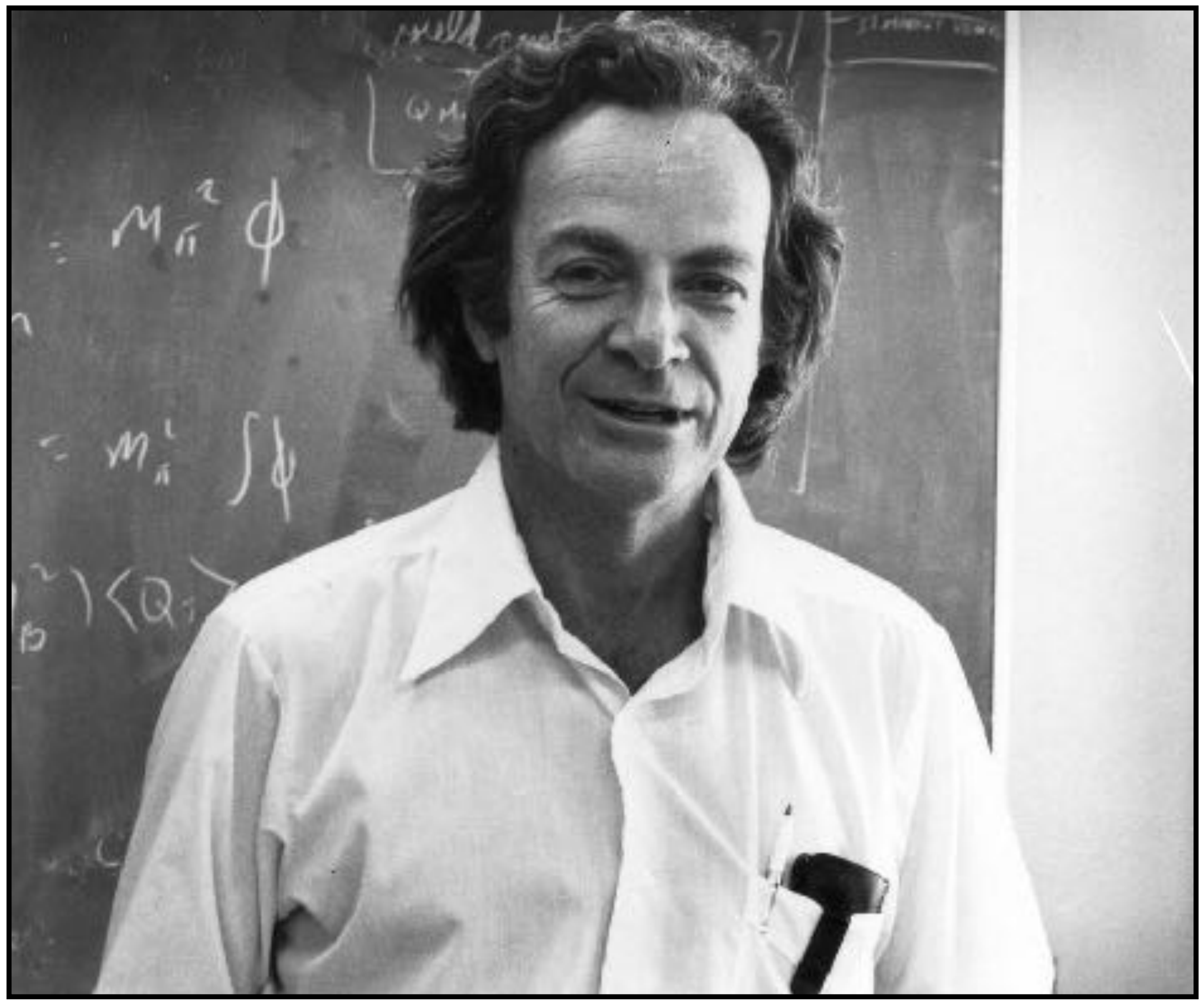
Feynman 100 and the Neutrino `72 , Balatonfüred



Feynman 100 at CALTEC, May 11, 2018

Welcome

Thomas F. Rosenbaum President, Caltech; Sonja and William Davidow Presidential Chair and Professor of Physics

Being Feynman's Curious Sister

Joan Feynman, Jet Propulsion Lab (Retired)

The Shuttle Accident & Other Man-made Disasters

Freeman Dyson, Professor Emeritus at the Institute for Advanced Study in Princeton

Dick's Tricks

Leonard Susskind, Felix Bloch Professor in Physics, Stanford

Bill Gates Remembers Richard Feynman

Bill Gates, Co-founder, Microsoft and Co-chair, Bill & Melinda Gates Foundation

Video courtesy of the office of Bill Gates

Feynman at Caltech

John Preskill, Richard P. Feynman Professor of Theoretical Physics, Caltech

and

Kip Thorne, Nobel Prize, Physics 2017; Richard P. Feynman Professor of Theoretical Physics, Emeritus, Caltech

The Art of Physics

Robbert Dijkgraaf, Director and Leon Levy Professor at the Institute for Advanced Study in Princeton; Professor, University of Amsterdam

Black Hole Blues

Janna Levin, Claire Tow Professor of Physics and Astronomy at Barnard College of Columbia University; Guggenheim Fellow

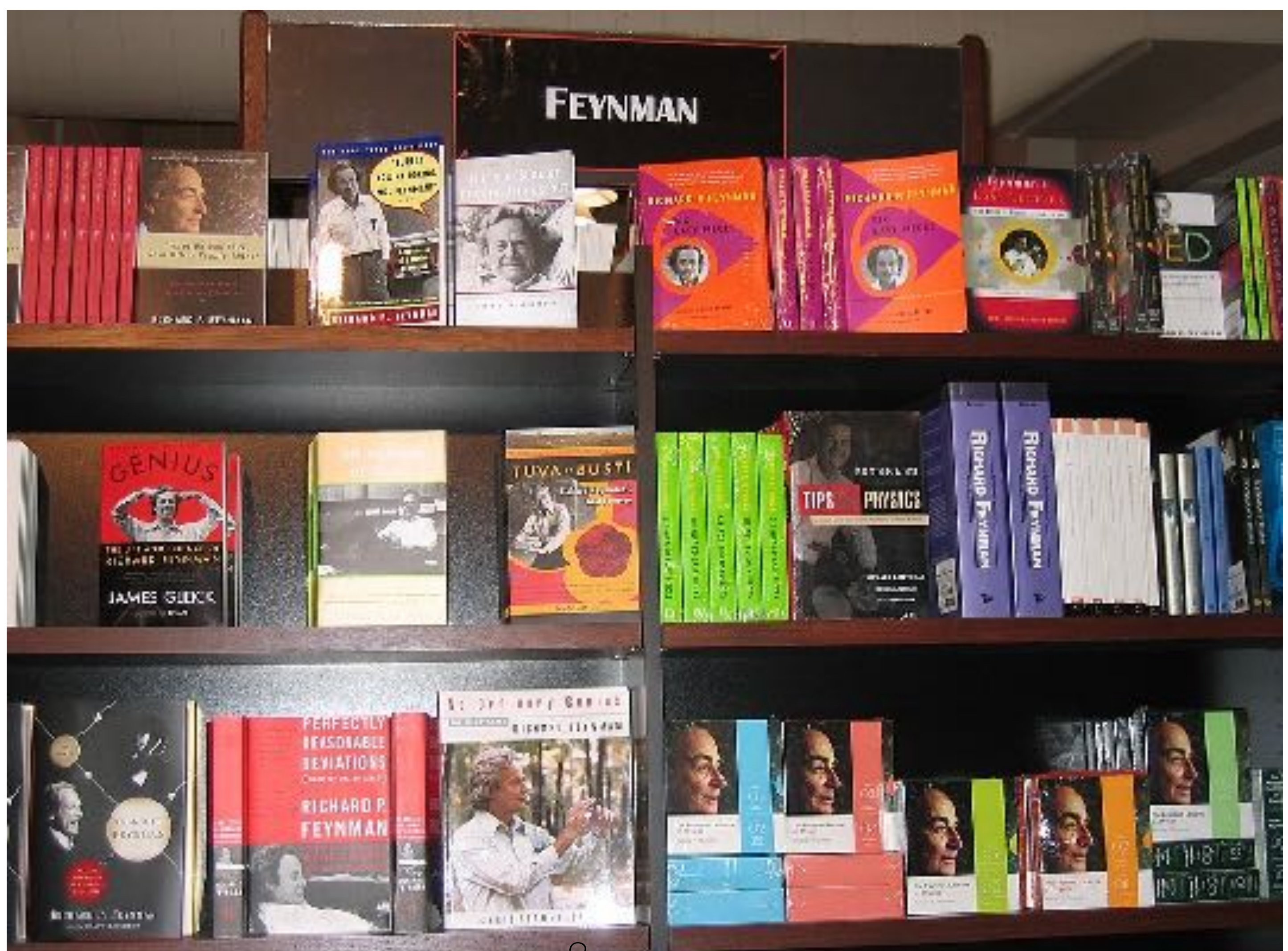
Growing Up Feynman

Michelle Feynman, Daughter of Richard P. Feynman

Closing

James Gleick: *Genius. Life and Science of Richard Feynman*
Pantheon Book New York (1992) 531pages

“Architect of QFT, brash young leader on the atomic bomb project, inventor the ubiquitous Feynman diagram, ebullient bongo player and storyteller, R.P. Feynman was the most brilliant, iconoclastic, and influential physicist of modern times… He had a lightening ability to see into the heart of the problem nature posed… It was permitted in connection with Feynman to use the word ***genius****. … He was the enemy of pomp, convention, quackery, and hypocrisy.”*



Richard Phillips Feynman(May 11, 1918 – February 15, 1988) American theoretical physicist, know for

- the Dirac-Feynman path integral formulation of QM,
- the theory of QED,
- the physics of the superfluidity of supercooled liquid helium,
- Quantisatio nQFT of gravity and YM theories
- The V-A form of the weak current of the “Fermi theory of weak interaction".
- the parton model interpretation of deep inelastic electron nucleon scattering.

For his contributions to the development of QED, he received the Nobel Prize in Physics in 1965 (jointly with J.Schwinger and S.Tomonaga).

- He has also been credited with the pioneering concepts of nanotechnology and quantum computing.

Perhaps he is most famous contribution is

- the diagrammatic approach to the mathematical expressions for the terms appearing in the perturbative expansion of QFT amplitudes (Feynman diagrams, Feynman integrals).

He held the R.C.Tolman professorship in theoretical physics in CALTECH (1950-1988). He was a keen popularizer of physics through both books and lectures

Topics studied by by Feynman

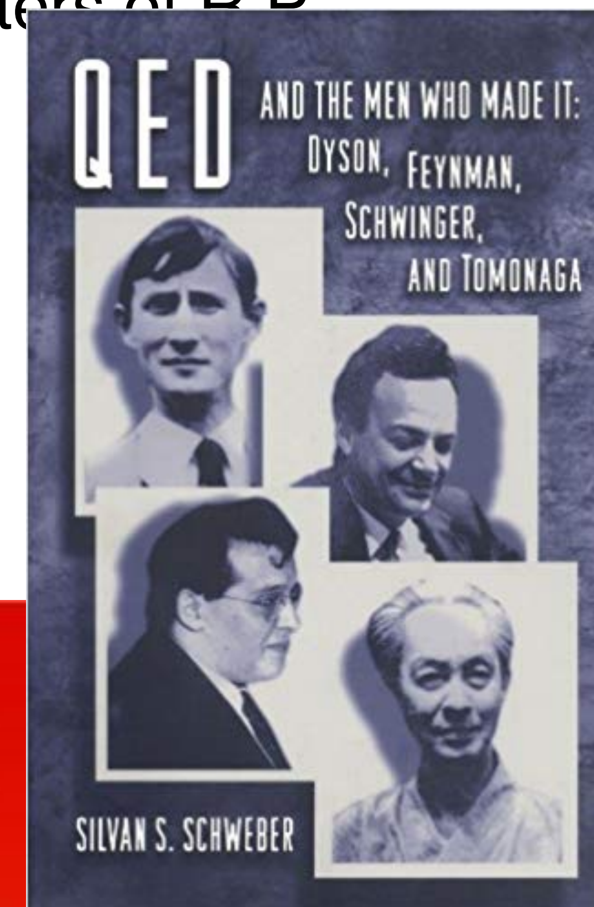
- Classical and Quantum Electrodynamics
- Path Integrals and Operator Calculus: QED and Other Applications
- Liquid Helium
- Physics of Elementary Particles
- Quantum Gravity
- Computer Theory

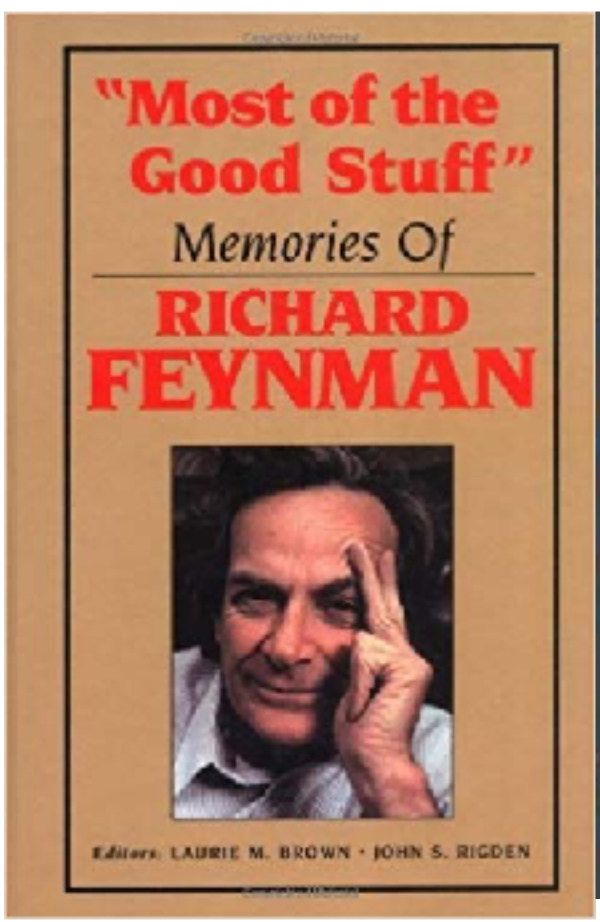
Books written by Feynman

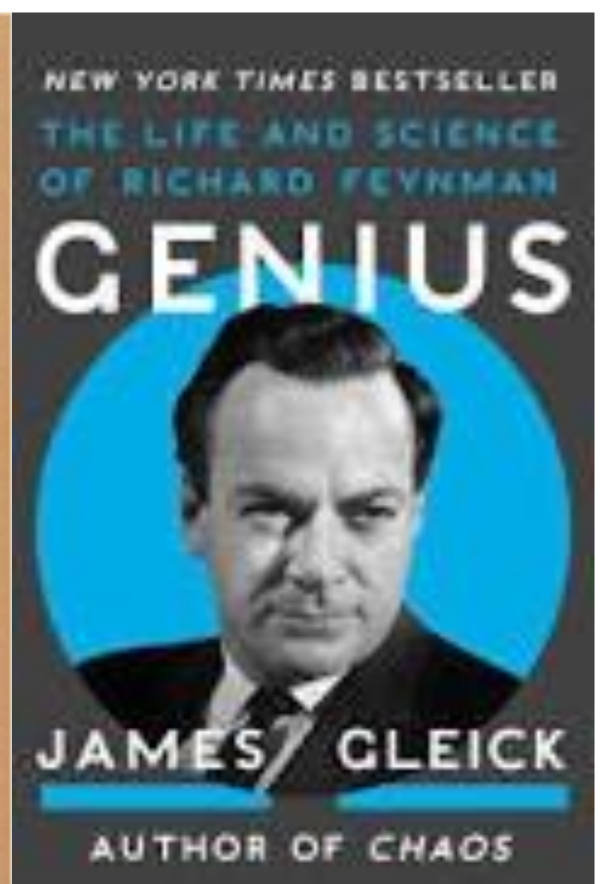
- Theory of Fundamental Processes, 1961
- Quantum Electrodynamics, 1961
- The Feynman Lectures on Physics, (with Leighton,R.B and Sands,M),1963
- The Character of Physical Law, 1965
- Quantum Mechanics and Path Integrals (with Hibbs,A.R.), 1965
- Photon-Hadron Interactions, 1972
- Statistical Mechanics: A Set of Lectures, 1972
- Surely you're joking Mr. Feynman, 1985
- QED the Strange Theory of Light and Matter, 1985
- What Do You Care What Other People Think?, 1988
- The Pleasure Finding Things Out
- *The Feynman Lectures on Gravitation (Moringo,F.B. and Wagner,W.G.),1995*
- *Feynman Lectures on Computation (Hey,A.J.G and All,RF.W.), 2000*

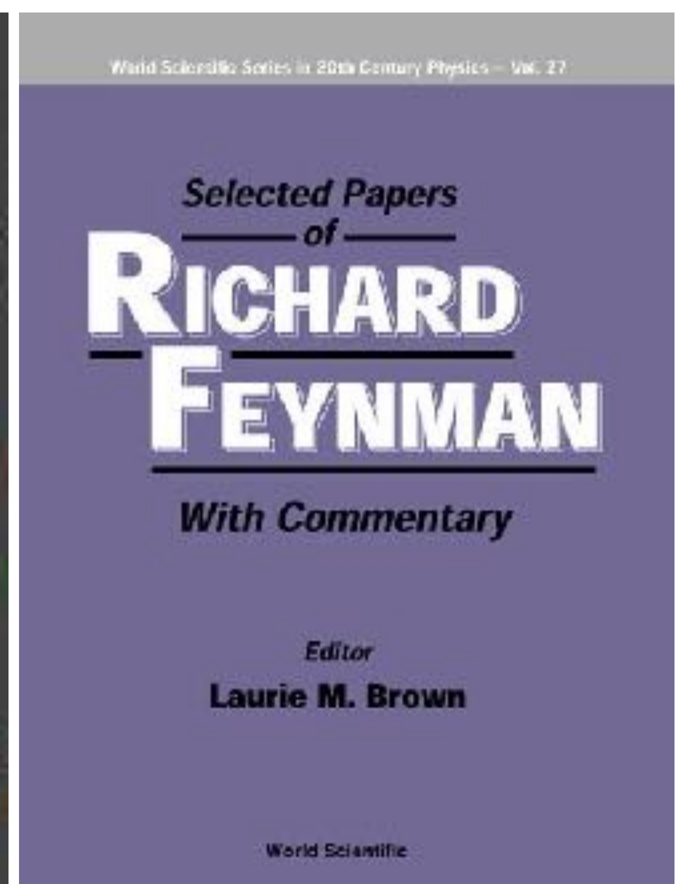
Books written about Feynman

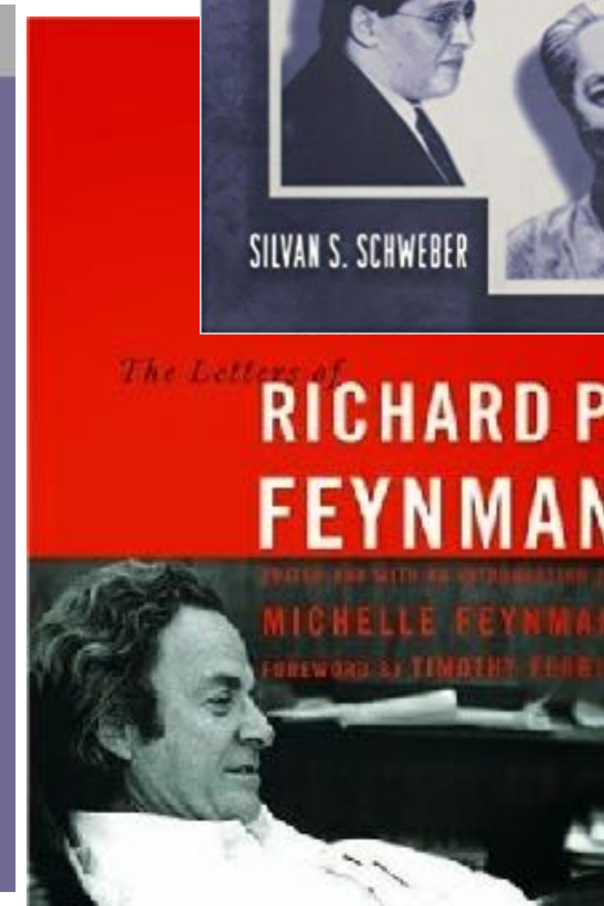
- QED and the man who made it (S.S. Schweber, 1994)
- Most of the Good Stuff: Memories of R.P. Feynman. (Brown,L and Rigden,J), 1993
- Selected Papers of Richard Feynman, (Brown,L)2000
- Perfectly Reasonable Deviations from the Beaten Track: The Letters of R.P. Feynman, (ed. Michelle Feynman),1993
- Quantum Man (L.M.Krauss)2012











Public figure

Feynman also became known through his semi-autobiographical books

Surely You're Joking, Mr. Feynman!

What Do You Care What Other People Think?

and books written about him such as

Tuva or Bust! (by R. Leighton)

Genius: The Life and Science of Richard Feynman (by J. Gleick.)

He assisted in the

development of the atomic bomb during World War II

became known to a wide public (1986-1988) as a member of the

Rogers Commission, the panel that investigated

the Space Shuttle *Challenger* disaster..

In a 1999 poll of 130 leading physicists worldwide by the British journal *Physics World* he was ranked as one of the ten greatest physicists of all time

The Dirac-Feynman path integral

Dirac: The Lagrangian in Quantum Mechanics (1932) Phys. Zeit. der Sowjetunion 3 (1933), 64

Dirac, "The Principles of Quantum Mechanics", p124 to 126. (Oxford 1935)

Thesis - 1942 - Feynman

FEYNMAN, R.P.
Principles of least
action in quantum
mechanics.

Two page citation from Dirac

mechanics. These remarks bear so directly on what is to follow and are so necessary for an understanding of it, that it is thought best to quote them in full, even though it results in a rather long quotation. Speaking of the transformation function (q_t' / q_T') connecting

[1] P. A. M. Dirac, *The Principles of Quantum Mechanics* (The Clarendon Press, Oxford, 1935), second edition, Section 33; also, Physik. Zeits. Sowjetunion 3, 64 (1933).
[2] P. A. M. Dirac, Rev. Mod. Phys. 17, 195 (1945).

QUANTUM THEORY OF GRAVITATION*

By R. P. Feynman

(Received July 3, 1963)

My subject is the quantum theory of gravitation. My interest in it is primarily in the

Fadeev-Popov Ghost

Feynman's tree theorem

Berezin integrals over fermions

Berezin, F.A.: The method of second quantization. "Nauka", Moscow (1965). English translation Academic Press, New York (1966)

A roaring come-back of the path integral method

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Feynman (?)-Faddeev-Popov Ghosts

FEYNMAN DIAGRAMS FOR THE YANG-MILLS FIELD

L. D. FADDEEV and V. N. POPOV
Mathematical Institute, Leningrad, USSR

Received 1 June 1967

ambiguity does not influence the physical re...
in quantum electrodynamics. It seems that ...
man [4] was the first to show that the matte...
not so simple in the cases of Yang-Mills an...
gravitational fields. Namely the contributio...
the closed loop diagrams depends essentiall...
the longitudinal part of the propagator and s...
the transversality and unitarity properties o...
scattering amplitudes. Feynman himself de...
scribed the necessary change of rules for c...
lation the contribution from diagrams with o...
closed loop. A more detailed derivation of t...
new rules was given by De Witt [5]. However it
seems that nobody gave the generalization of
these rules for arbitrary diagrams.

References

1. C. N. Yang and R. L. Mills, Phys. Rev. 96 (1954)
2. R. Utiyama, Phys. Rev. 101 (1956) 1597.
3. S. L. Glashow and M. Gell-Mann, Ann. of Phys. ... (1961) 437.
4. R. P. Feynman, Acta Physica Polonica, 24 (196... 697.
5. B. S. De Witt, Relativity, groups and topology. (Blackie and Son Ltd 1964) pp 587-820.
6. R. P. Feynman, Phys. Rev. 80 (1950) 440.

NEUTRINO '72

EUROPHYSICS CONFERENCE

BALATONFÜRED, HUNGARY,

11-17 JUNE 1972

organized by

THE HUNGARIAN PHYSICAL SOCIETY

PROCEEDINGS VOLUME II.

A. FRENKEL
G. MARX
Editors

List ot Participants

UNITED STATES OF AMERICA

J.Bahcall

R.P.Feynman NP,1965

B.C.Barish NP,2017

G.L.Cassiday

C.L.Cowan NP,1995

R.Davis Jr. NP,2002

K.Lande

T.D.Lee NP,1957

R.E.Marshak

F,Reines NP,1995

V.L.Telegdi

V.F.Weisskopf

HUNGARY

P.Gnädig

Z.Kunszt

J.Kuti

G.Marx

A.Patkós

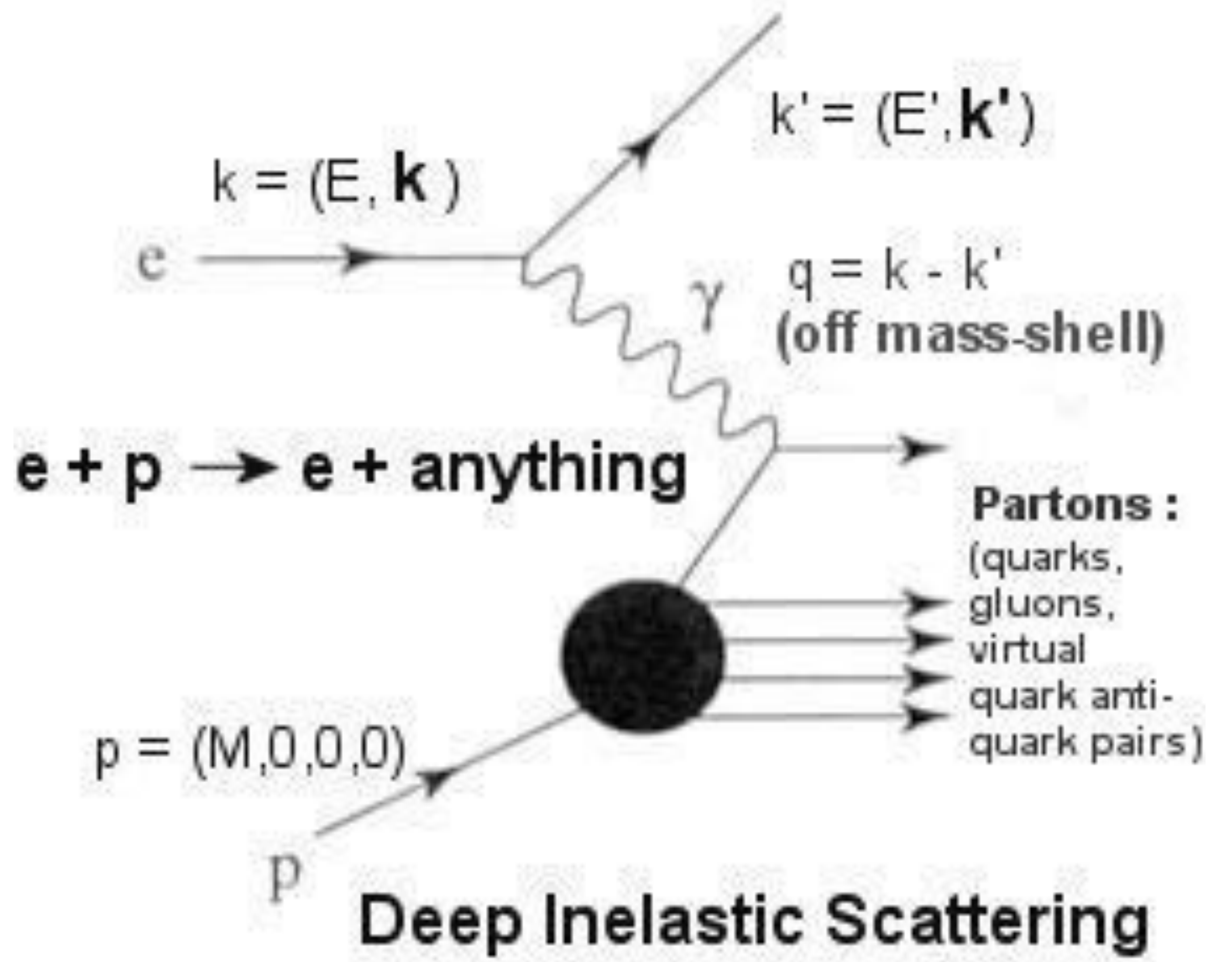
A.S.Szalay

Feynman’s parton model

Feynman and the colour quantum numbers of the quarks

Feynman and the subtraction method

The Parton Model



Why have not quarks and parsons been produce at SLAC?

Feynman:
I am so used to the idea that the quarks are not produced that I forgot to mention that there is a paradox: is it possible that quarks only have interactions for finite relative momenta and yet they do not get isolated, they cannot get separated? I do not understand that at all , and I am happy with that. I like paradoxes. So what I am trying to do is this: I deduce everything I can from a quark model, except that they should come apart. In the struggle to be consistent, to have quarks inside which do not come apart, I have to figure all this out and I must say that we might be headed for a paradox. One of the two things can happen: either we find that all this quart stuff, these quark quantum numbers, do not work…there are no quarks, so they do not come apart; or mystery of mysteries: all these predictions electron and neutrino deep inelastic scattering, all work, and yet the quarks do not come apart!….I am going to assume as long I can …that quarks cannot come apart as free and they are inside the hadrons.

... you said neutral quarks probably also exist. Where did they come from?

Feynman:
Not neutral quark, I said neutral parsons. I have not found any way by electron and neutrino scattering to tell us more about these neutral patrons except their existence, induced by the fact that the conservation of momentum does not work with the charged quarks.

Q: Do you think that the reason we do not see quarks is they posses very large masses and interact strongly with each other in peculiar ways?

Feynman:
This is a completely different direction, but not the direction I am going. If the quark masses are high… then the whole thing goes haywire…
My quarks have small masses, and they do not come apart because of something I ‘ll tell you about 25 years from now. The masses that I want are so law that we would have absolutely and definitely seen them. Thus perhaps the whole thing is nonsense, and the experiment will tell you very soon. Or if it is right then this is very exiting, because we are approaching a paradox, and the hope of physics is to find a paradox. This is the real way of making a revolution. We have to find a place where we are shocked. I thinks we are getting near to one.

What would be the effect of introducing partons with quantum numbers different from those of normal quarks?

Feynman:
Another system of parsons with other quantum numbers (such as the triplet quark model and other models) definitely have a big effect.

What would be the effect of introducing partons with quantum numbers different from those of the normal quarks

Feynman:
Another system of parsons with other quantum numbers (such as the triplet quark model ..) definitely have a big effect. It changes many of the numerical coefficients…iand a crude estimate of the total neutrino-nucleon cross-section …eliminates most of the alternatives…. New data will clarify the situation with the quark quantum numbers very soon

… you said neutral quarks probably also exist. Where did they come from?

Feynman:
Not neutral quark, I said neutral parsons. I have not found any way by electron and neutrino scattering to tell us more about these neutral patrons except their existence, induced by the fact that the conservation of momentum does not work with the charged quarks.

Finn Ravndal:

Back at Caltech in the fall we in the younger generation realized that renormalization and the calculation of Feynman diagrams would be necessary in order to participate in the exploration of the new QCD. But this was a direction of particle physics for which we were not prepared, in spite of having Feynman and Gell-Mann around us on a daily basis There had been very little or no quantum
field theory in standard courses with the weight
instead on more phenomenological aspects. In one of his Wednesday seminar Gell-Mann wanted to discuss the renormalization group and its use in QCD. It was not of much help and we felt disappointed, expecting more from one of the originators of this fundamental method.

Feynman and the colour quantum numbers of the quarks

Late in the spring 1973 we heard that the beta-function for QCD had been calculated on the East Coast and found to be negative, implying asymptotic freedom. The implications for deep inelastic scattering we already knew from the lecture notes of Sidney Coleman. My first reaction was great exhilaration since suddenly the treatment of partons as free particles could be understood. But Feynman showed little or no interest in this result. That was surprising since his parton model now had a field-theoretic formulation. One reason was the unsettling situation with the total e+e- cross section for which the latest experiments at the Cambridge accelerator still gave values much larger than expected. The factor of three due to the new colours didn't seem to be the solution.

Feynman and the subtraction method

THE PERTURBATIVE CALCULATION OF JET STRUCTURE IN e^+e^- ANNIHILATION*

R.K. ELLIS[1], D.A. ROSS[2] and A.E. TERRANO

California Institute of Technology, Pasadena, California 91125, USA

Received 4 July 1980

The structure of this paper is as follows. In sect. 2 we calculate the differential cross section for processes involving three particles in the final state. Representing this as $\sigma^{(3)}$ we obtain the distribution in C:

$$\frac{\mathrm{d}\sigma^{(3)}}{\mathrm{d}C} = \int \mathrm{d}\sigma^{(3)}\,\delta(C - C^{(3)})\,, \tag{1.17}$$

where $C^{(3)}$ is the expression given by eq. (1.13). The above expression contains divergences due to the emission of soft and collinear particles. In sect. 3 we calculate the contribution to the cross section due to the production of four partons

We are pleased to acknowledge useful discussions with R. P. Feynman, R. D. Field, T. Goldman, Z. Kunszt, H. D. Politzer, and S. Wolfram. We thank the MATHLAB at MIT for the use of MACSYMA.

in the final state. This may be schematically written as

$$\frac{\mathrm{d}\sigma^{(4)}}{\mathrm{d}C} = \int \mathrm{d}\sigma^{(4)}\,\delta(C - C^{(4)})\,, \tag{1.18}$$

where $C^{(4)}$ is given by eq. (1.14). Eq. (1.8) also contains singularities in the three-jet region. Thus the total contribution is given by,

$$\begin{aligned} \frac{\mathrm{d}\sigma}{\mathrm{d}C} &= \frac{\mathrm{d}\sigma^{(4)}}{\mathrm{d}C} + \frac{\mathrm{d}\sigma^{(3)}}{\mathrm{d}C} \qquad C \neq 0 \\ &= \mathrm{d}\sigma^{(4)}\,\delta(C - C^{(4)}) + \mathrm{d}\sigma^{(3)}\,\delta(C - C^{(3)})\,. \end{aligned} \tag{1.19}$$

As a calculational device it is convenient to deal only with finite quantities. Hence we evaluate the terms in $\mathrm{d}\sigma^{(4)}$ which contain singularities in the region in which four jets masquerade as three:

$$\mathrm{d}\sigma^{(4)} \overset{\substack{\text{singular}\\ \text{region}}}{\rightarrow} \mathrm{d}\sigma^{(s)}\,. \tag{1.20}$$

We thus rewrite eq. (1.19):

$$\frac{\mathrm{d}\sigma}{\mathrm{d}C} = \left[\mathrm{d}\sigma^{(4)}\,\delta(C - C^{(4)}) - \mathrm{d}\sigma^{(s)}\,\delta(C - C^{(3)})\right] + \left[(\mathrm{d}\sigma^{(s)} + \mathrm{d}\sigma^{(3)})\delta(C - C^{(3)})\right]. \tag{1.21}$$

Each of the terms in square brackets is now finite in the three-jet region [but still

Feynman and Field

4 *R.D. Field, R.P. Feynman / A parameterization of the properties of quark jets*

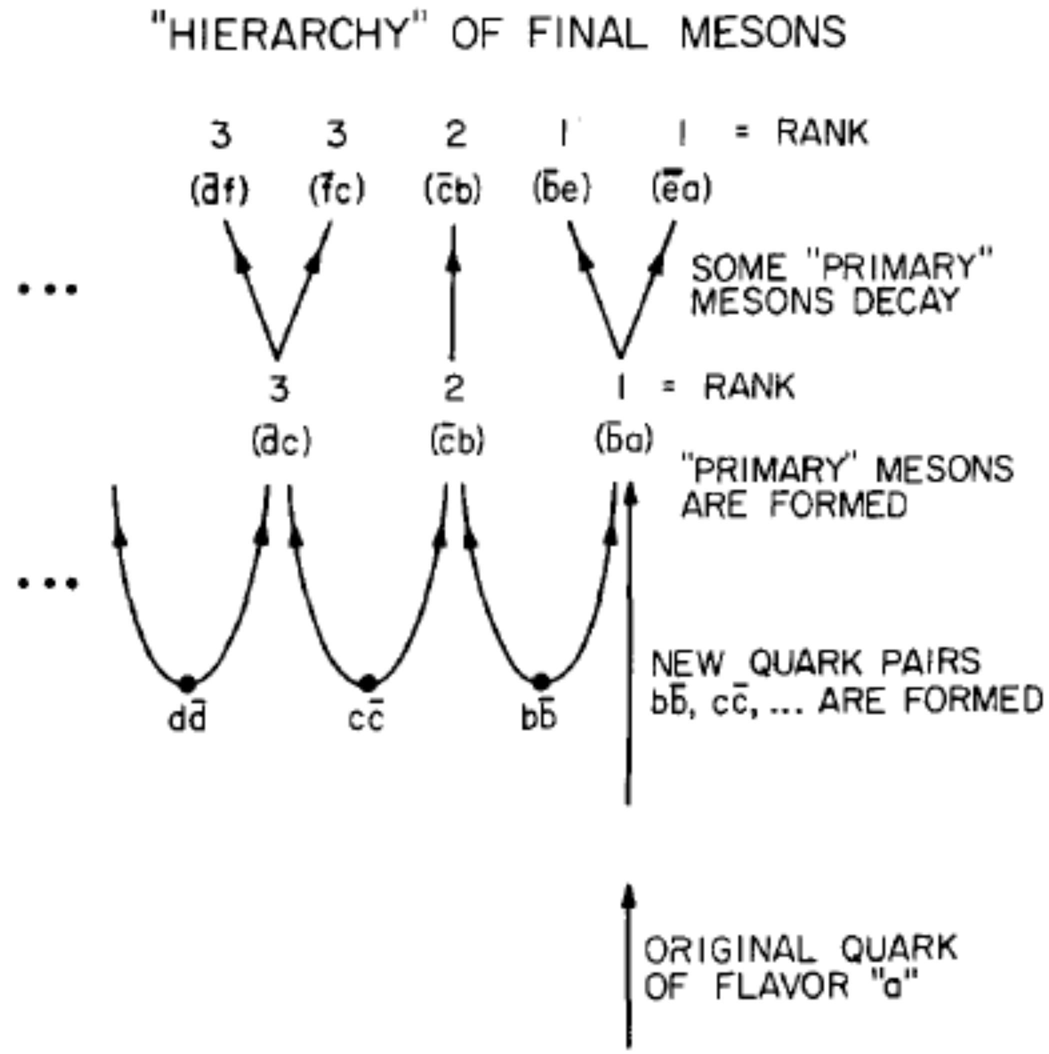


Fig. 1. Illustration of the "hierarchy" structure of the final mesons produced when a quark of type "a" fragments into hadrons. New quark pairs $b\bar{b}$, $c\bar{c}$, etc., are produced and "primary" mesons are formed. The "primary" meson $\bar{b}a$ that contains the original quark is said to have "rank" one and primary meson $\bar{c}b$ rank two, etc. Finally, some of the primary mesons decay and we assign all the decay products to have the rank of the parent. The order in "hierarchy" is *not* the same as order in momentum or rapidity.

Feynman’s tree at Balatonfüred

***R**abindranath Tagore planted the first tree. A group of indian trees is formed.(NP 1913). Much later Salvatore Quasimodo also planted a tree.(NP 1953). The tradition that if a Nobel-Prize laureat visits Balatonfüred he or she oughto plant a tree.*

After 10 years of dark period that followed the crushing of the revolution in 1956 the he communist Hungary a satellite country of the Soviet Union started to open itself for scientific collaboration. Hungarian scientist could go to visit US universities and one was allowed to organise international conferences . The Neutrino ’72 Conference in Balatonfured was a part of thiseffort. G. Marx made a brilliant organisation. Neutrino physics was an emergent field and
Marx worked on neutrino physics had already visited US universities and had holiday house in Balatonfured. He tried to get the best people. He suggested that Feynman as Nobel-prize holder should also plant a tree. But one had to have balance between East and West, so Bruno Pontecorvo has been asked to plant a tree. It happened on June 13.

Later Frank, Wigner, Dirac also followed.


Seeing Things