Two Particle Correlations and Viscosity in Heavy Ion Collisions

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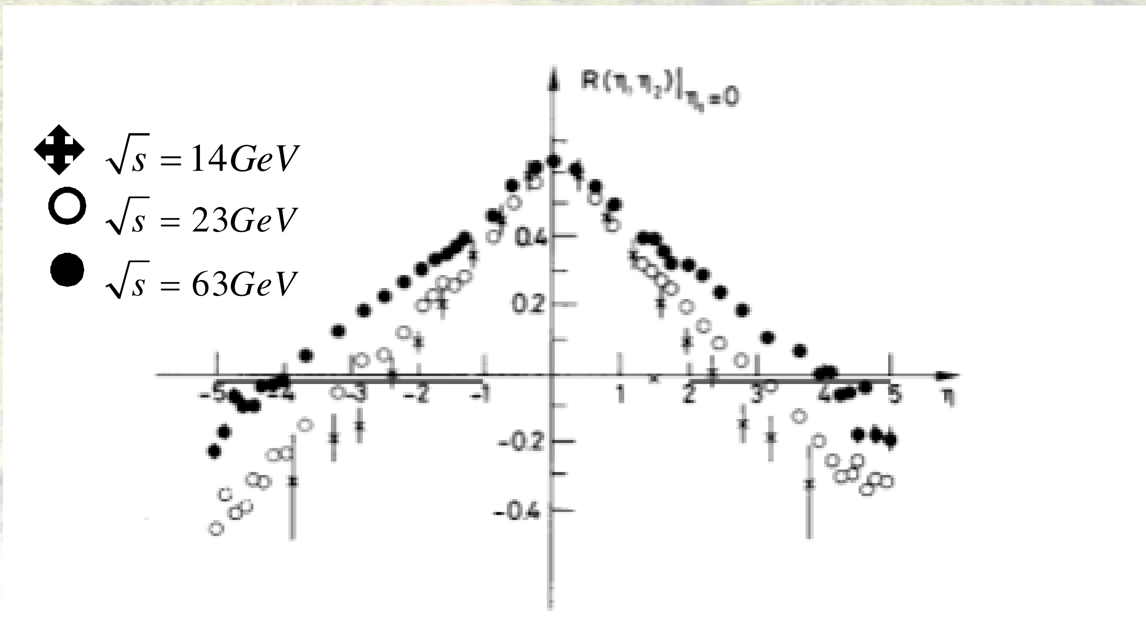
STAR Collaboration

Outline:

- ✓ Motivation
- ✓ Measurement method
- ✓ Observable definition
- ✓ Results discussion
- ✓ Summary

Two-particle correlations

✓ Two-body rapidity correlations have been studied for over 30 yrs in p+p and heavy-ion collisions.
✓ They provide powerful insight of particle production mechanism

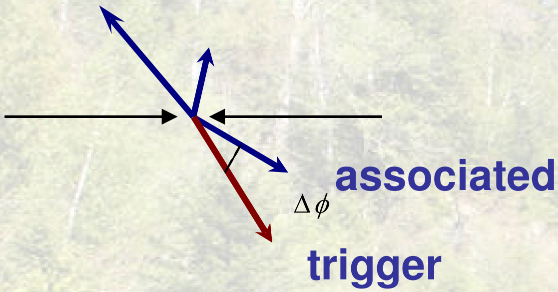


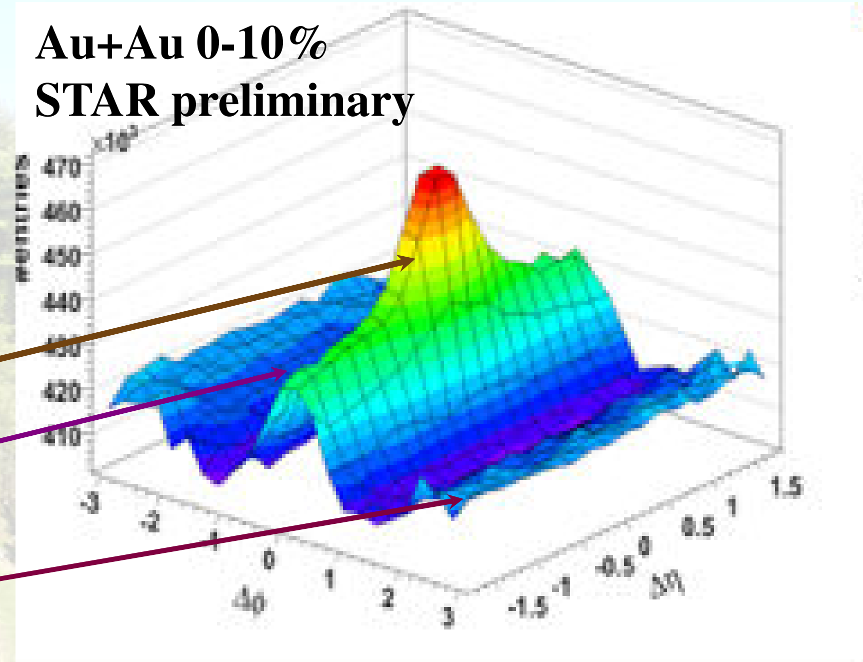
L. Foa, Physics reports, 22 (1975) 1-56

Fig: Correlation function R(η_1, η_2) for η_1=0 at various energies.

Observation of the ridge

Di-hadron correlations





Components:
a) Near-side jet peak
b) Near side $\Delta\eta$ independent ridge
c) Away side and elliptic flow (v_2)

Proposed explanations:
Glasma flux tubes: A. Dumitru et. al., hep-ph/0804.3858
Radial flow + trigger bias: S. Voloshin, nucl-th/0312065
E. Shuryak, nucl-th/0706.3531
S. Gavin et.al., nucl-th/0806.4718
And many more…………..

Correlation measure weighted with p_T could be used to Gain a different insight

Motivation II: medium viscosity

✓ **Why study $\frac{\eta}{s}$?**

Shear viscosity relative to entropy density of the system indicates:

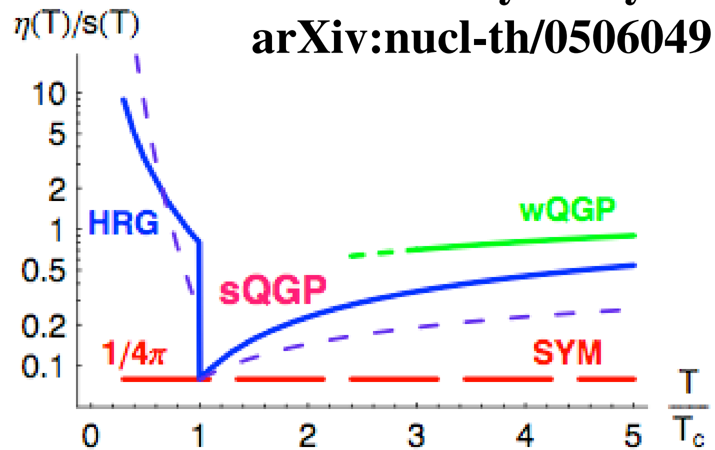
- how strongly a system is coupled?
- how perfect the liquid is?

✓ **Transverse momentum correlation measurements used to extract information on kinematic viscosity:** $\upsilon = \frac{\eta}{T_c s}$

T_c: temperature
s : entropy density
η: shear viscosity

Sean Gavin, Phys. Rev Lett. 97 (2006) 162302

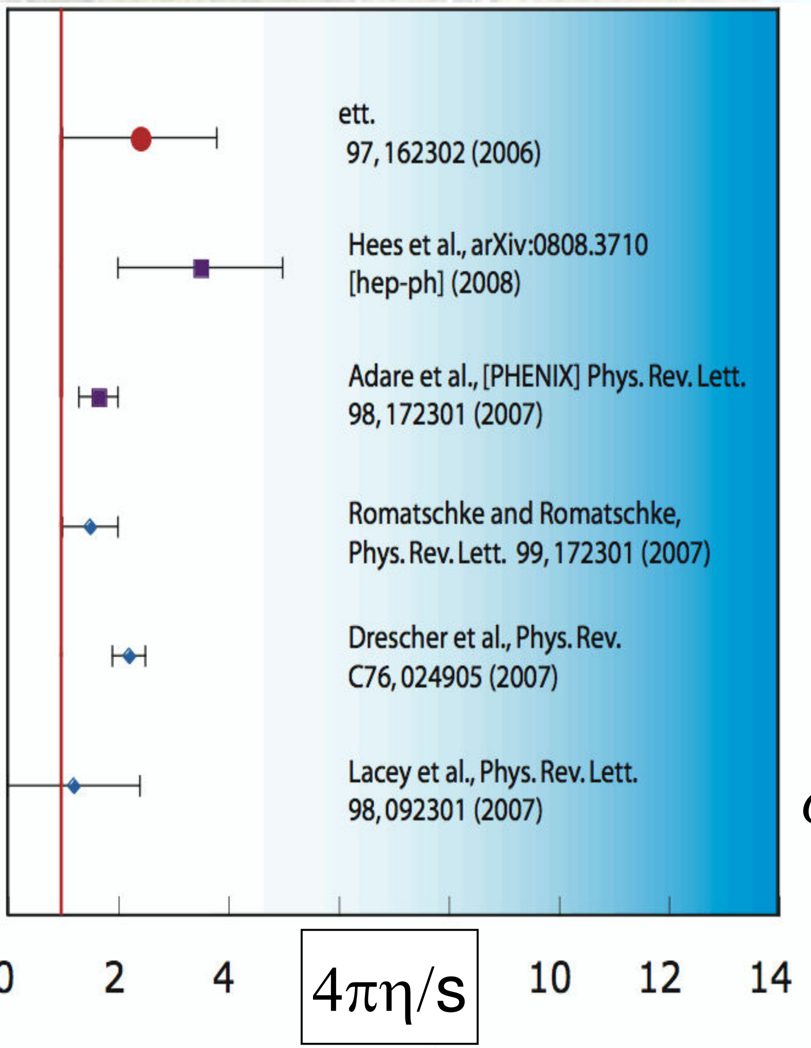
Hirano & Gyulassy
arXiv:nucl-th/0506049



υ estimated based on broadening of correlation function vs. pseudorapidity as a function of collision centrality

$$\sigma_c^2 - \sigma_p^2 = 4\upsilon\left(\tau_{f,p}^{-1} - \tau_{f,c}^{-1}\right)$$

Motivation & measurement method



Gavin estimated 0.08< $\frac{\eta}{s}$ <0.3 based on

where: 0.08 ⟶ p_T correlations

STAR, J. Phys. G32, L37, 2006 (AuAu 200 GeV)

0.3 ⟶ Number density correlations

STAR, PRC 73, 064907, 2006 (AuAu 130 GeV)

However, correct estimation of $\frac{\eta}{s}$ requires:

- **observable which has contributions from number density as well as p_T correlations**

Gavin advocates:

$$C = \langle p_{t1} p_{t2} \rangle - \langle p_t \rangle^2$$

Where:

$$\langle p_{t1} p_{t2} \rangle \equiv \frac{1}{\langle N \rangle^2} \left\langle \sum_{\text{pairs}\ i \neq j} p_{ti} p_{tj} \right\rangle$$

$$\langle p_t \rangle \equiv \frac{1}{\langle N \rangle} \left\langle \sum p_{ti} \right\rangle$$

Measurement method

Two particle p_T correlations studied vs. pseudorapidity and azimuth difference $\Delta\eta = \eta_1 - \eta_2$ $\Delta\varphi = \varphi_1 - \varphi_2$

$$\mathcal{C}(\Delta\eta\Delta\varphi) = \frac{\left\langle \sum_{i=1}^{n_\alpha(\eta_1,\varphi_1)} \sum_{i\neq j=1}^{n_\alpha(\eta_2,\varphi_2)} p_{\alpha,i}(\eta_1,\varphi_1) p_{\alpha,j}(\eta_2,\varphi_2) \right\rangle}{\langle n_\alpha(\eta_1,\varphi_1) n_\alpha(\eta_2,\varphi_2)\rangle} - \left(\frac{\left\langle \sum_{i=1}^{n_\alpha(\eta_1,\varphi_1)} p_{\alpha,i}(\eta_1,\varphi_1)\right\rangle}{\langle n_\alpha(\eta_1,\varphi_1)\rangle}\right)\left(\frac{\left\langle \sum_{j=1}^{n_\alpha(\eta_2,\varphi_2)} p_{\alpha,j}(\eta_2,\varphi_2)\right\rangle}{\langle n_\alpha(\eta_2,\varphi_2)\rangle}\right)$$

Pairs

Singles

Gavin's suggested Observable. We study it differentially

Differential observable contains much more information

$$\rho_2^{\Delta p_1 \Delta p_2}(\Delta\eta,\Delta\varphi) = \frac{\left\langle \sum_{i=1}^{n_\alpha(\eta_1,\varphi_1)} \sum_{j\neq i=1}^{n_\alpha(\eta_2,\varphi_2)} \left(p_{\alpha,i}(\eta_1,\varphi_1) - \langle p(\eta_1,\varphi_1)\rangle\right)\left(p_{\alpha,j}(\eta_2,\varphi_2) - \langle p(\eta_2,\varphi_2)\rangle\right)\right\rangle}{\langle n_\alpha(\eta_1,\varphi_1) n_\alpha(\eta_2,\varphi_2)\rangle}$$

STAR studied this observable integrally

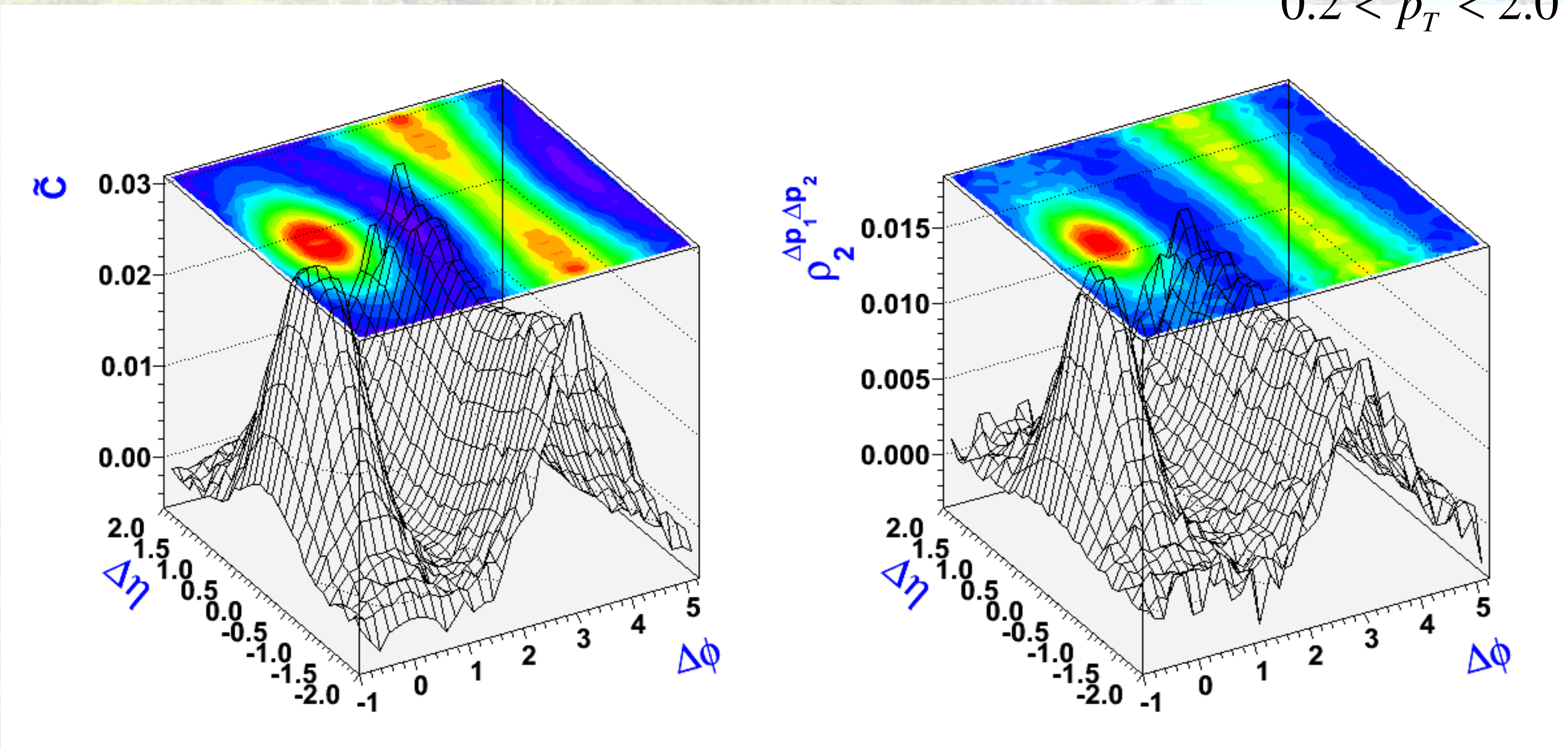
J. Adams et. al., Phys. Rev. C 72 (2005) 044902

Similar to: $\Delta\sigma^2_{p_t}(\Delta\eta\Delta\varphi)$ **STAR, J. Phys. G32, L37, 2006**

What do we expect? How different are $\rho_2^{\Delta p_1 \Delta p_2}$ and $\tilde{C}$

Comparative study with PYTHIA of $\rho_2^{\Delta p_1 \Delta p_2}$ & $\tilde{C}$ p+p collisions at $\sqrt{s} = 200$ GeV

$0.2 < p_T < 2.0$ **GeV/c**

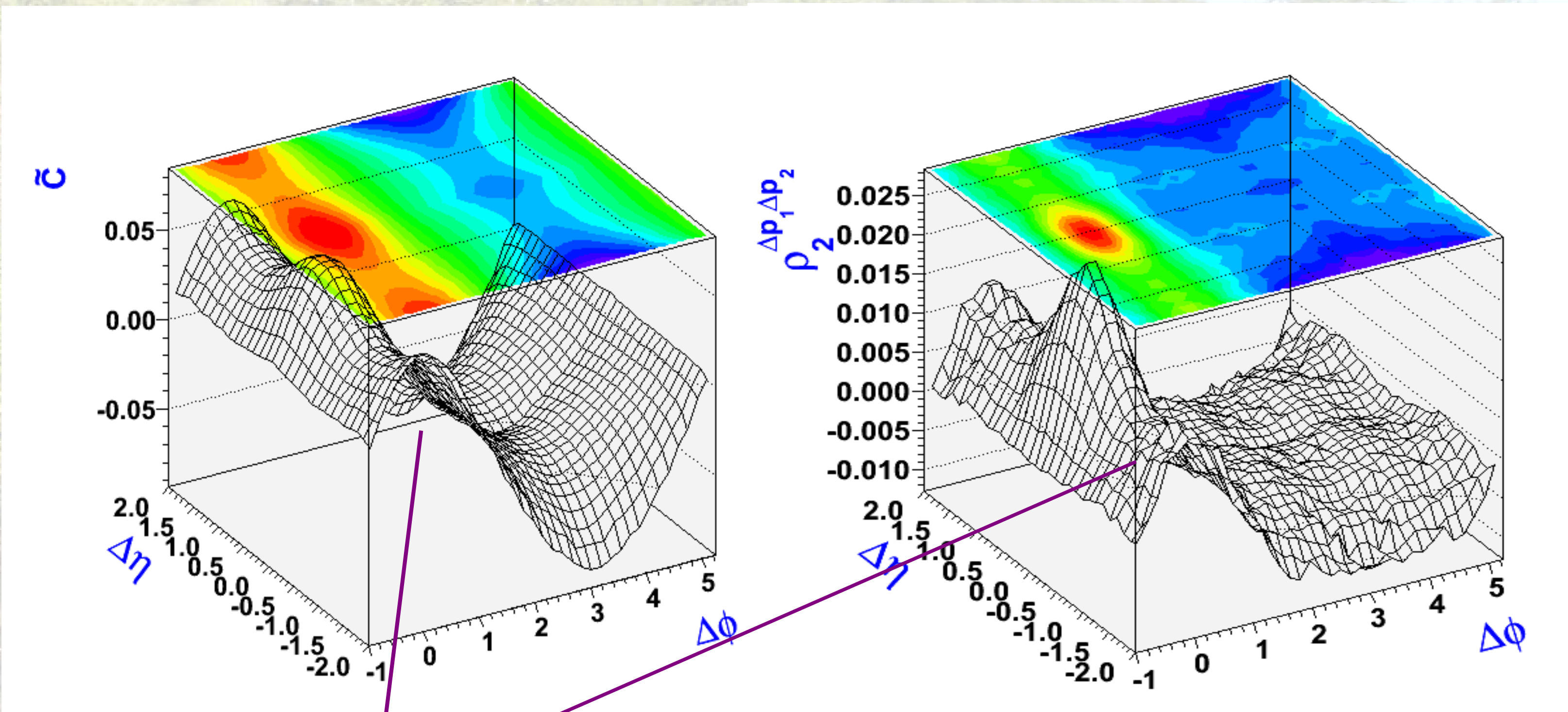


$\tilde{C}$ and $\rho_2^{\Delta p_1 \Delta p_2}$ have similar distributions but differ in magnitude

Discussed in more detail: M. Sharma & C. A. Pruneau, Phys. Rev. C 79 (2009) 024905

$\rho_2^{\Delta p_1 \Delta p_2}$ & $\tilde{C}$ are different to collectivity

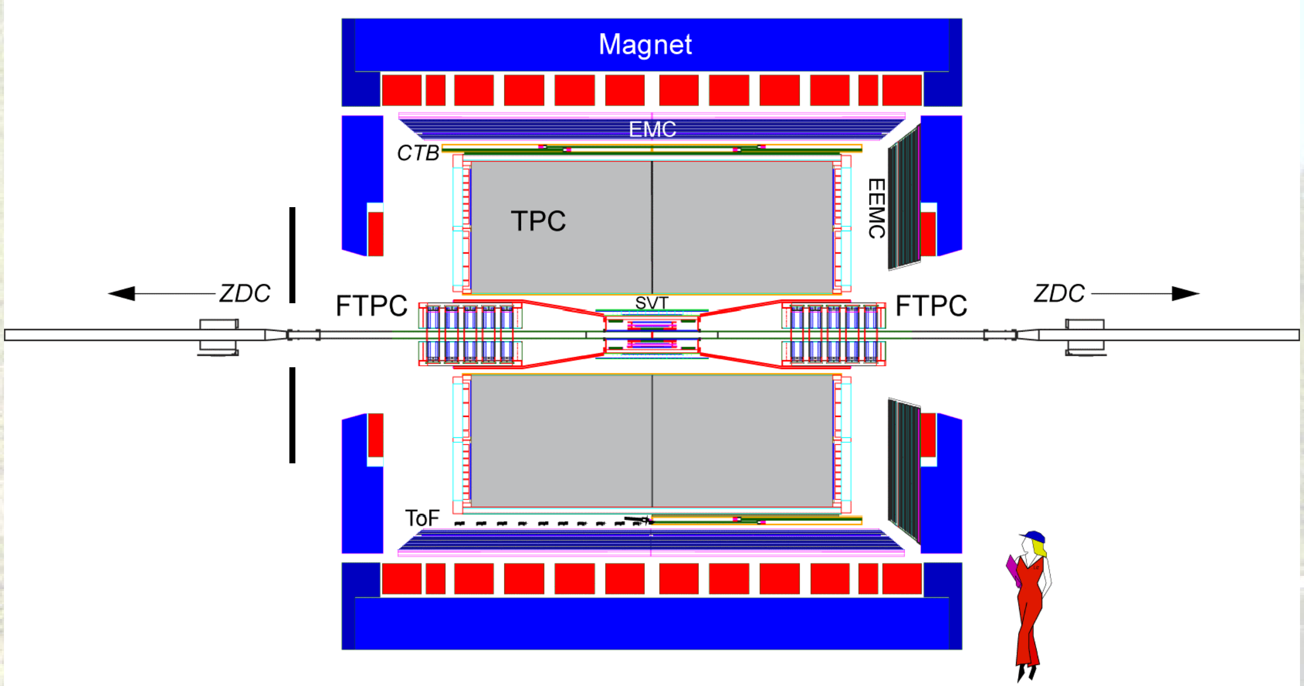
Example (radial flow): comparative study of $\rho_2^{\Delta p_1 \Delta p_2}$ & $\tilde{C}$ with radially boosted (v/c=0.3) p+p collisions at $\sqrt{s} = 200$ GeV.



M. Sharma & C. A. Pruneau, Phys. Rev. C 79 (2009) 024905

Particles pushed in the same direction (kinematic focusing),
Formation of the near side ridge-like structure: S. A. Voloshin, arXiv:nucl-th/0312065

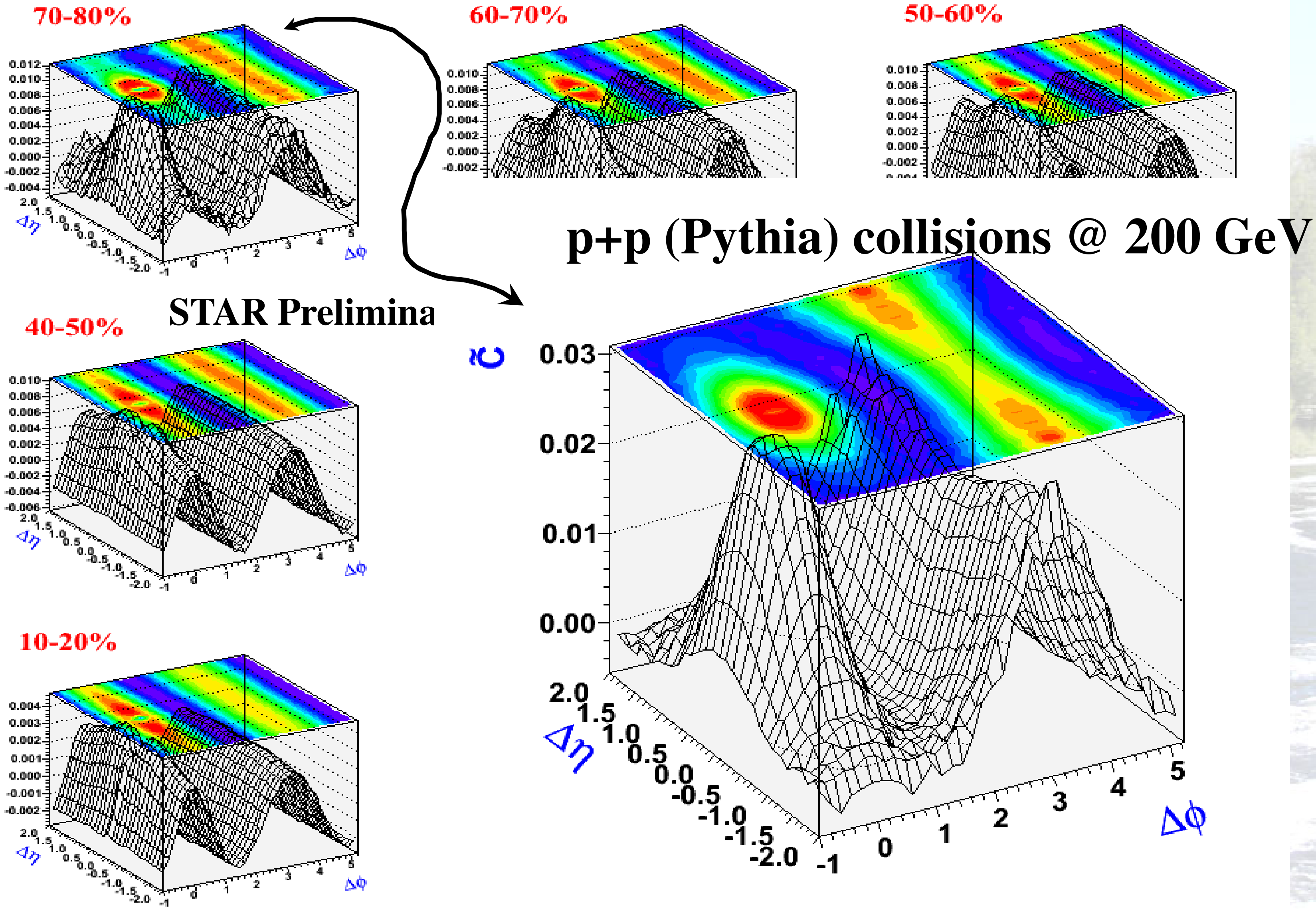
The STAR Experiment



- Cuts applied:
  - $|\eta| < 1.0$
  - $0.2 < p_T < 2.0$ GeV/c
  - Analysis done vs. collision centrality
  - Centrality slices: 0-5%, 5-10%, 10-20%…….

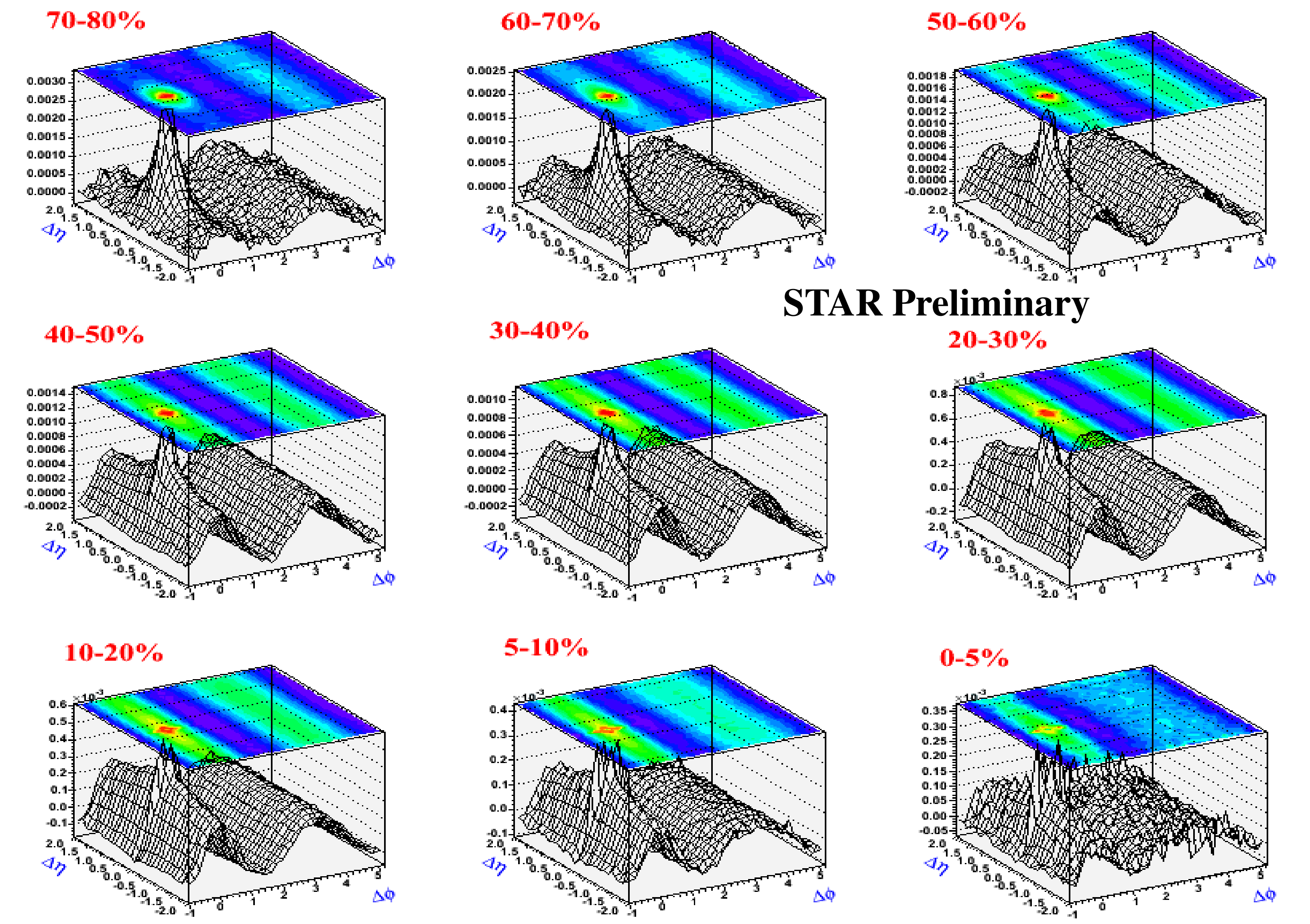
- Analyzed data from TPC, has 2π coverage
- Dataset: □Run IV AuAu 200 GeV
- Events analyzed: 10 Million
- Minimum bias trigger

Results - I


70-80%
60-70%
50-60%
40-50%
10-20%
STAR Prelimina
p+p (Pythia) collisions @ 200 GeV
$\tilde{C}$
$\Delta\eta$
$\Delta\phi$

$\rho_2^{\Delta p_1 \Delta p_2}$

Results - II



Functional Fit in $\Delta\eta$

Parameterization: fit based on $\Delta\eta$ projection with $|\Delta\varphi|<1$ radians

$$\tilde{C}(b, a_w, \sigma_w, a_n, \sigma_n) = b + a_w \exp(-\Delta\eta^2 / 2\sigma_w{}^2) + a_n \exp(-\Delta\eta^2 / 2\sigma_n{}^2)$$

Offset + Wide and Narrow Gaussians

b : Offset

a_n : amplitude of narrow Gaussian

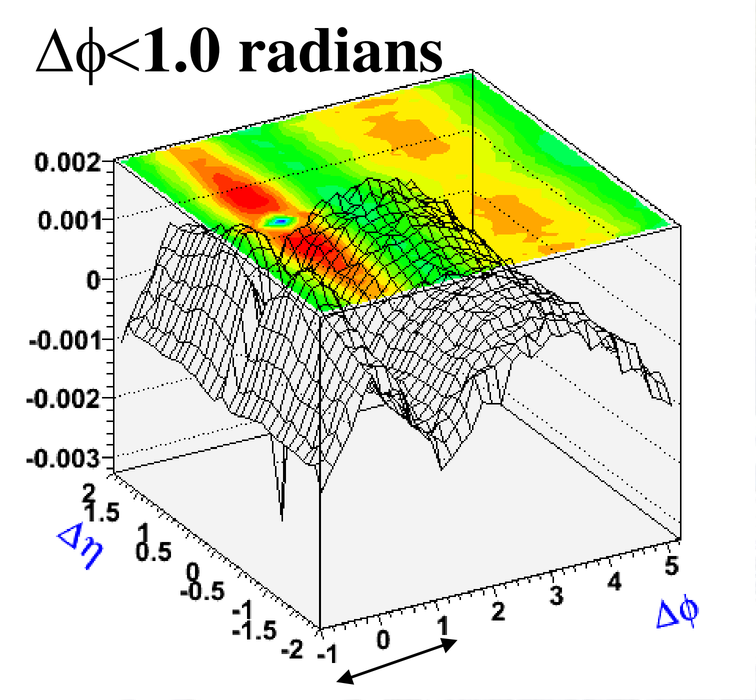
σ_n : width of narrow Gaussian

a_w : amplitude of wide Gaussian

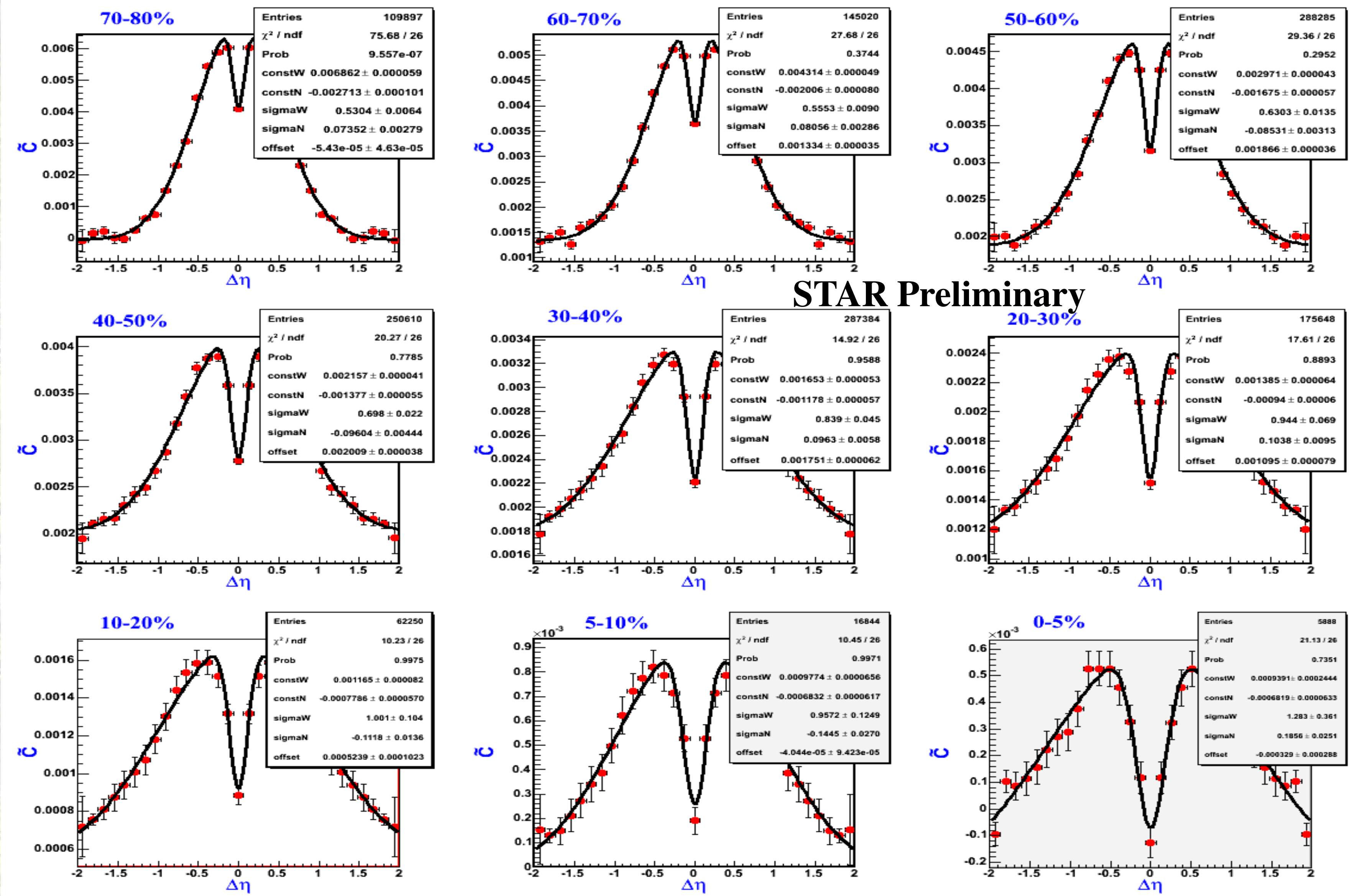
σ_w : width of wide Gaussian

↓

Used for the calculation of $\frac{\eta}{s}$

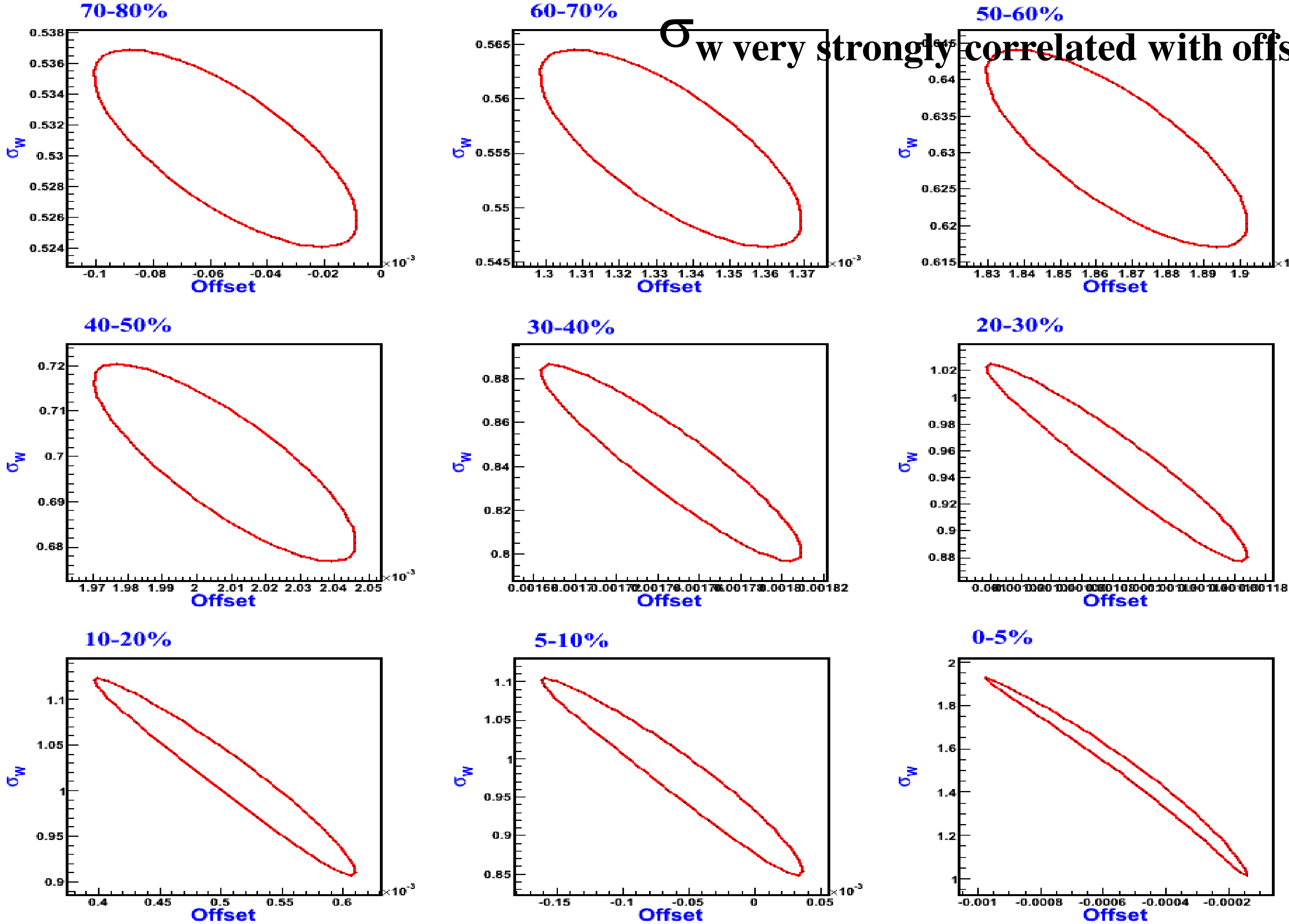


$\tilde{C}$ Projections + fit

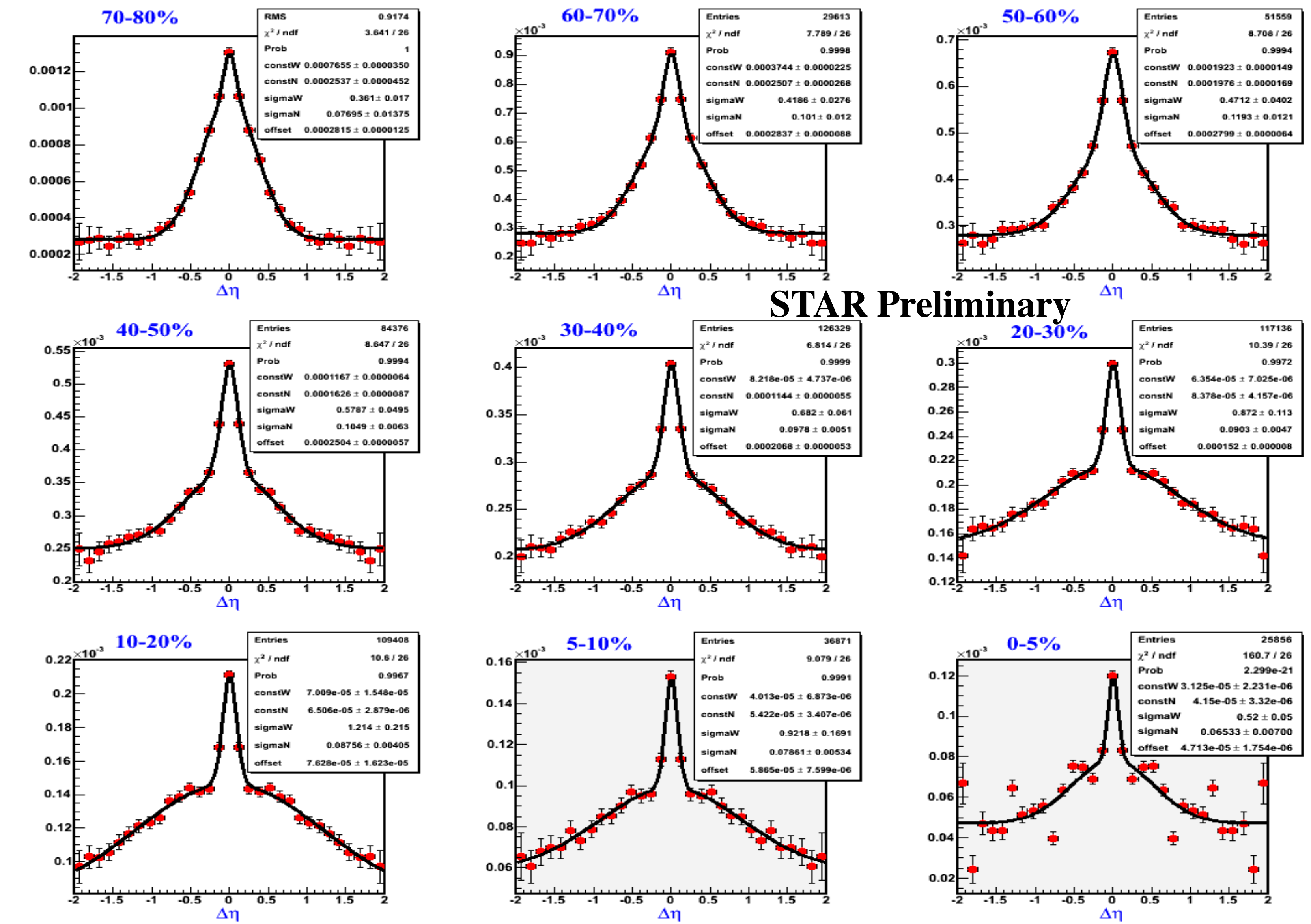


σ_w vs offset

σ_w very strongly correlated with offset

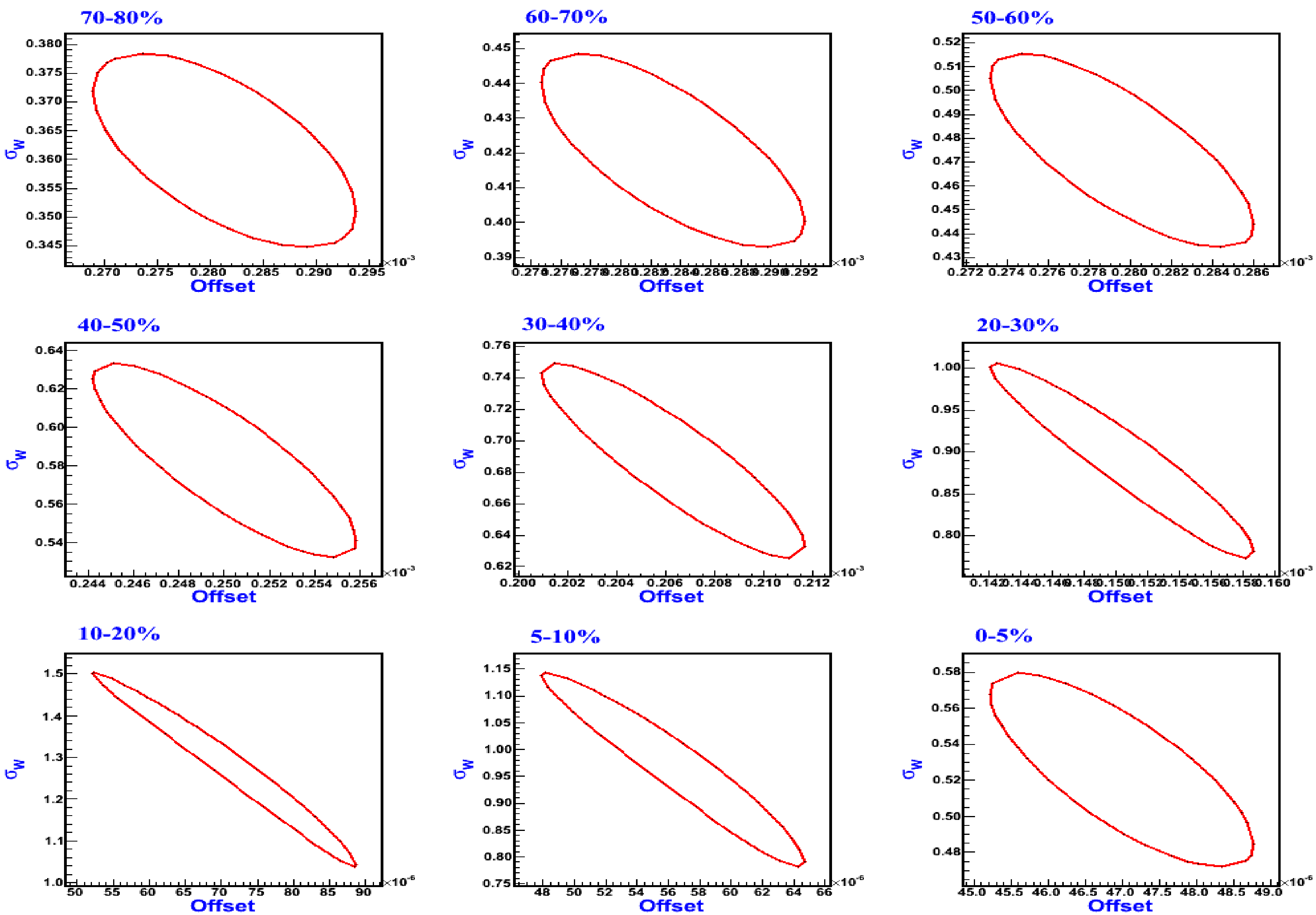


$\rho_2^{\Delta p_1 \Delta p_2}$ Projections + fit

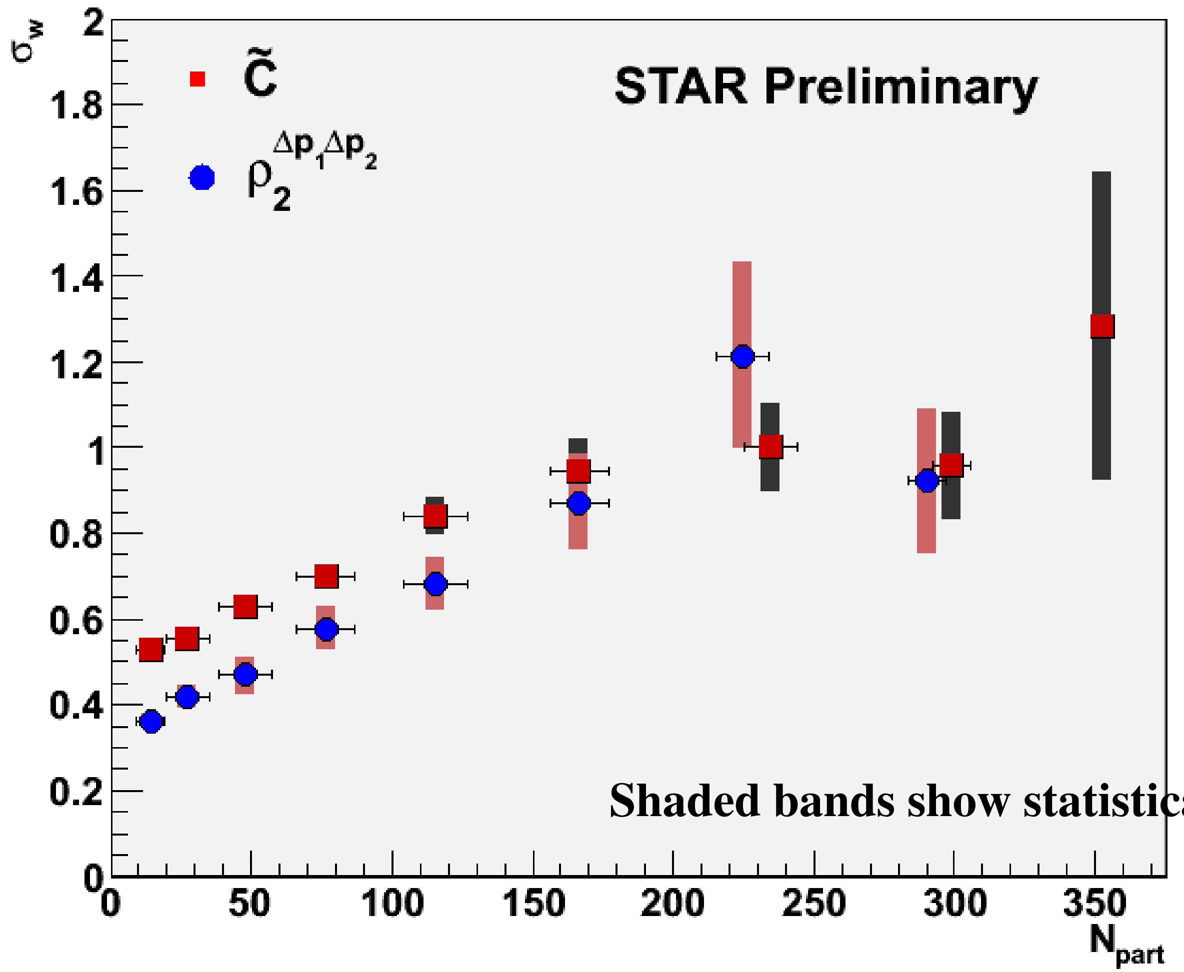


$\rho_2^{\Delta p_1 \Delta p_2}$

σ_w vs offset



Comparison of σ_w



Shaded bands show statistical errors

Widths (σ_w) & errors have changed since QM09

Summary

- Measured two different transverse momentum correlation functions, $\tilde{C}$ and $\rho_2^{\Delta p_1 \Delta p_2}$
  - Differences between them understood (partially).
  - $\tilde{C}$ will be used for the calculation of η / s
- Azimuthal dependence (away-side) of the correlation function can also be studied
- Model caveats:
  - Initial distribution is Gaussian
  - Diffusion is the dominant process
  - Rely on Gavin's estimated freeze-out times of peripheral and central collisions
- Experimental Caveats:
  - Relatively narrow rapidity coverage implies uncertainty in the offset
  - 5-component fit to data assumption
  - Systematic errors associated with track quality yet to be investigated