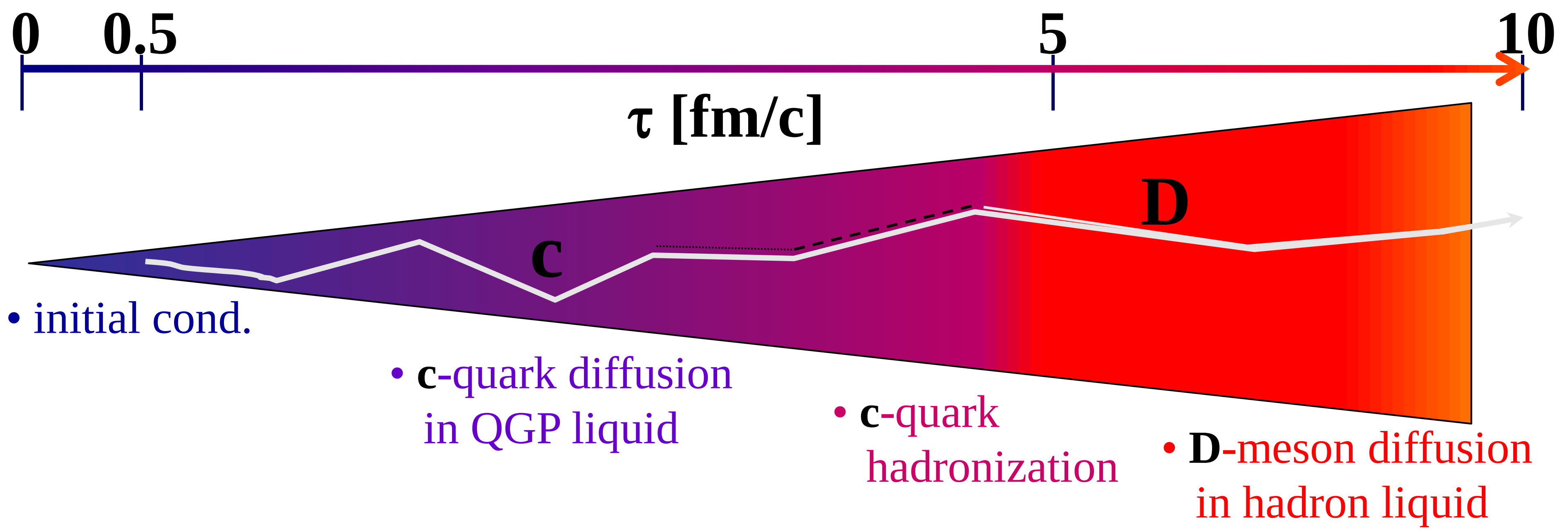
Directed flow of charm and light flavor with initial vorticity in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV from a multiphase transport model

Xinyue Ju

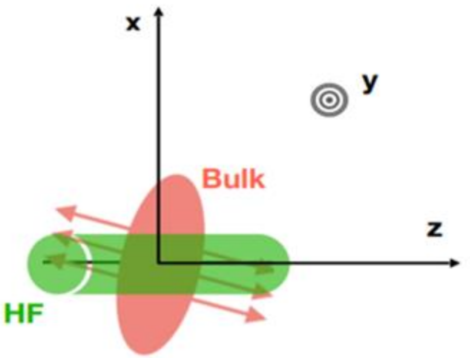
University of Science and Technology of China

Open Charm Transport in URHICs



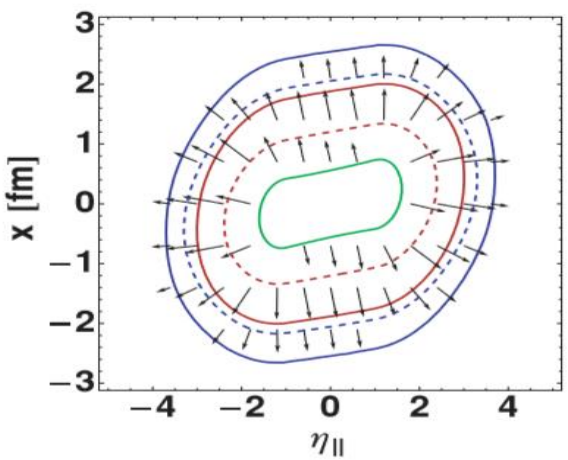
- Produced predominantly in initial hard-scatterings
- Experience the whole evolution of the system
- sensitive probe to the QGP because of their large masses

Charm quark directed flow



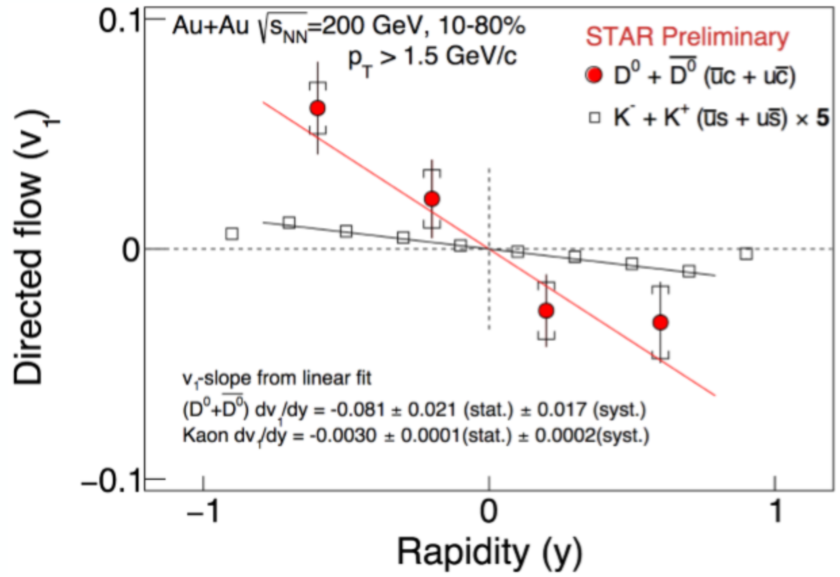
$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Phi_n)$$

Phys. Rev. C 81, 054902 (2010)



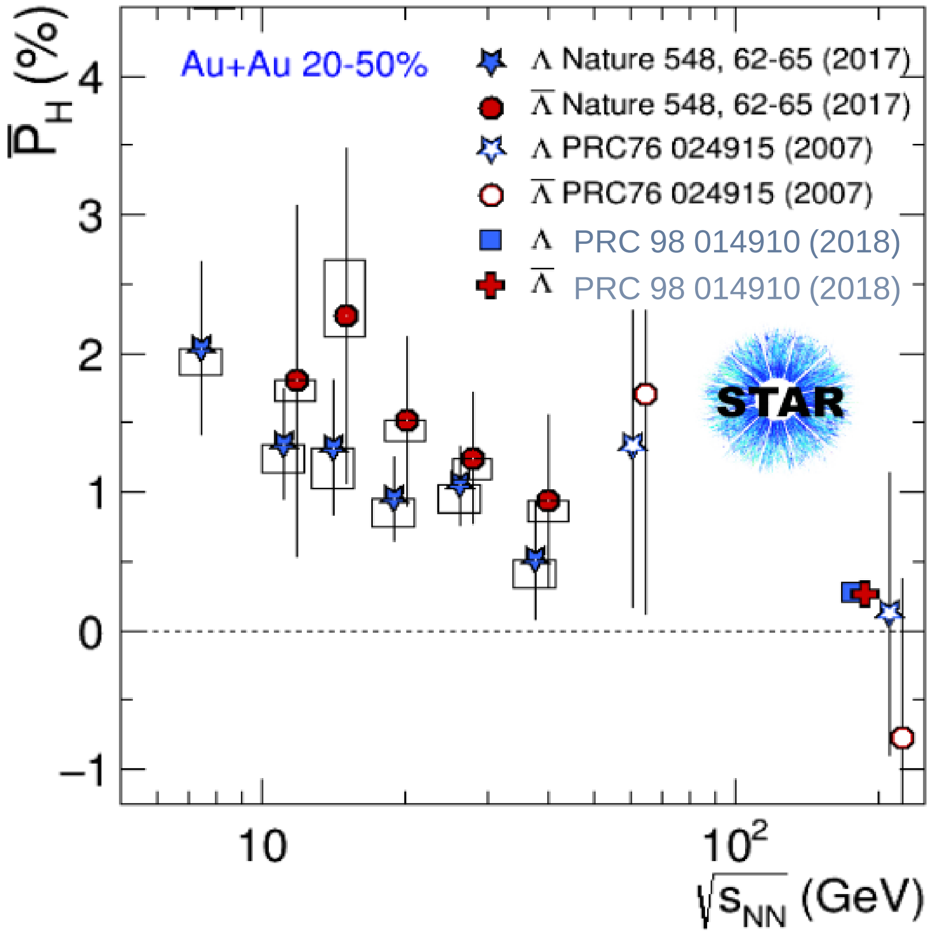
initial fireball energy density

Phys. Rev. Lett. 120, 192301(2018)



- Symmetric production density of charm quarks combined with a drag by initially tilted bulk result in a large anti flow
- The measurement of charm quark v1 can be used to constrain the drag coefficients of the tited bulk

Global Λ hyperon polarization



F. B., M. Lisa, Ann. Rev. Part, Nucl. Sc. 70, 395 (2020)

- Non-zero global Λ hyperon polarization was found in 20-50% centrality Au+Au collisions
- Indicating a large vorticity in the QGP fluid:

$$\omega \approx k_B T(\overline{\mathcal{P}}_{\Lambda'} + \overline{\mathcal{P}}_{\overline{\Lambda}'})/\hbar$$

- The $\sqrt{S_{NN}}$ - averaged polarizations gives a vorticity of $\omega \approx (9 \pm 1) \cdot 10^{21}\ s^{-1}$

Vortex identification methods

For a fluid with verticity field ***V***, there are several ways to find vortex:

1. vorticity $\omega = \nabla \times \boldsymbol{V} = \frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x}$

2. Q criterion

expansion rotation

$$\nabla \boldsymbol{V} = \frac{1}{2}(\nabla \boldsymbol{V} + \nabla \boldsymbol{V}^{\mathrm{T}}) + \frac{1}{2}(\nabla \boldsymbol{V} - \nabla \boldsymbol{V}^{\mathrm{T}}) = \boldsymbol{A} + \boldsymbol{B} \qquad Q = \frac{1}{2}(\|\boldsymbol{B}\|_F^2 - \|\boldsymbol{A}\|_F^2)$$

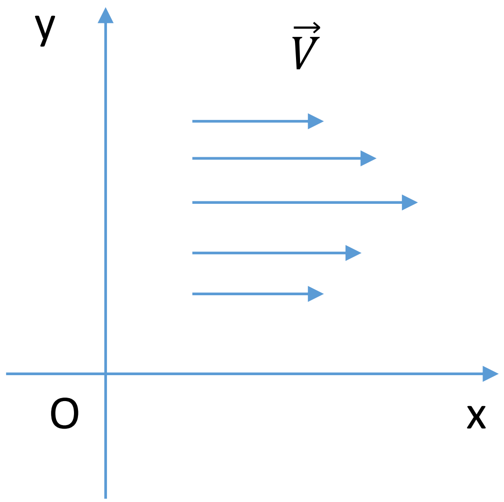
$\| \|_F$ represents the Frobenius norm. $Q > 0$ represents the existence of vortex

3. Ω method

$$\Omega = \frac{\|B\|_F^2}{\|A\|_F^2 + \|B\|_F^2 + \varepsilon} \qquad \varepsilon = 0.001\left(\|B\|_F^2 - \|A\|_F^2\right)_{\max}$$

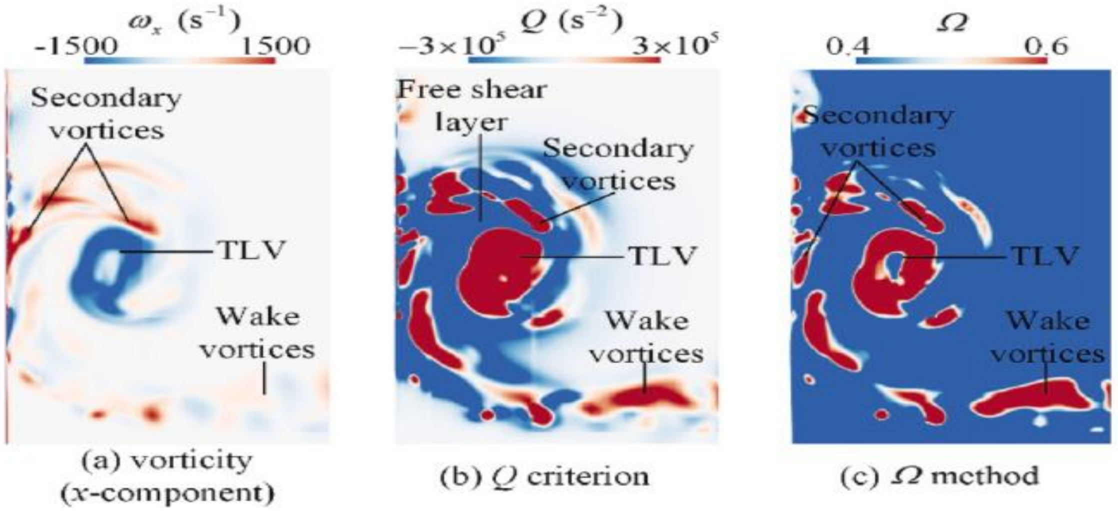
Represent the fractions of rotation part. A reference range for vortex visualization that is about Ω > 0.51–0.6 is provided to insure a local dominance of the vorticity

Vortex identification methods



$$\omega = \frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y} \neq 0$$

But no real vortex



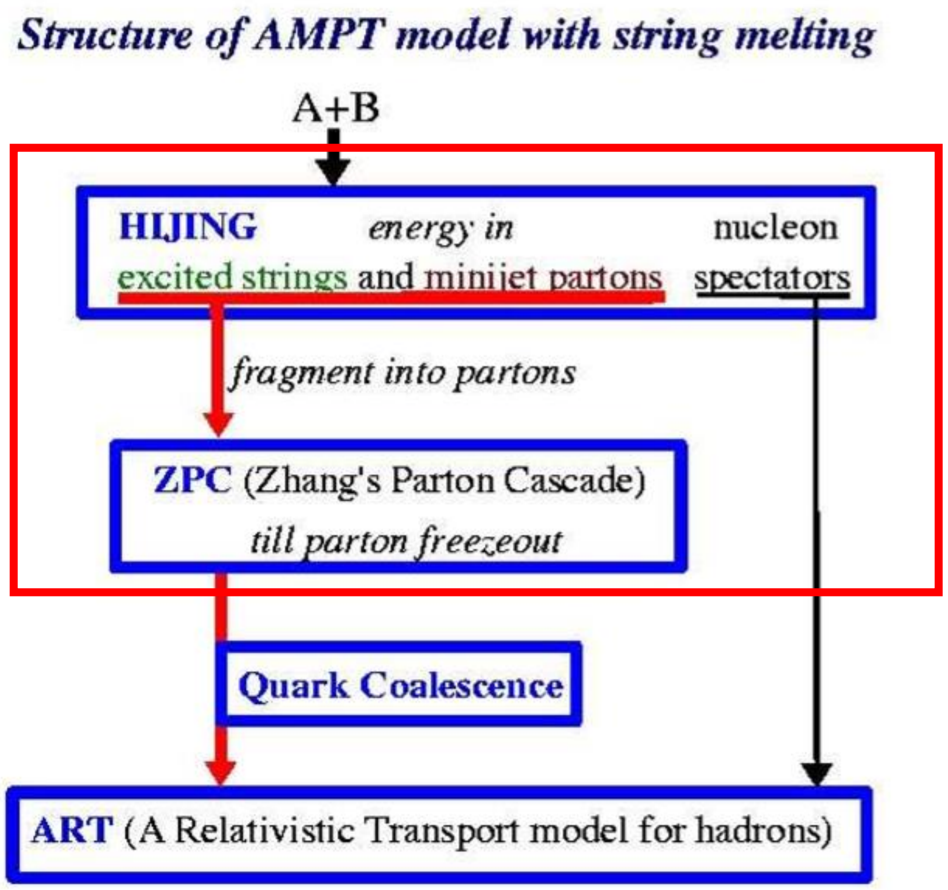
example of visualization of vortical structures with ω, Q and Ω

Vorticity (ω) is not a good way to defined vortex if density gradient exist in fluid

Q criterion and Ω method are better ways to find vortex structure

AMPT model

a multi-phase transport (AMPT) model with string melting



initial partons is generated by melting hadrons produced by elastic and inelastic scatterings of participant nucleons in HIJING

partonic interaction in the ZPC model is described by the partonic two-body elastic scatterings with the differential cross section:

$$\frac{d\sigma}{dt} \approx \frac{9\pi\alpha_s^2}{2(t-\mu^2)^2}$$

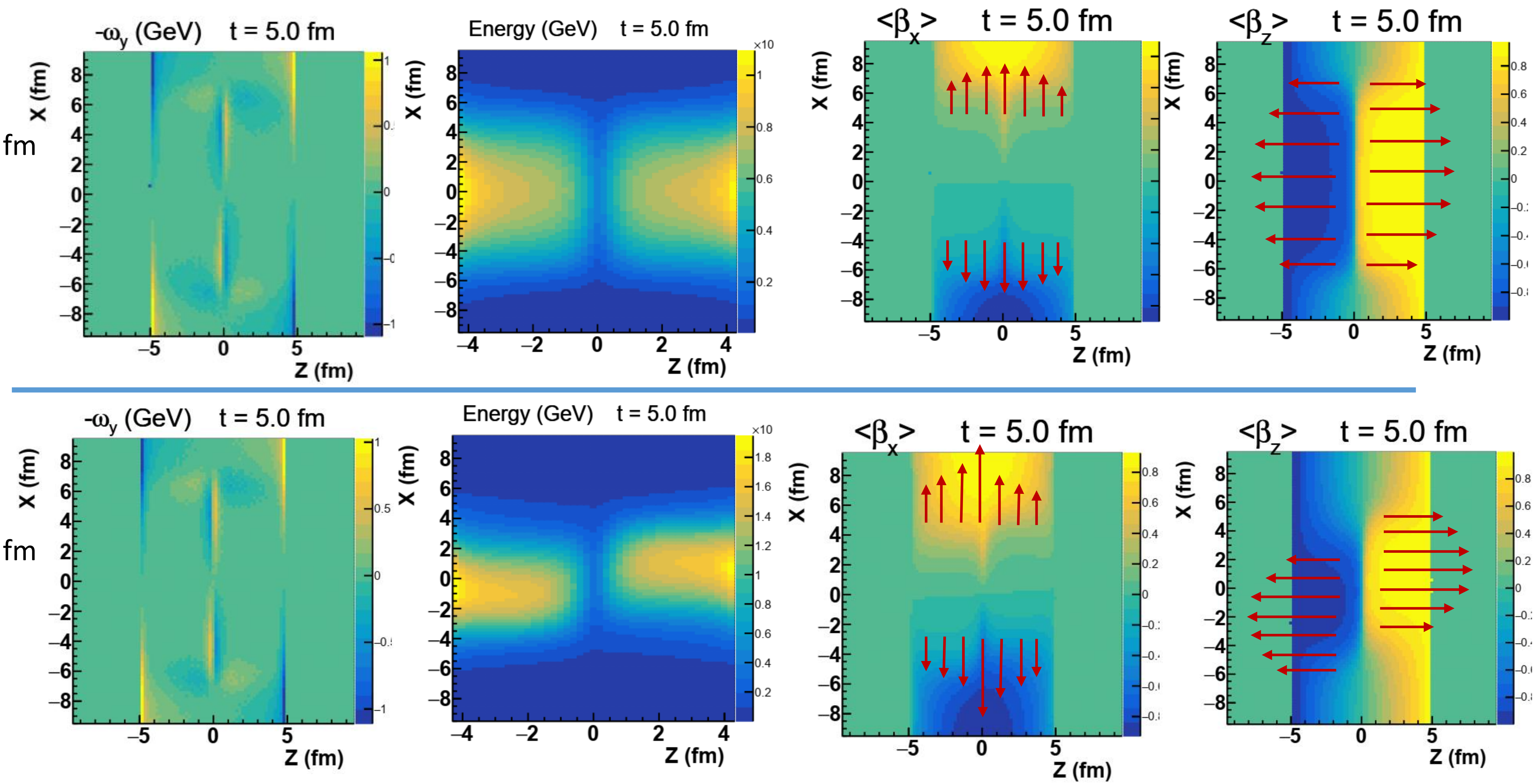
Version: ampt-v1.26t9b

α_s =0.4714 , μ = 2.265 fm^{-1}, total cross section ~ 6mb

Vorticity in AMPT model

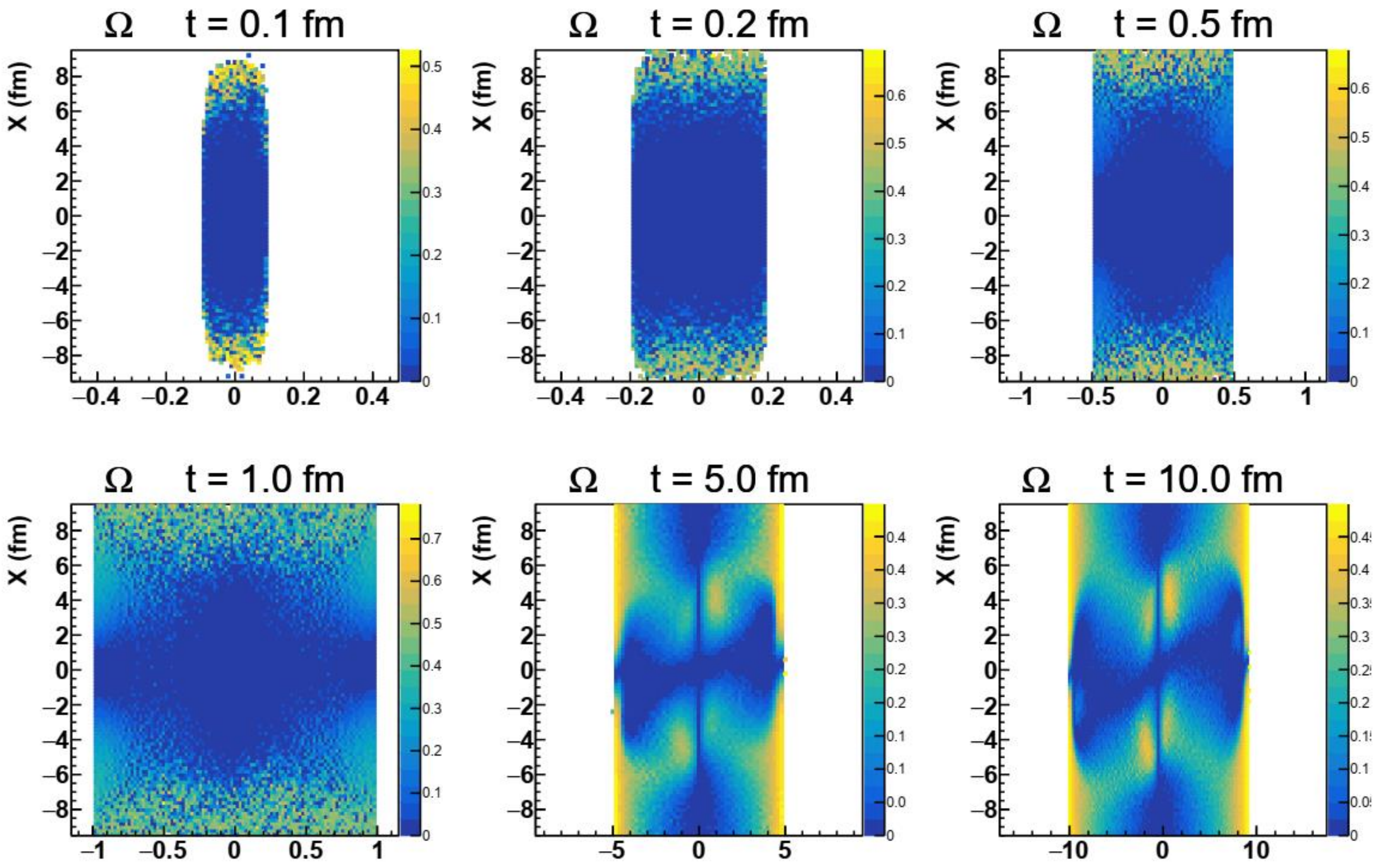
b_{imp} = 0 fm

b_{imp} = 7 fm



Vertex in AMPT model

b_{imp} = 7 fm



Except some points in x>6fm or x<-6fm area at t<1 fm, the Ω value are less than 0.5.

Indicate the expansion motion dominant the parton motion.

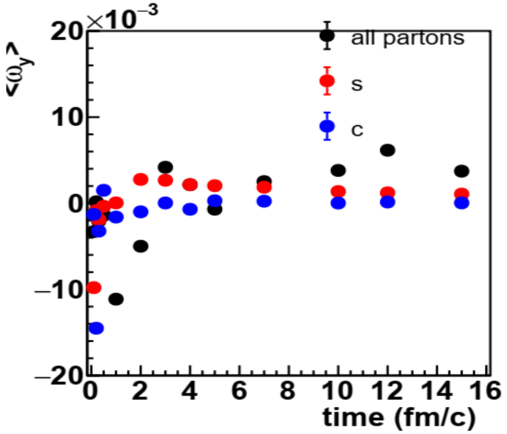
No obvious vertex structure are found in partonic evolution

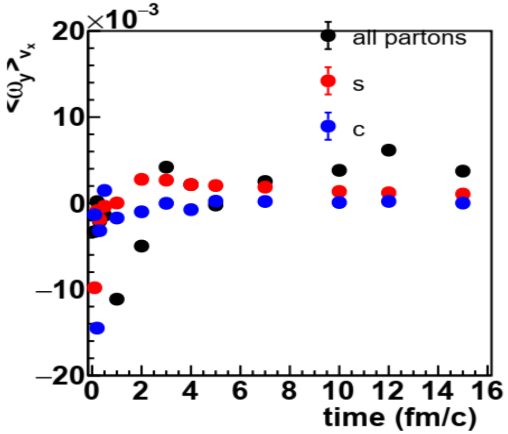
Vorticity in AMPT model with initial global rotation

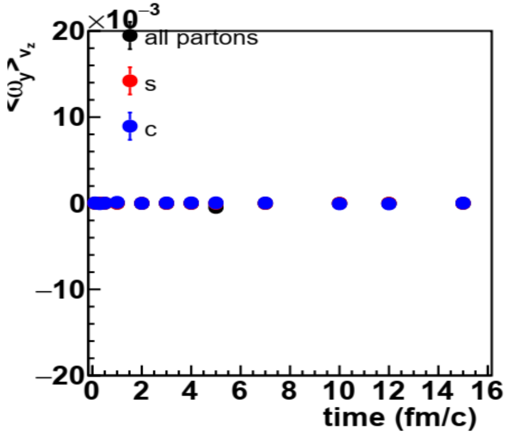
Adding Initial global rotation in xz plane $\vec{p}_{parton} = \vec{p}_{parton} + \omega_{iy} \times \vec{r} \times w(t)$

ω_{iy} = $9 \cdot 10^{21}$ s^{-1} to initial parton (t fromat < 0.5 fm) distribution, w(t) = 2 · (1- t/0.5)

b_{imp} = 0 fm
No initial
global rotation

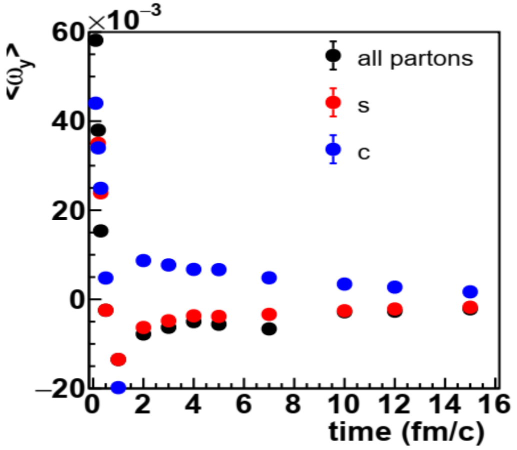


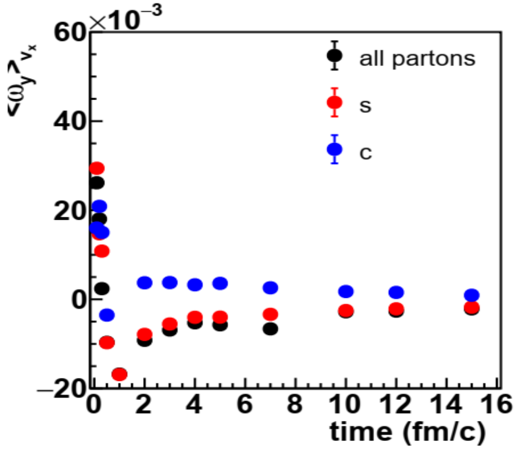


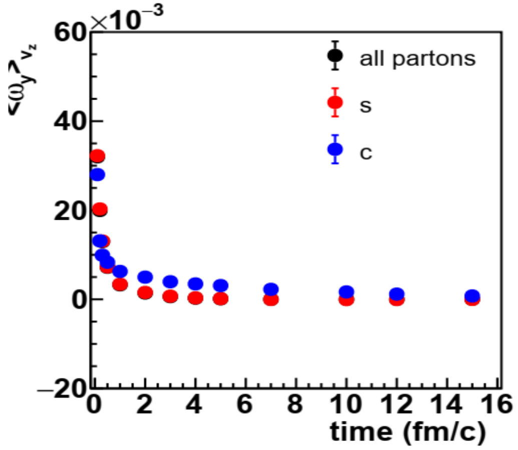


$\omega_y \approx 0$

b_{imp} = 0 fm
With initial
global rotation



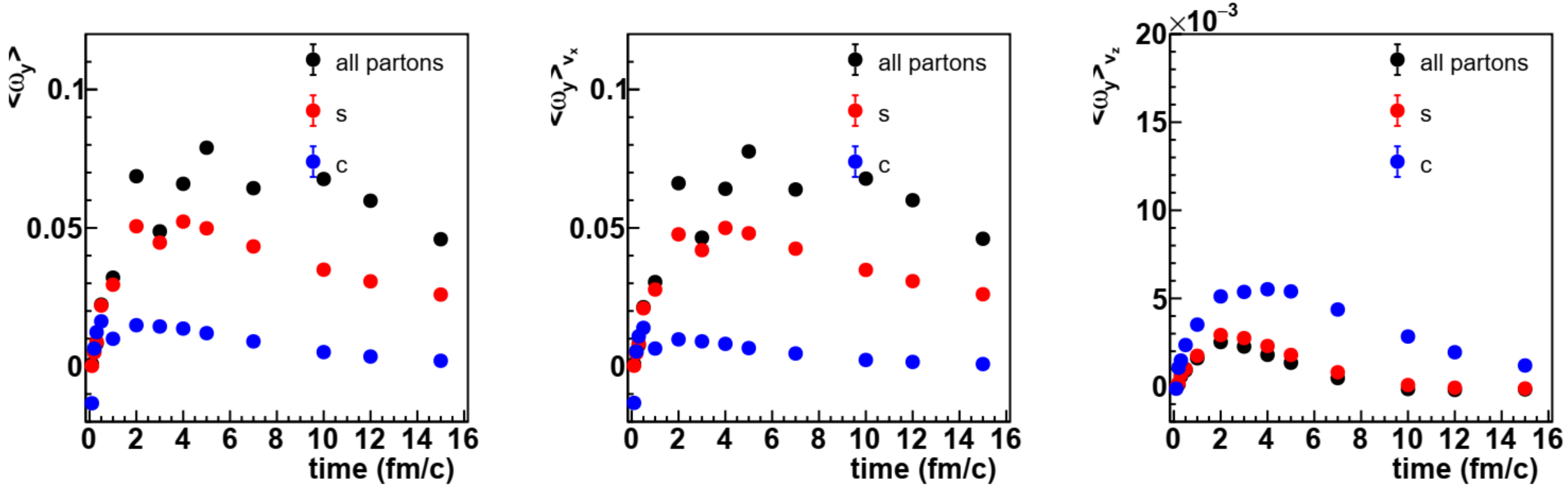




Initial ω_y decrease quickly because of the expansion

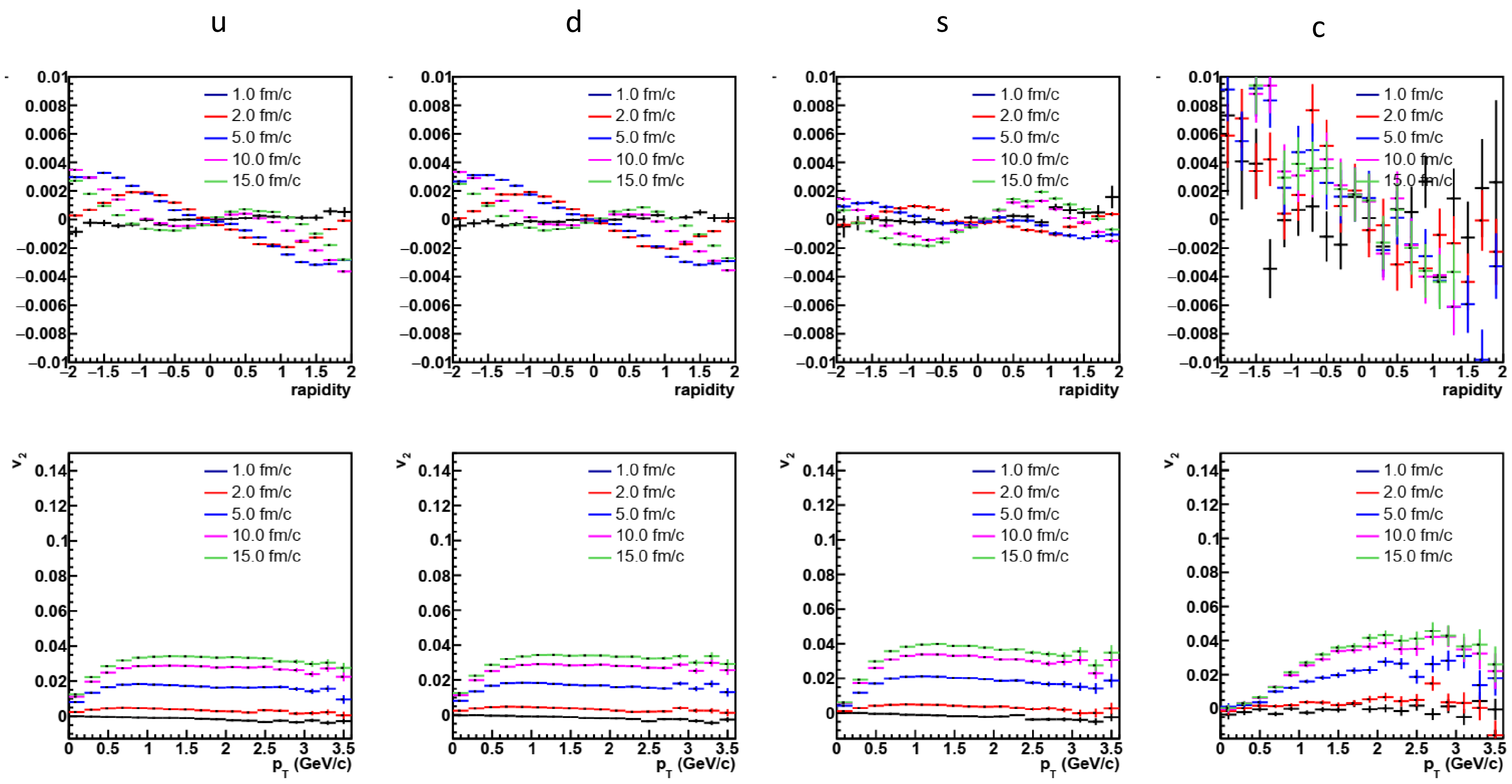
Vorticity in AMPT model with initial global rotation

b_{imp} = 7 fm
No initial
global rotatior



Non-zero ω from the inhomogeneous expansion of the fireball,
charm quark are more sensitive to the gradient of v_z on x direction

Parton v_1 v_2 time development in AMPT model



Parton v_1 v_2 time development in AMPT model with initial global rotation

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$\omega_{iy} = 9 \cdot 10^{21}$ s^{-1} to initial parton (t fromat < 0.5 fm) distribution, $w(t) = 2 \cdot (1 - t/0.5)$

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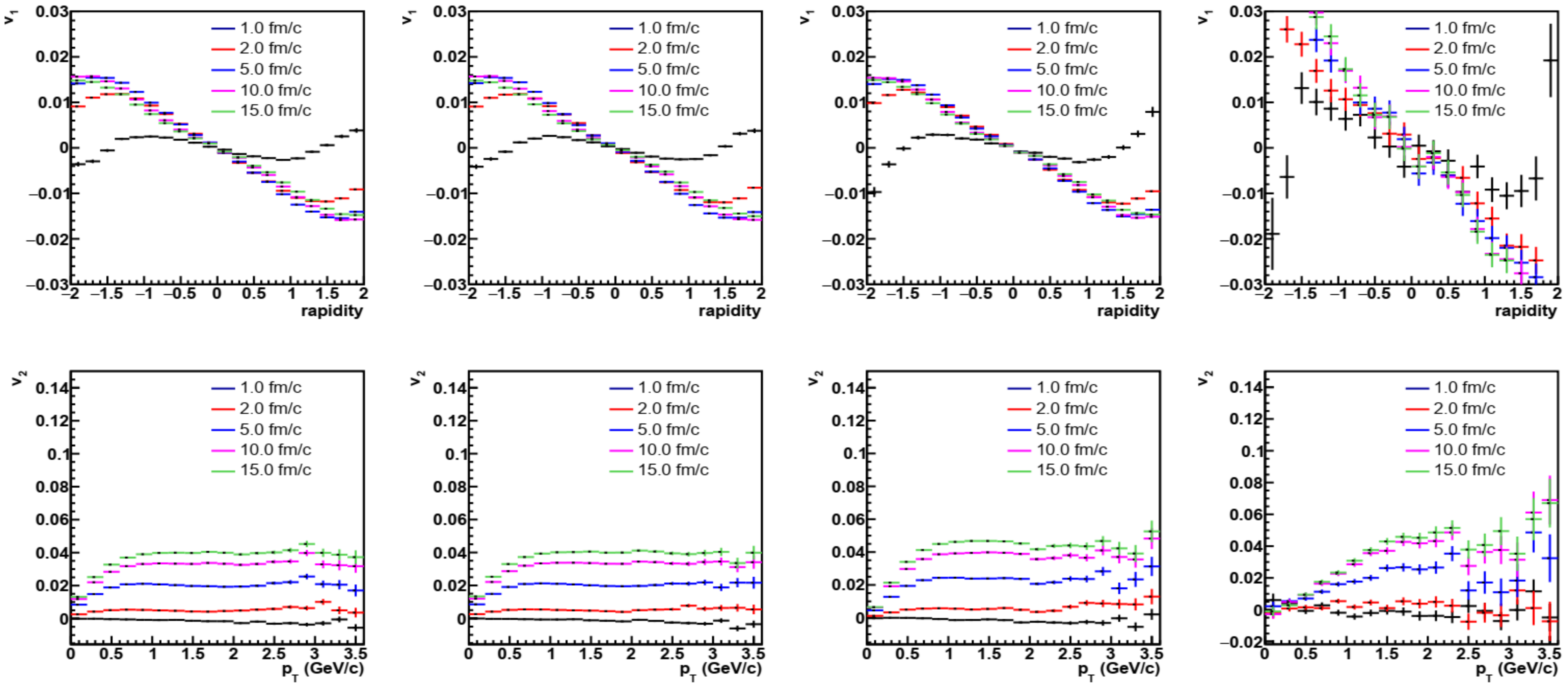
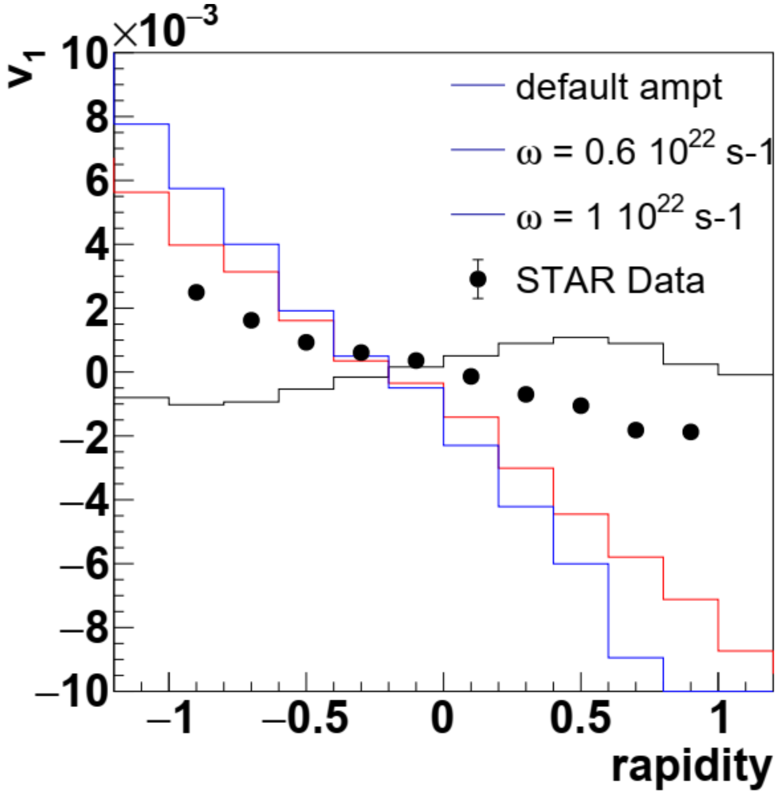
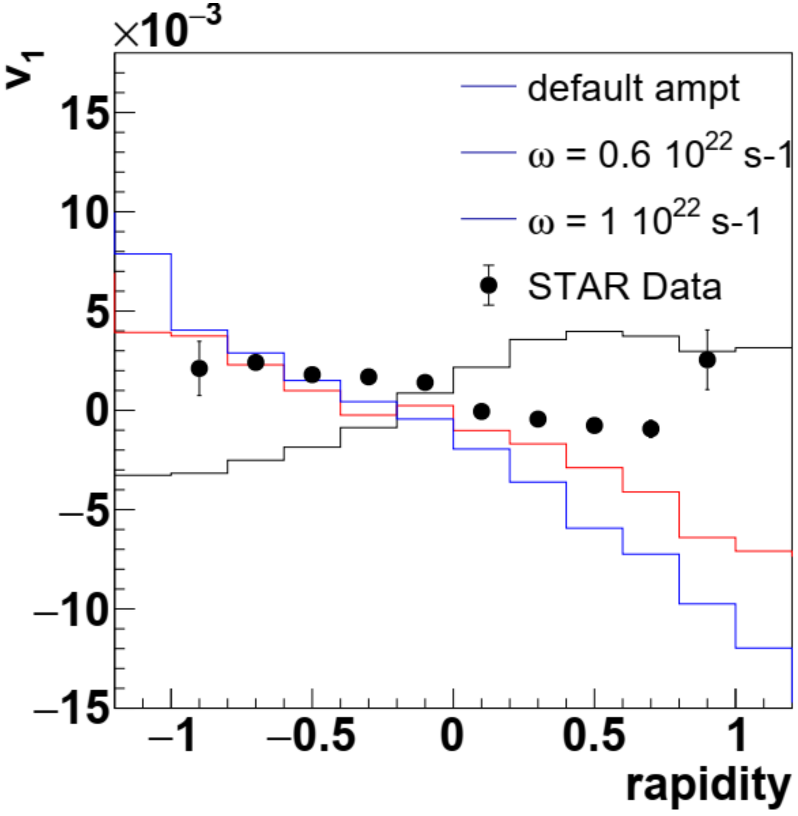


Particle dv_1/dy in AMPT model with addition initial $\langle\omega_y\rangle$

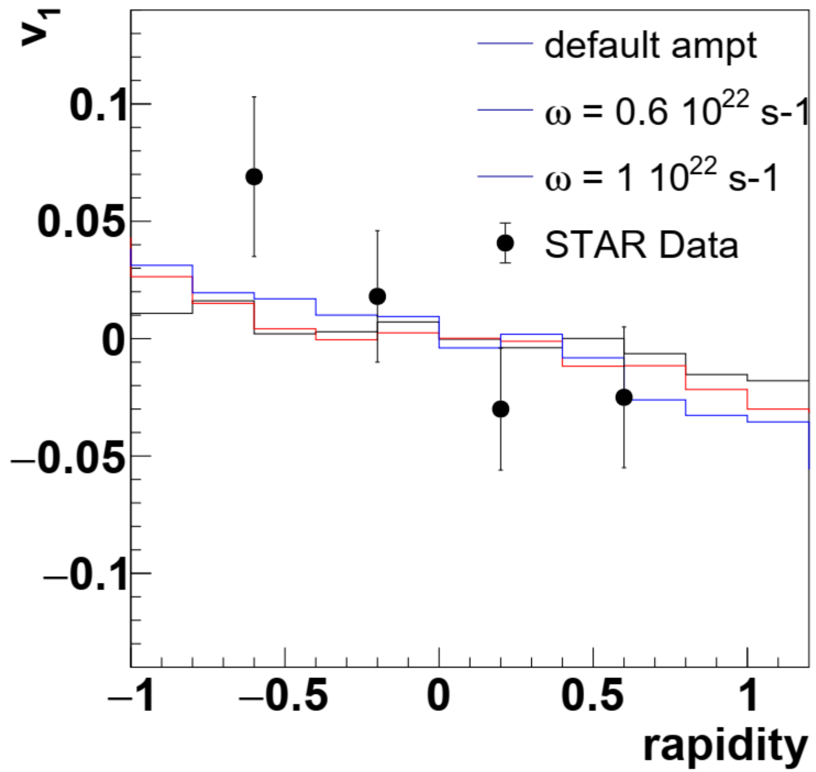
pion



kaon



D^0



Although the added Initial global rotation dissipative quickly, it will redistribution the parton momentum and change v_1 distribution

Summary

- ω, Q criterion and Ω value from the ampt model are calculated. No obvious vertex structure are found in partonic evolution stage.
- The effective vorticity < ω_y> are mainly from the thermal expansion and shows a flavor dependence.
- Heavy quark show more sensitivity to the velocity gradient in the QGP fluid
- By adding the additional initial <ω_y>, We find that the dv1/dy as a function of rapidity for pion and kaon are reversed compared to the default AMPT setting and are comparable to the measured value at RHIC energy. And the dv1/dy slope of D^0 meson increased by more than 2 times at mid rapidity.