# Multiplicity correlation of identified particles

**Stefania Bufalino**
Politecnico and INFN, Torino

2nd Italian Workshop on Hadron Physics and Non-Perturbative QCD, Pollenzo, 22nd - 24th May 2017

# Outline

- Collectivity in small collision systems?

- Collision systems at the LHC

- Analysis technique
    - Multiplicity estimation
    - PID techniques

  - Observables

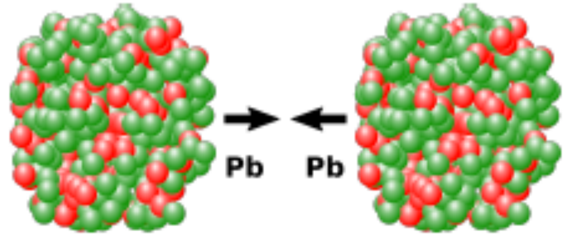
    - Particle production in pp and p-Pb collisions
    - Radial flow
    - Blast Wave fits
    - Baryon-to-meson ratios

- Summary

# Collision systems at the LHC

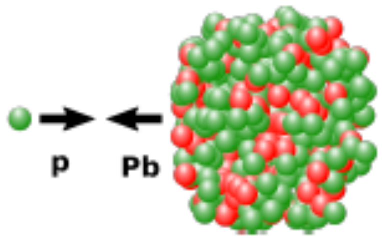
Study of hot and dense QCD matter

hydrodynamic evolution




Study of nuclear matter effects

intermediate system between the Pb-Pb and the pp



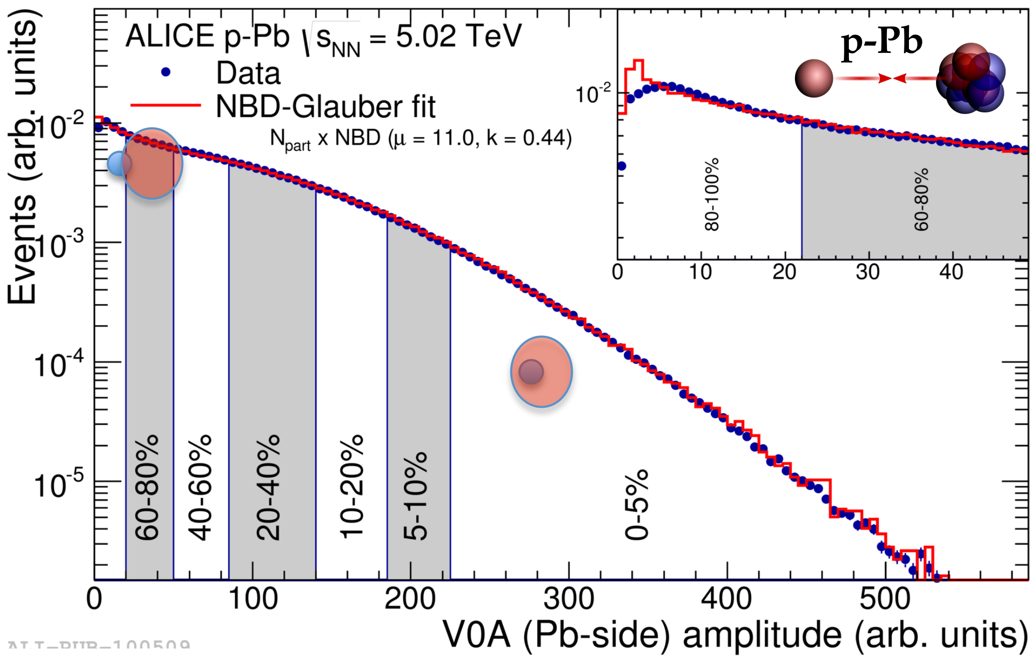

Reference for measurement in other systems

deconfinement not expected

collectivity not expected

# Multiplicity estimation

## We can control (a posteriori) the geometry of a collision

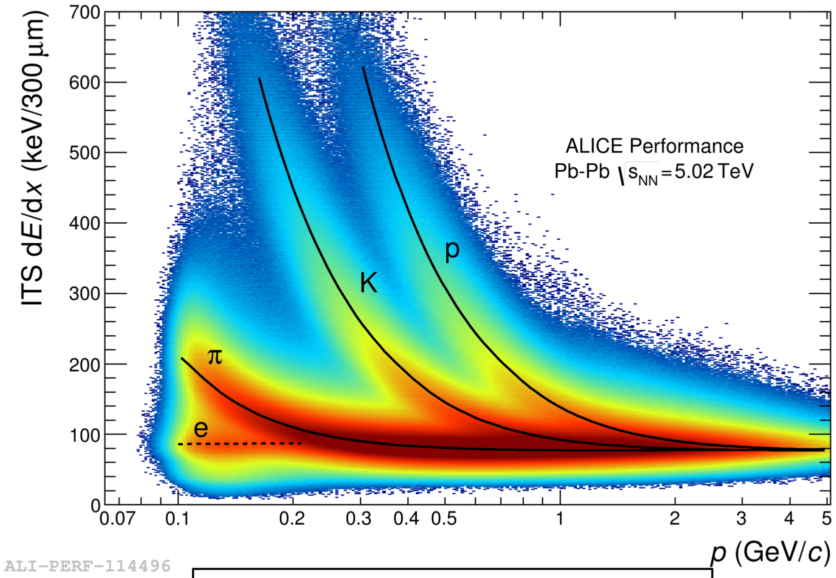



Phys. Rev. C 91 (2015) 064905

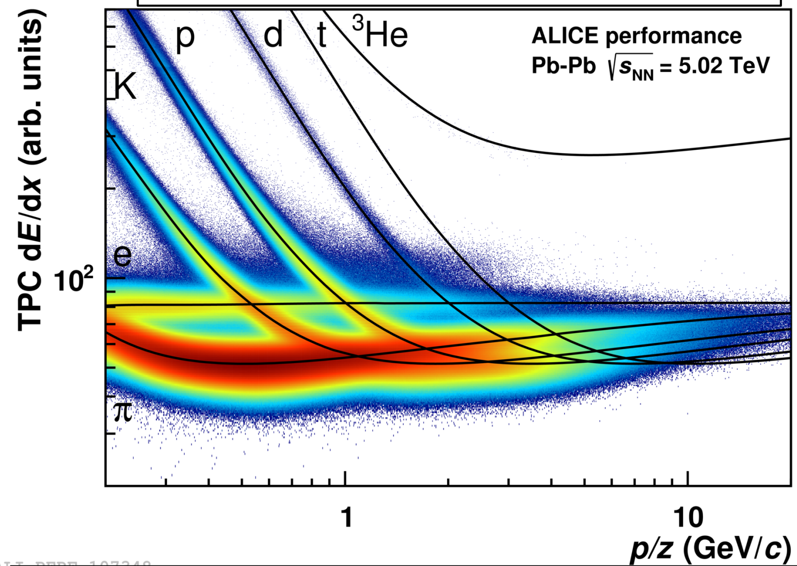
- Multiplicity is defined as the number of primary charged particles per event
- Linked through the impact parameter to the collision centrality in Pb–Pb
- ALICE measures the event activity at forward rapidity with the V0 detector
- Wide range of measured multiplicities
  - from $<dN_{ch}/d\eta> \approx$ 2 in pp
  - to $<dN_{ch}/d\eta> \approx$ 1600 in central Pb–Pb

# Particle identification

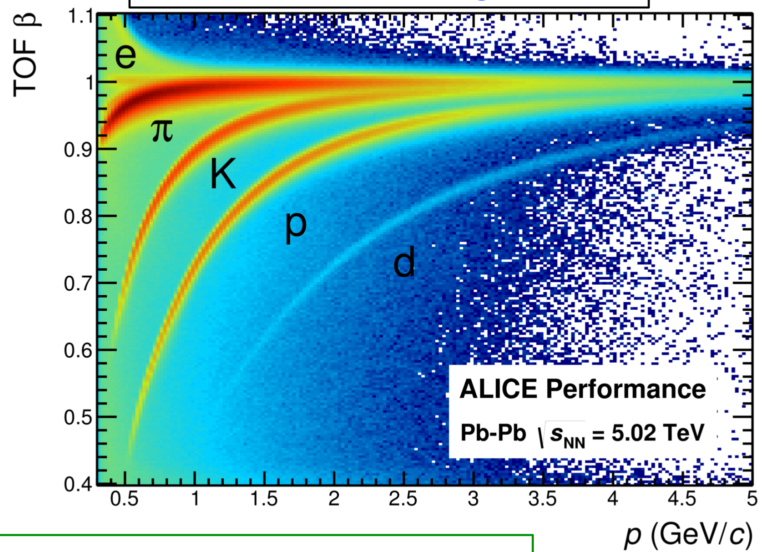
Inner Tracking System



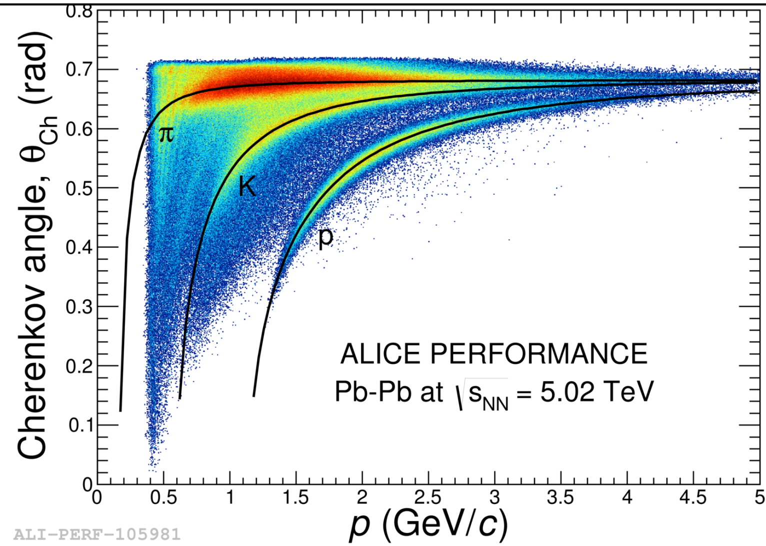

Time Projection Chamber




Time Of Flight



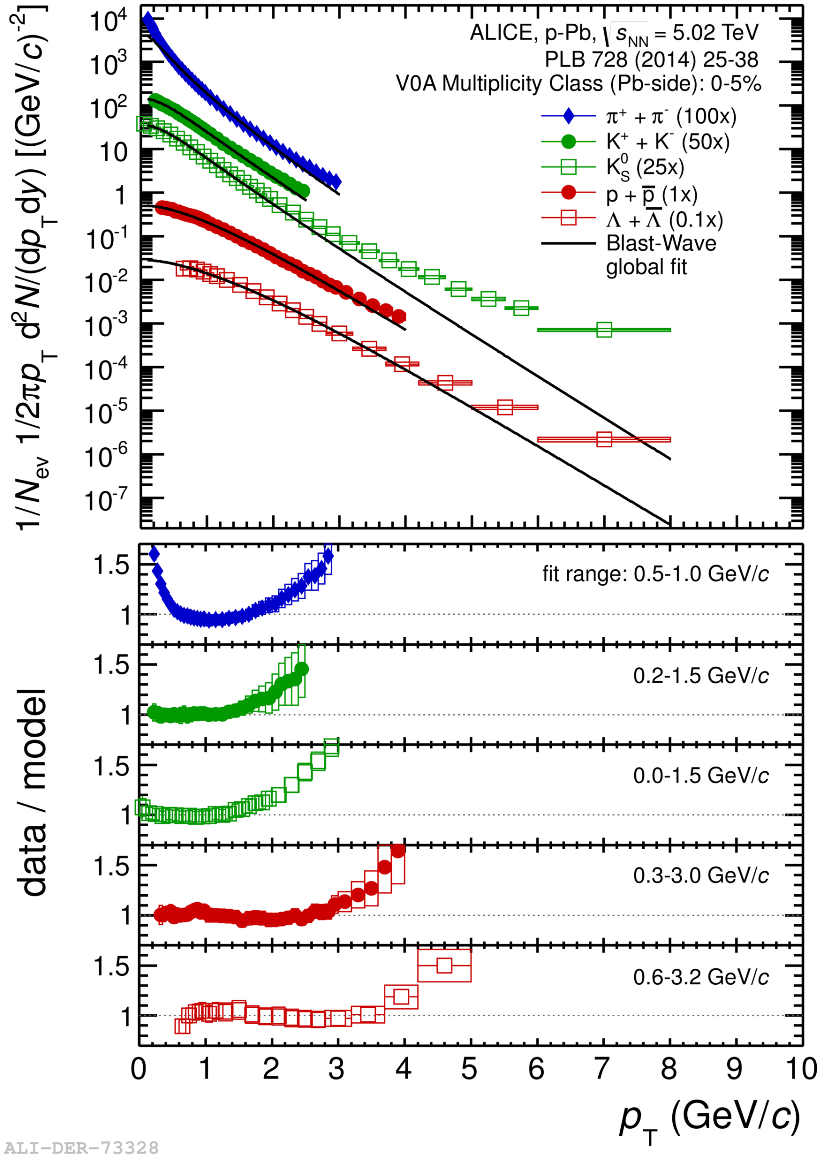

High Momentum Particle Identification




ALICE, IJMPA 29, (2014) 1430044

# Collectivity: $p_T$ spectra in p-Pb

V0A Multiplicity Class: 0-5%




ALI-DER-73328

The Blast-wave model is compared to the $p_T$ distributions:

- parameters obtained from the simultaneous fit to π, K, p and Λ
- combined BW fit describes the spectra fairly well also in p-Pb

Common kinetic freeze-out describes the spectra in high multiplicity p-Pb collisions

In central heavy-ion collisions, the multistrange particles experience less transverse flow
PLB 728 (2014) 216-227
PRC 90 (2014) 054912

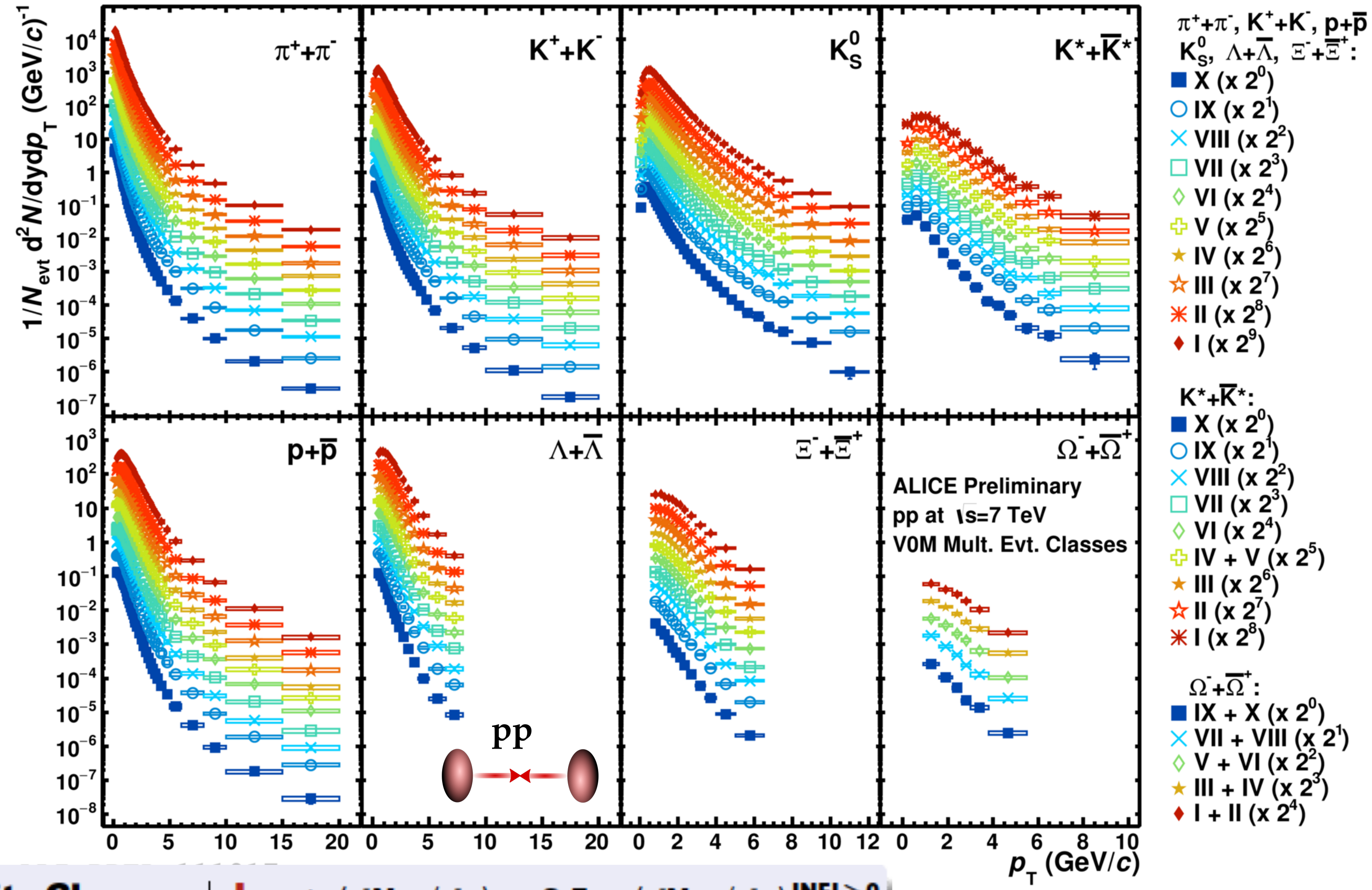
# Spectra evolution in pp

## Similarities to Pb-Pb results

multiplicity- and mass-dependent flattening of the $p_T$ spectra at low $p_T$ (< 2 GeV/c)

**High multiplicity**

**Low multiplicity**




**V0M Multiplicity Classes**
$\pi\ K\ p\ K^0_s\ K^*\ \Lambda\ \Xi\ \Omega$

$\langle dN_{ch}/d\eta \rangle^{INEL>0} \sim 6.0$

**I** $\rightarrow \langle dN_{ch}/d\eta \rangle \sim 3.5 \times \langle dN_{ch}/d\eta \rangle^{INEL>0}$

...

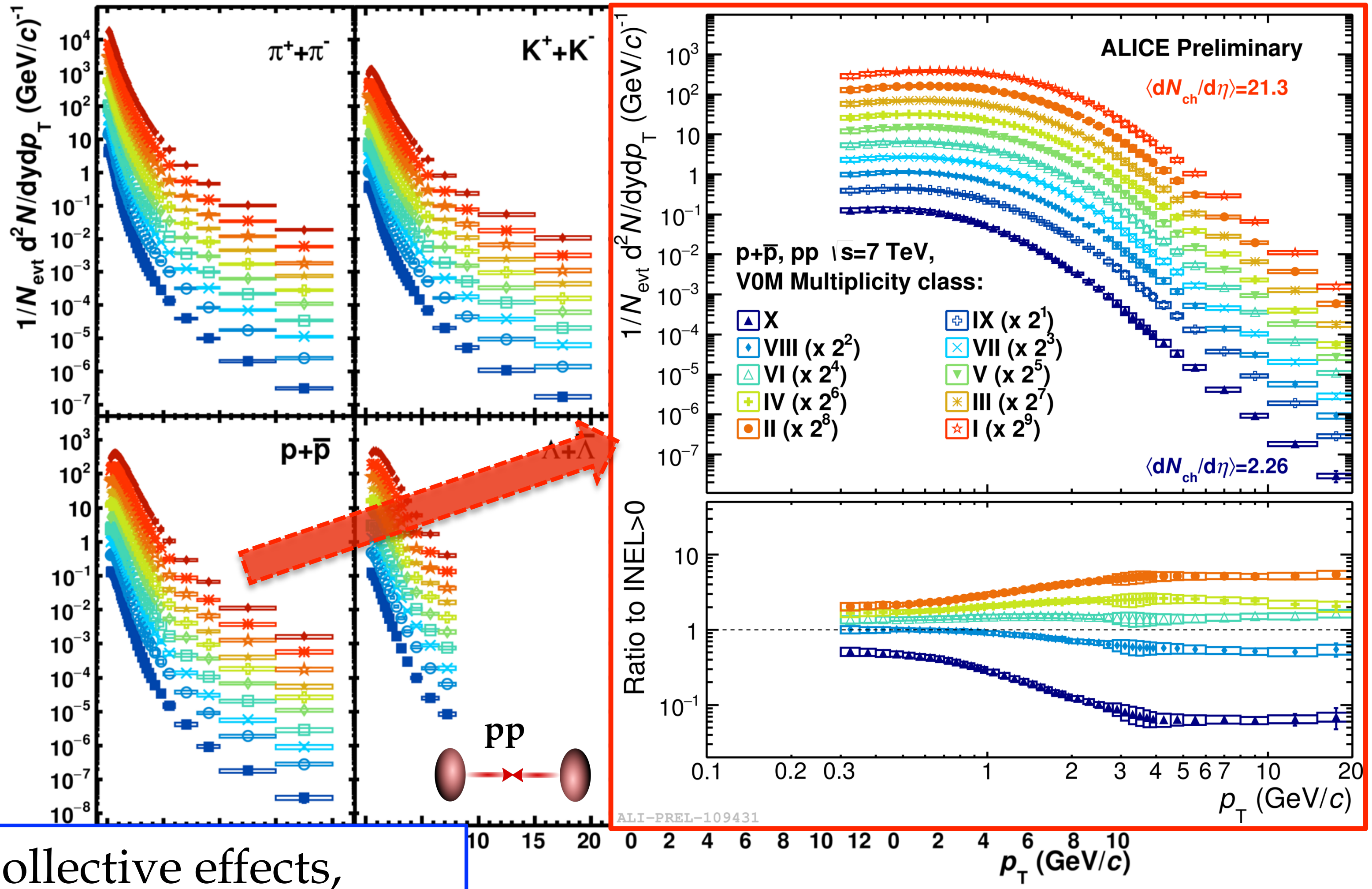
**IX** $\rightarrow \langle dN_{ch}/d\eta \rangle \sim 0.7 \times \langle dN_{ch}/d\eta \rangle^{INEL>0}$

**X** $\rightarrow \langle dN_{ch}/d\eta \rangle \sim 0.4 \times \langle dN_{ch}/d\eta \rangle^{INEL>0}$

# Spectra evolution in pp

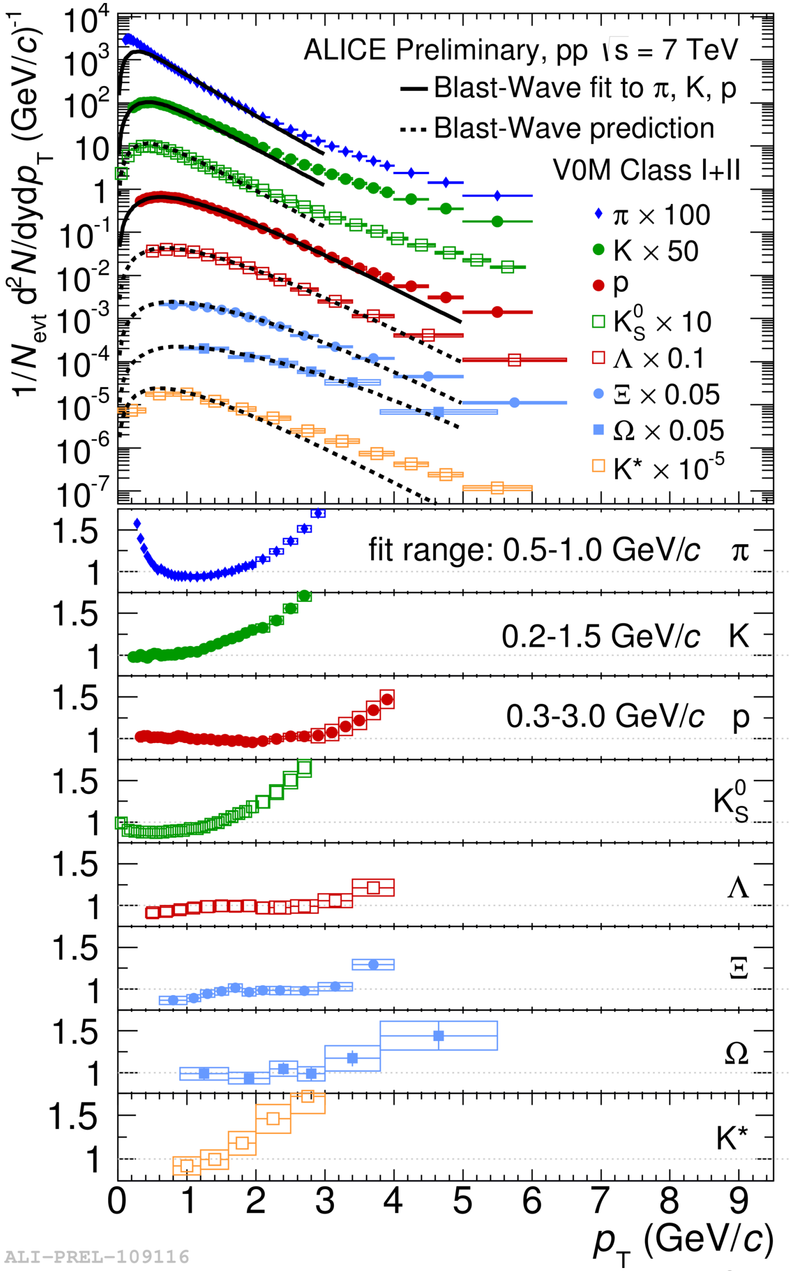
## Similarities to Pb-Pb results

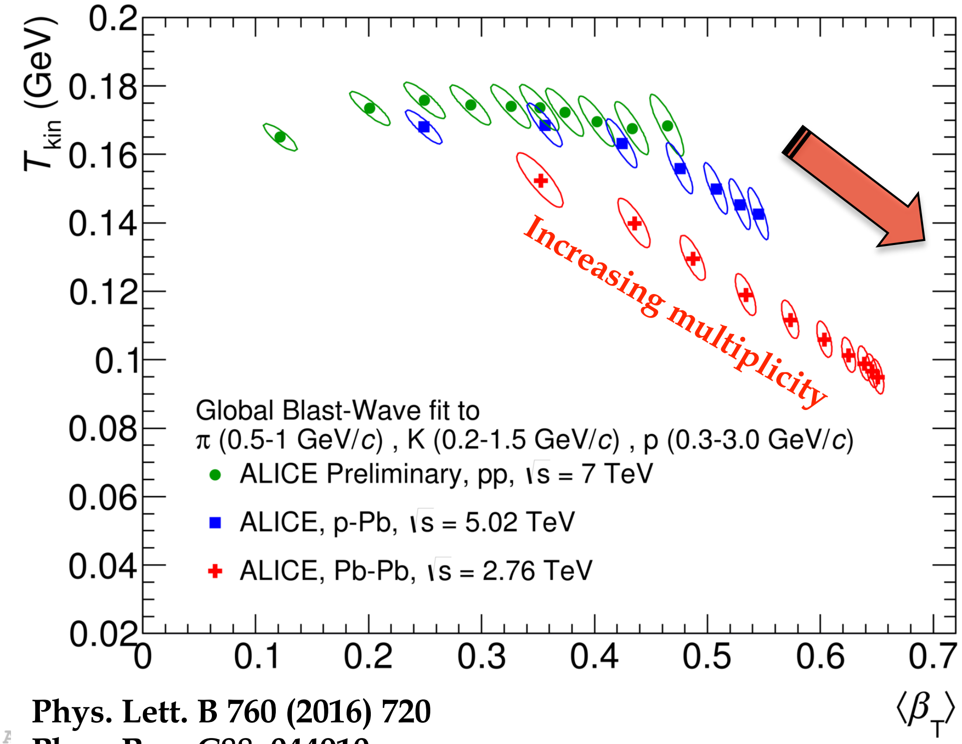
multiplicity- and mass-dependent flattening of the $p_T$ spectra at low $p_T$ (< 2 GeV/c)




Indication for collective effects, **reminiscent of** effects observed in **Pb-Pb →** attributed **to radial flow**

# Blast Wave fit in pp



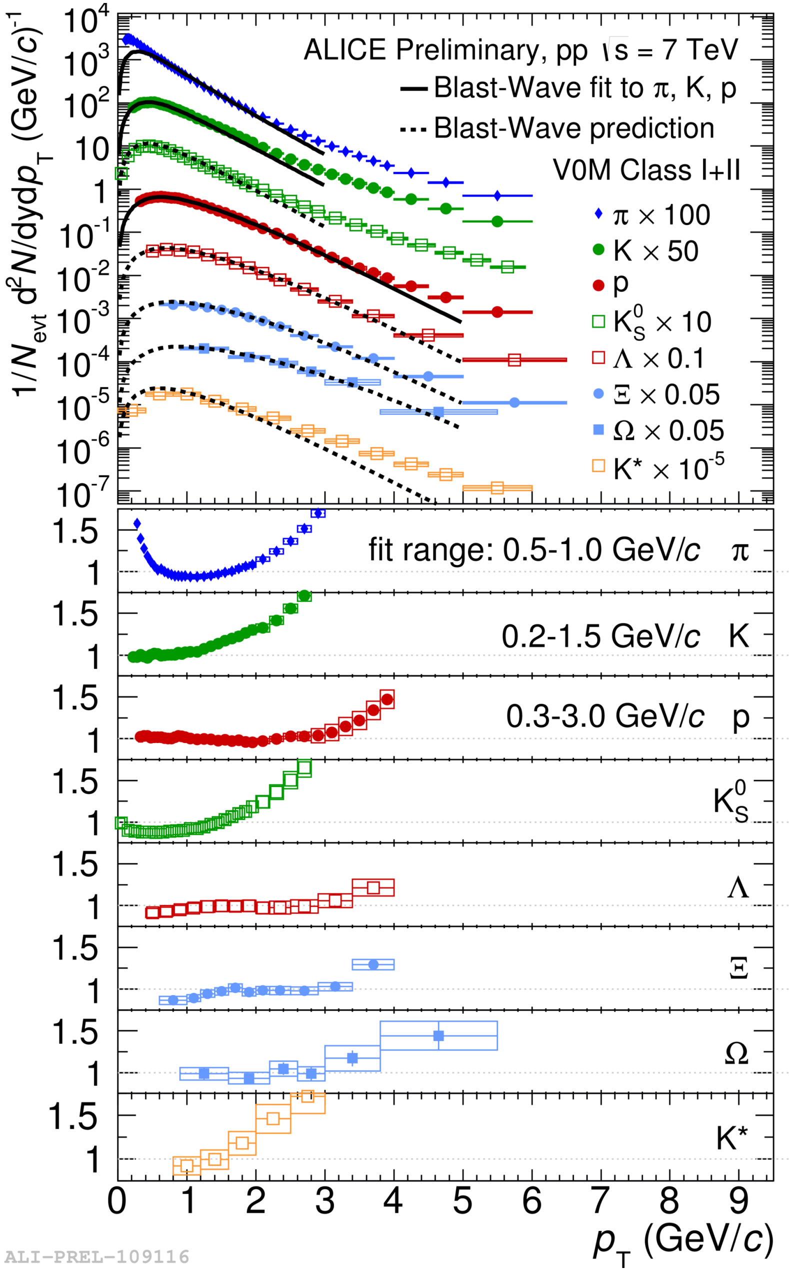



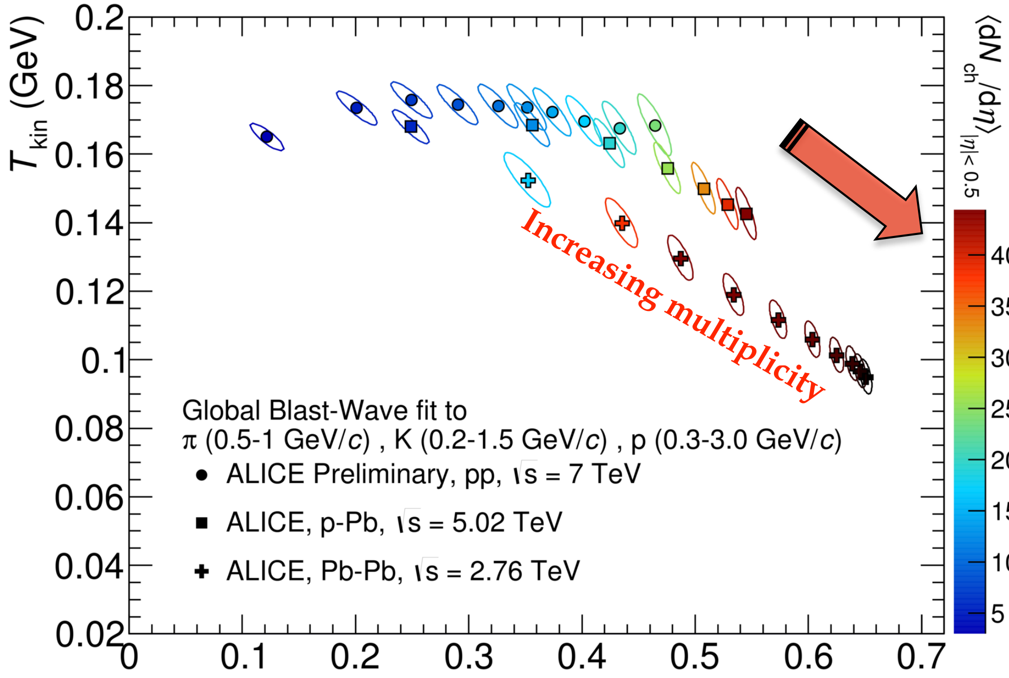

**Phys. Lett. B 760 (2016) 720**
**Phys. Rev. C88, 044910**

- V0M class I+II → highest multiplicity
- Simultaneous fit to the π, K and p spectra
- Hyperons follow the Blast Wave predicted with the π, K, p fit parameters

pp and p–Pb parameters follow the same trend

# Blast Wave fit in pp

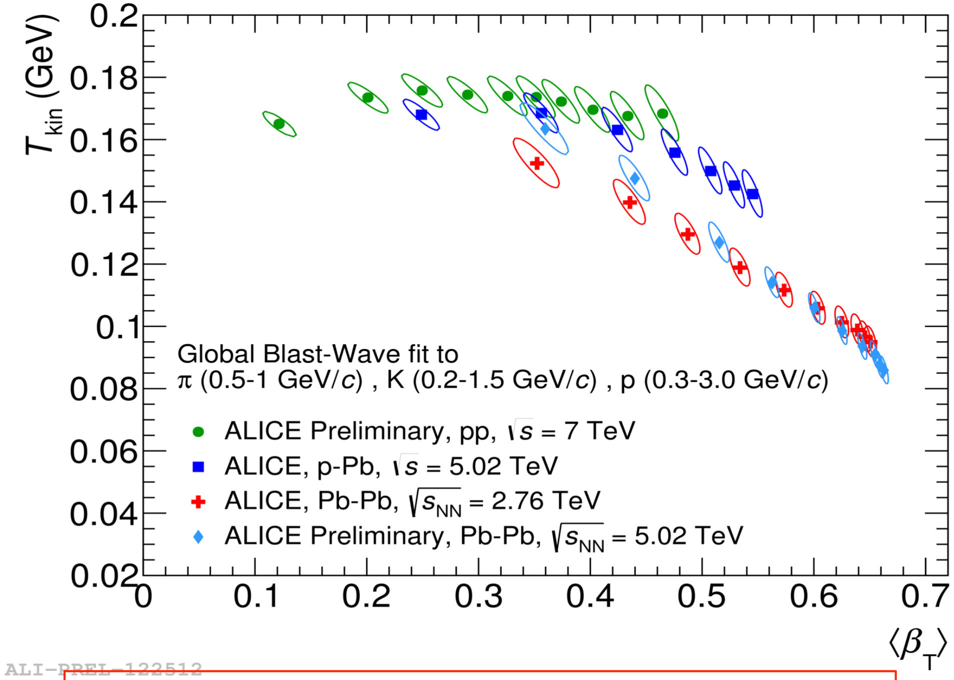



**Phys. Lett. B 760 (2016) 720**
**Phys. Rev. C88, 044910**

- Qualitatively similar behavior observed for pp, p-Pb and Pb-Pb collisions
- Larger radial flow parameter obtained in p-Pb than in Pb-Pb collisions for a similar multiplicity

# Blast Wave fit results

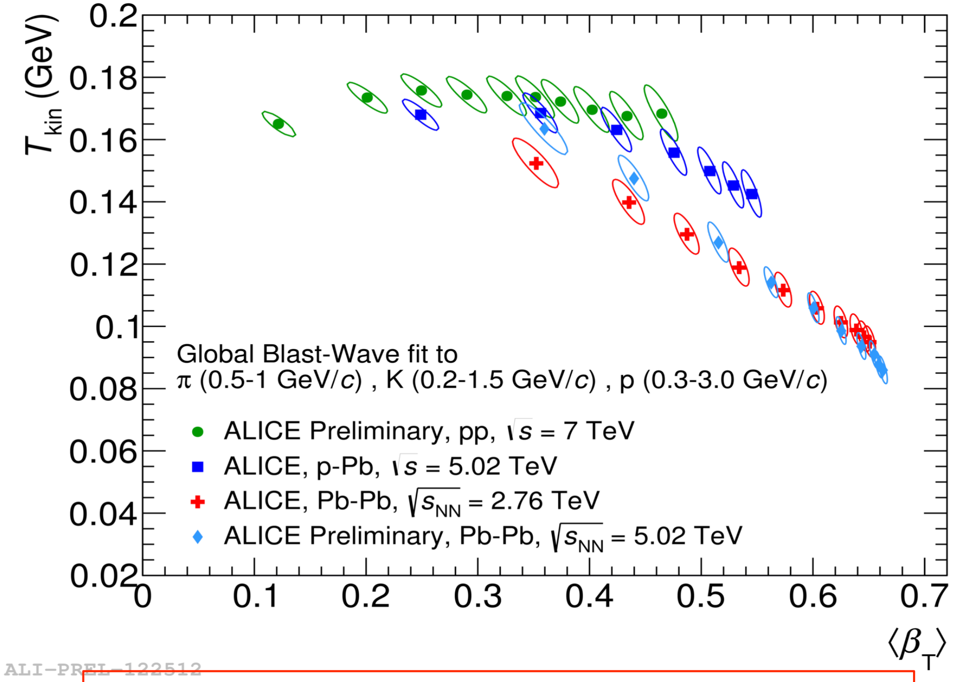



Results of the simultaneous Blast-Wave fit to $\pi$, K, p $p_T$ spectra

In pp and p-Pb, similar evolution of the parameters towards high multiplicity

**Does this imply that the trend in different systems is driven by the same type of collectivity?**

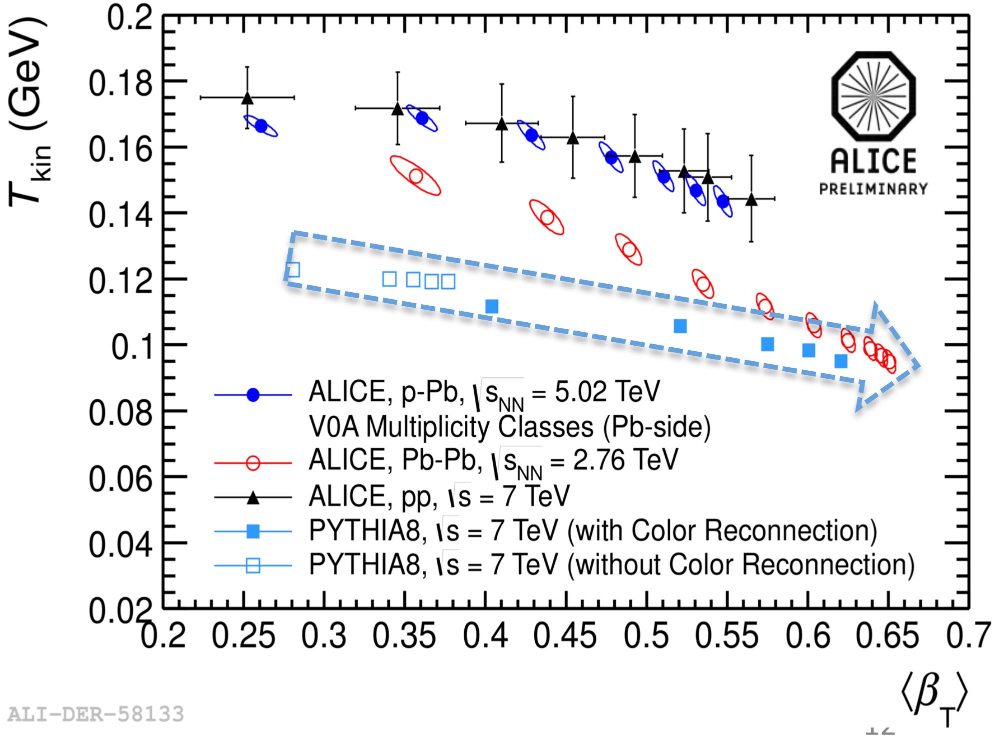
# Blast Wave fit results



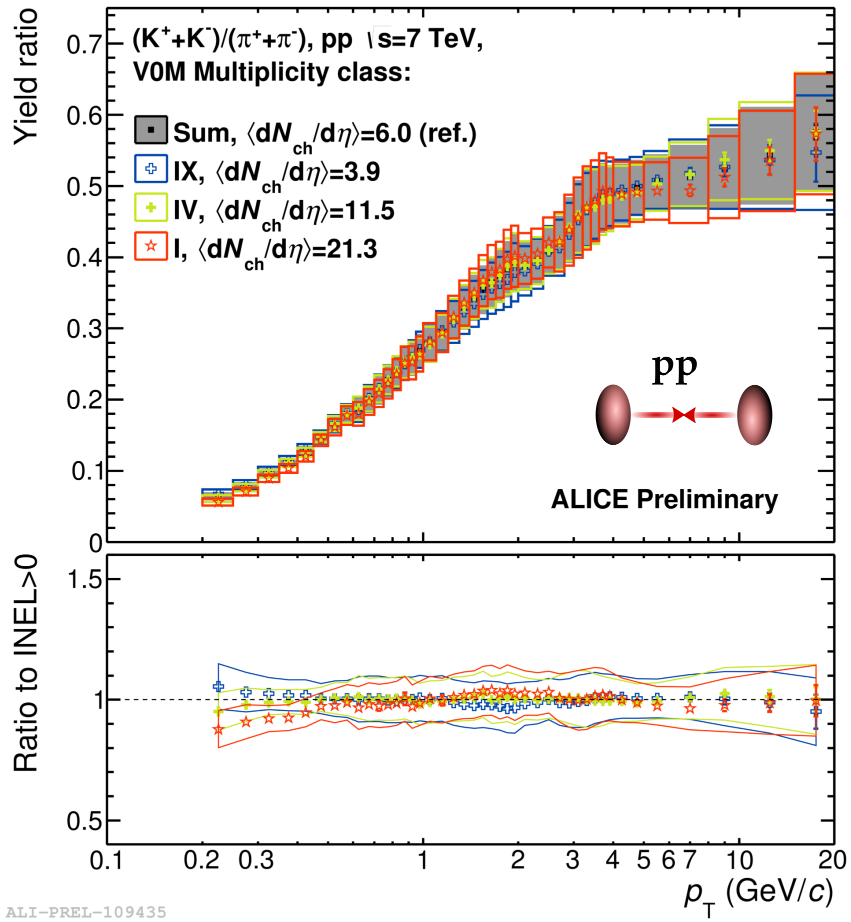

care needs to be taken with the interpretation because $p_T$ spectra of pp events generated with Pythia 8, where no hydro expansion is assumed, show a fair agreement

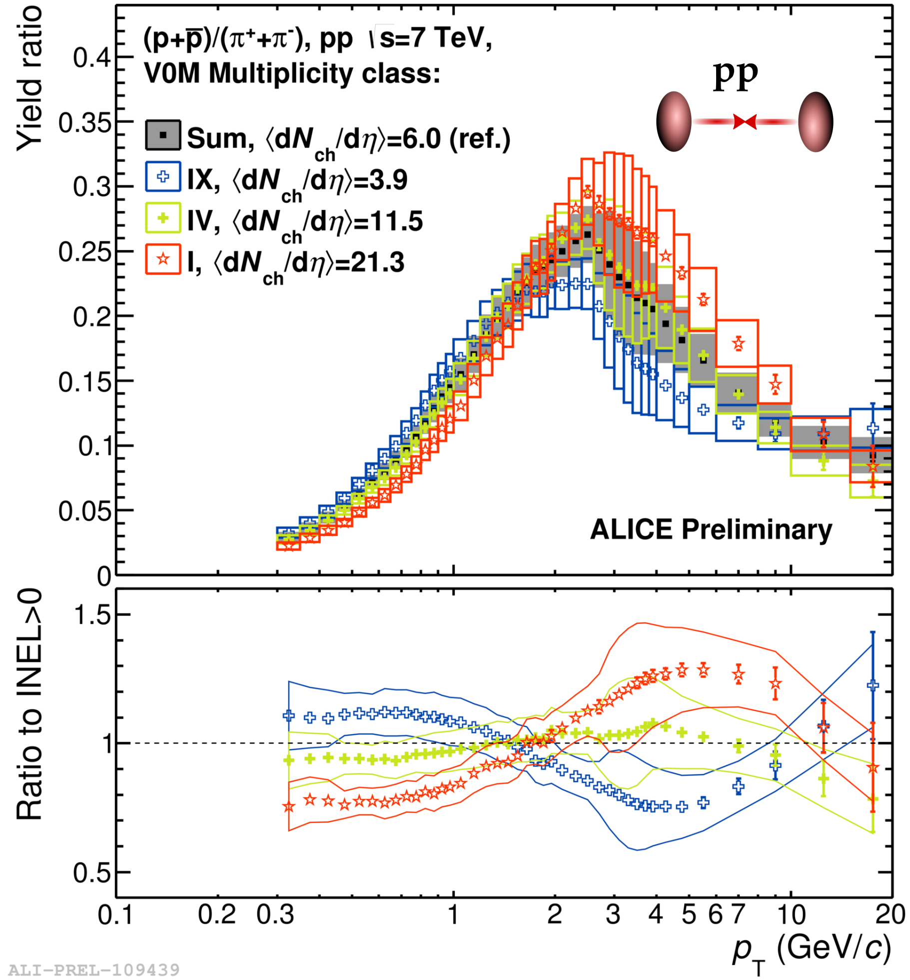
**Does this imply that the trend in different systems is driven by the same type of collectivity?**

**No! QCD effects (as CR) can mimic the effects of radial flow!**



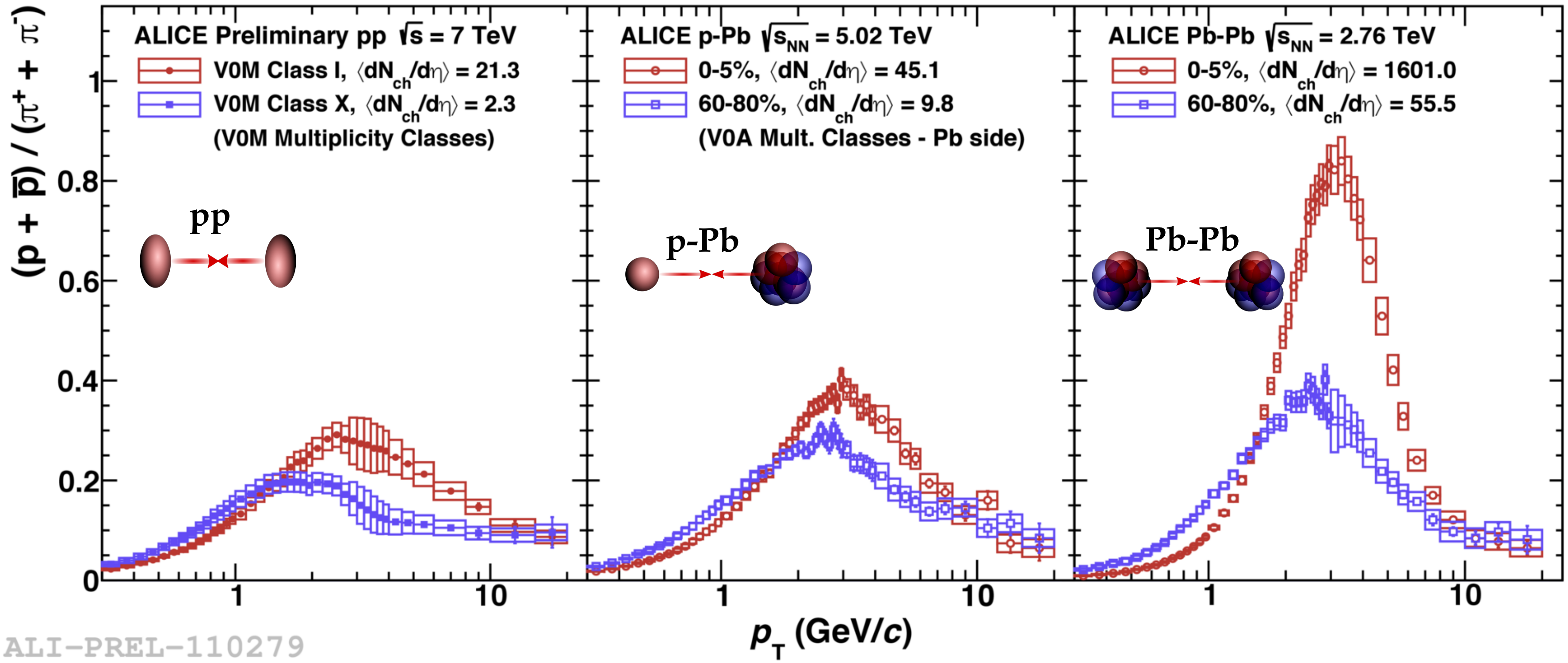
# Baryon to meson ratio



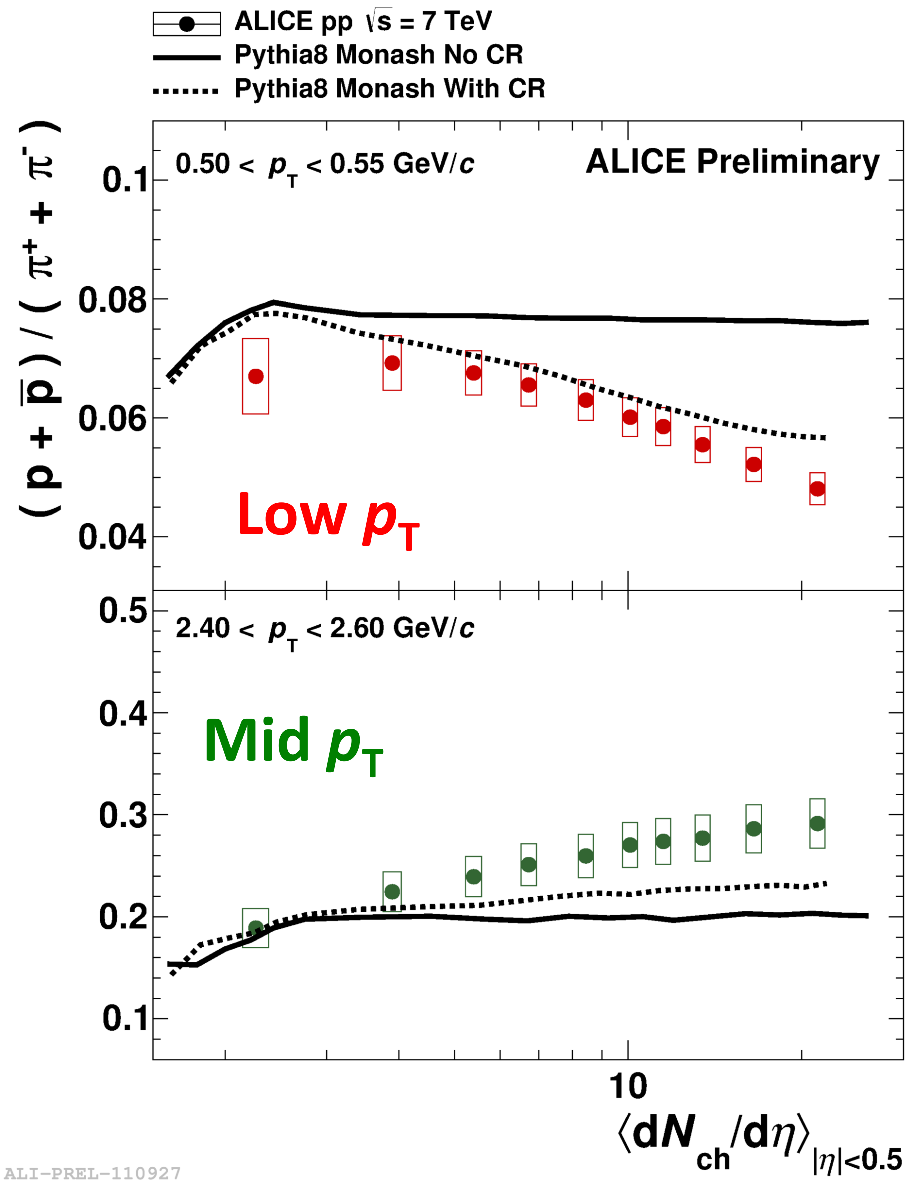

- No significant multiplicity evolution for the ratio K/π as a function of $p_T$
- Depletion at low $p_T$ and enhancement at intermediate $p_T$ for p/π

# Baryon to meson ratio




- At intermediate $p_T$ (2<$p_T$<10 GeV/c), the proton-to-pion ratio increases with event multiplicity
- The behaviour of this increase is qualitatively similar to that observed in Pb-Pb collisions
- At high $p_T$ (>10 GeV/c) the particle ratios in pp, p-Pb and Pb-Pb are consistent

# Baryon to meson ratio vs multiplicity

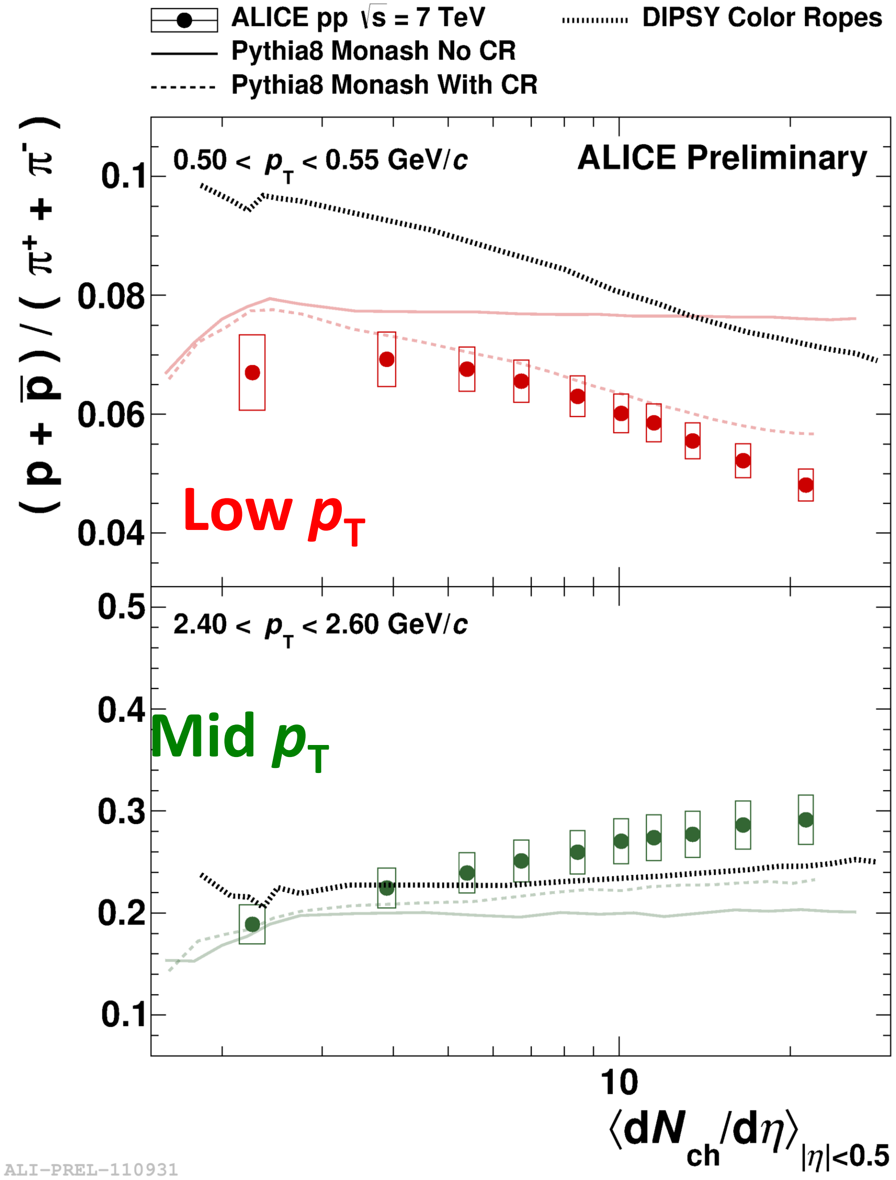



**PYTHIA 8 with and without colour reconnection**

→ colour reconnection describes qualitatively better the data

| | |
|---|---|
| **PYTHIA8** | T. Sjöstrand et al., Comput.Phys.Commun. 178 (2008) 852867 |
| **DIPSY** | C. Flensburg et al., J. High Energ. Phys. (2011) 2011: 103 |
| | C. Bierlich et al., J. High Energ. Phys. (2015) 2015: 148 |
| | C. Bierlich et al., Phys. Rev. D 92, 094010 |
| **EPOS LHC** | T. Pierog et al., Phys. Rev. C 92, 034906 (2015) |

# Baryon to meson ratio vs multiplicity




**PYTHIA 8 with and without colour reconnection**

→colour reconnection describes qualitatively better the data

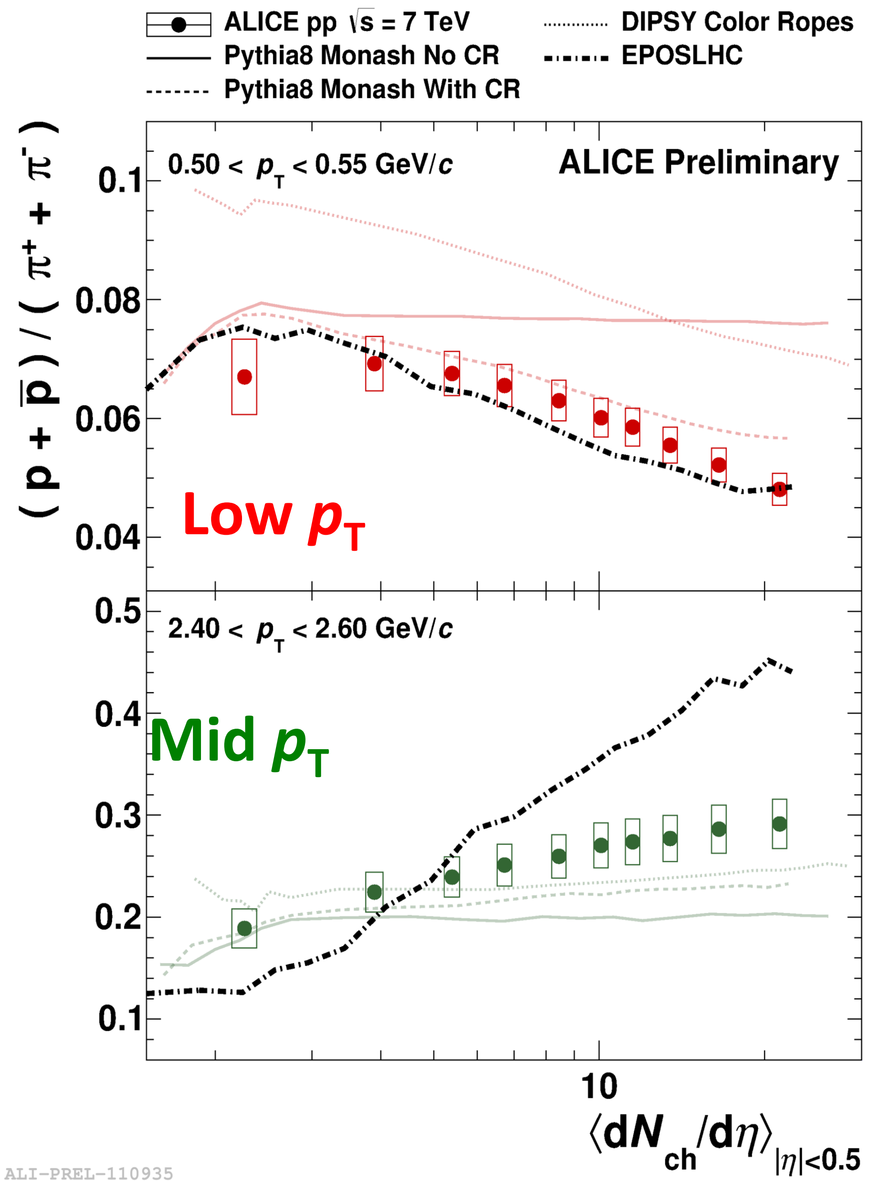
**DIPSY:**

→ Describes the measured trends in a qualitative way

→effect at low $p_T$ overestimated


**PYTHIA8** T. Sjöstrand et al., Comput.Phys.Commun. 178 (2008) 852867
**DIPSY** C. Flensburg et al., J. High Energ. Phys. (2011) 2011: 103
C. Bierlich et al., J. High Energ. Phys. (2015) 2015: 148
C. Bierlich et al., Phys. Rev. D 92, 094010
**EPOS LHC** T. Pierog et al., Phys. Rev. C 92, 034906 (2015)

# Baryon to meson ratio vs multiplicity




**PYTHIA 8 with and without colour reconnection**

→colour reconnection describes qualitatively better the data

**DIPSY:**

→ Describes the measured trends in a qualitative way

→effect at low $p_T$ overestimated

EPOS LHC:

Collective radial expansion

→Describes only the trends for the low $p_T$


**PYTHIA8** T. Sjöstrand et al., Comput.Phys.Commun. 178 (2008) 852867

**DIPSY** C. Flensburg et al., J. High Energ. Phys. (2011) 2011: 103

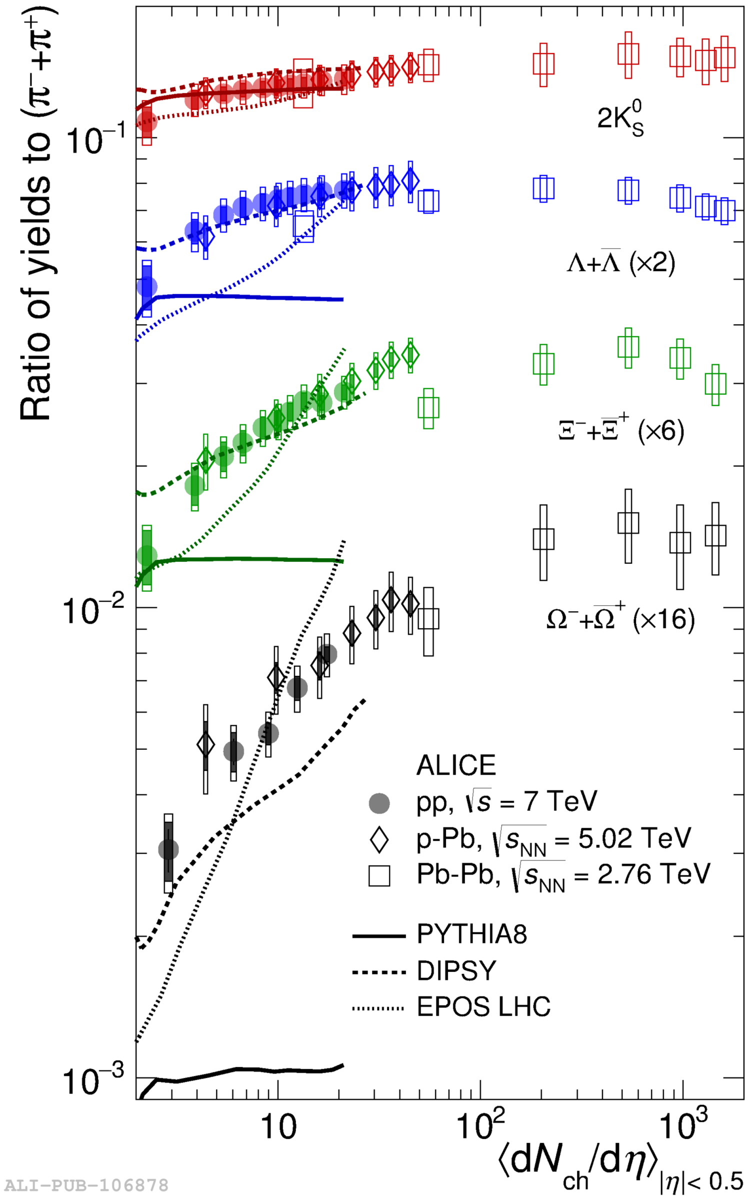
C. Bierlich et al., J. High Energ. Phys. (2015) 2015: 148

C. Bierlich et al., Phys. Rev. D 92, 094010

**EPOS LHC** T. Pierog et al., Phys. Rev. C 92, 034906 (2015)

# Strangeness in pp

NATURE PHYSICS DOI: 10.1038/NPHYS4111



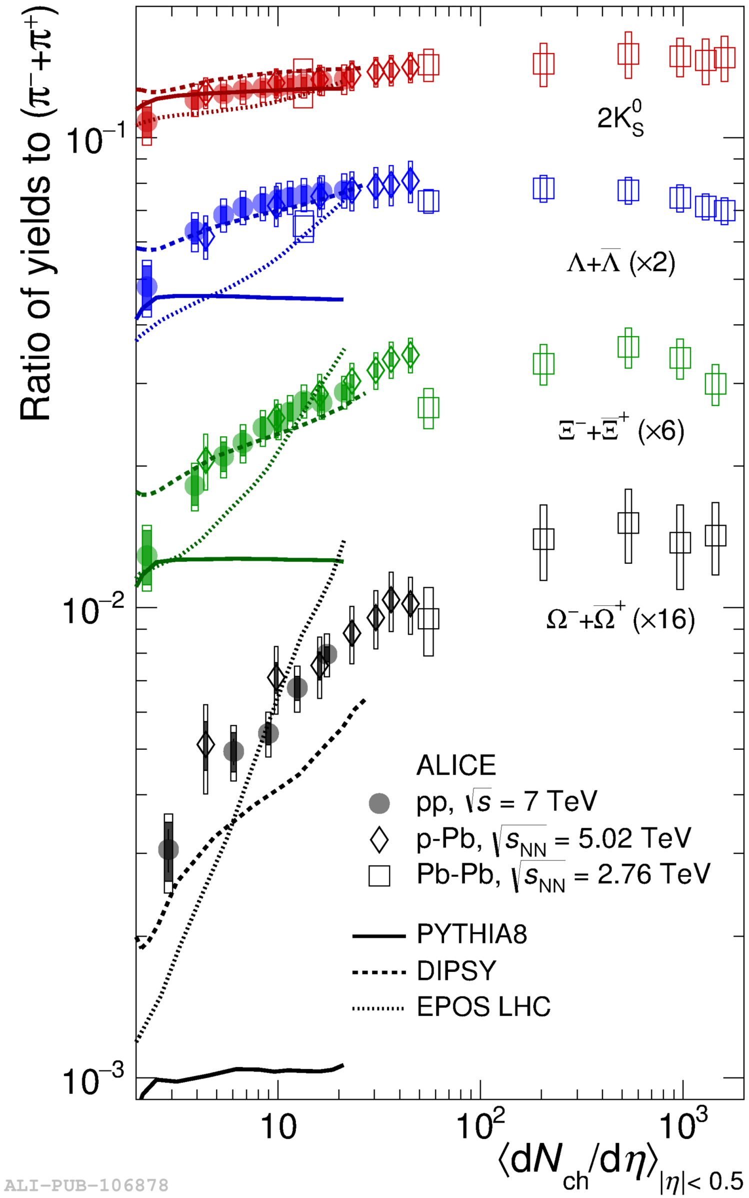

Smooth evolution of $p_{\mathrm{T}}$-integrated particle ratios across different colliding systems as a function of ‹$dN_{ch}/d\eta$› is observed.

- PYTHIA8: pQCD-inspired. Colour reconnection has little effect. Does not describe the strangeness enhancement.
- EPOS LHC: Collective hadronization + collective flow. shows enhancement qualita9vely 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!**

# Strangeness in pp

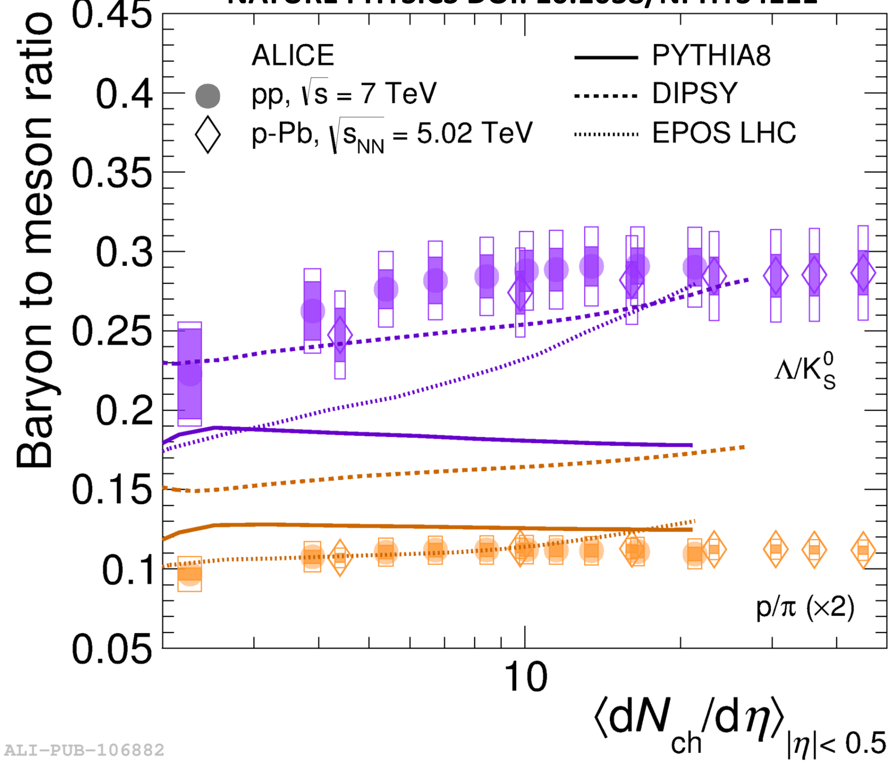
NATURE PHYSICS DOI: 10.1038/NPHYS4111



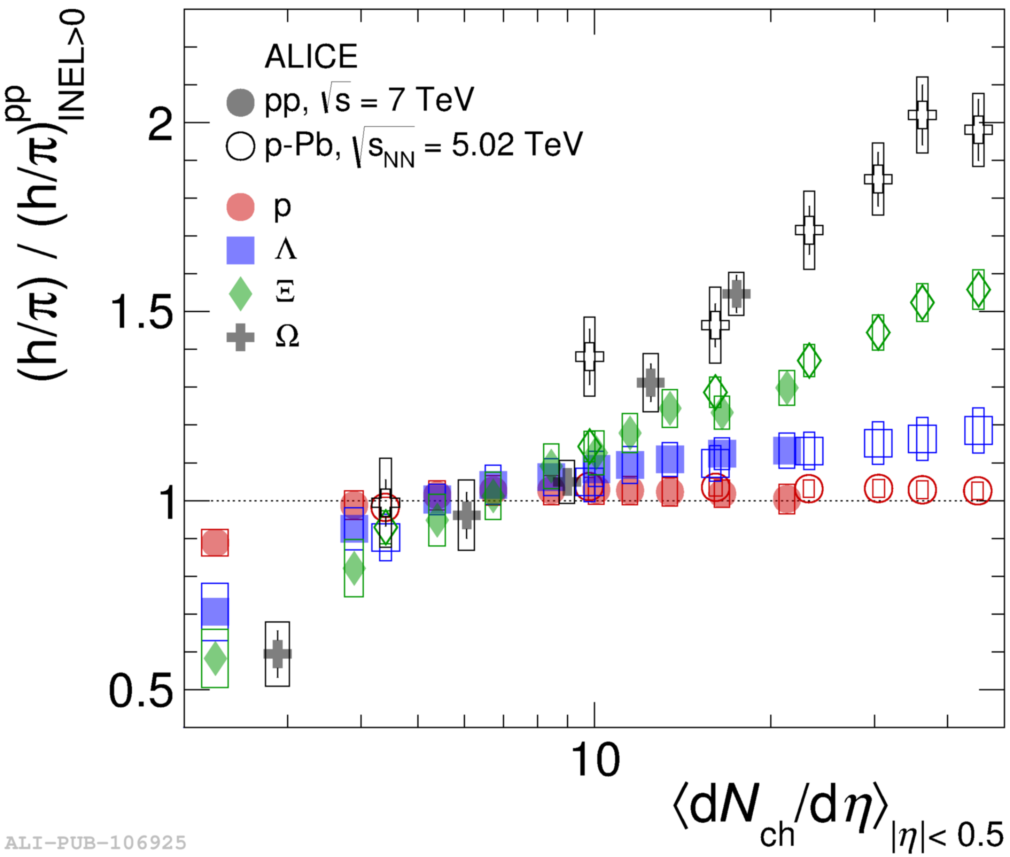

In p/ $\pi$ and $\Lambda/K^0_s$ the only effect could be baryon/meson or mass, because there is no net-strangeness difference

**→ the ratios are flat**

NATURE PHYSICS DOI: 10.1038/NPHYS4111



# Strangeness in pp




- Double-ratio in pp collisions 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**

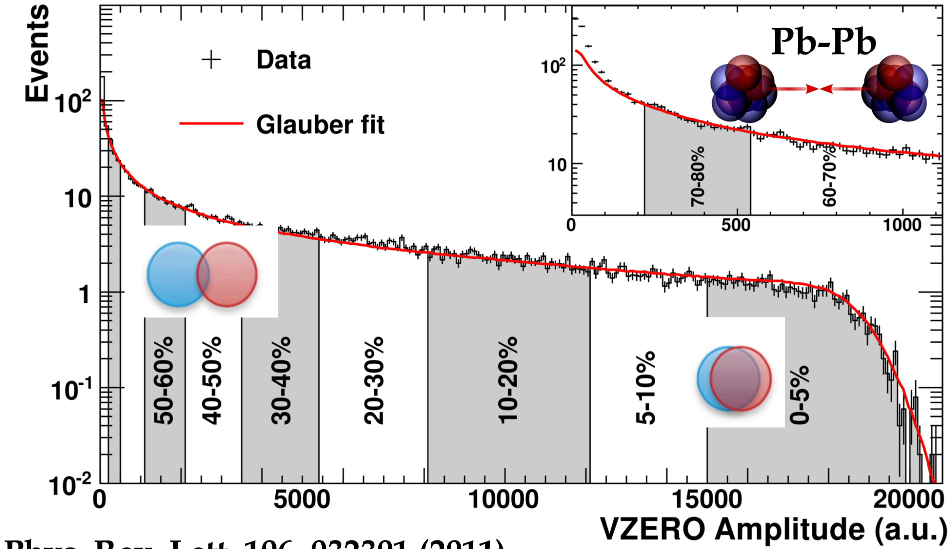
Is the same enhancement present at higher energy (13 TeV)?
Is it collision-energy dependent or multiplicity driven?

# Summary

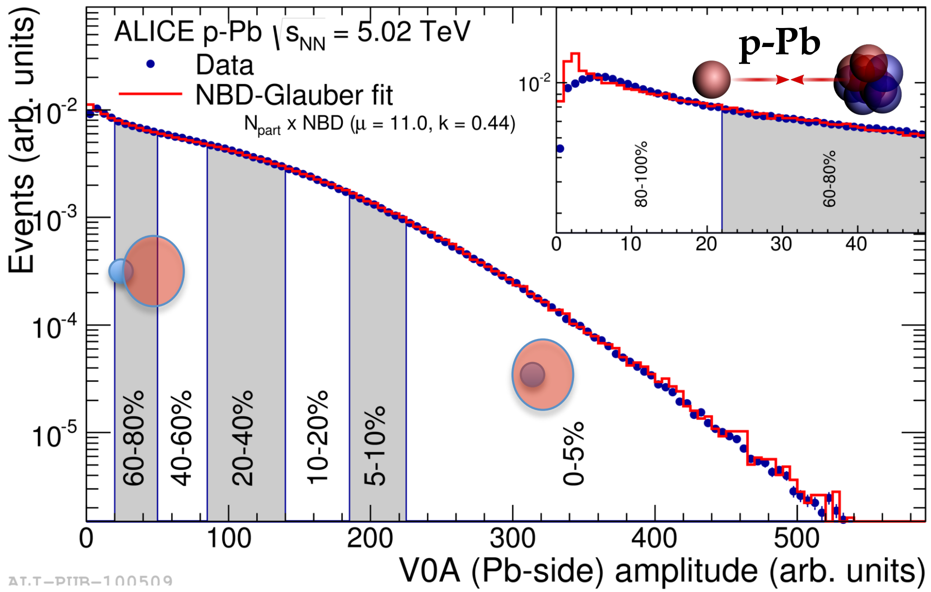
- Several similarities between pp, p-Pb, and Pb-Pb collisions have been reported
  - collectivity
  - baryon/meson ratio
  - strangeness production
- Predictions from Monte Carlo models show poor agreement with the measurements
- Further investigations are necessary to understand the underlying particle production mechanisms in smaller systems

# Backup

# Multiplicity estimation



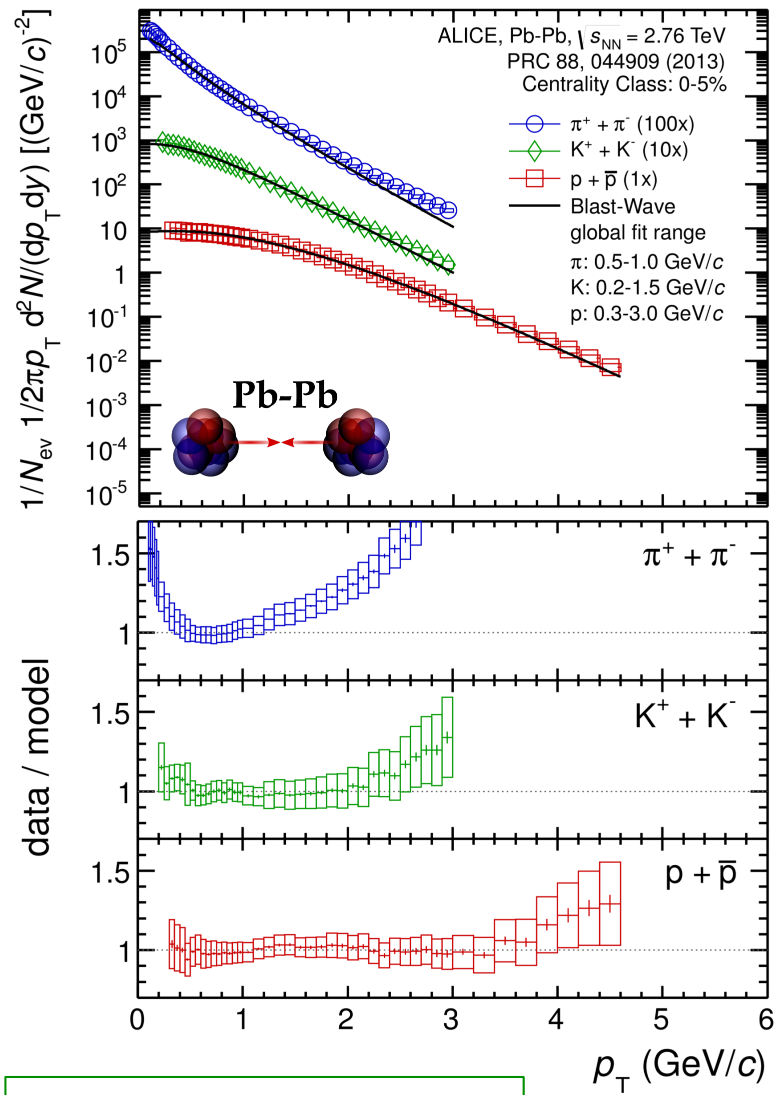

Phys. Rev. Lett. 106, 032301 (2011)



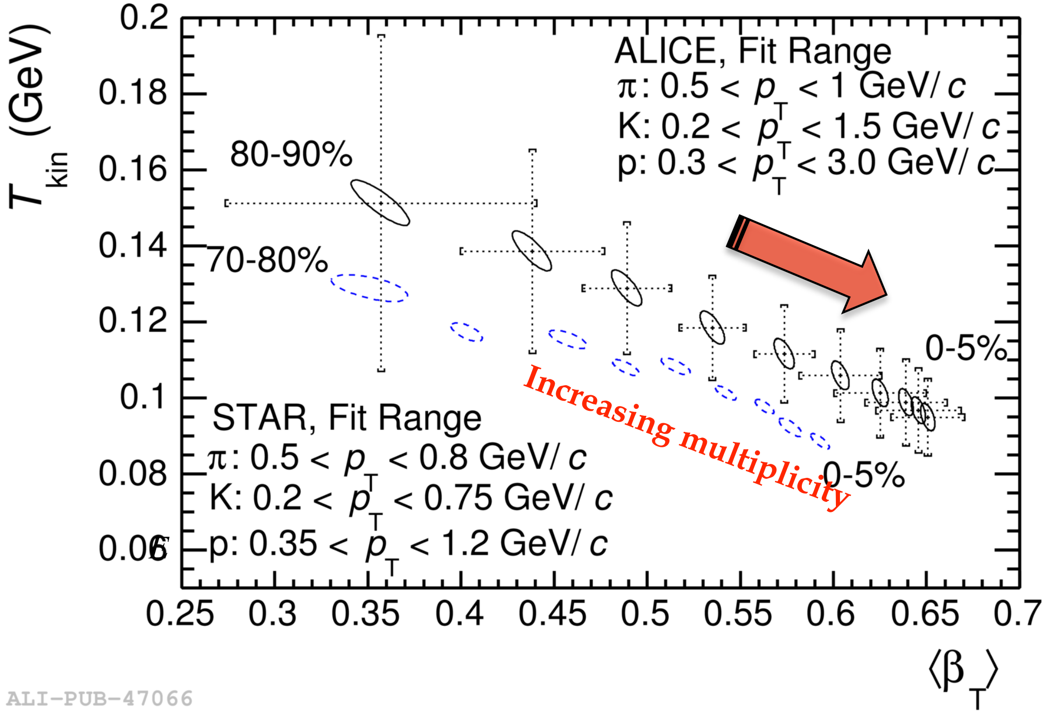

Phys. Rev. C 91 (2015) 064905

- Multiplicity is defined as the number of charged particles per event
- Linked through the impact parameter to the collision centrality in Pb–Pb
- ALICE measures the event activity at forward rapidity with the V0 detector
- Wide range of measured multiplicities
  - from $\langle dN_{ch}/d\eta \rangle \approx 2$ in pp
  - to $\langle dN_{ch}/d\eta \rangle \approx 1600$ in central Pb–Pb

# Spectra evolution in Pb-Pb




Phys. Rev. C 88, (2013) 044910




- Mass dependence of the spectral shape
  - **radial flow**
- Blast Wave
  - **simplified hydrodynamic model**
- Well described spectral evolution

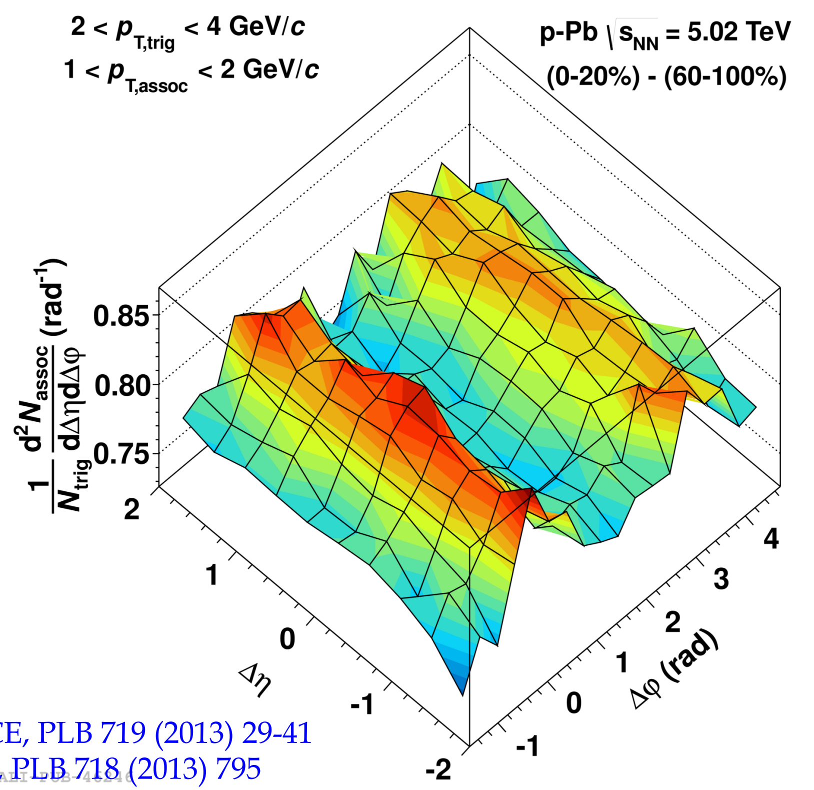
$$E\frac{d^3N}{dp^3} \propto \int_0^R m_T I_0\left(\frac{p_T \sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_T \cosh\rho}{T_{kin}}\right) r\,dr$$

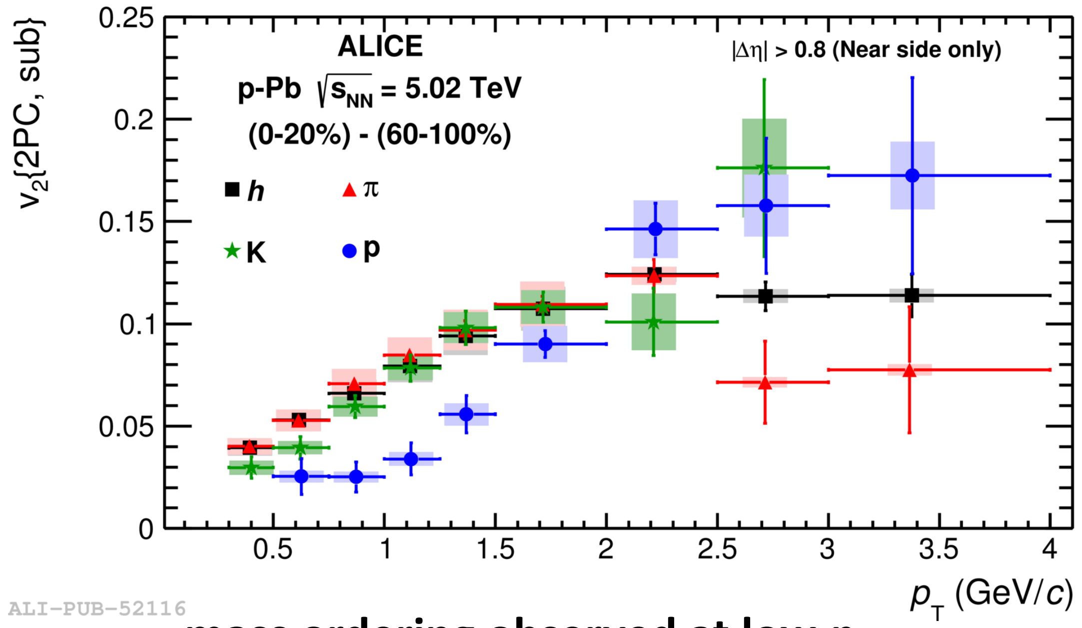
**Schnedermann, Sollfrank and Heinz Phys. Rev. C 48, 2462**

# Collectivity in small systems?

**So far, pp and p-A collisions were playing the role of control experiments**
- disentangle the so-called cold nuclear matter effects from those attributed to the hot and dense QCD medium (sQGP) produced in central heavy-ion collisions

## Striking findings in high multiplicity p-Pb events



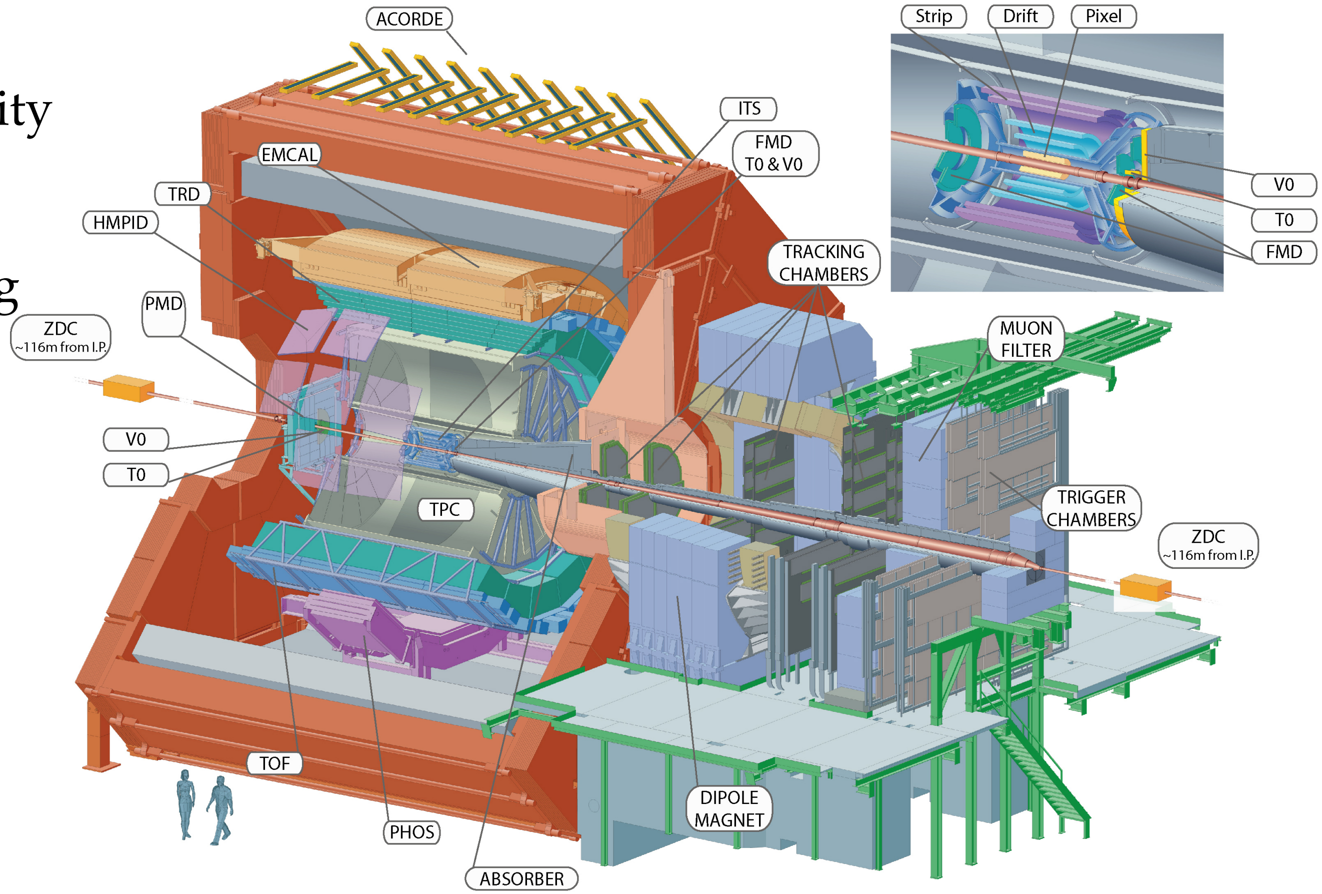




ALICE, PLB 719 (2013) 29-41
CMS, PLB 718 (2013) 795
ALICE, PLB 726 (2013) 164-177
ALICE, PLB 728 (2014) 25-38

**mass ordering observed at low $p_T$**
lower $v_2$ for heavier particles
crossing at higher $p_T$
**reminiscent of A-A observations**

# The ALICE apparatus

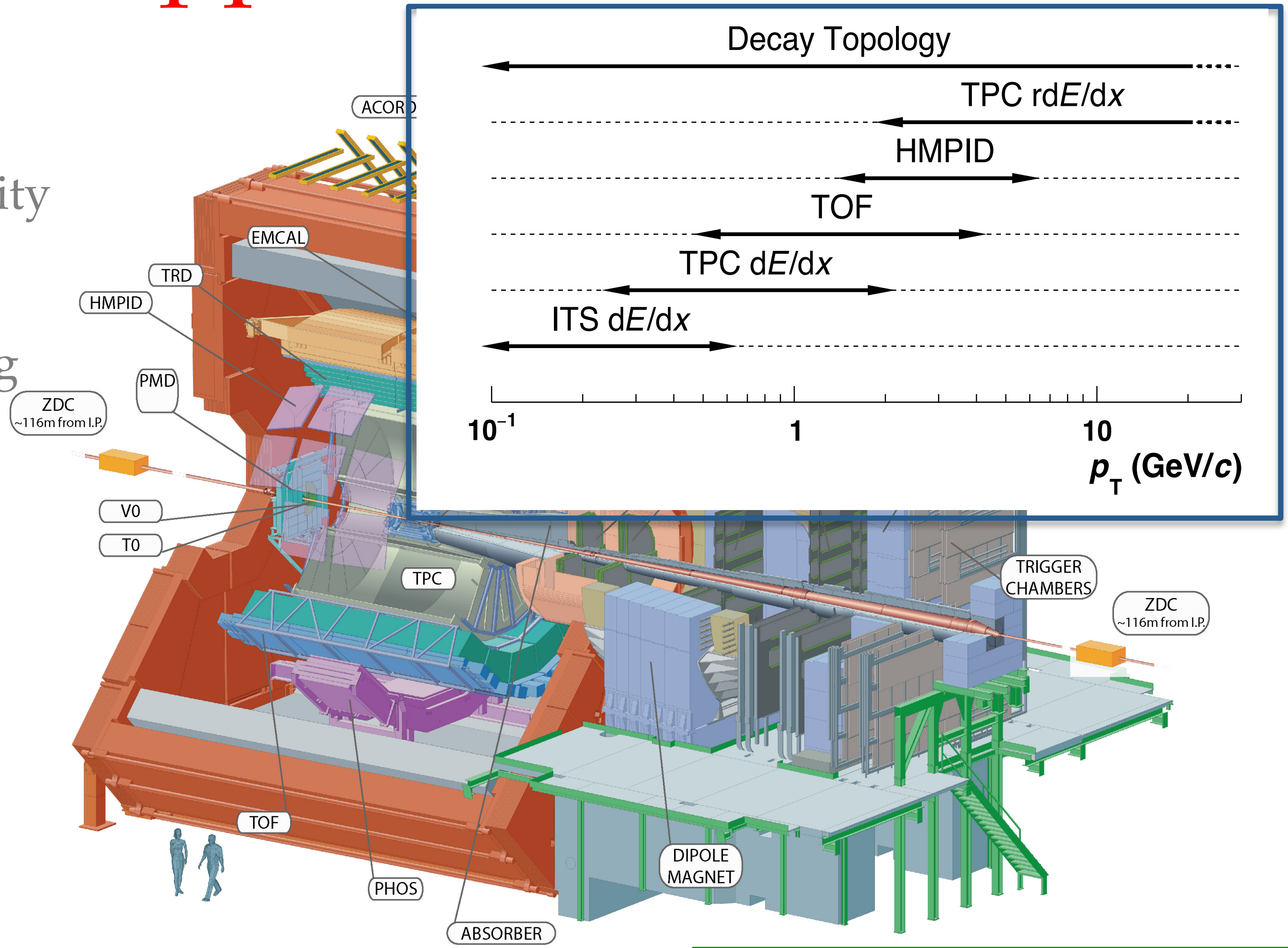
- Moderate magnetic field (B = 0.5 T) in the midrapidity region
- Low momentum tracking down to $p_T \approx 100$ MeV/$c$
- High granularity to cope with the high occupancy
- Extensive Particle IDentification (PID) capabilities




More information:
**ALICE, IJMPA 29, (2014) 1430044**

# The ALICE apparatus

- Moderate magnetic field (B = 0.5 T) in the midrapidity region
- Low momentum tracking down to $p_T \approx 100$ MeV/$c$
- High granularity to cope with the high occupancy
- Extensive Particle IDentification (PID) capabilities




Central barrel:

2π tracking and PID

|η|<1, B = 0.5 T

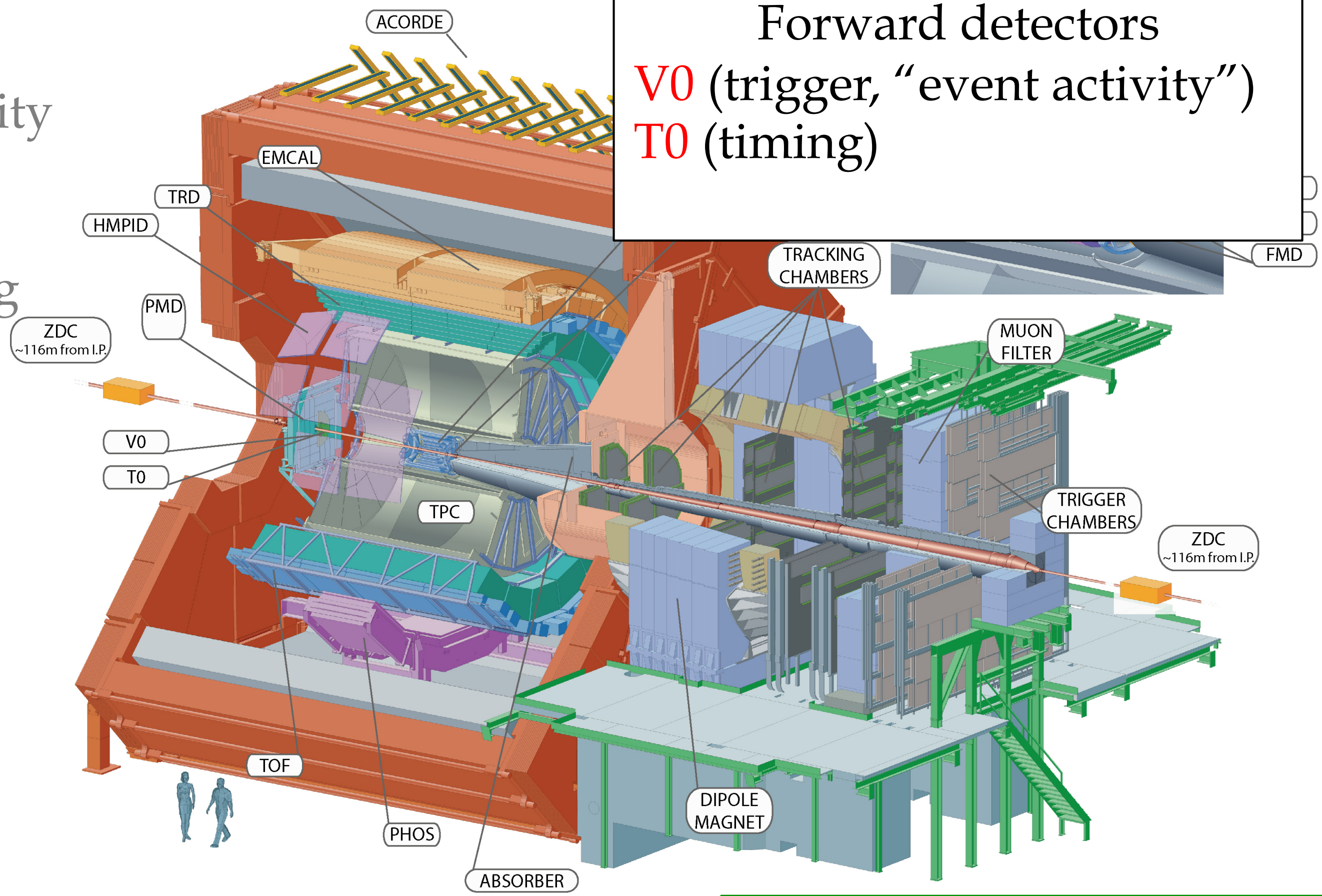
(HMPID RICH: |η|<0.6, Δφ=57°)

More information:
**ALICE, IJMPA 29, (2014) 1430044**

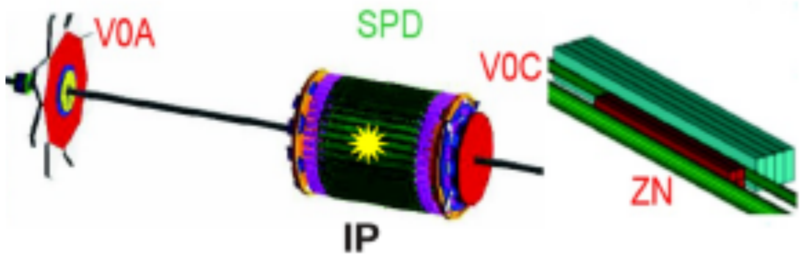
# The ALICE apparatus

- Moderate magnetic field (B = 0.5 T) in the midrapidity region
- Low momentum tracking down to $p_T \approx 100$ MeV/$c$
- High granularity to cope with the high occupancy
- Extensive Particle IDentification (PID) capabilities

Forward detectors
V0 (trigger, “event activity”)
T0 (timing)




More information:
**ALICE, IJMPA 29, (2014) 1430044**




V0A detector:
$2.8 < \eta < 5.1$, positioned in the Pb-going direction