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A CRITICAL REVIEW OF A QUANTITATIVE STUDY OF A SPECIALITY IN HIGH ENERGY PARTICLE PHYSICS*

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Abstract

A review is made of the authors' series of quantitative, historical and social studies of the weak interactions of elementary particles. A short intellectual history, the quantitative methodology and a summary of the papers analyzing specific episodes in this field is presented. We describe the social organization of the field, and discuss an overall policy for resource management.

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Introduction

In this paper we present our present intellectual view of a specialty in the field of high energy physics, the study of the weak interactions of elementary particles. We concentrate here on the theorists because they publish more papers and this leads to an emphasis on their activities when we use citation and publication indicators in our study of the field as a whole. A comparison paper[1] gives some preliminary data that we derive and synthesize using experimenters directly. We believe that the behavior of the theorists is calculated to optimize their individual return and in that sense is supremely rational. We hope that the reader of this paper will agree, that at least in a few selected episodes this view can be defended. We also believe that in order to understand the behavior of these scientists some understanding of the intellectual problems they face and the methods they use to make progress is imperative and so we have included a precis of the present view of this field.

WEAK INTERACTIONS

It is our intent here to give a brief outline of the intellectual field that is described by the participating physicists as the field of the weak interactions of elementary particles. We do not claim that this is a definitive history, but we offer it as a subjective outline that we think will be helpful for a proper appreciation of the behavior of the scientists that have participated in this activity. This intellectual framework is crucial to the existence of the field, it provides the coherence and allows a concensus to form that the subject has been "understood", and even allows for the reservations and dissentions that an active field will have. We claim, however, that this intellectual focus is not the whole story, and the body of this paper is addressed to some of the other features of the field that we believe influences the social behavior.

The field from a post hoc point of view showed signs of nativity in the thirties with the discovery of the form of radioactivity known as Beta decay. Unstable nuclei transform their charge by the emission of an electron (positive or negatively charged) in association with a massless neutral object, the neutrino. The nuclear charge is changed by one unit and an early and successful theory of the process was proposed by Fermi in close analogy to the established theory of electromagnetism. It is especially amusing to note that the efforts toward the unification of the theories of weak and electromagnetic processes have been ultimately successful over the last few years.

The field, as far as this study is concerned started in 1950. This date marks the start of a concerted program of study of the weak decays of the elementary particles with the assumption that those decays represent the most fundamental manifestation of the weak force that we have available to us at this time. The elementary particles we refer to are the constituents of nuclei, protons and neutrons, together with the mesons that seem responsible for the strong forces that bind them together. It is the present view that these elementary particles are composed of constituents, the quarks, with "gluons" that bind the quarks together. We shall use this most modern view of elementarity, partly because of a hope that it is a stable view of nature, but also because of the elegance and economy of the picture. We apologize for using yet unobserved entities in our description but we counsel faith, for even if the view turns out to be wrong, it has a great appeal.

We divert our attention momentarily to the structure of the "elementary" particles as a background for an appreciation of the decay processes that they suffer. The constituents of the "elementary" particles are called quarks and they come in pairs. Table I shows these particles with some of their properties.

Each of these constituents has an antiparticle with opposite charge, and in addition each of these quarks comes in three colors - red, yellow and blue. It is postulated that in nature the free particles are colorless, either white or black. We either have a mixture of the three basic colors, giving rise to particles called baryons that are white, or a quark-antiquark pair giving rise to particles called mesons that are black. These are the only combinations that exist freely.

There are another set of particles, the leptons, which appear to have a family structure like the quarks as in Table II. These particles appear to interact weakly and the coupling of these leptons to the quarks provides an intellectual focus to the study of the weak interactions. It must be admitted that particles reflecting the existence of the top quark (t) have not yet been observed and the tau neutrino ν_τ also has not been seen directly. Many elementary particle physicists would claim to believe that these observations will certainly be made eventually and the only real question that remains in this assignment is whether there are any more pairs in these series or is this all that there will be.

We caution the reader that this is a somewhat simplified picture, but for our purposes of understanding the behavior of the scientists it certainly represents the essence of the presently accepted view. These particles are all fermions, which implies a constraint on the statistical laws that govern the combinations of these basic entities that exist in nature.

There are forces between these particles, and the present view is that the forces are mediated by other particles called bosons. The forces that bind the quarks to form our "elementary" particles are mediated by gluons, and the electromagnetic forces that act between charged particles are mediated by photons. The weak forces that cause elementary particles to decay into one another are mediated by the intermediate vector bosons. The W boson induces transitions between quark flavors as vertical transitions in the doublets we show in Table III.

It is possible to have transitions between the doublets but only in a devious way that we can ignore for the moment. There are weak interactions that leave the flavor unchanged e.g. $u \to u$ and these are mediated by the Z°. These transitions are very like the transitions induced by photon exchange and a largely successful effort has been mounted to have a common description of the weak and electromagnetic forces which we will return to later.

The intermediate vector bosons also couple to the lepton pairs $(e\nu_e)(\mu\nu_\mu)(\tau\nu_\tau)$. So when a weak transition occurs as in the diagram of Fig. 1 then some of the end products can be a lepton pair $(e\bar{\nu}_e)$, $(\nu\bar{\nu})$ or even another quark pair. It is believed that the way elementary particles decay is through the emission and conversion of these mediating particles and this picture when formulated in mathematical terms allow the calculation of rates of decay and other characteristics of the debris.

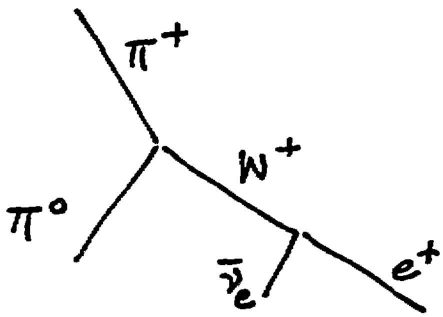


Fig. 1

Let us take a specific decay that is observed, and analyze it in these terms:

$$\pi^+ \to \pi^o + e^+ + \nu^e \ .$$

Figure 2 shows the reaction in more detail.

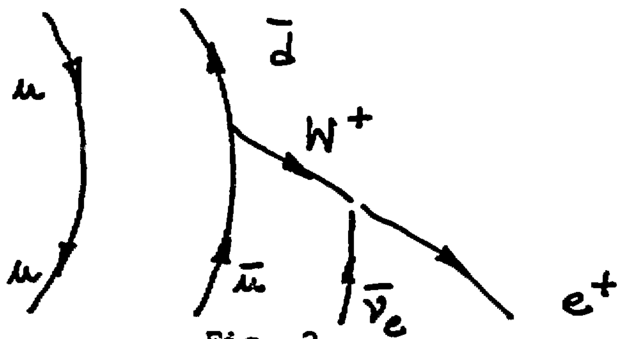


Fig. 2

the d changes to u with the emission of a W^+ and the W^+ decays to $e^+\bar{\nu}_e$. Time goes down the page and the arrow against time indicates an antiparticle. It would be nice if we could skip a complication but much of the study of weak interactions centers on the transition s → d. In our simple picture this cannot happen, in fact it does through a phenomenon called mixing but more slowly than the more normal transition u → d.

The W and Z° particles are not yet observed as we admitted above. It is believed that they are too massive and we have not made accelerators that can generate enough energy to produce them. This same mass accounts for the fact that weak interactions are weak because it is much harder for the heavy intermediaries to be created even for a short time.

This overview of the field will suffice as an introduction to the specific episodes that we have studied and which we will summarize below. We shall return then to this picture as a background to the behavioral aspects of this specialty.

THE DATA

In our design of the project, we imposed a number of limitations. They arose in part because of taste, and should not reflect a judgement on our part that other methods are inapplicable to the problem of understanding the activity patterns of a scientific group. We also want to claim that our somewhat mathematical, data-base oriented approach stems from the enormous mass of material that faced us in our analysis of this modern scientific enterprise. Far from rejecting the traditional approach, we only claim that a highly effective filter is necessary before an attempt at detailed understanding can begin. The previous section of this paper should be a testimony to the fact that we believe that an understanding of the underlying intellectual discipline is also required to appreciate the motivations of the individuals and groups. We also give notice here that the participants in this field are heavily constrained by the technology that they have available, so that we need to understand this situation also in some detail.

Our principal initial restriction was to the published work in weak interactions. Publication was defined as a paper in a serial journal or as proceedings of the international conferences that are a feature of this field. The reason for this choice was that the data gathering process was manageable even if large. We resisted the temptation to sample, because we were unsure of the biases that we would introduce, in retrospect we are delighted with this decision. One could counter that in a way we sample the activity by restricting ourselves to published articles, and that is certainly correct. We are convinced that in this highly international field the communication is still largely by telephone, seminar and face to face conversation. We will try to show the strengths and weaknesses of our method, for weaknesses there surely are. It is this point that convinces us that in parallel with data collection and mathematical analysis must go an attempt to understand in a less formal way the actions of the participants. As someone once said "mathematics is o.k. but it is better to know what you're doing."

If one were to discuss weak interactions with an elementary particle physicist, he would know with some precision the extent of the field. If this hypothetical person were shown an article and asked if it were weak interactions or not the answer would rarely be ambiguous (<5%) and moreover two such persons would agree essentially all the time. We used Nuclear Science Abstracts as a source of the articles in elementary particle physics and patient and impecunious physicists to classify the weak interactions articles. This classification was verified on a sample basis by the authors of this paper. We are happily not subject to much uncertainty in this problem of classification. Along with the articles we have recorded almost any other pertinent piece of information and then we have used the best data management techniques to ensure retrievability and manipulability. This latter need is hard to overstress.

We have published an article[2] describing the more obvious points of this article data, and a number of facts emerge. First, the rate of publication increased dramatically in this period. Figure 3 shows this trend between 1950 and 1976. Secondly, an exciting intellectual event can cause fluctuations on the general growth pattern and which can often be spotted easily. Thirdly, there are at least two groups of people whose publishing behavior is very different, they are the theorists and the experimenters. The theorists publish alone or in pairs, rarely more than that. The experimenters publish in groups and the size of the groups has increased steadily through the period.[4] In rough terms, the average experimenter has as many publications as the theorist but since the number of authors is larger, the number of experimental articles is much lower. This simple difference is only the first indication of a totally different pattern of organization of the two groups. The fluctuations of publishing rate alluded to earlier are entirely those of the theorists. The experimental technology works heavily against instant response measured in these terms.

We have the citations in our data set and in Fig. 5 we show the normalized reference half life.[3] Without being very technical we note that papers lose their apparent relevance very quickly in this field. This underscores the real progress that is made intellectually in this period but it also introduces a major problem for analysis. As we all realize, a paper must be published before it can be cited and the probability of being cited must depend on the number of potential referees. At least two influences can be discerned, as the field gathers more participants there should be more citations for an outstanding paper. However, if the citing behavior is such that the "lifetime" of a paper is short, regardless of the assessment of its impact, then an early paper does not benefit from the enhanced appreciating group in a citation count.

Co-citation analysis has captured our attention and we have used it extensively.[4] An example of a visual display that we have constructed is shown in Fig. 6. This activity function has been very useful to us in perceiving which topics were of interest at a given time. However, since theorists tend not to cite experimenters and also the reverse, and theorists publish many more papers than experimenters, so that we would expect experimental articles to be poorly represented, and they are.

This allows us to appreciate some of the pitfalls even if we do not draw many conclusions. The pitfalls come under the general class of "kinematic" problems. By this we mean that we can observe a number of effects which are artifacts of the overall behavior of this group of people and which have little to do with the internal dynamics of the group. Intuitively, we have understood this for some time but for the sake of being explicit we list some "kinematic" efffects of which we are wary and the consequences of which we take seriously.

A. The number of published papers depends more on the chosen technology of the authors than the real contribution to the field.[5]

B. The absolute number of citations a paper receives is more a function of the audience and the number of targt papers than the intrinsic excellence of the piece.[6]

C. Co-citations indicate related activity but the relation can be repulsive (i.e. espousing an opposite view) as well as attractive.[7]

These general considerations are of concern for they indicate that "top down" analyses using aggregated data can be easily wrong. One must build understanding of a complex system such as a scientific field by first looking closely as the basic working components. Only then, is aggregation possible.

We have developed a technique for avoiding the most obvious normalization problems with citation analysis and we describe it here. We have divided the papers in the field into the obviously different activities, i.e. general theory, phenomenology and experiment. We make use of the notion that individual variations in intellectual significance can be averaged over in a model that assumes that any paper has in the text an average number of references chosen at random from all applicable papers and weighted by the citation half life. If we divide the actual citations by this function we will begin to remove the "kinematic" effects of population size, citing behavior, etc. We believe that only the grossest fluctuations can be taken seriously without a normalizing procedure of this type.[8] Of course, the problem of deciding how many applicable published papers there are remains, but part of the difficulty is removed. One is left with the need to make comparisons within rather homogeneous groups unless other supporting information can be used.

The Episodic Papers

1. Interdependence of Theory and Experiment in Revolutionary Science: The Case of Parity Violation.[9]

At the start of this episode the experimenters were enjoying the discovery of many of the particles that were considered elementary at that time. In addition to these discoveries a major effort was expended in exploring the properties of these particles, especially their modes of decay. A problem emerged, which was called the (τ-θ) puzzle, in which two particles of approximately equal mass decayed into either three pions (τ) or two pions (θ). Dalitz in an elegant analysis showed that if parity was conserved (as was widely believed) then these two particles were distinct. As the experimental measurements of mass improved, and the masses of the θ and τ appeared to be identical this situation became a concern. In 1956 Lee and Yang advanced the hypothesis that in weak decays parity was not conserved and that invalidated the analysis which led to τ and θ being particles of different intrinsic parity. They are now thought to be different decay modes of the same particle the K meson.

This suggestion (parity nonconservation) was radical and only carried the weight that it did because Lee and Yang pointed out that none of the experiments that existed to that time had actually checked that parity was conserved or not in weak decays. They suggested, in addition, a list of feasible (if hard) experiments that could settle the matter. The result of all this was a frenzied period of activity in which experimenters and theorists worked relatively closely to confirm Lee and Yang and set the τ-θ puzzle to rest.

We see evidence of great theoretical activity in the total number of published papers subsequent to Lee and Yang. The experimenters do not own a similar bump although we know they responded. The reason seems to be that in order to respond they have to temporarily shelve their other activities leaving the total number of publications unaffected. This is an initial indication that the mainly mathematical technology that is used by the theorists can be speeded up easily when a seeding concept provides work. The experimental technology cannot speed up, however, and the interested experimenter must deflect his program in order to respond. Perhaps this kind of experimenter-theorist interaction most typifies the model that many people have of the way the field should work. Namely, that the theorists lead the field intellectually and by using general theoretical considerations suggest in some detail the experiments that will establish if the physical world as displayed by experiment is in accord with our intellectual description. Of course, if that accord does not exist we abandon the theory and start again. This episode does show the close proximity that these two groups can achieve.

2. $\Delta S - \Delta Q$ - Social Currents in Weak Interactions[10]

A little later than the earlier episode, occurred a theory-experiment interaction that was quite different. This story came to our attention by noticing that in 1963 the general theorists began to cite the experiments more than usual. Without repeating all the details that we explore in our paper, let us just say that Feynman and Gell-Mann had proposed a general theoretical description of weak interactions, the (V-A) theory, that included the parity problem and set a framework for the intellectual development of the field. It was moreover amenable to test and some experimenters had found a violation of the $\Delta S - \Delta Q$ rule which if true would invalidate the (V-A) theory.

We see that this enhancement of the normally modest level of theory-experiment interaction occurred because the experimenters had produced a result which threatened the established theoretical program. As soon as subsequent data refuted the initial observation the attention that had been drawn declined abruptly and things went back to normal.

The theorists tend to run their own affairs in which the internal consistency of the theory is the principal concern. Of course, the theory has to describe the real world and however elegant and consistent a theory may be, if it does not fit the facts it is dead. That is why this particular kind of experimental challenge was so noteworthy whereas experiments that confirmed the established theory view did not draw attention however reliable and credible they were.

From the point of view of the student of indicators this example is primarily cautionary. The flurry of excitement was a real point of crisis in the field and does not reflect credit in the initiating experimental papers. On the positive side, the fact that the theorists were able to maintain the coherence of the program and also mount an attempt to resolve the problem by amending the theory was especially credible. The collapse of the experimental position reinforced the strength of the theory, it had survived a challenge and became stronger as the intellectual basis of the field.

2. Problem Choice And the Sociology of Scientific Competition[11]

During the period 1962-1966 the principal focus in weak interactions was in the application of the enormously successful classification of elementary particles through unitary symmetry and the quark model. The principal theoretical activity centered on the clasification of the strongly interacting particles and in our specialty, the inclusion of this theory into the decays of the strongly interaction particles. There was considerable theoretical activity in the USA, in Europe and in relative terms in Japan. There was a more modest fraction of the papers in USSR devoted to this topic and even less in the rest of the world. In the USA and Europe the communication was excellent and progress in systematizing the decays of the elementary particles dominated the scene. The quark model of Gell-Mann and Zweig eventually became the accepted kernel of understanding. In this paper, however, we were especially impressed by the behavior of the Japanese group. They concentrated almost exclusively on a single problem, namely the unitary symmetry problem and we found this especially defensible in that there were few phenomenologists in Japan and no existing experimental program at this time. They pursued a model of hadrons, the Sakata model, until they became convinced of the utility of the quark model and then their attention switched very quickly. This strategy was calculated to enhance their group impact on the field, namely to reduce their dependence on rapid communication with USA and Europe and concentrate on the somewhat slower moving general theory. We believe that once the leaders in a group generate a strategy of this kind it is very hard for the bulk of the practitioners in this close knit group to do anything but follow.

In the USSR the relative isolation led to a different solution. They were unable to participate meaningfully in the unitary symmetry program and in spite of their best efforts they seem to have been effectively more isolated than Japan. As it has turned out, they have made important contributions in the appendages to the main development and were not influential in the main thrust, in spite of an apparently large effort in experiment through this period.

We conclude that major groups, either national or international move to try to emphasize their impact on the situation. If communication is poor then the problem of meaningful participation becomes almost impossible and can only succeed if an offshoot to the accepted path of the majority turns out to be the valid description of the physical world.

3. Weak Electromagnetic Unification

Late in the development of the theory of weak interactions there has been a successful attempt to unify the theory of weak and electromagnetic interactions[12]. This unification has been brought about by many people but the Nobel prize was given to Weinberg, Salam and Glashow. The essence of this attempt centers around the fact that one part of the weak interaction posseses most of the attributes of the electromagnetic interaction except that the mediating particke, the Z^0, is massive, in contrast to the photon in electromagnetism.

Physicists have long wanted to find a theory which explains the four forces of nature (gravitational, weak, electromagnetic and strong) as different manifestations of the same basic phenomenon. In 1967, Steven Weinberg and Abdus Salam each proposed a theory for the unification of two of these forces, the weak and electromagnetic. However, these two theories belonged to a class of gauge theories in which singularities occurred, (i.e. the equations describing the process go to infinity at high energies) and it was thus impossible to make predictive calculations. This problem was responsible for a lack of apparent theoretical interest in the Weinberg-Salam model in the first three years after it was proposed.

In 1971, Gerard t'Hooft showed how the gauge theories could be renormalized and interest in weak-electromagnetic unification grew dramatically. We have studied this period extensively[12] in two papers in which we review the growth of this interest and the rapid change in citation behavior which characterized the peak of activity when the outstanding problems became resolved.

As students of behavior, we can learn a great deal from some of the situations that faced the participants and their response to them in this exciting period of particle physics. Here we will highlight some of these situations, and encourage the reader to consult our two papers[12] for extensive details. The first situation we have referred to already. Namely, although Weinberg and Salam had presented the idea which was eventually to become accepted, there was no apparent interest until t'Hooft showed the way to make predictive calculations in the general class of theories.

The crucial intellectual problem then remaining was to reconcile the absence of strangeness changing neutral currents, which had been known for some time, with the predictions of Weinberg-Salam, namely that neutral currents should exist. The theorists were faced with an experimental paper which suggested that there were no neutral currents at all. Weinberg-Salam were undeterred although their model lost some credibility. Other theorists suggested ways out of the dilemma with alternate models and Glashow, Iliopolous and Maiani (GIM) showed a mechanism (charm) that could give standard neutral currents while suppressing the srangeness changing ones.

The initial experiment was not borne out and neutral currents were discovered in the Gargamelle bubble chamber at CERN and quickly verified in the USA. Charm was discovered in the form of the J/ψ by the Ting and Richter groups and the crucial parameter of the Weinberg-Salam theory, the Weinberg angle was measured in a number of reactions.

Again returning to behavior, we see that it was theoretically acceptable to pursue many parallel explanations and allow experiment to choose the right one. A false start on the part of one experiment did not deflect the proponents of the ultimately successful model in their programme. We notice a stability in the corporate behavior of the theorists in that it is acceptable to pursue all logically consistent alternatives with no loss of stature if the alternative proves wrong. The prize for being right is considerable, but the rewards are all positive - a characteristic of a healthy social system.

We also note that the experimental programme is used extensively by the theorists when it is useful to do so, in contrast to the relative disinterest that is displayed formally in the programme prior to the crisis period.

We conclude that these two groups have a good symbiotic relationship and at least the theorists are able to harness the participating group talents in a very effective way. This episode tests the system in a way that is different to the parity period and the $\Delta S = \Delta Q$ period and is in contrast to the indirect programmatic interaction of the unitary symmetry period, where the communication proceeded almost entirely through the phenomenologists.

SOCIAL ORGANIZATION

As we have noted, the field can be separated into two distinct groups, the theorists and the experimentalists. The behavior pattern and working methods of these two groups are very different and as we will discuss below, their formal communication is relatively slight. We discuss the theorists here and leave the experimenters to the preceeding paper.[1]

THEORETICAL PHYSICISTS

This group can be divided into two relatively distinct roles. These roles we have described as general theory and phenomenology. The overall stated goal of the field is to find a mathematical theory which will allow the correlation of all observed phenomena and also poses predictive power in enough depth to give an assurance that a complete description of this portion of the physical world is provided. In principle, it is possible for any physicist in the field of high energy physics to suggest concepts or ideas which can be formulated rigorously enough to form a basis for the mathematical theory. In practice, since the first requirement to which any concept is subjected is that it be logically consistent both internally and with the rest of the field, the group that possesses the mathematical skill to carry through the first step tends to have a monopoly on the initiating process. The mathematical tools that are used in elementary particle physics are sophisticated, and are frequently developed specifically to a greater extent then the forms available in the mathematical literature. We have described this group as general theorists and they are without question the high priests of the field. We believe that the mathematical tools form a constraint on the ability of the individual to contribute to the ongoing development of this part of the field and we have noted that many of the influential individuals migrate freely from one intellectual topic to another exploiting a common mathematical skill to analyze apparently disparate subjects in weak interactions and elsewhere.

A second theoretical group that we have identified are the phenomenologists. They are also mathematically adept in the formal sense although they appear to have two major functions, they correlate experimental data under the rubric of an existing general theory and they also translate the formalities of the general theory into specific predictions for experiments. They are heavily dependent on contacts with the general theorists as well as with the experimenters who both plan experiments and produce data which they expect to be relevant.

The communication between phenomenologists and both of the other groups is highly informal and proceeds at a pace considerably faster that the normal journal publication rate whenever that is possible. Apart from the need to understand the issues that are relevant to general theory at any given time the pheonomenologist needs access to data that are yet to be published and computing resources to make fits and for collation of data from disparate sources. This group frequently functions as rapporteurs at the yearly international conferences where the experimental and theoretical situation is reviewed. People do migrate from one role to another, although there is a strong tendency to adopt one role or the other over extended periods of time.

It is our firm belief that the behavior of the theorists in weak interactions are highly constrained by the technology they use and the society in which they work. Much of their group behavior can be explained this way. In the problem choice paper[13] we discuss the different responses of theorists in 4 areas - USSR, USA , Europe, and Japan. During the period we analyze, almost all of the experimental data were produced in USA and Europe where a flourishing phenomenological industry existed. Communication was excellent, not only at the informal level at seminars etc. but timely publication in Physical Review Letters and Physics Letters led to prompt dissemination of the data and also the developing theoretical ideas. In contrast, Japan as well as being relatively isolated appeared to have no phenomenologists and the group concentrated on general theory. This response to circumstances we deduced was wise, and calculated to emphasize the return to the group and to the individuals. The local coherence of view we also feel tends to be encouraged by the promotion process and by peer review so that the coalescence of the group in Japan on a single program, the exploitation of the Sakata model was sociologically expected. The USSR on the other hand was isolated by the long delays in communication with the West and Japan, and perhaps due to the rigid scientific bureaucracy was also internally relatively uncommunicative. As a result, the USSR tended to pursue lines of investigation that deviated from the major effort elsewhere and which were markedly less successful in influencing the general development of the science. In retrospect, the work in the USSR that has had impact has been in the deviations from the western view which were not dependent on the group coherence or on the rapid and effective communication that was characteristic of the US and Europe.

This period of this big science was the golden age in the US and Europe where almost all of the intellectual progress was made. As we have emphasized, the communication among the theorists was excellent with migration across the Atlantic as the norm and topical conferences coming thick and fast. Almost all apparently promising lines were pursued and the theoretical group enjoyed the successes of (V-A), unitary symmetry, Weinberg-Salam and survived easily the challenge of the $\Delta S = \Delta Q$ rule. We notice that theorists pay attention rarely to the experimentalists specifically because of the different time scale of experiments and theories. The phenomenologists collate and interpret and the general theorists only respond directly to the experiments when a choice between competing ideas is needed (Weinberg-Salam) or when the experimental data challenge an existing theoretical edifice ($\Delta S = \Delta Q$).

We believe that the existence of the corps of phenomenologists may be an indicator of general health in the field in that two quite separate technical endeavors, general theory and experiment, are matched to each other by a group that finds it intellectually rewarding to do just that.

In this section we have discussed the behavior of theorists and to some extent their relations with the experimenters. we have alluded to the disparity between the work patterns of the two groups, and the need to have a liason group between them. The analysis of the theory groups shows that they have a style which is reminiscent of many other academic activities. They publish singly or occasionally in pairs, and cite one another with reasonable care. We have been able to follow the major interests of this group using co-citation analysis, and we believe that this procedure has led us to an understanding of the internal dynamics of the group. In an atmosphere of free communication the exercise of perceived self-interest in a competitive system produces an efficient and effective attack on the intellectual problem with the methods at hand. There are a few people who make an impact creating seminal theories whose apparent interest derives from the opportunities that the theory offers for contribution by others. The citation patterns do not seem to offer a simple assessment of worth in the eyes of the group, but only carry an assessment of interest which can be good or bad. It is to be remembered also that a wrong theory (i.e., not in accordance with the physical world) does not imply poor performance, it is only that its lifetime of interest will probably be short when it is exposed to other ideas and to experimental data.

Conclusions

We have claimed here to understand in some detail the group dynamics of a subset of the authors publishing in weak interactions, the theorists. It is the purpose of this conference to address the quesion "Can one learn anything of value from academic studies of publication patterns that can have relevance to policy makers?" We review here some deductions that we have made from these data that influence us as policy makers and administrators which are helpful in discharging our separate administrative roles. We tend to confine ourselves to policy in the US although we believe that the social situation is very similar in Europe and that our deductions may have relevance outside both of these centers.

First, we deduce that at the size of the effort in the US and Europe together there is no obvious scale dependence of the activity. The tendency is for a small number of high priests to create intellectual programs and then surround themselves with people who exploit the seminal theories to calculate consequences, make predictions, collate the experimental data and make frequent global comparisons between the general theoretical situation and the apparent state of the physical world. The high priests are mobile both on a long and short term basis and are more than adequately visible to the community of phenomenologists. There appears to be no obvious optimum scale of support for a high priest and no overpowering need for these people to form local groups. We do note the need for the phenomenologists to be in close contact with experimenters and as we note also that the experimenters have their own highly concentrated center structure, so the phenomenological community must respond to the major experimental laboratory structure, and also be a part of the general theoretical network.

References

1. D. Sullivan, D. Koester and D.H. White, Proceedings International Conference on Evaluation in Science and Technology, Theory and Practice, Dubrovnik, Croatia, Yugoslavia, 1980.

2. Daniel Sullivan, D.Hywel White, Edward J. Barboni, The State of a Science: Indicators in the Specialty of Weak Interactions, Social Studies of Science, Vol. 7 (1977), p.167-200.

3. The rapid increase of papers requires that the reference half-life be normalized to remove this effect. For details of this procedure, ibid 2.

4. Cocitation Analysis in Science: An Evaluation, Daniel Sullivan, D. Hywel White and Edward J. Barboni, Soc. Studies of Science, Vol. 7, p.223 (1977).

Problem Choice, and the Sociology of Scientific Competition, D. Sullivan, D.H. White, E.J. Barboni, Research in the Sociology of Knowledge, Sciences and Art, Vol. III, 1981 (forthcoming).

Social Currents in Weak Interactions, D. Hywel White and Daniel Sullivan, Physics Today, April 1979;

Understanding Rapid Theoretical Change in Particle Physics: A Month by Month Cocitation Analysis, Scientometrics, Vol. 2, 4, 1980, p.309-319; D. Sullivan, D. Koester, D.H. White and R. Kern, Particles and Parchment; D. Koester, D. Sullivan, D.H. White and R. Kern, Social Studies of Science (forthcoming); D.H. White, D. Sullivan, and E.J. Barboni, Social Studies of Science, Vol. 9, p.303-27 (1979).

5. op cit, note 2.

6. ibid.

7. op cit note 4, D. Sullivan, D. Koester, D.H. White and R. Kern.

8. op cit note 2.

9. op cit note 4, D.H. White, D. Sullivan and E.J. Barboni.

10. op cit note 4, D.H. White, D. Sullivan.

11. op cit note 4, D. Sullivan, D.H. White, E.J. Barboni.

12. op cit note 4, D. Sullivan, D. Koester, D.H. White and R. Kern. D. Sullivan, D.H. White and R. Kern.

13. op cit note 4 D. Sullivan, D.H. White, E.J. Barboni.

Table I

			Q
u	c	t	2/3
d	s	b	1/3
			→ mass increasing

Table II

			Q
e	μ	τ	1
ν_e	ν_μ	ν_τ	0
			→ mass increasing

Table III

$$\begin{pmatrix} u \\ d \end{pmatrix} \qquad \begin{pmatrix} c \\ s \end{pmatrix} \qquad \begin{pmatrix} t \\ b \end{pmatrix}$$

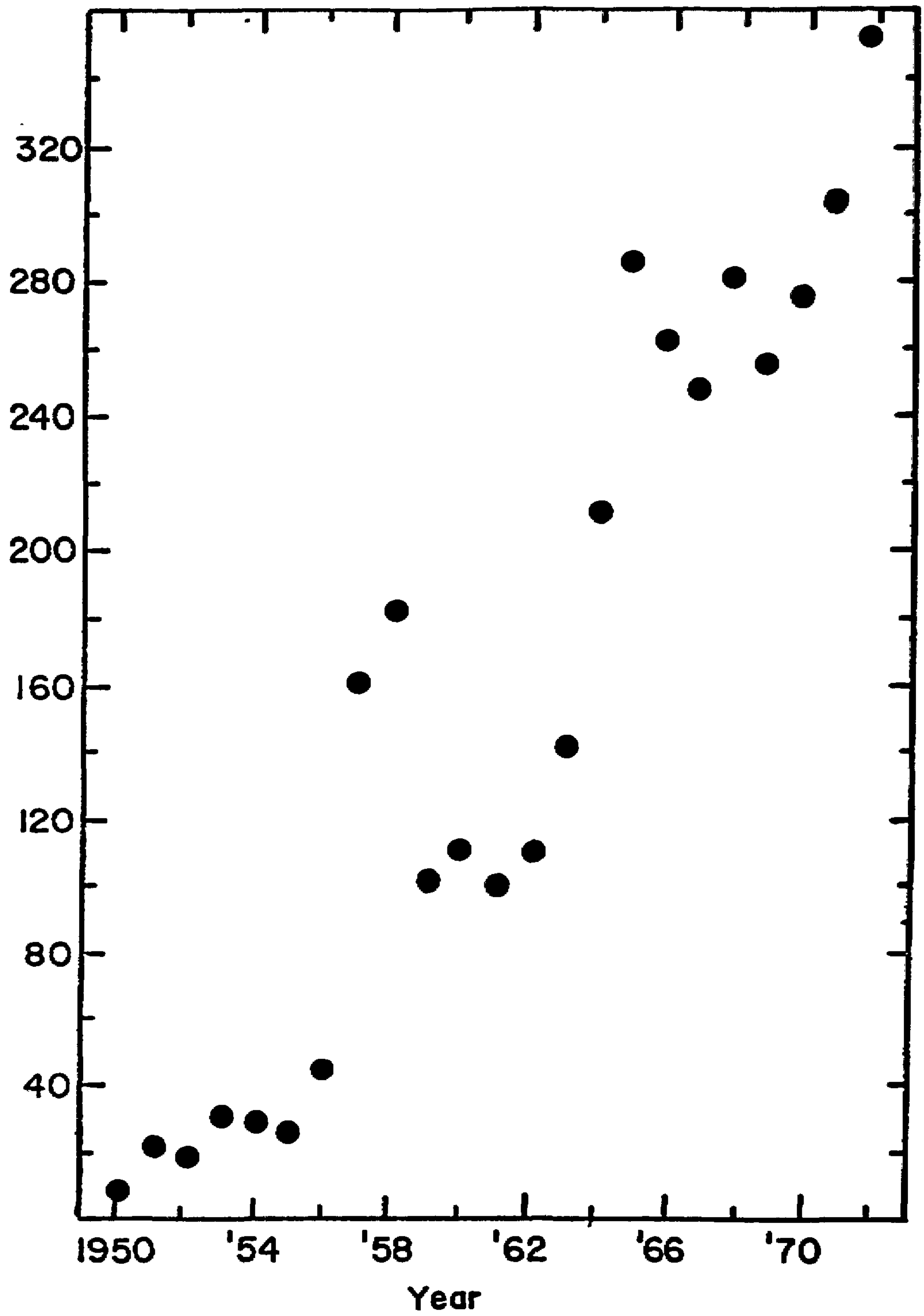


Fig. 3. Weak interactions theoretical articles by year of publication. Note the peak at parity time (1950) and also at CP violation (1963).

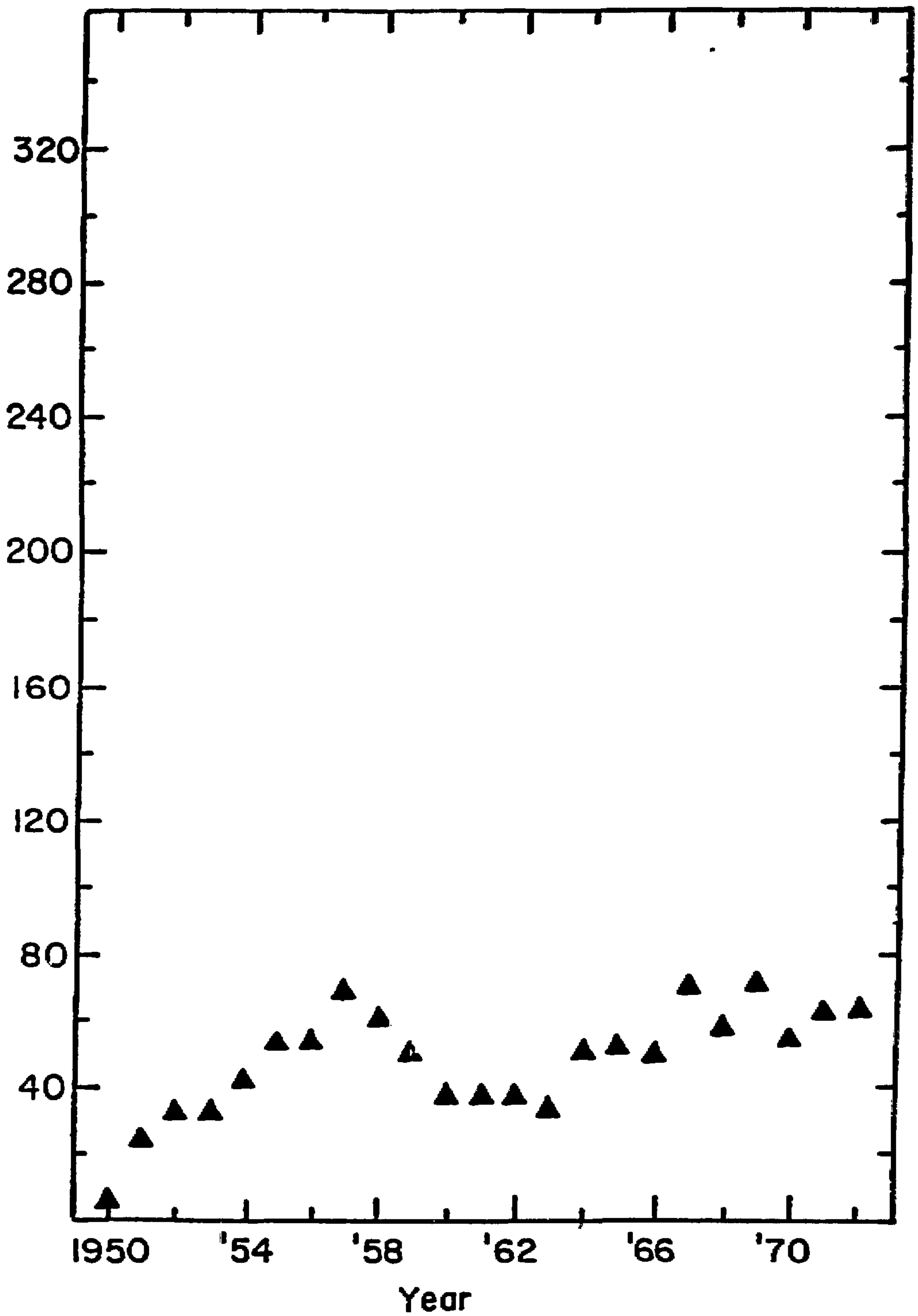


Fig. 4. Weak interactions experimental articles by year of publication. Note the relative absence of structure.

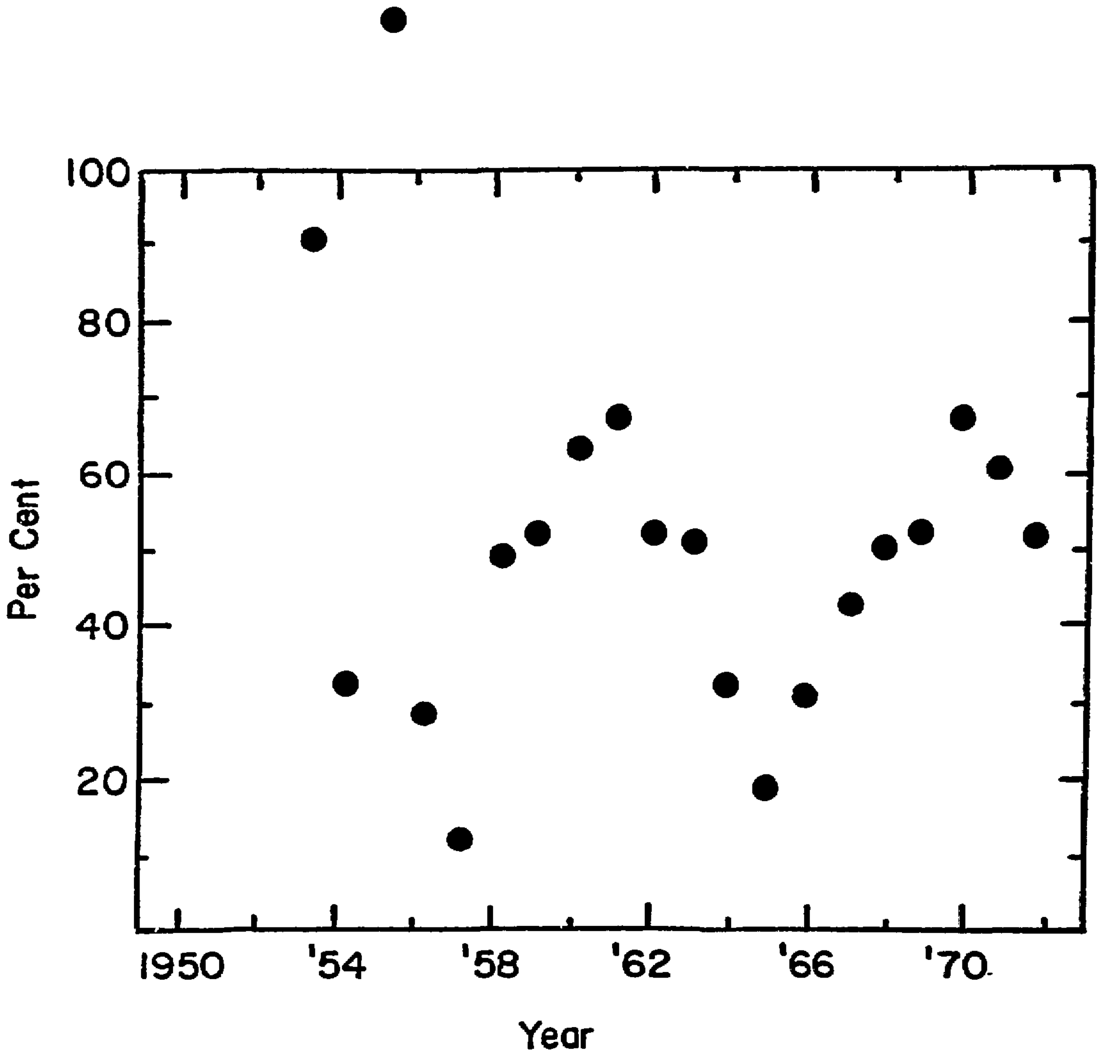
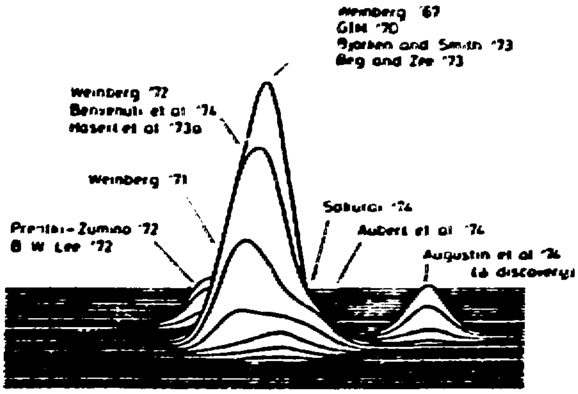
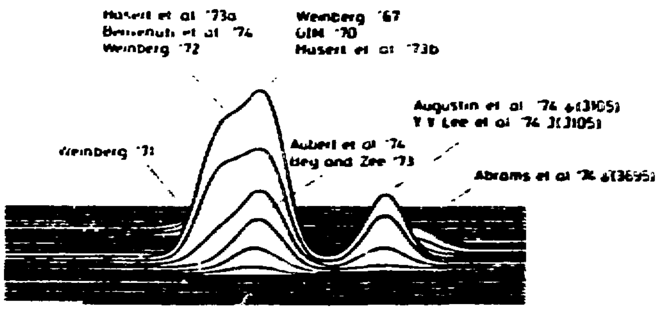


Fig. 5. Normalized reference half life. This is the ratio of the actual theory reference lifetime in a given year divided by that expected if references are made at random to the eligible population.



Weak interactions co-citation activity plot for 7/74–6/75



Weak interactions co-citation activity plot for 9/74 -8/75

Fig. 6. Co-citation activity plot in the weak electromagnetic unification period.