sPHENIX - a new jet detector at RHIC

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Abstract. sPHENIX is a new state-of-the-art detector optimized for measurements of jets and heavy flavor which will take advantage of increased luminosity available at the Relativistic Heavy Ion Collider (RHIC). It comprises vertex tracking and hadronic and electromagnetic calorimetry. This enables studies of jet structure, heavy flavor jets, open heavy flavor, and quarkonia, the pillars of the sPHENIX physics program. These measurements will complement measurements at the LHC and enable determination of the properties of the medium created in heavy ion collisions to high precision, including its temperature dependence. This talk will discuss the detector design and key measurements enabled by the new detector, as well as the status of the project itself.

1. Introduction
Measurements from the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) have provided ample evidence for the production of a hot, dense Quark Gluon Plasma (QGP) [1–4], but key questions remain. Measurements of global observables and probes of soft physics are limited by systematic uncertainties and their precision is near what is possible with our current technology. By contrast, measurements of jets and heavy flavor production from RHIC are limited by both statistical and systematic uncertainties. Improvements in both accelerator and detector technology enable measurements of these observables with comparable precision to those achievable at the LHC. The sPHENIX detector will combine precision tracking and calorimetry capable of taking advantage of increased collision rates available at RHIC. This will enable constraints of the properties of the medium with uncertainties comparable to those at the LHC.

2. Detector
The sPHENIX detector, shown in figure 1, consists of a silicon tracking system, time projection chamber (TPC), electromagnetic calorimeter (EMCAL), and inner hadronic calorimeter (HCAL) in a 1.4 T magnetic field surrounded by an outer HCAL. The magnet was previously used in BaBar [5] and successful full field tests were completed in February 2018, demonstrating that the magnet performs to specifications. A 3-layer MAPS pixel sensor detector surrounded by four layers of silicon strips is proposed as the inner tracking system in order to provide the high precision distance of closest approach (DCA) resolution necessary for the identification of final state particles from heavy flavor decays. The TPC for the outer tracking system will be gateless with continuous readout in order to take advantage of high luminosities.

The calorimetry consists of an EMCAL, an inner HCAL inside the magnet, and an outer HCAL. The performance of this system has been demonstrated in a number of test beams [6].
Figure 1. The sPHENIX detector consists of a silicon inner tracking system, a time projection chamber (TPC), an electromagnetic calorimeter (EMCAL) and inner hadronic calorimeter (HCAL) in a 1.4 T magnetic field surrounded by an outer HCAL.

Figure 2. Energy resolution for electrons (left) and pions (middle) and the nonlinearity of the calorimeter response (right).
The energy resolution for electrons and pions and the nonlinearity are shown in figure 2. The combination of precision calorimetry and tracking enables identification of photons and electrons from decays of heavy flavor hadrons, including quarkonia, and measurements of jets. These detectors will enable measurements not possible with the previous generation of RHIC detectors.

3. Physics milestones

3.1. Heavy flavor
To date, measurements of heavy flavor production are limited by uncertainties and the limited ability to reconstruct final state hadrons. While D mesons have been reconstructed [7], no RHIC detectors enable measurements of reconstructed B mesons or have high enough statistics to measure them. In contrast, B mesons have been measured at the LHC [8]. Figure 3 shows the projected uncertainties for measurements of the B meson nuclear modification factor $R_{cp}$, the ratio of B meson spectra in central to that in peripheral collisions, and azimuthal asymmetry $v_2$ for B mesons. These measurements will enable constraints of QGP properties at RHIC energies with precision comparable to that available at the LHC.

3.2. Quarkonia
Quarkonia measurements at RHIC to date [9,10] are also limited by their precision, in particular the ability to distinguish between the ground state and different excited states. Figure 4 shows the projected invariant mass peak for the $\Upsilon(1s)$, $\Upsilon(2s)$, and $\Upsilon(3s)$ (left) and uncertainties on the nuclear modification factor $R_{AA}$, the ratio of B meson spectra in central collisions to that in $p+p$ collisions, for the different $\Upsilon$ states, demonstrating that sPHENIX will be able to resolve the different quarkonia states and measure observables for quarkonia with precision comparable to that at the LHC.

3.3. Jets and jet structure
RHIC played a vital role in our understanding of partonic energy loss in the medium, providing critical evidence that hard partons lose energy in the medium and, as a result, final state jets are broader and softer in $A+A$ collisions than in $p+p$ and $d+Au$ collisions [11]. By taking advantage...
Figure 4. Projected invariant mass peak for the $\Upsilon(1s)$, $\Upsilon(2s)$, and $\Upsilon(3s)$ (left) and uncertainties on the nuclear modification factor $R_{AA}$ for the different $\Upsilon$ states.

Figure 5. Projected uncertainties for single hadron and reconstructed inclusive jet and $b$-jet nuclear modification factors $R_{AA}$ compared to measurements from PHENIX.

of higher rates, sPHENIX will extend the reach of single final state hadrons beyond that achieved at RHIC and enable high precision measurements of reconstructed jets. Figure 5 shows projected uncertainties for single hadron and reconstructed jet nuclear modification factors $R_{AA}$ compared to measurements from PHENIX.

Reconstructed jets and the emerging study of jet structure are important for constraining the jet transport coefficients. Neither PHENIX nor STAR were optimized for reconstruction of jets in heavy ion collisions and to date there have only been three papers from heavy ion collisions at RHIC published on measurements of reconstructed jets [12–14]. Complete information on
Figure 6. Projected uncertainties for the azimuthal asymmetry of reconstructed b-jets (left) and for the energy fraction of a jet in coincidence with a leading photon as a function of the angle relative to the reaction plane (right).

partonic energy loss comparable to that available at the LHC therefore requires a dedicated detector. sPHENIX is optimized to enable more differential measurements of jets. Figure 5 shows projected uncertainties for measurements of jets created from a bottom quark. Figure 2 shows the projected uncertainties for the azimuthal asymmetry of reconstructed jets and for the energy fraction of a jet in coincidence with a leading photon as a function of the angle relative to the reaction plane. The combination of these measurements will enable precision constraints of partonic energy loss in the medium.

4. Conclusions
Measurements at RHIC have provided critical information to establish the formation of the QGP and precision measurements of low momentum probes of the QGP enable some constraints of the properties of the medium. However, to date measurements at RHIC provide little differential information on jets and limited information on quarkonia states. sPHENIX is optimized to do these measurements, enabling determination of the properties of the QGP at RHIC energies with precision comparable to that available at the LHC.

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