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

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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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Medium-like properties in small systems?

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

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 $dE/dx$

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

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

**V0 detectors:**
- Multiplicity estimator
- Centrality
Heavy-flavour self-normalized yield

- 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.

D meson self-normalized yield

- **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**

- **3-pomeron CGC** (Colour Glass Condensate) = meson production via three pomerons (gluon shower) fusion.
  ➔ **Overpredicts the experimental data**
D meson self-normalized yields vs spherocity

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

\[
S_0 = \frac{\pi^2}{4} \left( \frac{\sum_i p_{T_i} \times \hat{n}}{\sum_i p_{T_i}} \right)^2
\]

Jetty \( (S_0 \rightarrow 0) \)
Isotropic \( (S_0 \rightarrow 1) \)

• D-meson production from jetty-like events dominates in high \( p_T \) intervals.
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Jetty ($S_0 \rightarrow 0$)
Isotropic ($S_0 \rightarrow 1$)

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

Randhir Singh
8th April, h 14:48
Prompt $\Lambda_c^+/D^0$ baryon-to-meson ratio

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

- $\Lambda_c^+/D^0$ 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.**
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 $\Lambda_c^+/D^0$ baryon-to-meson ratio

https://arxiv.org/abs/2111.11948

Mattia Faggin
7th April, h 11:10

Luigi Dello Stritto, QM 2022, Krakow (Poland)
Prompt $\Lambda_c^+/D^0$ baryon-to-meson ratio

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

- Compatible results in pp and p–Pb high-multiplicity intervals.
Prompt $\Lambda_c^+ / D^0$ baryon-to-meson ratio

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

Compatible results in pp and p–Pb high-multiplicity intervals.
Integrated prompt $\Lambda_c^+/D^0$ baryon-to-meson ratio

- The $p_T$-integrated $\Lambda_c^+/D^0$ 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?**

*Lucas Anne Vermunt 7th April, h 09:00*
Prompt $D_s^+/D^0$ strange to non-strange meson ratio

- $D_s^+/D^0$ 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.

Luigi Dello Stritto, QM 2022, Krakow (Poland)
Heavy-flavour decay muon elliptic-flow

- 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.

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

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

- 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!

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Hint of heavy-flavour collectivity in small systems.

Different hadronization mechanisms at play?

Further measurements needed to constrain the role of hadronization mechanisms and radial flow.
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, $\Lambda/K_S^0$ and $\Lambda_c^+/D^0$.

- Hint of a potential common mechanism for light- and charm-baryon formation in hadronic collisions at LHC energies.
Integrated prompt $\Lambda_c^+/D^0$ baryon-to-meson ratio