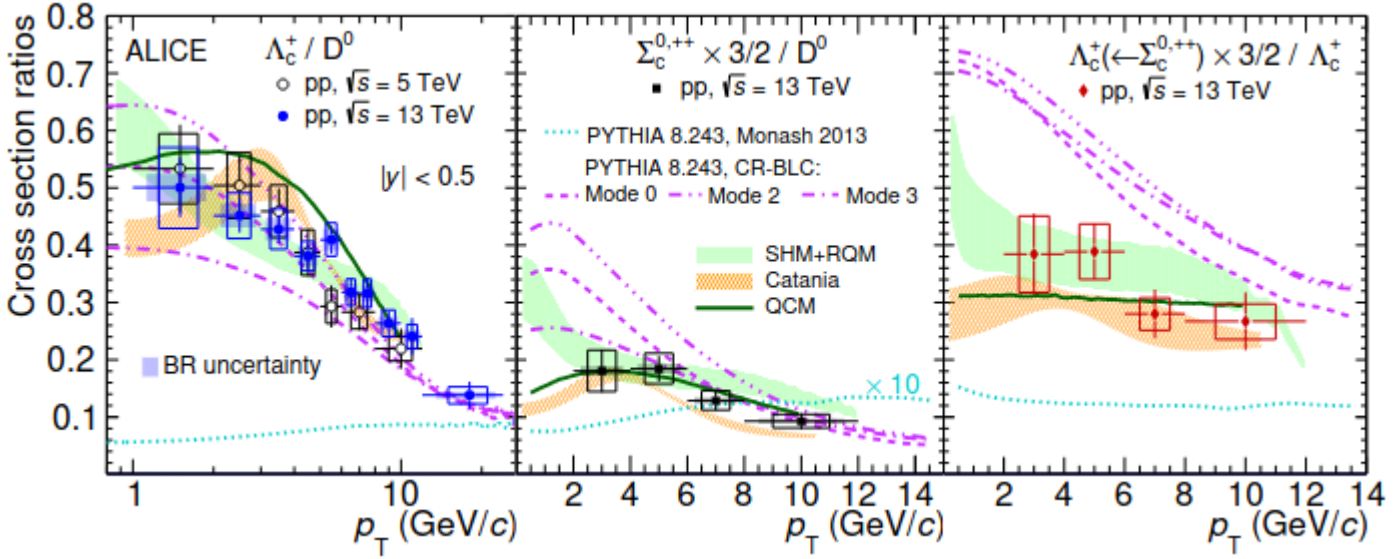
$$d\sigma^{hard}_{AB\to C} = \sum_{a,b} f_{a/A}(x_a, Q^2) \otimes f_{b/B}(x_b, Q^2) \otimes d\sigma^{hard}_{ab\to c}(x_a, x_b, Q^2) \otimes D_{c\to C}(z, Q^2)$$

Parton Distribution Function (PDF) | Partonic hard scattering cross-section | Fragmentation Function (FF)

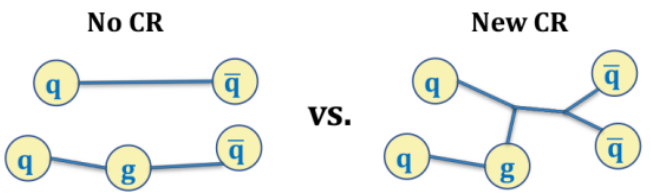
- Traditional assumption: fragmentation functions are **universal** for different collision systems
  - therefore often determined from e^-e^+ (or e^-p) collisions, where PDF plays no (or less important) role
- Recent experimental results (ALICE, CMS, LHCb) on charmed baryon production **do not support** this assumption!

Charm baryon enhancement

ALICE Coll., "Measurement of prompt D0, Lambda_c+, and Sigma_c{0,++}(2455) production in pp collisions at sqrt(s) = 13$ TeV" (arXiv:2106.08278)

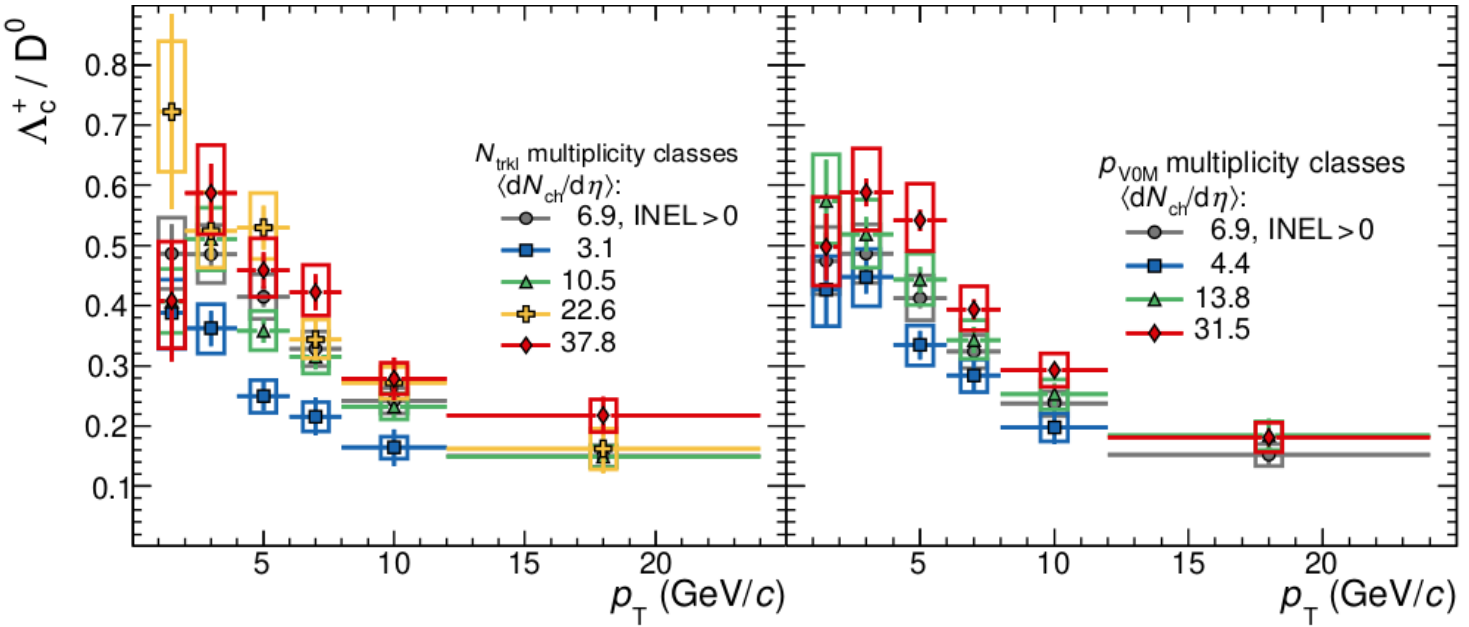


- **Ratios of charm-baryon to charm-meson yields show a p_T dependent enhancement compared to e^-e^+ results**
- **Several scenarios are proposed to explain this observation:**
  - String formation beyond leading color (CR-BLC) (arXiv:1505.01681 [hep-ph]),
  - Augmented set of charm baryon states (SHM + RQM) (arXiv:1902.08889 [nucl-th]),
  - Coalescence models: Catania (arXiv:1712.00730 [hep-ph]) and Quark Comb. Mech. (QCM) (arXiv:1801.09402 [hep-ph]).



The enhancement depends on the multiplicity

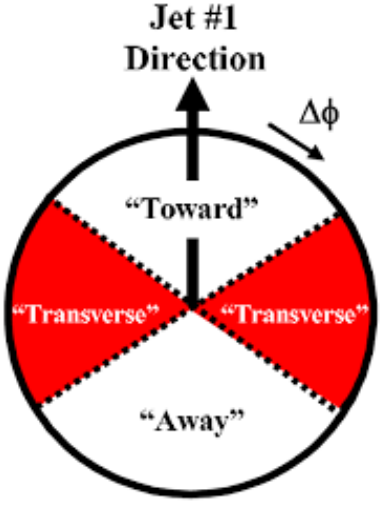
ALICE Coll. Observation of a multiplicity dependence in the pT-differential charm baryon-to-meson ratios in proton-proton collisions at s√=13 TeV (Phys.Lett.B 829 (2022) 137065)



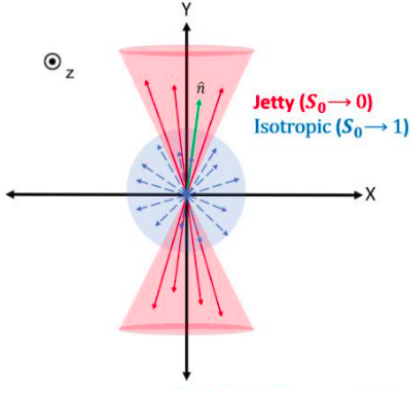
- The enhancement in Λ_c/D^0 also depends on the final state multiplicity at mid-/forward rapidity.
- The Λ_c/D^0 enhancement with respect to event-activity qualifiers provides sensitive propes to access the source of the enhancement and to differentiate between the different proposed mechanisms.
- **Goal: Understand the origin of the enhancement with detailed event activity studies.**
- Using standalone PYTHIA 8 to test the observable effects of the CR-BLC model.

Event activity classifiers

- **N_{CH}** – multiplicity at mid-rapidity ($|\eta| < 1$): number of final state charged particles, describing the activity of the whole event.
- **N_{fw}** - forward multiplicity at forward rapidity ($2 < \eta < 5$),
- **R_T** = $N_{CH}^{transverse}$ / $\langle N_{CH}^{transverse} \rangle$: underlying event activity, region excluding jets from the leading process. ($\pi/3 < |\Delta\phi| < 2\pi/3$)
- **R_{NC}** = $N_{CH}^{near\text{-}side\ cone}$ / $\langle N_{CH}^{near\text{-}side\ cone} \rangle$: activity connected to the jet region, containing the leading process. $\sqrt{(\Delta\phi^2+\Delta\eta^2)} < 0.5$
- **S_0**: spherocity, measures how spherical or jet-like the event is.

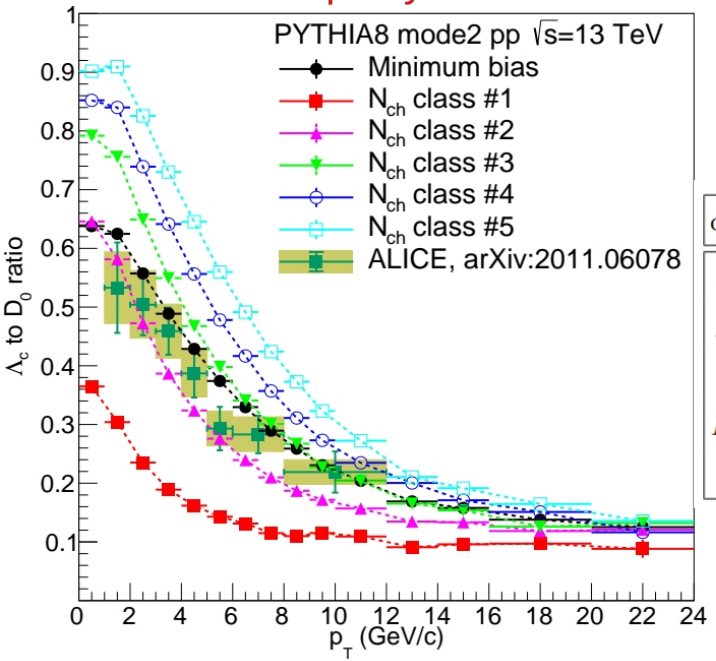


$$S_0 = \frac{\pi^2}{4} \times \min_{\hat{n}=(n_x,n_y,0)} \left(\frac{\Sigma_i \, | \vec{p}_{T_i} \times \hat{n} |}{\Sigma_i \, \vec{p}_{T_i}} \right)^2$$



Λ_c/D^0 yield ratios

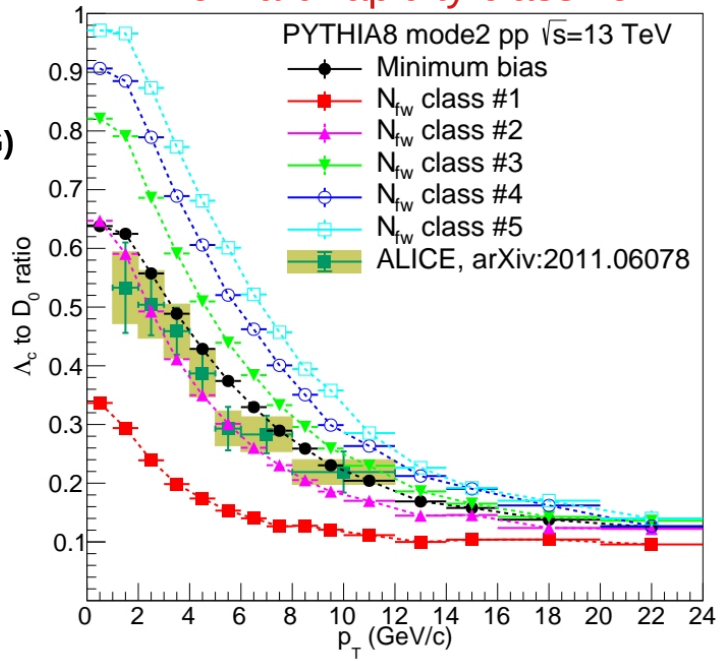
Central rapidity classifier



arXiv:2111.00060 (accepted in J.Phys.G)

class	#1	#2	#3	#4	#5
N_{ch}	≤15	16–30	31–40	41–50	≥51
N_{fw}	≤45	46–90	91–120	121–150	≥151
R_T	<0.5	0.5–1	1–1.5	1.5–2	>2
R_{NC}	<0.5	0.5–1	1–1.5	1.5–2	>2
S_0	0–0.25	0.25–0.45	0.45–0.55	0.55–0.75	0.75–1

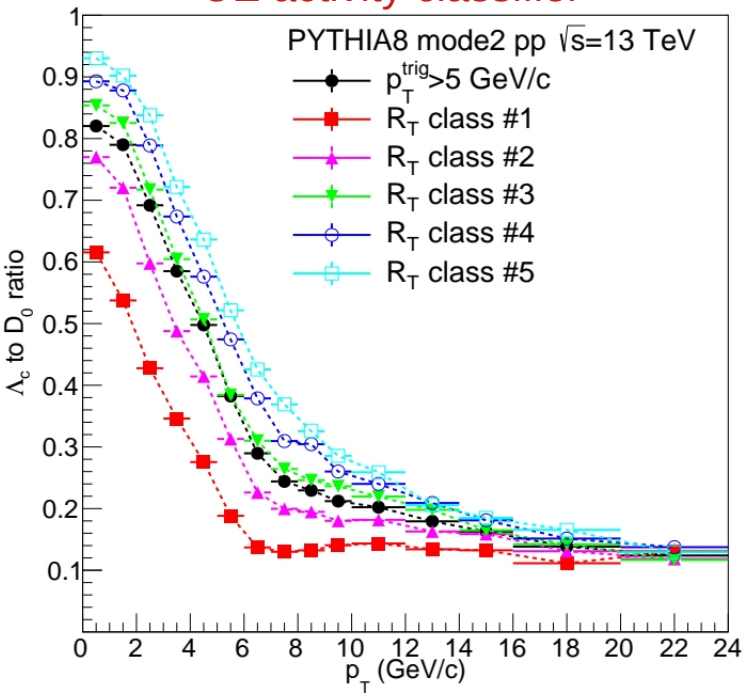
Forward rapidity classifier

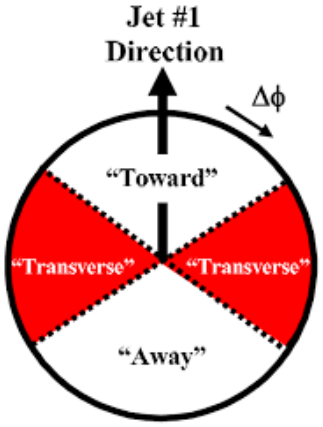


- Simulation results are **in agreement** with the ALICE **experimental data**.
- Recently observed multiplicity trends reproduced.
- For N_{fw}: a **rapidity gap** is present, which **reduces the correlation** between leading hard processes and the multiplicity.
- Multiplicity dependence <u>not driven</u> by charm production in jets.

Λ_c/D^0 yield in triggered events

UE activity classifier





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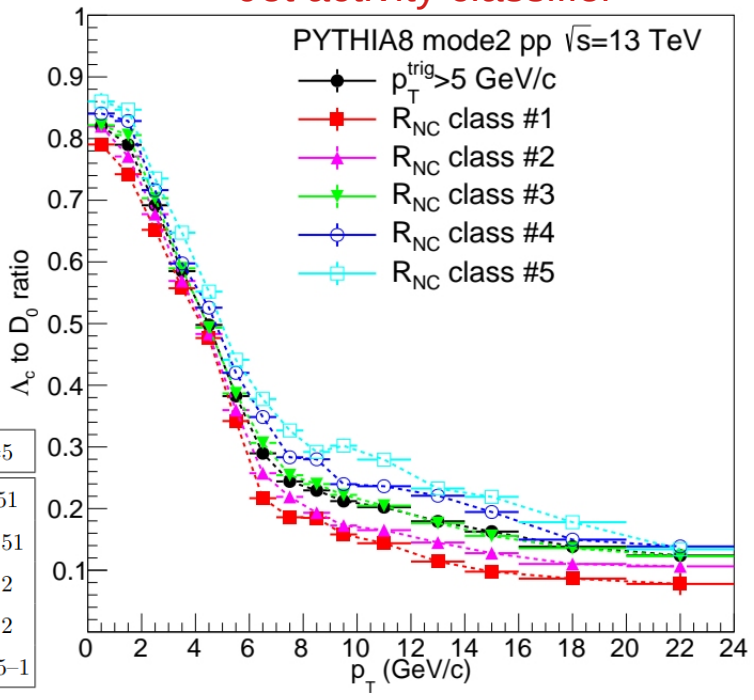
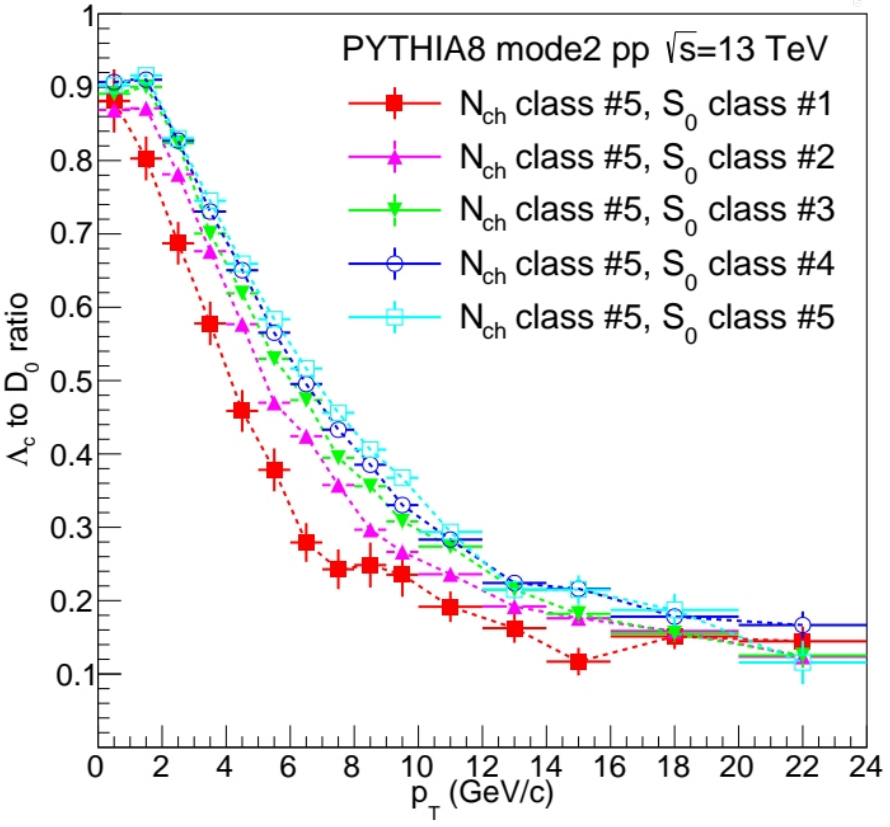
Jet activity classifier



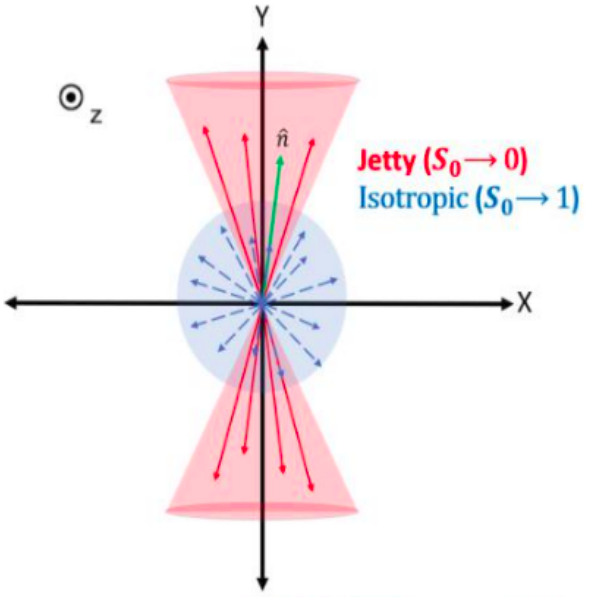
- Events require p_T>5 GeV/c hadron trigger.
- Significant difference is observable in case of R_T (UE classification).
- No significant difference when classified by R_{NC} classes (jet activity).

arXiv:2111.00060 (accepted in J.Phys.G)

Λ_c/D^0 yield in Min Bias Events



$N_{CH} > 50$



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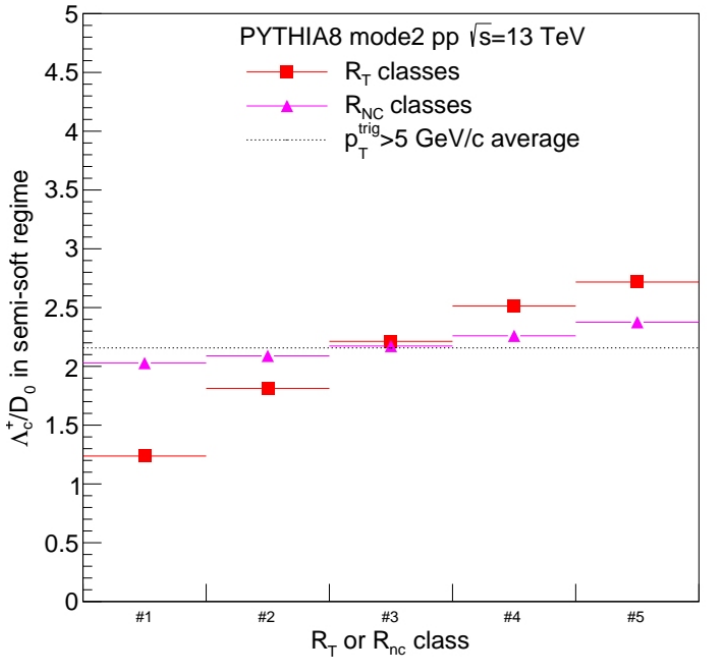
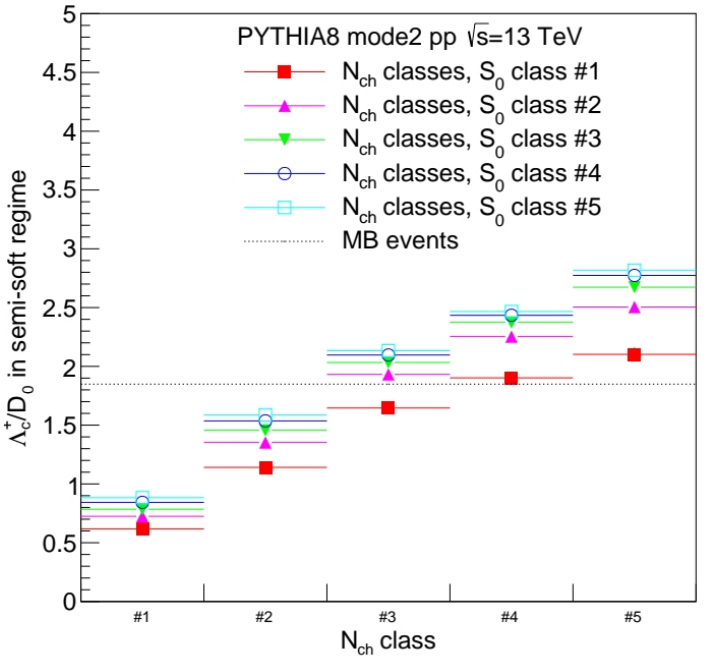
S_0	0–0.25	0.25–0.45	0.45–0.55	0.55–0.75	0.75–1

- Spherocity provides a measure for the jettines of the event.
- **Significant difference** is observed for **different spherocity classes** (at fixed event-multiplicity).

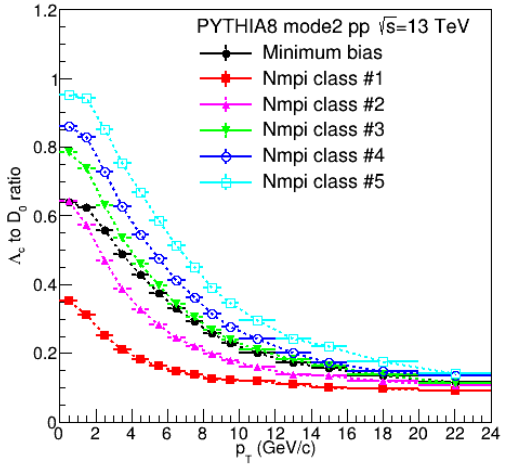
Λ_c/D^0 yield ratios - trigger vs. minbias



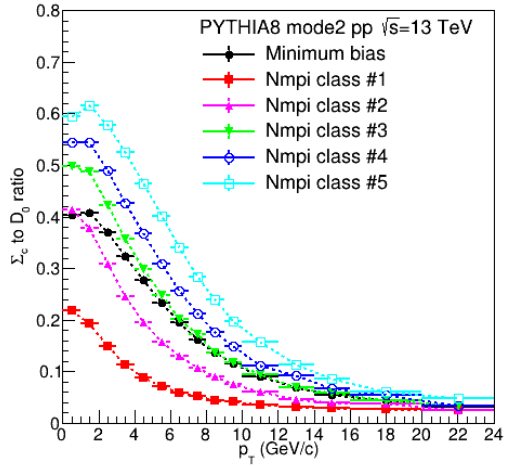


- If we require a hard process ($P_T^{trigger}$ > 5 GeV/c):
  - **Strong dependence** of ratios on the **UE activity**,
  - **No** pronounced **dependence** on the **jet multiplicity**.
- In minimum-bias events
  - For high final-state multiplicity, ratio **depends on jettiness**,
  - Dependence is minute for low final-state multiplicity.
- Using S_0 : dependence on jettiness observable in minimum-bias events. No need to use a trigger that biases the sample and decreases available statistics.

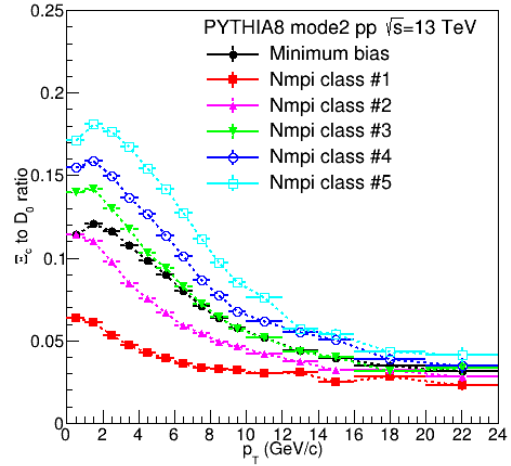
Heavier baryons to meson ratios



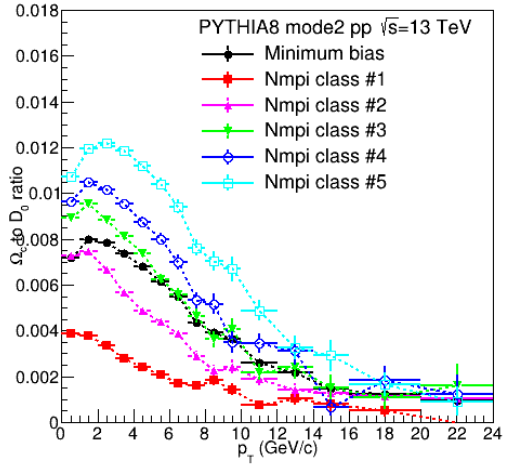
Λ_c(qqc), I = 0



Σ_c(qqc), I = 1



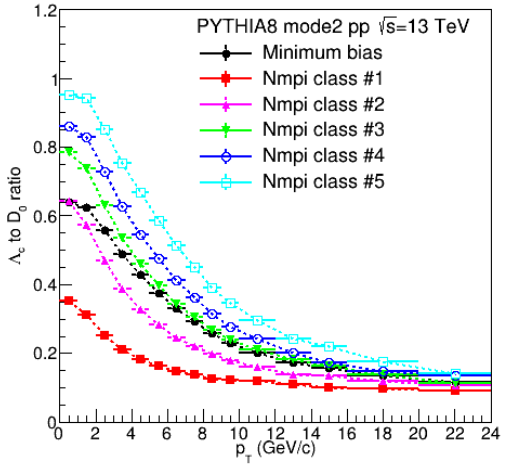
Ξ_c(qsc)



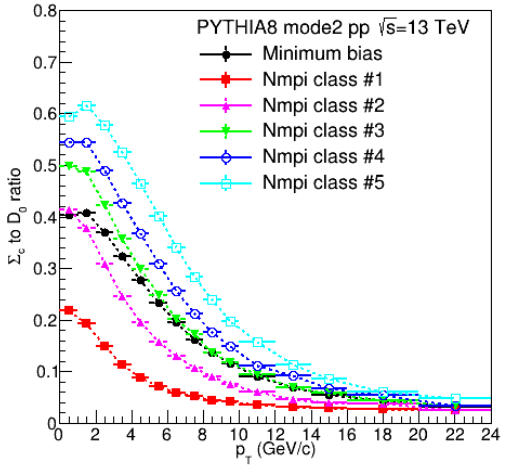
Ω_c^0(ssc)

- Similar trend for all baryon/meson ratios.
- For the Λ_c there is a significant feed-down from Ξ_c
    1. The result is expected to be an admixture of prompt Λ_c^+ and $\Xi_c^{0,+}$
    2. Pattern can be attributed to presence or lack of strange content

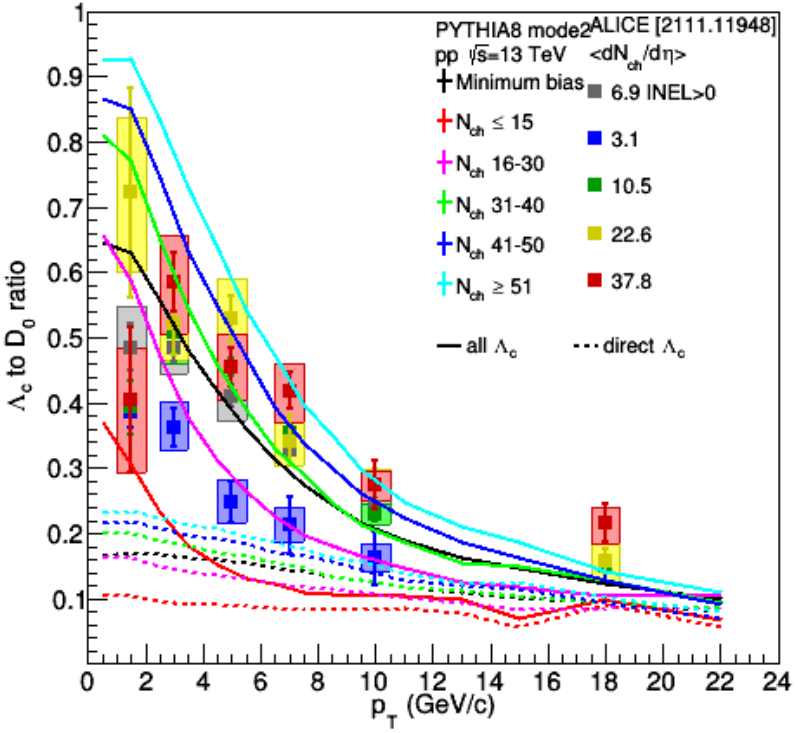
Heavier baryons to meson ratios



Λ_c(qqc), I = 0



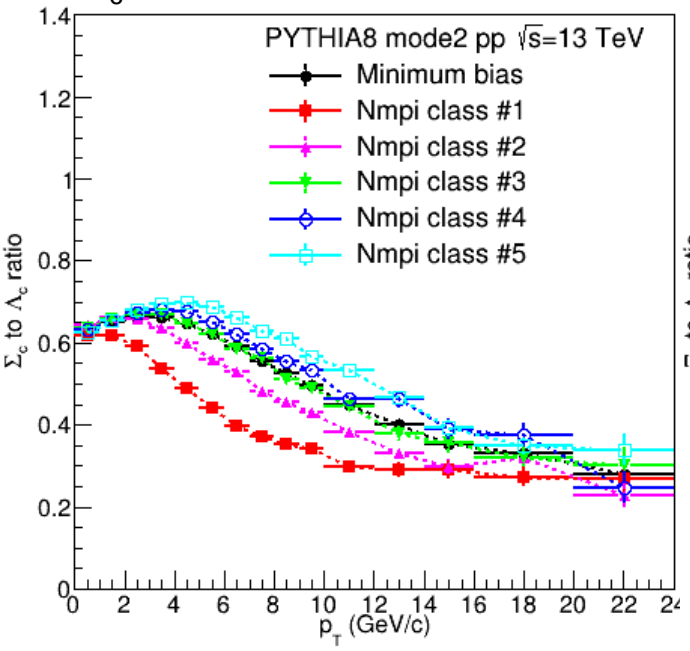
Σ_c(qqc), I = 1



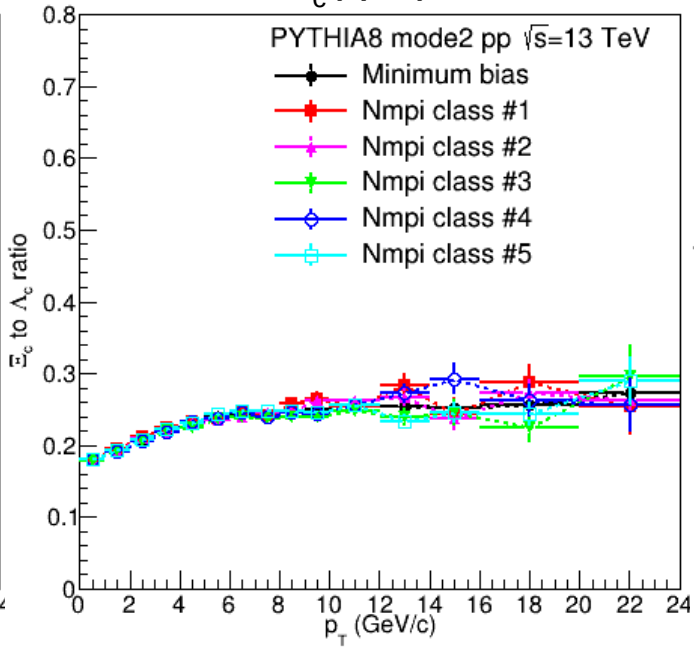
- Λ_c/D^0 from direct hadronization shows a similar ordering by N_{CH}
  - Indicates both sources are **sensitive to the UE**.

Baryon to baryon ratios

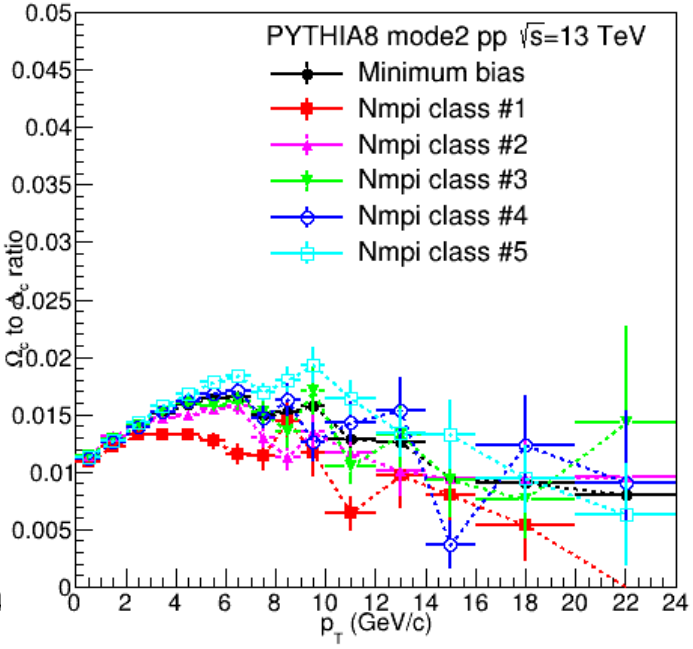
Σ_c(qqc), I = 1



Ξ_c(qsc)



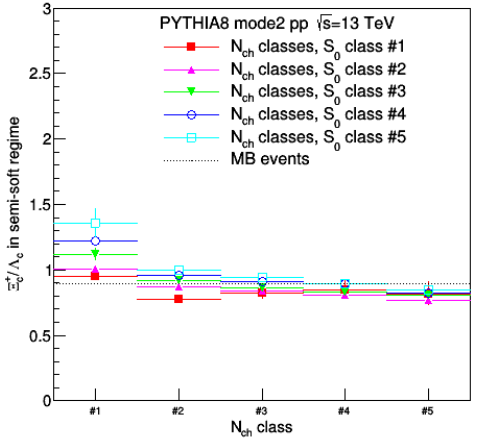
Ω_c^0(ssc)



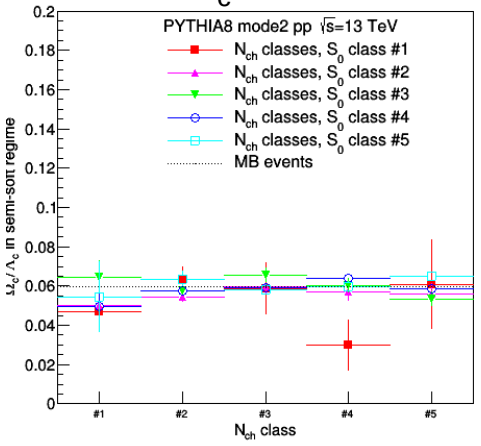
- There is a low p_T enhancement connected to the charm content.
  - Sensitive to the isospin effect.
- There is a high p_T relative enhancement connected to the strange content.
- **Strange enhancement is different from charm enhancement!**

Summary plots for strange content

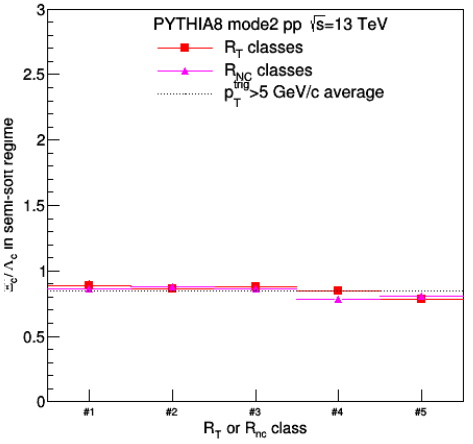
Ξ_c(qsc)



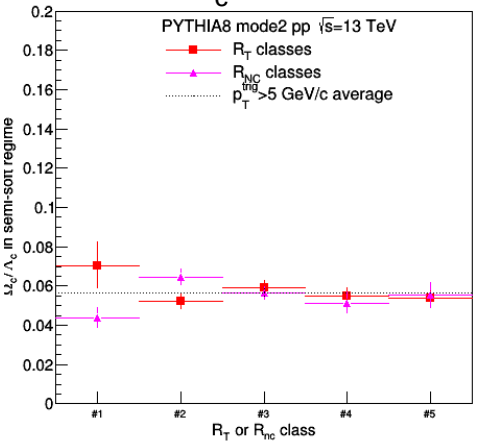
Ω_c^0(ssc)



Ξ_c(qsc)



Ω_c^0(ssc)



- **Strangeness content** has only **slight effect** in semi-soft (coalescence) regime.
- Studying the strange baryon enhancement vs. charm enhancement for enhanced CR modes is underway

class	#1	#2	#3	#4	#5
$N_{\rm ch}$	$\leq$15	16–30	31–40	41–50	$\geq$51
$N_{\rm fw}$	$\leq$45	46–90	91–120	121–150	$\geq$151
$R_{\rm T}$	<0.5	0.5–1	1–1.5	1.5–2	>2
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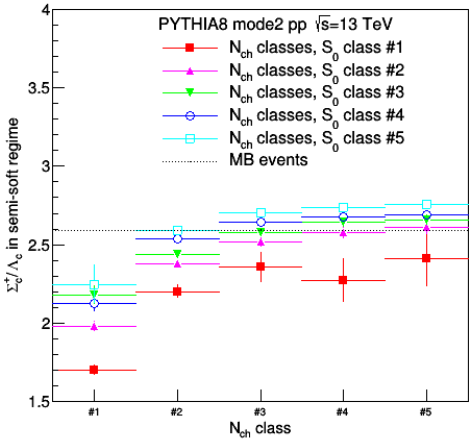
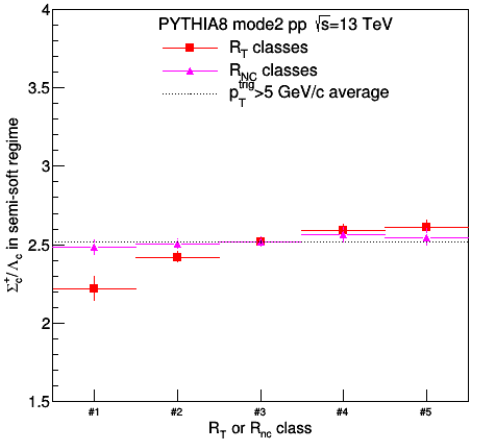
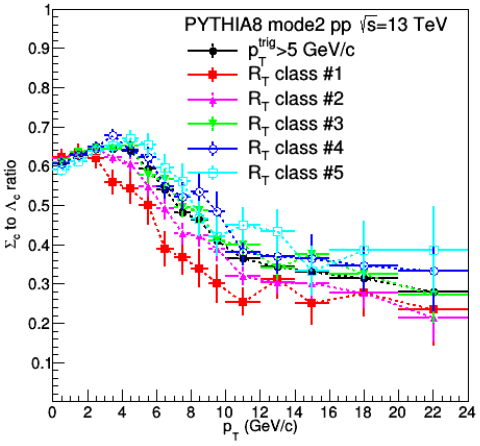
S_0	0–0.25	0.25–0.45	0.45–0.55	0.55–0.75	0.75–1

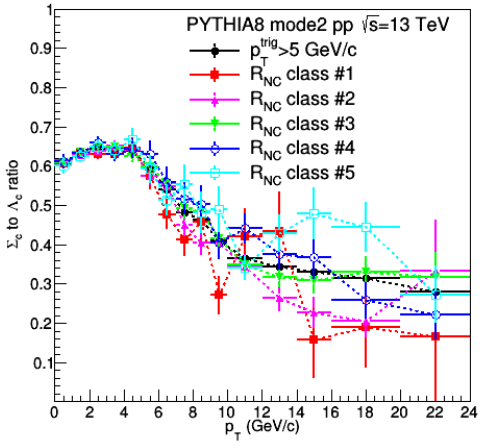
Isospin effect

Σ_c(qqc), I = 1









- Difference in the enhancement in semi-soft region (from UE), probably caused by an **isospin effect**.

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N_{ch}	≤15	16–30	31–40	41–50	≥51
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Summary

- Enhancement of Λ_C/D^0 in pp collisions compared to e^+e^- collisions questions the universality of charm fragmentation.
- We proposed event-activity classifiers which provide great sensitivity to the production mechanisms

  → directly accesible experimental observables in LHC Run 3
- In a model class considering color reconnection beyond leading approximation, the Λ_C enhancement is connected to the underlying event, not to the jet region.
- There is a significant difference between the production of Λ_c and Σ_c due to isospin effect.
- The observables are sensitive to the differences between the mechanism of strangeness and charm enhancement.

Thank you for your attention!