The Compact Muon Solenoid Experiment
Conference Report

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Signatures of AdS/CFT using the CMS experiment at the LHC

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Abstract

Measurements of jet suppression via heavy ion collisions at the RHIC suggest that the produced, high temperature nuclear matter is colour opaque. Furthermore, observation of large collective motions, known as elliptic flow, in this strongly interacting nuclear matter led to the suggestion that ideal hydrodynamic behavior was observed. We will have a look at what could be measured with the CMS experiment, and how the higher center-of-mass energy that will be available at the LHC will permit access to new observables and laboratory tests of AdS/CFT versus pQCD.

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1 Introduction

The study of relativistic nuclear collisions at RHIC has generated data that lends credence to the idea that Quantum Chromodynamics (QCD) may share a deep mathematical connection [1] with a form of string theory via anti-de Sitter/conformal field theory (*AdS/CFT* conjecture). The ideal hydrodynamic fluid like behavior observed at RHIC of the strongly interacting quark gluon plasma (sQGP) has prompted new theoretical work (see [2] and references therein) on comparing measurable quantities such as: nuclear matter flow; jet propagation through hot nuclear matter; jet energy loss via gauge boson tagging; p_T dependent quarkonia melting; and nuclear modification factors (R_{AA}), with perturbative QCD (pQCD) calculations and string theory inspired predictions for these effects. The Compact Muon Solenoid (CMS) experiment [3] is a unique general purpose particle detector that can provide results on each of these topics.

2 Experimental Signatures

2.1 Elliptic Flow

Much to the surprise of nuclear physicists, the analysis of the results of collisions between relativistic gold ions at RHIC favored a scenario in which the partons acted collectively (strongly) rather than individually, as was expected for a weakly interacting quark-gluon plasma.[4] Hydrodynamical calculations exhausted the elliptic flow (v_2) strength of the hot nuclear matter formed by the collision. Here, v_2 is defined as the coefficient of the second harmonic of the particle azimuthal distribution produced by the heavy ion collisions with respect to the nuclear reaction plane depicted schematically in Fig 1.

Figure 1: Schematic of momentum asymmetry of particles emitted during an off-center heavy-ion collision.

Elliptic flow data [5] obtained at RHIC using the STAR detector for is shown in Fig. 2. An analysis [7] using the *AdS/CFT* conjecture explained this data by requiring a minimum viscosity-to-entropy ratio $\geq 1/4\pi$ for the hot flowing nuclear matter. Ideal fluid hydrodynamical calculations [8] are also shown in Figure 2. The CMS detector at the Large Hadron Collider (LHC) should be capable of measuring low p_T elliptic flow. If the same ideal hydrodynamic behavior is observed at the LHC beam energy, then the LHC will also provide a testing ground for the *AdS/CFT* conjecture that would permit comparisons with pQCD. Particle identification for protons pions and kaons in the CMS detector will be done using the pixel barrel and silicon strip detectors.[6] In order to make a direct elliptic flow comparison this CMS capability should overlap with the region below $p_T \leq 1\text{GeV}/c$ in Fig. 2 designated 'Star at RHIC'.

Figure 2: A compilation of elliptic flow results from RHIC, along with perfect fluid hydrodynamical calculations.

2.2 Gauge Boson Tagging

The CMS will primarily reconstruct the Z^0 in the dimuon channel. The large p_T of its decay muons allows for a clean identification of this gauge boson over the underlying heavy-ion event background. Energy loss of the jet on the away side (fig. 3) can be compared against the gauge boson energy to determine jet energy loss in the colored medium.

Figure 3: A schematic of the gauge boson dimuon tag (left), with a PYQUEN generator level simulation of energy loss. [6] (right)

It is important to note that contributions from the γ^* to dimuons has only been simulated at the generator level in CMS-like acceptance. [6]

Figure 4: A simulated γ -jet coincidence in CMS plotted in η versus ϕ . Here a pp γ -jet final state was superimposed upon a PbPb event at the nominal LHC beam energy (left); the simulated comparative energy balance between the hadronic jet compared to the γ energy. [13] (right)

In principle, the high resolution CMS electromagnetic calorimeter with large coverage and segmentation may make it possible to reconstruct γ -jet events. The γ escapes the hot colored nuclear matter without depositing much energy. The quenched away side jet energy could be detected in the CMS hadronic calorimeter as indicated in Fig. 4.

2.3 Shock Waves

A heavy quark moving through a sQGP will generate a diffusion wake and a "sonic" boom (Mach cone) like pattern of emitted particles. Thermal AdS/CFT calculations in the rest frame of the sQGP lead to the suggestion that the energy flow from the sonic boom may dissipate approximately $\sim (1 + v^2)$ more energy than is fed in by the diffusion wake energy flow.[9] The CMS detector, with its ability to measure energy flow may allow an empirical check of this predicted velocity dependence in the suppression. This effect is illustrated in Fig. 5.

Figure 5: The Poynting vector components are designated by the black arrows. Here the dashed line is the Mach Cone (sonic boom), and the solid line shows the Diffusion Wake with the Poynting vectors adding energy to the jet.

Note that in Fig. 5. the Poynting vector is pointing into the jet, adding energy, while the vector is pointing outward

(removing energy) via the Mach cone. This calculation is for a heavy quark moving at 0.75 of the velocity of sound in the sQGP.

2.4 Quarkonia Melting

The dissociation of charmonium bound states was first suggested as a signal of the production of hot and deconfined quark gluon plasma by Matsui and Satz.[10] Similarly, It is expected that the melting of bottomonium bound states should occur in sQGP matter for centre-of-mass energies expected at the LHC.

Figure 6: A simulated production and generated CMS detection of high- p_T J/ψ (left) and Υ (right) for PbPb at 5.5 TeV.[6]

The total production of both charmonium and bottomonium with high- p_T is expected to be greatly enhanced at the LHC when compared to RHIC. In Fig. 6 the production and detection range of high- p_T quarkonia are simulated for the CMS detector. An observation of changes in the melting pattern of the quarkonia resonances (ψ' , Υ' and Υ''), predicted using AdS/CFT , can be used to explore this conjecture. It was recently predicted [11] that the melting temperatures for the various J/ψ and the Υ families should manifest an approximately

$$T(v)_{Melt} \sim T(0)_{Melt}(1 + v^2)^{1/4} \quad (1)$$

for heavy mesons as a function of their transverse momenta. Here, $T(0)_{Melt}$ is the dissociation temperature for a heavy quark meson in its rest frame.

2.5 Nuclear Modification Factor

Recently, there was a proposal [12] to use nuclear modification factors for a possibly more sensitive test comparing AdS/CFT with pQCD. The idea is to use the momentum independence and heavy quark inverse mass dependence of the AdS/CFT drag coefficient. The string inspired drag coefficient is completely different to the $\log(p_T/M)/p_T$ variation of the drag coefficient deduced from pQCD. The nuclear modification factor is

$$R(p_T, \eta)_{AA} = (d^2 N^{AA}/dp_T d\eta)/T_{AA}(d^2 \sigma^{pp}/dp_T d\eta) \quad (2)$$

Here, T_{AA} is proportional to the number of inelastic nucleon-nucleon collisions and the average number of binary collisions expected for a particular collision centrality bin. One can now take a ratio of the ratios in Eq.(2) for

charm and bottom jets,

$$double - ratio = (R^c)_{AA}/(R^b)_{AA} \quad (3)$$

The variation in the double-ratio is predicted to be striking (fig.7) at large (tens of GeV/c) transverse momentum. This experiment could only be done at the LHC where high p_T and significant production cross section should exist for charm and bottom quark jets.

Figure 7: The double-ratio nuclear modification factors for charm and bottom jets.

3 Conclusion

The LHC will extend the energy range and the high p_T reach of high density pQCD physics. This will enable further detailed tests of possible AdS/CFT predictions. The CMS, in particular [6], is preparing to take advantage of the LHC high energy capabilities with excellent detector hermetic coverage, mass resolution and particle ID for elliptic flow reaching very low p_T (like RHIC). Jet energy loss and broadening studies, heavy quarkonia melting for J/ψ and the Υ meson families, and a promising comparison of nuclear modification factors from heavy quark jets are possibilities for further studies of the AdS/CFT Conjecture using high energy heavy ion collisions.

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References

- [1] J. Maldacena, *Adv. Theor. Math. Phys.* **2** (1998) 231; *Int. J. Theor. Phys* **38** (1999) 1113.
- [2] W.A. Horowitz and Yuri V. Kovchegov, *Physics Letters* **B680** (2009) 5661; W.A. Horowitz, arXiv:0905.0504v1.
- [3] The CMS Collaboration, *JINST* **3** (2008) S08004.
- [4] B.B. Back et al. (PHOBOS Collaboration, *Nucl. Phys.* **A757** (2005) 28; J. Adams et al. (STAR Collaboration), *Nucl. Phys.* **A757** (2005) 102; K. Adcox et al. (PHENIX Collaboration), *Nucl. Phys.* **A757** (2005) 184.
- [5] Snellings R. *AIP Conf. Proc.* **756** (2005) 390.
- [6] The CMS Collaboration, *J. Phys. G: Nucl. Part. Phys.* **34** (2007) 2307-2455.

- [7] Kovtun P., Son D. T. and Starinets A. O., *Phys. Rev. Lett.* **94**(2005) 111601.
- [8] Huovinen P. and Ruuskanen P. V. *Ann. Rev. Nucl. Part. Sci.* **56** (2005) 163.
- [9] S.Gubser, S. Pufu, A. Yarom, *Phys. Rev. Lett.* **100** (2008) 012301 ; *JHEP* **07** (2008) 108.
- [10] T. Matsui and H. Satz, *Phys. Lett.* **B178** (1986) 416.
- [11] H. Liu, *J. Phys. G: Nucl. Part. Phys.* **34** (2007) S361-368.
- [12] W.A. Horowitz and M. Gyulassy, *Phys. Lett.* **B666** (2008) 320.
- [13] G.I Veres for the CMS Collaboration, *Nucl. Phys.* **A830** (2009) 793c.