Search For Contact Interactions at HERA

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On behalf of the H1 Collaboration

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Outline

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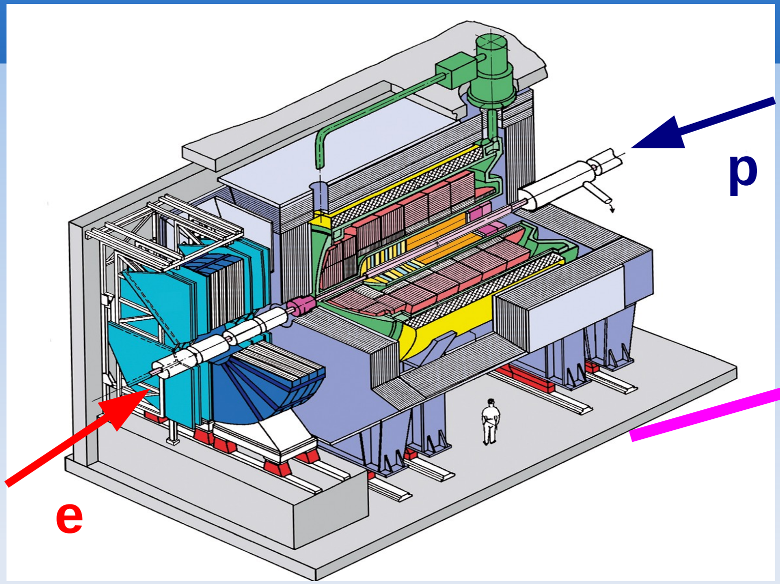
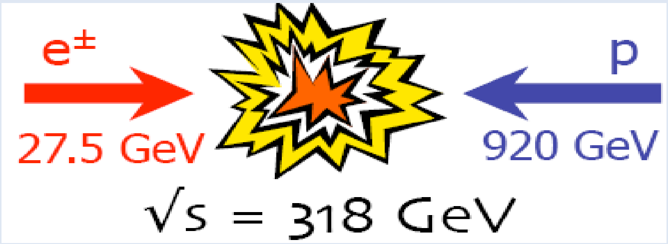
- Deep Inelastic Scattering at HERA
- Contact Interactions results
- Summary

HERA Collider and H1 Experiment

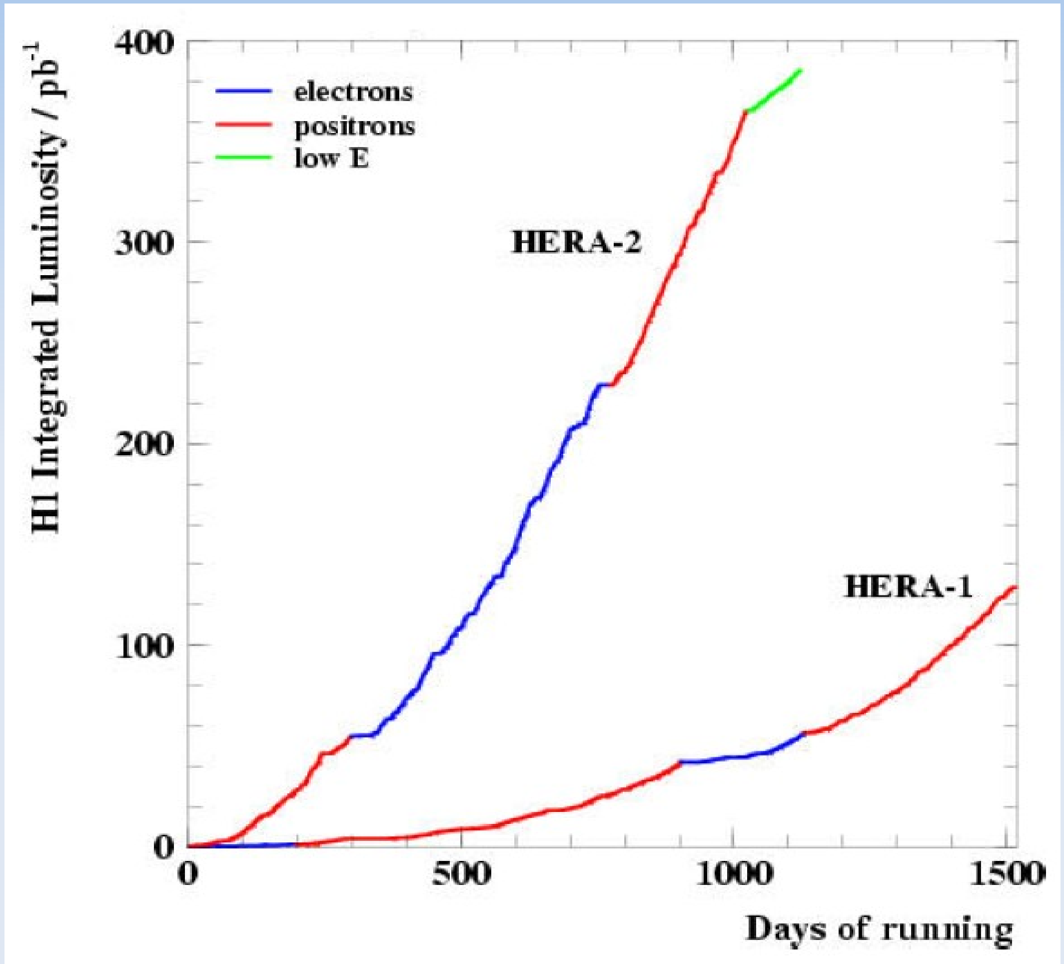




- World's only electron proton collider, at DESY, Hamburg.
- Was operating from 1992 to 2007.
- Two collider experiments H1 and ZEUS.

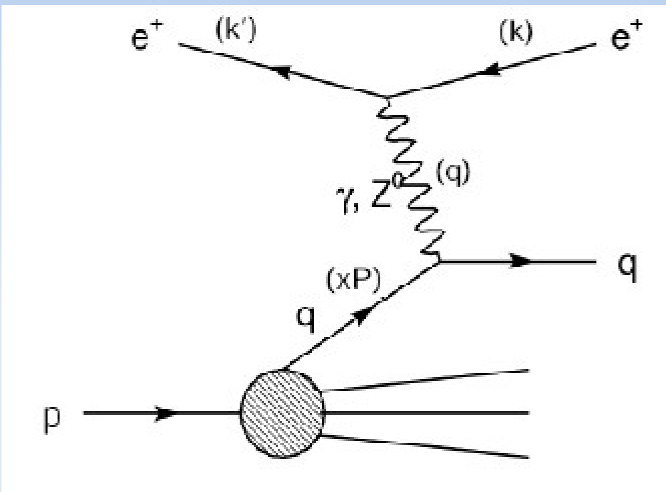
HERA Collider and H1 Experiment

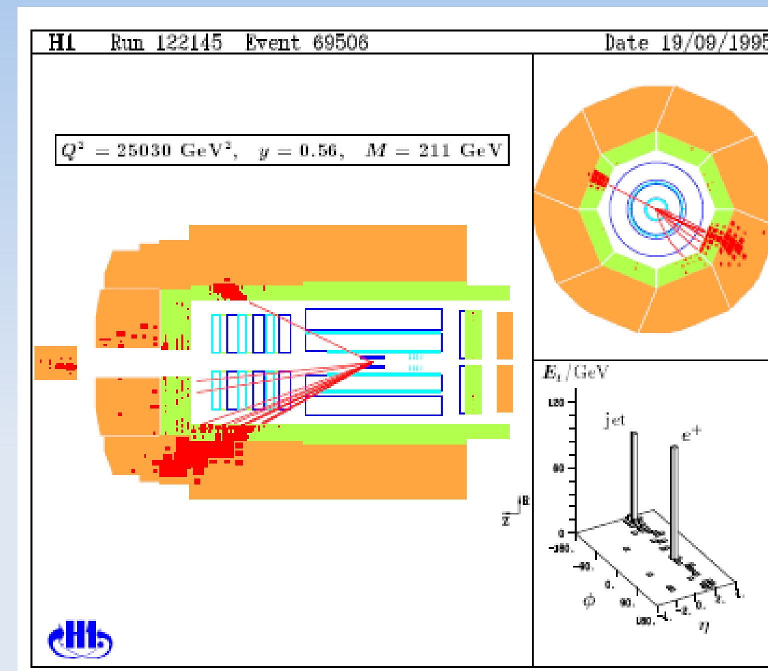
- 1994 – 2000: HERA I data.
- 2003 – 2007: HERA II data (luminosity upgrade)
- H1 experiment collected about $0.5 fb^{-1}$ data.



Deep Inelastic ep Scattering

Neutral Current Deep Inelastic scattering process:





Kinematic variables:

$$Q^2 = -q^2 = -(k - k')$$

$$x = \frac{Q^2}{2(P \cdot q)} \qquad y = \frac{P \cdot (k - k')}{P \cdot k}$$

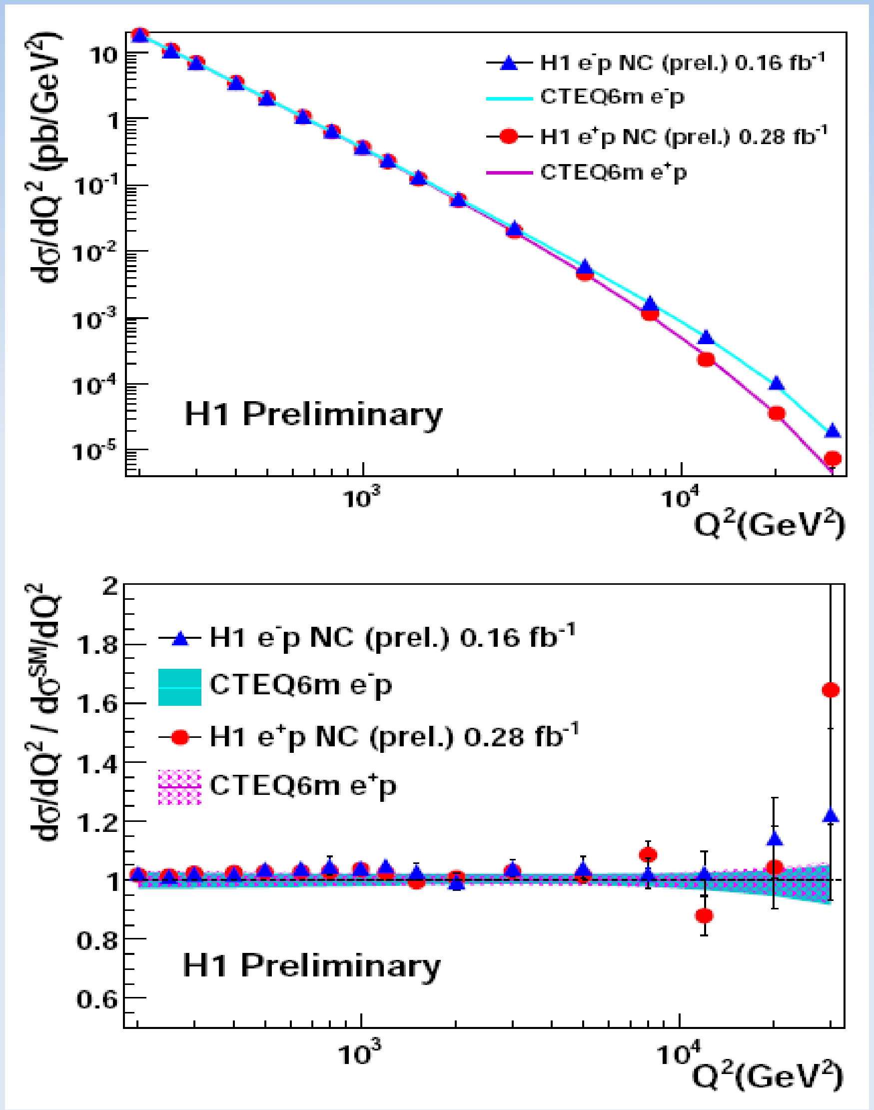
$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

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.

Deep Inelastic ep Scattering



- 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)

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

- 4 possible η coupling coefficients for each q flavor
- Any particular model can be constructed by appropriate choice of the coupling η
- Models currently tested:
  - compositeness
  - leptoquarks
  - large extra dimensions
  - quark radius

General (Compositeness) Models

Contact interactions coupling are related to the mass scale via:

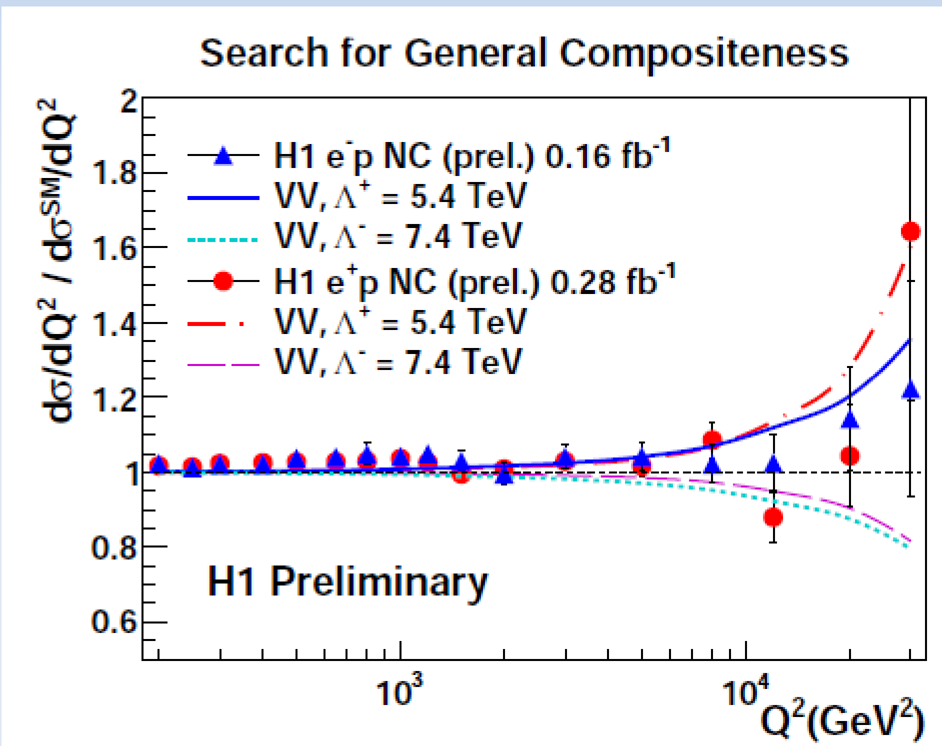
$$\eta_{ab}^{eq} = \frac{\pm 4\pi}{\Lambda^2}$$

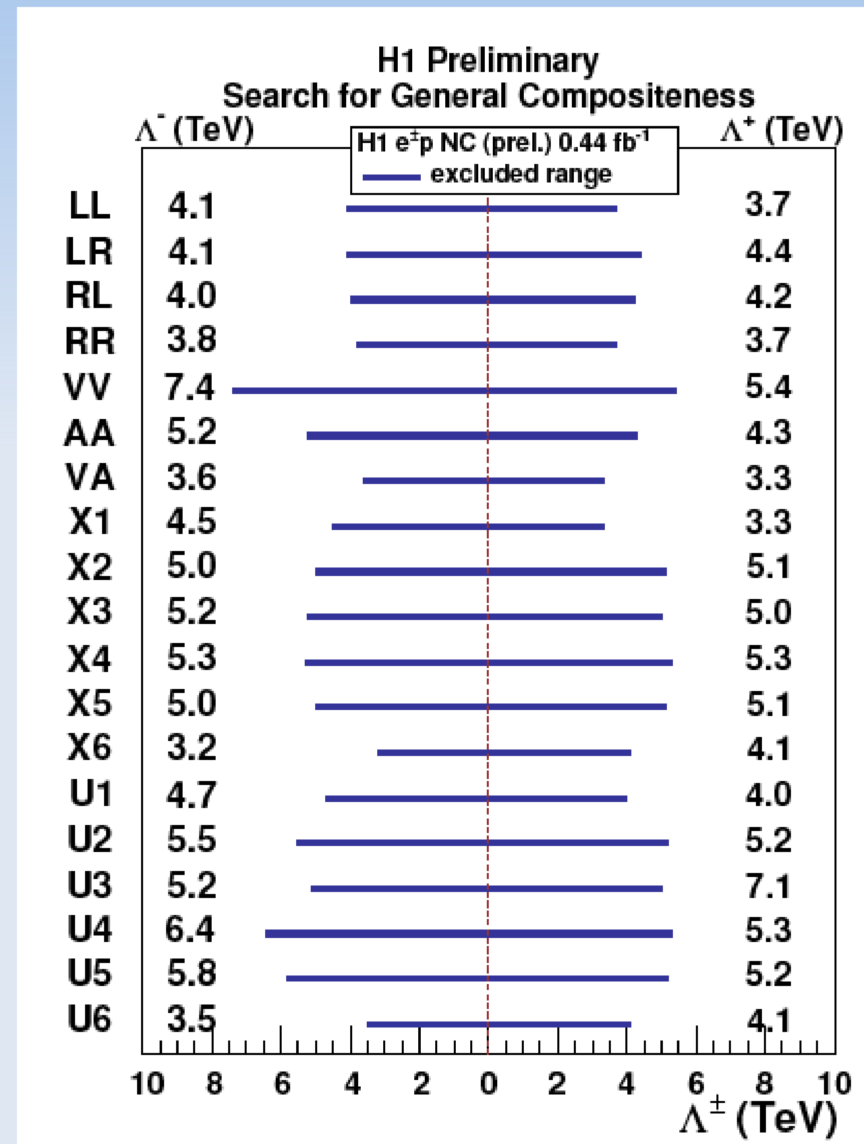
Different models assume different helicity structure of new interactions, given by a set of η couplings

Models conserving parity:								
Model	η_{LL}^{ed}	η_{LR}^{ed}	η_{RL}^{ed}	η_{RR}^{ed}	η_{LL}^{eu}	η_{LR}^{eu}	η_{RL}^{eu}	η_{RR}^{eu}
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$	
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$	
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$
U1					$+\eta$	$-\eta$		
U2					$+\eta$		$+\eta$	
U3					$+\eta$			$+\eta$
U4						$+\eta$	$+\eta$	
U5						$+\eta$		$+\eta$
U6							$+\eta$	$-\eta$
Models violating parity:								
LL	$+\eta$				$+\eta$			
LR		$+\eta$				$+\eta$		
RL			$+\eta$				$+\eta$	
RR				$+\eta$				$+\eta$

General (Compositeness) Models

95% CL lower limits on Λ compositeness scale between *3.2 – 7.4 TeV*.





Leptoquarks

For high mass leptoquarks

$$M_{LQ} \gg \sqrt{s}$$

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

$$\eta_{LQ} \sim \left(\frac{\lambda}{M_{LQ}} \right)^2$$

where λ is the leptoquark Yukava coupling.

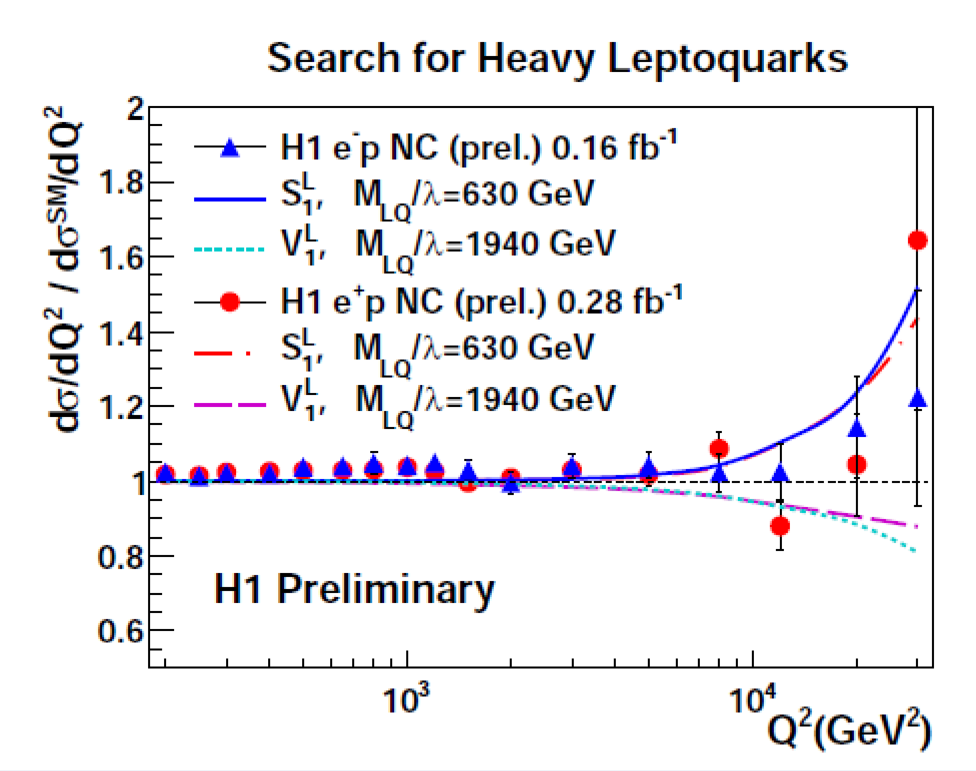
$\eta^q_{ab} = \epsilon^q_{ab} \cdot (\lambda / M_{LQ})^2$

LQ	ϵ^u_{ab}	ϵ^d_{ab}	F
S^L_0	$\epsilon^u_{LL} = +\frac{1}{2}$		2
S^R_0	$\epsilon^u_{RR} = +\frac{1}{2}$		2
$\tilde{S}^R_0$		$\epsilon^d_{RR} = +\frac{1}{2}$	2
$S^L_{1/2}$	$\epsilon^u_{LR} = -\frac{1}{2}$		0
$S^R_{1/2}$	$\epsilon^u_{RL} = -\frac{1}{2}$	$\epsilon^d_{RL} = -\frac{1}{2}$	0
$\tilde{S}^L_{1/2}$		$\epsilon^d_{LR} = -\frac{1}{2}$	0
S^L_1	$\epsilon^u_{LL} = +\frac{1}{2}$	$\epsilon^d_{LL} = +1$	2
V^L_0		$\epsilon^d_{LL} = -1$	0
V^R_0		$\epsilon^d_{RR} = -1$	0
$\tilde{V}^R_0$	$\epsilon^u_{RR} = -1$		0
$V^L_{1/2}$		$\epsilon^d_{LR} = +1$	2
$V^R_{1/2}$	$\epsilon^u_{RL} = +1$	$\epsilon^d_{RL} = +1$	2
$\tilde{V}^L_{1/2}$	$\epsilon^u_{LR} = +1$		2
V^L_1	$\epsilon^u_{LL} = -2$	$\epsilon^d_{LL} = -1$	0

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*.



Large Extra Dimensions

- 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:

$$\eta_G \sim \lambda / M_S^4$$

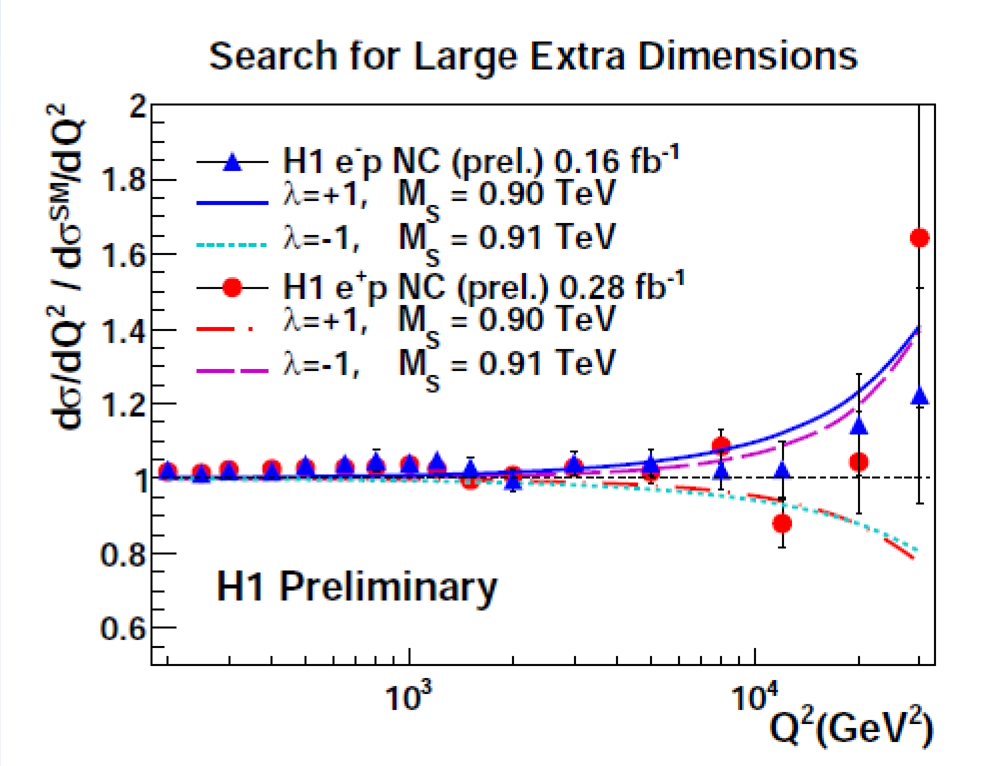
where λ is the coupling strength

Large Extra Dimensions

95% CL lower limits on *M* gravitation scale depending on the sign:

$$M_S^+ > 0.90\ TeV$$

$$M_S^- > 0.91\ TeV$$



Quark Radius

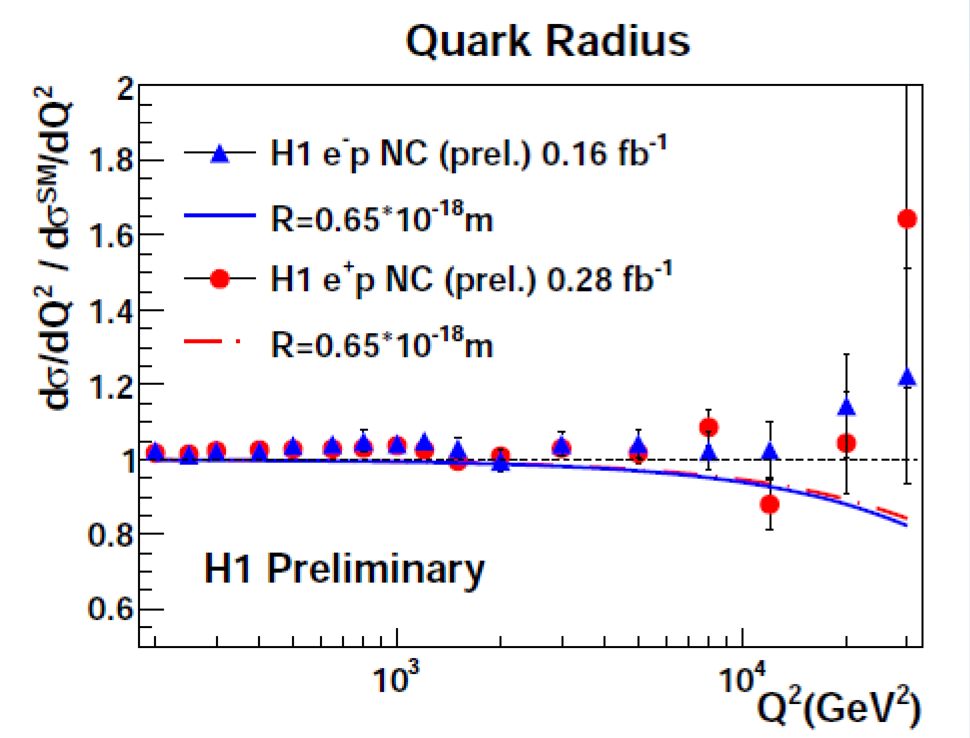
Finite size of the quark can be defined by introducing spatial distribution of the electroweak charge:

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

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

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

$$R < 0.65 \cdot 10^{-18}\, m$$



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 ($0.65 * 10^{-18} m$)

Backup

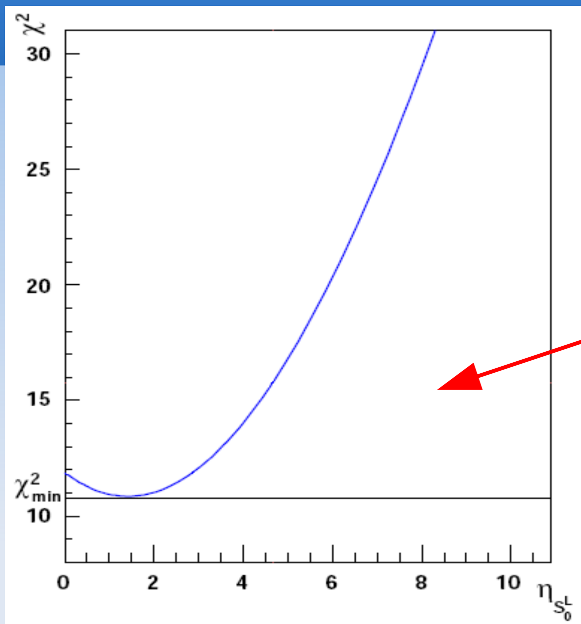
χ^2 Function (arXiv:0911.0884v2 [hep-ex])

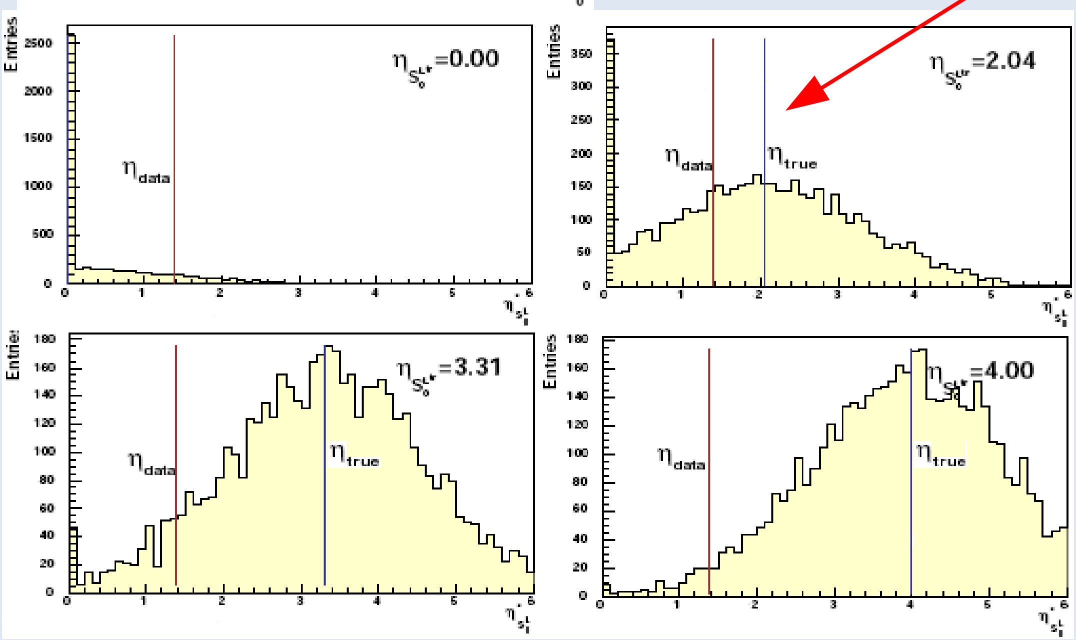
$$\chi^2 = \sum_i \frac{\left(\sigma_i^{\exp} - \sigma_i^{theo}\left[1 - \sum_k \Delta_{ik}^{corr}(\epsilon_k)\right]\right)^2}{\left(\delta_{i,stat}^2 \sigma_i^{\exp} \sigma_i^{theo}\left[1 - \sum_k \Delta_{ik}^{corr}(\epsilon_k)\right] + (\delta_{i,uncorr}\,\sigma_i^{theo})^2\right)} + \sum_k \epsilon_k^2$$

The χ^2 function is used as a measure of agreement between data and different theoretical predictions. The presented form of χ^2 function takes into account correlated systematic uncertainties for the H1 cross section measurements.

$\sigma_i^{\exp}$	*experimental cross section in Q^2 bin i*
σ_i^{theo}	*theoretical cross section*
$\Delta_{ik}(\epsilon_k)$	*effect due to correlated error k for bin i*
$\delta_{i,stat}$	*relative statistical error*
$\delta_{i,uncorr}$	*relative uncorrelated error*
ϵ_1	*f_{norm} normalization*
ϵ_2	*electron energy scale*
ϵ_3	*polar angle uncertainty*
ϵ_4	*PDF uncertainty*

Limit Estimation





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

2. For each η a number of MC experiments is performed. For each MC experiment χ_{min}^2 and corresponding η_{mce} is determined.

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