Search for collective expansion in pp collisions at the LHC

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Abstract. Proton-proton collisions at LHC energies reach a multiplicity density comparable to nuclear collisions at lower energy. It is therefore natural to ask whether the collective bulk behavior observed in heavy-ion collisions develops already in p-p collisions. In previous experiments, the study of $p_t$ distributions of identified particles in the framework of blast wave models provided considerable insight on the collective behavior and on the freeze-out parameters of the fireball created in heavy-ion collisions. These ideas have recently been applied also to p-p collisions at RHIC. The ALICE experiment, thanks to its excellent PID capabilities and $p_t$ coverage, offers an ideal test-bench for these studies at the LHC. In this work, we discuss the performance and analysis strategy of ALICE for blast wave studies and present some preliminary results on identified particle spectra, based on the data collected in the late 2009.

1. Introduction
Collective behaviour is one of the defining features of the matter produced in relativistic heavy ion collisions at RHIC ($\sqrt{s} = 200$ GeV) and SPS ($\sqrt{s} = 17$ GeV) energies, where several different observables are understood as due to a common velocity flow in the expanding fireball [1, 2, 3]. With the term “collectivity”, it is usually meant that the particles in a given space cell move with the same mean velocity. That is, one observes space-momentum correlations which may indicate significant final-state interactions. Collectivity could be a consequence of the pressure gradients developed in a thermalized medium, but this is not a necessary condition [2]. Proton-proton collisions at LHC energy reach multiplicity densities comparable to those of nuclear collisions at lower energies. At $\sqrt{s} = 7$ TeV, for instance, $dN/dy$ easily reaches values of several tens of particles, comparable to semi-central Cu-Cu collisions at RHIC [4, 5, 6]. It is therefore natural to ask whether collective behaviour already develops in p-p collisions at these energies.

There is no single “smoking gun” of collectivity: the understanding and discovery of collective behaviour will only come from the simultaneous study of several different observables: radial flow, HBT radii as a function of $k_T$, correlations between non-identical particles, elliptic flow, etc. The study of these observables will follow previous analyses of heavy ion collisions, but in some cases there will be important differences. In the case of elliptic flow ($v_2$), for instance the determination of the reaction plane and the subtraction of non-flow effects will be highly non-trivial [7]. In this paper, we focus on the study of radial flow through blast wave models and discuss the implications for p-p collisions.

A crucial part of this programme will be the study of the evolution of the different observables with multiplicity and with event shape: collective effects are more likely to be observed in high multiplicity and “soft” (see below) events. In the ALICE experiment, the number of pixel chips hit in a collision is available on-line. It can thus be used in the trigger logic, to produce a
“high multiplicity” trigger. This is a unique feature, which allows the experiment to enrich the sample of collected high multiplicity events (the luminosity of the LHC is high enough that it is not possible to collect all the minimum bias events produced). Hadron interactions are usually classified as either “hard” or “soft”, where by hard one means that there was an associated high \( E_T \) parton-parton interaction, leading to two collimated high \( p_T \) jets of particles. Collectivity is an inherently soft effect, so one would aim for a sample depleted of hard events. Studies to separate hard and soft events were already done in the past, for instance in Ref. [9] by the CDF collaboration, where two qualitatively different samples were indeed isolated. An issue with the strategy depicted in this reference, however, is that the selection was based on transverse energy clusters, so it could bias the transverse momentum distribution needed for this study. ALICE is pursuing several different approaches to separate hard and soft events and to characterize the shape of events: study of clusters (a la CDF or high density clusters), event shape variables, \( \Delta \eta - \Delta \phi \) and multiplicity correlations [10]. As none of the selections outlined above will be able to isolate purely soft events, similar to [9] a data driven approach will be adopted, looking for samples with different properties. The comparison of different event selection strategies will provide an estimate of the bias related to the selection itself.

2. Blast Wave models and conservation of energy and momentum
The term “blast wave” identifies a family of models inspired by hydrodynamics, which provide an analytical parametrization of the freezeout conditions. In its original implementation, the spectra of identified particles were described using only 2 parameters: a freezeout temperature and a velocity of radial expansion [11]. Over the years, this model was improved by relaxing some of its assumptions or by adding more parameters, to the purpose of describing more observables [3, 12]. A recent development, which could be particularly relevant for p-p collisions, is the so-called “Tsallis blast wave”. In this model, the Boltzmann-Gibbs statistics is replaced by Tsallis statistics, which adds a further parameter, \( q \), supposed to quantify the degree of non-equilibrium of the system. Tsallis statistics is reduced to the Boltzmann-Gibbs one for \( q \to 1 \). This model was applied to STAR p-p and Au-Au data [13], and it was found to give a very satisfactory description of the spectra up to \( p_T \approx 3 \text{ GeV/c} \). In Au-Au collision the parameter \( q \) was found to increase with decreasing centrality, as expected from its interpretation. In p-p collisions, however, it was not possible to fit both mesons and baryons with a single set of parameters. It is worth to mention that the interpretation of the parameter \( q \) is not straightforward nor uncontroversial (see for instance Ref. [14]) and one should be cautious before drawing physics conclusions. Blast wave models provide a useful tool to quantify the evolution of the spectra with event shape and multiplicity in a few simple parameters, and as such can contribute to the overall understanding of the system. Moreover, being able to describe different particles with the same set of parameters implies a specific mass ordering of the low \( p_T \) part of the spectrum, which could hint at the presence of radial flow. In p-p collisions one cannot ignore the power-law tail, which sets in at LHC energies already at moderately low \( p_T \). The Tsallis blast wave represents a possible approach to address this issue.

Another important aspect are the correlations and constraints induced by energy and momentum conservation on particle production, which cannot be ignored in small systems, including p-p collisions. These “trivial” phase-space effects introduce distortions to the \( p_T \) spectra, which weaken with increasing multiplicity and will need to be separated from collectivity/flow. These effects were investigated in Ref. [8], and it was found that p-p and peripheral Au-Au collisions are much more similar to central Au-Au once they are taken into account. The formalism developed in that reference, however, is still being debated, in particular because it depends on four unobservable parameters, which must be fitted to the data. It should be also stressed that those effects are complementary, not alternative, to collectivity: energy and momentum conservation are there whether the system is flowing or not.
3. Identified particle spectra with the ALICE detector

Identified particle spectra over a wide $p_t$ range are the basic ingredient for this kind of analysis. The ALICE detector is ideally suited for this, since it was designed to cope with the high multiplicities expected in Pb-Pb collisions at $\sqrt{s} = 5.5$ TeV, and to identify particles over a wide range of momenta. A detailed description of the apparatus can be found in [15]. In this section, we focus on the first ALICE measurements of $\pi$, K, p at $\sqrt{s} = 900$ GeV, based on a sample of about 300 000 events, collected at the end 2009 during the commissioning of the LHC. These particles are identified using the specific energy loss measurement in the Time Proportional Chamber (TPC) and in the Inner Tracking System (ITS) or using the time of flight information from the TOF detector at higher $p_t$. In the present work, the PID detectors are used independently, and the results (after checking for consistency) are combined at a later stage in the analysis, weighting the spectra for the not common part of the systematic error. The basic strategy is the same for all the detectors: the distribution of the response function is sliced in bins of $p_t$ and fitted with a superposition of gaussian-like functions, to extract the yield of the different species. The ITS can be used both in conjunction with the TPC or as a standalone tracker. In conjunction with the TPC, it allows to reduce the contamination from secondaries, by constraining the measurement close to the interaction vertex. As a standalone tracker, despite the poorer $p_t$ resolution, it allows to reconstruct tracks below $p = 200$ MeV/c, which are deflected or decay before they can reach the TPC. This is very important for blast wave studies, where the possible presence of flow mainly influences the low $p_t$ part of the spectrum. The ITS $dE/dx$ information is used in two independent analyzes, based on either ITS standalone or TPC/ITS tracks (see [16] for details). The TOF analysis uses the sub-sample of tracks reconstructed in the TPC which have a matching hit in this detector.

Figure 1 shows the very good agreement between the results of the different analyses. The spectra are normalized to inelastic collisions with a technique similar to that employed in the first ALICE publications [4, 5]. The combined spectra are fitted in Fig. 2 with the Lévy function $\frac{d^2 N}{dp_t dy} \propto p_t \left(1 + \frac{m_t - m_0}{nT} \right)^{-n}$, which provides a very good description of the data and can be used to extrapolate in order to extract yields and mean $p_t$. The Hagedorn function was also found to give a satisfactory description of the spectra, and yields results within 5%. Our results were also compared to several commonly used Monte Carlo models (Phojet and Pythia with tunes D6T, CSC and Perugia0), but none was found to give a satisfactory description of the data.
4. Conclusions

Proton collisions at LHC energies reach rather high multiplicity densities, and it becomes important to establish whether the signatures of collective behaviour observed in nuclear collisions at lower energies with similar multiplicity are already observed in p-p collisions. In this paper we argue that a conclusion on this topic will only come from the simultaneous understanding of different observables and we discussed in some detail one of those: radial flow trough blast wave fits. The basic ingredient for this kind of analysis are spectra of identified particles. ALICE has excellent experimental capabilities for these studies and we present some preliminary results for identified particle spectra integrated in centrality and event shape. These results show that the capabilities of the detector in terms of PID and tracking match the expectations, but the 900 GeV statistics does not allow for a more differential analysis. Concerning the specific question of flow, one can expect first results to come from the detailed analysis of the much larger 7 TeV sample (several hundred millions events collected in 2010), which is currently being analyzed.

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