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## SPIN EFFECTS FROM QUARK AND LEPTON SUBSTRUCTURE AT FUTURE MACHINES

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**Résumé** - Si les quarks et les leptons sont des états liés à l'échelle  $\Lambda^{-1}$ , la physique aux énergies supérieures à  $\Lambda$  procurera un grand nombre d'évidences de cette nouvelle sous-structure. Cependant, celle-ci pourrait déjà se manifester à des énergies inférieures à  $\Lambda$  à travers certaines déviations par rapport au modèle standard telles que des facteurs de forme, des interactions résiduelles et, peut-être, des nouveaux états "légers". Je discute les vertus des faisceaux polarisés de leptons et hadrons pour la recherche de nouvelles interactions et donne des exemples de production d'états excités fermioniques et bosoniques, insistant tout particulièrement sur les propriétés de spin.

**Abstract** - If quarks and leptons are composite on a distance scale  $\Lambda^{-1}$  the physics at energies larger than  $\Lambda$  will provide plenty of evidence for the new level of substructure. However, already at energies below  $\Lambda$  compositeness should become manifest in deviations from the standard model due to form factors, residual interactions and, possibly, new "light" states. I discuss the virtue of polarized lepton and hadron beams in searching for new interactions and exemplify the production of excited fermions and bosons focussing on spin properties.

Present-day experiments provide strong evidence that leptons and quarks are structureless at distance scales as small as  $10^{-16}$  cm, and that their interactions are correctly described by the standard  $SU(3) \times SU(2)_L \times U(1)$  gauge model up to energies in the few hundred GeV range. Given this fact, it may appear somewhat premature to speculate about effects from lepton and quark compositeness. On the other hand, it is quite conceivable /1/ that the key to some of the miracles of the standard theory, such as the complicated fermion mass spectrum, the existence of families, and the scale of the electroweak symmetry breakdown, is hidden at a deeper level of substructure: leptons and quarks (and some of the standard gauge bosons) may not be elementary but composite of more fundamental constituents (preons) bound together by a new strong force (hypercolour). The strength of this new (probably confining) force can be characterized by the energy  $\Lambda$  which is necessary to break up leptons and quarks or, equivalently, by their inverse radius  $r^{-1} \sim O(\Lambda)$ . The physics at scales larger than  $\Lambda$  would then be described by a new fundamental theory, while the presently known physics should emerge from the "low energy" limit of this ultimate theory. Clearly, the impressive success of the standard model implies that the latter must be a good approximation to the true effective low energy theory.

It is not an easy task to construct interesting models which have this property. Quite obviously, a minimal requirement is  $\Lambda > 0(G_F^{-1/2} \sim 300 \text{ GeV})$  that is  $r^{-1} \sim O(\Lambda) \gg m$ , where  $G_F$  is the Fermi constant and  $m$  is a lepton or quark mass.

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The only known way to obtain almost massless and, at the same time, almost point-like fermionic bound states is by requiring an unbroken symmetry /2/ (chiral, SUSY). This point is common to all preon models. As far as features are concerned such as the value of  $\Lambda$ , the spin nature and multiplet structure of the preons, the fundamental gauge fields (hypergluon, gluon, photon, weak bosons) etc, there is room for quite different scenarios /3/. Despite numerous interesting ideas, a fully satisfactory and compelling theoretical framework has still to be developed. In particular, the mysteries of the standard theory mentioned above have, at least so far, not found a "natural" explanation. Nevertheless, compositeness may be the correct route to go beyond the standard theory.

In this state of ignorance, clues from experiment are particularly important. Recent phenomenological studies /4-11/ have demonstrated the great virtues of the future  $e^+e^-$ ,  $\bar{p}p$  and  $ep$  colliders in the search for signals of compositeness. Figure 1 illustrates pictorially  $ep$ -scattering at various momentum transfers  $Q$

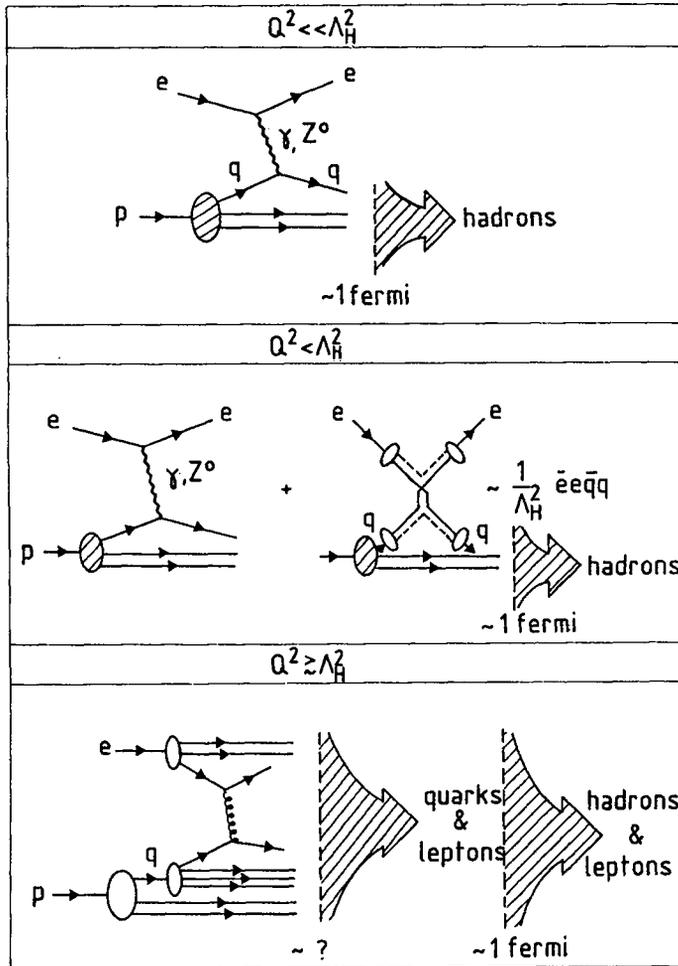


Fig. 1. Illustration of  $ep$  scattering in three regions of the momentum transfer  $Q$  assuming the electron and quarks possess substructure at a scale  $\Lambda$ .

assuming that the electron and u and d-quarks are composite with  $r^{-1} \sim \Lambda$ . At  $Q > \Lambda$ , one would basically have hard scattering processes between the preonic sub-constituents and the hypergluons. This would lead to a drastic change of the structure functions, the particle composition of the final states (high lepton and quark multiplicities), and the event topology. Furthermore, a whole spectrum of new excited fermions and bosons with exotic colour and spin quantum numbers and masses  $\sim O(\Lambda)$  should be produced. Clearly, at energies beyond  $\Lambda$  one would find plenty of direct evidence for the new layer of substructure. The opposite region,  $Q \ll \Lambda$ , is the regime of the standard model which apparently provides an excellent approximation to the low-energy limit of the new theory. However, remnants of the preon dynamics must be present and lead to more and more significant deviations from the standard model as the momentum transfer increases. Signals which can reasonably be expected at  $Q \ll \Lambda$  come from formfactors, residual interactions and new "light" ( $m < O(\Lambda)$ ) states. In fact, apart from the latter, such effects are practically unavoidable in any composite model.

The prospects of detecting signals of lepton and quark substructure at future machines depend, of course, crucially on the value of the compositeness scale  $\Lambda$ . It is possible to obtain bounds /12/ on  $\Lambda$  from proton lifetime, rare processes such as  $\mu \rightarrow e\gamma$  and  $K \rightarrow \mu e$ , and  $K^0 - \bar{K}^0$  mixing. These bounds are, generally, very strong:  $\Lambda > 10-1000$  TeV and larger. However, they are very model dependent and, therefore, not exceedingly informative. Less restrictive are the bounds /4,13/ put by muon decay and elastic  $\nu_{\mu}e$ -scattering:  $\Lambda > 2-6$  TeV. In contrast, the constraints /4,12,13/ inferred from Bhabha-scattering ( $\Lambda > 1-3$  TeV) and from g-2 of the muon ( $\Lambda > 700$  GeV) are relatively model independent. Finally, the absence of form factor effects /13/ implies that  $\Lambda > 200$  GeV. In summary, one cannot yet exclude  $\Lambda \sim O(1$  TeV) if one takes into account the model-dependence of the above bounds, the ambiguity in the definition of a compositeness scale and the fact that all of the above bounds are only rough order of magnitude estimates. On the other hand, as already pointed out  $\Lambda$  cannot be smaller than the electroweak scale  $G_F^{-1/2} \sim 300$  GeV in order not to endanger the evident success of the standard model. Thus, the (multi) TeV regime accessible at the next generation of colliders is certainly a promising energy range to search for effects of compositeness. Yet, it appears more likely that one will get a glimpse at the "low energy" effects exemplified in Fig. 1 rather than to actually penetrate to a new layer of substructure - if it exists at all.

Therefore, it is the "low energy" effects which I shall focus on in my talk. More specifically, I shall discuss two aspects: the virtue of polarized lepton and hadron beams in testing new interactions induced by the preon binding force (residual contact interactions) and the production and spin signatures of excited  $S=1/2$  and  $3/2$  fermions and  $S=0$  bosons.

Quite generally, "low-energy" deviations from the standard model due to the non-pointlike coupling of fundamental gauge fields to composite fermions are of the order of  $Q^2 / \Lambda^2$  and thus only visible if the momentum transfer  $Q$  is not too far from the compositeness scale  $\Lambda$ . However, in addition to form factors the preon binding force is expected to induce new effective interactions via preon interchange (see Fig. 1) or via the multiple exchange of hypergluons. Such residual interactions are described by non-renormalizable, higher dimensional operators with effective coupling strengths which depend on the scale  $\Lambda$ . The detailed structure of these operators is determined by the underlying preon dynamics. Instead of considering specific preon models, it suffices for the following phenomenological demonstrations to make an educated guess of the effective low energy Lagrangian /14/. Schematically, one may assume

$$\mathcal{L}_{\text{eff}} \approx \mathcal{L}_{\text{st}}(\text{incl. form factors}) + \sum \frac{g^2}{\Lambda^2} C_{ijk\ell}^{ab} (\bar{\psi}_i \Gamma^a \psi_j) (\bar{\psi}_k \Gamma^b \psi_\ell), \quad (1)$$

where  $\mathcal{L}_{\text{st}}$  is the standard model Lagrangian modified by form factors. The second term represents residual 4-fermion interactions compatible with  $SU(3) \times SU(2)_L \times U(1)$  symmetry and conservation of helicity. Parity, which is not respected by the standard model either, may be violated. The dimensionless coefficients  $C_{ijk\ell}^{ab}$  ( $i, j, k, \ell$  being quark and lepton flavour indices) and the matrices  $\Gamma$  (specifying

the Dirac-, weak isospin- and colour-structure) are supposed to be chosen according to the above restrictions. The parameter  $g$  in eq. (1) is a dimensionless effective coupling constant. These 4-fermion operators are expected to give the dominant effects /14/ in the lepton and quark scattering processes considered later on. From eq. (1) one can see that the general form of a scattering amplitude is given by

$$A \sim f \frac{\alpha_{st}}{Q^2} + h \frac{g^2}{\Lambda^2} C, \tag{2}$$

where  $\alpha_{st}$  is one of the gauge couplings of the standard model and  $f$  and  $h$  are functions of the external momenta. Qualitatively, interference between the known gauge interactions and the contact interactions will lead to sizeable deviations from the standard model if

$$g^2 C \alpha_{st} / \Lambda^2 \sim O(1). \tag{3}$$

Hence, if the effective low energy theory is a strong coupling theory, that is if  $g^2 C / 4\pi \sim O(1)$ , the impact of contact interactions is enhanced by the smallness of the standard gauge couplings and exceeds the form factor effects by far. As a rough order of magnitude estimate, for  $\Lambda \sim 1$  TeV one should already observe large effects at  $Q^2 \sim (100 \text{ GeV})^2$  in  $e^+e^-$  and  $ep$  collisions, whereas  $pp$  collisions must be somewhat harder,  $Q^2 \sim (300 \text{ GeV})^2$ , in order to produce a similar effect. At any rate, high energy reactions at future machines (LEP, SLC, HERA, LHC, SSC, etc.) will certainly be sensitive to contact interactions for compositeness scales in the range of a few to a few tens of TeV. This is illustrated below.

(1)  $e^+e^-$ -colliders /4,15/: It has been pointed out by Eichten, Lane and Peskin /4/ that contact interactions involving only a single lepton or quark species are an essentially unavoidable consequence of compositeness. Therefore, processes like Bhabha-scattering can put very serious bounds on  $\Lambda$ . Already at PETRA energies /13/ one can exclude contact terms of the form

$$\pm 2\pi/\Lambda^2 (\bar{e}\gamma^\mu e)_a (\bar{e}\gamma_\mu e)_b \tag{4}$$

at the level of  $\Lambda > 1-3$  TeV. Here, and in what follows,  $(\bar{\psi}\gamma^\mu\psi)_a$  with  $a = L(R)$  denote left (right)-handed lepton or quark currents. Fig. 2 exhibits the effects of LL (i.e.  $a = L, b = L$ ) and  $(L + R)(L + R)$  contact interactions /15/ on the angular distribution in polarized Bhabha scattering near the  $Z_0$  (LEP) assuming  $\Lambda = 2$  TeV. Evidently, LL contact terms affect only  $e_L^+ e_R^-$  scattering (Fig. 2a). For all other beam polarizations one simply observes the standard model behaviour. In contrast, a vector-type contact term (Fig. 2b) shows up for all polarizations. If one compares Fig. 2 with a similar study /4/ of unpolarized Bhabha scattering, one can clearly see the advantages of beam polarization: a considerably greater sensitivity of such tests to the detailed structure of contact interactions and a farther reach in  $\Lambda$ .

(2)  $ep$ -collisions /10,11/: Charged and neutral current processes at future  $ep$ -colliders such as HERA will reach considerably larger values of  $Q^2$  and, consequently, probe much deeper into leptons and protons than it is possible at present. A detailed analysis of the sensitivity of unpolarized and polarized  $e^\pm p$ -scattering to contact interactions of the form

$$\pm 4\pi/\Lambda^2 (\bar{e}\gamma^\mu e)_a (\bar{q}\gamma_\mu q)_b \tag{5}$$

with  $q=(u,d)$  is presented in ref. 10. Fig. 3 displays the neutral current cross sections for polarized electrons in terms of the reduced cross section

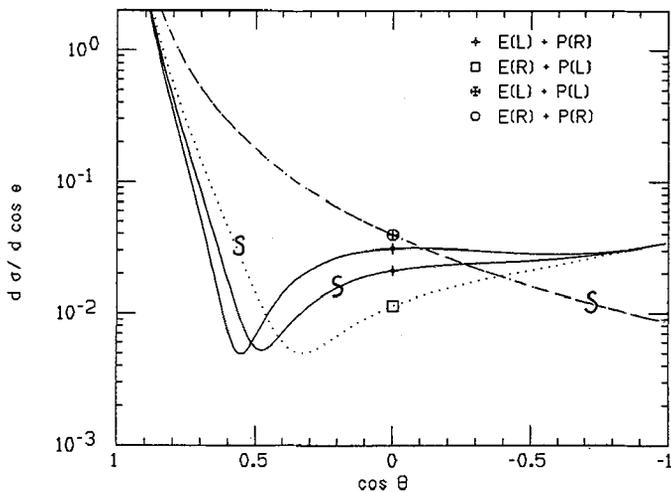
$$F_2(x, Q^2) \equiv \frac{d\sigma}{dx dy} / \frac{2\pi\alpha^2}{s x^2} \frac{1+(1-y)^2}{y^2}, \tag{6}$$

where  $x$  is the usual Bjorkenscaling variable,  $y = Q^2/xs$  and  $\sqrt{s}$  is the c.m. energy. The full and dashed curves include the effects of a variety of contact interactions, whereas the dotted curves are standard model predictions. Similarly as in the case of Bhabha scattering, for each of the models considered, the impact of contact interactions can be made maximal by a suitable choice of lepton charge and polarization. For the purpose of demonstration, a rather moderate scale of compositeness has been chosen in Fig. 3. From Fig. 4 one can see that, at HERA, one should be sensitive to  $\Lambda \sim 3$  TeV. Without polarization the sensitivity decreases by roughly a

factor of 1.5 - 2.

Bhabha Scattering  $E_{cm} = 100.00$  ; LL C.I.s

(a)



Bhabha Scattering  $E_{cm} = 100.00$  ; (L+R)(L+R) c.i.s (b)

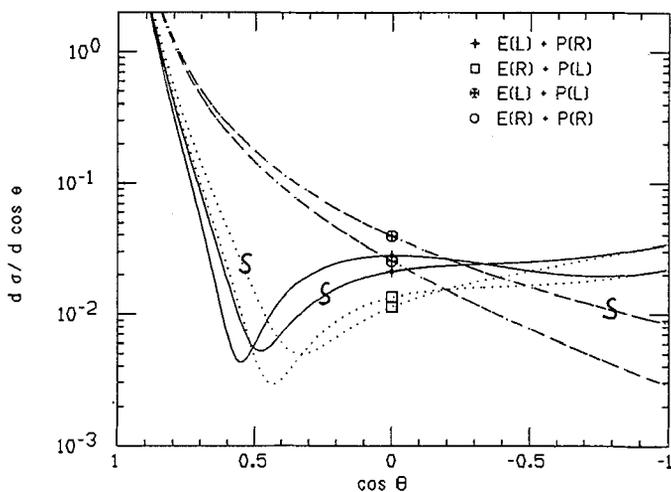


Fig. 2. Angular distributions in polarized Bhabha scattering near the  $Z_0$  for two models of contact interactions and  $\Lambda = 2$  TeV. The curves representing the standard model expectations are marked by "S" (from ref. 15).

Another interesting question is the gain in sensitivity by increasing the c.m. energy. This question is addressed in Fig. 5 which shows a comparison of the effects of LL-type contact interactions on unpolarized ep-scattering at HERA and at a hypothetical 2 TeV machine [11]. Somewhat surprisingly, the sensitivity increases only slowly with the energy. The reason is that the larger lever arm in  $Q^2$  at higher energies can be utilized only partly, since the number of events

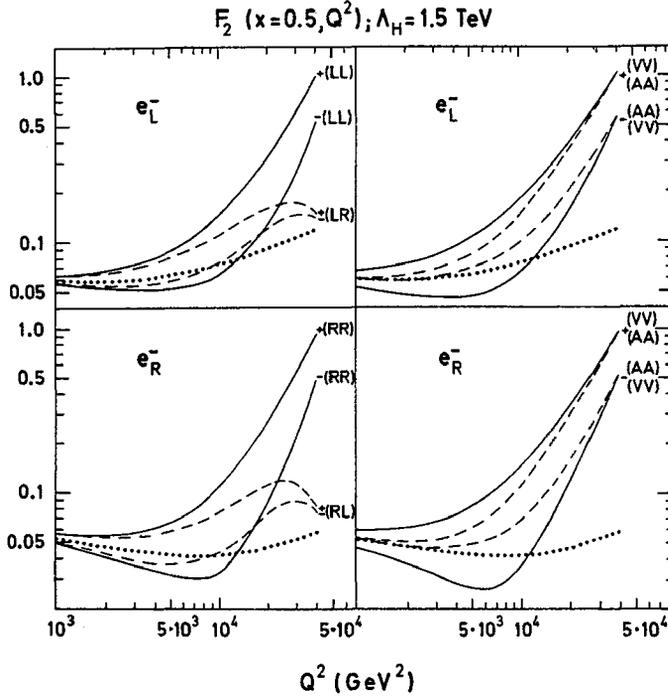


Fig. 3. Neutral current cross sections (as defined in equ. (6)) for polarized  $e^-p$  scattering at  $\sqrt{s} = 314$  GeV in the presence of contact interactions ( $V = L + R$ ,  $A = L - R$ ; the  $\pm$  signs refer to the signs in eq. (5)). The dotted curves represent the predictions of the standard model.

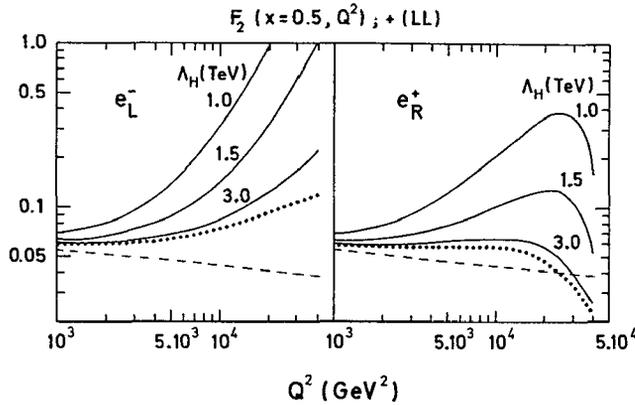


Fig. 4. Effects of LL contact interactions on the neutral current cross sections for polarized  $e^+p$  scattering at  $\sqrt{s} = 314$  GeV and for various values of the compositeness scale  $\Lambda$ . The dotted curves display the standard electroweak predictions, the dashed curves represent the electromagnetic contribution alone.

decreases quite rapidly with increasing  $Q^2$ . On the other hand, since the effects of contact interactions depend only marginally on  $x$ , one can afford to measure at

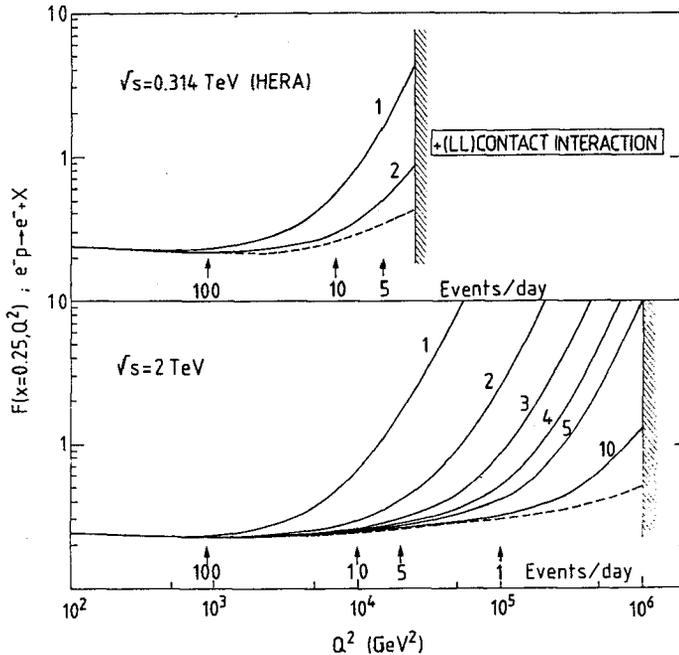


Fig. 5. Comparison of the effects of LL contact interactions in unpolarized  $e^-p$  scattering at two c.m. energies. The numbers at the full curves denote  $\Lambda$  in TeV. The dashed curves show the standard model result.

small  $x$  if the c.m. energy is high enough to reach sufficiently large  $Q^2 \sim xs$ . This allows to improve the statistics.

With polarized  $e^\pm$ -beams one can also look for effects of contact interactions in various asymmetries. Involving ratios of cross sections, asymmetries have the advantage that the uncertainties in the absolute normalizations of cross sections (e.g. due to the extrapolation of the structure functions in  $Q^2$ ) cancel. Clearly, having more precise standard model predictions it is also much easier to establish deviations. Fig. 6 displays the polarization asymmetries

$$A^{\mp} (+1, -1) = (d\sigma(e_L^{\mp}) - d\sigma(e_R^{\mp})) / (d\sigma(e_L^{\mp}) + d\sigma(e_R^{\mp})) \quad (7)$$

with and without contact interactions. One can see that the relative sign of the residual interactions and  $\mathcal{L}_{st}$  in eq. (1) plays a crucial role for the "low"  $Q^2$ -effects on asymmetries. Furthermore, the polarization asymmetries reflect very clearly the chiral structure of contact interactions and, therefore, provide good means to distinguish these signals of compositeness from other exotic effects which might occur. For electrons the largest effects are induced by (parity violating) LL and RR contact terms. In these cases experiments at HERA will be sensitive to values of  $\Lambda$  as large as 5 TeV. This is demonstrated in Fig. 7. Again, comparing the amount of information which can be obtained from polarized and unpolarized ep-scattering, the advantages of  $e^\pm$ -polarization is quite obvious.

(3)  $pp$ -scattering /7,9/: Compared to the tests of compositeness considered so far, hadronic collisions have a few disadvantages: (a) the contact interactions interfere with the standard colour force and therefore lead to effects by a factor  $(\alpha/\alpha_s) \sim (1/10)$  smaller than their effects in electroweak processes; (b) qq-contact interactions must compete with a large "background" from the standard gq and gg process and therefore become visible only at very large  $p_T$  where the valence quark

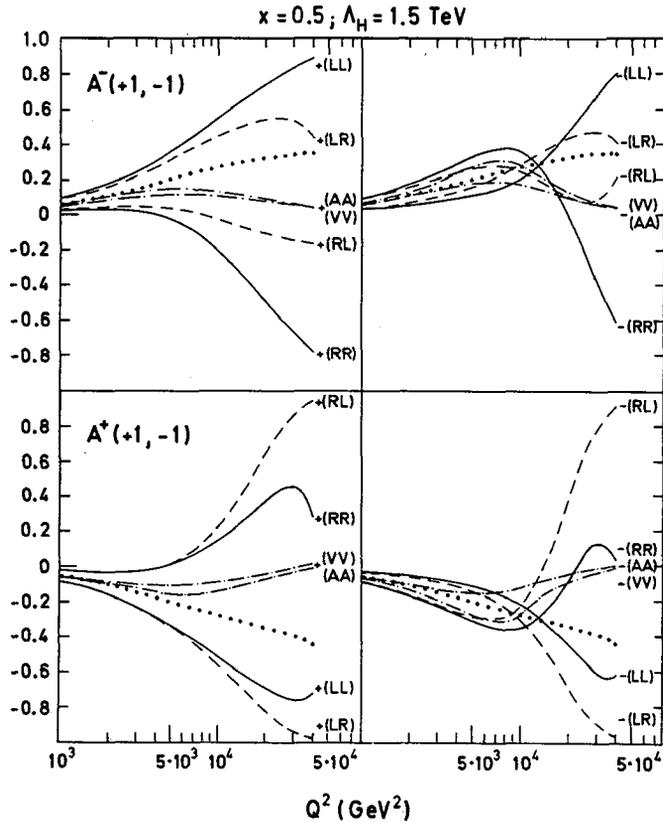


Fig. 6. Polarization asymmetries (as defined in eq. (7)) at  $\sqrt{s} = 314$  GeV in the presence of contact interactions (see Fig. 3). The standard model expectations are shown by the dotted curves.

processes dominate; (c) the uncertainties in the extrapolation of the structure functions enter quadratically and induce correspondingly large uncertainties in the standard model predictions. A thorough investigation of the effects of contact interactions of the type

$$\pm 4\pi/\Lambda^2 (\bar{q}\gamma^\mu q)_a (\bar{q}\gamma_\mu q)_b \tag{8}$$

with  $q = (u, d)$  on jet production in  $\bar{p}p$  collisions at 10-100 TeV can be found in ref. 7. Here, I will only emphasize that beam polarization would again increase the sensitivity of such tests substantially, at least in the case of parity violating contact interactions. The drawbacks of hadronic collisions mentioned above make this point particularly interesting. An example of the virtue of polarized p-beams is illustrated in Fig. 8. Of course, the large energy of several tens of TeV available at future  $\bar{p}p$  colliders pays off also without polarization. As can be seen from Fig. 9 (Eichten et al. ref. 7),  $pp$  collision at  $\sqrt{s} = 40$  TeV probe the internal nature of quarks at scales  $\Lambda \sim 7-15$  TeV for integrated luminosities of  $10^{38} - 10^{40} \text{ cm}^{-2}$ , respectively.

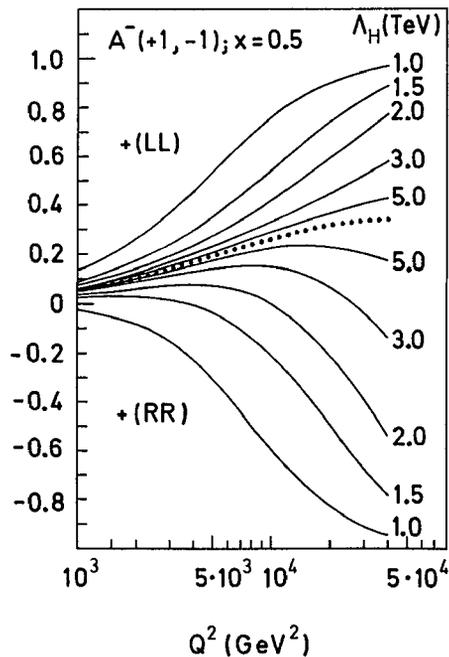


Fig. 7. Effects of LL and RR contact interactions on the polarization asymmetry  $A^- (+1, -1)$  at  $\sqrt{s} = 314$  GeV for various values of the compositeness scale  $\Lambda$ . The standard model prediction is shown by the dotted curve.

An even more direct evidence for lepton and quark substructure would be provided by the detection of excited leptons and quarks. Depending on the quantum numbers of the preons, these states may have "usual" ( $S=1/2$ ;  $I_w=1/2$ ;  $L_1^*$ ,  $Q_3^*$ ) and "unusual" ( $S=3/2$ ;  $I_w=0, 1$ ;  $L_3^*$ ,  $Q_8^*$ ) spin, weak isospin and colour properties. If leptons and quarks are bound states of two preons with  $S=0$  and  $S=1/2$ , the lowest lying excitations are expected to have  $S=1/2$ . On the other hand, if the fermions are composite of three  $S=1/2$  preons, the lightest excited states could have  $S=3/2$  (as in the case of the nucleon and the  $\Delta$ ). This shows that the determination of the spin of excited leptons and quarks would give important information on the nature of the preons and their dynamics (hyperfine splitting). Concerning the masses of excited fermions, one would naively expect  $m \sim 0(\Lambda)$ . However, since the ground states are obviously much lighter than  $\Lambda$ , it could well be that also some of the excited states have masses  $m \ll \Lambda$ . In that case, one can expect them to be copiously produced at future colliders and, maybe, even at the CERN  $\bar{p}p$ -collider and the FNAL Tevatron.

A limit on the mass of an excited  $S=1/2$  electron has been obtained /13/ from the absence of virtual contributions to  $e^+e^- \rightarrow 2\gamma$  at PETRA:  $M(e^*) > 60$  GeV. Furthermore, the interpretation /17/ of the anomalous  $\bar{z} \rightarrow \bar{\ell}'\ell\gamma$  decays /16/ found at the CERN  $\bar{p}p$ -collider as  $\bar{z} \rightarrow \bar{\ell}(\ell^* \rightarrow \ell\gamma)$  requires  $m_{\bar{z}} \sim 70$  GeV. Although this interpretation has some problems arising from the bremsstrahlung-like topology of these events, it led to attempts to understand also other "exotic" collider events /18/ such as the monojets in terms of excited quark production /19/. One has to wait for more data to really test these suggestions.

In a recent publication /20/, Kühn and Zerwas investigate quite systematically the production and decay properties of  $S=1/2$  and  $3/2$  excited fermions, emphasizing the features which allow to distinguish between different spin assignments. Let us

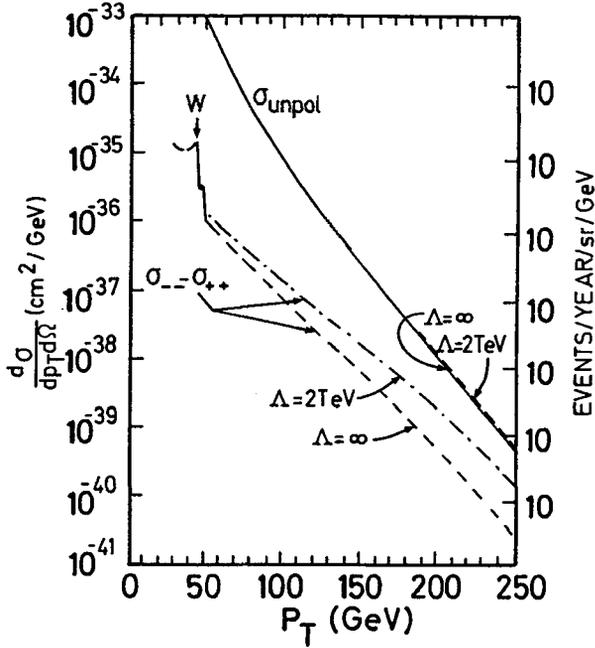


Fig. 8. Transverse momentum distributions of hadron jets for polarized and unpolarized pp collisions at 800 GeV. The curves corresponding to  $\Lambda = \infty$  represent the standard model predictions (from ref. 9).

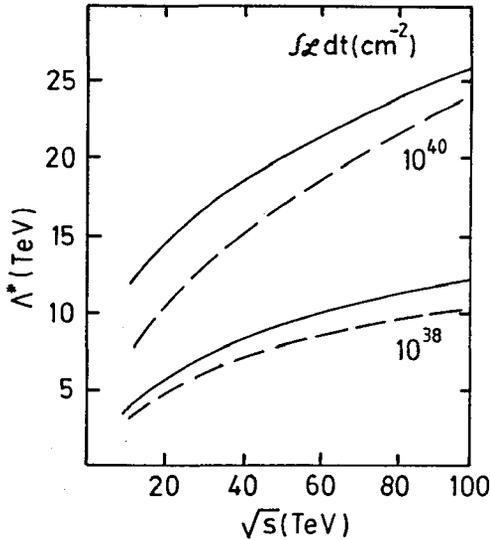


Fig. 9. Compositeness scale  $\Lambda$  of u and d quarks probed in jet production at  $y = 0$  in pp collisions, in the case of LL contact interactions (from Eichten et al., ref. 7).

consider the case of a weak isospin doublet - colour triplet quark  $Q^*(S)$ ,  $S$  denoting the spin. For  $S=1/2$ , gauge invariance requires the heavy - light quark couplings to be of magnetic moment type, whereas for  $S=3/2$ , one can, in general, have three different couplings. For illustration, the strong  $Q^*(1/2)qg$  - coupling can be written in the form

$$\mathcal{L}_s = \frac{g_s f_s}{2m^*} \bar{Q}^* \sigma_{\mu\nu} \frac{\lambda^a}{2} q_L G^{\alpha\mu\nu}. \quad (9)$$

The dominant decay mode is  $Q^*(S) \rightarrow q + g$  with the width

$$\Gamma(Q^*(S) \rightarrow q + g) = \frac{4}{3} \alpha_s f_s^2 \frac{m^*}{4} \begin{cases} 1 & S=1/2 \\ \frac{1}{4} \text{ or } \frac{1}{12} & S=3/2 \end{cases}. \quad (10)$$

The two numbers in the case  $S=3/2$  correspond to two different couplings. The above result with  $4/3 \alpha_s f_s^2 \rightarrow \alpha_s^2 f_s^2$  also applies to the radiative decay  $Q^*(S) \rightarrow q + \gamma$ , suggesting a branching ratio of  $O(10\%)$ . In  $\bar{p}p$  collisions,  $Q^*(S)$  is produced via quark - gluon fusion:  $q + g \rightarrow Q^*(S)$ . The cross section is given by

$$\sigma(\bar{p}p \rightarrow Q^*(S)) = \frac{\Gamma(Q^*(S) \rightarrow q + g)}{m^* 3} \frac{2S+1}{2} \pi^2 \tau \frac{dL_{qg}}{d\tau}, \quad (11)$$

where  $dL_{qg}/d\tau$  is the effective quark - gluon luminosity /21/ and  $\tau = m^{*2}/s$ . The numerical results plotted in Fig. 10 correspond to  $\Gamma(Q^*(1/2) \rightarrow q + g) \approx 5$  GeV and  $\Gamma(Q^*(3/2) \rightarrow q + g) = 2.5$  GeV for  $m^* = 150$  GeV, respectively. As can be seen, the production rates are comfortably high. In addition, the Jacobian peak of the transverse momentum distribution produced in  $Q^*(S) \rightarrow \text{jet} + \gamma$  provides a good signature. Thus, the prospects for detection of excited fermions at future hadron colliders look very good.

The spin of the excited quark can be determined from the angular distribution /20,22/ of its decay products. This is illustrated in Fig. 11. If both decay products can be identified, as in  $Q^* \rightarrow q + \gamma$ , one has the situation displayed in Fig. 11(a). However, if one cannot distinguish between the fermionic and bosonic decay products, as generally in  $Q^* \rightarrow q + g$  resulting in two hadron jets, one must symmetrize the decay distributions. This leads to the situation shown in Fig. 11(b). In the latter case one cannot distinguish between different  $S=3/2$  couplings, however, the two spin assignments can clearly be told apart.

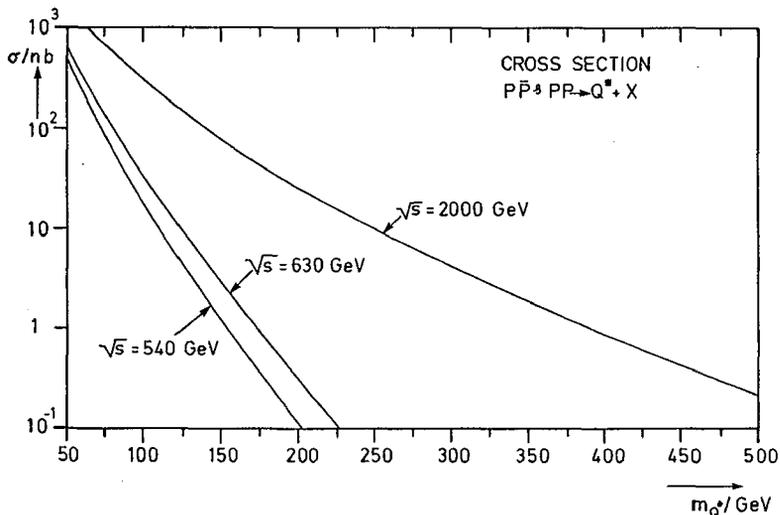


Fig. 10. Production cross sections of excited quarks in  $\bar{p}p$  collision (from ref. 20).

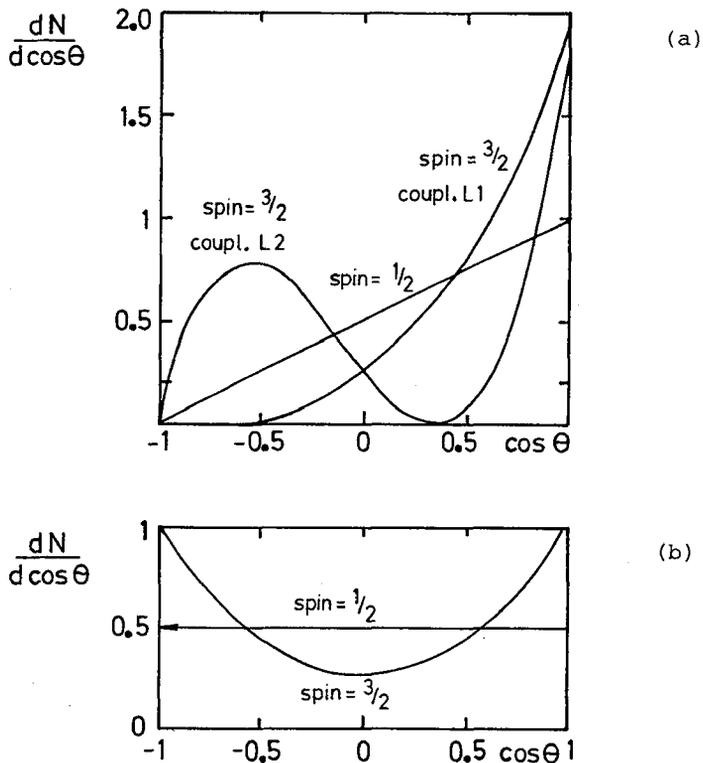


Fig. 11. Angular distributions of the decay products in  $Q^* \rightarrow q + g$  or  $\gamma$  :  
 (a) if both decay products can be identified,  
 (b) symmetrized.  
 $\theta$  is defined as the angle between  $Q^*$  and  $q$  (from ref. 22).

Turning to  $e^+e^-$  annihilation /20/ and  $ep$  collisions /24/, excited quarks and leptons can be produced singly and in pairs. The production cross sections for an excited electron in the mass range (100-400) GeV in  $e^-p$  collisions is illustrated in Fig. 12. Given the good signature pointed out earlier, HERA will be able to explore the mass range up to 200 GeV.

In competition with the excited lepton picture of the anomalous Z decays, the hypothesis has been made /23/ that these unusual decays indicate the existence of a composite scalar boson X:  $Z \rightarrow \gamma (X \rightarrow e^+e^-)$ . The event topology then requires  $m_X \sim (40-50)$  GeV. Such objects are naturally (but not exclusively) expected in composite models /25/ in which the standard weak interactions are assumed to be not fundamental, but short range, residual interactions of the fundamental hypercolour force. One then needs a clever dynamical scheme (e.g. W - dominance /27/) to mimic sufficiently closely the standard electroweak interactions. At any rate, if the weak bosons  $W^\pm$  and  $W^0$  are not elementary, but composite, many other composite bosons should exist. A small part of this spectrum /26/ is illustrated below:

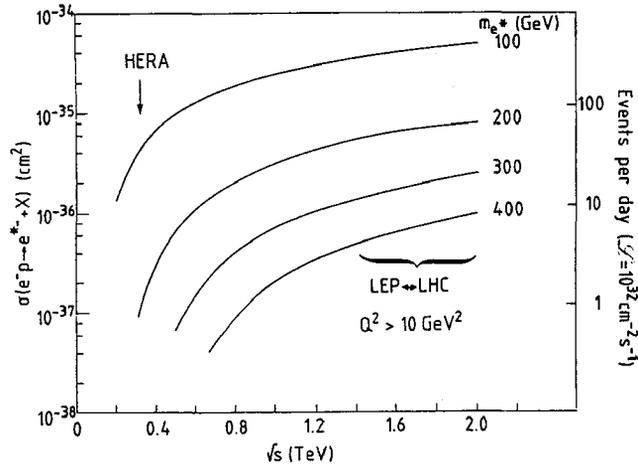


Fig. 12. Production cross sections and event rates of an excited S=1/2 electron in e-p collisions.

$$\begin{array}{ll}
 J = 0 & I_w = 0 : X \\
 & I_w = 1 : X^\pm \quad X^3 \\
 J = 1 & I_w = 0 : W \\
 & I_w = 1 : W^\pm \quad W^3
 \end{array}$$

+ coloured versions of the above, if the subconstituents carry colour.

If  $\Lambda \gtrsim O(1 \text{ TeV})$  as suggested by the experimental bounds mentioned earlier, such a model is only viable if one can make the ordinary weak bosons  $W^\pm, W^3$  light ( $m_w = 80 \text{ GeV}$ ) in comparison to  $\Lambda$  and, at the same time, keep the isoscalar vector boson and other excited vector bosons heavy ( $m \sim O(\Lambda)$ ). At energy scales smaller than  $\Lambda$ , the exchange of the latter states would then induce contact interactions of the kind studied in the first part of my talk. These effects can be probed experimentally along the lines indicated. On the other hand, the allowed mass range of scalar bosons is not very strongly constrained. In particular,  $m_x \ll m_w$  is not in conflict with the success of the standard model. Needless to say, the possible existence of light scalar bosons should be examined experimentally. This is not only desirable in the context of composite models, but also in other non-standard schemes (technipions), and even in the standard model (Higgs scalar).

The effects of a hypothetical isoscalar, S=0 boson X in  $e^+e^- \rightarrow e^+e^-, \gamma\gamma, \text{hadrons}$  at PETRA energies have been investigated in ref. 28. By scaling up the c.m. energy as well as  $m_x$ , this study may serve as a rough demonstration of possible effects due to composite scalar bosons at future machines. Let us assume that a parity doublet  $X=(S,P)$  of  $O^2$  composite bosons exists which couples to fermions as follows:

$$\mathcal{L}_{Xff} = h \bar{f} (S + i\gamma_5 P) f. \tag{12}$$

This coupling preserves the chiral symmetry eventually needed as protection mechanism /2/ for light quarks and leptons. The dimensionless coupling strength h is supposed to respect the bounds from neutral current data. Calculating from Eq. 12  $\Gamma(X \rightarrow \bar{f}f)$ , relating  $\Gamma(X \rightarrow \gamma\gamma)$  to  $\Gamma(Z \rightarrow X\gamma)$  via vector dominance and using  $\Gamma(Z \rightarrow e^+e^-\gamma) \sim 20 \text{ MeV}$  as input /28/, one can estimate the effects of such scalars

in  $e^+e^- \rightarrow e^+e^-, \gamma\gamma$  and  $\bar{q}q$ .

The angular distribution in Bhabha scattering again turns out to probe very sensitively the exchange of non-standard bosons. Writing

$$\frac{d\sigma}{d\Omega}(e^+e^- \rightarrow e^+e^-) = \frac{d\sigma^{QED}}{d\Omega} (1 + \delta_Z + \delta_X), \tag{13}$$

the photon contribution is given by

$$\frac{d\sigma^{QED}}{d\Omega} = \frac{\alpha^2}{4s} \left( \frac{3 + \cos^2\theta}{1 - \cos\theta} \right)^2, \tag{14}$$

while  $\delta_{Z,X}$  arise from Z and X exchange including interferences with the photon, and the photon and the Z, respectively. The Z and X contributions are illustrated

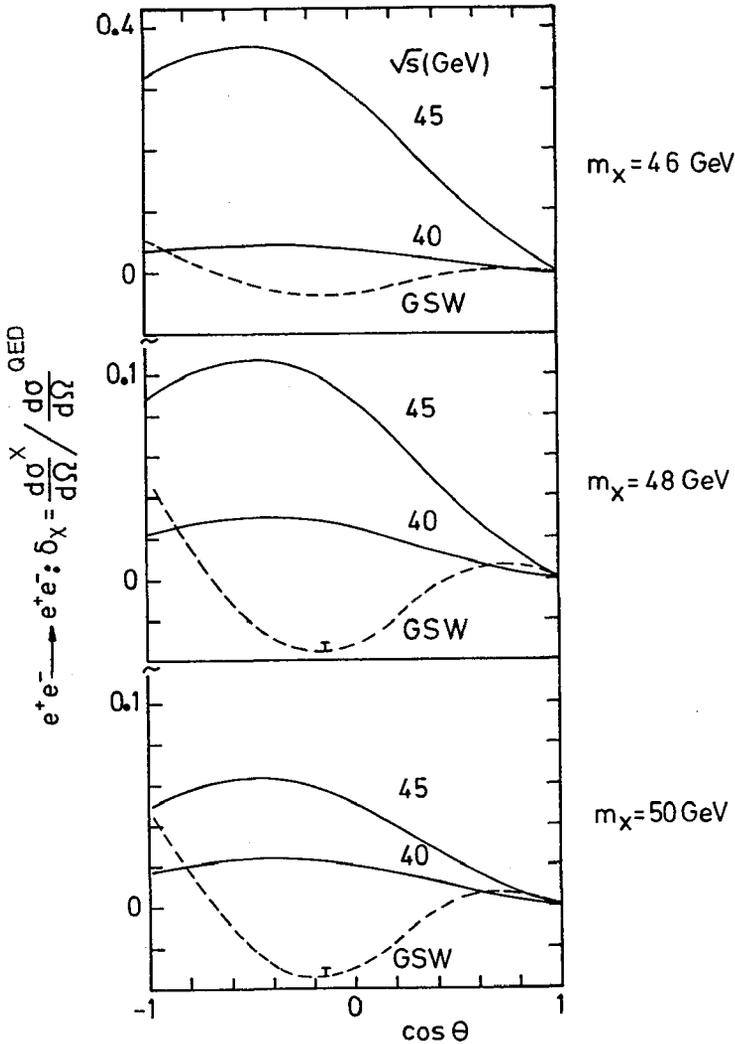


Fig. 13. Angular distributions in Bhabha scattering in the PETRA energy range  $40 < \sqrt{s} < 45$  GeV. The dashed curves show the standard model prediction normalized to pure QED. The error bars indicate the variation with  $\sqrt{s}$ . The full curves represent the effects of S=0 boson exchange (from ref.28).

in Fig. 13. One can nicely see the differences in the impact of spin 1 and spin 0 bosons (opposite sign!). Confrontation of these results with PETRA data yields the bound  $m_X > 50$  GeV. For lighter masses the effective coupling in Eq. 12 must be very small:  $h^2/4\pi < 10^{-4}$ .

I conclude this brief discussion on composite bosons with a few remarks on the production cross sections in hadronic collisions. As a rough estimate, one expects /29/

$$\tilde{\sigma}_X \sim \left( \frac{h^2/4\pi}{\alpha} \right) \left( \frac{m_w}{m_X} \right)^4 \tilde{\sigma}_w \quad (15)$$

which indicates that a large range of couplings and masses can be explored at the supercollider. In contrast to the parity doublet X which is produced via  $\bar{q}q$  annihilation, ordinary scalars are most likely produced via  $gg$ -fusion. The reason is that the coupling of ordinary scalars to fermions is suppressed by a factor  $m_f/\Lambda$  if chiral symmetry is preserved, apart from soft violation due to masses. In that case, one estimates /29/ for  $\bar{p}p \rightarrow S$  and  $m_S \lesssim 500$  GeV:

$$\frac{d\sigma}{dy} \Big|_{y \sim 0} \sim 100 \frac{\Gamma(S \rightarrow 2g)}{m_S^3} \quad (16)$$

To summarize, if leptons and quarks are composite at a scale  $\Lambda$ , the existence of a new layer of substructure will directly come to light in scattering processes at energies above  $\Lambda$  through a drastic change in the scaling behavior, spectacular final states and the production of a rich spectrum of excited states. However, given the present bounds on  $\Lambda$ , the energies available at future colliders may not be high enough. In that case, one is bound to search for "low energy" signals of compositeness: form factors, residual interactions and "light" excited states. The detailed form of the contact interactions and the spin of the excited fermions and bosons can give important clues on the basic preon structure and dynamics. Phenomenological studies show that polarization asymmetries and angular distributions of decay products probe most sensitively the chiral properties of contact interactions and the spin of new states. Thus, polarized beams and good angular coverage are of great advantage.

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