A GAUGE APPRECIATION OF DEVELOPMENTS IN PARTICLE PHYSICS - 1979

A. Salam,

ICTP, Trieste, Italy, and
Imperial College, London, England.

I. INTRODUCTION

A conference so vast and many-sided is impossible to summarize in forty-five minutes, and I will not even attempt to do so. My major theme is a gauge-theorist's appreciation of the developments in particle physics reported at the conference. In particular I wish to address myself to the question raised by Professor Zichichi in his opening address: Can we now indeed chart the course of the subject nearly up to Planck energies, of the order of 2×10^{-5} grams (1.2×10^{19} GeV)? If so, is there likely to be a long stretching Grand Plateau, unbroken by any high peaks of new physics, which is predictable on the basis of the gauge revolution of this decade?

There is no question as to the fact that the central feature of particle physics of this decade has been the recognition that the fundamental forces of nature appear to be governed by a universal gauge principle - a principle which made its first appearance with Maxwell and Einstein, whose hundredth anniversaries of death and birth, respectively, we celebrate this year. This principle has not only provided us with a quantitative theory of weak nuclear forces; it has also forced upon us a unification of the weak with the electromagnetic, in the electroweak $SU(2) \times U(1)$. Combined with the hope that the strong nuclear force is controlled by the gauge group $SU_C(3)$, one has been led to an elaboration of a standard model. There is then the natural and tantalizing hope that these weak nuclear, strong nuclear and electromagnetic gauges ($SU(2) \times U(1) \times SU_C(3)$) will combine, perhaps in a direct extrapolation, into the ELECTRO-NUCLEAR gauges of a grand unified theory and eventually perhaps into (gauged) super-gravity. As we know, it is this vast extrapolation which, within the context of particular grand unifying schemes, appears to lead to the "plateau" syndrome. And central to these schemes is the circular hypothesis that essentially no new forces (besides those described by $SU(2) \times U(1) \times SU_C(3)$) will manifest themselves, before one reaches the end of the plateau, deduced on this basis to extend nearly up to Planckian energies.

Now in this half century, in the science of biology, the analogue of our universal gauge principle was found in 1953 with the discovery of the double helix. Likewise in another scientific discipline, nearer to ours, a standard model was elaborated with the discoveries of the expanding universe and the big bang. However neither of these (admittedly intellectually inferior!) disciplines of science have on the basis of present knowledge entertained the death-wish for an unrelieved wasteland for all tomorrow. In fact, the universality of the double helix principle has not obscured from the biologist the fact that far from being the "end of molecular biology", this was only a beginning. "Something quite essential is missing in our basic understanding of life and we have not the slightest idea about the nature of lacunae in our knowledge"[1]. I believe that precisely the same applies to particle physics. As I would like to stress in the course of this talk, the remarkable successes of the gauge principle and the understanding of the fundamental forces it has given us should not obscure from us the fact that before we believe our vast extrapolations, we must fill in some glaring lacunae in our knowledge. There is something fundamentally essential missing in our understanding of the nature of the (flavour and colour) charges with which the gauging starts. In this respect, not till we match, at the very least, the type of understanding reached by Einstein (when he comprehended gravitational charge in terms of space-time curvature), can our quest in particle physics acquire the qualitative depth attained for example by gravity, nor more importantly, its quantitative freedom from some of the presently *ad hoc* parameters.

I shall divide my remarks about the conference into five parts:

1) Status of the Three Families of what we consider to-day as the elementary entities of matter;
2) Status of the electroweak SU(2) × U(1);
3) Status of QCD - the gauge theory of colour;
4) From the electroweak to the electro-nuclear (grand unification);
5) Post-Planck physics and Einstein's dreams, i.e. a unification of gravity with matter; and a comprehension of the nature of (flavour and colour) charges within space-time geometry or space-time topology.

II. THE THREE FAMILIES

1. The physics of the two familiar Families consisting of 15 (or if the neutrinos are massive, 16) two-component objects (ν_e, e_L, e_R; u_L, u_R, d_L, d_R; quarks in three colours) plus (ν_μ, μ_L, μ_R, c_L, c_R, s_L, s_R) is in good shape. In particular:

a) Charm is produced by hadrons as demonstrated both by indirect (prompt e, μ, ν, eμ) and direct (bump hunting and emulsion) methods. (The first paper presented at the conference was the emulsion picture of $\Lambda_c^+ \to p\pi^+K^-$; $m_{\Lambda_c} = 2.29 \pm 0.15$ GeV and (theoretically expected) lifetime $\tau = (7.3 \pm 0.1) \times 10^{-13}$ s.) The production mechanism is not quantitative yet, but presumably soon will be.

b) The detailed knowledge provided by e^+e^- annihilation of $\bar{c}c$ states (J/ψ, ψ', ψ'',..., P states χ) is however matched by the new problems of the charmed pseudoscalars reportedly missing at 2830 MeV and 3455 MeV.

2. Regarding the Third Family, assuming that it also follows the pattern of the first Two Families:

a) There is no evidence for toponium up to the centre-of-mass e^+e^- energies ≈ 27.4 GeV at PETRA.

b) Naked beauty has most likely been seen by the fortunate few in the SISI collaboration in $B \to (J/\psi) + \bar{K} + \pi$ [incident π^-'s (150-170 GeV), BR.σ = 0.8 nb, and estimated B production ≈ 100 nb, if B.R. $\approx 1\%$ for the channel quoted].

The status of the Third Family is thus at a tantalizing stage. It may not follow the pattern of the first Two Families (though after the observed b-decay, the case for a (t-b) doublet has become stronger). If it does, I would consider it evidence - in analogy with the universality of the double helix - that nature has discovered a dynamical stability about the system of the 15 (or 16) objects which constitute the first Two Families and that almost certainly there is a more basic layer of structure underneath.

III. THE ELECTROWEAK SU(2) × U(1)

After the beautiful presentations of Dydak (who emphasised the degree of precision achieved now in measuring the model independent parameters in neutrino neutral-current physics) and of Prescott, there is little that I can add about the agreement of the SU(2) × U(1) theory (containing one theoretically undetermined coupling, $\sin^2\theta = 0.230 \pm 0.015$) with all the currently measured weak and electromagnetic phenomena below 100 GeV or so. [2)]

Perhaps the most remarkable measurement in this respect is that of the parameter $\rho = \left(\frac{m_W}{m_Z \cos\theta}\right)^2$ which is currently determined from the ratio

THE NEUTRAL CURRENT COUPLING CONSTANTS (Dydak)

	Experiment	SU(2) × U(1)	$\sin^2\theta = 0.23$
u_L	0.32 ± 0.03	$\frac{1}{2} - \frac{2}{3}\sin^2\theta_W$	0.347
d_L	-0.43 ± 0.03	$-\frac{1}{2} + \frac{1}{3}\sin^2\theta_W$	-0.423
u_R	-0.17 ± 0.02	$-\frac{2}{3}\sin^2\theta_W$	-0.153
d_R	-0.01 ± 0.05	$\frac{1}{3}\sin^2\theta_W$	0.077
g_V	0.06 ± 0.08	$-\frac{1}{2} + 2\sin^2\theta_W$	-0.040
g_A	-0.52 ± 0.06	$-\frac{1}{2}$	-0.500
$\tilde{\alpha}$	-0.72 ± 0.25	$-1 + 2\sin^2\theta_W$	-0.54

$$\sin^2\theta = 0.230 \pm 0.015$$

$$\rho = 1.00 \pm 0.02$$

of neutral to charged current cross-sections. The predicted value $\rho = 1$ for weak iso-doublet Higgs is to be compared with the experimental $\rho = 1.00 \pm 0.02$. Presumably like (g-2) in QED, the radiative corrections to ρ from SU(2) × U(1) will provide important information, not only on the basic theory involved, but also about the masses of charged elementary fermions - and in particular leptons - which contribute to the radiative corrections [3] of ρ. (According to Ellis, the present accuracy of ρ appears to suggest $m_{lep} \lesssim 100$ GeV for a one-loop calculation.)

But why does nature favour the simplest suggestion of SU(2) × U(1) theory of the Higgs being iso-doublet? Is there just one physical Higgs?

Of what mass? Could the Higgs phenomenon be a manifestation of a dynamical breakdown of the symmetry?

Personally I see no theoretical reason for a prejudice against an elementary spin-zero object. The real problem with Higgs - and this is one of those unresolved problems which I mentioned earlier and one which calls for greater depth in our theories - is the large number of parameters - 21 out of 26 in the standard 6-quark, (K-M) $SU(2) \times U(1) \times SU_C(3)$ model - attributable to the Higgs sector [4]. What is needed is an extension of the gauge (or a similar) principle to embrace the Higgs sector.

IV. THE HIGGS SECTOR

I shall briefly comment on some of the ideas expressed in the theoretical sessions of the conference relating to the Higgs sector, particularly as I shall need some of these ideas later.

1) **Higgs mass:** Bjorken discussed in detail the attractive suggestion (Gildener and Weinberg; Ellis, Gaillard, Nanopoulos, Sachrajda) to use the Coleman-Weinberg mechanism to generate Higgs mass (one-loop) radiatively. With the assumption of one iso-doublet with bare mass zero, a low physical mass m_H is predicted

$$m_H \approx (38.53) \left[\frac{3\alpha}{8\pi}\left(\frac{2+\sec^4\theta}{\sin^4\theta}\right)\right]^{1/2} \text{GeV}$$

$$\approx 9.35 \text{ GeV} \quad (\sin^2\theta = 0.23) \quad .$$

2) The rival suggestion that if $m_H \gtrsim \sqrt{\frac{8\pi\sqrt{2}}{3G_F}} \approx 1$ TeV, partial wave unitarity is not respected at the tree level, and the Higgs sector is truly a strong interaction sector, has its own attractions for Isabelle and other accelerators in that energy range. This has been made quantitative by Grisaru and Schnitzer in a contribution to the conference: Assuming that $SU(2) \times U(1)$ is made part of a larger non-Abelian gauge group, and assuming that $m_H \gg 300$ GeV, one may expect Regge recurrences of $W^{\pm}$, Z^0 and the photon occurring around 2-4 TeV. If $m_H \lesssim 100$ GeV, these recurrences would still occur but regrettably near Planck energies $\approx m_W \exp \frac{c}{g^2}$.

3) To reduce the arbitrariness of the Higgs couplings and to motivate their iso-doublet character, one suggestion is to use supersymmetry [5]. Recall that supersymmetry is a Fermi-Bose symmetry, so that iso-doublet leptons for example must be accompanied in the same multiplet by iso-doublet Higgs.

Unhappily the concrete realization of supersymmetry has always necessitated adding in of further (heavy) multiplets. For example, in the simplest SU(2) × U(1) supersymmetric model that I know of, the three leptons (ν_L, e_L, e_R) must be accompanied by 9 new leptons before a realistic theory emerges. Likewise for quarks and other leptonic families. Frightful inflation!.

4) And finally in the context of the Higgs mechanism emerging as dynamical symmetry breaking (Dimopoulos, Susskind, Weinberg) (with assumed non-zero expectation values of bilinear products of Fermi fields ($\langle \bar{\psi}\psi \rangle \neq 0$), there is the attractive idea of technicolour.
One introduces a set of technicoloured quarks (and in extended versions of the theory, techni-gauge fields)but no Higgs. The techni-forces are new forces of which we have no cognizance at present low energies; these and the corresponding particles manifest themselves in the 1-100 TeV range. Once again, like supersymmetry, there is a vast inflation of new particles. For example, the three leptons (ν_L, e_L, e_R) must appear as humble members of a set of $5 + 5 + 5 + \overline{10}$ multiplets of $SU(5)|_{tech}$ - an inflation nearly three times worse as that for supersymmetry.

Clearly, there is no fear of any "desert" of new particles or of new forces, in the few TeV region if these or similar ideas (devised to diminish Higgs and their arbitrary couplings) make physical sense.

V. STRONG INTERACTIONS AND GAUGED COLOUR

The bulk of the Conference was occupied by the parton model and the theory of gauged colour, with a special session on the status of QCD, addressed by de Rujula and Preparata. So I can be brief.

To one coming as an outsider to the subject of strong interactions the first reaction is one of profound wonderment at the sureness of touch displayed in the initial formulation of the parton model. The second reaction is again of wonderment at how remarkable a theory QCD is - principally on account of its unique property of asymptotic freedom (shared possibly only by Einstein's gravity, as surmised by Fradkin and Vilkovisky[6]). The third reaction is still of wonderment, but this time at how little impress, quantitative QCD of quarks and gluons has yet made on the broad spectrum of strong interaction physics, in spite of a large number of exceedingly brilliant contributions made to the subject, particularly during the last year.

The present role of QCD is essentially one of perturbatively renormalizing the quark (and gluon) parton model, with which QCD is compatible but which it does not yet predicate. As Preparata and de Rujula both agreed, this situation will not change till QCD solves:

i) The problem of confinement of quarks and gluons in hadrons;

ii) The converse problem of hadronization of quarks and gluons;

iii) And the problem of determination of the spectrum of physical states (though we heard from de Rujula of the exciting prospect of qualitative considerations of E. Witten who has shown in the context of an $\frac{1}{N}$ expansion in an N colour $SU_C(N)$ that baryons for example may be understood as $\frac{1}{N}$ analogues of "monopole solitons").

5.1 Theoretical considerations

The next table summarizes the elucidation achieved of the interrelation between the ideas built into the parton model and the quantitative impress made on these by perturbative QCD.[7] (This is after the perturbative expansion is summed either through the operator product expansion method,or more generally, through the solution of an appropriate Bethe-Salpeter equation.)

5.2 Tests of QCD

The tests of QCD, discussed at the conference, fall into three categories:

1) The gluon: Since $SU(3)|_{colour}$ is a theory of spin-one gluons and their mutual self-interactions, the most positive evidence for QCD would be: discover the gluon G and test for $G \rightarrow 2G$, $G \rightarrow 3G$.

2) Negative tests:

(a) As emphasised at the Conference, QCD predicts

$$\langle p_T^2 \rangle \approx (\bar{g}^2/4\pi)\, Q^2 \quad .$$

This is unlike most other tests which depend on $\log Q^2$. If $\langle p_T^2 \rangle$ does not eventually exhibit a rising trend with Q^2, QCD must be discarded.

(b) Likewise, it should die if in hadron-hadron collisions, the cross-sections fail eventually to exhibit a behaviour like p_T^{-4} (rather than the(once)empirical p_T^{-8}). Both these are negative tests.

3) Indirect tests of perturbative QCD: i.e. scale breaking, Q^2-dependence of the structure and fragmentation functions and their moments. These tests include

(a) The (Reya-Gluck) characteristic prediction for coloured QCD: i.e. $\int F_2(x,Q^2)\, dx$ must decrease as Q^2 increase;

Parton model: Built-in features	Perturbative QCD and the manner of its "renormalization" of the built-in features of the parton model
Factorization $\{F(x) \times D(z)\}$ F(x): Hadronic structure function D(z): Parton fragmentation function	QCD replaces $\{F(x) \times D(z)\}$ by $\{F(x,Q^2) \times F(z,Q^2)\}$ or more precisely, in terms of moments [8] by $F^N_{parton}\left(\bar{g}^2 \ \ell n \frac{Q^2}{\Lambda^2}\right) D^M_{parton}\left(\bar{g}^2 \ \ell n \frac{Q^2}{\Lambda^2}\right) \times \left\{ \begin{array}{l} f^N\left(\bar{g}^2, \ \ell n \frac{\Lambda^2}{m^2}\right) \times d^M\left(\bar{g}^2, \ \ell n \frac{\Lambda^2}{m'^2}\right) \\ + O(\bar{g}^2) \end{array} \right\}$
Scaling	QCD gives a perturbative calculation of the F^N's and the D^M's. In the leading log order these scale-breaking factors behave like $\left(\ell n \frac{Q^2}{\Lambda^2}\right)^{-d_N}$, though the theory does not predict the magnitude of Λ^2. The f^N's and d^M's are QCD non-calculable probability amplitudes, universal in the same sense as the parton model's F(x)'s and D(z)'s are.
Jets are soft	1) Jets are characeristically hard: 2) There is the complementary theoretical development of "safe" jet variables, following the pioneering work of Sterman and Weinberg. Here one attempts to define such measurable quantities for which a reliable perturbation expansion exists in terms of $\bar{g}^2 \approx \left(\ell n \frac{Q^2}{\Lambda^2}\right)^{-1}$ rather than for the mass-singularity-containing parameter $\bar{g}^2 \ \ell n \frac{Q^2}{m^2}$.
Hadronization of partons: soft transfer of quantum numbers	Domains of perturbative QCD and of confinement phenomena shown to be distinct [9),10)].

(b) Log moment versus log moment plots for both structure and fragmentation functions;

(c) Corresponding plots of $(\text{moment})^{-1/d}$ versus $\log Q^2$;

(d) And predicted QCD corrections to Drell-Yan.

The status of these indirect tests have been discussed in detail at the conference by Gaillard, de Rujula, Preparata and (for Drell-Yan) by Altarelli. Battles have raged over the significance of singlet versus non-singlet structure functions, over higher than leading log corrections, over higher twist and resonance regime effects - over whether the present tests really do test QCD fairly. I make no comment, except to express, as always, a theorist's profound admiration to our experimental colleagues in making the theory commit itself by extracting significant numbers from difficult data.

5.3 The direct test; Discovery of the gluon (G)

Fig.1 shown by Brandt exhibits the status of $T \rightarrow 3G$ versus phase-space Monte-Carlo (plots of thrust, triplicity and other jet parameters). As Professor Schopper told us, in the next few months, the statistics on these jets are likely to improve vastly, but if we accept tentatively that $T \rightarrow 3G$ is the likeliest decay mode, one could in principle determine gluon spin, using ideas of Koller, Walsh and Kraseman who define a function $(\alpha(T))$ (T = thrust of the fastest jet)and plot the thrust axis angular distribution relative to the beam direction in terms of this.

Fig.2 shows the sharp distinction between spin-one and spin-zero gluons. The paucity of statistics makes an experimental comparison with theory difficult at present. As stressed by Gaillard, however, one may compute thrust averaged $\langle\alpha(T)\rangle$, and plot the corresponding angular distribution (Fig.3). The results favour spin-one.

One does not wish to rush into a conclusion, which the cautious men(and women) from PETRA themselves have not drawn. However, one might predict, that with the Cornell accelerator soon coming on stream, and more statistics from DORIS, the gluon is likely to be discovered sooner than the $W^{\pm}$'s and the Z^0.

To test for the $G \rightarrow 2G$ and $G \rightarrow 3G$ vertices, characteristic of QCD, one of the clearest tests will be the comparison of the evolution of gluon jets and in particular the moments of the gluon fragmentation for $T \rightarrow 3G$ versus the $t\bar{t} \rightarrow 3G$, once $t\bar{t}$ is discovered (Fig.4) (Koller, Walsh and Zerwas).

5.4 The negative tests

Figs.5 and 6 are plots of $\langle p_T^2 \rangle$ presented to the conference by Gabathuler and Altarelli consolidating the data on e, μ, ν, (e^+e^-) and Drell-Yan. As Gabathuler remarked, there is no agreement whether $\langle p_T^2 \rangle$ varies with W^2 or $\log W^2$; all one may infer at present is that $\langle p_T^2 \rangle$ is not flat, but rises. QCD lives. Fig.7 was presented by Jacob, showing the progressive transition trend from p_T^{-8} to p_T^{-4} in inclusive π^0 yield, when p_T increases from 3 to 15 GeV/c. Again prognosis for QCD's life and health is good. [11)]

To conclude:

1) QCD is a remarkable gauge theory, particularly on account of its asymptotic freedom;

2) It is not yet a theory of strong interaction and will not be till the problems of confinement and hadronization are solved;

3) Its present successes (or otherwise) lie in the field of perturbative QCD. However, there are serious problems at present in estimating corrections to the various predictions.

4) The gluon may have been discovered, together with its spin determination.

VI. GRAND UNIFICATION, THE ELECTRONUCLEAR FORCE AND THE ISSUE OF THE GRAND PLATEAU

6.1 The electronuclear force

Besides QCD, the second area of intense revival this year has been the attractive extension of the ELECTROWEAK unification to embrace strong forces as well - i.e.the emergence of the ELECTRONUCLEAR unification (of the weak nuclear, the strong nuclear and the electromagnetic forces). Related to this - as Professor Zichichi told us - is the issue of the possible existence of a GRAND PLATEAU with no high peaks of new physics to be scaled, except near Planck energies.

The main stages of the ELECTRONUCLEAR unification which go back to the years 1972-1974 are the following:

1) Embed $SU(2) \times U(1) \times SU_C(3)$ into a simple (or a semi-simple) non-Abelian gauge group G; all quantum numbers (flavour, colour, lepton and quark numbers) are then automatically quantized. [12)]

2) A gauging of this group G will assure asymptotic freedom [13)] for the full ELECTRONUCLEAR theory, provided the numbers of fermion fields (and Higgs) is restricted.

3) The gauge theory based on a technically "simple" (or with appropriate discrete symmetries, a "semi-simple") group contains one basic gauge constant, which manifests itself physically above the unification mass M exceeding all particle masses in the theory.

4) These particle masses must be introduced through the familiar Higgs mechanism, which breaks the symmetry through one or more mass stages down to $SU(2) \times U(1) \times SU_C(3)$ for low energies $\mu \approx 100$ GeV. Given the pattern of symmetry breaking and these mass stages [14)], the magnitudes of the observed couplings [15)] $\alpha_s(\mu)$, $\alpha(\mu)$ (i.e. why, SU(3) forces are strong and SU(2) forces weak at low energies) as well as the ratio of the two electroweak couplings ($\sin^2\theta(\mu)$) can in principle be determined by the renormalization group equations [37)].

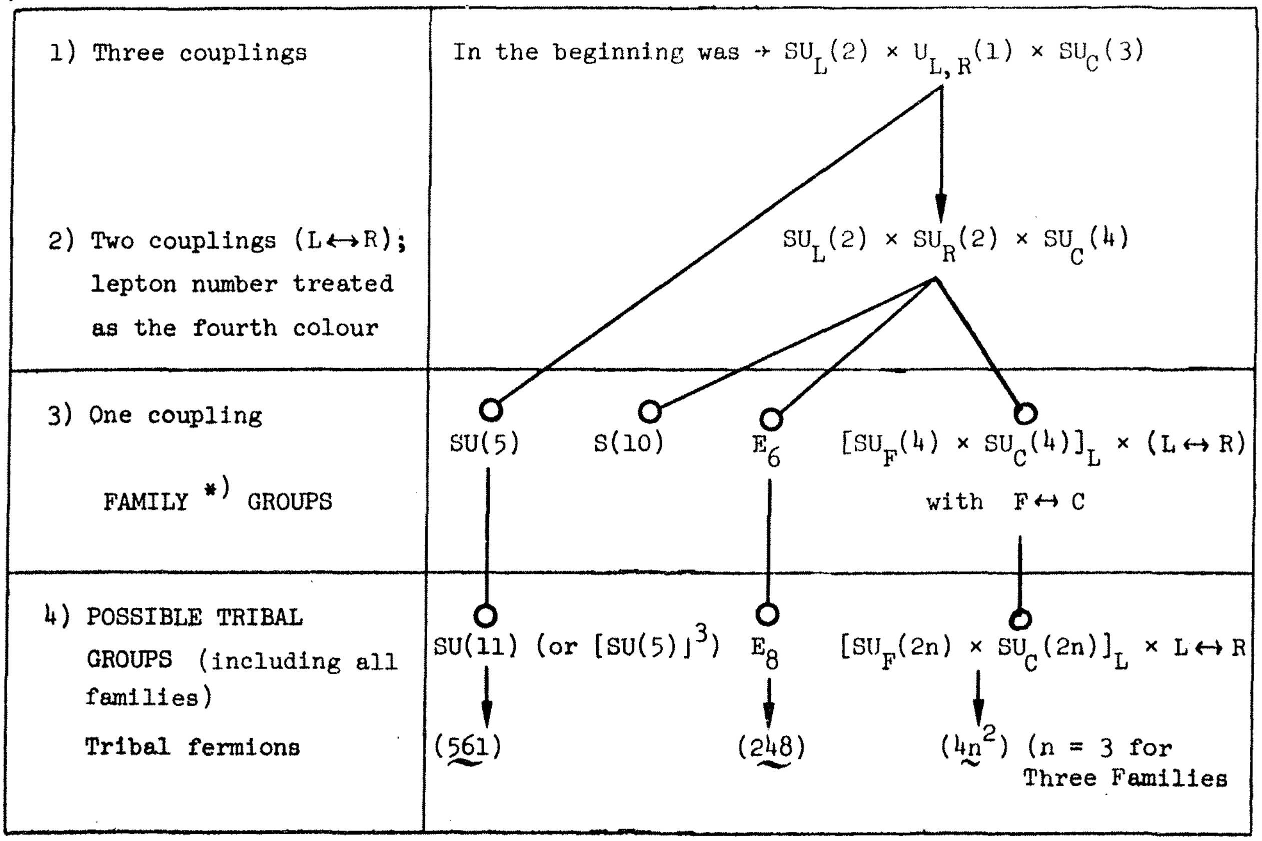
5) Clearly grand unified theories must treat leptons on par with quarks. This psychological break was first implemented in 1972 by grouping quarks and leptons in the <u>same</u> multiplet of the unifying group G. From this follows (through the processes of gauging) the prediction of the existence of lepto-quark gauge bosons - necessarily heavy, since they will induce exotic phenomena, particularly proton decays into leptons. The following two tables summarize the development of these ideas

<u>Quark-lepton unification</u>

Semi-simple groups *) (with left-right symmetry)	$G_L \to \begin{pmatrix} q \\ \ell \end{pmatrix}$, $G_R \to \begin{pmatrix} q \\ \ell \end{pmatrix}_R$ $G_L \times G_R$ $L \longleftrightarrow R$	<u>Exotic gauge particles</u> Lepto-quarks $\to (\bar{q}\ell)$	<u>Proton decay</u> Lepto-quarks $\to$ W + (Higgs) or Proton = $qqq \to \ell\ell\ell$
Simple groups	$G \to \begin{pmatrix} q \\ \ell \\ \bar{q} \\ \bar{\ell} \end{pmatrix}_L$	diquarks $\to (qq)$ dileptons $\to (\ell\ell)$ leptoquarks $\to (\bar{q}\ell), (q\ell)$	$qq \to \bar{q}\bar{\ell}$ or Proton P = $qqq \to \bar{\ell}$

*) Grouping (q and ℓ) (Pati <u>et al</u>. 1972) together, implies treating lepton number as the fourth colour, i.e. $SU_C(3)$ extends to $SU_C(4)$.

The emergence of the grand unifying groups



) The representations ($\underset{\sim}{5}$ + $\underset{\sim}{10}$) and ($\underset{\sim}{16}$), respectively, of the family groups SU(5) and SO(10) each describe One Family, while the basic representations [16] of E_6 and $[SU(4)]^4$ describe Two Families ((e,...) and (μ,...)).

6) An unresolved mystery is the replication of families, if this indeed is what is happening. Is there a larger "TRIBAL" group (as distinct from the smaller FAMILY groups) whose basic representation contains all the families? (Note the fermion-inflation for Tribal groups.)

6.2 Tests of grand unification

The most characteristic prediction from the existence of the ELECTRONUCLEAR force is proton decay, first discussed in the context of grand unification at the Aix-en-Provence Conference of 1973 - and if memory serves right - in the same session in which the first experimental discovery of the electroweak neutral currents was announced. It is indeed deeply gratifying that both in Europe and in the United States there now is intense interest in improving the half-life limits for the proton. For unifying groups with multiplets containing quarks and leptons only the lepto-quark masses are, as a rule, rather moderate $\sim 10^4 \sim 10^5$ GeV. For such models the characteristic proton decays (proceeding through exchanges of three lepto-quarks) conserve quark number + lepton number, i.e. $P = qqq \to \ell\ell\ell$, ($P \to 3\nu + \pi^+ \sim 80\%$; $\to 3\nu + \pi^+ + \pi^- + \pi^+ \sim 5\text{-}8\%$; $N \to 2\nu + e^- + \pi^+ \sim 80\%$; $\tau_p \sim 10^{29}\text{-}10^{34}$ years). On the contrary, for the "simple" unifying groups like SU(5), SO(10) and E_6 (with multiplets containing anti-quarks and anti-leptons as well $(q,\ell,\bar{q},\bar{\ell})$) and decays proceeding through an exchange of one lepto-quark, the decay of the proton is to an anti-lepton, with $P \to \ell$ or 3ℓ forbidden [17]. ($P \to e^+ + \pi^0$, ρ^0, ω^0, $\eta^0 \sim 75\%$; $\mu^+ + K^0 \sim 10\%$; $\bar{\nu} + \pi^+, \rho^+ \sim 15\%$; $N \to e^+ + \pi^-, \rho^- \sim 75\%$.)

An intriguing possibility in this context is that investigated recently by Pati et al. for the maximal unifying group SU(16) - i.e. the largest group to contain a 16-fold fermionic multiplet $(q,\ell,\bar{q},\bar{\ell})$. This can permit (irrespective of quark charges) the decay modes: $P \to 3\ell$ as well as $P \to \bar{\ell}$, $P \to \ell$ (e.g. $P \to e^- + \pi^+ + \pi^+$) and $P \to 3\bar{\ell}$ (e.g. $P \to 3\bar{\nu} + \pi^0$, $N \to 2\bar{\nu} + e^+ + \pi^-$), the relative magnitudes being model-dependent on how precisely SU(16) breaks down to SU(3) × SU(2) × U(1). Quite clearly, it is the central fact of the existence of the proton's decay (rather than precise details of its decay modes) for which the present experiments must be designed. [18]

Finally, grand unifying theories predict mass relations like:

$$\frac{m_d}{m_e} = \frac{m_s}{m_\mu} = \frac{m_b}{m_\tau} = \left[\frac{\alpha_s(\mu)}{\alpha_s(M)}\right]^{\frac{4}{11 - \frac{2}{3}f}} \approx 2.8$$

for 6 (or at most 8) flavours (f) below the unification mass. The important remark for proton decay, for mass relations of the above type (or for baryon excess) [19], is that these are essentially characteristic of the fact of grand unification - rather than of specific models.

It is also worth remarking that even for the simplest of grand unifying theories (Georgi & Glashow's SU(5) with just two Higgs (a 5 and a 24)) the number of ad hoc parameters needed (most of them attributable to the Higgs sector) is still unwholesomely large - 22, to compare with 26 of the six-quark Kobayashi-Maskava model based on the humble SU(2) × U(1) × $SU_C(3)$. We cannot feel proud.

6.3 The unifying mass, $\sin^2\theta$ and the grand plateau [20]

As discussed by Iliopoulos, the decoupling theorem of Applequist and Carazonne, as applied by Georgi, Quinn and Weinberg to grand unification, relates the observed low-energy couplings $\alpha(\mu)$ and $\alpha_s(\mu)$ ($\mu \approx 100$ GeV) to the grand unifying mass M and the observed value of $\sin^2\theta$. The demonstration that this leads inevitably to a grand plateau, stretching up to nearly Planckian energies, depends, very sensitively (qualitatively and quantitatively) on a number of assumptions which are strong extrapolations from present trends. In view of the importance of the subject, I wish to examine these assumptions critically, even though this makes this part of the talk heavy.

My conclusions (stated more fully later) are first: that even extrapolating from present theoretical ideas, the unifying mass M (and thus the stretch in energy scale for which new physics may not manifest itself) depends critically on the assumptions made by particular unifying models and may vary between 10^4-10^5 to 10^{13}-10^{15} GeV. Second, that even for those models which call for $M \sim 10^{13}$-10^{15} GeV there is an inevitable breaking up of the plateau by newer "heights" of physics at intermediate energy scales. This last result follows from the (rather high) value of $\sin^2\theta \approx 0.23$ suggested by the present data at this Conference.

6.4 The measure of the plateau problem (Occam's razor):

1) Given a grand unifying group G, there can, in general, exist a succession of stages of its descent, down to the low-energy gauge symmetry $SU(2) \times U(1) \times SU_C(3)$, with a hierarchy of mass stages $M_1 > M_2 > \ldots > \mu$ and corresponding stages of symmetry breaking.[21]

Clearly, at each stage, new physics enters, with the corresponding new gauge particles, new sets of interactions, new Higgs, new selection rules, new Regges, new monopoles[22] and new dyons.

To speak of a plateau, we must prove from internal consistency (or as is the more common practice, simply assume) that such hierarchies, either do not exist or - if they are forced upon us by experimental data - that they are few and far between.

2) However - for this descent, from G down to $SU(2) \times U(1) \times SU_C(3)$ - even if other complicated[21] intermediate stages are eschewed, two types of stages may not be rejected out of hand. i) The Family stage: The low-energy $SU_L(2)$ may have descended (as the diagonal sum) of $SU^I(2) \times SU^{II}(2) \times SU^{III}(2) \times \ldots$, where I, II, III,... refer to the various families[23] (e,...), (μ,...) and (τ,...). ii) The Chiral stage: The low-energy $SU_C(3)$ may, likewise, have descended (as the diagonal sum) from the chiral colour symmetry $SU_{CL}(3) \times SU_{CR}(3)$ as well as from the diverse families[24]. The physics of this situation is profoundly different from the physics of a straightforward descent to $SU(2) \times U(1) \times SU_C(3)$ but only for energies well above the (possibly high) masses of the fields orthogonal to $W^{\pm}$, Z^0 and

G's. Once again, the neglecting of such possibilities implies assuming from the start that the corresponding peaks of new physics simply do not exist: (OCCAM'S RAZOR).

3) Finally an absolutely crucial role in determining M and $\sin^2\theta$ is played by the parameter $\sin^2\theta_0 = \sin^2\theta(M^2) = \sum T_3^2 \to SU(2) \Big/ \sum Q^2$, and the conventional assumption that for fermions (including any superheavy ones with masses near M)[25] $\sin^2\theta_0 = \frac{3}{8}$.

The details of the demonstration of the statements below are given in the Appendix. Here I summarize the results.

6.5 Summary

A) The gauge plateau is the consequence of two assumptions:

1) That there is a gauge plateau! - more soberly, of the assumption that no new gauge forces except those represented by $SU(2) \times U(1) \times SU_C(3)$ exist, until we reach the grand unifying mass.

2) For certain grand unifying family groups (like SU(5) and SO(10)) the unifying mass M does edge towards the Planck mass [39] ($M \approx 10^{13}$ GeV, for $\sin^2\theta = 0.23$). This happens because together with assumption (1), we have also assumed that all fundamental fermions - past, present and future - (including any superheavy ones, to be discovered with masses $\approx 10^{13}$ GeV) belong to that representation of the eventual tribal group for which $\sin^2\theta_0 = \sin^2\theta(M^2)$ equals $\frac{3}{8}$.

This assumption may be correct [26] (and one of the goals of particle physics is to find this out [27]), but one should appreciate its full import in determining M.

B) There are other tribal grand unifying groups for which $\sin^2\theta_0 = \sin^2\theta(M^2)$ is different from $\frac{3}{8}$ (e.g. for the 6-flavoured $[SU(6)]^4$ with $\sin^2\theta_0 = \frac{9}{28}$). For these the unifying mass M can be much smaller. For $[SU(6)]^4$ it is $\approx 10^6$ GeV. If there are eight flavours i.e. $[SU(8)]^4$, M is even smaller $\approx 10^4$ GeV. The plateau has shrunk vastly.

c) A family group like SU(5) may be currently disfavoured on the basis that it cannot easily accommodate the experimental $\sin^2\theta \approx 0.23$ unless α_s is unseasonably small ≈ 0.07, see Appendix). Even if SU(5) could accommodate $\sin^2\theta \approx 0.23$, it gives a proton lifetime estimate [39] ($\tau_p \approx 10^{23}$ years) which may be too small, unless there are 15 Higgs doublets. The "simple" SO(10) may overcome these disabilities; however, at the price of introducing intermediate symmetry-breaking stages. But then, by definition, new physics does appear for energies considerably lower than the grand unifying mass. The plateau is not a plateau after all.

To conclude, I do not think any experimental physicist, who is still with me, need seriously worry about an unbroken plateau where there are no new physics heights to be scaled. I have tried to show that this holds even within the theoretical framework represented by a direct extrapolation of the present ideas to the highest energies. In some of the remaining parts of the talk I shall be questioning two of the notions which have gone into this direct extrapolation - first, do quarks and leptons represent the correct elementary[27)] fields, which should appear in the matter Lagrangian, and which are structureless for renormalizability; second, could some of the gauge fields themselves be composite?

6.6 The quest for elementarity, prequarks (preons and pre-preons)

While the rather large number (15) of elementary fields (for example, for the family group SU(5)) already makes one feel somewhat queasy, the number 561, for the three-family tribal group SU(11) (of which presumably $3 \times 15 = 45$ objects are of low and the rest of Planckian mass) is distinctly baroque. Is there any basic reason for one's instinctive revulsion when faced with these vast numbers?

The numbers by themselves would perhaps not matter so much. After all, Einstein in his description of gravity, chose to work with 10 fields ($g_{\mu\nu}(x)$) rather than with just one (scalar field) as Reissner and Nordström had done before him. Einstein was not perturbed by the multiplicity he chose to introduce, since he relied on the sheet-anchor of a fundamental principle - (the equivalence principle) - which permitted him to relate the 10 fields for gravity $g_{\mu\nu}$ with the 10 components of the physically relevant quantity, the tensor $T_{\mu\nu}$ of energy and momentum. Einstein knew that nature was not economical of structures; only of principles of fundamental applicability. The question we must ask ourselves is this: Have we yet discovered such principles in our quest for elementarity, to justify having fields with such large numbers of components as elementary.

Recall that quarks carry at least three charges (colour, flavour and a family number). Should one not, by now, entertain the notions of quarks (and possibly of leptons) as being composites of some more basic entities (PRE-QUARKS or PREONS), which each carry but one basic charge. These ideas have been expressed before but they have become more compulsive now, with the growing multiplicity of quarks and leptons. Recall that it was similar ideas which led from the eight-fold of baryons to a triplet of (Sakatons and) quarks in the first place.

The preon notion is not new. In 1975, among others, Pati et al. introduced 4 chromons (the fourth colour corresponding to the lepton number) and 4 flavons, the basic group being SU(8) - of which the family group $SU_F(4) \times SU_C(4)$ was but a subgroup. (With the preon stage, the gauge group does not change; the fermionic multiplet changes.) As an extension of these ideas, we now believe these preons carry magnetic charges and are bound together by very strong short-range forces, with quarks and leptons as their magnetically neutral composites.

In another form the preon idea has been revived this year by Curtright and Freund, who motivated by ideas of extended supergravity(to be discussed in the next section), reintroduce an SU(8) of 3 chromons (R,Y,B), 2 flavons and 3 familons (horrible name). The family group SU(5) could be a subgroup of this SU(8). (Recall that of the two representations used by SU(5) to describe quarks and leptons, the 10* could in any case be considered as a three-fold anti-symmetric composite of the fundamental $\underset{\sim}{5}$ - though unfortunately the quark-lepton numbers do not quite match. In a sense then, the preon idea is implicit in SU(5).) In the Curtright-Freund scheme, the $\underset{\sim}{3} \times \underset{\sim}{15} = \underset{\sim}{45}$ fermions of SU(5) can be found among the $\underset{\sim}{\bar{8}} + \underset{\sim}{\overline{28}} + \underset{\sim}{56}$ of SU(8) (or alternatively the $3 \times \underset{\sim}{16} = \underset{\sim}{48}$ of SO(10) among the vectorial $\underset{\sim}{56}$ fermions of SU(8)).

A second contribution on preons is due to Harari and(independently) Schupe. In his quest for elementary entities, Harari has followed the approach of starting with two objects, Tohu's (charge $\frac{1}{3}$) and Vohu's (charge zero), making up the set of what he calls Rishons ("basic entities" in Hebrew)(the "chiefs" in Arabic). The eight 4-component fermions in a typical SO(10) (or SU(2) × SU(2) × SU(4)) multiplet (e.g. u, d, ν, e) are composed as follows: 28)

T T T → $\bar{e}$	V V V → ν
T T V → u_R	V V T → $\bar{d}_R$
T V T → u_Y	V T V → $\bar{d}_Y$
V T T → u_B	T V V → $\bar{d}_B$

The other Two Families are assumed to be orbital excitations of these (with radii of composites $\lesssim 10^{-24}$ cms., deduced from upper limits on $\mu \to e + \gamma$, $s \to d + \gamma$).

I would personally like to interpret Harari's ideas as referring not to the three families but to pre-preons. In the above table, read flavons in place of e and ν; chromons (R,Y,B) instead of u_R, u_Y, u_B and familons for d_R, d_Y, d_B. The objection that one is trading space-time ideas for internal quantum numbers (with colour a "composite" quantum number - a new notion; and gluons as "composite" gauge fields - suggested also by Dürr and Saller) can possibly be met in the manner of the converse generation of spin from isospin for dyonic composites discussed several years ago by Goldhaber, Hasenfratz, 't Hooft, Jackiw and Rebbi. Splendid craziness.[29)]

Before I conclude this section, I would like to make a prediction regarding the course of physics in the next decade, extrapolating from our past experience of the decades gone by:

DECADE	1950-1960	1960-1970	1970-1980	1980 →
Discovery in early part of the decade	The strange particles	The 8-fold way, Ω^-	Confirmation of neutral currents	W, Z, G, Proton decay
Expectation for the rest of the decade		SU(3) resonances		Grand Unification, Tribal Groups
Actual discovery		Hit the next level of elementarity with quarks		May hit the preon level, composite structure of quarks, and composite gauge fields

VII. POST-PLANCK PHYSICS,[30)] SUPERGRAVITY AND EINSTEIN'S DREAMS

I now turn to the problem of a deeper comprehension of the charge concept (the basis of gauging) - which, in my humble view, is the real quest of particle physics. Einstein, in the last thirty-five years of his life lived with two dreams: one was to unite gravity with matter (the photon) - he wished to see the "base wood" (as he put it) which makes up the stress tensor $T_{\mu\nu}$ on the right-hand side of his equation $R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -T_{\mu\nu}$ transmuted through this union, into the "marble" of gravity on the left-hand side. The second (and the complementary) dream was to use this unification to comprehend the nature of electric charge in terms of space-time geometry in the same manner as he had successfully comprehended the nature of gravitational charge in terms of space-time curvature.

In case some one imagines [31] that such deeper comprehension is irrelevant to quantitative physics, let me adduce the tests of Einstein's theory versus the proposed modifications to it (Brans-Dicke for example). Recently (1974), the <u>strong</u> equivalence principle (i.e. the proposition that gravitational forces contribute equally to the inertial and the gravitational masses) was tested to one part in 10^{12} (i.e. to the same accuracy as achieved in particle physics for $(g-2)_e$) through lunar-laser ranging measurements. These measurements determined departures from Kepler equilibrium distances, of the moon, the earth and the sun to better than ± 30 cms. and triumphantly vindicated Einstein.

There have been four major developments in realizing Einstein's dreams:

1) The Kaluza-Klein miracle: An Einstein Lagrangian (scalar curvature) in five-dimensional space-time (where the fifth dimension is compactified in the sense of all fields being explicitly independent of the fifth co-ordinate) precisely reproduces the <u>Einstein-Maxwell</u> theory in four dimensions, the $g_{\mu 5}$ ($\mu = 0,1,2,3$) components of the metric in five dimensions being identified with the Maxwell field A_μ. From this point of view, Maxwell's field is associated with the extra components of curvature implied by the (conceptual) existence of the fifth dimension [32].

2) The second development is the recent realization by Cremmer, Scherk, Englert, Brout, Minkowski and others that the compactification of the extra dimensions - (their curling up to sizes perhaps smaller than Planck length $\lesssim 10^{-33}$ cms. and the very high curvature associated with them) - might arise through a spontaneous symmetry breaking (in the first 10^{-43} seconds) which reduced the higher dimensional space-time effectively to the four-dimensional that we apprehend directly.

3) So far we have considered Einstein's second dream, i.e. the unification of electromagnetism (and presumably of other gauge forces) with gravity, giving a space-time significance to gauge charges as corresponding to extended curvature in extra bosonic dimensions. A full realization of the first dream (unification of spinor matter with gravity and with other gauge fields) had to await the development of supergravity - and an extension to extra fermionic dimensions of superspace (with extended torsion being brought into play in addition to curvature). I discuss this development later.

4) And finally [33] there was the alternative suggestion by Wheeler that electric charge may be associated with space-time topology - with wormholes, with space-time Gruyère-cheesiness. This idea has recently been developed by Hawking [34] and his collaborators.

Extended supergravity, SU(8) preons and composite gauge fields

Thus far the developments in respect of Einstein's dreams as reported at the Tokyo Conference of 1978. A remarkable new development was reported at this conference by Julia (Julia and Cremmer) which started with an attempt to use the ideas of Kaluza and Klein to formulate extended supergravity theory in a higher (compactified) space-time - more precisely in eleven dimensions. This development links up, as we shall see, with preons and composite Fermi fields - and even more important - possibly with the notion of composite gauge fields.

Recall that simple supergravity is the gauge theory of supersymmetry - the gauge particles being the (helicity ±2) gravitons and (helicity $\pm\frac{3}{2}$) gravitinos. Extended supergravity gauges supersymmetry combined with SO(N) internal symmetry. For N = 8, the (tribal) supergravity multiplet consists of the following SO(8) families.

Helicity	± 2	$\underset{\sim}{1}$
	$\pm\frac{3}{2}$	$\underset{\sim}{8}$
	± 1	$\underset{\sim}{28}$
	$\pm\frac{1}{2}$	$\underset{\sim}{56}$
	0	$\underset{\sim}{70}$.

As is well known, SO(8) is too small to contain $SU(2) \times U(1) \times SU_C(3)$. Thus this tribe has no place for $W^{\pm}$ (though Z^0 and γ are contained) and no place for μ or τ or the t quark.

This was the situation at Tokyo. This year, Cremmer and Julia attempted to write down the N = 8 supergravity Lagrangian explicitly, using an extension of the Kaluza-Klein ansatz which states that extended supergravity (with SO(8) internal symmetry) has the same Lagrangian in 4 space-time dimensions as simple supergravity in (compactified) 11 dimensions. This formal - and rather formidable ansatz - when carried through yielded a most agreeable bonus. The supergravity Lagrangian possesses an unsuspected SU(8) "local" internal symmetry [35] although one started with an internal SO(8) only.

The tantalizing questions which now arise are the following.

1) Could this internal SU(8) be the symmetry group of the 8 preons (3 chromons, 2 flavons, 3 familons) introduced earlier?

2) When SU(8) is gauged, there should be 63 spin-one fields. The supergravity tribe contains only 28 spin-one fundamental objects which are not minimally coupled. Are the 63 fields of SU(8) to be identified with composite gauge fields made up of the 70 spin-zero objects of the form $V^{-1} \partial_\mu V$; Do these composites propagate, in analogy with the well-known recent result in CP^{n-1} theories, where a composite gauge field of this form propagates as a consequence of quantum effects (quantum completion)?

The entire development I have described - the unsuspected extension of SO(8) to SU(8) when extra compactified space-time dimensions are used - and the possible existence and quantum propagation of composite gauge fields - is of such crucial importance for the future prospects of gauge theories that one begins to wonder how much of the linear extrapolation which went into extrapolating $SU(2) \times U(1) \times SU_C(3)$ to the grand unifying gauges is likely to remain unaffected by these new ideas now unfolding.

But where in all this is the possibility to appeal directly to experiment? For grand unified theories, it was the proton decay. What is the analogue for supergravity? Perhaps the spin $\frac{3}{2}$ massive gravitino, picking its mass from a super-Higgs effect provides the answer. Fayet has shown that for a spontaneously broken globally supersymmetric weak theory the introduction of a local gravitational interaction leads to a super-Higgs effect. The gravitino acquires a mass and an effective interaction, but of conventional weak rather than just the gravitational strength - an enhancement by a factor of 10^{34}. One may thus search for the gravitino among the neutral decay modes [36)] of J/ψ. Notwithstanding the enhancement, this will surely tax all the ingenuity of Sam Ting, Burt Richter and their colleagues.

I would like to conclude, as at Tokyo, with a quotation from J.R. Oppenheimer which more than anything else expresses in my view the faith for the future with which this greatest of decades in particle physics ends: "Physics will change even more .... If it is radical and unfamiliar ..... We think that the future will be only more radical and not less, only more strange and not more familiar, and that it will have its own new insights for the inquiring human spirit."

J.R. Oppenheimer
Reith Lectures BBC 1953.

APPENDIX ON GRAND UNIFICATION

Here are stated the results used in the text which relate grand unifying mass, $\sin^2\theta$, and the intermediate symmetry-breaking stages.

In the sequel, I shall assume that $G \xrightarrow{M_1} [SU(2)]^q \times U(1) \times [SU_C(3)]^p \xrightarrow{M_2} SU(2) \times U(1) \times SU_c(3) \xrightarrow{\mu} U(1) \times SU_C(3)$, where p and q are the possible stages referred to in 2) of Subsec. 6.4 correlated for example with family or chiral symmetries. For simplicity, and without much loss of generality, I shall assume that $M_1 \approx M_2 \approx M >> \mu$, so that all fields not contained in $SU(2) \times U(1) \times SU_C(3)$ are very heavy and the parameters p and q make their explicit appearance only through how the physical α_s and α normalize in terms of the grand unifying coupling $\frac{g^2(M)}{4\pi}$.

<u>Theorem</u>

Assume that $G \xrightarrow{M_1} [SU(2)]^q \times U(1) \times [SU_C(3)]^p \xrightarrow{M_2} SU(2) \times U(1) \times SU_C(3) \xrightarrow{\mu} U(1) \times SU_C(3)$ (and assume for simplicity that $M_1 \sim M_2 \sim M$). One finds from Eqs.(B) and (C) of footnote 37

$$\frac{11\alpha}{3\pi} \ln \frac{M}{\mu} = \frac{(\sin^2\theta_0 - \sin^2\theta)}{\cos^2\theta_0} \quad . \tag{1}$$

Using (A) of footnote 37 and (1) above one gets:

$$\sin^2\theta(\mu) = \frac{(3q - 2p) \sin^2\theta_0 + \frac{\alpha}{\alpha_s}(2q) \cos^2\theta_0}{(3q - 2p \sin^2\theta_0)} \quad . \tag{2}$$

From this one deduces that

$$\frac{\sin^2\theta_0 - \sin^2\theta}{\cos^2\theta_0} = \frac{2}{3q-2p} \left(p \sin^2\theta - q \frac{\alpha}{\alpha_s}\right) \quad .$$

(If $M_1 \neq M_2$, the left-hand side of (1) reads $11\alpha/3\pi \ln \left[\left(\frac{M_1}{M_2}\right)^q \frac{M_2}{\mu}\right]$, with similar smooth limit $(M_1 \to M_2)$ changes to (2).)

1) Note the crucial result: If $\sin^2\theta$ is given, $\ln \frac{M}{\mu}$ <u>depends only on $\sin^2\theta_0$</u> (and not explicitly on $\frac{p}{q}$). On the contrary, the expression for $\sin^2\theta$ does depend explicitly on the ratios $\frac{p}{q}$, $\frac{\alpha}{\alpha_s}$ as well as on $\sin^2\theta_0$.

2) For SU(5) and SO(10), $p = 1 = q$ [38], $\sin^2\theta_0 = \frac{3}{8}$ and we obtain [39]

$$\sin^2\theta = \frac{1}{6} + \frac{5}{9}\frac{\alpha}{\alpha_s} \quad \text{and} \quad M = 1.3 \times 10^{13} \text{ GeV}.$$

This value of M is obtained from Eq.(1) if $\sin^2\theta = 0.23$ and $\sin^2\theta_0 = \frac{3}{8}$. It differs from the conventionally stated value of $\approx 10^{15}$ GeV, which is usually derived by substituting $\sin^2\theta = \frac{1}{6} + \frac{5}{9}\frac{\alpha}{\alpha_s}$ into the expression for $\ln\frac{M}{\mu}$. The following remarks are in order:

i) Note the extreme sensitivity of M on the presumed value of $\sin^2\theta$ (the conclusions below depend on $\sin^2\theta \approx 0.23$).

ii) The empirically indicated value of $\sin^2\theta$ is compatible with the SU(5) formula $(\frac{1}{6} + \frac{5}{9}\frac{\alpha}{\alpha_s})$ for an α_s which appears to be small ($\alpha_s \approx 0.07$).

iii) With M as small as 1.3×10^{13} GeV (small compared with 10^{19} GeV of Planck energies), one finds that the proton half-life τ_P as estimated by Marciano [39] is $\approx 6 \times 10^{23}$ years - perhaps already excluded experimentally. (Fifteen isodoublet Higgs [39] are needed to remedy this.)

3) For the semi-simple tribal group $[SU_F(6) \times SU_C(6)]_L \times [SU_F(6) \times SU_C(6)]_R$ (with $p = 2$, $q = 3$) describing six quark flavours [25] and colours, $\sin^2\theta_0 = \frac{9}{28}$. Thus $M \approx 10^6$ GeV and $\sin^2\theta = \frac{5}{24} + \frac{19}{36}\frac{\alpha}{\alpha_s}$ (≈ 0.23 for $\alpha_s \approx 0.18$).

Note the enormous difference between the predicted values for the grand unifying masses (10^6 GeV versus 10^{13} GeV) for the two cases of the "simple" versus the "semi-simple" groups considered. The size of the plateau has considerably shrunk for the latter case. It could shrink still more, with more flavours [40] and colours. (For $[SU(8)]^4$, $M \sim 10^4$ GeV.)

4) For the family groups SU(5) and SO(10), we have noted that a straight descent to $SU(2) \times U(1) \times SU_c(3)$ ($p = q = 1$) gives a small M (for comfort with the proton's life) and too small α_s (≈ 0.07) if $\sin^2\theta \approx 0.23$. Now SU(5) cannot admit any intermediate stages but SO(10) is larger and can, as noted by Georgi and Nanopoulos and Shafi and Wetterich (CERN Th.2667 (1979)). [41]

Could such stages help in resolving the problem of the "large" $\sin^2\theta$ and the "small" M? (Clearly the existence of such stages would mean that the plateau is broken up with peaks of new physics.) To concretize - and simply as an illustration - consider just one stage, i.e. take the simple case [42] of $G \xrightarrow{M} SU(2) \times U(1) \times SU(n) \xrightarrow{M_1} SU(2) \times U(1) \times SU_C(3)$. Formulae (1) and (2) for $\ln\frac{M}{\mu}$ and $\sin^2\theta$ still hold; however p must be replaced by

$$\frac{(3p)}{np(1-z) + 3z} \quad \text{where} \quad z = \ln\left(\frac{M_1}{\mu}\right) \Big/ \ln\left(\frac{M}{\mu}\right) .$$

For SO(10), with $n = 4$ (four colours) and $SU_C(4) \to U_C(1) \times SU_C(3)$, [43] one may indeed secure $\sin^2\theta = 0.23$, for $\alpha_s \approx \frac{1}{7}$, provided $M_1 \sim 10^7$ GeV.

In the preparation of this report I had assistance from: U. Amaldi, G. Altarelli, D. Amati, J. Augustin, E.L. Berger, J.D. Bjorken, S.J. Brodsky, J. Chadwick, M. Conversi, N.S. Craigie, V. Elias, J. Ellis, P. Fayet, S. Ferrara, G. Flügge, H. Fritzsch, S. Fubini, E. Gabathuler, M.K. Gaillard, R. Gatto, I.G. Halliday, J. Iliopoulos, M. Jacob, H.F. Jones, K. Koller, C.H. Llewellyn Smith, L. Maiani, B. Nagel, D.V. Nanopoulos, J. Nilsson, J.C. Pati, D. Perkins, J. Prentki, G. Preparata, S. Rajpoot, C. Rubbia, A. de Rujula, L.M. Sehgal, W.G. Scott, P. Söding, B. Stech, J. Steinberger, P.M. Stevenson, J. Schwarz, D. Storey, B. Tallini, J.G. Taylor, D. Treille, R. Turlay, S. Weinberg, B. Wiik, K. Winter, G. Wolf and A. Zichichi.

FOOTNOTES

1) "The End of Molecular Biology", by A. Sibatani, Trends in Biochemical Sciences, International Union of Biochemistry (Elsevier, North-Holland, 1979), Vol.4, No.7.

2) The situation for atomic physics was summarized by L.M. Barkov who gave $\frac{\langle R_{exp.}\rangle}{R_{theor.}} = 1.07 \pm 0.14$ as the ratio of the Novosibirsk bismuth measurements of atomic parity violation compared with the predictions of $SU(2) \times U(1)$. Into this comparison is folded the atomic theory calculations of Khriplovich <u>et al</u>. for the complicated bismuth atom. Since the Oxford group contest (among other things) this atomic theory, which has gone into Barkov's comparison, the issue of atomic parity violation is a problem for atomic physicists, rather than a problem for particle physics.

3) While on the subject of radiative corrections, it is worth mentioning that Marciano(and independently Goldmann and Ross)have examined the renormalization group corrections to the fine structure constant and find

$$\alpha^{-1}(m_W) = \alpha^{-1}(0) - \frac{80}{3\pi} \approx 128.5 \quad .$$

Here $\alpha(0)$ is the Josephson value, while $\alpha(m_W)$ is the quantity relevant for present low energy neutrino experiments. This 6% correction in α^{-1} reflects itself in the revised mass formulae for m_W and m_Z which, according to Marciano (COO-2232-B-1979) register a surprising 3% increase; surely of some concern tc the running of LEP at the m_Z peak.

$$\left[\begin{array}{ll} m_W \approx \frac{38.53}{\sin\theta} & \\ \left.\begin{array}{l} m_W \approx 77 - 84 \text{ GeV} \\ m_Z \approx 89 - 95 \text{ GeV} \end{array}\right\} & 0.25 \geqslant \sin^2\theta \geqslant 0.21 \end{array}\right] .$$

4) The 26 dimensionless parameters of the standard model are: 3 gauge couplings, 6 quark + 6 leptonic masses (assuming $m_\nu \neq 0$), 4 + 4 mixing angles, m_H, m_W and two "instanton" angles corresponding to non-Abelian SU(2) and $SU_c(3)$.

5) A different, somewhat more economical suggestion to motivate iso-doublet Higgs is the use of dimensional reduction. (I shall have occasion to mention this idea later in the context of extended supergravity.) Start with a gauge theory in 6 dimensions (x_μ , x_5, x_6; μ = 0,1,2,3). Reduce 6 dimensions to 4 in the sense of assuming that all fields are independent of the extra co-ordinates x_5 and x_6. On reducing to 4 dimensions, the 6-component vectorial field (A_μ , A_5, A_6) in 6 dimensions comprises a conventional spin-one gauge field A_μ plus a doublet of spin-zero Higgs fields A_5 and A_6.

For one concretization of these ideas (due to Y. Ne'eman, D. Fairlie, J.G. Taylor and others) embed SU(2) × U(1) into a graded internal symmetry SU(2|1) AND work in 6 dimensions. The combination of higher dimensions and the higher internal symmetry (1) makes an iso-doublet Higgs compulsive, (2) specifies the Higgs-Higgs coupling uniquely as part of the basic gauge coupling, (3) predicts $\sin^2\theta = \frac{1}{4}$ and (4) predicts $m_H = 2m_W$. This is fine; unfortunately, the theory as developed so far is not satisfactory, since to avoid ghosts characteristic of an internal graded SU(2|1), this symmetry must be broken explicitly. The hope however is that a more agreeable version may emerge where the desirable features like a compulsive "gauge" iso-doublet Higgs and $\sin^2\theta = \frac{1}{4}$ may remain, without the undesirability of the explicit symmetry breaking.

6) This statement refers to the sign of the one-loop computation of the analogue of QCD's β function in gravity theory. Since gravity, (on present ideas) is non-renormalizable, higher loops are (as yet) intractable, though they may not long remain so. If gravity is indeed asymptotically free, there may be no initial big bang singularity due to the progressive weakening of the effective Newtonian constant with diminishing radius of the universe.

7) While on the subject of perturbative QCD, I would like to quote a remark made by Res Jost at the Sienna Conference of 1963: "To my mind, the most striking feature of theoretical physics in the last thirty-six years is the fact that not a single new theoretical idea of a fundamental nature has been successful. The notions of relativistic quantum theory, so clearly in need of improvement, have been in every instance stronger than the revolutionary ideas of - as the saying goes - a great "number of highly talented theoretical physicists". We live in a dilapidated house and we seem to be unable to move out. The difference between this house and a prison is hardly noticeable". To Jost's words "relativistic quantum theory" in this quotation I would like to add "perturbative", for surely it is ironic, that in fifty-two years since Dirac's invention of QED, we have no quantum solution for QED (or for QCD) except the perturbative.

8) Note the independence of the F^N's and D^M's from mass ($m \to 0$) singularities ($\ln \frac{\Lambda^2}{m^2}$). These are junked into the primordial (empirical) parton factors f^N, d^M. The parton model factorization survives up to the leading order ($\{F \times D\} \to \{f^N \times d^M\}$) but breaks down in the next to the leading order (i.e. for terms of order $O(\bar{g}^2)$ in the { } brackets). As a rule this non-leading order is large for Drell-Yan processes and may necessitate a different type of resummation of perturbative QCD. Evidence relating to the "non-factorization" in non-leading logs was presented at the conference, This will surely be a major area of progress in the coming year.

9) A dramatic example of the independence of the domains of perturbative QCD and phenomena attributable to confinement has recently been provided by Davis and Elias and Rajpoot. Davis has defined a safe jet variable (to all orders of perturbation theory) which has the remarkable property of measuring charge (including fractional charge) in final states within a phase space "horn". The experimental failure to detect fractional charges must then imply at the very least that "perturbation theory apparently gives no signal of its own failure".

10) If confinement is indeed a non-perturbative dynamical phase (and has no status as an absolute selection rule), the question arises: is it under all circumstances absolutely exact? Using appropriate Higgs, could $SU_C(3)$ be broken spontaneously, with massive gluons, and with confinement only partial, in the sense of an Archimedes effect, i.e. QCD with Higgs may solve in such a way that quarks and gluons may exhibit an effective mass variation; light and

partially confined within an interaction zone; heavy, unconfined and liberated outside it. Practically nothing would need changing in the conventional parton model ideas and in their QCD perturbative renormalization, except for an additional type of "fragmentation" function, describing mass barrier penetration and the probability of finding massive physical quarks and gluons in the final states.

(Even without the heavy non-perturbative theory needed for confinement, one may understand the growth of the running gluon and quark masses as momenta diminish, as a consequence of the renormalization group. The Archimedes effect suggests that this growth is non-perturbatively sharper than logarithmic though not infinite as for full confinement.)

An illustrative mass formula for quarks and gluons exhibiting the Archimedes effect has been suggested by de Rujula, Giles and Jaffe on the basis of a string model of gluonic interactions (mass outside - mass inside) $\propto$ (gluon mass inside)$^{-1}$ times an essentially group-theoretic factor. For zero inside gluon mass (exact $SU_C(3)$) the quark and gluon masses outside are infinite and exact confinement ensues. For inside gluon masses of the order of 20-30 MeV, the outside quark masses could be in excess of several Gev. Bjorken described to the conference a quark model of this variety within a spontaneously broken QCD, to explain the high density hadronic droplets accreting around a liberated fractionally charged quark. (Such droplets are needed in his explanation of the peculiar Centauro events discovered in cosmic rays.)

Such ideas of eventual quark and gluon liberation and the Archimedes effect are unconventional but in view of the lack of any basic understanding of the confinement mechanism, I would like to rephrase for the remembrance of our experimental colleagues what Iliopoulos remarked in another context: "A test of quark-gluon liberation is too important to be left to vagaries of theoretical dogmas".

Earlier than this, Pati et al. had used the Archimedes effect and partial confinement to propose another unconventional version of spontaneously broken QCD. This is the gauge theory of (Han-Nambu) integer-charge quarks and gluons ($Q = Q_{flavour} + Q_{colour}$). Here the excitation of Q_{colour} in lepton-hadron collisions is automatically suppressed by a factor of the type

$$\frac{m^2(q^2)}{|q^2|\ (|q^2| + m^2(q^2))} \quad J_{lepton}\ J_{colour}$$

(compared with the usual factor $\frac{1}{|q^2|} J_{lepton} J_{flavour}$ for flavour-charge interaction with a mass relation of the type $m_{out}^2 \approx c\mu^2 \exp \int_{g(m_{in})}^{g(\mu)} \frac{dx}{\beta(x)}$. (Using dispersion relations for $e^+e^- \to \mu^+\mu^-$, Okun, Voloshin and Zakharov, have attempted to show that in a spontaneously-broken $SU_C(3)$ with integer charges, the gluon mass must be $\leqslant$ 1 GeV. Unfortunately this demonstration takes no account of the ideas of partial confinement and the Archimedes effect associated with the contribution of the intermediate gluonic state in this model, and thus has no bearing on what the (non-perturbative) physical mass of the gluon is.

11) In the context of the parton model, one of the important results presented at the conference concerns the efficacy of anti-quarks relative to quarks - (pions versus protons) producing T; $(\sigma_\pi \to T)/(\sigma_P \to T) \geqslant 30$ (Cern NA3; 200 GeV π^+; $(\sigma \cdot B)_T = 2.10^{-36}$ cm^2). This augurs very well for the prospects for Z^0 and $W^\pm$ production at the $P\bar{P}$ collider as emphasised by Rubbia.

12) The proton charge thus equals the positron's, without further hypotheses.

13) The necessity of requiring asymptotic freedom for the ELECTRONUCLEAR force on its own, for energies beyond Planckian ($m_P \approx 1.2 \times 10^{19}$ GeV) has been questioned by Cabibbo, Maiani, Parisi and Petronzio. They argue that by then gravity would profoundly affect the entire discussion. On this basis, they suggest (working essentially to a one-loop approximation) that the numbers of families below Planck mass must not exceed eight. They also give bounds on the expected Higgs and fermion masses. On the contrary, Oehme and Zimmerman (EFI/79/28) have deduced (from the positivity of the transverse gluon propagator) a lower bound on the number of quark flavours.

14) Ideally one would wish all these mass stages to emerge as radiatively generated multiples of the Planck mass - possibly with magnitudes $\sim \alpha m_P, \alpha^2 m_P, \alpha^3 m_P, \ldots$ or alternatively of magnitudes like $m_P \exp - \frac{c_n}{\alpha}$ (c_n's are constants). The problem of a "natural" generation of such mass hierarchies is another aspect of the unsolved problem of Higgs.

15) Likewise (from the renormalization group equations for the fermion mass ratios) one may hope to deduce the ratios of the physical quark to the lepton masses, the ratios at the grand-unifying M being specified by the Higgs couplings assumed.

16) The topless version of E_6 predicts b-quark decays to charmless quarks (B. Stech, private communication). The observed b-decays involving

charm may thus imperil E_6. (The suggestion of SU(11) as the tribal extension of Georgi and Glashow's simple SU(5) is due to Georgi; the suggestion of E_8 extending Gürsey et al.'s E_6 is due to Achiman and Stech.)

17) These decay modes have been brought into prominence during the last year through an improvement in the renormalization group estimates (for example, of $\alpha^{-1}(m_W)$ - 6% diminution [3] from $\alpha^{-1}(0)$ and a corresponding diminution in the estimates for τ_P which are now typically $\sim 10^{29}$-10^{33} years if unification masses range between 5×10^{14} and 3×10^{15} GeV and $\sin^2\theta$ ranges [3] between 0.210 and 0.20),

18) "Proton decay is too important to be left to theoreticians alone." - Iliopoulos.

19) The one really new feature of this year's work has been the estimation, within the context of grand unification, of baryon excess in the universe - more precisely an estimate of the ratio of the photon number N_γ to the baryon numbers N_B, which is empirically known to be $\approx 10^8$-10^9. The suggestion that baryon excess may be a consequence of baryon-non-conservation plus CP violation was first made by Yoshimura at the Tokyo Conference. The present quantitative estimates (which by and large - more "by" and less "large" - agree with data) were reviewed by Mohapatra for models with supermassive multi-Higgs and lepto-quarks (10^{15} GeV) and "hard" CP violation; as well as for models with low-mass lepto-quarks ($\sim 10^4$-10^5 GeV) and CP violation which is "soft".

20) Yet each man kills the thing he loves
By each let this be heard
Some do it with a bitter look
Some with a flattering word
The coward does it with a kiss
The brave man with a sword.

Oscar Wilde - The Ballad of the Reading Goal.

21) For example, for the Family group SO(10) of Fritzsch, Minkowski and Georgi, there is the possible chain (see Appendix)

$$SO(10) \overset{M}{\rightarrow} SU_L(2) \times SU_R(2) \times SU(4) \overset{M_1}{\rightarrow} SU_L(2) \times SU_R(2) \times U_C(1) \times SU_C(3) \overset{M_2}{\rightarrow} SU_L(2) \times U(1) \times SU_C(3) \overset{\mu}{\rightarrow} U(1) \times SU_C(3).$$

22) According to 't Hooft's theorem, a monopole corresponding to the $SU_L(2)$ gauge symmetry is expected to possess a mass of the order of $\frac{m_W}{\alpha}$. Even if such monopoles are (conveniently) confined, their indirect effects must manifest themselves, if they exist.

23) This is assuming that the concept of "families" which make up a "tribe", makes sense for ultimate grand unification.

24) Similar remarks apply to the U(1) in SU(2) × U(1) × $SU_C(3)$.

25) Even if it is <u>assumed</u> that all fermions are singlets or doublets of SU(2) and singlets or triplets of $SU_C(3)$, there is no reason for $\sin^2\theta_0$ to equal $\frac{3}{8}$. To see this note that with this assumption - which incidentally excludes supersymmetric gauge fermions in the adjoint representations - $\sin^2\theta_0 = (9N_q + 3N_\ell)/(20N_q + 12N_\ell)$, where N_q and N_ℓ are the numbers of quark and lepton doublets, respectively. Only if we make the <u>further</u> assumption that $N_q = N_\ell$, from anomaly cancellation between quarks and leptons, do we recover $\sin^2\theta_0 = \frac{3}{8}$. This assumption however is not compulsive; for example, anomalies cancel if (superheavy) mirror fermions exist, without the need for assuming $N_q = N_\ell$. This is the case for $[SU(2n)]^4$. (The anomalies also automatically cancel for the adjoint representations of the supersymmetric gauge fermions.) Note however that if $[SU(3)]^p \times [SU(2)]^q \times U(1)$ is embedded within a non-Abelian symmetry and the manner of descent specified, one can express $\sin^2\theta_0$ as a function of p and q.

26) The universal urge to extrapolate from what we know to-day and to believe that nothing new can possibly be discovered, is well expressed in the following:

"I come first, My name is Jowett
I am the Master of this College,
Everything that is, I know it
If I don't, it isn't knowledge" -

The Balliol Masque.

27) So long as we work with the concepts of elementary fields and <u>fundamental Lagrangians</u>, it is clear that some day we must hit the level of elementary fermions. Thus it does not dismay me that the succession of flavours and colours (or families) may end. But we cannot really argue about these matters on the basis of one-loop approximations.

I would here like to quote Feynman in a recent interview to the "Omni" magazine: "As long as it looks like the way things are built with wheels within wheels, then you are looking for the innermost wheel - but it might not be that way, in which case you are looking for whatever the hell it is you find!" In the same interview he remarks, "a few years ago I was very sceptical about the gauge theories..... I was expecting mist, and now it looks like ridges and valleys after all".

28) Zero mass neutrinos are the hardest objects to conceive of as composites.

29) Harari was kind enough to send me a pre-copy of his paper. He wondered if I considered his ideas were crazy enough in the sense of Niel Bohr's famous remark. I am afraid I had to express some reservations; from a follower of the world's first great monotheistic religious tradition, I would have appreciated one pre-preon rather than two.

30) I have called this "Post-Planck" physics, assuming that the thrust of the ideas discussed will be felt at and beyond Planck energies (10^{19} GeV). But let us make no mistake - the ideas are quite general and their import might be felt much earlier.

31) The following quotation from Einstein is relevant here. "Experiment alone can decide on truth ...... But how wrong are those theorists who believe theory comes inductively from experiment - and this includes the great Newton with his "Hypotheses Non Fingo"." I believe this is the only place where Einstein departed somewhat from his total veneration for Newton.

32) What is electric charge in this theory? To answer this, one must introduce charged matter - and in the last analysis, fermions. Kaluza and Klein foreshadowed the answer - charge corresponds to the variable conjugate to the fifth dimension - quantized if the fifth dimension curls onto itself. Perhaps the most detailed and elegant working out of this idea is due to Olive and Witten (reported by Olive at the conference). Consider a supersymmetric Georgi-Glashow model in six-dimensional compactified space-time. One can show that all objects in this theory (elementary fields, monopoles, dyons) satisfy a light-like mass relation (exact, including quantum corrections):

$$P_\mu^2 - P_5^2 - P_6^2 = 0 \quad .$$

Here P_5 and P_6 are the momenta conjugate to x_5 and x_6 and one shows by an explicit calculation that $P_5 = m \times$ electric charge, topologically defined $\rightarrow \int \partial_i F_{i0}\, d^3x$ and $P_6 = m \times$ magnetic charge on the particle, defined similarly. Thus by an explicit construction one demonstrates that momenta conjugate to the extra dimensions correspond to (topologically defined) electric and magnetic charges.

33) An attractive suggestion pursued recently by Budini and Rączka ascribes the existence of higher internal symmetries to the Cartan reflections in conformal space (projectively realized in 6 dimensions).

34) The Einstein Lagrangian allows large fluctuations of metric and topology on Planck-length scale. Hawking has surmised that the dominant contributions to the path integral of quantum gravity come from metrics which carry one unit of topology per Planck volume. On account of the intimate connection (de Rham, Atiyah-Singer) of curvature with the measures of space-time topology (Euler number, Pontryagin number) the extended Kaluza-Klein and Wheeler-Hawking points of view may not be so different after all.

An example of the possible relevance of topological ideas is a result of Kiskis, who shows that under certain conditions a space-time with handles would permit global violations of charge. One wonders if this result extends to other (violated) charges (like I-spin, hypercharge,...) and what its significance for the topology of our space-time may then be.

In a very different context, I might mention a recent topological result of Witten. In a Yang-Mills theory, he shows that for a theory with a non-zero "vacuum" angle θ, dyons must carry (possibly fractional or even irrational) electric charges = $\left(n + \frac{\theta}{2\pi}\right) e$. Physics, as we have known it, may be made to stand on its head by an infusion of topology.

35) The full result is this: The Lagrangian in [11]-dimensions possesses an invariance as large as $E_7|_{\text{global}} \times SU(8)|_{\text{local}}$. The analogy is with Weyl's version of Einstein's gravity theory which has the invariance $GL(4,R)|_{\text{global}} \times SO(3,1)|_{\text{local}}$. Now the graviton in Weyl-Einstein theory with its 16 - 6 = 10 components lives in the coset space $\frac{GL(4,R)}{SO(3,1)}$ with its 10 generators. Likewise the coset space $\frac{E_7}{SU(8)}$ with its 133 - 63 = 70 generators can carry 70 spin-zero objects which are the "gravitons" of the internal space. These are just the 70 spin-zero fields in the N = 8 supergravity tribe.

36) Fayet estimates, for a light gravitino, a rate 10^{-5}-10^{-7} to compare with $\Gamma(\psi \to \text{unobserved neutrals}) \approx 7 \times 10^{-3}$ and $\Gamma(\psi \to e^+e^-) = (7 \pm 1) \times 10^{-2}$. He has made the assumption that the (spontaneous) breakdown of supersymmetry occurs at masses $\approx m_W \approx m_p \exp(-c/g^2)$. (There is the alternative proposal of a linear progression from grand unification to extended supergravity which suggests that the characteristic mass for the breakdown of supersymmetries - and for all the unwanted supersymmetric partners of $W^{\pm}$, Z^0, , etc - as well as for the gravitinos - is of the order of Planck mass m_P.)

37) This follows from the standard one-loop renormalization group equations:

$$\alpha_s^{-1}(\mu) = p(4\pi g^{-2}(M)) - 3.\ \frac{11}{6\pi}\ \ln\ \frac{M}{\mu} \qquad \text{(A)}$$

$$\alpha^{-1}(\mu)\ \sin^2\theta(\mu) = q(4\pi g^{-2}(M)) - 2.\ \frac{11}{6\pi}\ \ln\ \frac{M}{\mu} \qquad \text{(B)}$$

$$\alpha^{-1}(\mu)\ \cos^2\theta(\mu) = q(4\pi g^{-2}(M))\ \cot^2\theta_0\ . \qquad \text{(C)}$$

For simplicity we have ignored the effects of the fermionic (and the Higgs) loops on the right-hand side. These are discussed by Marciano [39].

38) These family groups are too small to permit $p, q > 1$. The tribal group SU(11) however may accommodate larger p's and q's.

39) W.J. Marciano (COO-2232-B-173) who gives the same result for $\frac{11\alpha}{3\pi}\ \ln\ \frac{M}{\mu}$, as above, except that the factor 11 is replaced by $\frac{109}{9}$ if one takes fermion and one Higgs loops into account. For N_H Higgs isodoublets, replace 11 by $\frac{110 - N_H}{9}$. Thus for $N_H \sim 15$, $\sin^2\theta \simeq 0.23$ is compatible with $M \approx 10^{15}$-10^{16} GeV. The extreme sensitivity of M on assumptions relating to renormalizations should be stressed once again.

40). For the semi-simple group $[SU(2n)]^4$ describing 2n flavours of quarks (and $4n^2 - 6n$ leptons; the majority possibly superheavy), Elias and Rajpoot give:

$$\sin^2\theta_0 = \frac{3n}{4(3n - 2)}$$

$$\sin^2\theta = \frac{3n-4}{12(n - 1)} + \frac{\alpha}{\alpha_s}\ \frac{9n-8}{18(n - 1)}$$

$$\frac{11\alpha}{\pi}\ (n - 1)\ \ln\frac{M}{\mu} = 1 - (2n - \frac{4}{3})\ \frac{\alpha}{\alpha_s}\ .$$

41) Consider one more example of the introduction of intermediate energy scales - and the plateau-breaking peaks - which may have their location almost anywhere, so far as the internal logic of the symmetry-breaking is concerned. The example is that of the tribal group $SU^I(5) \times SU^{II}(5) \times SU^{III}(5)$ corresponding to the Three Families. Assume each $SU^i(5)$ breaks to $[SU(2) \times U(1) \times SU_C(3)]^i$, i = I, II, III, with mass scales M^i. The final breaking stage corresponds to the emergence of the diagonal sum $[SU(2) \times U(1) \times SU_C(3)]^{I+II+III}$ ($\not\to U(1) \times SU_C(3)$) with the associated scale M. The results of the computations of $\sin^2\theta$ and the unifying masses are:

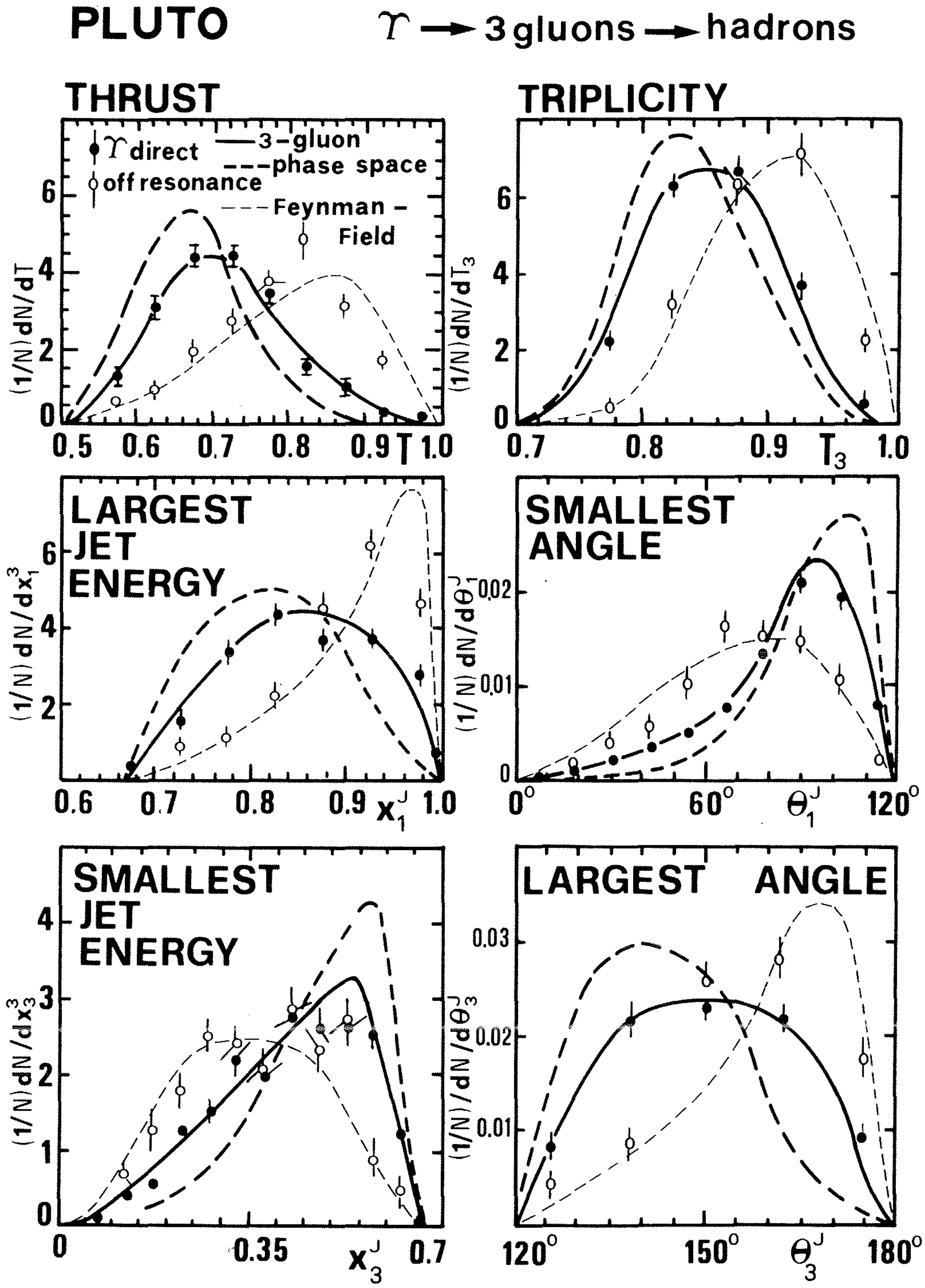
$\sin^2\theta = \frac{1}{6} + \frac{5}{9}\frac{\alpha}{\alpha_s}$ (i.e. the same result as for the Family group SU(5)); and

$$\frac{\alpha_s}{\alpha} = \frac{8}{3}\left[1 - \frac{11\alpha}{\pi}\,\ell n\,\frac{M^I M^{II} M^{III}}{\mu M^2}\right] .$$

For $M^I = M^{II} = M^{III} = M$, we recover the well-known Family SU(5) result. Now M^I may be restricted on account of proton decay, but the restrictions on the locations of M^{II} and M^{III} need not be too stringent. (Elias has conjectured that the ratios of fermionic masses among the three Fermi Families may differ on account of the three differing mass scales M^I, M^{II}, M^{III}. The point is that not till we understand the deeper relationship of the Family and the Tribal groups can we reject such possibilities.)

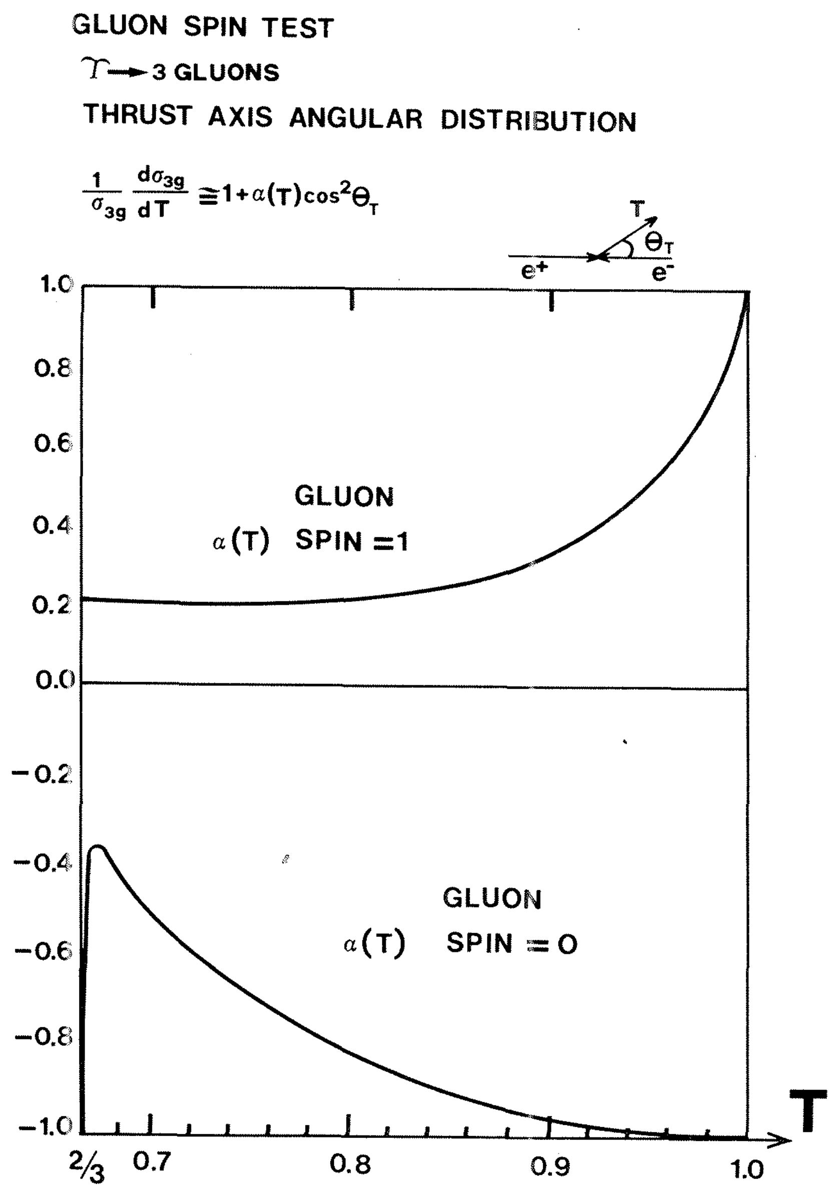
42) This analysis is relevant also if there exist new forces of which we may, at present, have no apprehension – for example the techni-colour forces of Dimopoulos and Susskind, with $G = SU(10) \to SU(2) \times U(1) \times SU(8) \to SU(2) \times U(1) \times SU_C(3) \times SU_{tech}(5)$. (The Higgs needed to break the symmetry this particular way have to be specially chosen.)

43) In Shafi and Wetterich's analysis the intermediate stage is through the breaking of $SU_R(2)$ at around 10^6 GeV, i.e. (V+A) forces make their appearance then. I believe both types of stages may be necessary to shore up $\sin^2\theta$, as well as M and τ_P.



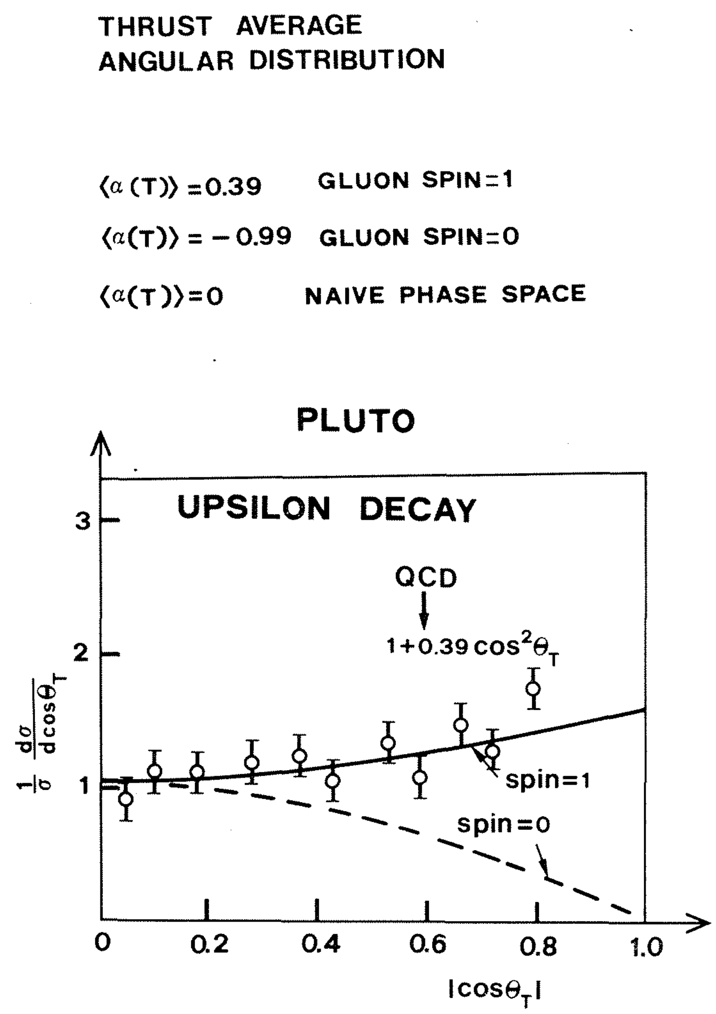
Experimental distributions of thrust T, triplicity T_3 reconstucted gluon energies x_1^J, x_3^J and reconstructed angles θ_1^J, θ_3^J between gluons. compared to Monte-Carlo calculations based on various models

Fig. 1



GLUON SPIN TEST
ϒ → 3 GLUONS
THRUST AXIS ANGULAR DISTRIBUTION
$\frac{1}{\sigma_{3g}} \frac{d\sigma_{3g}}{dT} \cong 1+\alpha(T)\cos^2\Theta_T$
T
Θ_T
e^+
e^-
GLUON
α(T) SPIN =1
GLUON
α(T) SPIN = 0
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
2/3
0.7
0.8
0.9
1.0
T

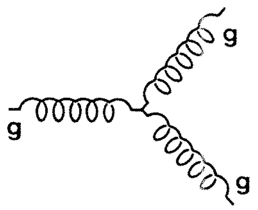
Fig. 2



THRUST AVERAGE
ANGULAR DISTRIBUTION
⟨α(T)⟩ =0.39 GLUON SPIN=1
⟨α(T)⟩ = −0.99 GLUON SPIN=0
⟨α(T)⟩=0 NAIVE PHASE SPACE
PLUTO
UPSILON DECAY
QCD
$1+0.39\cos^2\theta_T$
spin=1
spin=0
$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_T}$
3
2
1
0
0.2
0.4
0.6
0.8
1.0
$|\cos\theta_T|$

Fig. 3

Measuring presence of 3 gluon vertex



M^2 Evolution of Gluon Jets

Fragmentation function Moments

$D_g(n,M^2)$ $n = 2,3,4 \ldots$

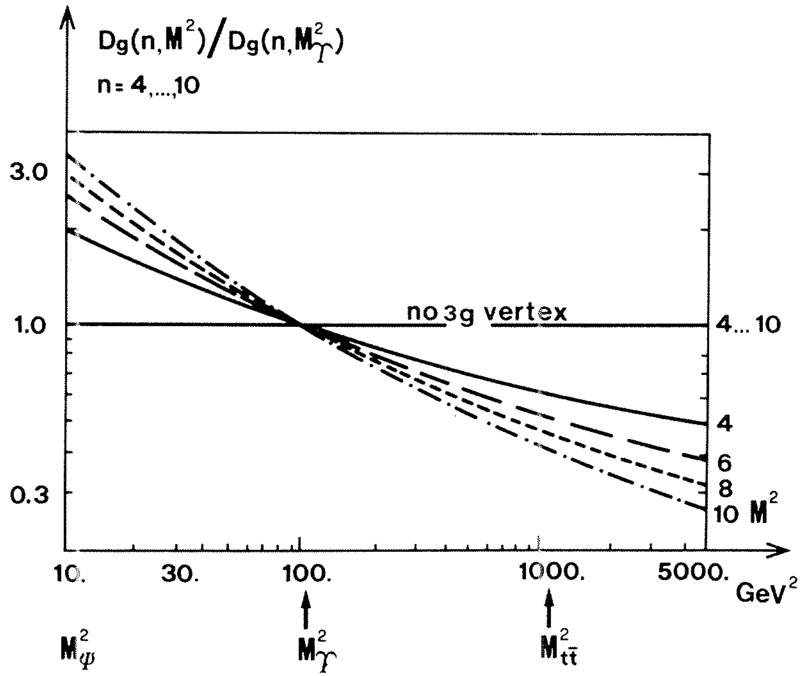
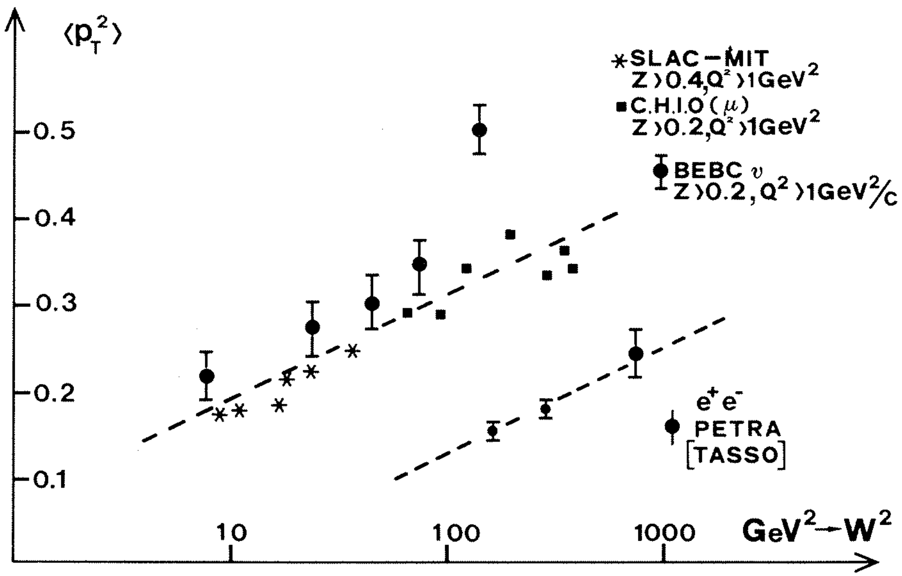


Fig. 4



Variation of $\langle p_T^2 \rangle$ with respect to W^2

Fig. 5

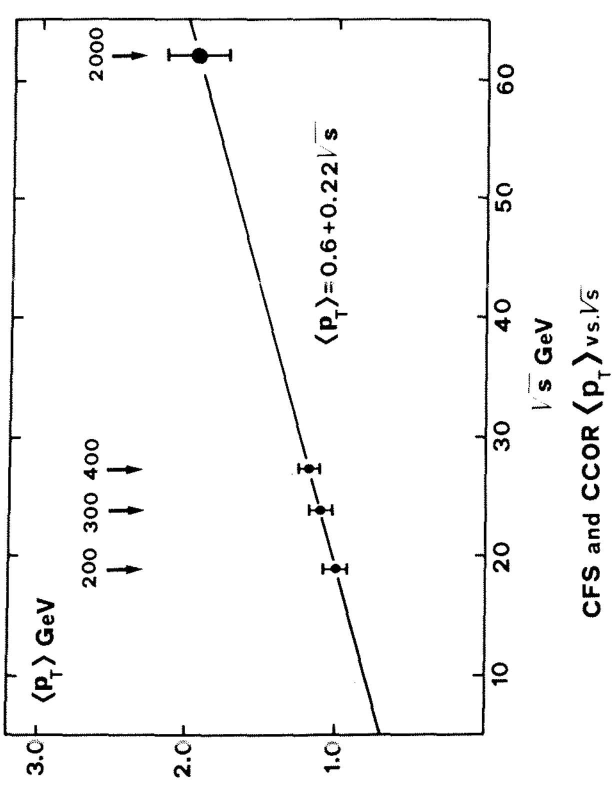

⟨pT⟩ GeV
3.0
2.0
1.0
200 300 400
2000
⟨pT⟩=0.6+0.22√s
10
20
30
40
50
60
√s GeV
CFS and CCOR ⟨pT⟩ vs.√s

Fig. 6

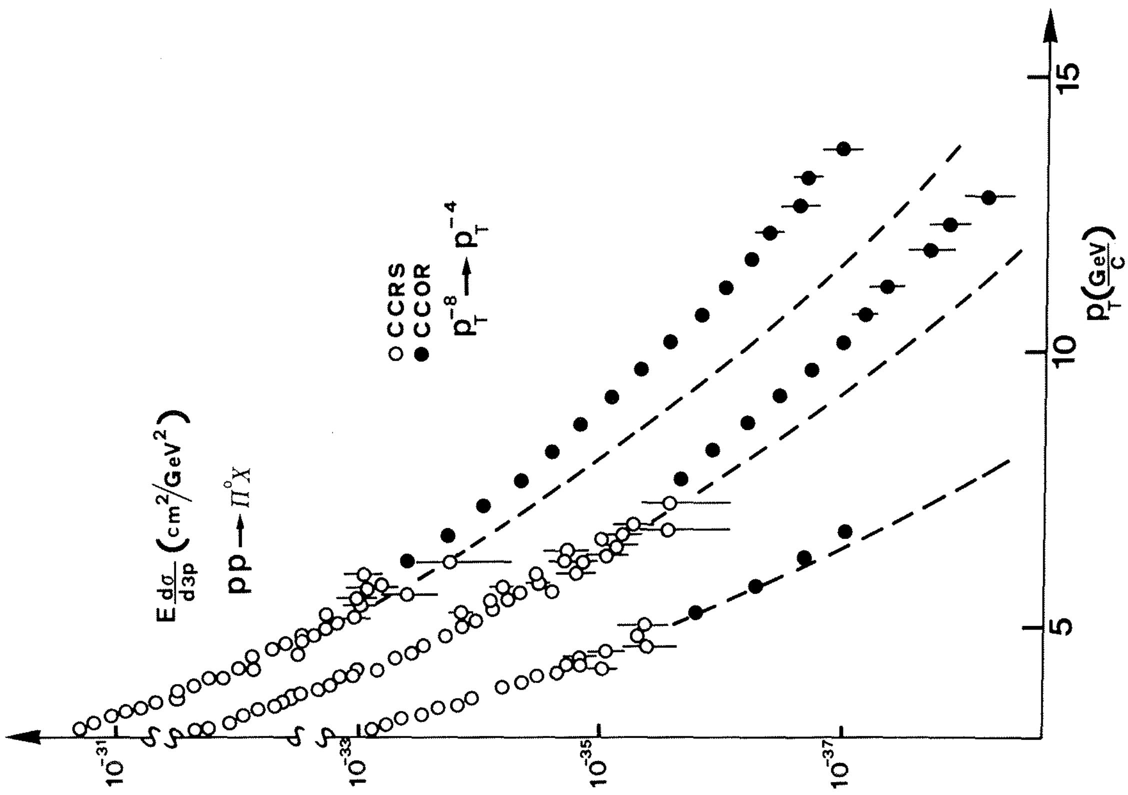

E dσ/d3p (cm²/GeV²)
pp → π°X
○ CCRS
● CCOR
pT⁻⁸ → pT⁻⁴
10⁻³¹
10⁻³³
10⁻³⁵
10⁻³⁷
5
10
15
pT(GeV/c)

Fig. 7