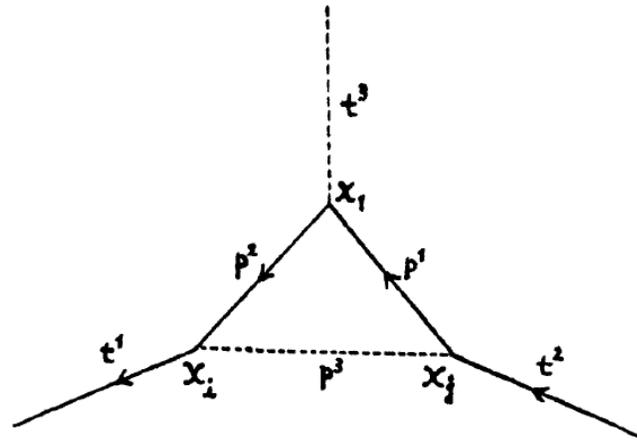


Feynman's struggle and Dyson's surprise revelation

Inconspicuous but fundamental revisions to the foundations of quantum electrodynamics through the development of an appropriate means of representation



Feynman ca. 1946



Dyson 1949

1 Introduction: genesis, modern application and interpretation of Feynman diagrams

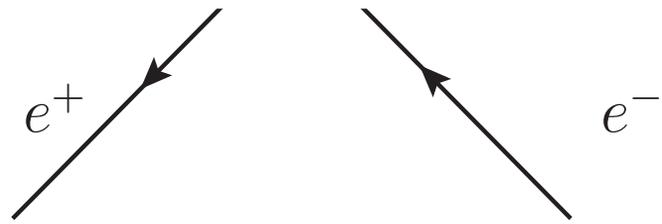
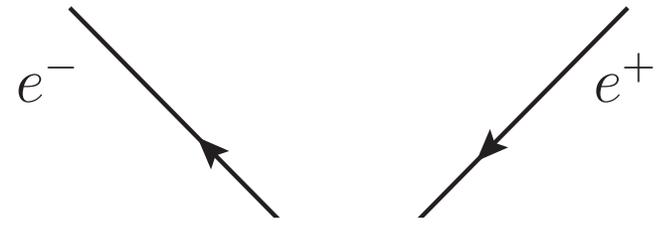
2 Feynman's struggle for a physical interpretation of the Dirac equation

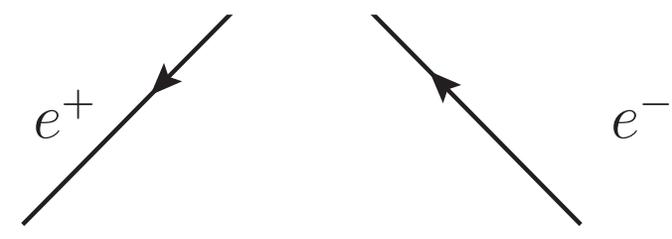
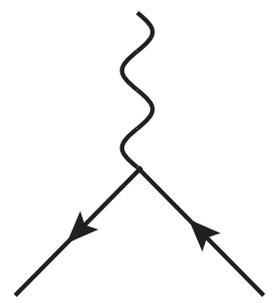
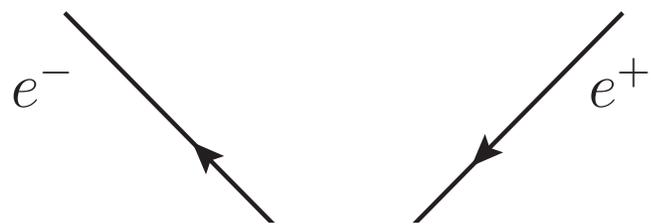
- Feynman's programme
- Quivering electron
- Positrons and interaction
- Abandoning the microscopic model

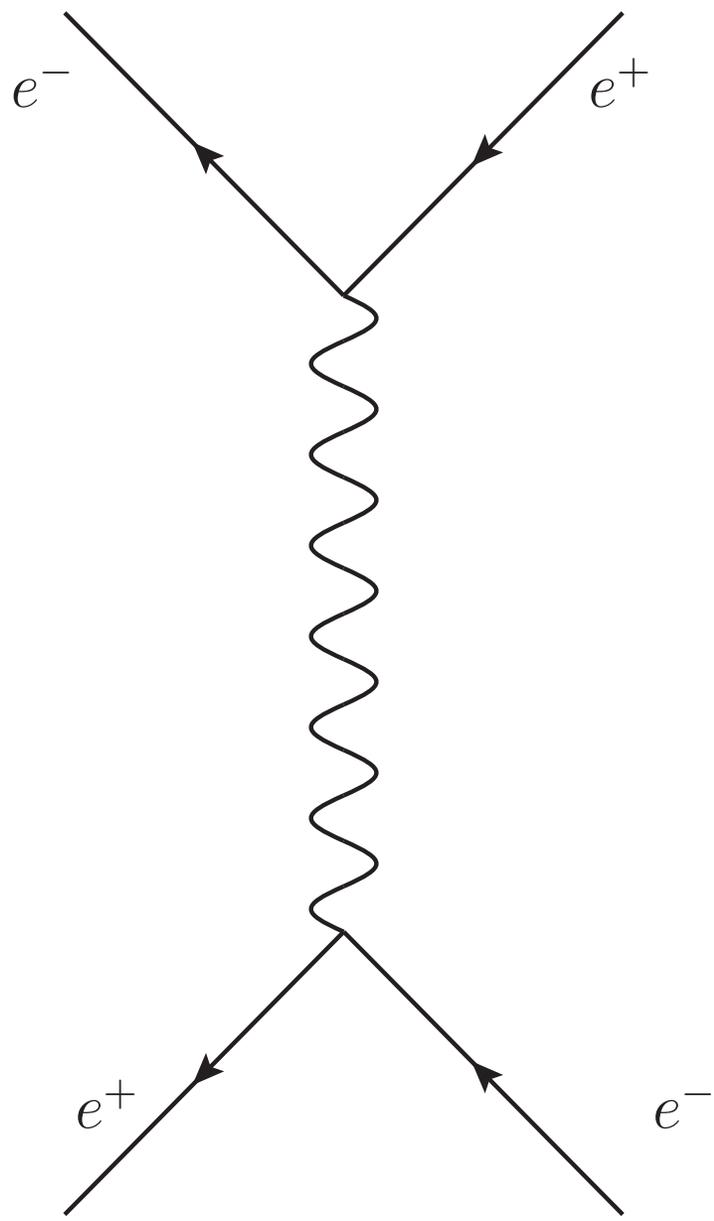
3 Dyson's systematization and theoretical update

- Renormalization
- Removal of divergences through appropriate representation

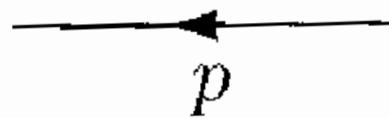
Genesis, modern application and interpretation of Feynman diagrams





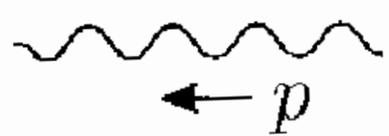


Feynman rules



A horizontal line with an arrow pointing to the left, labeled with the momentum p below it.

$$= \frac{i(\not{p} + m)}{p^2 - m^2 + i\epsilon}$$



A wavy horizontal line with an arrow pointing to the left, labeled with the momentum p below it.

$$= \frac{-ig_{\mu\nu}}{p^2 + i\epsilon}$$



A vertex where a wavy line labeled μ meets two fermion lines. The fermion lines have arrows pointing away from the vertex.

$$= iQe\gamma^\mu$$

Peskin and Schroeder 1995, pp. 801–802

Received view

- Not a representation of a physical process

Received view

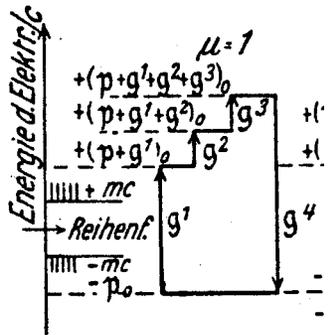
- Not a representation of a physical process
- Invention of a system of abbreviations

Received view

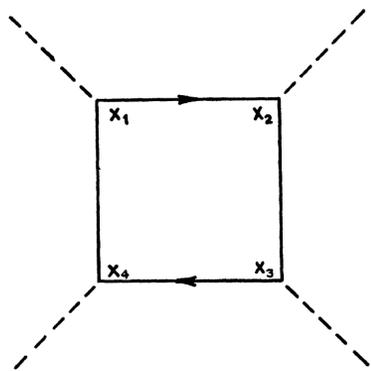
- Not a representation of a physical process
- Invention of a system of abbreviations
- No modifications to the physical content

Brown (1996): Illustration and Inference; Schweber (1994): QED; Dyson (1965): Nobel Prize

Light-by-light scattering

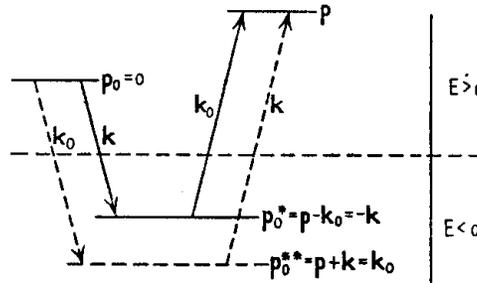


Euler 1936



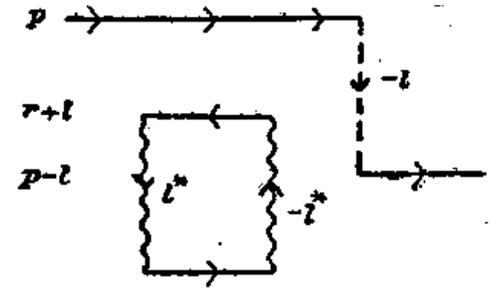
Karplus 1950

Compton scattering

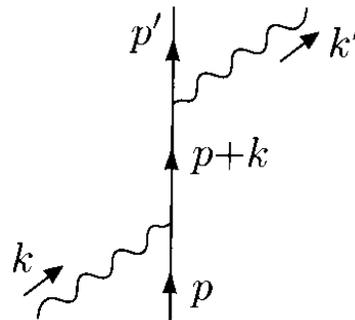


Heitler 1944

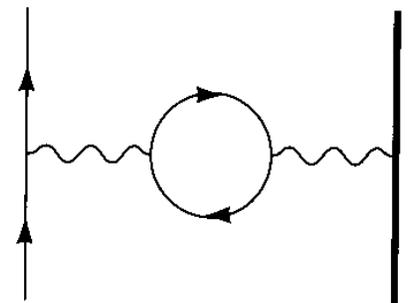
Electron scattering off a potential



Koba & Takeda 1949



Peskin & Schroeder 1995



Peskin & Schroeder 1995

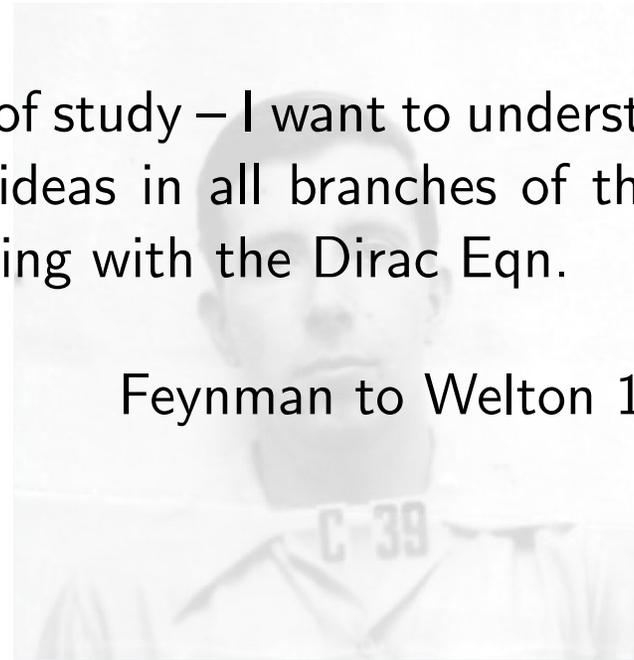
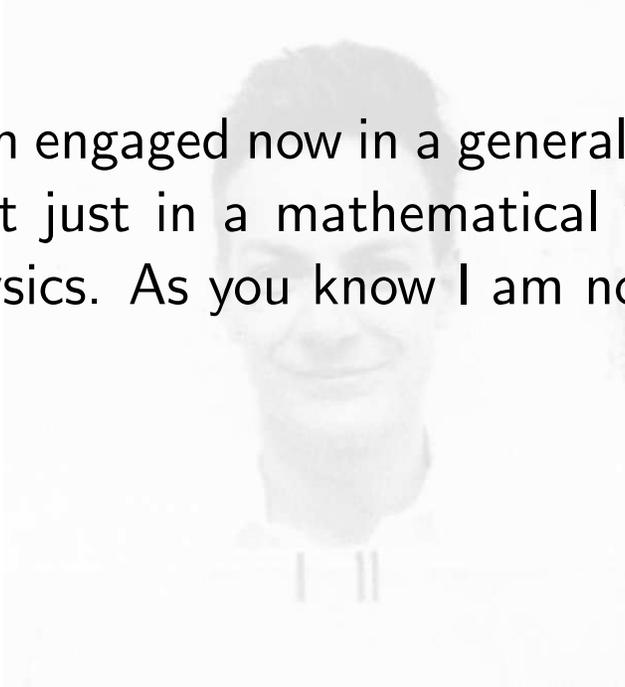
Feynman's struggle for a physical interpretation of the Dirac equation



Los Alamos badge photos from Welton 2007

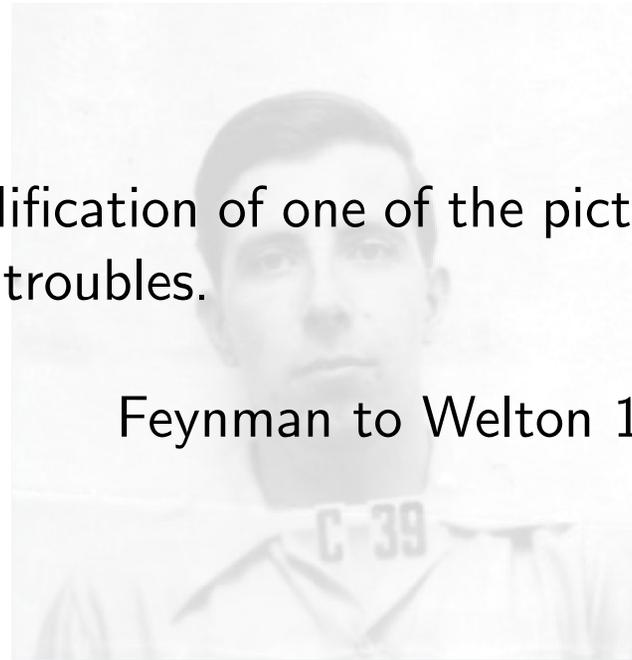
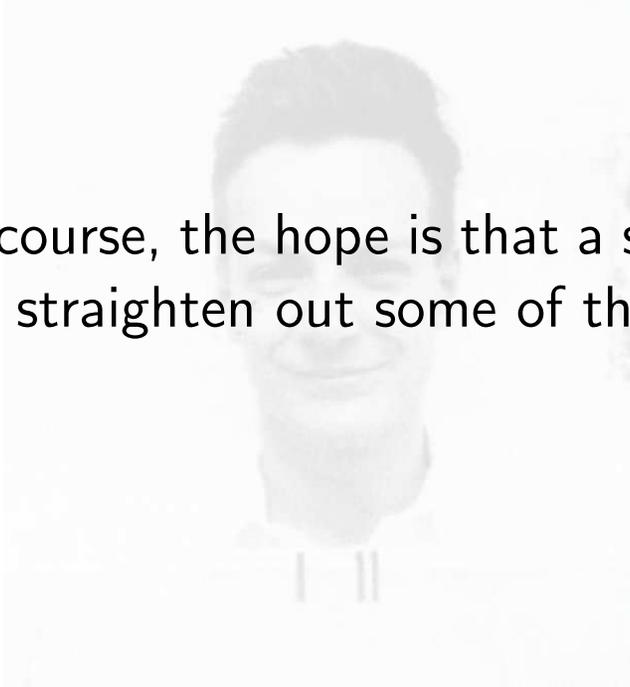
Feynman's programme

I am engaged now in a general program of study – I want to understand (not just in a mathematical way) the ideas in all branches of theor. physics. As you know I am now struggling with the Dirac Eqn.



Feynman to Welton 1947

Of course, the hope is that a slight modification of one of the pictures will straighten out some of the present troubles.



Feynman to Welton 1947

Zitterbewegung

The one dimensional Dirac Eqn.

$$\frac{\partial \psi_1}{\partial t} + \frac{\partial \psi_3}{\partial z} = -i\mu\psi_1$$

$$\frac{\partial \psi_3}{\partial t} + \frac{\partial \psi_1}{\partial z} = +i\mu\psi_3$$

$$H\psi = \phi\psi + \alpha(p - A)\psi - \beta\mu\psi$$

$$\dot{F} = i(HF - FH) + \frac{\partial F}{\partial t}$$

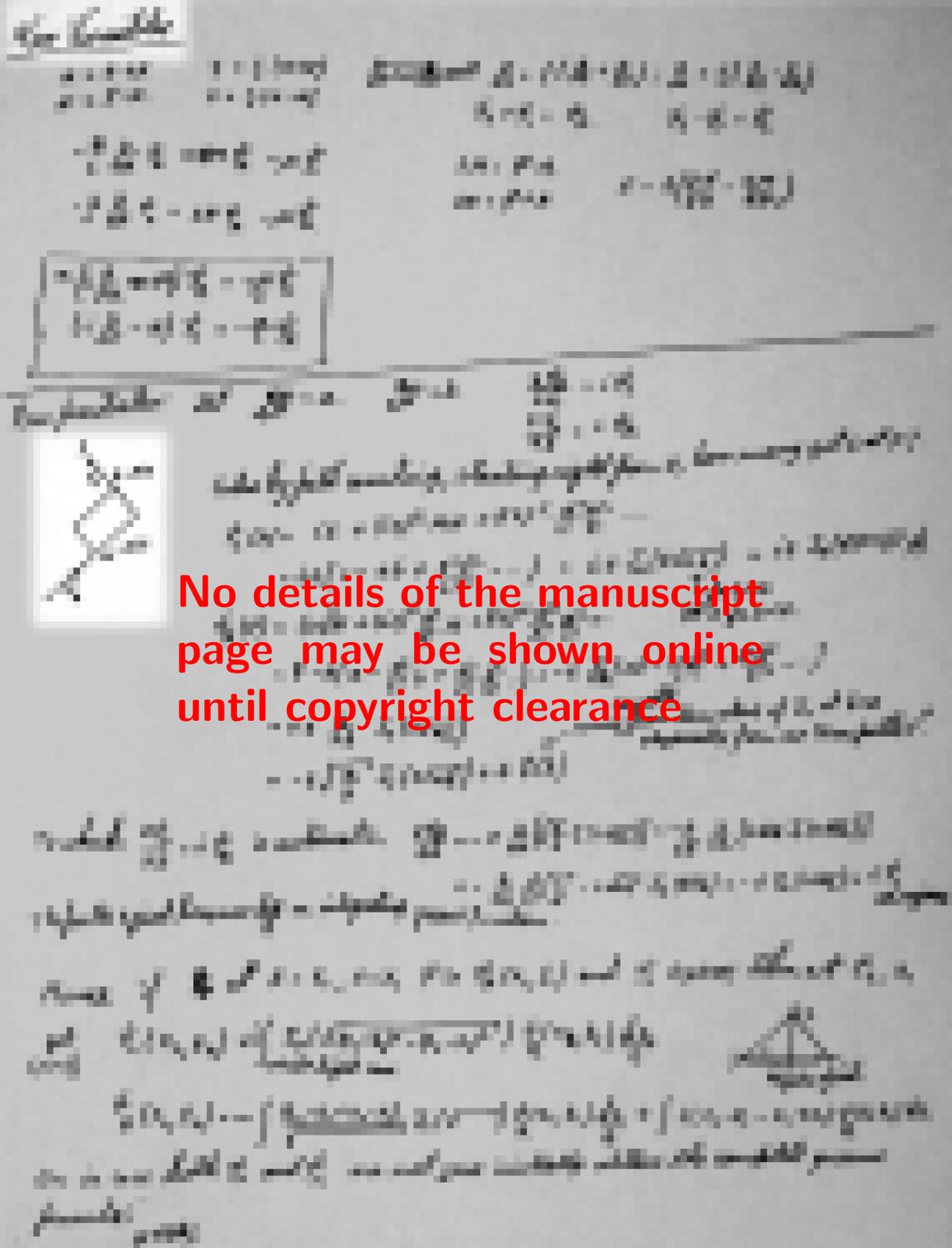
$$\dot{x} = \alpha$$

(Breit 1928, Schrödinger 1930,
Dirac 1933, 1935)

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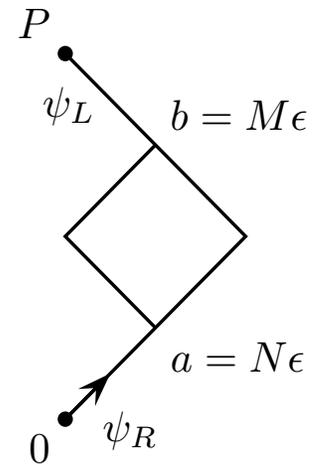
New Variables

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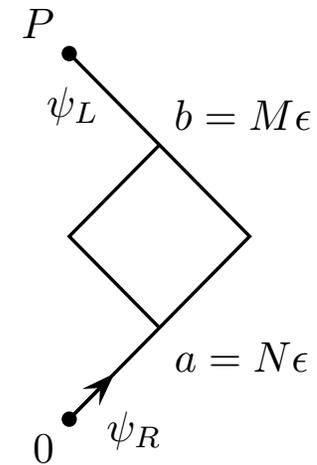


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New Variables



New Variables

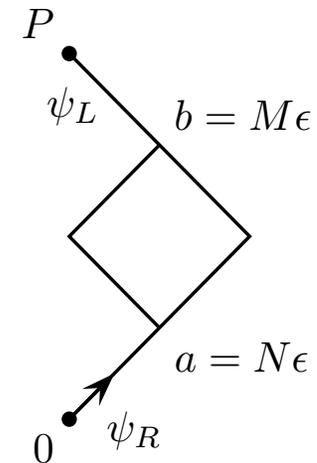


Solve by path counting

$$\begin{aligned}\psi_L(P) &= i\epsilon \\ &+ (i\epsilon)^3 MN \\ &+ (i\epsilon)^5 \frac{M^2}{2!} \frac{N^2}{2!} \dots\end{aligned}$$

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New Variables



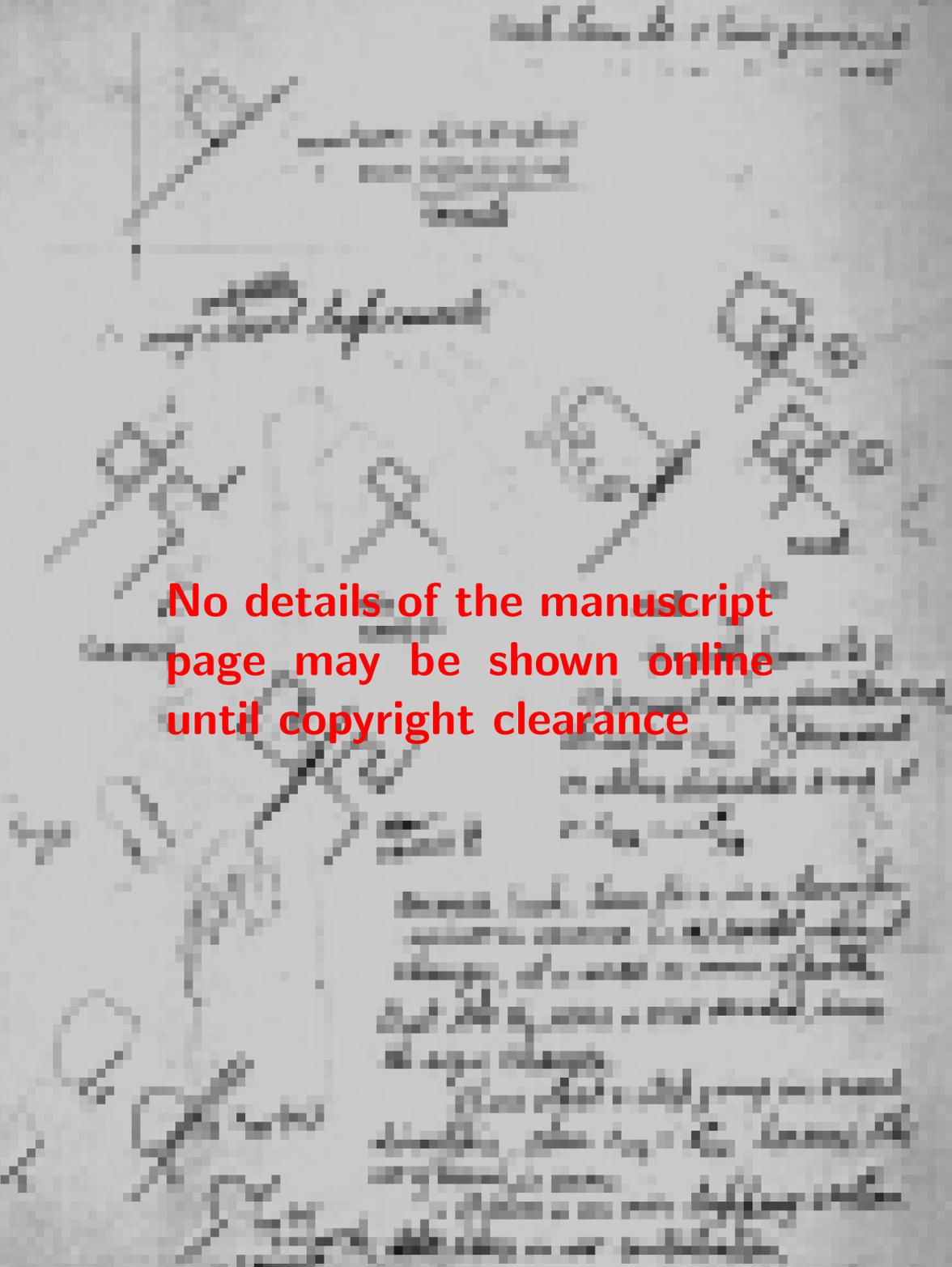
Solve by path counting

$$\begin{aligned}\psi_L(P) &= i\epsilon \\ &+ (i\epsilon)^3 MN \\ &+ (i\epsilon)^5 \frac{M^2}{2!} \frac{N^2}{2!} \dots\end{aligned}$$

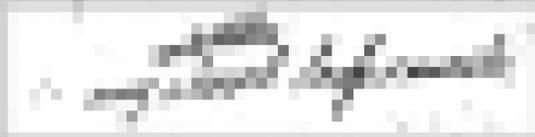
Green's function

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Positrons and interaction



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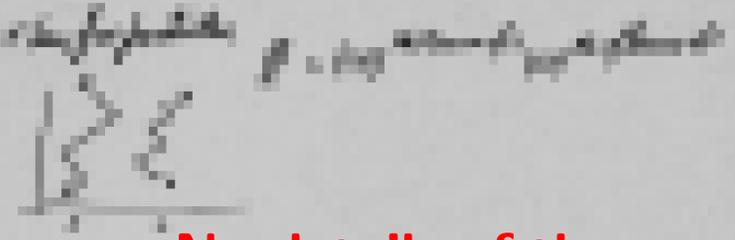


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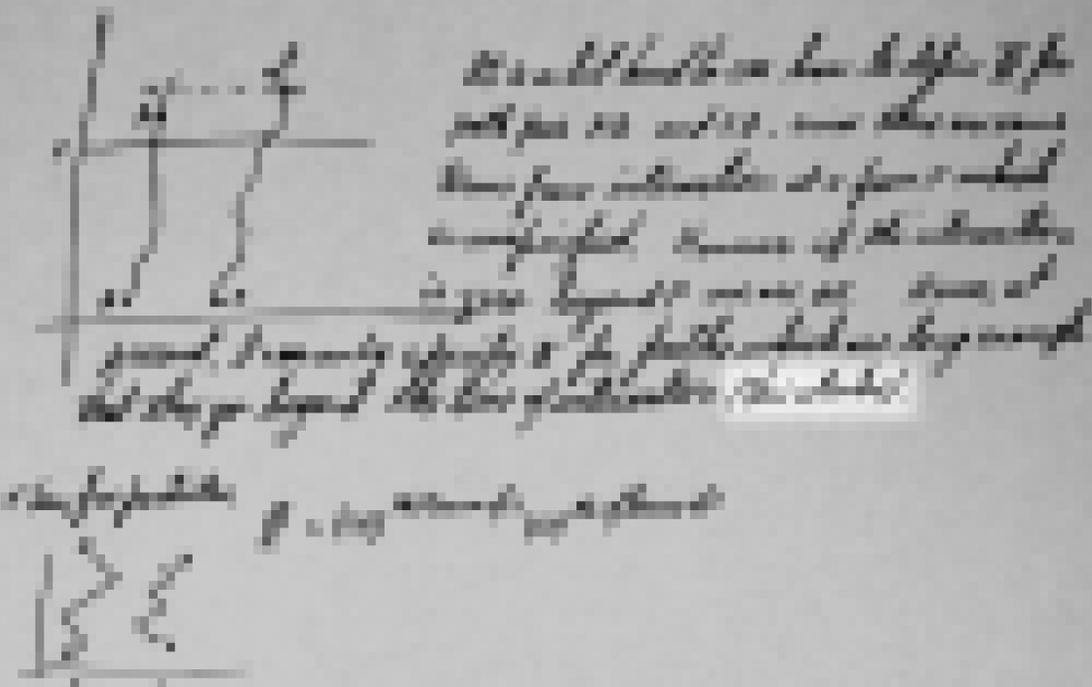
∴ any completely closed
loop cancels



The world has been the subject of the
past few years and it is now the
time for a new era of growth and
development. The world is
a great place and we are proud
to be a part of it. We are
committed to the future and
we are committed to the world.



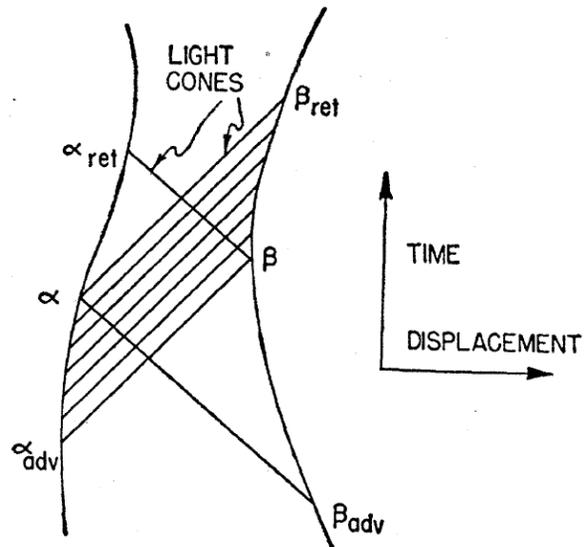
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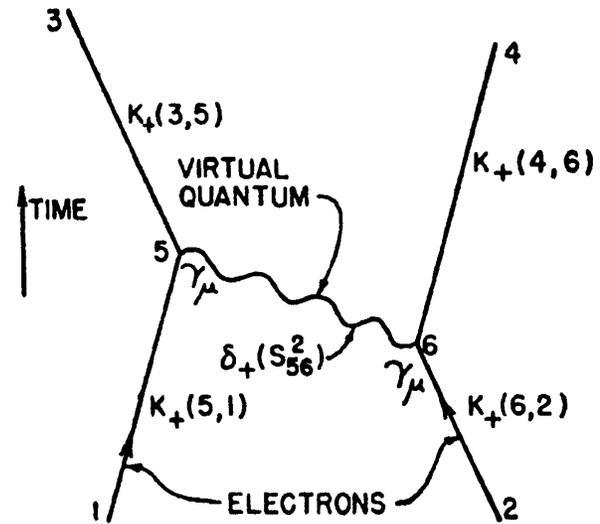
this stinks

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Abandoning the microscopic model



Wheeler and Feynman 1949

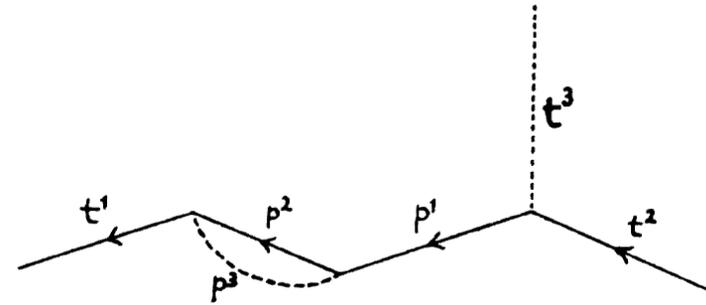
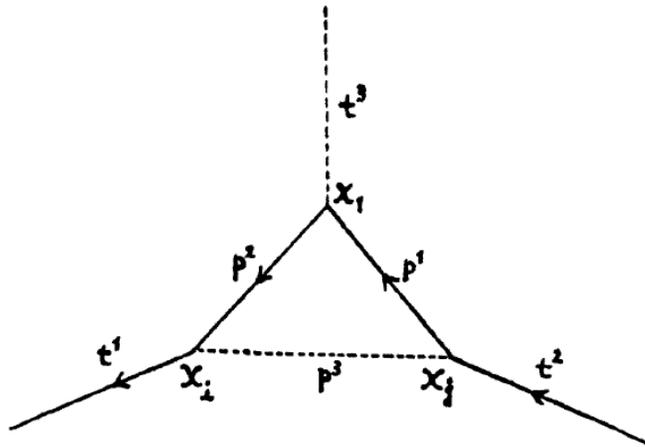


"Space-Time Approach to QED"
(Feynman 1949)

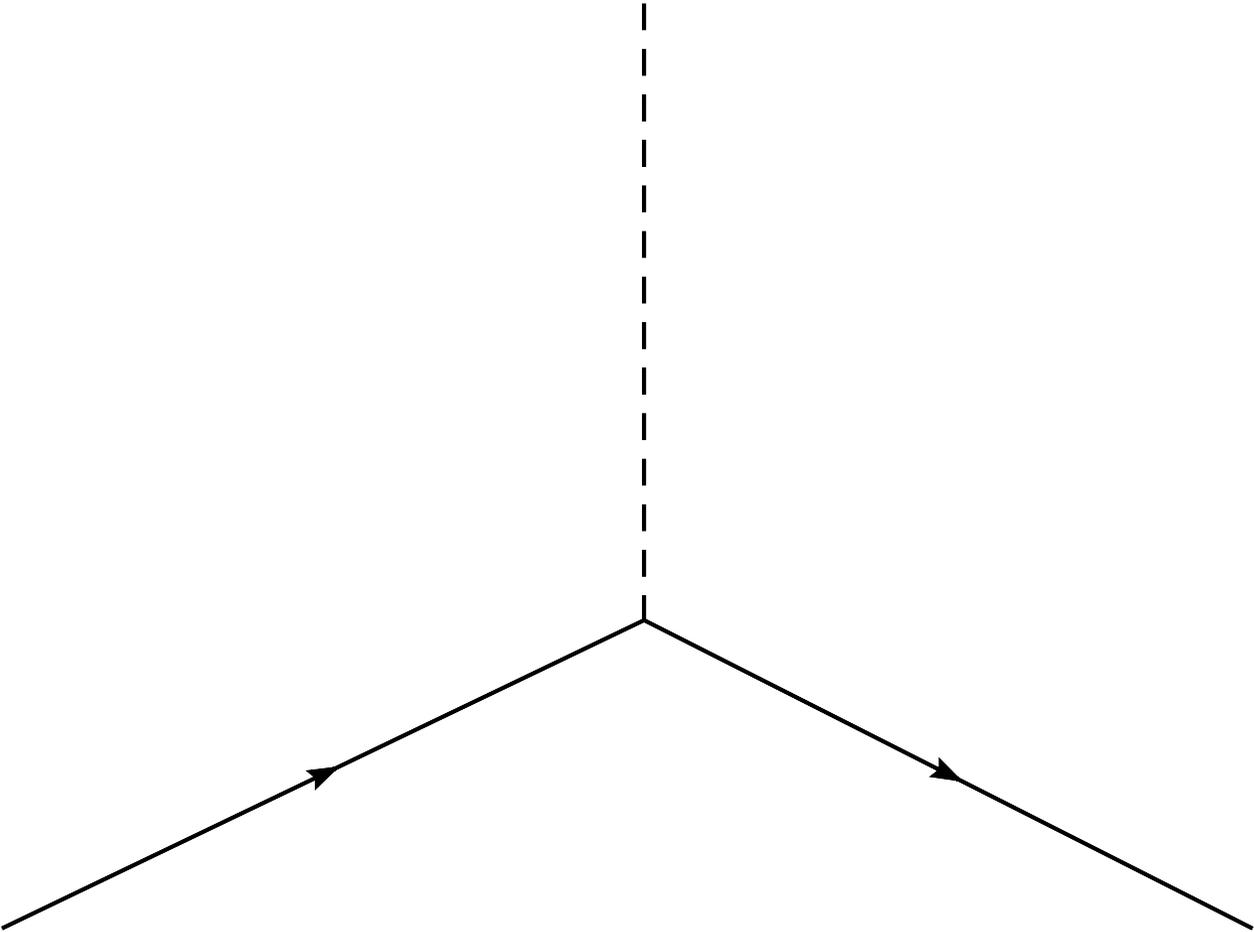
Dyson's systematization and theoretical update

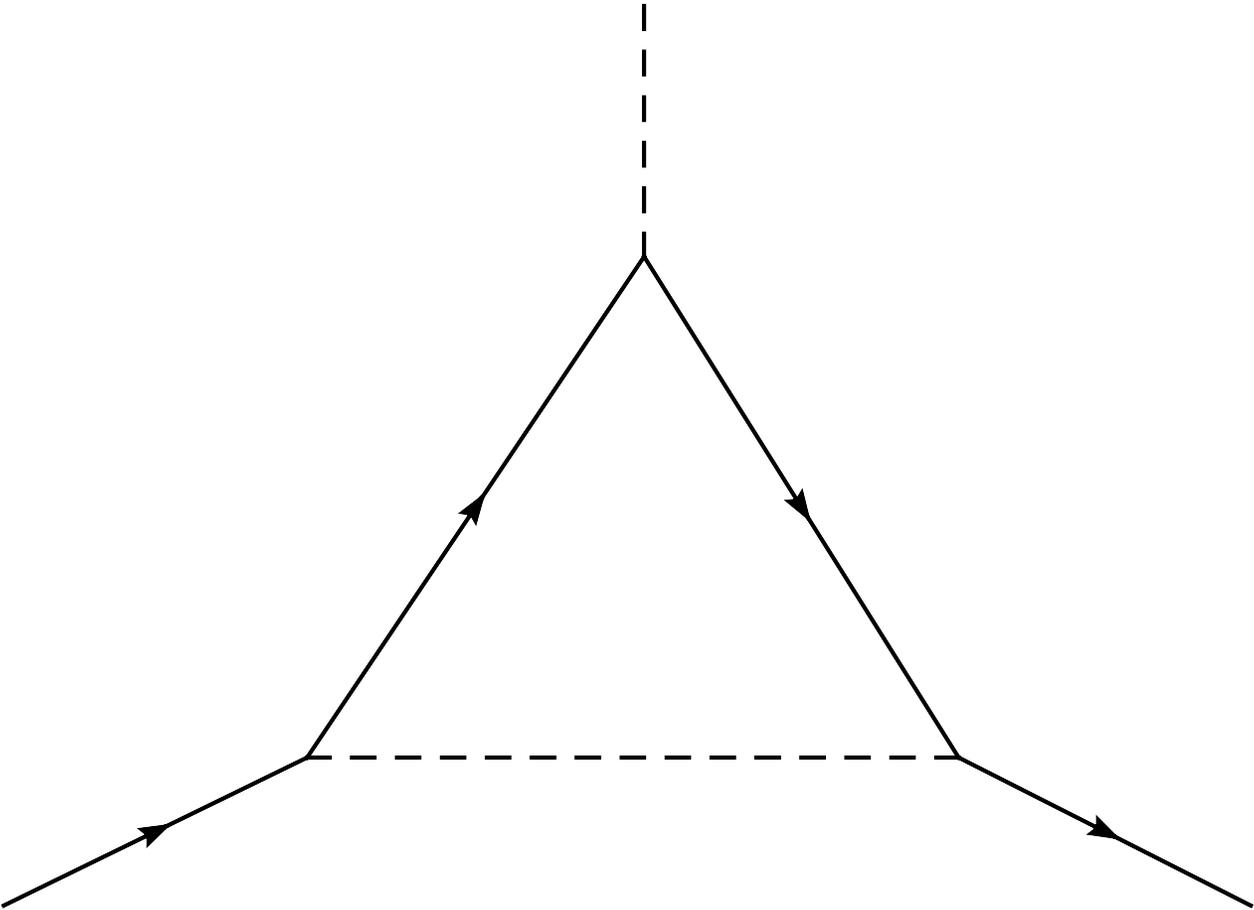


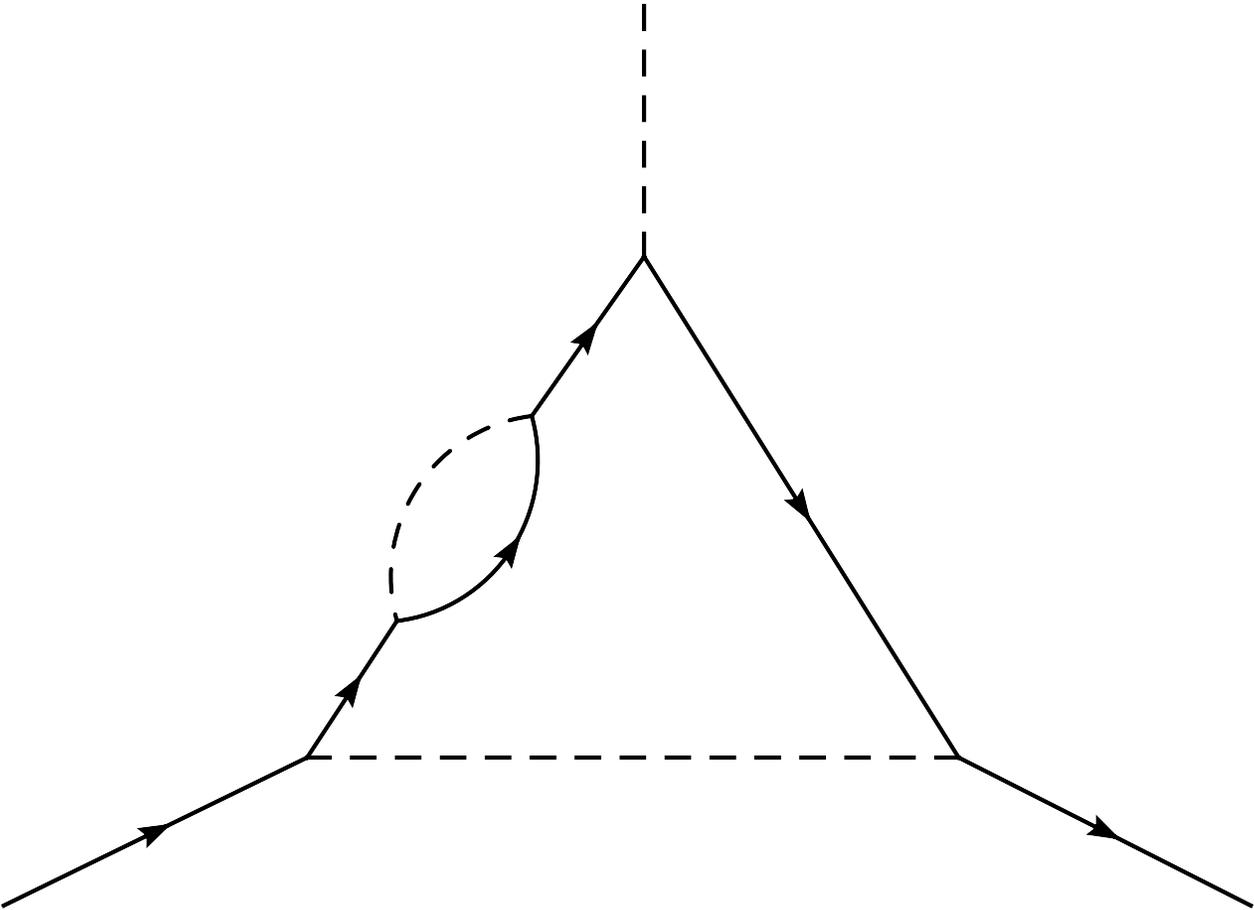
Freeman Dyson at Princeton, 1972. From www.nytimes.com

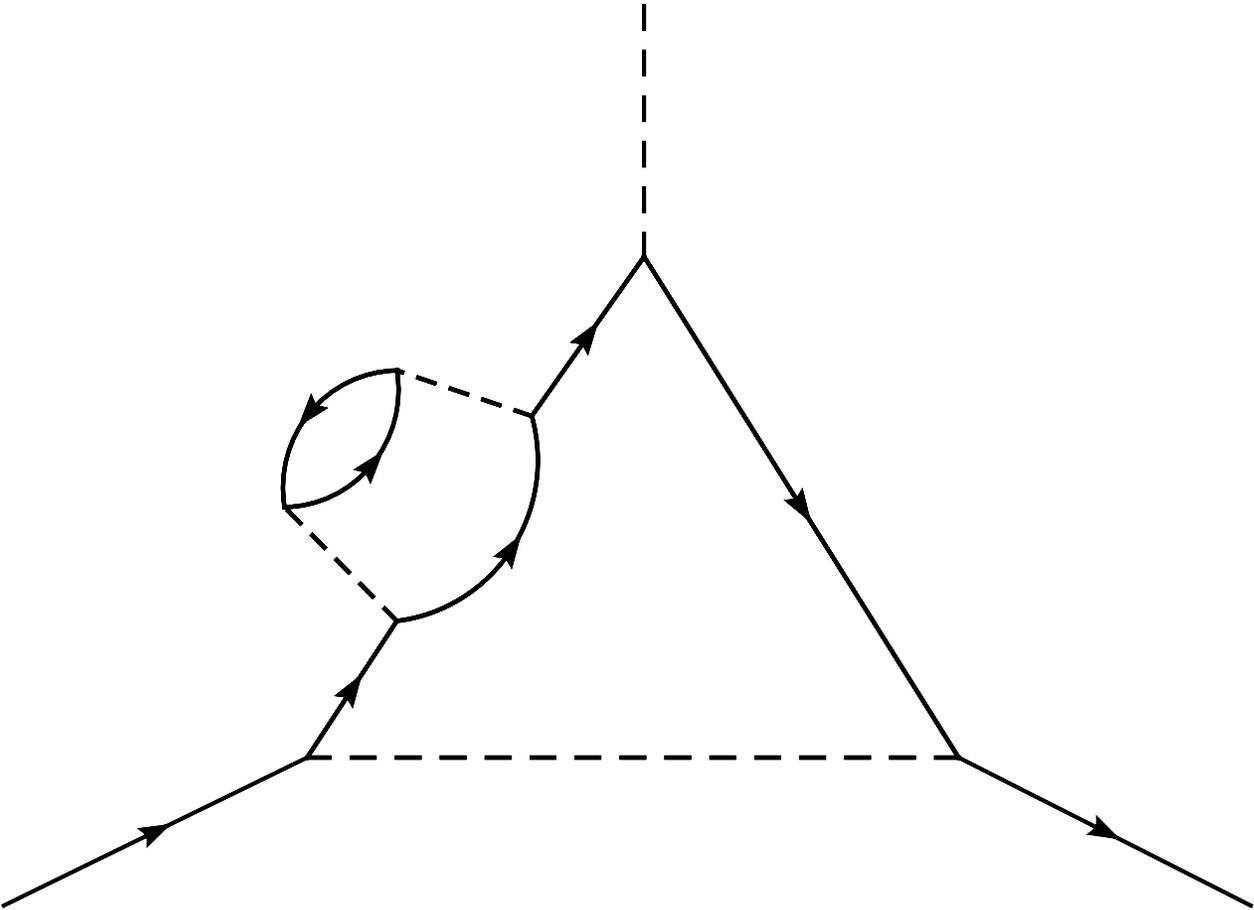


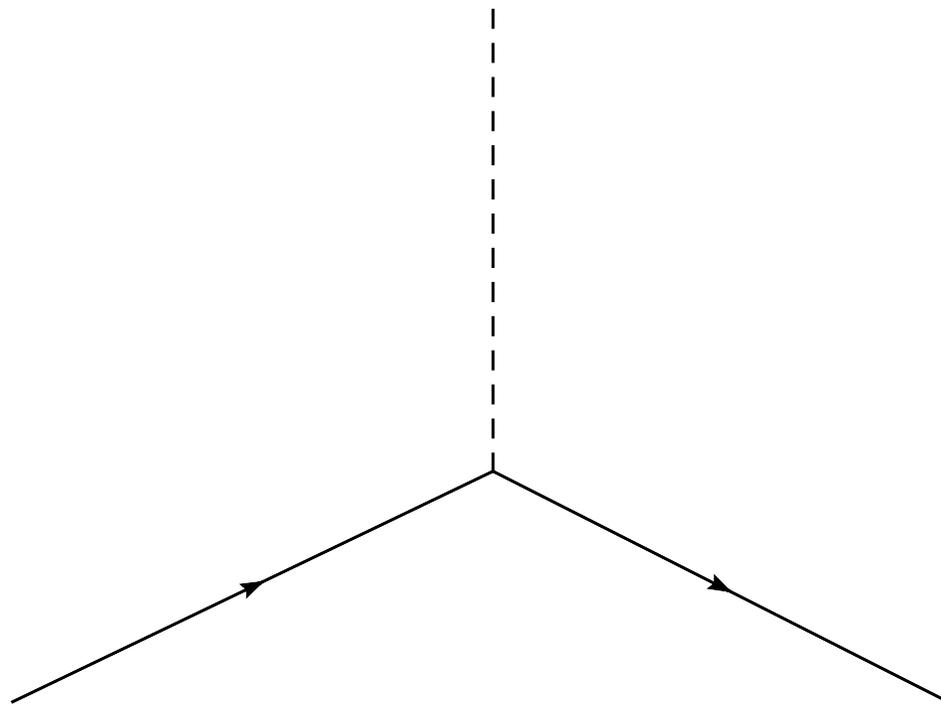
“The S Matrix in QED” (Dyson 1949)











$$S_F \rightarrow S'_F = Z_2 S'_{F1}(e_1)$$

$$D_F \rightarrow D'_F = Z_3 D'_{F1}(e_1)$$

$$\gamma_\mu \rightarrow \Gamma_\mu = Z_1^{-1} \Gamma_{\mu 1}(e_1)$$

Renormalization

Removal of divergences through appropriate representation

The surprising feature of the S matrix theory, as outlined in this paper, is its success in avoiding difficulties. Starting from the methods of Tomonaga, Schwinger and Feynman, and using no new ideas or techniques, one arrives at an S matrix from which the well-known divergences seem to have conspired to eliminate themselves. This automatic disappearance of divergences is an empirical fact, which must be given due weight in considering the future prospects of electrodynamics.

“The S Matrix in QED” (Dyson 1949, p. 1754)

Acknowledgements: Gerd Graßhoff, Tilman Sauer

Reference: Adrian Wüthrich (Sept. 2010): *The Genesis of Feynman Diagrams*. Archimedes Series, Dordrecht: Springer