The directed flow of charged particle and D^0 meson at RHIC and LHC

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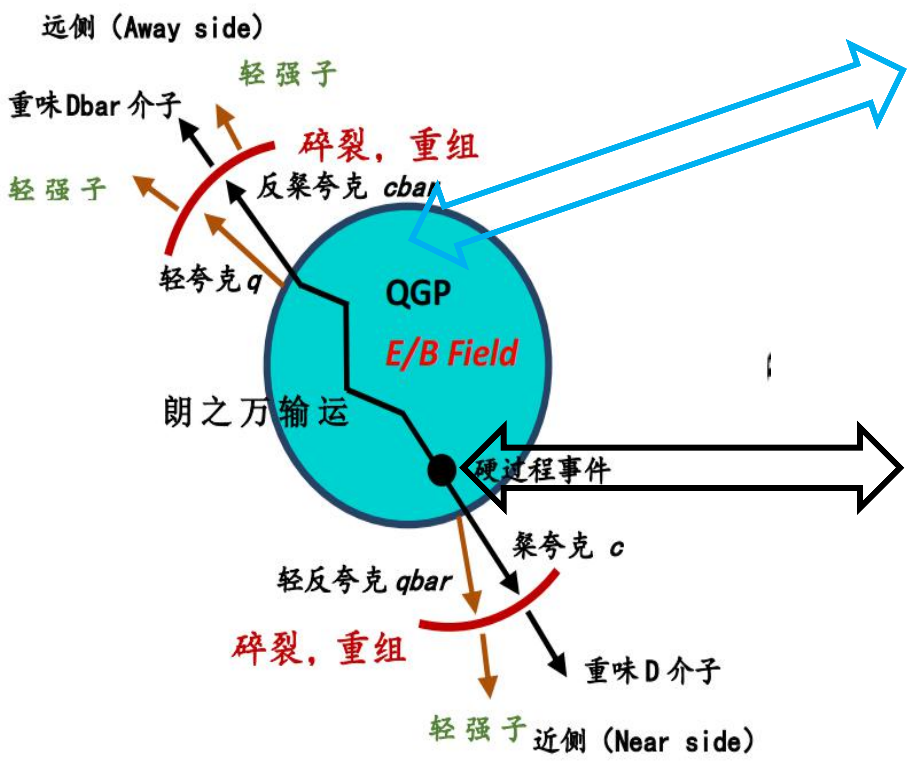
中国物理学会 高能物理分会 第13届全国粒子物理学术会议（青岛，中国）.
2021年 8月

Outline



1. Introduction

2. Optical Glauber model with CLVisc hydrodynamic simulation for charged particle directed flow v_1.

3. Heavy quarks dynamics in QGP within Langevin transport approach for D meson directed flow v_1.

4. Summay and outlook

Long-Gang Pang, H. Petersen, and Xin-Nian Wang, Phys. Rev. C 97 (2018) 6, 064918. arXiv: 1802.04449
Shanshan Cao, Guang-You Qin and S. A. Bass, Phys. Rev. C 92 (2015) 2, 024907. arXiv: 1505.01413

1.Motivation

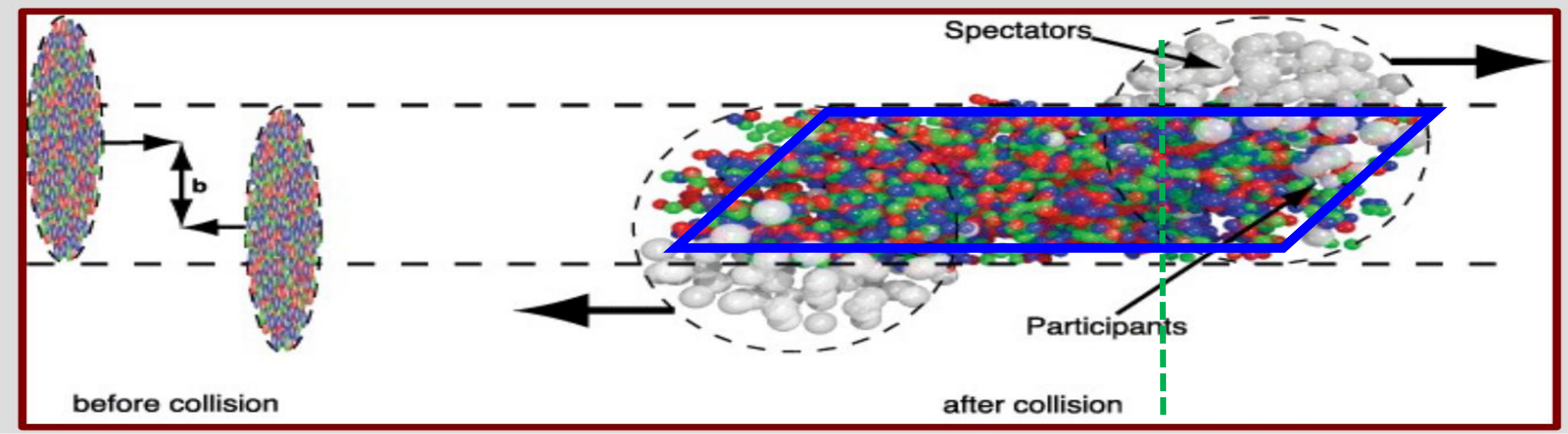
直接流(Directed flow，定向流)描述粒子沿 x 方向的集体偏转：

$$v_1 = \langle p_x / p_T \rangle$$

研究轻强子直接流 v_1

1. 研究早期火球初始纵向倾斜及横平面压强梯度不对称影响；

A. Adil and M. Gyulassy. Phys. Rev. C, 72:034907, 2005.
P. Bozek and I. Wyskiel. Phys. Rev. C, 81:054902, 2010.
U. Heinz and R. Snellings. Ann. Rev. Nucl. Part. Sci., 63:123–151, 2013.
Chun Shen and S. Alzhrani. Phys. Rev. C, 102(1):014909, 2020. ...
郭崇强. 高能重离子碰撞直接流的研究[D].中国科学院大学(上海应用物理研究所)，2018.



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   郭崇强. 高能重离子碰撞直接流的研究[D].中国科学院大学(上海应用物理研究所)，2018.

2. 研究高能核核对撞早期电磁场（磁流体）；

   D. E. Kharzeev et al., Phys. Rev. C, 89(5):054905, 2014.
   U. Gürsoy et al., Phys. Rev. C, 98(5):055201, 2018.
   A. Dubla, U. Gürsoy, and R. Snellings. Mod. Phys. Lett. A, 35(39):2050324, 2020.
   G. Inghirami et al., Eur. Phys. J. C, 80(3):293, 2020...

3. 作为研究Λ整体极化的约束条件。

   Chun Shen et al., arXiv:2106.08125...

1. Motivation

直接流(Directed flow，定向流)描述粒子沿 x 方向的集体偏转：

$$v_1 = \langle p_x / p_T \rangle$$

研究重味介子直接流 v_1

STAR Collaboration, Phys. Rev. Lett. 123, 162301 (2019)
ALICE Collaboration, Phys. Rev. Lett., 125(2):022301, (2020).

1. **探测火球早期纵向倾斜；**

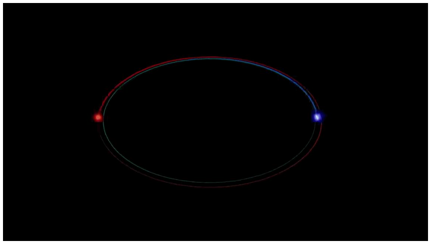
P. Bozek et al., Phys. Rev. Lett.,120(19):192301, 2018.
P. Bozek et al., Phys. Lett. B, 798:134955, 2019.
A. Beraudo et al., JHEP, 05:279, 2021.
Baoyi Chen et al., Phys. Lett. B802 (2020) 135271.

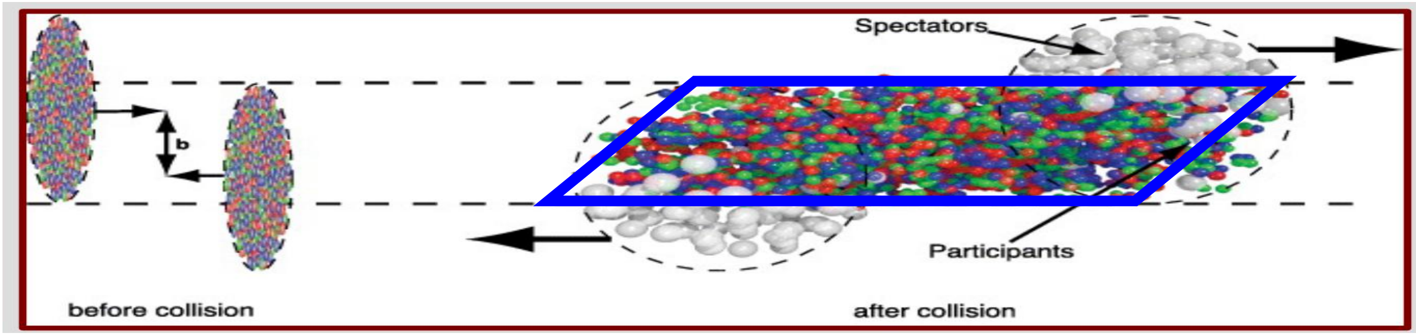
2. **探测高能核核对撞早期电磁场。**

Santosh K. Das et al., Phys. Lett. B, 768:260–264, 2017.
Yifeng Sun and V. Greco, Phys. Lett. B, 816:136271, 2021.
L. Oliva et al., JHEP, 05:034, 2021...

研究方法及目标：
1. 构建了3种纵向倾斜的3维初始条件(*P. Bozek, Chun, CCNU-Ht*)，结合**CLVisc**流体力学演化，描述 STAR, ALICE 等大型国际合作组直接流v1结果，目标在于研究高能核碰撞产生的QGP早期3维结构。
2. 通过**CLVisc + Duke-Langevin**混合构架，研究*D*介子直接流，构建新的观测量。目标在于利用*D*介子为探针研究高能核碰撞早期3D结构及电磁场效应。

2. Longitudinal structure of the fireball





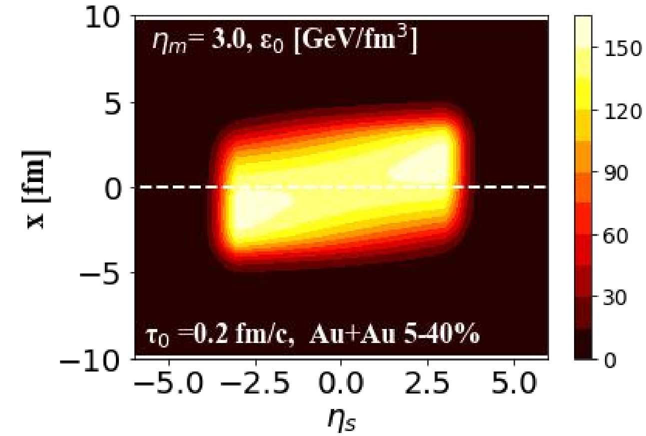
3 parametrizations for the *longitudinal structure of the fireball* are used in the optical Glauber model: ***P. Bozek et al., Chun & Sahr, CCNU-Ht.***

Main idea: asymmetry in local participant density from forward and backward going nuclei.

1. *P. Bozek* et al.'s longitudinal structure:

$$W(x,y,\eta) = 2(T_1(x,y)f_-(\eta) + T_2(x,y)f_+(\eta))$$

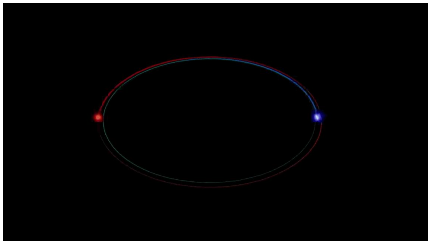
$$f_-(\eta) = \begin{cases} 1 & \eta < -\eta_m \\ \frac{-\eta+\eta_m}{2\eta_m} & -\eta_m \le \eta \le \eta_m \\ 0 & \eta > \eta_m \end{cases} \qquad f_+(\eta) = \begin{cases} 0 & \eta < -\eta_m \\ \frac{\eta+\eta_m}{2\eta_m} & -\eta_m \le \eta \le \eta_m \\ 1 & \eta > \eta_m \end{cases}$$

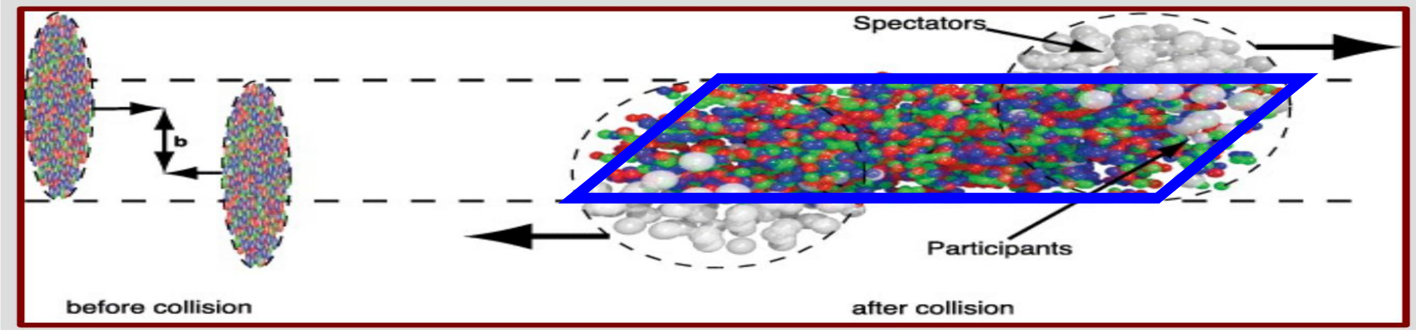


Here η_m *makes* the longitudinal tilting structure of the fireball.

P. Bozek and *I. Wyskiel, Phys. Rev. C, 81:054902, 2010.*

2. Longitudinal structure of the fireball





2. *Chun & Sahr's* 3D initial condition:

$$e(x, y, \eta_s; y_{\rm CM} - y_L) = \mathcal{N}_e(x,y)\exp\left[-\frac{(|\eta_s - (y_{\rm CM} - y_L)| - \eta_0)^2}{2\sigma_\eta^2} \times\theta(|\eta_s - (y_{\rm CM} - y_L)| - \eta_0)\right].$$

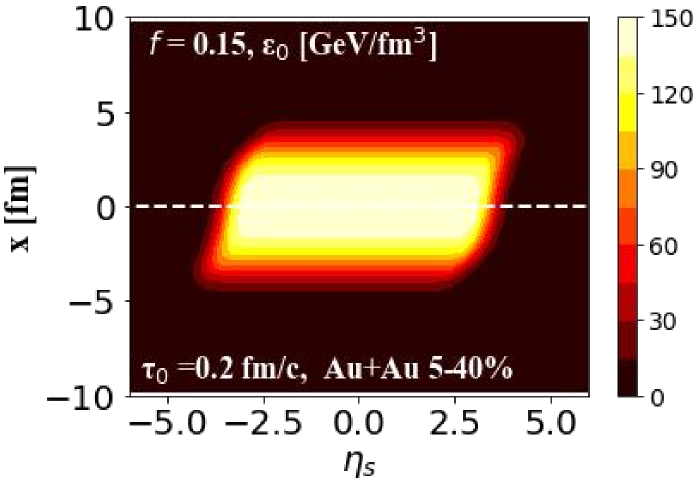
$$y_L \equiv f y_{\rm CM}$$

$$\mathcal{N}_e(x,y) = \frac{M(x,y)}{2\sinh(\eta_0) + \sqrt{\frac{\pi}{2}}\sigma_\eta e^{\sigma_\eta^2/2}C_\eta}$$

$$C_\eta = e^{\eta_0}\mathrm{erfc}\left(-\sqrt{\frac{1}{2}}\sigma_\eta\right) + e^{-\eta_0}\mathrm{erfc}\left(\sqrt{\frac{1}{2}}\sigma_\eta\right)$$

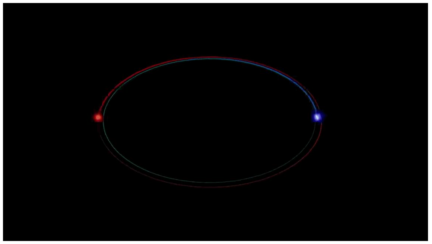
$$y_{\rm CM}(x,y) = \mathrm{arctanh}\left[\frac{T_A - T_B}{T_A + T_B}\tanh(y_{\rm beam})\right]$$

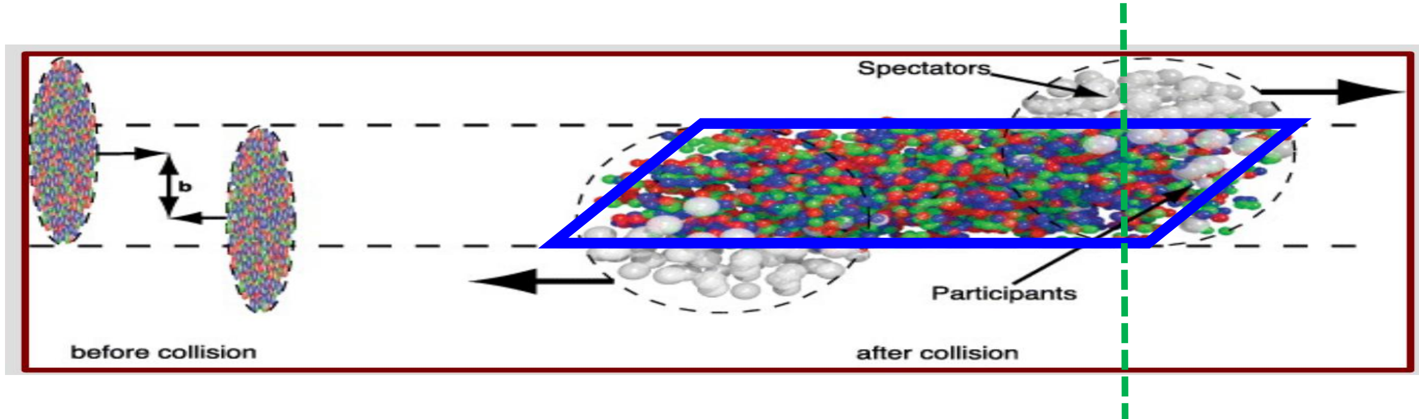
$$M(x,y) = m_N\sqrt{T_A^2 + T_B^2 + 2T_AT_B\cosh(2y_{\rm beam})}.$$



Chun & Sahr Phys. Rev. C 102 (2020) 1, 014909 • e-Print: 2003.05852 [nucl-th]
arXiv:2106.08125.

2. Longitudinal structure of the fireball

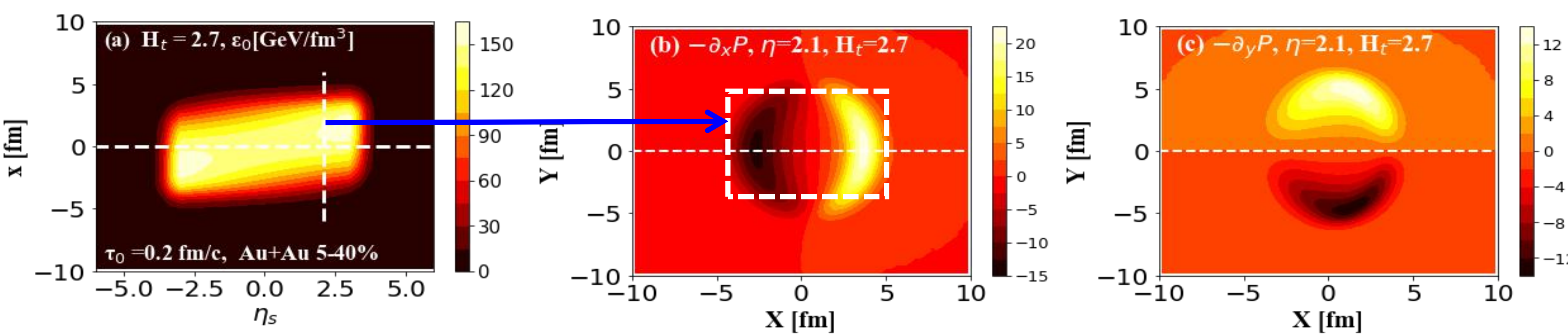




3. ***CCNU-Ht*** longitudinal structure:

In order to create a titled fireball along the longitudinal direction, the wounded nucleons weight function W_N is modified as follow,

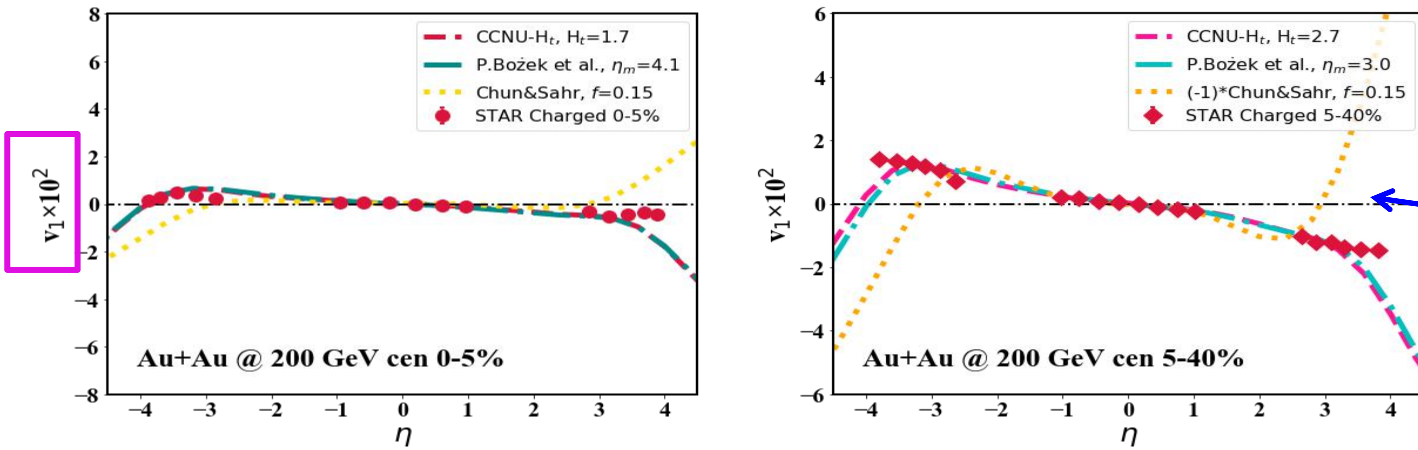
$$W_N(x,y,\eta) = [T_1(x,y) + T_2(x,y)] + H_t [T_2(x,y) - T_1(x,y)] \tan\left(\frac{\eta}{\eta_t}\right)$$



Magnitude asymmetry of pressure gradient in x direction ⇒ Soft hadron v_1

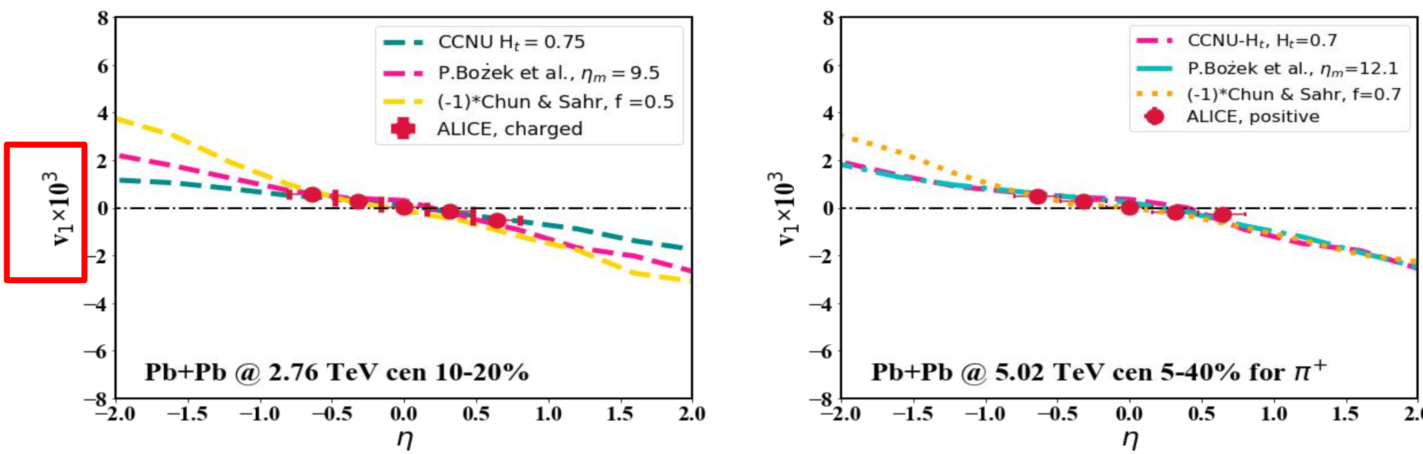
2. *charge Directd flow* v_1 from 3 tilted fireballs

RHIC Au+Au @ 200 GeV



v_1 = 0 if the fireball is not tilted.

LHC Pb+Pb @ 2.76 TeV and 5.02 TeV

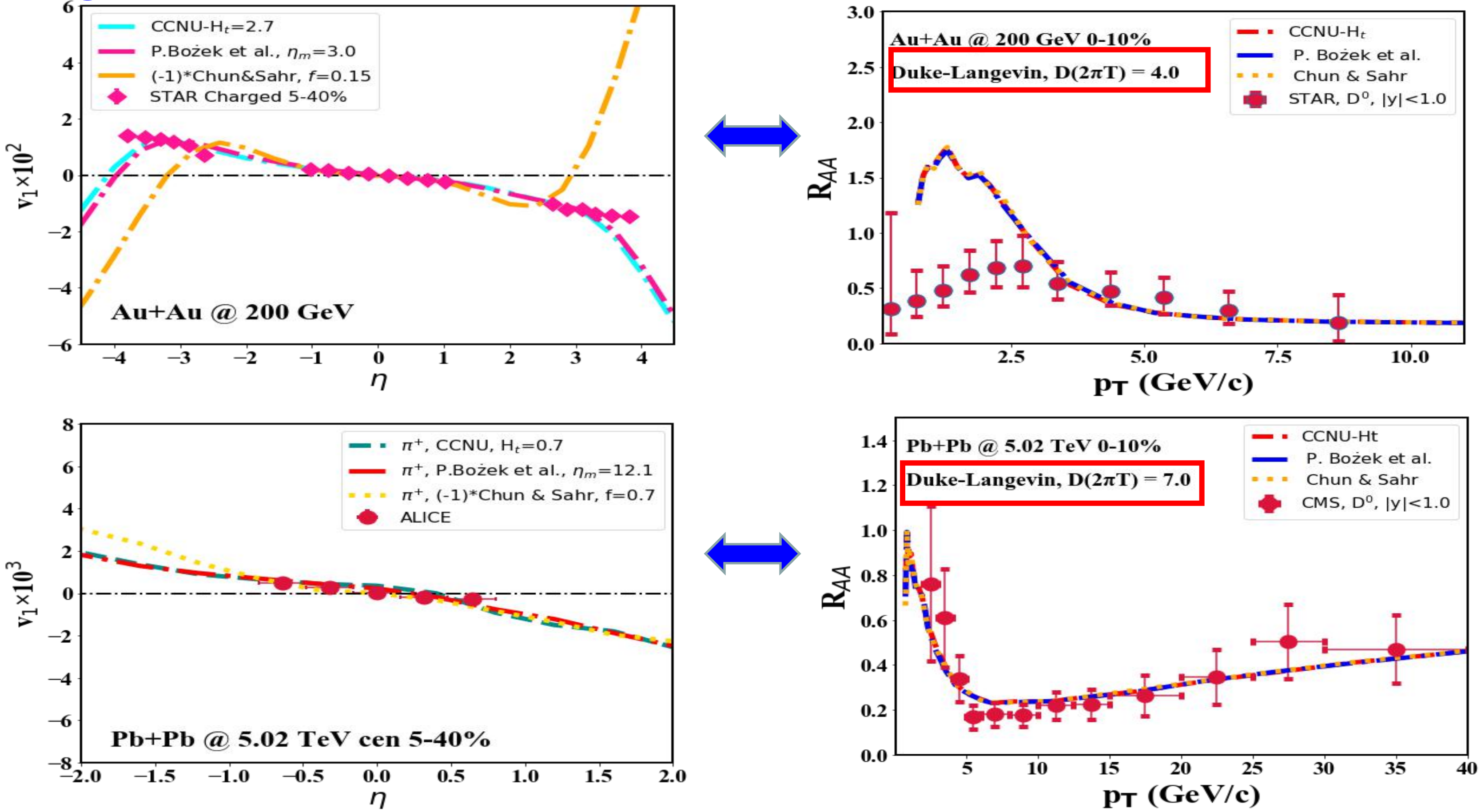


A much weaker singal than at RHIC, consistent with the milder tilting of the fireball.

The tilt of the fireball induce a negative slope in the η dependence of the v_1 of bulk particles.

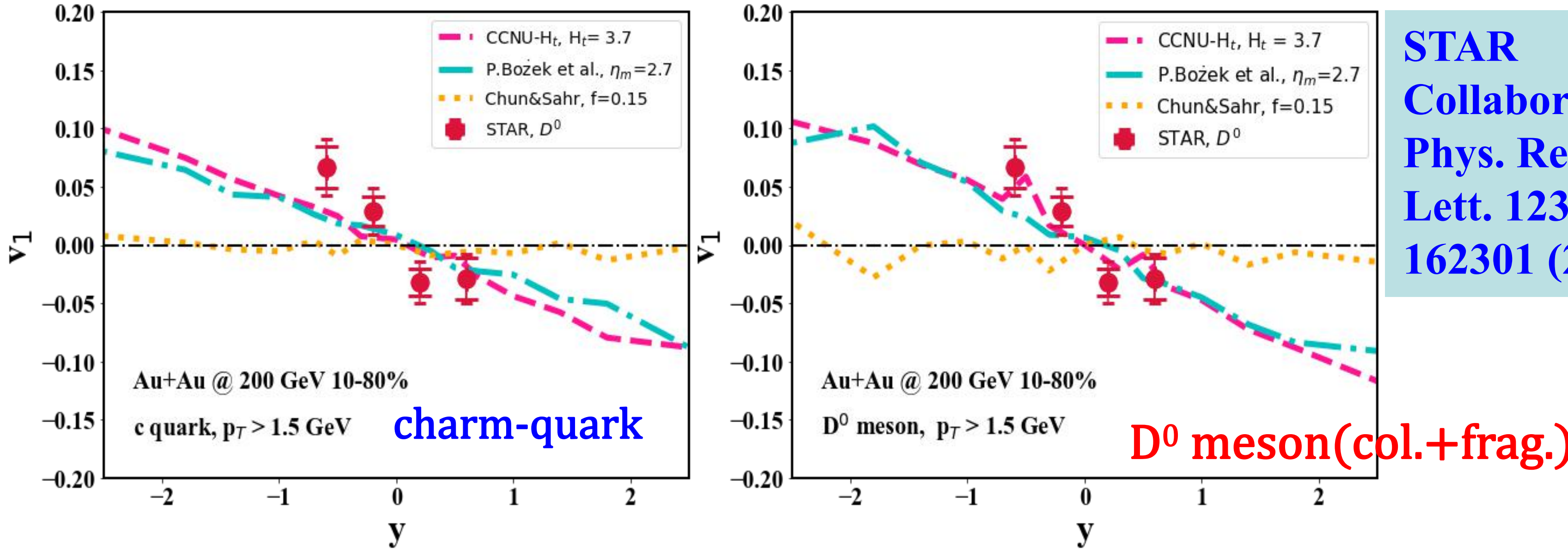
3. CLVisc 3D medium + Duke Langevin

Are HEAVY QUARKS affected by the initial tilt of the fireball and the directed flow of bulk medium?
Or in other words, are the directed flow of HEAVY productions allow one to put tighter constrainst on the initial tilted fireballs?



Shu-Qing Li, Wen-Jing Xing, Feng-Lei Liu, Shanshan Cao, and Guang-You Qin. ***Chin. Phys. C***, 44(11):114101, 2020.
Caio A.G. Prado, Wen-Jing Xing, Shanshan Cao, Guang-You Qin, and Xin-Nian Wang. ***Phys. Rev. C***, 101(6):064907, 2020.

3. v_1 of c quark and D0 in 10-80% Au+Au @ 200 GeV



STAR Collaboration, Phys. Rev. Lett. 123, 162301 (2019)

1. P. Bozek et al.'s longitudinal fireball + CLVisc + Langevin, $\eta_m = \mathbf{2.7}$

Langevin:	Chatterjee and Bozek, Phys. Rev. Lett. 120, 192301 (2018)
POWLANG:	Beraudo, Pace, Monteno, Nardi and Prino, JHEP 05, 279 (2021)
Boltzmann:	Oliva, Plumari and Greco, JHEP 05, 034 (2021)

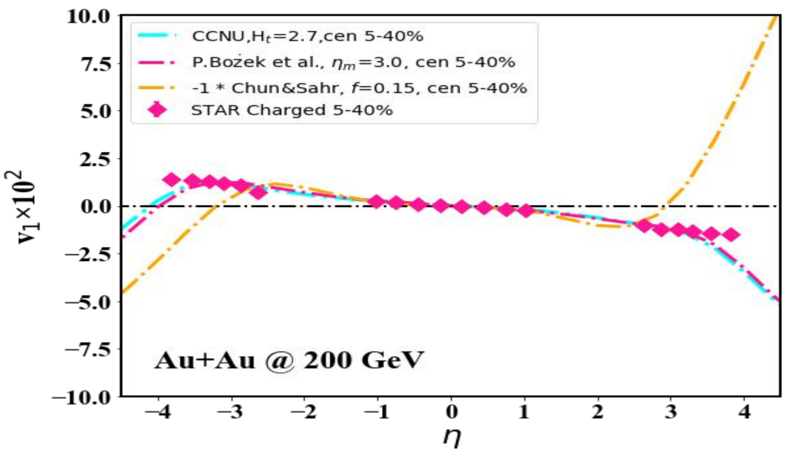
2. CCNU-Ht's longitudinal fireball + CLVisc + Langevin, Ht = **3.7**

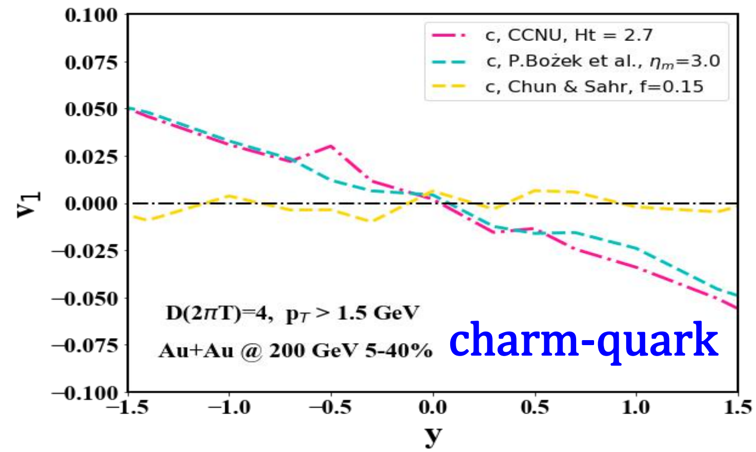
   Similar conclusions with P. Bozek et al.'s approach + CLVisc.

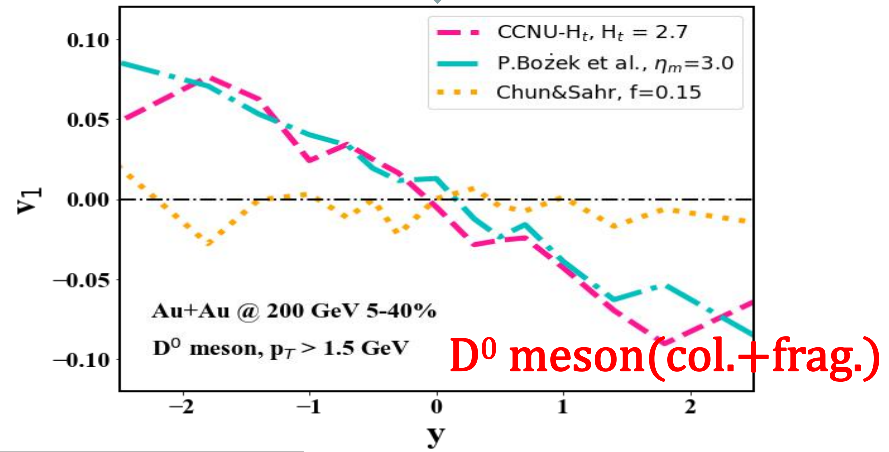
3. Chun & Sahr's longitudinal fireball + CLVisc + Langevin, *f* = **0.15**
   ***Chun et al.*, arXiv:2106.08125**

3. v_1 of c quark and D0 in 5-40% Au+Au @ 200 GeV

Directed flow coefficients v_1 predictions with different longitudinal tilted medium.



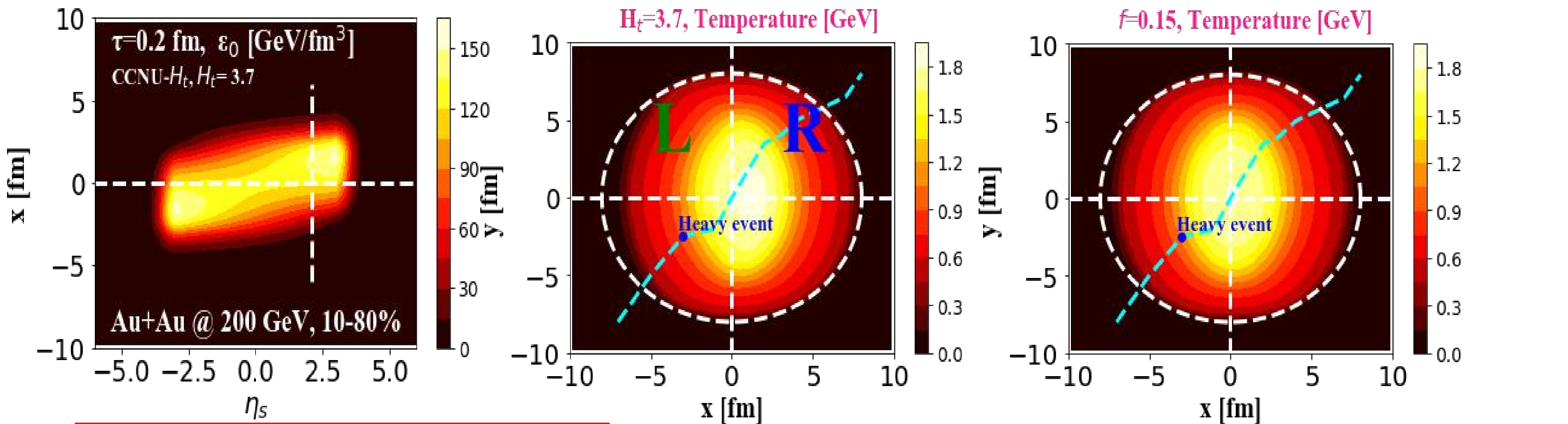




if the v_1 of D mesons is confirmed to be of tilt origin, is it a proof of twisted sQGP formation ?

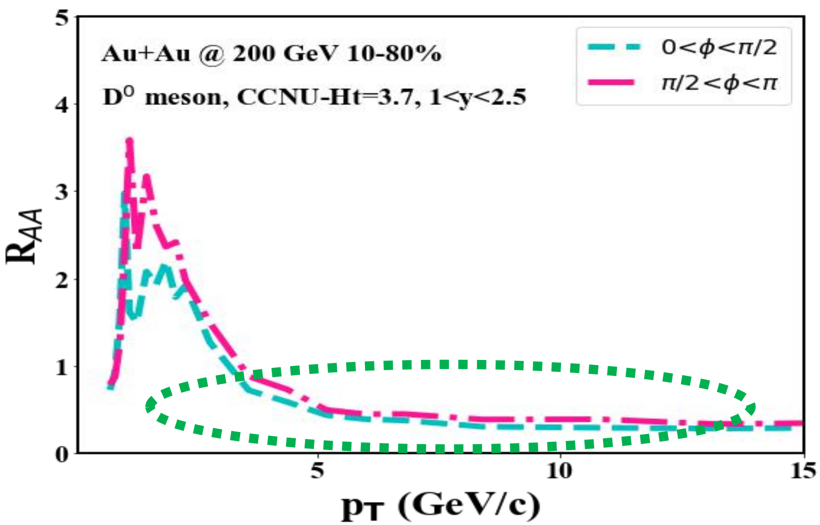
A. Adil and M. Gyulassy Phys. Rev. C 72 (2005) 034907

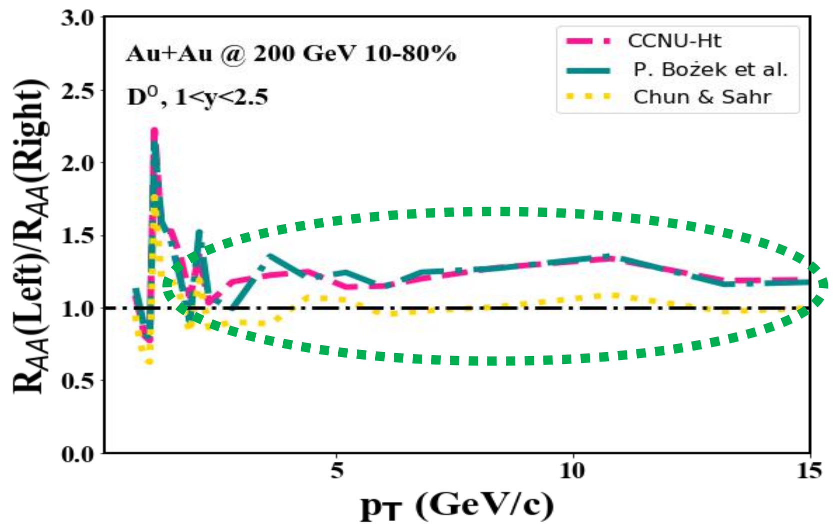
$RAA(\phi, p_T).VS.\ p_T$



$\phi \in [-180^\circ\ , 180^\circ\ ]$

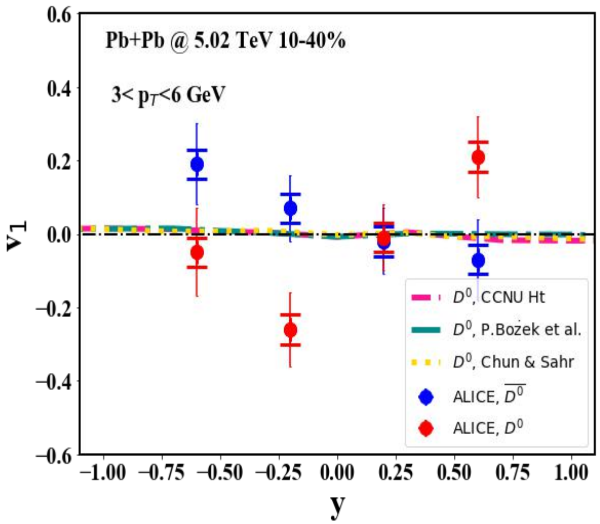
$R_{AA}|_{(Left)}/R_{AA}|_{(right)}$





A. Adil and M. Gyulassy Phys. Rev. C 72 (2005) 034907 v_1 and RAA(ϕ, p_T) Twisted sQGP ?

3. v_1 of c quark and D0 in 10-40% Pb+Pb@ 5.02 TeV



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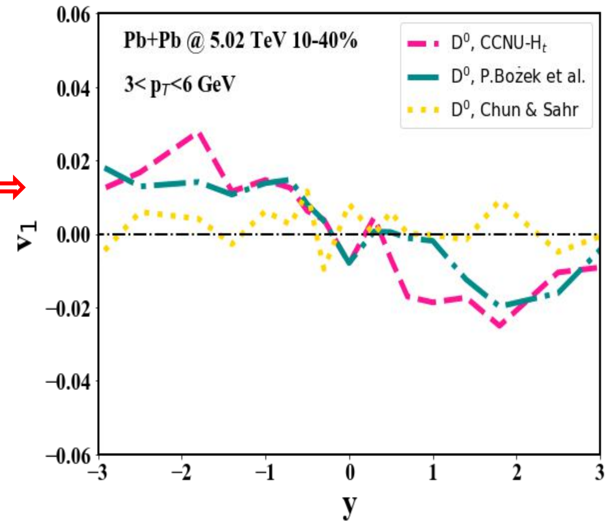
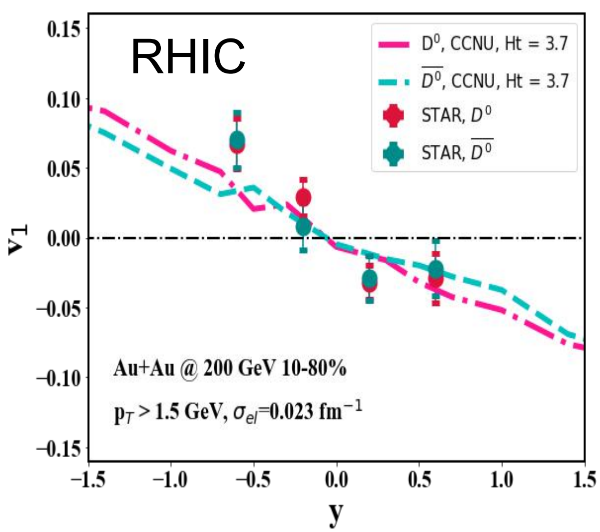
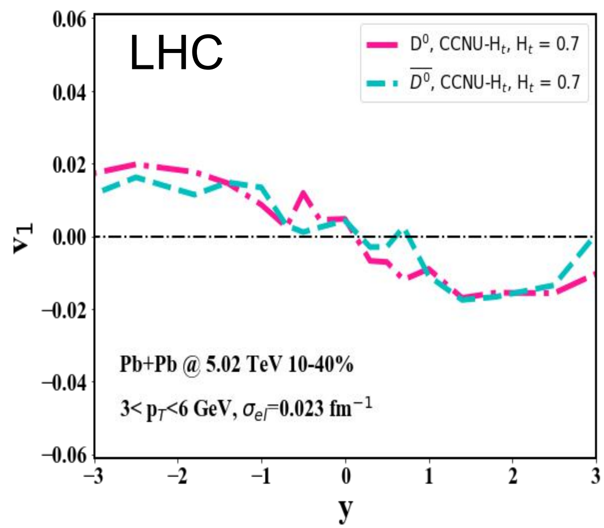


ALICE Collaboration, Phys. Rev. Lett., 125(2):022301, 2020.

Large statistical and systematic uncertainties, prevent one from drawing firm conclusions.





Electromagnetic field effect?

Santosh K. Das et al., Phys. Lett. B, 768:260–264, 2017.

Yifeng Sun, S. Plumari, and V. Greco. Phys. Lett. B, 816:136271, 2021.

4. Summary and outlook

Summary

- ✓ Three different tilted structure of fireballs are presented. The directed flow v_1 for charged particle can be generated if there is a longitudinal asymmetry bulk matter.

- ✓ The v_1 of neutral D mesons is well described at RHIC within tilted initial conditions + CLVisc + Duke Langevin hybrid model energy but still a challenge at LHC.

Outlook

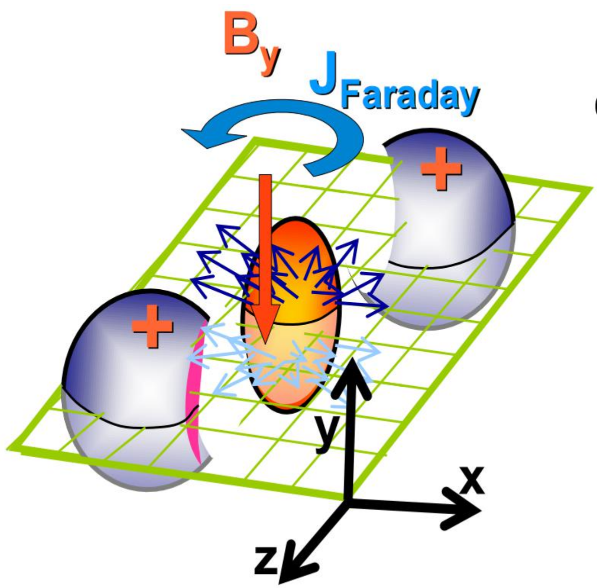
- ➢ ***CLVisc 2.0.*** Xiang-Yu Wu et al., arXiv: 2107.04949.

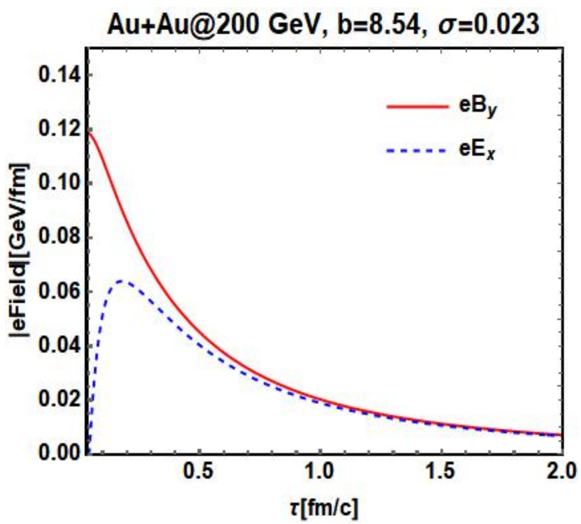
- ➢ Vorticity and electromagnetic origin.

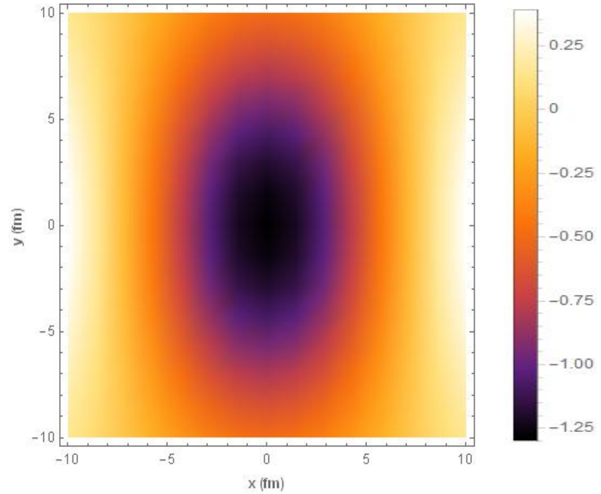
Thank you！

中国物理学会 高能物理分会 第13届全国粒子物理学术会议（青岛，中国）.
2021年 8月

3. v_1 and Δv_1 of D meson in E/B field







Maxwell equations for the EMF can be solved analytically considering a medium with constant electric conductivity.

E/B field at x=y=0, η =-1.0
电导率 0.023 (Lattice QCD)

Magnitude of eBy/m_π^2 in transverse plane at τ =0.5 fm/c

Tuchin, Adv. High Energy Phys. 2013, 1 (2013)

Santosh K. Das et al., Phys. Lett. B, 768:260–264, 2017.

G. Inghirami et al., Eur. Phys. J. C, 80(3):293, 2020

U. Gursoy, D. E. Kharzeev, and K. Rajagopal. Phys. Rev. C, 89(5):054905, 2014.
Hui Li, Xin-li Sheng, and Qun Wang, Phys. Rev. C, 94(4):044903, 2016
Yang Zhong, Yang C. B., Xu Cai, and Sheng-Qin Feng. Chin. Phys. C, 39(10):104105, 2015.