Leptoquarks and Contact Interactions at LeHC

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The sensitivity of LeHC to different models of "new physics" has been studied, both for the resonance production and in the contact interaction approximation. Expected limits are compared for different running scenarios. Direct leptoquark production can be studied for masses up to about 2 TeV. For contact interaction models scales up to about 70 TeV can be explored. Significant improvement of existing limits is also expected for models with large extra dimensions. Effective Plank mass scales up to about 5.4 TeV can be probed. LeHC will be sensitive to the quark substructure of the order of 10^{-19} m.

1 Introduction

Search for "new physics" has always been one of the most important subjects in the field of particle physics. The first electron-proton collider HERA proved to be well suited both for precise tests of the Standard Model and for constraining its possible extensions. Large Hadron electron Collider (LeHC) is the proposal for the next-generation electron-proton machine. It would bring 7 TeV proton beam of the LHC into collisions with high-energy electrons (or positrons). Both linac and ring options for the electron machine are considered.

Presented analysis was developed in 2000/2001 as a contribution to TESLA TDR and the THERA Book [2]. Same approach (with only minor modifications) has been used since 2005 to demonstrate physics capabilities of the *ep* upgrade option of the LHC. Results presented here were obtained assuming four different running scenarios for LeHC:

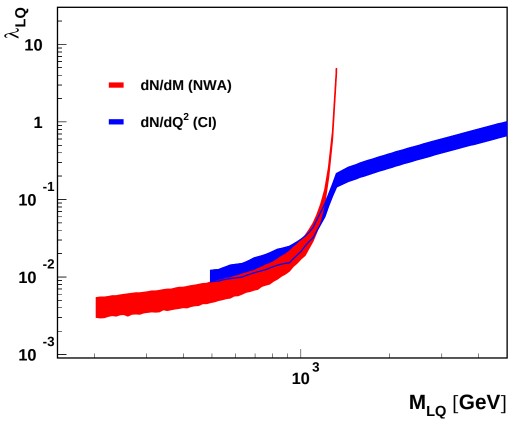
- lepton beam energy of 70 GeV, integrated luminosities of 2×10 or 2×100 fb^{-1},
- lepton beam energy of 140 GeV, integrated luminosities of 2×1 or 2×10 fb^{-1}.

For details of the analysis method and the considered models the reader is referred to the previous study [3].

2 Analysis method

In this contribution production of leptoquark states, as classified by Buchmüller, Rückl and Wyler [4], are considered. For leptoquark masses, M_{LQ}, smaller than the available *ep* center-of-mass energy direct production of single leptoquarks can be studied. If leptoquark Yukawa coupling, λ_{LQ}, is of the order of the electroweak coupling or smaller, the resonance width is small compared to the expected precision of mass reconstruction. In such a case the narrow-width approximation (NWA) can be used to describe the cross-section for single leptoquark production in electron-proton (for leptoquarks with fermion number $F = 2$) or positron-proton (for $F = 0$) scattering:

$$\sigma^{ep \to LQ\ X}(M_{LQ}, \lambda_{LQ}) \quad = \quad (J+1) \cdot \frac{\pi \lambda_{LQ}^2}{4 M_{LQ}^2} \cdot x_{LQ} q(x_{LQ}, M_{LQ}^2)$$



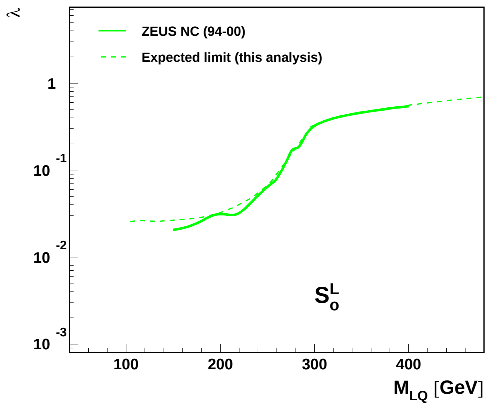


Figure 1: Left: comparison of limits for S_0^L leptoquark obtained with NWA and in modified CI approach, as expected for LeHC running with 70 GeV lepton beam energy and luminosity of 2×10 fb^{-1}. The width of the limit curves shows the level of expected statistical fluctuations, as obtained from simulation of multiple MC experiments. Right: results of the ZEUS collaboration [5] compared with the limits expected for given luminosity calculated with presented approach.

where $q(x, Q^2)$ is the quark momentum distribution in the proton and $x_{LQ} = \frac{M_{LQ}^2}{s}$. Resonance production should manifest itself by a narrow peak in the electron-jet invariant mass distribution for high Q^2 NC DIS events. To suppress SM background contribution additional cut on the y variable, related to the eq scattering angle in the center-of-mass frame, is imposed. Assuming that the measured distribution comes from the SM processes only, expected limits on λ_{LQ} as a function of M_{LQ} can be calculated for different running scenarios.

In the limit of heavy leptoquark masses ($M_{LQ} \gg \sqrt{s}$) the effect of leptoquark production or exchange is equivalent to a vector type $eeqq$ contact interaction (CI). The influence on the NC ep DIS cross-section can be described by introducing additional terms η_{ij}^{eq} in the tree level $eq \to eq$ scattering amplitudes:

$$\eta_{ij}^{eq} \quad = \quad a_{ij}^{eq} \cdot \left(\frac{\lambda_{LQ}}{M_{LQ}} \right)^2$$

where the subscripts i and j label the chiralities of the initial lepton and quark respectively ($i, j = L, R$) and the coefficients a_{ij}^{eq} depend on the leptoquark type. In the CI method limits on the leptoquark mass to the Yukawa coupling ratio are extracted from the measured Q^2 distribution of NC DIS events. For leptoquark masses comparable with the ep center-of-mass energy modified CI approach can be used. Dependence of the η_{ij}^{eq} terms on the process kinematics is included, separately for u-channel leptoquark exchange process and the s-channel production contribution.

Modified CI approach can be used also for $M_{LQ} < \sqrt{s}$. However, for low leptoquark masses better constraints are obtained from NWA approach. Shown in Figure 1a is the

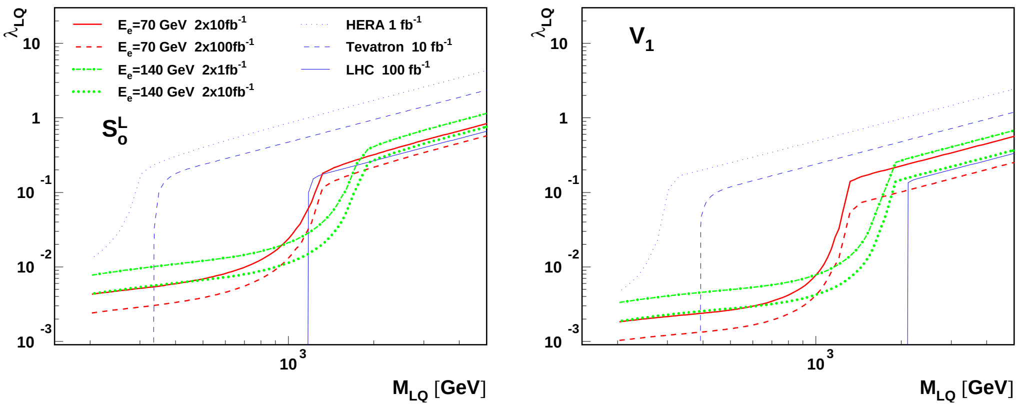


Figure 2: Expected 95% CL exclusion limits in (λ_{LQ}, M_{LQ}), for considered LeHC running scenarios, for S_0^L and V_1 leptoquark models. Expected final limits from HERA, the Tevatron and the LHC are included for comparison.

comparison of limits on Yukawa coupling of S_0^L leptoquark, as expected at LeHC from invariant mass distribution measurement (NWA) and form Q^2 distribution measurement (CI method) of NC DIS events. Both kinds of limits are always calculated for leptoquark masses $M_{LQ} < \sqrt{s}$ and the stronger one is taken. Presented approach has been verified by comparison with published ZEUS results [5], see Figure 1b.

3 Results

Shown in Figure 2 are expected 95% CL exclusion limits in (λ_{LQ}, M_{LQ}), for selected leptoquark models and four considered LeHC running scenarios. Expected final limits from HERA, the Tevatron and the LHC are also indicated. Discovery reach of LeHC is not larger than that of LHC. However, if any leptoquark-like states are discovered at the LHC, with masses below 1 TeV, they could be precisely studied at LeHC.

CI approach can also be used to constrain other extensions of the SM. for which low energy effects coming from "new physics" at much higher energy scales can be approximated by four-fermion contact interactions. Shown in Figure 3 are 95% CL exclusion limits on the mass scales Λ^+ expected from the measurement of high-Q^2 NC DIS cross-sections at LeHC for the general contact interaction models VV and LL. Current ZEUS limits [6] and expected final HERA limits are included for comparison. LeHC will be sensitive to CI mass scales of the order of 50 TeV. However, uncertainties of SM expectations and other systematic effects have to be reduced to few % level.

Corresponding limits on the effective Planck mass scale, M_S, in model with large extra dimensions [7] and on the effective quark charge radius, R_q, are presented in Figure 4. LeHC will be sensitive to the mass scales of extra dimensions of the order of 4–5 TeV. For the effective quark-charge radius, in the classical form-factor approximation, constraints below 10^{-19} m can be obtained.

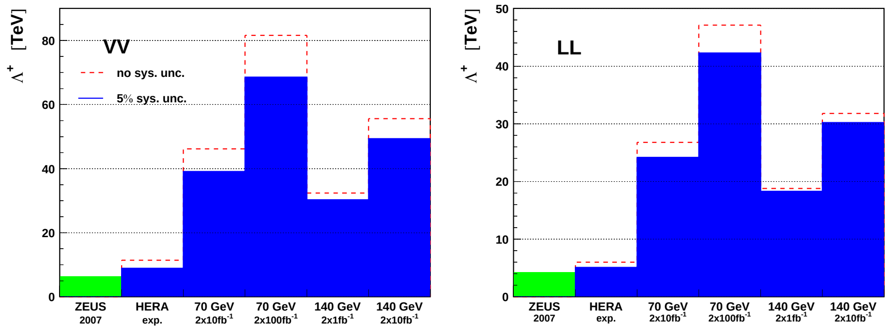


Figure 3: 95% CL exclusion limits on the mass scales Λ^+ expected from the measurement of high-Q^2 NC DIS cross-sections at LeHC, for the general contact interaction models VV and LL.

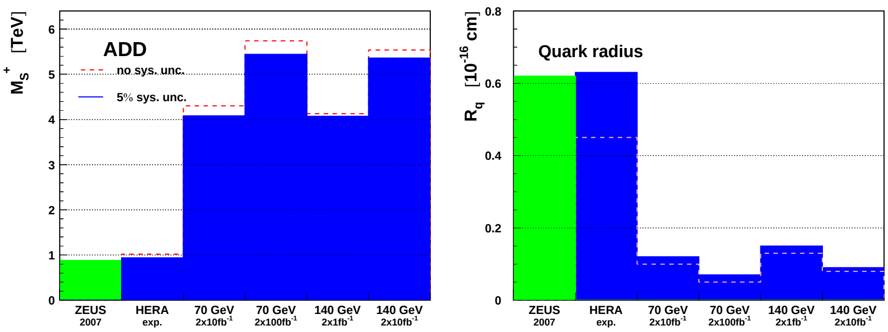


Figure 4: 95% CL exclusion limits on the effective Planck mass scale in models with large extra dimensions (left) and on the effective quark charge radius (right) expected from the measurement of high-Q^2 NC DIS cross-sections at the LeHC.

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