

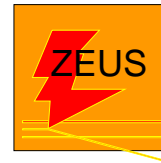
Searches for Contact Interactions at HERA

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for



XVI International Workshop on Deep-Inelastic Scattering and Related Subjects
7-11 April 2008, University College London



Outline

- Introduction
HERA running



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- Neutral Current Deep Inelastic $e^\pm p$ Scattering
Possible Contact Interaction contribution



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Possible Contact Interaction contribution
- Contact Interaction results
Compositeness models
Large Extra Dimensions
Heavy leptoquarks
Quark form factor



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 - Possible Contact Interaction contribution
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 - Compositeness models
 - Large Extra Dimensions
 - Heavy leptoquarks
 - Quark form factor
- Conclusions

Introduction

HERA

electron(positron)-proton collider at DESY

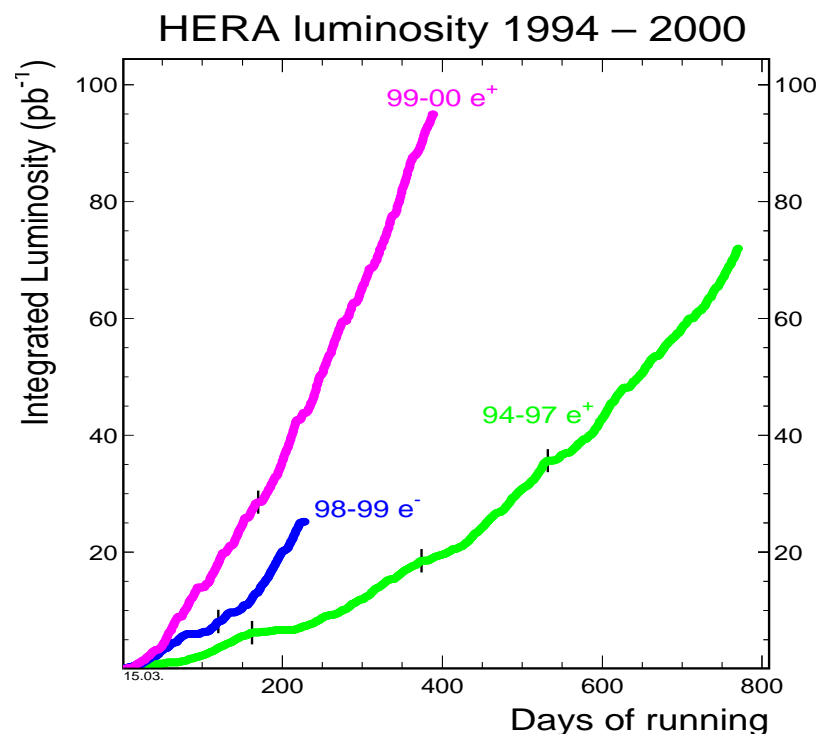


HERA I

1994-2000

over 100 pb^{-1} collected per experiment

mainly e^+p data





Introduction

HERA

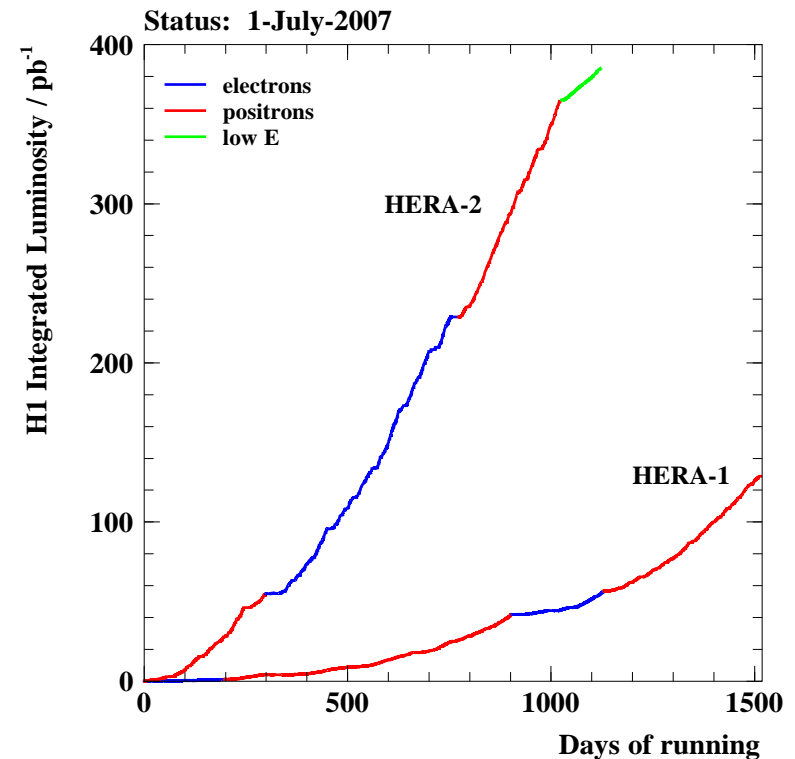
electron(positron)-proton collider at DESY



HERA I 1994-2000
over $100 pb^{-1}$ collected per experiment
mainly e^+p data

HERA II 2002-2007
about $400 pb^{-1}$ per experiment
similar amount of e^-p and e^+p data

$\sim 20 pb^{-1}$ of data from low and medium energy running: not considered here

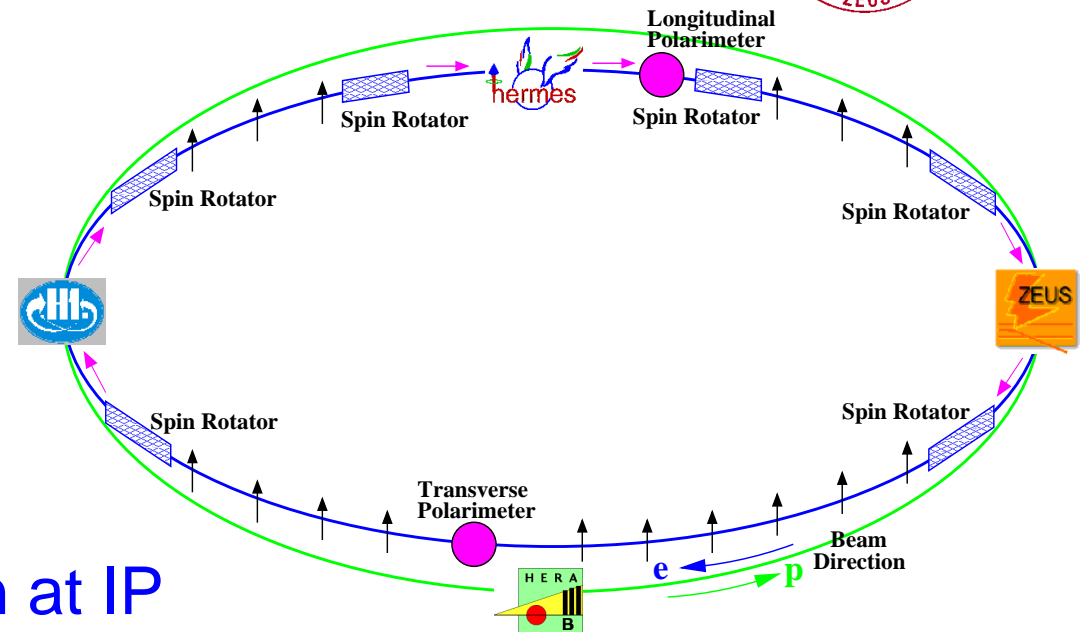


Introduction

HERA II

Through the emission of synchrotron radiation **electron beam** at HERA becomes transversely polarized

Spin Rotators installed to obtain longitudinal polarization at IP

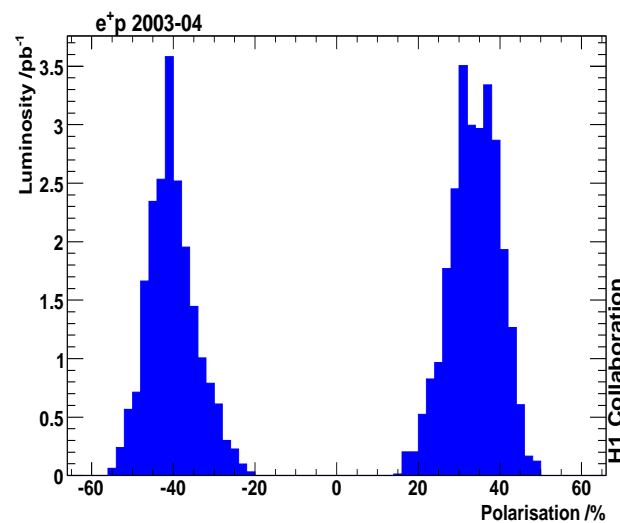
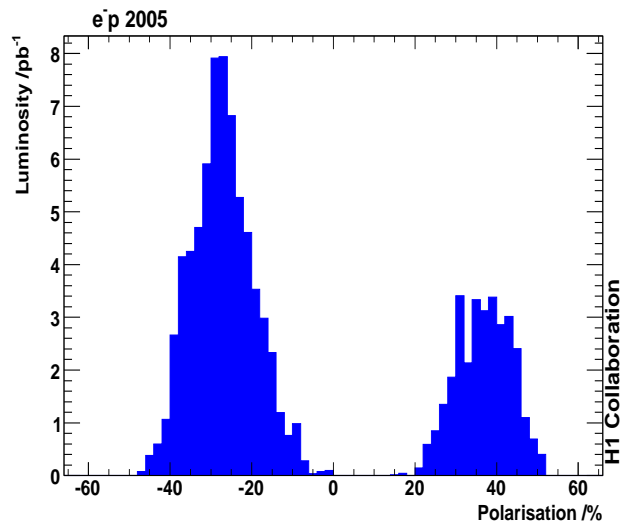
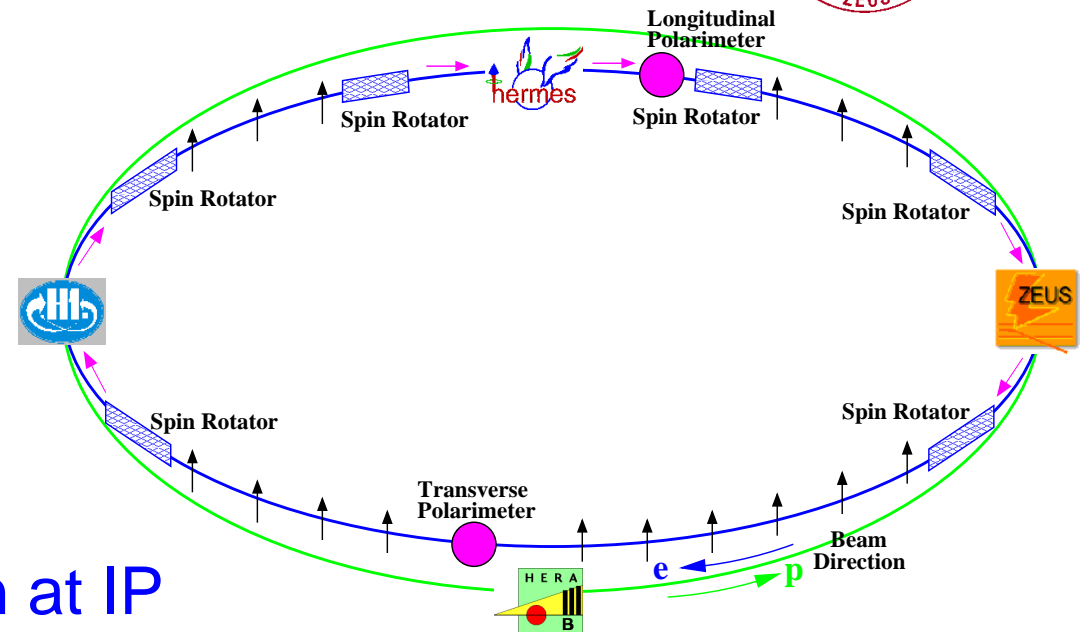


Introduction

HERA II

Through the emission of synchrotron radiation **electron beam** at HERA becomes transversely polarized

Spin Rotators installed to obtain longitudinal polarization at IP



Polarization measured in dedicated polarimeters

Average polarization
30-40%

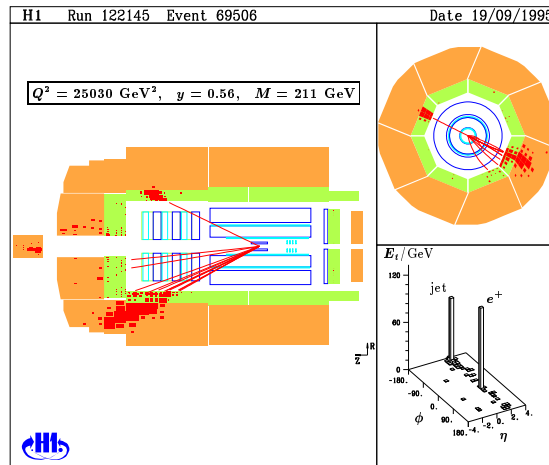


Deep Inelastic $e^\pm p$ Scattering

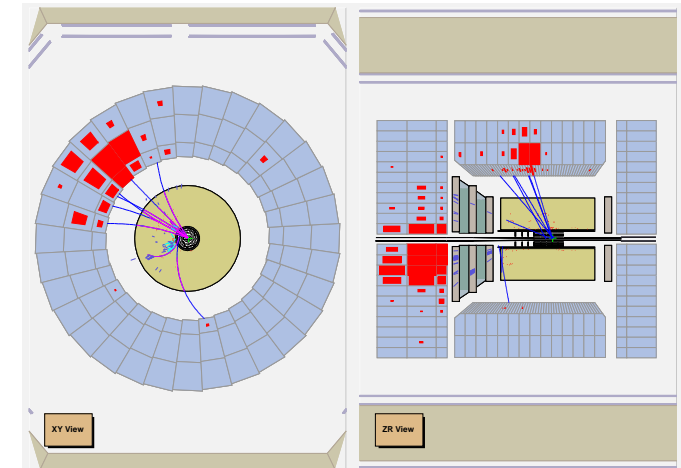


Main process studied at H1 and ZEUS

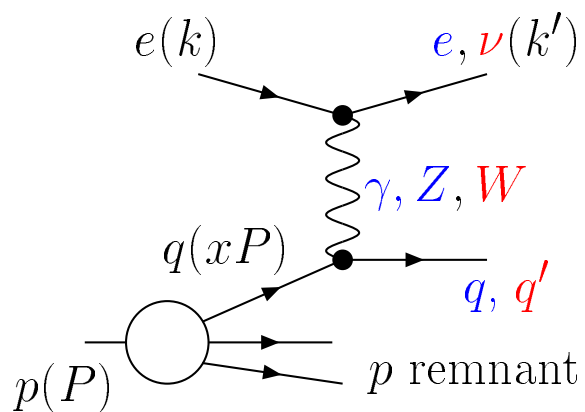
NC DIS



CC DIS



Kinematic variables:



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

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

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

[virtuality] of the exchanged boson

⇒ spatial resolution $\lambda \sim 1/Q$

⇒ sensitivity to mass scales $\Lambda \sim Q$

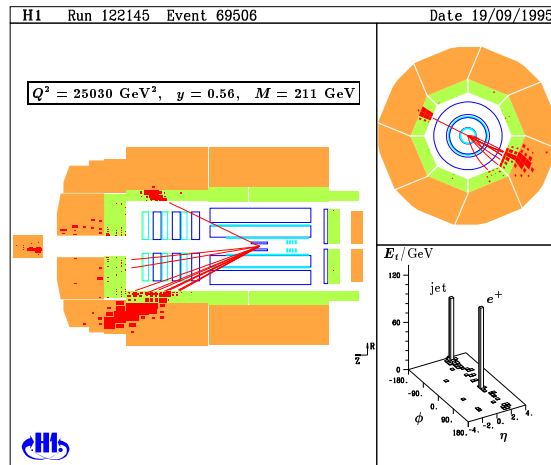


Deep Inelastic $e^\pm p$ Scattering

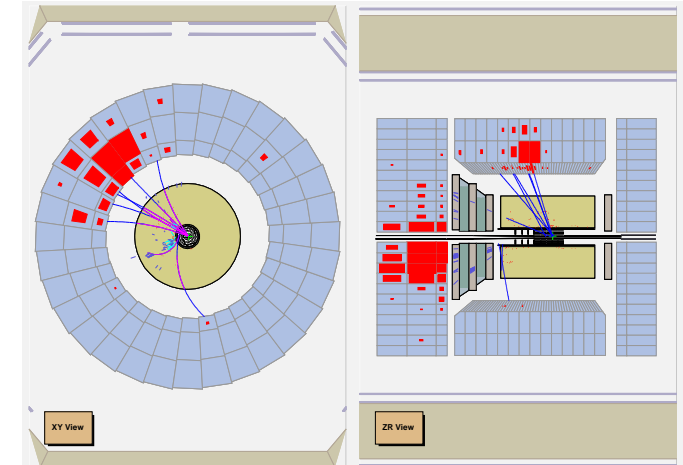


Main process studied at H1 and ZEUS

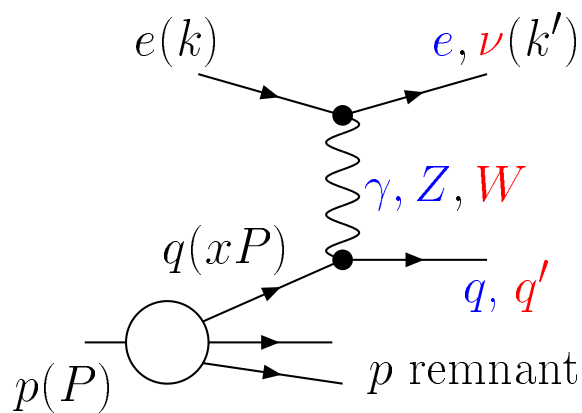
NC DIS



CC DIS



Kinematic variables:



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

[virtuality] of the exchanged boson

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

fraction of proton momenta carried by struck quark

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

fraction of lepton energy transferred in the proton rest frame



Deep Inelastic $e^\pm p$ Scattering



Neutral Current DIS at **highest Q^2**
 Z^0 contribution significant

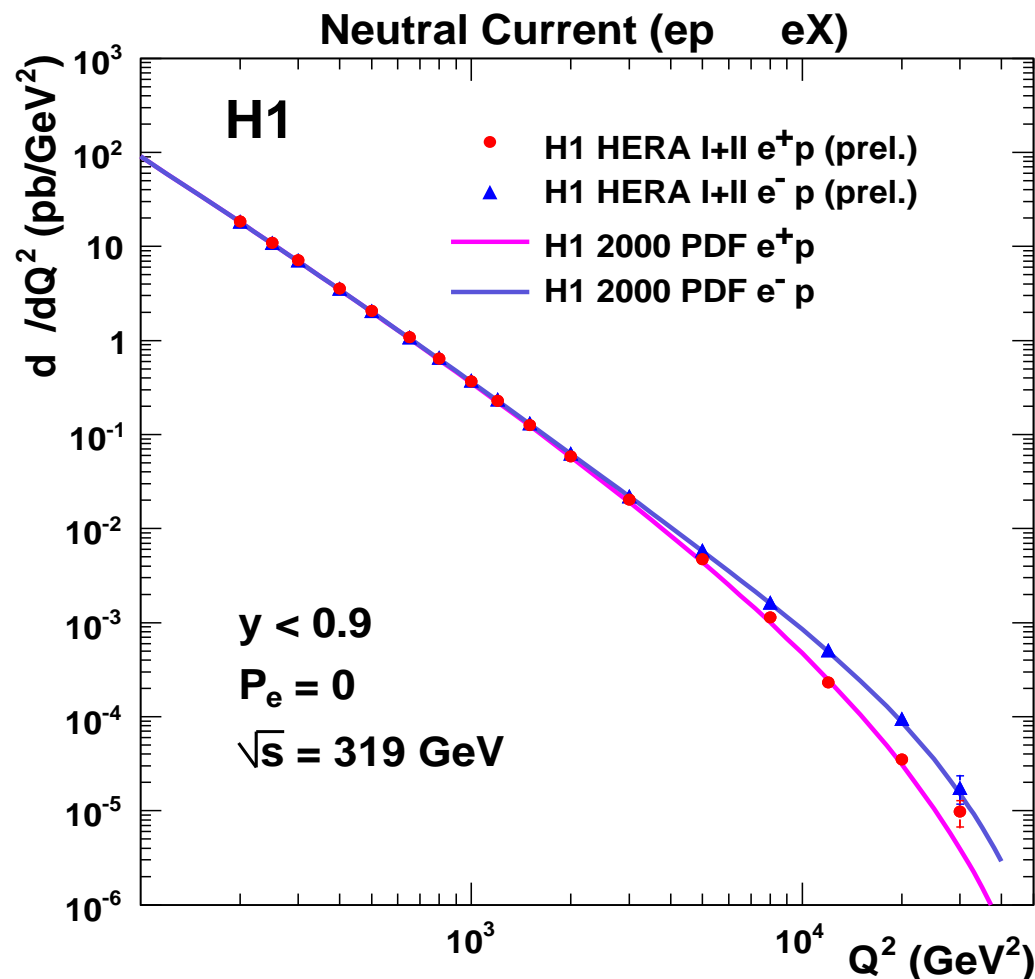
Excellent agreement of **precise**
data with **Standard Model** over
many orders of magnitude
 \Rightarrow test ground for SM and QCD

Contact Interactions analysis:
search for possible deviations at
highest Q^2

Considered data samples:

ZEUS: $Q^2 > 1000 \text{ GeV}^2$

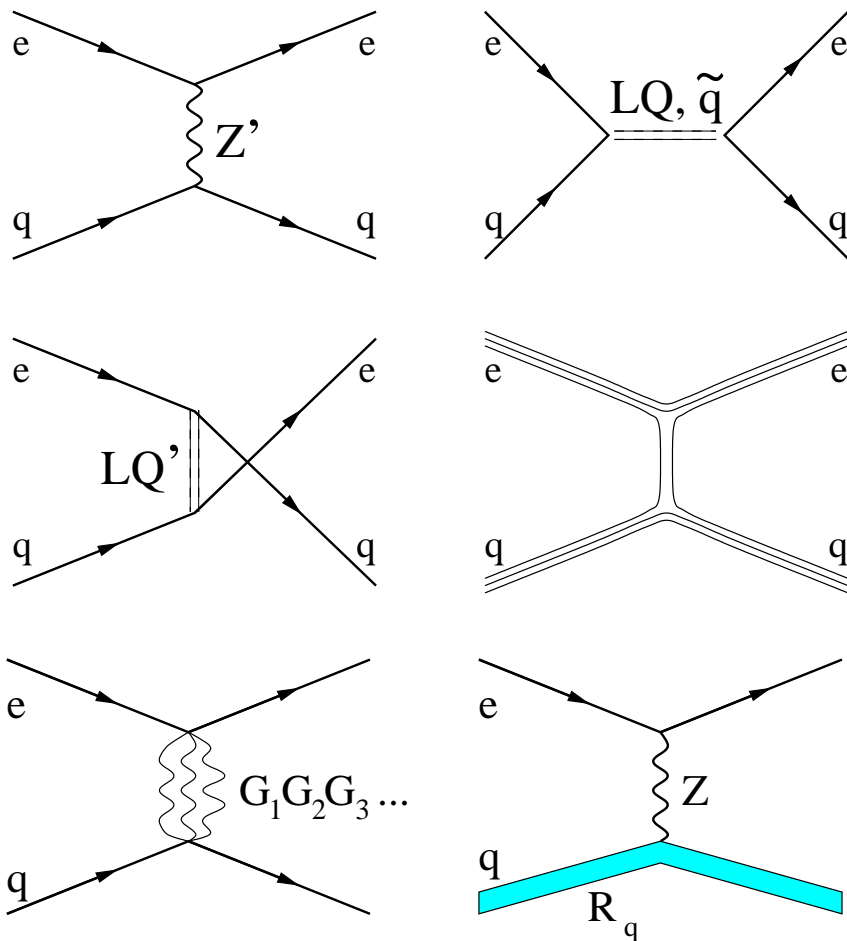
H1: $Q^2 > 200 \text{ GeV}^2$



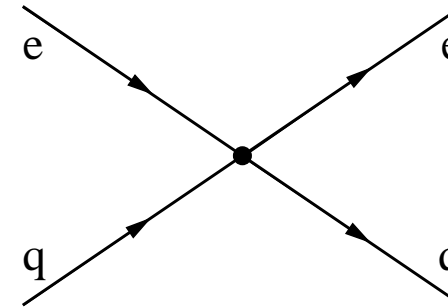
Deep Inelastic $e^\pm p$ Scattering



Possible “new physics” in NC DIS:



For \sqrt{s} much smaller than process scale Λ
 \Rightarrow effective parametrization:



$eeqq$ contact interactions (CI)

Effective Lagrangian for **vector** $eeqq$ contact interactions:

$$\mathcal{L}_{CI} = \sum_{\alpha, \beta=L,R} \eta_{\alpha\beta}^{eq} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha) (\bar{q}_\beta \gamma_\mu q_\beta)$$

$\eta_{\alpha\beta}^{eq}$ - 4 possible couplings for every flavor q

Scalar and tensor CI constrained beyond HERA sensitivity.

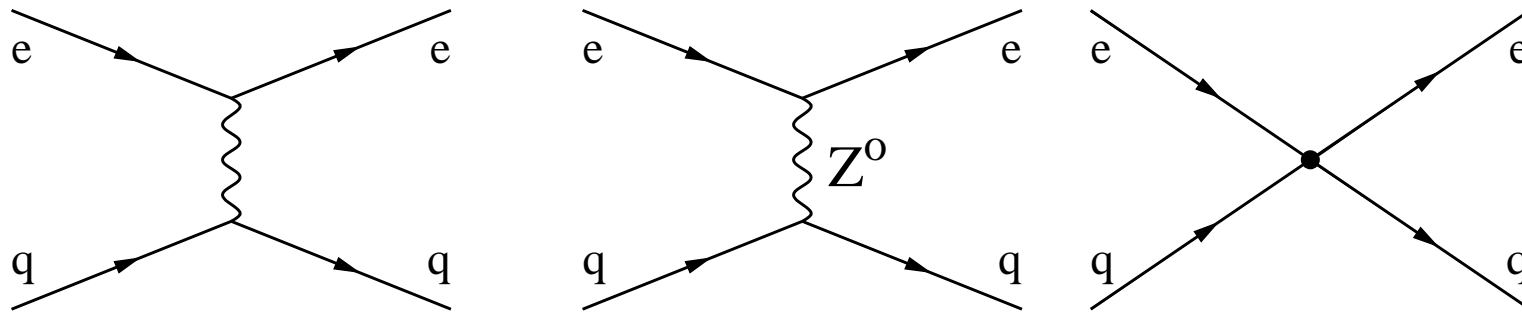




Deep Inelastic $e^\pm p$ Scattering

Contact Interactions

Contact Interactions modify tree level $eq \rightarrow eq$ scattering amplitudes $M_{\alpha\beta}^{eq}$:



$$M_{\alpha\beta}^{eq}(Q^2) = \frac{e^2 e_q}{Q^2} - \frac{e^2}{\sin^2\theta_W \cdot \cos^2\theta_W} \cdot \frac{g_\alpha^e g_\beta^q}{Q^2 + m_Z^2} + \eta_{\alpha\beta}^{eq}$$

$\alpha, \beta = L, R$ γ Z^0 ?

Different models assume different **helicity structure** of new interactions, given by set of couplings $\eta_{\alpha\beta}^{eq}$ (4 for every flavor q)



Deep Inelastic $e^\pm p$ Scattering



Cross-section formula Leading Order

For NC $e^\pm p$ DIS with unpolarized beam

$$\frac{d^2\sigma^{e^-p}}{dxdy} = \frac{sx}{16\pi} \sum_q q(x) \left\{ |M_{LL}^{eq}|^2 + |M_{RR}^{eq}|^2 + (1-y)^2 [|M_{LR}^{eq}|^2 + |M_{RL}^{eq}|^2] \right\} \\ + \bar{q}(x) \left\{ |M_{LR}^{eq}|^2 + |M_{RL}^{eq}|^2 + (1-y)^2 [|M_{LL}^{eq}|^2 + |M_{RR}^{eq}|^2] \right\}$$

$$\frac{d^2\sigma^{e^+p}}{dxdy} = \frac{sx}{16\pi} \sum_q q(x) \left\{ |M_{LR}^{eq}|^2 + |M_{RL}^{eq}|^2 + (1-y)^2 [|M_{LL}^{eq}|^2 + |M_{RR}^{eq}|^2] \right\} \\ + \bar{q}(x) \left\{ |M_{LL}^{eq}|^2 + |M_{RR}^{eq}|^2 + (1-y)^2 [|M_{LR}^{eq}|^2 + |M_{RL}^{eq}|^2] \right\}$$

e^-p most sensitive to η_{LL}^{eq} and η_{RR}^{eq}

e^+p most sensitive to η_{LR}^{eq} and η_{RL}^{eq} (q=u,d)





Deep Inelastic $e^\pm p$ Scattering

Cross-section formula Leading Order

For NC $e^\pm p$ DIS with polarized beam

$$\frac{d^2\sigma^{e^-p}}{dxdy} = \frac{sx}{16\pi} \sum_q q(x) \left\{ \mathcal{P}_- |M_{LL}^{eq}|^2 + \mathcal{P}_+ |M_{RR}^{eq}|^2 + (1-y)^2 [\mathcal{P}_- |M_{LR}^{eq}|^2 + \mathcal{P}_+ |M_{RL}^{eq}|^2] \right\} \\ + \bar{q}(x) \left\{ \mathcal{P}_- |M_{LR}^{eq}|^2 + \mathcal{P}_+ |M_{RL}^{eq}|^2 + (1-y)^2 [\mathcal{P}_- |M_{LL}^{eq}|^2 + \mathcal{P}_+ |M_{RR}^{eq}|^2] \right\}$$

$$\frac{d^2\sigma^{e^+p}}{dxdy} = \frac{sx}{16\pi} \sum_q q(x) \left\{ \mathcal{P}_+ |M_{LR}^{eq}|^2 + \mathcal{P}_- |M_{RL}^{eq}|^2 + (1-y)^2 [\mathcal{P}_+ |M_{LL}^{eq}|^2 + \mathcal{P}_- |M_{RR}^{eq}|^2] \right\} \\ + \bar{q}(x) \left\{ \mathcal{P}_+ |M_{LL}^{eq}|^2 + \mathcal{P}_- |M_{RR}^{eq}|^2 + (1-y)^2 [\mathcal{P}_+ |M_{LR}^{eq}|^2 + \mathcal{P}_- |M_{RL}^{eq}|^2] \right\}$$

e^-p most sensitive to η_{LL}^{eq} and η_{RR}^{eq}

e^+p most sensitive to η_{LR}^{eq} and η_{RL}^{eq} (q=u,d)

where: $\mathcal{P}_\pm = (1 \pm P)$ P is lepton beam polarization

Combining polarized e^+p and e^-p data we can set better constraints on $M_{\alpha\beta}^{eq}$





Contact Interaction results

General models

Also referred to as **compositeness models**

Couplings $\eta_{\alpha\beta}^{eq}$ are related to the “new physics” mass scale Λ by the formula:

$$\eta = \frac{\varepsilon \cdot g_{CI}^2}{\Lambda^2}$$

where g_{CI} is the coupling strength of new interactions and $\varepsilon = \pm 1$.

By convention we set $g_{CI}^2 = 4\pi$.

Models **conserving parity**:

$$\eta_{LL}^{eq} + \eta_{LR}^{eq} - \eta_{RL}^{eq} - \eta_{RR}^{eq} = 0$$

Family universality assumed !

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				$+\eta$				$+\eta$



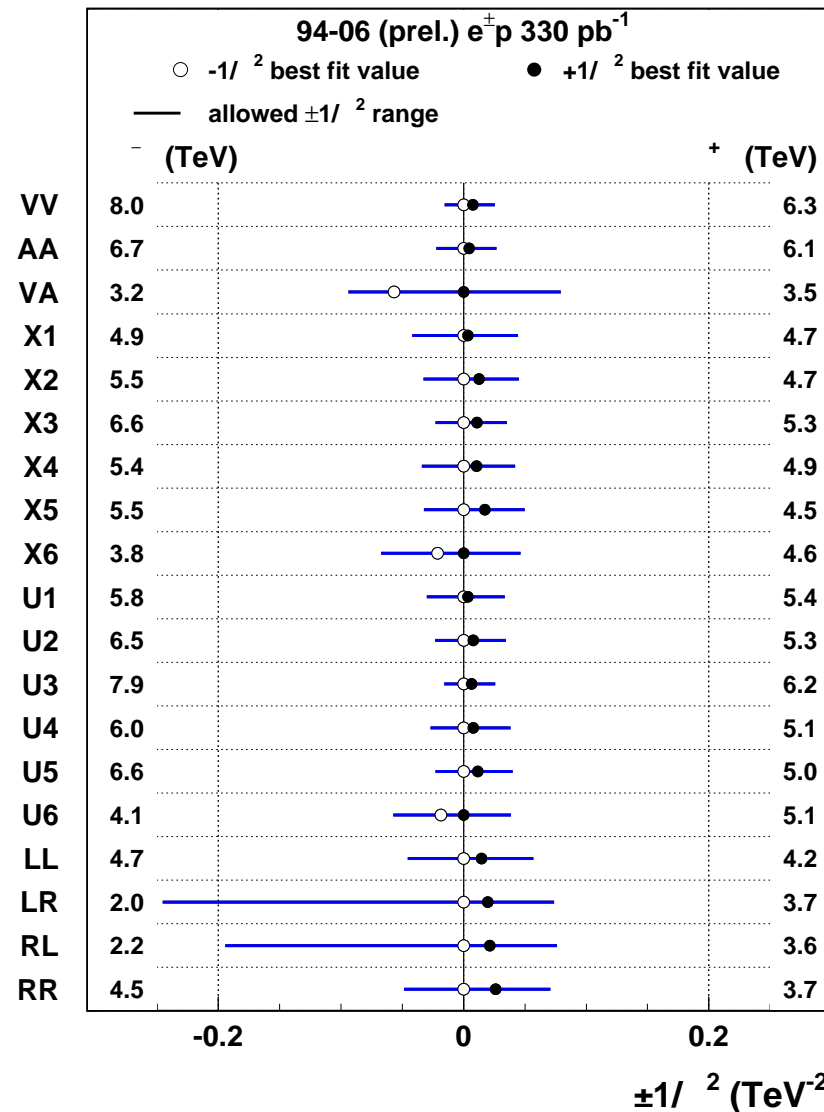
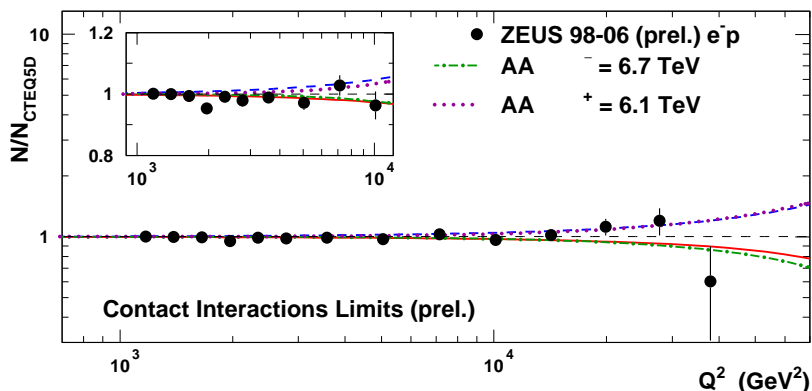
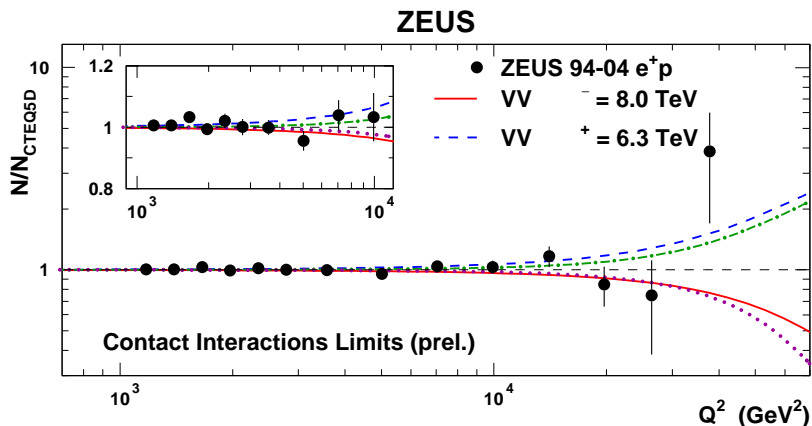


Contact Interaction results

ZEUS

General models

ZEUS data 1994-2006 compared with SM:



ZEUS 95% CL limits: $\Lambda > 2.0 - 8.0$ TeV

H1 95% CL limits: $\Lambda > 1.6 - 5.5$ TeV (HERA I; Phys Lett B568 (2003) 35-47)



Contact Interaction results

Large Extra Dimensions

Arkani-Hamed–Dimopoulos–Dvali Model

If gravity propagates in $4 + \delta$ D, effective mass scale M_S can be as low as 1 TeV.

⇒ gravity becomes comparable in strength to electroweak interactions.

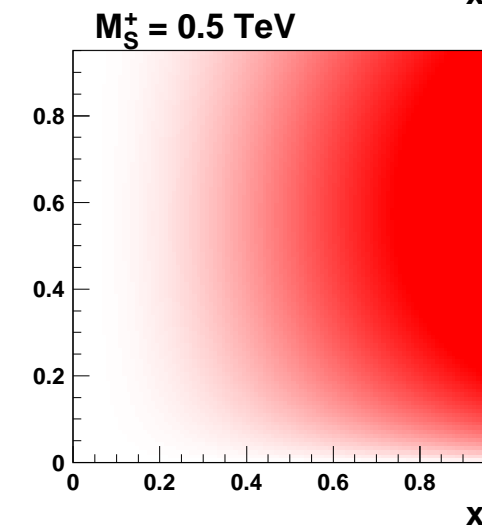
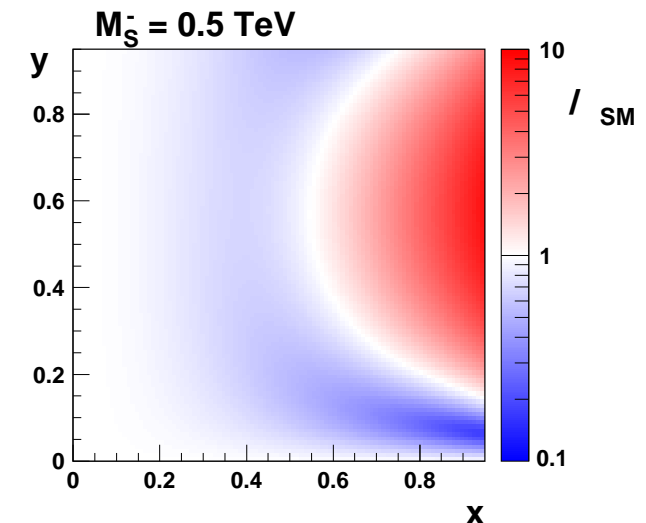
Contribution of graviton (Kaluza-Klein tower) exchange to the $e^\pm p$ NC DIS:

effective contact interaction type **coupling**

$$\eta_G = \pm \lambda \cdot \frac{\mathcal{E}^2}{M_S^4}$$

where λ is the coupling strength and \mathcal{E} is related to the energy scales of hard interaction. (\sqrt{s}, Q^2)

Cross-section deviations for $e^- p$:



Contact Interaction results

Large Extra Dimensions

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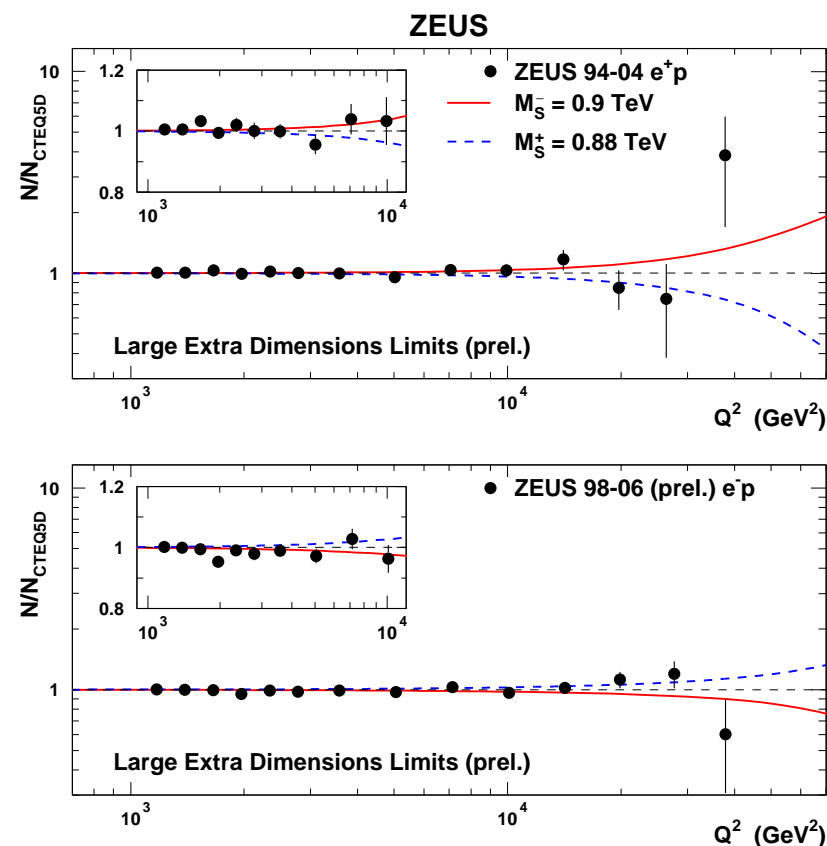
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where λ is the coupling strength and \mathcal{E} is related to the energy scales of hard interaction. (\sqrt{s}, Q^2)

ZEUS data 1994-2006:



ZEUS 95% CL limits:

$$M_S^- > 0.90 \text{ TeV}, M_S^+ > 0.88 \text{ TeV}$$

H1 (HERA I): $M_S^- > 0.78 \text{ TeV}, M_S^+ > 0.82 \text{ TeV}$





Contact Interaction results

Quark form factor

“classical” method to look for possible fermion (sub)structure.

If a quark has **finite size**, the standard model cross-section is expected to decrease at high momentum transfer:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot \left[1 - \frac{R_q^2}{6} Q^2 \right]^2 \cdot \left[1 - \frac{R_e^2}{6} Q^2 \right]^2$$

where R_q is the root mean-square radius of the electroweak charge distribution in the quark.

We do not consider the possibility of finite electron size...

same dependence expected for e^+p and e^-p !

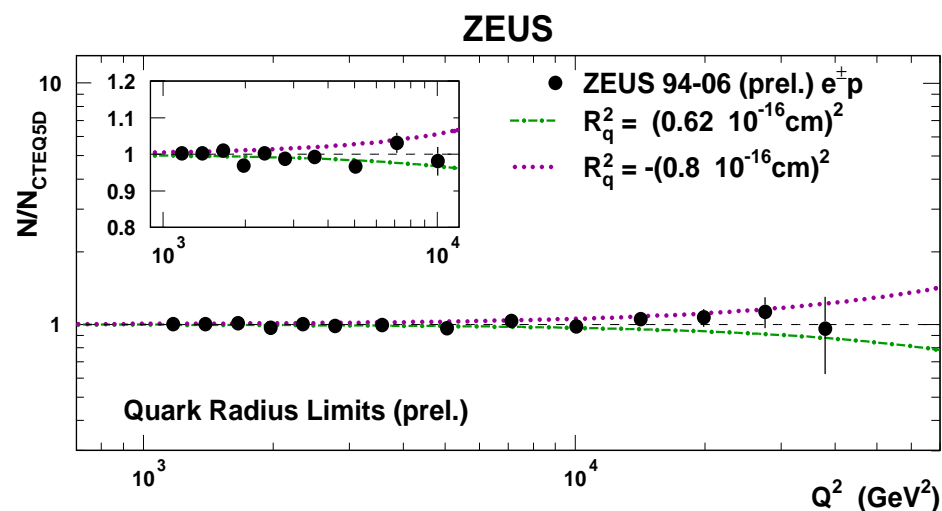
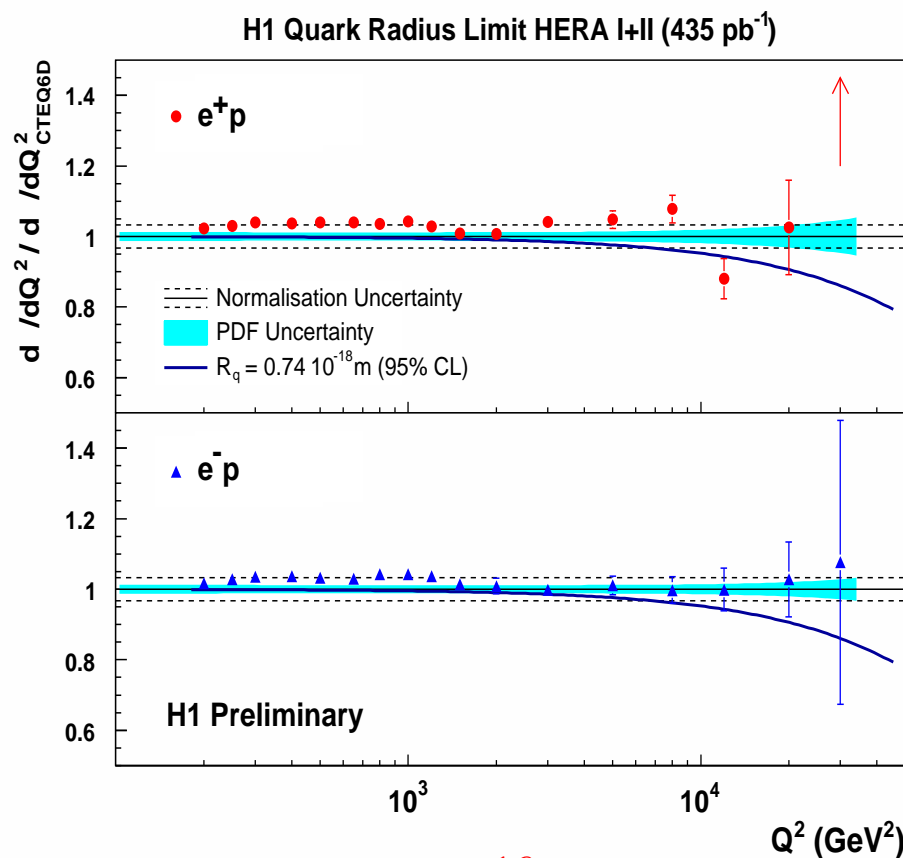


Contact Interaction results

Quark form factor

H1 1994-2007:

ZEUS 1994-2006:



$$R_q < 0.62 \cdot 10^{-16} \text{ cm}$$

$$R_q < 0.74 \cdot 10^{-16} \text{ cm} \quad (\text{H1prelim-07-141 for LP'2007})$$



Contact Interaction results

High mass leptoquarks

For high mass leptoquarks

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

virtual LQ production/exchange results in an **effective CI coupling**:

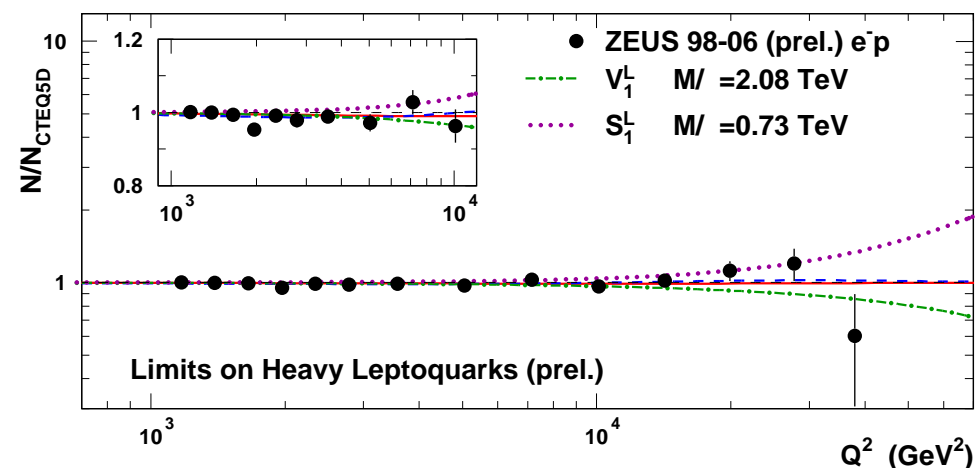
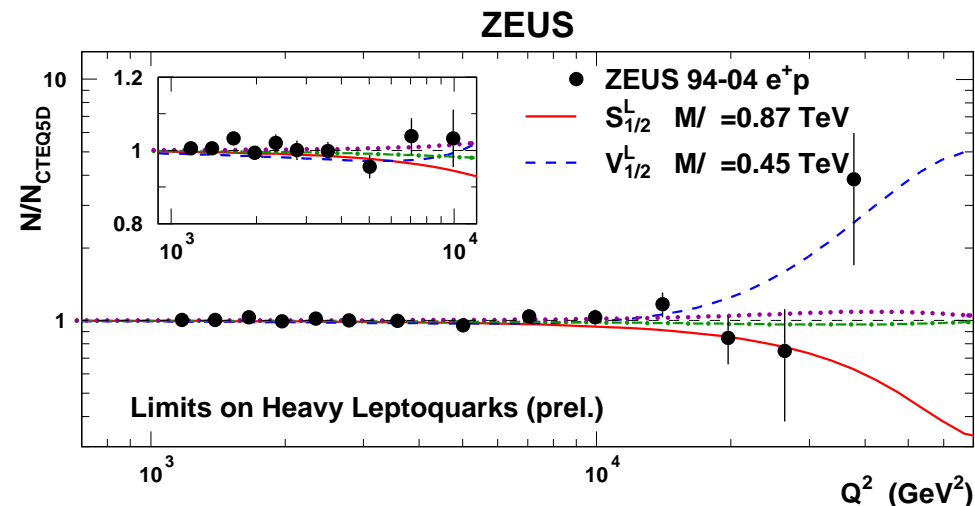
$$\eta_{CI} \sim \left(\frac{\lambda}{M} \right)^2$$

both s - and u -channel exchange important!

λ - leptoquark Yukawa coupling

ZEUS 95% CL limits (1994-2006):

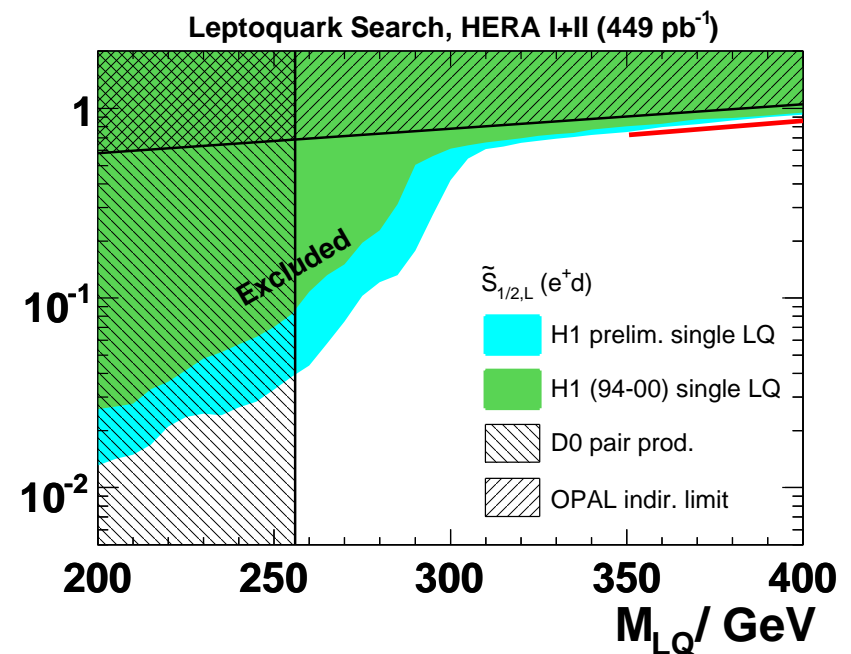
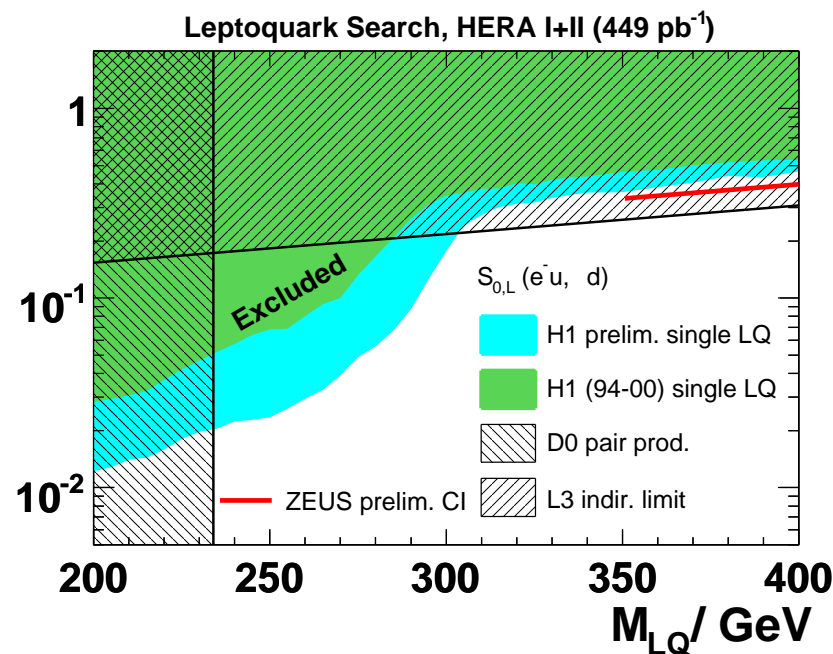
$$M_{LQ}/\lambda_{LQ} > 0.29 - 2.08 \text{ TeV}$$



Contact Interaction results

High mass leptoquarks

Comparison of **ZEUS** limits from **CI analysis** with limits from **LQ analysis** of H1 and limits from other experiments:



HERA limits competitive to LEP and Tevatron limits.

H1 1994-2000: A. Aktas et al., Phys. Lett. B629 (2005) 9-19

H1 prel.: result submitted to LP'2007 (H1prelim-07-164)



Conclusions

HERA II

High luminosity + polarization \Rightarrow new window for precise EW studies.





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HERA II

High luminosity + polarization \Rightarrow new window for precise EW studies.

NC DIS at high Q^2 in very good **agreement with SM**
limits on deviations from SM set in different models

- General Contact Interaction models,
- Large Extra Dimensions,
- Quark radius,
- High mass leptoquarks





Conclusions

HERA II

High luminosity + polarization \Rightarrow new window for precise EW studies.

NC DIS at high Q^2 in very good **agreement with SM**
limits on deviations from SM set in different models

- General Contact Interaction models,
- Large Extra Dimensions,
- Quark radius,
- High mass leptoquarks

HERA running finished, but large samples of data collected with polarized lepton beams still **being analyzed**.

Many more interesting results expected.

