Collective behaviour in small collision systems measured by ALICE at the LHC

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Introduction

The interpretation of heavy-ion (AA) results depends on the outcome of the corresponding control measurements in proton-proton (pp) and proton-nucleus (pA) collisions, where the system size and the produced number of particles are relatively small and final state effects (attributed to the hot and dense QCD medium) are not expected to be present.

However, recent results from different measurements at the LHC (ALICE, CMS, ATLAS) in high multiplicity pp and p-Pb collisions revealed QGP-like effects (flow-like patterns and long range angular correlations [1]).

Beside the application of hydrodynamical calculations in the description of the observed phenomena, models, which do not require the formation of the hot and dense QCD medium, also can give meaningful predictions. For example, long range angular correlations can be produced in the framework of Color Glass Condensate [2], which is also able to reproduce the anisotropic flow coefficients. In addition, it has been shown, that in PYTHIA flow-like effects can be produced via boosted strings [3].

In heavy ion collisions the p_T distributions of identified hadrons carry information about the collective expansion of the system. In this work we study the evolution of the spectral shapes of identified hadrons as a function of event multiplicity, N_{ch}, in pp and p-Pb collisions.

Particle Identification (PID) is done using the central barrel detectors in ALICE (**Fig.1**). ALICE has unique PID capabilities, among the other LHC experiments, to identify hadrons in a broad p_T range.

N_{ch} was measured using the V0A detector of ALICE, which is a small angle detector consisting of scintillator counters and installed on the "A" side (Pb-going side) of the ALICE interaction point.

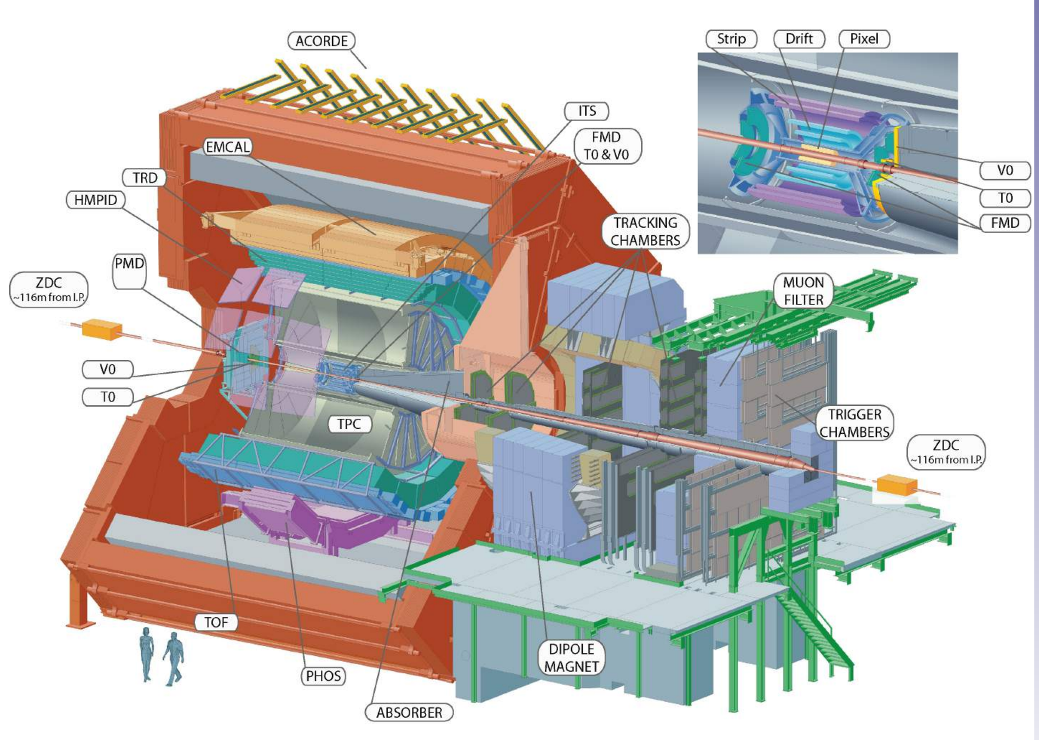


Fig.1 Schematic view of ALICE at the LHC.

Particle Identification in ALICE

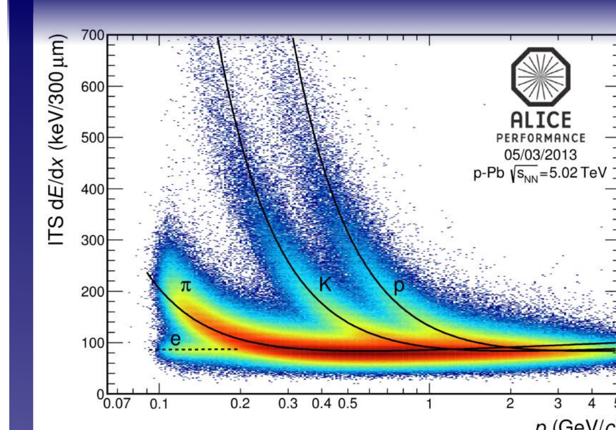


Fig.2 The specific energy loss as a function of momentum p in the Inner Tracking System (ITS).

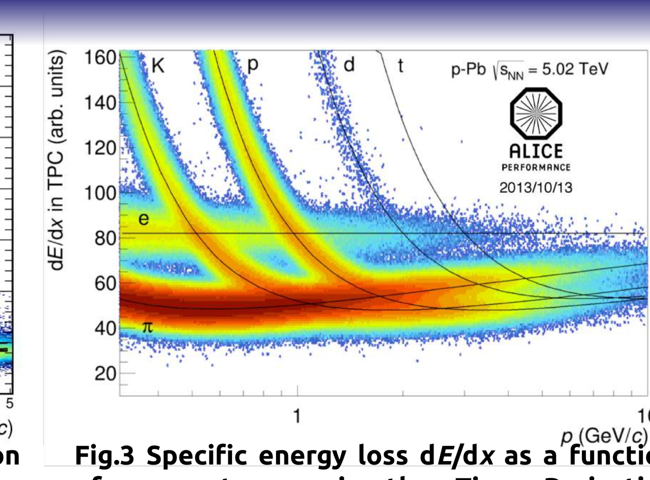


Fig.3 Specific energy loss dE/dx as a function of momentum p in the Time Projection Chamber (TPC).

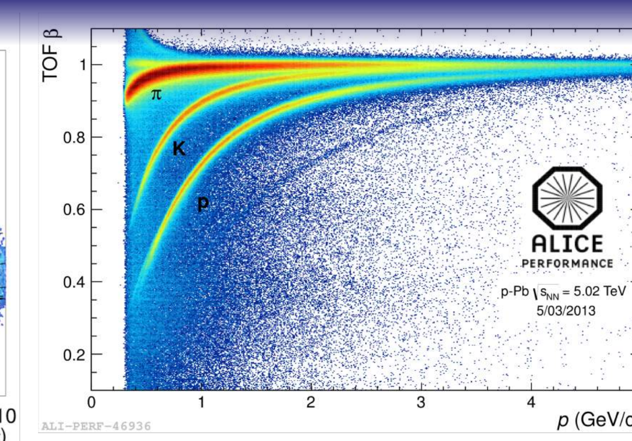


Fig.4 Velocity of particles as a function of p measured by the Time Of Flight detector (TOF).

PID approaches[5]

Three approaches are used for the identification of $\pi^{\pm}, K^{\pm}$ and $p(\bar{p})$, called "ITS standalone", "TPC/TOF" and "TOF fits". **Tab. 1** shows the corresponding p_T reach for each approach.
In addition, K^0_s and $\Lambda(\bar{\Lambda})$ particles were reconstructed using their V^0decay topology in the channels $K^0_s \to \pi^+\pi^-$ and $\Lambda(\bar{\Lambda}) \to p\pi^-(\bar{p}\pi^+)$.

ITS standalone (ITSsa)

A probability for each particle species is calculated in each layer based on the measured energy loss signal and the known response function. The information from all layers is combined in a Bayesian approach and the type with the highest probability is assigned to the track.

TPC/TOF

In this region a track-by-track ID is possible by requiring that the measured dE/dx of the particle and time-of-flight are within ±3σ from the expected values in the TPC and/or TOF. For lower p_T only the TPC is used.

TOF fits

In this method the time distribution of the time of flight is fitted to extract the particle yields, with the expected shapes based on the knowledge of the TOF response function for different particle species.

Tab.1 p_T ranges in the different analyses (GeV/c)

Analysis	π	K	p
ITSsa	$0.1-0.7$	$0.2-0.6$	$0.3-0.65$
TPC/TOF	$0.2-1.5$	$0.3-1.3$	$0.5-2.0$
TOF fits	$0.5-3.0$	$0.5-2.5$	$0.5-4.0$

Results and discussion

Average transverse momentum $\langle p_T \rangle$ versus N_{ch}

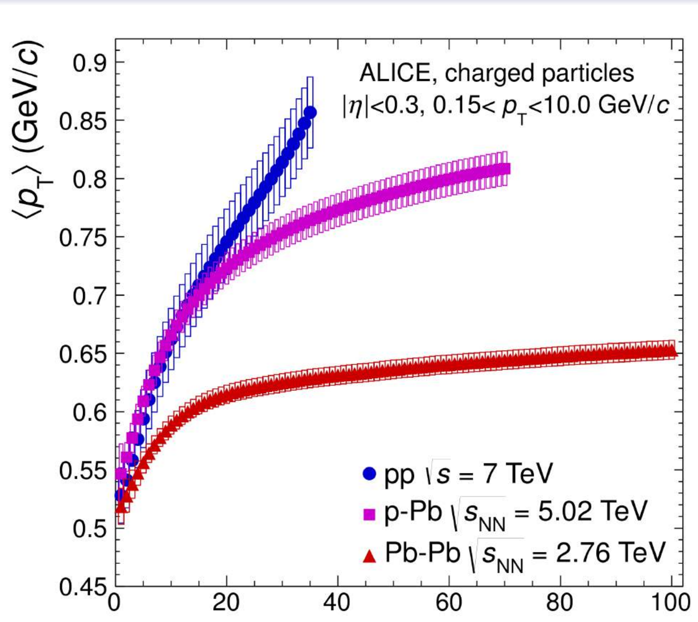
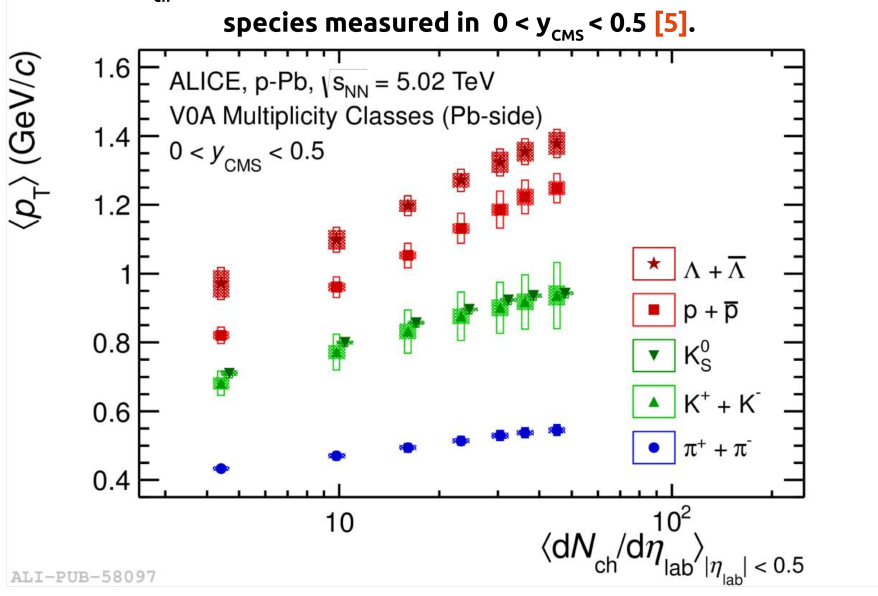


Fig.6 Average transverse momentum $\langle p_T \rangle$ versus charged particle multiplicity N_{ch} in pp, p–Pb, and Pb–Pb collisions for $|\eta|<0.3$ [4].

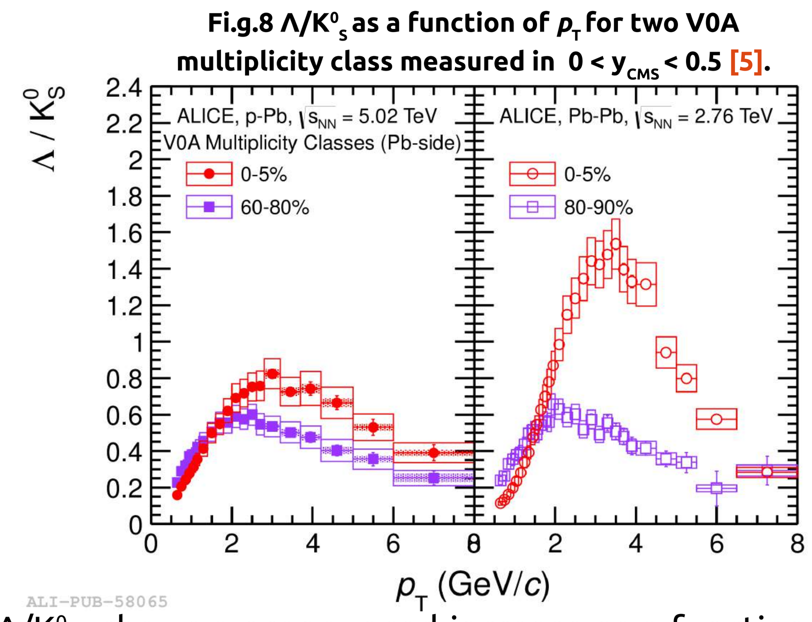
- In pp collisions the average transverse momentum as a function of charged particle multiplicity (N_{ch}) shows change in slope at the value of $N_{ch} \approx 10$.
- PYTHIA (with color reconnection [9]) and EPOS (collective effects via parametrization) captures the observed behaviour of $\langle p_T \rangle$ vs. N_{ch} in pp.
- In p-Pb collisions the $\langle p_T \rangle$ follows pp up to ≈ 14 N_{ch}. For $N_{ch} > 14$ it saturates at smaller values than in pp. This behaviour cannot be described by a superposition of individual pp collisions.
- EPOS describes the p–Pb data assuming collective flow.
- Pb-Pb data shows only a moderate increase of $\langle p_T \rangle$ with N_{ch}.

Fig.7 Average transverse momentum as a function of dN_{ch}/dη in V0A multiplicity class for different particle species measured in $0 < y_{CMS} < 0.5$ [5].



- $\langle p_T \rangle$ shows an increase with multiplicity, which is stronger for heavier particles.
- A similar mass ordering was observed in pp and Pb-Pb collisions as a function of multiplicity.

Fig.8 Λ/K^0_s as a function of p_T for two V0A multiplicity class measured in $0 < y_{CMS} < 0.5$ [5].



- Λ/K^0_s shows a pronounced increase as a function of multiplicity at intermediate p_T and a corresponding depletion at low p_T.
- In Pb-Pb collisions the observed rise of the particle ratios and its multiplicity dependence for pT ≤ 1 GeV/c is a feature of radial flow.
- In p-Pb collisions similar behaviour is observed.

Indication of flow patterns in p-Pb

- The p_T spectra in high multiplicity pp and p-Pb collisions show a clear evolution with multiplicity [5]; this effect is well known from heavy ion collisions.
- In heavy ion collisions the flattening of the p_T spectra and its mass ordering (due to the collective radial expansion of the system) as a function of multiplicity can be tested using the blast-wave model [6].
- For the 5-10% V0A multiplicity class, models, e.g. the Kraków hydrodynamic model, reproduce the kaon and pion spectra fairly well below 1 GeV/c.
- A deviation for higher p_T might show the limit of hydrodynamical models. The data could indicate the onset of a non-thermal (hard) component, which in more peripheral collisions is not dominated by the flow-boosted thermal component.
- Models incorporating final state effects, such as EPOS, give good description of the data.

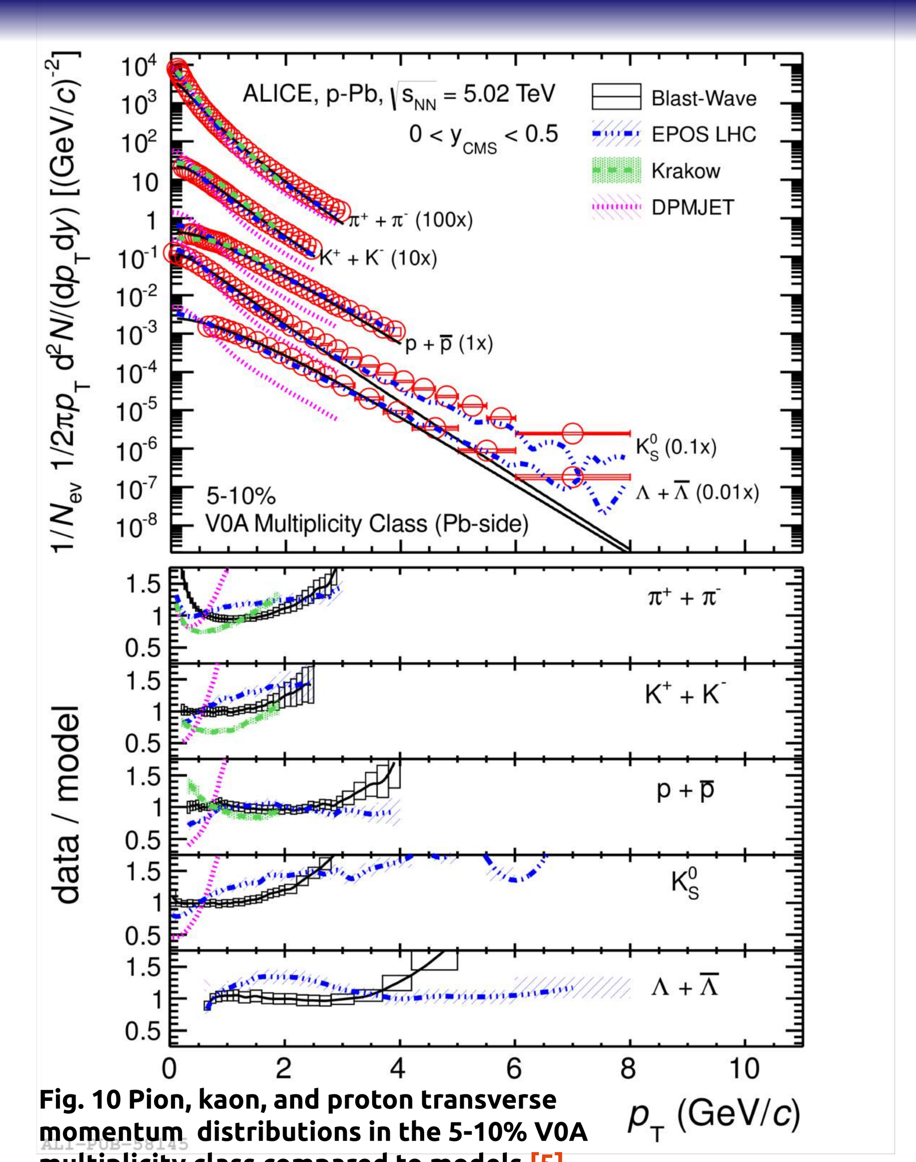


Fig. 10 Pion, kaon, and proton transverse momentum distributions in the 5-10% V0A multiplicity class compared to models [5].

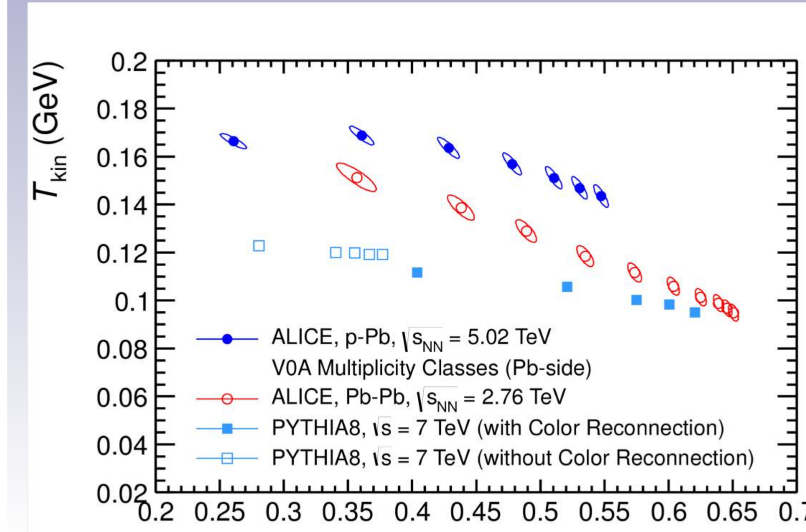


Fig. 9 Results of blast-wave fits, compared to Pb–Pb data and MC simulation [5].

- In p-Pb data there is a presence of flow-like effects – in Pb-Pb strong radial flow is observed [7].
- At similar dN_{ch}/dη p-Pb and Pb-Pb systems show similar T_{kin}, but p-Pb has larger radial flow $\langle \beta_T \rangle$ – this could be explained as a consequence of the selection bias of harder events.; howerver, in [8] this observation was suggested as a consequence of stronger radial gradients.
- PYTHIA8 [9] (with color reconnection) can mimic radial flow.

Conclusions

(1) Long range angular correlations were observed in high multiplicity pp and p-Pb collisions.
(2) To gain further insight into these effects, the evolution of the spectral shapes of identified particles with event multiplicity in pp and p-Pb collisions has been studied.
(3) Flow-like effects have been also observed in data, but the origin of the effects is not clear.
(4) Hydrodynamic models can describe the observed effects in smaller systems, but models, where the formation of the hot and dense QCD medium is not needed, might also show good qualitative description of the data.

References

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