Searches from ep energy frontier at HERA

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Outline:

➔ HERA Collider and Experiments
➔ Search for Contact Interactions (CI)
➔ First Generation Leptoquarks (LQ)
➔ Lepton Flavor Violation (LFV)
➔ Single-top production
➔ Summary
The HERA Collider

- World's only electron proton collider, at DESY, Hamburg.
- HERA I (1992 – 2000): \( \sim 130 \text{ pb}^{-1} / \text{exp}, \text{mainly } e^+p. \)

- Two multipurpose detectors: H1 and ZEUS
- About 0.5 \( \text{fb}^{-1} \) of data collected by each of the experiments.
Deep Inelastic ep Scattering

**Neutral Current (NC)**

**Charged Current (CC)**
Contact Interactions

- Possible new interactions between $e$ and $q$ could modify the DIS cross section at high $Q^2$ via virtual effects.

- **Four-fermion eeqq contact interactions (CI)** → convenient method to investigate the interference of new fields.

- Effective Lagrangian for neutral current vector-like contact interactions:

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

  4 possible couplings for each $q$ flavor

- Various models can be constructed by appropriate choice of the coupling $\eta$
Full HERA neutral current data (0.44 fb$^{-1}$ per experiment) are used to set constraints at 95% CL on various CI models.

**General Compositeness**

- CI couplings related to the mass scale:
  \[
  \eta_{ab}^{eq} = \frac{\pm 4\pi}{\Lambda^2}
  \]

- Limit on effective mass scale:
  
  **H1**: \(\Lambda > 3.2 - 7.2\) TeV  
  **ZEUS**: \(\Lambda > 3.8 - 8.9\) TeV
Search for Contact Interactions at HERA


### Quark Radius

- Assuming spatial distribution of the electroweak charge of quark:

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

- Upper limit on quark radius:
  - **H1**: \( R < 0.65 \cdot 10^{-18} \text{ m} \)
  - **ZEUS**: \( R < 0.63 \cdot 10^{-18} \text{ m} \)

### Large Extra Dimensions

- ADD model: 4+n dimensions.
- Effective CI type coupling with scale \( M_S \):
  \[
  \eta_G \sim \frac{\lambda}{M_S^4}
  \]
- Lower limit on gravitational scale:
  - **H1**: \( M_S > 0.90 - 0.91 \text{ TeV} \)
  - **ZEUS**: \( M_S > 0.94 \text{ TeV} \)

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Moriond 2012, La Thuile, March 12

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Leptoquarks at HERA

- Leptoquarks (LQ), compound states of leptons and quarks
  
  Fermion number \( F = L + 3B \) \( F = 2 (e^p) \) \( F = 0 (e^+ p) \)

- **Buchmüller-Rückl-Wyler** framework: 14 different types (7 scalar, 7 vector)

- LQ at HERA:
  
  - **s-channel:** (resonant production)
  - **u-channel:** (LQ exchange)

  1st gen: \( e q \rightarrow LQ \rightarrow e(\nu)q \) (**LQ**)
  2nd gen: \( e q \rightarrow LQ \rightarrow \mu(\nu)q \) (**LFV**)
  3rd gen: \( e q \rightarrow LQ \rightarrow \tau(\nu)q \) (**LFV**)

- Signature is similar to NC or CC DIS.

- Leptoquarks are chiral particles → additional sensitivity at HERA due to polarised lepton beam
Search for First Generation LQs

Full HERA NC and CC data were analysed by H1 and ZEUS.

No evidence for LQ signal found → results are interpreted in terms of exclusion limits.
Search for First Generation LQs

- The exclusion ranges for vector type leptoquarks from ZEUS and H1.
- $eq \rightarrow LQ \rightarrow e(\nu)q$ excluded by ZEUS up to 630 GeV for $\lambda = 0.3$ (EM coupling strength) and by H1 up to 800 GeV.

**ZEUS**

F=0 vector LQ limit

ZEUS (prel.) $e^+p$ (498 pb$^{-1}$)

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**H1**

Search for First Generation F = 2 Vector Leptoquarks

Excluded at 95% CL

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Search for LFV: Second and Third Generation LQs

No evidence for LQ signal found $\rightarrow$ results are interpreted in terms of exclusion limits.

- $e^i q \rightarrow LQ \rightarrow \mu q$ excluded up to 712 GeV for $\lambda = 0.3$.
- $e^i q \rightarrow LQ \rightarrow \tau q$ excluded up to 479 GeV for $\lambda = 0.3$.

DESY 11-044, arXiv:1103.4938
Search for Single-top production in ep Collisions at HERA


- SM cross section for single top quarks at HERA is very small \( \sim 1 \text{fb} \).
- However flavor changing neutral current (FCNC) processes could enhance single-top production.

- A search for deviations from the SM due to FCNC top production was performed by ZEUS using full HERA data.
- No deviations from the SM were observed, the results were used to set limits on anomalous top production.
Summary

- Searches based on the full HERA data performed by the H1 and ZEUS collaborations.
- Data show good agreement with the Standard Model predictions.
- Exclusion limits at 95% CL are determined for:
  - Compositeness (3.8 - 8.9 TeV)
  - Large Extra dimensions (0.94 TeV)
  - Quark Radius (0.63 \cdot 10^{-18} m)
  - First Generation LQs (up to 800 GeV)
  - LFV LQs (up to 712 GeV)
  - Single top (Br_{uz} up to 0.3, Br_{uy} up to 0.04)
- HERA provides limits competitive with the rest of the world.