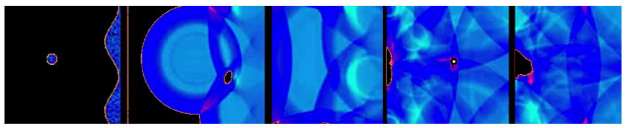
Δη-Δφ correlations and ridge in STAR

L.C. De Silva

for the STAR collaboration

University of Houston

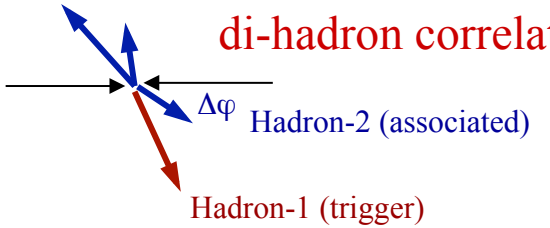


28th Winter Workshop on Nuclear Dynamics
Dorado del Mar, Puerto Rico

Outline

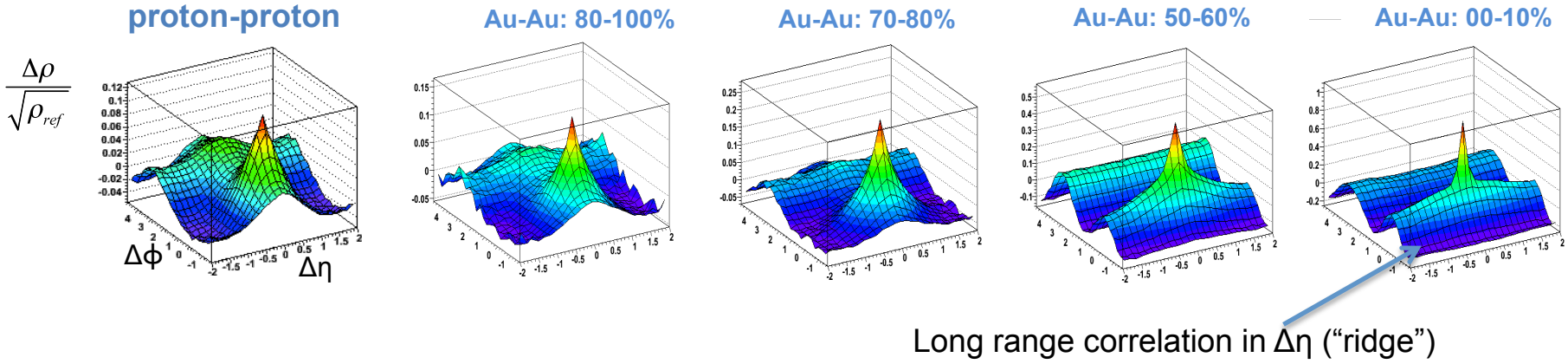
- Motivation
- Correlation measure
- P_T dependence of $\Delta\eta$-$\Delta\varphi$ correlations
- Model fit function
- Data interpretation
- Other ridge studies from STAR
- Summary and discussion

Motivation – long range correlation in Δη



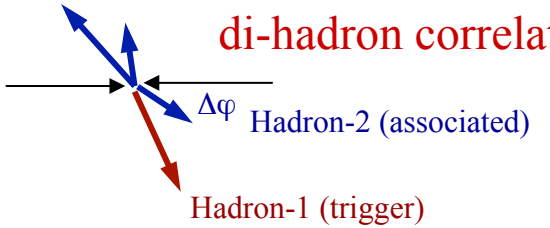
Centrality evolution using all charged particles – Untriggered analysis

STAR preliminary



Long range correlation in Δη (“ridge”)

Motivation – long range correlation in Δη

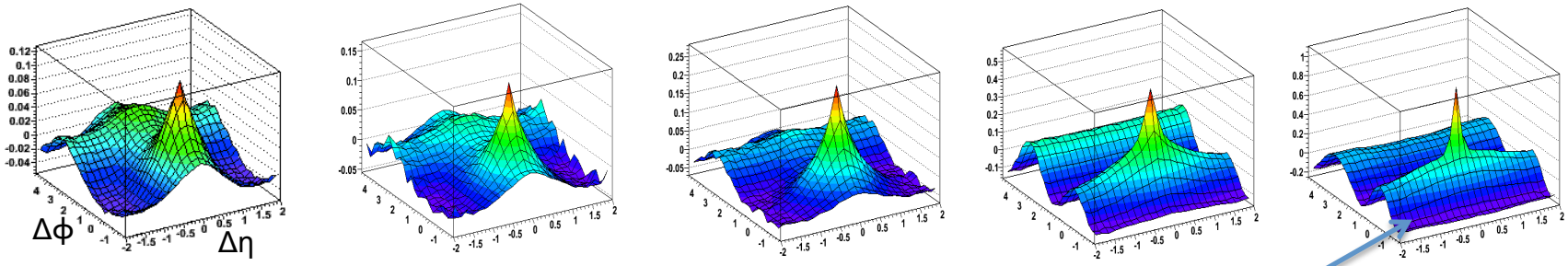


Centrality evolution using all charged particles – Untriggered analysis

STAR preliminary

proton-proton | Au-Au: 80-100% | Au-Au: 70-80% | Au-Au: 50-60% | Au-Au: 00-10%

$\frac{\Delta\rho}{\sqrt{\rho_{ref}}}$

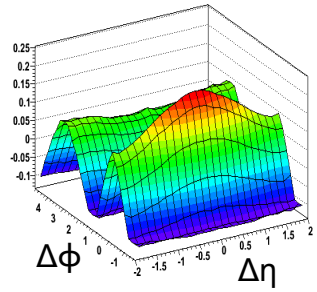


Long range correlation in Δη ("ridge")

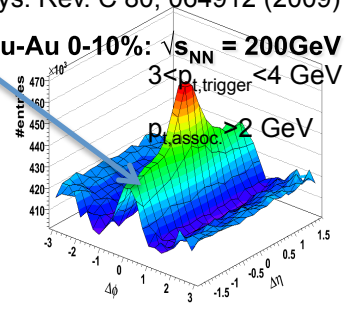
Momentum evolution – Untriggered analysis

p_T>0.15GeV/c Au-Au: 00-10%

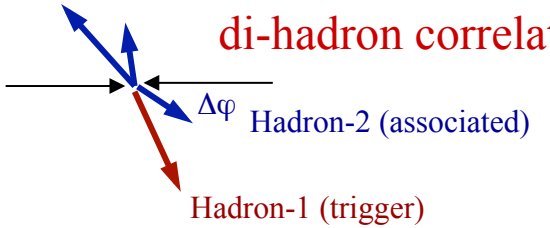
$\frac{\Delta\rho}{\sqrt{\rho_{ref}}}$



Phys. Rev. C 80, 064912 (2009)



Motivation – long range correlation in Δη

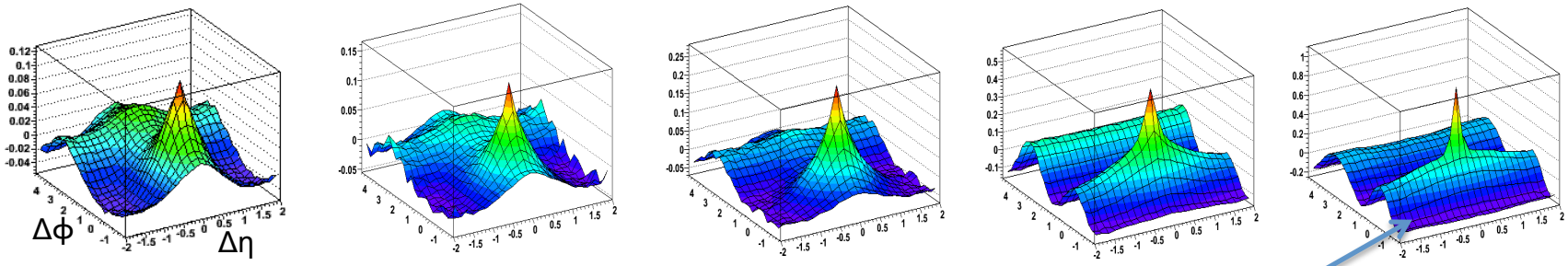


Centrality evolution using all charged particles – Untriggered analysis

STAR preliminary

proton-proton | Au-Au: 80-100% | Au-Au: 70-80% | Au-Au: 50-60% | Au-Au: 00-10%

$\frac{\Delta\rho}{\sqrt{\rho_{ref}}}$

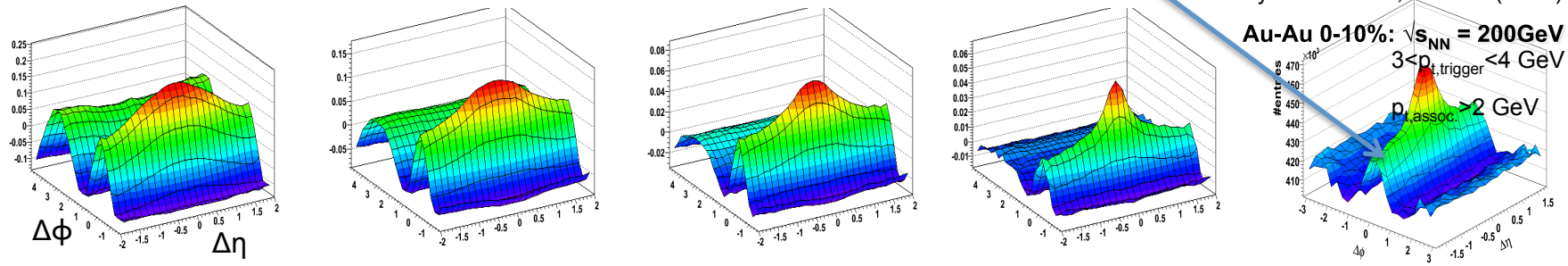


Long range correlation in Δη ("ridge")

Momentum evolution – Untriggered analysis

p_T>0.15GeV/c Au-Au: 00-10% | p_T>1.1GeV/c | p_T>1.7GeV/c | p_T>2.1GeV/c

$\frac{\Delta\rho}{\sqrt{\rho_{ref}}}$



Phys. Rev. C 80, 064912 (2009)

Au-Au 0-10%: $\sqrt{s_{NN}}$ = 200GeV

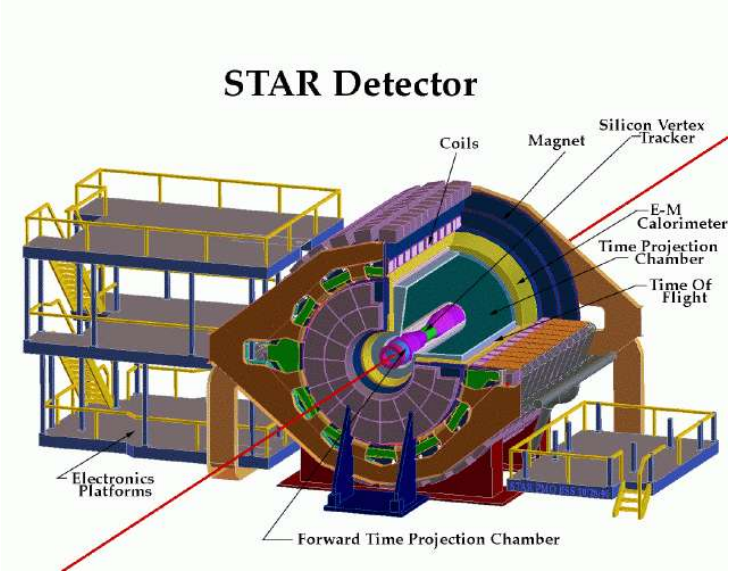
$3<p_{t,trigger}<4$ GeV

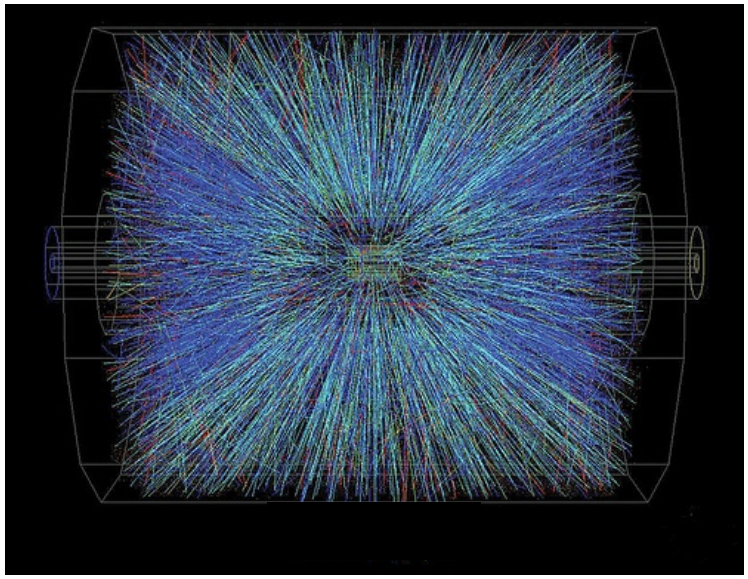
$p_{t,assoc.}>2$ GeV

• We increase the momentum of both particles

Data and cuts

- Au+Au 200GeV – 0-10%, 11M events
- p+p 200GeV – Minimum bias, 264M events
- Event cuts: Primary vertex cut (+/- 25cm) and z-vertex sub binning
- Track cuts:
  - Charged particle tracks in TPC were used
  - $p_T \geq x$ GeV/c; lower limit x is varied for both particles for the p_T evolution (0.15, 0.3, 0.5 GeV/c, ……)
  - $-1 \leq \eta \leq 1$





Tracks produced in a central event

Correlation Measure

❖ We construct the Pearson's correlation coefficient

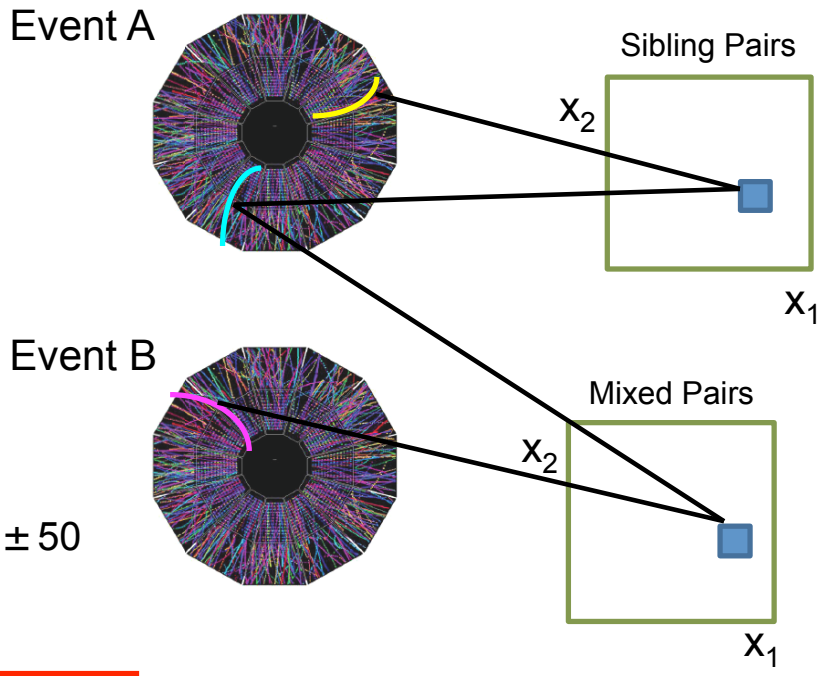
- ρ = Two particle density
- Sibling Pairs

$$\rho_{sib}(p_t,\eta,\phi) = \frac{\overline{n_a n_b}}{Area}$$

- Mixed Pairs

$$\rho_{ref}(p_t,\eta,\phi) = \frac{\overline{n_a}\,\overline{n_b}}{Area}$$

Mix events in a multiplicity window of ± 50



- Final Measure:

$$\frac{\rho_{sib}-\rho_{ref}}{\sqrt{\rho_{ref}}} = \frac{\Delta\rho}{\sqrt{\rho_{ref}}} \rightarrow \sqrt{\rho_{ref}}\,\frac{\Delta\rho}{\rho_{ref}}$$

Normalized Ref Pairs: Total number of sibling to mixed pairs

$$\frac{dN_{ch}}{d\eta d\phi}$$

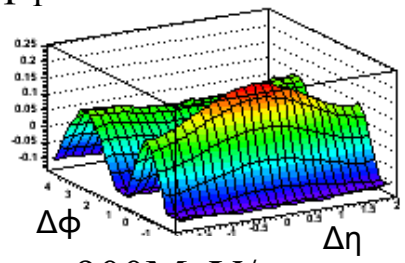
- Number of correlated pairs *per* final state particle

Momentum evolution – AuAu200GeV

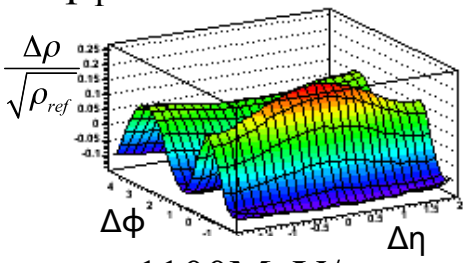
0 – 10%

STAR preliminary

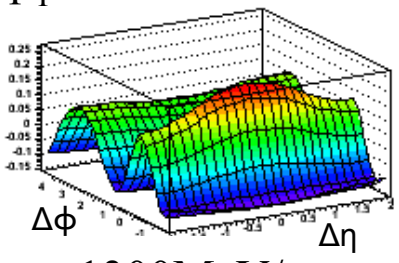
p_T>150MeV/c



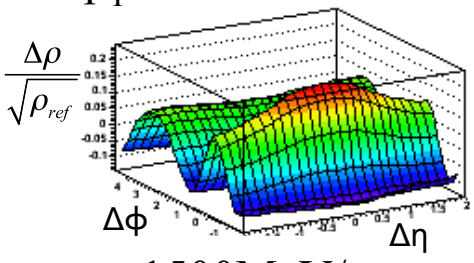
p_T>300MeV/c



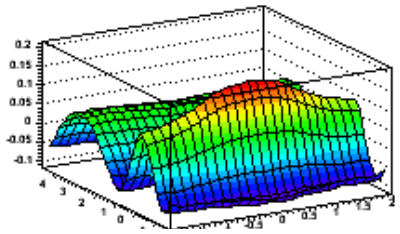
p_T>500MeV/c



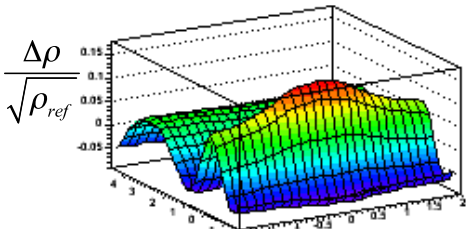
p_T>700MeV/c



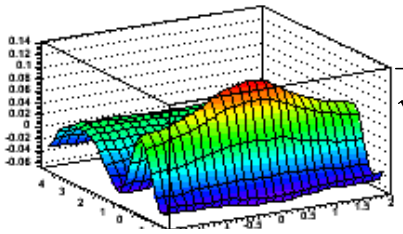
p_T>900MeV/c



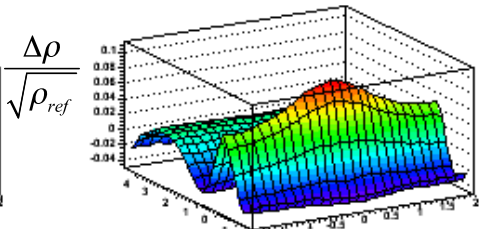
p_T>1100MeV/c



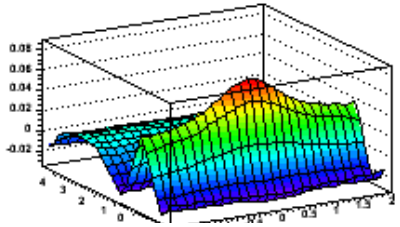
p_T>1300MeV/c



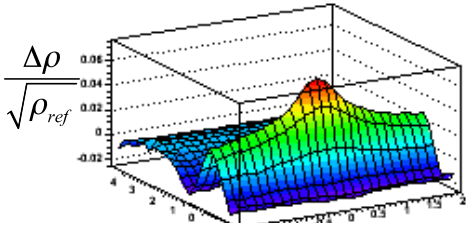
p_T>1500MeV/c



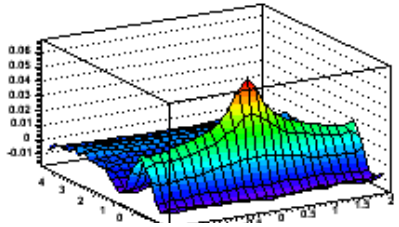
p_T>1700MeV/c



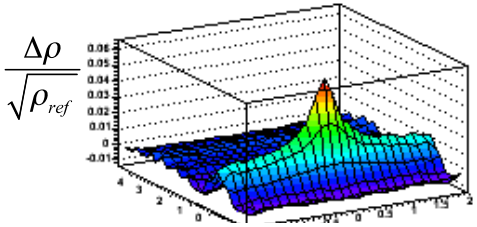
p_T>1900MeV/c



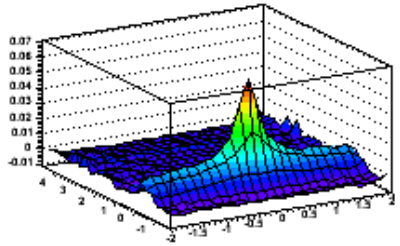
p_T>2100MeV/c



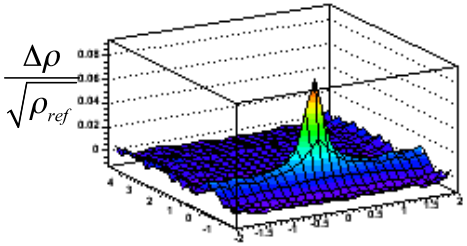
p_T>2300MeV/c



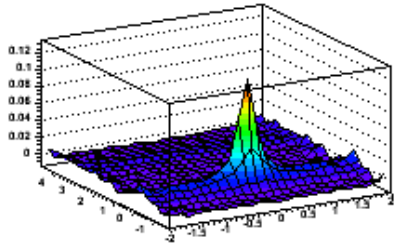
p_T>2500MeV/c



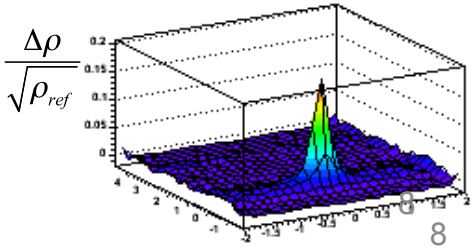
p_T>2700MeV/c



p_T>2900MeV/c



p_T>3100MeV/c

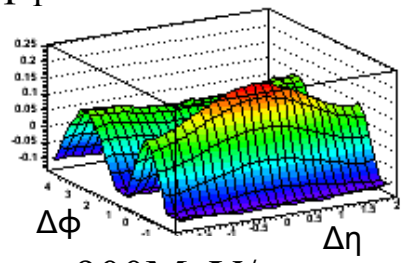


Momentum evolution – AuAu200GeV

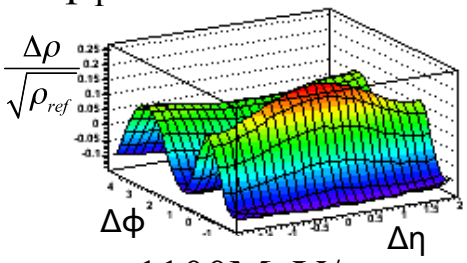
0 – 10%

STAR preliminary

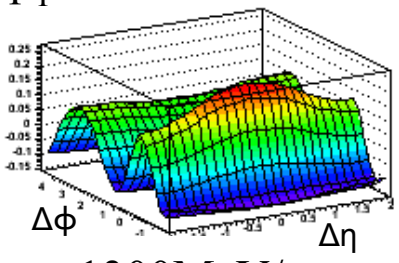
p_T>150MeV/c



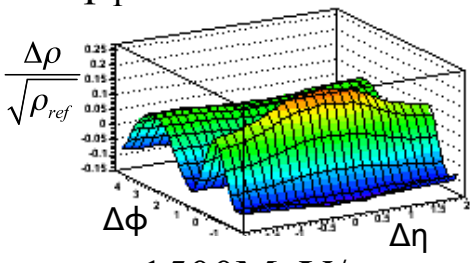
p_T>300MeV/c



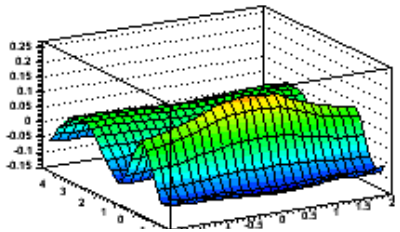
p_T>500MeV/c



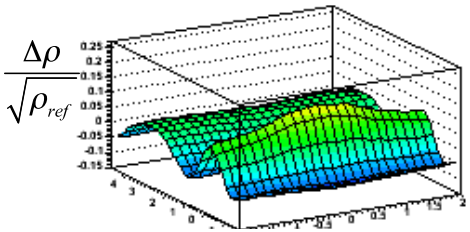
p_T>700MeV/c



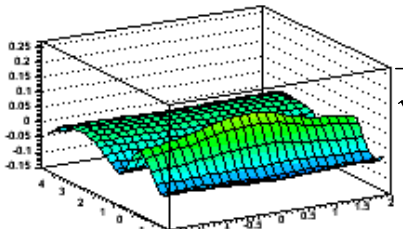
p_T>900MeV/c



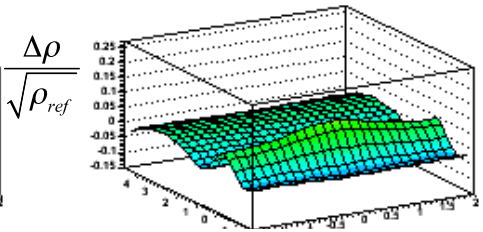
p_T>1100MeV/c



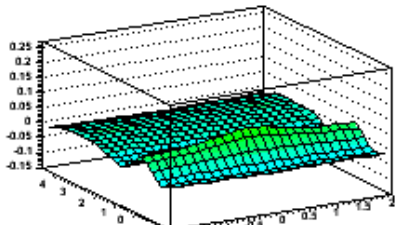
p_T>1300MeV/c



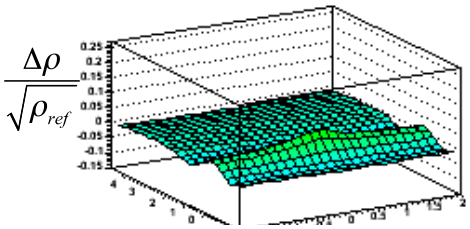
p_T>1500MeV/c



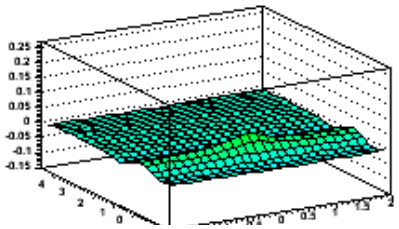
p_T>1700MeV/c



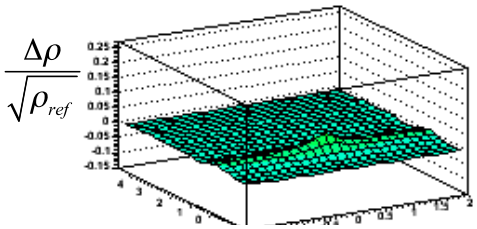
p_T>1900MeV/c



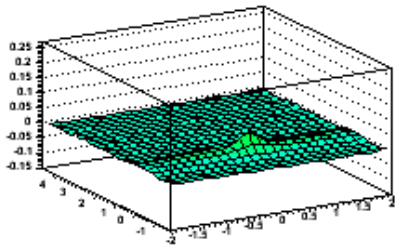
p_T>2100MeV/c



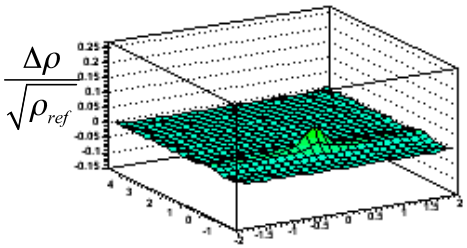
p_T>2300MeV/c



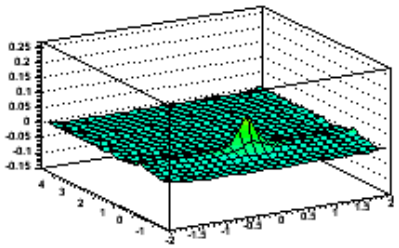
p_T>2500MeV/c



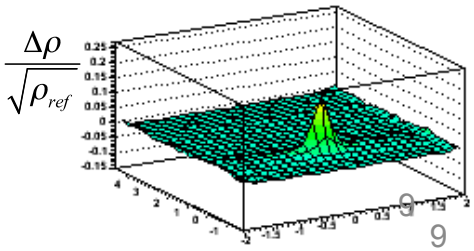
p_T>2700MeV/c



p_T>2900MeV/c



p_T>3100MeV/c



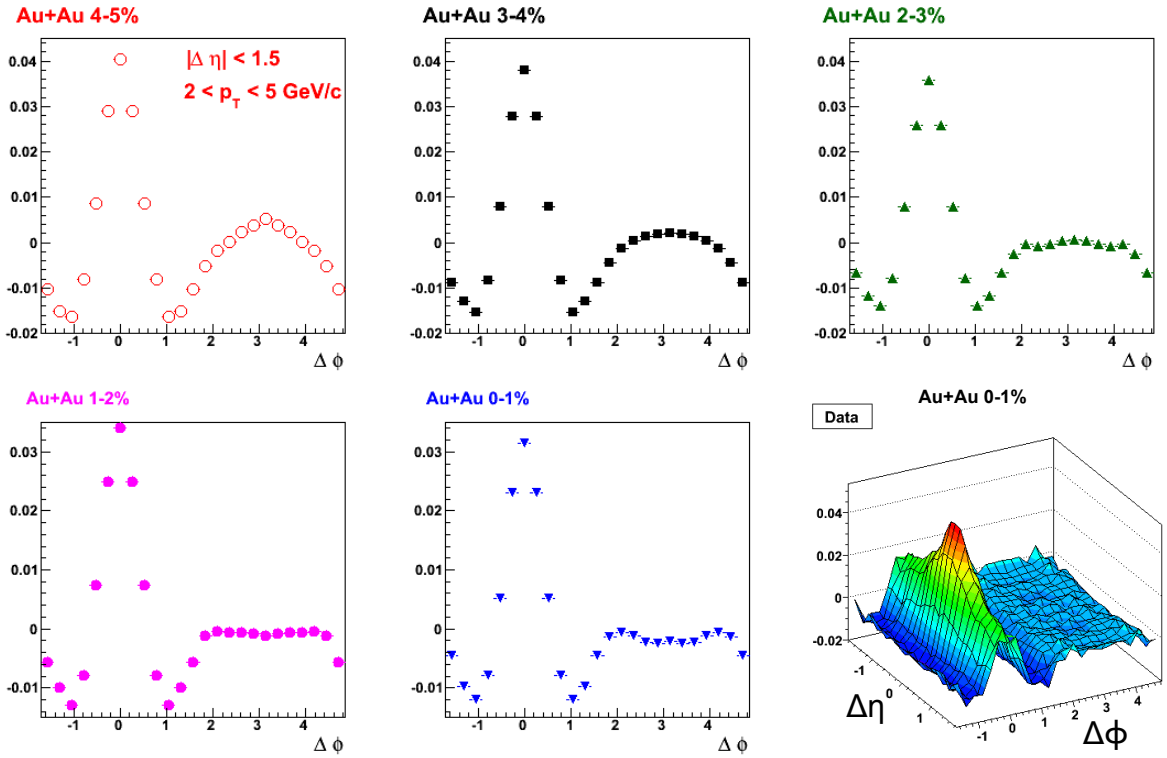
9

Does the data support higher order harmonics?

Higher order Fourier coefficients seen in high p_T very central (0-1%) raw di-hadron correlation spectra at RHIC and LHC

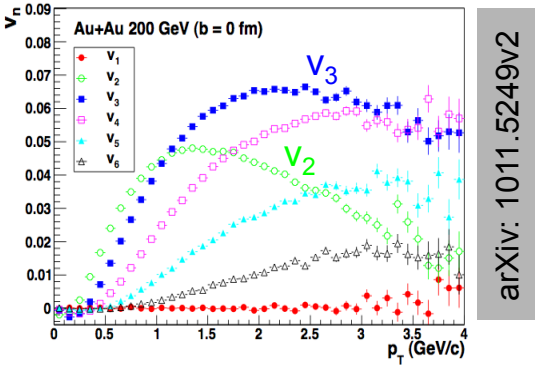
$2<=p_T<=5$ GeV/c

STAR preliminary



Theory prediction

Using a transport model theorists have predictions for higher order azimuthal anisotropies in very central events



arXiv: 1011.5249v2

FIG. 2: (Color online) Azimuthal anisotropies of hadron spectra $v_n(p_T)$ $(n = 1 - 6)$ in central $(b = 0)$ $Au + Au$ collisions at $\sqrt{s} = 200$ GeV from AMPT model calculation.

Model Fit function

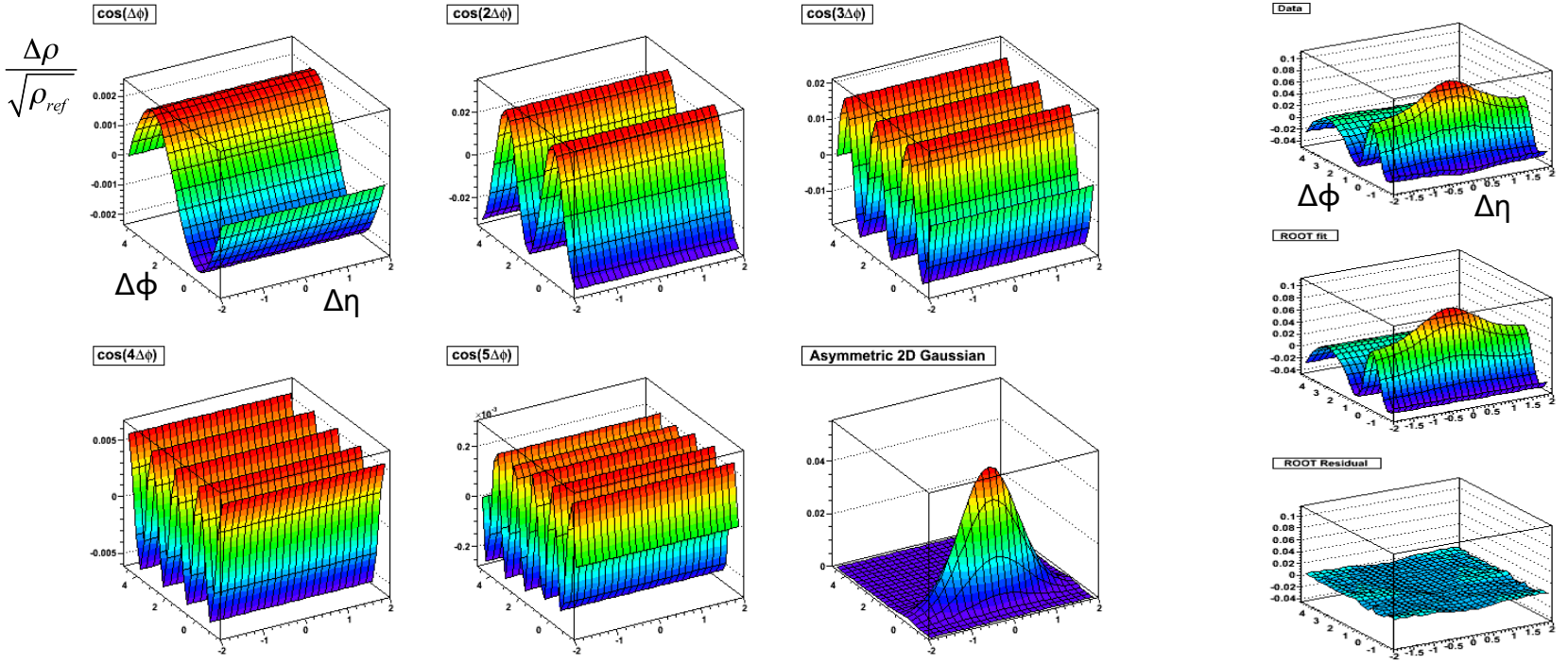
$f_1 \propto c_0$	Offset
$f_2 \propto c_1 * \cos(\Delta\phi)$	Away-side momentum conservation
$f_3 \propto c_2 * \cos(2\Delta\phi)$	2nd order Fourier term
$f_4 \propto c_3 * \cos(3\Delta\phi)$	3rd order Fourier term
$f_5 \propto c_4 * \cos(4\Delta\phi)$	4th order Fourier term
$f_6 \propto c_5 * \cos(5\Delta\phi)$	5th order Fourier term
$f_7 \propto c_6 * \exp(-0.5*((\Delta\eta/c_7)^2 + (\Delta\phi/c_8)^2))$	Asymmetric 2d Gaussian

❖Asymmetric 2d Gaussian assumed to be modified jet fragmentation

p_T > 1.5GeV/c : 0-10%

$f = f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7$

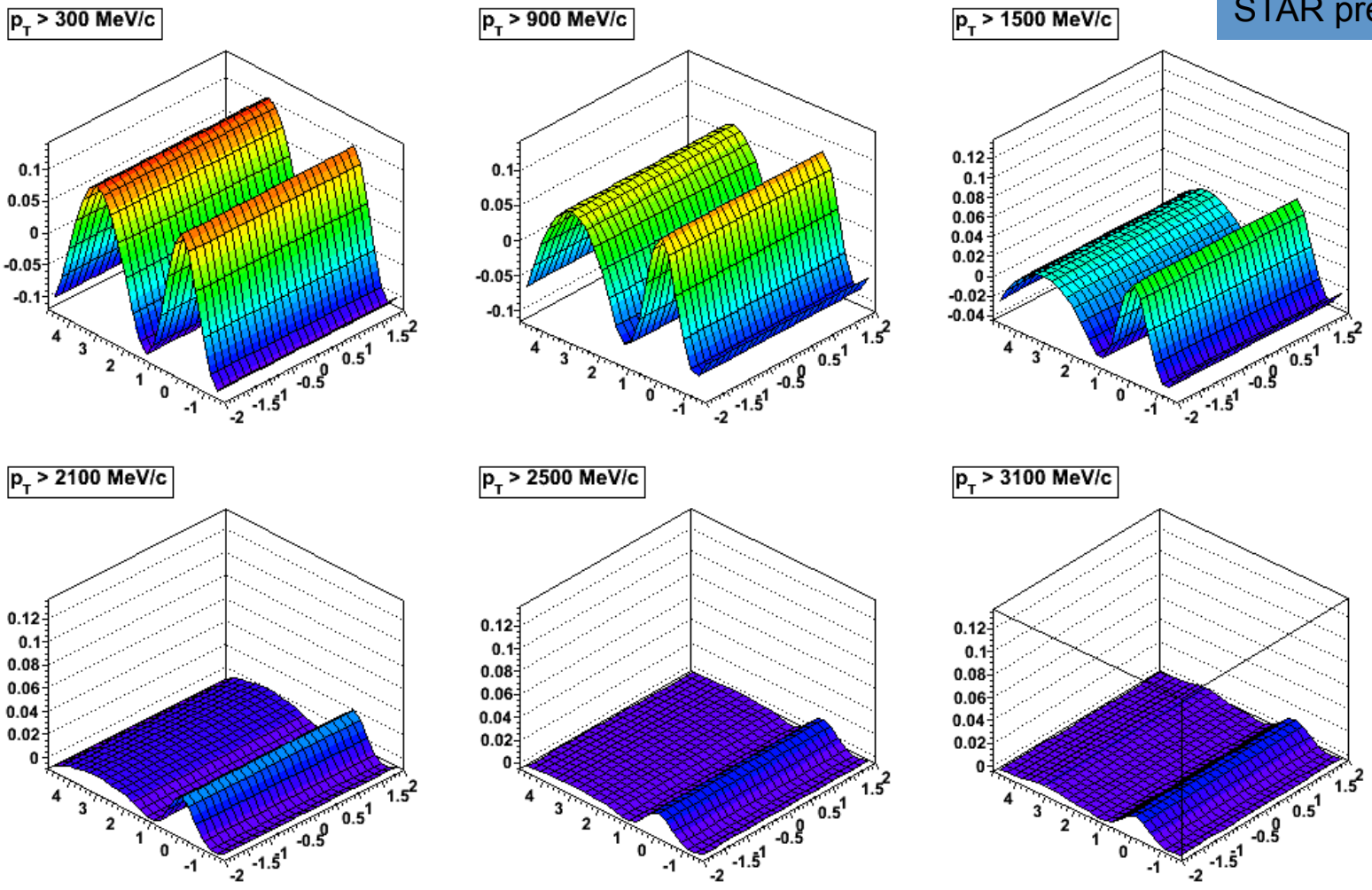
STAR preliminary



Model fit - harmonics

- $\langle p_T \rangle$ evolution of resulting harmonics structure : $v_2 + v_3 + v_4 + v_5$

STAR preliminary

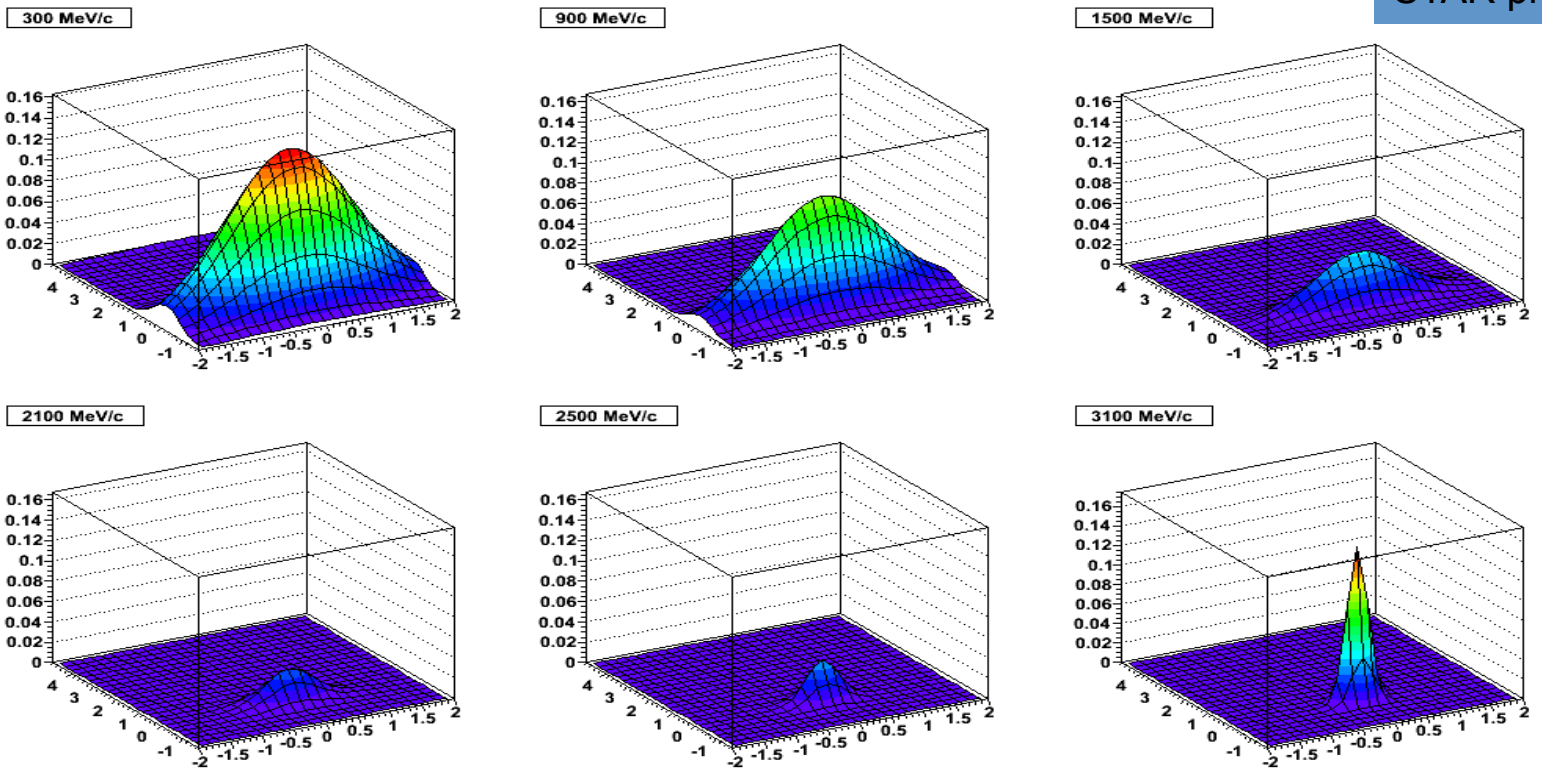


- Harmonics do not model Δη dependence

Model fit - asymmetric 2d Gaussian

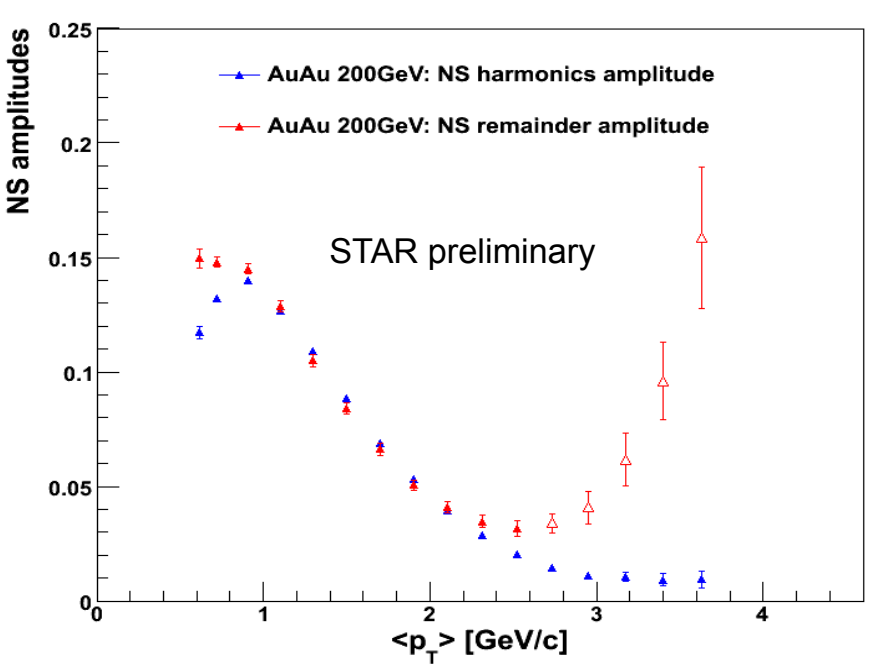
- Shows the asymmetric 2d Gaussian ("remainder") component p_T cut evolution after higher harmonics subtraction

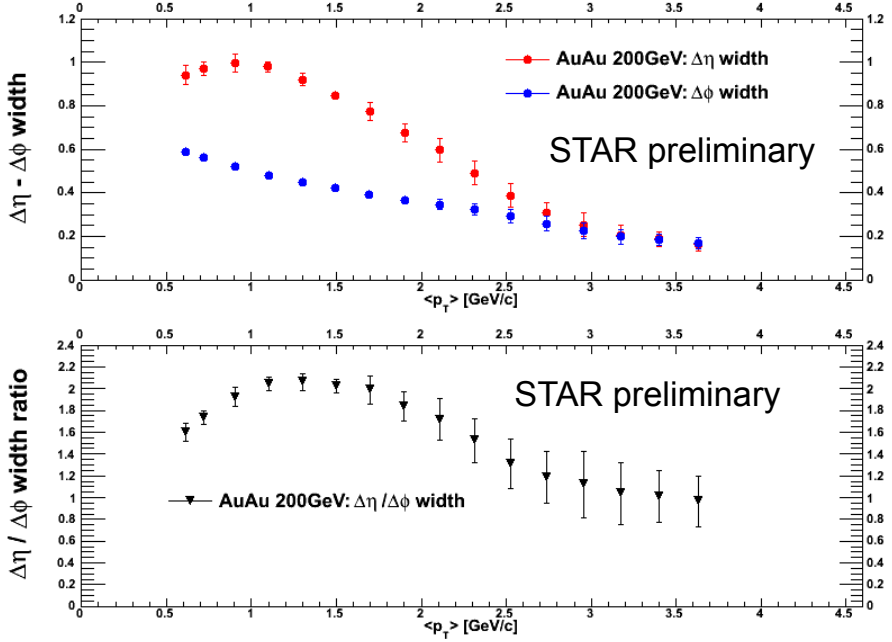
STAR preliminary



- Near side (NS) peak strength around (0,0) increases at higher p_T cuts
  - An effect due to definition of correlation measure (also visible in raw correlation)
  - The effect is constrained in a narrow Δη-Δφ region around (0,0) ("jet region")
  - In this region the raw same event and mixed event pair count fall off exponentially
  - The relative fall off for same event pairs is smaller compared to mixed pairs as a function of p_T cut

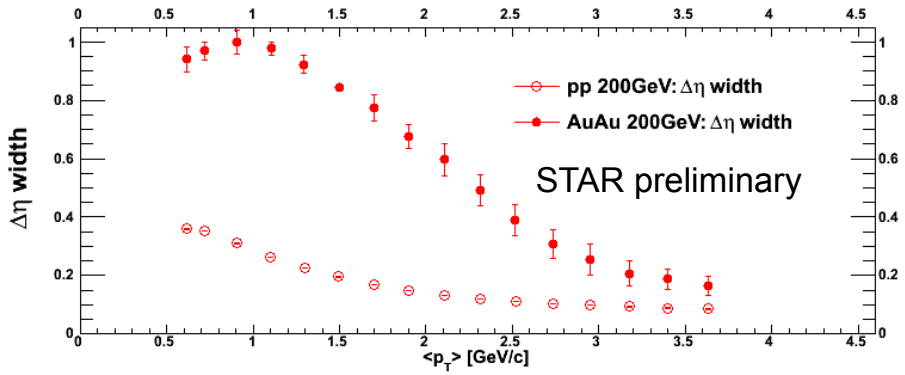
Free parameter comparison

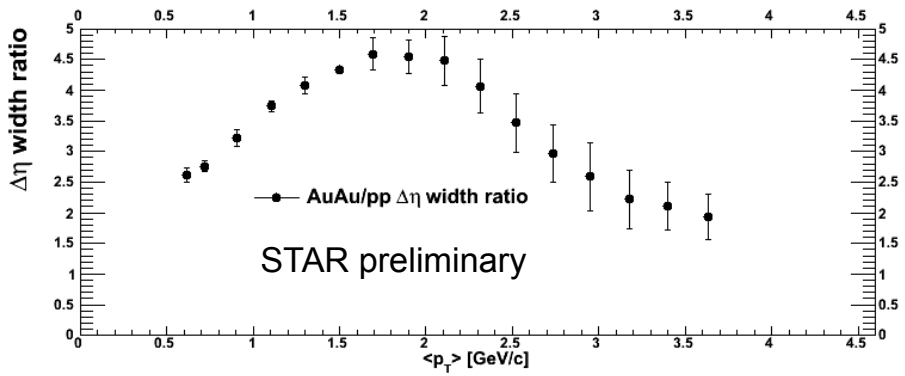


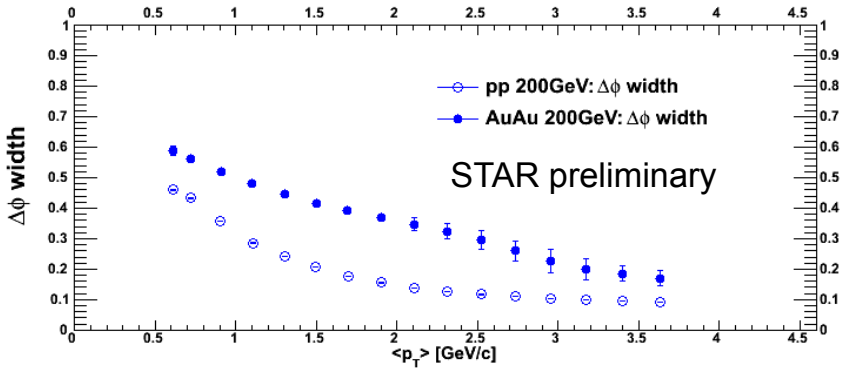


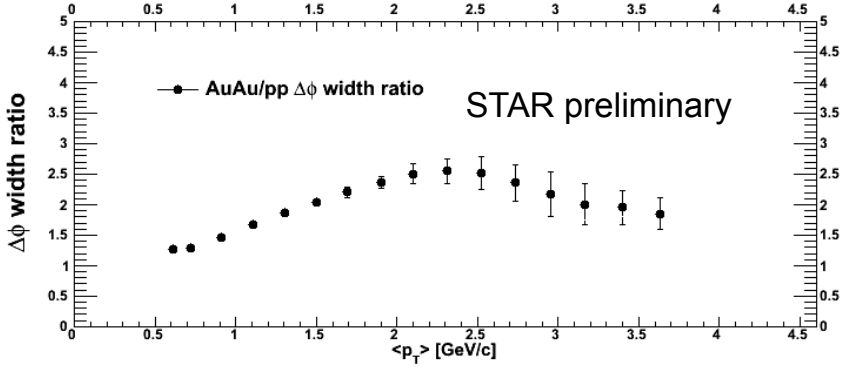
- NS harmonics and remainder amplitudes are compared
- Asymmetry of remainder is quantified
- NS harmonics strength reaches a minimum value at higher p_T
- NS harmonics amplitude in the $\langle p_T \rangle$ region from 1-2 GeV/c is comparable to remainder amplitude
- Above $\langle p_T \rangle$ ~ 2.5GeV/c the remainder models possible unmodified jet correlation
  - The widths become symmetric above ~2.5GeV/c
  - Correlation function strength increases in jet region
- Below $\langle p_T \rangle$ ~ 2.5GeV/c remainder could be due to possible modified jet phenomena
  - Δη width peaks around 0.9 GeV/c. Δη/Δφ widths ratio is ~ 2:1 around 0.9 GeV/c
  - See next slide for comparison to widths in 200 GeV p+p collisions

Asymmetric 2d Gaussian – p+p comparison





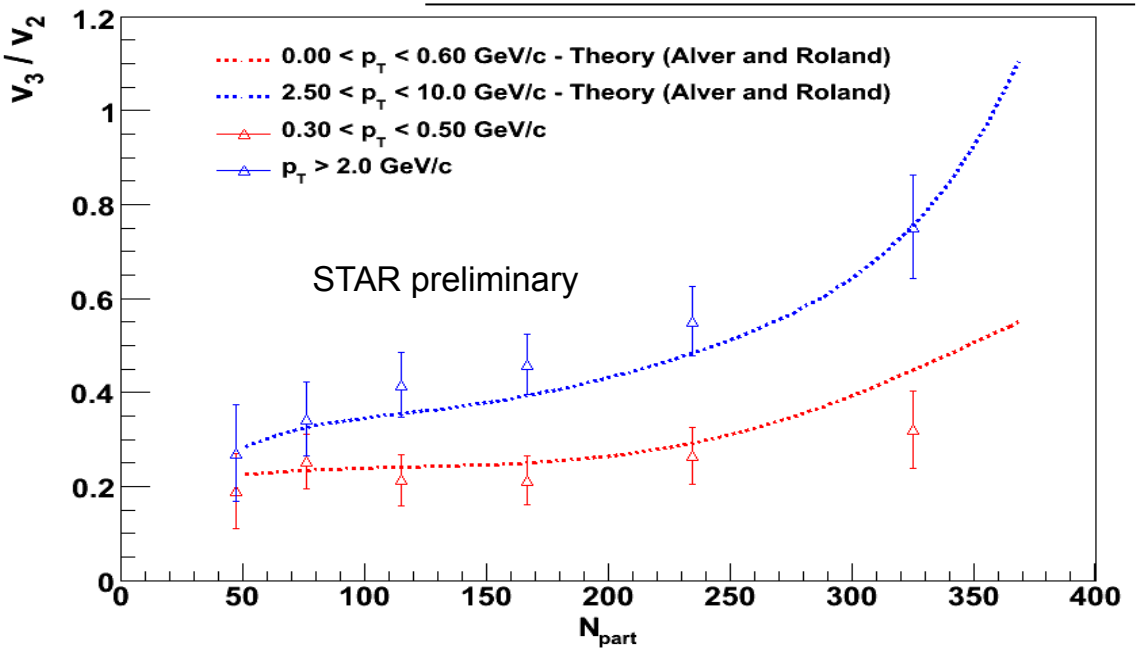


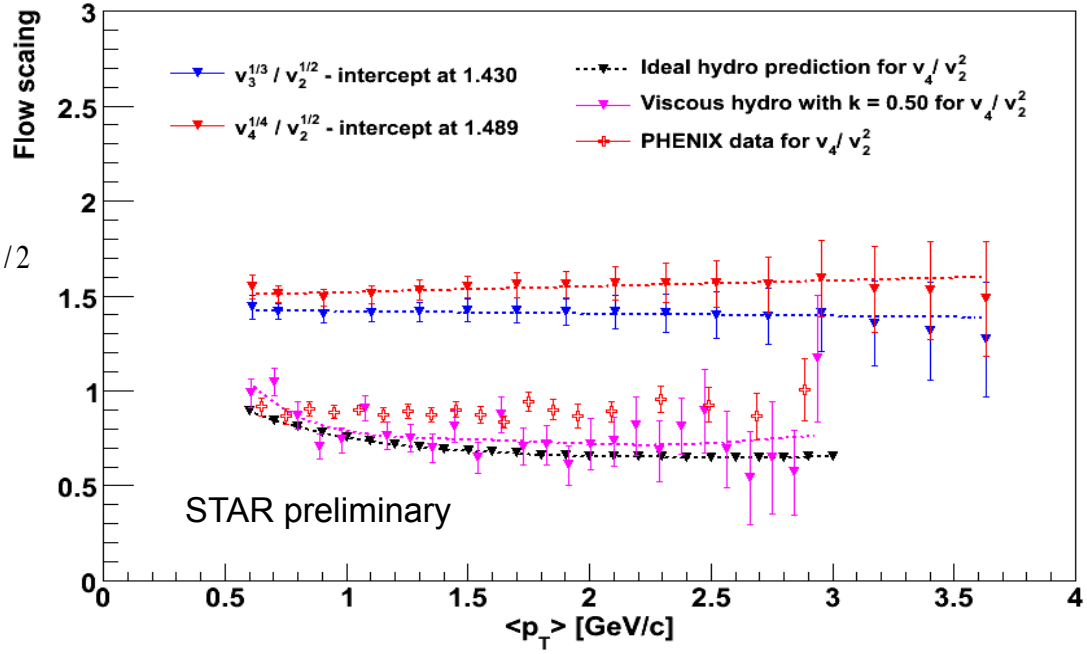


- At the highest momenta ($\langle p_T \rangle$ > 2GeV/c) the Au+Au widths are increased by about a factor of 2 relative to the p+p widths

- Asymmetry in p+p widths disappears at $\langle p_T \rangle$ ~ 1.5 GeV/c
- Maximum Δη width modification is larger (by a factor 2) than that of Δφ

Flow comparisons





$$V_n^{1/n} \propto V_2^{1/2}$$

- Alver and Roland :

Phys. Rev. C 81, 054905 (2010)

- Hydro scaling relation plot at 0 – 10% :

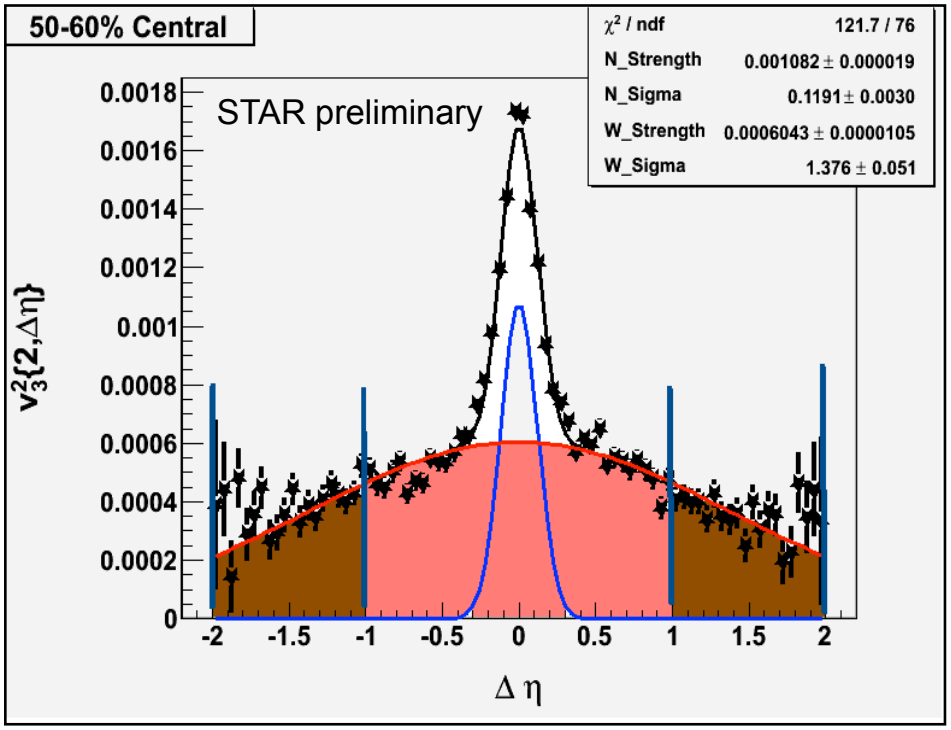
Phys. Rev. C 81, 014901(2010)

All scaled flow ratios are flat as a function of p_T at higher p_T as predicted by hydrodynamics

Other ridge studies from STAR

Δη dependence of triangular flow (v_3)

❖ Focus on mid central, $0.15<p_T<2$ GeV/c, 2 – particle cumulant



Main Idea:

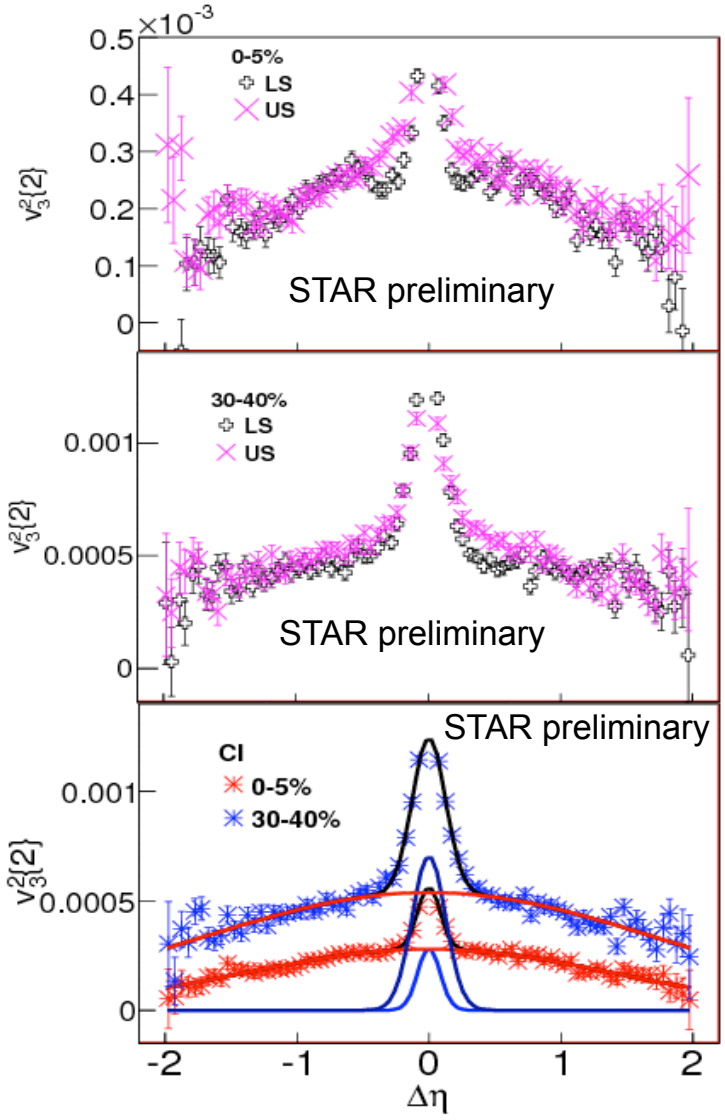
v_3^2 {2, Δη} as a function of Δη data can be fitted with sum of two Gaussians:

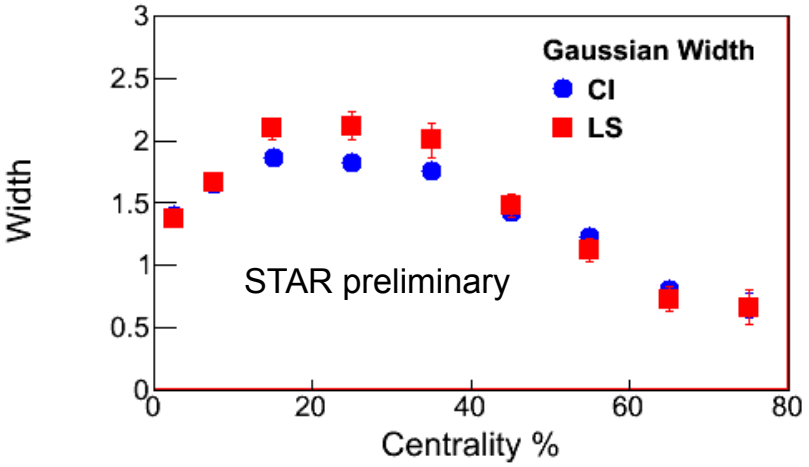
1. A narrow Gaussian: Short range non flow (HBT/e^+e^-)
2. A wide Gaussian: Flow + Flow fluctuations + Long range non flow

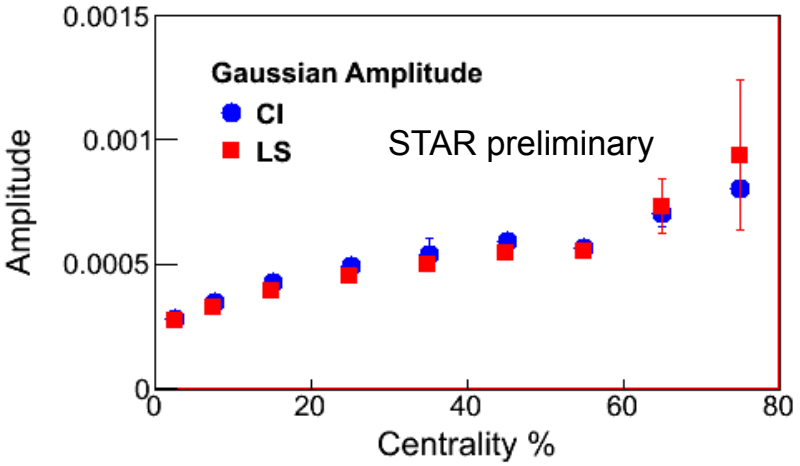
Triangular flow harmonic shows Δη dependence

Triangular flow (v_3): Flow, flow fluctuations and non- flow

Charge dependence studies estimate possible non-flow contribution

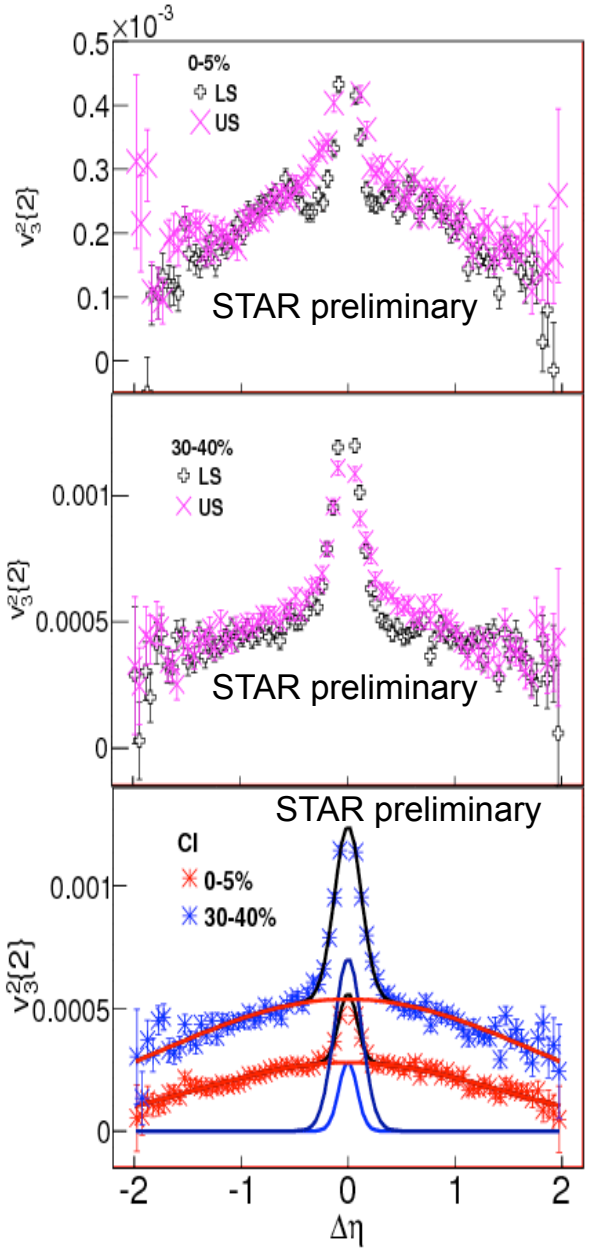


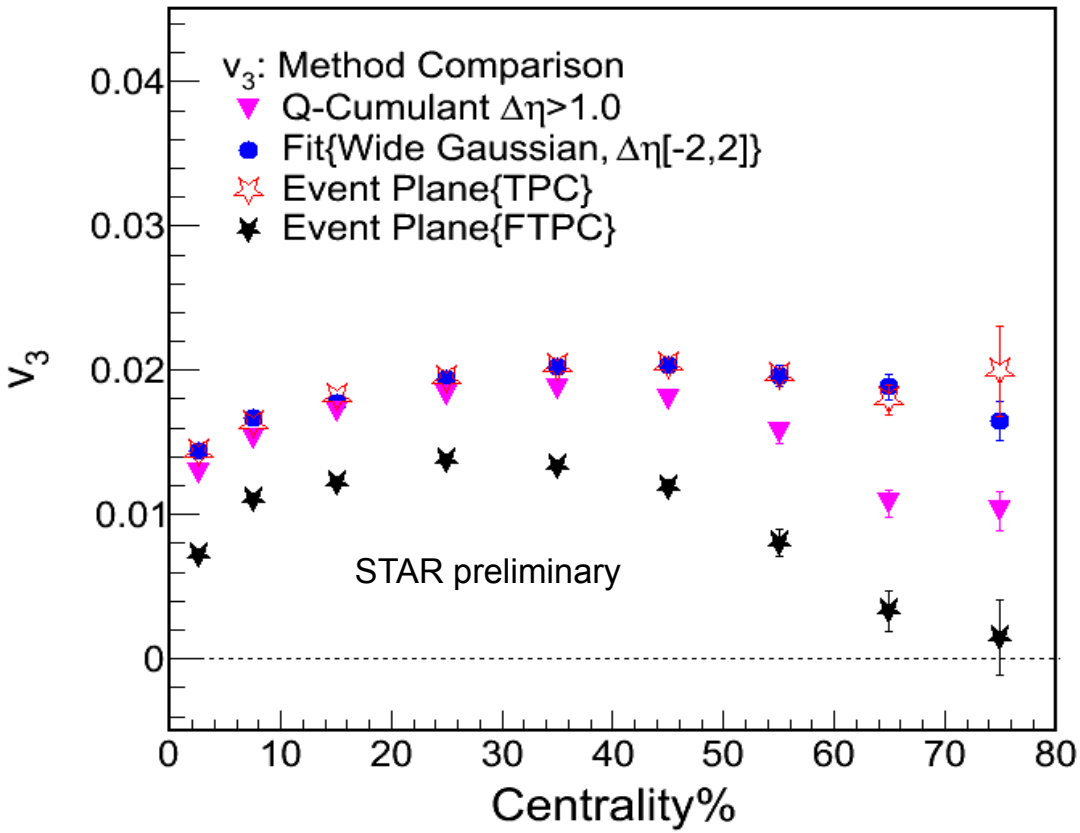




Width and amplitude of the wide Gaussian

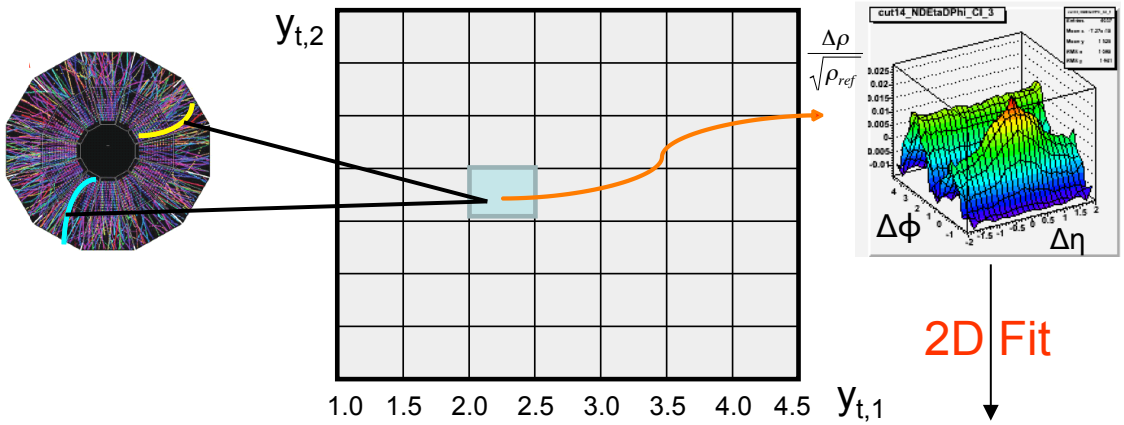
Triangular flow (v_3): Flow, Fluctuations and Non Flow





Gaussian fit parameters are used to calculate $v^2_{3\ and}$ compared to various other methods

Additional study of 2d correlations

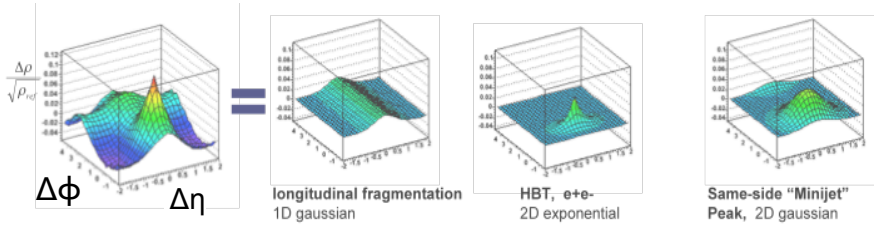


Intend to form a measure which is $\propto \log(p_t)$

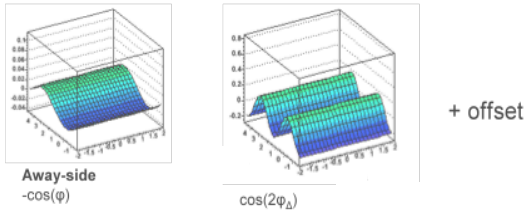
$$y_t = \ln\left(\frac{m_t + p_t}{m_\pi}\right), \quad \text{where } m_t = \sqrt{p_t^2 + m_\pi^2}$$

$f = f_1 + f_2 + f_3 + f_4 + f_5 + f_6$

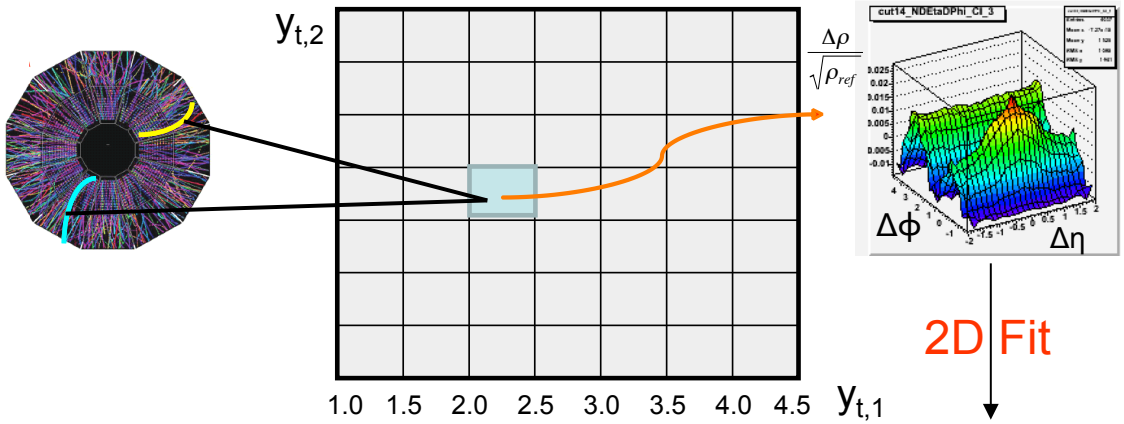
$f_1 \propto c_0$	Offset
$f_2 \propto c_1 * \cos(\Delta\phi)$	Away-side momentum conservation
$f_3 \propto c_2 * \cos(2\Delta\phi)$	2nd order Fourier term
$f_4 \propto c_3 * \exp(-0.5*((\Delta\eta/c_4)^2 + (\Delta\phi/c_5)^2))$	Modified jet fragmentation
$f_5 \propto c_6 * \exp(-1.0*\sqrt{((\Delta\eta/c_7)^2 + (\Delta\phi/c_8)^2)})$	HBT/e^+e^-
$f_6 \propto c_9 * \exp(-0.5*(\Delta\eta/c_{10})^2)$	Longitudinal fragmentation



Alternate fit model without harmonics can also describe the data



Additional study of 2d correlations



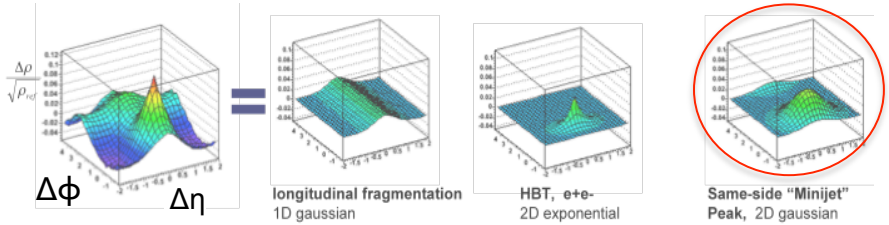
Intend to form a measure which is $\propto \log(p_t)$

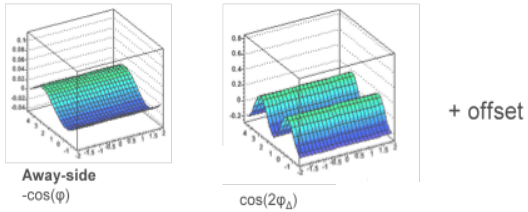
$$y_t = \ln\left(\frac{m_t + p_t}{m_\pi}\right), \quad \text{where } m_t = \sqrt{p_t^2 + m_\pi^2}$$

2D Fit

$f = f_1 + f_2 + f_3 + f_4 + f_5 + f_6$

$f_1 \propto c_0$	Offset
$f_2 \propto c_1 * \cos(\Delta\phi)$	Away-side momentum conservation
$f_3 \propto c_2 * \cos(2\Delta\phi)$	2nd order Fourier term
$f_4 \propto c_3 * \exp(-0.5*((\Delta\eta/c_4)^2 + (\Delta\phi/c_5)^2))$	Modified jet fragmentation
$f_5 \propto c_6 * \exp(-1.0*\sqrt{((\Delta\eta/c_7)^2 + (\Delta\phi/c_8)^2)})$	HBT/e^+e^-
$f_6 \propto c_9 * \exp(-0.5*(\Delta\eta/c_{10})^2)$	Longitudinal fragmentation

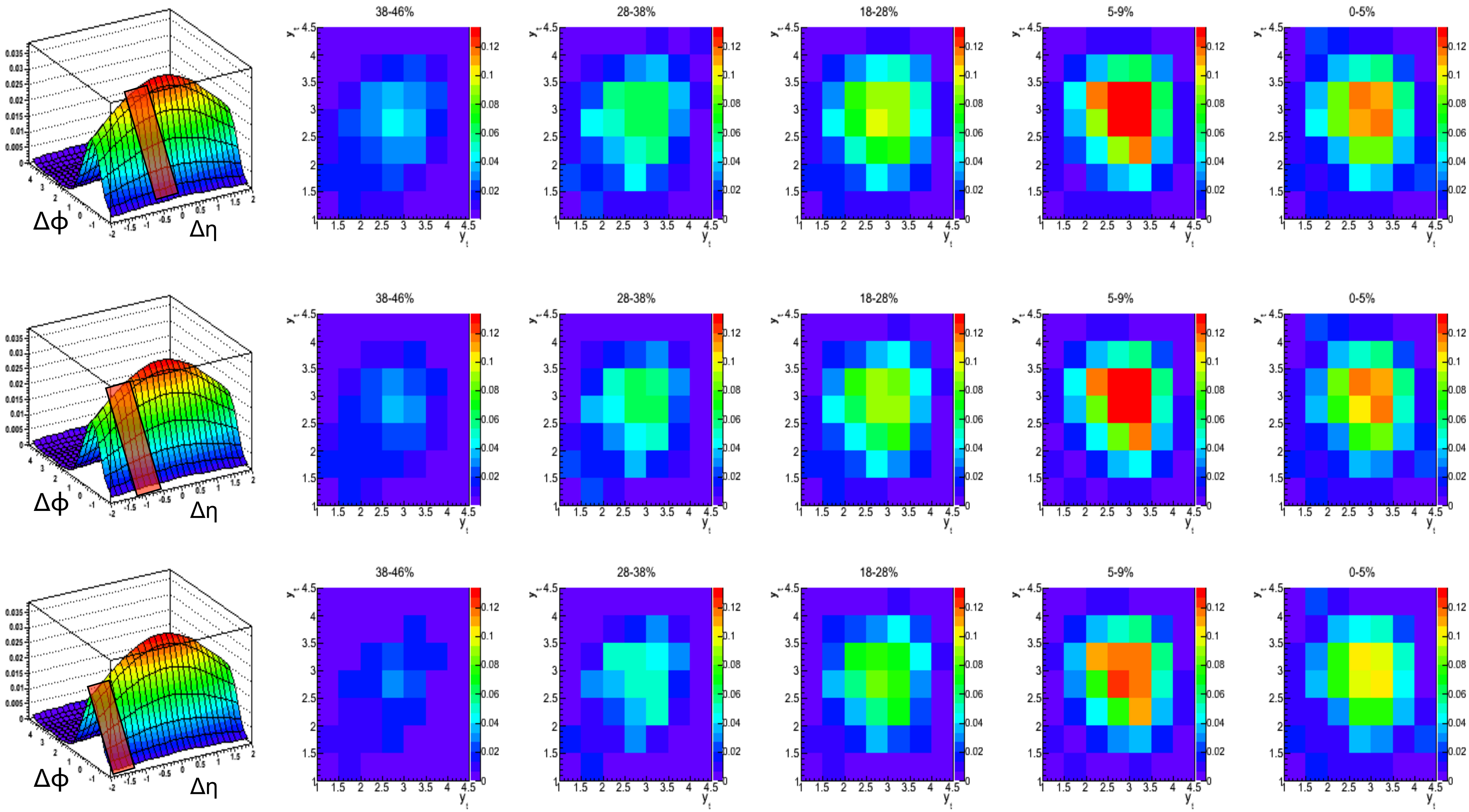




Alternate fit model without harmonics can also describe the data

NS 2d Gaussian Volume by Δη Region

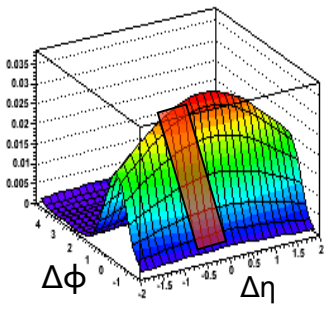
NS 2d Gaussian <p_T> ~ 1.4 GeV/c

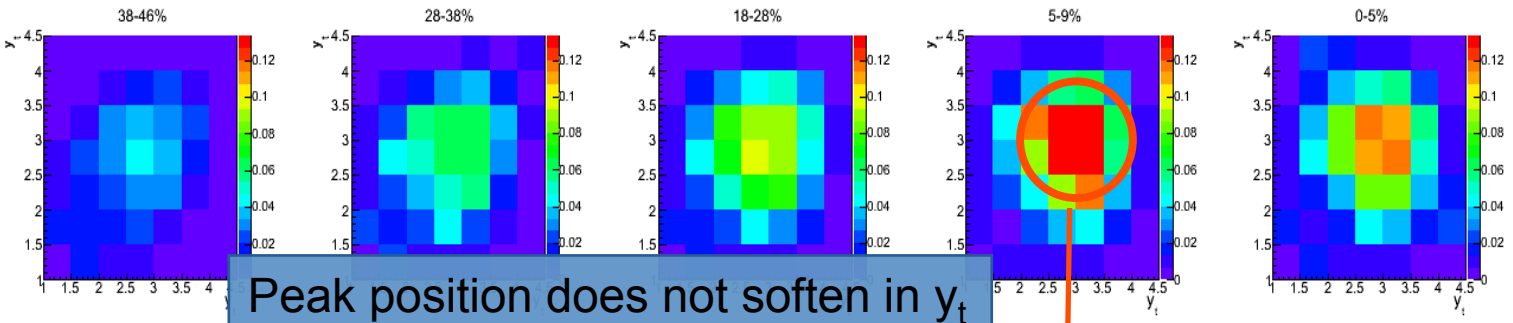


*STAR Preliminary

NS 2d Gaussian Volume by Δη Region

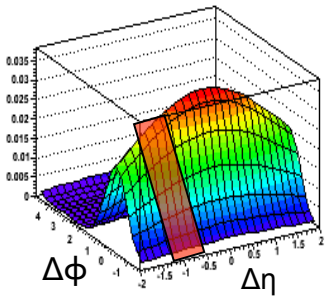
NS 2d Gaussian $\langle p_T \rangle$ ~ 1.4 GeV/c

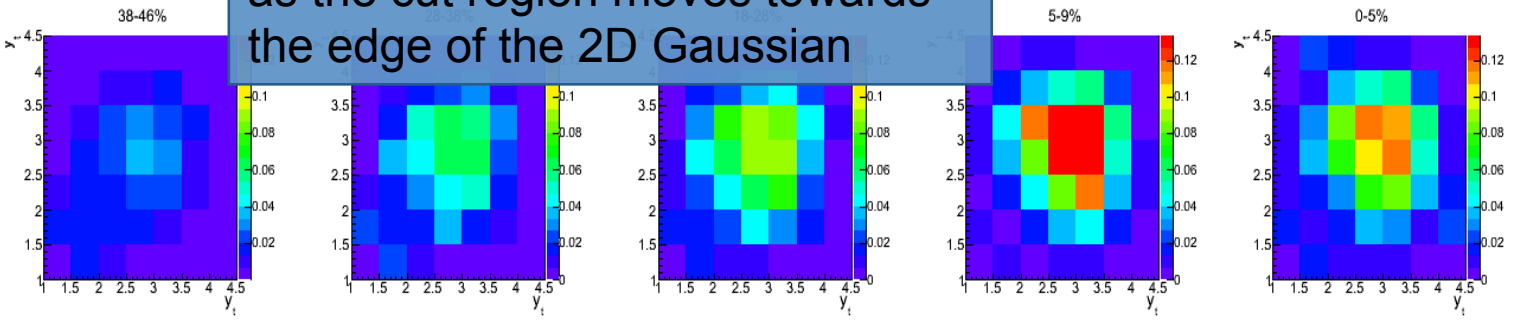


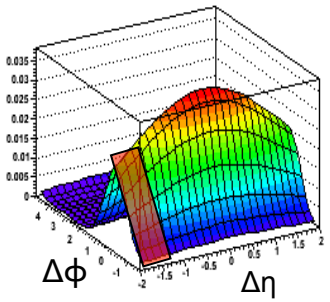


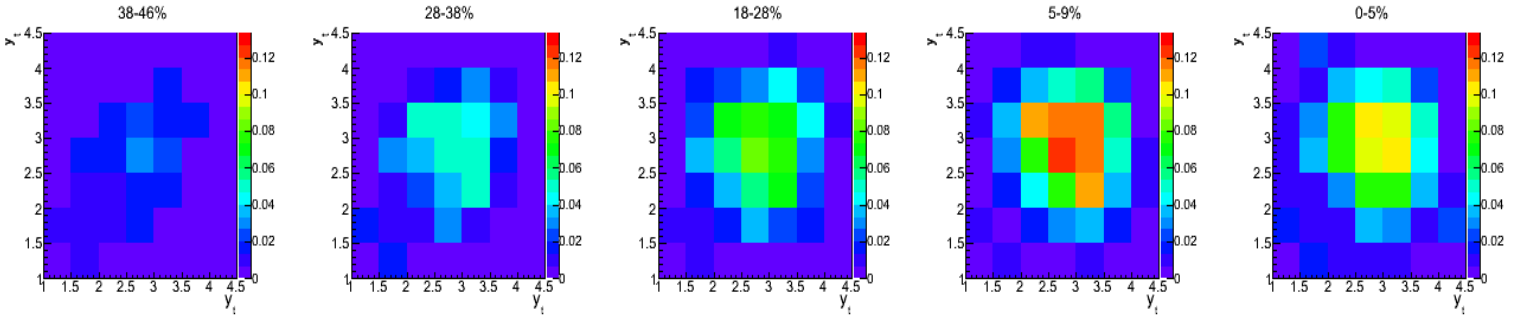
Peak position does not soften in y_t as the cut region moves towards the edge of the 2D Gaussian

y_T =3 -> p_T ~1.4 GeV/c



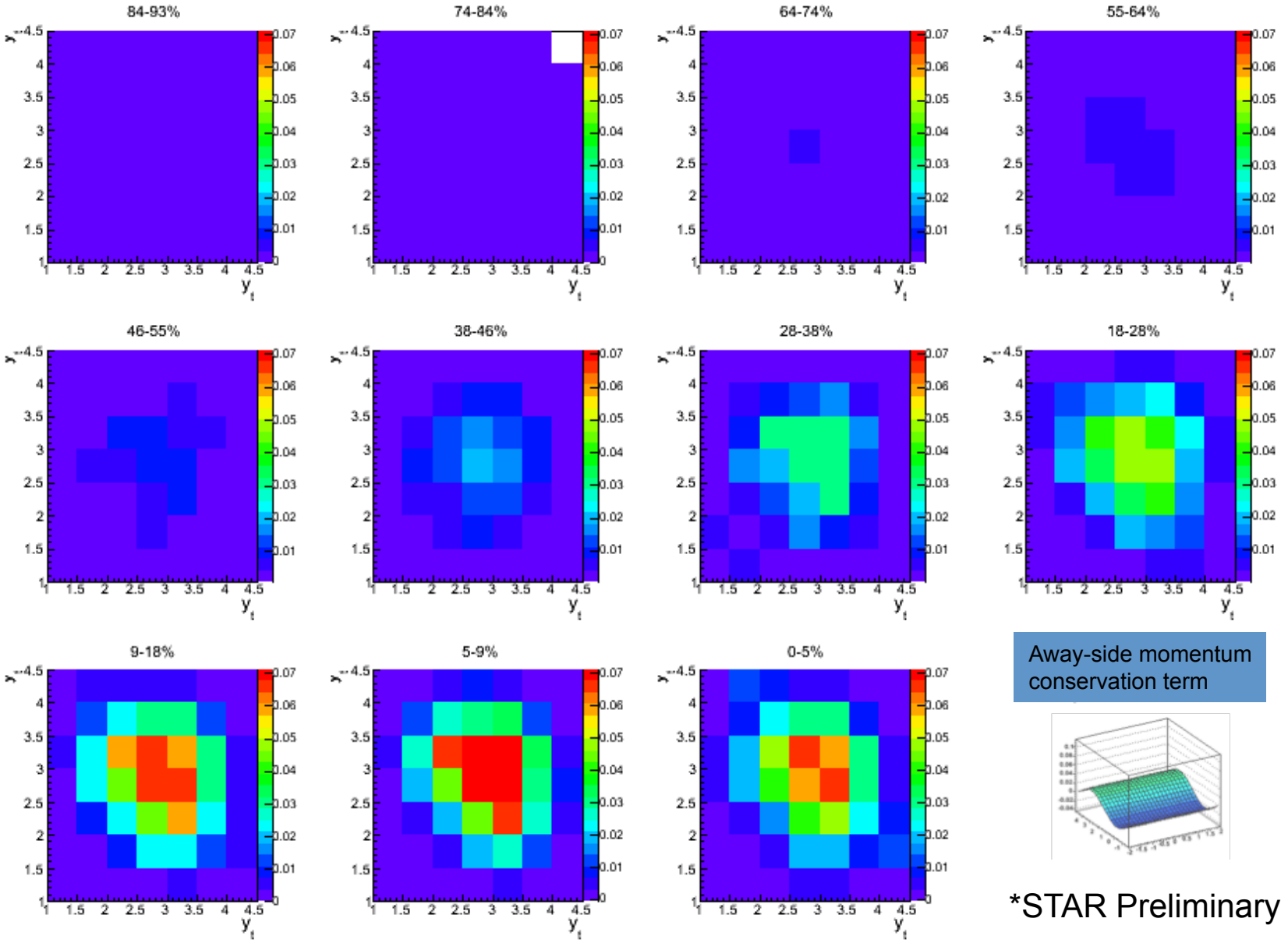






*STAR Preliminary

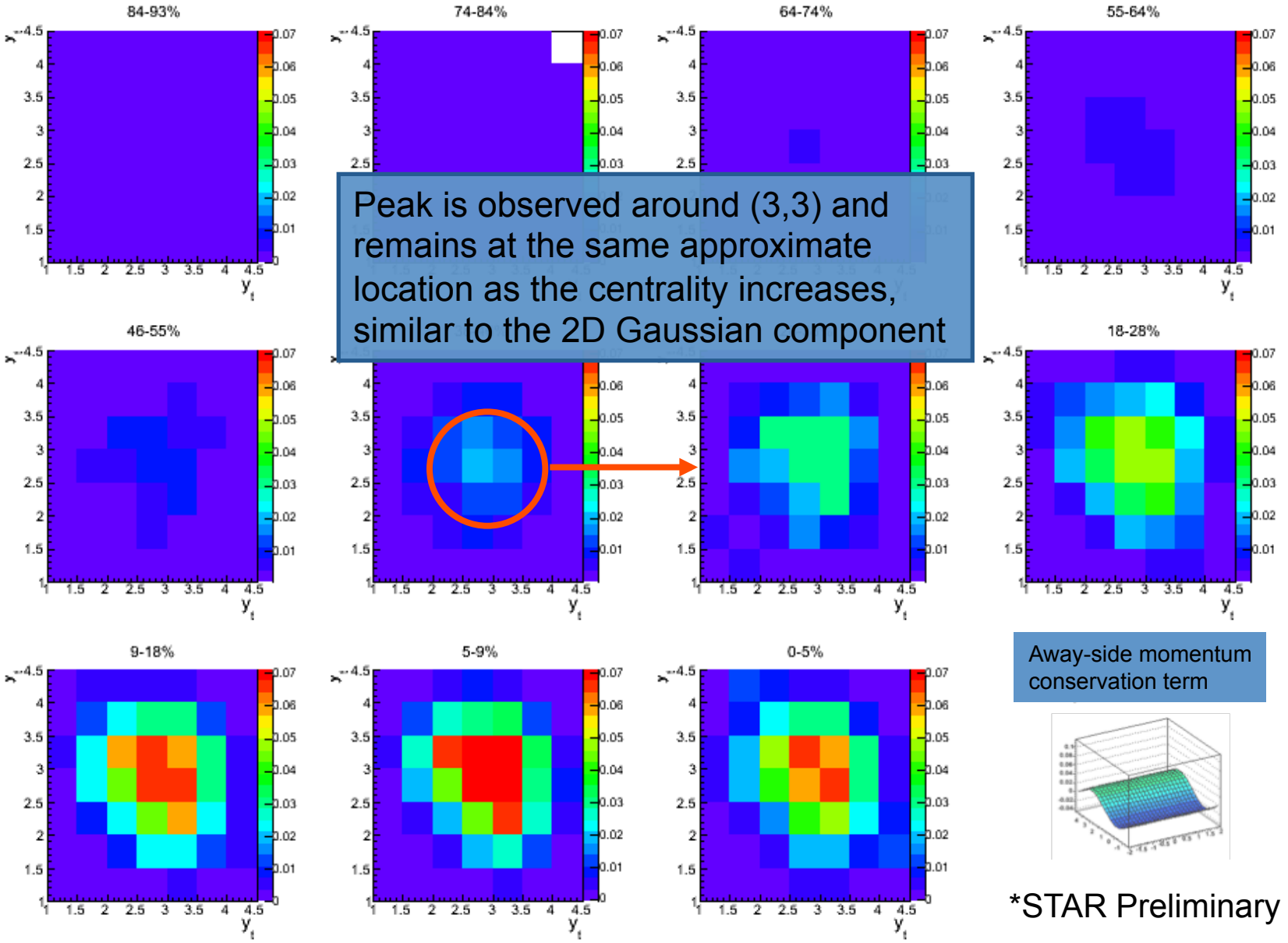
Away-side momentum Distribution



Away-side momentum conservation term

*STAR Preliminary

Away-side momentum Distribution



Summary and discussion

- Near side Δη-Δφ correlations show a smooth evolution as a function of $\langle p_T \rangle$. One interpretation of the "Ridge structure" is a sum of “initial state density fluctuations” in addition to a “modified jet-like structure”
- Possible initial state density fluctuation contributions are extracted using higher harmonics model components which agree reasonably well with predicted hydro scaling relations
- Higher harmonics correlation strength (yield*v_n) reduces at higher $\langle p_T \rangle$
- The remaining structure after higher harmonics subtraction is quantified using p+p data at the same collision energy
- Within the assumptions of the model presented, a “modified jet” structure is observed as a function of $\langle p_T \rangle$

- Additional studies reveal possible Δη dependency in triangular flow
- An alternate model without higher harmonics and representing possible modified jet formation can describe the data and indicates a $\langle p_T \rangle$ at large Δη that is higher than the $\langle p_T \rangle$ of the inclusive spectra