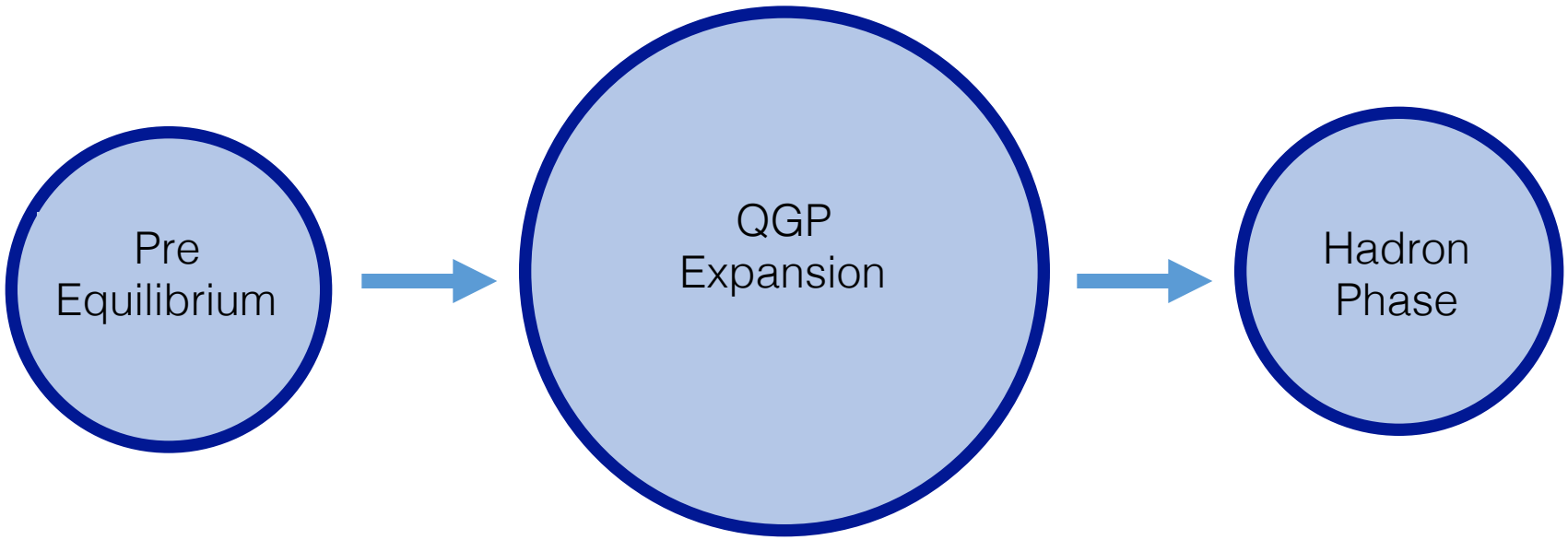
33rd Winter Workshop on Nuclear Dynamics
Snowbird, UT
Jan 2017

Results on Azimuthal Anisotropy and Longitudinal Dynamics in the *d*+Au Beam Energy Scan

Javier Orjuela-Koop
University of Colorado Boulder
For the PHENIX Collaboration

The Hydrodynamic Picture in A+A



In Ideal Hydro: $v_2 \propto \varepsilon_2$

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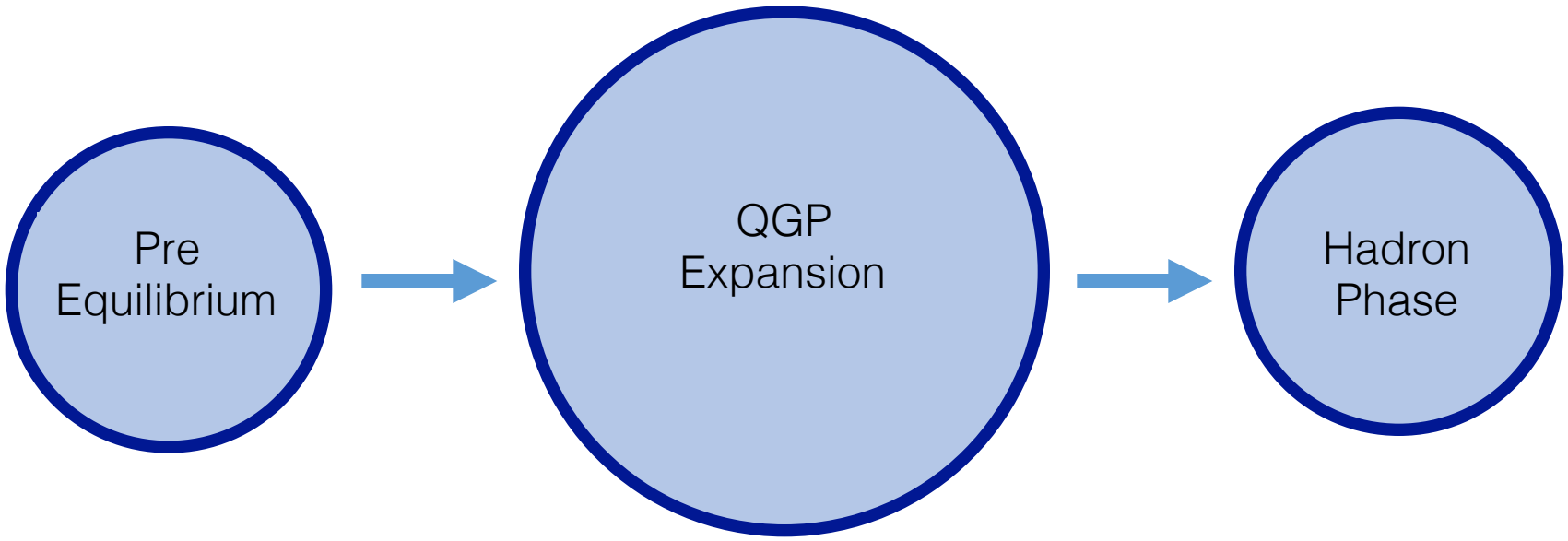
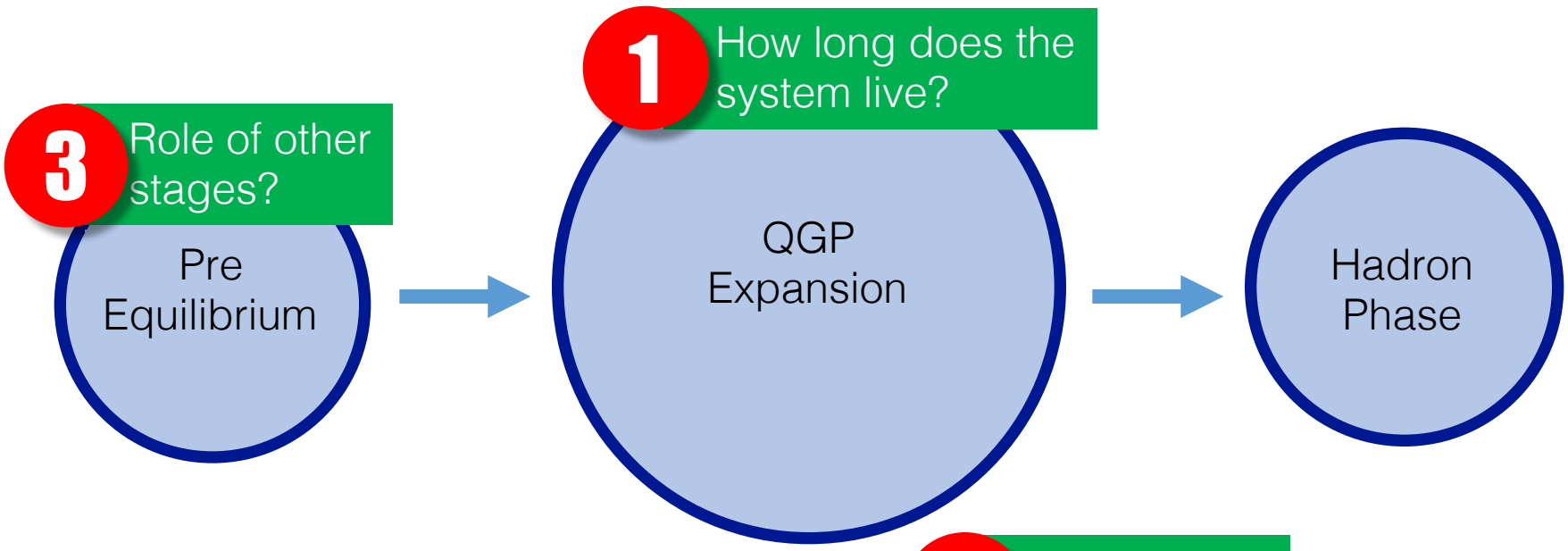


In Ideal Hydro: $v_2 \propto \varepsilon_2$

Momentum Anisotropy

Initial Geometry

Revisiting the Hydrodynamic Picture in Small Systems



2 Is hydro still applicable?

In Ideal Hydro: v_2 ? ε_2

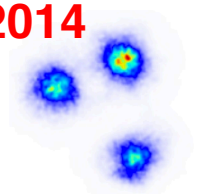
Momentum Anisotropy

Initial Geometry

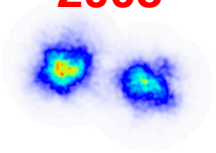
Experimental Handles on Small System Collectivity at RHIC

Geometry Engineering

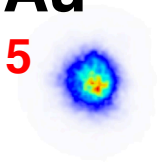
^{3}He+Au
2014



d+Au
2008



p+Au
2015



See talk by S. Huang

Experimental Handles on Small System Collectivity at RHIC

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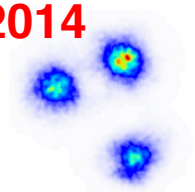

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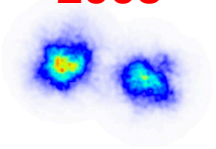

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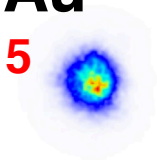

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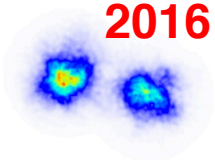
Beam Energy Scan

d+Au
2016



20 GeV

39 GeV

62.4 GeV

200 GeV

Experimental Handles on Small System Collectivity at RHIC

Geometry Engineering

Beam Energy Scan

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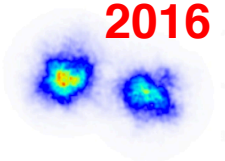

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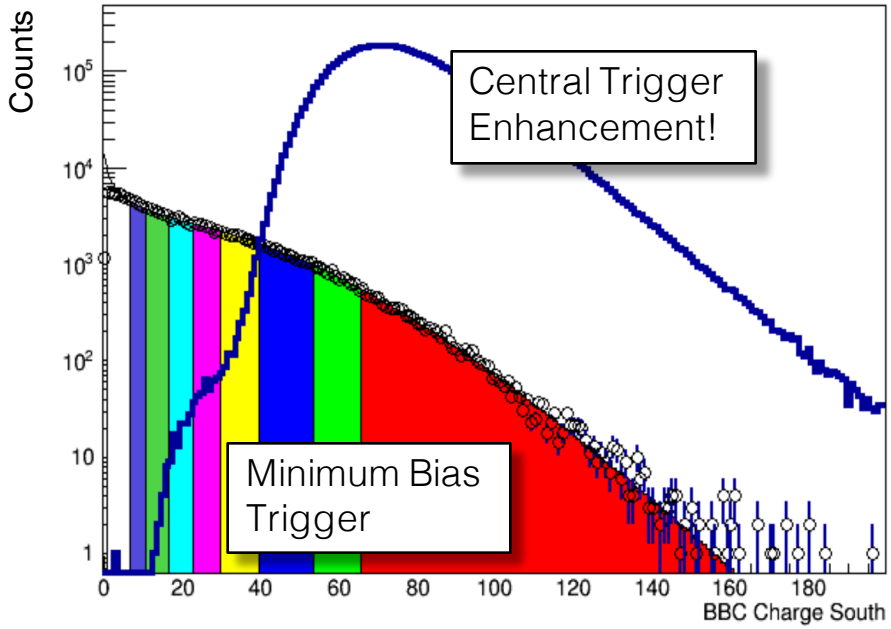
Run16 d+Au at 200 GeV – Triggers and Event Sample Size



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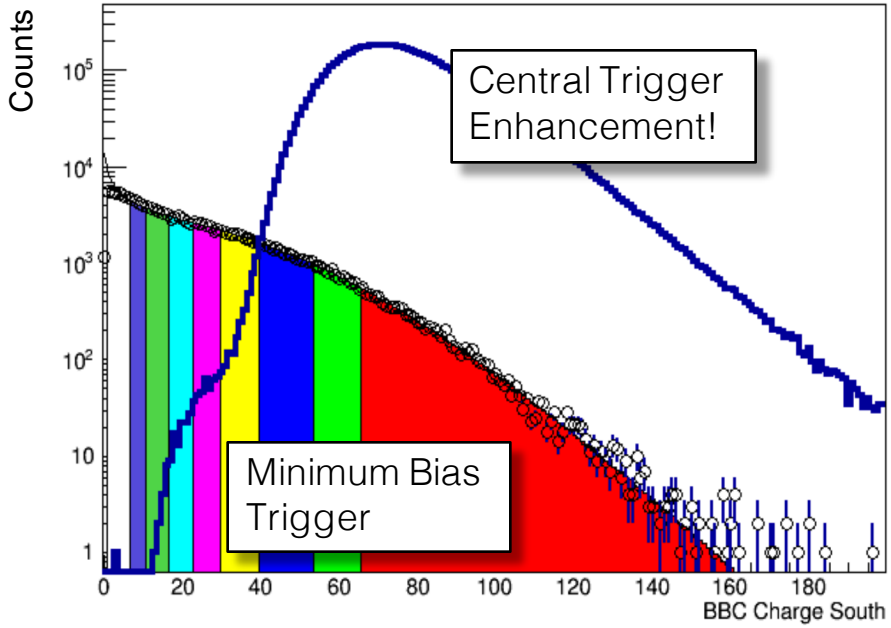
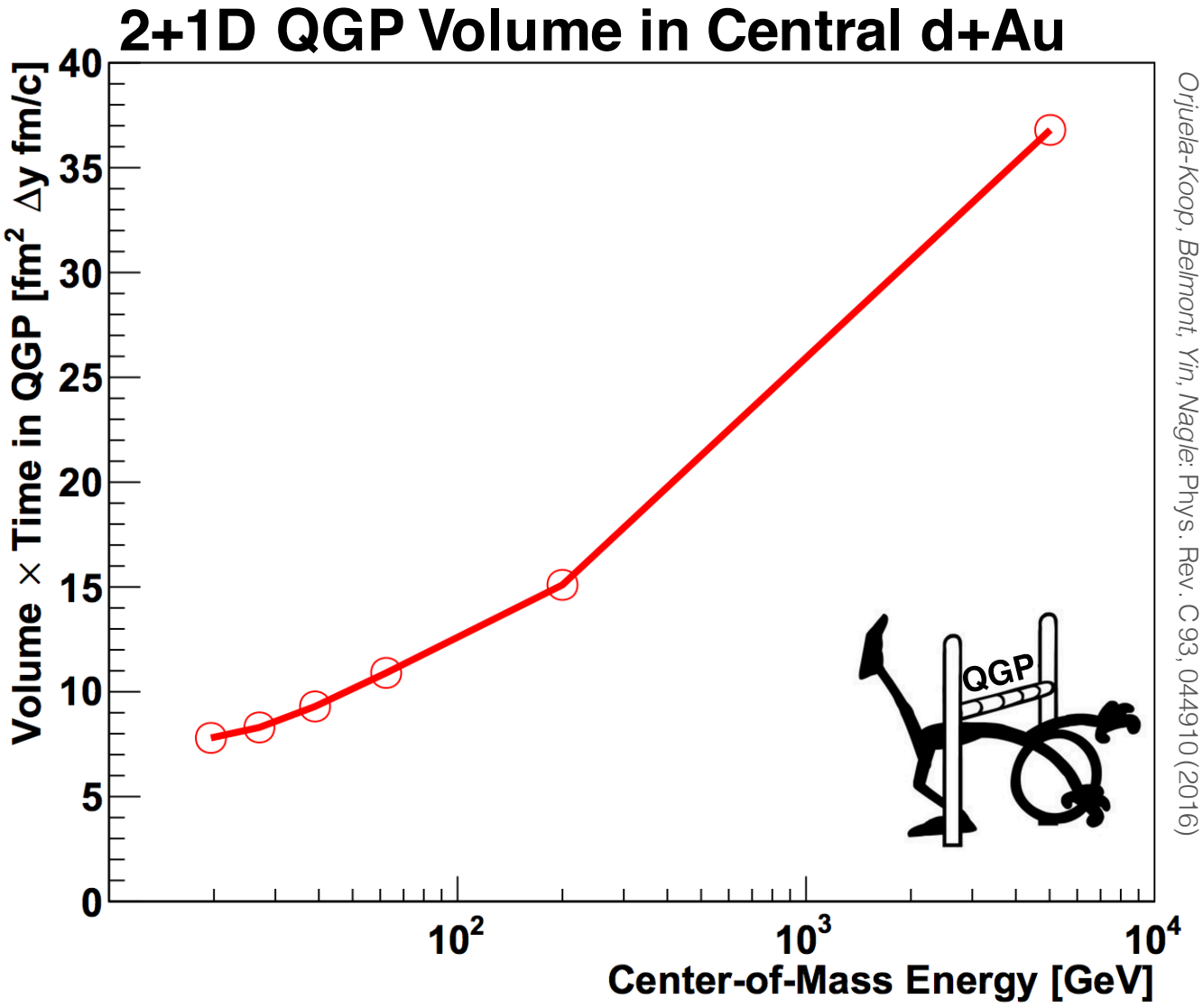


	Number of Central Events Recorded
20 GeV	15 Million
39 GeV	137 Million
62.4 GeV	131 Million
200 GeV	636 Million

How Small a Droplet of QGP Can You Get?



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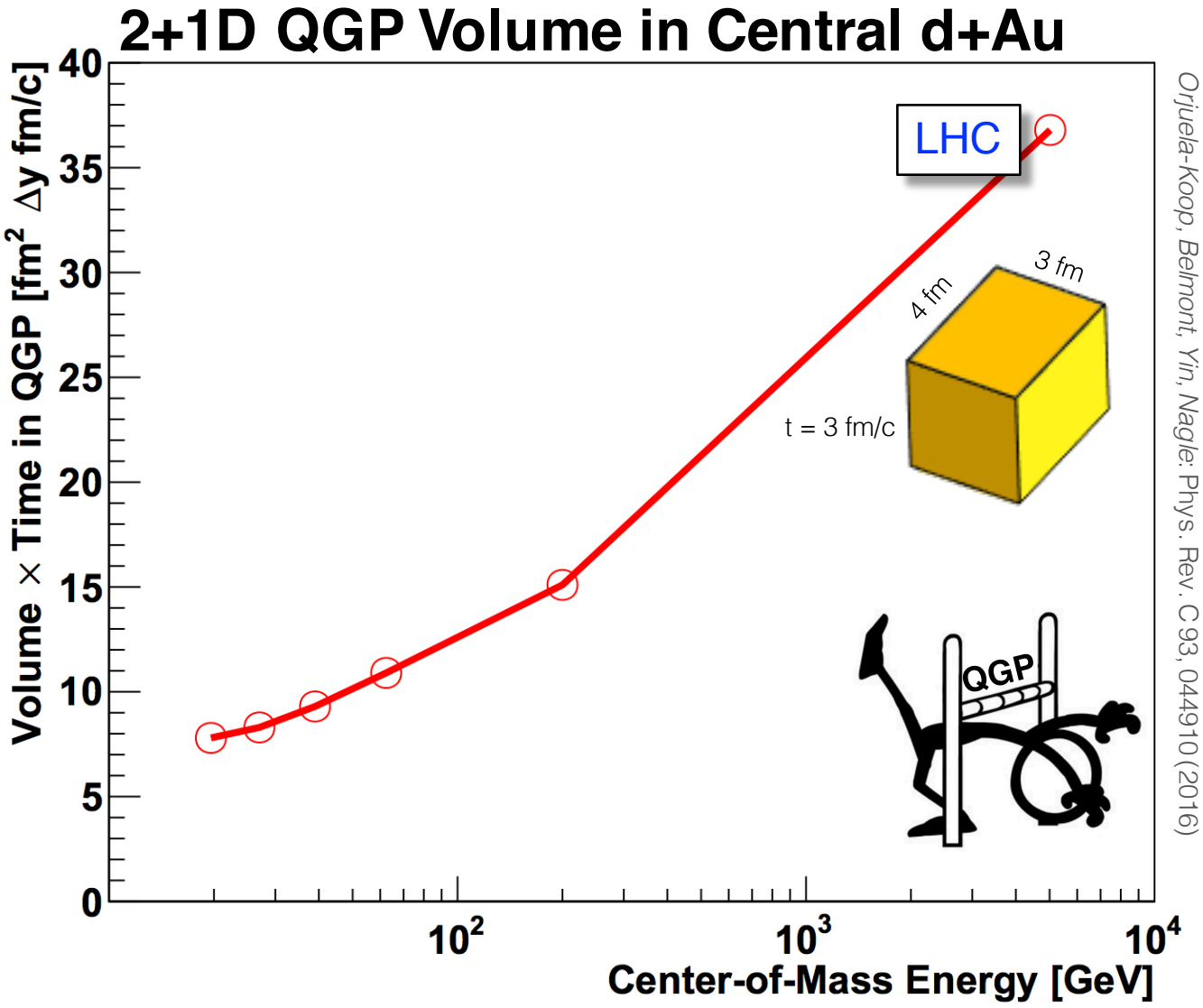

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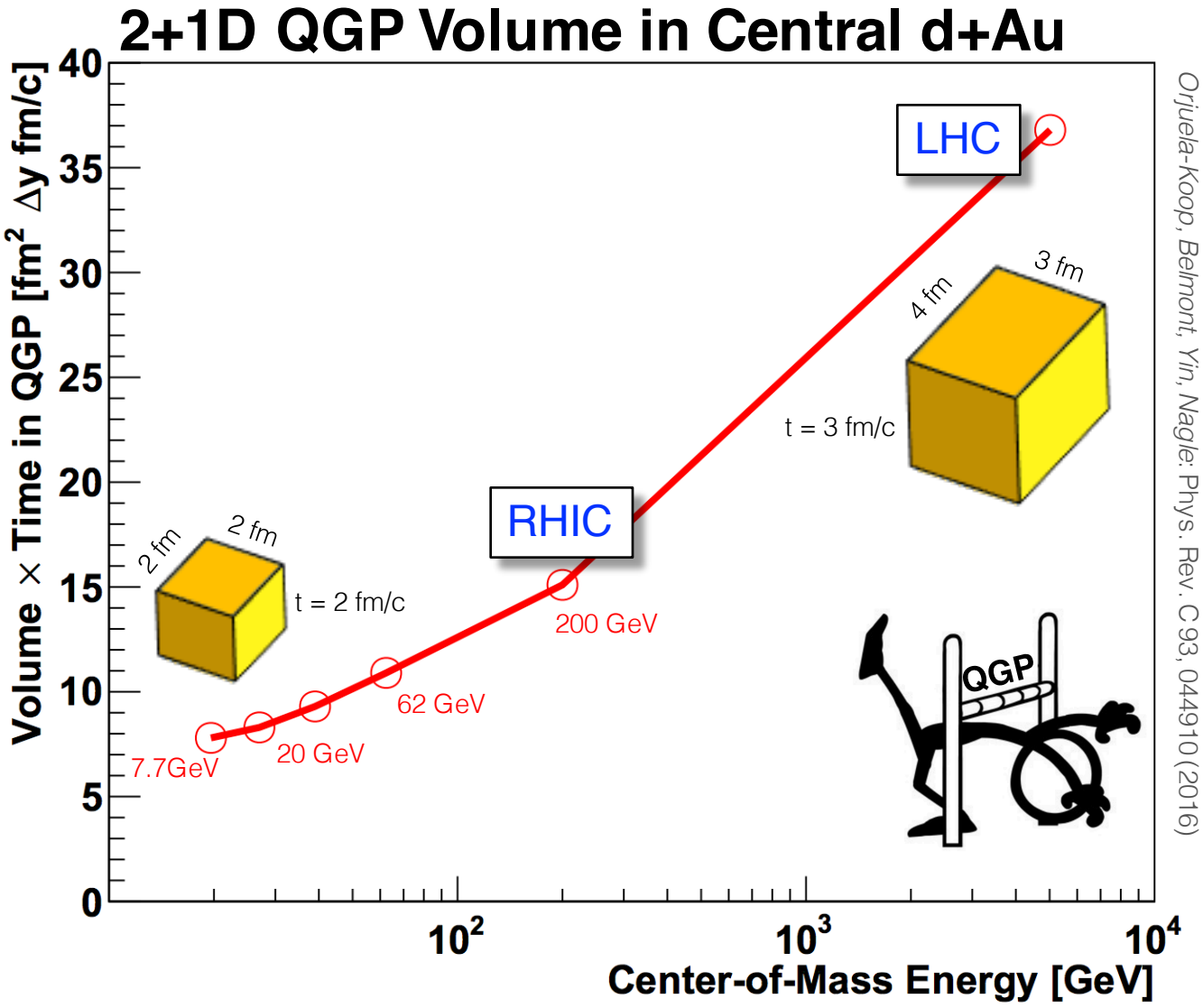
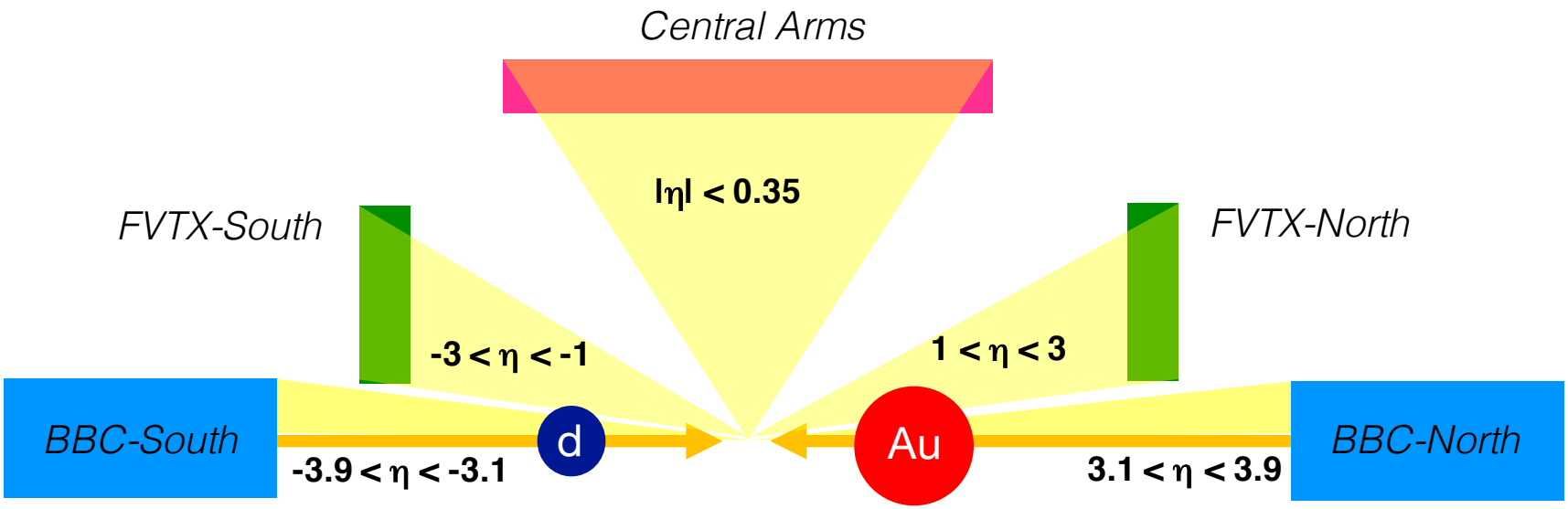


Measuring Azimuthal Anisotropy with PHENIX



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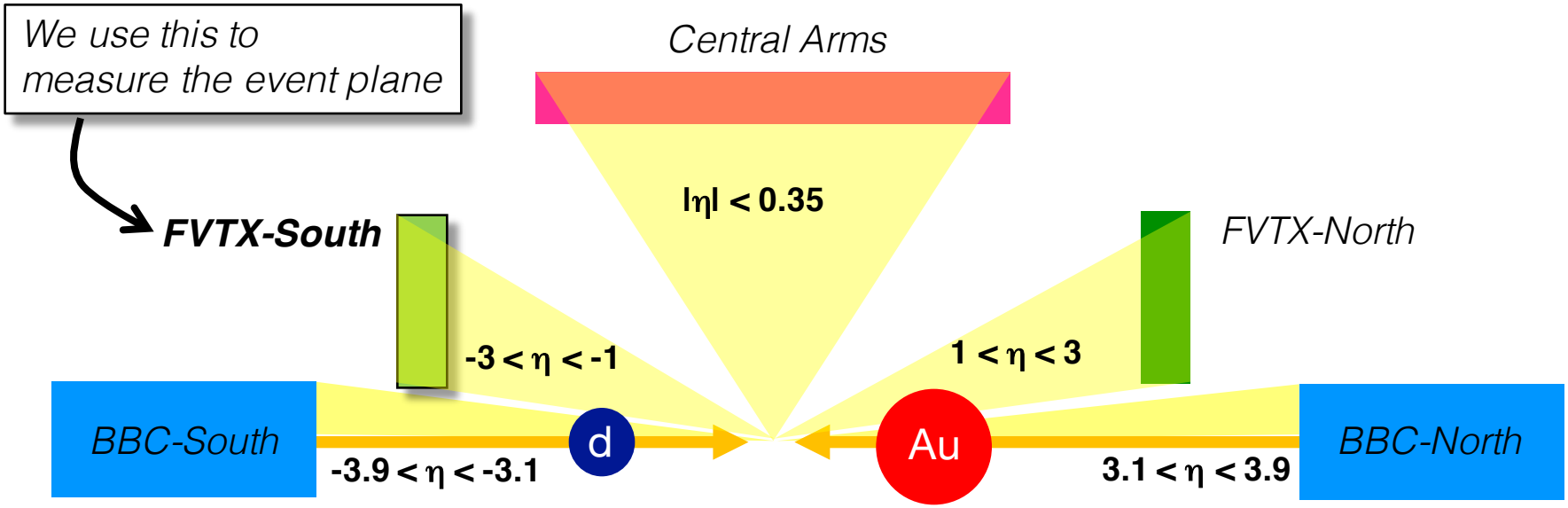
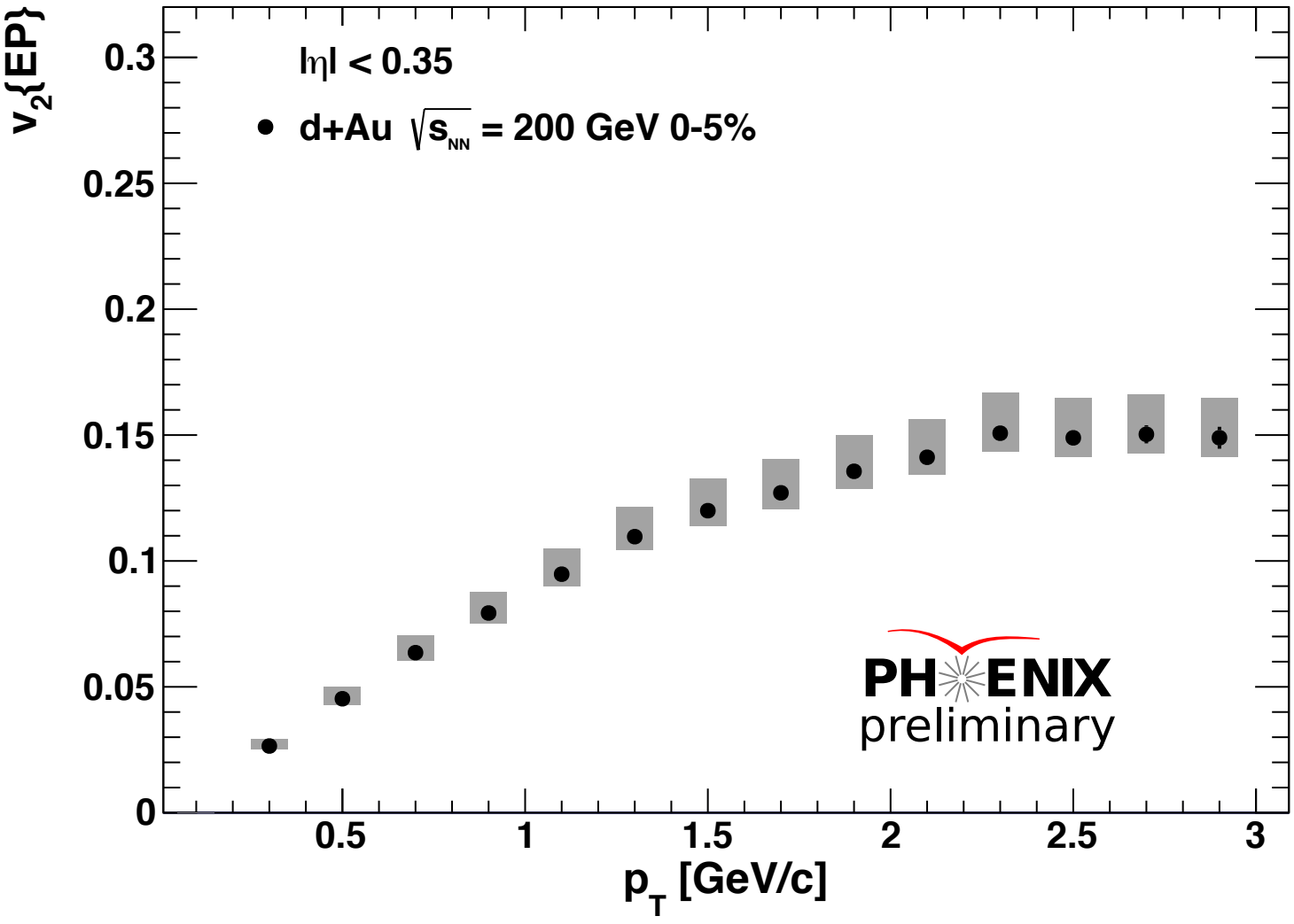


$$v_2 = \frac{\langle \cos 2(\phi - \Psi_2) \rangle}{\mathrm{Res}(\Psi_2)}$$

Calculate Resolution With:

- Central Arms
- FVTX-South
- BBC-South

Transverse Momentum Dependence of v_2



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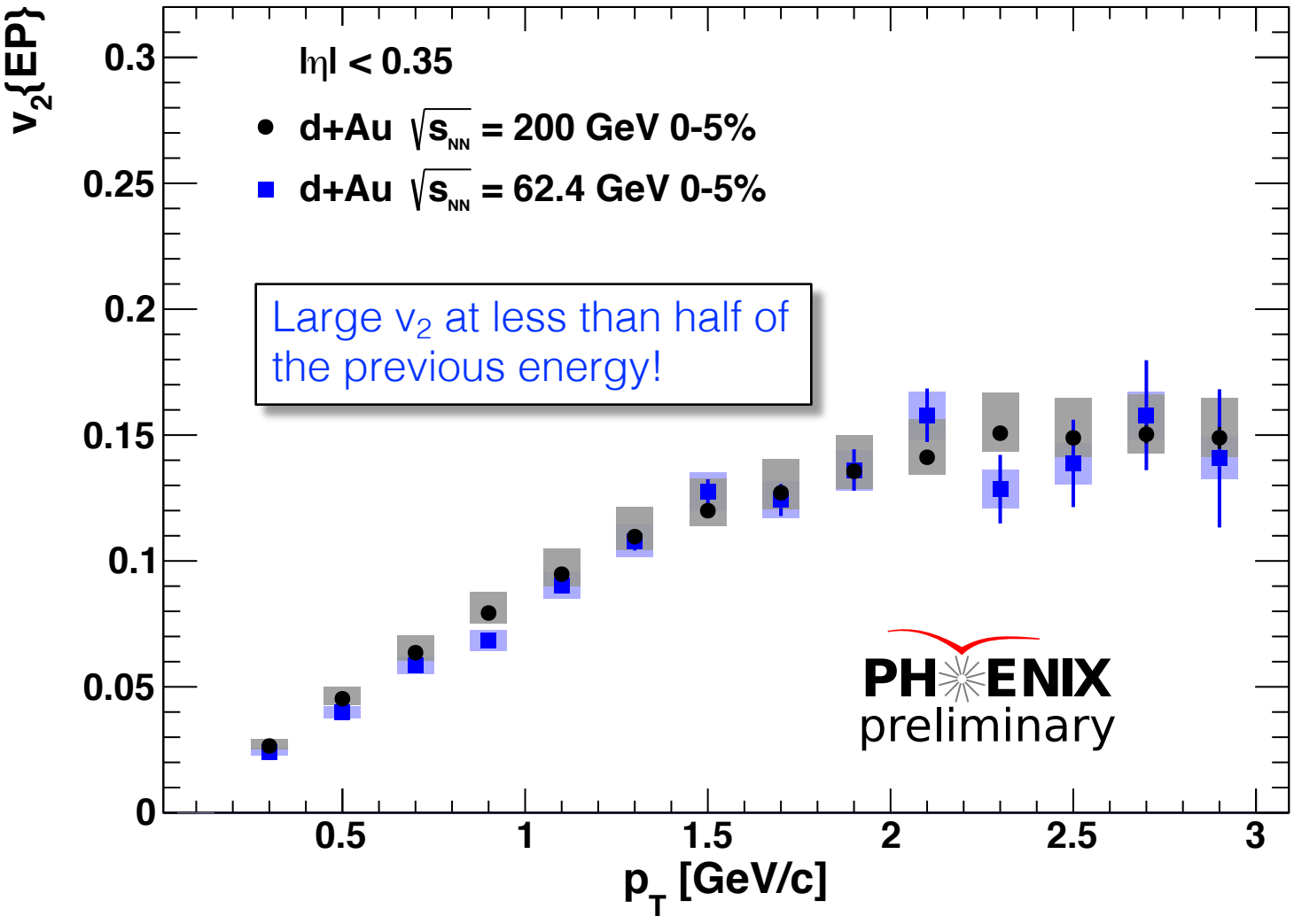

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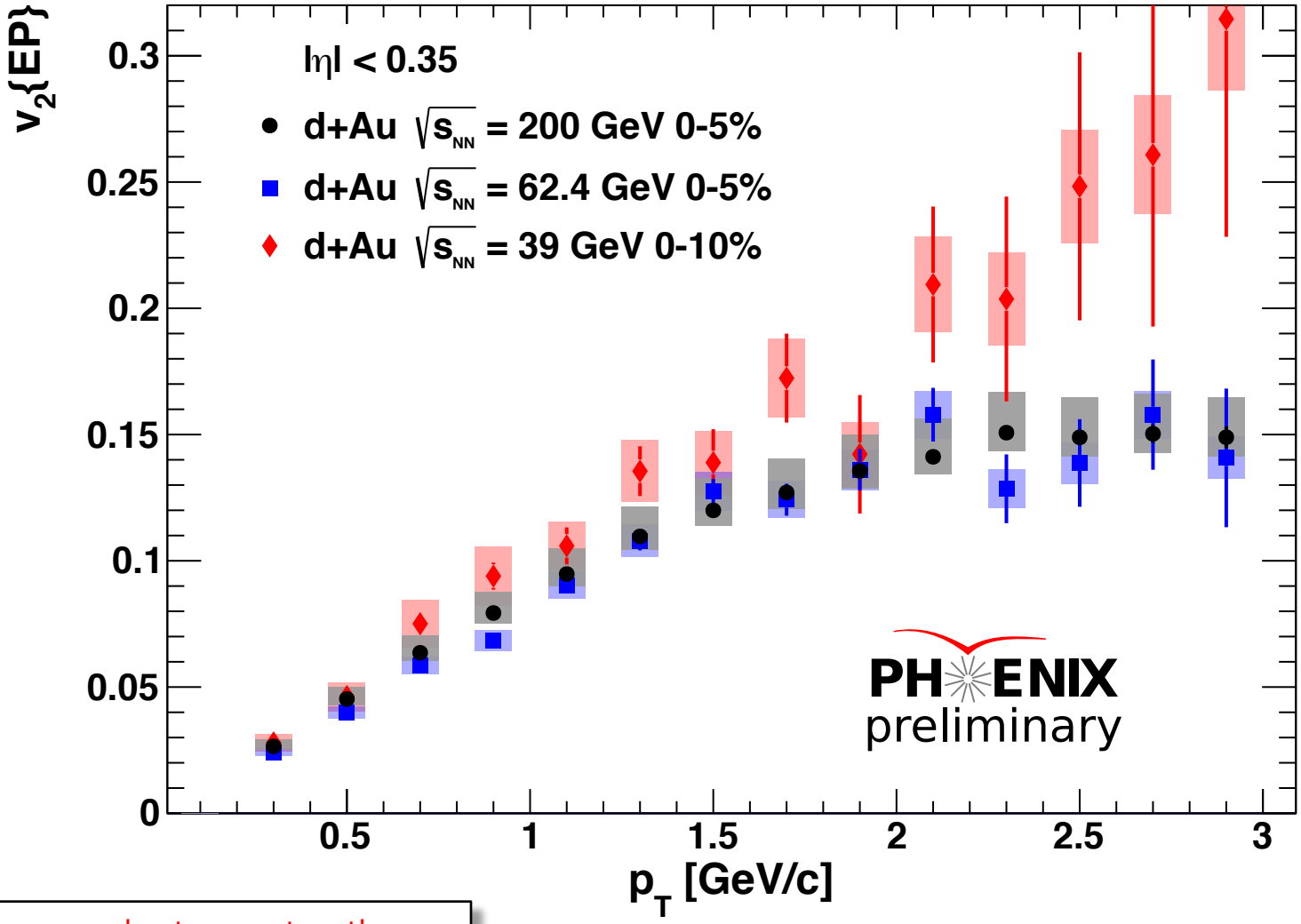


Large v_2, but greater than at 200 Gev???

FLOW

Initial Geometry + Final State Interactions

NON-FLOW

- Jet Correlations
- Momentum Conservation
- Quantum Correlations
- Coulomb Interactions…

FLOW

Initial Geometry + Fi… …nteractions

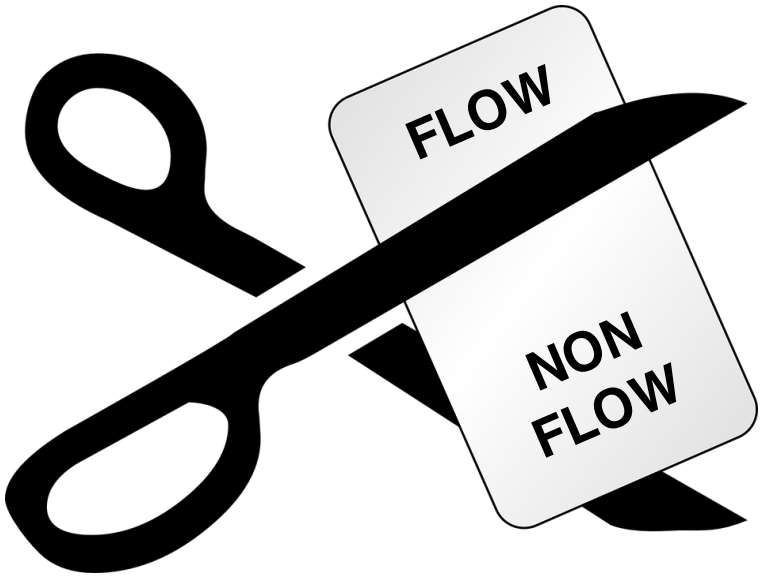
Correlated with Initial Geometry

NON-FLOW

- Jet Fragmentation
- Momentum Conse…
- Quantum C… …ons
- Cou… …nteractions…

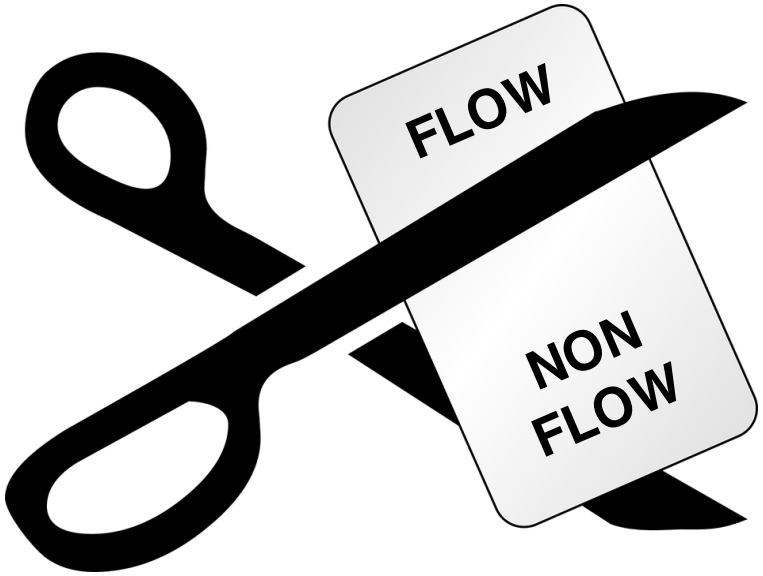
NOT Correlated with Initial Geometry

A Challenge in Interpreting the Results



- Both flow and non-flow contain physics!

A Challenge in Interpreting the Results



- Both flow and non-flow contain physics!

- Different experiments treat non-flow in data-driven ways
- We choose to show data with **no non-flow correction**…

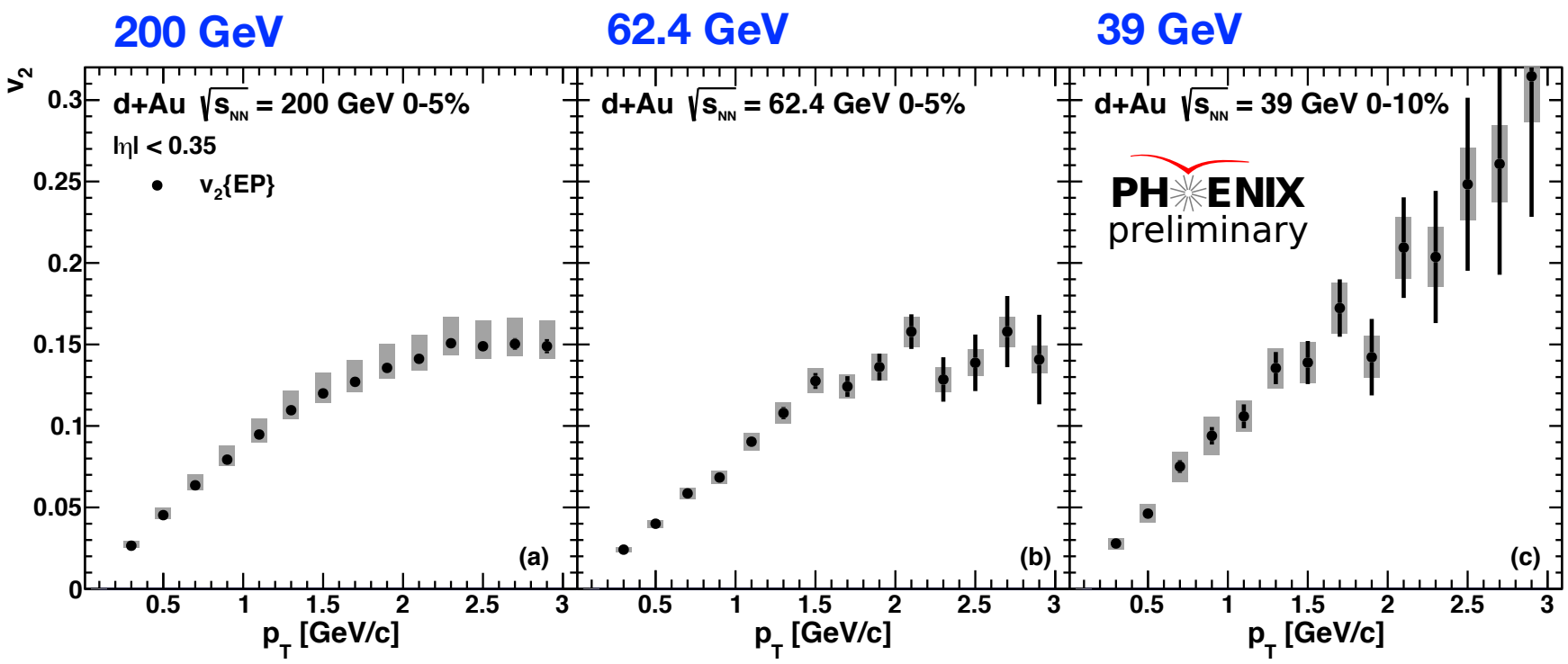
Controlled comparisons with models!

Available Model Comparisons

- *Orjuela-Koop, Belmont, Yin, Nagle: Phys. Rev. C 93, 044910 (2016)*
- *Romatschke: Eur. Phys. J. C75 (2015) no.7, 305*

	Pre-Equilibrium	Expansion	Hadronization	Final Stage
SONIC	NO	Hydro	Cooper-Frye	Hadron Cascade
superSONIC	YES	Hydro	Cooper-Frye	Hadron Cascade

Transverse Momentum Dependence of v_2



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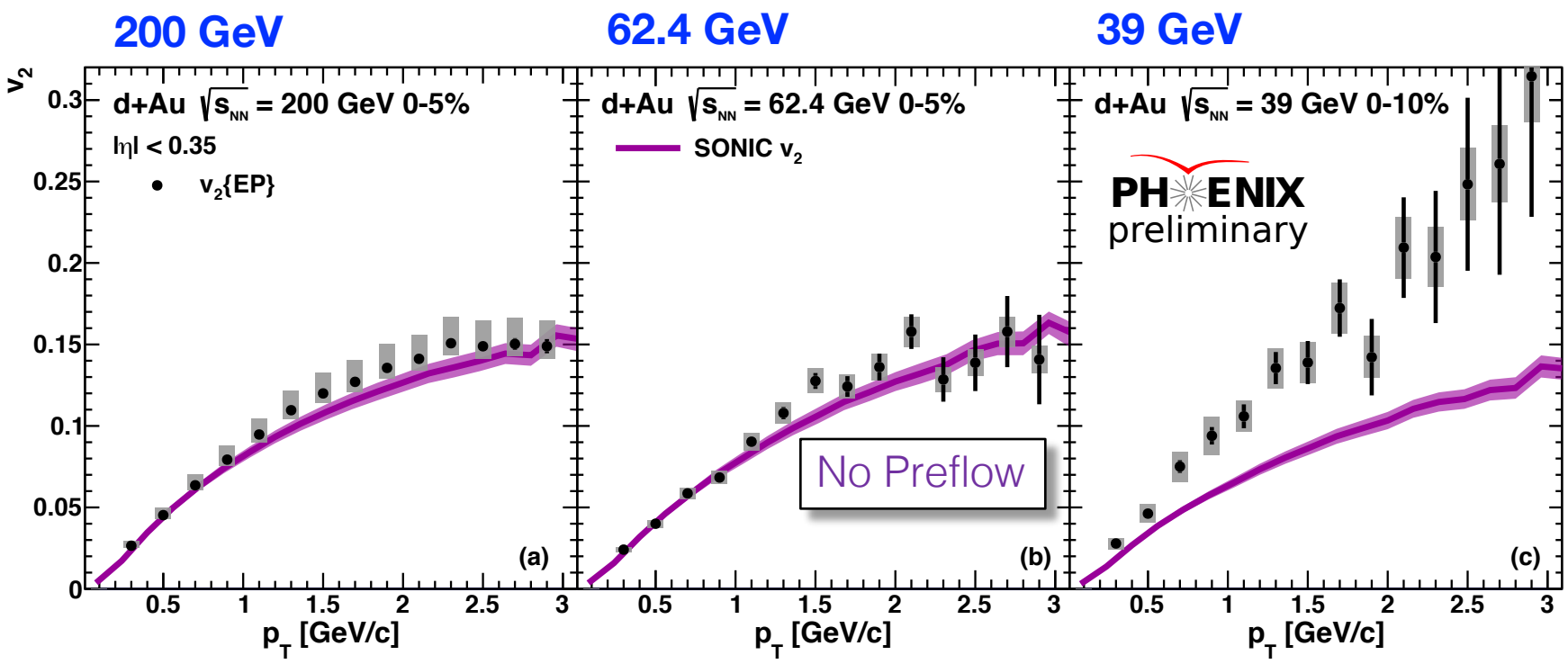

- Hydro models are pure geometry + flow

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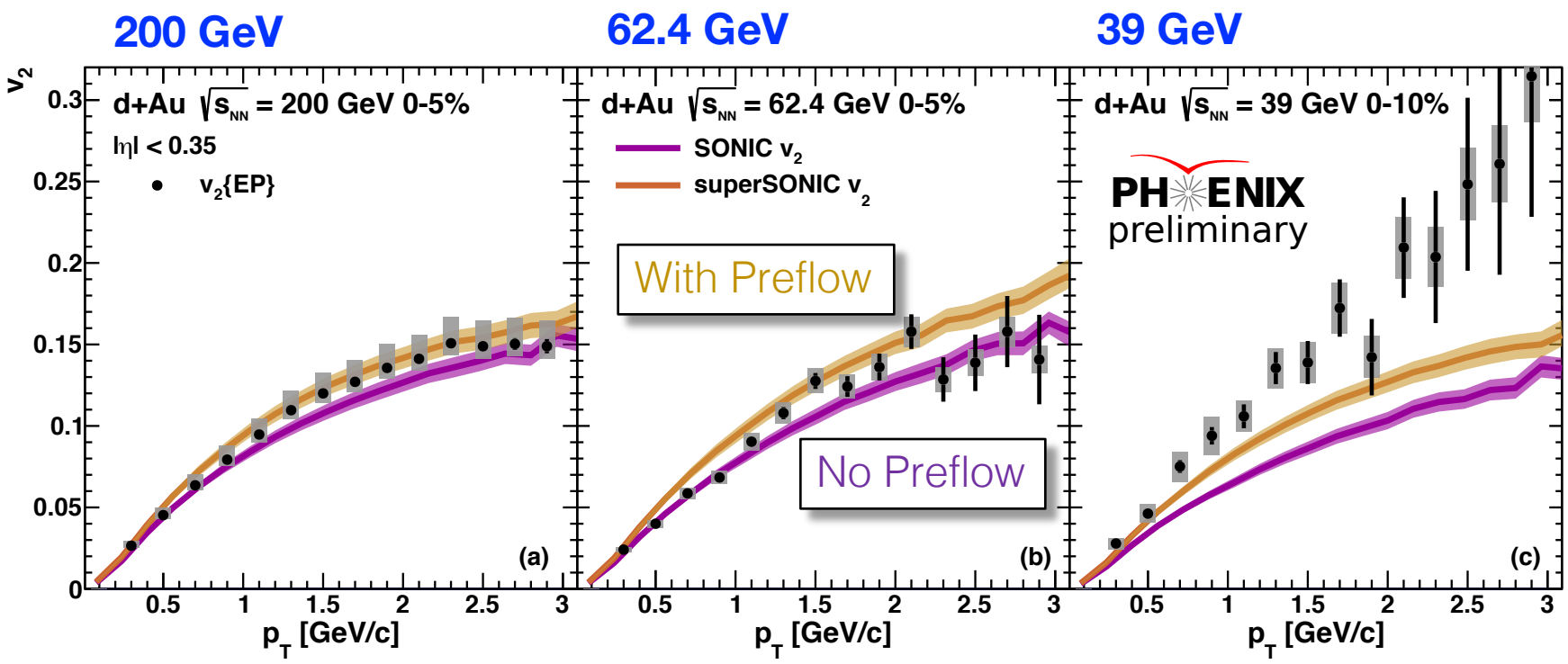

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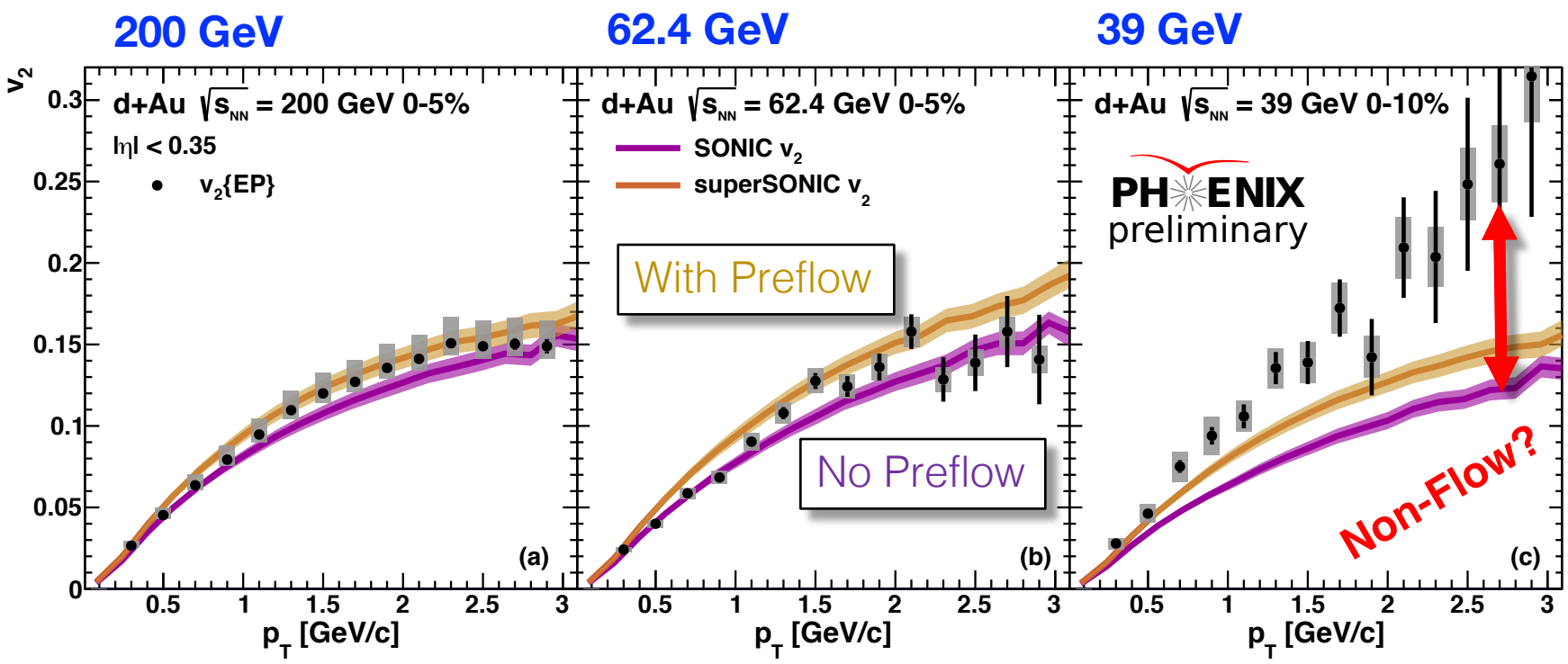

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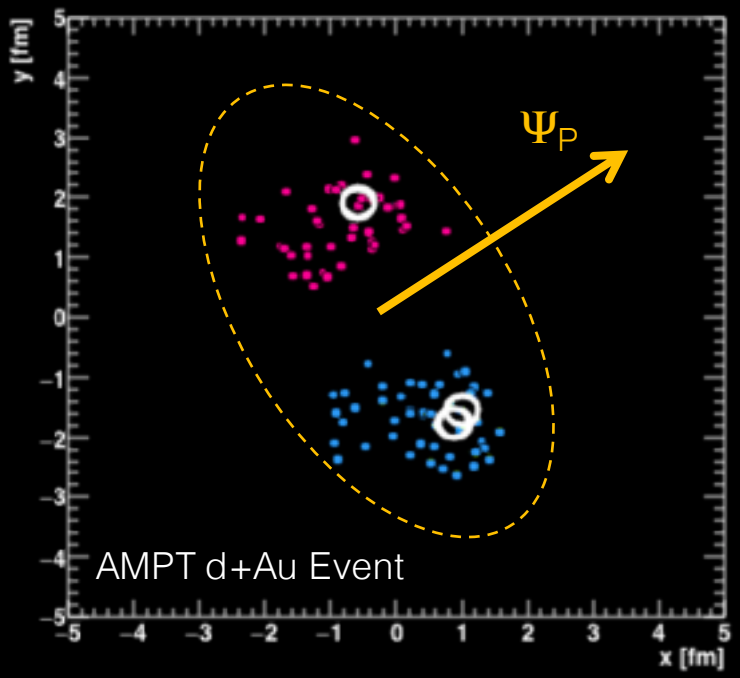
SONIC	NO	Hydro	Cooper-Frye	Hadron Cascade
superSONIC	YES	Hydro	Cooper-Frye	Hadron Cascade
AMPT	N/A	Parton Scattering TUNABLE	Coalescence	Hadron Cascade TUNABLE

Using AMPT to Isolate Non-Flow



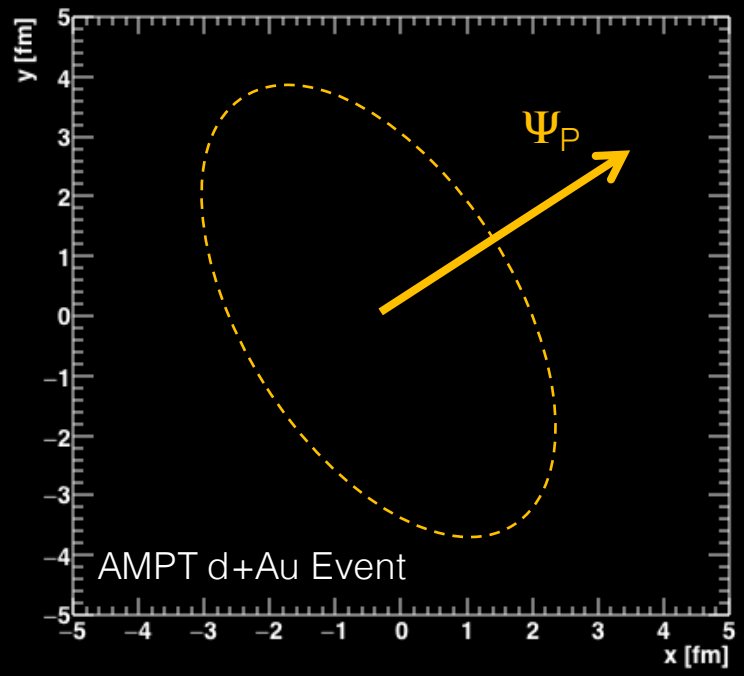
Take a Snapshot of Partons at t~0 fm/c

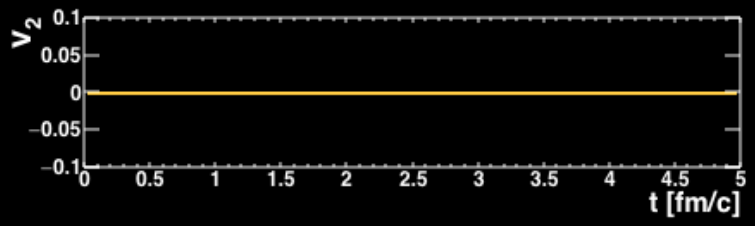
Initial Parton Configuration

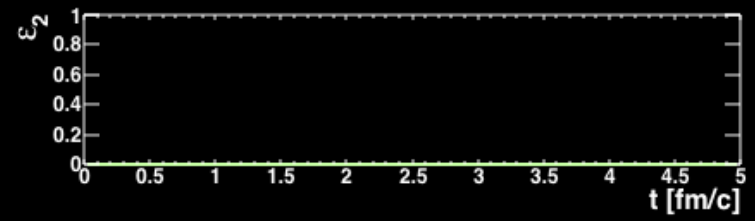
↓

Participant Plane Ψ_P

Using AMPT to Isolate Non-Flow





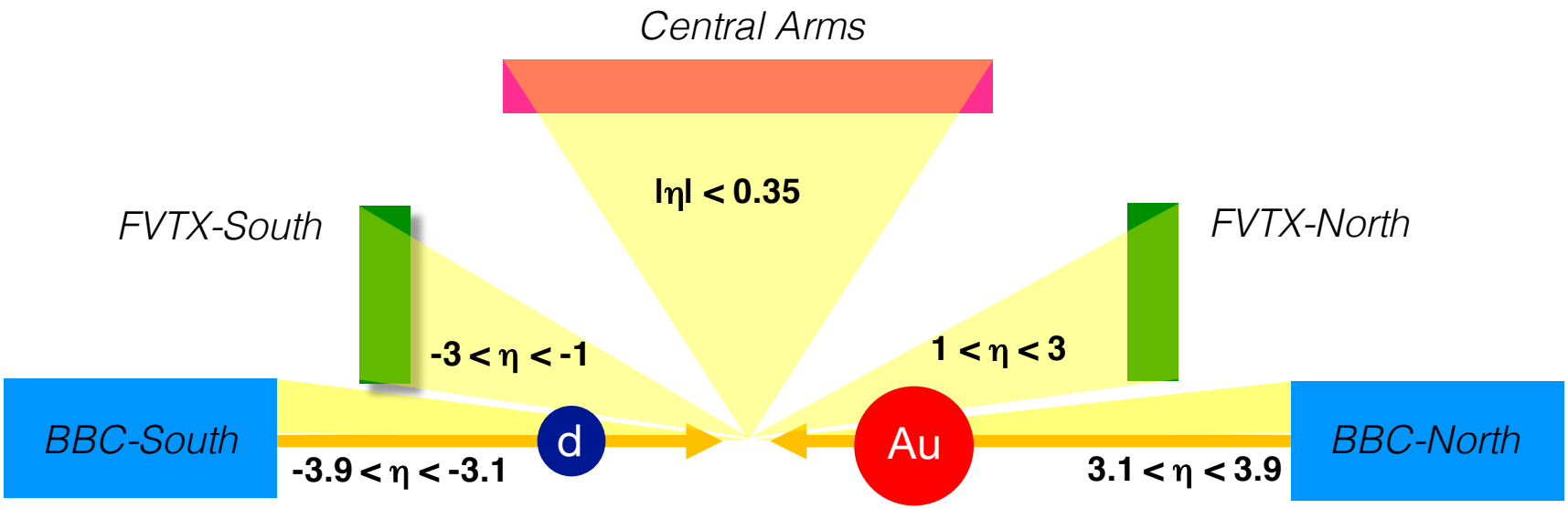


Flow v_2

Initial Geometry
+
Partonic Interactions
+
Hadronic Interactions

$$v_2 = \langle \cos 2(\phi - \Psi_P) \rangle$$

Using AMPT to Isolate Non-Flow



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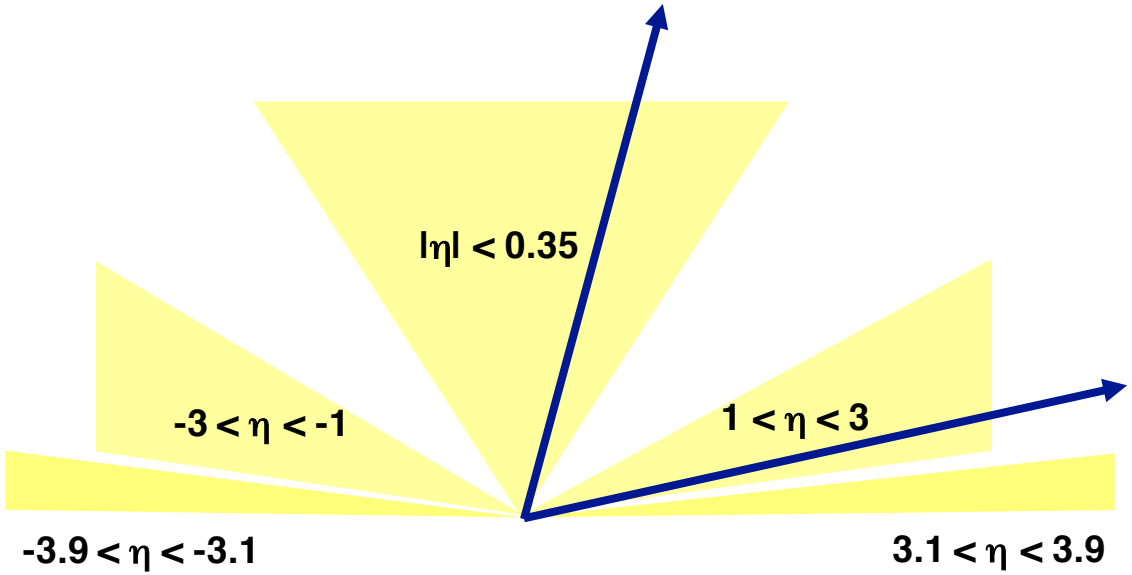
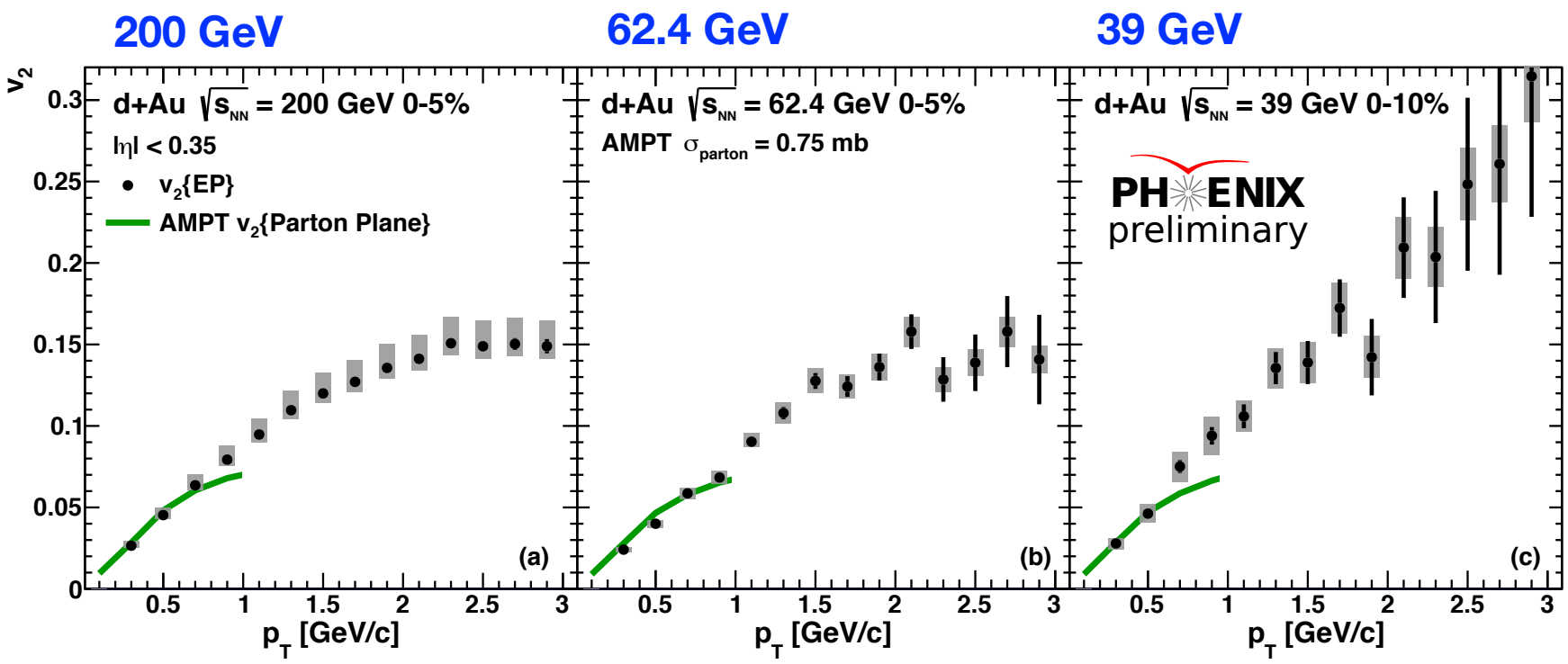
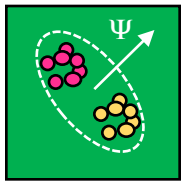


Use AMPT final-state particles in the acceptance covered by PHENIX subsystems

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

Using AMPT to Understand Non-Flow

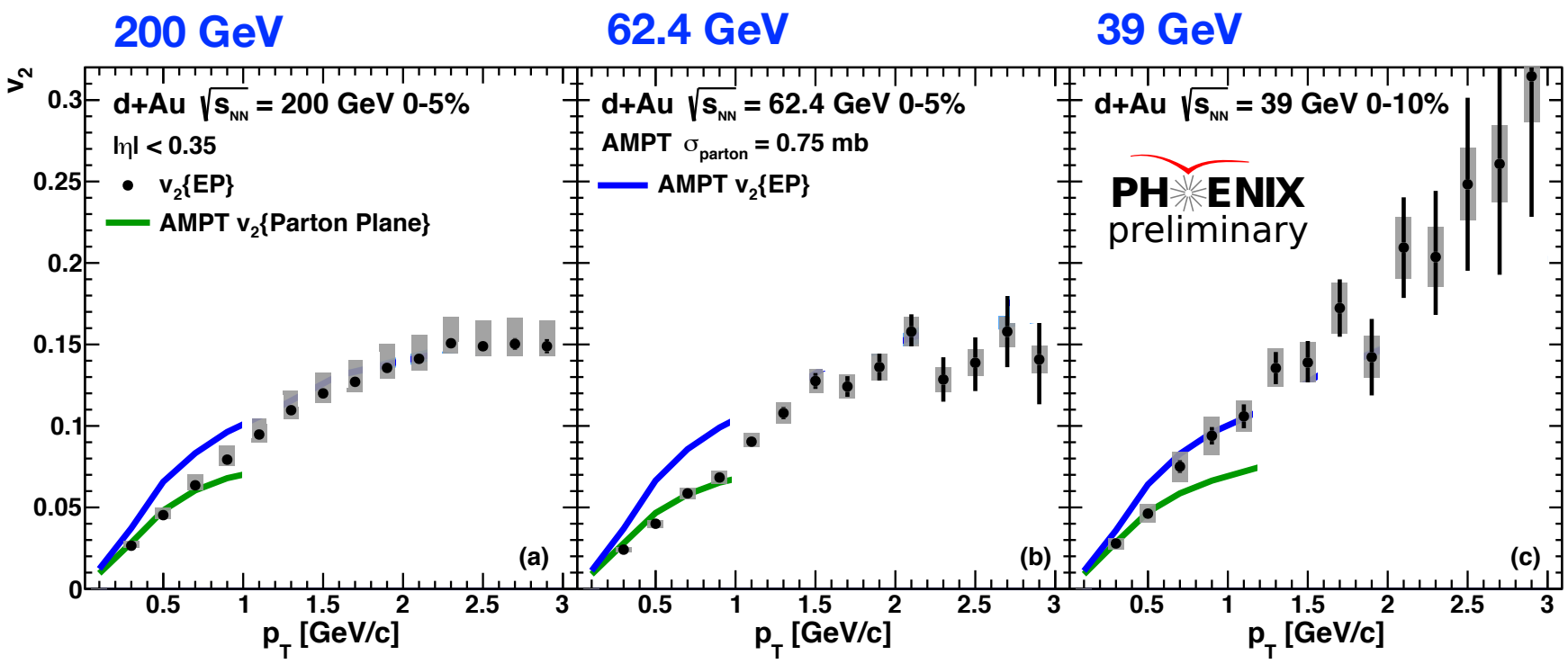


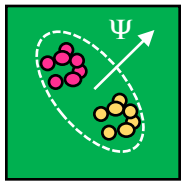


Pure Flow

Pure flow from AMPT describes the data well, below 1 GeV/c

Using AMPT to Understand Non-Flow





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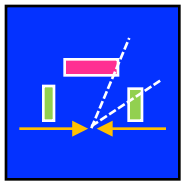

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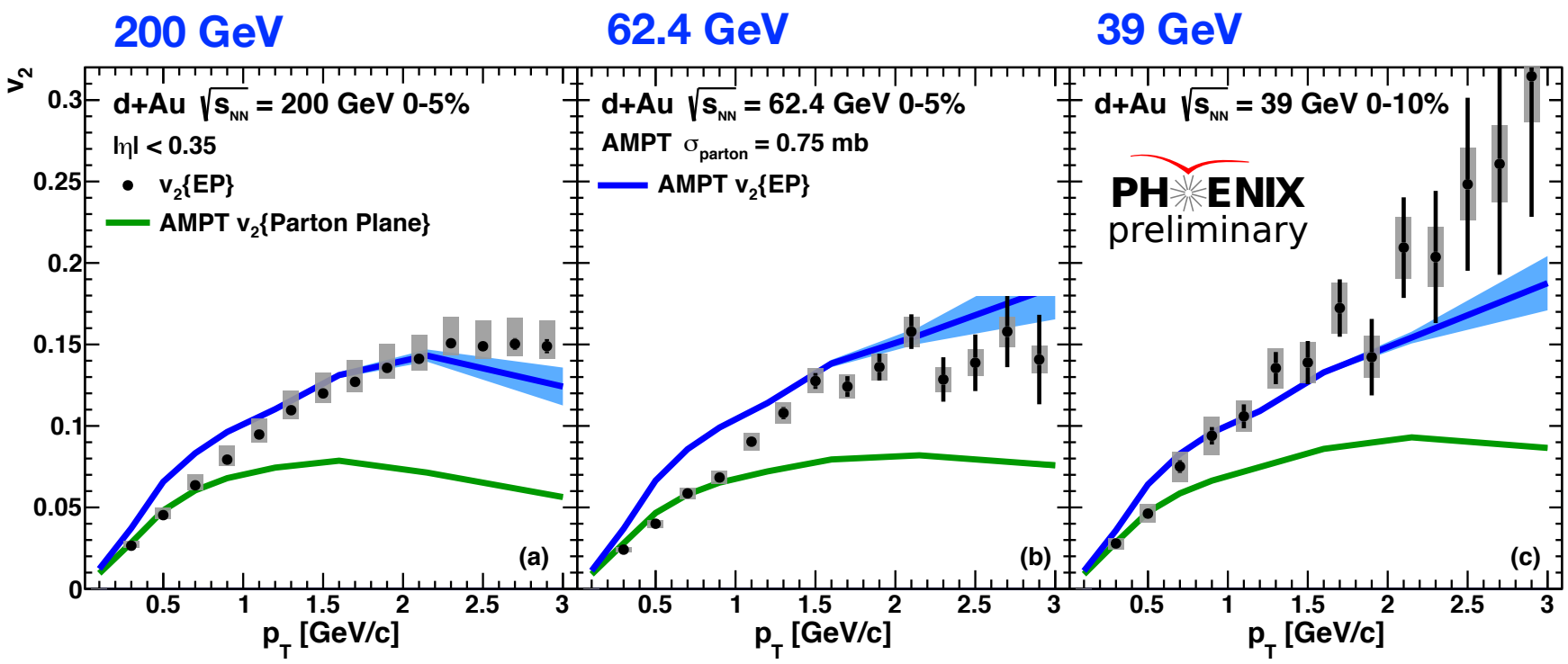
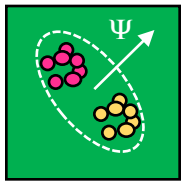
We overestimate the data when adding non-flow, but…

Using AMPT to Understand Non-Flow





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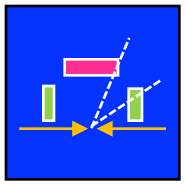

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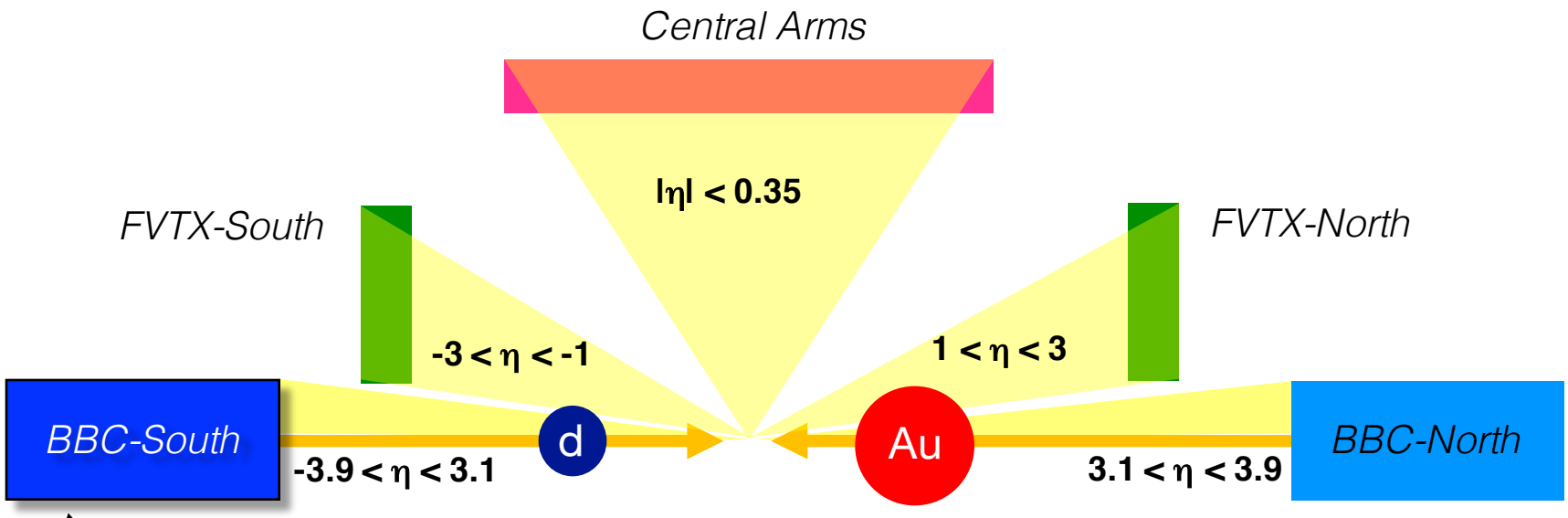
Measuring the Pseudorapidity Dependence of v_2 with PHENIX

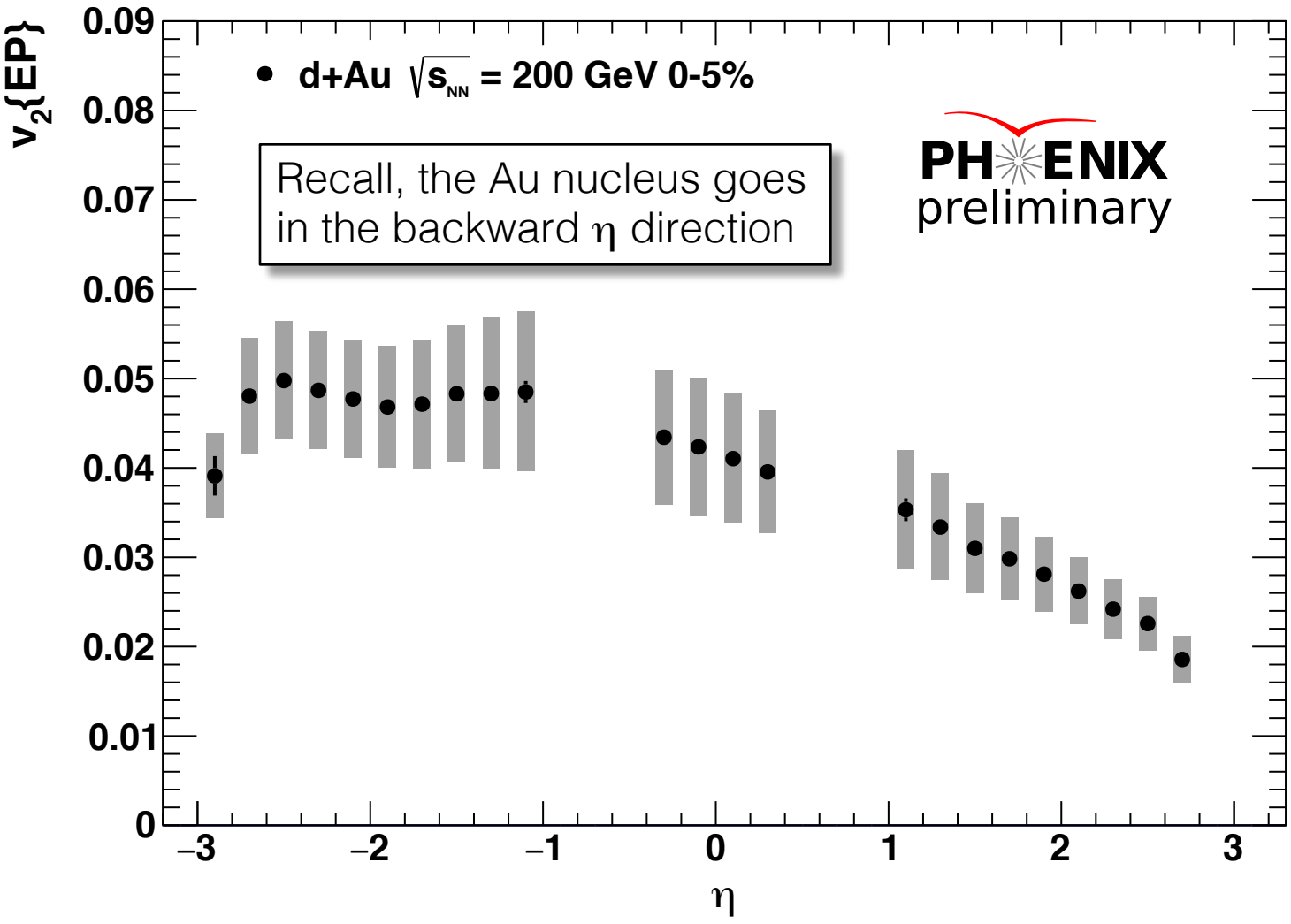


Measure the Event Plane With This Detector

Calculate Resolution With:

- Central Arms
- FVTX-South
- BBC-South

Pseudorapidity Dependence of v_2



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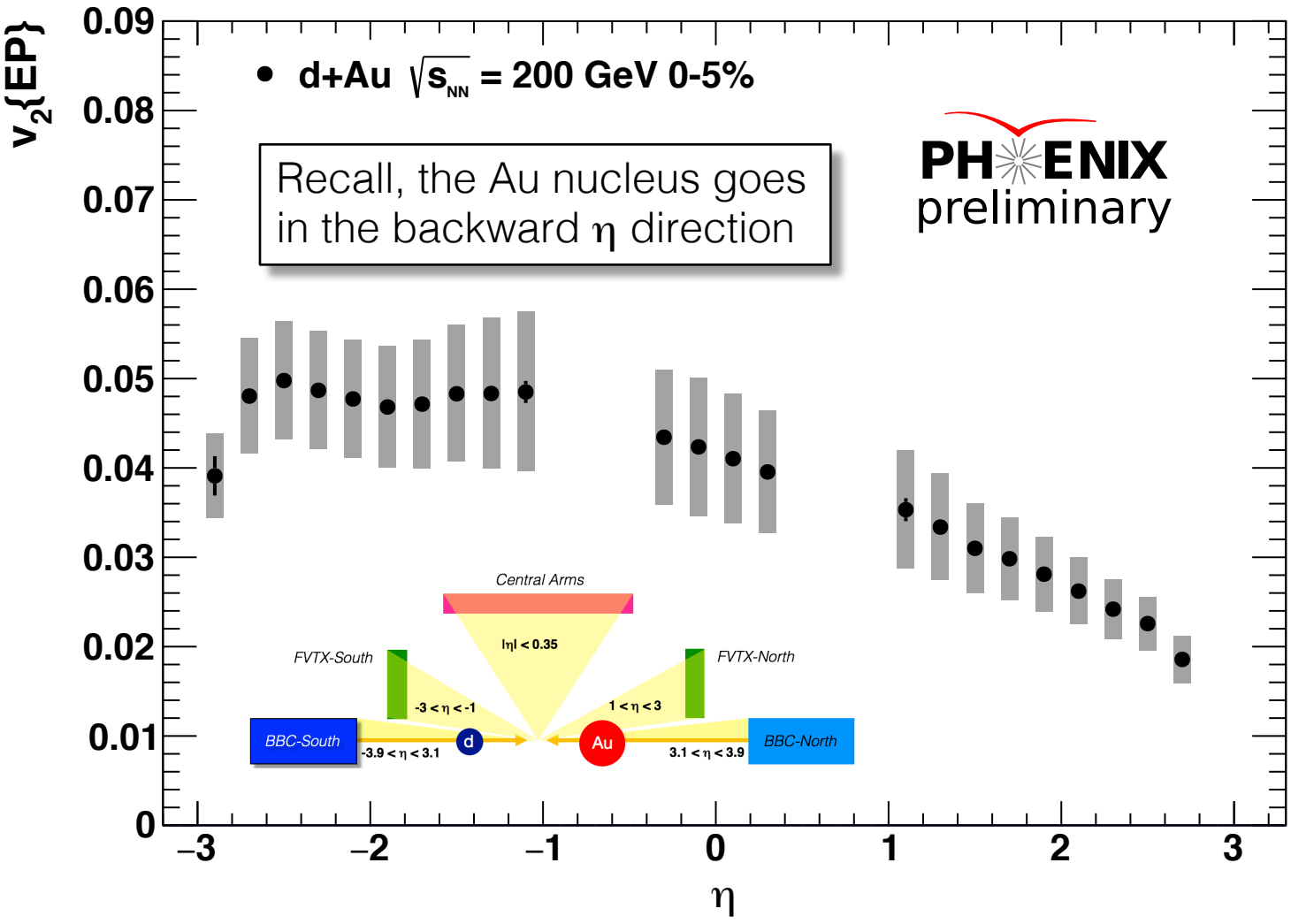

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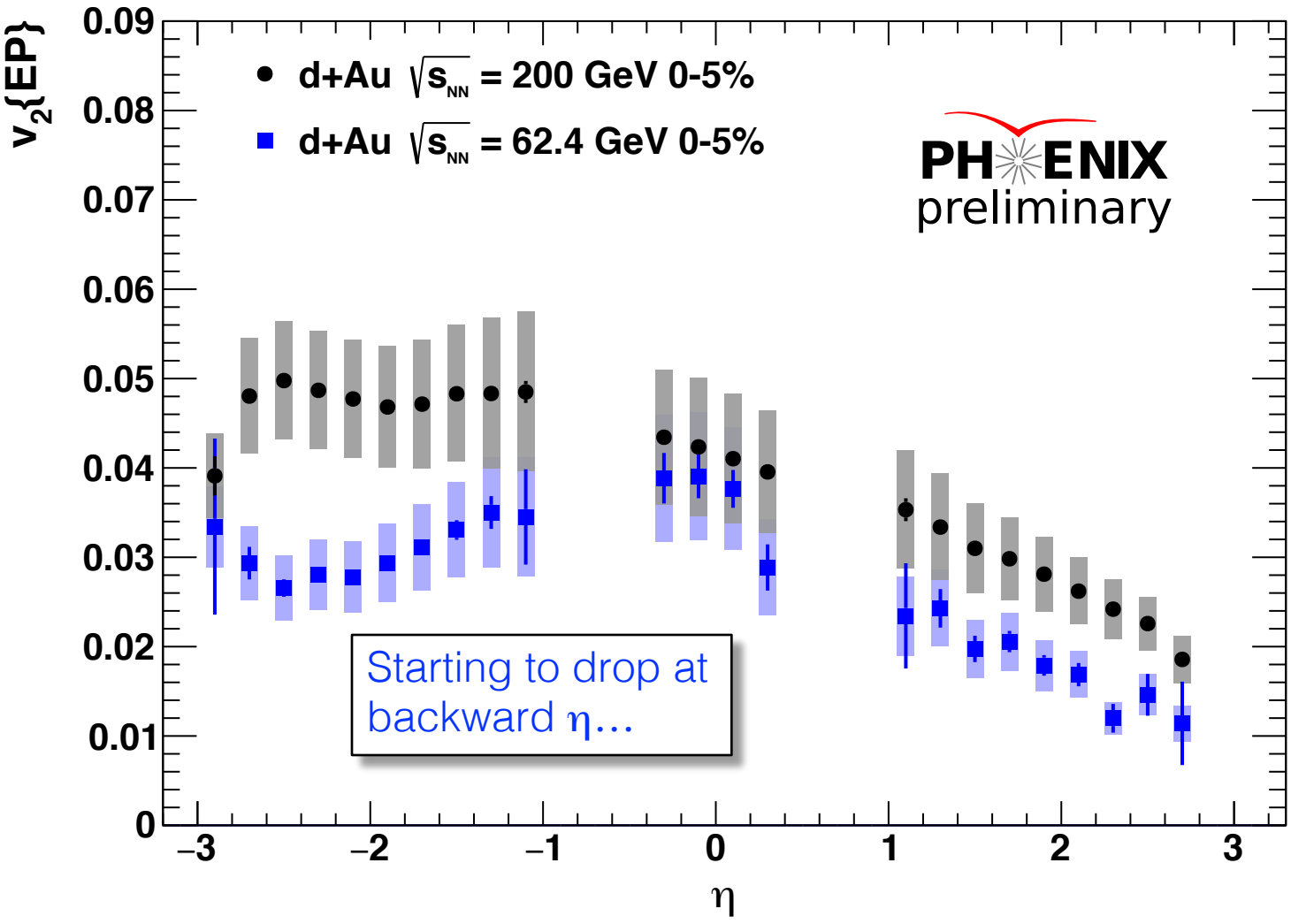

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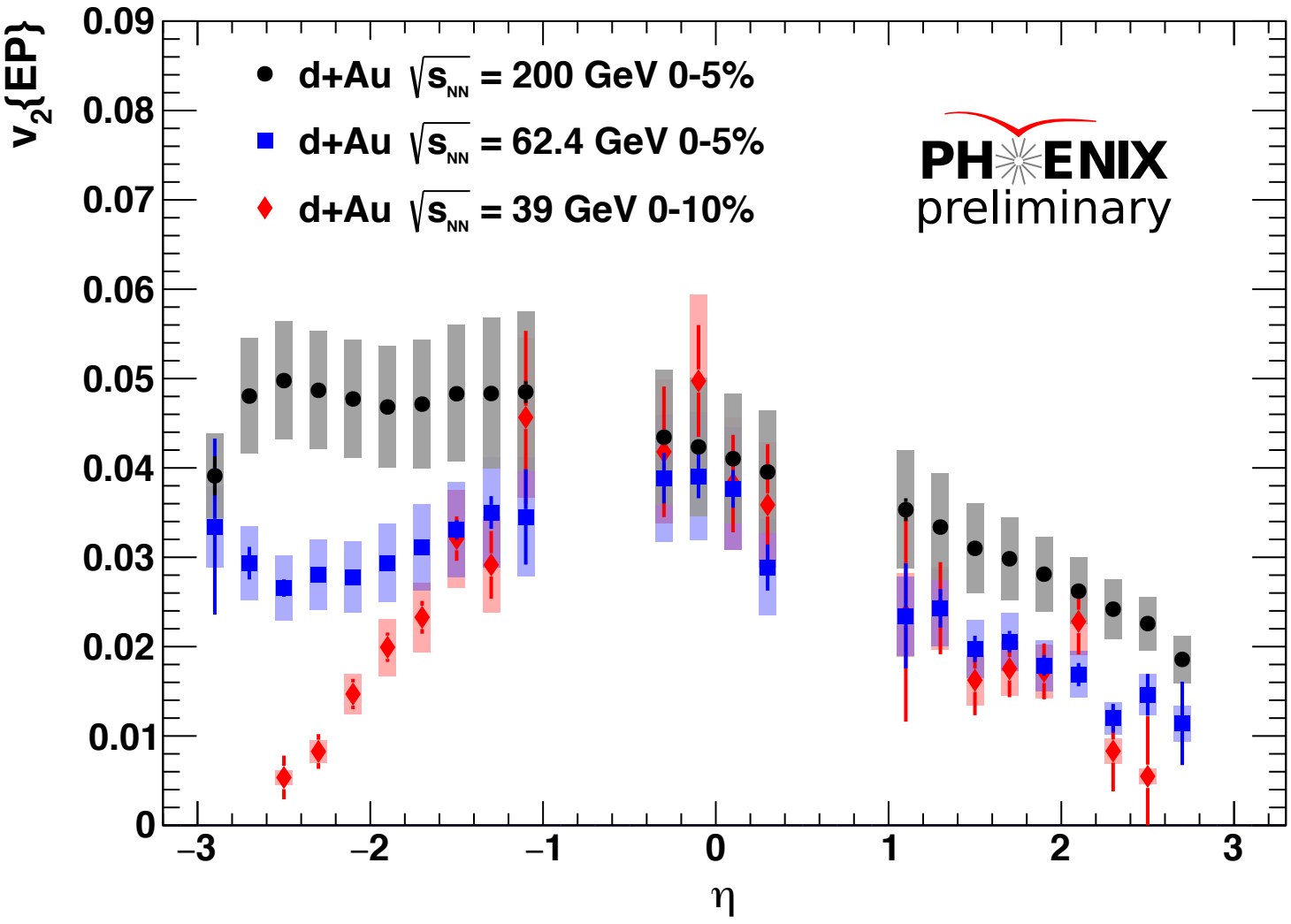

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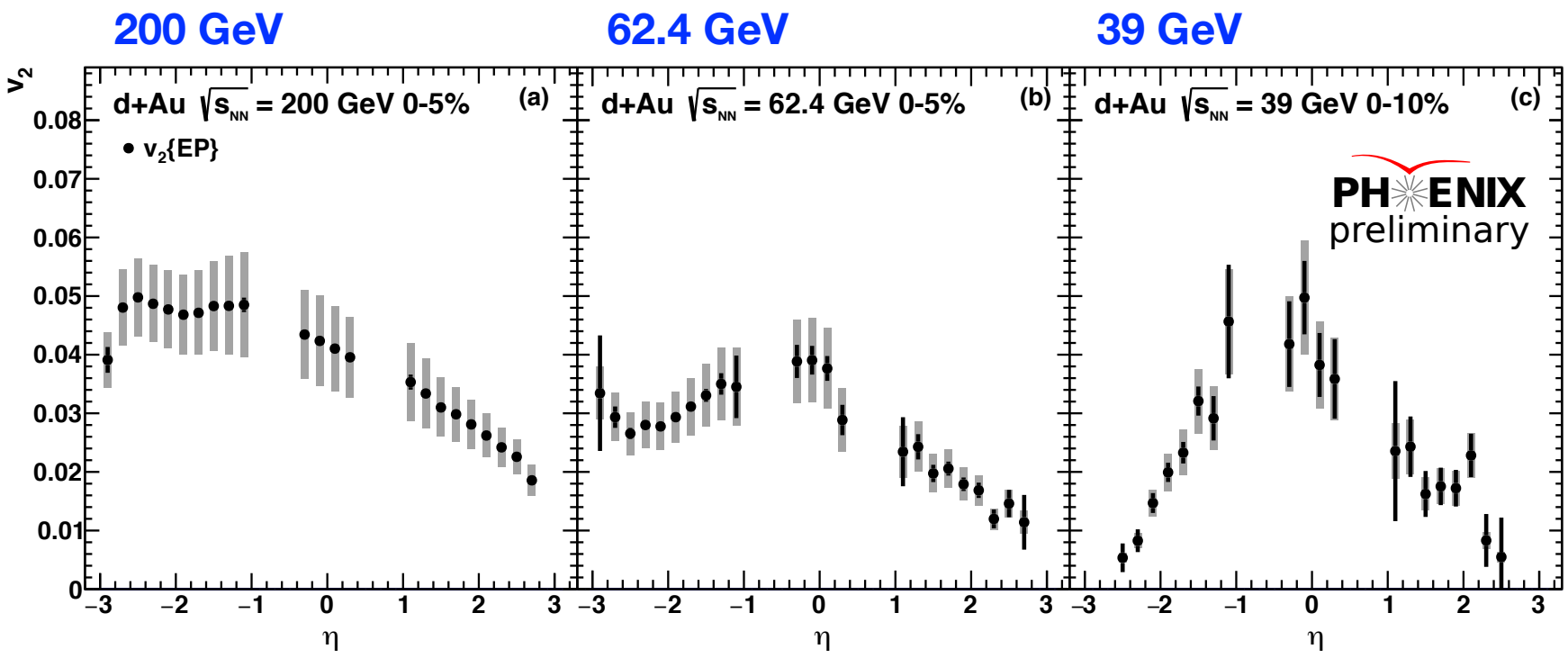

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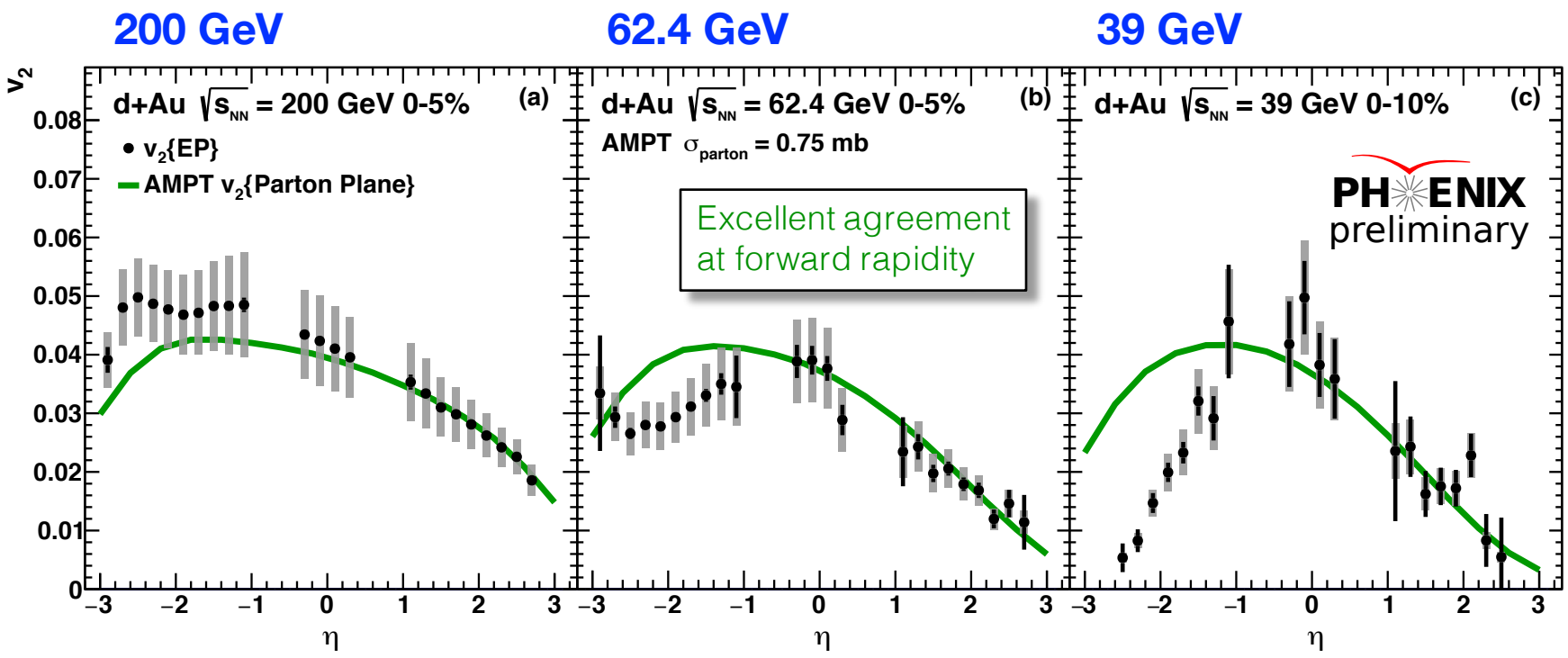
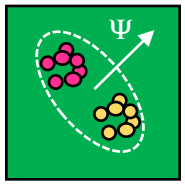
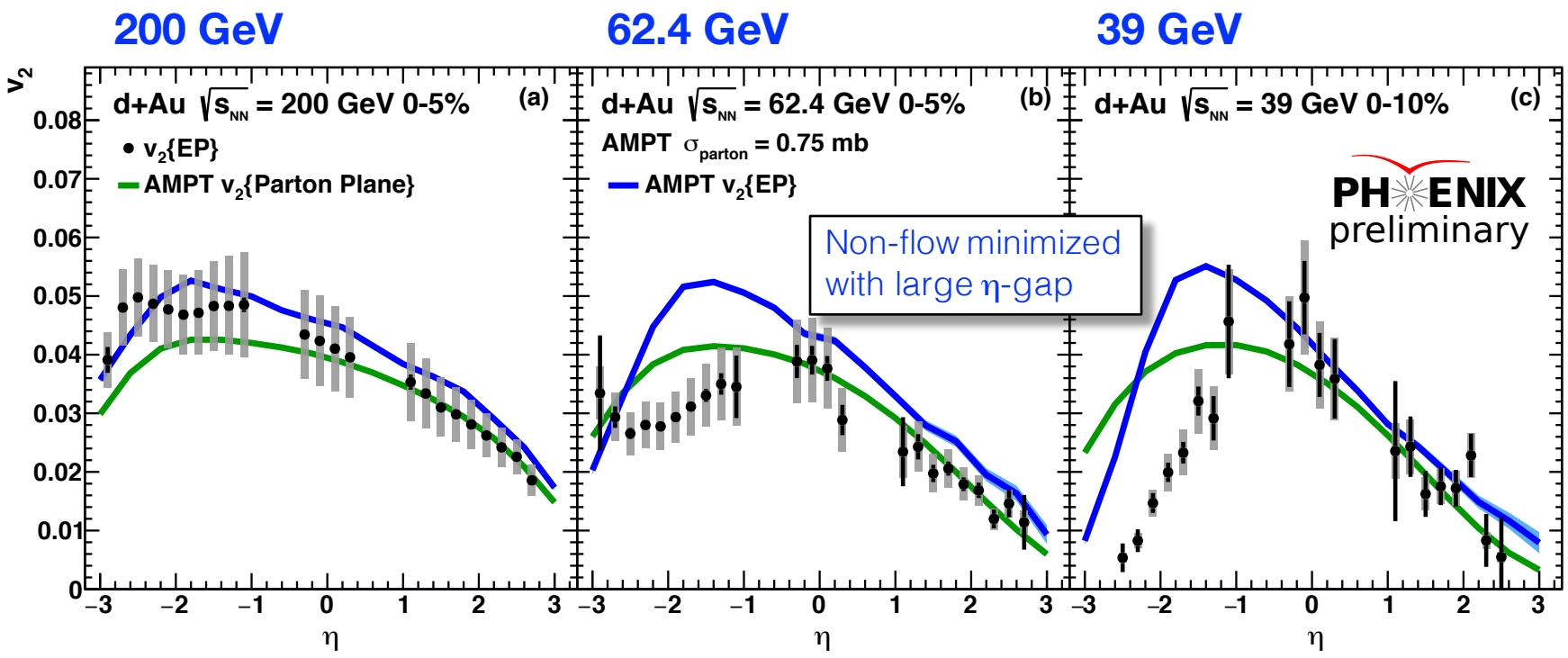
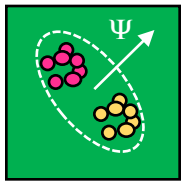




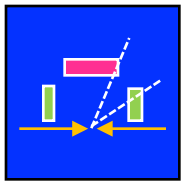
Pure Flow

Pseudorapidity Dependence of v_2



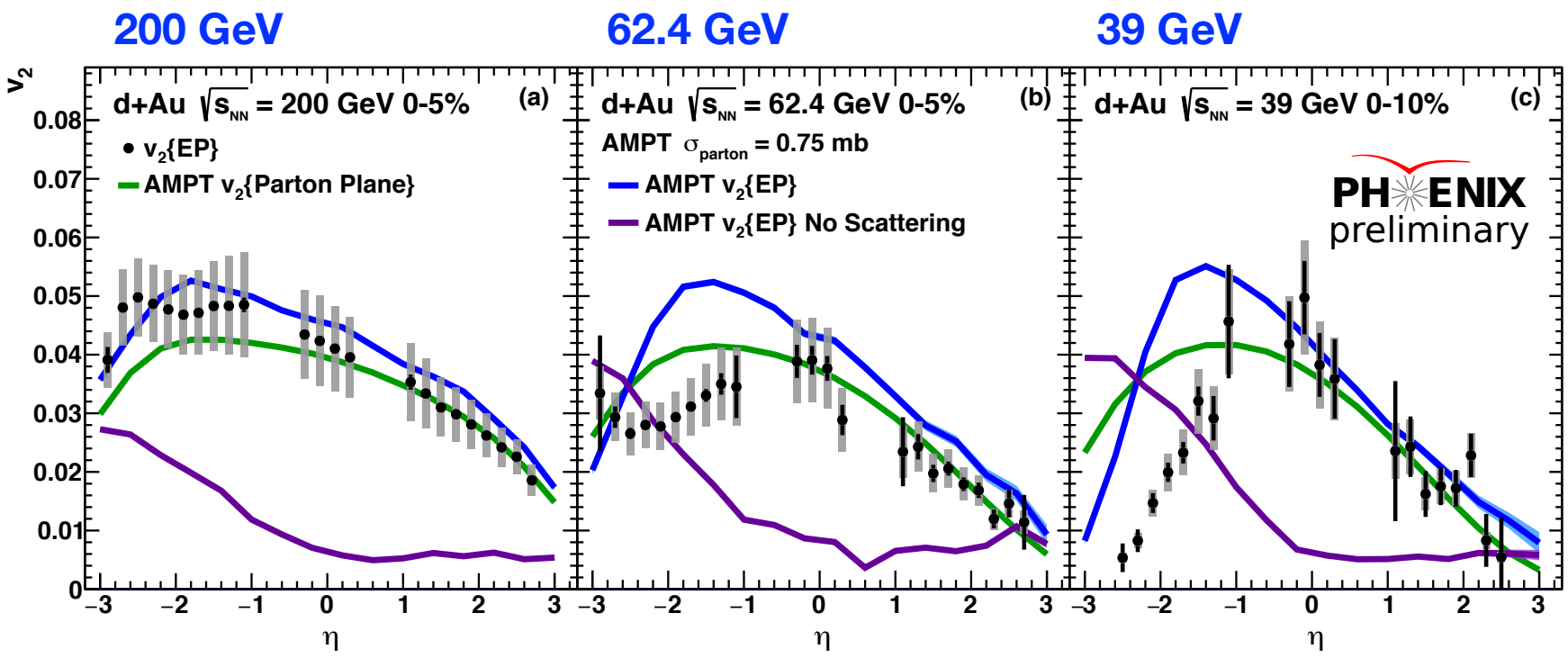


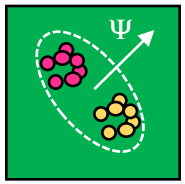
Pure Flow



With Non-Flow

Pseudorapidity Dependence of v_2





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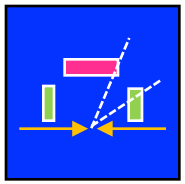
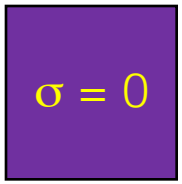
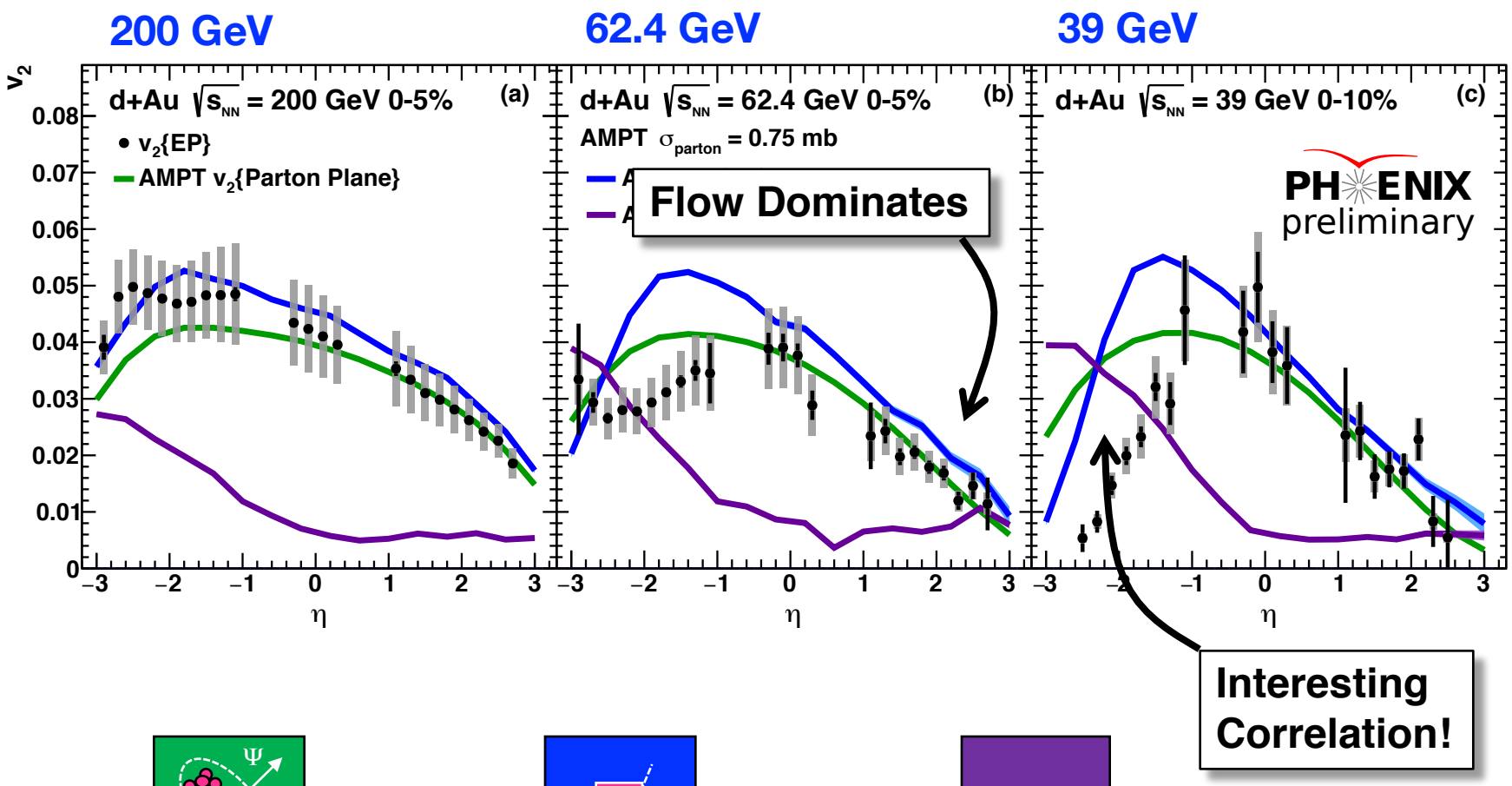


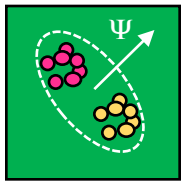
With Non-Flow



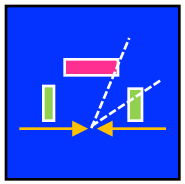
All Non-Flow

Pseudorapidity Dependence of v_2

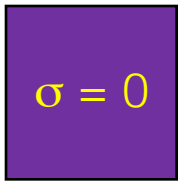




Pure Flow

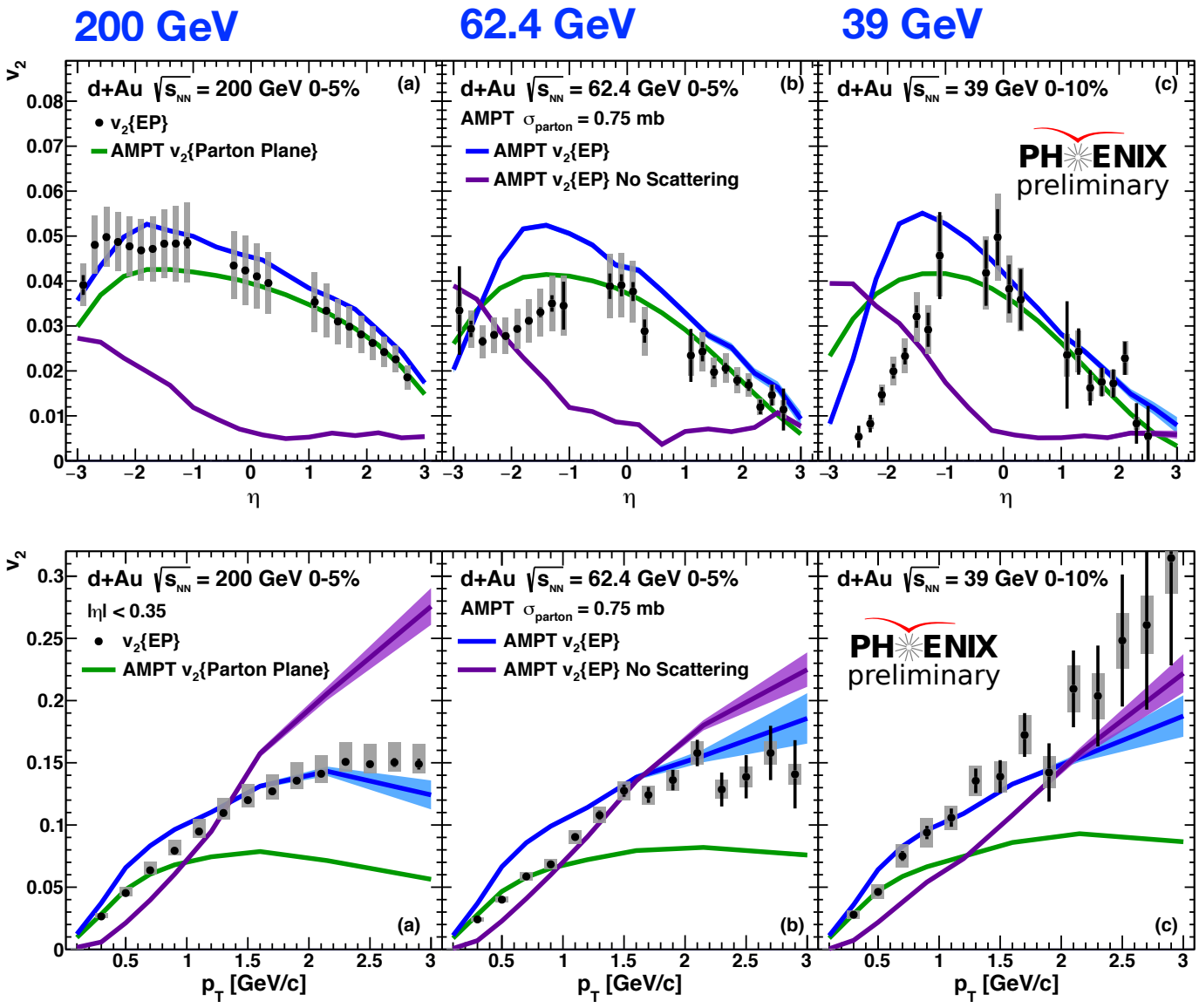


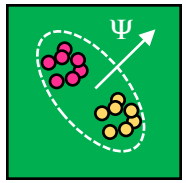
With Non-Flow



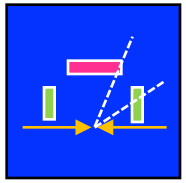
All Non-Flow

Putting it all Together

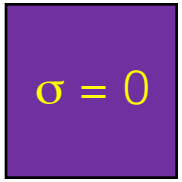




Pure Flow



With Non-Flow



All Non-Flow

Big Take-Home Messages

1. There is clear evidence of collectivity persisting even at low collision energies

2. There is evidence that this collectivity is related to the initial geometry

3. The interplay of flow and non-flow is a window to interesting physics, which must be understood further.

See you all at…

…for more d+Au BES results!

Backup Material

Pseudorapidity Distribution of Charged Particles from AMPT