Chiral vortical and magnetic effects in anomalous hydrodynamics

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Outline

- Motivation
- Hydro Set and Initial Conditions
- Numerical Results
- Conclusion

Motivation

- Chiral effects in HIC: still in focus and debate
- γ correlation of identified particles?
- In low energy and peripheral collisions, CVE is stronger than CME
- Hydrodynamics simulation of CVE is necessary

3+1D Anomalous Ideal Hydrodynamics

with chiral magnetic effect

$$\partial_\mu T^{\mu\nu} = eF^{\nu\lambda} j_\lambda$$

$$\partial_\mu j^\mu = 0 \qquad j^\mu = nu^\mu + \kappa_B B^\mu$$

$$\partial_\mu j_5^\mu = -CE_\mu B^\mu \qquad j_5^\mu = nu_5^\mu + \xi_B B^\mu$$

EOS: ideal massless quark-gluon gas

$$\epsilon = 3p = \frac{19\pi^2}{12} T^4 + \frac{9}{2}(\mu^2 + \mu_5^2) T^2 + \frac{9}{4\pi^2}(\mu^4 + 6\mu^2\mu_5^2 + \mu_5^4)$$

Y. Hirono, T. Hirano and D. E. Kharzeev, arXiv:1412.0311

Transport Coefficients

$$e\kappa_B = C\mu_5(1 - \frac{\mu_5 n_5}{\epsilon + p}) \qquad e\xi_B = C\mu(1 - \frac{\mu n}{\epsilon + p})$$

Determined by requiring entropy does not decrease[1,2].

Two more coefficients if including CVE:

$$e^2\kappa_\omega = 2C\mu\mu_5(1 - \frac{\mu n}{\epsilon + p}) \quad e^2\xi_\omega = C\mu^2(1 - \frac{2\mu_5 n_5}{\epsilon + p})$$

[1]D. T. Son and P. Surowka, Phys. Rev. Lett. **103**, 191601(2009)
[2]D. E. Kharzeev and H. -U. Yee, Phys. Rev. **D84**, 045025(2001)

Magnetic Field

Exponentially decaying Gaussian distribution:

$$eB_y(\tau, \eta, x, y) = eB_0 \frac{b}{2R} \exp\left(-\frac{x^2}{\sigma_x^2} - \frac{y^2}{\sigma_y^2} - \frac{\eta^2}{\sigma_\eta^2} - \frac{\tau}{\tau_B} \right)$$

$$eB_0 = 0.5GeV^2 \qquad \sigma_x = 0.8(R - \frac{b}{2})$$

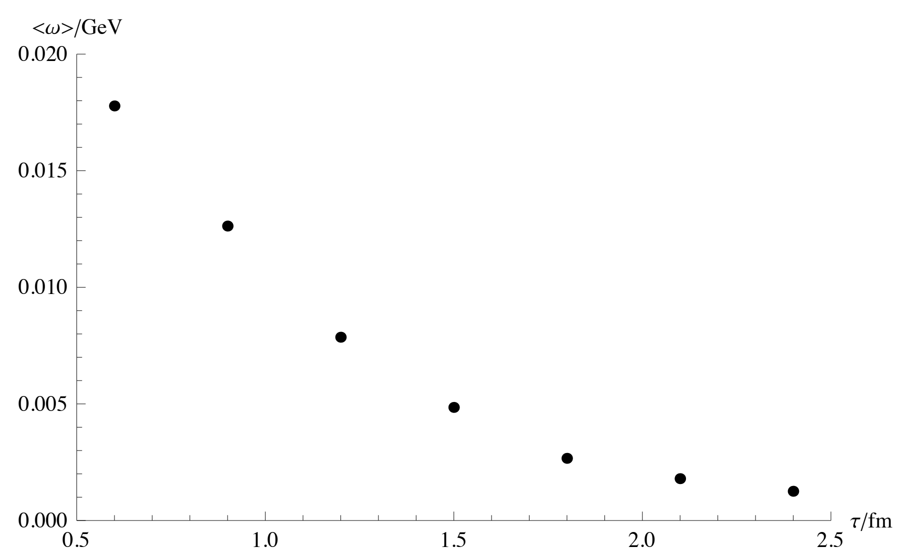
$$\sigma_y = 0.8\sqrt{R^2 - (b/2)^2} \qquad \sigma_\eta = \sqrt{2}$$

Recent magneto-hydrodynamics simulation[1] gave time evolution very similar to exponential decay

[1]Inghirami, G., Del Zanna, L., Beraudo, A. et al. Eur. Phys. J. C (2016) 76: 659

Initial Conditions

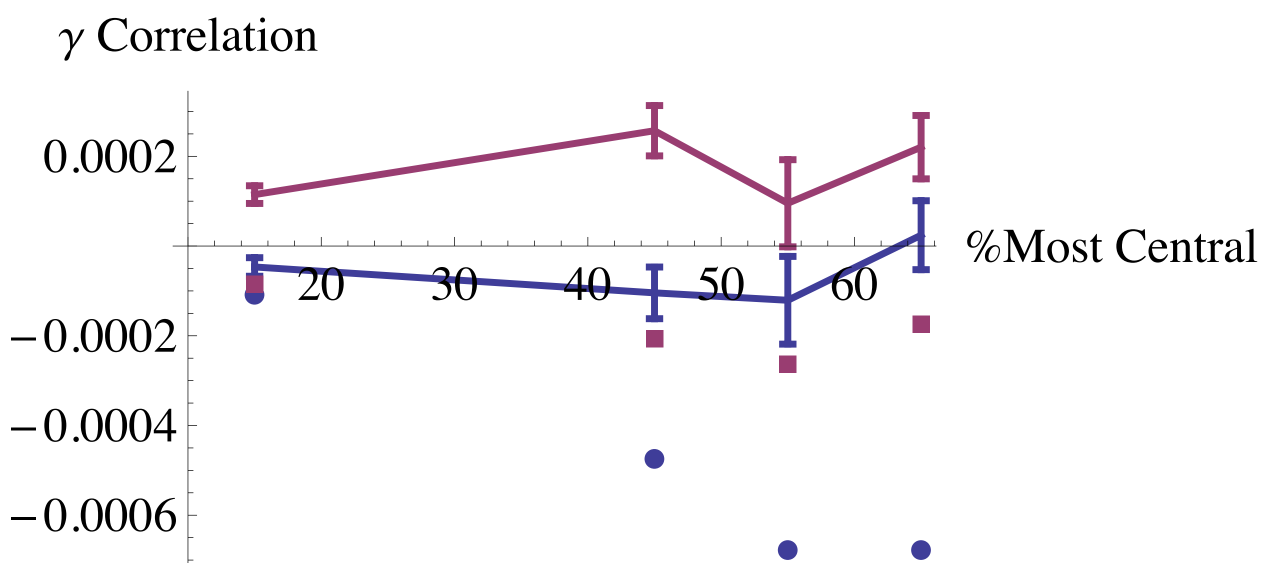
- MC-Glauber model is sufficient for CME simulation but gives zero initial vorticity
- HIJING model has been used to describe vorticity of initial system[1] but has no chiral charge distribution



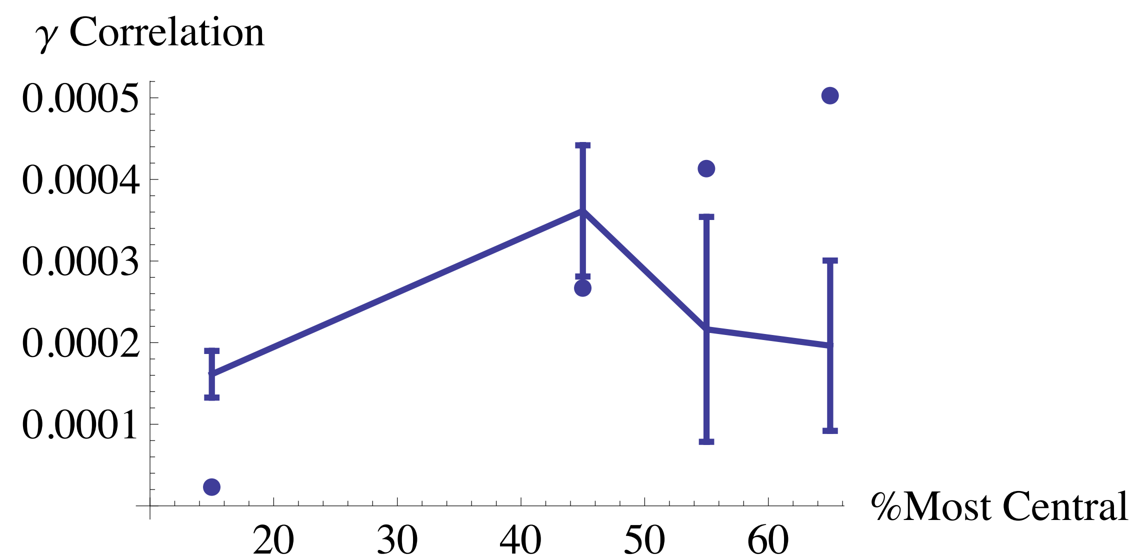
Average vorticity in QGP as a function of time for RHIC 200Gev Au-Au 40~50% centrality collisions, with HIJING initial condition

[1]W. Deng, X. Huang, Phys. Rev. **C93**, 064907

γ Correlation of Identified Particles with CME for RHIC 200GeV Au-Au Collisions



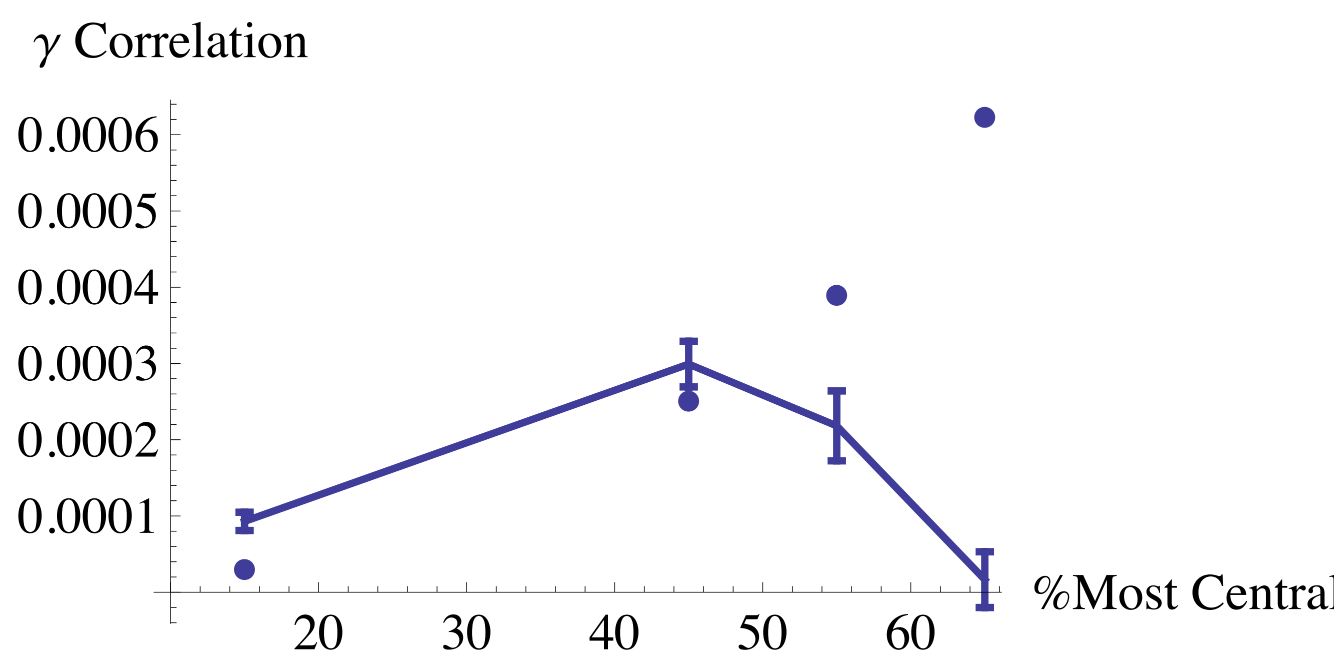
p-π opposite-sign(red line) and same-sign(blue line) correlation in comparison with experimental data(dots)



p-π OS-SS correlation(line) in comparison with experimental data(dots)

A lot of other contributions are cancelled out in OS-SS correlation

γ Correlation of Identified Particles with CME for RHIC 200GeV Au-Au Collisions



π-π OS-SS correlation(line) in comparison with experimental data(dots)

possible indication of strong CVE in more peripheral collisions

Comparison of CVE and CME Contributions

Simulation of pion and proton a1 with different effects included,
for RHIC 200Gev Au-Au 40~50% centrality collisions

	π	p
$NONE(Glauber)$	-0.0007 ± 0.0019	-0.0058 ± 0.0063
$NONE$	-0.0023 ± 0.0014	-0.0120 ± 0.0038
CME	0.0013 ± 0.0013	-0.0027 ± 0.0042
$CVE + CME$	0.0048 ± 0.0018	0.0109 ± 0.0044

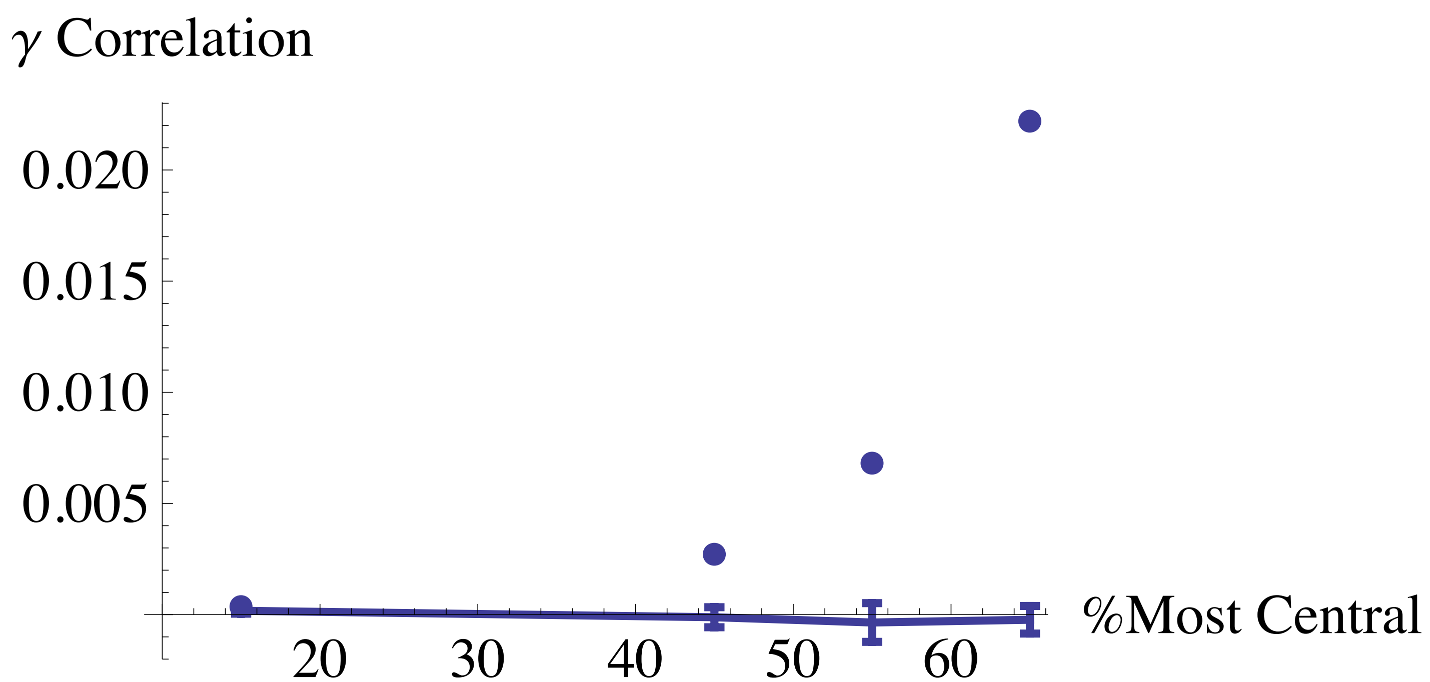
- CVE calculated as perturbation
- Initial chiral charge taken as proportional to temperature
- None-zero background comes from fluctuation in HIJING events

Conclusion and Outlook

- We calculated γ correlation of protons and pions for RHIC 200Gev Au-Au Collisions.
- We also made a comparison of CVE and CME contribution in a given condition.
- Both show signs of strong CVE contribution

- More observables: electric quadrupole, Λ polarization, different collision energy…
- Improvements: resonance decay…
- CVE hydrodynamics: initial condition, stable evolution…

γ Correlation of Identical Particles with CME for RHIC 200GeV Au-Au Collisions



p-p correlation(line) in comparison with experimental data(dots)