Correlations and fluctuations in STAR

A review with an emphasis on topics under-represented elsewhere...

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Hot and Dense Matter in the RHIC-LHC Era, Tata Institute of Fundamental Research, Mumbai

Content

- Two-particle correlations: axial and transverse collectivity, femtoscopy challenge
- Three-particle correlations: gluon radiation, strong P- and CP-breaking

Introduction

Relativistic kinetics – relaxation space/time scales, approach to equilibrium

need advanced studies including bottom-up correlation approaches

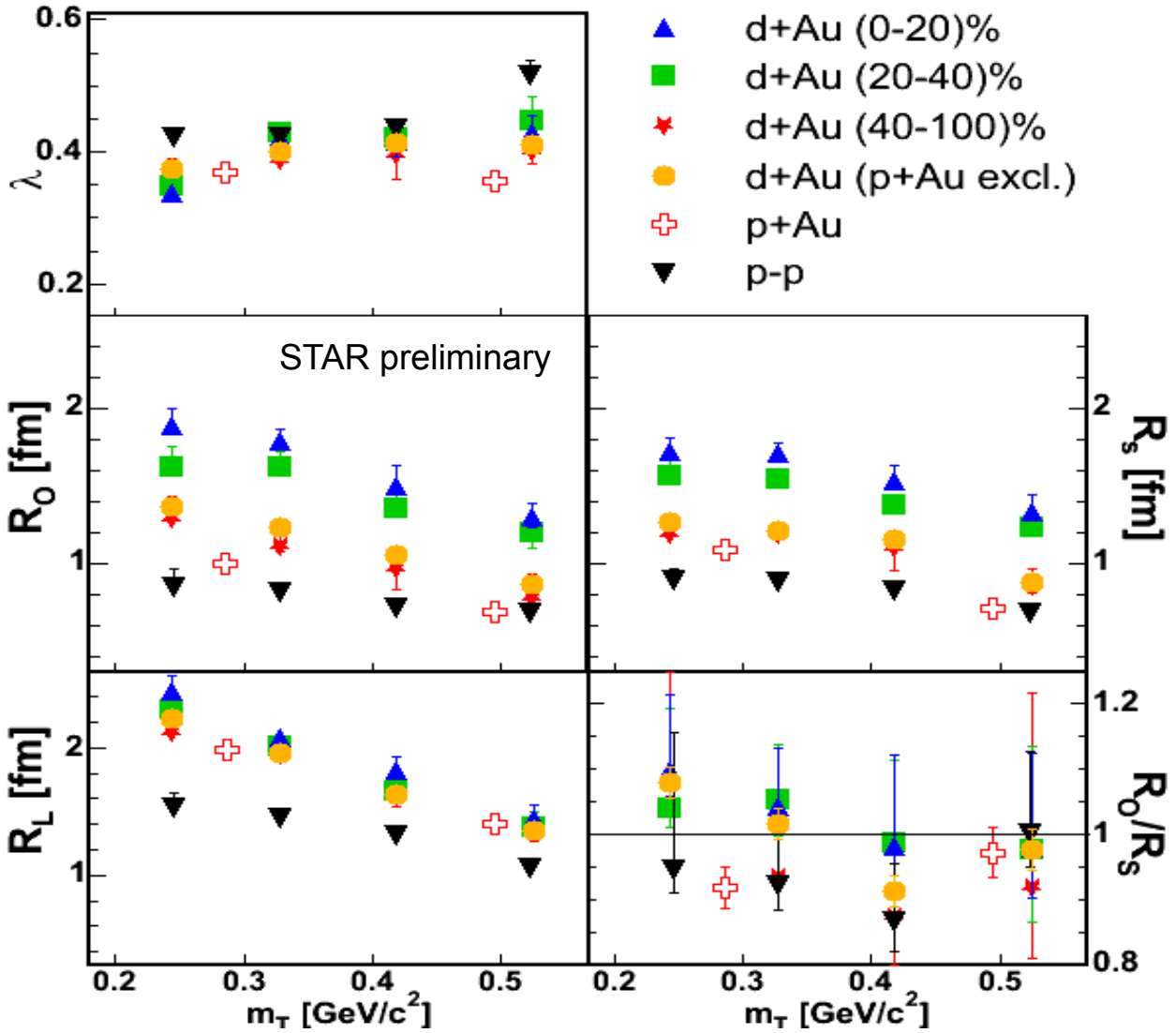
Relativistic hydro – locally equilibrated chunks of matter

spectra, flow, HBT

Classical thermo"dynamics" -- timeless – global equilibrium

particle yields, spectra

STAR HBT in light systems: p+p, d+Au

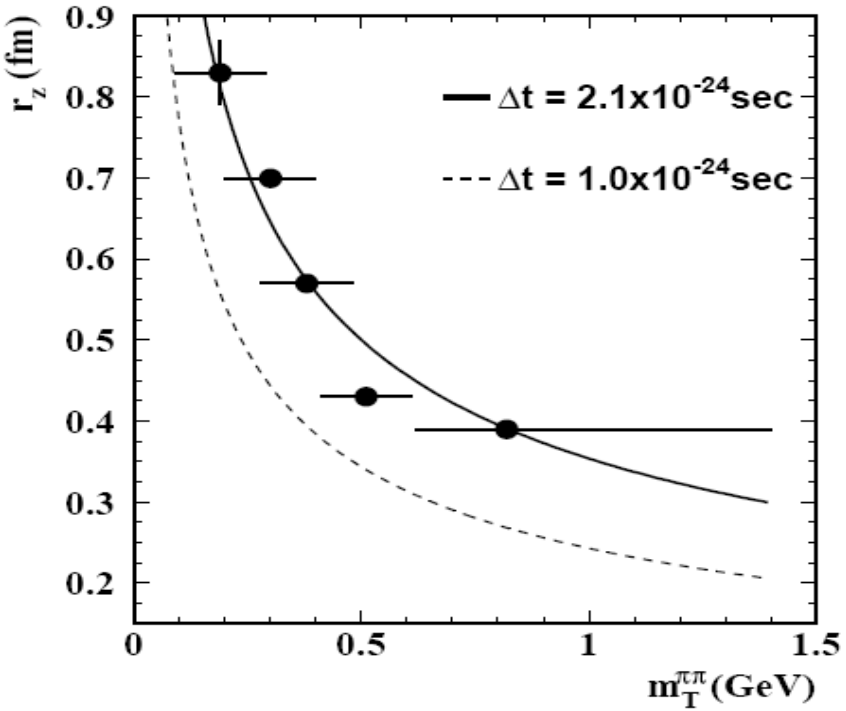


- m_t trend is usually explained by coordinate-momentum (r,p) correlation
- (r,p) correlation in the final state can be caused by a “blast wave” (Hubble-like) expansion

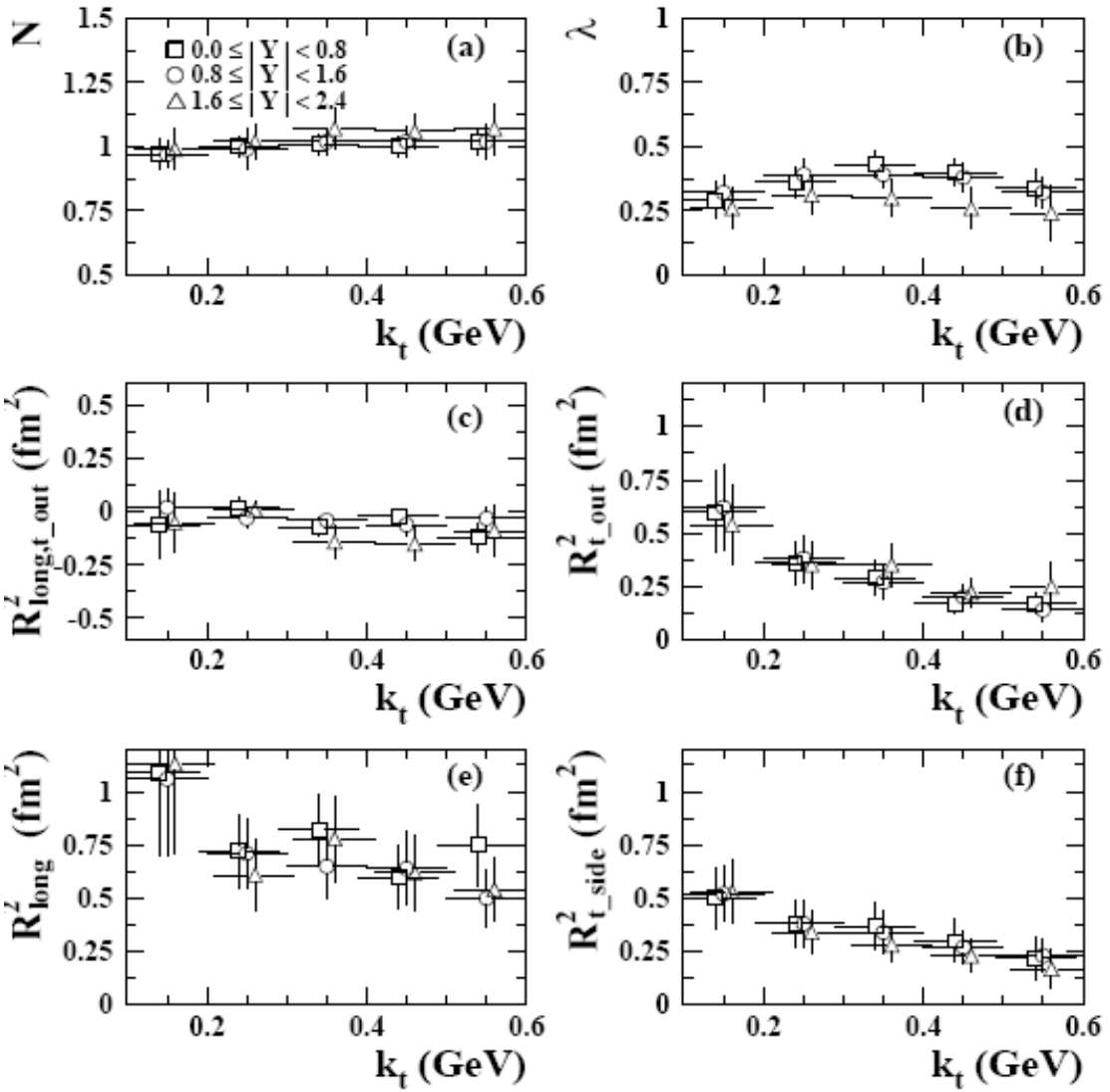
e^+e^- at Z^0 peak

Measuring thickness of a jet?

Points: Lorstadt, Smirnova for DELPHI, ISMD'97

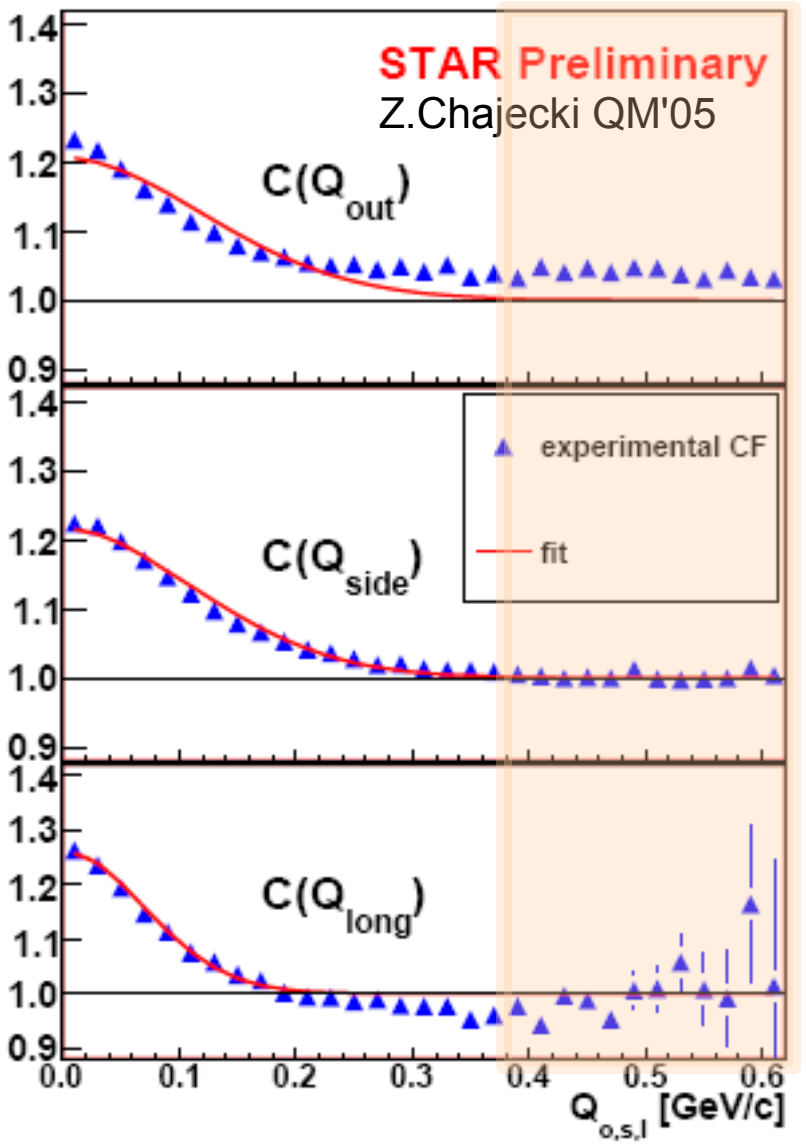


OPAL CERN-PH-EP/2007-025



Heisenberg relation fits: Alexander, Rep. Progr. Phys.66:481, 2003

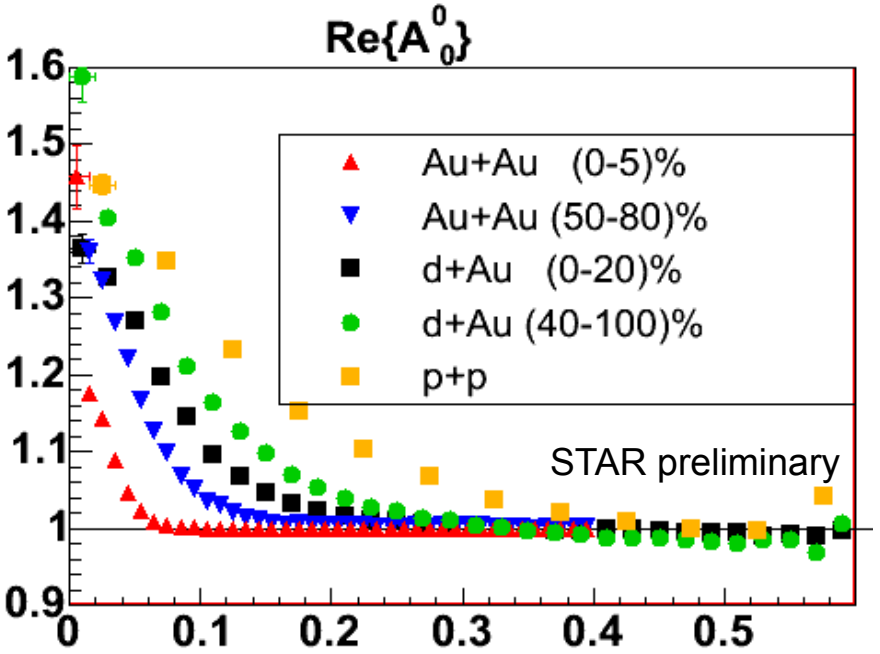
STAR HBT in light systems: d+Au

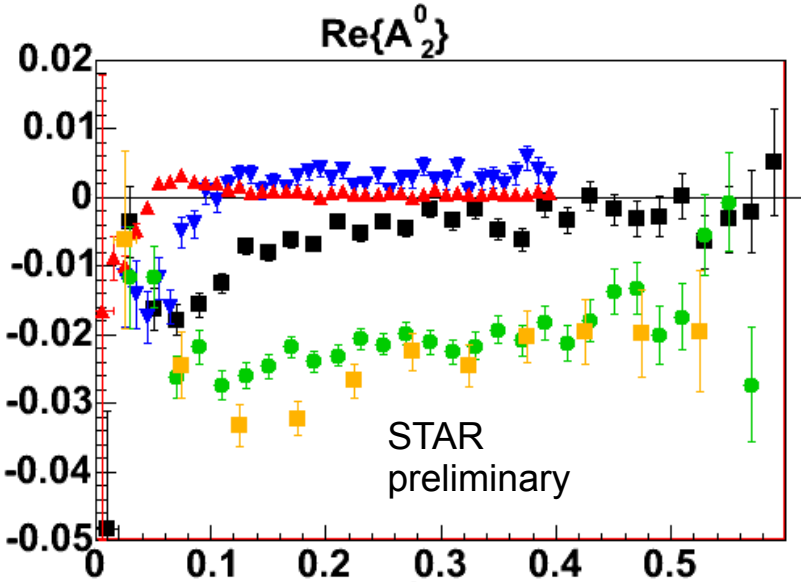


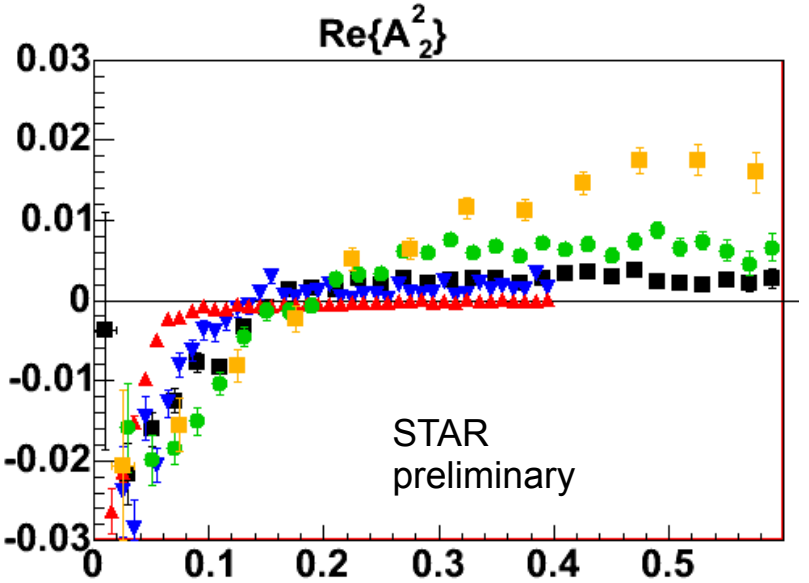
"Tail" non-unity:

- "non-femtoscopic" (outside the HBT bump area)
- Q-anisotropic (not a simple vertical offset)
- seen by others (NA22, OPAL)
- does it affect femtoscopy?

Spherical harmonic analysis of Q-anisotropy







A complete, formal, model-independent description of a CF in the popular basis:

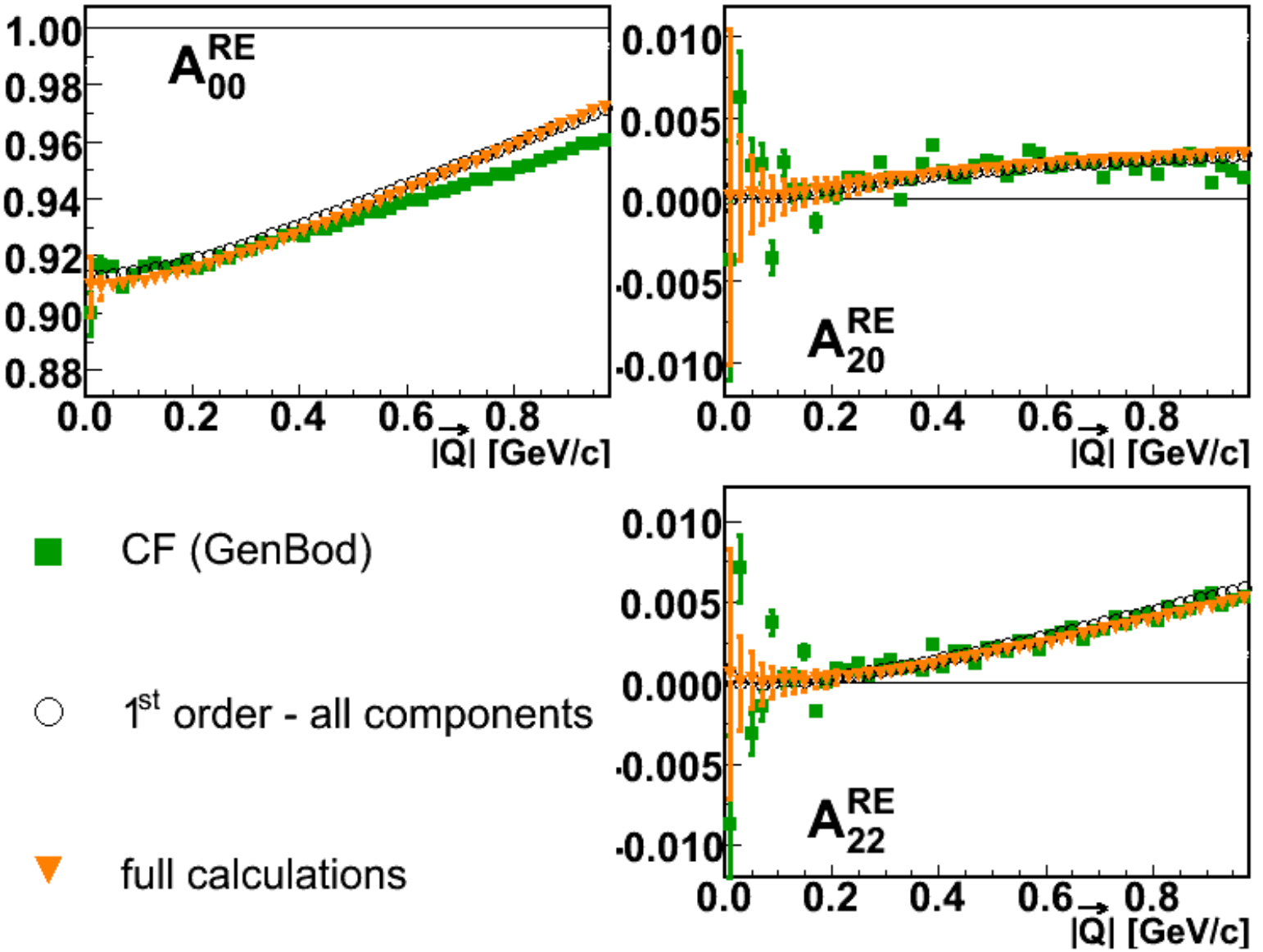
$$A_{l,m}(|\vec{Q}|)=\frac{\Delta_{\cos\theta}\Delta_{\varphi}}{\sqrt{4\pi}}\sum_{i}^{all.bins} Y_{l,m}(\theta_i,\varphi_i)\,C(|\vec{Q}|,\cos\theta_i,\varphi_i)$$

Respect pair-permutation symmetry:
$\phi\rightarrow\phi+\pi$ => no odd m; $\theta\rightarrow\pi-\theta$ => no odd l

Not easy to selectively suppress harmonics; anisotropy decreases with multiplicity

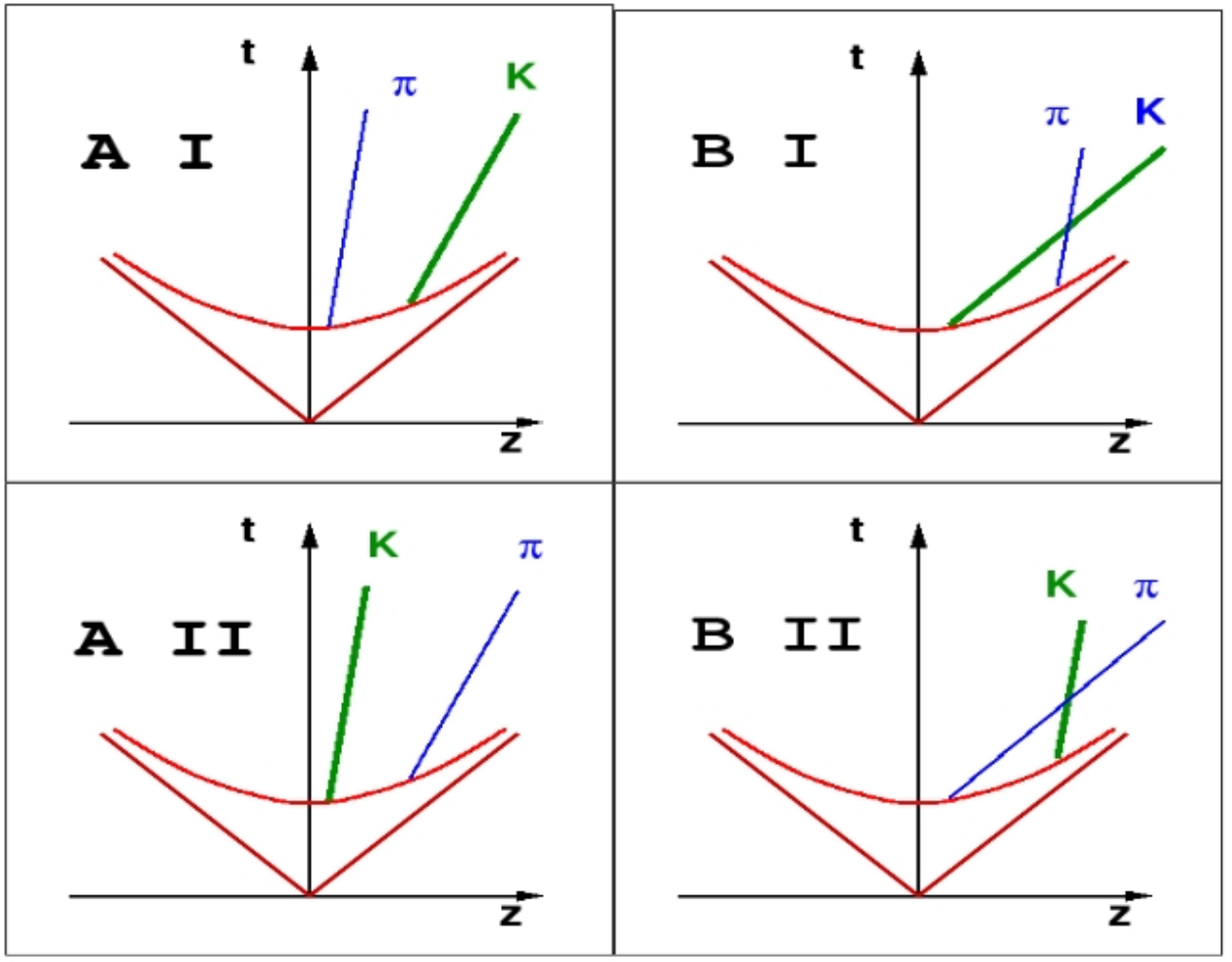
Energy-Momentum-Conservation-Induced Correlation: EMCIC

GENBOD: EMCIC on a global event scale

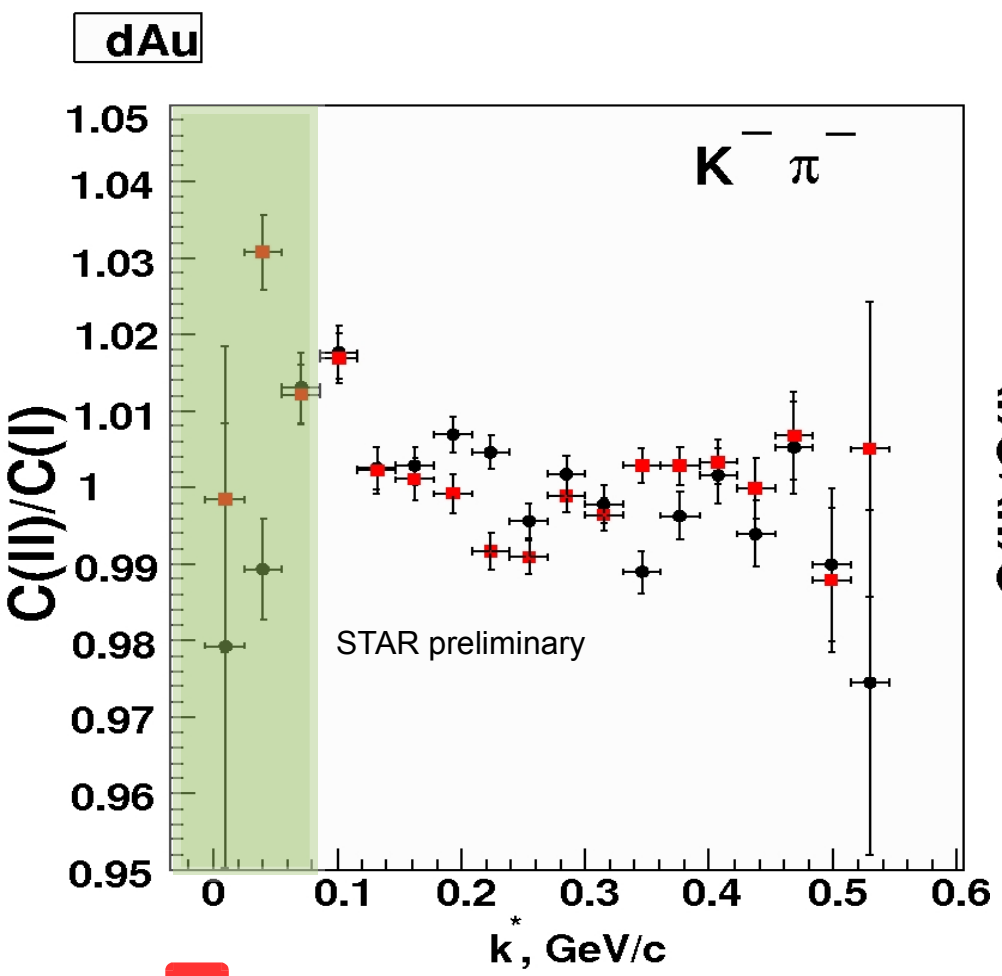


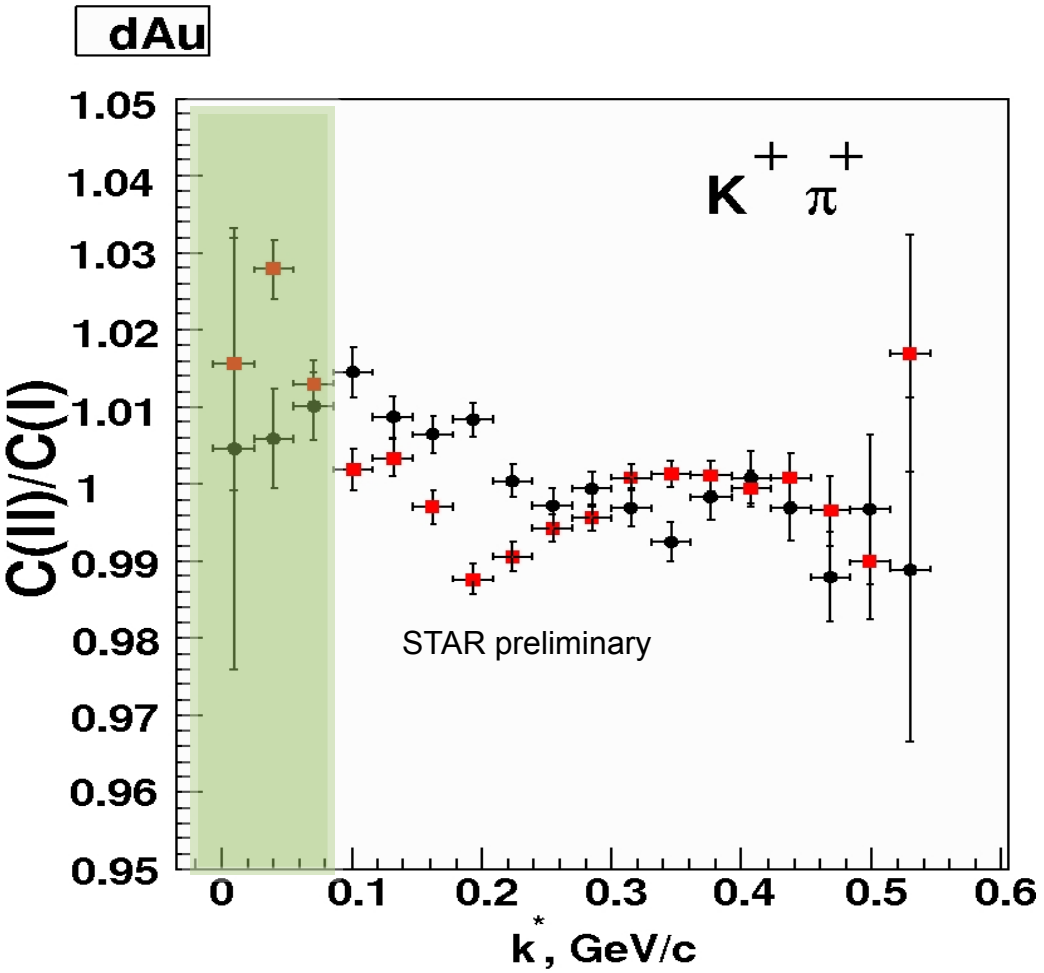
Chajecki, Lisa (WPCF'06) approximate phase-space-based event generator GENBOD with an analytical expression based on the CLT – not quite the data trends

Non-identical particle correlations: Coulomb-based femtoscopy



- Final state interaction: A - weak,B -strong
- Discriminate I and II by sign of k^*_{out}, C=C(|k*|)
- C(I)/C(II) not 1 => A and B have different weights for I and II
- flow=>AI,BII

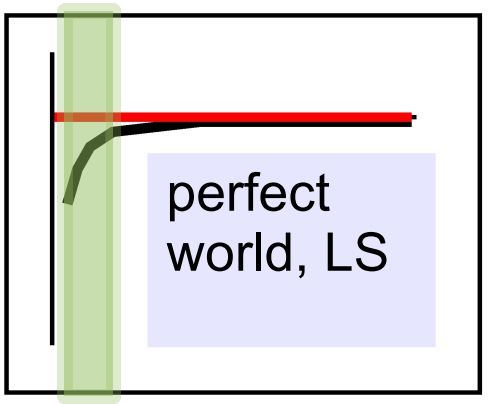




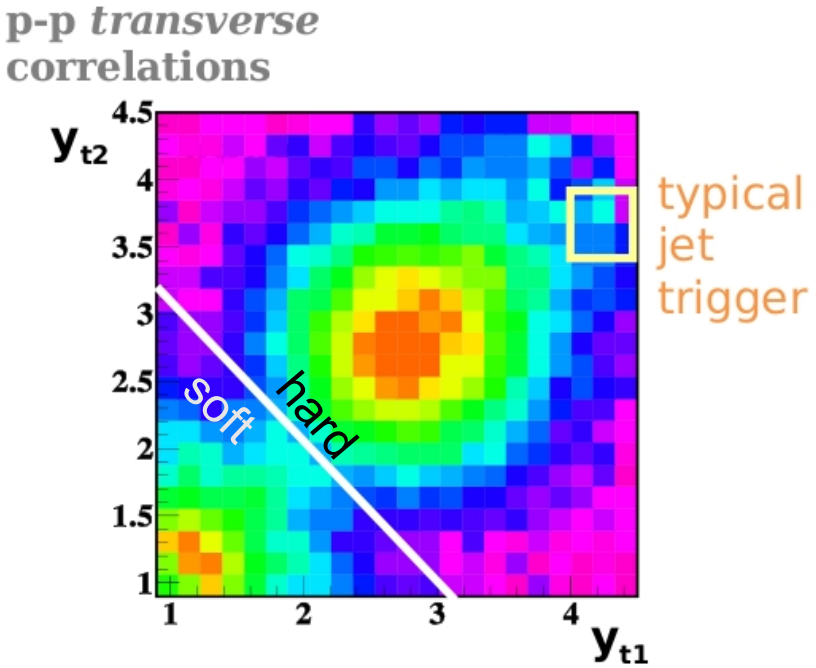
hh reference

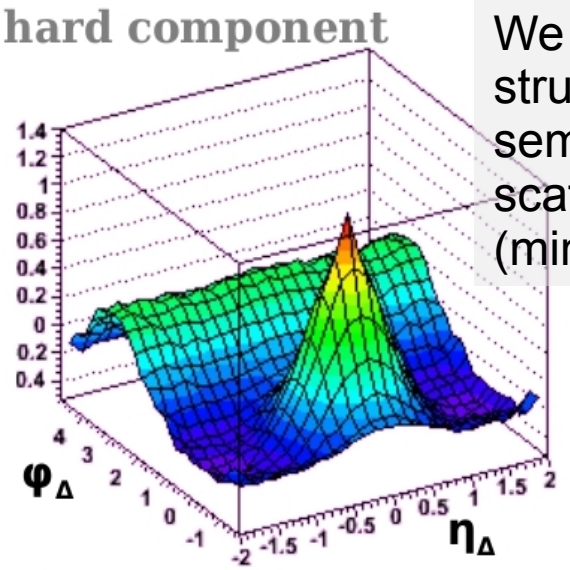
Kπ double ratio

Coulomb-related signal of transverse collectivity seen at low k* on top of a broader structure related to acceptance cuts and energy-momentum conservation

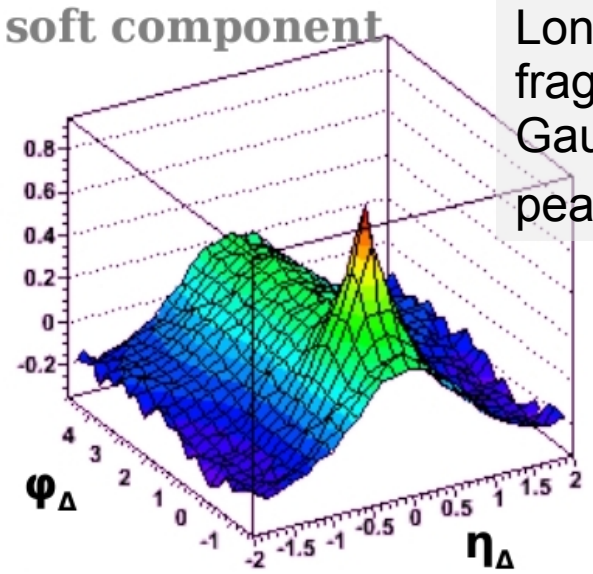


Soft and hard components in pp

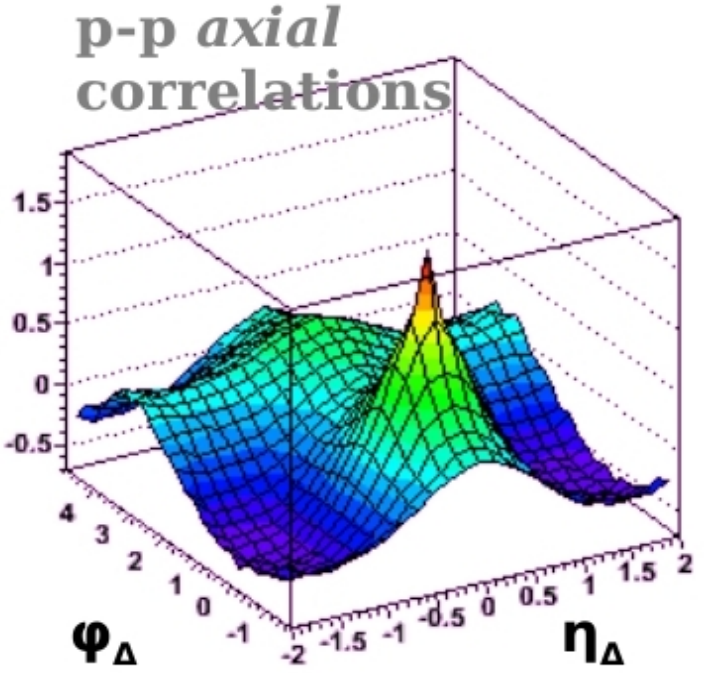


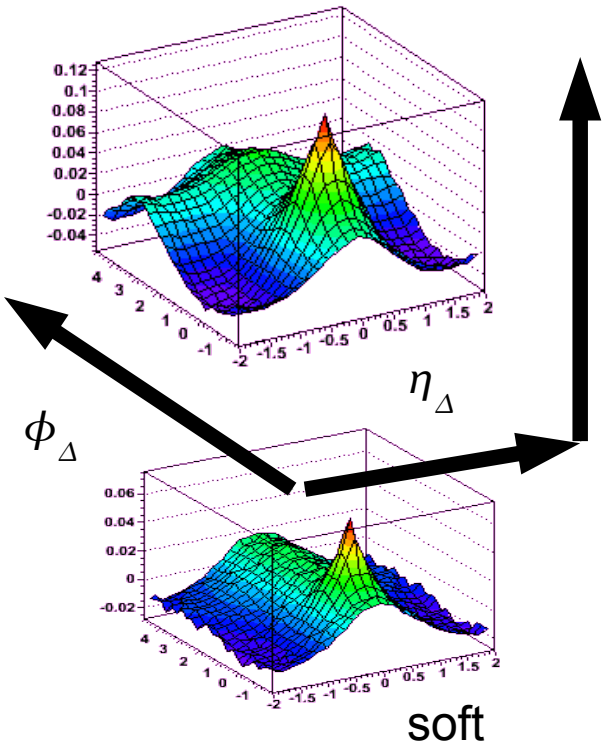


We hypothesize that this structure is caused by semi-hard partonic scattering , fragmentation (minijets)



Longitudinal fragmentation 1D Gaussian on η_Δ ; HBT peak at origin (LS only)





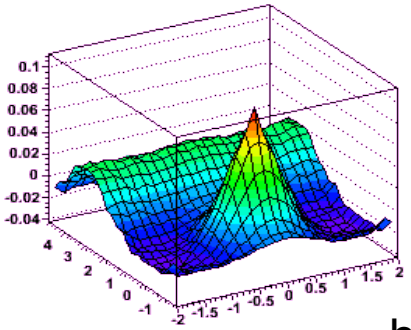
soft

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

same - mixed

mixed

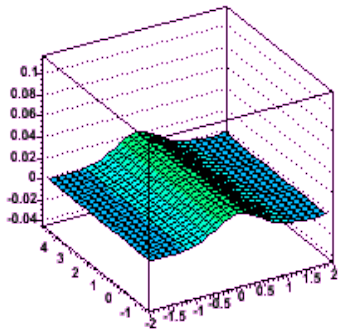
correlation "per-particle"



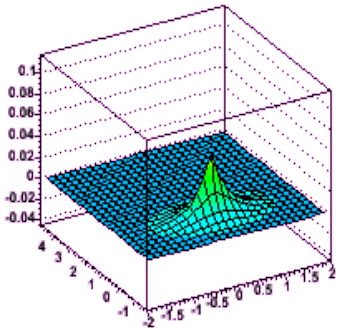
hard

Decompose and fit correlation components

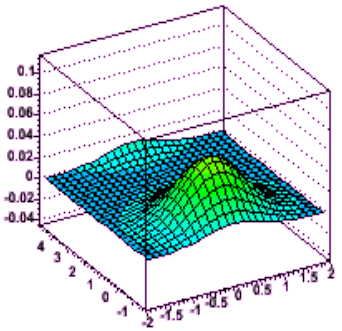
See M.Daugherity's QM'08 talk



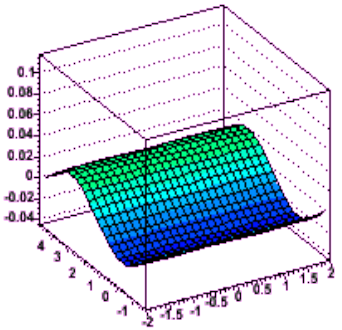
longitudinal fragmentation



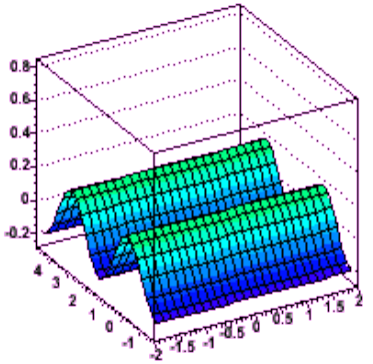
HBT



minijet



v1 "dipole"

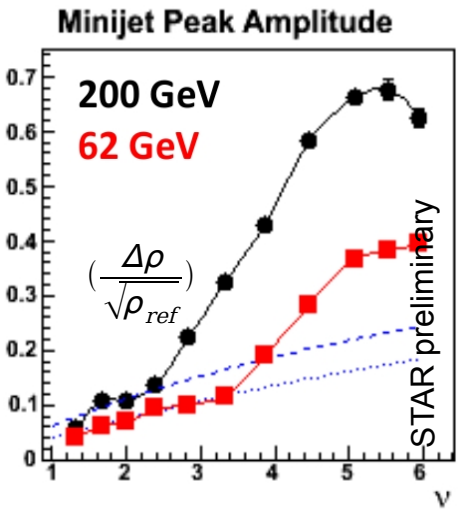


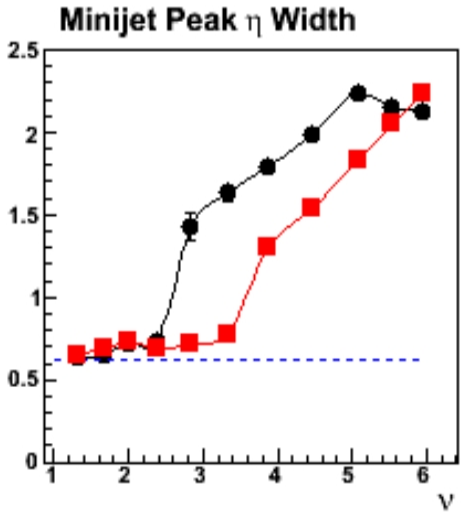
v2 "quadrupole"

Anomalous centrality variation of the Au+Au axial correlation peak

binary collisions per participant pair grows with centrality

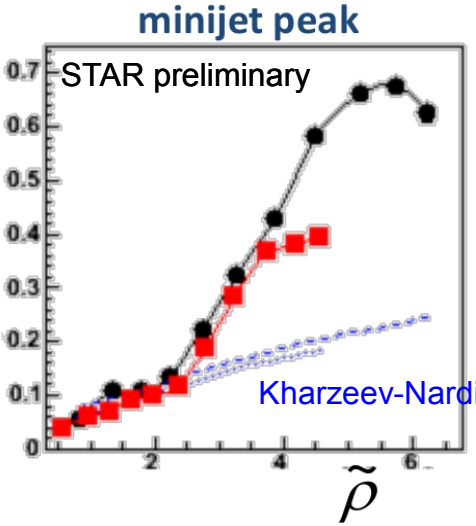
$$\nu = \frac{\langle N_{bin} \rangle}{\langle N_{part}/2 \rangle}$$

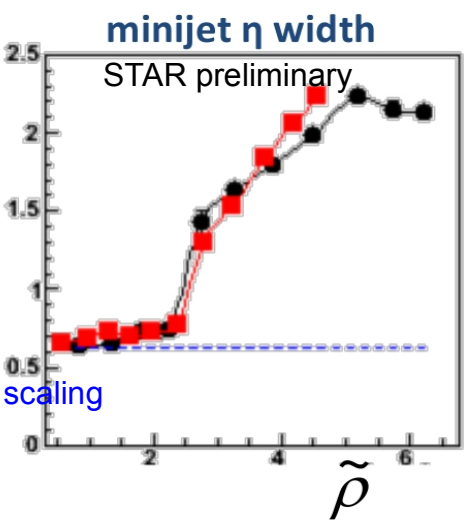


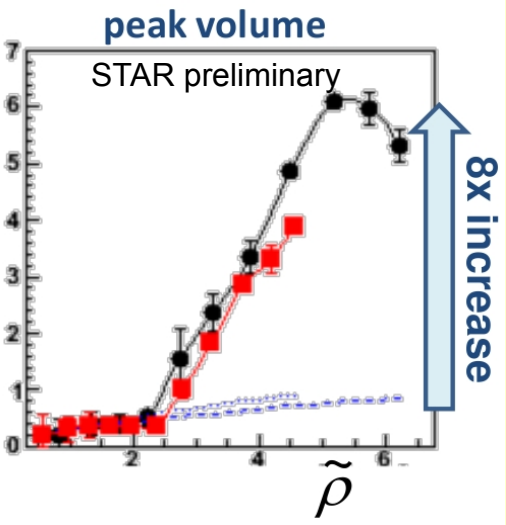


See M.Daugherity's QM'08 talk

Sudden rise in peak population with centrality



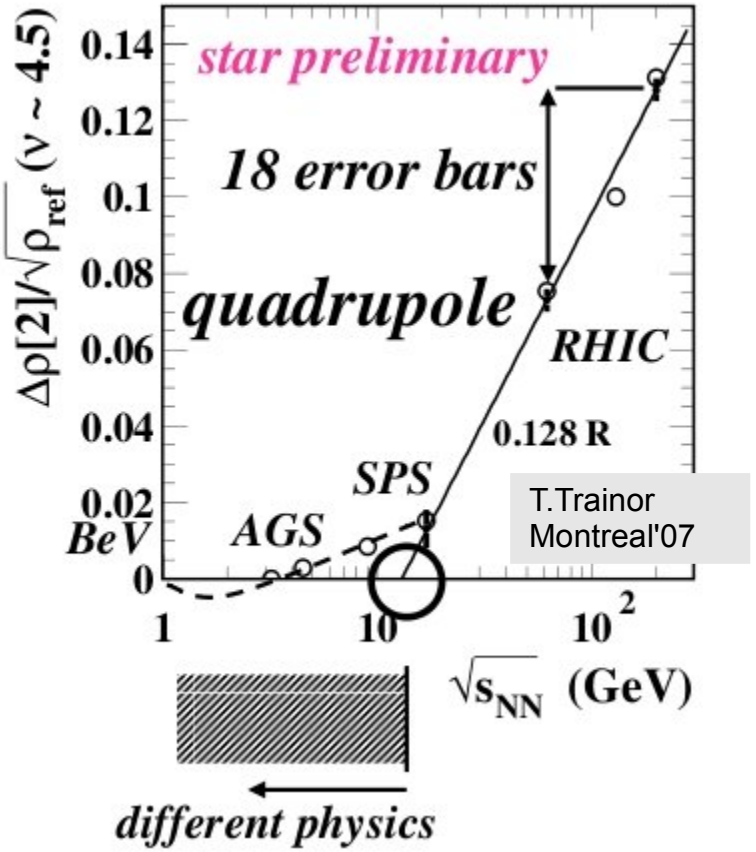




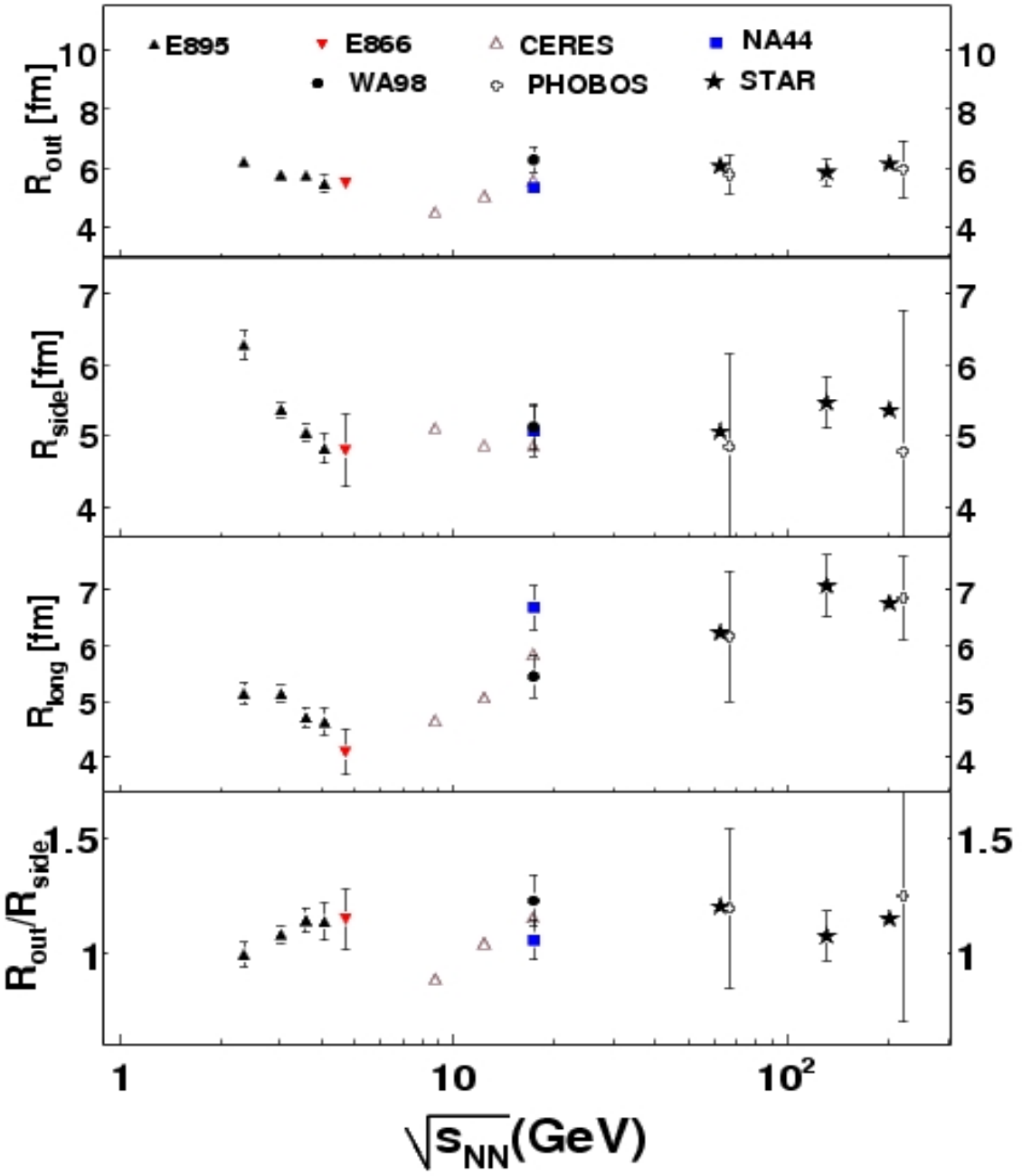
$$\tilde{\rho} = \frac{3}{2}\frac{dN_{ch}}{d\eta} / A$$

transverse density of produced particles obtains scaling

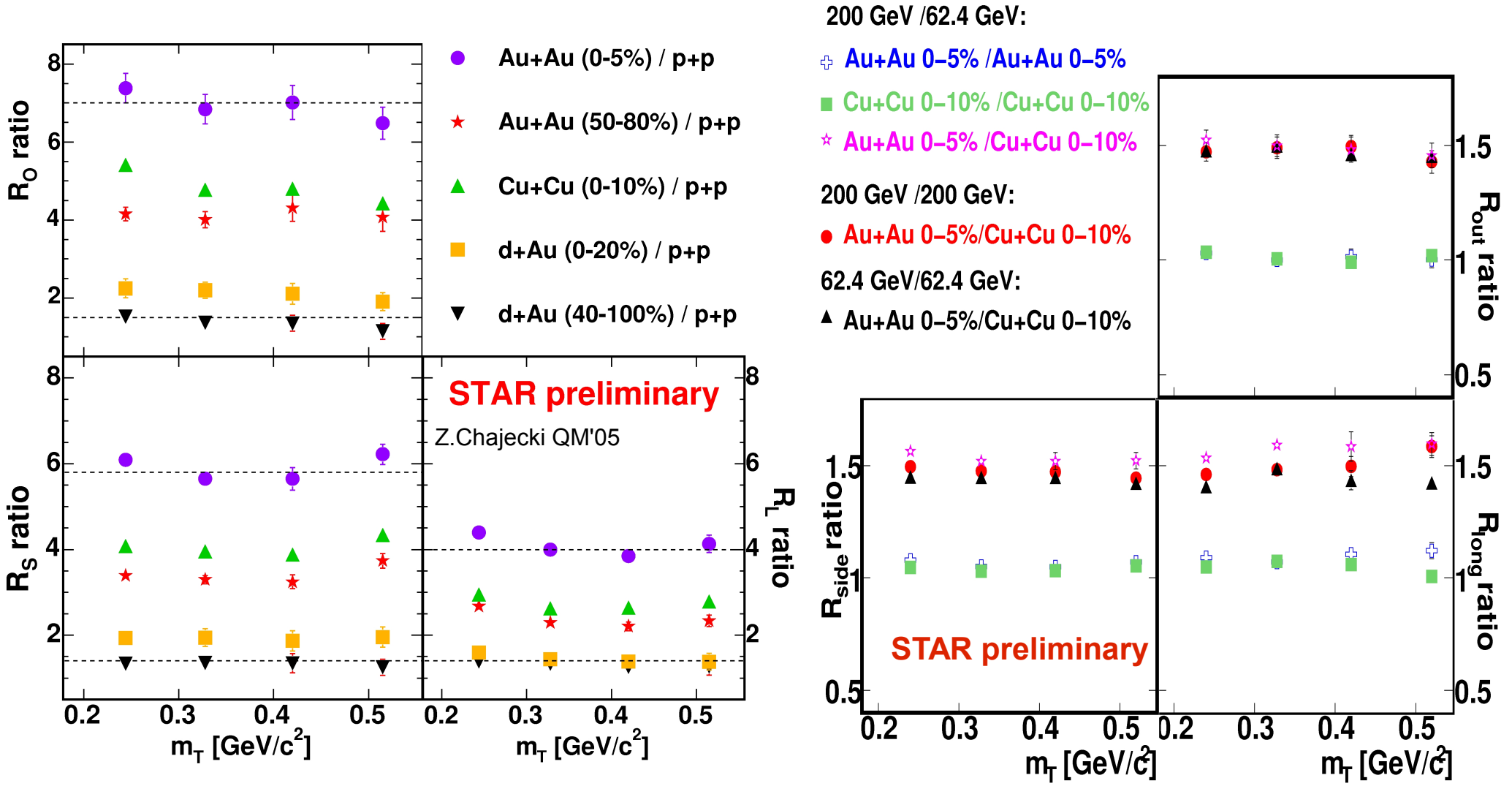
Why?



A common trend transition around 10 GeV in azimuthal and HBT correlations – a coincidence? Hydro-style transverse expansion or minijettiness would both reduce homogeneity lengths



However...



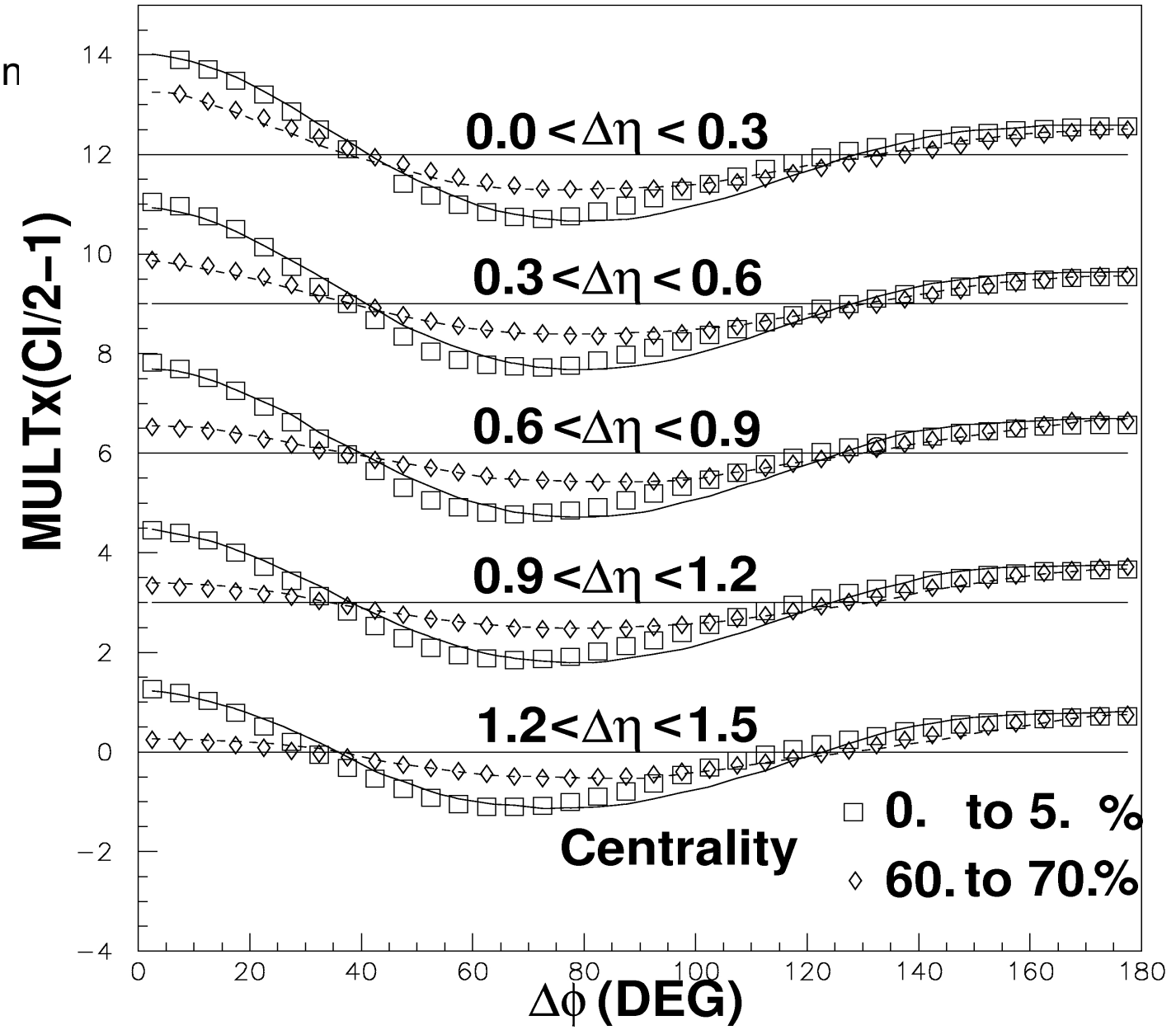
…transverse collectivity has to originate (stay?) on a low level for such scaling of HBT radii to work – binary collisions level? Hard to reconcile the **lack of system dependency** with bulk collectivity (hydro)

An alternative: Partonic Bubble Model (PBM)

PBM: Lindenbaum, Longacre
Euro Phys. J C49, 767 (2007)

CI = like-sign + unlike-sign

PBM assumes particle production via fragmentation of QGP bubbles. They are approx 2fm big, moving transversely at mid-rapidity



——— PBM fit

- - - - - HIJING

Are there clashes of interpretations? Or just a co-existence of different level concepts

Relativistic kinetics – relaxation space/time scales, approach to equilibrium

need advanced studies including bottom-up correlation approaches

(mini) jets

Relativistic hydro – locally equilibrated chunks of matter

spectra, flow, HBT... Bubbles?!

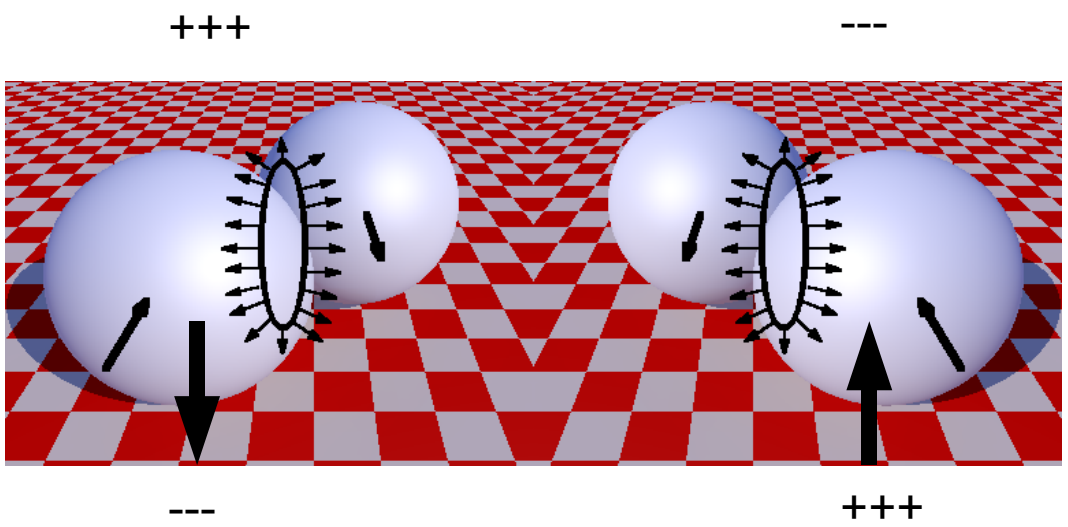
Classical thermo"dynamics" -- timeless – global equilibrium

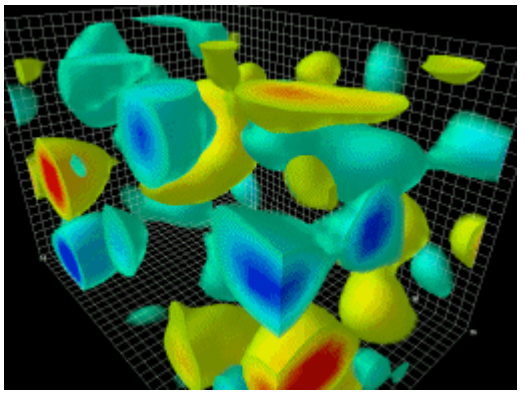
particle yields, spectra

Proving these inadequate -- a matter of time and experimental accuracy. Nevertheless these simpler concepts will remain attractive for a long time.

Strong P-symmetry breaking ?

Does not break QCD! Topological charge (gluonic field winding number) fluctuates, possibly creating P-odd domains in HIC



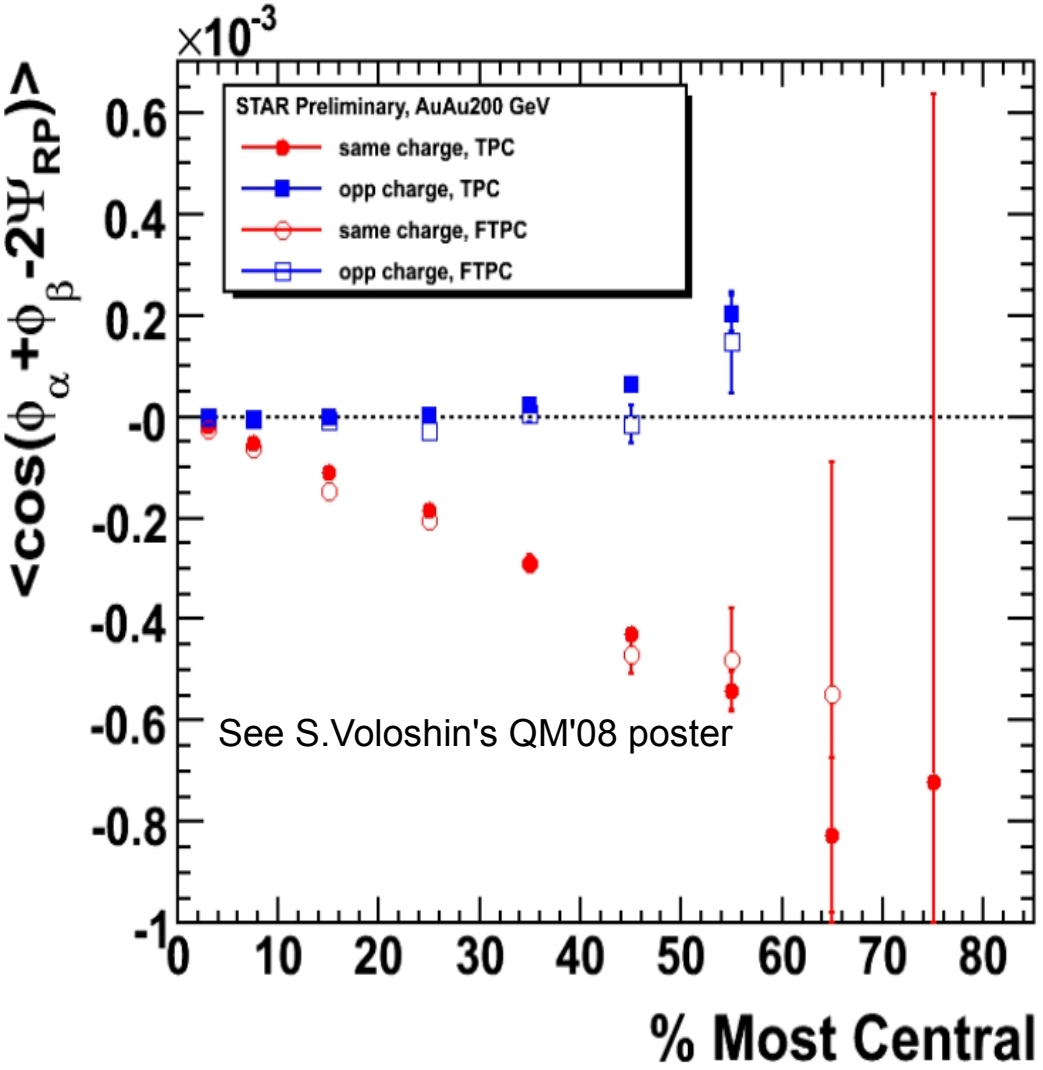


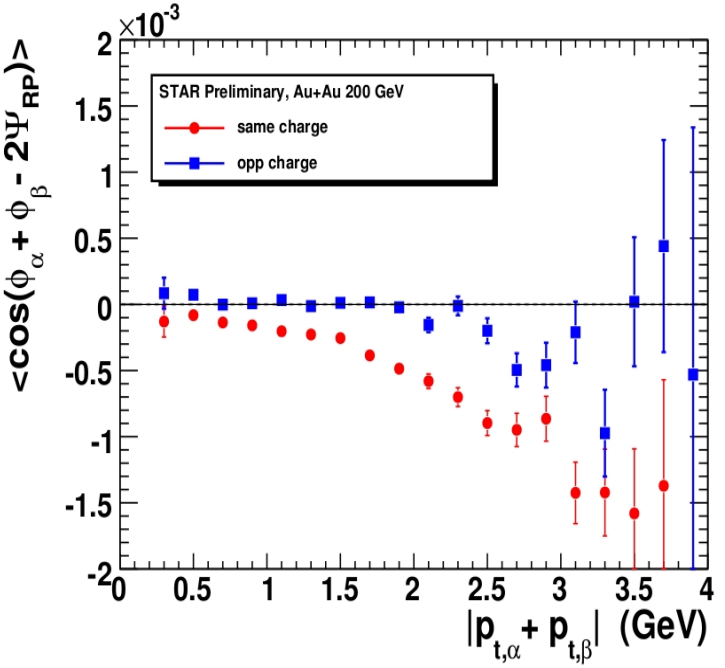
Topological charge animation by Derek Leinweber

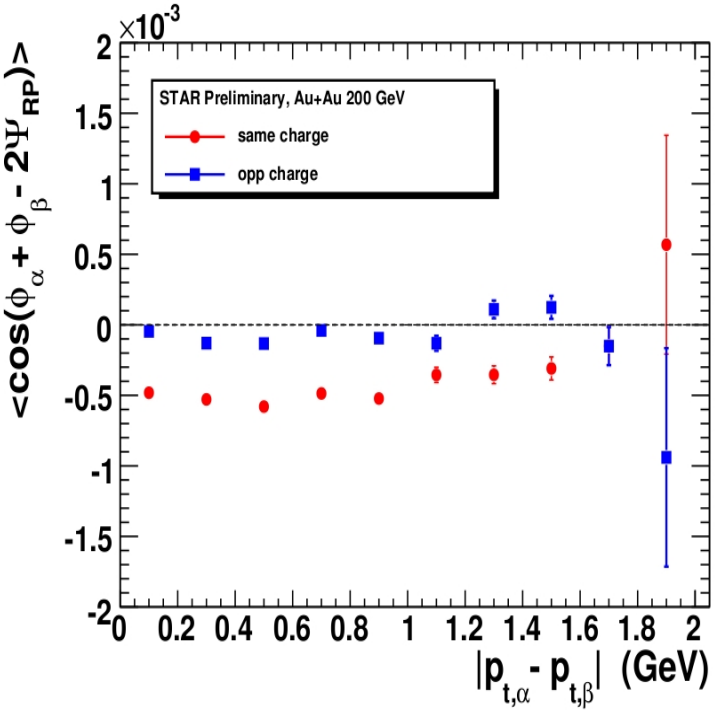
$$dN_{\pm}/d\phi \propto (1 + 2a_{\pm}\sin(\phi - \Psi_{RP}))$$

measure charge separation along the orbital momentum

$$\langle \cos(\phi_a + \phi_\beta - 2\phi_c) \rangle = \langle \cos(\phi_a + \phi_\beta - 2\Psi_{RP}) \rangle \; v_{2,c}$$

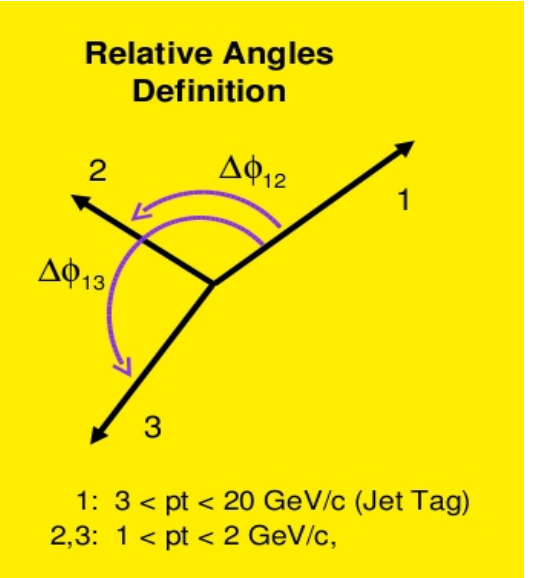






Convincing non-zero signal not reducible to flow; not a sufficient evidence of P-violation – are there other mechanisms?

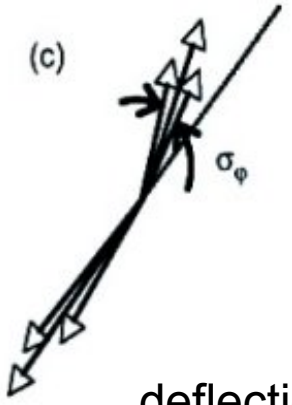
Search for conical emission associated with hard scattering



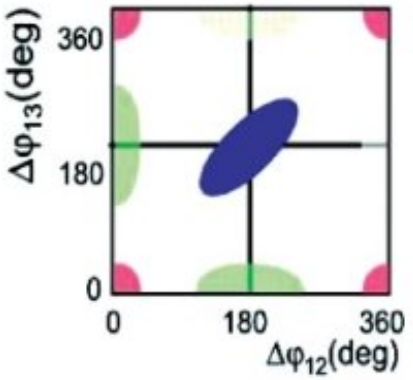
Mach cone or Cherenkov gluon "rings" would look similar. 3-particle cumulant technique relies on subtraction of 2-particle correlations (cumulants).

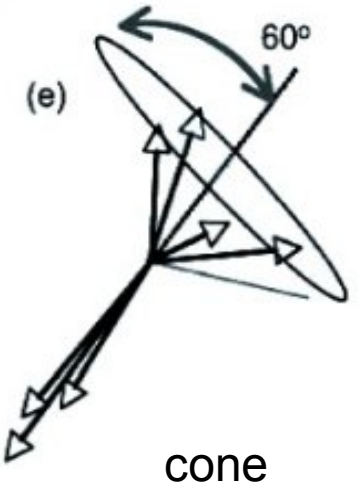
$$\kappa_2^{(12)} = \rho_2^{(12)} - \rho_1^{(1)}\,\rho_1^{(2)}$$

C.Pruneau PRC 74, 064910 (2006)

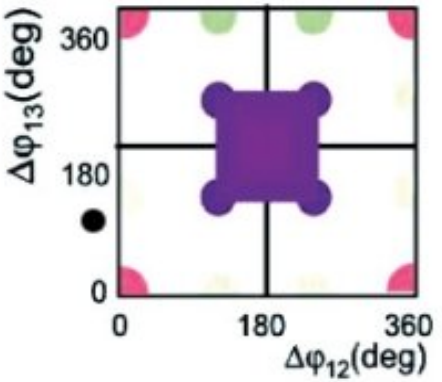


deflection

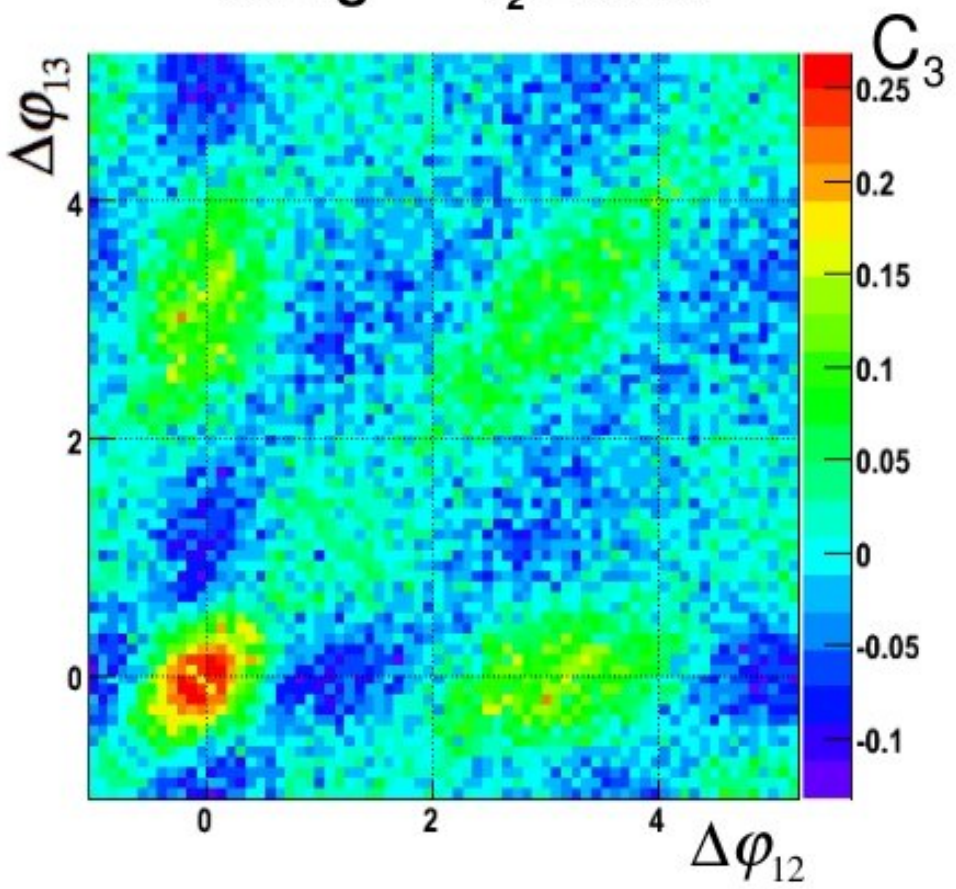


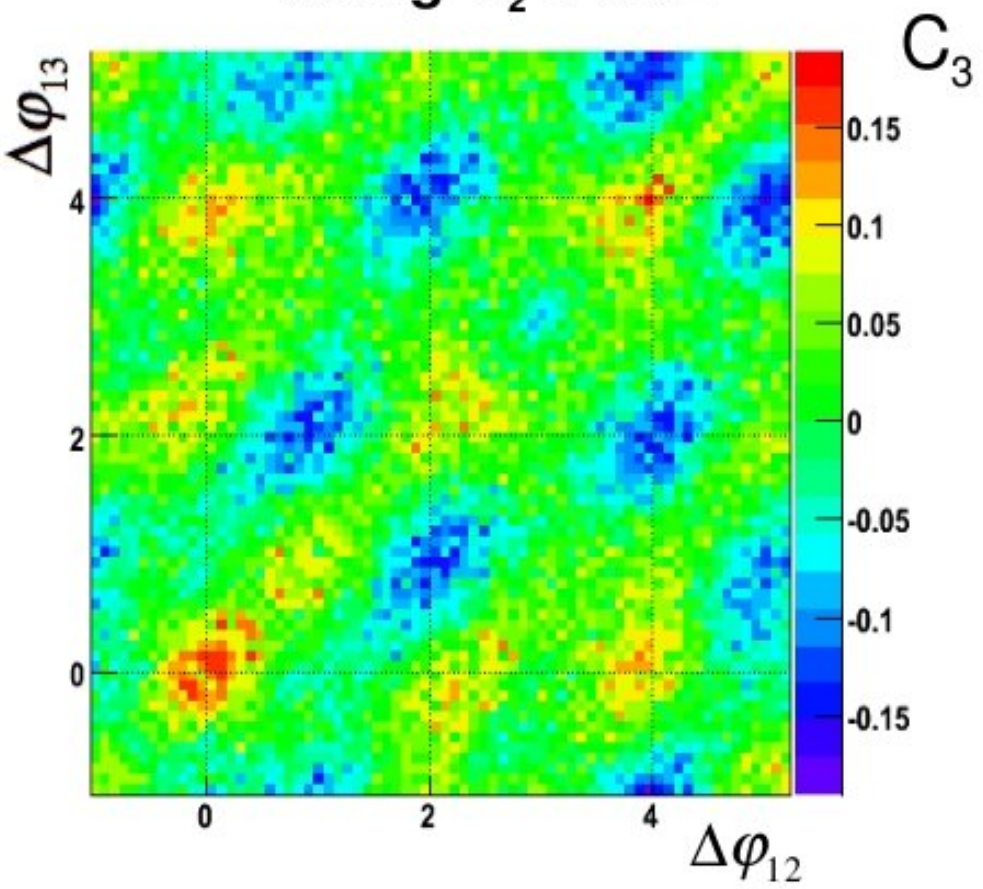


cone



$$C_3 = \kappa_3^{(123)} = \rho_3^{(123)} - \rho_2^{(12)}\,\rho_1^{(3)} - \rho_2^{(13)}\,\rho_1^{(2)} - \rho_2^{(23)}\,\rho_1^{(1)} + 2\,\rho_1^{(1)}\,\rho_1^{(2)}\,\rho_1^{(3)}$$





- C_3 structure depends on the subtraction of $v_2v_2v_4$ term
- For measured v_2, no conclusive evidence of conical emission from this method
- C_3 consistent with jet deflection

Summary:

- HBT needs a treatment of non-femtoscopic correlations – work in progress
- Femtoscopic signal of transverse collectivity seen in d+Au
- Transverse collectivity seems minijet-driven – will hydro be out of vogue?
- A sharp increase in minijet peak population at 2.4 particles/fm^2/unit $\Delta\eta$ seen
- Minijet peak properties scale with transverse density of produced particles
- QCD-related P-violation in Au+Au – an intriguing interpretation of a 3-particle correlation signal
- Mach cones or Cherenkov gluons – no conclusive evidence from cumulants; jet deflection is seen