Two- and Three-particle azimuthal correlations from STAR

as a measure of viscous and non-linear effects and what they tell us about the ridge in p+A and A+A collisions

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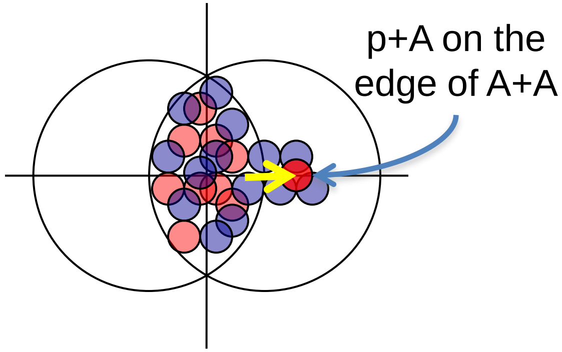
Things we think we understand about flow but don't

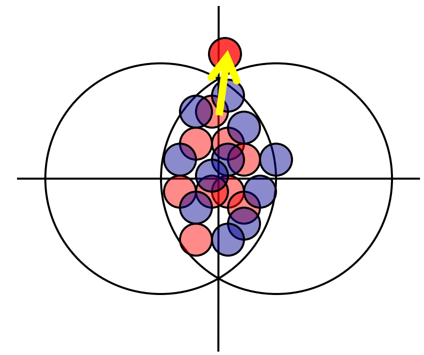
Thing number 1: v_3 is just due to fluctuations

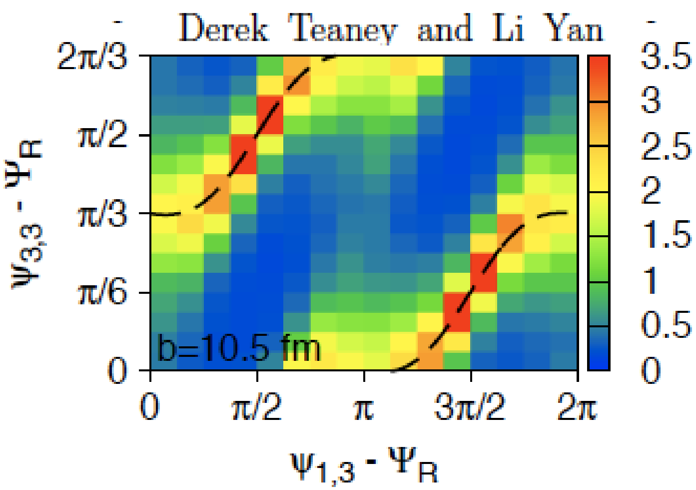
Overlap Geometry Leads to Strong Correlations Between Harmonic Planes

In-plane fluctuation: large impact creating higher harmonics especially ε_3



Out-of-plane fluctuation: no impact





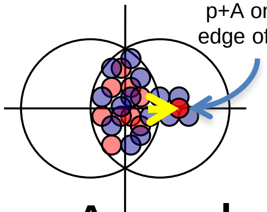
We should expect the 3[rd] and 1[st] plane to be correlated with the 2[nd]

If they aren't: we don't have a clue about what's happening

We can measure this with $\langle\cos(1\varphi_1+2\varphi_2-3\varphi_3)\rangle$

We need to understand these correlations to understand the relationship between v_3 and the ridge in p+A and A+A

Motivation for 3-particle correlations



Map out geometry that causes v_3 and the ridge

Better understand relationship between the ridge in p+A and A+A

Map out the distribution of particle pairs relative to the reaction plane

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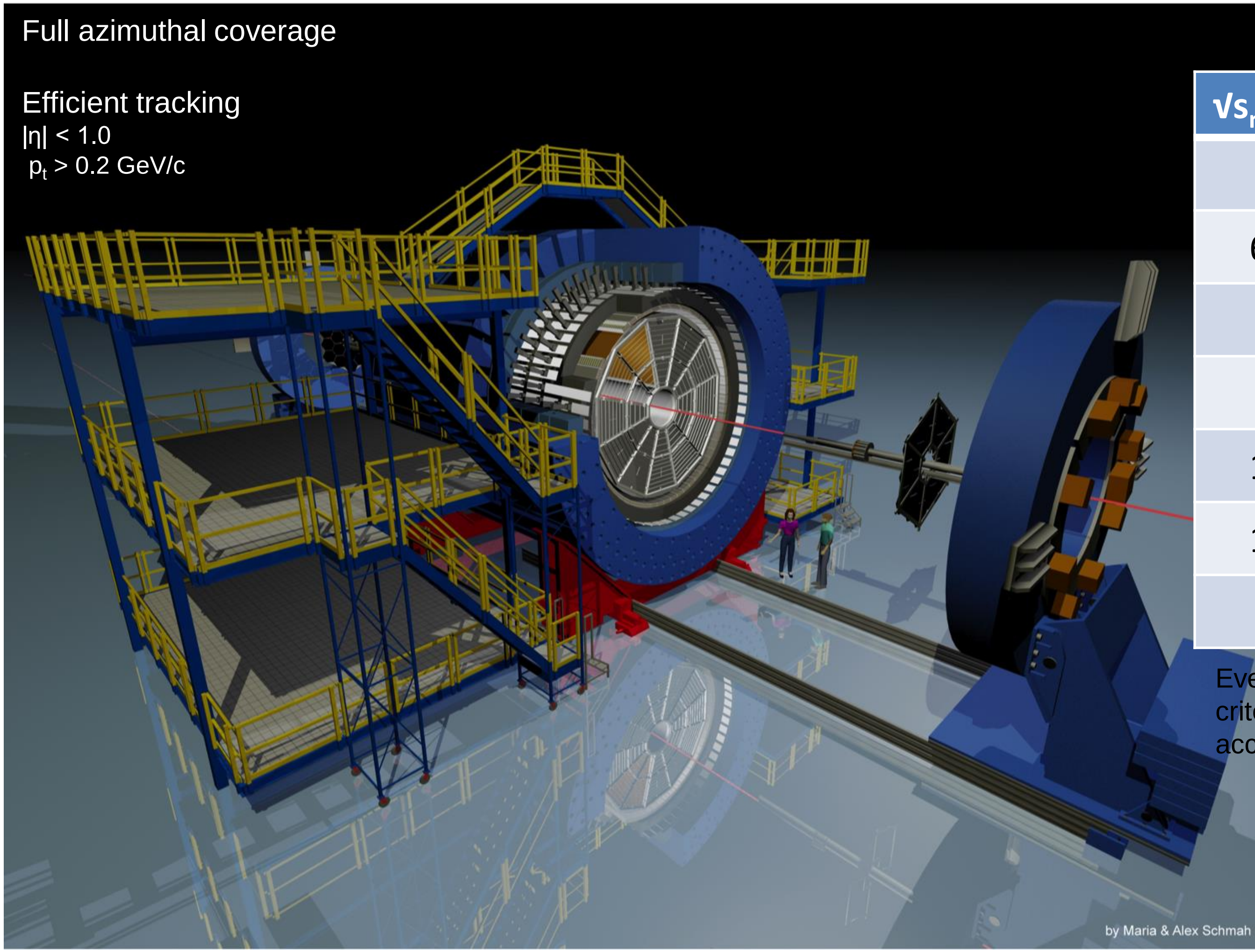
Over-constrain hydro models to extract η/s vs T

We compare models to 2- and 4-particle correlations: why not 3?

Gain insight into the source of two-particle correlations

STAR Detector and Data Set



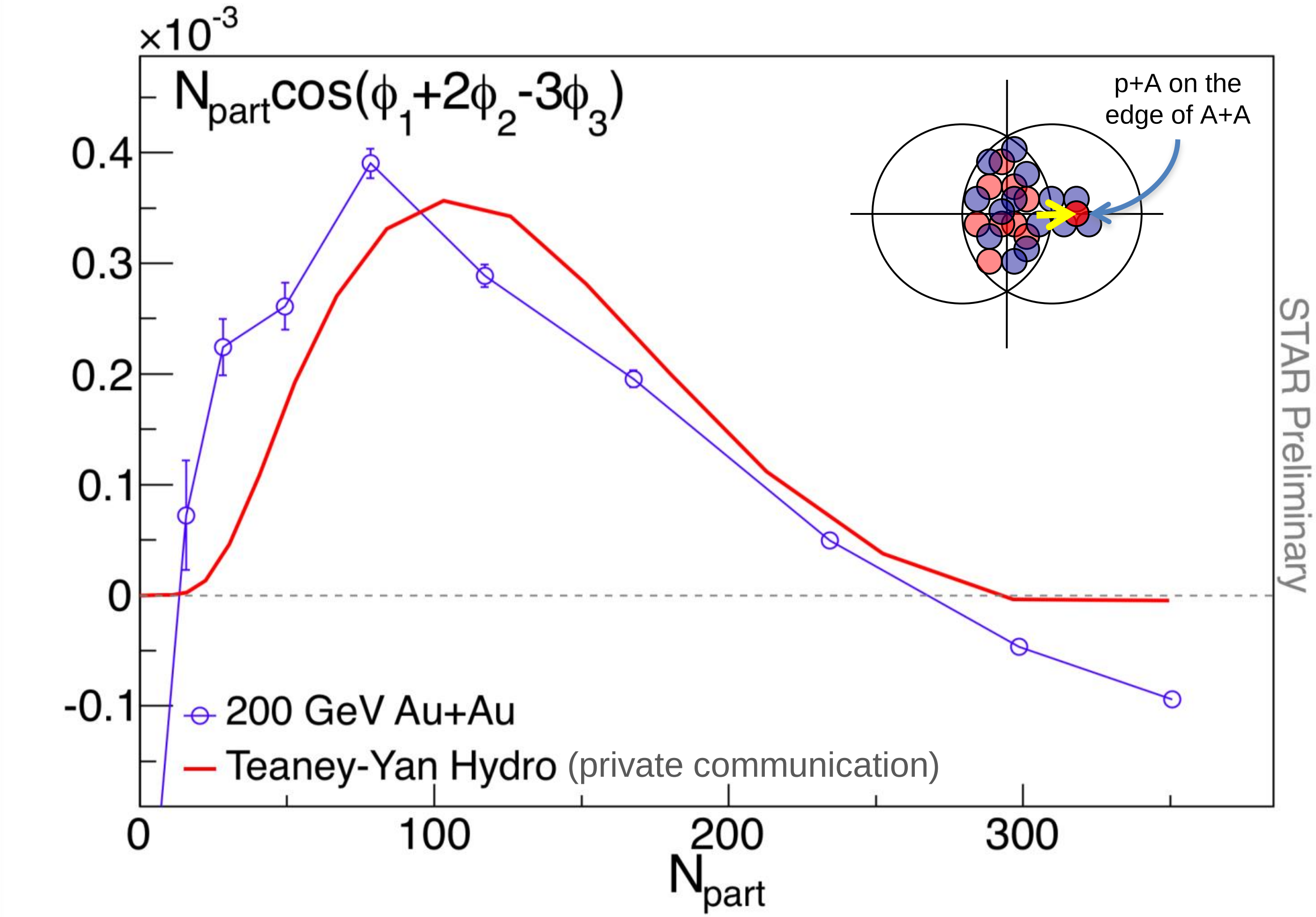
$\sqrt{s_{nn}}$ GeV	Year	Events (10^6)
200	2011	350
62.4	2004	4
39	2010	10
27	2011	20
19.6	2011	16
11.5	2010	3.5
7.7	2010	3

Event counts reflect stringent selection criteria required for analysis and acceptance corrections

We've measured the efficiency and acceptance corrected 2- and 3-particle correlations using Q-cumulants for p_T>0.2 GeV

Bilandzic, et. al. Phys. Rev. C 83: 044913,2011
Bilandzic, et. al. arxiv.org/1312.3572

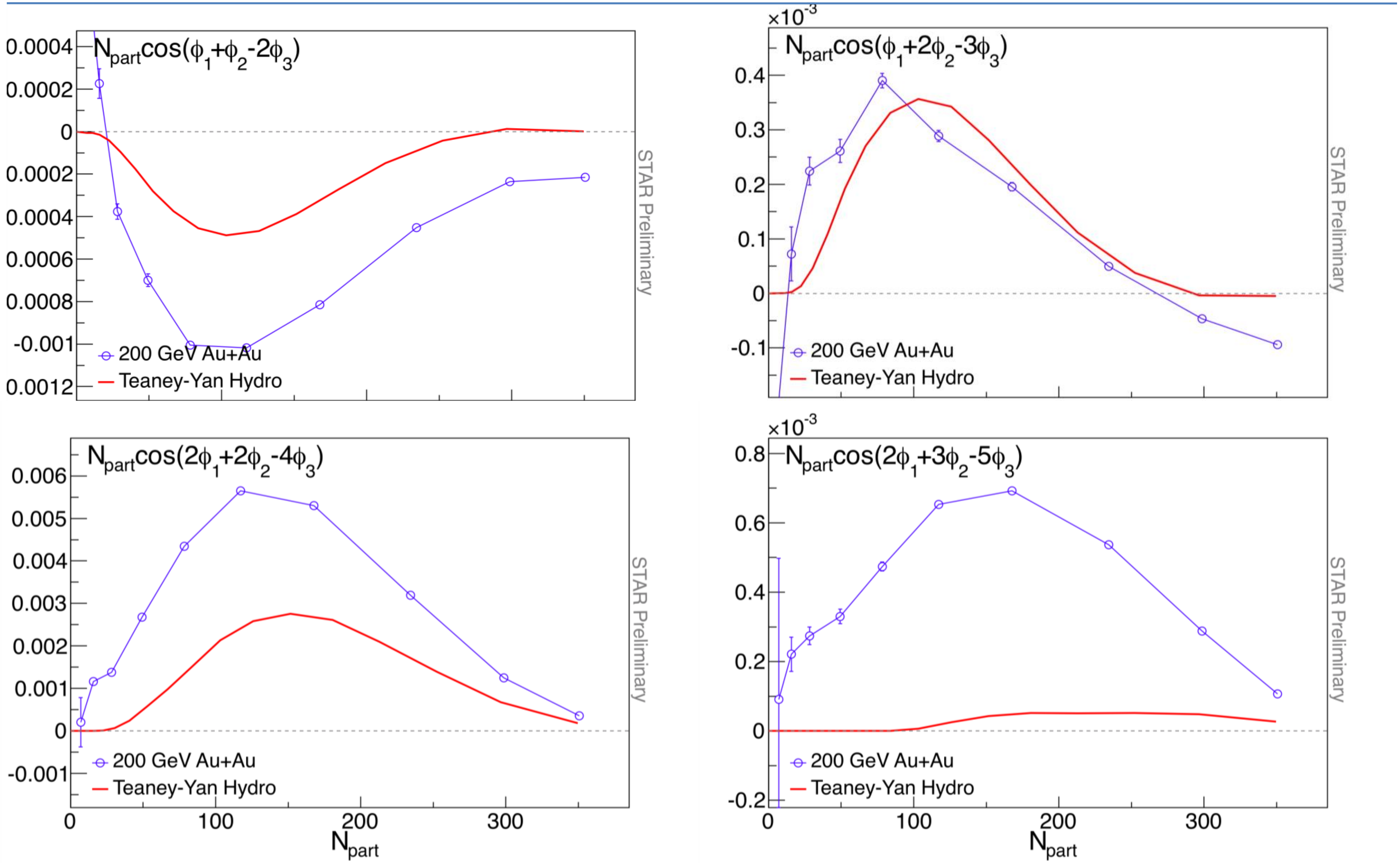
Measured Correlations



We see a correlation of harmonic 1, 2, and 3 as expected from geometry fluctuations (p+A on the edge of A+A)

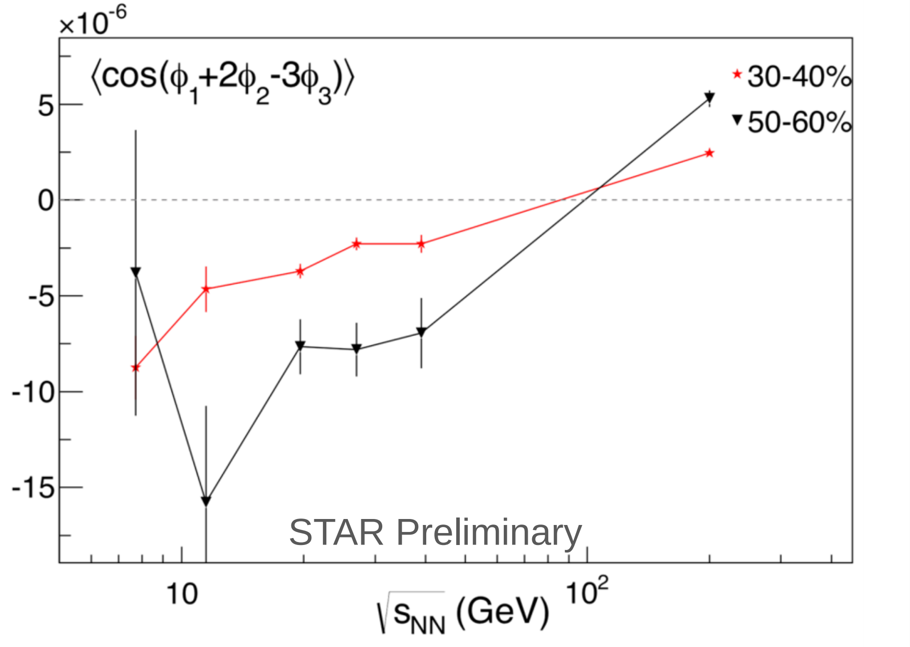
Hydro model with $\eta/s=1/4\pi$ describes the data well

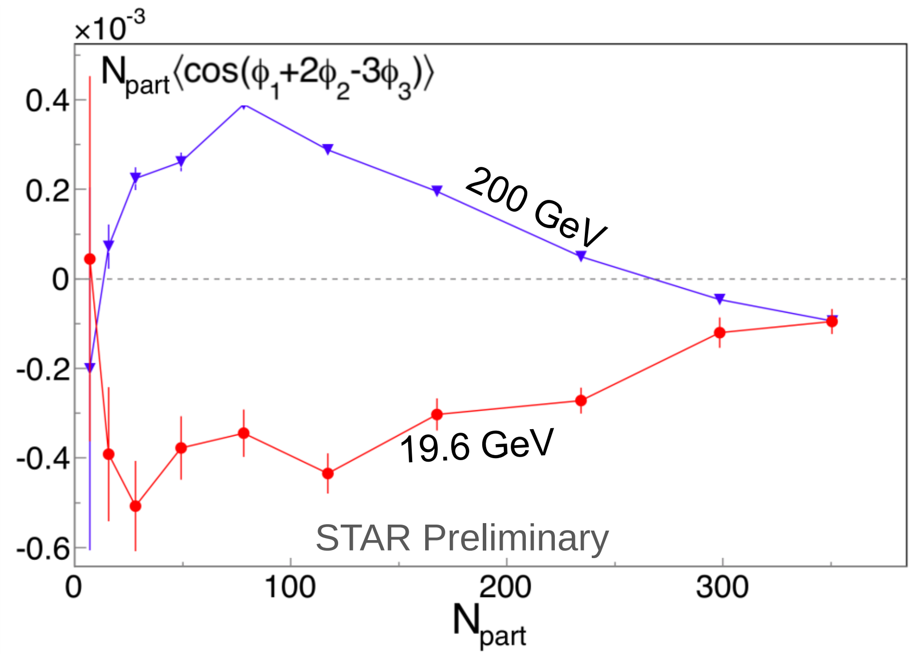
Exploration of other harmonics



Poorer agreement especially with the higher harmonics; lowest harmonics are the most robust in the model. Model uncertainties need to be evaluated

Energy Dependence



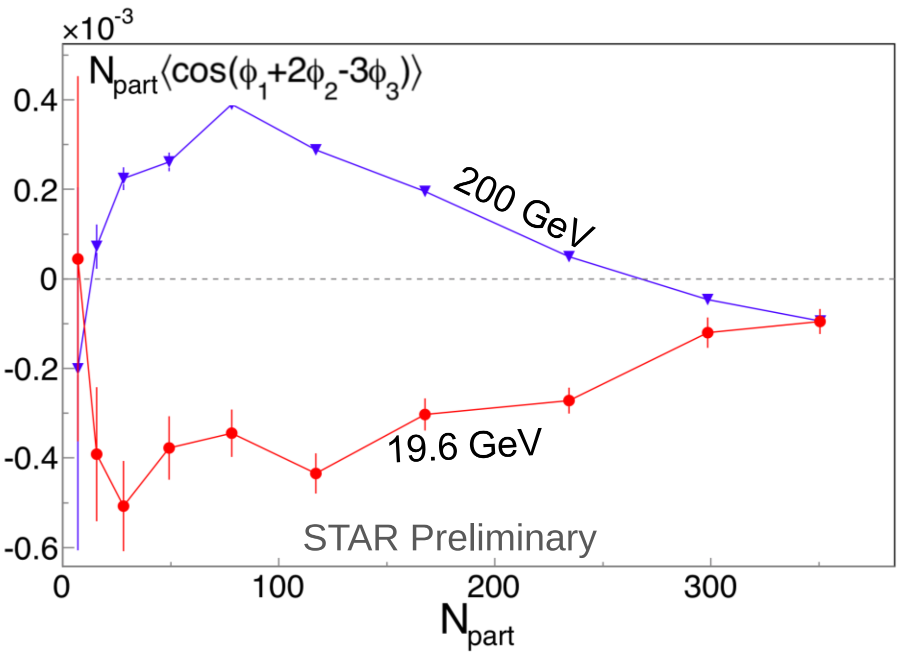


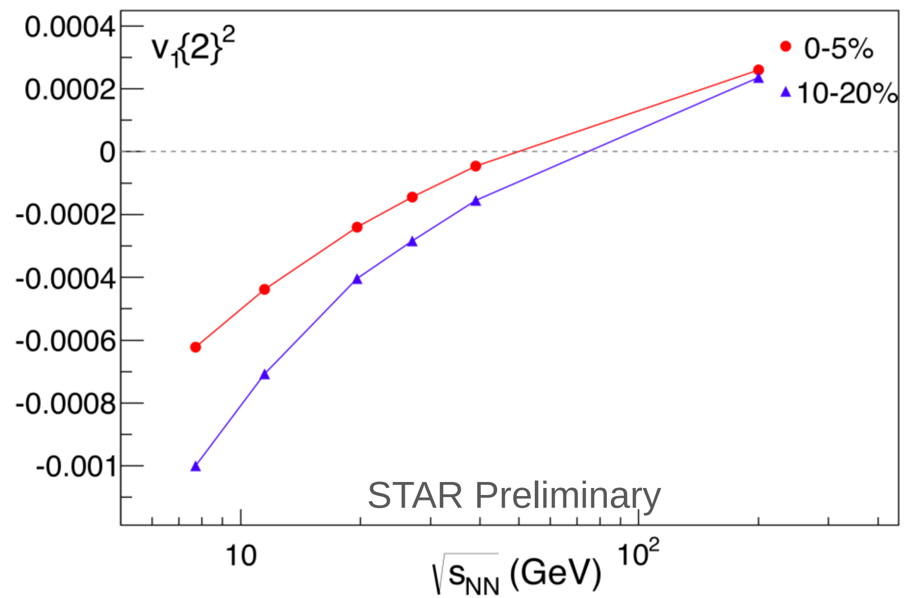
The $\langle\cos(1\varphi_1+2\varphi_2-3\varphi_3)\rangle$ correlation becomes negative at lower beam energies

Robust observation across all centralities

Energy Dependence

back-to-back pairs lead
to negative $\langle\cos(\varphi_1-\varphi_2)\rangle$

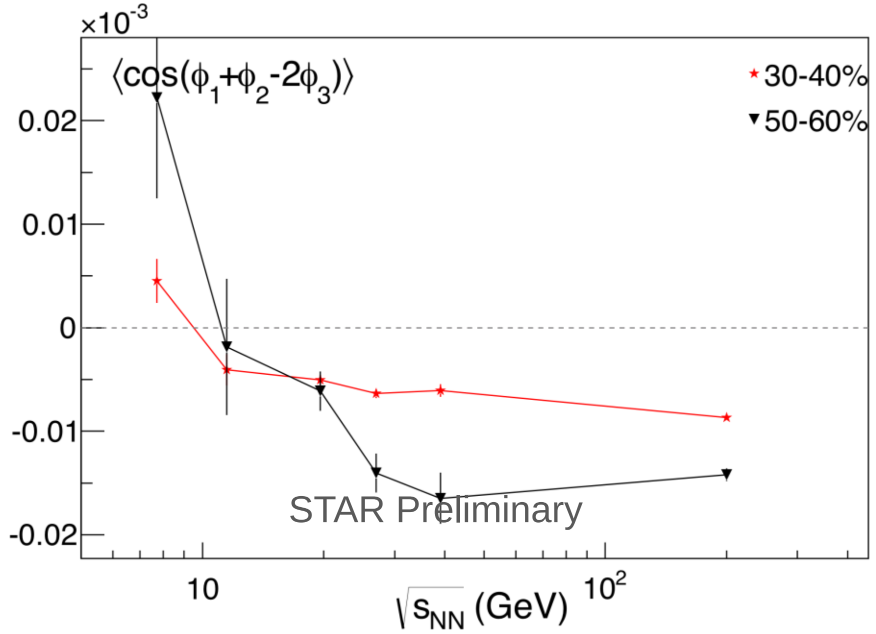


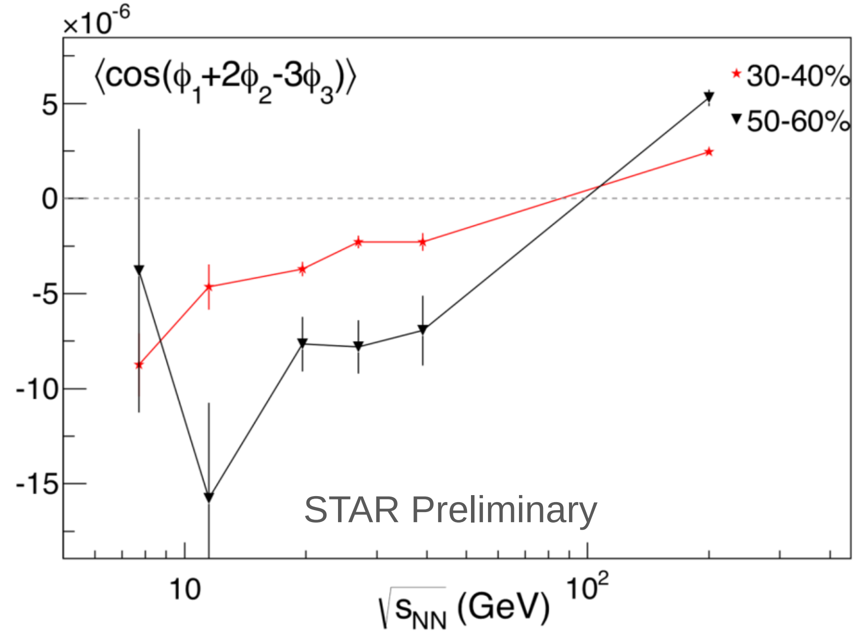


The $\langle\cos(1\varphi_1+2\varphi_2-3\varphi_3)\rangle$ correlation becomes negative at lower beam energies

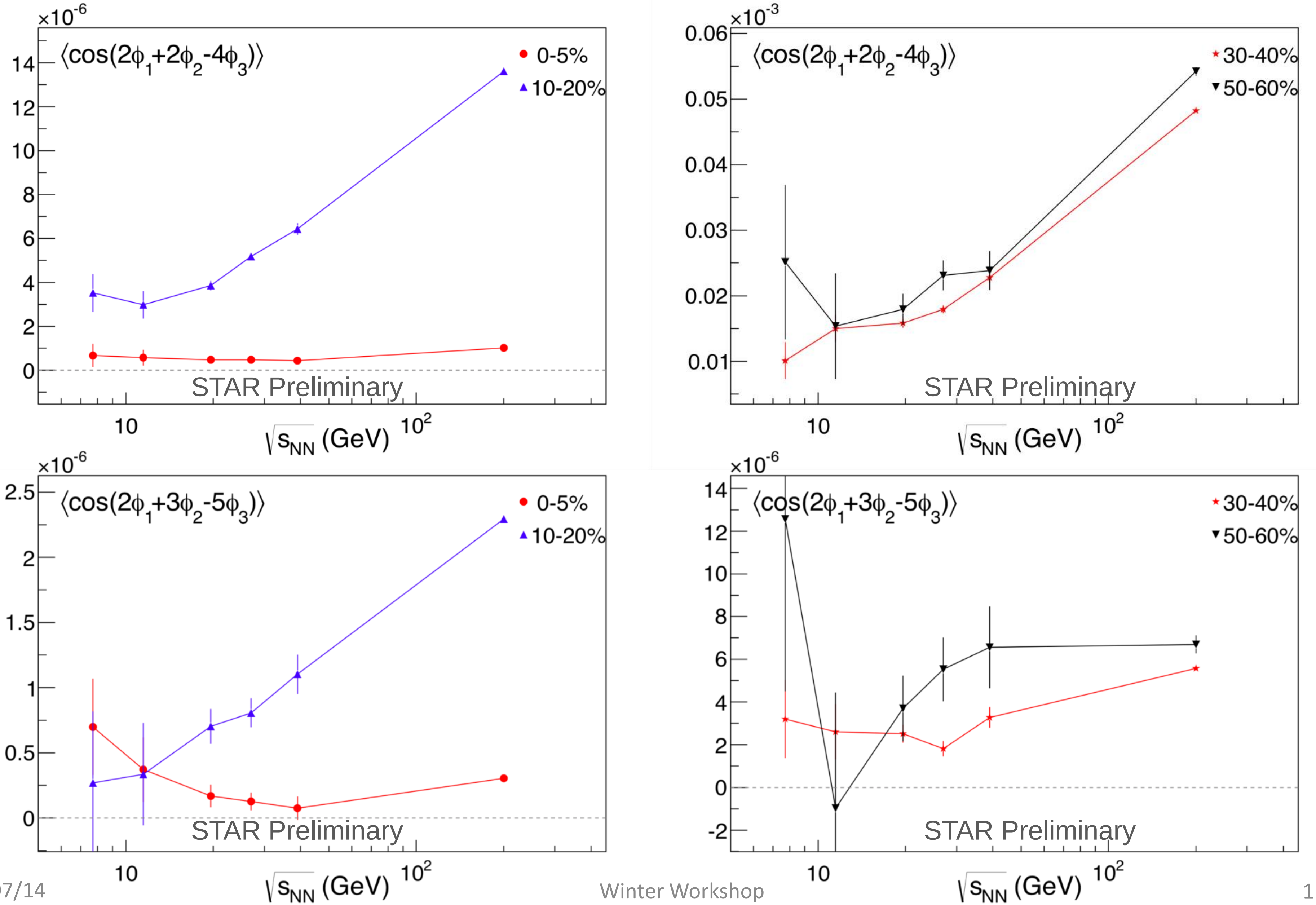
This also shows up in $\langle\cos(\varphi_1-\varphi_2)\rangle$: likely related to momentum conservation

Energy Dependence

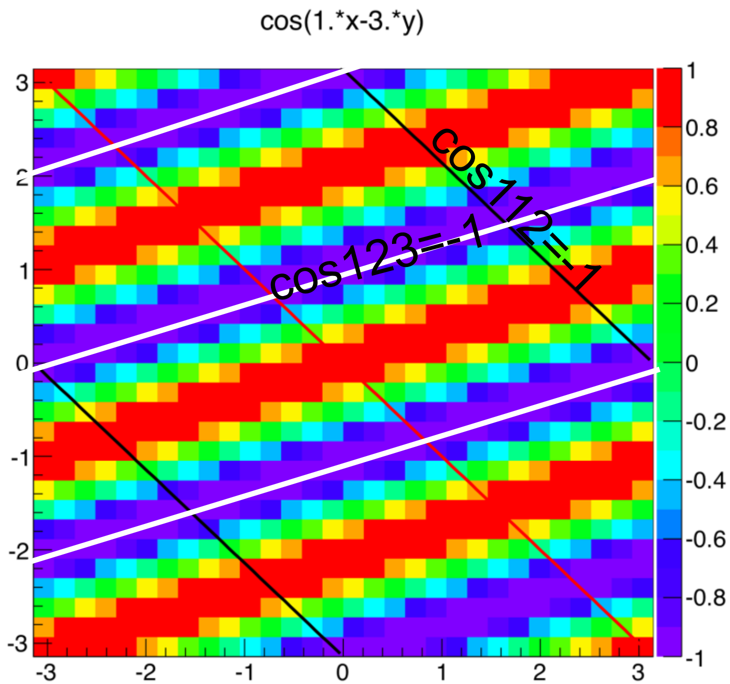




Even More Data…



What does it mean?



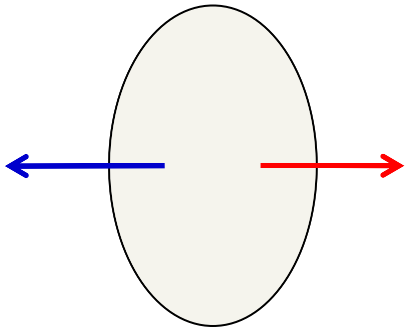
n=2 is dominated by the reaction plane so taking $\varphi' = \varphi - \Psi_2$

$$\langle \cos(1\varphi+2\varphi-3\varphi)\rangle \approx \langle \cos(1\varphi'-3\varphi')\rangle$$

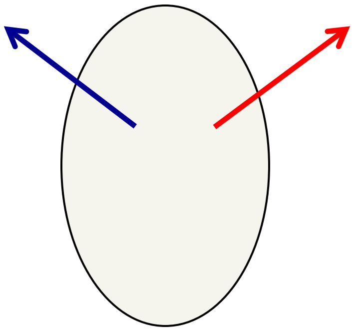
$$\langle \cos(1\varphi+1\varphi-2\varphi)\rangle \approx \langle \cos(1\varphi'+1\varphi')\rangle$$

The values we showed in the previous slide can be combined to conclude what configurations might explain the observed correlations

At low energies:
cos112<0, cos123<0 and cos224>0



At high energies:
cos112<0, cos123>0 and cos224>0



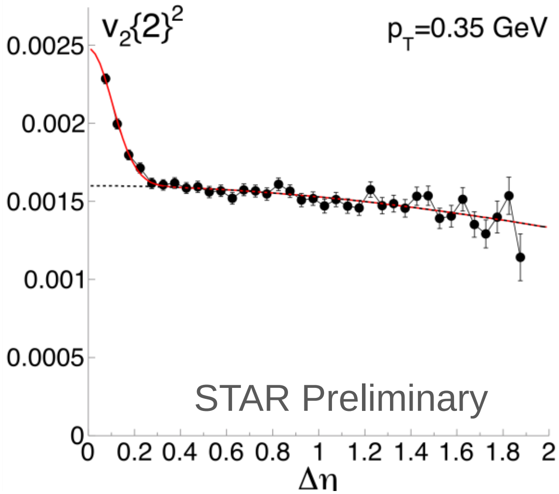
TWO PARTICLE CORRELATIONS

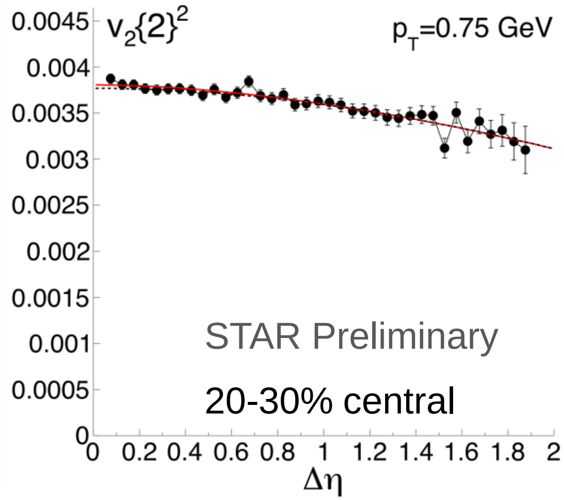
v_n vs centrality, p_T and energy:

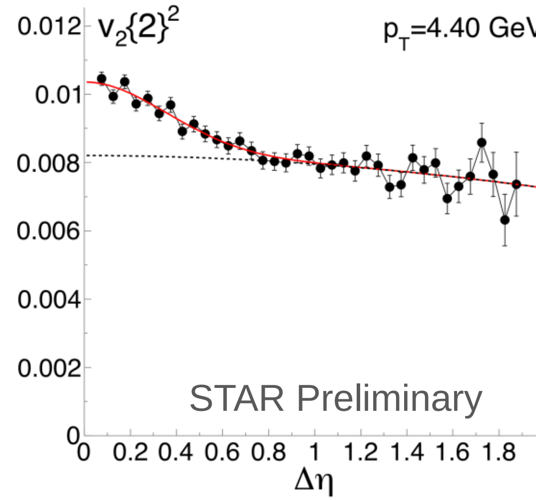
In what follows, $v_n^2\{2\}=\langle \cos n\Delta\phi \rangle$ with no assumptions about the underlying source of the correlations except where obvious short-range correlations can be isolated

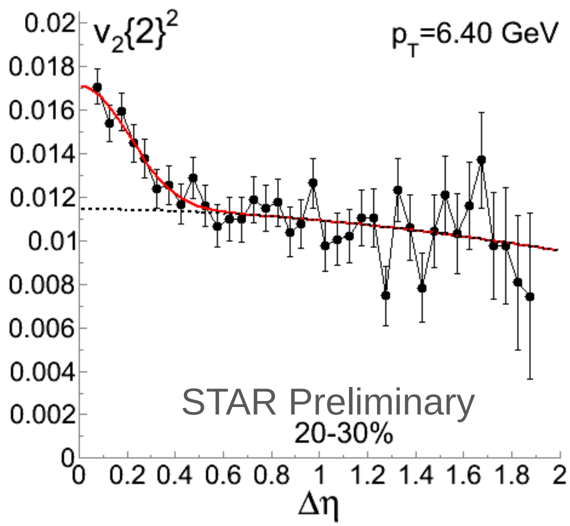
Extracting $v_n\{2\}$ from Δη dependence

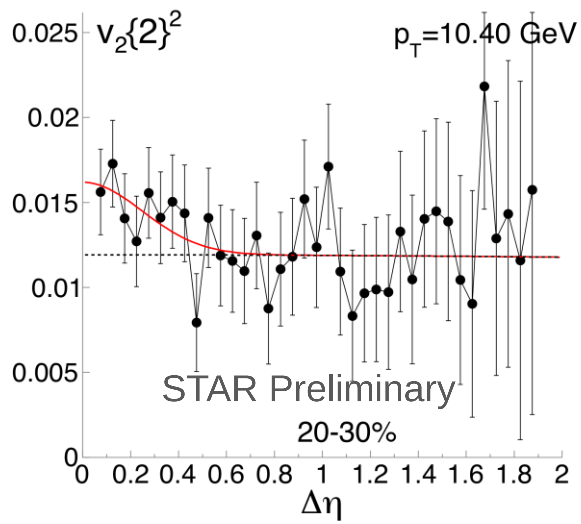
200 GeV











HBT, track-merging and short-range jet-like correlations isolated and removed

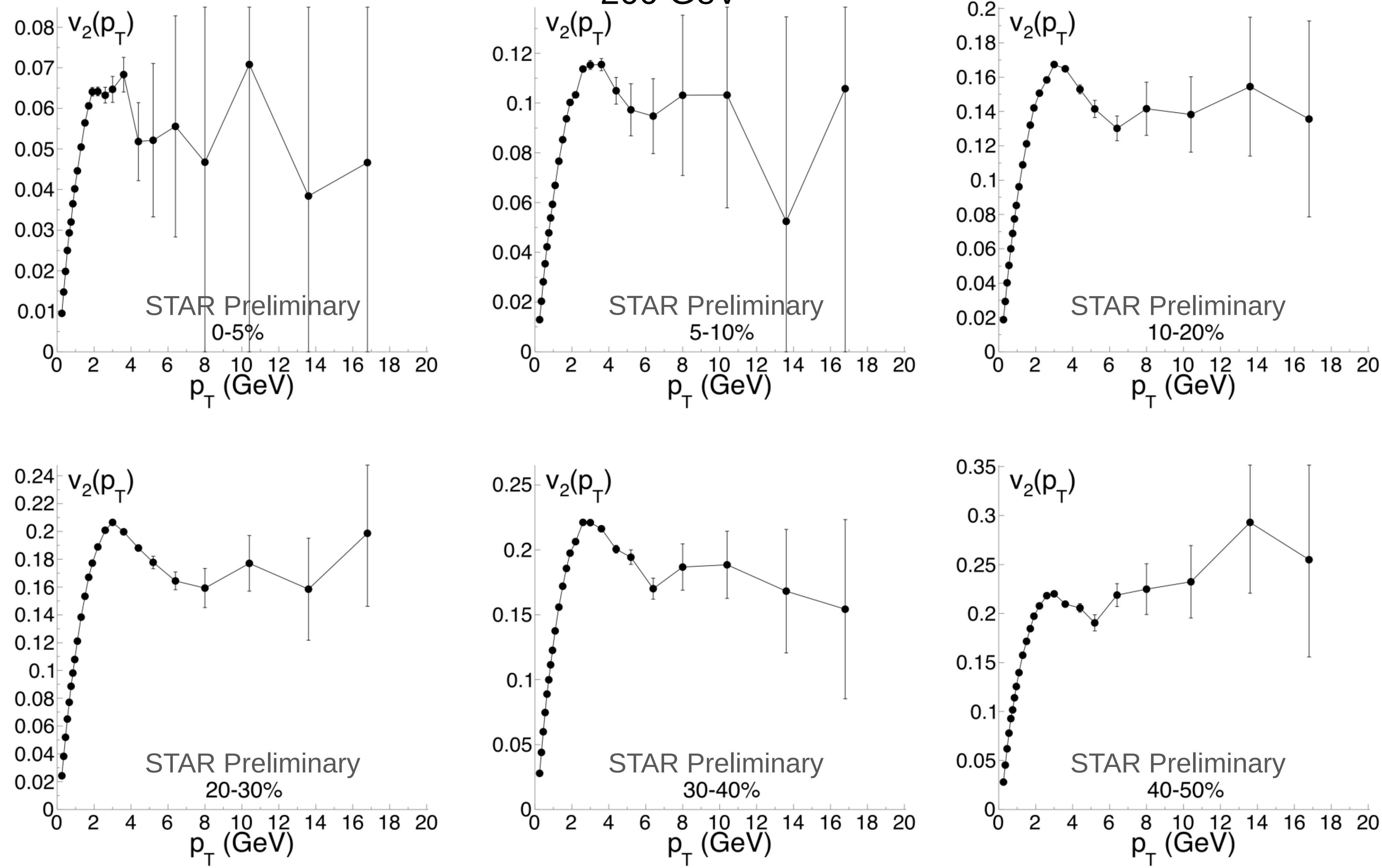
Analysis technique:

$$v_2(p_T) = \frac{\langle \cos 2(\varphi_i(p_T) - \varphi_j) \rangle}{\sqrt{\langle \cos 2(\varphi_i - \varphi_j) \rangle}}$$

HBT and jet-like small Δη correlations subtracted from $\langle \cos 2(\varphi_i - \varphi_j) \rangle (\Delta\eta)$ for each p_T bin.

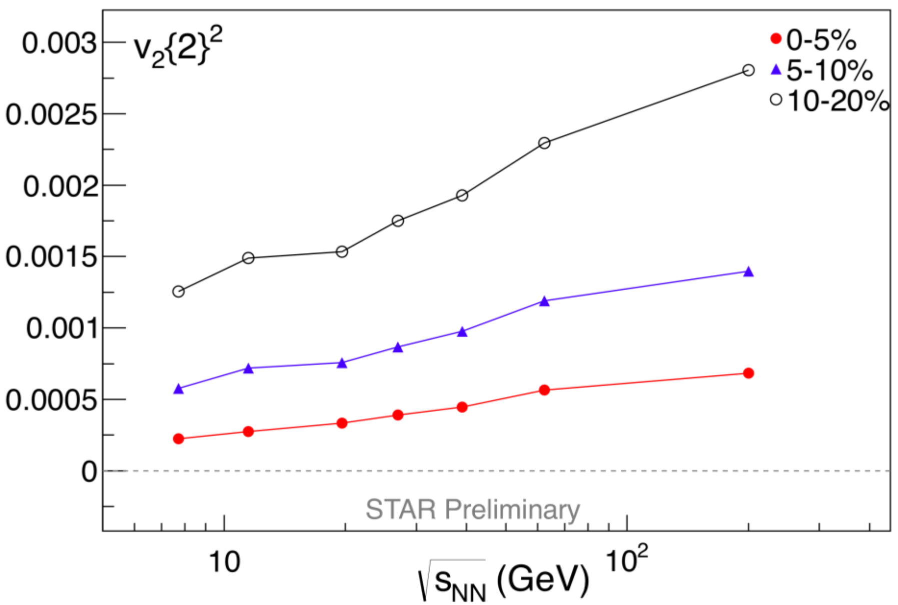
$v_2(p_T)$: narrow jet-peak removed

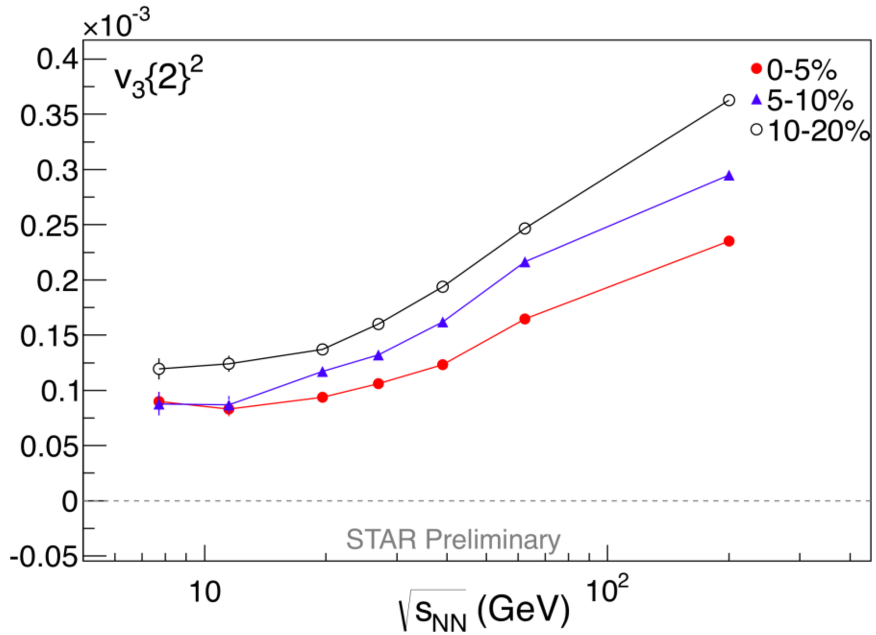
200 GeV



Energy Dependence of $v_n^2\{2\}$

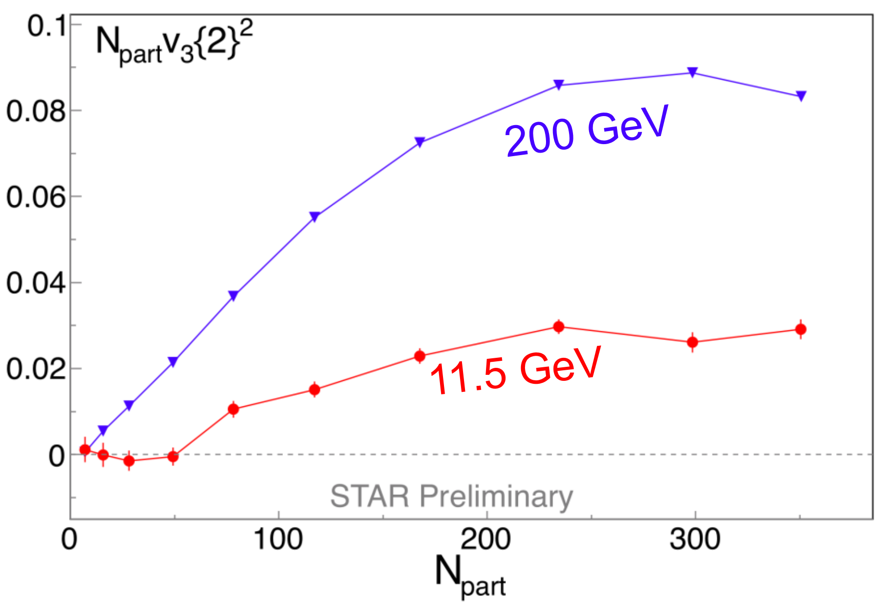
$v_3\{2\}$ persists down to 7.7 GeV

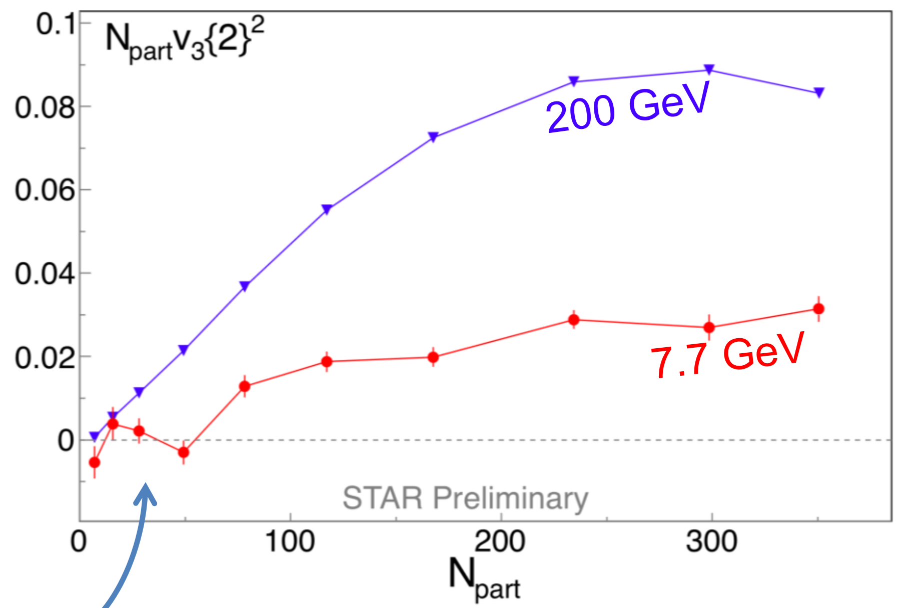




Some interesting structure: under study

Energy Dependence of $v_3^2\{2\}$





For N_{part}<50, $v_3\{2\}$ at 11.5 and 7.7 GeV is consistent with zero

consistent with sharp transition in STAR Phys.Rev.C.86.064902

but at 7.7 GeV, minjets are not a likely source for the non-zero $v_3\{2\}$ in central

Conclusions

- Three-particle correlations show the expected geometry fluctuations (p+A next to A+A)
- Comparisons made with a hydro model
  - $\langle\cos(\phi_1+2\phi_2-3\phi_3)\rangle$ agrees but others strongly deviate
  - models are sensitive to viscosity, freeze-out temperature, etc. and vary a lot: lack of predictive power? vs data are highly sensitive to parameters? We need a better evaluation of model systematics.
  - overconstrains and challenges the models
- v_2 measured out to almost 20 GeV vs centrality. Data shows a flat high p_T region
- v_n measured vs energy: v_3 persists down to 7.7 GeV in sharp contrast to a mini-jet picture

REFERENCE SLIDES

New Calculations, now w/Non-linear Terms

2. Linear response assumes, in the spectrum,

$$v_n(p_T)e^{-in\Psi_n} = w_n(p_T)e^{-in\Phi_n}$$

so i. $v_n \propto w_n \propto \varepsilon_n$ and ii. $\Phi_n = \Psi_n$.

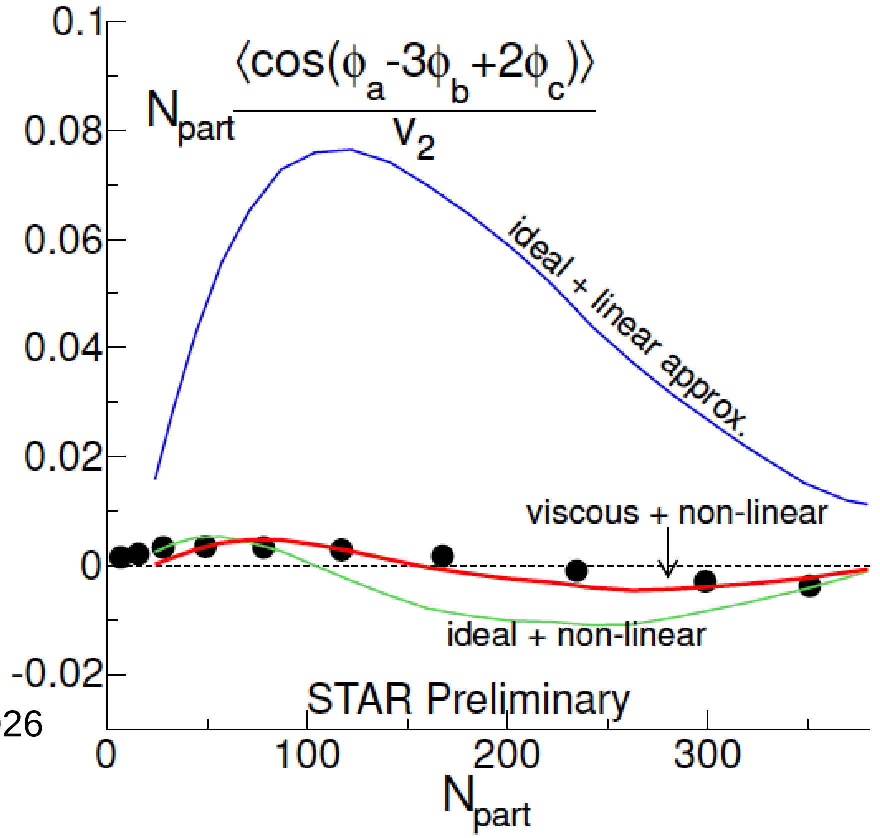
Linear response neglects non-linear terms

$$v_1 e^{-i\Psi_1} = w_1 e^{-i\Phi_1} + \underline{w_{1(23)}e^{-i(3\Phi_3 - 2\Phi_2)}}$$

$$v_4 e^{-i4\Psi_4} = w_4 e^{-i4\Phi_4} + \underline{w_{4(22)}e^{-i4\Phi_2}}$$

$$v_5 e^{-i5\Psi_5} = w_5 e^{-i5\Phi_5} + \underline{w_{5(23)}e^{-i(3\Phi_3 + 2\Phi_2)}}$$

Teaney and Yan: see for example, 1206.1905, 1210.5026



Very sensitive probe of viscous and non-linear effects in the evolution

→Chance to over-constrain models and pin down the characteristics of the expansion