Cancelling Infinities

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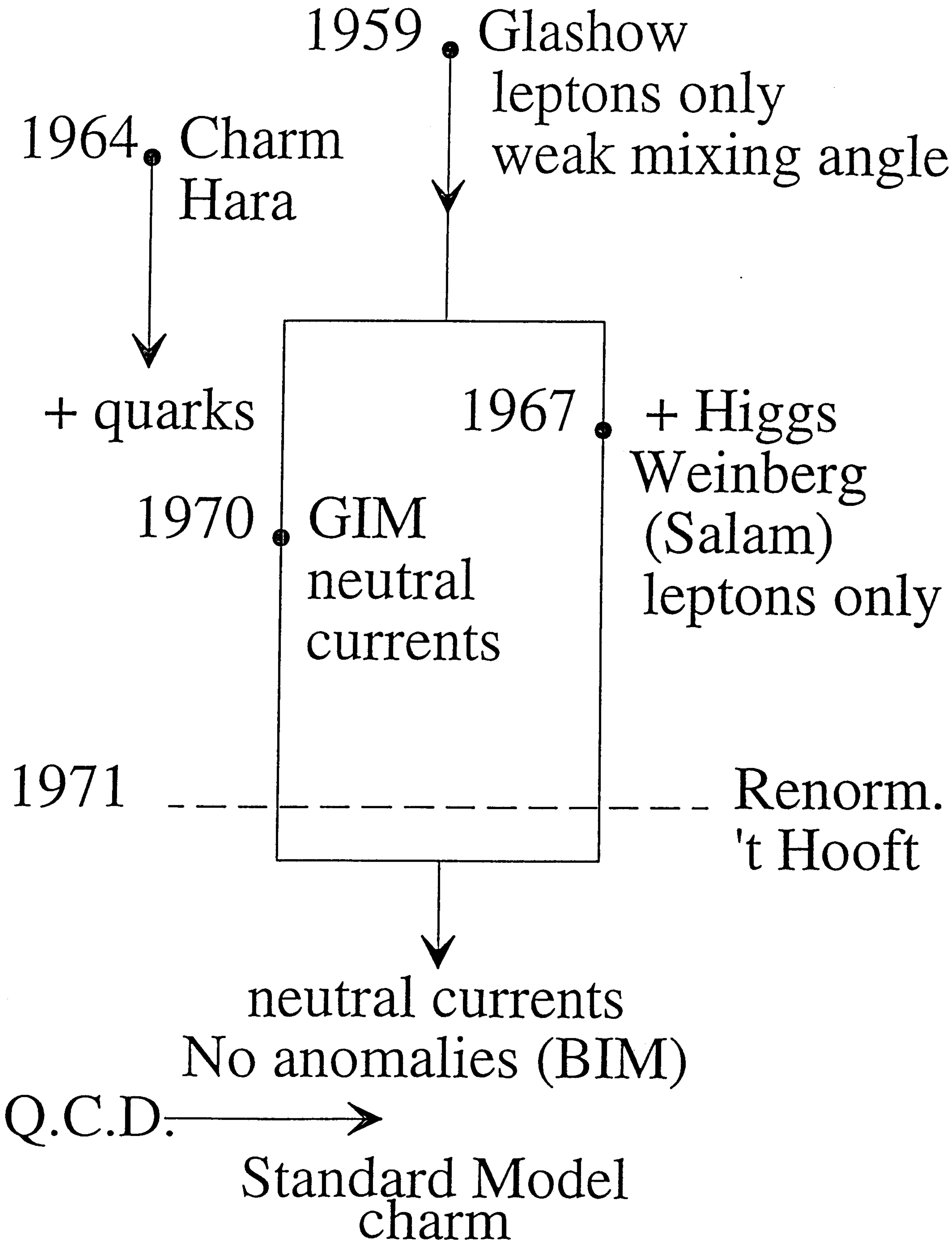
DISCLAIMER

The article in the CERN courier about the Nobel prize 1999 is a work of fiction.

Any resemblance to the facts described in this lecture is purely coincidental.

Standard Model development



Contributions

Why and how Yang–Mills

1. Physics:
   Adler–Weisberger relation
   Divergence conditions
   Ward identity of a
   gauge theory (J.S. Bell)

2. Renormalizability:
   Old calculation of
   photon–W interaction
   Use of Schoonschip

3. Technical progress:
   Need for new Feynman rules
   Concept of change of gauge
   Transformation to (almost)
   renormalizable gauge

Contributions with 't Hooft.
Dimensional regularization etc.

PHYSICS

PCAC equation:

$$\partial_\mu \vec{J}^A_\mu = ia\,\vec{\pi}.$$

Add e.m. interactions, $\partial_\mu \to \partial_\mu - ieA_\mu$:

$$(\partial_\mu - ie\vec{A}_\mu \;\times)\,\vec{J}^A_\mu = ia\,\vec{\pi}.$$

E.m. field and weak bosons in same multiplet:

$$\partial_\mu \vec{J}^A_\mu = ia\vec{\pi} + ie\vec{A}_\mu \times \vec{J}^A_\mu$$

$$+ ig\vec{W}^V_\mu \times \vec{J}^A_\mu + ig\vec{W}^A_\mu \times \vec{J}^V_\mu.$$

Divergence equation.

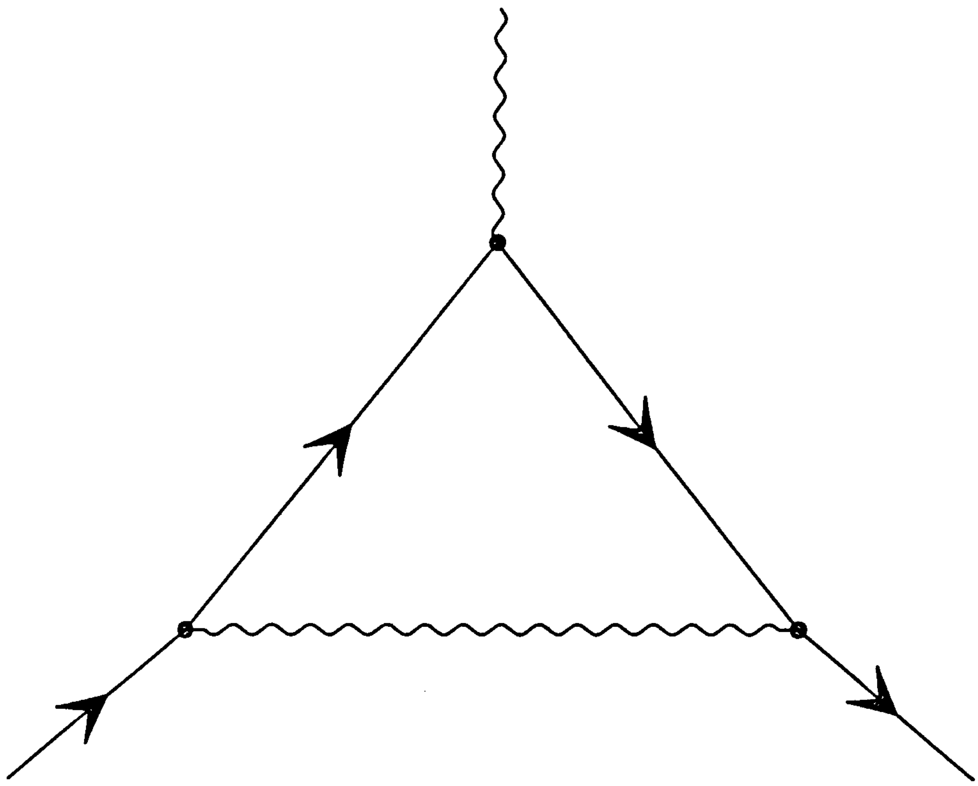
This equation leads to A–W relation with a difference: it becomes a relation between G_A and π – Nucleon scatt. length.

No Schwinger terms.

Gauge type construction, recognized by J.S. Bell.

RENORMALIZATION

Radiative correction to
photon – charged W interaction.



Calculation very complicated:
W–propagator unitary gauge,
parameters ξ and κ.
ξ = cut–off parameter.
κ = magnetic moment W.

Schoonschip (First version 1963)
There is a best value for κ.

TECHNICAL PROGRESS

Lagrangian

Canonical formalism
Operators

Path integrals

For gauge theories:

S–matrix
Feynman rules
Diagrams

Advantage due to study of unstable particles (1960).
Unitarity understood.
No need for any derivation.
Work directly with diagrams.

Rockefeller intermezzo 1968.

Consider Y–M for renormalization
Many cancellations seen.
That is not enough.

Concerning renormalization:
to carry through renormalization renormalizable Feynman rules are necessary, because renormalization needs renormalizable Greens functions.

Thus it is necessary to find new Feynman rules that are renormalizable

Modified Vector boson propagator

$$\frac{\delta_{\mu\nu} + k_\mu k_\nu/M^2 + \kappa\, k_\mu k_\nu/M^2}{k^2 + M^2 - i\varepsilon}$$

Stueckelberg addition:
scalar particle φ.
Required $\kappa = -1$
Negative norm. Unphysical.

For abelian theory φ is a free particle.
Not for non–abelan gauge theory.

Idea: introduce new interactions such that φ is free, i.e. that φ becomes a ghost.

This worked up to one loop (1968). However, at the two loop level the new interactions were non–renormalizable.

Intermezzo (1969–1970).

Patched up various holes:

– Derivation Ward identities

– Vector boson propagator

– Limit massless – massive Y–M.

Enter 't Hooft (1969).

First task: σ–model study.
(σ model = Higgs sector).

Second task: make lecture notes of path integral lecture series.

First part thesis: mass–less Y–M.

Then 't Hooft had idea: introduce Higgs (extra scalar particle).

He worked that out completely. Leave it to him to talk about.

Amsterdam conference 1971.

Dimensional regularization.
Rigorous combinatorial proof.

Experimental progress:
Neutral currents. ρ param.
Charm.

1975: Standard Model.
How many generations ?
Radiative corrections depend on top mass squared.
Only log. on Higgs mass.

What is LEP energy required to either see the Higgs or deduce its mass from radiative corr. ?
Program: compute rad. corrections to W–W scattering.
With Passarino (1979): μ pair prod.
and Lemoine (1980): W^+W^- production.
Result: 250 GeV absolute minumum.....

Higgs and radiative corr.

Cosmological constant (1974).
Because of neutral currents:
introducing ρ parameter (1975).
In 1975 dominant question: Higgs.
Effects depending on Higgs mass ?
Because of one–loop renorm. only
log at one loop (screening).
In W, Z mass corr. could have been m^2.
For $\rho = 1$ only log.
Luckily, for top quark ~ m_t^2.

However, Unitarity limit ~ m^2.
This from W–W scattering (tree).
Therefore study one–loop W–W.

Program: one–loop radiative corr.
Also needed for WW prod. at LEP.

One loop radiative corr.

Two major problems seen:
- One–loop expr. needed for general internal and external masses.
- Form factors : huge matrix to be inverted ?

Solution to first problem:
trick such that the product of two propagators could be written as a sum of two similar terms, but with either one internal or one external mass zero.

Solution to second problem: luck.
Only 3×3 matrices to be inverted.

Even with all this large (50 dec.) numerical precision needed.

WW scattering.

Passarino + V (1979)
Lemoine + V (1980)
and finally :
V + Yndurain (1989).

Result: only log m.
However, for large m :
s^2 terms.
Strongly interacting W's (V^2),
or Higgs or something else ?

LHC, TESLA and CLICK.