DIS 2002

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Parallel session

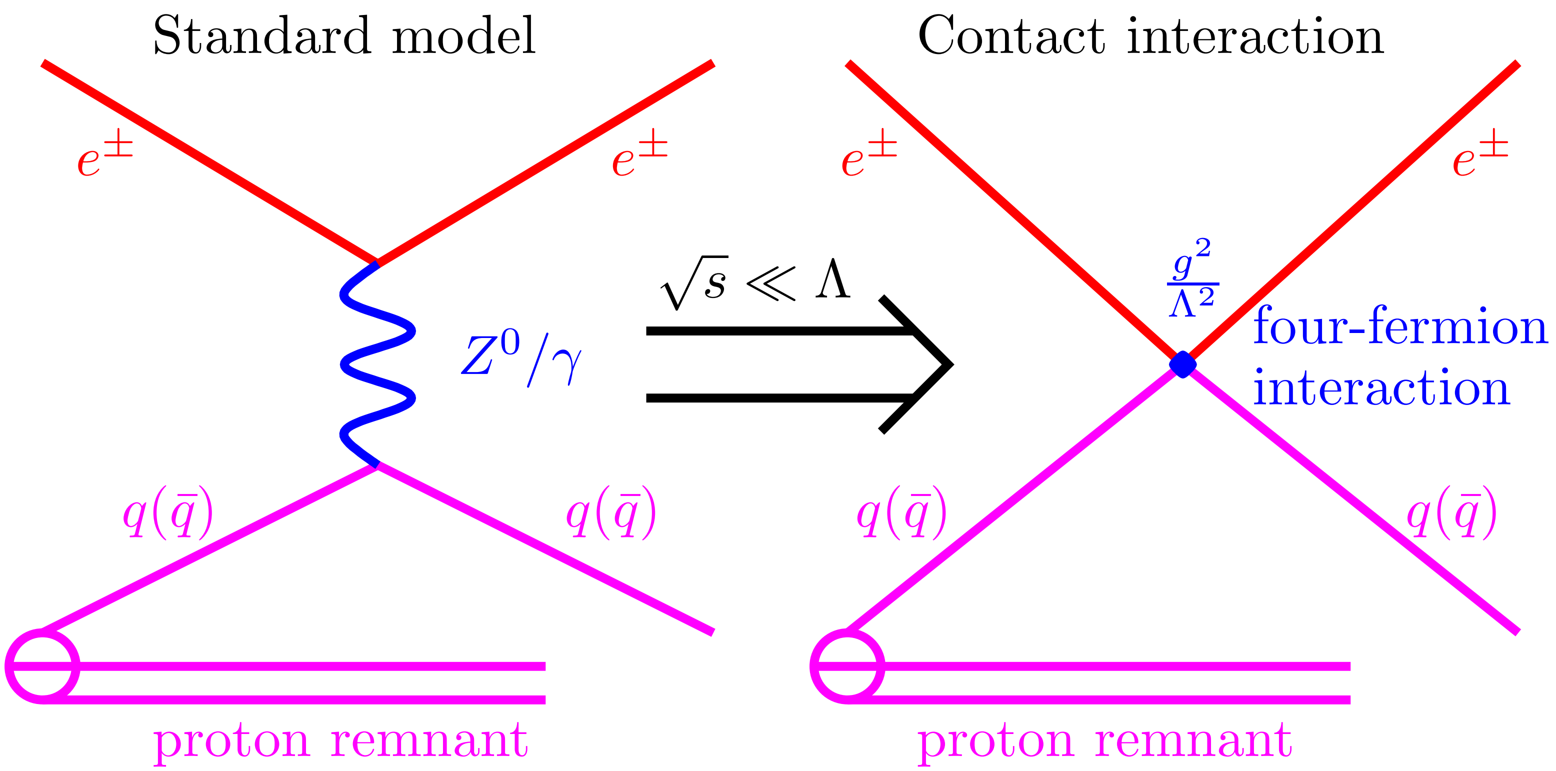
Search for Contact Interactions at HERA

Stefan Schmitt, DESY Hamburg

for the ZEUS and H1 collaborations

- Introduction
- HERA data at high momentum transfer
- Compositeness models
- Leptoquarks
- Quark radius
- Large extra dimensions
- Conclusions

Introduction

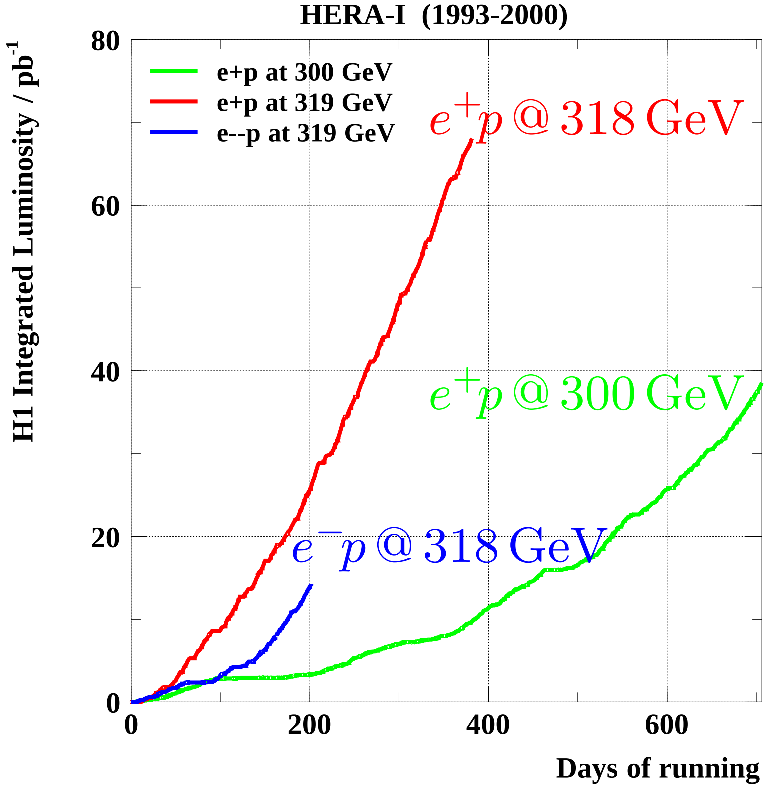


Four-momentum transfer Q^2

Cross-section $\frac{d\sigma}{dQ^2}$ is altered in presence of contact interactions

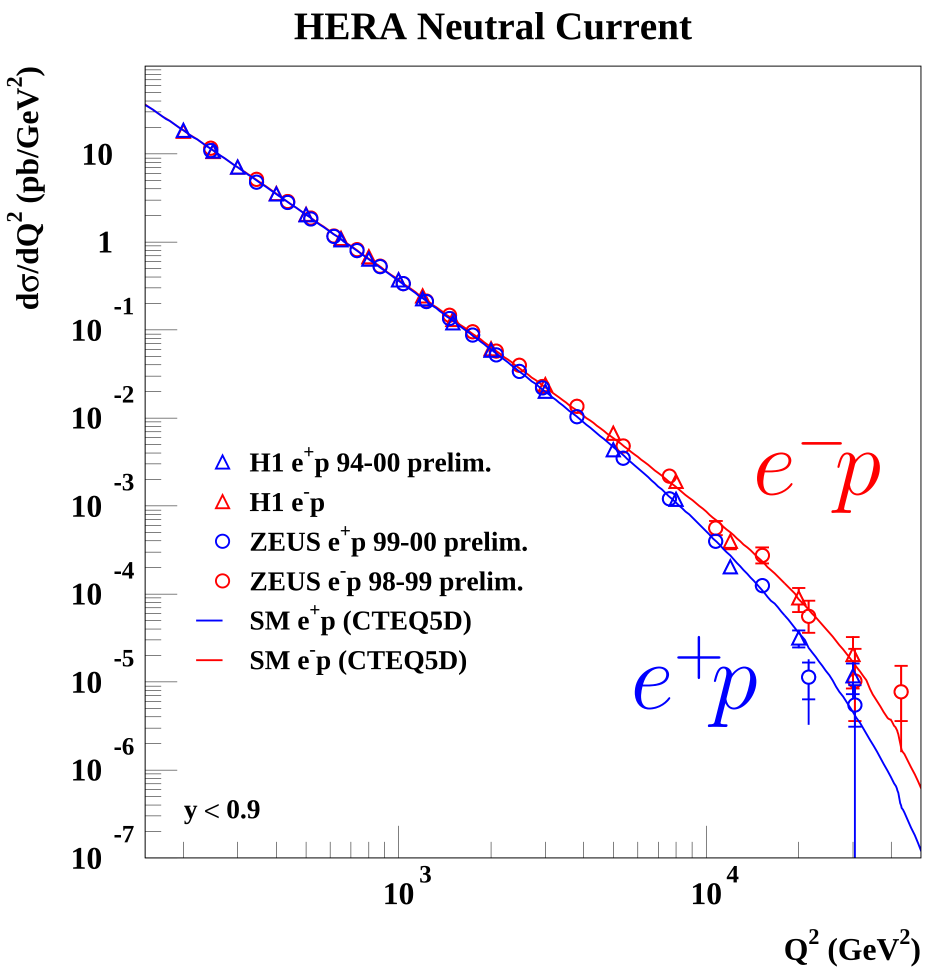
The data

Both ZEUS and H1 have analyzed the full HERA I dataset (collected during the years 1994–2000) at $\sqrt{s} = 300 - 318\,\mathrm{GeV}$.



- in e^-p: $\approx 16\,\mathrm{pb}^{-1}$ collected by each experiment at $\sqrt{s} = 318\,\mathrm{GeV}$
- in e^+p: $\approx 100\,\mathrm{pb}^{-1}$ collected by each experiment
  - $^1/_3$ at $\sqrt{s} = 300\,\mathrm{GeV}$
  - $^2/_3$ at $\sqrt{s} = 318\,\mathrm{GeV}$

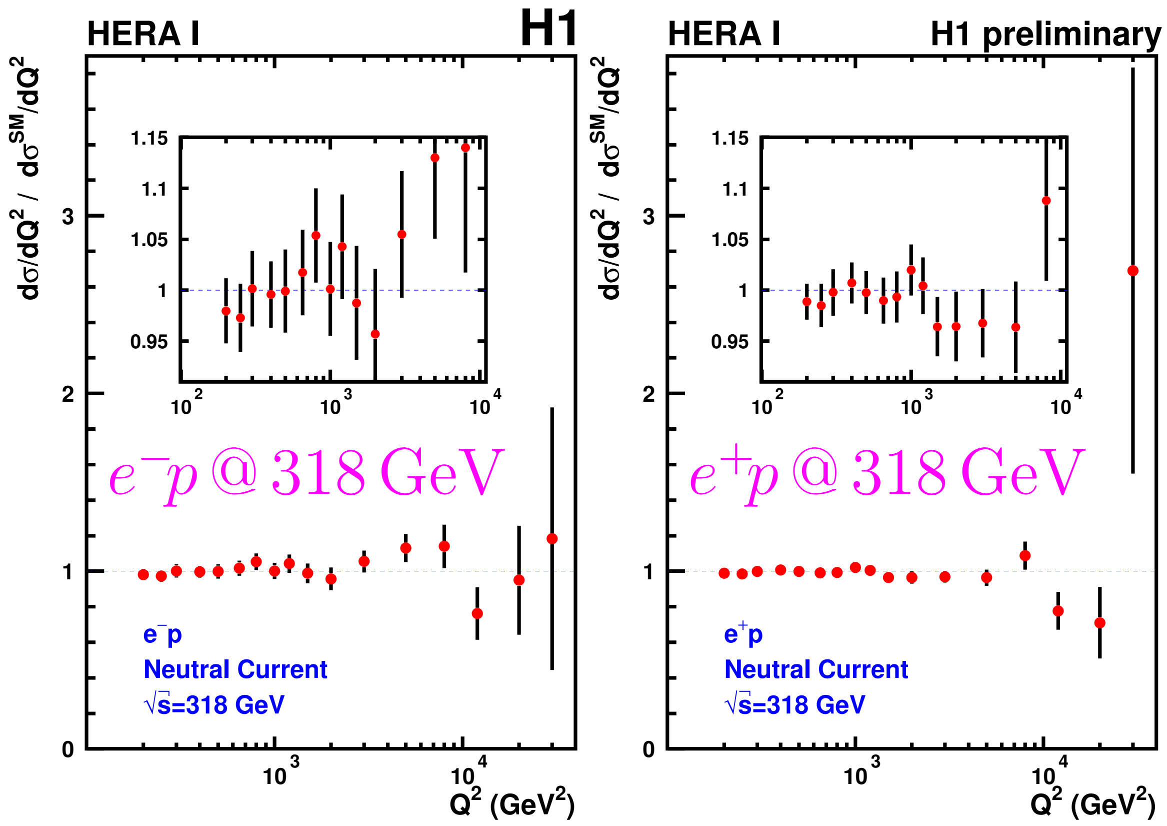
Single differential cross-sections $\frac{d\sigma}{dQ^2}$



Contact interaction analyzes are based on single differential inclusive cross-section measurements $\frac{d\sigma}{dQ^2}$ at high momentum transfer

$200\,\mathrm{GeV}^2 < Q^2 < 50000\,\mathrm{GeV}^2$

Comparison of the data to Standard model predictions



SM prediction:
NLO calculation with CTEQ5D PDF

Good description of the data for $e^{\pm}p$ and both experiments

e.g H1 e^+p @ 318 GeV:
$\chi^2 = 14.5/17\,\mathrm{dof}$

No significant deviations $\rightarrow$ derive limits on contact interactions

Contact interaction phenomenology

Lagrangian contains coupling constants η^q_{ab}

$$\mathcal{L} = \sum_{q=u,d} \eta^q_{LL}(\bar{e_L}\gamma^\mu e_L)(\bar{q_L}\gamma^\mu q_L) + \eta^q_{RL}(\bar{e_R}\gamma^\mu e_R)(\bar{q_L}\gamma^\mu q_L) + \eta^q_{LR}(\bar{e_L}\gamma^\mu e_L)(\bar{q_R}\gamma^\mu q_R) + \eta^q_{RR}(\bar{e_R}\gamma^\mu e_R)(\bar{q_R}\gamma^\mu q_R)$$

Depending on the chiral structure of the theory which is probed, only some of the couplings are active

$$\eta^q_{ab} = \epsilon^q_{ab}\frac{g^2}{\Lambda^2}$$

quark flavour

quark helicity

lepton helicity

Valid for many models (compositeness, leptoquark, Z', W',...)

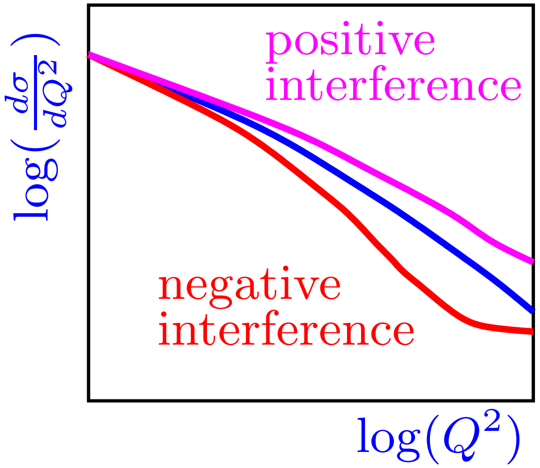
Cross-section in presence of contact interactions

Differential cross section:

$$\frac{d\sigma}{dQ^2} = \underbrace{\frac{d\sigma^{\rm SM}}{dQ^2}}_{\text{standard model contribution}} \pm \underbrace{\frac{d\sigma^{\rm IF}}{dQ^2}}_{\text{interference term}} + \underbrace{\frac{d\sigma^{\rm CI}}{dQ^2}}_{\text{pure contact interaction}}$$

Contact interactions change the cross-section at high Q^2

Sensitivity to scales Λ beyond the centre-of-mass energy

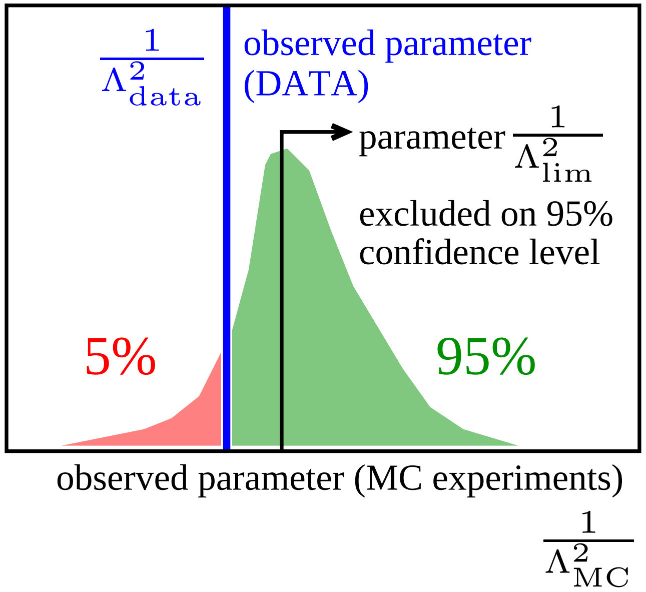


Effective theory $\longrightarrow$ well defined in leading order only.

Predicted cross-sections are corrected by $\frac{\sigma_{SM}^{NLO}}{\sigma_{SM}^{LO}}$ in order to match the NLO prediction for $\frac{1}{\Lambda^2} = 0$

Limit calculation

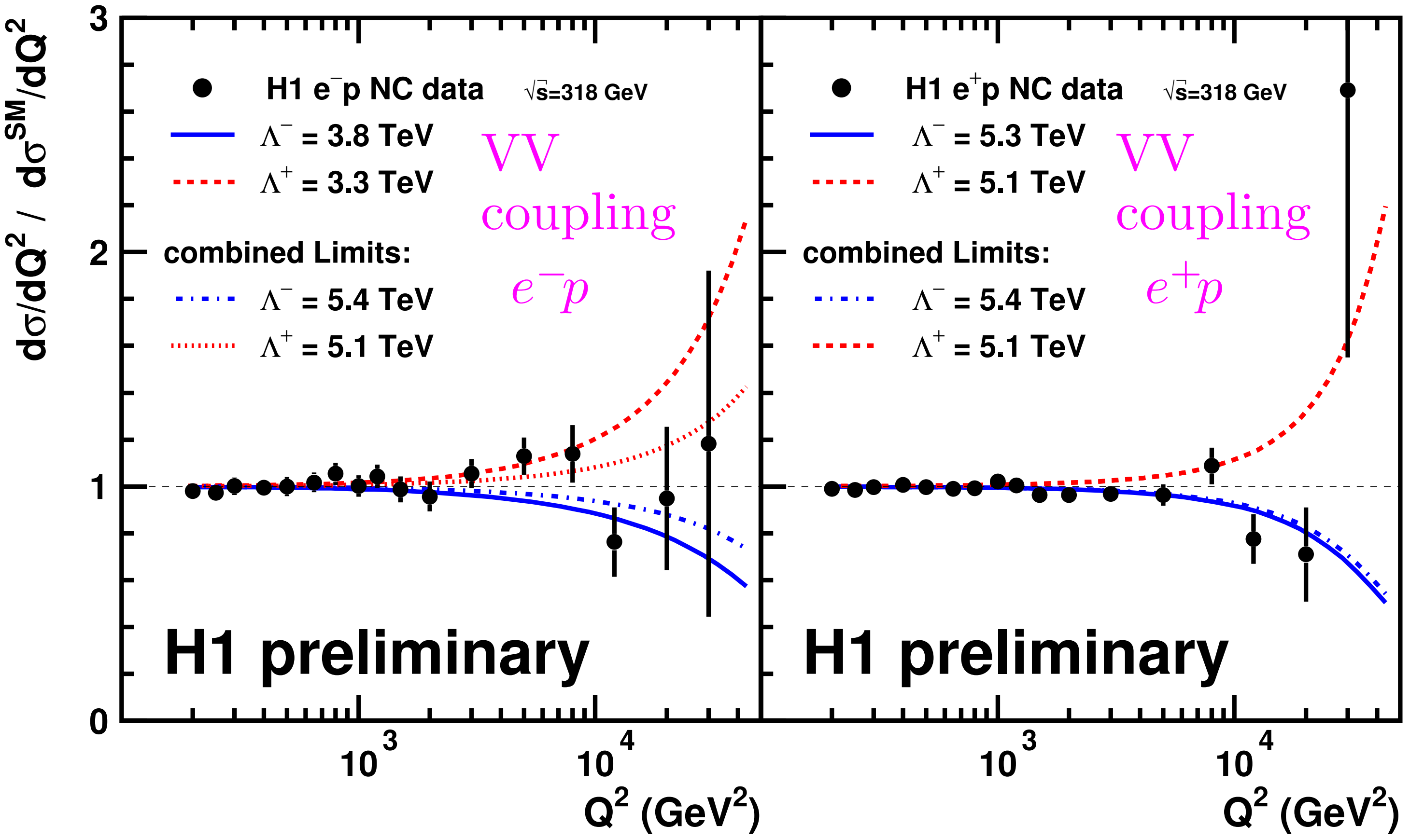
Limit calculation: define $-\log \mathcal{L}$ or χ^2 function, then use frequentist approach to calculate 95% confidence intervals.



1. determine $\frac{1}{\Lambda^2_{\rm data}}$ from data (minimize χ^2)
2. do many MC experiments for a fixed test parameter $\frac{1}{\Lambda^2_{\rm lim}}$, each MC experiment corresponding to the data luminosity
3. plot distribution of $\frac{1}{\Lambda^2_{\rm MC}}$ (minimize χ^2 for each MC exp.)
4. if confidence level is not 95% try with a different $\frac{1}{\Lambda^2_{\rm lim}}$

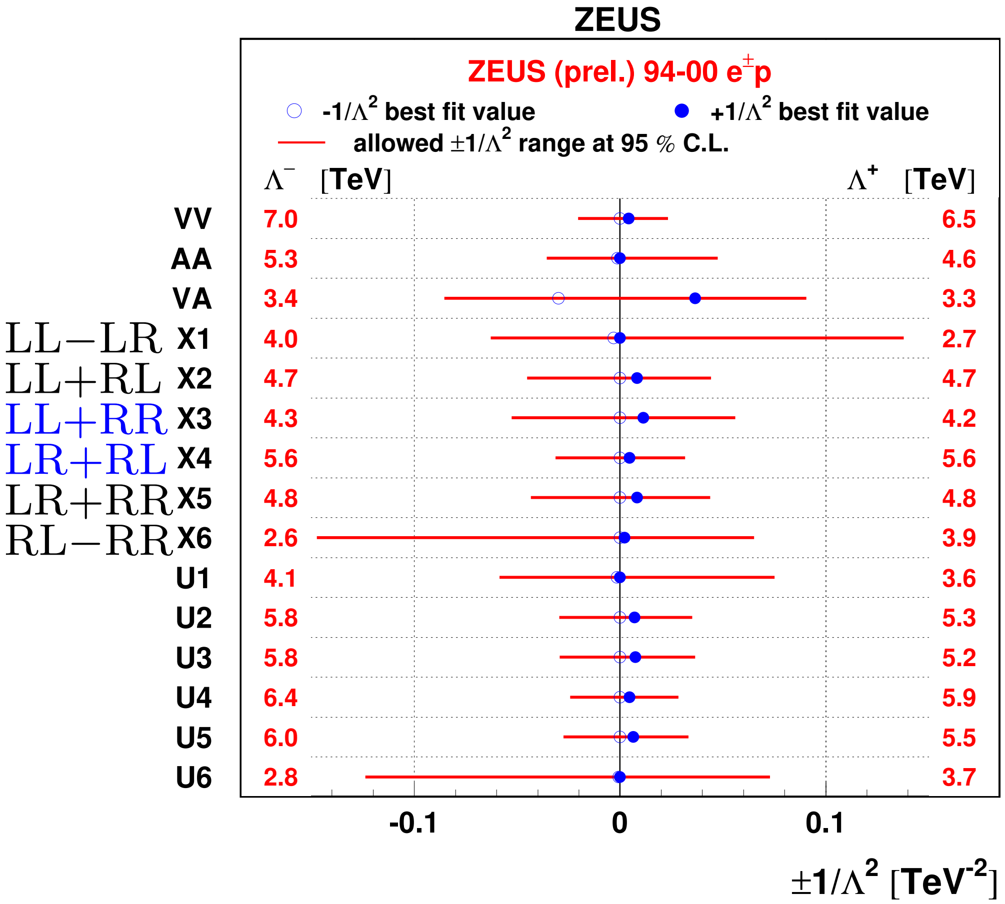
Compositeness models

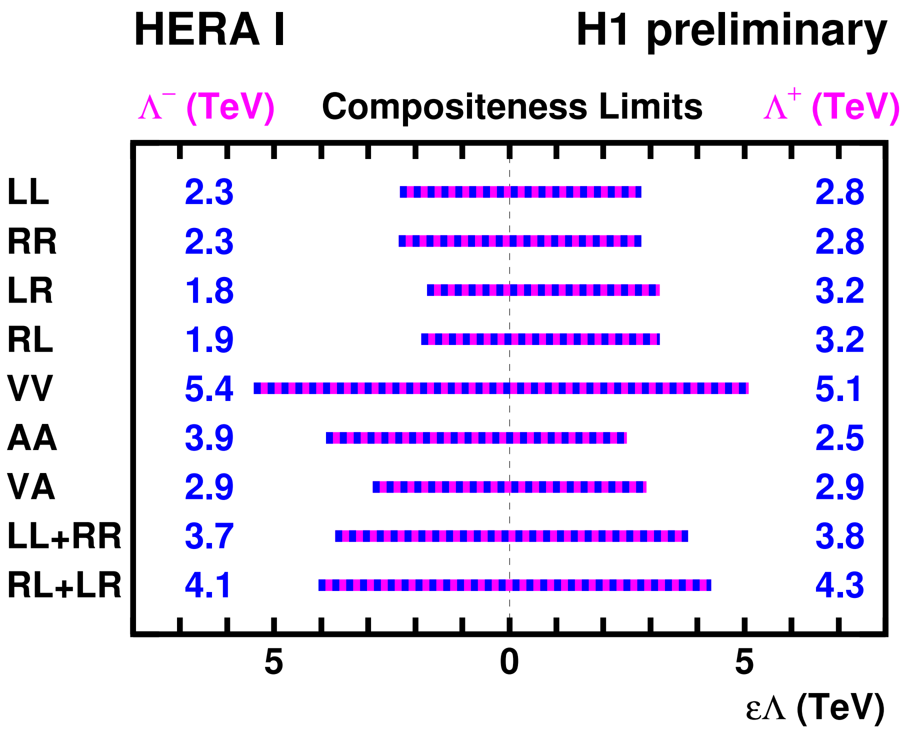
Limits are derived on the scale Λ, for a coupling constant $g^2 = 4\pi$



VV models: $\eta^q_{LL} = \eta^q_{LR} = \eta^q_{RL} = \eta^q_{RR} = \pm\frac{4\pi}{\Lambda^2}$

Limits on Compositeness models from HERA





LL, LR, RL, RR: stringent limits from atomic $\not{P}$

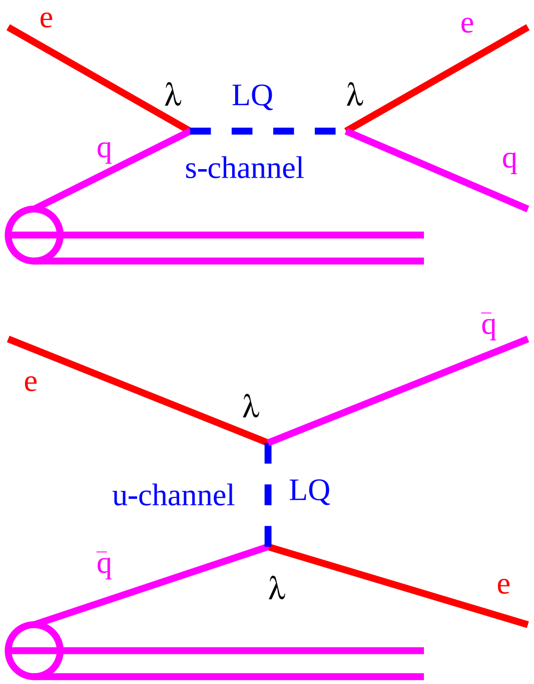
U1–U6: assume only u quark couples

Limits of order $2 - 7\,\mathrm{TeV}$, depending on the model

Leptoquark production at HERA for $M_{LQ} \gg \sqrt{S}$

Leptoquarks (LQ) appear in many extensions of the SM. New quantum number $F = 3B + L$. 14 possible types of LQs.

F	Scalar LQ	Vector LQ	couples to
2	S_0^L, S_0^R	$\tilde{V}_{1/2}^L$	e^-u
	$\tilde{S}_0^R$	$V_{1/2}^L$	e^-d
	S_1^L	$V_{1/2}^R$	e^-u and e^-d
0	$S_{1/2}^L$	$\tilde{V}_0^R$	$e^-\bar{u}$
	$\tilde{S}_{1/2}^L$	V_0^L, V_0^R	$e^-\bar{d}$
	$S_{1/2}^R$	V_1^L	$e^-\bar{u}$ and $e^-\bar{d}$

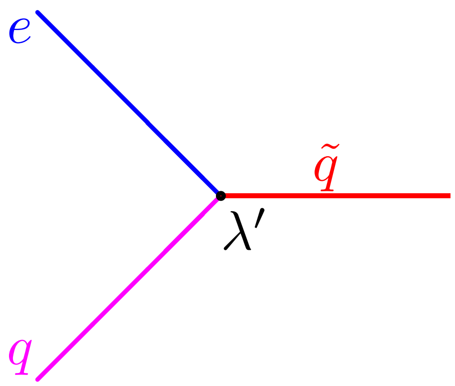


Note: e^-q implies $e^+\bar{q}$ and $e^-\bar{q}$ implies e^+q

CI limit: $\eta \sim \frac{\lambda^2}{M_{LQ}^2}$ for masses $M_{LQ} \gg \sqrt{s}$

Leptoquarks and R_p violating squarks

In R_p violating SUSY models ($R_p = (-1)^{3B+L+2S}$):
coupling λ'_{ijk} of lepton, quark, squark



$e^- \bar{d} \xrightarrow{\lambda'_{1j1}} \bar{\tilde{u}},\ \bar{\tilde{c}},\ \bar{\tilde{t}}$

coupling identical to generic LQ $\tilde{S}^L_{1/2}$

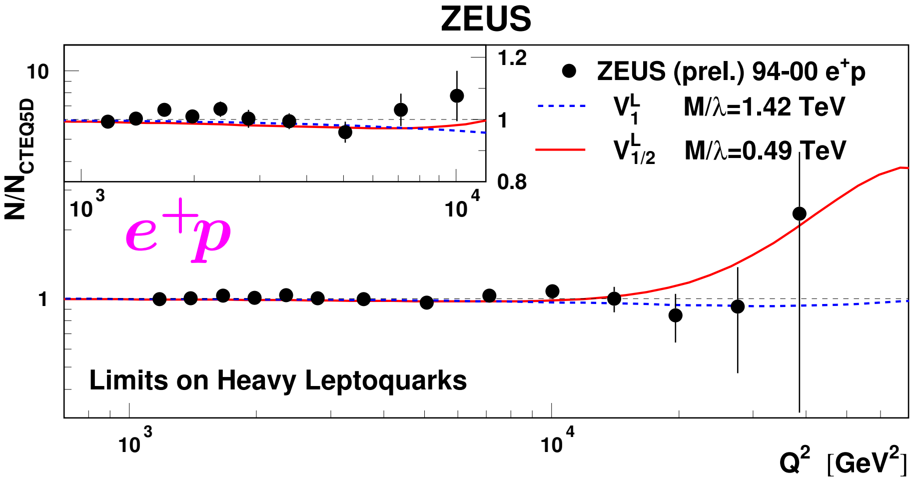
$e^- u \xrightarrow{\lambda'_{11k}} \tilde{d},\ \tilde{s},\ \tilde{b}$

coupling identical to generic LQ S^L_0

Assume $\mathfrak{Br}(\tilde{q} \to eq) = 1$: reinterpret LQ results for R_p violating SUSY models

Contact interaction limit: $\eta \sim \frac{\lambda'^2}{M^2_{\tilde{q}}}$ for masses $M_{\tilde{q}} \gg \sqrt{s}$

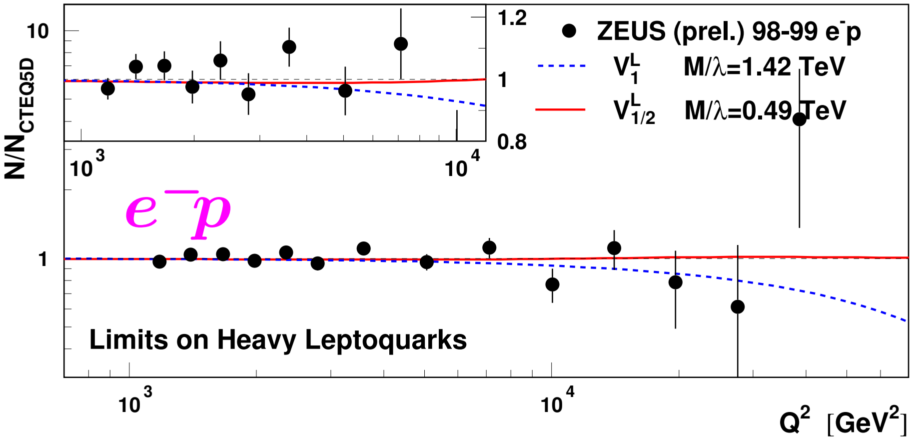
Leptoquark search in contact interactions



$V^L_{1/2}$ excluded for $M/\lambda < 0.49\,\mathrm{TeV}$

e^+ data more sensitive than e^- data

Note: $\int \mathcal{L}_{e^-p} \approx \frac{1}{7} \int \mathcal{L}_{e^+p}$



V^L_1 excluded for $M/\lambda < 1.42\,\mathrm{TeV}$

e^- data more sensitive than e^+ data

Leptoquark and squark limits from CI analysis

prel. limits on $\frac{M}{\lambda}$ [GeV]				prel. limits on $\frac{M}{\lambda}$ [GeV]			
	F	ZEUS	H1		F	ZEUS	H1
S_0^L or $\tilde{d}$	2	750	720	V_0^L	0	690	770
S_0^R	2	690	670	V_0^R	0	580	640
$\tilde{S}_0^R$	2	310	330	$\tilde{V}_0^R$	0	1030	1000
S_1^L	2	550	480	V_1^L	0	**1420**	**1380**
$S_{1/2}^L$	0	**910**	**870**	$V_{1/2}^L$	2	490	420
$S_{1/2}^R$	0	690	370	$V_{1/2}^R$	2	1150	940
$\tilde{S}_{1/2}^L$ or $\tilde{u}$	0	500	430	$\tilde{V}_{1/2}^L$	2	1260	1020

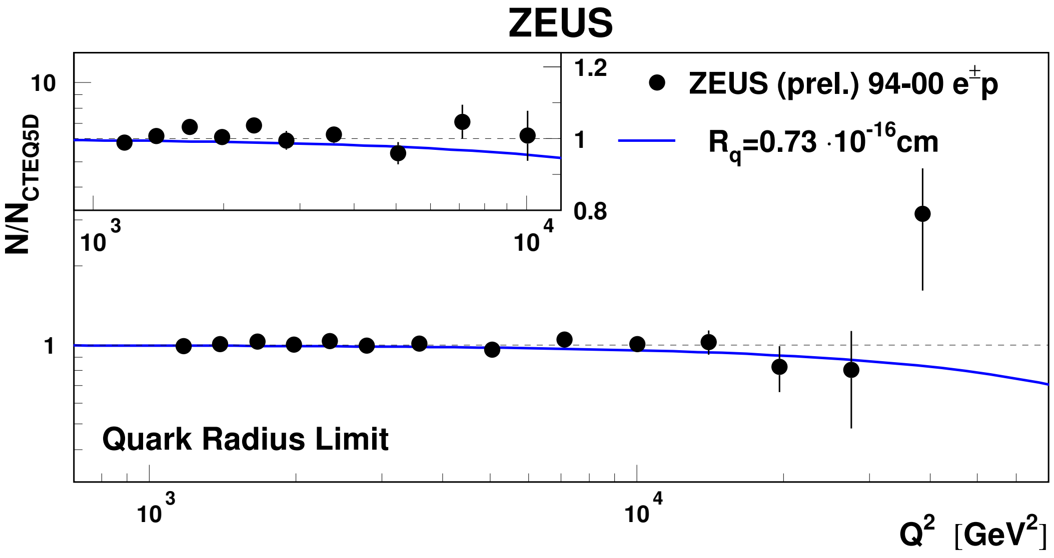
For coupling $\lambda = 1$ some LQs are excluded up to $M_{LQ} = 1.4\,\text{TeV}$

$\not{R}_p$ SUSY: for λ'_{1j1} (λ'_{11k}) $= 1$ exclude $\tilde{u}$ ($\tilde{d}$) for $M_{\tilde{q}} < 0.5\,(0.75)\,\text{TeV}$

Quark radius

Introduce form factors for non point-like electron and quark

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{\mathrm{SM}}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2), \quad f_{e,q} = 1 - \frac{\langle r_{e,q}^2 \rangle}{6} Q^2, \langle r_{e,q}^2 \rangle = R_{e,q}^2$$



ZEUS $(f_e \equiv 1)$:
$R_q < 0.73 \cdot 10^{-3}$ fm

H1 $(f_e \equiv 1)$:
$R_q < 0.82 \cdot 10^{-3}$ fm

H1 $(f_e = f_q)$:
$R_{e,q} < 0.57 \cdot 10^{-3}$ fm

Large extra dimensions

Consider models with space time of $4 + n$ dimensions, where the compactified extra dimensions are of size R.

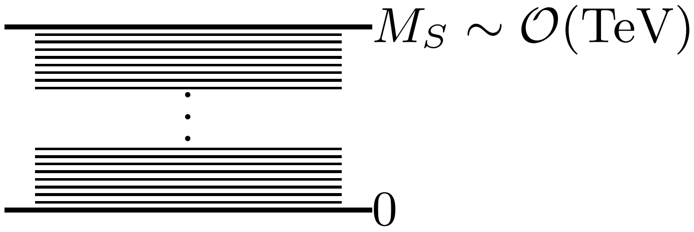
Reduced effective Planck scale M_S in the volume R^n:

$$M_P^2 = M_S^{2+n} R^n, \quad M_P \approx 10^{19}\mathrm{GeV}$$

A single graviton i has tiny coupling in normal space-time:

$$\mathcal{L}_G = -\frac{\sqrt{8\pi}}{M_P} G^i_{\mu\nu} T^{\mu\nu}$$

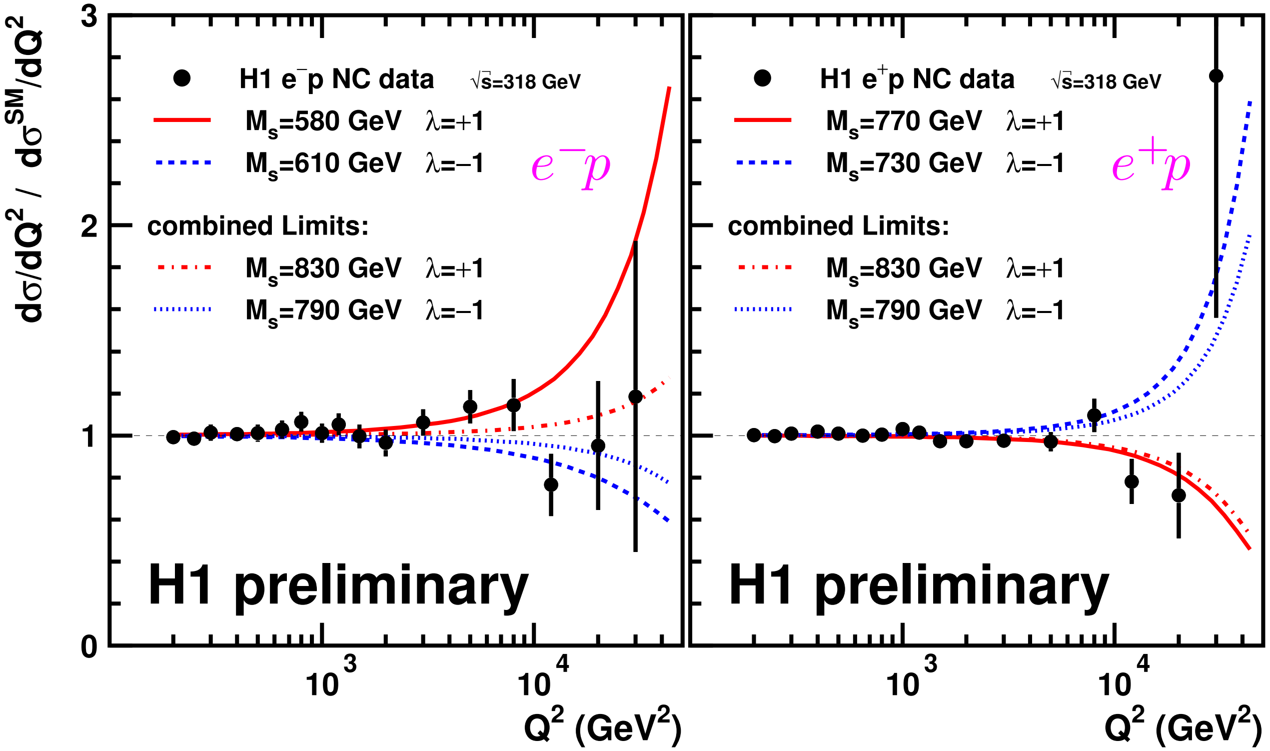
But: gravitons can propagate into the extra dimensions, visible in 4 dimensions as excited Kaluza-Klein states with level-spacing $\Delta m = \frac{1}{R}$



$\rightarrow$ After summing all states up to M_S, gravitation can have sizeable effects in particle physics.

Effective coupling constant: $\eta^G = \frac{\lambda}{M_S^4}$, where λ is of order 1

Limits on large extra dimensions



H1 limits on M_S

$\lambda = +1 :\ 0.83\,\text{TeV}$

$\lambda = -1 :\ 0.79\,\text{TeV}$

ZEUS limits on M_S

$\lambda = +1 :\ 0.81\,\text{TeV}$

$\lambda = -1 :\ 0.82\,\text{TeV}$

Large extra dimensions ruled for $M_S \lesssim 0.8\,\text{TeV}$

Note: analysis is done for $\lambda = \pm 1$, but only $\lambda = +1$ corresponds to an attracting gravitational force

Summary and conclusions

- HERA is sensitive to physics far beyond its center-of-mass energy, probing the structure of the eu and ed systems
- Explore light quarks $\leftrightarrow$ complementary to LEP
- Limits on the contact interaction scale Λ up to $7\,\mathrm{TeV}$
- Limits on leptoquark masses (coupling $\lambda = 1$) up to $1.4\,\mathrm{TeV}$
- Limits on Squarks in $\not{R}_p$ SUSY (coupling $\lambda = 1$) up to $0.75\,\mathrm{TeV}$
- Probe quark radius down to $0.7 \cdot 10^{-3}\,\mathrm{fm}$
- Rule out large extra dimensions up to scales $M_S \lesssim 0.8\,\mathrm{TeV}$

HERA II has just started:

- Collect factor of 10 more data
- Use polarized $e^{\pm}$ to disentangle left and right-handed couplings

Limits on Compositeness models from LEP