An Asymptotically Free Extension of QCD and ALEPH Four Jet Events

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We show that a recently proposed extension of QCD by the addition of a multiplet of scalars transforming as (2,2,1) under SU(2)_L x SU(2)_R x SU(3)_colour provides a natural and parameter-free explanation for many observed features of the excess 4 jet events reported by ALEPH.

We have recently proposed a theory that is an extension of QCD by the addition of a multiplet of elementary scalars (\(\bar{\sigma}, \bar{\tau}\)) transforming as (2,2) under an SU(2)_L x SU(2)_R and as a singlet under the colour group SU(3) and interacting only with quarks. We showed that such a theory could have an asymptotically free (AF) phase, where all couplings including the yukawa and scalar self couplings are AF, if the initial value of the the ratio of the yukawa coupling, \(g_y\), and the QCD coupling, \(g_3\), was smaller than a critical value \([3]\).

A version of this theory with the chiral scalars having light masses had all the properties of conventional QCD and in fact only the high-precision Z- width data could favour QCD over this theory \([3]\).

The other possible version of this theory where chiral symmetry is manifest in the scalar sector, and the scalar mass is \(\geq 45\) Gev is without any conflict with known data.

In such a theory, a distinctive signal will be the appearance of an excess of four jet events in \(e^+e^-\) collisions over what is to be expected from the standard model. Such four jet signals arise as the massive scalars eventually decay into \(qq\) pairs.

Recently, the ALEPH collaboration \([3]\) has reported seeing such an excess of four jet events in \(e^+e^-\) collisions at \(\sqrt{s} = 130,136,161\) and 172 Gev respectively. It was reported that there was a preponderance of light flavours in the jets and also no associated leptons were reported. Both these features are significant because extensions of the standard model available in the literature like ‘two Higgs Doublet models’ (THDM), and supersymmetric extensions like SSM, MSSM etc generically predict dominant branching ratios for heavy flavours as well as associated leptons.

In contrast, our model requires more or less uniform coupling to all flavours if significant flavour changing neutral currents are to be avoided, and naturally avoids events with associated leptons.

At the same time none of the precision tests of the standard model including the so called oblique parameters S,T&U or the branching ratio of Z into \(bb\) are in conflict with our model. In this letter we present the salient features of our model and discuss the ALEPH four jet events in its light.

The Model: our model is described by the lagrangean

\[
\mathcal{L} = \mathcal{L}_{QCD} - \frac{1}{2} [(\partial_\mu \bar{\sigma})^2 + (\partial_\mu \bar{\tau})^2] - \lambda (\bar{\sigma}^2 + \bar{\tau}^2)
\]

\[
- \bar{\Psi}_q [g_y (\bar{\sigma} + i\gamma_5 \bar{\tau} \cdot \vec{\pi})] \Psi_q + \frac{M^2}{2} (\bar{\sigma}^2 + \bar{\tau}^2)
\]

(1)

\(g_y\), and \(\lambda\) are the Yukawa, and scalar self-couplings respectively. \(\bar{\Psi}_q\) is the quark field.

A model described by eqn(1) automatically implies that the chiral multiplet to the electroweak gauge bosons. Representing the chiral multiplet as a complex doublet \(\Phi^c\) transforming as \((2,2)\) under an \(SU(2)_L\) and interacting only with quarks. We showed that such a theory could have an asymptotically free (AF) phase, where all couplings including the yukawa and scalar self couplings are AF, if the initial value of the the ratio of the yukawa coupling, \(g_y\), and the QCD coupling, \(g_3\), was smaller than a critical value \([3]\).

A version of this theory with the chiral scalars having light masses had all the properties of conventional QCD and in fact only the high-precision Z- width data could favour QCD over this theory \([3]\).

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In contrast, our model requires more or less uniform coupling to all flavours if significant flavour changing neutral currents are to be avoided, and naturally avoids events with associated leptons.

The RNG Flows: the \(\beta\) function for the QCD coupling, \(\alpha_s = g_3^2\), is unchanged at one loop level. The yukawa coupling \(g_y\) has the following one-loop \(\beta\) function (assuming 3 colours, 6 flavours and ignoring the contributions from the standard model gauge couplings)

\[
\frac{\partial g_y^2}{\partial \ell} = \frac{g_y^2}{8\pi^2} [36g_y^2 - 8\alpha_s]
\]

(4)

The chiral multiplet couples to all generations of quarks.

The detailed analysis of these flow equations will be presented elsewhere \([3]\). The result relevant to us here
is that there is a regime $0 < \rho < 1/36$ (here $\rho = g_\sigma^2/\alpha_s$) where $g_\sigma$ is asymptotically free with the deep asymptotic behaviour $g_\sigma^2 \sim K_\alpha^{8/7}$. This means that $g_\sigma^2$ vanishes faster than $\alpha_s$. Therefore, the leading behaviour of this theory in the ultraviolet is given by the QCD coupling with the yukawa coupling contributing only in sub-leading order. There is a whole family of solutions corresponding to different $K$’s.

The above analysis is valid for $q^2 \geq m_\ell^2$. For the region $m_\ell \leq q \leq m_t$, one has: $\rho_c = 1/108, \rho \sim K\alpha^{1/3}$. For $N_F \leq 4$, eqn(4) has no AF solution. Inclusion of contributions due to the standard model gauge couplings, however, improves the situation in that $\rho_c$ is increased and AF persists for all values of $N_F$ [3]. The self-coupling $\lambda$ also admits AF flows.

Thus we have classes of theories that are not only asymptotically free in all their couplings, but become increasingly indistinguishable from QCD at high energies.

As far as AF is concerned one loop analysis is stable against higher loop corrections [6]. Since these classes of theories are AF with chiral symmetry, they are all candidates for a consistent theory of strong interactions.

In order to apply these results to energy scales of practical interest, threshold effects associated with masses of particles. One expects the additional interactions to produce particles. One expects the additional interactions to produce particles. One expects the additional interactions to produce particles. The detailed analysis of the FCNC is the Dirac field in the gauge - eigenstate basis, one must have

$$L_{yukawa} = F_{AB} \bar{\Psi}_A (\bar{\sigma} + i\gamma_5 \vec{\tau} \cdot \vec{\sigma}) \Psi_B$$

Here $\Psi_A'$ is the Dirac field in the gauge - eigenstate basis. There are potential FCNC terms even at tree level in eqn(5) but the mass degeneracy of $\bar{\sigma}$ and $\bar{\sigma}^0$ leads to a complete cancellation. This is true both for $\Delta F = 2$ and $\Delta F = 1$ processes. This cancellation persists even for the one-loop contributions. This is unlike the situation in generic two Higgs doublet models where the couplings have to be fine-tuned to keep tree-level FCNC under control. In such models, the analogs of $\bar{\sigma}$ and $\bar{\sigma}^0$ are not mass-degenerate. The detailed analysis of the FCNC problem will be presented elsewhere [3]. Here we shall only quote the main result: F must be a multiple of unit matrix and the interaction in the mass-eigenstate basis is given by

$$L_{yukawa} = g_y [\bar{p}_L W^a_d (\bar{\sigma} + i\gamma_5 \vec{\tau} \cdot \vec{\sigma}) + \bar{n}_L W^a_d (\bar{\sigma} - i\gamma_5 \vec{\tau} \cdot \vec{\sigma})]$$

$$+ i\bar{\pi} \bar{n}_L V_{CKM} W^a_d p_R + i\bar{\pi} \bar{\pi} \bar{n}_L V_{CKM} W^a_d n_R$$

where $W^{1,2}_d$ are diagonal unitary matrices and $V_{CKM}$ the CKM-matrix.

In the absence of spontaneous symmetry breaking of $SU(2)_L \times U(1)$ and the limit of no $U(1)$-coupling, our solution enhances the symmetry in the quark sector from $SU(2)_L \times SU(2)_R$ to $SU(3)_{\text{hor}} \times SU(2)_L \times SU(2)_R$ and hence does not amount to fine-tuning. Minimal CP-nonconservation can be achieved by taking $W^{1,2}_d$ to be unit matrices, in which case the CKM matrix again governs the entire CP-violation in this model too.

**Unitarity Constraints:** one of the key properties of the standard model is the unitarity of all scattering amplitudes. The standard model Higgs kills the bad high-energy behaviour of processes like $W W \rightarrow WW$ and $WW \rightarrow f f$ where $f$ is any fermion. Introduction of new bosons into the theory that couple to fermions and gauge bosons should not spoil this. The necessary and sufficient conditions for this are [9]

$$\Sigma_i g_{h_i VV}^2 = g_{h VV}^2$$

$$\Sigma_i g_{h_i VV} \cdot g_{h_i f j} = g_{h VV} \cdot g_{h f j}$$

where $h$ is the standard model Higgs and $h_i^0$ are all the neutral scalar fields of the theory including the analog of $h$. In our theory, since there is no spontaneous symmetry breaking in the chiral - multiplet sector, no $\chi VV$ coupling is introduced and the above conditions are trivially satisfied.

**Other Precision Tests for the Model:** the coupling of the chiral multiplet to the electroweak bosons leads to additional contributions to various processes of the electroweak theory. One of the sensitive tests for QCD is the value of the R-parameter. As the cross-section for the pair production of the scalars at LEP energies is of the order of a 1 pb, the R-parameter is not very sensitive to the presence of the scalars. The other important precision test is the $g$-2 for muons. There are two types of additional contributions to $g$-2 that arise. One is due to the enhanced ultraviolet degrees of freedom and the other due to additional hadronic interactions. The contributions due to the former arise out of the modification of the photon propagation function. The analytic result is $\Delta g = \frac{\alpha}{2\pi} \frac{m_\gamma}{188\pi m_\gamma^2}$ For $m_\gamma = 45 GeV$ this amounts to $\Delta g = 4 \cdot 10^{-14}$ and hence insignificant. The shift due to the modification of hadronic interactions is much harder to estimate precisely. One should expect very little difference between QCD and the extended theories here because of the expected decoupling of massive particles. One expects the additional interactions to produce...
changes in g-2 at the level of not more than \( \frac{\sigma}{\sqrt{\sigma}} \) times the dominant hadronic contributions. This amounts to less than 2 parts in 1000 of the dominant hadronic contributions and is hence much less than the known theoretical uncertainties in g-2.

The so called oblique parameters \( \tilde{S}, \tilde{T}, \tilde{U} \) (see for example [1]) can also be used as precision tests for our model. We skip the details of their calculations which are presented elsewhere [11] and give here the corrections to these parameters:

| Scalar Mass (GeV) | \( \delta \tilde{T} \) | \( \delta \tilde{S} \) | \( \delta \tilde{U} \) |
|------------------|----------------|----------------|----------------|
| 50               | -0.010        | -0.027         | 0.005          |
| 55               | -0.005        | -0.018         | 0.002          |
| 60               | -0.003        | -0.013         | 0.001          |

These corrections are much smaller than the uncertainties in even the most precise LEP measurements [3].

The Aleph Experiment: the ALEPH collaboration has recently reported seeing an excess of four jet events in \( e^+e^- \) -collisions at LEP. At \( \sqrt{s} = 130 \) and 136 GeV they had reported seeing 16 four jet events (after imposing various cuts; for details see [3]) while only 8.6 events were expected from the standard model. The sum of the di-jet masses was observed to peak around 105 GeV, while the difference in dijet masses peaked at low values but not exactly at zero. Subsequently, the initial runs carried out at \( \sqrt{s} = 161 \) GeV with an integrated luminosity of about 2.5 pb\(^{-1}\) failed to confirm the excess seen earlier. The status of the runs at \( \sqrt{s} = 161 \) GeV with increased data collection (10 pb\(^{-1}\)) was that while the excess could not be confirmed, it could not be ruled out either [11].

After completing some preliminary runs at \( \sqrt{s} = 172 \) GeV with roughly 7 pb\(^{-1}\) of data, the ALEPH collaboration has confirmed seeing the excess of four jet events again [11]. They report 18 events as against 3 expected, with the di-jet mass sum peaking at 106 GeV, not very different from what was seen at 130-136 GeV.

The initial runs with \( \sqrt{s} = 130 \) and 136 GeV with an integrated luminosity of \( \sim 5.7 \) pb\(^{-1}\) corresponded to a cross-section of 3.1 \( \pm 1.7 \) pb [3] with certain assumptions regarding efficiencies. The integrated data 130/172 GeV yields a somewhat smaller cross-section of 2.5 \( \pm 0.7 \) pb under the same assumptions about efficiencies, while the higher energy runs 161/172 GeV yield 1.5 \( \pm 0.8 \) pb [11].

The dijet mass sum peaked at 103-109 GeV with a resolution 1.6-9 GeV [3]. The global fit including the higher energy runs yields the peak at 106.1 \( \pm 0.8 \) GeV with a resolution of 2.1 \( \pm 0.4 \) GeV [11]. For the initial runs at 130,136 GeV the following additional features were reported [3]: a) no lepton with high transverse momentum wrt its jet was found. b) only 1 out of the 12 peak events could be identified as having at least 2 b(\( \bar{b} \)) jets c) no event can be identified as having all four b(\( \bar{b} \)) jets d) the number of \( K_0^* \) found was compatible with a normal flavour mixture of four-jet events and e) no events of the type \( \tau^+ \nu_\tau \bar{c}s \) and \( \tau^+ \nu_\tau \tau^- \bar{\nu}_\tau \) were found.

In our model the excess events are identified with the decay products of the scalars which have no couplings to the leptons naturally explaining the points a) and e). The following table gives in pb the cross-sections obtained from the higher energy runs are quite significantly higher than what our model predicts, the cross-sections obtained from the higher energy runs are quite consistent with our values. Considering that detector efficiencies further reduce the expected number of events, our \( R_{2b} \) and \( R_{4b} \) reproduce the observed features b) and c) reasonably well. As far as \( \bar{q}s\bar{s}e \) is concerned, more work is needed before we can confront d) with our model.

| \( \sqrt{s} \) (GeV) | \( M_\bar{s} \) | \( \sigma_{\text{neut}} \) | \( \sigma_{\text{char}} \) | \( R_{2b} \) | \( R_{4b} \) |
|-------------------|---------------|----------------|--------------|-------------|-------------|
| 130               | 50            | 0.63           | 0.54         | 1/5         | 1/46        |
| 130               | 55            | 0.37           | 0.31         | 1/5         | 1/46        |
| 130               | 60            | 0.14           | 0.12         | 1/5         | 1/46        |
| 161               | 50            | 0.43           | 0.57         | 2/13        | 1/58        |
| 161               | 55            | 0.35           | 0.46         | 2/13        | 1/58        |
| 161               | 60            | 0.27           | 0.35         | 2/13        | 1/58        |
| 172               | 50            | 0.38           | 0.55         | 1/7         | 1/61        |
| 172               | 55            | 0.32           | 0.46         | 1/7         | 1/61        |
| 172               | 60            | 0.26           | 0.37         | 1/7         | 1/61        |

While the quoted cross-section for the initial runs is significantly higher than what our model predicts, the cross-sections obtained from the higher energy runs are quite consistent with our values. Considering that detector efficiencies further reduce the expected number of events, our \( R_{2b} \) and \( R_{4b} \) reproduce the observed features b) and c) reasonably well. As far as \( \bar{q}s\bar{s}e \) is concerned, more work is needed before we can confront d) with our model.

Another concept measured for the initial runs was the rapidity weighted charge separation, \((\Delta Q)^y\) : the result quoted is 0.64 \( \pm 0.09 \) while standard processes give 0.38 for \( u\bar{u}u\bar{u} \) and 0.38 for \( q\bar{q}g\bar{g} \). A crude estimate for this quantity can be made for our model using Table 6 of [3] which gives 0.48.

The Gaussian fit to the data in [11] gives a width of 1.5-2.5 GeV for the dijet mass-sum distribution. At this stage it is not clear how much of this can be attributed to the natural width of the scalars. In our model \( \Gamma_{\bar{q}q}^s = \frac{\alpha^2}{4\pi} \frac{3M_s}{2} \) and \( \Gamma_{\bar{q}q}^{\bar{s}\bar{s}} = \frac{\alpha^2}{4\pi} 3M_\bar{s} \). At \( \rho = 1/36 \), the former amounts to about 0.375 GeV/ flavour, and with a top mass of 170 GeV, only five flavours contribute to the decay of neutrals, leading to a width of about 1.88 GeV. Likewise, the latter works out to 0.75 GeV/generation, and the width of charged scalars is about 1.5 GeV.


While all these features are consistent with our model, the experiment seems to indicate that the invariant masses of the dijets to be different while our theory predicts them to be degenerate. Also it was claimed that angular distributions do not favour colour singlet scalars. In our theory the dijets are colour singlet scalar or pseudoscalar.

Other explanations: soon after the ALEPH reports a number of papers have appeared proposing supersymmetric candidates for the excess events. It is not possible to give a detailed comparison between these proposals and ours but some generic remarks can be made about these proposals. The negative outcome of the direct searches for SUSY particles rules out many of these explanations except the ones invoking R-parity violation. But most such models predict more than 4 jets, leptons in final states besides requiring fine tuning to keep the FCNC problem as well as the limits on proton decay under control. We shall present a detailed comparison of these proposals elsewhere but merely outline such a comparison in Table 1.

We therefore feel that the scenario presented here is quite promising. It also has many striking predictions for $e^- e^+, e^- p$ as well as $p\bar{p}$ collisions which will be elaborated elsewhere. With ALEPH hoping to collect 100 $pb^{-1}$ of data at 172 GeV, we can look forward to a vindication of the model presented here.

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**TABLE I. COMPARISON**

| Additional Particles | Charginos, Squarks | $H A, H^+ H^-$ | $\tilde{\sigma}, \tilde{\pi}$ |
|----------------------|-------------------|----------------|------------------|
| Two Higgs | $2$ Yukawa, $5$ Self | $1$ Yukawa, $2$ Self |
| Our Model | $\sigma_{\text{tot}}$ $(pb)$ | $\sim 1$ | $\sim 1.17$ |
| Experiment | $(\text{Lower } \sqrt{s})$ | $\sim 1.5 \pm 0.7$ |
| | $(\text{Higher } \sqrt{s})$ | $\sim 1.5 \pm 0.8$ |
| Width Of Mass Dist | Large | Depends on Yukawa coupling | $1$ to $2$ Gev |
| Final State | Expected | Expected | No leptons |
| Leptons | | | No leptons |
| $R_{4b}$ | Expected | Predominant | $1/5-1/7$ with $100\%$ eff |
| | | | $1/12$ |
| $R_{4b}$ | Expected | Predominant | $1/45-1/63$ |
| | | | none seen |
| FCNC | Fine tuning | Fine Tuning | Naturally fulfilled |
| | | | Demanded |

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[1] V. Soni, Mod. Phys. Lett. A Vol.11No.4,331(1996).
[2] N.D. Hari Dass and V Soni. Quantum Chromodynamics and the Z-width, IMSc preprint.
[3] The ALEPH Collaboration, Zeitsschrift für Physik C71(1996) 179
[4] N.D. Hari Dass and V. Soni. Asymptotically Free Alternatives to QCD, IMSc preprint.
[5] V. Soni and N.D. Hari Dass. RNG analysis of chirally extended QCD with electroweak couplings. IMSc preprint.
[6] S. Coleman and D. J. Gross, Phys. Rev. Lett. 31,851(1973).
[7] N. D. Hari Dass and V. Soni, FCNC in chirally extended QCD, IMSc preprint
[8] "The Higgs Hunter’s Guide", J.F. Gunion et al, Addison Wesley, 1990, p 194
[9] K. Hagiwara, Implications of Precision Electroweak Data, KEK-TH-461
[10] N.D. Hari Dass and Rahul Sinha, Electroweak Precision tests for chirally extended QCD, IMSc preprint
[11] F. Ragusa, Status Report before LEP Council, 19 November 1996
[12] G.R. Farrar, hep-ph 9512306, D.K. Ghosh et al. hep-ph/9605461, D. Choudhary et al. hep-ph/9608264, P.H. Chankowski et al. hep-ph/9606415, A.K. Grant et al. hep-ph/9601392 and many more.