

A heavy flavor tracker for STAR

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We propose to construct a heavy flavor tracker for the STAR experiment at RHIC in order to measure the elliptic flow of charmed hadrons in the low p_T region and identify B-meson contributions in the region $p_T > 4$ GeV/c. In this talk, we will present the design of the detector in-depth and its expected performance as studied in detailed simulations and analytic calculations. Physics potentials of the detector will also be discussed.

1. INTRODUCTION

Elliptic flow measurements have demonstrated that partonic collectivity, collective flow of partons, has been developed in 200 GeV Au+Au collisions at RHIC [1]. To pin down the partonic EOS of matter produced at RHIC, one must address the status of thermalization in such collisions. Since the masses of heavy flavor quarks, e.g. charm quarks, are much larger than the maximum possible excitation of the system created in the collision, heavy flavor collective motion could be used to indicate the thermalization of light flavors (u, d, s).

The development of collectivity at the partonic level (among quarks and gluons) and the degree of thermalization are closely related to the equation of state of partonic matter: rescattering among constituents and the density profile lead to the development of collective flow. In case of sufficient rescattering, the system might be able to reach local thermal equilibrium.

Heavy flavor quarks are special probes because of their heavy mass. If chiral symmetry is restored in a QGP, light quarks obtain their small current masses. On the other hand, heavy quarks get almost all their mass from their coupling to the Higgs field [2]. Thus, heavy quarks stay heavy - even in a QGP. The observation of heavy quark collective flow indicates multiple interactions among partons. This would suggest that light quarks are thermalized. Here, the heavy flavor transverse elliptic flow is an especially promising early stage observable, while transverse radial flow might be cumulated throughout the whole collision history.

First results on heavy flavor production at RHIC have been reported from observing electrons stemming from the decay of heavy flavor quarks [3,4]. However, due to the decay kinematics, important information on heavy flavor dynamics is smeared out [5,6]. This is

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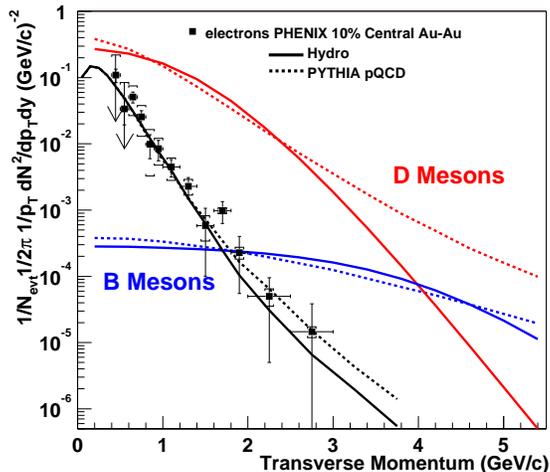


Figure 1. Invariant yield of non-photonic single electrons from central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [3]. The dashed curves show results from pQCD calculations (zero heavy quark flow) for D , B mesons and the combined resulting decay electrons. The solid curves represent results from hydrodynamical model calculations (full heavy quark flow). This figure has been taken from [5].

demonstrated in Fig. 1. The data points show the invariant yield of non-photonic single electrons from central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [3]. The dashed curves show results from pQCD calculations (zero heavy quark flow) for D , B mesons and the combined resulting decay electrons. The solid curves represent results from hydrodynamically inspired model calculations (full heavy quark flow). Both extreme dynamical scenarios reproduce the measured electron spectra.

At this conference, recent results on electron R_{AA} have triggered lots of exciting discussions. It seems that we do not fully understand the underlying mechanism of heavy flavor interaction with the dense medium. At higher p_T , therefore, it is also important to measure distributions from directly reconstructed D -mesons in order to isolate the bottom contributions in collisions at RHIC.

STAR has measured D -mesons in d +Au and Au+Au collisions by direct reconstruction through the invariant mass of decay-daughter candidates [4,7]. Due to the large multiplicities of π , K, p and the rather small production cross section for charmed hadrons, the combinatorial background in the invariant mass distribution is roughly 1000 times larger than the signal [7]. Extending particle identification by time of flight information will improve the statistical significance by a factor of five. This large combinatorial background leads to systematic uncertainties of the extracted charmed hadron yields in the order of 30%. On the other hand, elliptic flow modulates particle yields with respect to the reaction plane in the order of 10%. To overcome these large systematic uncertainties and make precise heavy flavor elliptic flow measurements feasible, we propose to upgrade STAR with μ -vertex capabilities to identify heavy flavor hadrons through their displaced decay vertex [8].

2. MECHANICAL SETUP

A perspective view of the mechanical setup of the proposed Heavy Flavor Tracker (HFT) is shown in Fig. 2. It sits inside the STAR Time Projection Chamber. The length is 20 cm,

covering ± 1.1 units in pseudorapidity. It has two tracking layers composed of $2 \times 2 \text{ cm}^2$ monolithic CMOS sensors with $30 \times 30 \text{ }\mu\text{m}$ square pixels at radii 1.5 cm and 5.0 cm, covering full azimuth. The pixel granularity is $100\text{k}/\text{cm}^2$ or 100M pixels in total. Several prototypes of these sensors, called MIMOSA, have been built by the IReS group in Strasbourg [9]. A sensor efficiency of better than 99% has been achieved. These sensors are thinned down to $50 \text{ }\mu\text{m}$. The total material budget of 0.36% radiation length per layer includes the active sensors, readout chip, cabling and support structure. This minimizes distortion of charged particles through multiple Coulomb scattering. Low power consumption of less than $100 \text{ mW}/\text{cm}^2$ allows for air cooling of the detector. A single-sided mounting support will hold the HFT on a finger-like structure. This mounting support fits into the present STAR detector mechanical setup enabling reproducible detector alignment to better than $10 \text{ }\mu\text{m}$. The mechanical stability was tested on an optical setup applying interferometry. The stiffness and bending characteristics meet our specifications. E.g. vibrations induced by air flow for cooling introduced an uncertainty in the position location of less than $2 \text{ }\mu\text{m}$.

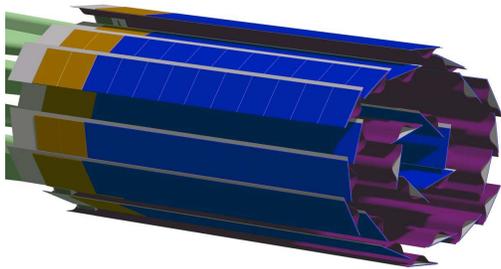


Figure 2. Perspective view of the STAR Heavy Flavor Tracker. The length of the ladders is 20 cm in beam-direction, the two layer radii are 1.5 cm and 5.0 cm, covering full azimuth. The pixel granularity is $100\text{k}/\text{cm}^2$ or 100M pixels in total. On the left, the single-sided finger-like support structure is partially visible.

3. TRACKING SIMULATIONS

The expected performance of the HFT has been studied in detailed simulations. We used a Monte Carlo event generator, parametrizing experimental particle distributions from Au+Au collisions at $\sqrt{s_{\text{NN}}} = 200 \text{ GeV}$. Charged particles were propagated through the full detector geometry by means of GEANT 3.21. The generated information was then fed through realistic response simulators and a full tracking algorithm was applied. For the HFT, Monte Carlo hits were smeared by a Gaussian function of width $\sigma = 6 \text{ }\mu\text{m}$ in y and z -direction to account for the finite pixel-hit resolution. The decay channel $D^0 \rightarrow K + \pi$ (BR= 3.8%, $c\tau = 123 \text{ }\mu\text{m}$) was studied. Decay and topological cuts were optimized [10] using the minimization package MINUIT. A D^0 signal with a statistical significance of $3\text{-}\sigma$ is observed with 8k central collisions.

Figure 3 shows results on the elliptic flow of D^0 -mesons from model predictions [11] assuming full charm quark flow (solid line) and no charm quark flow (dashed line). The expected statistical uncertainty after one year of data taking, assuming 50M events, is shown on the top line. The uncertainties are largest at low momentum due to the rather small D^0 reconstruction efficiency, they reach a minimum around $2 \text{ GeV}/c$, and then increase due to the exponentially falling D^0 yield at larger momentum. The differences in the predictions for both extreme scenarios are in the order of a factor two, while the projected statistical uncertainties are expected to be smaller than 10% in the momentum region 1-3GeV/c. Hence, with one year of data taking, the question of charm quark flow can be fully addressed.

We also studied another charmed hadron decay, namely $D_s^+ \rightarrow \phi + \pi$ (BR= 3.6%, $c\tau = 150 \mu\text{m}$), with $\phi \rightarrow K^+ + K^-$ (BR= 49.2%). Here, the momentum coverage is $1.0 < p_T < 3.0 \text{ GeV}/c$, covering 60% of the integrated yield. The ratio D^0 / D_s^+ is especially sensitive to different charm quark hadronization scenarios, giving further insight into charm quark dynamics [12].

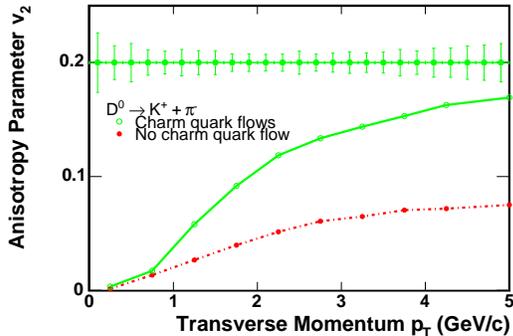


Figure 3. Results on the elliptic flow of D^0 -mesons from model predictions [11] assuming full charm quark flow (solid line) and no charm quark flow (dashed line). The expected statistical uncertainty after one year of data taking, assuming 50M events, are shown by solid circles.

4. SUMMARY

The precise measurement of heavy flavor hadron elliptic flow, spectra and yield will help address the exciting topic of light quark thermalization in high-energy nuclear collisions. These measurements require large momentum coverage to low p_T at small background. The proposed Heavy Flavor Tracker for STAR applies active pixel sensor technology with a position resolution better than $10 \mu\text{m}$, at a low material budget (0.36% radiation length per ladder) and high mechanical stability. Precise measurements on heavy flavor production will be feasible. Our goal is to complete construction and installation of the HFT before the next long Au+Au run at RHIC.

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