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Dependence of the non-photonic electron spectrum on the charmed baryon-to-meson ratio

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Abstract. In this talk I argue that a substantial fraction of the non-photonic electron suppression in Au + Au collisions could arise as a result of an enhanced Λ_c/D ratio rather than purely from jet-quenching. At intermediate transverse momentum ($2 < p_T < 6$ GeV/c), the baryon-to-meson ratio in Au + Au collisions is enhanced compared to $p + p$ collisions. Since charm-baryon decays produce electrons less frequently than charm-meson decays, the non-photonic electron spectrum is sensitive to the Λ_c/D ratio. I show the dependence of the non-photonic electron spectrum on the baryon-to-meson ratio for charm hadrons. As an example, I assume that the Λ_c/D ratio is the same as the Λ/K^0_S ratio. I show that even if the total charm quark yield in Au + Au collisions scales with the number of binary nucleon-nucleon collisions ($N_{\rm bin}$), the electron spectrum at $2 < p_T < 5$ GeV/c will be suppressed relative to $N_{\rm bin}$ scaled $p + p$ collisions by as much as 20%.

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1 Introduction

Non-photonic electrons from heavy flavor decays have been used to study charm production because direct measurements of heavy flavor hadrons are experimentally difficult. Radiative energy loss models that successfully describe the large hadron suppression in central Au + Au collisions predict a smaller energy loss for heavy flavor quarks (the dead-cone effect) [1, 2]. Recent measurements, however, show that for $3 < p_T < 8$ GeV/c the non-photonic electron spectrum in central Au + Au collisions is supressed by a factor of five compared to expectations from $N_{\rm bin}$ scaled $p + p$ collisions: a suppression that is as large as that seen for charged hadrons [3, 4]. No radiative energy loss models predict such a large suppression for heavy-flavor quarks. Facing the large discrepancy between the parton radiative energy loss results and data, scenarios that involve collisional energy loss are being revisited [5]. We note, however, that to relate non-photonic electron spectra to charm quark energy loss, requires knowledg of the charm fragmentation, the hadron decay kinematics, and the number of decay electrons from beauty quarks. We believe that it is not just possible, but actually likely, that the charm fragmentation in Au + Au collisions will be modified compared to $p + p$ collisions. Particularly, it's possible that charm quarks in Au + Au collisions will fragment more frequently to baryons than to mesons. This could partially resolve the discrepency between predictions and measurements of non-photonic electron suppresion.

RHIC experiments have observed an enhancement of baryon production in the intermediate transverse momentum region ($1.5 < p_T < 6$ GeV/c) [6–8]. At $p_T = 3$ GeV/c, the proton to pion ratio is three times larger in Au + Au collisions than it is in $p + p$ collisions. This enhancement also exists for hyperons (Λ (uds), Ξ (dss) and Ω (sss)) [9]. The enhancement can be described by models involving multi-quark or gluon dynamics during hadronization [10–16], models making use of baryon junction loops [17–20], or models with long range coherent fields (i.e. strong color fields) [21]. Until now, however, the implications of possible charm-baryon enhancements on the non-photonic electron spectra have not been considered.

The branching ratio for $\Lambda_c \to e + anything$ ($4.5\% \pm 1.7\%$) is smaller than that for $D^\pm \to e + anything$ ($17.2\% \pm 1.9\%$) or $D^0 \to e + anything$ ($6.87\% \pm 0.28\%$) [22]. In this case, even if charm quark production is unchanged, increasing the Λ_c/D ratio will lead to a reduction in the number of observed non-photonic electrons. In this report we assume that the Λ_c/D ratio is the same as the Λ/K^0_S ratio [23]. Unless specified otherwise, the symbol D represents the sum of D^0, D^+, and D_s. PYTHIA [24] is used to generate the decay electron spectrum from the input charm hadrons. We find that even when the total charm hadron production in Au + Au collisions scales with the number of binary nucleon-nucleon collisions $N_{\rm bin}$ (*i.e.* total charm hadron $R_{AA} = 1$ [25]), the non-photonic electron spectrum at intermediate p_T can be supressed by as much as 20%. We also present the non-photonic electron spectrum when the total charm hadron R_{AA} follows the measured charged hadron R_{AA} [26, 27]. We find that if charm baryons are

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enhanced as much as lighter flavor baryons, preliminary non-photonic electron measurements imply a smaller suppression of charm quarks than light quarks [28, 29].

2 Results

Figure 1 shows the Λ/K^0_S ratio in $p+p$ and Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV [23]. The Λ/K^0_S ratio is larger than the p/π ratio and the baryon enhancement becomes even stronger for multi-strange baryons [30]. In the following analysis we take the Λ_c/D ratio to have the same form as the Λ/K^0_S ratio. For $p_T > 6.5$ GeV/c where the Λ/K^0_S ratio is unknown, we take the value $\Lambda_c/D = 0.33$. Since the source of the baryon enhancement at intermediate p_T is still under debate, it's difficult to assess the validity of our assumed Λ_c/D ratio. Possible explanations for the enhancement include [9] radial flow pushing heavy baryons from lower p_T into the intermediate p_T region, baryon junction dynamics, and enhanced production through coalesence or recombination of quarks. We are not aware, however, of predictions for the p_T dependence of the Λ_c/D ratio.

Figure 2 shows the spectra for D^0, $D^\pm$, D_s, and Λ_c. The spectra are derived such that the sum of the D^0, $D^\pm$, D_s, and Λ_c spectra follows a power-law, the Λ_c/D ratio has the form shown in Fig. 1, and the D-meson spectra all have the same p_T dependence. Since we are interested in the shape of the spectra, the scale of the y-axis is arbitrary. The non-photonic electron spectrum will also be sensitive to the $D^\pm/D^0$ and the D_s/D^0 ratios (the $D_s \to e + anything$ branching ratio is 8^{+6}_{-5} % [22]). An increase in the $D_s/D^\pm$ ratio can therefore lead to fewer decay electrons depending on the poorly known branching ratio. At intemediate p_T, the K/π ratio in Au + Au collisions is enhanced compared to $p+p$ collisions [31]. One can also investigate how

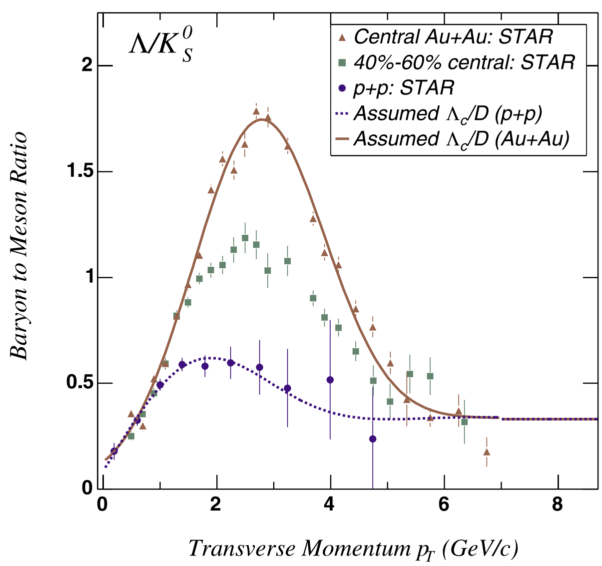

Fig. 1. Λ/K^0_S ratio. The *lines* show the functional form of the the Λ_c/D-meson ratio used in our analysis

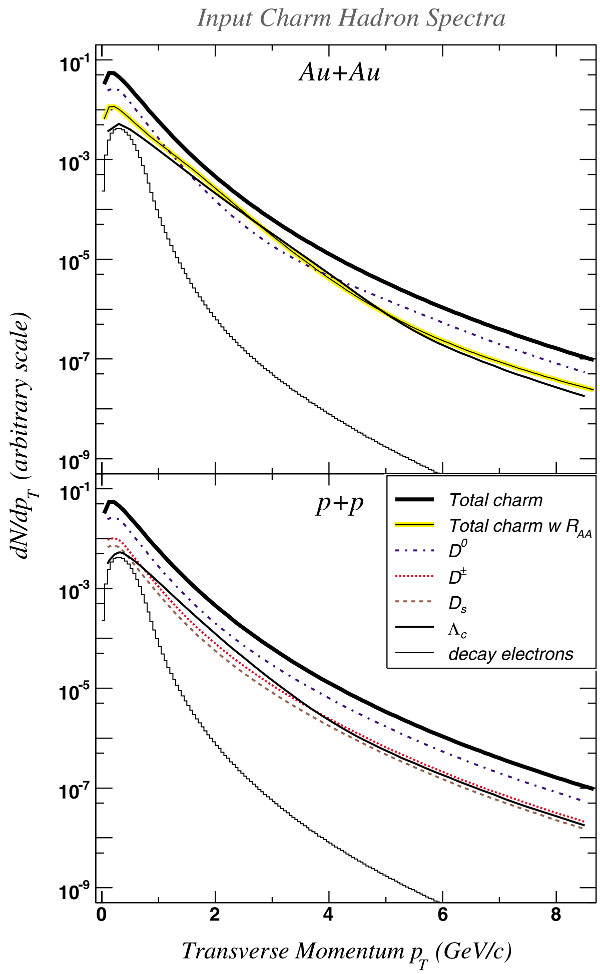

Fig. 2. The individual charm hadron and total charm hadron spectra. Here, the total charm hadron spectrum is assumed to follow a power-law shape with $\langle p_T \rangle = 1.3$ GeV/c and $n = 9$. The individual charm hadron spectra are derived using the total charm spectrum and the assumed shape of the Λ_c/D ratio in $p+p$ collisions (*bottom panel*) or Au + Au collisions (*top panel*). We also show the total charm hadron spectra assuming a total charm hadron R_{AA} similar to the measured charged hadron R_{AA}. The D_s and $D^\pm$ spectra are omitted from the top panel for clarity

modifications to the $D_s/D^\pm$ ratio in Au + Au collisions affect the non-photonic electron spectrum. Since the enhancement in the Λ/K^0_S ratio is larger than the enhancement in the K/π ratio, and since the branching ratios for $D_s \to e + anything$ and $D^0 \to e + anything$ are similar, we expect a charm baryon enhancement to have a larger effect on the decay electron spectrum. For this reason, in this report we use p_T independent relative D-meson abundances of 18, 7, and 5 for D^0, $D^\pm$, and D_s respectively [32].

In Fig. 3 we show the effect of a Λ_c enhancement on the charm decay electron spectrum. The ratio of two cases is taken: Λ_c/D follows the shape of the Λ/K^0_S ratio in Au + Au collisions, or it follows the shape of the Λ/K^0_S ratio in $p+p$ collisions. A supression of electrons from heavy flavor decays due to the larger charm baryon-to-meson ratio in Au + Au collisions is visible. The suppression in this

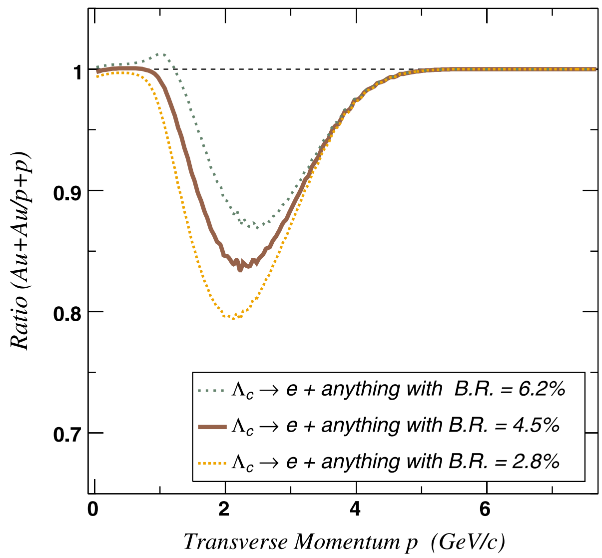

Fig. 3. Electron spectrum with Λ_c enhancement divided by the spectrum without Λ_c enhancement

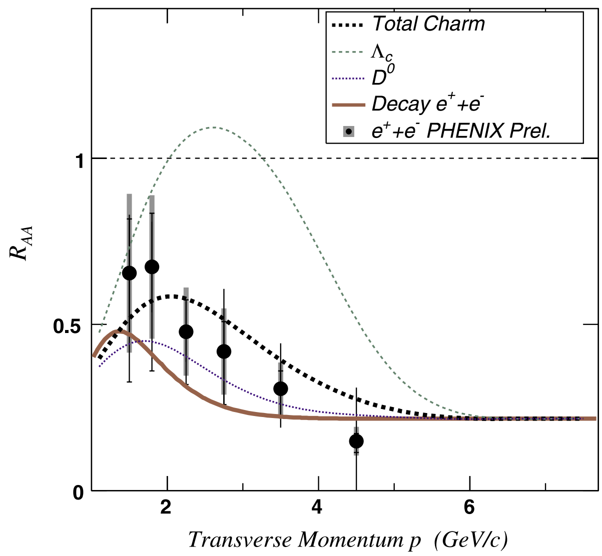

Fig. 4. R_{AA} for charm hadrons and non-photonic electrons. The total charm spectrum in Au + Au collisions is scaled by the charged hadron R_{AA} values. In this way the total charm hadron R_{AA} has the same form as the charged hadron R_{AA}. The Λ_c/D ratio is given the same form as the preliminary Λ/K^0_S ratio. For $p_T < 6$ GeV/c, the resulting decay electron R_{AA} is smaller than either the D-meson or total charm R_{AA}

figure is a result of smaller $\Lambda_c \to e +$ *anything* branching ratio, which has large uncertainties. The highest and lowest curves show the cases corresponding to the upper and lower experimental uncertainties on the branching ratio [22]. The figure demonstrates that even if the total charm yield follows $N_{\rm bin}$ scaling, the non-photonic electron spectrum may be suppressed. The magnitude of the suppression depends on the Λ_c/D ratio and the $\Lambda_c \to e +$ *anything* branching ratio. The Λ_c/D ratio in Au + Au collisions is unknown but for the charm baryon-to-meson ratio assumed here, the suppression can be as large as 20%.

The presence of a charm baryon enhancement will change the charm quark energy loss inferred from the preliminary non-photonic electron R_{AA} data. In Fig. 4 we show the case when the total charm R_{AA} has the same shape as charged hadron R_{AA} [26, 27]. In the lower p_T region, this assumption may not be realistic since the total charm quark production is expected to follow $N_{\rm bin}$ scaling. The error introduced, however, will mostly affect the region below $p_T = 1.5$ GeV/c and may be irrelevant to the higher p_T regions of interest. Our analysis shows that if the Λ_c/D ratio has the form shown in Fig. 1, then the decay electron R_{AA} at $p_T < 6$ GeV/c will be smaller than the total charm R_{AA}.

In this report we have not considered contributions to the non-photonic electrons from beauty decays. The p_T value where the yield of electrons from beauty decays is larger than from charm decays is experimentally unknown. Theoretical calculations indicate that the crossover happens somewhere between $p_T = 3$ GeV/c and $p_T = 10$ GeV/c [34]. The branching ratios for beauty mesons and baryons are not well know. We refer the reader to [34] for discussion of the contribution of beauty to the non-photonic electron spectrum.

In the intermediate p_T region, the preliminary non-photonic electron data are systematically above our calculations for the decay electron R_{AA} [28, 29]. In the case that the heavy flavor baryons have an enhancement similar to the light flavor baryons, the non-photonic electron data indicate that the suppression for charm quarks is smaller than that for light quarks. We varied the input total charm hadron R_{AA} and made a χ^2 comparison to the PHENIX data (with the systematic and statistical errors added in quadrature). For $p_T > 2.0$ GeV/c, the PHENIX non-photonic electron data are better represented when the total charm hadron R_{AA} is 35% greater than charged hadron R_{AA}. At p_T near 6 GeV/c the derived decay electron R_{AA} matches the charged hadron R_{AA} and the preliminary non-photonic electron R_{AA} data reported in [33]. This *may* indicate that at $p_T = 6$ GeV/c (within the large errors) the total charm hadron suppression is as large as the light hadron suppression. In light of the results of this analysis, however, we believe one must also consider that a charm baryon enhancement could extend to a higher p_T than assumed here. Direct measurements of heavy flavor hadrons are therefore needed in order to accurately assess the energy loss of charm quarks.

3 Pions

It was pointed out by J. Nagle, at the end of this talk that the same effect could be present for pion R_{AA}. If quarks and gluons in Au + Au collisions combine or fragment into baryons more frequently than they would in $p + p$ collisions, then since baryons decay into pions far less frequently than mesons do, the number of pions seen in Au + Au collisions will be suppressed relative to scaled $p + p$ collisions. This scenario is consistent with data. We observe that the baryon to meson ratio is enhanced at intermediate p_T and that in the same region pions are suppressed more than kaons are. In this case, pion R_{AA} would not be the best proxy for comparing to calculations of partonic energy loss.

4 Conclusions

I've shown how non-photonic electron R_{AA} depends on the Λ_c/D ratio. Even when the total charm hadron production scales with the number of binary nucleon-nucleon collisions, an increase in the Λ_c/D ratio similar to that seen for the Λ/K_S^0 ratio leads to a suppression in central Au + Au collisions of non-photonic electrons at intermediate p_T. Because of this, the link between non-photonic electron R_{AA} charm quark energy loss is made weaker and comparisons to theory require careful consideration. If the Λ_c/D ratio has the form assumed in this report, the PHENIX non-photonic electron data at intermediate p_T prefer a total charm hadron R_{AA} 35% larger than the charged hadron R_{AA} – implying less energy loss for charm quarks than light quarks. If the relative fractions of charm hadrons are not altered in Au + Au collisions compared to $p+p$ collisions, the non-photonic electron R_{AA} values are difficult to understand within current radiative energy loss models. Since the non-photonic electron measurements depend on the D^0/D, $D^{\pm}/D$, D_s/D and the Λ_c/D ratio, direct measurements of heavy-flavor hadron yields are needed to draw firm conclusions regarding energy loss for heavy quarks.

References

1. Y.L. Dokshitzer, D.E. Kharzeev, Phys. Lett. B **519**, 199 (2001)
2. M. Djordjevic, M. Gyulassy, Nucl. Phys. A **733**, 265 (2004)
3. PHENIX Collaboration, S.S. Adler, arXiv:nucl-ex/0510047
4. STAR Collaboration, J.C. Dunlop, arXiv:nucl-ex/0510073
5. Private Comm. M. Gyulassy, 2005
6. PHENIX Collaboration, S.S. Adler et al., Phys. Rev. Lett. **91**, 172 301 (2003)
7. P.R. Sorensen, arXiv:nucl-ex/0309003
8. STAR Collaboration, J. Adams et al., Phys. Rev. Lett. **92**, 052 302 (2004)
9. P.R. Sorensen, arXiv:nucl-ex/0510052
10. D. Molnar, S.A. Voloshin, Phys. Rev. Lett. **91**, 092 301 (2003)
11. R.C. Hwa, C.B. Yang, Phys. Rev. C **67**, 064 902 (2003)
12. R.J. Fries, B. Muller, C. Nonaka, S.A. Bass, Phys. Rev. C **68**, 044 902 (2003)
13. V. Greco, C.M. Ko, P. Levai, Phys. Rev. C **68**, 034 904 (2003)
14. V. Greco, C.M. Ko, P. Levai, Phys. Rev. Lett. **90**, 202 302 (2003)
15. R.J. Fries, B. Muller, C. Nonaka, S.A. Bass, Phys. Rev. Lett. **90**, 202 303 (2003)
16. STAR Collaboration, P. Sorensen, J. Phys. G **30**, S217 (2004)
17. D. Kharzeev, Phys. Lett. B **378**, 238 (1996)
18. S.E. Vance, M. Gyulassy, X.N. Wang, Phys. Lett. B **443**, 45 (1998)
19. I. Vitev, M. Gyulassy, Nucl. Phys. A **715**, 779 (2003)
20. V.T. Pop, M. Gyulassy, J. Barrette, C. Gale, X.N. Wang, N. Xu, Phys. Rev. C **70**, 064 906 (2004)
21. V.T. Pop, M. Gyulassy, J. Barrette, C. Gale, R. Bellwied, N. Xu, arXiv:hep-ph/0505210
22. Particle Data Group, S. Eidelman et al., Phys. Lett. B **592**, 848 (2004)
23. STAR Collaboration, J. Adams et al., arXiv:nucl-ex/0601 042
24. T. Sjöstrand, L. Lönnblad, S. Mrenna, arXiv:hep-ph/0108 264 and references therein
25. R_{AA} is the ratio of the p_T spectrum in nucleus-nucleus collisions and $p+p$ collisions where each has been scaled by N_{bin} to account for the trivial increase in particle production with collision system-size
26. PHENIX Collaboration, K. Adcox et al., Phys. Rev. Lett. **88**, 022 301 (2002)
27. STAR Collaboration, J. Adams et al., Phys. Rev. Lett. **91**, 172 302 (2003)
28. X. Dong, arXiv:nucl-ex/0509038
29. PHENIX Collaboration, S.S. Adler, arXiv:nucl-ex/ 0510047
30. STAR Collaboration, S. Salur, arXiv:nucl-ex/0509036
31. PHENIX Collaboration, S.S. Adler et al., Phys. Rev. C **69**, 034 909 (2004)
32. X. Dong, arXiv:nucl-ex/0509011
33. J. Bielcik, arXiv:nucl-ex/0511005
34. M. Cacciari, P. Nason, R. Vogt, Phys. Rev. Lett. **95**, 122 001 (2005)