What do Azimuthal Angular Correlation Measurements tell us about sQGP Production at RHIC?

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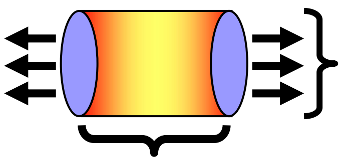
for the PHENIX collaboration

NUCLEAR CHEMISTRY
@ STONY BROOK

High Energy density matter created at RHIC!

Extrapolation From E_T Distributions

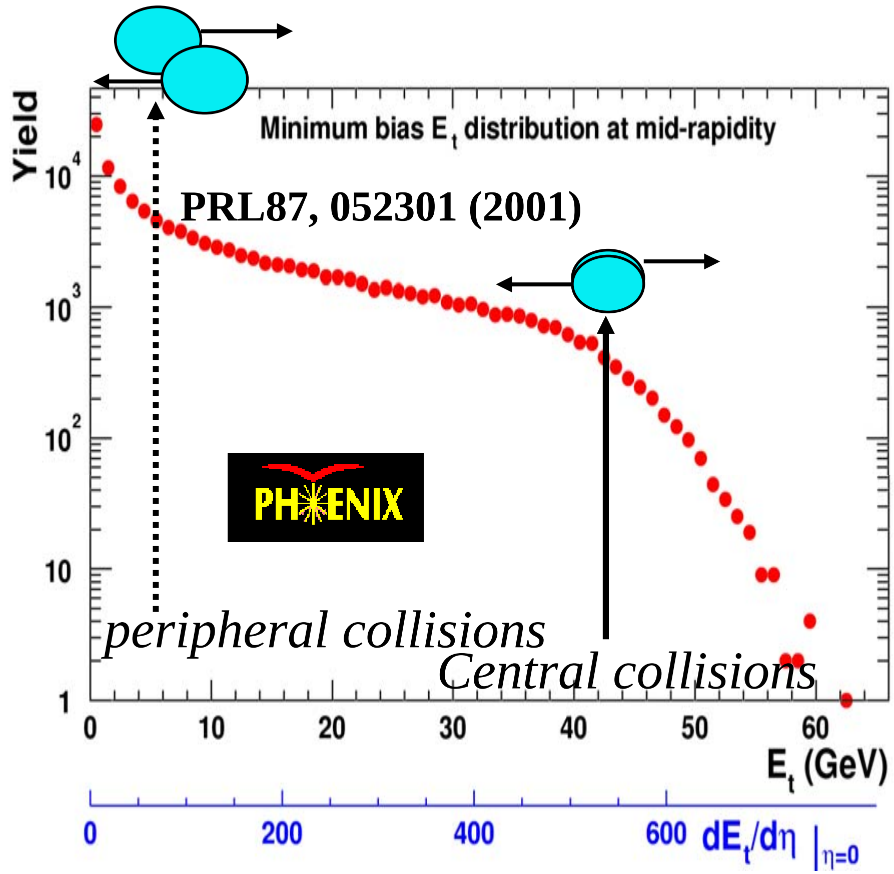


$$\varepsilon_{Bj} = \frac{1}{\pi R^2} \frac{1}{\tau_0} \frac{dE_T}{dy}$$

time to thermalize the system ($\tau_0 \sim 0.2 - 1$ fm/c)

$\varepsilon_{Bjorken} \sim 5 - 15\ GeV/fm^3$

$\sim 35 - 100\ \varepsilon_0$



Phase Transition:

$T \approx 170 MeV$

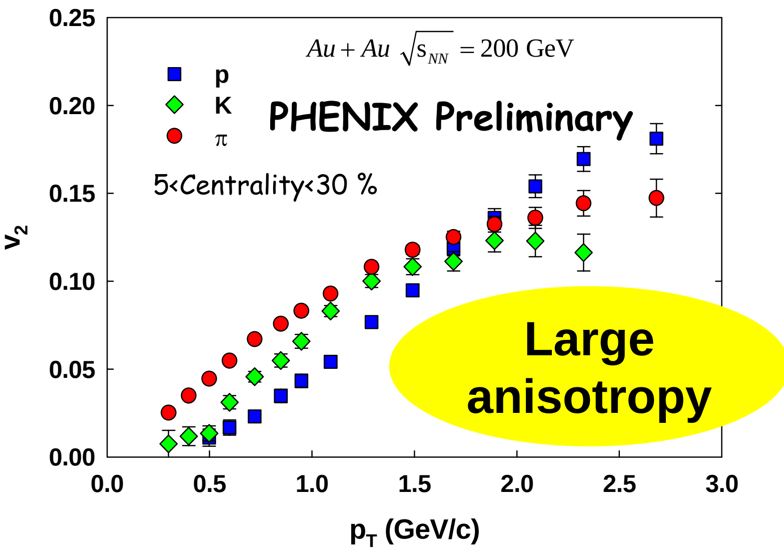
$\varepsilon \approx 1 GeV/fm^3$

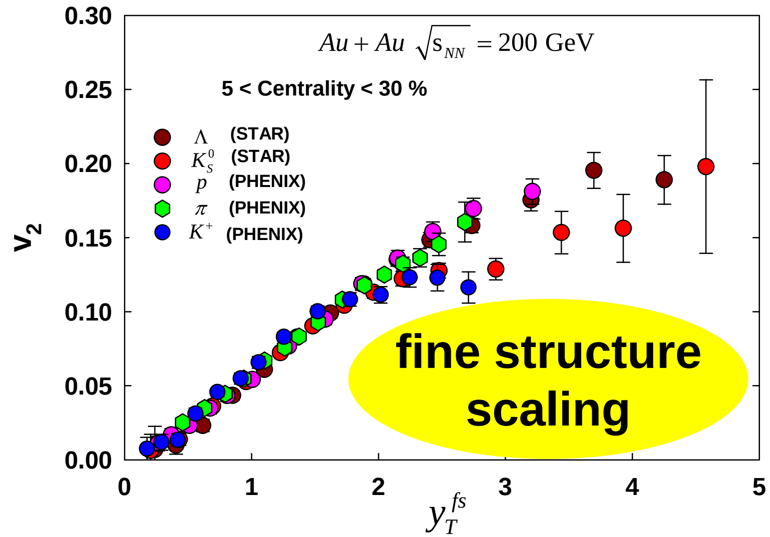
The Energy Density is Well Above the Predicted Value for the Phase Transition !

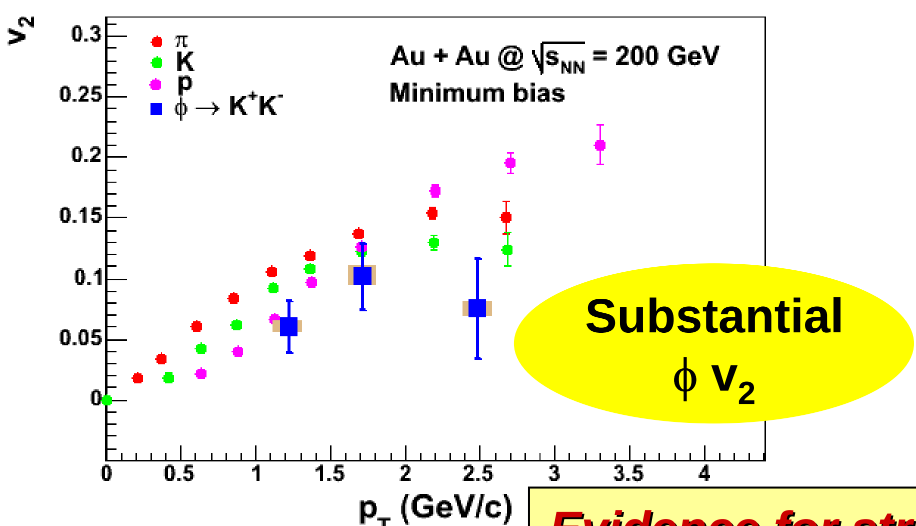
$$\left(P = \rho^2 \cdot \left(\partial\varepsilon / \partial\rho \right) \Big|_{s/\rho} \right)$$

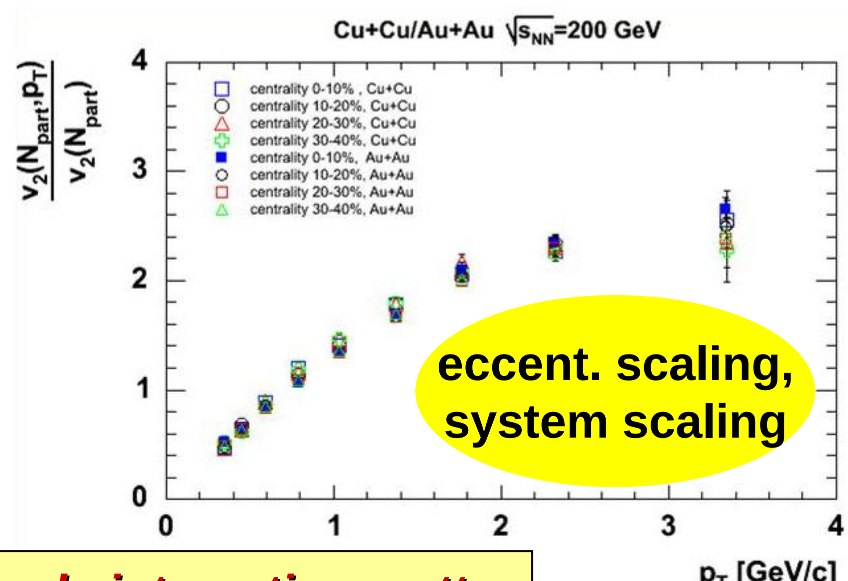
Pressure ⟶ Flow

The Matter is strongly interacting!







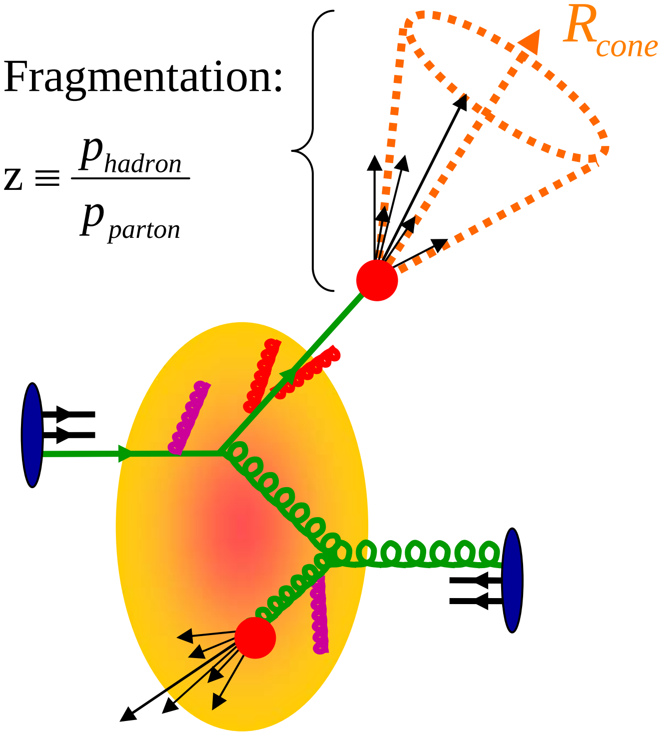


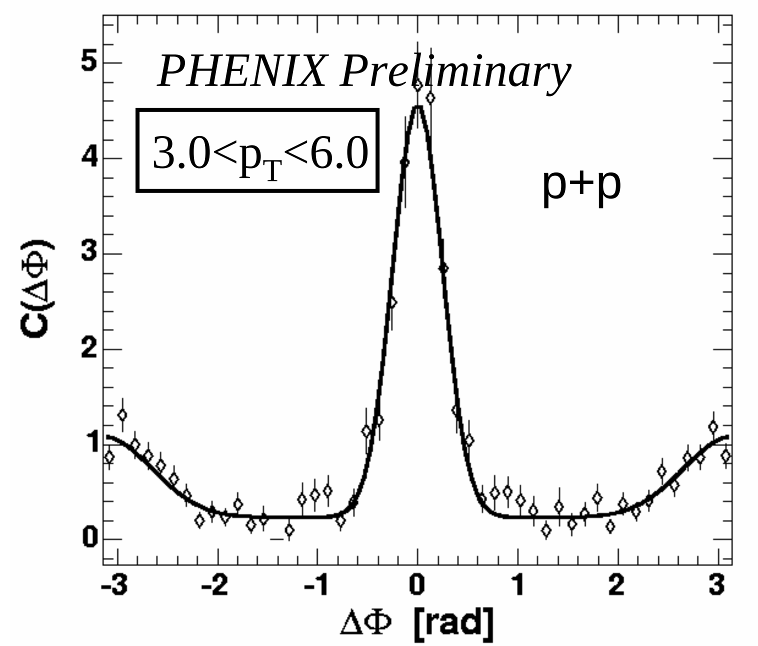
Evidence for strongly interacting matter at RHIC is compelling

Tomographic Probe of the medium: Jets

Fragmentation:

$$z \equiv \frac{p_{hadron}}{p_{parton}}$$

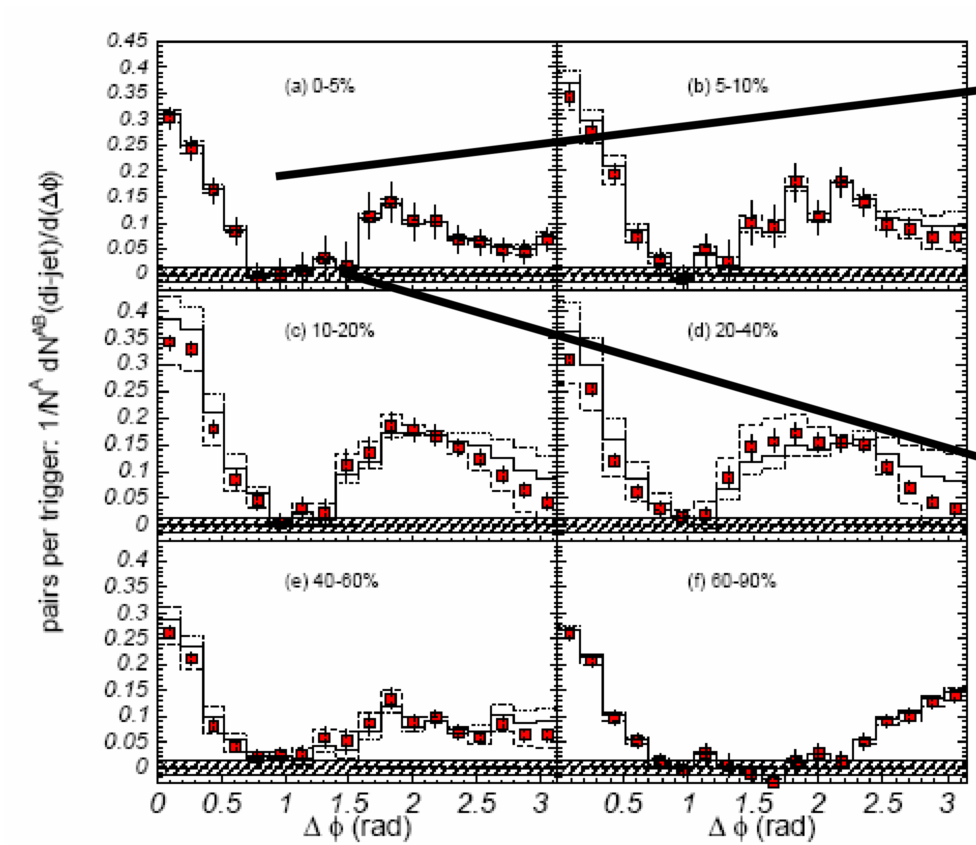




Jets are Remarkable Probes for this High-density Matter

- ***Auto-Generated on the right time-scale***
- ***Calibrated***
- ***Calculable (pQCD)***
- ***Accessible statistically via correlations in Au+Au***

Reminder: (Di)Jet correlations strongly modified in Au+Au



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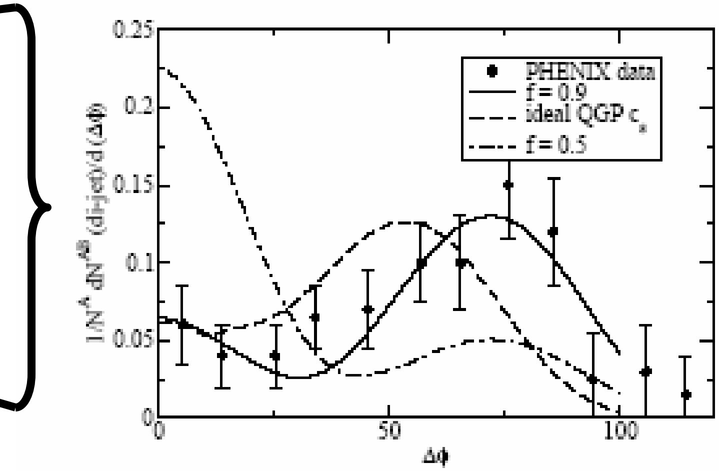


T. Renk, J. Ruppert
hep-ph/0509036

Away-side peak consistent with mach-cone scenario
Not the only explanation:

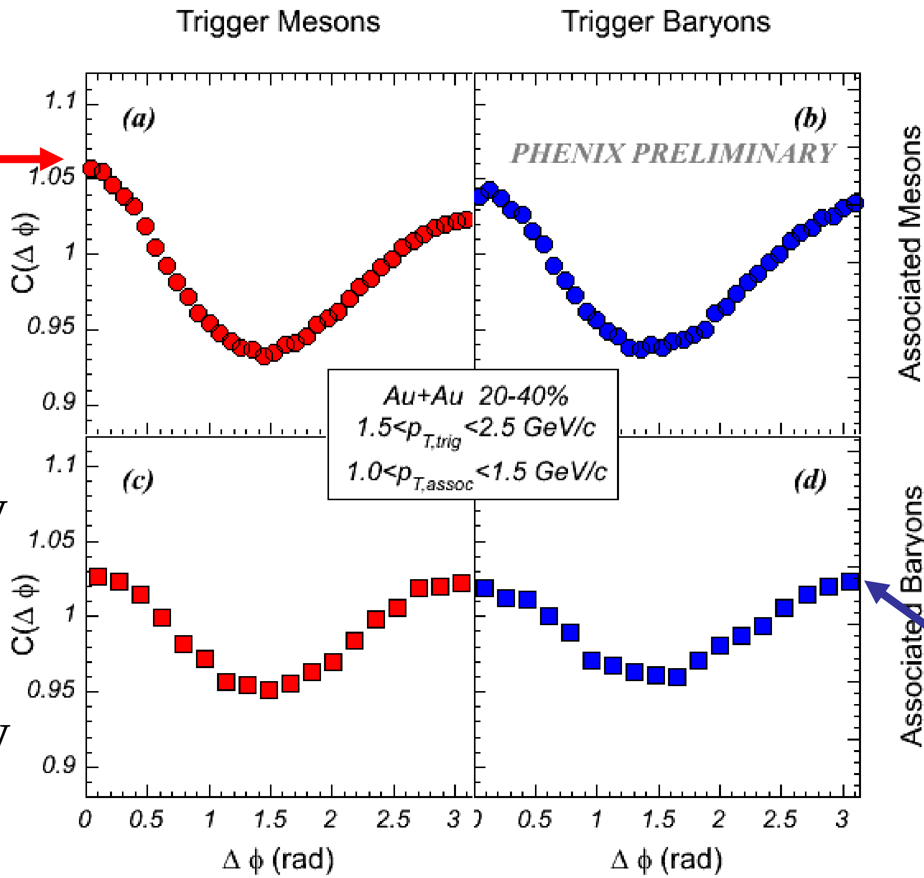
Strong centrality dependent modification of away-side jet in Au+Au

Cherenkov gluon radiation: nucl-th/0507063
Koch, Majumder, X.-N. Wang

Issues: mechanistic details of quenching?
flavor dependence?
mach cones?
system size?, etc…

Jets and Flow couple: hep-ph/0411341
Armesto,Salgado,Wiedemann

Flavor dependent correlations



Flow → anisotropy

Jet → asymmetry

Strongly flavor dependent Asymmetries and Anisotropies observed in Two-Particle Correlations

Decomposition of flow and jet signals

Subtraction *Phys. Rev. C 72, 011902 (2005)* **Extinction**

Two source model : Flow (H) & Jet (J)

$$\overbrace{C(\Delta\phi)}^{Correlation\ Function} = a_0 \left[\overbrace{H(\Delta\phi)}^{Harmonic} + \overbrace{J(\Delta\phi)}^{Jet\ Function} \right]$$

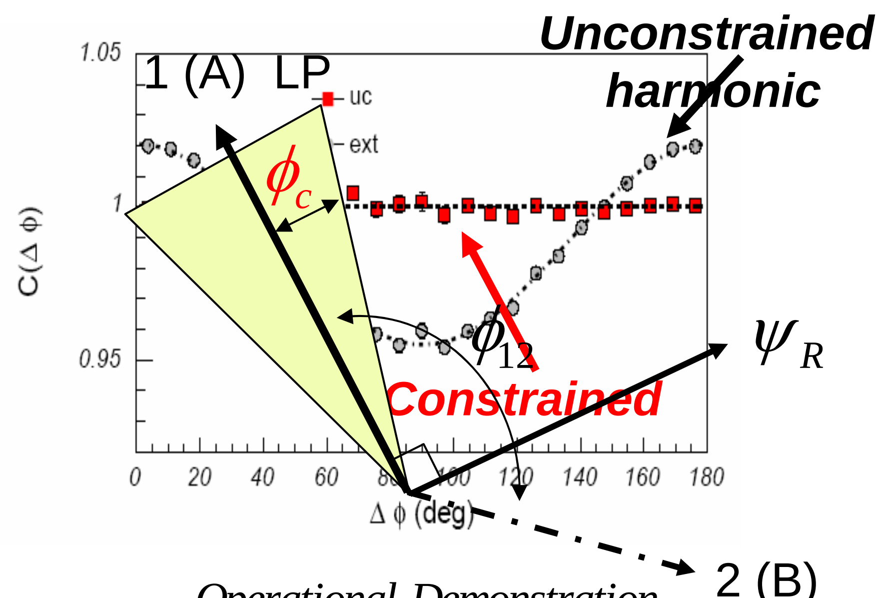
$$\overbrace{J(\Delta\phi)}^{Jet\ Function} = \frac{[C(\Delta\phi) - a_0 H(\Delta\phi)]}{a_0}$$

a_0 is obtained without putting any constraint on the Jet shape by requiring

$$J(\Delta\phi_{min}) = 0$$

i.e. Zero Yield At Minimum (ZYAM)

High pt particle constrained perpendicular to RP



Operational Demonstration

vary $\Delta\phi_c$ Constraint byte

untill $v_2^{out} \sim 0$

Reliable decomposition of flow and jet signal via two separate methods!

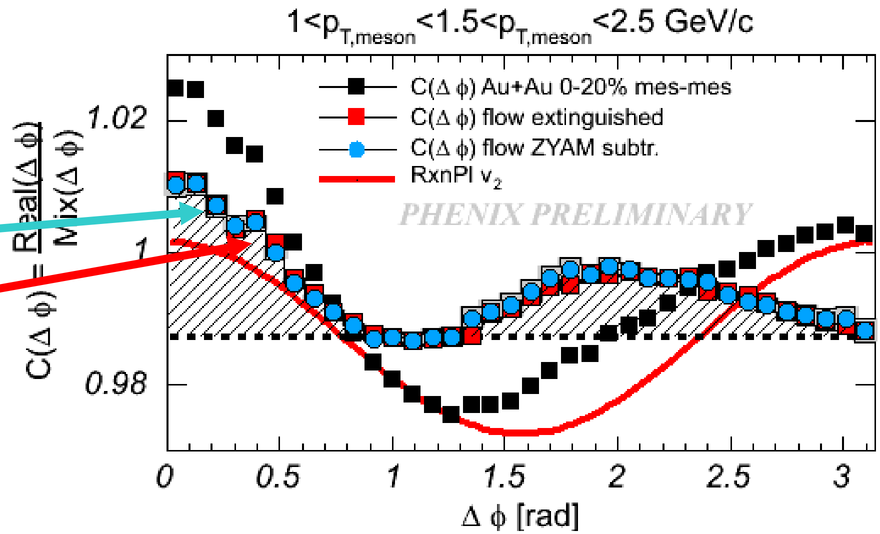
Decomposition of PHENIX correlation function

Meson-Meson

ZYAM subtracted J(Δϕ)

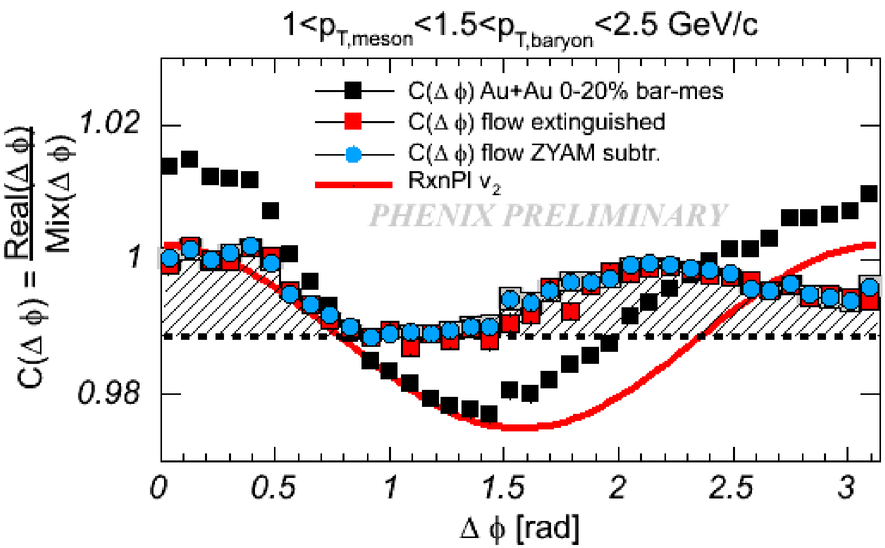
Flow extinguished C(Δϕ) = J(Δϕ)

Both methods agree!

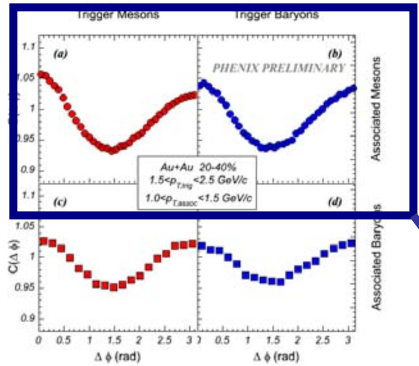


Baryon-Meson

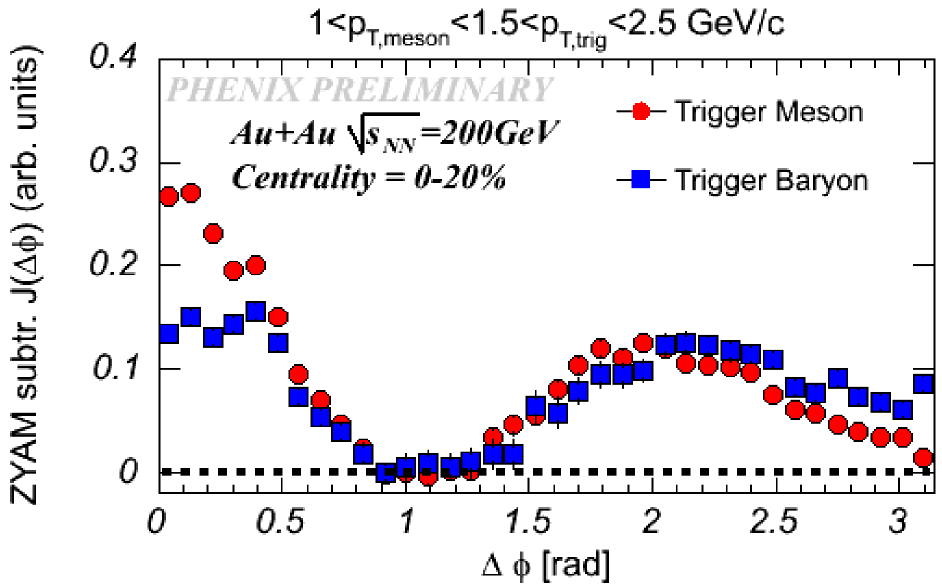
Meson-triggered and Baryon-triggered J(Δϕ) are different on near- and away-side!



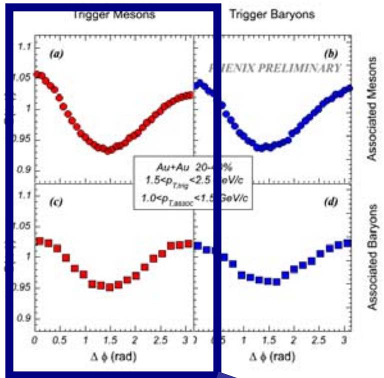
Flavor dependent away-side modification



Meson vs.
Baryon trigger
(for fixed *Meson* partner)

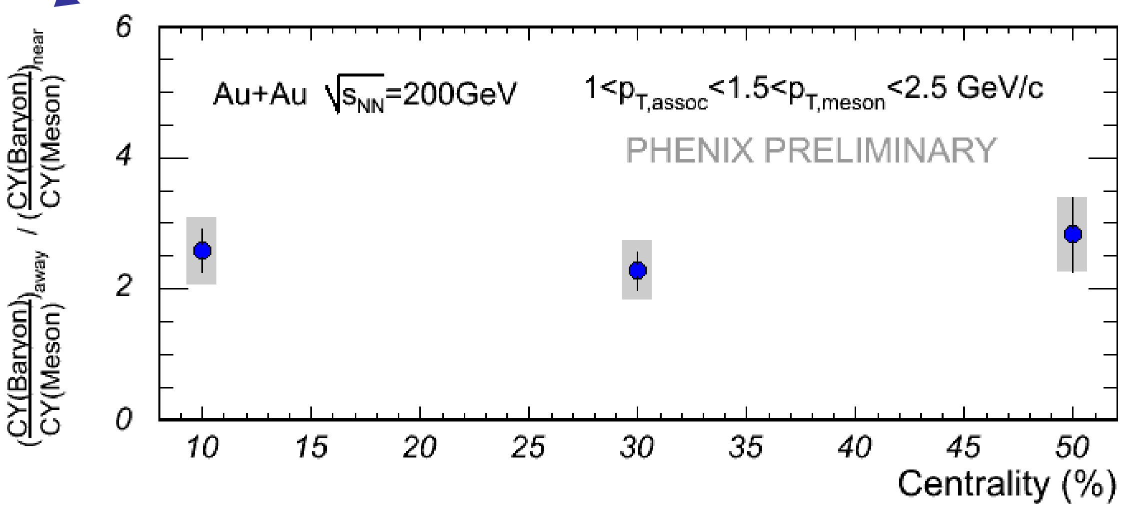


Distribution of partner mesons per trigger-particle depends on trigger particle species in this p_T range



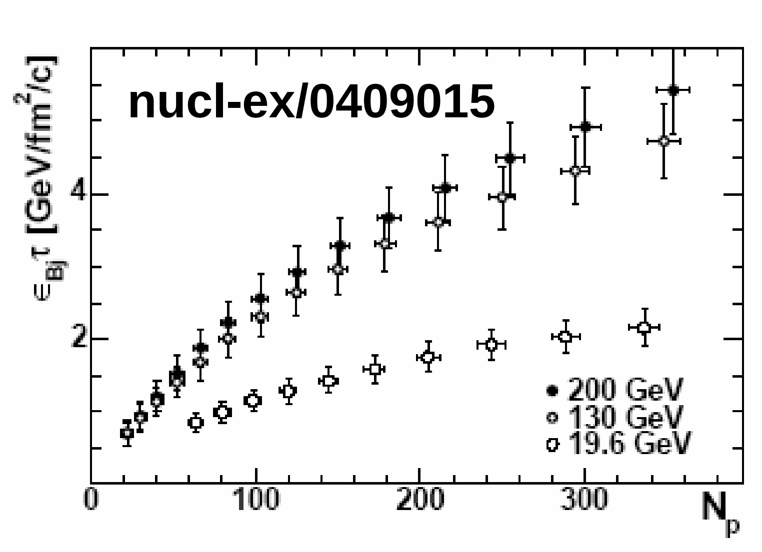
Flavor dependent away-side modification

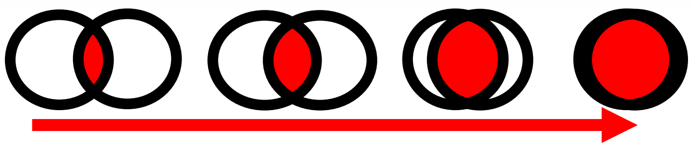
Meson vs. Baryon partner (for fixed Meson trigger)



Away-side partner baryon to meson ratio ~2.5 times larger than near-side partner baryon to meson ratio for meson triggered correlations

Mechanistic Details of Jet Quenching

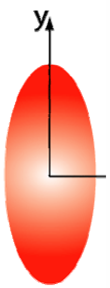


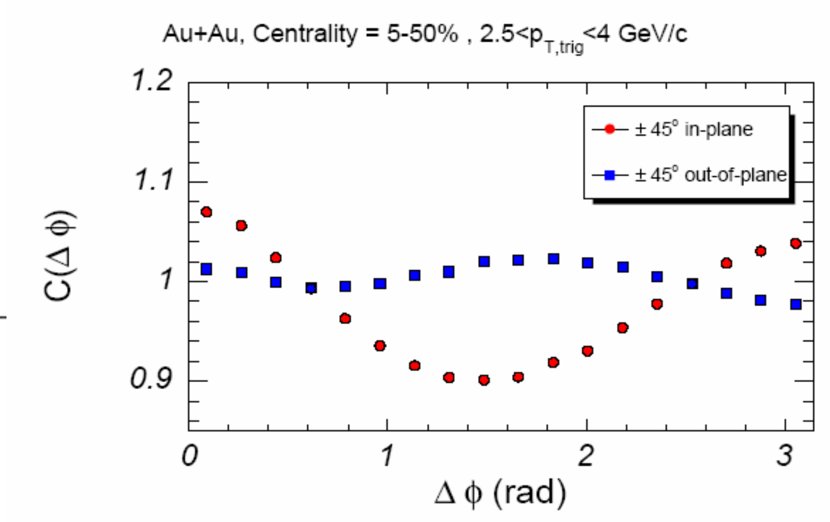


What are the relative influences of:
Energy-density
Path-length (L, L^2, L^α)

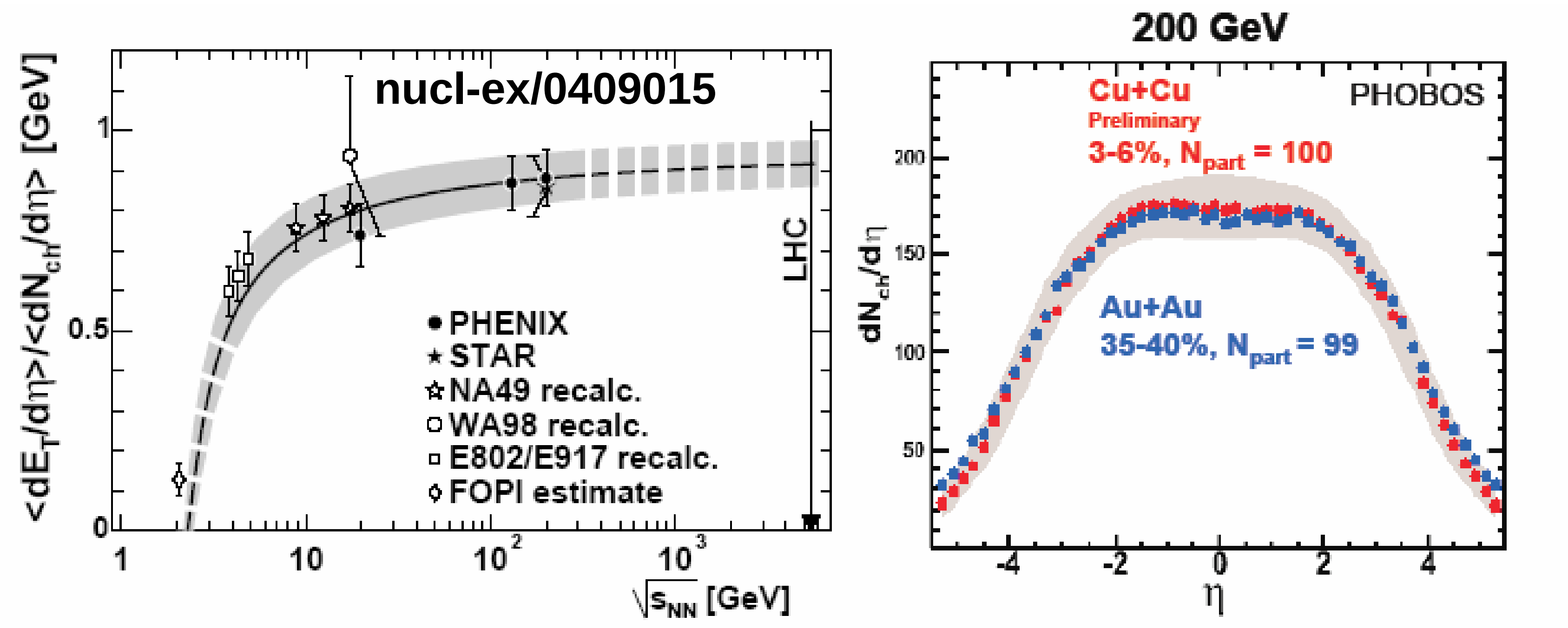
Need to look at problem in several different ways to pin down mechanistic details!

One approach:
fix ε via N_{part},
vary path length by looking in and out of reaction plane





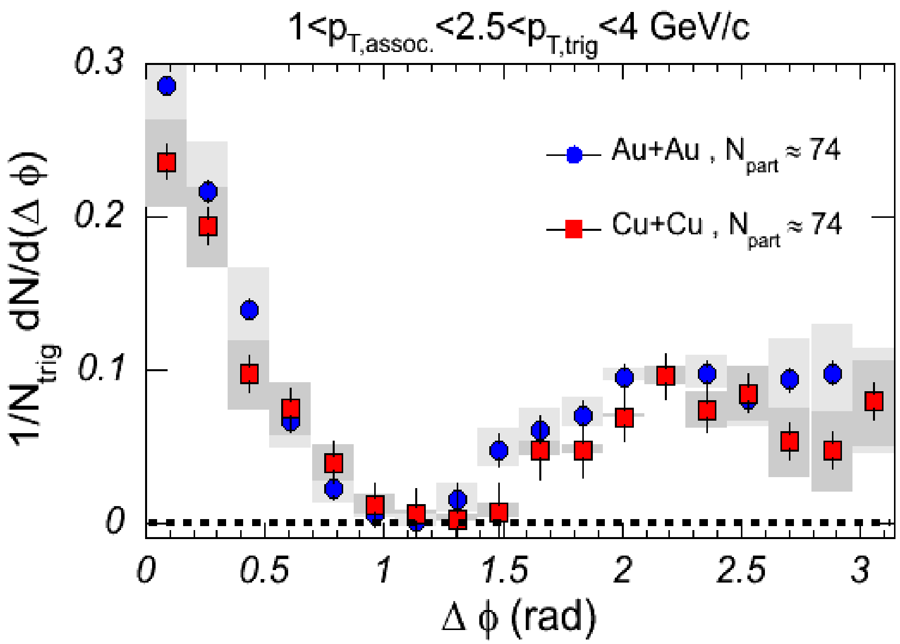
Complimentary Approach: Varying System Size



$dN_{ch}/d\eta$ very similar for Au+Au and Cu+Cu at the same N_{part} !
At RHIC almost all transverse energy goes into particle production

Complementary opportunity for jet-tomography:
-> fix energy density
-> vary path length

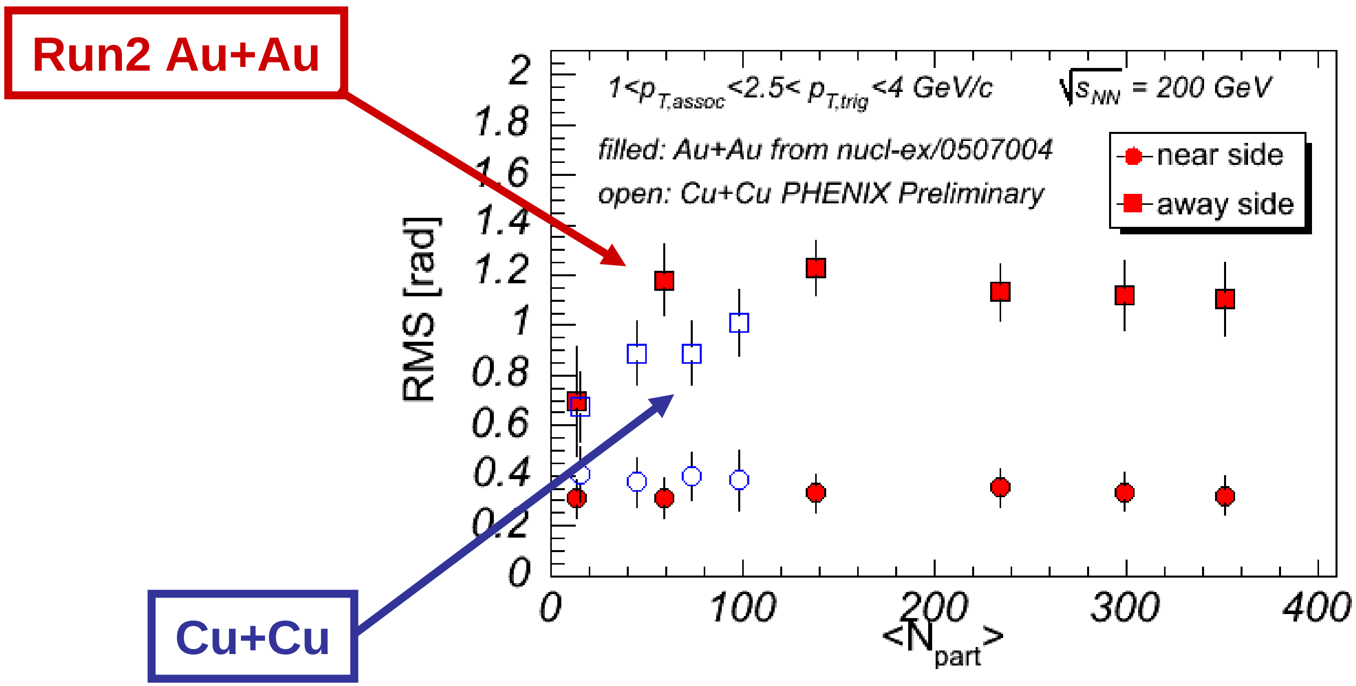
System Size Dependence of Jet Quenching



Broadening of away-side jet observed in central/semicentral Cu+Cu collisions

No striking differences for jet functions in Cu+Cu and Au+Au at same N_{part}

System Size Dependence of Jet Quenching



Away-side jets significantly broadened in Au+Au, Cu+Cu
Unclear if identical for both systems
N_{part} dependent evolution of away-side broadening

Summary and Outlook

❖ ***Flow measurements give compelling evidence of strongly interacting low viscosity fluid with quark degrees of freedom***

❖ ***Robust decomposition techniques allow detailed study of jets***

Extracted jet functions indicate:

- ***Strong away-side jet modification in h-h correlations***
- ***Flavor dependence of modification***

❖ ***Jet modification/quenching show dependence on:***

- ***centrality, eccentricity and system size***
- ***for same N_{part} Au+Au and Cu+Cu show similar jet functions (similar energy density, path length not too different)***

❖ ***Smooth N_{part} evolution of near and away side jet width***

❖ ***Combination of observations crucial for elucidating mechanistic origin of jet quenching***

… much more to come!

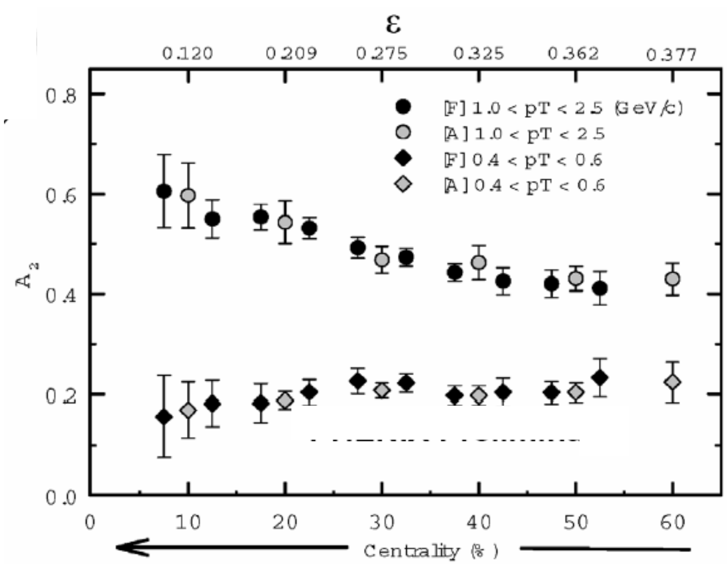
Backup Slides

Probing the hydrodynamic origin of v2 via scaling relations

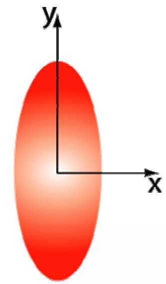
Hydro Limit

$$\frac{v_2}{\varepsilon} \propto \frac{p_T < u_T >}{T} - 1 \qquad p_T u_T >> T$$

$$\frac{v_2}{\varepsilon} \propto \frac{p_T^2 < u_T^2 >}{T^2} \qquad p_T u_T << T$$



Scaling Tests



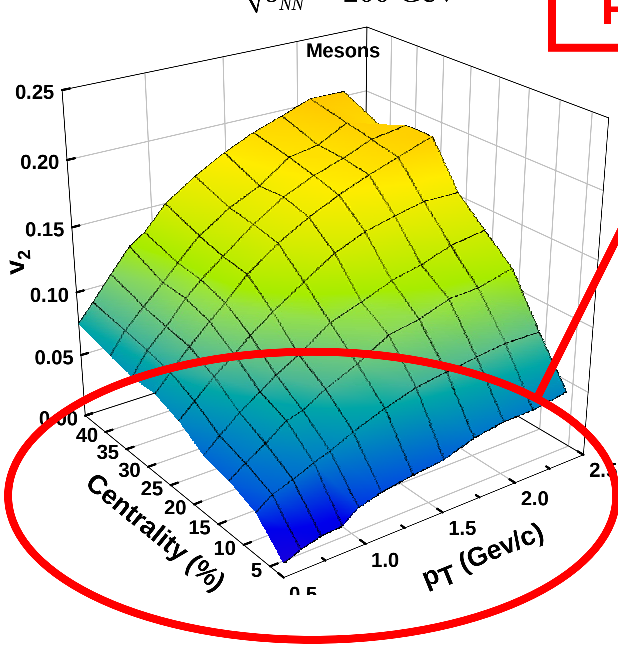
$$A_2 = \frac{v_2}{\varepsilon}$$

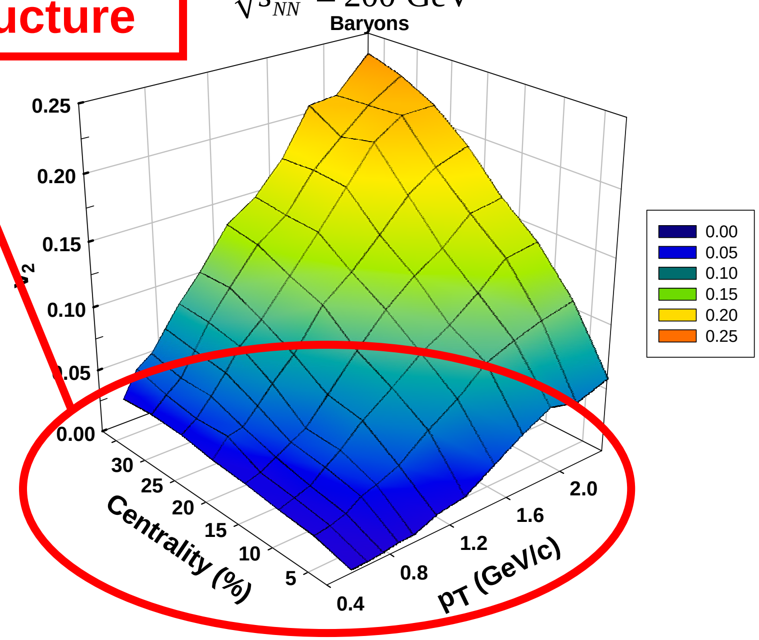
$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

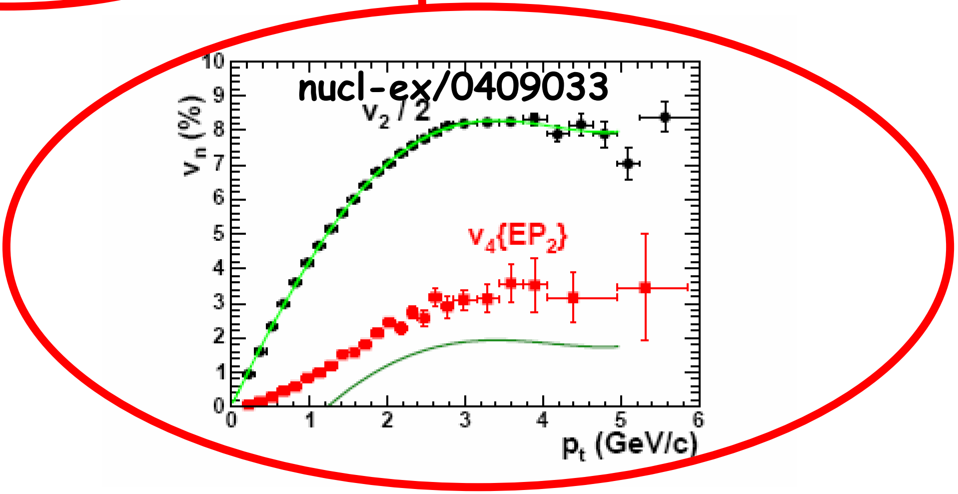
→ v2 scales with initial geometry

A novel type of scaling: Fine Structure Scaling

Fine structure

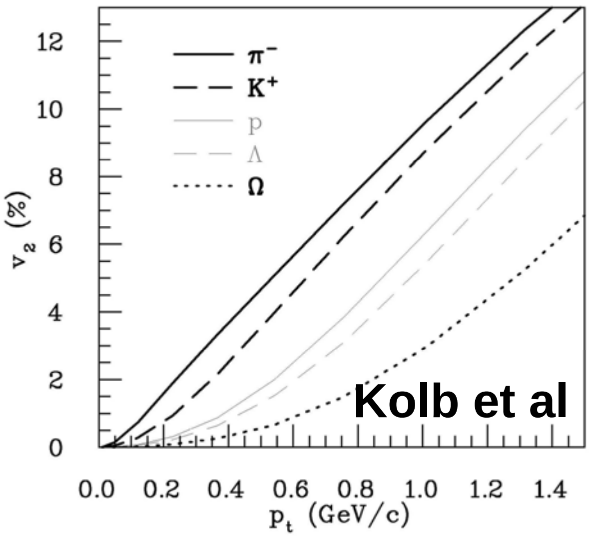




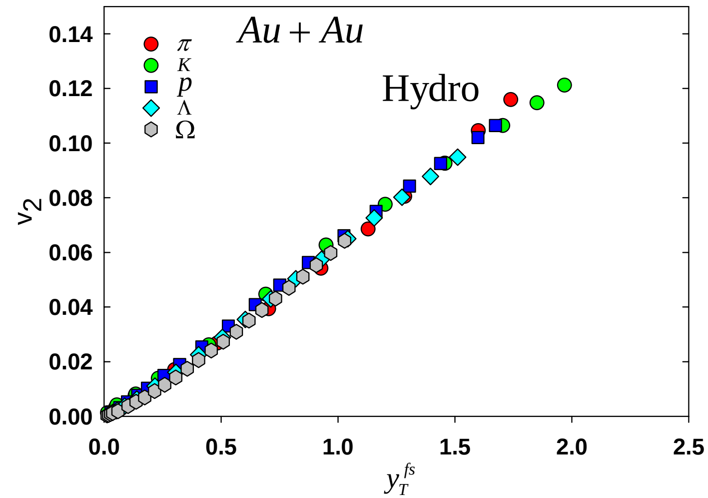


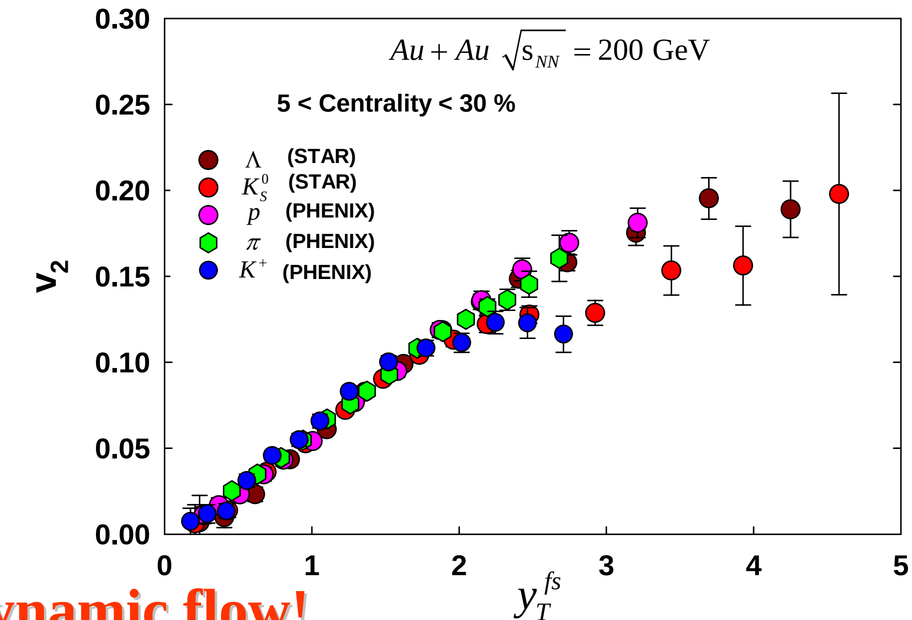
Look for scaling in the whole wealth of available v2 data!

Fine structure scaling at RHIC?



Scaling hydro





$$p_T \rightarrow y_T = \sinh^{-1}(p_T / m)$$

Buda Lund Hydro Model:

$$v_2 \sim \frac{k_1}{T_0} \times y_T^2 m \left(1 + \frac{k_2}{k_1}\frac{T_0}{m} + \frac{k_3}{k_1}\left(\frac{T_0}{m}\right)^2 + ..\right)$$

$$y_T^{fs} \equiv k_m \times y_T^2 m$$

Compelling evidence for hydrodynamic flow!

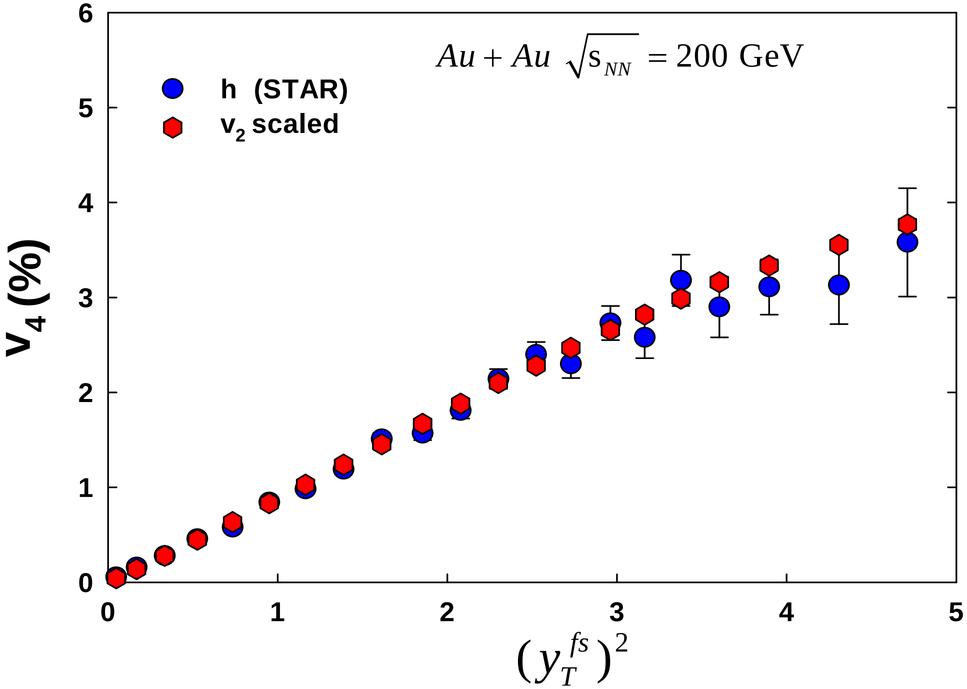
Extended Fine Structure scaling: higher harmonics

$$v_{2n} = \frac{I_n(w)}{I_0(w)}, n = 1,2,...$$

$$v_2 \rightarrow v_4$$

$$v_{2,4} \rightarrow v_6$$

$$v_4 = k_3 y_T^4 \frac{m^2}{T_0^2}\left(1 + \frac{k_4}{k_3}\frac{T_0}{m} + ...\right)$$

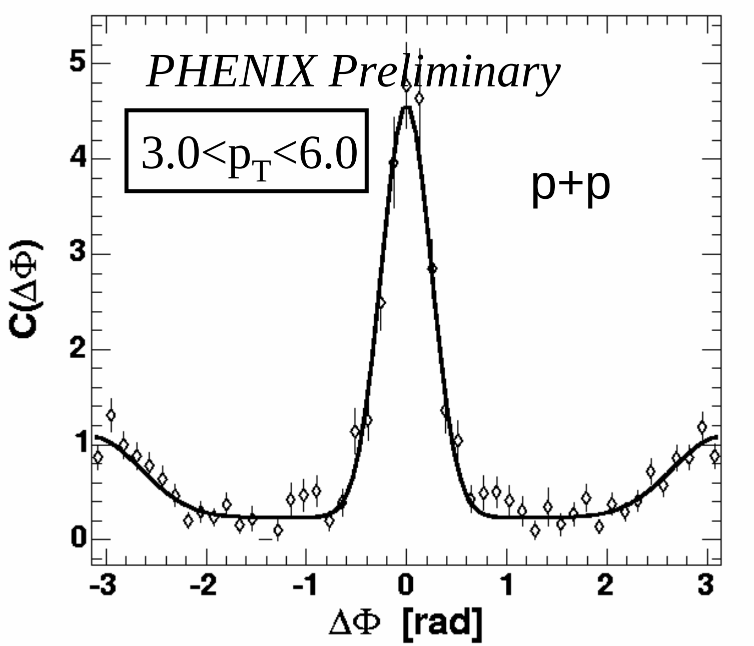


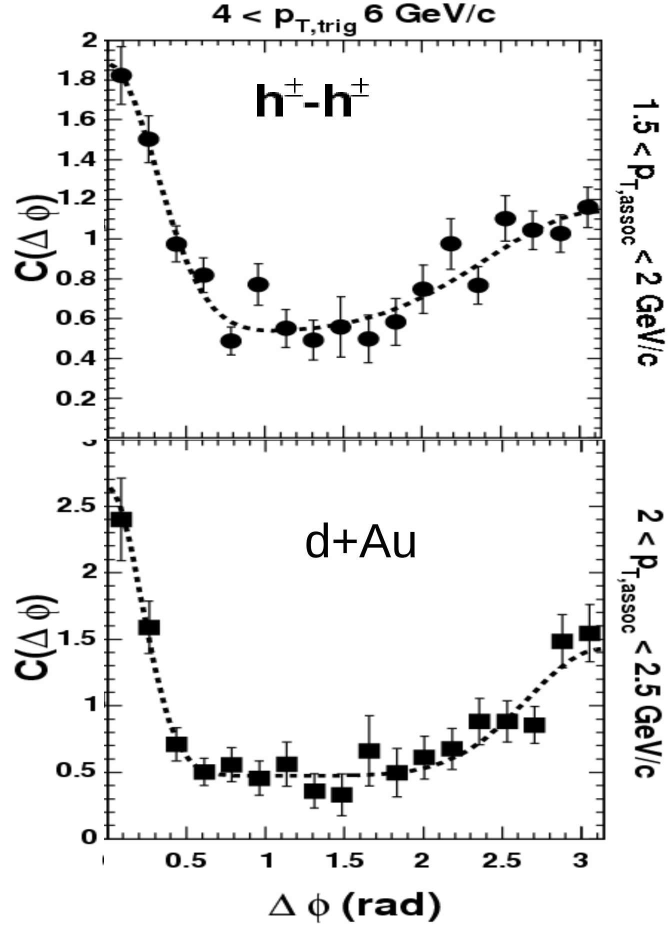
STAR data:

nucl-ex/0409033

Universal scaling prediction!

Calibrated Signal





Distinct Di-jet peaks observed for p + p and d + Au

Extracted Di-jet properties similar for both systems

Extracting Yields from Correlation Functions

Two Source Model

$$\overbrace{C(\Delta\phi)}^{\text{Correlation Function}} = a_0 \left[\overbrace{H(\Delta\phi)}^{\text{Harmonic}} + \overbrace{J(\Delta\phi)}^{\text{Jet Function}} \right]$$

$$H(\Delta\phi) = 1 + 2p_2 \cos(2\Delta\phi)$$

$$p_2 = v_2^A \times v_2^B$$

Jet-Pair Fraction:

$$JPF = \sum a_0 J(\Delta\phi) / \sum C(\Delta\phi)$$

Efficiency corrected Conditional yield (CY):

$$CY = JPF \times \frac{n_t^{AB}}{n_t^A \times n_t^B} \times n_t^B$$

Eff. Corrected pair rate

Eff. Corrected Singles yields

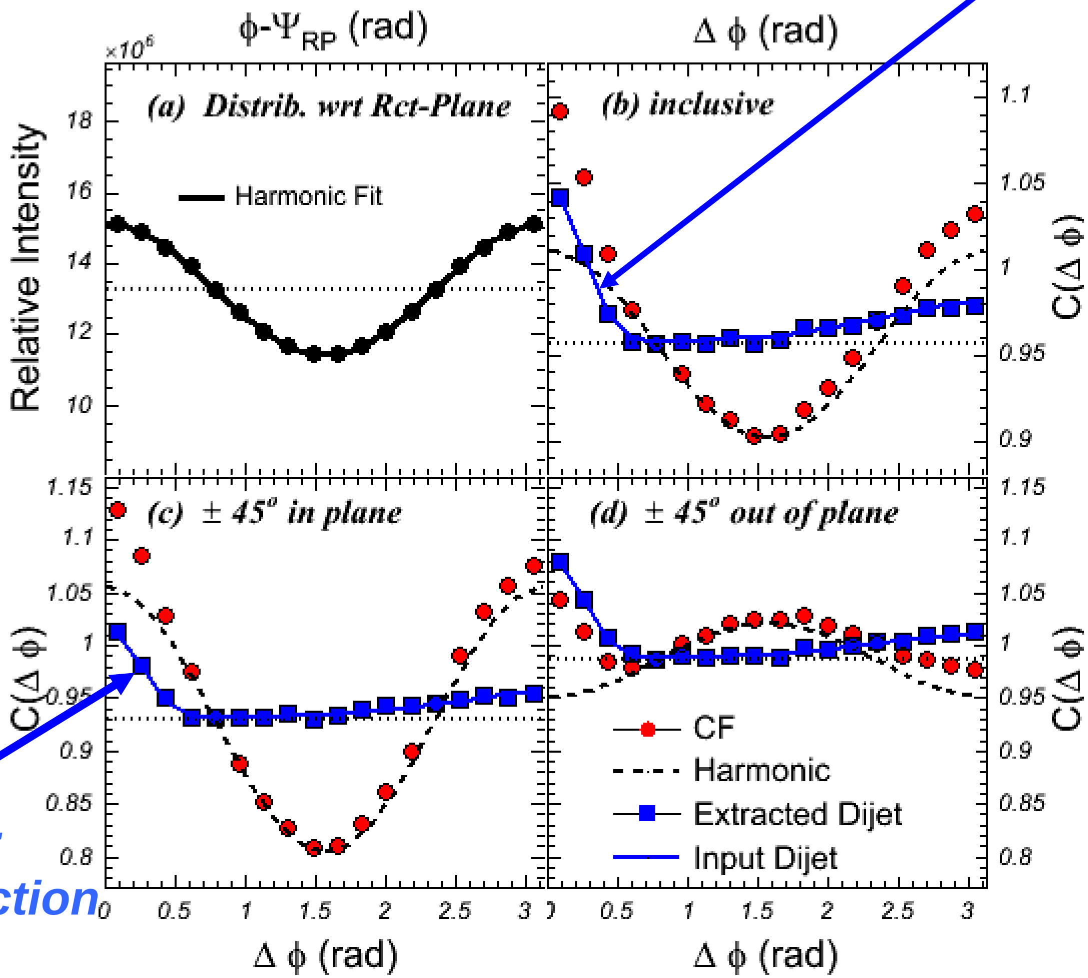
Efficiency corrected Conditional yield (CY):

$$CY = JPF \times \frac{n^{AB}}{n^A \times n^B} \times n_t^B$$

Recorded values

Simulation Test of Ansatz

Blue line: input jet-function obtained from Tagging jet-particles in simulation



Blue squares: Extracted jet-function

Input jet extremely well recovered!