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Event shape analysis and jet shapes at LHC

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The collisions at LHC be they proton-proton or heavy ions ones will open a completely new energy range. ALICE, the LHC experiment dedicated to the study of heavy ions will also study soft physics in proton+proton collisions. In the present work we review some recent works connected to the identification of typical event topologies in order to isolate specific cases using the so called Event Shape Analysis (ESA) and to study the effect of parton energy loss on jet shapes using existing Monte Carlo generators Q- Pythia and PYQUEN .

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Introduction

The collisions of protons result in the emission of hadrons in the available phase space. The measurements of the distribution of fragments try to identify specific features of the collisions like the momentum spectra, azimuthal correlations, jets, momentum correlations etc. In a certain manner all these measurements, for are largely inclusive. A good example is the leading particles one measures. They may belong to various jets sources: where only one jet enters in the acceptance of the detector, totally or even only partially; particles belonging to dijet or multijet events or to gamma - jet events. One does not a priori know to what event does belong the leading particle. We therefore propose to add as a common way of analysis another tool, namely the event shape analysis (ESA).
Event shape studies at hadron colliders, are still rather uncommon in the community. The work of Banfi et al.[1] has made possible to apply the event shape analysis to hadronic collisions and to experiment of limited acceptance in pseudorapidity. At LHC a large part of the studies will be linked with jets, their multiplicities, their correlations and the characteristics of the jets themselves.
In the first part we explain shortly the bases of the Event Shape Analysis (ESA) using only two of the parameters proposed by ref [1] and the results obtained for simulated Pythia results with ESA, extracting the azimuthal correlations for three distinct regions of the thrust map.
In the second part we will discuss the effect of two methods (Q-Pythia and PYQUEN) for calculating the energy loss in heavy ion collisions on the transverse momentum of the particles within different distances from the jet axis

The event structure analysis

Event shapes measure the geometrical properties of the energy flow in the collision. We present the simplest event shape analysis based on just two variables: the thrust and the recoil.

Definition of the shape variables

The shape variables at hadron colliders are defined over particles within the acceptance of the detector. The thrust (T) is defined as in the e^+e^- case, but using only transverse variables:

$$T_\perp \equiv \underbrace{max}_{\vec{n}_T} \frac{\sum_i |\vec{q}_{\perp,i} \cdot \vec{n}_T|}{\sum_i |\vec{q}_{\perp,i}|}, \qquad (1)$$

where the sum runs over all particles in the final state within the acceptance, $\vec{q}_{\perp,i}$ represent the momentum components transverse to the beam and $\vec{n}_T$ is the transverse vector that maxi-

mizes the ratio. Actually in the presentation of the analysis we will use the variable (1-*T*) corresponding to the sphericity of the event.
The definition leads to the following results: in the case of a completely isotropic distribution of the particle emitted in the transverse plane the value of *T* is 0.5, while in the case of a pure back to back jet the value will be 1.

The recoil term *R* is the normalized vector sum of the transverse momenta.

$$R_\perp \equiv \frac{|\sum_i \vec{q}_{\perp i}|}{\sum_i |\vec{q}_{\perp i}|}, \qquad (2)$$

where again the sum runs over all particles.
This quantity measures the balance of momenta of the event. For example for a di-jet event, with only one jet inside the acceptance of the detector (single jets in the further text): *R* tends to 1, i.e. maximum imbalance; in the case of back-to-back jet completely inside the acceptance: *R* tends to 0.

Selection of events

Unfortunately it is not possible to analyze the events without any cuts on the transverse momenta. The presence of low momenta particles swamps the thrust map so that a careful assesment of the necessary cuts is in order. We proceed in two steps. In the first step we determine the pseudorapidity range in which we accept the leading particles to be, and the minimum transverse momentum for the leading particle. Fig.1. shows the thrustmap obtained for 10 TeV proton--proton minimum bias collisions using only primary charged tracks. For the following analysis the pseudorapidity range was chosen +/- 0.5 and the minimum accepted transverse momentum to be 3 GeV/c. In the second step the events chosen are subjected to ESA using the full acceptance of the ALICE experiment $|\eta|<1$,and a p_t cutoff at 0.9 GeV/c.

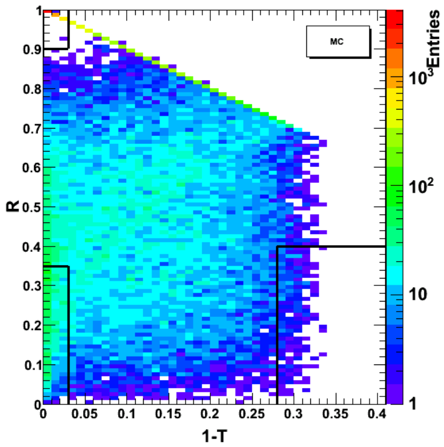

Fig.1. Thrustmap *R* vs (1-*T*) for minimum bias collisions pp collisons generated by Pythia at 10TeV. The black squares shows the three regions investigated as mentionned in the text.

We concentrate at present on 3 distinct regions of the map. The low (1-*T*) and low *R* region, low(1-*T*) and high *R* region, and finally the highest (1-*T*) and low *R* region.

Results

To study the characteristics of each region we have plotted the azimuthal correlations of the particles emitted in each region with respect to the leading particle. Recently, a similar analysis was carried for pp collisions at 200 GeV [2].
In Fig.2. we show the azimuthal correlations obtained for the 3 regions studied using charged particles only. In the low 1-*T* low R region, as expected we find well defined peaks at 180 degrees(labelled dijets); the high R region has only one peak corresponding to events with one jets in the pseudorapidity acceptance (labelled single jets), be it for the acceptance reasons, a gamma-jet event or a strong neutral/ charged fluctuation.
The high 1-*T* region on the contrary reveals a very special behavior: the peaks in the backward hemisphere are located symmetrically around the direction opposite to the leading particle suggesting three prong events known from the LEP times as "mercedes" events in electron positron collisions. It is worth noticing that the three-prong structure is very small compared with the other two topologies, which gives a measure of the sensitivity of the event shape analysis. Furthermore it is interesting that the three prong events exhibit very few associated particles at π/2 so that the the leading particle is almost alone, at least in the analysed p_t range.
In Fig 3. we show the p_t distributions of the particles in azimuth including the leading particle. We observe that the p_t distributions of the region show that the leading and associated peaks have a much softer distribution than the particles corresponding to regions of dijets and/or monojets. In Fig. 4 we plot the distribution of the leading particles for the three regions. One sees that the 3-prong events, although their slope is rather similar to the other events, due to their low probability, reach lower transverse momenta than the other leading particles. This of course influences the "detectability" of the three-prong events. If one chooses too high a threshold in the transverse momentum these events will not be visible!

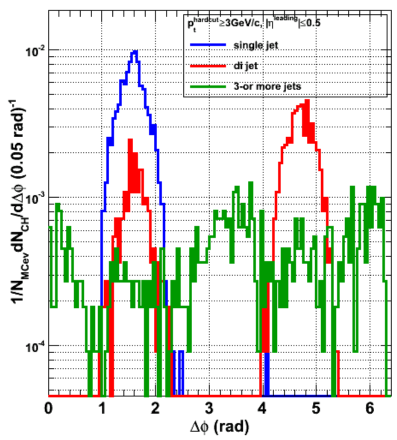

Fig.2 Azimuthal correlation obtained for 3 distinct parts of the thrustmap in Fig.1. See text for details.

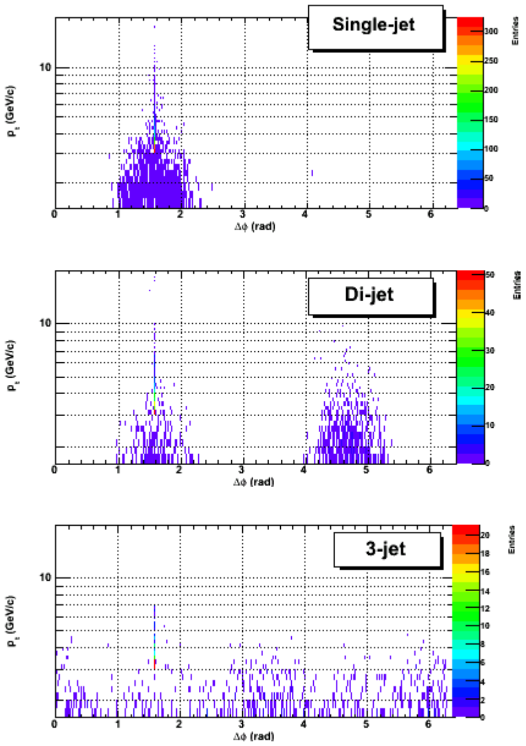

Fig.3 distribution of p_t in azimuth. The upper part belongs to the high *R* region, the middle part to the low *R* and low (1-*T*) values as specified in the text. The bottom part corresponds to the low *R* and high (1-*T*) part of the spectrum. The leading particles are also plotted in this view.

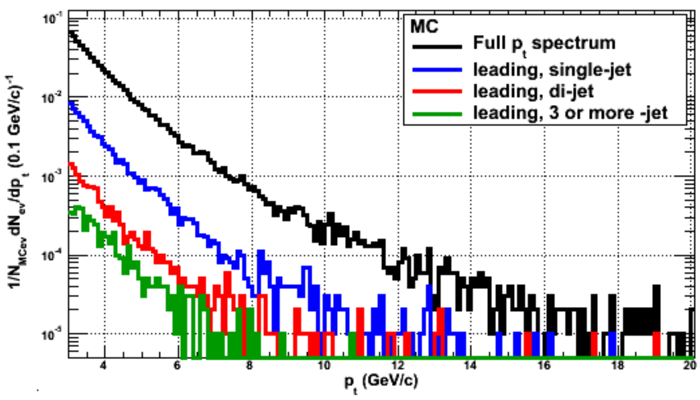

Fig. 4.: transverse momentum spectra of leading particles of all events and the spectra corresponding to the 3 different regions.

Jet shapes

The measurement of the jet shape allows a study of the transition between a parton produced in a hard process and the collimated flow of hadrons observed experimentally

The internal structure of a jet is dominated by multigluon emissions from the primary outgoing parton and is expected to depend mainly on the type of parton, quark or gluon, creating the jet and the transverse momentum of the jet. Essentially all the processes accompanying the showering and/or energy should manifest themselves in the jet shapes.

The method has been successfully used by CDF in $p\bar{p}$ collisions, and without doubt the behavior of the jet shapes in heavy ion collisions compared to the ones in pp collisions will be one of the ways to study the parton energy loss. The energy loss of the leading parton results in a redistribution of the associated jet energy in transverse phase space or multiplicity. Among other variables amenable to detection of such redistribution is j_t, the transverse momentum of jet particles with respect to the jet axis as sketched in the p_t Fig.4.

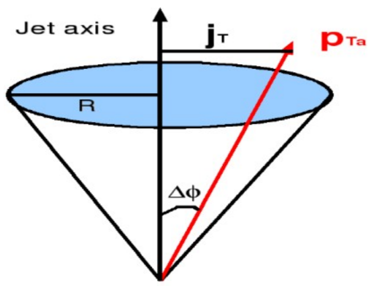

Fig.5 A jet cone with the sketch of the j_t variable.

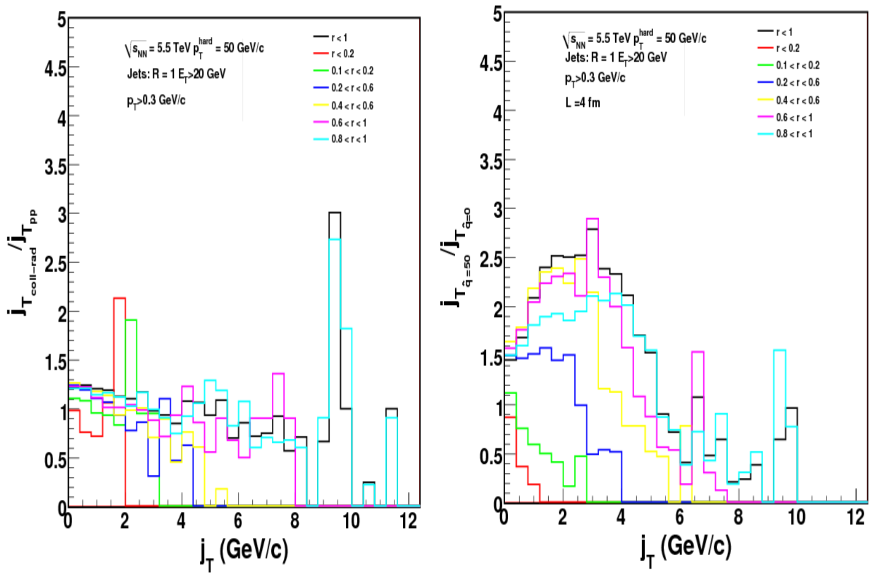

Fig.6 ratio of the j_t calculated with energy loss generators and Pythia. On the left, the results for Q-Pythia for a $\hat{q}$ of 50 GeV^2/ fm and a pathlength of 4fm in the medium; on the right, the same ratio for the PYQUEN generator. The black curves shows the ratio for the whole jet cone r<1 while the colored histograms show the ratio for different r ranges.

We have calculated the integral j_t spectra for jets generated with Pythia, PYQUEN [4] and Q-Pythia [5]

The mean values of j_t obtained for PYQEN are almost equal to the one obtained with Pythia (485 MeV/c vs 499 MeV/c), while for Q-Pythia the values are about 12 percent higher for a moderate value of $\hat{q}$ of 5 GeV^2/fm and reach about a 20 percent increase with a $\hat{q}$ of 50 GeV^2/ fm. We also did a detailed study of the j_t distributions in function of Δr slices around the jet axis as established by the jet cone analysis. In Fig.8 we show the ratios of the energy loss generators obtained with Q-Pythia and PYQUEN with respect to Pythia. The ratios show that in Q Pythia there is a strong dependence of the ratio in the range 0.4< r <0.8 compared with PYQUEN where almost no change is observed with respect to Pythia. It obviously represents an additional tool to check on the features of parton energy loss, although in the real world of heavy ion collisions one will be confronted to the challenge separating the jet and background contributions.

Conclusions

We have demonstrated the possibilities that the event shape analysis opens in hadron-hadron collisions. The possibility to identify parts of the thrust map where special topologies can be identified merits surely the attention of the LHC experiments. The present application of azimuthal correlation has opened an important application with the isolation of the dijets specifically. We believe that the use of the event shape may be of great help in identifying “pure” back to back jets for posterior treatment via jet recognition algorithms to study details of the jet structure as for example in the case of the modification of the jet profile as explained in the section on jet shapes. Finally the “three prong” structures observed in this work bear troubling likeness to the “double hump” structures observed in heavy ion collisions [5]. It is important to mention that the present results were obtained with very small event sample of only 400000 events which indicates that in the first runs one might expect important results on the jets of low energy.

The comparison of the jet profiles in pp and heavy ion collisions using two different Monte Carlo generators has shown sensitivity to the energy loss chosen and to the values of the $\hat{q}$ parameter.

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