Heavy flavor directed flow as a probe of matter distribution in heavy-ion collisions

Sandeep Chatterjee and Piotr Bożek
AGH-UST, Krakow

AGH

National Science Centre Poland

XIII Polish Workshop on Relativistic Heavy-Ion Collisions-
Wroclaw, 6-7 January, 2018

based on arXiv:1712.01189

Matter distribution in heavy-ion collisions

- Can be largely factorised into a transverse ($\perp$ to beamline) and longitudinal (along the beamline) direction
- Particle distributions at mid-rapidity have been extensively studied, described within relativistic hydrodynamics that assumes an equilibrated matter distribution in the transverse plane with boost invariance in the longitudinal direction, among many important things such studies have led to extraction of the transport coefficients of the hot and dense strongly interacting matter
- Studies that go beyond this, include breaking of boost invariance and probe the rapidity distributions have picked up as well

Rapidity distribution of matter- Tilted fireball

- Along the rapidity direction, one important aspect is to understand the mechansim and scale of breaking of boost invariance,
- A natural cause of rapidity odd quantities in a symmetric collision is the local asymmtery in participant densities in the transverse plane

  Adil, Bass, Bialas, Bozek, Brodsky, Broniowski, Bzdak, Czyz, Greiner, Gunion, Gyulassy, Kuhn, Moreira, Petersen, Teaney,...

Initial condition for a tilted fireball

$$s\left(\tau_0, x, y, \eta_{||}\right) = s_0\left[\alpha N_{coll} + (1-\alpha)\left(N^{+}_{part} f_{+}\left(\eta_{||}\right) + N^{-}_{part} f_{-}\left(\eta_{||}\right)\right)\right] f\left(\eta_{||}\right) \quad (1)$$

$$f\left(\eta_{||}\right) = \exp\left(-\theta\left(|\eta_{||}| - \eta^0_{||}\right) \frac{\left(|\eta_{||}| - \eta^0_{||}\right)^2}{2\sigma^2}\right) \quad (2)$$

$$f_{+}\left(\eta_{||}\right) = \begin{cases} 0, & \eta_{||} < -\eta_T \\ \frac{\eta_T + \eta_{||}}{2\eta_T}, & -\eta_T \leq \eta_{||} \leq \eta_T \\ 1, & \eta_{||} > \eta_T \end{cases} \quad (3)$$

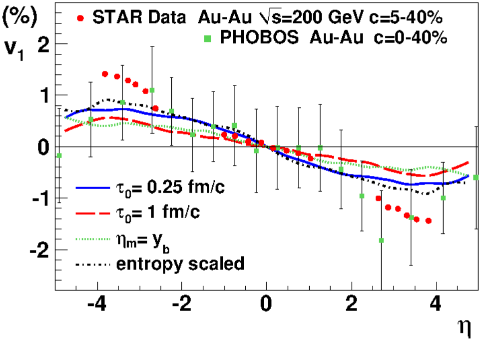
with $f_{-}\left(\eta_{||}\right) = f_{+}\left(-\eta_{||}\right)$.

Bożek, Wyskiel 2010

Rapidity distribution of matter- Tilted fireball

- Along the rapidity direction, one important aspect is to understand the mechansim and scale of breaking of boost invariance,
- A natural cause of rapidity odd quantities in a symmetric collision is the local asymmtery in participant densities in the transverse plane
  Adil, Bass, Bialas, Bozek, Brodsky, Broniowski, Bzdak, Czyz, Greiner, Gunion, Gyulassy, Kuhn, Moreira, Petersen, Teaney,...
- Consequences: Forward-backward (FB) asymmetric charged particles v_1, longitudinal decorrelation of v_2, v_3, p_T,...

Rapidity distribution of matter- Tilted fireball



Bożek, Wyskiel 2010

- Tilted IC captures the charged particle v_1
- Observable largely insensitive to change in the tilt scale, η_T

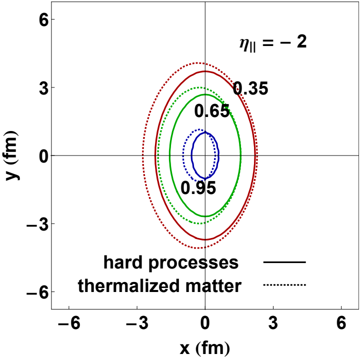
Heavy Quarks (HQs) as probes of matter distribution in HICs

- - HQs produced early
    - HQs have larger thermalization time

  These properties make them unique probes of HICs.
- HQs have been employed to probe the matter distribution, all studies so far have been restricted to probing the transverse matter distribution at mid-rapidity
- So far, HQ nuclear modification factor R_{AA} and v_2 have been studied extensively to probe the mid-rapidity bulk matter and its evolution
- In this talk, we discuss the possibility of studying rapidity distribution of bulk matter through HQ v_1.

Relative shift between hard and soft bulk

- The binary collision profile characterises the distribution of the initial hard scattering- the seat for HQ production
- Unlike participant sources, binary collision sources deposit entropy in FB symmteric way- this results in an initial shift between the soft bulk and the HQ production sites



SC, Bożek 1712.01189

Langevin dynamics for charm

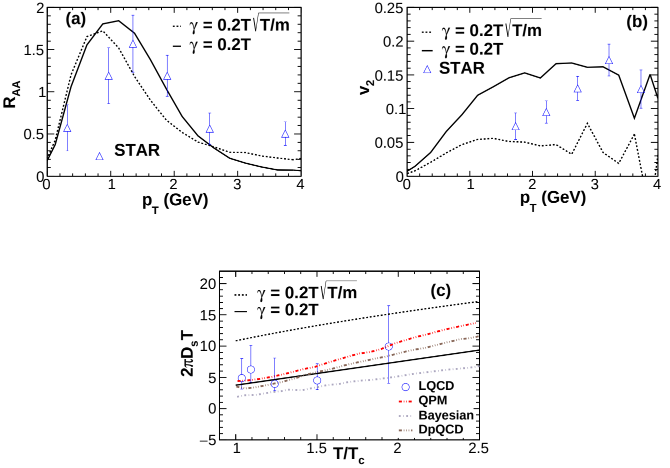
$$
\begin{aligned}
\Delta \mathbf{r}_i &= \frac{\mathbf{p}_i}{E} \Delta t & (4) \\
\Delta \mathbf{p}_i &= -\gamma \mathbf{p}_i \Delta t + \rho_i \sqrt{2D\Delta t} & (5)
\end{aligned}
$$

- $\langle \rho_i \rangle = 0$, $\langle \rho_i \rho_j \rangle = \delta_{ij}$
- We work in the post-point realization of the stochastic term and take $D = \gamma E T$. This ensures the long time approach of the heavy quark phase space distribution to the equilibrium Boltzmann-Juttner distribution
  He, Hees, Gossiaux, Fries, Rapp 2013
- γ captures the interaction between the HQ and bulk. Currently, the jury is still out on its estimate. For our purpose, we assume the ansatz $\gamma = \gamma_0 T \left(T/m\right)^x$, γ_0 and x are fixed by comparing to the measured HQ R_{AA} and v_2 at mid-rapidity

HQ evolution

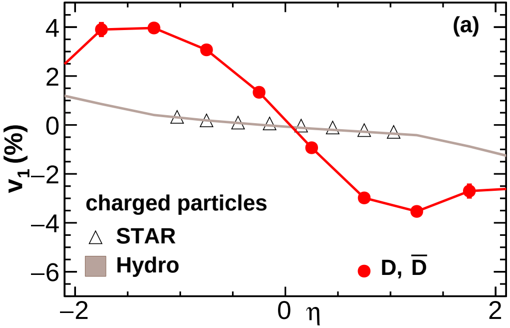
- The spacetime history of T and u^{μ} fields is provided by hydrodynamic evolution
- The intial phase space distribution of HQs is sampled from binary collision profile of Glauber model, momentum distribution sampled from measured distribution in p+p collisions
- The phase space coordinates of HQs are updated through Langevin dynamics which are valid in the local rest frame (LRF) of the fluid. So we first perform Lorentz transformation into the LRF on the HQ coordinates, perform Langevin update and then inverse Lorentz transformation to the lab frame
- All our results shown here is for a fixed impact parameter, $b = 8.3$ fm which corresponds to min bias $0 - 80\%$ centrality

Calibrating the drag on HQs



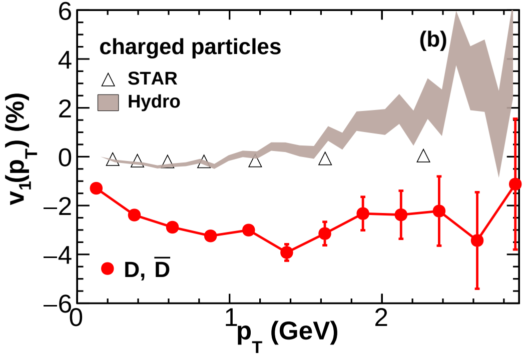
SC, Bożek 1712.01189

HQ v_1



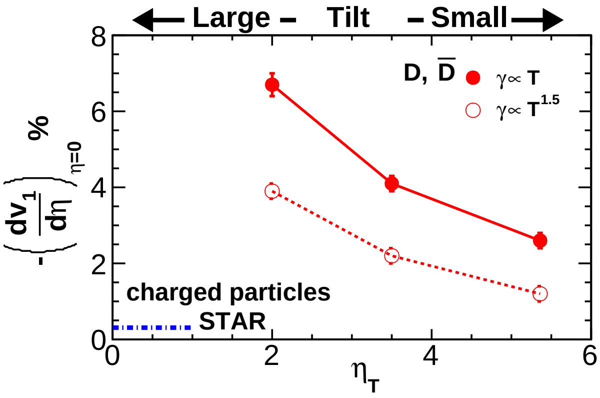
SC, Bożek 1712.01189

HQ v_1



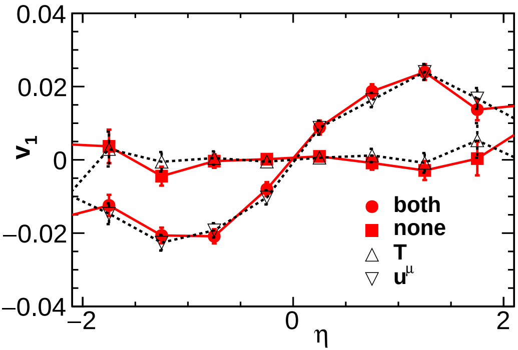
SC, Bożek 1712.01189

Determining the tilt



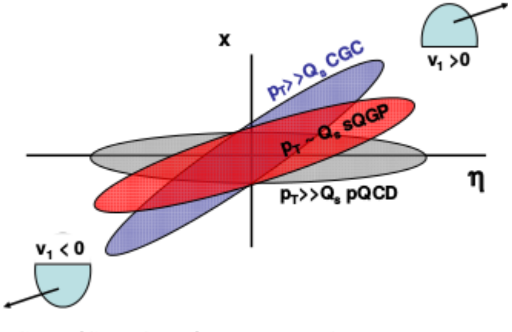
SC, Bożek 1712.01189

T or u^μ ?



- FB asymmtery of which hydro field causes the large HQ v_1 ?
- By selectively choosing profiles with broken boost invarinace, we find the HQ v_1 is mainly caused by the FB asymmetric drag by the flow field u^μ

Twisted CGC vs pQCD



Adil, Gyulassy, Hirano 2005

- unlike pQCD, saturation schemes seem to indicate a larger tilt for hard processes than the bulk
- this would imply large v_1 of HQ but of opposite sign to that of bulk charged particle

summarising..

- Large rapidity-odd directed flow of charm quarks / D mesons predicted that is several times larger than that of the bulk (>5 times). This is unlike the mid-rapidity HQ v_2 whose magnitude is of similar order as the bulk.
- It is sensitive to the initial tilt in the bulk and hence offers a novel observable to constrain the scale of FB asymmetry in the initial state of HICs
- Mostly driven/dragged by the rapidity odd fluid flow and not asymmteric scattering with the medium
- The sign of HQ v_1 itself can distinguish between different production mechanism
- Thus, HQ v_1 adds to the existing list of HQ R_{AA} and v_2 to provide information on the 3-dimensional distribution of matter in HICs
- Strong electromagnetic (EM) fields can give rise to rapidity odd HQ v_1, though it is of different sign for charm and anti-charm Das, Plumari, SC, Alam, Scardinia, Greco 2016
  In the future, it will be interesting to study the combined effect of tilt and EM fields