Parton Structure through Two Particle Correlations in Au-Au at RHIC

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Abstract. A method for determining the presence of partonic scattering through two-particle correlations is developed and applied to models which have jets and mini-jets in them. We only consider the correlation of mid-rapidity particles because they will be easily measured in large numbers at RHIC. The level of two-particle correlations will be a direct measure of how dense a system is made in Au-Au collisions at RHIC. The STAR TPC will be ideal for making these measurements in the first year of running.

INTRODUCTION

Collisions of high energy protons are dominated by pQCD (perturbative Quantum Chromo-Dynamics), where the parton picture of quarks and gluons is the main player with hadrons being the final state manifestation of the former. The well established relationship between partons and the fragmentation into hadrons (jets) is the underlying process that must certainly take place in a ultra high energy AA (nucleus nucleus) collision when one considers hadrons with large transverse momentum. In proton colliders the large transverse momentum of hadrons coming from jets are translated into transverse energy spikes in a cross sectional region of a energy measuring device (calorimeter), this cross sectional region is called a jet cone [1]. Thus in pp collisions calorimeters can be used to measure jet cross sections which can be compared with predictions of pQCD [2]. The situation for jets in AA collisions is alot harder because of the large number of soft particles which can contribute to transverse energy. In the jet cone region for central Au-Au collisions at the RHIC collider (39.4 TeV) the transverse energy is around 200 GeV. Even though this is only 1/2% of the total energy, it makes it very

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difficult to measure 10 GeV jets since the signal would be $1/20^{th}$th of the background.

The jet formation in colliding systems takes place at early times. Thus the hard scattered partons propagate in the dense system formed in a central AA collision. As the partons fragment into hadrons they also propagate in this same high density. The theoretical understanding of the interactions involved during propagation should make it possible to determine the density of the created system. Therefore, the ability to measure jets in this very hostile environment is a very important experimental challenge. This article will develop a method using two-particle correlations, which can detect even mini-jets in the face of overwhelming backgrounds. On the theoretical side we will use the Monte Carlo program VNI [3] to simulate creation, fragmentation, and propagation of jet fragments.

THE PARTON DISTRIBUTION AND FRAGMENTATION

In the introduction we stressed the measurement of the partons since they are active at early times in a ultra high energy AA collision. For the remainder of this article let us only consider central Au-Au collisions at 200 GeV per intial colliding nucleon (RHIC 39.4TeV total). We will see what happens in a specific model(VNI). The parton cascade model(VNI) predicts that in the above Au-Au system partons will cascade for about the time it takes light to travel 3 Fermis(10^{-23} seconds). During the first Fermi of time of the three Fermis time, hadron clusters start to form from the lower momentum partons. By the end of the 3 Fermis time all of the partons that have interacted have become hadron clusters. In VNI, hadron clusters propagate onshell and interact according to a cross section given by the additive quark model derived from the quarks inside the hadron cluster. As the hadron clusters propagate they expand and breakup into two or more clusters by quark pair creation. These clusters become hadrons after a formation time that was tuned to the data from Pb Pb collisions at fixed target SPS heavy ion program [4]. Many of the hadrons are excited hadrons and will quickly decay into hadrons that are stable (with respect to the strong decay) with a time related to the total width of the excited state. When clusters become hadrons they scatter with cross sections that come from experiments or predictions of the quark model. If no clear predictions exist then the additive quark model is used. For partons that do not carry large longitudinal momentum the process of forming hadron clusters which interact and decay into hadrons and finally freezing out takes around 20 Fermis in time. In Fig. 1, we show the parton distribution as a function of pseudorapidity (η) for one central Au-Au collision at RHIC. Only partons with η between plus and minus one are headed toward the central TPC of STAR.

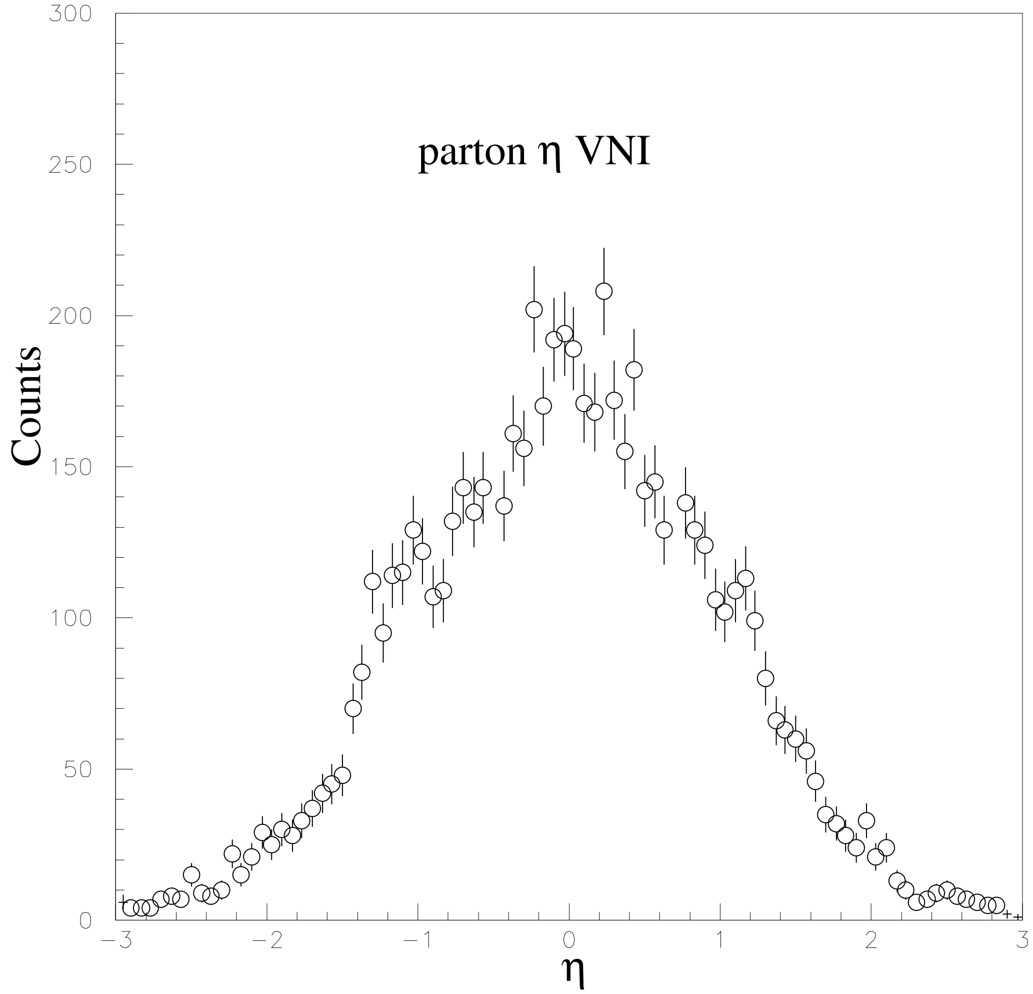

FIGURE 1. Pseudo-rapidity (η) distribution for partons from one VNI central Au-Au event at RHIC energy 39.4 TeV.

In Fig. 2, we show the ϕ angle(angle around the beam axis) of the partons. There are no clear isolated jets in either figure, however if we plot the p_t of the partons for hundreds of central events we see clearly the high p_t tail of jets generated in VNI (see Fig. 3).

PARTON CORRELATION

Partons shower into partons as part of the parton cascade. These showered partons in pQCD for the most part are emitted almost collinear to the intial parton. This is the characteristic of the pine tree structure of pQCD. We can take advantage of this and form a correlation function based on the angle of emission of partons. For partons we calculate the angle between them forming an angular distribution of all pairs of partons in one event. For each given angle, we determine a normalization by using mixed events. We take partons from different events, thus forming a uncorrelated angular distribution of pairs. In forming this correlation function which is a ratio of in event divided by out of event as a function of angle, we consider partons that have a p_t greater than some value. Figure 4, shows the correlation function generated by central Au-Au events for partons with four different p_t cuts. We see a strong signal for collinear partons or small angles. This correlation does not directly address the density of the parton cascading system because showering will always lead to small angle correlations. The density of the system is best measured by knowing how much is the cross section of a high p_t parton reduced because it is showered into a lower p_t partons traveling in the same direction. Since the total p_t is not really reduced in the direction of the parton, the density effect is purely a fragmentation question. For this article and for year one RHIC physics, detailed cross sections and good jet resolution with changing fragmentation functions is too demanding. Instead we are looking for a yes no approach to parton structure.

Next we explore this correlation function for the pions. If we turn off the possibility of hadronic final state scattering, then the collinear partons will fragment into pions that are also somewhat collinear. In Fig. 5. we form a correlation function using pions which have varying p_t cuts. We see that if we only consider pions with p_t greater than 1.0 GeV/c no correlation is observed. However as we increase the p_t cut from 1.0 to 2.0 GeV/c the small angle correlation becomes clear. The correlation holds up to angles as large as 20° (20° is a typical jet cone). This calculation used VNI but the correlation due to mini-jets should be present in any model which have mini-jets. Figure 6, shows the $\pi\pi$ angular correlation given by the generator HIJING [5] for Au-Au central RHIC events. For HIJING a correlation shows up at a p_t cut of 1.0 GeV/c.

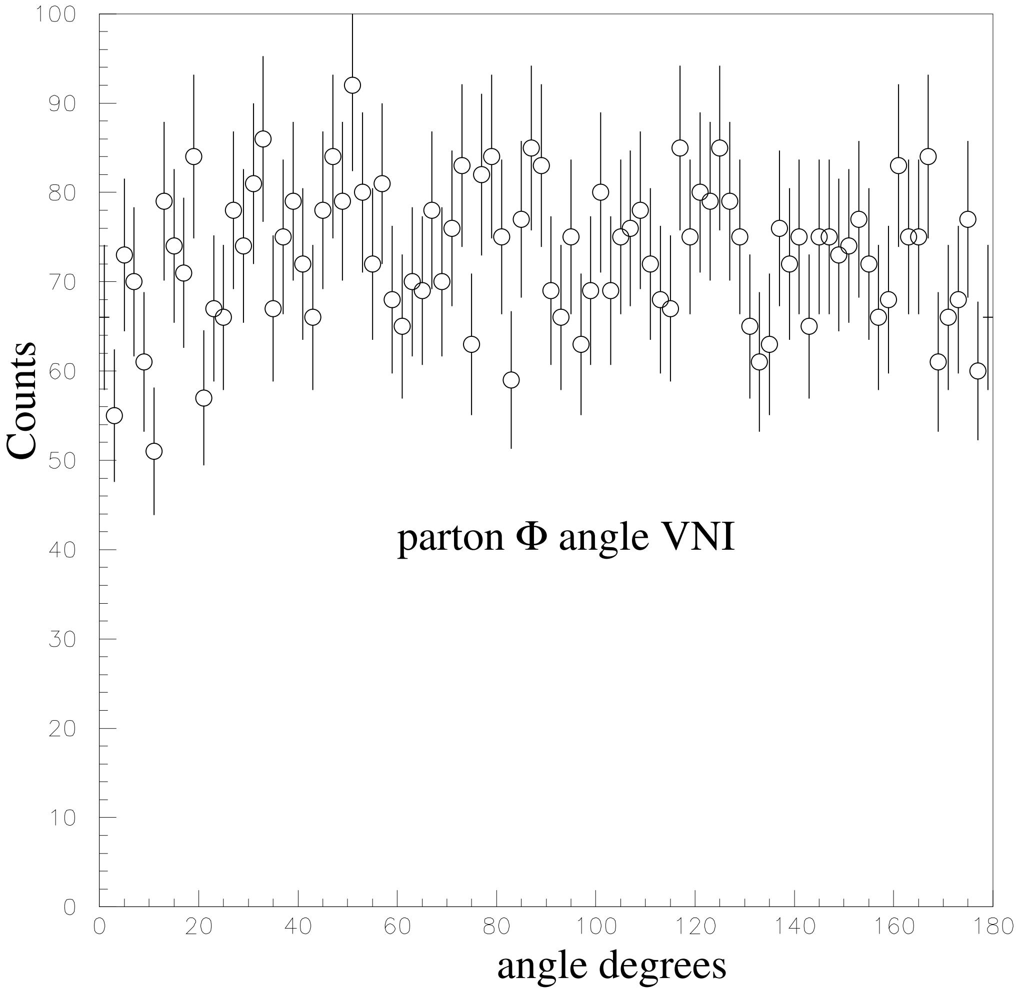

FIGURE 2. The ϕ angular distribution about the colliding Au-Au beams for one VNI central event at RHIC energy 39.4 TeV.

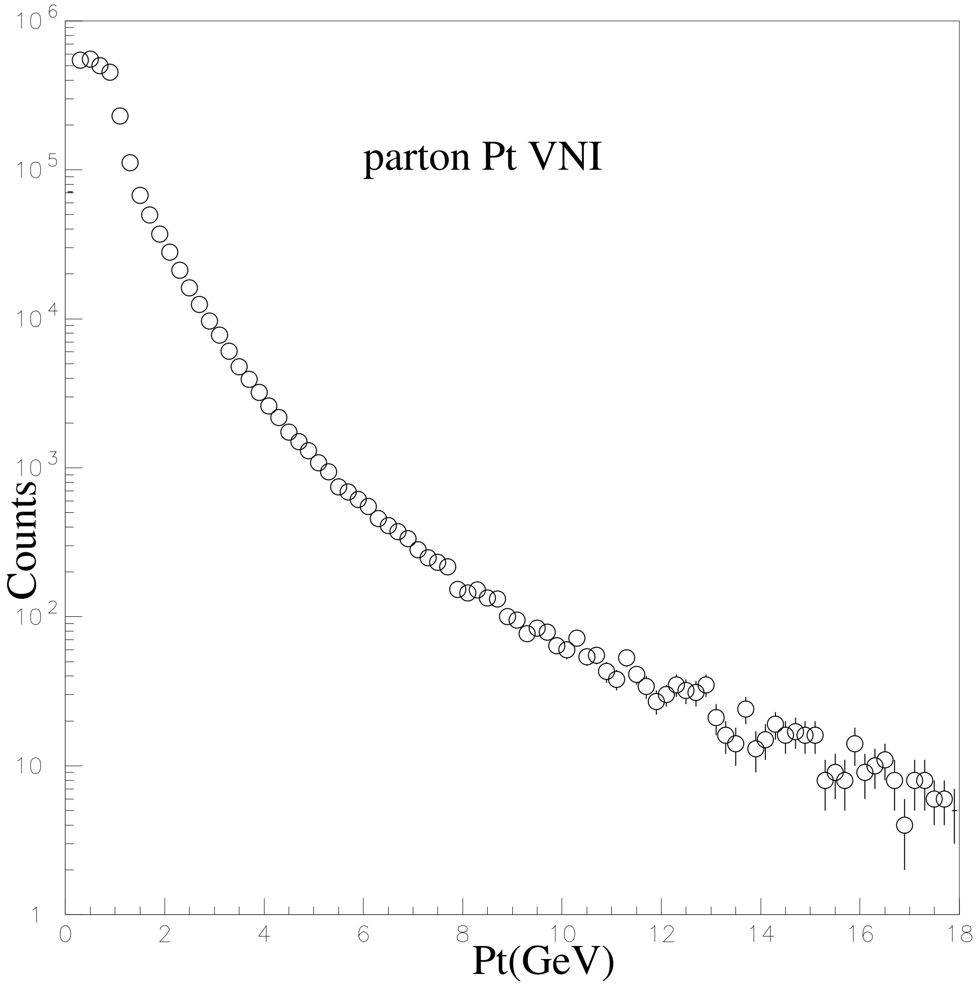

FIGURE 3. The distribution of tranverse momentum (p_t) for partons from hundreds of central Au-Au VNI events at RHIC energy 39.4 TeV.

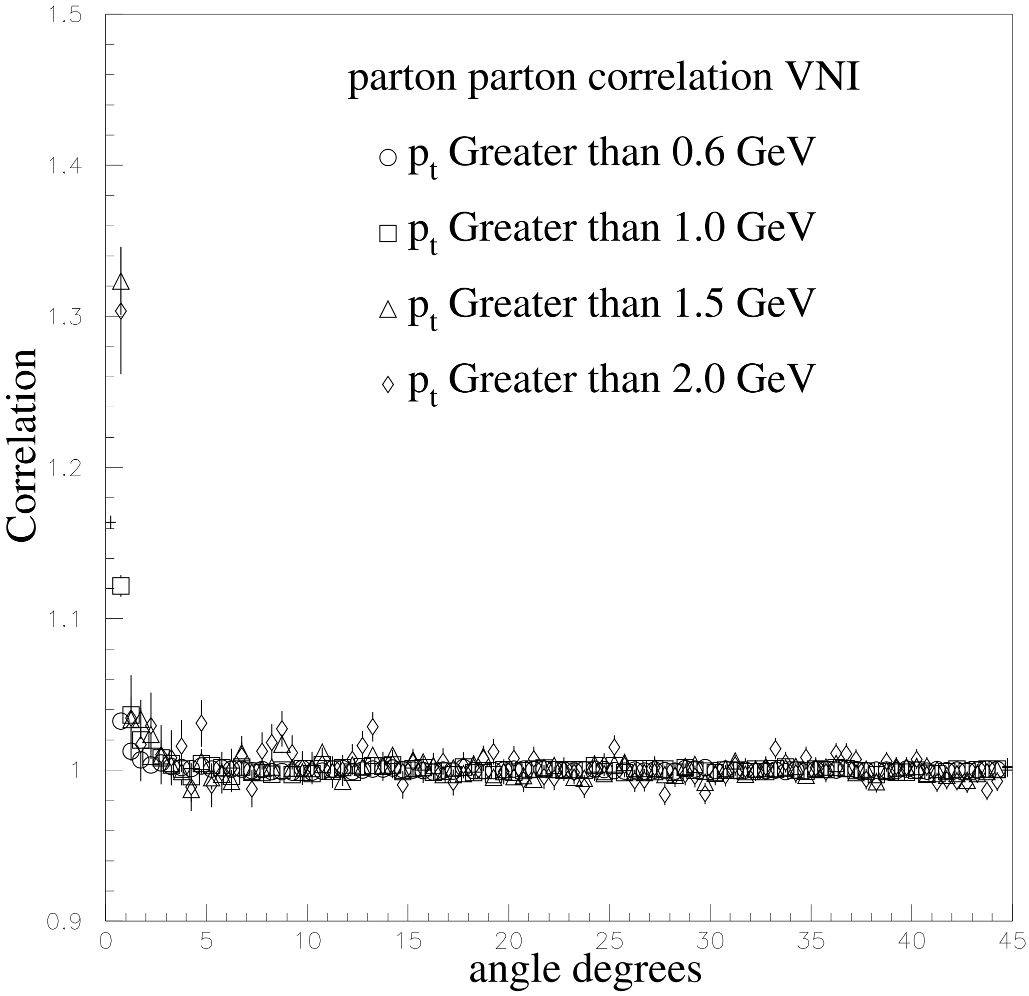

FIGURE 4. The parton parton angular correlation function for VNI central Au-Au RHIC events constructed from partons which have a p_t: above 0.6 GeV/c (circles); above 1.0 GeV/c (squares); above 1.5 GeV/c (triangles); and above 2.0 GeV/c (diamonds).

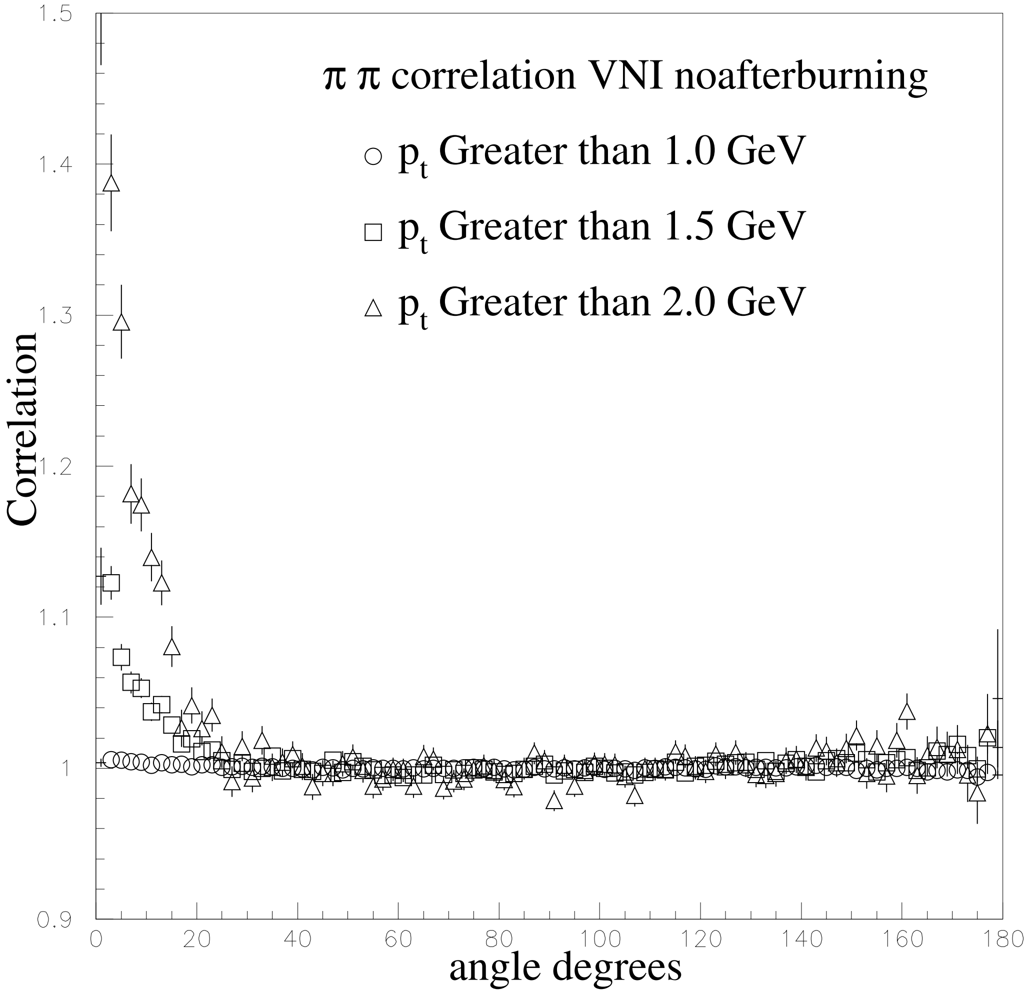

FIGURE 5. The $\pi\pi$ angular correlation function for VNI central Au-Au RHIC events which do not have hadron rescattering constructed from pions which have a p_t: above 1.0 GeV/c (circles); above 1.5 GeV/c (squares); and above 2.0 GeV/c (triangles).

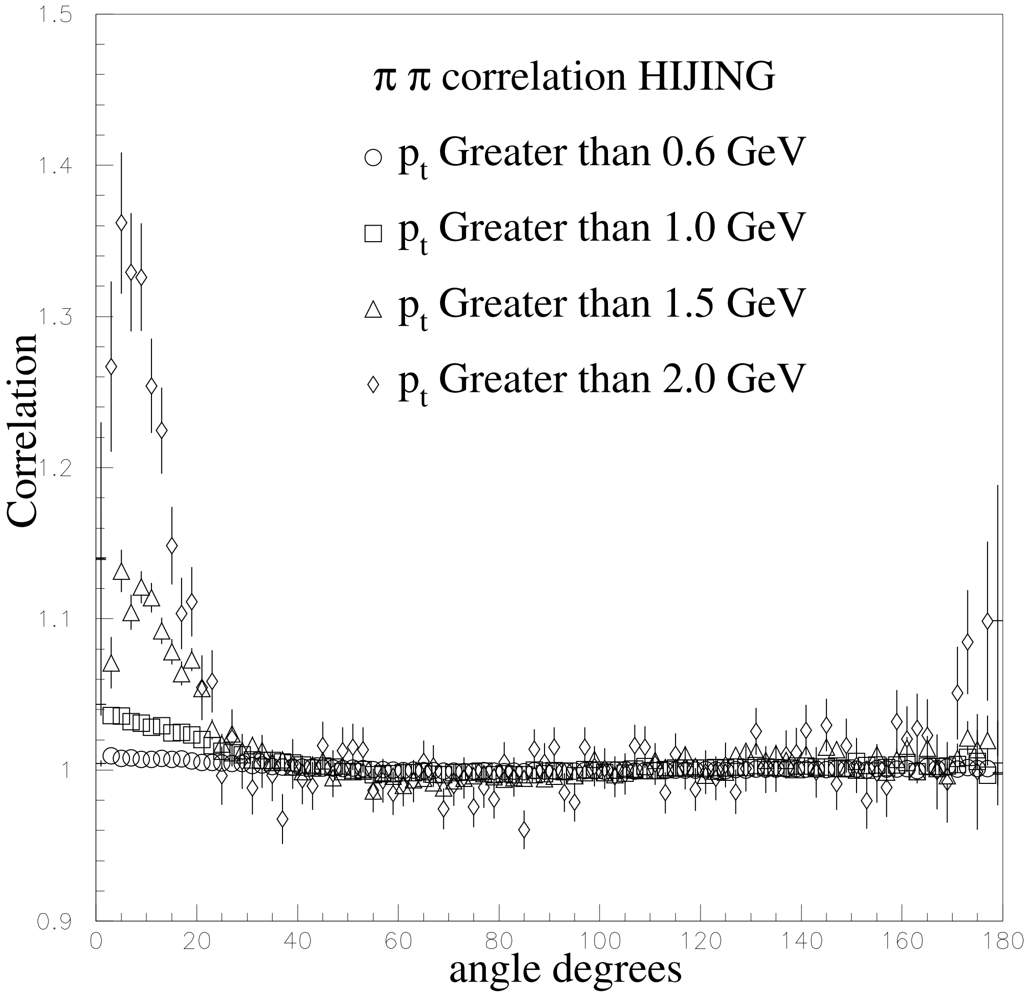

FIGURE 6. The $\pi\pi$ angular correlation function for HIJING central Au-Au RHIC events constructed from pions which have a p_t: above 0.6 GeV/c (circles); above 1.0 GeV/c (squares); above 1.5 GeV/c (triangles); and above 2.0 GeV/c (diamonds).

BACKGROUND CORRELATIONS

A possible background source of correlations is single high p_t resonance production (ρ, ω, and η). If resonance production is the source of this correlation then it should be very strong in unlike pions and very weak in like pions. The correlation function for unlike pions is shown in Fig. 7, where the correlation for like pions is shown in Fig. 8. We see that the correlation is about the same for both like and unlike as jet fragmentation would predict.

Another possible source of correlation is Bose-Einstein correlation (HBT) (Hanbury-Brown-Twiss) plus final state Coulomb interactions. Thanks to Professor Lanny Ray, Coulomb plus HBT correlations were added to a version of simulated VNI Au-Au central RHIC events. The simulated VNI events have the same single-particle distribution as VNI for π, k, protons, ...etc. but no mini-jet correlation. MEV is the name of the generator and it was tuned for VNI and Fig. 9 shows the pion correlation for p_t greater than 1.5 GeV/c. A q-invariant source size of 5-7 Fermi was created using Ray's afterburner code. Figure 10 shows the correlation function for p_t cut running from 0.6 to 2.0 GeV/c. For the 0.6 and 1.0 GeV/c p_t cut, a small signal is seen in the lowest 2 and 4 degree bins due to the HBT and Coulomb correlation. The reason this effect is so small comes from the fact that the correlation exists for small Δq thus small angles, but is not present for small angles with a larger Δq.

CORRELATION REDUCTION DUE TO HADRON RESCATTERING

After hadronic clusters are formed they can begin rescattering with each other. The rate of rescattering is directly proportional to the density of the clusters in the Au-Au cascade. Where parton showering tends to maintain collinear direction, cluster rescattering is more random and can destroy the mini-jet structure of the final state pions. This process continues through the cluster decay and excited hadron decay phase. For hadrons that ends up in the mid-rapidity region the rescattering can continue for a time lasting up to 20 Fermis in the model VNI. Figure 11, shows the $\pi\pi$ correlation for a central RHIC Au-Au event in VNI (afterburning), where Fig. 5 is the correlation without hadron rescattering (no afterburning). The STAR TPC will be able to measure charged particle tracks up to 2.0 GeV/c momentum very easily. However particle ID will be very limited without large time of fight coverage. The angle measurements for these tracks will be very good, making it possible to create a charged particle correlation that we show in Fig. 12 for VNI (no afterburning). We see that the difference between Fig. 5 and 12 is very small. The same can also be said for the correlation of charged particles after final state rescattering Fig. 13 and the $\pi\pi$ correlation Fig. 11. Finally we can compare the same charged particle correlation for HIJING with jet quenching

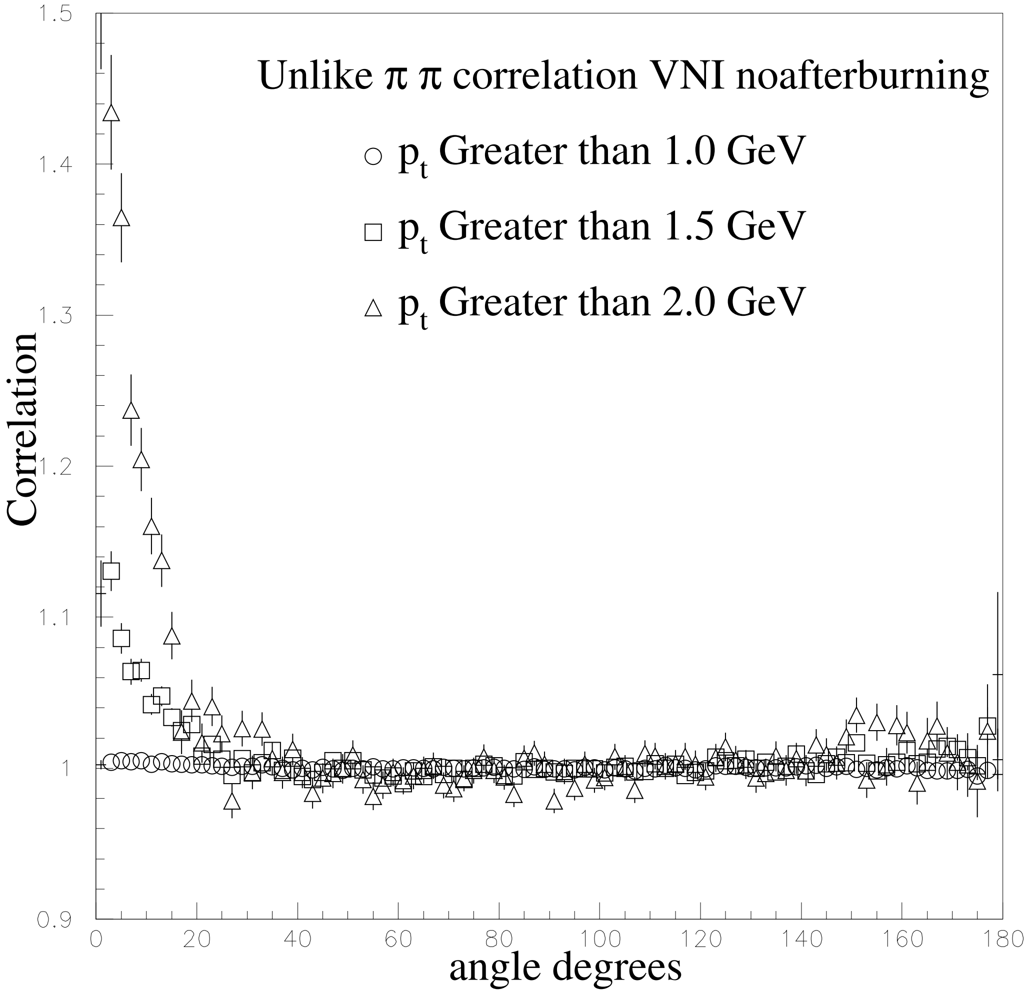

FIGURE 7. The unlike $\pi\pi$ angular correlation function for VNI central Au-Au RHIC events which do not have hadron rescattering constructed from pions which have a p_t: above 1.0 GeV/c (circles); above 1.5 GeV/c (squares); and above 2.0 GeV/c (triangles).

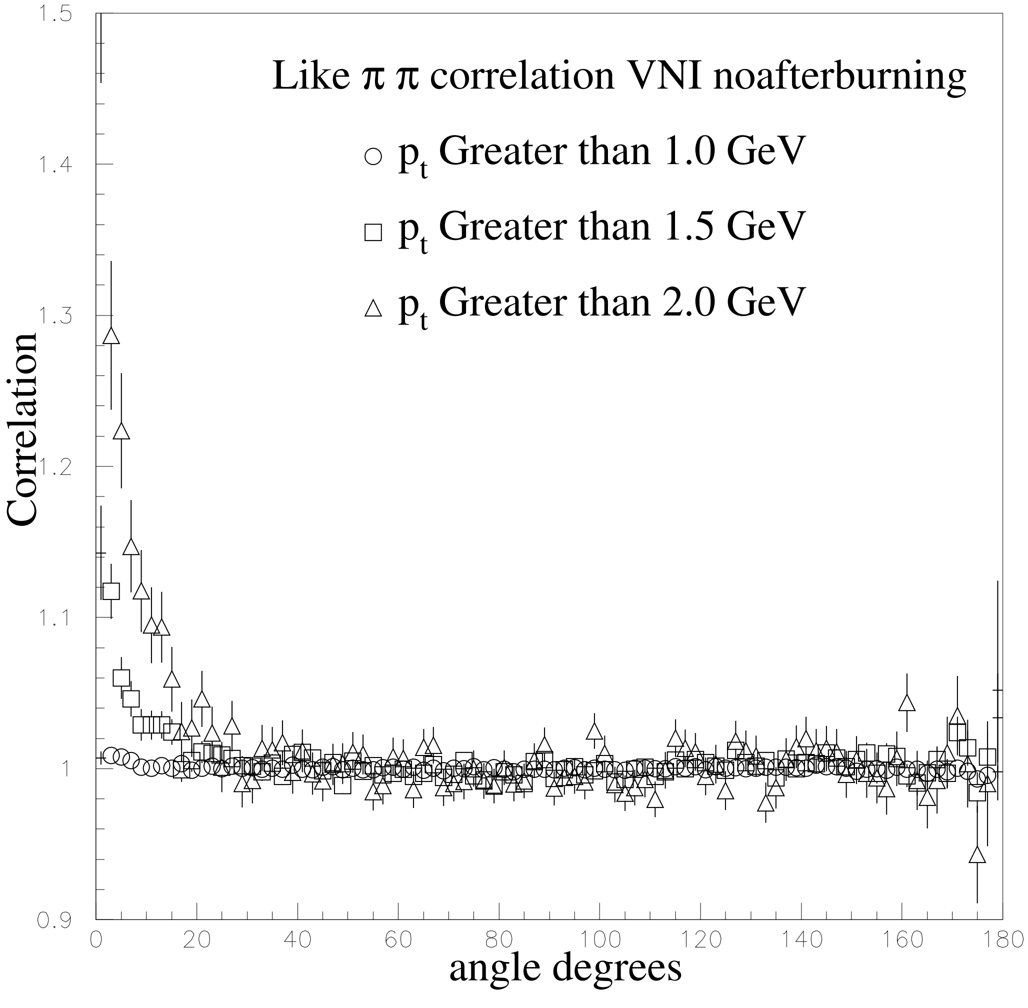

FIGURE 8. The like $\pi\pi$ angular correlation function for VNI central Au Au RHIC events which do not have hadron rescattering constructed from pions which have a p_t: above 1.0 GeV/c (circles); above 1.5 GeV/c (squares); and above 2.0 GeV/c (triangles).

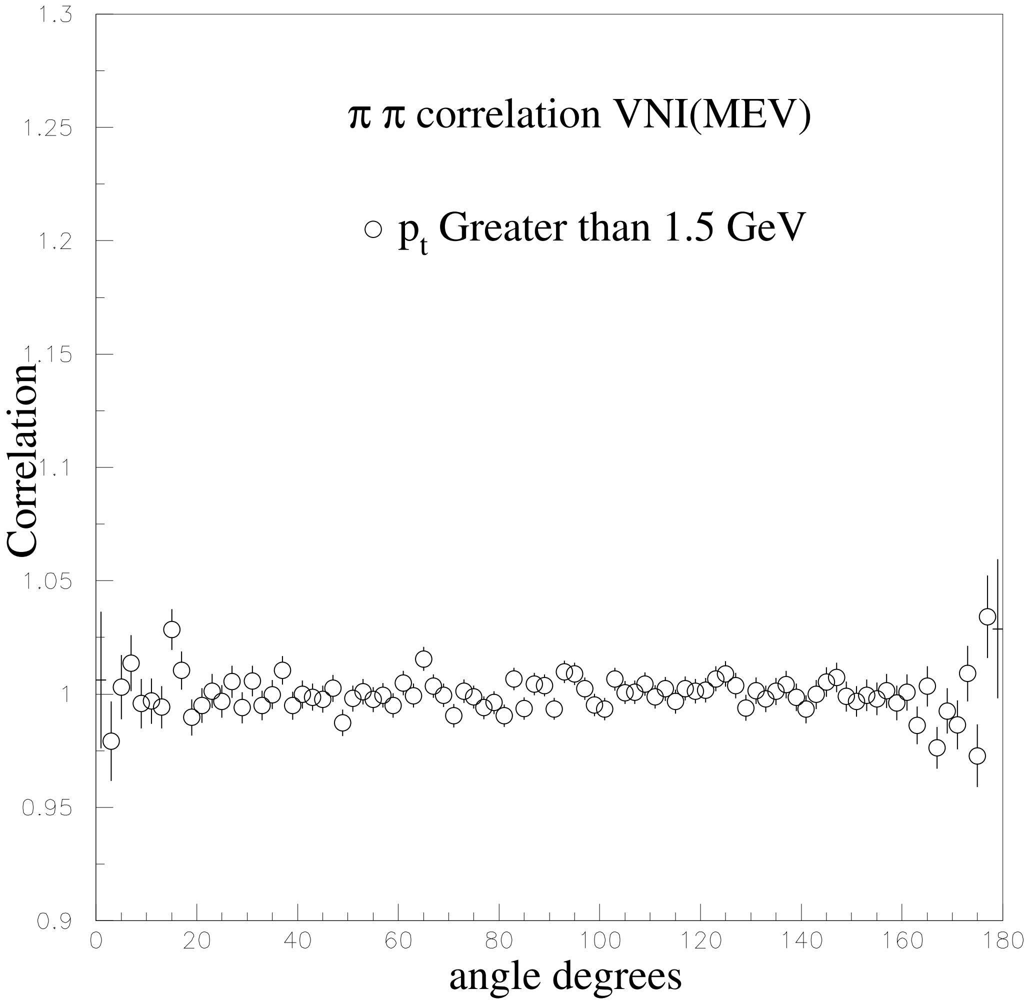

FIGURE 9. The $\pi\pi$ angular correlation function for MEV which is a program that simulates VNI central Au-Au RHIC events but does not have mini-jets constructed from pions which have a p_t above 1.5 GeV/c (circles).

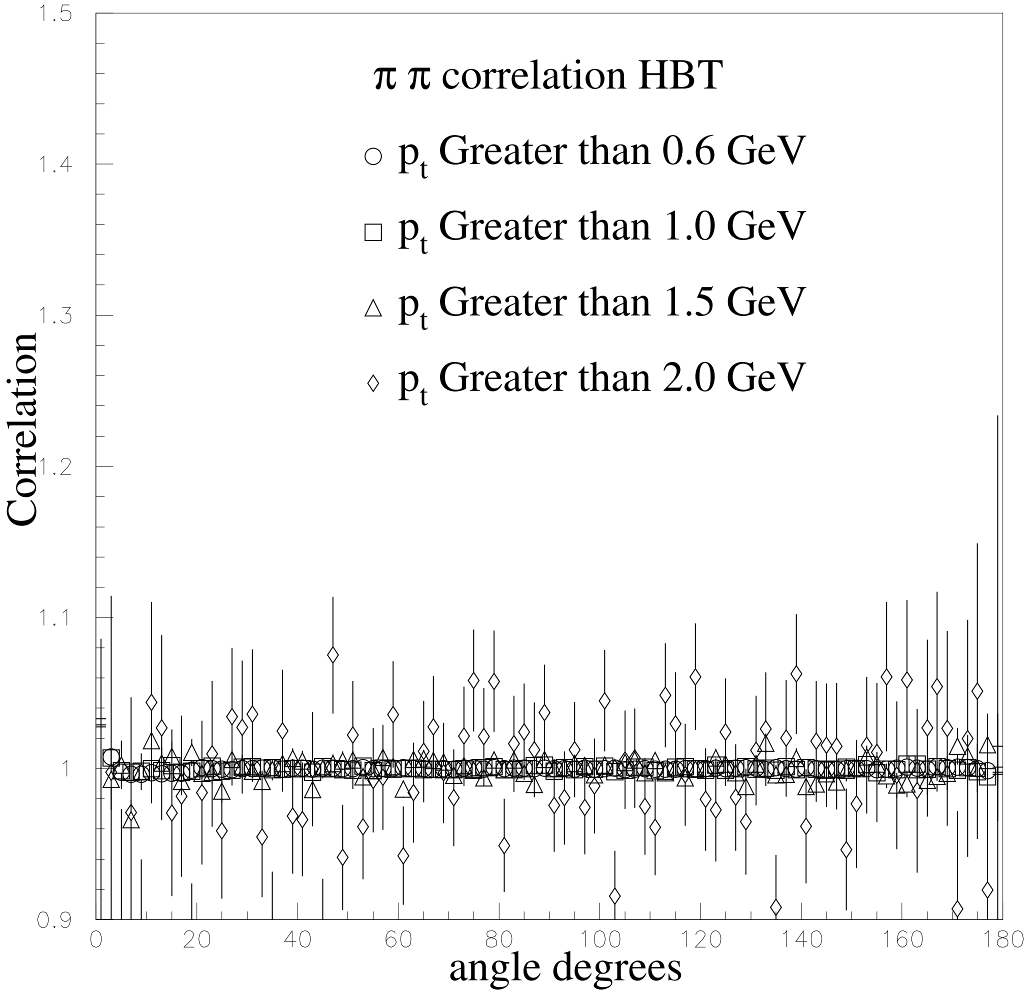

FIGURE 10. The $\pi\pi$ angular correlation function for HBT central Au-Au RHIC events which have a q-invarint source size of 5-7 fermis constructed from pions which have a p_t: above 0.6 GeV/c (circles); above 1.0 GeV/c (squares); above 1.5 GeV/c (triangles); and above 2.0 GeV/c (diamonds).

(Fig. 14). In the STAR TPC the charged particle correlation will be very easily measured when one gets around 10,000 central Au-Au events. The comparison to Figs. 13 and 14 will show if the anticipated final state effects on mini-jets are greater or less than the to models give. One should go further and study the correlation as a function impact parameter. For the more peripheral collisions the mini-jet correlation should approach that of *pp* collisions, since no final state in teractions can take place. As one reduces the impact parameter one should see a greater or less reduction of the correlation compared to the predictions of the models.

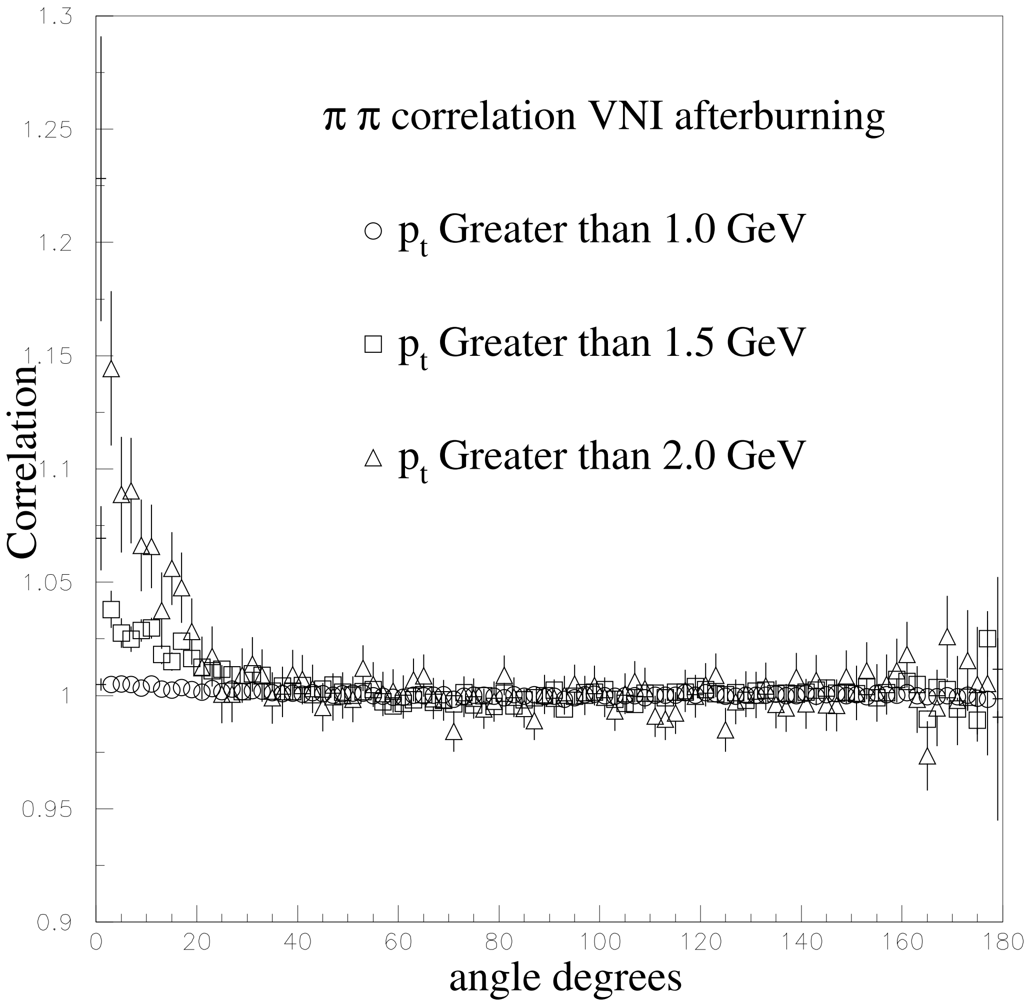

FIGURE 11. The $\pi\pi$ angular correlation function for VNI central Au-Au RHIC events which do have hadron rescattering constructed from pions which have a p_t: above 1.0 GeV/c (circles); above 1.5 GeV/c (squares); and above 2.0 GeV/c (triangles).

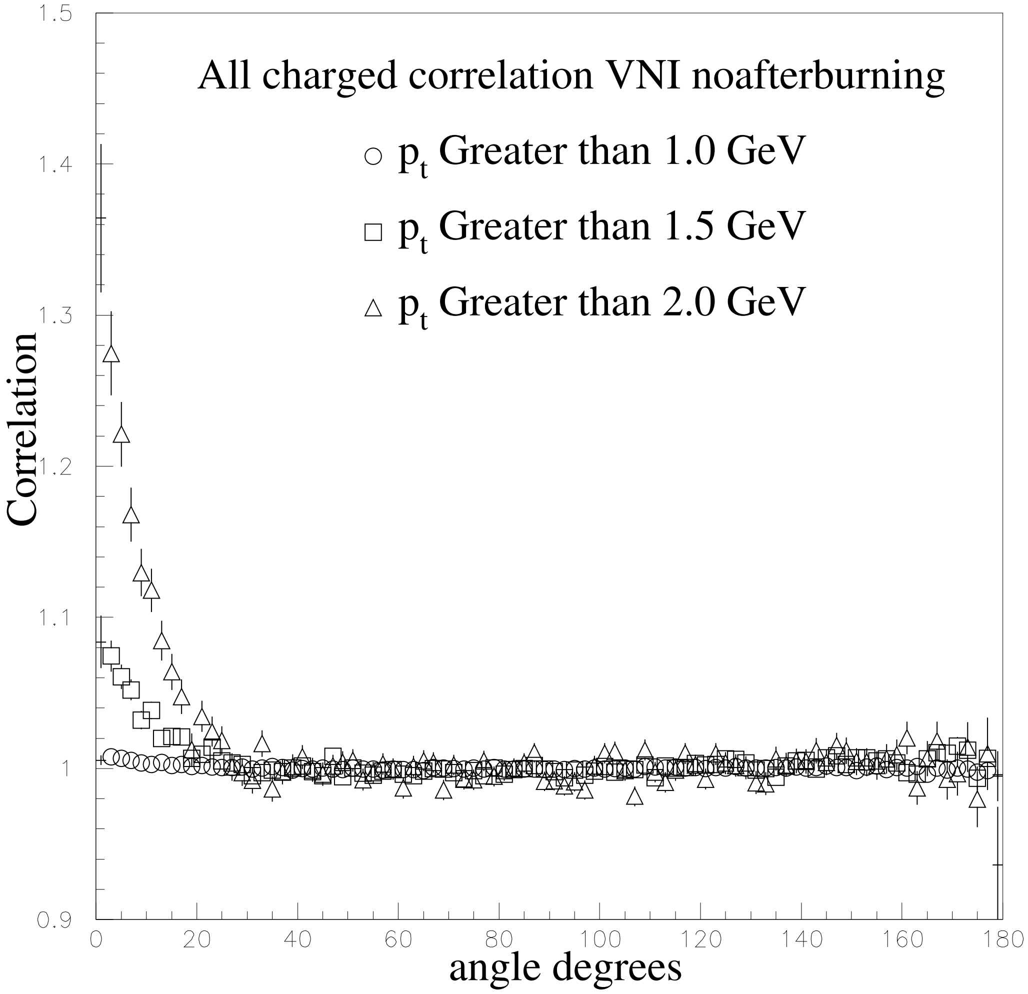

FIGURE 12. The charged particle angular correlation function for VNI central Au-Au RHIC events which donot have hadron rescattering constructed from particles which have a p_t: above 1.0 GeV/c (circles); above 1.5 GeV/c (squares); and above 2.0 GeV/c (triangles).

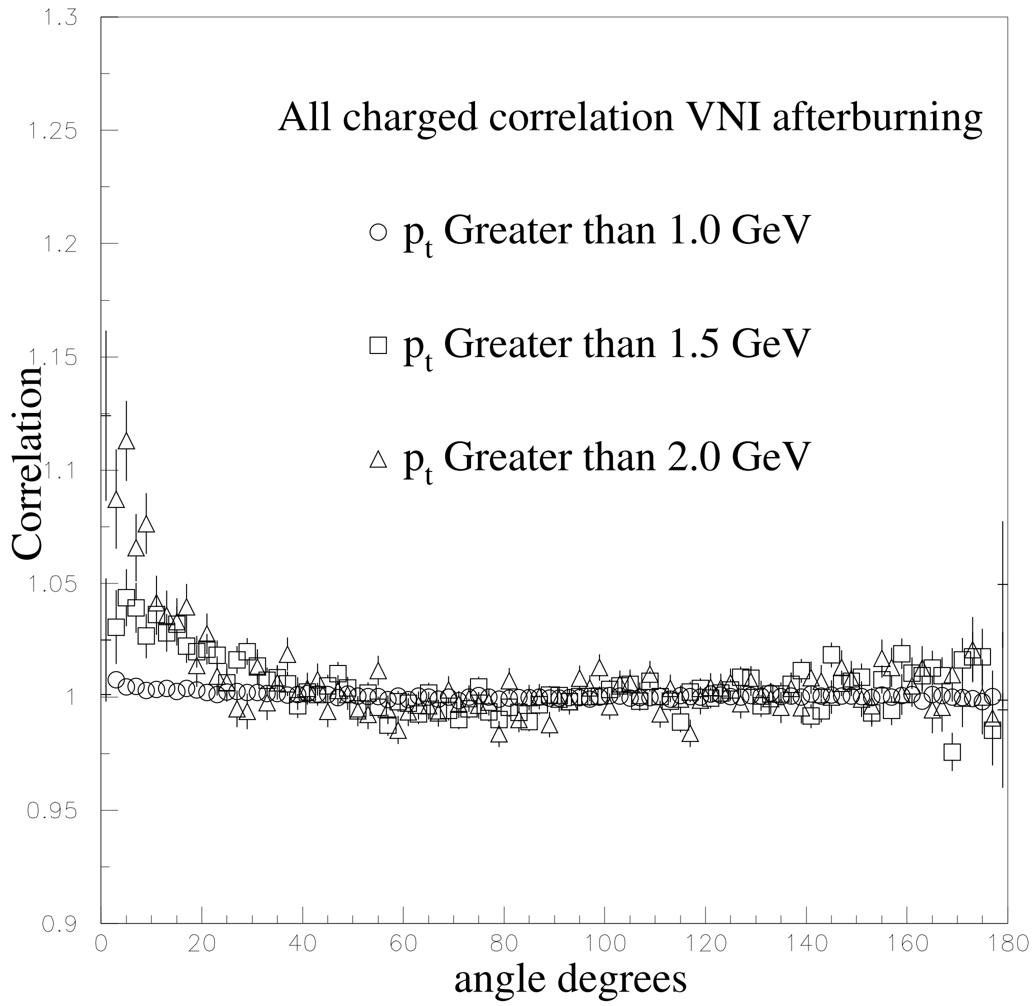

FIGURE 13. The charged particle angular correlation function for VNI central Au-Au RHIC events which do have hadron rescattering constructed from partcles which have a p_t: above 1.0 GeV/c (circles); above 1.5 GeV/c (squares); and above 2.0 GeV/c (triangles).

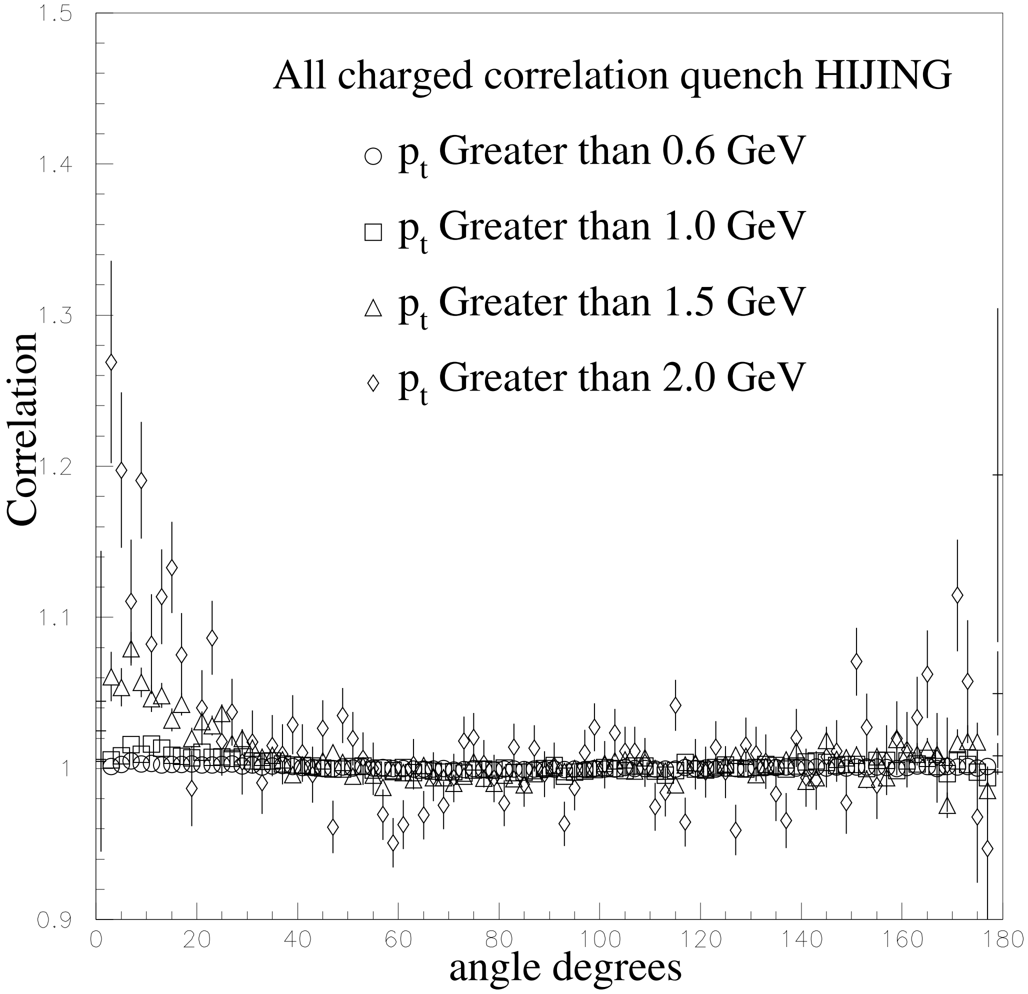

FIGURE 14. The charged particle angular correlation function for HIJING central Au-Au RHIC events where the jets under go quenching constructed from particles which have a p_t: above 0.6 GeV/c (circles); above 1.0 GeV/c (squares); above 1.5 GeV/c (triangles); and above 2.0 GeV/c (diamonds).

SUMMARY

A method for determining the presence of partonic scattering through two-particle angular correlations was developed and applied to VNI which has jets and mini-jets. We only consider the correlation of mid-rapidity particles because they are easily measured in large numbers at RHIC using the STAR TPC.

The level of two-particle correlations will be a direct measure of how dense a system is created in Au-Au collisions. However this study will only give a yes no answer about the survival of partonic structure in the most central Au-Au collisions at RHIC. One will have to study pp, pA, and lighter AA systems in order to understand how this type of correlation changes under different conditions. In the lighter systems one will have a direct measurement of jets to calibrate models and the correlation itself.

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