Heavy Ion Collisions: Studying the QGP Through Jets

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Abstract

In Heavy Ion Collisions the formation of a Quark Gluon Plasma (QGP) has brought up many questions in the field of nuclear and particle physics. In this paper we focus on trying to determine the degrees of freedom of the QGP. Using a theoretical model of the formation and evolution of a QGP we tested different Parton Distribution Functions(PDF's) through the observation of Jets to see weather or not any of our functions could help determine the degrees of freedom of the QGP.

1 Introduction

Heavy ion collisions are a very interesting topic of physics as they can teach us what the universe was like moments after the big bang and may also explain how matter interacts at such high temperature and density. An interesting finding from heavy ion collisions is the Quark-Gluon Plasma they create. In the LHC at CERN detectors observe what happens when two heavy nuclei, such as Au or Pb, collide. As the nuclei collide at nearly the speed of light, they heat up immensely and "melt" into what we call the QGP. This QGP is a soup of "quasi" free quarks and gluons that lasts for $10^{-}23$ seconds before cooling and forming a hadronic gas. The properties of this QGP are not well known but there are some things we do know. First of all scientists have found that the QGP is similar an ideal liquid in that the plasma has almost 0 viscosity/entropy density. Another property of the QGP is how they expand. It has been observed that they have anisotropic flow rather than expanding equally in all directions. In this paper we study the composition of the QGP by testing different PDF's for the plasma and observing how jets travel through the medium. We then compare our results to experimental data to try and determine properties of the QGP.

2 Parton Distribution Functions (PDF's)

The way we determine the composition of something in particle physics comes with the use of Parton Distribution Functions. These are functions that tell us what happens when a particle, such as a proton, is broken apart. It gives probability of finding a particle with certain fraction of total momentum at a given energy scale. The PDF for the proton(Fig.1) has been studied a lot and determine almost exactly by scientists all over the world. These distribution were used as a starting point for us in determining the degrees of freedom of the QGP because protons and neutrons of nuclei are what creates the plasma. We tested 3 different PDF's with specific properties to see what affect they had on the evolution of the jets as they cross through the medium. The properties of these functions were that they only took x values between 0 and 1. This x value represents the fraction of total momentum a particle has and therefore can not be greater than 1. Another property is that the integral of the function between 0 and 1 was made to be 1. This is because the integral represents the total number of particles in the plasma and for the number of particles in the plasma to equal the number of particles in the nucleons to be equal, the integral must be equal to 1.

3 Jets

The way in which we study the QGP is through the observation of Jets. Jets are collimated sprays of hardons created when two quarks scatter at high momentum. As these hadrons cross the QGP they interact with the medium and lose energy. When they exit the plasma we measure the number of hadrons it produced in the detector. These Jets can be created in any type of particle accelerator collision regardless of the size of atom used. In proton-proton collisions these Jets are observed and used as a comparison to the jets created in heavy ion collisions. In p-p collisions, there is no QGP to quench the jets so comparing the relative yield of hadrons created in p-p collisions to the relative yield of hardons in heavy ion collisions, can tell us how much energy is being lost to the QGP. This measure of jet quenching is known as the nuclear modification factor Raa and is defined as,

$$R_{AA} = \frac{d^2 N_{AA}(b_{min}, b_{max})/dp_t^2 dy}{N_{bin}(b_{min}, b_{max}) d^2 N_{PP}/dp_t^2 dy}$$

As the Jets traverse the plasma they interact with the particles inside it and radiate away energy based on what they interact with. As we don't know what exactly the mediums degrees of freedom are, we use the measure of Raa to determine how many hadrons are lost to the medium, then relate that value to an energy in hopes that it will tell us something about the medium.

4 Results

We started out by testing three different PDF's(Fig.2) to see what affect they had on the Jets as the crossed through the QGP. After comparing our data to experimental results, we observed that the PDF similar to the gluon distribution fit experimental data fairly well(Fig.3). With this observation we then took our PDF that best fit the data and altered it to see what affects changes on this function had on the Raa output. We tested higher powers of x and saw that it started to deviate away from the experimental data. Next we tested a similarly shaped function(Fig.4) but with a different form. This seemed to fit experimental data even better(Fig.5). Our results show that the PDF of the QGP is similar to the gluon distribution for a proton.

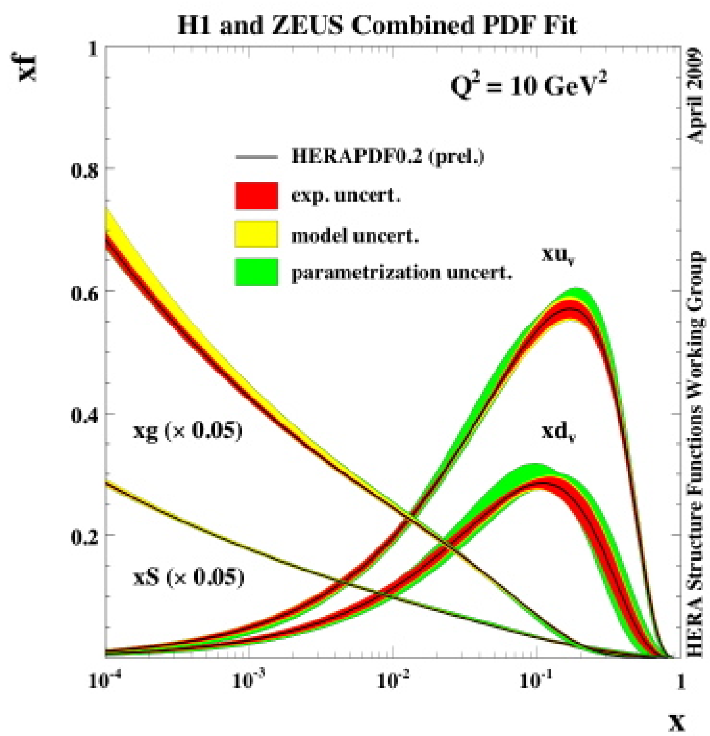

Figure 1: The parton distribution functions for a proton

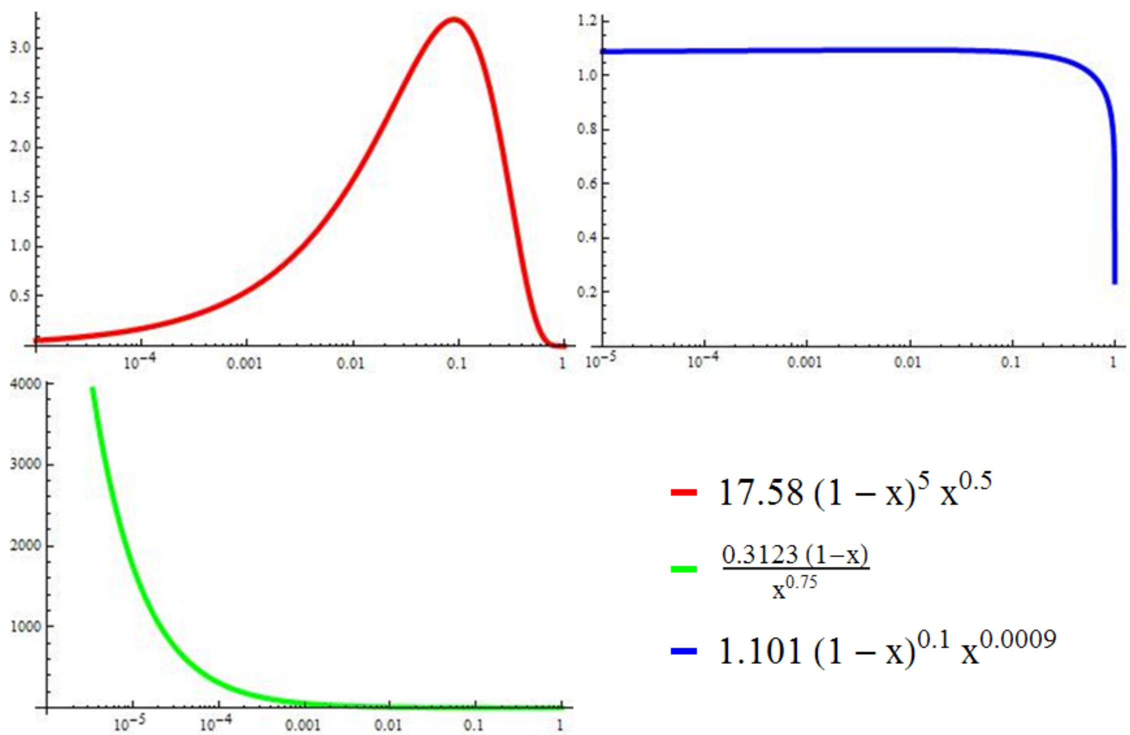

Figure 2: The 3 different PDF's we tested first

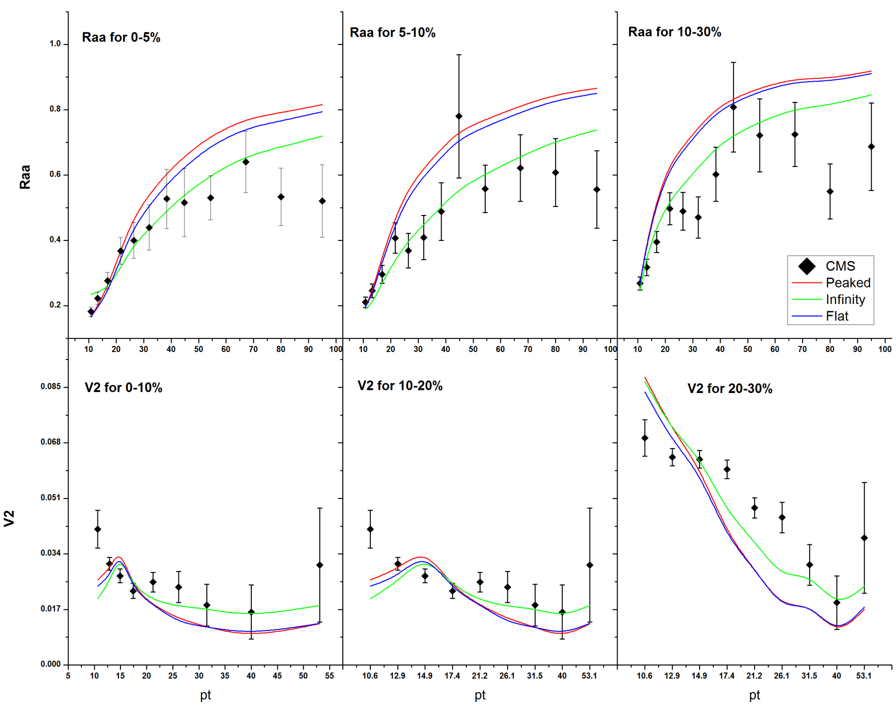

Figure 3: Results after testing all 3 PDF's

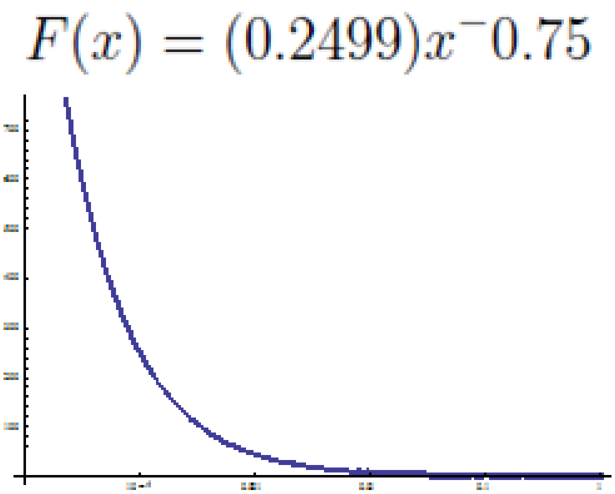

Figure 4: Second version of the gluon-like PDF

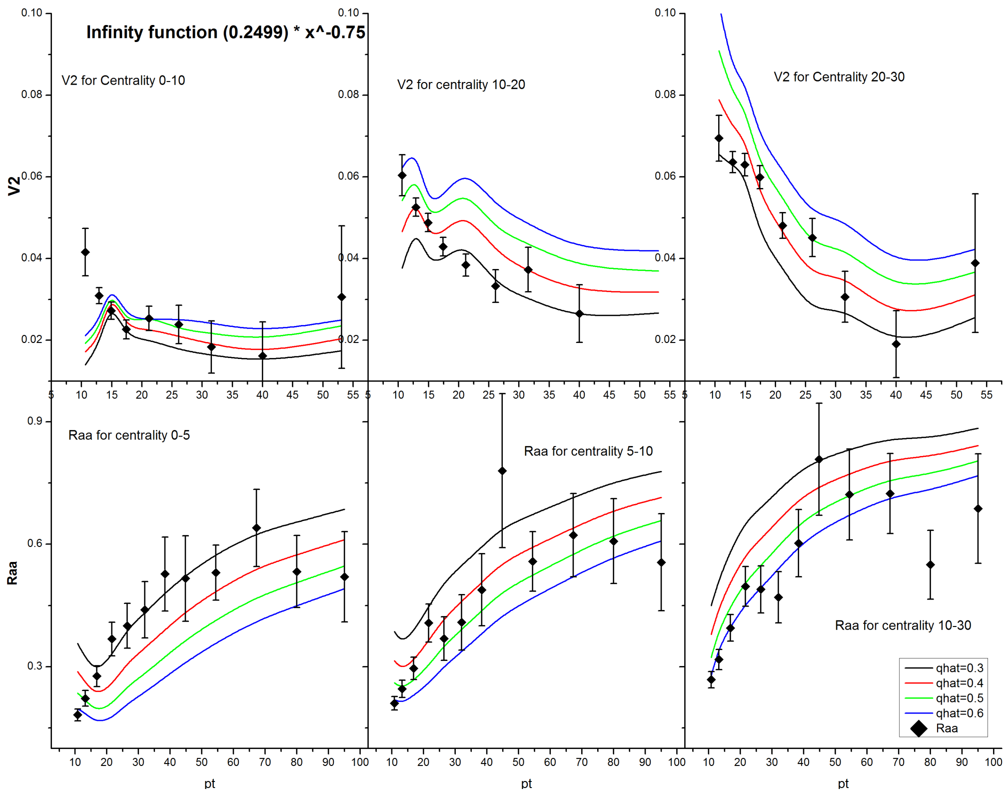

Figure 5: Results from the $(0.2499)x^{\frac{-3}{4}}$ distribution