Suspicion on Engrafting HBT From Astronomy to Heavy Ion Collision

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HBT method in astronomy and heavy ion collision is contrasted in present article. Some differences are found and validity of using HBT in heavy ion collision is suspected.

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I. INTRODUCTION

The method of two-particle intensity interferometry was discovered in the early 1950’s by Hanbury Brown and Twiss (HBT) [1] who applied it to the measurement of the angular diameter of stars and other astronomical objects. Then several authors [2, 3, 4, 5] have proposed HBT studies to probe source structure in heavy ion collision. The spirit of this method is reviewed and explained by Ulrich Heinz [2]: “two random point sources $a$ and $b$ on a distant emitter, separated by the distance $R$, emit identical particles with identical energies $E_p = (m^2 + p^2)^{1/2}$ which, after travelling a distance $L$, are measured by two detectors 1 and 2, separated by the distance $d$ (see Figure 1). $L$ should to be much larger than $R$ or $d$. For some time, the two-particle intensity correlation function is thus given by

$$C(R, d) = \frac{\langle I_1 I_2 \rangle}{\langle I_1 \rangle \langle I_2 \rangle} = \frac{\langle A_1 A_1^\dagger A_2 A_2^\dagger \rangle}{\langle A_1 A_1^\dagger \rangle \langle A_2 A_2^\dagger \rangle} = 1 + \frac{2|\alpha|^2|\beta|^2}{|\alpha|^2 + |\beta|^2} \cos\left(\theta_{1a} - \theta_{2a} + \theta_{1b} - \theta_{2b}\right).$$

For large $L \gg R, d$, the argument of the second, oscillating term becomes

$$r_{1a} - r_{2a} - r_{1b} + r_{2b} \rightarrow \frac{d R}{L} \left(\cos(d, R) - \cos(d, L) \cos(R, L)\right).$$

Note the symmetry of this expression in $d$ and $R$, the separations of the detectors and of the emitters. This symmetry is lost in the two practically relevant limits:

1. In case of $R \gg d$, the cosine-term in (2) reduces to $\cos(d \cdot (p_a - p_b))$, with $p_{a,b} = p e_{a,b}$.

2. In case of $R \ll d$, then (see Figure 1) the cosine-term in (2) becomes $\cos(R \cdot (p_1 - p_2))$.

So we can get the intensity correlation function

$$C(p_1 - p_2) = 1 + \int d^3 R \rho(R) \cos(R \cdot (p_1 - p_2)).$$

for a continuum of a static sources described by a distribution $\rho(R)$ of their relative distances.

The upper is deduction in theory. Now let’s see how to get the correlation function in experiment [2]. Experimentally, the two-particle correlation function is obtained from the ratio $C_2(q) = A(q)/B(q)$ (normalized to unity at large $q$).
where \( A(q) \) is the measured two-pion distribution of pair momentum difference \( q = p_2 - p_1 \), and \( B(q) \) is the mixed background distribution \( E \), calculated in the same way using pairs of particles taken from different events. Note \( p_2, p_1 \) is the primary momentum of particle, i.e., the momentum of the particle when the particle is nearest to the source. It corresponds to the momentum when the particle leaves the source in theory.

Really, the variable used in correlation is a Lorentz invariant \( Q_{\text{inv}} \) \( Q_{\text{inv}} = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2} \). After transforming \( 4 \) and \( C_2(q) \) into function of \( Q_{\text{inv}} \), it is believed that relationship between experiment and theory is established.

II. ESSENTIALS IN HBT AND SUSPICION

Correlation function in \( 2 \) contains five variables \( R, d, p_1, p_2 \) and \( L \). Correlation function in \( 1 \) contains four variables \( d, p_1, p_2 \) and \( L \). The diminishing of \( R \) is caused by the integral over \( R \). The process using HBT equals the process retrieving these variables from experiment.

In astronomy, \( d \) is known quantity, \( L \) can be got from other astronomical method. Although measuring \( p_1 \) and \( p_2 \) is difficult, we can cancel them by integral over them that is recording all particles entering the detector in experiment. So all variables are got from experiment and HBT succeeds in astronomy.

In heavy ion collision, in order to retrieve the correlation function from experiment, these four variables \( d, p_1, p_2 \) and \( L \) must be fixed. We can get \( p_1 \) and \( p_2 \) from detector easily. The following and last question is to get \( d \) and \( L \). In other words, where the position the particles are detected is. The thought that we can cancel \( d \) and \( L \) after the integral over them in experiment is wrong because we can’t place point detectors throughout the space and even if we place point detectors throughout the space in ideal we still can’t make this integral in experiment just because that particle entering the second detector after entering the first detector has changed its quantum property by the first detector so \( 1 \) becomes invalid. Another opinion regarding the first point left in TPC as the position the particle be detected is also wrong because that the reconstructed track of particle is classical and the point is on this classical track, as well as \( 1 \) becomes invalid.

If \( d \) and \( L \) can’t be got from experiment, HBT can’t be used in heavy ion collision. Now let’s see what we got from experiment in \( 3 \). The process in experiment is: firstly, determining the momentum and position of particle by the points left in detector; secondly, reversing the particle along the track, by this way the classical concept of orbit are needed; the nearest point in the track to the source and calculating the momentum at the point; thirdly, obtaining the correlation function \( C_2(q) = A(q)/B(q) \) (normalized to unity at large \( q \)), where \( A(q) \) is the measured two-pion distribution of pair momentum difference \( q = p_2 - p_1 \), and \( B(q) \) is the mixed background distribution \( E \), calculated in the same way using pairs of particles taken from different events. From these process we can know the momentum used in calculating the correlation function is the momentum when particle is in the point that is nearest to the source. This point corresponds to the point in which the particle emits from the source in theory.

Now we can reply the question how to get \( d \) and \( L \). In other words, where the position the particles are detected is in \( 3 \), the particles are detected on the surface of the source and \( L = 0 \), \( d \sim 0 \). So the deduction in \( 2 \) is disabled here.

III. FORMULA FOR EXPERIMENT

Now let’s see what we have done in data analysis in \( 3 \). Define \( P(\theta, \phi, \tau) \) is the emitting probability of the source where \( \theta, \phi \) is polar angle and azimuth angle respectively and \( \tau \) is the proper time of the source. For an event with \( M \) particles considered, \( n_{s,i}(q, q + dq) \) is the number of particles whose momentum difference with the \( i \)-th particle locates \( q \) and \( q + dq \), where \( q = p_2 - p_1 \) or \( q_{\text{inv}} \) in different cases. \( n_{m,i}(q, q + dq) \) is the number of particles in other event whose momentum difference with the \( i \)-th particle locates \( q \) and \( q + dq \), it is like \( n_{s,i}(q, q + dq) \) expect that \( n_{m,i}(q, q + dq) \) is for different events whereas \( n_{s,i}(q, q + dq) \) for same event.

For a completely random source, such as an artificial source produced by computer obeying the distribution \( P(\theta, \phi, \tau) \) of real data, it is easy to know

\[
\bar{n}_{s,i}(q, q + dq) = \bar{n}_{m,i}(q, q + dq)
\]

\[
C_2(q) = \frac{\sum_{i=0}^{M} \bar{n}_{s,i}(q, q + dq)}{\sum_{i=0}^{M} \bar{n}_{m,i}(q, q + dq)} = 1
\]

in which average is over all events. By now, it is clear that the correlation function has no direct relation with the emitting probability \( P(\theta, \phi, \tau) \).
In real data, if there are some mechanisms can change \( n_{s, i}(q, q + dq) \) to \( n_{s, i}(q, q + dq) + n_{c, i}(q) \), whereas the sum number of particles and the distribution have not changed so \( \bar{n}_{m, i}(q, q + dq) \) have not changed, we can get

\[
C_2(q) = \frac{\sum_{i=0}^{M} \bar{n}_{s, i}(q, q + dq) + \bar{n}_{c, i}(q)}{\sum_{i=0}^{M} \bar{n}_{m, i}(q, q + dq)}
\]

(7)

\( \bar{n}_{m, i}(q, q + dq) \) can be got from simulation by computer after knowing the distribution \( P(\theta, \varphi, \tau) \). \( n_{c, i}(q) \) is a variable connecting to physical process on the surface of the source i.e. what happens when particle is produced from partons. Let \( q = q_2 - q_1 \), become the result in 3.

IV. MECHANISMS PRODUCE \( n_{c, i}(q) \) FOR SMALL \( q \)

As what are interesting is the performance of correlation function at \( q \sim 0 \), i.e. the difference of momentums is small, only this part is discussed here.

The meaning of \( n_{c, i}(q) \) is the variance of number of particles whose momentum \( p \) satisfies \( p - p_i = q \) from completely random distribution. If the \( i \)-th particle was produced, the probability of production of particle whose momentum is close to \( p_i \) would increase. In this case \( n_{c, i}(q) > 0 \). Now if the \( i \)-th particle was produced, that probability would decrease. In this case \( n_{c, i}(q) < 0 \).

Let’s see some mechanisms making \( n_{c, i}(q) \) positive or negative. On the surface of the source, if a fermion is produced, it will hold a state of specified momentum and prevent particle of this kind produced after it entering this state. Qualitatively, \( n_{c, i}(q) \) will become negative. Interaction will also affect \( n_{c, i}(q) \). If there an attractive force between a kind of particles, \( n_{c, i}(q) \) will become positive, vice versa, attractive force leading negative \( n_{c, i}(q) \).

V. CONCLUSIONS

The most important problem in engrafting HBT from astronomy to heavy ion collision is the position where particle is detected can not correspond to corresponding variables in quon dam theory. The momentum used in HBT is that when particle leave the source. At this point \( L = 0 \), \( d \sim 0 \). So the deduction is disabled for experiment.

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