Exploring the Hadron Production from Jets and Quark Gluon Plasma at LHC

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Abstract

In this project, we improved the jet quenching code PPM to describe the high-momentum hadron data recently published by the ALICE experiment at the LHC. PPM Glauber calculations of the initial transverse densities were updated by changing the previous hard sphere approximation of a nucleus to Woods-Saxon profiles. Impact parameters were matched to centrality bins published by the ALICE experiment. Using the sLPM (Landau-Pomeranchuk-Migdal effect) energy loss model for partons in PPM, the energy loss parameter c_{sLPM} = qhat/s was adjusted to achieve a consistent description of high momentum ALICE data. A blast wave model calculation at low momentum was also added to achieve a comprehensive fit to ALICE data.

High Energy Nuclear Collisions

There are three distinct regions of hadron production in nuclear collisions which can be seen in Figure 1 [1]. Hadrons from jets dominate the transverse momenta of the spectrum above $P_T \approx$ 5-8 GeV/c in nuclear collisions at RHIC and LHC.

Quantum Chromodynamics (QCD) jets are sprays of hadrons created from a single quark or gluon at high energy. At smaller momenta, below $P_T \approx 2$ GeV/c, hadron production is well described by hydrodynamics or blast-wave models assuming thermalized quark gluon plasma (QGP) and hadron gas, while between 2 and 5 GeV/c hadron production proceeds through quark recombination of an off-equilibrium QGP. QGP is the phase of QCD at high temperatures where quarks and gluons can exist without confinement.

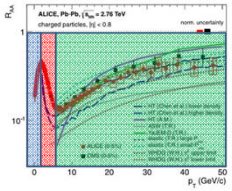

Figure 1: ALICE data showing the three distinct regions of hadron production[1].

Ultimately, the work in this project will be used to analyze the role of quark recombination at LHC. Here, we focus on describing the spectra above transverse momenta $P_T \approx$ 5-8 GeV/c.

PPM Jet Quenching

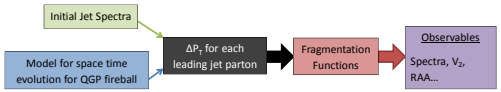

Figure 2: Process illustrating inputs and outputs of PPM code.

We improved the jet quenching code PPM [2] to describe the high-momentum hadron data recently published by the ALICE experiment at the LHC. The PPM code process is illustrated in Figure 2. PPM uses input of initial jet spectra calculated from perturbative QCD and a model for the space time evolution of the QGP fireball to calculate the energy loss of jets. Here we use the sLPM model from [2] with momentum lost per time step,

$$\frac{dP_T}{d\tau} = -c_{sLPM} * \left(P_T/\mu\right)^{\frac{1}{3}} * \tau * S(x,y,\tau).$$

Where

$$S(x,y,\tau) = C * \frac{1}{\tau} * n_{Part}(x,y)$$

is the local entropy density for a longitudinally expanding fireball. C has been fitted to multiplicity data from ALICE.

PPM Jet Quenching (cont.)

The density of nucleons colliding has been calculated in a Glauber model, see next section. The energy loss parameter c_{sLPM} ~ qhat/s was adjusted to accurately describe ALICE data on charged hadron production.

Two preferred observables are the Nuclear Modification Factor (R_{AA}), the ratio of spectra in nucleus-nucleus and proton-proton collisions

$$R_{AA} = \frac{dN^{AA}/d^2P_T}{N_{coll} * dN^{pp}/d^2P_T}$$

and the coefficient v_2. v_2 describes the azimuthal anisotropy of the system and is defined as the second coefficient in the Fourier series:

$$\frac{dN^{AA}}{d^2P_T} = \frac{dN^{AA}}{2\pi P_T dP_T}[1 + 2v_2(P_T)\cos(2\emptyset) + 2v_4(P_T)\cos(4\emptyset) \dots].$$

Transverse Profiles

We updated Glauber profiles in PPM from hard sphere to Woods-Saxon densities. We calculate the collision and participant densities (n_{coll} and n_{part}) of nucleons.

One of the defining characteristics of particle collisions is the impact parameter (b) as shown in Figure 4. The larger the impact parameter, the larger the ellipticity of the fireball.

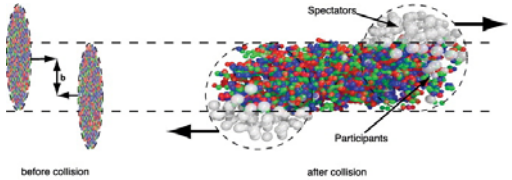

Figure 4: the impact number (b) is the center to center distance between colliding particles (Image Source: CERN)

The impact parameters used in this project were chosen to match centrality bins published by the ALICE experiment [1]. Results at right in Figure 5.

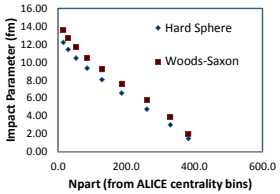

Figure 5: A graph of Impact Parameter vs. Npart illustrating the calcuation differences between using hard sphere as opposed to Woods-Saxon profiles. Npart data is from ALICE [1].

Results

Using PPM, R_{AA} for pions was calculated and compared to ALICE charged hadron data [1] for different impact parameters, see Fig. 6. c_{sLPM} was fitted to optimize the fit to data. c_{sLPM} = 0.0062 GeV fm , μ=1 GeV provide a consistent description of ALICE data.

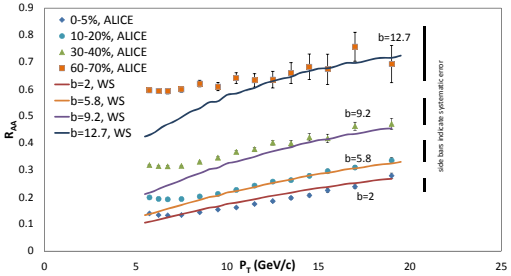

Figure 6: Pion R_{AA} calculated in PPM. Data on charged hadrons from ALICE.

The coefficient v_2 was graphed and compared to ALICE data [3]. An example graph of impact parameter b=5.8 fm is shown in Figure 7.

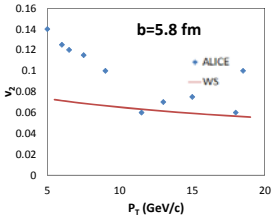

Figure 7: v_2 vs. momenta for theoretical and ALICE data at centrality 20-30% [3]. Error bars of ALICE data are not shown but are generally between 10-30%.

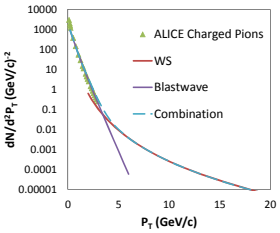

Figure 8: Charged pion spectrum from blastwave and jets compared to ALICE charged pions for b=2 fm [4].

Charged pion spectrum from jets and a blastwave calculation (T = 100 MeV, Surface velocity = 0.87c) compared to ALICE data [4].

Conclusions

In this project, we improved the PPM code by implementing different Glauber profiles and adjusting the energy loss parameter c_{sLPM}. We achieve a reasonable description of hadron RAA in the target region between 5 and 15 GeV. Deviations at low momenta and large impact parameters are presumably from soft hadron production mechanisms and due to fluctuations in smaller systems. The azimuthal asymmetry coefficient v_2 is roughly consistent with ALICE data at large momenta without fitting any additional parameters. Future work will use the results of this project to create a more complete description of hadron production in high energy nuclear collisions.

References

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