AdS/CFT predictions for azimuthal and momentum correlations of heavy quarks in heavy ion collisions

R. Hambrock and W.A. Horowitz
University of Cape Town

Motivation & Outline

- Want to understand relevant coupling scale of QGP
- Need observables to differentiate between strong- and weakly-coupled energy loss mechanisms
- We compare perturbative QCD [2] with our AdS/CFT predictions [1] for azimuthal correlations of bottom quarks in Pb+Pb collisions ($\sqrt{s} = 2.76$TeV)
- We probe with two plausible 't Hooft coupling constants, $\lambda_1 = 5.5$ with $T_{QCD} = T_{SYM}$, and $\lambda_2 = 12\pi\alpha_s \approx 11.3$ with $\alpha_s = 0.3$ and $E_{QCD} = E_{SYM}$

Energy Loss Model

- Momenta of bottom pairs initialized either to leading order with FONLL [4] or to next-to-leading order with aMC@NLO [5] matched to Herwig++ [6]
- Bottom quarks are propagated through the plasma via the energy loss mechanism $D(p)$ or D_{const}

$D(p)$

The stochastic equation of motion for a heavy quark is given by

$$\frac{dp_i}{dt} = -\mu p_i + F_i^L + F_i^T$$

where $\mu = \pi\sqrt{\lambda}T^2/(2M_Q)$ [1].

The correlations of transverse and longitudinal momentum kicks are given by

$$\langle F_i^T(t_1)F_j^T(t_2)\rangle = \kappa_T(\delta ij - \frac{\vec{p}_i\vec{p}_j}{|p|^2})\,\partial(t_2 - t_1)$$

$$\langle F_i^L(t_1)F_j^L(t_2)\rangle = \kappa_L\frac{p_i p_j}{|p|^2}\partial(t_2 - t_1)$$

where

$$\kappa_T = \pi\sqrt{\lambda}T^3\gamma$$

$$\kappa_L = \gamma^2\kappa_T = \pi\sqrt{\lambda}T^{5/2}$$

D_{const}

In this model [3], we calculate the average squared distance travelled by offshell quarks by considering $s^2(t, a)$ of the free endpoint of a string initially at rest, where the other endpoint is fixed to a black hole horizon in AdS_5. For asymptotically late times, where the motion is diffusive, we extract

$$D(a) \sim \frac{s^2(t \gg \beta, a)}{2} = 2\beta/(\pi\sqrt{\lambda})$$

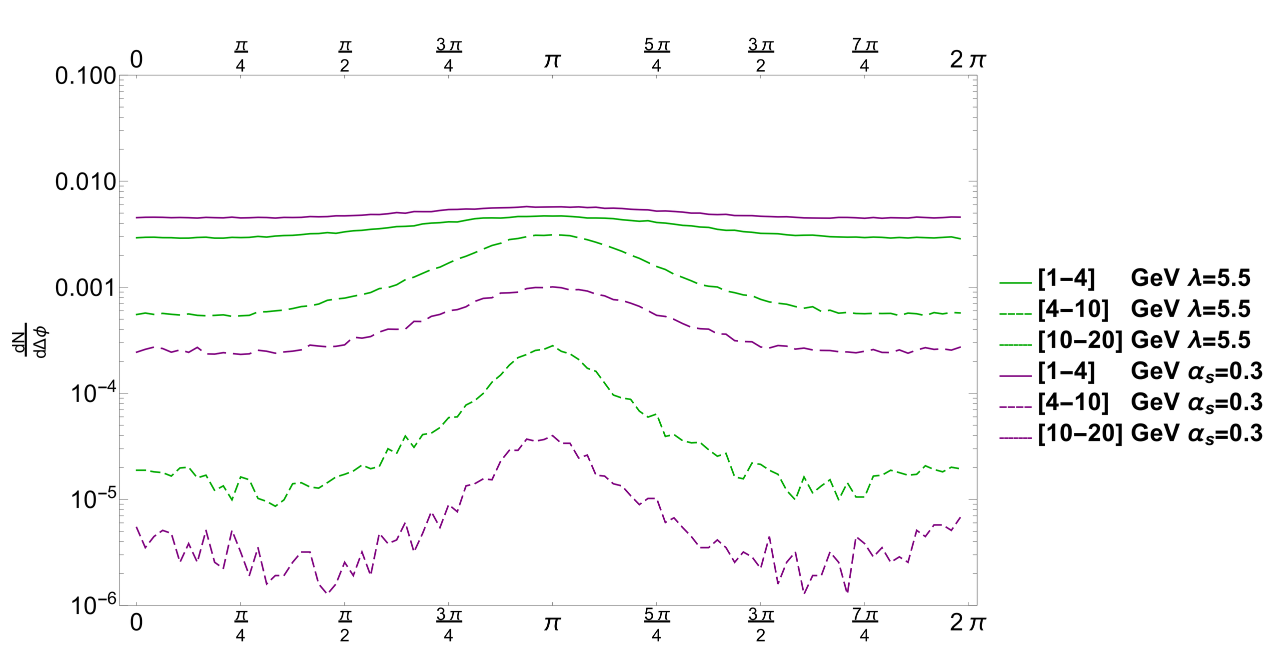
and thus

$$\kappa_T = 2T^2/D = \pi\sqrt{\lambda}T^3$$

and

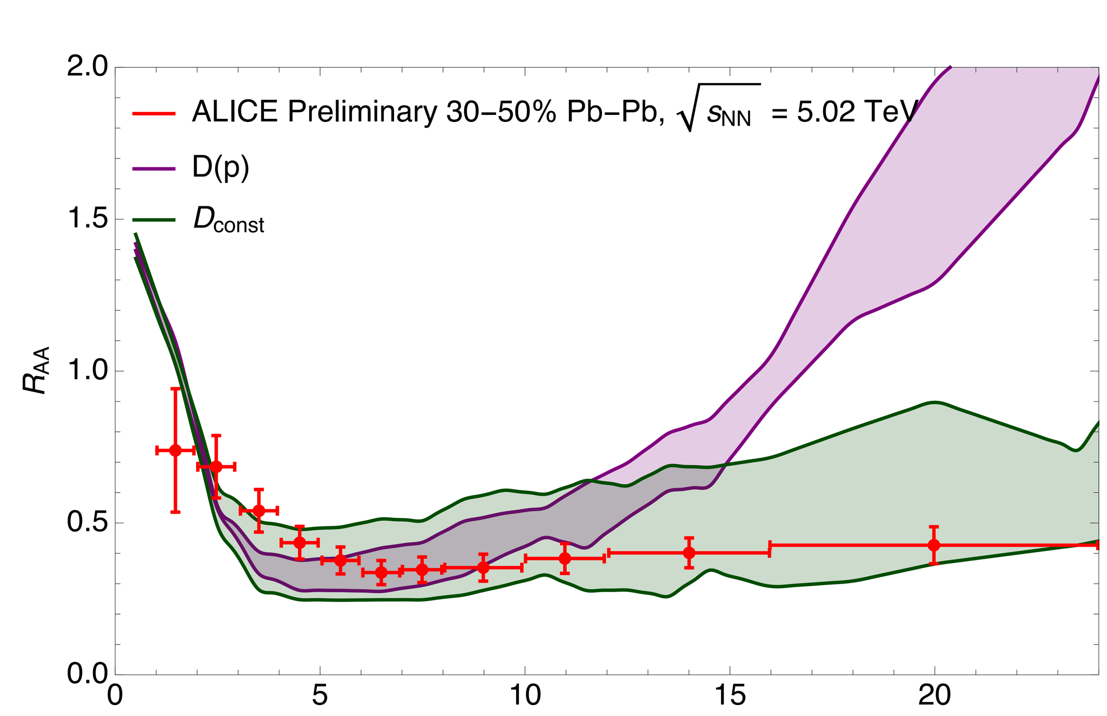
$$\hat{q} = \frac{\langle p_\perp(t)^2\rangle}{\lambda} \approx \frac{2\kappa_T t}{\lambda} = \frac{\pi T^3 t}{\sqrt{\lambda}}$$

NLO Azimuthal Correlations



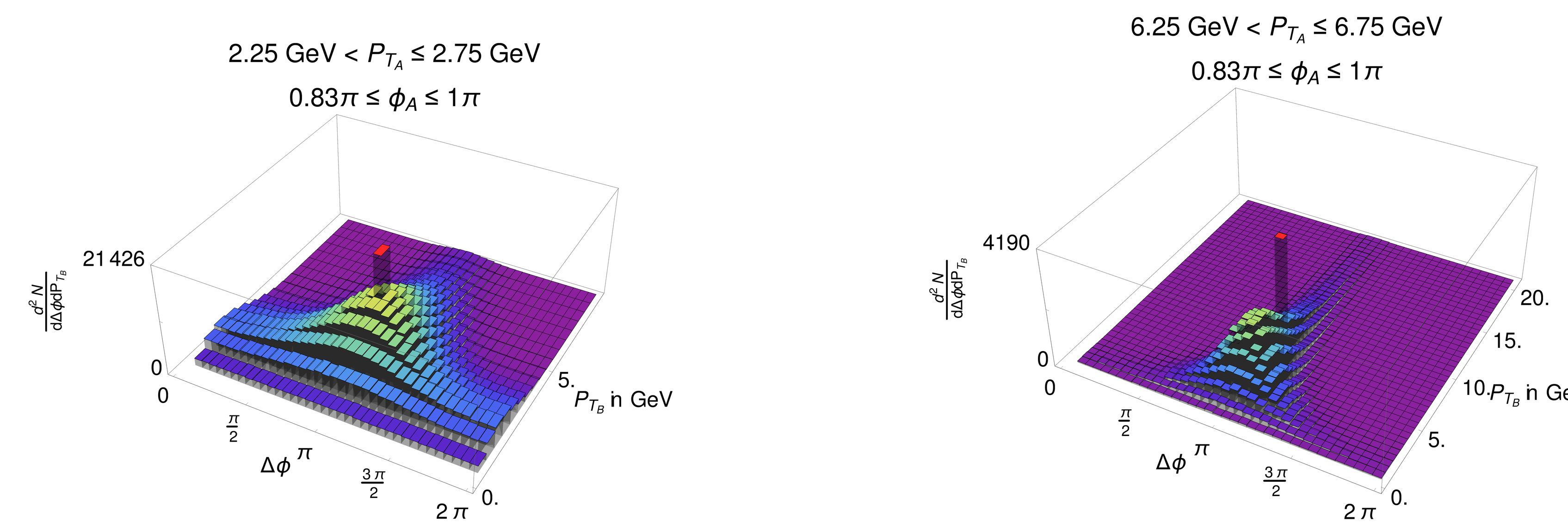
$\frac{dN}{d\phi}$ correlations for NLO initialization of the $D(p)$ model. The $[1-4]$GeV correlations are entirely washed out, but the signal is still observable for the higher p_T classes.

R_{AA}



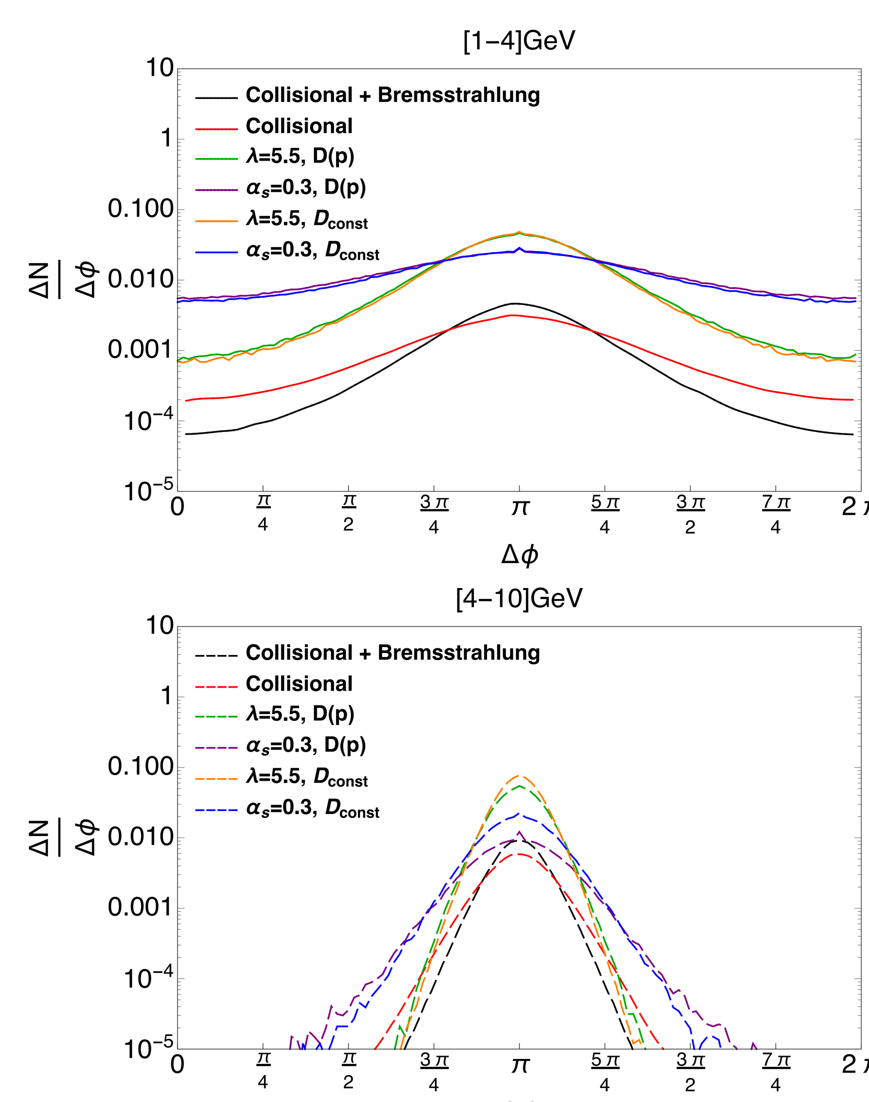
R_{AA} of prompt averaged D^0, D^+ and D^{*+} compared with preliminary data from ALICE. The $D(p)$ model breaks down for high p_T since the longitudinal fluctuations grow as $\gamma^{\frac{5}{2}}$.

Leading Order Correlations



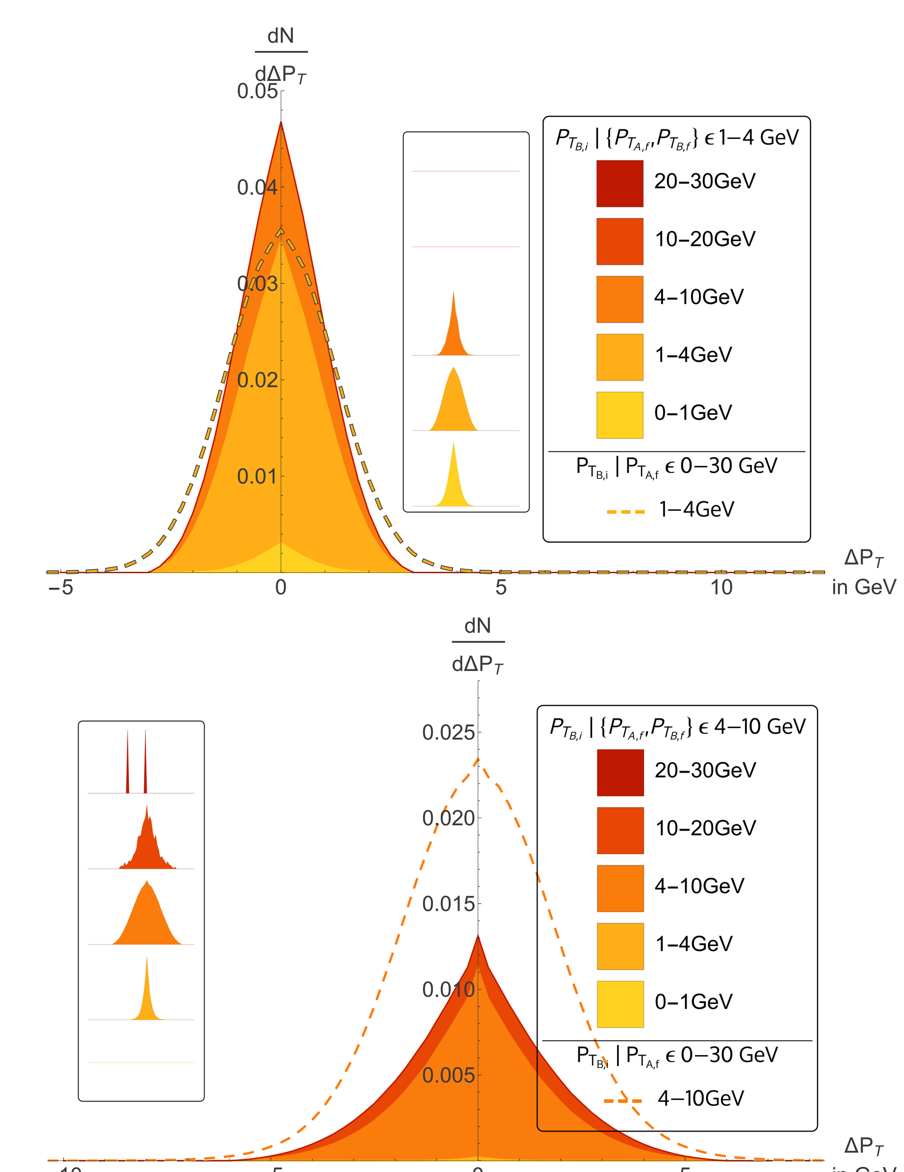
$\frac{d^2N}{d\phi dp_T}$ correlations of $b\bar{b}$ pairs for $p_A = \{2.5, 6.5\}$GeV at 40-60% centrality with $\alpha_s = 0.3$ and $D(p)$

Comparison with pQCD



$\frac{dN}{d\phi}$ correlations for 40-60% centrality. Of note is the order of magnitude difference between the strong and weak coupling based correlations in the $[1-4]$GeV momentum class. Naïvely, one may expect this difference to be caused by more efficient suppression of high p_T particles in the strongly coupled plasma, but as the inital momentum correlations show, this is not the case.

Inital p_T correlations



$\frac{dN}{d\Delta p_T}$ of $b\bar{b}$ pairs with initial momentum in some given class. We observe that the bulk of particles in the $[1-4]$GeV momentum class were initially in this class too. Hence, the order of magnitude difference to the pQCD momentum correlations must be due to weaker correlation of low momentum bottom quarks in the weakly coupled plasma.

Conclusion

- Azimuthal correlations similar for pQCD and AdS/CFT
- Momentum correlations exhibit order of magnitude difference for low p_T
- Initial momentum correlations reveal difference in momentum correlations is explained by bottom quarks pairs in a strongly coupled plasma being more strongly coupled in momentum than in a weakly coupled plasma

Acknowledgements

The authors wish to thank the South African National Research Foundation (NRF) and the SA-CERN Collaboration for generous support of this work.

References

[1] W. A. Horowitz, Phys. Rev. D **91**, no. 8, 085019 (2015)

[2] M. Nahrgang, J. Aichelin, P. B. Gossiaux and K. Werner, Phys. Rev. C **90**, no. 2, 024907 (2014)

[3] R. W. Moerman and W. A. Horowitz, arXiv:1605.09285 [hep-th].

[4] M. Cacciari, S. Frixione, N. Houdeau, M. L. Mangano, P. Nason and G. Ridolfi, JHEP **1210**, 137 (2012)

[5] J. Alwall *et al.*, JHEP **1407**, 079 (2014)

[6] M. Bahr *et al.*, Eur. Phys. J. C **58**, 639 (2008)