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# Heavy flavor physics with the sPHENIX MAPS vertex tracker upgrade

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**Abstract**

The sPHENIX detector at the Relativistic Heavy Ion Collider will measure a suite of unique jet and Upsilon observables with unprecedented statistics and kinematic reach. A MAPS-based vertex detector upgrade to sPHENIX, the MVTX, will provide a precise determination of the impact parameter of tracks relative to the collision vertex in high multiplicity heavy ion collisions. The MVTX utilizes the latest generation of MAPS technology to provide precision tracking with high tracking efficiency over a broad momentum range in the high luminosity RHIC environment. These new capabilities will enable precision measurements of open heavy flavor observables, covering an unexplored kinematic regime at RHIC. The physics program, its potential impact, and recent detector development of the MVTX will be discussed.

*Keywords:* Heavy flavor, QGP, heavy ion collision, MVTX detector, sPHENIX detector, RHIC

## 1. Introduction

sPHENIX detector is a planned state-of-art next-generation detector at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. As it was stated in the 2015 US Nuclear Physcis Long Range Plan, one of the focus in the hot QCD area is to probe the inner workings of the Quark-Gluon Plasma (QGP) over a range of momentum and length scales [1]. The complementarity of the RHIC and the Large Hadron Collider (LHC) is essential to this goal, and the sPHENIX detector is designed to fulfill this goal.

The sPHENIX collaboration was formed in the end of 2015, and currently is comprised of nearly 80 institutions. In 2019, the sPHENIX was granted PD 2/3, which is the approval for starting contruction. Also in this year, the sPHEINX became one of the CERN recognized experiments. The construction and full installation of the detector at RHIC would be finished at 2022, then the first data taking would be started at 2023.

The key physics programs planned at sPHENIX include jet measurements, upsilon spectroscopy, and open heavy flavor meansurements. The heavy flavor program heavily relies on the precision vertexing capability provided by Monolithic Active Pixel Vertex (MVTX) detector. In this presentation, the open heavy flavor physics program at sPHENIX and the MVTX detector developments will be discussed.

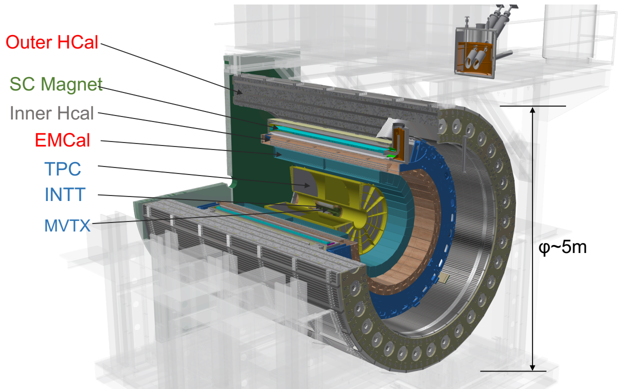


Fig. 1. A schematic view of the sPHENIX detector

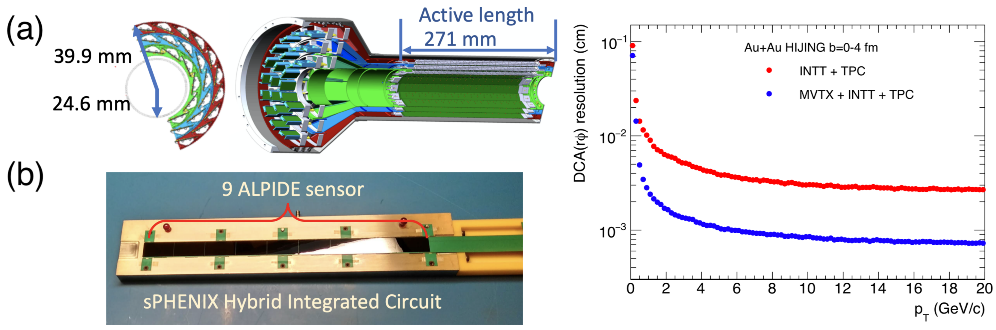


Fig. 2. Left: (a) Schematic view of the MVTX detector (b) ALPIDE sensor with sPHENIX readout citcuit; Right: Simulated DCA resolution with (blue) and without (red) MVTX added into the tracking system.

## 2. sPHENIX Detector

The sPHENIX detector would be housed in where PHENIX was located in the RHIC ring. The detector is designed utilizing proven and cost-effective technology [2, 3]. The schematic layout of the detector is shown in Fig. 1. The tracking system, from innermost to outer, is consist of MVTX, Silicon Strip Intermediate Tracker (INTT) and Time Projection Chamber (TPC). The tracking system will high precision momentum and displayed vertex measurement. The calorimeter system includes electromagnetic calorimeter (EMCal), inner and outer hadronic calorimeter (HCal). Both the tracking and calorimeter system will cover $|\eta| < 1.1$ in pseudorapidity within $|z_{vertex}| < 10$ cm with full azimuthal acceptance. The sPHENIX detector trigger rate can reach 15 kHz in A+A collisions, and the DAQ data rate is higher than 10 GB/s, so as to fully utilize the increased lumilosity of the RHIC in the future. Over the planned 3-year operation of sPHENIX, we expect to record 143 billion minimum-bias Au+Au collisions, which can be extended to 239 billion with a possible two-year extension. A comparable reference sample in $p + p$ and $p + A$ collisions is also planned.

## 3. MVTX detector

The high precision vertexing capability of MVTX in combination with the large data sample enables detailed study of many rare heavy flavor observables for the first time at RHIC, such as $B$-hadrons and $b$-jets [4]. MVTX is a 3-layer silion pixel detector based on ALPIDE sensor, which is the 2nd generation MAPS sensor developed for the ALICE ITS upgrade [5]. The MVTX mechanism design are modified from the ITS and the additional readout electronics are developed to fit the sPHENIX envelope. The MVTX schematic view is shown in Fig. 2 (left). Full chain beam test, including a complete readout system, had been carried

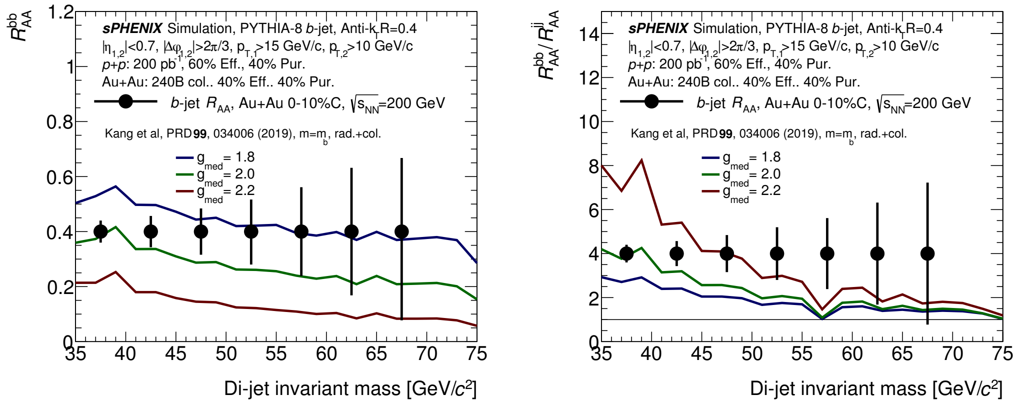


Fig. 3. The projected $b$-dijet $R_{AA}$ (left) and the $b$-dijet to inclusive dijet $R_{AA}$ ratio (right) as function as dijet invariant mass in central Au+Au events from the full simulation of the sPHENIX detector. The red, green and blue curves show the theory predictions under different coupling strength between the jet and the medium ($g_{med}$) [6].

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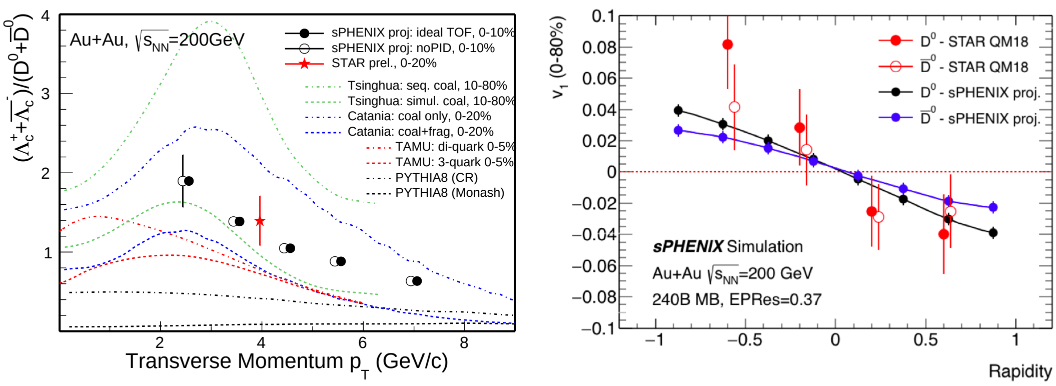


Fig. 4. Left: projected $\Lambda_c/D^0$ in central Au+Au events; Right: projected $D^0$ and $\bar{D}^0$ $v_1$ in central Au+Au events.

out successfully during May 2019, which confirmed the performence of the system. The full simulation of the sPHENIX detector shows the distance of closet approach (DCA) resolution would be significantly improved with MVTX added into the tracking system, shown in Fig. 2 (right).

## 4. Heavy flavor physics program

Heavy quark, in particular, the $b$-quark, is a unique hard probe of the QGP as its mass is much higher than the scale of QGP temperature and QCD scales. They are dorminatly produced in the initial hard scattering process and experience the whole evolution of the system. Thus heavy-flavor hadrons are regarded as penetrating probes of the QGP. The recent studies on the heavy flavor measurement enabled by sPHENIX detector will be discussed in this section.

### *4.1. Energy loss in QGP medium and QGP transport coefficients*

As shown in Ref. [4], the nuclear modification factor of the bottom quark will be measured over a board kinematics range from non-perturbative to perturbative regions. Those include non-prompt $D^0$ mesons from $B$-hadron decays at lower $p_T$ region and $b$-jets in $15 < p_T < 35$ GeV$/c$. Together, they will provide stringent constraint over energy loss models for $b$-quark in the QGP. Recently, Kang and his collaborators further proposed a new $b$-jet observable, the $b$-dijet invariant mass $R_{AA}^{bb}$ [6], which shows enhanced sensitivity to transport property and parton-QGP coupling. Furthermore, if we take the ratio of $b$-dijet to inclusive dijet invariant mass $R_{AA}$, the mass effect will be enhanced. The projected $b$-dijet $R_{AA}^{bb}$ and heavy to light flavor dijet $R_{AA}$ ratio at sPHENIX are shown at Fig. 3.

Elliptic flow $v_2$ measurements for $B$ mesons would be also be enabled, which will provide clean access to spatial diffusion coefficient at RHIC energy. The projected physics plots for $B$ mesons and inclusive $b$-jets could be found at MVTX proposal Chapter 2 [4].

### *4.2. Heavy flavor hadronization*

Heavy flavor baryon measurements provide us a unique opportunity to understand heavy quark hadronization mechanism in QGP. Strong enhancement of $\Lambda_c/D^0$ with respect to PYTHIA calculation has been observed from STAR [7]. Models based on coalescence mechanism are close to data, but different models still have large difference at low $p_T$. What's more, $\Lambda_c/D^0$ ratio from STAR measurement indicates that $\Lambda_c$ contributes sizely to total charm cross section at low $p_T$. Thus the possiblility of precise $\Lambda_c$ measurements at sPHENIX is explored. As shown in Fig. 4 (left), $\Lambda_c/D^0$ ratio will be measured over a broad $p_T$ range from 2-8 GeV/c even in the 10% most central Au+Au collisions, which will be very useful in differentiating various hadronization modules as shown by the curves. The lowest $p_T$ point will be further improved if a PID capability could be introduced to the sPHENIX detector.

### *4.3. Initial condition*

Strong magnetic fields are believed to be generated in the heavy ion collisions. Charm hadrons are regarded as clean access to the initial magnetic field [8]. Due to the Lorentz force, this field will give $D^0$ and $\bar{D}^0$ a same magnitue direct flow ($v_1$) but opposite in sign. Current STAR measurement cannot give a solid conclusion whether the $D^0$ $v_1$ differs from $\bar{D}^0$ [9]. The projected D meson $v_1$ versus rapidity is shown in the Fig. 4 (right). Such spliting can be observed in the future sPHENIX experiment assuming the $v_1$ difference between $D^0$ and $\bar{D}^0$ follows the model predictions [8].

## 5. Summary

To complete the science mission of RHIC and complementary to the LHC measurements in 2020s, the sPHENIX detector is planned for probing the microscope property of the QGP utilizing hard probes. The sPHENIX detector construction is underway and the first data taking will be started at 2023. The MVTX detector upgrade will open up rich heavy flavor physics opportunities at sPHENIX with many new and high precision observables brought to RHIC energy for the first time. Besides those discussed in this talk, broader topics are also being studied, such as heavy flavor and hadron correlations, $D^0$ and $\bar{D}^0$ correlation, jet and heavy flavor hadron correlations, heavy flavor tagged jet substructure, total bottom cross-section.

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