m_T and centrality scaling properties of source size and duration time measured by Bose-Einstein correlations at RHIC-PHENIX

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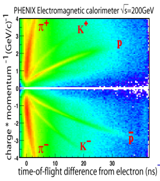
Abstract: We present a HBT measurement of charged pions by RHIC-PHENIX in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}}$ = 62.4 GeV. 3-D freeze-out source size (HBT radii) of charged pion are measured for several collision centrality and momentum regions. Comparisons with pion HBT radii in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV prove that HBT radii are well scaled as a function of multiplicity rather than the number of participants, implying that the energy density decides the final freeze-out source size. The 3-D HBT radii as a function of m_T indicates that there is no particle dependence between charged pion and kaon, and R_{side} and R_{long} are systematically slightly decreased as the collision energy decreases from 200GeV to 62.4GeV while R_{out} doesn't change significantly.

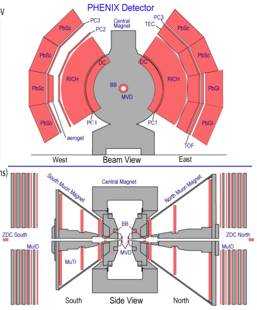
The Experimental Setup

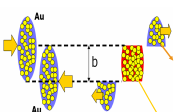
Tracking devices
- Drift Chamber
- Pad Chamber (PC1,PC2,PC3)
- Muon Tracking

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

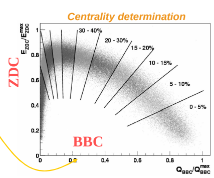
Event Trigger and Characterization
- Beam-Beam Counter
- Zero Degree Calorimeter
- Forward Calorimeter (for d+Au)







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

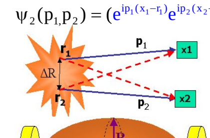


Year	Species	$\sqrt{s_{NN}}$	int.Ldt	Ntot	Data
2000	Au+Au	130	1 mb^{-1}	10M	3 TB
2001/2002	Au+Au	200	24 mb^{-1}	170M	10 TB
2002/2003	d+Au	200	2.74 nb^{-1}	5.5G	46 TB
2003/2004	Au+Au	200	241 mb^{-1}	1.5G	270 TB
	Au+Au	62	9 mb^{-1}	58M	10 TB
2004/2005	Cu+Cu	200	3 nb^{-1}	8.6G	173 TB
	Cu+Cu	62	0.19 nb^{-1}	0.4G	48 TB
	Cu+Cu	22.5	2.7 mb^{-1}	9M	1 TB

What's HBT / Purpose / Problem ?

Quantum statistical correlation: *Symmetric (asymmetric) property of wave-function*

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



$$C_2(p_1,p_2) \equiv \frac{P_2(p_1,p_2)}{P(p_1)P(p_2)} \approx 1+|\rho(q)|^2 = 1+\lambda \exp(-R^2q^2)$$

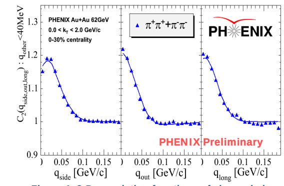
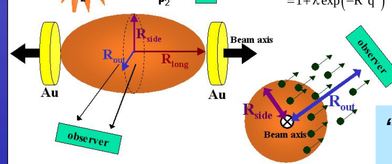


Figure 1: 3-D correlation functions of charged pions for 0-30% centrality in Au+Au collisions at 62.4GeV



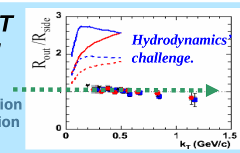
3-D (side-out-long) analysis

$$C_2 = [(1+\lambda G)F_C] + [1-\lambda] \quad F_C = \text{coulomb correction}$$

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

R_{long} = Longitudinal HBT radius
R_{side} = Transverse HBT radius
R_{out} = R_{side} + particle emission duration

"The HBT Puzzle"



Why the emission duration is so short?
Why the HBT radii are unable to be reproduced by hydrodynamics model?

Pair momentum (m_T) dependence

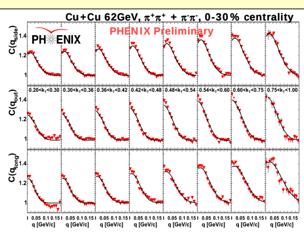
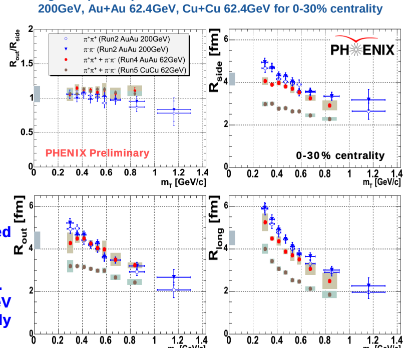


Figure 2 (left): 3-D correlation functions of charged pions for 8 different k_T bins in Cu+Cu 62.4GeV for 0-30% centrality

Figure 3 (Bottom): Pion HBT radii as a function of mT in Au+Au 200GeV, Au+Au 62.4GeV, Cu+Cu 62.4GeV for 0-30% centrality



- **R_{side} and R_{long} at Au+Au 62.4GeV are smaller than those at Au+Au 200GeV.**
- **Weaker m_T dependence for transverse HBT radii in Cu+Cu at 62.4GeV compared to Au+Au 200 GeV.**
- **R_{long} dependence doesn't change with collision energy except for the absolute.**
- **R_{out}/R_{side} at Au+Au and Cu+Cu 62.4GeV are consistent and slightly systematically larger than 1 for entire m_T region.**

Centrality and multiplicity dependences

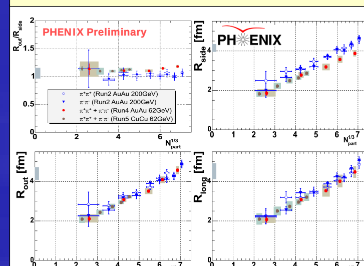


Figure 4: Pion HBT radii as a function of the number of participants in Au+Au 200GeV and Au+Au/Cu+Cu 62.4GeV for 0.2<k_T<2.0 GeV (<m_T>~0.46GeV/c)

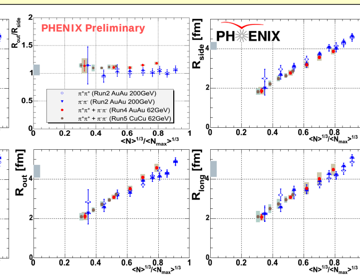


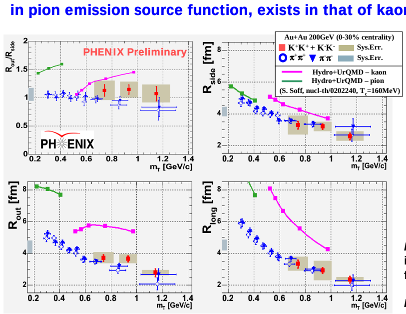
Figure 5: Pion HBT radii as a function of normalized multiplicity in Au+Au 200GeV and Au+Au/Cu+Cu 62.4GeV for 0.2<k_T<2.0 GeV (<m_T>~0.46GeV/c)

- **All HBT radii show linear increase as the cubic root of the number of participants ($N_{part}^{1/3}$).**
- **R_{side} as a function of N_{part} shows a deviation between 200GeV and 62.4GeV data sets, especially at the central collisions.**

- **All pion HBT radii from Au+Au 200GeV, Au+Au and Cu+Cu 62.4GeV data sets fall on the one line as a function of multiplicity.**
- **R_{out}/R_{side} ratio is systematically larger than 1 for the entire centrality.**

Charged kaon HBT radii and HBT imaging

- **m_T dependence is consistent between pion and kaon HBT radii in Au+Au central collisions at 200GeV.**
- **Large systematic errors in the imaged kaon source function make it difficult to conclude whether or not the non-Gaussian structure, which has been measured in pion emission source function, exists in kaon.**



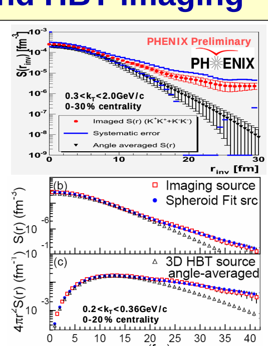


Fig. 6 (top): 1-D source functions measured by HBT imaging for charged kaon and pion correlation functions in Au+Au collisions at 200GeV

Fig. 7 (left): m_T dependence of pion and kaon HBT radii comparing to hydrodynamics prediction

Conclusion/Discussion

- Pion HBT radii in Cu+Cu and Au+Au are well scaled as a function of multiplicity rather than the number of participants, from 62.4GeV to 200GeV.
  - Freeze-out system size is determined by the energy density.
- R_{side} and R_{long} at Au+Au 62.4GeV are systematically smaller than Au+Au 200GeV while R_{out} is almost consistent for the same centrality and k_T bin.
  - Due to the difference of multiplicity between different energies.
- R_{out}/R_{side} at Cu+Cu / Au+Au 62.4GeV are systematically larger (~1.1-1.3) than the result at Au+Au 200GeV.
  - Difference of opacity?, less flow effect?
- Kaon HBT radii well agree with those of pion as a function of pair momentum (m_T).
  - No differences of space-time correlation and freeze-out time between charged pions and kaons.
- 1-D imaged source function of kaon suggests a possibility of deviation from Gaussian shape.
  - Need more studies to minimize the systematic errors.

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