LHCP 2017

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Multiplicity dependence of particle production with ALICE

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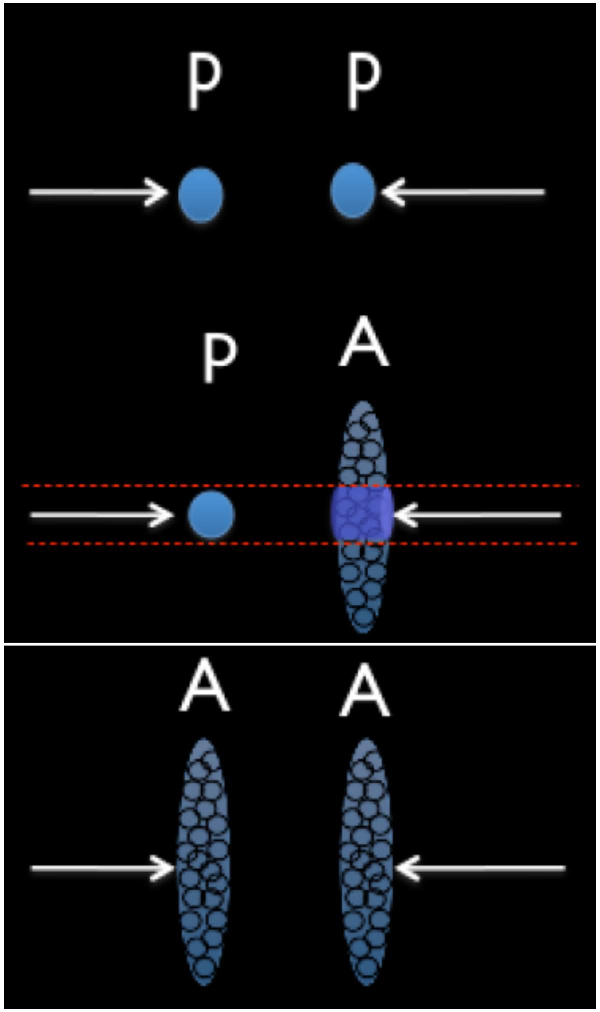
Outline

- ❑ Goals of the ALICE experiment
- ❑ Multiplicity in the different colliding systems
- ❑ Results from pp collisions at 7 TeV and 13 TeV versus multiplicity
    - ❑ Collectivity in small system
    - ❑ Strangeness production
- ❑ Conclusions

Goals of the ALICE experiment

ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy densities to investigate the properties of the **quark-gluon plasma**.

- proton-proton collisions:
  - **high energy QCD reference**.
  - collected pp data at $\sqrt{s}$ = 0.9, 2.76, 5.02, 7, 8, 13 TeV (2009-2012, 2015, 2016)
- proton-nucleus collisions:
  - **initial state/cold nuclear matter**.
  - collected p-Pb data at $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV (2012, 2013, 2016)
- nucleus-nucleus collisions:
  - **quark-gluon plasma formation!**
  - collected Pb-Pb data at $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV, (2010, 2011, 2015)



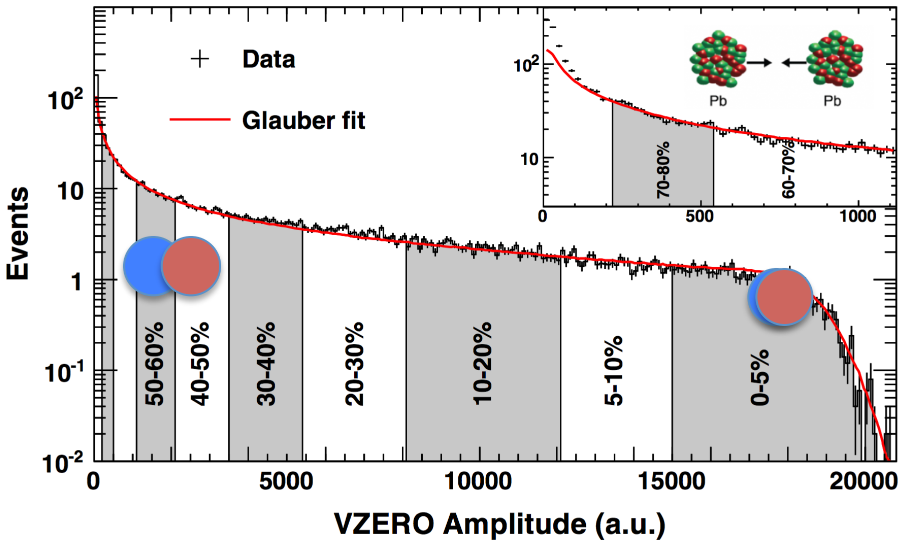
Goals of the ALICE experiment

ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy densities to investigate the properties of the **quark-gluon plasma**.

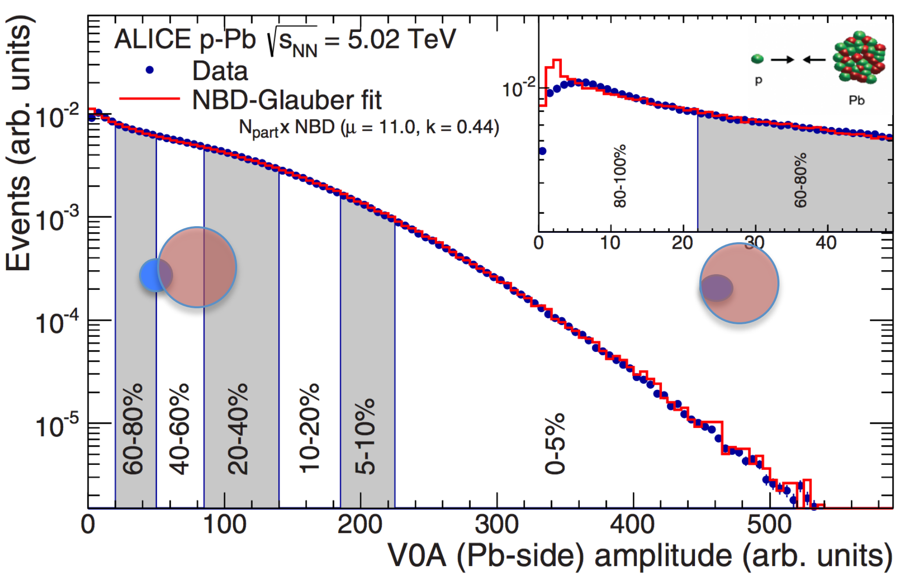
• proton-proton collisions:

- ALICE has measured the yields of produced charged hadrons (π, K, p, $K^0{}_s$, Λ, Ξ, Ω, K^{0*}) in a wide momentum range and in several colliding systems as a function of event multiplicity.
- pp and p-A collisions play only the role of control experiments?!
- No!! I will show why!

Multiplicity estimate in ALICE



Phys. Rev. Lett. 106, 032301 (2011)

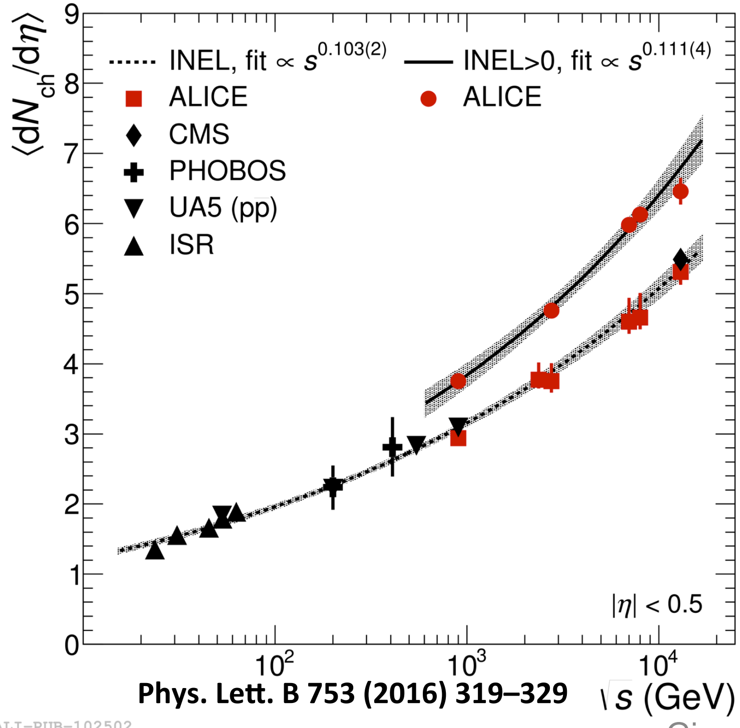


Phys. Rev. C 91 (2015) 064905

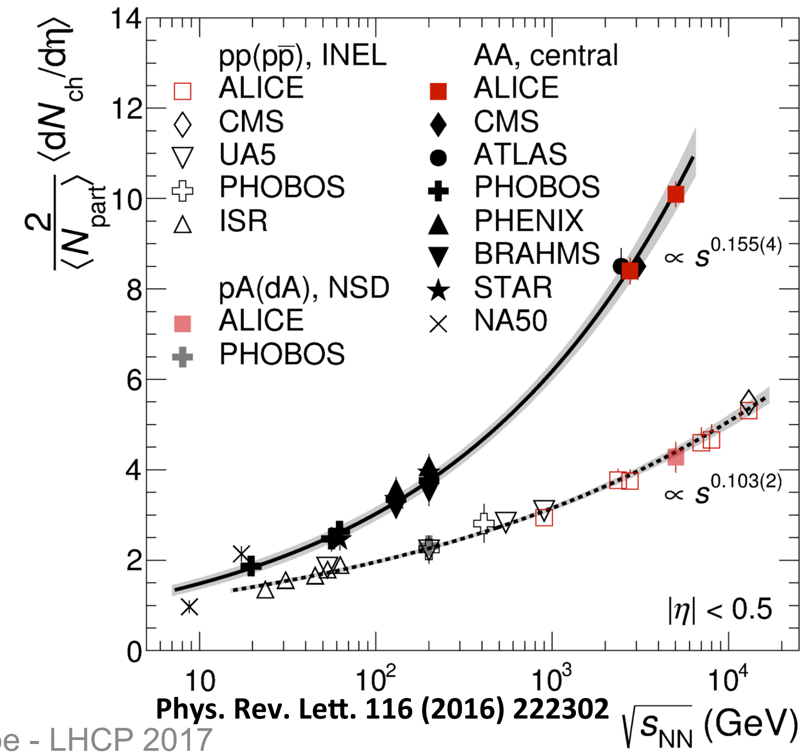
- Multiplicity is defined as the number of charged particles per event in $|\eta| < 0.5$
- Linked through the impact parameter to the collision centrality in Pb–Pb (**Glauber model**)
- ALICE measures the event activity at forward rapidity with the **V0 scintillators** placed at $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C)
- Wide range of measured multiplicities
  - from $\langle dN_{ch}/d\eta \rangle \approx 2$ in low multiplicity pp collisions
  - to $\langle dN_{ch}/d\eta \rangle \approx 1600$ in central Pb–Pb collisions

Energy dependence of charged particle multiplicity

- Measured inclusive charged particle yield at the highest center of mass energy available at LHC.
- $\langle dN_{ch}/d\eta\rangle/(N_{part}/2)$ increase with $\sqrt{s}$ following a power law, along the trend from lower center of mass energies
  - pp: $\approx s^{0.103}$
  - central A+A: $\approx s^{0.155}$
- In pp collisions about **20% increase** from 7 TeV to 13 TeV.



Phys. Lett. B 753 (2016) 319–329



Phys. Rev. Lett. 116 (2016) 222302

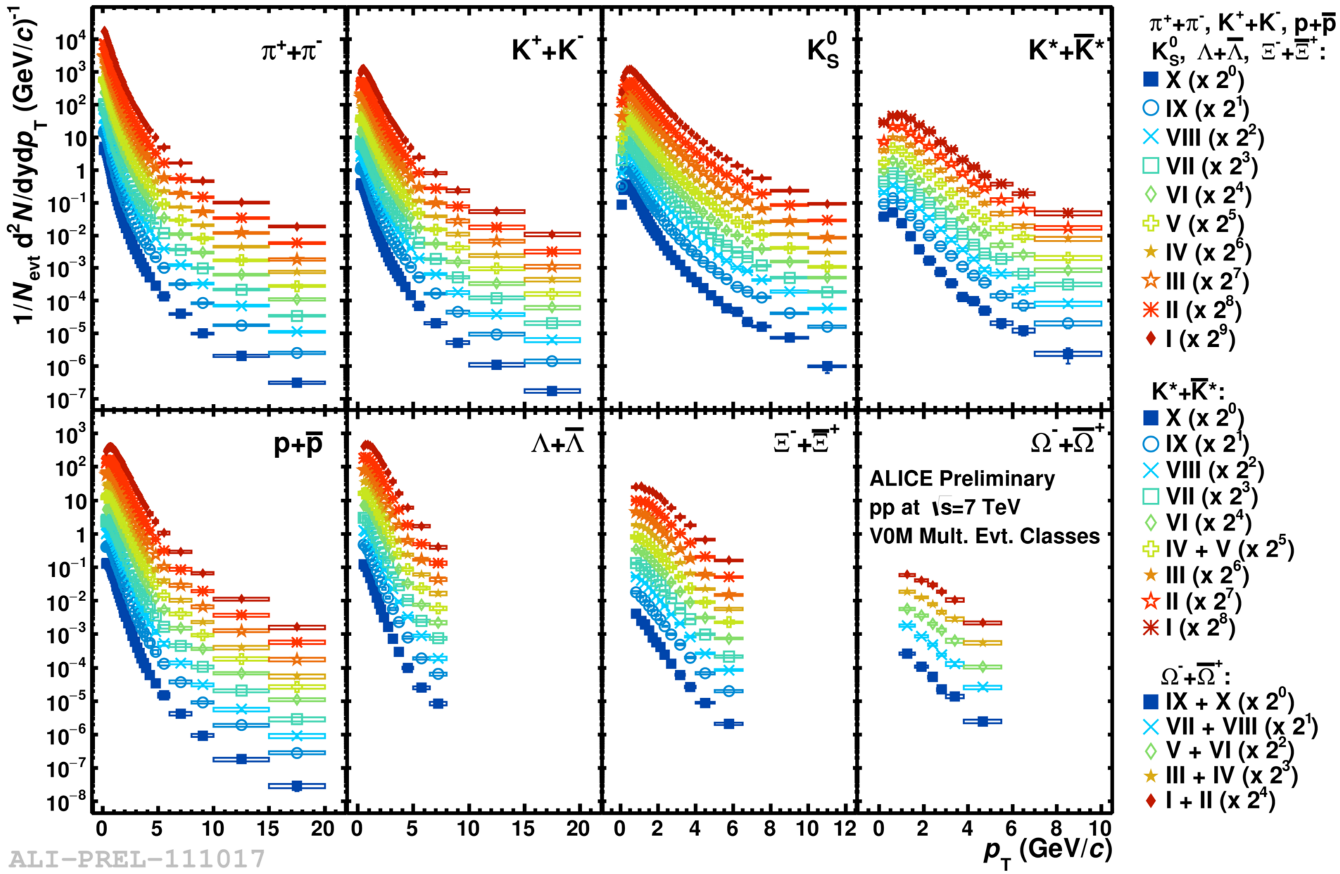
Collectivity in small system: p_T spectra

Class name	I	II	III	IV	V	VI	VII	VIII	IX	X
$\sigma/\sigma_{INEL>0}$	0–0.95%	0.95–4.7%	4.7–9.5%	9.5–14%	14–19%	19–28%	28–38%	38–48%	48–68%	68–100%
$\langle dN_{ch}/d\eta \rangle$	21.3±0.6	16.5±0.5	13.5±0.4	11.5±0.3	10.1±0.3	8.45±0.25	6.72±0.21	5.40±0.17	3.90±0.14	2.26±0.12

High mult.

Low mult.

pp @ 7 TeV



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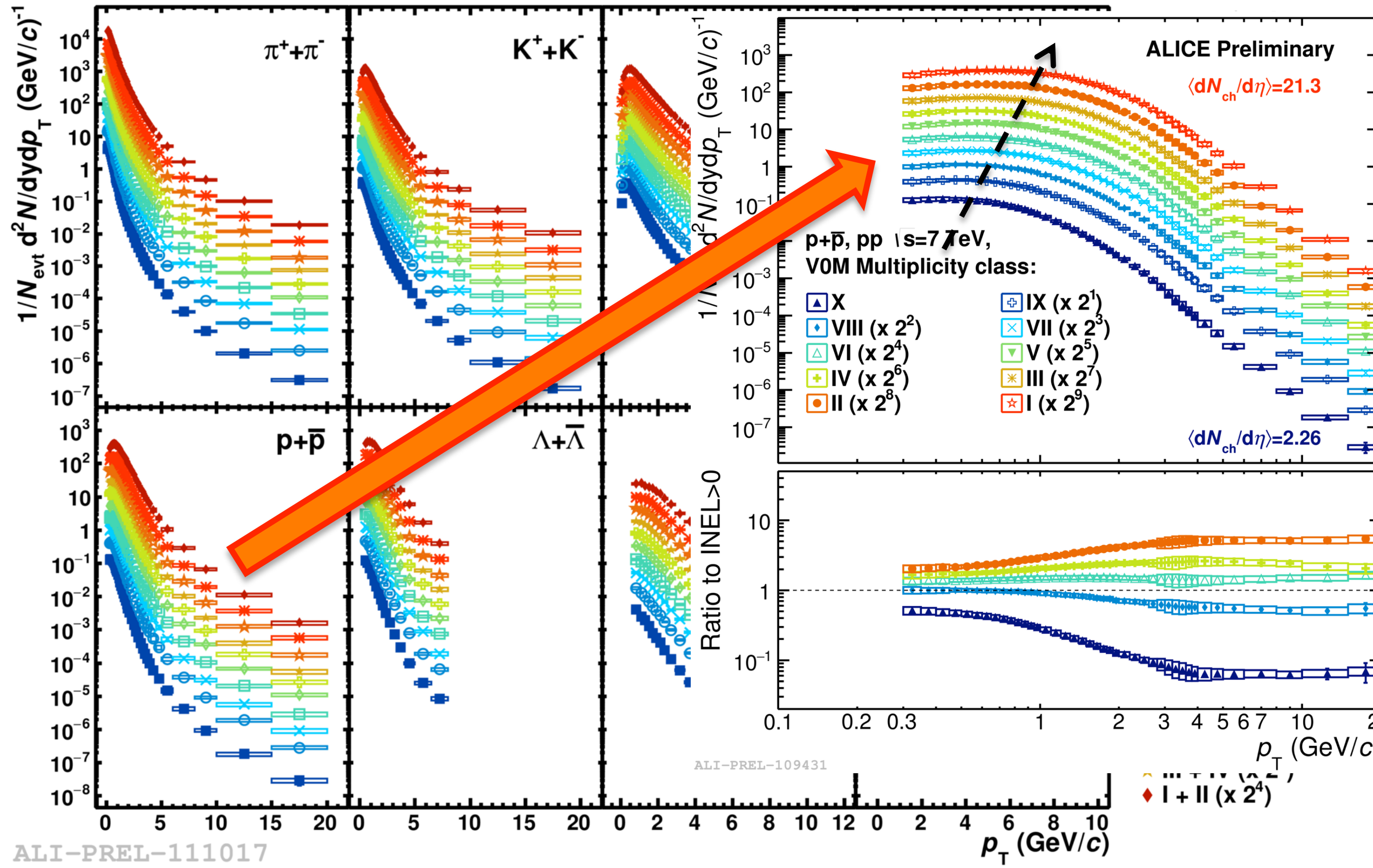

- Hardening with multiplicity and particle mass at low p_T (< 2 GeV/c)
- Indication for collective effects, reminiscent of observed effects in Pb-Pb → attributed to radial flow

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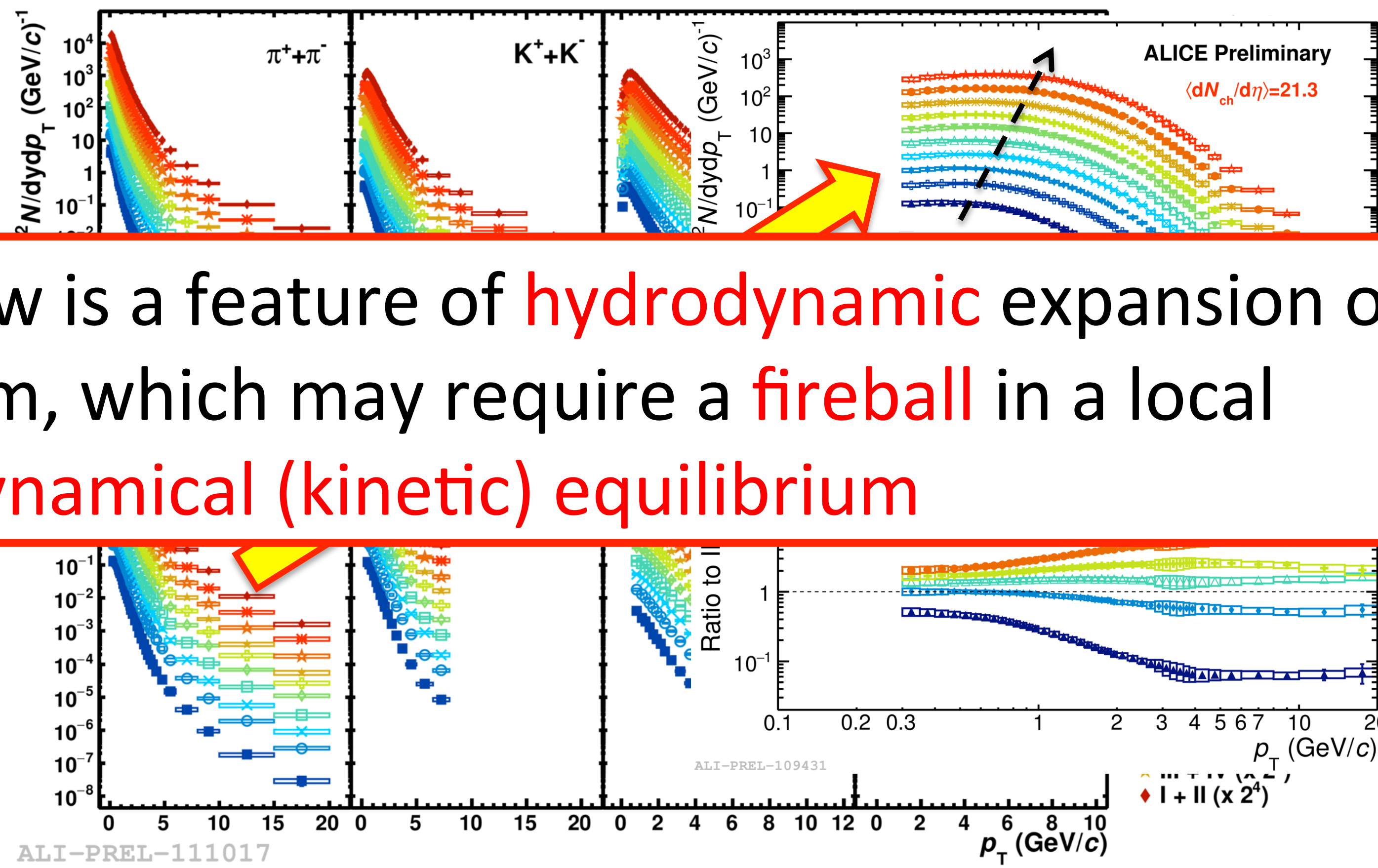

Radial flow is a feature of hydrodynamic expansion of the system, which may require a fireball in a local thermodynamical (kinetic) equilibrium

- Hardening with multiplicity and particle mass at low p_T (< 2 GeV/c)
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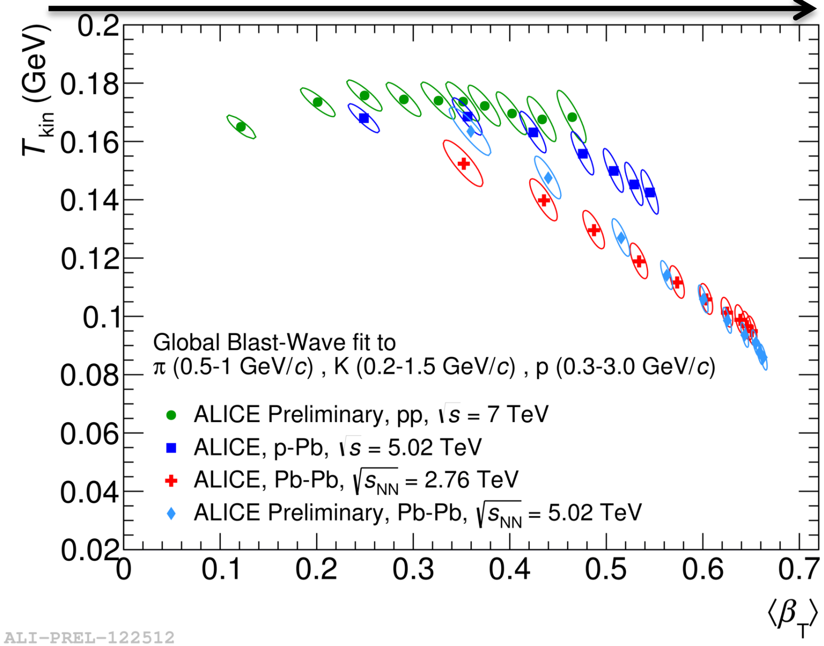
Collectivity in small system: p_T spectra

- Simultaneous **Global Blast-Wave** (simplified hydrodynamic model) fit to the π, K, p spectra:
  - in **Pb-Pb** increasing of $\langle \beta_T \rangle$ with centrality.
- In **pp** and **p-Pb**, similar evolution of the parameters towards high multiplicity

At similar multiplicity, $\langle \beta_T \rangle$ is larger for smaller systems

Increasing multiplicity



- Does this imply that the trend in different systems is driven by the same type of collectivity (e.g. radial flow)?!

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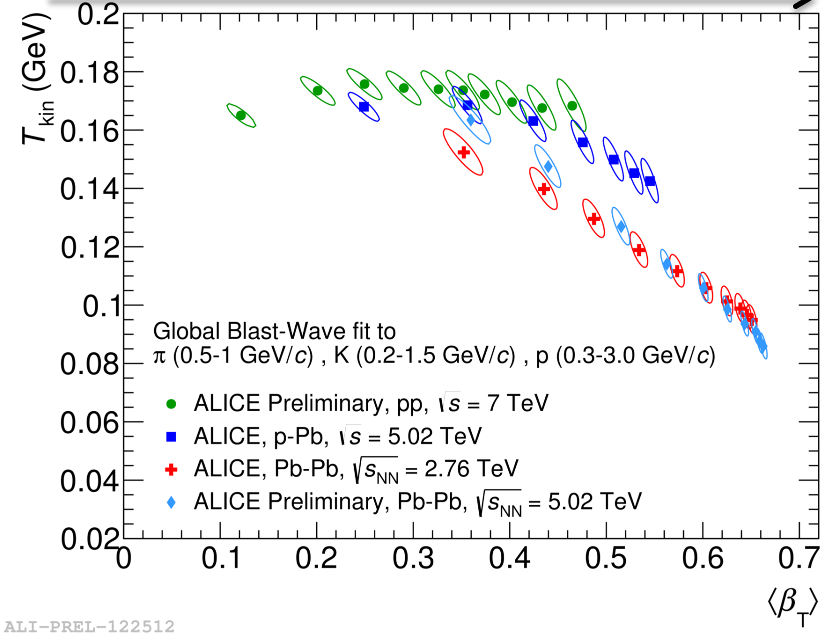
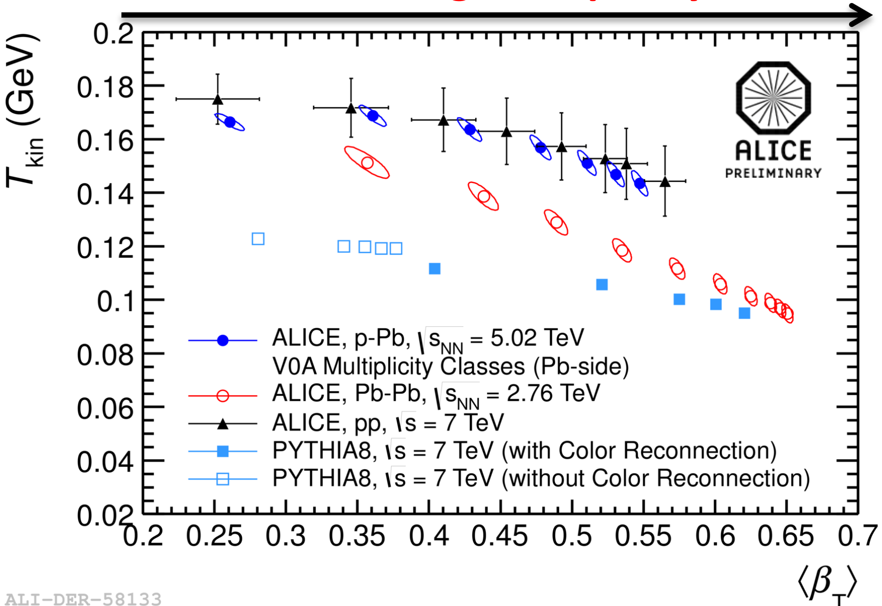


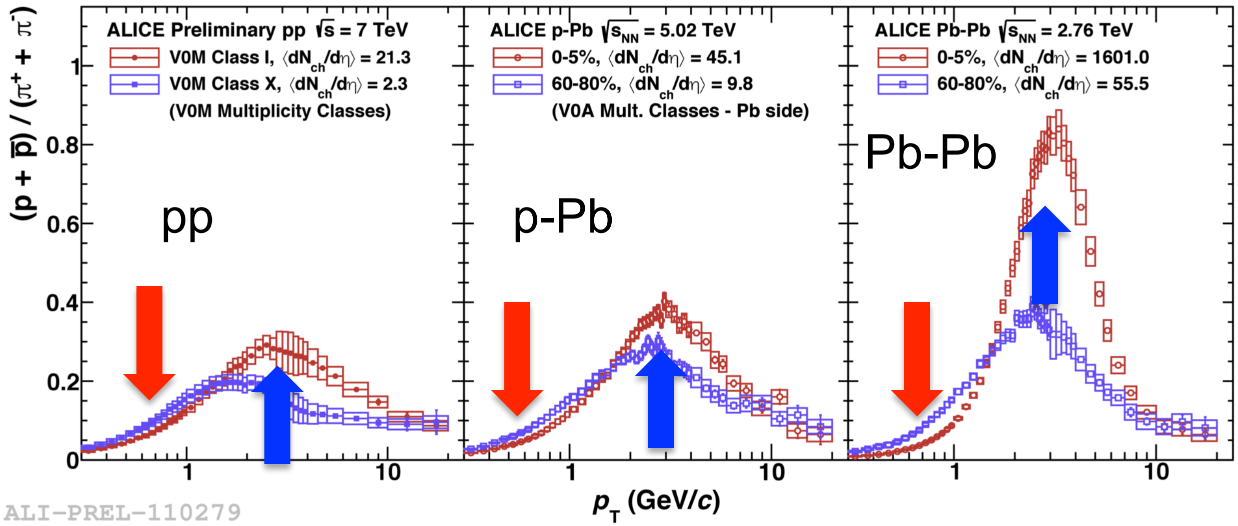
Increasing multiplicity

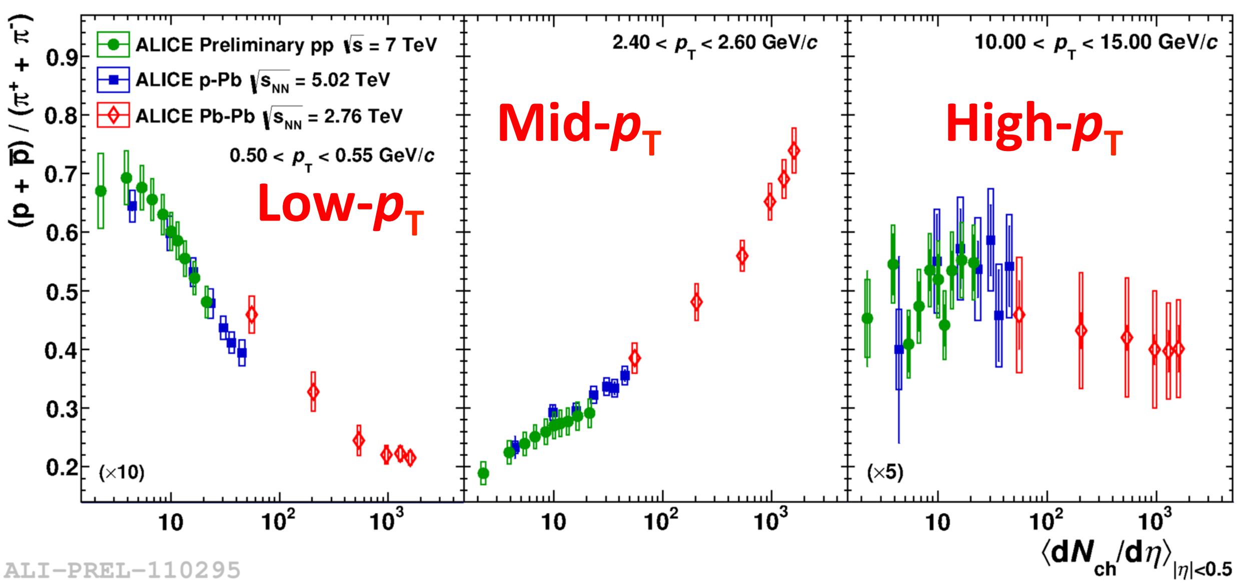


- Does this imply that the trend in different systems is driven by the same type of collectivity (e.g. radial flow)?!

- No!! QCD effects such as **color reconnection** (CR) can **mimic the effects of radial flow.**

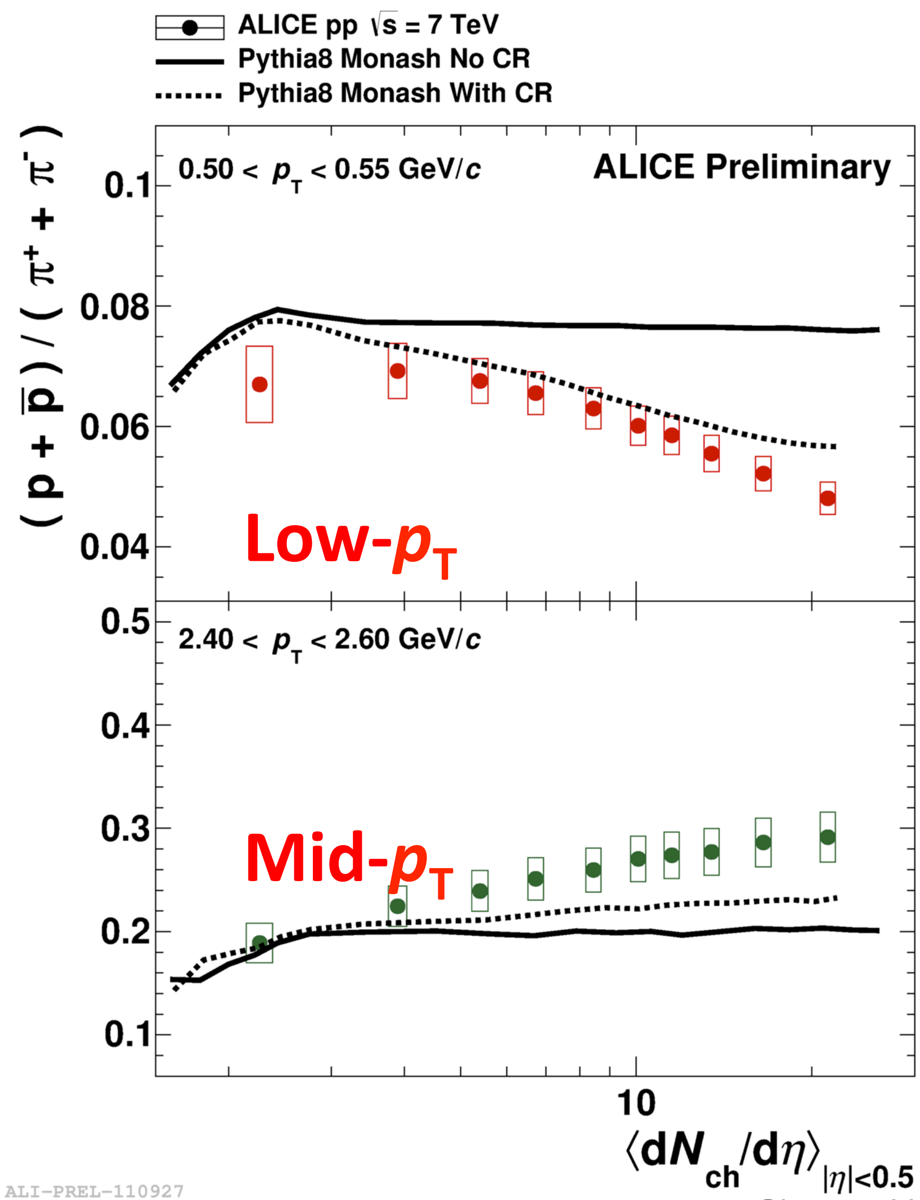
Collectivity in small system: baryon/meson





- Qualitatively similar features observed for bulk particle production in pp, p-Pb and Pb-Pb.
  - in qualitatively similar way: **depletion** at low p_T, **enhancement** at intermediate p_T.
  - In Pb-Pb explained by radial flow or recombination (both collective effects)
- Similar scaling with $\langle dN_{ch}/d\eta \rangle$ is observed at a fixed p_T for the p/π ratio, across different systems.

Collectivity in small system: baryon/meson

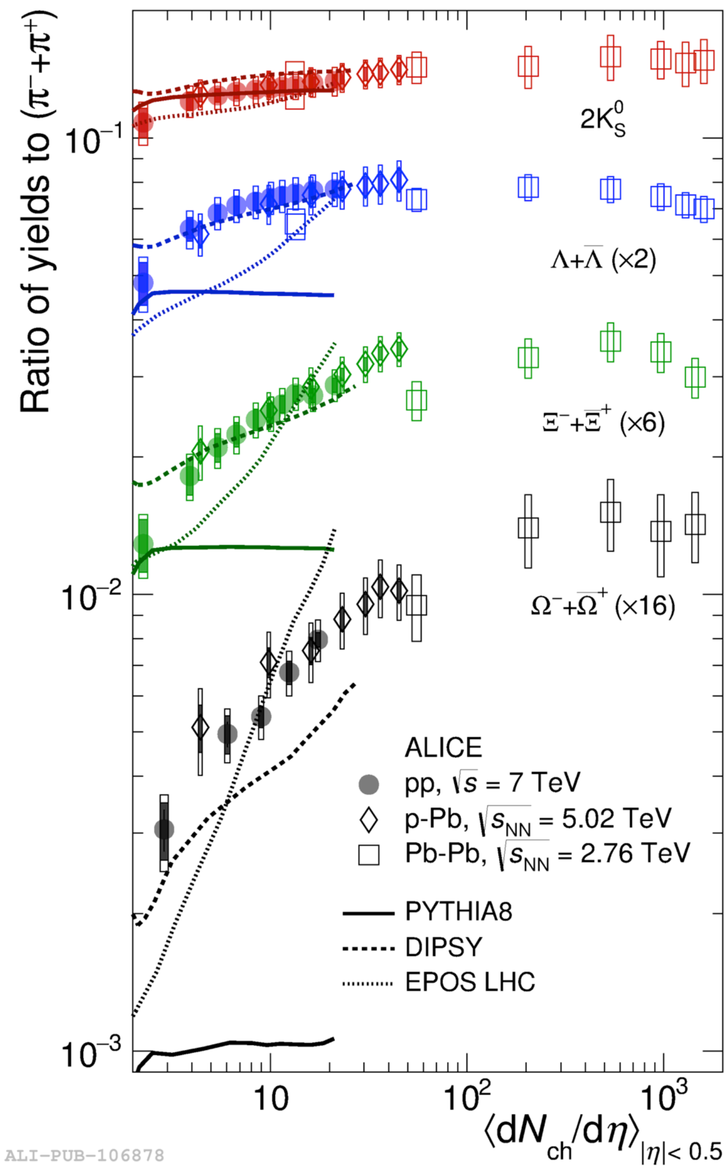


- PYTHIA with Color Reconnection describes rather well the trend.
  - Also in this case, in pp collisions, radial flow can be mimicked by QCD effects.

→ Let's look at particle composition of the system to investigate if it also shows similarities in the chemical particle composition.

Hadrochemistry in small system: strangeness

NATURE PHYSICS DOI: 10.1038/NPHYS4111



- Smooth evolution of p_T-integrated particle ratios across different colliding systems as a function of $\langle dN_{ch}/d\eta \rangle$ is observed.
  - PYTHIA8: pQCD-inspired. Color reconnection has little effect. Does not describe the strangeness enhancement.
  - EPOS LHC: Collective hadronization + collective flow. shows enhancement qualitatively but not quantitatively
  - DIPSY: Baryons from color ropes. It enhances all baryons (also not strange) with multiplicity

flow-like effect can be mimicked by color reconnection but strangeness enhancement cannot!

In pp strange particle ratio to π increases
→ Is the enhancement due to
(a) Mass?
(b) baryon/meson nature of the particle?
(c) strangeness content?

Hadrochemistry in small system: strangeness

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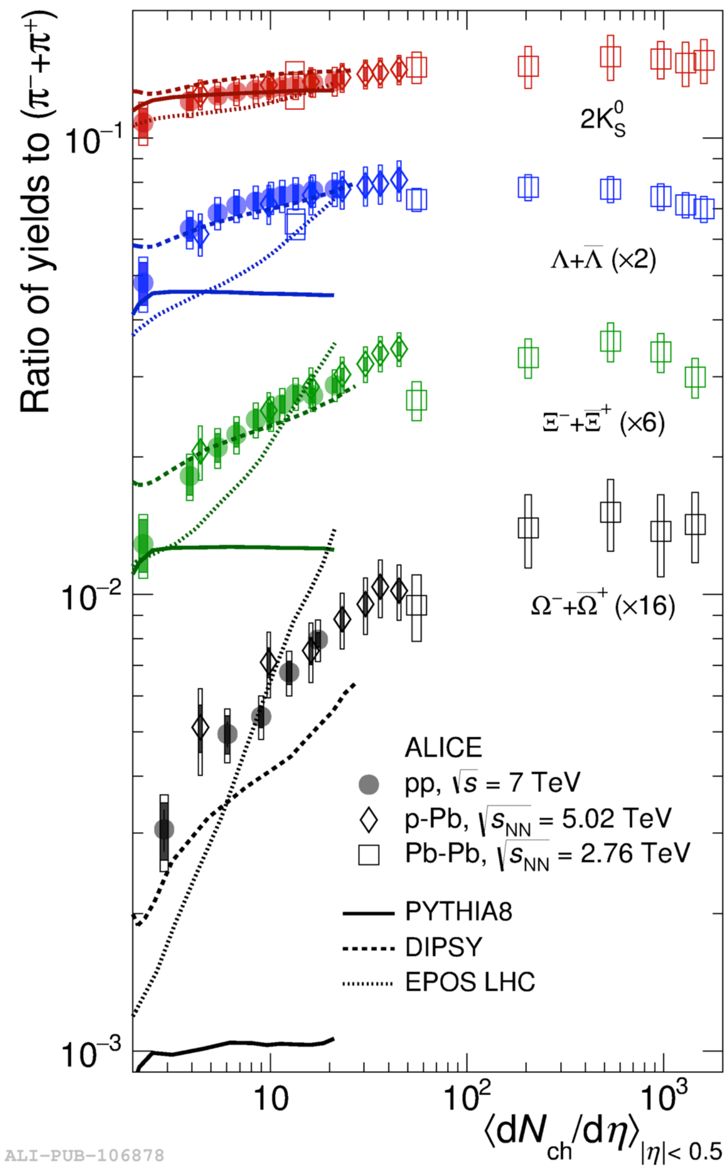
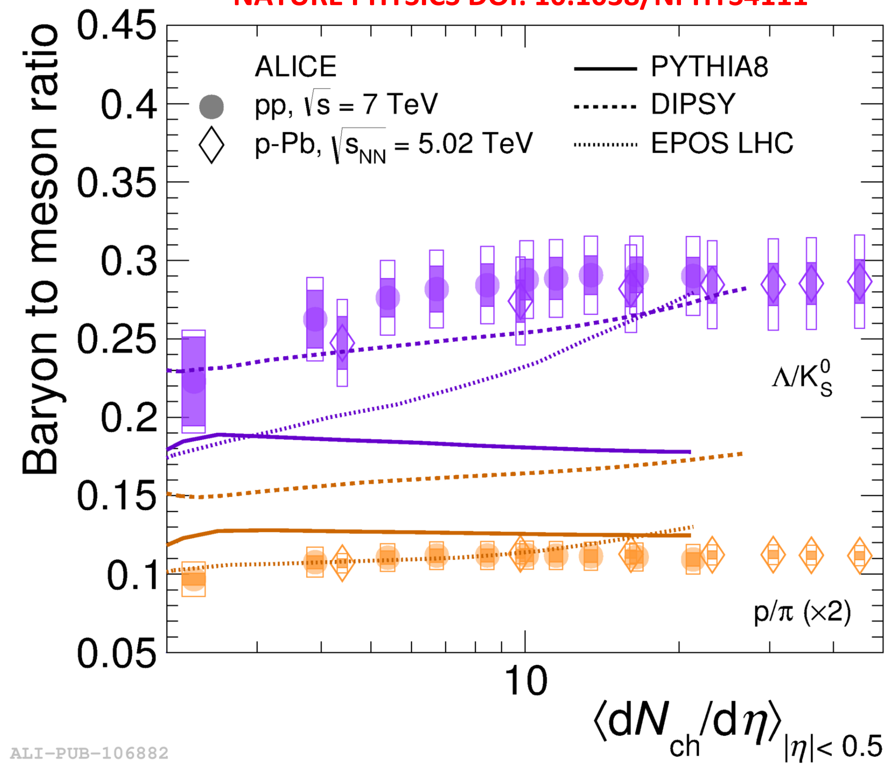
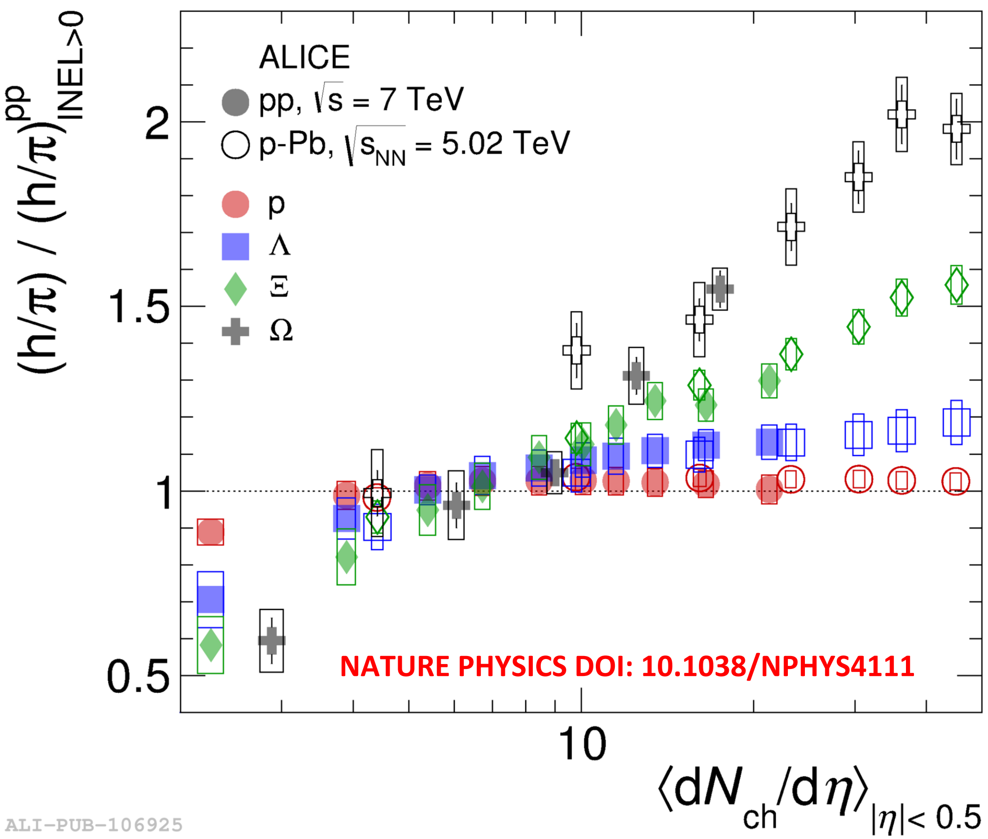


In p/π and Λ/K^0_s the only effect could be baryon/meson or mass, because there is no net-strangeness difference → **the ratios are flat**

NATURE PHYSICS DOI: 10.1038/NPHYS4111



Hadrochemistry in small system: strangeness

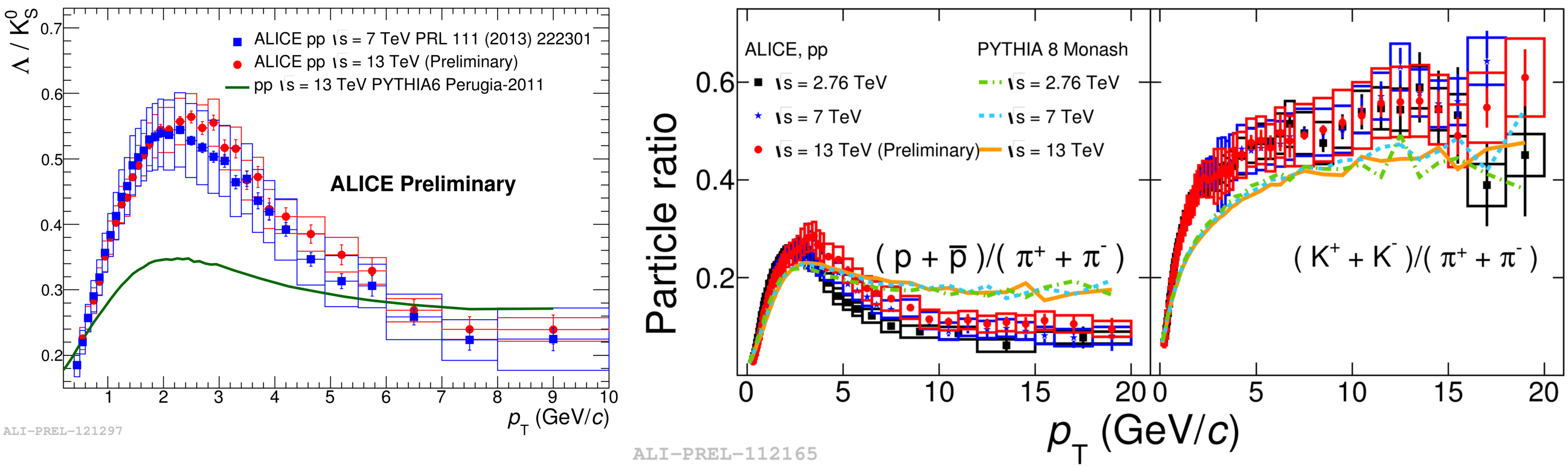


- Double-ratio in pp collisions (and p-Pb, also shown) evolves smoothly with multiplicity density.
- Proton (S=0) is consistent with unity up to highest $\langle dN_{ch}/d\eta \rangle$
- Hyperon production increases from low to high multiplicity in pp and p-Pb
- The larger the valence strange quark content, the steeper the slope

→ **the effect is due to strangeness**

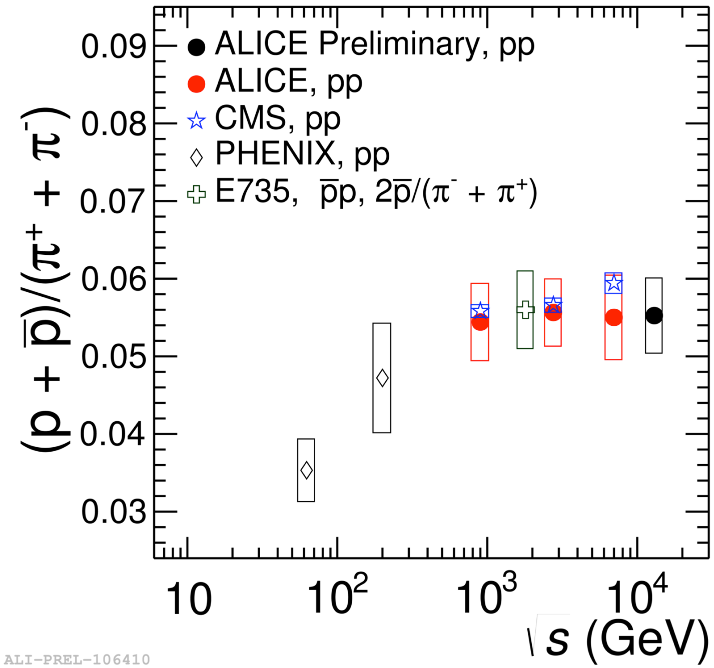
Is the same enhancement present at higher energy (13 TeV)?
Is it collision-energy dependent or multiplicity driven?

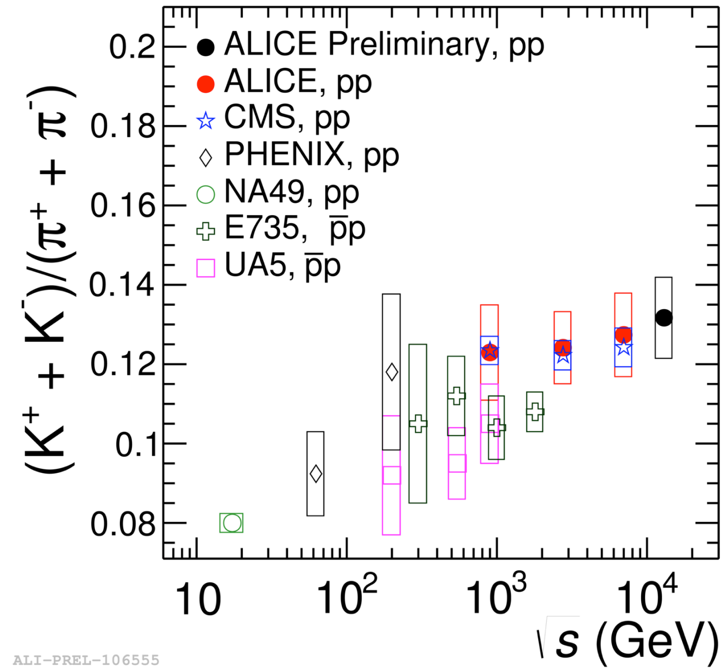
Particle ratios in pp collisions at √*s* = 13 TeV

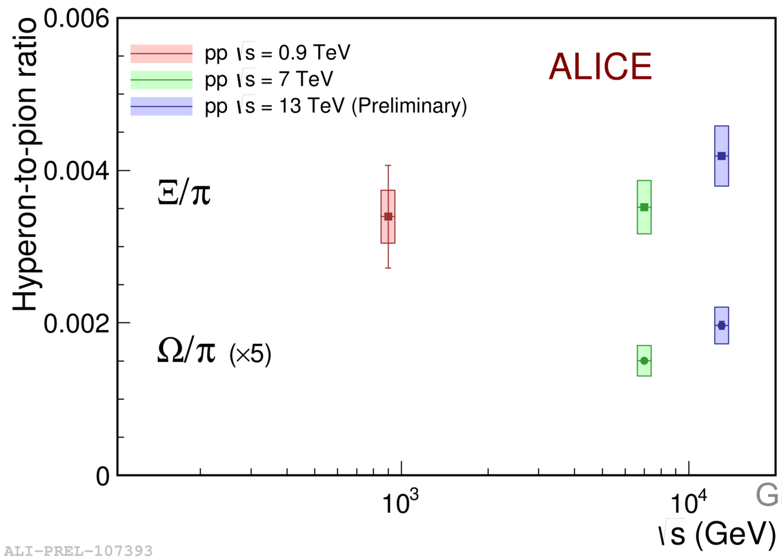


- K/π shows no significant evolution with √*s*
- The maximum value of ratio for both Λ/K^0_s and p/π shifts to slightly larger values of p_T with increase of √*s*

Particle ratios in pp collisions at √s = 13 TeV



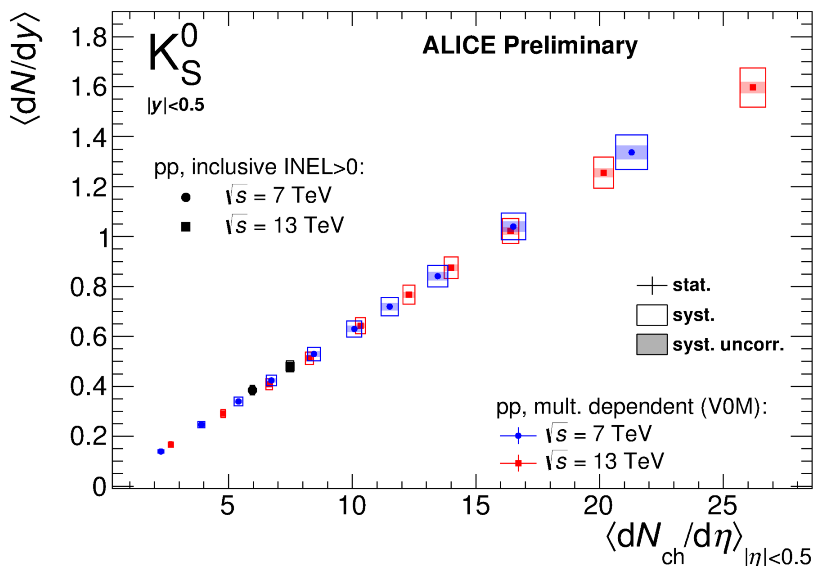




Comparison of p_T-integrated yield ratios, measured at different √*s* :

- p/π saturates at LHC energies
- K/π: no conclusion possible due to systematics
- Data hints at an increase of hyperon production with increasing √*s*
  - **How does it scale with multiplicity density?**

Strangeness production: pp at 7 and 13 TeV



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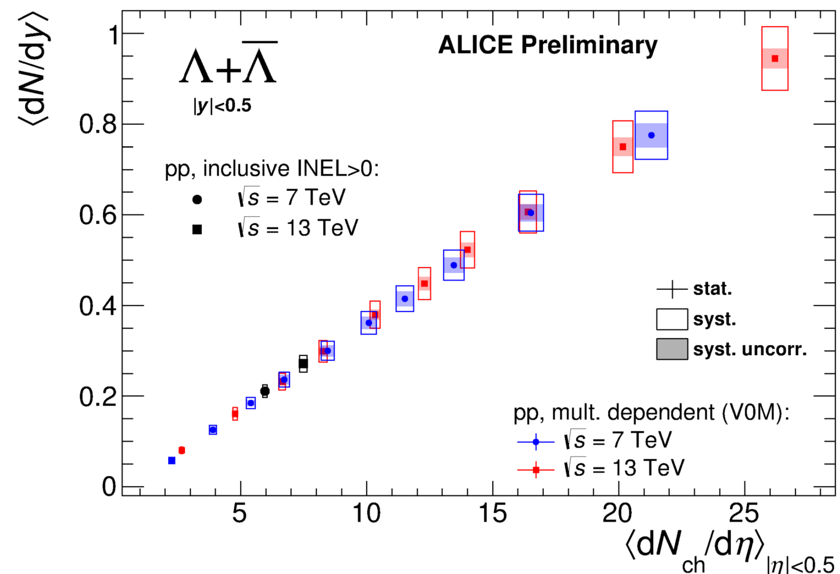

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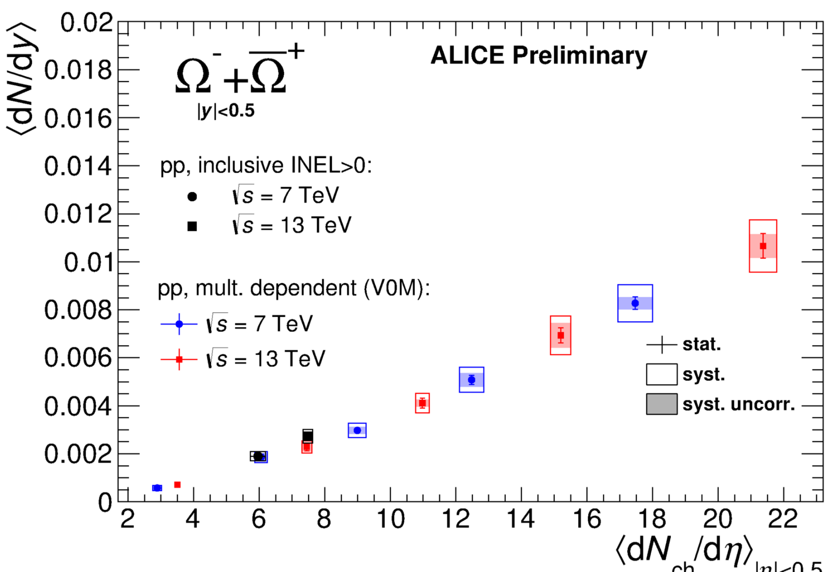

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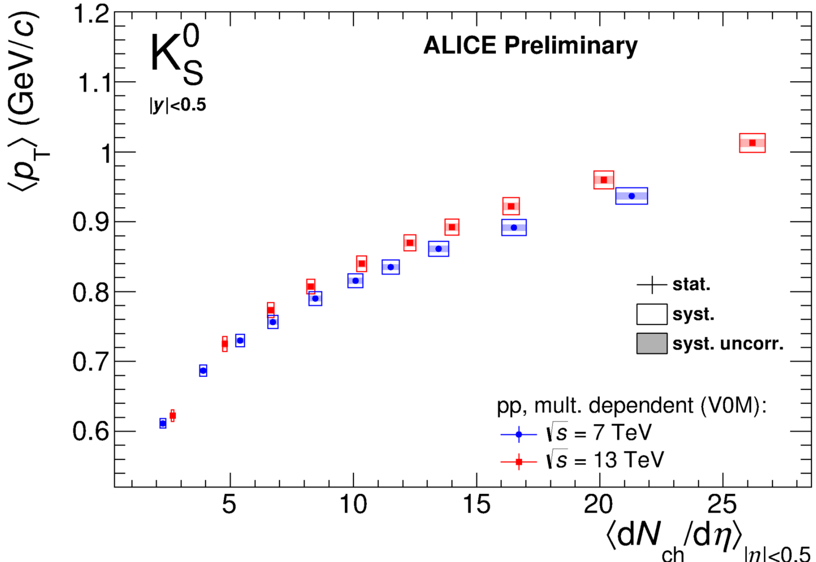
- Similar scaling is observed for strangeness production with $\langle dN_{ch}/d\eta \rangle$ in pp collisions at √s = 7 TeV and 13 TeV.

- **Strange hadron production is collision energy independent at similar multiplicity.**

Strangeness production: pp at 7 and 13 TeV



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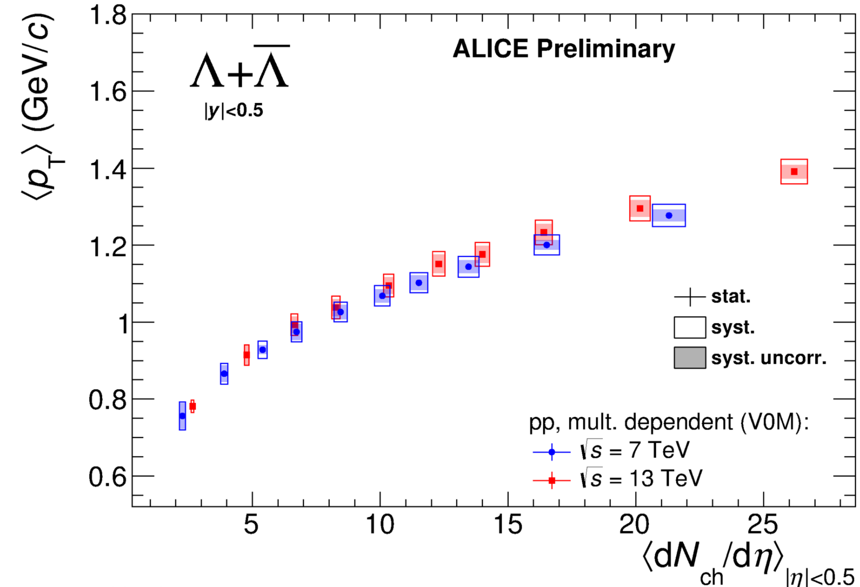

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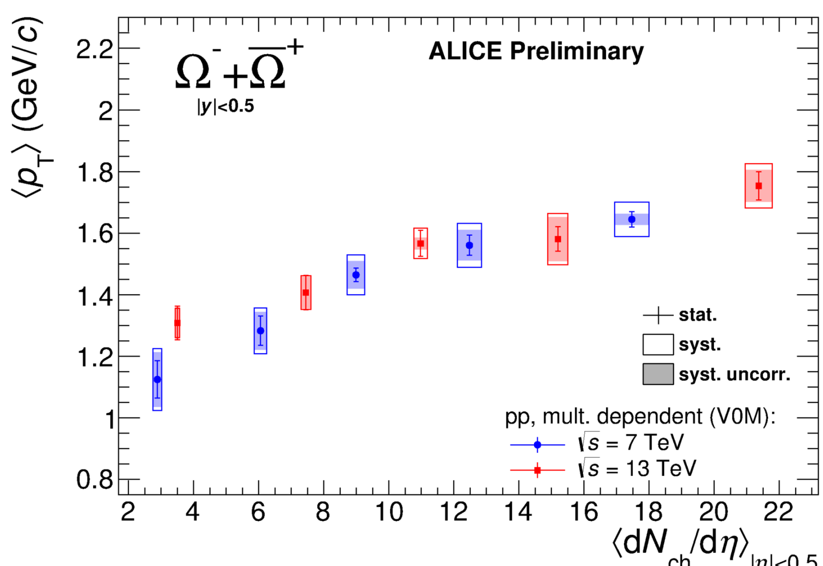

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- $\langle p_T \rangle$ of K^0_s at 13 TeV $\gtrsim \langle p_T \rangle$ of K^0_s at 7 TeV at similar charged particle multiplicity densities.
- Λ and Ω: $\langle p_T \rangle$ are similar within systematic uncertainties.
- **Yields scale well with √s, while $\langle p_T \rangle$ not!**

Conclusion

- ALICE is probing QCD in a wide range of particle densities and soft/hard regime by measuring identified particle production

- We have presented a comprehensive study of identified particles (π, K, p, K^0_s, Λ, Ξ, Ω, K^{0*}) done by the ALICE Collaboration in **pp collisions** at $\sqrt{s}$ = **7 TeV** and **13 TeV** versus event **multiplicity**.

- Interesting similarities among different systems are observed:

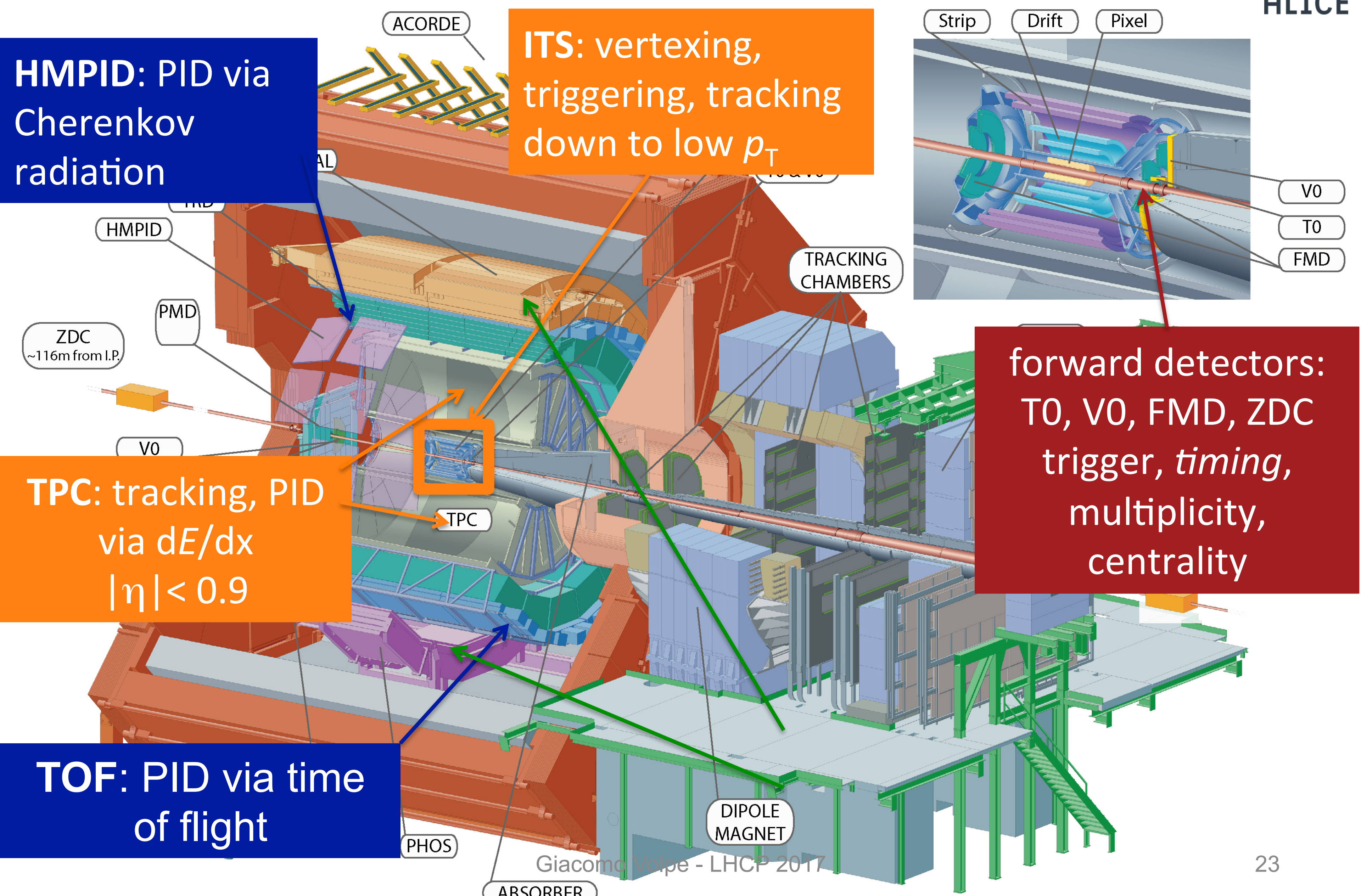
  - Hints for the presence of **collectivity in small systems**, whose origin and phenomenology is under investigation.

  - **Enhancement of strangeness** production observed from low to high-multiplicity pp events at $\sqrt{s}$ = 7 TeV , poorly described by commonly used MC generators.

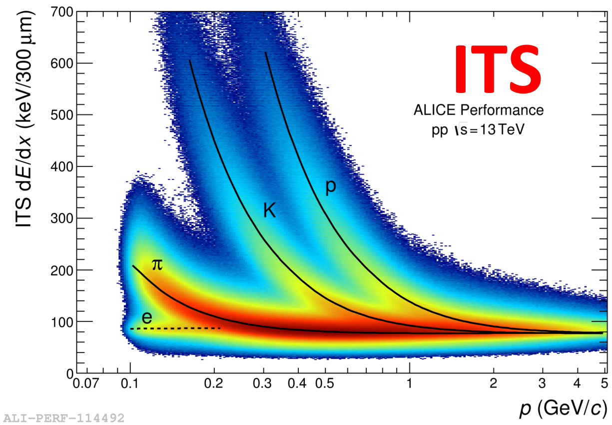
  - Measurements at different energies as a function of multiplicity seem to indicate that the **hadrochemistry** is driven by **event activity** regardless of collision energy.

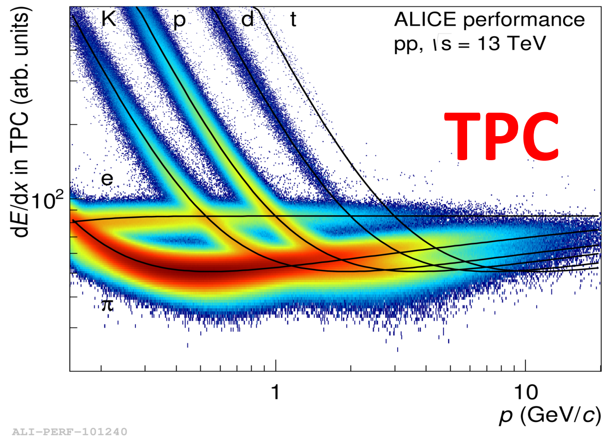
Backup

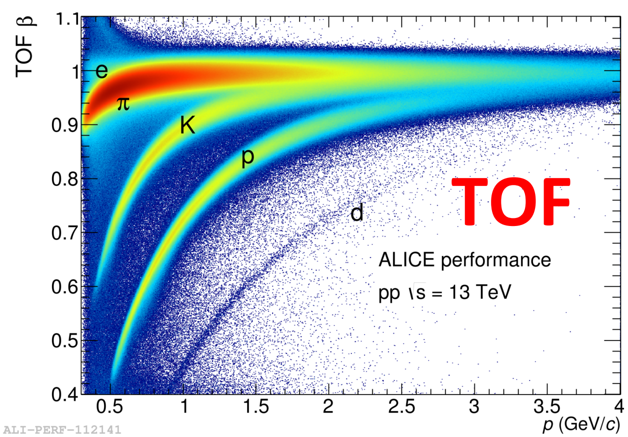
ALICE apparatus

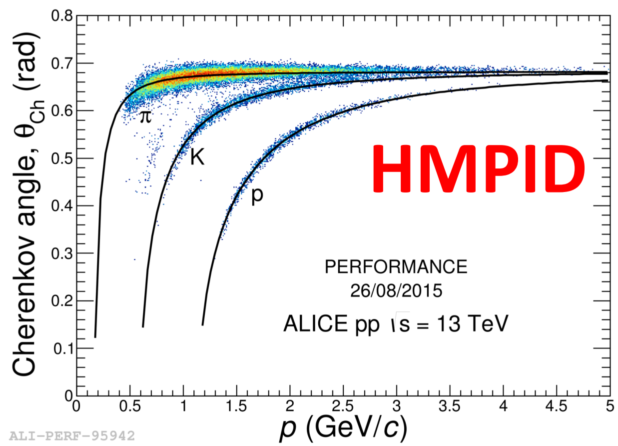


Charged hadrons PID in ALICE



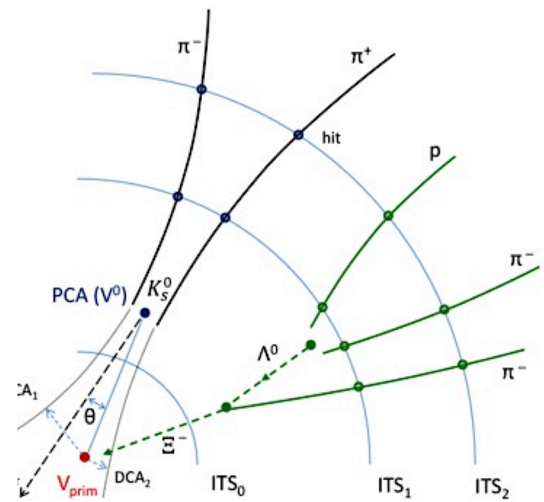


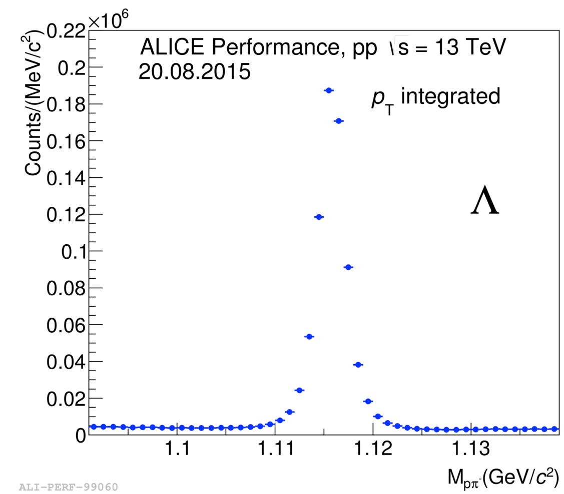




Topological PID

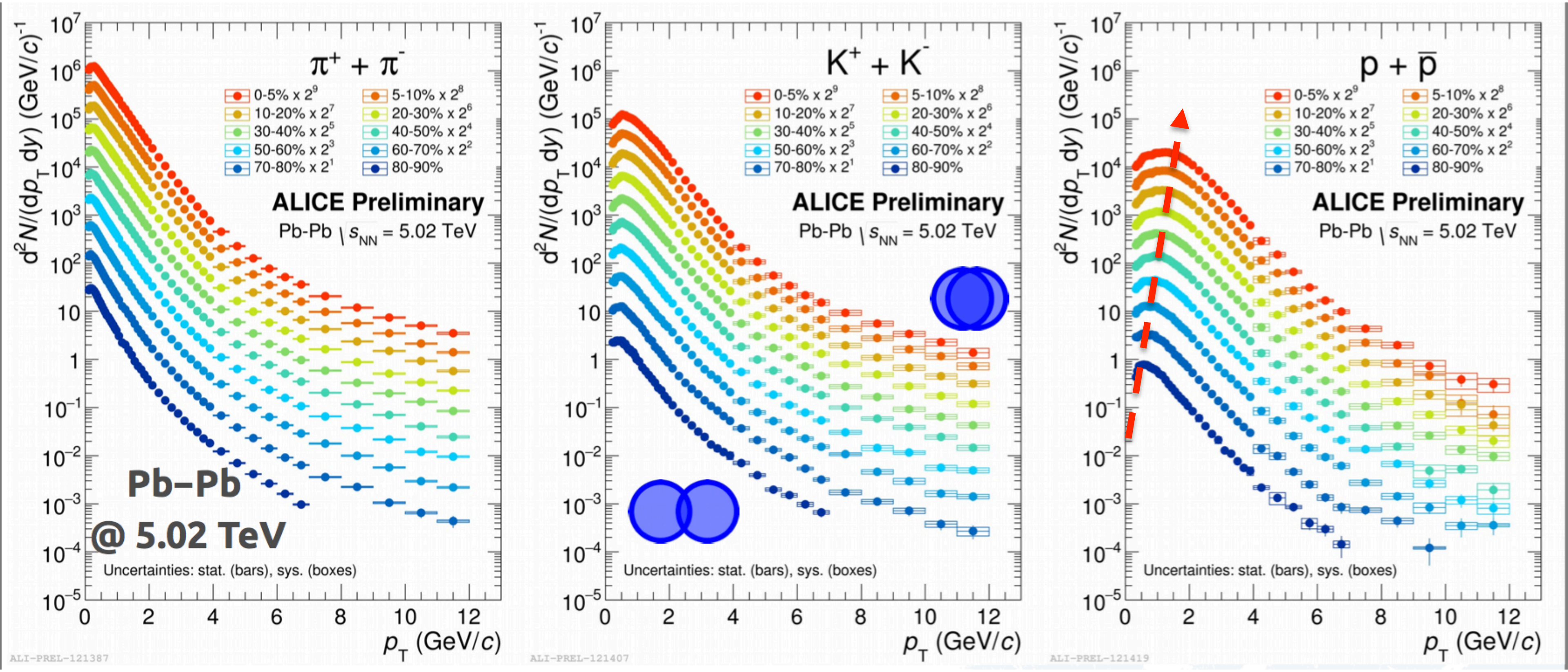
secondary vertex reconstruction + invariant mass analysis





Identification of light flavour hadrons and light (anti-)nuclei via all known PID techniques in **0.1 GeV/c < p_T < 30 GeV/c**

p_T spectra of charged partclesin Pb-Pb



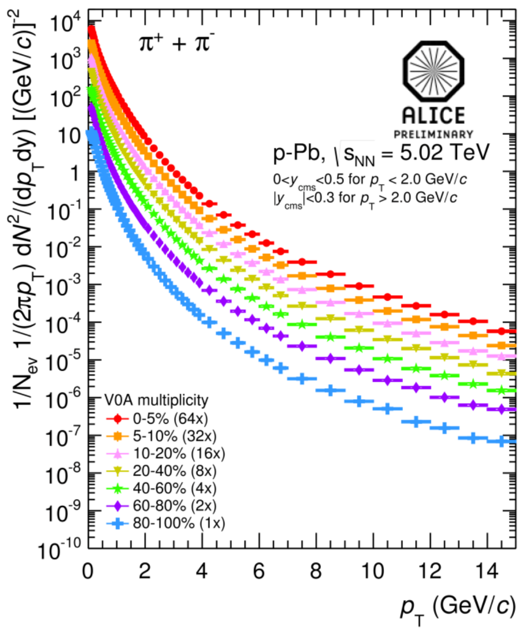
- spectra get flatter for more central collisions
- stronger effect for heavier particles
- consistent with a collective hydrodynamic expansion
  - Heavier particles have larger momenta than lighter ones with the same velocity

Collectivity in small system: p_T spectra

- Hardening with multiplicity and particle mass at low p_T
- Indication for collective effects, reminiscent of observed effects in Pb-Pb → attributed to radial flow

High mult.

Low mult.



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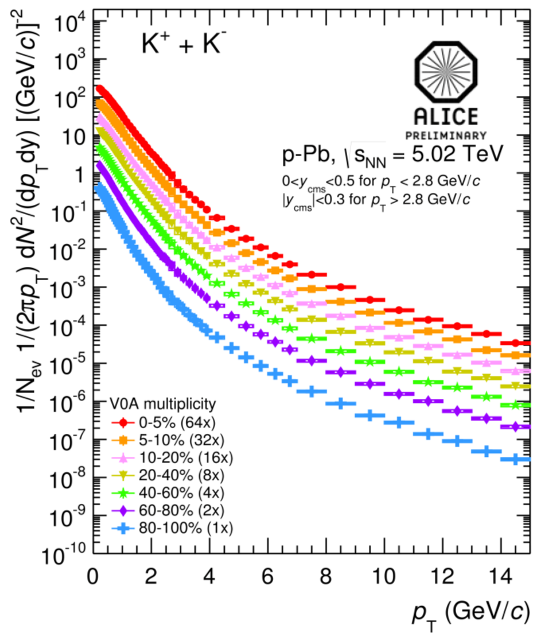

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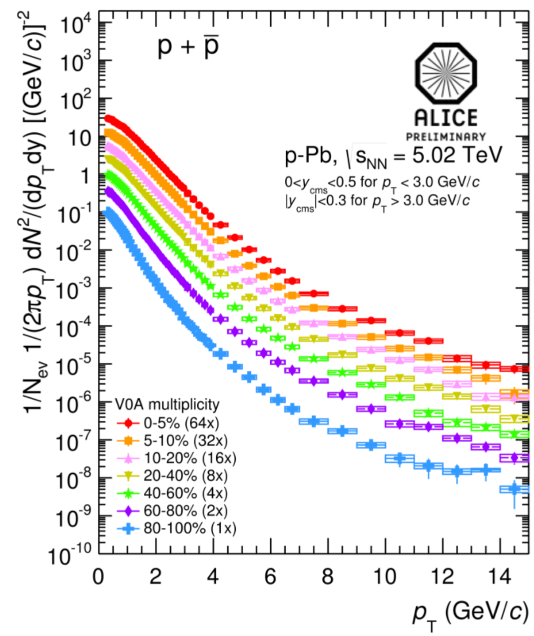

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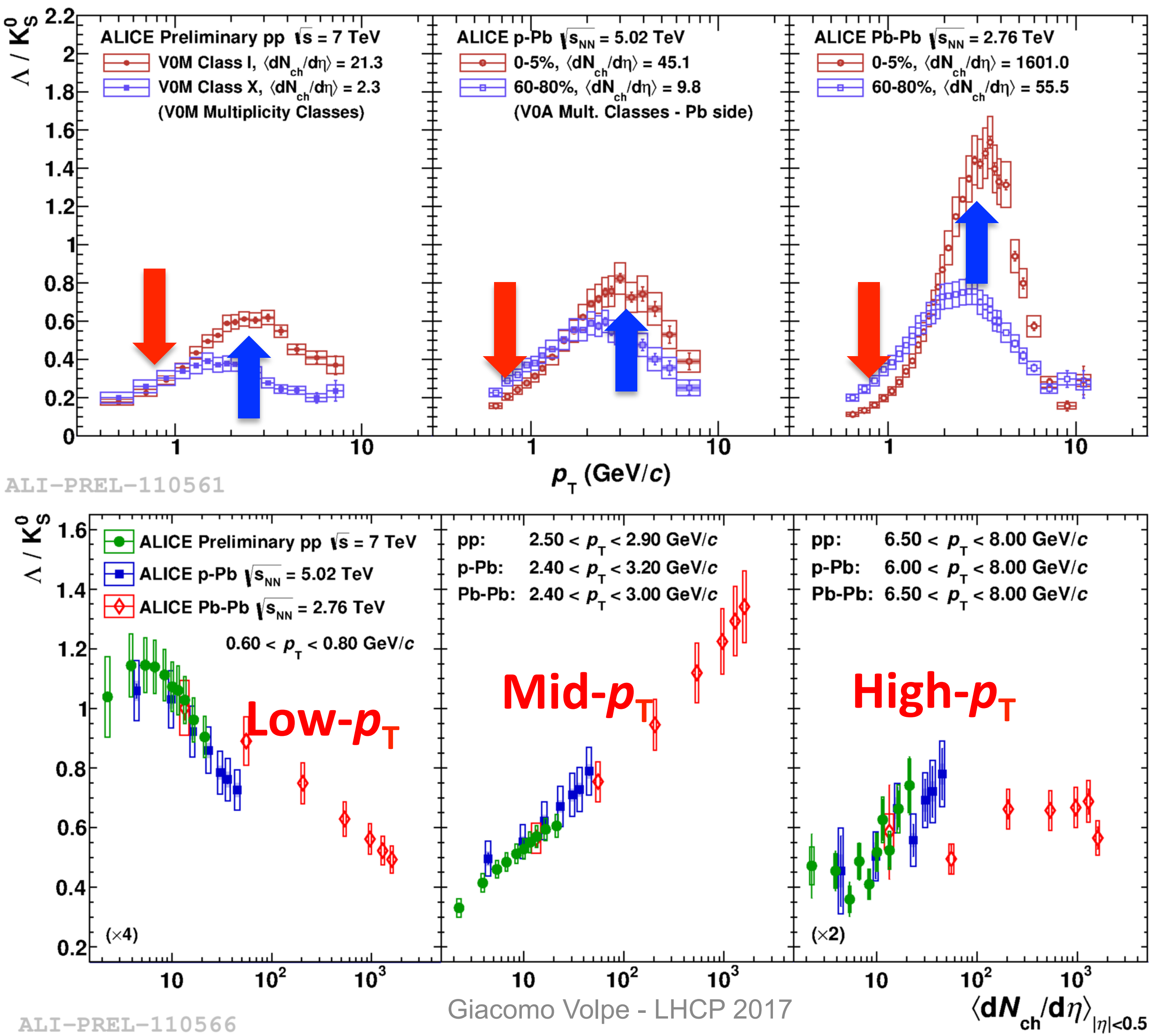
p-Pb @ 5.02 TeV

Collectivity in small system: barion/meson

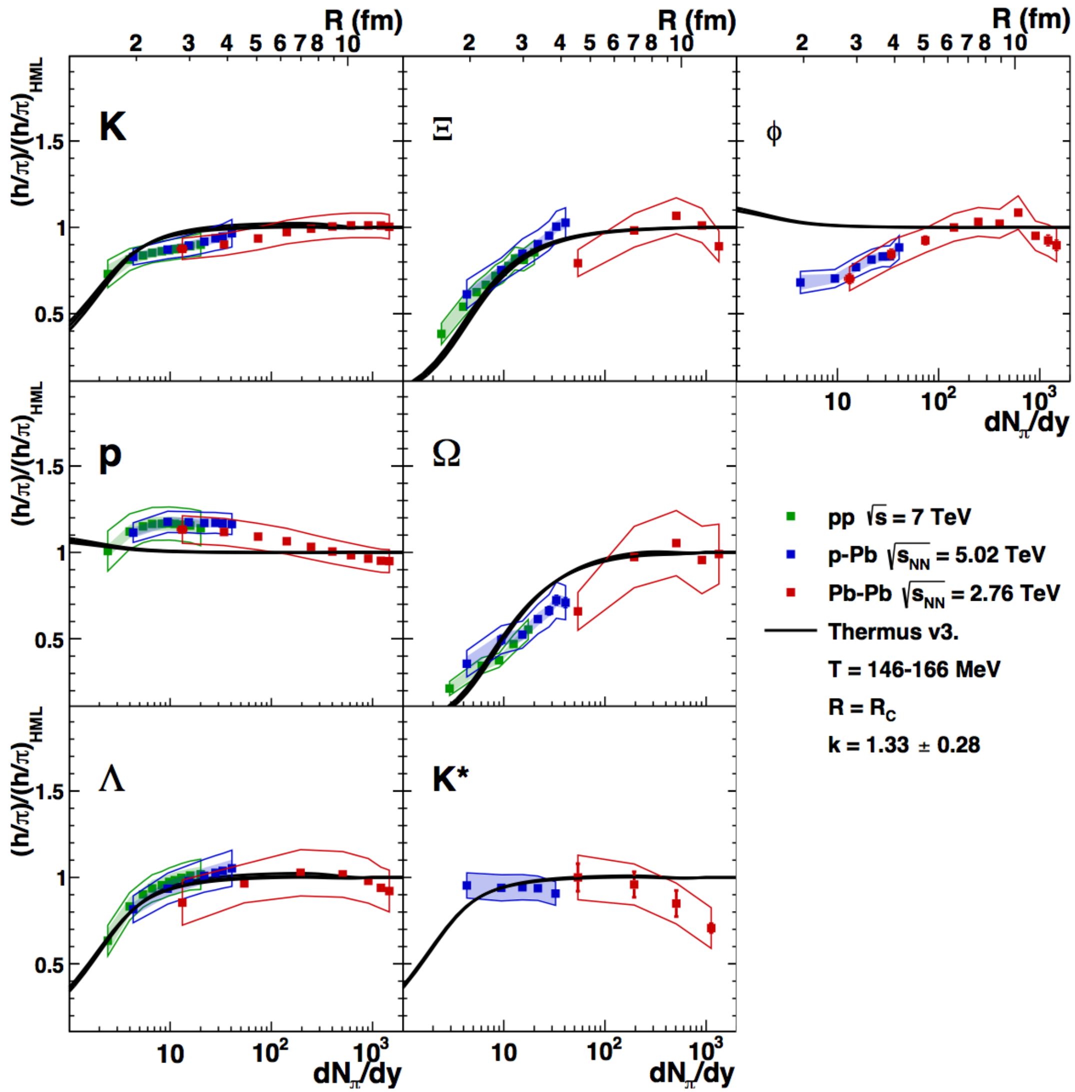


Statistical (Thermal) Hadronization Model

- In equilibrium statistical-thermal models strangeness enhancement is a result of the suppression of strange hadron production in small systems due to the explicit conservation of the strangeness quantum number (strangeness canonical ensemble)

- First comparisons to model calculations based on THERMUS code [THERMUS: S. Wheaton and J. Cleymans, Comput. Phys. Commun. 180 (2009) 84].

- Model describes the data well for most particles, overpredicts for ϕ meson.

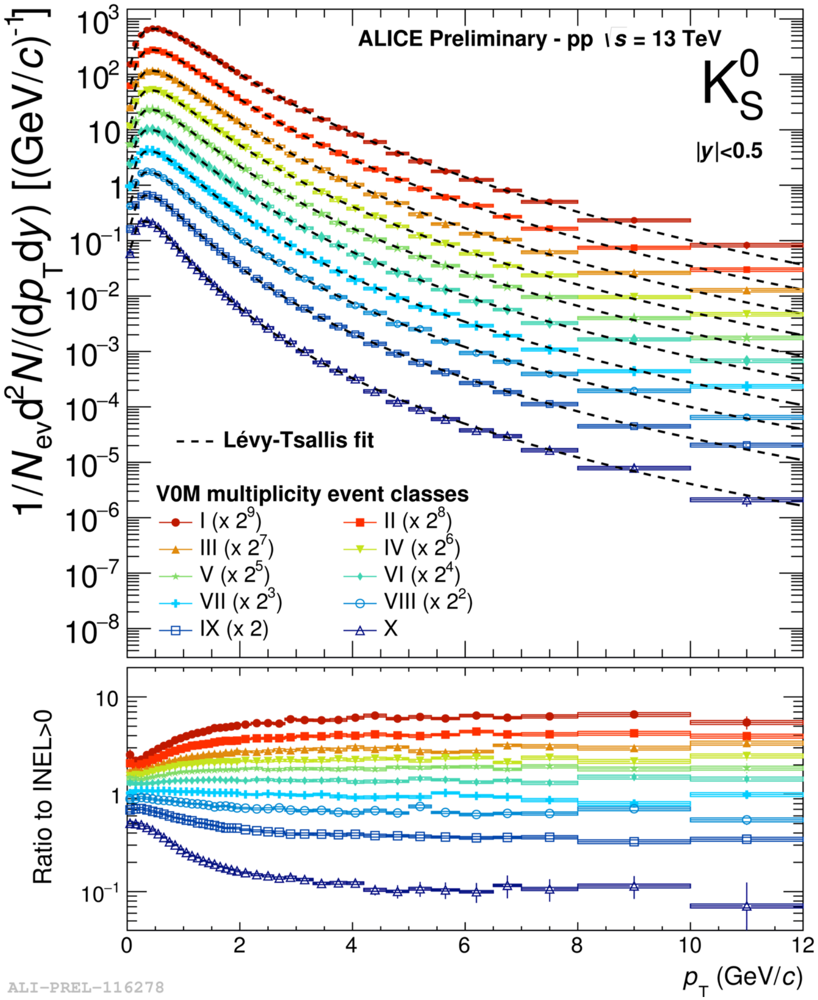


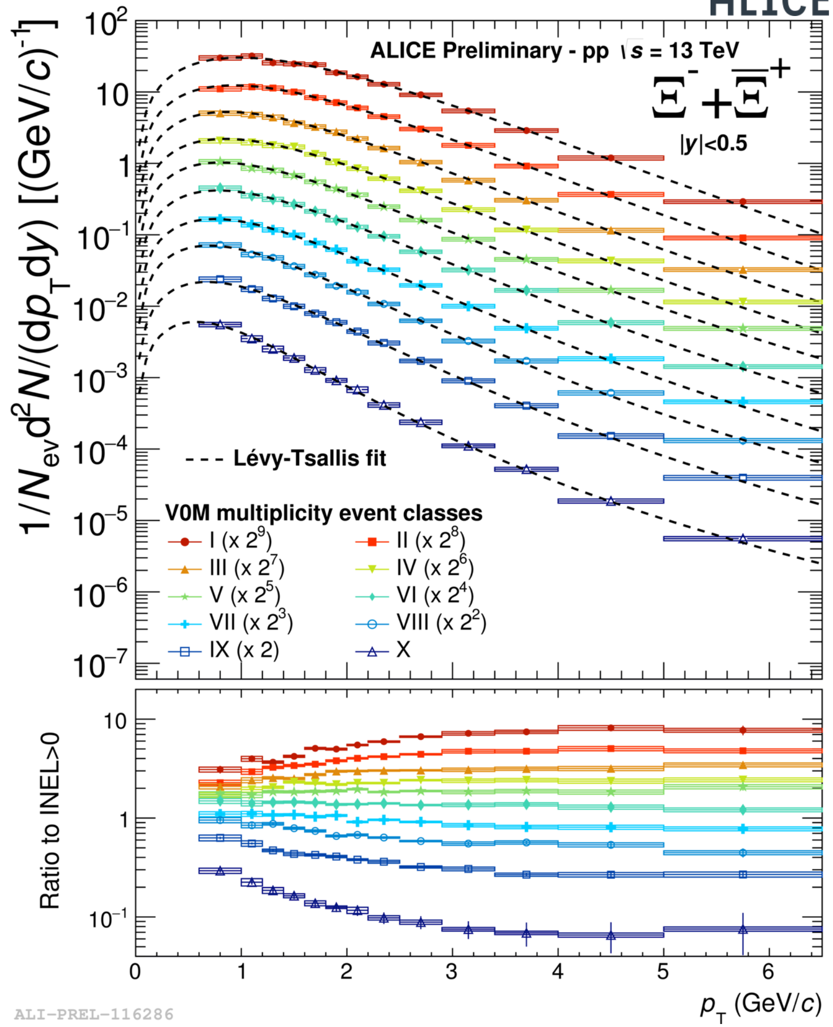
[V. V., A. Kalweit, arXiv:1610.03001]

High p_T strangeness

High mult.

Low mult.





- Spectra become harder at higher multiplicities
- Ratios to integrated (over multiplicity) spectra show a saturation above $p_T \approx 3$ GeV/c

EPOS model

Phys. Rev. C **93** 014911 (2016) “fluid-jet interaction”

Describes pp, p–A ,and A–A collisions with common framework

Hydrodynamical phase + **hadronization processes** at intermediate p_T where the interaction between bulk matter and jets is considered

Baryon-meson effect where a quenched jet hadronizes with flowing medium quarks

“Considering transverse fluid velocities up to 0.7*c*, and thermal parton momentum distributions, one may get a “push” of a couple of GeV/c to be added to the transverse momentum of the string segment. This will be a crucial effect for intermediate p_T jet hadrons.”