PHENIX results on elliptic and triangular flow at midrapidity in d+Au collisions from 19.6 to 200 GeV

Julia Velkovska

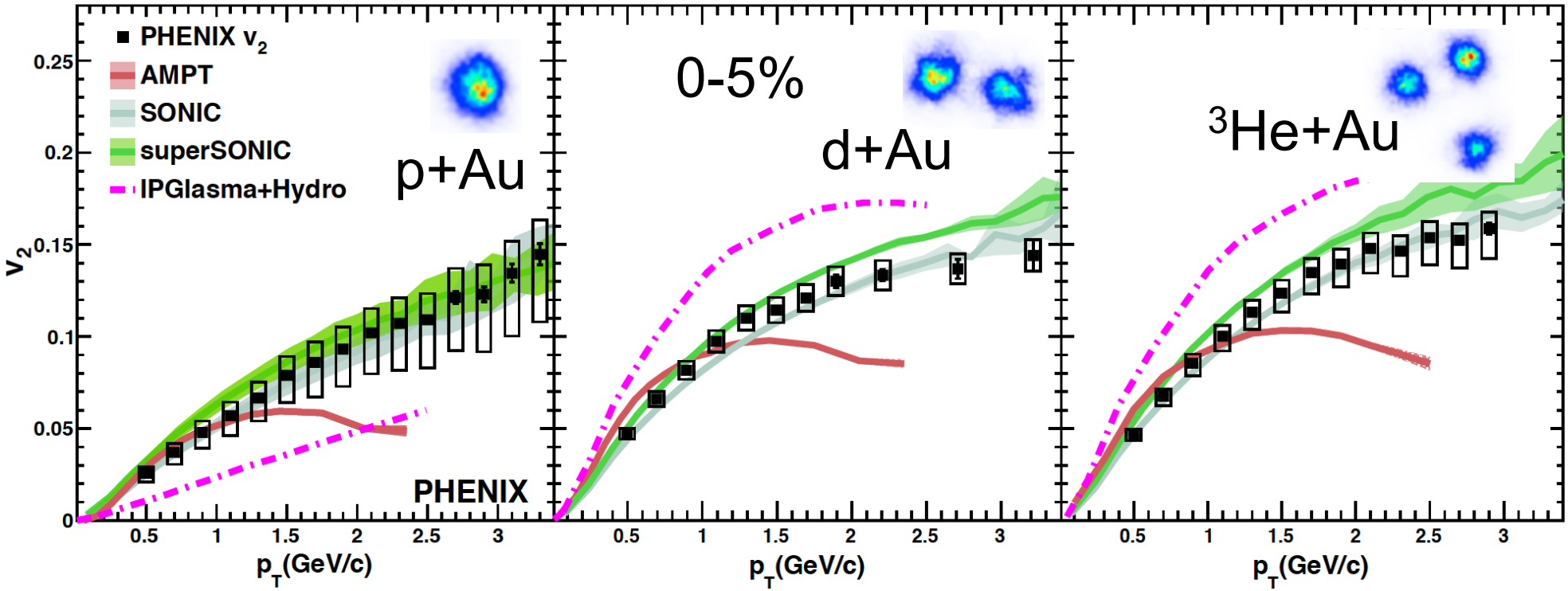
VANDERBILT UNIVERSITY

PHENIX

Quark Matter 2017

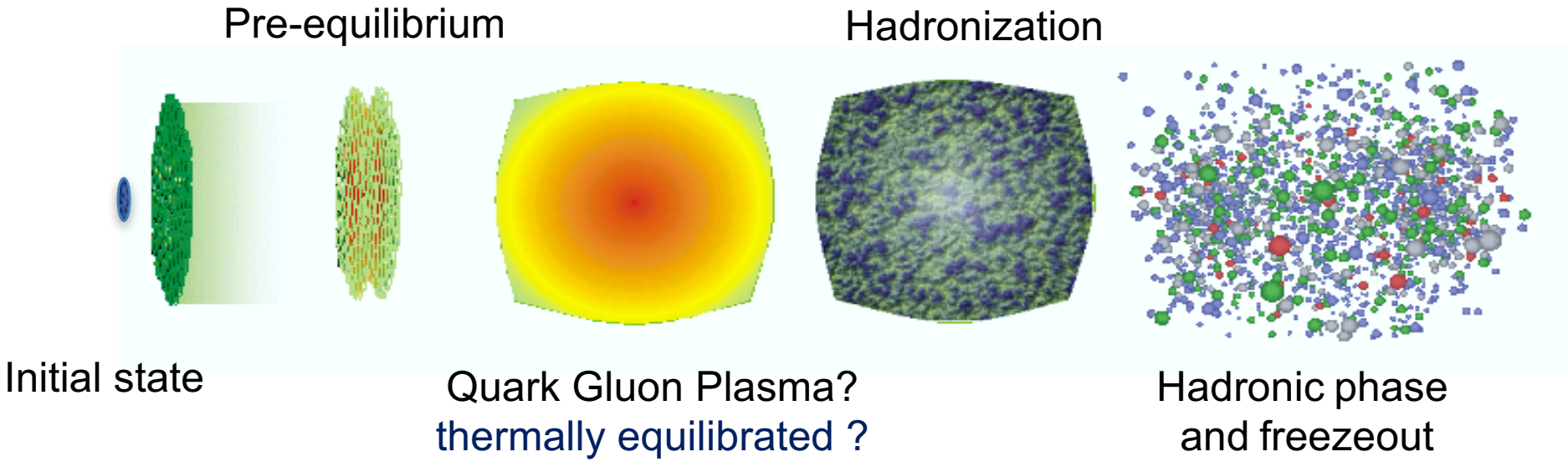
Collectivity in small systems at RHIC: geometry engineering at 200 GeV

arXiv 1609.02894 PRL 114, 192301, (2015) PRL 115, 142301, (2015)



- Hydrodynamics works!
- AMPT: weakly coupled partonic cascade+quark coallescence+hadronic cascade also works at low p_T. Why?
- What other knobs can we turn to understand the origin?

Why study small systems in a BES ?

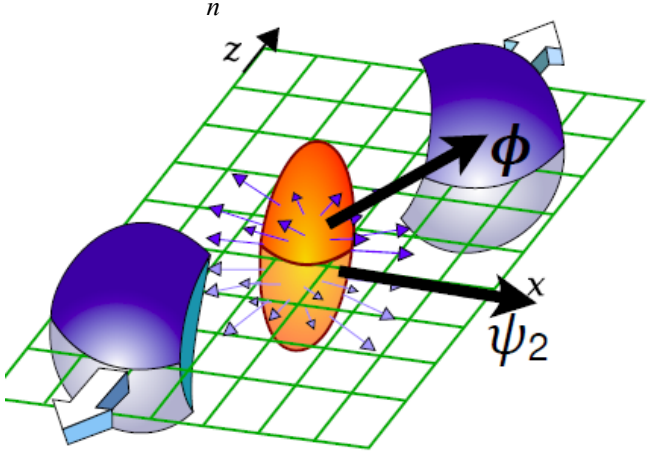


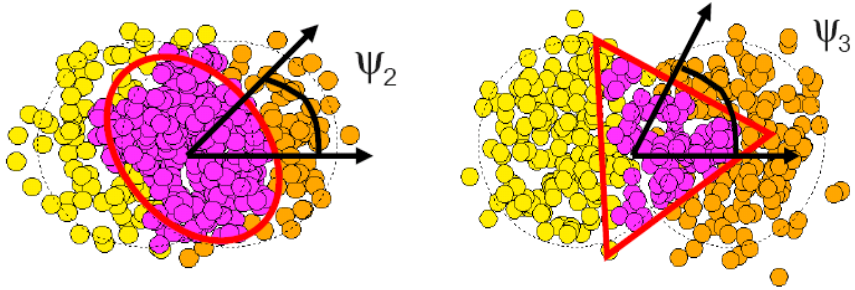
- The time spent in QGP is reduced with energy
- BES gives a good handle to understand the role of pre-equilibrium and hadronic flow
- Study of the pseudorapidity dependence
  - to gain insight in the longitudinal dynamics
  - discriminate between initial state models
- Run 16 d+Au: 200, 62, 39, 20 GeV

Experimental methods in PHENIX

Event plane: determined at large backward pseudorapidity
Particles: tracked over a large pseudorapidity range

$$dN/d\phi = 1 + \sum_n 2v_n \cos(n(\phi - \Psi_n))$$



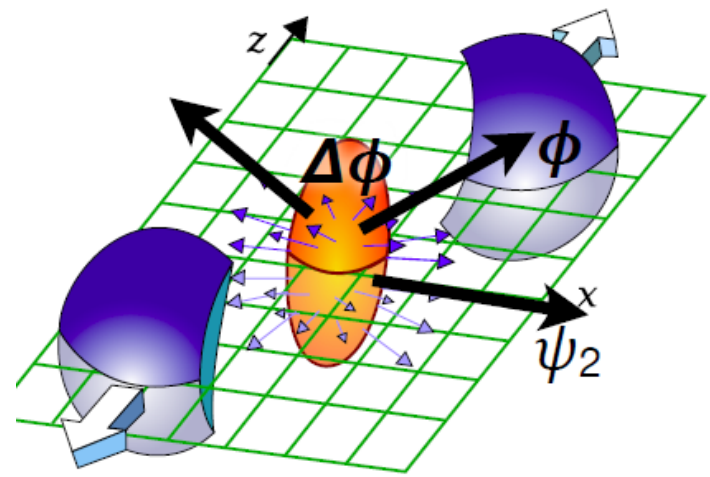


Or
2-particle correlations comprised of:

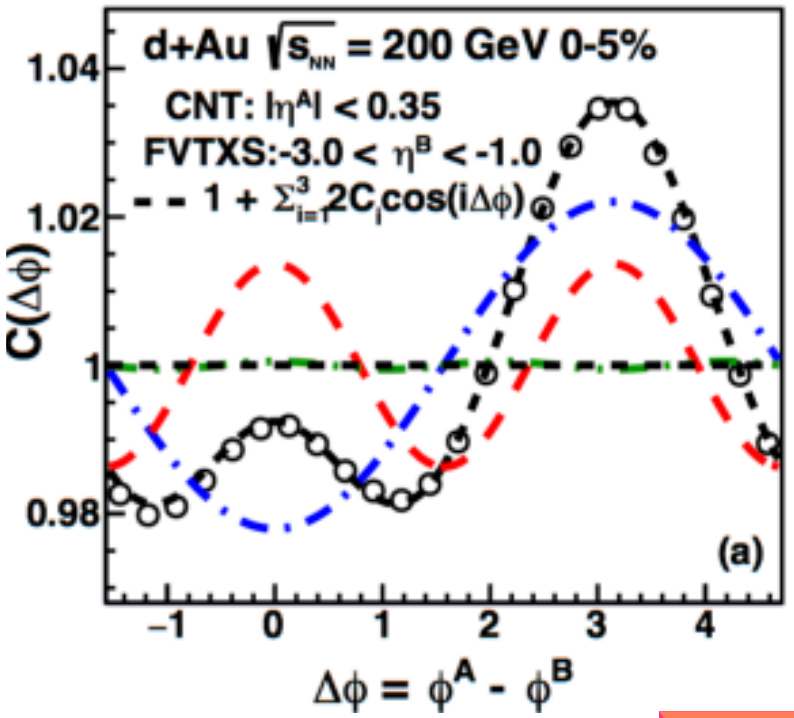
1) particle at midrapidity
2) energy cluster in BBC
3) tracks in FVTX

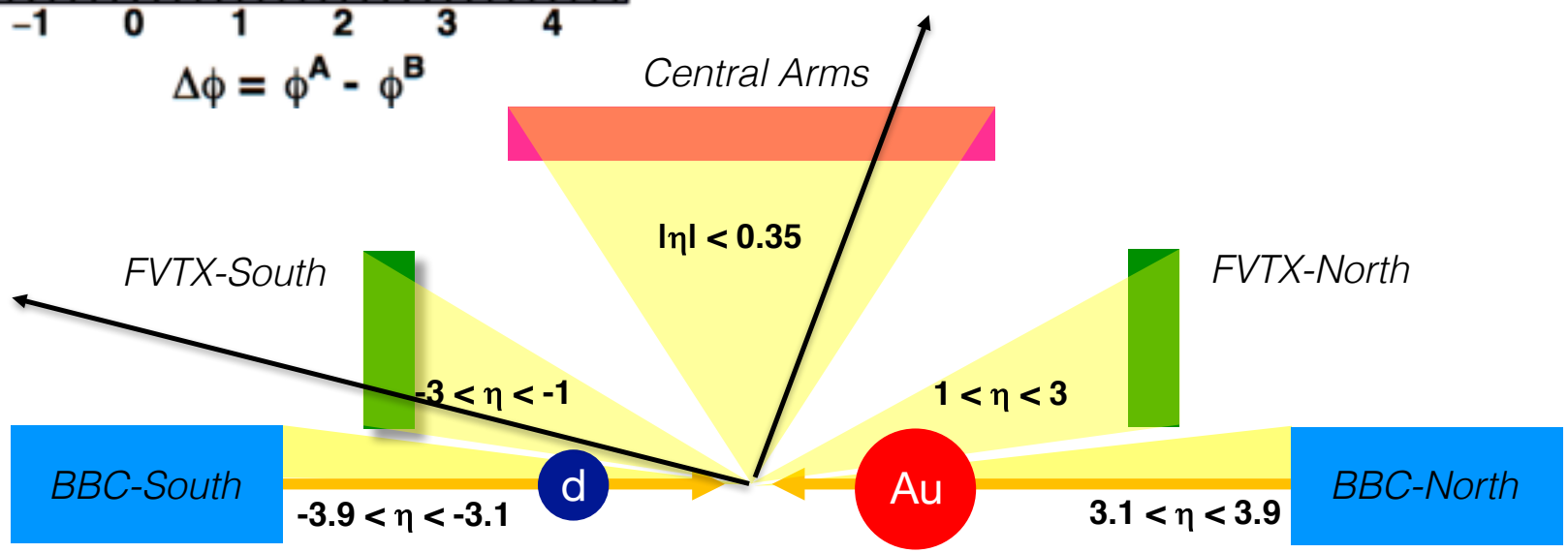
pair amplitude modulation

$$c_n = v_n^a \times v_n^b$$

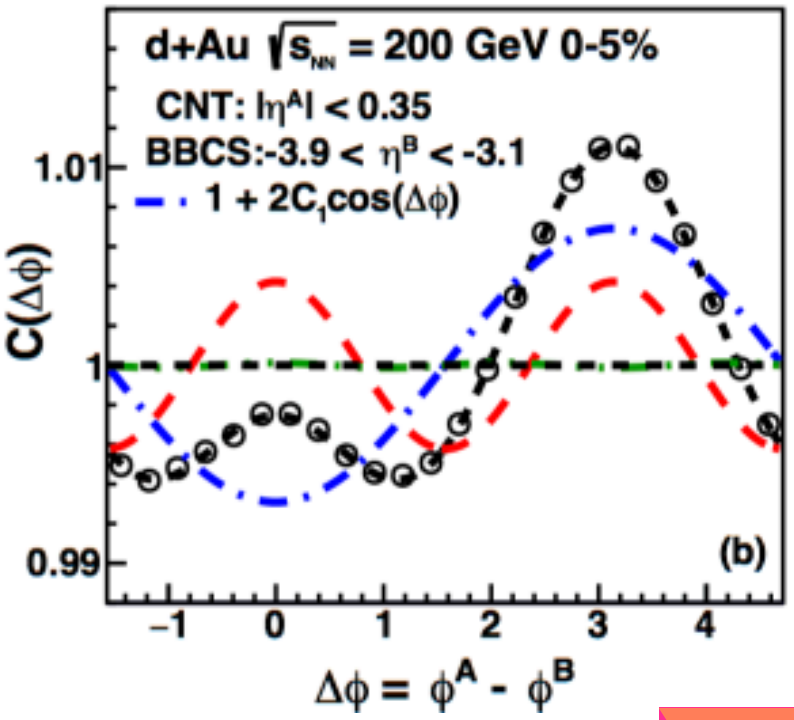


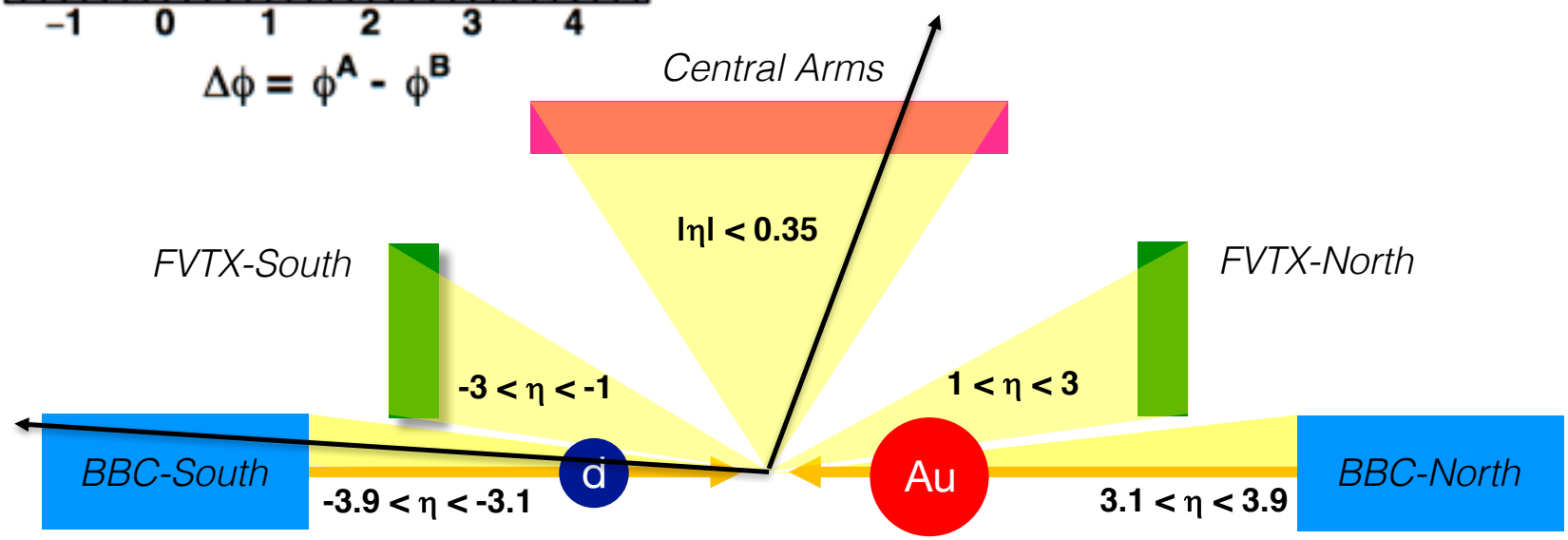
d+Au at 200 GeV: 2-particle correlations



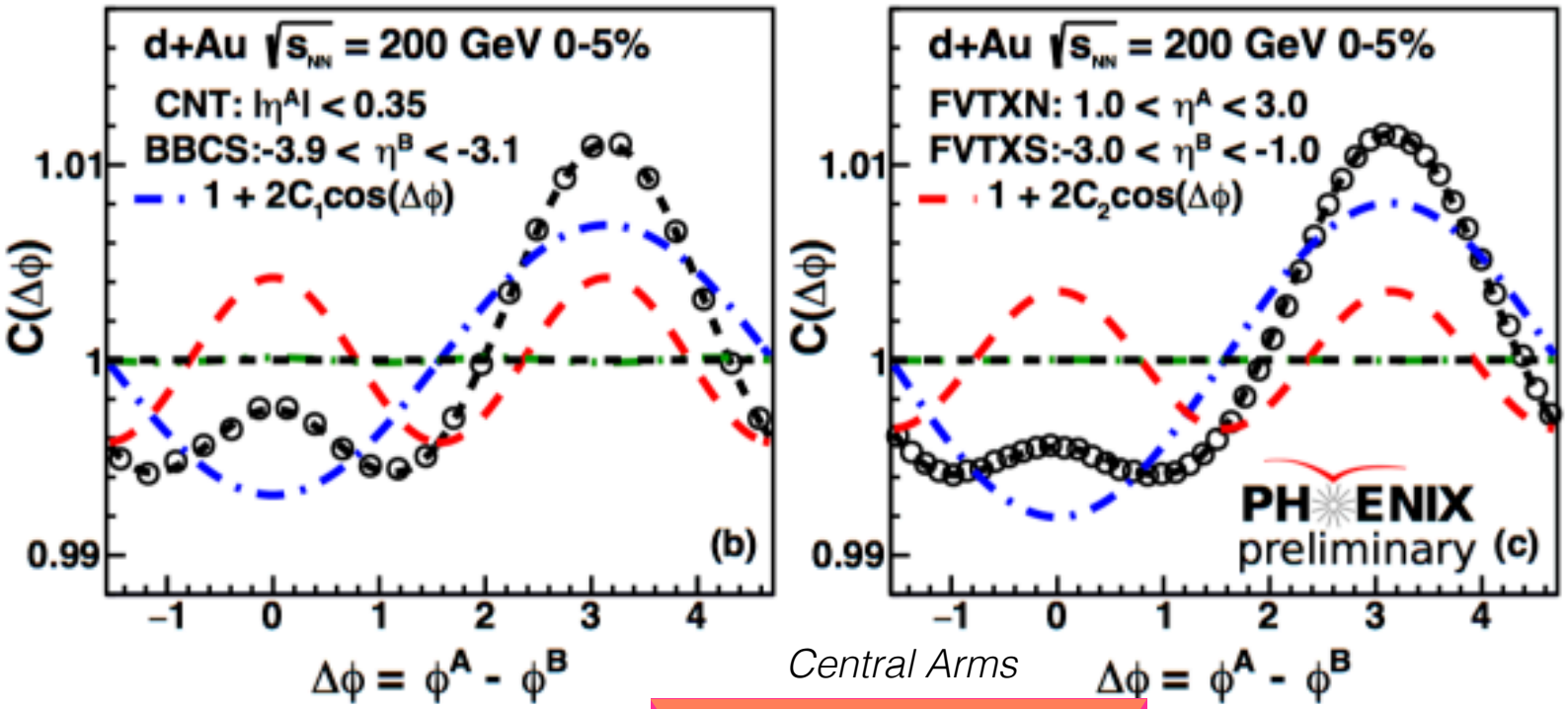


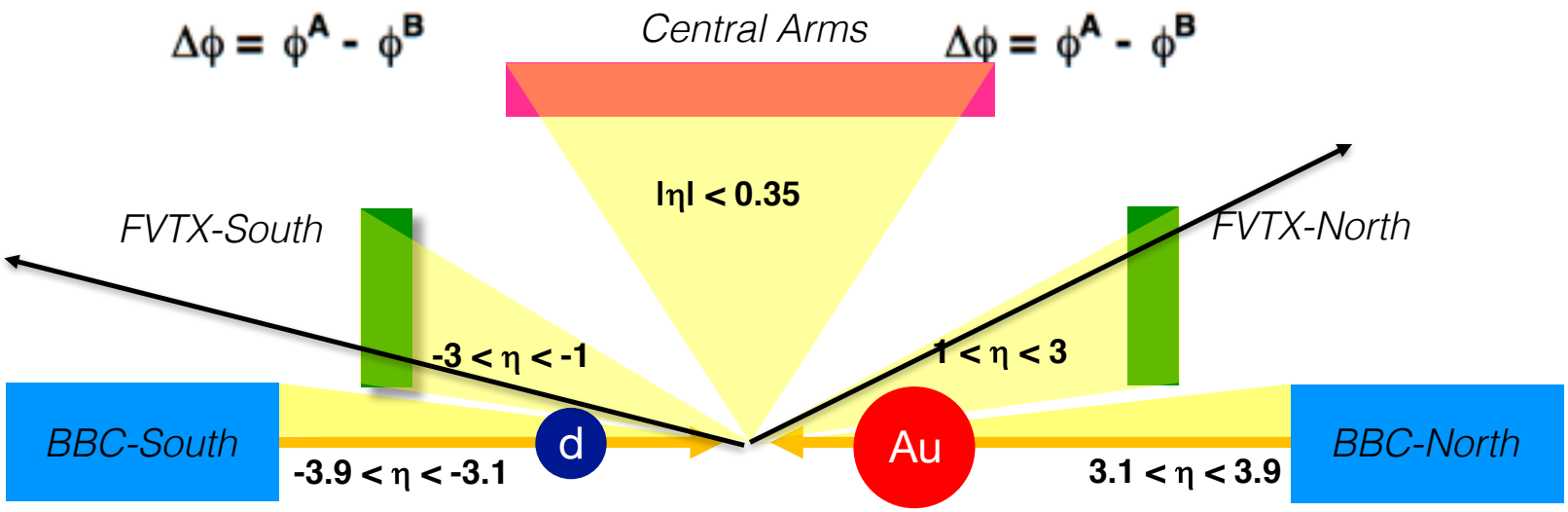
d+Au at 200 GeV: 2-particle correlations



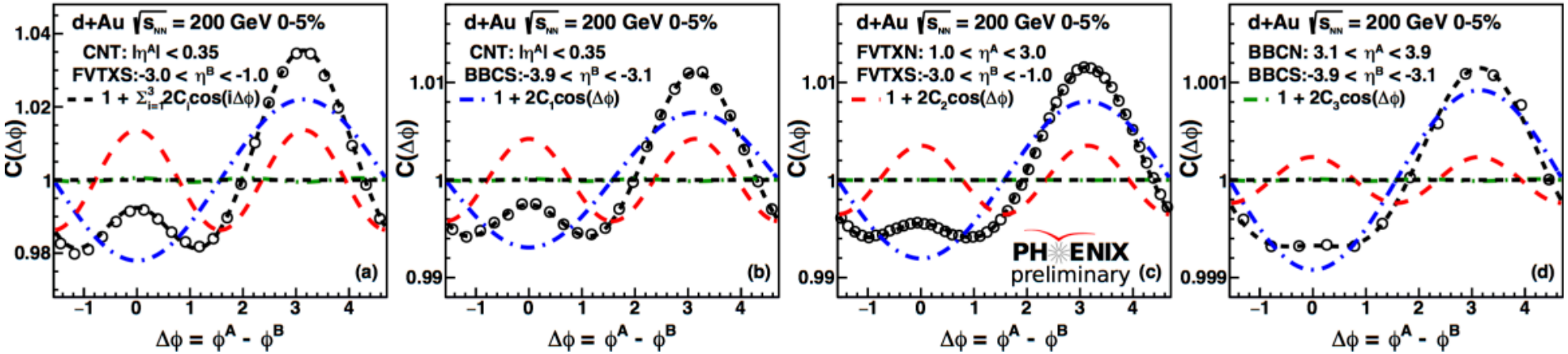


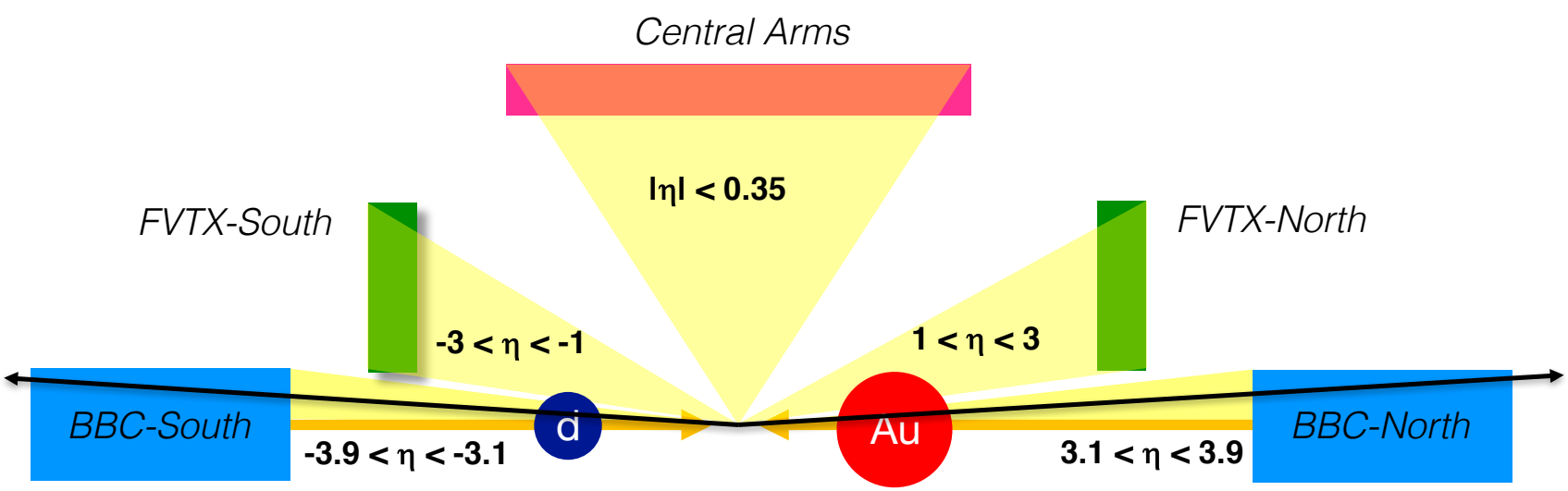
d+Au at 200 GeV: 2-particle correlations





d+Au at 200 GeV: 2-particle correlations





A clear ridge is seen with all detector combinations, even for **$\Delta\eta > 6.2$**

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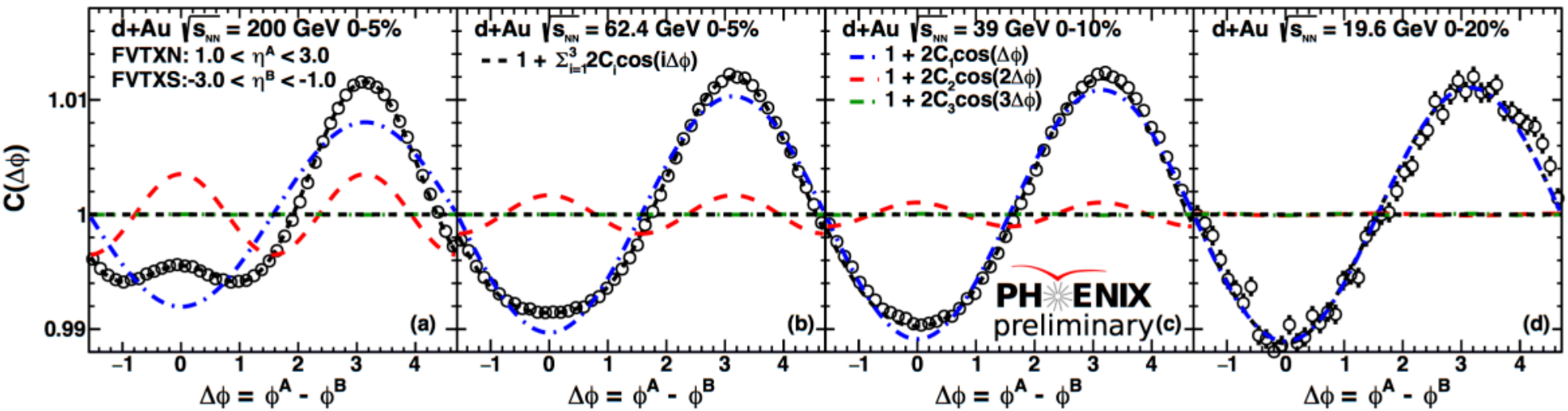
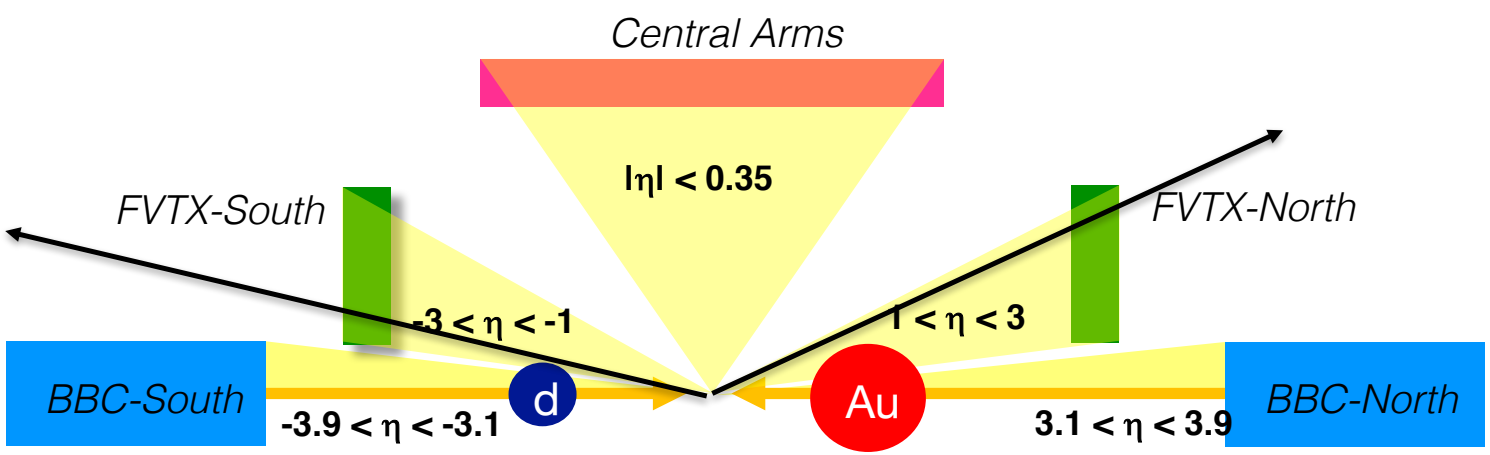
Energy dependence of ridge in d+Au

200 GeV **62 GeV** **39 GeV** **20 GeV**





Energy dependence of ridge in d+Au

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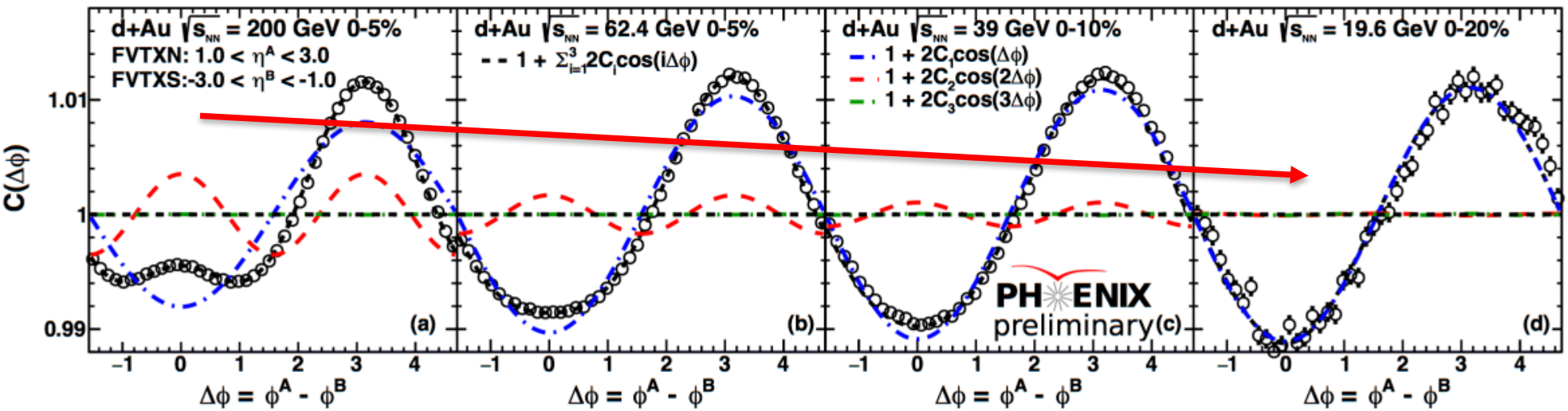
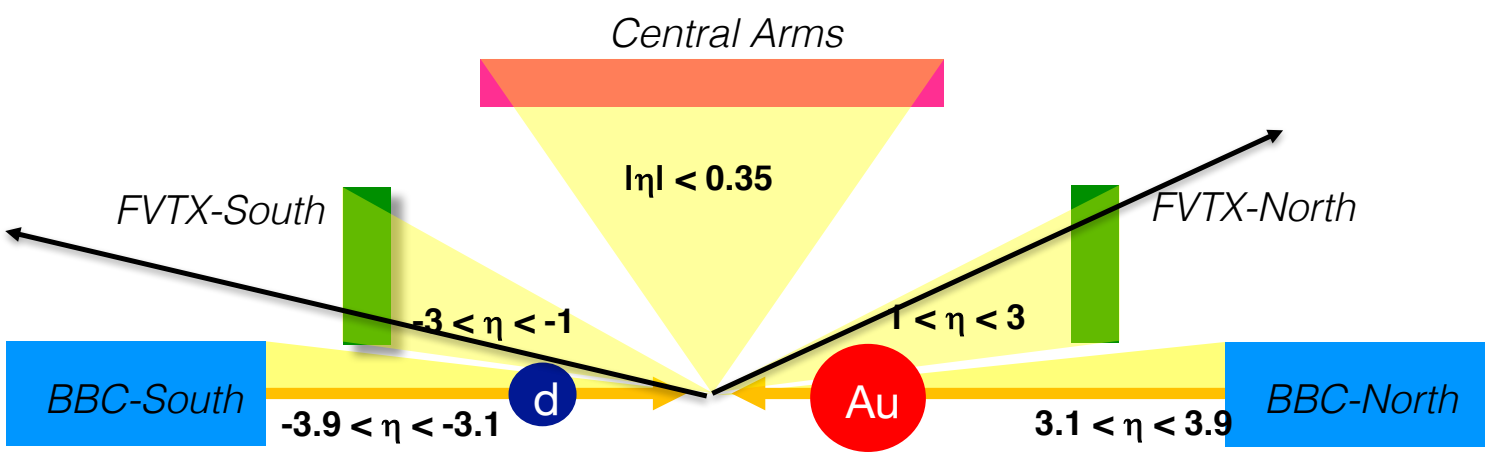
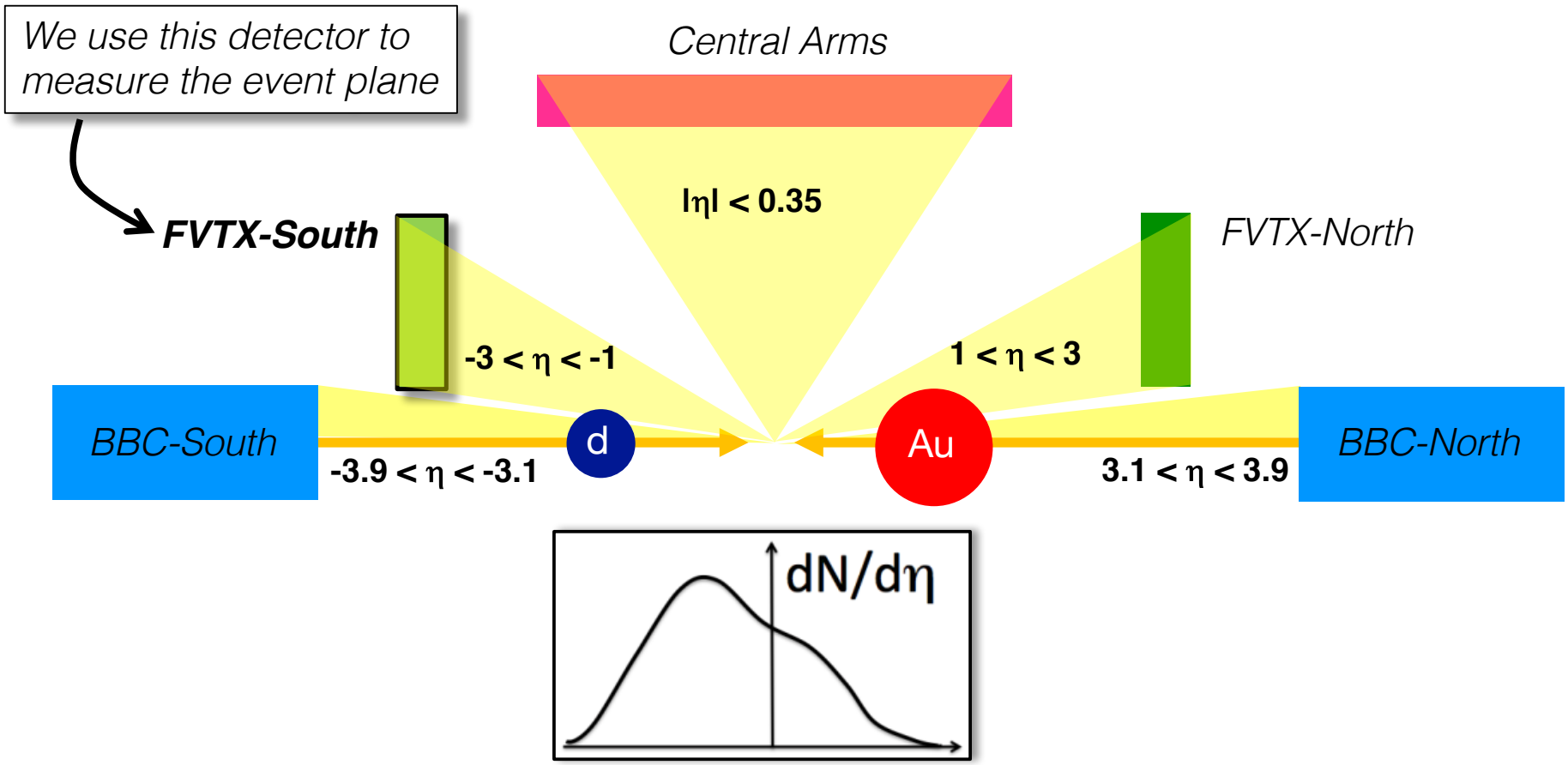




The c_2 amplitude decreases with energy,
but so do multiplicity and resolution.

Event plane measurements



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

To optimize Resolution, we use:

- Central Arms
- FVTX-South
- BBC-South

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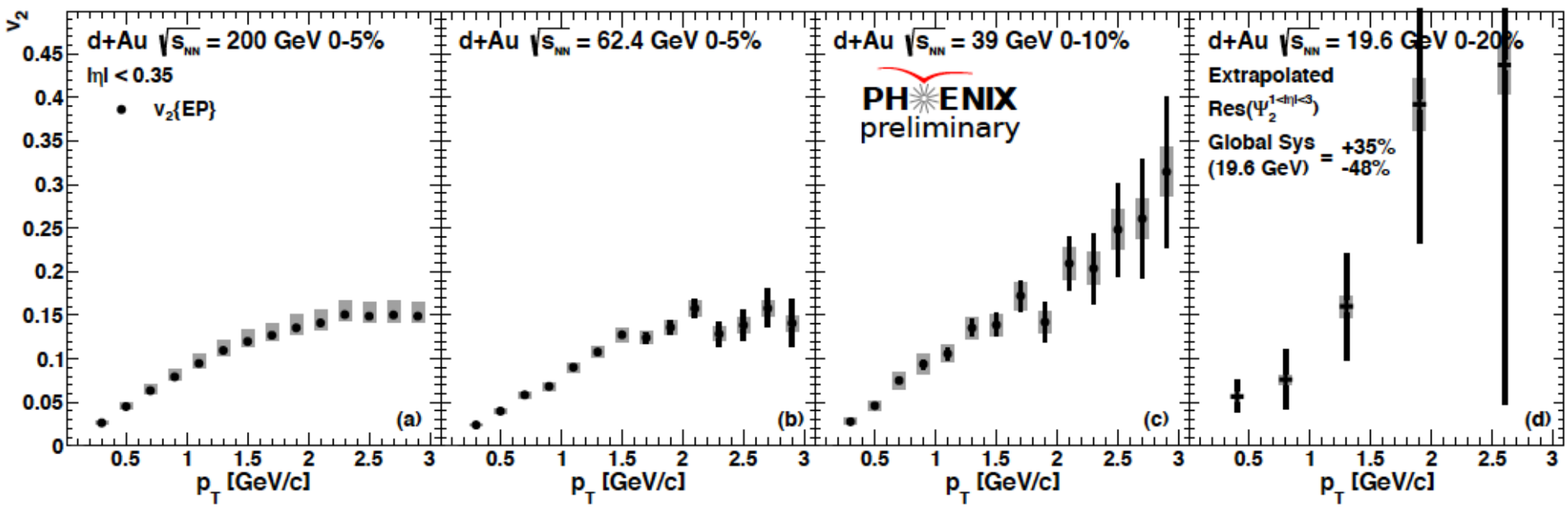
Midrapidity event-plane measurements of v_2

200 GeV **62 GeV** **39 GeV** **20 GeV**

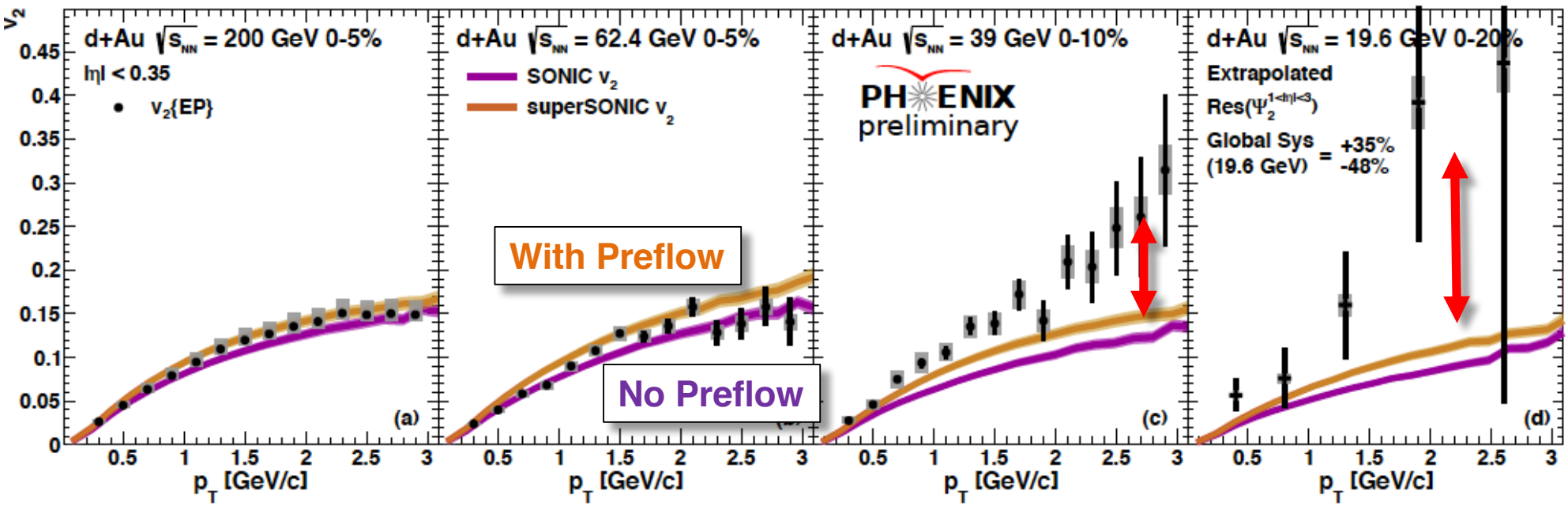


Nearly identical

Increase at high p_T ?

Event plane measurements of v_2

200 GeV **62 GeV** **39 GeV** **20 GeV**



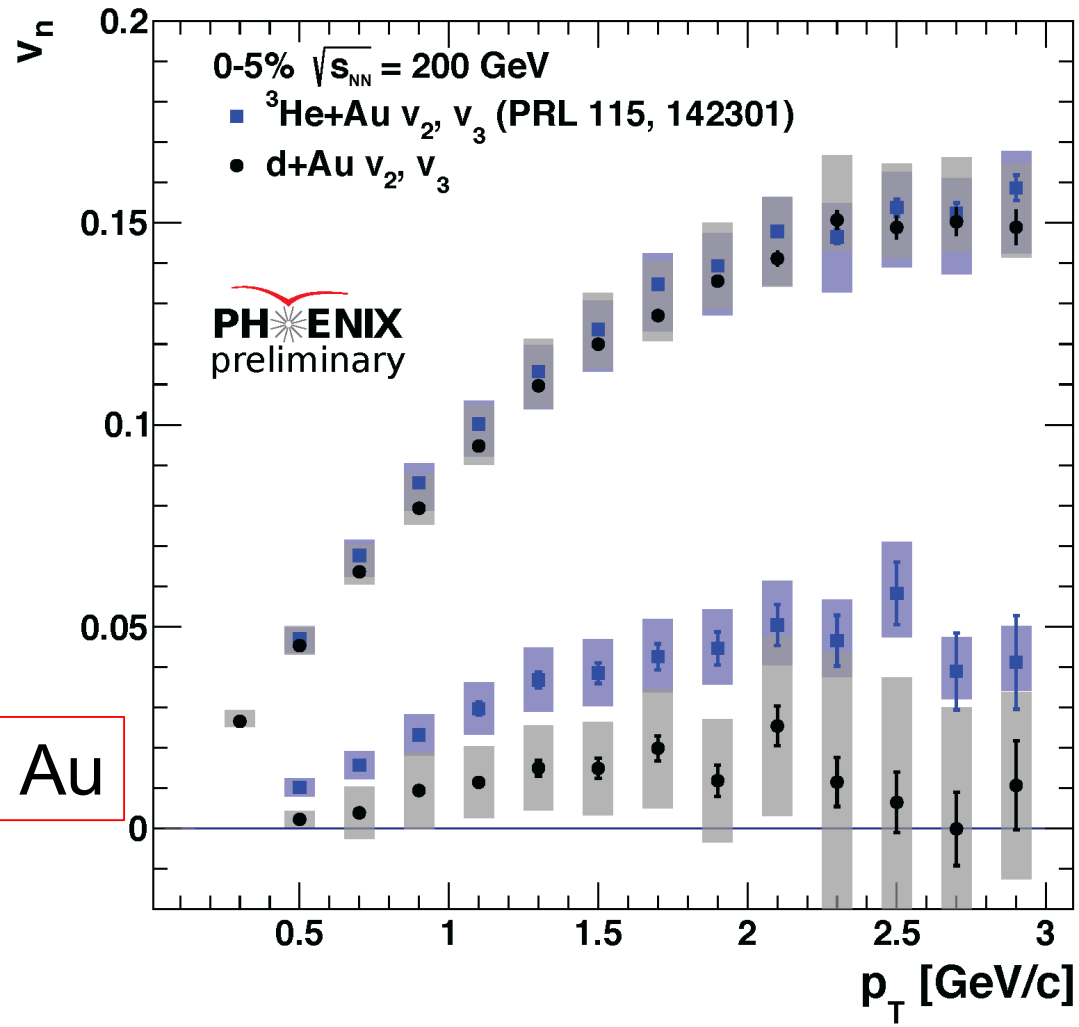
Nearly identical
Well described by hydro
No clear trend with preflow

Increase at high p_T ?
Nonflow ?

Triangular flow at 200 GeV in different systems: insights about the role of preflow

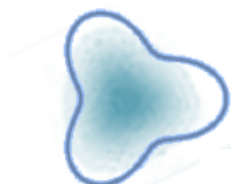
v_2 in d/^{3}He+ Au
Nearly identical

v_3 smaller in d+ Au



v_2

v_3



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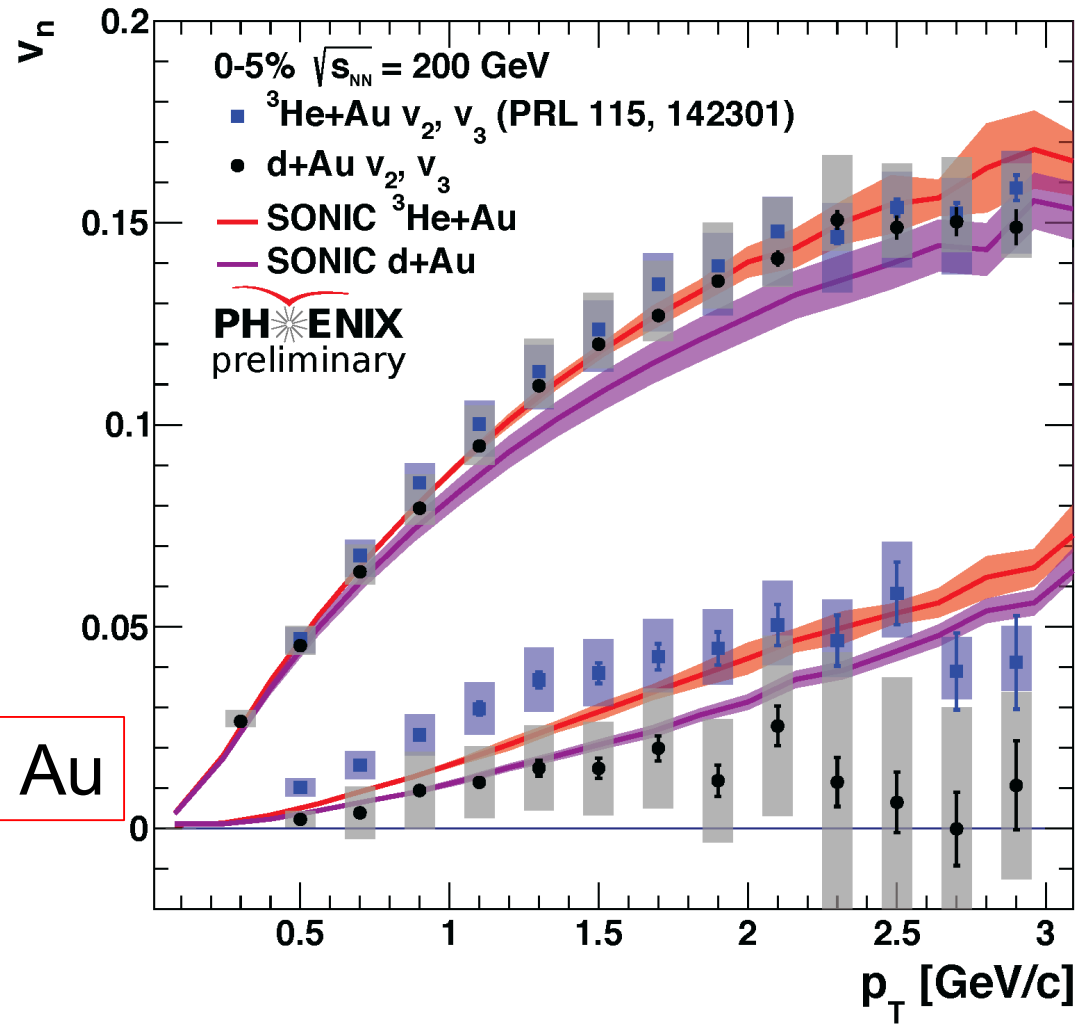
See talk by Qiao Xu: Wed 11:20 , Session 6.1

Triangular flow at 200 GeV in different systems: insights about the role of preflow

v_2 in d/^{3}He+ Au
Nearly identical

v_3 smaller in d+ Au



- Trends well described with hydro without preflow

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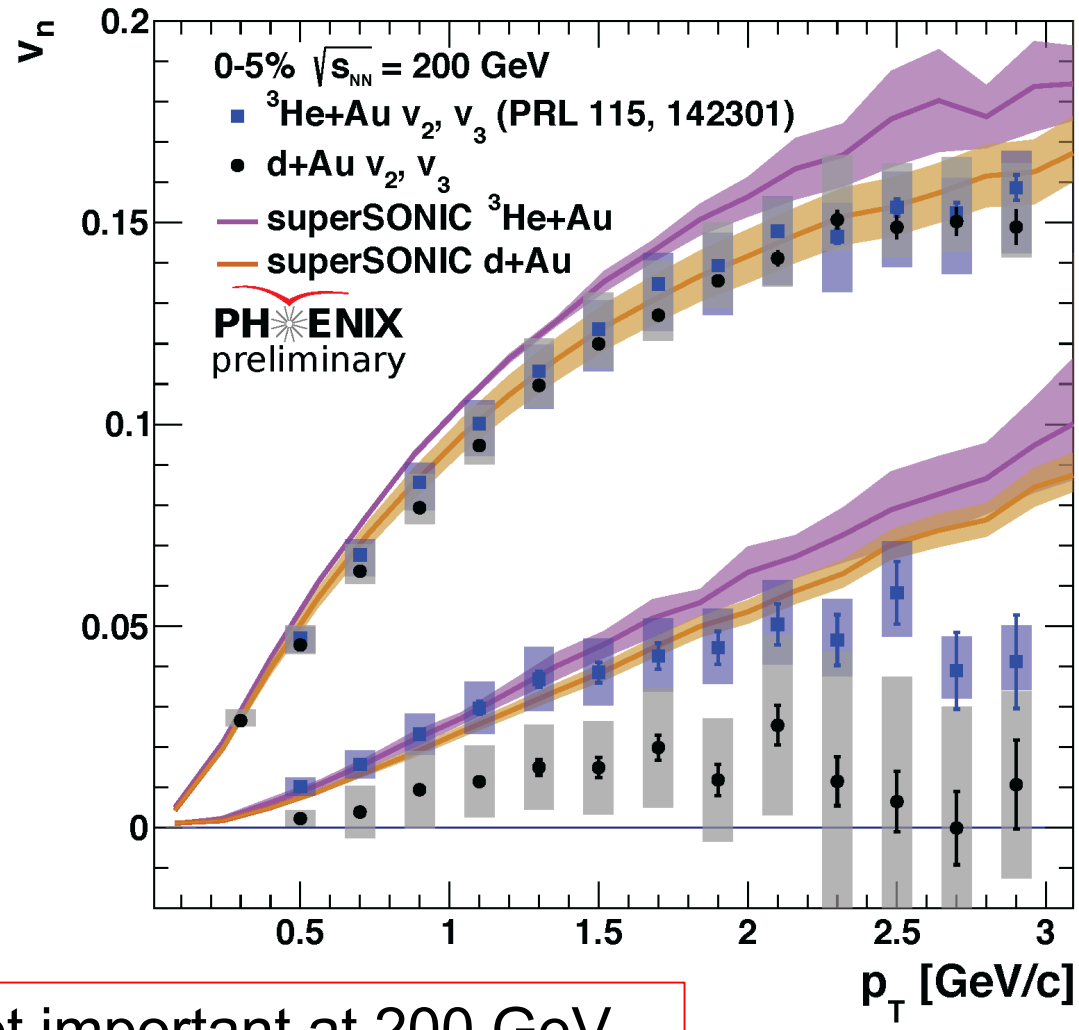
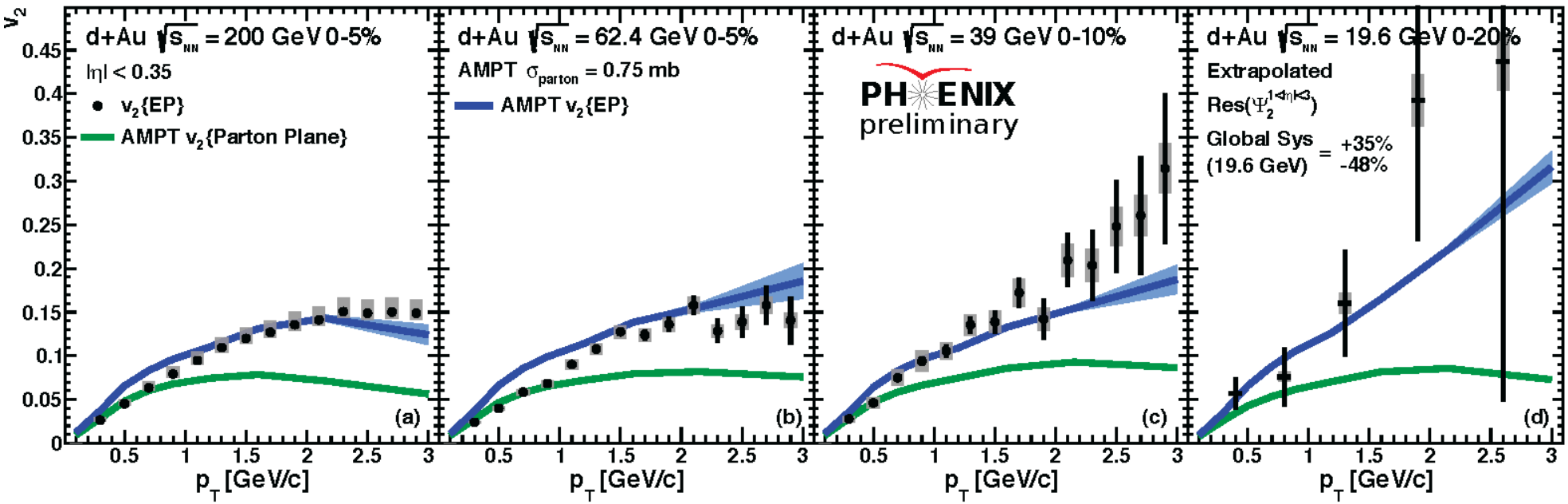
Is there pre-equilibrium flow ?

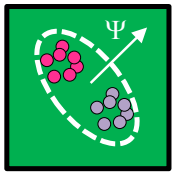


Preflow seems not important at 200 GeV

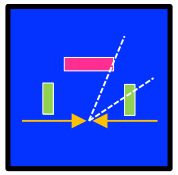
Nonflow correlations: insights from AMPT

200 GeV **62 GeV** **39 GeV** **20 GeV**





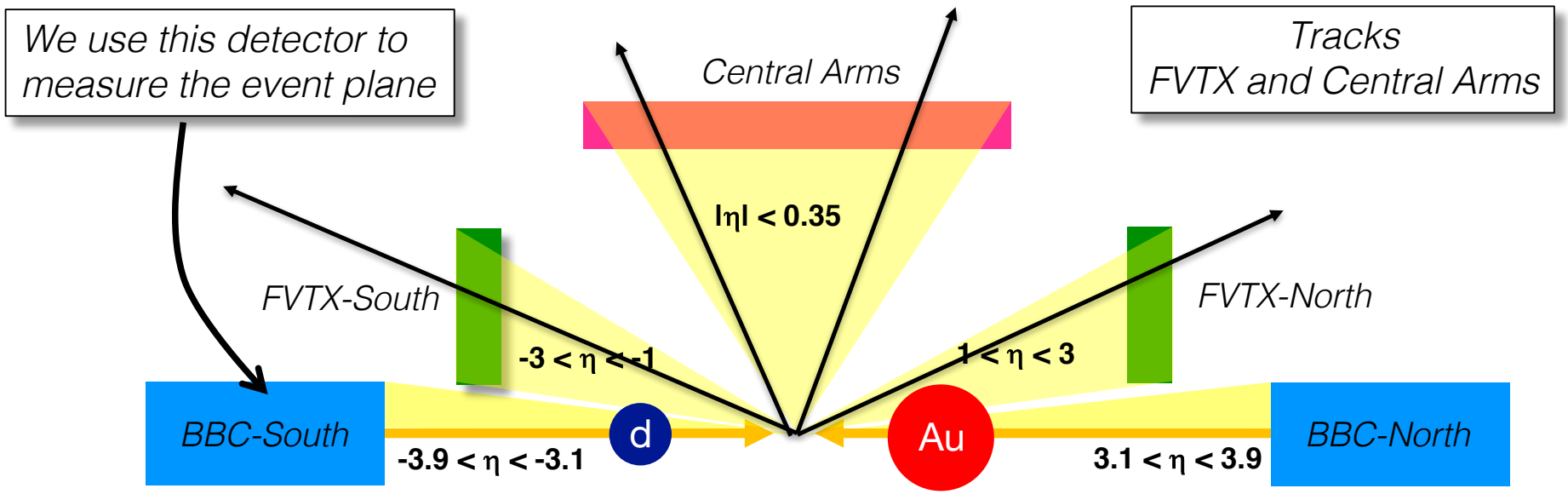
Pure Flow



With Non-Flow

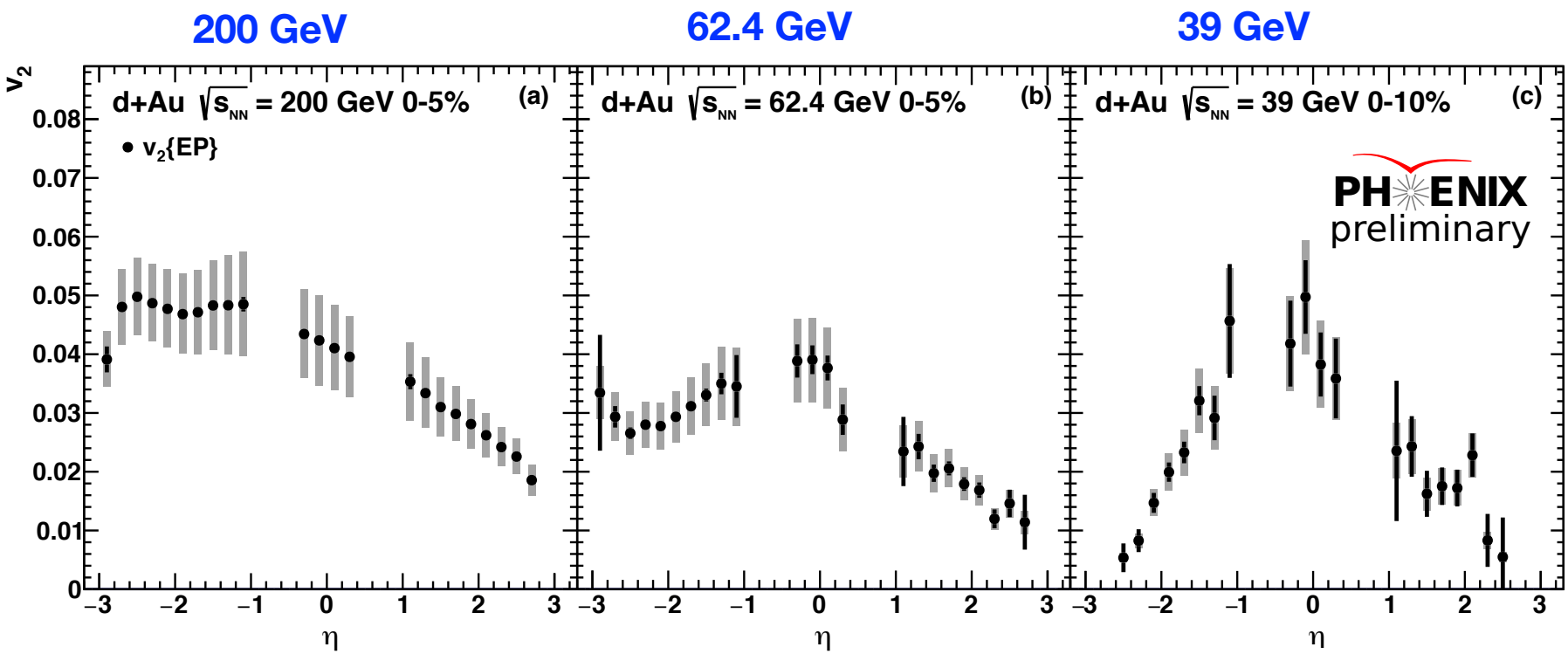
- Evidence for collective effects down to 39 GeV
- Nonflow correlations at 20 GeV require further studies

v_2 vs η: analysis method

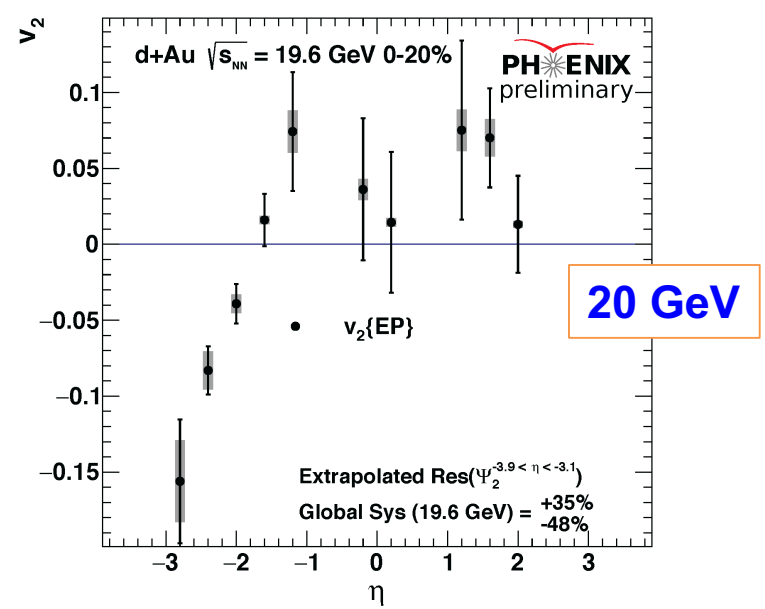


- We want to measure integrated v_2 ($0<p_T<\infty$)
- No p_T information available from FVTX
- Devise a correction based on AMPT

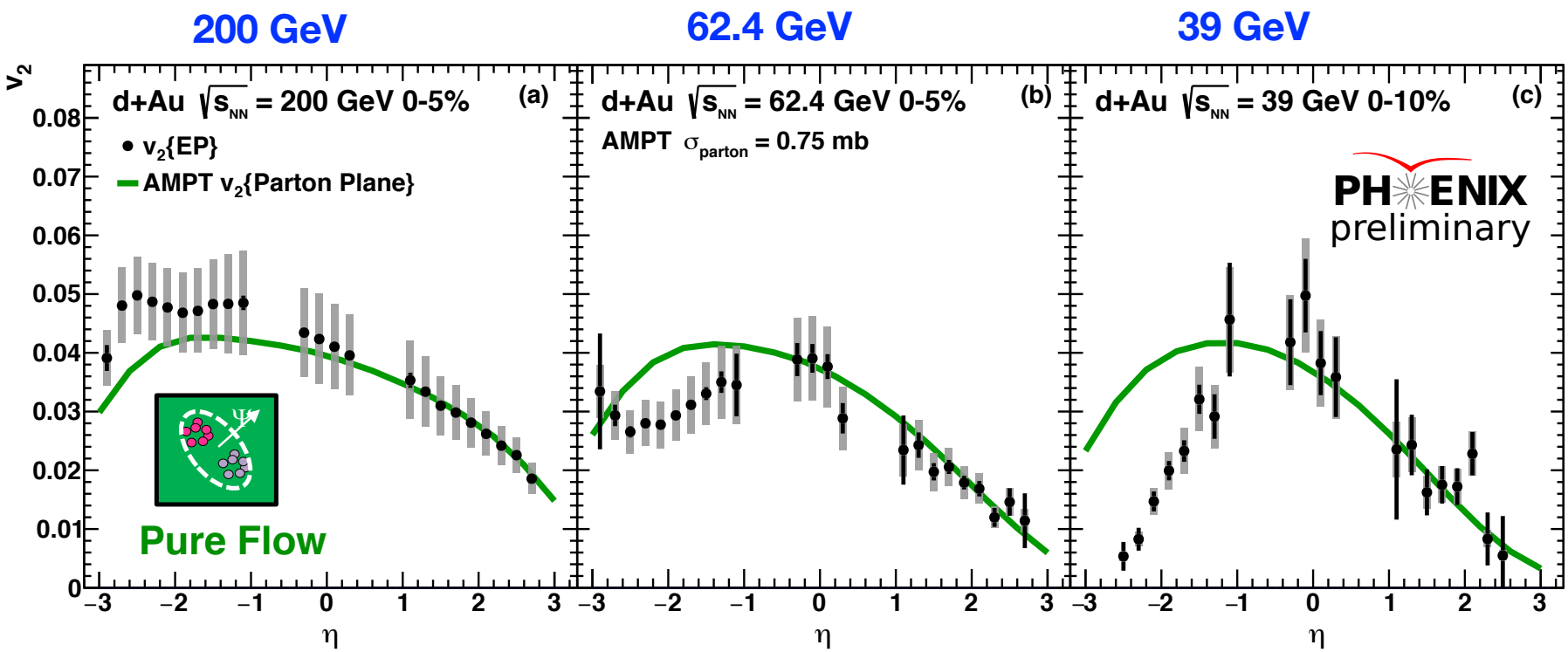
v_2 vs η



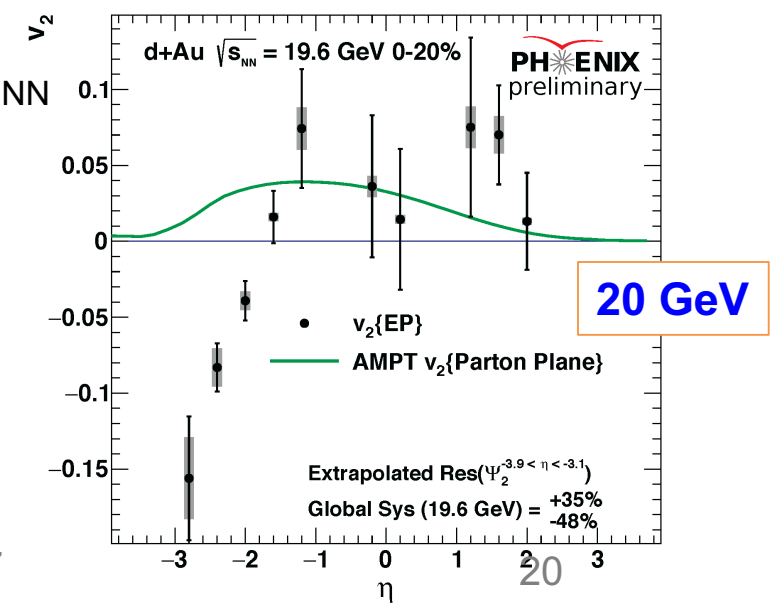
- Forward: similar values at all $\sqrt{s_{NN}}$
- Backward: decrease with $\sqrt{s_{NN}}$



Insights from AMPT

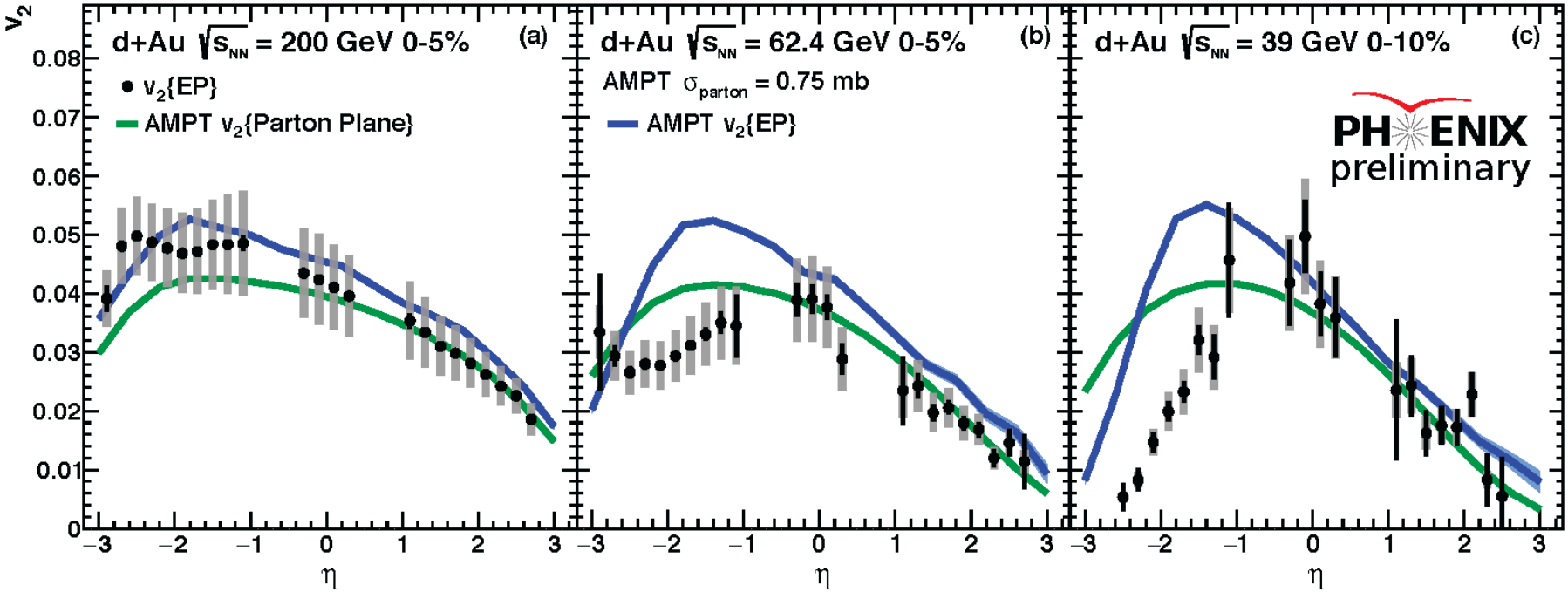


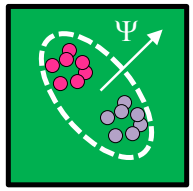
- Forward: well described at all $\sqrt{s_{NN}}$
- Backward: AMPT deviates from data at low energy



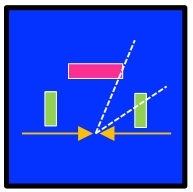
Insights from AMPT

200 GeV | 62.4 GeV | 39 GeV

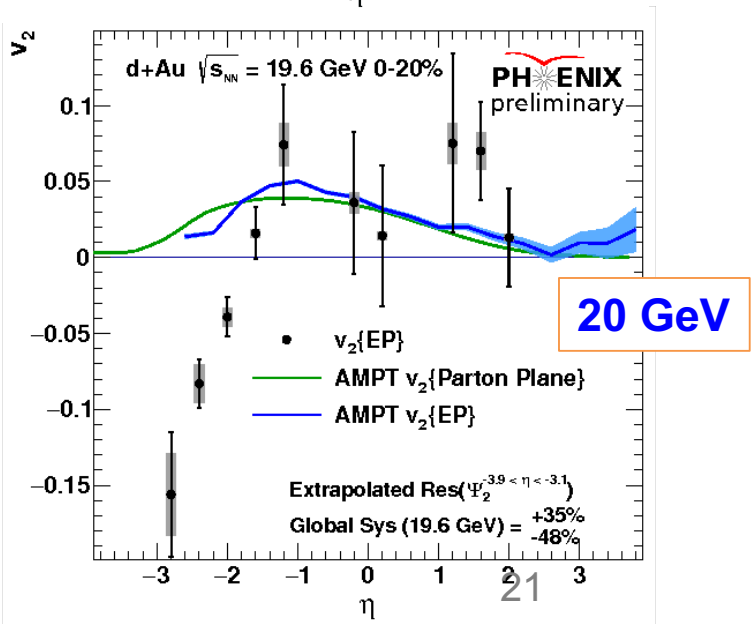




Pure Flow



With Non-Flow



20 GeV

- Flow dominates at forward and middle pseudorapidity

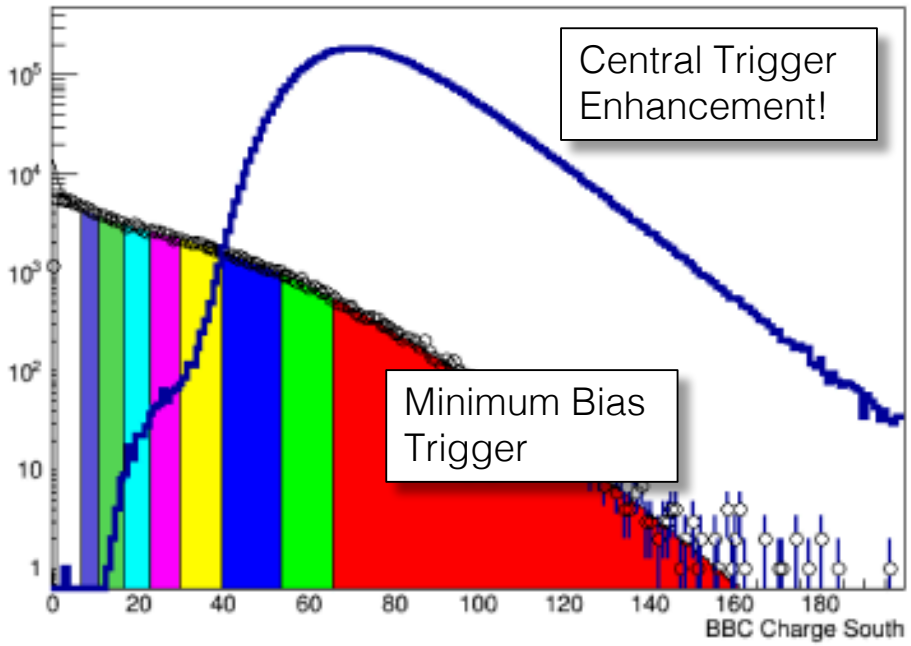
Summary

- In d+Au BES clear collective effects are observed in central collisions down to 39 GeV
- Interesting interplay between flow and nonflow correlations at 39 and 20 GeV d+Au
- Indication of flow in 20 GeV d+Au from $v_2\{4\}$
- At 200 GeV in d/^{3}He+Au collisions elliptic and triangular flow are well described with viscous hydrodynamics with small η/s
  - preflow contributions seem insignificant
- Stay tuned for more results at the lower energies

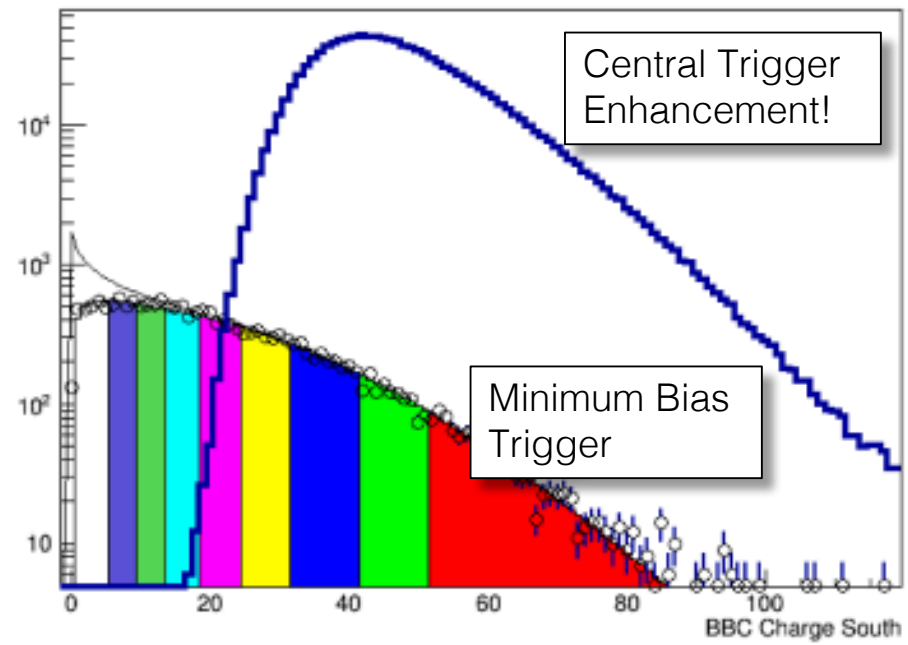
BACKUP

Run 16 d+Au BES: Event Sample Size

200 GeV



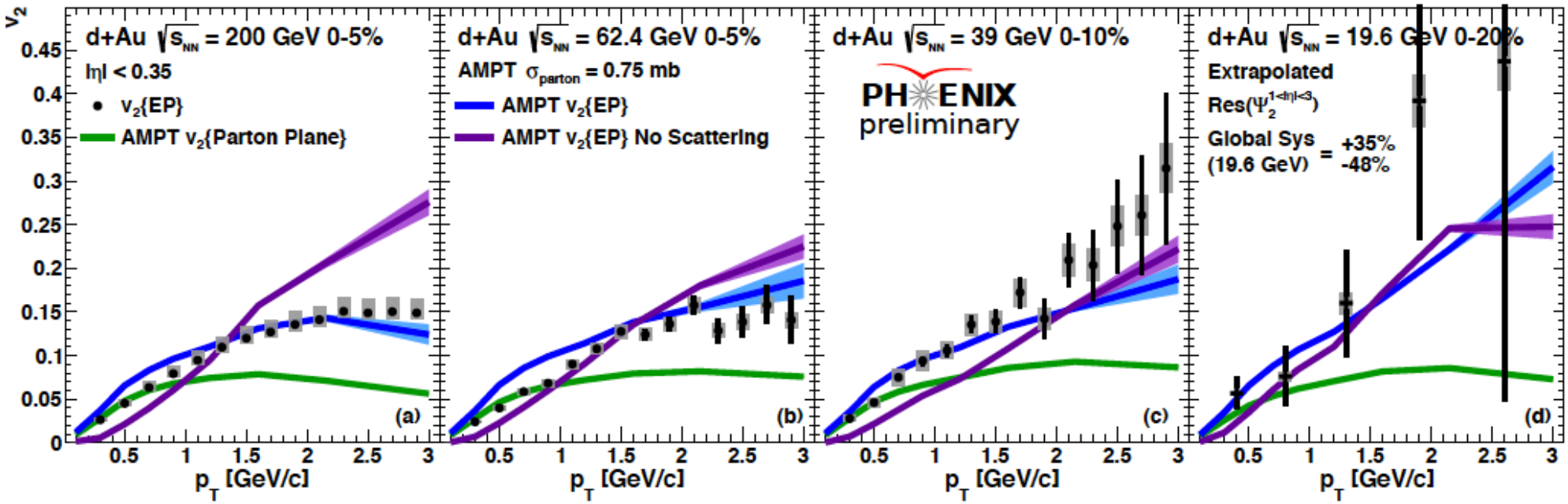
62 GeV

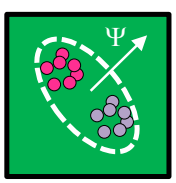


	Number of Central Events Recorded
20 GeV	15 Million
39 GeV	137 Million
62.4 GeV	131 Million
200 GeV	636 Million

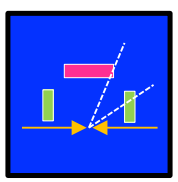
Nonflow correlations: insights from AMPT

200 GeV **62 GeV** **39 GeV** **20 GeV**

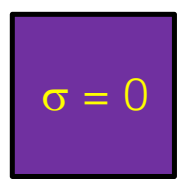




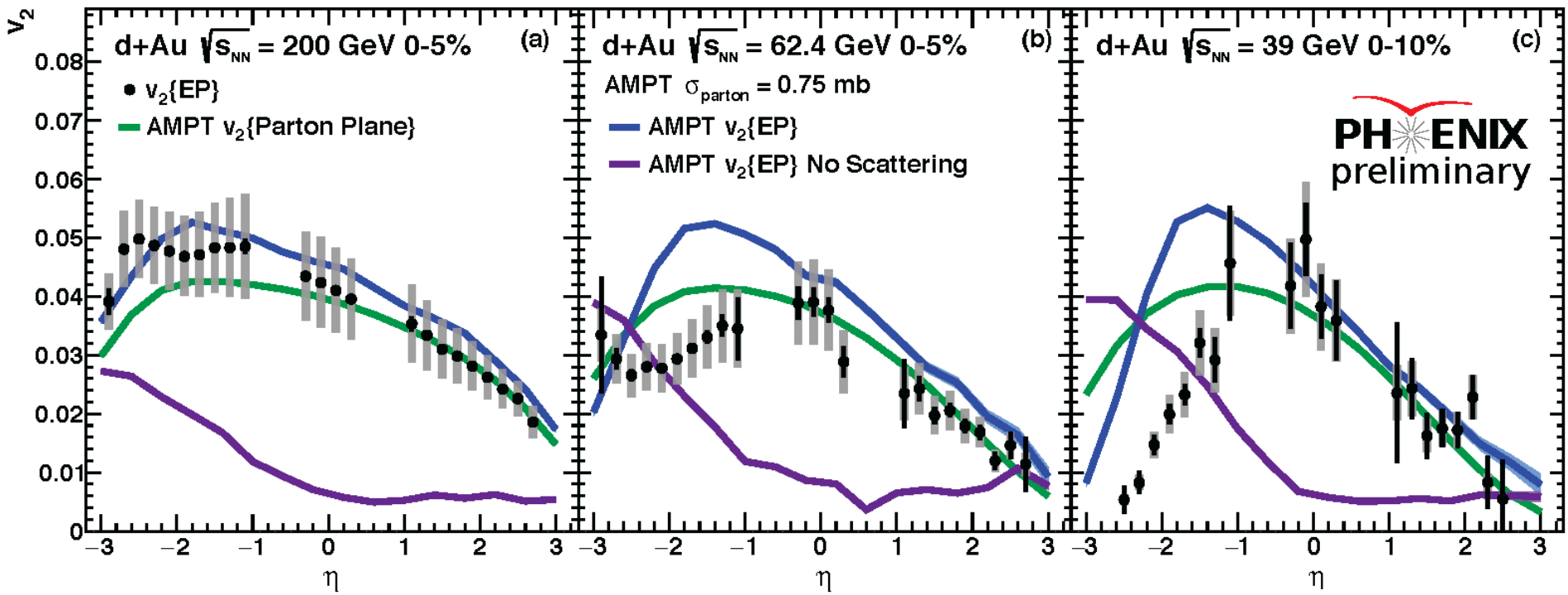
Pure Flow

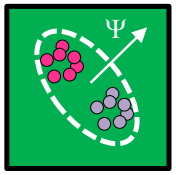


With Non-Flow



All Non-Flow





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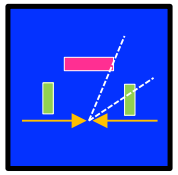
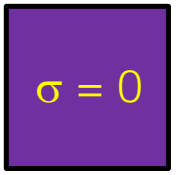
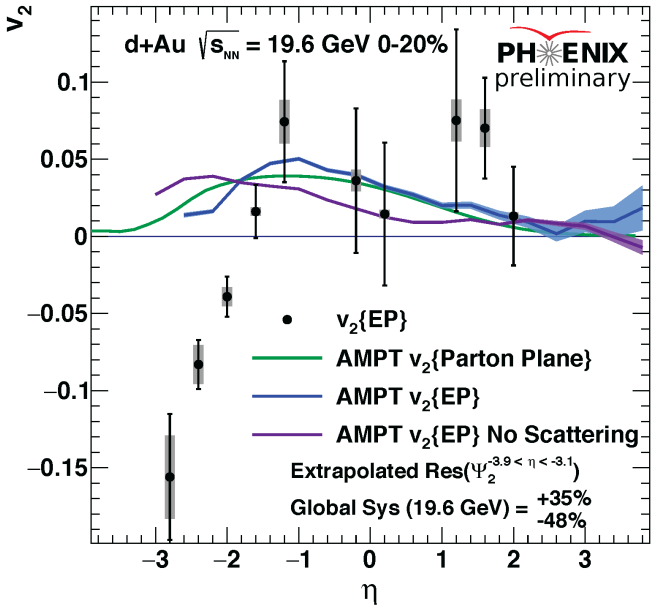


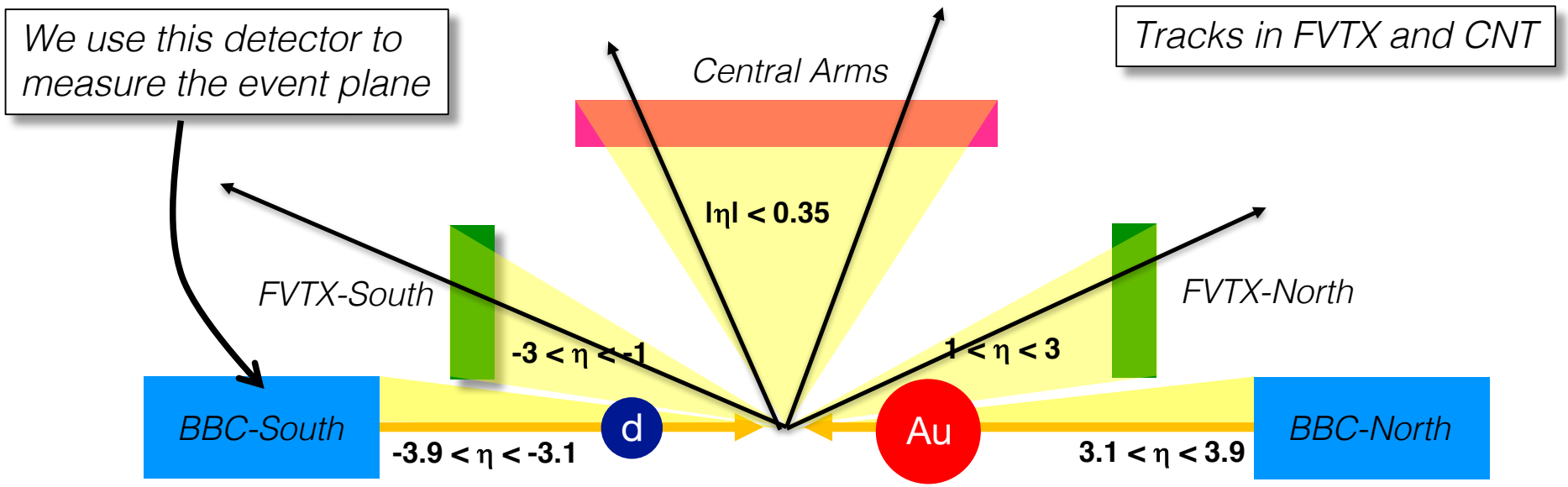
With Non-Flow



All Non-Flow



v_2 vs η: analysis method



1. d+Au collisions generated with AMPT

- Determine parton-plane angle ,"true" ψ_2
- Use all final-state charged particles to determine "true" $v_2(\eta)$

2. reconstruct events with full GEANT simulation in PHENIX

- Analyze using final-state particles in the PHENIX acceptance to get $v_2(\eta)$

Correction factor = v_2 from step (2)/ (1)

- Apply correction to data $v_2(\eta)$
- Change the AMPT input parton cross section (and resulting v_2)→ repeat
- Change the input p_T spectra → repeat

Table 6: Summary of the systematic uncertainties on the v_2 vs p_T measurements at 200, 62.4, and 39 GeV.

Sys	200	62.4	39
Double interactions	+9.4%	< 1%	< 1%
Event Plane	4.5%	4.5%	4.5%
East vs West	1.6%	3.6%	5.9%
PC3 Match	1%	1%	1%
ϕ shift	1%	1%	10% $p_T < 1$ and 5% $p_T > 1$
Total	$^{+10.6\%}_{-4.9\%}$	±5.8%	±7.5%

Table 8: A summary of the systematic uncertainties applied to the measurement of v_2 vs η in 200, 62.4, and 39 GeV d+Au collisions.

Sys	Type	200	62	39
Double Interactions	B	+2%	< 1%	< 1%
Event Plane	B	4.8%	4.8%	4.8%
Fake Tracks	B	3.3%	3.3%	3.3%
E vs W	B	1.6%	3.6%	5.9%
AMPT correction	B	$\sim 0-3\%$	$\sim 0-3\%$	$\sim 0-3\%$
Total (approx.)	B	$^{+8\%}_{-7\%}$	±8%	±9%