Fifty Years of Parity Violation and Salam's Contributions

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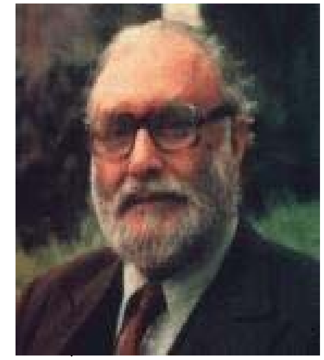
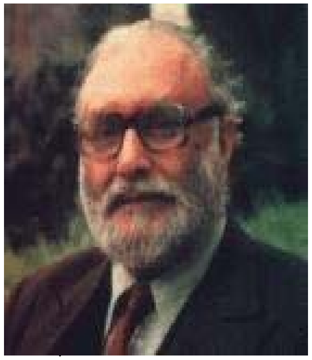
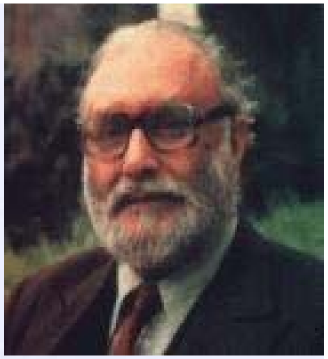


50 years ago, Yang and Lee questioned the validity of a fundamental law of nature, namely parity or Left-Right symmetry in weak interactions as experimental evidence at that time did not exclude its violation. This was indeed found to be violated in weak interactions. Salam was the first one to introduce in physics chiral symmetry for neutrinos and



as a result showed that if this symmetry is satisfied in weak interactions involving neutrions, (e. g. β Decay, μ decay, $\pi \rightarrow \mu \nu$) parity is necessarily maximally violated as found experimentally and neutrino has zero mass.

Abdus Salam
1957, Gennaio
Il Nuovo Cimento
Serie X, Vol. 5, pag. 299-301

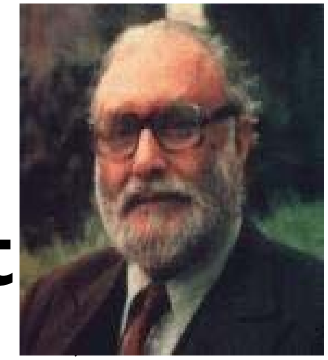


On Parity Conservation and Neutrino Mass.

Abdus Salam

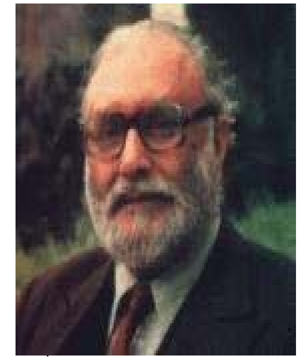
St. John's College - Cambridge

(ricevuto il 15 Novembre 1956)

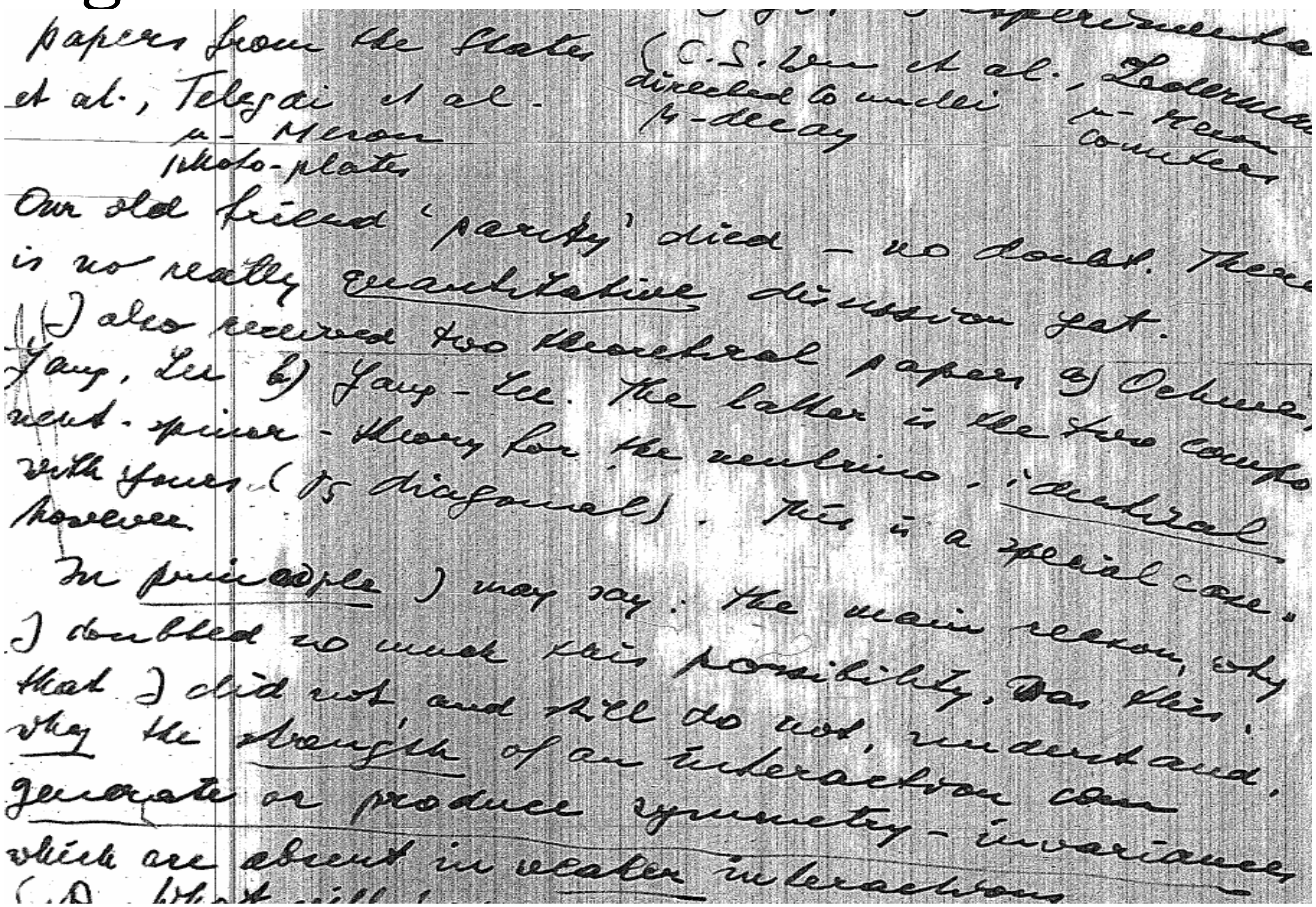


To Capture The Atmosphere At That Time.

- When Salam presented this idea to Peirels who asked the original question: "Why is the neutrino mass zero"?, he said: "I do not believe left-right symmetry is violated in weak nuclear forces at all." Salam communicated his paper to Pauli, who gave the message: "Give my regards to my friend Salam and tell him to think of something better."



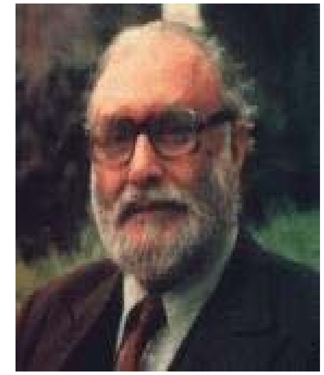
- On January 01, 1957 Pauli sent somewhat apologetic letter to Salam.



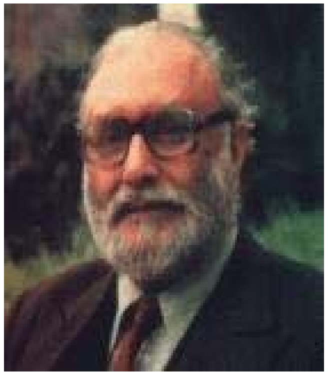
papers from the States (C. S. Wu et al., Lederman
et al., Telegdi et al. — directed to under μ-decay
μ-Meson photo-plate   μ-Meson counter

Our old friend 'parity' died — no doubt. There
is no really quantitative discussion yet.
I also received two theoretical papers of Oehme,
Yang, Lee b) Yang-Lee. The latter is the two compo-
nent-spinor-theory for the neutrino — identical
with yours (γ_5 diagonal). This is a special case,
however.

In principle I may say: the main reason, why
I doubted so much this possibility, was this:
that I did not, and still do not, understand
why the strength of an interaction can
generate or produce symmetry-invariances
which are absent in weaker interactions —

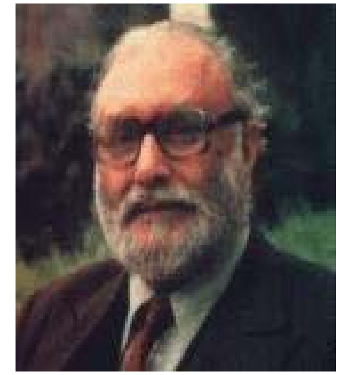


"What a landslide! I got 3 experimental papers, Mrs. Wu's, Lederman's and Telegdi's … Our old friend "parity" died – no doubt … I did not and still do not, understand <u>why</u> the <u>strength</u> of an interaction <u>generate</u> or <u>produce</u> symmetry – invariance which are absent in <u>weaker</u> interaction.



Main Problem: Why are the strong interactions reflection-invariant?

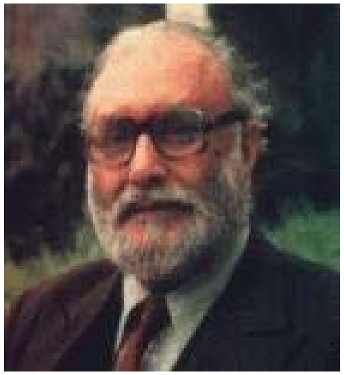
It was premature, however, to use this ignorance as a priori argument against the possibility (considered by Yang – Lee and yourself) that in β decays (for instance) there could be a violation of spatial reflection (=parity) invariance as I believe until now.



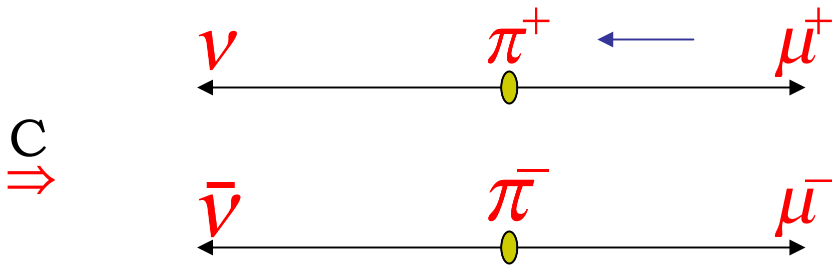
- Then he goes on to some general considerations about TCP – invariance.

  Pauli's CPT theorem, which he proved, should naturally follow for a Lorentz invariant local field theory, took a new significance.

  If P were violated, at least one other discrete symmetry must also be violated: C or T or both?



- It is easy to see that C must also be violated in weak interactions:



polarized, -ve helicity

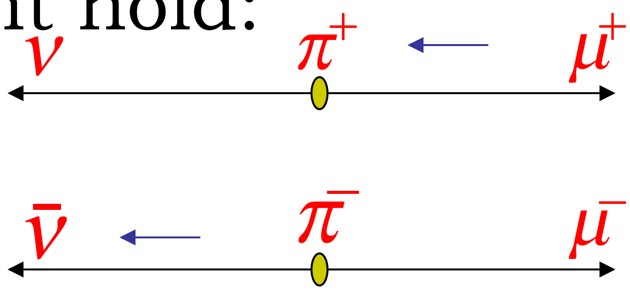
(-ve helicity)

If invariant under C, rates will be same. Experimentally:

$$\Gamma_{\pi^+ \to \mu^+ \overset{(-)}{\bar{\nu}}} \gg \Gamma_{\pi^- \to \mu^- \overset{(-)}{\nu}}$$

Thus C is violated.

What about CP invariance, which Landau, who independently expressed ideas similar to Salam, Lee – Yang about 2 – component neutrinos, suggested (1957) might hold:



CP $\Rightarrow$

Note that the momentum is reversed. Two Processes are observed with the same rate:

$$\Gamma_{\pi^+ \to \mu^+ \bar{\nu}} = \Gamma_{\pi^- \to \mu^- \nu}$$

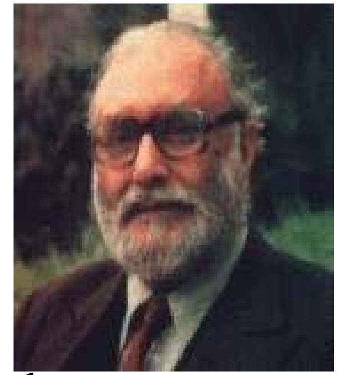
$(-)$ $(+)$

Thus CP is conserved here.

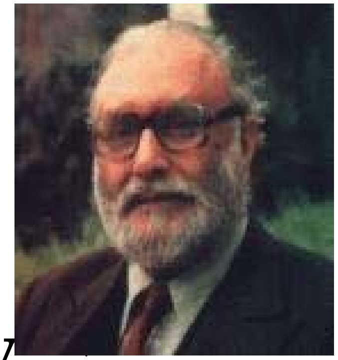
We now know that CP although a small effect is not conserved, first discovered in K^0 - $\bar{K}^0$ complex in 1964, still its origin is not clear but it can be incorporated in the standard model.

It turned out that

CP violation has a great significance. It is necessary to understand the following puzzle:



The strength of the four known forces do not depend on whether the particles that experience them are made of matter or anti matter. Yet, the universe we live in is completely dominated by matter. How did the universe evolve into this very asymmetric state when the underlying forces do not know the difference between matter and antimatter. CP violation is one of the three conditions of Sakharov to understand this puzzle. The other 2 conditions are

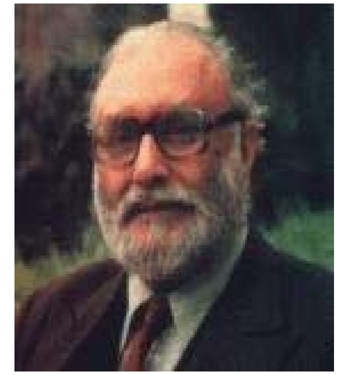


(i) Baryon number violation provided by unification theories

(ii) Departure from thermal equilibrium provided by the expansion of the universe.

- After this digression, let me come back to Salam.

  In an unpublished Imperial College, London preprint, he extended his γ^5 – invariance (chirality) principle to the four – fermion interaction involving electron and muon, which yielded the correct V – A interactions for leptons but not fermions.



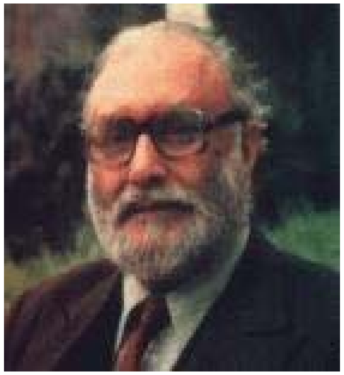
In the same unpublished paper, in a lengthy footnote, there was an outline of an idea, which one would now call dynamical symmetry breaking in the context of spontaneous breakdown of a symmetry in particle physics, showing how an asymmetrical system can still be described by symmetrical equations.

Reprinted from Imperial College preprint.

On Fermi Interactions

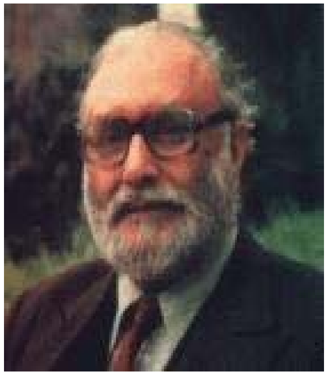
ABDUS SALAM

Imperial College of Science and Technology,
London

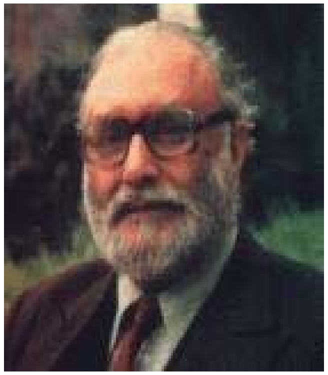


- Salam sent the above note and another one to Pauli. In the words of Salam:

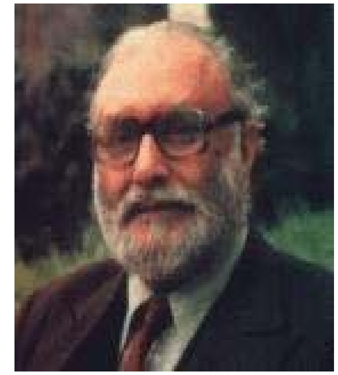
- With chiral symmetry for electrons, muons, and neutrinos, the only mesons that could mediate weak decays of the muons would have to carry spin one.



- Reviving thus the notion of charged intermediate spin-one bosons, one could then postulate for these a type of gauge invariance which I called “neutrino gauge. Pauli’s reaction was swift and terrible. He wrote on 13 March: “I am reading (along the shores of Lake Zurich) in bright sunshine quietly your paper…”

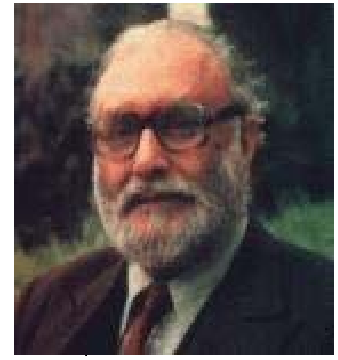


- "I am very much startled on the title of your paper 'Universal Fermi Interaction'… For quite a while I have for myself the rule if a theoretician says *universal* it just means pure <u>nonsense</u>. This hold particularly in connection with the Fermi interaction, but otherwise too, and now you too, Brutus, my son, come with this word…"
- Earlier, on 30 January, he had written "there is a similarity between this type of gauge invariance and that which was published by Yang and Mills… In the latter, of course, no γ^5 was used in the exponent.



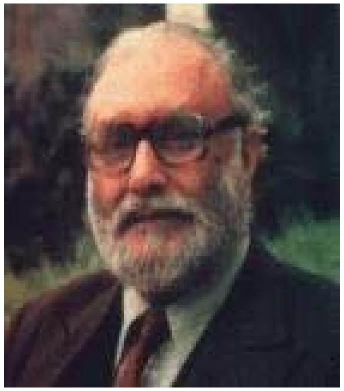
However, there are dark points in your paper regarding the vector field B_μ. The rest mass is infinite (or very large), how can this be compatible with the gauge transformation $B_\mu \rightarrow B_\mu - \partial_\mu \Lambda$? and he concludes his letter with the remark: “Every reader will realize that you deliberately conceal here something and will ask you the same questions.”

- Salam Says: “I must admit I was taken aback by Pauli’s fierce prejudice against universalism – against what we would today call unification of basic forces – but I did not take this too seriously. I felt this was a legacy of the exasperation which Pauli had always felt at Einstein’s somewhat formalistic attempts at unifying gravity with electromagnetism – forces which in Pauli’s phrase “cannot be joined – for God hath rent them asunder.”
- But Pauli was absolutely right in accusing me of darkness about the problem of the masses of the Yang – Mills fields; one could not obtain a mass without wantonly destroying the gauge symmetry one had started with.



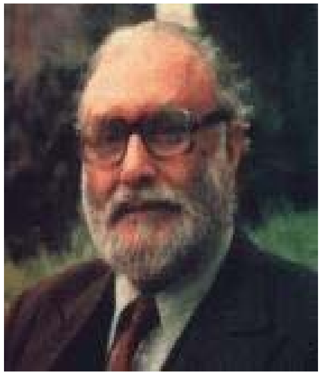
And this was particularly serious in this context, because Yang and Mills had conjectured the desirable renormalizability of their theory with a proof which relied heavily and exceptionally on the masslessness of their spin-one intermediate mesons. The problem was to be solved only seven years later with the understanding of what is now known as the Higgs mechanism”.

In the meantime, many ideas started to become clear.

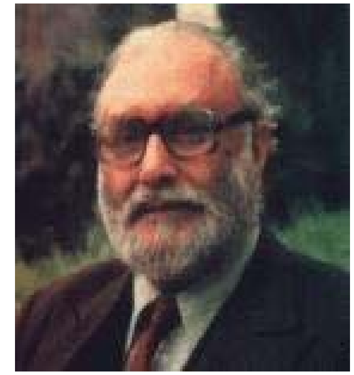


(i) the extension of γ^5 – (or chiral) symmetry by Marshak and Sudarshan (1957) and independently by Feynman and Gell-Mann (1958) to the spin ½ leptons and hadrons in general, resulted in the V – A theory for charged current weak interactions.

(ii) Spontaneous symmetry breaking in particle physics.



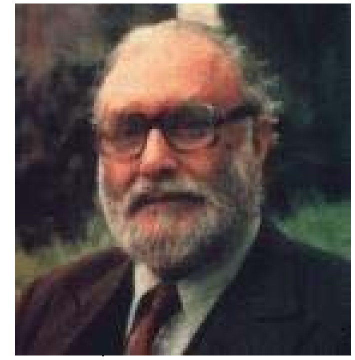
- The latter is described succinctly nowadays by the statement that the symmetry of the Lagrangian is not a symmetry of the ground state.
- Later Salam, together with Steven Weinberg and Geoffrey Goldstone, proved Goldstone's conjecture that a massless spin-zero object, called the Goldstone boson, must appear in a theory as a result of the spontaneous breaking of a continuous global symmetry.



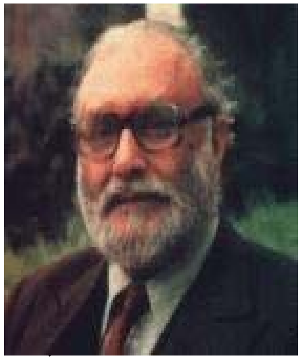
- Both the γ^5-invariance principle and spontaneous symmetry breaking in the papers referred to above hold in the context of global symmetries. Subsequently, Abdus Salam and John Ward worked on a local gauge theory for the weak and electromagnetic interaction, obtaining the *SU (2)* x *U (1)* model in 1964. This was a continuation of their work in the same topic that they had started in 1959. In the intervening period and thereafter, Salam had become deeply convinced that all elementary particle interactions are gauge interactions.

This was a recurrent theme in his papers and lectures in the sixties.

- Sheldon Glashow in 1961 had also proposed the group *SU (2)* x *U (1)* for describing the electromagnetic and weak interactions.
- However, in the papers of Salam and Ward as well as in Glashow’s paper, the problem of generating the masses form the gauge bosons of weak interactions remained unsolved.
- So, things remained dormant for some time as far as a viable mechanism for mass generation was concerned.

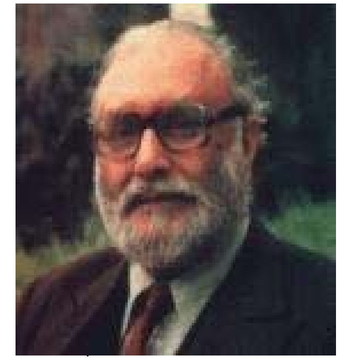


- In the years 1961-64, a lively debate developed about whether the Goldstone theorem could be evaded.
- P.W. Anderson, using an analogy with the superconductor, pointed out that the Goldstone (Plasmon) mode becomes massive due to the gauge field interactions whereas the electromagnetic modes are also massive due to the Meissner effect, despite gauge invariance. However, Anderson had not explicitly given a proof of the evasion of the Goldstone theorem in a relativistic theory.



- This proof was provided in subsequent theoretical developments pioneered by Peter Higgs, and independently by F. Englert and R. Brout. They also proposed a mechanism by which local symmetries could be broken spontaneously without introducing Goldstone boson.
- That this was a way to give masses to the gauge bosons and fermions without introducing explicit mass terms in the Lagrangian was immediately sensed by Salam, and independently by Steven Weinberg.

- So, all the ingredients mentioned earlier, namely local gauge theory, γ^5- symmetry (leading to chiral fermions), and renormalizability, on which Salam had worked for years, were there.
- In 1967/68, these developments culminated in the famous papers of Weinberg and Salam resulting n the electroweak unification (a name coined by Salam), based on the *SU (2)* x *U (1)* group with spontaneous symmetry breaking. This was a crucial step in the construction of a viable theory of weak interactions, made possible by the imaginative strokes of genius of Higgs, Salam and Weinberg.



- In 1971, G.'t Hooft proved the renormalizability of the Salam-Weinberg theory, and shortly thereafter B.W. Lee and J. Zinn-Justin gave a proof based on the path-internal formalism, thus removing any residual doubts in the minds of the skeptics.

Only then and with the discovery of neutral currents, people took the theory seriously.

The *SU (2)* x *U (1)* theory with the specific choice of the Higgs fields adopted by Salam and Weinberg made a number of predictions; all of which have been verified with great precision, The rest is history.

Thanks