Energy dependence of the freeze out eccentricity from azimuthal dependence of HBT at STAR

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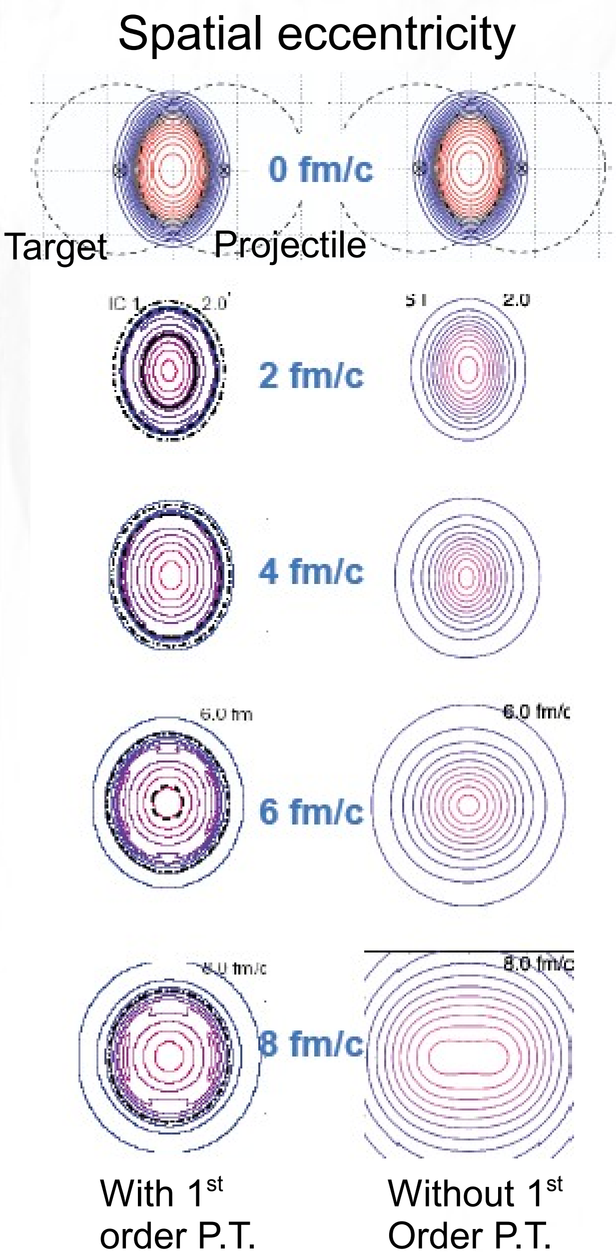
Outline

- Introduction and motivation
- Analysis methods
- Results
- Model Comparisons
- Summary and outlook

Time evolution of the collision geometry



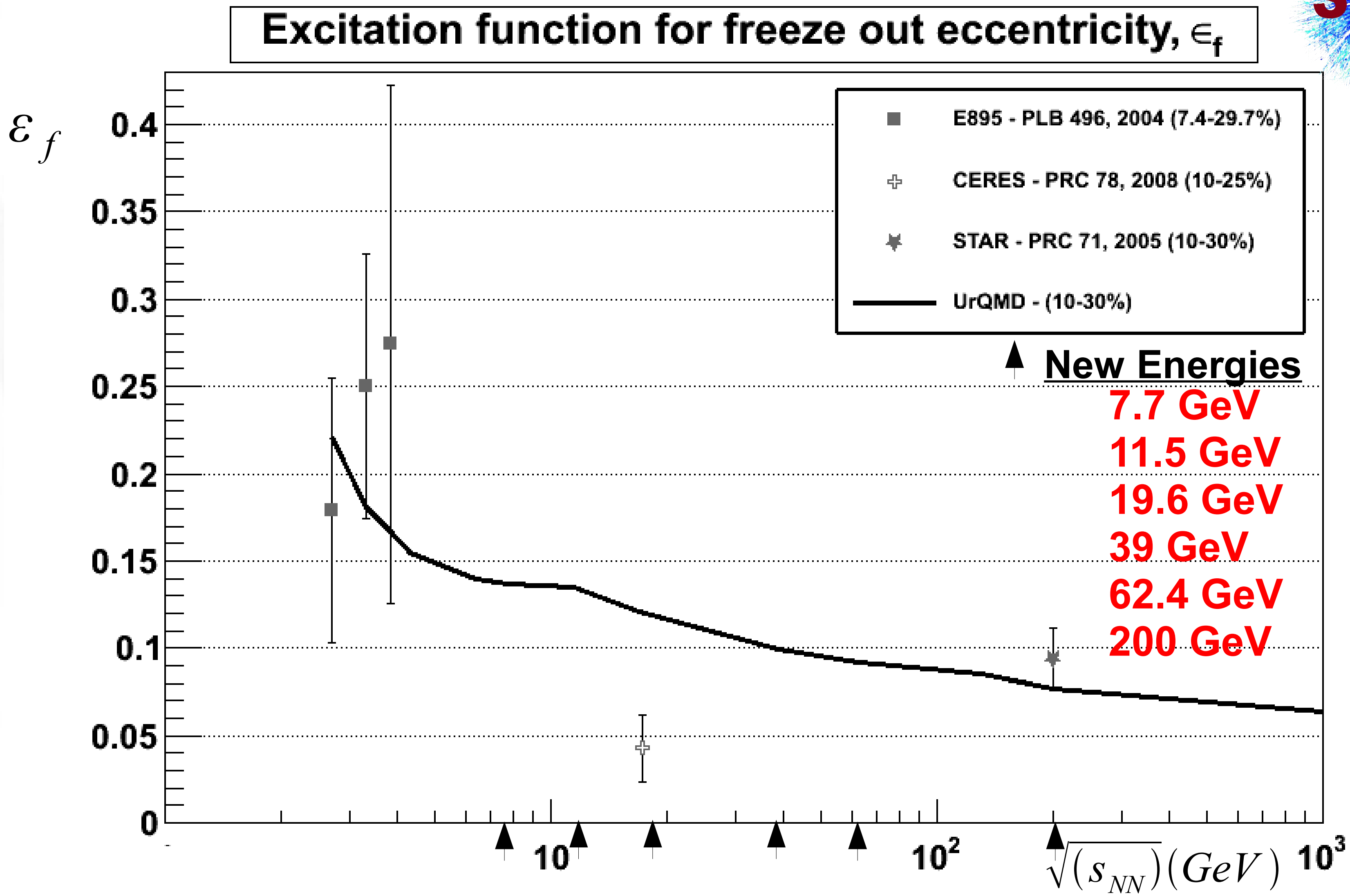
Reference: Kolb and Heinz, 2003, nucl-th/0305084

- Initial out-of-plane eccentricity
- Stronger in-plane pressure gradients drive preferential in-plane expansion
- Longer lifetimes or stronger pressure gradients cause more expansion and more spherical freeze-out shape
- We want to measure the eccentricity at freeze out, ε_F, as a function of energy using azimuthal HBT:

$$\varepsilon_F = \frac{R_y^2 - R_x^2}{R_y^2 + R_x^2}$$

- Non-monotonic behavior could indicate a soft point in the equation of state.

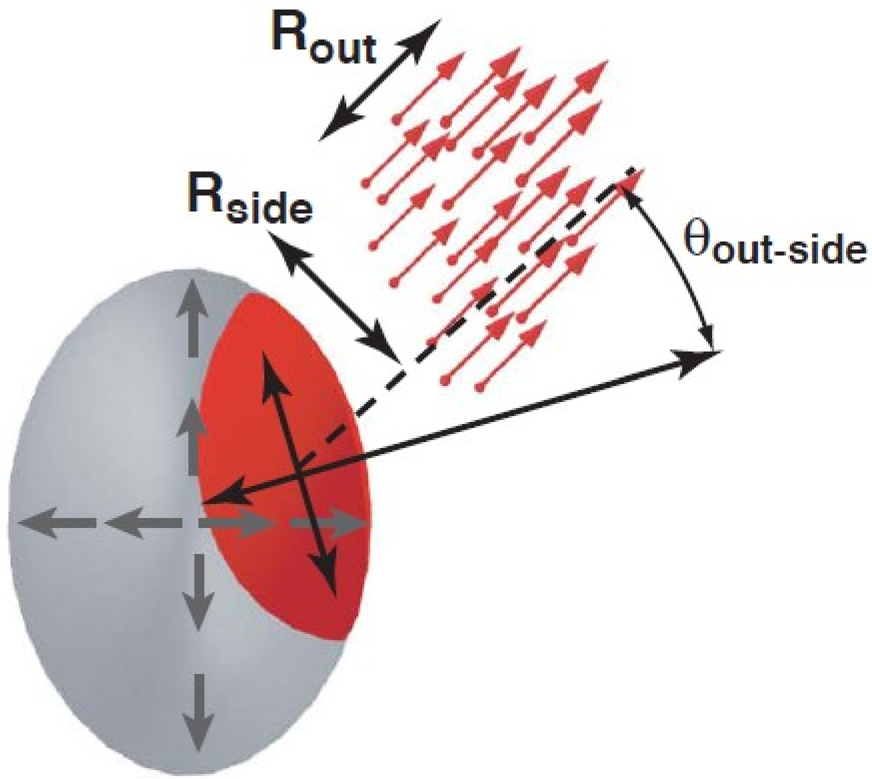
Motivation



- **Non-monotonic behavior may indicate interesting physics.**
- **Excitation function can constrain models.**

Reference: Lisa, Frodermann, Graef, Mitrovski, Mount, Petersen, Bleicher, *New J. Phys.* 2011, arxiv:1104.5267

Coordinate system (out-side-long)



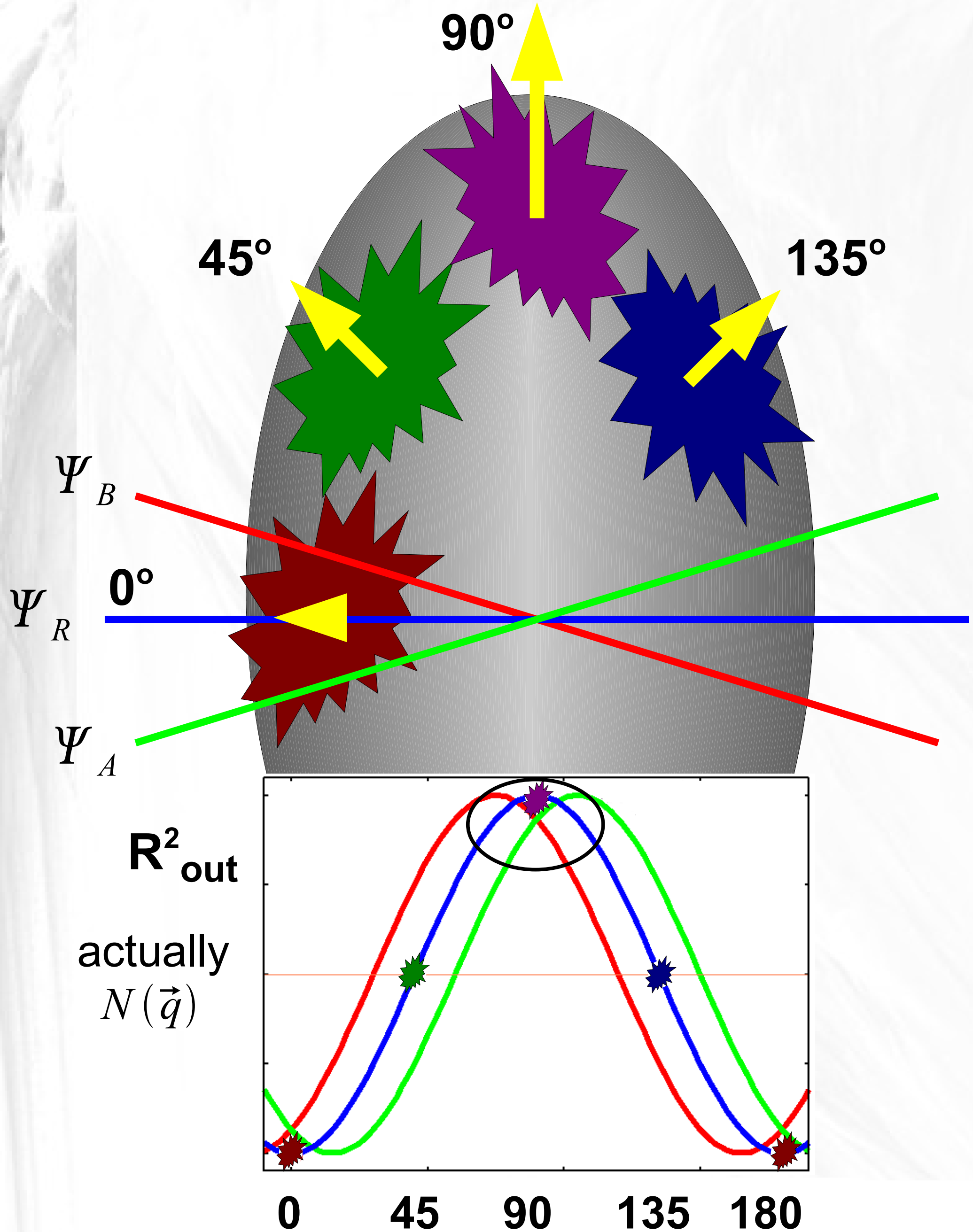
$$\vec{k}_t = \frac{1}{2}(\vec{p}_{t1} + \vec{p}_{t2})$$

$$\vec{q} = \vec{p}_1 - \vec{p}_2$$

- Particles from similar source region tend to have similar momentum.
- Project $\bar{q}$ onto out-side-long coordinates.
- The same event distribution, $N(\bar{q})$, has enhancement near q = 0.
- The mixed event distribution, D(q), has no enhancement.
- The correlation function is

$$C(q_o, q_s, q_l) = \frac{N(\vec{q})}{D(\vec{q})}$$

Event plane resolution and finite angular bins



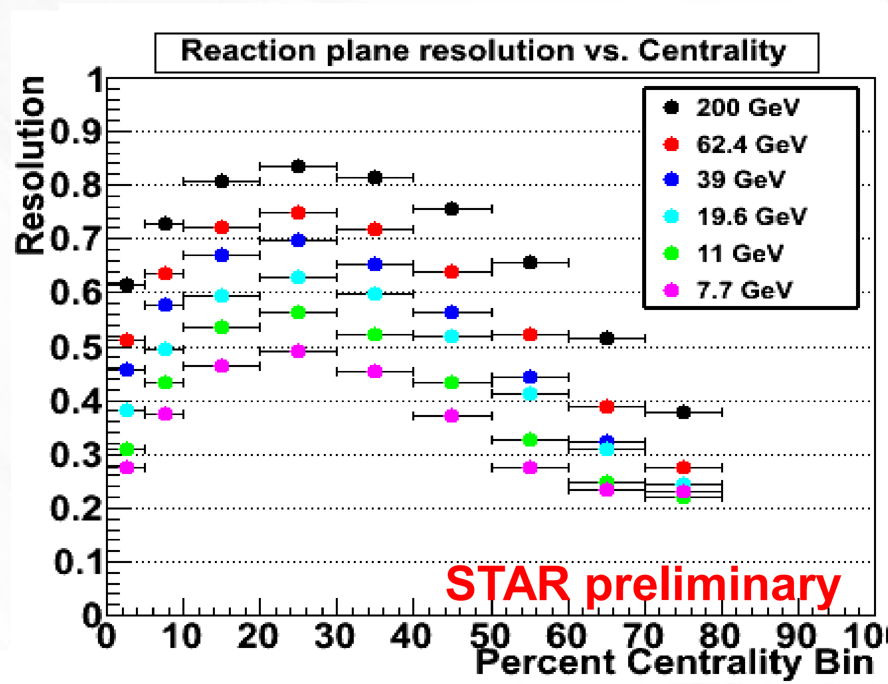
Oscillations reduced by

- reaction plane resolution

$$\langle \cos[2(\Psi_m - \Psi_R)] \rangle$$

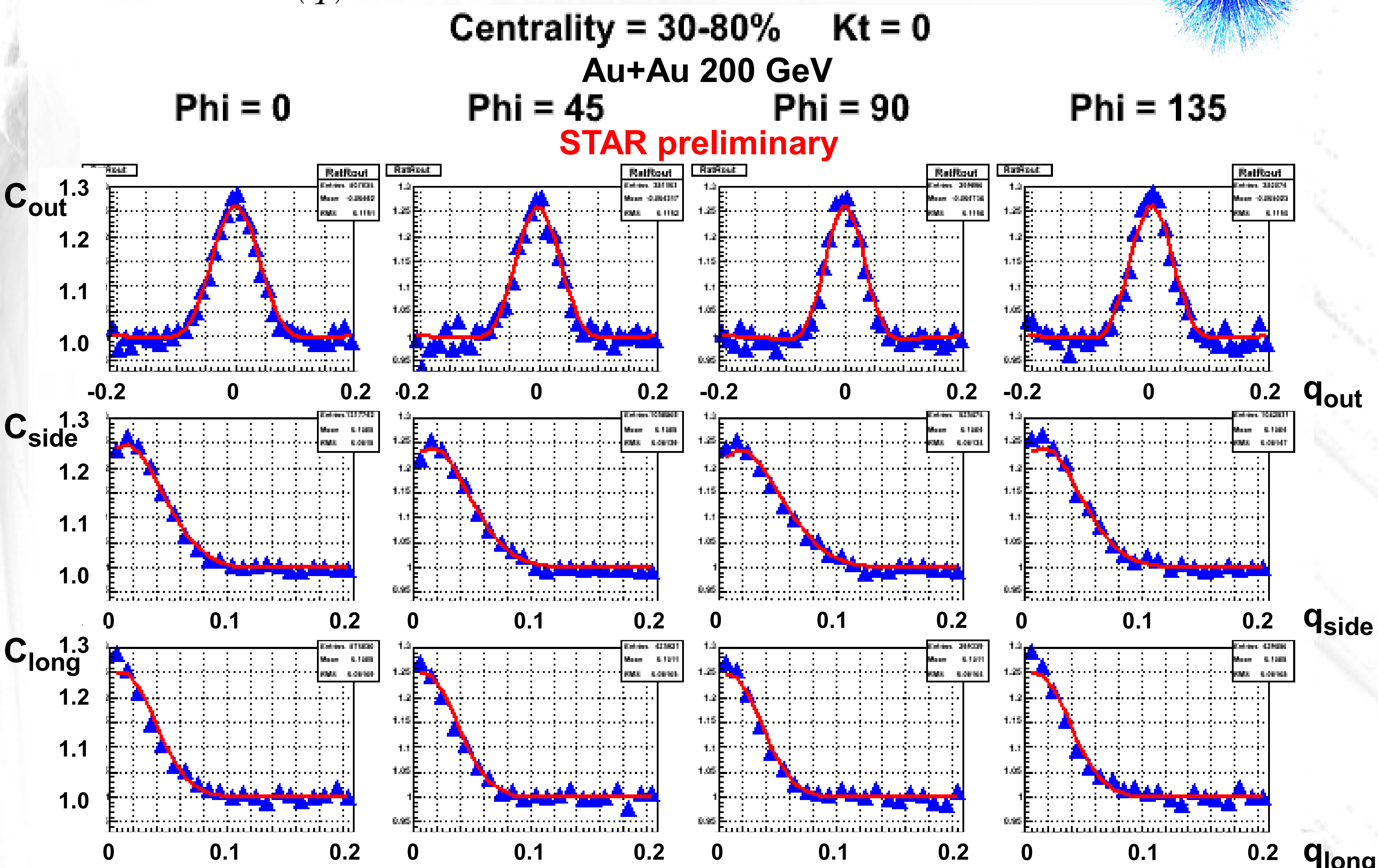
- and finite angular bins

$$\frac{\sin(n\Delta/2)}{n\Delta/2}$$



Fitting procedure

$$C(q_o, q_s, q_l) = \frac{N(\vec{q})}{D(\vec{q})} = (1-\lambda) + \lambda K_{Coul}(q_{inv})(1 + e^{-q_o^2 R_o^2 - q_s^2 R_s^2 - q_l^2 R_l^2 - 2 q_o q_s R_{os}^2})$$



Computing Fourier Coefficients

Fourier coefficients computed from radii:

$$R^2_{0,i} = \frac{1}{N_{bins}} \sum_{j=1}^{N_{bins}} R^2_i(\Phi_j) \qquad i = o, s, l, os$$

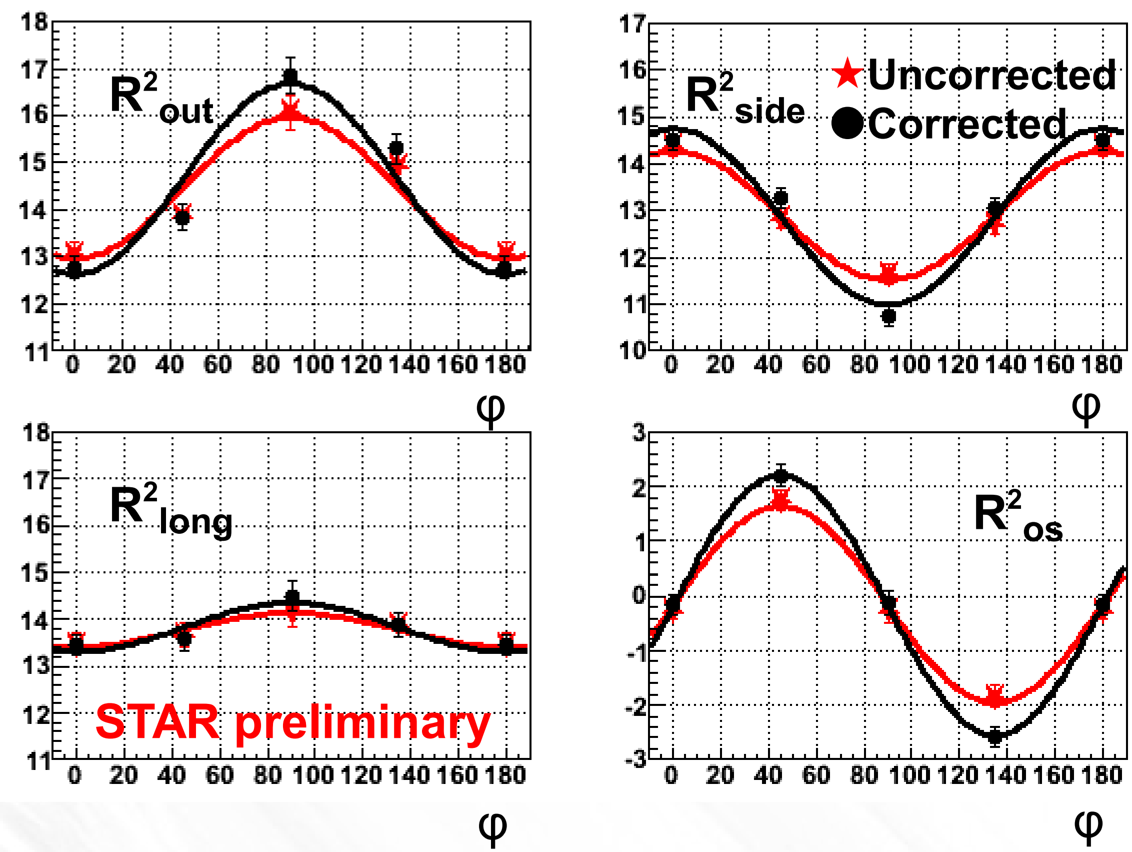
$$R^2_{2,i} = \frac{1}{N_{bins}} \sum_{j=1}^{N_{bins}} R^2_i(\Phi_j) \cos(2\Phi_j) \qquad i = o, s, l$$

$$R^2_{2,i} = \frac{1}{N_{bins}} \sum_{j=1}^{N_{bins}} R^2_i(\Phi_j) \sin(2\Phi_j) \qquad i = os$$

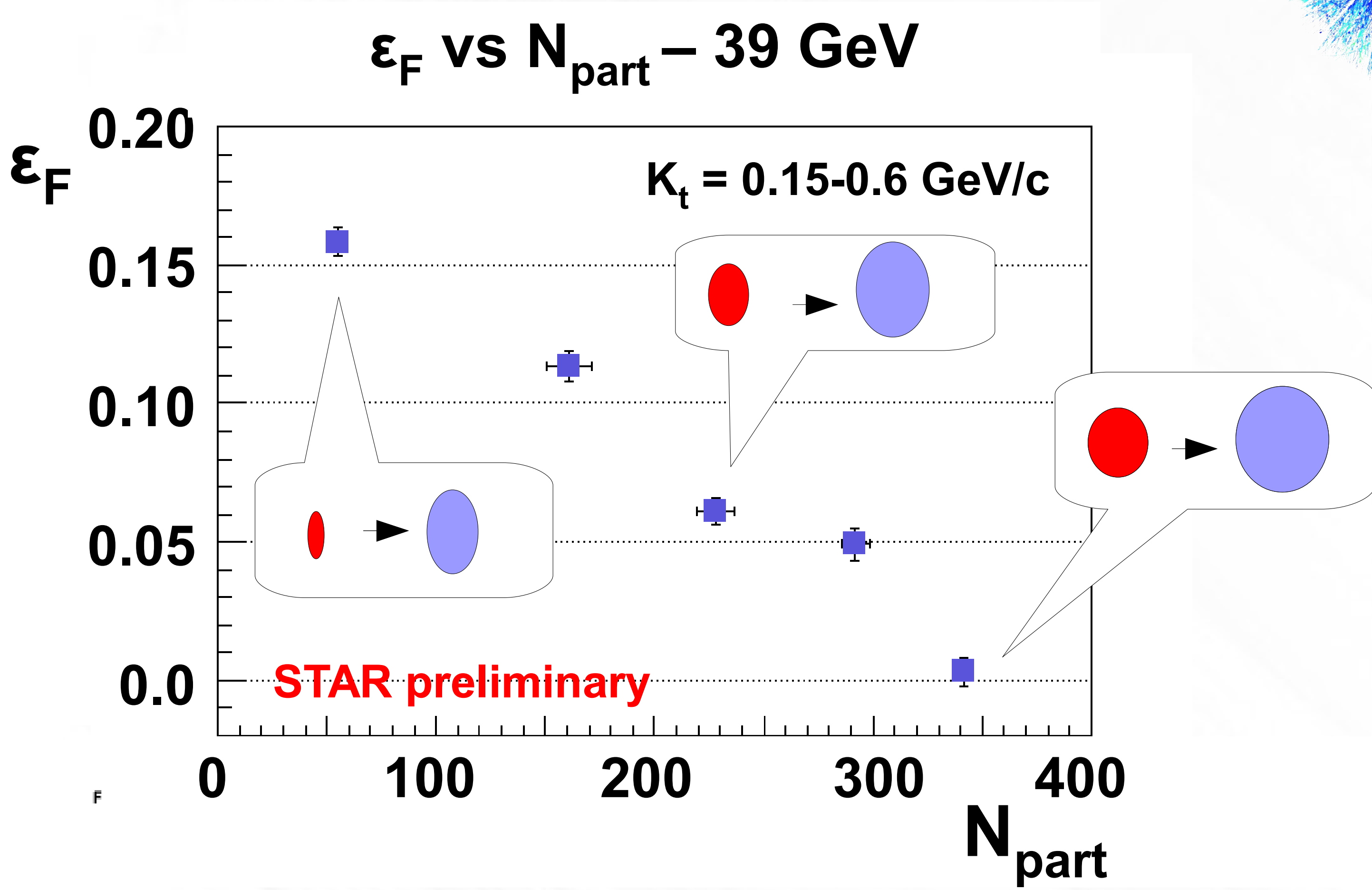
$$\varepsilon_F = \frac{R^2_y - R^2_x}{R^2_y + R^2_x} \approx 2\frac{R^2_{2,s}}{R^2_{0,s}}$$

Reference: Lisa, Retiere, *Phys. Rev. C*, 70, 044907

Au+Au 200 GeV
Oscillations for 20-30% Centrality and K_t = 0.35-0.60 GeV/c

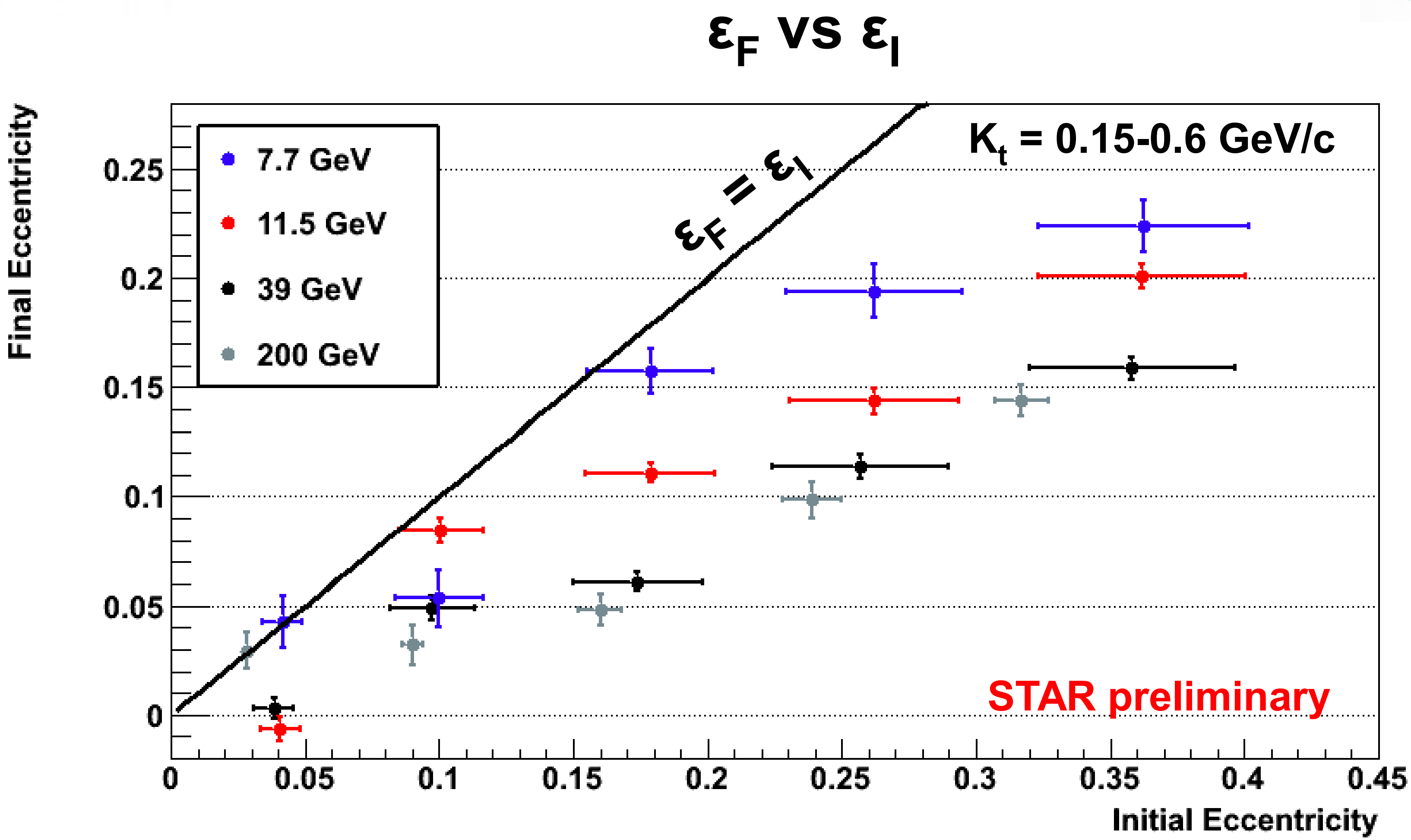


Centrality dependence of ε_F



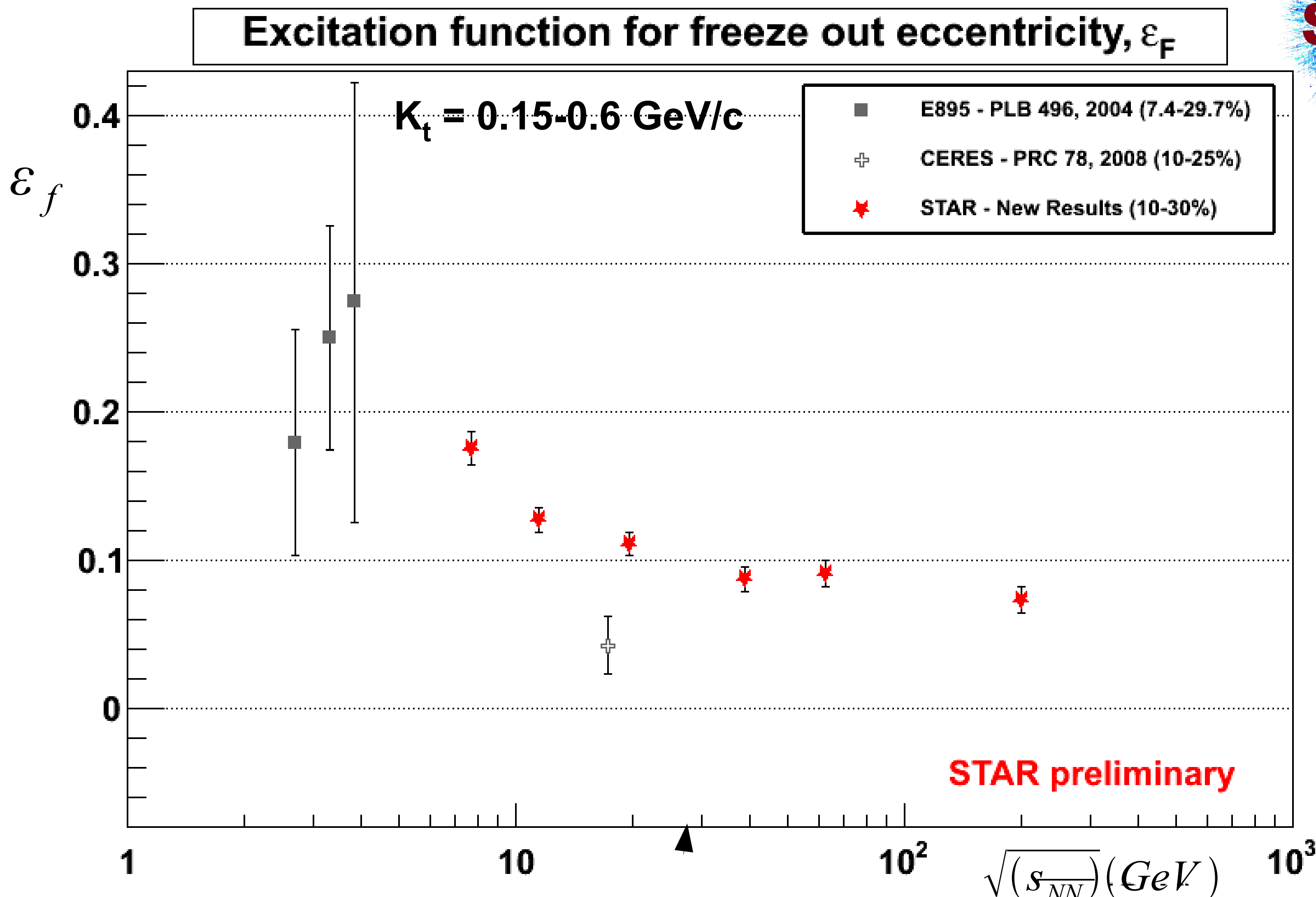
- Peripheral events remain more out-of-plane extended than central events.

Evolution of participant zone shape



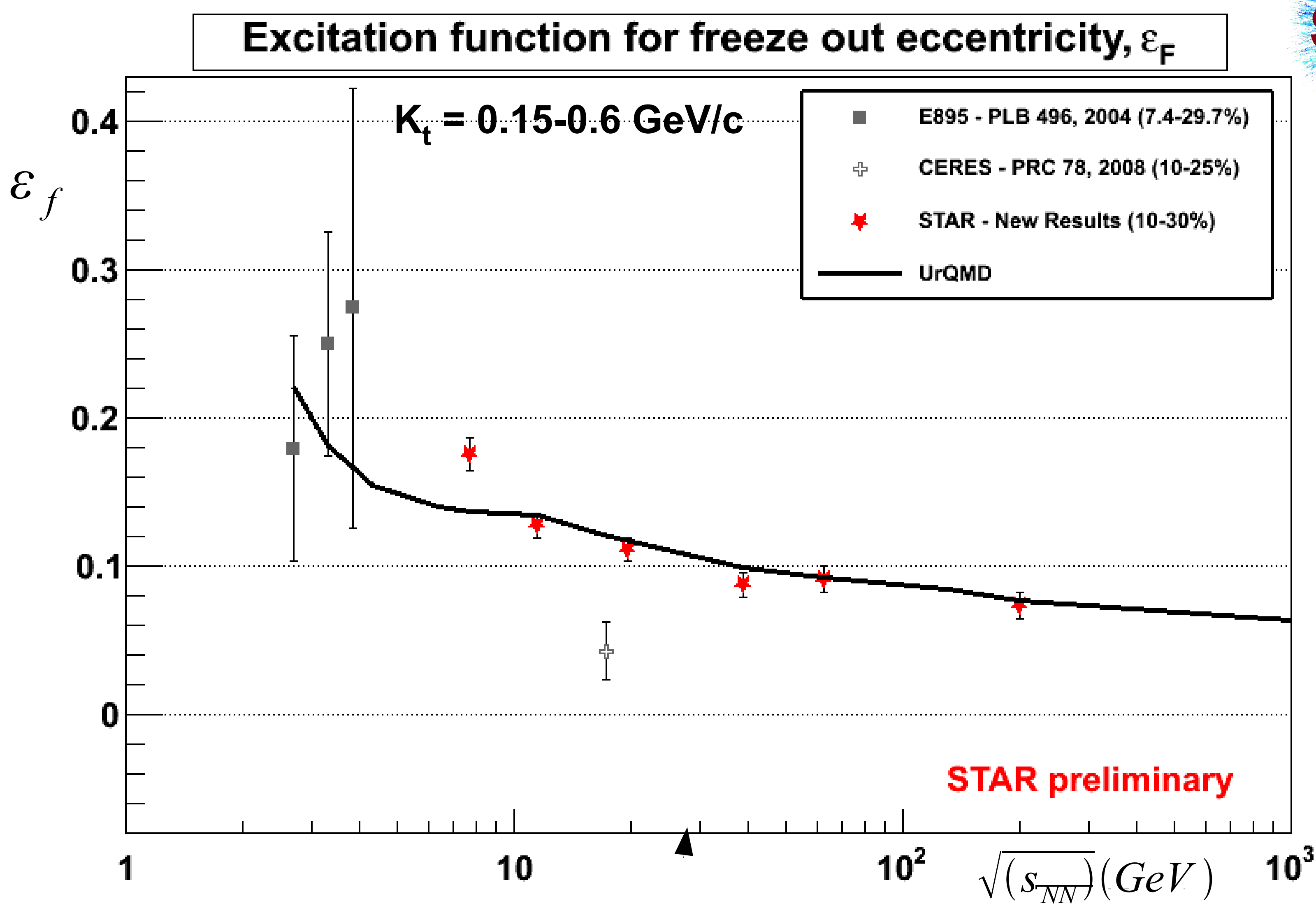
- The shape evolves more for higher energy in the 7 – 39 GeV range.
- Results remain similar to 39 GeV at higher energies.
- Central events evolve less than peripheral.
- Similar trend with centrality for all energies.

Energy dependence of ε_F



- BES results suggest ε_F falls monotonically with energy.
- New 19.6 GeV result does not reproduce the minimum near 17.3 GeV.
- Recent 27 GeV data will provide an additional point.

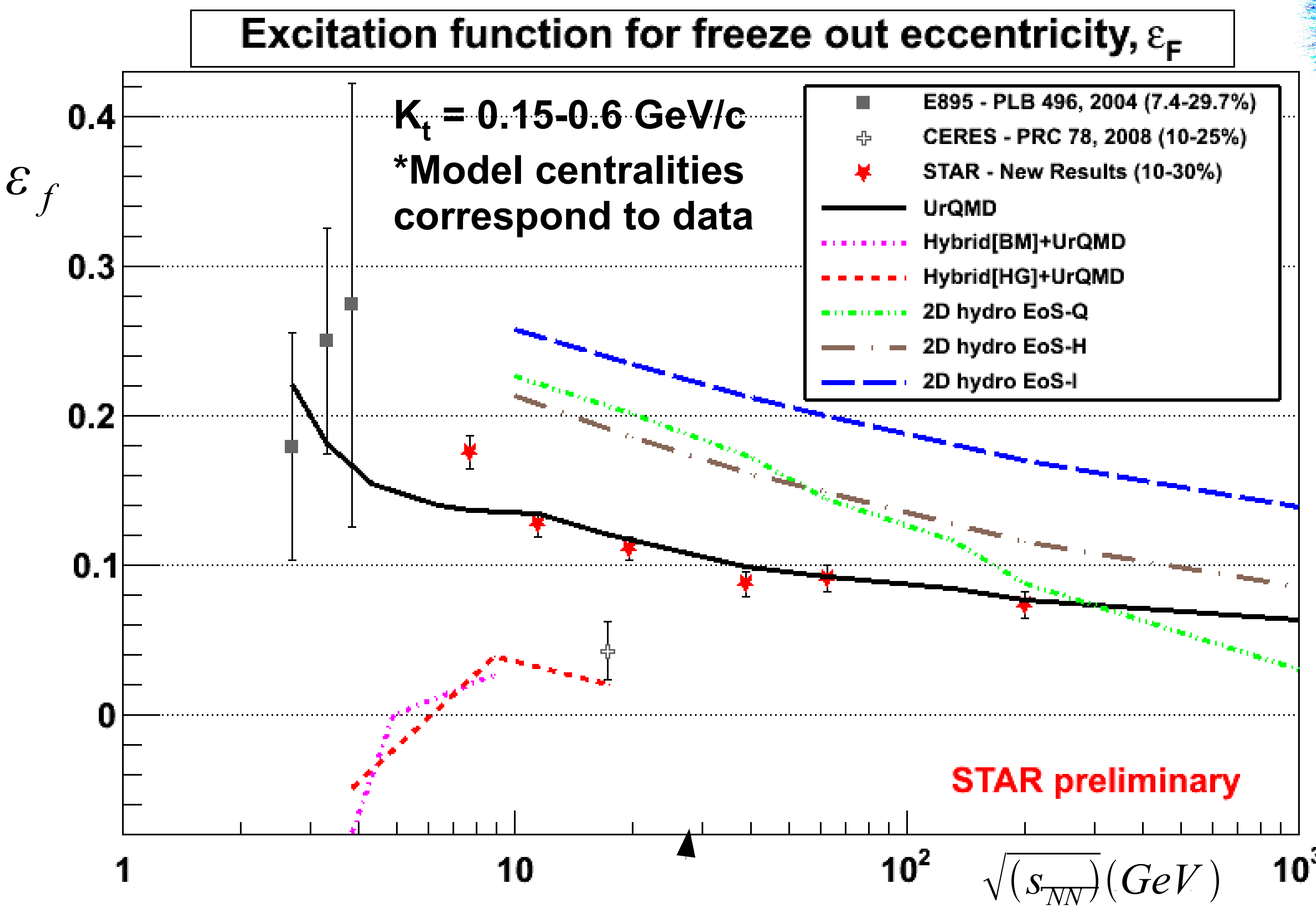
Model Comparisons



- **UrQMD generally predicts the trend seen in the STAR data.**

Reference: Lisa, Frodermann, Graef, Mitrovski, Mount, Petersen, Bleicher, *New J. Phys.* 2011, arxiv:1104.5267

Model Comparisons



- UrQMD appears to predict the STAR data most closely.
- All models predict monotonic decrease with energy.

Reference: Lisa, Frodermann, Graef, Mitrovski, Mount, Petersen, Bleicher, *New J. Phys.* 2011, arxiv:1104.5267

Summary and outlook

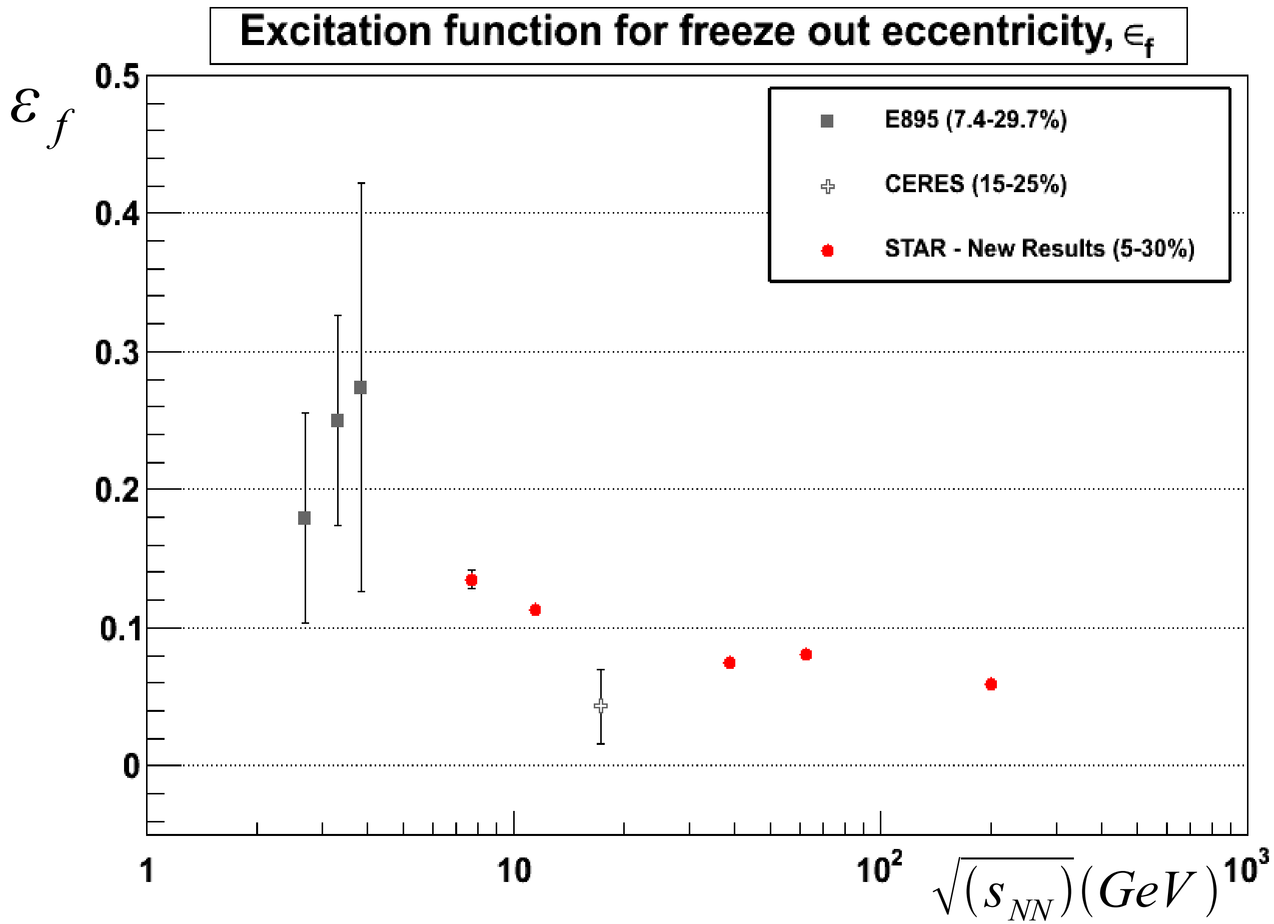
- Azimuthal HBT searches for signals of a phase transition.
- The current Beam Energy Scan results suggest a monotonic decrease in the freeze-out eccentricity with energy.
- The minimum suggested by the CERES point at 17.3 GeV is not reproduced by the STAR data at 19.6 GeV.
- UrQMD appears to best describe the STAR results.
- The sensitivity of model predictions of ε_F to the equation of state should allow this observable to constrain models.
- Recent 27 GeV data will provide additional information..

Backup slides

5-10% + 10-20% + 20-30%
STAR small cent + CERES large cent

STAR
10-20% = x1
20-30% = x1
5-10% = x1

CERES
15-25% = x1



STAR
5-30%

CERES
15-25%

E895
7.4-29.7%

STAR 5-30% includes 10% more central + 5% more peripheral than CERES 15-25%. The error bar for CERES 15-25% is larger in this case. This is the case where no weights are applied to account for the centrality bin widths so the STAR values are the lowest of the possible cases.

Data Sets and Cuts

$\sqrt{(s_{NN})}(GeV)$	**Event Cuts**
7.7	$\lvert V_z \rvert < 50$ cm $V_r < 2.0$ cm ½ TPC empty cut
11.5	$\lvert V_z \rvert < 50$ cm $V_r < 2.0$ cm ½ TPC empty cut
39	$\lvert V_z \rvert < 30$ cm $V_r < 2.0$ cm $\lvert \eta_{SymTPC} \rvert < 3$
62.4	$\lvert V_z \rvert < 30$ cm $\lvert V_x \rvert$& $\lvert Vy \rvert$< 1.0 cm $\lvert \eta_{SymTPC} \rvert < 3$
200	$\lvert V_z \rvert < 25$ cm $\lvert V_x \rvert$& $\lvert Vy \rvert$< 1.0 cm $\lvert \eta_{SymTPC} \rvert < 3$

Track Cuts:

Reaction Plane

$0.15 < P_t < 12.0$ GeV/c

$\lvert \eta \rvert < 1.3$

15<nFitPts<50

0.52<nFitOverMax<1.05

HBT analysis

$0.1 < P_t < 1.0$ GeV/c

$\lvert y \rvert < 0.5$

NHits >= 10

2D DCA < 3.0 cm

nσ π <= 2

nσ k,p,e > 2

Pair Cuts:

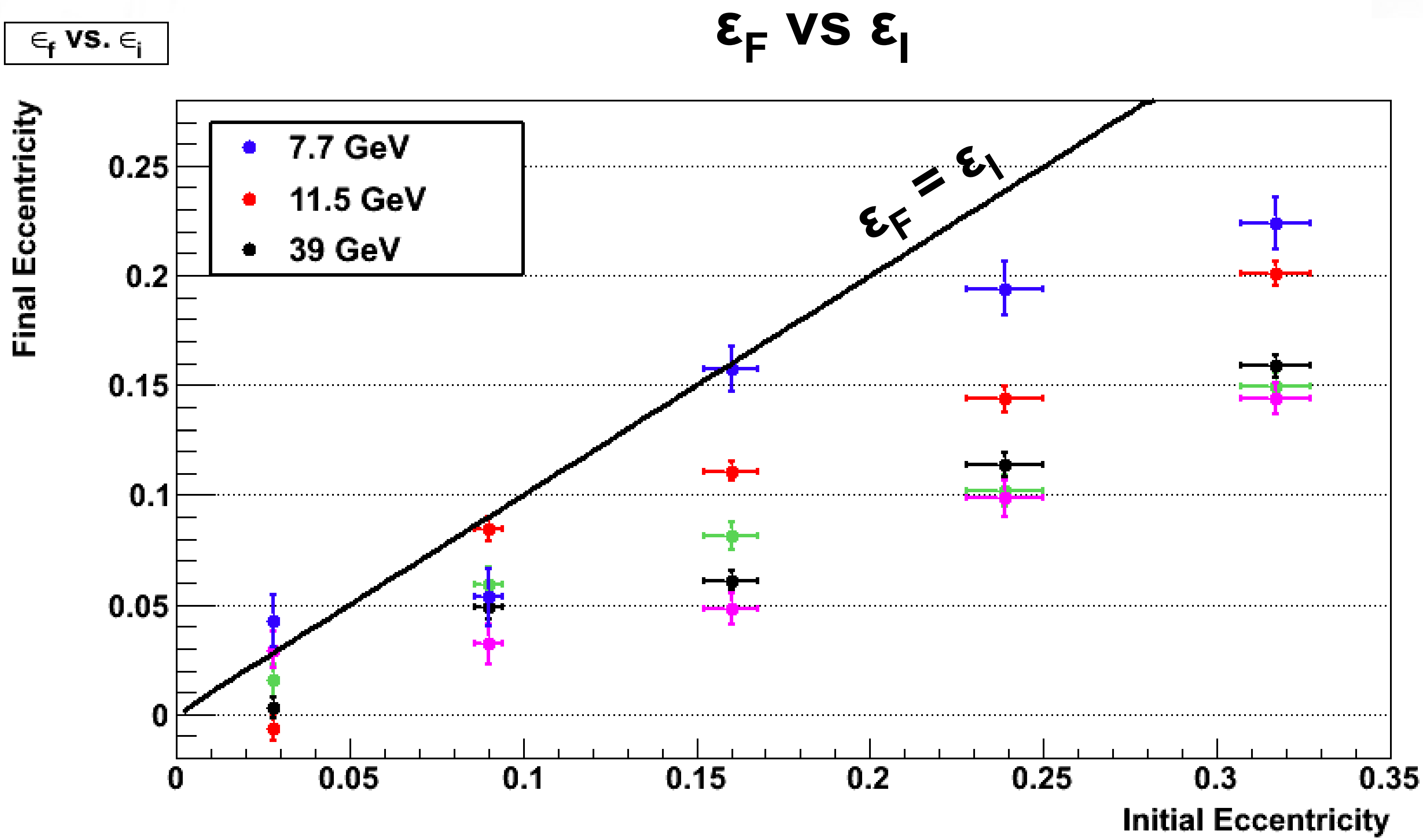
HBT analysis

$0.15 < K_t < 0.6$ GeV/c

Fraction Merged Hits < 0.1

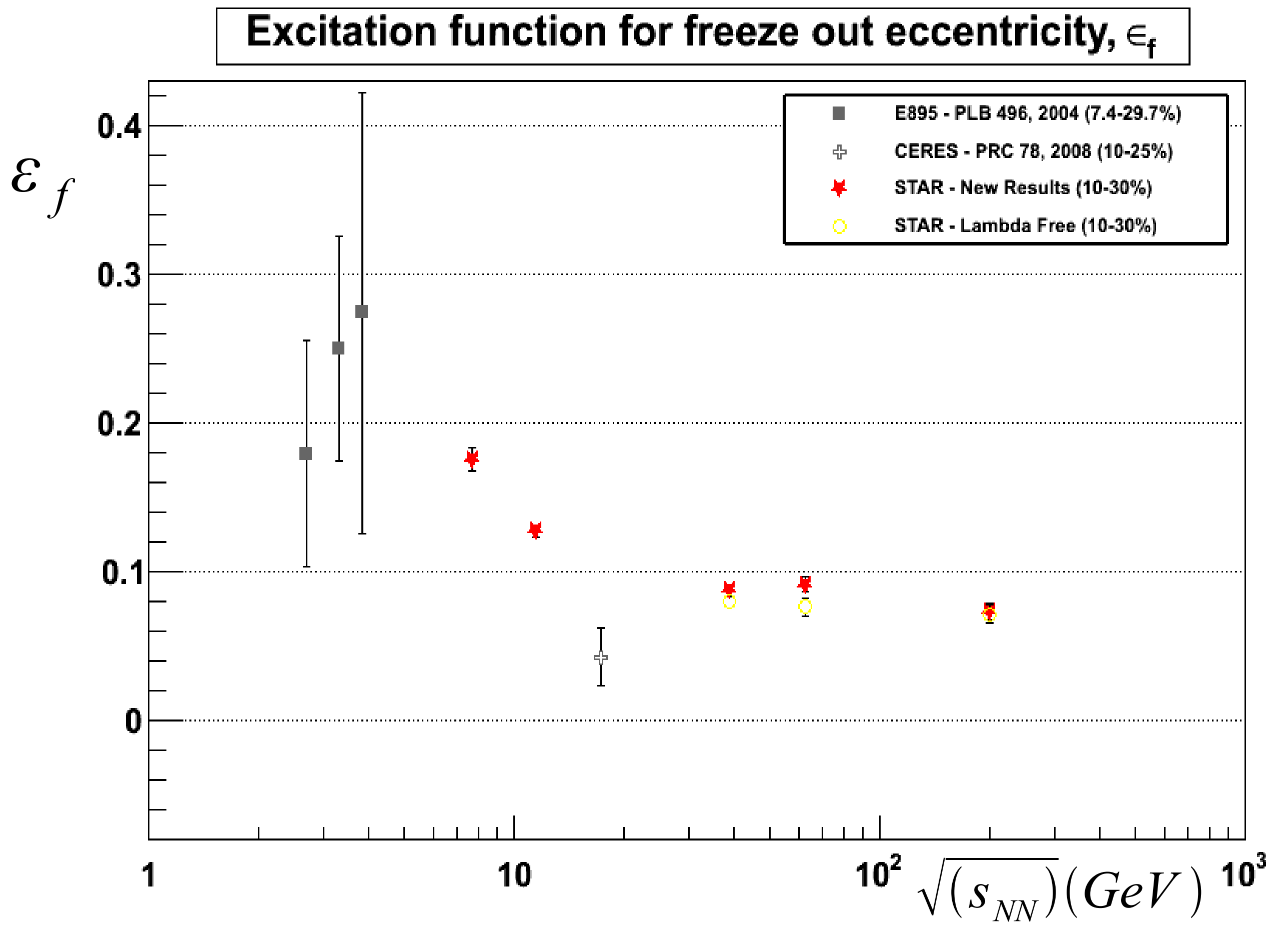
-0.5<Quality<0.6

Evolution of participant zone shape



- The shape evolves more for higher energy in the 7 – 39 GeV range.
- The 62.4 and 200 GeV results remain similar to 39 GeV.
- ε_I was computed using a Monte Carlo Glauber model for 200 GeV collisions, same percent centrality binning is used for each energy.

A Quick Lambda Free Check



Conclusions:
Using the lambda Free results gives the same conclusion. The results are very similar for 39 and 200 GeV while the 62.4 GeV point is a little lower for lambda free. The Lambda Fixing is not responsible for the difference in STAR and CERES points.

Y4 62.4 GeV – Two correction schemes