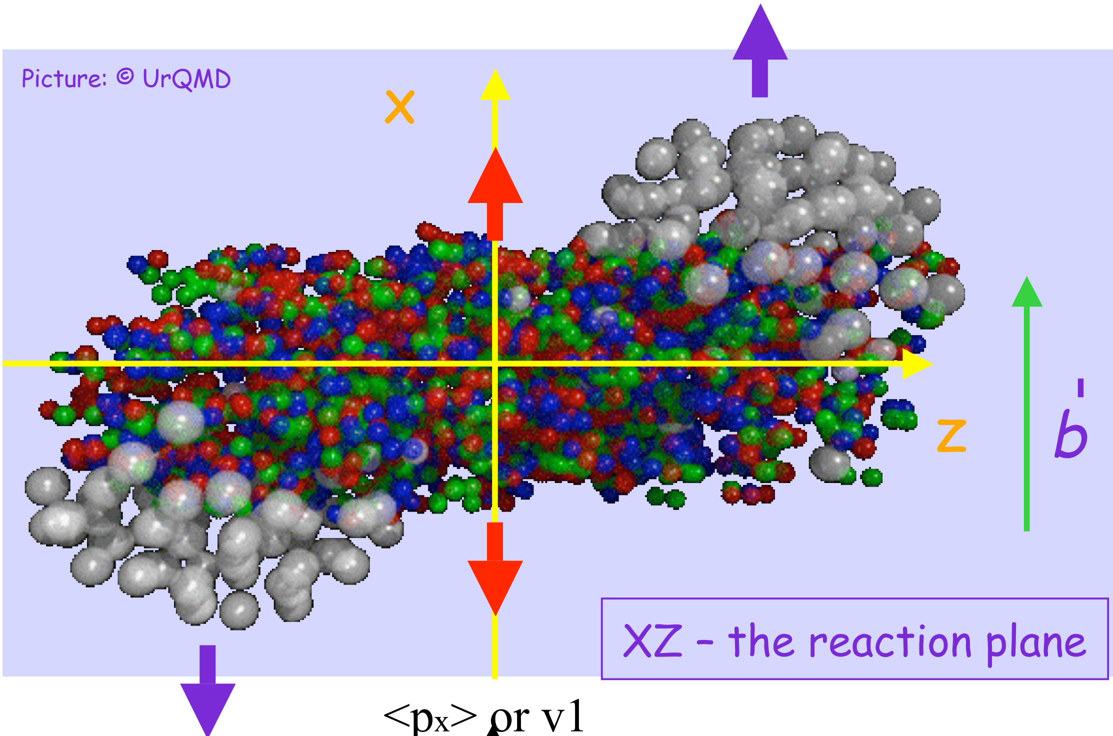
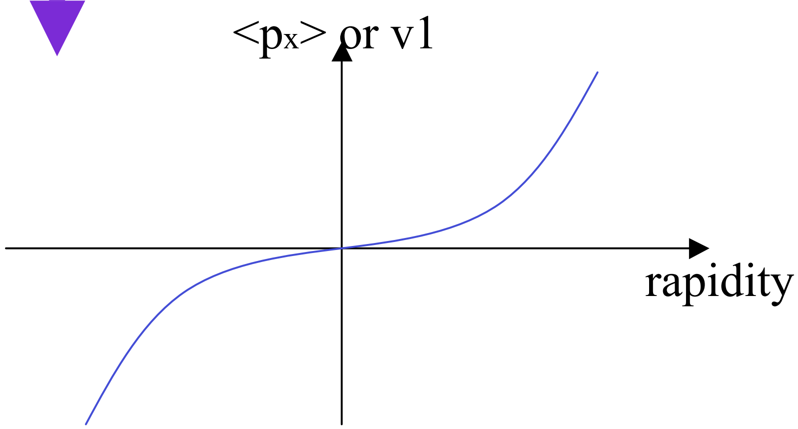
Directed and elliptic flow from Au+Au collisions at 200 GeV and azimuthal correlations in p+p and d+Au collisions at 200 GeV

Aihong Tang for the STAR Collaboration

Directed flow (v1)

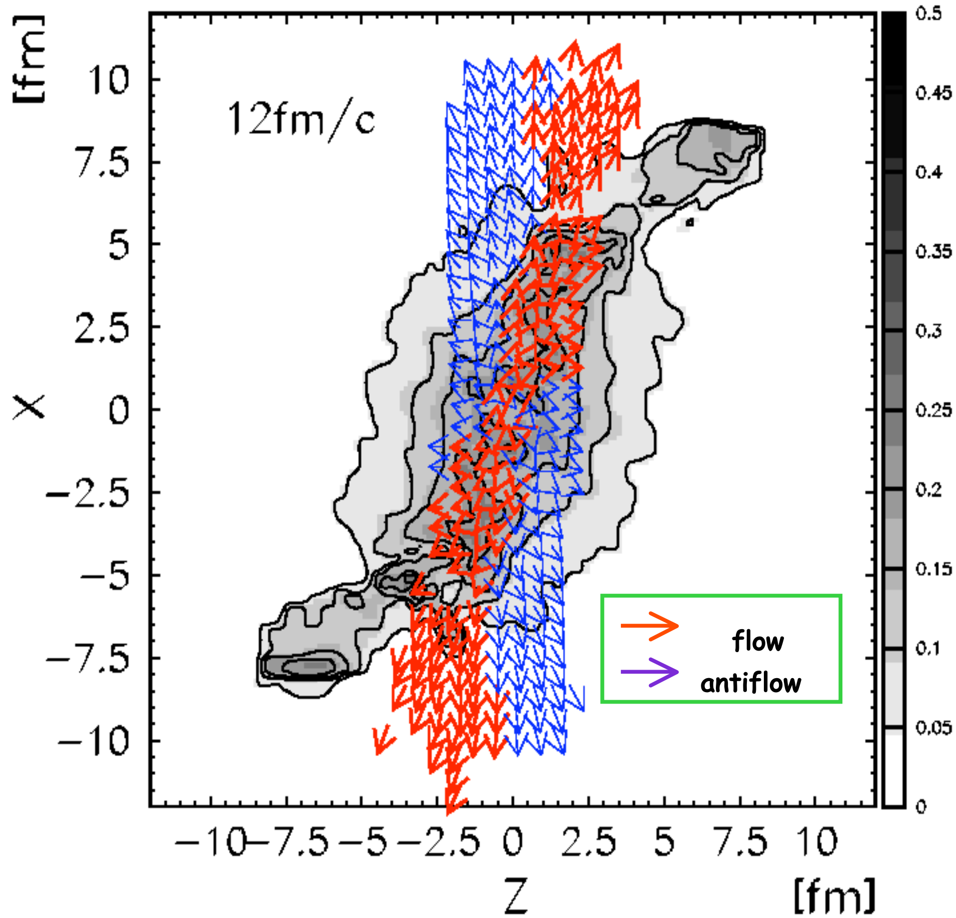


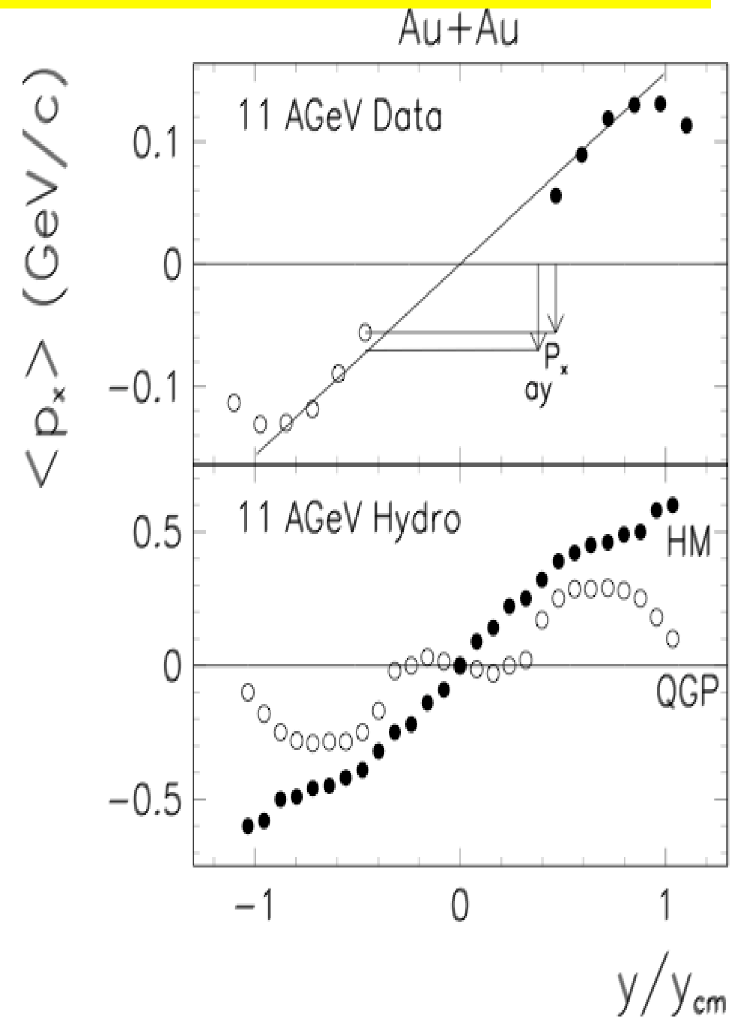
- Developed early - pre - equilibrium !
- Sensitive to the EOS
- As important as v2
- Well studied at lower energies
- Hard to be measured at RHIC because it is small



Directed flow (v1) and phase transition

Anti-flow/3rd flow component, with QGP-> V1 flat at middle rapidity.

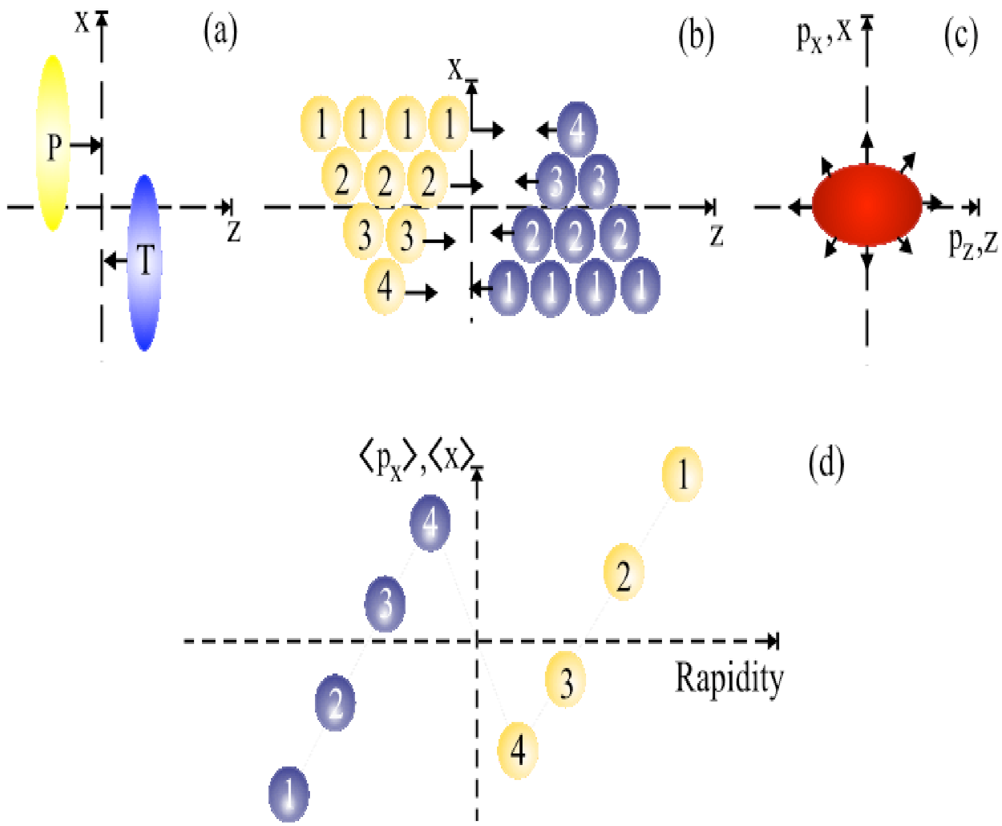


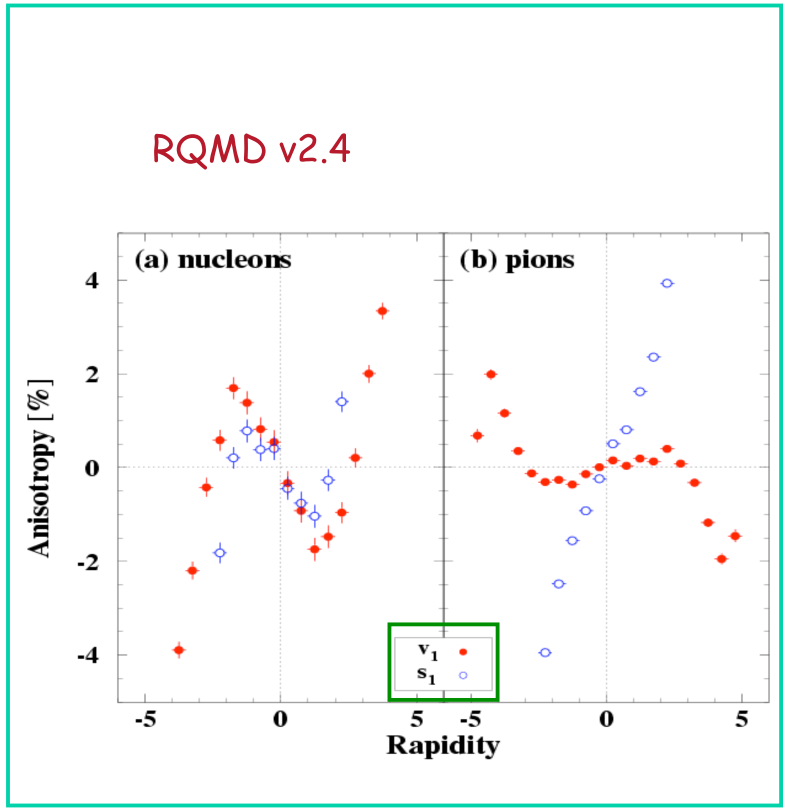


Brachmann, Soff, Dumitru, Stocker, Maruhn, Greiner Bravina, Rischke , PRC 61 (2000) 024909.
L.P. Csernai, D. Roehrich PLB 458, 454 (1999) M.Bleicher and H.Stocker, PLB 526,309(2002)

Directed flow (v1) and baryon stopping

Positive space-momentum correlation, no QGP necessary -> V1 wiggle.





R.Snellings, H.Sorge, S.Voloshin, F.Wang, N. Xu, PRL (84) 2803(2000)

Directed flow (v1) - three particle correlation method

$$\left\langle \cos(\phi_a - \Psi_2)\cos(\phi_b - \Psi_2) - \sin(\phi_a - \Psi_2)\sin(\phi_b - \Psi_2) \right\rangle \approx v_{1a} v_{1b} v_2$$

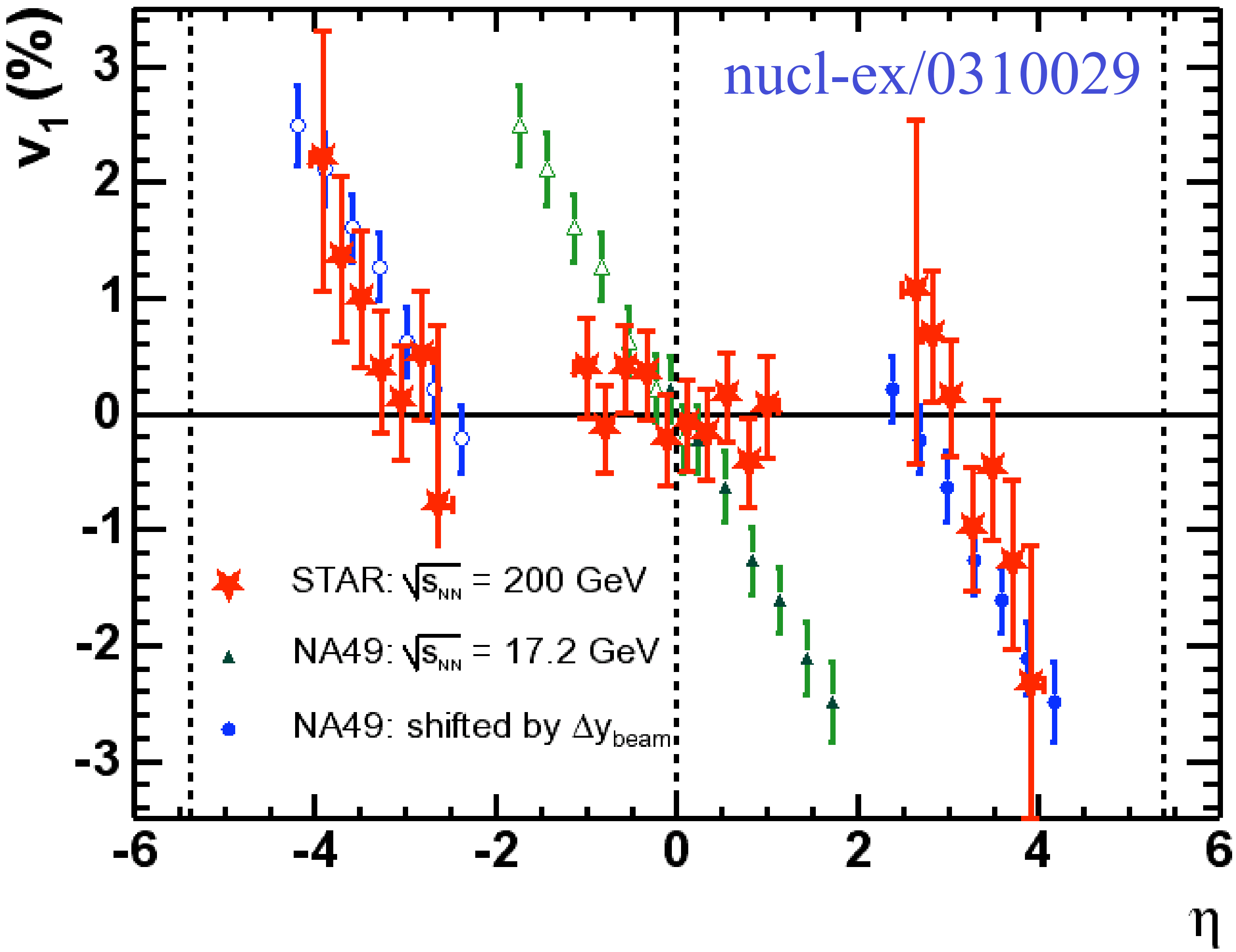
Flow+nonflow

Nonflow

Basic formula of three particle cumulant method
N.Borghini, P.M.Dihn,J-Y.Ollitrault, PRC 014905(2002)

- Takes advantage of the knowledge about the reaction plane derived from the large elliptic flow - minimized nonflow effect
- Can measure the sign of v2

Directed flow at RHIC



In-plane elliptic flow confirmed

Consistent with a "limiting fragmentation" hypothesis.

Shows no sign of a "wiggle" (also does not exclude the magnitude as predicted)

V1 Conclusions

- V1 from 3 particle cumulant analysis confirms the *in-plane* elliptic flow
- V1 at RHIC supports the “limiting fragmentation” hypothesis.
- V1 is found to be flat at middle rapidity -> consistent with theoretical predictions.

High pt v2 and correlation : the test of jet quenching

LBNL-52533

High-p_T Hadron Spectra, Azimuthal Anisotropy and Back-to-Back Correlations in High-energy Heavy-ion Collisions

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The … jet-like … shown t… between … enhance… is show… PACS n…

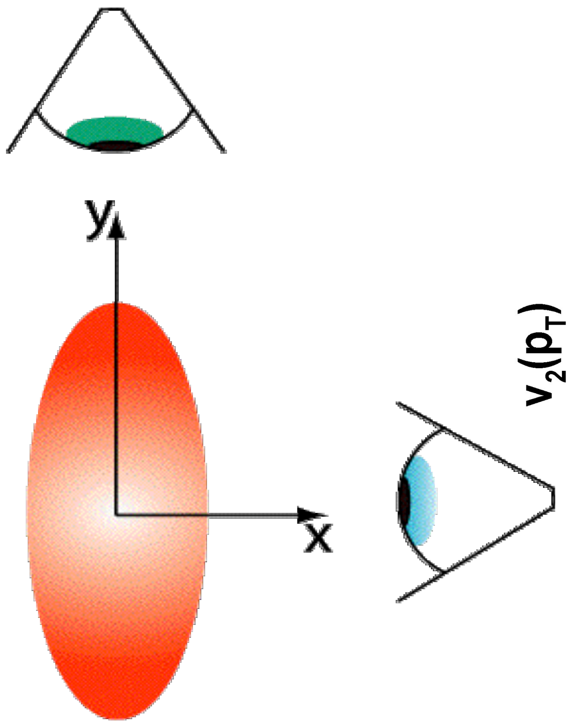
Such a phenomenon, known as jet quenching …, one also observes the disappearance of back-to-back jet-like hadron correlations and finite azimuthal anisotropy of high pt hadron spectra. These three seemingly unrelated high pt phenomena are all predicted as consequences of jet quenching. Together they can provide unprecedented information on the properties of dense matter produced at RHIC

The degradation … agation in the dens… mation necessary fo… the strongly interacting matter produced in high-energy heavy-ion collisions. Because of radiative parton energy loss induced by multiple scattering, the final high-p_T hadron spectra from jet fragmentation are expected to be significantly suppressed [1]. Such a phenomenon, known as jet quenching, was observed for the first time in $Au+Au$ collisions at the Relativistic Heavy-ion Collider (RHIC) [2,3]. One also observes the disappearance of back-to-back jet-like hadron correlations [4] and finite azimuthal anisotropy [5] of high-p_T hadron spectra. These three seemingly unrelated high-p_T phenomena are all predicted as consequences of jet quenching [1,6–8]. Together, they can provide unprecedented information on the prop-

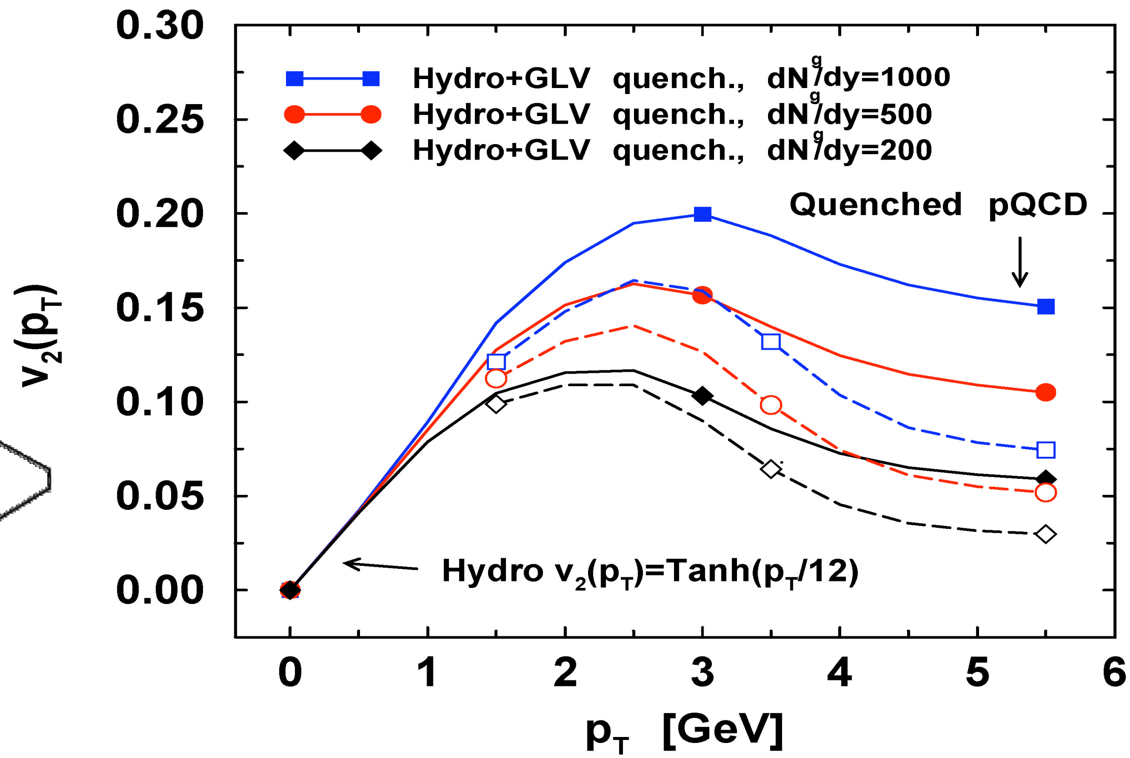
… pQCD corrections. The parton distributions per nucleon $f_{a/A}(x_a, Q^2, r)$ inside the nucleus are assumed to be factorizable into the parton distributions in a free nucleon given by the MRS D−′ parameterization [11] and the impact-parameter dependent nuclear modification factor [12,13]. The initial transverse momentum distribution $g_A(k_T, Q^2, b)$ is assumed to have a Gaussian form with a width that includes both an intrinsic part in a nucleon and nuclear broadening. Details of this model and systematic data comparisons can be found in Ref. [9].

As demonstrated in recent studies, a direct consequence of parton energy loss is the medium modification of FF's [14,15] which can be well approximated by [16]

High pt v2 and correlation : the test of jet quenching

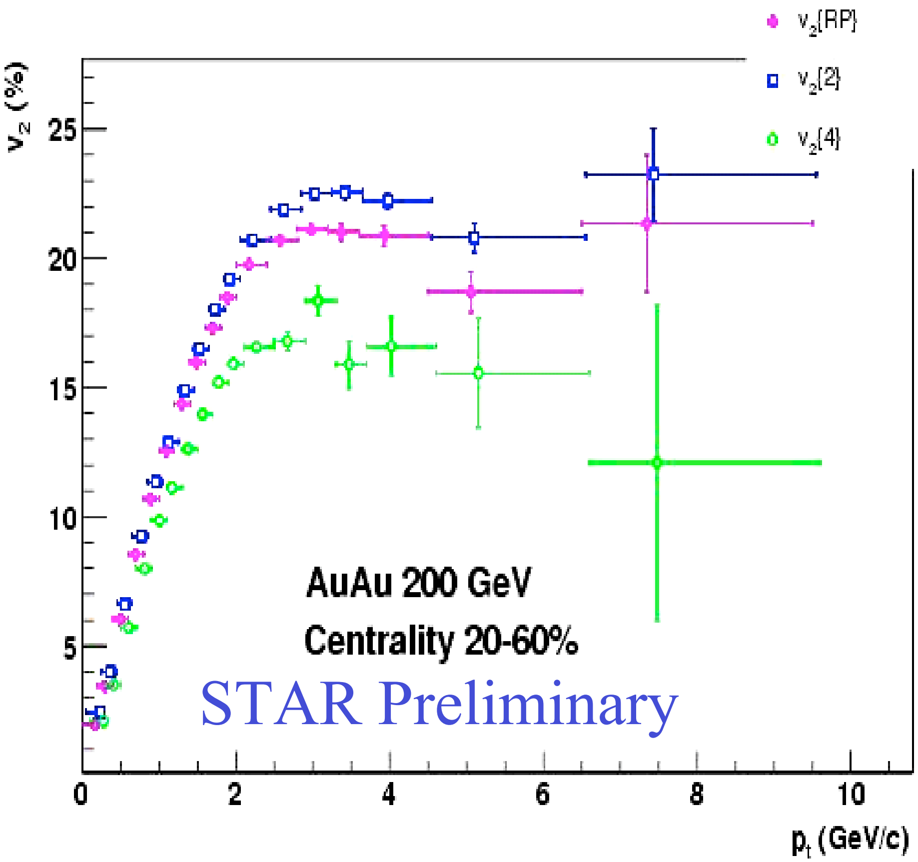


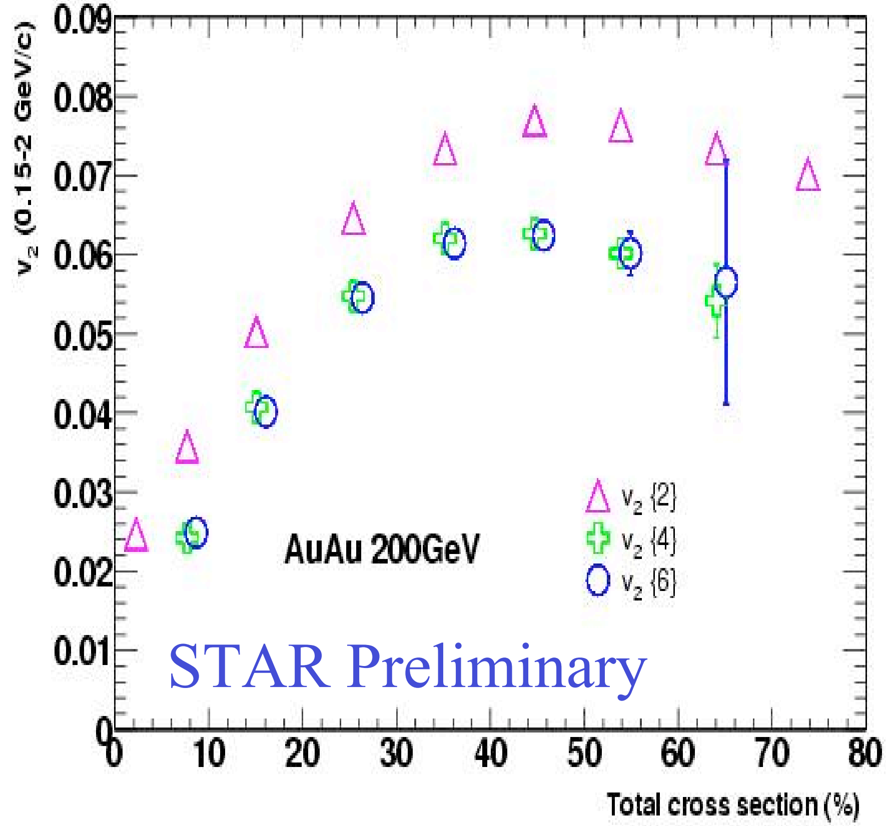
M. Gyulassy, I. Vitev and X.N. Wang



Results from jet energy loss from different emission angles with respect to the reaction plane. Sensitive to the medium density profile

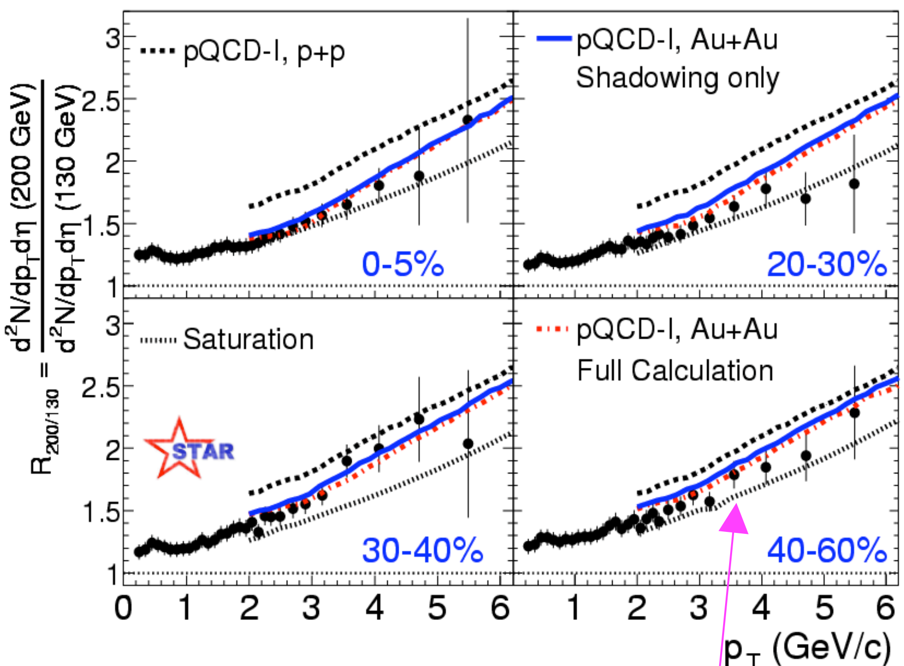
High pt v2 and correlation : the test of jet quenching



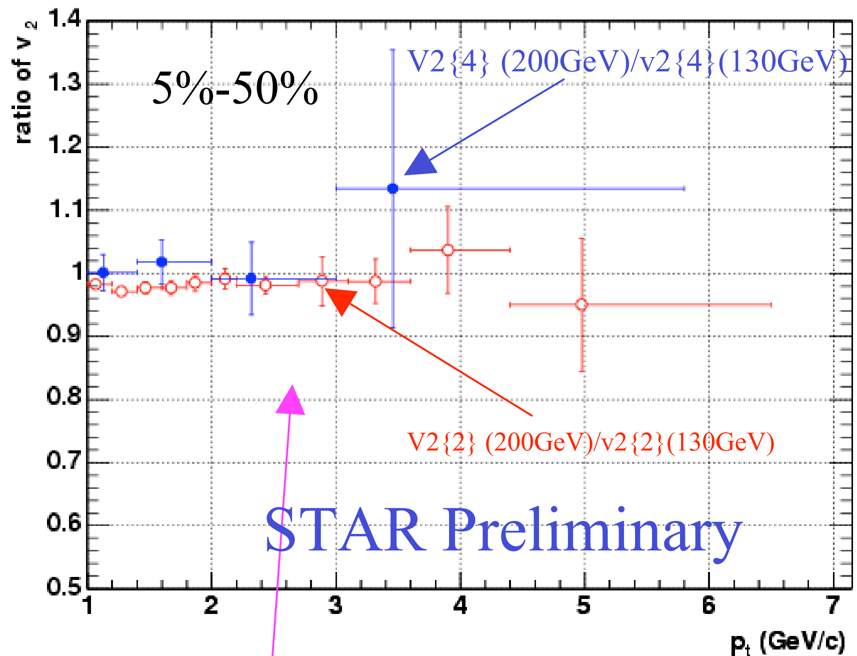


Significant v2 up to ~7 GeV/c in pt, the region where hard scattering begins to dominate. Nonflow from 4 particle correlation, v{6}-v{4} is negligible.

High pt v2 and correlation : the test of jet quenching 200 GeV/130 GeV

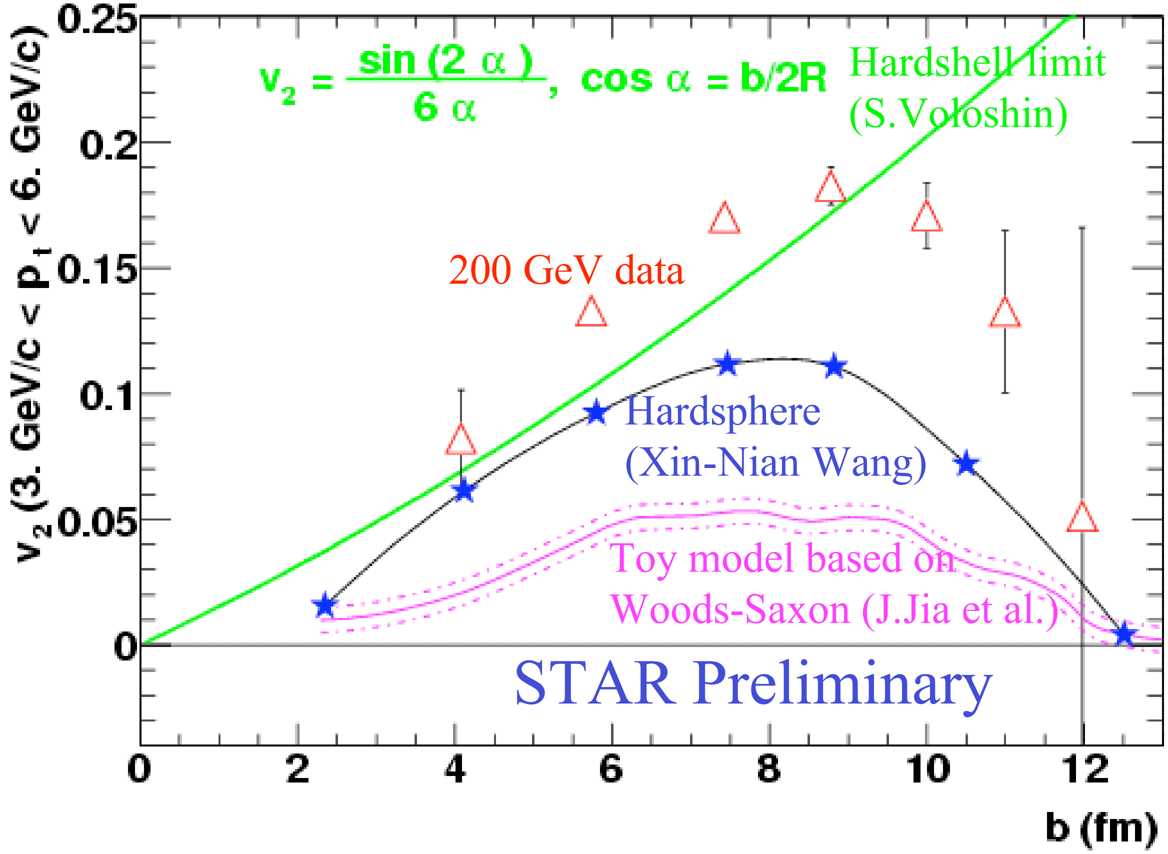


Nucl-ex/0305015



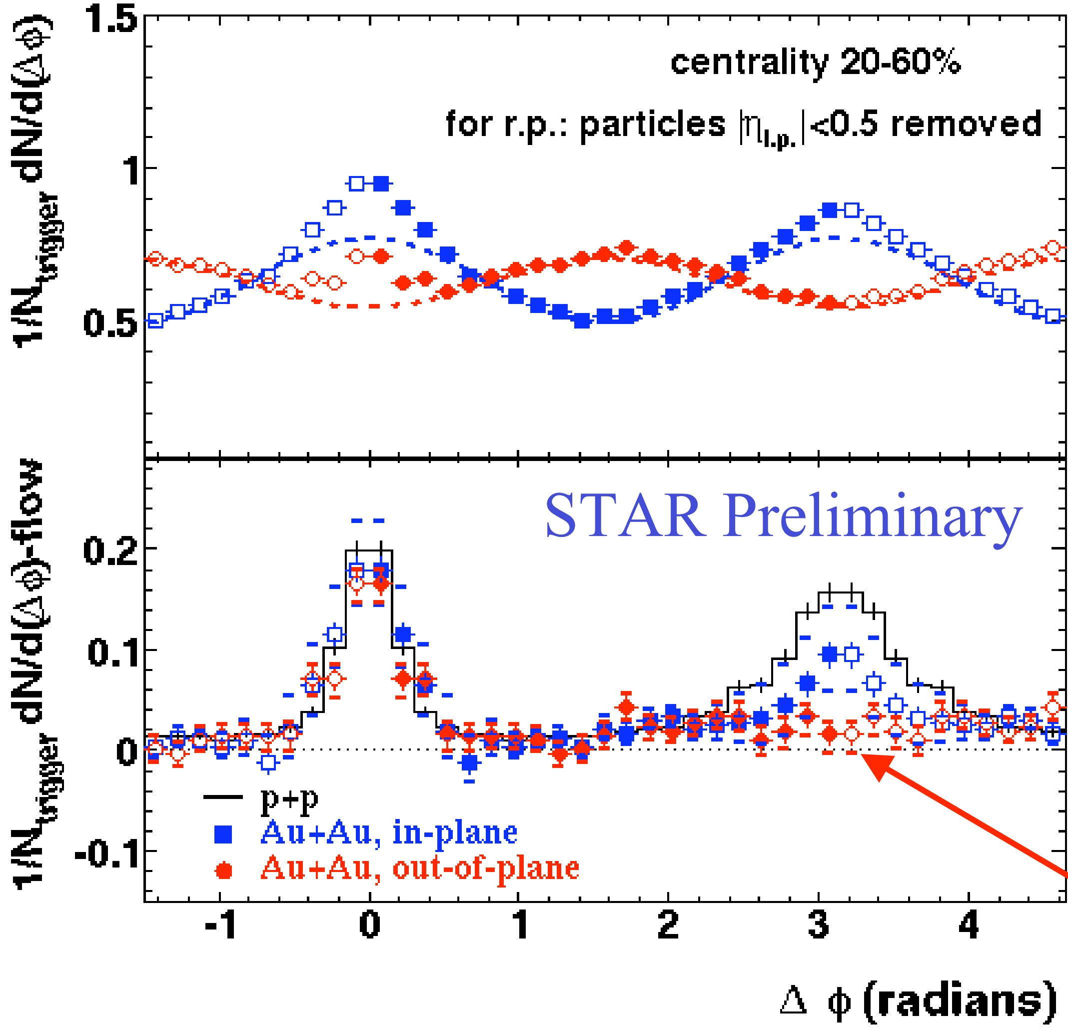
<u>Yields increases</u> but <u>v2 stays the same</u>
consistent with “jet quenching” picture.

High pt v2 and correlation : the test of jet quenching



V2 from middle central collisions exceeds the upper limit set by hard shell emission - why ? Coalescence?

High pt v2 and correlation : the test of jet quenching



Back-to-back suppression is larger in the out-of-plane direction

V2 Conclusions

- Sizable v2 is found up to 7 GeV/c in pt.
- Nonflow contribution to 4 particle correlations is negligible.
- V2 at moderate pt increases little from 130 GeV to 200 GeV, while yields increases significantly -> qualitatively consistent with geometrical v2
- V2 at moderate pt is too high to be explained by “jet quenching” alone.
- Back-to-back suppression is larger in the out-of-plane direction

Is there "elliptic flow" in dAu collisions ?

- V2 does not scale --- need to find a multiplicity (or Nbinary) independent quantity to compare azimuthal correlations between two different systems.

$$M^2\left\langle e^{in(\phi_1-\phi_2)}\right\rangle = M \bullet M\left\langle e^{in(\phi_1-\phi_2)}\right\rangle = M \bullet \left\langle uQ^*\right\rangle = M\tilde{v}_2$$

Scaling !

Multiplicity independent non-flow

In S. Voloshin's language

$$\langle u_b Q^* \rangle = (v_b v_p + \delta_{bp}^{AA}) M^{AA}$$

$$\delta_{bp}^{AA} \approx \frac{\delta_{bp}^{pp}}{N_{coll}} \approx \frac{\delta_{bp}^{pp} M^{pp}}{M^{AA}}$$

$$\Rightarrow \quad \langle u_b Q^* \rangle^{AA} \approx v_b v_p M^{AA} + \langle u_b Q^* \rangle^{pp}$$

$$Q = \sum_{i \in "pool"} u_i; \quad u_i = e^{i2\phi_i}$$

v_p - Flow in a particle pt/eta "bin"

v_b - Average flow for particles used ("pool partiles") to define RP

δ_{bp}^{pp} - Azimuthal correlations in pp ($\langle u_a u_b^* \rangle$, $u = e^{i2\phi}$)

Then non-flow/flow contribution ratio in AA would be:

$$\frac{\delta_{bp}^{pp}}{N_{coll}} : v_2^2$$

Could be significant for peripheral ($N_{coll} \sim 5, v \sim 0.08$) or very central ($N_{coll} \sim 200, v \sim 0.01$) collisions

In J.-Y Ollitrault et al′s language

The format of generating function used in cumulant analyses is:

$$G_n(z) = \prod_{j=1}^{M} \left(1 + \frac{z^* e^{in\phi_j} + z e^{-in\phi_j}}{M}\right)$$

It is good for extracting v2, but it does not scale. If we change it to

$$G_n(z) = \prod_{j=1}^{M} \left(1 + z^* e^{in\phi_j} + z e^{-in\phi_j}\right)$$

Then for a system that is superposition of two independent system 1 and 2, and only “nonflow” correlations are present, we have

$$G(z) = G1(z)G2(z)$$

So if a Nucleus-Nucleus is a simple superposition of N independent pp collisions, then

$$G(z) = \left[G_{pp}(z)\right]^N$$

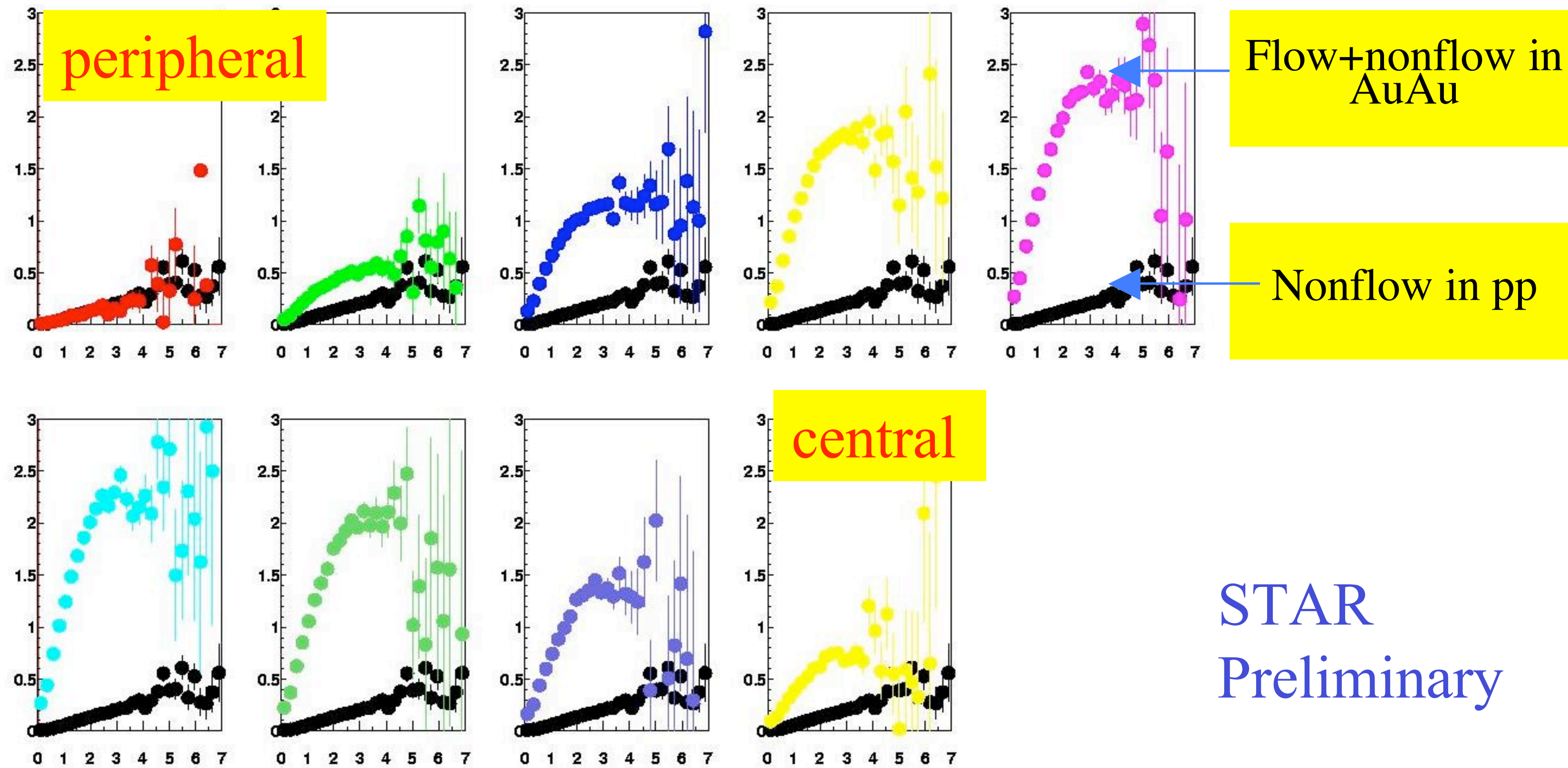
Log(G(z)) then should scale linearly with the number of pp collisions, so should cumulants, which is the coefficient of z of Log(G(z)).

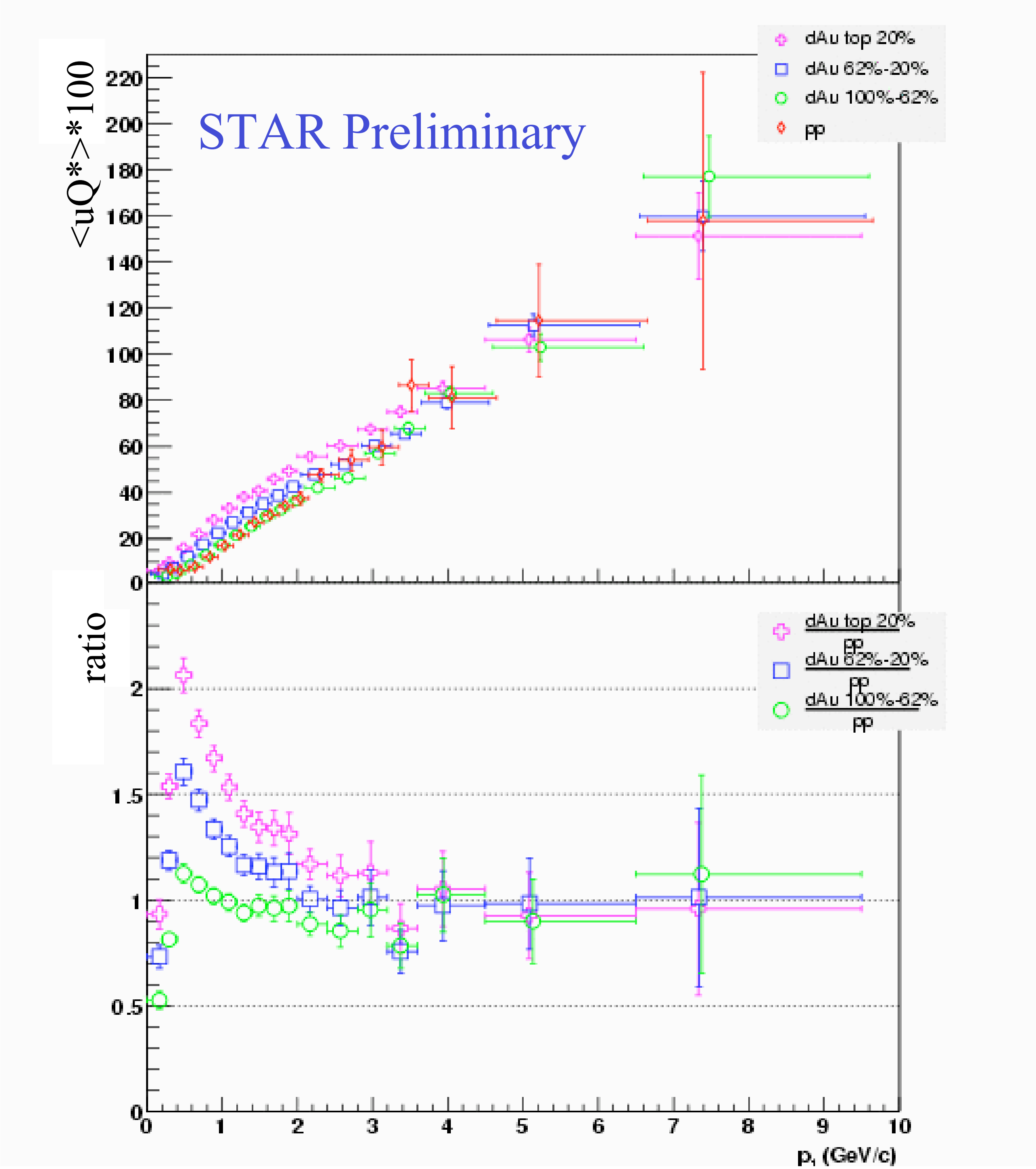
In the case of a second order cumulant, this is

$$M^2\left\langle e^{in(\phi_1-\phi_2)}\right\rangle = M \bullet M\left\langle e^{in(\phi_1-\phi_2)}\right\rangle = M \bullet \langle uQ^*\rangle = M\tilde{\square}_2$$

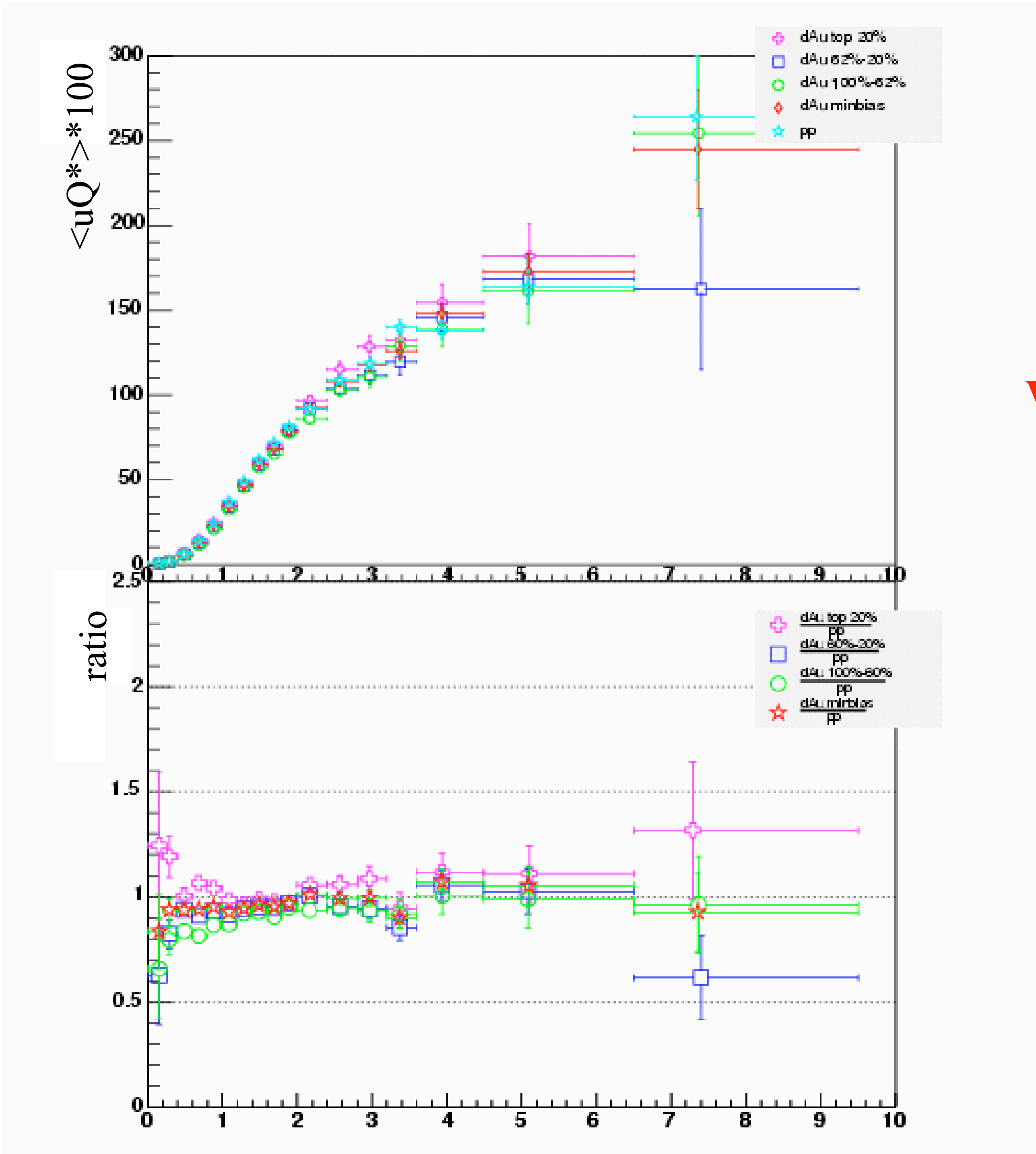
Azimuthal correlation in AuAu and pp collisions

$$\left\langle u_b Q^* \right\rangle^{AA} \approx v_b v_p M^{AA} + \left\langle u_b Q^* \right\rangle^{pp}$$





there "elliptic flow" in dAu collisions ?



What does it look like in HIJING ?

Conclusion of azimuthal correlation in dAu

- Some azimuthal asymmetry is developed at low pt in dAu collisions, could be due to multiple hadronic rescattering.
- As expected, such azimuthal asymmetry is not found in Hijing due to the fact that Hijing does not have collectivity.