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PARTICLE PHYSICS - Recent Successes and Future Prospects*

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INTRODUCTION

The situation in particle physics today is highly analogous to that which existed in chemistry towards the end of the 19th century. During the preceding two centuries, remarkable progress has been achieved in that discipline, progress that culminated in the periodic table of Mendeleyev. This table summarized not only the realization that our everyday matter is composed of basic building blocks, called elements, but also that these different elements had certain similarities which could be used to properly arrange them in the periodic table. Thus the inert gases (helium, neon, argon, etc.) had very similar chemical properties, namely chemical inertness; the halogens (chlorine, iodine, florine) on the other hand were highly reactive. Other similarities were seen among the rare earth group of elements, alkaline earths, and alkali metals. What was missing, however, was a deep understanding of the reason for these regularities.

In particle physics today we also believe that we know what are the fundamental building blocks of matter. These are the quarks and leptons. We also observe regularities: both quarks and leptons come in doublets; they both have three families; both of them have the charge difference between the two members of the same family equal to one electronic charge. The charges of quarks are $+2/3e$, and $-1/3e$; of leptons $-e$ and zero. These regularities naturally lend themselves to the construction of a periodic table of quarks and leptons, illustrated in Fig. 1, a modern version of Mendeleyev's table.

	QUARKS				LEPTONS		
Up	u	d	Down	Electron	▲	△	Electron Neutrino
Charm	c	s	Strange	Muon	●	○	Muon Neutrino
Top	t?	b	Bottom	Tau	■	□	Tau Neutrino

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Fig. 1. "Periodic table" of quarks and leptons.

But just as the 19th century scientists, we also lack a deep understanding of the reasons for this simple and regular pattern. Why the similarities between the quarks and leptons? Why three families (or are there more)? Why differences in charge between quarks and leptons? These and many other questions need answers that can come only through some deeper understanding.

We know that the regularities in the atomic picture were explained by discovery of new laws and new constituents. New ideas such as quantum mechanics, Fermi-Dirac statistics, and half-integral spin combined with the electromagnetic Coulomb potential were necessary to explain the features of the periodic table. The other key ingredient came from the discovery that there are particles that are more basic than the atoms: the electrons and the nuclei. The intellectual revolution that was generated by these new concepts and discoveries is well known and need not be repeated here.

Will the history repeat itself on the quark-lepton level? There is no doubt that as yet we do not have an ultimate theory of matter and forces in spite of the remarkable successes of the past decade. Whether the solutions to the questions posed above will be just as revolutionary as those that solved the atomic dilemma remains to be seen. In this talk I shall attempt to summarize briefly the historical background that led us to the present level of understanding, or more specifically to the "standard model" of particle physics. Subsequently I would like to describe several difficulties with this picture, continue with some possible indications of new physics, and finally end with the discussion of the prospects for the future.

THE STANDARD MODEL TODAY

According to our present understanding of the particle physics, the matter is composed of elementary spin 1/2 constituents: quarks and leptons. All the experimental evidence is consistent with these being truly elementary, i.e., point like, without any structure on the scale larger than 10^{-16} cm. In addition to these elementary fermions, there

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exist also gauge bosons, with spin unity, which mediate the fundamental interactions. These consist of the familiar massless photon responsible for electromagnetic interactions, and the recently discovered massive $W^{\pm}$ and Z°, the carriers of the weak force. The strong interactions are believed to be mediated by an octet of bosons called gluons. Finally, there are conjectured to exist heavy scalar particles, called Higgs, whose mass is only vaguely indicated by the theory as having to be somewhere between 7 GeV/c^2 and 1 TeV/c^2. These Higgs particles, invented to provide a mechanism for symmetry breaking in the electroweak sector, could be elementary but also might be composites of as yet undiscovered new particles.

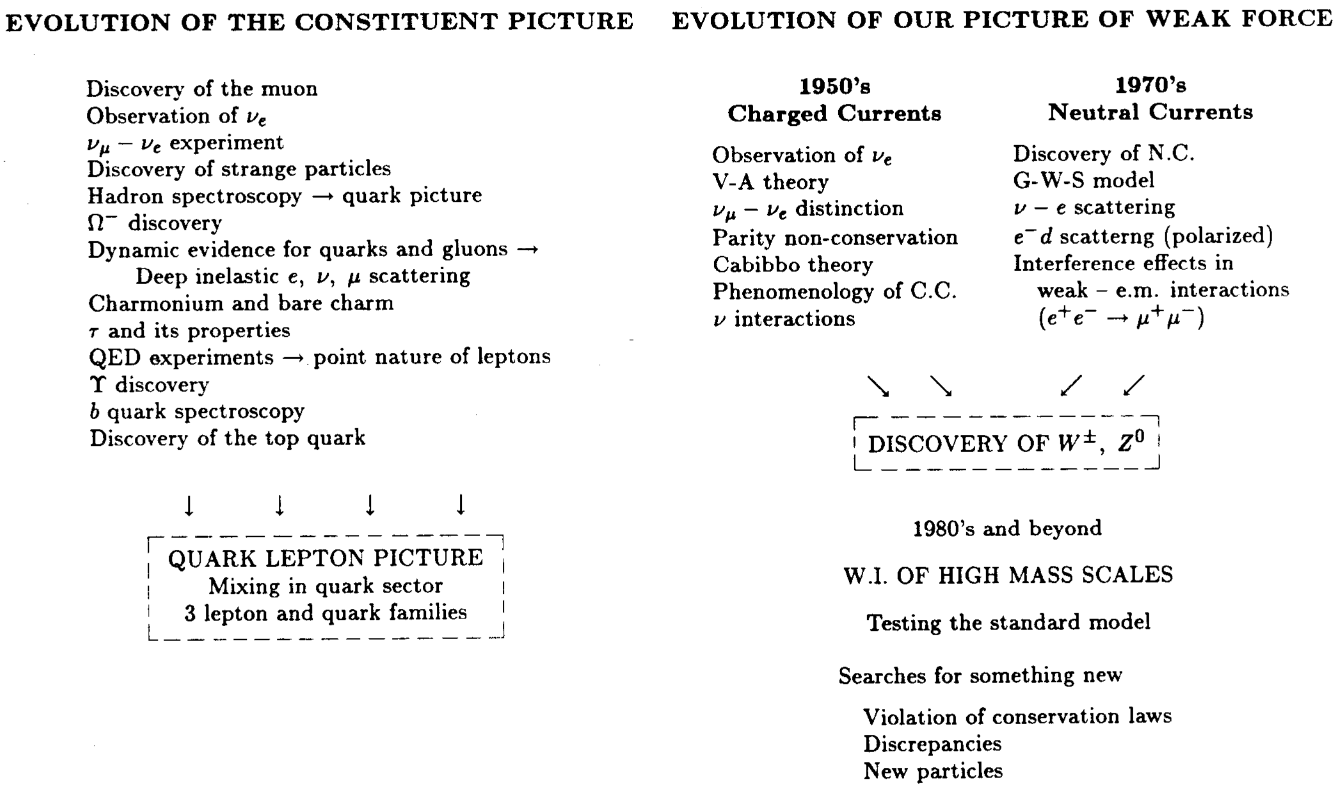
The interactions are believed to be described by forces obeying an SU(3) ⊗ SU(2) ⊗ U(1) symmetry. The SU(3) part describes the so called Quantum Chromodynamics (QCD) that is thought to be the theory of strong interactions of quarks and gluons. The SU(2) ⊗ U(1) part provides the description of the electroweak sector.

HISTORICAL DEVELOPMENT OF THE STANDARD MODEL

We proceed next to discuss the historical development of the standard model. We shall outline some of the key experiments and theoretical ideas that led us to our present understanding of the constituent picture and of the strong, electromagnetic, and weak interactions. Clearly, this kind of enumeration is somewhat subjective, but it does present a rough outline of the intellectual evolution of each sector.

The development of the constituent picture is shown in Fig. 2. Rather arbitrarily I take the discovery of the muon, almost 50 years ago, as the start of our story since that was really the first indication that the constituent spectrum is richer than one might expect by merely looking at the composition of ordinary matter.

The progression of events and ideas illustrated in Fig. 2 led to our present belief in the existence of (at least) three quark and lepton families, each family composed of two members. The mass and weak interaction eigenstates



EVOLUTION OF THE CONSTITUENT PICTURE

Discovery of the muon
Observation of ν_e
$\nu_\mu - \nu_e$ experiment
Discovery of strange particles
Hadron spectroscopy → quark picture
Ω^- discovery
Dynamic evidence for quarks and gluons →
  Deep inelastic e, ν, μ scattering
Charmonium and bare charm
τ and its properties
QED experiments → point nature of leptons
Υ discovery
b quark spectroscopy
Discovery of the top quark

QUARK LEPTON PICTURE
Mixing in quark sector
3 lepton and quark families

EVOLUTION OF OUR PICTURE OF WEAK FORCE

1950's Charged Currents	1970's Neutral Currents
Observation of ν_e	Discovery of N.C.
V-A theory	G-W-S model
$\nu_\mu - \nu_e$ distinction	$\nu - e$ scattering
Parity non-conservation	$e^- d$ scatterng (polarized)
Cabibbo theory	Interference effects in weak – e.m. interactions ($e^+e^- \to \mu^+\mu^-$)
Phenomenology of C.C.	
ν interactions	

DISCOVERY OF $W^{\pm}$, Z^0

1980's and beyond

W.I. OF HIGH MASS SCALES

Testing the standard model

Searches for something new
  Violation of conservation laws
  Discrepancies
  New particles

Fig. 2. A rough outline of the historical development of our present picture of quarks and leptons and their weak interactions.

in the quark sector are different. The mixing matrix, U, first introduced by Kobayashi and Maskawa[1] can be expressed in terms of 4 real parameters, three of which are analogous to the Euler angles, and the fourth one is a phase which can, by virtue of being non-zero (or $\neq \pi$) give rise to CP violation. There are several different parametrizations of the matrix U, the original one being

$$U \equiv \begin{array}{c} \\ \\ \\ \end{array}\begin{array}{ccc} d & s & b \\ \end{array}$$

$$\begin{array}{cc} & \begin{array}{ccc} \quad d \quad & \qquad s \qquad & \qquad b \qquad \end{array} \\ U \equiv & \begin{pmatrix} C_1 & -S_1C_3 & -S_1C_3 \\ S_1C_2 & C_1C_2C_3 - S_2S_3e^{i\delta} & C_1C_2S_3 + S_2C_3e^{i\delta} \\ S_1S_2 & C_1S_2C_3 + C_2S_3e^{i\delta} & C_1S_2S_3 - C_2C_3e^{i\delta} \end{pmatrix} \begin{array}{c} d' \\ s' \\ b' \end{array} \end{array}$$

where we have used the notation $S_i \equiv \sin\theta_i, C_i \equiv \cos\theta_i$. The primed symbols denote the weak interaction eigenstates; the unprimed refer to the mass eigenstates.

The first six elements (i.e., top 2 rows) have been determined experimentally. The experimental values of those elements are[2]

$$U \equiv \begin{pmatrix} .9733 \pm .0024 & .225 \pm .005 & < 0.01 \\ .24 \pm .03 & .82 \pm .13 & .058 \pm .009 \\ - & - & - \end{pmatrix}$$

If we introduce the constraint of unitarity, the errors on those matrix elements decrease significantly. In addition, the bottom three elements become also rigidly constrained. The matrix becomes

$$U \equiv \begin{pmatrix} .9733 \pm .0024 & .225 \pm .005 & 0 - 0.01 \\ .225 \pm .006 & .971 \pm .002 & .058 \pm .009 \\ .013 \pm .009 & .058 \pm .009 & .998 \pm .001 \end{pmatrix}$$

The fact that the matrix is almost diagonal indicates that the mass eigenstates are very similar to the weak eigenstates. Alternatively, one can say that charged current couplings out of the doublets are rather weak.

Some of the key recent input on these questions were the experiments determining the upper limit on the $b \to u/b \to c$ relative branching ratio and the measurements of the b quark lifetime coming from the high energy e^+e^- colliding beam experiments. The former has been obtained by studying the lepton spectrum originating from b decays produced in e^+e^- annihilations near the $b\bar{b}$ threshold[3] (see Fig. 3). The data on b lifetime are summarized[4] in Table I.

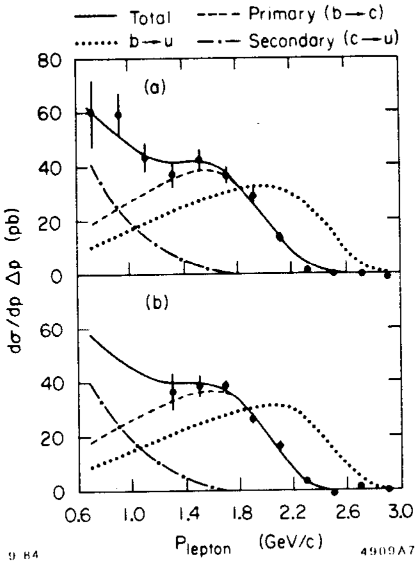


Fig. 3. Electron (a) and muon (b) energy spectra from b decay as obtained by the CLEO collaboration. The solid curve represents the calculated spectrum on the assumption of no direct $b \to u\ell\nu$ decay.

Table I

Summary of b lifetime results.

Collaboration	Value (ps)
Mark II	$0.85 \pm 0.17 \pm 0.21$
MAC	$1.6 \pm 0.4 \pm 0.4$
DELCO	$1.16^{+.37}_{-.34} + .23$
JADE	$1.8^{+.5}_{-.3} \pm .35$
TASSO	$1.9 \pm .4 \pm .6$

Since the techniques are quite similar in all of these experiments, a straightforward statistical average probably does not make sense here.

In contrast, in the lepton sector the present data are consistent with the conservation of the separate lepton number. Figure 4 demonstrates the progress achieved over the last 4 decades in the limits on various μ decay channels that would violate the independent conservation of e and μ lepton numbers.

Turning now to the weak interactions, their evolution is illustrated in the other half of Fig. 2. One can identify two rather distinct lines of investigation dealing with charged and neutral currents respectively and occurring in two

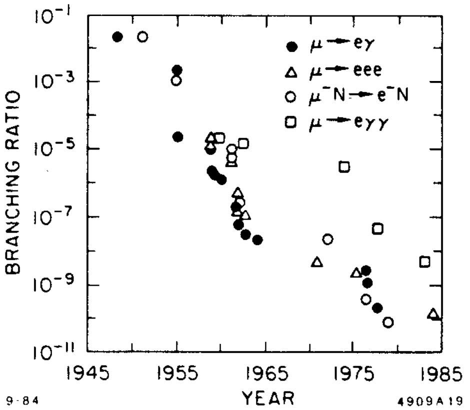


Fig. 4. Upper limits for separate lepton number violating processes as a function of time.

different time frames. Again the start of the charged current study is somewhat arbitrary; both of these lines of investigation have culminated in the CERN experiments responsible for the discovery[5,6] of $W^\pm$ and $Z°$ (see Fig. 5).

The evolution of strong interaction theory is outlined in Fig. 6. The initial spectroscopic evidence led to the formulation of the famous eightfold way. The necessity to introduce color as a hidden variable later led to the development of the QCD which has a hope of being the ultimate theory of strong interactions. The evidence for the existence of gluons (Fig. 7), first observed at PETRA in e^+e^- annihilations[7] is undoubtedly one of the recent highlights in this evolution. Another exciting development, coming from the $\bar{p}p$ studies at $Sp\bar{p}S$, is the spectacular evidence for high p_T jets[8] in the hadron-hadron collisions (Fig. 8). The very obvious nature

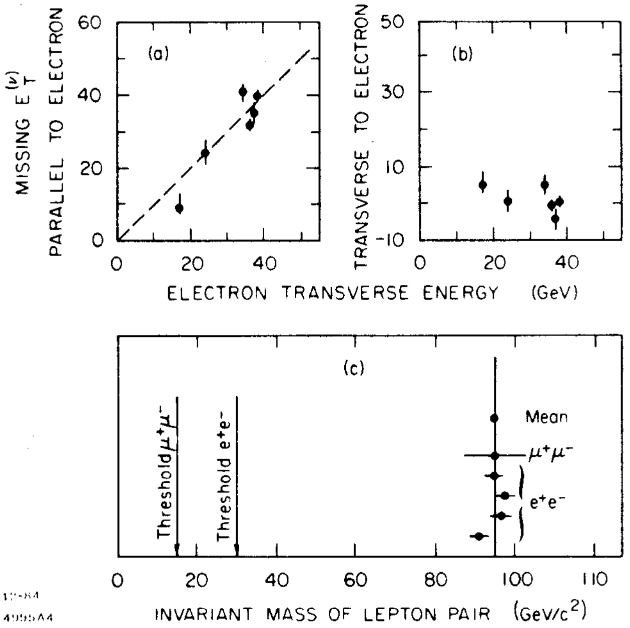


Fig. 5. The first evidence from the UA1 experiment for $W^\pm$ (a,b) and $Z°$ (c) bosons.

EVOLUTION OF OUR PICTURE OF STRONG AND ELECTROMAGNETIC FORCES

STRONG INTERACTIONS → QCD

Spectroscopy of resonances
SU(3) - the eightfold way
Quark picture
Color hypothesis - empirical evidence
Deep inelastic scattering
Confinement and asymptotic freedom
QCD effects in scale breaking
Quarkonium states
Jets in e^+e^-
Evidence for gluon
R in $\sigma(e^+e^-)$ and α_s
Hard scattering in hadron-hadron collisions
Second order (in α_s) effects

ELECTROMAGNETIC INTERACTIONS (QED)

Lamb shift (theory & experiment)
QED formulation
Muonium and positron (μ^+e^-, e^+e^-) tests
g-2 experiments (e, μ)
high q^2 tests in e^+e^- (e^-e^-) collisions
2-photon processes in e^+e^-
G-W-S model
Weak - e.m. interference effects

$$\boxed{SU(3) \times SU(2) \times U(1)}$$

$$? \downarrow \quad \downarrow \quad \downarrow ?$$

Grand Unified Theories

Fig. 6. A rough outline of the historical development of our present picture of strong and electromagnetic interactions.

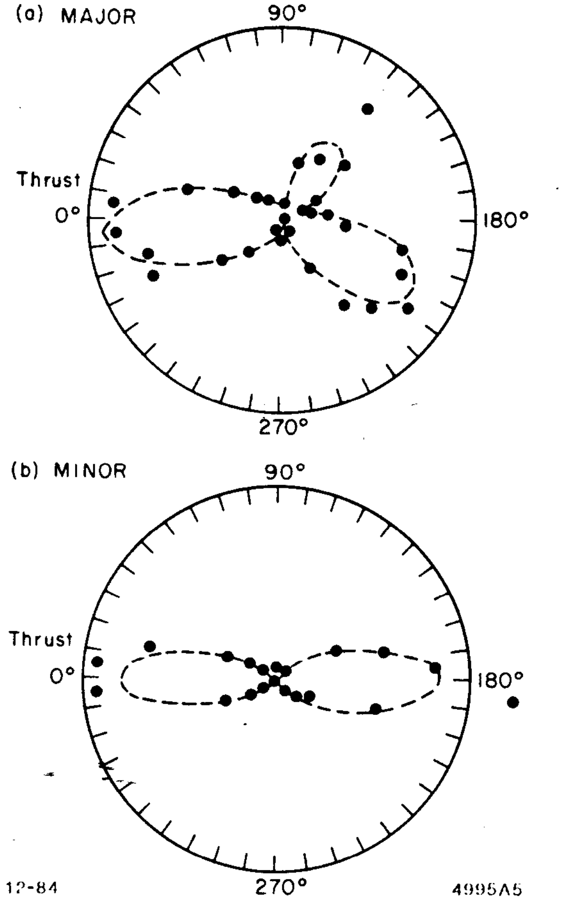


Fig. 7. (a) Energy distribution in the plane as defined by the thrust and the major axes for all the events with thrust < 0.8 and oblateness > 0.1 at $\sqrt{s} = 27.4$, 30, and 31.6 GeV. The energy value is proportional to the radial distances. The superimposed dashed line represents the distribution calculated with use of the $q\bar{q}g$ model. (b) The measured and calculated energy distribution in the plane as defined by the thrust and the minor axes.

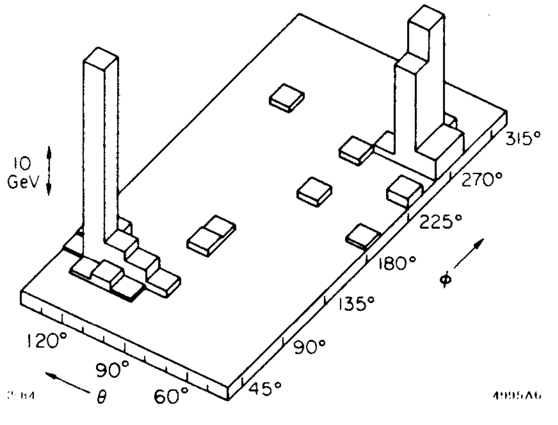


Fig. 8. An early example of the two-jet event from the UA2 experiment.

to these high energy jets opens up possibilities of using them for spectroscopic studies, investigations of nucleon structure and detailed tests of QCD (Fig. 9) as well as for searches for new phenomena that would signify new physics.[9)]

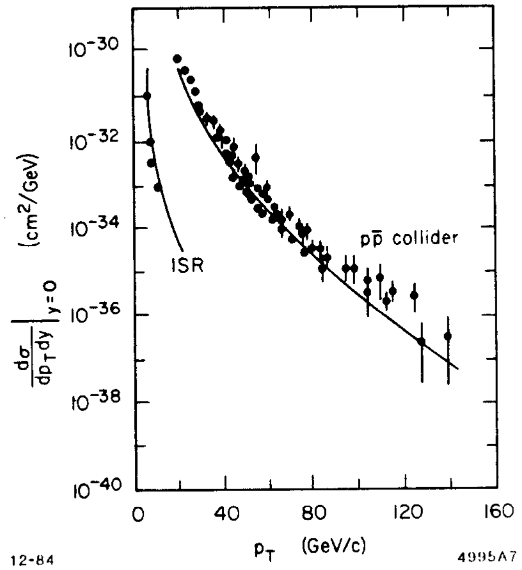


Fig. 9. Inclusive jet yields at collider and ISR energies. The data came from R807, UA1, and UA2 experiments. The curves represent the predictions based on perturbative QCD calculations.

Some of the key developments in the history of electromagnetic interactions are shown in the other half of Fig. 6. The initial thrust of the workers in the field was on the test of the quantum electrodynamics (QED). These ranged from very high precision but low q^2 experiments on systems such as muonium, positronium, hydrogen atom, and muon and electron to high q^2 tests in the e^+e^- annihilations. More recently, with the advent of the Glashow-Weinberg-Salam theory[10)] unifying the weak and electromagnetic interactions the emphasis has shifted on detecting the weak-electromagnetic interference effects. The results of some of these tests,[11)] from the e^+e^- annihilations, are shown in Fig. 10. Furthermore, the results of these interference experiments, when interpreted in terms of the axial and vector coupling constants, can be compared with the ν experiments that address the same fundamental questions. As can be seen from Fig. 11 the two sets of data yield compatible results and allow one to deduce a value for the $\sin^2\theta_W$ of 0.25 ± 0.05.

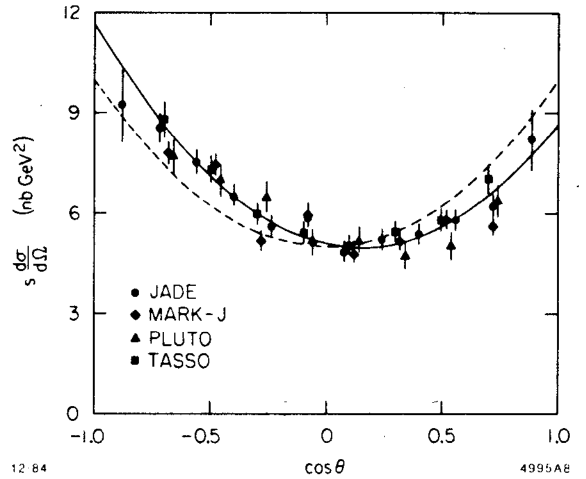


Fig. 10. summary of PETRA data on the angular distributions for $e^+e^- \rightarrow \mu^+\mu^-$ at $\sqrt{s} = 34.5$ GeV. Pure QED and QED + weak predictions are shown as dashed and solid lines respectively.

THE STANDARD MODEL - DIFFICULTIES

The brief discussion above should have conveyed the impression that the standard model has been tested extensively experimentally and has turned out to be a remarkable success. Its greatest theoretical triumph has been the unification of the weak and electromagnetic theory; the overwhelming experimental successes were the discoveries of the $W^\pm$ and Z° gauge bosons.

However the theory is undoubtedly incomplete. The dominant question deals with the problem of symmetry breaking. This mechanism leaves the photon massless and gives large masses to both the $W^\pm$ and the Z° bosons. Whether this mechanisms manifests itself in a single fundamental scalar particle (the Higgs) with a mass in the neighborhood or below the 1 TeV or whether it has a more complex manifestation is unclear at the present time. There are many other difficulties with the standard model. We enumerate some of them briefly below:

a) The theory has an alarmingly large number of arbitrary parameters. The masses of quarks and leptons, the mixing angles, the values of coupling constants and the Higgs parameters already lead to over 20 free parameters. If our present picture is really the ultimate theory, the theory is disappointingly unesthetic.

b) The similarities and differences between quarks and leptons need to be explained. Are these constituents truly elementary?

c) There is the problem of families. Why are there 3 of them? Are there more?

d) Why are weak interactions lefthanded? Is it just a low energy limit of a right-left symmetric theory?

e) Where does CP violation come from? Is it somehow related to the preferred handedness of the weak interactions?

f) We would like to incorporate gravity into the overall picture.

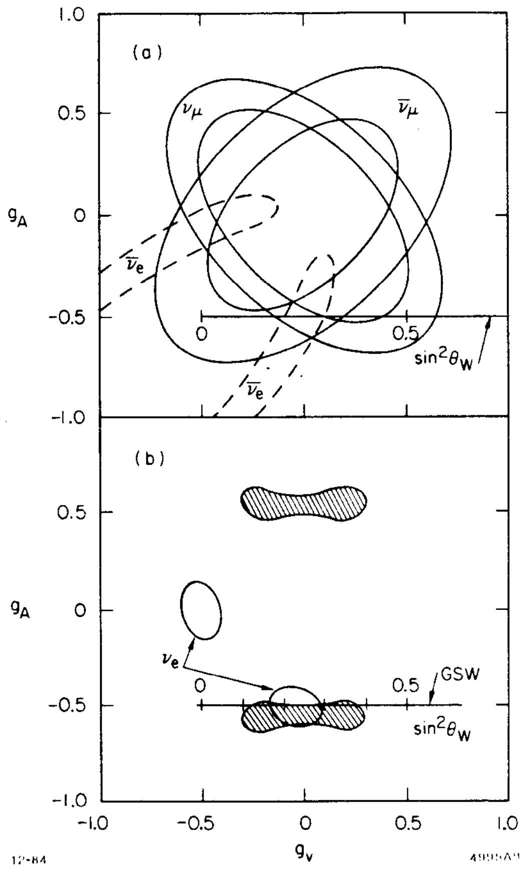


Fig. 11. (a) 90% confidence level contours for g_V and g_A from $\nu_\mu e$, $\bar{\nu}_\mu e$ and $\nu_e e$ scattering, all fitted separately. (b) 95% confidence level contours for g_V and g_A from $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow e^+e^-$ from JADE, MARK J and TASSO (shaded area). The open areas are the 95% conf. level contours from a common fit to all ν_e data. Also indicated is the prediction of the Standard Model.

There have been a number of ingenious ideas put forth to explain as many of these problems as possible. The most prominent of these are Grand Unified Theories,[12)] Compositeness schemes,[13)] Supersymmetry,[14)] Technicolor,[15)]

Extended Technicolor[16) and Left-right symmetric theories.[17) None of them gives truly satisfactory answers to all of the above questions. They all have germs of interesting ideas, however, and all could provide a basis for the next fundamental theory. Only more data will be able to resolve the question as to what is the correct explanation of the many dilemmas before us.

THE NEXT STEP

More work is clearly needed. How do we make progress from here? We can see three possible fruitful avenues.

a) New and better ideas based on the existing information. Are we ignoring the hints that nature might have already provided us? Maybe these mysterious masses of quarks and leptons and the equally unexplainable values of the mixing angles in the quark sector already provide us with serious clues about the nature of the ultimate theory.[18) Maybe the values of coupling constants can also teach us about the fundamental principles.

b) The existing accelerator, and non-accelerator experimental data and the results from the low energy experiments probing high masses through propagator effects can all provide information about ultimate theory. The divergence of the experimental results from the predictions of the standard model might provide us with some of the earliest clues as to the nature of the true theory of particle physics.

c) New energy frontiers that will be opened up by the next generation of accelerators. During the next few years new energy domains will be explored by the accelerators now under construction. Even more ambitious accelerator projects are right now on the drawing boards. It is almost certain, if history is to be our guide, that the experiments in these new energy regions will generate new and revolutionary insights into the nature of particle physics.

Next I would like to discuss briefly some of the hints in the existing data that there is new physics beyond the standard models. After that discussion, I would like to end by summarizing the status of the new accelerator projects that hopefully will become a reality during the next decade.

HINTS OF NEW PHYSICS

There exist now several experimental hints that we may be on the threshold of physics beyond the standard model. I shall discuss five of those results, roughly in order of increasing significance.

a) Same sign dimuon events from ν and $\bar{\nu}$ interactions. The present evidence, coming from several different experiments, suggests that there may exist anomalously high yield of same sign dimuon events in ν and $\bar{\nu}$ interactions.[19) The combined world data for the reaction

$$\nu N \to \mu^- \mu^- X$$

are shown in Fig. 12. One should note that the lower momentum cut is not identical in all the experiments so the data are not directly comparable. However there do appear to be inconsistencies between the different experiments contributing to this summary.

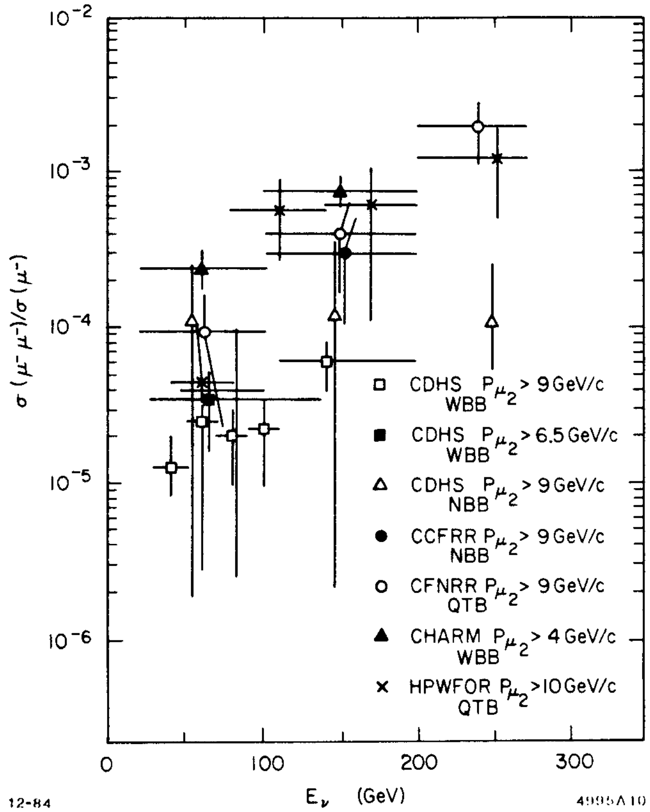


Fig. 12. Summary of same sign dimuon production data in ν interactions as a function of neutrino energy.

Within the standard model there are several mechanisms which could contribute to the reaction in question. Associated production of charm or bottom quark production, followed by the semileptonic decay of the heavy quark, are two such possible channels. Their calculated rates, however, are significantly lower than indicated by the data in

Fig. 12. The difficult experimental question here is whether the backgrounds from π and K decays have been calculated properly. Until that point can be settled conclusively it would be premature to conclude that new physics has manifested itself here.

b) Recently, considerable excitement has been generated by the observation of high mass narrow peaks in e^+e^- annihilations. The channels studied were of the type

$$\text{Quarkonium} \to \gamma + X$$

and the interesting observation consisted of narrow γ-ray lines which would correspond to a state with a unique mass recoiling against the photon. There were two examples of such phenomena. In the ψ/J decay,[20] a study of the $K^+K^-\gamma$ final state revealed a narrow K^+K^- state with a mass of 2.2 GeV. The reaction could be described as proceeding via

$$\psi/J \to \gamma+\xi(2.2)\text{GeV}$$
$$\hookrightarrow K^+K^-$$

and the evidence is displayed in Fig. 13. Except for a 2σ peak in the $K^0_S K^0_S$ channel, no evidence for this effect was seen in any other final state. The situation is even more confused by the fact that there appear to be some difference in the central mass value of the peak in the two different subsets of data collected a year apart.

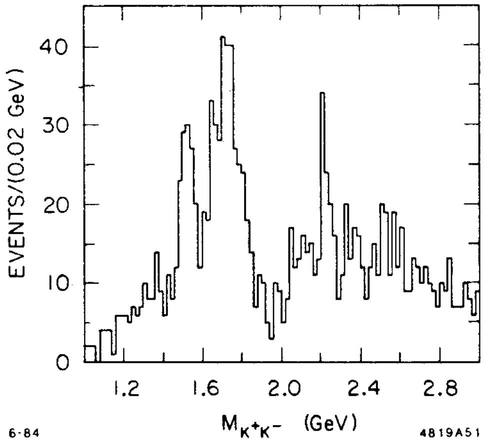


Fig. 13. K^+K^- invariant mass distribution in $J/\psi \to \gamma K^+K^-$ from Mark III Collaboration at SPEAR.

Evidence for similar phenomenon was reported by the Crystal Ball group at the Leipzig meeting and SLAC Summer Institute.[21] More specifically, they saw evidence for

$$\Upsilon \to \gamma+\varsigma(8.3\text{GeV})$$
$$\hookrightarrow \text{hadrons}$$

The more recent data, as well as work at CESR by the CUSB group, do not appear to support the initial evidence, however.[22]

If one or both of those effects are real they could easily be harbingers of new physics. Independent confirmation, however, is necessary before any firm conclusions can be reached.

c) ν physics. Two recent experimental results might indicate surprising developments in the ν sector. About 4 years ago a Russian group presented evidence[23] for a nonzero ν_e mass. This experiment has now been significantly improved and the new results provide supporting evidence for a finite ν_e mass.[24] The experimental technique consists of measuring the shape of the electron energy spectrum near its endpoint from the decay

$$^3H \to {}^3He + e^- + \nu_e$$

The latest ITEP data are shown in Fig. 14, together with the fits to the $m_{\nu_e} = 0$ and $m_{\nu_e} = 33ev$ hypotheses. The latter value, even though corresponding to the optimum fit, still yields a rather poor χ^2 when fitted to all the data (522 for 295 degrees of freedom) indicating probably presence of still not understood systematics. There is an extensive program all over the world at the present time to repeat this measurement using different techniques.

Another recent surprising result comes form the data taken at the Bugey reactor in France.[25] Comparison of the $\bar{\nu}_e$ interaction rates at two different distances away form the reactor core, 13.6 and 18.3 m, show differences (Fig. 15) which can be most naturally interpreted as ν oscillations. Comparison of these results with those obtained from the Goesgen reactor two-location experiment indicates that the values of $\delta m^2 \approx 0.2eV^2$ and $\sin^2 2\theta \approx 0.2$ are mutually consistent. On the other hand, the Bugey results appear to contradict the Goesgen results if predictions of the expected $\bar{\nu}_e$ flux are included in the analysis (see Fig. 16).

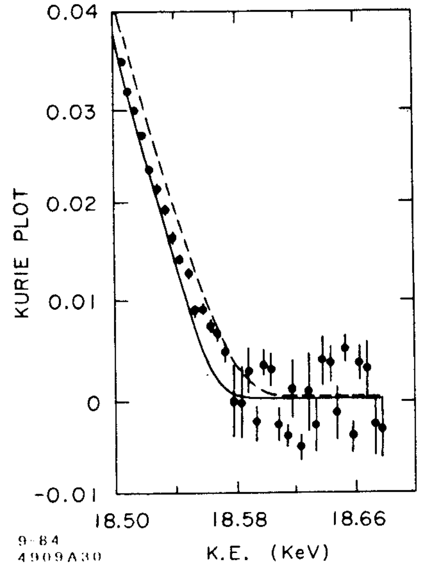


Fig. 14. The edge of the Kurie plot from the 1983 ITEP experiment. The solid line is the best fit to the $m_{\nu} = 33$ ev hypothesis; the dashed line assumes $m_{\nu} = 0$.

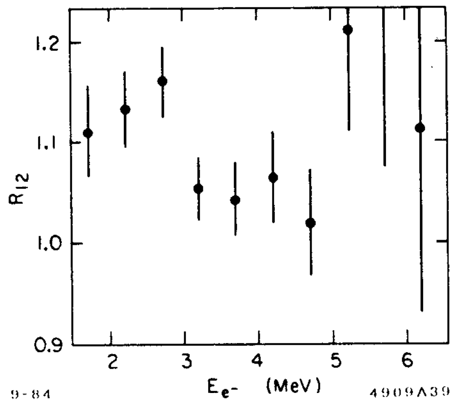


Fig. 15. The ratio of the $\bar{\nu}_e$ fluxes, as measured by $\bar{\nu}_e$ interactions, at the 2 different locations in the Bugey experiment.

d) CP violation results. The value of ϵ parameter can be calculated within the framework of the standard model if we believe that the box diagram provides the dominant contribution. This prediction relies on K-M matrix parameters S_2, S_3 and δ and on the mass of the top quark. In turn, the S_2 and S_3 values are strongly constrained by the value of the b quark lifetime. Figure 17 shows the allowed m_t contours in the S_2, S_3 space drawn on the assumption that ϵ is determined by the box diagram and that $\tau_b = 1$ psec.[26] Clearly, if $m_t \lesssim 40$ GeV as indicated by the CERN data, no satisfactory solution exists.

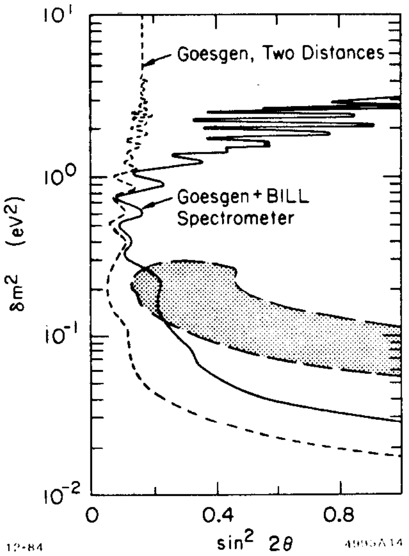


Fig. 16. Comparison of the allowed Bugey $\delta m^2, \sin^2 2\theta$ range of values (shaded region) with the Goesgen limits.

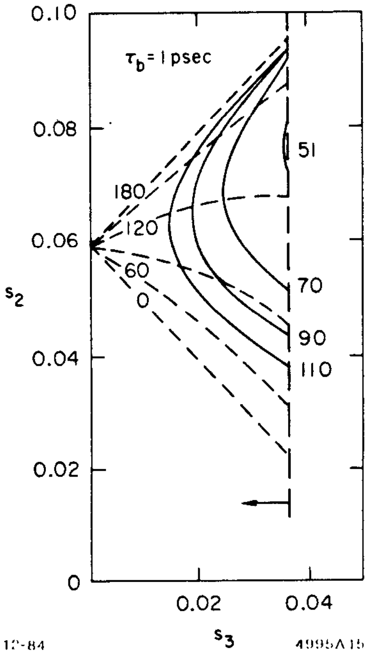


Fig. 17. The allowed values of S_2 and S_3 as a function of the phase δ and the mass of the top quark m_t. The dashed lines are contours of constant δ; the solid lines represent constant m_t (from Ref. 26).

An independent test of the standard model in this subfield is provided by the ϵ'/ϵ value. The latest Gilman-Hagelin calculation[27] for this ratio is shown in Fig. 18 together with the latest results from the Chicago-Saclay[28] and Brookhaven-Yale[29] experiments.

Clearly all of those results are strongly suggestive that an additional mechanism, besides the K-M phase, is needed to explain the CP violation. Improved results, expected during the next 3 years, should allow one to answer this question.

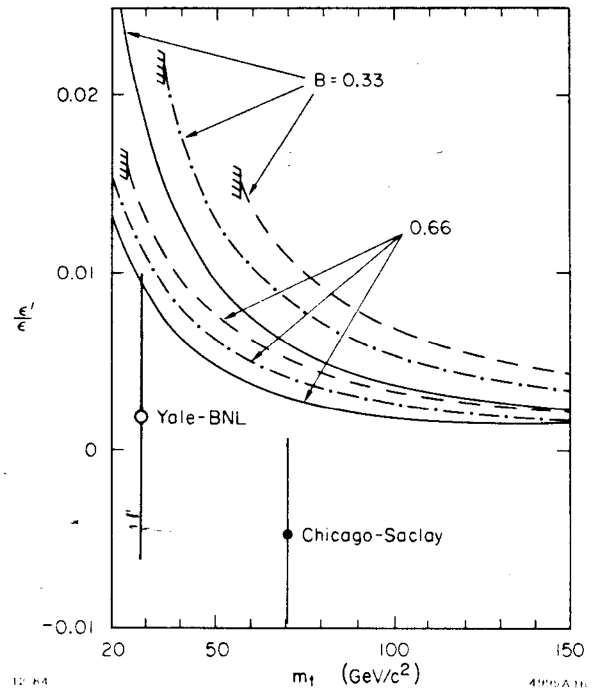


Fig. 18. Lower bounds on ϵ'/ϵ as calculated by Gilman and Hagelin. Two different values of the bag factor B are used as well as 3 different values of b quark lifetime: 0.6 psec (solid line), 0.9 psec (dashed-dot) and 1.2 psec (dashed line). The experimental results of Chicago-Saclay and Yale-BNL experiments are also indicated. The horizontal location of the experimental points is arbitrary.

e) CERN anomalous $\bar{p}p$ events. Probably the most exciting indication of potential new physics are the anomalous events from the $\bar{p}p$ collider at CERN. These fall into two distinct categories: the decays $Z^\circ \rightarrow \ell^+\ell^-\gamma$[30] and the monojet events with large missing transverse momentum.[31] The distribution of the missing transverse energy versus total transverse energy for the second class of events is shown in Fig. 19.

The events mentioned above do not appear amenable to any conventional explanation. The space does not allow us to discuss the many hypotheses, reaching beyond the standard model, that have been put forth to provide possible explanation. A detailed discussion of the experimental facts is provided elsewhere in these Proceedings.[32]

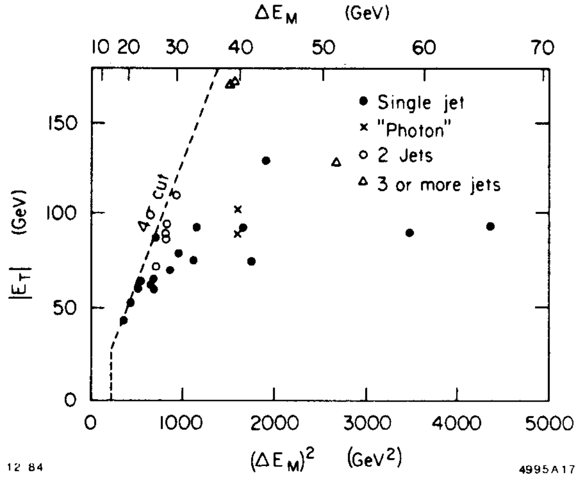


Fig. 19. The distribution of missing transverse energy versus the total transverse energy for the anomalous CERN events from UA1. The different event topologies are indicated by different symbols.

FUTURE COLLIDERS

There is a number of ongoing collider construction projects which should open up new energy frontiers during the next decade. On the most immediate time scale, the Z° boson will be investigated in detail once the SLC and LEP come into operation. The Tevatron $\bar{p}p$ collider will enable one to extend further the CERN $\bar{p}p$ investigations both in energy and luminosity domains. The KEK machine might reach energies high enough to be able to reach the toponium state; finally HERA will open up new opportunities with a qualitatively new machine, the e^-p collider.

On a longer time scale the SSC and/or LHC will be able to address directly the many questions that today appear far away on the horizon. Undoubtedly, they will also provide us with a host of new surprises and new questions. The relevant data for all of these collider projects are summarized in Table II.

Table II

Est. Compl. Date	Location	Collider	Colliding Particles	E_{cm} (GeV)	No. of Interac. Regions
1986	Fermilab	Tevatron	$\bar{p}p$	2000	2
1986	SLAC	SLC	e^+e^-	200	1
1986	KEK	TRISTAN	e^+e^-	70	4
1988	CERN	LEP	e^+e^-	120	4
1990	DESY	HERA	e^-p	314	4
>1990	Serbukhov	UNK	$\bar{p}p$	1900	
$\geq$ 1993	? ?	SSC	pp	40000	
?	CERN	LHC	pp or $\bar{p}p$	10-16000	

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