A new detector at RHIC, sPHENIX goals and status

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Abstract.
The study of heavy-ion collisions, which create a new form of matter called the Quark Gluon Plasma (QGP), where quarks and gluons are no longer confined into nucleons, forming a nearly ideal strongly interacting fluid is on the frontier QCD studies. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL) has had a long and successful program of QGP study since 2001, with many upgrades that have increased the delivered luminosity considerably in the last decade. The sPHENIX proposal is for a second generation experiment at RHIC, which will take advantage of the increased luminosity, and allow measurements of jets, jet correlations and Υs, with a kinematic reach that will overlap with measurements made at the large hadron collider (LHC). Complementary measurements at RHIC and at the LHC probe the QGP at different temperatures and densities, which are necessary to determine the temperature dependence of transport coefficients of the quark-gluon plasma. The sPHENIX detector will have large acceptance electromagnetic and hadronic calorimetry, as well as precision tracking, which are necessary for precision jet and Υ observables. The experiment will enable a program of systematic measurements at RHIC, with a detector capable of acquiring a large sample of events in p+p, p+A, and A+A collisions. This proceedings outlines the key measurements enabled by the new detector, and status of the project itself.

1. Introduction

In relativistic heavy-ion collisions, the extreme temperature and net baryon density cause a new state of matter, called the Quark Gluon Plasma (QGP) to be formed. In order to study these collisions and determine the dynamical changes in the QGP in terms of quasiparticles and excitations as a function of the temperature, one needs to probe the medium at a variety of length scales. Particle jets, formed when two quarks or gluons (partons), under go a hard scatter and fragment and then hadronize into a calumniated spray of particles, are one such probe. It is especially important to understand how the transport coefficients, $\hat{q}$ and $\hat{e}$, evolve with temperature. Techniques for measuring jet observables have been developed at the Large Hadron Collider (LHC), where the cross-section for hard processes is much larger than the cross-section for soft processes, giving us a wealth of observables. In order to fully constrain models, these measurements need to be repeated at Relativistic Heavy Ion Collider (RHIC) energies. In order to map the temperature dependence, it is necessary to measure the temperature. Heavy quarkonia, specifically bottomonium, formed by a bottom and anti-bottom quark, is useful for this task. The three lightest states of the Υ meson have proven to be a useful metric, and has been measured at the LHC and at RHIC. However, the Υ(2S) and Υ(3S) states have not been separated at RHIC energies.

With these observables in mind, the 2015 Nuclear Science Long Range Plan explicitly

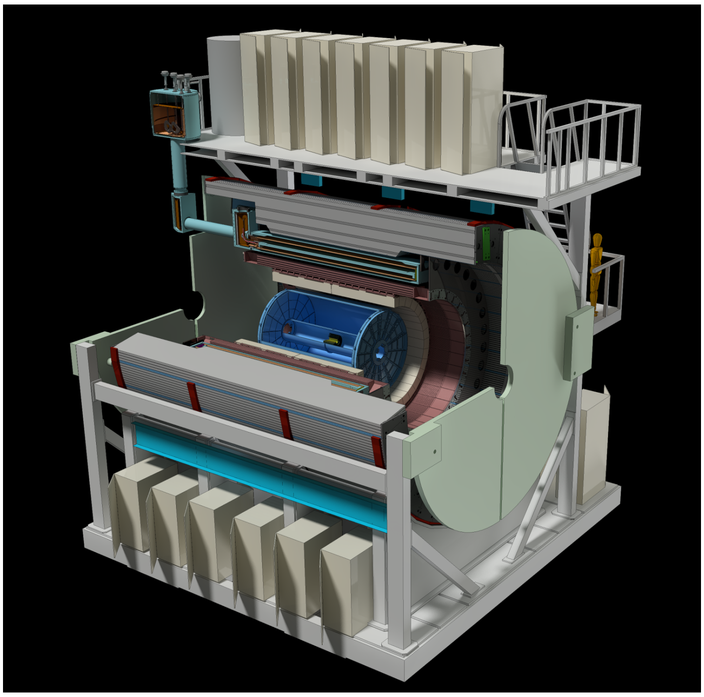

Figure 1. A schematic of the sPHENIX detector showing the different tracking and calorimeter systems.

states the need for a state-of-the-art" jet and Υ detector at RHIC, called sPHENIX in its recommendations [1]. This detector will allow us to probe the inner workings of QGP by resolving its properties at decreasingly shorter length scales. The complementarity of this facility with the Large Hadron Collider (LHC) is essential to fully quantify the key signatures of Quantum Chromodynamics (QCD) at extreme temperature and density. As RHIC completes its scientific mission, sPHENIX will play a crucial role in understanding the microscopic properties of the QGP [2]. Fully reconstructed jets at RHIC probe the medium near the critical temperature (T_c), where the coupling between the partons that ultimately fragment into jets and the medium is the strongest. A detector capable of detailed measurements of the modifications to the jet structure due to parton-QGP interactions at these collision energies will greatly enhance our understanding of energy loss in the QGP. Capabilities for heavy flavor jet measurements will provide the ability to study the flavor dependence of energy loss, which will clarify the roles of radiative and collisional energy loss in the medium. In addition, the high resolution tracking of the sPHENIX detector should be capable of separating the three lowest mass states of the upsilon (Υ) meson, which can be used to study the density dependence of the color screening.

A high data acquisition rate ($\tilde{~}$15 kHz) combined with the high luminosity RHIC can deliver due to 15 years of accelerator developments, will allow sPHENIX to collect large statistics data

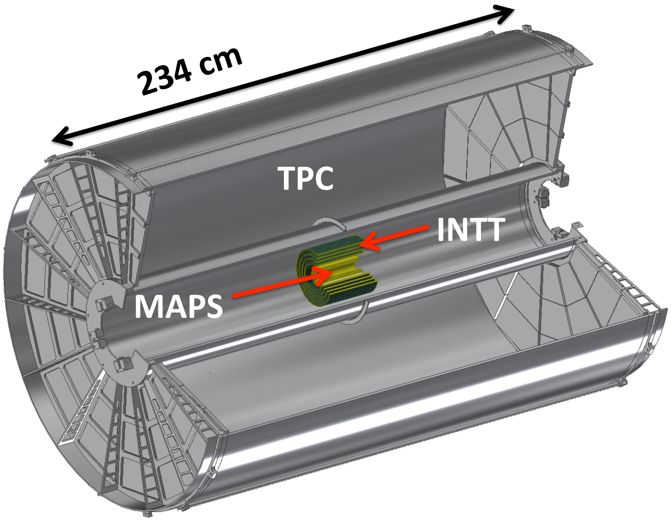

Figure 2. Schematic of the sPHENIX tracking system, indicating the three different subsystems and their relative positions. The 3-layer MAPS detector extends from 2.3 cm $< r <$ 3.9 cm. The four layer Intermediate Silicon Strip Tracker (INTT) extends from 6 cm$< r <$12 cm. The outer tracker is a compact TPC extending from 20 cm $< r <$78 cm.

sets which will increase the kinematic reach of previous measurements and the accessibility of rare probes. To fully utilize information gathered from experiments at both the LHC and RHIC, one should measure the same observables in the same kinematic range. The increased kinematic range and statistics from sPHENIX will provide sufficient overlap in observables between RHIC and LHC to constrain models and improve our understanding of the properties of the QGP at different temperatures.

2. The sPHENIX Design

The sPHENIX detector shown in Figure 1 will be housed where PHENIX was located on the RHIC ring and will utilize the existing PHENIX infrastructure. The PHENIX detector is currently being decommissioned after its last run during 2016. The schedule lists sPHENIX as fully installed and ready for beam in 2022 and includes at least two years of data taking. The detector would then be available for use at an electron ion collider (EIC) in the following years. The sPHENIX detector is comprised of a tracking system surrounded by calorimetry based around the 1.5 Telsa Babar solenoid magnet. The calorimetry design includes an electromagnetic calorimeter (EMCal) and two hadronic calorimeters (HCal). The inner and outer HCals are located inside and outside the solenoid magnet respectively. The hadronic calorimeter serves as the flux return for the magnet. The solenoid magnet has already been obtained by Brookhaven National Lab (BNL) from the Babar experiment for use in sPHENIX and has undergone a successful round of low power cold tests. The magnet has a diameter of 2.8 m and is 3.8 m long. The sPHENIX detector will have full azimuthal coverage and span $-1.1 < \eta < 1.1$ in pseudorapidity.

2.1. Tracking System

To complete the sPHENIX physics programs, a high resolution tracking system is important, both for separating the Υ states and for jet structure measurements. The proposed tracking system was positively reviewed in a BNL science review and it was concluded that the design, cost and schedule will be able to meet the sPHENIX physics objectives, that the cost is reasonable, and that the schedule can be met. The Tracker system has three subsystems which will provide primary and secondary vertex reconstruction, pattern recognition, and good momentum resolution.

The three systems are:

(i) Monolithic Active Pixel Sensors (MAPS) three layers identical to Inner ALICE ITS ($r =$ 2.3 cm, 3.1 cm, and 3.9 cm) [3]
(ii) Intermediate Silicon Strip Tracker (INTT) Four layer Si strip detector ($r =$ 6 cm, 8 cm, 10 cm, and 12 cm)
(iii) Compact Time Projection Chamber (TPC) (20 cm $< r <$78 cm)

All cover $|\eta| < 1.1$ and 2π in azimuth. The INTT will be provided to sPHENIX by RIKEN, the MAPS detector received a recent boost by the approval of a LANL LDRD in support of its development for sPHENIX. A schematic of the tracking system can be seen in Figure 2.

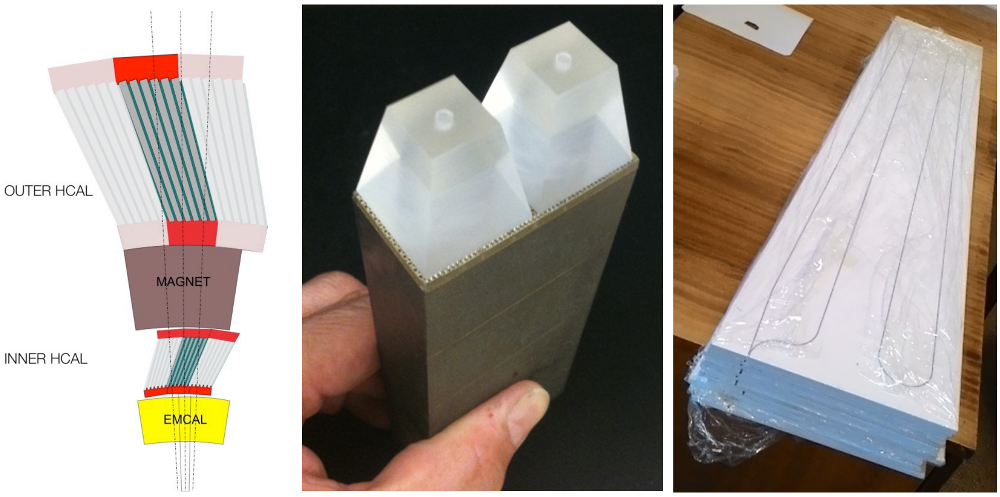

Figure 3. The left figure shows a cross section of the calorimeters and the solenoidal magnet. The middle figure shows two 1D EMCal towers and their light guides. The right figure shows unwrapped HCal tiles and their embedded fibers.

2.2. Electromagnetic Calorimeter

A cross-section of the sPHENIX calorimeters is shown on the left side of Figure 3, with the solenoidal magnet between the inner and outer Hadronic Calorimeter. The EMCal is designed to measure electrons and photons through electromagnetic showers. The electron identification is important for measuring the different Υ states, as the cleanest measures of the Υ meson are through the dilepton channel. Direct photon measurements at high $p_{T,\gamma}$ will be used to identify photon-jet events. These are especially crucial for understanding partonic energy loss as the correlation between the photon and the hard scattered partons that fragment into jets is better than between the final state jets and the partons. Additionally, photon-jet pairs come preferentially from photon-quark pairs, which removes some of the flavor dependence. The segmentation of the current EMCal design is 0.025 x 0.025 for $\Delta\eta \times \Delta\phi$, which results in a total of 96×256 readout channels. Each tower is assembled by threading scintillator fibers through screens that are then positioned into a mold. Tungsten powder and epoxy are poured into the mold. After the tower has hardened the mold is removed, a light guide is attached as shown in the middle of Figure 3. The signal is read out by silicon photo-multipliers (SiPMs). The Moliere radius for the EMCal design is approximately 2.3 cm. 1D projective modules as shown in Figure 3 have been assembled and studied in prototype testing. However, 2D projective towers, which would improve the electron-pion separation, are also under investigation.

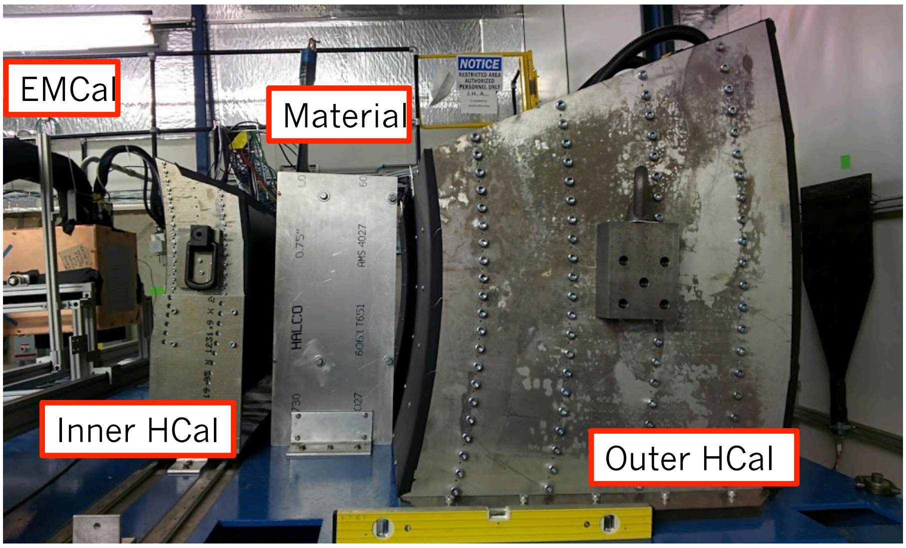

Figure 4. The calorimeter test beam set up used at FNAL for prototype tests held in April 2016. The material between the inner and outer HCal was placed in order to mock up the material budge of the solenoidal magnet.

2.3. Hadronic Calorimeter

The purpose of the Hadronic Calorimeters is to measure the energy from hadrons produced in the collisions. The combination of the energy measured in the HCals and the EMCal is used to reconstruct the energy of jets, which are reconstructed from the calorimeters directly. To provide a jet energy resolution of approximately 20%, a key ingredient for all jet observable, the required single particle energy resolution for the HCal is $\sigma_E/E < 100\%/\sqrt{E}$. The HCals are comprised of alternating layers of steel plates and scintillator tiles. The scintillator tiles are 7mm thick polystyrene with a 1mm wave length shifting fiber embedded into them. An unwrapped outer HCal tile is shown on the right in Figure 3. This shows the routing pattern of the fiber used in the HCAL prototype. The ends of the fiber come together at the edge of tile and each tile illuminates a single SiPM. The SiPMs of five tiles are read out by a single pre-amplifier board as a single tower. This results in 3072 (2 x 24 x 64) total readout channels. The plates are tilted such that a straight line from the center of the detector will hit four tiles. Due to the difference in size, this results in a stronger tilt angle for the inner HCal than for the outer HCal. The plates in the inner HCal are tilted in the opposite direction from the outer HCal.

Prototypes of the EMCal, inner and outer HCal have been constructed at BNL and were tested at the test beam facility at Fermilab in April 2016. A photo of the prototype is included in Figure 4. The energy resolution of these detectors is being studied at beam energies ranging from 2 to 64 GeV. Analysis of the data collected during the beam test is ongoing.

3. Conclusions

The scientific case has been established for the need to build the proposed sPHENIX detector as demonstrated in the Nuclear Science Long Range Plan recommendations [1]. At present a total of 58 institutions have joined the sPHENIX collaboration. Open meetings for the collaboration, topical groups and detector subsystems are held regularly and participation by new members and those interested in joining the sPHENIX collaboration is welcomed. Early results from the April 2016 test beam study for the calorimeter prototypes are promising, and should be completed soon. Another prototype test for the calorimeters is planned in early 2017. The proposed tracking system has been favorably reviewed and will meet the sPHENIX science goals. The project is on track to have sPHENIX fully installed by 2022 and ready to take data. The new detectors and high luminosity from RHIC will allow sPHENIX to make high statistics measurements over a larger kinematic range than previous RHIC experiments. This is essential for measuring important observables such as jet structure, γ-jet and heavy flavor jets as well as separating the three Υ states. sPHENIX will play a crucial role as RHIC completes its scientific mission to understand the properties of the sQGP that it first created over a decade ago.

References

[1] Reaching For the Horizon, The 2015 Long Range Plan for Nuclear Science, `http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf` (DOE,NSF).

[2] A. Adare *et al.*, “An Upgrade Proposal from the PHENIX Collaboration,” arXiv:1501.06197 [nucl-ex].

[3] B Abelev *et al.* [The ALICE Collaboration] ”Technical Design Report for the Upgrade of the ALICE Inner Tracking System” J. Phys. G **41**, 087002 (2014). doi:10.1088/0954-3899/41/8/087002