Studies of Hadronic Jets with the Two-Particle Azimuthal Correlations Method

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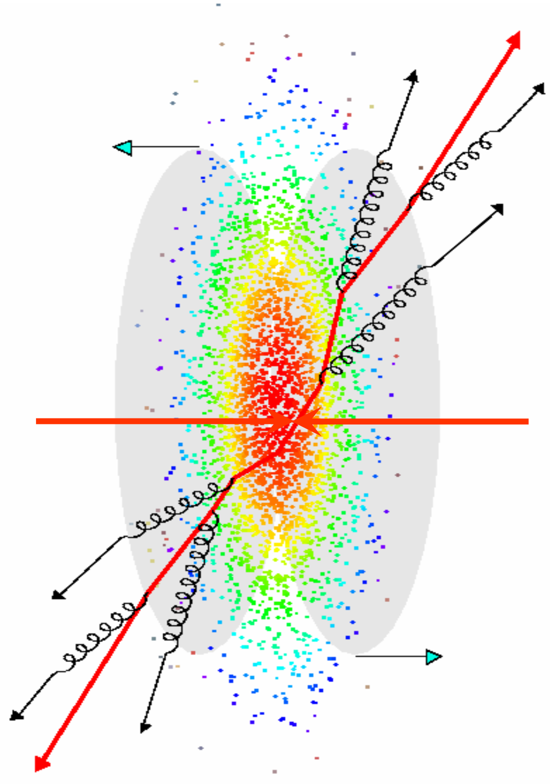
Hadronic Jets as investigation tool of soft QCD states

Jet event in a hot QCD medium



Bulk (soft) QCD particle production:

- low-Q^2, long range strong processes, well described by hydro-/thermo-dynamical models;
- ~90% of all final state particles are from vacuum !

Jet (hard) QCD particle production :

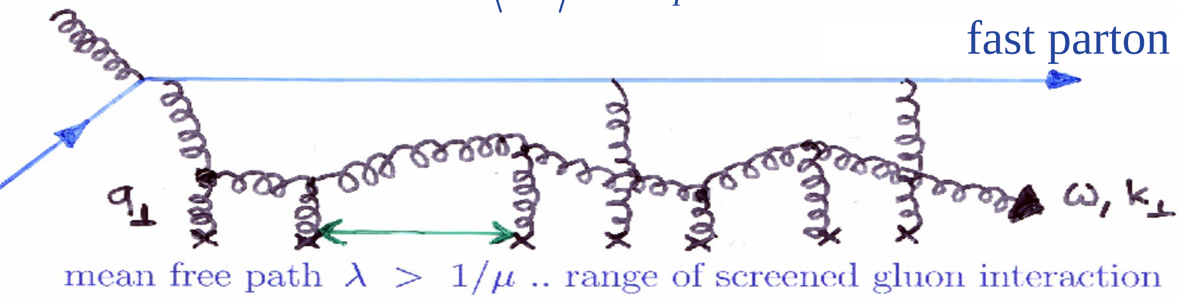
- from partonic hard scattering (primarily gluons);
- high-Q^2 processes with calculable cross section ($\alpha_S(Q^2) \ll 1$) produced early (τ<1fm);
- interact strongly with the bulk QGP: loose energy via gluon radiation ≡ jet quenching and broadening

Observed via:

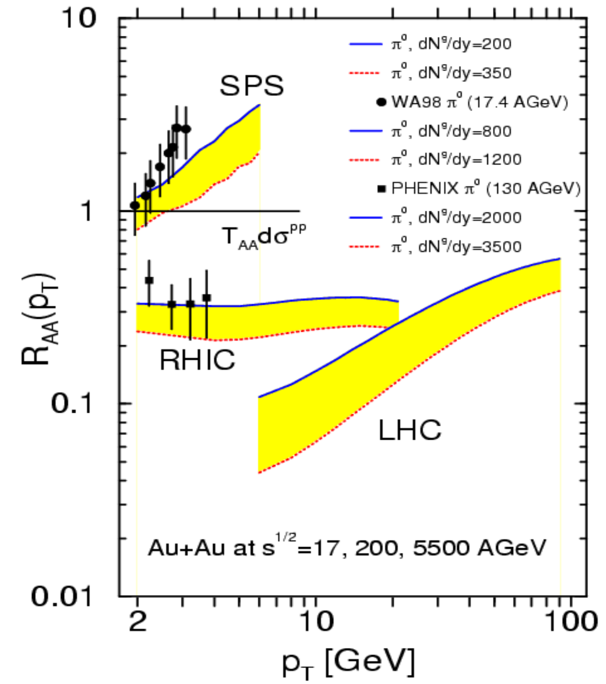
- leading (high p_T) hadron spectra;
- two-particle azimuthal correlations.

Quenching and Broadening of Hadronic Jets in QGP

$$\Delta E \propto \left\langle k_T^2 \right\rangle \propto \rho_{plasma} L^2$$



<u>*Energy loss through gluon radiation*</u>:
reduction of fast parton energy
(high p_T suppression)
in many low energy
(low p_T enhancement)
and large angle gluons
(jet transverse momentum k_T broadening).



I.Vitev and M. Gyulassy, PRL 89 (2002)

Probe Calibration – Jets in pp and p(d)A collisions

- All *hot nuclear (QGP) effects* are established with respect to *vacuum (pp collision) effects* and *cold nuclear (p(d)A collisions) effects*:

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

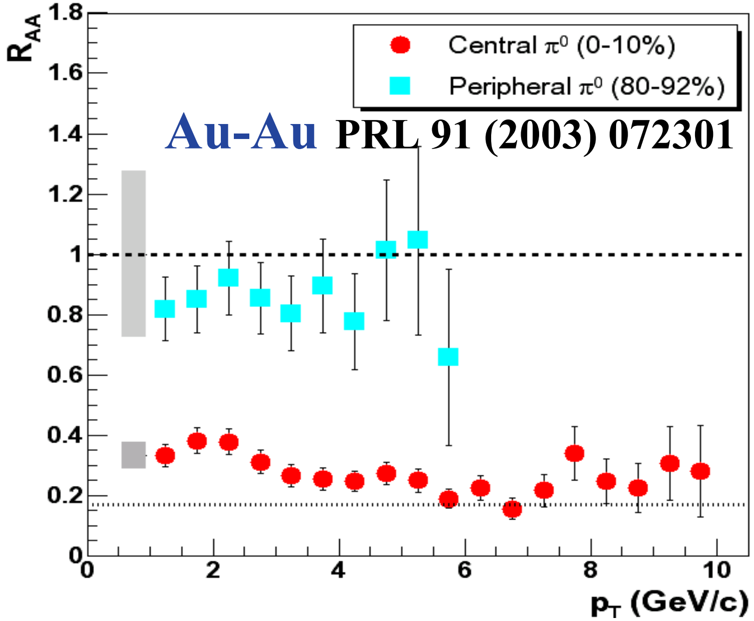
pp cross section!

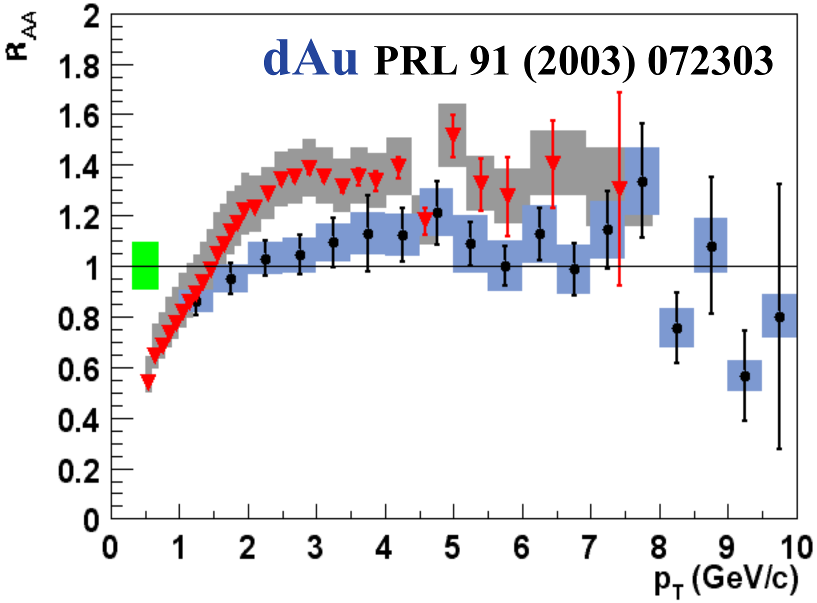
$$\langle k_\perp^2 \rangle_{\mathrm{AA}} = \langle k_\perp^2 \rangle_{\mathrm{vac}} + \langle k_\perp^2 \rangle_{\mathrm{IS\ nucl}} + \langle k_\perp^2 \rangle_{\mathrm{FS\ nucl}}$$

p+p ⟶ p(d)+A ⟶ A+A

- Cold nuclear effects are generated by initial state effects like the Cronin effect and gluon saturation effects which *could produce similar effects* as the final state effects (energy loss) in the hot nuclear matter.

Hadronic Jet Quenching at High p_T – R_{AA} measurements

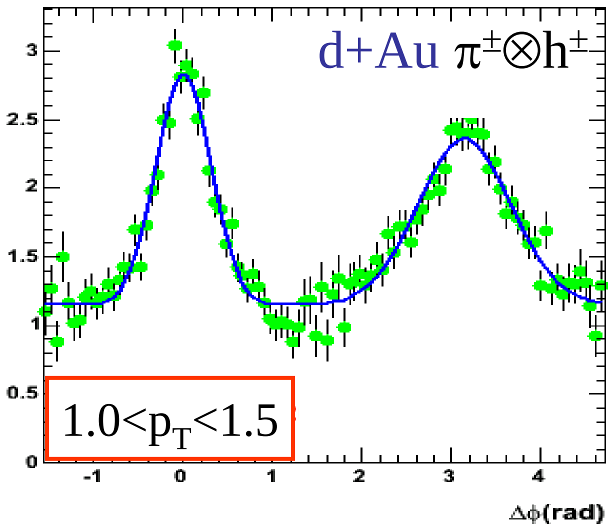


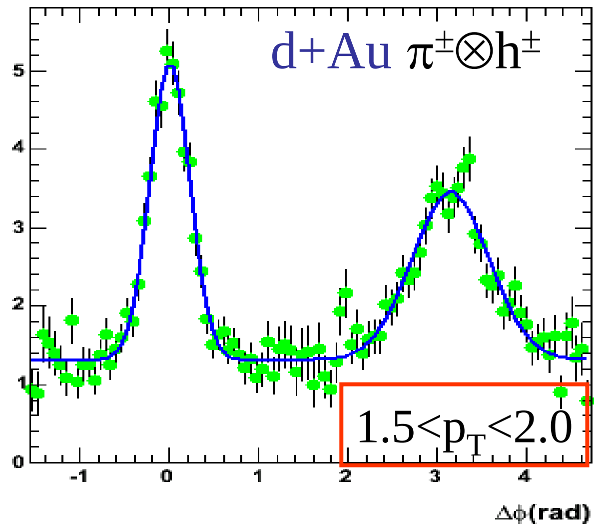


- Strong suppression in central AuAu hadron spectra at high pT
- Cronin effect in dAu hadron spectra at high pT
- Jet suppression at high p_T is clearly a final state effect (gluon radiation)
- Jet enhancement at low p_T and jet broadening are to be studied via the two-particle angular correlation method

Two-Hadron Azimuthal Correlations in pp and pA collisions

- The basic distribution is $1/N_{trigg} \times dn_{trigg\text{-}assoc}/d\Delta\varphi$
- It is described by a flat combinatorial background and two Gaussians: the *near-side* (around $\Delta\varphi \sim 0$, with $\varphi \equiv 0$ being the high p_T trigger) – vacuum jet fragmentation, and the *away-side* (around $\Delta\varphi \sim \pi$) – vacuum (pp case) and Cronin (pA case) k_T jet broadening

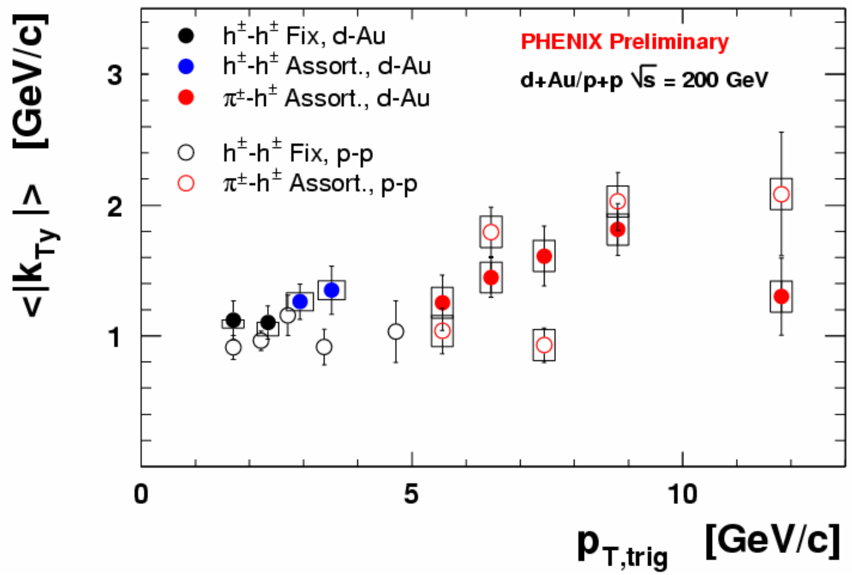


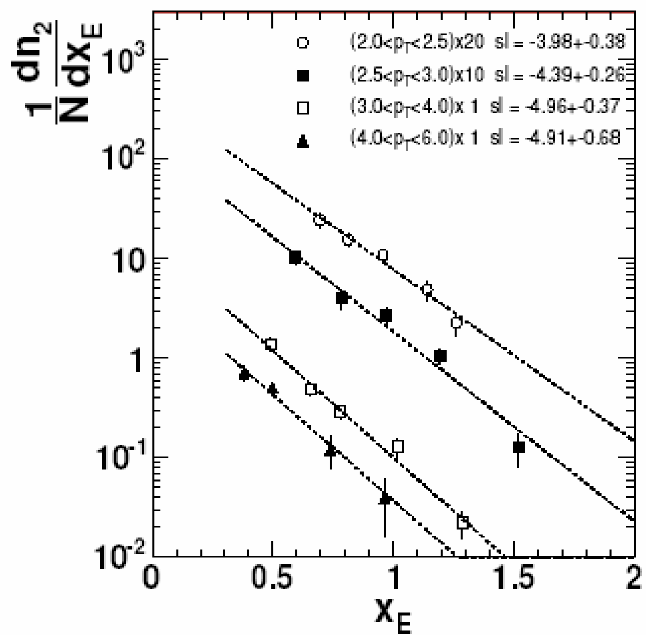


two-hadron correlations triggered on a $\pi^{\pm}$ with p_{Ttrigg}>5GeV/c in dAu: Gaussian Shape

$\langle k_T \rangle$ and conditional yields in pp and dAu collisions

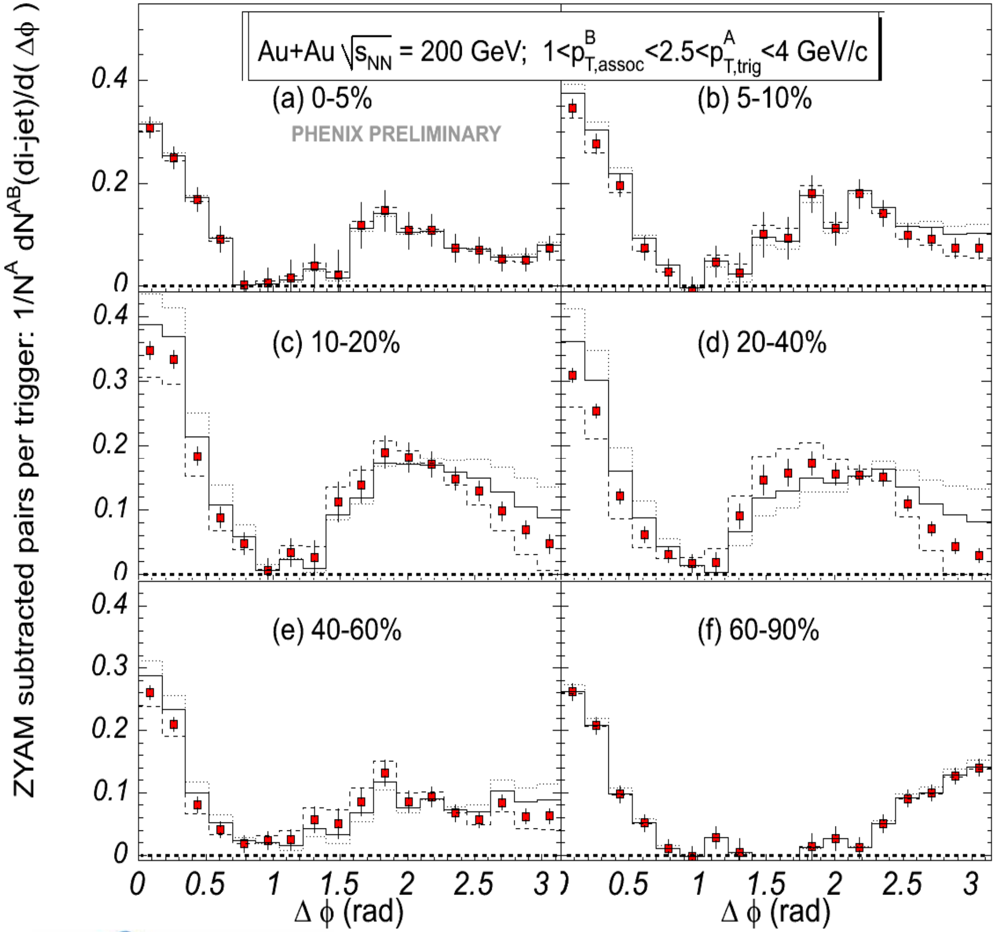
- Away-side k_T broadening is similar for pp and dAu collisions
- Away-side conditional yield (number of associated hadrons per trigger pion) follows the typical vacuum fragmentation function





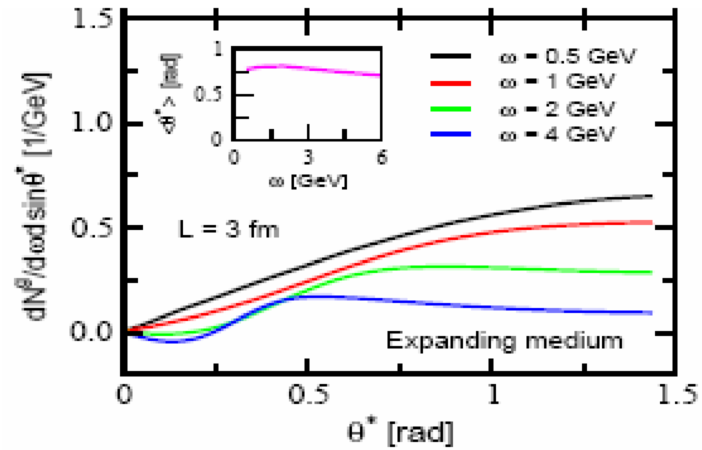
$$x_E = -\frac{\vec{p}_T \cdot \vec{p}_{Ttrigg}}{|\vec{p}_{Ttrigg}|^2}$$

Two-Hadron Azimuthal Correlations in AuAu collisions



- AuAu: a source of correlated background *global collective flow*:

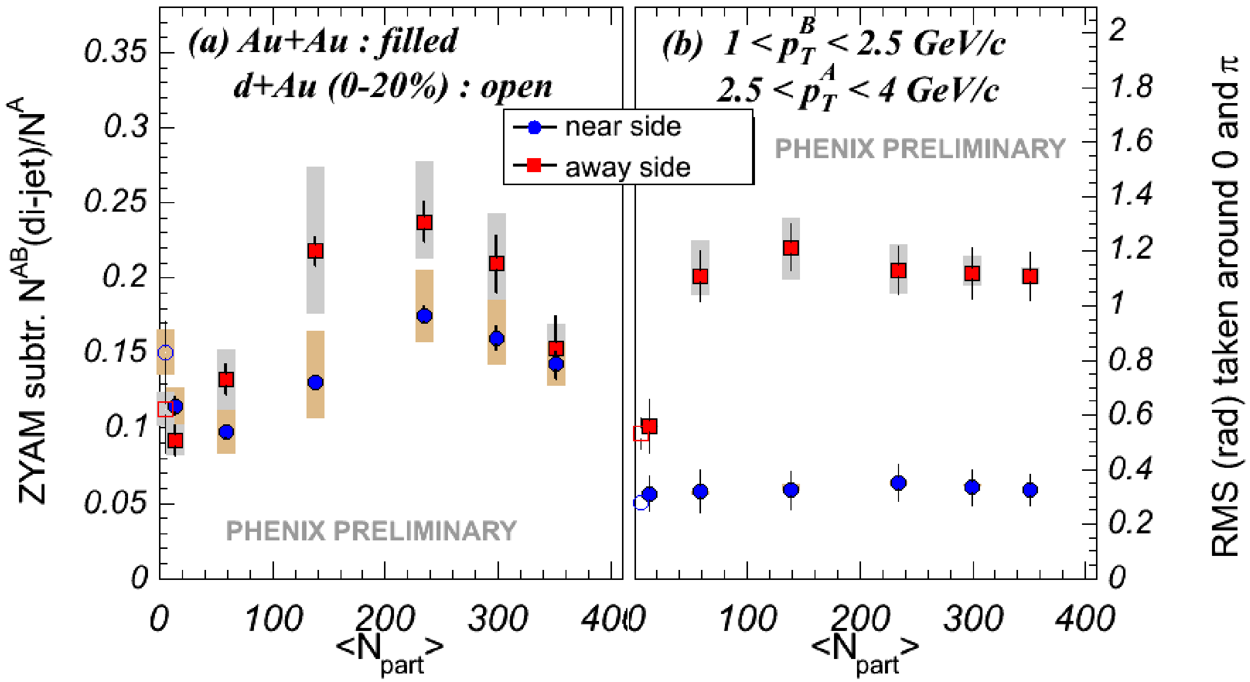
  $N(1+2v_{2assoc}v_{2trigg}\cos(2\Delta\varphi))$
- Figure is background subtracted (only pairs from the di-jet source)
- Away-side is pronouncely non-gaussian and broadened



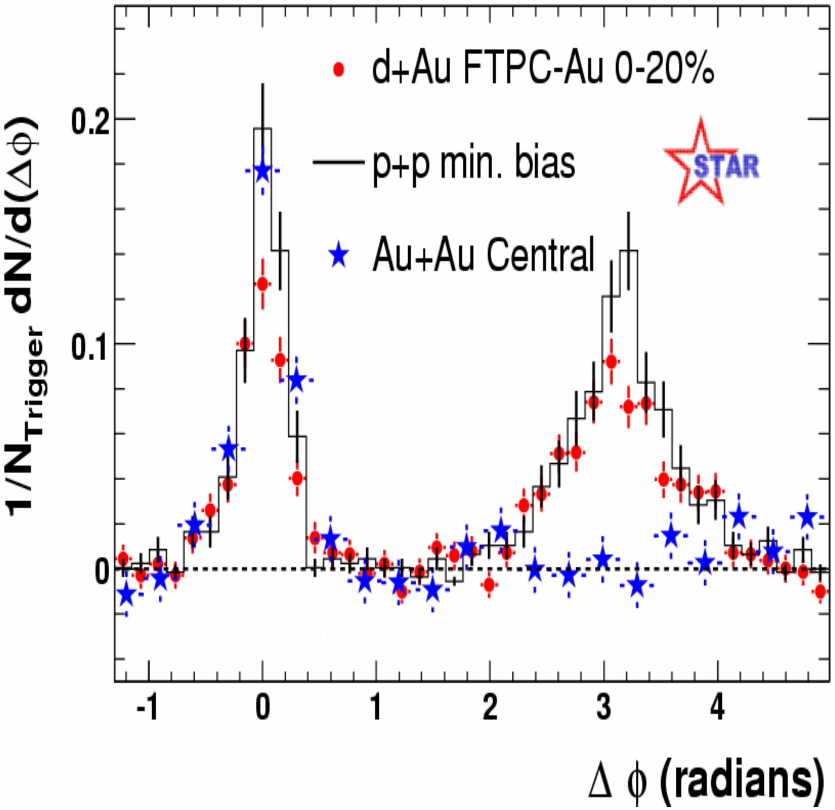
I.Vitev, hep-ph/0501255

Away-side broadening and enhancement in AuAu collisions

- Away-side conditional yield is enhanced (red, left panel) with centrality
- Away-side RMS broadens (red-points, right panel) with centrality
- This happens for low p_T (p_{Tassoc}~1.5GeV/c, p_{Ttrigg}~3GeV/c)

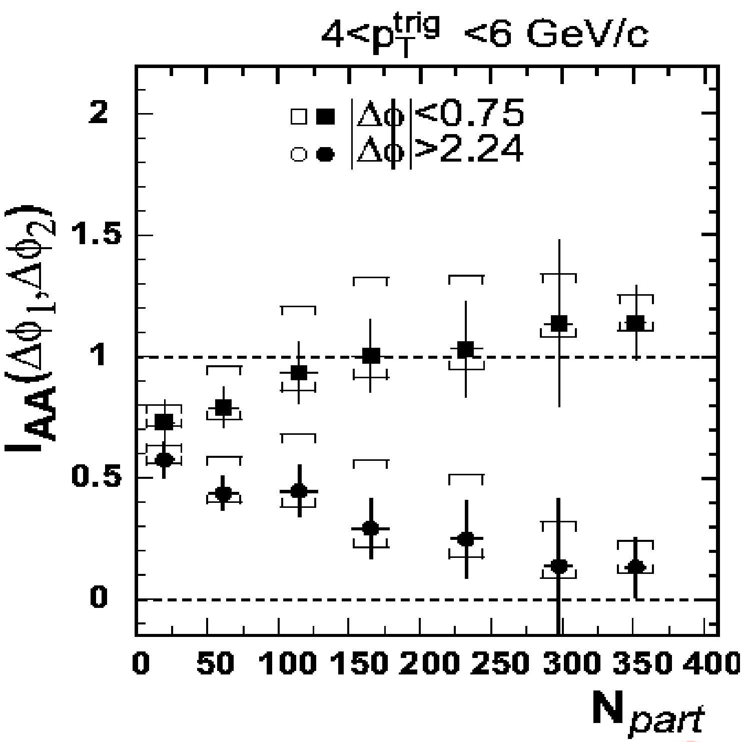


STAR – away-side suppression at high p_T in AuAu



Adler *et al.*, PRL90 (2003), PRL 91 (2003)

- STAR experiment sees a strong suppresion of the away-side at high p_T of the associated hadron



Current efforts in AuAu two-particle correlation analysis (I)

- A new AuAu data set with ~13 times more statistics is being analyzed now; this will allow significant improvements of the existing results:
  - higher statistical significance;
  - higher transverse momentum reach: where does the transition from suppression to enhancement happens?
- New types of two-particle correlations:
  - correlations of mid-rapidity trigger hadrons (π^0) with high-rapidity associated hadrons ($\mu^\pm$ from hadron decays in the muon arms) to establish the x-dependence of these effects → *initial state gluon saturation effects*;
  - Correlations of trigger dileptons (mid-rapidity e^+e^- and high-rapidity $\mu^+\mu^-$) with associated hadrons for detailed jet shape studies.
- Posibility to pursue this physics at the next heavy ion collider (the LHC at CERN) with the CMS detector.

Current efforts in AuAu two-particle correlation analysis (II)

- *Higher rapidity* means lower x, $x=p_T/\sqrt{s}\cdot(e^{+\eta}+e^{-\eta})$, and at low enough x gluon saturation effects become significant. Gluon fusion becomes the dominant elementary process and two-particle correlations should make the transition from a di-jet shape to a mono-jet shape.
- *Dilepton (virtual photon) tagged jets* have several advantages, the main ones being:
  - there is no correlated background (photons don't couple to flowing QGP);
  - the initial 4-momentum of the jet is directly measured by measuring the photon (dilepton pair);
  - however, this is a low cross section process