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Excess Cross-Sections at the Electroweak Scale in the Sextet Quark "Standard Model" *

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Abstract

If dynamical electroweak symmetry breaking is due to a flavor doublet of color sextet quarks, enhanced electroweak scale QCD instanton interactions may produce a large top mass, raise the η_6 axion mass, and also explain the excesses in the DIS cross-section at HERA and jet cross-sections at the Tevatron.

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DISCLAIMER

1. INTRODUCTION

It is possible that the large x and Q^2 events seen at HERA are simply an excess in the cross-section compared to the standard model prediction. Since the scales are similar, the same physics could also be responsible for the large E_T excess in the jet cross-section observed by CDF at the Tevatron. If this is the case, these phenomena could be a crucial pointer towards improvement of the Standard Model. In this talk[‡] I will describe the "sextet quark model" (SQM) obtained by replacing the Higgs sector of the Standard Model with a flavor doublet of color sextet quarks. In this model both QCD and the electroweak interaction are modified above the electroweak scale, and a number of phenomena are inter-related. In particular enhanced instanton interactions are important for electroweak-scale CP violation, the axion mass, the top mass and new, *chirality violating*, light quark interactions.

2. ELECTROWEAK SYMMETRY BREAKING

We add to the Standard Model (with no scalar Higgs sector), a massless flavor doublet $Q \equiv (U, D)$ of color sextet quarks with the *usual quark quantum numbers*, except that the role of quarks and antiquarks is interchanged. (To cancel the $SU(2) \otimes U(1)$ anomaly other fermions with electroweak quantum numbers must also be added.) We expect that the axial part of the $U(2) \otimes U(2)$ chiral flavor symmetry breaks spontaneously and produces four massless pseudoscalar mesons - π_6^+, π_6^-, π_6^0 and η_6. Since the pseudoscalars couple longitudinally to the sextet axial currents, the usual technicolor mechanism leads to the π_6^+, π_6^- and π_6^0 becoming, respectively, the third components of the W^+, W^- and Z^0, with $M_W \sim g\ F_{\pi_6}$, where F_{π_6} is the sextet QCD chiral scale. The "Casimir Scaling" rule $C_6\alpha_s(F_{\pi_6}^2) \sim C_3\alpha_s(F_\pi^2)$ (with $C_6/C_3 = 5/2$) is clearly consistent with $F_{\pi_6} \sim 250$ GeV ! Asymptotic freedom allows only one sextet doublet and so $\rho = M_W^2/M_Z^2 cos^2\theta_W = 1$, as required by experiment.

3. THE η_6 AND CP VIOLATION

The η_6 couples to the QCD color anomaly, and is *an axion*. In conventional QCD, instanton interactions give only a very small indirect contribution to the axion mass. As we discuss below, within the SQM instanton interactions are strongly enhanced above the electroweak scale. Adding instanton and anti-instanton interactions produces factors of $\cos[\tilde{\theta} + \langle\eta_6\rangle]$ so that the axion potential generated naturally

‡See hep-ph/9704248 for a fuller account, together with a full set of references.

retains the CP-conserving minimum at $\tilde{\theta} + \langle \eta_6 \rangle = 0$ while simultaneously producing a large contribution to the η_6 mass.

Above the electroweak scale, we can not write a lagrangian involving both the η_6 and the gluon field to describe general sextet quark interactions. We must use the full QCD lagrangian, which clearly has no axion. Hence QCD interactions above the electroweak scale will naturally be *Strong CP-violating.* The triplet quark mesons will contain a small admixture of sextet quark states which will provide CP violating interactions. Therefore *electroweak scale CP-violation may actually be "Strong CP-violation" within the SQM.*

4. THE QCD β-FUNCTION AND WALKING COLOR

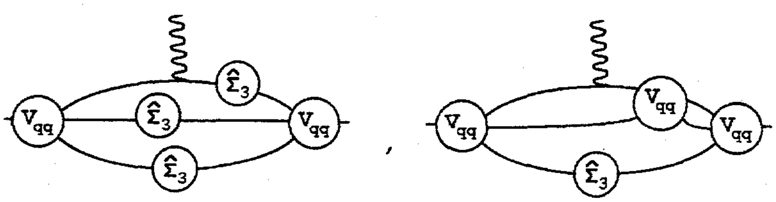
Adding two sextet flavors, the QCD β-function has an infra-red fixed point at $\alpha_s \approx 1/34$. Between the ultra-violet and infra-red fixed points $\beta(\alpha_s)$ remains very small ($< 10^{-6}$). As a result, α_s will dramatically stop it's conventional evolution at some scale and will then evolve extremely slowly. (It is possible that α_s can be defined via jet cross-sections in such a way that the evolution stops just above the electroweak scale, and so effectively explains the CDF excess.) When $\beta(\alpha_s)$ is approximated as a small constant, the linearized Dyson-Schwinger equation has a solution for the dynamical (sextet) mass of the form $\Sigma(p) \sim \mu^2 \, (p)^{-1}$. When this behavior is inserted into the perturbative formula for the high-momentum component of the sextet condensate $\left\langle Q\bar{Q} \right\rangle$, there is a strong enhancement. There is no corresponding enhancement of the chiral constant.

5. ENHANCED INSTANTON INTERACTIONS

Because of the infra-red fixed-point, QCD instanton interactions have no infra-red divergences in the massless SQM. In the ("physical") massive SQM these interactions provide all of the non-perturbative physics down to the electroweak scale. The extremely slow evolution of α_s implies that there is almost no short-distance cut-off for such interactions.

The large sextet Casimir leads to a surprizingly high-order one instanton interaction. The one instanton zero modes produce an interaction which involves one quark/antiquark pair of each triplet flavor and five pairs of each sextet flavor. If we close-up sextet lines pairwise with the sextet condensate, we obtain the usual QCD triplet interaction - enhanced by a factor of $\left\langle Q\bar{Q} \right\rangle^{10}$. The resulting (electroweak scale) contribution to the triplet quark mass matrix is $\Sigma_3 \sim det\ m_3^0 \, [m_3^0]^{-1} \equiv \prod_{j \neq i} m_j^0$, effectively inverting the "bare" mass matrix m_3^0. If we make the (extremely oversimplifying) assumption that the single instanton interaction represents the dynamical effects of instantons between an upper (cut-off) scale and the electroweak scale, the electroweak scale top quark mass can be explained as a consequence of an anomalously small bare mass. In addition, above the electroweak scale, *the light quark dynamical masses will become comparable to that of the top quark mass.*

There are also four-quark interactions (Vqq) involving pairs of quarks with distinct flavors. The largest interactions will involve the top quark, if indeed it has the smallest bare mass. Chirality non-conserving light quark couplings to a gauge field are obtained from "higher-order" interactions of the form



For such interactions chirality-violating and chirality-conserving amplitudes should be comparable in order of magnitude.

Since the bare triplet quark masses badly break the relevant U(1) symmetry, a large η_6 mass arises straightforwardly from sextet instanton interactions. A very crude estimate gives a mass close to, or not too far below, the electroweak scale. The η_6 will be produced in association with the W or the Z and could decay predominantly into $b\bar{b}$ states. (This could lead to confusion with the standard model Higgs experimently.)

6. EXCESS CROSS-SECTIONS

At HERA the excess cross-section appears for $x \gtrsim 0.5 \leftrightarrow xP \gtrsim 400\ GeV$ and $Q \gtrsim 150\ GeV$ and so is kinematically just where we expect the new instanton vertices to contribute. Similarly, the CDF jet excess is for $E_T \gtrsim 200\ GeV$. At lowest order in the instanton interaction, only the light quark dynamical mass terms contribute in both cases. Although we expect higher-order and multi-instanton interactions to be essential quantitatively, the dynamical masses give some qualitative idea of the properties to be expected. In particular dynamical masses give -

* additional helicity-flip quark final states
* quark jet cross-sections increase with the jet mass
* jet angular distributions are unchanged
* quark parton distributions are enhanced at large x
* the presence of gluon initial and final states at the Tevatron implies effects of the new interactions will be less dramatic than at HERA.