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Bose-Einstein Correlation within the Framework of Hadronic Mechanics[1]

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Abstract. The Bose-Einstein correlation is the phenomenon in which protons and antiprotons collide at extremely high energies; coalesce one into the other resulting into the fireball of finite dimension. They annihilate each other and produces large number of mesons that remain correlated at distances very large compared to the size of the fireball. It was believed that Einstein's special relativity and relativistic quantum mechanics are the valid frameworks to represent this phenomenon. Although, these frameworks are incomplete and require arbitrary parameters (chaoticity) to fit the experimental data which are prohibited by the basic axioms of relativistic quantum mechanics, such as that for the vacuum expectation values. Moreover, correlated mesons can not be treated as a finite set of isolated point-like particles because it is non-local event due to overlapping of wavepackets. Therefore, the Bose-Einstein correlation is incompatible with the axiom of expectation values of quantum mechanics. In contrary, relativistic hadronic mechanics constructed by Santilli allows an exact representation of the experimental data of the Bose-Einstein correlation and restore the validity of the Lorentz and Poincare symmetries under nonlocal and non-Hamiltonian internal effects. Further, F. Cardone and R. Mignani observed that the Bose-Einstein two-point correlation function derived by Santilli is perfectly matched with experimental data at high energy.

Keywords: Bose-Einstein correlation, theory of relativity, Lorentz and Poincare symmetries, Lie-Santilli isoalgebras
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INTRODUCTION

The main ingredient of hadronic mechanics [1, 2] is that strong interactions have a nonlocal component of contact, due to deep wave-overlappings at mutual distances of 1 Fermi. This nonlocal component can not be represented by the conventional quantum mechanics. However, novel hadronic mechanics encompass entire local and nonlocal effects with remarkable experimental evidences. Thus, the most fundamental experimental verifications of hadronic mechanics are, those which manifested the expected nonlocality of the strong interactions. Among them, the most important tests are those on the Bose-Einstein correlation [3, 4, 5, 6, 7], in which protons and antiprotons are made to collide at very big or very small energies and annihilate each other in a region called the fireball. The annihilation produces various unstable hadrons whose final states are given by correlated mesons which are "in phase" with each other despite large mutual distances compared to the size of the fireball. Correlated mesons can not be treated as a finite set of isolated point-like particles. It is non-local event due to overlapping of wavepackets. There are several nonlocal theories which attempted to reduce nonlocal event into a finite set of isolated points distributed over the finite volume of the fireball. However, these theories are discarded by Santilli for the fact that the Bose-Einstein correlation is incompatible with the axiom of expectation values of quantum mechanics. It is purely manipulated nonlocal interaction to verify the quantum laws.

The first exact and invariant formulation of the Bose-Einstein correlation via relativistic hadronic mechanics was done by R. M. Santilli [8] in 1962. F. Cardone and R. Mignani [9, 10] was the first to verify Santilli's theoretical isorelativistic calculation with experimental data (**FIGURE 1**) and they published their result in 1996.

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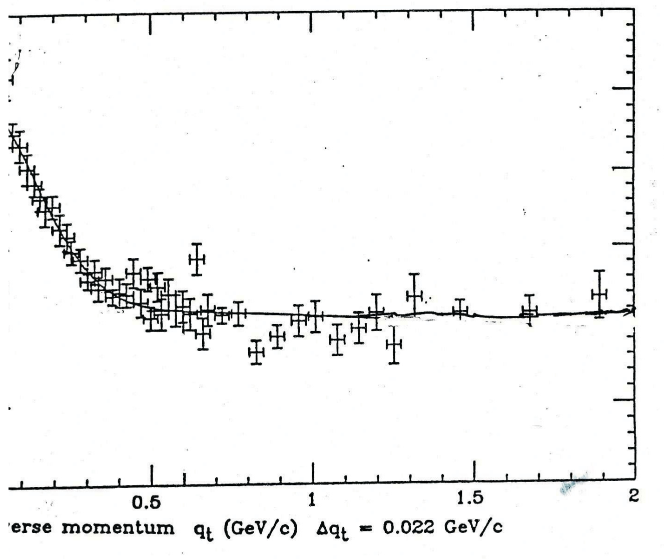

FIGURE 1. The exact fit Santilli's two-point isocorrelation function with experimental data at high energy

CONVENTIONAL TREATMENT OF THE BOSE-EINSTEIN CORRELATION

Consider a quantum system in 2-dimensions represented on a Hilbert space H with initial and final states $|a_k\rangle, |b_k\rangle, k = 1,2$. The vacuum expectation values of an observable A are given by [3]

$$\langle A\rangle = \langle a_k| \times A \times |b_k\rangle = \sum_{k=1,2} a_k \times A_{kk} \times b_k \tag{1}$$

which is necessarily diagonal, to fulfill the condition that operator corresponds to observable quantity must be Hermitian. The two-points correlation function of the Bose-Einstein correlation is defined by

$$C_2 = \frac{P(p_1,p_2)}{P(p_1) \times P(p_2)} \tag{2}$$

where $P(p_1,p_2)$ is the two particles probability density subjected to Bose-Einstein symmetrization, and $P(p_k), k = 1,2$ is the corresponding quantity for the k^{th} particle with 4-momentum, p_k. The two-particles density is computed via the vacuum expectation value

$$P(p_1,p_2) = \int \psi_{12}^{\dagger}(x_1,x_2;r_1,r_2) \times \psi_{12}(x_1,x_2;r_1,r_2) \times F(r_1,r_2) \times d^4_{r_1} \times d^4_{r_2} \tag{3}$$

where ψ_{12} is the probability amplitude to produce two bosons at r_1 and r_2 that are detected at x_1 and x_2. With the use above equations, one reach in this way the final expression for the two-point correlation function

$$C_2 = 1 + e^{-Q_{12}^2 R^2}, \tag{4}$$

where $Q_{12} = p_1 - p_2$ is the momentum transfer,where R is the Gaussian width and r is generally assumed to be the radius of the fireball.

INCOMPATIBILITY OF THE BOSE-EINSTEIN CORRELATION WITH RELATIVISTIC QUANTUM MECHANICS

The Bose-Einstein correlation given by eq.(4) deviates from experimental data. This lead to the introduction of a first, completely unknown parameter λ, called "chaoticity parameter", namely;

$$C_2 = 1 + \lambda e^{-Q_{12}^2 R^2}. \tag{5}$$

Note that it is impossible to derive the above parameter from any axiom of relativistic quantum mechanics. Hence, the chaoticity parameter λ introduced in eq.(5) is the first direct evidence of the incompatibility of the Bose-Einstein correlation with quantum axioms. In order to fit the desired experimental data eq.(5) was further modified by introducing an increasing number of completely unknown and arbitrary parameter, namely,

$$C_2 = 1 + \lambda_1 e^{-Q_{12}^2 R^2} + \lambda_2 e^{-Q_{12}^2 R^2} + \lambda_3 e^{-Q_{12}^2 R^2} + \lambda_4 e^{-Q_{12}^2 R^2} \tag{6}$$

which is strongly objected by Santilli.

REPRESENTATION OF THE BOSE-EINSTEIN CORRELATION WITH RELATIVISTIC HADRONIC MECHANICS

The axiom of isoexpectation value for relativistic hadronic mechanics [8] is given by

$$\langle \widehat{A} \rangle \langle \widehat{a}_k | \times \widehat{T} \times \widehat{A} \times \widehat{T} \times | \widehat{b}_k \rangle = \Sigma_{ijk} \widehat{a}_i \times \widehat{T}_i^j \times \widehat{A}_{jj} \times \widehat{T}_j^k \times \widehat{b}_k \tag{7}$$

where $\widehat{T}$ is the isotopic element, and the "hat" denotes quantities defined on isospaces over isofields. The main new feature is that the operator $\widehat{A}$ must be Hermitian, thus diagonal, to be observable, but the isotopic element does not need to be diagonal.The correlation function on an iso-Hilbert space $\widehat{H}$ with initial and final isostates $|\widehat{a}_k\rangle, |\widehat{b}_k; k = 1,2$ and the non-diagonal isotopic element in the explicit form is given by [8]

$$\widehat{T} = Diag\left(b_1^2, b_2^2, b_3^2, b_4^2\right) \times \Gamma = Diag\left(1/n_1^2, 1/n_2^2, 1/n_3^2, 1/n_4^2\right) \times \Gamma. \tag{8}$$

It observed that the characteristic quantities must represent physically measurable quantities, namely, $1/b_k^2 = n_k^2, \quad k = 1,2,3$ must characterize the semiaxes of the Bose-Einstein fireball according to a proper normalization and $1/b_4^2 = n_4^2$ must characterize the density of the fireball in a way compatible with other experiments. The continuation of calculations via a simple isotopy of the conventional treatment, the final expression of the two-points isocorrelation function, derived for the first time by Santilli is given by [8]

$$\widehat{C}_2 = 1 + \frac{1}{3}\sum_{\mu} b_\mu^2 \times e^{-q_t^2 K^2/b_\mu^2} = 1 + \frac{1}{3} b_1^2 \times e^{\left(-q_t^2 K^2/b_1^2\right)} +$$
$$\frac{1}{3} b_2^2 \times e^{\left(-q_t^2 K^2/b_2^2\right)} + \frac{1}{3} b_3^2 \times e^{\left(-q_t^2 K^2/b_3^2\right)} - \frac{1}{3} b_4^2 \times e^{\left(-q_t^2 K^2/b_4^2\right)}, \tag{9}$$

In the above isorepresentations, all operations are now conventional. Hence, the above expressions are the projections in our spacetime of the isocorrelation functions on isospace.

EXACT POINCARÉ SYMMETRY UNDER NONLOCAL AND NON-HAMILTONIAN INTERACTION

As indicated earlier, a crucial insufficiency of the conventional treatment of the Bose-Einstein correlation, is the inability to provide an invariant representation of the fireball, due to its prolate character under which the conventional rotational symmetry no longer applies. The Bose-Einstein correlation creates a fireball characterized by a spheroid prolated in the direction of the proton-antiproton flight. Following its creation, the fireball expands rapidly, resulting in the correlated mesons. Consequently, the original characteristic quantities, here denoted $b_k'^2 = 1/n_k^2$, have an explicit dependence on time. By assuming that the prolateness is along the third axis, we have

$$K^2(t) = b_1'^2(t) + b_2'^2(t) + b_3'^2(t) \neq const, \quad b_3'^2(t) \gg b_1'^2(t) = b_2'^2(t). \tag{10}$$

However, the fireball must preserve its shape during its expansion when considered as isolated from the rest of the universe. This implies that all characteristic quantities have the same factorizable time dependence. In conclusion, the fireball can be studied at the time of its formation with constant characteristic quantities $b_k^2 = 1/n_k^2$ and the following isoinvariant formulated on the Euclide-Santilli isospace [11] with isounit

$$\widehat{R}^2 = \left(x_1^2 b_1^2 + x_2^2 b_2^2 + x_3^2 b_3^2\right) \times \widehat{I} = \left(\frac{x_1^2}{n_1^2} + \frac{x_2^2}{n_2^2} + \frac{x_3^2}{n_3^2}\right) \times \widehat{I}, \tag{11}$$

$$\widehat{I} = Diag\left(1/b_1^2, 1/b_2^2, 1/b_3^2\right) = Diag\left(n_1^2, n_2^2, n_3^2\right). \tag{12}$$

The reconstruction of the exact Lorentz symmetry $\widehat{O}(3)$ [11] for the Bose-Einstein correlation follows the same lines. Since the speed of light is assumed to be locally varying, we have mutated light cones of the type,

$$\widehat{n}^2 = \left(x_3^2 \times b_3^2 - x_4^2 \times b_4^2\right) \times \widehat{I} = \frac{x_3^2}{n_3^2} - \frac{x_4^2}{n_4^2}, \tag{13}$$

$$\widehat{I} = Diag\left(1/b_3^2, 1/b_4^2\right) = Diag\left(n_3^2, n_4^2\right). \tag{14}$$

It is again easy to see that the mutated light cone in our spacetime is the perfect light cone in isospace, called light isocone, because, again, the mutation of each axis is complemented by the inverse mutation of the corresponding unit.

THEORETICAL PREDICTION

It is important now to identify the theoretical prediction of isorepresentation so that we can compared them below with experimental data.

Prediction 1: The minimum value of the two-points isocorrelation function, first identified by Santilli,

$$\widehat{C}_2^{Min} = 1 \tag{15}$$

evidently holding for infinite momentum transfer.

Prediction 2: The maximal value is predicted to be

$$\widehat{C}_2^{Min} = 1 + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1.67 \tag{16}$$

evidently holding for null momentum transfer.

Prediction 3: Isorepresentation also predicts the maximum value of the isodensity, occurring for $\widehat{C}_2^{Max}$. In fact, for $q_t = 0$ we have no correlations, in which case we have

$$b_k^2 = 1, \quad k = 1,2,3, \quad K^2 = b_1^2 + b_2^2 + b_3^2 = 3, \tag{17}$$

$$\widehat{C}_2^{Max} = 1 + \frac{K^4}{3} - \frac{K^2 b_4^2}{3} = 1.67, \tag{18}$$

$$b_4^2 = 2.33, \quad n_4^2 = 0.429, \quad b_4 = 1.526, \quad n_4 = 0.654. \tag{19}$$

Prediction 4: By assuming that $K^2 = 3$ and that the fireball is very prolate,with $b_3^2 = 30 b_1^2 = 30 b_2^2$, we obtain the following prediction on the remaining characteristic quantities

$$b_1^2 = b_2^2 = 0.043, \quad b_3^2 = 2.816, \quad b_1^2 = n_1^2 = n_2^2 = 10.666, \quad n_3^2 = 0.355. \tag{20}$$

From the isoaxioms, Santilli also have the following additional predictions:

Prediction 5: The maximal causal speed within the fireball is bigger than that in vacuum,$V_{max} = c_0 \times \frac{b_4}{b_3} > c_0$.

Prediction 6: Time t within the fireball flows faster than time predicted by special relativity, $t = \widehat{\gamma} \times t_0 > \gamma \times t_0$.

Prediction 7: Lengths 'l inside the fireball are smaller than lengths predicted by special relativity, $l = \widehat{\gamma}^{-1} \times l_0 < \gamma^{-1} \times l_0$.

Prediction 8: Mass behavior with speed is bigger than that predicted by special relativity, $m = \widehat{\gamma} \times m_0 > \gamma \times m_0$.

Prediction 9: The energy equivalence of the fireball is bigger than that predicted by special relativity or, equivalently, for a given energy, the mass is smaller, $E = m \times V_{max} > E_0 = m \times c_0^2$.

Prediction 10 : Frequencies of light emitted inside the fireball, exist the same isoblueshifted, namely, with an increase of frequency as compared to the corresponding behavior predicted by special relativity, $\omega = \widehat{\gamma} \times \omega_0$.

Prediction 11: The speed of light within the fireball is bigger than that in vacuum, $c = c_0 > b_4 > c_4$ by smaller than the maximal causal speed, $c = c_0 \times b_4 < V_{max} = c_0 \frac{b_4}{b_3}$.

EXPERIMENTAL VERIFICATION

F. Cardone and R. Mignani [9, 10] in 1992 had contested the eq.(15) for actual experimental data. The Bose-Einstein two-point correlation function derived by Santilli is perfectly matched with experimental results at high energy. The numerical values of the characteristic functions for the fireball of the Bose-Einstein correlation resulting from this exercise are $b_1 = 0.267 \pm 0.054$, $b_2 = 0.437 \pm 0.035$, $b_3 = 1.661 \pm 0.013$ and $b_4 = 1.653 \pm 0.015$. A most important feature of the above data is that they characterize the medium inside the fireball as being iso-Minkowskian of Group III, Type 9, thus confirming that all hadrons heavier than kaons have the same iso-Minkowskian features. The fit of **FIGURE 1** and the above values provide that the experimental data do indeed lie between the theoretically minimum and maximal value; the experimental data confirm all eleven theoretical predictions; the experimental proof confirms the reconstruction of the exact character of the Poincare symmetry for the Bose-Einstein correlation. F. Cardone and R. Mignani investigation provides remarkable experimental verification of Santilli isorelativity and relativistic hadronic mechanics. This experimental verification on Bose-Einstein Correlation reveals the nonlocality of strong interactions of correlated mesons.

CONCLUDING REMARKS

Santilli's thorough investigation found that Einstein's special relativity and relativistic quantum mechanics is not the valid frameworks to represent the Bose-Einstein correlation because there is a large deviation of experimental results from theoretical ones. Moreover, these representations fail to tender logical explanation for introduction of chaoticity parameters which are needed to fit the experimental data. Further, it is observed that there was several conceptual flaws in treating correlated mesons as a finite set of isolated point-like particles as this is purely non-local event with deep overlapping of wavepackets and can not be treated by conventional quantum mechanics. The relativistic hadronic mechanics constructed by Santilli is appropriate for the representation of Hamiltonian and non-Hamiltonian type interactions. It allows an exact representation of the experimental data. Further it restors the exact validity of the Lorentz and Poincare symmetries. Santilli's theoretical calculations on Bose-Einstein two-point correlation function are verified by F. Cardone and R. Mignani. These theoretical calculations are perfectly matched with experimental data at high energy.

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