Transverse sphericity of minimum bias proton-proton collisions in ALICE

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Abstract. In this work we report the measurement of the shape of minimum bias events reconstructed by ALICE at 0.9 and 7 TeV. The evolution of the transverse sphericity ($S_{\perp}$) with the multiplicity is studied as an approach to test the MC models using the transverse sphericity as the event shape variable. The results show that at high multiplicity the sphericity of ALICE events is 15% larger than predicted by the MC models. A second approach is based on the hardness. The sample was divided in the so-called "soft" and "hard" events defined by a cut in the transverse momentum of the leading particle ($p_{\perp} = 2$ GeV/c). With this definition, the soft events are more spherical than the hard ones. We found that MC models describe very well the soft events, but they fail for the hard ones.

Keywords: Nucleon-nucleon interactions, inelastic scattering: many-particle final states.
PACS: 13.75.Cs, 13.85.Hd

INTRODUCTION

The goal of the present work is to investigate the minimum bias (MB) proton proton collisions data at 900 and 7000 GeV taken with the ALICE detectors in the framework of the Event Shape Analysis (ESA), and more specifically of the transverse sphericity parameter. The event shapes characterize the global structure of the high energy collisions. They are among the simplest experimental measurements sensitive to the parameters of perturbative QCD and fragmentation models. They were widely studied in e^{+} e^{-} and DIS, both theoretically and experimentally [1]. More recently a modification of the concept (reducing the parameters to the transverse plane) has been studied in hadronic interactions [2]. The studies currently available applying this approach to hadronic collisions utilize datasets triggered on high energy jets. We report here the first study of an ESA applied to Minimum Bias events. The measurement of minimum bias proton-proton events in a large multiplicity interval offers the possibility to study the behavior of the sphericity parameter with the following aims [3, 4]:

- Study of the evolution of the transverse sphericity with multiplicity and as a function of the separation of the events into two categories: soft and hard events comparing the results to existing generators
- Identification of possible special event topologies.

EVENT SHAPES AND THE MULTI PARTON INTERACTIONS (MPI).

At hadron colliders the event shapes are restricted to the transverse plane in order to avoid the bias from boost along the beam axis. Commonly, the sphericity is a variable used for discriminating symmetric multi-jet topologies. It is defined in terms of the eigenvalues: $\lambda_1 > \lambda_2$ of the transverse momentum tensor:

$$\mathbf{S_{xy}} = \sum_i \begin{pmatrix} {p_x^{(i)}}^2 & p_x^{(i)} p_y^{(i)} \\ p_x^{(i)} p_y^{(i)} & {p_y^{(i)}}^2 \end{pmatrix}$$

where $\overrightarrow{p}^{i}_{\perp} = (p_x^{(i)}, p_y^{(i)})$ is the transverse momentum of the particle i in a given acceptance. The sphericity is given by:

$$S_{\perp} \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1} \tag{1}$$

The limits of $S_{\perp}$ are:

$$S_{\perp} = \begin{cases} = 0 & \text{“pencil-like” limit} \\ = 1 & \text{“isotropic” limit} \end{cases}$$

On the other hand, thrust is defined according to:

$$T \equiv \underbrace{max}_{\overrightarrow{n}_t} \frac{\sum_i |\overrightarrow{p}_{t,i} \cdot \overrightarrow{n}_t|}{\sum_i |\overrightarrow{p}_{t,i}|} \tag{2}$$

in the following, T is replaced by $1 - T \equiv \tau$.

$$\tau = \begin{cases} = 0 & \text{“pencil-like” limit} \\ = 1 - \frac{2}{\pi} & \text{“isotropic” limit} \end{cases}$$

Using the PYTHIA [5] event generator version 6.421, MB pp collisions at 7 TeV of energy in the center of mass were simulated. PYTHIA provides a set of parameters which regulate the underlying event (UE), among the processes there is the multiparton interactions (MPI). Fig.1 shows the τ spectra for events with different cuts in the $p_{\perp}$ of the leading particle. The events have at least three primary charged particles with transverse momentum above 0.5 GeV/c in $|\eta| \leq 0.8$. The tune ATLAS-CSC [6] was used in the simulations. The pictures also show the case where the MPI was switched-off. Note that as the cut in the leading $p_{\perp}$ is increased both spectra become more similar. One observes an important change in the behavior in function of sphericity of the events chosen, which encouraged us to see the behavior in real data measured in ALICE.

The Fig.2 shows the correlation between the average transverse momentum versus multiplicity for events with different topologies i. e. transverse sphericity. As in Fig.1, the cases with MPI (tune ATLAS-CSC) and without it are shown. The left side plot considers the full sample, the middle plots correspond to events with a very small transverse sphericity and finally on the right plots we show the behavior for the events with the maximum sphericity.

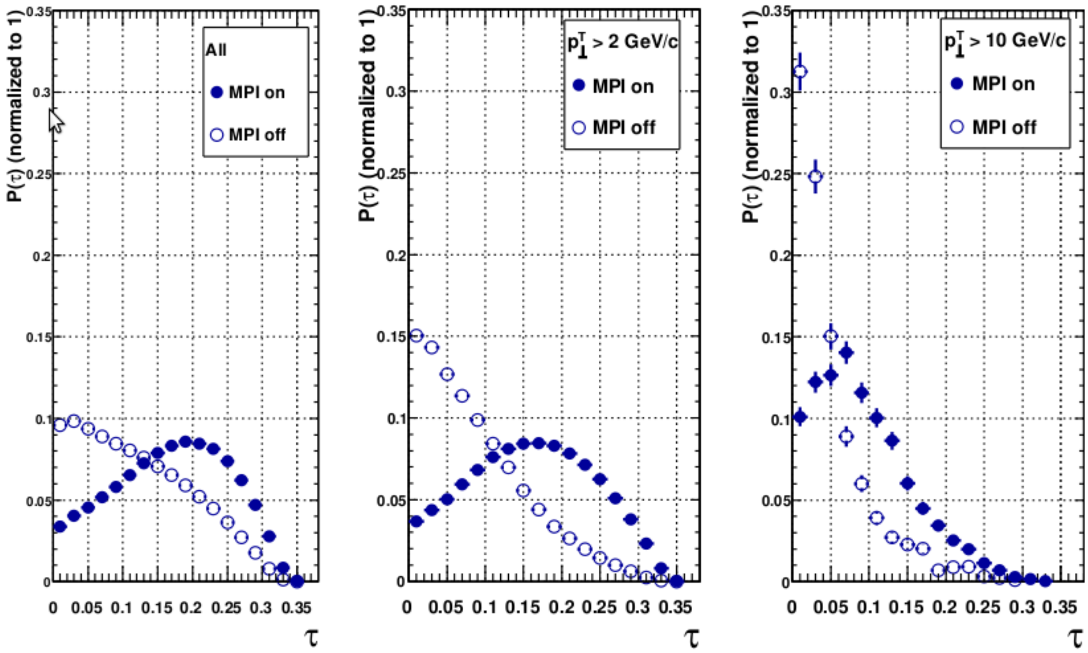

FIGURE 1. τ spectra for MB events generated with PYTHIA. Two cases are shown: MPI simulated with the tune ATLAS-CSC (full circle) and events where the MPI was switched-off (empty circle).

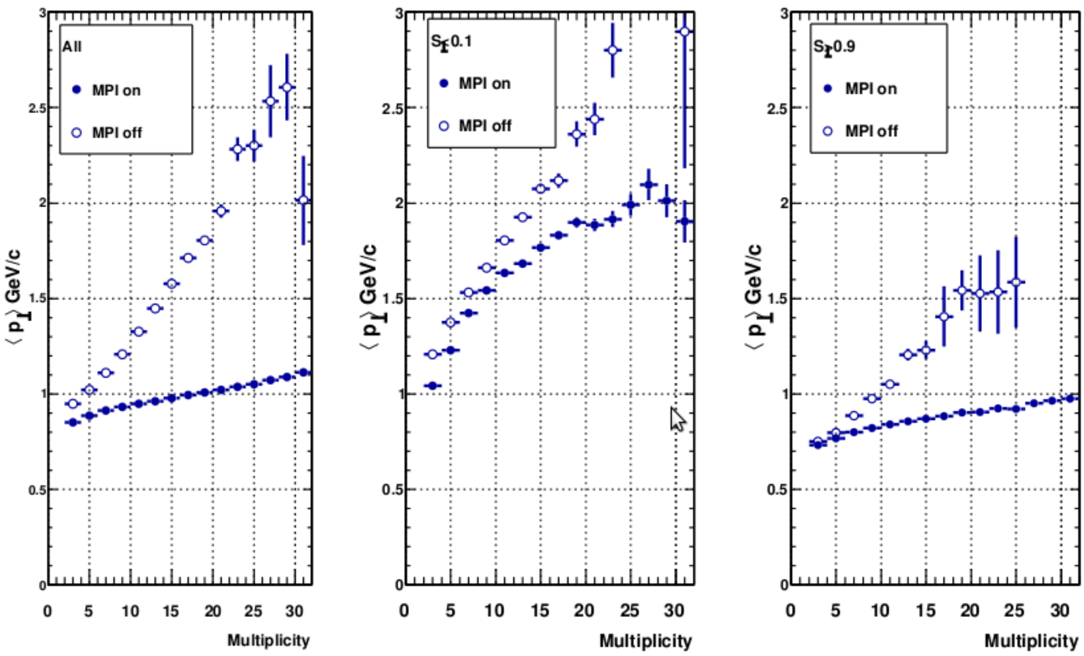

FIGURE 2. $\langle p_\perp \rangle$ vs. Multiplicity for events with MPI (full circles) and without it (empty circles). The events were classified according to their topologies. The left side plots correspond to the full sample. The middle plots corresponds to events with sphericity $S_\perp$ <0.1. The right side plot considers the case of the events with $S_\perp$ >0.9.

MEASUREMENT OF THE EVENT SHAPES IN ALICE DATA.

The analysis uses events reconstructed during the first period of data taking, at $\sqrt{s}$=0.9 and 7.0 TeV. An offline selection is applied to reject beam-induced background [7]. The tracks were reconstructed in the TPC and ITS. They passed standard cuts that select only primary tracks, and have $p_{\perp} > 0.5$ GeV/c in $|\eta| < 0.8$. A good resolution on the sphericity demands at least 3 primary tracks. The contribution from secondaries after the selection is $\sim 2.3\%$. In order to get the average sphericity versus multiplicity, the following approach was used.

Using an unfolding procedure we compute $\langle S_{\perp}\rangle^{\mathtt{unf}}$ (N_m). Where N_m is the measured multiplicity. But we are looking for: $\langle S_{\perp}\rangle^{\mathtt{unf}}$ (N_t) (N_t is the true multiplicity). In order to get the true plot we did:

- Evaluate the χ^2-minimization method in measured multiplicity bins (N_m[1], bin size: $\Delta N_m = 3$).
- Extract the $< S_{\perp} >$ as a function of N_m by χ^2-minimization.
- Compute the response matrix for the multiplicity case: $\mathtt{R}(N_t, N_m)$ using a bin size of 3. (PYTHIA).
- Extraction of $\langle S_{\perp}\rangle$ (N_t) by assignation:

$$\langle S_{\perp}\rangle (N_t) = \sum_m \langle S_{\perp}\rangle^{\mathtt{unf}} (N_m)\mathtt{R}(N_t, N_m) \tag{3}$$

For more details see [4].

Fig.3 shows the average sphericity versus multiplicity measured by ALICE at 7 TeV. Data were corrected using the response matrices computed with PYTHIA. ALICE data are compared with three different models of MB interactions plus UE: PHOJET[8] and PYTHIA (tunes PERUGIA-0[9] and ATLAS-CSC[6]). The systematic uncertainties are plotted.

The first observation seeing the data is the following: while ALICE data show a "plateau" behavior at high multiplicity ($N_t > 28$), the event generators have a decreasing behavior at such ranges of multiplicity. This is an interesting feature of the data which could be related to a more active MPI.

Next we applied the same analysis separating the total sample into two classes: events which do not have any particle with $p_{\perp} > 2$ GeV/c ("soft"); and events which do have a leading particle with $p_{\perp} > 2$ GeV/c ("hard"). Table 1 shows the statistics used in the analysis and also the ratio between the number of soft events to the number of hard ones[2]. The best prediction of the yield of the two classes is attained with PERUGIA-0, the differences in the ratios at both energies are about $\sim 12\%$.

The Fig.4 shows the average sphericity versus multiplicity at two energies: 0.9 and 7 TeV. The left side is dedicated to ALICE results while the right panel shows the MC results. In both cases the results for all, soft and hard events are plotted separately.

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[1] To get the measured multiplicity the tracks passed by the selection criteria previously described

[2] In real data, assuming that $\sim 20\%$ of the true hard events (N_t^H) are reconstructed as soft events (N_m^S). The ratio was computed using: $\frac{N_t^S}{N_t^H} = 0.8\,\frac{N_m^S}{N_m^H} - 0.2$

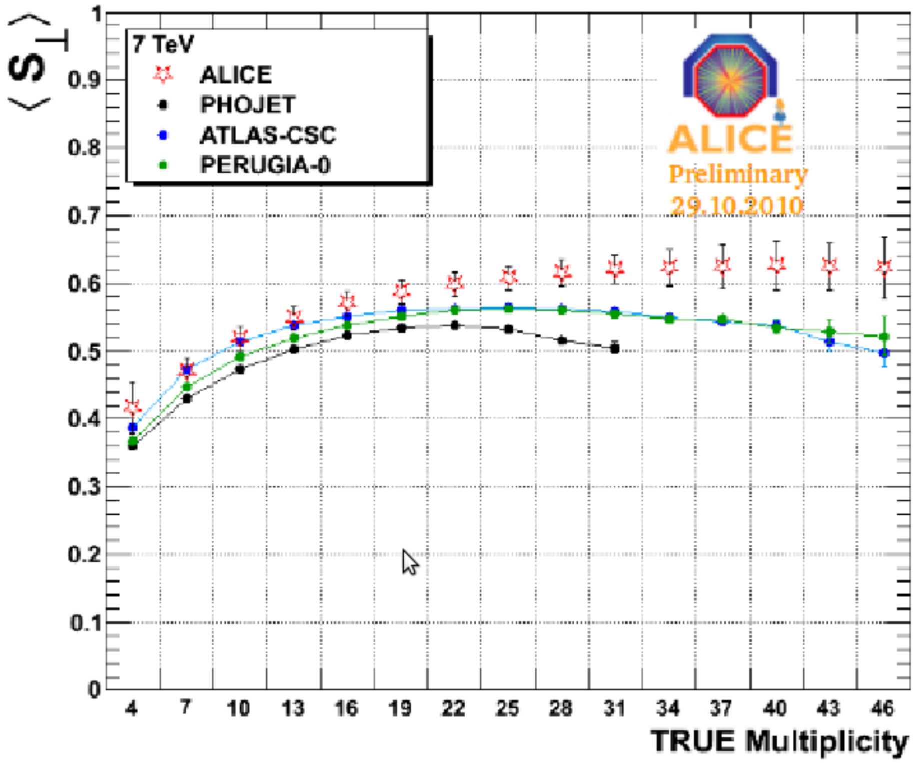

FIGURE 3. $\langle S_\perp \rangle$ vs. Multiplicity. The mean sphericity was computed using events triggered as minimum bias and with at least 3 primary tracks having $p_\perp > 0.5$ GeV/c in $|\eta| < 0.8$. Data points were corrected using response matrices from PYTHIA. Data are compared with 3 models of MB interactions plus UE. The systematic uncertainties are plotted.

TABLE 1. Ratio of the number of soft and hard events. In the present analysis, more than three primary tracks (particles) in $|\eta| < 0.8$ $p_\perp > 0.5 GeV/c$ are required. The number of events used in the analysis is shown. The corrections for reconstruction were made.

	900 GeV/c		**7 TeV**	
	No. Events*	**Soft/Hard**	**No. Events**	**Soft/Hard**
ALICE	0.52	4.83	18.4	1.92
PERUGIA-0	0.58	5.6	18.6	2.06
ATLAS-CSC	1.1	10.95	3.5	3.41
PHOJET	1.2	8.53	0.9	2.52

* Million of events.

The ALICE results indicate that the sphericity depends strongly on the multiplicity while the dependence on the collision energy is very weak. However, at the highest multiplicities the MC simulations show an altogether smaller sphericity and a trend of diminishing the mean sphericity with multiplicity while in the data we observe more like

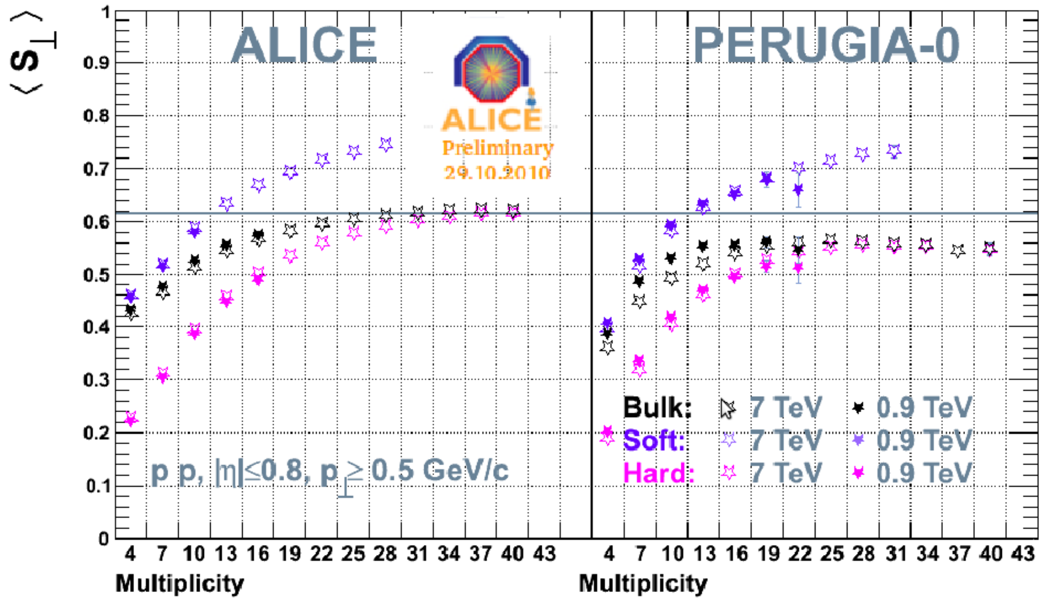

FIGURE 4. $\langle S_\perp \rangle$ vs. Multiplicity. ALICE (right) and MC predictions (left). Two energies are plotted: 0.9 and 7 TeV. In both cases the bulk (all the events), soft and hard events are treated separately.

a saturation trend. The observation seems to indicate that the high multiplicity events do have a larger proportion of jetlike events than encountered in the data. The observed difference is well outside the statistical and systematic errors.

CONCLUSIONS

From the ESA applied to the minimum bias proton-proton ALICE data at 900 and 7000 GeV we can conclude

- The analysis of the mean transverse sphericity of hard and soft events shows that the latter are well reproduced by the existing generator codes, while for the selection of hard events we observe a substantial difference in the behavior of the sphericity. The highest multiplicity events do show a difference of about 15% with respect to the generator prediction.
- There is a marked difference in the behavior of the hard and soft events in the sphericity parameter up to rather important multiplicities - at low multiplicities the difference is of a factor of two diminishing to a value of 1.2 at the highest multiplicities in the data while in the generators the difference a high multiplicity is of the order of 30%.
- The mean transverse sphericity shows a saturation in the data at high multiplicity while the generators indicate a fall in the sphericity. Studies of systematic errors like: secondaries rejection, pile-up, track cuts, model dependence do not allow to

explain the discrepancy in trend.

The study of the events shape in function of the multiplicity may provide a useful manner to tune MC generators.

ACKNOWLEDGMENTS

This work has been done with the close collaboration of Guy Paic and Eleazar Cuautle. I acknowledge useful discussions and suggestions from A Morsch, J-P Revol and K. Safarik. The work has been supported by DGAPA-UNAM under PAPIIT grants IN116008, IN115808 and IN116508 as well as by CONACyT grant 103735, 101597 and the CERN-UNAM mobility program.

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