The sPHENIX Barrel Upgrade: Jet Physics and Beyond

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Abstract

The past decade of heavy ion physics at RHIC has produced many surprising discoveries and puzzles. Currently the experiments at the LHC are providing a first look at things to come: a burgeoning program for studying the quark-gluon plasma with reconstructed jets. The PHENIX collaboration has developed a long term plan involving a series of upgrades designed to expand the physics capabilities and make use of the full enhanced luminosity at RHIC. With increased coverage and the addition of hadronic calorimetry, we demonstrate that the sPHENIX upgrade will be well positioned to provide a broad and exciting program of jet probe measurements. Sampling 50 billion Au+Au events annually, we will collect 10 million jets with transverse energy above 20 GeV and 100 thousand jets above 40 GeV. With the addition of new tracking layers and an EM preshower, a crucial program of upsilon measurements, as well as neutral pion measurements with a 40 GeV/c reach, can be made in a flexible accelerator facility capable of providing a diverse range of collision systems across many beam energies. And, ultimately, the sPHENIX detector will provide the base for staging a future electron-ion collider detector at eRHIC.

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1. Introduction

Experiments at RHIC have determined that the matter produced under the extreme conditions of temperature and density in highly relativistic nuclear collisions undergoes a phase transition to a strongly coupled fluid which has been called the strongly-coupled quark-gluon plasma (sQGP). The lifetime of the sQGP is too short to investigate its properties with external probes, hence they must be explored by probes emerging from the sQGP itself. Quarks and gluons produced with large transverse momentum are abundant at RHIC and LHC energies, and these hard processes can be used to characterize the medium. The partons cannot be directly observed in the laboratory, so high p_T particle production or jet production must be used as surrogates for measurements of the partons. Study of the modification of the parton shower by the sQGP can provide key information on the nature and dynamics of the scattering particles in the medium, and full jet reconstruction can provide important insight into the behavior of the parton shower. Thus, experimental measurement of jets, jet-hadron correlations, and γ-jet correlations provide important new information on the behavior of the parton shower in medium. Fully reconstructed jets at LHC energies have been studied by the ATLAS and CMS experiments with superb calorimetric detectors, but the sQGP is produced at a higher initial temperature at LHC than at RHIC,

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[1] A list of members of the PHENIX Collaboration and acknowledgments can be found at the end of this issue.

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so jet measurements at RHIC provide important and complementary measurements of the sQGP. Therefore, the PHENIX experiment is proposing a substantial upgrade to be ready before the end of the decade to make measurements of jets with a large acceptance calorimetric detector at RHIC energies.

2. Probing the sQGP

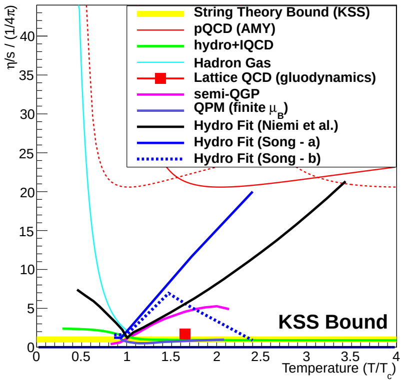

Figure 1: Shear viscosity divided by entropy density, η/s, renormalized by the conjectured KSS bound as a function of the temperature relative to the transition temperature with a number of calculations for the quark-gluon plasma.

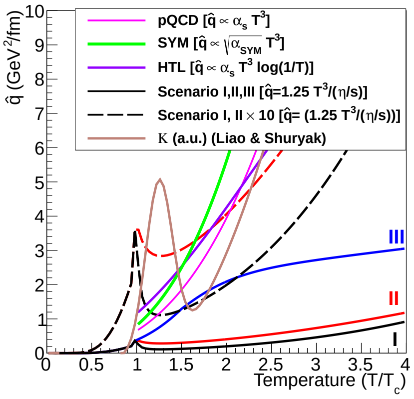

Figure 2: Calculations for the scaling of $\hat{q}$ under a variety of weak and strong coupling assumptions near the transition temperature.

Lattice QCD calculations of hadronic matter under extreme conditions predict a rapid change in properties at a transition temperature, $T_c \simeq 170$ MeV[1]. The initial temperature of heavy ion collisions measured at RHIC by means of direct photons and compared with hydrodynamic models is estimated to be around 300 MeV[2], so the initial state is produced at about 1-2 T_c. Measurements of radial and elliptic flow of hadrons when compared to hydrodynamic calculations indicate a very small ratio of shear viscosity to entropy density, η/s, comparable to the lower limit suggested by the calculation of Kovtun, Son, and Starinets (KSS)[3] for a broad class of strongly coupled gauge field theories, as shown in Figure 1. The passage of hard scattered partons through the quark-gluon plasma provides a measure of the coupling strength to the medium which can be characterized by the transverse momentum it accumulates traversing the medium $\hat{q} = d(\Delta p_T^2)/dt$; some of the calculations of this quantity are shown in Figure 2. Collisions at RHIC can thus provide key measurements close to the transition temperature, where the properties of the medium are changing quickly and the dynamics are not well understood, which complement and extend measurements at the LHC at higher temperatures.

3. Production and Detection at RHIC

A prerequisite for a program of precision jet measurements at RHIC is a sufficiently high rate of jets to allow high statistics measurements of jet properties and an adequate rate for measuring rare processes, like γ-jet correlations.

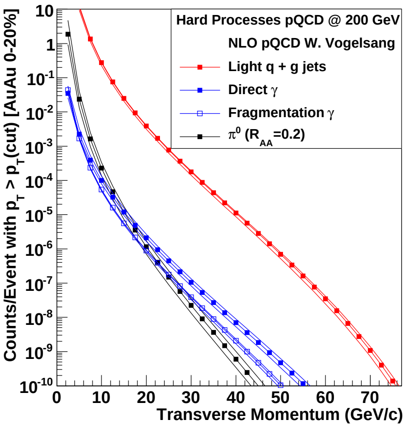

Figure 3: Jet, photon and π^0 rates with $|\eta| < 1.0$ from NLO pQCD calculations scaled to Au+Au central collisions.

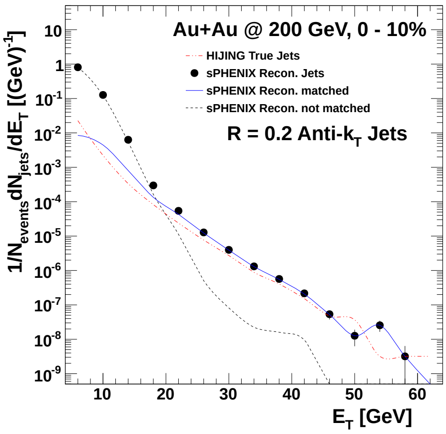

Figure 4: A study of 750M simulated HIJING events demonstrated the ability to distinguish real jets from "fake" jets above 20 GeV[5].

Vogelsang has calculated the inclusive jet yield in Next-to-Leading-Order (NLO) perturbative QCD contained within $|\eta| < 1.0$ in 200 GeV p+p collisions and we have scaled up by the expected number of binary collisions to estimate the jet rate for 0-20% central Au+Au collisions[4]. The results of this calculation are shown in Figure 3 along with calculations for π^0's and direct and fragmentation photons. The bands correspond to the renormalization scale uncertainty in the calculation.

Taking account of the increased luminosity which resulted from the "RHIC II" luminosity program, the number of jets or direct photons in a twenty week Au+Au run typical for RHIC operation is about 10^7 jets above 20 GeV in the 20% most central collisions, and about 10^4 γ-jet events. Comparable large statistics can be accumulated in p+p and d+Au collisions, yielding a rich set of comparison data.

Due to the high multiplicity of charged particles produced in heavy ion collisions at both RHIC and LHC energies, fluctuations can result in detection of spurious jets. A number of methods have been proposed for separating the spurious or "fake" jets from real jets resulting from parton fragmentation, and a recent study[5] using a large sample of HIJING events has concluded that jets with an E_T above 20 GeV can be detected with a signal to background of greater than unity in 200 GeV central Au+Au collisions, as shown in Figure 4.

4. The sPHENIX Detector

Electromagnetic and hadronic calorimeters covering a full 2π in azimuth a a pseudorapidity range $|\eta| < 1$ are essential for these measurements. Since the hadronic calorimeter must be five nuclear interaction lengths or more to contain hadronic showers, a thickness of nearly one meter of steel absorber is required, which is also utilized as the flux return for the central 2T solenoid. In order to minimize the size and mass and hence the cost of the detector, the inner radius of the detector should be no larger than needed to achieve good momentum resolution, which implies a high magnetic field and precision tracking measurements.

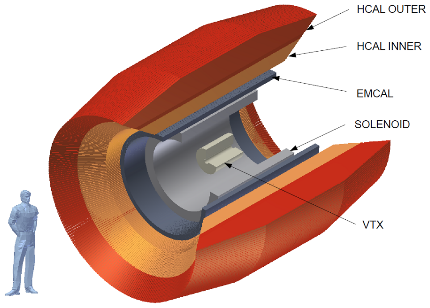

Figure 5: A rendering of the sPHENIX upgrade showing the existing silicon tracker, and the electromagnetic and hadronic calorimeters outside a thin 2 T solenoid.

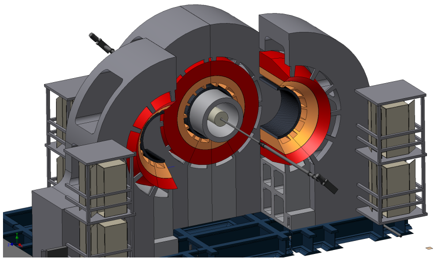

Figure 6: A concept for support and service of the sPHENIX detector in the PHENIX interaction region at RHIC.

Technological advances have allowed us to design a more compact detector than previously possible by use of solid state photodetectors, tungsten absorber with a radiation length of just 3.5 mm for the electromagnetic calorimeter, and wavelength shifting fiber embedded in scintillator sandwiched between steel absorber plate for the hadronic calorimeter. Silicon photomultipliers (also known as Multi Pixel Photon Counters or MPPC's) or avalanche photodiodes (APD's) are much smaller than photomultiplier tubes, work in a magnetic field, and do not require bulky high voltage cabling. Light collection from both calorimeters can be achieved with $\sim$10 cm of radial space, and the support electronics for the sensors require small radial space and minimal cooling. The proposed detector provides a large acceptance and high rate detector for future experiments at RHIC, which can be substantially enhanced with high resolution tracking and an electromagnetic pre-shower detector, which can also form the basis for a detector at a future Electron-Ion Collider.

5. Summary

Jet physics accessible at RHIC complements and extends measurements at the LHC in the extremely interesting region of temperature near the transition temperature. A major upgrade to the PHENIX detector using innovative technology to build a compact yet powerful calorimetric detector is being designed which builds on the existing infrastructure in the PHENIX interaction region. Many more details of the detector and the physics justification are available in the proposal[6].

References

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