GIM and ME

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INTRODUCTION

Relevant Events prior to & after the 1969–1970
Glashow-Iliopoulos-Maiani Collaboration at Harvard, 1969-1970.

I became Schwinger's grad student in 1956, when each of the four forces. Nuclear, Weak, E&M, and Gravity, were taught in isolation. Many attempts had failed to unify some or all of them, by:

Eddington, Einstein, Heisenberg, Kaluza, Nordstrom, Pauli, Schroedinger Yukawa, Weyl, ...

Some string theorists have come to a contrary view. They prefer Accomodation to Unification:

"Our universe may have come out differently," they surmise,
"...but it didn't!"   Apologies to Jane Austen

MORE INTRODUCTION

How different be weak and electromagnetic interactions!

One is short range, the other long.

One conserves strangeness, parity and CP, the other does not.

One feeble and elusive,

The other underlying all we see, feel, hear, smell, taste and do.

But, said Schwinger to me:

Both interactions are VECTORIAL!

Both interactions are UNIVERSAL!

With the Yang-Mills triplet of gauge bosons in mind, he said:

Go Forth Young Man, and Unify!

I could NOT find an SU(2) electroweak gauge theory correctly describing parity violation. [Howard Georgi and I would do just that in 1972!]

But for any electrically charged spin-one $W^{\pm}$, I knew that...

i. The massless limit of the model exists, and

ii. The one-loop weak correction to the electron's anomalous magnetic moment is finite **IF AND ONLY IF:**

The Magnetic Moment of $W^{\pm}$ coincides with that of the charged bosons of a unified non-Abelian gauge theory:

Thus was I convinced that Schwinger's dream must be realizable.

Meanwhile, Gary Feinberg showed the IVB hypothesis to demand $\nu_e \neq \nu_\mu$, as Schwinger prophecied. This led to an amusing interchange between Schwinger and Yang Chen-Ning during my final oral examination in Madison, Wisconsin (1958).

SOLVING THE PARITY PUZZLE

In Spring 1960 in Copenhagen I found parity violation correctly described if leptons were doublets under an enlarged $SU(2) \times U(1)$ gauge group, with the massless photon a superposition of the two neutral gauge fields. The remaining massive neutral boson would mediate then-unobserved neutral current interactions.

My paper was published in Nuclear Physics in 1961. A substantially identical paper by Salam and Ward was published in Nuovo Cimento in 1964.

But no one knew how $W^{\pm}$ and Z^0 could acquire mass without sacrifying the renormalizability of the electroweak model, nor how to avoid the strangeness-changing neutral currents that would arise were the model somehow extended to describe hadrons.

SPONTANEOUS SYMMETRY BREAKING

In 1960 Jeffrey Goldstone explored SSB of relativistic quantum field theories.. For a system of spinless fields invariant under a GLOBAL symmetry, he finds one massless 'Goldstone boson' to arise for each spontaneously broken symmetry generator.

In 1964 Brout, Englert, Guralnik, Haber, Higgs and Kibble explore SSB for a system of spinless bosons invariant under a LOCAL symmetry. They devise the Higgs mechanism whereby the gauge fields of broken symmetries acquire mass, with at least one surviving *Higgs Boson.*

In 1967 Steven Weinberg brilliantly injects the Higgs mechanism into my electroweak model so as to provide mass to $W^{\pm}$, Z^0 and other particles. His Phys. Rev. Letter A Theory of Leptons is followed one year later by a substantially identical paper by Abdus Salam.

THE EIGHT-FOLD WAY and THE CABIBBO CURRENT

Back to 1961, when Sidney and I had great fun at CalTech with Murray and Yuval's newly-presented flavor SU(3), wherein we found our only eponymous result: *The Coleman-Glashow Electromagnetic Mass Formula.*

More significantly: Cabibbo, in 1963 — Using the angle previously introduced by Gell-Mann in the context of the Sakata model — showed that the charged weak current of flavor SU(3) correctly describes leptonic and semileptonic decays of strange particles.

And the Samios group's 1964 discovery of the Ω^- quieted the last opponents of the 8-fold way (including my dear friend Gary Feinberg) and made way for quarks.

MEANWHILE, THE CHARMED QUARK WAS BORN

Very soon after Gell-Mann invented quarks (with apologies to Petermann and Zweig), James Bjorken and I idly proposed a fourth 'charmed' quark. It was neat to have two weak doublets of quarks, just as we then had two weak doublets of leptons, thus exhibiting the sort of lepton-hadron symmetry imagined by Gamba, Marshak and Okubo in 1959. Little did we imagine that soon there would be THREE doublets of each!

The commutator of our augmented charged weak currents yields a perfectly innocuous strangeness-conserving neutral current but we said nothing more, How could I have abandoned, forgotten, ignored or rejected my earlier electroweak thoughts. Shame!

The **GIM** Mechanism, or, Why We Are Here Today

In 1969, I had the good fortune to have Luciano Maiani and John Iliopoulos join me at Harvard. Together, we showed how charm earns its name as a device to avert evil, in this case the evil being the unseen and unwanted strangeness-changing neutral currents that would appear with or without electroweak synthesis.

With the GIM mechanism, the electroweak model was trivially extended to apply to all known elementary particles. But was the resulting theory mathematically acceptable, i.e., renormalizable?

THE DUTCH MIRACLE

In 1970, John and I found suggestive cancellations of certain divergences of massive non-Abelian gauge theories, such as the electroweak model with masses put in by hand. But the theory remained stubbornly unrenormalizable.

During the summer of 1971, while both John and I were visiting Marseille, we learned that we had been wasting our time: Our brilliant friends, Gerard 'tHooft and Tini Veltman, had shown the spontaneously-broken Glashow-Salam-Weinberg electroweak theory to be renormalizable!

At long last, experimenters became motivated to test the theory.

EXPERIMENTERS CONFIRM AND SURPRISE US

Ten Marvelous Years of Discovery

1973 Neutral Currents observed at CERN.

1974 J/Psi particle, Charmonium spectroscopy.

1975 First charmed baryon observed at Brookhaven.

1976 First charmed mesons observed at SLAC.

1983 Weak bosons $W^{\pm}$ and Z^0 observed at CERN.

And a Third Family of Fundamental Fermions

1975 The 3rd charged lepton, tau,

1977 The 3rd $Q = -1/3$ bottom quark & bottomonium,

1995 The 3rd $Q = 2/3$ top quark,

2000 The 3rd (tau) neutrino. Match, Set & Rubber!

MOMENTS OF IRONY

In 1974 most of our colleagues were reluctant to accept, or firmly opposed to, the existence of a fourth quark flavor.

And yet, in 1977 all of them were so very eager and delighted to accept the existence of a fifth and even a sixth quark flavor.

AND I AM EMBARRASSED TO CONFESS THAT...

In 1972, Howard Georgi and I conceived and published a false electroweak model with no charmed quark, and...

In 1980, Howard Georgi and conceived and published a false electroweak model with no top quark.

How to Violate CP Symmetry?

In 1964, Fitch, Cronin and Turlay first detect CP Violation in the strange-quark sector. Since then it has been observed and studied in both the bottom and charmed quark sectors.

CP is an obligatory symmetry of the minimal two-family Standard Model. Both T.D. Lee and Steven Weinberg tried to account for observed CP violation with elaborate and contrived systems of scalar bosons.

Such notions were abandoned when the third Fermion family emerged. In 1973, Kobayashi and Maskawa had shown how CP violation is readily introduced into the mass matrix of systems of six or more quarks.

The CKM matrix of the 3-family Standard Theory has been thoroughly tested by experiment. It offers a correct and complete description of all observed CP-violating phenomena.

! July Fourth, 2012 !

After Decades of Heroic Struggle

THE HIGGS BOSON IS DISCOVERED AT CERN!

Very many puzzles remain, not least of which are:

Why is the Higgs mass so close to those of W and Z?

What is the origin of neutrino masses.

Why are they comparable to the fourth root of the cosmologcal constant? And so on and on...

To all those physicists whose unmentioned efforts contributed critically to my story, my apologies!

THANK YOU!