Final state effects on charge asymmetry of pion elliptic flow in high-energy heavy-ion collisions

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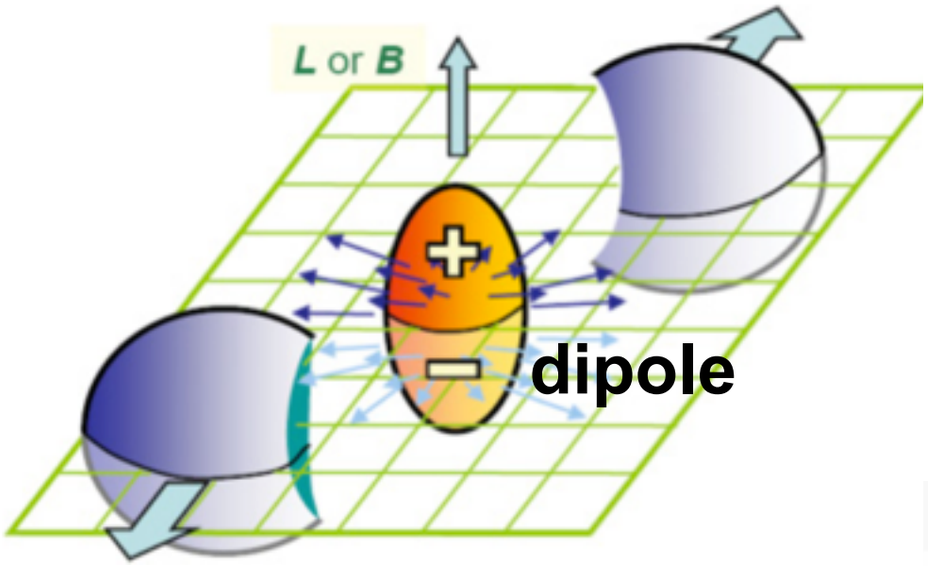
Outline

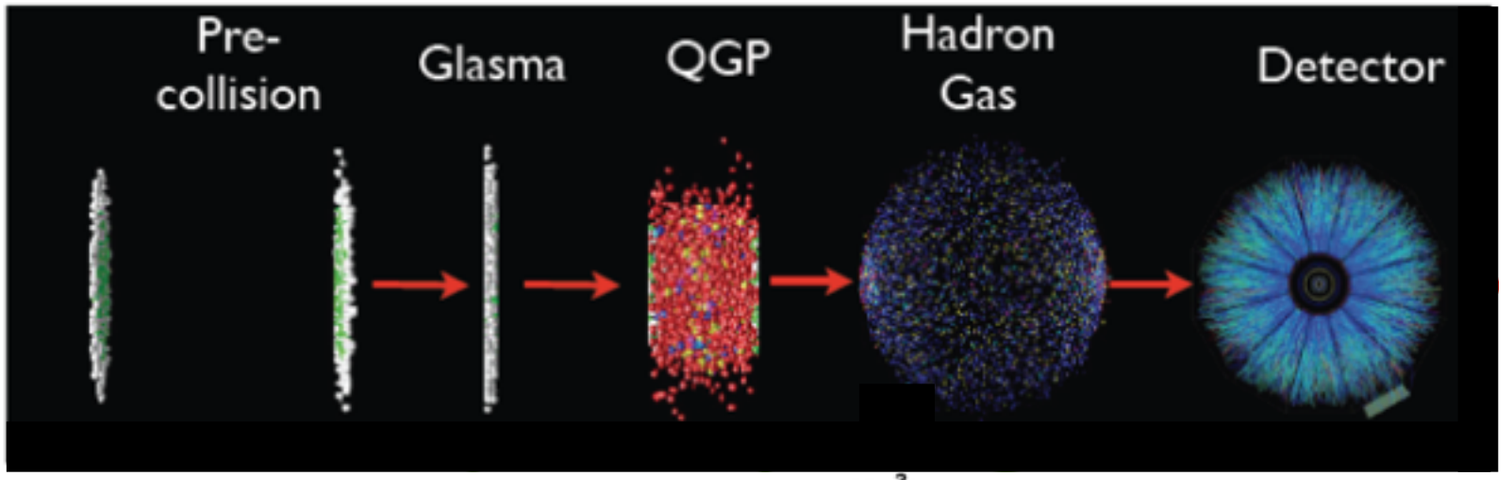
- Introduction
- Charge dipole separation

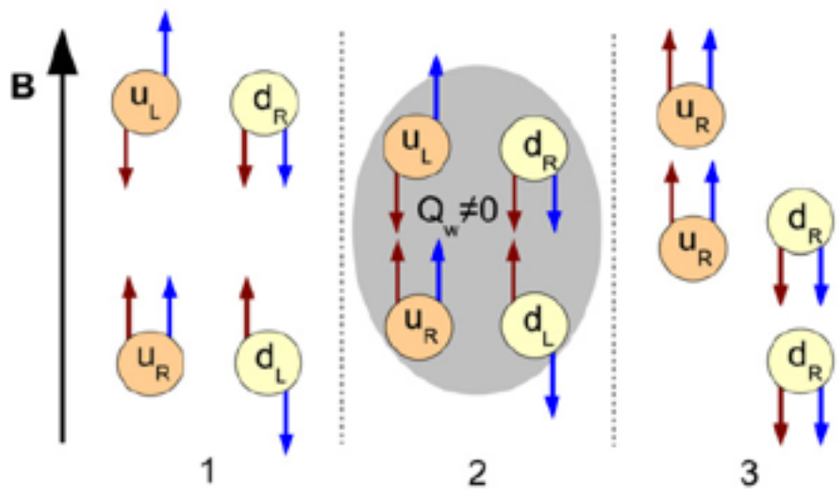
  [1] G.-L. Ma and B. Zhang, PLB 700 (2011) 39 [arXiv: 1101.1701].
  [2] Q. -Y. Shou, G.-L. Ma and Y. -G. Ma, arXiv: 1405.2668.
- Charge quadrupole separation

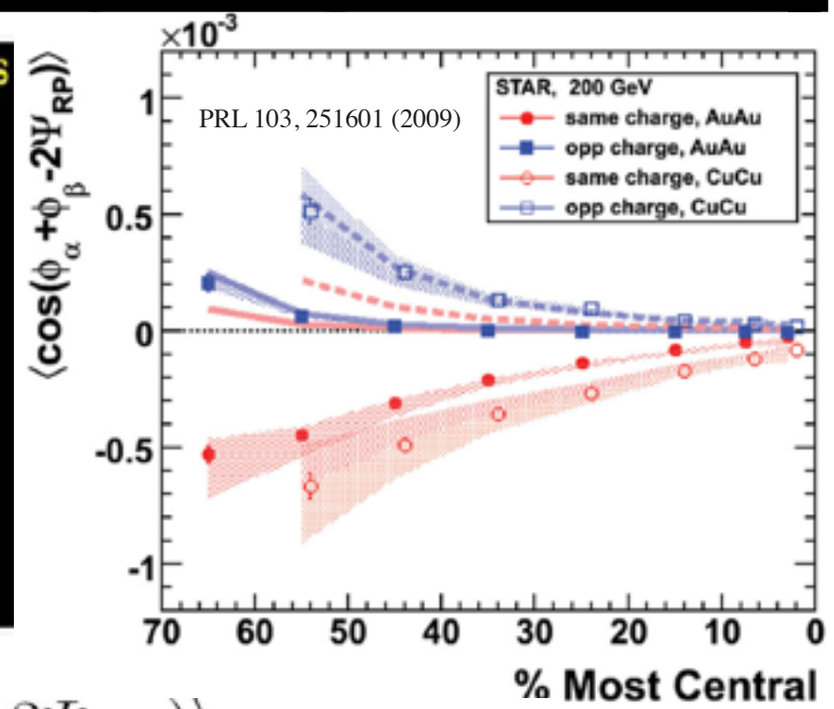
  [3] G.-L. Ma, arXiv: 1401.6502.
- Summary

Dipole charge separation









- RHIC data are consistent with the CME expectation that charges could be distributed asymmetrically w.r.t reaction plane, i.e. charge separation.

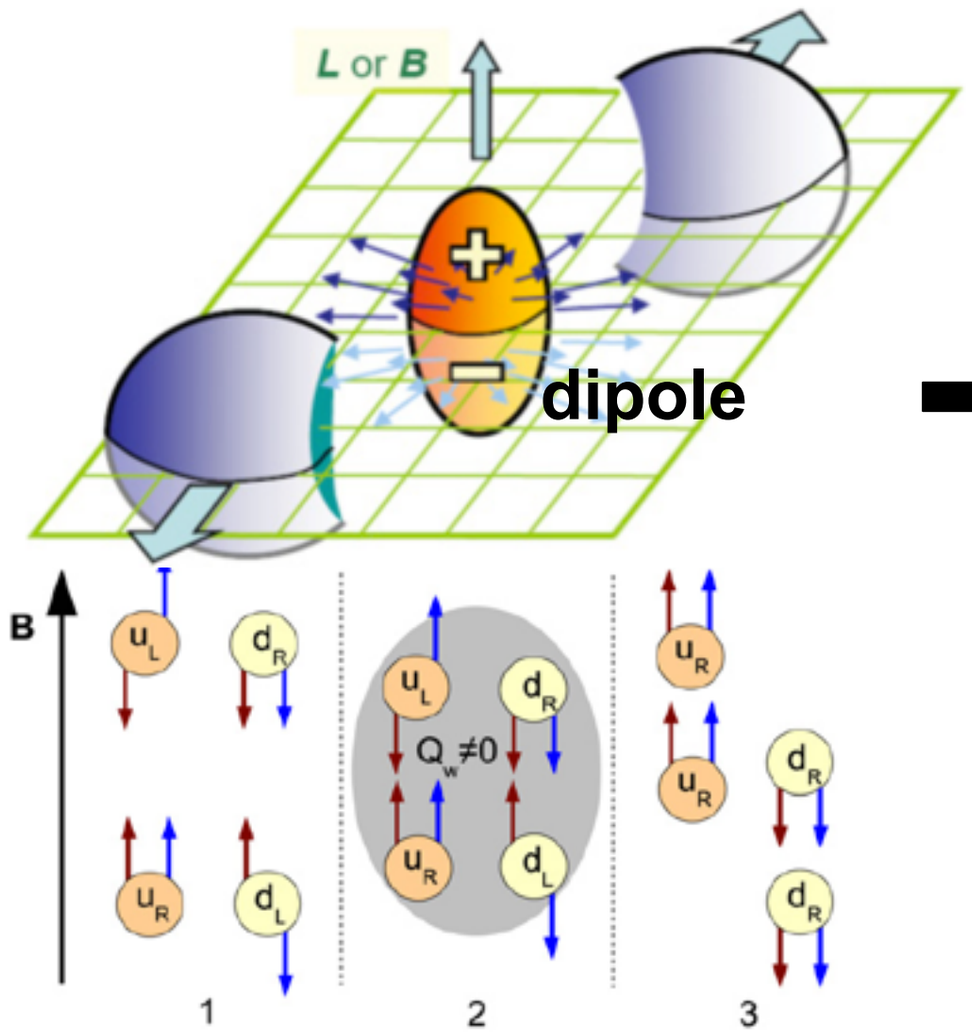
$$\langle\cos(\phi_\alpha+\phi_\beta-2\Psi_{RP})\rangle = [\langle v_{1,\alpha}v_{1,\beta}\rangle + B_{in}] - [\langle a_\alpha a_\beta\rangle + B_{out}]$$

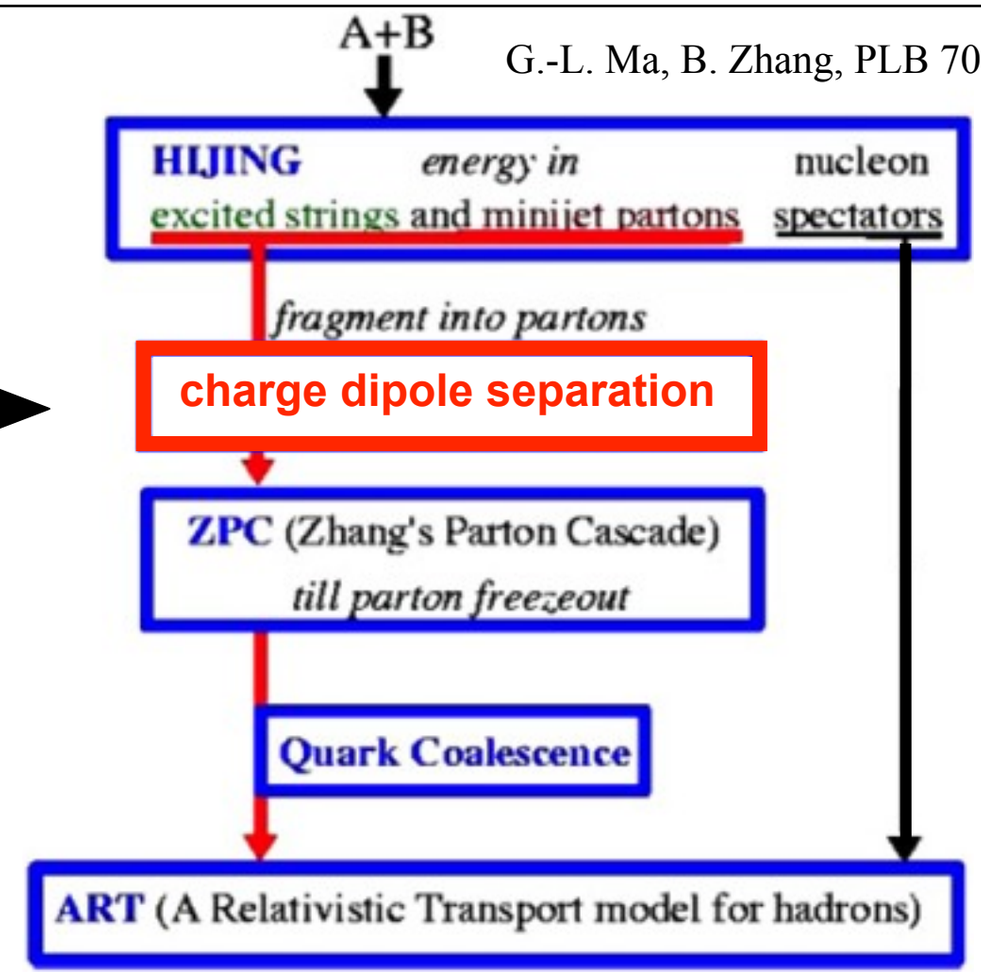
Non-flow/non-parity effects: largely cancel out

Directed flow: vanishes if measured in a symmetric rapidity range

P-even quantity: still sensitive to charge separation

Study dipole charge separation with AMPT model





G.-L. Ma, B. Zhang, PLB 700 (2011) 39

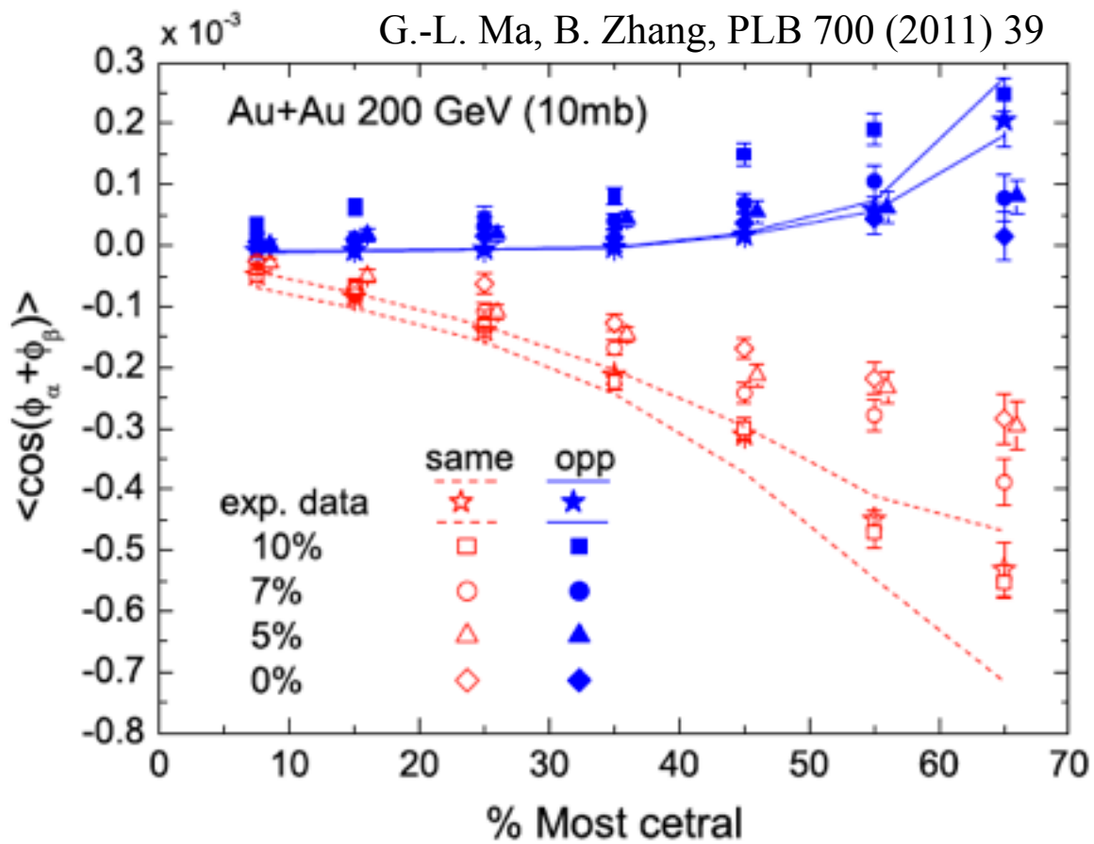
- **We include initial dipole charge separation mechanism into AMPT model.**

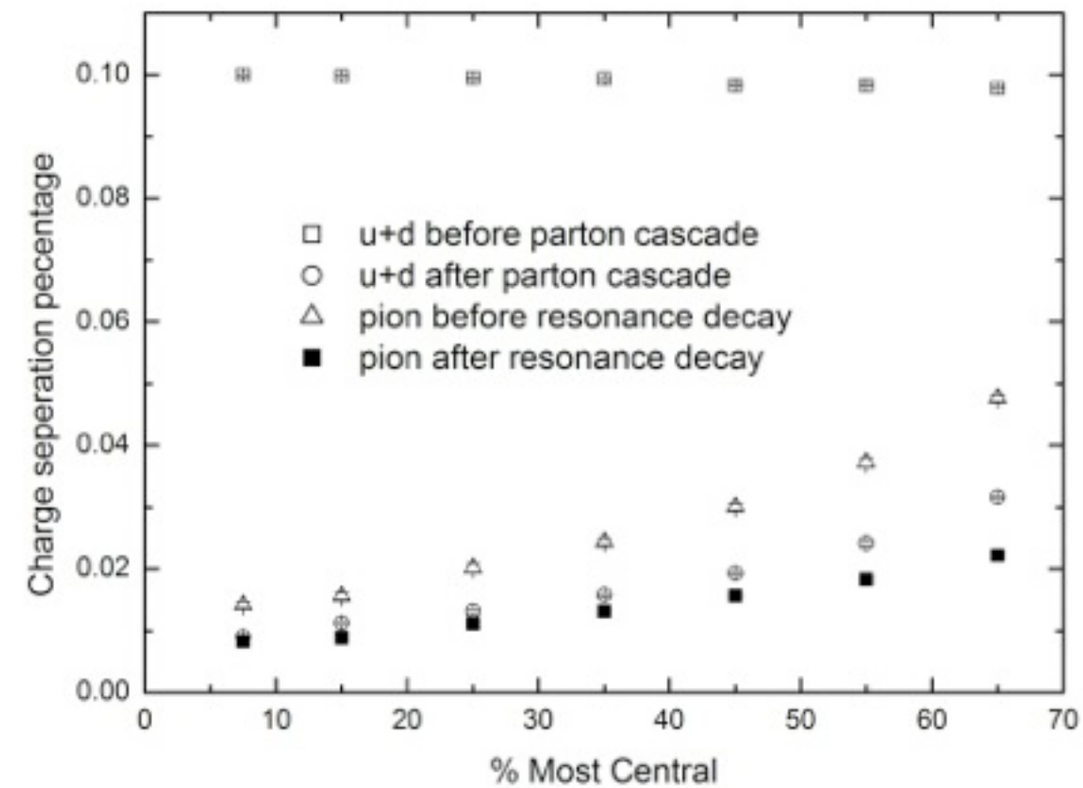
We switch the p_y values of a percentage of the downward moving u quarks with those of the upward moving u-bar quarks, and likewise for d-bar and d quarks. (The percentage is a relative ratio with respect to the total number of quarks.)

- **We focus on final interaction effects on the charge separation, including parton cascade, hadronization, resonance decays.**
- Resonance decays are implemented to ensure charge conservation.

<cos(φα+φβ)> from AMPT with a global charge separation

G.-L. Ma, B. Zhang, PLB 700 (2011) 39

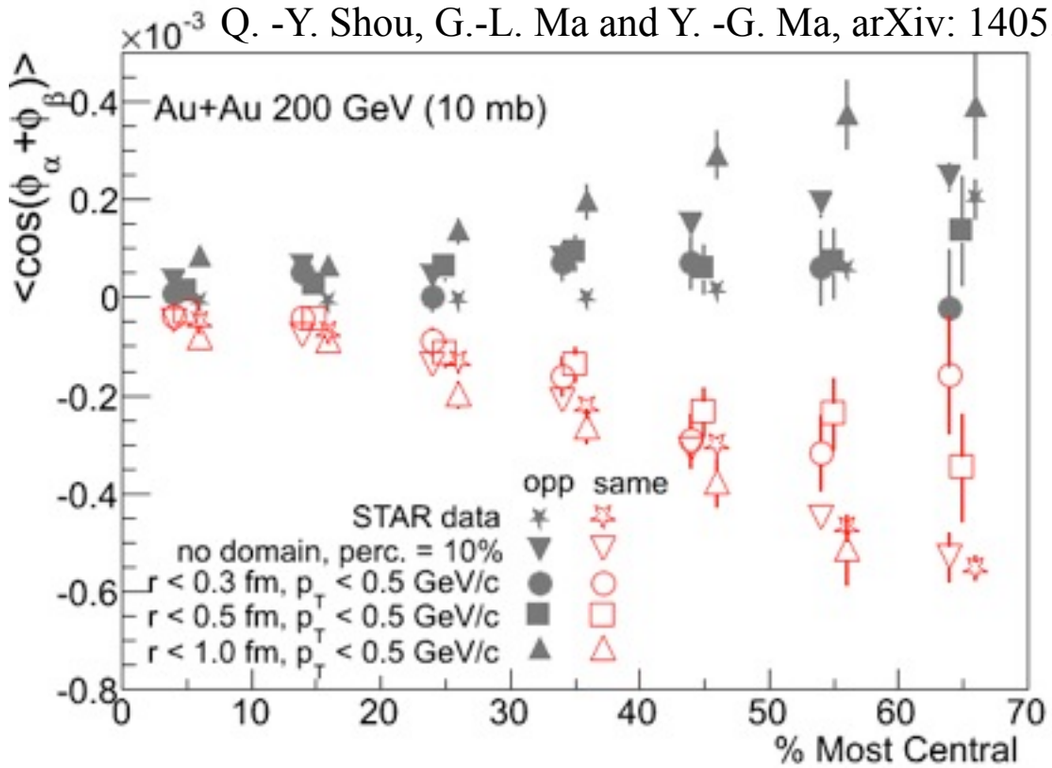


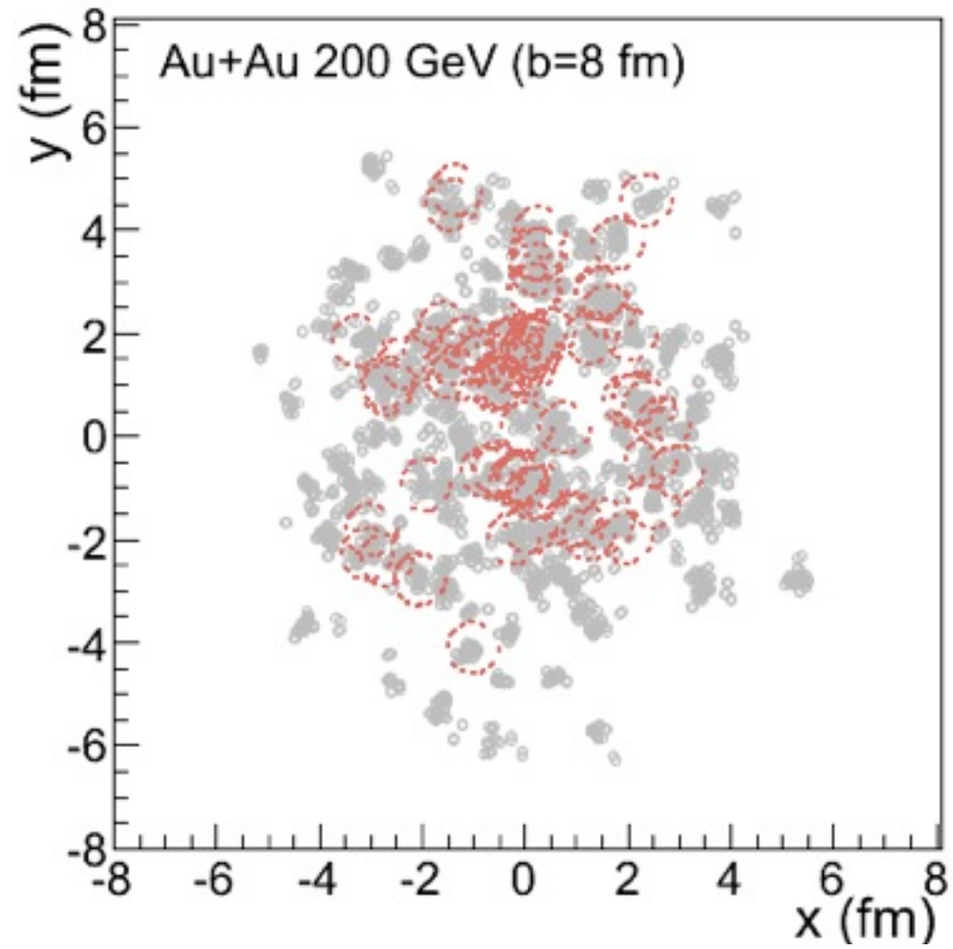


- An initial charge separation ~10% can describe same-charge data in the presence of strong final state interactions.
- From a percentage of charge separation of 10% in the beginning →1-2% percentage at the end.

$\langle\cos(\varphi_\alpha+\varphi_\beta)\rangle$ from AMPT with a local charge separation

Q. -Y. Shou, G.-L. Ma and Y. -G. Ma, arXiv: 1405.2668



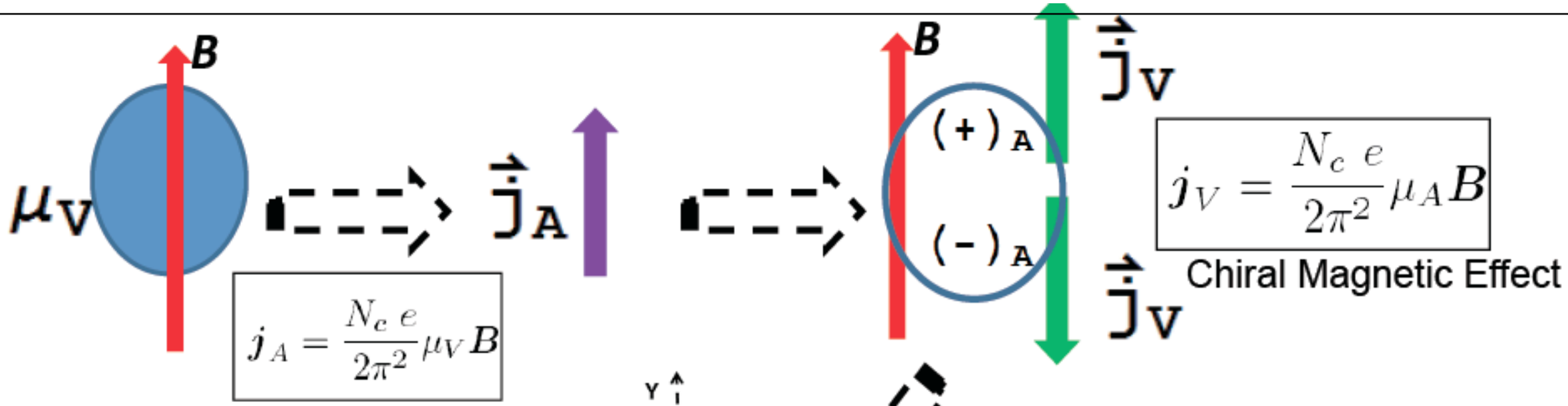


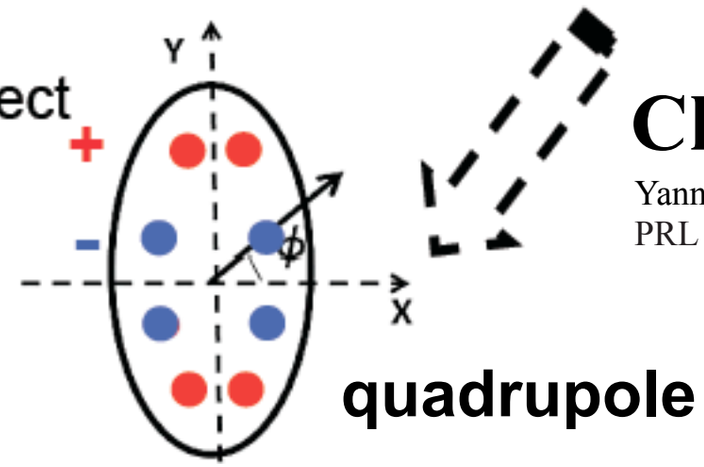
- A domain-based charge separation improves the description of opposite-charge correlation.
- The size and number of metastable domains should be relatively small in the early stage of QGP.

TABLE I: The occupancy factors of the total volume of domains over the fireball volume as functions of centrality bin in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

% Most Central	$r < 0.3$ fm	$r < 0.5$ fm	$r < 1$ fm
0-10	0.38 %	4.15 %	65.81 %
10-20	0.40 %	4.29 %	70.62 %
20-30	0.36 %	4.00 %	67.31 %
30-40	0.31 %	3.35 %	59.71 %
40-50	0.26 %	2.69 %	48.79 %
50-60	0.19 %	2.20 %	42.33 %
60-70	0.21 %	2.19 %	41.66 %

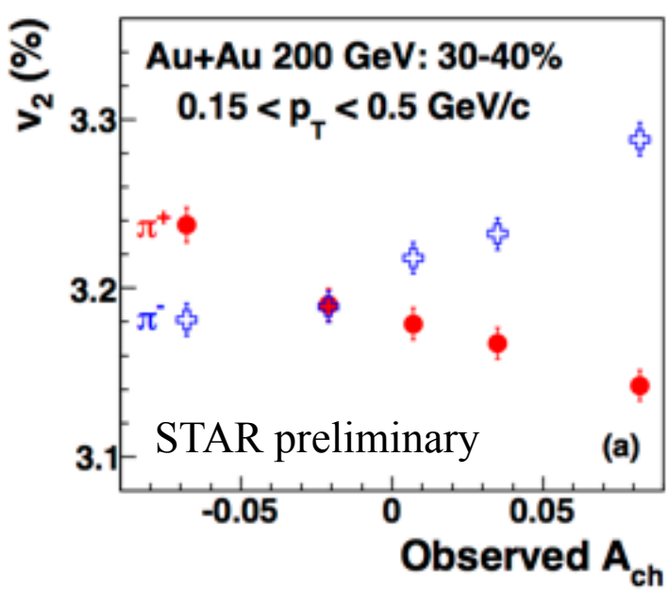
Quadrupole charge separation: charge asymmetry of pion v2

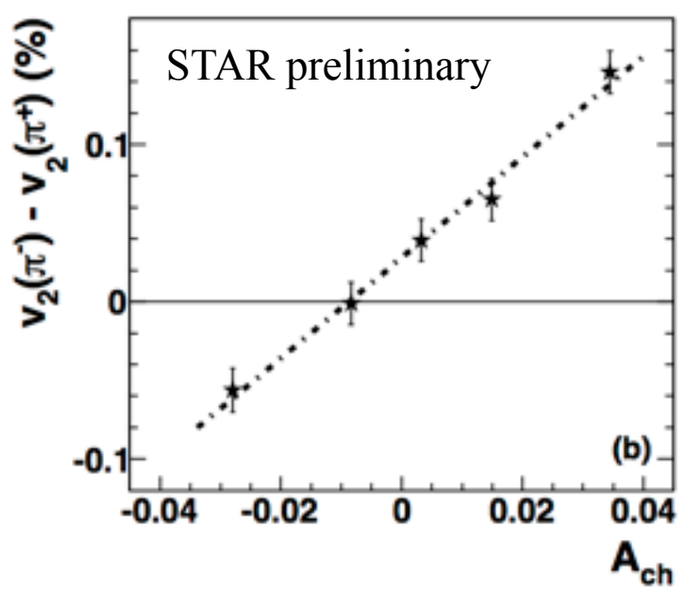




Chiral magnetic wave

Yannis Burnier, Dmitri Kharzeev, Jinfeng Liao, Ho-Ung Yee, PRL 107, 052303 (2011)



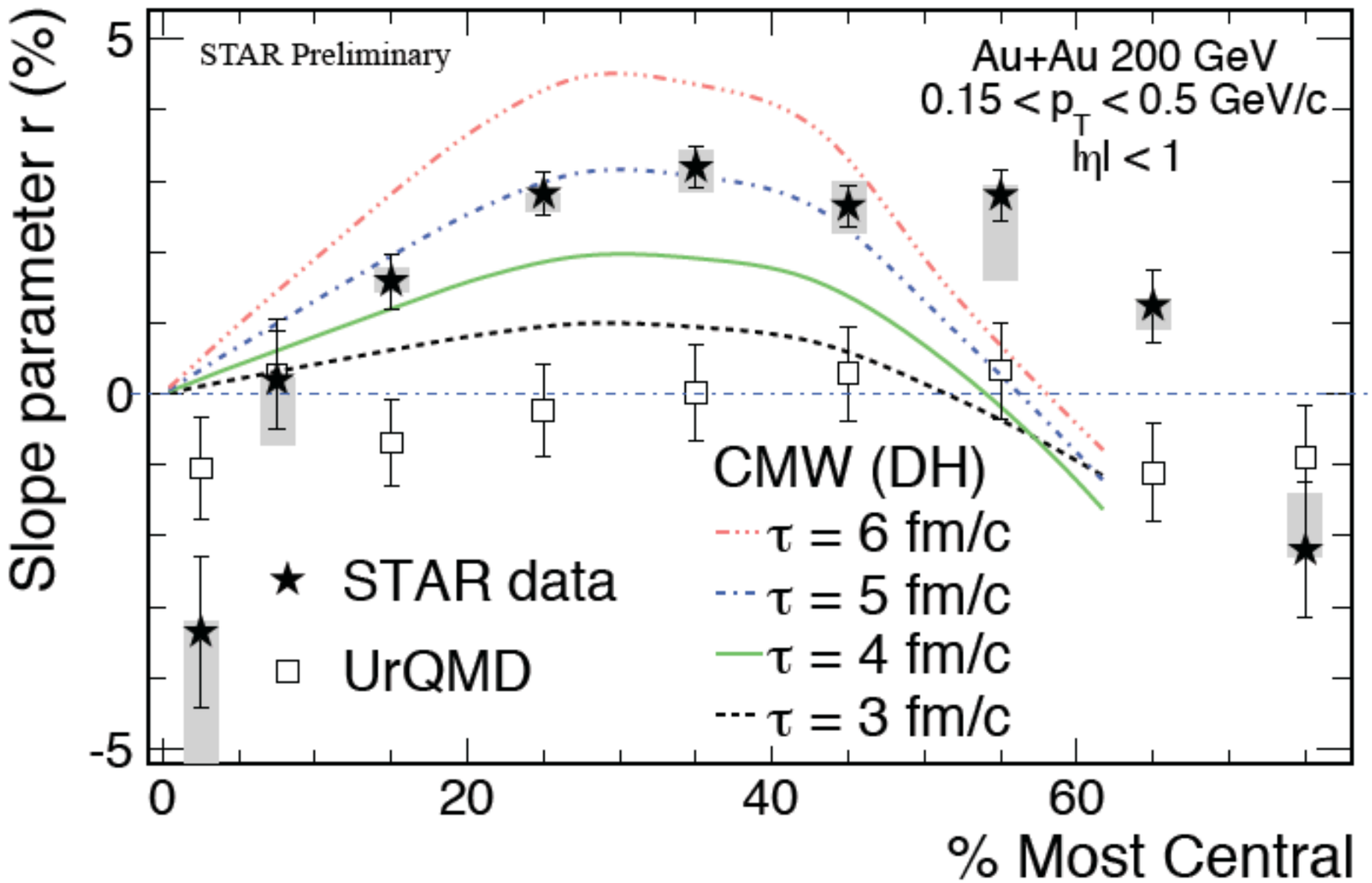


$$v_2^{\pm} = v_2 \mp \frac{r}{2} A_{ch}$$

$$v_2^{-} - v_2^{+} = r A_{ch}$$

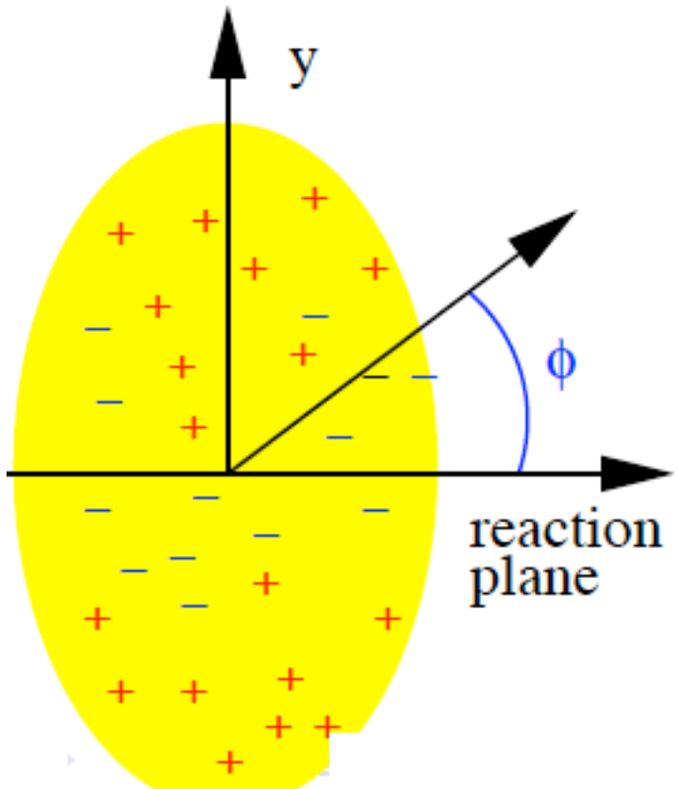
- RHIC-STAR preliminary data are consistent with the CMW expectation of charge asymmetry of pion elliptic flow.

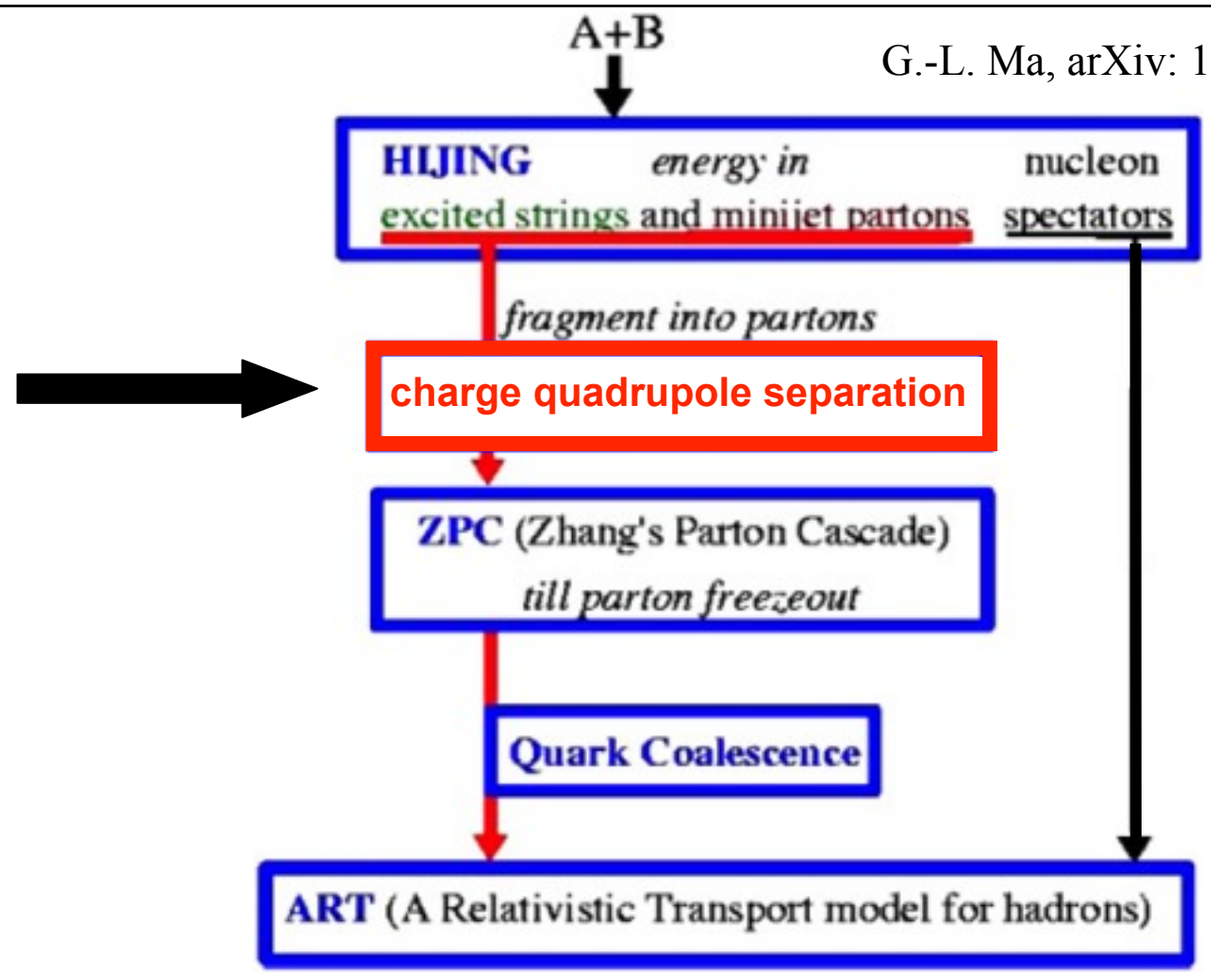
Charge asymmetry slope r of pion v2



- RHIC-STAR preliminary data can be described by the CMW expectations with different CMW duration times.
- UrQMD can not reproduce the slopes r.

Study quadrupole charge separation with AMPT model





G.-L. Ma, arXiv: 1401.6502

- **How to include initial quadrupole charge separation into the AMPT model:**

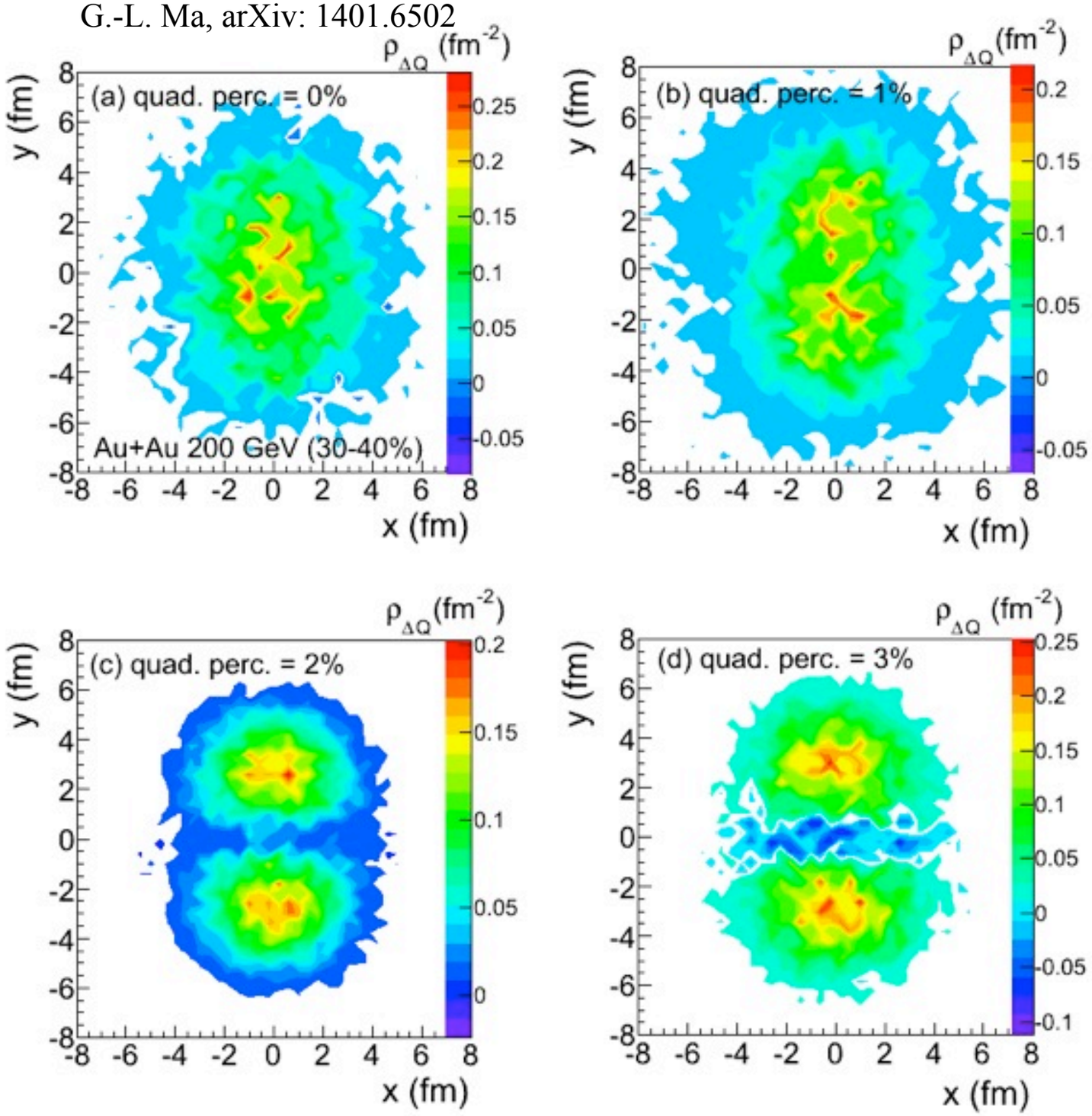
I switch the positions (x,y,z) of a fraction of the small-|y| u quarks with those of large-|y| u-bar quarks, and likewise for d-bar and d quarks for Ach>-0.01 events; A contrary manner for A_{ch}<-0.01 events. (The percentage is a relative ratio with respect to the total number of quarks.)

- **The goal is to learn some properties of chiral magnetic wave through how final charge asymmetry of pion v_2 depends on the quadrupole fraction without $\vec{B}$ and $\vec{E}$.**

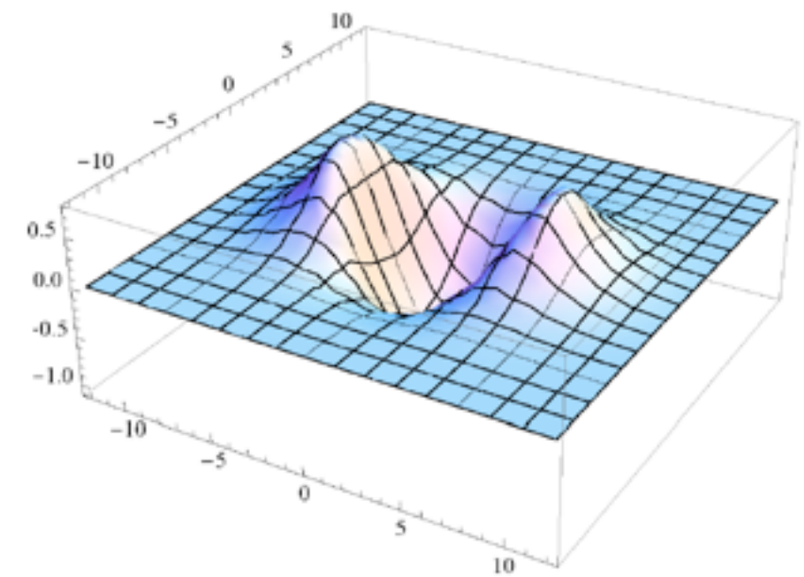
(Note: only resonance decays are employed to ensure charge conservation, no hadron scatterings for hadronic phase here.)

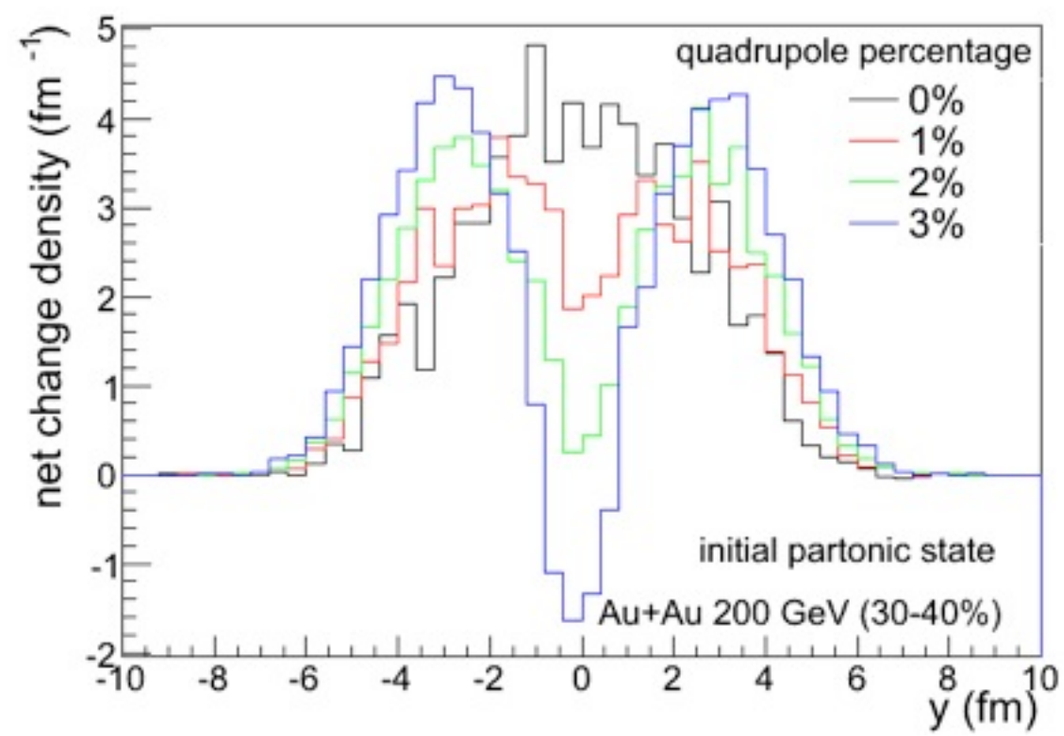
Initial charge quadrupole distribution

G.-L. Ma, arXiv: 1401.6502



Yannis Burnier, Dmitri Kharzeev, Jinfeng Liao, Ho-Ung Yee,PRL 107, 052303 (2011)

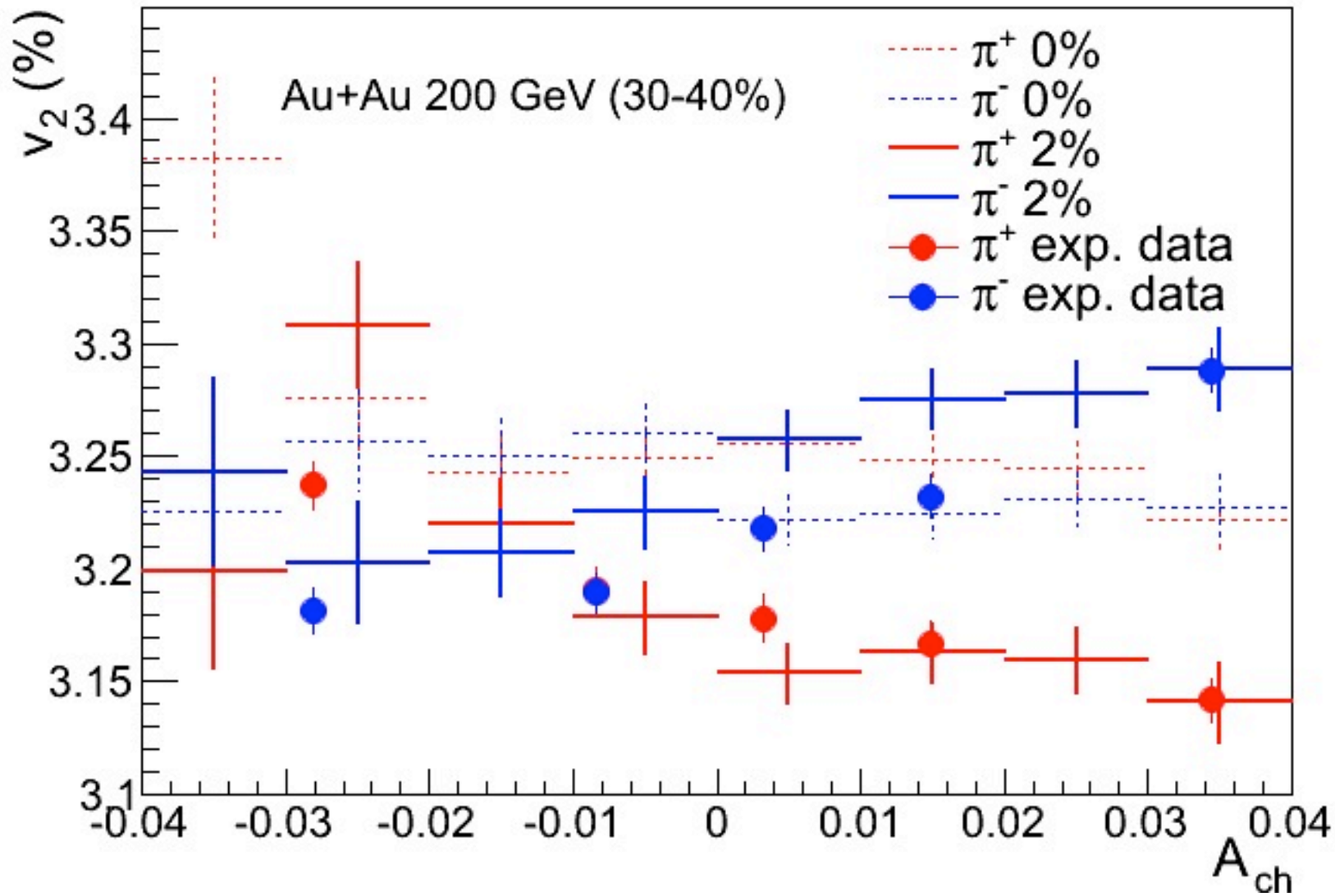




- Initial partonic net charge distribution changes with quadrupole percentage.

Charge asymmetry of pion v2

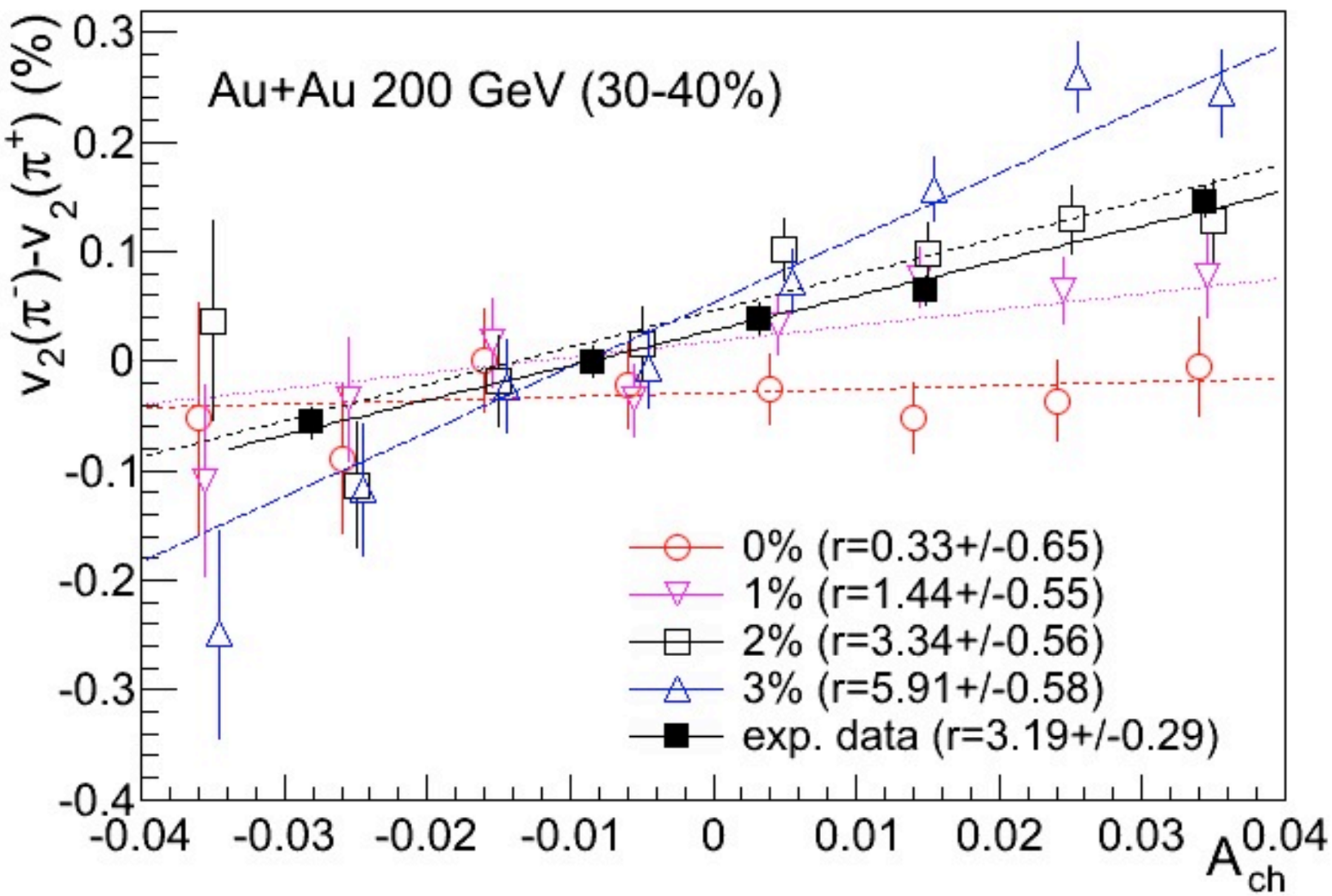
G.-L. Ma, arXiv: 1401.6502



- The Ach dependences of pion+/- v_2 appear with a non-zero initial charge quadrupole.

Δv_2 vs A_{ch}

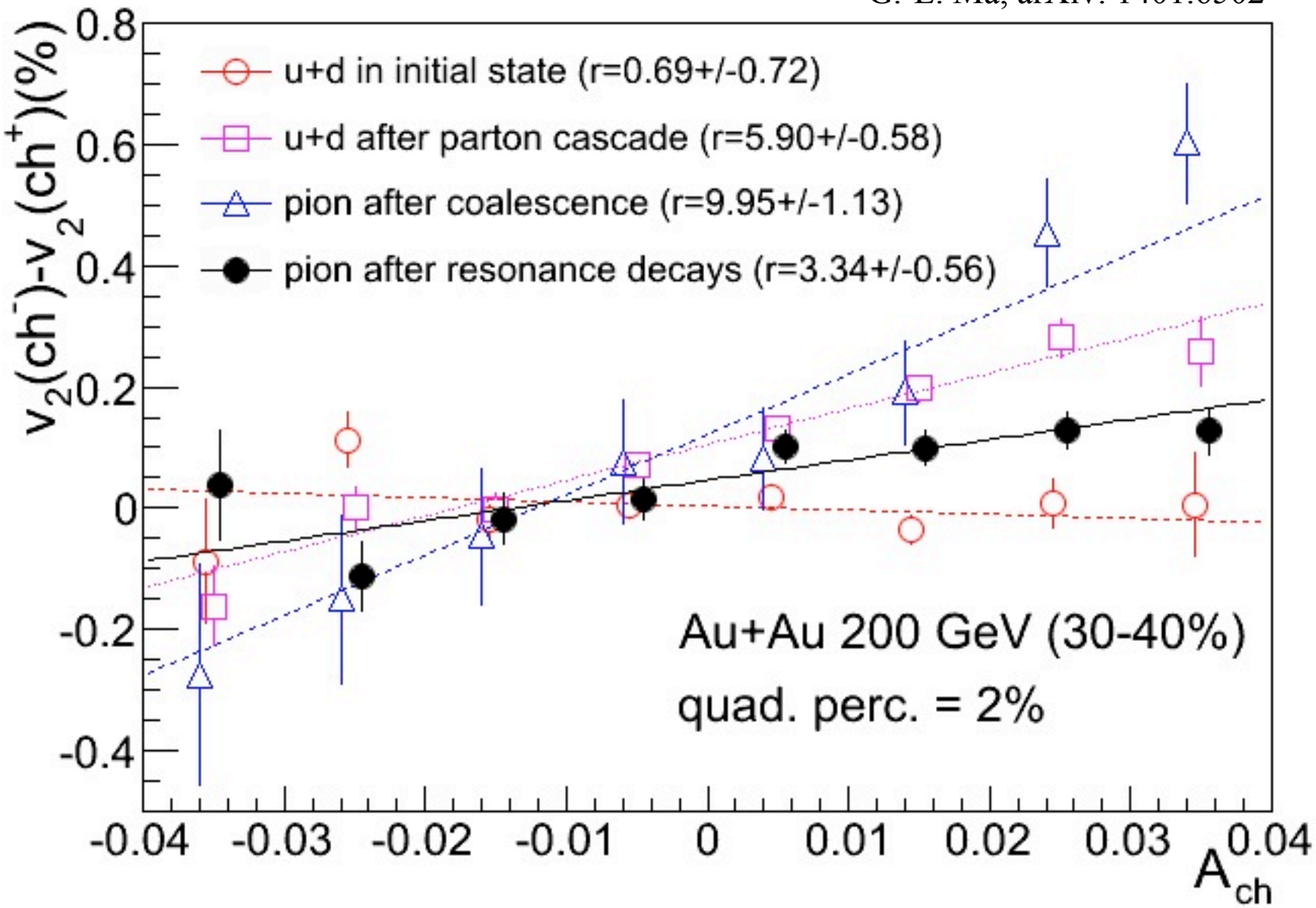
G.-L. Ma, arXiv: 1401.6502



- No charge asymmetry of pion v_2 for the initial quadrupole percentage of 0%.
- Δv_2 increases with A_{ch} for non-zero initial quadrupole percentages.
- Δv_2 increases faster with larger initial quadrupole percentage.

Stage evolution for charge asymmetry of v2

G.-L. Ma, arXiv: 1401.6502



r=9.950 +/- 1.134 ③

r=5.898 +/- 0.577 ②

r=3.343 +/- 0.558 ④

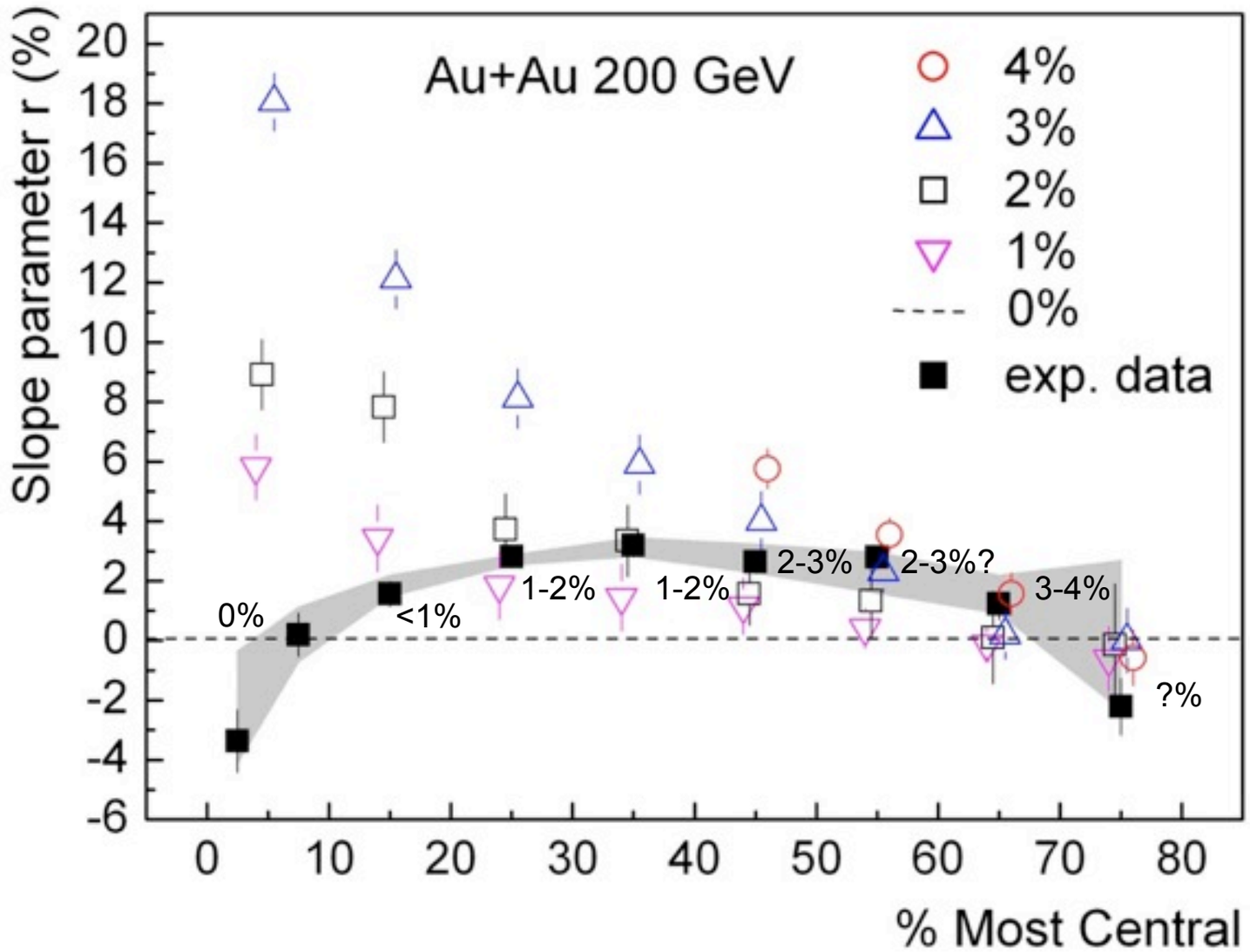
r=-0.690 +/- 0.718 ①

exp. data:
r=3.187 +/- 0.286

- The slope r appears after parton cascade.
- The slope r increases after coalescence.
- The slope r is largely weaken due to resonance decays.

A helpful constraint on CMW

G.-L. Ma, arXiv: 1401.6502



centrality bin	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%
initial quad. perc.	0%	<1%	1-2%	1-2%	2-3%	2-3%	3-4%	?%

- It gives a constraint (<4%) to the centrality dependence of initial quadrupole percentage.

Summary

- Final interactions reduce charge azimuthal correlation$<\cos(\phi_a+\phi_\beta)>$, it indicates the percentage of initial dipole charge separation > 5%[1].
- Domain-based AMPT results indicates that the size and number of metastable domains should be relatively small in the early stage of QGP[2].
- The slope r of charge asymmetry of pion v2 is sensitive to the percentage of the initial charge quadrupole separation, which give a helpful constraint (<4%) to the CMW effect[3].

References:

[1] G.-L. Ma, B. Zhang, PLB 700, 39 (2011) [arXiv: 1101.1701].

[2]Q. -Y. Shou, G.-L. Ma and Y. -G. Ma, arXiv: 1405.2668.

[3] G.-L. Ma, arXiv: 1401.6502.