Polarized Beams at HERA : Analyzing the Chiral Structure of Contact Interactions

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Abstract

In the context of HERA with polarized lepton and proton beams, we explore the sensitivity of the collider to contact interactions. We emphasize that the measurement of longitudinal spin asymmetries in such a polarized context could give some crucial informations on the chiral structure of these hypothetical new interactions.

1 Introduction

A contact interaction (CI) between electron and quark could mimic any new physics manifestation in $eq \to eq$ scattering [1]. It can represent a common substructure between electron and quark [2], or the exchange of a Z' [3, 4] or of a leptoquark [5, 1], if the boson mass is such that $M \gg \sqrt{s}$. We consider a new eq CI, which is normalized to a certain energy scale Λ, with the following effective Lagrangian [2, 6]:

$$\mathcal{L}_{eq} = \sum_q (\eta^q_{LL}(\bar{e}_L\gamma_\mu e_L)(\bar{q}_L\gamma^\mu q_L) + \eta^q_{RR}(\bar{e}_R\gamma_\mu e_R)(\bar{q}_R\gamma^\mu q_R) + \eta^q_{LR}(\bar{e}_L\gamma_\mu e_L)(\bar{q}_R\gamma^\mu q_R) + \eta^q_{RL}(\bar{e}_R\gamma_\mu e_R)(\bar{q}_L\gamma^\mu q_L)) \quad (1)$$

with $\eta^q_{ij} = \epsilon g^2/(\Lambda^q_{ij})^2$ where $g^2 = 4\pi$ and $\epsilon = \pm 1$. The sign ϵ caracterises the nature of the interferences with the Standard Model (SM) amplitudes. The four subscripts LL, RR, LR and RL caracterise the chiral structure of the new interaction. Assuming the existence of contact terms for the first generation of quarks and u-d "universality" *i.e.* $\eta_{ij} = \eta^u_{ij} = \eta^d_{ij}$, these four chiralities, along with the sign ϵ, define eight individual models. The CI could correspond to one of these models or to any combination of them.

These individual models are constrained by several experiments involving eq scattering (see [1] for a nice review). In particular, the atomic parity violation experiments on Cesium atoms give some bounds of the order of $\Lambda \sim 10$ TeV [1, 7]. However it appears that it is easy to find some combinations of the chiralities which evade these constraints [8]. Nevertheless, for simplicity, we will consider the eight models individually and then observe the effects of more complicated models at the end.

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 $\sigma_+ \equiv$

$d\sigma/dQ^2(e^+p \to e^+X)$ [9]. This excess could be interpreted as a manifestation of new physics (see [10] for a very recent review) : leptoquarks, squarks with R parity violation or contact interactions. We will give a remark on leptoquarks in the conclusion, but now we concentrate on CI. The HERA anomaly could be interpreted as a CI with a scale $\Lambda \sim 3 - 4\,TeV$, in the up quark sector. Note that, since the lepton beam is made of positrons, the cross section σ_+ is sensitive to the chiralities $LR^\pm$ and/or $RL^\pm$ where $\pm$ correspond to ϵ.

With the present values for the parameters of the HERA experiments [9], but with higher integrated luminosities ($L_{e^-} = L_{e^+} = 1\,fb^{-1}$), we can show [11, 4] that the cross section measurements can probe an energy scale of the order of $7\,TeV$ for constructive interferences ($\epsilon = +1$), and of the order of $6\,TeV$ in the destructive case. We conclude 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 σ_- and σ_+ allow the distinction of two classes of chiralities : $(LL^\pm, RR^\pm)$ and $(LR^\pm, RL^\pm)$ [12, 3, 11]. But we have to note that cross section measurements are unable to discriminate between chiralities within each class.

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 part of the HERA program, and that proton polarization is the aim of this workshop !

The evaluation of the cross sections, of the asymmetries and the corresponding errors is made with the following parameters : $\sqrt{s} = 300\,GeV$, $0.01 < y < 0.95$, $L_{e^\pm} = 250\,pb^{-1}$ per spin configuration. This choice for the integrated luminosity is maybe too high, but if we divide this value by a factor two, the bounds given in the following decrease by $\sim$15%, which is in remarkable agreement with the scaling law given in [13]. Concerning the Q^2 resolution we take $\Delta Q^2/Q^2 = 34.3\,\%$ and $Q^2_{min} = 200\,GeV^2$. We note that the GRSV polarized parton distributions [14] 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 [15]. As a consequence, the spin effects are weaker giving smaller bounds on Λ. Note that this uncertainty will be strongly reduced thanks to the spin asymmetries measurements at the RHIC-BNL polarized pp collider, for γ, jets and $W^\pm$ productions [16]. The degrees of polarization of the beams are taken such that $P_{e^-} = P_{e^+} = P_p = 70\,\%$. Finally, we have chosen a total systematical error of 10% for the asymmetries : $\Delta A_{syst}/A = 10\,\%$.

2 Results

We have simulated sixty spin asymmetries that we can construct with the eight independent cross sections :

$$\sigma_-^{--} \quad \sigma_-^{++} \quad \sigma_-^{-+} \quad \sigma_-^{+-} \quad \textit{and} \quad \sigma_+^{--} \quad \sigma_+^{++} \quad \sigma_+^{-+} \quad \sigma_+^{+-} \tag{2}$$

where $\sigma_t^{\lambda_e \lambda_p} \equiv (d\sigma_t/dQ^2)^{\lambda_e \lambda_p}$, where t refers to the electric charge of the colliding lepton and λ_e, λ_p are the helicities of the lepton and the proton, respectively.

It appears that the observables which are the most sensitive to the presence of the CI, are the Parity Violating (PV) spin asymmetries :

$$A_{LL}^{PV}(e^-) \;=\; \frac{\sigma_-^{--} - \sigma_-^{++}}{\sigma_-^{--} + \sigma_-^{++}} \qquad \textit{and} \qquad A_{LL}^{PV}(e^+) \;=\; \frac{\sigma_+^{--} - \sigma_+^{++}}{\sigma_+^{--} + \sigma_+^{++}} \;, \tag{3}$$

and the "mixed" charge-spin asymmetry :

$$B_2^2 \;=\; \frac{\sigma_-^{++} - \sigma_+^{++}}{\sigma_-^{++} + \sigma_+^{++}} \;\; . \tag{4}$$

The Parity Conserving (PC) spin asymmetries, which are defined when only the proton spin is flipped, are also relevant, in particular for the chiral structure analysis (see below) :

$$A_2^1 \;=\; \frac{\sigma_-^{--} - \sigma_-^{-+}}{\sigma_-^{--} + \sigma_-^{-+}} \qquad \textit{and} \qquad A_2^2 \;=\; \frac{\sigma_-^{++} - \sigma_-^{+-}}{\sigma_-^{++} + \sigma_-^{+-}} \;\; , \tag{5}$$

$$A_2^3 \;=\; \frac{\sigma_+^{--} - \sigma_+^{-+}}{\sigma_+^{--} + \sigma_+^{-+}} \qquad \textit{and} \qquad A_2^4 \;=\; \frac{\sigma_+^{++} - \sigma_+^{+-}}{\sigma_+^{++} + \sigma_+^{+-}} \;\; . \tag{6}$$

Using a χ^2 analysis we obtain the bounds presented in Table 1.

Λ (TeV)	Λ^+_{LL}	Λ^+_{RR}	Λ^+_{LR}	Λ^+_{RL}	Λ^-_{LL}	Λ^-_{RR}	Λ^-_{LR}	Λ^-_{RL}
$A_{LL}^{PV}(e^\pm)$ *or* B_2^2	6.6	7.2	7.0	7.0	6.3	7.0	6.8	6.7
$A_2^{PC,x}$	5.3^1	5.2^2	5.6^4	5.2^3	5.6^1	5.5^2	5.8^4	5.5^3

Table 1: Limits on Λ at 95% CL.

We find that the limits are comparable to the unpolarized case [11, 12]. They are slightly better for destructive interferences ($\epsilon = -1$). The sensitivity of the PC asymmetries is $\sim$20% smaller than the PV one's.
The asymmetries $A_{LL}^{PV}(e^-)$ and $A_{LL}^{PV}(e^+)$ are represented on Fig.1.a-b, they are sensitive to the chiralities $(LL^\pm, RR^\pm)$ and $(LR^\pm, RL^\pm)$, respectively. Now, the direction of the deviation from SM expectations allows the distinction between two classes of chiralities. For instance, a positive deviation for $A_{LL}^{PV}(e^-)$ pins down the class (LL^+, RR^-) and, a negative one, the class (LL^-, RR^+). Similarly, an effect for $A_{LL}^{PV}(e^+)$ makes a distinction between (LR^-, RL^+) and (LR^+, RL^-). We deduce that the measurement of these two asymmetries would allow to separate the four 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 additionnal asymmetries. For instance, B_2^2 is strongly sensitive to the presence of the chiralities $(RR^\pm, LR^\pm)$, see Fig.1.c. Again the direction of the deviation from SM distinguish (RR^+, LR^-) from (RR^-, LR^+). Since these two classes are distinct from the four previous ones, we conclude that the measurements of the three spin asymmetries $A_{LL}^{PV}(e^-)$, $A_{LL}^{PV}(e^+)$ and B_2^2 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, measuring the three asymmetries mentionned above will be sufficient to identify the precise chiral structure. However, for some special cases, like for instance the VV model [6] which conserves parity, some cancellations occur. Then we need to measure some other spin asymmetries. It appears that the four PC spin asymmetries, defined above, are particularly interesting, since they are roughly sensitive to one chirality only. For instance, the asymmetry A_2^4, which is mainly sensitive to $LR^\pm$, is represented on Fig.1.d. The problem of these PC asymmetries is that they are less sensitive to new physics than the PV one's (see Table 1). Then, if the new interaction has a complicated structure, we can obtain some valuable informations at a lower value of Λ (~ 5 TeV) only.

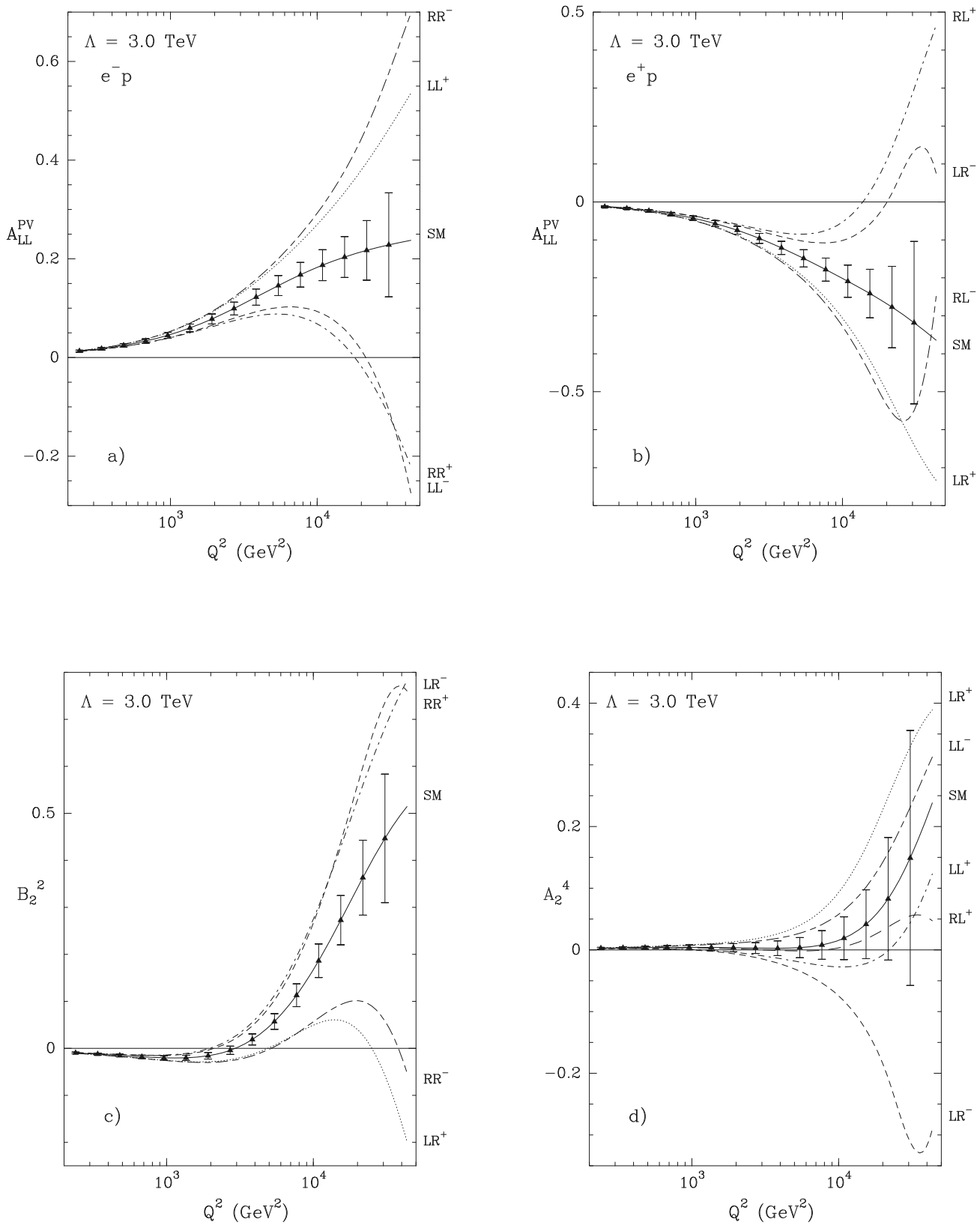

Figure 1: Spin asymmetries : a) $A_{LL}^{PV}(e^-)$, b) $A_{LL}^{PV}(e^+)$, c) B_2^2 and d) A_2^4 for the SM predictions (plain curves) and for the eight individual CI for the scale $\Lambda = 3\,TeV$. The chiralities not mentionned are close to the SM.

Finally, we can make some remarks on the one spin asymmetries defined when only the lepton beams are polarized. The behaviour of these asymmetries has been presented some years ago in [6]. It appears [11] that these asymmetries are less sensitive to the presence of new physics than the double spin asymmetries. The same behaviour has been noticed in the case of polarized pp collisions at RHIC [17]. Moreover, we can't define as many asymmetries as in the two spin case. For instance, we can not define the PC spin asymmetries. Then, if the structure of the new interaction is complicated, we can loose the opportunity to identify its chiral structure.

In conclusion, we can make a remark on the leptoquarks. Indeed, in order to be phenomenologically acceptable at present or future experiments, we know from pion decays and $(g-2)_\mu$ measurements that the leptoquarks must be of chiral nature [18]. Then we conclude that if a leptoquark is present and detectable at HERA, it will certainly induce some deviations in the PV spin asymmetries presented here.

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