# Energy and System-Size Dependence of $p_T$ Fluctuations and Correlations at the STAR Experiment

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*for the STAR Collaboration*

## Abstract

The study of fluctuations and non-monotonic changes in $p_T$ correlations as a function of centrality and/or incident energy have been proposed to be one of the possible signals of QGP formation [1, 2]. Alternatively, analysis based on $p_T$ autocorrelations ha ve indicated that basic correlation mechanism could be dominated by the process of parton fragmentation [3]. We present experimental measurements of event-by-event average transverse momentum fluctuations and correlations for Cu+Cu collisions with $\sqrt{s_{NN}}$ of 62.4 and 200 GeV at the STAR experiment, and compare these to mixed events and gamma distributions. The dynamical mean transverse momentum fluctuations are found to decrease with increasing collision centrality. We also show two particle transverse momentum correlations at the same collision energies which decrease with centrality. The correlations are slightly more for Cu+Cu collisions than those for Au+Au collisions at the same collision energy and similar $N_{part}$. However, it is found that the squa re root of the correlation divided by the event-wise average event transverse momentum, which takes care of the changes in mean transverse momentum with incident energy and/or collision centrality, seems to be independent of both energy and system size. T he results on the correlation for forward and backward hemispheres and its dependence on the collision vertex will be discussed. We also present dependence of the correlation on the rapidity and azimuthal gaps. The contribution of resonances, charge-order ing effects and HBT correlations on $p_T$ correlations have been estimated and will be discussed.

## Motivation

1. The non-monotonic change in $p_T$ correlations as a function of centrality and/or as the incident energy is possible signal of the QGP [1].
2. Centrality dependence of $\langle p_T \rangle$ and correlations can indicate whether the thermalization is achieved in heavy ion collisions or not [2].
3. Basic $p_T$ correlation mechanism could be dominated by process of parton fragmentations as analyzed through $p_T$ auto-correlations [3].

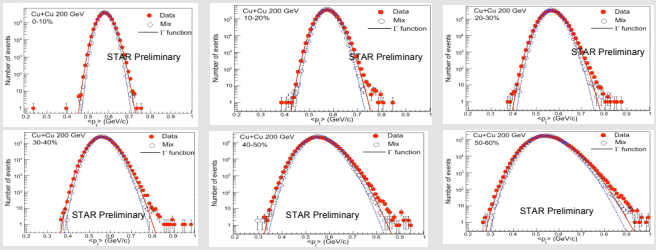
## Data Analyzed and Cuts Applied

**Data analyzed**
Cu + Cu at 200 and 62.4 GeV.
Events analyzed : 15 M at 200 GeV and 7.5 M at 62 GeV.

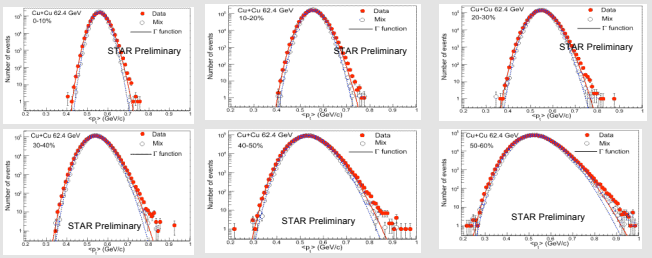
**Cuts applied**
Cut used as mentioned in the paper PRC 72(2005)044902.
TPC tracks with 0.15 GeV/c $\leq p_T \leq$ 2.0 GeV/c with $|\eta| < 1.0$
DCA < 1.0 cm , Number of hits >20.

**Centrality:** Star centrality bin based on reference multiplicity for Cu + Cu i.e., 0-10% (most central), 10-20%, 20-30%, 30-40%, 40-50% and 50-60%. $N_{part}$ for these centrality bins obtained from Glauber MC.

## Event-by-Event $\langle p_T \rangle$ Distribution - CuCu 200 GeV




## Event-by-Event $\langle p_T \rangle$ Distribution - CuCu 62.4 GeV



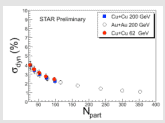

## Comparison of $\alpha/\langle N \rangle$ ( = $\mu^2/(\sigma^2 * \langle N \rangle)$)

| Centrality (%) | Cu+Cu 200 GeV α/n | Cu+Cu 62.4 GeV α/n |
|---|---|---|
| 0-10 | 2.04 | 2.18 |
| 10-20 | 2.08 | 2.23 |
| 20-30 | 2.08 | 2.26 |
| 30-40 | 2.11 | 2.28 |
| 40-50 | 2.12 | 2.31 |
| 50-60 | 2.13 | 2.30 |

$\alpha/n \sim 2$ , follow gamma distributions [4].

## Dynamical Fluctuations in $\langle p_T \rangle$

Dynamical fluctuations ,
$\sigma_{dyn} = \sqrt{(\sigma^2_{data} - \sigma^2_{mix})}$, where
$\sigma_{data}$ = relative width of $\langle p_T \rangle$ distribution in data,
$\sigma_{mix}$ = relative width of $\langle p_T \rangle$ distribution in mixed events,
Dynamical fluctuations decrease with increasing $N_{part}$ and independent of beam energy and system size for similar $N_{part}$.




## References

[1]. H. Heiselberg, Phys. rep. 351 (2001) 161.
[2]. S. Gavin, PRL 92 (2004) 162301.
[3]. J. Adams et al., (STAR Collaboration), J. Phys. G33 (2007) 451; J. Phys. G32 (2006) L37.
[4]. M. J. Tannenbaum PLB 498 (2001) 29.

## Two Particle Transverse Momentum Correlations

Two particle transverse momentum correlations:

$$\langle \Delta p_{t,i} \Delta p_{t,j} \rangle = \frac{1}{N_{event}} \sum_{k=1}^{N_{event}} \frac{C_k}{N_k (N_k - 1)}$$

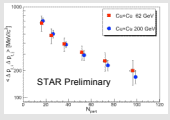
$$C_k = \sum_{i=1}^{N_k} \sum_{j=1, j \neq i}^{N_k} \left(p_{t,i} - \langle \langle p_t \rangle \rangle\right)\left(p_{t,j} - \langle \langle p_t \rangle \rangle\right)$$

where,
$N_{event}$ = number of events,
$N_k$ = number of tracks in $k^{th}$ event,

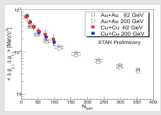
$$\langle \langle p_t \rangle \rangle = \left(\sum_{k=1}^{N_{event}} \langle p_t \rangle_k\right) / N_{event} \qquad \langle p_t \rangle_k = \left(\sum_{i=1}^{N_k} p_{t,i}\right) / N_k$$

$p_{t,i} = p_t$ for the $i^{th}$ track in an event, $\langle p_t \rangle_k$ = average $p_t$ of $k^{th}$ event.

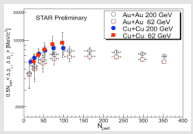
## Energy and System-Size Dependence




$p_T$ correlation decreases with $N_{part}$ for Cu+Cu and Au+Au collisions for both energies as expected if correlations are dominated from particle pairs from same nucleon-nucleon collision and gets diluted with increasing $N_{part}$.

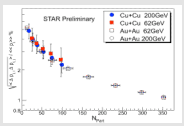



## $p_T$ Correlation : Scaling

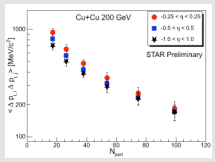



Correlation scaled by $N_{part}$ pairs shows saturation for Au + Au collisions indicating signs of thermalization.

Correlation scaled by $\langle\langle p_T \rangle\rangle$ exhibits little or no dependence on the incident energy and system size but decreases with increasing $N_{part}$.

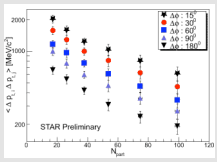



## η & φ Dependence

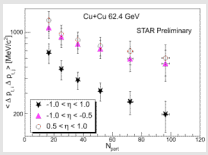



$p_T$ correlation shows slight decrease with increasing Δη for peripheral collisions whereas it is independent of Δη for central collisions.

Correlation increases as the Δφ decreases but decreases with increasing $N_{part}$.

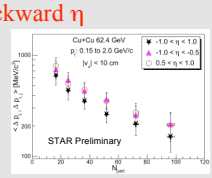



## Correlations in Forward & Backward η



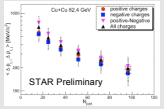

Correlation in forward and backward is similar but it is larger compared to $|\eta| < 1.0$ whereas no difference is seen decreasing $v_z$ : +/- 10 cm.

Correlation for the region $|\eta| < 1.0$ is independent of vertex cut.



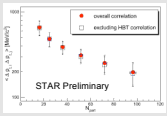

## Resonance Decays & HBT Effect

Resonance decays & charged-ordering :




$p_T$ correlation
- decreases by maximum 15% taking like charges only.
- increases by max. 12% taking only the unlike charges.
- reduces by 5% excluding pairs with relative momentum less than 0.1 GeV/c.

HBT:




## Summary

i) $\langle p_T \rangle$ distributions for the Cu+Cu are broader than those for the mixed events indicating presence of non-statistical fluctuations. Dynamical fluctuations are independent of beam energy and system size but decreases with increasing collision centrality.

ii) $p_T$ correlations decrease with increasing centrality , Δη and Δφ as expected if the correlations are dominated by pairs of particles that originate from the same nucleon-nucleon collision.

iii) Correlations scaled by participant pairs saturate for Au+Au : Indicating signs of thermalization.

iv) Correlation scaled by $\langle\langle p_T \rangle\rangle$ exhibits little or no dependence on the incident energy and system size but decreases with increasing $N_{part}$.