On Reconstructing D_s Mesons Using the STAR Heavy Flavor Tracker

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ABSTARCT

The quark-gluon matter produced in RHIC collisions has high s-quark content [1]. This suggests an equally high probability of D_s mesons formation during the different decay processes. We reconstructed D_s mesons using data from earlier runs; these encompass about ten thousand events. We also investigated the significance of the reconstructed signal as well as the efficiency of the method. We studied two different decay channels ($D_s \rightarrow k^+ + k^- + \pi$, $D_s \rightarrow \varphi^+ + \pi$), each at displaced vertices, as a function of transverse momentum. We ran GEANT simulations to calculate the significance of the reconstructed signal up to 500 million events. We found that for the 3-body decay, the significance remains extremely low regardless of the number of events, while the 2-body yields rather good results starting fifty million events and above. These results hint that our chances of observing D_s mesons through the $k^+ + k^- + \pi$ channel in a real experiment using HFT are very minute.

Introduction

The reconstruction of particles produced in high energy collisions is an integral part in experimental nuclear physics research. At the Relativistic Heavy Ion Collider (RHIC) in Brook Haven, NY the Solenoidal Tracker At RHIC (STAR) is an ongoing experiment whose main aims are (1) the study of quark-gluon matter under extreme temperature and energy density conditions; (2) the tacking and identification of all charged hadrons produced in the collisions [1] [2]. The Heavy Flavor Tracker (HFT) is a detector upgrade which will allow for the direct topological reconstruction of open charm hadrons [1] [2] [4].

Atoms are made of electrically positive nucleons and electrically negative electrons, which are kept together by the electromagnetic interaction. Nucleons are hadrons and they contain color-charged quarks and gluons. Those quarks and gluons are kept together within the nucleon's "membrane" by the strong force.

In studying electromagnetic interactions, it is customary to input energy to separate different charges, analyze how they affect their surroundings, and draw conclusions. However when one tries to separate quarks in function of their color and/or flavor in an effort to gain knowledge about the strong interaction, the task reveals impossible. One finds that adding energy to the system results in particle formation—described by $E=mc^2$-- rather than particle separation [1]. We call this fundamental (yet not understood) feature of the quark-gluon interaction confinement. Confinement is described in the theory of Quantum Chromo-Dynamics. To further study the strong force, one needs to produce de-confined matter, that is, quark-gluon matter whose degrees of freedom are not constrained by the "membrane" i.e. the membrane needs to be melted, so that one cannot distinguish individual hadrons [3].

At Brook Haven National Laboratory, RHIC accelerates Au (or Pb) nuclei at nearly .99995c [1]. Upon colliding, two nuclei "pass through" each other. We speculate that during the evolution of this collision, the system undergoes a partonic stage [1] [4]. These partons are a proxy for quark-gluon matter. Our present understanding of the vacuum (sea of c-quarks with energy content below a threshold value) warrants the formation of charm quarks in these high energy collisions.

The quark-gluon matter has a high s-quark content. This suggests a high probability of Ds mesons formation immediately following the collisions. This was the motivation for this research project.

All the analysis was done using computer simulations. We start with a set of data from RHIC (see the "Methods" section below for more details) and topologically reconstruct the D_s signal. Topological reconstruction consists in studying the decay process at displaced vertices as a function of transverse momentum, p_t. See fig-1 for reference. The primary vertex is the collision spot. Immediately following the collision many particles, including D_s mesons are created. (To be precise, partons are created and after a short cooling phase more familiar particles are formed) [3]. They all fly away in accordance with conservation laws. We are interested only on the D_s mesons and assume there is no interaction (other than electromagnetic, perhaps) with the other particles. The mean decay length r is the average distance a particle decays in its mean lifetime τ, that is, before it decays. For D_s meson r = cτ = 149.9 µm [5]. At the secondary vertex the decay occurs. The probability that a particle will decay in one set of

particles rather than another is called the branching ratio. $D_s \rightarrow k^+ + k^- + \pi^+$ has branching ratio (5.2+/-.9)%. Θ is the angle between P_{Ds} and **r**.

In order to perform a reasonable statistical analysis successive cuts are made on the data based on some critical parameters. With each cut, the number of counts diminishes. The difficulty however resides in finding the balance between efficiency and significance (defined in the next section). Efficient cuts are those that allow us to filter out the signal. As can be seen in fig-2, while the peak changes with the number of counts its relative position on the x-axis remains the same (as expected). It is about 1.97 GeV/c^2 which is the true/expected value (1.9682 ± 05 GeV/c^2) for the mass of a D_s meson. Here's the meaning of a few critical cuts: (1) Daughter pair DCA (Distance of Closest Approach): we look at the separation between daughter (kaons pair) particles and discard those pairs that are further apart than a critical value. (2) Detector acceptance cut: the number of events that occur is much larger than that the detector can register. (3) Cos(θ) cut: we want θ to be as small as possible. (4) r <100μm: the mean life is known to be nearly 150μm, but it is an average; taking values up to 100μm guarantees that we are tracking the right particles and decays [5]. In sum we perform 7 different cuts.

Methods and Material

We used data from previous runs of RHIC. Each set of data represented 9576 (10,000) events and 5 to 6 D_s were observed per event [3]. The detector registers the decay daughters in function of their invariant mass and transverse momentum, and produces histograms. These histograms (with all seven cuts) are the starting point for the following investigation.

We use the 05/22/2009 version of ROOT, the analysis software developed by scientists at CERN. We wrote a program to reconstruct the D_s signal, as a function of the transverse momentum. The program first fits the data histogram with a normalized function which is the sum of a Gaussian with a polynomial of degree 4. The Gaussian represents the signal and is expected to peak near 1.97 GeV/c, the expected mass for D_s mesons (see fig-2). The polynomial describes the background. Values from the fit are then used to calculate the statistical significance of the signal. The statistical significance is defined as $SIG = \frac{signal}{\sqrt{signal+noise}}$. It has units of standard deviation σ. The quantities "signal" and "noise" are given by $signal = \int_{x_0-3\sigma}^{x_0+3\sigma} sig\ dx$, $noise = \int_{x_0-3\sigma}^{x_0+3\sigma} bac\ dx$. The peak x_0 and width σ are obtained from the fit. The Gaussian used to fit the signal is "sig" and "bac" is the polynomial used to fit the

background/noise. Both "signal" and "noise" are weighted. The first scale factor is related to the number of events and is $E\_weight = \frac{number\ of\ events}{9576}$. It applies to both "signal" and "noise" and appears when we perform extrapolations to determine the significance for larger number of events, i.e. 50 and 500 millions. It is 1 for our initial set of data, as it should. The second scale factor is related to the cross section and only applies to "signal," in order to match the true signal. Once all the significance values are obtained, they are plotted.

Results

All of the results are summarized in fig-3, fig-4, and fig-5. The significance for the $D_s \rightarrow$ $k^+ + k^- + \pi^+$ channel remains very low regardless of the amount of events, while that for the $D_s \rightarrow$ $\varphi^+ + \pi^+$ channel quickly grows as the number of events increases. Typically a value of 4σ or greater for the significance is considered statistically significant and thus desirable. This is consequently a positive result. The error bars in fig-4 are smaller for larger number of events.

Discussion

These results suggest that to observe D_s mesons it is better to use the $\varphi^+ + \pi$ channel. This was somewhat predictable. $D_s \rightarrow \varphi^+ + \pi^+$ is a 2-body decay. It is much easier to track and discriminating against the background proves to be less difficult, especially with HFT. Fig-5 shows that the greater the number of events the smaller the error. This is good news although counter intuitive since one would expect a huge number of events to render the tracking of particles impossible thence decreasing the accuracy of the measurement. Our method clearly is efficient.

Looking at fig-3 one would rightly question the values of the significance for pt < 4GeV/c. These are extrapolated values. The algorithm was not able to consistently provide values for $p_t < 4$ GeV/c. We resorted to a different method to calculate these. The fact that the cross section follows a power law accounts for the decreasing trend in fig-3 and fig-4 for $p_t >$ 4GeV/c.

$D_s \rightarrow \varphi^+ + \pi^+$ was not mentioned in the introduction. This is because we first endeavored to investigate $D_s \rightarrow k^+ + k^- + \pi^+$. The negative result pushed us to explore other avenues. How was the significance for this channel calculated? As already mentioned above, increasing the number of events for the 3-body decay was not very helpful, as the background also increased.

Fortunately 80% of the D_s 3-body decay happens through the φ channel (and phions decay into $k^+ + k^-$), making the process a 2-body decay and this is much easier to track. Knowing both the reconstructed D_s signal through $k^+ + k^- + \pi^+$, we can reduce the background (hence boosting the signal and improving the significance) using $\varphi^+ + \pi^+$. This works because once we have reconstructed the signal, it is reconstructed; which channel it came from is irrelevant as it (the initial signal) is the same for all channels. All we do is we add a constraint on the $k^+ + k^-$ pair invariant mass so that it be nearly equal to that of φ. (Mass has to be conserved). This has the effect of reducing the background to nearly 1/500 times what it was prior to this new constraint. When this is done we reevaluate the significance and the result is displayed in fig-4. It should be noted that in doing this a new scale factor appears. We modified the codes accordingly.

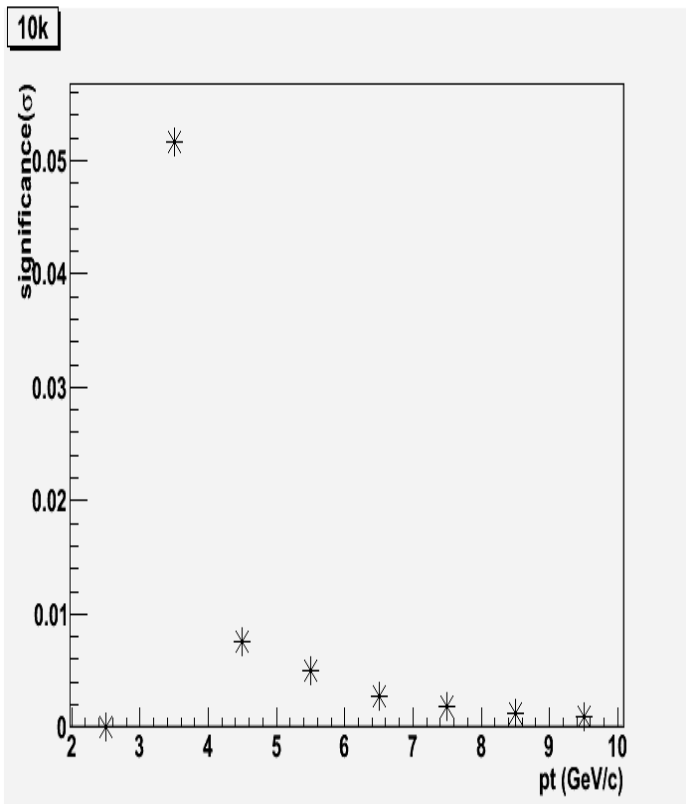**Figures**
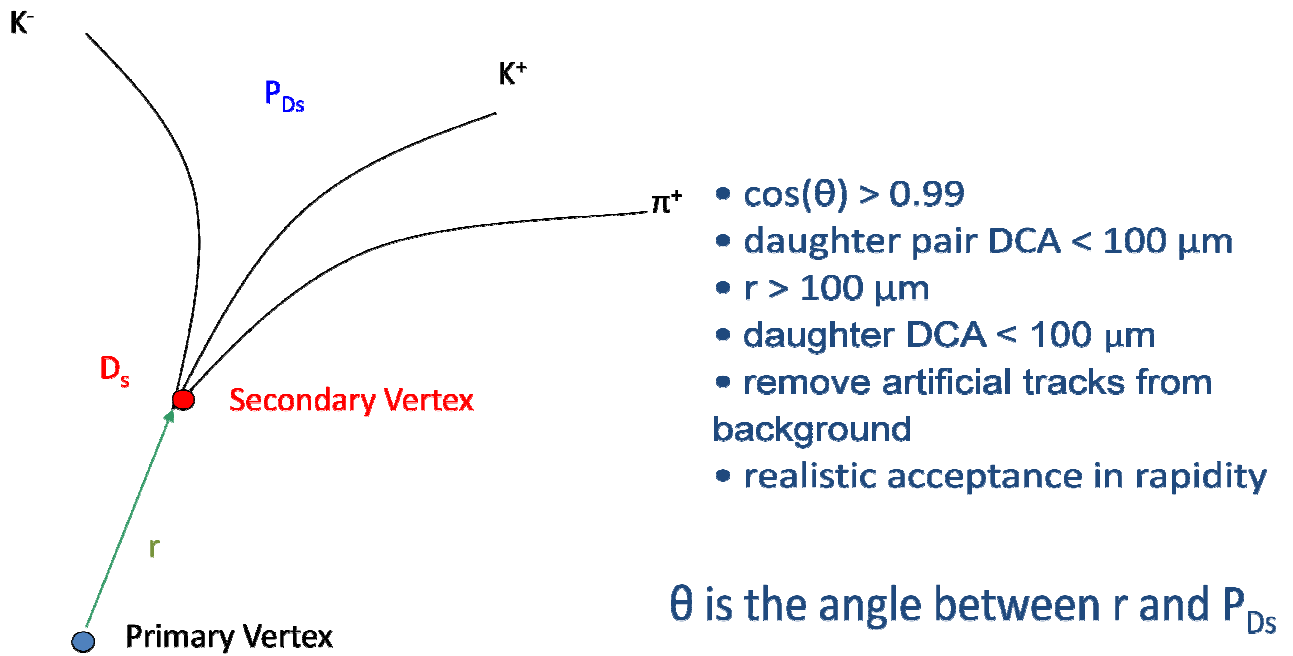
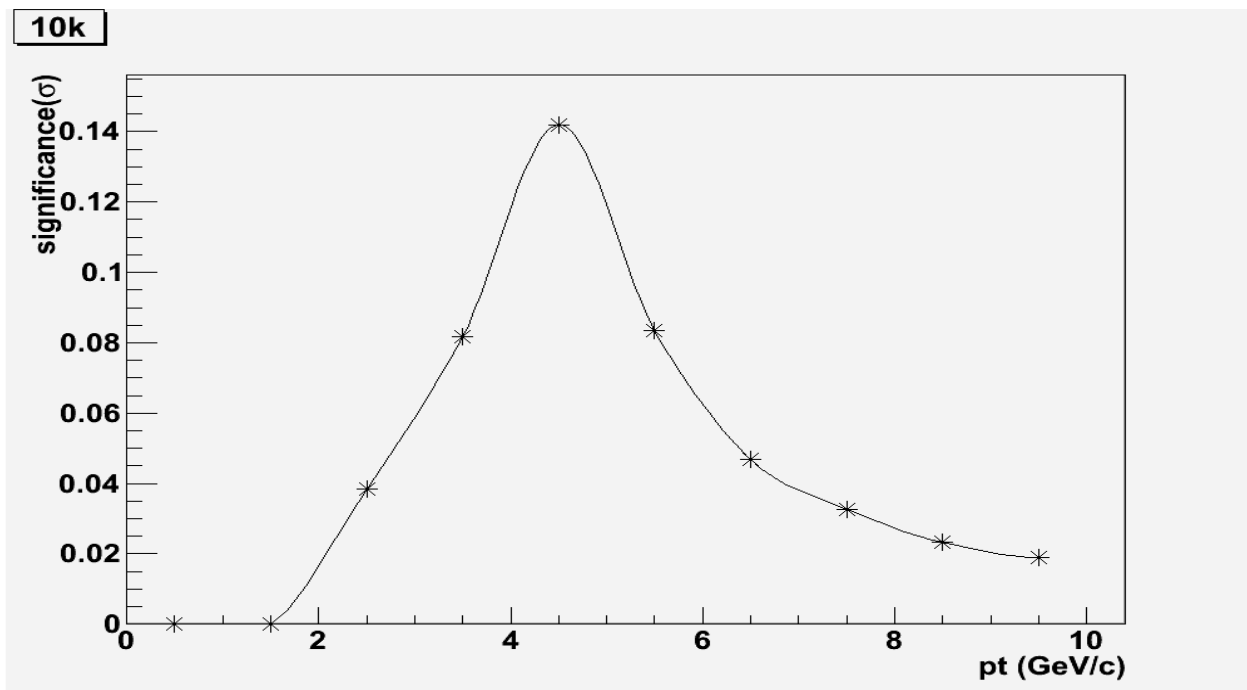Figure-1 Topological reconstruction
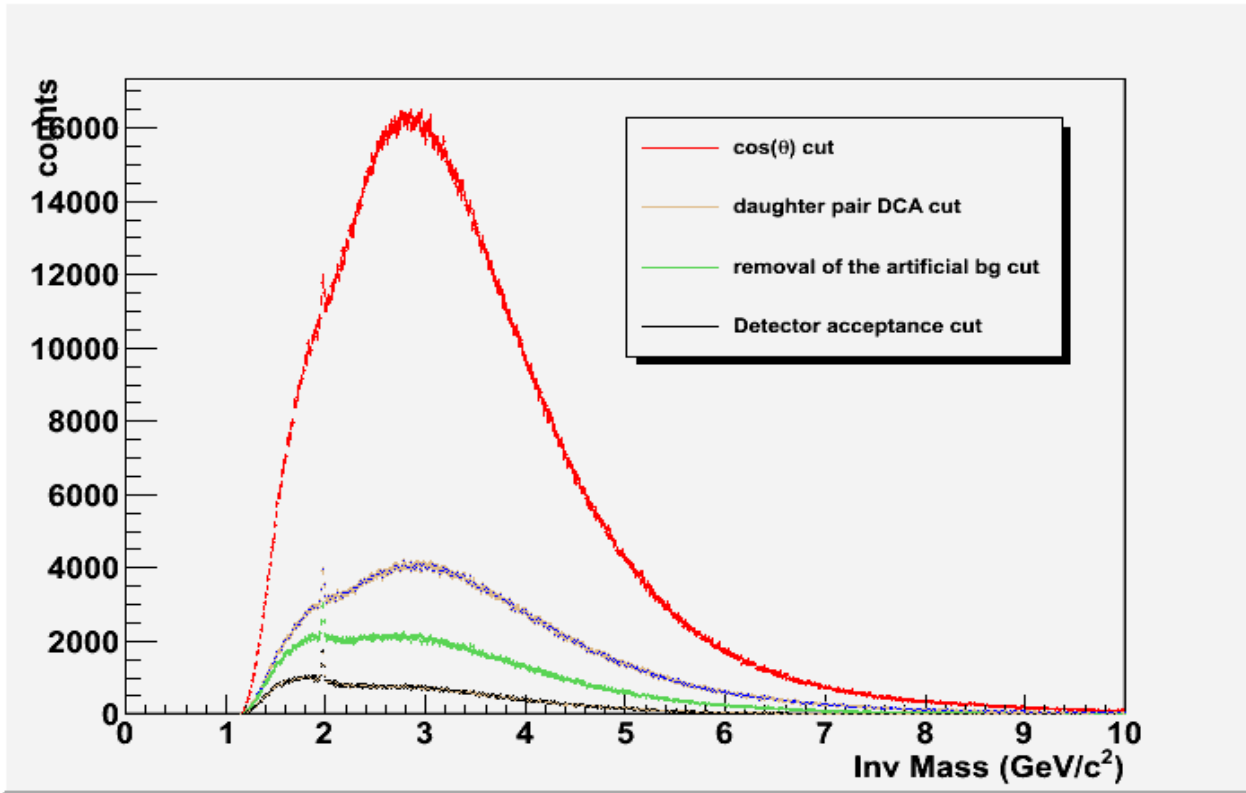
Figure-2 A few cuts
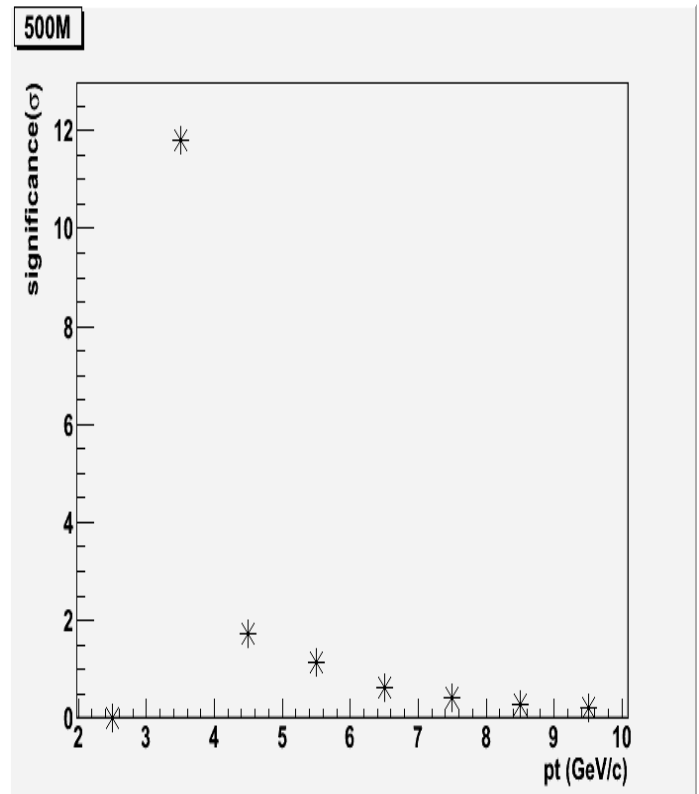
Figure-3 Significance for k+k-pi
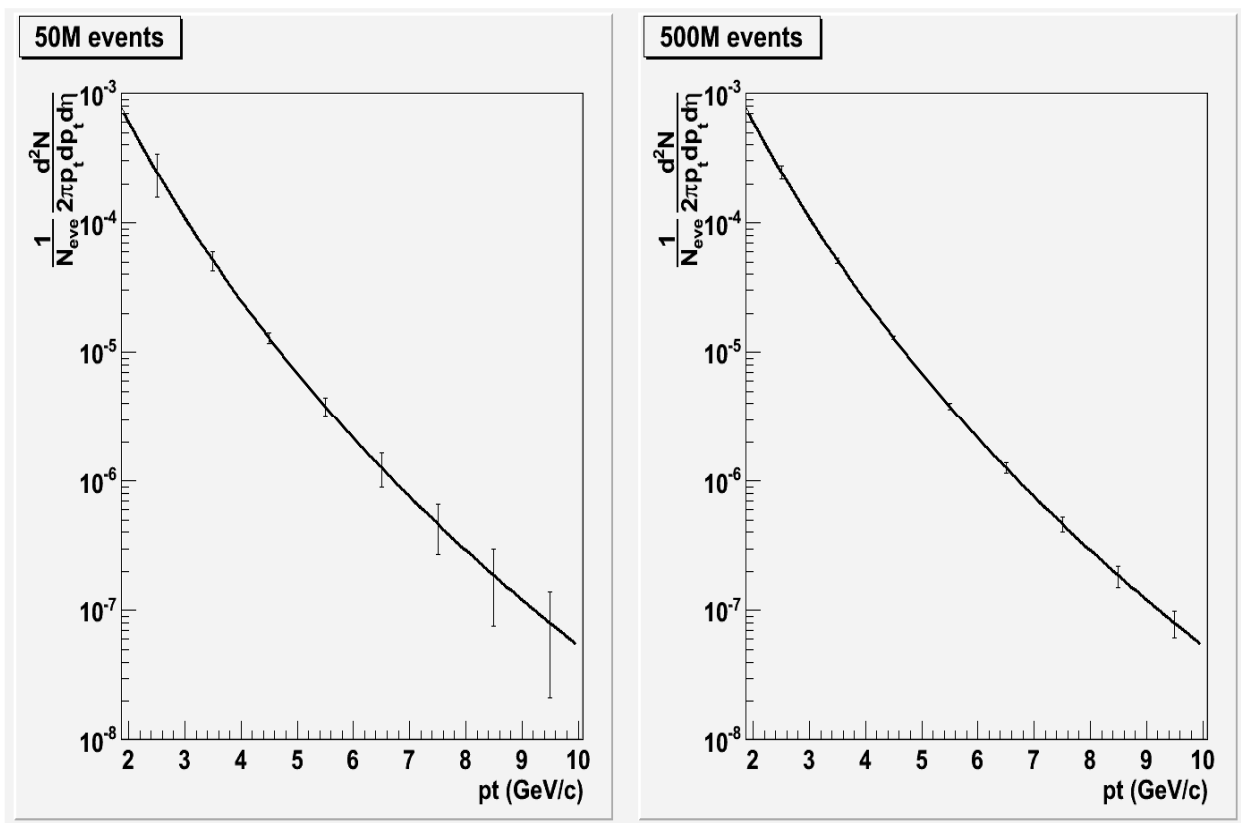
Figure-4 Significance for phi+pi

Figure-5 Cross section for phi+pi

References

[1] Wang, G. (2005, December 8). Matter Flows in high energy heavy ion collisions. Kent State University, OH.

[2] Greiner, L. (2006, March 15). Research and Development for the HFT at STAR. Brook Haven National Laboratory, NY.

[3] Wang, G. (2009, June 5). Reconstructing Ds Mesons with HFT. UCLA.

[4] Thomas, Jim. (2006, July 7). HFT Issues that may bear on the Fate of the SSD and SVT. Lawrence Berkley National Laboratory, CA.

[5] 2008 Particle Physics Booklet

[6] HFT Proposal

[7]

Acknowledgements