A method to investigate relativistic heavy ion collision

E. Cuautle [*], I. Domínguez[*], E. Garcia[*,†] and G. Paić[*]

[*]*Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70-543, México Distrito Federal 04510, México.*
[†]*Chicago State University, Chemistry and Physics Department, 9501 South King Dr., Chicago Il, 60628*

Abstract. Parton energy loss in heavy ion collisions has been dealt in many different way. At low collision energy, the high multiplicity and low energy partons are close in momentum space making difult the identification of a jet. We propose a method which could be complementary to the dihadron correlation analysis. The method select events where there is at least one particle with certain transverse momentum minimum, then is draw the momentum spectra of all particle belonging to such event, from those events is possible to extract information of the collision. We discuss the applicability of the method in parton energy loss and other quantities.

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INTRODUCTION

Many methods have been developed to extract the maximum of information on the ways the partons loose energy in the dense medium and on the manifestation of these processes in the experiments. The analysis of the transverse momentum obtained in ion-ion collisions, compared with the scaled proton-proton data in the well known R_{AA} variable as well as the dihadron analysis yielded a wealth of important observations. The R_{AA} illustrates the suppression of the high momentum particles only, while the analysis of the dihadron correlation [1] relies on trigger particles chosen in a certain momentum range and subsequent plotting of the azimuthal correlation with the so called "associated particles". The dihadron correlation offers more information about the partons that loose energy, but the selection of the interval for the trigger momentum and associated particle is usually not explained as in the studies of dijet correlations [2] and disappearance of back-to-back high p_t hadrons [3]. The high momentum part of the spectra (larger than 4-5 GeV/c) is dominated by particles corresponding to high z events, $< z >= p_t/\hat{p}$, *i.e* low energy jet events that can not be identified otherwise than by their leading particle. In the present work we were guided by the wish to study a selection of events that could be, at least partially, assimilated to hard initial collisions.

We present in detail a study of the leading particles and the remaining *associated particles* which we call Associated Spectra Approach (ASA). The main argument for this kind of approach is, is to identify without large uncertainties jets at low energies. We want to illustrate that analyzing all the particles belonging to a hard collisions can yield to interesting results complementing the dihadron correlations method. The next

section, will present details of the method and then the results obtained by PYTHIA [4] and HIJING [5] particle event generators at energies of RHIC and LHC. We discuss the sensitivity of the leading particle spectra to the ingredients applied to the generators *e.g.* different fragmentation functions and parton distribution functions.

THE METHOD: ASSOCIATED SPECTRA APPROACH

In order to study the dynamics of the QCD processes we generated hadron momentum spectra using PYTHIA.

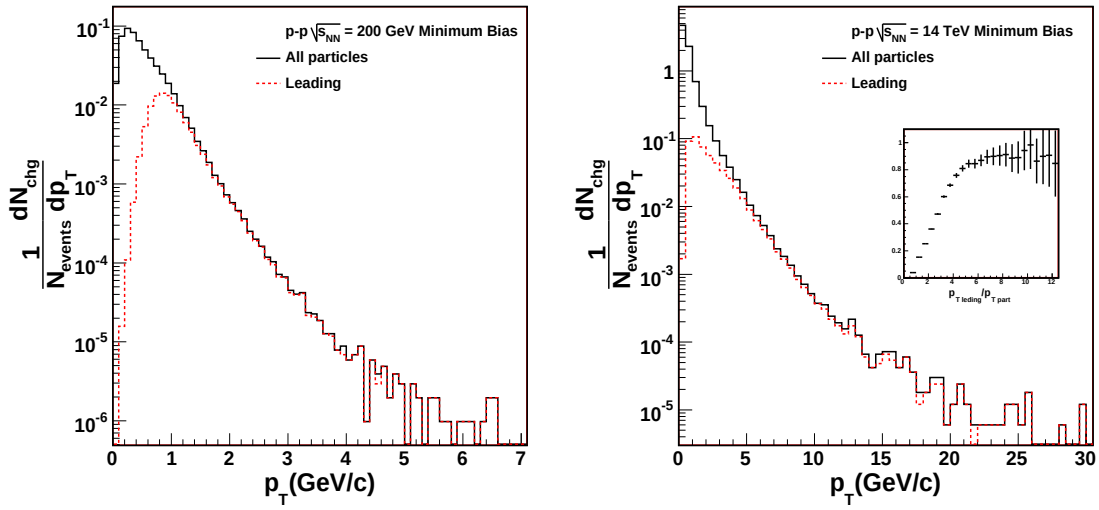


FIGURE 1. Color online. p_t for all and leading particles from pp collisions at 200 GeV (left) and 14 TeV (right). The insert in the last one, shows the ratio between spectra of leading and all particles.

Figure 1 shows the spectra obtained using PYTHIA at 200 GeV (left) and 14 TeV (right), with the default parameters. The spectra generated for all particles in $|\eta| < 0.9$ are compared to the *leading particle spectra*, that is, to the spectra of the particle with the highest momentum. We observe that already at relatively low momenta the ratio of the two curves is very close to unity (see insert in the right figure). This is not unexpected since exactly in that momentum range the events are being governed by hard parton processes. When one imposes a trigger on the leading particle and not in the jet energy, the production cross section of low energy jets arise over the low probability of jet fragmenting with high z value. The results is that picking up a leading particle one collects low energy jets with a hard fragmentation. The difference between unity and the observed ratio is due mostly to the effect of particles associated with the fragmentation of higher energy partons. To eliminate this effect we apply the following procedure: we choose events with leading particles in a restricted momentum range. For these events we then plot the momentum spectra of all particles, which we call in further text, *associated particles*. To allow for the jet structure we add an additional acceptance cut restricting the leading particles taken into account to the range $\eta < 0.5$ while the particles associated with it are taken in the range $\eta < 0.9$ to take into account the acceptance criteria. The

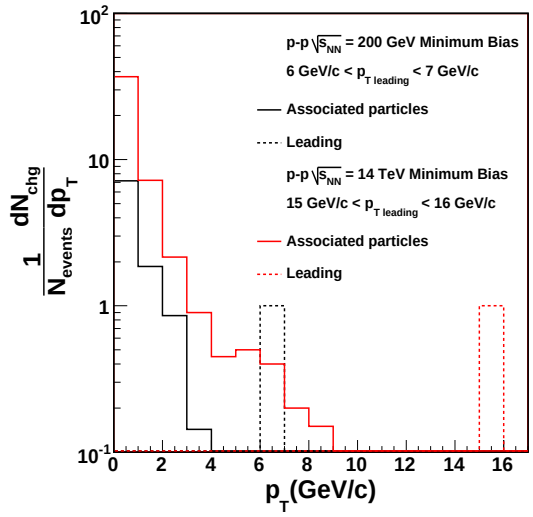


FIGURE 2. Color Online. ASA spectra for two pp energies. The 200 GeV spectra correspond to a p_t range from 6-7 GeV/c for the leading particles (black). The 14 TeV spectra correspond to leading particles chosen between 14 and 16 GeV/c (the leading particles are represented by dotted and the associated are in full lines). The data represent a generated sample of 10^5 events

results obtained for events with leading particles between 5-7 GeV/c at 200 GeV and 14-16 GeV/c at 14 TeV are shown in Fig. 2.

The spectra in Fig. 2 clearly indicate two features: a peak of the chosen leading particles corresponding to the hadronization in hard processes where the event is triggered and a peak of low momentum particles. This corresponds exactly to a fragment with a high fraction of the momentum z and the remainder of the fragmented associated particles sharing $1-z$ of the total momentum of the parton. The selected events have a high probability to be in the tail of the distribution of the leading particle spectrum due to the steepness of the production spectrum of jets. This explains the scarcity of particles with high z in the remainder of the event. The associated particles to the first approximation in pp collisions include: the particles which belong to the jet around the leading particle; those belonging to the "away-side" jet in the opposite direction as well as the beam remnants. Obviously it is possible to refine further the analysis, separating the different components by introducing geometrical cuts. The away side fragmenting parton does not have a constraint concerning the leading particle so that it will decay with a much lower z value (≈ 0.2). The spectra of hadrons, obtained by ASA, illustrate clearly the possible pitfalls that can occur when one is analyzing the experimental data in a dihadron correlation. In the worst case one could reach the point where the dihadron correlations give a partial picture of the process. By choosing the associated particle momentum range too close to the trigger particle one in fact introduces an additional bias towards events that have a special topology *i.e.* a high z associated particle.

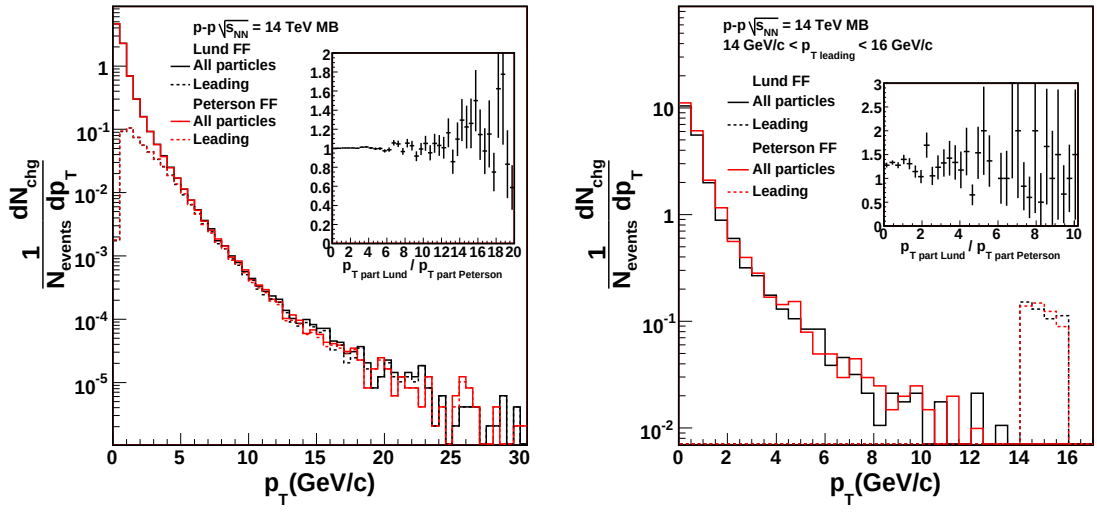


FIGURE 3. Color Online. Left: p_t spectra and the corresponding leading particle spectra for the two fragmentation functions with the ratio of the original spectra in the insert. Right: the ASA spectra for a given range of p_t for leading and the ratio of the two spectra.

APPLICATIONS IN PROTON-PROTON COLLISIONS

In the QCD parton model, the inclusive production of single hadrons is described by means of fragmentation function (FF), $D_a^h(z,\mu^2)$. Those functions are obtained by phenomenological models. The value of this function corresponds to the probabilities for the parton a produced at short distance $1/\mu$ to form a jet that includes the hadron h carrying the fraction z of the longitudinal momentum of a. The FF allows to test QCD quantitatively within one experiment observing single hadrons at different values of the center of mass energy or transverse momentum p_t. We investigate different FF to see the effect on the shape of the spectra obtained with the method described in previous section. The results are show in the figure 3. On the left of the figure we have the p_t spectrum for all and for the leading particle, those spectrum are generated with two fragmentation function: Peterson and Lund. In the insert the ratio between the spectra generated is shown. In the right part of the figure we show the spectra and their ratios in the ASA obtained for a range of 14-16 GeV/c for the leading particles. The result shows now a significative difference between the two fragmentation functions, as it is indicated in the insert of the figure.

Another possibility to see the effects on the spectra obtained with our method is using different Parton Distribution Functions (PDFs), which can not be obtained by perturbative QCD. The PDFs are obtained by analysis of experimental data. These functions are available from various groups worldwide. The left of Fig. 4 shows two total hadron spectra generated with two PDFs together with p_t spectrum for leading particles for each case. In the right are show theirs ASA spectrum for a leading between 14-16 GeV/c. Clearly, again the ASA spectra exhibit a sensitivity that is absent in the total spectra

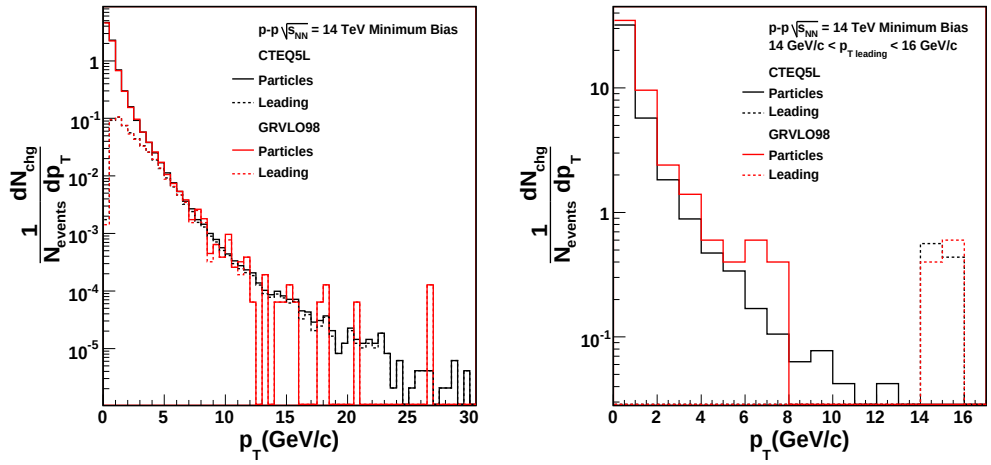


FIGURE 4. Color Online.Left: p_t spectra with Lund fragmentation function and two sets of PDFs. Right: ASA spectra and p_t for leading between 14-16 GeV/c.

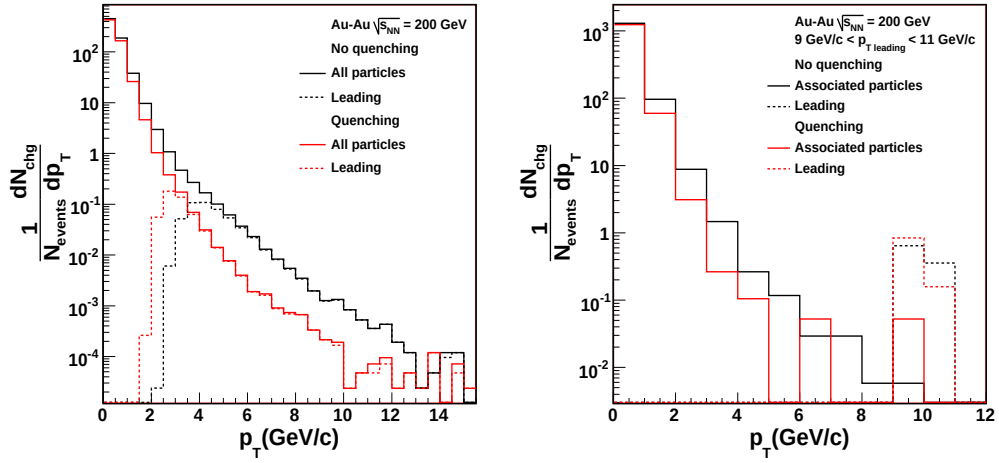


FIGURE 5. Color Online. Left: Total spectrum for quenched and unquenched HIJING prediction and the corresponding leading particle spectrum. Right: spectrum for leading particle in the range of p_t of 9-11 GeV/c and the corresponding associated particle

APPLICATION IN HEAVY ION COLLISIONS

The simulation of heavy ion collision is more complicated than pp collisions. In our case we have used the HIJING [5]. We have applied ASA to heavy ion spectra, to check whether the same features observed in pp collisions are present in heavy ion collisions. The persistence of the “hole” between the leading particle and the subsequent rise in the ASA spectrum indicate that one has to be very cautious in determining the range taken for the associated particle in dihadron correlation.

The results obtained at 200 GeV are shown in the left part of Fig.5. The simulations

have been done without and with partonic energy loss (jet quenching) of 2 GeV/fm. The right part of Fig.5 shows the spectrum of leading particles between 9-11 GeV/c and their associated particles with and without quenching.
The features of the ASA spectrum correspond qualitatively to the observed suppression in the away peak of dihadron correlation. Using ASA one gets at one glance the behavior of the associated particles for a given leading hadron momentum. The associated particle momentum spectra for the quenched case show a steeper behavior with p_t. The difference between the two maximum of the associated momentum spectrum, with and without jet quenching is related to the energy loss. The energy loss from those spectrum could be obtained comparing the associated spectrum for ion-ion collision, respect to associated spectrum from pp collisions.

CONCLUSION

We have presented a complementary method to the dihadron correlation analysis, to investigate high transverse momentum particles. The method is applied to proton-proton and ion-ion collision at RHIC and LHC energies. The advantages of the method is that it can be used as complementary, specifying the range of momentum spectra to define a jet and consequently improve the analysis of events with jets. The method allow us to make and analysis event by event, providing a tools to investigate rare events, for instance, rare fragmentation topologies.

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