A Comparison of HBT Measurements for d+Au and Au+Au collision systems at $\sqrt{s_{NN}}$ = 200 GeV at RHIC-PHENIX

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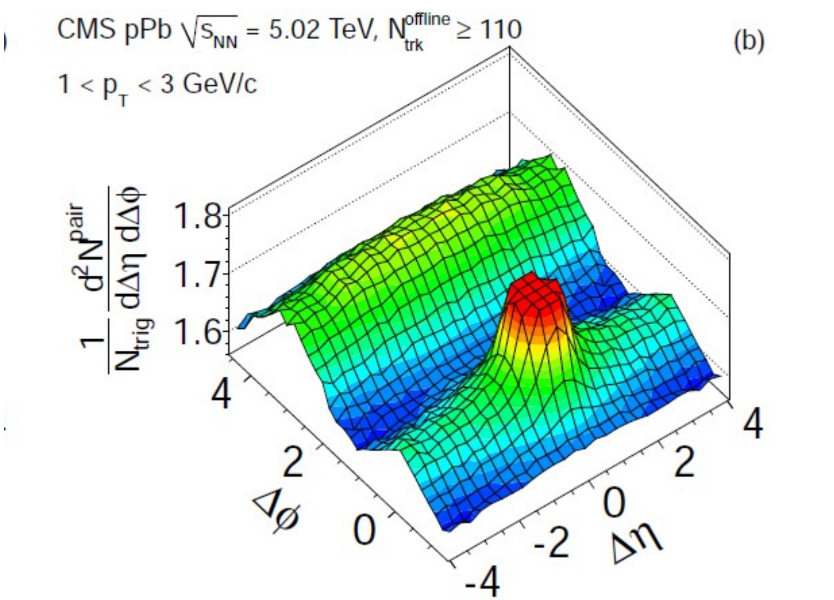
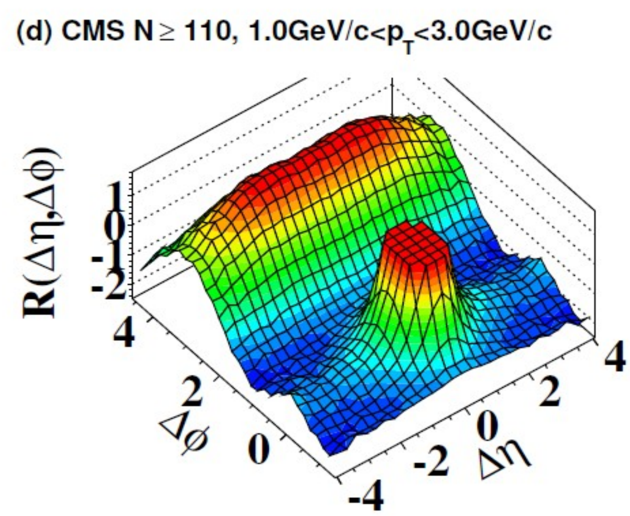
Observed long-range correlations in high multiplicity events in p+p and p+Pb

Ridge in p+Pb



Phys. Lett. B 718 (2013) 795

Ridge in p+p

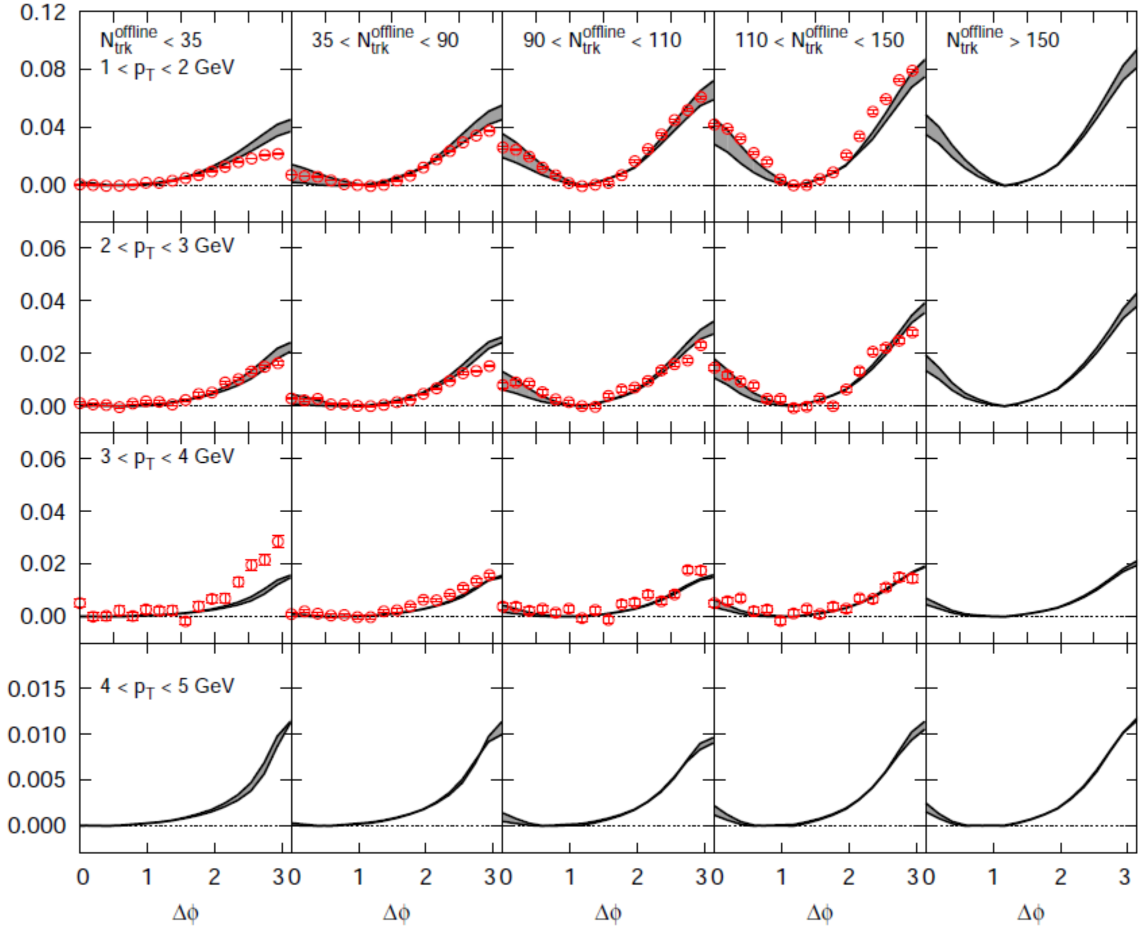


JHEP 1009 (2010) 091

- Near-side ridge structure observed at LHC for high multiplicity p+p (7 TeV) and p+Pb (5.02 TeV) collisions suggest that these small systems are large enough (and last long enough) for significant medium effects previously only seen in A+A collisions
- Two theories on the origin of ridge structure:

(1) Color Glass Condensate Framework

arXiv: 1302.7018

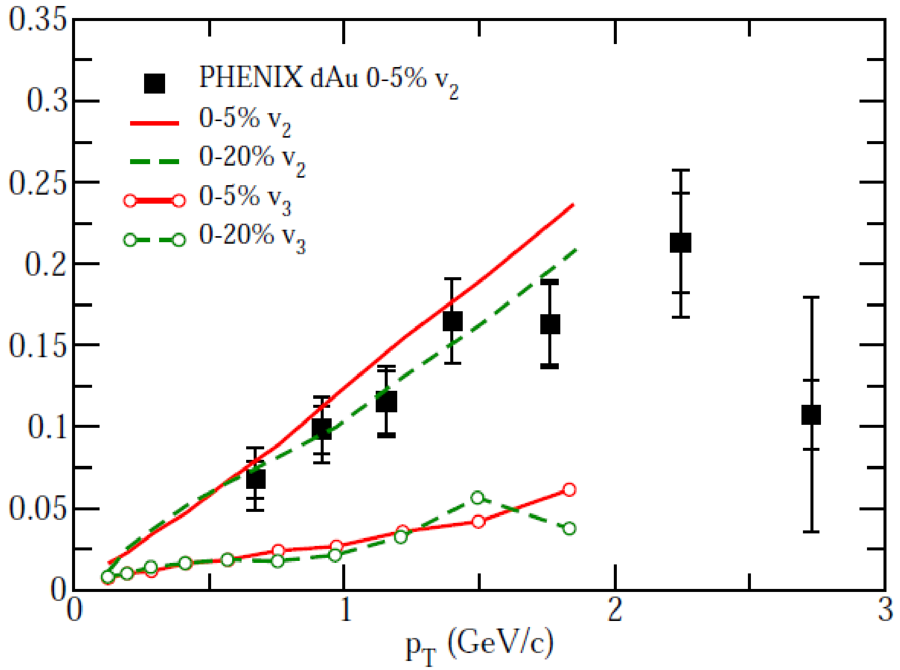


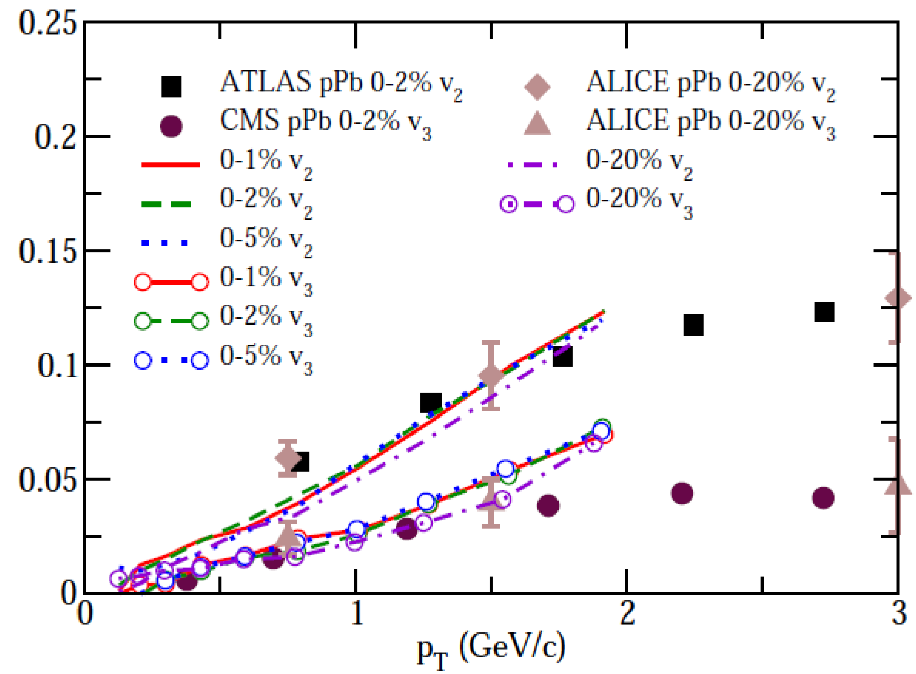
long-range per-trigger-yields of charged hadrons p+Pb CMS: Data compared to model

CGC framework: Observed two-ridge structure is as a result of quantum interference effects between correlated gluons due to gluon saturation at small impact parameters

(2) 3+1-dimensional hydrodynamic model

arXiv:1306.3439





Flow hydro results compared to the experimental d+Au results at RHIC at both 0-5% and 0-20% centrality

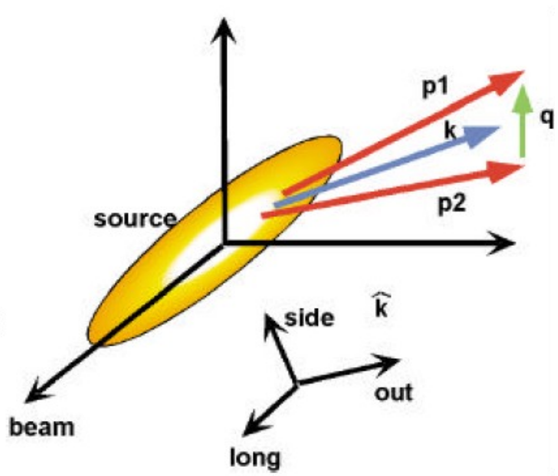
Elliptic and triangular flow hydro results compared to experimental p+Pb results at LHC at 0-2% and 0-20% centrality

Viscous hydro model: Observed collective effects could be due to fluctuations of initial state carried through final-state hydrodynamic evolution

Motivation for HBT studies in d+Au

- With two equally successful interpretations of the near-side ridge structure, need for an independent check of the role of final-state interactions
- HBT measurements are well studied and show characteristic patterns due to collective effects in A+A collisions
- Similar measurements can provide constraint for final-state effects in p+A collisions
- Common trends in A+A and p+A systems in HBT measurements would be a strong indication of final-state effects in p+A systems

HBT Methodology



Based on quantum interference of identical particles whose space-momentum correlation can be expressed as:

$$C_2(q,k)-1=\int(d^3 r S_k(r)[|(\psi(k,r))|^2-1])$$

$$q=p_1-p_2 \quad k=(p_1+p_2)/2$$

Space-time information extracted by fitting $C_2(q_i)$ with:

$$C_2(q_{side},q_{out},q_{long})=1+\lambda\exp(-R_{side}^2 q_{side}^2-R_{out}^2 q_{out}^2-R_{long}^2 q_{long}^2)$$

Here, q is decomposed in the longitudinal co-moving system (LCMS): q_{side}, q_{out}, q_{long}

q_{side} - is perpendicular to the beam direction

q_{out} - is parallel to the average transverse momentum of pair or k_T

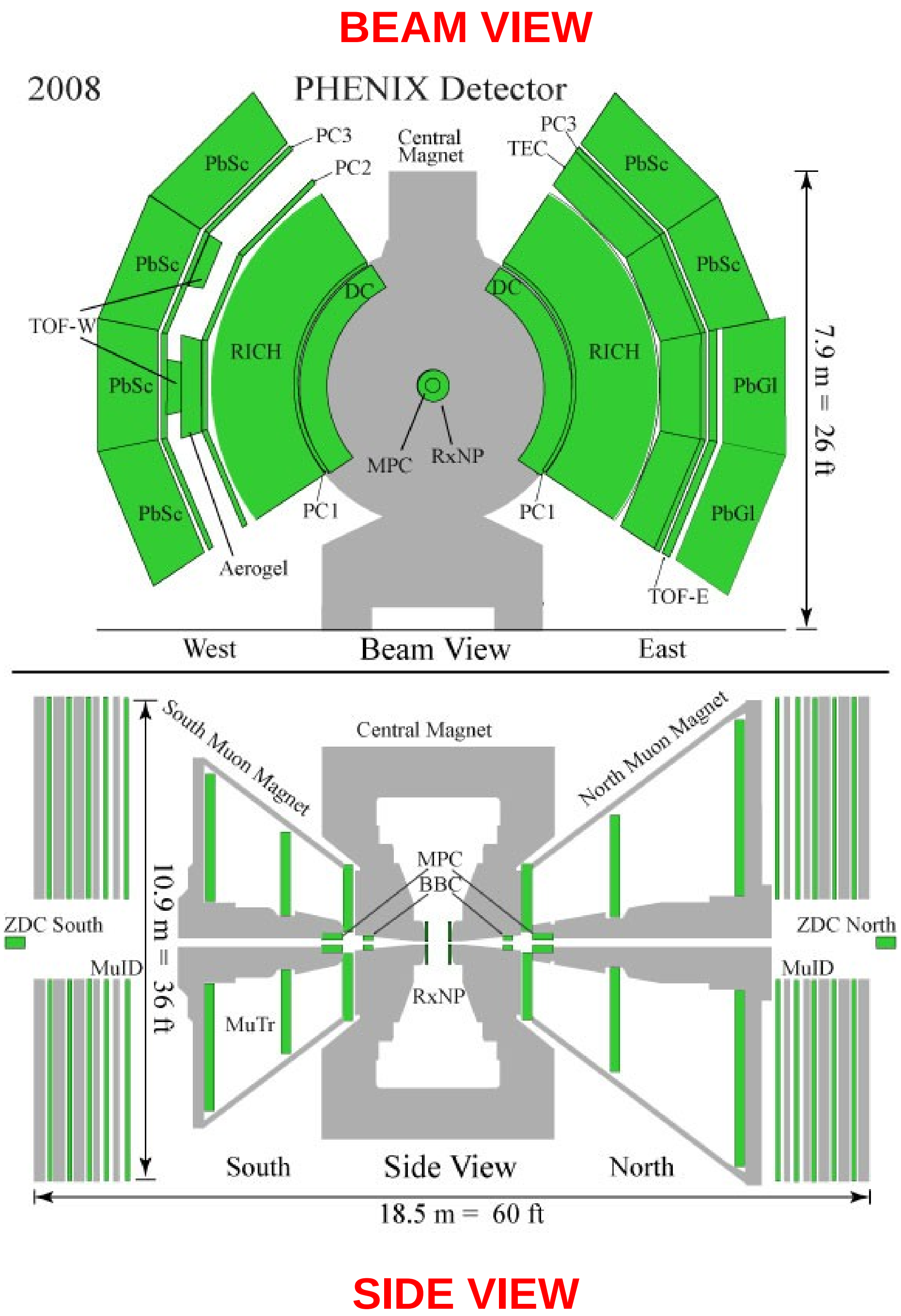
q_{long} - is along beam direction

R_{side} - carries information about the geometrical size of the dynamic system, R_{geom}

R_{out} - encodes information about the size and the emission duration of the system at freeze-out, $\Delta\tau$

R_{long} - provides information about the lifetime of the system, τ

The PHENIX Experiment



Zero Degree Calorimeter (ZDC) & Beam Beam Counter (BBC)
Vertex and centrality determination

Drift Chamber (DC) & Pad Chamber (PC)
Tracking information

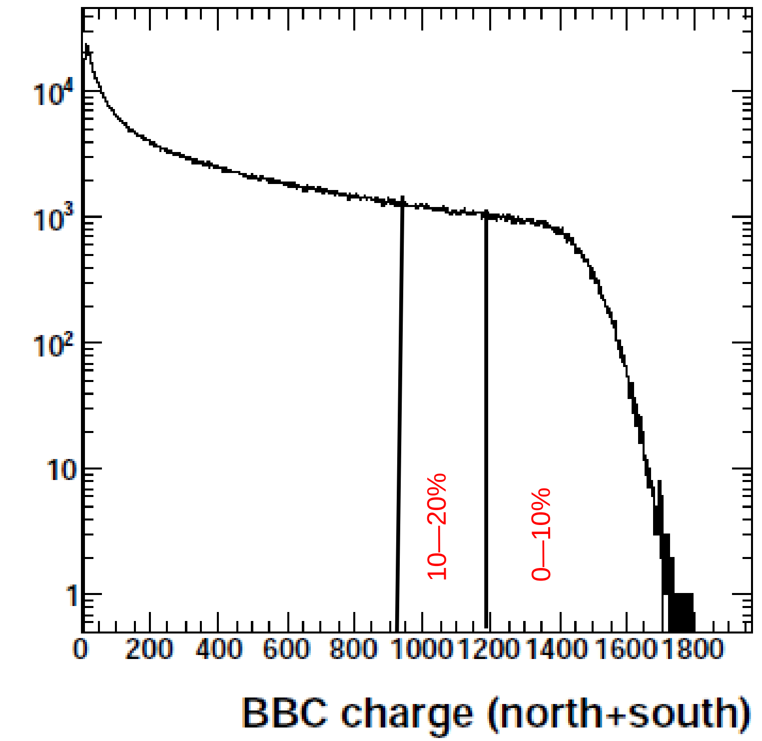
Electromagnetic Calorimeter (EMC) Lead Scintillator Sectors (Six Total)
PID information

Time-of-Flight Detector (TOF)
PID information

With their good timing resolution, the EMC and TOF detectors provide for very good PID capabilities

Centrality and PID Determination

Centrality Determination

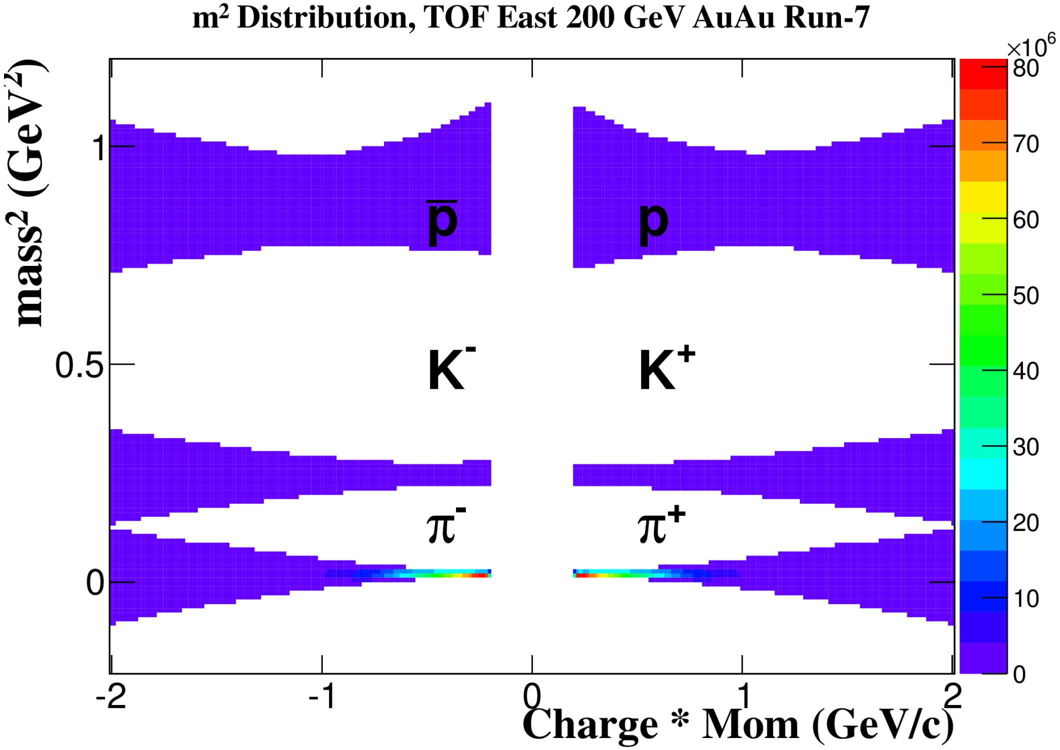


Centrality determined from total charge deposited in BBC

N_{part} and R_{bar} obtained from MC-Glauber simulation of each centrality class.
R_{bar} is the initial transverse size of the system defined as: $1/R_{bar} = \sqrt{(1/\sigma_x^2 + 1/\sigma_y^2)}$

σ_x, σ_y : RMS widths of density distributions

PID Determination



PID done using the time-of-flight method
Very good pion separation obtained in both d+Au and Au+Au systems

Analysis Summary and Outline

Analysis outline

- Select particles
- Build correlation functions ($C_2(q)$)
  - Apply appropriate cuts to remove spurious correlations
- Fit to extract for HBT radii in 3-D and study as a function of:
  - collision centrality
  - average transverse mass (m_T)

  for each collision system
- Fit HBT radii m_T dependence to obtain geometrical radius and system lifetime

Analysis summary

Analysis done for charged pions for:

$\sqrt{s_{NN}}$ = 200 GeV Au+Au 3.5 billion events

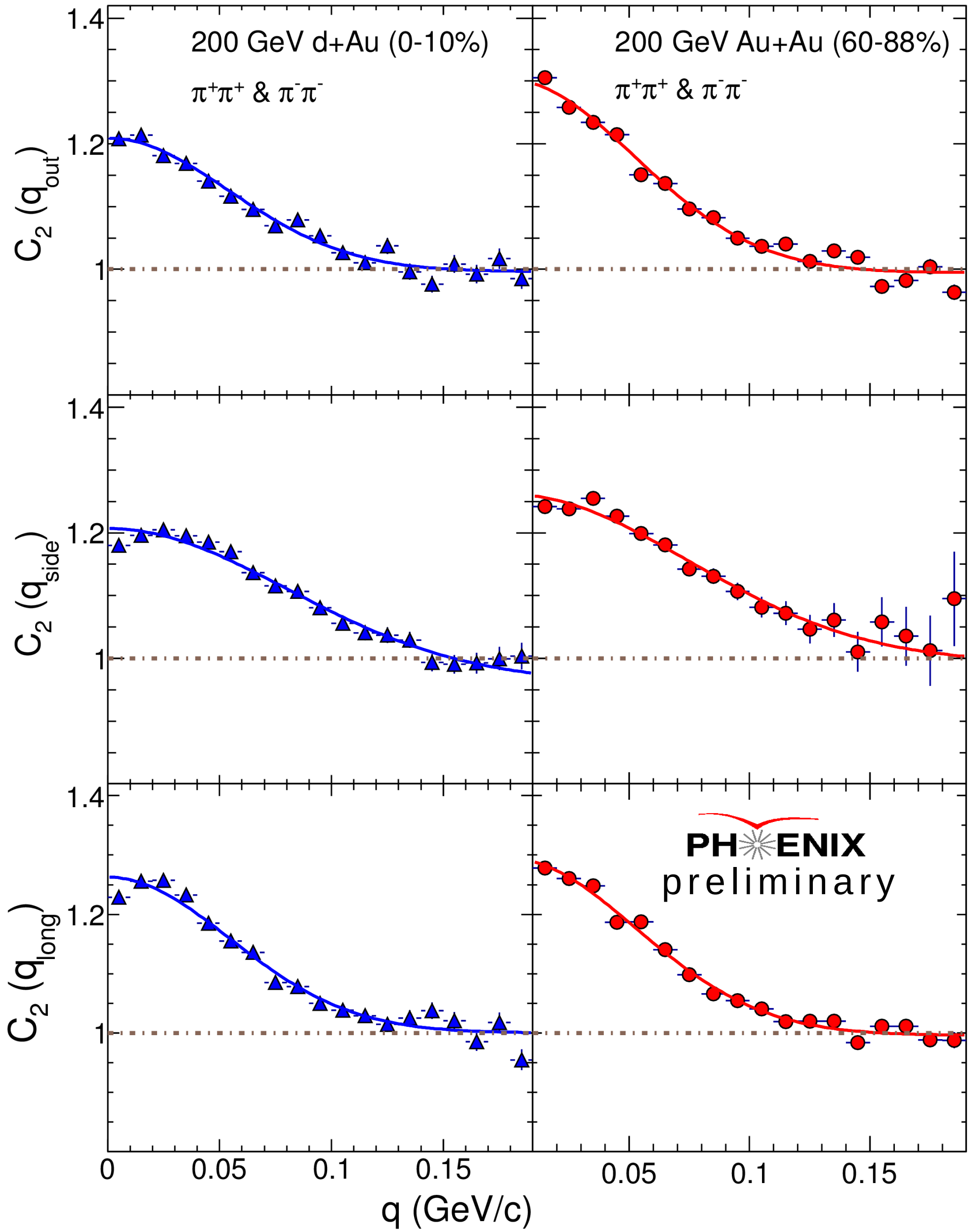
$\sqrt{s_{NN}}$ = 200 GeV d+Au 1.8 billion events

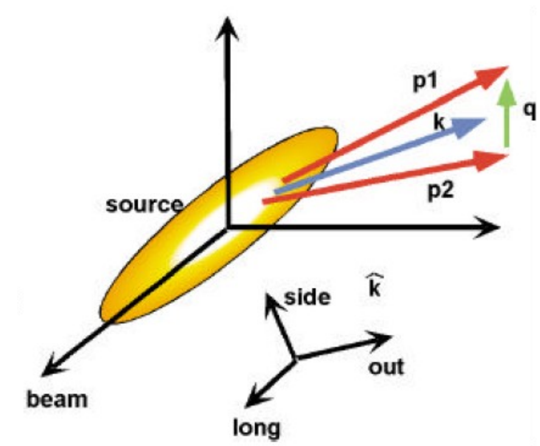
PID: 2σ for pion acceptance; 3σ for kaon rejection

k_T range: $0.2 < k_T < 0.7$ GeV/c

k_T average: 0.39 GeV/c (for collision geometry dependence)

Correlation Functions



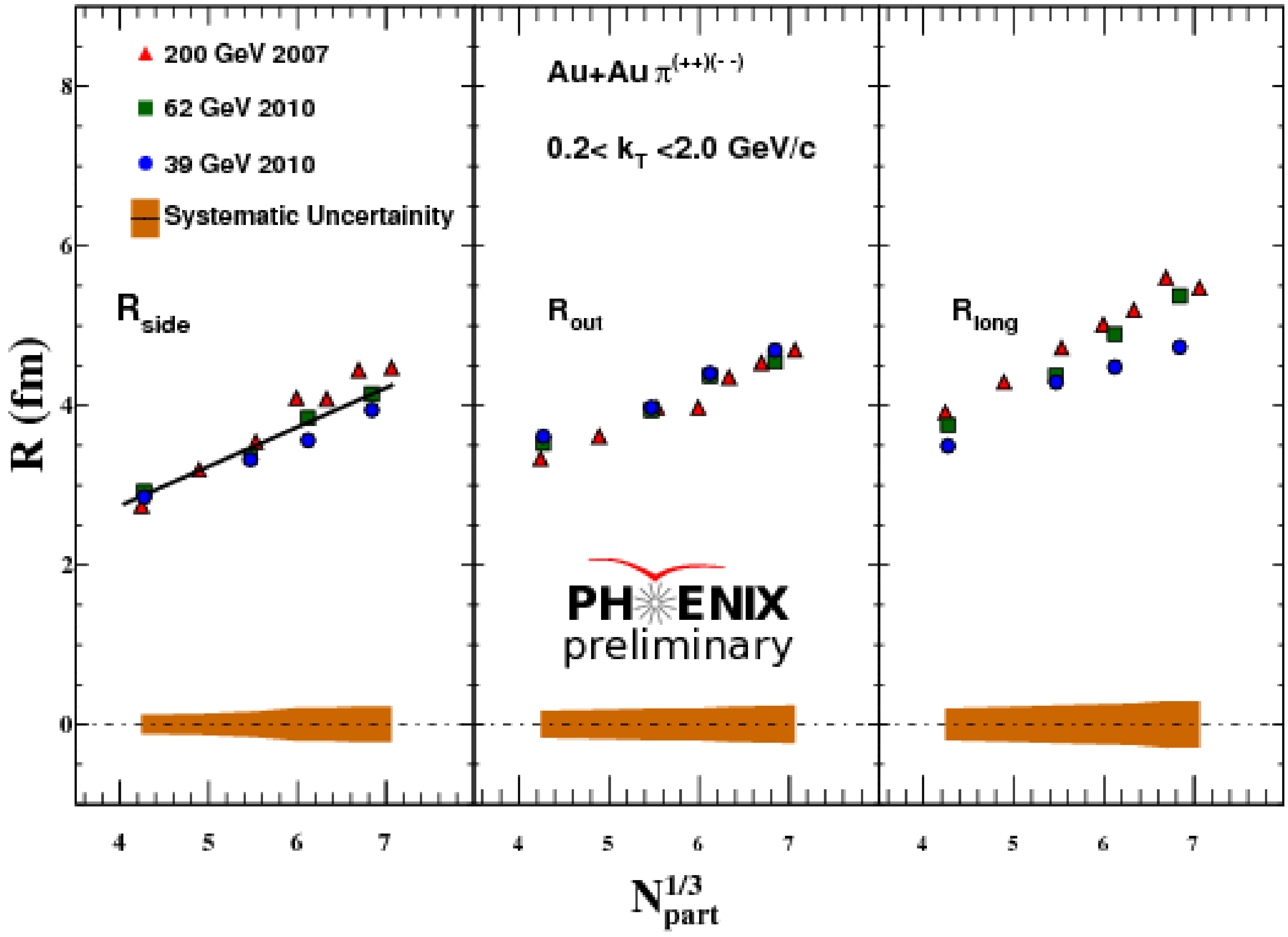


$$C_2(q_{side}, q_{out}, q_{long}) = 1 + \lambda \exp\left(-R_{side}^2 q_{side}^2 - R_{out}^2 q_{out}^2 - R_{long}^2 q_{long}^2\right)$$

- In both d+Au and Au+Au, correlation functions were generated in 3-D and projected for q_{side}, q_{out}, and q_{long} in different centrality and k_T selections.
- (R_{out}, R_{side}, R_{long}) were obtained and compared at similar N_{part} values in d+Au (central collisions) and Au+Au (peripheral collisions) for m_T dependence. The centrality dependence was also studied.

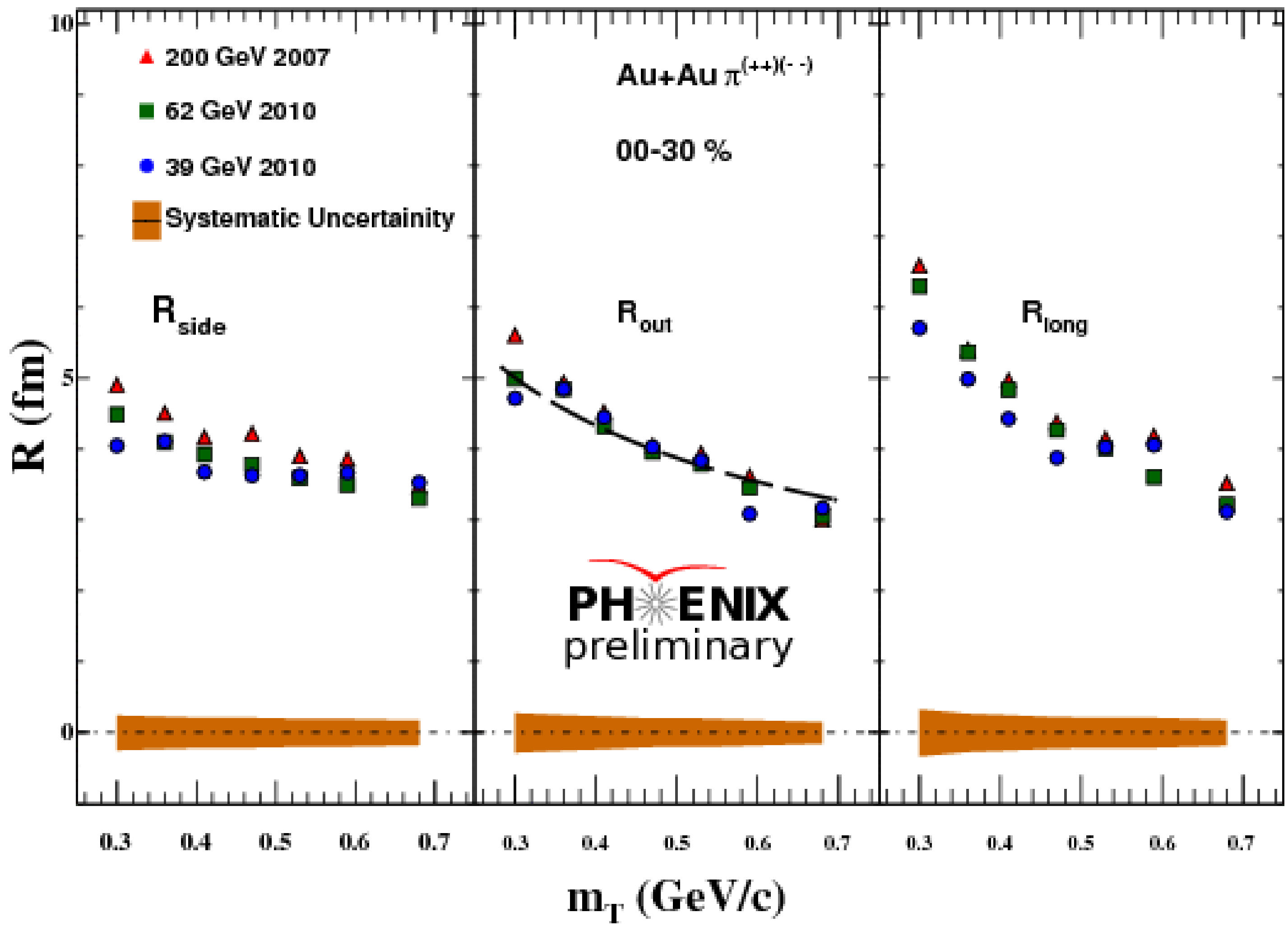
Excellent fits to the correlation functions found in both d+Au and Au+Au

HBT measurements in Au+Au: $N_{part}^{1/3}$ dependence



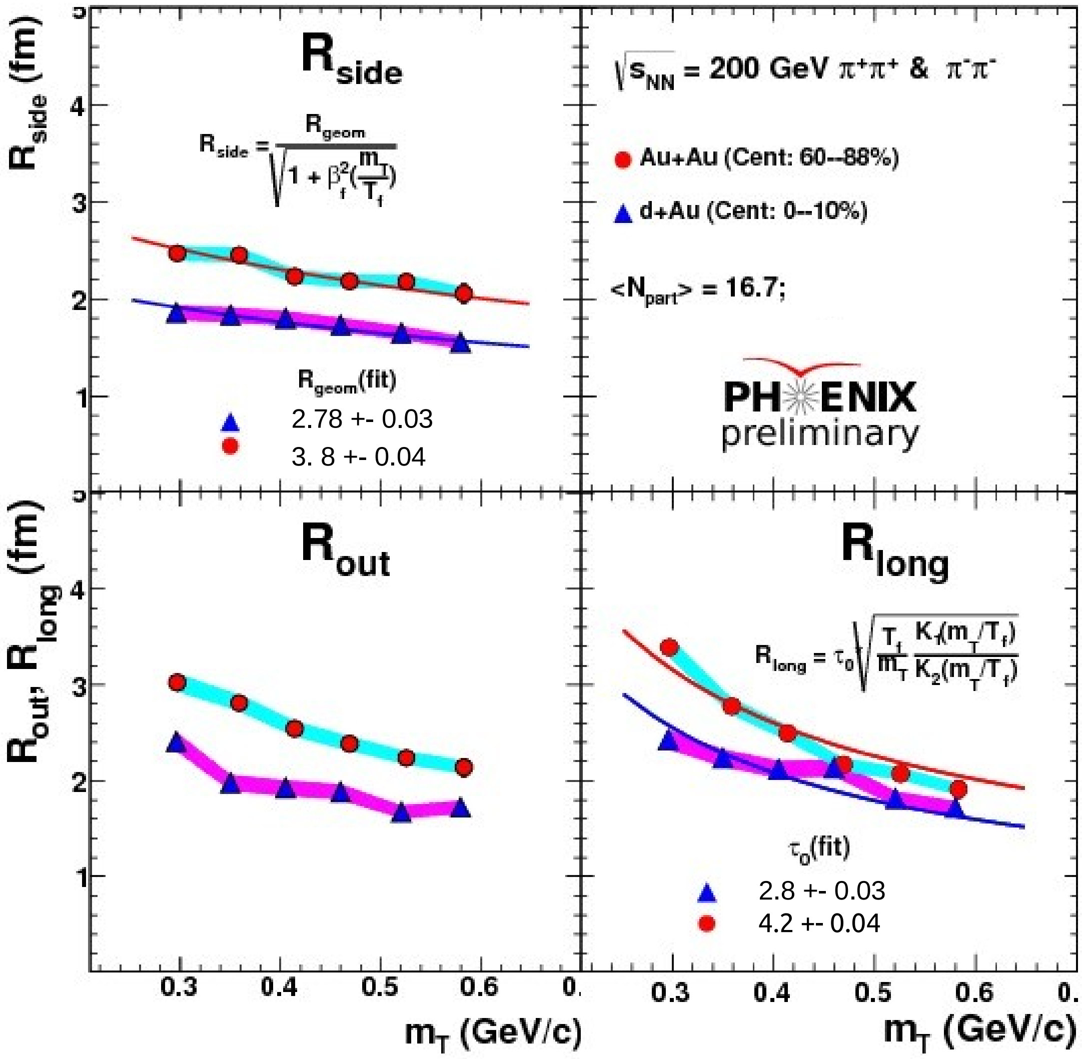
Au+Au collisions show a linear increase of HBT radii with an increase in $N_{part}^{1/3}$

HBT measurements in Au+Au: m_T dependence



Au+Au collisions show a systematic decrease of the HBT radii with an increase in m_T.
This trend indicates a radially expanding source.

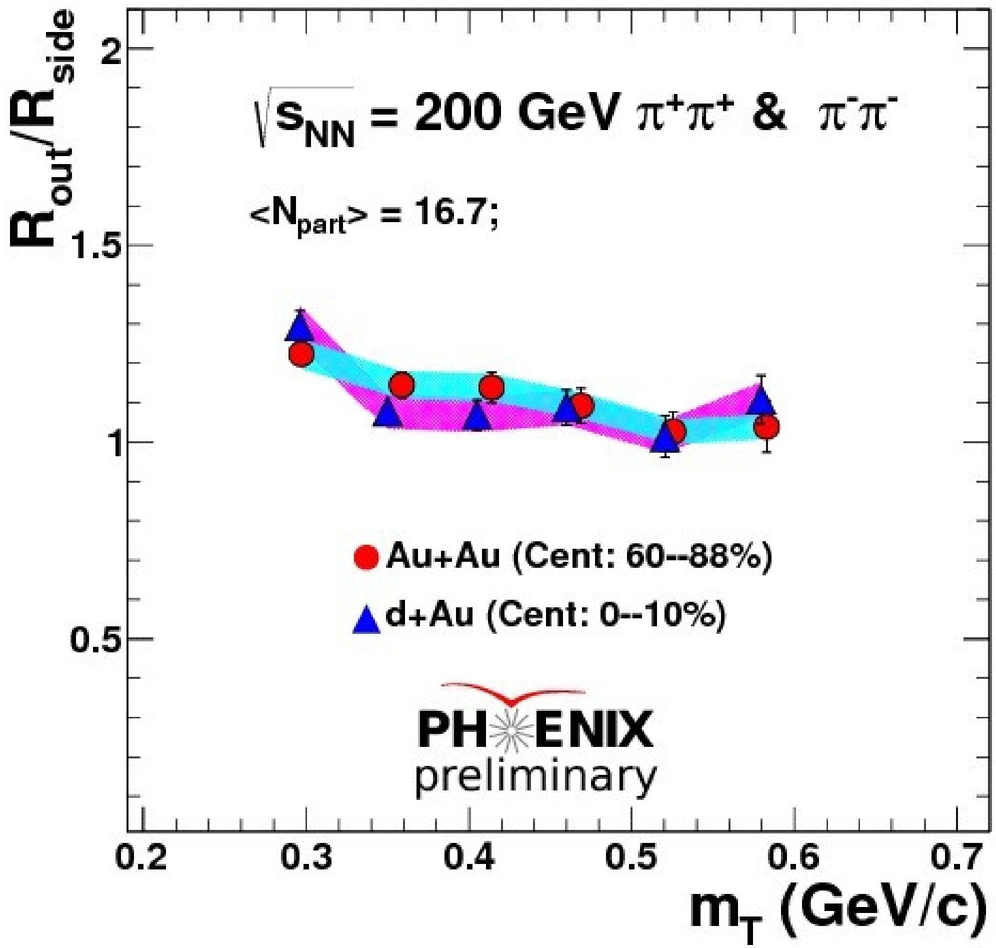
m_T dependence of HBT radii in d+Au vs. Au+Au



Freeze-out temperature and expansion velocities obtained from blast wave fit to p_T spectra for identified charge hadrons.(d+Au: T = 0.118 +- 0.02; β = 0.42 +-0.03 c) (Au+Au: T = 0.123 +- 0.02; β = 0.38 +-0.08 c)

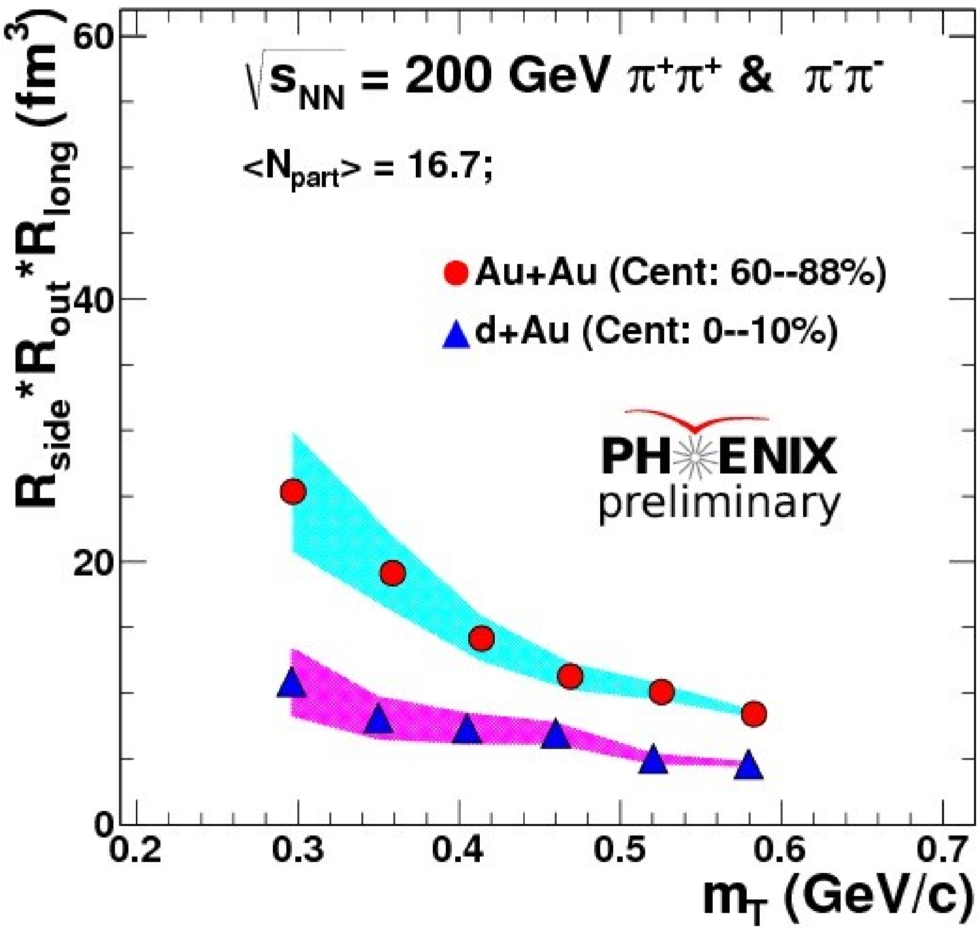
- The m_T dependence was studied for similar values of N_{part} in d+Au and Au+Au
- Decreasing trend with m_T in all HBT radii for both d+Au and Au+Au
- Similar trend found in Au+Au and Pb+Pb systems – indicative of an expanding source
- Fits done based on the blast wave model to extract:
  - R_{geom} – Geometrical radius at freeze-out
  - τ_0 – System lifetime
- d+Au system shows smaller transverse freeze-out size and lifetime

m_T dependence of R_{out}/R_{side}: d+Au vs. Au+Au



- The m_T dependence for R_{out}/R_{side} was also studied for similar values of N_{part} in d+Au and Au+Au
- Ratio found to be flat (close to unity)
- This trend suggests a system, both in d+Au and Au+Au, with a very short emission duration

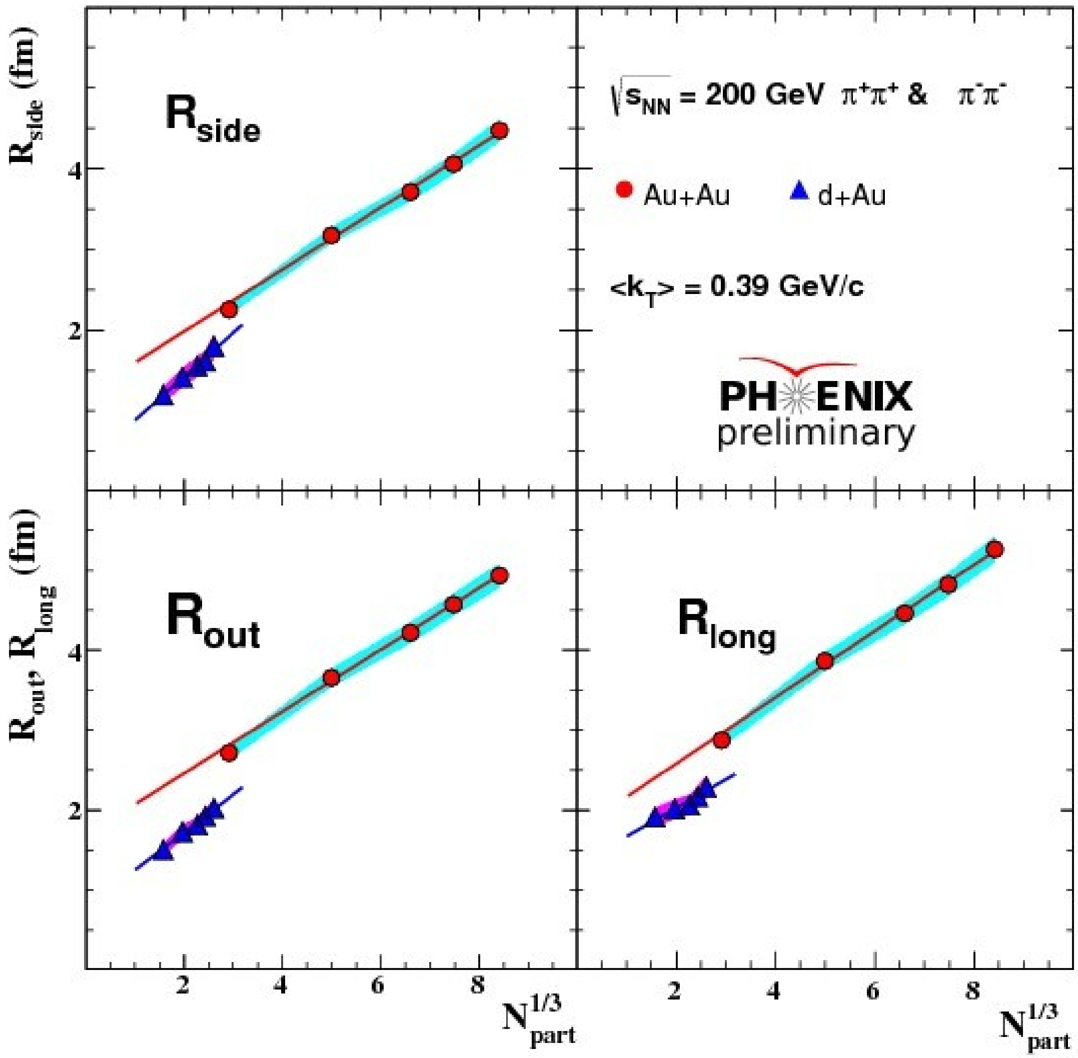
m_T dependence of freeze-out volume: d+Au vs. Au+Au



- The freeze-out volume is proportional to R_{out} x R_{side} x R_{long}
- The d+Au freeze-out volume found to be smaller than Au+Au
- Fall-off with m_T is comparable to that in Au+Au within systematic error

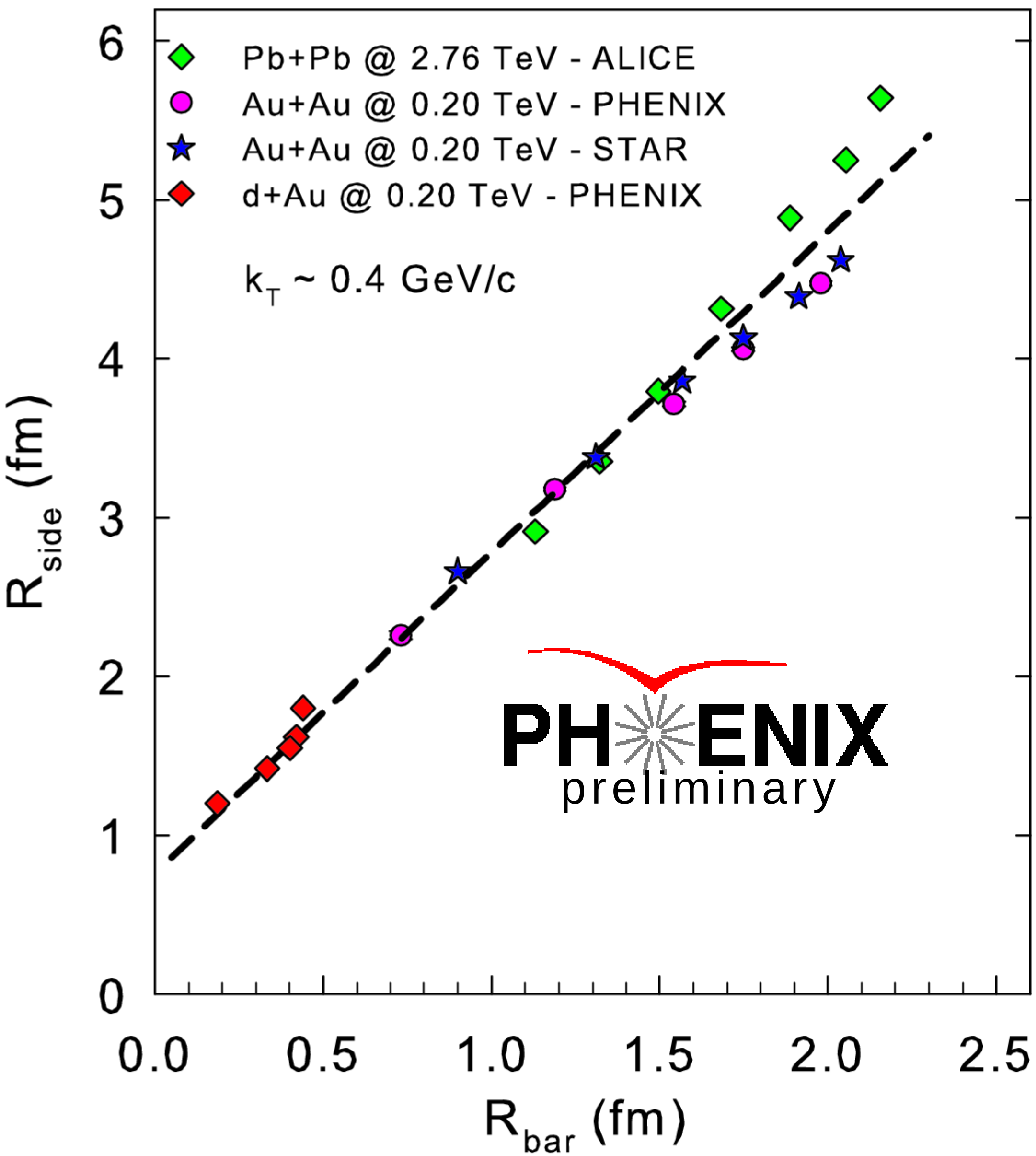
HBT studies of the collision geometry dependence of d+Au vs. Au+Au

N_{part} dependence of HBT radii: d+Au vs. Au+Au



- The N_{part} dependence was studied at the same average k_T
- A similar linear increase with $N_{part}^{1/3}$ seen in R_{out} and R_{side} for both systems
- A slight slope difference in R_{long} could be from differences in longitudinal dynamics between d+Au and Au+Au
- Results suggest that strong correlation between transverse size and initial geometry common in d+Au and Au+Au
- Dependence of transverse expansion rate with collision geometry similar in the two systems

R_{side} vs. R_{bar}



- Expansion time (τ) proportional to R_{bar}

  therefore

- R_{bar} better scaling variable for HBT radii
- R_{side} has linear relationship with R_{bar} (so does R_{out})
- Similar slopes for d+Au and Au+Au
  - -Probably larger slope for Pb+Pb since stronger expansion rate at 2.76 TeV expected

This dependence emphasizes the role of final-state re-scattering effects in d+Au typical of a hydrodynamic evolution scenario

Summary and Conclusion

- Two differing theories on the origin of the two-ridge structure in p+p and p+A systems
  (1)Initial effects from interference of correlated gluons due to gluon saturation
  (2)Final-state hydrodynamic effects

- HBT studies provide an independent check of existing models

- m_T dependence of HBT radii shows decreasing trend with increase in m_T for d+Au and Au+Au indicative of expanding source. R_o/R_s is flat and about unity suggesting a short emission duration

- d+Au system also found to be smaller than Au+Au and with shorter lifetime

- Similar dependence of transverse expansion rate with collision geometry evident in both systems

- R_{side} found to have linear relationship with R_{bar} and a similar slope for both d+Au and Au+Au systems.

- Results strongly suggest that final-state re-scattering effects play important role in d+Au