Reply

Reply to comment on ‘non-monotonic projection probabilities as a function of distinguishability’

Gunnar Björk and Saroosh Shabbir
Department of Applied Physics, Royal Institute of Technology (KTH) AlbaNova University Center, SE-106 91 Stockholm, Sweden
E-mail: saroosh@kth.se

Received 19 September 2014
Accepted for publication 13 October 2014
Published 28 November 2014
New Journal of Physics 16 (2014) 118004
doi:10.1088/1367-2630/16/11/118004

Abstract
We reiterate that a non-monotonic behavior of projection probabilities can occur for most states irrespective of the number of particles involved, based solely on the choice of the projectors chosen for measurement. We further clarify that, contrary to the claim in the comment, our analysis is not intended to demonstrate quantum to classical transition. However, our results show that a non-monotonic behavior is not a necessarily a signature of such a transition.

Keywords: interference, distinguishability, Hong–Ou–Mandel effect

There are two main claims in our paper ‘non-monotonic projection probabilities as a function of distinguishability’ (2014 New J. Phys. 16 013006), namely:

(1) that a non-monotonic projection probability as a function of distinguishability is not unusual, not even for single-particle or semi-classical states. This holds for both bosonic and fermionic states.

(2) that if one chooses the proper projector to measure distinguishability, then the projection probability is a monotonic function of the distinguishability.

To begin with, it is worth noting that our paper discusses projection probabilities as a function of distinguishability as is clear from the title and the abstract. We do not discuss,
except indirectly, the ‘quantum-to-classical transitions’ the comment makes reference to. We
only mention ‘quantum-to-classical transitions’ four times in the paper—the first time in the
introduction to motivate our investigation and to survey the field. The following three times we
state what logically follows from our investigation; namely that a non-monotonic projection
probability is not necessarily a signature of what the authors of [1, 2] call a classical-to-quantum
transition. Nowhere in our paper do we discuss why or how such a classical-to-quantum
transition would take place, or if our examples should be interpreted as such transitions. We
only discuss how transition probabilities change as a function of distinguishability. The authors
of the comment state, a few lines below equation (3) in the comment, that the example we
discuss in equation (8) in our paper ‘cannot be regarded as a quantum-to-classical transition by
any means’. The comment finishes by stating that ‘the non-monotonic probabilities in [1] are
not rooted in the quantum-to-classical transition, but in a unitary evolution of pure quantum
states’. Both statements may well be true, we do not express any opinion about this either in our
paper or here. What we do find is that when measuring interference of different states with an
‘improper’ projector one often, and perhaps even typically, gets a non-monotonic probability as
a function of distinguishability. Thus, and especially in view of the two statements in the
comment cited above, it is clear that a non-monotonic behavior should not be taken as a
signature of a quantum-to-classical transition. It is our understanding that the opposite belief
was one of the ‘selling points’ of the paper we criticized.

The comment criticizes our use of the term distinguishability. This criticism may have
some merit, because we have not subdivided the ability to predict the ‘path’ the particle(s) took
into predictability, distinguishability, or decoherence. Of course these causes can be further
subdivided or combined in various ways. However, to keep the picture as simple as possible we
have abstained from any such subdivision, but instead collected them all together into a single
‘cause’ we have called distinguishability and which is operationally defined in our paper in the
last two paragraphs of section 2. For simplicity we define distinguishability as any means (even
in principle) an observer can get access to ‘path’ information and thereby increase his
probability of correctly guessing which path one or more particles took in an interferometric
setting. Subdivision of the cause of the path information, such as into unitary or non-unitary
evolution, may possibly lead to a more precise insight on the causality of the effect, but it will
not change the price, in terms of decreased interference, one has to pay for the increased
distinguishability due to the obtained information. In the example discussed in the comment’s
equation (3), it is indeed the predictability that is changing, and therefore the path
distinguishability according to our operational definition. We find it pointless in this context
to invoke the concept of ‘coherence’ as an additional term. It is not needed as
indistinguishability alone dictates quantitatively how much interference can be seen.

Finally, at the beginning of section 4 in our paper we state that fermions can also show
non-monotonic decay as a function of distinguishability. Since our sole aim was to demonstrate
that single particle, fermionic states can also exhibit non-monotonic features irrespective of their
particle statistics, we did not consider many-particle, fermionic states. However, we do not find
it surprising in the least that indeed the nonmononicity is not coupled to a particular excitation
number and that a non-monotonic behavior as a function of distinguishability is not unnatural
for many-particle fermionic states either. This further strengthens our enumerated claims (1) and
(2) above.
References

[1] Ra Y-S, Tichy M C, Lim H-T, Kwon O, Mintert F, Buchleitner A and Kim Y-H 2013 Proc. Natl Acad. Sci. USA 110 1227–31

[2] Ra Y-S, Tichy M C, Lim H-T, Kwon O, Mintert F, Buchleitner A and Kim Y-H 2014 New J. Phys 16 118003