Study of (multi-) strange hadron production in jets and the underlying event with ALICE at the LHC

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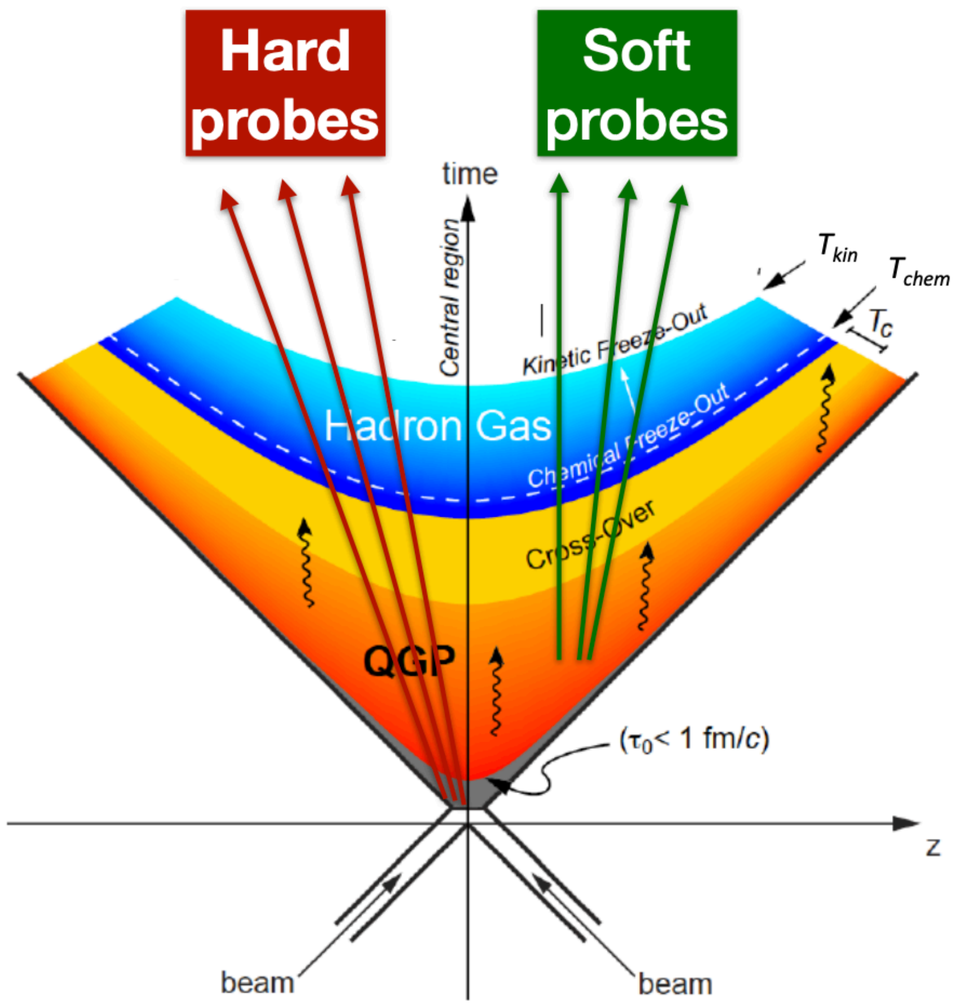
Quark-gluon plasma

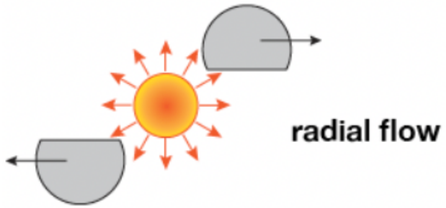


- Heavy-ion collisions probe the strongly-interacting matter — the quark-gluon plasma (QGP) under extreme conditions of high temperature and energy density
- **Hard probes** created at the initial stage of the collision
  - ➡ Jet, heavy-flavor quarks
- **Soft probes** created in the "fireball"
  - ➡ Collective expension

Collective properties

Collective expansion — results in complex azimuthal structure of final state particles

➡ "Zero order" — radial flow



➡ Push low p_T particles toward intermediate p_T

$$p = p_0 + \beta m$$

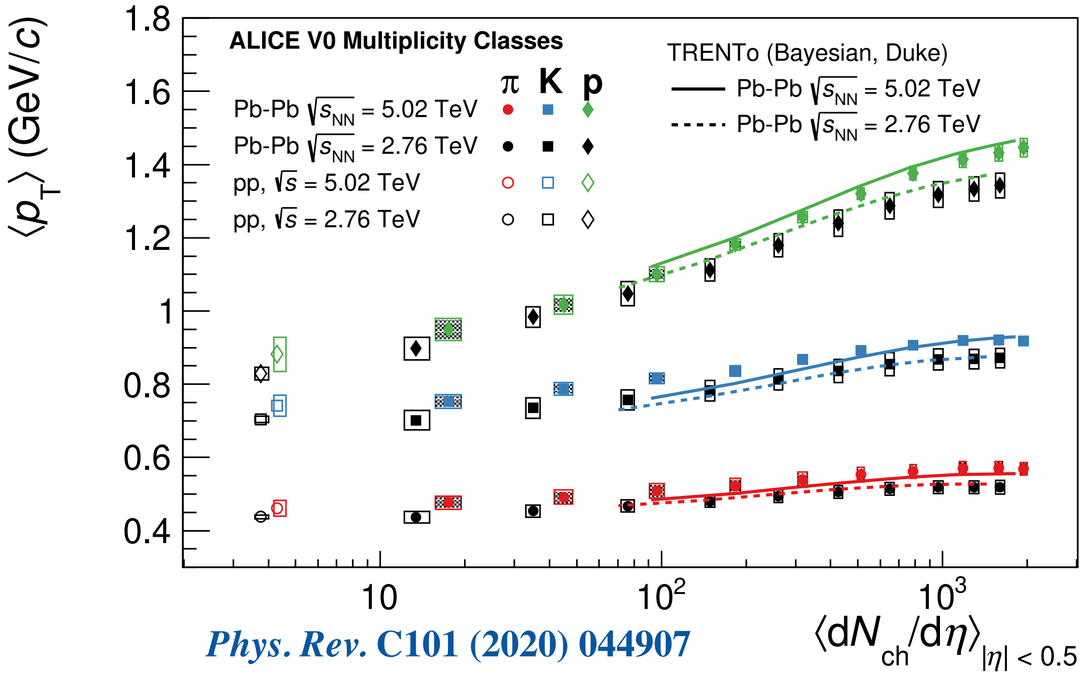
p_0: the initial momentum

β: flow velocity

m: particle mass

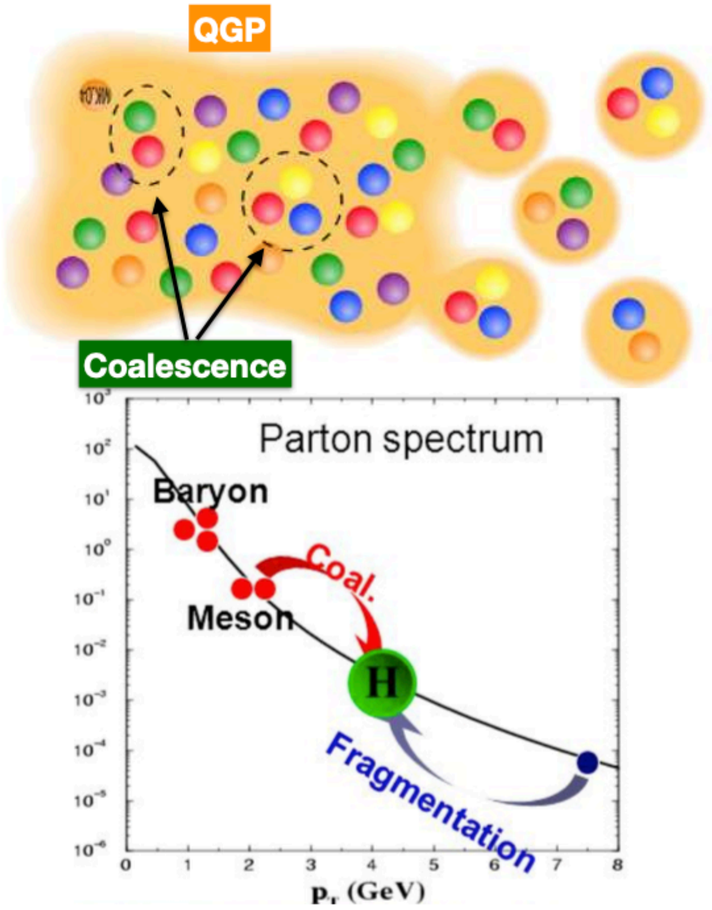
➡ More produced in central collisions

➡ Mass dependence



peripheral collisions → central collisions

Hadronization in heavy-ion collisions



- **Fragmentation** — hadrons from high p_T (hard) partons

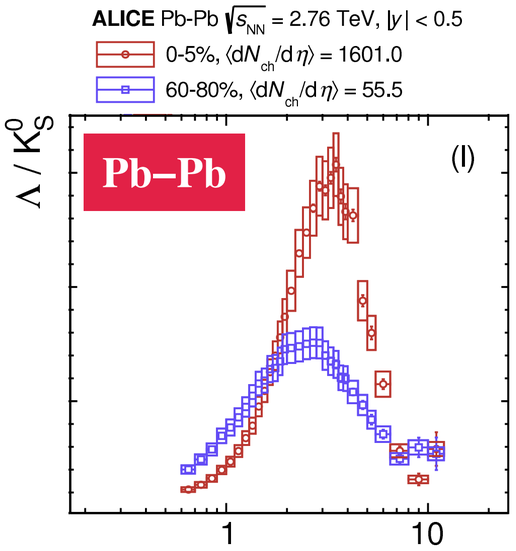
- Coalescence/recombination — hadrons formation via (di-)quark combination in the QGP medium
  - $p_{T,hadron} \simeq n\, p_{T,parton}$, n = 2 (meson), 3(baryon)
  - Sensitive to baryon and meson species
  - Baryons from lower momenta partons (denser)

Rapp *et al. Phys. Lett.* **B655** (2007) 126

Greco *et al. Phys.Rev.* **C92** (2015) 054904

Ko *et al. Phys. Lett.* **B792** (2019) 132

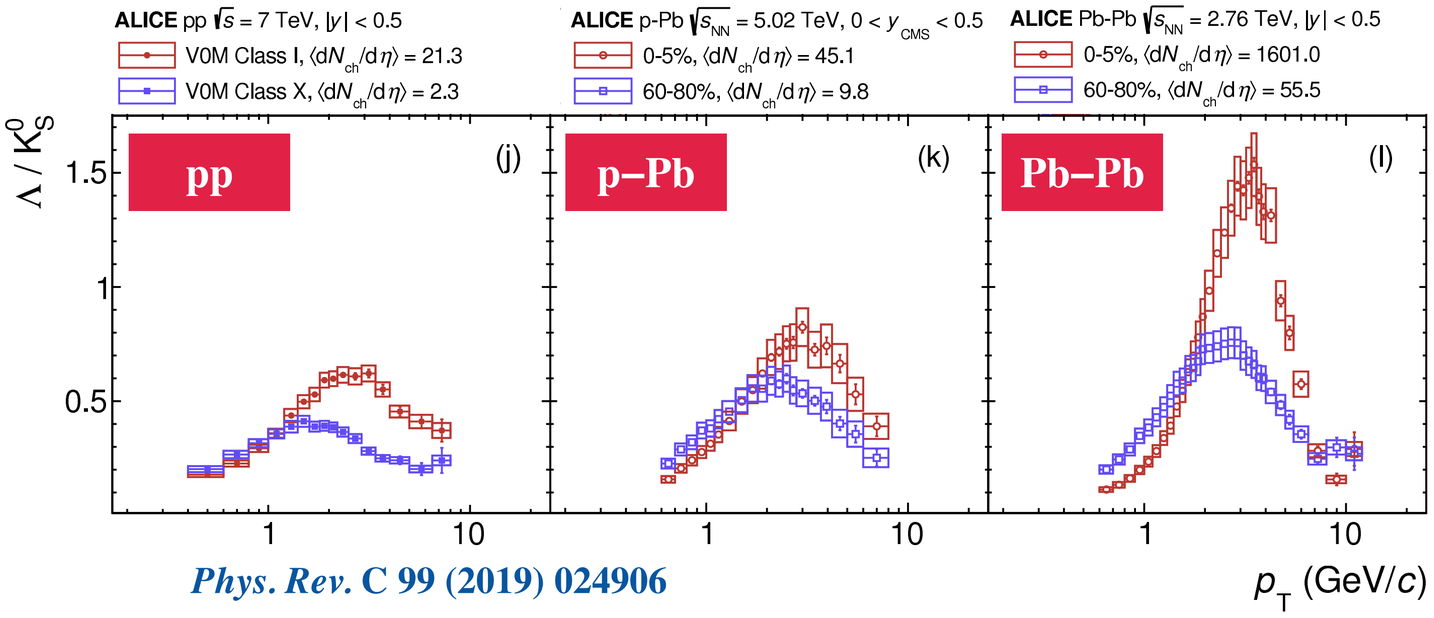
Baryon-to-meson enhancement



Phys. Rev. C 99 (2019) 024906

- Baryon-to-meson ratio (Λ/K^0_S) increases at intermediate p_T in central Pb–Pb collisions compared to peripheral ones
  - ➡ Interplay of radial flow and coalescence
  - ➡ Reflect QGP effects in heavy-ion collisions

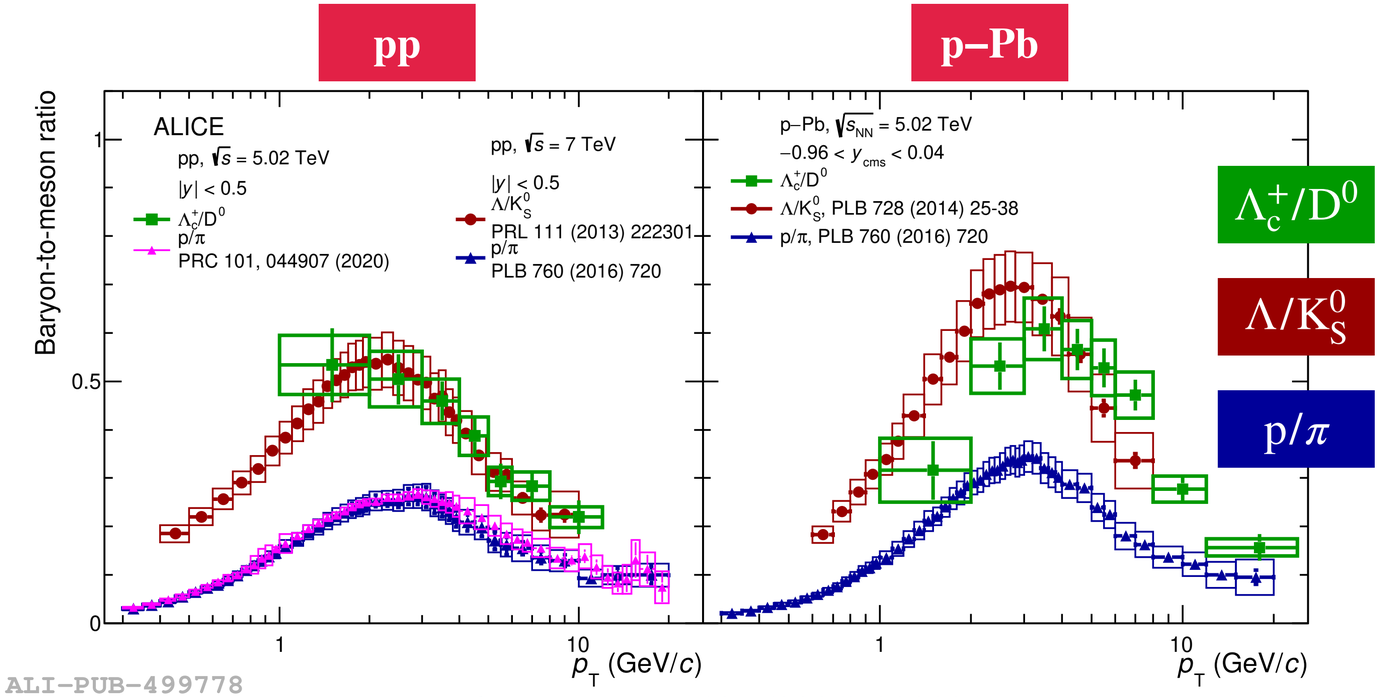
Baryon-to-meson enhancement



Phys. Rev. C 99 (2019) 024906

- Baryon-to-meson ratio (Λ/K^0_S) increases at intermediate p_T in central Pb–Pb collisions cercompared to peripheral ones
- Λ/K^0_S ratio enhancement is observed in different collision systems (pp, p–Pb and Pb–Pb) at high multiplicity

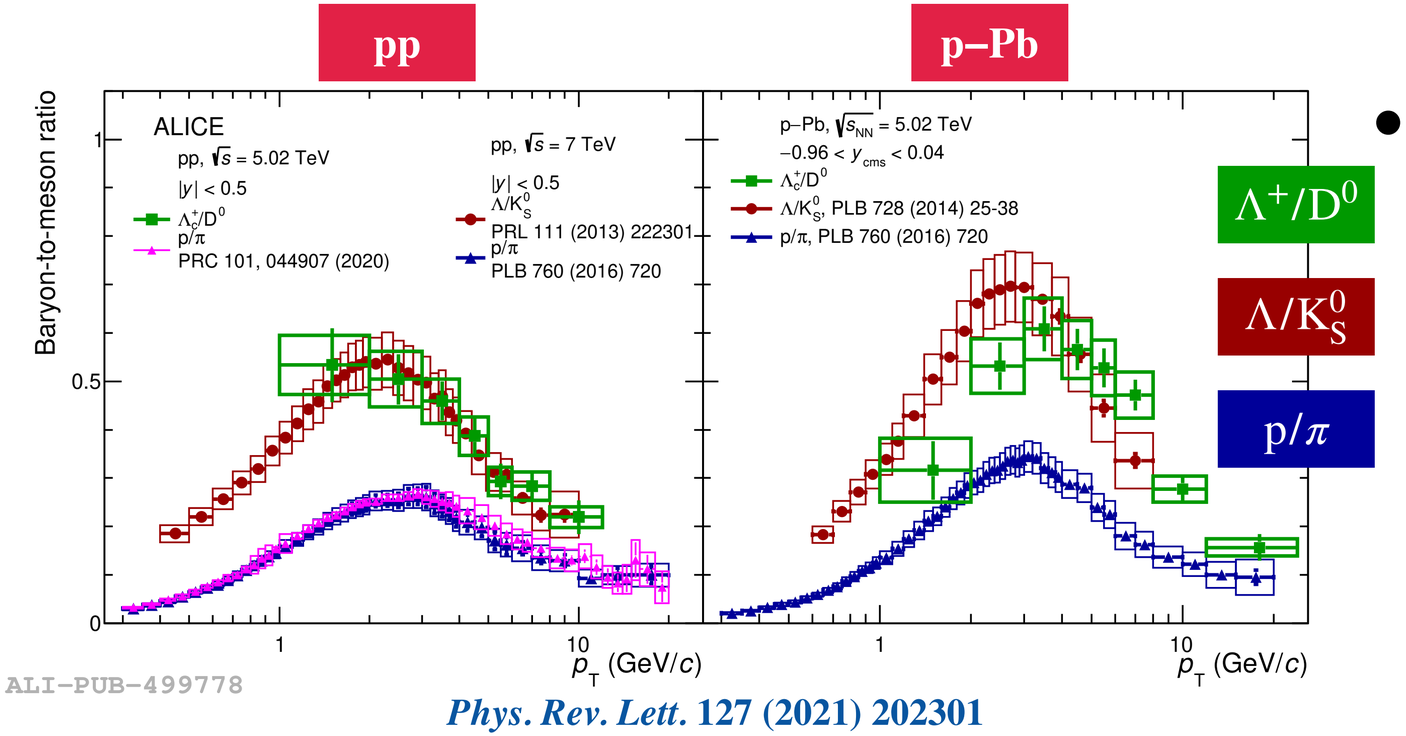
Baryon-to-meson enhancement



Phys. Rev. Lett. 127 (2021) 202301

- Similar behavior is oberserved in the charm sector in small systems (pp and p–Pb) collisions

Baryon-to-meson enhancement



Phys. Rev. Lett. 127 (2021) 202301

- Similar behavior is oberserved in the charm sector in small systems (pp and p–Pb) collisions

- To constrain hadronization mechanisms in all systems, it's important to separate particles from hard and soft processes

  ➡ Jet is a natural tool to separate the particles produced in hard processes and the underlying event (UE)

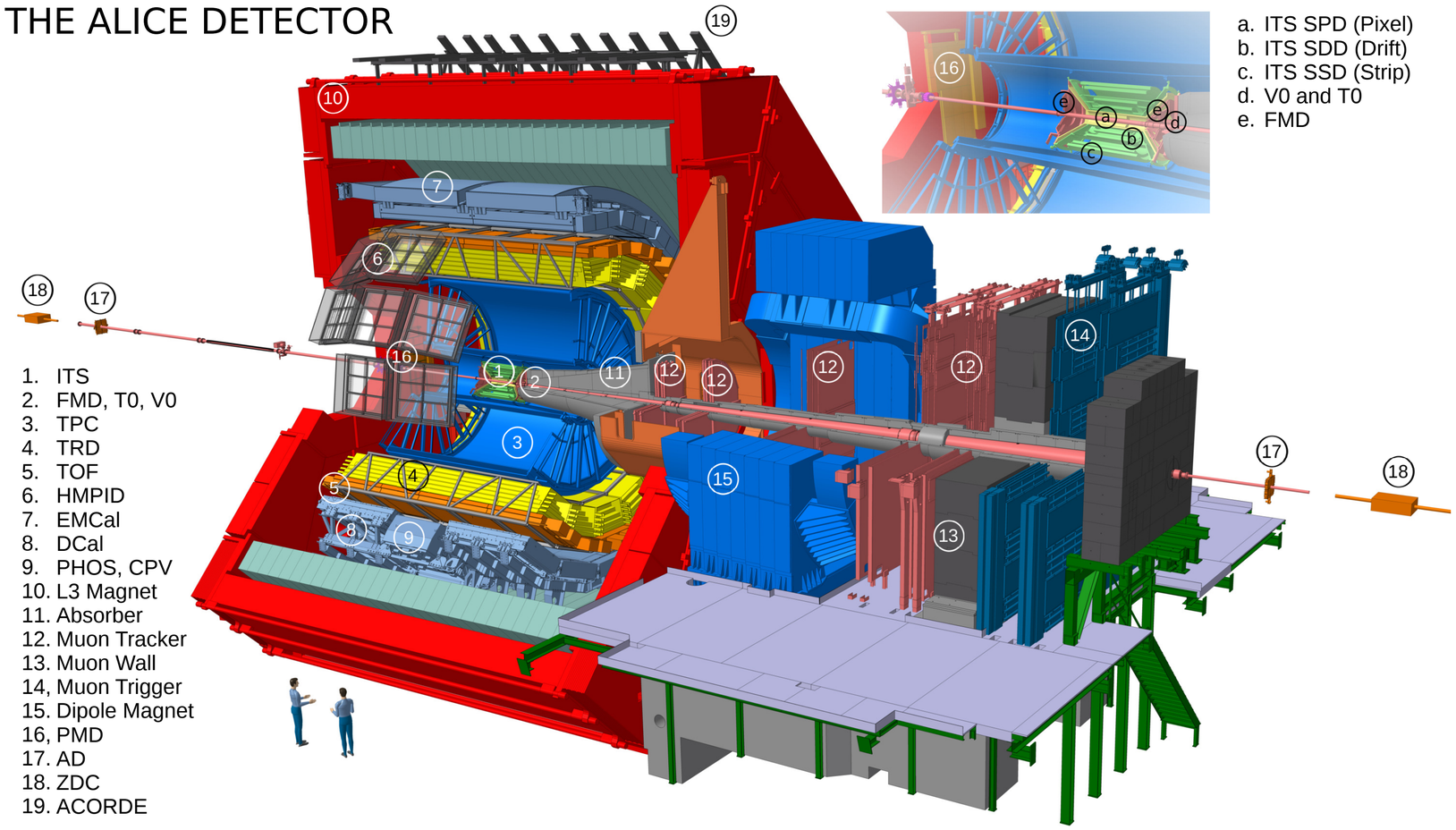
  ➡ In this talk, we concertrate on (multi-) strange hadrons production in jets and UE with ALICE

Experimental setup

- **V0 (V0A and V0C)**
  - V0A: $2.8 < \eta < 5.1$, V0C: $-3.7 < \eta < -1.7$
  - Event trigger and multiplicity determination
- **ITS (Inner Tracking System)**
  - $|\eta| < 0.9$
  - Vertex reconstruction and event trigger
- **TPC (Time Projection Chamber)**
  - $|\eta| < 0.9$
  - Charged particle tracking and identification
- **TOF (Time Of Flight)**
  - $|\eta| < 0.9$
  - Charged particle identification

Data samples

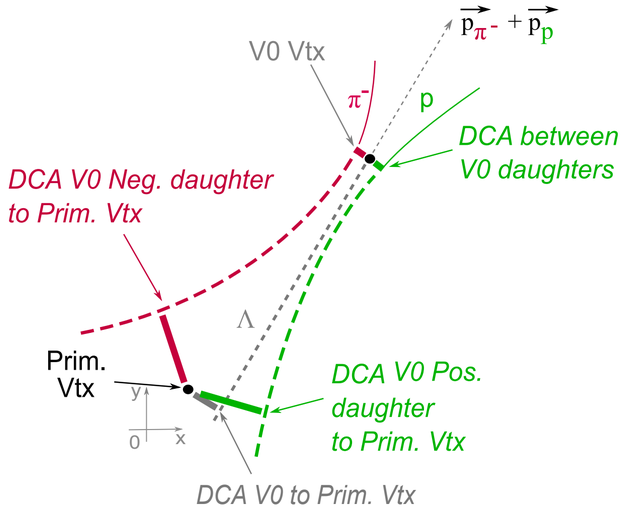
- pp at $\sqrt{s} = 7$ and 13 TeV
- p–Pb at $\sqrt{s_{NN}} = 5.02$ TeV

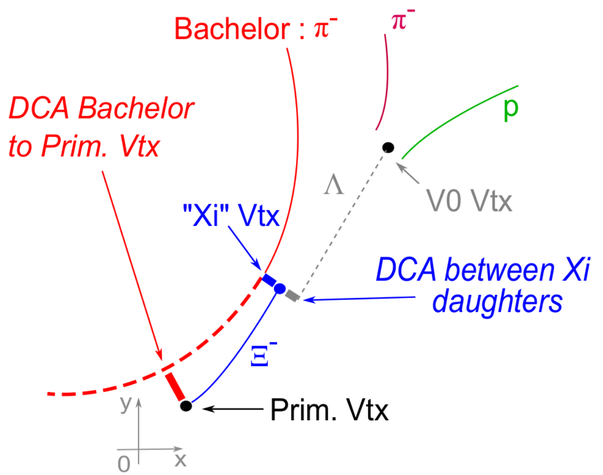


Strange particle reconstruction

Decay channels:

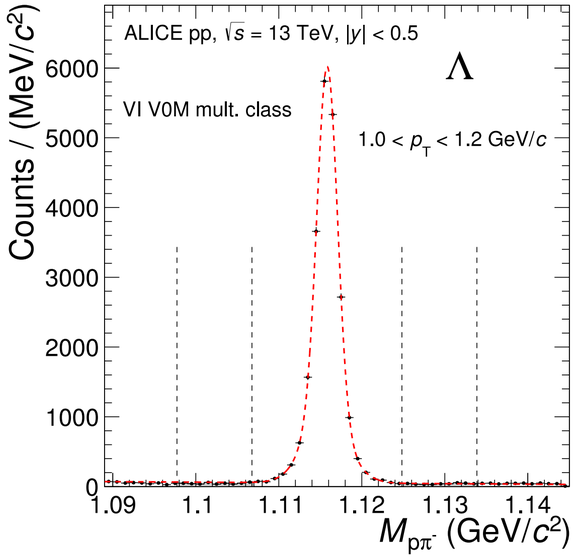
- $K^0_S \rightarrow \pi^+ + \pi^- \ (B.R.\ 69.2\%)$
- $\Lambda \rightarrow p + \pi^- \ (B.R.\ 63.9\%)$
- $\Xi^- \rightarrow \Lambda + \pi^- \ (B.R.\ 99.887\%)$
- $\Omega^- \rightarrow \Lambda + K^- \ (B.R.\ 67.8\%)$

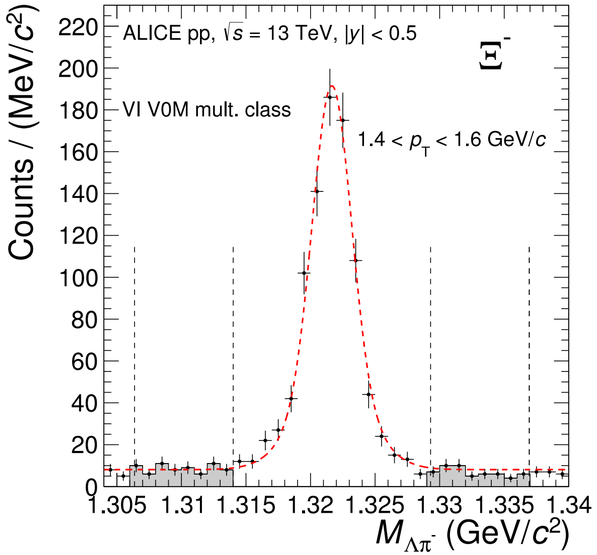




Candidate selection:

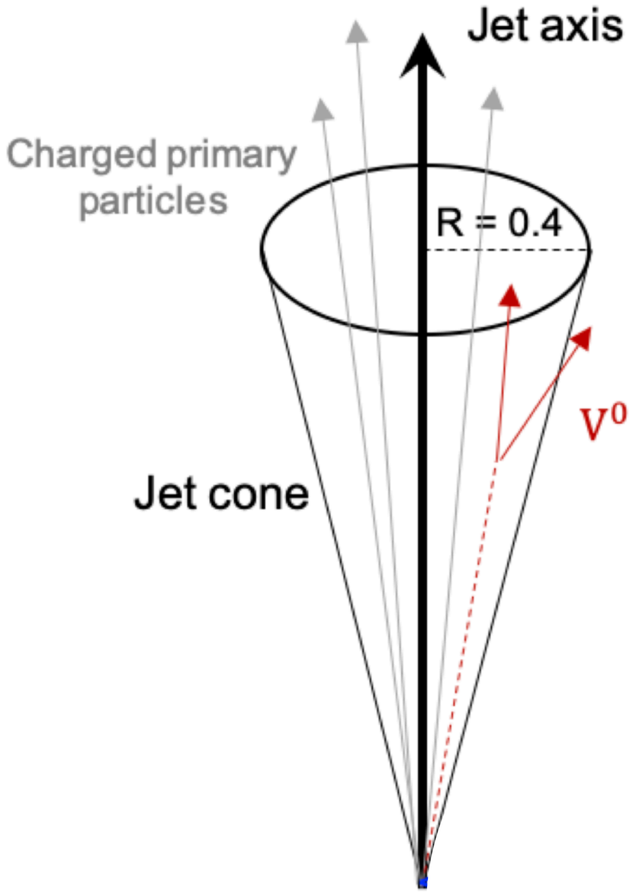
- Pairs/triples of tracks with proper charge-sign combination
- Particle identification of decay tracks
- Topological and kinematical selections (e.g. $|\eta_{\text{strange particle}}| < 0.75, \ldots$)





Eur. Phys. J. C80 (2020) 167

Tag hard process using jets



Charged-particle jet reconstruction:

- Jet finder: anti-k_{T}, $R = 0.4$
- $p_{\mathrm{T,track}} > 0.15$ GeV/c, $\left|\eta_{\mathrm{track}}\right| < 0.9$
- $p_{\mathrm{T,jet}}^{\mathrm{ch}} > 10, 20$ GeV/c, $\left|\eta_{\mathrm{jet}}\right| < 0.35$

(Strange) Particle-jet matching:

- Strange particles in jet cone (**JC** selection)

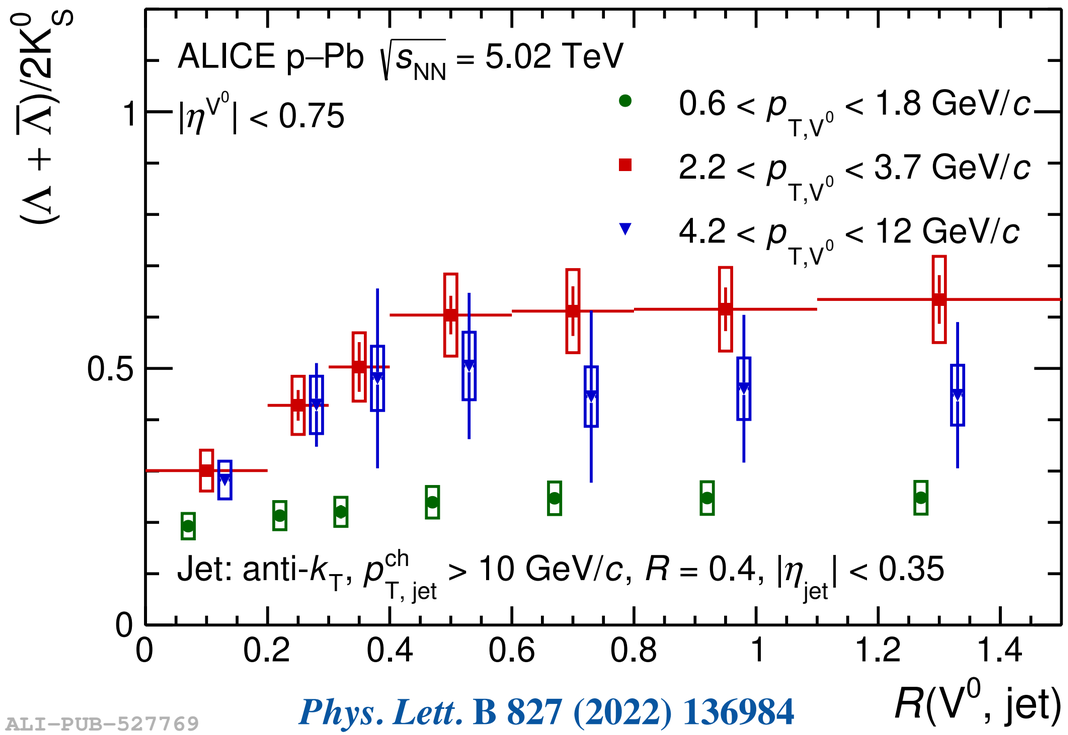
$$R(\mathrm{S,jet}) = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

- There still remaining underlying event contribution in the JC selection

R(S, jet)-dependent Λ/K^0_S ratio

Λ/K^0_S (baryon/meson)

- Λ and K^0_S in jet cone **w/o** UE subtraction
- The ratio at low p_T is independent of the distance of the jet axis
- Lack of enhancement close to the jet axis
- The enhanced Λ/K^0_S ratio is not associated with the jets



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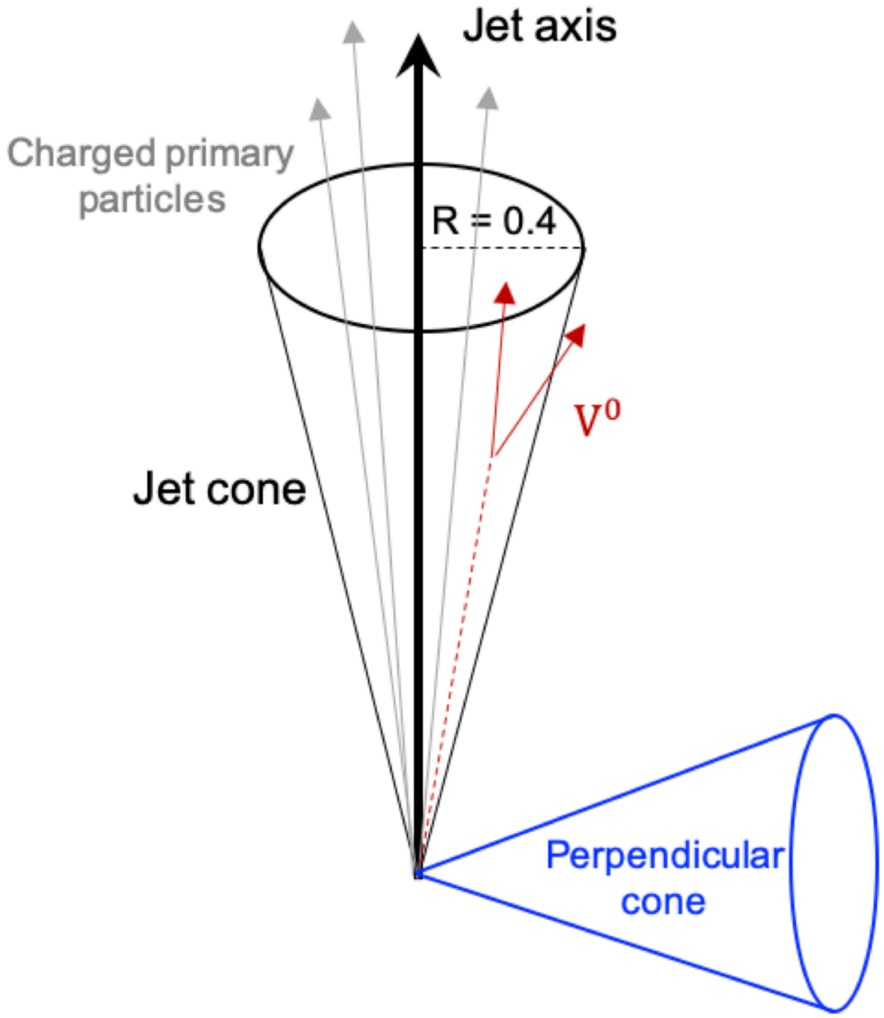
Intermediate p_T

High p_T

Low p_T

Hard processes dominant → **UE dominant**

Tag hard process using jets



(Strange) Particle-jet matching:

- Strange particles in jet cone (**JC** selection)

$$R(\mathrm{S,jet}) = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2} < 0.4$$

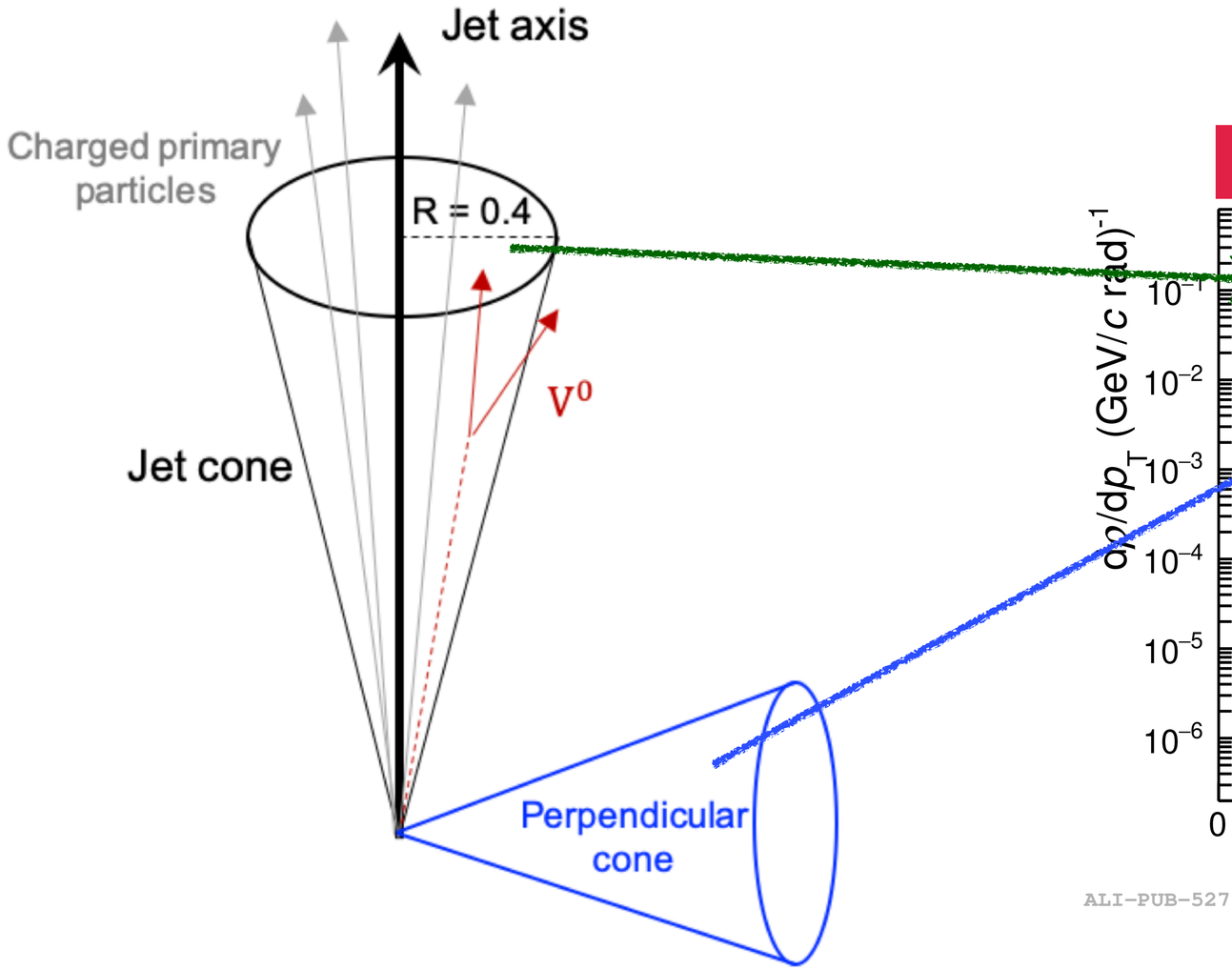
- Strange particles from the underlying event (**UE**) obtained with perp. cone method
- Density distribution

$$\frac{\mathrm{d}\rho}{\mathrm{d}p_{\mathrm{T}}} = \frac{1}{N_{\mathrm{ev}}} \times \frac{1}{\langle \text{Area acceptance} \rangle} \times \frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}}$$

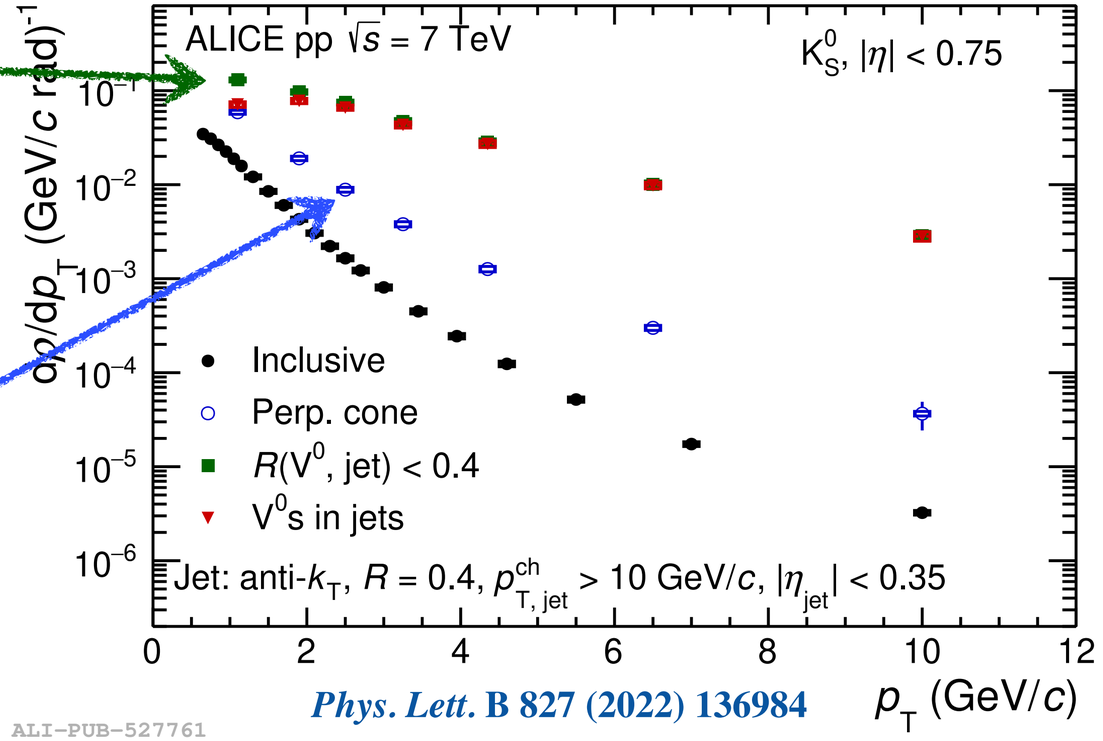
- Strange particles in jets (**JE** particles)

$$\frac{\mathrm{d}\rho_{\mathrm{JE}}}{\mathrm{d}p_{\mathrm{T}}} = \frac{\mathrm{d}\rho_{\mathrm{JC}}}{\mathrm{d}p_{\mathrm{T}}} - \frac{\mathrm{d}\rho_{\mathrm{UE}}}{\mathrm{d}p_{\mathrm{T}}}$$

Strangeness in jets and UE



pp 7 TeV K^0_S



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ALI-PUB-527761

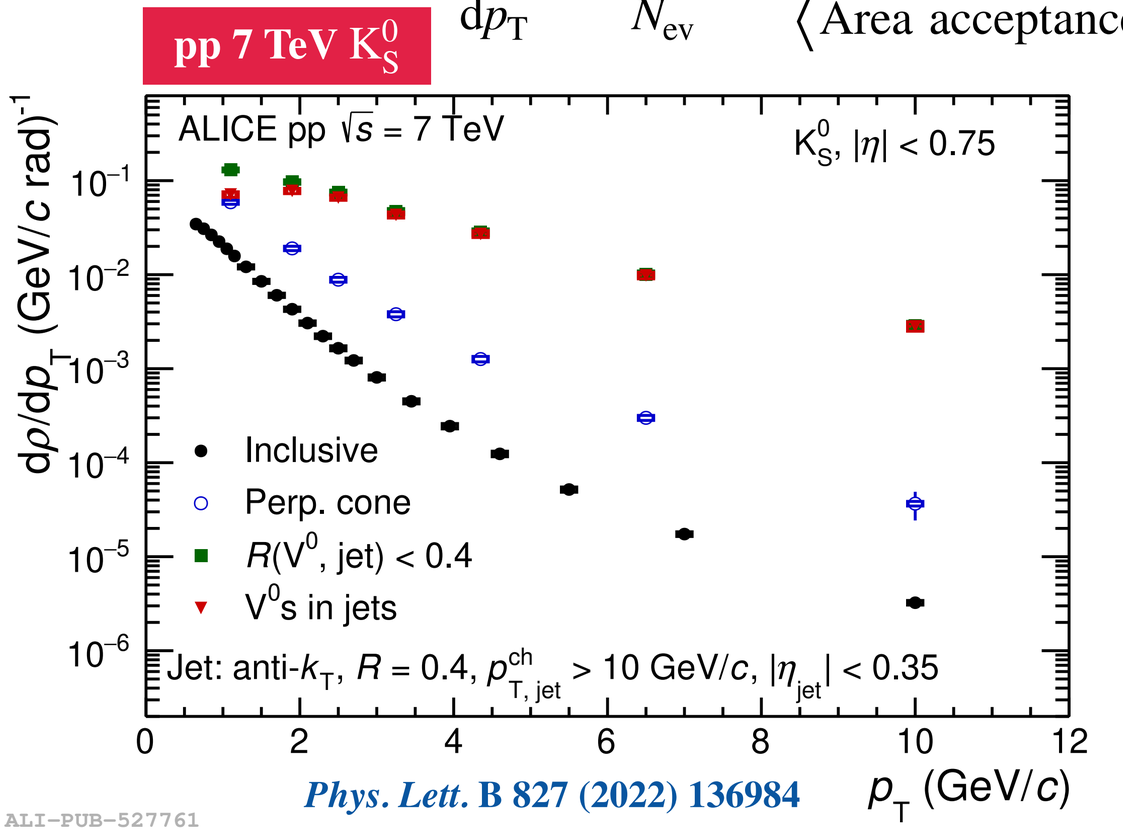
$$\frac{d\rho}{dp_T} = \frac{1}{N_{ev}} \times \frac{1}{\langle \text{Area acceptance} \rangle} \times \frac{dN}{dp_T}$$

$$\frac{d\rho_{JE}}{dp_T} = \frac{d\rho_{JC}}{dp_T} - \frac{d\rho_{UE}}{dp_T}$$

Strangeness in jets and UE

- UE background is dominant at low p_T
- p_T-differential production density in jets (JE particles) is harder than that in UE (PC selection)
- The inclusive density distribution is softer than the UE — jet selection bias

$$\frac{d\rho}{dp_T} = \frac{1}{N_{ev}} \times \frac{1}{\langle \text{Area acceptance} \rangle} \times \frac{dN}{dp_T}$$



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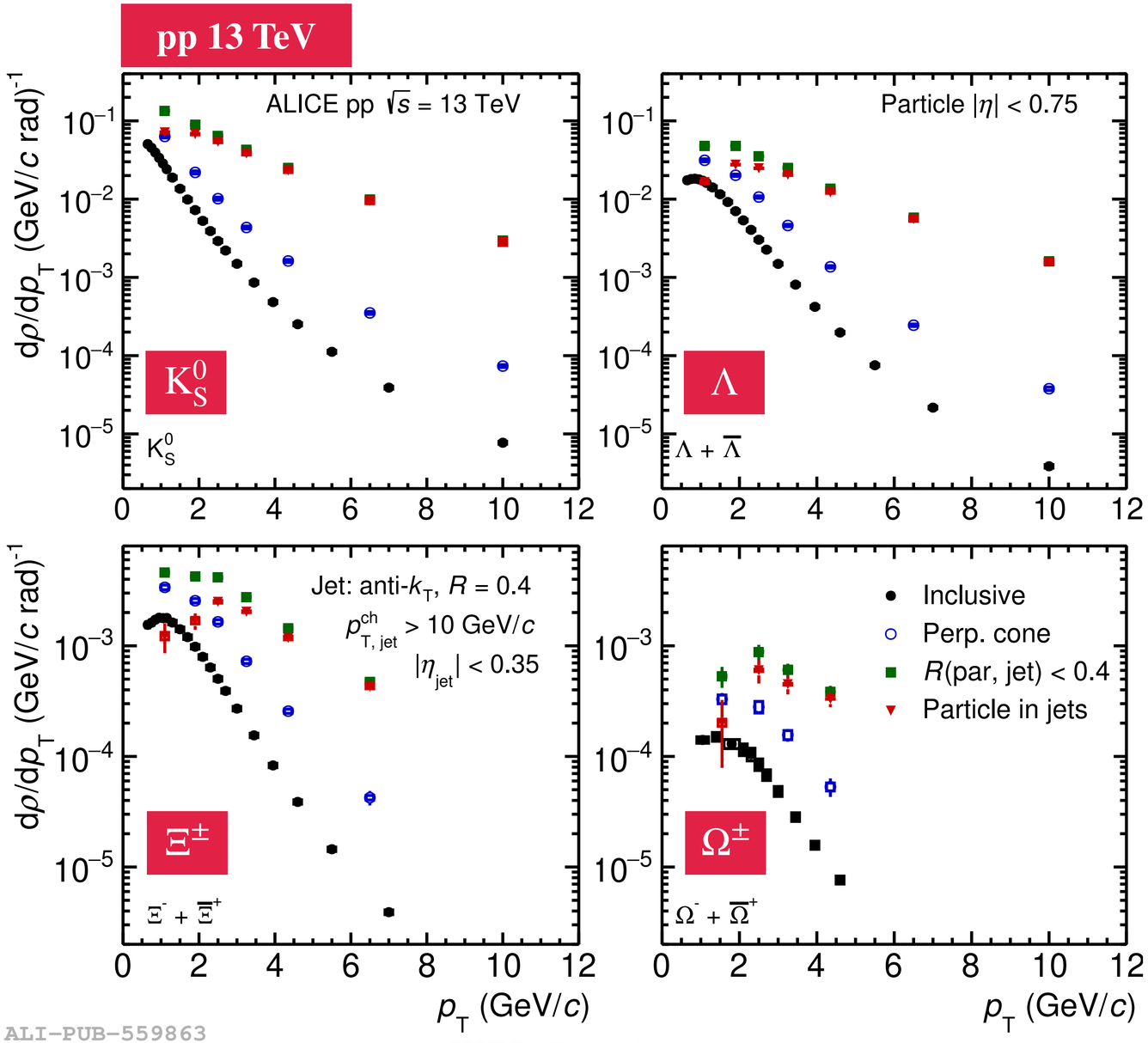
$$\frac{d\rho_{JE}}{dp_T} = \frac{d\rho_{JC}}{dp_T} - \frac{d\rho_{UE}}{dp_T}$$

(Multi-) Strange hadron production in jets and UE



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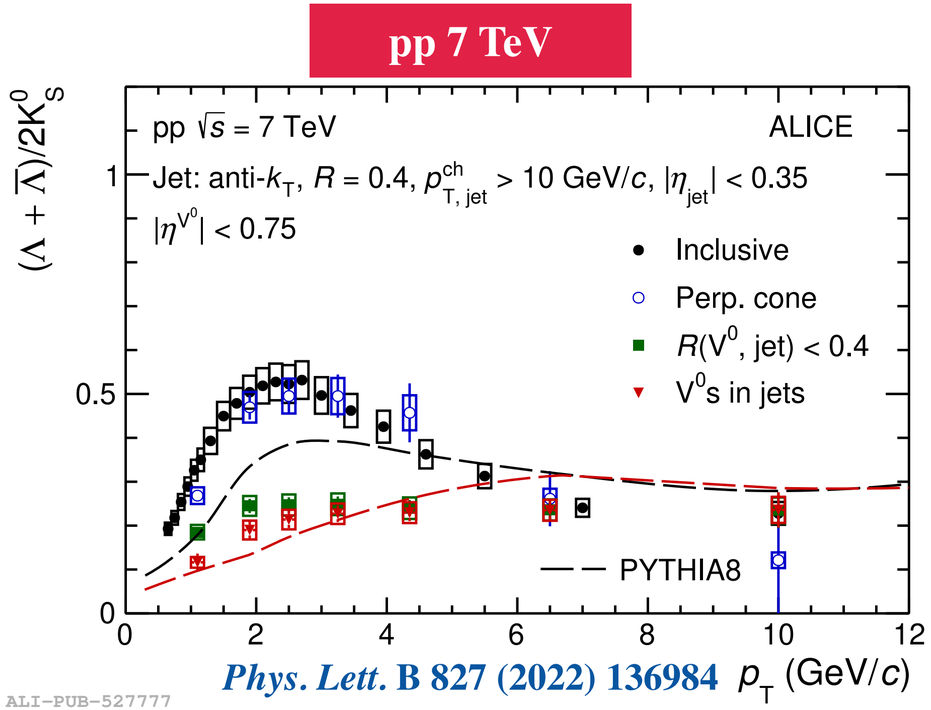
- In pp collisions at 13 TeV, this measurement is able to be extended to multi-strange hadrons with higher statistic

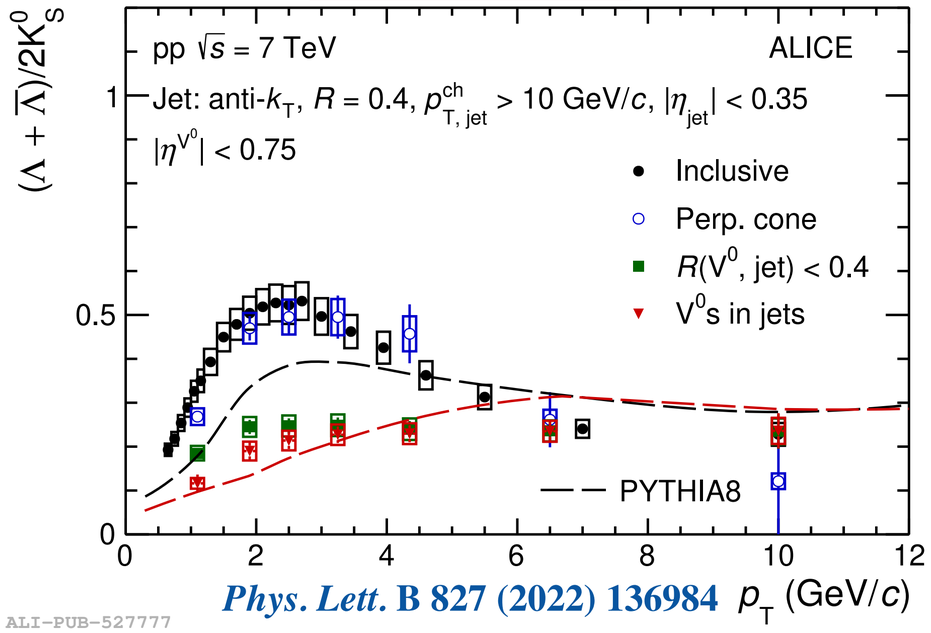
Λ/K^0_S ratio in pp at 7 TeV



- Λ/K^0_S ratio in jets does not show a maximum at intermediate p_T, ratio with UE selection is systematically higher than the inclusive in $2 < p_T < 5$ GeV/c
- PYTHIA8 hard QCD is consistent with Λ/K^0_S ratio in jets but does not reproduce the inclusive ratio at low and intermediate p_T

Λ/K^0_S ratio in pp at 7 TeV and p–Pb at 5.02 TeV

pp 7 TeV



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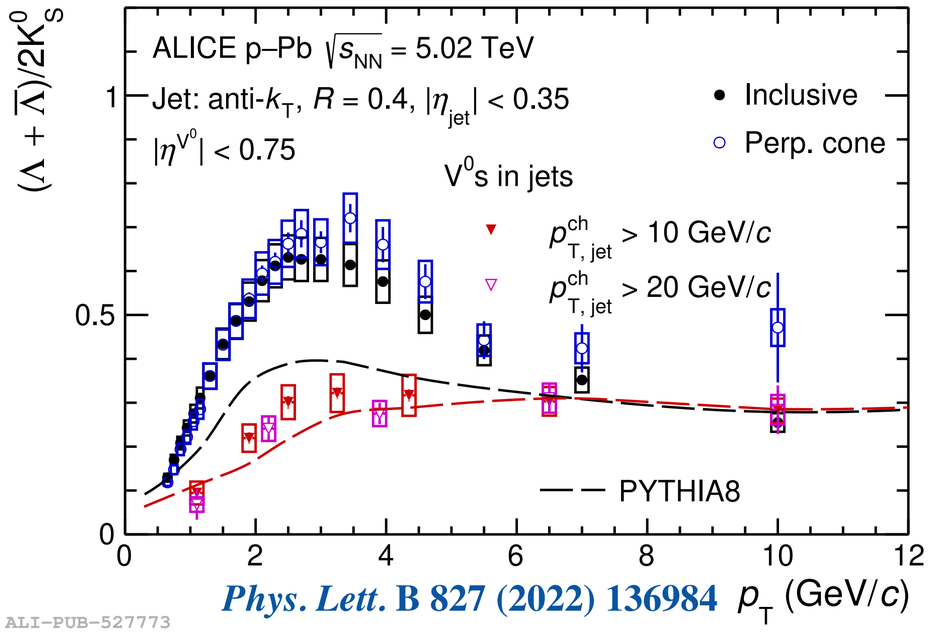
p–Pb 5.02 TeV



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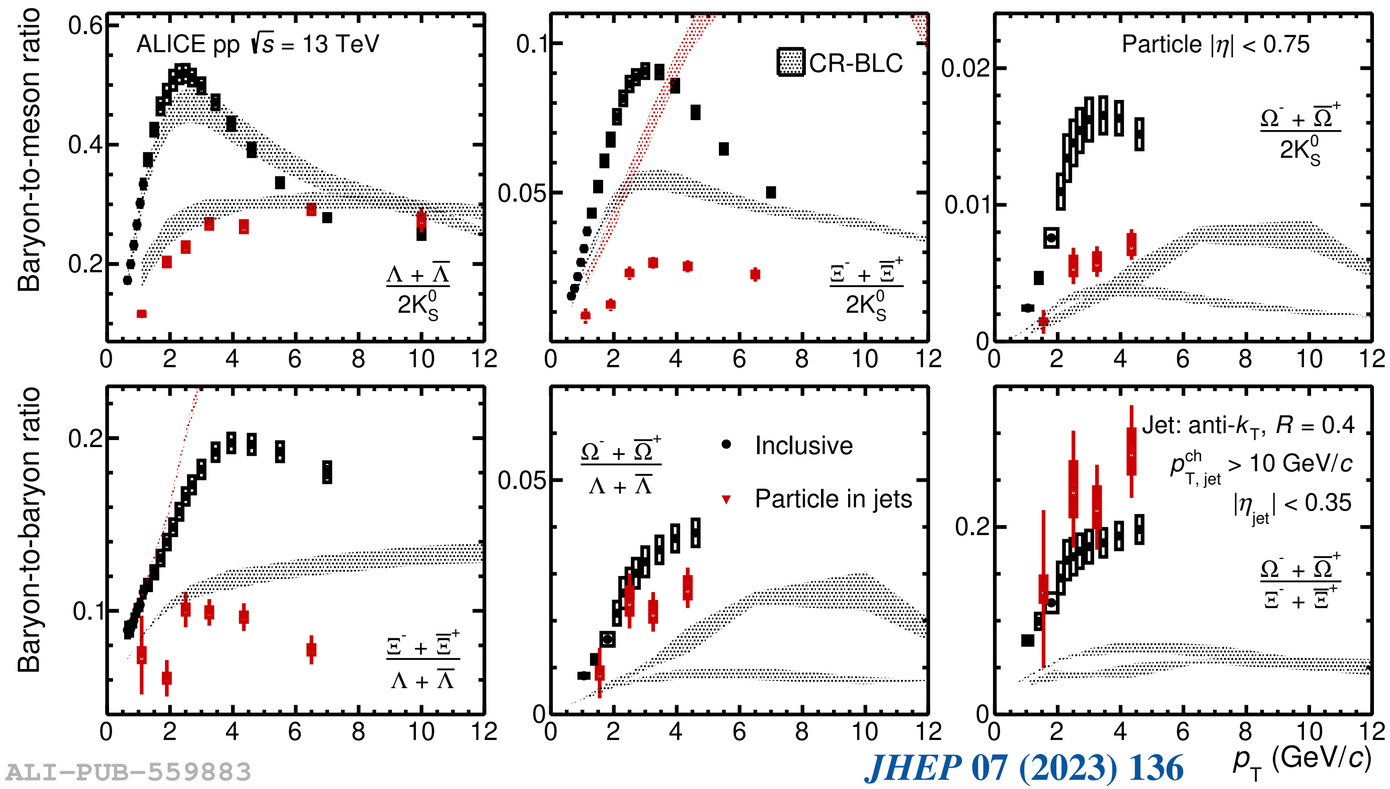
Production ratios in pp at 13 TeV



- PYTHIA8 CR-BLC tunes generally agree with the Λ/K^0_S ratios for both inclusive and in jets results
- Large discrepancies between data and MC are observed when containing multi-strange hadrons

Summary

- Productions of strange particles have been investigated in jets and the underlying event (UE) in pp and p–Pb collisions
- Λ/K^0_S (baryon-to-meson) ratio:

  ➡ The ratio enhancement is not present within the jets, but is related to the UE
- The inclusive ratio enhancement absent in jets, out-of-jet production is the dominant contribution to strange particle production
- PYTHIA8 CR-BLC tunes generally agree with the Λ/K^0_S ratios for both inclusive and in jets results, however, have large discrepancies with data when containing multi-strange hadrons
- The measurement provides novel constraints on hadronization and its MC description and demonstrates that the fragmentation of jets alone is insufficient to describe the strange and multi-strange particle production in hadronic collisions at LHC energies

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Between

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and

IP2I, Université Claude Bernard Lyon 1

PhD candidate:

- Lang Xu

Thesis title:

- Probing hadronization properties in hadronic collisions with ALICE at the LHC

Thesis supervisors:

- Xiaoming Zhang, IOPP, CCNU
- Cvetan Valeriev Cheshkov, IP2I, UCBL1

Topics:

- Measurement of the transverse-momentum fraction of (multi-) strange particle in jets to study the hadronization properties

Thanks for listening!