Measurement of the Λ_c^+ production in pp, p-Pb, and Pb-Pb collisions with ALICE Run-2 data

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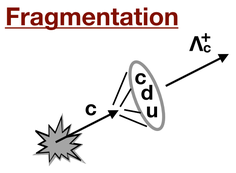
Λ_c^+ as a proof for recombination

Charm-baryon measurements provide unique insights into **hadronisation processes in the QGP**.

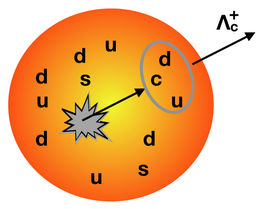
Λ_c^+ baryons were measured in Run-2 by the ALICE Collaboration in three systems:

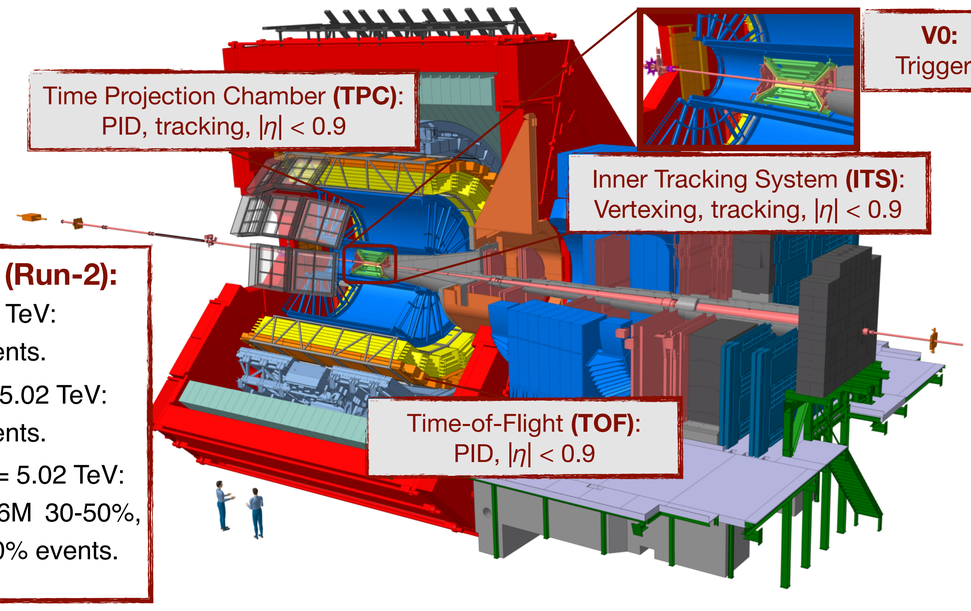
- **pp:** Test pQCD predictions and hadronisation models in vacuum. Needed reference for heavier systems.
- **p-Pb:** Distinguish cold-nuclear-matter (CNM) effects.
- **Pb-Pb:** Study hadronisation processes in the QGP.

Fragmentation



Recombination





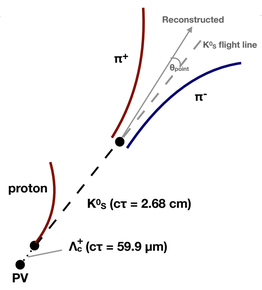
Data samples (Run-2):

- **pp,** $\sqrt{s}$ = 5.02 TeV: 980M MB events.
- **p-Pb,** $\sqrt{s_{NN}}$ = 5.02 TeV: 600M MB events.
- **Pb-Pb,** $\sqrt{s_{NN}}$ = 5.02 TeV: 100M MB, 76M 30-50%, and 89M 0-10% events.

Reconstruction and selection of the Λ_c^+ baryon

Λ_c^+ baryons fully reconstructed in hadronic decay channels:

- $\Lambda_c^+ \rightarrow p\ K_S^0 \rightarrow p\ (\pi^+\pi^-)$ (total BR = (1.10 ± 0.21)%[1])
- $\Lambda_c^+ \rightarrow p\ K^-\ \pi^+$ (total BR = (6.28 ± 0.05)%[1])



Further selection to reduce combinatorial background using:

- Rectangular topological selections[2].
- Toolkit for Multivariate Analysis (TMVA, using AdaBoost)[3].
- MachineLearningHEP package (MLHEP, using XGBoost. **New framework!**)[4].

► Training based on **signal from MC** and **background from the sidebands** of the invariant mass distribution from data. **Topological and PID variables** included in training.

The MachineLearningHEP package

The Λ_c^+ analysis with the 2018 Pb-Pb data sample is the **first exploiting a newly developed python-based fast analysis framework** for high-energy physics, exploiting both rectangular and machine-learning optimisation techniques.

- Framework purely python based.
- Data stored in Pandas DataFrames.
- Using python multiprocessing tool.
- Analysis performed on local server with large SSD and RAM resources.

Reconstructed data (ROOT objects)
Pb-Pb 2018 = ~1PB (@GRID)

Skimming (No signal loss)

Skimmed Λ_c^+ objects (Pandas DataFrames)
Pb-Pb 2018 = ~1TB (@Local server)

Training

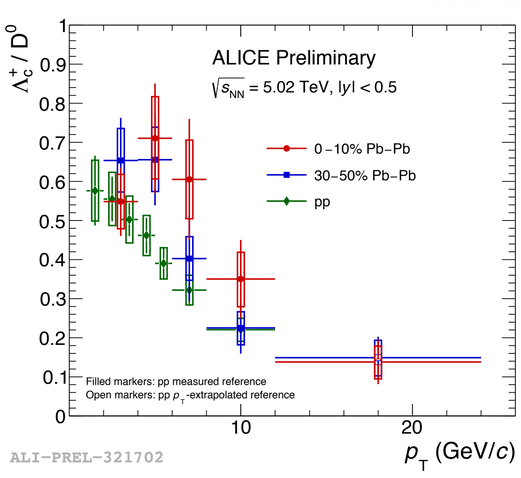
Selection optimisation
Both rectangular selections and machine-learning optimisation:
- XGBoost, SciKit, Keras.
- Many validation tools available.

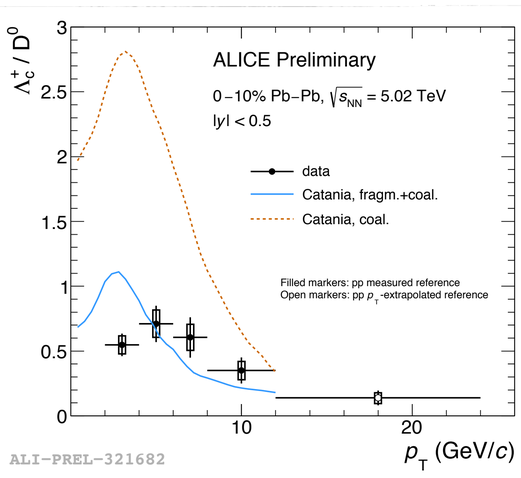
Applying (Loose selection)

Selected Λ_c^+ objects (Pandas DataFrames)
Pb-Pb 2018 = ~100GB (@Local server)

Improvements in significance and p_T reach (from [4-8] GeV/c in semi-central to [2-24] GeV/c in both central and semi-central collisions).

Baryon-to-meson ratio





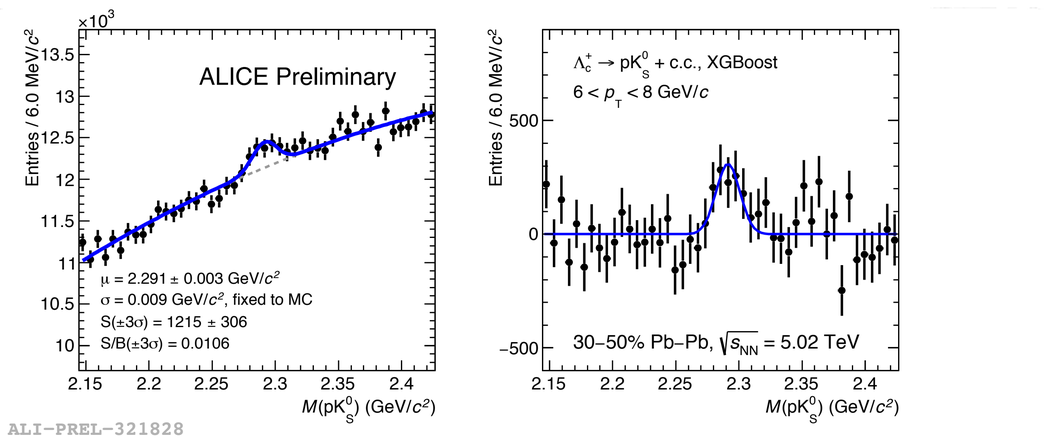
Hint of **enlarged Λ_c^+/D^0 ratio in Pb-Pb collisions** with respect to pp collisions.

- Favours a scenario with both fragmentation and coalescence present.
- The ratio is underestimated in pp and p-Pb by models with fragmentation parameters derived from e^+e^- collision data[6].

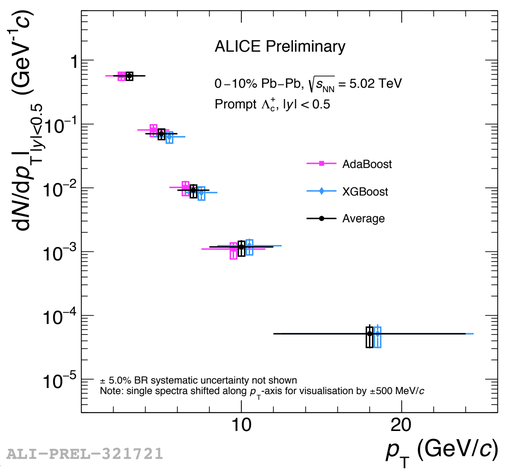
References

[1] Particle Data Group, Phys. Rev. D 98, 030001 (2018)
[2] ALICE Collaboration. Phys.Lett. B793 (2019) 212-223
[3] A. Hoecker et al., PoS ACAT 040 (2007)
[4] https://github.com/ginnocen/MachineLearningHEP
[5] M. Cacciari et al., JHEP 9805 (1998) 007
[6] ALICE Collaboration, JHEP 1804 (2018) 108

Signal extraction



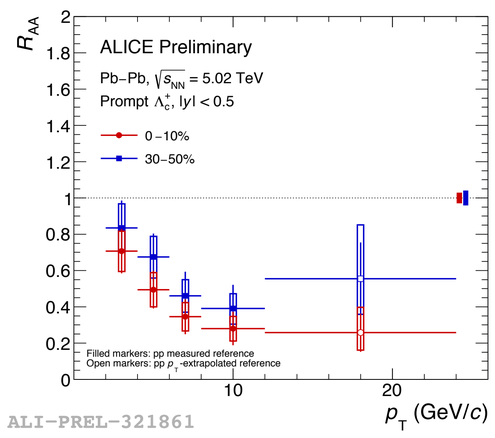
- Signal extracted via fit to **invariant mass distribution** after selections. Modelled with Gaussian function and second-order polynomial for background.
- Raw signal **corrected for selection efficiency** using MC simulations.
- **Feed-down subtraction** using FONLL[5] calculations of beauty production.

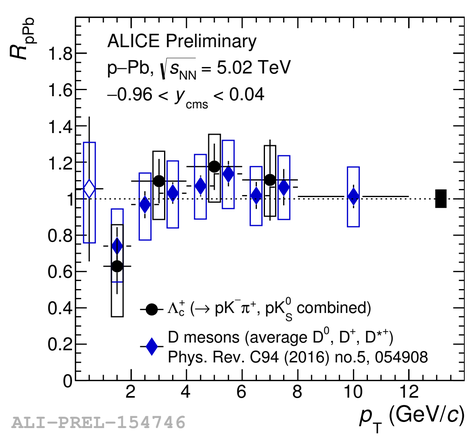


Final corrected Λ_c^+ spectra for all three systems are averaged:

- Combining multiple analysis methods and/or decays.
- Weighted by the inverse of the sum in quadrature of the relative uncorrelated systematics (i.e. yield extraction).

Nuclear modification factor





- Hint of **lower nuclear modification factor** for central Pb-Pb collisions.
- The Λ_c^+ R_{pPb} is consistent with unity.
  - ► Pb-Pb suppression in $4 < p_T < 12$ GeV/c due to hot nuclear matter effects.

Summary

LHC Run-2 was successful for Λ_c^+ measurements in ALICE.

- Λ_c^+ production measured for the first time in Pb-Pb collisions in a large kinematic range for both central and semi-central collisions.
- Improved statistical precision and wider p_T range for Λ_c^+ measurements in pp and p-Pb collisions.
- A new and general fast analysis framework developed and used for the first time for the Λ_c^+ analysis with the 2018 Pb-Pb data sample.