Journal of Physics:
Conference Series

PAPER • OPEN ACCESS

Configuration Space Interference in Hong-Ou-Mandel-Type Experiments: A de Broglie–Bohm Analysis

To cite this article: Chris Dewdney 2026 *J. Phys.: Conf. Ser.* **3189** 012012

Journal of Physics: Conference Series **3189** (2026) 012012 doi:10.1088/1742-6596/3189/1/012012

Configuration Space Interference in Hong-Ou-Mandel-Type Experiments: A de Broglie–Bohm Analysis

Chris Dewdney

School of Maths and Physics, University of Portsmouth, Portsmouth, UK

E-mail: chris.dewdney@port.ac.uk

Abstract. This paper examines how quantum mechanics, interpreted through the de Broglie–Bohm (deBB) framework, can reveal a deeper underlying reality in configuration space. Rather than proposing new predictions, the aim is to clarify how deBB theory provides a coherent, realist account of massive particle, Hong–Ou–Mandel (HOM)-type correlations—often regarded as uniquely quantum. It is suggested that in this interpretation, configuration space is not simply a mathematical convenience but the fundamental arena in which quantum processes unfold. Observable non local behaviour in space and time arises as a projection of local configuration-space dynamics. The analysis illustrates the explanatory power of the deBB approach and supports the view that the configuration-space wave function carries ontological significance.

1 Introduction

It is a particular pleasure to contribute to this commemorative volume in honour of Basil J. Hiley, whose work with David Bohm contributed to the shaping of modern discussions of quantum ontology. The present paper is framed within the de Broglie[1]–Bohm theory[2, 3] that Bohm and Hiley further elaborated together in *The Undivided Universe* (1992)[4]. While that framework provides the basis for the present analysis, it is worth noting that Hiley himself later moved toward a more radical reformulation, in which the algebraic structure of quantum theory itself is regarded as ontologically fundamental, and both particles and fields are seen as emergent features of a deeper, noncommutative process.[5]

The aim of this paper is to discuss how Hong-Ou-Mandel (HOM) [6] experiments can be understood in their massive particle analogues using the de Broglie-Bohm Schrödinger wave function configuration space approach. While HOM interference has been widely studied in the standard quantum optical formalism, it has not previously been analysed within the de Broglie–Bohm framework. Here it serves as a new and instructive example illustrating how configuration-space dynamics can account for multi particle interference effects. Detailed deBB configuration space trajectories (and by projection - non locally correlated individual particle trajectories) are computed using a straightforward one dimensional model that has two wave packets and two particles. We investigate the HOM experiment with and without a beam splitter. This work supports and illustrates the viewpoint that the deeper structure of physical reality resides in configuration space, with structures in three dimensional space emerging as an *effective* description of typical macroscopic phenomena.

2 Brief Resumé of Multi-Particle de Broglie–Bohm Theory

Consider an N-particle system with configuration space coordinates $\mathbf{x} = (\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_N)$ and total wave-function:

$$\Psi(\mathbf{x}, t) = R(\mathbf{x}, t) e^{iS(\mathbf{x},t)/\hbar} \tag{1}$$

governed by the N-particle Schrödinger equation

$$i\hbar \frac{\partial \psi(\mathbf{x}, t)}{\partial t} = \hat{H} \psi(\mathbf{x}, t) \tag{2}$$

where $\hat{H}$ is the system's Hamiltonian. As Bohm showed in 1952, the complex Schrödinger equation can be separated into two real equations: the quantum Hamilton–Jacobi (like) equation

$$\frac{\partial S(\mathbf{x}, t)}{\partial t} + \sum_{i=1}^{N} \frac{(\nabla_i S(\mathbf{x}, t))^2}{2m_i} + V(\mathbf{x}, t) + Q(\mathbf{x}, t) = 0 \tag{3}$$

with quantum potential:

$$Q(\mathbf{x}, t) = -\sum_{i=1}^{N} \frac{\hbar^2}{2m_i} \frac{\nabla_i^2 R}{R} \tag{4}$$

and a continuity equation

$$\frac{\partial R^2}{\partial t} + \sum_{i=1}^{N} \nabla_i \cdot \left(R^2 \frac{\nabla_i S}{m_i} \right) = 0 \tag{5}$$

which ensures conservation of probability density $\rho(\mathbf{x}, t) = R^2(\mathbf{x}, t)$. Individual particle velocities are defined by

$$\frac{d\mathbf{x}_i}{dt} = \frac{\nabla_i S(\mathbf{x}, t)}{m_i}, \quad \text{for } i = 1, 2, \ldots, N \tag{6}$$

and integrating these equations produces individual particle and configuration trajectories. In this second order in time account of de Broglie-Bohm theory, a force arises which has both classical and quantum components, dependent on both classical and quantum potentials

$$\mathbf{F}_i = -\nabla_i \left(U + Q \right). \tag{7}$$

The force accelerating an individual particle depends on the classical potentials U (distinguished by the fact they are fixed, pre assigned functions of the particle coordinates) and on the quantum potential whose functional form is not pre assigned but rather depends on the configuration space wave function. The theory is manifestly non local when the system wave function is not of the form of a simple product of functions dependent on only one of the coordinates x_i.

In practice, equation 6 or equivalently

$$v_i = \frac{\hbar}{m} \operatorname{Im} \left(\frac{\nabla_{x_i} \Psi(x_1, x_2, t)}{\Psi(x_1, x_2, t)} \right), \tag{8}$$

in conjunction with the Schrödinger equation 2 is all that is needed to define a minimalist de Broglie-Bohm theory, shorn of what some argue are inelegant and unnecessary quantum potentials and accelerations. These approaches to deBB theory treat equation 8 as a form of law in which the right hand side is interpreted as an "Aristotelean" force which determines, not acceleration, but velocity [7],[8],[9].

Each of the approaches to deBB theory just mentioned entails a particular ontology, but both yield the same velocities and the same definite trajectories. Here, we do not enter into discussion or evaluation of these different approaches, we just rely on equation 8 to determine the configuration space trajectories. Equation 8 shows that the velocity of an individual particle depends non locally, through the gradients of the wave function, not only on its own coordinates but also those of any other particles in the system. Furthermore, the particles are intrinsically non locally correlated though the global evolution of the wave function; distant interactions can affect local motions.

In the 1980s and 1990s many computations were first carried out demonstrating exactly how de Broglie-Bohm theory could account for otherwise mysterious quantum phenomena including two-slit interference[10], quantum tunnelling[11], neutron interferometry[12], Wheeler's delayed choice experiment [13], spin measurement[14], spin superposition[15] and Einstein-Podolsky-Rosen non local spin correlations[16], orbital angular momentum measurement and Einstein-Podolsky-Rosen non local correlation[17], non locality in correlated particle interferometry[18], [19] and so-called surrealistic trajectories[20]. This work was also extended to Bohm's quantum field theory for the spin zero field[21] and field-matter transition interactions including the anticorrelation of detectors in a single photon field[22].[1] Through these calculations it was possible to see the deBB quantum world emerge in sharp relief from the fog of Copenhagen.

A key consequence of the deBB formalism is that, with the exception of position, measurements are generally not faithful—they do not simply reveal a pre-existing value of the measured quantity (unless the system is in an eigenstate of the operator representing the measured observable). Previous studies, for example [14], have shown that in deBB theory, although the value assigned to an observable is not necessarily an eigenvalue of the corresponding operator, during the measurement interaction the deBB assigned value evolves to match one of the allowed eigenvalues. deBB theory does not have a measurement problem, the combined system of object plus apparatus always has a definite configuration. There is a unique point in the configuration space that represents the actual state of affairs at the outset of the measurement interaction and this " system" point evolves deterministically along its trajectory finally entering one of the distinct measurement channels that develop in the configuration space during the interaction. The specific channel the system actually enters yields the definite result of measurement. In deBB theory, just as in classical mechanics, unique initial conditions yield unique outcomes. Of course, it is not possible to control the exact initial configuration, attempting to do so would change completely the associated wave function, so it is not possible to determine in advance by experimental means which of the possible results of measurement will occur in a given case. Consequently, measurement results, although determined, appear to arise randomly. It is clear that it is the denial the existence of trajectories that leads to the "Measurement Problem" and the consequent plethora of attempts to resolve it [27].

The standard quantum statistical predictions can naturally be recovered from the well defined individual processes if we assume that in an ensemble of experiments the actual initial configurations are distributed according to the probability density determined by the initial wave function, then equation 5 ensures that the actual configuration remains distributed this way. Some have used typicality arguments to argue that this must be the case [28]. Others have argued that the quantum equilibrium assumption, although convenient, is not essential as it can be reasonably shown that any initial distribution will relax to the $|\psi|^2$ under reasonable mixing assumptions, furthermore non equilibrium distributions have quite radical properties.[29],[30],[31].

Single-particle quantum phenomena are often discussed in introductory textbooks and in presentations of de Broglie–Bohm (dBB) theory. They provide clear insight into how dBB works, and many of its salient features have been brought out in that setting. Nevertheless, the single-particle case is an extreme abstraction and can be misleading, because it fails to exhibit what is essential to quantum mechanics—namely, that the theory is formulated on configuration space. For many-particle systems the wave function does not propagate in ordinary three-dimensional space and time, the single-particle case being the special exception where configuration space coincides with physical space. This latter fact leads to common misconceptions, encouraging a picture of independent waves propagating in three-dimensional space and guiding particles there. To understand the essential features of dBB mechanics—especially non locality and contextuality—and its implications for quantum ontology, it is necessary to examine many-particle motion in configuration space. We proceed with a simple illustrative model.

3 A simple model of the HOM experiment.

For N particles the quantum description requires that the wave function of the system be described in $3N$ dimensional configuration space. For two particles, the description of their configuration now requires six dimensions (which is difficult to picture). However, if the two particles propagate only in one dimension, as in the model shown in figure 1, the configuration space required for their description is only two dimensional and we can still visualise the motion as we now proceed to demonstrate.[2] The model has two position entangled particles, of mass m, with coordinates labelled x_1 and x_2, one in each of the two one-dimensional gaussian packets ψ_1 and ψ_2. Initially ψ_1 is centred around x_{01} with central momentum k_{01} and ψ_2 is centred around x_{02} with central momentum k_{02}, both packets have initial width σ_0 and are initially separated by $\delta x = x_{02} - x_{01}$, as shown in figure 1. The symmetrized (or antisymmetrized)

[1] Many of the original calculations carried out in the latter twentieth century were collected together in Bohm and Hiley's book[4] and also Peter Holland's definitive book [23] both published in 1993. More recent discussions include [24],[25],[26]

[2] A similar single particle model was used in the original deBB two slit experiment calculations [10] and explored in detail for the two particle, two slit experiment by Sanz [32]

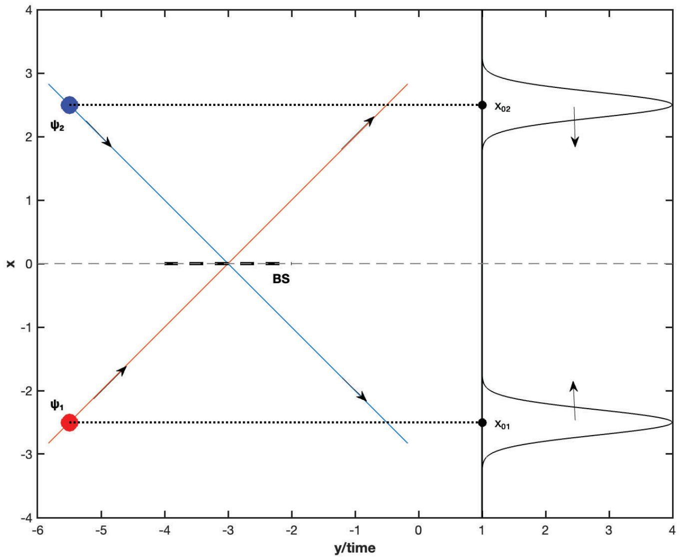

Figure 1: One dimensional model of HOM experiments. Packet ψ_2 has central momentum k_{02} from x_{02}, whilst packet ψ_1 has central momentum k_{01} from x_{01}. BS labels the balanced beam splitter which may be present or removed.

two-particle wave function can be written

$$\Psi_{\pm}(x_1, x_2, t) = \frac{1}{\sqrt{2}}\Big(\psi_1(x_1,t)\,\psi_2(x_2,t) \;\pm\; \psi_2(x_1,t)\,\psi_1(x_2,t)\Big), \tag{9}$$

where each single-particle packet evolves as

$$\psi_j(x,t) = \frac{1}{(2\pi\sigma_0^2)^{1/4}}\,\frac{1}{\sqrt{1+i\tau}}\,\exp\left[-\frac{(x - x_{0j} - \frac{\hbar k_{0j}}{m}t)^2}{4\sigma_0^2(1+i\tau)}\right] \times \exp\left(ik_{0j}(x - x_{0j}) - i\frac{\hbar k_{0j}^2}{2m}t\right). \tag{10}$$

with $\tau = \frac{\hbar t}{2m\sigma_0^2}$.

The corresponding joint probability density is

$$\rho_{\pm}(x_1,x_2,t) = \frac{1}{2}\Big(|\psi_1(x_1,t)|^2\,|\psi_2(x_2,t)|^2 + |\psi_2(x_1,t)|^2\,|\psi_1(x_2,t)|^2 \pm 2\,\mathcal{A}(x_1,x_2,t)\,\cos\big[\Phi(x_1,x_2,t)\big]\Big), \tag{11}$$

where

$$\mathcal{A}(x_1,x_2,t) = |\psi_1(x_1,t)|\,|\psi_2(x_2,t)|\,|\psi_2(x_1,t)|\,|\psi_1(x_2,t)|, \tag{12}$$

and

$$\Phi(x_1,x_2,t) = (k_{02} - k_{01})(x_2 - x_1) + \mathrm{Im}\left[\frac{(x_2 - x_1)\delta x}{2\sigma_t^2}\right], \qquad \sigma_t^2 = \sigma_0^2(1+i\tau). \tag{13}$$

The interference term is clearly only appreciable where the two packets overlap.

4 HOM experiment with the beam splitter removed

Consider now the particular case of the two Gaussian packets initially centred at $x_{01} = -d$ and $x_{02} = +d$, moving toward the origin with $k_{01} = k_1 > 0$ and $k_{02} = -k_2 < 0$. In space and time the two wave packets form intersecting beams, the packet parameters may be chosen so that they cross and separate before they have spread appreciably. Neglecting dispersion, the (anti)symmetrized wave function at exact overlap ($t = t_*$, where the envelopes coincide) is

$$\Psi_\pm(x_1, x_2, t_*) \propto e^{i\frac{k_1-k_2}{2}(x_1+x_2)} \times \begin{cases} 2\cos\left[\frac{k_1+k_2}{2}(x_1-x_2)\right], & (+), \\ 2i\sin\left[\frac{k_1+k_2}{2}(x_1-x_2)\right], & (-). \end{cases} \tag{14}$$

Hence the interference phase in the joint density is

$$\Phi(x_1, x_2, t_*) = (k_1 + k_2)(x_1 - x_2),$$

so the fringe spacing in the relative coordinate is

$$\Delta(x_1 - x_2) = \frac{2\pi}{k_1 + k_2}. \tag{15}$$

When the packets are still separated, the general phase is

$$\Phi(x_1, x_2, t) = -(k_1 + k_2)(x_2 - x_1) + \mathrm{Im}\left[\frac{(x_2 - x_1)\,\Delta\mu(t)}{2\sigma_t^2}\right],$$

where

$$\Delta\mu(t) = 2d - \frac{\hbar(k_1 + k_2)}{m}.$$

The dispersion causes a slight change of fringe spacing, the entire fringe pattern does not translate.

Away from nodal lines, the overall phase of $\Psi_\pm$ is

$$\arg\Psi_\pm = (\tfrac{k_1-k_2}{2})(x_1 + x_2), \tag{16}$$

so the Bohm velocities are equal and constant:

$$v_1 = v_2 = \frac{\hbar}{m}\,\frac{k_1 - k_2}{2}. \tag{17}$$

The sum $(k_1 + k_2)$ thus governs the interference fringes, while the difference $(k_1 - k_2)$ determines the velocities. If $|k_1| = |k_2|$ then $v_1 = v_2 = 0$ and the particles are momentarily stationary at overlap, otherwise $v_1 = v_2 = \frac{\hbar}{2m}(k_1 - k_2)$, with motion along the $x_1 = x_2$ direction (parallel to the fringes).

Fig.2 shows four possible, two-dimensional configuration space-time (x_1, x_2, t), deBB motions, for $|k_1| = |k_2|$. Fig.3 shows four possible, two-dimensional configuration space-time (x_1, x_2, t), deBB motions, but for $|k_{1|} \neq |k_2|$. The two-dimensional configuration space wave packets cross over, but the deBB trajectories bounce back from the overlap region as the trajectories swap packets and the particles swap momenta. The individual particle trajectories shadow plotted on the (x_1, t) and (x_2, t) planes show the characteristic "serpent-like wiggles" of interference but in an ensemble of trajectories these indicators of interference are masked by the overlapping of the trajectories.[3]. Fig.4 shows a larger ensemble of such trajectories, for $|k_1| = |k_2|$, and illustrates the masking of individual particle individual trajectory signatures of interference.

If $|k_1| \neq |k_2|$, the wave packets, and hence the particles, are distinguishable by their momentum, nonetheless two-particle interference can be observed in the region of overlap provided that the detectors are blind to the momentum. Detectors that could distinguish the momenta would not reveal interference, instead they would reveal which path information. Position measurements made in the far field reveal which beam the particles are in there but, according to the deBB trajectories, the beams identified are not those in which the particles approached the interference region. According to deBB theory, interpreting the position measurements as time-of-flight momentum measurements, it is clear that the outcomes do not reveal the actual initial momenta at all, but rather the opposite.

The configuration space trajectories from each initial configuration space wave packet approach the centre, bunch into the two-particle interference fringes, and then return along the path on which they

[3]The character of the deBB configuration space-time trajectories can easily be deduced from the fact that they may not cross in the configuration space (as the phase must be single valued)

Journal of Physics: Conference Series **3189** (2026) 012012 doi:10.1088/1742-6596/3189/1/012012

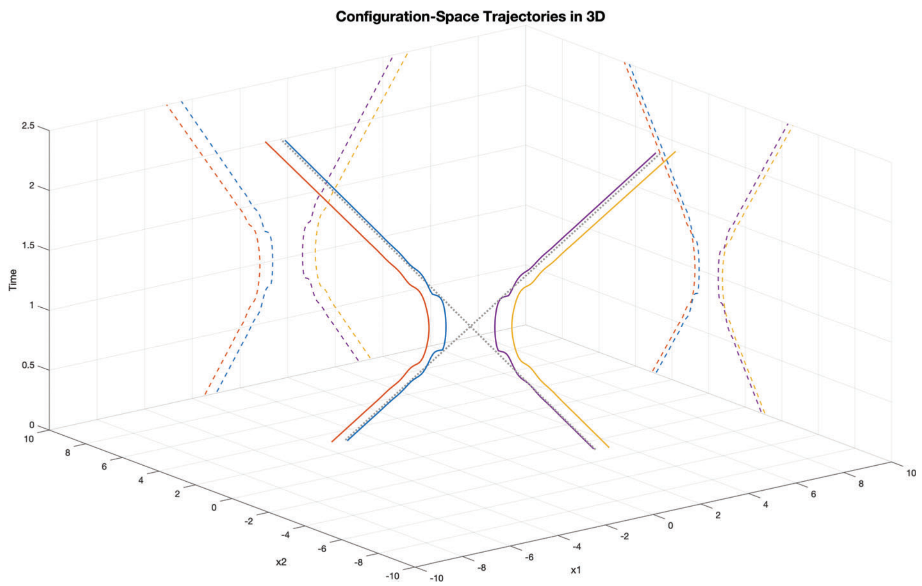

Figure 2: Four possible deBB configuration space - time (spanned by x_1, x_2 and t) trajectories and their projections onto individual particle axes (x_1, t and x_2, t) for two entangled bosons in a crossed beam experiment. The trajectories and their projections are colour coordinated. The black dotted lines indicate the paths of the centre of the packets in configuration space. $|k_1| = |k_2|$

came.[4] Each of the individual particles changes its momentum as the trajectories "bounce back" from the interference region, that is the particles switch packets. During the bounce, the particle that initially had momentum k_1 adopts the momentum $-k_2$ and vice versa. Extrapolating the effect to a more colourful context, if the particles in question were to be photons and the two beams associated with red and blue photons respectively, given a suitable photon trajectory theory, the deBB motions would have the blue photon emerging as red while the red photon emerges as blue. The momenta (or colour) may be distinguishable, but in the deBB account the momentum (or colour) cannot be used to *identify* the particles. The colour of a photon is not part of its identity.

5 The Hong-Ou-Mandel experiment, with beam splitter

The complete HOM experiment demonstrates a pure two-particle interference phenomenon in which two photons one incident from each side on a balanced beam splitter always both exit in the same direction. Analogous two-particle interference effects have now been demonstrated with cold atoms [34] and other massive particles, making such analyses more than merely conceptual, (for a review see [35]) and it is this context that we describe in detail here.

In the standard second quantised treatment, the beam splitter transformation acts on the creation operators and the bosonic bunching, or fermionic antibunching emerges automatically from the corresponding commutation relations. Particle statistics are encoded in the operator algebra itself.

Several alternative de Broglie-Bohm-type formulations of quantum field theory are relevant to HOM-type experiments. In his 1952 appendix [3], Bohm proposed a hybrid scheme: bosons were described by a field ontology, with the actual configuration a classical field guided by the wave functional Ψ, while fermions were still treated as particles with trajectories. In this picture, particle effects in boson fields such as bunching and antibunching emerge as excitations of the field at detection by fermion particle systems. Bell-type Bohmian quantum field theories, developed later by Dürr, Goldstein, Tumulka and Zanghì [36], instead employ a Fock-space ontology of particle configurations, with a stochastic jump process implementing creation and annihilation; HOM statistics arise from the equivariance of the $|\Psi^2|$ distribution and the symmetry of the Fock-space wave functional. Valentini, by contrast, has advocated a common field ontology, treating both bosons and fermions as fundamentally Bohm fields, with deterministic dynamics and particle properties emerging on interaction with detectors [37], [38]. Struyve[39] has

[4]This bounce phenomenon has been previously described in the single particle case in [33] and in the context of the Wheeler delayed choice experiment at https://youtu.be/muiIskIZ428?si=qJ1MR-k9EpnHW7Cj

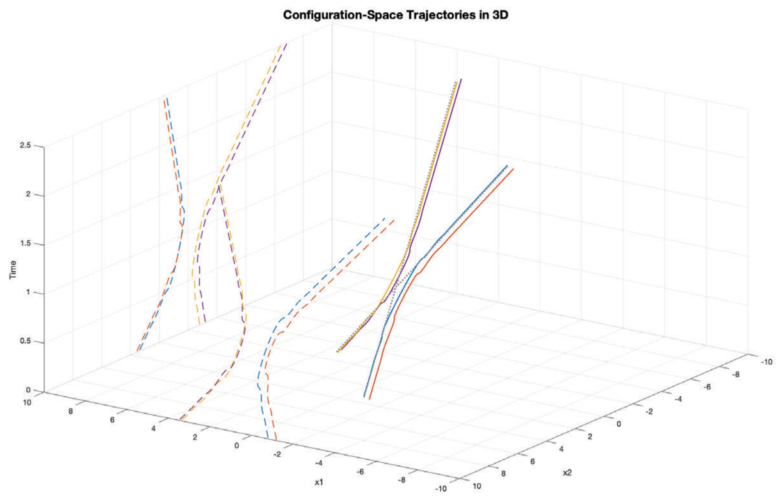

Figure 3: Four possible deBB configuration space - time trajectories and their projections onto individual particle axes (x_1, t and x_2, t) for two entangled bosons in a crossed beam experiment. The trajectories and their projections are colour coordinated. The black dotted lines indicate the paths of the centre of the packets in configuration space. $|k_1| \neq |k_2|$

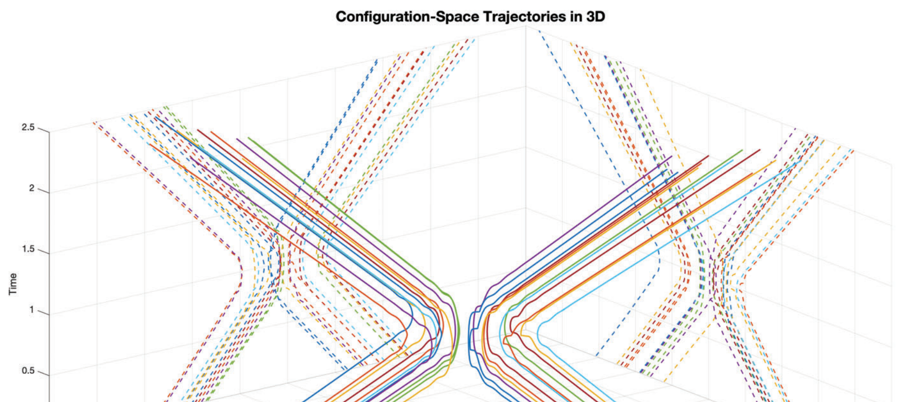

Figure 4: Possible deBB configuration space - time trajectories and their projections onto individual particle axes (x_1, t and x_2, t) for two entangled bosons in a crossed beam experiment with $|k_1| = |k_2|$. The trajectories and their projections are colour coordinated. An animation is available as a supplementary file HOMnoBStrajectories.mp4 online, see also HOMnoBSdensity.mp4 for the probability density evolution.

provided a useful comparison of approaches. The present work employs a first-quantised, fixed number of particles approach to HOM experiments relevant to the case of ultra cold atoms [34] in which particle statistics must be imposed explicitly through wave function symmetry.

The set up is as described above, but now a beam splitter (BS) is introduced in the paths of the wave packets, see Fig. 1. To determine the evolution in time of the configuration space wave function, it was necessary to compute it, step-by-step, by numerical solution of the two-dimensional time-dependent

Schrödinger equation. The beam splitter was modelled as a gaussian potential barrier with a transmission coefficient of one-half.[5] The specific form of the potential barriers, which appear in the form of a cross in the configuration space (x_1, x_2), was defined by

$$V(x_1) = V_0 \exp(-x_1^2/2\sigma^2) \tag{18}$$

and

$$V(x_2) = V_0 \exp(-x_2^2/2\sigma^2), \tag{19}$$

where V_0 and σ were tuned so that the transmission coefficient of each barrier was one half. The initial two-particle configuration space wave function is given in equation 9. The bunching or antibunching behaviour emerges from the *pre-imposed* symmetry requirements rather than from fundamental operator properties.

If the initial two-particle wave function for non entangled particles is not that given in equation 9 but rather by a simple product,

$$\Psi_{\mathrm{MB}}(x_1, x_2) = \psi_2(x_1)\psi_1(x_2), \tag{20}$$

then each particle obeys its own single particle Schrödinger equation giving equal transmitted and reflected wave packets after the beam splitter. The evolution of the configuration space probability density for this non entangled case is shown in Fig. 5[6]. The probability of both particles emerging in the same direction is one half, as is the probability of the particles emerging in different directions. The deBB trajectories for the non entangled, no symmetry case are just the single particle, non correlated trajectories first calculated in [11], as shown in the bottom row of Fig. 8.[7] In the single particle case it is the position of the particle in the wave packet as it approaches the beam splitter that determines which way the particle goes and hence which one of two detectors, placed one in each output, records the arrival of the particle.[8]

The initial wave function for entangled particles has been given in equation 9. There are now two initial configuration space wave packets reflecting the symmetry requirements.

Fig.6 shows the evolution of the configuration space probability density for the symmetric case. The probability of both particles emerging in the same direction is effectively unity.

Figure 7 shows the evolution of the configuration space probability density for the antisymmetric case. The probability of both particles emerging in the same direction is effectively zero.

Given the evolution of the wave function, the deBB trajectories from randomly chosen initial positions within the configuration space wave packets could be calculated by integrating equation 8 in time. The HOM deBB configuration space trajectories for the no symmetry, boson symmetry and fermion symmetry cases are shown in Fig. 8, they simply follow the flow of the configuration space probability density.[9]

Given that trajectories may not cross in configuration space-time, coupled with the fact that the configuration space velocity must, for both symmetric and antisymmetric wave functions, be zero along $x_1 = x_2$, they have an intuitive form. In the antisymmetric case the trajectories from each packet approach the region of overlap where they form two-particle interference fringes, come to rest and then execute the same motion in reverse. This reversal of the motion ensures that the particles always emerge on opposite sides of the beam splitter: a phenomenon referred to as anti-bunching. In the symmetric case the trajectories approach the centre, but now as each packet splits and recombines in the bunching sectors the trajectories turn through ninety degrees, or two hundred and seventy degrees, depending on their initial position in the initial wave packets. If the initial positions are such that $x_2 < x_1$, the two particles both exit in the $x_1 < 0, x_2 < 0$ sector, that is both exit below the beam splitter. Similarly, if the initial positions are such that $x_| < x_2$, the two particles both exit in the $x_1 > 0, x_2 > 0$ sector. The particles

[5] We developed a similar numerical model in 1990 [18] to describe the deBB configuration space trajectories associated with the correlated two particle interferometry experiments proposed by Horne, Shimony and Zeilinger (HSZ) [19].

[6] Time is in arbitrary units in all of the figures presented here.

[7] An animated version of the trajectories and quantum potential for the beam splitter modelled as a potential barrier can be seen at https://www.youtube.com/watch?v=NC6yVkbAIzk

[8] In Bohm's field ontology, by contrast, the actual Bohm field for the incident single photon wave packet scatters into both outputs (the "photon" goes both ways). The Bohm field is dominated by vacuum-like fluctuations and carries no observable trace of the packet. However, if two detectors are placed one in each output then they become energy entangled, and anticorrelated, by interaction with the photon field. There is nothing in the photon field itself that determines which detector fires. The decisive factor is not the Bohm photon field at all, but rather the hidden variables of the detectors themselves, which become non locally correlated in three space and which alone determine which detector records the photon. During the interaction the quantum of energy is swept from the entire Bohm photon field into just one of the detectors, making it *appear* that the photon went only one way. [21, 22].

[9] Animations showing the configuration space motion synchronised with the everyday space motions can be viewed at https://youtu.be/s-EAgS9z8Mk

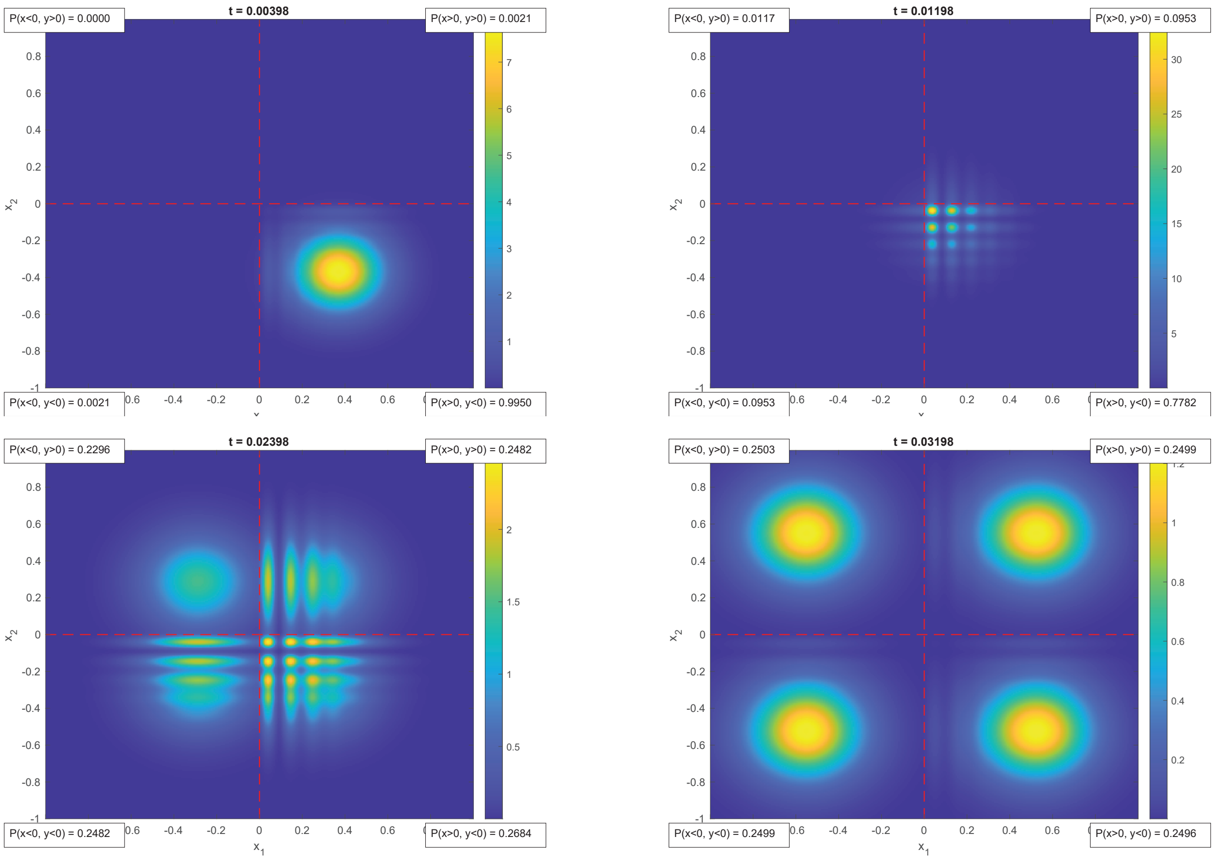

Figure 5: Configuration space probability density intensity snapshots for the HOM experiment with distinguishable particles. **Top left:** $t = 0.00398$. There is a single two-particle wave packet in the $x_1 > 0, x_2 < 0$ sector as the wave function is a simple product; **Top right:** $t = 0.01198$. Each wave packet meets the beam splitter creating interference fringes; **Bottom left:** $t = 0.02398$. The transmitted and reflected wave packets move away from the beam splitter; **Bottom right:** $t = 0.03198$. There is an equal probability in each sector of configuration space. The particles can emerge from the beam splitter on the same side or opposite side with equal probability. The particles behave independently.

The full animation, of which these are snapshots, is available in Supplementary Material as HOMMBdensity.mp4

Journal of Physics: Conference Series **3189** (2026) 012012 doi:10.1088/1742-6596/3189/1/012012

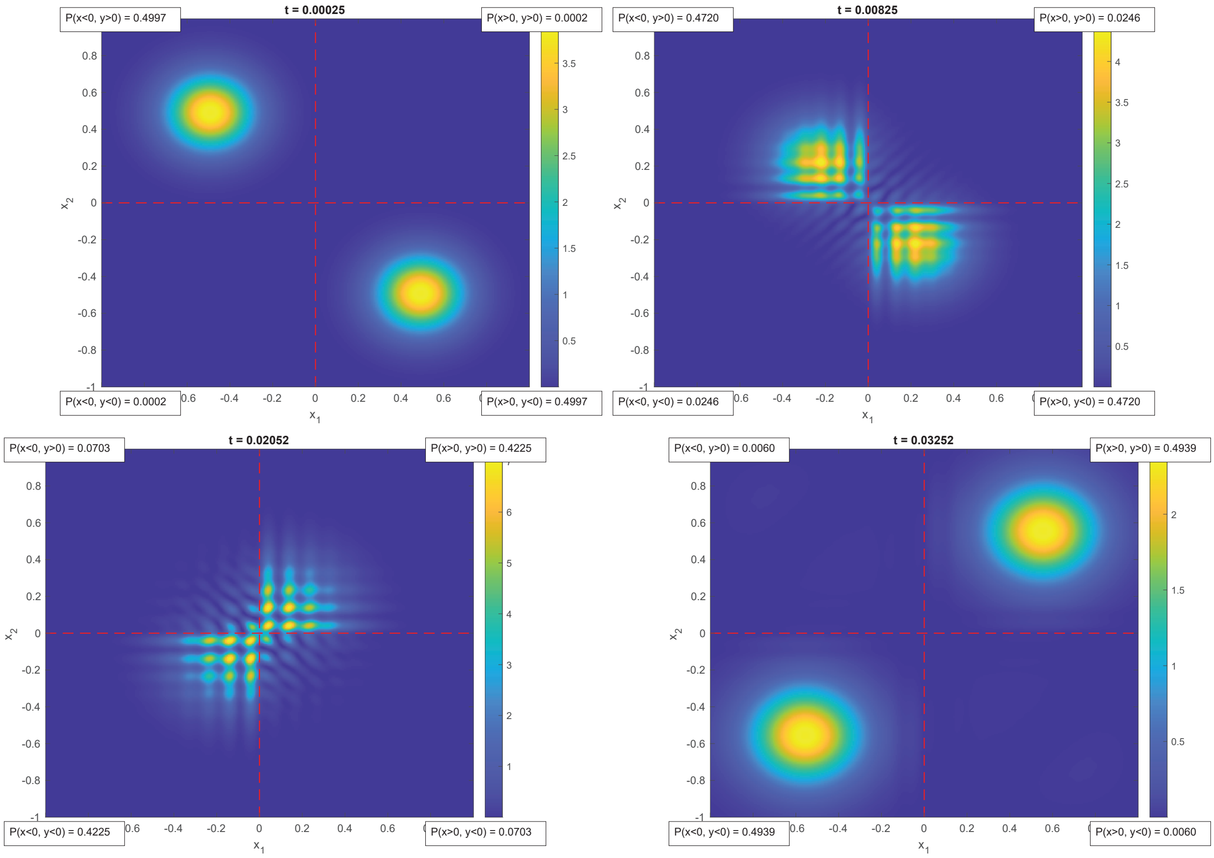

Figure 6: Configuration space probability density intensity plots for the HOM experiment symmetric wave function. Both particles exit in the same output arm (bunching). **Top left:** $t = 0.00025$. The particles approach the beam splitter from opposite sides (either $x_1 > 0, x_2 < 0$ or $x_1 < 0, x_2 > 0$); **Top right:** $t = 0.008257$. Interference fringes are formed as the two-particle wave packets reach the beam splitter; **Bottom left:** $t = 0.02502$.; **Bottom right:** $t = 0.03252$. Destructive interference of the wave packets in the $x_1 < 0, x_2 > 0$ and $x_1 > 0, x_2 < 0$ sectors and constructive interference in the $x_1 < 0, x_2 < 0$ and $x_1 > 0, x_2 > 0$ takes place. The particles leave the beam splitter on the same side $x_1 > 0, x_2 > 0$ and $x_1 < 0, x_2 < 0$, demonstrating bunching.

The full animation, of which these are snapshots, is available in Supplementary Material as HOMBosondensity.mp4

Journal of Physics: Conference Series **3189** (2026) 012012 doi:10.1088/1742-6596/3189/1/012012

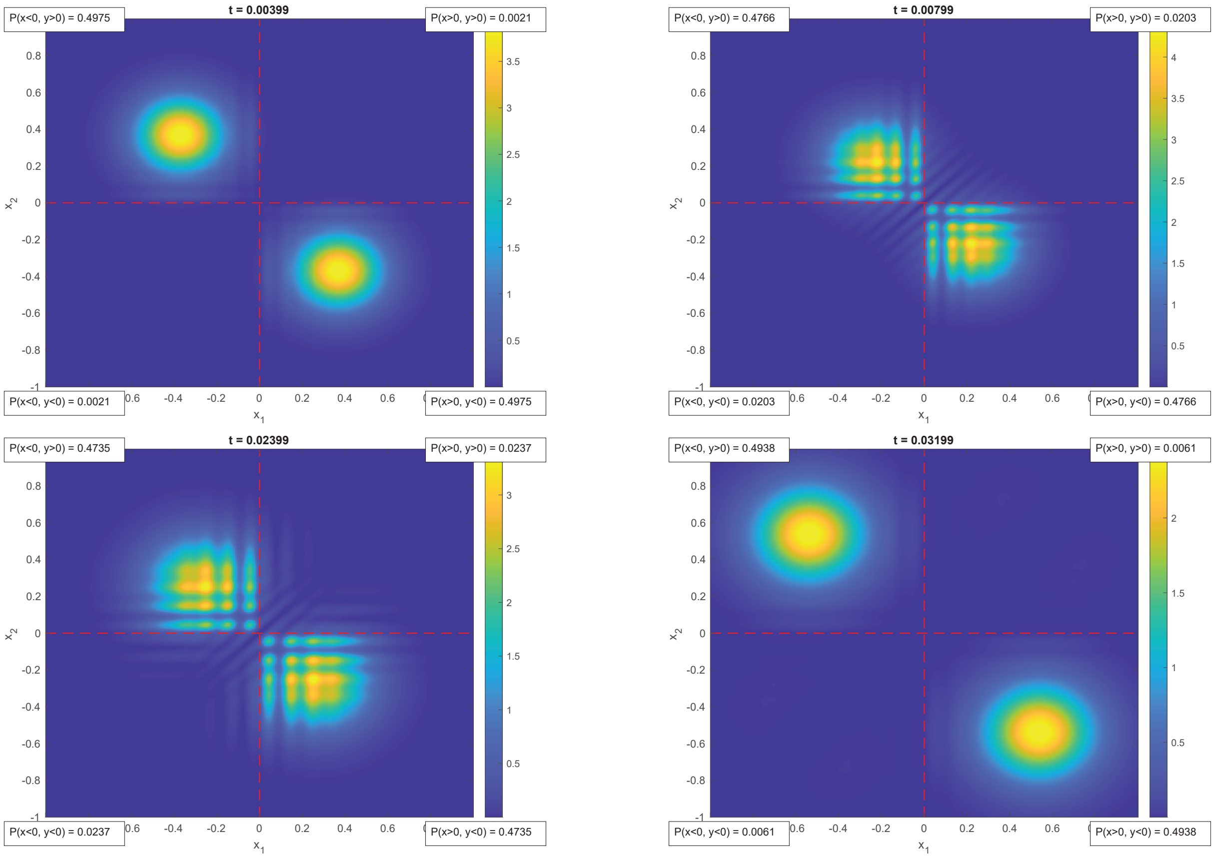

Figure 7: Configuration space probability density intensity plots for the HOM experiment with antisymmetric wave function. Both particles exit in different output arms (antibunching). **Top left:** $t = 0.00399$. The particles approach the beam splitter from opposite sides (either $x_1 > 0, x_2 < 0$ or $x_1 < 0, x_2 > 0$; **Top right:** $t = 0.00799$. Interference fringes are formed as the two-particle wave packets reach the beam splitter; **Bottom left:** $t = 0.02399$. ; **Bottom right:** $t = 0.03199$. Destructive interference of the wave packets in the $x_1 < 0, x_2 < 0$ and $x_1 > 0, x_2 > 0$ sectors and constructive interference in the $x_1 < 0, x_2 > 0$ and $x_1 > 0, x_2 < 0$ takes place.The particles leave the beam splitter on opposite sides into the $x_1 > 0, x_2 < 0$ and $x_1 < 0, x_2 > 0$ sectors, demonstrating anti-bunching.
The full animation, of which these are snapshots, is available in Supplementary Material as HOMFermidensity.mp4

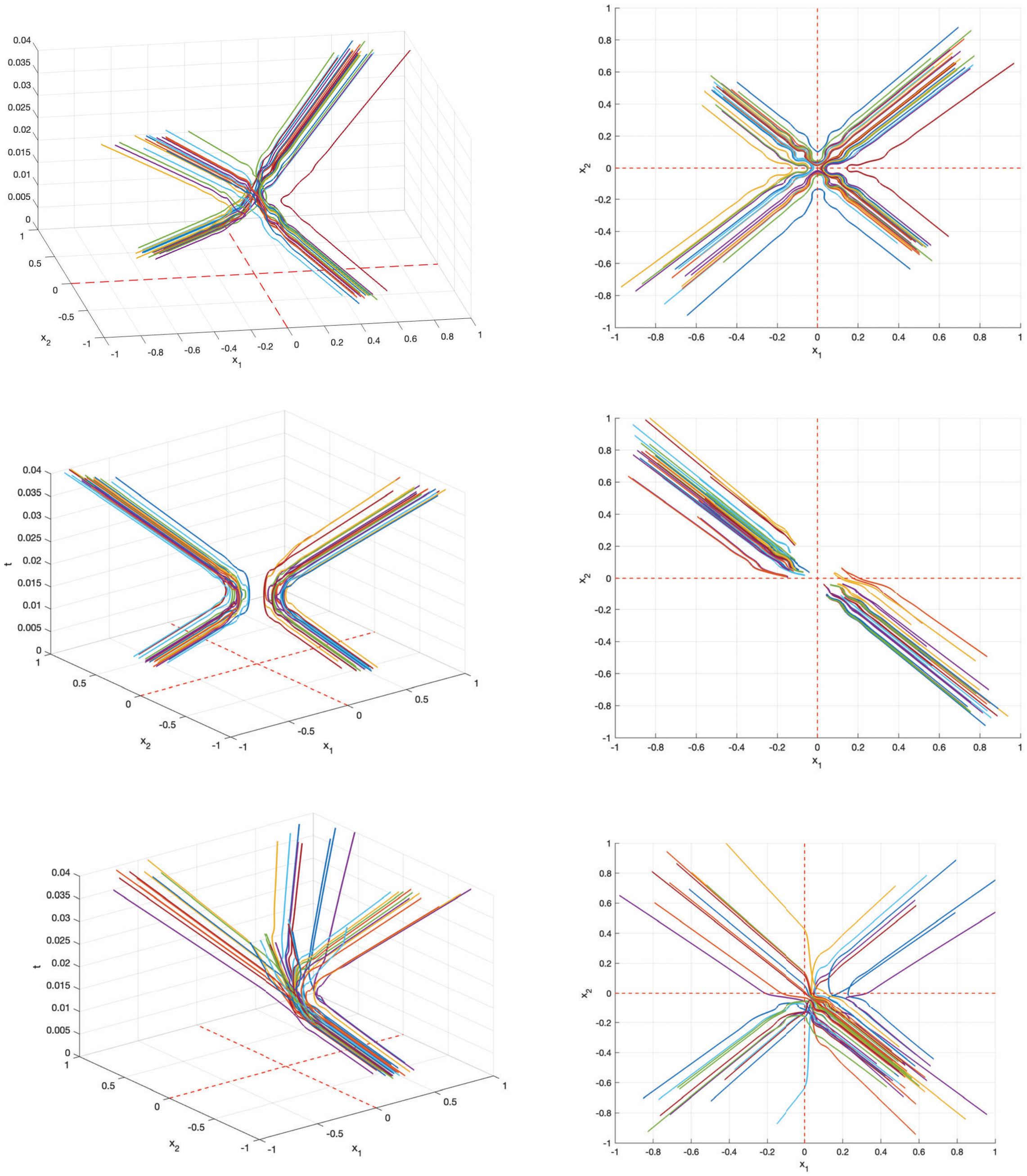

Figure 8: Configuration space Bohmian trajectories for the HOM experiment. Left side (x_1, x_2, t) 3D plots, right side (x_1, x_2) plots. **Top row - Bunching:** symmetric wave function. The particles approach the beam splitter from opposite sides but both always leave on the same side $(x_1 > 0, x_2 > 0)$ or $(x_1 < 0, x_2 < 0)$. No trajectories cross the $x_1 = x_2$ line along which the velocity is zero; **Middle row - anti-bunching:** antisymmetric wave function - the particles approach the beam splitter from opposite sides and both always leave on opposite sides $(x_1 > 0, x_2 < 0)$ or $(x_1 < 0, x_2 > 0)$. No trajectories cross the $x_1 = x_2$ line along which the velocity is zero; **Bottom row:** no symmetry, non entangled simple product wave function - the particles approach the beam splitter from opposite sides and can leave on the same side or opposite sides. Each particle behaves independently;

always emerge from the beam splitter interaction on the same side: a phenomenon referred to as bunching. Clearly, the outcome for particle one depends not only on its own initial position within its wave packet but also (non locally) on the initial position of particle 2 and the symmetry of the configuration space wave function. Whichever interpretation of de Broglie-Bohm quantum theory we prefer, the accelerations suffered by the individual particles are clearly not locally determined.[10] It should be emphasised that the behaviour illustrated here cannot be understood with individual particle wave functions obeying individual Schrödinger equations described solely in the one dimensional space.[11]

In the HOM case, delaying one of the input packets so that they do not overlap at the beam splitter prevents the overlap and interference of the output packets in the configuration space and so there is no bunching. The deBB trajectories are then as for the simple product case. As the delay is gradually removed the trajectories gradually transform into those where the output packets do interfere, giving rise to the "HOM dip".[12]

6 Conclusion

This paper has illustrated several key insights into how quantum mechanics might describe a deeper underlying reality in configuration space. The configuration space dynamics project into the everyday world of space and time, giving rise to the behaviour observed in quantum experiments. A central theme has been the ontological role of configuration space. In deBB theory, it is not a mere abstraction or mathematical device, but the fundamental arena in which quantum phenomena play out. Non locality, contextuality, and the apparent indeterminism of measurement outcomes all arise from the projection of global configuration space structure into three-dimensional space.

Our analysis of two-particle systems reveals that effects such as two particle bunching and anti-bunching are not properties of individual particles, but of the holistic configuration. Interference patterns that are invisible in single-particle measurements become apparent only through coincidence detections that probe the full configuration. Although configuration space, in general, does not correspond to a physically visualisable space, it captures the complete relational structure among particles in a quantum system. In this sense, it provides a natural language for, and intuitive description of, the intrinsically nonlocal reality suggested by quantum mechanics. Behaviour that seems strange, requiring non local influences, if only the everyday three dimensional space trajectories are examined, appears completely natural in the local configuration space description. The deBB particle analysis of the HOM-type experiments considered here further illustrates the explanatory power of this framework and suggests that the configuration space wave function possesses deep ontological significance. It expresses what we might call the "ultimate wholeness of quantum reality"—a single, nonlocal structure that determines all particle behaviour. In deBB quantum theory, the universe is described by one universal wave function on configuration space, evolving unitarily, with a unique actual configuration following a trajectory determined by the guiding equation. From this, the familiar world of events in space and time emerges through the appearance of autonomous, locally behaving substructures within the broader configuration.

Our view aligns with the configuration space realism advocated by Albert [40] and Ney [41], and discussed critically by Maudlin [42], in which the wave function is treated as a physically real field on configuration space. On this view, the familiar 3D world, including observers and measuring devices, emerges as a higher-level pattern within the evolving configuration space wave function. This emergence is compatible with the perception of inhabiting a classical, three-dimensional world, as argued, for example, by Lewis [43] and Pinkel [44].

In closing, it is fitting, in a volume dedicated to Basil Hiley, to reflect on the broader conceptual setting of the present work. The analysis developed here has remained within the realist, trajectory-

[10]Within Bohm's alternative quantum field ontology, with two indistinguishable bosonic inputs incident from opposite ports, the post beam splitter wave functional has vanishing weight for the "one in each output" branch (the symmetric interference that underlies the HOM dip), leaving only the "both left" or "both right" detector branches; the *d*etectors' actual configurations (hidden variables) picks one of these. The Bohm field itself does not determine the outcome. For fermionic inputs, antisymmetry suppresses the double-occupancy branches, yielding anti-bunching.

[11]The calculations presented here have another interpretation. They could also be seen as describing single particle motion in two spatial dimensions, with ($x_1 \to x$ and $x_2 \to y$). The two wave packets, describing a single particle superposition of ψ_1 and ψ_2, would then describe a single particle incident on a pair of perpendicular beam splitters centred on the origin. The x and y components of the motion are obviously correlated, just as x_1 and x_2 are in the HOM case. The correlation arises as in reality there is a single two-particle trajectory in two dimensional space time. In the HOM case, in reality there is a single configuration in configuration space.

[12]HSZ's joint interference survives big asymmetries because the correlated two-particle branches still overlap in configuration space; there's no HOM-type dip to erase. Since the HSZ interferometers could be arbitrarily far apart, the space time non locality is rather more stark, but equally understandable as arising from the local behaviour in configuration space.

based framework of the de Broglie–Bohm theory. Hiley himself, however, came to regard this framework as only one level of description, seeking instead a deeper account in which the algebraic structure of quantum theory is primary, and the familiar notions of particles, fields, and even space–time emerge from an underlying noncommutative order. From that perspective, phenomena such as Hong–Ou–Mandel interference arise not from interactions between independent quanta but as unfoldings of a single, holistic algebraic process. The trajectory-based treatment presented here can thus be viewed as complementary to Hiley's later vision: it retains the explanatory clarity of motion in configuration space, while his algebraic approach points toward the deeper level of process from which such explicate structures originate. It is hoped that the work presented here stands in the spirit of inquiry and openness that characterised Hiley's lifelong exploration of the quantum world.

In further work, it would also be of interest to carry out similar explicit calculations for alternative Bohmian formulations of quantum field theory — including Bohm's original field ontology, Bell-type stochastic QFTs, Valentini's uniform field approach and, perhaps, even Hiley's algebraic approach.

References

[1] de Broglie L 1928 La nouvelle dynamique des quanta *Électrons et photons: Rapports et discussions du cinquième Conseil de Physique Solvay* ed Einstein A, Lorentz H A, Minkowski H and Weyl H (Paris: Gauthier-Villars) pp 105–132 originally presented at the Fifth Solvay Conference, Brussels, 1927

[2] Bohm D 1952 *Phys. Rev.* **85**(2) 166–179 URL `https://link.aps.org/doi/10.1103/PhysRev.85.166`

[3] Bohm D 1952 *Phys. Rev.* **85**(2) 180–193 URL `https://link.aps.org/doi/10.1103/PhysRev.85.180`

[4] Bohm D and Hiley B J 1993 *The Undivided Universe* (Routledge)

[5] Hiley B J 2018 *Entropy* **20** 382 URL `https://doi.org/10.3390/e20060382`

[6] Hong C K, Ou Z Y and Mandel L 1987 *Physical Review Letters* **59** 2044–2047

[7] Valentini A 1992 *On the Pilot-Wave Theory of Classical, Quantum and Subquantum Physics* Ph.D. thesis International School for Advanced Studies (SISSA) Trieste, Italy ph.D. Thesis

[8] Goldstein S and Zanghì N 2013 *The Stanford Encyclopedia of Philosophy* Summer 2013 Edition, Edward N. Zalta (ed.)

[9] Norsen T 2017 *Foundations of Quantum Mechanics: An Exploration of the Physical Meaning of Quantum Theory* (Cham: Springer)

[10] Philippidis C, Dewdney C and Hiley B J 1979 *Il Nuovo Cimento B (1971-1996)* **52** 15–28 URL `https://doi.org/10.1007/BF02743566`

[11] Dewdney C and Hiley B J 1982 *Foundations of Physics* **12** 27–48 URL `https://doi.org/10.1007/BF00726873`

[12] Dewdney C 1985 *Physics Letters A* **109** 377–384 ISSN 0375-9601 URL `https://www.sciencedirect.com/science/article/pii/0375960185900787`

[13] Bohm D J, Dewdney C and Hiley B H 1985 *Nature* **315** 294–297 URL `https://doi.org/10.1038/315294a0`

[14] Dewdney C, Holland P and Kyprianidis A 1986 *Physics Letters A* **119** 259–267 ISSN 0375-9601 URL `https://www.sciencedirect.com/science/article/pii/0375960186901441`

[15] Dewdney C, Holland P and Kyprianidis A 1987 *Physics Letters A* **121** 105–110 ISSN 0375-9601 URL `https://www.sciencedirect.com/science/article/pii/0375960187904002`

[16] Dewdney C, Holland P R, Kyprianidis A and Vigier J P 1988 *Nature* **336** 536–544 URL `https://doi.org/10.1038/336536a0`

[17] Dewdney C and Malik Z 1993 *Phys. Rev. A* **48**(5) 3513–3524 URL `https://link.aps.org/doi/10.1103/PhysRevA.48.3513`

[18] Lam M and Dewdney C 1990 *Physics Letters A* **150** 127–135 ISSN 0375-9601 URL `https://www.sciencedirect.com/science/article/pii/037596019090107Y`

[19] Horne M A, Shimony A and Zeilinger A 1989 *Phys. Rev. Lett.* **62**(19) 2209–2212 URL `https://link.aps.org/doi/10.1103/PhysRevLett.62.2209`

[20] Dewdney C, Hardy L and Squires E 1993 *Physics Letters A* **184** 6–11 ISSN 0375-9601 URL `https://www.sciencedirect.com/science/article/pii/037596019390337Y`

[21] Lam M M and Dewdney C 1994 *Foundations of Physics* **24** 3–27 URL `https://doi.org/10.1007/BF02053906`

[22] Lam M M and Dewdney C 1994 *Foundations of Physics* **24** 29–60 URL `https://doi.org/10.1007/BF02053907`

[23] Holland P R 1993 *The Quantum Theory of Motion: An Account of the de Broglie-Bohm Causal Interpretation of Quantum Mechanics* (Cambridge: Cambridge University Press)

[24] Dürr D and Teufel S 2009 *Bohmian Mechanics: The Physics and Mathematics of Quantum Theory* (Berlin: Springer)

[25] Sanz Á S 2018 *Frontiers in Physics* **6** 52

[26] Benseny A, Albareda G, Sanz Á S, Mompart J and Oriols X 2014 *The European Physical Journal D* **68** 286

[27] Wiseman H M and Milburn G J 2009 *Quantum Measurement and Control* (Cambridge: Cambridge University Press)

[28] Dürr D, Goldstein S and Zanghì N 1992 *Journal of Statistical Physics* **67** 843–907

[29] Bohm D and Vigier J P 1954 *Phys. Rev.* **96**(1) 208–216 URL `https://link.aps.org/doi/10.1103/PhysRev.96.208`

[30] Valentini A 1991 *Physics Letters A* **156** 5–11 ISSN 0375-9601 URL `https://www.sciencedirect.com/science/article/pii/037596019190116P`

[31] Valentini A 2025 *Beyond the Quantum: A Quest for the Origin and Hidden Meaning of Quantum Mechanics* (Oxford: Oxford University Press) ISBN 9780192595423

[32] Sanz Á S 2023 *Entropy (Basel)* **25** ISSN 1099-4300 (Electronic); 1099-4300 (Linking)

[33] Dewdney C 2023 *Foundations of Physics* **53** 24 URL `https://doi.org/10.1007/s10701-022-00655-w`

[34] Lopes R, Imanaliev A, Aspect A, Cheneau M, Boiron D and Westbrook C I 2015 *Nature* **520** 66–68 URL `https://doi.org/10.1038/nature14331`

[35] Kaufman A M, Tichy M C, Mintert F, Rey A M and Regal C A 2018 Chapter seven - the hong–ou–mandel effect with atoms (*Advances In Atomic, Molecular, and Optical Physics* vol 67) ed Arimondo E, DiMauro L F and Yelin S F (Academic Press) pp 377–427 URL `https://www.sciencedirect.com/science/article/pii/S1049250X18300077`

[36] Dürr D, Goldstein S, Tumulka R and Zanghì N 2003 *Journal of Physics A: Mathematical and General* **36** R1–R40

[37] Valentini A 1996 Pilot-wave theory of fields, gravitation and cosmology *Bohmian Mechanics and Quantum Theory: An Appraisal* ed Cushing J T, Fine A and Goldstein S (Dordrecht: Kluwer Academic) pp 45–66

[38] Valentini A 2001 Hidden variables and the large-scale structure of spacetime *Chance in Physics: Foundations and Perspectives* (*Lecture Notes in Physics* vol 574) ed Bricmont J, Diederik G, Dupré M, Earman J, Ghirardi G C, Niedermaier M and Schlogl I (Springer) pp 165–181

[39] Struyve W 2011 *Journal of Physics: Conference Series* **306** 012047 (*Preprint* `1101.5819`)

[40] Albert D Z 1996 Elementary quantum metaphysics *Bohmian Mechanics and Quantum Theory: An Appraisal* ed Cushing J T, Fine A and Goldstein S (Dordrecht: Springer) pp 277–284

[41] Ney A 2013 *Noûs* **47** 409–430

[42] Maudlin T 2013 *The Metaphysics Within Physics* (Oxford: Oxford University Press) ISBN 9780199915527

[43] Lewis P J 2003 *The British Journal for the Philosophy of Science* **55** 713–729 URL `https://philsci-archive.pitt.edu/1272/`

[44] Pinkel D 2024 Living in configuration space `http://philsci-archive.pitt.edu/24136/` URL `https://philsci-archive.pitt.edu/24136/`