Event shape variables, a tool for QCD study

M. Fernández, E. Cuautle and G. Paic
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70-543, Ciudad de México 04510, México

Abstract. The proton-proton collisions at LHC energies reveals important new phenomena observed in heavy ions collisions and not completely understood in small systems. Different approaches and techniques have been implemented to study those processes, but still the details of the underlying event, which correspond at certain level to soft processes remains unknown. Here we present a study of proton-proton collisions using the event shape variable sphericity for identified particles combined with multiplicity bins. The results allow us to get important features of collisions, which could be used to explore in more details and extract phenomena of QCD processes.

1. Introduction
The event shape [1] variables provide a measure of the geometry of hadronic energy momentum flow, that offer the possibility to classify the events on pencil-like and isotropic[2]. The event shape variables had a very important role in the LEP accelerator to determine the strong coupling constant, for test models of corrections by hadronic effects and for the validation of the Monte Carlo event generators. The correction by hadronization is possible because the event shape variables are calculated with the information of the final hadrons of the event.

2. PYTHIA and PHOJET event generators
QCD perturbation theory, formulated in terms of quarks and gluons, is valid at short distances. At long distances, QCD becomes strongly interacting and perturbation theory breaks down. In this confinement regime, the colored partons are transformed into colorless hadrons, through hadronization or fragmentation processes. The PYTHIA event generator allows us to compute QCD processes to simulate high-energy physics events. These are simulation of collisions at high energies between elementary particles or hadrons such as $e^+$, $e^-$, $p$, $\bar{p}$ among others, and their different combinations[3]. The generator also contains phenomenological models to describe the soft physics aspects. It incorporates parton distributions functions, initial and final state interactions, multiparton interactions, decays and string fragmentation as the main hadronization mechanisms.

An alternative generator is PHOJET[4] whose main difference with others is that the hadronization processes described by Dual Parton Model (DPM) in terms of Reggeon and Pomeron exchanges combined with the QCD improved parton model[5]. PHOJET has in particular a detailed modeling for diffractive and soft interactions.
3. Event Shape Variable

The transverse sphericity $S_T$ [6] is defined in terms of the eigenvalues $\lambda_1 > \lambda_2$ of the linearised version of the transverse momentum tensor:

$$S_{XY}^L = \frac{1}{\sum_i p_T^{(i)}} \sum_i \frac{1}{p_T^{(i)}} \left( \begin{array}{cc} p_x^{(i)} & p_y^{(i)} \\ p_y^{(i)} & p_x^{(i)} \end{array} \right)$$

(1)

where $\vec{p}_T^i = (p_x^{(i)}, p_y^{(i)})$ is the vector of transverse momentum of the $i$-th particle in a given acceptance. The transverse sphericity is given for:

$$S_T \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}.$$  

(2)

It has the property that it tends to 1 for isotropic and is 0 for pencil-like events. The definition is inherent in the multiplicity, for example $S_T$ goes to 0 for events with a low multiplicity.

4. Results

The sphericity distribution given by Eq.(2) was calculated with PYTHIA 6.421 Perugia0 and PHOJET 1.12, generating $17.5 \times 10^6$ and $13.5 \times 10^6$ of inelastic $p+p$ events at $\sqrt{s} = 7$ TeV respectively, in the central pseudorapidity region, $|\eta| < 0.8$, and transverse momentum $0.15 \leq p_T \leq 10$ GeV/c, selecting only primary particles, which include strong decay products, plus weak decay products from heavy flavour.

Figure 1 shows the invariant transverse momentum distributions for charged hadrons comparing the two event generators normalized to the respective event numbers. The ratio between them is shown in the bottom; right panel of the same figure shows the comparison of the transverse sphericity and the ratio on the bottom.

Figure 2 shows the sphericity distribution for soft and hard events, defined as those which have $p_T^\text{leading}$ less than 2 GeV/c and largest than 5 GeV/c respectively. The main differences between
two event generators are observed for hard processes, while the soft ones seem to be compatible between them. It is important to mention that the distributions are normalized to 1, to compare the shape of the distributions.

Figure 3 illustrates how the hardness (softness) of the event could be measured using multiplicity bins of the sphericity distribution: higher (lower) multiplicity means more isotropic (jetty-like) events. This kind of studies could be extended to other variables, like the number of multiple parton interactions.
A detailed analysis of the sphericity in terms of the multiplicity reveals important features of the structure of the events. Figure 3 shows the transverse sphericity for four multiplicity bins, from low to high multiplicity we see that the events evolve from dijets to isotropic events.

5. Conclusions
The sphericity variable has been studied in proton-proton collisions, comparing two different event generator models, PYTHIA and PHOJET. Transverse momentum distributions used to compute sphericity present larger differences at higher values. The sphericity obtained shows the main differences for hard QCD processes, identified by the cuts on the $p_T^{leading}$ variable. On the other side, lower and higher multiplicity bins allow to split between hard and soft sphericity distributions. A combination of the different variables (multiplicity and $p_T^{leading}$) could bring an insight of structure of the events.

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