Measurement of Λ_c^+ production in pp, p-Pb, and Pb-Pb collisions with the ALICE experiment at the LHC

Clara Bartels (University of Liverpool) on behalf of the ALICE collaboration

HADRON2023 - 20th International Conference on Hadron Spectroscopy and Structure

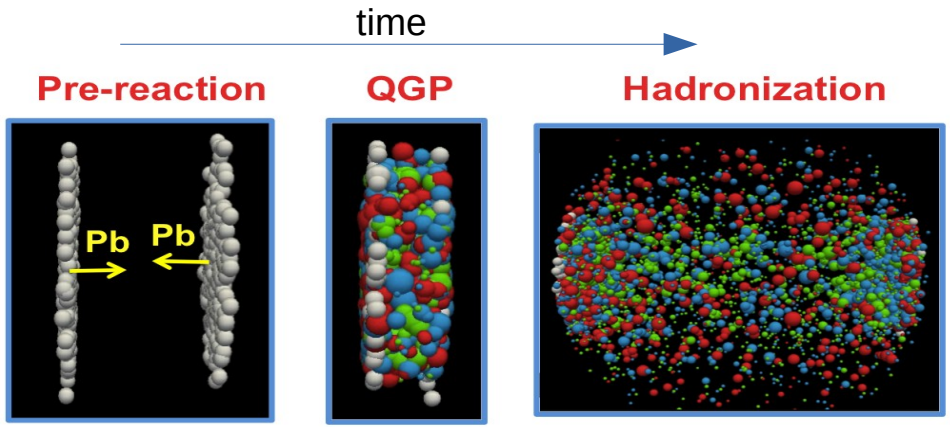
Quark-Gluon Plasma

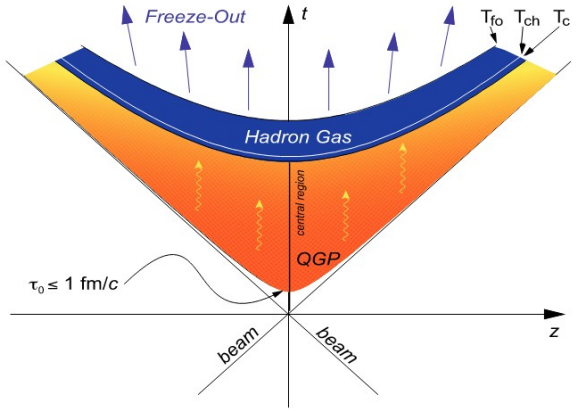
Quark-gluon plasma:

- Deconfined state of quarks and gluons
- Created during Pb-Pb collision
- Quickly cools down and hadronises

Heavy-flavour quarks:

- Produced in the early stages of the collision
- Interact with medium during all stages of the system's evolutions
- Excellent probe of QGP and its properties

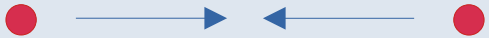




Heavy-flavour production across collision systems

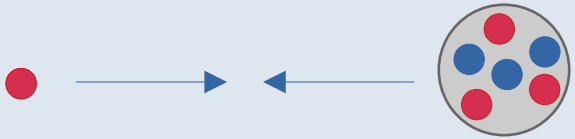
pp collisions

- Test perturbative QCD calculations
- Investigate hadronization mechanisms
- Baseline for p-Pb and Pb-Pb collisions



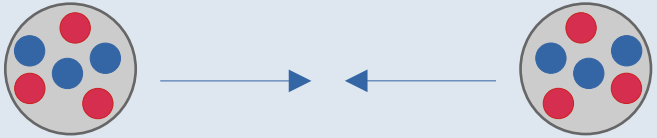
p-Pb collisions

- Cold nuclear matter effects



Pb-Pb collisions

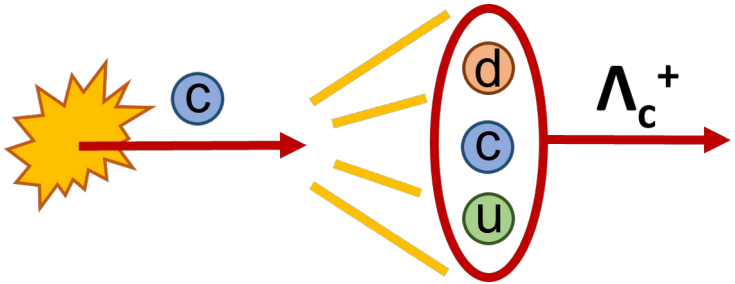
- Study parton interaction in Quark Gluon Plasma
- Investigate modification of hadronisation mechanisms



Hadronisation mechanisms

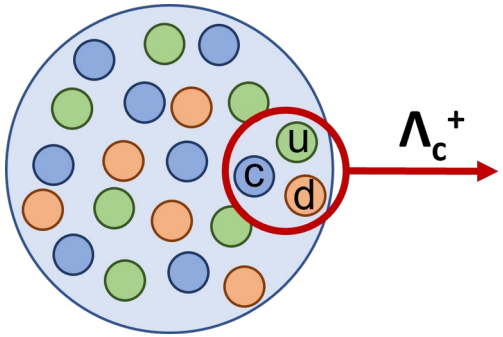
Fragmentation:

- Energetic quark or gluon excites the vacuum and creates a pool of quarks and antiquarks
- It combines with them into hadrons
- Predicted to be universal in collision systems



Coalescence:

- Predicted to occur in high parton density systems
- Quark and gluons get close enough in space and momentum to recombine into hadrons directly



Hadronisation mechanisms

Mechanisms can be probed by relative production of hadrons:

- Three low energy quarks recombine into a baryon
- Two intermediate energy quarks recombine into a meson
- High energy quark fragments into lower p_T meson

→ **Expect enhanced baryon-to-meson ratio at intermediate momentum**

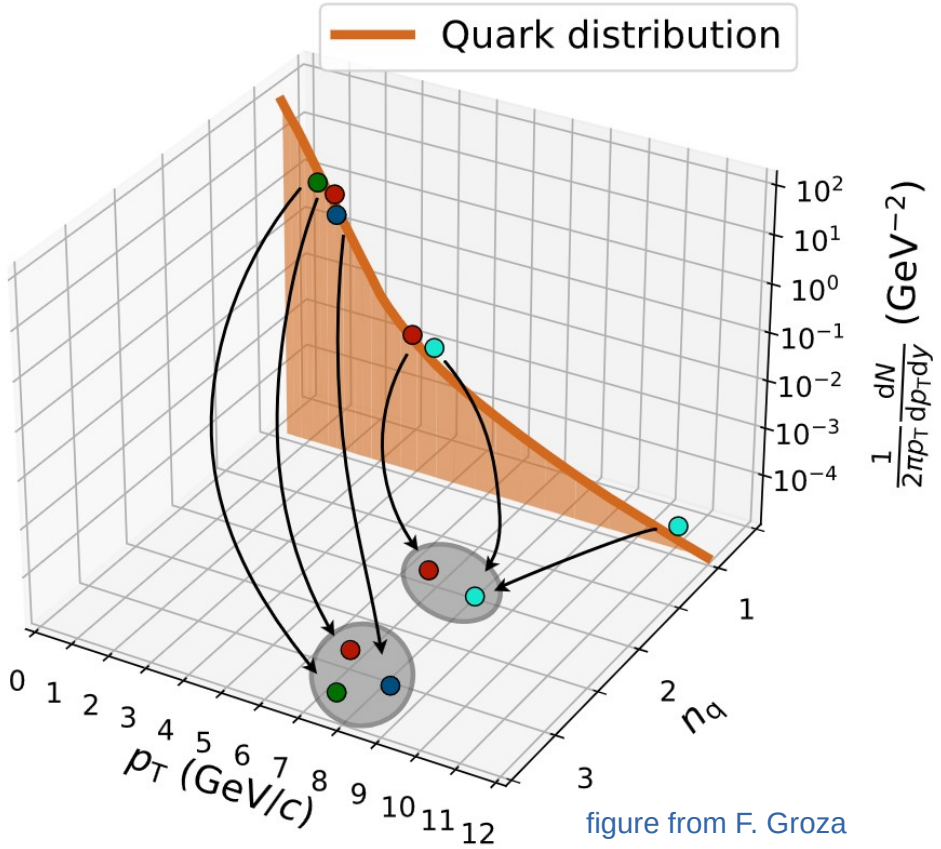
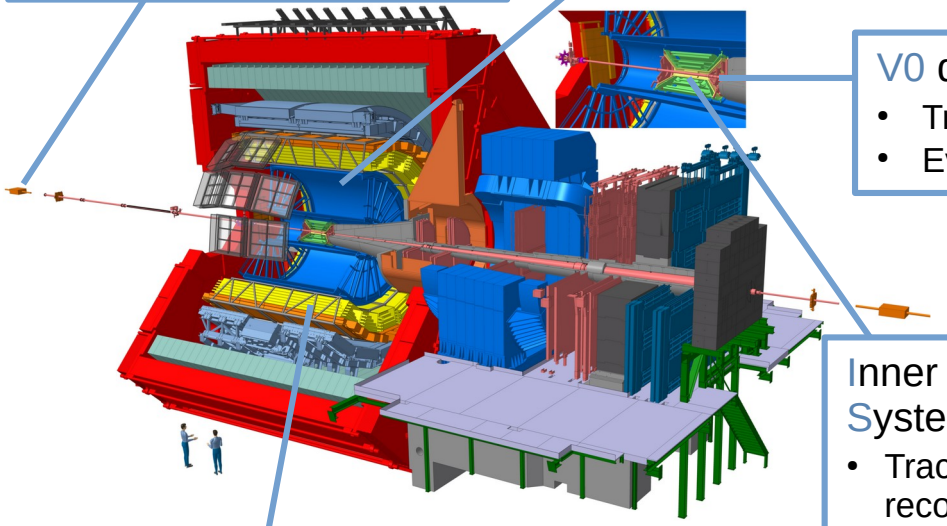


figure from F. Groza

The ALICE detector

- One of the 4 main LHC experiments
- Optimised for heavy-ion (Pb-Pb) collisions, but also provides excellent performance in pp collisions
  - Track and PID down to low p_T
  - Identification of short-lived particles
  - Low material budget
- Heavy-flavour decay reconstruction achieved with several different techniques and detectors



Zero Degree Calorimeter
- Measure collision centrality

Time Projection Chamber
- Track reconstruction
- Particle identification

V0 detectors
- Trigger
- Event selection

Inner Tracking System
- Track reconstruction
- Primary and secondary decay vertices reconstruction

Time of Flight detector
- Particle identification

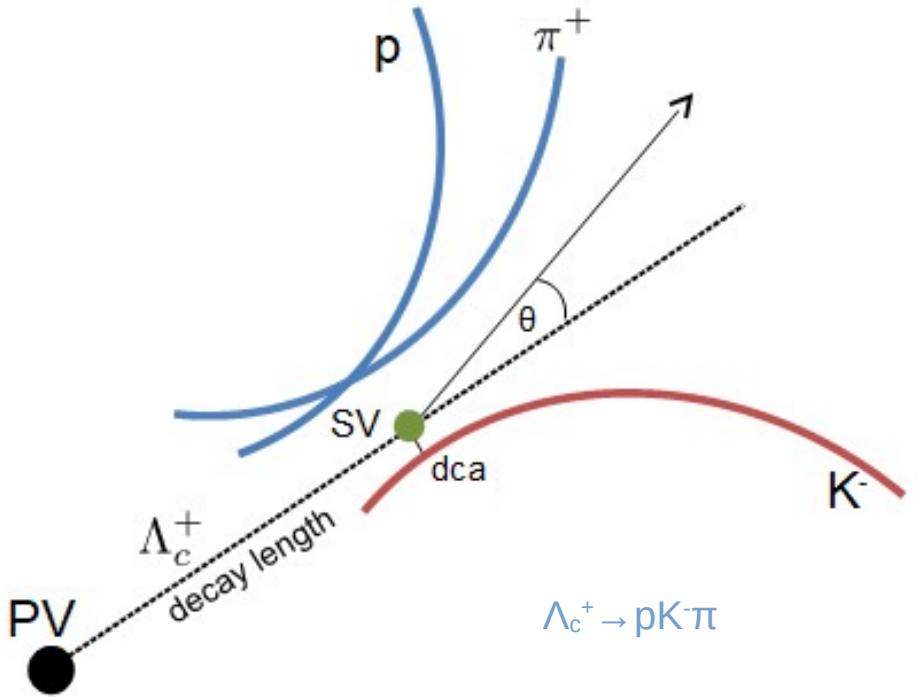
Reconstruction of the Λ_c^+ baryon

Λ_c^+ = udc, m = 2286.46 ± 0.14 MeV, cτ = 60μm

$\Lambda_c^+ \rightarrow pK^-\pi^+$ (BR = 6.28%)

$\Lambda_c^+ \rightarrow pK_s^0$ (BR = 1.59%)

- Reconstructed via hadronic decay channel
- Candidates built as combinatorial of track triplets
- PID selection
- kinematic and topological cuts applied using rectangular cuts or Boosted Decision Trees (BDT)



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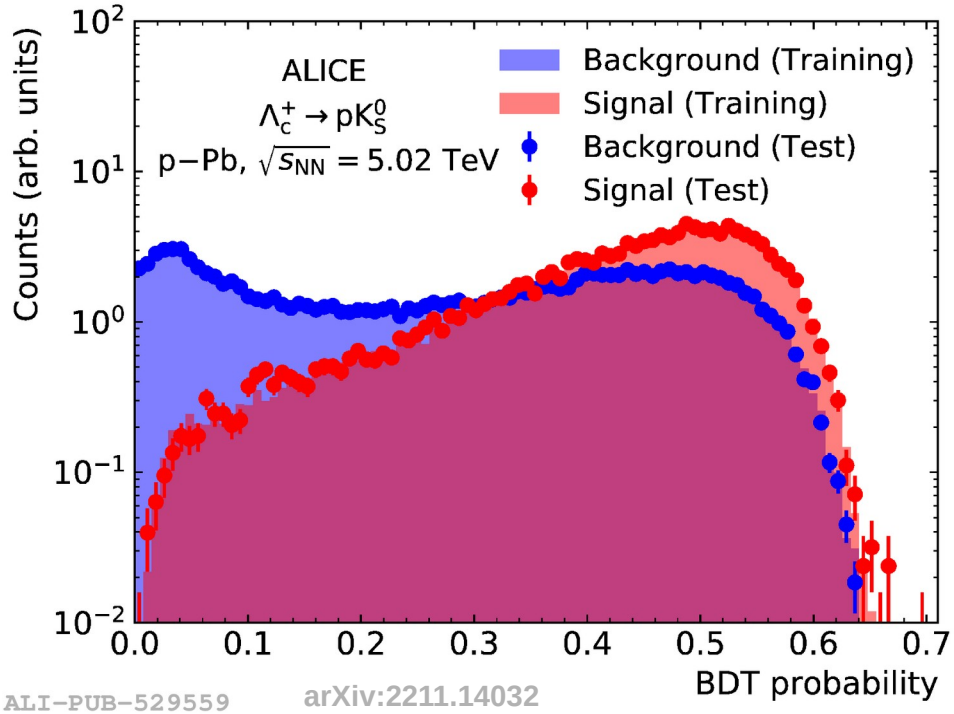

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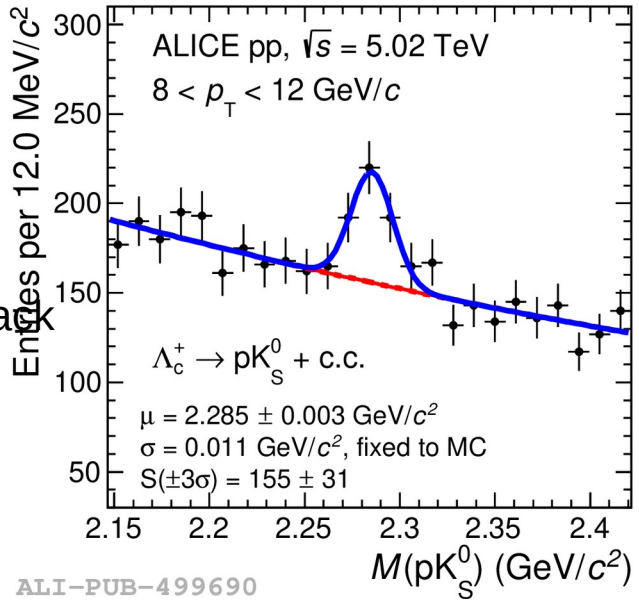
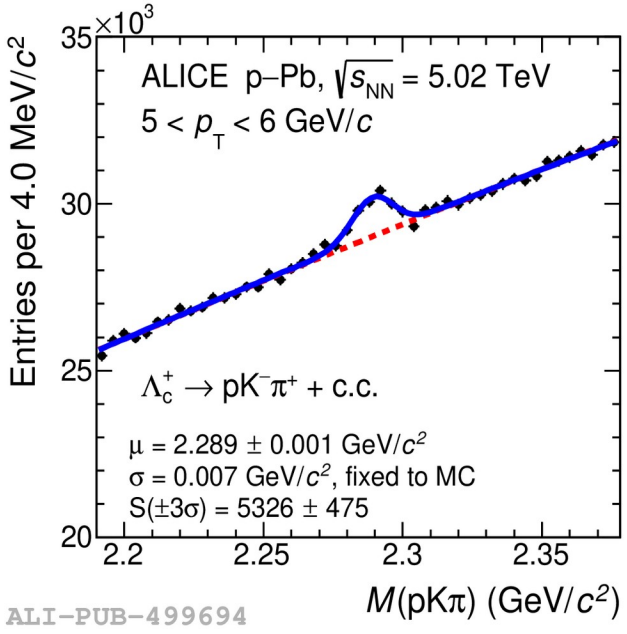


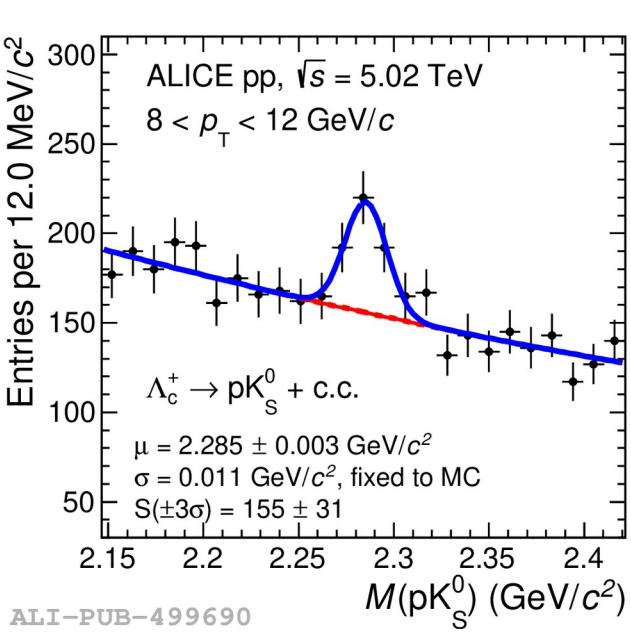


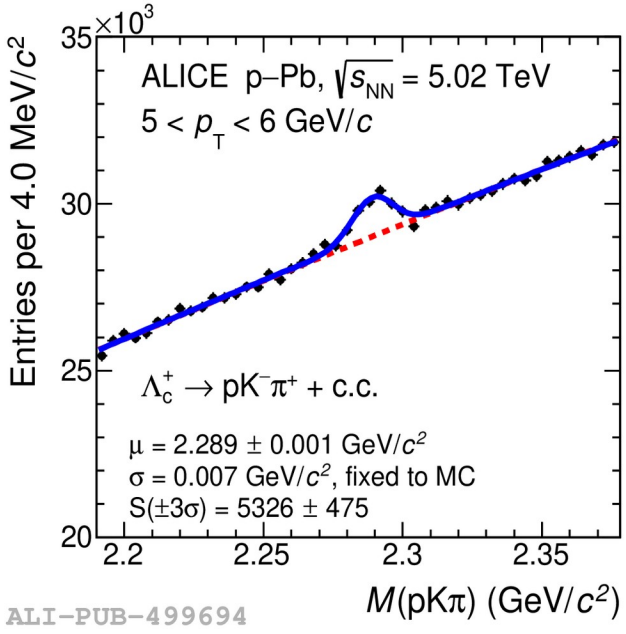
arXiv:2011.06079

Λ_c^+ cross section evaluation

Corrections are applied to the yield:

- Branching ratio
- Feed-down
  - Account for Λ_c^+ produced through beauty-hadron decays
- Efficiency
- Detector acceptance





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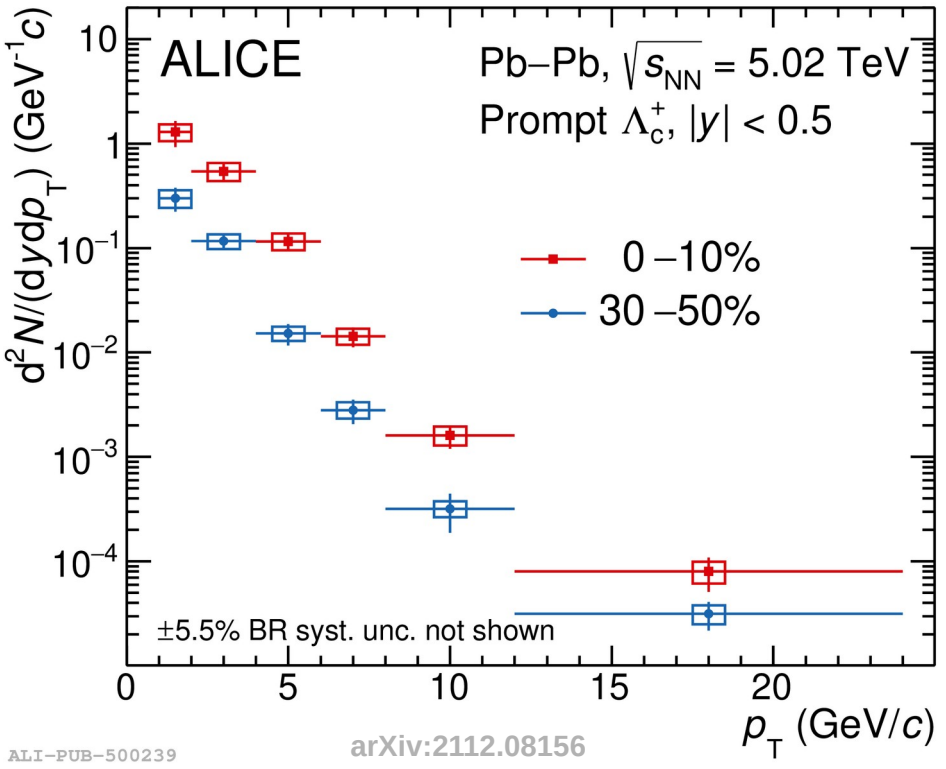
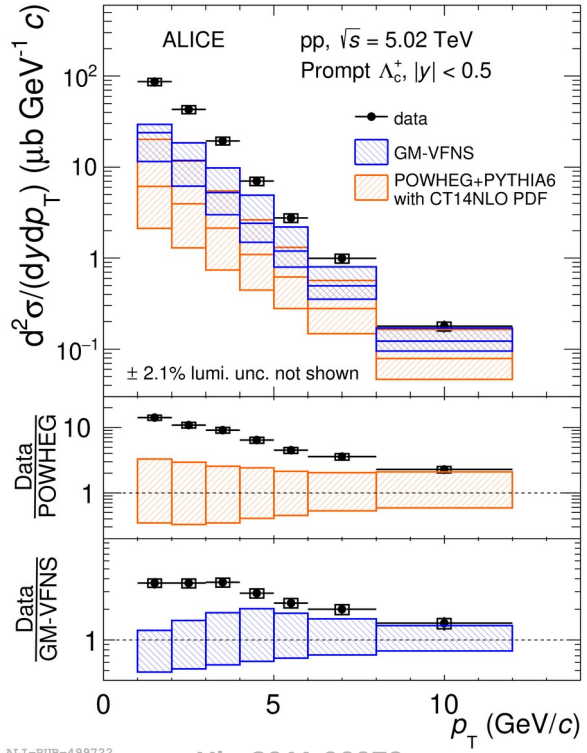


Λ_c^+ cross section in pp collisions

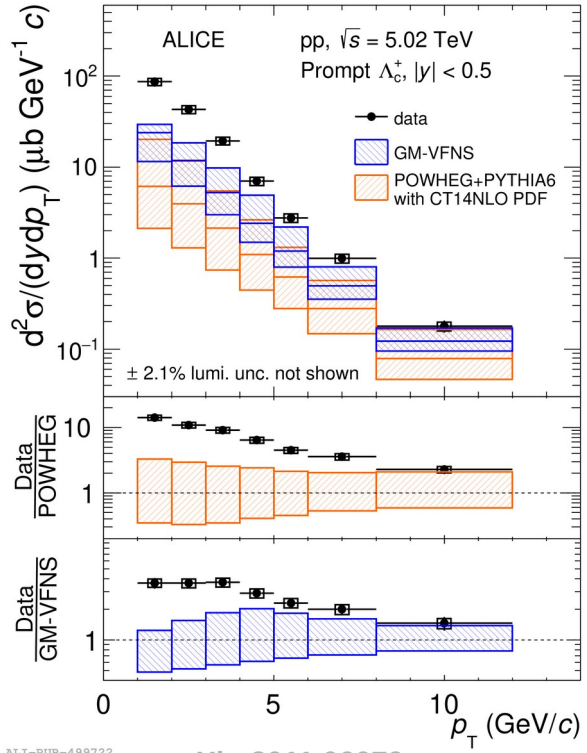
- Λ_c^+spectra underestimated by models



arXiv:2011.06079

Λ_c^+ cross section in pp collisions

- Λ_c^+spectra underestimated by pQCD calculations with fragmentation function tuned on leptonic collisions
- D^0 spectra in agreement with the same calculations



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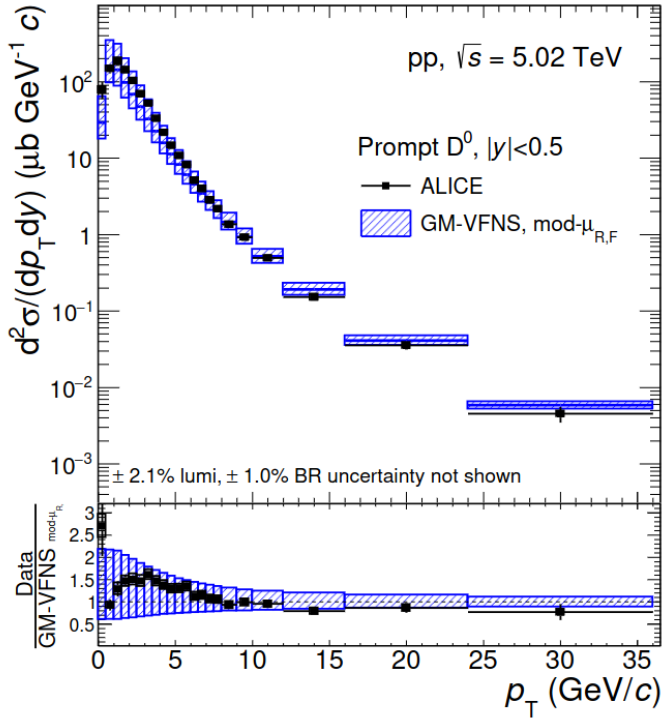
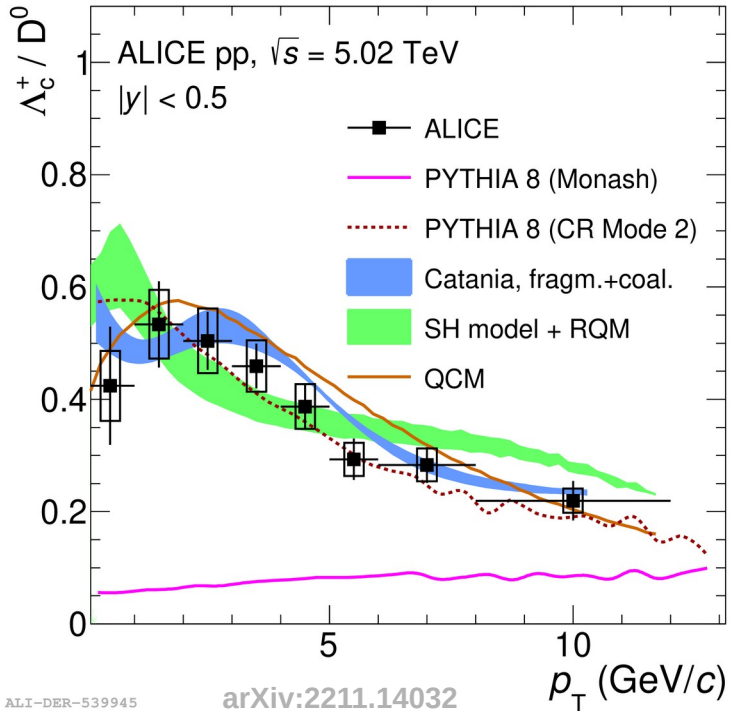


arXiv:1901.07979

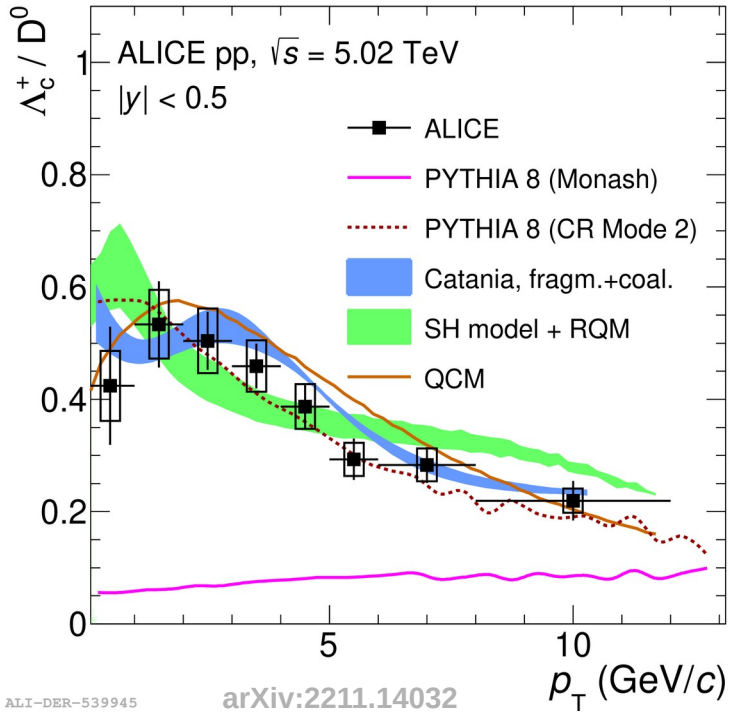
Λ_c^+/D^0 ratio in pp collisions



- Pythia 8 (Monash)[1]: fragmentation function taken from e^+e^- measurements
- PYTHIA 8 CR Mode 2[2]: string formation beyond leading colour order
- Catania[3]: coalescence and fragmentation in de-confined system
- SHM+RQM[4]: statistical hadronisation model with additional charm states
- QCM[5]: quark combination model assuming coalescence

[1] P. Skands, S. Carrazza, and J. Rojo, "Tuning PYTHIA 8.1: the Monash 2013 Tune", Eur. Phys. J.C 74 (2014) 3024, arXiv:1404.5630 [hep-ph].
[2] J. R. Christiansen and P. Z. Skands, "String Formation Beyond Leading Colour", JHEP 08 (2015) 003, arXiv:1505.01681 [hep-ph].
[3] V. Minissale, S. Plumari, and V. Greco, "Charm hadrons in pp collisions at LHC energy within a coalescence plus fragmentation approach", Phys. Lett. B 821 (2021) 136622, arXiv:2012.12001
[4] M. He and R. Rapp, "Charm-Baryon Production in Proton-Proton Collisions", Phys. Lett. B 795 (2019) 117–121, arXiv:1902.08889 [nucl-th].
[5] H. Li, F. Shao, and J. Song, "Production of light-flavor and single-charmed hadrons in pp collisions at p_s = 5□02 TeV in an equal-velocity quark combination model", Chin. Phys. C 45 (2021) 113105, arXiv:2103.14900 [hep-ph]

Λ_c^+/D^0 ratio in pp collisions



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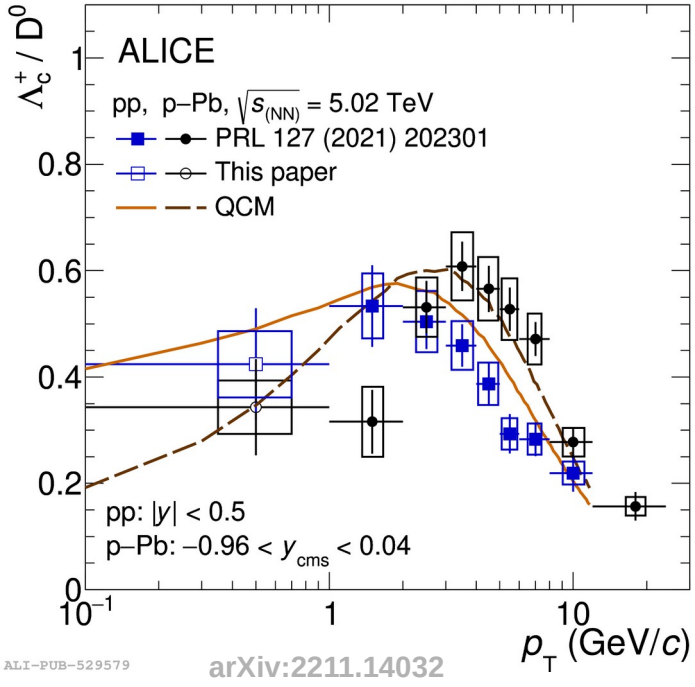
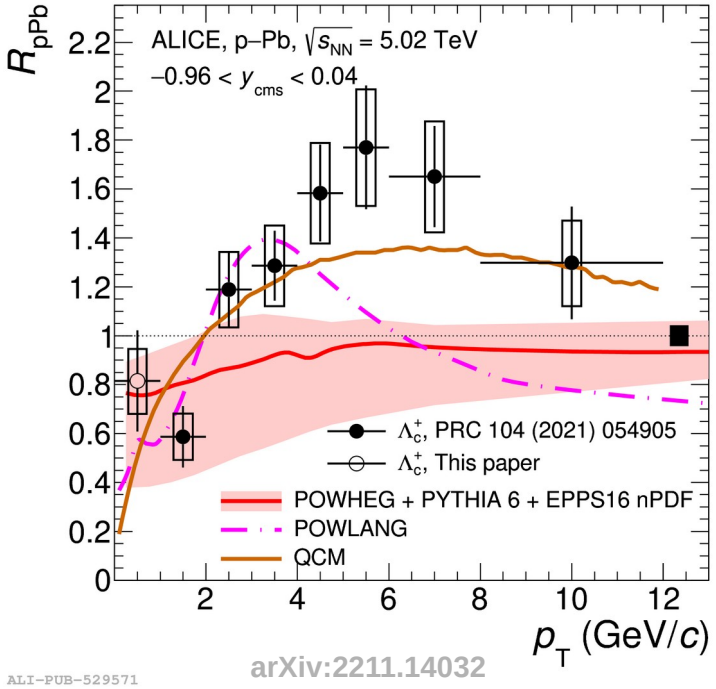
- Significantly underpredicted by expectations from e^+e^- collisions
- Models that modify hadronisation or include additional charm baryon states do better

Results in p-Pb collisions



- Hint of shift of peak towards higher momentum
- Trend is reproduced by QCM model

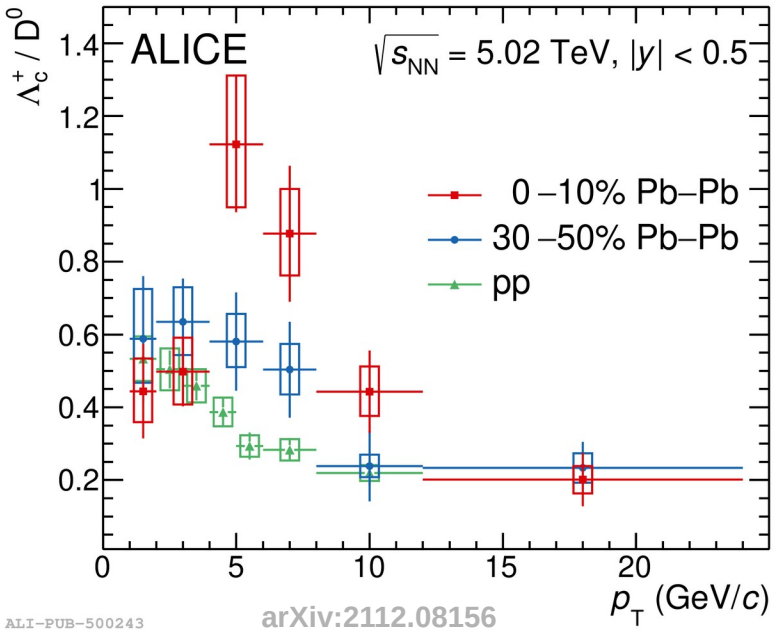


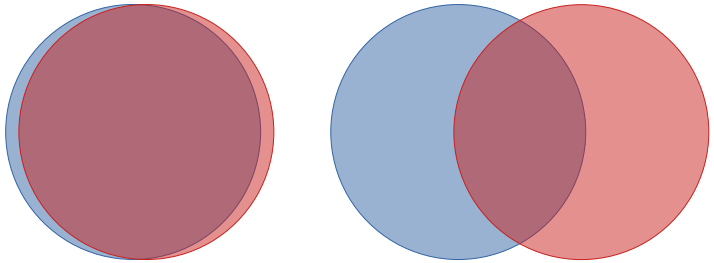
- Hint of intermediate p_T bump

- QCM[1]: quark combination model assuming coalescence
- POWHEG+PYTHIA[2]: NLO pQCD calculations coupled with MC parton shower
- POWLANG[3]: uses the Langevin approach and Hard Thermal Loop (HTL) transport coefficients

[1] H. Li, F. Shao, and J. Song, "Production of light-flavor and single-charmed hadrons in pp collisions at p_s = 5□02 TeV in an equal-velocity quark combination model", Chin. Phys. C 45 (2021) 113105, arXiv:2103.14900 [hep-ph]
[2] S. Frixione, P. Nason, and G. Ridolfi, "A Positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction", JHEP 09 (2007) 126, arXiv:0707.3088 [hep-ph].
[3] A. Beraudo, A. De Pace, M. Monteno, M. Nardi, and F. Prino, "Heavy-flavour production in high-energy d-Au and p-Pb collisions", JHEP 03 (2016) 123, arXiv:1512.05186 [hep-ph].

Results in Pb-Pb collisions



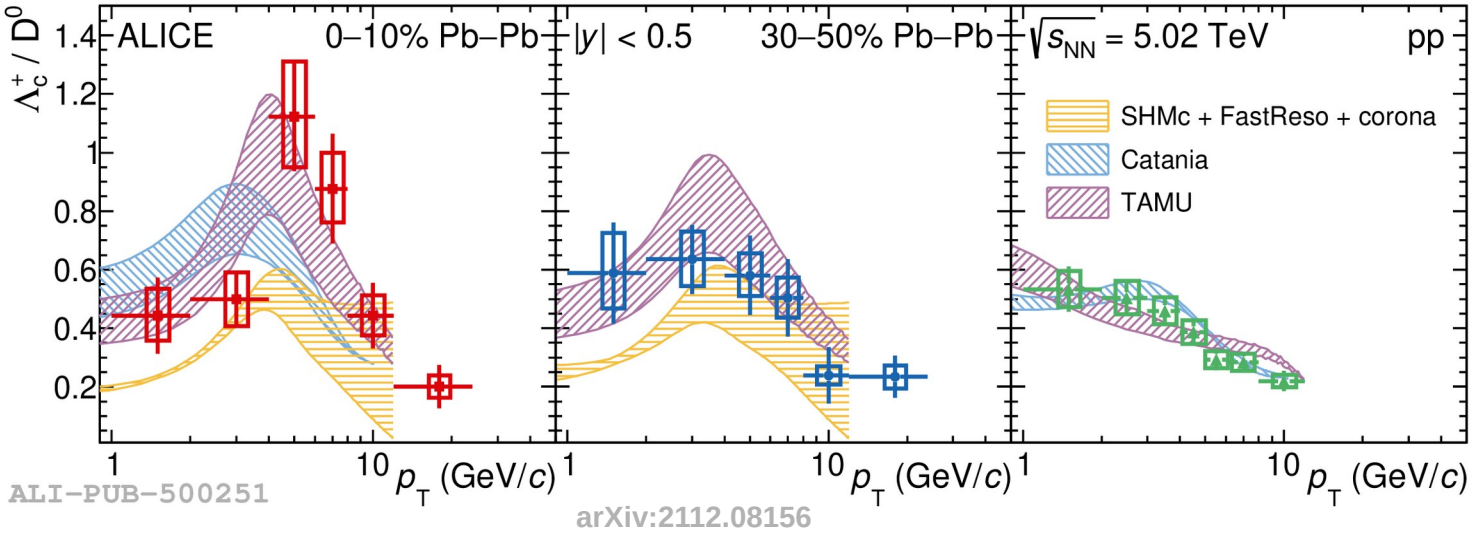


central collision

semi-central collision

- Increasing trend at intermediate p_T: pp < semi-central Pb-Pb < central Pb-Pb

Results in Pb-Pb collisions



- Increasing trend at intermediate p_T: pp < semi-central Pb-Pb < central Pb-Pb
- Described by models with charm hadronisation via both fragmentation and coalescence

- SHMc[1]: statistical hadronisation model
- Catania[2]: coalescence and fragmentation in de-confined system
- TAMU[3]: implements coalescence via a resonance recombination method

[1]A. Andronic et al., "The multiple-charm hierarchy in the statistical hadronization model", JHEP 07 (2021) 035, arXiv:2104.12754 [hep-ph]
[2] S. Plumari et al., "Charmed hadrons from coalescence plus fragmentation in relativistic nucleus–nucleus collisions at RHIC and LHC", Eur. Phys. J. C 78 no. 4, (2018) 348, arXiv:1712.00730 [hep-ph]
[3] M. He and R. Rapp, "Hadronization and Charm-Hadron Ratios in Heavy-Ion Collisions", Phys. Rev. Lett. 124 no. 4, (2020) 042301, arXiv:1905.09216 [nucl-th]

Summary

- Λ_c^+ baryons are an excellent probe of hadronisation mechanisms in different collision systems at the LHC
- Λ_c^+ baryon hadronisation modified in pp and p-Pb collisions with regard to e^+e^- collisions
- The observed intermediate p_T production enhancement hints that Λ_c^+ production in Pb-Pb collisions could occur via both fragmentation and coalescence
- Higher-precision measurements will be done with Run3
  - Inner Tracker upgrade has greatly increased impact parameter resolution
  - Much higher data taking rate ⟶ larger data samples collected