Search for compositeness and leptophobic gauge bosons 
(with polarized beams)

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Abstract
In a first step, we explore the discovery and analysis potentials of the HERA collider, with and without polarized beams, in the search for electron-quark compositeness in the neutral current channel. Then we study the parity violating effects, for jet production in polarized $pp$ collisions at RHIC, which could be due to the presence of quark subconstituents or new massive gauge bosons. We emphasize that the measurement of spin asymmetries in such a polarized context could give some crucial informations on the chiral structure of these hypothetical new interactions.

To appear in the proceedings of the Workshop "Beyond the Desert", Ringberg, Germany, June 1997.

PACS Numbers : 12.60.Cn; 13.87.-a; 13.88.+e; 14.70.Pw
Key-Words : Compositeness, New Gauge bosons, Jets, Polarization.
Number of figures : 2
July 1997
CPT-97/P.3514
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1 Electron-quark compositeness at HERA

The idea of compositeness has been introduced in the hope of solving some of the problems of the Standard Model (SM). For instance, it could explain the generation pattern of the SM, or, like the technicolor idea, represent an alternative to the scalar sector of the theory. The phenomenological approach is to consider a new contact interaction between electron and quark subconstituents, which is normalized to a certain compositeness scale $\Lambda$. This is represented by the following effective lagrangian [1, 2]:

$$L_{eq} = \sum_q \left( \eta_{LL}^q (\bar{e}_L \gamma_\mu e_L)(\bar{q}_L \gamma_\mu q_L) + \eta_{RR}^q (\bar{e}_R \gamma_\mu e_R)(\bar{q}_R \gamma_\mu q_R) + \eta_{LR}^q (\bar{e}_L \gamma_\mu e_L)(\bar{q}_R \gamma_\mu q_R) + \eta_{RL}^q (\bar{e}_R \gamma_\mu e_R)(\bar{q}_L \gamma_\mu q_L) \right)$$

(1)

with $\eta_{ij}^q = \epsilon \frac{g^2}{(\Lambda_{ij}^q)^2}$ where $g^2 = 4\pi$ and $\epsilon = \pm 1$. The sign $\epsilon$ characterises the nature of the interferences with SM amplitudes. The four subscripts $LL$, $RR$, $LR$ and $RL$ characterise the chiral structure of the new interaction. These four chiralities, along with the sign $\epsilon$, define 8 individual models. The composite interaction could correspond to one of these models or to any combination of them.

We know from atomic parity violation (APV) experiments on Cesium atoms that these individual models are severely constrained, giving some bounds of the order of $\Lambda \sim 10$ TeV [3]. However it appears that it is easy to find some combinations of the chiralities which evade these constraints [4]. In the following, for simplicity, we will consider the 8 models individually and then observe the effects of more complicated models at the end of this section.

Recently, the H1 and ZEUS collaborations at HERA have observed an excess of events, in comparison with the SM expectations, at high $Q^2$, in the deep inelastic positron-proton cross section $\sigma_+ \equiv \frac{d\sigma}{dQ^2}(e^+p \rightarrow e^+X)$ [5]. It could be interpreted as a manifestation of electron-quark compositeness [6] for a scale $\Lambda \sim 3 TeV$ in the up quark sector. Note that, since the lepton beam is made of positrons, the cross section $\sigma_+$ is sensitive to the chiralities $LR^\pm$ and/or $RL^\pm$ where $\pm$ correspond to $\epsilon$. Several other possible explanations have also been mentioned in this conference.

With the present values for the parameters of the HERA experiment [5] but with higher integrated luminosities ($L_{e^-} = L_{e^+} = 1 fb^{-1}$), we can show [5, 8] that cross section measurements can probe a compositeness scale of the order of $7 TeV$ for constructive interferences ($\epsilon = +1$), and of the order of $6 TeV$ in the destructive case. We deduce that the present HERA anomaly will be soon confirmed or invalidated. However it appears that electron and positron beams are necessary to cover all the possible chiralities of the new interaction. The comparison of the two cross section $\sigma_-$ and $\sigma_+$ allow the distinction of 2 classes of chiralities: $(LL^\pm, RR^\pm)$ and $(LR^\pm, RL^\pm)$ [5, 6, 7].

Now, we want to emphasize that the measurement of some spin asymmetries, defined in the context of HERA with polarized lepton beams and also with a polarized proton beam, could give some very important information on the chiral structure of the new interaction. Note that lepton polarization is a part of the HERA program, and that proton polarization is seriously under discussion [10].
The evaluation of the cross section, asymmetries and their errors is made with the following parameters: $\sqrt{s} = 300 \, \text{GeV}$, $L_{e\pm} = 250 \, \text{pb}^{-1}$ per spin configuration, $0.01 < y < 0.95$. Concerning the $Q^2$ resolution we take $\frac{\Delta Q^2}{Q^2} = 34.3\%$ and $Q^2_{\text{min}} = 200 \, \text{GeV}^2$ which defines 16 points of analysis on the energy domain $200 \, \text{GeV}^2 < Q^2 < 5.10^4 \, \text{GeV}^2$. GRSV polarized parton distributions [11] are used for the calculations. This choice corresponds to a conservative attitude since for this set of distributions the quarks are weakly polarized in comparison with other sets which are currently used, like GS96 or BS [12]. As a consequence, the spin effects are weaker giving smaller bounds on $\Lambda$. The degrees of polarization of the beams are taken to $P_{e^-} = P_{e^+} = P_p = 70\%$. Finally, we have chosen a total systematical error of 10% for the asymmetries: $\Delta A^{\text{syst}} = 10\%$.

Results [7]:

We have simulated 60 spin asymmetries that we can construct with the 8 independent cross sections:

\[
\begin{align*}
\sigma^{-} & \quad \sigma^{+} & \quad \sigma^{-} & \quad \sigma^{+} \\
\sigma^{-} & \quad \sigma^{+} & \quad \sigma^{-} & \quad \sigma^{+}
\end{align*}
\] (2)

where $\sigma_i^{\lambda_e \lambda_p} \equiv \left( \frac{d\sigma_i}{dQ^2} \right)_{\lambda_e \lambda_p}$, $i$ refers to the electric charge of the colliding lepton and $\lambda_e, \lambda_p$ are the helicities of the lepton and the proton.

It appears that the observables which are the most sensitive to the presence of contact interactions, are the parity violating spin asymmetries:

\[
A^{PV}_{LL}(e^-) = \frac{\sigma^{-} - \sigma^{+}}{\sigma^{-} + \sigma^{+}} \quad \text{and} \quad A^{PV}_{LL}(e^+) = \frac{\sigma^{+} - \sigma^{-}}{\sigma^{+} + \sigma^{-}}
\] (3)

and the "mixed" charge-spin asymmetry:

\[
B_2^2 = \frac{\sigma^{++} - \sigma^{--}}{\sigma^{++} + \sigma^{--}}
\] (4)

Using a $\chi^2$ analysis we obtain the bounds presented in Table 1.

| $\Lambda$ (TeV) | $\Lambda_L^L \Lambda_R^R$ | $\Lambda_L^R \Lambda_R^L$ | $\Lambda_{L/R}^L$ | $\Lambda_{L/R}^R$ |
|-----------------|--------------------------|--------------------------|------------------|------------------|
| $A^{PV}_{LL}(e^\pm) \ & B_2^2$ | 6.6 | 7.2 | 7.0 | 7.0 | 6.3 | 7.0 | 6.8 | 6.7 |

Table 1: Limits on $\Lambda$ at 95% CL.

We find that the limits are comparable to the unpolarized case [4, 3]. They are slightly better for destructive interferences ($\epsilon = -1$).

$A^{PV}_{LL}(e^+)$ is represented on Fig.1. This asymmetry is sensitive to the chiralities ($LR^\pm, RL^\pm$). On the other hand, the direction of the deviation from SM expectations allows now the distinction between 2 classes of chiralities: ($LR^-, RL^+$) for a positive deviation or ($LR^+, RL^-$) for a negative one. Similarly, we can show easily that $A^{PV}_{LL}(e^-)$ is sensitive
Figure 1: The asymmetry $A_{LL}^{PV}(e^+)$. Predictions for SM (plain curve) and for contact interactions (labels on fig.) with $\Lambda = 3\, TeV$. The chiralities which are not mentioned are close to SM.

to the chiralities $(LL^\pm, RR^\pm)$. Then, the same procedure allows to discriminate between $(LL^+, RR^-)$ and $(LL^-, RR^+)$. We deduce that the measurement of these two asymmetries would allow to separate the 4 classes: $(LL^+, RR^-)$, $(LL^-, RR^+)$, $(LR^+, RL^-)$ and $(LR^-, RL^+)$. We can go further in the identification of the chiral structure of the new interaction by the use of additional asymmetries. For instance, $B_2^P$ is strongly sensitive to the presence of the chiralities $(RR^\pm, LR^\pm)$. Again the direction of the deviation from SM distinguish $(RR^+, LR^-)$ from $(RR^-, LR^+). But, since these 2 classes are distinct from the 4 precedent ones, we conclude that the measurements of the three spin asymmetries $A_{LL}^{PV}(e^-)$, $A_{LL}^{PV}(e^+)$ and $B_2^P$ should give a clear identification of the chiral structure of the new interaction in this naive model.

Now, it turns out that if the chiral structure of the new interaction is more complicated, in general, the three asymmetries mentioned above will be sufficient to identify the precise chiral structure. But for some special cases, like for instance the $VV$ model which conserves Parity, some cancellations occur, then we need some other spin asymmetries. It appears that the (four) Parity Conserving spin asymmetries, defined when only the proton spin is flipped (which minimizes systematical errors), are particularly interesting since they are mainly sensitive to only one chirality. The problem of these PC asymmetries
is that they are less sensitive to new physics than the PV ones. Then, if the new interaction have a complicated structure, we can obtain valuable informations at lower value of $\Lambda$ ($\sim 5$ TeV).

To conclude this part, we can make some remarks on the one spin asymmetries defined when only the lepton beams are polarized. The behaviour of these asymmetries had been presented some years ago in [2]. It appears [4] that these asymmetries are less sensitive to the presence of new physics than the double spin asymmetries. Moreover, we can’t define as many asymmetries as in the 2 spin case. For instance, we can’t define the Parity Conserving spin asymmetries. Then, if the structure of the new interaction is complicated, we can loose the opportunity to identify its chiral structure.

2 New Physics at RHIC

Around the year 2000, the RHIC Spin Collaboration (RSC) will use the RHIC machine as a polarized $pp$ collider. The center of mass energy will be as high as 500 GeV, the degree of beam polarization near 70% and the luminosity as high as $\mathcal{L} = 2.10^{32} \, cm^{-2} \, s^{-1}$ which gives after a few months of run $L = 800 \, pb^{-1}$ [13]. Moreover, the possibility of accelerating polarized $^3He$ nuclei, which has been discussed recently [14], will open some new perspectives since polarized $pn$ collisions will be allowed. With these figures, spin asymmetries as small as 1% should be measurable. For example, the PC double-spin longitudinal asymmetry $A_{LL}$ in inclusive one-jet production or in direct photon production will be obtained with very small errors, hence allowing to test the spin structure of QCD.

Adding the measurement of some PV asymmetries in $W$ and $Z$ boson production, it will be possible to determine very accurately the various polarized partonic distributions inside the proton (see [15] and references therein). On the other hand, as was noticed some time ago [16], non conventional PV effects in hard-hadron reactions have never been searched for. Then, we will focus (again) on the double helicity PV asymmetry $A_{PV}^{LL}$ for the inclusive production of one jet. The definition of $A_{PV}^{LL}$ is similar to eq.3 but now $\sigma^{\lambda,\lambda'}$ means the cross section in a given helicity configuration for the production of a single jet with transverse energy $E_T$, integrated over some rapidity interval around $y = 0$.

According to the Standard Model, this process is essentially governed by QCD plus a small contribution due to electroweak boson exchanges. The latter induces a small $A_{LL}^{PV}$ which should be visible at RHIC. This SM effect, using GRSV distributions, is represented by the plain curve on the figure 2. The rise with $E_T$ is due to the increasing importance of quark-quark scattering relatively to other terms involving gluons. The asymmetry is small but clearly visible at RHIC (the errors are calculated with $L = 0.8 \, fb^{-1}$). On the other hand, a new interaction between quarks could be at the origin of some deviations from the expected $A_{LL}^{PV}$, provided that it presents a particular chiral structure.

Quark compositeness [17]:

In the framework of compositeness, an effective handed interaction due to a contact
term between quarks can be present \[1\] :

\[ L_{qq} = \epsilon \frac{\pi}{2\Lambda_{qq}^2} \bar{\Psi} \gamma_\mu (1 - \eta \gamma_5) \Psi \bar{\Psi} \gamma^\mu (1 - \eta \gamma_5) \Psi \]  

(5)

where \( \Psi \) is a quark doublet, \( \Lambda \) is the compositeness scale, \( \epsilon \) and \( \eta \) taking the values \( \pm 1 \).

Last year, the CDF collaboration has reported an excess of events in jet production at high \( E_T \) and invariant mass \( M_{jj} \) [18]. This can be interpreted as a manifestation of quark compositeness for a scale \( \Lambda \sim 1.6 \) \( TeV \). The situation is controversial, since D0 doesn’t observe such an excess. Then we will take this value as the present limit.

![Figure 2: Asymmetry \( A_{PV}^{LL} \) for inclusive one-jet production at RHIC.](image)

The effects of such contact interactions at RHIC (the scale is \( \Lambda = 1.6 \) \( TeV \)) are represented by the dot-dashed curves on Fig.2. The effect on \( A_{LL}^{PV} \) is spectacular. Moreover, if the contact term is indeed present, this measurement should allow to get a unique information on its chiral structure since the sign of \( A_{LL}^{PV} \) is sensitive to the sign of the product \( \epsilon \eta \) (\( \epsilon = -1 \) means constructive interference, see \[1\], \[17\]).

In the absence of deviation from SM expectations, it will be possible to place some bounds on \( \Lambda \). Using a \( \chi^2 \) analysis, we have obtained the limits given in Table 2. For comparison, we have also given the bounds achievable from the measurement of the unpolarized one-jet cross section at the upgrade TEVATRON (\( \sqrt{s} = 2 \) \( TeV \)) and at LHC (\( \sqrt{s} = 14 \) \( TeV \)).
Table 2: Limits on $\Lambda$ in TeV at 95% CL.

| $L$ (fb$^{-1}$) | RHIC | TEVATRON | LHC |
|----------------|------|----------|-----|
|                | 0.8  | 3.2      | 1.0 | 10.0 | 100.0 | 10.0 | 100.0 |
| $\epsilon = -1$ | 3.30 | 4.40     | 3.20 | 3.70 | 4.10   | 25.5 | 33.0 |
| $\epsilon = +1$ | 3.25 | 4.35     | 2.90 | 3.35 | 3.75   | 16.0 | 19.5 |

It appears that the luminosity is a key parameter for the polarized analysis on $A_{LL}^{PV}$ (see the rise of the RHIC bounds with $L$). Finally, in spite of its four time lower energy, the RHIC could compete with the TEVATRON for the observation of compositeness thanks to beam polarization.

**Leptophobic $Z'$**[^19]:

Concerning new neutral gauge bosons ($Z'$), we can show that there is an equivalence (to a good approximation) between the exchange of a $Z'$ and a contact term[^8][^4]. Then, $A_{LL}^{PV}$ in the $pp$ mode is also sensitive to the presence of a new neutral current. We know that the best constraints on $Z'$ bosons (will) come from the analysis of the Drell-Yan process. But, a particular $Z'$ could exist, called ”leptophobic”, which have zero or very small couplings to leptons, implying that the traditional $Z'$ searches at future collider through the leptonic decay channel will be hopeless. Such leptophobic $Z'$ arise naturally in some models derived from string theories[^20]. For illustration we use the ”flipped SU(5)” model(s) from[^21] and the ”$\eta$-kinetic” model from[^22]. A general and interesting property of these models is that there is parity violation in the up quark sector. Then, if a leptophobic $Z'$ is present at a relatively low mass, some effects should be visible on $A_{LL}^{PV}$. We have represented on Fig.2 the effects of the ”flipped SU(5)” model with $M_{Z'} = 300 \text{GeV}$ and $\kappa = g_{Z'}/g_z = 1$, and the ”$\eta$-kinetic” model with $M_{Z'} = 150 \text{GeV}$ and $\kappa = 1$. Using a $\chi^2$ analysis on $A_{LL}^{PV}$ with $L = 800 \text{pb}^{-1}$, we obtain the bounds : $M_{Z'_{SU(5)}} > \kappa.350 \text{GeV}$ and $M_{Z'_{\eta-k}} > \kappa.170 \text{GeV}$.

**$W'$ search**[^23]:

Finally, it appears that $A_{LL}^{PV}$ is also sensitive to the presence of a new charged current, essentially in the context of polarized $pn$ collisions. For a $W'_R$ originating from Left-Right Models[^24] the present limits depend on several parameters, and, in general, they are stringent[^25]. But, there is a particular window, for the right-handed quark mixing matrix $V^R \sim 1$ and for a heavy Dirac right-handed neutrino, where the limits are very weak[^25]. In this case, $A_{LL}^{PV}$ measurements at RHIC could be really interesting, see[^23] for a detailed analysis.

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