

# **What is Realism in Physics?**

## **What is the Price for Maintaining It?**

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What do we/can we mean by “realism”?

Philosophers discuss “reality” of (e.g.)

the human mind

the number 5

moral facts

atoms (electrons, photons...)

.....



but, difficult to  
think of input  
from physics

So: in what sense can physics as such say something about “realism”?

(My) proposed definition:

At any given time, the world is in a definite state, irrespective of whether or not it is observed by any human agency to be so.

To make this proposition (possibly) experimentally testable, need to extend it to finite “parts” of the world.

Irrespective of the universal validity (or not) of QM, what can we infer about this proposition

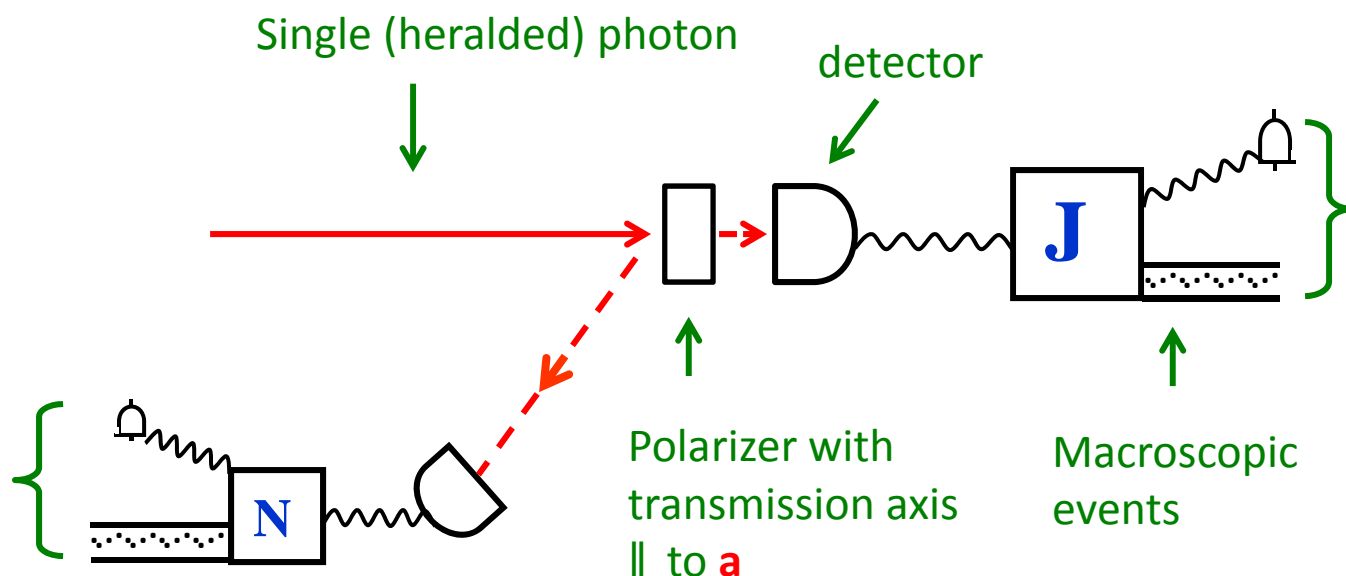
directly from experiment?



Quantum mechanics

## THE SIMPLEST CASE: A TWO STATE SYSTEM

(Microscopic) example: photon polarization



“Question” posed to photon:

**Are you polarized along **a**?**

Experimental fact:

for each photon, **either** counter J clicks (and counter N does not) **or** N clicks (and J does not).

natural “paraphrase”:

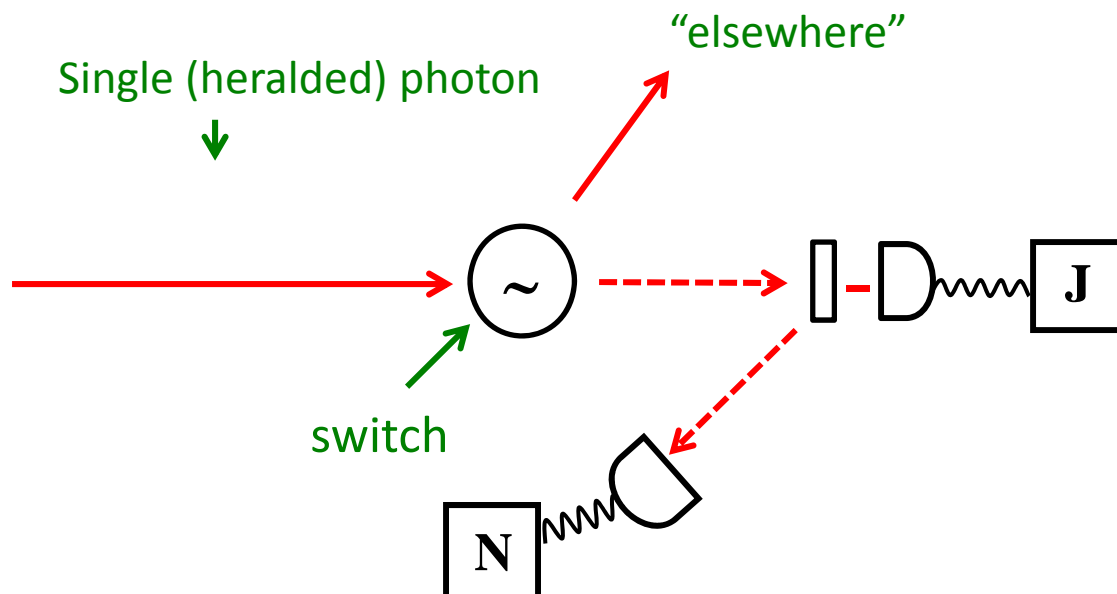
**when asked**, each photon answers either “yes” ( $A = +1$ ) or “no” ( $A = -1$ )

But: what if it is **not** asked?

Single (heralded) photon  $\rightarrow$  (no measuring device...)

## MACROSCOPIC COUNTERFACTUAL DEFINITENESS (MCFD)

(Stapp. Peres...)



Suppose a given photon is directed “elsewhere”.

What does it mean to ask “does it have a definite value of  $A$ ?”?

A possible quasi-operational definition:

Suppose photon had been switched into measuring device:

Then:

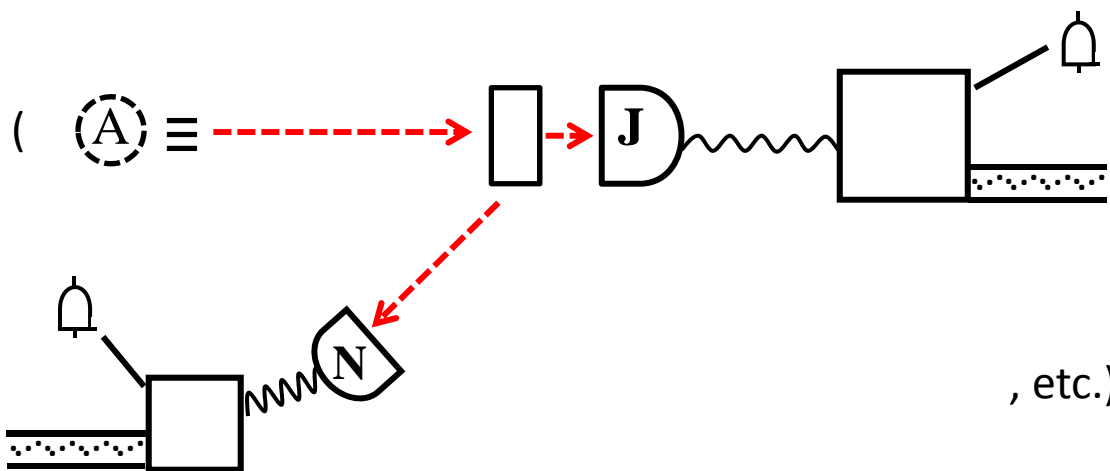
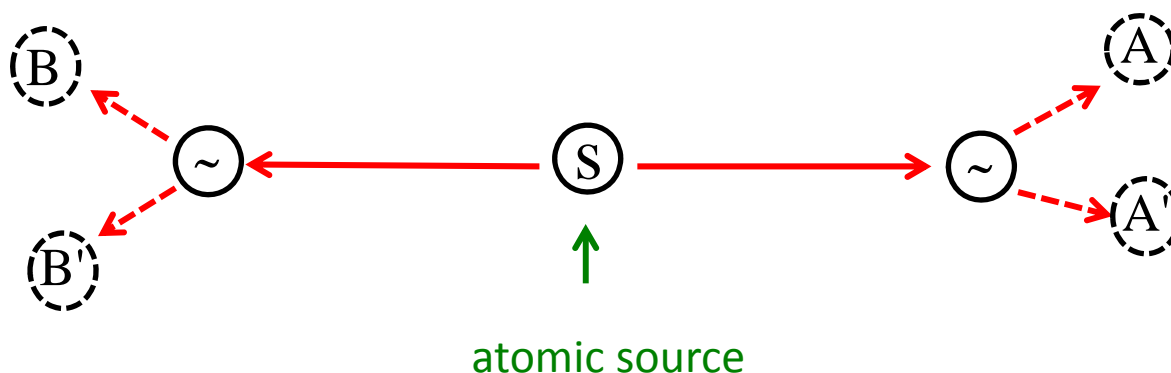
Proposition I (truism?): It is a fact that **either** counter J would have clicked ( $A = +1$ ) **or** counter N would have clicked ( $A = -1$ )



Proposition II (MCFD): **Either** it is a fact that counter J would have clicked (i.e. it is a fact that  $A = +1$ ) **or** it is a fact that counter N would have clicked ( $A = -1$ )

**DO COUNTERFACTUAL STATEMENTS HAVE TRUTH VALUES?**  
(common sense, legal system... assume so!)

THE EPR-BELL EXPERIMENTS (idealized)



CHSH inequality: all objective local theories (OLT's) satisfy the constraints

$$\langle AB \rangle + \langle A'B \rangle + \langle AB' \rangle - \langle A'B' \rangle \leq 2 \quad (*)$$

(\*) is violated by predictions of QM, and by experimental data.

(↑: “loopholes” – individually blocked except for “collapse locality” loophole\*)

\*AJL, Proc. 2<sup>nd</sup> Intl. Symp. Foundations of Quantum Mechanics, Tokyo 1986, p. 289  
 A. Kent, Phys. Rev. A 72, 012107 (2005)

Thus, modulo “loopholes”, all OLT’s are refuted by experiment.

Defining postulates of an OLT: conjunction of

- 1) Induction ( $\cong$  standard “arrow of time”)
- 2) Einstein locality (no superluminal causality)
- 3) Microrealism / MCFD

If we decide to keep 1), which of 2) or 3) should we abandon?

“Crypto-nonlocal” (CNL) theories: abandon 2), but add postulate that statistical properties of photons emitted in pairs are identical to those of photons emitted singly. (†)

Can prove \* that predictions of any such theory must satisfy inequality different from (original) CHSH inequality.

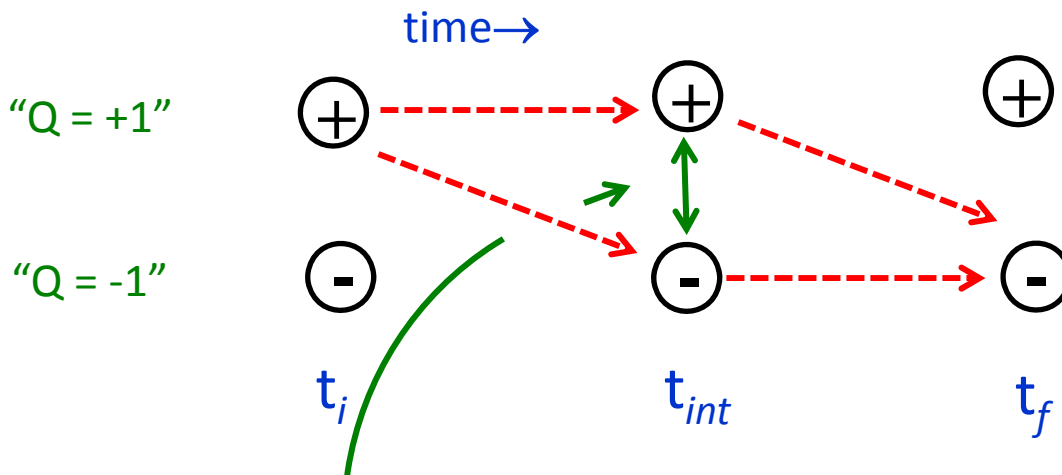
CNL theories also refuted by experiment (Wien, Singapore)

$\Rightarrow$  suggests (but does not prove) that it is more natural to abandon MCFD.

↑: does (†) amount to smuggling locality back in ?

\*AJL, Found. Phys. **33**, 1469 (2003)

## MACROSCOPIC QUANTUM COHERENCE (MQC)



macroscopically  
distinct states

Example: “flux qubit”:



Existing experiments: if raw data interpreted in QM terms,  
state at  $t_{int}$  is **quantum superposition** (not mixture!) of  
states  $\oplus$  and  $\ominus$ .

↑: how “macroscopically” distinct?

Analog of CHSH theorem for MQC:

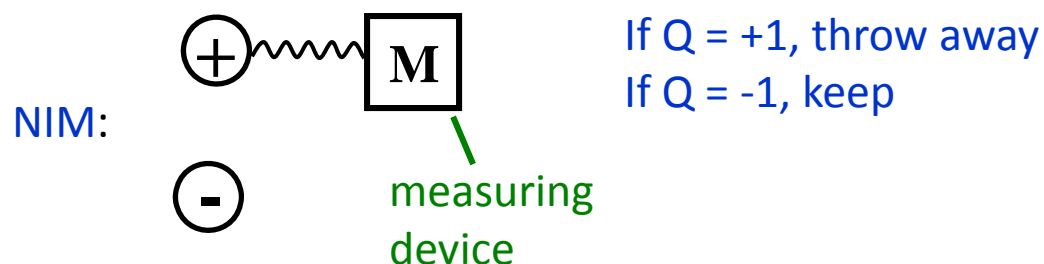
Any **macrorealistic** theory satisfies constraint

$$\langle Q(t_1)Q(t_2) \rangle + \langle Q(t_2)Q(t_3) \rangle + \langle Q(t_3)Q(t_4) \rangle - \langle Q(t_1)Q(t_4) \rangle \leq 2$$

which is violated (for appropriate choices of the  $t_i$ ) by the QM predictions for an “ideal” 2-state system

Definition of “macrorealistic” theory: conjunction of

- 1) induction
- 2) macrorealism ( $Q(t) = +1$  or  $-1$  for all  $t$ )
- 3) noninvasive measureability (NIM)



In this case, unnatural to assert 3) while denying 2).

NIM cannot be explicitly tested, but can make “plausible” by ancillary experiment to test whether, when  $Q(t)$  is **known** to be (e.g.)  $+1$ , a noninvasive measurement does or does not affect subsequent statistics. But measurements **must be projective** (“von Neumann”).

Existing experiments use “weak-measurement” techniques (and states are not macroscopically distinct)



## CONCLUSIONS

Macroscopic counterfactual  
definiteness



1. Realism in physics  $\cong$  MCFD
2. To maintain MCFD in EPR-Bell experiments, must sacrifice either induction or locality
3. To maintain MCFD in MQC experiment (if it comes out according to QM) must sacrifice either induction or NIM  $\leftarrow$  noninvasive measureability
4. If we are unwilling to make (both) these sacrifices, **must give up MCFD.**

Two experiments for the (distant) future:

1. Megascale EPR-Bell  
(would definitely close  
“collapse locality” loophole)



$\geq 10^6$  km

2. Wigner’s friend  
(cat  $\rightarrow$  friend: death  $\rightarrow$  mild electric shock)