Particle Physics and Philosophy

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Evening Lecture

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What's Philosophy Got to Do with It?

Common historical roots:

- Presocratic natural philosophers (Anaximander, Democritos etc.) proposed models of matter in terms of particles ("atoms").
- The founders of modern science primarily considered themselves as philosophers (cf. Newton's "Philosophiae Naturalis Principia Mathematica").

Some contemporary interactions:

- Research unit "The Epistemology of the LHC" www.lhc-epistemologie.uni-wuppertal.de
- Philosophical foundations of quantum gravity: www.beyondspacetime.net

Outline

What Is Scientific Realism?

Starting point: common sense realism

Everyday entities like tables and trees really do exist.

Although there are some philosophical reasons to question common sense realism, most people (even philosophers ☺) are common sense realists.

By contrast, the following claim is much more controversial:

Scientific realism

Scientific entities like electrons and black holes really do exist.

So the central question is: What arguments are there to doubt the existence of electrons or black holes, when one accepts the existence of tables and trees?

What Is Special about Scientific Entities?

1. Many scientific entities are unobservable. ("Observe" is here used in a narrow sense, which excludes the use of devices like microscopes or detectors.)
   → Constructive empiricism
2. When scientific theories change, entities described by the old theory may no longer be accepted in the new theory.
   → Pessimistic (meta-)induction
3. More than one scientific theory may be compatible with empirical data. And different theories may posit different entities.
   → Underdetermination of theory by evidence

Experimental Realism

Ian Hacking (1983):

"Experimental work provides the strongest evidence for scientific realism. This is not because we test hypotheses about entities. It is because entities that in principle cannot be 'observed' are regularly manipulated to produce new phenomena and to investigate other aspects of nature. They are tools, instruments not for thinking but for doing."

Reply to antirealistic arguments (cf. previous slide):

1. Science is not just about observation, but about manipulation.
2. Our hypotheses and theories may change, but our ability to manipulate entities does not.
3. Theories may be underdetermined by evidence, but the causal properties underlying our manipulations are not.

Refinement: Causal Scientific Realism

Two kinds of warrant for scientific realism (Egg 2014):

- In general, *Inference to the best explanation (IBE)* generates theoretical warrant.
- Some particularly strong instances of IBE generate causal warrant.

Criteria for causal warrant

Causal inference: The explanation has to be in terms of properties for which there is a clear notion of what it means to modify them.

Empirical adequacy: The explanation has to give an accurate account of what is observable.

Non-redundancy: It has to be the only (serious) explanation which does so.

The Neutrino Story: From Hypothesis to Detection

1930: Wolfgang Pauli postulates the neutrino to account for missing energy in nuclear beta decay.

1934: Enrico Fermi integrates the neutrino hypothesis into his theory of beta decay.

1956: Frederick Reines and Clyde Cowan "directly" detect the neutrino.

A puzzle for non-causal realism

After 1934, belief in the neutrino is warranted by IBE. What then is the importance of the 1956 experiment?

Warrant for the Neutrino Hypothesis

Situation before 1956

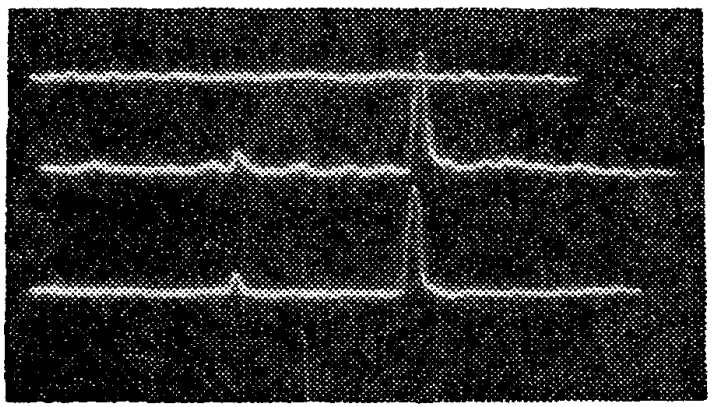
- The neutrino hypothesis (as part of Fermi's theory) was by far the best explanation of several phenomena in nuclear physics. $\rightarrow$ excellent theoretical warrant
- But there was still a redundancy of explanations, since these phenomena could also be explained by a failure of conservation laws (Niels Bohr). $\rightarrow$ no causal warrant

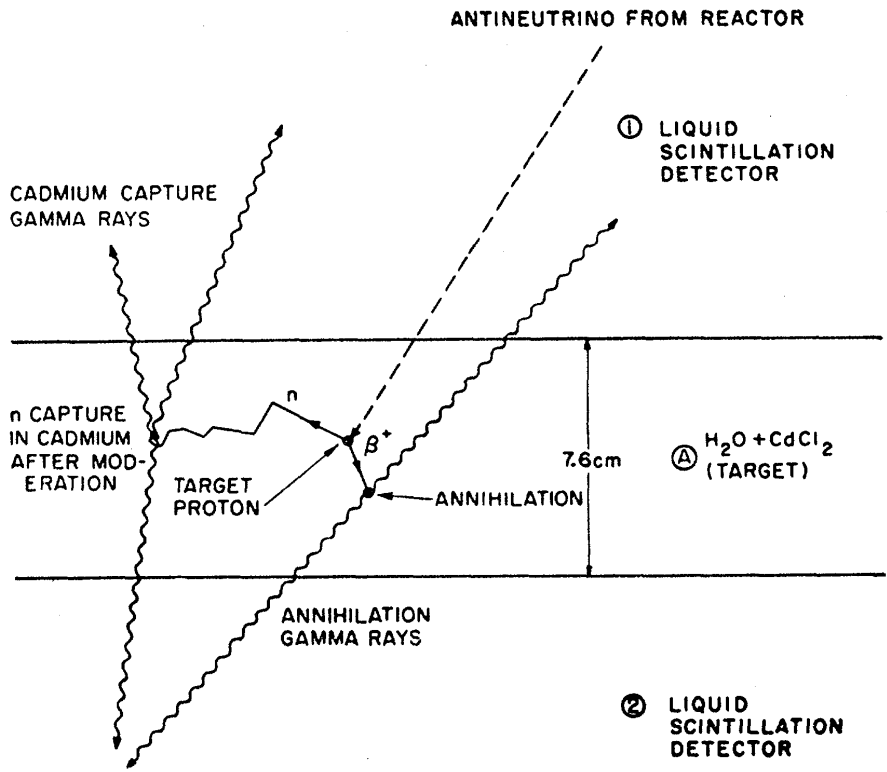
While the [neutrino] hypothesis has had great usefulness, it should be kept in the back of one's mind that it has not cleared up the basic mystery, and that such will continue to be the case until the neutrino is somehow caught at a distance from the emitting nucleus. Some physicists prefer to say simply that energy and momentum are apparently not conserved, giving full recognition, of course, to the energy and momentum relations that have been established experimentally, and to the success of the beta-ray theory which has been built upon the neutrino hypothesis. Perhaps all one can say is that this is a matter of taste. (Crane 1948, 278)

"Direct" Detection and Causal Warrant

The Reines-Cowan experiment (1956)

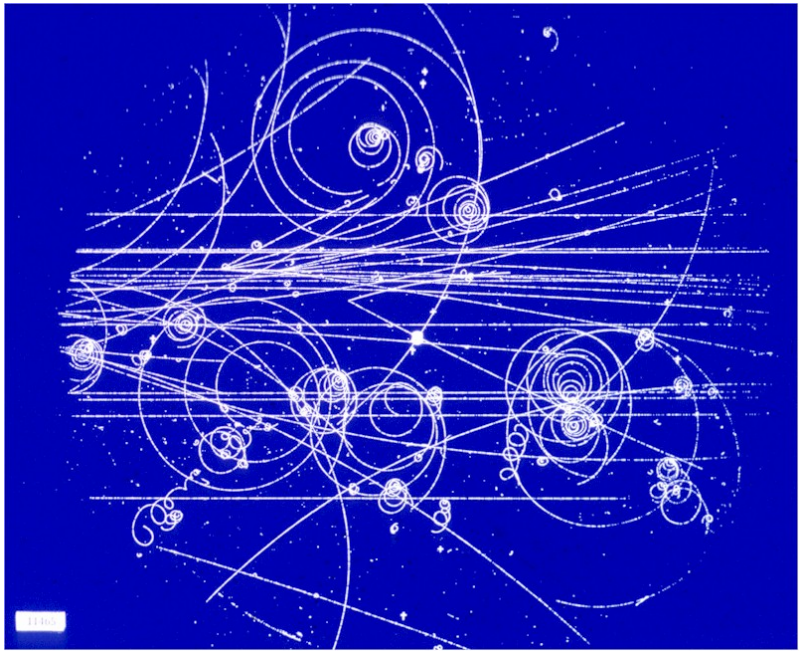
- detection of *inverse beta-decay*: $\bar{\nu} + p \rightarrow \beta^{+} + n$
- demonstration of a causal link between the activity of a nuclear reactor (which produces neutrinos) and the detected processes; $\rightarrow$ causal warrant





Particle Realism: Experiment and Theory

So, particle physics experiments seem to give us causal warrant for realism about particles (i.e., localizable, countable entities).



On the other hand, some results from QFT seem to speak against such realism:

- No-go theorems concerning localizability (Reeh-Schlieder, Malament, Hegerfeldt etc.)
- Problems for countability: no unique number operator (Haag's theorem, Unruh-effect)

Balancing Two Kinds of Warrant

Two opposing views on causal and theoretical warrant

1. When the two kinds of warrant pull in opposite directions, causal warrant trumps theoretical warrant.
2. Causal warrant does not hold any special status.

- An extreme version of 1, which completely disregards theoretical considerations, is implausible in light of experiment-theory interdependence.
- A moderate version of 1 is supported by the neutrino case study discussed above.
- By contrast, the QFT-based case against particles seems to presuppose 2.
- Surprisingly, however, one version of this case turns out to be committed to 1.

Wallace vs. Fraser on QFT

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Taking particle physics seriously: A critique of the algebraic approach to quantum field theory

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ABSTRACT

I argue against the currently prevalent view that algebraic quantum field theory (AQFT) is the correct framework for philosophy of quantum field theory and that "conventional" quantum field theory (CQFT)

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How to take particle physics seriously: A further defence of axiomatic quantum field theory

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ABSTRACT

Further arguments are offered in defence of the position that the variant of quantum field theory (QFT) that should be subject to interpretation and foundational analysis is axiomatic quantum field theory

Fundamentally Different Approaches to QFT

- Wallace's particle realism in a nutshell: The standard model of particle physics (based on QFT with renormalization and a finite cutoff, CQFT) is empirically successful, hence it is approximately true (by IBE).
- Fraser (2009, 2011): Algebraic QFT (AQFT) offers an alternative (incompatible) explanation, hence there is underdetermination.
- Wallace (2011): There is not (yet) any realistic AQFT model in 3+1 dimensions, so there is no actual underdetermination.
- Fraser: Still, AQFT puts constraints on any acceptable account of particle physics. In particular, they should admit unitarily inequivalent representations, which CQFT does not.

Wallace vs. Fraser on Inequivalent Representations

- Wallace: The inequivalent representations which distinguish AQFT from CQFT are associated with short-distance behaviour, and there we should not trust QFT anyway:

  > *Whatever our sub-Planckian physics looks like (...), there are pretty powerful reasons not to expect it to look like quantum field theory on a classical background spacetime. (Wallace 2011, 120–121)*

  This justifies the application of renormalization group methods in QFT, in analogy to condensed matter physics.
- Fraser: This analogy does not hold, because in the condensed matter case we have experimental evidence for a discrete structure responsible for the breakdown of field theory at small distances.

Two Kinds of Evidence (Warrant) Revisited

Two opposing views on causal and theoretical warrant

1. When the two kinds of warrant pull in opposite directions, causal warrant trumps theoretical warrant.
2. Causal warrant does not hold any special status.

Conclusion

For this argument against particle realism to go through, Fraser needs to admit that causal warrant trumps theoretical warrant (option 1 above). But this undermines AQFT-based arguments against particles in general.