Fireball tomography with heavy flavor

Sandeep Chatterjee
IISER Berhampur
in collaboration with
Piotr Bożek
AGH-UST, Krakow

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arXiv: 1804.04893

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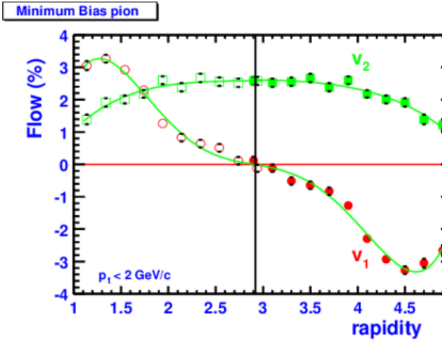
Tomography of the fireball

- Tomography = imaging a specific cross-section of the object (fireball)
- In case of the fireball, highly dynamical structure, hence the image is expected to have a strong dependence on the time at which it is taken
- Further, the transverse dynamics is mostly decoupled and vastly different from the longitudinal one, hence the tomography of the transverse cross-section is expected to be very different from the longitudinal one
- With respect to the above points, in this talk we will argue heavy flavor tomography is expected to bring in new understanding that adds to the already established paradigm based on the light flavor tomography

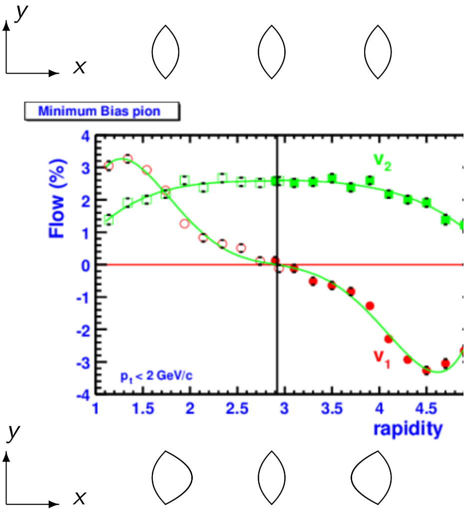
Light flavor tomography

- $\frac{d^3N}{dydp_Td\phi} \to v_0 + v_1\cos(\phi) + v_2\cos(2\phi) + ..;$
  $v_2 \sim \langle \cos(2\phi) \rangle$ elliptic flow

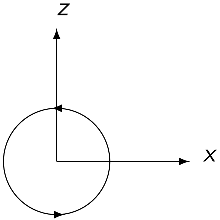


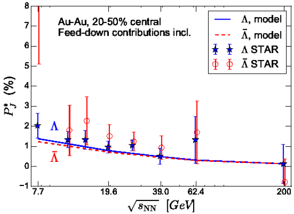
Light flavor tomography

- $\frac{d^3N}{dydp_T d\phi} \to v_0 + v_1 \cos(\phi) + v_2 \cos(2\phi) + ..;$
  $v_2 \sim \langle \cos(2\phi) \rangle$ elliptic flow; $v_1 \sim \langle \cos(\phi) \rangle$ directed flow



no way to comprehend the 'most vortical fluid' without diagnosing the longitudinal profile



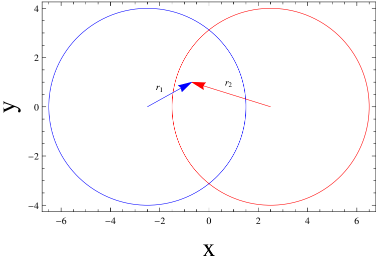


Karpenko, Becattini 2017

heavy flavor tomography

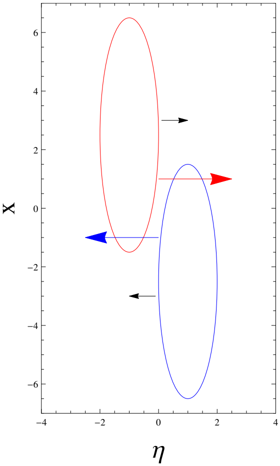
- distinct production mechanism: mainly produced in the initial state by hard binary collisions
- longer time to thermalize with the medium
- the above lead to heavy flavor as an invaluable probe for the tomography of the longitudinal cross-section
- In addition, also carries signature of specific early time physics, like those of the electromagnetic fields

entropy deposition in non-central collision



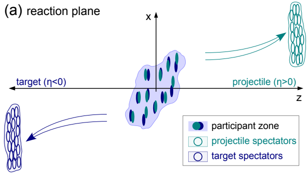
$$r_1 < r_2 \to \rho(r_1) > \rho(r_2)$$

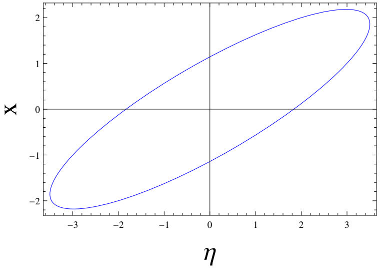
entropy deposition in non-central collision



entropy deposition from participant sources

Tilted bulk: Brodsky et. al. 1977; Adil, Gyulassy 2005; Bialas, Czyz 2005





from 1306.4145

Bulk profile

Initial condition for a tilted fireball

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

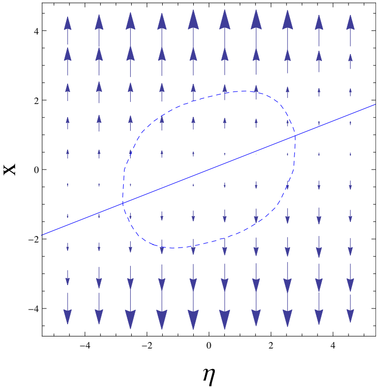
$$f\left(\eta_{||}\right) = \exp\left(-\theta\left(|\eta_{||}| - \eta^0_{||}\right)\frac{\left(|\eta_{||}| - \eta^0_{||}\right)^2}{2\sigma^2}\right)$$

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

with $f_-\left(\eta_{||}\right) = f_+\left(-\eta_{||}\right)$ (rapidity-odd component)

Bożek, Wyskiel 2010

Tilted bulk → directed fluid velocity



Tilted bulk → directed fluid velocity

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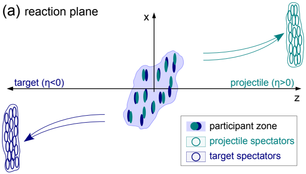
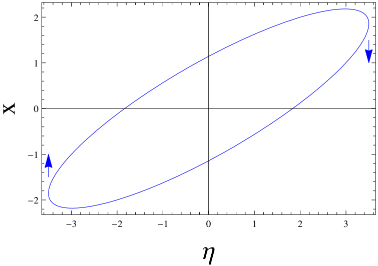
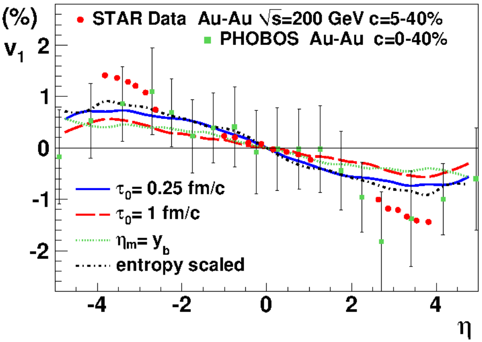




from 1306.4145

Bulk directed flow

Tilted bulk → directed fluid velocity → charged particle v_1



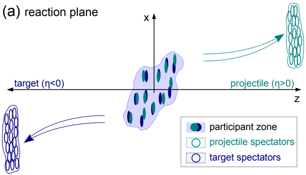
Bożek, Wyskiel 2010

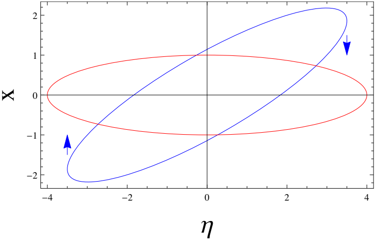
- Tilted IC captures the charged particle v_1
- small v_1

entropy depositing sources: participant vs binary collision sources

HQ from hard processes $\rightarrow$ FB-symmetric

Rapidity-even HQ dragged by Rapidity-odd bulk



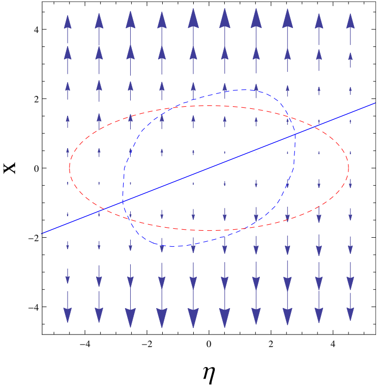


from 1306.4145

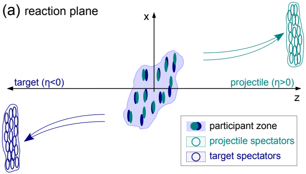
Bulk vs heavy flavor

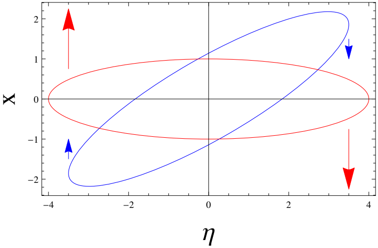
Heavy Quark Tomography

charm, anti-charm stronger probes of the tilt than the light flavor



entropy depositing sources: participant vs binary collision sources





from 1306.4145

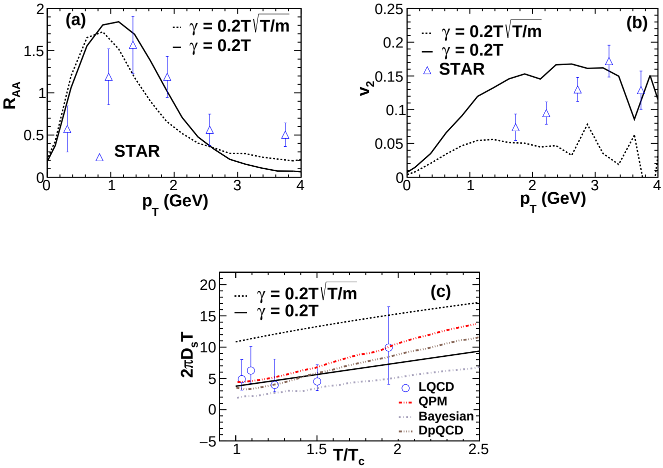
$v_1(HQ) > v_1(Bulk)$

to quantify the heavy flavor v_1

need to calibrate

- the tilt of the bulk: constrained by charged particle v_1, Bożek, Wyskiel 2010
- drag between the bulk and heavy flavor: constrained by heavy flavor R_{AA} and v_2 at mid-rapidity, we use an ansatz $\gamma = \gamma_0 T \left(\frac{T}{m}\right)^x$

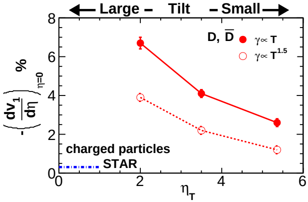
Calibrating the drag on HQs

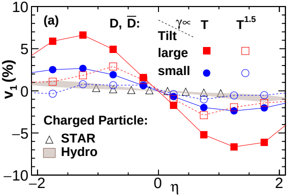


SC, Bożek PRL,**120**, 192301 (2017)

HQ v_1 $\mathcal{O}(10)$ larger !

predicted to be 5 - 20 times larger than charged particle v_1 slope !

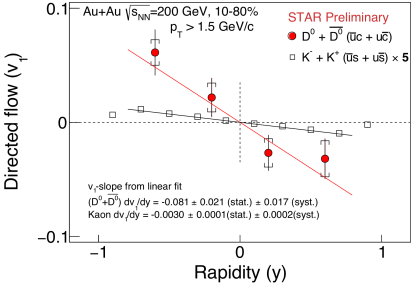




SC, Bożek PRL,**120**, 192301 (2017)

QM 2018: heavy flavor is pushed 30 times more than bulk !!

v_1 comparison: D^0 vs. kaon



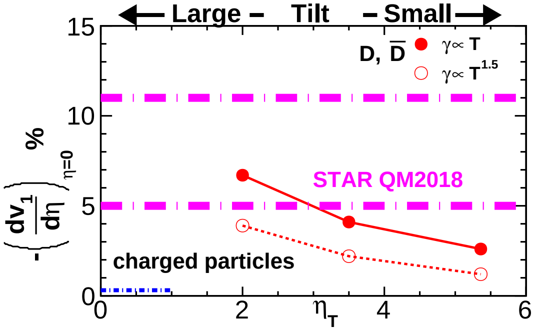
- First observation of non-zero D^0 v_1
- D^0 v_1-slope much larger than that of kaons

Charm v_1-slope > light flavor v_1-slope

So far the largest v_1-slope measured at mid-rapidity at 200 GeV

comparison to data

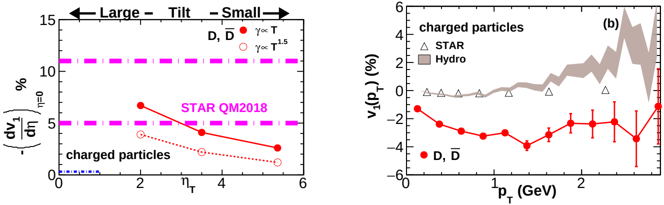
largest measured v_1: order of magnitude larger than that of charged particle



SC, Bożek PRL,**120**, 192301 (2017)

comparison to data

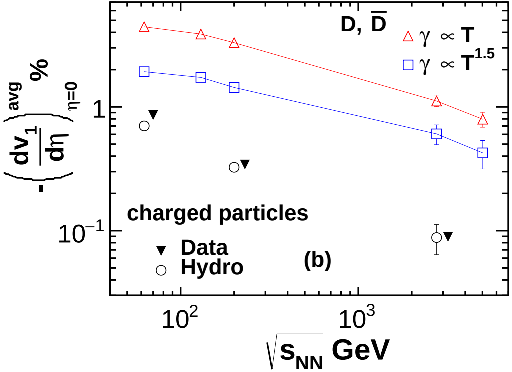
largest measured v_1: order of magnitude larger than that of charged particle



NOTE: data with $p_T > 1.5$ GeV, similar cut in model will result in larger v_1

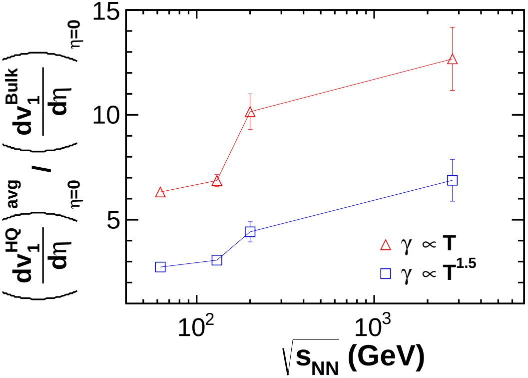
SC, Bożek PRL,**120**, 192301 (2017)

Beam energy dependence



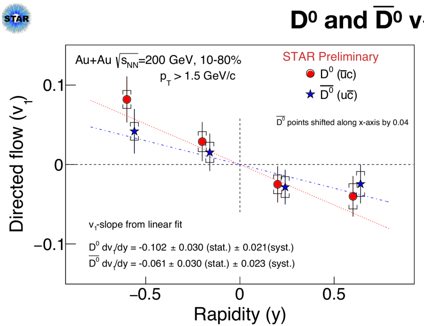
SC, Bożek 1804.04893

Ratio of HQ to bulk v_1



SC, Bożek 1804.04893

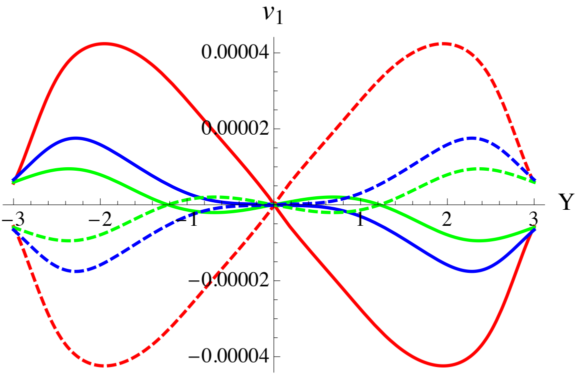
QM 2018: hint of split in v_1 of D^0 and $\overline{D^0}$



- First observation of non-zero D^0 v_1
- Both D^0 and $\overline{D^0}$ v_1 show a negative slope at mid-rapidity

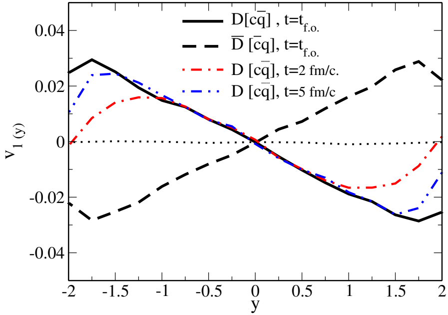
$$D^0 \; dv_1/dy = -0.102 \pm 0.030 \pm 0.021$$
$$\overline{D^0} \; dv_1/dy = -0.061 \pm 0.030 \pm 0.023$$

v_1 split between positive and negative charged particles due to EM field



Gursoy, Kharzeev, Rajagopal 2014

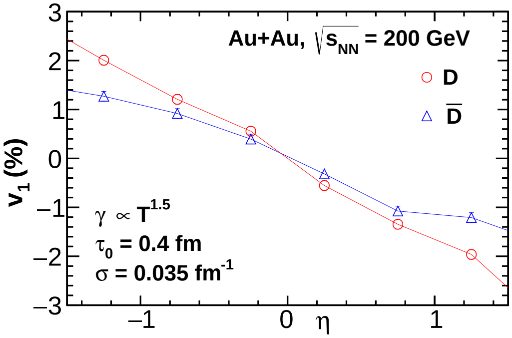
EM field on HQ $v_1 \rightarrow$ split in v_1 of D^0 and $\overline{D^0}$



Das, Plumari, SC, Alam, Scardina, Greco 2016

- $$\begin{aligned} v_1^{\text{avg}} &= \frac{1}{2}\left(v_1\left(D^0\right) + v_1\left(\overline{D^0}\right)\right) \\ v_1^{\text{diff}} &= v_1\left(D^0\right) - v_1\left(\bar{D}^0\right) \end{aligned}$$
- Tilt: $v_1^{\text{avg}} \neq 0$, $v_1^{\text{diff}} = 0$; EM: $v_1^{\text{avg}} = 0$, $v_1^{\text{diff}} \neq 0$;

HQ v_1 with Tilt+EM field



- $v_1^{avg} \neq 0$, $v_1^{diff} \neq 0$

SC, Bożek 1804.04893

Summarising

- Heavy flavor tomography, mainly from the POV of the longitudinal structure was discussed
- Order of magnitude larger directed flow was predicted for heavy flavor compared to bulk.
- Early time EM field splits the v_1 of charm and anti-charm- a measure of the electric conductivity of the medium
- Comparison to STAR QM2018 data suggests preference for large tilt (effect of p_T cut is expected to allow for smaller tilt)
- Ratio of HQ to bulk v_1 is predicted to be larger at LHC than at RHIC- stronger drag due to higher temperature
- NOTE: ALICE has presented D^0 v_1 measurements at Hard Probes 2018 and the results are in contrary to STAR: avg. $v_1 \sim 0$ while non-zero & opposite sign Δv_1 indicating dominance of the B field. However, this data is with $p_T > 3$ GeV cut. A more elaborate systematic study is required to understand the data trends if they are to stay.