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Rate Estimates for HBT Analysis at STAR

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In this note I estimate rates in STAR for pairs of tracks separated by small momentum differences. Within a simple phase space model, I have calculated the rates of close pairs of identical pions and kaons as a function of p_t. Consideration of these rates is important for discussion of STAR's capability to undertake detailed HBT correlation studies of radii as a function of the mean p_t of the emitted pair. Models predict a strong dependence of correlation functions on the mean p_t of the pair (see e.g. discussion in S. Pratt, T. Csorgo and J. Zimanyi, Phys. Rev **C42** (1990) 2646), due both to dynamical effects of resonance decay. The measurement of correlation functions as a function of p_t is an important tool for constraining models of the collision, and will help to disentangle the various physical contributions to the extracted radii. In addition, while there are many pions produced in a central Au-Au event, phase space is vast and there may still not be sufficient numbers of close lying pairs to enable single-event HBT analysis; this is also a rate question. Of course, rate is not enough: it is also necessary to have sufficient resolution in the components of the three-momentum difference q, as well the ability to identify the close-lying tracks in the TPC (P. Jacobs, STAR Note #12; this is especially important for kaon HBT, where positive identification is essential).

My approach is to investigate the phase space density of q for uncorrelated particles within a simple but representative phase space model, using the following recipe for the single particle distribution:

- particles are distributed uniformly in azimuthal angle ϕ and rapidity y, subject to $|y| < 1$.
- particle are distributed in transverse momentum p_t according to the probability distribution

$$P(p_t)dp_t = \frac{p_t \cdot e^{-(p_t/T)}}{T^2} dp_t$$

where $T = 200$ MeV/c for pions and $T = 400$ MeV/c for kaons. This distribution is a reasonable match to the p_t distributions given in Figure 10 of the original STAR LOI (K. Kadija et al., LBL-29651). The different T parameters account for the differing $< p_t >$ between pions and kaons.

- $dN/dy = 300$ for a single species of pion; $dN/dy = 10$ for a single species of kaon. These were extracted from Table #1 of Bill Christie's STAR Note #7, which gives the total number of tracks (generated for a central Au-Au event by Fritiof) momentum-analyzed in the TPC. One can argue with these numbers (e.g. demanding *identified* pions reduces dN/dy to 200), but the point of the present calculation is to give a rough idea of rates. The results can be scaled by $(dN/dy)^2$ to get the rate estimate for your favorite dN/dy. Since I am interested only in order-of-magnitude estimates, the conclusions presented here should not vary for reasonable variations in dN/dy.

One million Monte Carlo events were generated for pions and for kaons. Within each event, tracks were ordered in $|p|$ to gain speed when matching pairs (i.e. define Lorentz invariant $Q_{ij}^2 = 2(m^2 - E_iE_j + |p_i||p_j|\cos\theta)$ with $|p_j| > |p_i|$ for $j < i$. The minimum absolute value of Q_{ij}^2 for fixed $|p_i|$ and $|p_j|$ is given by $K_{ij}^2 = 2(m^2 - E_iE_j + |p_i||p_j|)$. If $|K_{ij}^2| > |Q_{cut}^2|$ for $j > i$, then $|K_{ik}^2| > |Q_{cut}^2|$ for $k > j$, meaning that all tracks close to p_i in $|Q^2|$ space have been found and the search can be truncated.

I first study the rates for single-event HBT. It is clear that the number of pairs in the event will be low; therefore I only consider the correlation function in a single dimension, namely Lorentz invariant $|Q|$, despite the difficulty in interpreting this quantity. Figure 1 shows the number of pairs of single pion species falling into 5 MeV/c wide bins of $|Q|$ per event, for $|y| < 1$ and different p_t cuts as indicated. No corrections for the correlation enhancement, Coulomb repulsion or strong interaction effects have been made. It can be seen that the number of pions of one species having $|Q| < 10$ MeV/c is 1.5–3.5, depending on the p_t cut. Taking into account both pion species (a factor 2) and extending the momentum tracking to $|y| < 1.5$ (a factor 1.5) gives a total number of pairs of about 5–10 per event for $|Q| < 10$ for $dN/dy = 300$ (one species). This appears to be inadequate to reliably reconstruct an invariant radius, especially taking into account the reduction in statistics that will occur due to the Coulomb repulsion. The occurance of a phase transition will result in an increased entropy density (i.e. increased dN/dy),which in turn will increase the number of available pairs in the correlation region. However, the long time duration of the plasma phase (which, after all, is what we are looking for) will result in more stringent requirements on measuring $|Q|$ (i.e. the enhancement will occur at smaller $|Q|$). I do not speculate further on this, but refer you to Richard Morse's STAR Note on this subject, which examines the error on the extracted radii under various assumptions of radius and dN/dy. My conclusion here, without fitting correlation functions, is that single-event HBT in the scenario of conventional physics (i.e. without a phase transition) is marginal at best in STAR.

I next consider fine phase space binning as a function of p_t and components of q. Such binning of phase space is clearly only achievable on an inclusive basis, especially for high p_t. To estimate the limitations due to rate, I consider the STAR baseline design of 1 central Au-Au event/second over a data taking period of 100 days (roughly 10^7 events). Table 1 shows the number of pairs per event for a single species of pion or kaon within various bins of p_t and magnitude of the Lorentz invariant momentum difference $|Q|$. Again, correlation, Coulomb and strong interaction effects have not been accounted for. Coulomb repulsion is especially important for kaons, where the net effect of correlation and Coulomb repulsion is expected to decrease the rate by a factor ~ 5 at small $|Q|$ (this was pointed out to me

p_t bin (MeV/c)	$\|Q\|$ bin (MeV/c)	# pairs/100 days (1 event/sec)	
		π	K
$75 < p_t < 125$	$5 < \|Q\| < 10$	3×10^6	500
	$20 < \|Q\| < 25$	2×10^7	5×10^3
$175 < p_t < 225$	$5 < \|Q\| < 10$	2×10^6	300
	$20 < \|Q\| < 25$	10^7	3×10^3
$275 < p_t < 325$	$5 < \|Q\| < 10$	9×10^5	200
	$20 < \|Q\| < 25$	7×10^6	2×10^3
$575 < p_t < 625$	$5 < \|Q\| < 10$	7×10^4	< 10
	$20 < \|Q\| < 25$	6×10^5	300
$875 < p_t < 925$	$5 < \|Q\| < 10$	10^3	< 10
	$20 < \|Q\| < 25$	2×10^4	50

Table 1: Rates within $|\eta| < 1$ for uncorrelated pairs of close tracks for a single species of π or K in central Au-Au events at STAR, within selected bins of mean p_t of the pair and Lorentz invariant momentum difference $|Q|$. $dN/d\eta(\pi) = 200$, $dN/d\eta(K) = 10$; these are roughly what is expected for one species of charged π or K identified via dE/dx in the STAR TPC (ref. 6). Calculation of the number of pairs per 100 days is based on a rate of 1 central Au-Au event recorded per second.

by Declan Keane). Since Table 1 gives rates only as a function of $|Q|$, rates for restricting components of q will necessarily be smaller than those given in the table. The expected rate of pion pairs is adequate for fine phase space binning at low $|Q|$ (< 10 MeV/c) up to at least $p_t = 700$ MeV/c, which is the limit for π-K particle identification via dE/dx. The rate for close kaon pairs is much smaller, reflecting the much lower dN/dy for kaons. Fine phase space binning for large radii appears impossible in this case. On the other hand, the freezeout radius of kaons is expected to be smaller than that for pions, so that the correlation will be apparent at larger $|Q|$. On the third hand, q resolution for kaons may be substantially worse than for pions due to the larger $< p_t >$ (to first order, q resolution is a function of p_t, i.e. the track separation power of the magnetic field), and multiple scattering is more significant for kaons at a given value of p_t.

In conclusion,

- single event HBT at STAR for central Au-Au events is statistically marginal for conventional physics scenarios, though it may be possible for elevated dN/dy due to the presence of a plasma phase. While event selection cannot be performed on the basis of extracted invariant radii, good statistics for HBT will be available for a small sample of unusual events based on other selection criteria (K/π ratio, unusual fluctuations, etc.)

- binning in phase space of pairs of pions into bins of mean p_t and components of q is statistically possible on an inclusive basis roughly up to the momentum resolution limit.

- binning in phase space for kaons is possible on an inclusive basis for smaller radii than for pions; however, there are many open questions regarding the reconstruction of close kaon pairs.

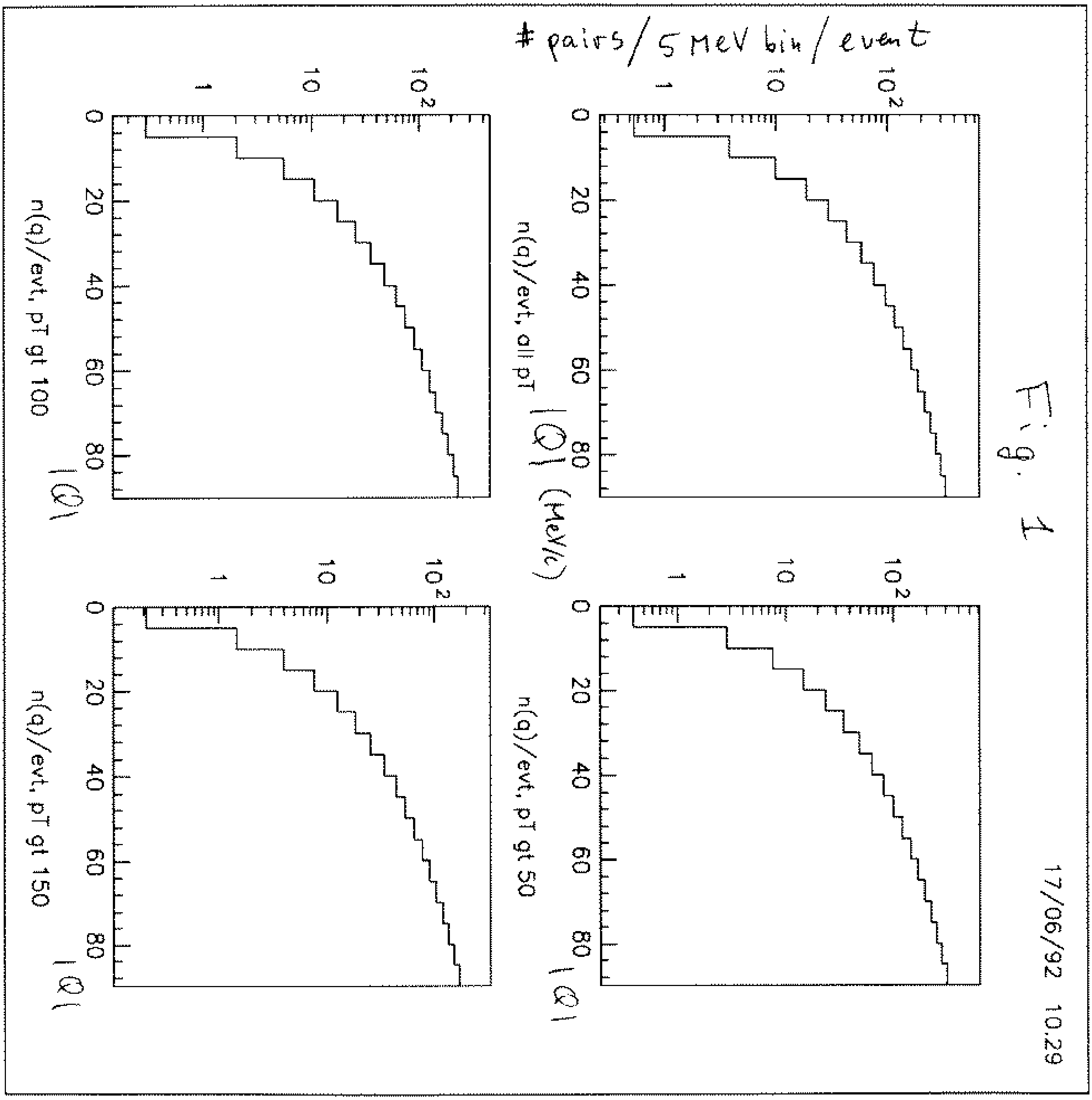
Fig. 1
17/06/92 10.29
pairs / 5 MeV bin / event
n(q)/evt, all pT
n(q)/evt, pT gt 50
n(q)/evt, pT gt 100
n(q)/evt, pT gt 150
|Q| (MeV/c)
|Q|