Anomalous centrality variation of two-particle angular correlations associated with minijets in Cu-Cu and Au-Au collisions at 62 and 200 GeV from STAR

Duncan Prindle *University of Washington* (STAR Collaboration)

We have measured 2D autocorrelations on (η,ϕ) for all unidentified charged hadrons with $p_t > 0.15$ GeV/c, $|\eta| < 1$ and 2π azimuth from minimum bias Cu-Cu and Au-Au collisions at 62 and 200 GeV. The correlation structure is dominated by a "same-side" 2D peak centered at zero relative opening angle on η and π which we hypothesize is caused by minimum-bias jets (minijets), *i.e.* jets without lower-p_t acceptance cut-offs. We observe a large excess of minijet-induced correlations in more-central Au-Au collisions relative to binary-collision scaling (more correlated pairs than expected even from volume emission and fragmentation of scattered partons). The minijet peak amplitude and η width undergo a sudden and dramatic increase relative to binary-collision scaling at an energy and A-dependent transition point on centrality. The transition point may scale with transverse particle density.

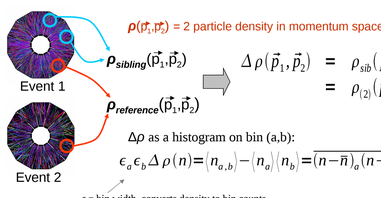
Our results confirm a rapid transition of minijet correlation properties observed previously at 130 GeV [1]. Minijet systematic trends correspond well with the two-component systematics of single-particle p_t spectra, specifically the hard component and possible parton energy loss. Minijet structure is also evident in complementary 2D correlations on transverse rapidity (y_{t1},y_{t2}) [where $y_t = \log((p_t + m_t)/m_0)$]. Results will be shown for the 200 GeV Au-Au data which indicate that back-to-back minijets persist even in most-central Au-Au collisions. The strong increase of minijet correlations from peripheral to central Au-Au collisions is strongly inconsistent with expectations for thermalization in heavy ion collisions.

[1] J. Adams *et al.* (STAR Collaboration), Phys. Rev. C **73**, 064907 (2006).

Correlation Measure

Start with a standard definition in statistics:

$$Corr(x,y) = Cov\frac{(x,y)}{\sigma_x \sigma_y}$$ Pearson's Correlation Coefficient



$$\Delta\rho(\vec{p}_1,\vec{p}_2) = \rho_{sib}(\vec{p}_1,\vec{p}_2) - \rho_{ref}(\vec{p}_1,\vec{p}_2) = \rho_{(2)}(\vec{p}_1,\vec{p}_2) - \rho_{(1)}(\vec{p}_1)\rho_{(1)}(\vec{p}_2)$$

Δρ as a histogram on bin (a,b):

$$\epsilon_a \epsilon_b \Delta\rho(n) = \langle n_{a,b}\rangle - \langle n_a\rangle\langle n_b\rangle = \overline{(n-\bar{n})_a (n-\bar{n})_b} = Cov(a,b)$$

ε = bin width, converts density to bin counts

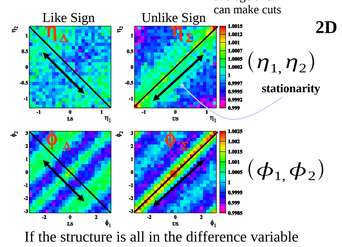
Normalize $\sigma_a \sigma_b \to \frac{1}{\epsilon_a \epsilon_b}\sqrt{\bar{n}_a \bar{n}_b} = \sqrt{\rho_{ref}} \Rightarrow \frac{\Delta\rho(n)}{\sqrt{\rho_{ref}}}$ measures number of correlated pairs *per final state particle*

Multivariable Correlations

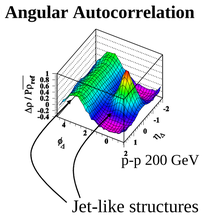
Original measurement space → Full angular space → Autocorrelation space

$$(\eta_1,\phi_1,p_{t1},\eta_2,\phi_2,p_{t2}) \to (\eta_1,\phi_1,\eta_2,\phi_2) \to (\eta_\Delta,\phi_\Delta)$$

average over can make cuts; project



2D Angular Autocorrelation



No trigger

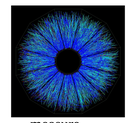
If the structure is all in the difference variable then you can project without loss of information

Make use of η_Δ dependence to distinguish different structures

Autocorrelations

Step-by-step procedure :

- Loop over *all possible pairs of particles*
- Create two-particle correlation
- Project on to difference axis
- Average over many events



measure tracks in TPC

Define: $\rho(\phi)$ is single-particle density in one event

$$\phi_\Delta \equiv \phi_1 - \phi_2 \qquad \phi_\Sigma \equiv \phi_1 + \phi_2$$

consider ϕ_Δ at bin centers

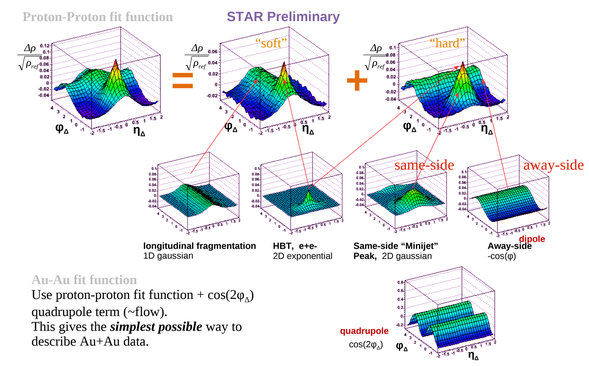
Loop over all particle pairs, make a histogram of their angular difference: $r_\rho(\phi_\Delta)$ bin width δ

$$r_\rho(\phi_\Delta) = \frac{1}{2\pi\delta}\int_{-\pi}^{\pi} d\phi_\Sigma \int_{-\delta/2}^{\delta/2} d\phi_\Delta' \rho(\phi_1')\rho(\phi_2') = \frac{1}{2\pi\delta}\int_{\phi_\Delta-\delta/2}^{\phi_\Delta+\delta/2} d\phi_\Delta' \int_{-\pi+\phi_\Delta'/2}^{\pi+\phi_\Delta'/2} d\phi_1' \rho(\phi_1')\rho(\phi_1'-\phi_\Delta') = \frac{1}{2\pi\delta}\int_{-\pi}^{\pi} d\phi' \rho(\phi')\rho(\phi'-\phi_\Delta') \quad \delta\to 0$$

Exact same form as the autocorrelation in conventional signal analysis

Then average over many events

Fit Function (5 easy pieces)



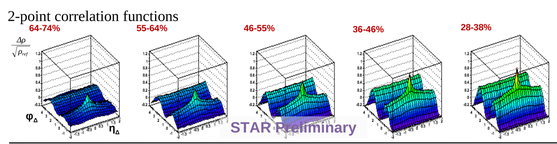
Au-Au fit function

Use proton-proton fit function + $\cos(2\phi_\Delta)$ quadrupole term (~flow).
This gives the ***simplest possible*** way to describe Au+Au data.

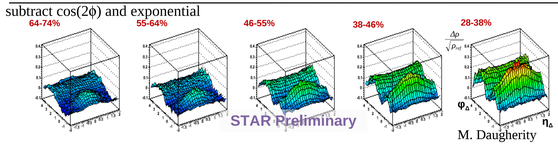
200 GeV Au-Au Data, selected centralities

Analyzed 1.2M minbias 200 GeV Au+Au events;
included all tracks with $p_t > 0.15$ GeV/c, $|\eta| < 1$, full φ

2-point correlation functions



subtract cos(2ϕ) and exponential



M. Daugherity

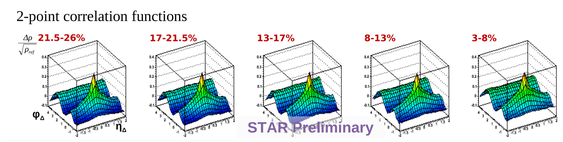
CI=LS+US **Subtracting cos(2ϕ) and narrow exponential shows sharp increase in amplitude and η_Δ width of same-side peak**

200 GeV Cu-Cu Data, selected centralities

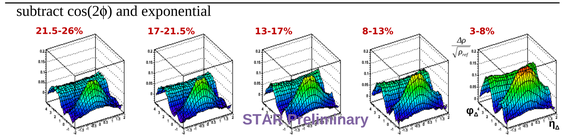
Analyzed 17M minbias 200 GeV Cu+Cu events;
included all tracks with $p_t > 0.15$ GeV/c, $|\eta| < 1$, full φ

Note: No track efficiency has been applied to Cu-Cu data shown in this poster.

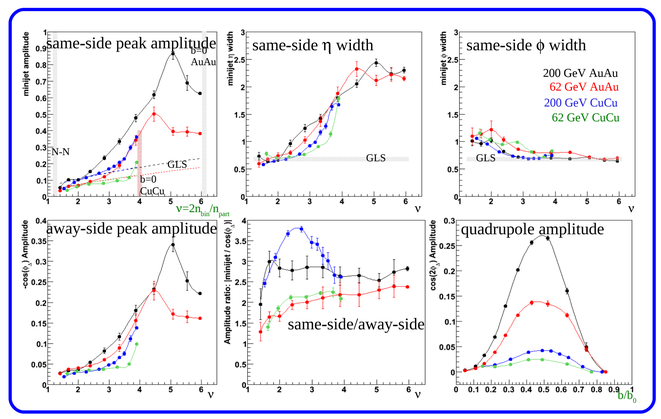
2-point correlation functions



subtract cos(2ϕ) and exponential



CI=LS+US **200 GeV CuCu also shows growth in same-side amplitude and η_Δ width, but for more central collisions**



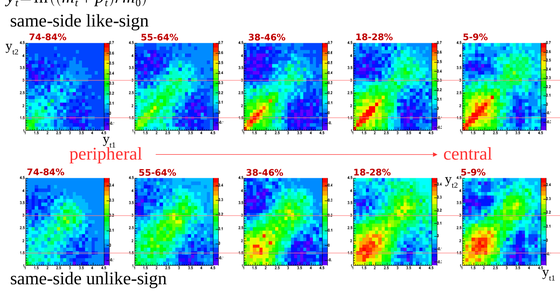
Subtracting $\cos(2\phi_\Delta)$ term from measured 2-point autocorrelations allows one to observe a same-side peak and away-side ridge that both grow with centrality. Fitting to a model function helps quantify features and indicate these features are due to 'hard' scattering of partons.

- Minijet amplitudes follow binary scaling for peripheral collisions, greatly exceeding binary scaling for more central collisions
- Minijet η width increases with centrality
- Minijet ϕ widths are large for peripheral collisions, minijets go from elongation in ϕ to elongation in η
- Away-side $\cos(\phi_\Delta)$ ridge is tightly correlated with minijet amplitude. Ratio of amplitudes depends on minijet multiplicity and acceptance of away-side jet
- Away-side $\cos(\phi_\Delta)$ ridge is **not** attenuated by 'medium'. Particles separated by π in azimuth are correlated
- $\cos(2\phi_\Delta)$ amplitude is smoothly varying while minijet amplitudes transition from binary collision scaling to greatly exceeding binary scaling

200 GeV Au-Au Data, selected centralities

$y_t = \ln((m_t + p_t)/m_0)$

same-side like-sign

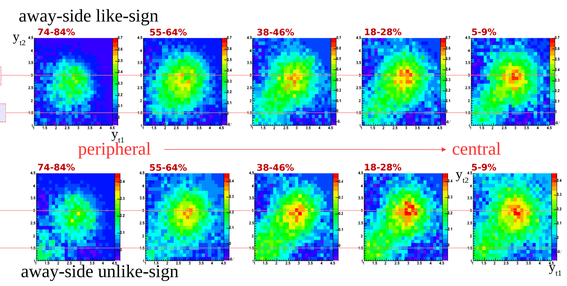


same-side unlike-sign

P_t=1.4 GeV/c

P_t=0.33 GeV/c

away-side like-sign



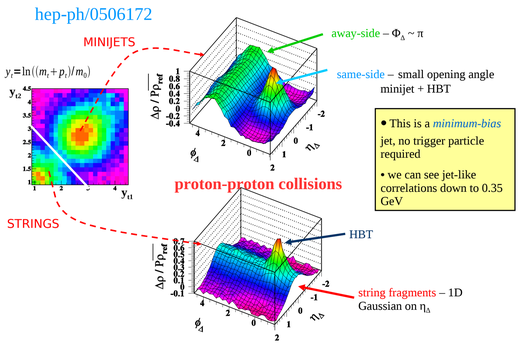
away-side unlike-sign

For same-side we see HBT on the like-sign diagonal
Low-y_t correlation strength increases with centrality for like-sign
Correlated high-y_t pairs continue to most-central events

Away-side is largely independent of charge sign (like-sign~unlike-sign)
Few low-y_t pairs for peripheral events
Correlation strength of high-y_t pairs increases with centrality

Understand Au-Au and Cu-Cu by referring to proton-proton collisions.

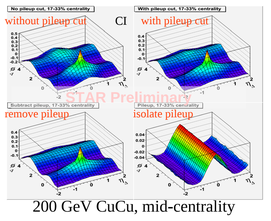
hep-ph/0506172



- This is a *minimum-bias* jet, no trigger particle required
- we can see jet-like correlations down to 0.35 GeV

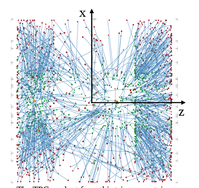
Pileup contamination is a problem

Collisions occurring within 40 μs of a trigger can be reconstructed as the trigger or contribute to triggered vertex.



200 GeV CuCu, mid-centrality

5% of 200 GeV Cu-Cu and 0.5% 62 GeV AuAu are contaminated with pileup. We reject 75% of those and extrapolate to no pileup.



The TPC readout from this trigger contains tracks from a collision 20 μs earlier. The tracks on the right are reconstructed to a vertex near the triggered primary.

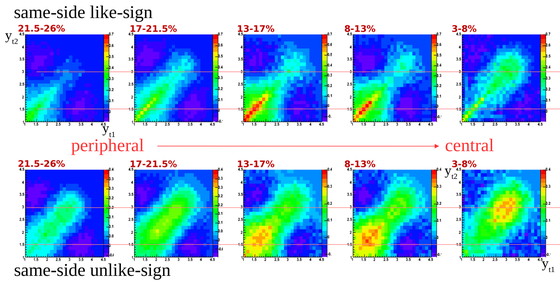
Subtract (or isolate) pileup.
Estimate rejection factor f = 0.75

$$\frac{\Delta\rho}{\sqrt{\rho_{ref}}}(noCut) = \frac{\Delta\rho}{\sqrt{\rho_{ref}}}(noPileup) + \frac{\Delta\rho}{\sqrt{\rho_{ref}}}(pileup)$$

$$\frac{\Delta\rho}{\sqrt{\rho_{ref}}}(cut) = \frac{\Delta\rho}{\sqrt{\rho_{ref}}}(noPileup) + (1-f)\frac{\Delta\rho}{\sqrt{\rho_{ref}}}(pileup)$$

200 GeV Cu-Cu Data, selected centralities

same-side like-sign

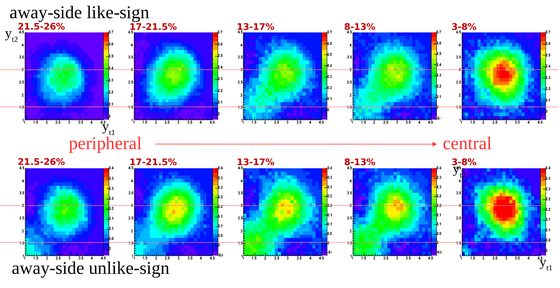


same-side unlike-sign

P_t=1.4 GeV/c

P_t=0.33 GeV/c

away-side like-sign



away-side unlike-sign

Cu-Cu (y_{t1},y_{t2}) correlations are qualitatively similar to Au-Au correlations. Note that the $\cos(2\phi_\Delta)$ amplitude is an order of magnitude smaller for Cu-Cu.

No indication of centrality-dependent energy loss.
Expect particle traversing medium to lose energy, so peak should move to lower y_t and spread off diagonal

Conclusions

We have measured 2-point correlations in subspaces of the six dimensional ($\vec{p}_1$,$\vec{p}_2$) space. There is little structure along the (η_1,η_2) and (ϕ_1,ϕ_2) diagonals allowing us to concentrate on (y_{t1},y_{t2}) and (η_1-η_2,ϕ_1-ϕ_2) = (η_Δ,ϕ_Δ) sub-spaces.

In the axial subspace the major structures are described by $\cos(2\phi_\Delta)$, $\cos(\phi_\Delta)$ and 2D Gaussian centered at (0,0) terms. The $\cos(\phi_\Delta)$ and 2D Gaussian are strongly correlated, increasing greatly in strength with centrality. The 2D Gaussian is elongated in ϕ for peripheral events, becoming strongly elongated in η for central events.

The (y_{t1},y_{t2}) subspace shows a strong feature centered near p_t=1.5 GeV/c. This is strongly Correlated with the 2D Gaussian and $\cos(\phi_\Delta)$ component seen in the axial space.
No evidence for energy loss.

Observed 2-particle correlations are consistent with abundant particle production via hard parton scattering and strongly inconsistent with a thermalized opaque medium.

Supported in part by the Office of Science of the U. S. Department of Energy