NEW PHYSICS IN HADRONIC DIFFRACTION

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ABSTRACT

We suggest that a short-lived axion-like η_6 of mass $30\,GeV$, with two photons as a major decay mode, should be produced diffractively at hadron colliders. This causes a genuine physical threshold around $\sqrt{s} = 500\,GeV$, which enables us to explain all high energy elastic scattering data, diffractive cosmic-ray exotics and hadronic photon events. New physics involving the new particle η_6 as well as other observable effects are also discussed.

1 - Introduction

The idea of dynamical symmetry breaking of the electroweak gauge symmetry is to effectively provide the role of the Higgs sector by a dynamical bound-state of some fundamental fermions. In the usual technicolor models[1], dynamical bound-states are formed by some fundamental techniquarks that have an extra-strong technicolor interaction. Another possibility[2] is to form dynamical condensates of some hyper-quarks belonging to a higher-color representation of the ordinary color group SU(3). The latter scheme is not only simpler but also attractive because the ordinary QCD is also responsible for the electroweak symmetry breaking. The color–exotic hyper-quarks can have a dramatic effect on the β-function in the renormalization equation and chiral symmetry breaking can occur at around 1 TeV scale. Because of asymptotic freedom in QCD, the simplest extension [3] beyond the six flavors of the ordinary color–triplet quarks is to assume a doublet of color–sextet quarks. In other words, the color sextet quarks play the role of technicolor fermions and the electroweak scale is a QCD scale of dynamical condensation which generates masses for the $W^{\pm}$ and Z^0 and also for the color–triplet quarks and leptons. We then expect a host of electroweak-strong unification effects not too far above the condensation scale. A flavor doublet of color–sextet quarks $Q_6 = (U, D)$ would produce new "hadrons" containing sextet quarks such as new pseudoscalar mesons, vector mesons, baryons and their antiparticles. In addition, because of a new component in the color anomalies due to the sextet current, there will be a new axion η_6, a Goldstone bason associated with the U(1) axial current which is made of an appropriate combination of color–triplet and sextet currents. The conservation of this axial current is violated by the instanton generated interactions, making η_6 to be massive. It is expected that the effective interactions responsible for the mass of η_6 will acquire a large anomalous dimensions (such is the case for the heavy top condensations[4]) in the strong-coupling large momentum region where sextet-quark condensates are formed so that η_6 mass may be as large as $30\,GeV$, which is much larger than the ordinary axion mass anticipated from the naive dimensional estimate. Nevertheless this axion-like η_6 will be the lightest new particle due to the sextet-quark sector that will produce new physical effects beyond that which the standard model can anticipate.

We believe that [5] we may have already seen several "exotic" experimental phenomena which may all be related to the existence of a new quark sector. They are: (1) the large real part of the forward $p\bar{p}$ amplitude observed by UA4[6]; (2) new diffractive physics[7] seen in cosmic ray air showers above $\sqrt{s} = 500\,GeV$, and (3) the excess muons[8]. It can easily be shown from a derivative dispersion relation[9] that such a large real part of the forward amplitude as observed by UA4 is incompatible with a slowly varying and low total cross-sections as reported[6] by E710. If both results are right it seems that [5] a genuine physical threshold must occur just below the UA4 energy. Exotic cosmic ray events, in particular "mini-Centauros" and "Geminions", exhibit a similar threshold[7] at $\sqrt{s} = 400 \sim 500\,GeV$ and can consistently be interpreted as different decays of the same diffractively produced and short-lived particle with a mass around $30\,GeV$. The excess muon events[8] observed in high energy cosmic point source showers suggest a new hadronic interaction for the photon which both absorbs the electromagnetic e^+e^- pair production process and produces hadrons diffractively. The three phenomena are consistent with the existence of a threshold for a diffractively produced particle of a mass around $30\,GeV$ with partial cross sections $2 \sim 3\,mb$ for 2γ decay mode (Geminion events) and $1 \sim 2\,mb$ for hadronic decay modes (mini- Centauro events). It will be interesting to see if CDF can detect the 2γ mode of this new $30\,GeV$ state (their present em calorimeter covers down to 2^o to the beam[11]).

2 - Sextet Quark Model

The idea to replace the spontaneous symmetry breaking via elementary Higgs scalars by a dynamical condensation mechanism of techni-fermions has been around for some time. At some strong enough value of the effective coupling, certain bound state condensates of the new fermions are formed to give rise to chiral symmetry breaking whereby producing Goldstone bosons which play the effective role of Higgs scalars. In order to give the right mass of $W^{\pm}$ in this picture, the Goldstone boson coupling F, i.e., the technipion decay constant, to the gauge current should be about 2,600 times larger than the pion decay constant $f_\pi \simeq 132\,MeV$, the chiral breaking parameter of the ordinary hadron physics. To achieve this, one can either suppose a new extra-strong interaction based on an unbroken (larger) technicolor group along with additional technifermions[1] belonging to its fundamental representation or new exotic quarks belonging to a higher dimensional representation[2] of the ordinary SU(3) color group. In the latter case, because of their large quadratic Casimir invariant, the exotic quarks have a dramatic effect on the β function and chiral-symmetry breakdown in exotic sectors may occur at around the 1 TeV scale.

An attractive possibility for the second type of dynamical symmetry breaking scheme is the minimal color–condensate model[3] which contains the gauge and fermion sectors of the standard model and a flavor doublet Q_6 = (U,D) with conventional electric charges and transforming as **6** under SU(3) color. With the usual three doublets of ordinary quarks with color **3**, the requirement of asymptotic freedom of the SU(3) color group allows just one such doublet. As the QCD running coupling $\alpha_s(\mu_6)$ grows a $\bar{Q}_6 Q_6$ condensate forms at a scale $\Lambda_6 = | < \bar{Q}_6 Q_6 > |^{\frac{1}{3}} \sim 250\, GeV$ signaling the spontaneous breaking of chiral U(2) × U(2) symmetry down to SU(2)× U(1) in the sextet quark sector and producing a triplet of Goldstone pions, $\pi_6^{\pm}$ and π_6^0, and a singlet eta-like meson. The triplet of Goldstone pions is then responsible for $W^{\pm}$ and Z^o masses a la the Higgs mechanism. There will be new QCD baryons and vector mesons that are made of sextet quarks. (In the simplest model there are two new lepton doublets with conventional electric charges to cancel the electroweak gauge anomaly but further higher-color quarks appearing at an even larger energy scale may play this role[12]). The physical axion η_6 is associated with the axial U(1) chiral symmetry with the axial current made of an appropriate anomaly free combination of the axial U(1) currents of color triplet and sextet quarks.

As noted above, the composite operators involving sextet quarks are expected to acquire large anomalous dimensions which should make the sextet quark interaction very strong in the large momentum range and also give a major effect to the large mass of η_6. Recently Fukazawa et al[13] estimated the sextet quark mass to be about $350\, GeV$, which is rather insensitive to the choice of the t-quark mass in the range $77 - 160\, GeV$, by studying the nontrivial solution of the ladder Schwinger-Dyson equation for the sextet quark propagator. The sextet quarks of such mass should be visible in the 6-jet final states at LHC[14]. But the new effects associated with η_6 should soon be tested by the projected new experiment at CERN[15] and at Fermilab Tevatron collider[11].

3 - New Physics in Hadronic Diffraction

We suggest that[5] several "exotic" experimental phenomena mentioned above may all be related to the existence of the sextet quark sector and in particular to the diffractive production of the new axion-like particle η_6.

The UA4 Real Part - In an asymptotic regime a derivative dispersion relation[9] implies that the real part of the elastic scattering amplitude is directly given by the derivative of the total cross-section (if there is no Odderson[16]). Therefore a SLOWLY VARYING total cross-section and a LARGE real part are INCOMPATIBLE. In particular the "large" UA4 value[6] of 0.24 ± 0.04 for $\rho = \mathrm{ReA}/\mathrm{ImA}$ and the "low" E710 results[10] of $\sigma_{tot} = 72.1 \pm 3.3$ mb for the total cross-section, can not be fit by any smooth asymptotic model (for example a minijet model) which also fits the lower energy data. IF both results are right, the only possible explanation seems to be **A** GENUINE PHYSICAL THRESHOLD just below the UA4 energy. To see this we can write a simple threshold model[5,17] for Im A, e.g.,

$$ImA/s = 37 + 80\sqrt{s} + 6.5\ln\left[\sqrt{s}/25\right] + 9\left[1 - 520^2/s\right]^{1/2}\theta\left[s - 520^2\right] \qquad (1)$$

which when the real part is constructed from a dispersion relation, fits the data as shown in Fig. 1.

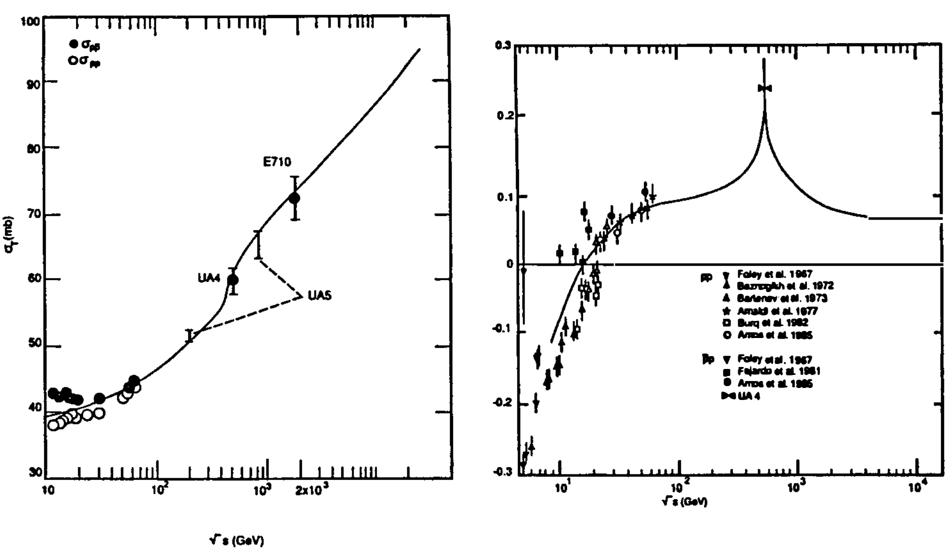

Fig. 1: σ_{tot} and ρ from Eq. (1).

While the effect of the threshold in this simple model is surely too dramatic, it does illustrate how the data could be compatible. A more important issue is what the "New Physics" represented by the threshold could possibly be. Could it perhaps be related to "exotic" Cosmic Ray events? The existence of a threshold for such events was a major part of the argument[18] for raising the SPS collider energy to $\sqrt{s} = 900\,GeV$ in 1982.

Diffractive Air-Shower "Exotics" - The lowest energy exotics fall into two classes[7].

Mini-Centauros - which can be characterized as 1) diffractive, 2) hadron-rich, 3) average multiplicity ~ 15, 4) fireball mass $\sim 30GeV$ 5) cross-section $\sim 2 - 4\%$ of inelastics, 6) threshold - $\sqrt{s} \sim 400 - 500\,GeV$ and

Geminions - which can be characterized as 1) diffractive, 2) JUST two widely separated cores, 3) fireball mass $\sim 30\,GeV$, 4) cross-section $\sim 5 - 10\%$ of inelastics, 5) threshold - $\sqrt{s} \sim 400 - 500\,GeV$.

Our proposal[5] is that diffractive production of a new state of mass O(30) GeV is the new threshold represented by our simple model of Eq. (1) and we identify Geminions and Mini-Centauros as different decay modes of this new state. We note that the cross-sections are of the right magnitude and the threshold the right energy for this identification. The kinematics also fits well with a diffractive threshold i.e. $M^2/s < 0.01 => M/0.1 > 300GeV$

Hadronic Photons - An accumulating number of observations[8] of Cosmic point sources (Cygnus X-3, Hercules X-1, Crab Nebula ...)indicate that photon showers above some threshold energy in the range 10-100 TeV contain at least as many muons as a hadron shower. Since this is more than an order of magnitude greater than expected from a normal photon shower, a new "hadronic" photon interaction is suggested. This phenomenon, and all the "hadron- rich" air-shower phenomena[7] (including Centauros, mini-Centauros etc.), can be explained[19] if the photon develops a new diffractive interaction which both absorbs the electromagnetic e^+e^- pair production process and diffractively produces hadrons. In addition the Geminion events described above can be directly interpreted as TWO-PHOTON decays of a SHORT-LIVED state.

Our conclusion from study of the above three phenomena is that they are all consistent with the existence of a threshold for diffractive production of a new state with mass 20-40 GeV and the cross-sections (of the order of magnitude), 2 - photon decay mode (Geminions) $\sim$ 2-3 mb and hadronic decay mode (mini-Centauros) $\sim$ 1-2 mb.

4 - Concluding Remarks

We suggest[5] identifying the axion η_6 as a candidate for the new particle of $30\,GeV$ mass associated with the diffractive threshold mentioned above. Because of the instanton interactions coupled with very strong sextet quark QCD interactions in the dynamical momentum range of $100\,GeV - 100TeV$ the η_6 can acquire a mass as high as $30\,GeV$, much larger than the naive estimate of an ordinary axion. As a light Goldstone boson, i.e., $30\,GeV << \Lambda_6$, the η_6 automatically has a major two-photon decay via the anomaly giving a lifetime $\tau(\eta_6 \rightarrow 2\gamma) \sim (100keV/m_{\eta_6})^3 \sim 3 \times 10^{-17}$ sec which is very close to the π^o lifetime and is nicely consistent with the fireball interpretation of Geminion events. Also the approximate equality for the cross-sections of mini-Centauros and Geminions interpreted as hadronic and electromagnetic decay modes of the η_6 respectively, combined with the appropriate axial current divergence equation gives $\alpha_{e.m.} \sim (m_{\eta_6}/F_{\eta_6})^2$ so that $m_{\eta_6} \simeq 25\,GeV$ for $F_{\eta_6} = \Lambda_6$ providing a nice consistency.

We note that an appropriately increased diffractive cross- section due to the diffractive production of η_6 would explain the apparent low collider results for diffraction. The measured single diffractive cross-sections at the collider energies are lower than that anticipated from a straightforward extrapolation of the ISR value, while the threshold term in Eq. (1) contributes 2mb at UA4 energy and about 8 mb at the Tevatron energy. As we mentioned above, CDF may be able[11] to look for the 2γ decay mode in their current diffractive data. Their electromagnetic calorimeter covers down to 2^o and this may be just enough to see a $30\,GeV$ state.

The cross-section for perturbative QCD production of Q_6 is, apart from color factors, the same as that of color–triplet quarks with the same mass M_{Q6}. The consistent mass M_{Q6} for sextet quarks appears [13] to be around $300\,GeV$ - $400\,GeV$ for the t-quark mass range of $77 - 160\,GeV$. The hard cross-section is therefore less than 1 pb at CDF making the η_6 undetectable in such processes in hadron colliders.

It could be seen[20] at LEP in the future as a rare radiative Z^o decay when LEP accumulates enough Z^o's, as the branching ration $\Gamma(Z^o \to \eta_6\gamma)/\Gamma(Z^o \to \mu^+\mu^-)$ is about 10^{-5}. However we expect that diffractive production of sextet flavors and of the η_6 in particular will be large. This can be thought of as due to instanton interactions contributing to the small t component of high-energy hadron collisions.

A strongly interacting Q_6 sector has an absorption effect for e^+e^- pair production via the interference[19] between the diffractive excitation of a photon into a $Q_6\bar{Q}_6$ state (and the Z^o in particular) that decays into e^+e^-, and the electromagnetic production of e^+e^- pairs. The production of hadrons and 2γ via the η_6, together with direct production of the Z^o, will drastically modify the properties of high-energy photon-initiated air showers and the development of electromagnetic clusters within hadron initiated showers. This could be an explanation of the muon-rich photon showers and the wide range of anomalous shower development seen in high energy cosmic ray events.

Since Eq. (1) gives σ_{tot} that increases slower than the conventional $(\ln s)^2$ - fit and the threshold term disappears rapidly with energy, the large value of ρ must be very localized with respect to energy. Projected new measurements of ρ at CERN[15] and of total cross-sections at Fermilab covering a number of energies should soon determine the existence of a new hadronic diffractive threshold that we suggest to associate with diffractive production of η_6.

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