Search For Contact Interactions at HERA

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On behalf of the H1 Collaboration
HERA Collider and H1 Experiment

- World's only electron proton collider, at DESY, Hamburg.
- Was operating from 1992 to 2007.
- Two collider experiments H1 and ZEUS.
HERA Collider and H1 Experiment

- 2003 – 2007: HERA II data (luminosity upgrade)
- H1 experiment collected about 0.5fb$^{-1}$ data.
Deep Inelastic ep Scattering

Neutral Current Deep Inelastic scattering process:

\[ Q^2 = -q^2 = -(k - k') \]

\[ x = \frac{Q^2}{2(P \cdot q)} \]

\[ y = \frac{P \cdot (k - k')}{P \cdot k} \]

\[ s = (p + k)^2 \quad Q^2 = x \cdot y \cdot s \]

\( Q^2 \) is the virtuality of the exchanged boson.

\( x \) is the fraction of proton momentum, carried by the interacting quark.

\( y \) is the fraction of lepton energy transferred in the proton rest frame.
Data are well described by Standard Model.

*Standard Model prediction is based on CTEQ6M parton distribution function.*

Signs of new physics would be expected at highest $Q^2$ region.

Four-fermion $eeqq$ contact interactions provide a convenient method to investigate the interference of new fields.
Contact Interactions

- Effective Lagrangian for neutral current vector-like contact interactions:
  (scalar and tensor CI are constrained beyond HERA sensitivity)

\[ L_{CI} = \sum_{i,j=L,R} \eta_{ij}^{eq} (\bar{e}_i \gamma_\mu e_i)(\bar{q}_j \gamma^\mu q_j) \]

- 4 possible \( \eta \) coupling coefficients for each \( q \) flavor
- Any particular model can be constructed by appropriate choice of the coupling \( \eta \)
- Models currently tested:
  - compositeness
  - leptoquarks
  - large extra dimensions
  - quark radius
Contact interactions coupling are related to the mass scale via:

\[ \eta_{ab}^{eq} = \frac{\pm 4\pi}{\Lambda^2} \]

Different models assume different helicity structure of new interactions, given by a set of \( \eta \) couplings.
95% CL lower limits on $\Lambda$ compositeness scale between 3.2 – 7.4 TeV.
Leptoquarks

For high mass leptoquarks

\[ M_{\text{LQ}} \gg \sqrt{s} \]

virtual leptoquark production (exchange) results in an effective contact interaction type coupling:

\[ \eta_{\text{LQ}} \sim \left( \frac{\lambda}{M_{\text{LQ}}} \right)^2 \]

where \( \lambda \) is the leptoquark Yukawa coupling.

BRW classification: 14 different leptoquarks (7 scalar and 7 vector)
Leptoquarks

95% CL lower limits on the mass to coupling ratio for the different types of leptoquarks vary in the range $0.4 - 1.9$ TeV.
Arkani-Hamed-Dimopoulos-Dvali (ADD) model assumes that space-time has 4+n dimensions.

Gravity can propagate into the extra dimensions.

Contribution of graviton exchange to neutral current DIS cross section can be described by an effective contact interaction type coupling:

\[ \eta_g \sim \frac{\lambda}{M_s^4} \]

where \( \lambda \) is the coupling strength.
95% CL lower limits on $M$ gravitation scale depending on the sign:

$M_S^+ > 0.90 \text{ TeV}$

$M_S^- > 0.91 \text{ TeV}$
Finite size of the quark can be defined by introducing spatial distribution of the electroweak charge:

\[
\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \left(1 - \frac{R^2}{6} \cdot Q^2\right)^2
\]

where \( R \) is root mean squared of the electroweak charge distribution.

Assuming electron point-like 95\% CL upper limit on the quark radius:

\[ R < 0.65 \cdot 10^{-18} \text{ m} \]
Summary

- H1 NC data are in a good agreement with the Standard Model predictions.
- Limits on deviations from Standard Model set in different models:
  - Compositeness (3.2 - 7.2 TeV)
  - Leptoquarks (0.4 - 1.9 TeV)
  - Large Extra dimensions (0.90 - 0.91 TeV)
  - Quark Radius ($0.65 \times 10^{-18} m$)
The $\chi^2$ function is used as a measure of agreement between data and different theoretical predictions. The presented form of $\chi^2$ function takes into account correlated systematic uncertainties for the H1 cross section measurements.

$$\chi^2 = \sum_i \frac{\left( \sigma_i^{\text{exp}} - \sigma_i^{\text{theo}} \left[ 1 - \sum_k \Delta_{ik}^{\text{corr}} (\epsilon_k) \right] \right)^2}{\delta_{i,\text{stat}}^2 \sigma_i^{\text{exp}} \sigma_i^{\text{theo}} \left[ 1 - \sum_k \Delta_{ik}^{\text{corr}} (\epsilon_k) \right]^2 + \left( \delta_{i,\text{uncorr}} \sigma_i^{\text{theo}} \right)^2} + \sum_k \epsilon_k^2$$

- $\sigma_i^{\text{exp}}$: experimental cross section in $Q^2$ bin $i$
- $\sigma_i^{\text{theo}}$: theoretical cross section
- $\Delta_{ik} (\epsilon_k)$: effect due to correlated error $k$ for bin $i$
- $\delta_{i,\text{stat}}$: relative statistical error
- $\delta_{i,\text{uncorr}}$: relative uncorrelated error
- $\epsilon_1$: $f_{\text{norm}}$ normalization
- $\epsilon_2$: electron energy scale
- $\epsilon_3$: polar angle uncertainty
- $\epsilon_4$: PDF uncertainty
Limit Estimation

1. Scan through the $\eta$. Determine $\eta_{\text{data}}$ from $\chi^2(\eta)$ dependence that will correspond to minimal value of $\chi^2$.

2. For each $\eta$ a number of MC experiments is performed. For each MC experiment $\chi_{\text{min}}^2$ and corresponding $\eta_{\text{mce}}$ is determined.

3. Set the limit at the value of $\eta$ at which 95% of events would have $\eta_{\text{mce}} > \eta_{\text{data}}$. 