Probing the longitudinal matter distribution in heavy-ion collisions with heavy flavor

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based on:
Phys. Rev. Lett. **120**, 192301 (2018) (arXiv: 1712.01189);
arXiv: 1804.04893

AGH

National Science Centre Poland

xQCD, Frankfurt, 22 May, 2018

at mid-rapidity: heavy flavor flows as strong as bulk

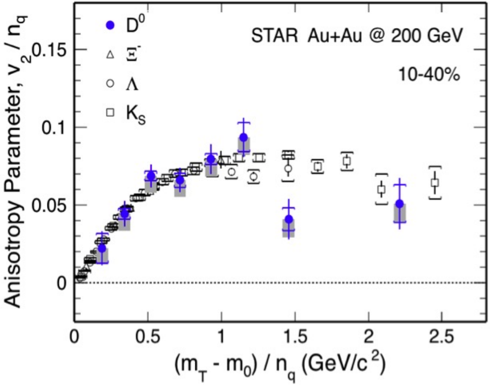
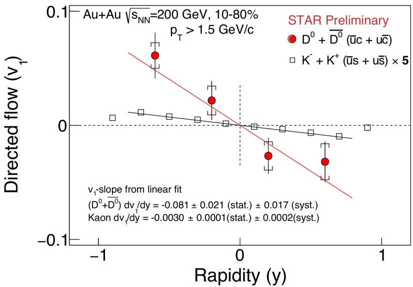


fig. from PRL, 118, 212301 (2017)

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

v_1 comparison: D^0 vs. kaon



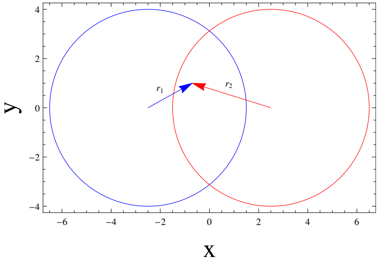
- First observation of non-zero D^0 v_1
- D^0 v_1-slope much larger than that of kaons

Charm v_1-slope > light flavor v_1-slope

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

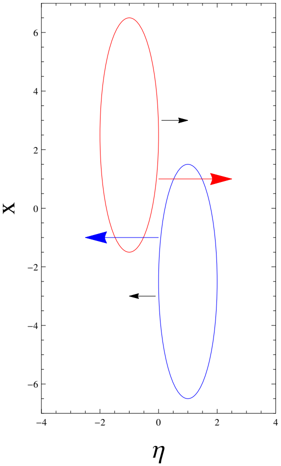
Subhash Singha, 10

entropy deposition in non-central collision



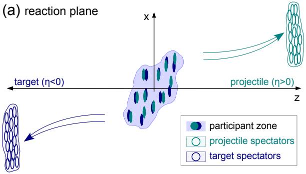
$r_1 < r_2 \rightarrow \rho\left(r_1\right) > \rho\left(r_2\right)$

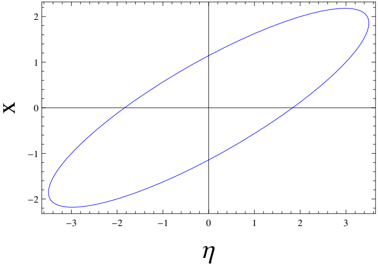
entropy deposition in non-central collision



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

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

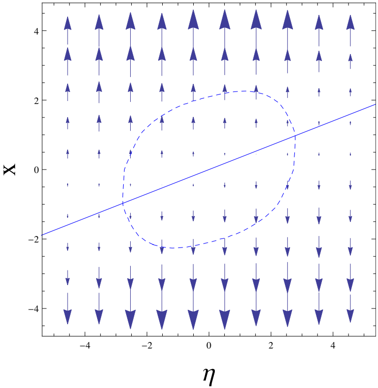
$$f\left(\eta_{||}\right) = \exp\left(-\theta\left(|\eta_{||}| - \eta^0_{||}\right)\frac{\left(|\eta_{||}| - \eta^0_{||}\right)^2}{2\sigma^2}\right)$$

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

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

Bożek, Wyskiel 2010

Tilted bulk → directed fluid velocity



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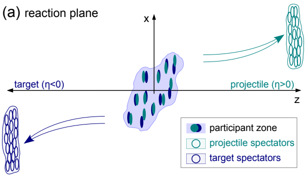
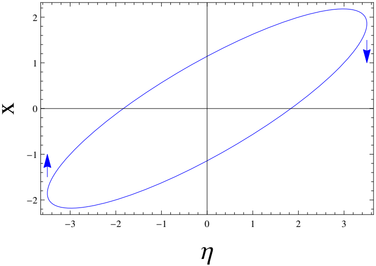
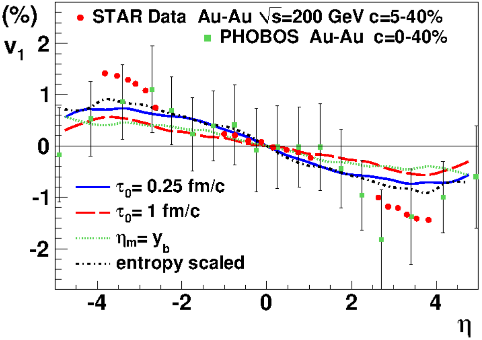




from 1306.4145

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

Tilt gives rise to longitudinal decorrelation

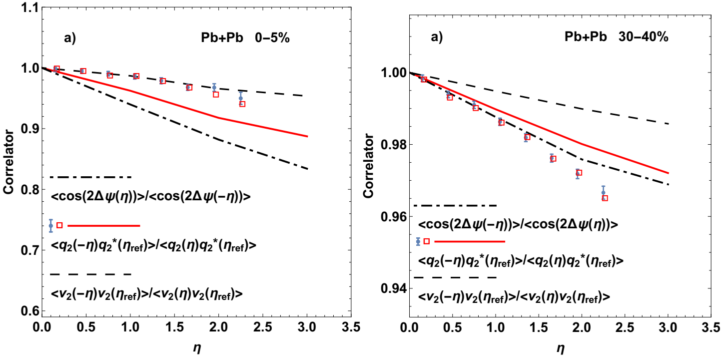
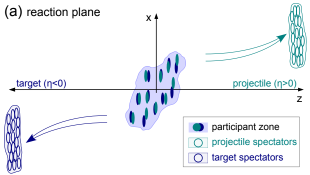
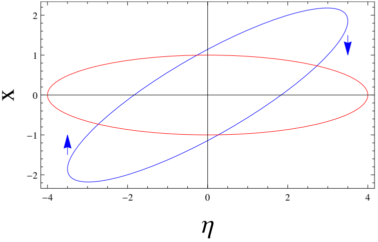


fig. from 1711.03325 Bożek, Broniowski

entropy depositing sources: participant vs binary collision sources

HQ from hard processes $\rightarrow$ FB-symmetric
Rapidity-even HQ dragged by Rapidity-odd bulk



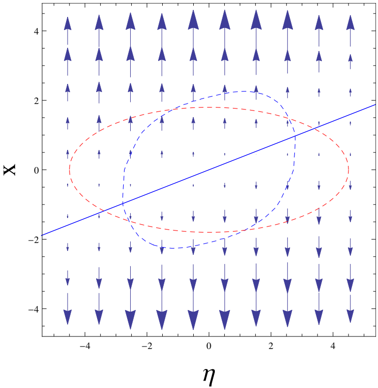


from 1306.4145

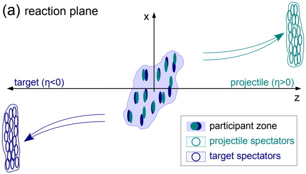
Bulk vs heavy flavor

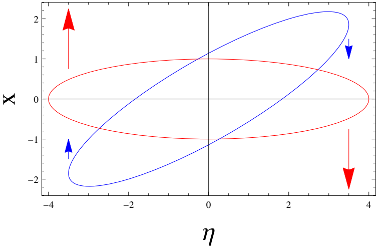
Heavy Quark Tomography

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



entropy depositing sources: participant vs binary collision sources





from 1306.4145

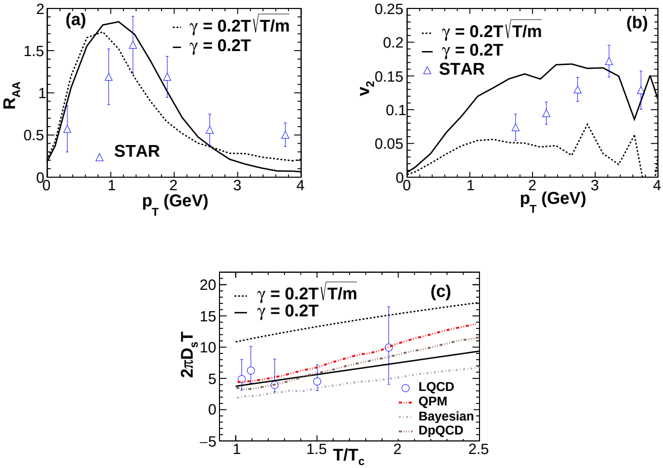
$v_1(HQ) > v_1(Bulk)$

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 $\gamma = \gamma_0 T \left(\frac{T}{m}\right)^x$

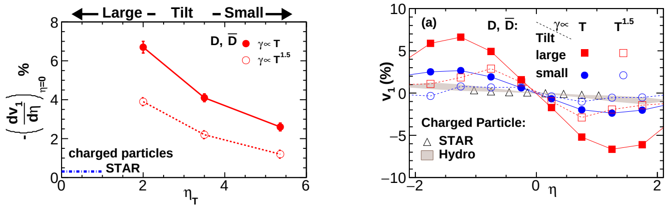
Calibrating the drag on HQs



SC, Bożek PRL,**120**, 192301 (2017)

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

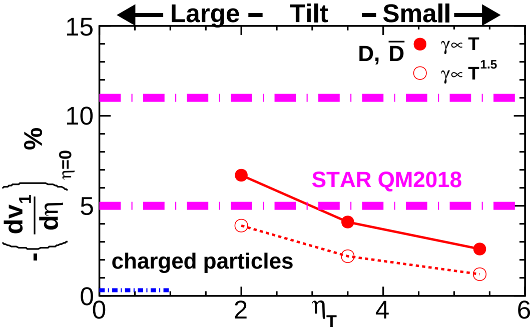
predicted to be 5 - 20 times larger than charged particle v_1 slope !



SC, Bożek PRL,**120**, 192301 (2017)

comparison to data

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



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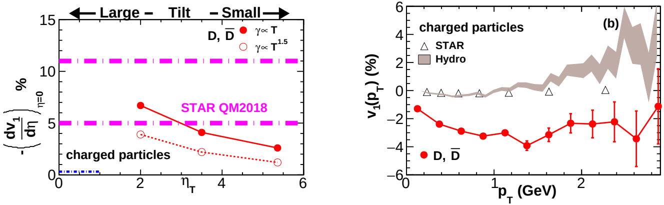
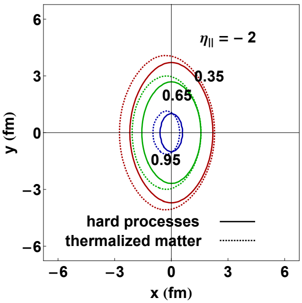
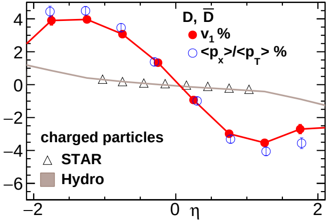


NOTE: data with $p_T > 1.5$ GeV, similar cut in model will result in larger v_1

SC, Bożek PRL,**120**, 192301 (2017)

HQ acquires non-zero $\langle p_X \rangle$ - a clear signal of the initial shift between HQ and bulk

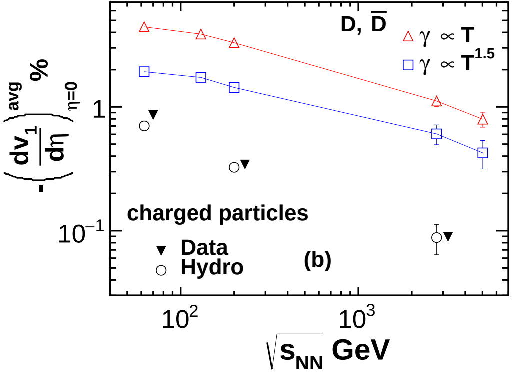




$\langle p_x \rangle \sim 40$ MeV at $\eta = 1$

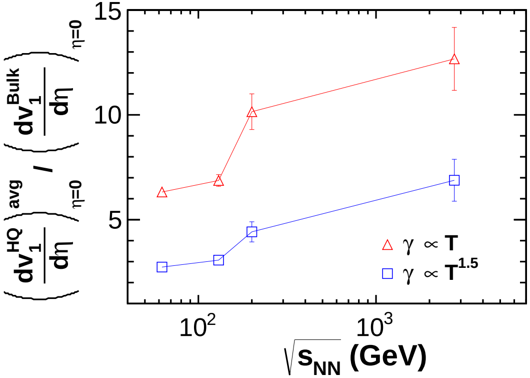
SC, Bożek PRL,**120**, 192301 (2017)

Beam energy dependence



SC, Bożek 1804.04893

Ratio of HQ to bulk v_1



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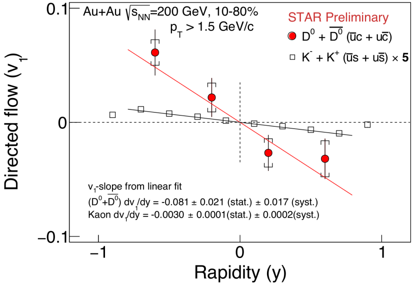
fresh from QM 2018: heavy flavor is pushed 30 times more than bulk !!

v_1 comparison: D^0 vs. kaon



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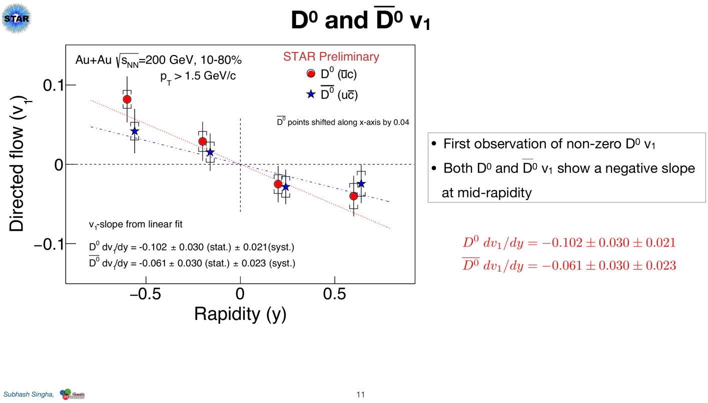
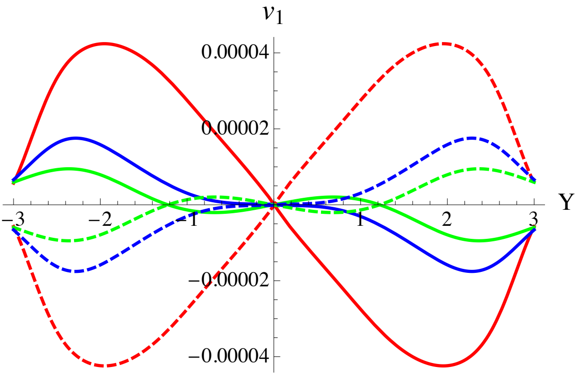
fresh from QM 2018: hint of split in v_1 of D^0 and $\overline{D^0}$



$D^0 \; dv_1/dy = -0.102 \pm 0.030 \pm 0.021$

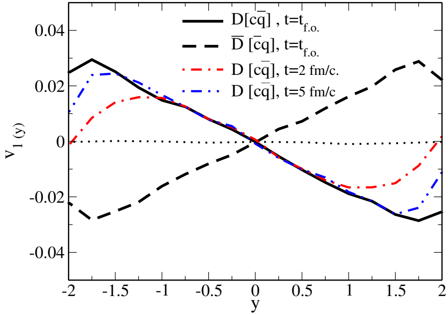
$\overline{D^0} \; dv_1/dy = -0.061 \pm 0.030 \pm 0.023$

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 $\overline{D^0}$



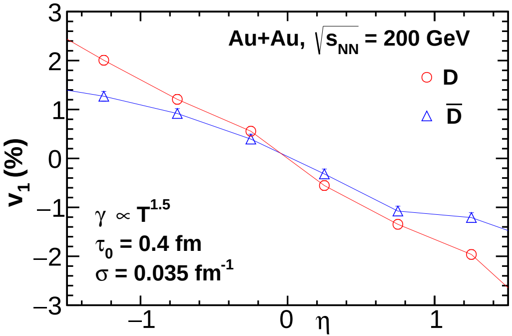
Das, Plumari, SC, Alam, Scardina, Greco 2016

-

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

- Tilt: $v_1^{\text{avg}} \neq 0$, $v_1^{\text{diff}} = 0$; EM: $v_1^{\text{avg}} = 0$, $v_1^{\text{diff}} \neq 0$;

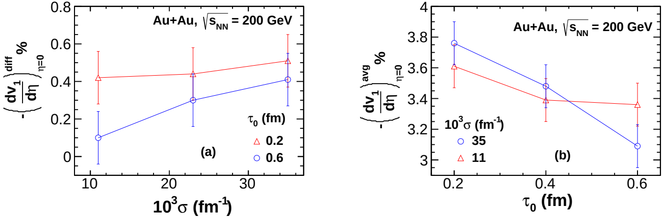
HQ v_1 with Tilt+EM field



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

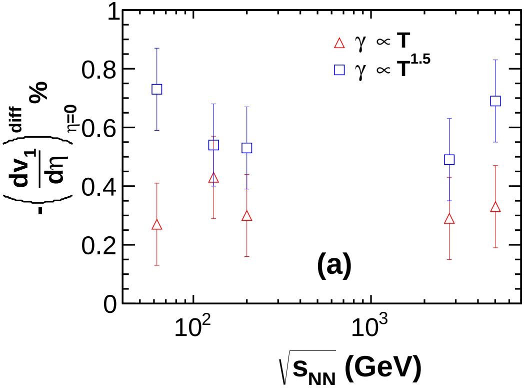
SC, Bożek 1804.04893

Dependence on conductivity and initialization time



SC, Bożek 1804.04893

Beam energy dependence

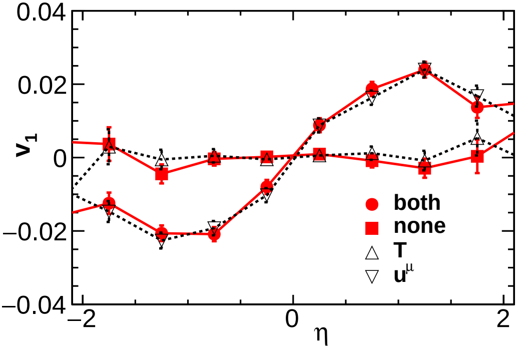


SC, Bożek 1804.04893

Summarising

- Heavy flavor directed flow as a probe of 2 initial state physics was discussed: longitudinal profile of matter distribution and the electromagnetic field and medium conductivity
- Order of magnitude larger directed flow was predicted for heavy flavor compared to bulk. Split due to EM field is smaller compared to the average directed flow due to tilted bulk, resulting in same sign flow of both D^0 and $\overline{D^0}$
- 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
- HQ v_1 adds to the existing list of HQ R_{AA} and v_2 to provide information on the drag coefficient between the bulk matter and HQ

BACKUP: what causes the large v_1: 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