α-clustering nuclei effect in relativistic heavy ion collisions by AMPT model

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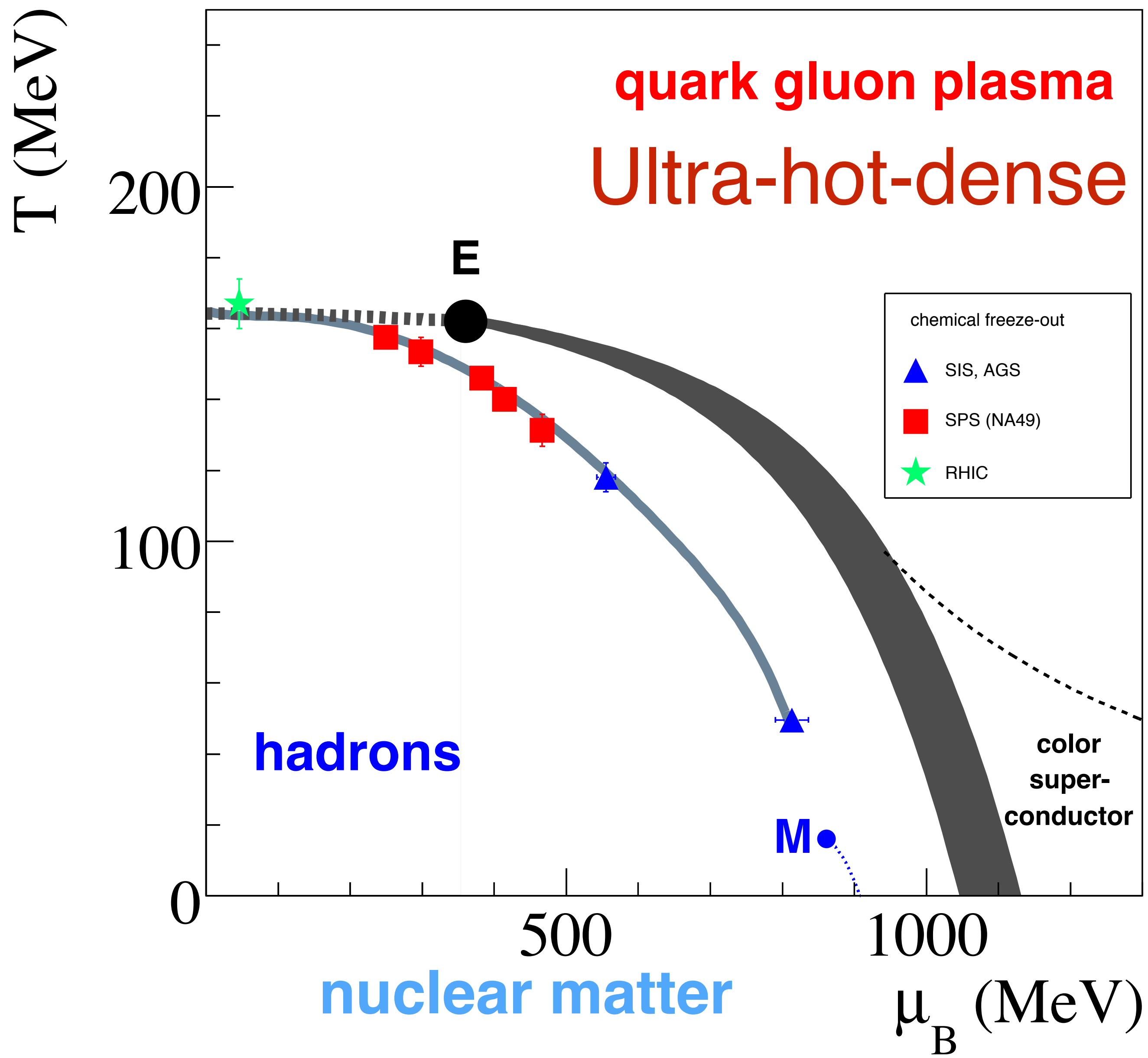
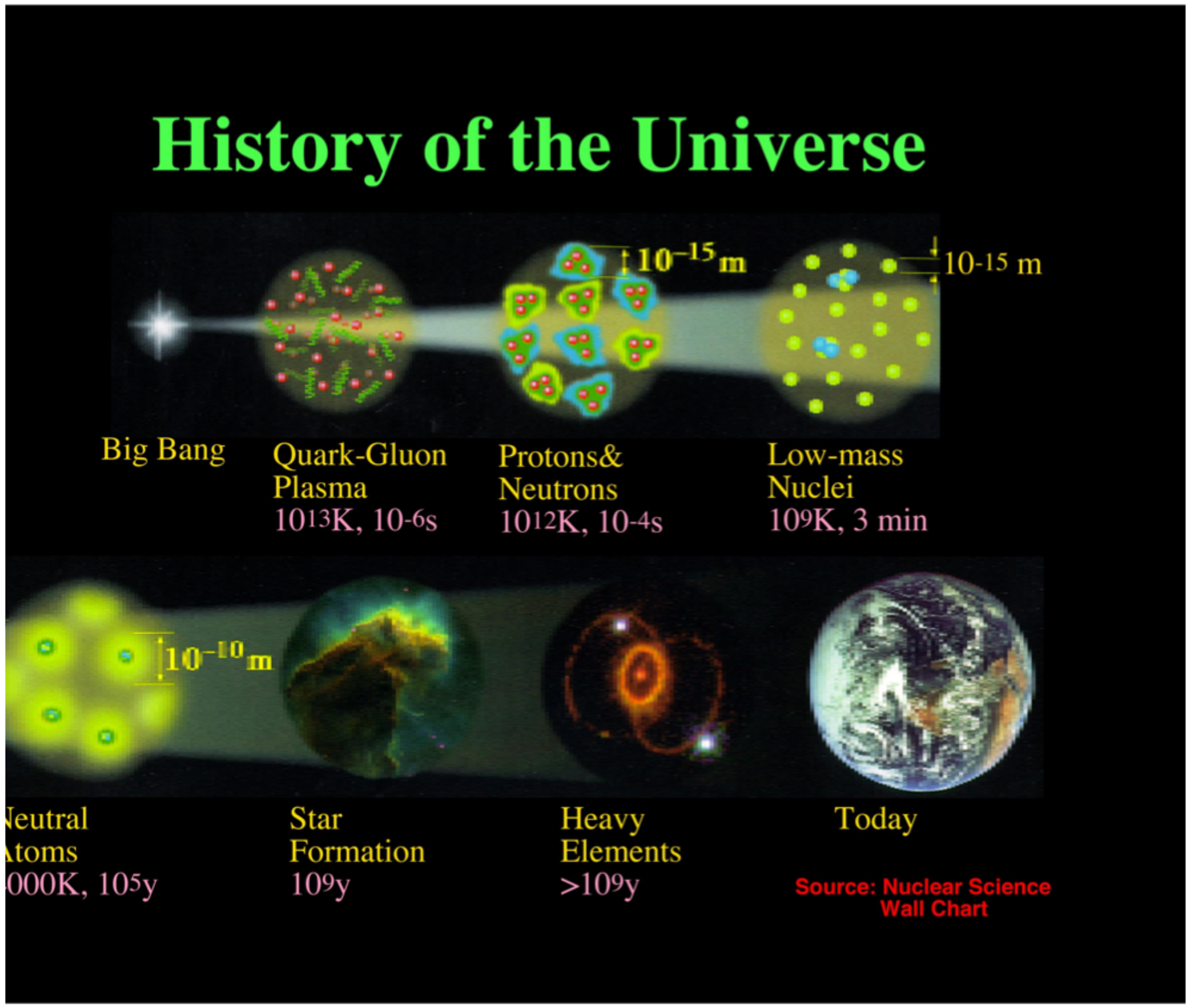
Outline

- Introduction to RHIC
- Initial geometry distribution/fluctuation and α-clustered nuclei
- Model and α-cluster nuclei effect
- Summary

Nuclear matter & History of universe





nuclear matter

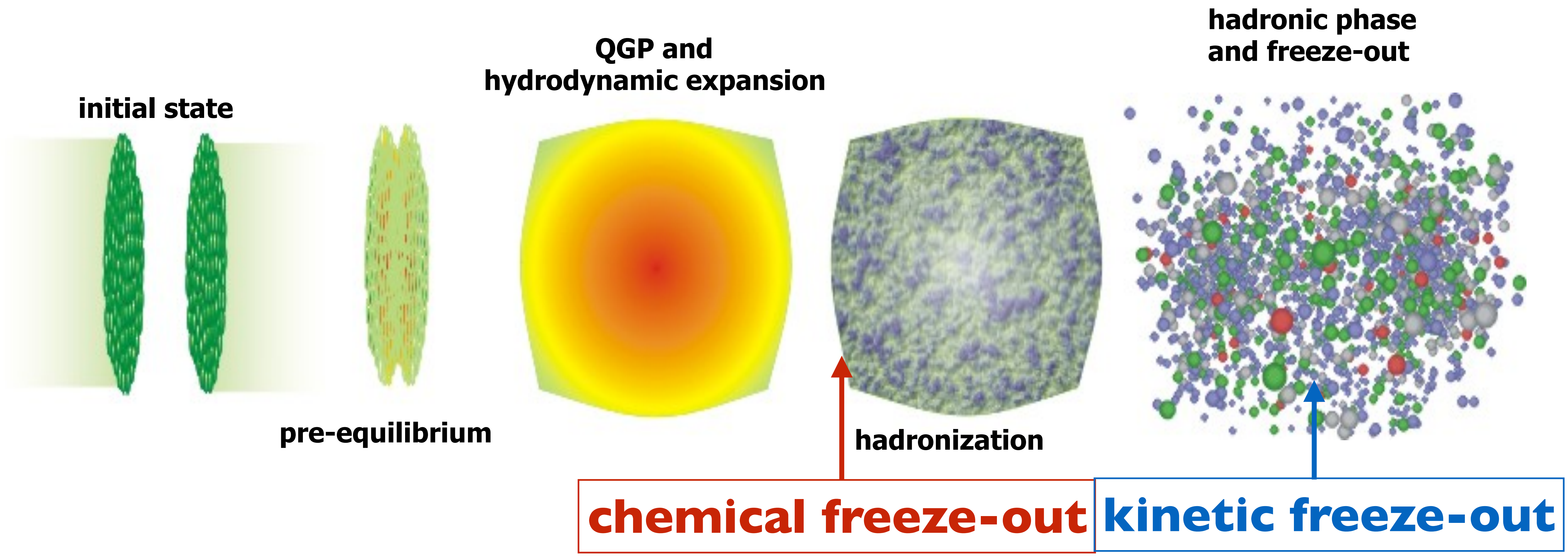
history of universe

✓QCD, quark-gluon plasma (QGP)

✓Early stage of universe, relativistic heavy-ion collisions at laboratory

High energy nucleus-nucleus collisions

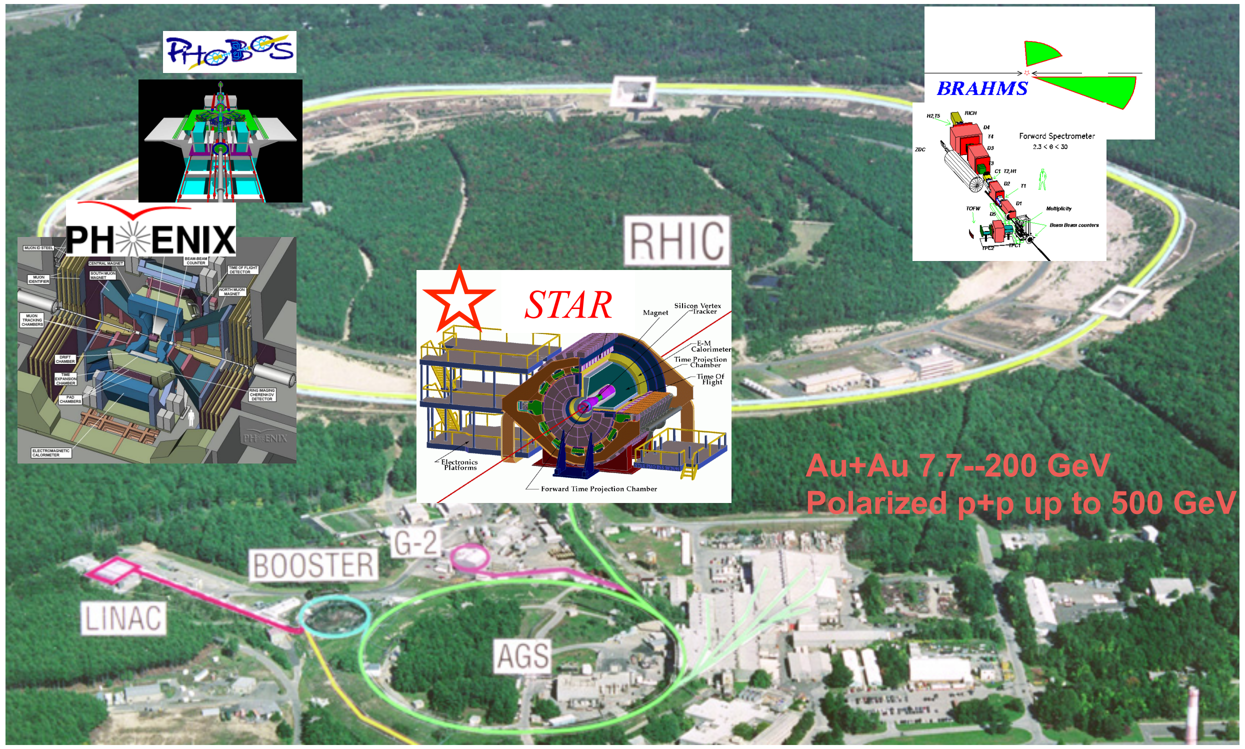
Micro-bangs in A+A collisions at laboratory

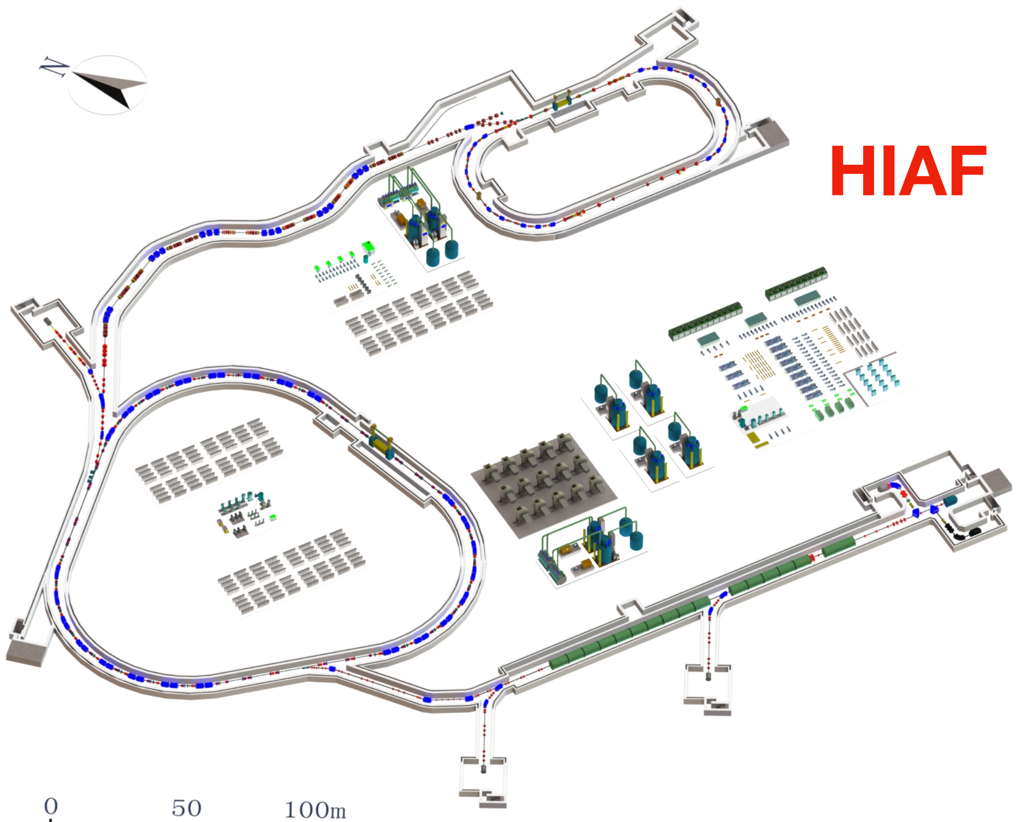


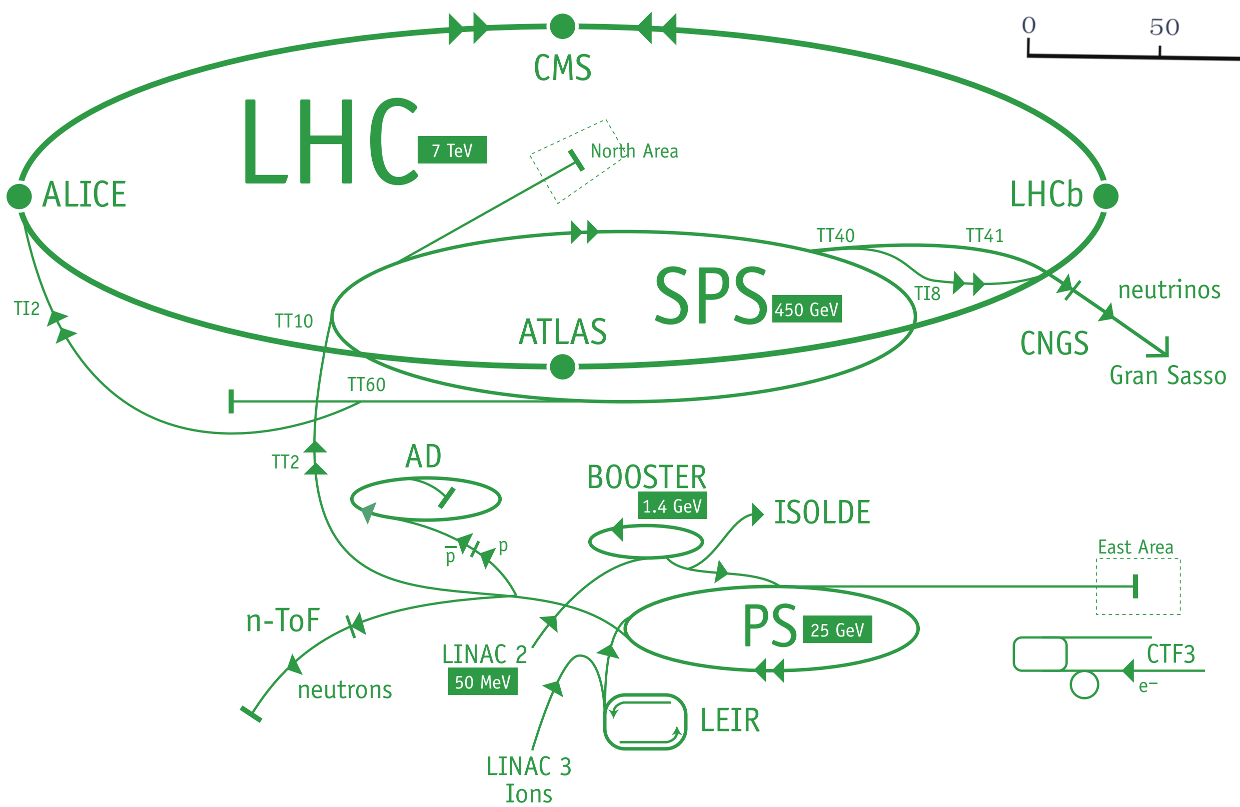
Physics:

1) Parton distributions in nuclei
2) Initial conditions of the collision
3) a new state of matter – Quark-Gluon Plasma and its properties
4) hadronization

Relativistic heavy-ion collider—RHIC





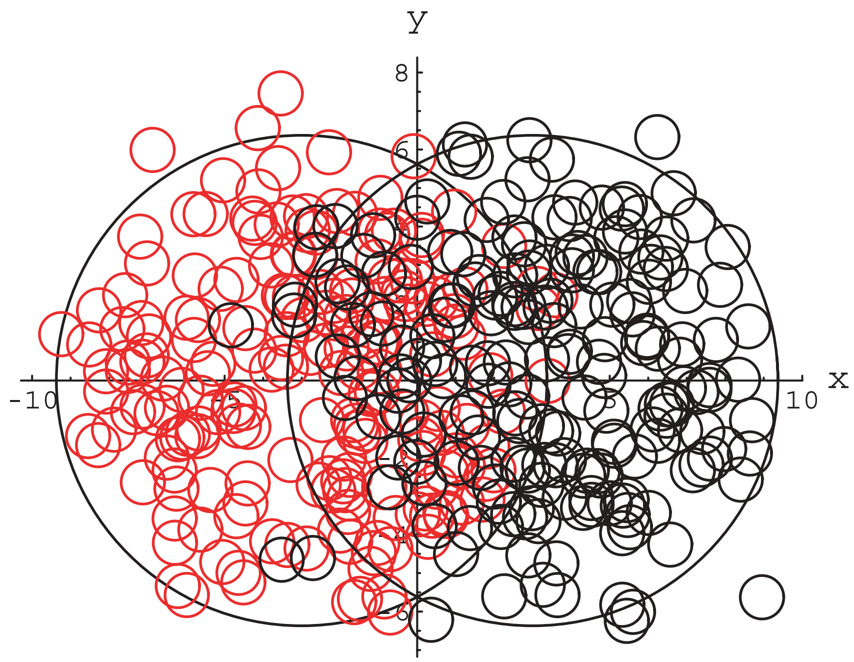


Initial fluctuation and intrinsic geometry

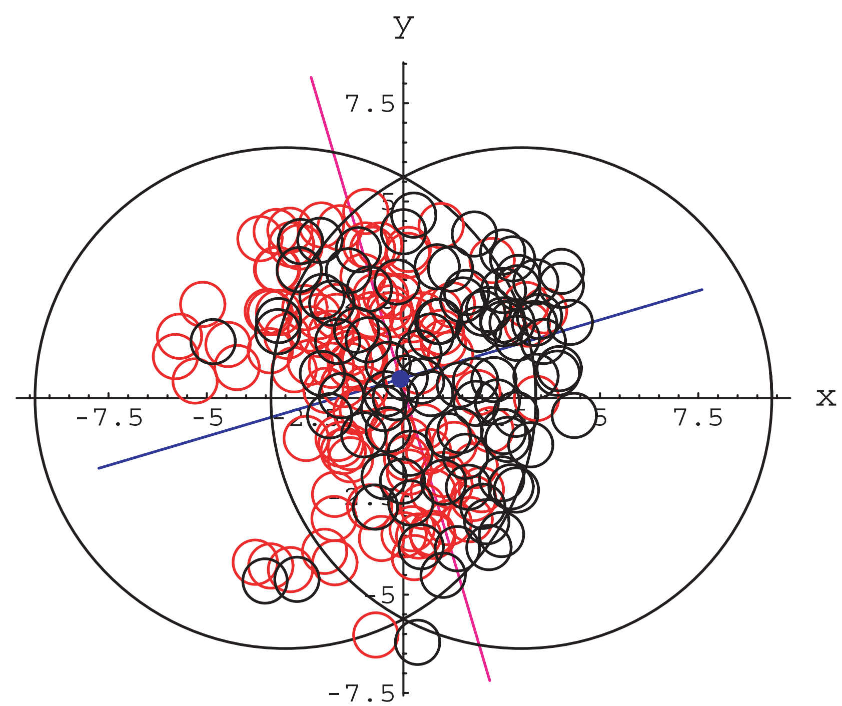
- Initial fluctuation
- Intrinsic geometry
- Flow in small system

Initial geometry fluctuation

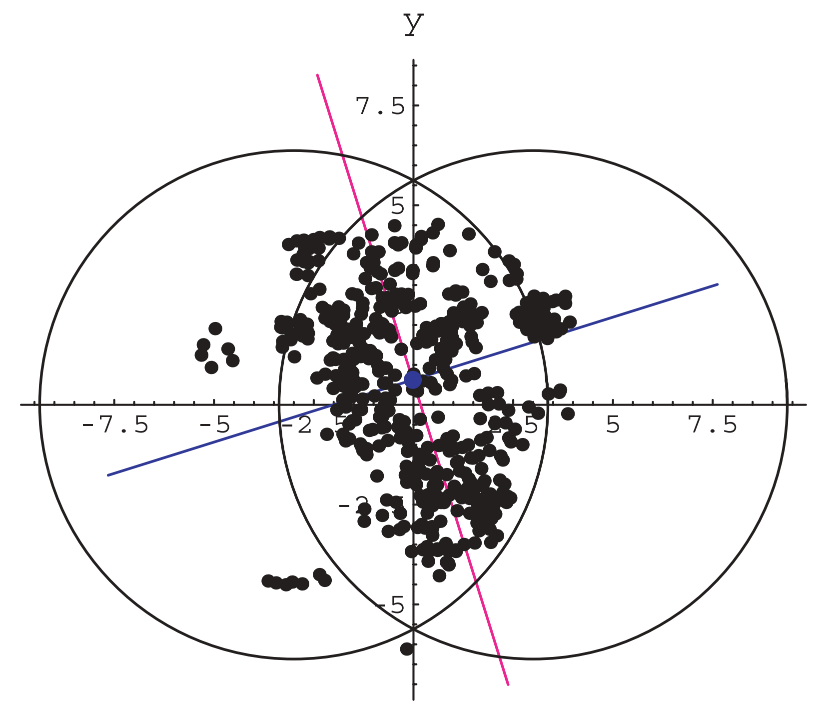
W. Broniowski et al., PRC-76-054905



Nucleon from nuclei A and B



Participant initial coordinates

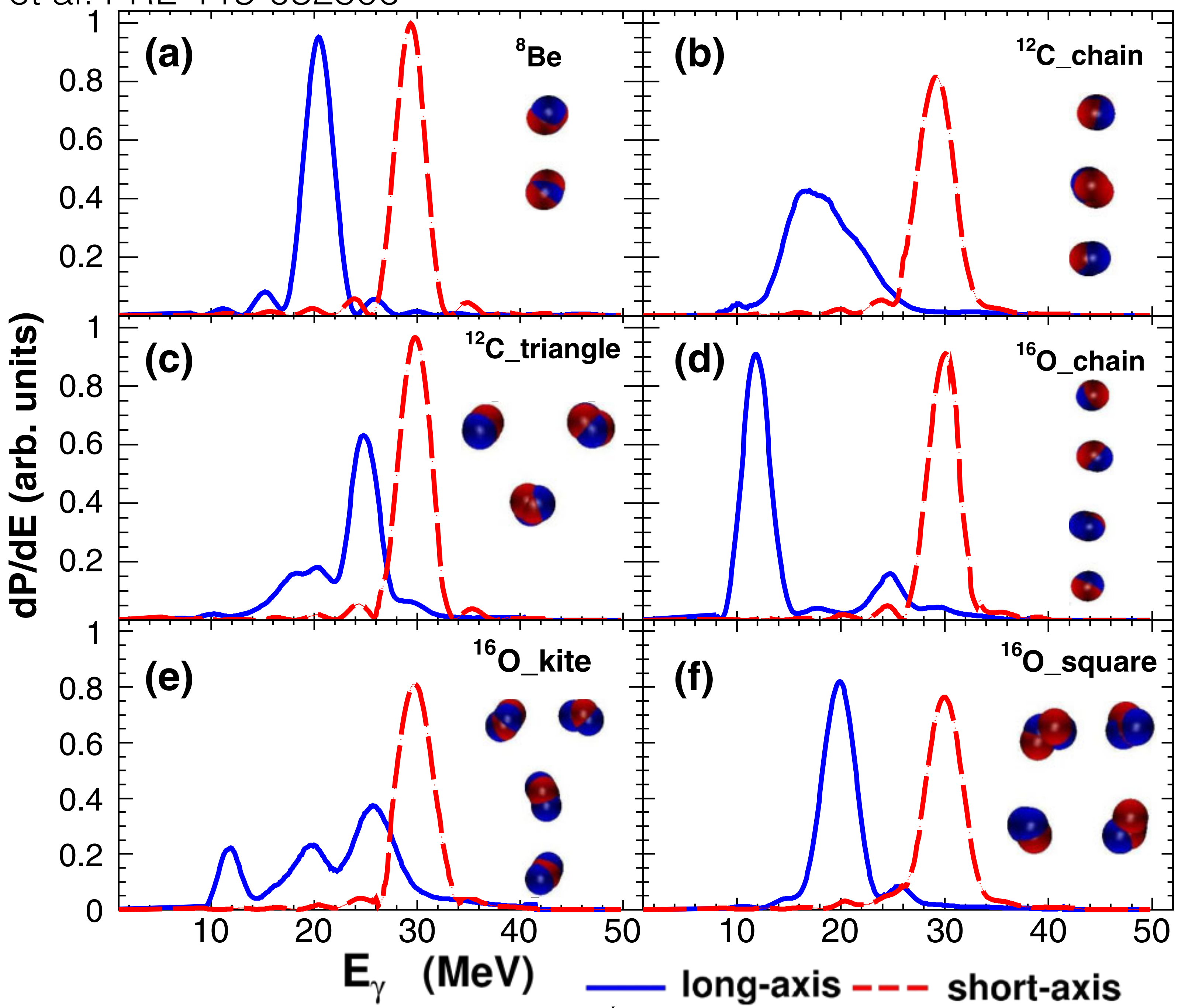


Participant in center of mass frame after binary collision

✓ **Fluctuation, significant in small system**

α-cluster nuclear structure

W. B. He, Y. G. Ma et al. PRL-113-032506

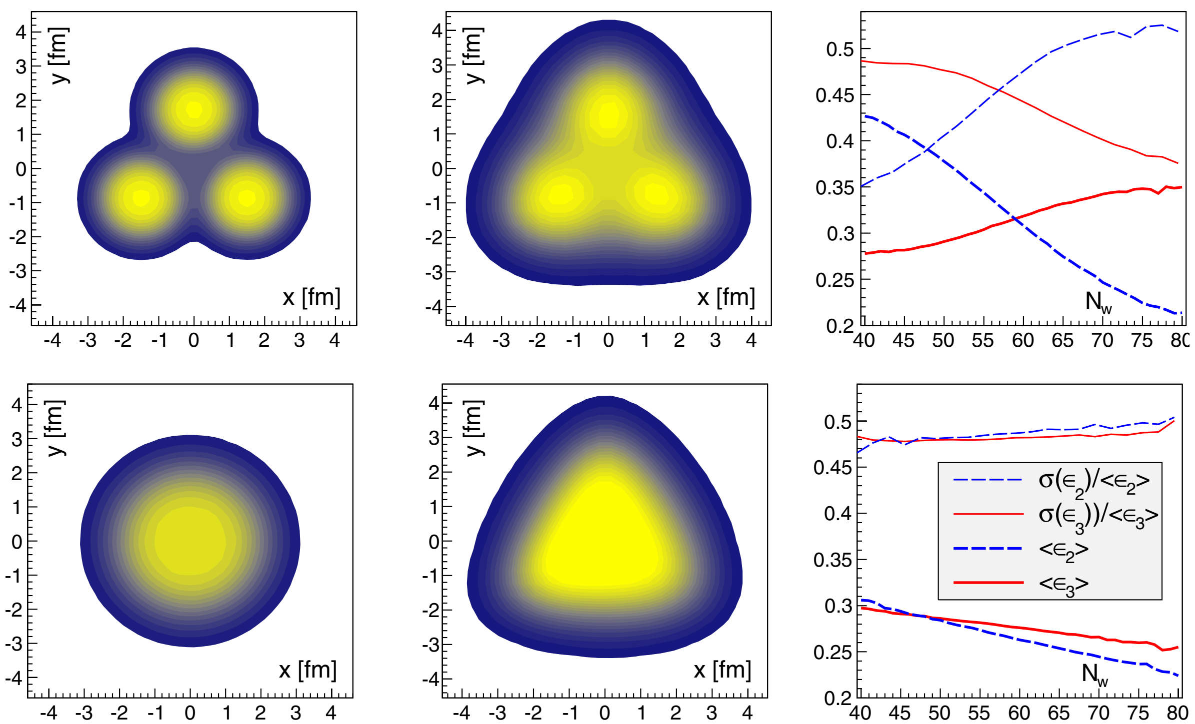


✓ Intrinsic geometry distribution

α-cluster nuclei collide against heavy nuclei

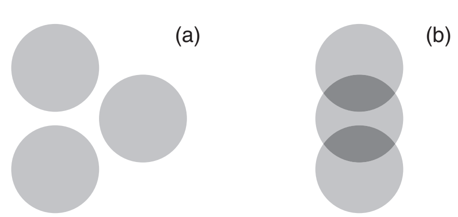
W. Broniowski, E. R. Arriola, PRL-112-112501

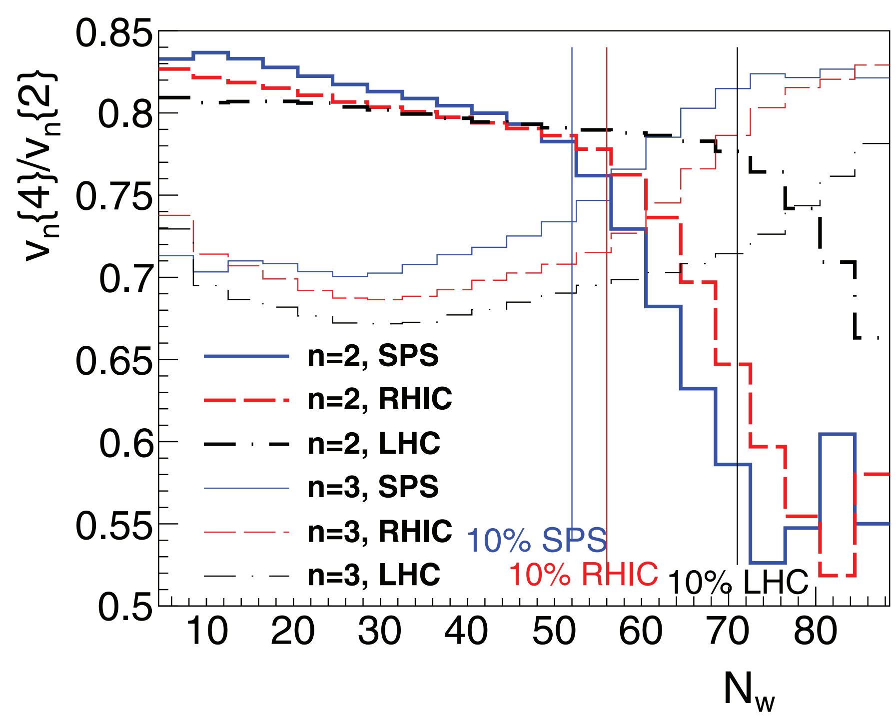
^{12}C-^{208}Pb



P. Bozek, W. Broniowski et al., PRC-90-064902

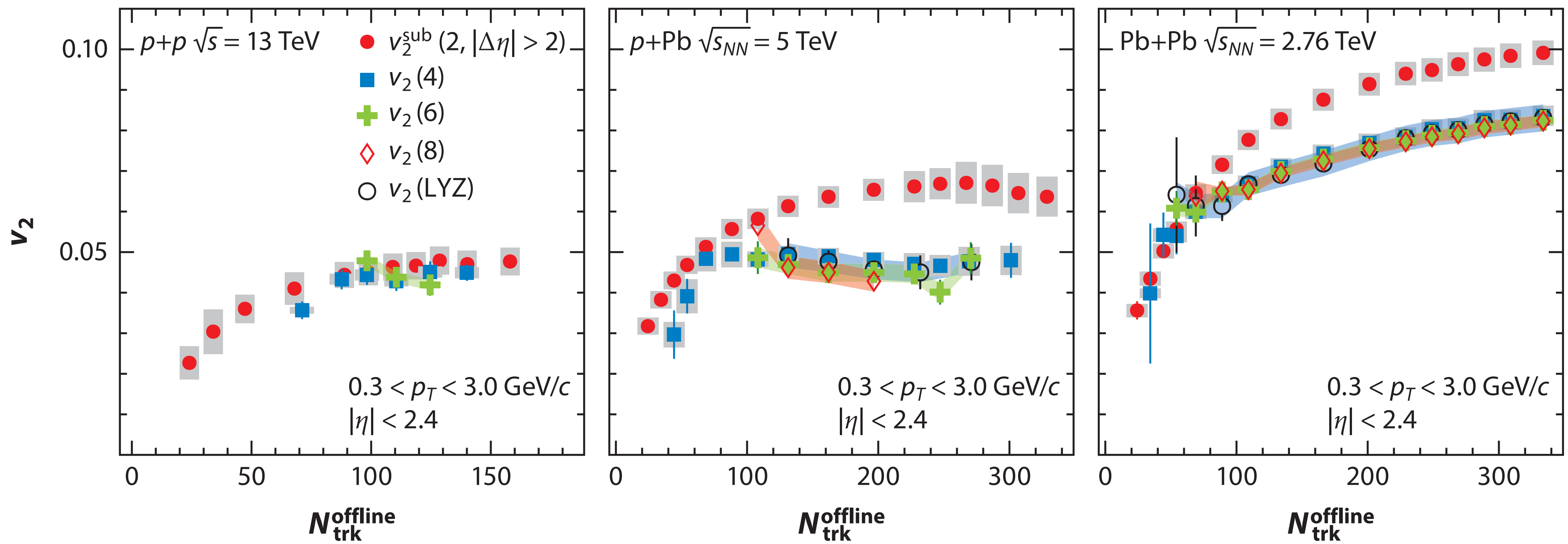
$$\frac{\epsilon_n\{4\}}{\epsilon_n\{2\}} \simeq \frac{v_n\{4\}}{v_n\{2\}}.$$

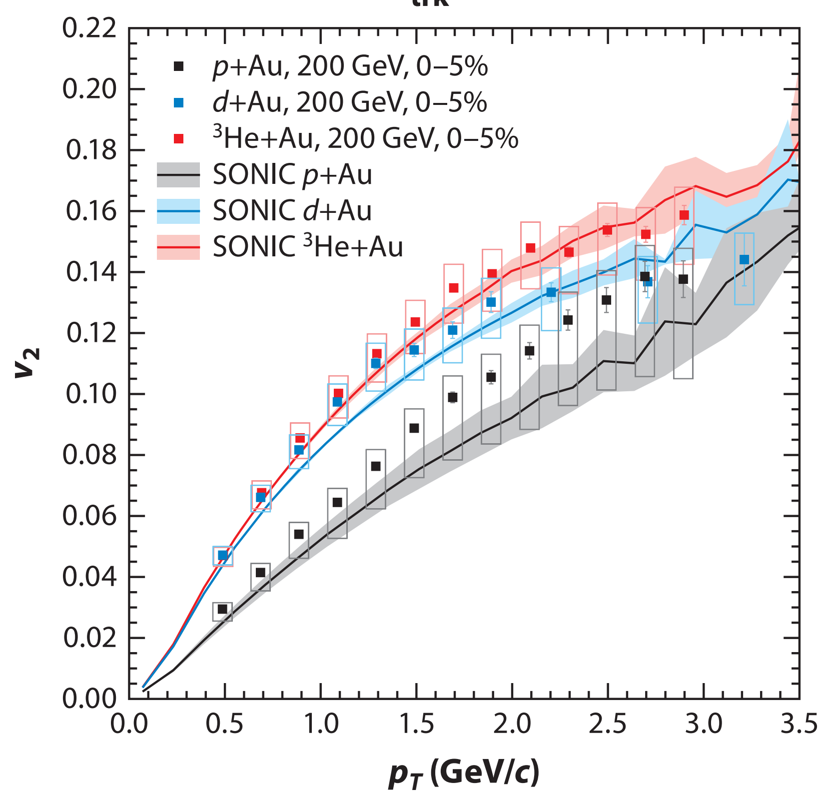


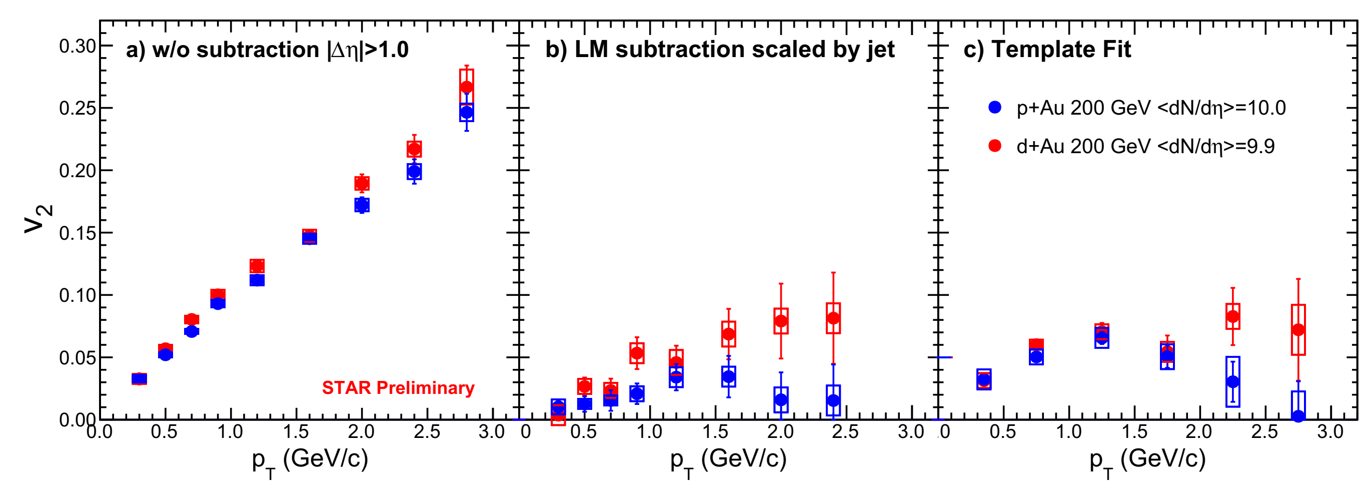


Collective flow in small system from experiments

Khachatryan V, et al. (CMS), *Phys. Lett. B* 765:193 (2017)



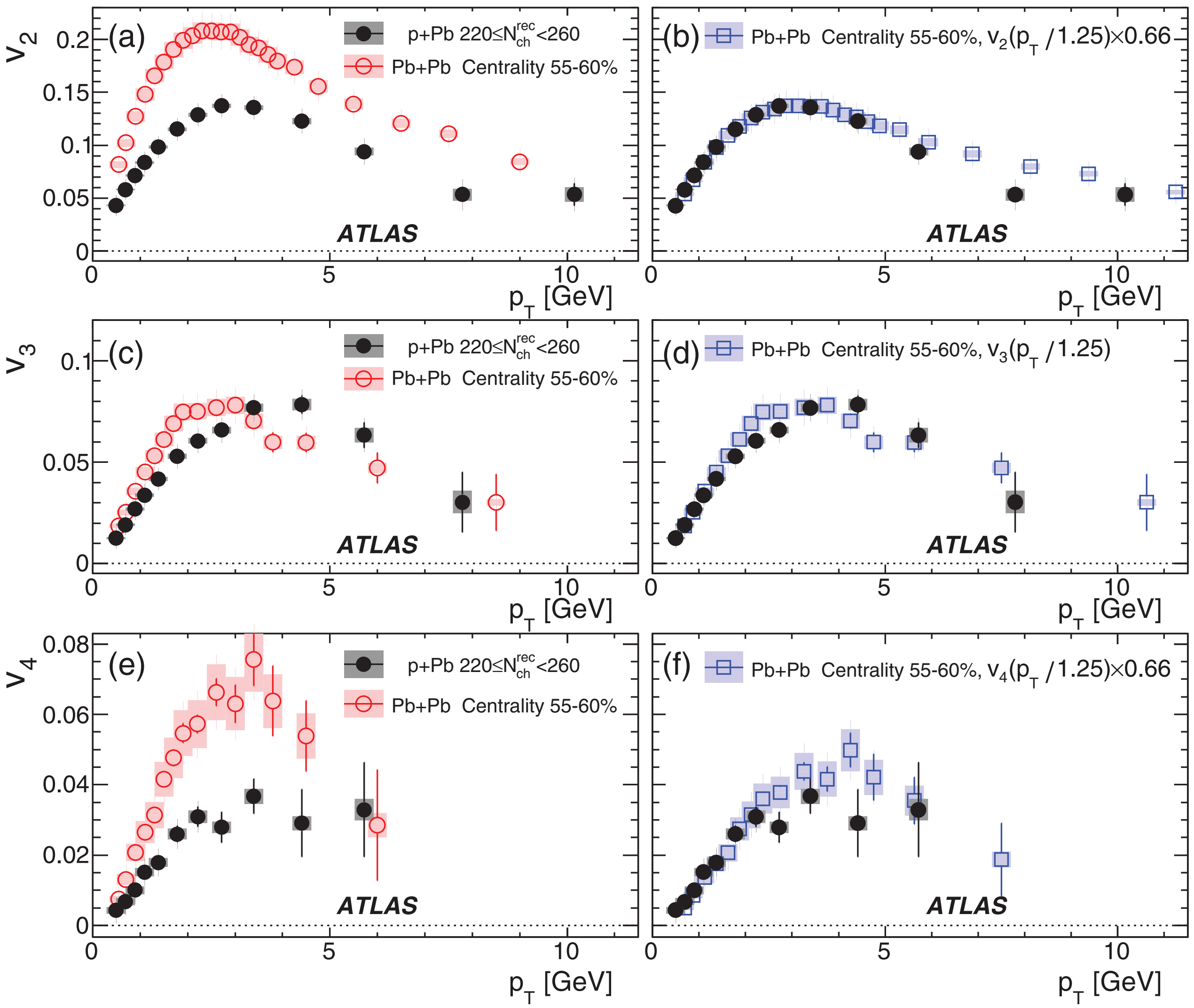




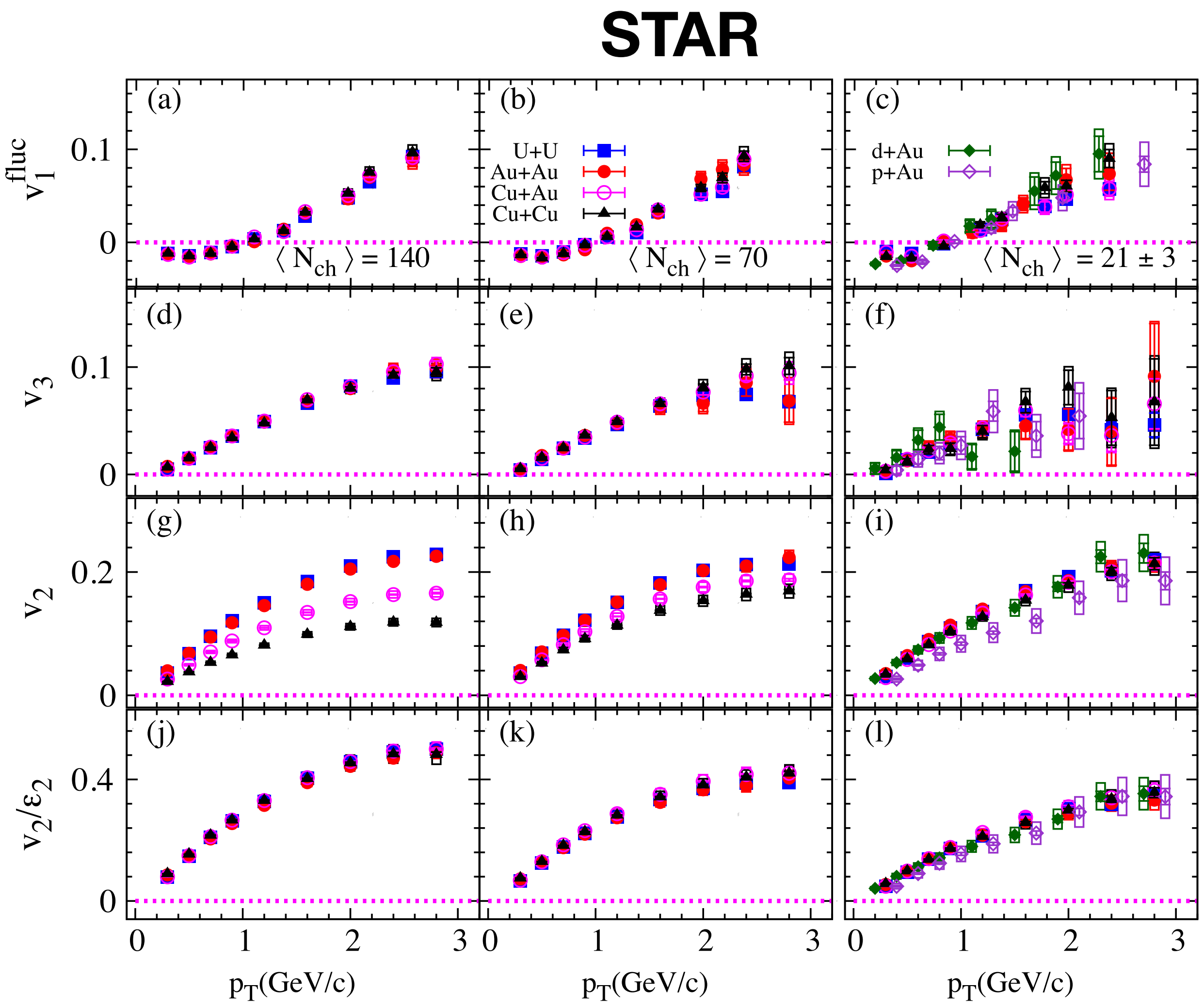
S. Huang, Nuclear Physics A 982 (2019) 475

Aidala C, et al. *Phys. Rev. C* 95:034910 (2017)

Collective flow in small/large system from experiments

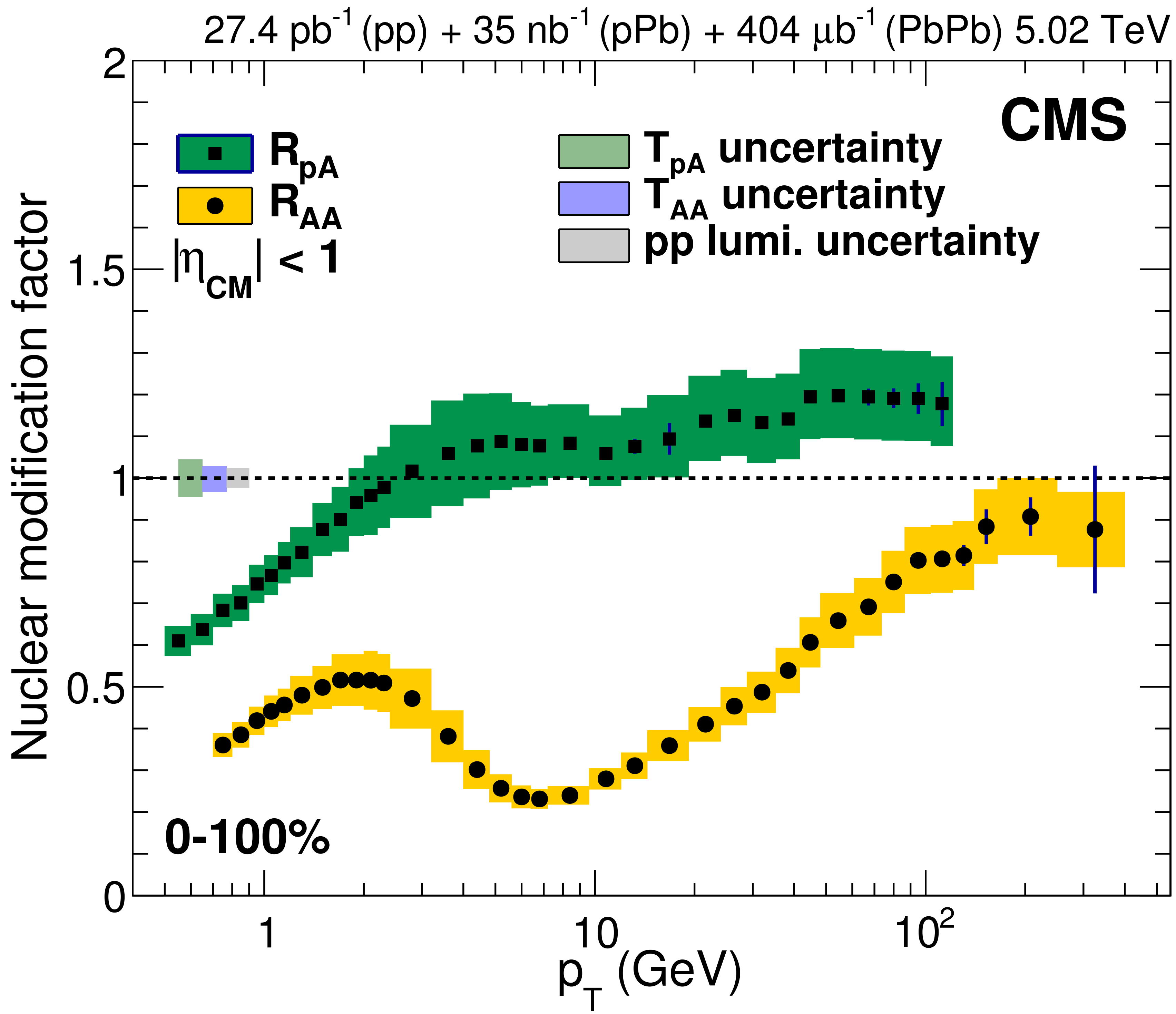


Aad G, et al. *Phys. Rev. C* 90:044906 (2014)



J. Adam, et al. STAR, Phys. Rev. Lett. 122, 172301 (2019)

Jet “quenching” in small system

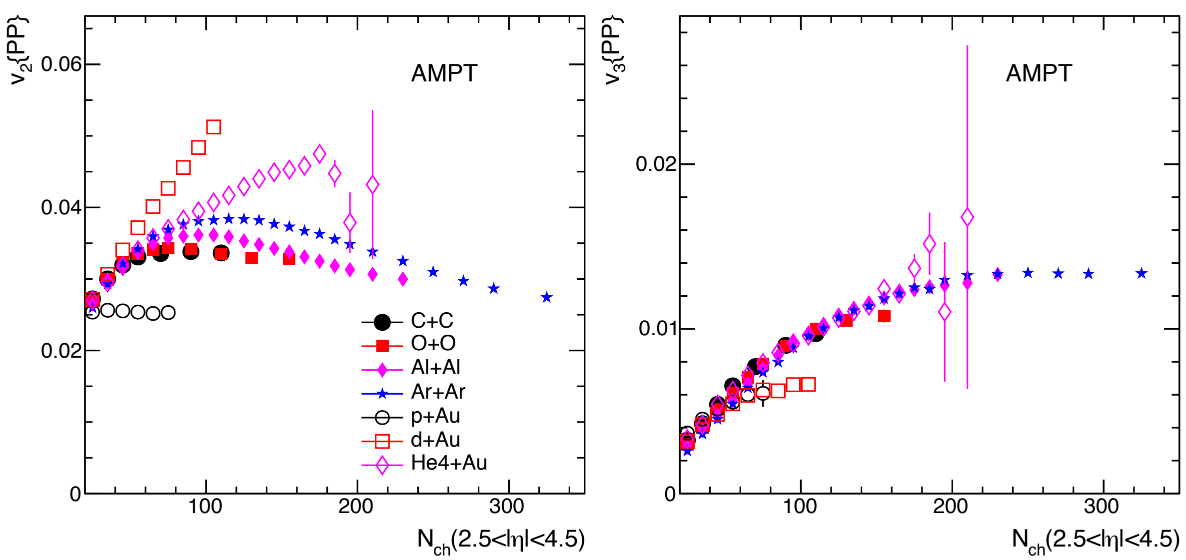


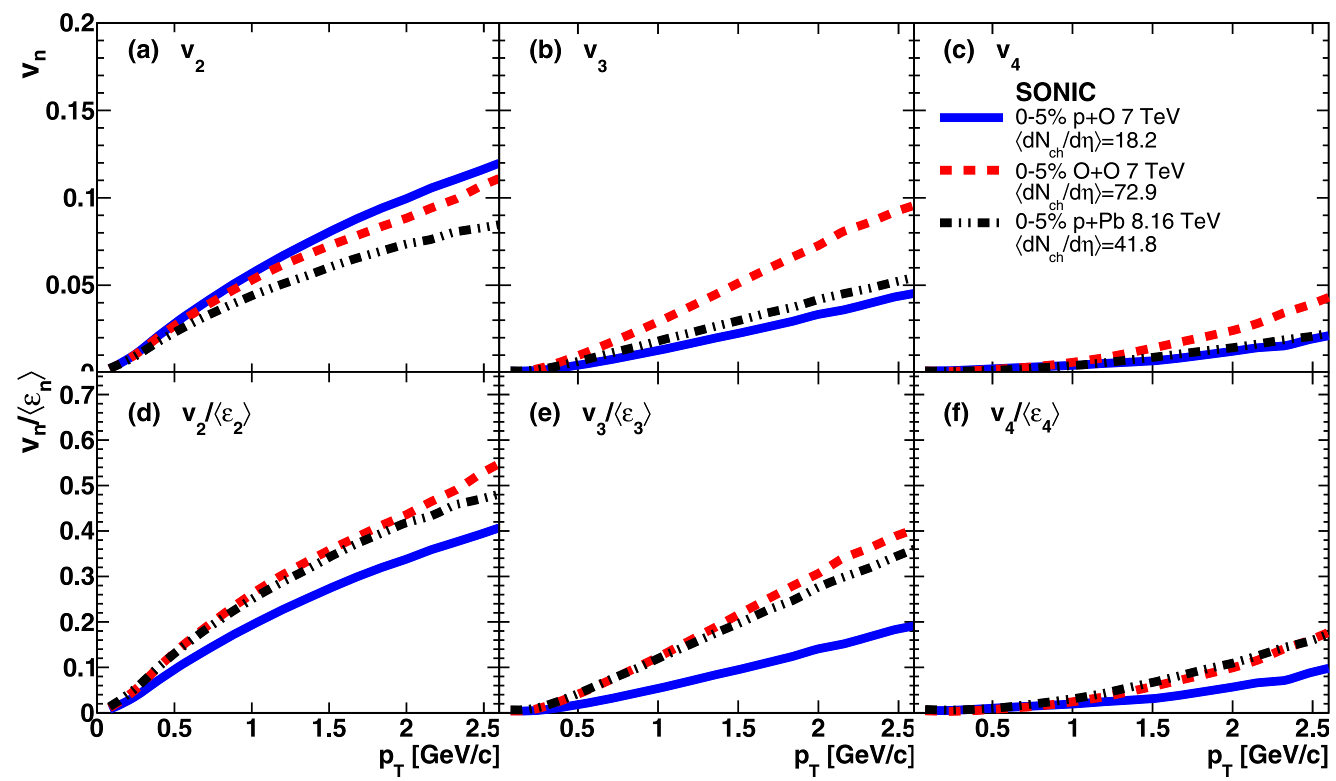
Khachatryan V, et al. *J. High Energy Phys.* 04:039 (2017)

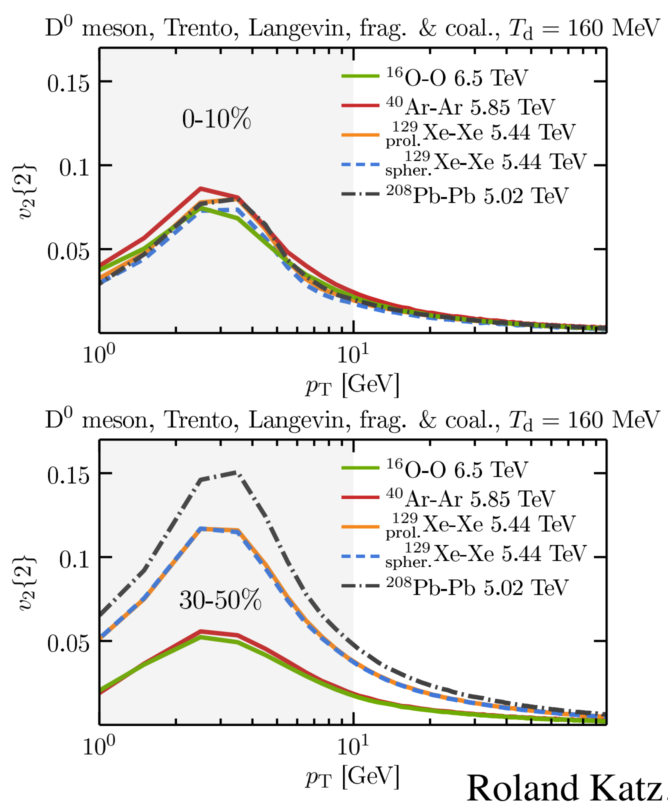
Some recent theoretical works on collective flow in small system

Shengli Huang, et al., arXiv:1904.10415v1

S. H. Lim, et al., Phys. Rev. C **99**, 044904 (2019)







Roland Katz, et al., arXiv:1907.03308v1

FIG. 3. D^0 meson $v_2\{2\}$ for PbPb, XeXe with spherical and prolate initial nuclei, ArAr, and OO collisions at the LHC top energies in 0–10% (top) and 30–50% (bottom) centrality classes.

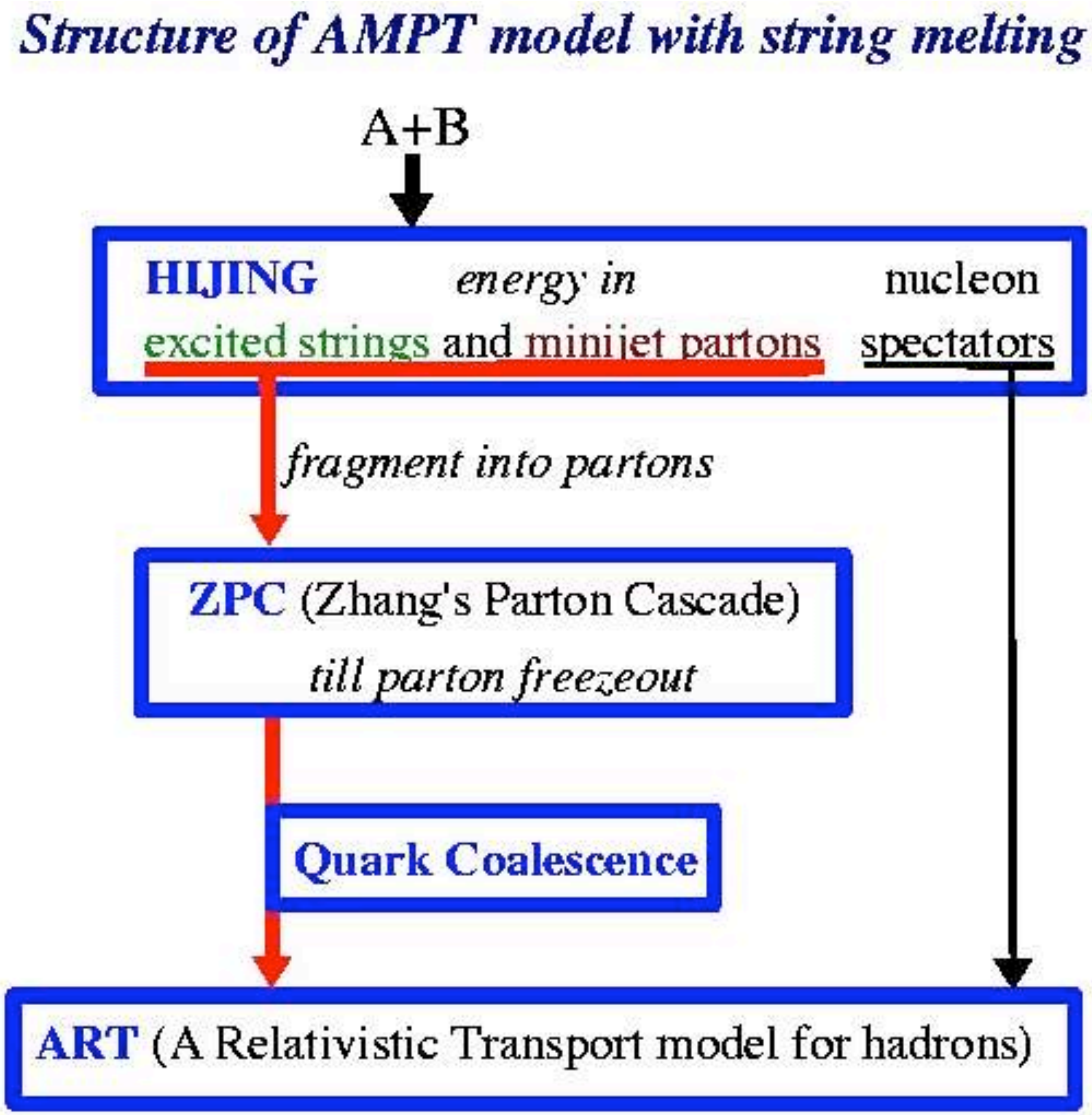
Recently some theoretical works propose the system scan in experiments
AMPT, SONIC, Hydro.
RIHC & LHC

AMPT model and α-cluster nuclei effect

- AMPT
- α-cluster nuclei effect on collective flow
- α-cluster nuclei effect on electromagnetic field
- α-cluster nuclei effect on HBT correlations

AMPT

AMPT (a multi-phase transport model), Z. W. Lin, C. M. Ko, B. A. Li, S. Pal, PRC-72-064901(2005)



(1) initial condition (HIJING);

(2) parton cascade (ZPC);

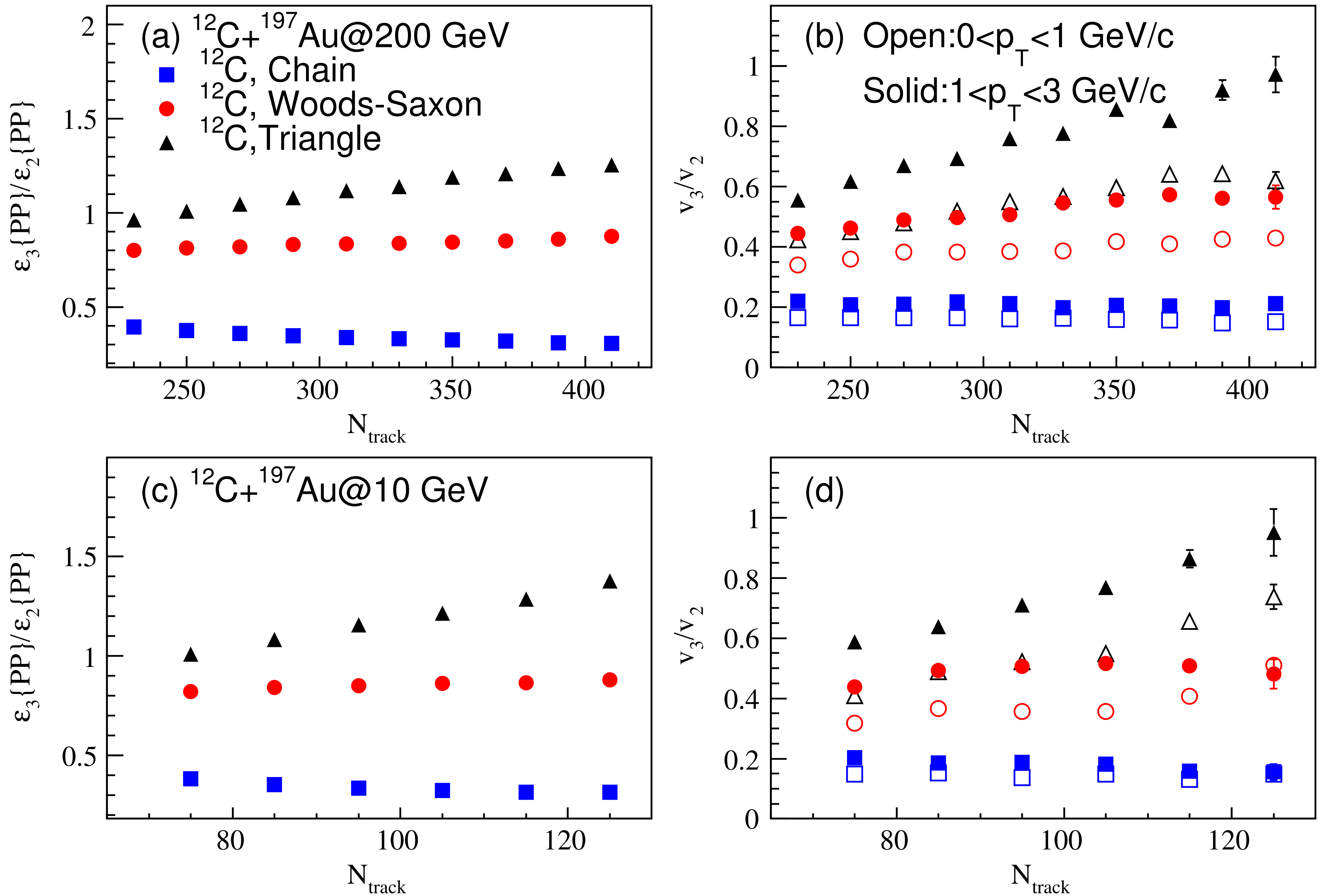
(3) hadronizition;

(4) hadronic rescattering (ART)

For high energy heavy ion collisions

α-cluster nuclei effect on collective flow

S. Zhang, Y. G. Ma, et al., Phys. Rev. C 95, 064904 (2017); S. Zhang, Y.G. Ma et al., Eur. Phys. J. A (2018) 54

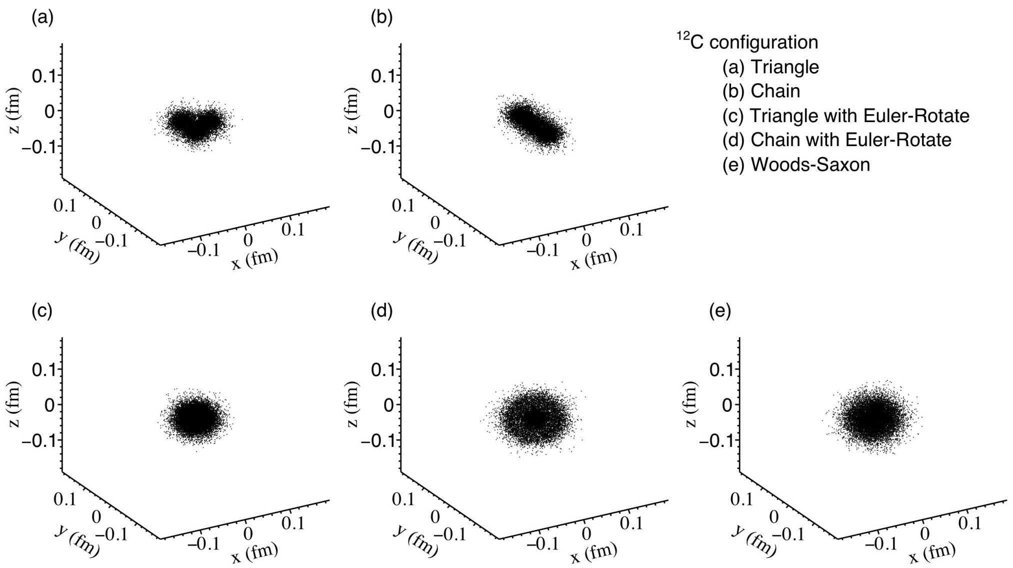


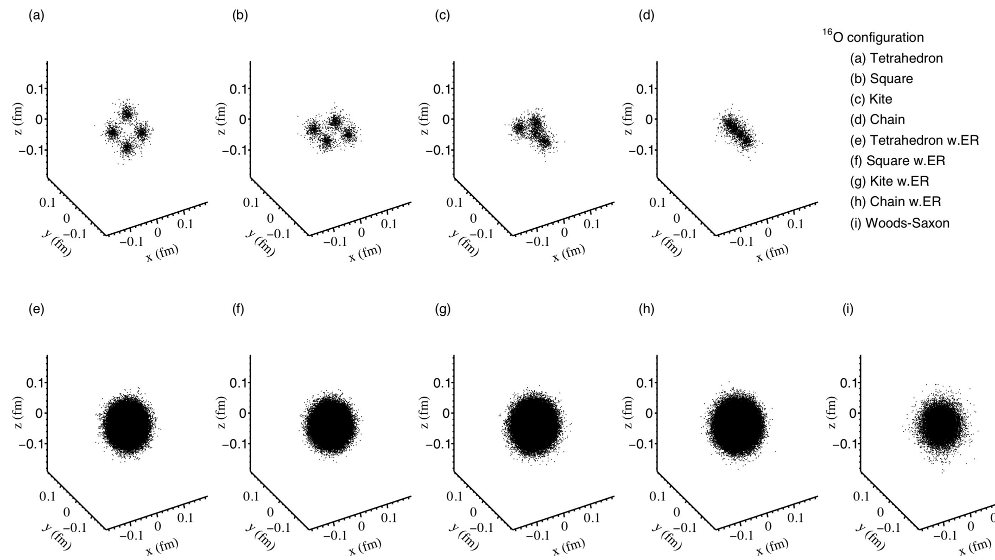
✓The ratio keep flat tend with increasing of N_{track} for Woods-Saxon distribution and chain structure of ^{12}C

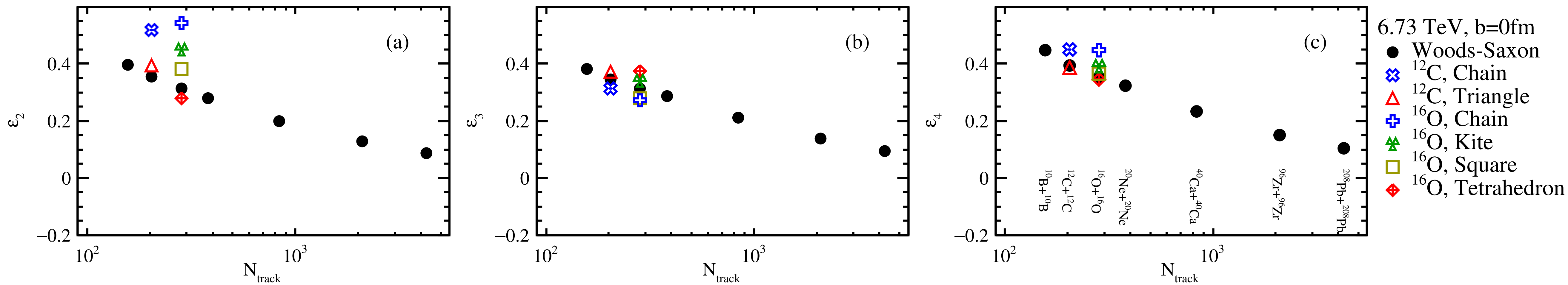
✓ The ratio increases with increasing of N_{track} for triangle structure.

System scan of collective flow and α-cluster nuclei effect

Eccentricity coefficients

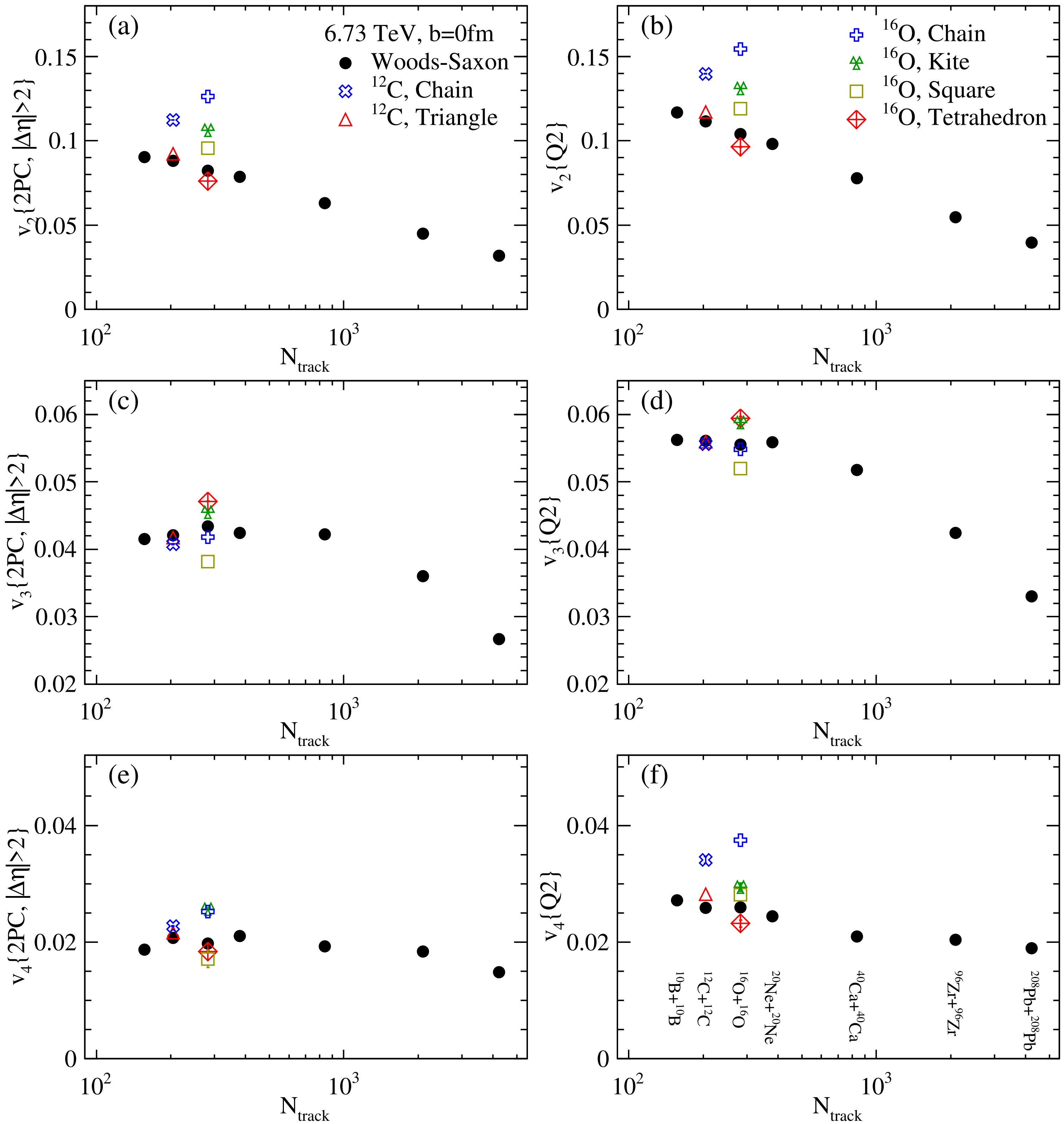






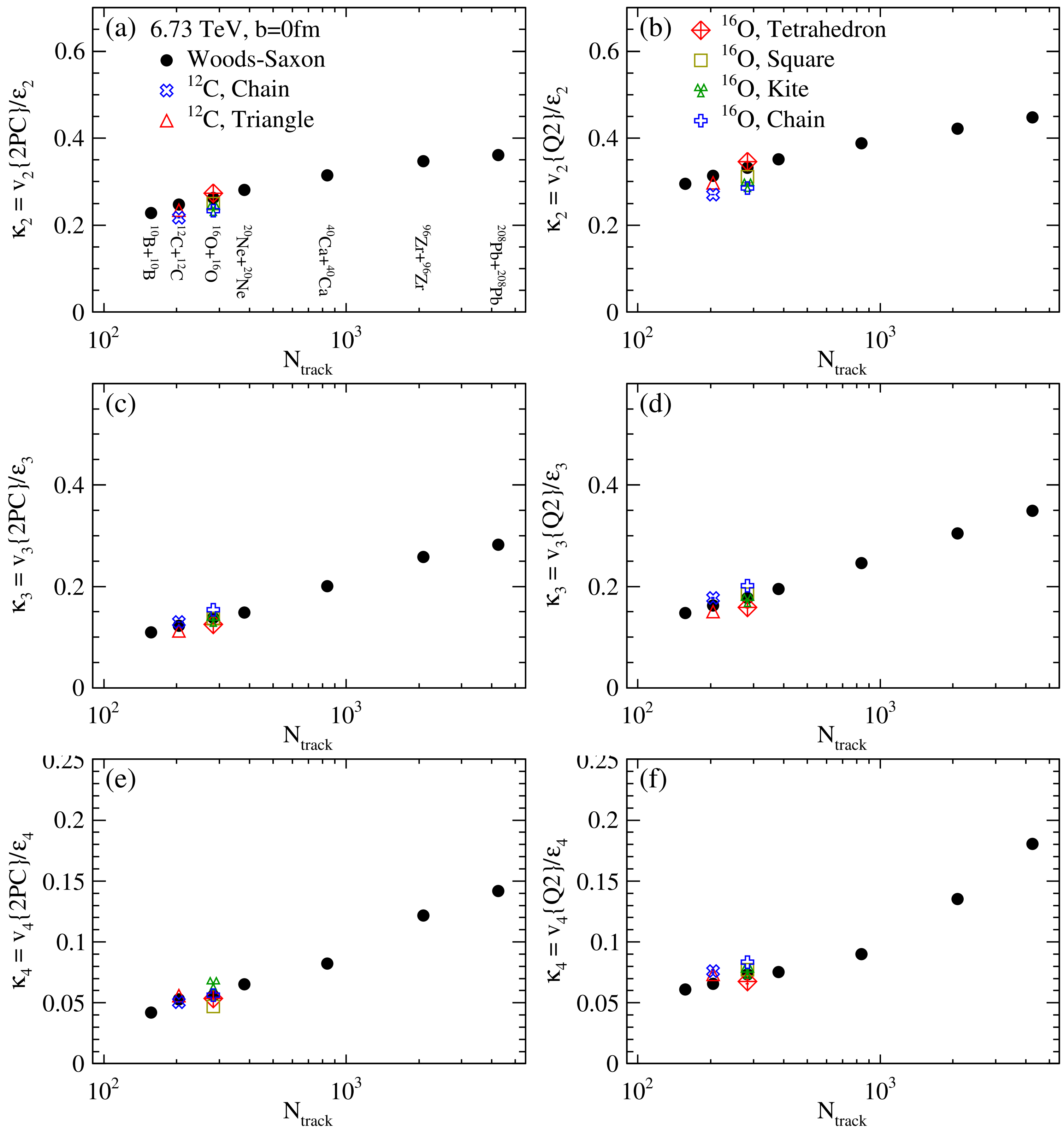
- ✓**Sensitive to fluctuation**
- ✓**Also sensitive to intrinsic geometry (α-cluster structure)**

Collective flow



- ✓ **Method1: two particle correlation with Δη gap**
- ✓ **Method2: Q- cumulant**
- ✓ **Smoothly decrease with increasing size of collision system (most central, Woods-Saxon distribution)**
- ✓ **Deviation from Woods-Saxon case for α-clustered initial system**

Ratio of flow to eccentricity

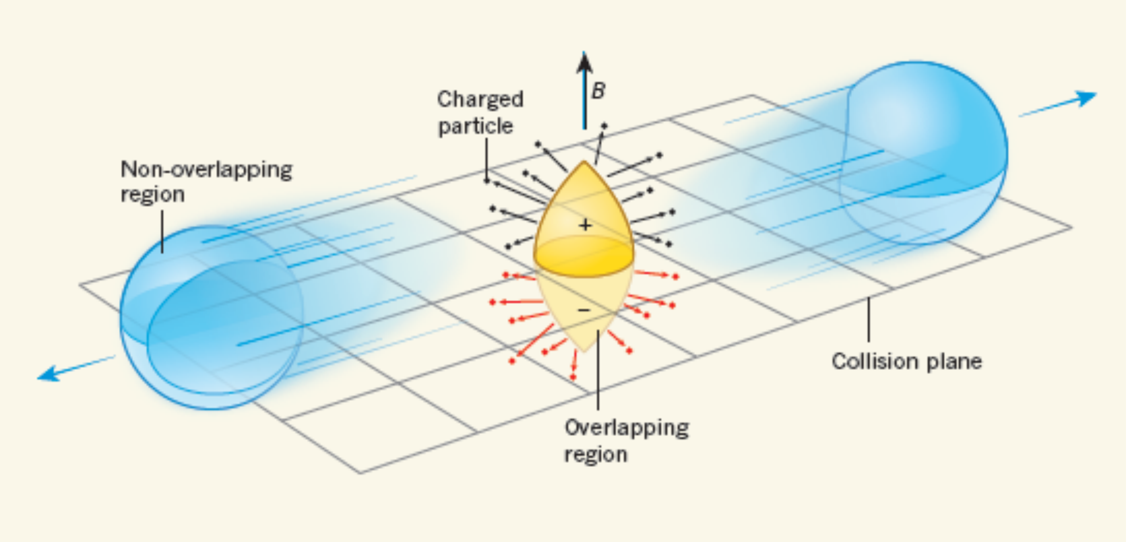


- ✓ κ_n increasing with the increasing of system size (most central collisions)
- ✓ Same A+A collisions with different initial structure configuration, the similar κ_n

System dependence and of electromagnetic fields and α-cluster nuclei effect (I)

Li´enard-Wiechert potentials

Huang,(PRC) 85, 044907 (2012)



$$e\vec{E}(\vec{r}_i,t)=\frac{e^2}{4\pi}\sum_n Z_n \frac{1-\upsilon_n^2}{(R_n-\vec{R}_n\cdot\vec{\upsilon}_n)^3}(\vec{R}_n-R_n\upsilon_n)$$

$$e\vec{B}(\vec{r}_i,t)=\frac{e^2}{4\pi}\sum_n Z_n \frac{1-\upsilon_n^2}{(R_n-\vec{R}_n\cdot\vec{\upsilon}_n)^3}\vec{\upsilon}_n\times\vec{R}_n$$

Zn : coordinate position

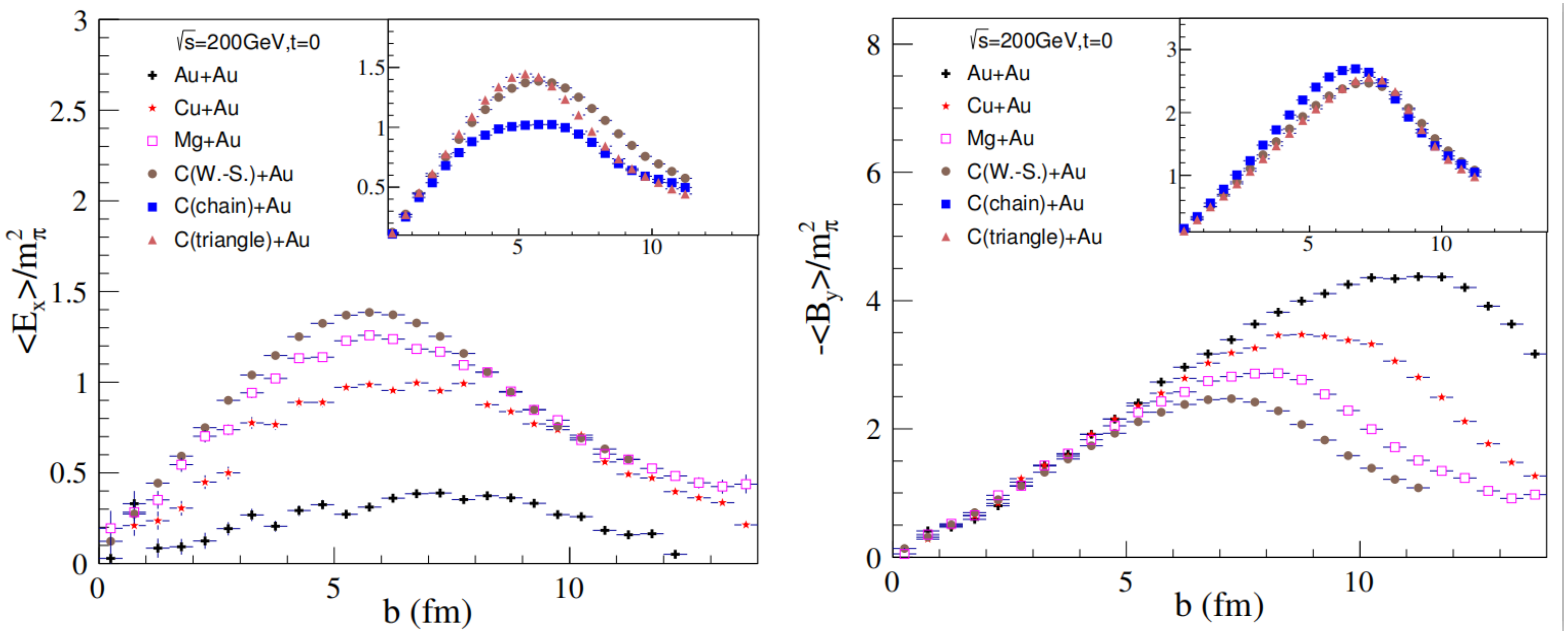
Rn = r − r_n : r is the position of source point

r_n is the position of the n-th particle at the retarded time tn = t − |r − r_n| and t_n < t

$v_x = v_y = 0,\ v_z^2 = 1 - (2m_N/\sqrt{s})^2$ (the Lorentz contraction is considered)

System dependence and of electromagnetic fields and α-cluster nuclei effect (II)

Y. L. Cheng (程艺琳), S. Zhang, Y. G. Ma, et al., Phys. Rev. C 99, 054906 (2019)



- ✓ $<E_x>$: the asymmetric projectile and target nuclear collisions produce stronger electric field than symmetrical collision system
- ✓ $-<B_y>$: the magnetic field will be in the reverse trend
- ✓ α-cluster effect at semi-central collisions for chain structure

HBT correlation and α-cluster nuclei effect (I)

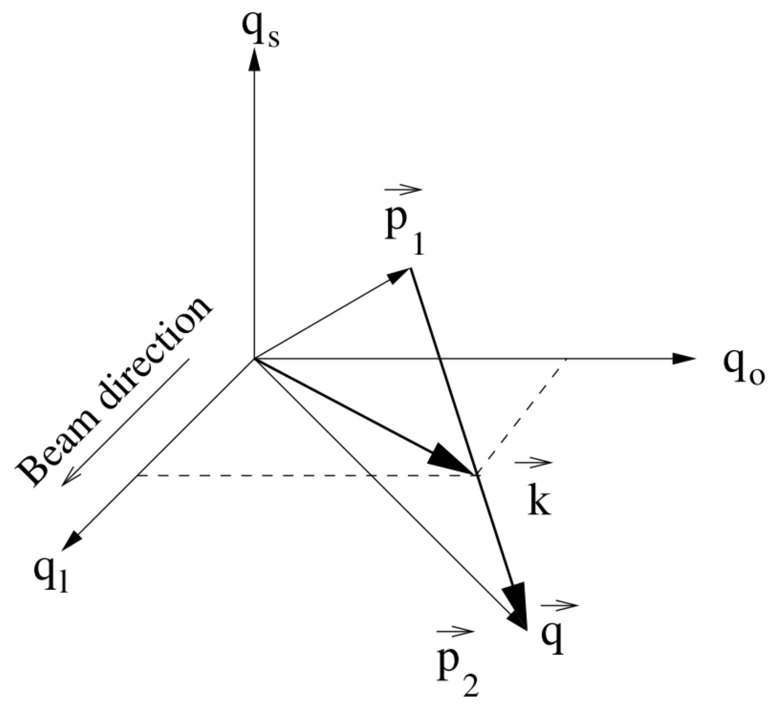
$$C(\vec{q},\vec{K})=\frac{\int d^4x_1d^4x_2S(x_1,p_1)S(x_2,p_2)|\phi(\vec{q'},\vec{r'})|^2}{\int d^4x_1S(x_1,p_1)\int d^4x_2S(x_2,p_2)} \quad (1)$$

$$C(\vec{q},\vec{K})=1\pm\left|\frac{\int d^4xe^{i\vec{q}\cdot(\vec{x}-\vec{\beta}t)}S(x,K)}{\int d^4xS(x,K)}\right|^2 \quad (2)$$

$$C(\vec{q},\vec{K})=1\pm e^{-\sum_{i,j=o,s,l}R_{ij}^2(\vec{K})q_iq_j} \quad (3)$$

$$\begin{aligned}R_s^2(K_T,\Phi,Y)=&\langle(y\cos\Phi-x\sin\Phi)^2\rangle\\&-\langle y\cos\Phi-x\sin\Phi\rangle^2\end{aligned} \quad (4)$$

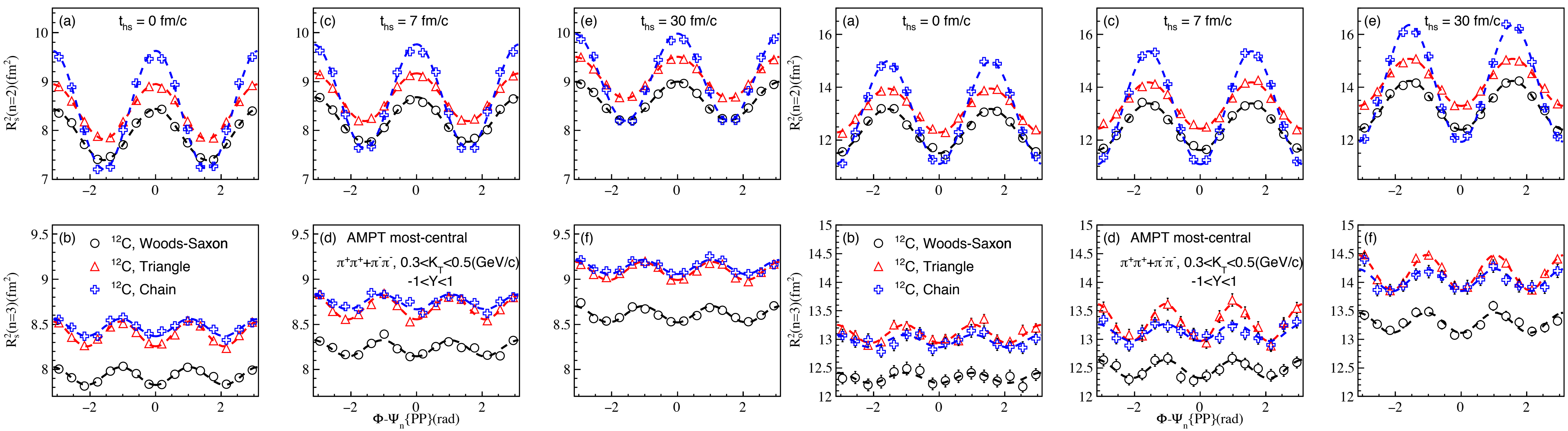
$$\begin{aligned}R_o^2(K_T,\Phi,Y)=&\langle(x\cos\Phi+y\sin\Phi-\beta_\perp t)^2\rangle\\&-\langle x\cos\Phi+y\sin\Phi-\beta_\perp t\rangle^2\end{aligned} \quad (5)$$



HBT correlation and α-cluster nuclei effect (II)

✓**Small HBT-radius in collisions with triangle nuclei structure**

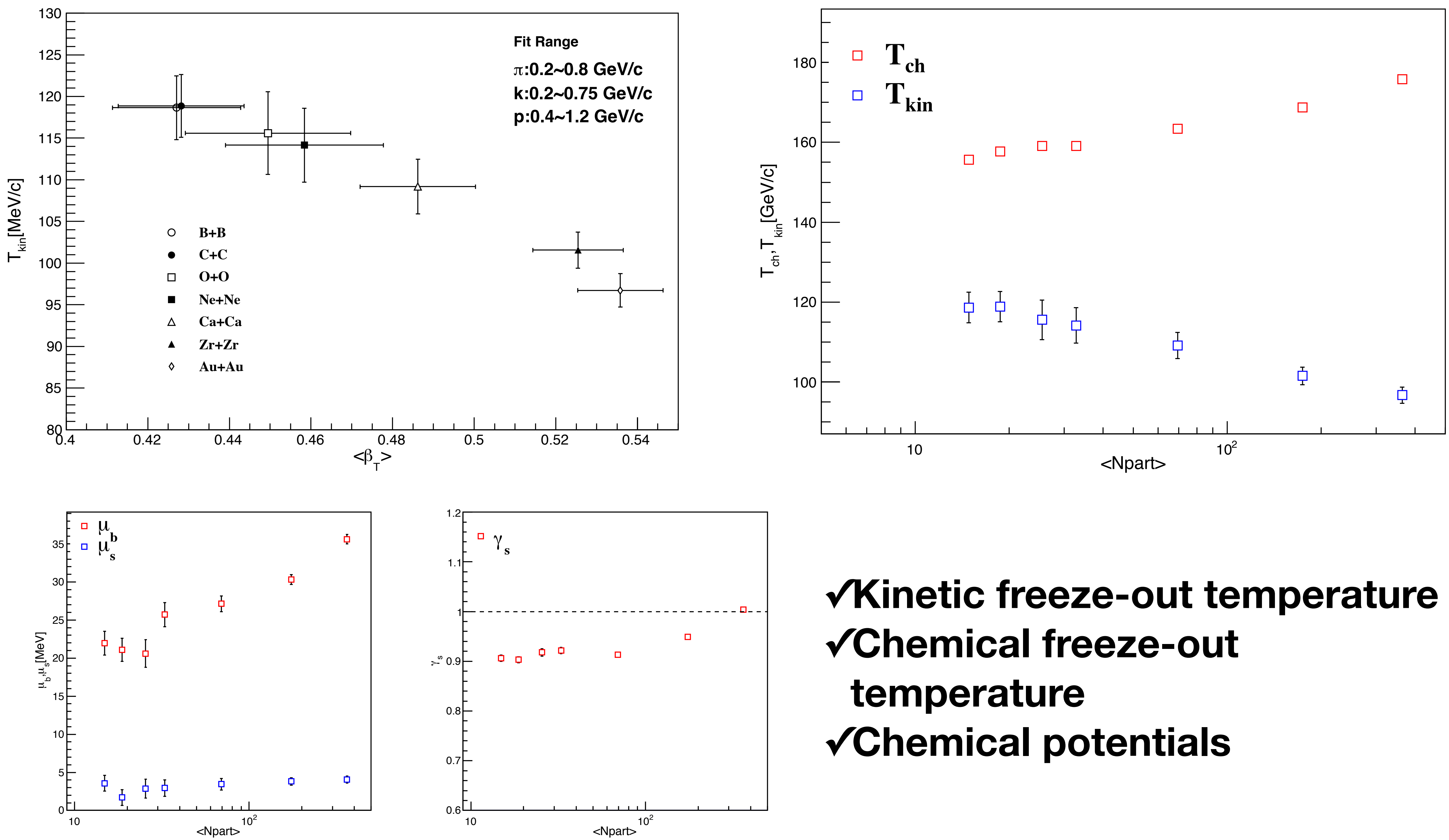
✓**Significant participant plane dependence**



Junjie He (何俊杰)

Freeze-out properties

Dongfang Wang (王东方), draft preparing



- ✓Kinetic freeze-out temperature
- ✓Chemical freeze-out temperature
- ✓Chemical potentials

Summary

- Collective flow change smoothly with system size in most central collisions, Woods-Saxon distribution of nucleon
- α-cluster effect significant with the baseline from Woods-Saxon distribution
- Symmetry and asymmetry collision system result in different electromagnetic field effect
- HBT-radius sensitive to the α-cluster effect
- Freeze-out properties in system scan
- Proposal of system scan experiments, experimentally illustrate how initial geometrical asymmetry transfer to momentum space

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主要方向：ALICE&STAR物理（exp. & th.）；中低能核物理；激光核物理；
Email: song_zhang@fudan.edu.cn

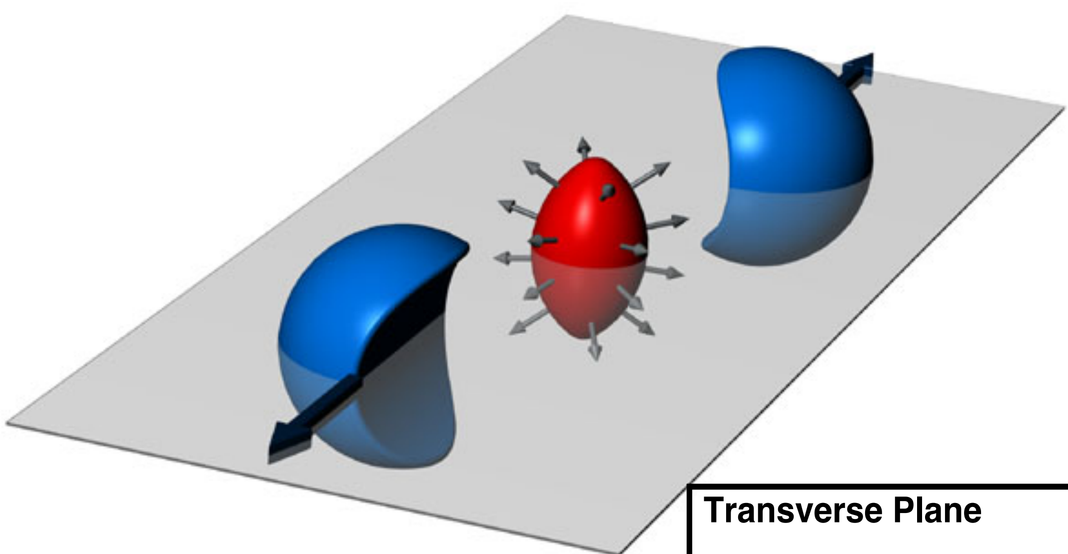
Thank you for your attention!

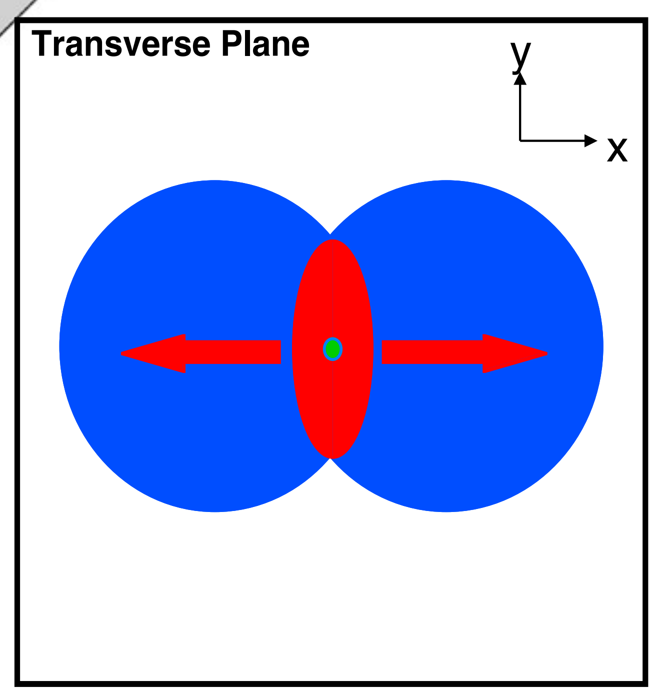
Collective flow

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos[n(\phi-\Psi_r)]\right)$$

A. M. Poskanzer, S. A. Voloshin, Phys. Rev. C 58 (1998) 1671

$$v_n = <\cos[n(\phi-\Psi_r)]>$$





S.A. Voloshin et al. / Physics Letters B 659 (2008) 537–541