Collision system dependence of 3-D Gaussian source size measured by RHIC-PHENIX

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UCRL-PRES-228029

Outline

- Physics Motivation
- 3-D HBT measurement
- HBT puzzle, how should we do to deal with this issue.
- PHENIX detector and used data sets.
- Measurement of 3-D HBT radii as a function of pair momentum
- Measurement of 3-D HBT radii as a function of centrality
- Summary and prospect

Physics motivation: Study of space-time evolution

Indication that thermalized, dense and hot, small viscosity, quark matter is created in Au+Au collisions at 200 GeV by measurements of hard probes.

The next step is to investigate the detailed characteristic of the space-time evolution.

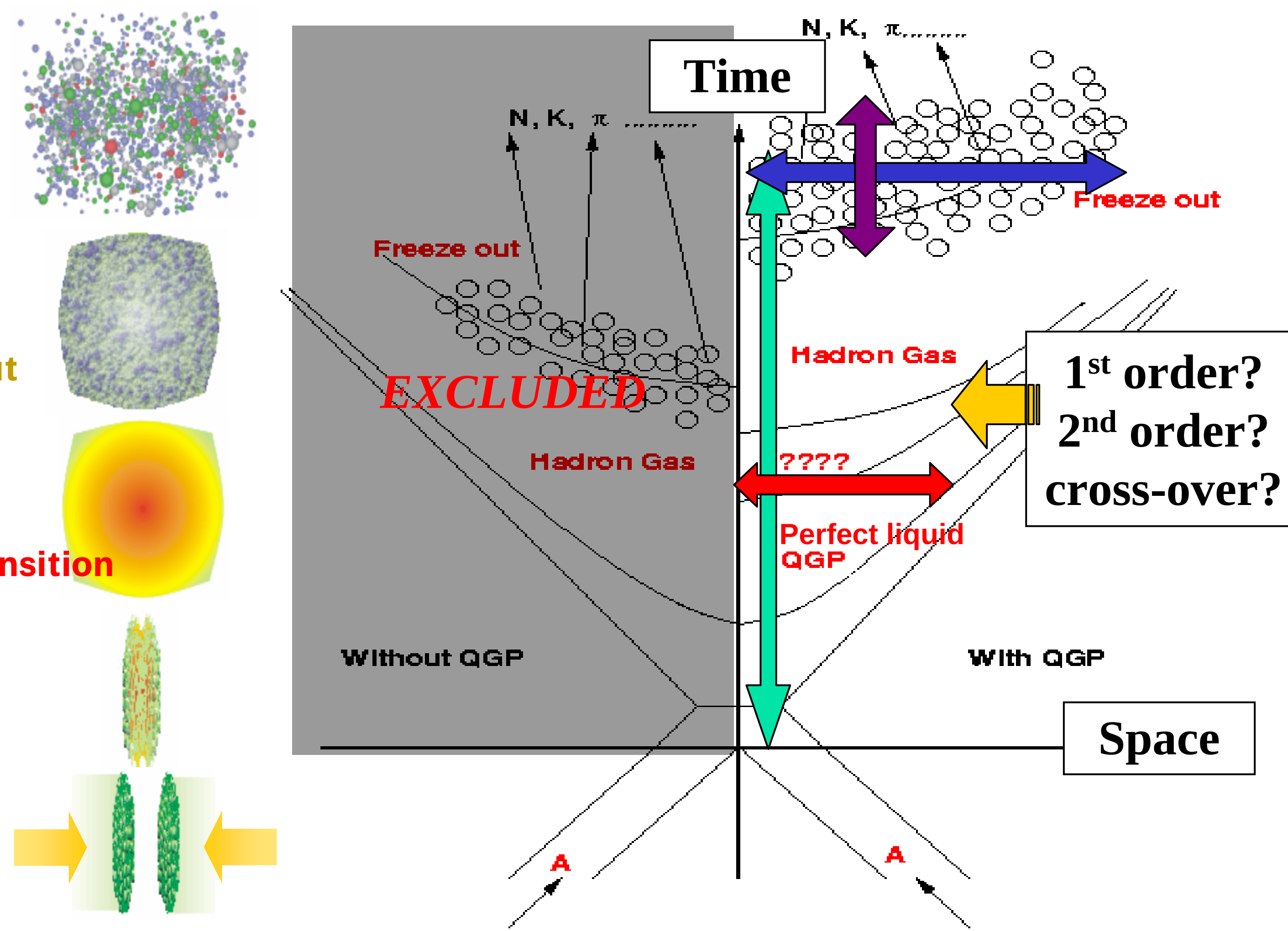
Hadron phase
→
Kinetic freeze-out

Mixed Phase
→
Chemical freeze-out

QGP phase
→
(?) order phase transition

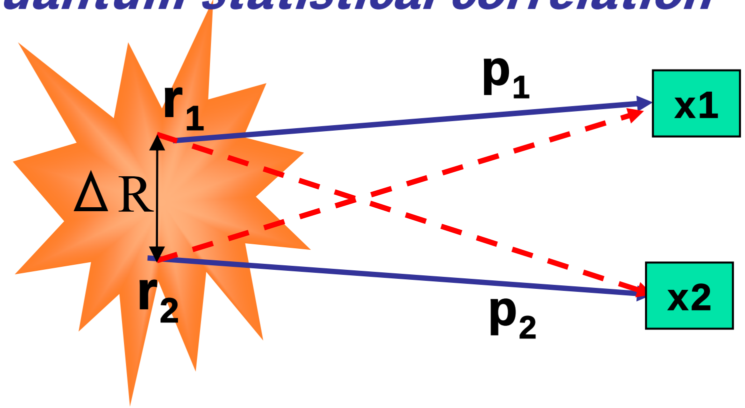
pre-equilibrium

Pre-collision



HBT: Two particle interferometry: Femtoscopy

Quantum statistical correlation



$$\psi_2(p_1,p_2) = \left\{ A(p_1,r_1)e^{ip_1(x_1-r_1)}A(p_2,r_2)e^{ip_2(x_2-r_2)} \pm A(p_1,r_2)e^{ip_1(x_1-r_2)}A(p_2,r_1)e^{ip_2(x_2-r_1)} \right\} / \sqrt{2}$$

$$P_2(p_1,p_2) = \int \rho(r_1)\rho(r_2)d^4r_1d^4r_2 A^2(p_1,r_1)A^2(p_2,r_2) \pm \left| \int \rho(r)d^4r A(p_1,r)A(p_2,r)e^{-ir(p_1-p_2)} \right|^2$$

$$C_2(p_1,p_2) \equiv \frac{P_2(p_1,p_2)}{P(p_1)P(p_2)} \sim 1 + \left|\tilde{\rho}(q)\right|^2$$

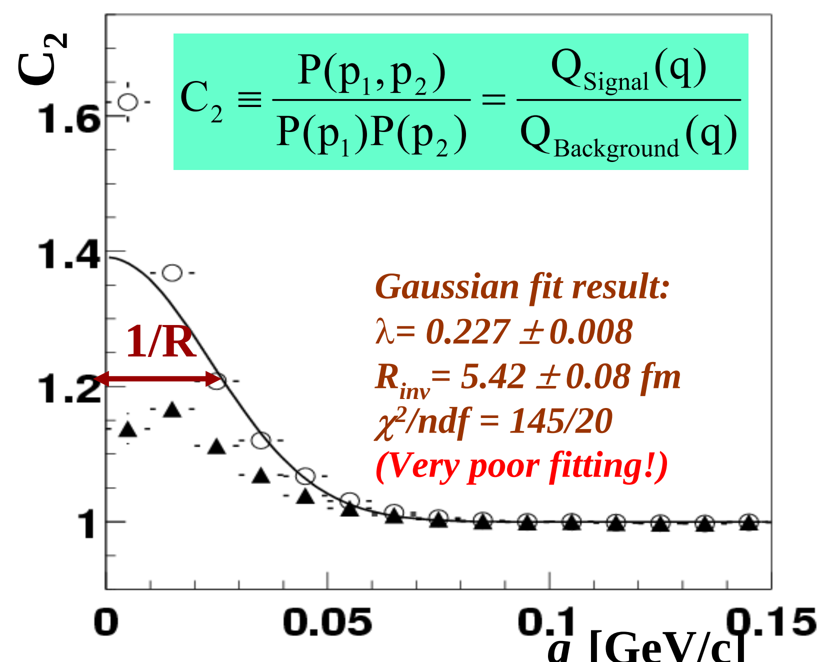
Assuming the Gaussian source,

$$C_2 = 1 + \left|\tilde{\rho}(q)\right|^2 = 1 + \lambda \exp\left(-R_{inv}^2 q_{inv}^2\right)$$

where $q_{inv} = \sqrt{\mathbf{q}^2 - q_0^2}$

R_{inv} : 1-dimensional HBT radius
(3D emission source size + emission duration)

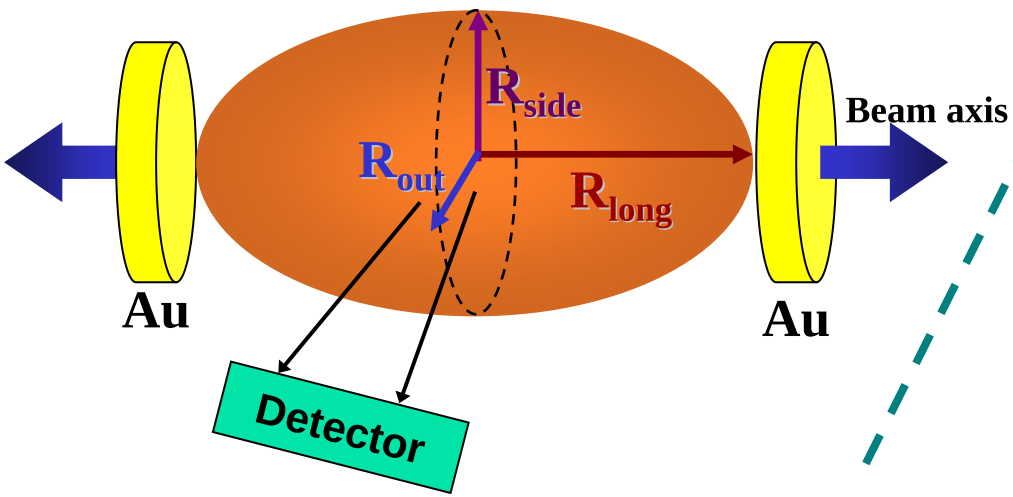
λ : = 1 (incoherent source)
< 1 (coherence, resonance decay, background)



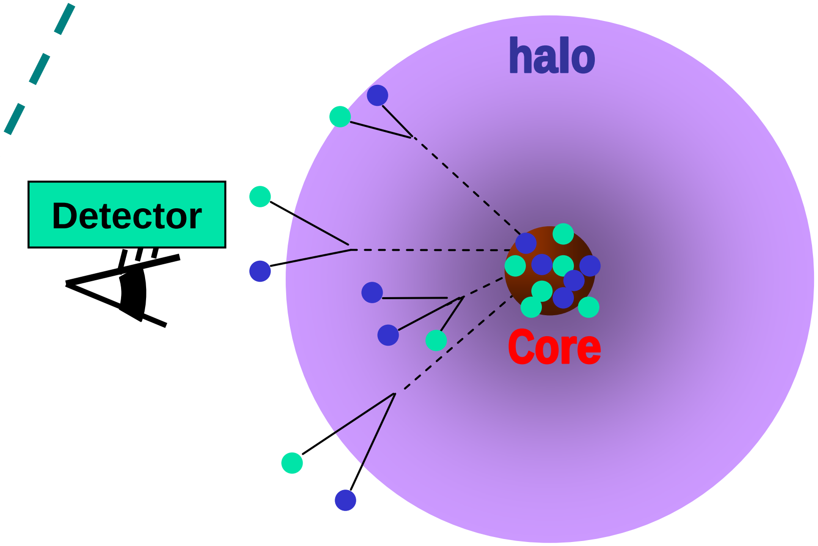
$$C_2 \equiv \frac{P(p_1,p_2)}{P(p_1)P(p_2)} = \frac{Q_{Signal}(q)}{Q_{Background}(q)}$$

3-D Gaussian fit function with core-halo Coulomb correction

"side-out-long" decomposition



"Core-Halo" model



$$C_2^{raw} = C_2^{core} + C_2^{halo} = [\lambda(1+G)]F_C + [1-\lambda]$$

$$G = \exp\left(-R_{side}^2 q_{side}^2 - R_{out}^2 q_{out}^2 - R_{long}^2 q_{long}^2\right)$$

F_C : Coulomb correction function (iteratively estimated)

$R_{long} \propto$ Life time

$R_{side} \propto$ Core source size

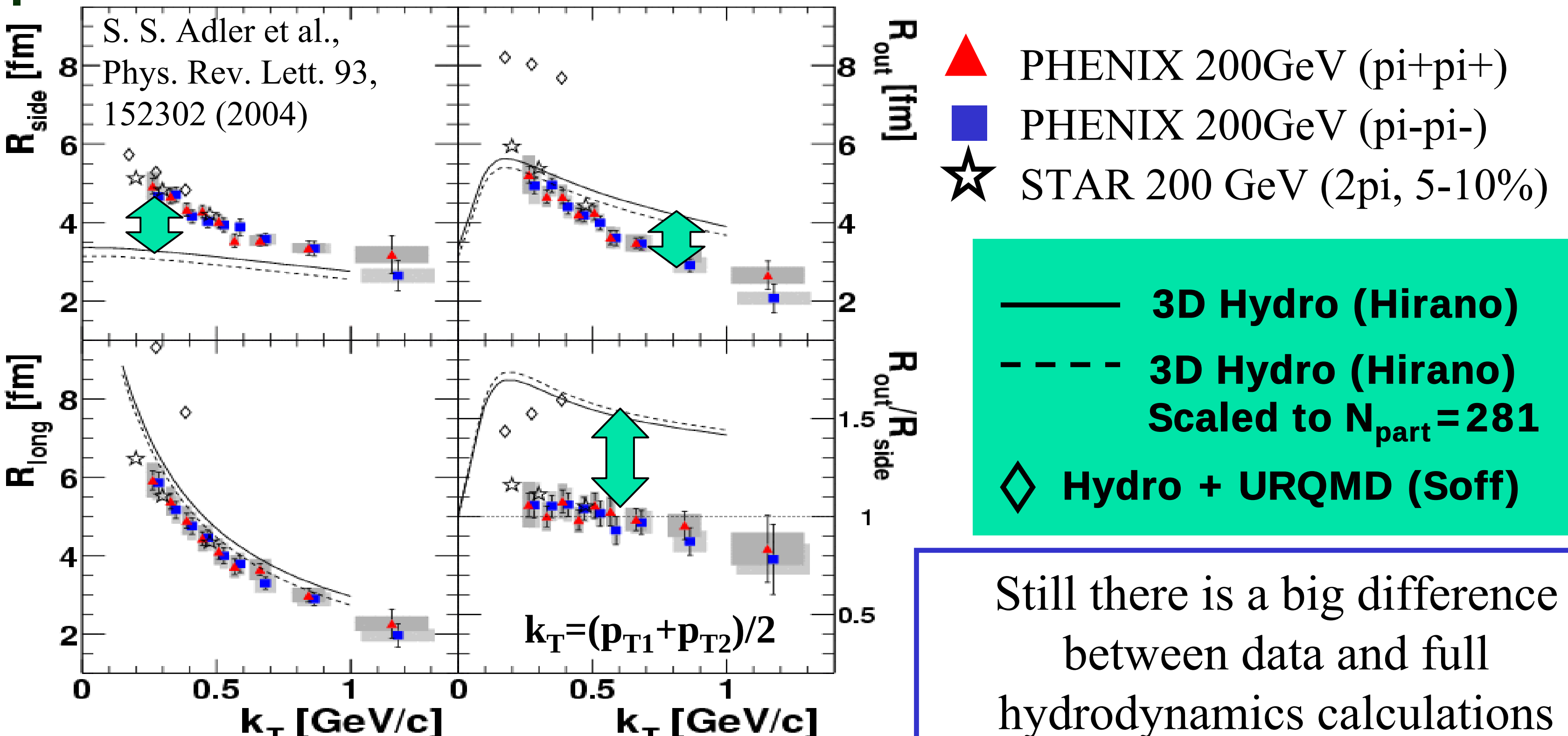
$R_{out} / R_{side} \propto$ Emission duration

R_{long} = Longitudinal HBT radius

R_{side} = Transverse HBT radius

R_{out} = Transverse HBT radius + particles emission duration

HBT puzzle, or not puzzle?



Still there is a big difference between data and full hydrodynamics calculations

Dynamical x-p correlation is hard to predict, and a problem is "indirect" and "inconsistent" comparison of fitted HBT radii:

- Do ad hoc corrections for FSI (e.g. Coulomb effect).
- Fit to correlation in a assumption of Gaussian shape.
- Even comparisons between experimental results are done with different Coulomb corrections, Gaussian assumptions, rapidity acceptances…

Solution 1: Detailed Source structure by HBT-imaging

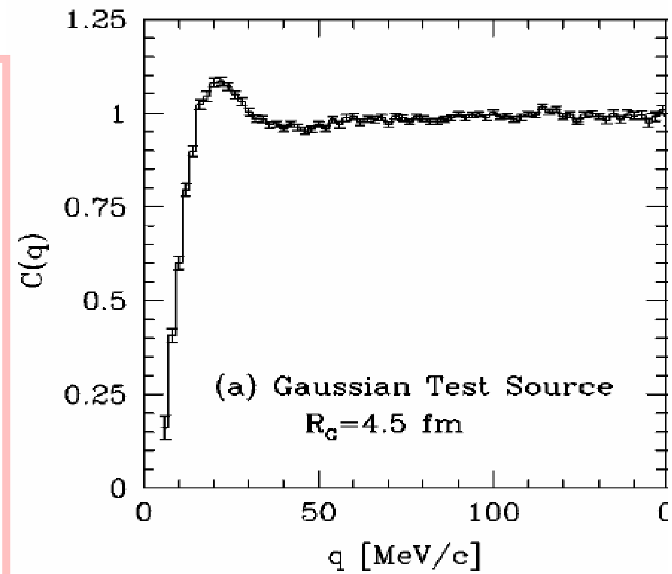
$$R^{obs}_{\vec{P}}(\vec{q}) \equiv C^{obs}_{\vec{P}}(\vec{q}) - 1 = \int d\vec{r} K(\vec{q},\vec{r}) S_{\vec{P}}(\vec{r})$$

$$K(\vec{q},\vec{r}) = \left|\Phi_{\vec{q}}(\vec{r})\right|^2 - 1$$

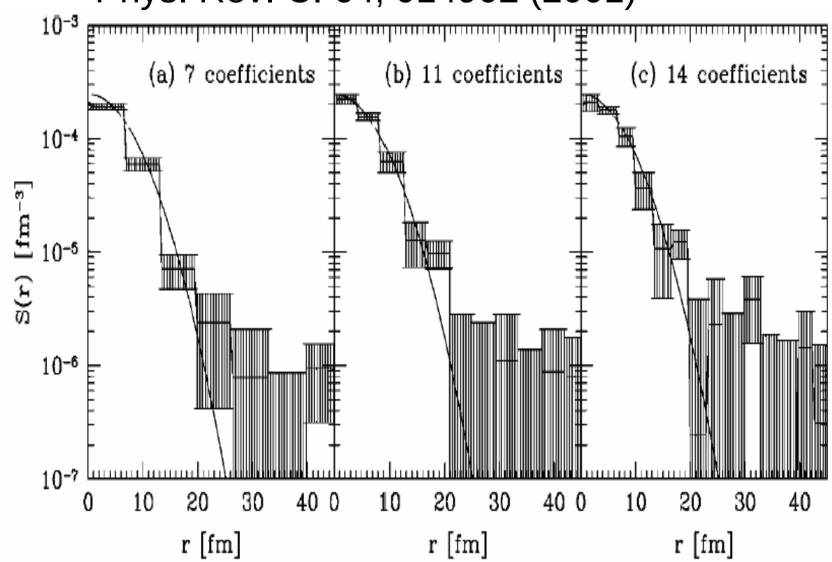
is kernel which can be calculated from BEC and known final state interactions of pairs.

$$S_{\vec{P}}(\vec{r})$$

is source function which represents the emission probability of pairs at r in the pair CM frame.



D.A. Brown and P. Danielewicz
Phys. Rev. C. 64, 014902 (2001)



S(r) is expanded in a function basis.

$$S(r) = \sum_{i=1}^{N_M} S_i B_i(r) \qquad \Delta S(r) = \sqrt{\sum_{i,j=1}^{N_M} \Delta^2 S_{ij} B_i(r) B_j(r)}$$

Imaging by minimization of χ^2

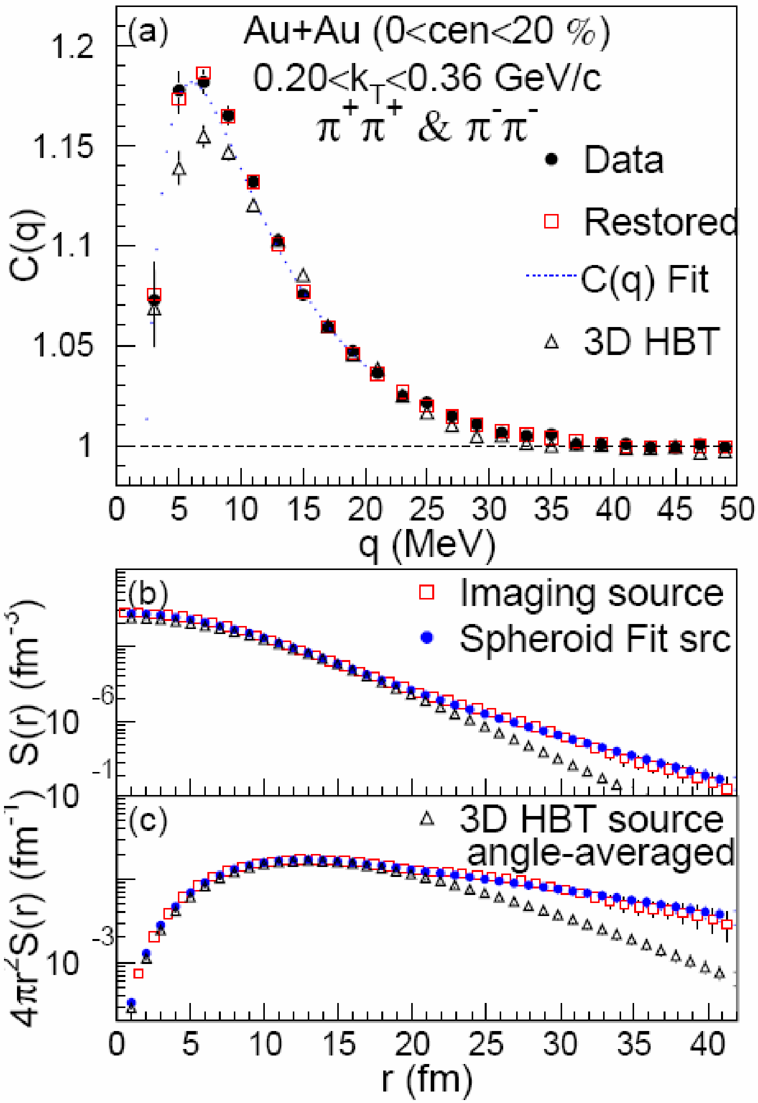
$$\chi^2 = \sum_i \left(R_i^{obs} - \sum_j K_{ij} S_j \right)^2 \Big/ \Delta^2 R_{ii}^{obs}$$

Most probable source function is

$$S = \Delta^2 S \cdot K^T \cdot (\Delta^2 R^{obs})^{-1} \cdot R^{obs}$$

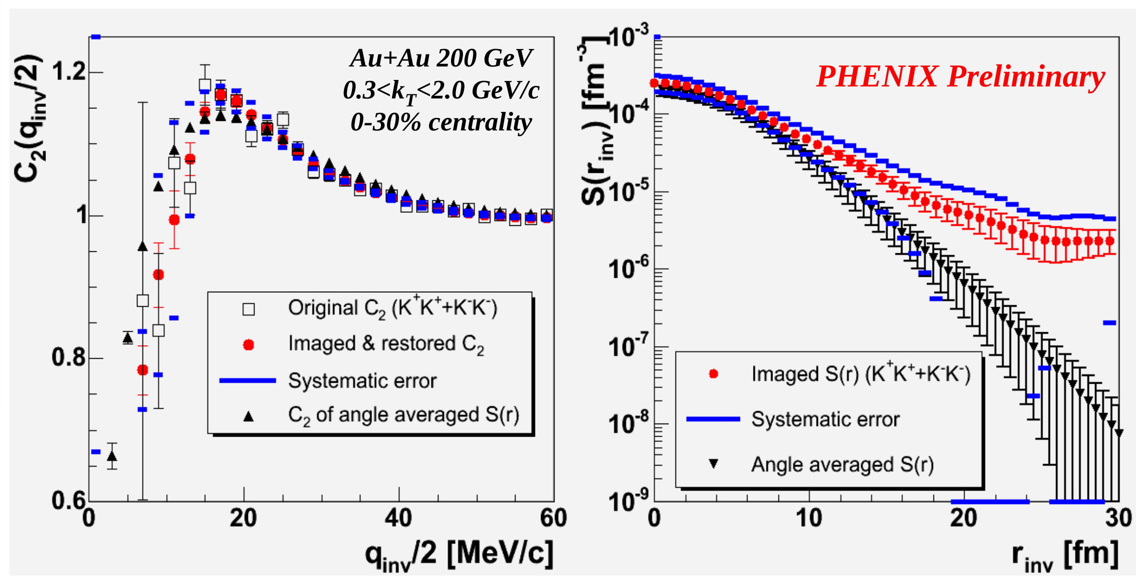
$$\Delta^2 S = \left(K^T \cdot (\Delta^2 R^{obs})^{-1} \cdot K \right)^{-1}$$

PHENIX HBT-imaging results



PHENIX Au+Au 200GeV
S.S. Adler *et al*, nucl-ex/0605032
Phys. Rev. Lett. Accepted.

- 1-D imaging for charged pion shows a clear signature of "non-Gaussian" feature of the source at r_{inv} region more than ~20 fm.
  - "core-halo" structure due to omega meson?
  - Kinetic effect? "Anomalous diffusion" due to hadron rescattering?
- Also 1-D HBT-imaging analysis for charged kaon has been done.
  - Need to be very careful about the experimental uncertainties.

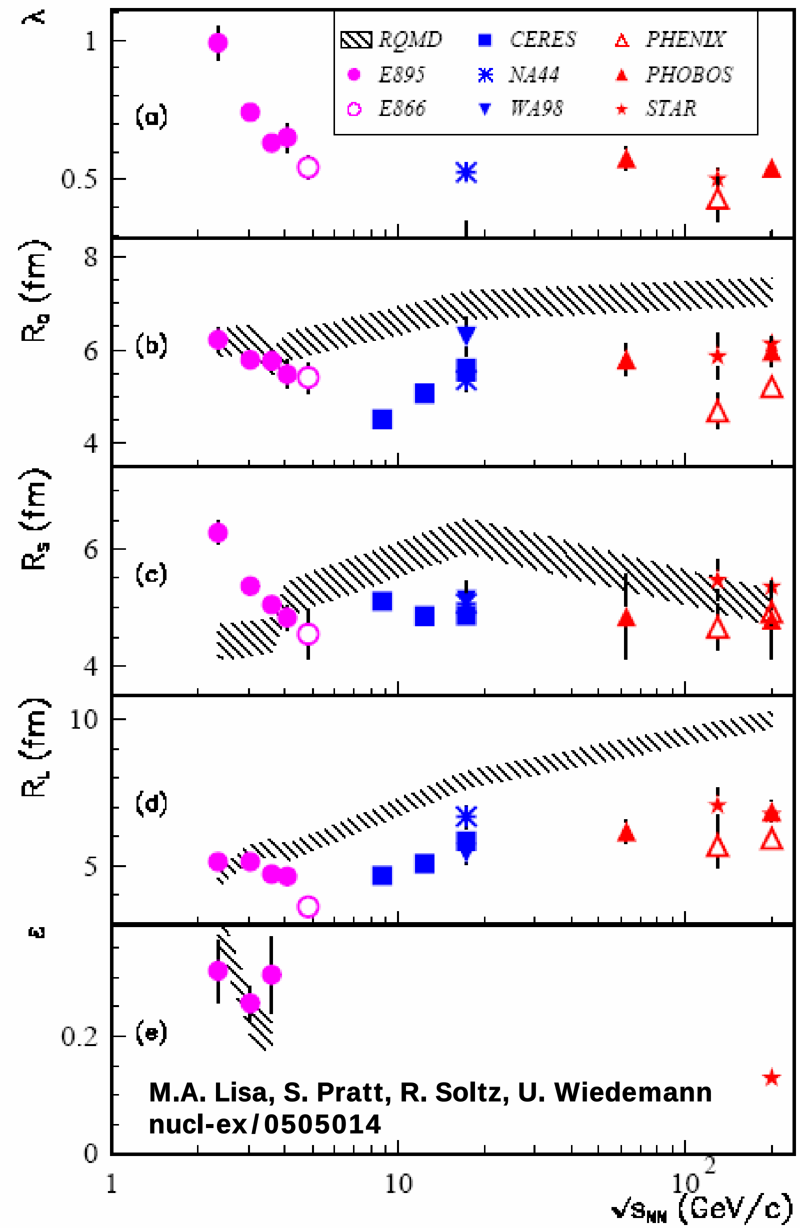


Solution 2: Systematic study on 3-D HBT radii

- 3-D HBT radii have been extensively measured from AGS, SPS to RHIC energy regions. However,
  - HBT radii don't change dramatically,
  - Coulomb correction method is being updated (becomes more accurate),
  - Measurements have been done for different momentum ranges, detector acceptances.

Need for detailed systematic studies of the 3-D HBT radii in a completely same condition.

While HBT-imaging technique is being developed, traditional measurements of 3-D HBT radii are still good values to investigate the space-time evolution of system in systematical and qualitative way.

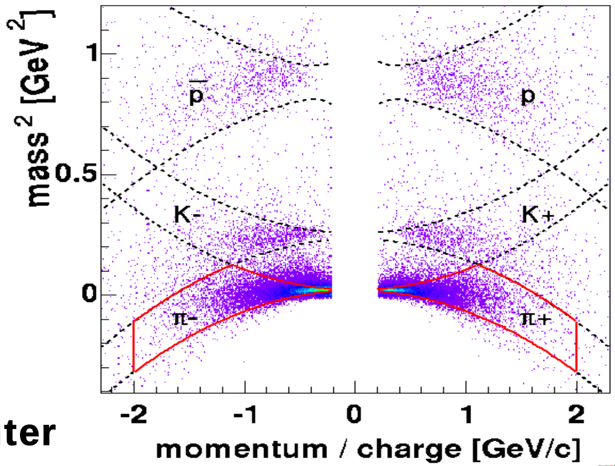


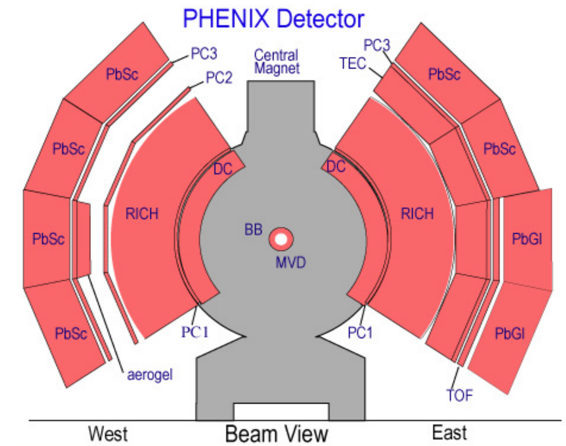
PHENIX detector

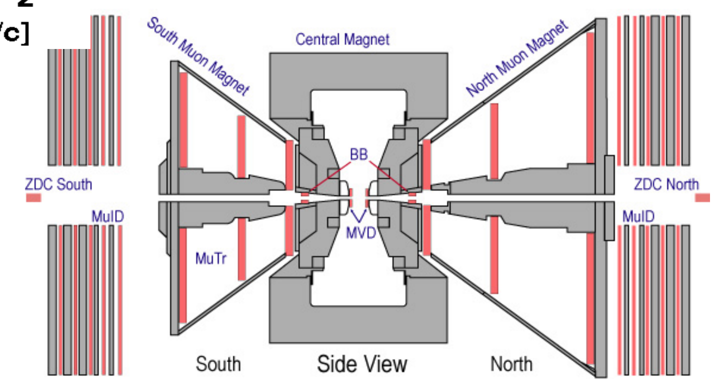
Tracking devices
- Drift Chamber
- Pad Chamber (PC1,PC2,PC3)
- Muon Tracking

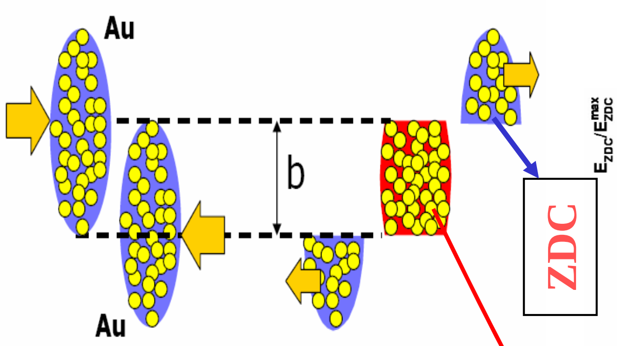
Particle Identification and Calorimetry
- EMCal (PbSc and PbGl)
- Time of Flight Counter
- Aerogel Cherenkov Counter
- Ring Imaging Cerenkov Counter
- Muon ID

Event Trigger and Characterization
- Beam-Beam Counter
- Zero Degree Calorimeter
- Forward Calorimeter (for d+Au)

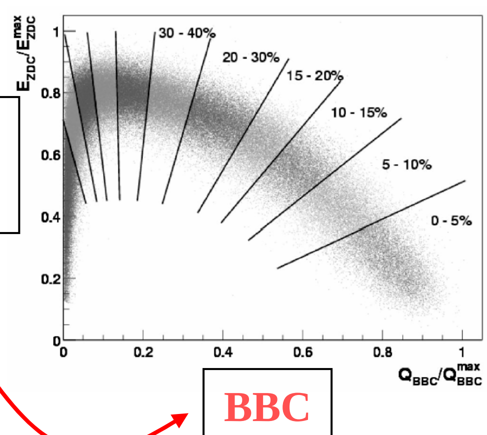








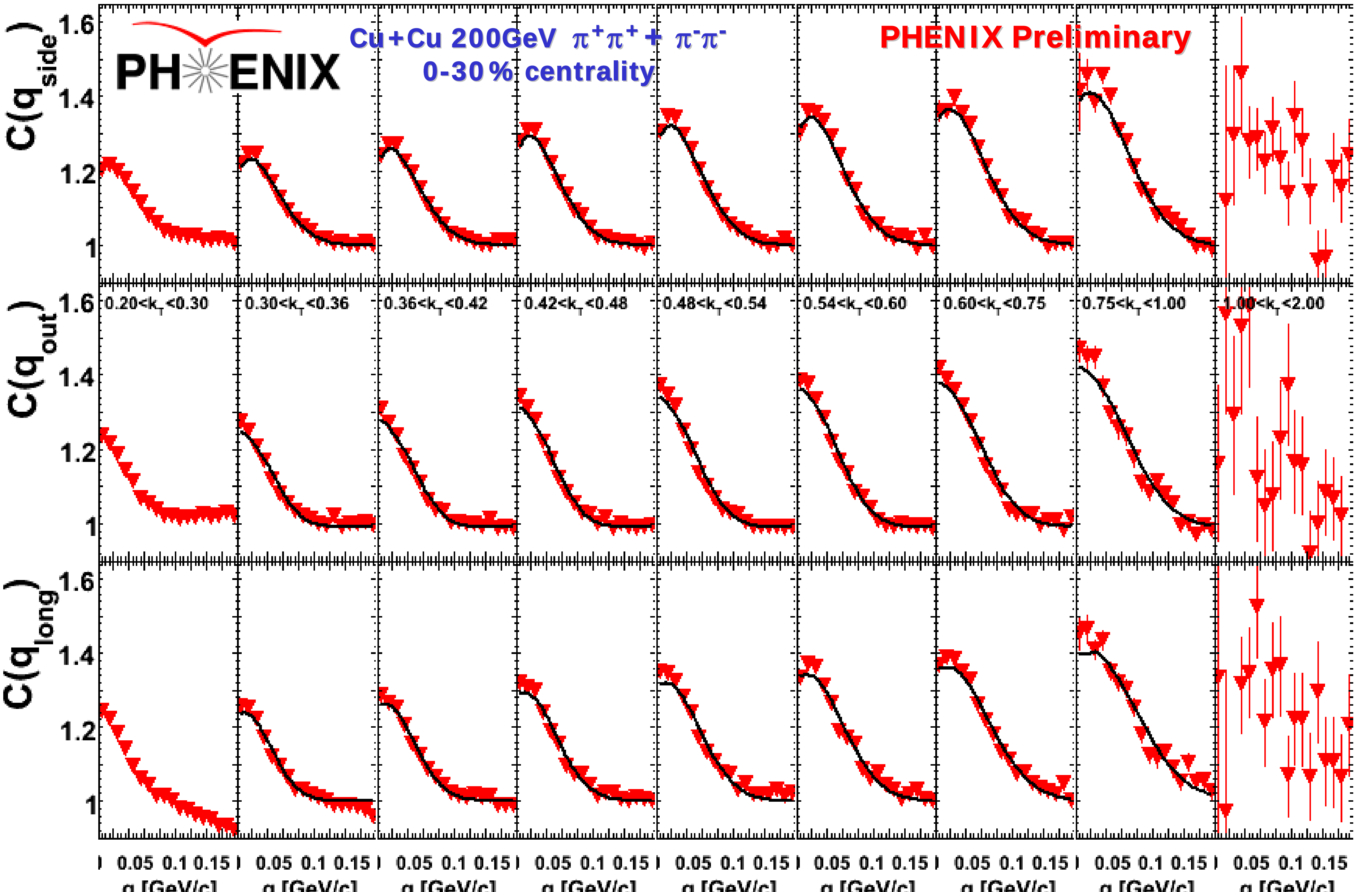
Centrality determination



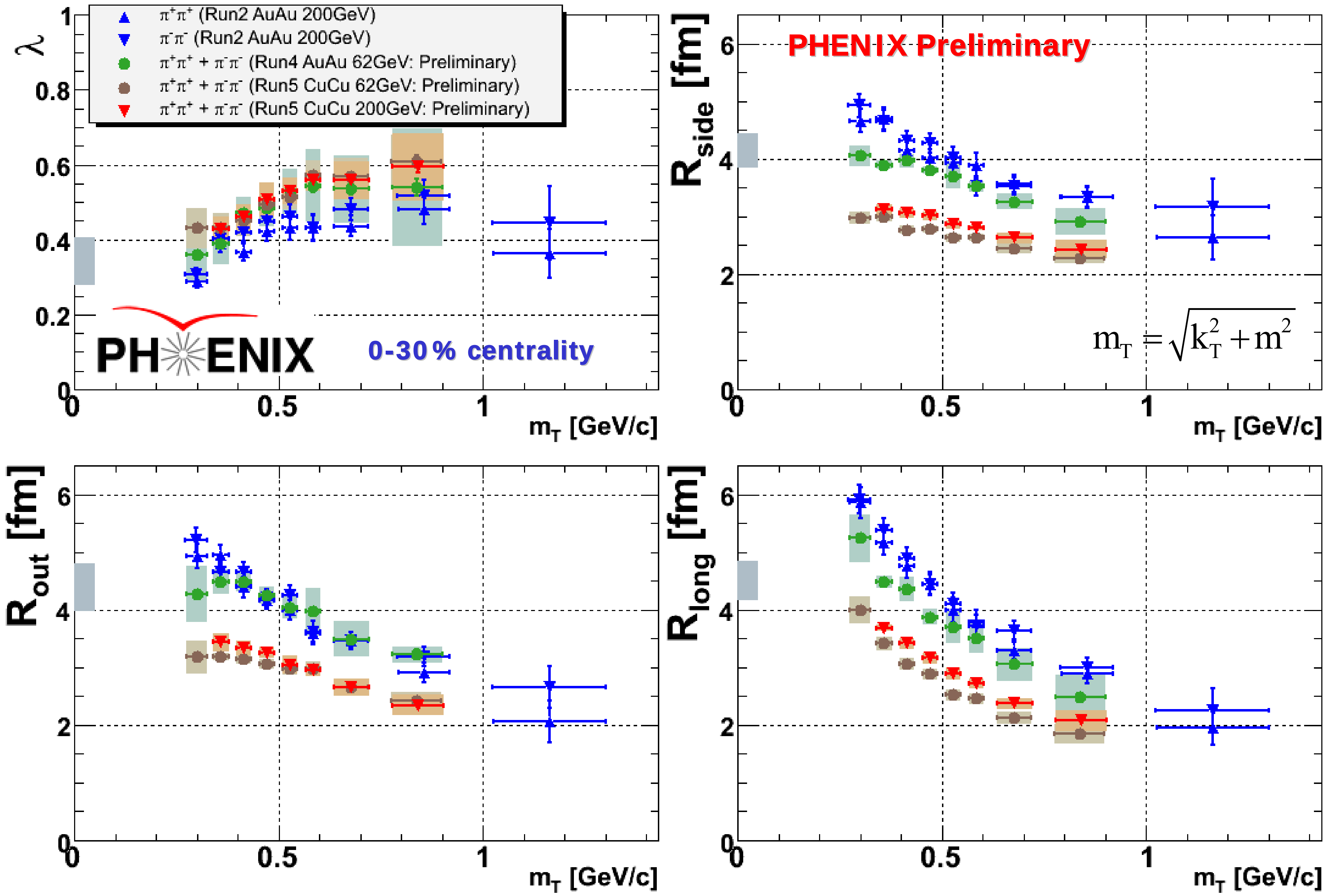
N_{part} is evaluated by Glauber model and MC simulation.

Year	Species	$\sqrt{s_{NN}}$	int.Ldt	Ntot
2000	Au+Au	130	1 mb^{-1}	10M
2001/2002	Au+Au	200	24 mb^{-1}	170M
2002/2003	d+Au	200	2.74 nb^{-1}	5.5G
2003/2004	Au+Au	200	241 mb^{-1}	1.5G
	Au+Au	62	9 mb^{-1}	58M
2004/2005	Cu+Cu	200	3 nb^{-1}	8.6G
	Cu+Cu	62	0.19 nb^{-1}	0.4G
	Cu+Cu	22.5	2.7 mb^{-1}	9M

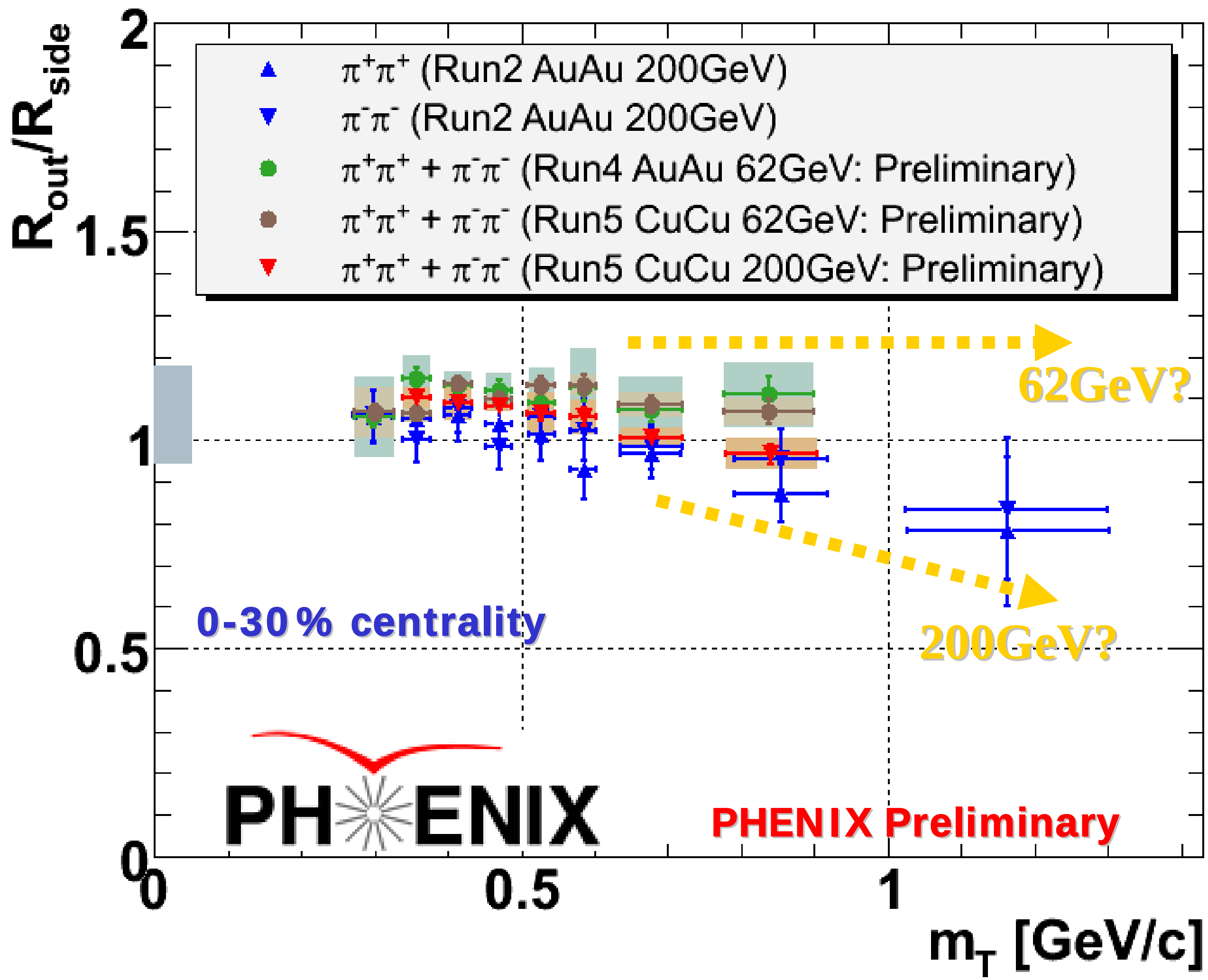
Pair momentum dependence of 3-D correlation functions



m_T dependence of 3-D HBT radius parameters

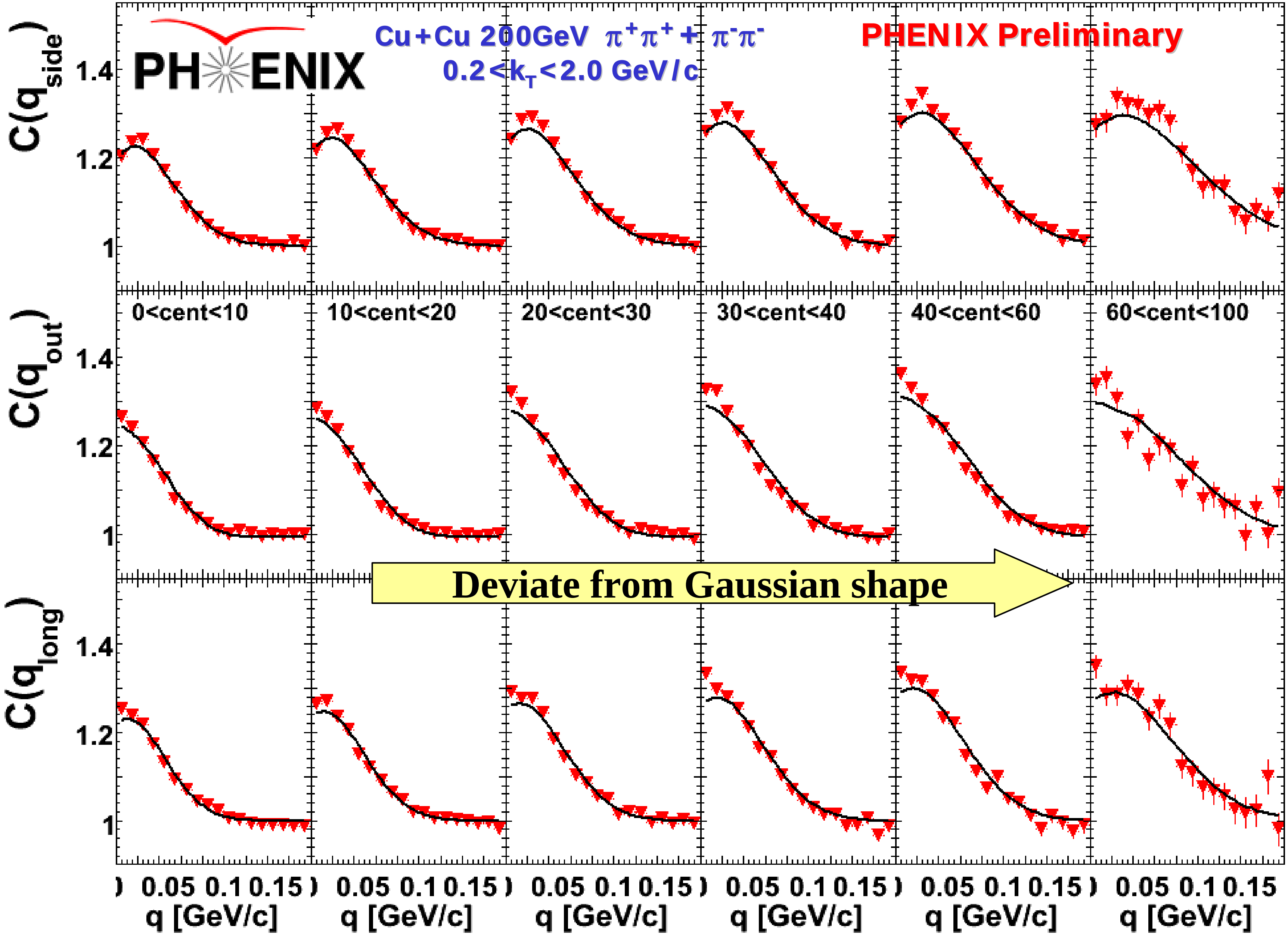


m_T dependence of R_{out}/R_{side} ratio

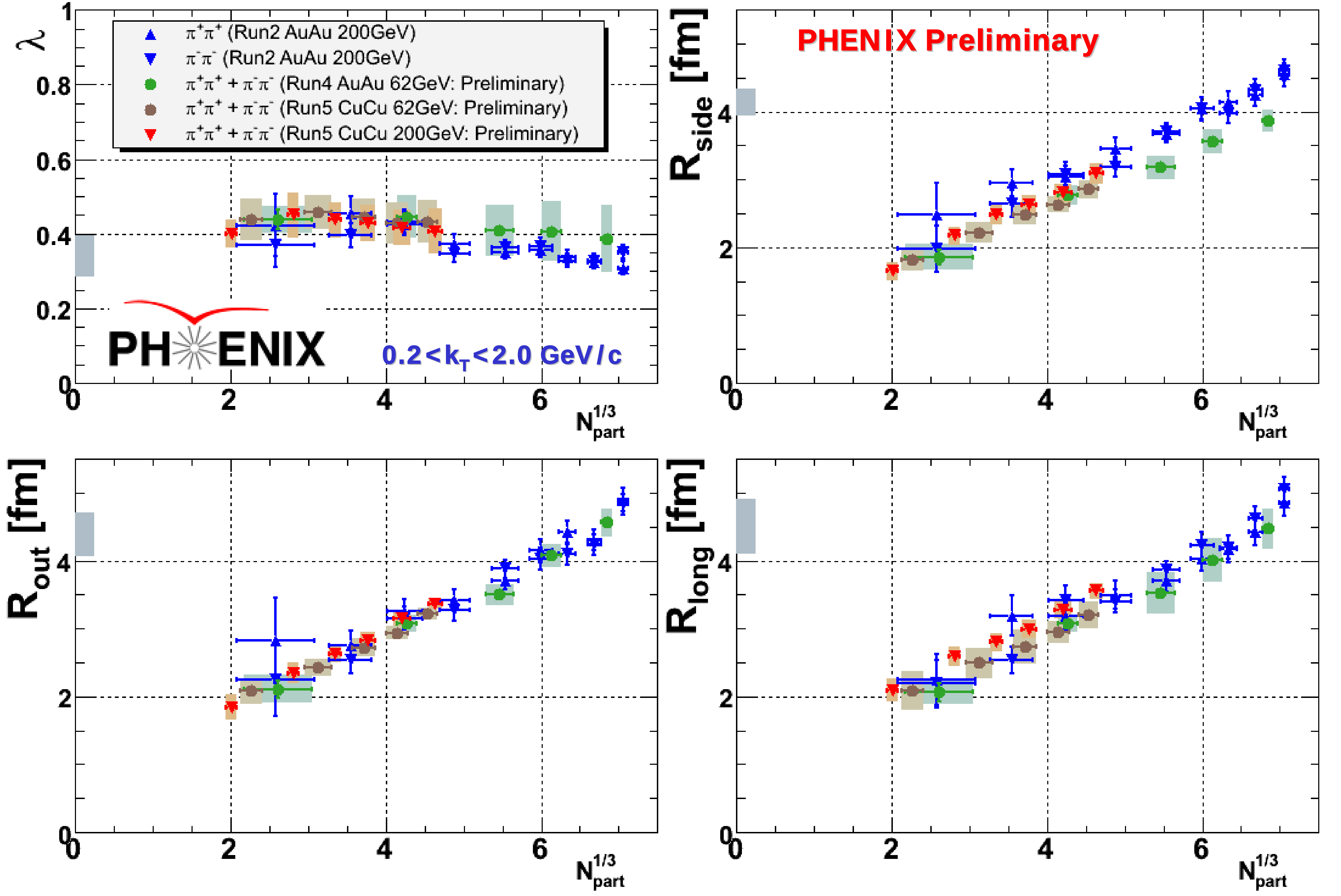


R_{out}/R_{side} ratio decreases as a function of m_T at 200 GeV but not at 62GeV?
Need further investigation for higher m_T region.

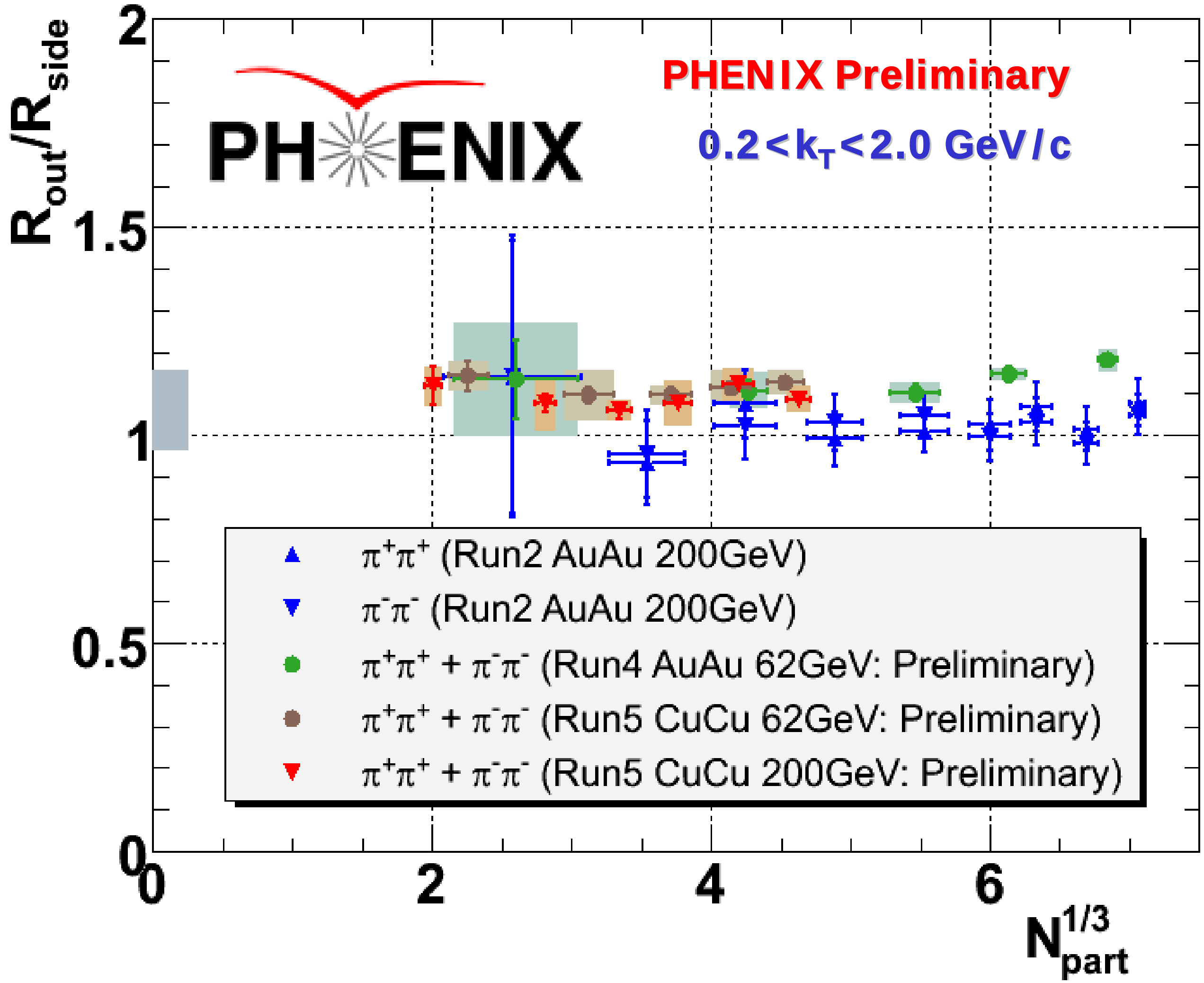
Collision size dependence of 3-D correlation functions



N_{part} dependence of 3-D HBT radius parameters



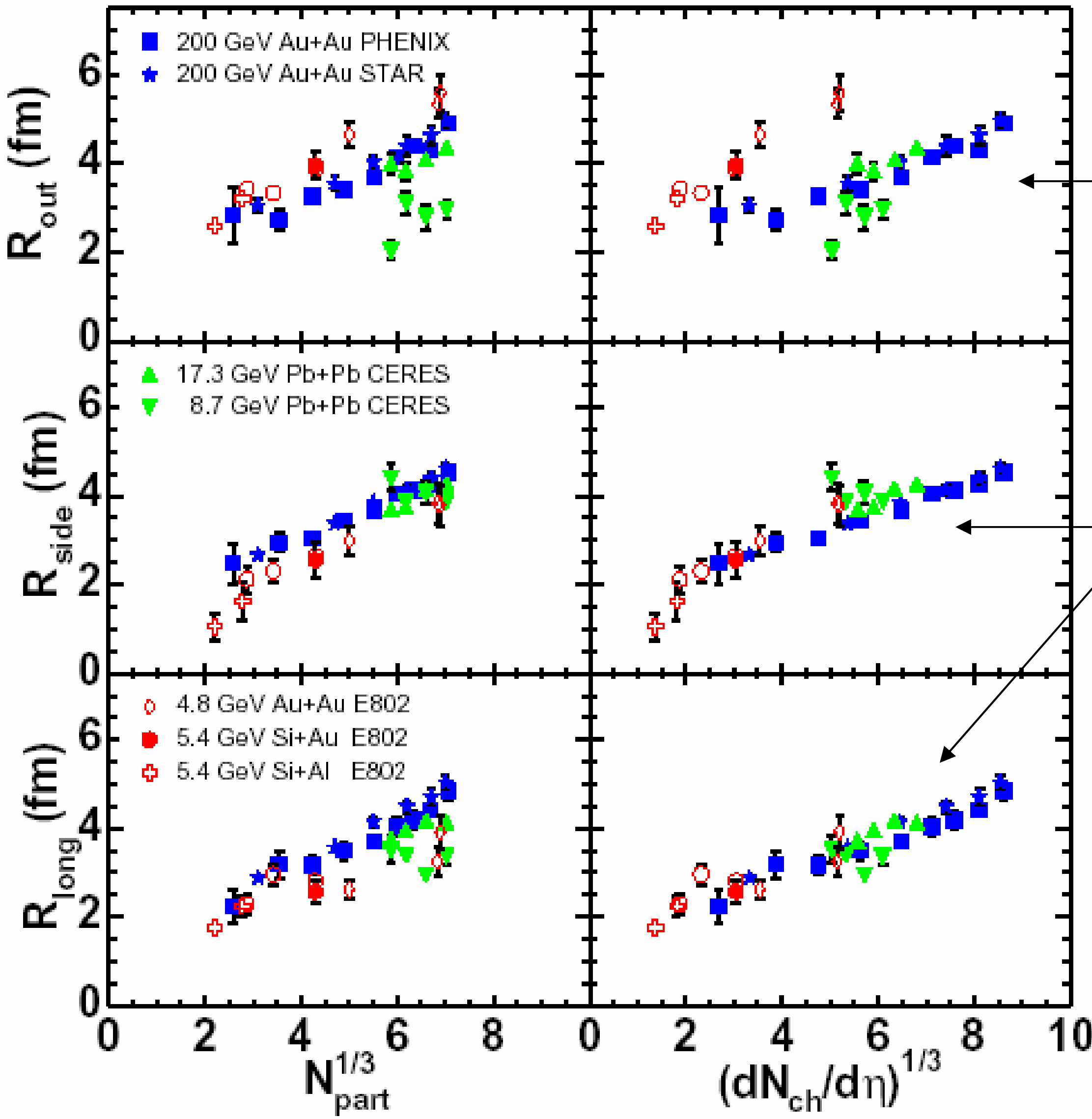
N_{part} dependence of R_{out}/R_{side} ratio



All R_{out}/R_{side} ratios are consistent when the collision size is small, but seem to be different between 62.4 and 200 GeV in central Au+Au collisions.

What is the scaling parameter for 3-D HBT radii?

M.A. Lisa, S. Pratt, R. Soltz, U. Wiedemann
nucl-ex/0505014



R_{out} seems to not scale with dN/dy. (rather scale with N_{part}?)

R_{side} and R_{long} seem to scale with dN/dy rather than N_{part}.

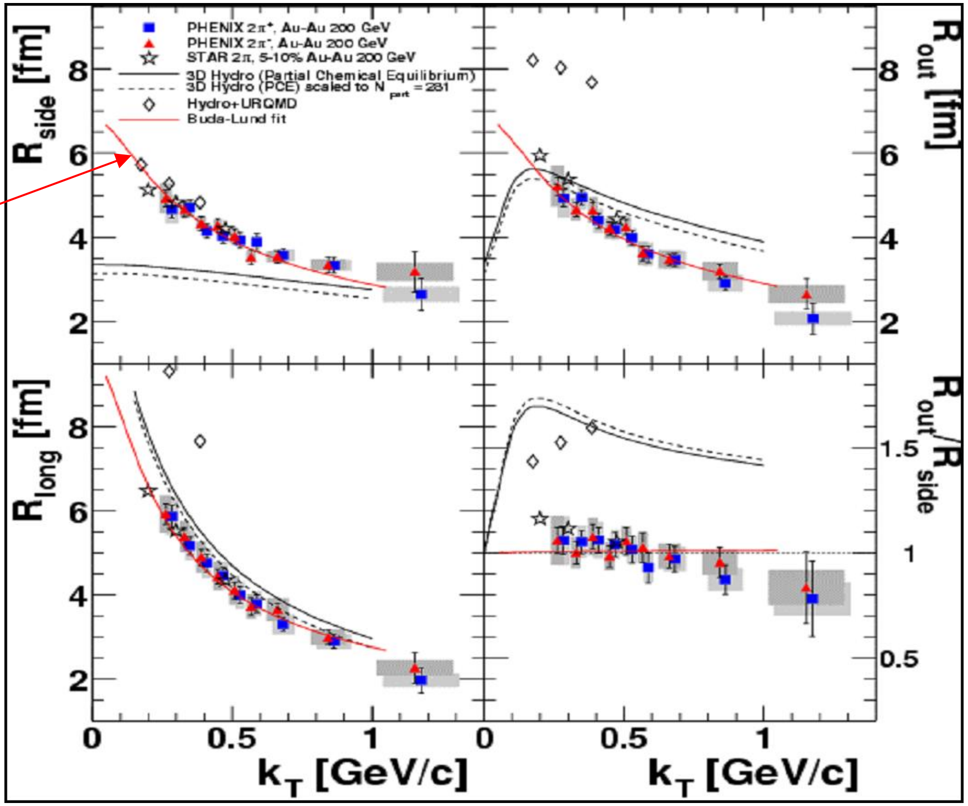
Need systematic study as a function of dN_{ch}/dy

Summary

- 3-D Gaussian HBT radii of charged pions have been measured as a function of pair momentum and centrality in Au+Au and Cu+Cu collisions at 62.4 and 200 GeV by RHIC-PHENIX.
  - 3-D correlation function deviates from Gaussian shape as the collision size decreases, especially in q_{out} direction.
  - Trend of m_T dependence is very similar between Au+Au 62.4-200 GeV, also Cu+Cu 62.4-200 GeV
    - Systematical increases of R_{side} and R_{long} from 62.4 to 200 GeV for entire k_T region.
  - R_{out}/R_{side} ratio tends to decrease as a function of m_T at 200 GeV but not at 62GeV.
  - N_{part} scaling of HBT radii (especially R_{side}, R_{long}) doesn't work for results between 62.4 GeV and 200 GeV
    - Results should be compared as a function of multiplicity.
  - R_{out}/R_{side} ratio seems to be consistent at peripheral Au+Au and Cu+Cu collisions but may be different in central Au+Au collisions between 62.4 and 200 GeV.

Prospects

- More studies for higher k_T region (more statistics).
- Extend the collision system dependence studies to 1-D HBT-imaging analysis.
- Development and application of 3-D HBT-imaging technique..
  - More wide energy range scan.
  - Systematic study using hydrodynamics analytical fits.
  - Comparison with hydrodynamics calculations.



PHENIX

Thanks!

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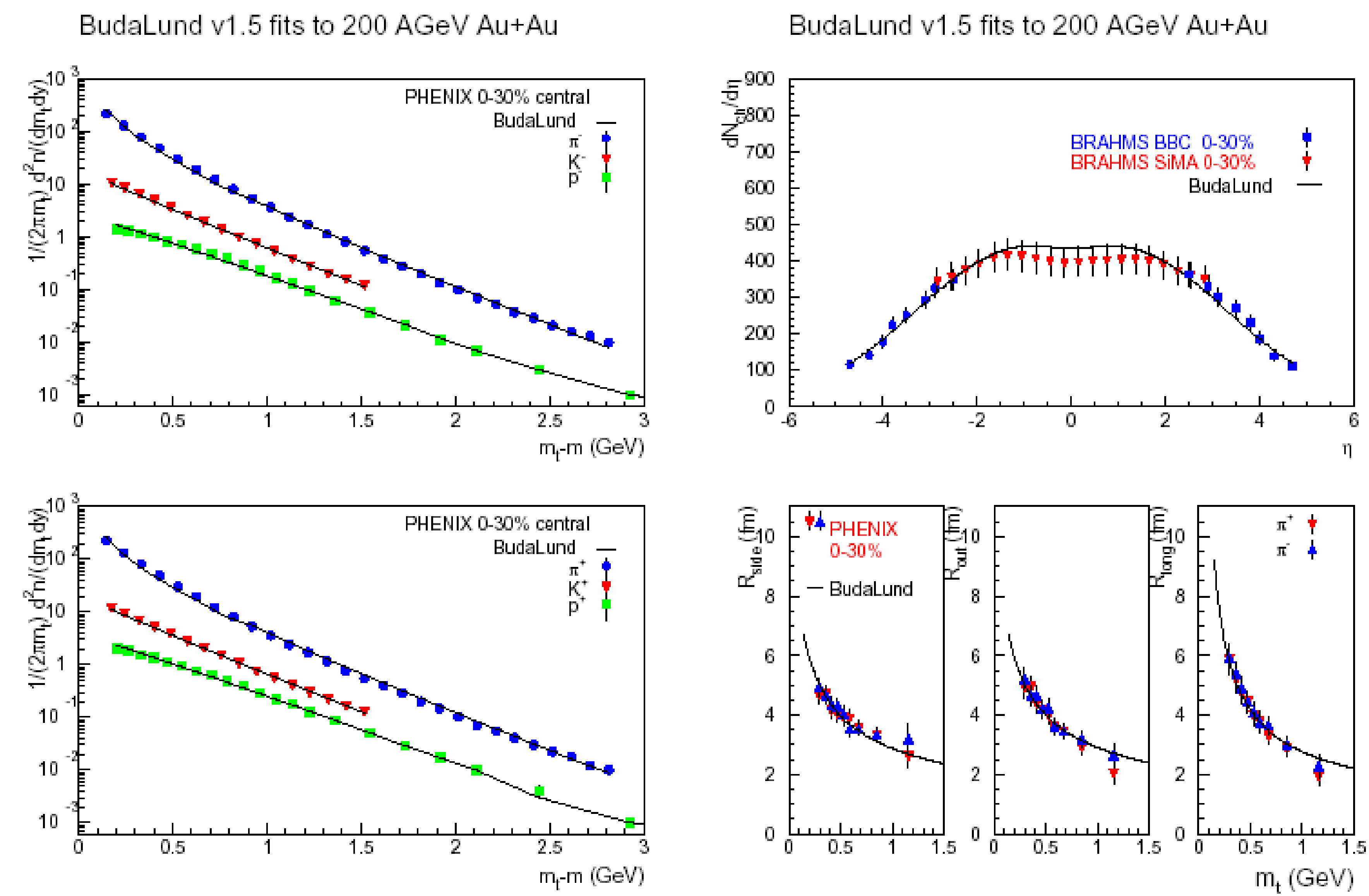
*as of March 2005

Back up slides

BudaLund fit

M. Csanad, T. Csorgo, B. Lorstad and A. Ster, J. Phys. G 30, S1079 (2004)



Comparison with cascade, hydrodynamics models

M.A. Lisa, S. Pratt, R. Soltz, U. Wiedemann
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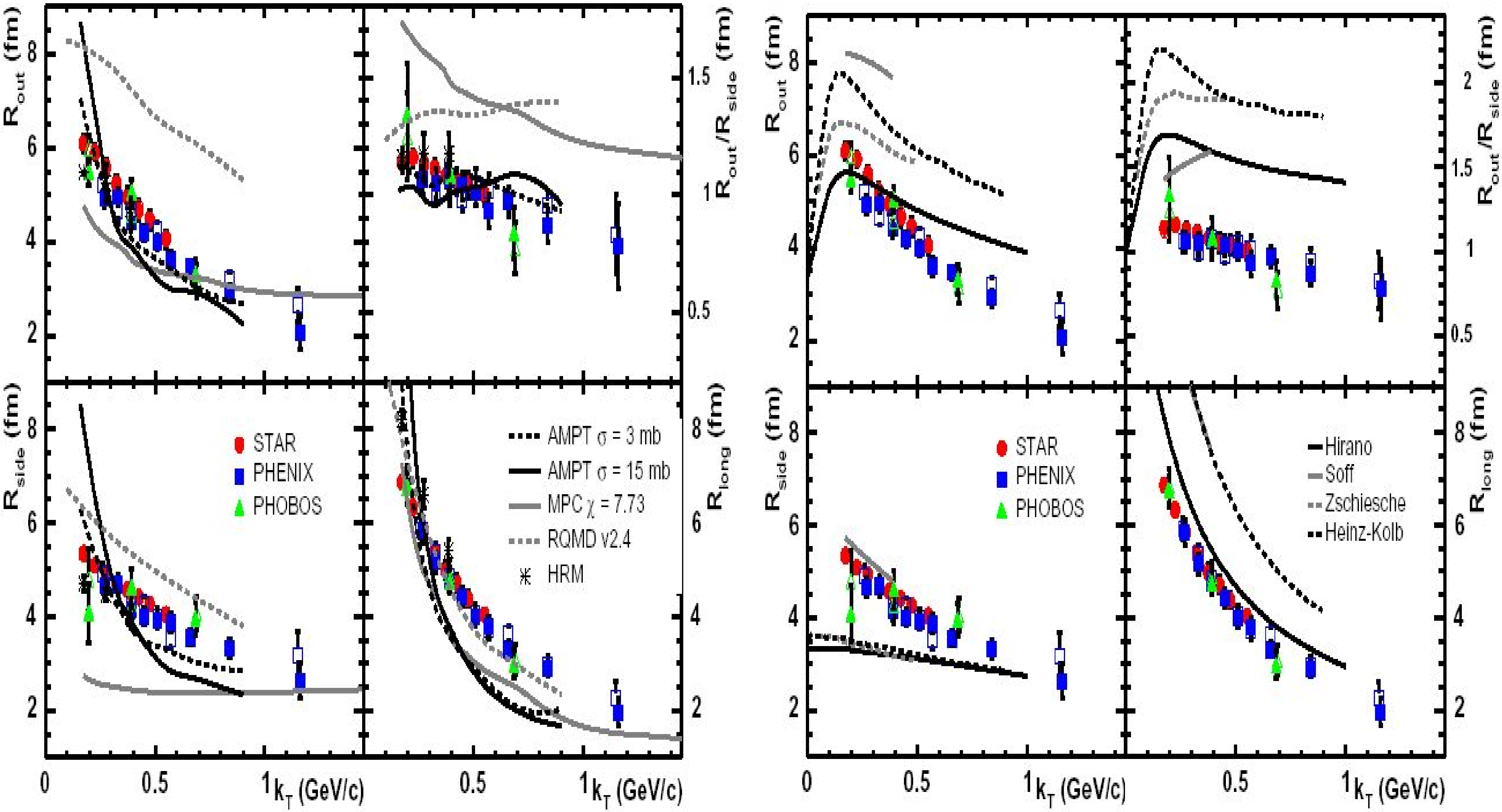
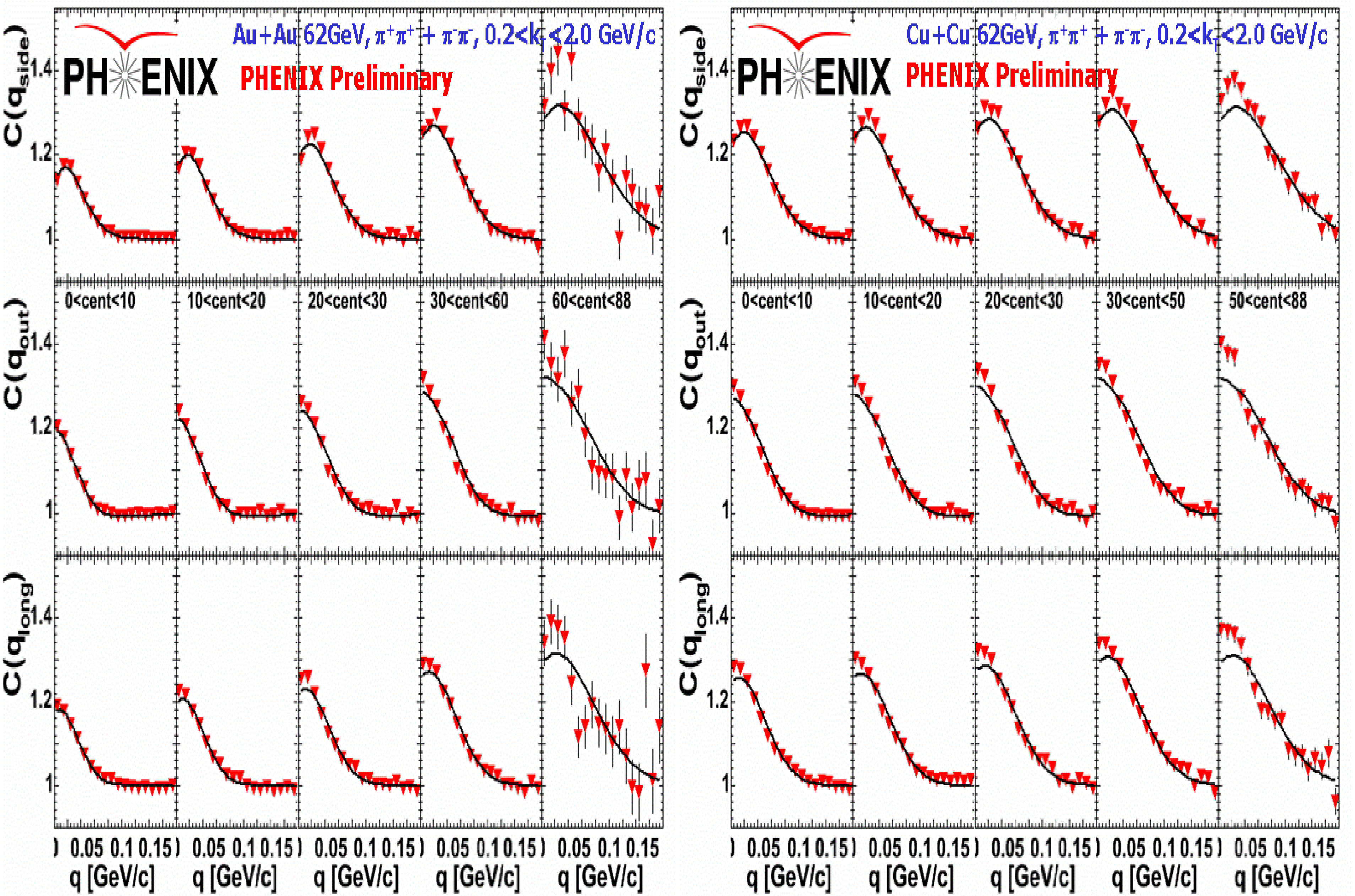


Collision size dependence of 3-D C_2 at 62.4GeV



m_T dependence of 3-D pion and kaon HBT radii