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Speed dependent polarization correlations in QED and entanglement*

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Abstract. Exact computations of polarizations correlations probabilities are carried out in QED, to the leading order, for initially *polarized* as well as *unpolarized* particles. Quite generally they are found to be *speed dependent* and are in clear violation of Bell's inequality of Local Hidden Variables (LHV) theories. This dynamical analysis shows how speed dependent entangled states are generated. These computations, based on QED are expected to lead to new experiments on polarization correlations monitoring speed in the light of Bell's theorem. The paper provides a full QED treatment of the dynamics of entanglement

PACS. 12.20.Ds Specific calculations – 12.20.Fv Experimental tests – 03.65.Ud Entanglement and quantum nonlocality (e.g. EPR paradox, Bell's inequalities, GHZ states, etc.)

1 Introduction

We carry out exact computations of joint probabilities of particle polarizations correlations in QED, to the leading order, for initially *polarized* and *unpolarized* particles. The interesting lesson we have learn from such studies is that the mere fact that particles emerging from a process have non-zero speeds to reach detectors implies, in general, that their polarizations correlations probabilities *depend* on speed [1]. The present extended, and needless to say, dynamical analysis shows that this is true, in general. This is unlike formal arguments based simply on combining angular momenta. As a byproduct of this work, we obtain clear violations with Bell's inequality (cf. [2–4]) of LHV theories. We will also see how QED generates speed dependent entangled states.

Several experiments have been performed in recent years (cf. [4–8]) on particles' polarizations correlations. And, it is expected that the novel properties recorded here by explicit calculations following directly from field theory, which is based on the principle of relativity and quantum theory, will lead to new experiments on polarization correlations monitoring speed in the light of Bell's Theorem. We hope that theses computations will be also useful in such areas of physics as quantum teleportation and quantum information in general.

The relevant quantity of interest here in testing Bell's inequality of LHV [2] theories is, in a standard notation,

$$S=\frac{p_{12}(a_1,a_2)}{p_{12}(\infty,\infty)}-\frac{p_{12}(a_1,a_2')}{p_{12}(\infty,\infty)}+\frac{p_{12}(a_1',a_2)}{p_{12}(\infty,\infty)}+\frac{p_{12}(a_1',a_2')}{p_{12}(\infty,\infty)}$$
$$-\frac{p_{12}(a_1',\infty)}{p_{12}(\infty,\infty)}-\frac{p_{12}(\infty,a_2)}{p_{12}(\infty,\infty)} \tag{1.1}$$

as is *computed from* QED. Here a_1, a_2 (a_1', a_2') specify directions along which the polarizations of two particles are measured, with $p_{12}(a_1,a_2)/p_{12}(\infty,\infty)$ denoting the joint probability, and $p_{12}(a_1,\infty)/p_{12}(\infty,\infty)$, $p_{12}(\infty,a_2)/p_{12}(\infty,\infty)$ denoting the probabilities when the polarization of only one of the particles is measured. $[p_{12}(\infty,\infty)$ is normalization factor.] The corresponding probabilities as computed from QED will be denoted by $P[\chi_1,\chi_2]$, $P[\chi_1,-]$, $P[-,\chi_2]$ with χ_1, χ_2 denoting angles the polarization vectors make with certain axes spelled out in the bulk of the paper. To show that QED is in violation with Bell's inequality of LHV, it is sufficient to find one set of angles χ_1, χ_2, χ_1', χ_2' and speed β, such that S, as computed in QED, leads to a value of S with $S>0$ or $S<-1$. In this work, it is implicitly assumed that the polarization parameters in the particle states are directly observable and may be used for Bell-type measurements as discussed.

The need of a relativistic treatment based on explicit quantum field *dynamical* calculations in testing Bell-like inequalities is critically important. An intriguing and very recent reference [9], which appeared after the submission of our paper for publication, discusses the role of relativity in quantum information, in general, and traces the

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