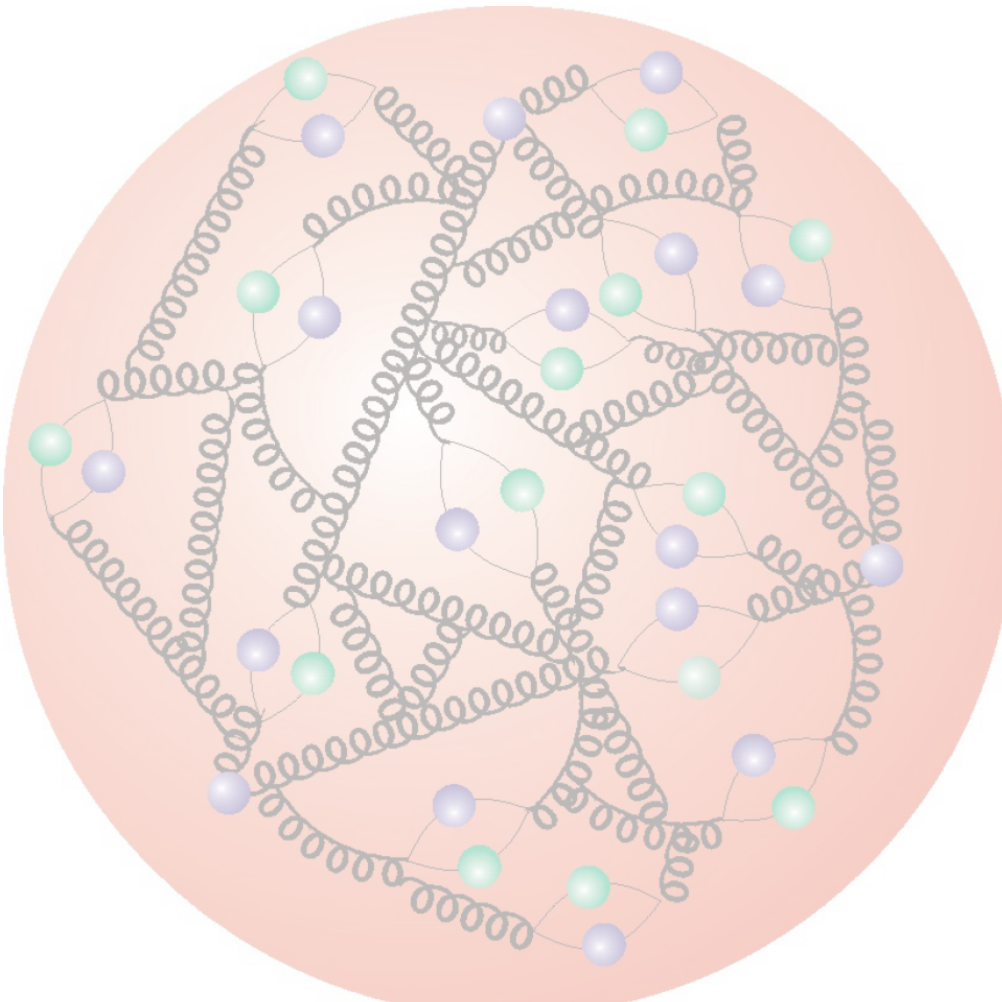
Search for Contact Interactions at HERA



- General Compositeness
- Heavy Leptoquarks
- Large Extra Dimensions
- Quark Radius

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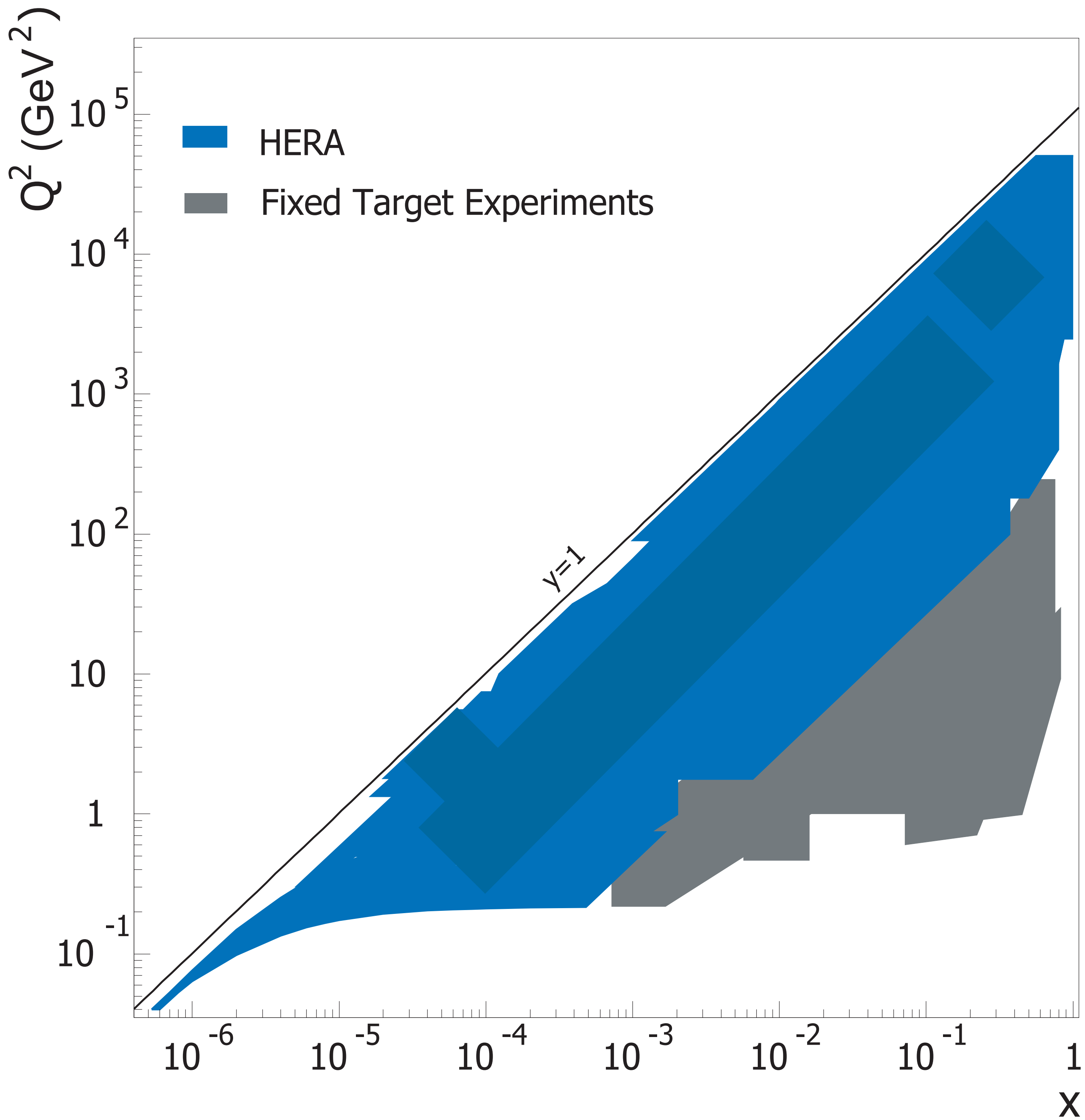
Melbourne, Australia – July 2012

Kinematic Range



HERA accesses large reach in kinematic plane

High mass states produced at large Q^2

Sensitive to 4-fermion contact interactions

Look at Q^2 dependence of DIS cross section...

Deep Inelastic Scattering

$$\frac{d\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{x} \left[\frac{1}{Q^2}\right]^2 \left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right]$$

$$\frac{d\sigma^{\pm}_{CC}}{dxdQ^2} = \frac{G_F^2}{4\pi x} \left[\frac{M_W^2}{M_W^2+Q^2}\right]^2 \left[Y_+\tilde{W}_2^{\pm} \mp Y_- x\tilde{W}_3^{\pm} - y^2\tilde{W}_L^{\pm}\right]$$

$$Y_{\pm} = 1 \pm (1-y)^2$$

Weaker ln (Q^2) dependence from QCD part of SM

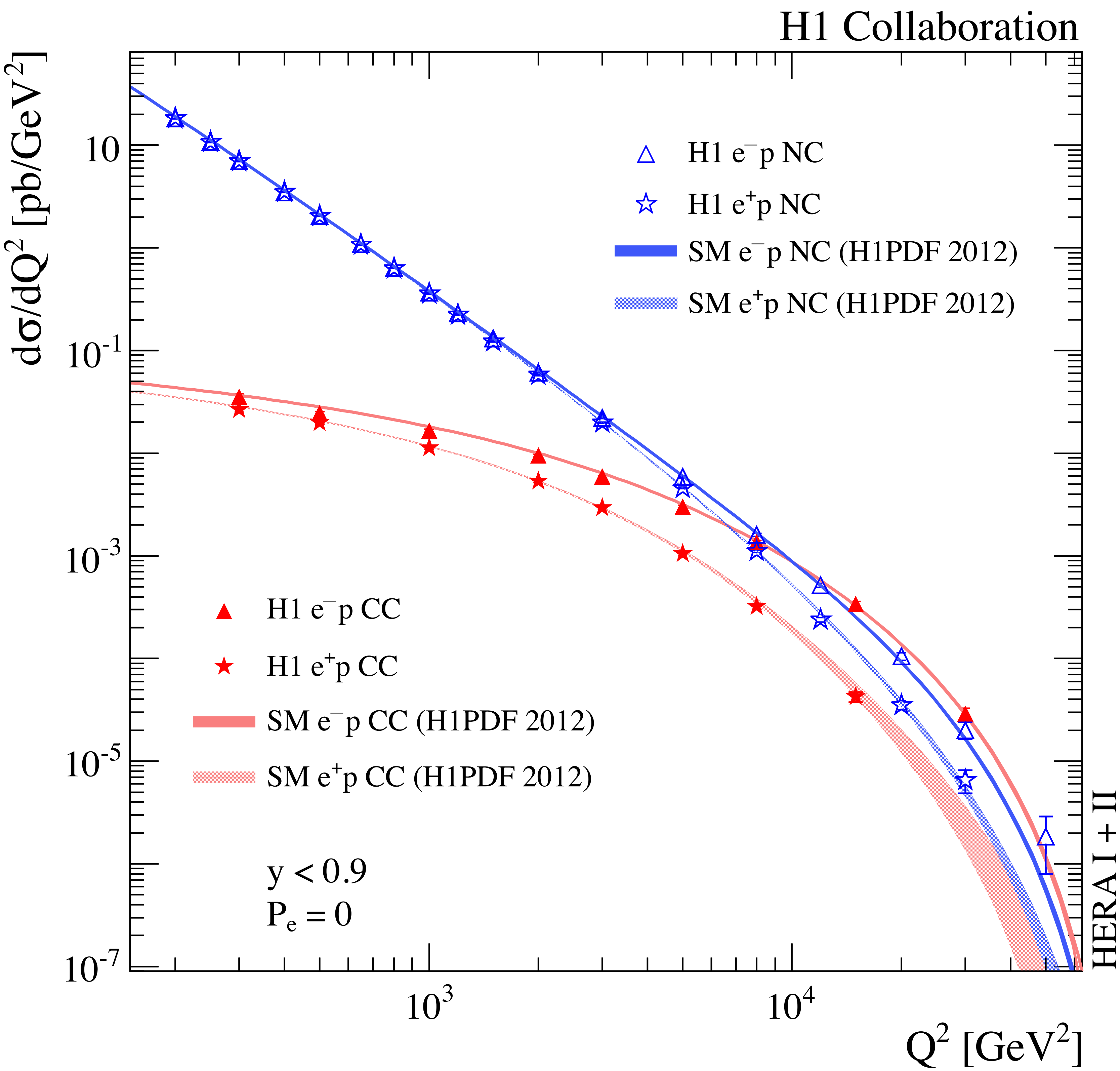
Dominant Q^2 dependence from electroweak part of SM

$\tilde{F}_2 \propto \sum(xq_i + x\bar{q}_i)$	Dominant contribution
$x\tilde{F}_3 \propto \sum(xq_i - x\bar{q}_i)$	Only sensitive at high $Q^2 \sim M_Z^2$
$\tilde{F}_L \propto \alpha_s \cdot xg(x,Q^2)$	Only sensitive at low Q^2 and high y

similarly for pure weak CC analogues:

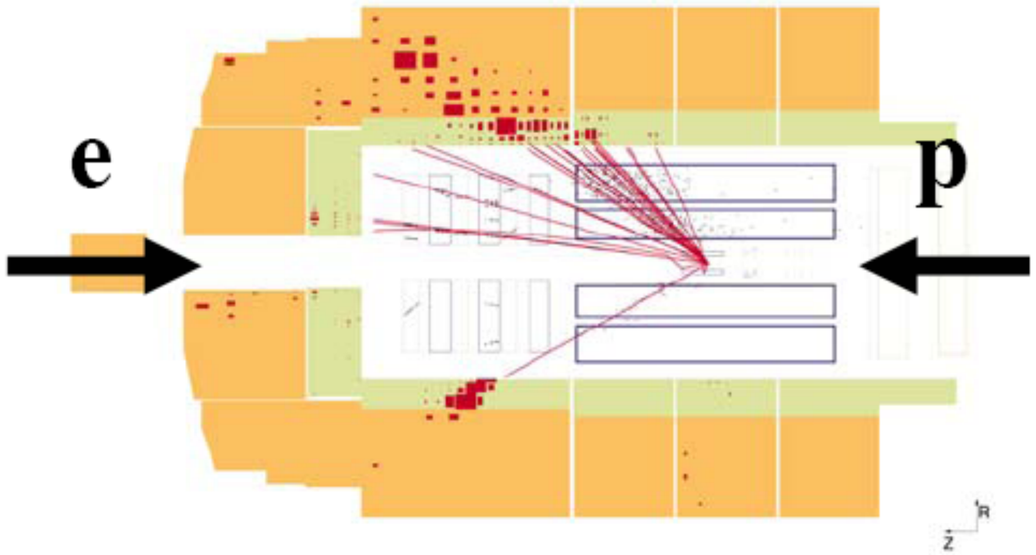
$W_2^{\pm}$, $xW_3^{\pm}$ and $W_L^{\pm}$

arXiv:1206.7007



Neutral and charged current processes measured across wide Q^2 range

Full HERA data set used



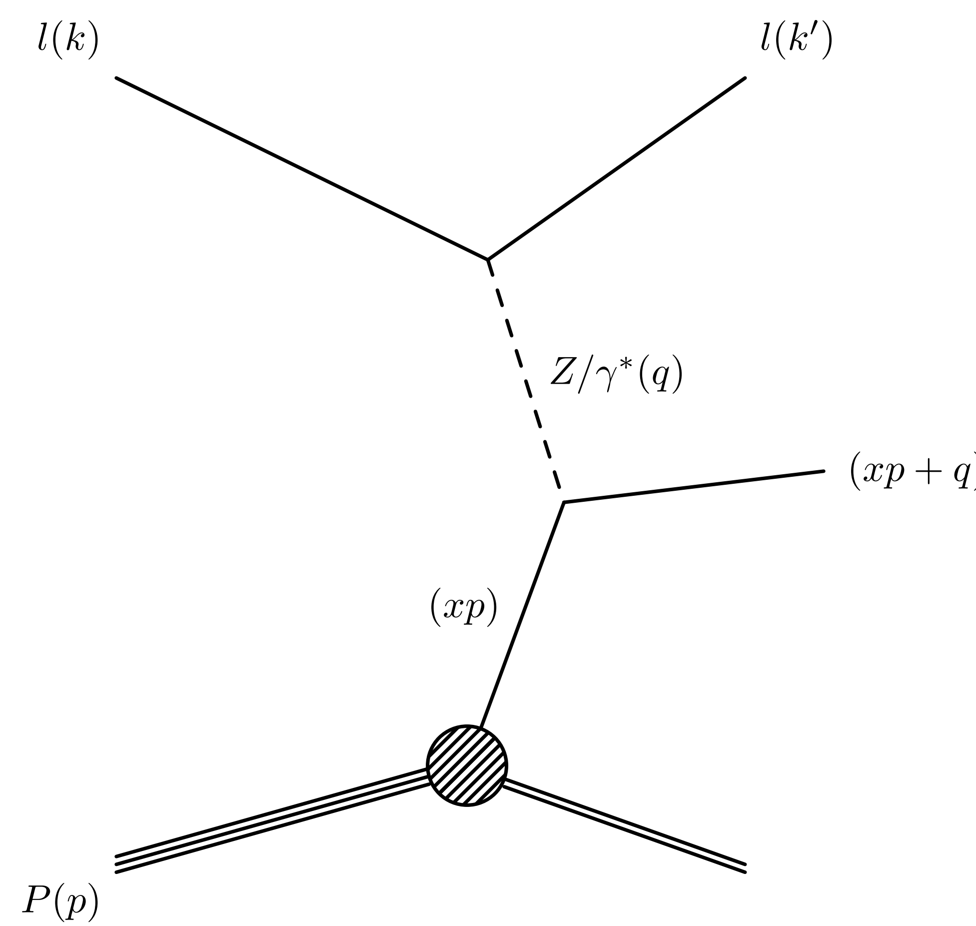
Neutral current event selection:

High P_T isolated scattered lepton
Suppress huge photo-production background by imposing longitudinal energy-momentum conservation

Kinematics may be reconstructed in many ways:
energy/angle of hadrons & scattered lepton
provides excellent tools for sys cross checks

Removal of scattered lepton provides a
high stats "pseudo-charged current sample"
Excellent tool to cross check CC analysis

Final selection: ~10^5 events per sample at high Q^2
~10^7 events for $10 < Q^2 < 100$ GeV^2

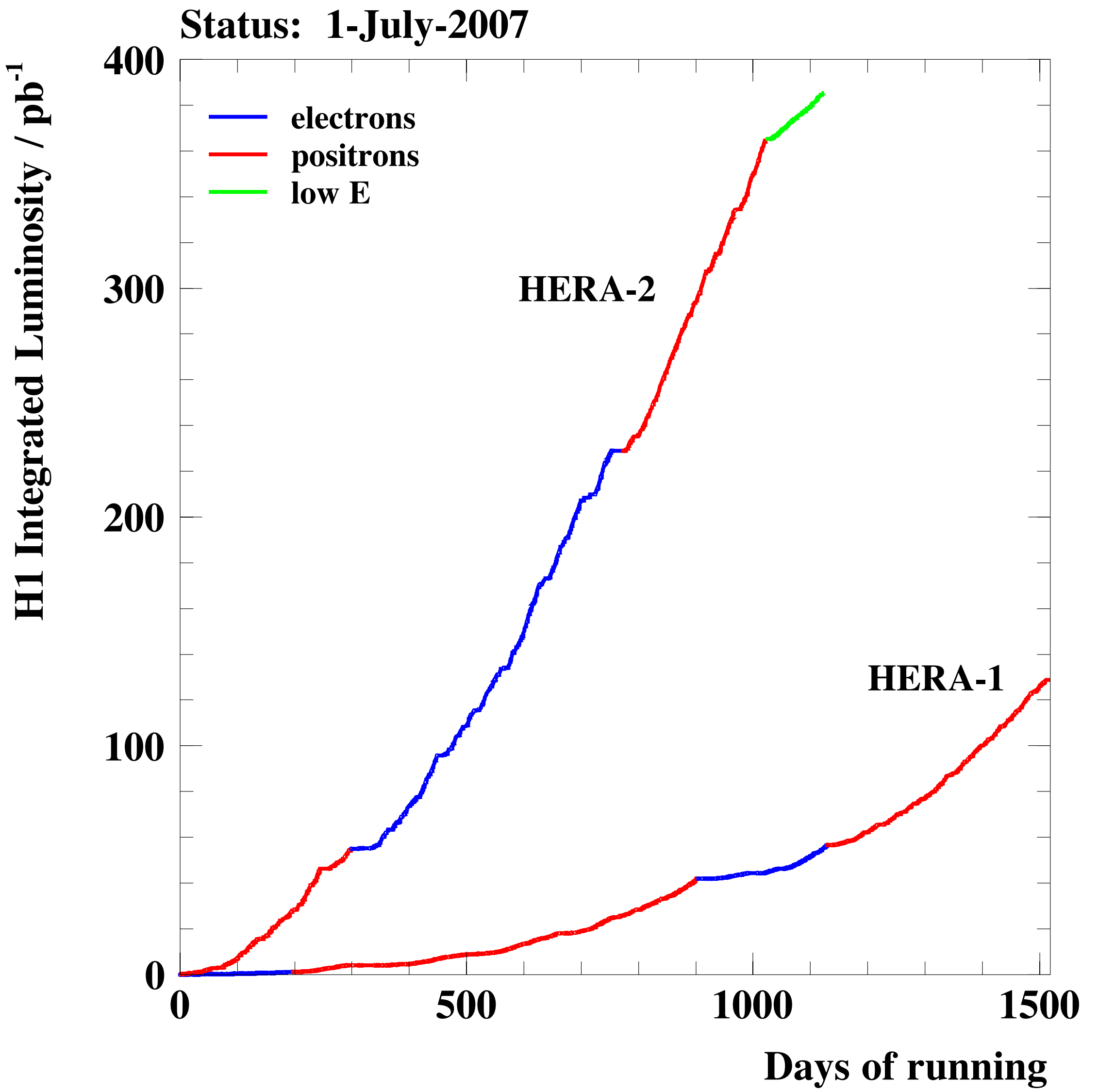


HERA Operation

<u>HERA-I operation 1993-2000</u>
Ee = 27.6 GeV
Ep = 820 / 920 GeV
$\int\mathcal{L}$ ~ 110 pb^{-1} per experiment

<u>HERA-II operation 2003-2007</u>
Ee = 27.6 GeV
Ep = 920 GeV
$\int\mathcal{L}$ ~ 330 pb^{-1} per experiment
Longitudinally polarised leptons

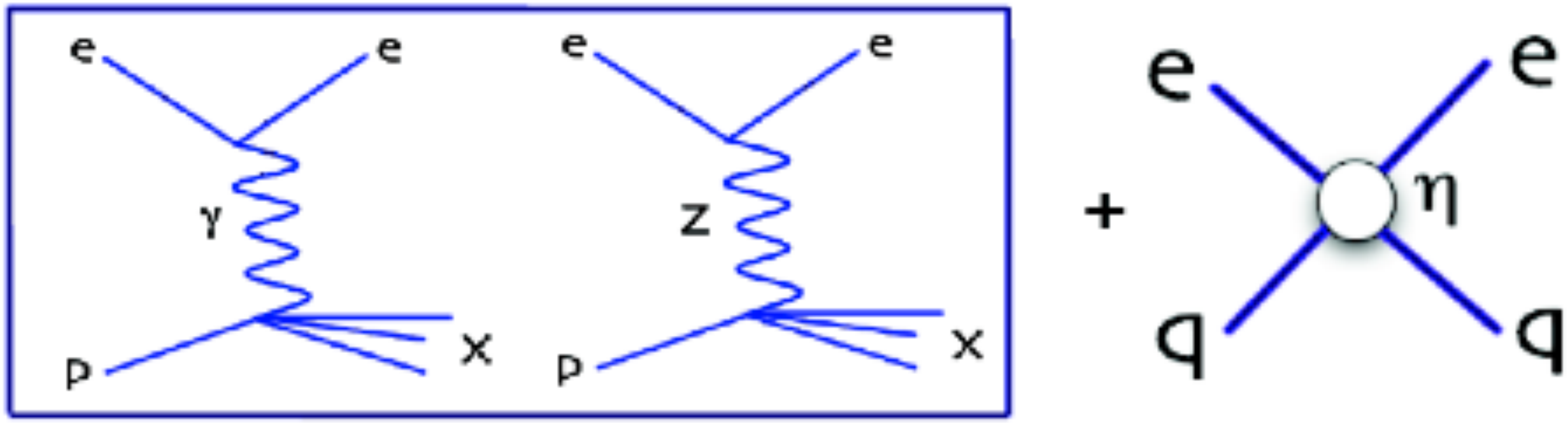
<u>Low Energy Run 2007</u>
Ee = 27.6 GeV
Ep = 575 & 460 GeV
Dedicated F_L measurement



Total luminosity presented here = 446 pb^{-1}

Reaction	$\mathcal{L}_{int}$ [pb^{-1}]	$\sqrt{s}$ [GeV]	Polarisation (P_e [%])
$e^+p \to e^+X$	36	301	Unpolarised
$e^-p \to e^-X$	16	319	Unpolarised
$e^+p \to e^+X$	65	319	Unpolarised
$e^-p \to e^-X$	46	319	Right ($P_e = +37$)
$e^-p \to e^-X$	103	319	Left ($P_e = -26$)
$e^+p \to e^+X$	98	319	Right ($P_e = +33$)
$e^+p \to e^+X$	82	319	Left ($P_e = -38$)

Search for New Phenomena - Deviations from SM



$$\chi^2(\eta,\varepsilon) = \sum_i \frac{\left(\sigma_i^{\exp} - \sigma_i^{\rm th}(\eta)\left(1-\sum_k \Delta_{ik}(\varepsilon_k)\right)\right)^2}{\delta_{i,{\rm stat}}^2\, \sigma_i^{\exp}\sigma_i^{\rm th}(\eta)\left(1-\sum_k \Delta_{ik}(\varepsilon_k)\right) + \left(\delta_{i,{\rm uncor}}\,\sigma_i^{\exp}\right)^2} + \sum_k \varepsilon_k^2$$

A selection of new physics models are tested
Minimise χ^2 function w.r.t. model parameters η
Take into account systematic uncertainties on measurements $\Delta_{i,k}$ for each error source ε_k

PDFs taken from CTEQ6m
Unbiased PDFs - constrained by:

- fixed target data at low Q^2 and high x
- Tevatron W/Z production data
- HERA data at lower Q^2 < 200 GeV^2

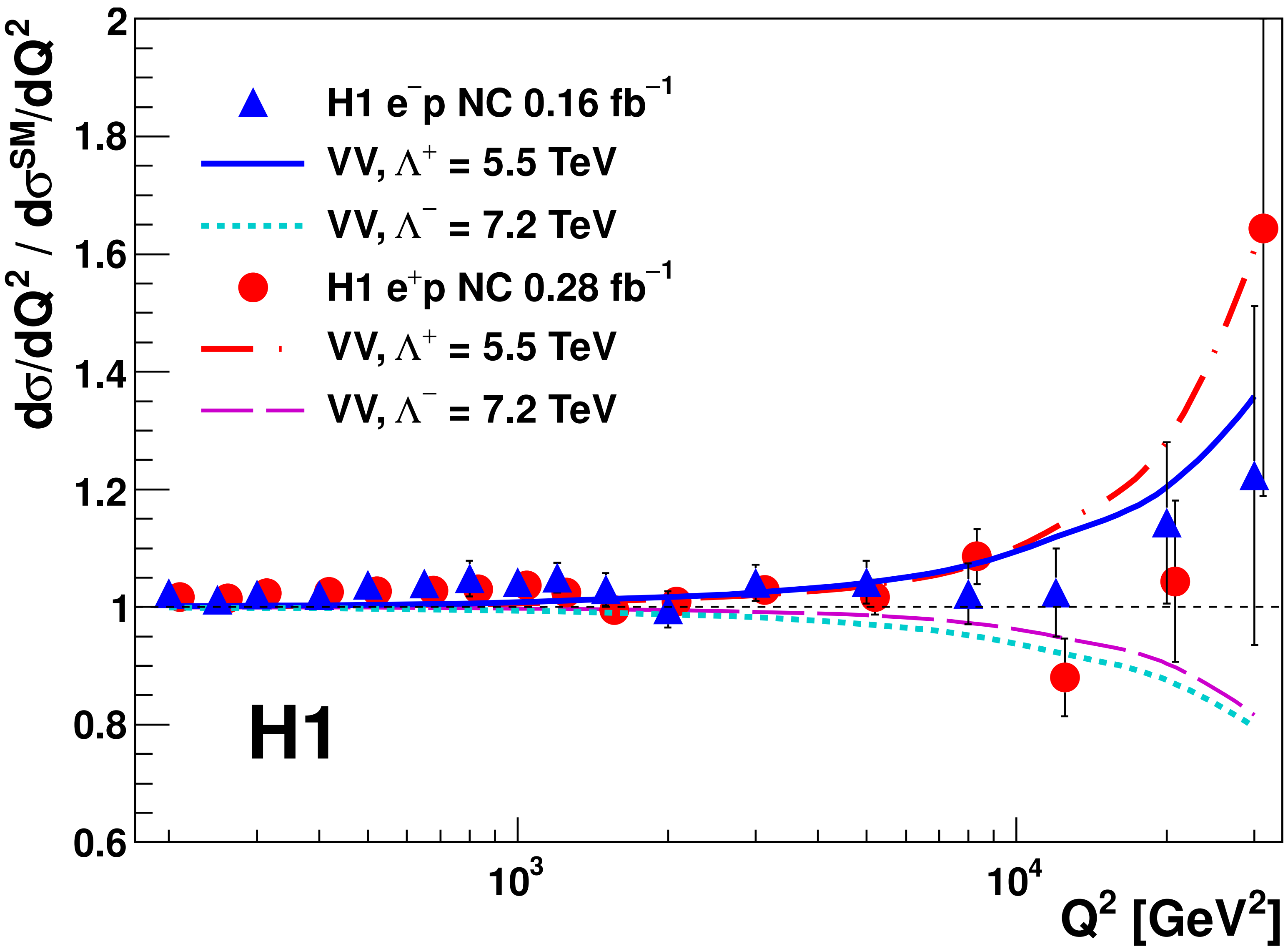
} insensitive to eq contact interactions

χ^2/ndf (η=0) = 16.4/17 for e^+p
7.0/16 for e^-p

Alternative H1PDF2009 also used as check

arXiv:0904.0929

arXiv:1107.2478



Include additional term to SM lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{CI}$$

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

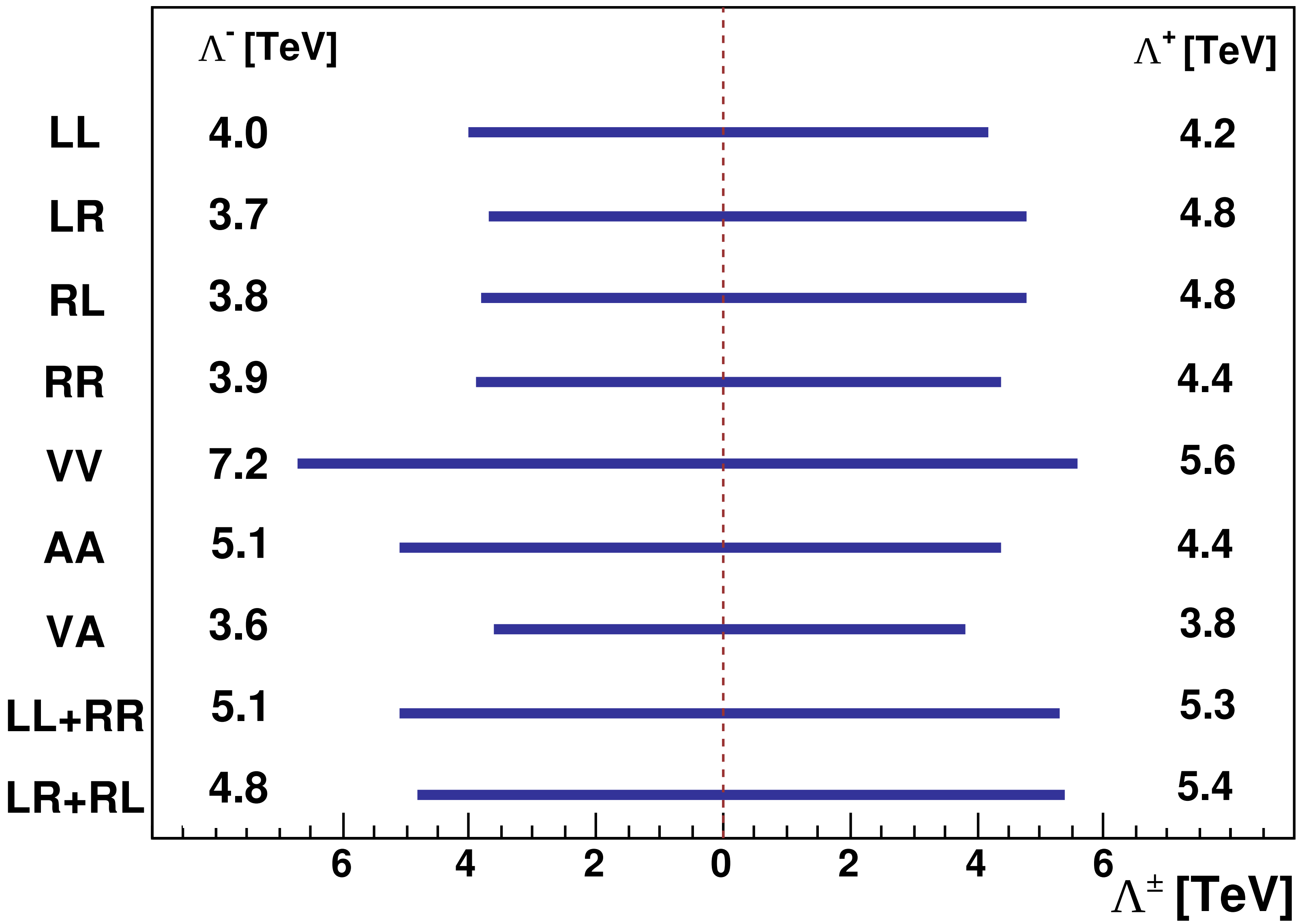
$$\eta_{L,R}^{eq} = \frac{\pm 4\pi}{\Lambda^2}$$

Several general models tested
Single common compositeness scale Λ
Different L,R fermion helicities
Different Vector / Axial-vector chiral couplings

Different models will interfere constructively or destructively with SM

Search For General Compositeness

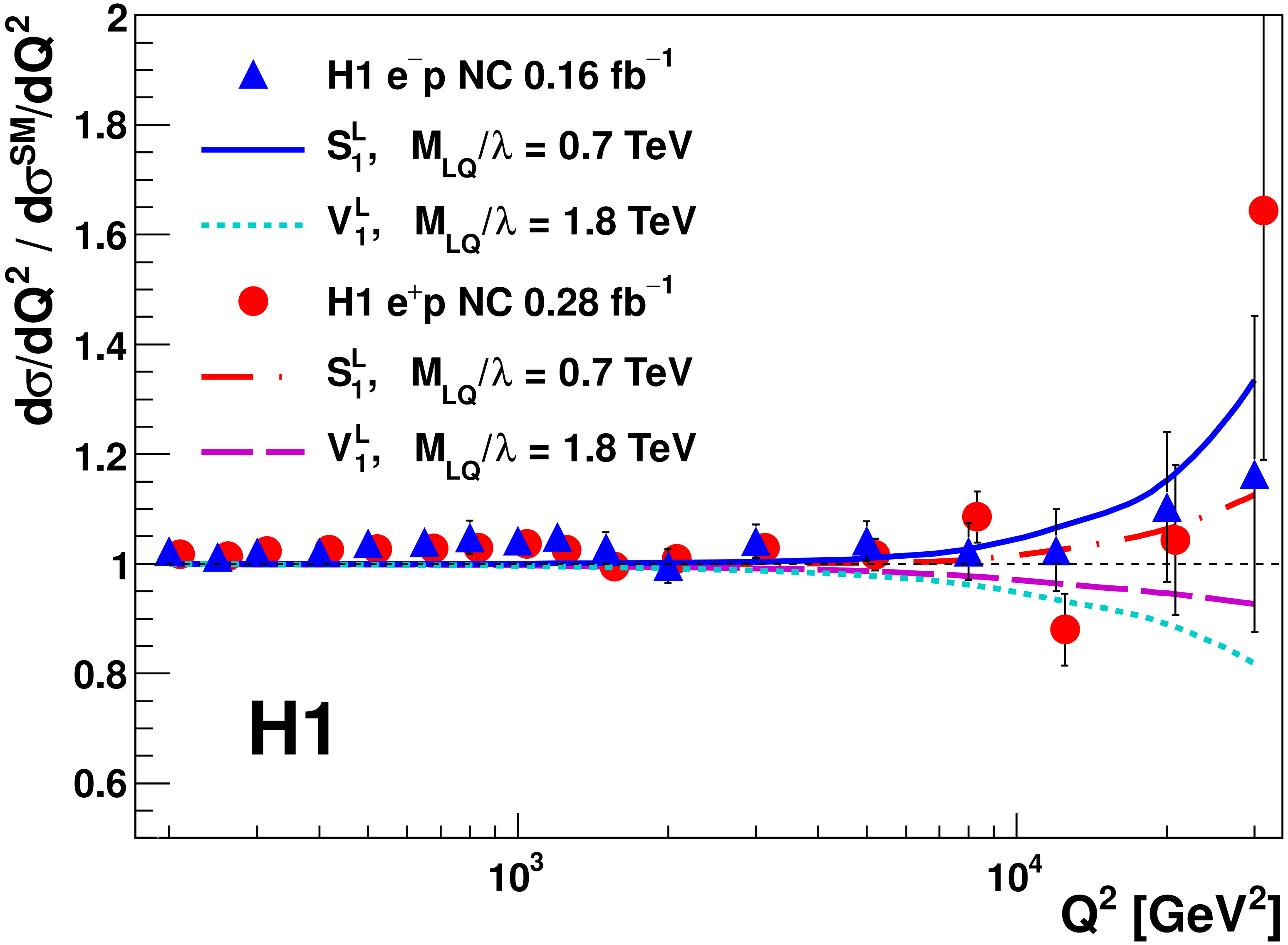
arXiv:1107.2478



Lower limits at 95% CL on effective mass scale: Λ > 3.2 to 7.2 TeV

Search For Heavy Leptoquarks

arXiv:1107.2478



Search for lepto-quarks with masses $M_{LQ} \gg \sqrt{s}$ produced with coupling λ

Search for scalar and vector LQs with:
L and R chirality
fermion number F=0 or 2

$$\eta = \epsilon \frac{\lambda^2}{M_{LQ}^2}$$

$\epsilon = 0, \pm½, \pm1, \pm2$

Lower limits at 95% CL:
M_{LQ}/λ > 0.41 to 1.86 TeV

Search For Heavy Leptoquarks

arXiv:1107.2478

$\eta^q_{ab} = \epsilon^q_{ab}\,\lambda^2/M^2_{\rm LQ}$

LQ	ϵ^u_{ab}	ϵ^d_{ab}	F	$M_{\rm LQ}/\lambda$ [TeV]
S_0^L	$\epsilon^u_{LL} = +\frac{1}{2}$		2	1.10
S_0^R	$\epsilon^u_{RR} = +\frac{1}{2}$		2	1.10
$\tilde{S}_0^R$		$\epsilon^d_{RR} = +\frac{1}{2}$	2	0.41
$S_{1/2}^L$	$\epsilon^u_{LR} = -\frac{1}{2}$		0	0.87
$S_{1/2}^R$	$\epsilon^u_{RL} = -\frac{1}{2}$	$\epsilon^d_{RL} = -\frac{1}{2}$	0	0.59
$\tilde{S}_{1/2}^L$		$\epsilon^d_{LR} = -\frac{1}{2}$	0	0.66
S_1^L	$\epsilon^u_{LL} = +\frac{1}{2}$	$\epsilon^d_{LL} = +1$	2	0.71
V_0^L		$\epsilon^d_{LL} = -1$	0	1.06
V_0^R		$\epsilon^d_{RR} = -1$	0	0.91
$\tilde{V}_0^R$	$\epsilon^u_{RR} = -1$		0	1.35
$V_{1/2}^L$		$\epsilon^d_{LR} = +1$	2	0.51
$V_{1/2}^R$	$\epsilon^u_{RL} = +1$	$\epsilon^d_{RL} = +1$	2	1.44
$\tilde{V}_{1/2}^L$	$\epsilon^u_{LR} = +1$		2	1.58
V_1^L	$\epsilon^u_{LL} = -2$	$\epsilon^d_{LL} = -1$	0	1.86

Search for lepto-quarks with masses $M_{LQ} \gg \sqrt{s}$ produced with coupling λ

Search for scalar and vector LQs with:
L and R chirality
fermion number F=0 or 2

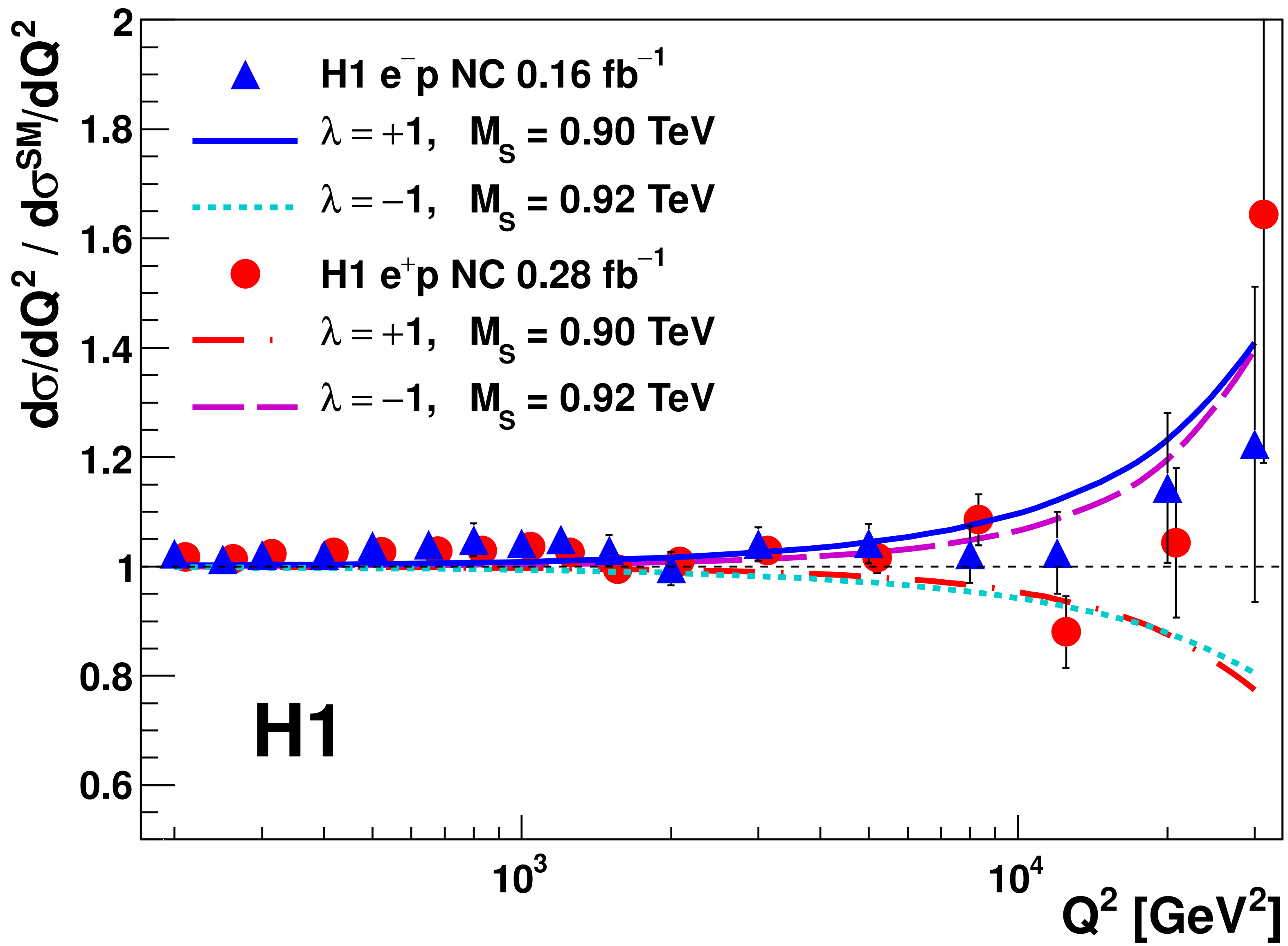
$$\eta = \epsilon \frac{\lambda^2}{M^2_{LQ}}$$

$\epsilon = 0, \pm\frac{1}{2}, \pm 1, \pm 2$

Lower limits at 95% CL:
M_{LQ}/λ > 0.41 to 1.86 TeV

Search For Large Extra Dimensions

arXiv:1107.2478



Compactified extra dimensions of size *R* could become accessible at high energies below Planck scale M_P. New gravity scale in *n* extra dimensions is M_S

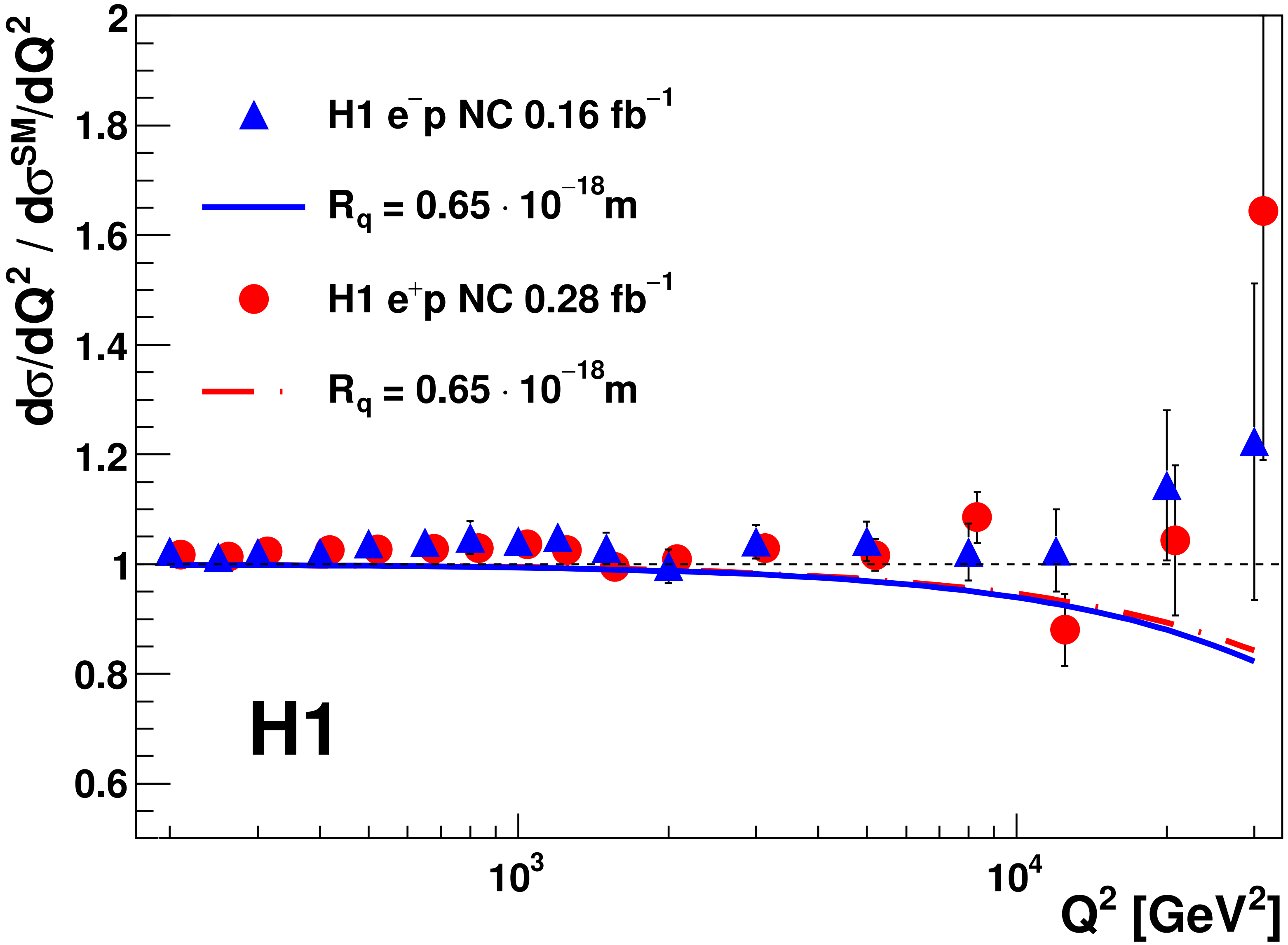
$$M_S^{2+n} = \frac{M_P^2}{R^n}$$

coupling $\eta_G = \frac{\lambda}{M_S^4}$

with $\lambda = \pm 1$

Lower limits at 95% CL on effective mass scale: M_S > 0.9 TeV

arXiv:1107.2478



Search for quark sub-structure
Assume point-like electron
Simple form-factor model for the mean squared radius of electroweak charge on the quark $\langle R^2 \rangle$

$$f(Q^2) = 1 - \frac{\langle R^2 \rangle}{6} Q^2$$

Upper limit at 95% CL
$R < 0.65 \times 10^{-18}$ m

Conclusions

A range of new phenomena models are explored
New limits on compositeness models factor ~2 higher than previous H1 measurements
Comparable limits to LEP and Tevatron