System Size, Collision Energy and Rapidity Dependence of Collective Dynamics Measured by the PHENIX Experiment at RHIC

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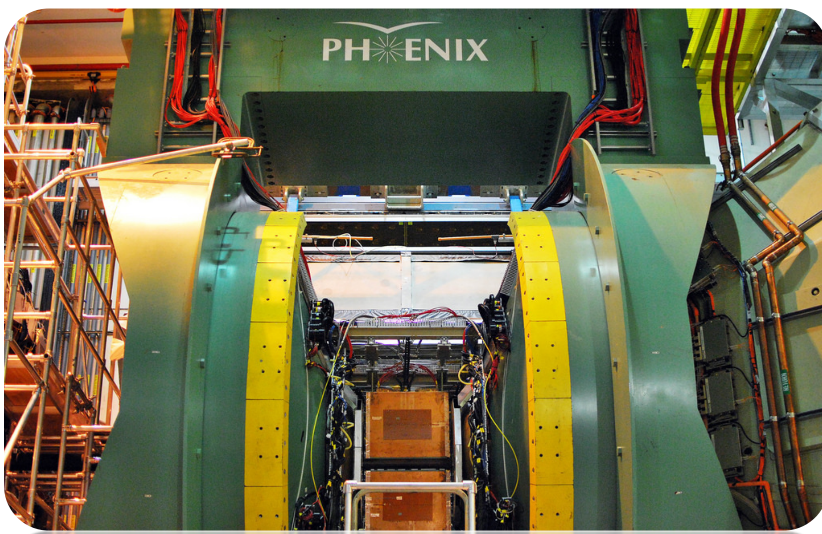
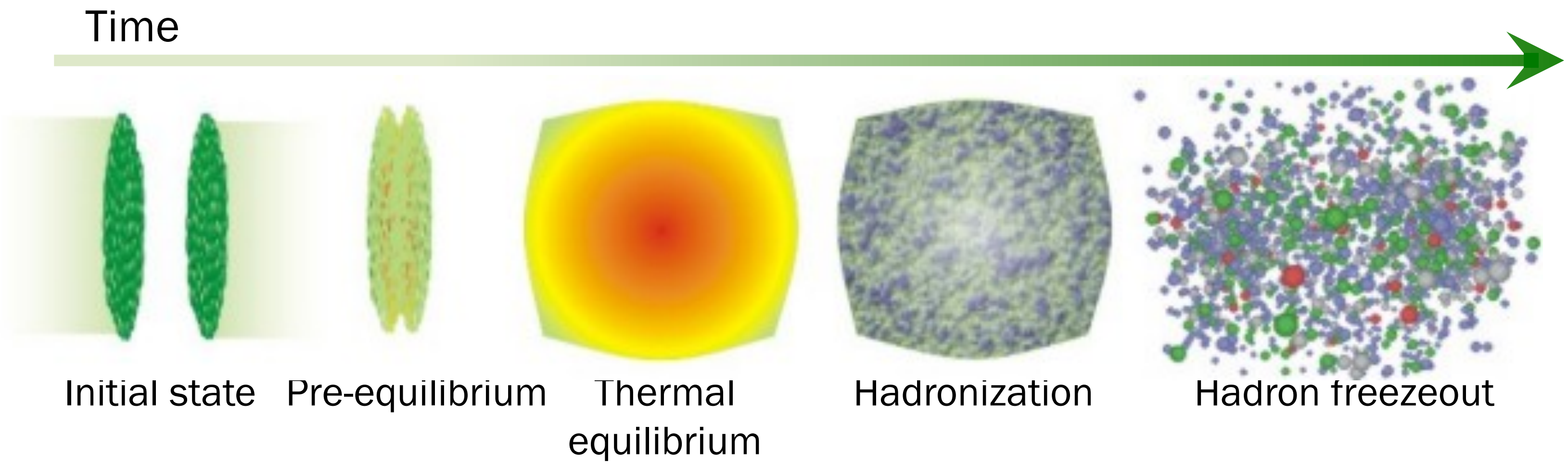
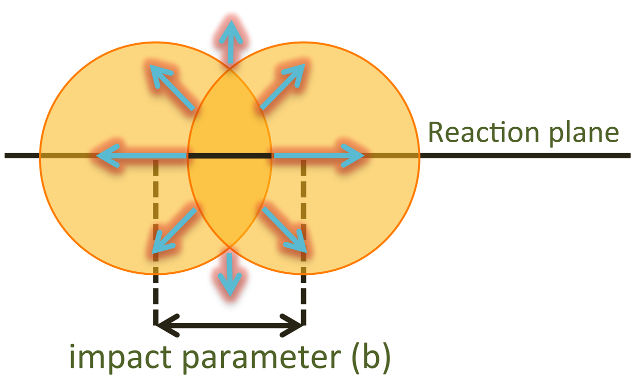


Collective behavior in heavy ion collision



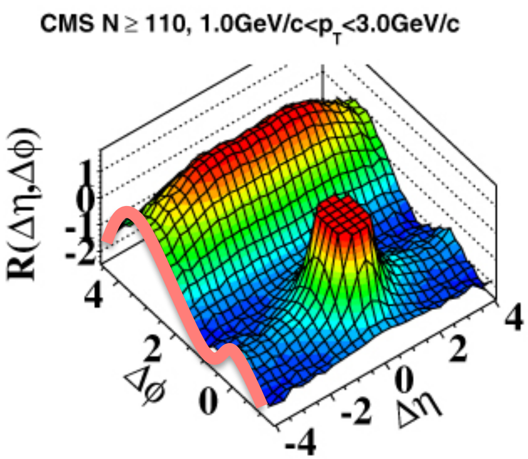


- Standard model of A+A collisions
- Ideal fluid created – sQGP.
- Multi-particle correlations between the rapidities which originated from a common source.
- Non-collective originated correlation also exists;jet, particle decays, etc.
- In dihadron correlations Fourier harmonics v_n commonly attributed to hydrodynamic flow.

Small systems data taken by PHENIX

	^{3}He+Au	d+Au	p+Au	p+p
200 GeV	✔	✔	✔	✔
62.4 GeV		✔		
39 GeV		✔		
19.6 GeV		✔		

JHEP09(2010)091



Considerable size of near-side long-range ridge structure measured at p+p 7TeV(CMS)

- What is the smallest system condition which can create QGP?
- Contribution of pre-equilibrium and hadronization stage?
- Initial geometry?
- How to quantify these long-range ridge structure in small systems?
- How can we interpret physically?

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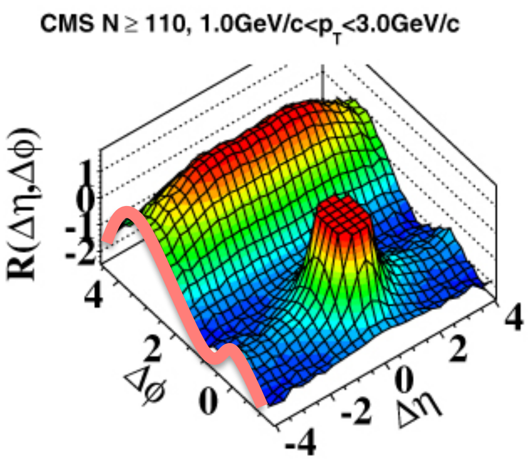

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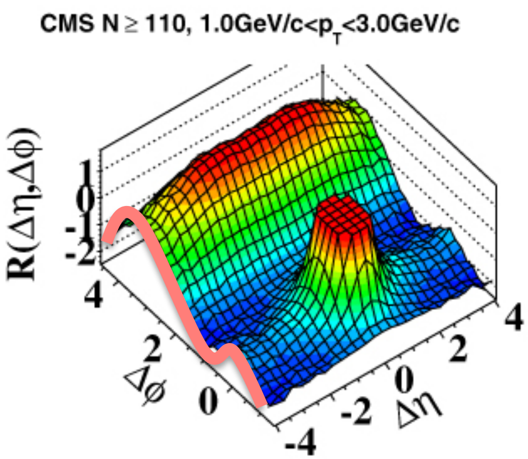

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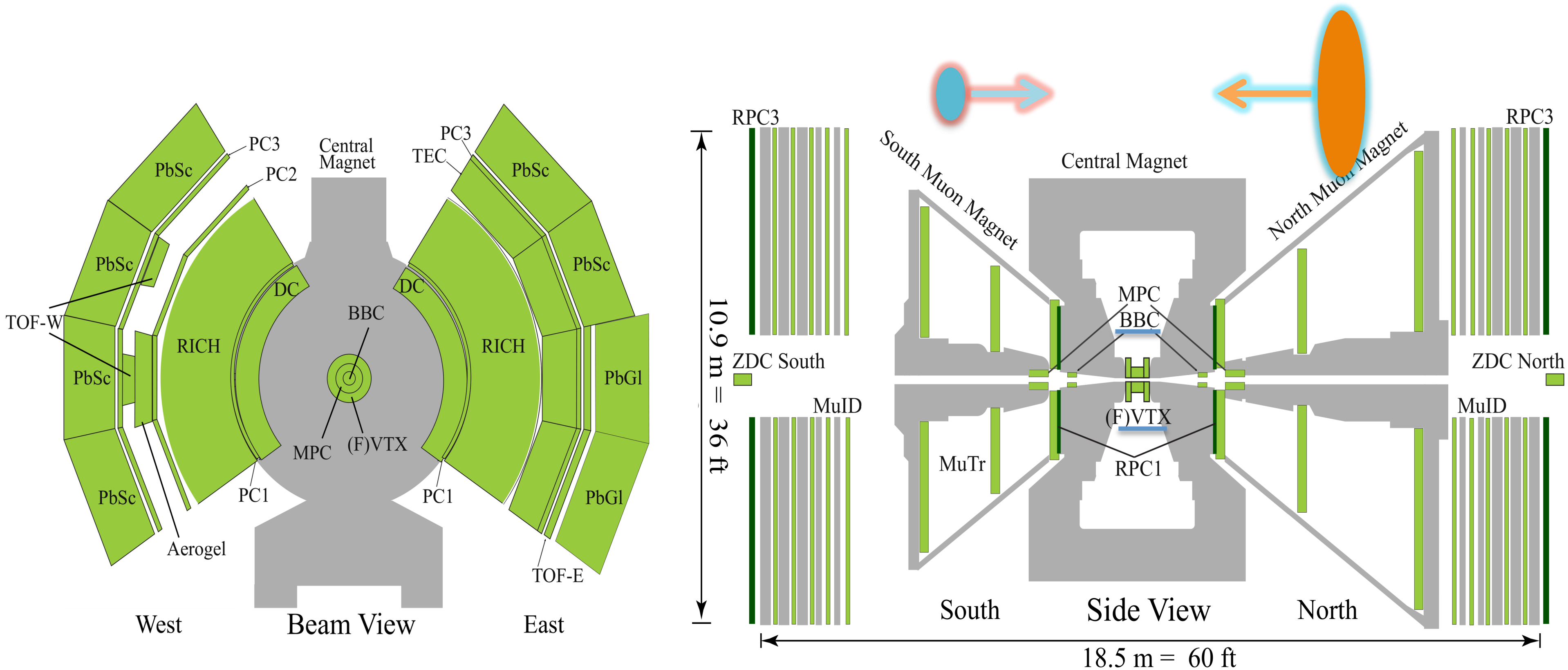
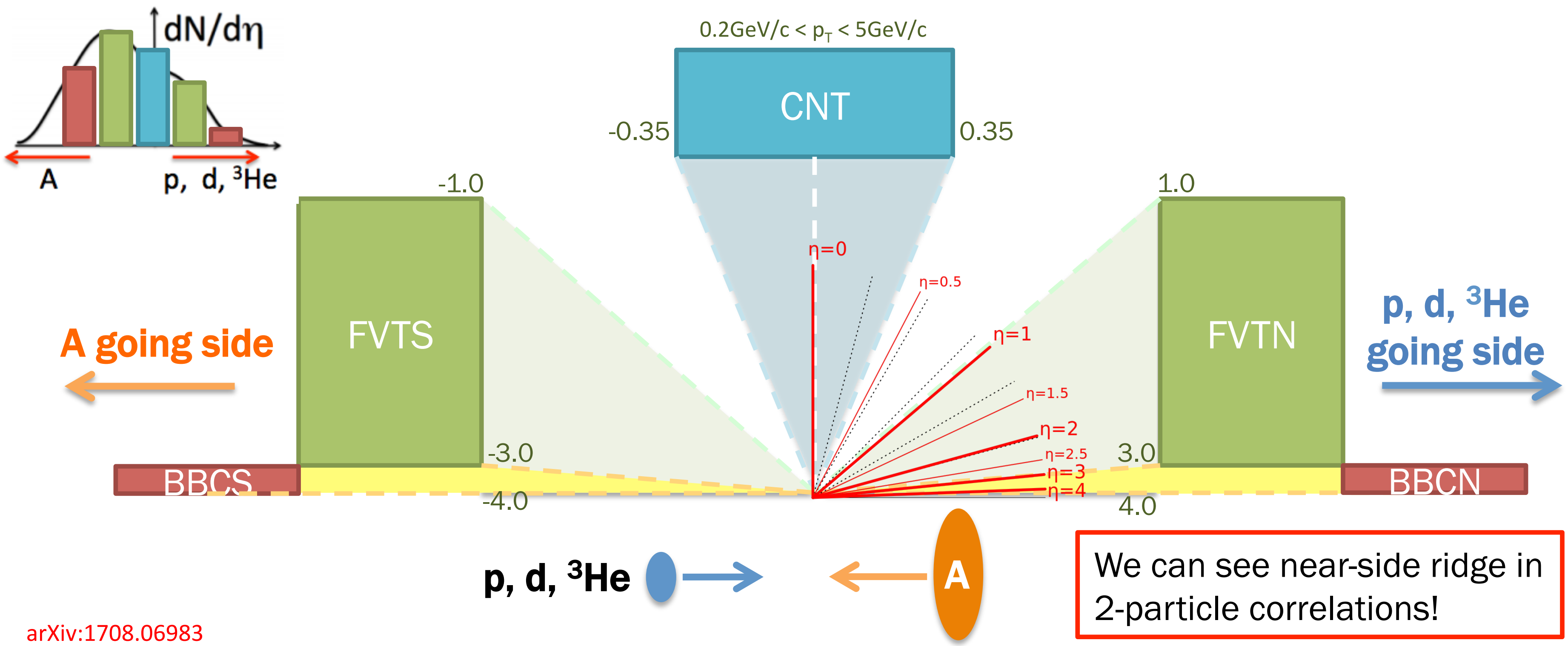
PHENIX detectors



Central arm :
charged particle measurement,
particle identification

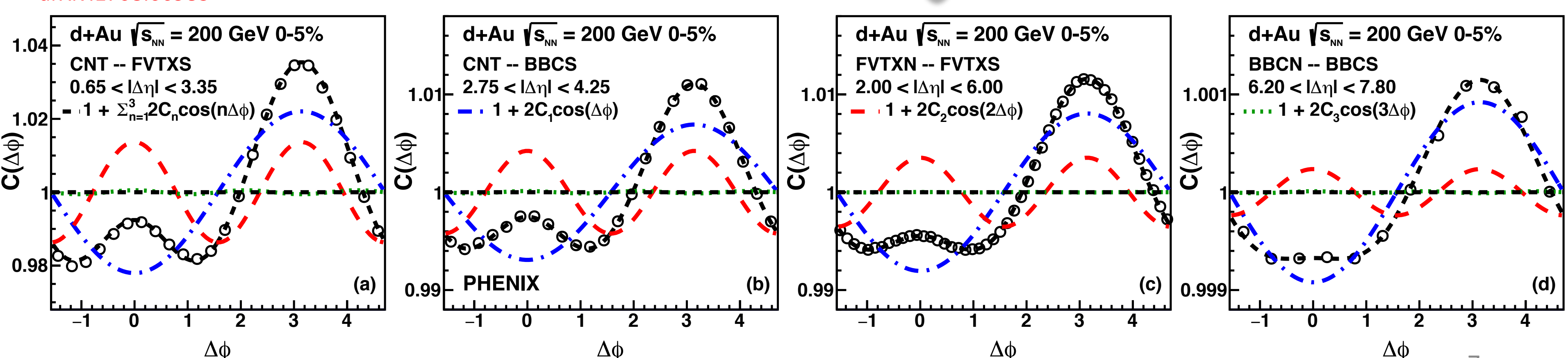
Forward-backward arm :
charged particle measurement, triggering,
event-plane determination

PHENIX detectors



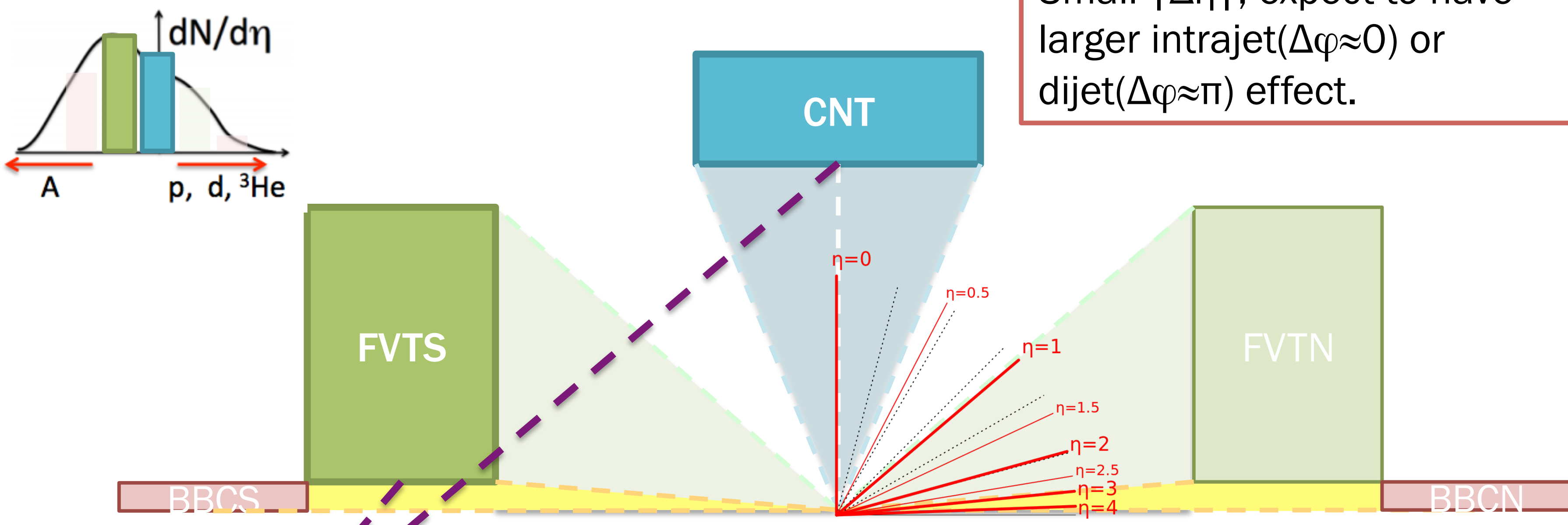
We can see near-side ridge in 2-particle correlations!

arXiv:1708.06983



PHENIX detectors

Small |Δη|, expect to have larger intrajet(Δφ≈0) or dijet(Δφ≈π) effect.



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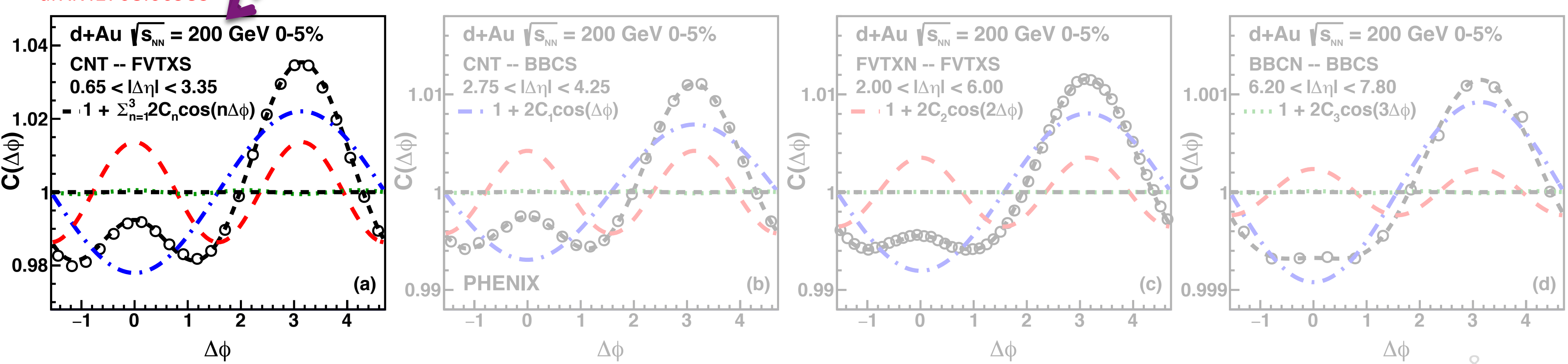

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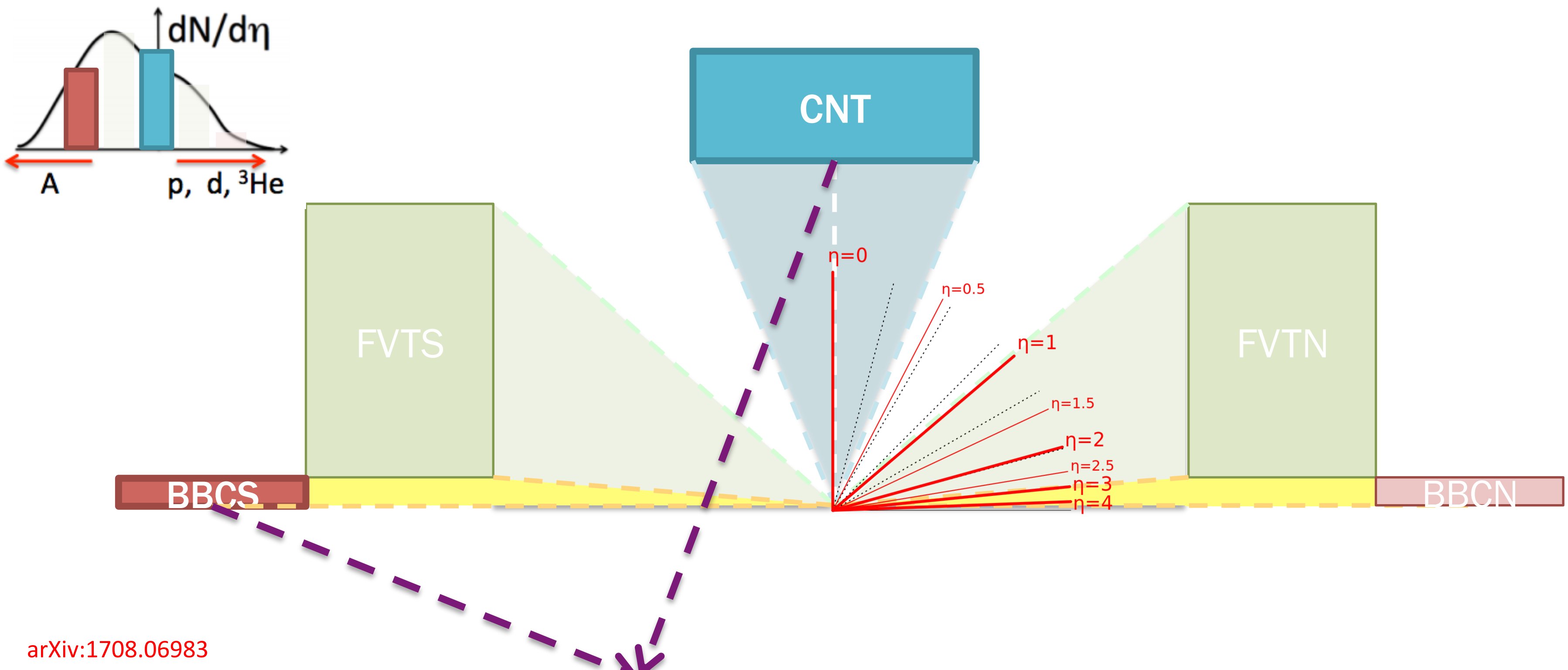

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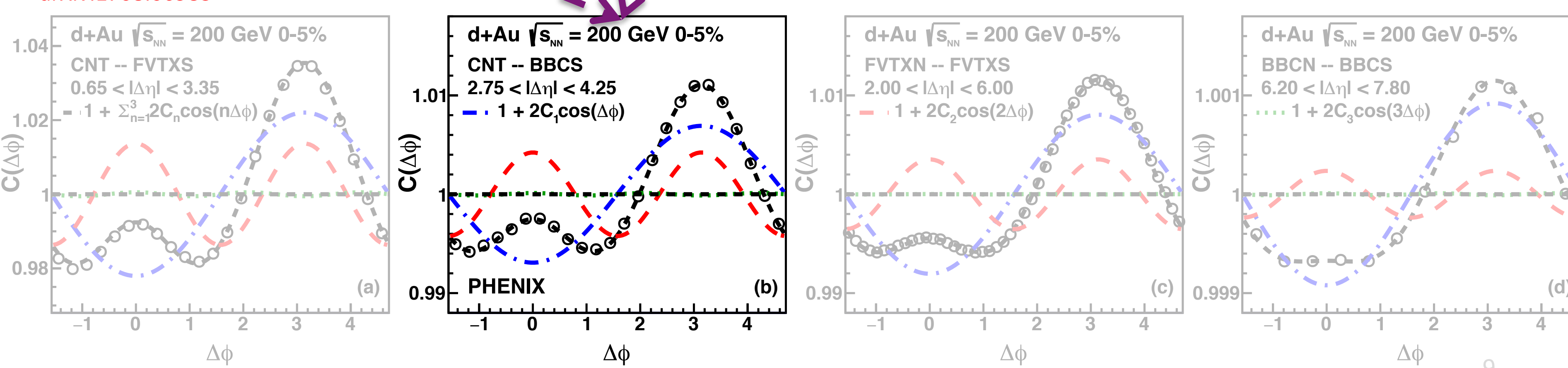

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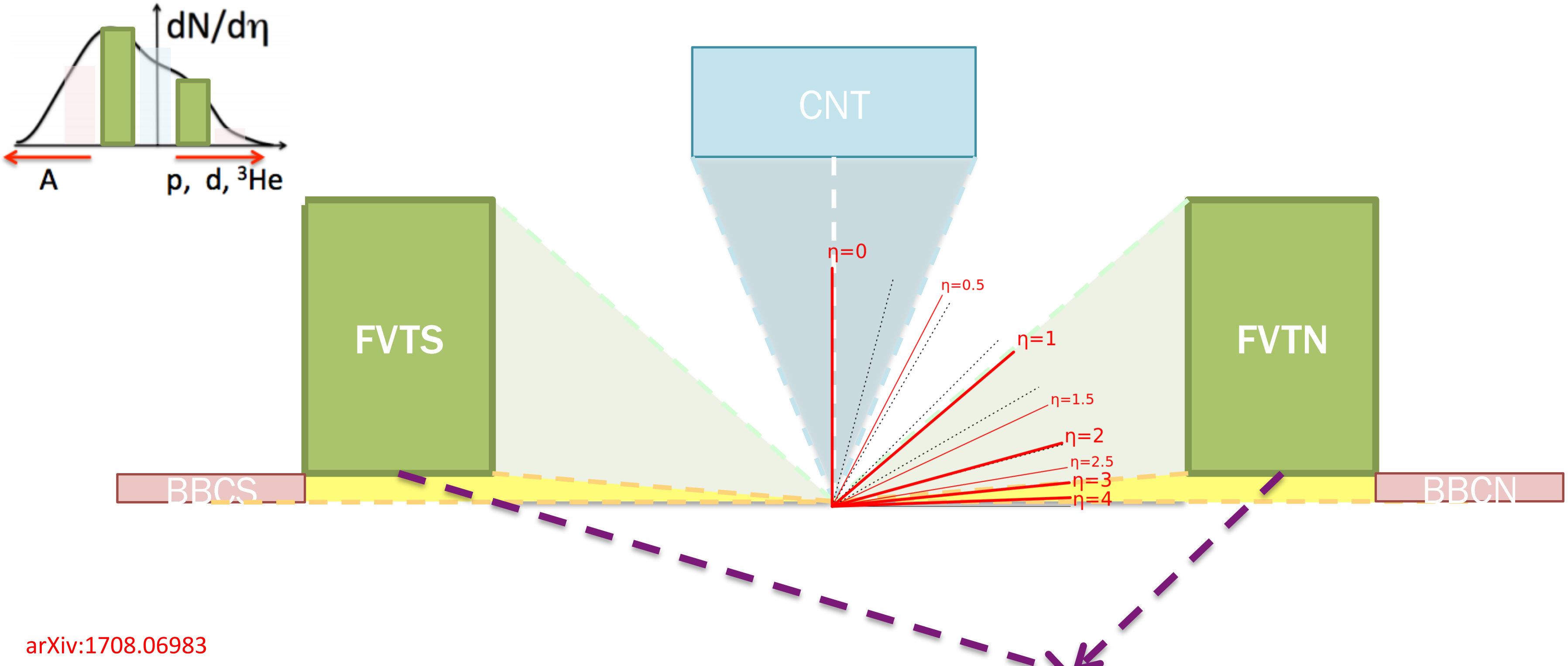

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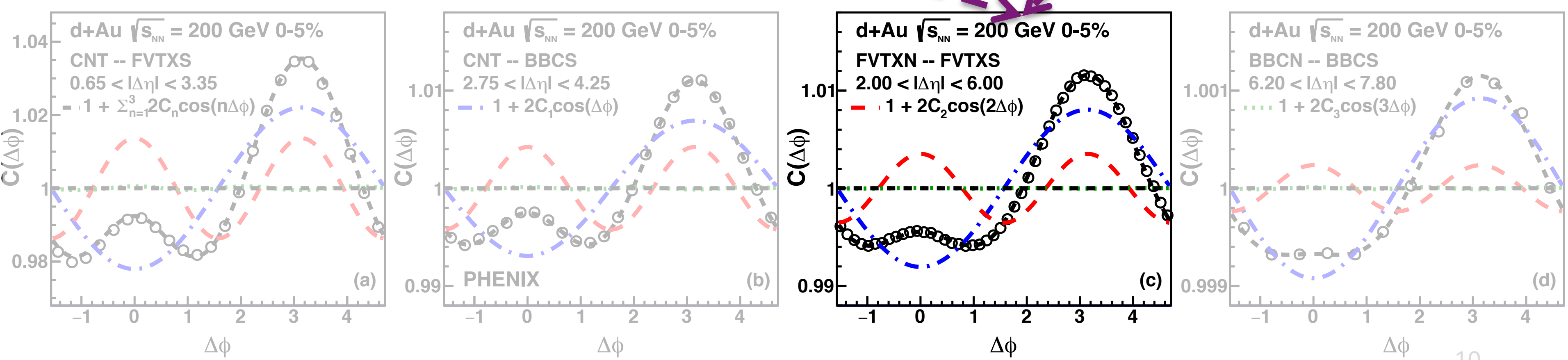
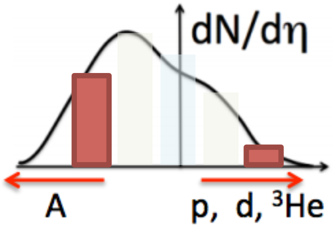
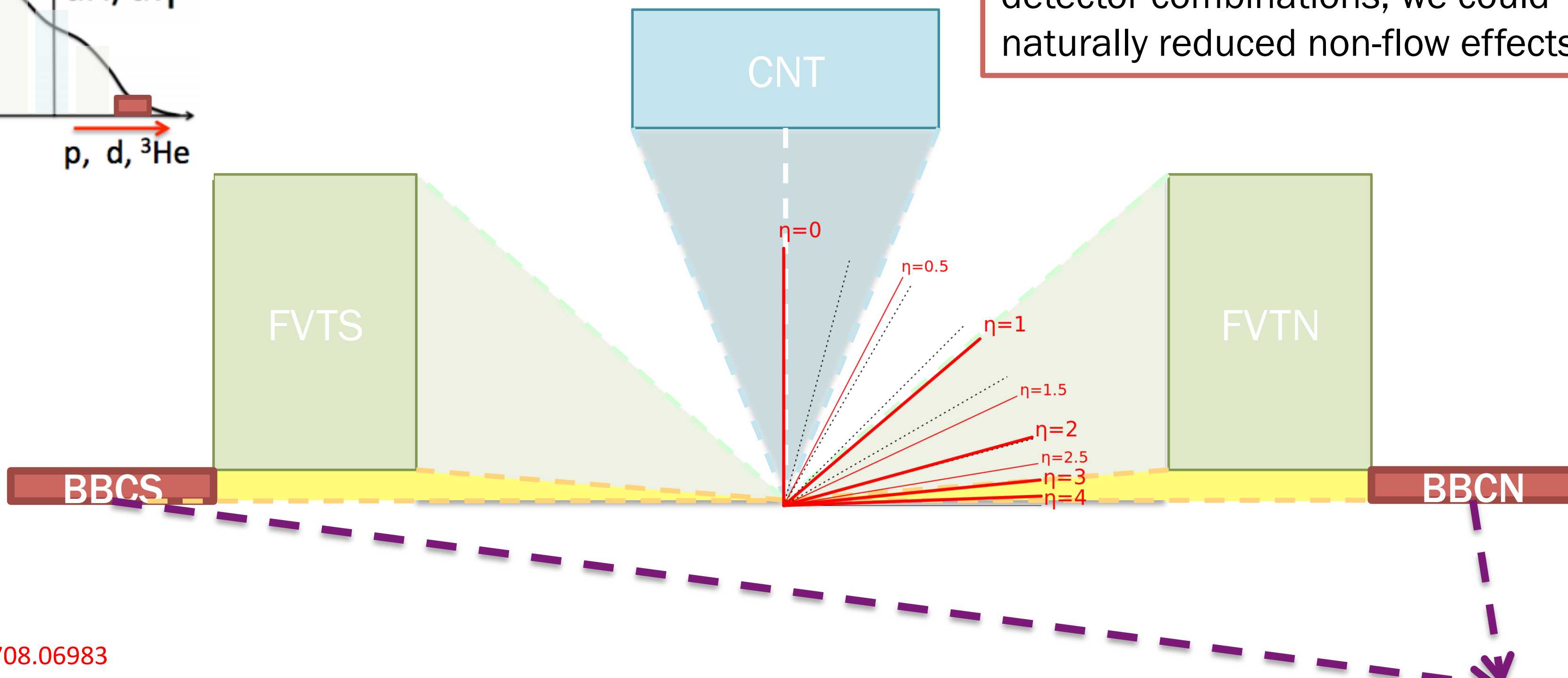


PHENIX detectors



By increasing |Δη| using different detector combinations, we could naturally reduced non-flow effects.



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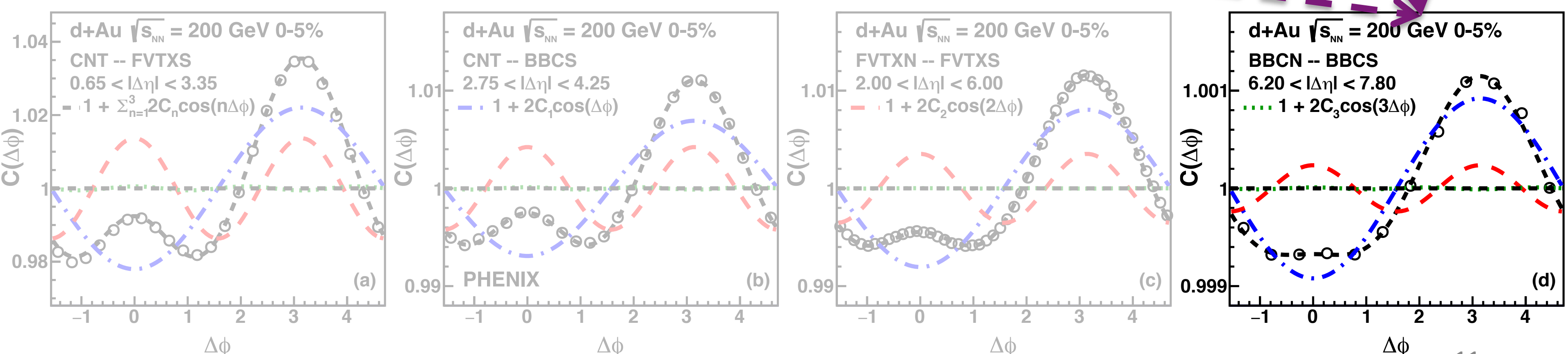

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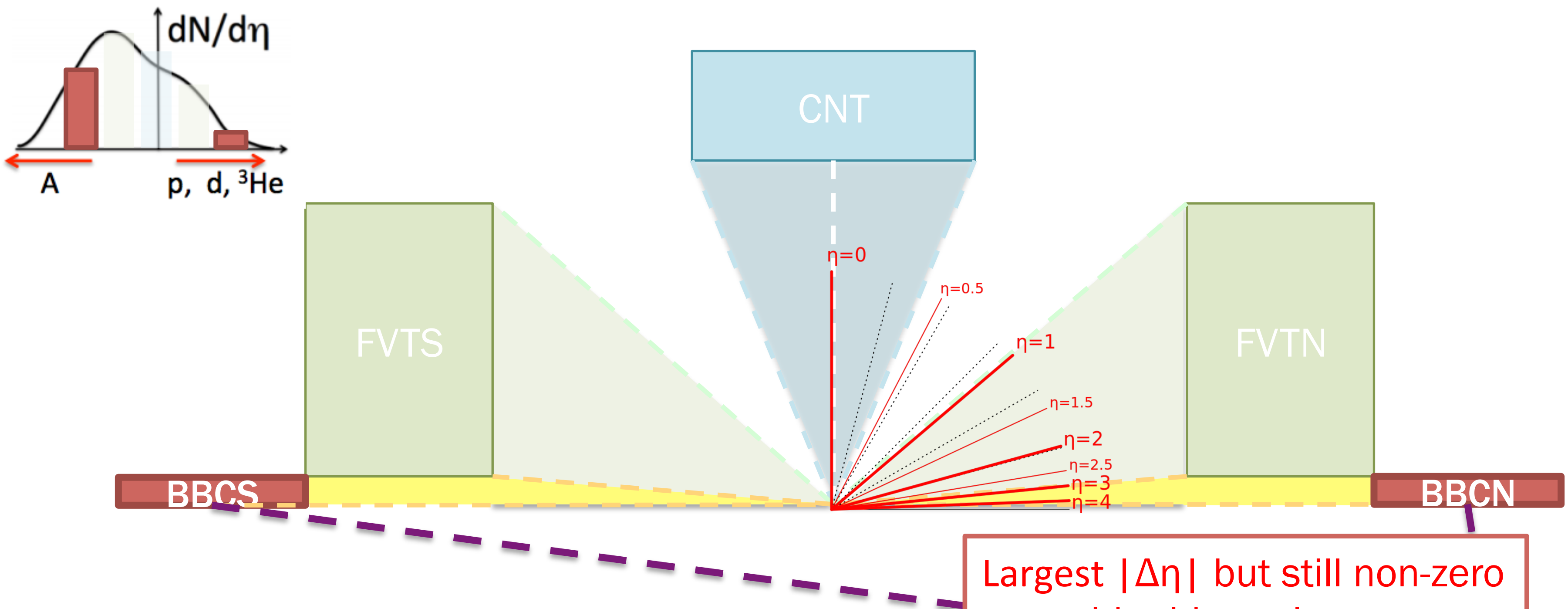

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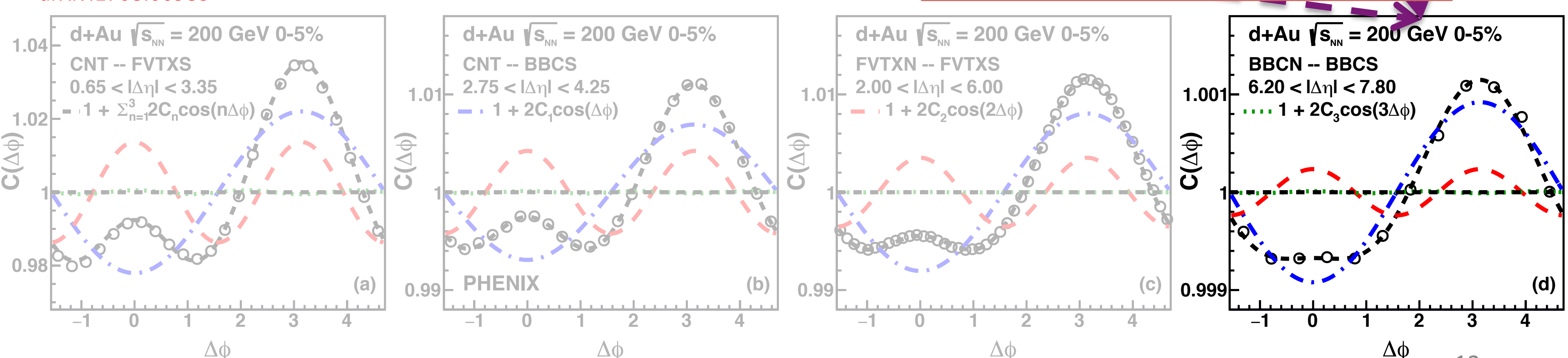
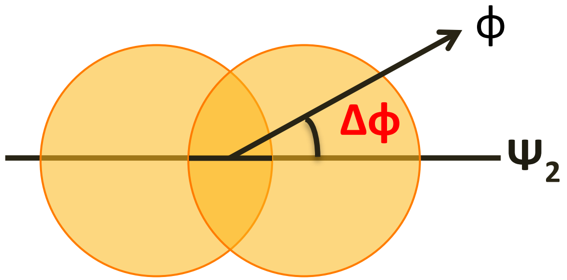


Analysis method

Event-plane method

- Define event-plane using FVTX-S clusters(hits)
- Calculate resolution of event-plane(Ψ_2) with 3 detectors; CNT,FVTS,BBCS

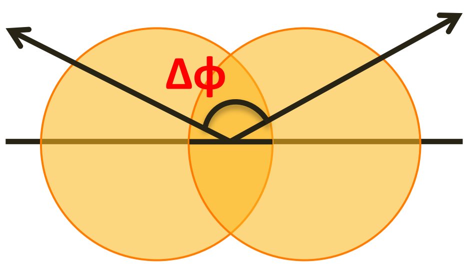
$$v_2^{CNT} = \frac{\left\langle \cos 2(\phi^{CNT} - \Psi_2) \right\rangle}{\mathrm{Res}(\Psi_2)}$$



2-particle correlation

- Calculate correlation of two tracks Δϕ in two different detectors
- Normalize with background correlations
- Fourier expansion fitting and coefficient of cos 2ϕ modulation c_2,

$$v_2^{CNT} = \sqrt{\frac{c_2^{CNT-BBCS} * c_2^{CNT-FVTS}}{c_2^{BBCS-FVTS}}}$$



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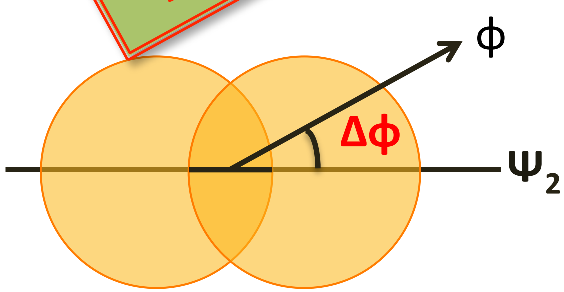

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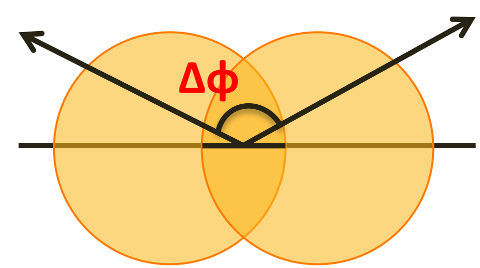
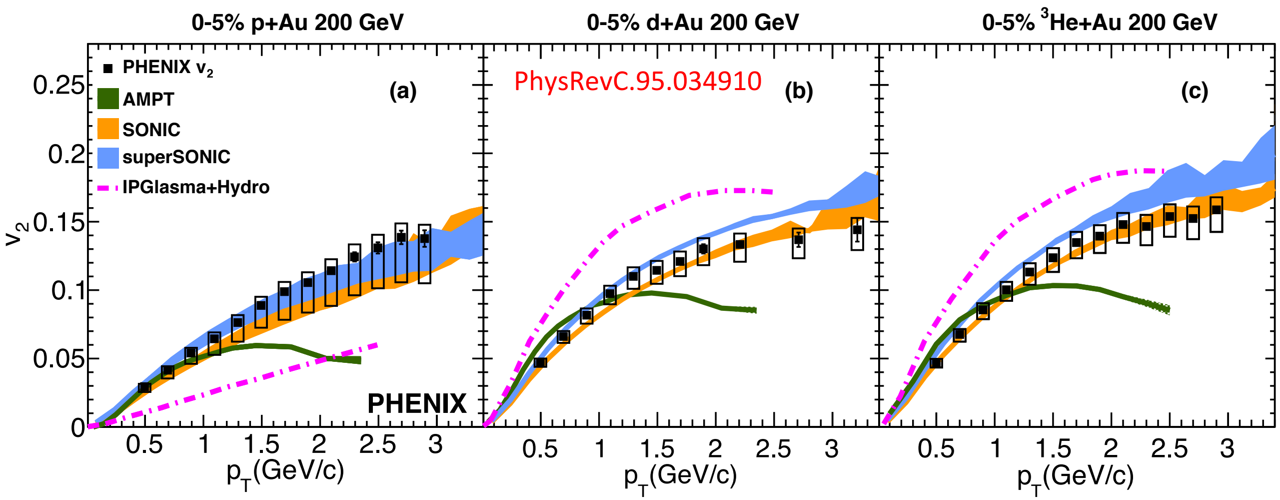
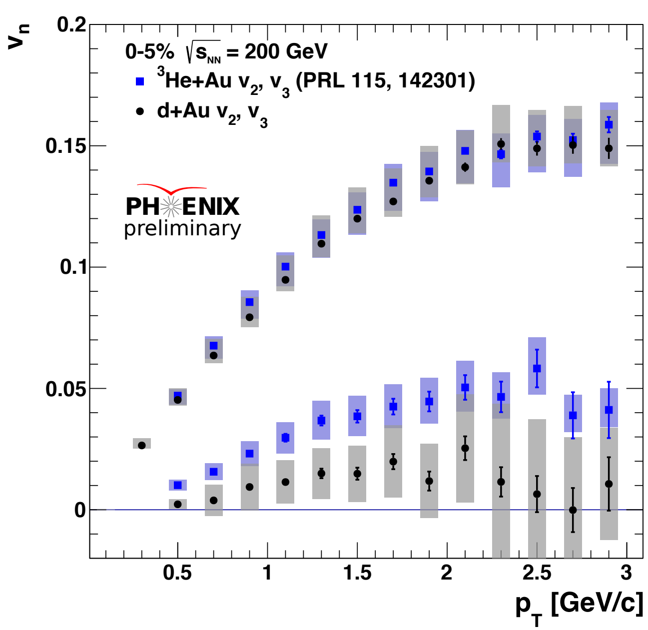
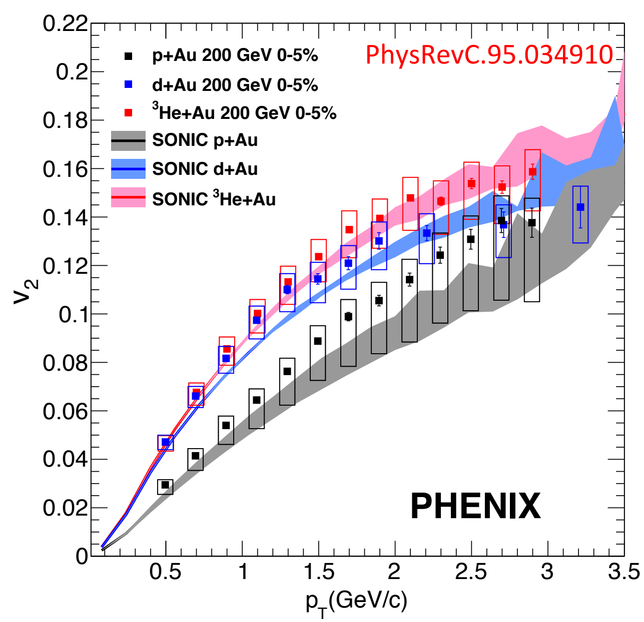


Results are consistent with each other!

System size dependence of v_2 and v_3







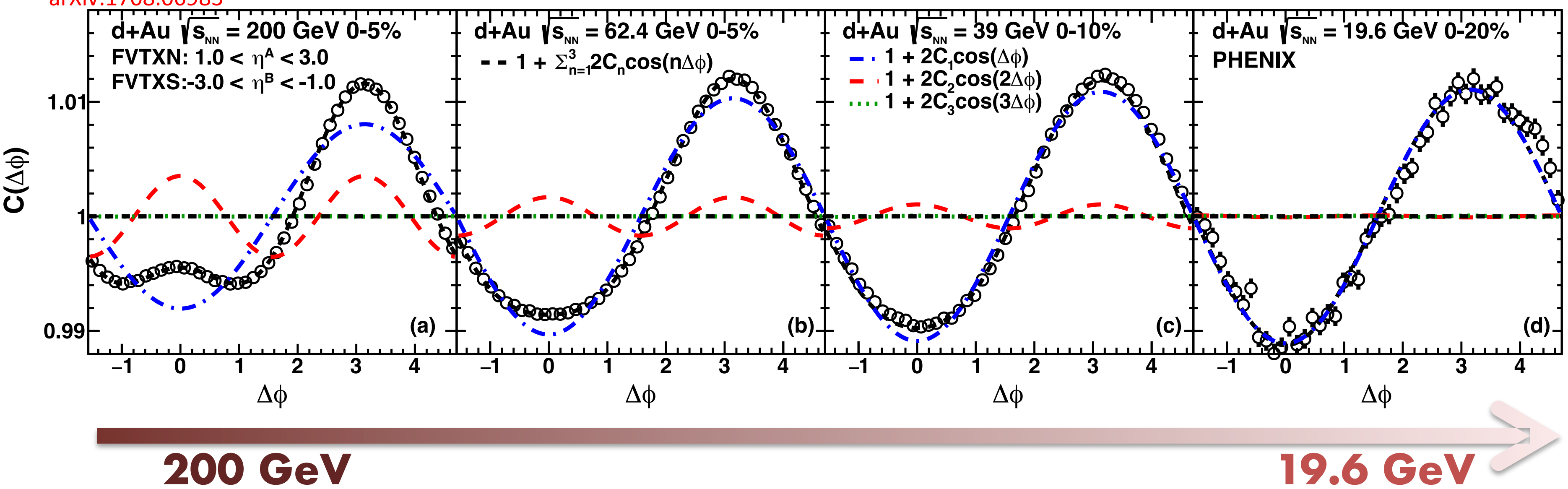
Initial condition geometry studied using different size of systems.

v_2 vs. p_T 0-5% in all 3 systems are similar each other, but p+Au bit smaller compare to d+Au and ^{3}He+Au.
SONIC and superSONIC well describe measured v_2.
AMPT could predicts low p_T(<1.5GeV/c, generally).

$v_2^{pAu} < v_2^{dAu} \approx v_2^{3HeAu}$
$v_3^{dAu} < v_3^{3HeAu}$

d+Au v_2 beam energy scan

arXiv:1708.06983



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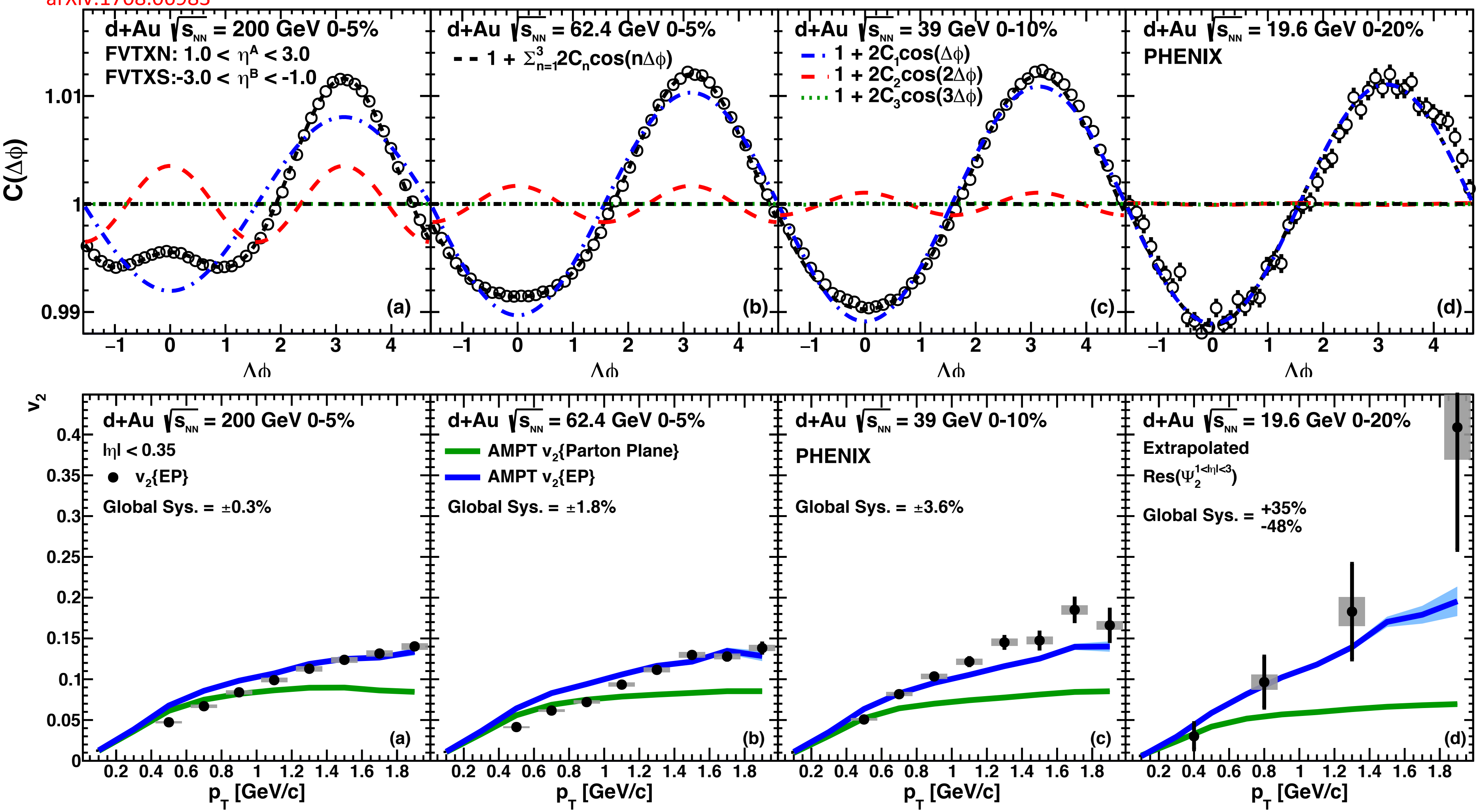

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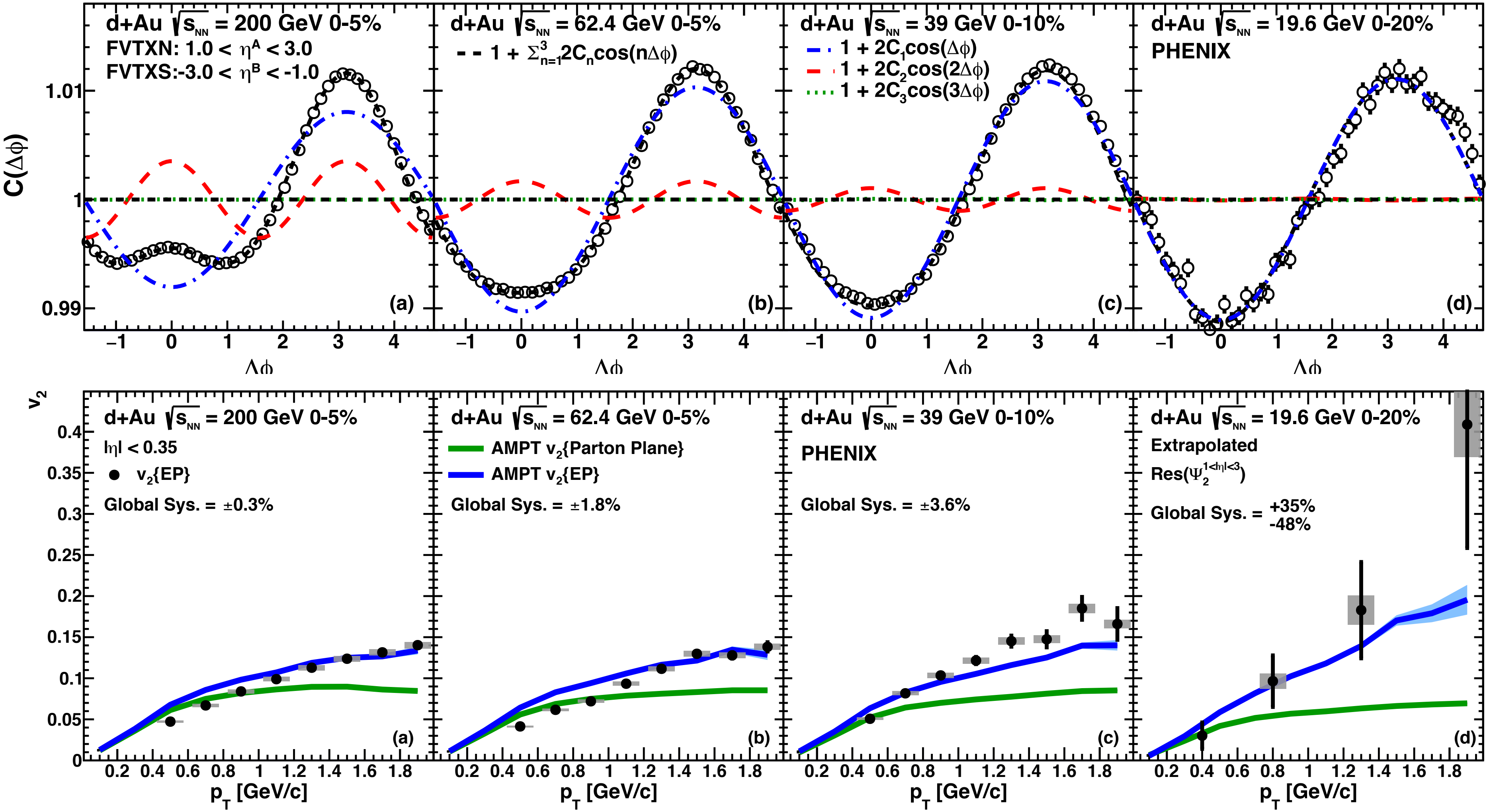
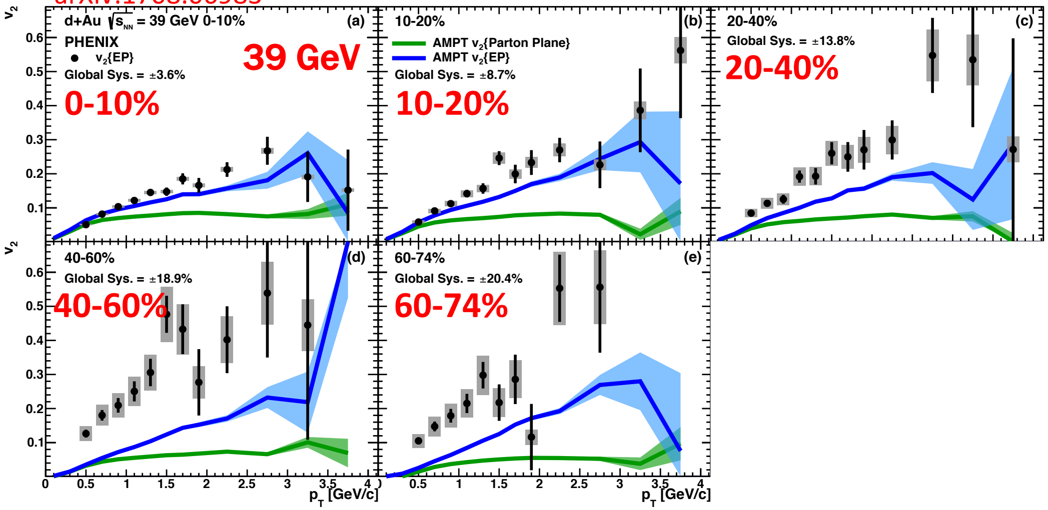


Non-zero v_2 measured at all energies and AMPT reproduces event plane result pretty well. Discrepancies between $v_2^{\{EP\}}$ and $v_2^{\{Parton\ Plane\}}$ in AMPT became larger in lower energy and it implies measured v_2 might be more and more dominated by non-collectivity effects.

d+Au v_2 vs. p_T centrality dependence

arXiv:1708.06983



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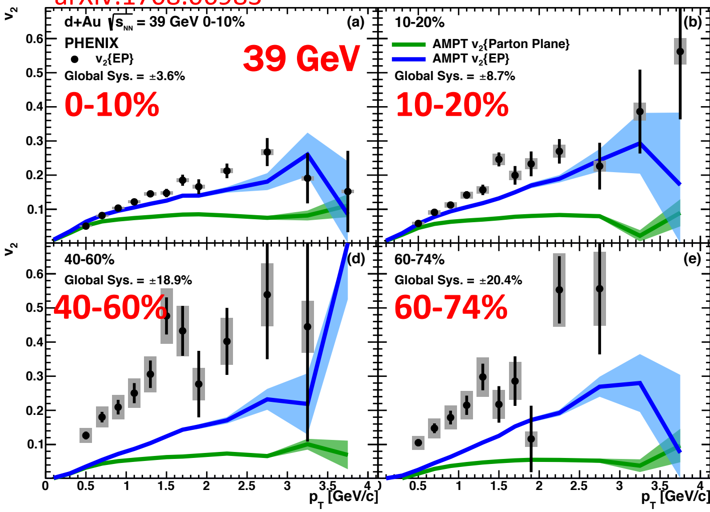

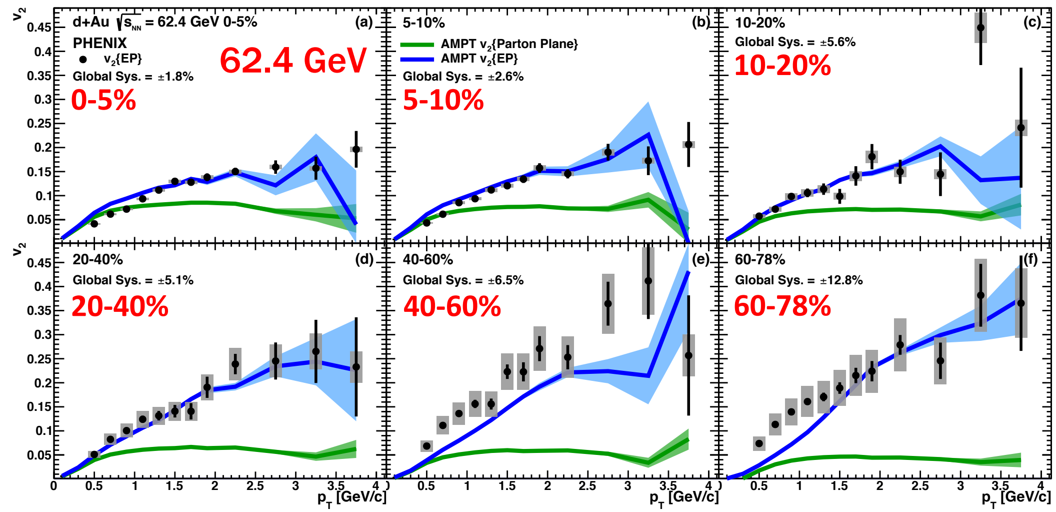

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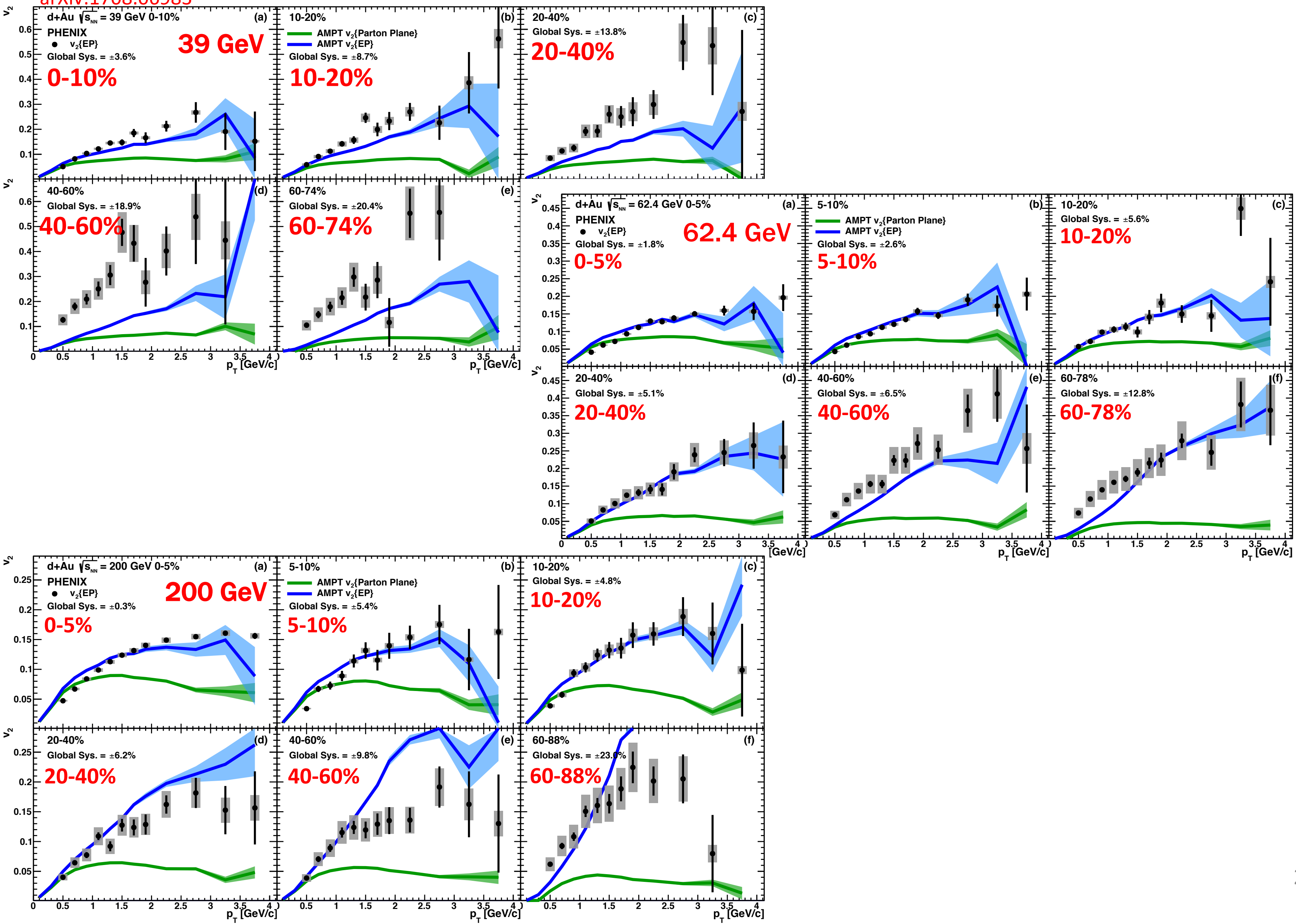

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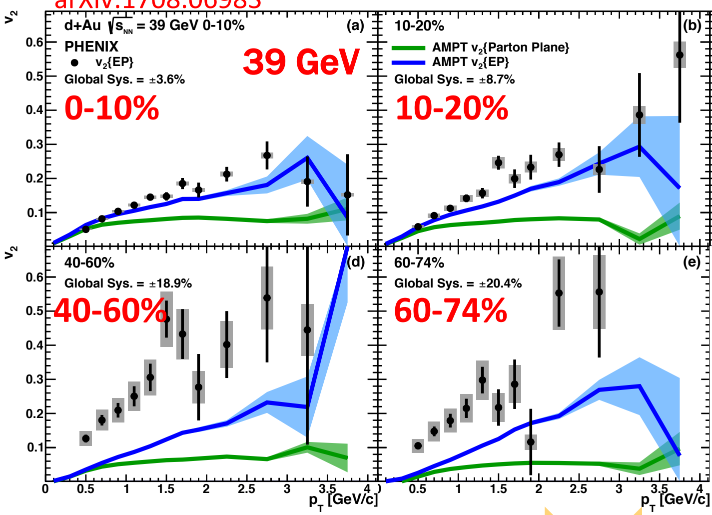
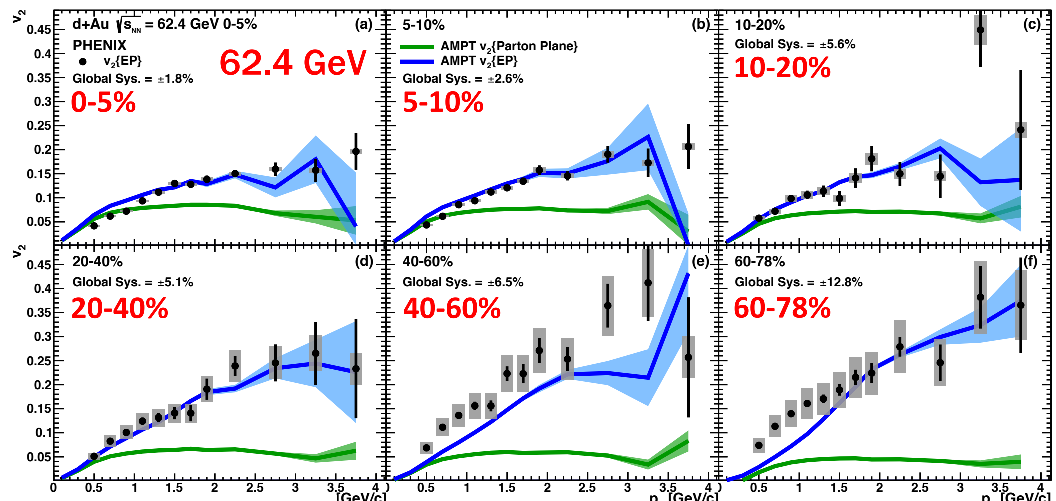
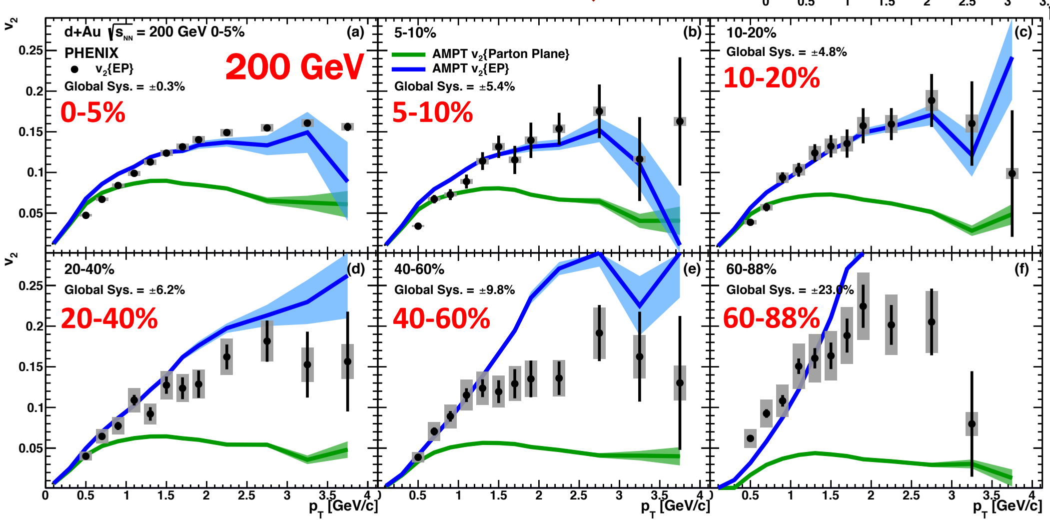


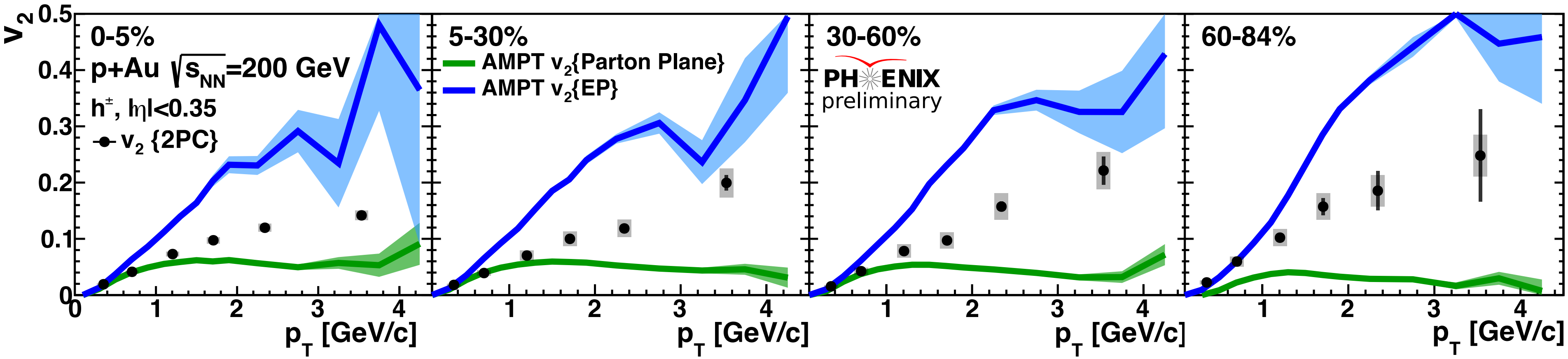


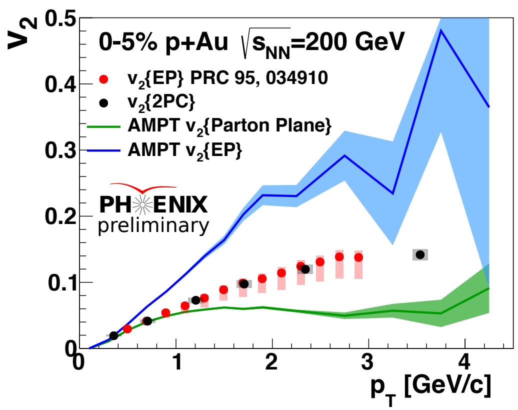
Energy higher



In all 3 different energies,
AMPT $v_2^{\{EP\}}$ reproduces general shape of data.
Non-flow contribution becomes significant in peripheral collisions or high p_T.
In lower collision energy,
AMPT $v_2^{\{EP\}}$ starts to underestimate v_2 especially at high p_T or peripheral collisions.

p+Au v_2 vs. p_T centrality dependence



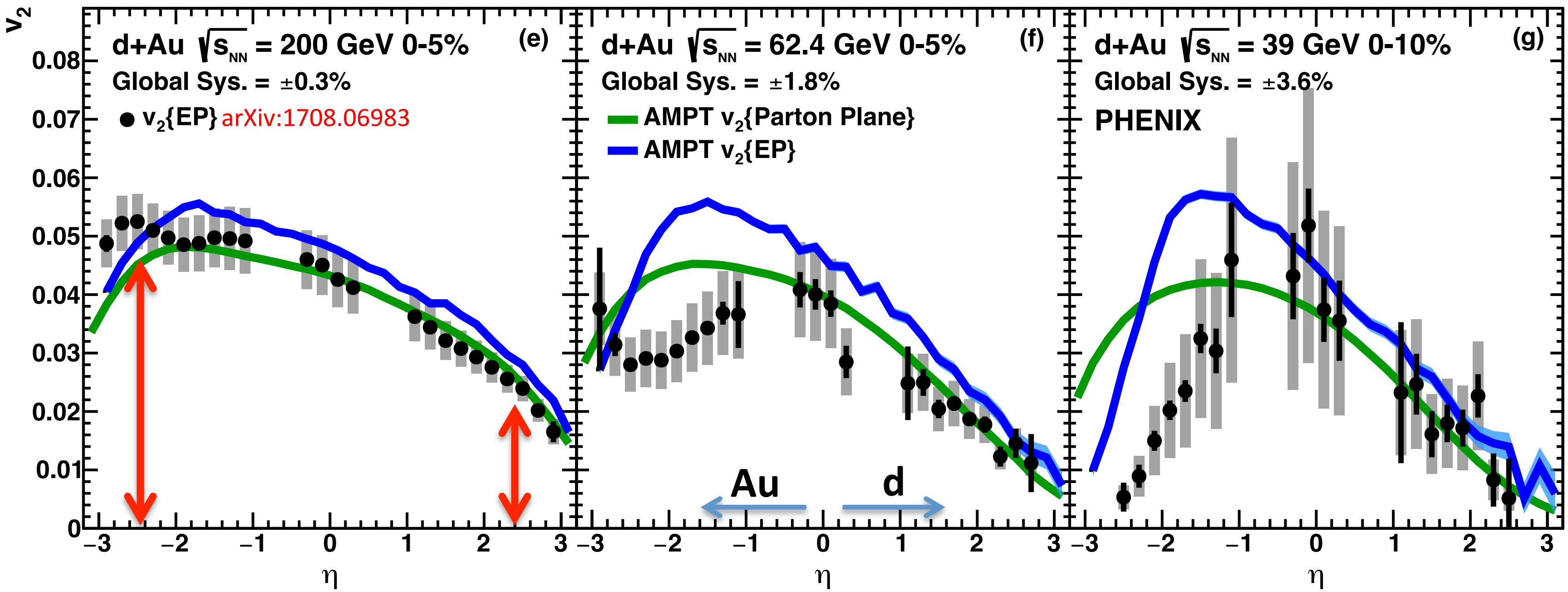


This measurement also shows good agreement with published data calculated with the event-plane method.

A similar v_2 with d+Au is seen in p+Au.
v_2 in peripheral collisions are larger than central collisions which is possibly due to a larger non-flow contribution in peripheral collisions.

Used same parton screening mass as d+Au. AMPT $v_2^{\{EP\}}$ overestimate v_2 in p+Au collisions which is different from the d+Au collisions.

Rapidity dependence



Larger v_2 in Au-going direction, but this asymmetry becomes smaller in lower energies.

Forward (p-going, η>0)

- 3 energies have similar size of v_2
- AMPT $v_2^{\{EP\}}$ describes the data quite well in all three collision energies with small non-flow contribution.

Backward (Au-going, η<0)

- v_2 decreasing at the lower energy
- AMPT $v_2^{\{EP\}}$ described data points well, but tends to overshoot in lower energies.

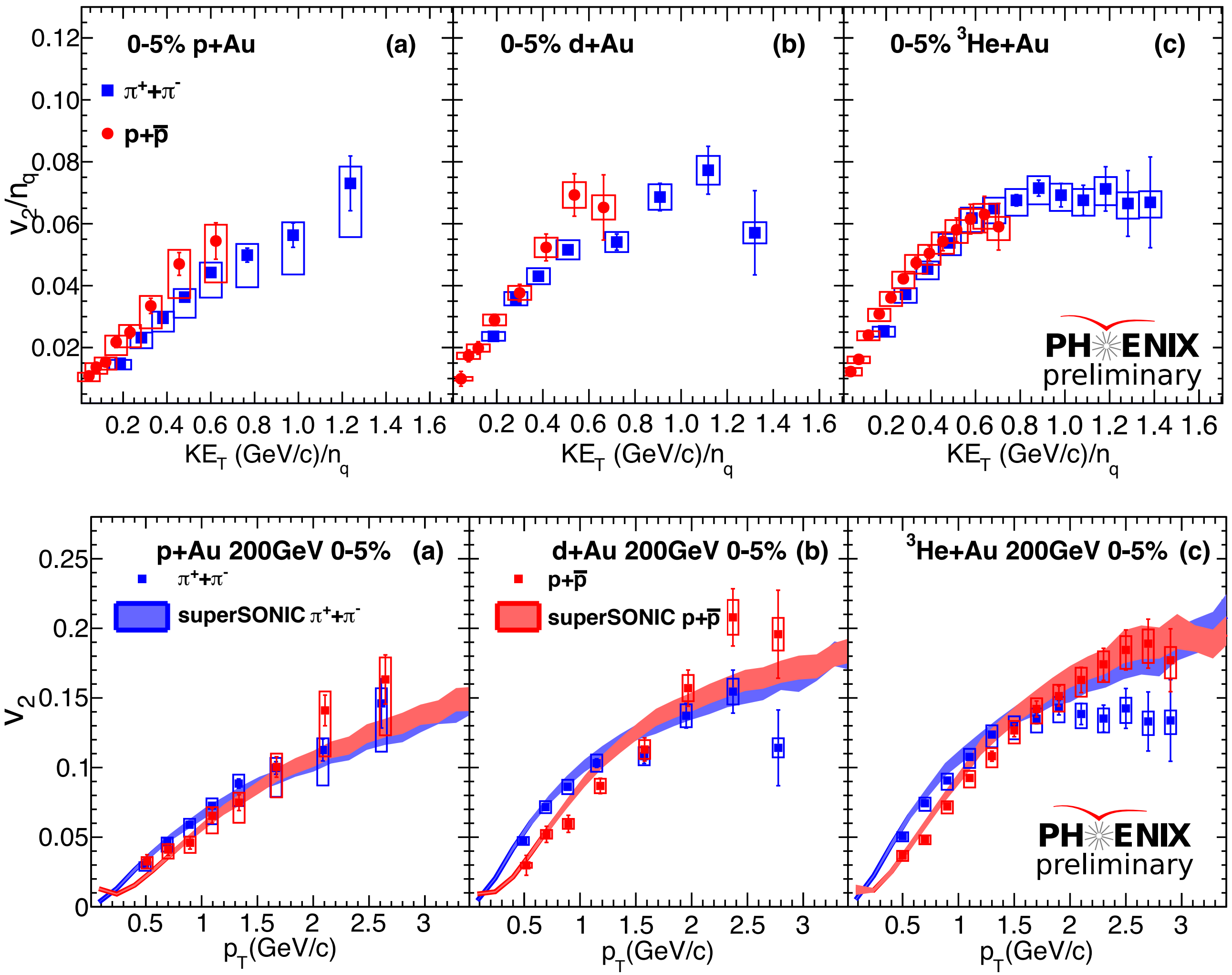
Summary

- Collective-like behavior was observed in small systems by the PHENIX experiment.
  - Measured v_n well described by viscous hydro model.
  - Checking following dependencies to identify the collectivity
    - System size(p/d/^{3}He + Au)
    - Collision energy
    - Centrality defined by the multiplicity(at $-4<\eta<-3$)
    - Rapidity(η)
    - p_T (measured at central region)
- Understanding non-flow contribution is especially important for small systems and lower energies.
- Non-flow contribution needs to be studied further to be conclusive.

THANK YOU

BACKUP

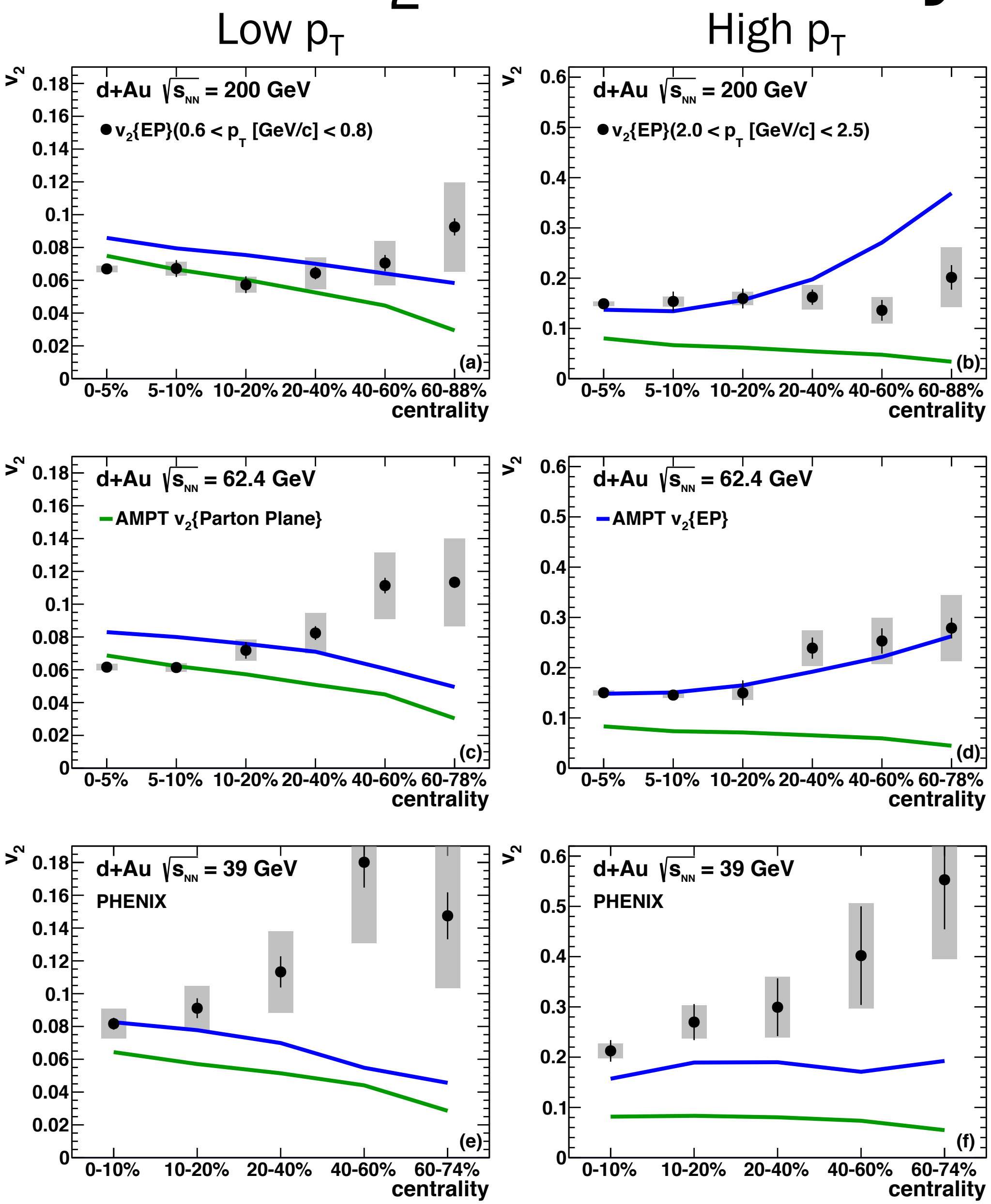
v_2 with identified particles



Clear mass ordering in ^{3}He+Au and d+Au while p+Au not working well.

Smaller split in p+Au predicted in hydro from smaller radial push.

d+Au v_2 vs. centrality



v_2 increases

-goes peripheral collisions.

-goes smaller collision energy.

AMPT predicts

-$v_2^{PartonP}$ decrease as centrality becomes peripheral as expected from ellipticity of initial geometry and lower particle multiplicity.

-At lower p_T, v_2 between event plane and parton plane are similar where flow effects dominant.

-At high p_T, v_2 in AMPT with event plane is significantly larger than v_2 with parton plane where non-flow effects may dominant.

May indicate non-flow contributions are larger in the data than in AMPT.