

Status and Physics Opportunities of the STAR Heavy Flavor Tracker and the Muon Telescope Detector Upgrades

Qiu Hao (for the STAR Collaboration)

Lawrence Berkeley National Lab, 1 Cyclotron Road, Berkeley, CA 94720, U.S.A.

E-mail: hqiu@lbl.gov

Abstract. The STAR Collaboration will complete the Heavy Flavor Tracker (HFT) and the Muon Telescope Detector (MTD) upgrades by 2014. HFT utilizes the state-of-art active pixel detector technology, which will greatly enhance the STAR physics capabilities by measuring heavy quark yield, collectivity and correlations via the topological reconstruction of charmed hadrons over a wide momentum range. The MTD is based on the long Multi-Gap Resistive Plate Chamber detector technology designed to measure muons penetrating the bulk of other detectors and the magnet yoke. It will enable STAR to study di-muon and electron-muon correlations and enhance heavy quarkonium studies. With the addition of these upgrades, STAR is well suited to perform precise measurements of production as well as correlations of rare probes (heavy flavors, dileptons) to systematically investigate the quark-gluon plasma properties at RHIC. For Run 13 63% of the MTD has been installed and data have been taken. Prototype PXL sectors (30% coverage) have also been installed and commissioned. Anticipated physics results and current status of these upgrades is reported.

1. Introduction

With full azimuthal particle identification ability at middle rapidity, the STAR [1] experiment made many important measurements in order to discover and study the Quark Gluon Plasma (QGP) produced at the Relativistic Heavy Ion Collider (RHIC) [2]. In the future, heavy flavor and di-leptons will be two new physics focuses for the STAR heavy ion program.

The mass of heavy flavor quarks is significantly higher than the critical temperature at RHIC energies, Λ_{QCD} or the mass of u, d, and s quarks. As a consequence, heavy quarks are produced by hard processes early in the collision. Because heavy quarks decay weakly to light quarks within a much longer time scale than the collision, they can be treated as conserved in total number. These features make heavy quarks an ideal probe for studying the QGP medium properties at RHIC.

Leptons are produced during the whole evolution of the created matter and can traverse the medium with minimal interactions. Different kinematics of di-lepton pairs (mass and transverse momentum ranges) can selectively probe the properties of the formed matter throughout its entire evolution. The di-lepton spectra in the intermediate mass range ($1.1 < M < 3.0$ GeV/ c^2) are expected to be directly related to the thermal radiation of the Quark-Gluon Plasma (QGP) [3, 4].

In order to better study heavy flavor and di-leptons, the STAR Collaboration will complete the Heavy Flavor Tracker (HFT) [5] and the Muon Telescope Detector (MTD) [6] upgrades by 2014. HFT will greatly enhance the measurements of open heavy flavor particles, while MTD will improve heavy quarkonium as well as di-lepton studies. In the following, the physics motivation, design, status and performance of HFT and MTD will be discussed.

2. Heavy Flavor Tracker (HFT)

2.1. Physics motivation

Most heavy quarks produced in heavy ion collisions end up as open heavy flavor particles. However, the rare production of heavy quarks and large combinatorial background in heavy ion collisions makes the measurements of open heavy flavor particles very difficult with current STAR detectors. Using precise silicon vertex detectors, decay vertices of open heavy flavor particles displaced from primary vertices can be measured, which will greatly reduce combinatorial background from primary tracks.

By systematically measuring the yields of ground state charmed hadrons, the total charm yield can be deduced, which provides a very important baseline for charmonium suppression and coalescence. At high p_T , the R_{CP} and R_{AA} of charm and bottom quarks can be used to study their energy loss mechanism in the QGP matter. Figure 1 shows the projected error of D^0 R_{CP} measurement using HFT with 1 billion minimum bias events. Very good precision can be achieved over a wide p_T range, a large improvement over the current STAR measurements [7]. The B meson and bottom quark yields, R_{CP} , and R_{AA} can also be measured with the HFT, for example, through the B to J/ψ decay. Unlike prompt J/ψ , J/ψ from B meson decay have a displaced vertex. This can be used to measure the contribution of J/ψ from B meson decay.

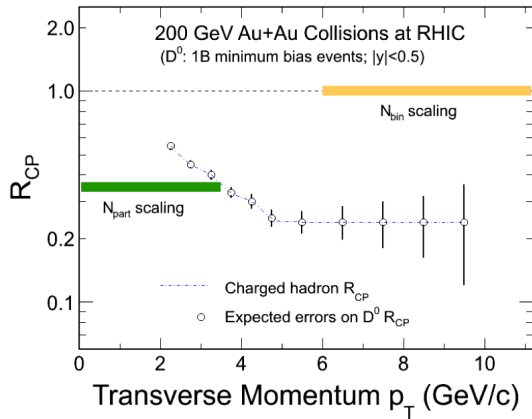


Figure 1. Expected errors on D^0 R_{CP} with HFT .

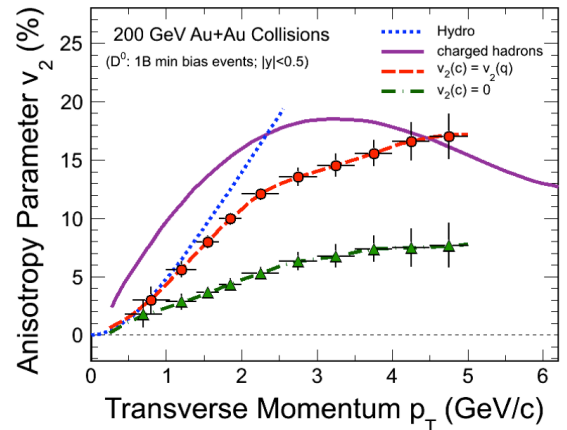


Figure 2. Expected errors on D^0 v_2 with HFT.

With much larger mass than that of light quarks, heavy quarks are more resistant to having their velocity changed, and are thus expected to thermalize slower than light partons. If charm quarks are observed to have sizable collective motion, then light partons, which dominate the medium, should be fully thermalized. The charm quark flow can be measured through D^0 v_2 and non-photonic electron v_2 [8]. The former is a more direct measurement as the latter is influenced by decay kinematics. As shown in Figure 2, with the HFT STAR will be able to measure the D^0 v_2 precise enough to distinguish between the case of full charm collectivity and no charm collective motion in the low p_T region.

With the HFT we can also study charm interactions with the medium by measuring $c\bar{c}$ ($D^0\bar{D}^0$) angular correlations. By measuring the Λ_c^+/D^0 ratio we can test the coalescence model,

which explains the enhancement of baryon over meson ratio at intermediate p_T in the light quark sector. There are many other interesting physics topics that will be enabled by the HFT.

2.2. Design

The decay length of open heavy flavor particles is very small. For example, the $c\tau$ of D^0 mesons is about 120 microns. Thus position resolution is the primary concern for the design of the HFT. The HFT consists of 3 sub-detectors: Silicon Strip Detector (SSD), Intermediate Silicon Tracker (IST) and the PIXEL (PXL) detector, as shown in Figure 3. Table 1 shows technical details of the 3 sub-detectors. The innermost sub-detector PXL uses state-of-art active pixel detector technology to achieve a position resolution of 12 microns, which will be the most precise position detector used in collider experiments so far. The low radiation length of the HFT is crucial for the reconstruction of D^0 at low p_T , enabling charm total cross section and flow measurements.

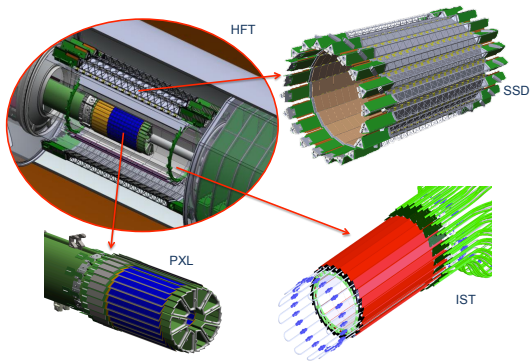


Figure 3. HFT overview.

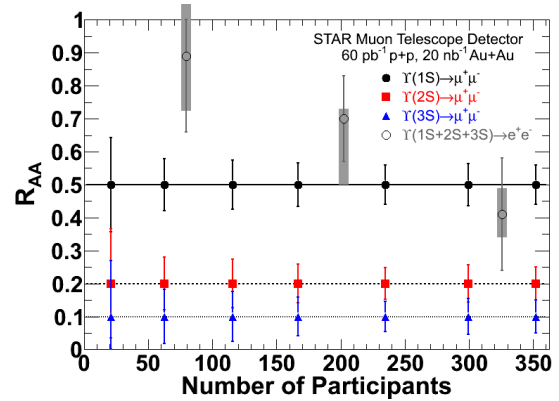


Figure 4. Expected errors for R_{AA} of different Υ states with the MTD.

Table 1. HFT technical details

Sub detector	r (cm)	Sensitive units	$\sigma_{R\phi}(\mu m)$	$\sigma_z(\mu m)$	$X/X_0(\%)$
Silicon Strip Detector	22	2 side strips with 95 μm pitch	20	740	1
Intermediate Silicon Tracker	14	600 $\mu m \times 0.6$ cm strips	170	1800	< 1.5
PIXEL	2.5/8	20 μm pixel pitch	12	12	0.4/layer

2.3. Status

The PXL detector employs new technology. It is also the key detector to achieve the HFT target pointing resolution ($< 50 \mu m$ for 750 MeV/c Kaons). An engineering run for a PXL prototype with 3 out of 10 sectors was carried out in 2013. The engineering run was very successful. The prototype was installed in STAR within 14 hours, and first data were obtained after only 2 days. From the data a clear TPC track and PXL hit position correlation is observed. The construction of IST and SSD is also on schedule.

3. Muon Telescope Detector (MTD)

3.1. Physics motivation

The ability to identify and trigger muons enables physics studies of both di-muon pairs and single muons. Different kinematics of di-lepton pairs (mass and transverse momentum ranges) can selectively probe the properties of the formed matter throughout its entire evolution. Single muons can be used to study the parent heavy flavor hadrons. With the TPC, TOF and BEMC detectors, STAR already has a good ability to detect electrons at mid-rapidity. However, muons have several advantages over electrons. There is no γ conversion and much less Dalitz decay contribution for muons. Muons are also less affected by radiative losses in the detector materials. Furthermore, muons can be triggered in Au+Au collisions, enabling STAR to sample the full luminosity for studies with muons.

Sequential suppression of different Υ states can be used as a QGP thermometer [9]. The MTD will enable STAR to measure the R_{AA} of different Υ states. As shown in Figure 4, the projected error for R_{AA} of different Υ states is much smaller than for current measurements of the R_{AA} for all Υ states measured through the di-electron channel.

Similarly, the J/ψ R_{AA} and v_2 measurements will have much smaller errors with MTD, especially in the low p_T region. Systematical measurements of J/ψ R_{AA} and v_2 can probe its production mechanism, especially the magnitude of $c\bar{c}$ recombination contribution, thus deduce the magnitude of the suppression due to the color screening effect [10].

The di-lepton spectra in the intermediate mass range ($1.1 < M < 3.0 \text{ GeV}/c^2$) are expected to be directly related to the thermal radiation of the Quark-Gluon Plasma (QGP) [3, 4]. However, di-leptons from correlated open heavy-flavor decays also have significant contribution in the same invariant mass range. Although this two sources are difficult to separate in both di-electron and di-muon correlations, the $e - \mu$ correlation only has contribution from the correlated $c\bar{c}$ quarks. By subtracting $e - \mu$ correlation from di-electron correlation we can obtain the di-electron correlation from thermal production. Additionally, the $c\bar{c}$ correlation is important in itself to study the charm interaction with the medium. Figure 5 shows the simulated $e - \mu$ invariant mass distribution from $c\bar{c}$ quarks with a amount of data taken with MTD. The precision is good enough to distinguish two scenarios: charm correlation fully preserved as in p+p collisions, and charm de-correlated and softened due to interaction with the medium.

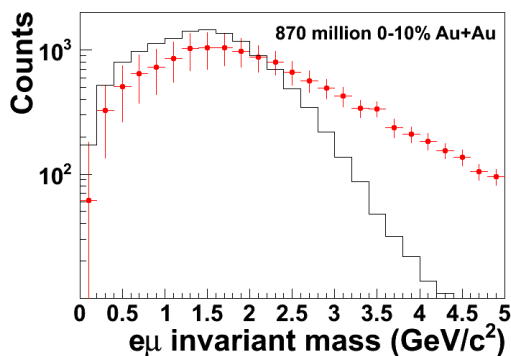


Figure 5. Simulated $e - \mu$ invariant mass from $c\bar{c}$ quarks with MTD. The red points assume correlated $c\bar{c}$ directly from PYTHIA, while the black line assumes de-correlation and softening of charm due to interaction with the medium.

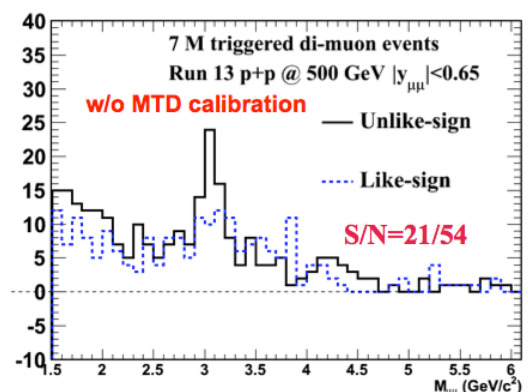


Figure 6. J/ψ signal from di-muon trigger events

3.2. Design

The MTD uses the magnet iron yoke as absorber, so that most other charged particles, except muons, will be absorbed and not reach the MTD modules placed outside the magnet yoke. The MTD employs the long Multi-gap Resistive Plate Chamber (MRPC) technique. It has 122 modules, 1464 readout strips, and 2928 readout channels.

3.3. Status

For the 2013 RHIC run, 63 % of the MTD was completed. The whole project will be finished for Run 2014. A clear correlation between TPC track projection and fired MTD channels is observed. The time resolution is measured with cosmic data to be 96 ps. The intrinsic space resolution along the beam line direction is 2.6 cm. The efficiency for $p_T > 4\text{GeV}/c$ is about 90 %. In Run 2013, a di-muon trigger was set up. Even with 7 M di-muon events out of a total of 120 M and without time calibration, a clear J/ψ signal is observed, as shown in Figure 6.

4. Summary and Outlook

In summary, STAR is conducting two major upgrades for the heavy ion program: the HFT for open heavy flavor measurements and the MTD for muon detection. These upgrades will enable or enhance a rich set of physics programs, including open and closed heavy flavor measurements, which is a clear probe for the QGP phase, and thermal radiation, which is considered as a QGP thermometer. The combination of HFT and MTD, together with the existing mid-rapidity subsystems, will make STAR the best suited detector to carry out the mission of studying the hot QCD matter properties. Construction of both detectors is going well. The technical run for the PXL prototype just finished successfully, and 63 % of MTD took data in Run 2013 with excellent performance. Both detectors will be completed for Run 2014.

In the coming 2 years, RHIC will focus on 200 GeV Au+Au, p+p and p+Au collisions for heavy ion programs. We can foresee that new physics results with HFT and MTD will greatly enhance our understanding of the QGP created at RHIC.

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