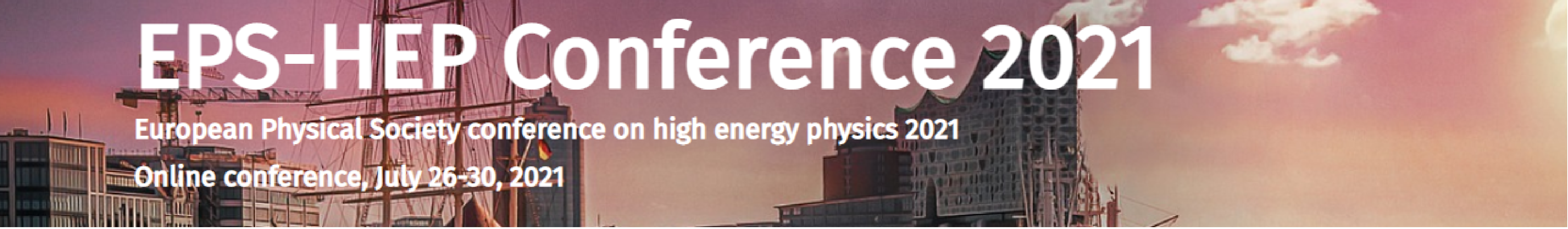


Light flavor particle production across different systems and energies

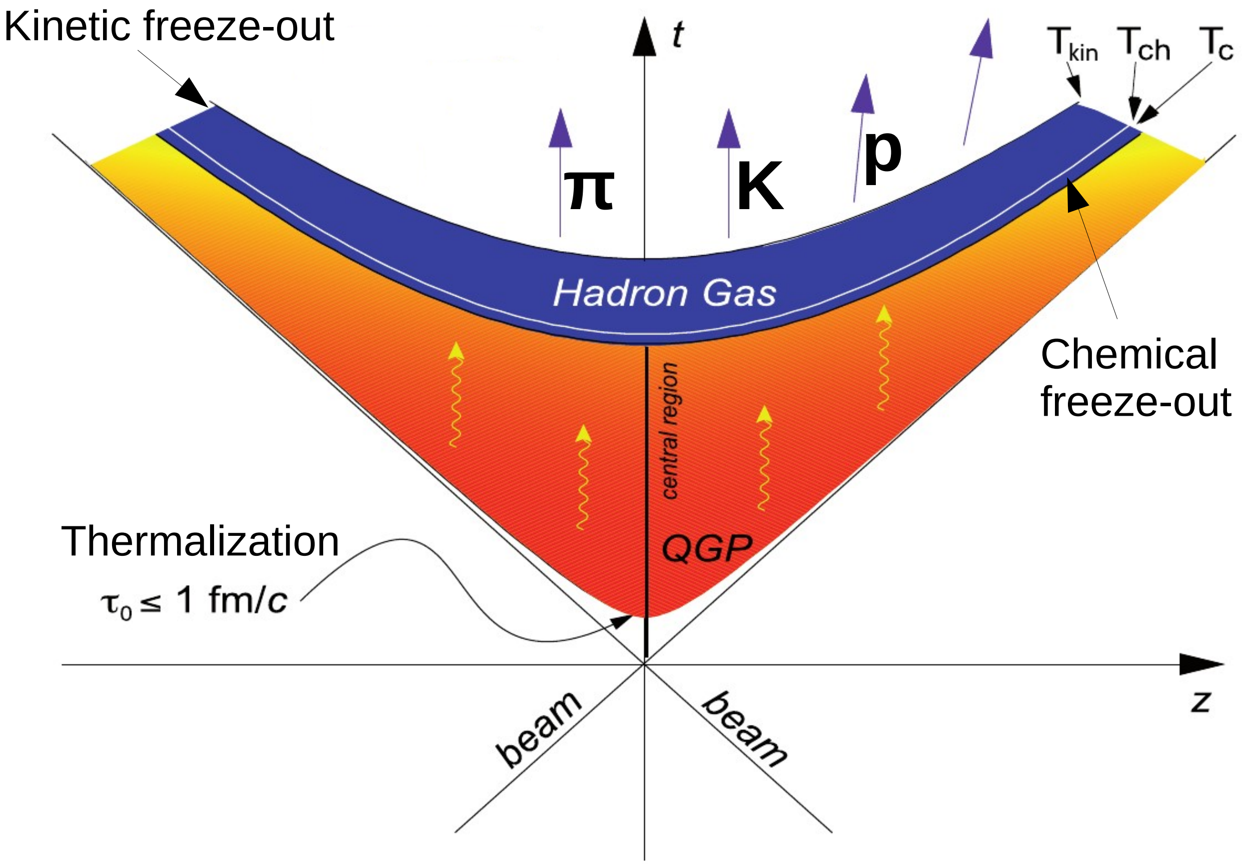
Michael Habib
for the ALICE Collaboration

ALICE

TECHNISCHE UNIVERSITÄT DARMSTADT

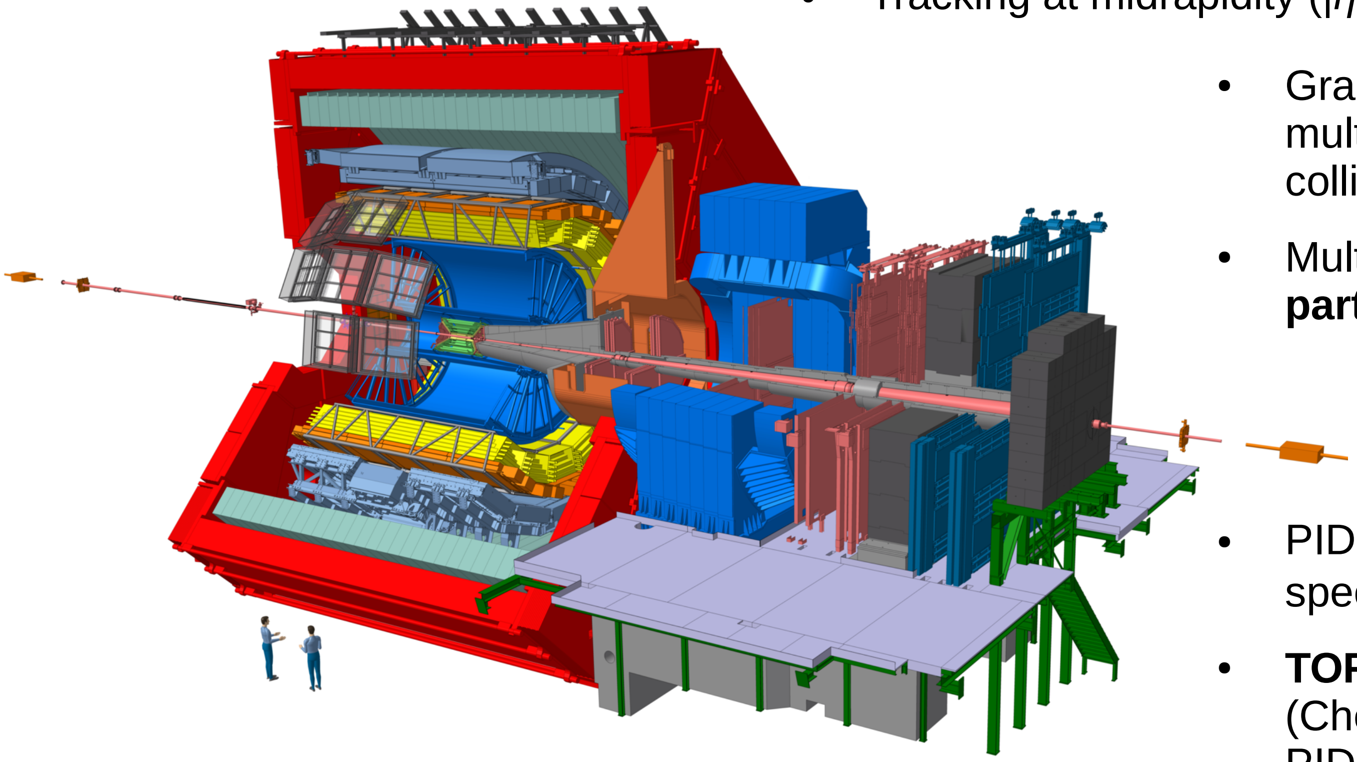
GSI

Evolution of a heavy-ion collision



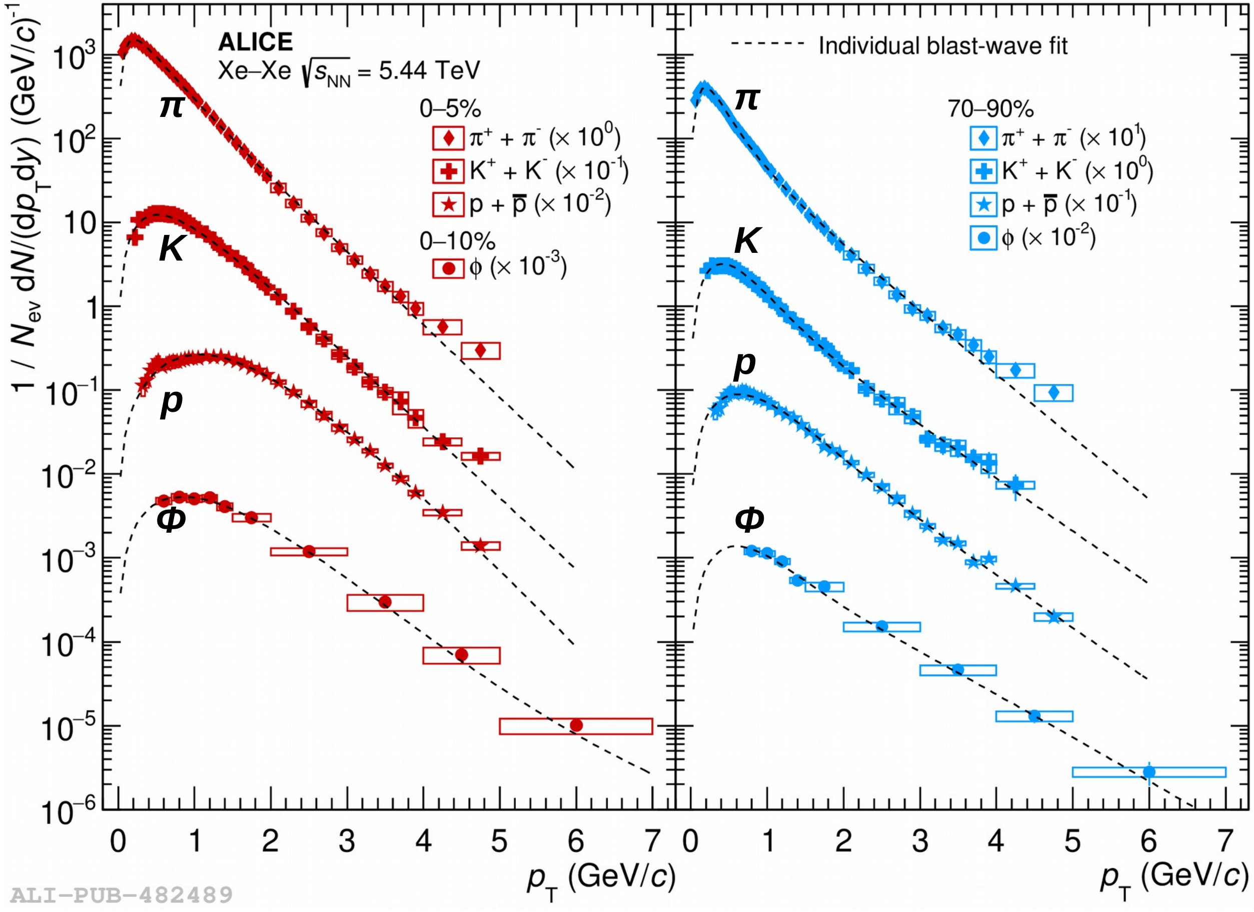
- Thermodynamic properties of the medium can be accessed by measuring soft probes
- p_{T}-differential measurements of identified particles allow the collective evolution of the system to be studied
- How does hadron chemistry evolve with event multiplicity?
- Do soft or hard processes drive particle production?

The ALICE detector



- Tracking at midrapidity ($|\eta| < 0.9$) down to p_T ~ 100 MeV/c
- Granularity to measure very high multiplicity events in central Pb-Pb collisions
- Multiple detectors for excellent **particle identification** (PID)
- PID with **ITS** and **TPC** at low p_T via specific energy loss
- **TOF** (time-of-flight) and **HMPID** (Cherenkov radiation) complete the PID at intermediate p_T

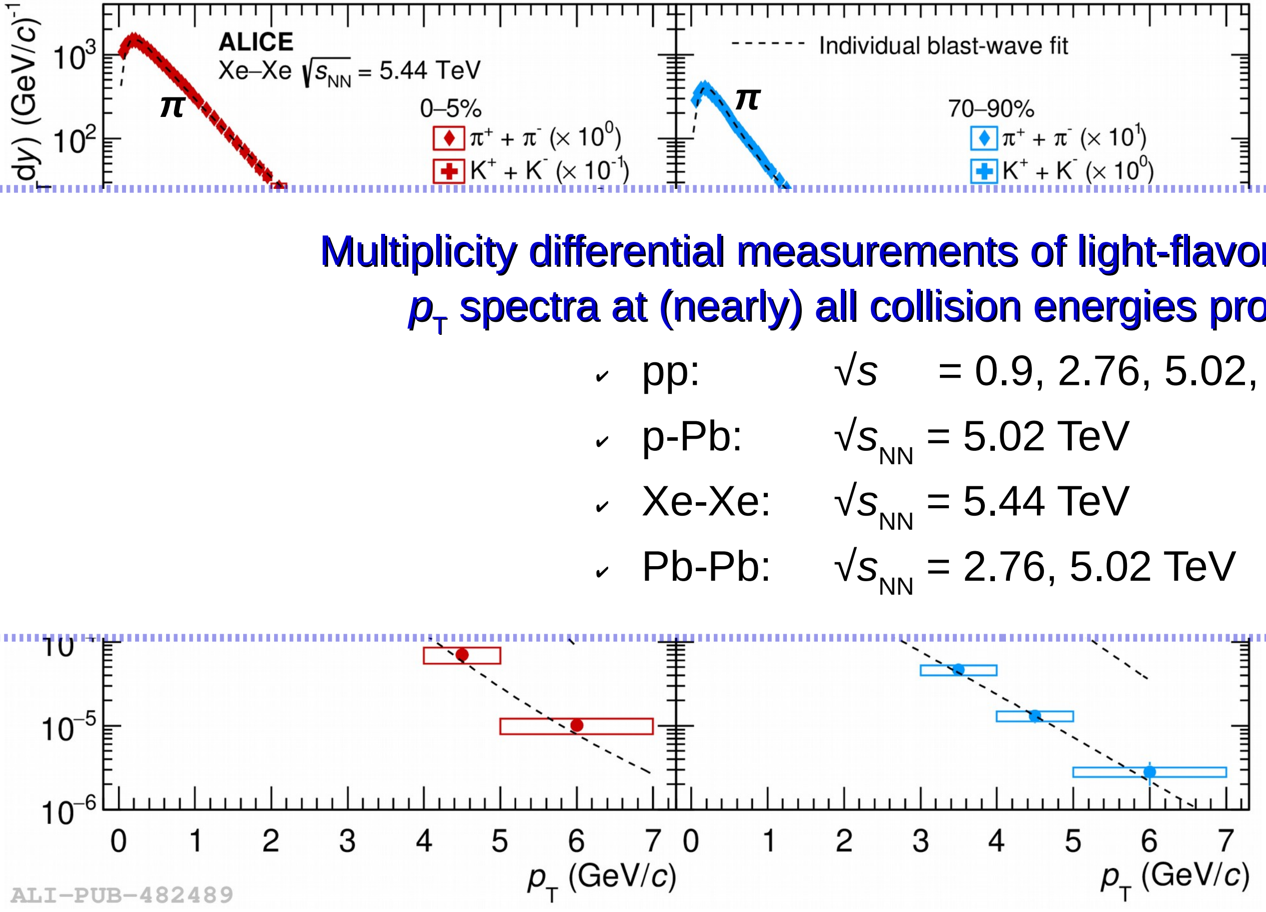
Spectra of π, K, p, Φ in Xe-Xe at $\sqrt{s_{NN}}$ = 5.44 TeV



- **Spectra hardening** with increasing centrality due to the collective evolution
  - ➔ Radial flow

arXiv:2101.03100

Spectra of π, K, p, Φ in Xe-Xe at $\sqrt{s_{NN}}$ = 5.44 TeV



- **Spectra hardening** with increasing centrality due to the collective evolution

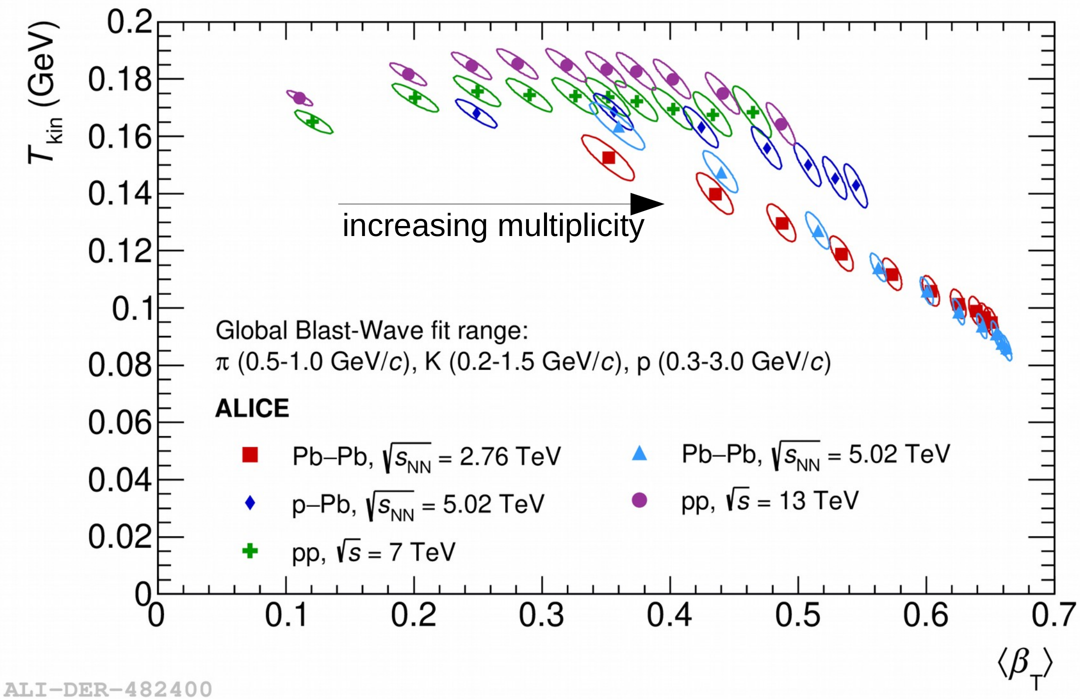
Multiplicity differential measurements of light-flavor hadrons (π, K, p,…)
p_T spectra at (nearly) all collision energies provided by the LHC

- ✓ pp: $\sqrt{s}$ = 0.9, 2.76, 5.02, 13 TeV
- ✓ p-Pb: $\sqrt{s_{NN}}$ = 5.02 TeV
- ✓ Xe-Xe: $\sqrt{s_{NN}}$ = 5.44 TeV
- ✓ Pb-Pb: $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV

arXiv:2101.03100

Blast-wave model

At T_{kin} particles are released thermally and boosted in transverse direction by a common velocity field $\langle \beta_T \rangle$



ALI-DER-482400

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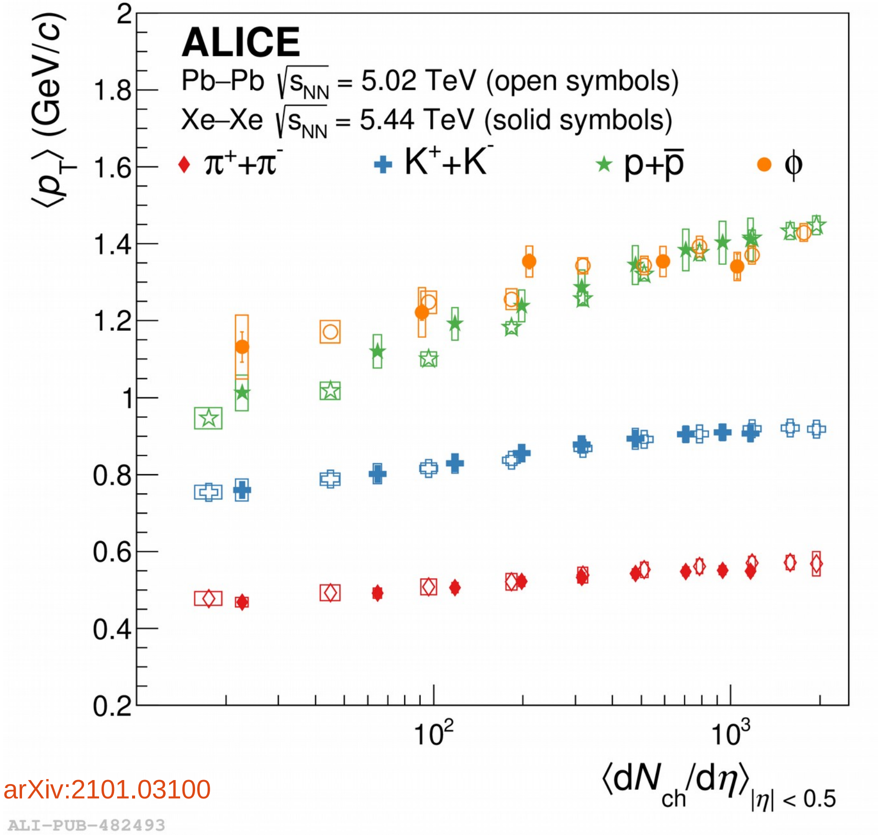
- Simultaneous blast-wave fits to π, K, and p spectra
- Lower freeze-out temperature at larger multiplicity and higher energies
  - ➔ Expansion time increases with multiplicity
- Larger expansion velocities (and $\langle p_T \rangle$) for comparable multiplicities in smaller systems

$\langle p_T \rangle$ in Pb-Pb and Xe-Xe

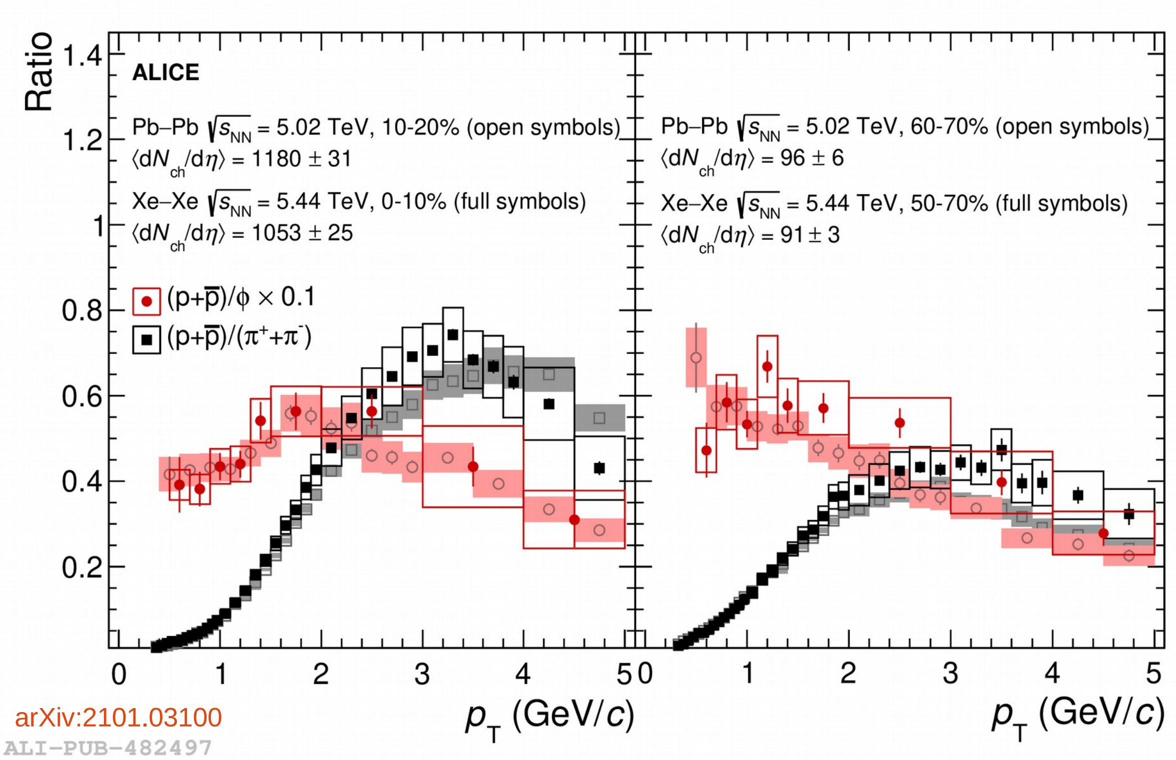


arXiv:2101.03100

- Continuous evolution: $\langle p_T \rangle$ increases with charged-particle multiplicity
  - ➔ Spectra become harder
  - ➔ Radial flow increases at high multiplicity
- Larger relative increase for heavier particles
  - ➔ Mass dependent hardening
- Similar trend for similar hadron mass at high multiplicities: p and Φ

  $m_p \sim 0.938$ GeV/c^2, $m_\Phi \sim 1.019$ GeV/c^2
- Xe-Xe to Pb-Pb comparison:
  - ➔ **Dynamics is system independent**

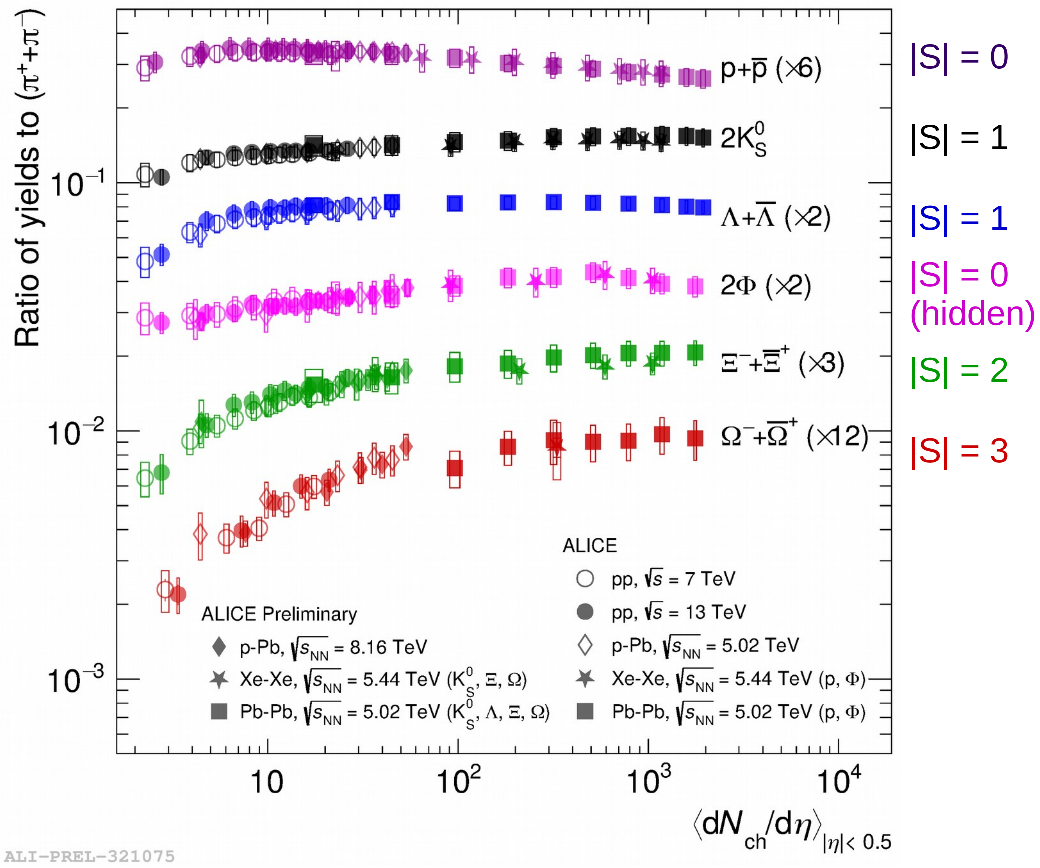
Baryon-to-meson ratios in Pb-Pb and Xe-Xe



arXiv:2101.03100

- At matching multiplicity baryon-to-meson ratios agree for Xe-Xe and Pb-Pb
- Radial flow independent of the collision system
- Radial flow decreases for peripheral collisions
- **p-to-Φ ratio**: less dependent on p_T
  - ➔ Particle mass drives radial flow instead of quark content

Hadron chemistry

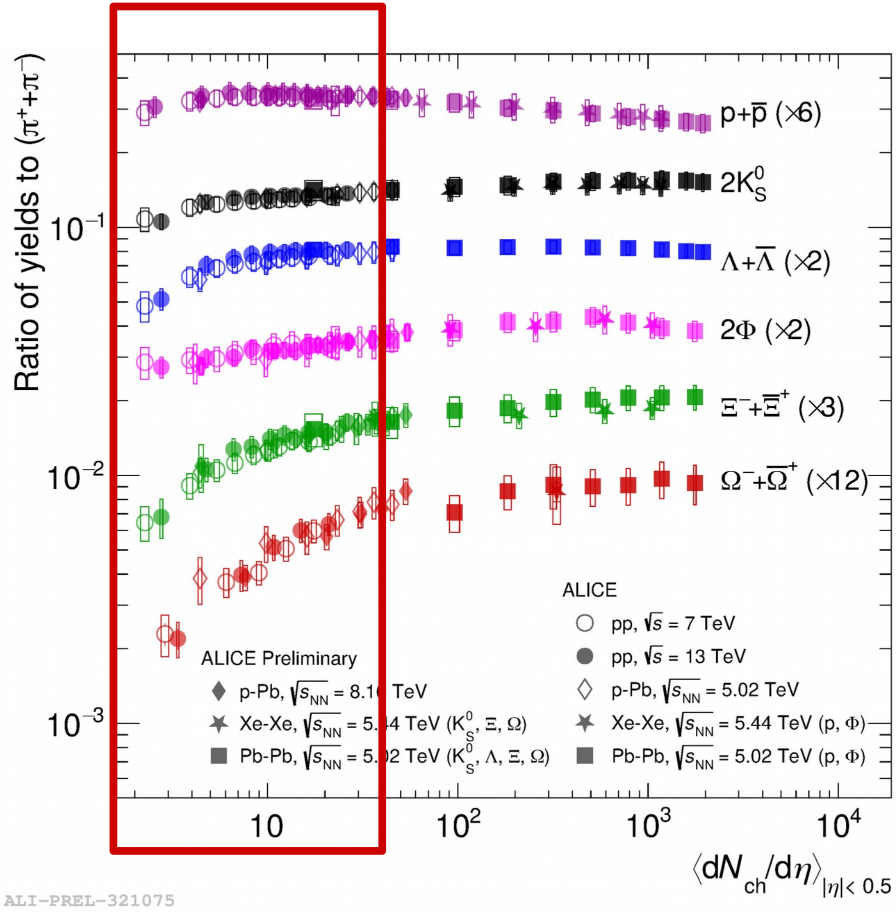


Nat.Phys. 13 (2017) 535–539
Eur.Phys.J.C 80 (2020) 167

- Continuous evolution of particle production throughout collision systems and energies
- Strangeness production increases with system size

resonances
P. Ganoti
T05: Tu. 16:45

Hadron chemistry



|S| = 0

|S| = 1

|S| = 1

|S| = 0 (hidden)

|S| = 2

|S| = 3

- Continuous evolution of particle production throughout collision systems and energies
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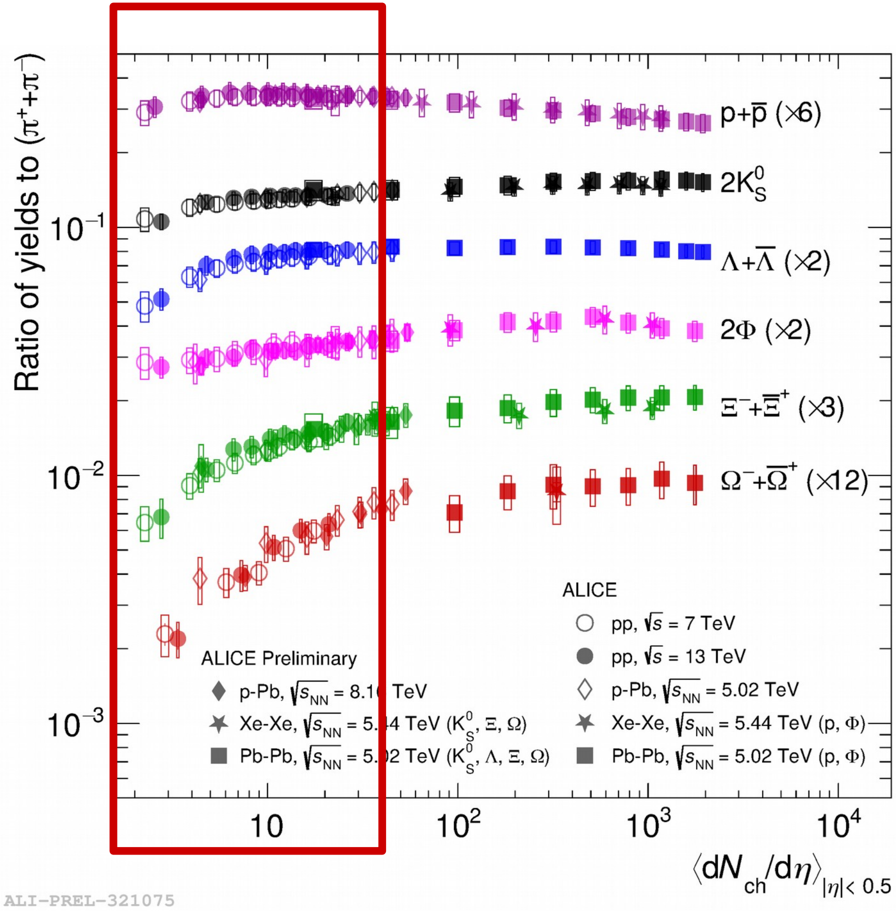
Hadron chemistry



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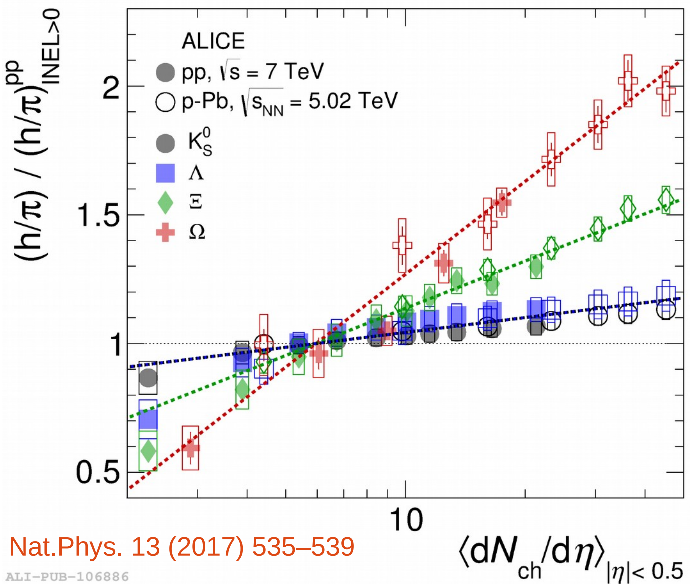
Nat.Phys. 13 (2017) 535–539
Eur.Phys.J.C 80 (2020) 167

- Continuous evolution of particle production throughout collision systems and energies
- Strangeness production increases with system size
- Strangeness enhancement stronger with increasing strange quark content



|S| = 3

|S| = 2

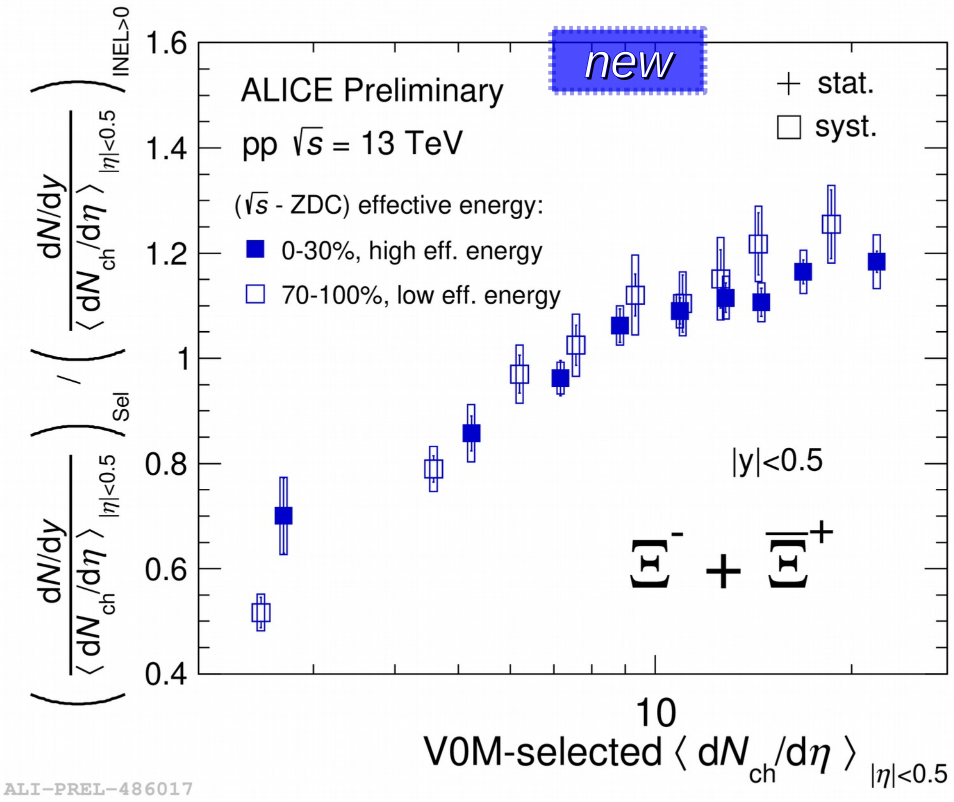
|S| = 1

Nat.Phys. 13 (2017) 535–539

Strangeness in multiplicity and energy classes

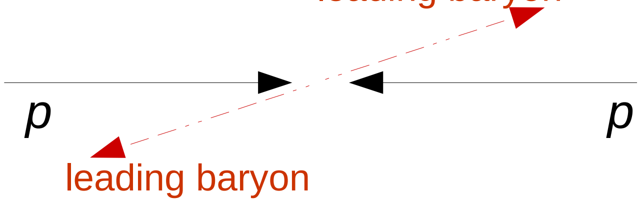
effective energy
C. Oppedisano
T06: We. 10:30

Ξ to average charged-particle multiplicity (normalized to INEL>0) ratio vs. multiplicity classes for given effective energy



Effective energy:

- Leading baryons are measured in the Zero Degree Calorimeters (ZDC)



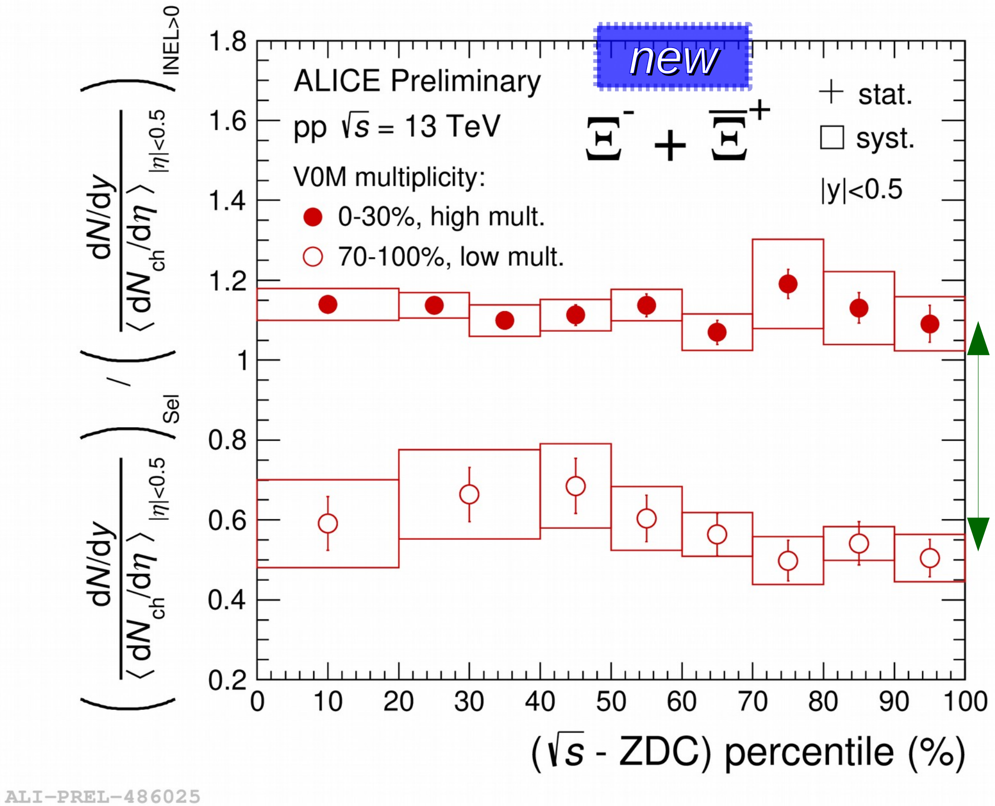
- Energy available for particle production in the initial state

$$E_{eff} = \sqrt{s} - (E_{leading,1} + E_{leading,2})$$

➔ Does strangeness production increase with multiplicity independent of effective energy?

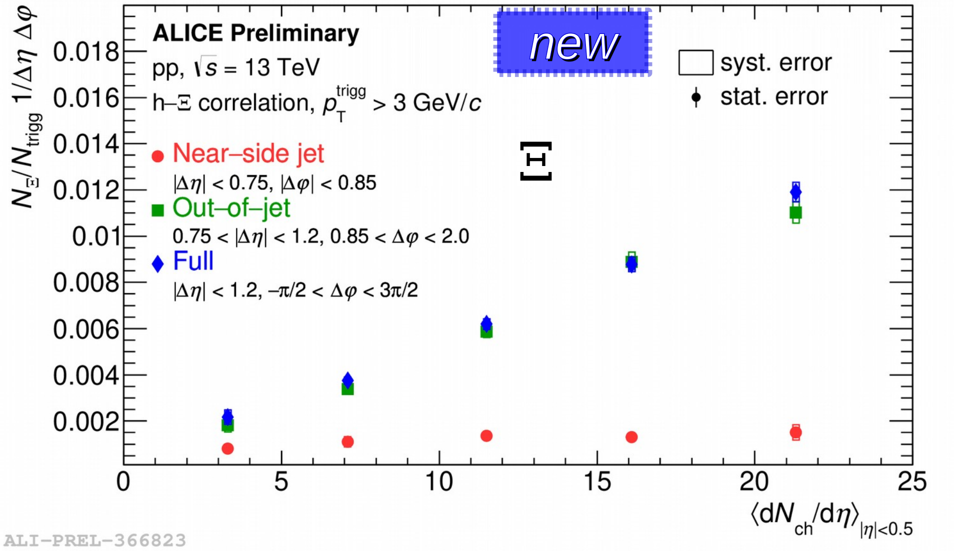
Strangeness in multiplicity and energy classes

Ξ to average charged-particle multiplicity (normalized to INEL>0) ratio vs. effective energy classes for given the multiplicity



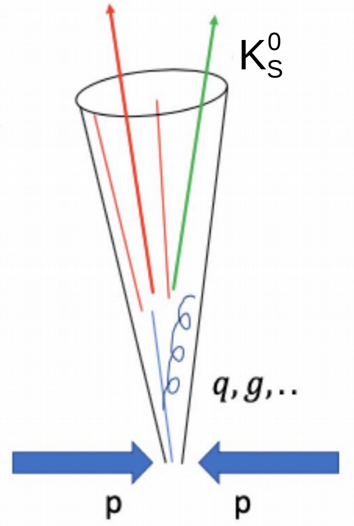
- Split compatible with dependence seen in multiplicity classes
- No strangeness enhancement vs. effective energy estimator
  - ➔ Final-state multiplicity is the dominant factor

Strangeness production in and out-of-jet

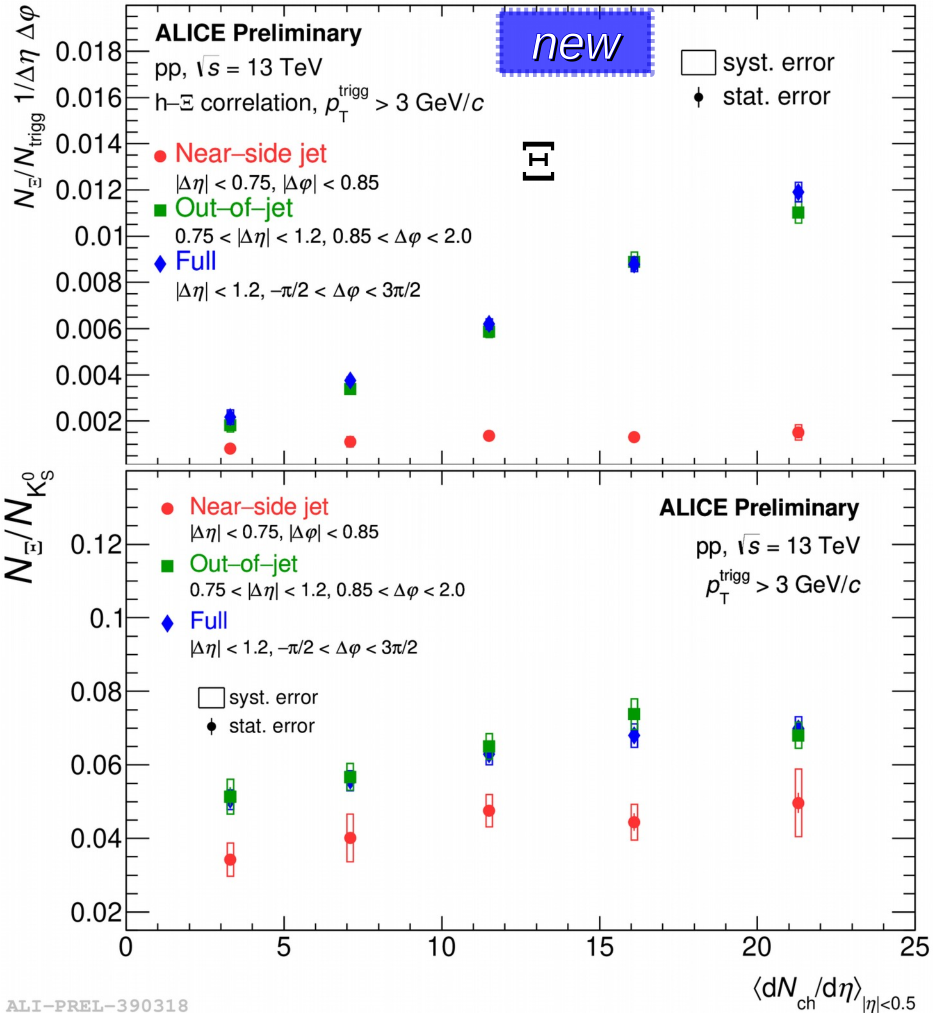


- Ξ and K^0_S are measured in the near-side jet and out-of-jet region
- Out-of-jet yield increases faster w.r.t the near-side jet production vs. multiplicity
  - ➔ With increasing multiplicity out-of-jet component dominates total yield

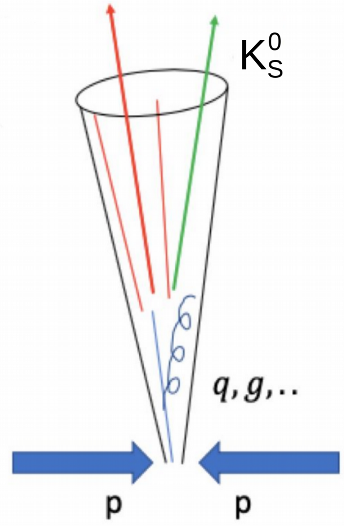
high-p_T hadron as jet proxy



Strangeness production in and out-of-jet



high-p_T hadron as jet proxy



- Ξ and K^0_S are measured in the near-side jet and out-of-jet region
- Out-of-jet yield increases faster w.r.t the near-side jet production vs. multiplicity
  - ➔ With increasing multiplicity out-of-jet component dominates total yield
- Ξ-to-K^0_S ratio tends to increase with multiplicity for out-of-jet and near-side jet component (with current precision not conclusive)
- Out-of-jet processes are dominant contribution to strange-particle production

Summary

- Mass ordering of the $\langle p_T \rangle$ is consistent with radial-flow expectation
- Enhancement of p/π ratio at intermediate p_T indicates collective motion
- Relative particle abundances are mostly dependent on charged-particle multiplicity
- Strangeness production is mostly driven by the final-state multiplicity
- Out-of-jet (soft) processes are the dominant contribution to strange particle production

Summary

- Mass ordering of the $\langle p_T \rangle$ is consistent with radial-flow expectation
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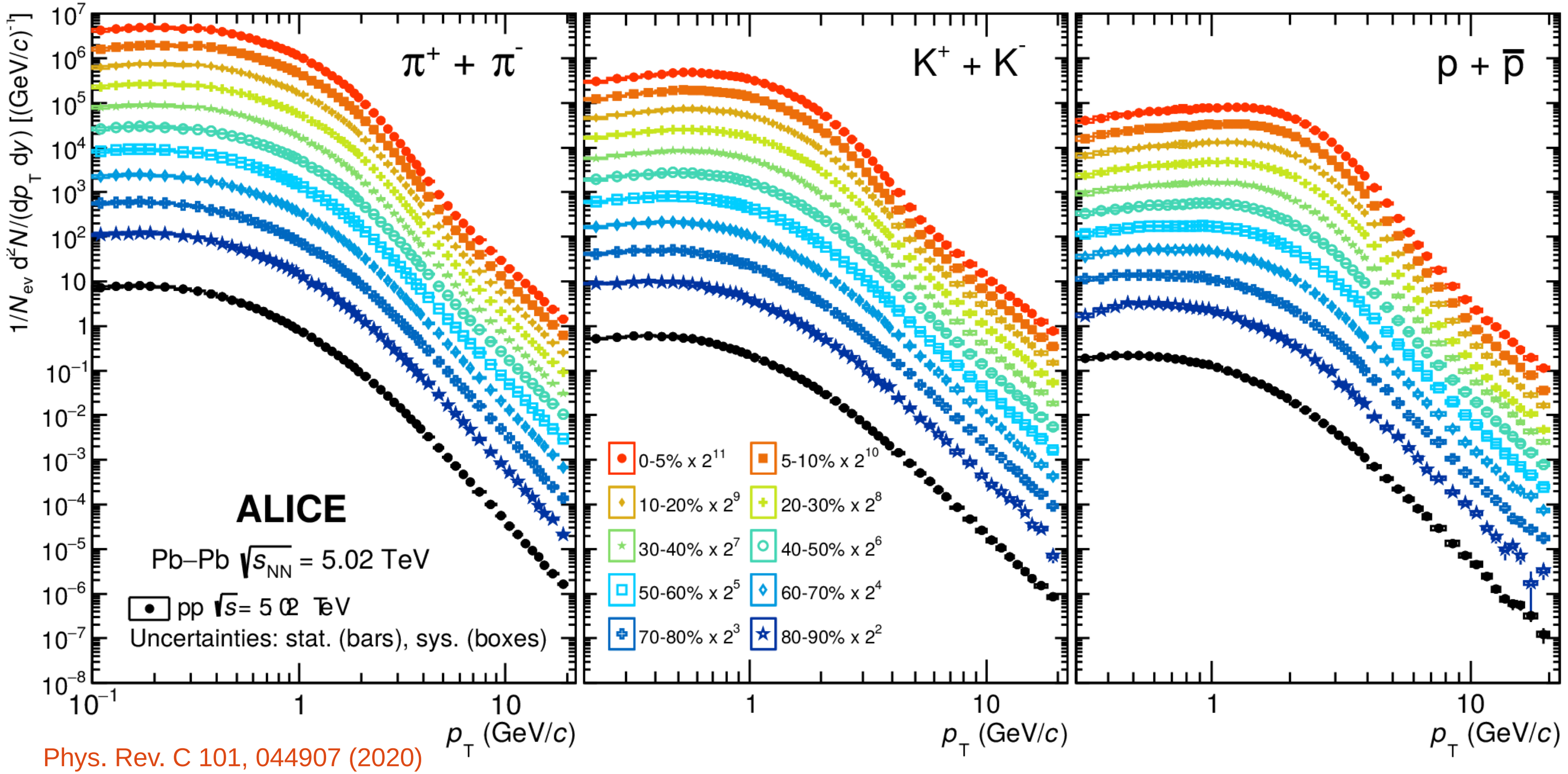
Thank you for you attention!

Backup

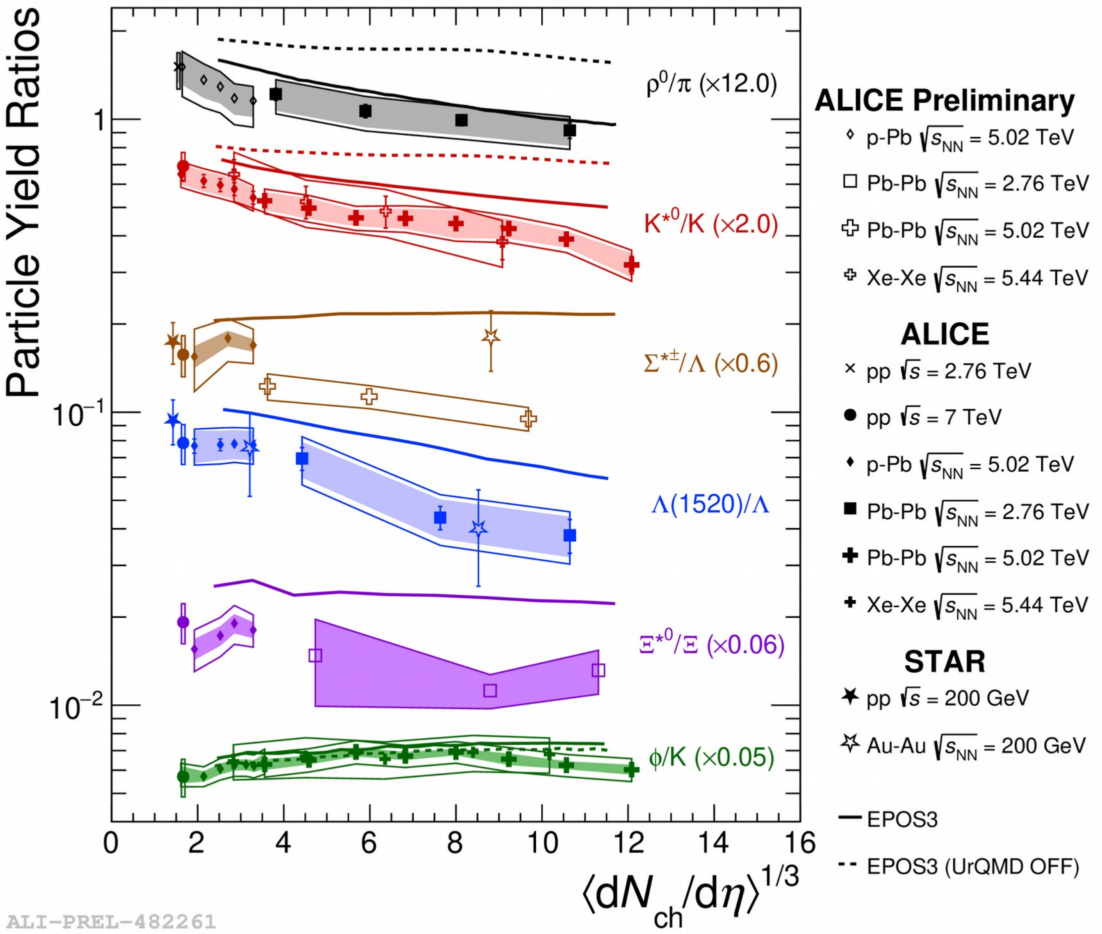
Spectra of π, K, p in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- **Spectra hardening** with increasing centrality due to the collective evolution → **Radial flow**



Phys. Rev. C 101, 044907 (2020)

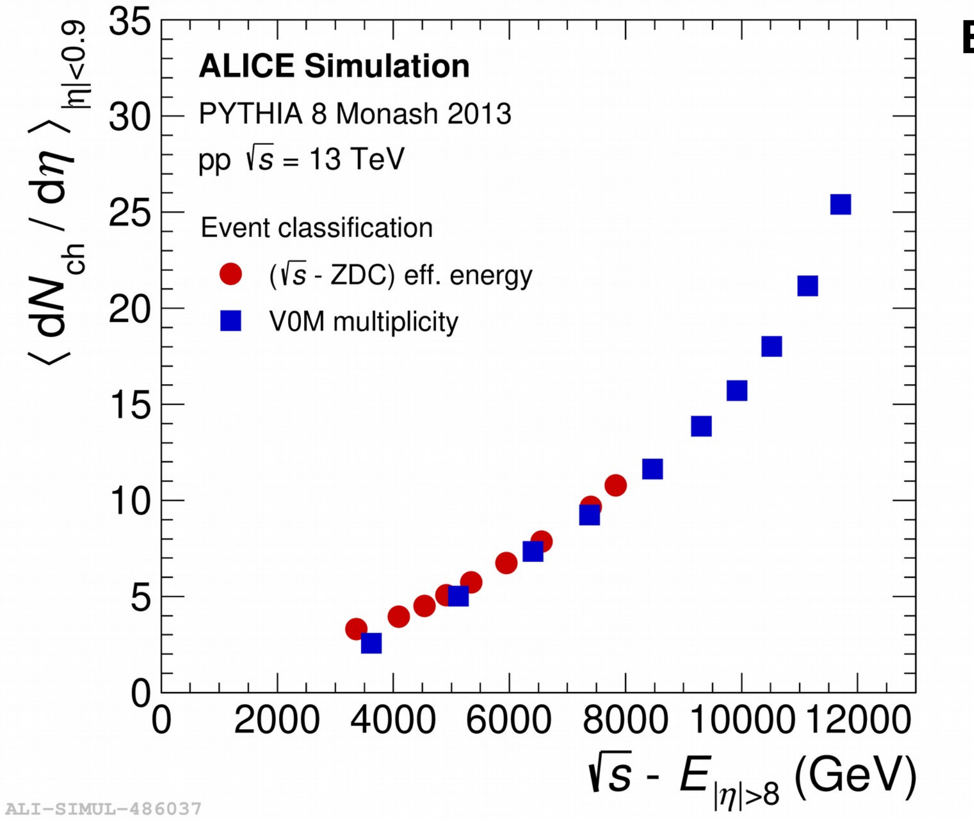
Resonances



- Short-lived resonances (ρ^0, K^{*0} , $\Sigma^{*\pm}$, $\Lambda(1520)$) show suppression in large systems
- Rescattering in hadronic phase of collision
- Long-live resonances (Φ and Ξ^{*0}) show no suppression
- EPOS +UrQMD described the trend qualitatively

Strangeness in multiplicity and energy classes

Expected correlation between average charge particle multiplicity and effective energy



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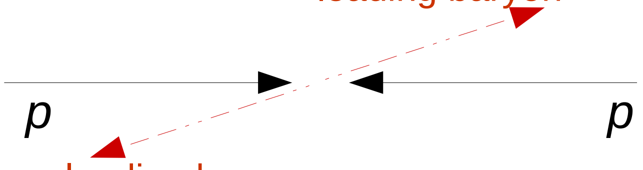
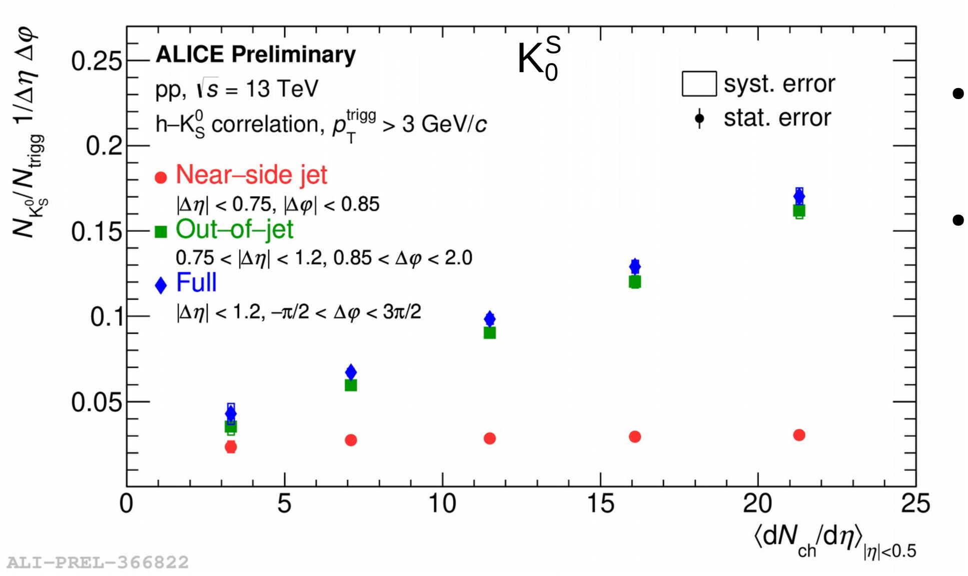


- Energy available for particle production in the initial state

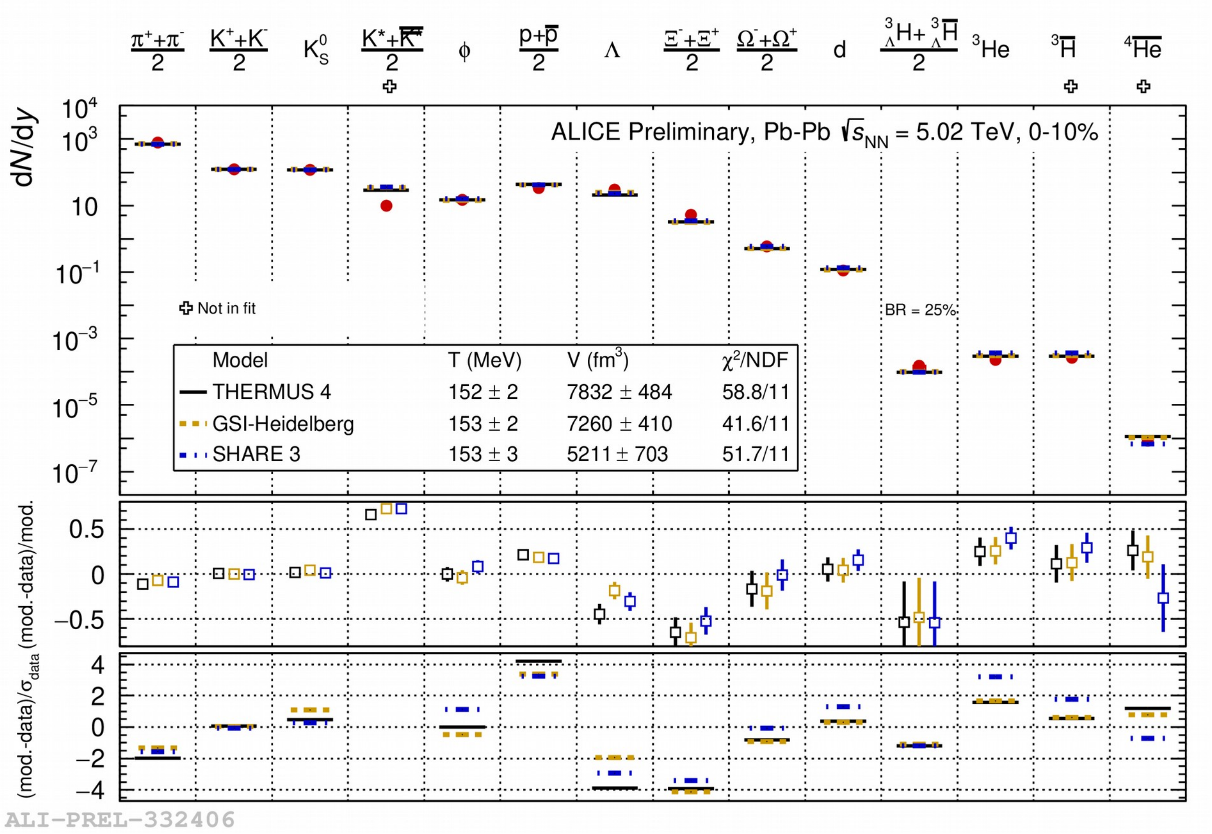
$$E_{eff} = \sqrt{s} - \left(E_{leading,1} + E_{leading,2}\right)$$

Strangeness production in and out-of-jet



- K^0_S and Ξ are measured near-side jet and out-of-jet
- Out-of-jet yield increases faster w.r.t the near-side jet production vs. multiplicity
  - ➔ With increasing multiplicity out-of-jet component dominates

Thermal model prediction



- Hadron formation happens at chemical free-out with μ_B and T_{ch} as free parameter

  T_{ch} = 153 MeV

- Particle yields are described for large mass range by the thermal model