STAR Heavy Flavor Tracker (HFT)

Response to CD-1 Physics Questions

April 8, 2010

1. Introduction

This report is written in response to the questions raised in the DOE document " Report on the Technical, Cost, Schedule and Management Review of the STAR Heavy Flavor Tracker". This review took place at Brookhaven National Laboratory in November 12-13, 2009, and is referred to here as the CD-1 review.

In the first part we describe the simulations that have been performed since the review and then address all the relevant questions.

In the Appendix we list the relevant excerpts from the DOE CD-1 report that we have attempted to answer in this report.

2. New HFT Simulations

The CD-1 questions emphasize the impact on physics of the HFT design parameters, especially in the low p_T region that is very sensitive to detector thickness. In this report we study the impact of increasing the mass of the first layer of the PXL detector from a value of 0.32 % of a radiation length (X_0) (thin configuration) to a value of 0.62 % X_0 (thick configuration), and of increasing the internal stability from 20 μm (design value) to 30 μm (CD-4 parameter). The thickness of the "thin" configuration is close to the present design parameter of 0.37% X_0, while the value for the "thick" configuration is close to what could be achieved by using Cu cables for the PXL readout and is also close to the CD-4 parameter for the thickness of the first pixel layer.

All simulations in this report were performed in the same environment as the ones included in the CDR and CD-1 presentations, i.e. the standard STAR reconstruction chain is used as well as the same HFT detector configuration (geometry). The HFT geometry used in all simulations (slightly different than the latest design) comprises of two layers of PIXEL detectors at 2.5 and 8 cm radius, one IST layer of 600 (r-ϕ) x 6000 (z) micron strip-lets at a radius of 14 cm and the existing SSD detector at 23 cm radius.

To summarize the additional simulation efforts after the CD-1 review:

- We ran new productions for thin/thick scenarios to more than quadruple our available statistics in the low p_T region.
- We performed cut-optimization studies for enhanced low p_T D^0 significance.
- We re-evaluated our capability to measure the Λ_C /D^0 ratio.

3. Answers to CD-1 questions

- **Studies should be carried through to the final physics measurement, showing the degradation of the final physics significance if key requirements are not met:**

–Give an explicit evaluation of what the loss in low-pT efficiency does regarding the fundamental physics questions relating to flow and energy loss of heavy quarks in the hot-dense medium. Evaluate this loss in terms of current theoretical models and show whether these are well tested by the measurement above ~2 GeV/c or if the loss of statistics at lower pT is a critical loss.

The low p_T region is important for studies of collectivity. Energy loss is a high p_T phenomenon. Here we limit our discussion to v_2, where low p_T is important. It is important to understand that flow is a hydrodynamic phenomenon. Data and hydro predictions agree up to about 1.5 GeV p_T at which point data deviate dramatically from the hydro prediction. In Figure 1 we present the precision of measurement that may be achieved by assuming two limiting cases for a model calculation[1]. The model is based on the coalescence assumption[2]. Coalescence is an empirical observation deducted from v_2 systematics. At low p_T we observe mass scaling/splitting (hydro) and at high p_T leveling off and scaling with the number of constituent quarks. The shape of v_2 at high p_T is not a hydro effect but is due to quark energy loss.[3] Reference 1 has no predictive power at high p_T (above 2 GeV) since it only assumes coalescence and does not include the effects of energy loss mechanism. The model uses light quark momentum distribution and for the heavy quark either non-interacting distributions (no flow) or completely thermalized distributions with transverse expansion (flow). In fact, if constituent quark scaling is to hold in the charm sector, the v_2 value at high p_T is determined only by the fact that the D^0 is a meson (not a baryon). In this scenario, the two theoretical curves must merge at high p_T. There is no realistic model on the market that would give quantitative guidance for v_2 values at low p_T and realistic predictions for v_2 at high p_T. The comparison has to rely on systematic studies of v_2 scaling at low p_T as a function of particle mass. If the heavy quark flows, such systematics will show it. Figure 1 also shows data for charged hadrons. The measured v_2 vales do not saturate, but decrease at high p_T. This is further evidence that the calculations from Reference [1] are not realistic at high p_T.

However, this further emphasizes the importance of testing coalescence in the charm sector. Besides v_2 scaling, the Λ_C to D^0 cross-section ratio represents an ideal test. Later in this document we will summarize the capability of the HFT to determine a baryon to meson ratio in the charm sector.

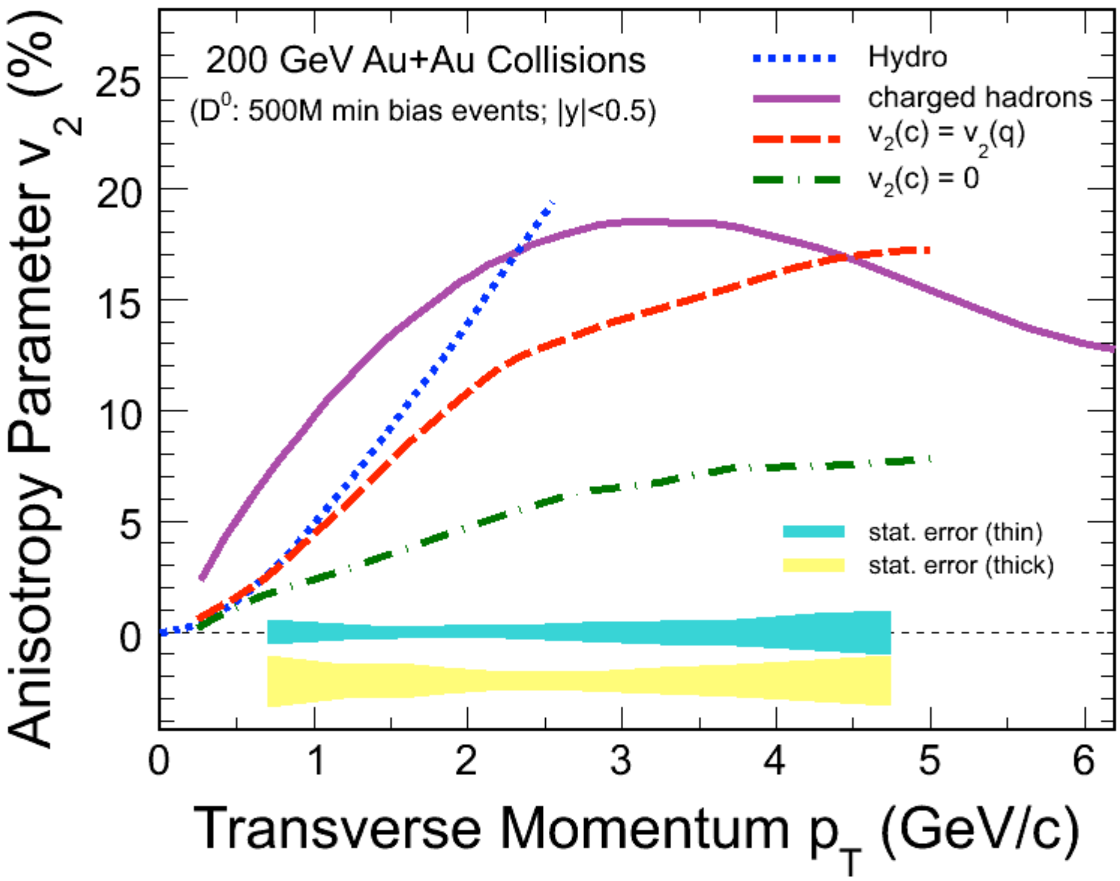


Figure 1: Elliptic flow (v2) vs **p_T in Au+Au collisions at 200 GeV/c. The purple curve shows the measured value for charged hadrons. The red and the green curves show calculations from Ref [1] for the limiting cases that the charm quark flows like the light quarks and that the charm quark does not flow. The Cyan band indicates the statistical error that can be achieved with 500 M minimum bias events and the thin detector configurations and the yellow band is for the thick configuration.**

2. figure:

As a function of pT calculate ratio of significance for the three cases

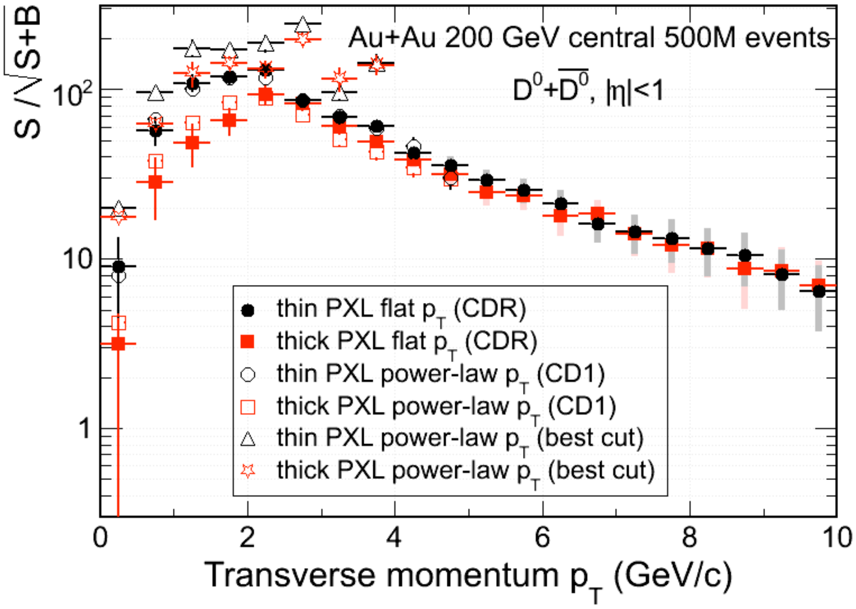
(reference is thin)

Thick/thin

Thin with incr. resolution/thin

Figure 3: placeholder

Thick with incr. resolution /



thin

Figure 4: text

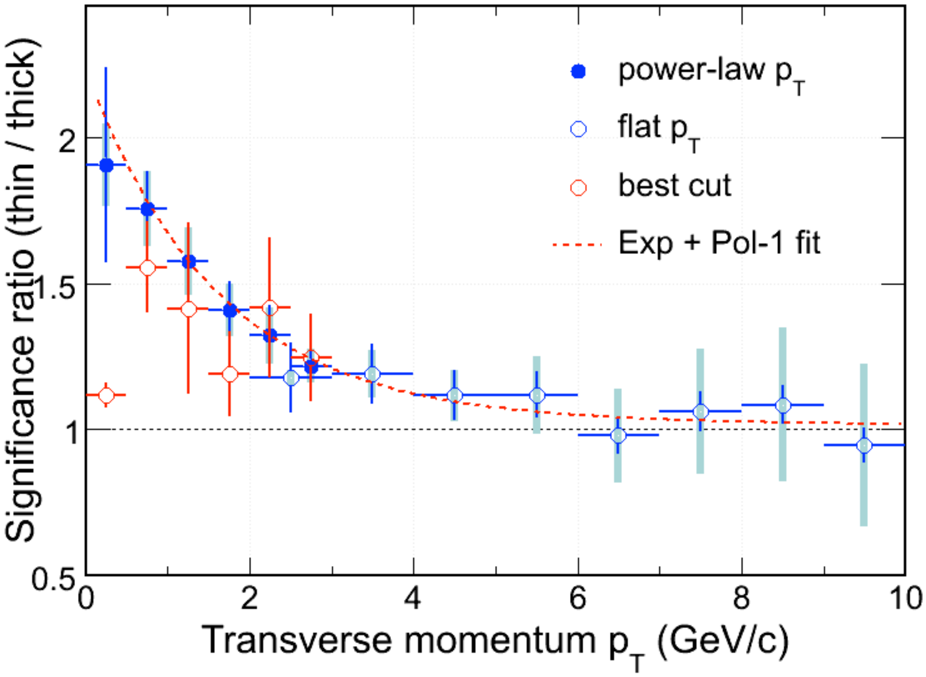


Figure 5: text

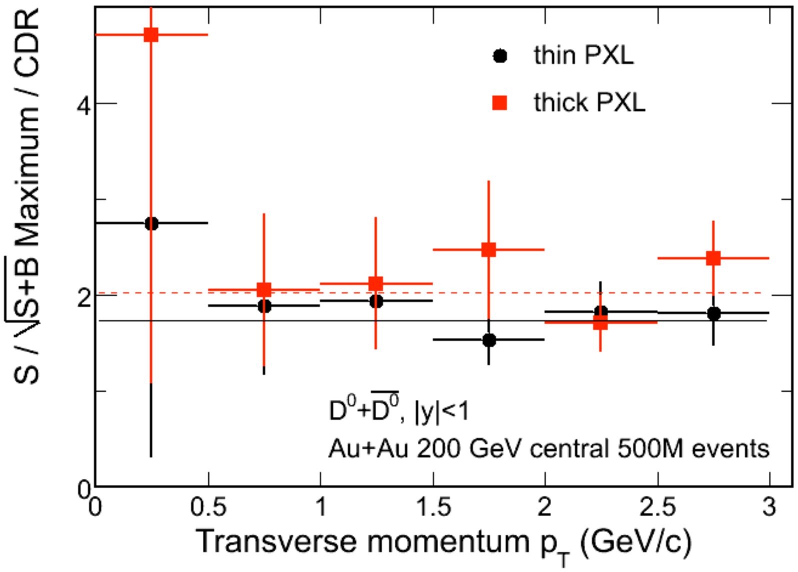


Figure 6 (PLACE HOLDER) Signal significance as a function of pT

The resolution (stability) data will come from fast simulations

- **Compare the significance of planned charm and beauty measurement to be done with the HFT to similar measurements expected from the upgraded PHENIX detector. Comment on how significant an advance in theoretical understanding of energy loss and flow for the hot-dense medium the HFT would provide compared to the earlier anticipated PHENIX measurements**

PHENIX has not shown simulations that would establish the capability to do topological reconstruction of D-mesons.[4] Therefore we will attempt a qualitative comparison of what can be done with the HFT and PHENIX with respect to the physics extracted from the measurement of the electrons from semi-leptonic D- and B-meson decays. We believe the following statements to be correct:

- The theory development in the area of energy loss is progressing rapidly and it is not obvious what it will be in a few years. It is, however, safe to say that quality data are the requirement for theory progress.
- All measurements by STAR based on topological reconstruction are original and without competition at RHIC.

- PHENIX and STAR will both measure charm/beauty production cross sections from the electron spectra.

PHENIX will measure the spectra of non-photonic electrons from charm and beauty decays. The new information that the HYBRID vertex detectors will provide is the electron impact parameter (DCA) from the event vertex. The reconstruction technique is based on applying DCA cuts to reject background and then fit the yields in various p_T bins. This will result in a spectrum of the sum of D and B decays. Taking the difference in $c\tau$ for charm and bottom into account, separation can be achieved through unfolding. The unfolding process is complicated by the fact that the different D states have quite different ct values, where for example the D+ ct is very close to the B ct. Unfolding has to make assumptions about the production ratio for the individual D states. For p+p this is well known. However, in case that the production ratio is modified in heavy ion reactions, unfolding becomes unreliable.

This potentially large uncertainty can be mitigated in the STAR non-photonic electron measurement because STAR will directly measure D^0 and D^+ production.

D and B production can be separated also by multi-particle correlations.[5] Neither PHENIX nor STAR have shown this capability in simulations. Since 2π acceptance is important for two- and multi-particle correlations, it can be assumed that STAR has advantages for this particular measurement.

PHENIX will perform a measurement of the R_{AA} for electrons from D and B decay as a function of p_T. Due to momentum smearing from the decay process, the parent pT cannot be determined, thus preventing a precision measurement of R_{AA} as a function of pT, which might be very important for a precision comparisons with model calculations which might be important to determine the mechanism of energy loss.

PHENIX also will determine v_2 of non-photonic electrons. This measurement cannot contribute to the question of thermalization. The parent p_T is not determined to better than 3 GeV. We have argued above that only a measurement at low p_T (< 2.5 GeV/c) might be able to answer this important question.

In summary, a measurement of non-photonic electrons has a very limited reach. The full potential of heavy flavor physics in heavy ion collisions can only be reached through full topologic reconstruction.

3.1. Update on Λ_C Simulations

Since CDR we have increased statistics of our simulations, to allow for better optimization of cuts also in the Λ_C analysis. Despite these improvements, estimated errors in the 2-3 and 3-4 GeV/c p_T bins haven't changed significantly, showing robustness of our CDR estimates.

A significant improvement was achieved in the 4-5 GeV/c p_T bin, where we didn't require full identification of daughter particles, which resulted in improvements in

Λ_C reconstruction efficiency and (as background is modest in this higher p_T bin) increased the Λ_C signal significance.

Note that in the figure, the discrimination should be made between estimated errors and the 2 scenarios of Λ_C /D_0 ratio - not between the two sets of estimated errors. The significance of this discrimination is in the range 2-4 sigma in the case of an enhanced ratio and about 4-6 sigma in the extreme case of no-enhancement.

Similar simulations and analysis of simulated data were conducted for the "thick" detector configuration. However, Λ_C /D^0 measurement with similar errors turned out not to be feasible with reasonable statistics in the "thick" detector configuration.

In summary, we will be able to make a significant measurement of the Λ_C /D^0 ratio only with the thin HFT configuration. This will not be possible with the thick detector configuration.

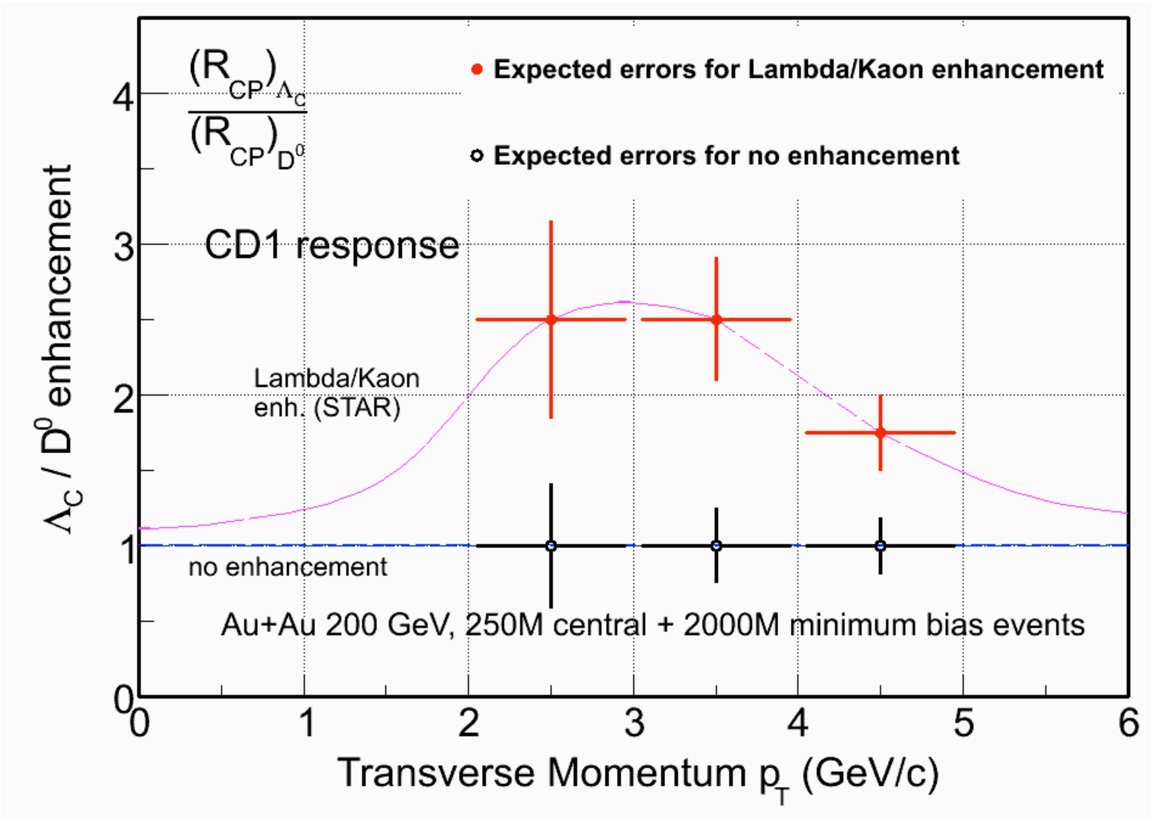


Figure 7: Ratio of Λ_C to D^0 meson production.

References:

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[1] V. Greco, C.M. Ko and R. Rapp, Phys. Lett. B 595 (2004) 202

[2] Coalescence refs

[3] G.D. Moore and D. Teaney, Phys. Rev. C 71, (2005) 064904

[4] W. Zajc, private communication

[5] STAR publication