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Event-activity-dependent production of charmed baryons at LHC energies

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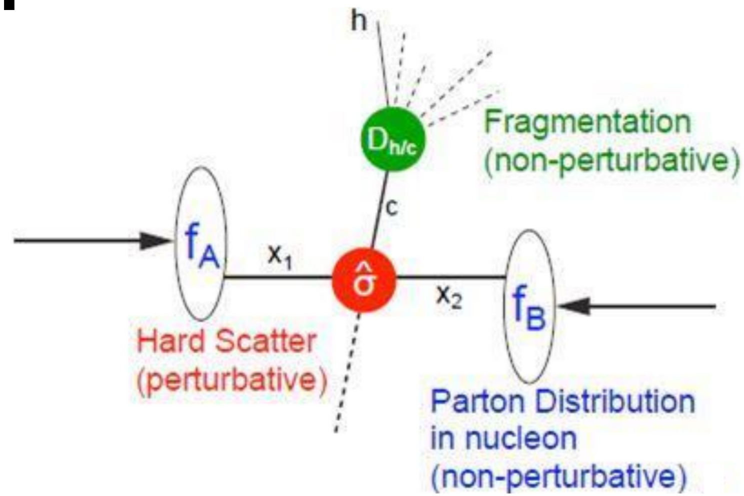
Motivation



- Heavy-flavor hadrons are created through the fragmentation of heavy quarks into mesons and baryons.
- The production of heavy-flavor hadrons in high-energy collisions is usually described by the factorization approach, in which the production cross section of the heavy-flavor particles factorizes into independent contributions of the incoming PDFs, the parton-parton scattering cross-section and the fragmentation function:

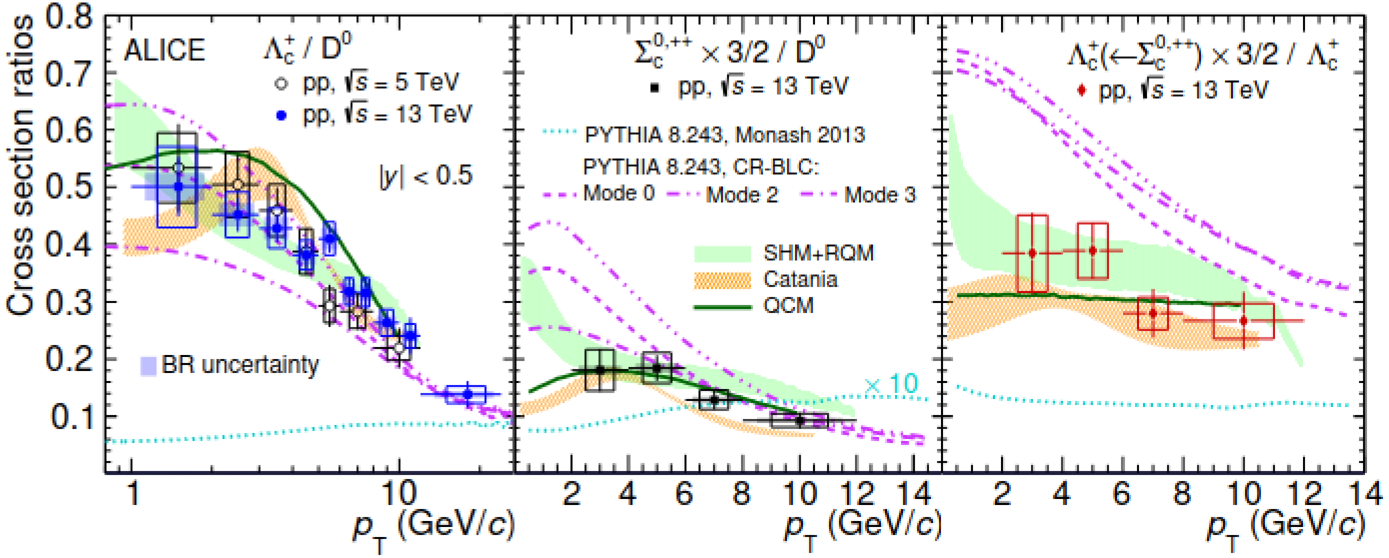
$$d\sigma^{hard}_{AB\to C} = \sum_{a,b} f_{a/A}(x_a, Q^2) \otimes f_{b/B}(x_b, Q^2) \otimes d\sigma^{hard}_{ab\to c}(x_a, x_b, Q^2) \otimes D_{c\to C}(z, Q^2)$$

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

- Traditional assumption: fragmentation is universal for different collision systems.
- Baryon-to-meson ratios are therefore representative of the different fragmentation.

Charm baryon enhancement

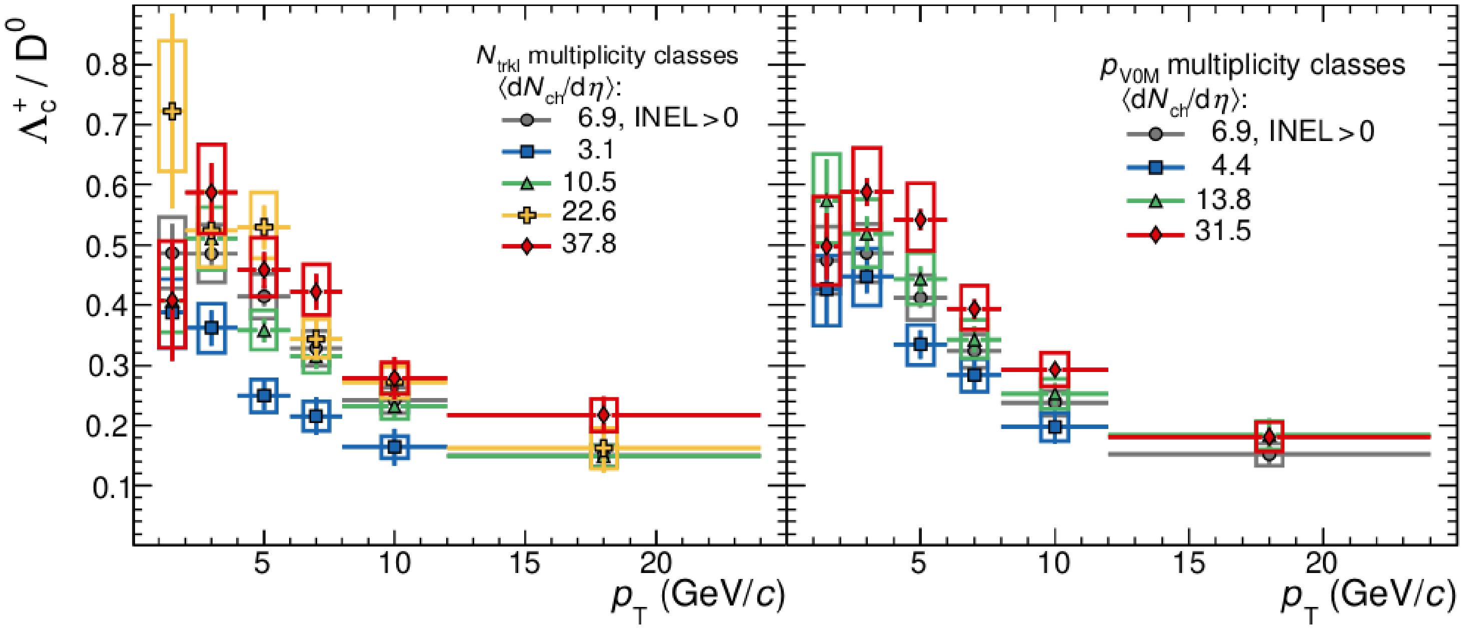
ALICE Coll., “Measurement of prompt D0, Lambda_c+, and Sigma_c{0,++}(2455) production in pp collisions at sqrt(s) = 13$ TeV” (arXiv:2106.08278)



- **Baryon production is enhanced vs. meson-production in hadron-collisions compared to electron-positron collisions.**
- **Several scenarios are proposed for explaining 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

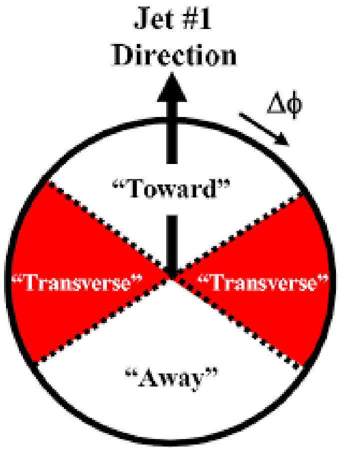
ALICE Coll. Observation of a multiplicity dependence in the pT-differential charm baryon-to-meson ratios in proton-proton collisions at s√=13 TeV (arXiv:2111.11948 [nucl-ex])



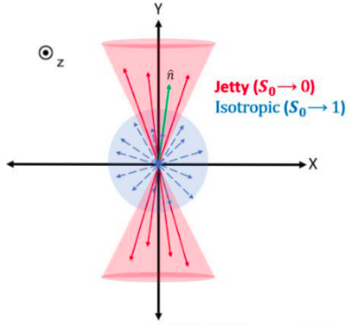
- The enhancement in Λ_c/D^0 depends on the final state multiplicity at mid- and forward rapidity.
- **Goal: Understand the origin of the enhancement with detailed event activity studies.**
- Does it come from the jet or the underlying event?
- Using standalone PYTHIA 8 to test the observable effects 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.

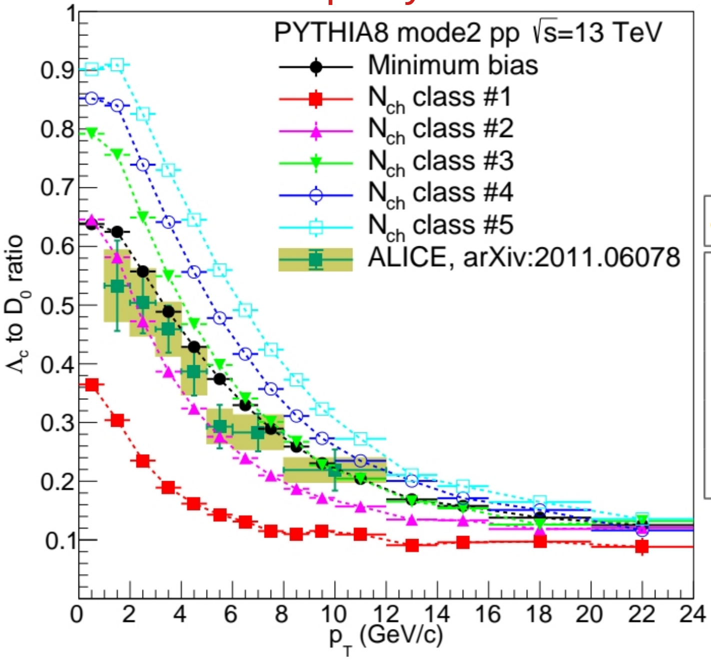


$$S_0 = \frac{\pi^2}{4} \times \min_{\hat{n}=(n_x,n_y,0)} \left(\frac{\Sigma_i |\vec{p}_{T_i} \times \hat{n}|}{\Sigma_i \vec{p}_{T_i}} \right)^2$$



Λ_c/D^0 yield ratios

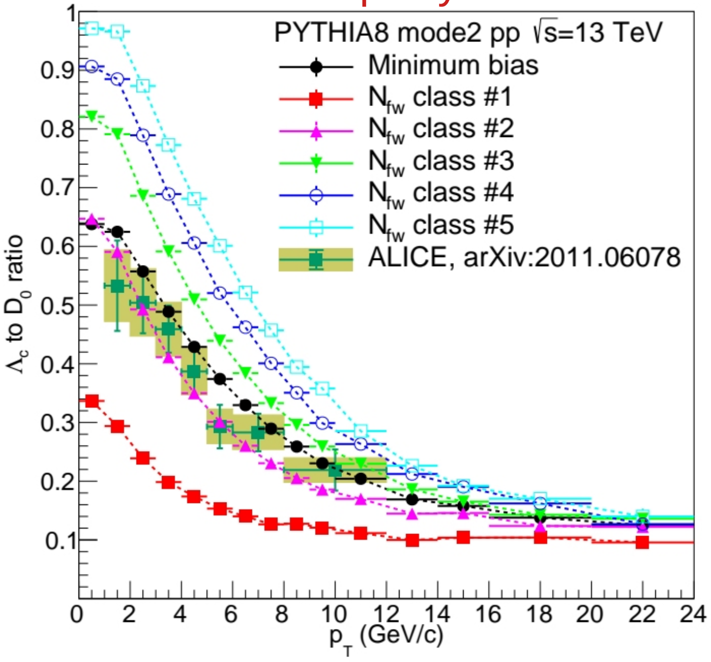
Central rapidity classifier



arXiv:2111.00060

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

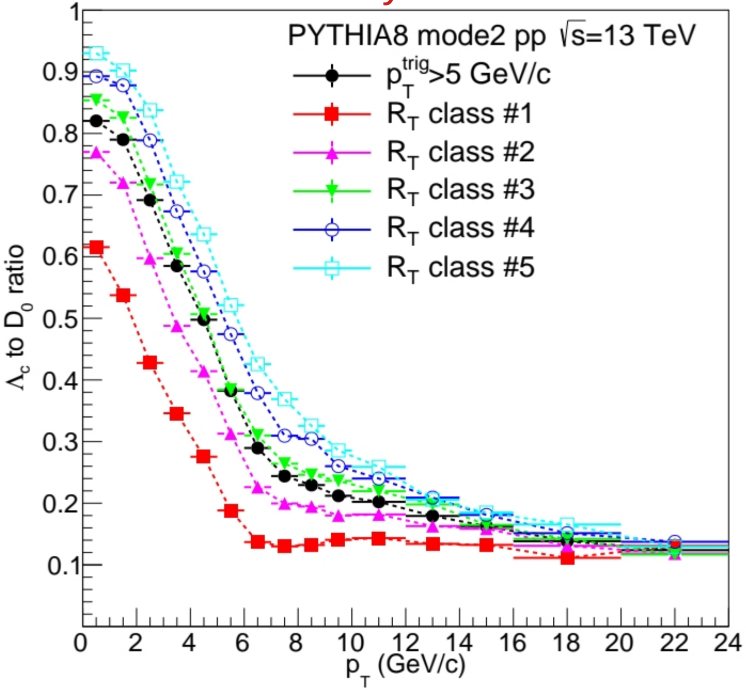
Forward rapidity classifier

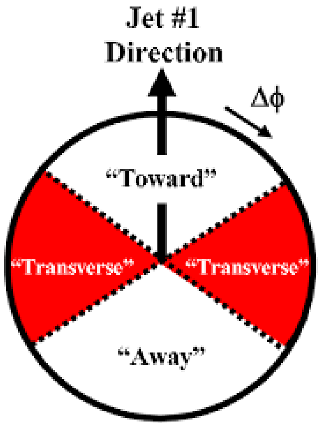


- Simulation results are in agreement with the ALICE experimental data.
- Recently observed multiplicity trends reproduced.
- For N_{fw}: a rapidity gap is present, which reduces the correlation between leading hard processes and the multiplicity.
- Multiplicity dependence not driven by charm production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

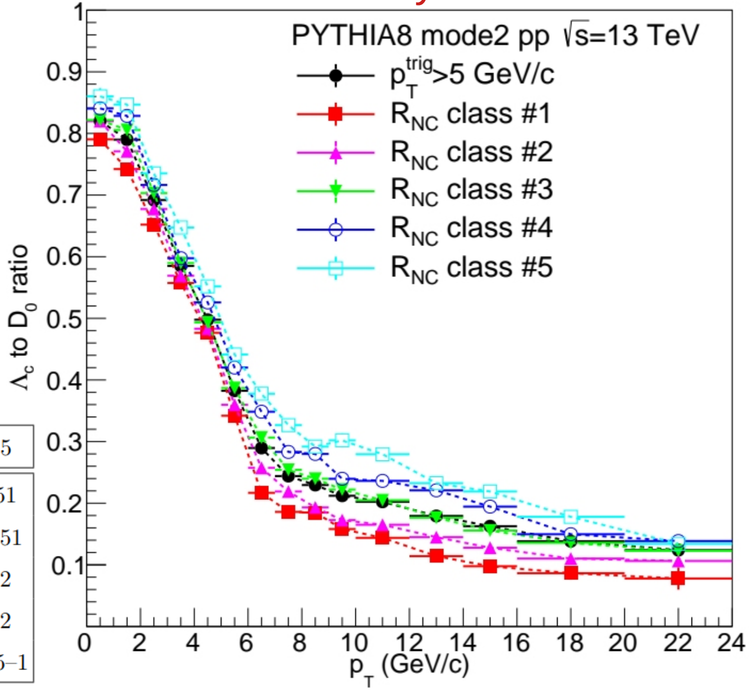
Λ_c/D^0 yield in case of trigger

UE activity classifier





Jet activity classifier



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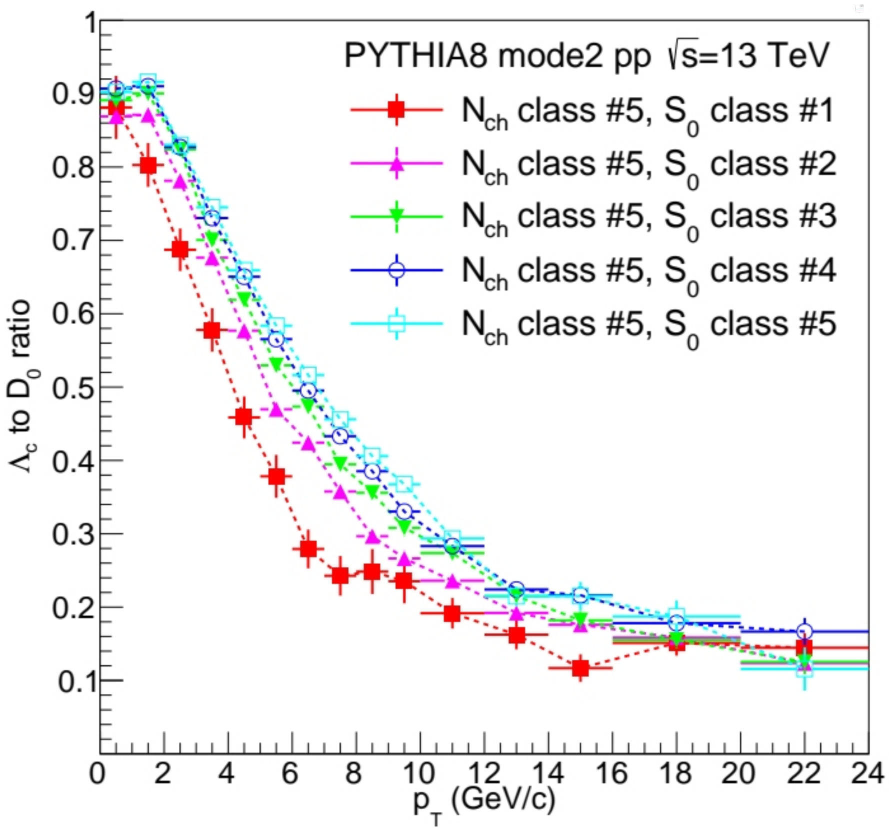
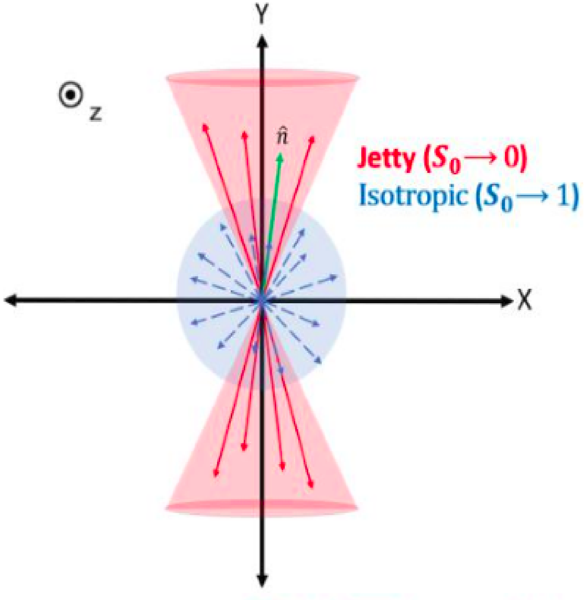
- Events require p_T>5 GeV/c hadron trigger.
- Significant difference is observable in case of R_T (UE classification).
- No significant difference when classified by R_{NC} classes (jet activity).

Λ_c/D^0 yield in Min Bias Events



$N_{CH} > 50$



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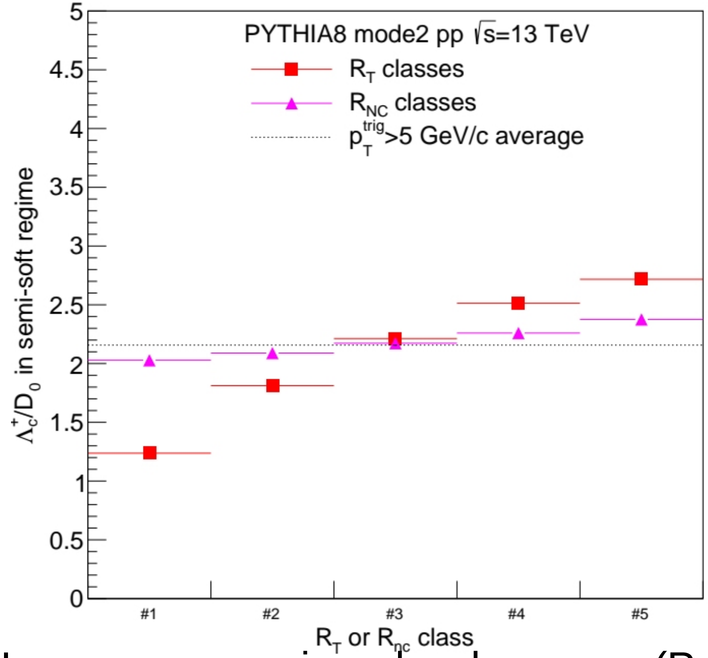
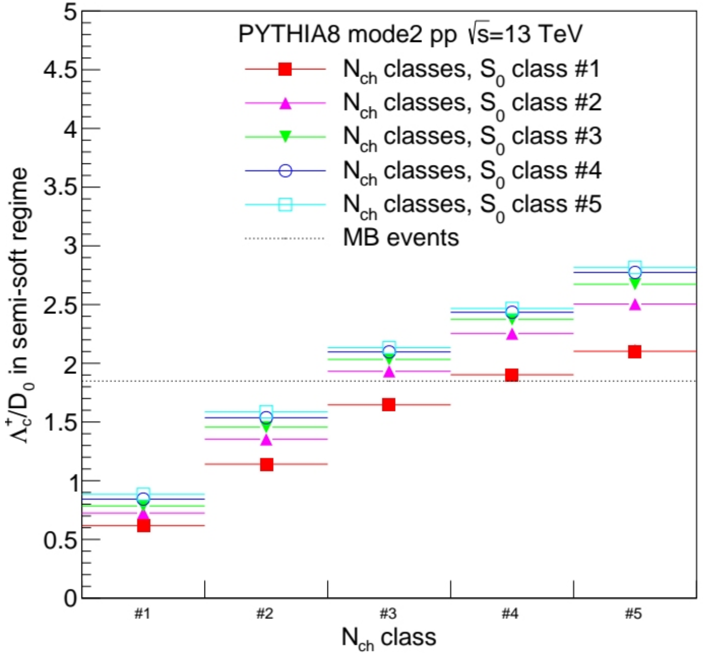
- Spherocity provides a measure for the jettines of the event.
- Significant difference is observed in different spherocity classes at fixed event-multiplicity.

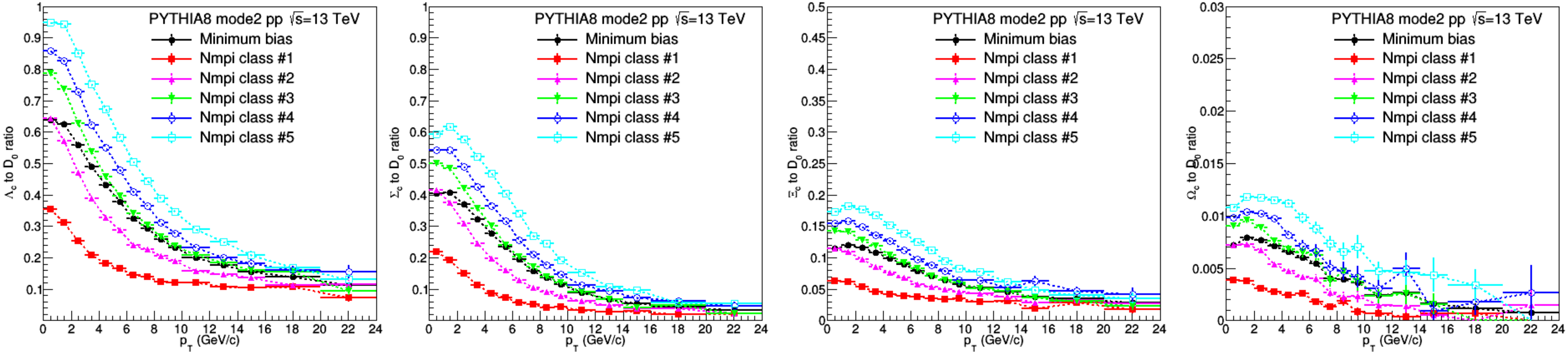
Λ_c/D^0 yield ratios - trigger vs. minbias





- In case 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
  - In case of high final-state multiplicity, ratio depends on jettiness,
  - Dependence is minute for low final-state multiplicity.
- With S_0, dependence on jettiness observable in minimum-bias events. No need to use a trigger that biases the sample and decreases available statistics.

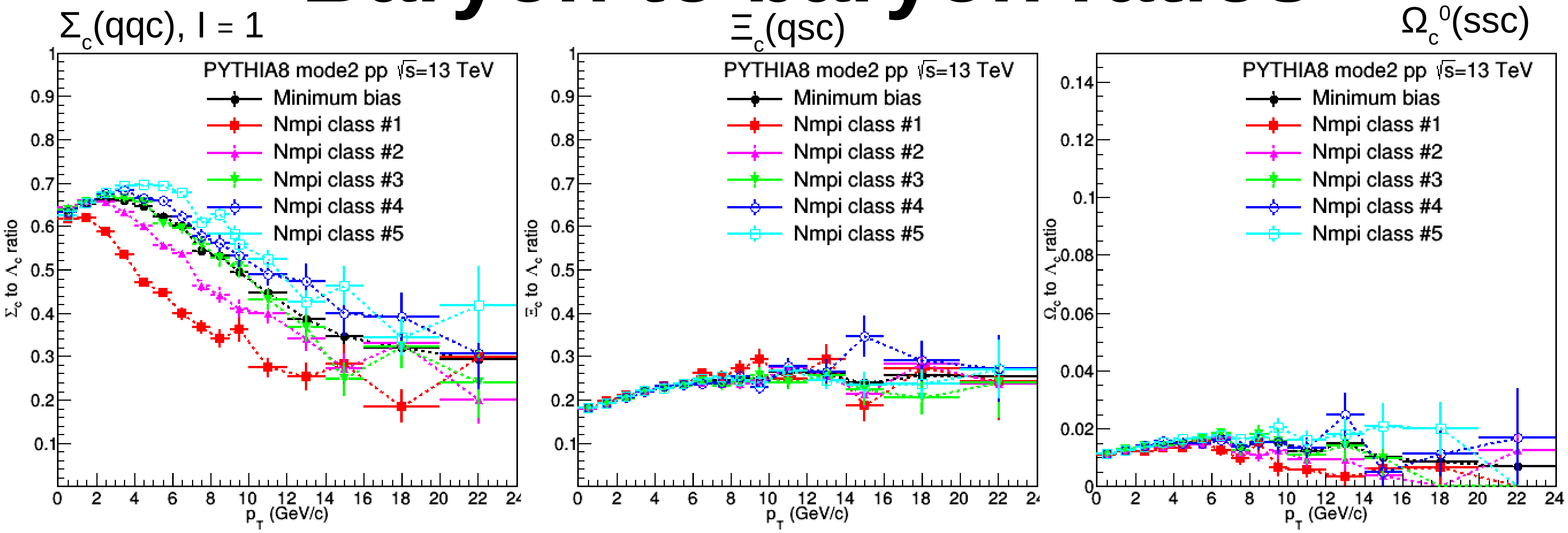
Other charmed baryon to meson ratios



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.

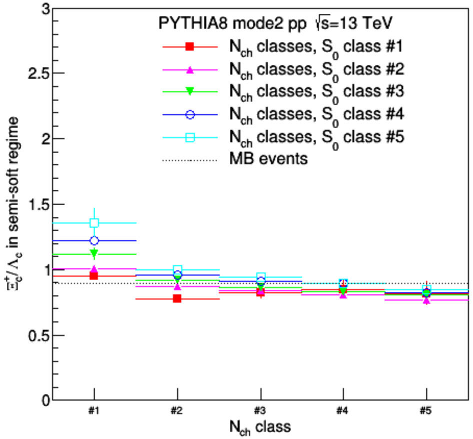
Baryon to baryon ratios



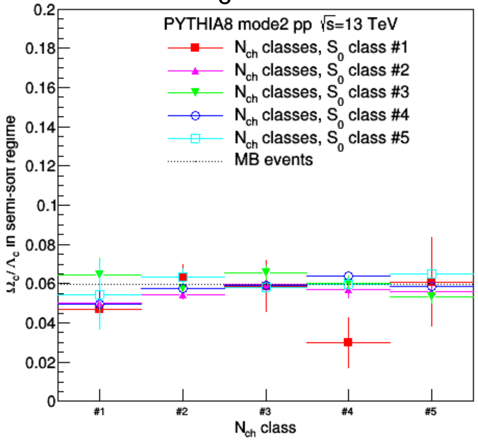
- There is a low p_T enhancement connected to the charm content
- There is a high p_T relative enhancement connected to the strange content
- Bottomline: strange enhancement is different from charm enhancement

Summary plots for strange content

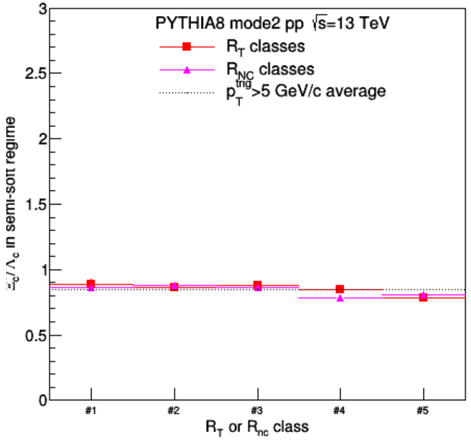
Ξ_c(qsc)



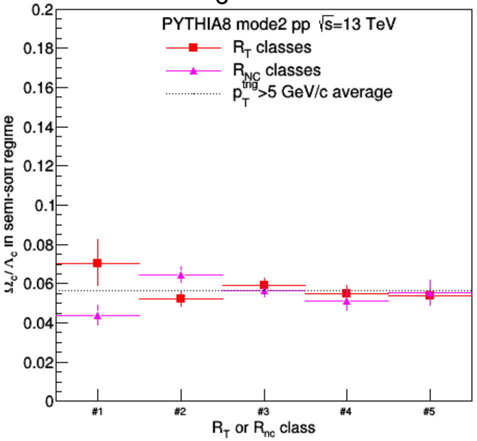
Ω_c^0(ssc)



Ξ_c(qsc)



Ω_c^0(ssc)



- Strangeness content has only slight effect in semi-soft (coalescence) regime.

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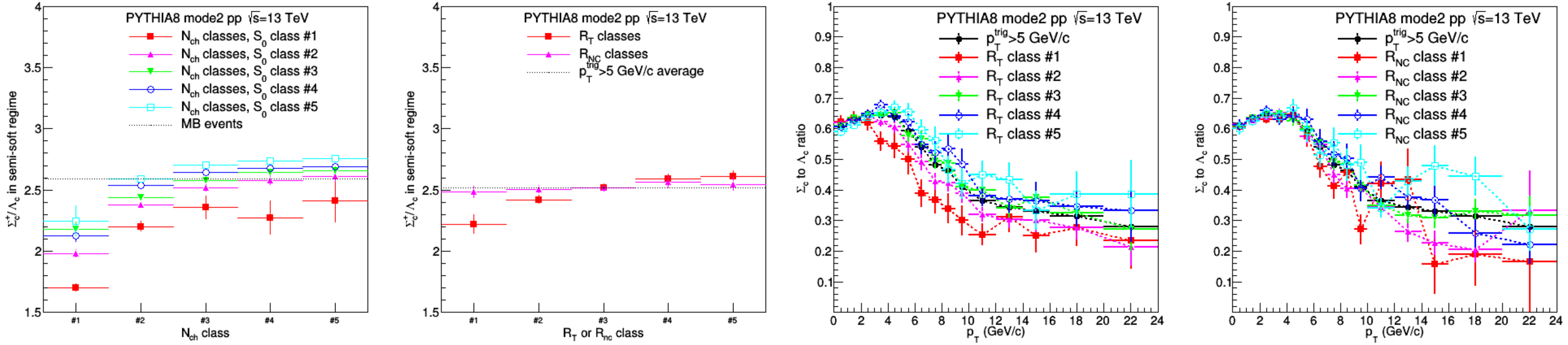
Summary plots for strange content

$\Sigma_c(qqc)$, I = 1



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

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Summary

- Enhancement of Λ_C/D^0 in pp collisions compared to e^+e^- collisions question the universality of charm fragmentation.
- We propose 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 comes from the underlying event, not from the the jets.
- The observables are sensitive to differences between mechanisms of strangeness and charm enhancement.

Thank you for your attention!