Heavy-flavour production as a function of the event activity with ALICE

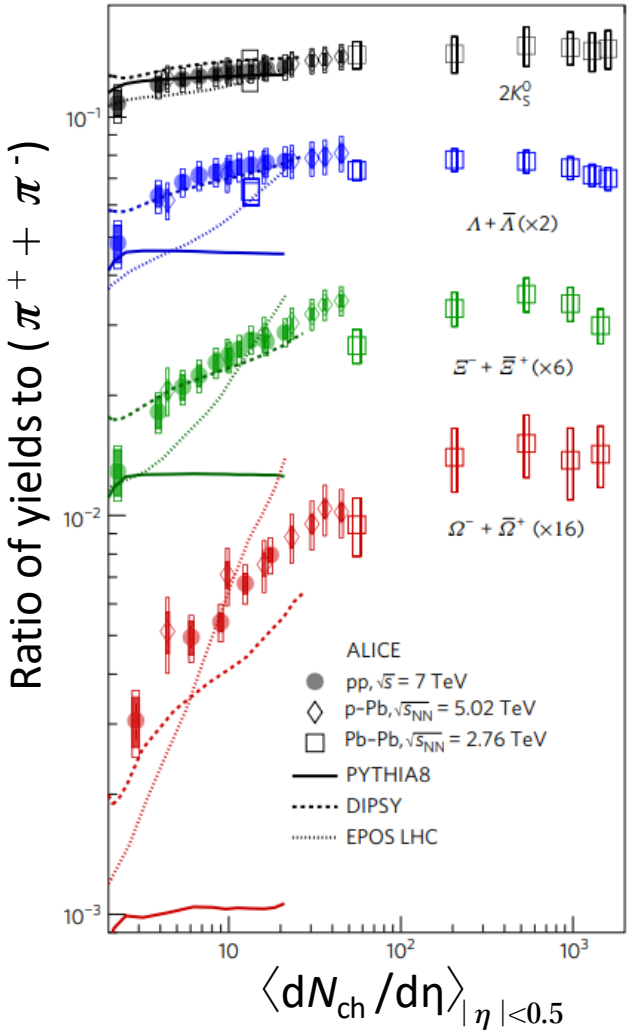
L. Dello Stritto (University and INFN Salerno, Italy)
on behalf of the ALICE Collaboration

Krakow, 04–10 April 2022

Physics motivations

- Similarities between measurements performed in high multiplicity events in pp and p–Pb collisions and heavy-ion collisions has been observed at the LHC:
  - **Strangeness enhancement in the light flavour sector**

Nature Physics **13**, 535–539 (2017)



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  - **Collectivity (ridge formation)**

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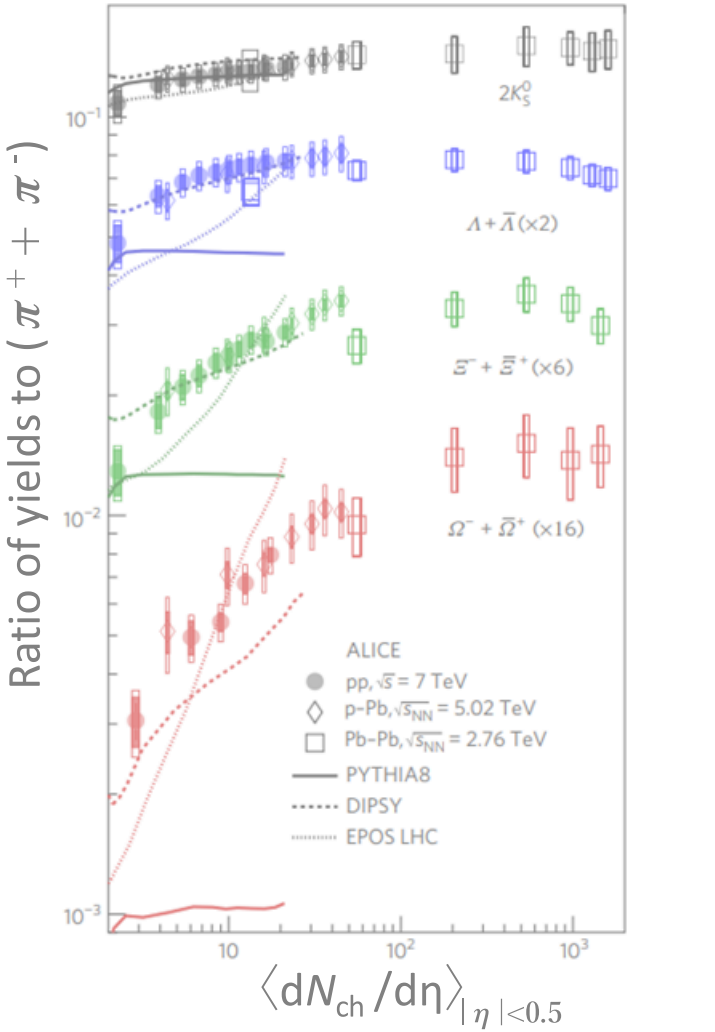
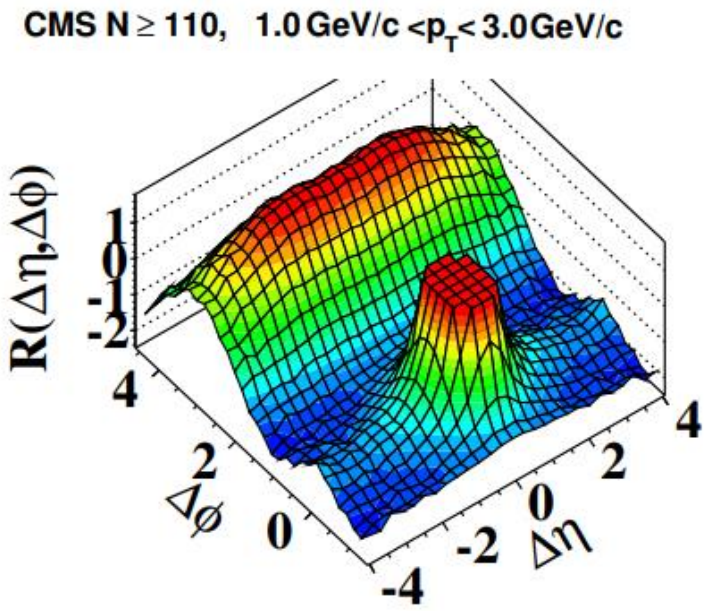


CMS: JHEP 09 (2010) 091



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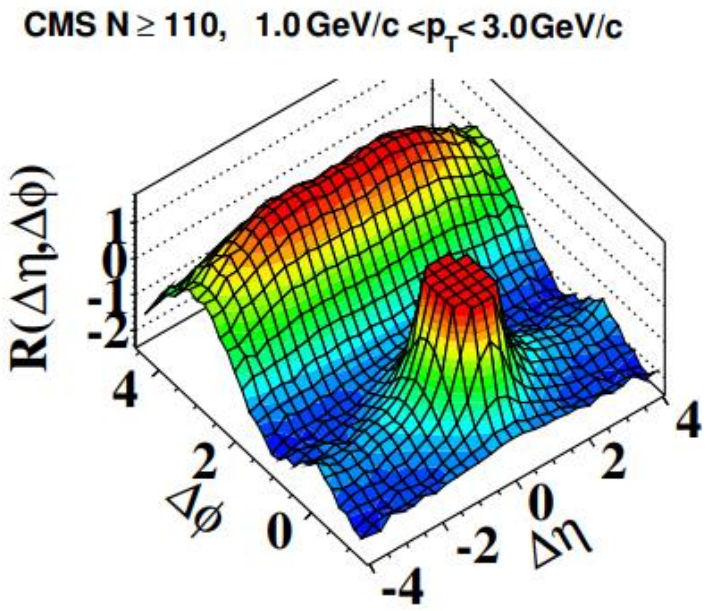
Medium-like properties in small systems?

What about the charm-hadron production measurements as a function of multiplicity?

CMS: JHEP 09 (2010) 091



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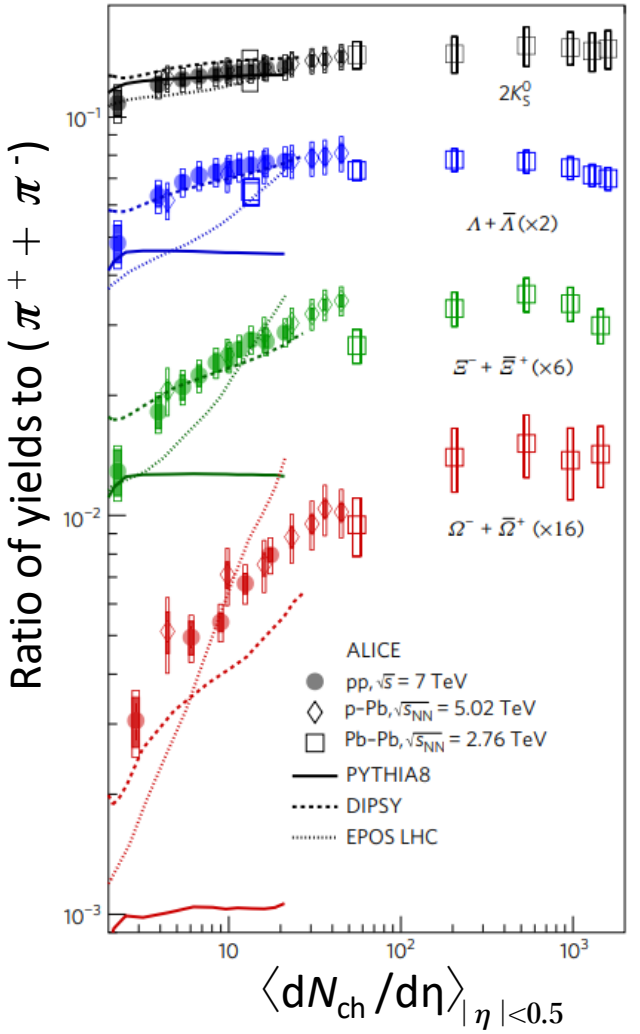


Physics motivations

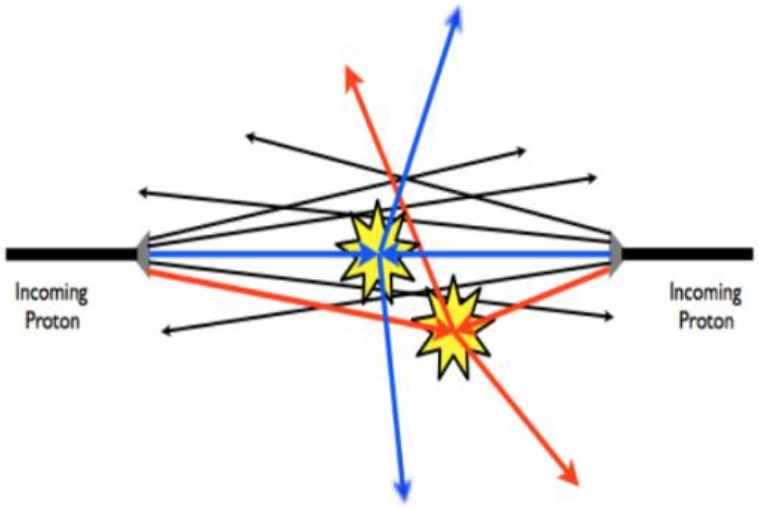
- Measurements of heavy-flavour production **as a function of the event activity** allow us to investigate:

  - interplay between the hard and soft particle production

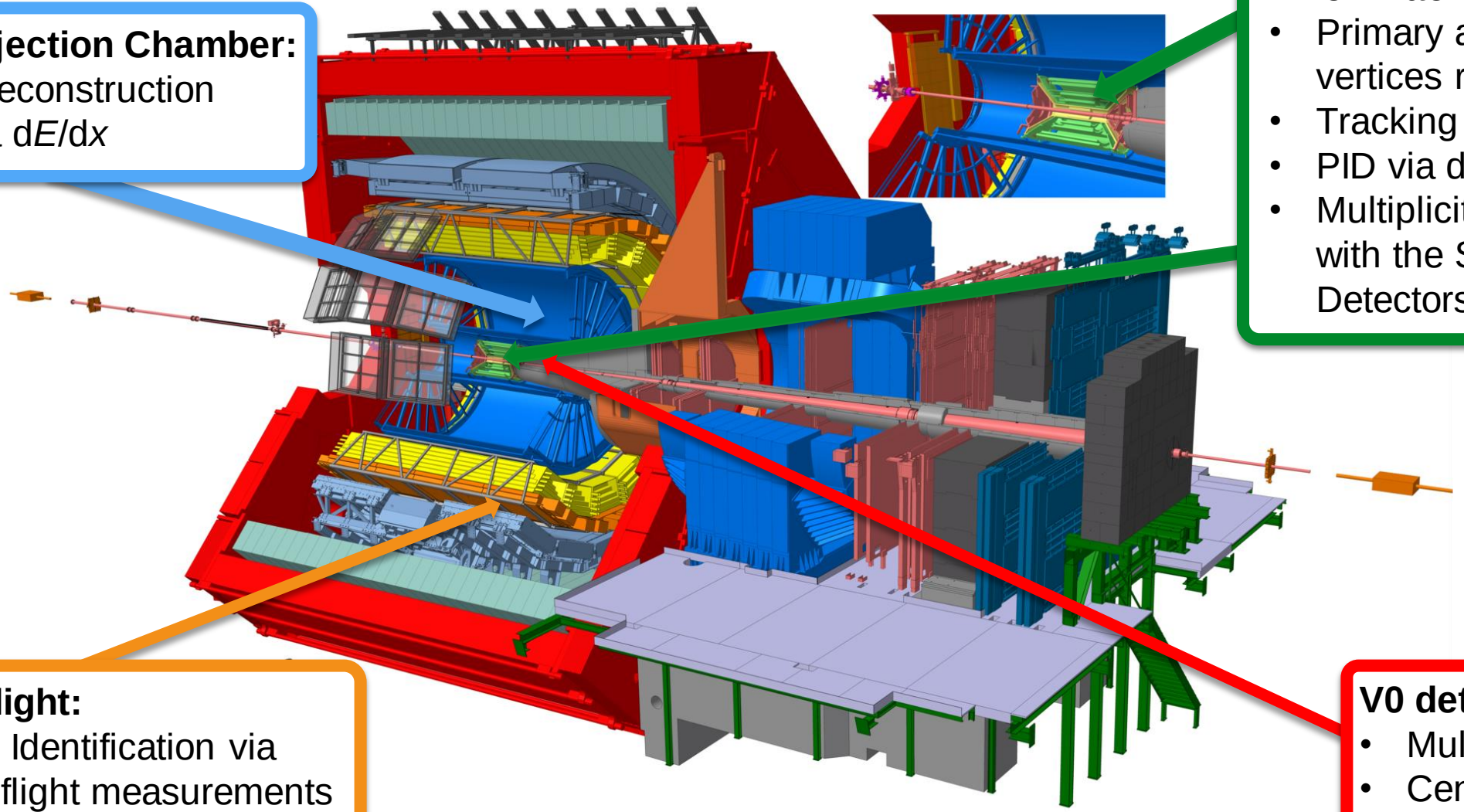
  - role of multiparton interactions (MPI)

  - colour-reconnection (CR) mechanisms

  - hadronization mechanisms: evolution from small to large systems?



The ALICE detector



Time Projection Chamber:
- Track reconstruction
- PID via d*E*/d*x*

Inner Tracking System:
- Primary and decay vertices reconstruction
- Tracking
- PID via d*E*/d*x*
- Multiplicity measurement with the Silicon Pixel Detectors (SPD)

Time of Flight:
- Particle Identification via time-of-flight measurements

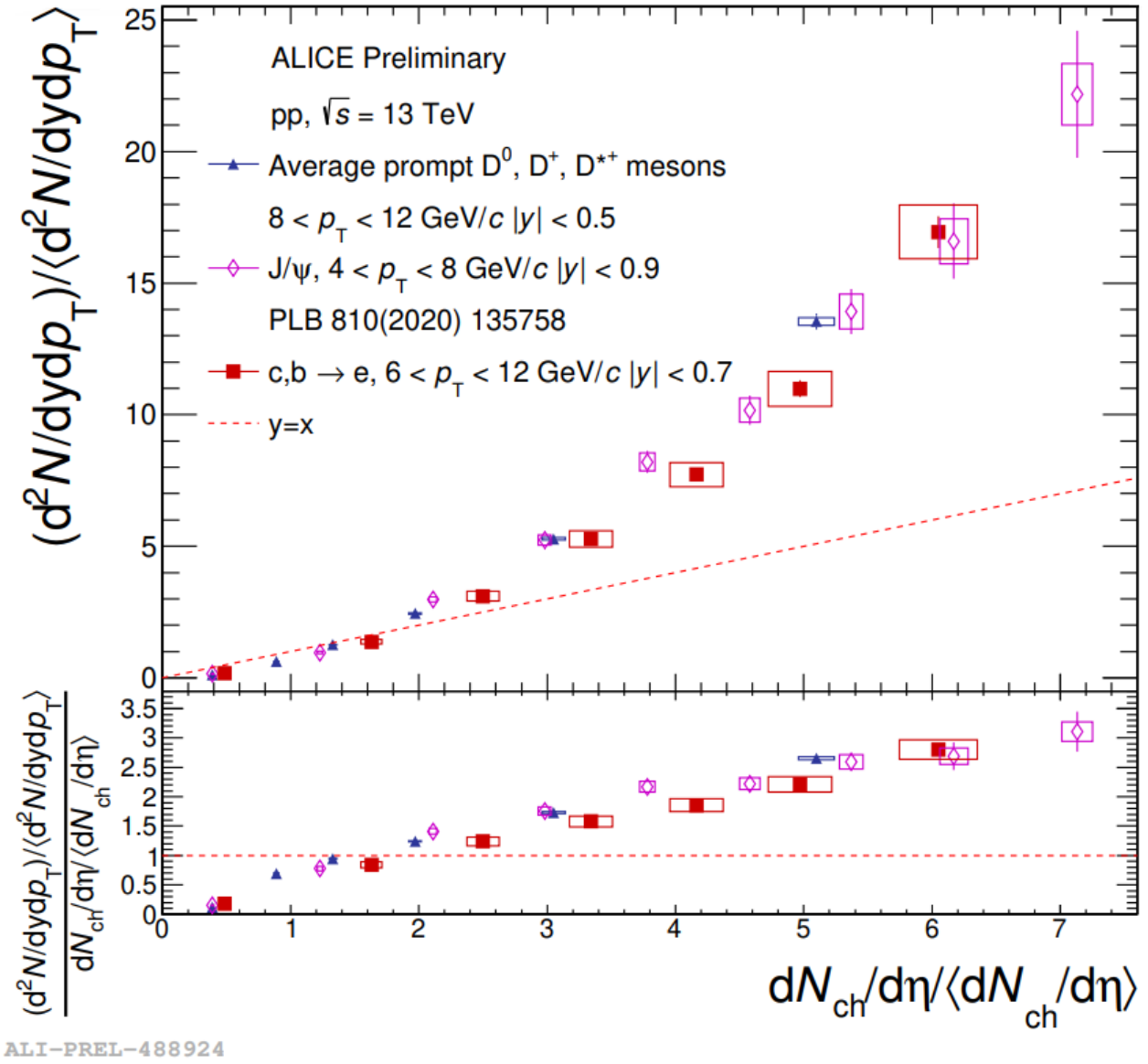
V0 detectors:
- Multiplicity estimator
- Centrality

Heavy-flavour self-normalized yield

pp

- Faster than linear increase with charged-particle multiplicity.
  - ➡ MPI introduce a correlation between heavy-flavour yields and charged-particle production **but in models like Pythia and EPOS cannot explain such a high increase.**

- Contribution from autocorrelation between heavy-flavour yield and charged-particle multiplicity.
  Weber et al, EPJ C **79**, 36 (2019)



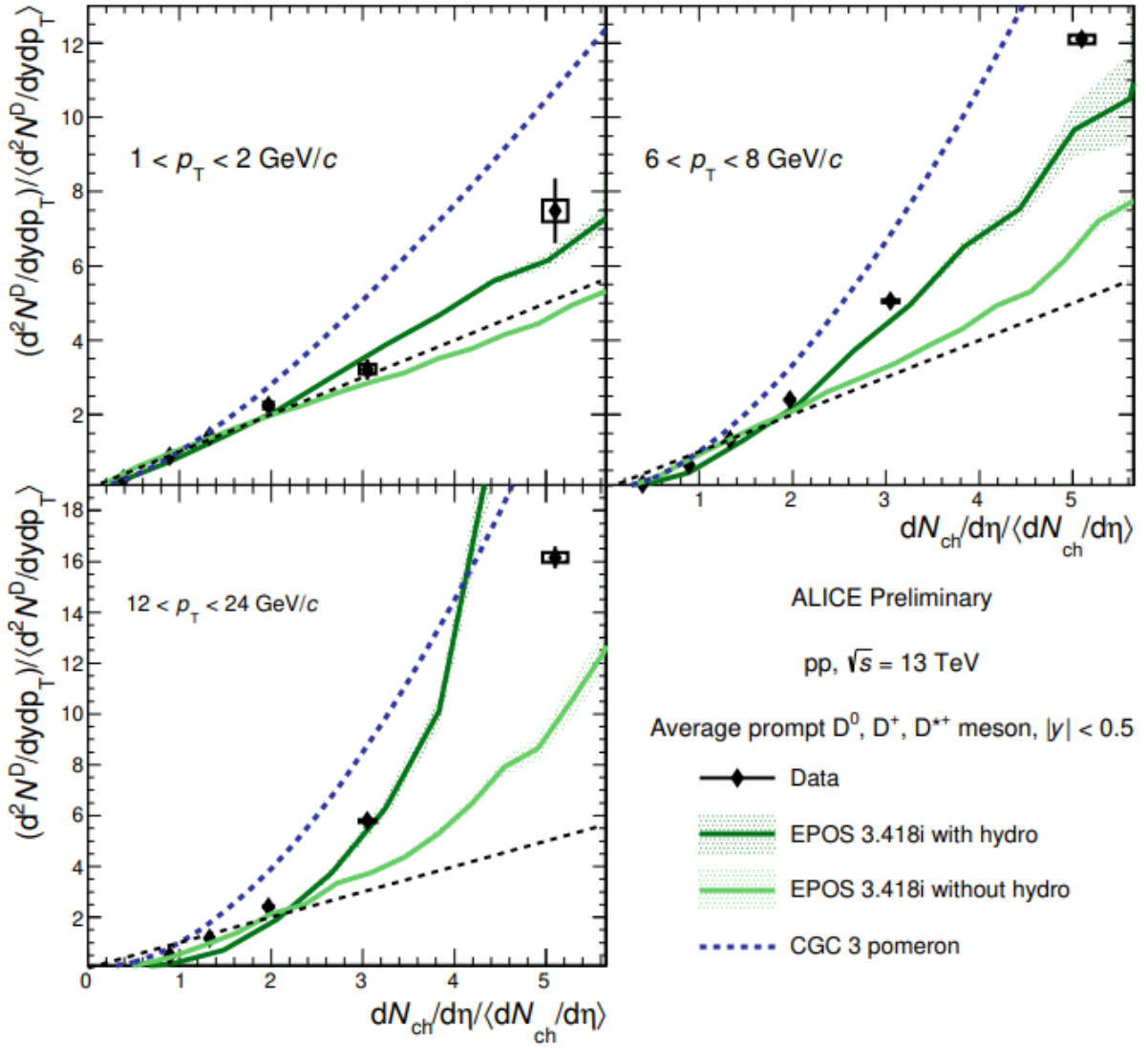
D meson self-normalized yield

pp

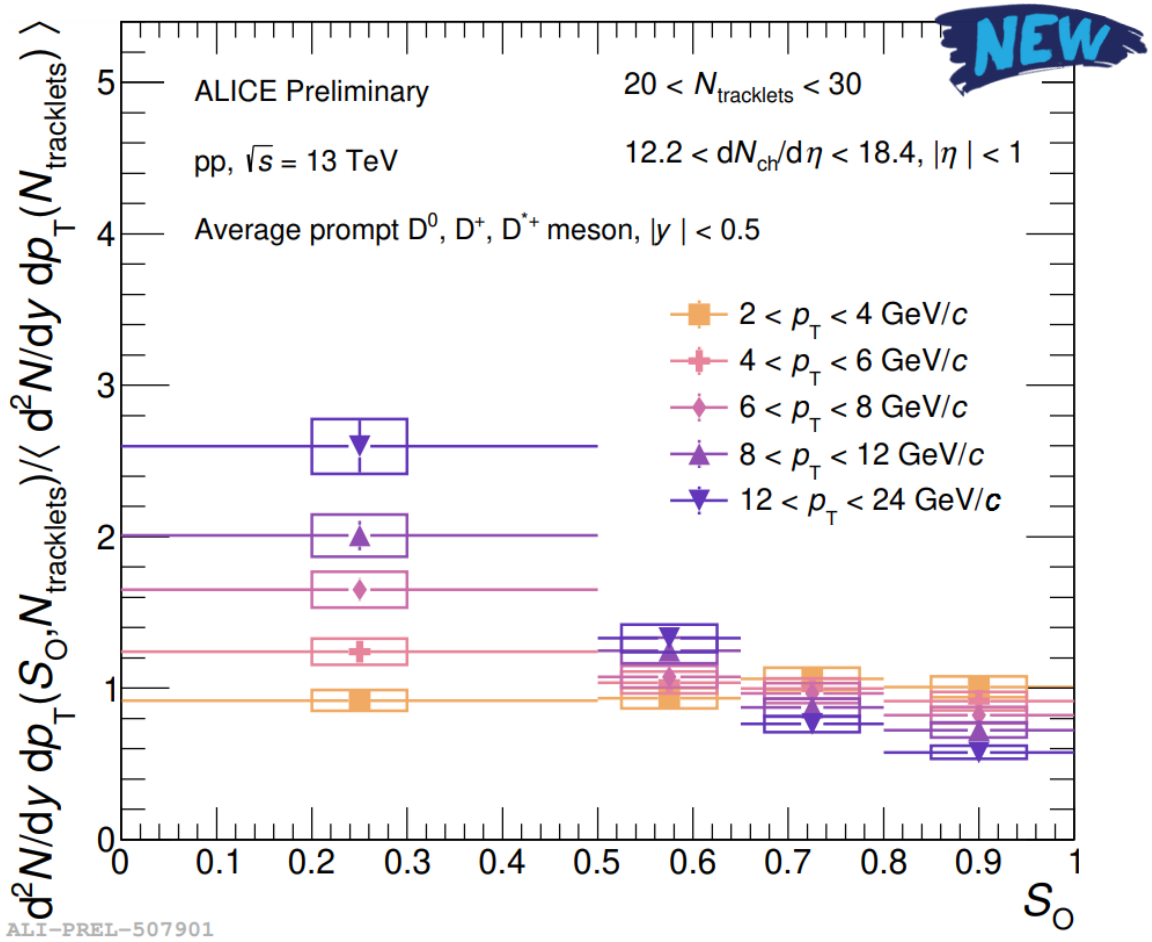
- **EPOS3 without hydro** = particle production via flux tubes expansion and fragmentation. 1 flux tube for each PI. → **Underestimates the results**

- **EPOS3 with hydro** = string formation followed by a hydrodynamical evolution.
  → **Describes the faster than linear increase, reduces multiplicity**
  Werner et al, Phys. Rev. C 89.064903 (2014)

- **3-pomeron CGC** (Colour Glass Condensate) = meson production via three pomerons (gluon shower) fusion.
  → **Overpredicts the experimental data**
  Schmidt & Siddikov, Phys. Rev. D 101.094020 (2020)



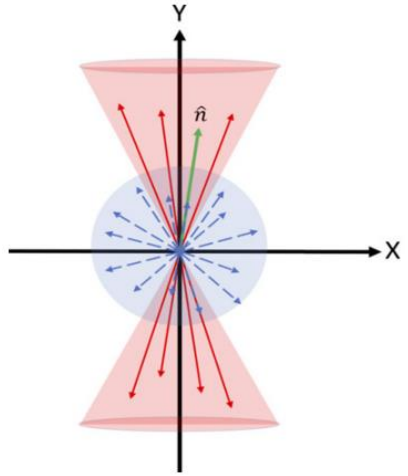
D meson self-normalized yields vs spherocity



- The **transverse spherocity** (S_0) allows isolating D-meson production in jetty and isotropic events.

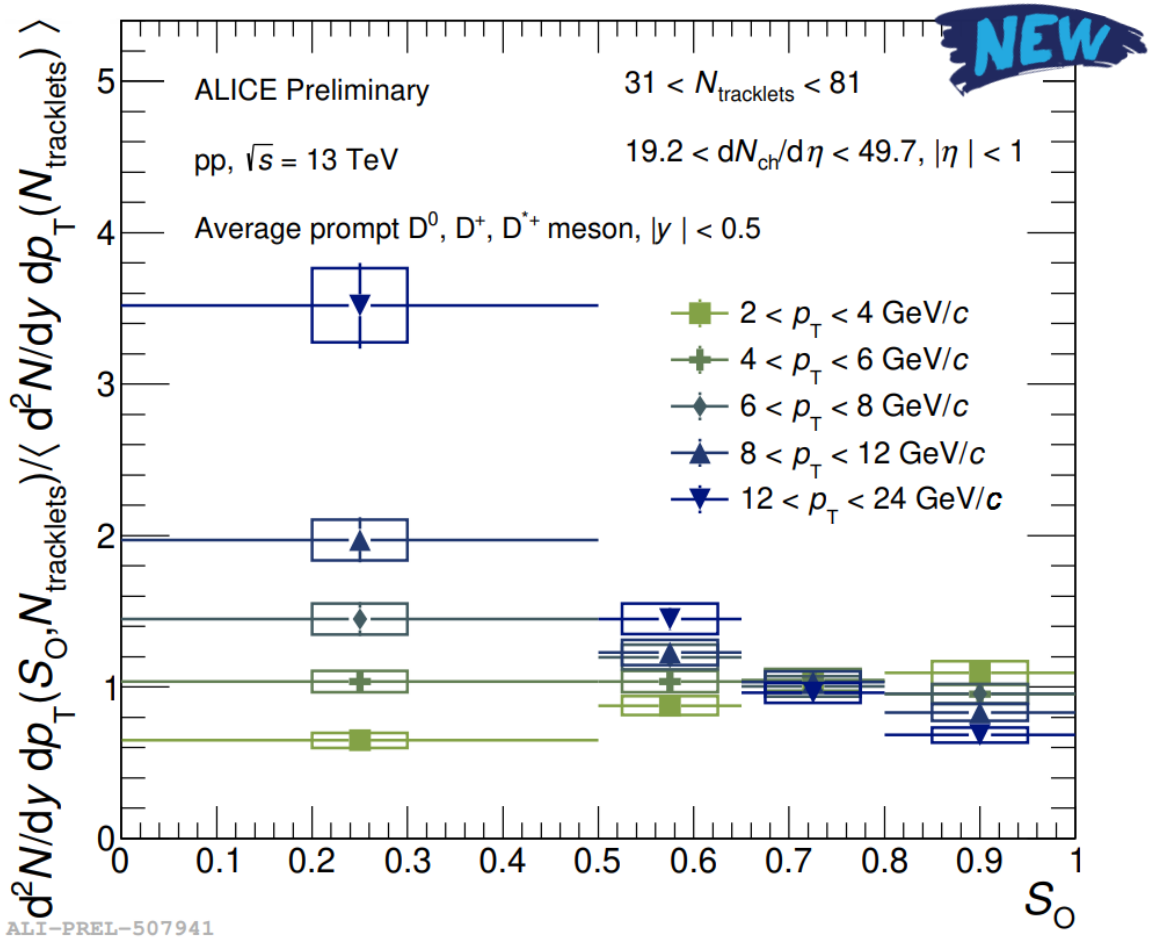
$$S_0 = \frac{\pi^2}{4}\left(\frac{\Sigma_i\ \vec{p}_{Ti} \times \hat{n}}{\Sigma_i\ p_{Ti}}\right)^2$$

Jetty ($S_0 \longrightarrow 0$)
Isotropic ($S_0 \longrightarrow 1$)



- D-meson production from jetty-like events dominates in high p_T intervals.

D meson self-normalized yields vs spherocity



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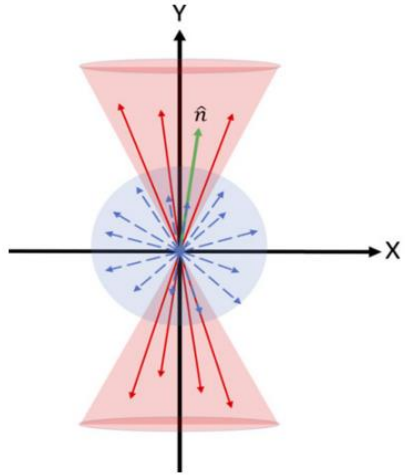


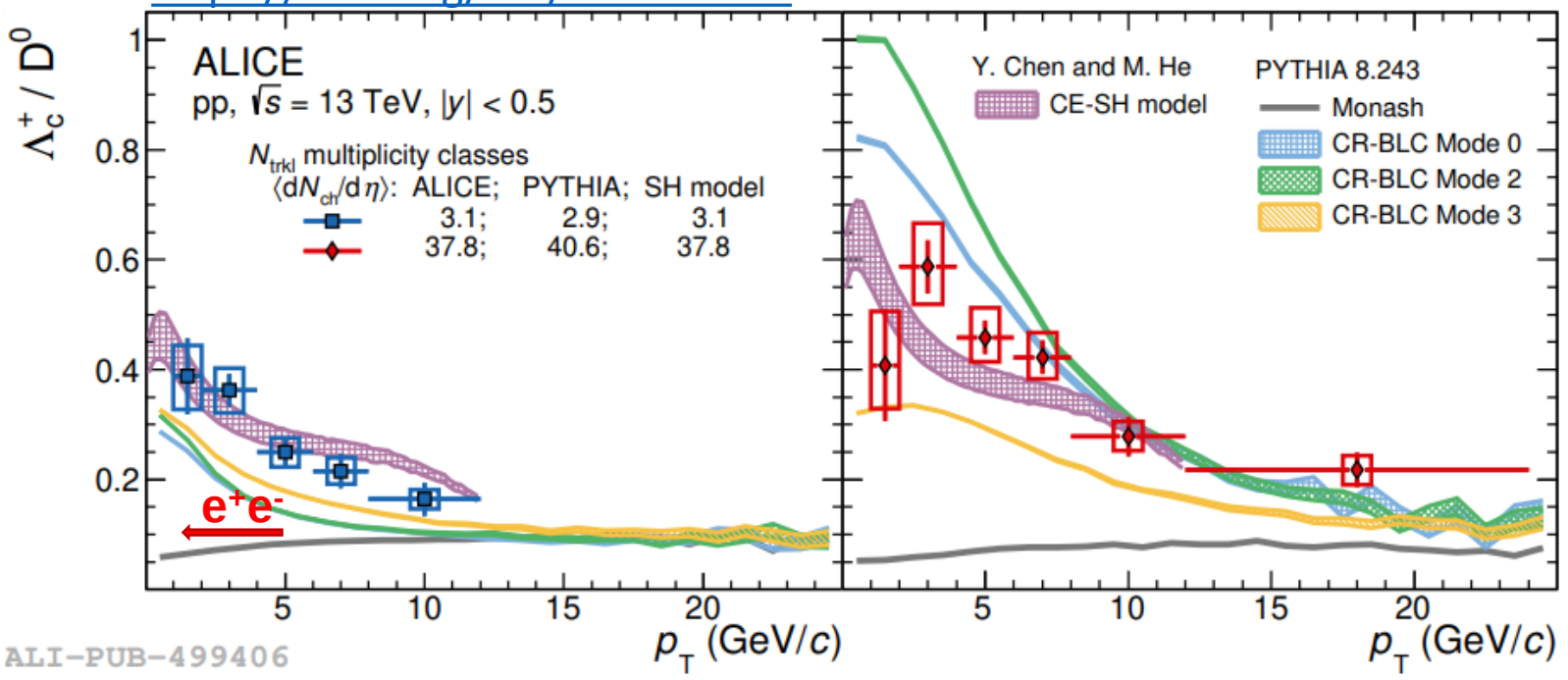
Randhir Singh
8th April, h 14:48

- Hint of enhancement of D-meson production from jetty-like events at high multiplicity.

Prompt Λ_c^+/D^0 baryon-to-meson ratio

pp

https://arxiv.org/abs/2111.11948



- Strong p_T dependence.
- Significant (5.3σ) dependence on multiplicity in $1 \leq p_T < 12$ GeV/c.

- Λ_c^+/D^0 ratios in pp are enhanced w.r.t. e^+e^- collisions, also in the lowest multiplicity interval.

→ **Fragmentation fractions of charm quarks are not a universal process among different collision systems.**

Prompt Λ_c^+/D^0 baryon-to-meson ratio

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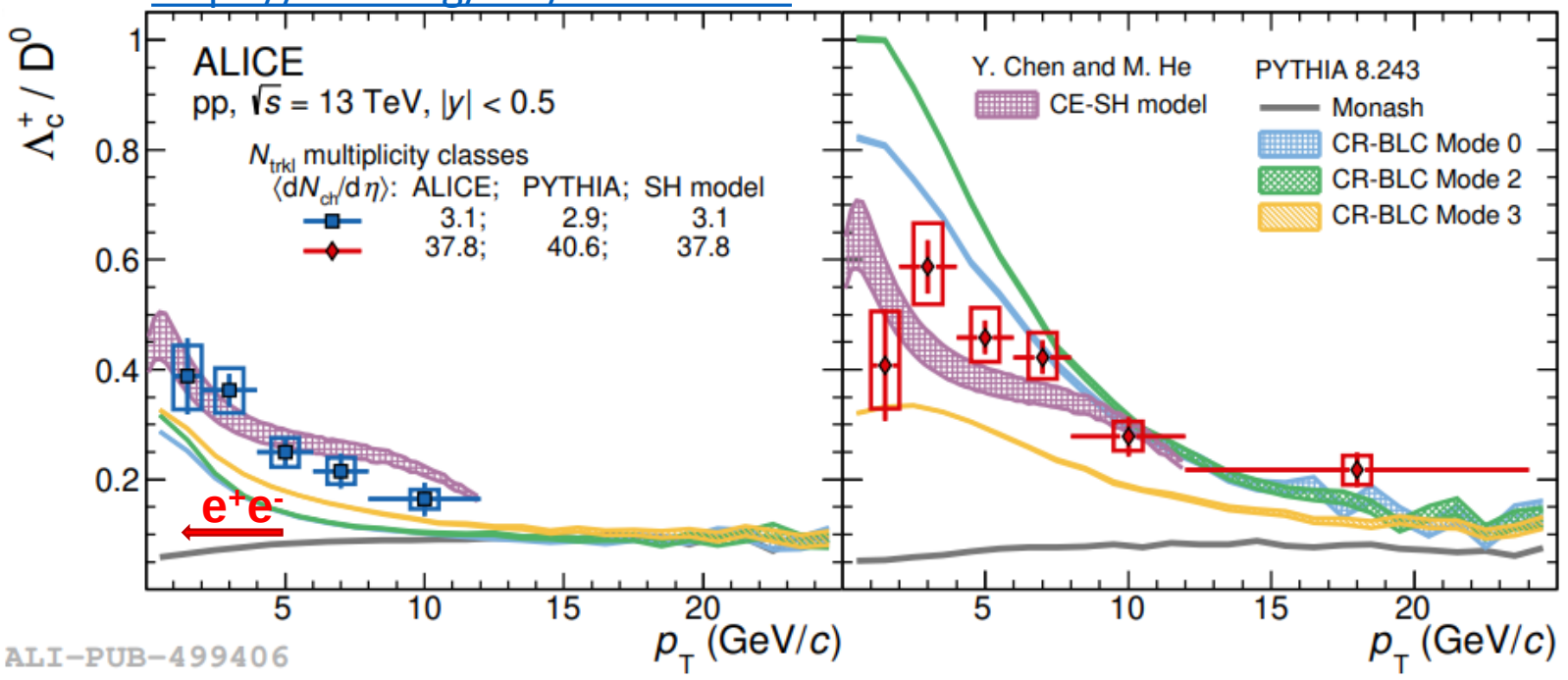
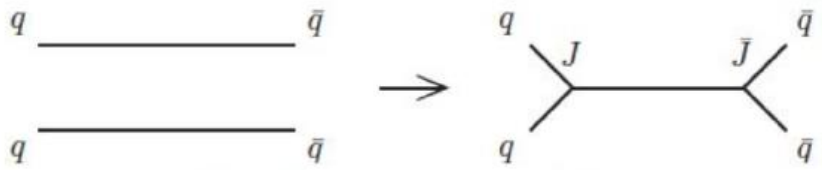


Mattia Faggin
7th April, h 11:10

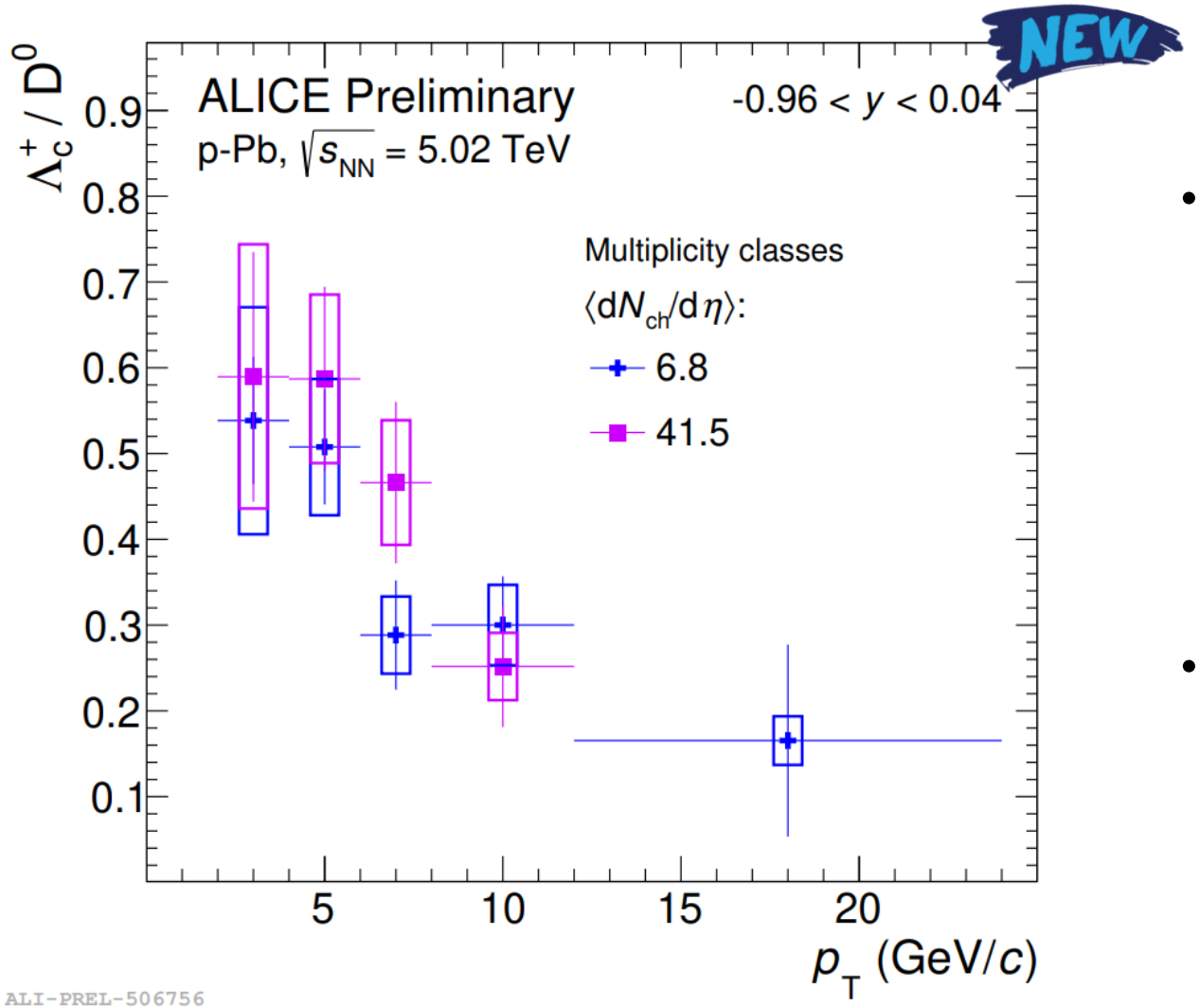
- **PYTHIA Monash** = simple string fragmentation model. Fragmentation functions tuned on e^+e^-.
  Skands et al, Eur. Phys. J. C 74 (2014) 3024

- **PYTHIA CR-BLC** = string formation beyond the leading colour approximation. Baryon production enhanced via **junction**. Christiansen & Skands, JHEP 1508 (2015) 003



- **CE-SH + RQM** = canonical ensemble statistical hadronization model including feed-down from additional excited baryon states predicted by the Relativistic Quark Model (RQM). Hee & Rapp, PLB 795 117-121 (2019)

Prompt Λ_c^+/D^0 baryon-to-meson ratio

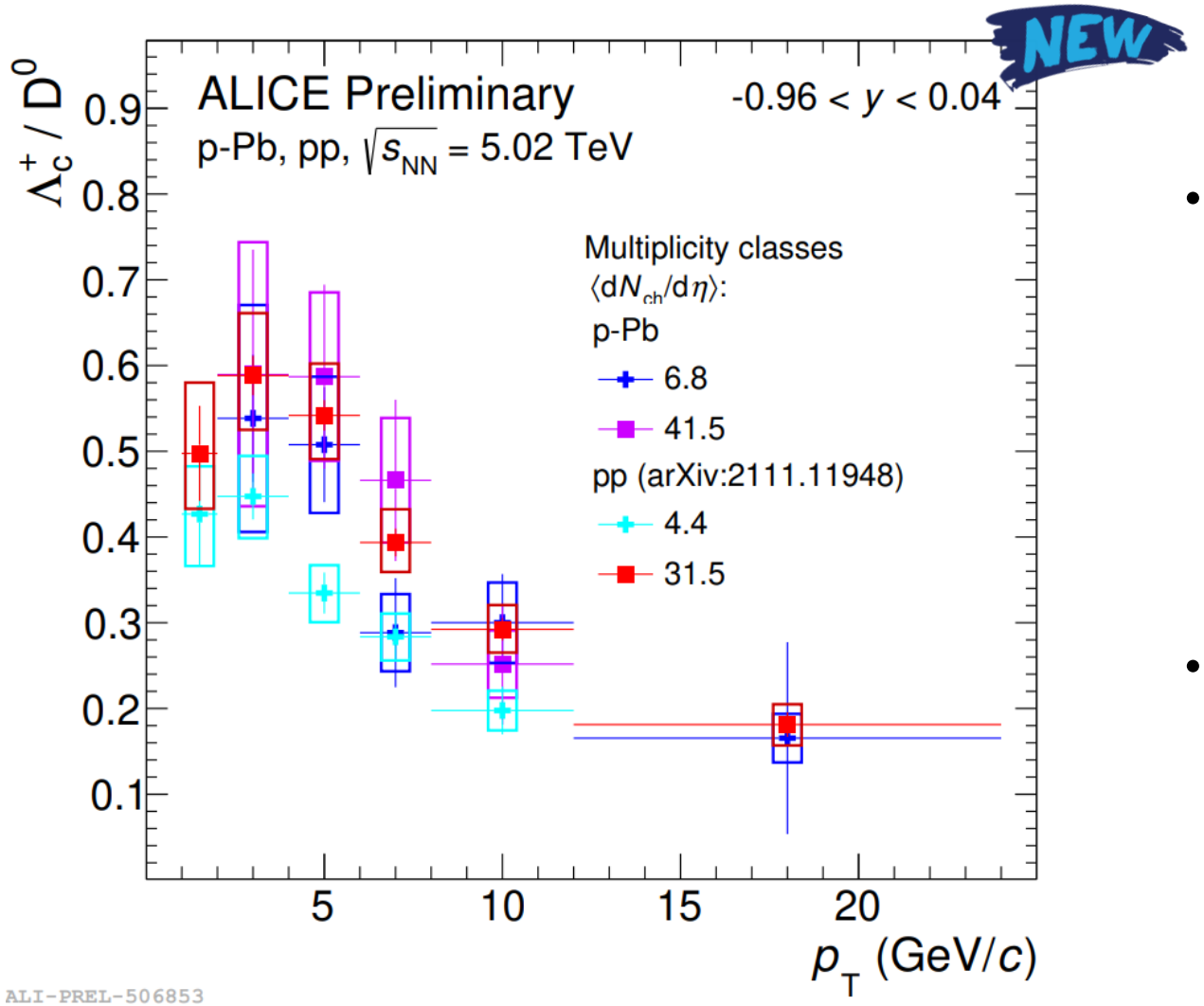


- With the current precision, no evidence of multiplicity dependence of Λ_c^+/D^0 p_T spectra from the lowest to the highest multiplicity interval in p–Pb.

- Compatible results in pp and p–Pb high-multiplicity intervals.

Oveis Sheibani
8th April, h 14:20

Prompt Λ_c^+/D^0 baryon-to-meson ratio



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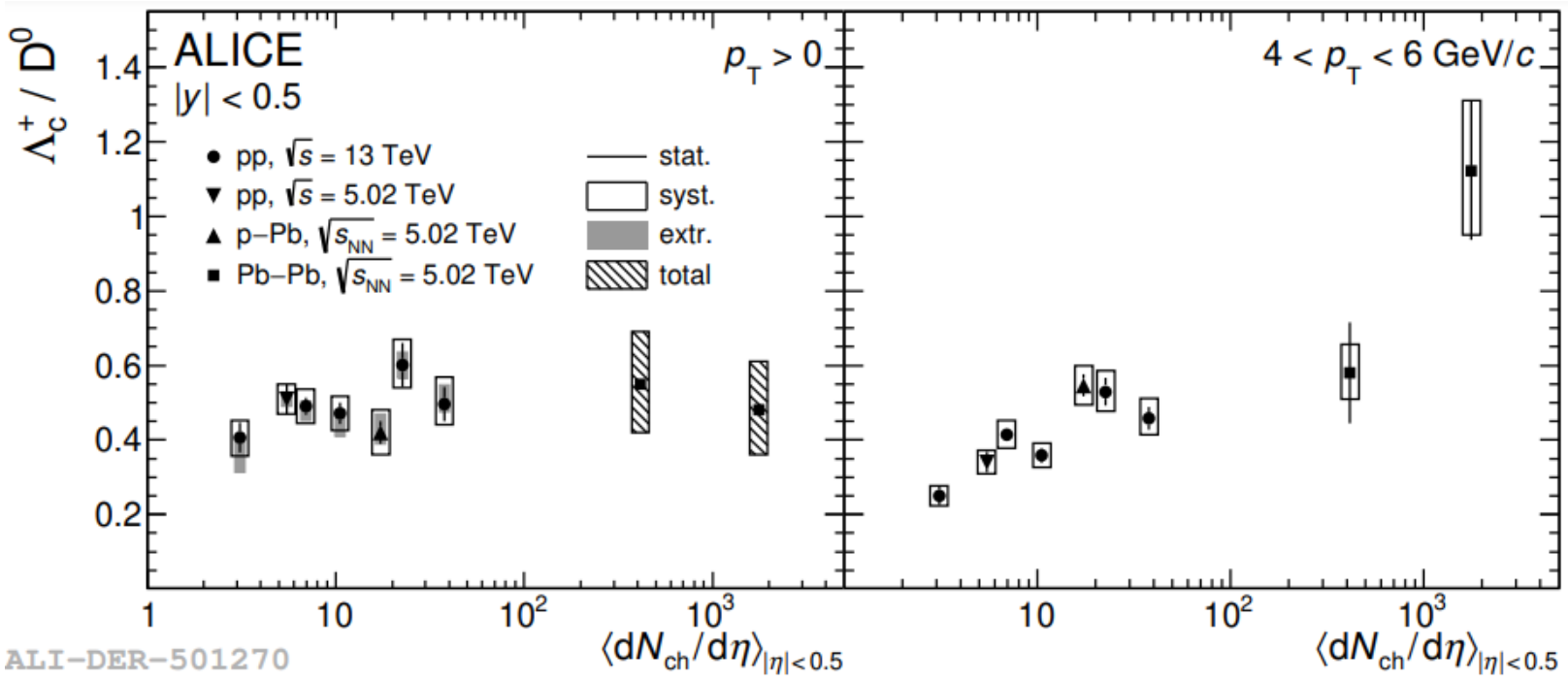
8th April, h 14:20

Integrated prompt Λ_c^+/D^0 baryon-to-meson ratio

pp pPb PbPb



p–Pb:Phys. Rev. C **104**, 054905

Pb–Pb: arXiv:2112.08156

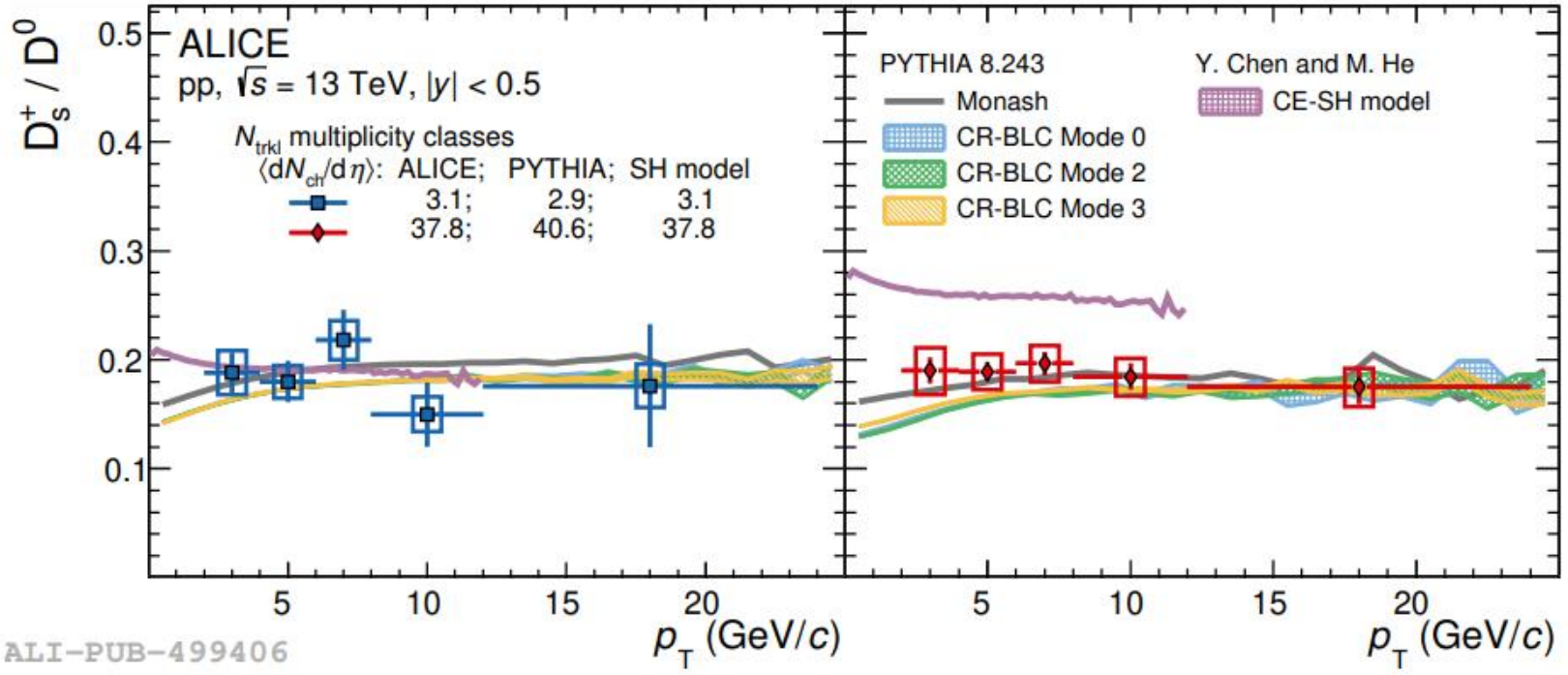
Lucas Anne Vermunt
7th April, h 09:00

- The p_T-integrated Λ_c^+/D^0 ratio vs multiplicity in pp, p–Pb and Pb–Pb measurements are compatible with each other.
- 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 hadronization? Radial flow?

Prompt D_s^+/D^0 strange to non-strange meson ratio

pp



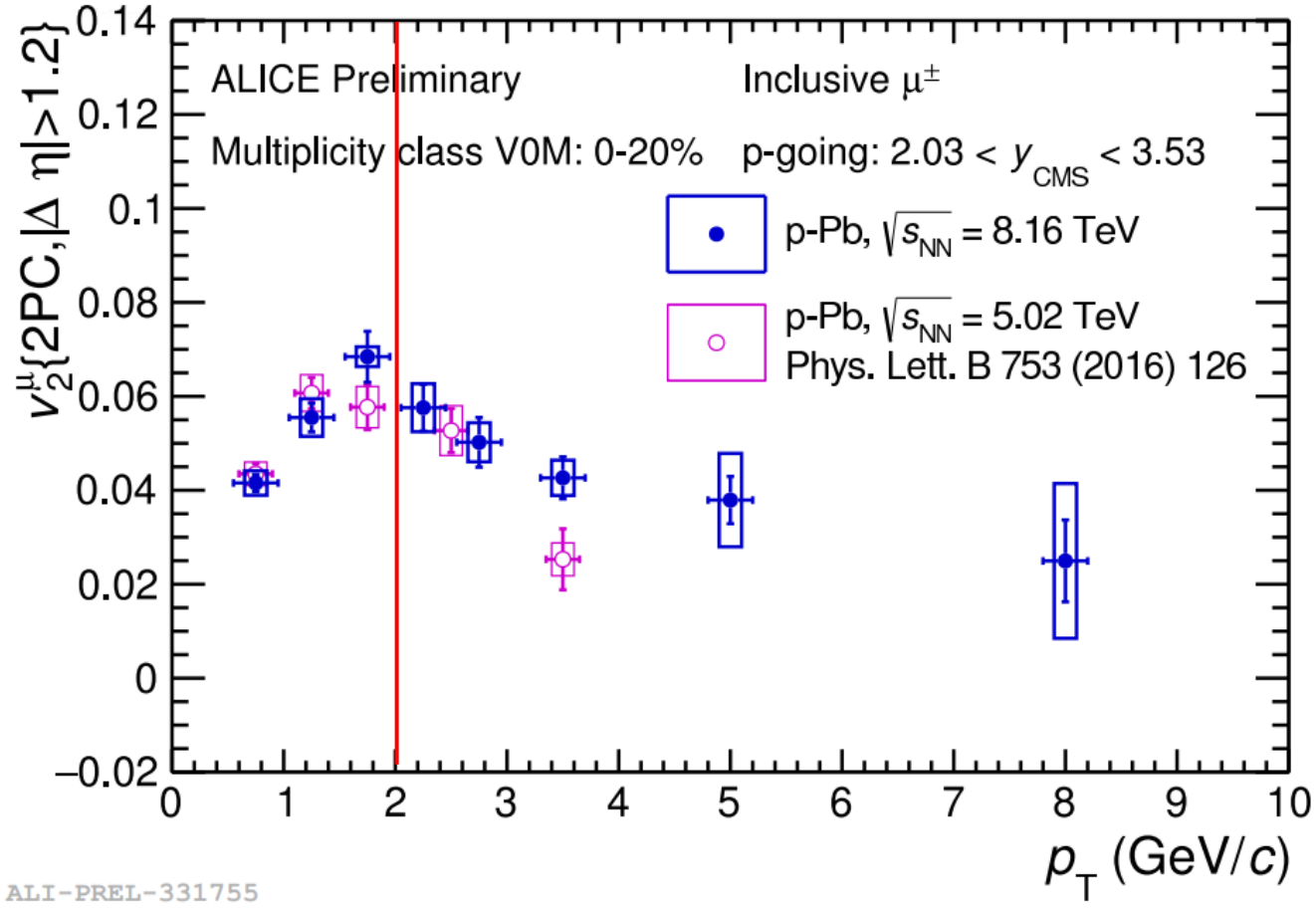
- D_s^+/D^0 ratios are p_T independent in the measured p_T range.
- Dependence of D_s^+/D^0 ratio on multiplicity not observed within the uncertainties.
- The results are comparable with the measurements performed in e^+e^- collisions.

- D_s^+/D^0 ratios compatible with **PYTHIA Monash** and **CR-BLC**.
- The **CE-SH** model describes the low multiplicity D_s^+/D^0 measurement, but it overestimates the data in the highest multiplicity interval.

Heavy-flavour decay muon elliptic-flow

p-Pb

- Positive v_2 in central p–Pb events. **Possibility of collective phenomena** in high-multiplicity p–Pb collisions.
- Dominant contribution of muons from heavy-flavour hadron decays is expected at $p_T > 2$ GeV/c.
- Participation of heavy quarks in the collective expansion of the system?



Conclusions

- Extension to a larger p_T interval of the heavy-flavour decay muon elliptic flow coefficient measurement in high-multiplicity p–Pb collisions.

Hint of heavy-flavour collectivity in small systems.

- Λ_c^+/D^0 ratios in pp collisions are enhanced w.r.t. e^+e^- collisions also in the lowest multiplicity class.

Different hadronization mechanisms at play?

- Prompt Λ_c^+/D^0 p_T-integrated ratio trend is multiplicity independent and compatible in pp, p–Pb and Pb–Pb collisions.

Further measurements needed to constrain the role of hadronization mechanisms and radial flow.

- **Run 2:** qualitative discovery of surprising phenomena similar to that originated from medium effects in small systems.
- **Run 3:** ALICE detector upgrade in LS2. Quantitative understanding of the microscopic mechanisms at play.

Stay tuned on the upcoming Run 3!

More on heavy flavour production

- **Xinye Peng** – 6th April, h 12:10*

  "Beauty production in heavy-ion collisions with ALICE at the LHC"

- **Lucas Anne Vermunt** – 7th April, h 09:00*

  "Charm production: constraint to transport models and charm diffusion coefficient with ALICE"

- **Mattia Faggin** – 7th April, h 11:10*

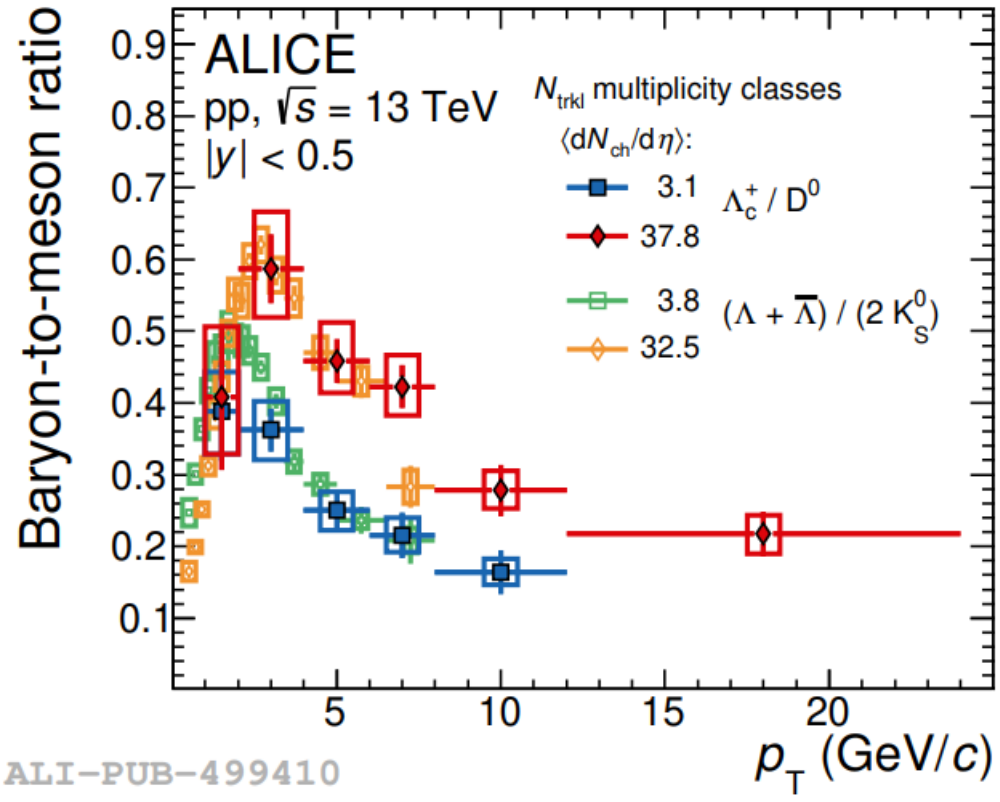
  "Constraining hadronization processes with charm baryons in pp and p–Pb collisions with ALICE"

*CEST timezone

Baryon-to-meson ratio

- Similar trend as a function of multiplicity for light- and heavy-flavour baryon-to-meson ratios, Λ/K_s^0 and Λ_c^+/D^0 .

- Hint of a potential common mechanism for light- and charm-baryon formation in hadronic collisions at LHC energies.



Integrated prompt Λ_c^+/D^0 baryon-to-meson ratio