Probing the Constituent of QCD Plasma in CUJET3.1/CIBJET Framework

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In this proceeding we report results of a comprehensive global analysis of ultra-relativistic heavy-ion collision data using the updated CUJET3.1 framework. By comparing CUJET results with (CUJET3.1) versus without (CUJET2.0) chromo-magnetic monopole (cmm) degrees of freedom, we find that the cmm scenario is more favored by experimental data. Finally, we use the event-by-event generalization of the CUJET framework, CIBJET, and show that fluctuations in the initial conditions do not significantly alter our conclusions for R_{AA} and v_2.

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1. Introduction

High energy quark and gluon jets, initially generated in rare perturbative QCD processes, lose energy and diffuse transversely along their paths due to interactions with microscopic constituents of the hot quark-gluon plasma created by heavy ion collisions. Such high p_T processes provide an independent probe of the evolution history of the QCD matter produced in such collisions. Recent high-precision data from LHC Pb + Pb collisions on jet quenching and azimuthal asymmetry observables over wide kinematics and centrality ranges provide an opportunity to quantitatively constrain and differentiate competing models of jet-medium interactions, as well as varied assumptions of the chromo-electric and magnetic field structure of the bulk QCD "perfect fluids" produced in ultra-relativistic nuclear collisions.

In this work we utilize the CUJET3 model, a jet energy loss simulation framework, to probe the color structure of semi-quark-gluon-monopole plasma (sQGMP), which integrates two essential elements of confinement, i.e. the suppression of quarks/gluons and emergent magnetic monopoles. The CUJET3 model employs the TG elastic energy loss formula [1] for collisional processes, and the dynamical DGLV opacity expansion theory [2] with the Liao–Shuryak chromo-magnetic-monopole scenario [3] for radiational processes. Detailed description can be found in previous CUJET publications [4, 5, 6, 7, 8, 9].

2. Parameter Calibration

There are two key parameters in the CUJET3 model. One is α_c, the value of QCD running coupling at the non-perturbative scale $Q^2 = T_c^2$. It sensitively influences the overall opaqueness of the hot medium. The other is c_m, being the coefficient to scale the magnetic screening mass in the medium $c_m = \mu_M/(g\mu)$. It influences the contribution of the magnetic component to the jet energy loss. The increase of c_m leads to the enhancement of monopole mass, hence overall opaqueness.

To constrain these two parameters, we compare the results from CUJET3.1 calculations with high p_T experimental data of both R_{AA} and v_2, for central ($0-5\%$, $0-10\%$) and semi-central ($10-30\%$, $20-30\%$) heavy-ion collisions at beam energy $\sqrt{s_{NN}} = 0.2$, 2.76 and 5.02 TeV [10, 11, 12, 13, 14, 15, 16, 17, 18]. In Fig. 1 we show the corresponding χ^2/d.o.f., which is defined as the ratio of the squared difference between the experimental data points and corresponding CUJET3 expectation, to the quadratic sum of experimental statistic and systematic uncertainties for that data point. With the smallest χ^2/d.o.f. closest to unity, we obtain the optimal parameter set as $\alpha_c = 0.9 \pm 0.1$ and $c_m = 0.25 \pm 0.03$.

With taking the optimal parameter, we show in Fig. 2 the comparison with the experimental data. While both sQGMP schemes (χ_T^L and χ_T^u, see e.g. [7] for more detail) give similar jet quenching variables, the QGP scheme gives similar R_{AA} but less azimuthal anisotropy. In particular, one can see clearly from the quantitative value of their χ^2/d.o.f. that the theoretical expectations of both sQGMP schemes are in good consistency with the experimental data, and that of the QGP scheme, without cmm degree of freedom, differs significantly from the highly precise LHC v_2 measurements. The χ^2 analysis strongly supports the need of cmm degrees of freedom, but remains robust on the specific quark liberation scheme.

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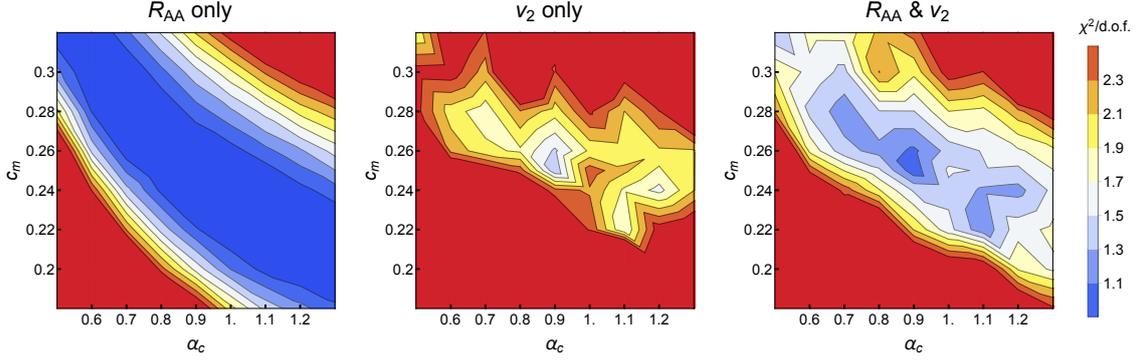
Figure 1: $\chi^2/\text{d.o.f.}$ comparing CUJET3.1 results with RHIC and LHC data. Left: $\chi^2/\text{d.o.f.}$ for R_{AA} only. Middle: $\chi^2/\text{d.o.f.}$ for v_2 only. Right: $\chi^2/\text{d.o.f.}$ including both R_{AA} and v_2.
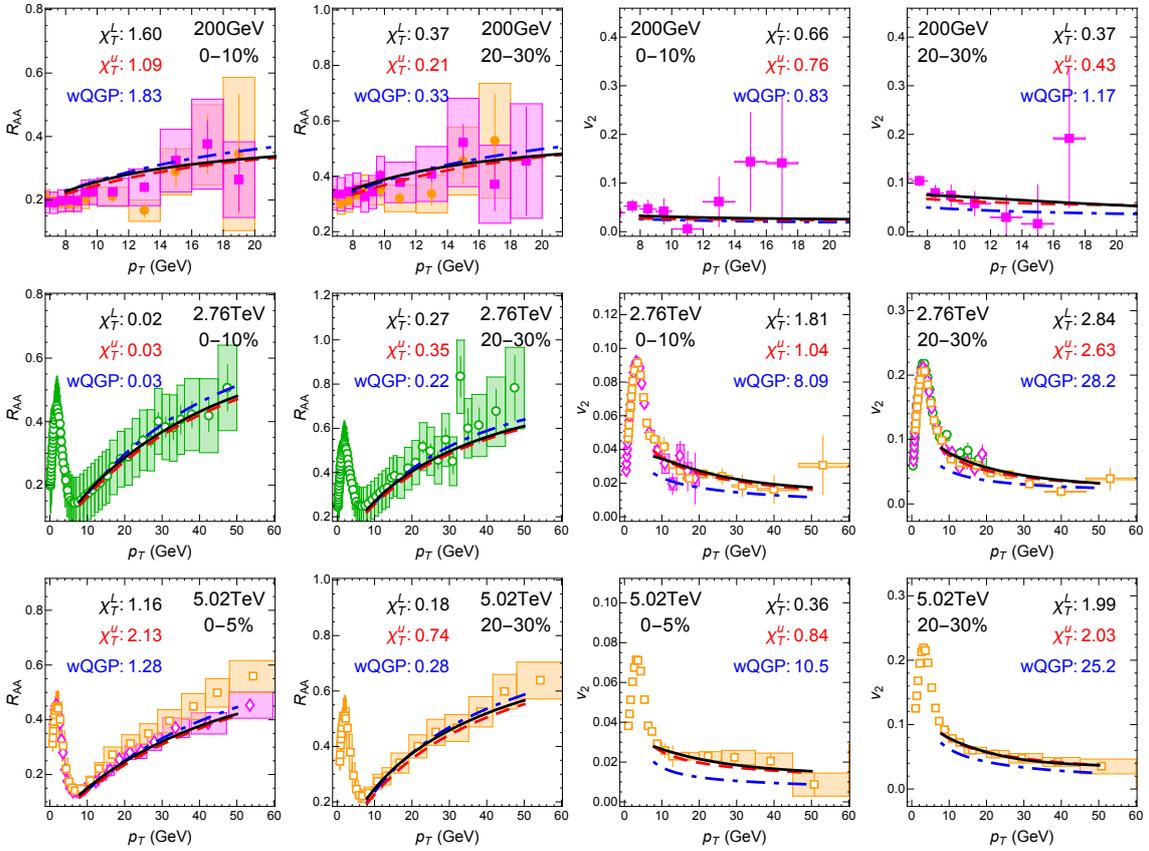
Figure 2: CUJET theoretical expectation of light hadron R_{AA} and v_2 using three different schemes: sQGMP χ_T^L-scheme (black solid), sQGMP χ_T^u-scheme (red dashed), wQGP/CUJET2 scheme (blue dashed dotted). Corresponding $\chi^2/\text{d.o.f.}$ are shown, with respect to following experimental data: PHENIX 2008 (orange solid circle) [10], PHENIX 2012 (magenta solid square) [11]; ALICE (magenta open diamond) [12, 15], ATLAS (green open circle) [13, 16], CMS (orange open square) [14, 17, 18].

3. Influence of Soft-Hard Correlation

Some recent research [21] points out that the experimental measurements of hard particle har-
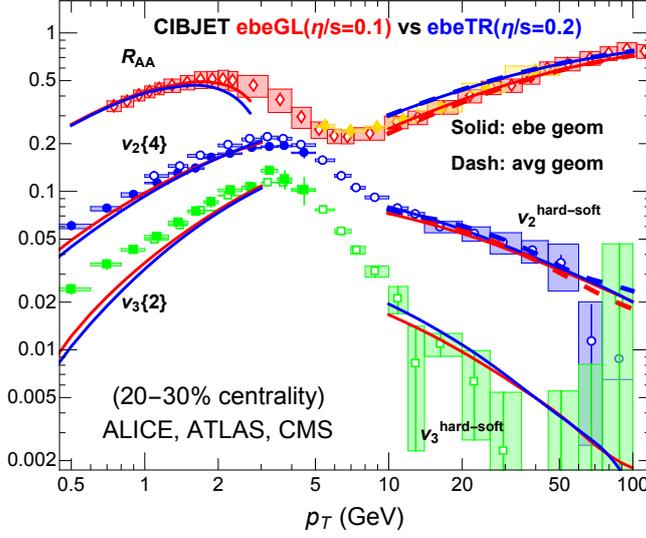
Figure 3: Nuclear modification factor R_{AA} as well as the second and third harmonic coefficients v_2 and v_3 of final hadron azimuthal distribution as functions of p_T for 20–30% Pb + Pb collisions at 5.02 ATeV. Solid curves are obtained from ebe calculations, while the dashed curves depict averaged smooth geometry. CIBJET results in both soft and hard regions, with either Monte-Carlo Glauber (red) or Trento (blue) initial conditions, are in good agreement with experimental data from AL-ICE, ATLAS, and CMS [16, 17, 18, 19, 20].

monics v_n^f are performed with respect to event-wise soft harmonics, and event-by-event (ebe) fluctuations of the bulk initial condition may play an important role. Within the CUJET3 framework, we investigated the influence of ebe fluctuating hydro initial conditions with a generalized CIBJET framework, with the results reported in Ref. [8, 9]. In Fig. 3, we present the CIBJET results of R_{AA}, v_2 and v_3 for centrality of 20–30%, which show excellent agreement with experimental data and demonstrate the correct centrality dependence of the CIBJET results. One conclusion found with CIBJET is that the p_T and centrality dependence of the elliptic $v_2^f(p_T, C)$ azimuthal harmonics shows quantitative consistency at a $\sim 10\%$ level between calculations with averaged smooth bulk geometry and those with fluctuating initial conditions. This conclusion is true for a variety of centrality class, while different from the ebeIC + vUSPhydro + BBMG framework in Ref. [21], which found a much larger sensitivity (factor ~ 2) of the hard elliptic harmonic to ebe fluctuations. The CIBJET computation justifies the use of averaged smooth geometry in the CUJET3 framework.

4. Summary and Outlook

To summarize, we report results of a comprehensive global analysis of nuclear collision data using the updated CUJET3.1 framework. By comparing CUJET results with wQGP versus sQGMP scenarios, we find that RHIC and LHC experimental data favor the existence of chromo-magnetic monopole. We further find that our conclusions for R_{AA} and v_2 are insensitive to fluctuation of hydro initial conditions. We end by discussing our expectation for di-jet measurements. Di-jet accoplanarity and imbalance observables are sensitive to different jet path-length and temperature dependence, and are biased to different geometric distribution of initial jet creation spots. Consequently, we expect that future precise measurements could offer another opportunity to distinguish color constituent models. Some of the CUJET preliminary results have been reported in Ref. [22], and more detailed, systematic theoretical predictions will be presented in the near future.

Acknowledgments

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