Studying the CME with the AMPT model

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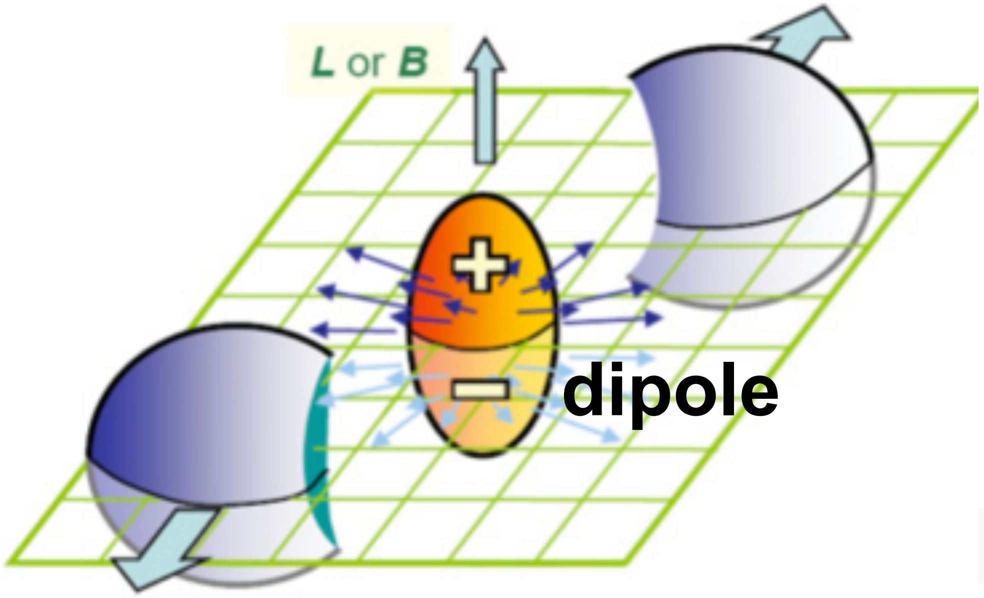
Outline

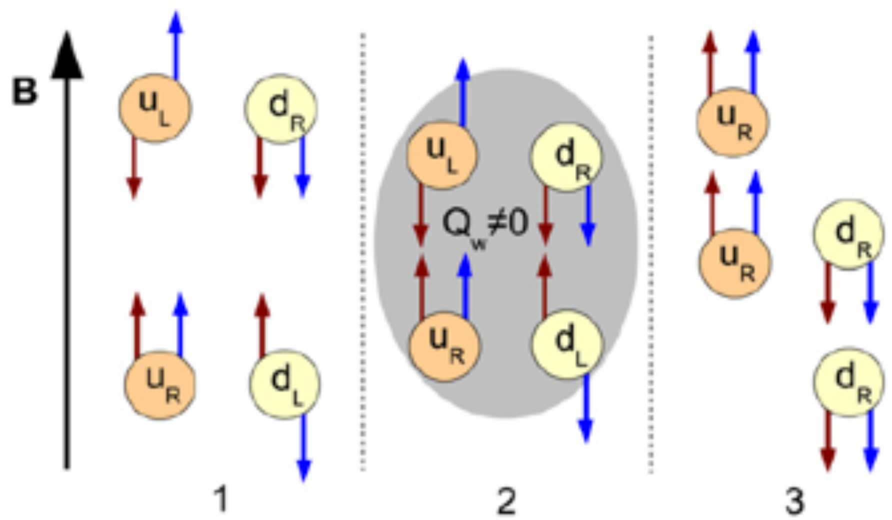
- **Introduction**
- **AMPT results on CME at RHIC**
- **AMPT results on CME at LHC**
- **AMPT simulations on Isobar exp.**
- **Summary**

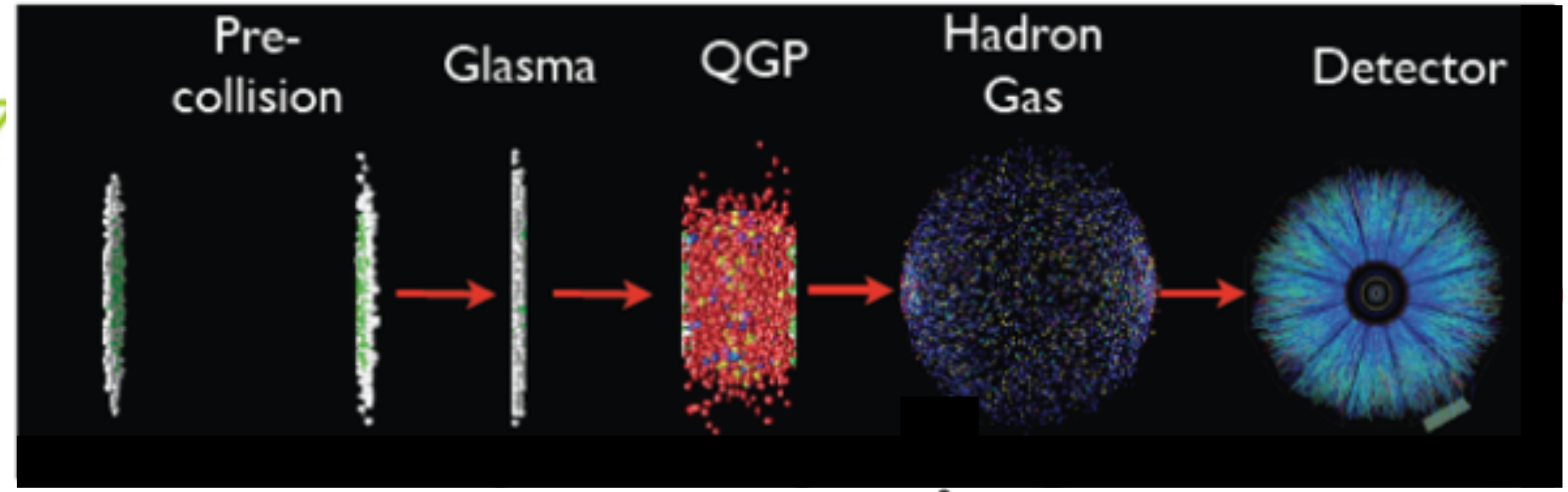
(I)AMPT results on CME

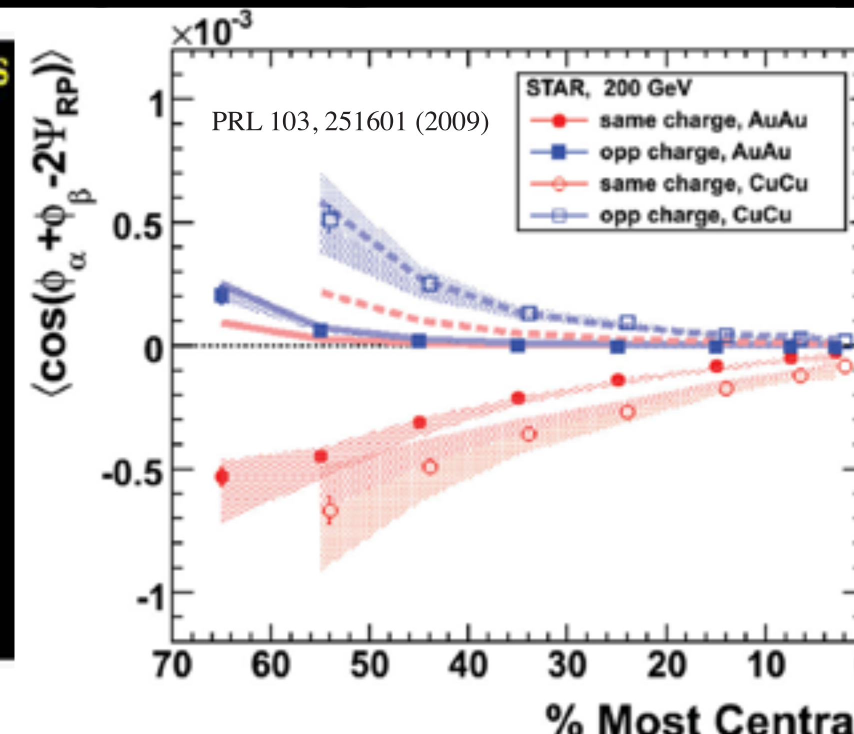
[1] G.-L. Ma and B. Zhang, PLB 700 (2011) 39 [arXiv: 1101.1701].
[2] Q. -Y. Shou, G.-L. Ma and Y. -G. Ma, PRC 90 (2014) 047901 [arXiv: 1405.2668].

Chiral Magnetic Effect=> dipole charge separation









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

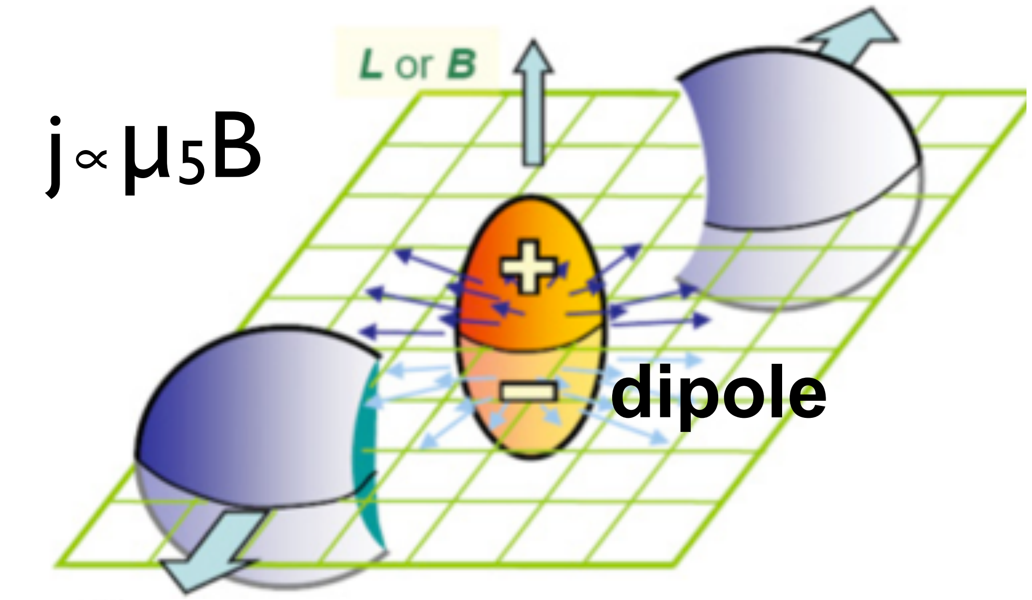
$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle$$
$$= [\langle v_{1,\alpha} v_{1,\beta}\rangle + B_{in}] - [\langle a_\alpha a_\beta\rangle + B_{out}]$$

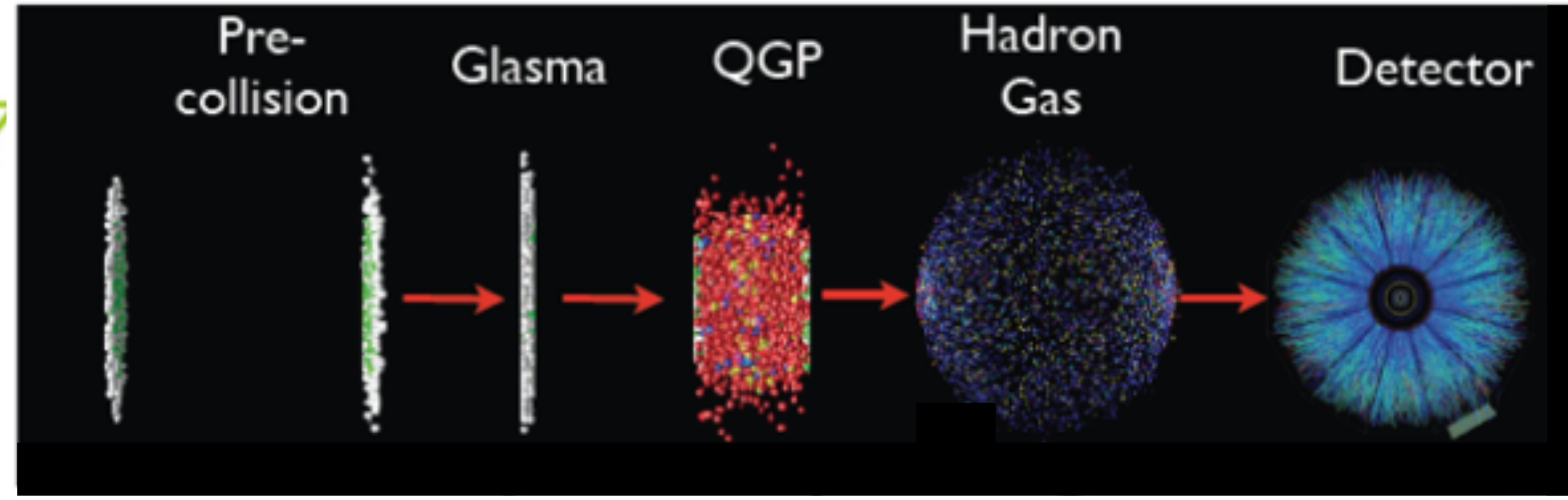
Directed flow: vanishes
if measured in a symmetric rapidity range

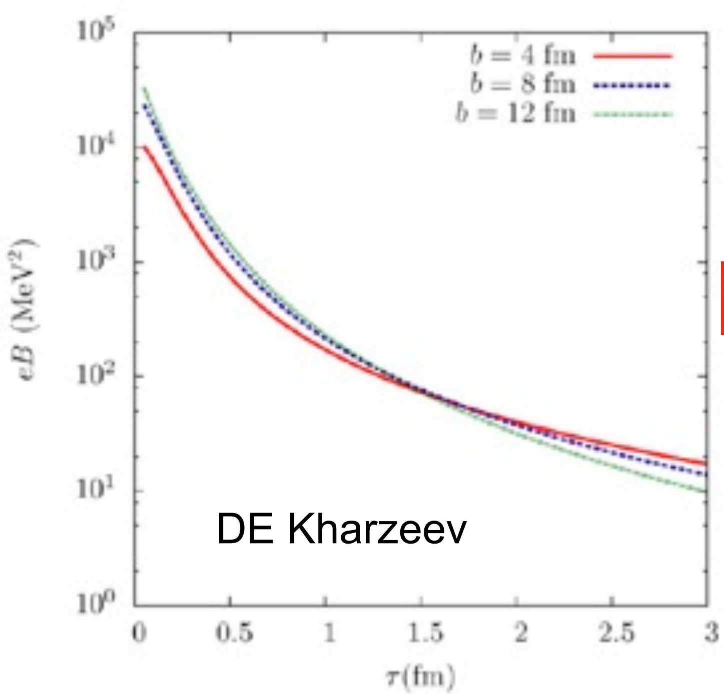
Non-flow/non-parity effects:
largely cancel out

P-even quantity:
still sensitive to charge separation

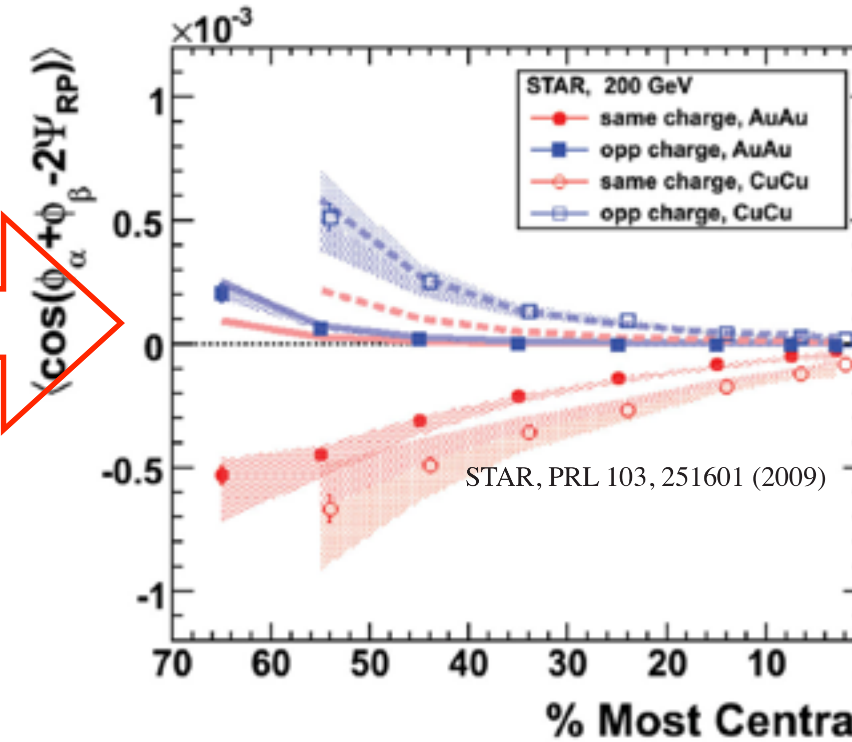
Can CME signal survive from final state interactions?





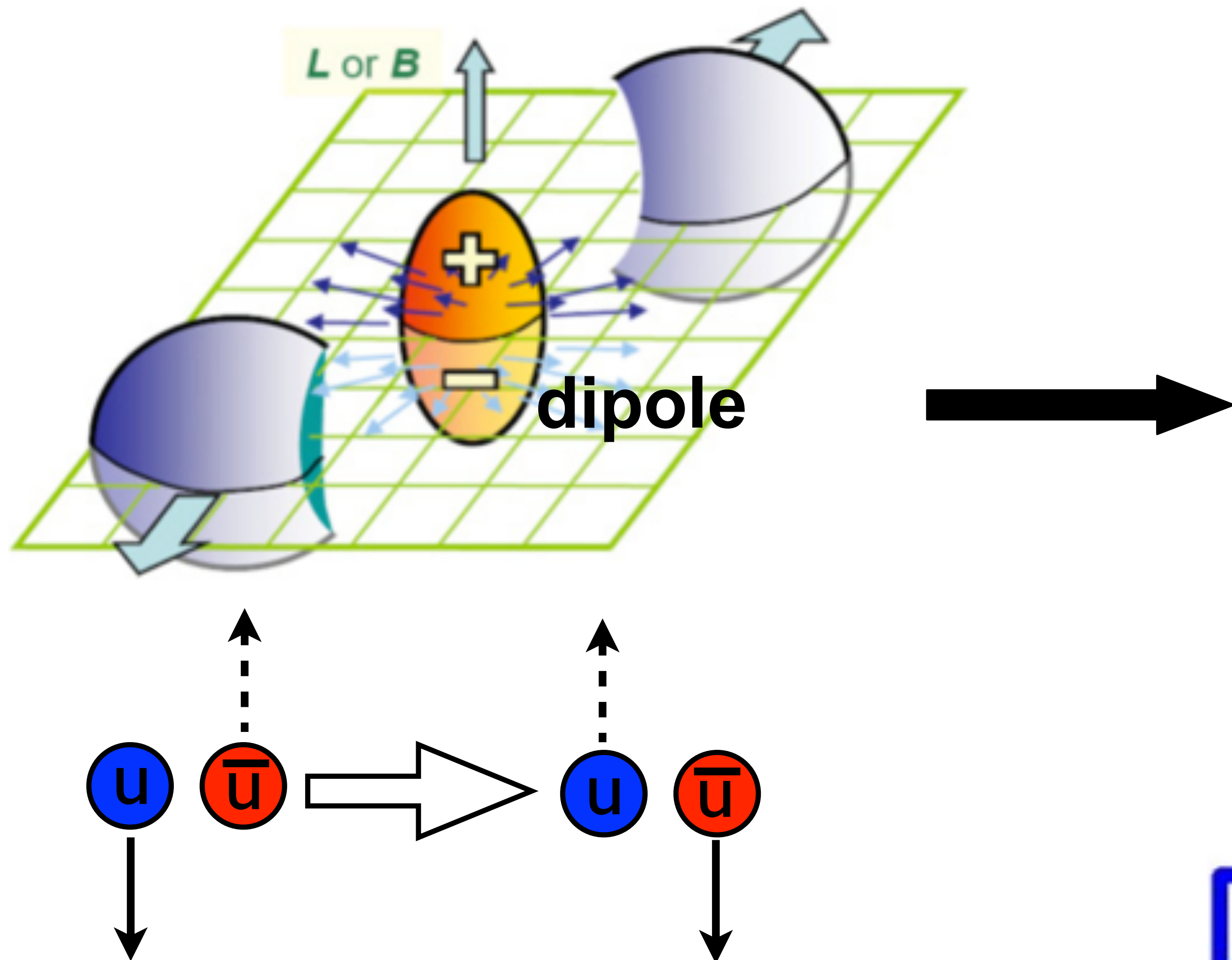


final state interaction effects

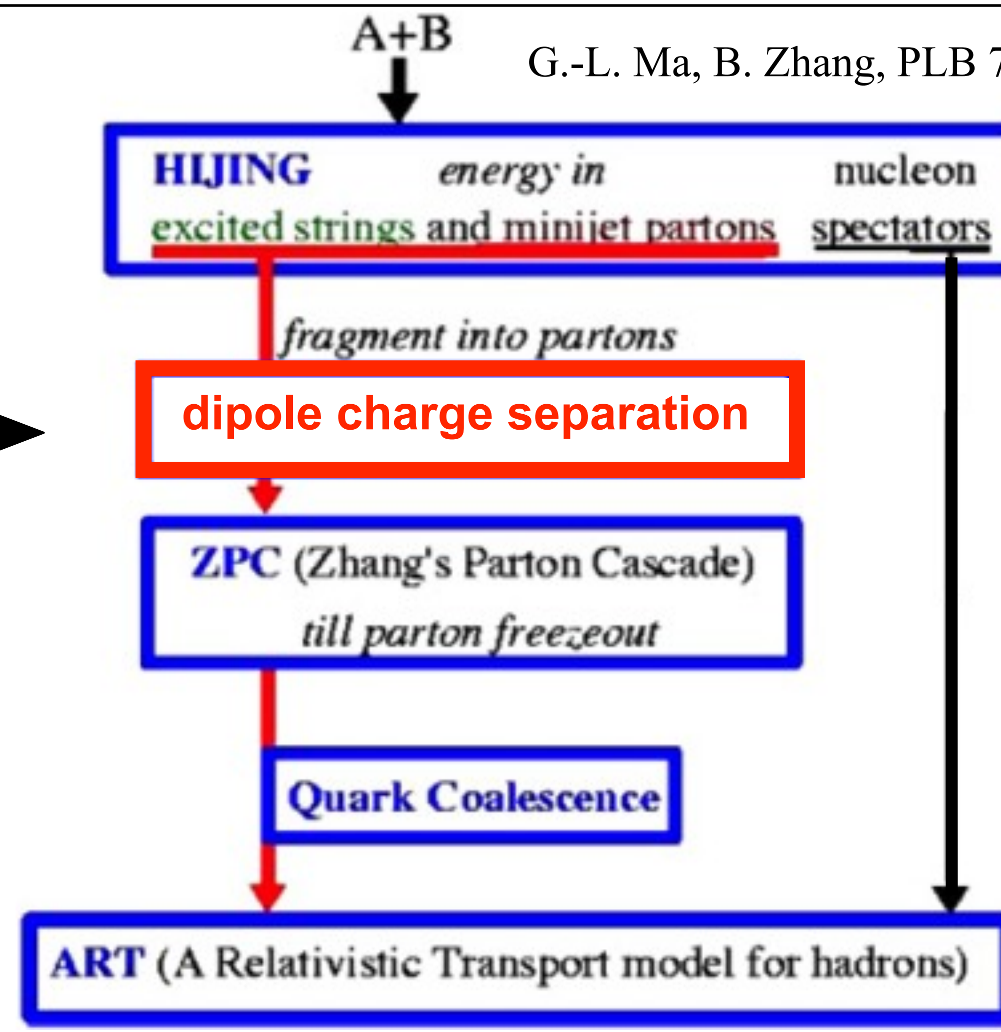


- The lifetime of B field is short. →The CME is an initial effect.
- Final state interaction effects on the CME could be important.

The AMPT model with dipole charge separation



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



$f\% = (N^{+}_{upward} - N^{+}_{downward}) / (N^{+}_{upward} + N^{+}_{downward})$

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

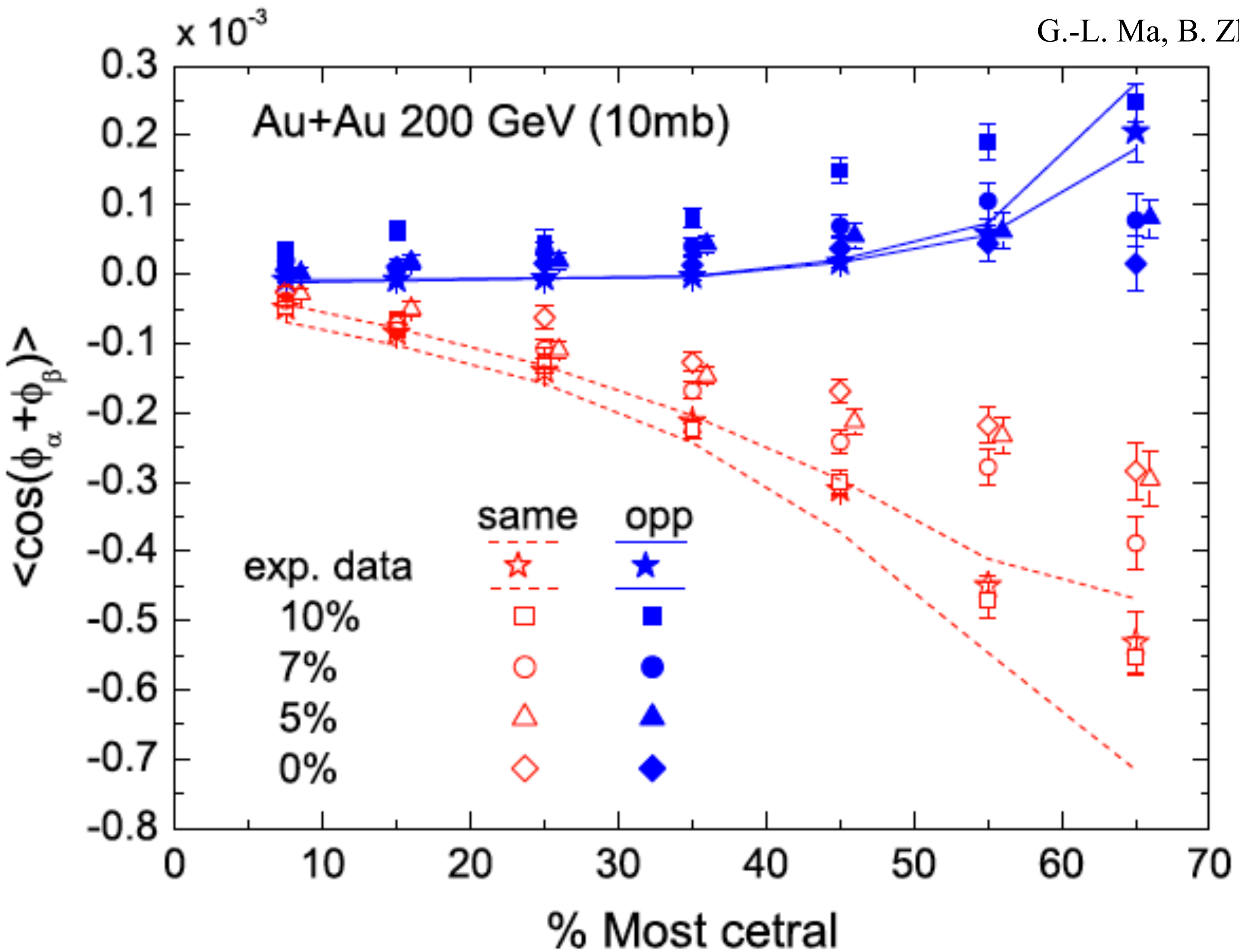
We switch the p_y values of a percentage of the downward moving u quarks with those of the upward moving u-bar quarks, and likewise for d-bar and d quarks, where the percentage is a relative ratio with respect to the total number of quarks.

- **We focus on final state effects on the charge separation, including parton cascade, hadronization, resonance decays after $\vec{B}$ and $\vec{E}$ vanish quickly.**

- **Resonance decays only are employed to ensure charge conservation, without hadron rescatterings.**

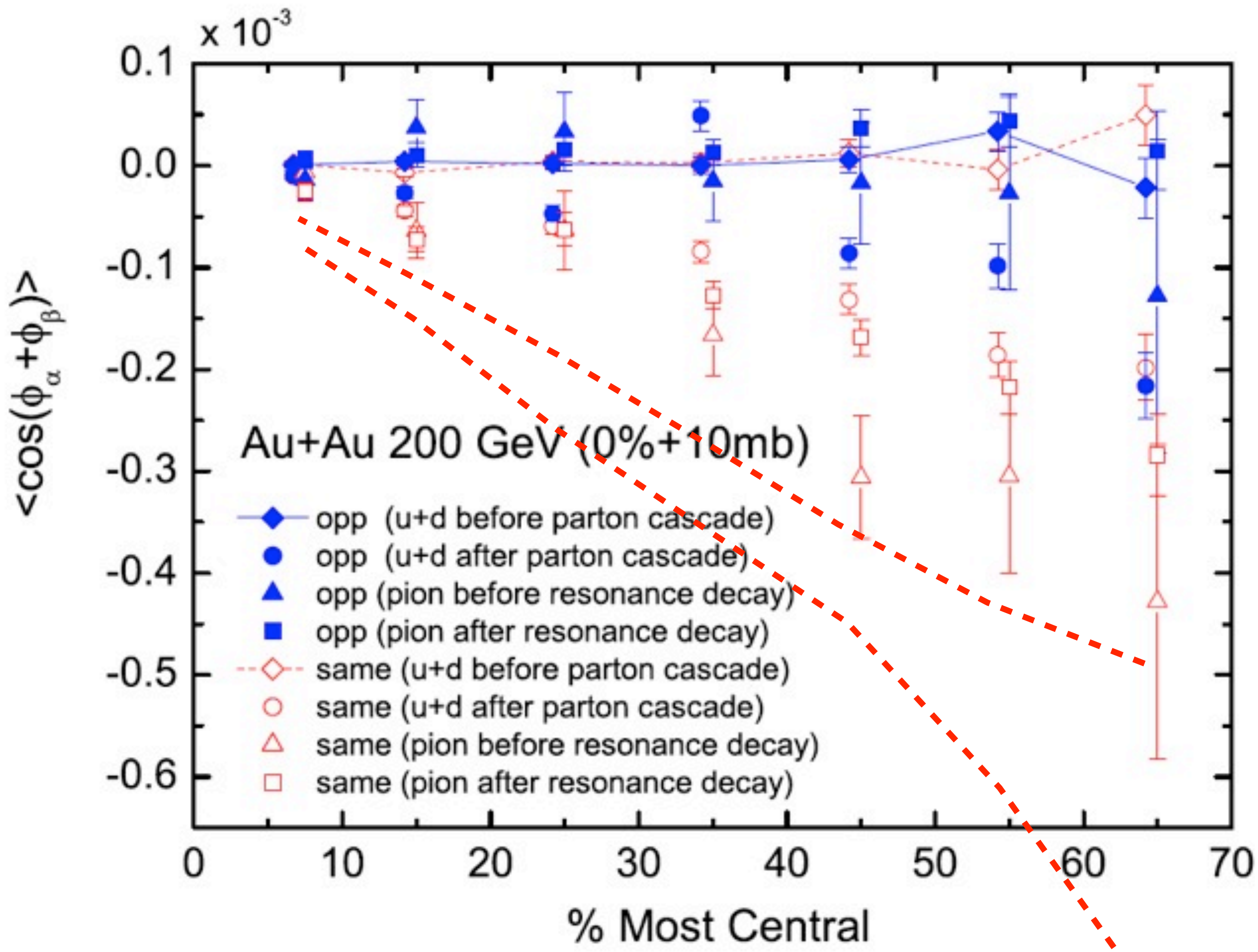
AMPT results on <cos(φα+φβ)>

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



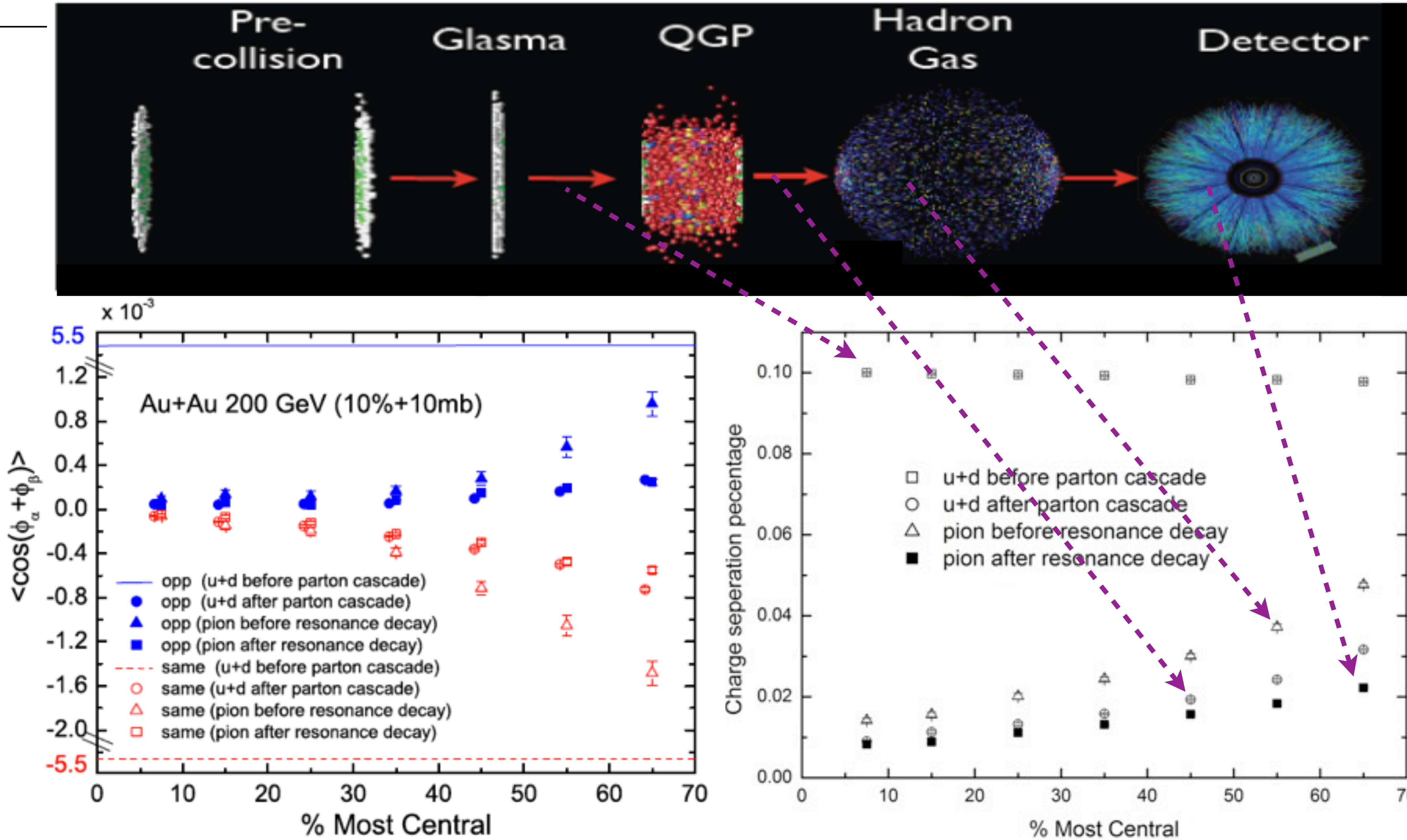
- Original AMPT (0%) underestimates exp. data.
- 10% initial charge separation can describe same-charge data.
- But 10% only can describe opposite-charge data for 60-70%.

Original AMPT=Background?



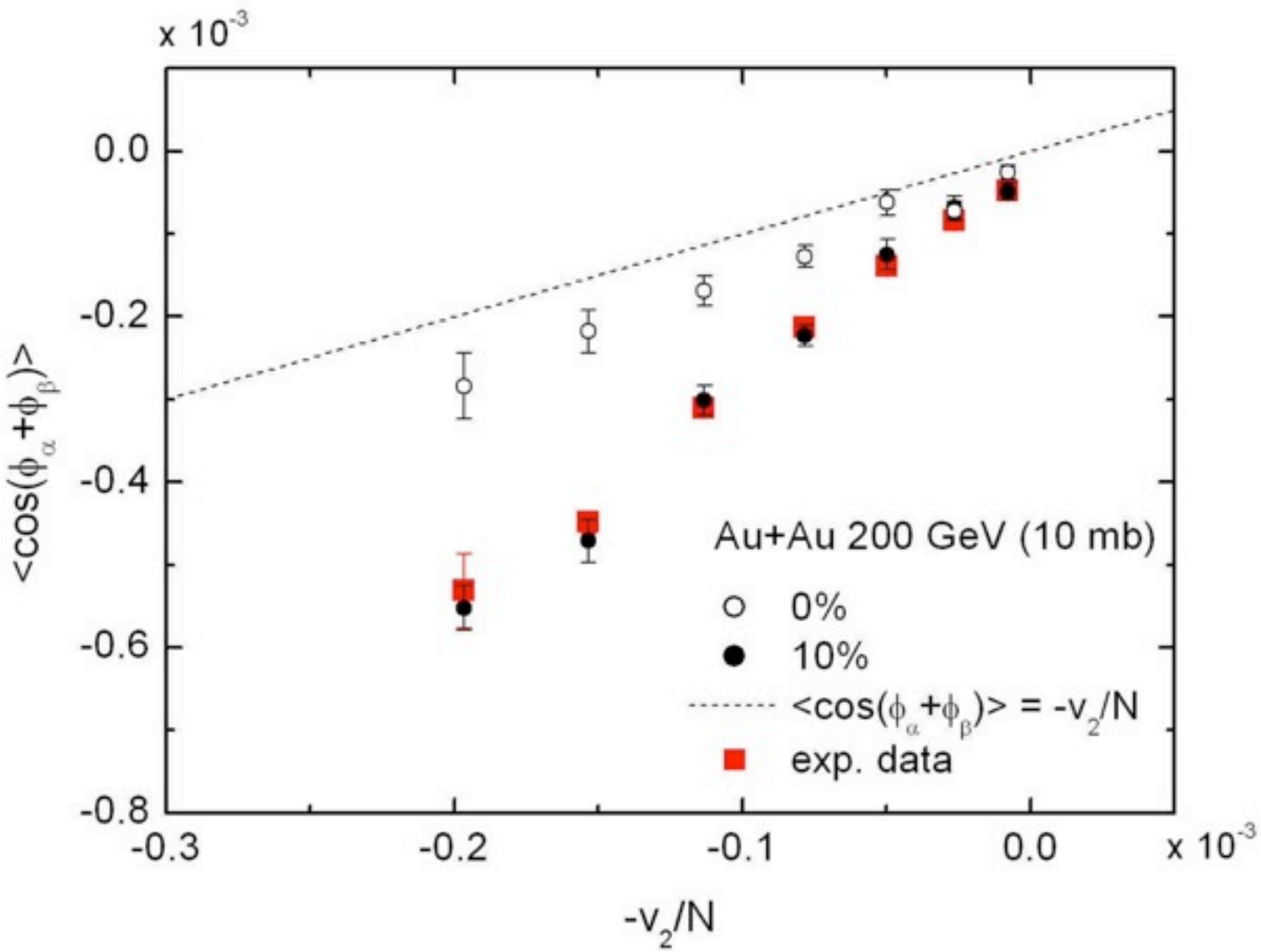
- Opp-charge and same-charge are consistent with zero initially.
- They become negative through parton cascae due to flow/TMC.
- Coalesce enhances same-charge and reduce opp-charge.
- Resonance decays reduce signal magnitude.

Final state effects on charge separation



- Parton cascade reduces charge separation significantly; Coalescence recovers some charge separation in part; Resonance decays reduce charge separation.
- 10% in the beginning →1-2% percentage at the end.

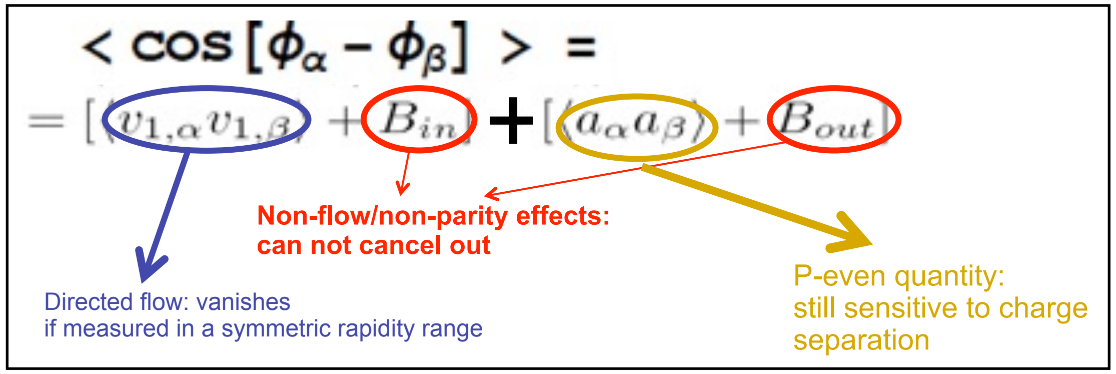
CME vs trans. mom. conservation



- The original AMPT result is very close to the expectation of trans. mom. conservation [dashed: $<\cos(\varphi_\alpha+\varphi_\beta)>=-v_2/N$].

- TMC can partly account for data, and an initial 10% dipole charge separation is needed.

AMPT results about <cos(φα-φβ)>



- AMPT gives the same trends as data.
- Initial charge separation is not enough to make up for the large difference between AMPT and data.
- **Other mechanisms needed for CME + BG?**

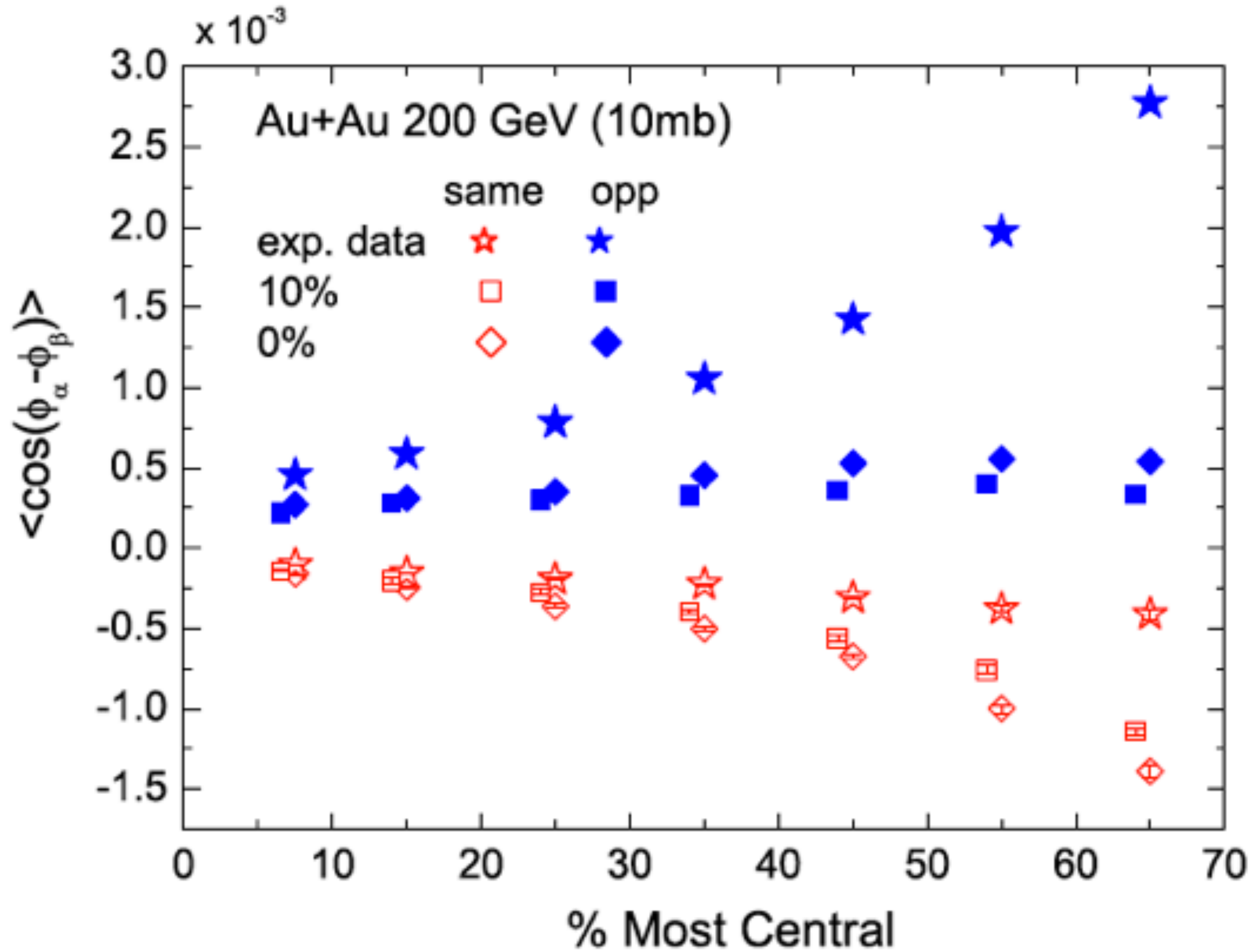


TABLE I. Estimated contributions to azimuthal correlations from various effects and comparison with data. The DATA are from the STAR measurement for AuAu 200-GeV collisions at ~50%–60% centrality.

Bzdak et. al., PRC **83**, 014905 (2011)

$\hat{O} \times 10^3$	$\langle\cos(\phi_1+\phi_2)\rangle_{++}$	$\langle\cos(\phi_1+\phi_2)\rangle_{+-}$	$\langle\cos(\phi_1-\phi_2)\rangle_{++}$	$\langle\cos(\phi_1-\phi_2)\rangle_{+-}$
CME	$-(0.1-1)$	$+(0.01-0.1)$	$+(0.1-1)$	$-(0.01-0.1)$
LCC	~ 0	$+(0.1-1)$	~ 0	$+(1-10)$
TMC	~ -0.1	~ -0.1	~ -1	~ -1
DATA	-0.45	$+0.06$	-0.38	$+1.97$

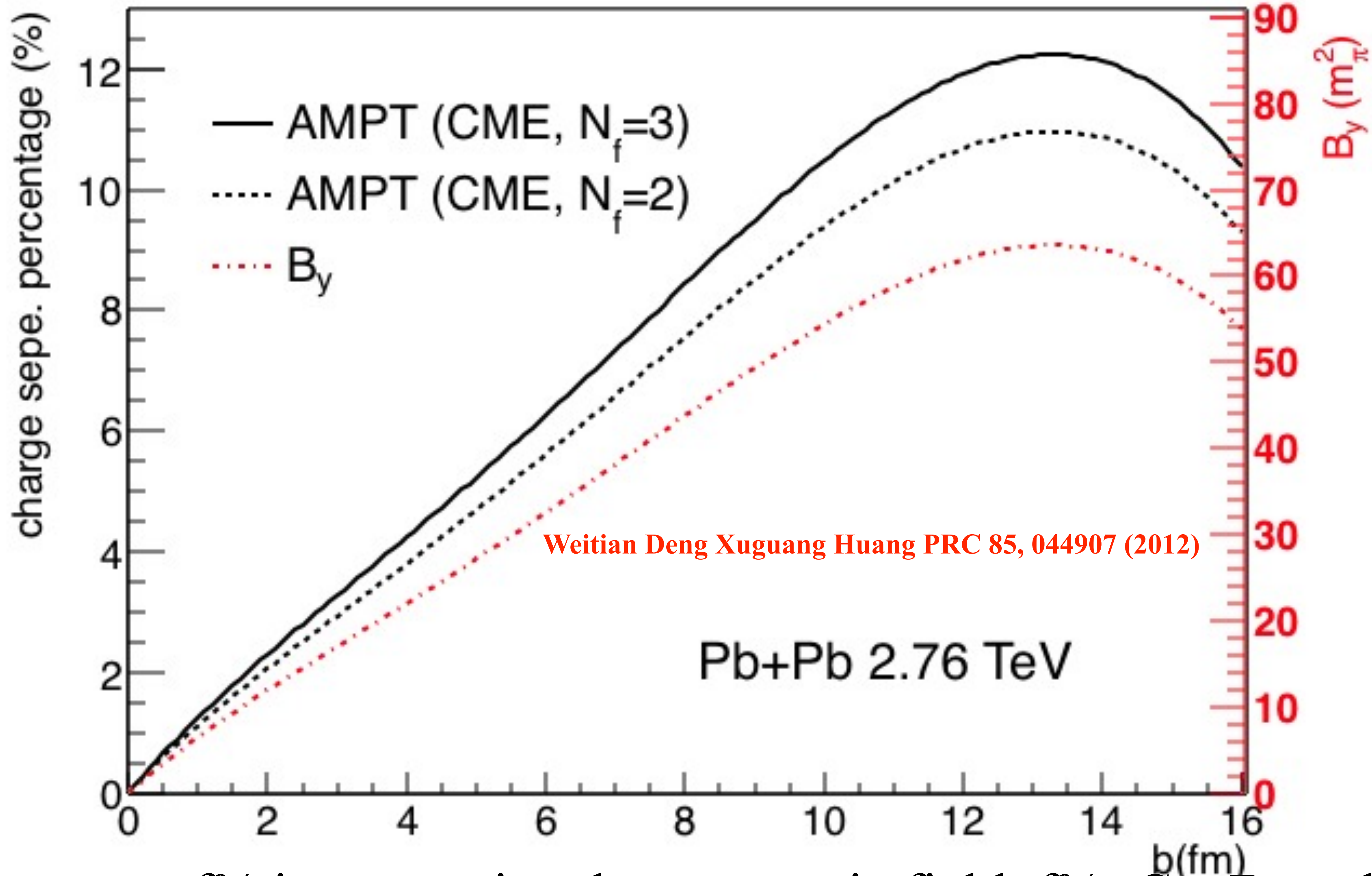
(II) AMPT results on the CME in Pb+Pb @LHC

Ling Huang, Chun-Wang Ma, Guo-Liang Ma, in preparation

AMPT results on the CME in p+Pb @LHC

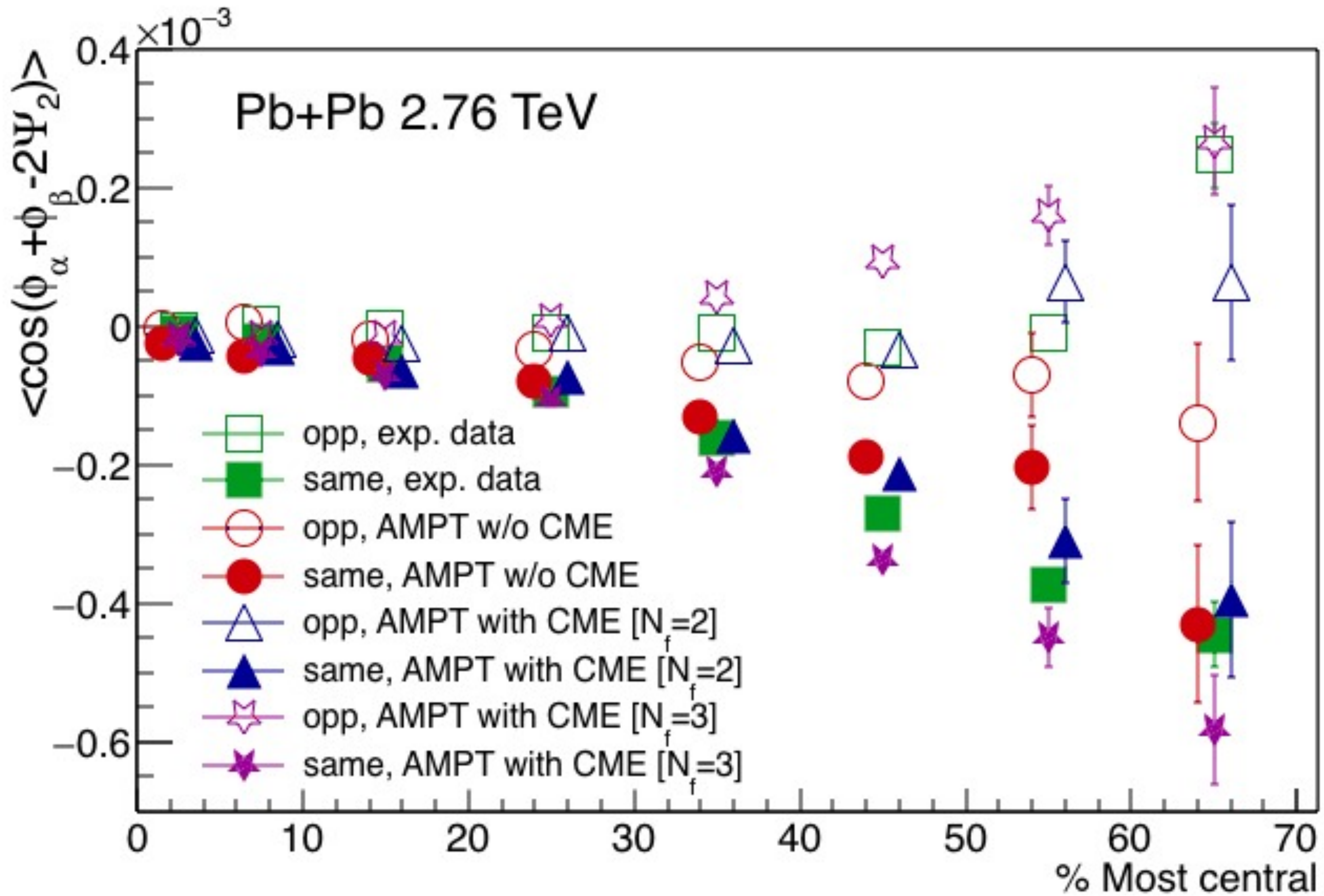
See Xinli Zhao's next talk

Centrality-dependent charge sepe. percentage



- We assume f% is proportional to magnetic field, f%=C x By, where C is determined by fitting the experimental data.
- Two types of CMEs: N_f=2(u, d) vs N_f=3(u, d, s)

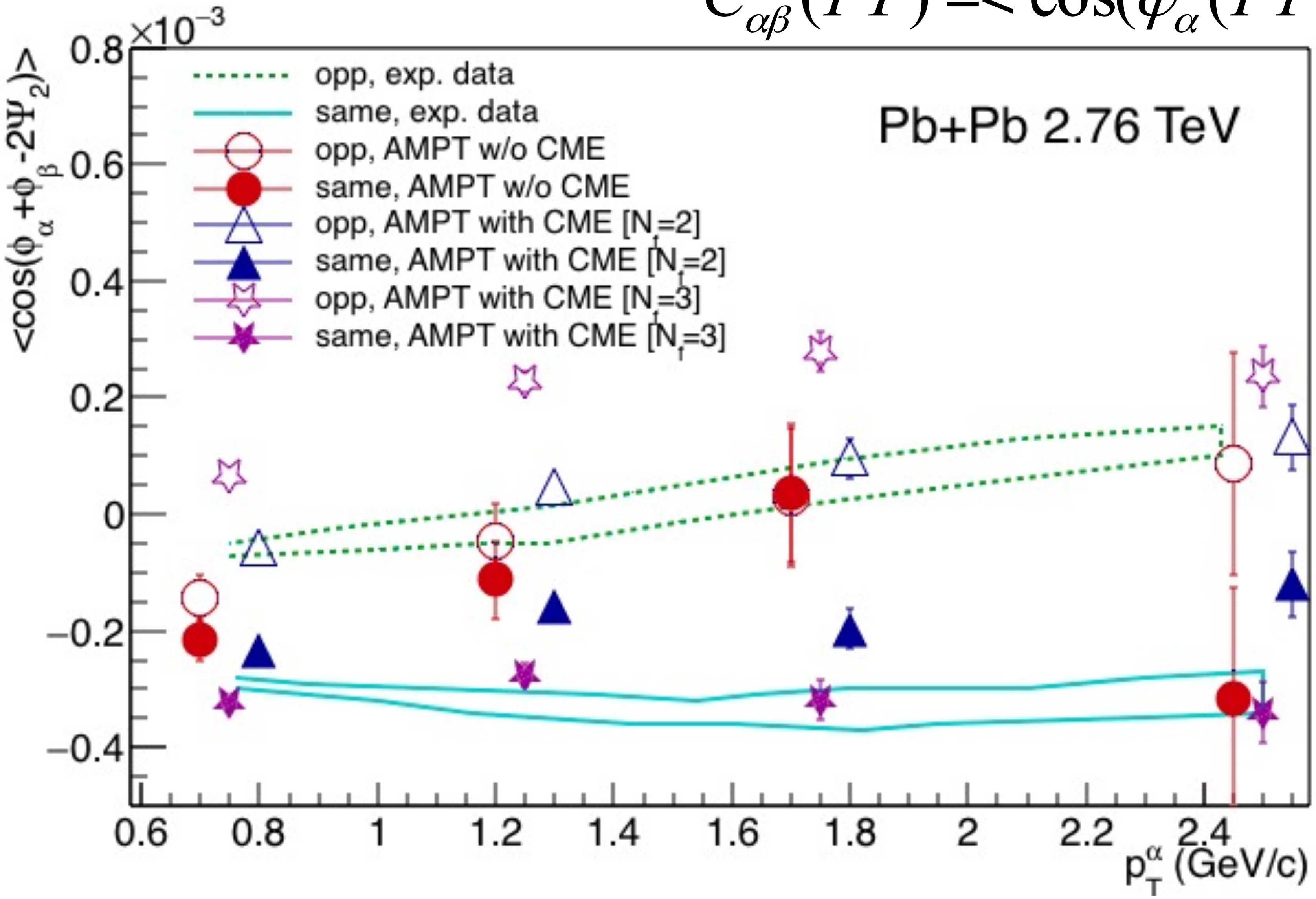
AMPT results on <cos(φα+φβ)>



- AMPT w/o CME can not match experiment data, gives ~60-70% magnitude.
- Both Nf=2 and Nf=3 can match data.

hadron-hadron correlation (h-h)

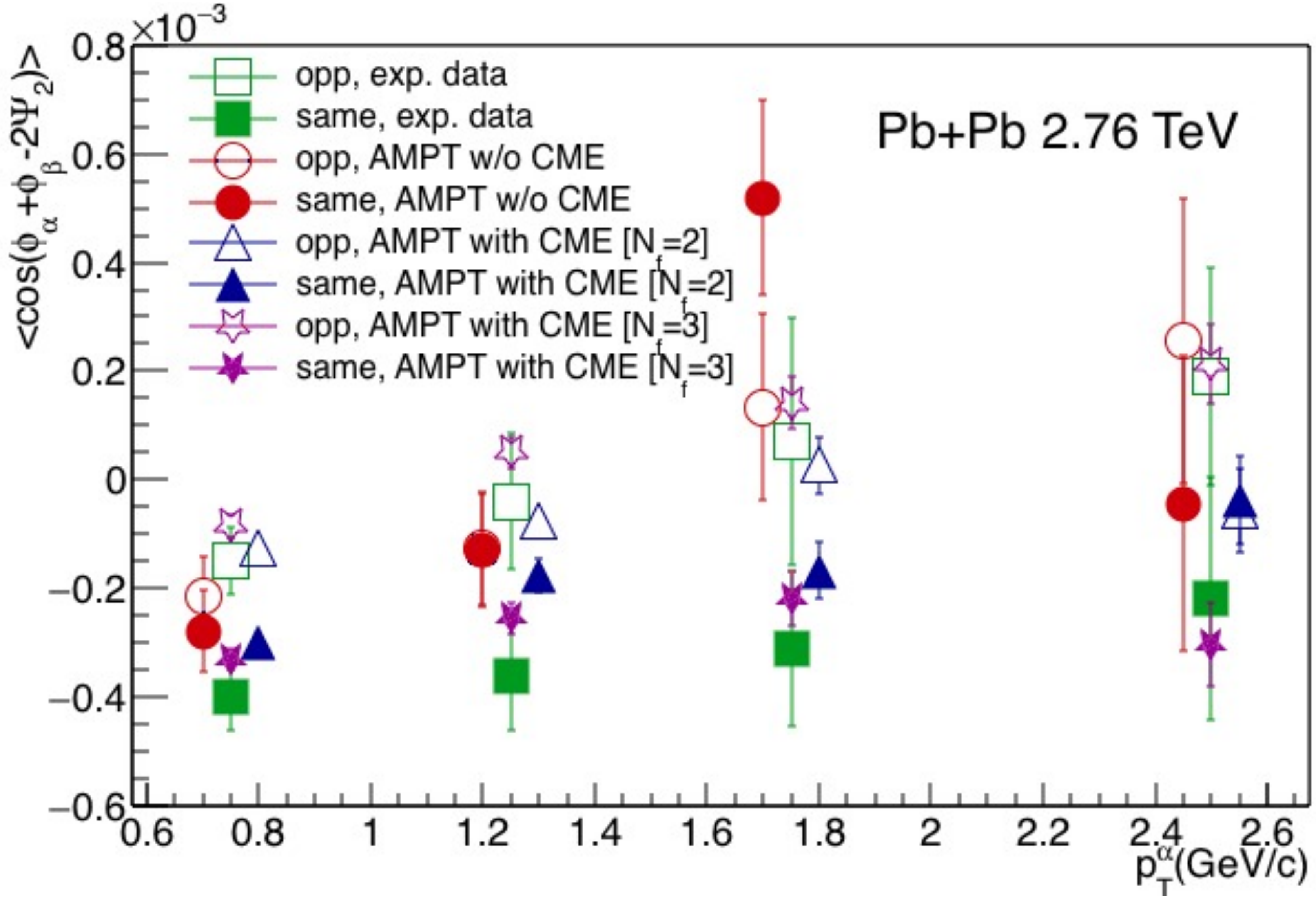
$$C^{ij}_{\alpha\beta}(PT) = <\cos(\varphi^{i}_{\alpha}(PT) + \varphi^{j}_{\beta} - 2\psi_{RP})>$$



- AMPT w/o CME can not reproduce opp-charge and same-charge data.
- AMPT with CME can improve the description to the data. But neither Nf=2 nor Nf=3 can describe opposite-charge and same-charge data simultaneously.

Kaon-hadron correlation (k-h)

$$C^{ij}_{\alpha\beta}(PT) = <\cos(\varphi^i_\alpha(PT) + \varphi^j_\beta - 2\psi_{RP})>$$



- AMPT w/o CME can not reproduce exp. data.
- Nf=2 can describe opp-charged data, but overestimate same-charged data.
- Nf=3 can describe opp-charged and same-charged data simultaneously.

(III) AMPT results on CME in isobar exp.

Deng, Huang, Wang and Guo-Liang Ma, in preparation

— $^{96}_{40}$Zirconium vs $^{96}_{44}$Ruthenium

Glauber parameters for Zr96 and Ru 96

Radius[4,5,6] (fm) & Deformation[3]

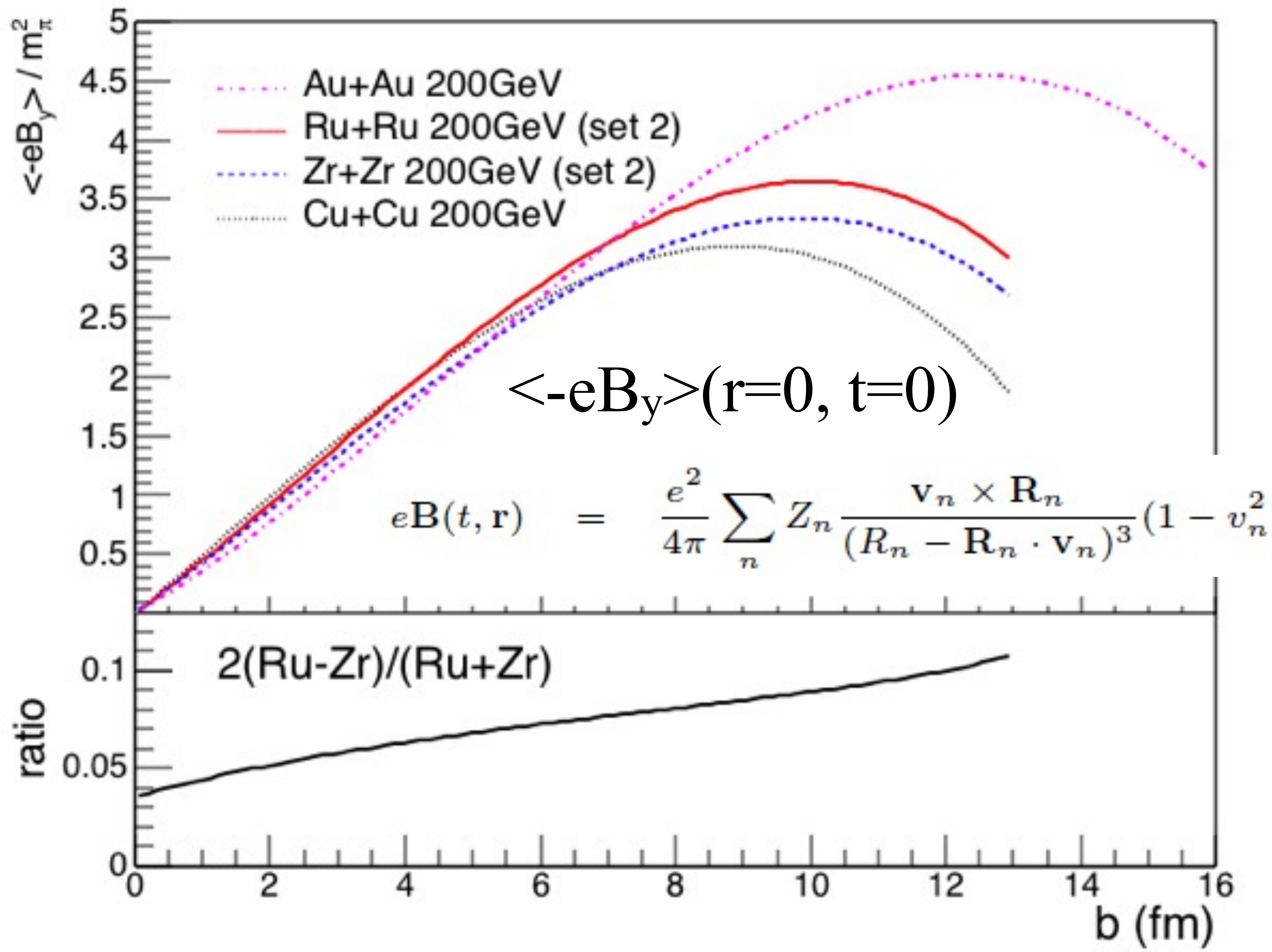
setting 1	R0	a(d)	β2	β4
Ru96	5.0845	0.567	0.1579	0.00
Zr96	5.0212	0.574	0.08	0.00

El.-Magn properties

setting 2	R0	a(d)	β2	β4
Ru96	5.0845	0.567	0.053	0.009
Zr96	5.0212	0.574	0.217	0.01

- Two opposite settings of Glauber parameters for Ru96 and Zr96 (http://nrv.jinr.ru/nrv/webnrv/map/).
- Which is more ellipsoidal? Ru96 or Zr96? We tried both, show setting 2 only.

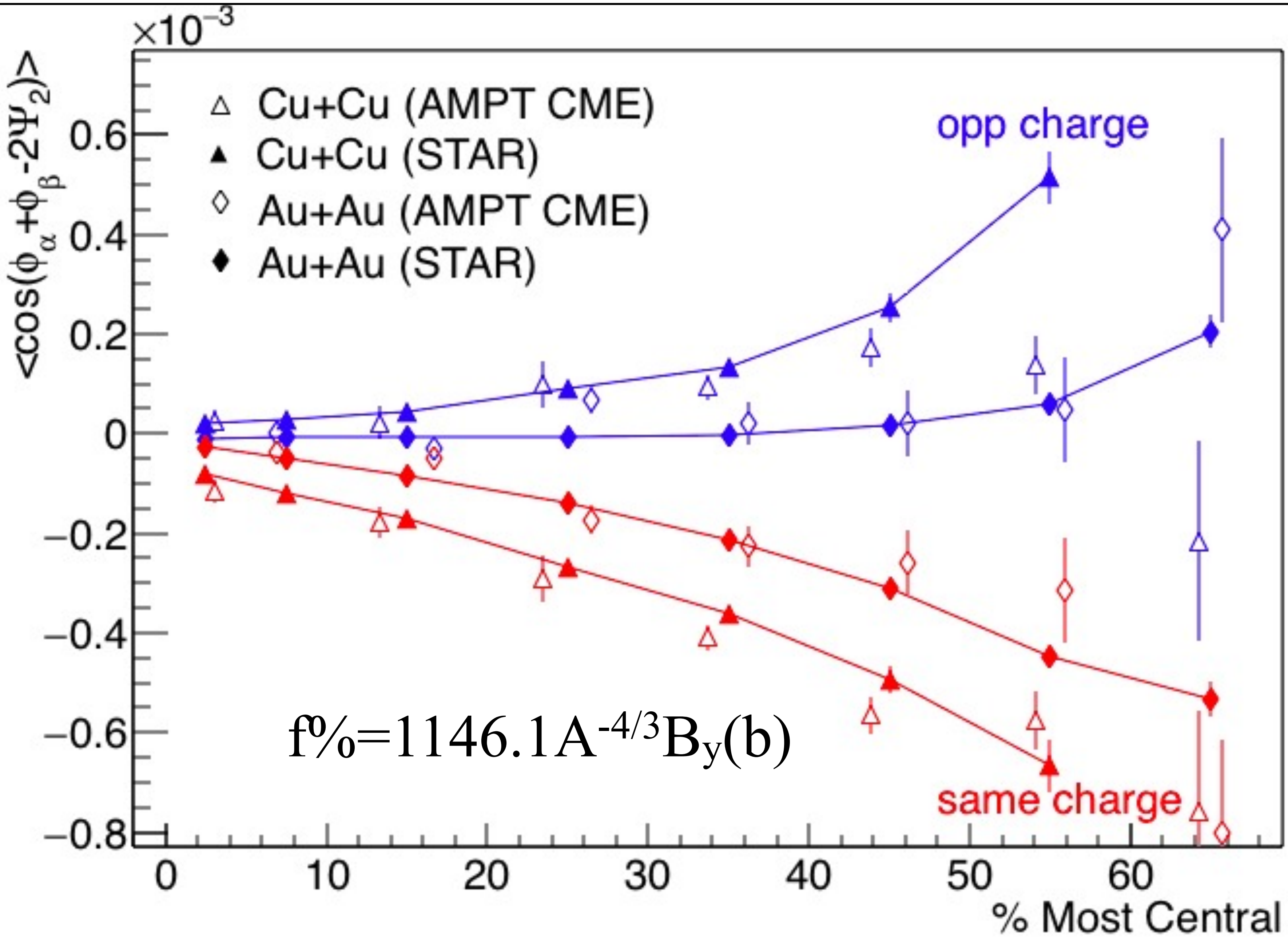
b-dependent Magnetic field



$$eB(t,\mathbf{r}) = \frac{e^2}{4\pi}\sum_n Z_n \frac{\mathbf{v}_n \times \mathbf{R}_n}{(R_n - \mathbf{R}_n \cdot \mathbf{v}_n)^3}(1 - v_n^2)$$

- We use Lienard-Wiechert potential to calculate b-dependent <By> .
- $<B_y>$(Ru+Ru) is larger than $<B_y>$(Zr+Zr) by 10% at large b.

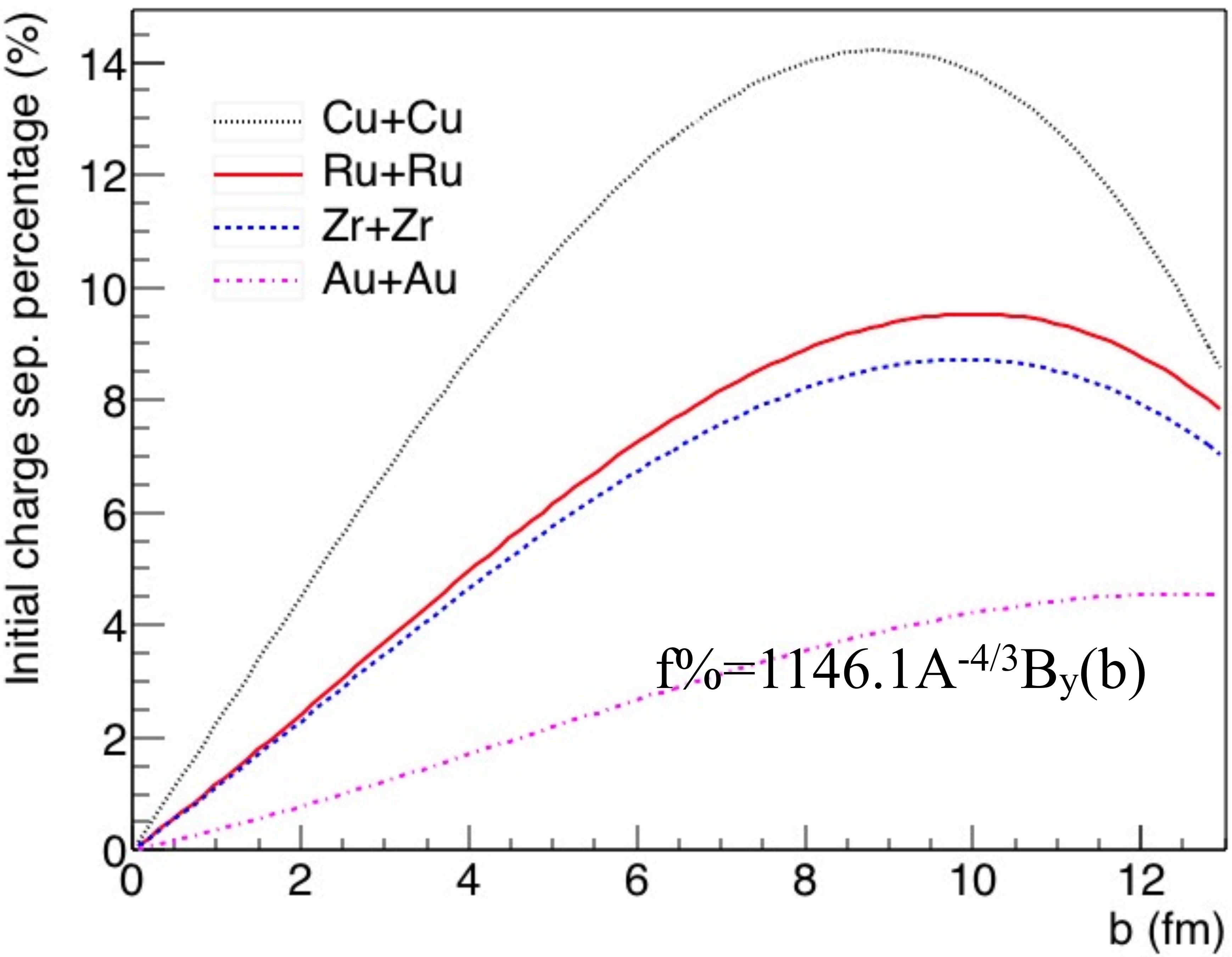
b-dependent initial charge sep. percent



$$f\%=(N^{+}_{upward}-N^{+}_{downward})/(N^{+}_{upward}+N^{+}_{downward})\sim J\pi R^{2}/N_{mult}\sim A^{-4/3}B_{y}$$

- We fit Au+Au and Cu+Cu exp. data.
  →An empirical initial charge separation percentage: $f\%=1146.1A^{-4/3}B_{y}$.

b-dependent initial charge sep. percent

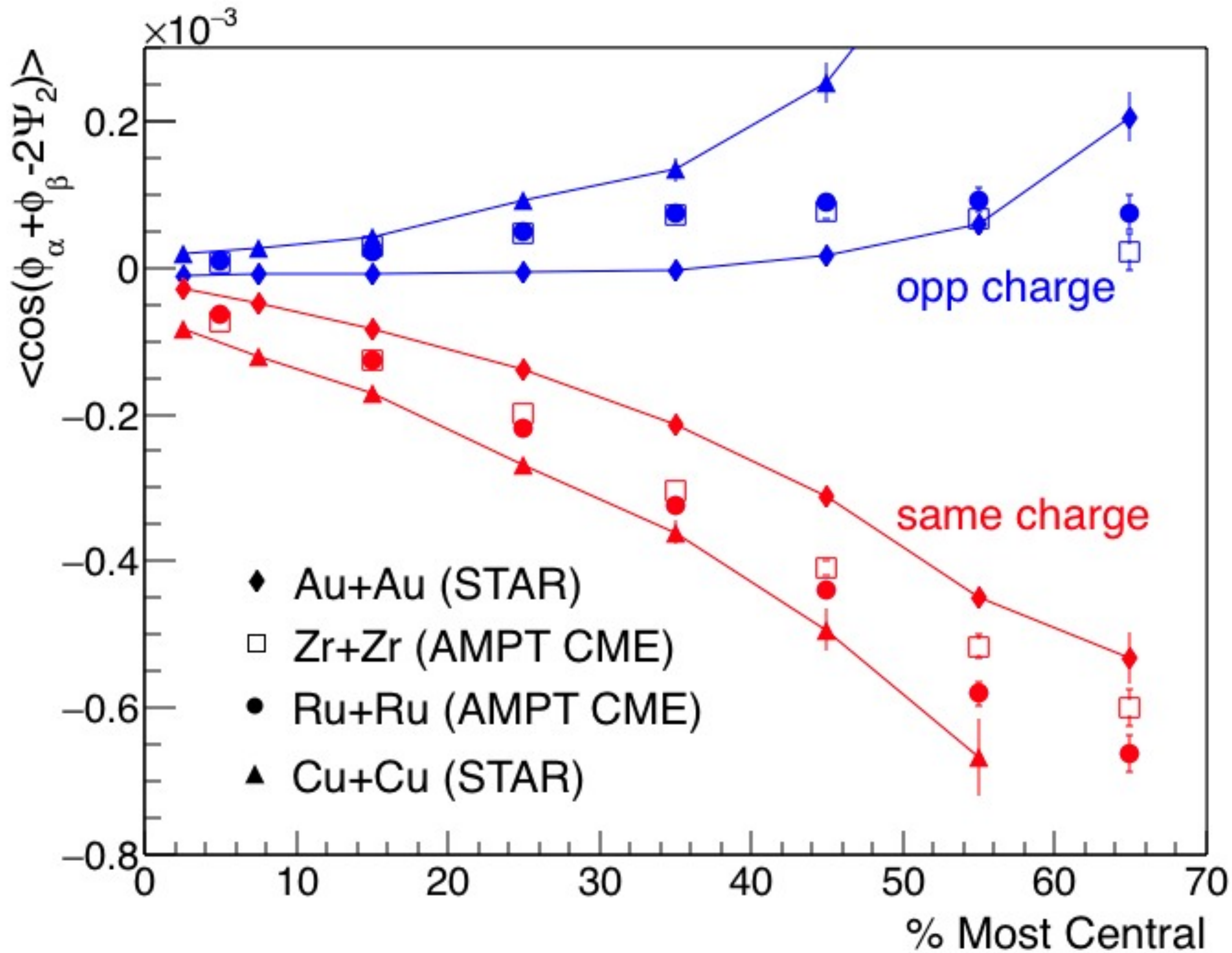


Centrality cuts for Ru+Ru and Zr+Zr

Centrality	b_{min} (fm)	b_{max} (fm)
0-10%	0	3.9
10-20%	3.9	5.5
20-30%	5.5	6.8
30-40%	6.8	7.8
40-50%	7.8	8.8
50-60%	8.8	9.6
60-70%	9.6	10.3

- We apply $f\%=1146.1A^{-4/3}B_y(b)$ to introduce the initial charge separation into Ru+Ru and Zr+Zr.

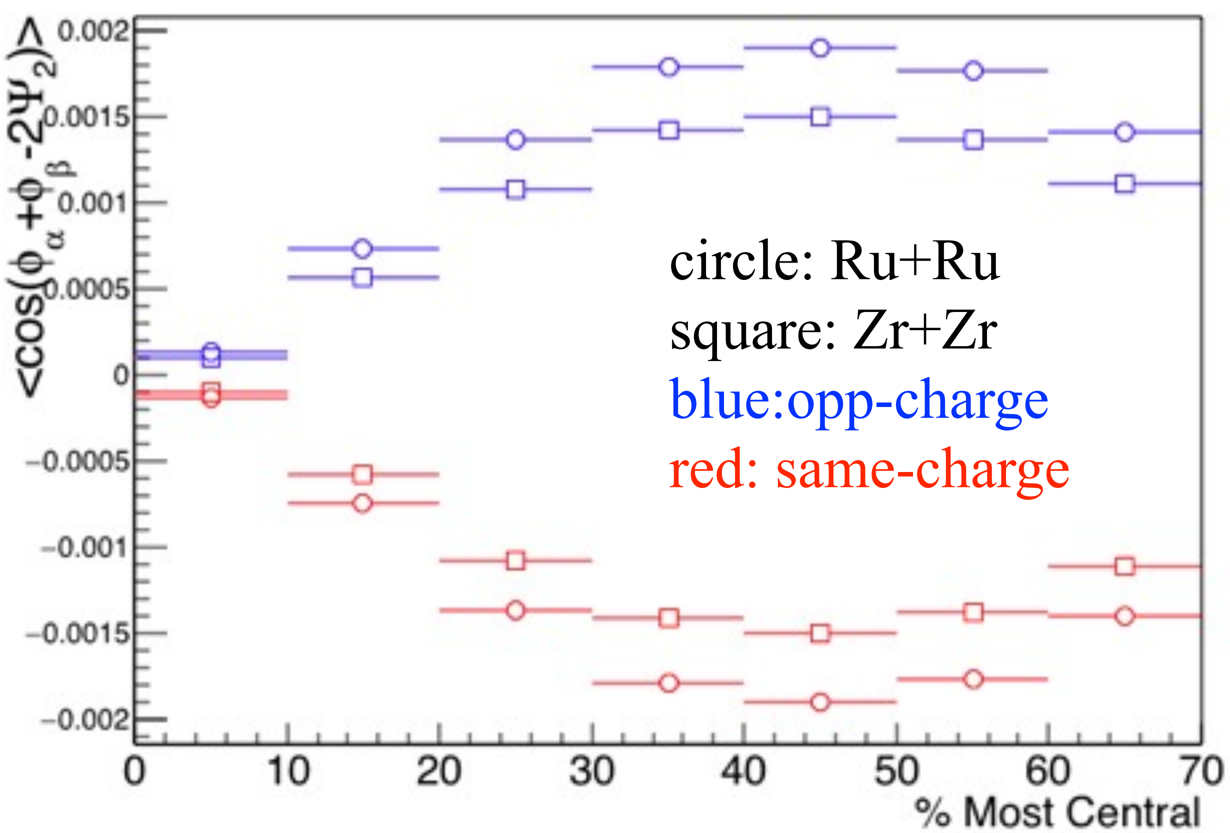
AMPT (CME) results on <cos(ϕa+ϕβ-2ψ2)>

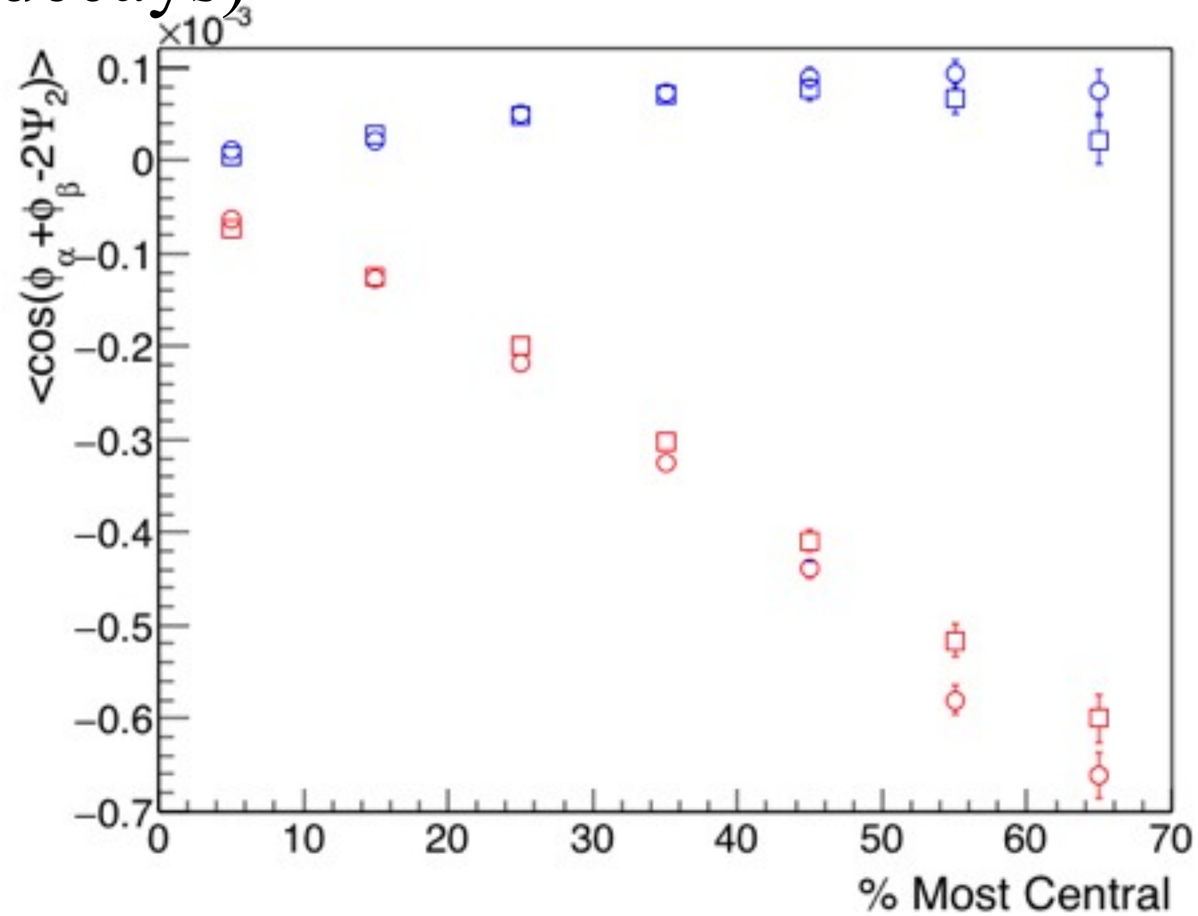


- We see a reasonable magnitude ordering of | <cos(ϕa+ϕβ-2ψ2)> |, i.e., Au+Au < Zr+Zr < Ru+Ru < Cu+Cu.

$\langle\cos(\phi a+\phi\beta-2\psi 2)\rangle$ in Ru+Ru and Zr+Zr

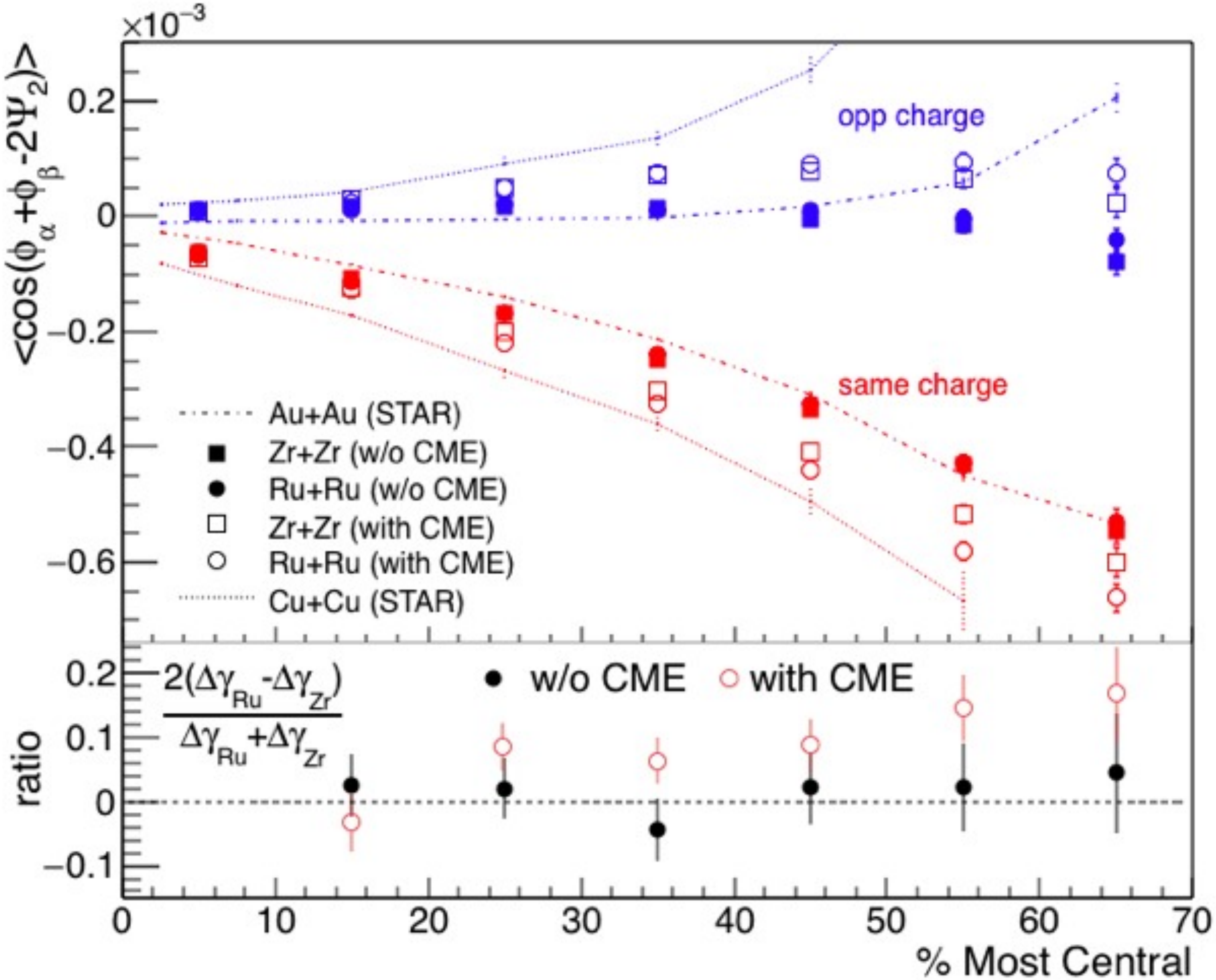
Initial state → (parton cascade, hadronization, resonance decays) → Final state





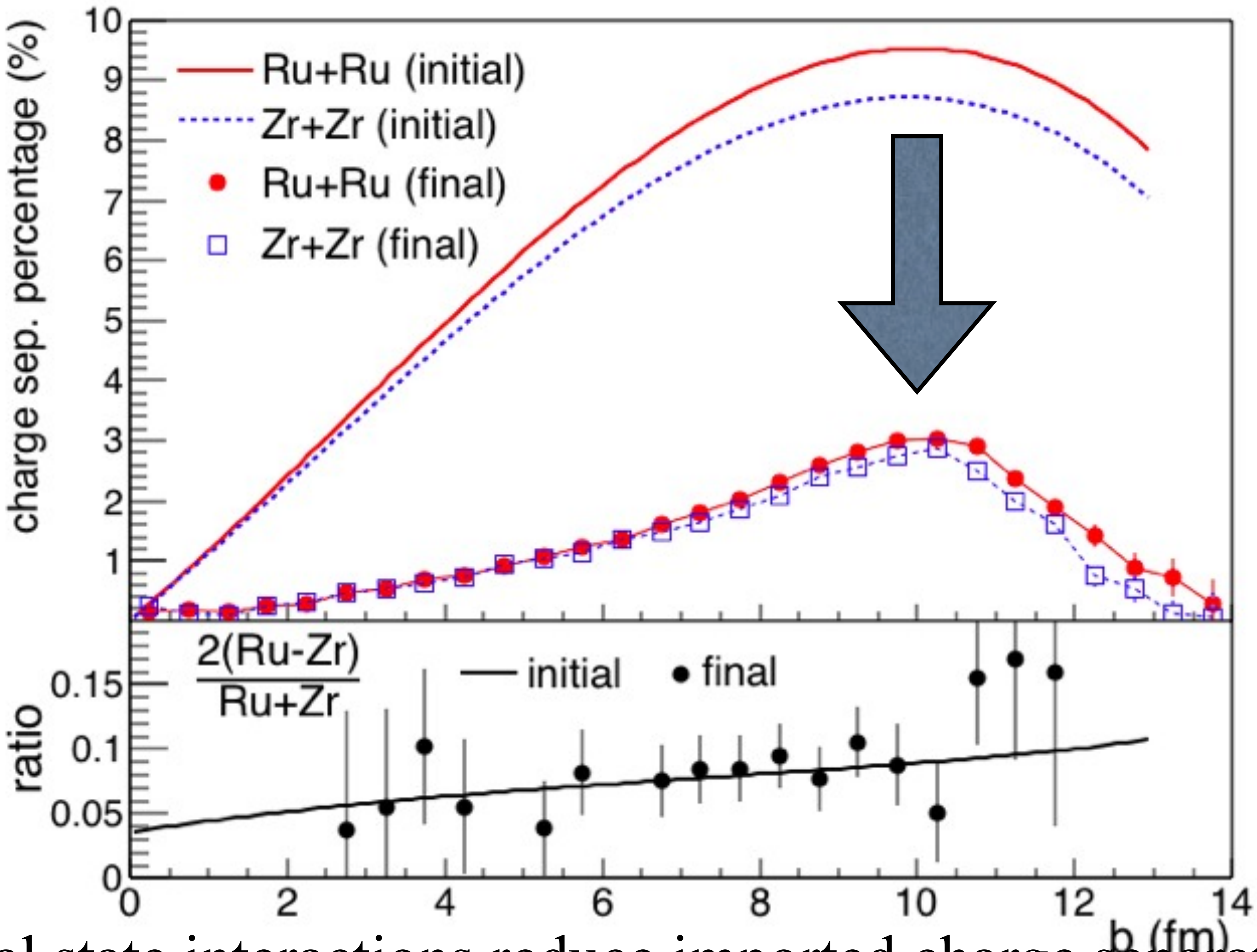
- Final state interactions reduce the $\langle\cos(\phi a+\phi\beta-2\psi 2)\rangle$ difference between Ru+Ru and Zr+Zr.

CME effect on <cos(ϕa+ϕβ-2ψ₂)> in isobar collisions



- **If w/o CME(solid symbol),** the signals are almost same between Ru+Ru and Zr+Zr from the regular AMPT model.
- **If with CME (open symbol),** the magnitudes of signals increase, the difference between Ru+Ru and Zr+Zr appears.

Final interaction effect on charge separation ratio



initial state

(parton cascade, hadronization, resonance decays)

final state

- Final state interactions reduce imported charge separations.
- The relative ratio of charge separation percentage is kept, same as <B_y> ratio.
- Ones could observe the CME signal difference even after strong final state interactions, if with enough statistics.

Summary

- Because final state interactions largely reduce the CME signal=> The percentage of initial dipole charge separation due to CME should reach~10%.

- PID-triggered charge correlation can help us to understand the N_f of CME and explore the QCD deconfinement.

- The CME difference between Ru+Ru and Zr+Zr collisions could survive from final state interactions, hopefully can be observed with enough statistics in the future experiment.

Thanks for your attention!