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January 20, 1993

UCLA–PPH0043–8/92

UNIVERSAL IMPORTANCE OF WEAK NEUTRAL CURRENTS IN NATURE

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ABSTRACT

Neutral Currents play an important role in Nature. We trace the early history of Neutral and Charged Weak Current studies from the 1930's to the discovery of the W and Z in 1983. In the 1960's the null search for Neutral Currents that change Family combined with models of Weak Neutral and Charged Currents and led to the concept of Natural Family Conservation in Neutral Currents. In rapid order: Weak Neutral Currents (WNC) were discovered in 1973, were well understood by 1978 and were followed by the discovery of the W and Z in 1983. Neutral Currents are important in Supernova explosions and the Early Universe. The search for NC that change Family extends our study of the subatomic world into the incredible range of 100 TeV and is on-going today. The super colliders, SSC at Dallas and LHC in Geneva, Switzerland, will allow us to extend this search considerably. Recently, the bold speculation has been made that NC can give rise to the chirality of life (DNA). We discuss the pros's and cons of the possibility here.

The year 1993 is a banner anniversary for our understanding of nature: it marks the 10th anniversary of the discovery of the carriers of the Weak force: the W and Z particles at CERN, the laboratory near Geneva, Switzerland; the 20th anniversary of the discovery of the Weak Neutral Currents, and the 30th anniversary of the first revealing but null searches for Weak Neutral Currents that change the Quark Family! All of these developments have left a profound mark on our study of the most fundamental aspects of nature: "the Elementary Particles and their Forces". These observations helped develop the foundation of the Standard Model of Elementary Particles. This article is a partial celebration of this anniversary and an attempt to peer into the future implications and gain a perspective on these accomplishments. As in the telling of the history of any human accomplishments, it will appear more logical than when it actually occurred. We will also describe how the intervening years have taught us the way in which Neutral Currents contribute to Astrophysics and the Explosion of Supernova, will help in future possible break-throughs in the study of Elementary Particles and possibly even the very nature of life on Earth: the double helix structure of DNA, present in all life forms!

It can now be said the there have been three major advances in Physics during the past 100 or so years. The Theory of Relativity can be dated as taking place during 1905-1919: the development of Quantum Mechanics between 1913-1930: the experimental and theoretical formulation of the Standard Model of Elementary Particles (Rise of the Standard Model), which began around 1960 and continued until approximately 1983. Of course, there have been many other important advances in Nuclear Physics, Condensed Matter Physics, Cosmology and so forth. However, the three advances mentioned above are distinguished by having led to a nearly complete picture of a major area of fundamental science that has stood the test of time and verification by many experiments. The period of the "Rise of the Standard Model" was full of major theoretical and experimental discoveries. Among the most important events during this

period was the discovery of Neutral Currents (NC) in 1973 (Illustrations 1 and 2). (See "The Detection of Neutral Weak Current," Scientific American, 1974, D. Cline, A.K. Mann, C. Rubbia.)

All three of the break-through mentioned above have one thing in common: the basic theory has been greatly tested by experiment very early. For General Relativity the observed deflection of Starlight by the Sun in 1919 was a crucial experiment. For the Quantum Theory it was the study of various Atomic Physics systems as well as the observation of the particle-like nature of light (Compton Effect) and the wave like-nature of matter (2-Slit Electron Interference Pattern). For the Standard Model of Elementary Particles the key period of experimentation was between 1974 and 1978. It was during this period that the newly discovered Neutral Currents were quickly confirmed and studied in numerous experiments around the world. Given the breadth of the physical phenomena involved, this was a truly remarkable period.

To trace the history of the Weak interaction, it is necessary to place particular emphasis on the discovery of NC and the underlying theory of the Standard Model (Illustrations 2,3 and 4). The impact of the discovery of NC on our understanding of nature could turn out to be as important as that of the Weak Interaction or Radioactive Decay, which was discovered by H. Bequerel in 1896, and which we now know to be a Charged Current interaction in contrast to the Neutral Current, as illustrated in Illustration 1. By 1933, thirty-seven years later, the source of the energy of the Sun was shown to come from the Weak Interactions by Hans Bethe of Cornell University, illustrating the great significance of that discovery.

Let us trace the early history of the NC concept. The earliest ideas concerning the unity of Weak Interactions and Neutral Currents seems to have been described by the Swedish Physicist Oscar Klein in 1938 in a very obscure paper presented to the

League of Nations meeting in French and in wartime Warsaw, Poland. In the 1940's T. D. Lee of Columbia University, C. N. Yang of Stony Brook and M. Rosenbuth of the University of California San Diego invented the concept of the W (for Weakon, the carrier of the Weak Force). It was not until the 1960's that S. Glashow of Harvard University, S. Weinberg of the University of Texas and A. Salam of the Theoretical Center at Trieste developed the modern concept of the W and Z Bosons, implying the existence of Neutral Currents in Nature (W-S-G Model).

By 1973, when the Fermi National Accelerator Laboratory (FNAL) neutrino beam was just being commissioned and the very large bubble chamber Gargamelle was taking copious data at CERN: the issue of the existence of Neutral Currents was coming to a boil! It was in this year, starting with Gargamelle and the Harvard-Penn-Wisconsin (HPW) experiments (Illustration 2b), that Neutral Currents were observed.

The search for Family Changing Neutral Currents (FCNC) was carried out with strange particles mainly in the period 1963 – 1970. The first definitive search for Neutral Currents that change the Quark Family was undertaken by the author and his colleagues using the Lawrence Berkeley Laboratory Strange Particles Beam. In Illustration 2a we trace the historical development of the various Neutral Current Studies. In the mid seventies the absence of FCNC prompted the concept of "Natural Family Conservation" for the Neutral Currents*. This has come to be a key development in the "Rise of the Standard Model" and strongly limits the types of quarks that exist in nature. This is an example of how null experiments can strongly influence the direction of a field of science.

During the period of 1974 to 1978 a remarkable synthesis occurred: the NC pa-

* One of the key results of this search is the direct evidence that the massive 6th quark or t-quark must exist. (Experiments are underway at Fermilab to search for this particle)

rameters were found to fit precisely the expectation of the W-S-G Model! And the key parameter of the Standard Model was born; $sin^2\theta_w$. We trace the remarkable measurements of $\sin^2\theta_w$ from 1973 to the present in Illustration 3. In Illustration 2b we show the 1976 version of the HPW experiment that measured the NC parameter, obtaining the modern observed value of the $\sin^2\theta_w$. There were many other developments that lead to the remarkable "Rise of the Standard Model", as shown in Illustration 4.

In 1976 an idea was put forward by C. Rubbia of CERN, P. McIntyre of Texas A & M and the author to convert either the CERN or FNAL Synchrotron to a proton-antiproton collider in order to discover the W and Z particles. In 1983 the W and Z were discovered at CERN, the pinnacle of the Rise of the Standard Model! (See "Search for the Intermediate Vector Boson", Scientific American, 1982, D. Cline, C. Rubbia and S. van der Meer.)

During the intervening years we have learned that the NC plays a key role in the Universe. It drives the explosions of Supernova and the subsequent production of all the heavy elements required for life on our planet. In addition, the formation of neutron stars or black holes from the Supernova in the Universe are related to the NC forces. Perhaps the most exciting possibility is that NC could provide the central mechanism for the basic structure of the DNA double helix. Illustration 5 shows some of the large variety of phenomena affected by Neutral Currents. We now discuss two of these frontiers.

The future study of elementary particles depends partially on two factors: (1) the detailed and precise measurements of NC parameters and (2) the continued search for Family Changing Neutral Currents. A machine in Geneva, Switzerland, called LEP is being used to study the Z^0 by the millions and has improved our knowledge of the NC parameters (see Illustration 3). Illustration 6a shows the kind of tools that will be used in the future to refine these measurements. By the year 2000, $\sin^2\theta_w$ may be known to

five decimal points, an incredible accomplishment in 25 years of study!

The search for Neutral Currents that change Quark Family (FCNC) is also entering into a sensitive period. Illustration 6b shows one such experiment where the b (Beauty) quark to s (Strange) quark transition

$$b \rightarrow s + X^0 \hookrightarrow \ell + \bar{\ell}$$

is being searched for. We can consider the X^0 particle to indicate a new level of substructure in physics. The most sensitive search to date was carried out at the CERN $\bar{p}p$ collider by the authors group. The other interesting FCNC process (s quark to d (Down) quark)

$$s \rightarrow d + X^0 \hookrightarrow \nu + \bar{\nu}$$

can be searched for by the reaction

$$K^+ \rightarrow \pi^+ + \nu + \bar{\nu}$$

This search was started in 1965 by the author in order to search for a clean example of FCNC and continues today. The level of sensitivity to the mass of the X^0 particle has now reached well beyond 10 TeV, the Superconducting Super Collider (SSC) energy. Future experiments can extend the range to 100 and even possibly 1000 TeV, far beyond that available to the SSC or LHC Super Colliders.

While the earliest searches for Family Changing Neutral Currents used the decay of K mesons and failed to observe neutral currents, we now know that these null results are a key component of the Standard Model. In the simplest version there is a sort of Family Conservation built into the Neutral Currents which in turn prescribes that only two types of quarks should exist in nature: charges $Q = -1/3$ and $Q = 2/3$. In other words,

one of the great successes of the Standard Model is the inability to observe Neutral Currents that change the Family of the quark. In contrast, the observation of even a tiny FCNC signal would imply structure beyond the Standard Model!

What can we hope to discover with such precise measurements of NC or searches for FCNC: A process that goes beyond the Standard Model to possibly illuminate the physics waiting there. We strongly believe that there should be some new substructure in the energy range from the W and Z to the Planck Scale, $\sim 10^{19}$ GeV. As illustrated in Illustration 7, there are many possibilities, some of which are far beyond that covered by the energy range of the SSC and LHC.

For more than one century there has been evidence for the chiral, or handedness, nature of life forms on Earth. The origin of this effect is one of the great mysteries of life. Pasteur was among the first to point this out (1884) and the universal nature of chiral symmetry breaking in DNA and RNA is now very well established for all life forms. The following quote is from one of Richard Feynman's lectures, reproduced here because of its' clarity. In this quote Feynman describes an experiment in which sugar is reproduced by chemical means. This sugar which was produced in the laboratory, exactly the same in chemical composition, is compared to natural sugar and certain differences are found to exist.

> "This is a most remarkable fact, and it seems at first sight to prove that the physical laws are not symmetric for reflection. However, the sugar that we used that time may have been from sugar beet; but sugar is a fairly simple molecule, and it is possible to make it in the laboratory out of carbon dioxide and water, going through lots of stages in between. If you try artificial sugar, which chemically seems to be the same in every way, it does not turn the light. Bacteria eat sugar; **if you put bacteria in the**

> **artificial sugar water it turns out that they only eat half the sugar, and when the bacteria are finished and you pass polarized light through the remaining sugar water you find it turns to the** <u>left</u>. The explanation of this is as follows. Sugar is a complicated molecule, a set of atoms in a complicated arrangement. If you make exactly the same arrangement, but with left as right, then every distance between every pair of atoms is the same in one as in the other, the energy of the molecules is exactly the same, and for all chemical phenomena not involving life they are the same. **But living creatures find a difference**. Bacteria eat one kind and not the other."

So, bacteria only eat right handed sugar: this is an example of a chiral substance†.

With the discovery of parity violation in Charged Current reactions in 1956, and of the weak Neutral Currents (NC) in 1973, two universal symmetry breaking processes were uncovered that may have effected the structure of DNA and RNA. The main problem is that this interaction represents an extremely small symmetry breaking effects, ($\mathcal{E}/\mathrm{kT} \sim 10^{-17}$)‡ however, there are plausible non linear mechanisms that could have amplified this small symmetry breaking process up to the full symmetry breaking observed in life forms. We note that there is a long standing controversy as to whether or not these non linear effects are actually large enough to have caused the selection of the chirality of the bio-molecules.

This type of chiral symmetry breaking effect could have aided or perhaps even effected this transition. The key parameter is the time to effect the transition and

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† Objects that are different from their mirror image are called Chiral.

‡ Symmetry Breaking divided by the Thermal Fluctuation is less than one part in 10^{17} kT (represents the level of Thermal Fluctuations).

is given by the parameter τ, which is related to the inverse of $\gamma N \mathcal{E}^2$ where γ is the replication time of the system, N the number of bio-molecules and $\mathcal{E}$ the chiral symmetry breaking parameter ($\mathcal{E} = 10^{-17}$ kT for NC or Charged Currents). This is an example of the field non-equilibrium thermodynamics.

If we consider the totality of bio-molecules in the oceans of the earth, we estimate the number to be:

$$N \sim 10^{23}$$

and assuming a replication time of for $\gamma \sim 1\text{hr}^{-1}$ we find that $tau > 10^7$ years for $\mathcal{E} \sim 10^{-17}$ kT. This is a plausible period of time for life to have formed on earth, given the amplification mechanisms pointed out above.

Thus, over very long period of time, small effects can be magnified. A likely sequence for bio-molecular formation is shown in Illustration 8. <u>It is remarkable that all current and detailed calculations of energy force for different bio-molecules</u> (including the NC interaction level) <u>find the lowest energy level occurs for the ones actually observed in Nature</u>.

Recently, Y. Liu, a graduate student at UCLA, and I have studied this problem. Following the ideas of I. Prigogine and pioneering work done at the University of Texas at Austin, we have carried out simulations of the possible transition of the system from the unbroken symmetry to the broken symmetry due to Weak Neutral Currents (Illustration 9). We agree with the previous works and have tried to address some of the criticisms of these earlier works in our simulation, including the effects of large random noise at the critical transition point in the system.

There are many examples in Nature where small effects can be magnified to make large effects over sufficient time. One example is found in the annealing of a metal, where the very slow cooling can lead to a near crystalline structure. Another example is the

build up of the Polarization or direction of the spin of an electron in a storage ring due to the magnetic field direction. While this effect is very tiny during each revolution of the electron around the machine, in several hours (there will be 100 million revolutions in an hour) a large effect ($\sim 90\%$ of the spins in one direction) builds up. The build up of the chiral structure of the biomolecules of life on Earth could have followed a similar path but instead taking millions of years.

Another interesting idea has been put forward recently by Abdus Salam concerning the origin of bio-molecular chirality. Suppose the Neutral Current interaction causes a phase transition at low temperature (such as water turning into ice) that selects the chirality of the bio-molecular system. In this case, life could have arisen in the cold reaches of outer space! Nevertheless, <u>all</u> life forms in the universe would have the same chiral structure of the bio-molecules. Another possibility that we are currently studying is that the neutrino burst from a very nearby Supernova Explosion in the early years of our planet could have caused a "chiral catastrophe" in the bio-molecules, and have aided the transition to the presently observed system.

The final word is not in on this issue. It should be noted that experimental studies are going on at various places and these studies could determine if the structure of the DNA building blocks can arise from the Weak Interaction. In the words of the late and great Russian physicist Ya Zeldovich, who, along with the Physicist C. Franck, in some ways initiated these ideas; in one of his last works wrote,

> "We can thus conclude only that an analysis of this question <u>does not rule out</u> the possibility that the chirality of biomolecules was determined by the asymmetry of the weak interactions."

In this article we have described the Rise of the Standard Model of Elementary Particles mainly through the study of the Neutral Currents and the W,Z particles that were observed throughout the 1970's and 1980's. In the meantime we have learned that

Neutral Currents play an extremely important role in nature, not only to further elucidate the structure of elementary particles, but in natural phenomena such as element creation in Supernova explosions; and perhaps the very basis of life, the chirality of the biomolecules. If this is so, then perhaps all life forms in the Universe will have the same chiral structure of that found on Earth. While this is the 30th anniversary of the beginning of our study of Neutral Currents, it is clear that the next 30 years may be just as fruitful!

Illustration 1

Neutrino Quark Scattering Illustration: All the Types of the Weak Interactions

We illustrate the different types of Weak Interaction process by the type of scattering that would be observed by neutrinos or quarks (a) For Charged Currents the neutrino converts to a charged lepton (i.e. positron) and converts the quarks from a $Q = 2/3$ to a $Q = -1/3$ state (b). For Neutral Currents the scattering occurs on quarks of either $Q = +2/3$ or $Q = -1/3$, but there is no change of Quark Family in the transition (c) For the Family Changing Neutral Current the initial quark is converted into another Quark Family, i.e. down quark to strange quark. So far only process (a) (or equivalent) and (b) have been observed in nature. Strong limits exist have been placed for processes (c), which helped the Rise of the Standard Model of Elementary Particles. The three known Quark Families are also illustrated.

Illustration 2a

The Experimental History of the Study of Weak Neutral Currents

The key periods for experiment were 1963 – 1970, 1973 and 1983. In the period 1963 – 1970 the first definitive searches for Family Changing Neutral Currents were started. In 1973 Neutral Currents were discovered. Two major experiments were engaged in searching for evidences of Neutral Currents. The large Gargamelle Bubble Chamber at CERN and the HPW detector at Fermilab. Both experiments went through a period of confusion in 1973 with the CERN experiment reporting their results just before the HPW experiment. In 1983 the Z^0, the carrier of the NC force, was discovered at CERN. The search for Family Changing Weak Neutral Currents started with Strange particles and following the initial experiments it was carried out with Charm particles mainly in the period 1976 – 1985. Most recently it was carried out with Beauty particles in mainly the period of 1980 – 1989. All of these searches continue today. We also trace the period when the important theory work was carried out.

Fundamental Processes

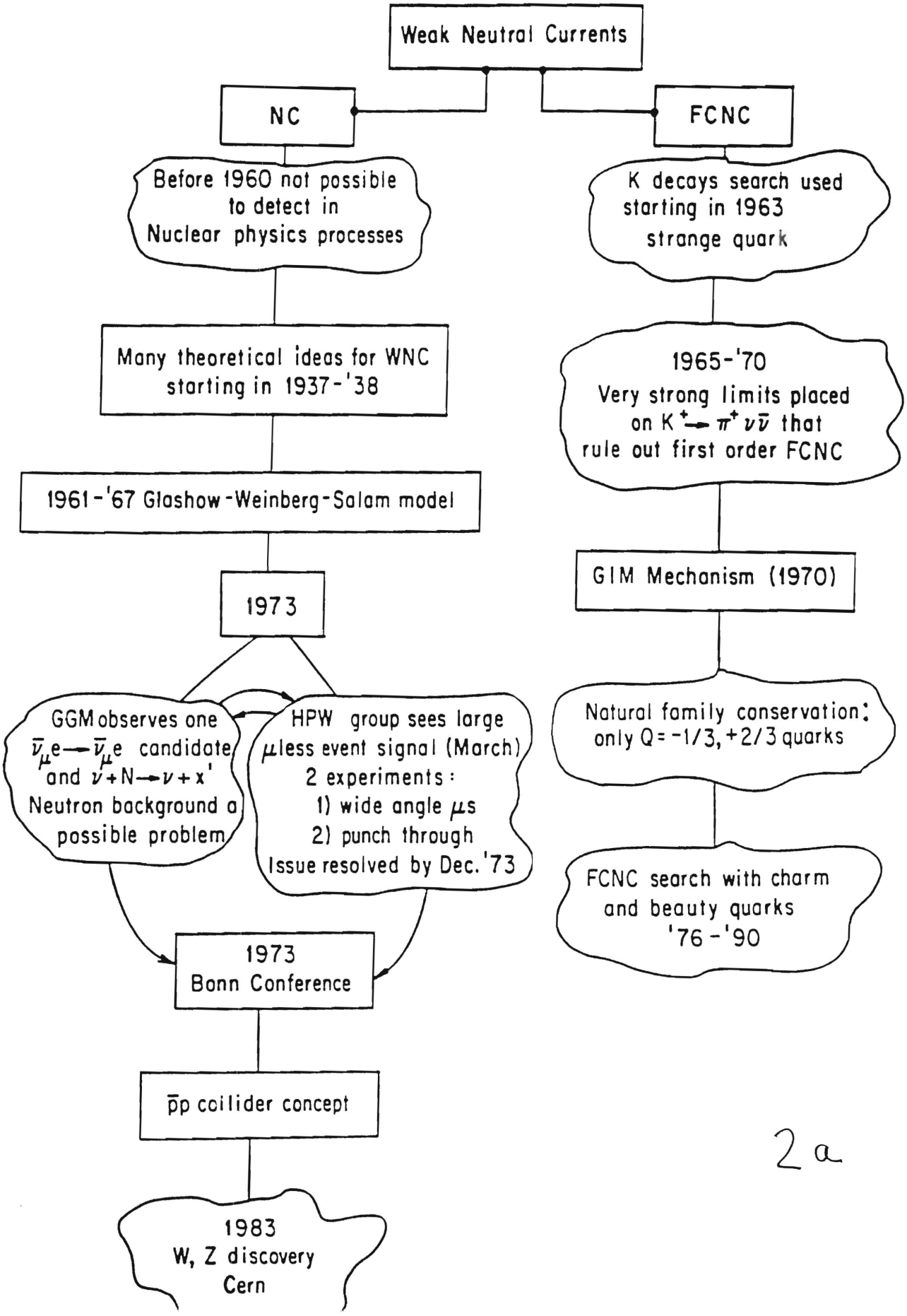
Neutrino-Quark Scattering

Eq.:		First Observation or Dedicated Search:
Charged Current:		
(a)	$\nu + q \rightarrow q' + e$ $q = u, c, t$ $q' = d, s, b$	1896
Weak Neutral Current:		
(b)	$\nu + q \rightarrow q + \nu$ $q = u, c, t, d, s, b$	1973
Family Changing Weak Neutral Current:		
(c)	$\nu + q \not\rightarrow q' + \nu$	1963

$$eg. \qquad g = \begin{pmatrix} u \\ d \\ b \\ \vdots \end{pmatrix}, \quad g' = \begin{pmatrix} c \\ s \\ s \\ \vdots \end{pmatrix}$$

$\begin{pmatrix} +\frac{2}{3} \\ -\frac{1}{3} \end{pmatrix}$	$\begin{pmatrix} u \\ d \end{pmatrix}$	$\begin{pmatrix} c \\ s \end{pmatrix}$	$\begin{pmatrix} t \\ b \end{pmatrix}$
Quark Families	(1)	(2)	(3)

EXPERIMENTAL HISTORY OF WEAK NEUTRAL CURRENTS



2a

Illustration 2b

Experimental Detector Used to Obtain Modern Values of the NC Parameters

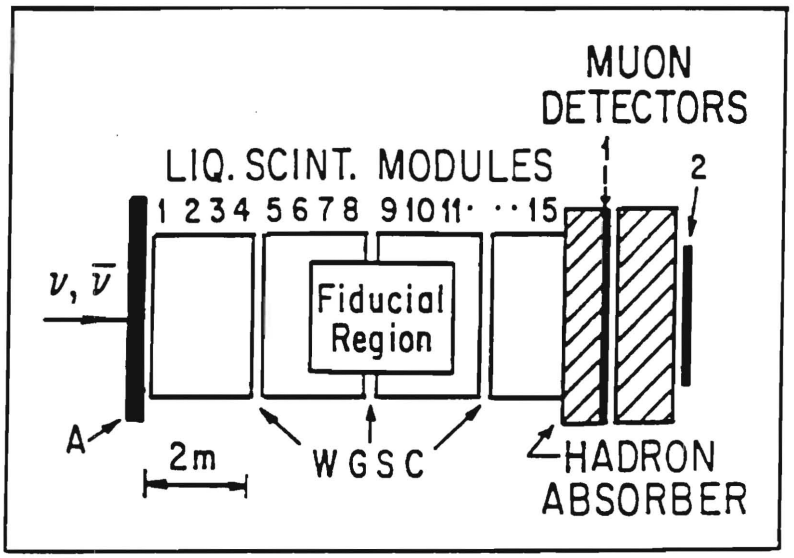
After the discovery of the Neutral Currents in 1973 it was crucial to measure the key parameters of the neutral current interaction. The first experiment that observed the modern value of these parameters was the HPW detector at Fermilab (also involved in the initial observation of NC). This detector consisted of 100 Tons of mineral oil and about 2,000 Tons of magnetic iron to measure the μ particles. A small region called the Fiducial volume was used to limit effects from the edge of the detector. The author was the spokesperson for this project.

Illustration 3

History of the Measurement of the Key Parameter of the NC

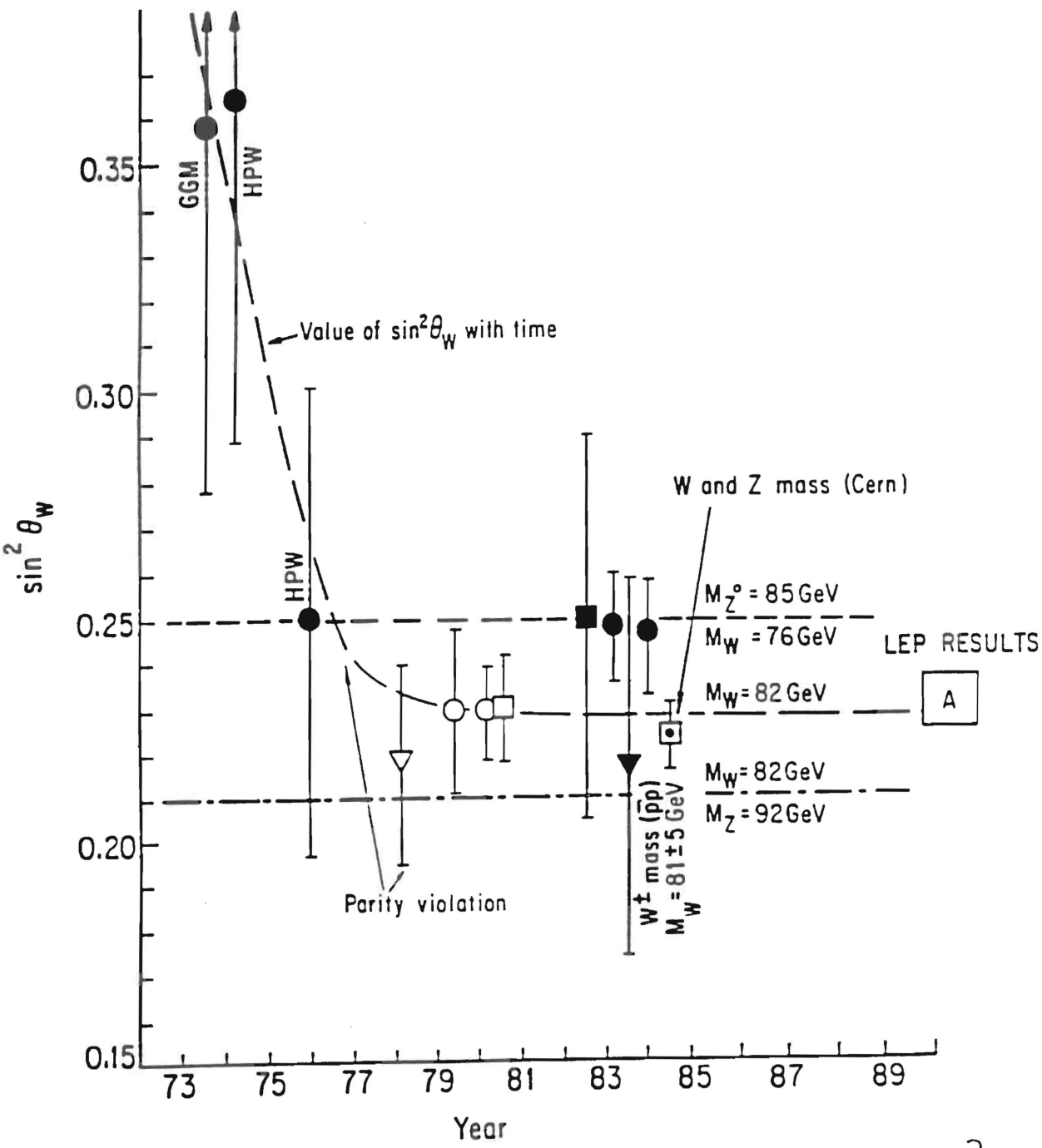
These measurements were carried out with amazing rapidity. This illustration shows various measurements as time progressed. By 1978 a fairly small error was obtained and established the Standard Model. By 1985 the W and Z masses could be used to further refine the measurement. With the advantage of the high energy e^+e^- colliders (SLC at SLAC and LEP at Geneva) amazing precision has now been obtained. Insert A shows that the current measurement of this parameter from many different experiments.

THE HPW DETECTOR AT FNAL IN 1975
THAT MEASURED THE MODERN VALUE OF $\sin^2\theta_W$

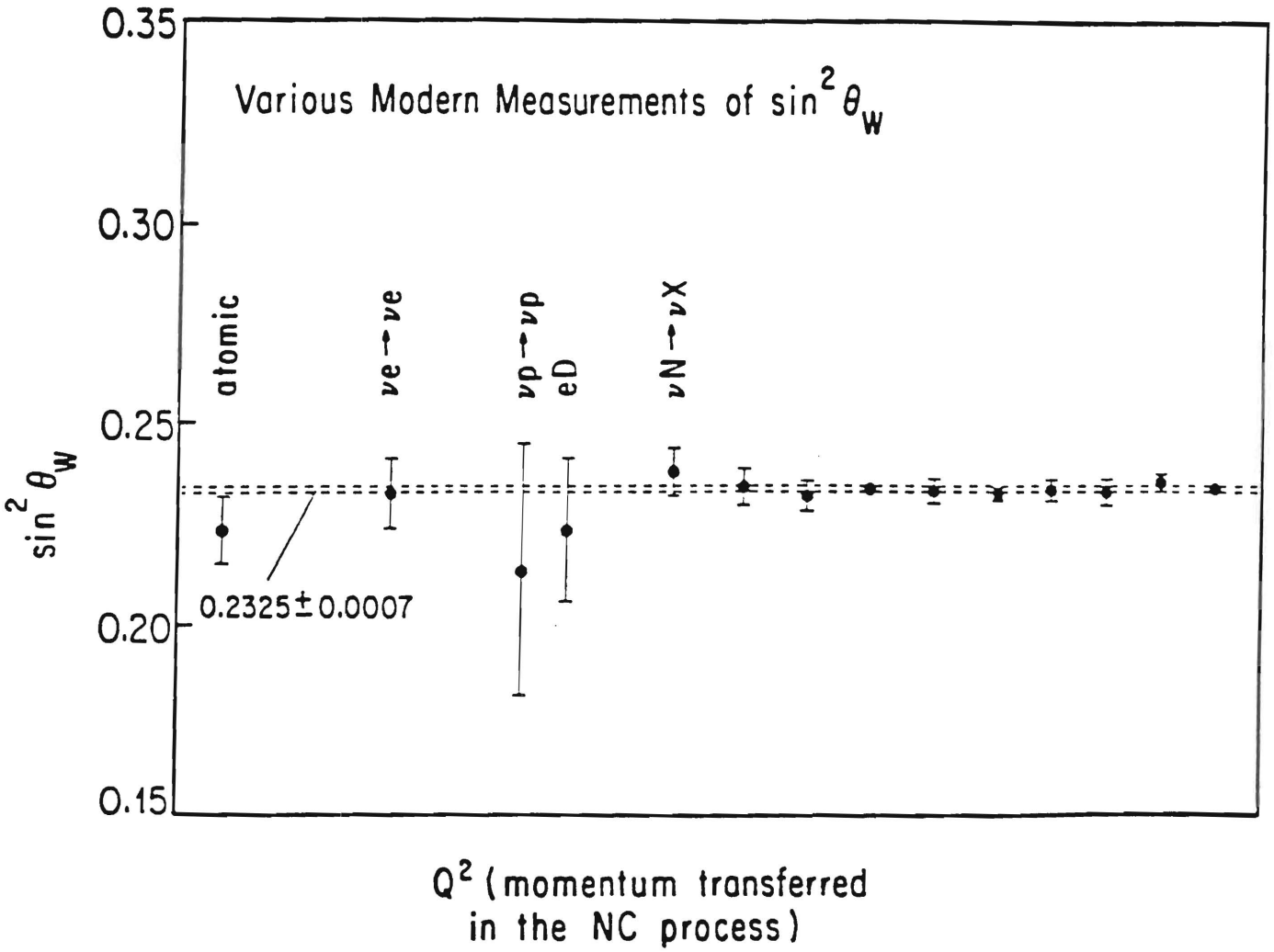


2b

HISTORY OF THE VALUE OF $SIN^2\theta_W$



3


Various Modern Measurements of $\sin^2\theta_W$
0.35
0.30
0.25
0.20
0.15
$\sin^2\theta_W$
atomic
$\nu e \to \nu e$
$\nu p \to \nu p$
eD
$\nu N \to \nu X$
0.2325 ± 0.0007
Q^2 (momentum transferred in the NC process)

3 - INSERT A -

Illustration 4

The Rise of the Standard Model of Elementary Particles and Forces

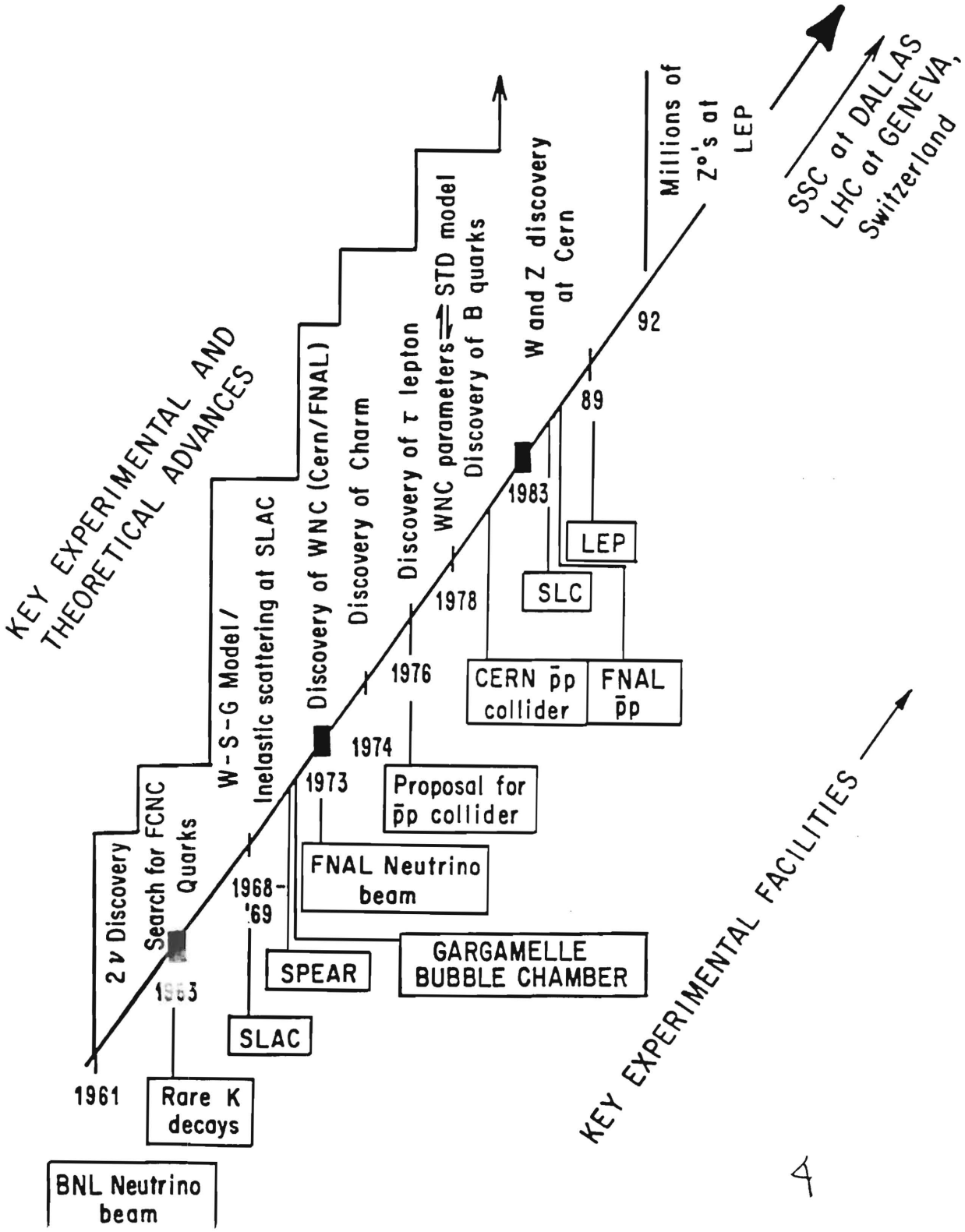
We show the key developments in both theory experiment and new machines to carry out experiments. The key developments were in the years spanning 1963 to 1983. A remarkable achievement for science which stands as one of the great accomplishments of science in the 20th Century which also includes the Theory of Relativity and Quantum Mechanics. The study of Neutral Currents played a crucial role in this development.

Illustration 5

Neutral Currents in Nature

Neutral Currents play an even greater role in nature as a whole than was initially imagined. From the future study of the Standard Model and its underlying theory to an important role in Astrophysics and the Early Universe and even to the possibility that NC influenced the Origin of Life on Earth.

THE RISE OF THE STANDARD MODEL OF ELEMENTARY PARTICLES



WEAK NEUTRAL CURRENTS IN NATURE

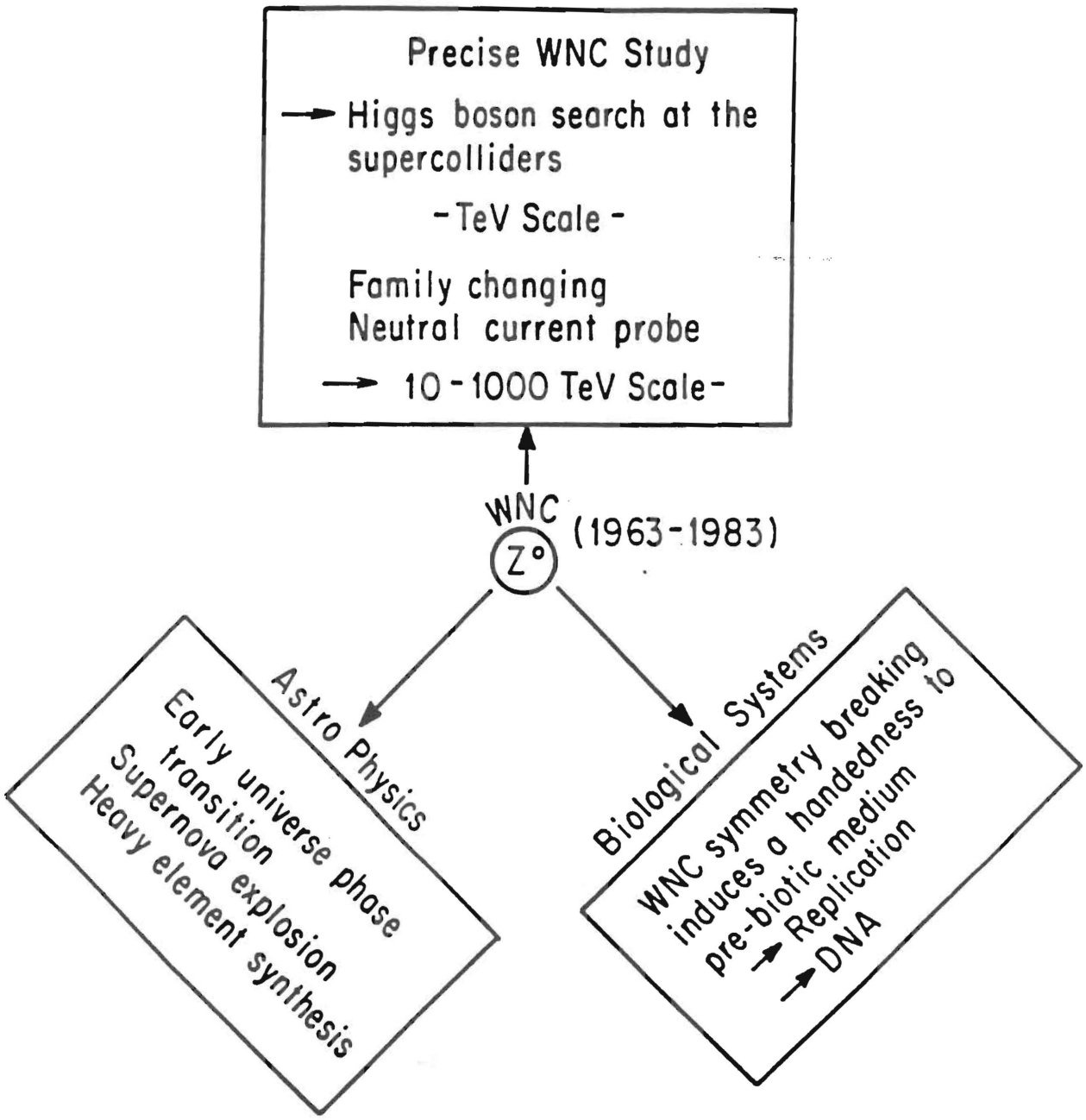


Illustration 6

The Future Study of Neutral Currents at Accelerators and Elsewhere

(a) The future study of Neutral Currents will involve experiments that measure effects in atoms and low energy neutrino scattering and on to the study of millions of W and Z particles at LEP and elsewhere and then on to the search for the Higgs Particles at the Super Colliders: the LHC at Geneva and the SSC at Dallas.

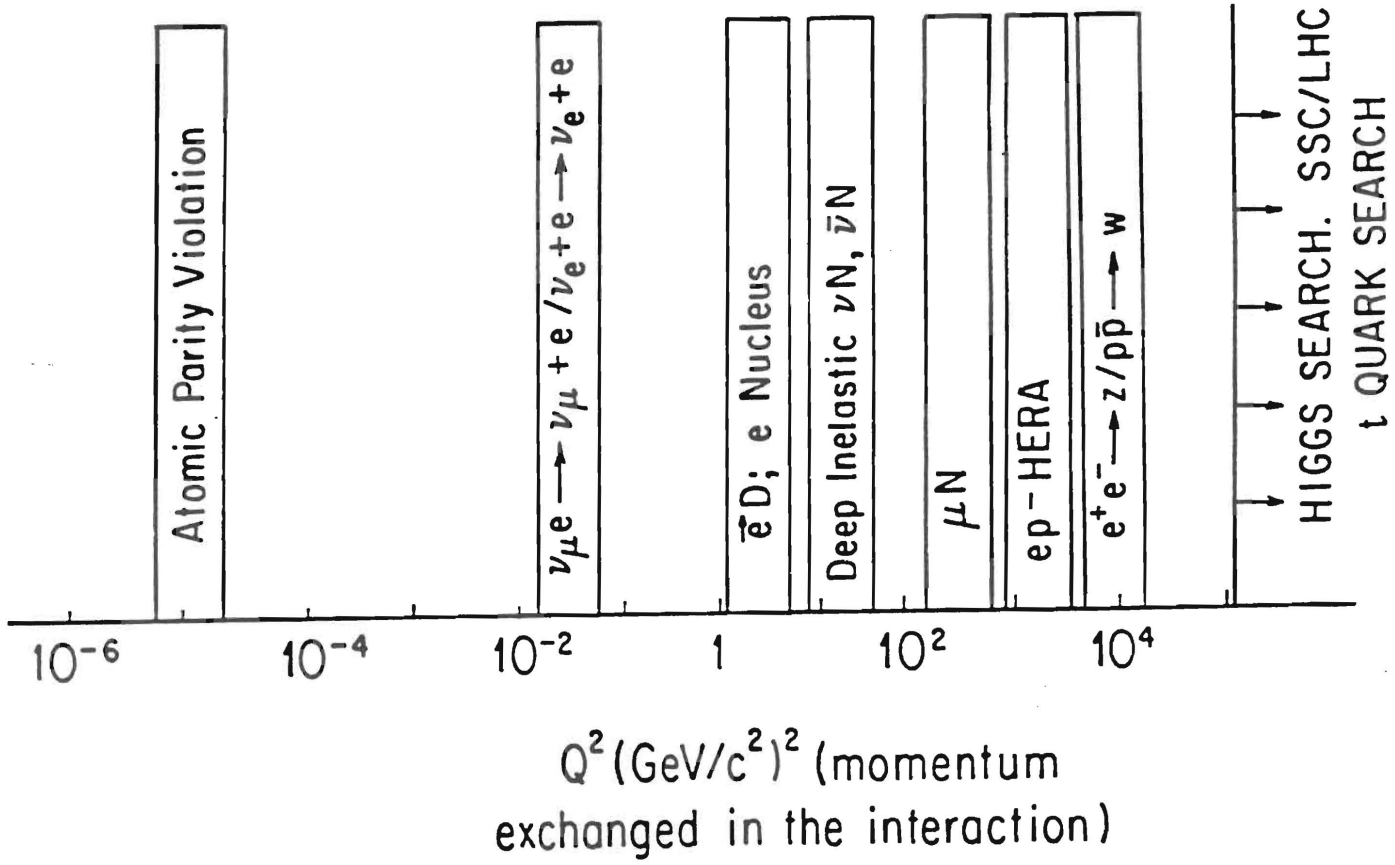
(b) The future search for different types of Family Changing Neutral Currents may teach us about the next level of sub structure in nature (i.e. X^0 particle). This is very important since we now think the Standard Model is an incomplete description of Nature.

Illustration 7

Beyond the Standard Model to the Next Substructure in Nature

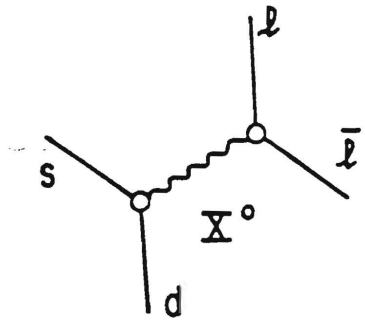
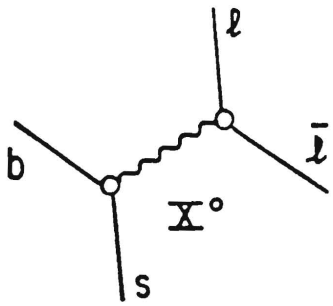
While the Standard Model is a great accomplishment it is still incomplete. Now we know that the Natural Scale of Physics is at the Planck mass of 10^{19} GeV ($10^{17} \times M_Z$). This illustration shows where "Physics Beyond the Standard Model" may occur in terms of the energy scale. Among the first steps in this probe will be with the search for FCNC and experiments at the Super Colliders. FCNC can eventually probe the (100 – 1000) TeV range and the Super Collider the 1 – 10 TeV range. Precise study of NC can reach $\sim$ 1 TeV. Other probes such as proton decay and a tiny neutrino mass are expected from the very high energy scale.

FUTURE STUDY OF WEAK NEUTRAL CURRENT PARAMETERS

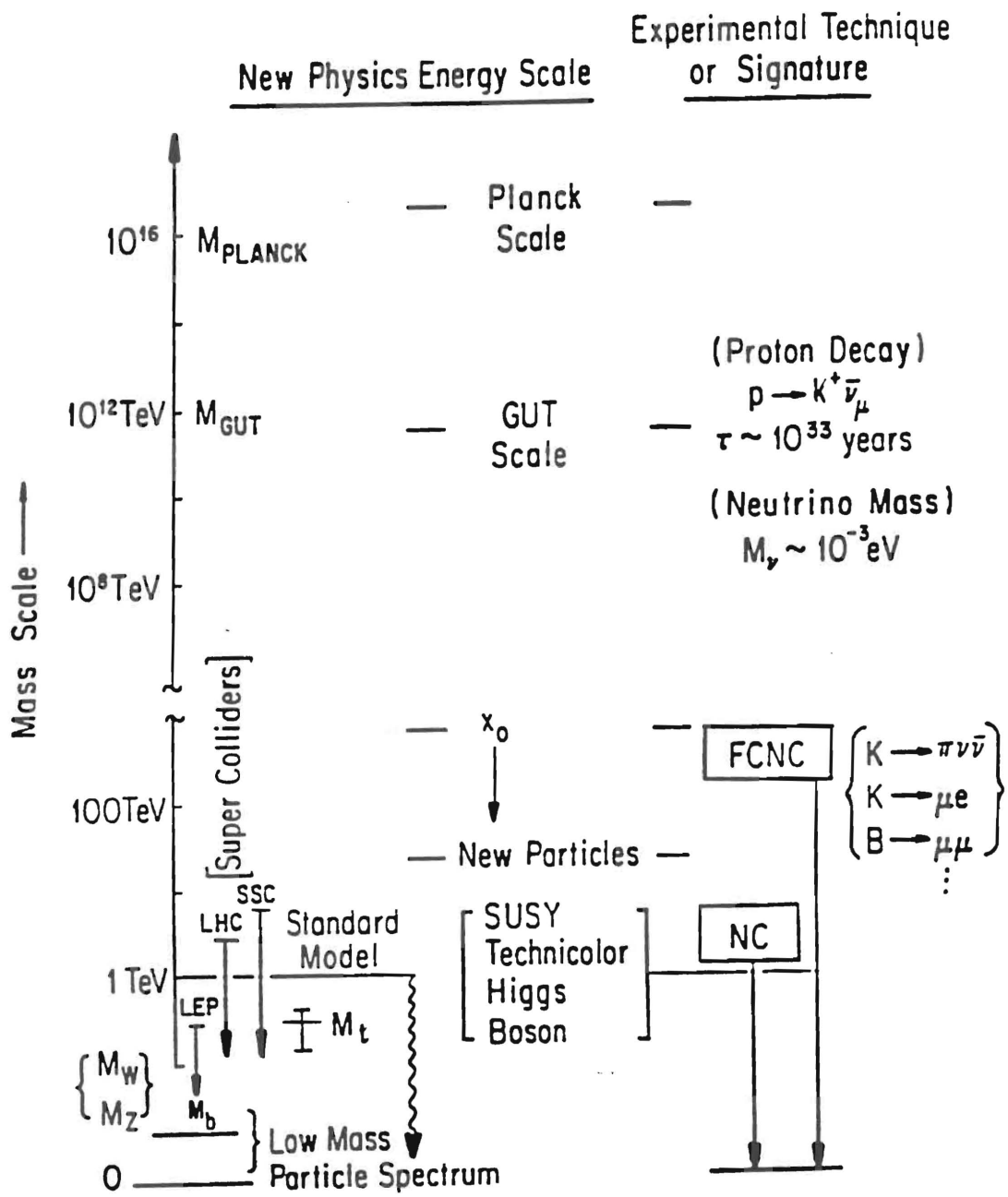


6(a)

SEARCH FOR FAMILY CHANGING WEAK NEUTRAL CURRENTS

		Process	Current limit on branching fraction
LIGHT QUARKS	$[s \longrightarrow d]$		
		$K^+ \to \pi^+ \nu\bar{\nu}$	2×10^{-9}
(BNL K Beam)		(first search 1963-'65 limit ~ 10^{-4})	
		ULTIMATE SEARCH	
		$\sim 10^{-10}$	
		$M_X \leq 100$ TeV	
HEAVY QUARKS	$[b \longrightarrow s]$		
		$b \to s + \mu^- + \mu^+$	5×10^{-5}
(Cern $\bar{p}p$ collider)		ULTIMATE SEARCH	
		$\sim 10^{-6} - 10^{-8}$	

6(b)


New Physics Energy Scale
Experimental Technique or Signature
Mass Scale
10^{16}
M_{PLANCK}
Planck Scale
10^{12}TeV
M_{GUT}
GUT Scale
(Proton Decay)
$p \to K^+ \bar{\nu}_\mu$
$\tau \sim 10^{33}$ years
(Neutrino Mass)
$M_\nu \sim 10^{-3}$eV
10^8TeV
Super Colliders
X_0
FCNC
$K \to \pi \nu \bar{\nu}$
$K \to \mu e$
$B \to \mu\mu$
100TeV
New Particles
SSC
LHC
Standard Model
SUSY
Technicolor
Higgs
Boson
NC
1 TeV
LEP
M_t
M_W
M_Z
M_b
Low Mass Particle Spectrum
0

7.

Illustration 8

Possible Role of NC in the Formation of Life on Earth

During the past 15 years there has been increased interest in the possibility that the NC give rise to the underlying structure in the chiral structure of DNA – the molecule of life. This illustration shows the likely method of development of the life forming molecules. We still don't know definitely where the fundamental chemical reactions occurred: (The early Earth or from Comets and Meteors that brought the material to Earth) In the Ocean over millions of years the NC could have influenced the chiral symmetry breaking of the pre biotic medium. From then on it is believed that the key replication and other aspects of life may have almost been inevitable after the prebiotic medium was all of one chirality: The other two steps in the formation of the molecule of life refer to detailed chemical processes not described here.

Illustration 9

Simulation of the Effect of WNC on a Prebiotic System

An example of the evolution of a system with a small symmetry breaking or chiral effect like the NC force showing how a tiny effect can influence the final outcome of the system. This simulation was done at UCLA by the author and his group. A detailed model of how the Neutral Current influenced the formation of life is still lacking: however, these types of studies show that it is plausible that it did! The system evolves in time and two states are possible. Detailed calculations have shown that the lowest energy level states occur through the influence of the Neutral Current interaction.

THE ROLE OF WEAK NEUTRAL CURRENTS IN FORMATION OF PRE-BIOLOGICAL SYSTEMS

	PROCESS	POSSIBLE ORIGIN
1	Synthesis of organic compounds	Early earth atmosphere or Formed extraterrestrially
2	Mirror symmetry breaking	Weak neutral current forces over (10^5-10^6) years in saline solution
3	Polymer domination of the medium	Homochiral polymers
4	Formation of special enzymatic activity in medium	Homochiral chemical automata

SELF REPLICATING SYSTEMS

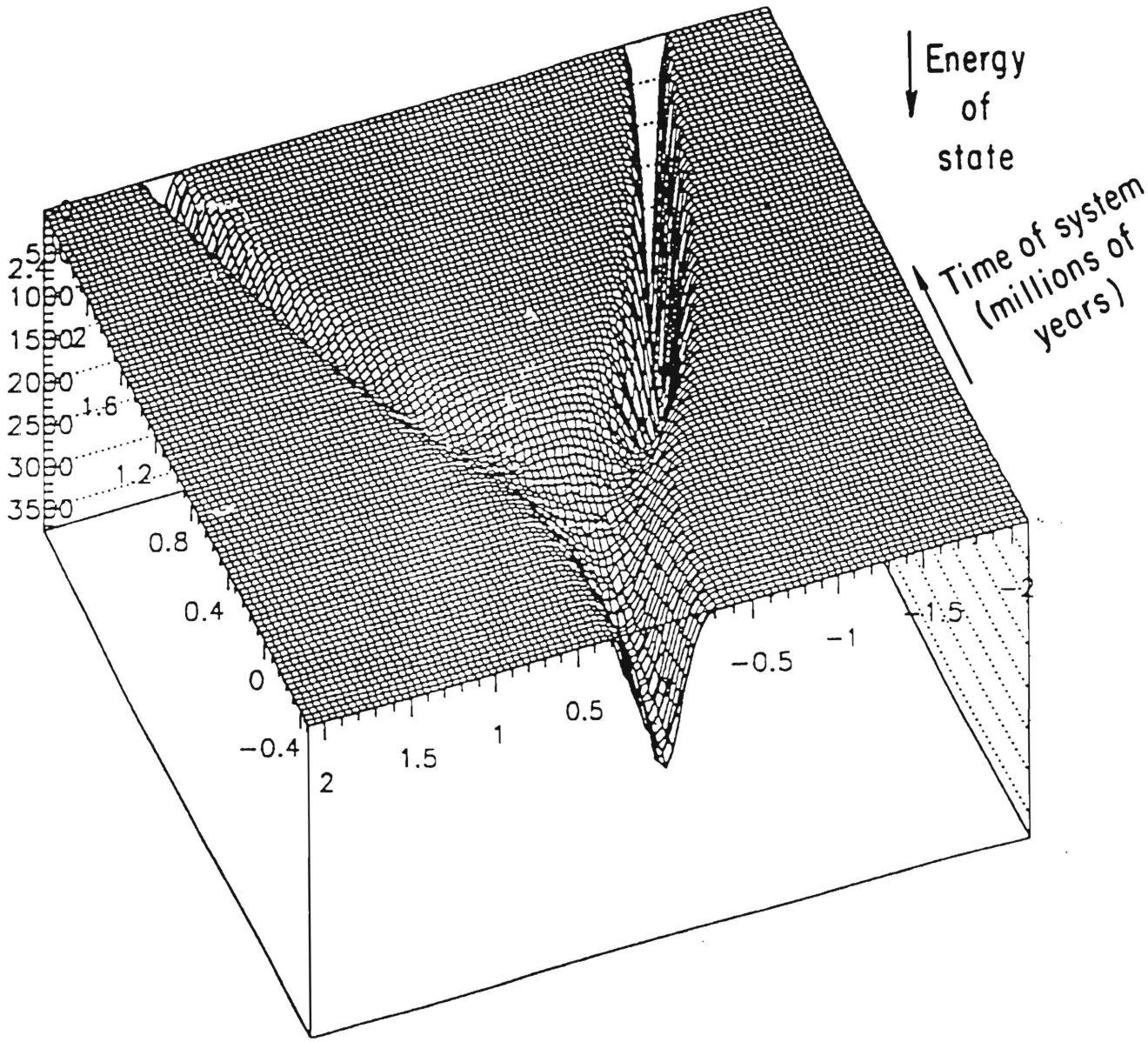



Illustration of the effect of a symmetry breaking interaction such as weak neutral currents on a system of pre-biotic molecules