Heavy Flavor Tracker (HFT) : A new Silicon Detector for the STAR experiment at RHIC*

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The HFT is a silicon detector for the STAR experiment at RHIC. It is replacing the decommissioned silicon drift detector (SVT) with active pixel technology close to the beam pipe in order to achieve about an order of magnitude better track pointing (DCA) resolution. This will allow for a direct and full topological reconstruction of charmed meson decays (e.g. D^0) and a better determination of the B–meson spectra. Key measurements include D^0 elliptic flow (v_2) determination, especially in the lower transverse momenta (p_T) region, and identified heavy quark suppression studies at high p_T via the nuclear modification factor (R_{CP} and R_{AA}).

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1. Introduction

Due to their large masses, heavy flavor (c and b) quarks are produced in the early stages of heavy ion collisions where the full initial energy is available for particle production [1]. Radiative energy loss in dense partonic matter is thought to be inversely proportional to the quark mass. Early measurements of heavy flavor energy loss at RHIC using the decay-electron spectra (NPE, non-photonic electrons) of D and B mesons showed a suppression similar to that of light quarks [2]. This puzzling result lead theorists to search for an explanation and various effects are being re-evaluated, like the impact of elastic collisions to the total energy loss as well as a more precise evaluation of various geometrical factors among other things. Experimentally, it is difficult to separate the charm and bottom contributions in the electron spectra and so far only inclusive measurements were possible. Another complication with the NPE spectra is the momentum smearing due to

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decay kinematics which makes hard to connect the decay electron p$_T$ with that of the original meson [2].

Both major experiments at RHIC, PHENIX and STAR, decided to upgrade their central silicon detectors in order to be able to improve their measuring capabilities. The STAR approach and goal is to obtain a precise measurement of heavy flavor production by identifying the decay of charmed mesons using direct topological reconstruction and thus disentangling the c and b contributions in an unambiguous way. The Heavy Flavor Tracker (HFT) [3] is a proposed state-of-the-art micro-vertex detector utilizing active pixel sensors combined with standard silicon strip technology. With the HFT, the Time-of-Flight detector and the TPC we will be able to study the physics of mid-rapidity charm and bottom production. This will significantly extend the physics reach of the STAR experiment for precision measurements of the yields and spectra of particles containing heavy quarks. This goal will be accomplished through topological identification of mesons and baryons containing charm quarks, such as D^0, $D^{\pm}$, D_S and Λ_C, by the reconstruction of their displaced decay vertices with a precision of approximately 50 μm in p+p, d+A, and A+A collisions. The combined measurements of directly identified charm hadrons and of the total non-photonic electrons (NPE) will enable us to identify the bottom production at RHIC, including the bottom production cross section, the R_{AA} and v_2 of the decay electrons.

Table 1. Characteristics of each silicon layer of the HFT

Detector	Radius (cm)	Technology	Silicon thickness (μm)	Hit resolution $R/\phi - Z$ (μm - μm)	Thickness in X_0
SSD	22	2-side strips	300	30 - 857	1.0%
IST	14	strip-pads	300	170 -1700	1.2%
PIXEL	2.5, 8	Active Pixels	50	10 - 10	0.4%

The HFT consists of 4 layers of silicon detectors grouped into three subsystems with different technologies, guaranteeing increasing resolution when tracking from the TPC towards the vertex of the collision. The Silicon Strip Detector (SSD) is an existing detector made of double-sided strip technology. It forms the outermost layer of the HFT. The Intermediate Silicon Tracker (IST), consisting of a layer of single-sided strip-pixel detectors, is located inside the SSD. Two layers of silicon pixel detector (PXL) are inside the IST. The pixel detectors have the resolution necessary for a precision measurement of the displaced vertex. The pixel detector will use CMOS Active Pixel Sensors (APS), an innovative technology never used before in a collider experiment [3]. The APS sensors are only 50 μm thick with the first layer at a distance of only 2.5 cm from the interaction point. This opens up a new realm of possibilities for physics measurements. In particular, a thin detector ($0.4 - 0.5\%$ of a radiation length per layer) in STAR makes it possible to do the direct topological reconstruction of open charm hadrons down to very low transverse momentum by the identification of the charged daughters of the hadronic decay.

2. Physics performance simulations

Simulations presented in these proceedings were performed using the full STAR geometry package with about 20k AuAu HIJING central events at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ embedded with several D^0 and Λ_C particles, forced to decay to their hadronic channels ($D^0 \rightarrow K^-\pi^+$, $\Lambda_\mathrm{C} \rightarrow K^-\pi^+p$). Their reconstruction efficiencies are partially based on particle identification of daughter particles provided by the TPC ionization energy loss measurements (dE/dx) and extended to higher p_T with the Time of Flight detector (TOF) : K-π and $(K+\pi)$-p separations were done up to $p_\mathrm{T} \leq 1.6$ GeV/c and $p_\mathrm{T} \leq 3$ GeV/c, respectively. Standard topological cuts have also been applied to the D^0 candidates in order to greatly suppress the combinatorial background. The effect of *out of time* hits (from collider background and out of time events) in the PIXEL layers due to its finite readout time was also included in the simulation at a rate corresponding to the anticipated RHIC-II luminosity. The resulting spectra were obtained after appropriate scaling of the obtained signal and background levels.

2.1. Estimated D^0 p_T spectra

The following figures show the statistical error projections for the key measurements with the HFT in 500 M minimum bias AuAu collisions. Fig. 1 (left panel) shows the obtained D^0 p_T spectrum. Notice the broad range of p_T reach and the expected accuracy of the measured points. This event sample is expected to be the result of a single year's run (about 6 months of RHIC running). We observe that we can achieve good signal significance for a wide range of transverse momentum values, starting almost at zero p_T (a realistic cut off value for an acceptable S/N ratio is around 300 MeV/c).

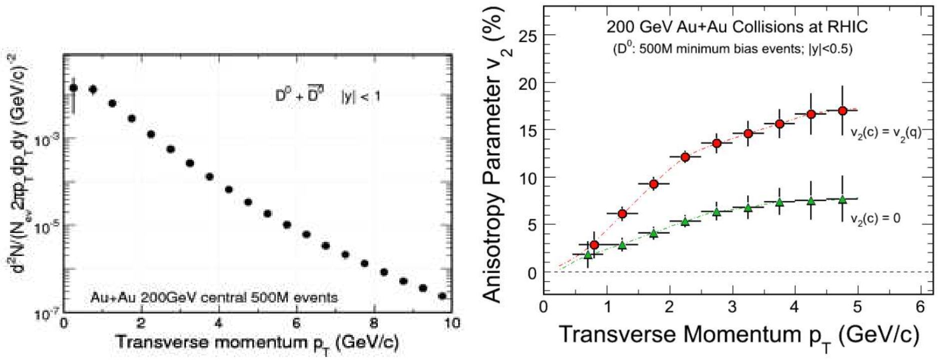

Fig. 1. Projections of key measurements with HFT. The left panel shows the anticipated first year (or a sample of 500 million events) p_{T} spectra of D^0s. The right panel shows the anticipated accuracy in determining the D^0 elliptic flow. The error bars shown in both plots are based on S/N estimates for this event sample.

2.2. Charm flow

At RHIC, partonic collectivity has been well established via the measurements of hadrons containing light quarks (u, d, and s). Recent v_2 results from multi-strange hadrons, phi mesons and Omega baryons, further confirm this important discovery. Charm quarks are abundantly produced at RHIC energies. Due to their high mass and small interaction cross-section, the strength of elliptic flow of heavy flavor hadrons may be a good indicator of thermalization occurring at the partonic level. If all quarks in heavy flavor hadrons flow with the same pattern as the quarks in the light flavor hadrons, this indicates frequent interactions between all quarks. Hence, thermalization of light quarks is likely to have been reached through partonic re-scattering. Fig. 1 (right panel) shows what precision in flow measurement can be reached with 500 M minimum-bias events taken in STAR with the HFT. The red points (open circles) show expectations from a transport model for the case that the charm quark has the same size partonic flow as measured for the light quarks. The green points (open triangles) show the limiting case where the charm quark has zero partonic v_2. A measurement close to the red points would mean that frequent rescattering has induced collectivity for the heavy quark, while a measurement close to the green points would indicate little partonic rescattering and thus no thermalization. Our measurement is expected to fall between those limits. It is obvious that the HFT will allow for a precision measurement that will shed light on the question of thermalization.

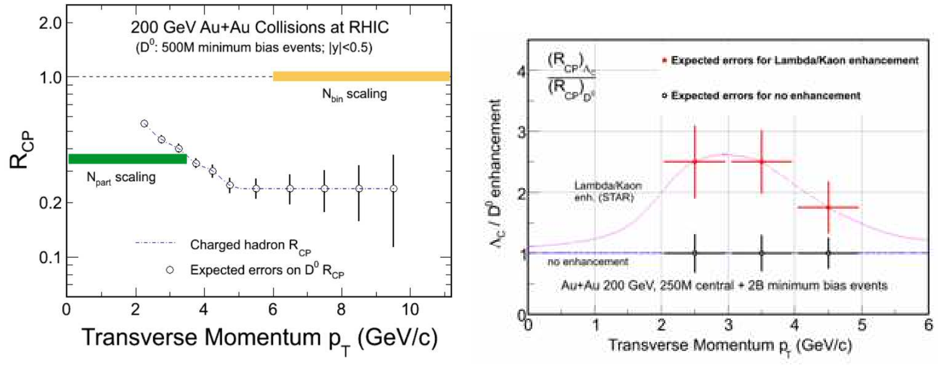

Fig. 2. (left panel) Expected errors for the RCP measurement as a function of p_{T}. (Right panel) Statistical errors of the Λ_C/D^0 ratio for the case of no enhancement and of Λ/K^0_S-like enhancement.

2.3. Heavy Flavor suppression at high p_{T}

The discovery of a factor of 5 suppression of high p_{T} hadrons ($5 < p_{\mathrm{T}} < 10$ GeV/c) produced in Au+Au collisions at RHIC and the disappearance of the away-side jet has been interpreted as evidence for jet quenching. This effect was predicted to occur due to radiative energy loss of high energy partons that propagate through a dense and strongly interacting medium [4]. The energy loss of heavy quarks is predicted to be significantly less compared to light quarks because of a suppression of gluon radiation at angles $\Theta < M_Q/E$, where M_Q is the heavy quark mass and E is the heavy quark energy. This kinematic effect is known as the 'dead cone' effect [5]. However, a recent measurement of the nuclear modification factor, R_{AA}, for non-photonic electrons, the products of charm and bottom hadron decay, yielded the surprising result that heavy quarks may also be strongly suppressed in the medium. This clearly indicates that the energy loss mechanism is not yet understood. This fact has triggered new theoretical developments as we have mentioned above. In order to make progress in understanding the nature of the energy loss mechanism, it is important to measure R_{AA} or R_{CP} for identified D mesons. Fig. 2 (left panel) shows the precision for R_{CP} that can be achieved with 500 M minimum-bias events in STAR with the HFT under the assumption that the suppression for heavy quarks is of the same size as the suppression for the light quarks. With the HFT STAR will be able to perform a precision measurement of R_{CP} of D mesons.

2.4. Λ_C *reconstruction*

In central Au+Au collisions at RHIC, a baryon to meson enhancement has been observed in the intermediate p_{T} region ($2 < p_{\mathrm{T}} < 6$ GeV/c) [6] This is explained by a hadronization mechanism involving collective multi-parton coalescence rather than independent vacuum fragmentation. The success of the coalescence approach implies deconfinement and the development of collectivity of the light quarks prior to hadronization. Since Λ_C is the lightest charmed baryon and its mass is not far from that of the D^0 meson, a similar pattern of baryon to meson enhancement is expected in the charm sector. Λ_C/D^0 enhancement is also believed to be a signature of a strongly coupled quark-gluon plasma. Therefore it would be very interesting to measure R_{CP} of Λ_C baryons and compare it to R_{CP} of D^0 mesons. In addition, large Λ_C/D^0 enhancement could be an explanation for the large suppression of high-pT electrons from charm and bottom decays. With the HFT STAR will be able to identify Λ_C baryons and to perform a measurement of R_{CP}. Fig. 2 (right panel) shows the estimated statistical errors for the Λ_C/D^0 ratio, for the case where there is no baryon enhancement, i.e. that the ratio is equal to 0.2 and flat in p_{T}, in black and for the case of the same enhancement as for Λ/K^0_S in red (higher points) [7]. Given the D^0 yield and $c\tau$, the errors coming from its measurement are negligible.

3. Summary

The HFT, by using low–mass, precision CMOS sensors near the interaction point, will be able to directly reconstruct charm hadron decays over a large momentum range and, thus, study elliptic flow and energy loss of heavy flavor particles. Other physics capabilities such as baryon/meson ratio in the charm sector have also been studied.

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