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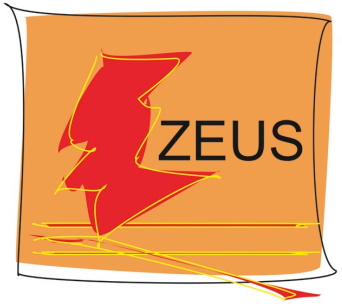


Search for Contact Interactions at HERA

on behalf of the ZEUS and H1 collaborations

Outline

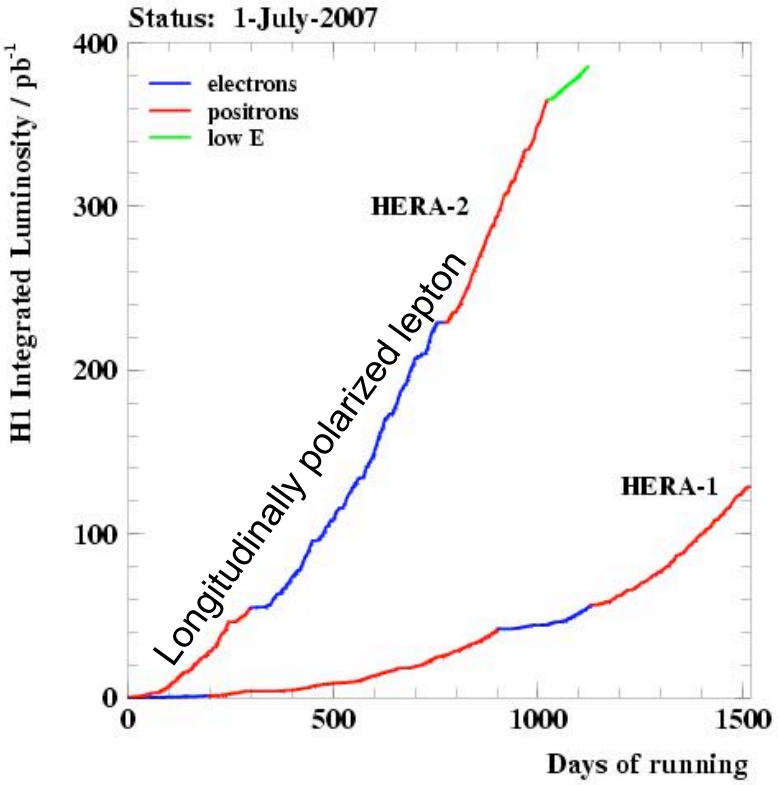
- Introduction
  - HERA operation
- Neutral Current deep inelastic $e^{\pm}p$ scattering
  - Possible contact interaction contribution
- Results
  - Quark form factor
  - Compositeness models
  - Heavy leptoquarks
  - Large extra dimensions
- Summary

HERA operation

HERA: electron(positron)-proton collider at DESY, Hamburg
delivered luminosity between 1992 and 2007

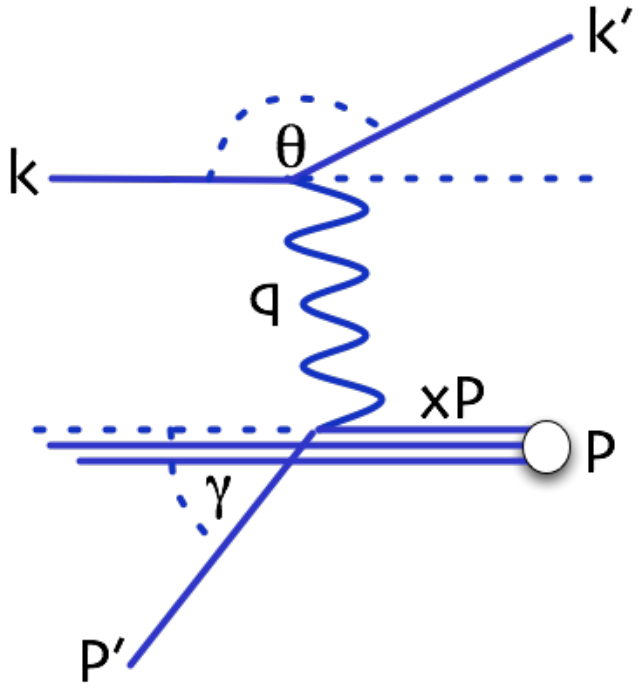
HERA operation

$\sqrt{s}$ = 300/318 GeV



- average (lumi weighted) polarization achieved: 30 - 40%
- ~20 pb^{-1} from low & medium energy running: not considered
- ~0.5 fb^{-1} collected per experiment!

Deep inelastic e±p scattering



Two deep inelastic scattering processes:

- Neutral current: exchange of γ or Z°
- Charged current: exchange of W±

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

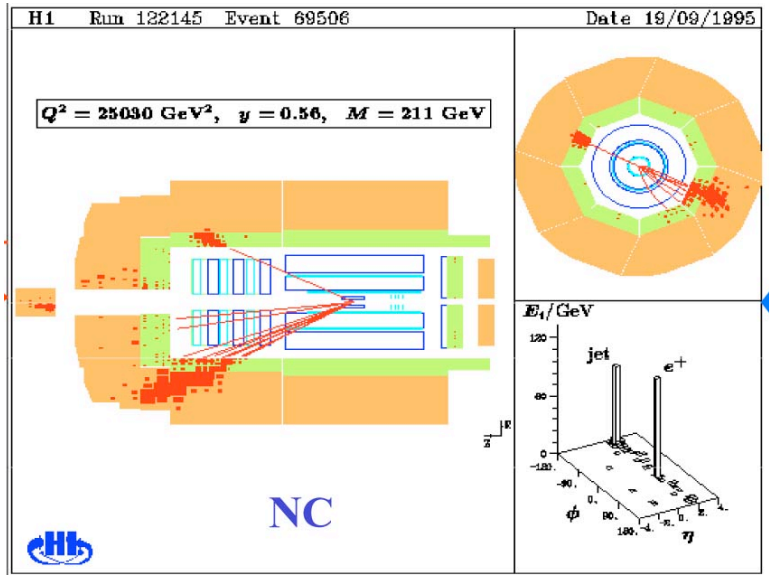
$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

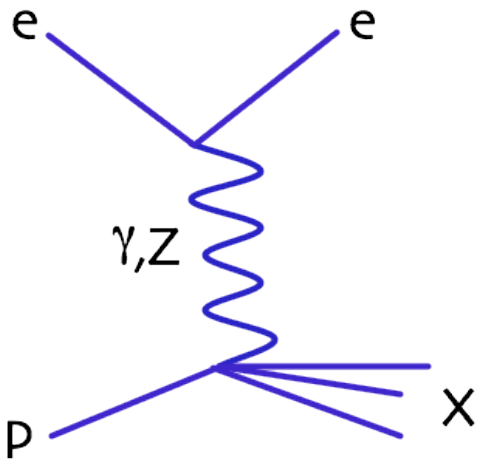
$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

Q^2 is the probing power
x is the Bjorken scaling variable
y is the inelasticity

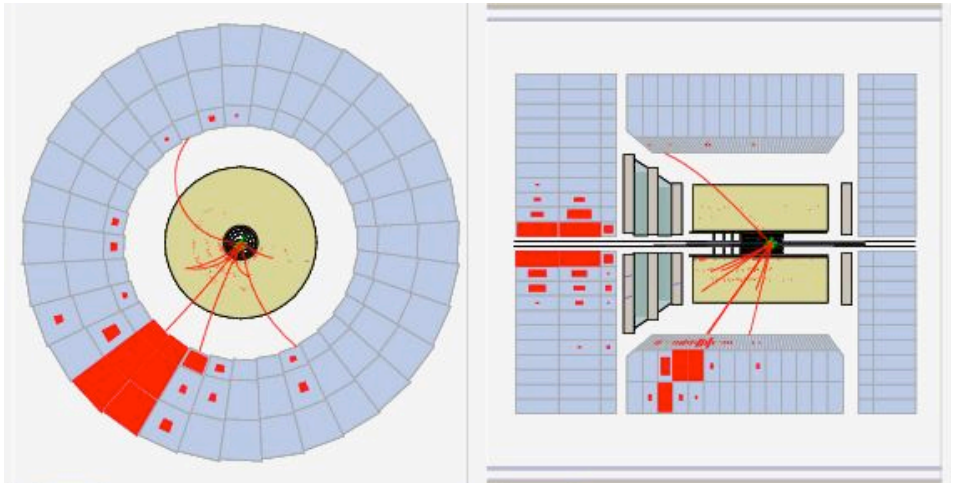
Deep inelastic e±p scattering

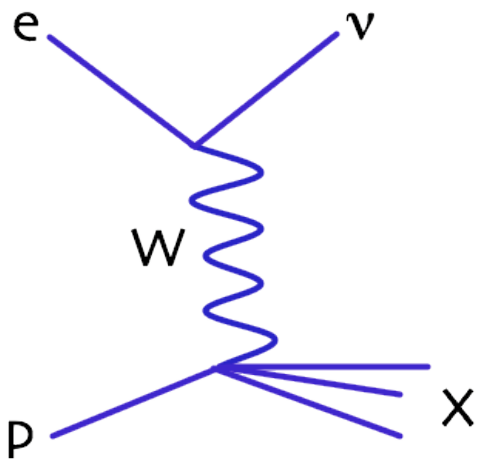
NC DIS





CC DIS





Deep inelastic $e^{\pm}p$ scattering

Neutral Current DIS at highest Q^2:

Z^0 contribution significant

Data well described by SM over many orders of magnitude

➔ testing ground for SM and QCD

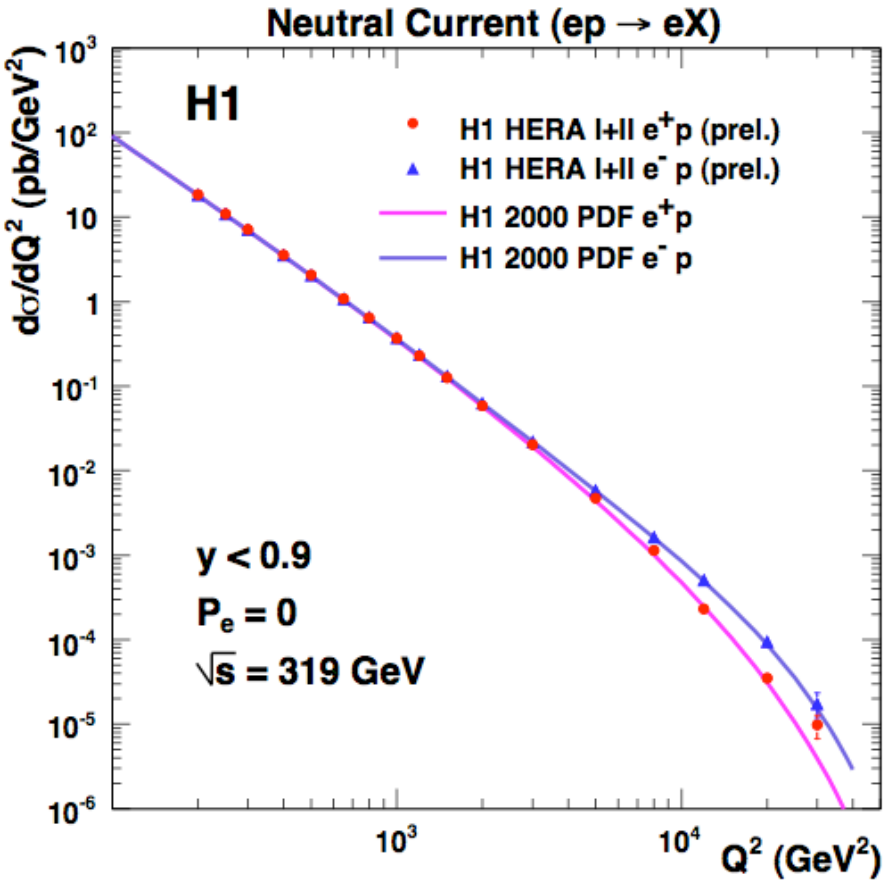
Existence of new physics or deviations from SM at highest Q^2

➔ Contact Interactions

Data samples considered:

ZEUS: $Q^2 > 1000\ GeV^2$

H1: $Q^2 > 200\ GeV^2$



Quark form factor

How would the SM cross section be modified if quarks had a finite size? It is expected to decrease at high-momentum transfer:

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

Where:

- R_q is the RMS radius of the EW charge distribution of the quark
- electron assumed to be point-like

Can search for possible fermion (sub)structure or quark radius...

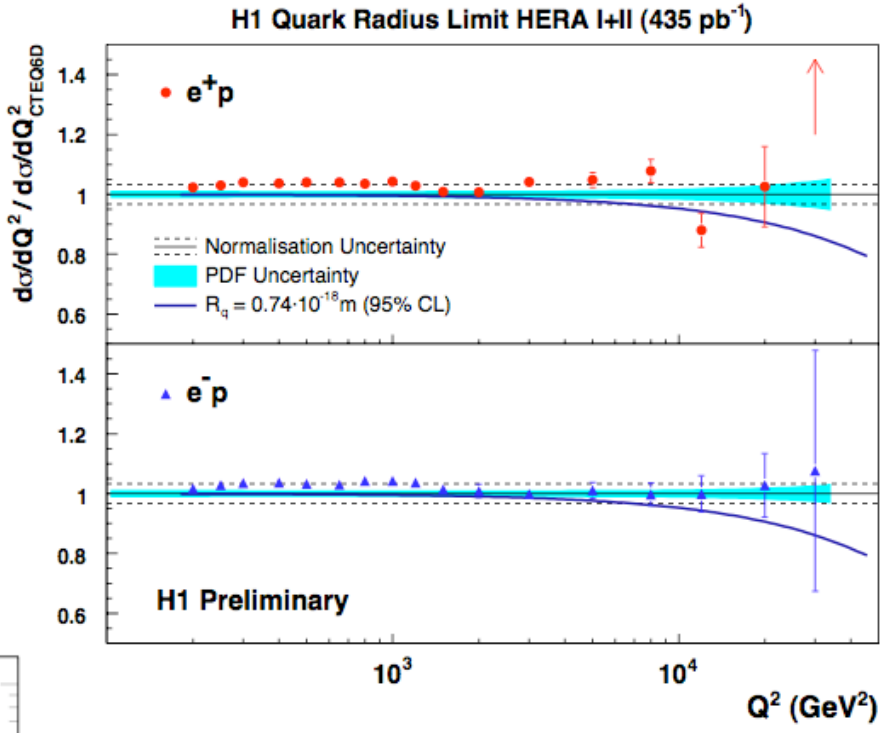
Quark form factor: results

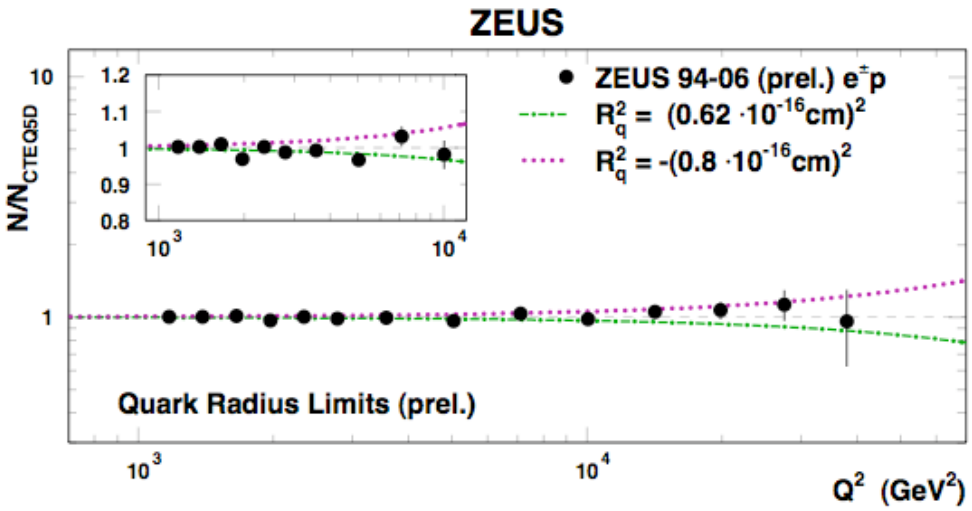
H1 94-07 data

$R_q < 0.74 \times 10^{-16}$ cm at 95% CL

ZEUS 94-06 data

$R_q < 0.62 \times 10^{-16}$ cm at 95% CL

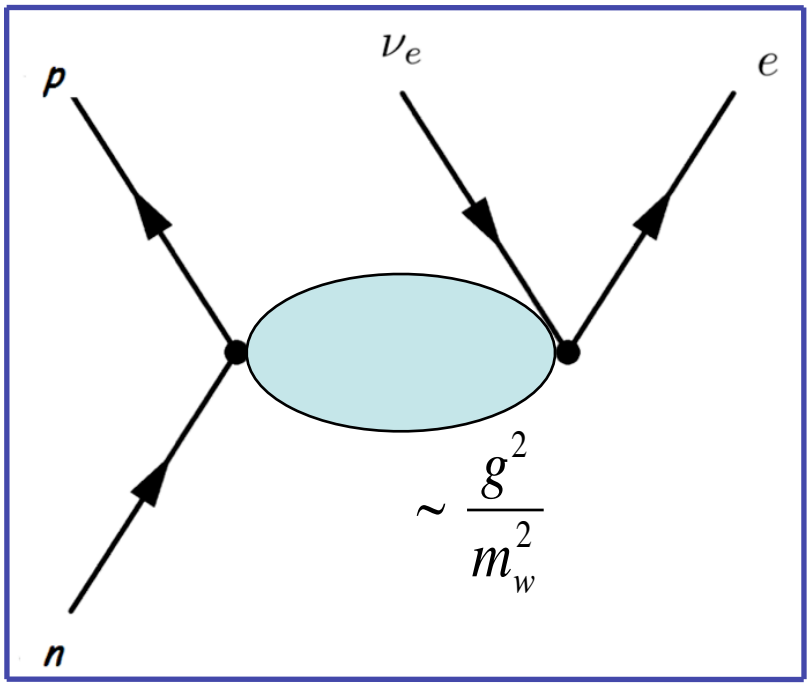




NB: 10^{-16} cm = 10^{-3} fm
we are probing down to 1/1000 proton radius!

Intermezzo…

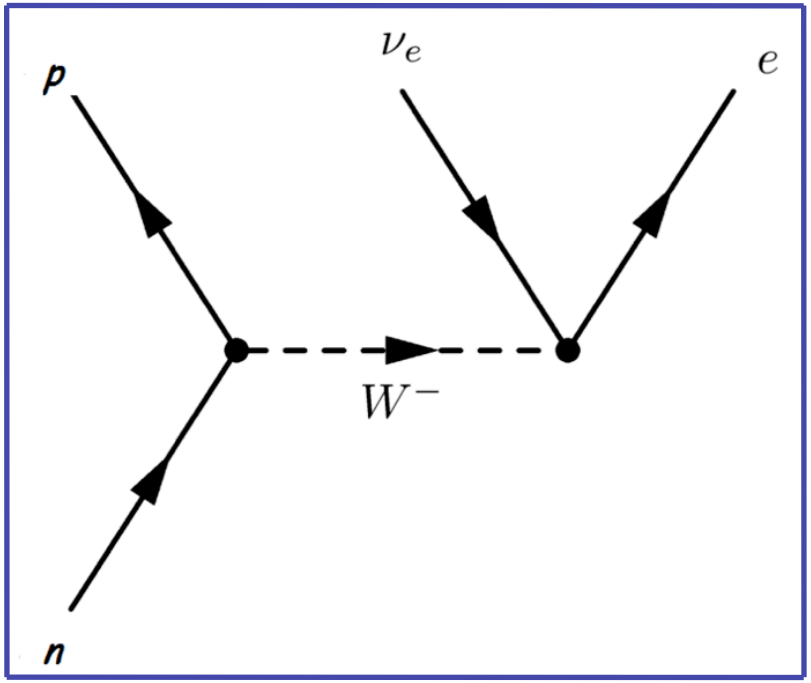
Contact interactions in the past have been an effective way to characterize interactions we didn't fully understand...
Before the form of the weak interaction was known, it was understood through this CI-type diagram as an 'effective four-fermion interaction with the Fermi constant'… (PDG)



Intermezzo…

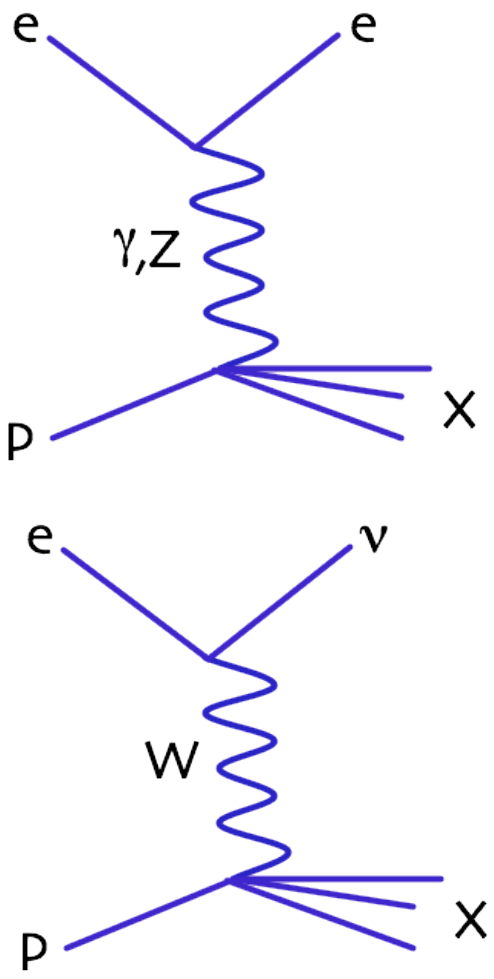
… but now we know what that form is!

We can play the same game today to search for new physics or deviations from the Standard Model (or set limits)…

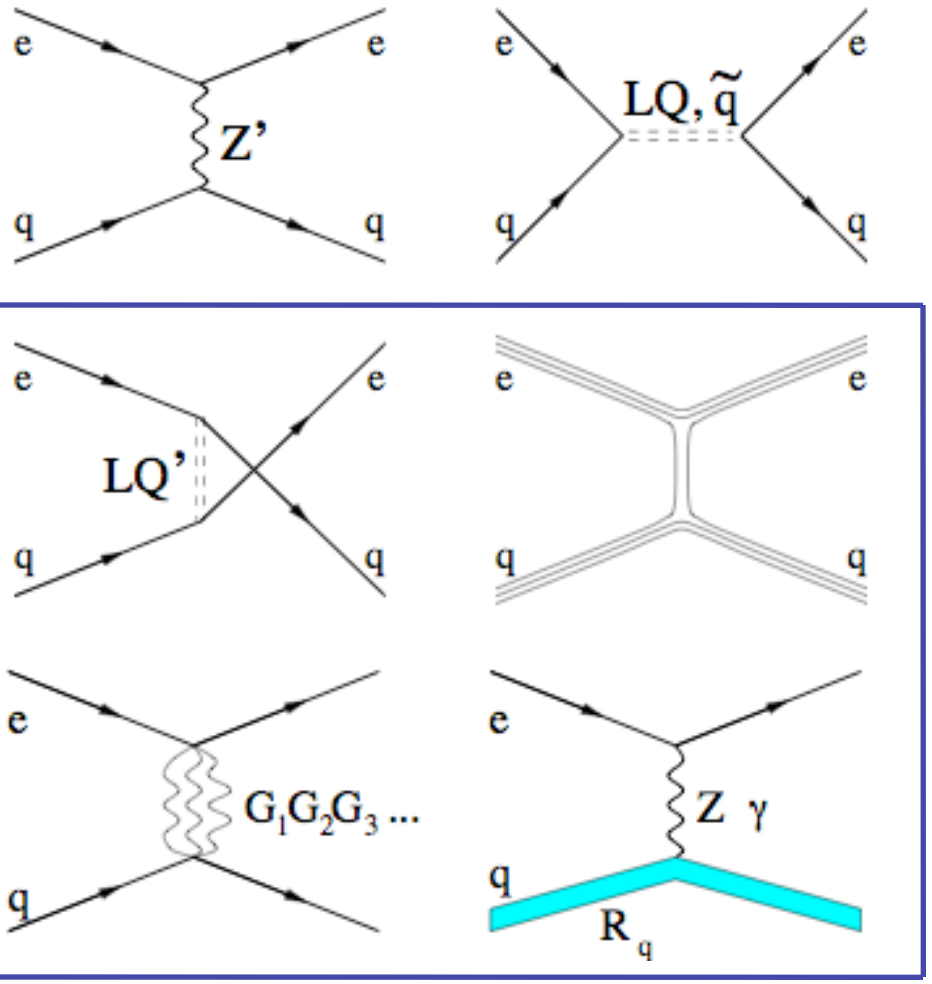


Deep inelastic e±p scattering

NC DIS

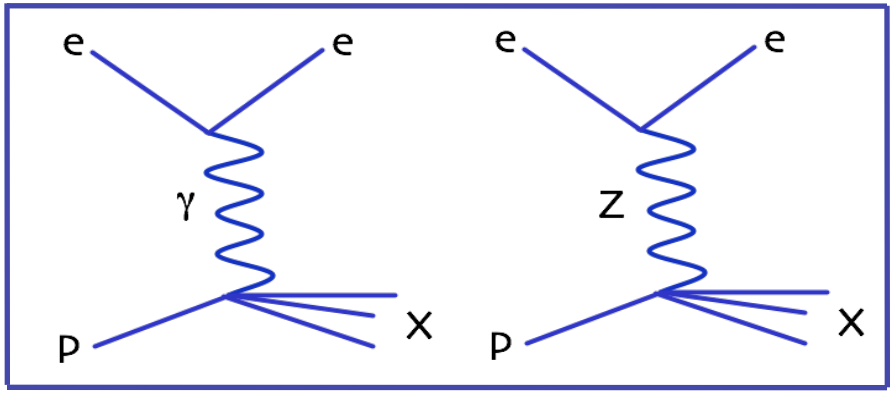


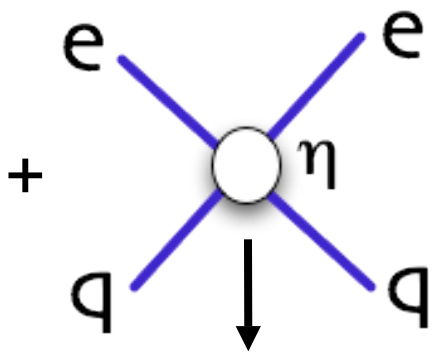
Possible new physics in NC DIS



Deep inelastic e±p scattering

Contact interactions modify tree level eq → eq scattering amplitudes $M^{eq}_{\alpha\beta}$:





$$M^{eq}_{\alpha\beta}(Q^2) = \frac{e^2 e_q}{Q^2} - \frac{e^2}{\sin^2\theta_W \bullet \cos^2\theta_W} \bullet \frac{g^e_\alpha g^q_\beta}{Q^2 + m_Z^2} + \eta^{eq}_{\alpha\beta}$$

γ Zº ?

Where η is the effective parameterization for √s << process scale Λ

$$L_{CI} = \sum_{\substack{\alpha,\beta = L,R \\ q = u,d}} \eta^{eq}_{\alpha\beta} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$

General (Compositeness) models

Couplings $\eta^{eq}_{\alpha\beta}$ are related to "new physics" mass scale Λ by:

$$\eta = \frac{\varepsilon \cdot g_{CI}^2}{\Lambda^2} = \pm \frac{4\pi}{\Lambda^2}$$

where $g_{CI}^2 = 4\pi$ is the coupling strength of new interactions and $\varepsilon = \pm 1$.

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

Models conserving parity:

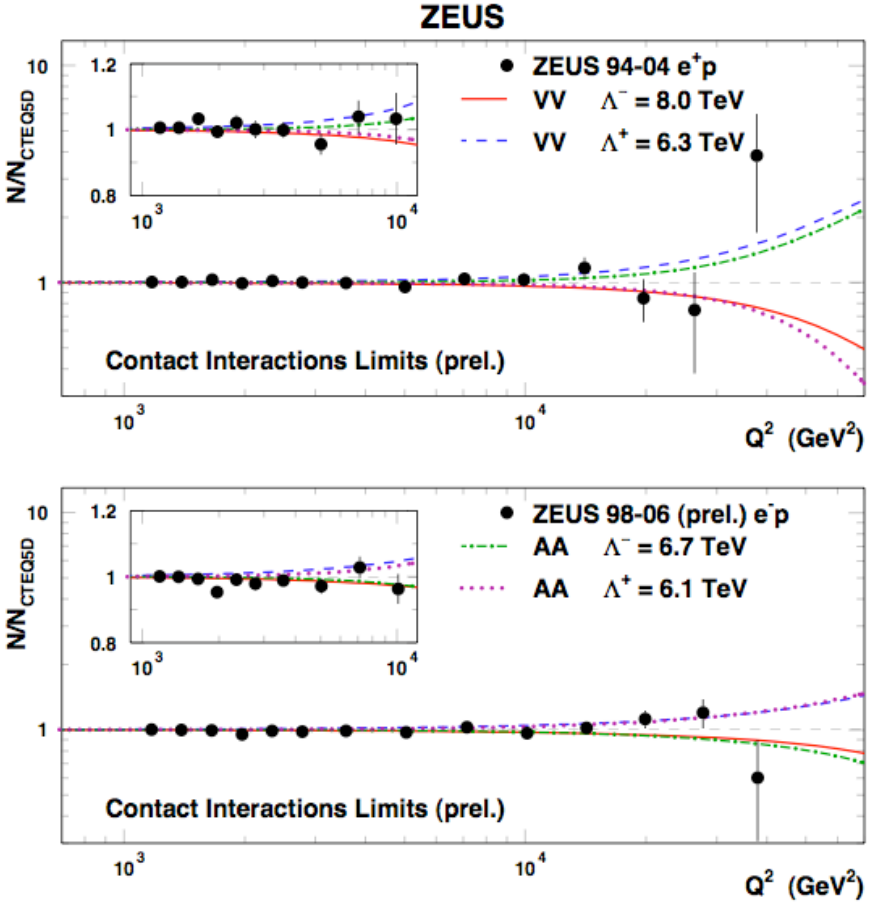
Model	η^{ed}_{LL}	η^{ed}_{LR}	η^{ed}_{RL}	η^{ed}_{RR}	η^{eu}_{LL}	η^{eu}_{LR}	η^{eu}_{RL}	η^{eu}_{RR}
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
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							$+\eta$	$-\eta$

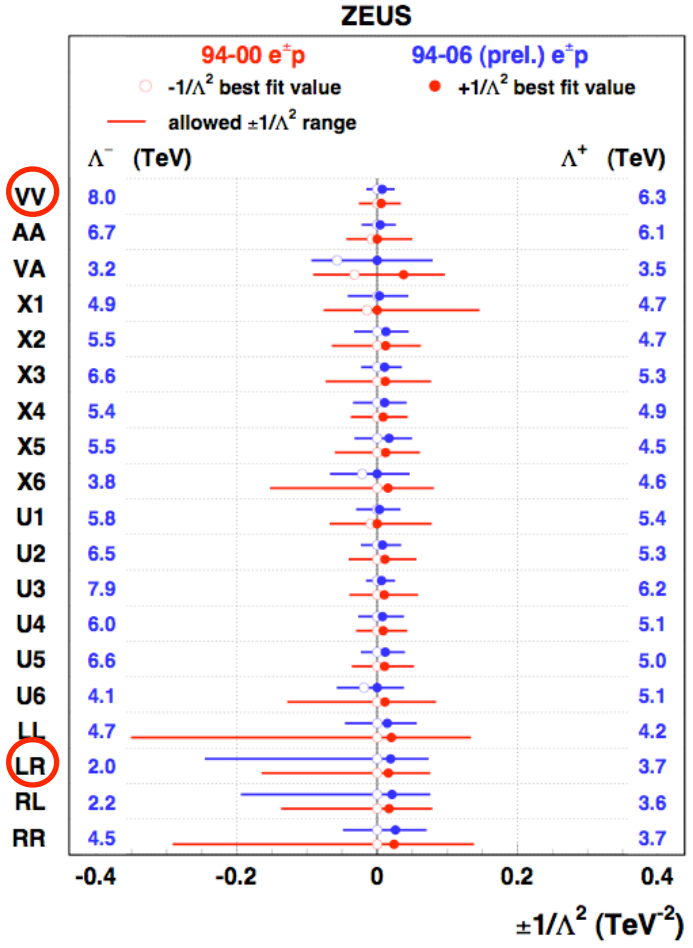
Models violating parity:

LL	$+\eta$				$+\eta$			
LR		$+\eta$				$+\eta$		
RL			$+\eta$				$+\eta$	
RR				$+\eta$				$+\eta$

General (Compositeness) models: results

Fit to NC DIS data yields limits on Λ.





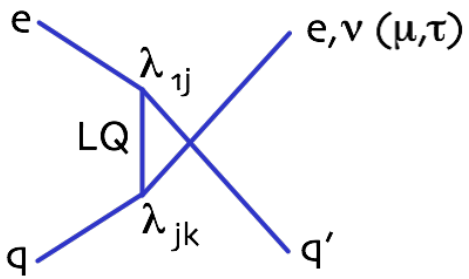
ZEUS (94-06 data): Λ = 2.0 - 8.0 TeV at 95% CL ➔ comparable to

H1 (HERA I): Λ = 1.6 - 5.5 TeV at 95% CL LEP & Tevatron

Heavy leptoquarks

For high mass leptoquarks

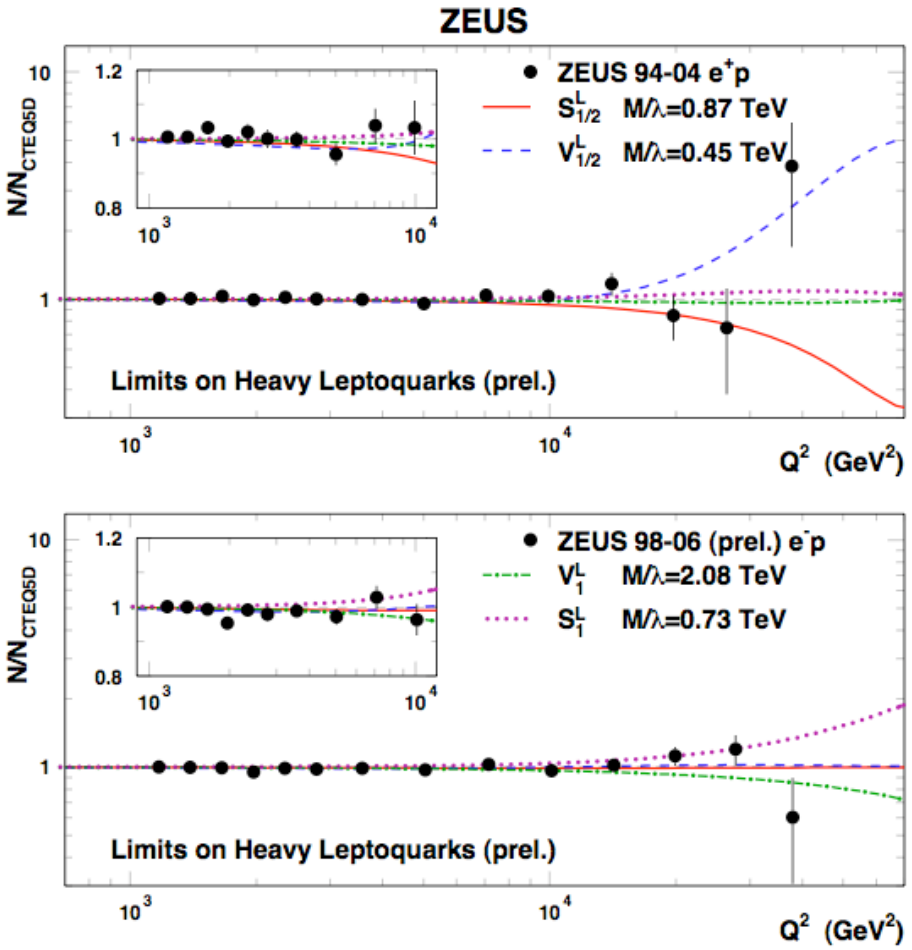
$M_{LQ} >> \sqrt{s}$



virtual LQ production/exchange results in an effective contact interaction type coupling:

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

where λ is the leptoquark Yukawa coupling



ZEUS 94-06 data

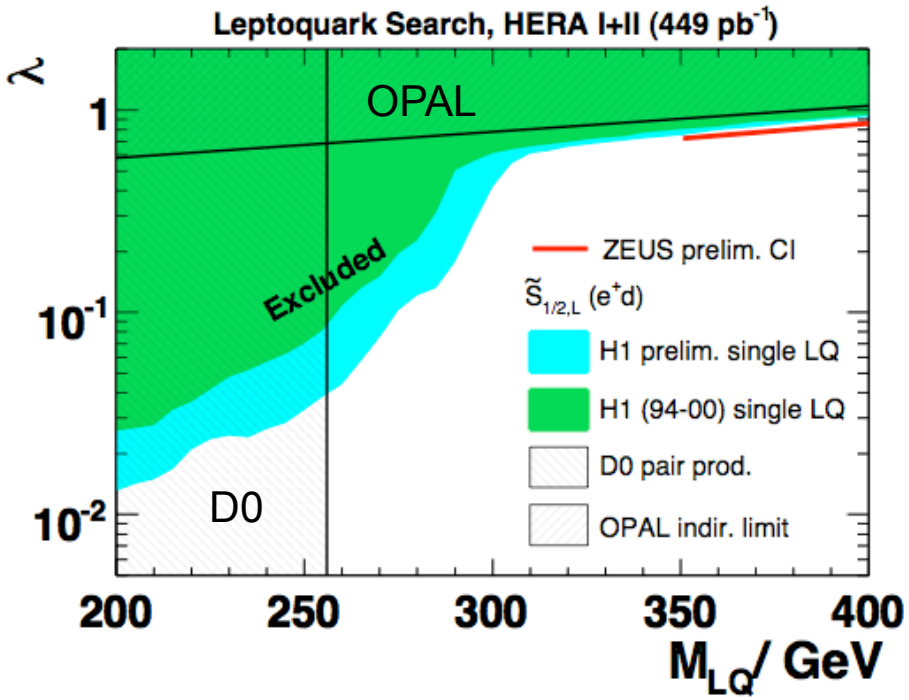
M_{LQ}/λ_{LQ} > 0.29 - 2.08 TeV at 95% CL

Heavy leptoquarks: comparison

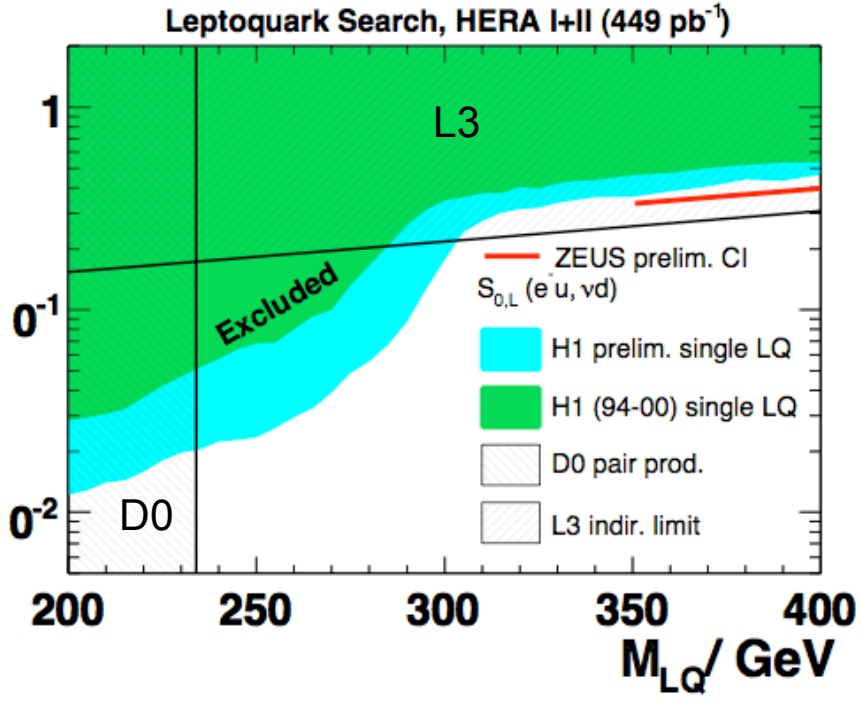
Comparison of ZEUS limits from CI analysis with:
- H1 limits from LQ analysis (resonant production)
- D0 (pair production); OPAL & L3 (indirect limit)

Fermion number F = 3B+L

F = 0



F = 2



HERA limits competitive with LEP and Tevatron limits

Large extra dimensions

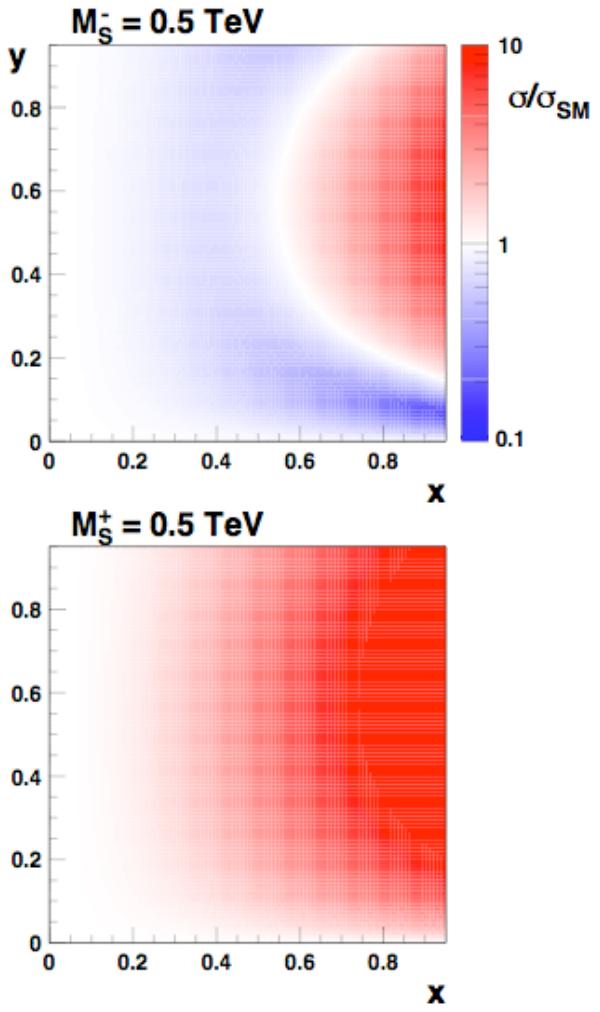
In one model which predicts large extra dimensions (Arkani-Hamed-Dimopolous-Dvali) , contributions from graviton exchange can contribute to the NC DIS cross section.

If gravity propogates in 4 + δ D, effective mass scale M_S can be as low as 1 TeV ➔ gravity becomes comparable in strength to EW interactions.

Describe by effective contact interaction type parameterization: $\eta_G = \frac{\pm\lambda\cdot\varepsilon^2}{M_S^4}$

where λ is the coupling strength and ε is related to energy scales of hard interaction

HERA kinematic plane



Large extra dimensions: results

Fit to NC DIS data yields limits on M_S …

ZEUS (94-06 data):

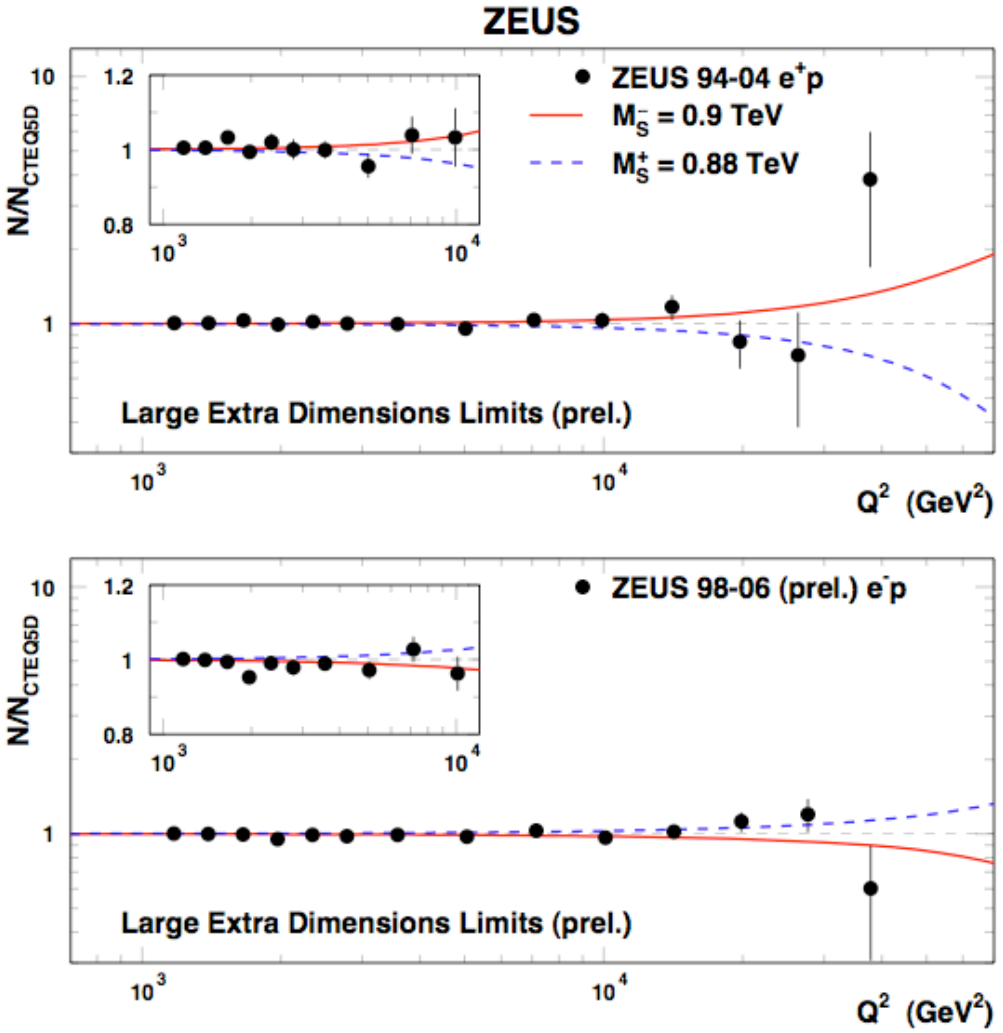
$M_S^- > 0.90$ TeV at 95% CL

$M_S^+ > 0.88$ TeV at 95% CL

H1 (HERA I data):

$M_S^- > 0.78$ TeV at 95% CL

$M_S^+ > 0.82$ TeV at 95% CL



Summary

HERA II: high luminosity + polarization

➔ new window for precise EW studies

NC DIS at high Q^2 in very good agreement with SM

Limits on deviations from the SM set in different models:

- Quark radius
- General contact interaction models
- Heavy leptoquarks
- Large Extra Dimensions

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

End of an (H)ERA

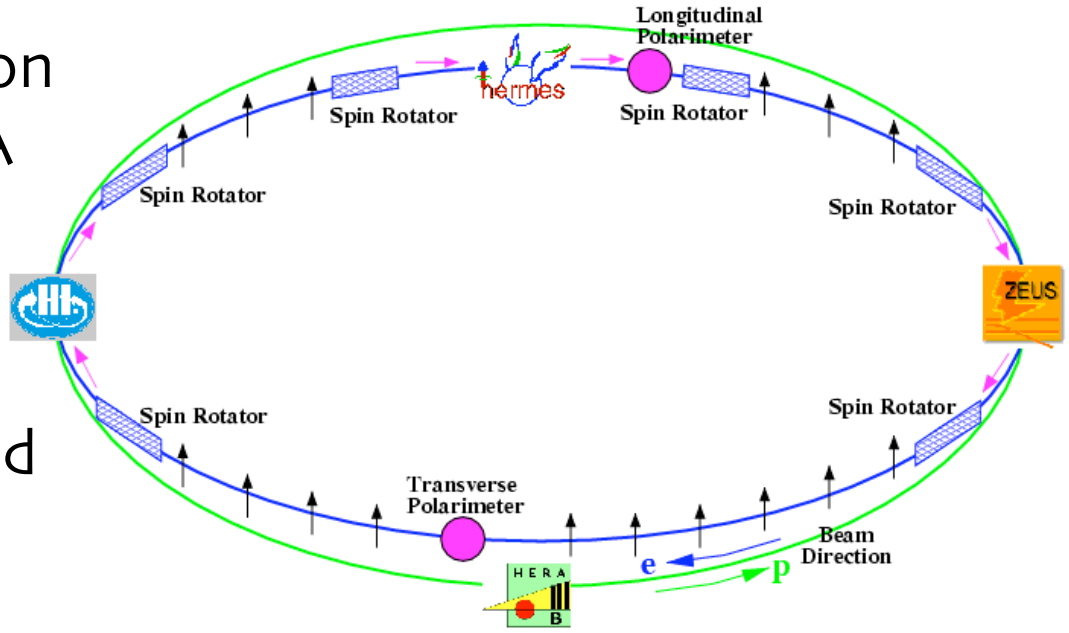
ZEUS HALL on midnight June 30, 07 (--> July 1st, 6 A.M.)

HERA operation

HERA II: 2002 - 2007

Via emission of synchrotron radiation, e beam at HERA becomes transversely polarized

Spin rotators were installed to obtain longitudinal polarization at both IPs



- polarization was measured in dedicated polarimeters
- average (lumi weighted) polarization achieved: 30 - 40%