Energy and multiplicity dependence of strange and non-strange particle production in pp collisions at the LHC with ALICE

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on behalf of the ALICE Collaboration

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Strangeness in Quark Matter 2017

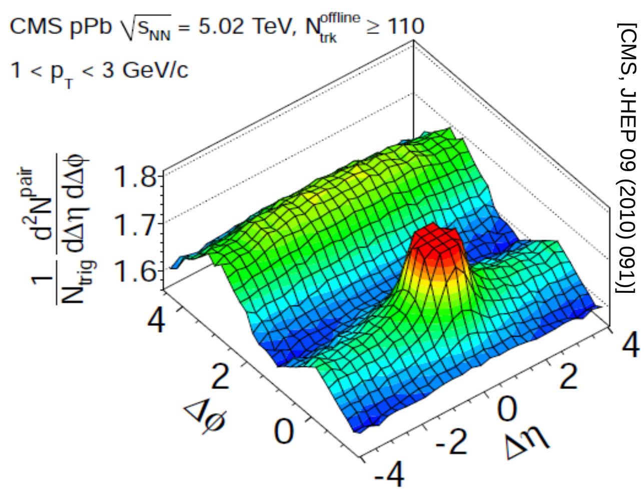
Utrecht, 10-15 July

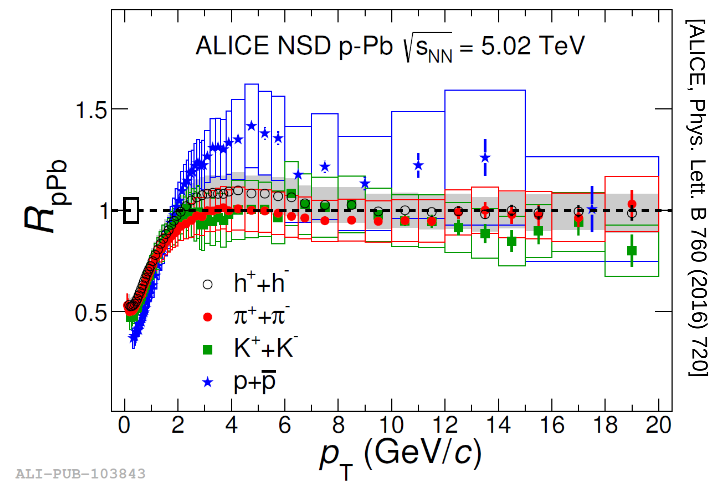
Outline

- Physics motivations
- The ALICE detector at the LHC
- Results:
  - p_T spectra shapes
  - Hadrochemistry
  - Evolution of particle production with $\sqrt{s}$ and multiplicity
  - Outlook
- Conclusions

Physics motivations

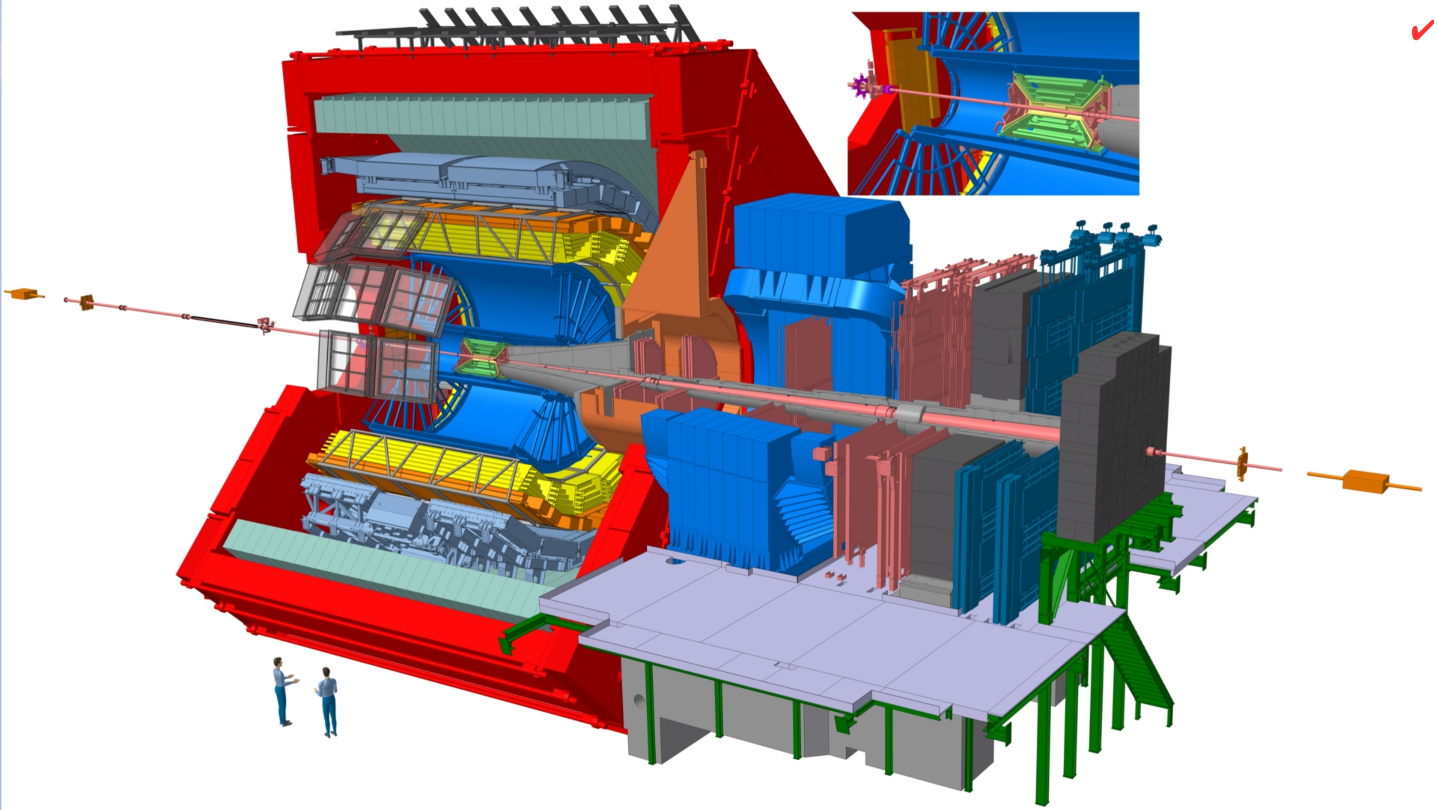
- Main goal of the ALICE experiment: study nucleus-nucleus (AA) collisions
  - Deconfined phase of matter, hydrodynamical evolution, thermal / chemical equilibrium, energy loss
- pA and pp collisions: usually play the role of control experiments
- **Intriguing observation**: multiplicity dependent studies in small colliding systems show remarkable commonalities with AA
  - Strong hints of collectivity; no sign of energy loss





- Is there *thermal* and / or *chemical* equilibrium ? ⟶ **p_T spectra shapes, hadrochemistry**
- Is the *event multiplicity* the steering variable ? ⟶ **Comparison of different √s / systems at similar multiplicities**
- what are the *microscopic processes* at play ? [are these related to AA ?] ⟶ **Comparison with models**

The ALICE detector



- Multiplicity dependent light flavour production measurements in pp collisions ($\sqrt{s}$ = 5, 7, 13 TeV, mid-rapidity):
  - Inclusive charged particles
  - π, K, p
  - $K^0_S \rightarrow \pi\pi$
  - $\Lambda \rightarrow p\pi$
  - $\Xi \rightarrow \Lambda\pi$
  - $\Omega \rightarrow \Lambda K$
  - Resonances: $K^{*0} \rightarrow K\pi$, $\phi \rightarrow KK$
  - $K^0_S, \Lambda, \Xi, \Omega$ → **extended to HM multiplicity triggered data !**

- Efficient low momentum tracking (down to p_T ~ 100 MeV/c)
- Excellent vertexing performance
- Extensive PID capabilities

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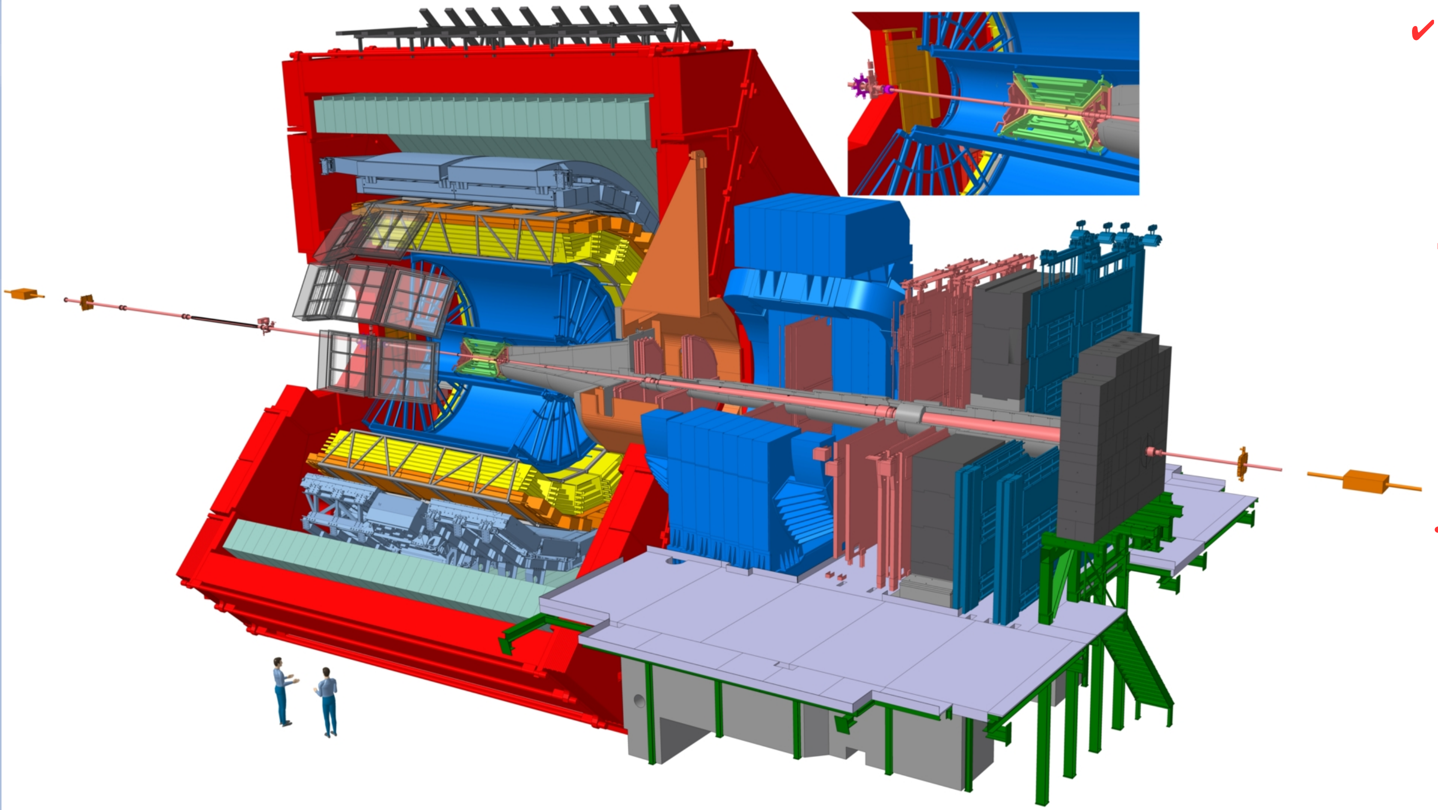

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N. Agrawal, parallel session (Friday 14/7) ←
- Resonances: $K^{*0} \rightarrow K\pi$, $\phi \rightarrow KK$

R. De Souza, Poster session ←
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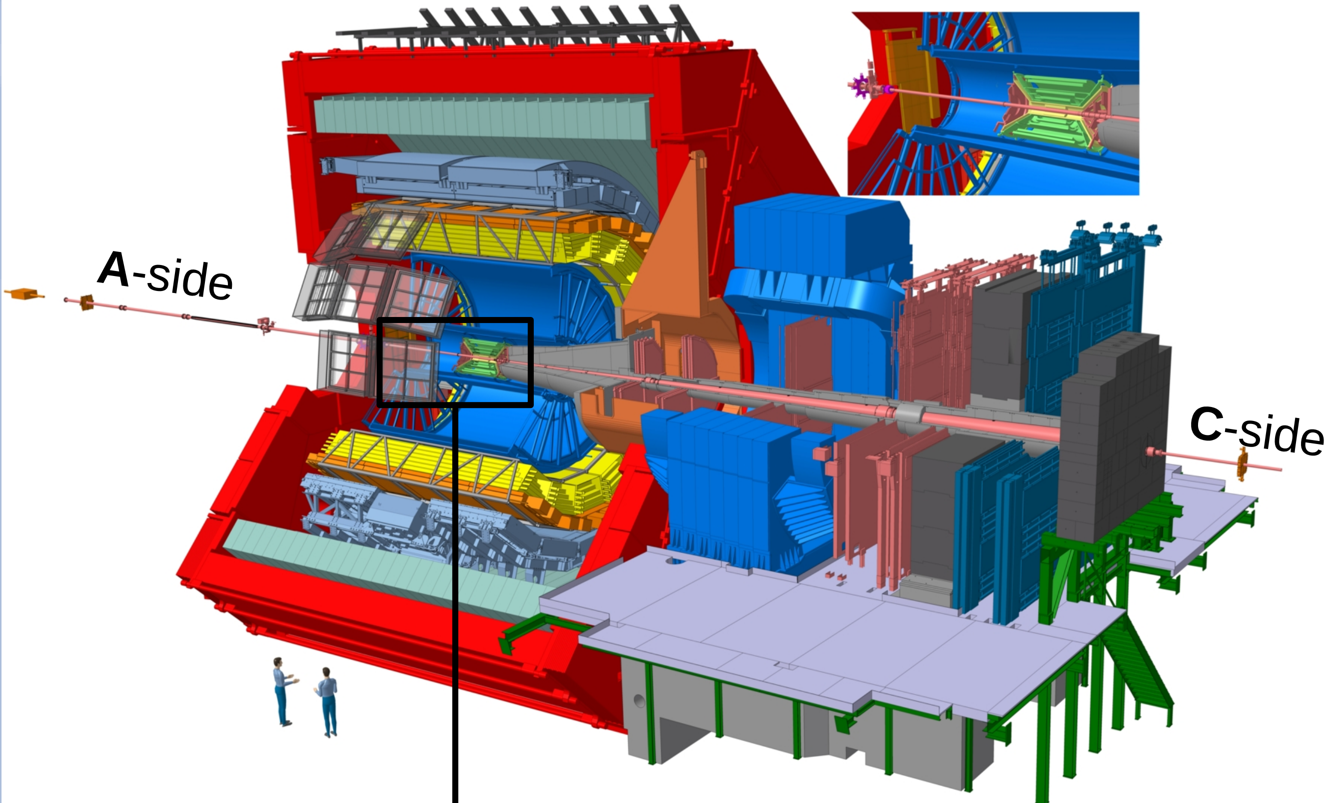
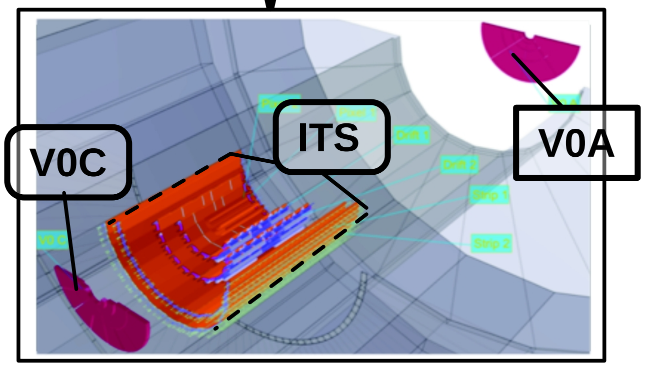
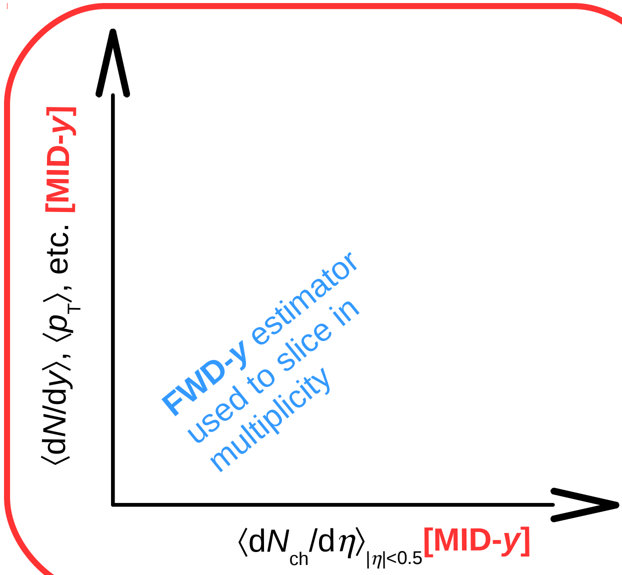






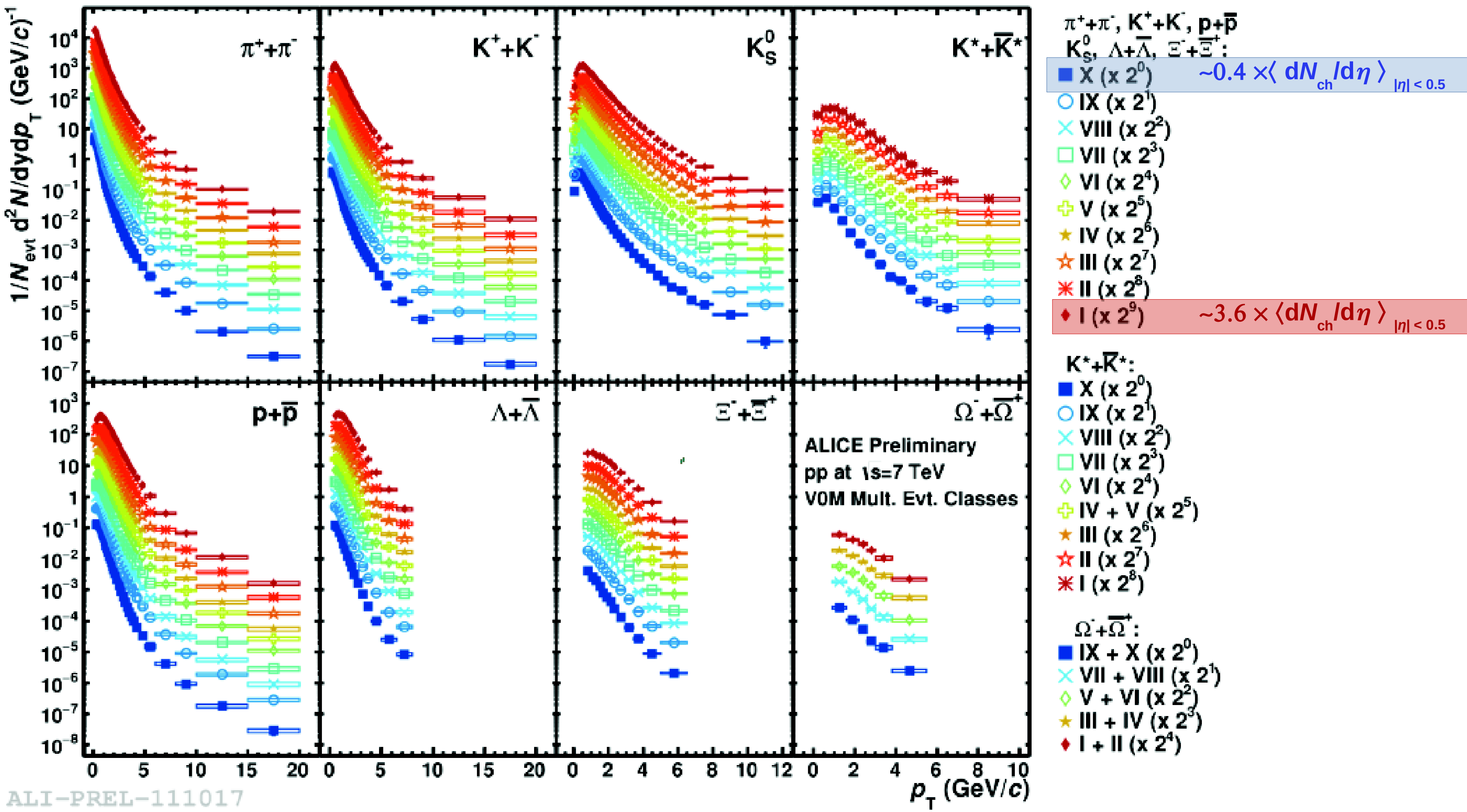
V0 ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$):

- ✔ Forward arrays of scintillators placed on either side of the interaction region
- ✔ trigger, beam gas rejection, **multiplicity estimation**

- ✔ Event selection performed via percentiles of the V0M amplitude distribution (V0A+V0C)
- ✔ $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$ represents the average number of primary charged tracks in $|\eta| < 0.5$

Transverse momentum spectra

pp, √s = 7 TeV



- Spectra become **harder** for increasing multiplicity
  - **flattening** of the spectra at low p_T, more pronounced for heavier particles
- In Pb-Pb interpreted in terms of collective expansion of a thermalized system (radial flow) which may require a fireball in a local thermodynamical (kinetic) equilibrium

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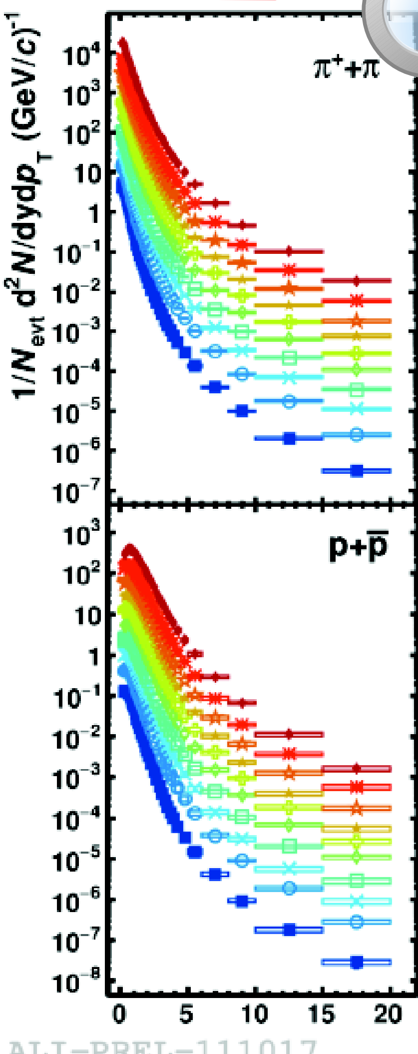

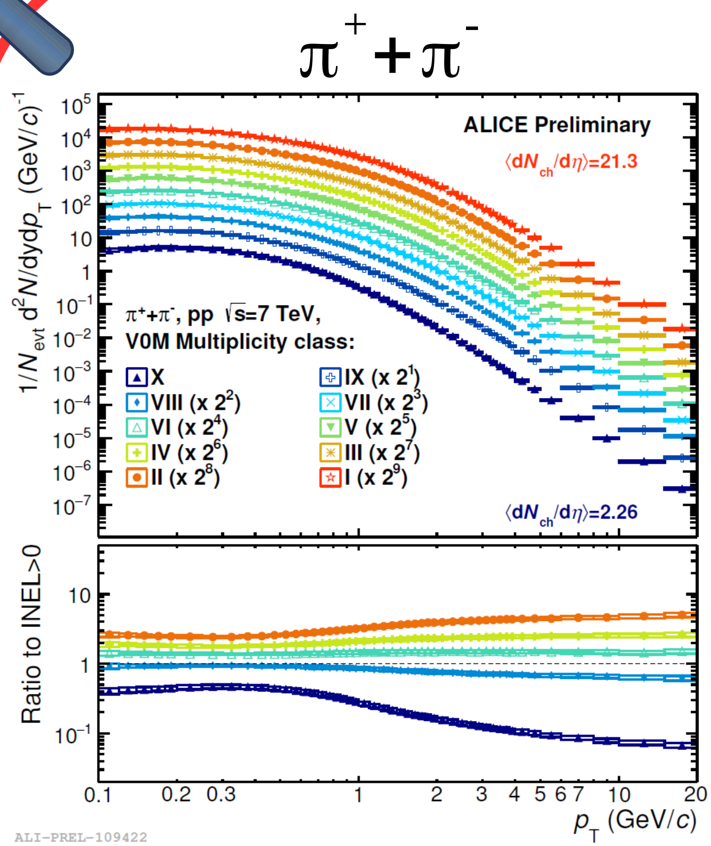

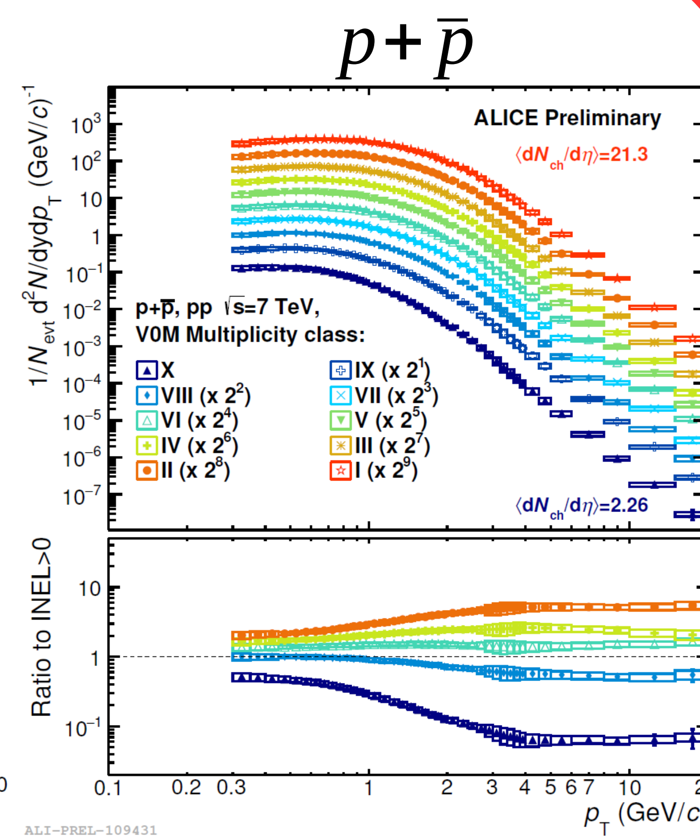

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Baryon-to-meson ratio

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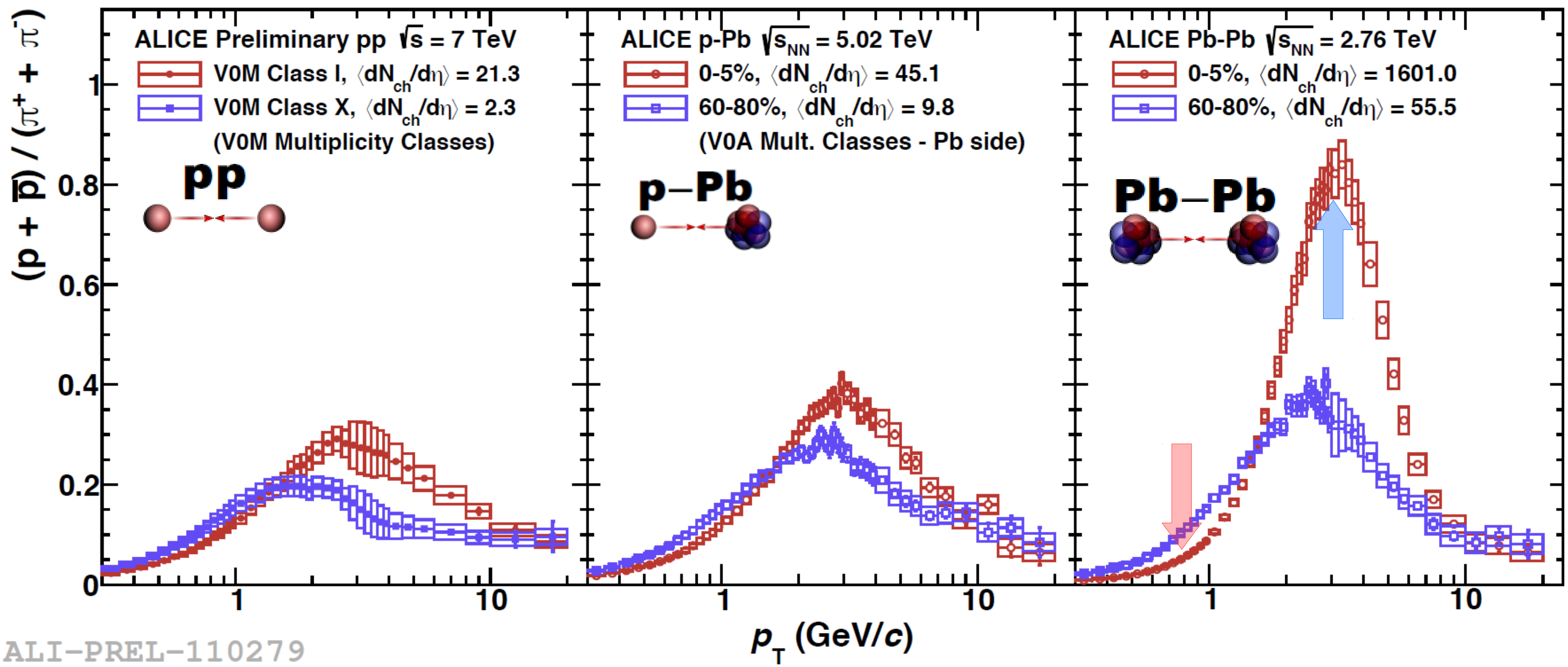
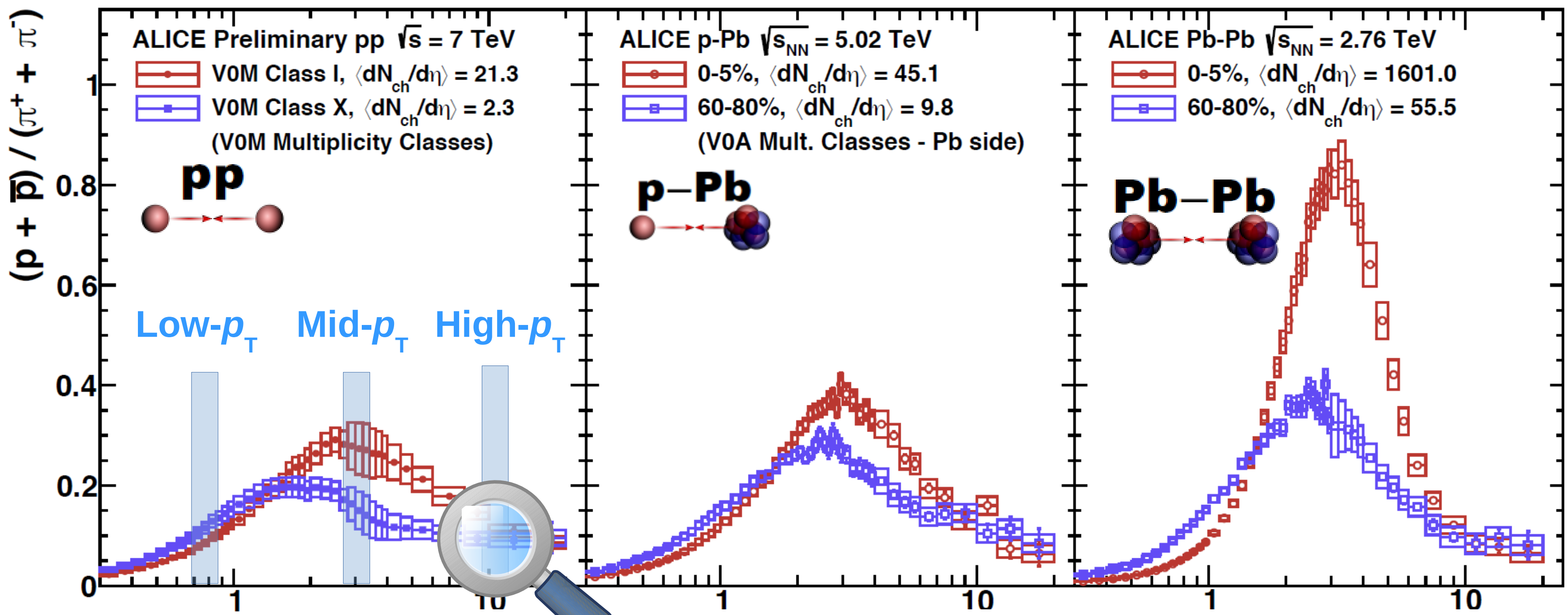
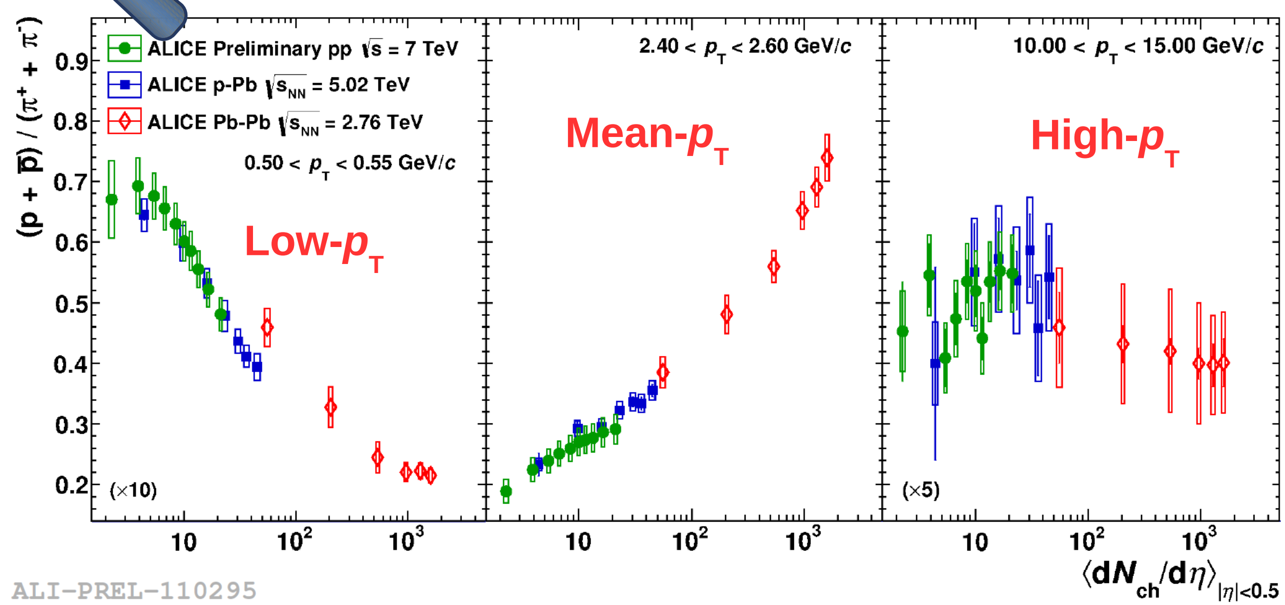


- Dependence of the bulk particle production on the event multiplicity in pp qualitatively similar to the one observed in p-Pb and Pb-Pb (different multiplicities!)
  - **Depletion** at low p_T / **enhancement** at intermediate p_T
- In Pb-Pb discussed in terms of collective flow and / or quark recombination (depending on p_T and centrality)

Baryon-to-meson ratio

pp, $\sqrt{s}$ = 7 TeV



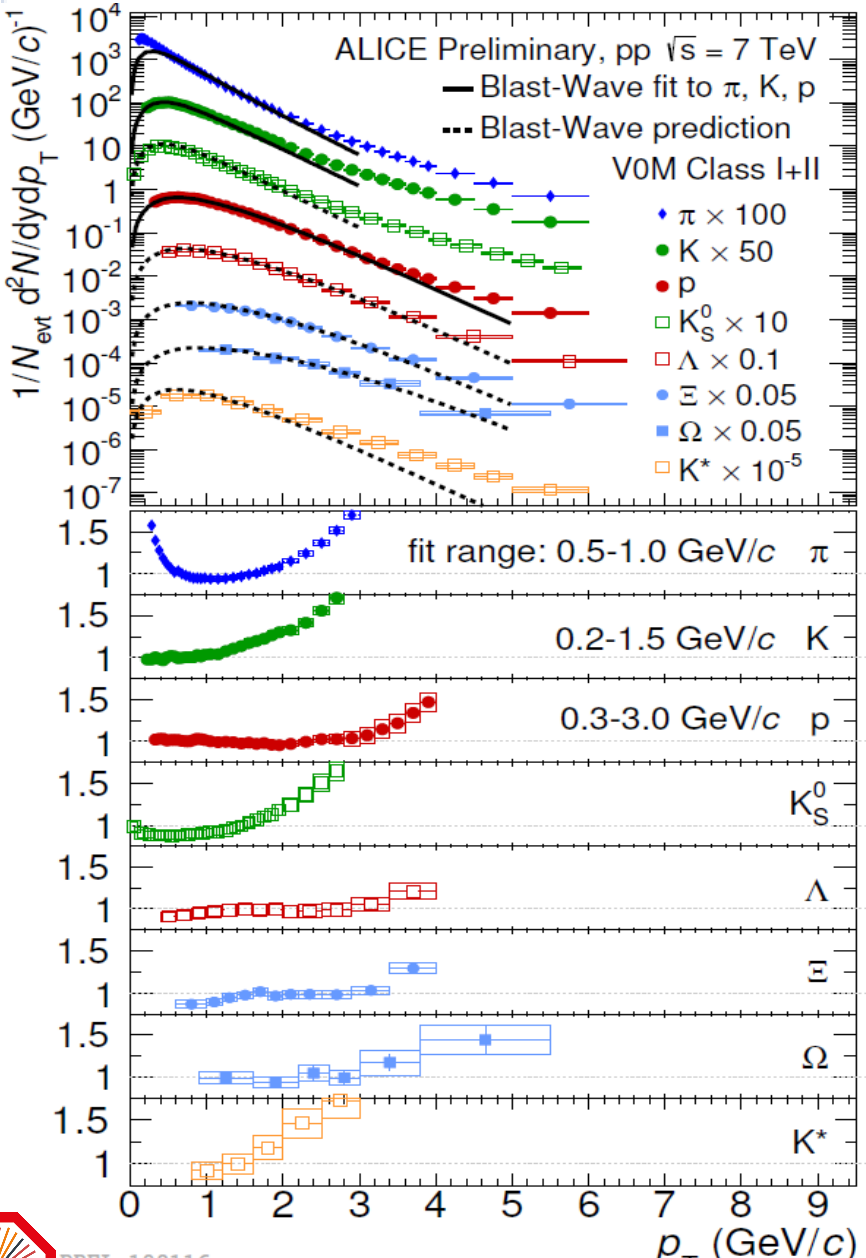


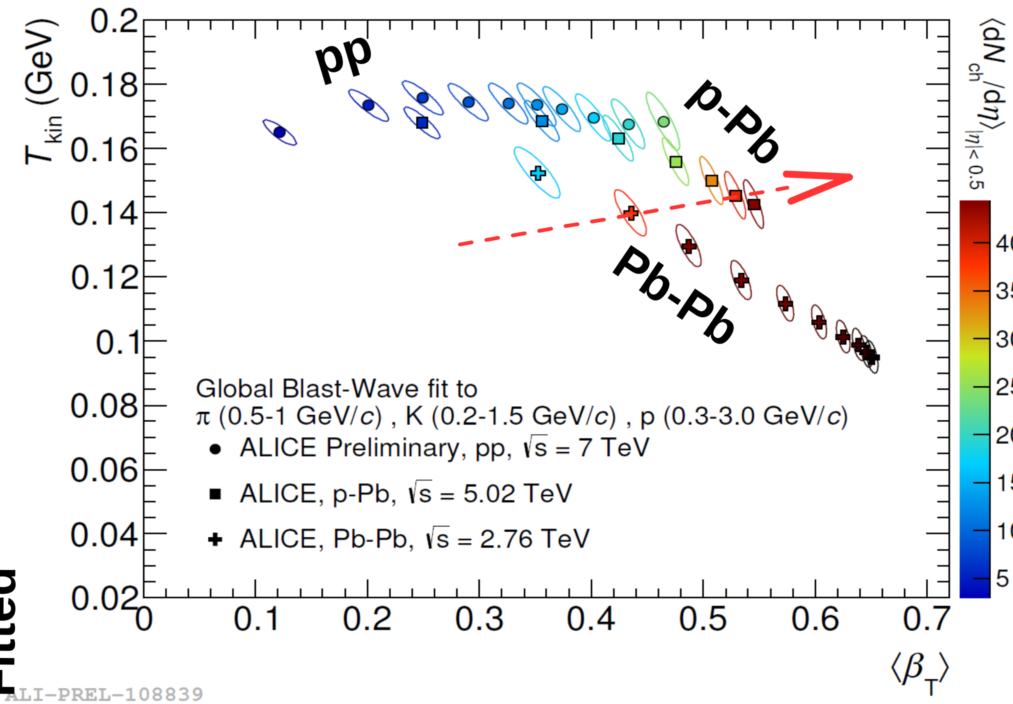
- ✔ Remarkable smooth trend observed across several colliding systems!

  → Points toward one common driving mechanism in all systems

Blast Wave model in pp

pp, √s = 7 TeV





- ✔ Hyperon spectra reasonably reproduced in high multiplicity pp collisions
- ✔ Similar evolution in pp and p-Pb
- ✔ At similar multiplicities small systems have similar $\langle T_{Kin}\rangle$ but larger $\langle\beta_T\rangle$ → more **"explosive"** than Pb-Pb

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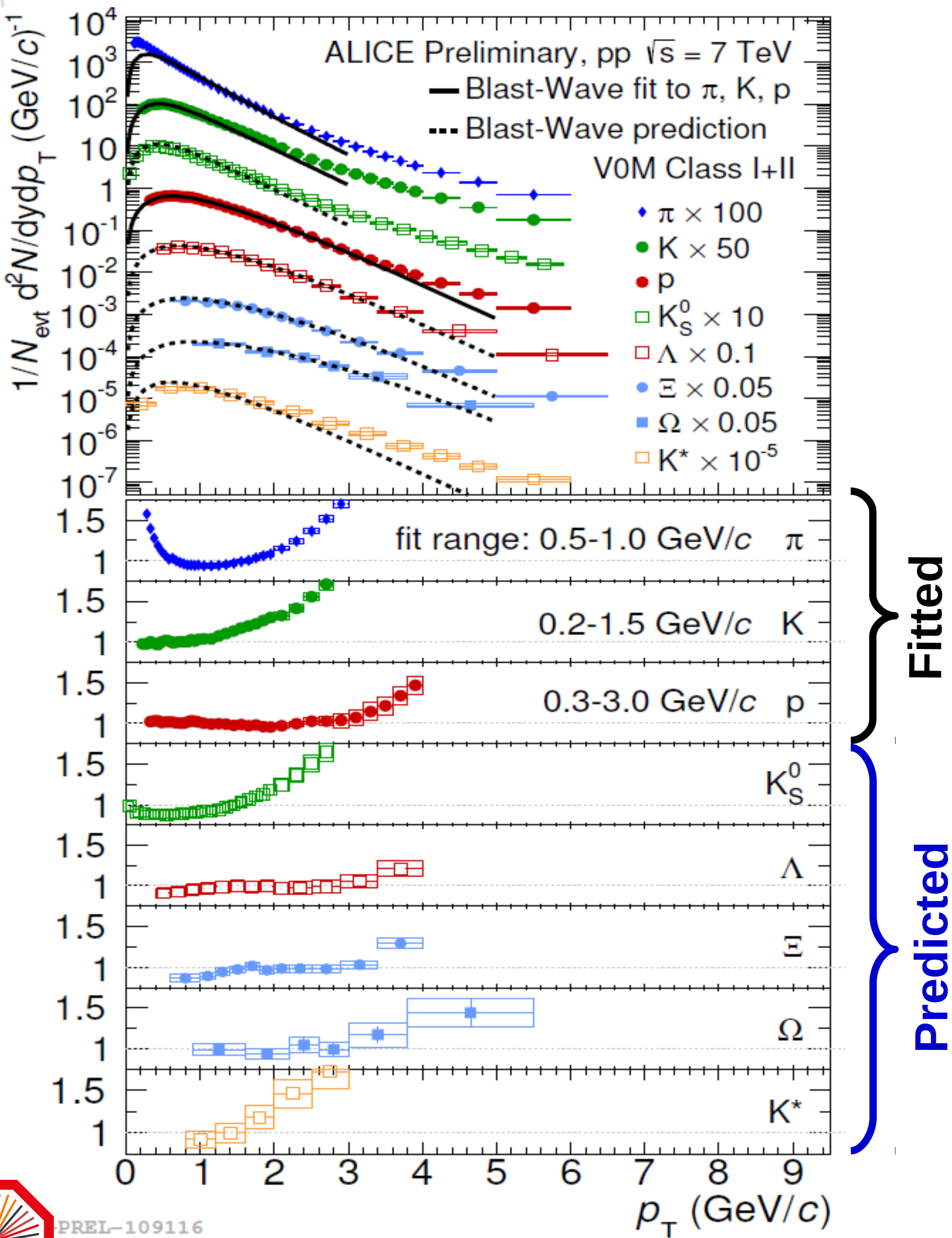

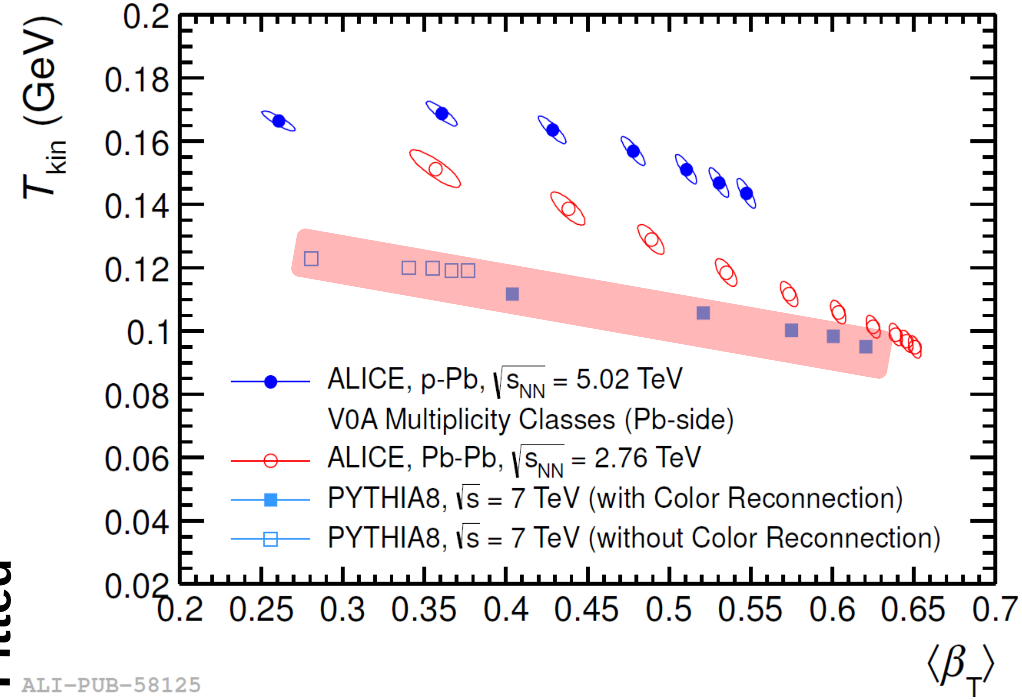

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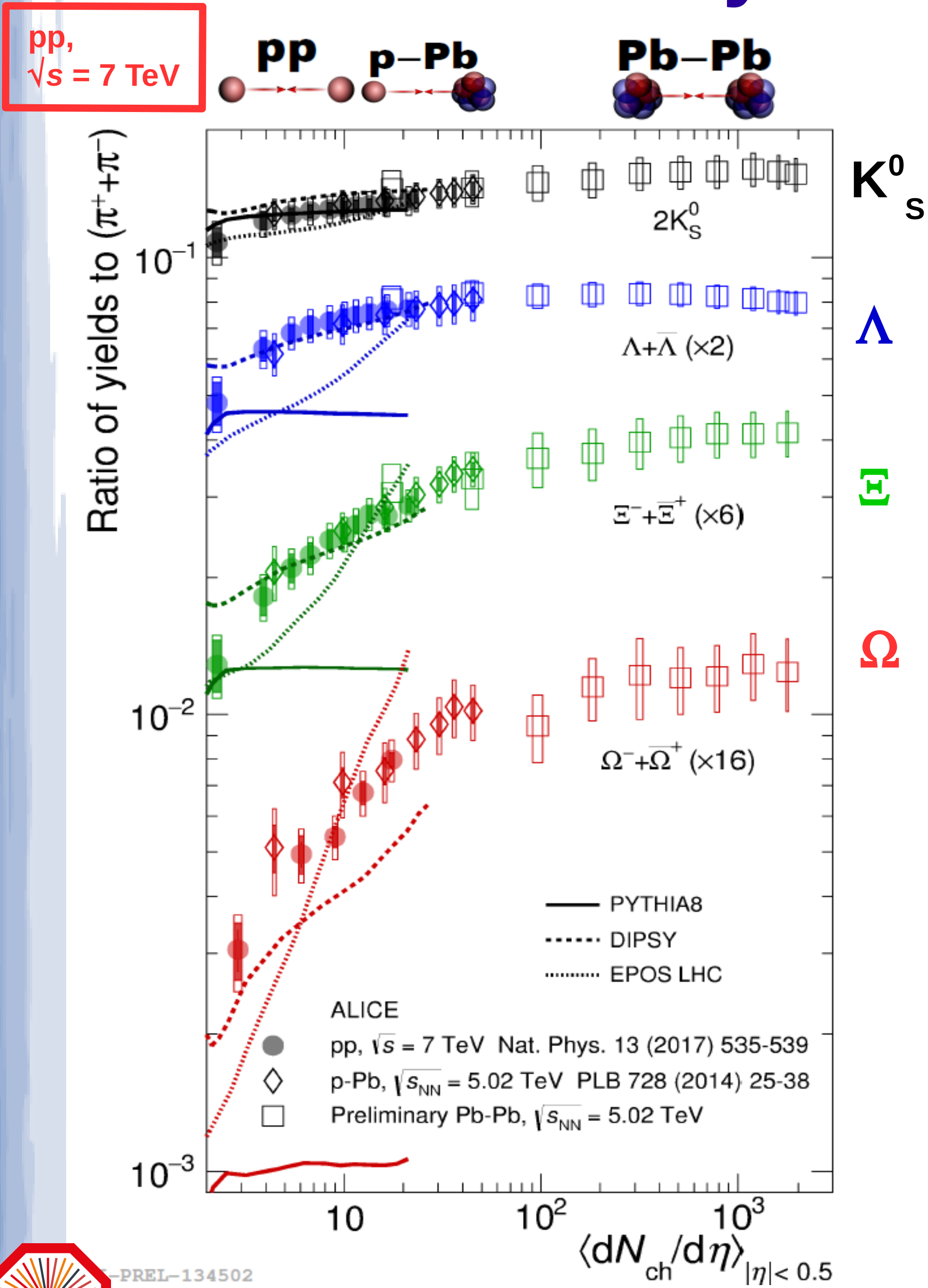
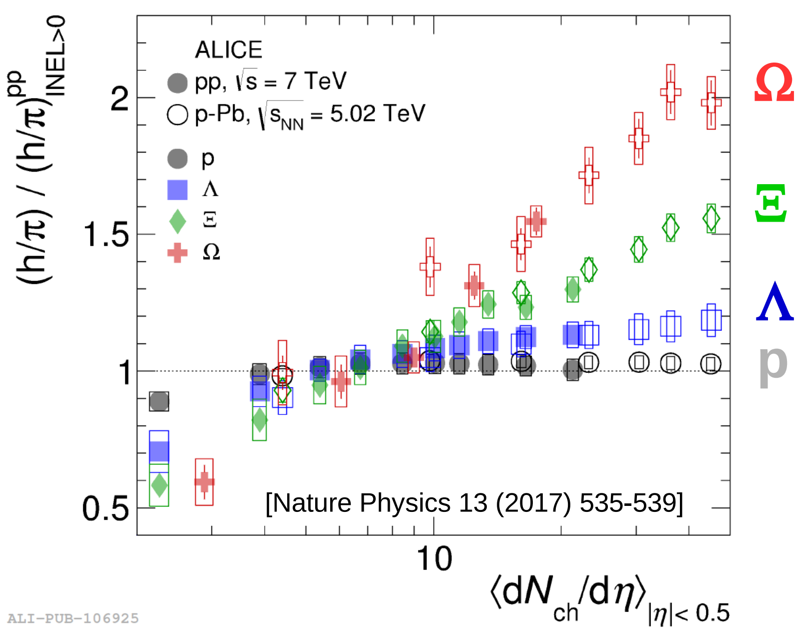
PYTHIA8 with Color Reconnection "mimics" collective-flow !

Hadrochemistry: Strangeness enhancement



- Strangeness enhancement observed in small systems
  - No commonly-used MC model is able to reproduce quantitatively the observed trends
- Double-ratio $(h/\pi)/(h/\pi)^{pp}_{INEL>0}$
  - in pp and p-Pb collisions evolves smoothly with multiplicity density
  - for proton (S=0) is consistent with unity up to highest $\langle dN_{ch}/d\eta \rangle$
  - Increases faster for particles with a larger strangeness content



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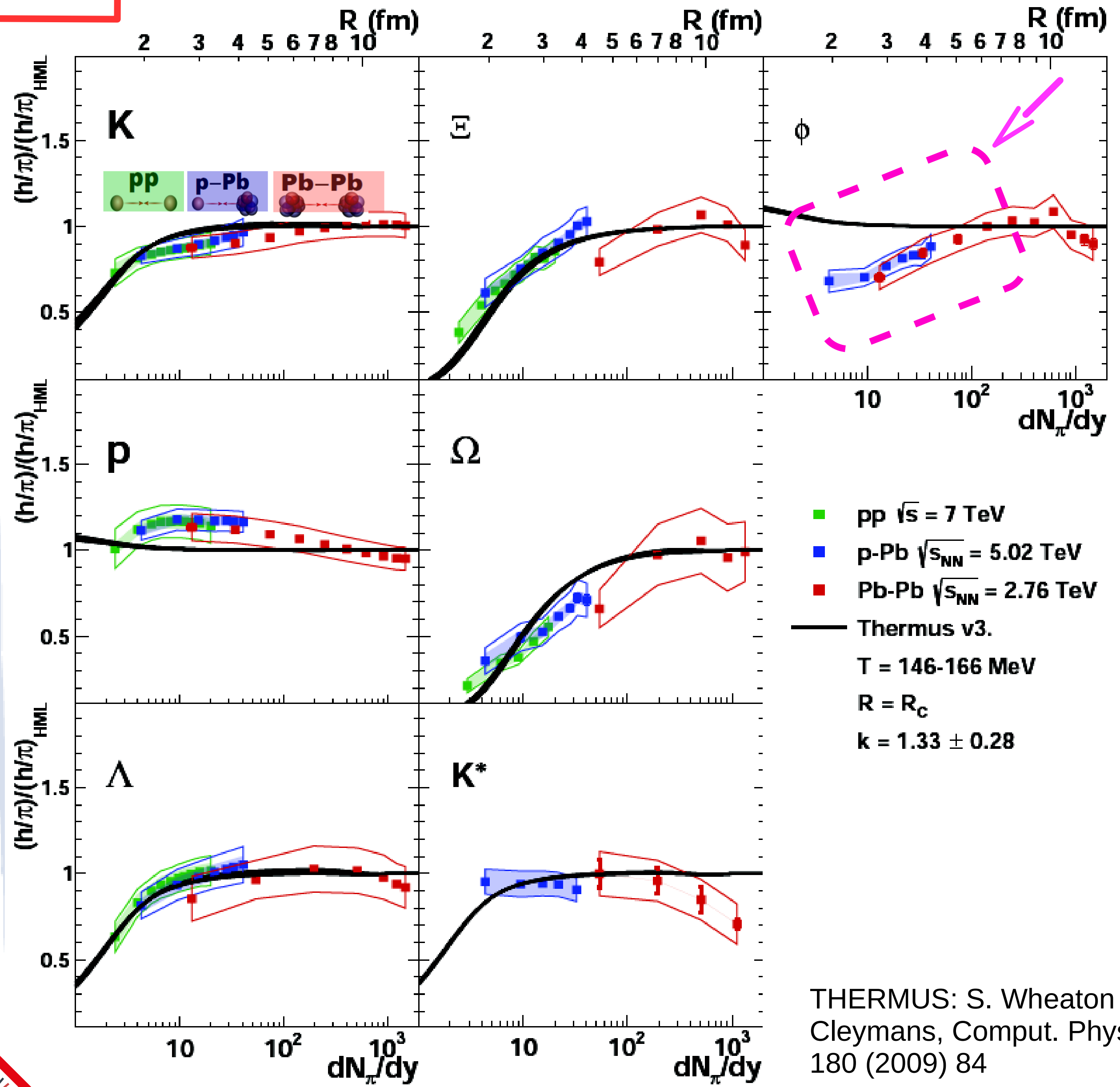
Hadrochemistry: comparison with thermal models

pp,
√s = 7 TeV

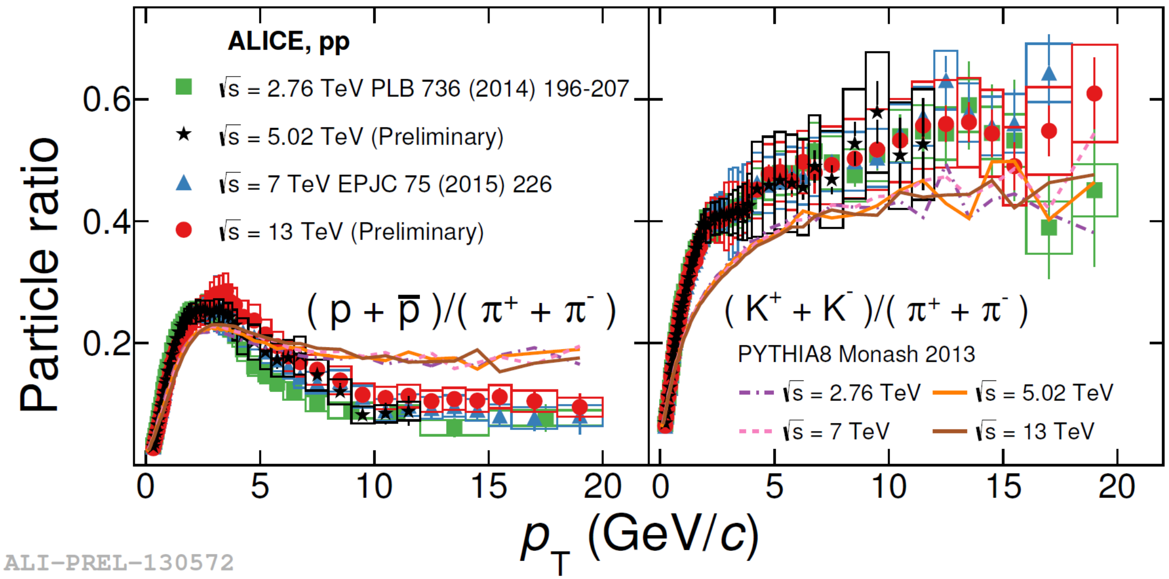
[V. Vislavicius, A. Kalweit, arXiv:1610.03001]



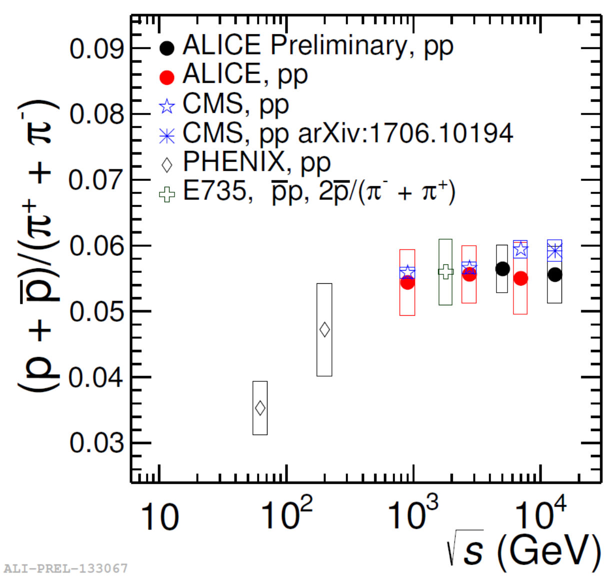
- Statistical (thermal) hadronization model → strange hadron production suppressed in small systems due to the local strangeness conservation
- Multiplicity dependence of particle ratios can be described within ~1-2 standard deviations
- **Different behaviour observed for the ϕ**

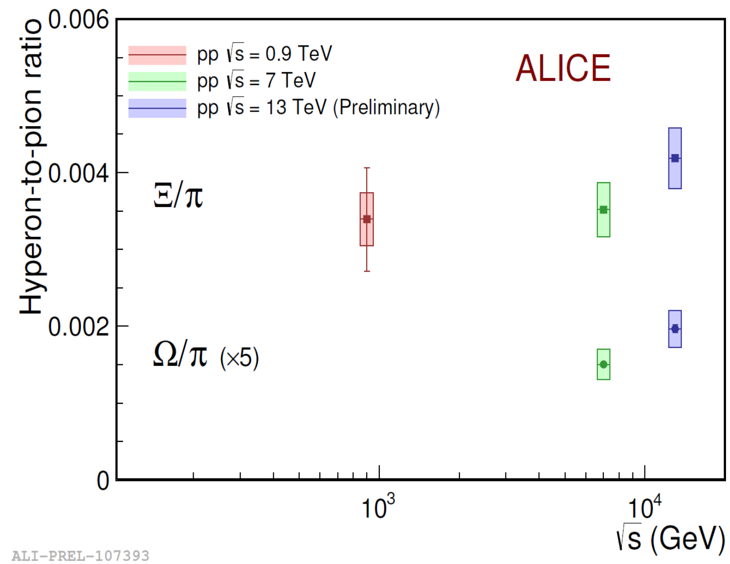
THERMUS: S. Wheaton and J. Cleymans, Comput. Phys. Commun. 180 (2009) 84

Particle ratios: evolution with √s



- ✔ p_T differential spectra:
  - ✔ K/π shows no significant evolution with √s
  - ✔ At higher √s maximum slightly shifted towards higher p_T values for p/π
  - ✔ Pythia8 (Monash) doesn't reproduce satisfactorily the measured ratios



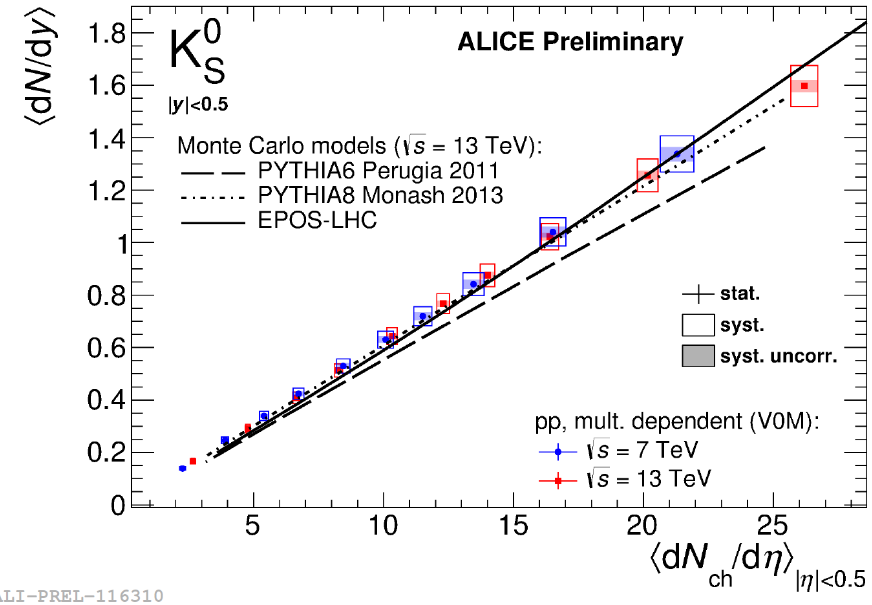


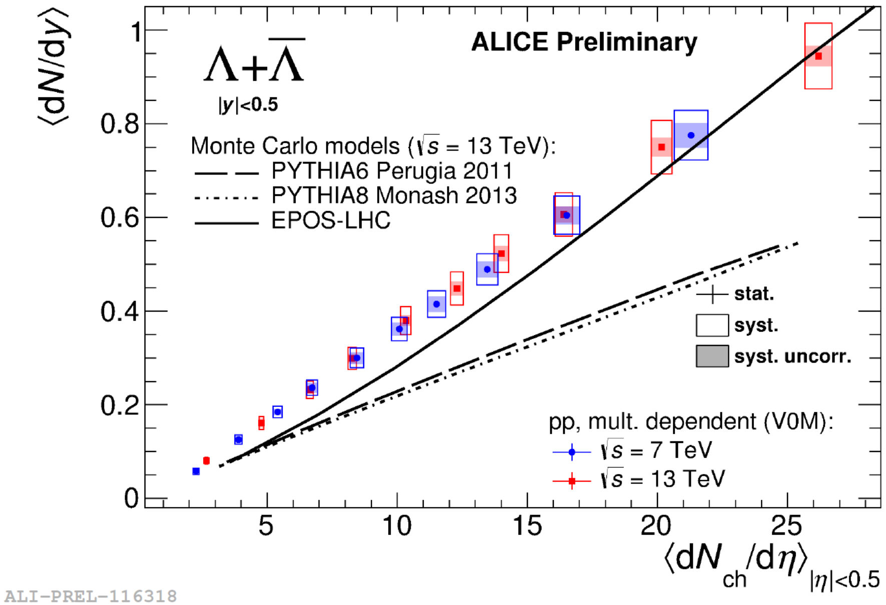
- ✔ p_T integrated ratios:
  - ✔ p/π seems to saturate at LHC energies
  - ✔ Strange / π ratios show a hint of increase with √s

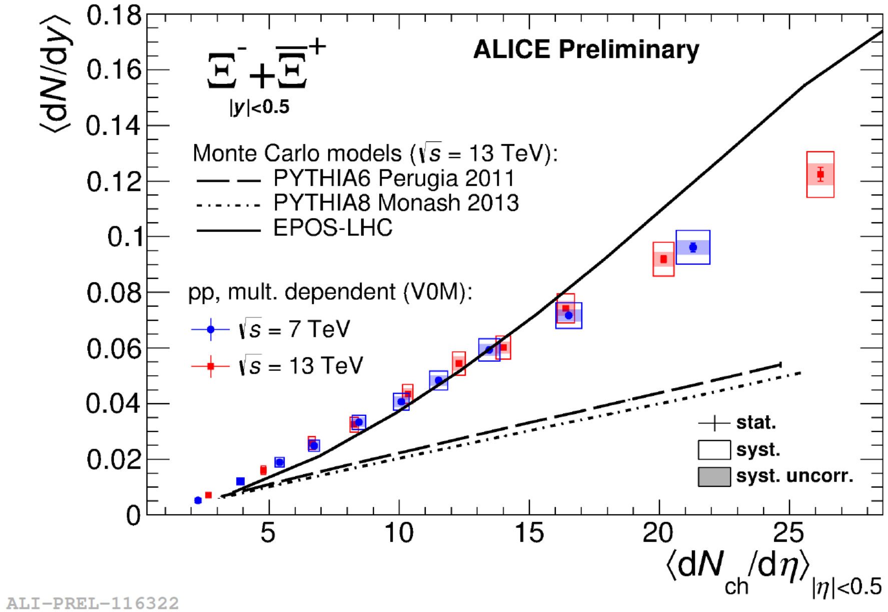
How does it scale with the event multiplicity ?

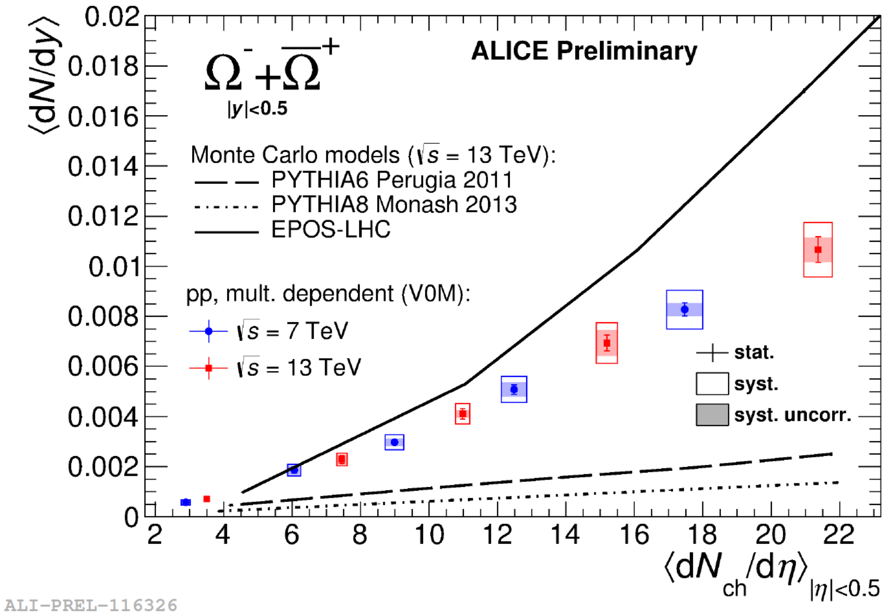
Strangeness: evolution with ⟨dN_{ch}/dη⟩ and $\sqrt{s}$

7 TeV vs 13 TeV









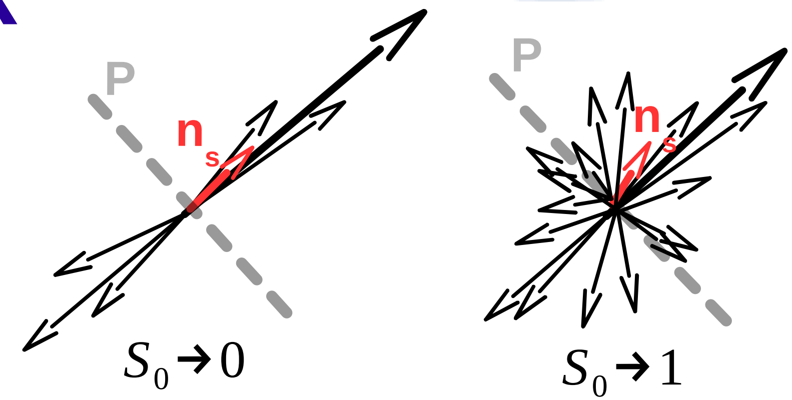
✔ Multiplicity dependence doesn't change with $\sqrt{s}$; no model describes correctly all observed trends

Outlook

✔ **Event shape studies based on Spherocity**

$$S_0 \equiv \frac{\pi^2}{4} \min_{\hat{\mathbf{n}}_\mathbf{s}} \left(\frac{\sum_i |\vec{p}_{\mathrm{T},i} \times \hat{\mathbf{n}}_\mathbf{s}|}{\sum_i p_{\mathrm{T},i}} \right)^2$$

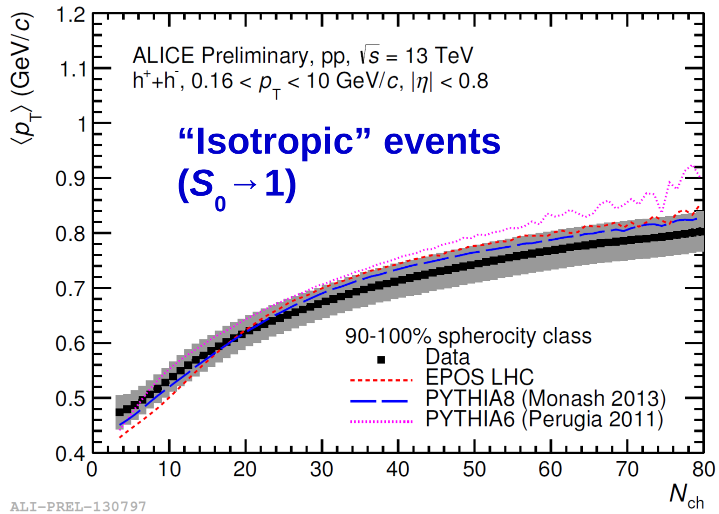
[$p_\mathrm{T} \geq 0.15$ GeV/c, $|\eta| < 0.8$]

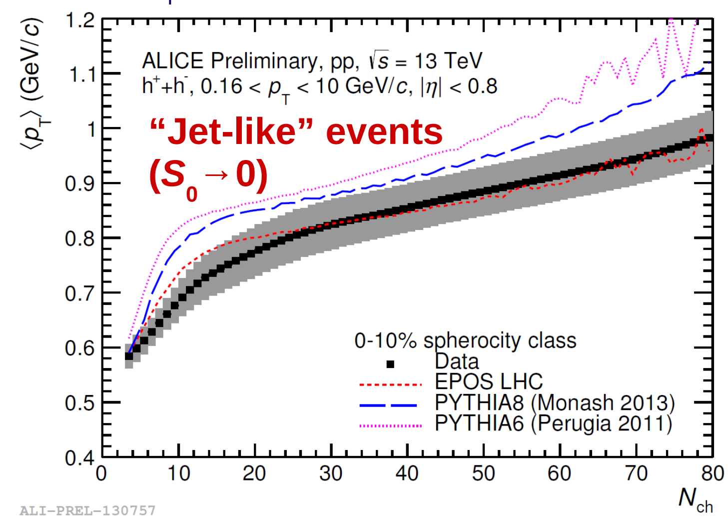


$\boldsymbol{n}_\mathrm{s}$ defined in order to minimize the ratio above (~axis of the main scattering)

✔ **Isotropic events**: good agreement with models (same observed also without spherocity selection)

✔ **Jet-like events**: Pythia models overestimate the $\langle p_\mathrm{T} \rangle$ → input to improve CR





✔ More differential studies including identified particle production vs S_0 will allow to put additional constraints for further tuning and/or new model ingredients !

✔ **High multiplicity triggered data** ⟹ **see R. De Souza poster**

✔ will complement all multiplicity dependent studies reaching $\langle dN_\mathrm{ch}/d\eta \rangle \sim 50$ → minimum bias multiplicity reach will be significantly extended !

Conclusions

- A comprehensive study of particle production in pp collisions at several $\sqrt{s}$ versus event multiplicity has been presented:
  - detailed studies of PID spectra shape confirm sign of **collectivity** in high multiplicity pp; origin and phenomenology still under investigation
  - **hadrochemistry**:
    - strangeness enhancement and baryon/meson ratio show a smooth evolution across all colliding systems
    - changes in the integrated particle ratios across different $\sqrt{s}$ are consistent with the increase observed in $\langle dN_{ch}/d\eta \rangle$
  - **comparison with models**: none of the existing models is able to reproduce simultaneously all observed features, namely spectra modifications and hadrochemistry

- First results based on **high multiplicity** triggered data and **event shape** studies already available... and many more to come → stay tuned !

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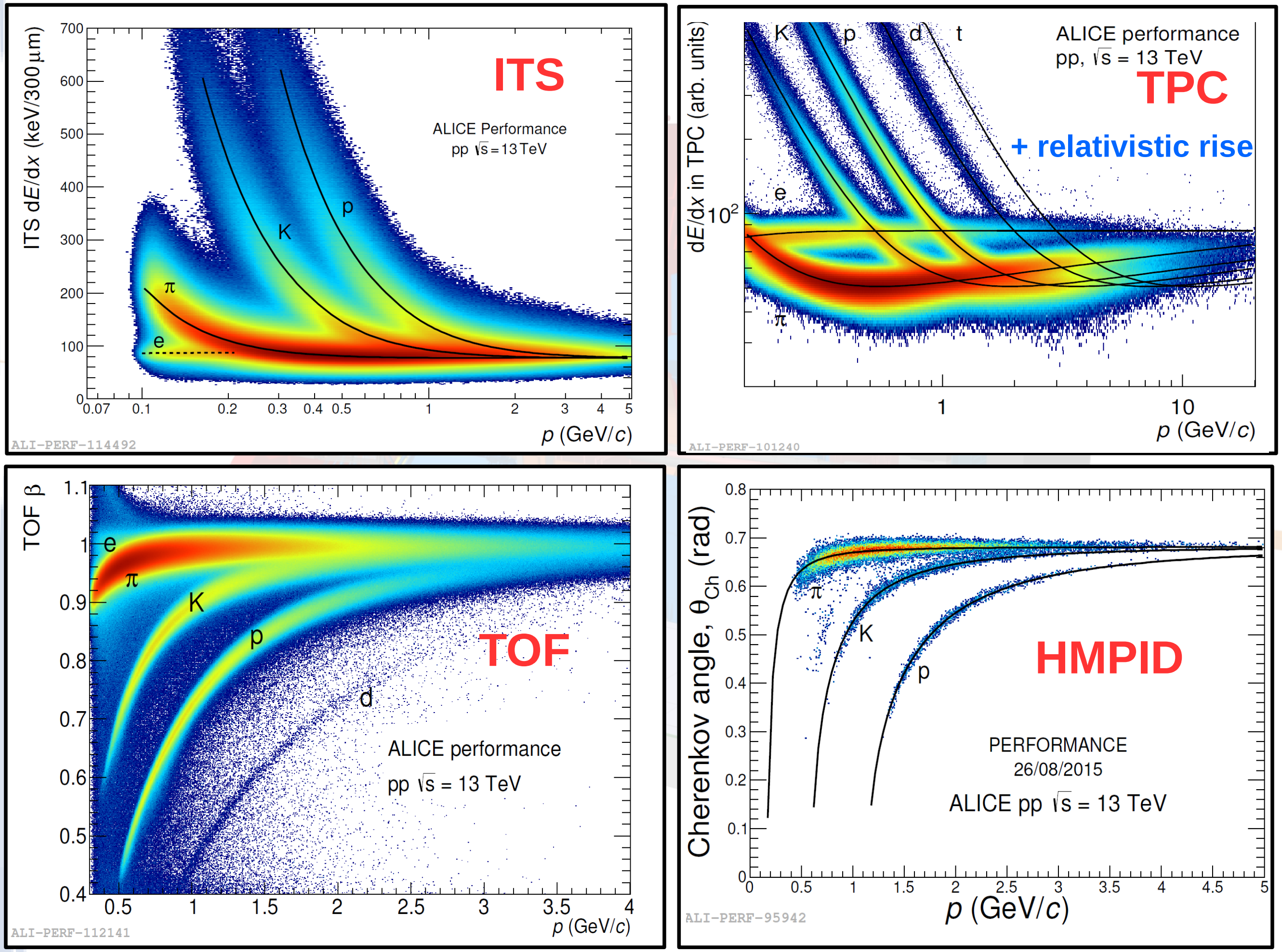
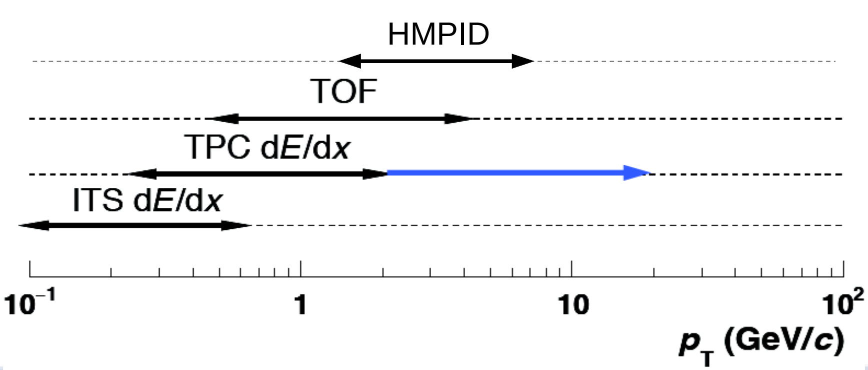
Thank you for your attention!

BACK-UP

The ALICE PID in ALICE





ITS:

- ✔ 6 layers of silicon detectors based on three different technologies (pixel, drift, strip)
- ✔ primary vertex, tracking, PID at low p_T (via dE/dx)

TPC:

- ✔ Gas-filled (Ne/CO_2) cylindrical barrel; MWPC used for the read-out
- ✔ tracking (up to 159 points / track), PID (via dE/dx) at intermediate and **high p_T (relativistic rise)**

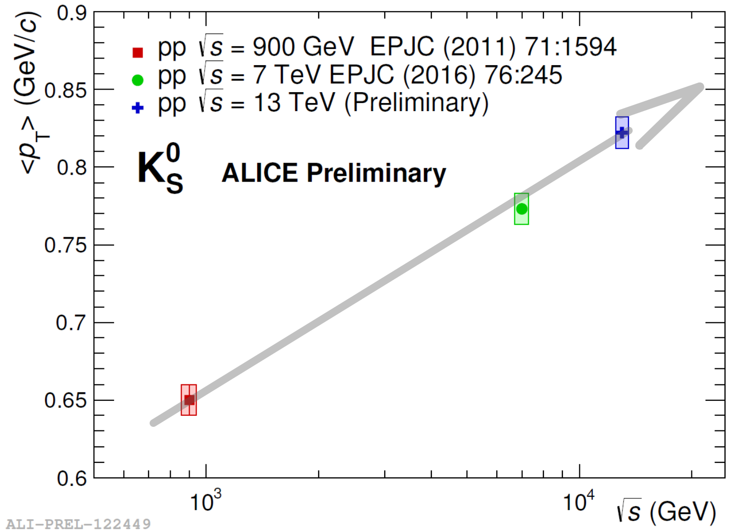
TOF:

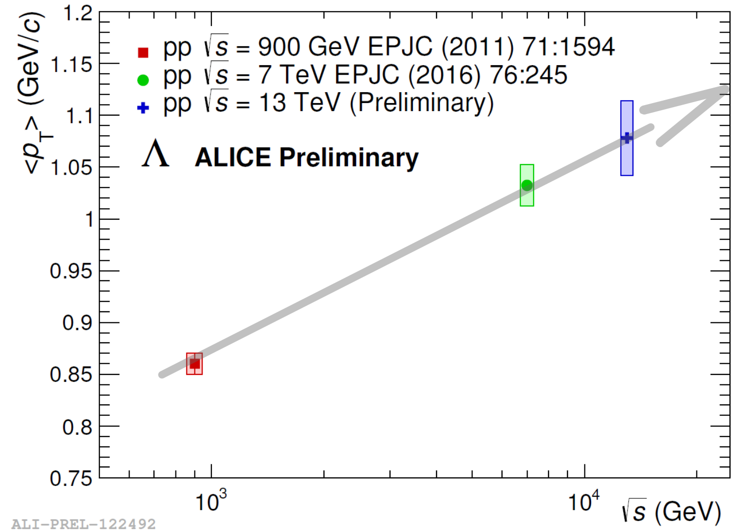
- ✔ Multi-gap resistive plate chambers
- ✔ PID via velocity (β) measurement

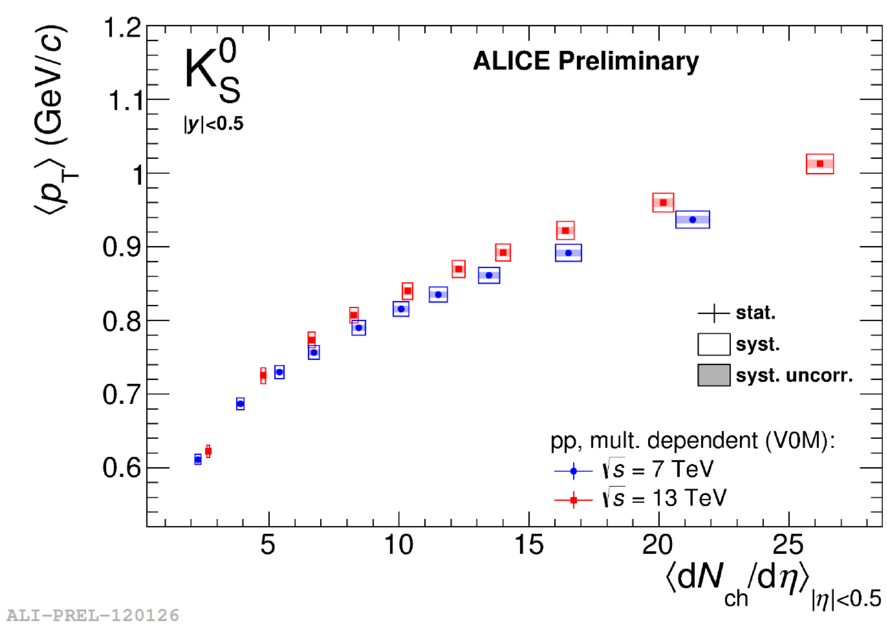
HMPID:

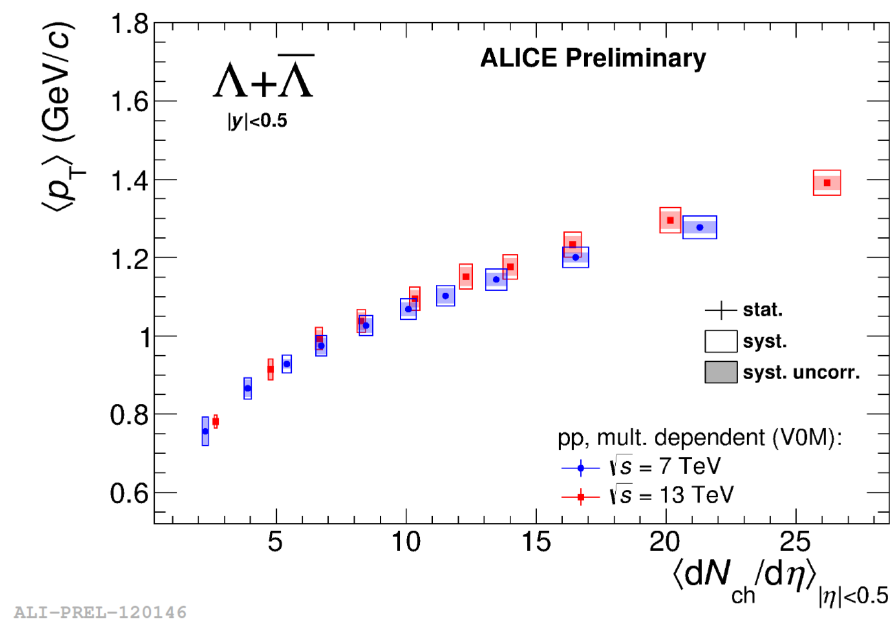
- ✔ based on Ring Imaging Cherenkov (RICH) counters

Strangeness: evolution with $\langle dN_{ch}/d\eta \rangle$ and $\sqrt{s}$





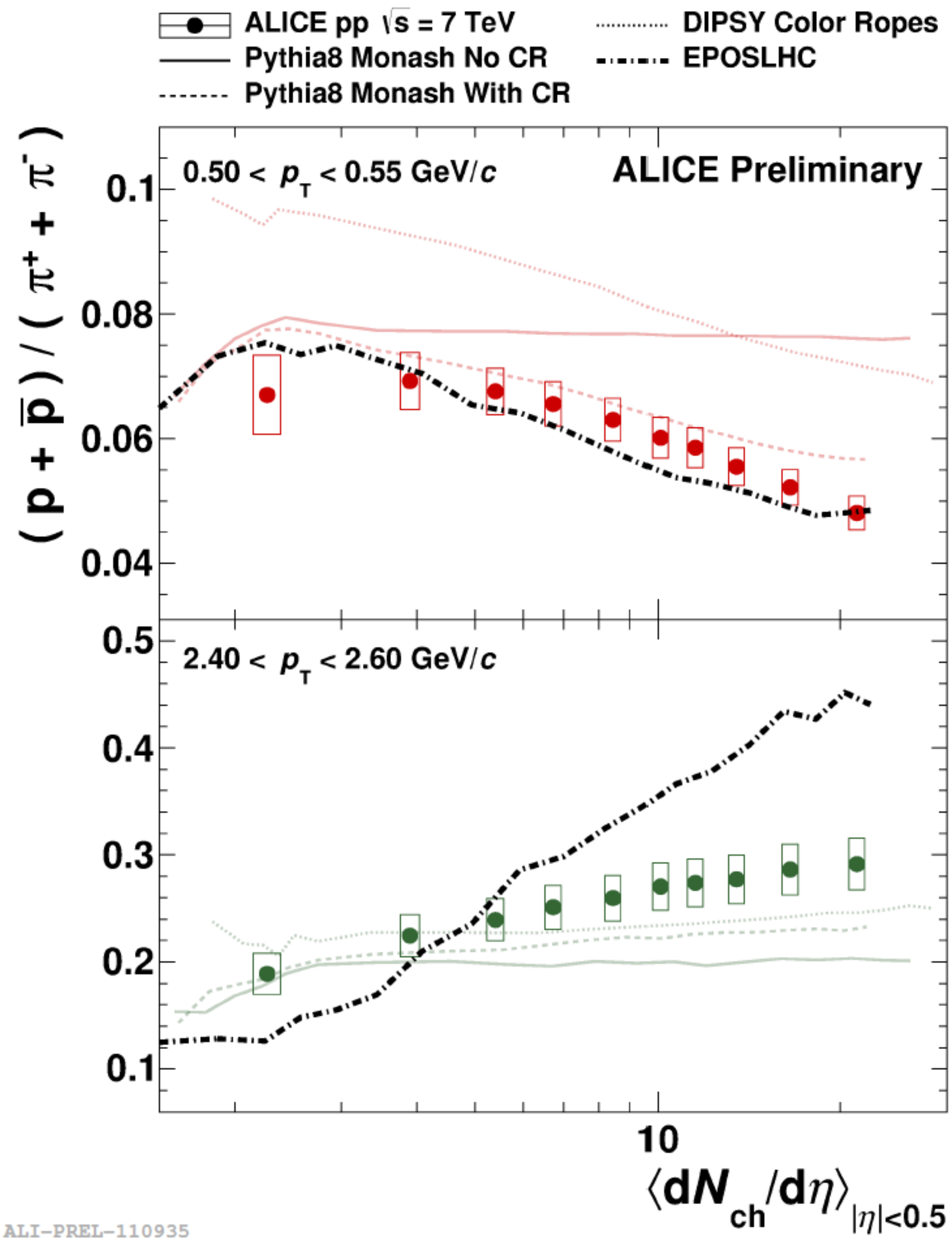




- ✔ $\langle p_T \rangle$ systematically larger at $\sqrt{s}$ = 13 TeV for K^0_S; not conclusive for Λ and multi-strange baryons (not shown) because of the large systematics

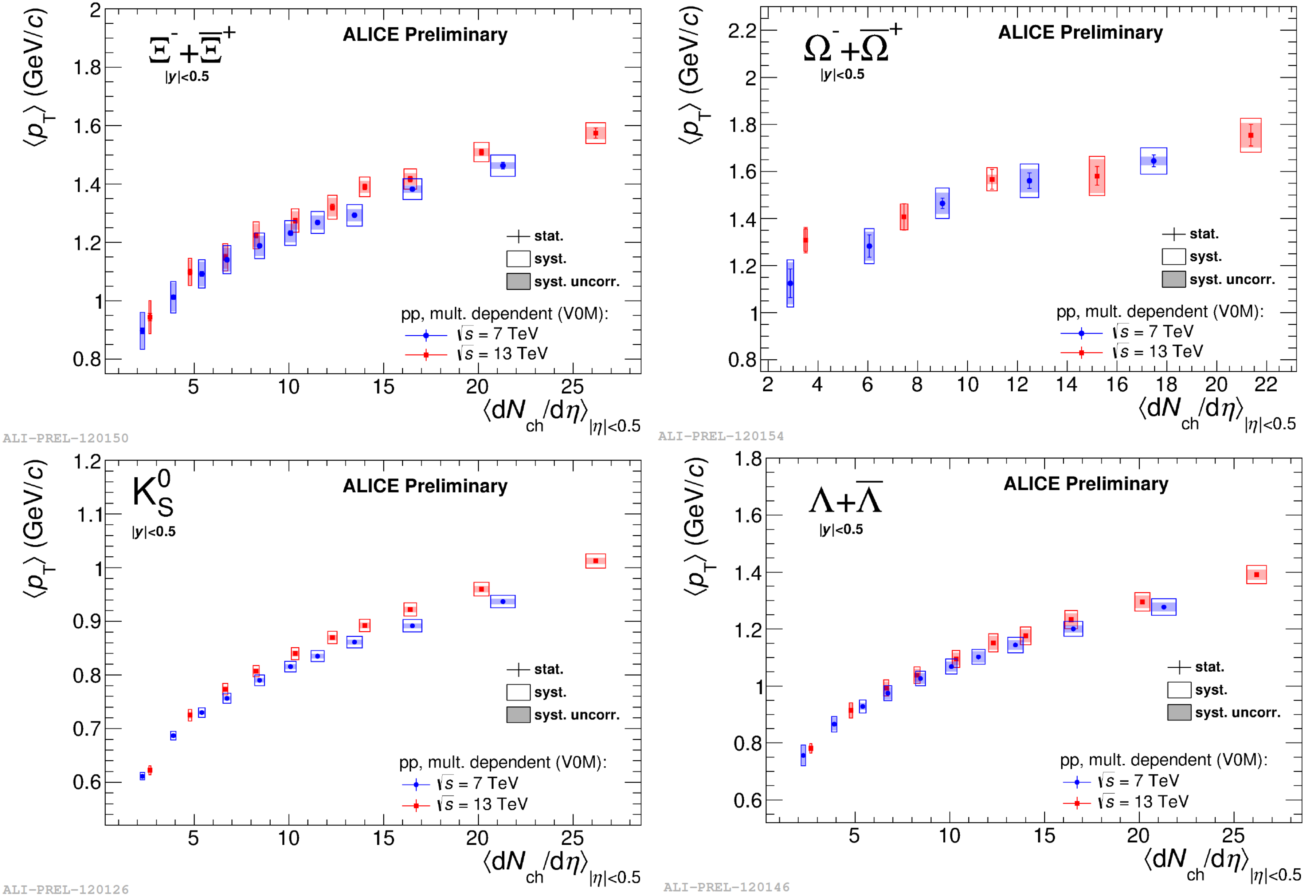
p/π: comparison with models

pp, √s = 7 TeV



- **PYTHIA8 (Monash):** ***Color Reconnection*** may explain the observed behaviour at low / intermediate p_T
- **DIPSY**: ***Color Ropes*** create similar features as Color Reconnection.
- **EPOS LHC**: based on ***core-corona*** model
  - *collective expansion* of the core seems to overestimate the enhancement

Strangeness: evolution with $\langle dN_{ch}/d\eta \rangle$ and $\sqrt{s}$



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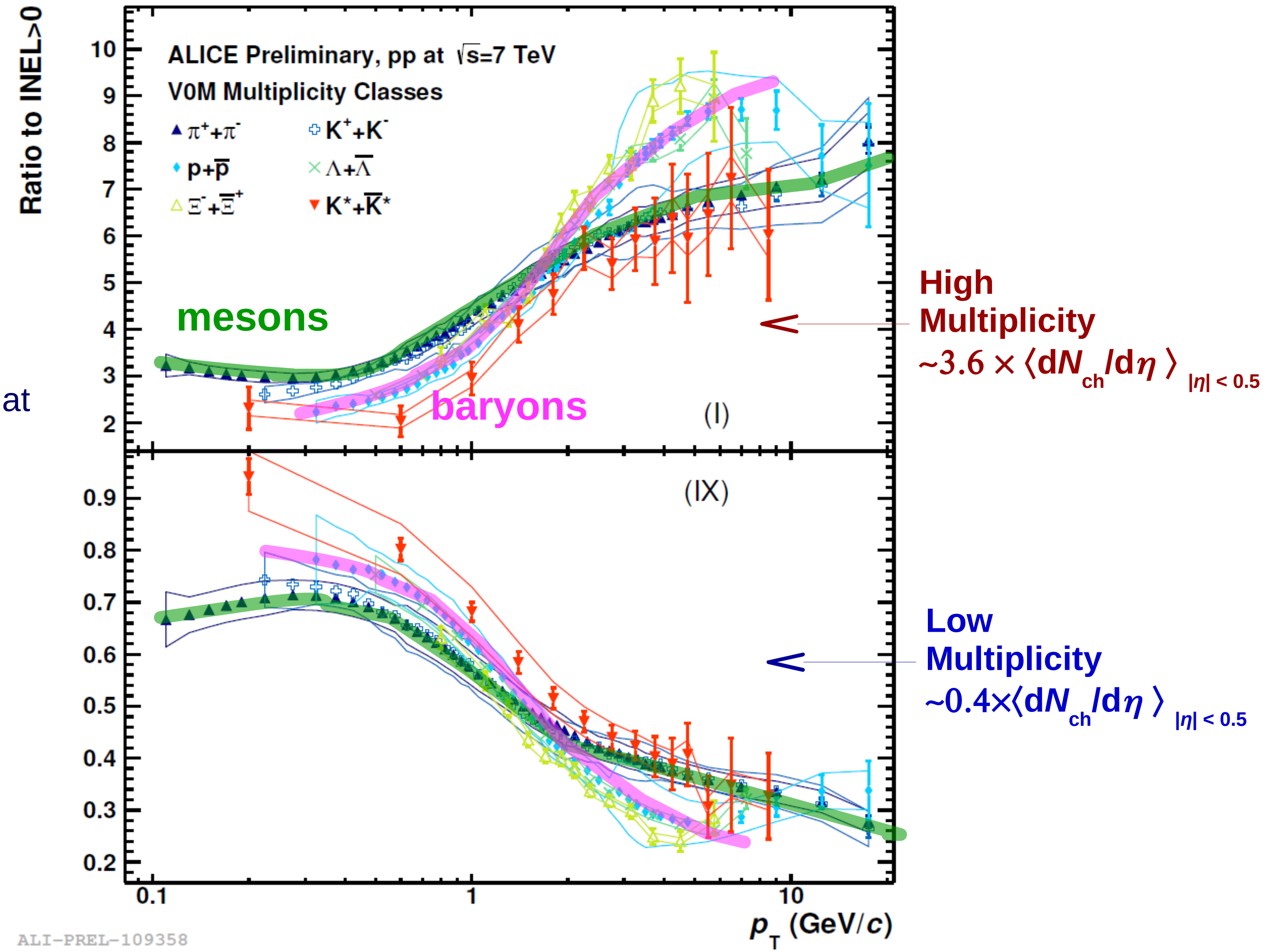
Transverse momentum spectra

- Spectra modifications w.r.t INEL>0
  - Ratios become flat within uncertainties at high-pT
  - hint of a baryon / meson difference (except K*)

pp, $\sqrt{s}$ = 7 TeV



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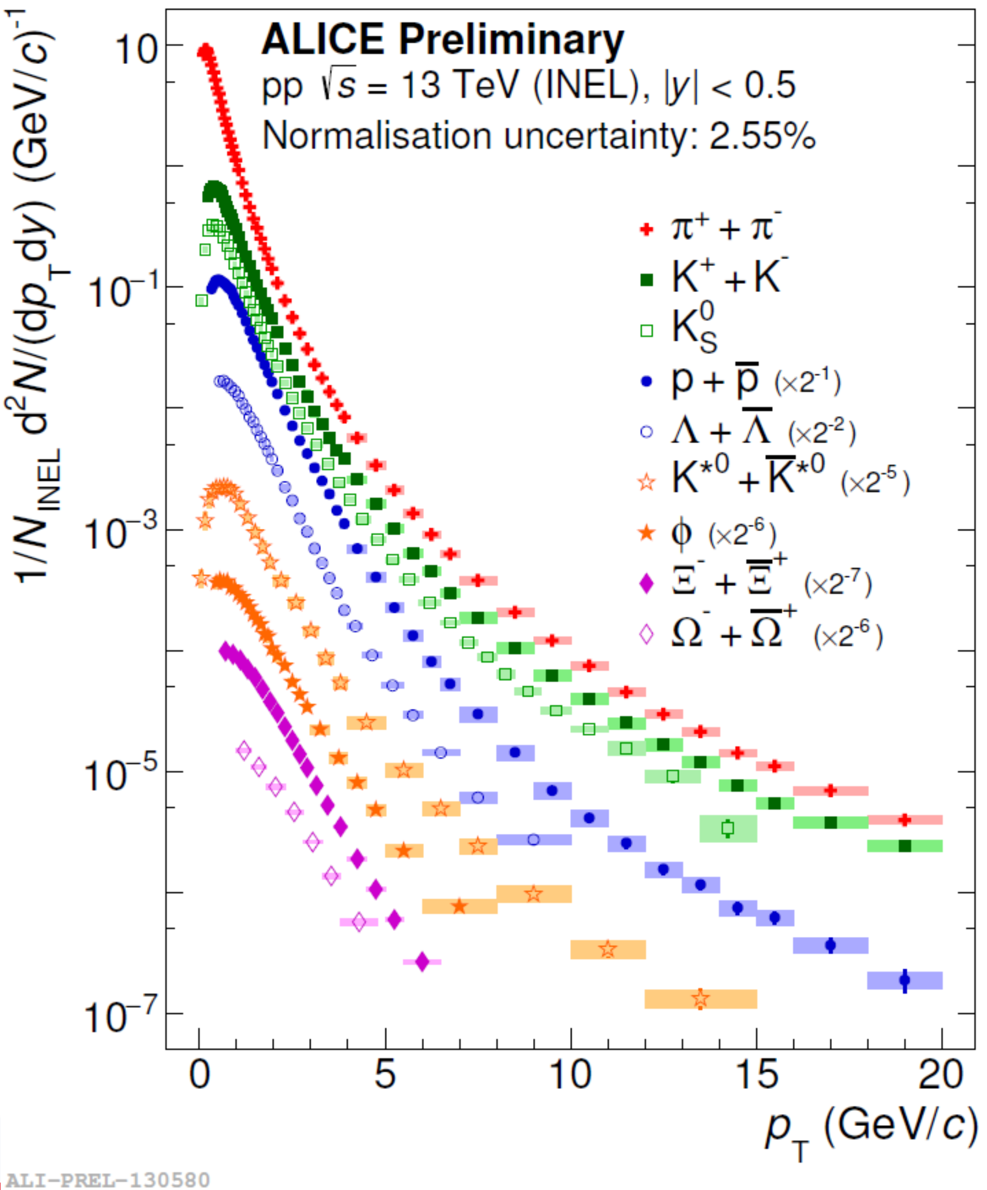
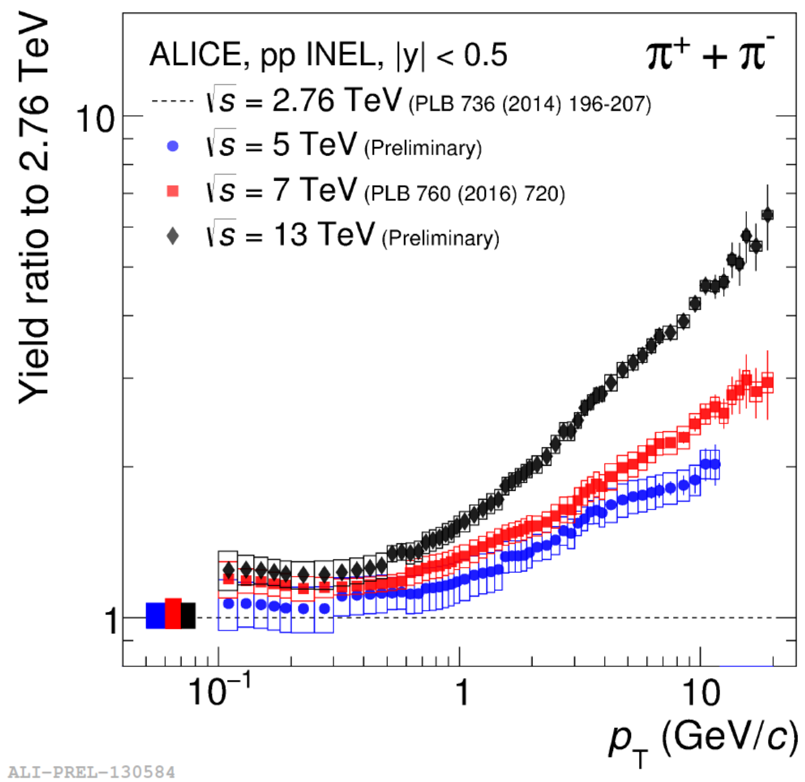
- In Pb-Pb interpreted in terms of collective expansion of a thermalized system (radial flow) which may require a fireball in a local thermodynamical (kinetic) equilibrium

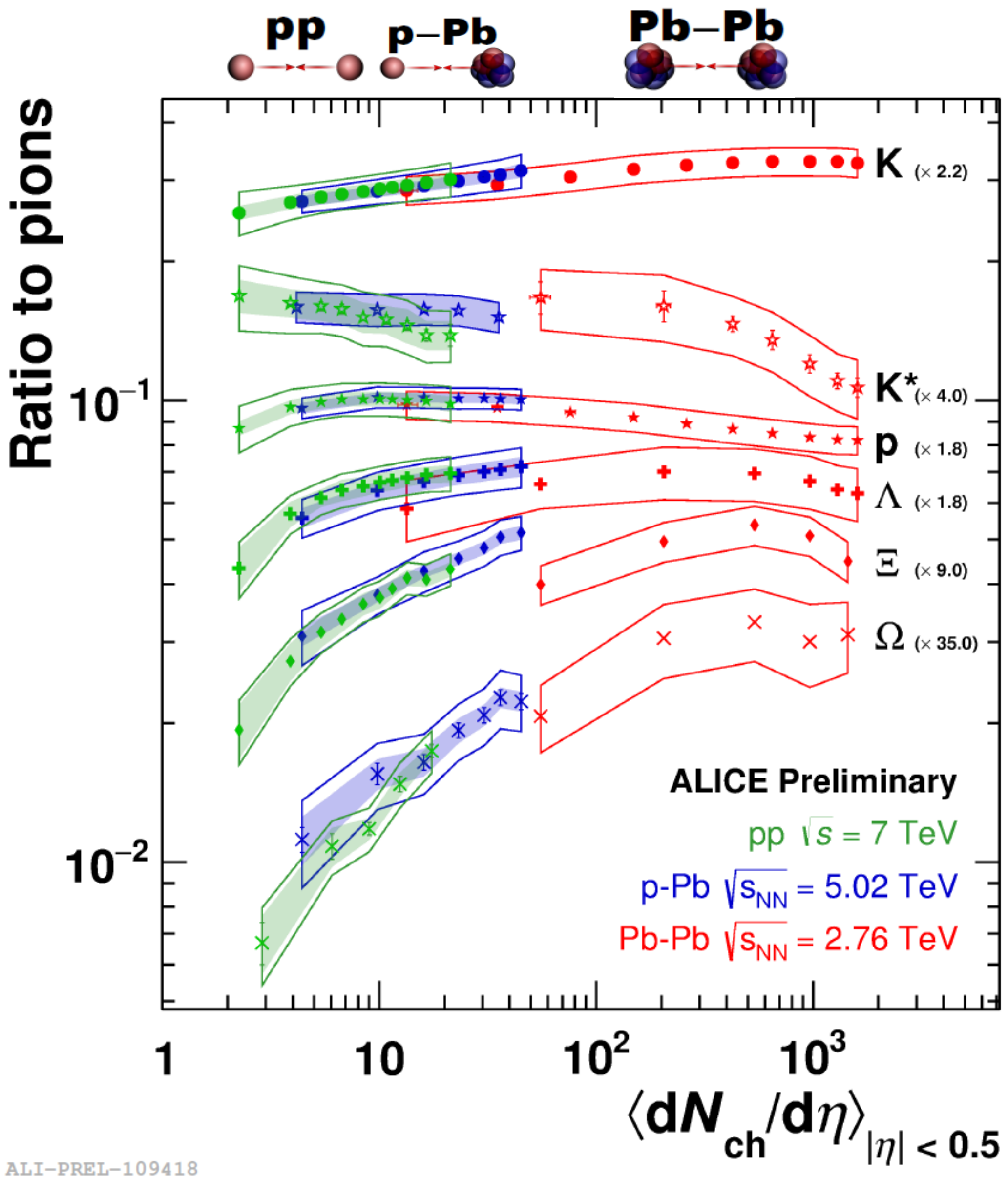
Identified particle spectra in pp





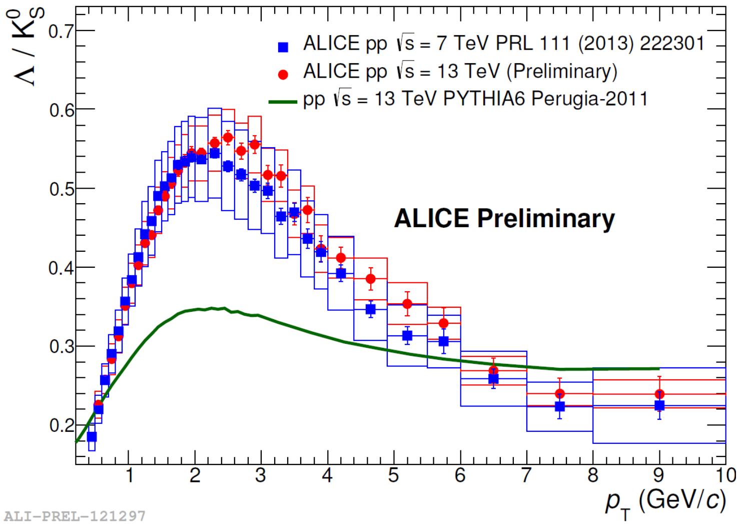
- ✔ Identified particle spectra measured over a wide p_T range
- ✔ Spectra become harder at higher $\sqrt{s}$

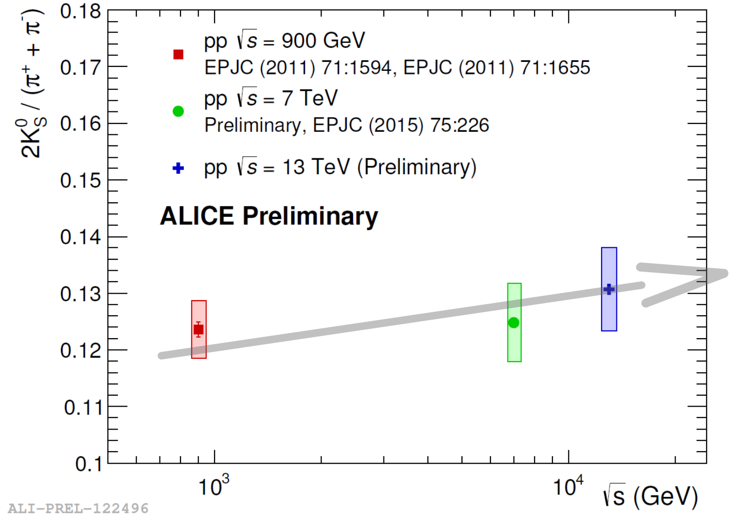
Hadrochemistry: ratio to pions



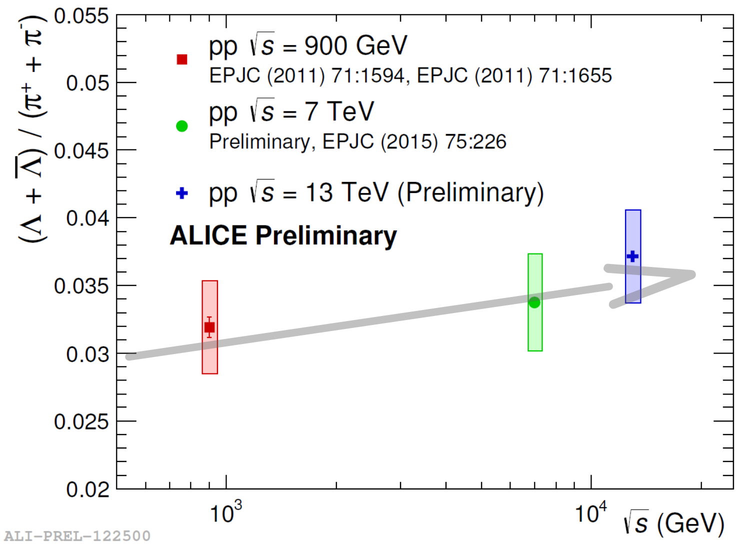
- ✔ Smooth evolution with $\langle dN_{ch}/d\eta \rangle$ across all colliding systems !
- ✔ Decrease of K*/π vs $\langle dN_{ch}/d\eta \rangle$ in Pb-Pb
- ✔ p/π stays constant within uncertainties
- ✔ **Strangeness enhancement** observed in small systems

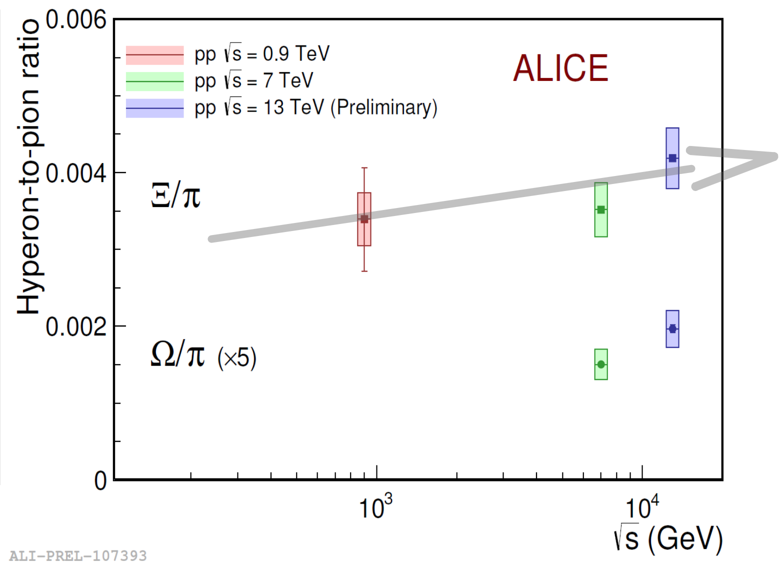
Particle ratios: evolution with √s





- ✔ p_T spectra ratio: maximum shifted towards higher p_T also in the strangeness sector



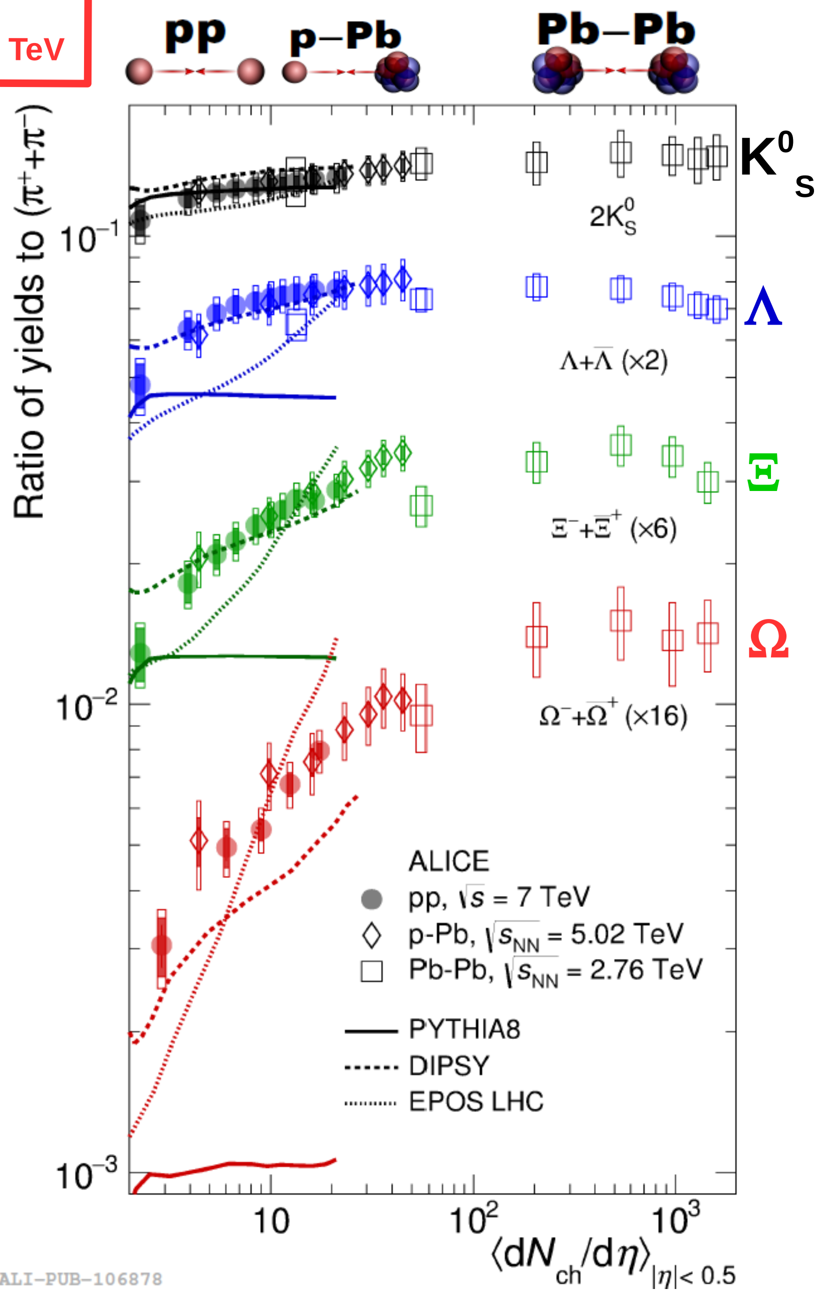


- ✔ K^0_S/π and Hyperon/π ratios show a hint of increase with √s

How does it scale with the event multiplicity ?

Hadrochemistry: Strangeness enhancement

pp, √s = 7 TeV



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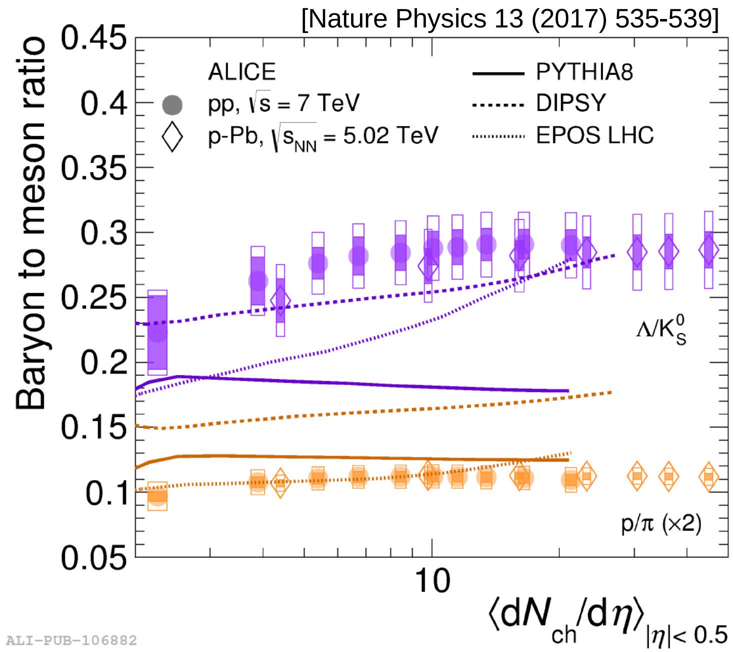
[Nature Physics 13 (2017) 535-539]



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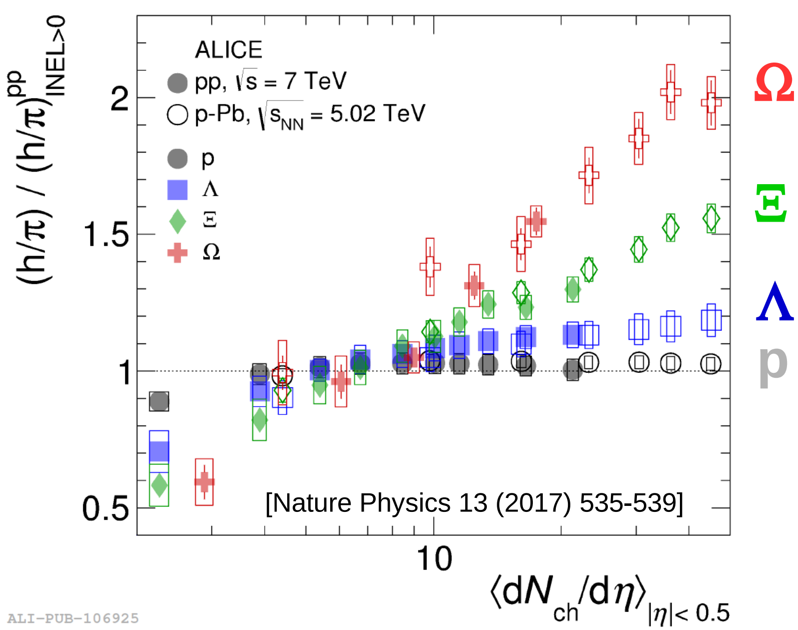

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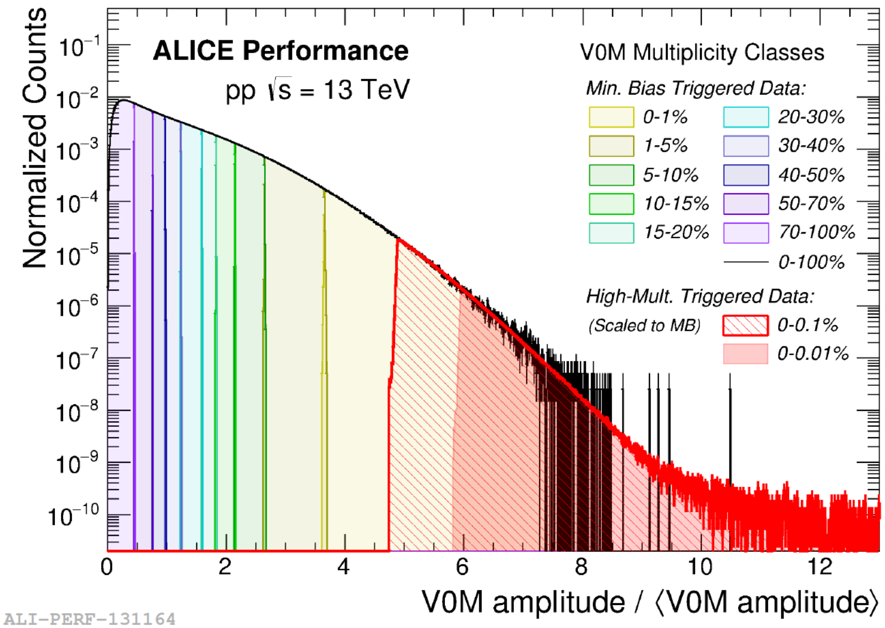
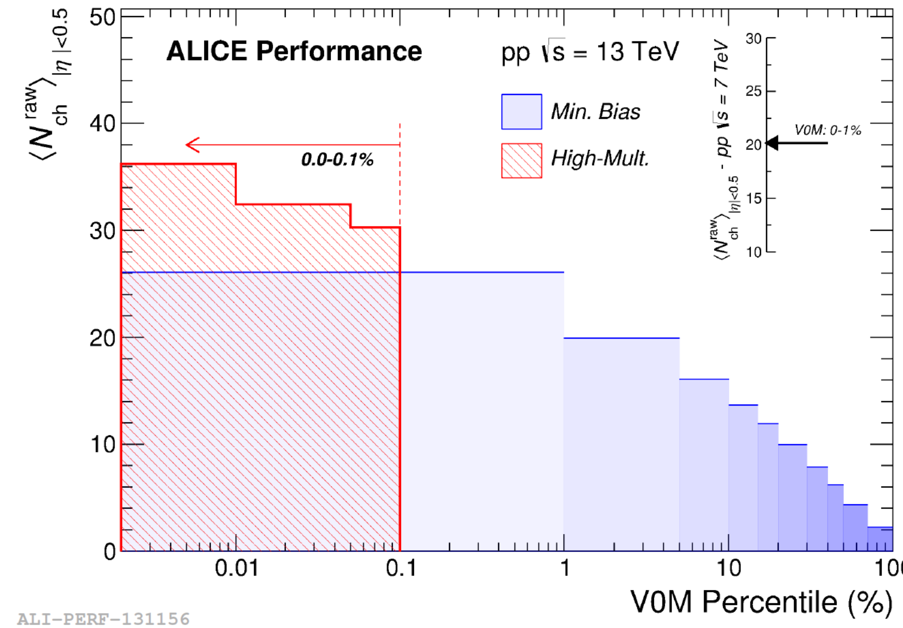
Outlook

✔ **High multiplicity triggered data:** ⟹ **see R. De Souza poster**





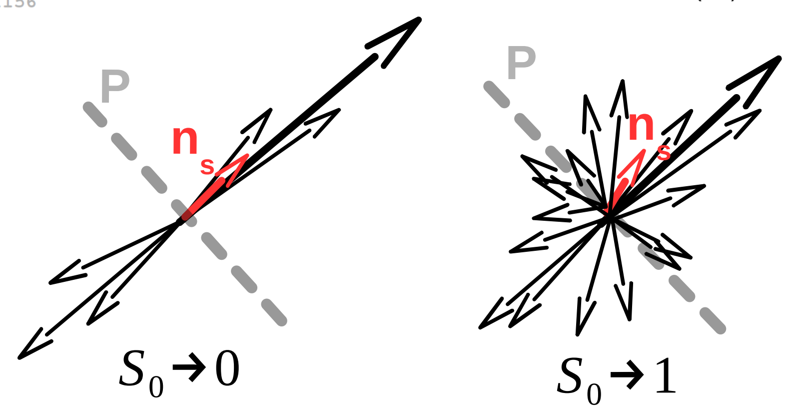
✔ **Event shape studies based on Spherocity**

$$S_0 \equiv \frac{\pi^2}{4} \min_{\hat{\mathbf{n}}_\mathbf{s}} \left(\frac{\sum_i |\vec{p}_{\mathrm{T},i} \times \hat{\mathbf{n}}_\mathbf{s}|}{\sum_i p_{\mathrm{T},i}} \right)^2$$

[$p_\mathrm{T} \geq 0.15$ GeV/c, $|\eta| < 0.8$]

n_s defined in order to minimize the ratio above (~axis of the main scattering)

$S_0 =$ { **0 "pencil-like" limit (hard events)**; **1 "isotropic" limit (soft events)** }



✔ More differential studies including identified particle production vs S_0 will allow to put additional constraints for further tuning and/or new model ingredients !