A1 report: virtual particles and more…

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Different projects under way

- From Yukawa to Feynman: development of the virtual particle concept in the meson theory
- Virtuality in nuclear physics in the 1930s: meanings of an emerging concept
- Energy conservation and virtual particles: an historical approach (with Karla Weingarten)
- The end of the particle era (with Robert and Gregor)

Project 1: From Yukawa to Feynman (Further inquiries on the 1940s)

Output: submission of an article to a journal yet to be determined (summer/autumn 2022).

Yukawa’s meson theory in North America in the 1940s

- The meson theory was in 1947 one of the main themes of the Shelter Island Conference, which was a landmark in the American history of theoretical physics and, more specifically, for the developments of QED.
- There, Marshak and Bethe postulated their two-meson hypothesis (muons are the decay products of nuclear pions) which was responsible for elucidating the structure of the mesonic component of cosmic-rays.
- It was supported by the concomitant experimental discovery of the pion by Powell, Lattes, and Occhialini.

→ **A popular research topic of which Marshak was one of the main proponents.**

From Rochester to Cornell? (1/2)

"[a]fter these physicists left Los Alamos for their home institutions, Marshak, Bethe, Feynman, and the others inaugurated a series of regular, informal meetings between the Rochester and Cornell groups".

David Kaiser, *Drawing Theories Apart*, 2005.

- Marshak's first use of the terminology "virtual meson" appeared in a paper published in May 1949 with Foldy (the meson theory was then the only field where such terminology of "virtual particle" was used).

PHYSICAL REVIEW VOLUME 75, NUMBER 10 MAY 15, 1949

Production of π-Mesons in Nucleon-Nucleon Collisions

L. L. FOLDY
Case Institute of Technology, Cleveland, Ohio

AND

R. E. MARSHAK
University of Rochester, Rochester, New York

(Received December 23, 1948)

calculation. These "exchange" terms arise from the creation of the real meson in the second step (in the scheme of perturbation theory) while the virtual meson is created in the first step and destroyed in the third. The "ordinary" terms in which the virtual meson is created and destroyed in the first two steps or the last two steps comprise the terms which are essentially taken into account by our method. Fortunately, it can be shown[4] that the

From Rochester to Cornell? (2/2)

- This is where Feynman comes into play, since he directly contributed to the calculations of the Foldy and Marshak’s article.
- His 1949 article, which introduced Feynman diagrams, was then published only four months later.
- It presented Feynman's first generalization of the "virtual particle" terminology, including numerous references to "virtual mesons."

PHYSICAL REVIEW VOLUME 76, NUMBER 6 SEPTEMBER 15, 1949

Space-Time Approach to Quantum Electrodynamics

R. P. Feynman
Department of Physics, Cornell University, Ithaca, New York
(Received May 9, 1949)

Just a coincidence? Probably not.

- Feynman used the meson theories to put his QED method to the test.
- His article included diagrams that represented the processes of meson emission in a nucleus.
- This testifies of his good knowledge of the meson theories.
- Interestingly, his work was initially better received by specialists of the meson physics.

10. APPLICATION TO MESON THEORIES

The theories which have been developed to describe mesons and the interaction of nucleons can be easily expressed in the language used here. Calculations, to lowest order in the interactions can be made very easily for the various theories, but agreement with experimental results is not obtained. Most likely all of our present formulations are quantitatively unsatisfactory. We shall content ourselves therefore with a brief summary of the methods which can be used.

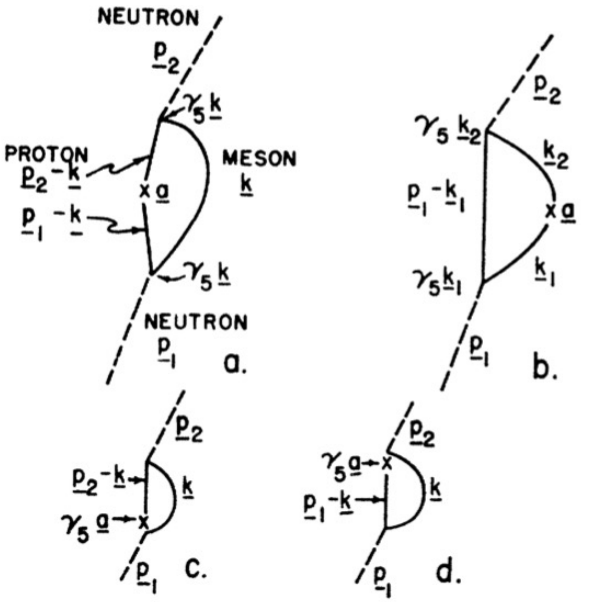

FIG. 10. According to the meson theory a neutron interacts with an electromagnetic potential ***a*** by first emitting a virtual charged meson. The figure illustrates the case for a pseudoscalar meson with pseudovector coupling. Appendix D.

Project 2: Virtuality in nuclear physics in the 1930s (Clarifications on the origins of the term virtual)

Output: an article to be published in *Perspectives on Science.*
Part of a special issue on "Virtual entities in science" whose guest editors are the members of A1.
Result from the Workshop organized by A1 in March 2021.
10 contributions (deadline for submission: 31st of March 2022).

Structure of the article (1/2)

Main idea: Two paths of development of the notion of virtuality in nuclear physics in the 1930s. Their comparative study can help to better understand the meaning of the term virtual.

- **Section 1**: Beck's virtual states (1930) / Resonances
  - Virtual states are responsible for resonance effects in nuclear scattering processes.
- **Section 2**: Raman's virtual transitions (1929) / Virtual particles
  - Virtual transitions to intermediate states (emission and absorption) are responsible for the nuclear force (nucleon-nucleon interaction).

Structure of the article (2/2)

- **Section 3**: why virtual?
  - Strong influence (but mere analogies) of the 1924 BKS theory of radiation (short-lived theory which was the first to introduce the notion of virtuality in modern physics – virtual oscillators).
  - All works (Beck, Raman, BKS) strongly tied to optics.
  - Virtual states, virtual transitions, and virtual oscillators as mathematical constructs. Support an understanding of the virtual in Charles Sanders Peirce’s sense: a virtual X (where X is a common noun) is something, not an X, which has the efficiency (virtus) of an X.
- **Section 4**: alteration of meaning
  - The physical features nowadays strongly attached to the notion of virtuality in modern physics (such as unobservability and non-conservation of energy) were not determinant in the original choice of the term “virtual” (not present in Beck’s work).
  - Nevertheless, from the mid-1930s, these physical features were used to justify such a terminological choice in the case of virtual transitions. Nowadays, the popularity of the concept of virtual particle (and the lack of knowledge of that of virtual state) accentuates their role.

Future project?

Many points of convergence throughout history between Beck's virtual states and Raman's virtual transitions, i.e., between the concept of resonance in nuclear scattering processes and virtual particles. Among others:

- Beck's "virtual electron" in 1933
- Breit and Wigner analogy of nuclear scattering and the problem of absorption of light in 1936
- Resonances as particles in accelerator physics from the 1960s.

Lots of confusion, no consistent use of terms in current physics:

- Wikipedia's page on "virtual state"
- Modern distinction between resonances and virtual states (different poles of the S-Matrix)
- Negative binding energy
- Virtual particles and resonant particles…

→ Interest in further investigating such issues.

Project 3: Virtual particles and energy conservation (a historical approach)

With Karla Weingarten

Output: submission of an article to a journal yet to be determined (end of year 2022).

Weingarten, K. (2021). *The Reality of Virtual Particles and the Question of Energy Conservation*. Bachelor Thesis, RWTH Aachen University.

Problematics: how is the problem of energy conservation approached by physicists? And how does it influence the reality debate?

- Highlights the disagreements on the energy conservation of virtual particles in the physics community and discusses the nature of the different points of view.
- Evaluates the importance of this question in debates about reality and shows that although important to physicists, it is relatively ignored by philosophers.

A historical perspective?

The thesis suggests that the different views expressed on energy conservation may have been strongly influenced by different historical developments.

- Energy conserved as a statistical quantity only: BKS theory
- The Heisenberg's uncertainty relation allows for violation of the conservation principle: Yukawa's meson theory
- Virtual particles become off-shell to satisfy energy conservation: time-dependent perturbation theory

→ Preparation of an article that further elaborates on this point

Project 4: The end of the particle era

With Robert Harlander and Gregor Schiemann

Output: submission of an article to a journal yet to be determined (spring 2022).

We do know that there is physics beyond the SM. This be because of a number of shortcomings of the SM. However, we do not know which energy is required to prove the existence of this new physics. This implies two possibilities:

1. All shortcomings of the SM will be solved by physics that can be discovered at particle colliders. This means that we will have a complete theory of nature within the era of particle colliders. It would mark the successful end of fundamental physics.

2. At least some open problems in fundamental physics remain after the end of particle colliders. Progress to physics will then no longer come from the discovery of particles (at least in its current form).

It is therefore inevitable that the end of particle discoveries will be reached, unless the requirement of "on-shellness" will be discarded from the notion of particle observation. One of the main points of this paper is to point out the possibility that this end has already been reached.

An interdisciplinary approach

- In this work, historical and philosophical considerations are developed to support the physical arguments related to the view that the "particle era" could be coming to an end. More precisely, a history of the concept of particle is proposed.
- It puts forward an understanding of the particle era as starting from the early years of subatomic physics (at the turn of the 19^{th} and 20^{th} centuries) and characterized by the highly formative role played by the particle concept, in other terms, by its powerful illustrative, operational, and heuristic values.
- Also, it emphasizes a very diverse and progressive path of development dealing with the particle properties relevant for their discovery (kinetics, tracks, peaks).

Structure of the article

- **Section 1**: history of the particle concept
- **Section 2**: current state of particle physics
  - Discusses the possible sources from which hints for physics beyond the SM could be derived (observational and theoretical sources / experimental anomalies) and argues that none of them let us expect fundamentally new physics at energies accessible by a new particle collider.
- **Section 3**: the desert ahead
  - The gap between the energies accessible at any conceivable particle collider and the scale of gravity is too large to consider that the next step, solving the current anomalies of the SM, would provide the "final theory." Then, the hunt for "bumps" in colliders would not be the successful discovery method any longer.
  - This section therefore discusses the need to accept or develop new means of observation (as it has been the case several times in history) which would be accompanied by a profound upheaval, or even the abandonment, of the particle concept.

Thank you for your attention!