Contact Interaction and Lepton Flavour Violation

Carsten Niebuhr

DESY

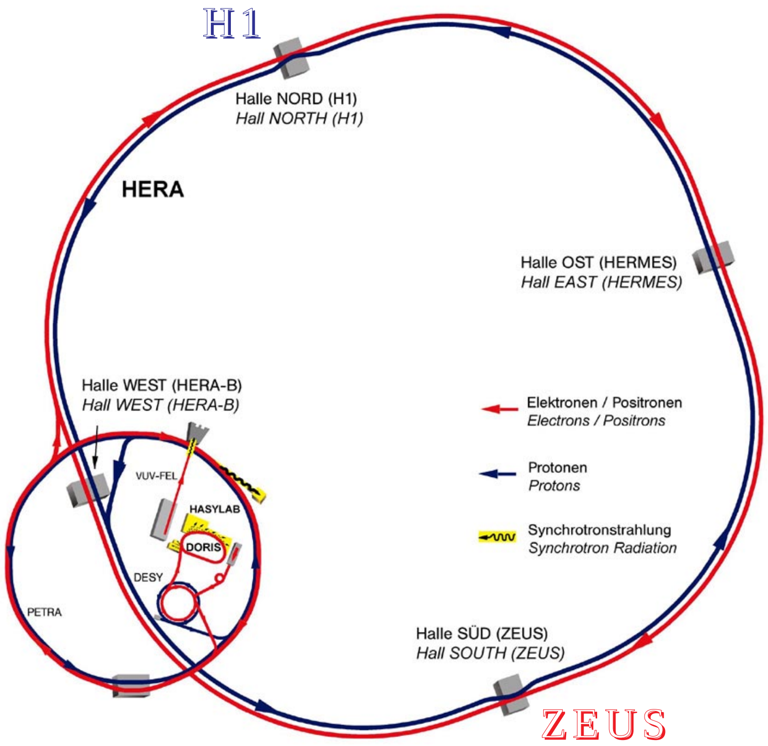
representing

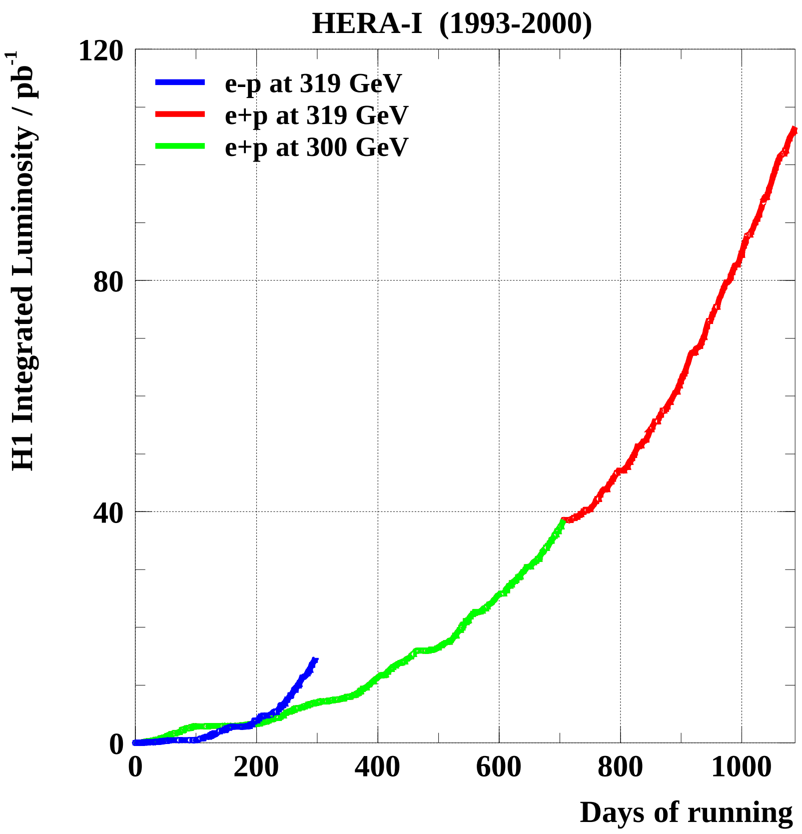
H1

and

ZEUS

HERA ep Collider





$e^+(e^-)$ → 27.6 GeV

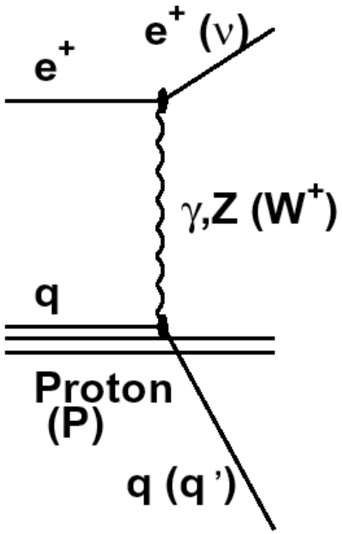
p ← 920 GeV (820 GeV)

HERA I data: each experiment

- L ~ 16 pb^{-1} e^-p
- L ~ 100 pb^{-1} e^+p

Electron-Quark Scattering and DIS Kinematics

DIS



$Q^2 = -(k - k')= -q^2$	four momentum transfer squared
$x = -q^2 /(2 \cdot P \cdot q)$	Bjorken scaling variable
$y = (q \cdot P)/(k \cdot P) = (1 - \cos\theta^*)/2$	inelasticity
$s = 2 \cdot k \cdot P = Q^2 /(x \cdot y)$	ep CM energy squared

Electron-Quark Scattering and DIS Kinematics

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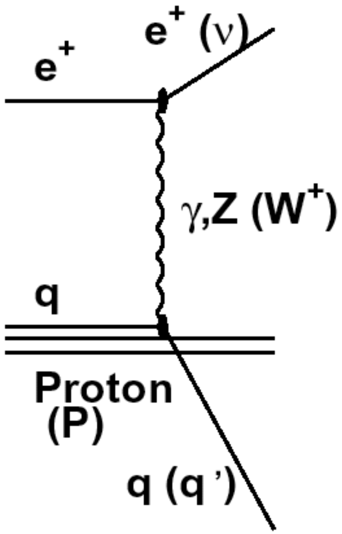
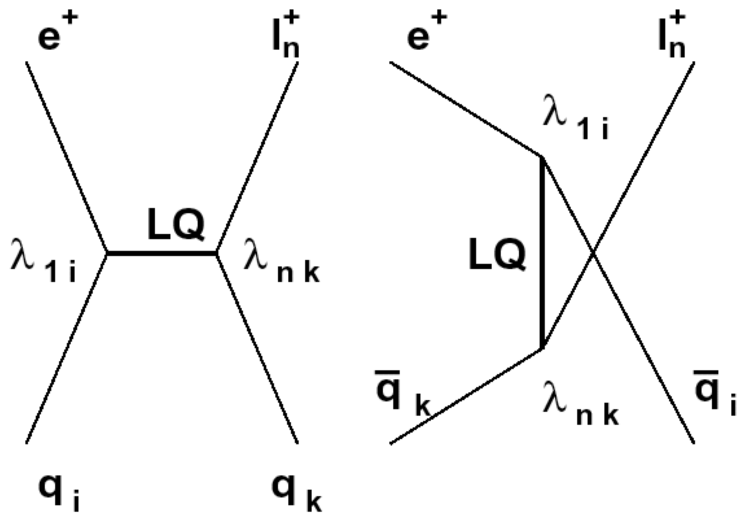


"New Physics"



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Electron-Quark Scattering and DIS Kinematics

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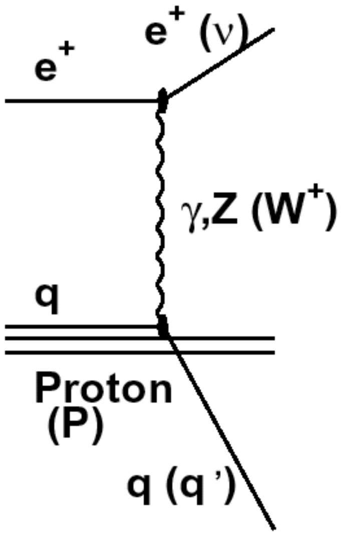

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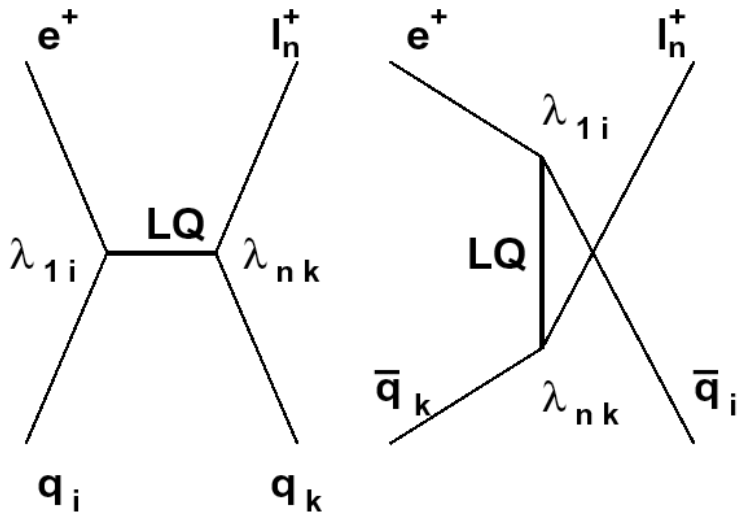
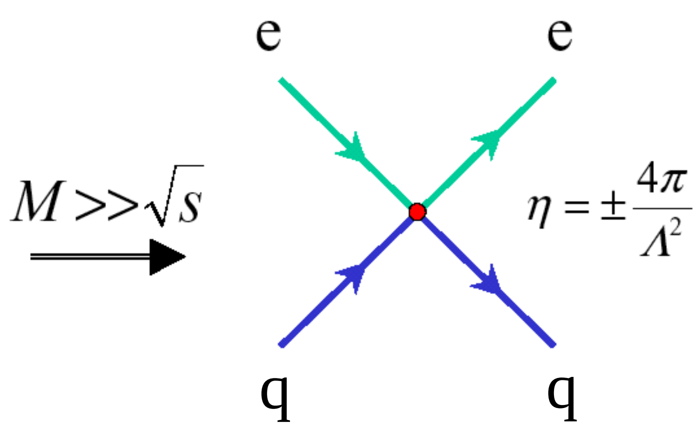


Low energy limit



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$s = 2 \cdot k \cdot P = Q^2/(x \cdot y)$	ep CM energy squared

Contact Interaction Phenomenology

- Effective Lagrange Density (vector terms only) modifies scattering amplitude

$$L_V = \sum_{q=u,d} \sum_{a,b=L,R} \eta^q_{ab} (\overline{e}_a \gamma^\mu e_a)(\overline{q}_b \gamma_\mu q_b)$$ with $\eta^q_{ab} = \varepsilon^q_{ab} \frac{4\pi}{\Lambda^2}$ and effective mass scale Λ

- Depending on chiral structure of model which is probed, only some of the couplings contribute. Formalism applicable for many different models (Compositeness, LQs, Quark Structure, Large Extra Dimensions, ...)

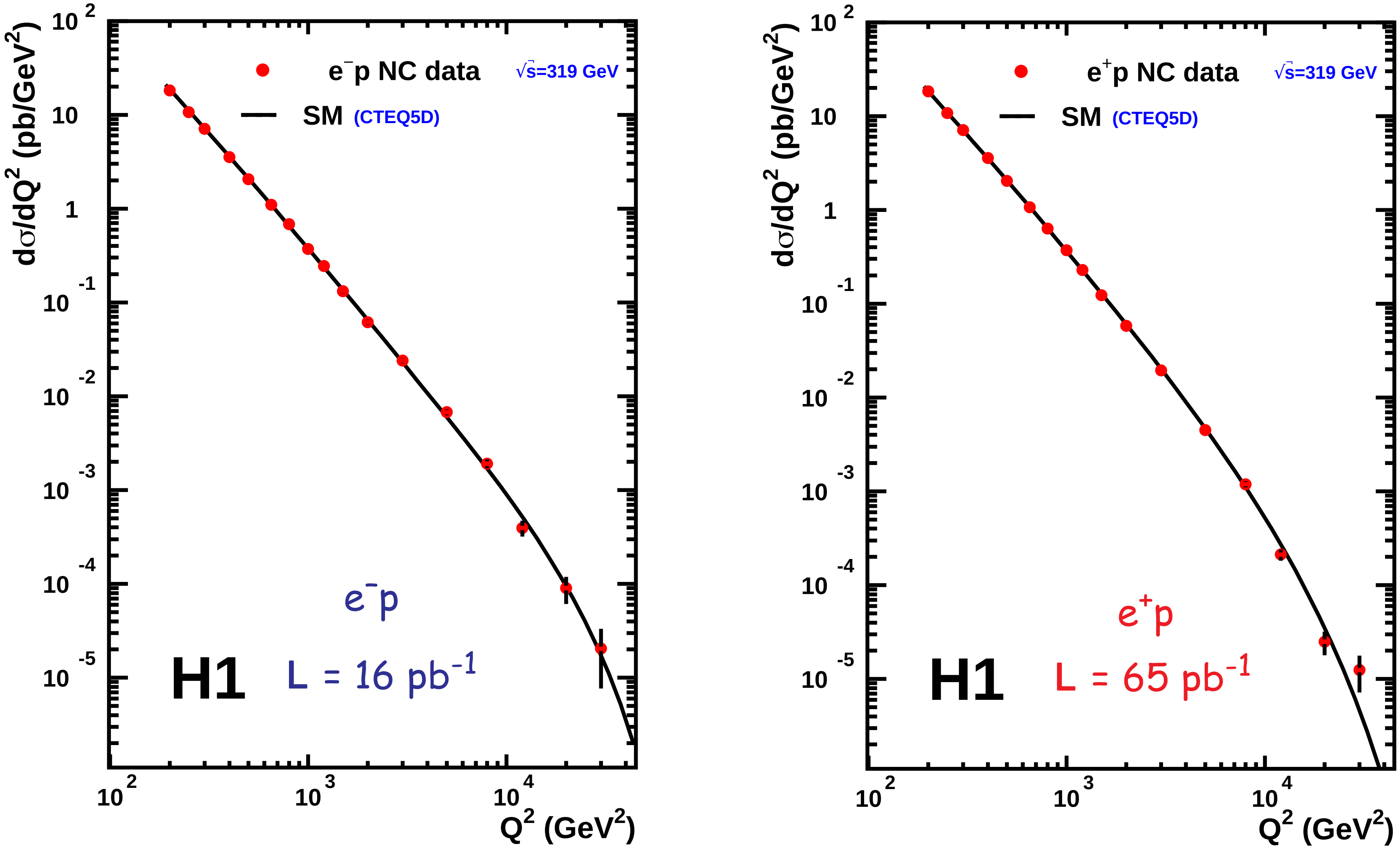
  → see separate talk by Eric Kajfasz

- Cross section in presence of CI gets modified at high Q^2 :

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \pm \frac{d\sigma^{IF}}{dQ^2} + \frac{d\sigma^{CI}}{dQ^2}$$

- ⇒ sensitivity to scales Λ beyond centre-of-mass energies

Neutral Current Cross Section $d\sigma/dQ^2$

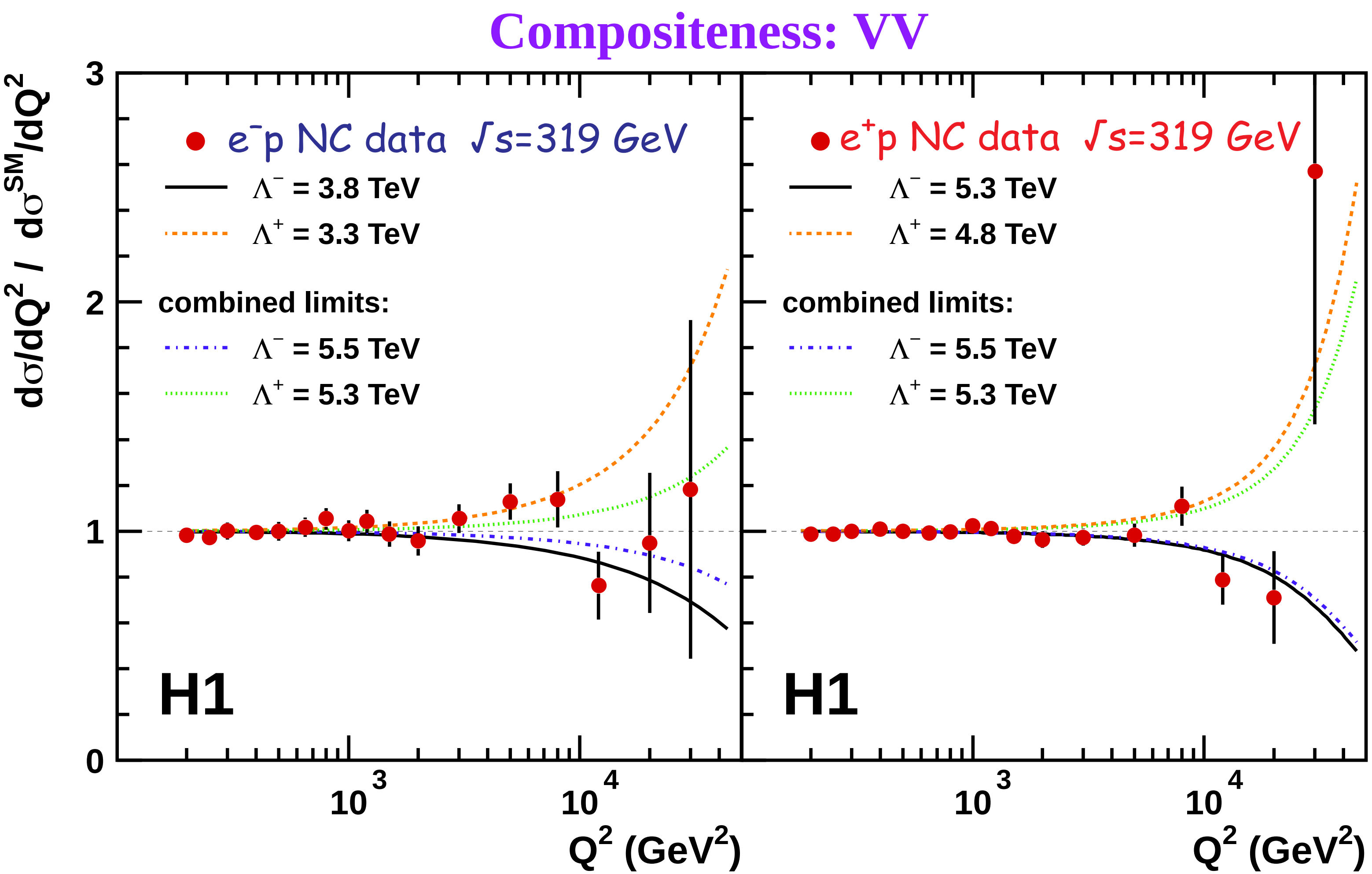


- data are well described by SM over more than 6 orders of magnitude
- possible deviations from SM would show up at large Q^2

Example for Compositeness

VV corresponds to chiral structure: $\varepsilon_{LL} = \varepsilon_{LR} = \varepsilon_{RL} = \varepsilon_{RR} = 1$

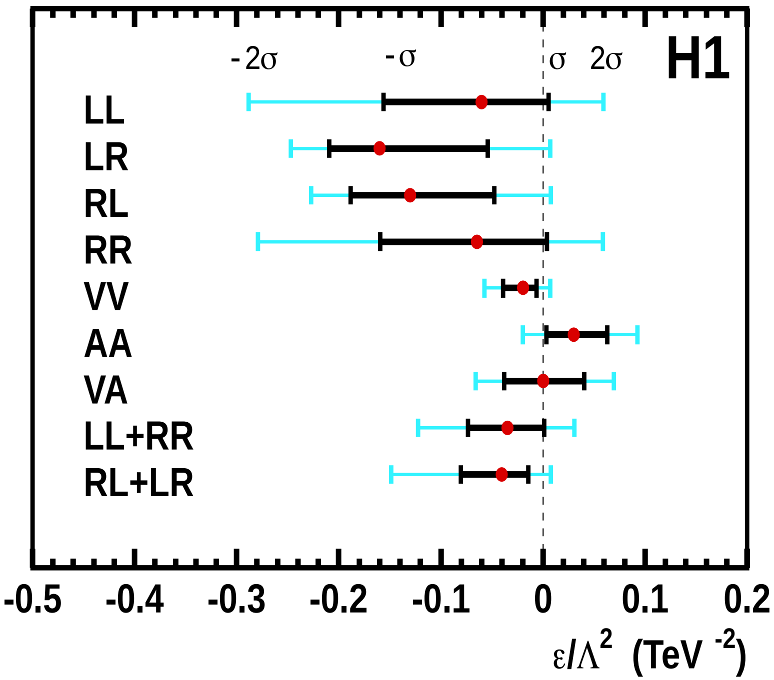
abstract 12-0158



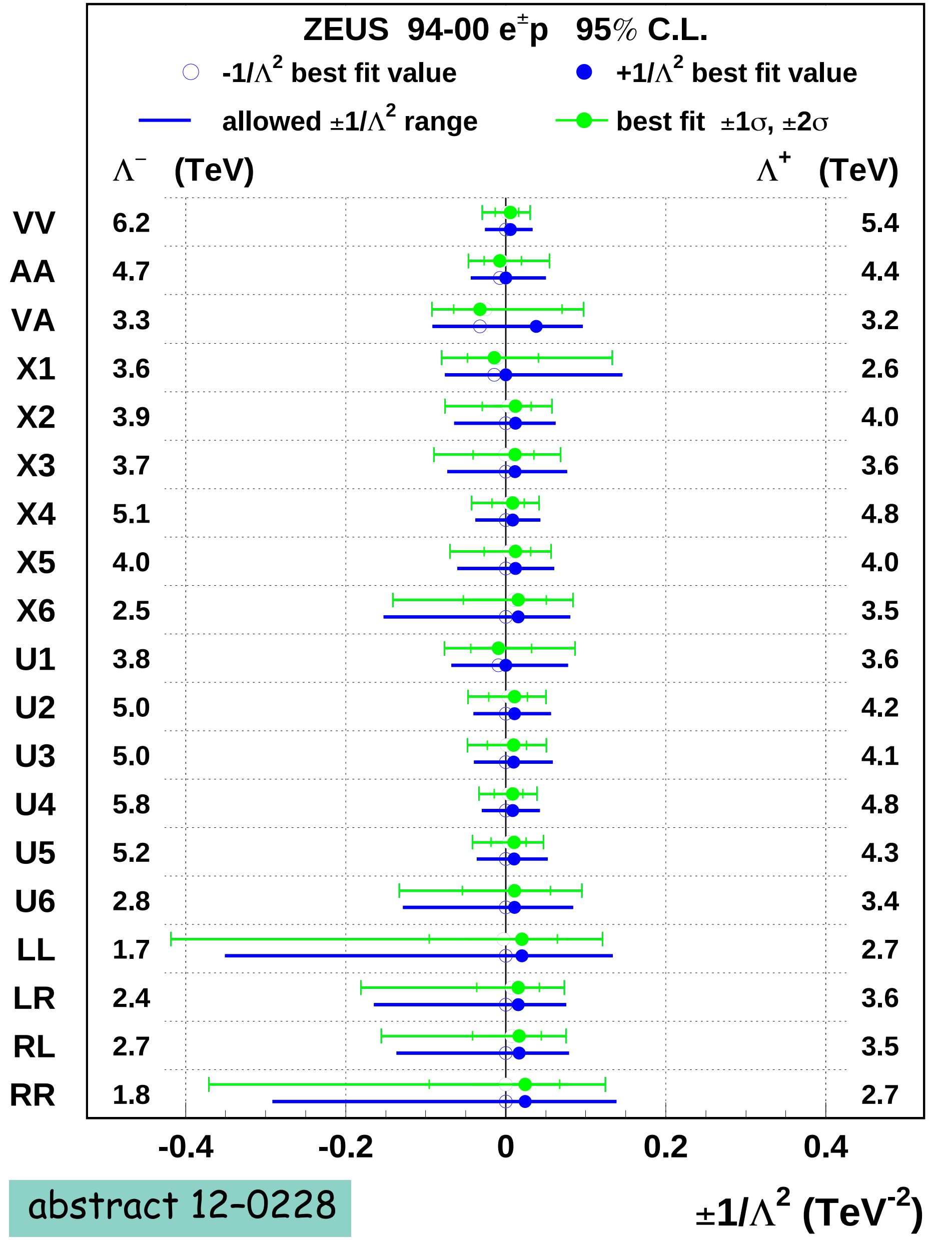
- e^-p and e^+p exhibit complementary sensitivity
- despite much lower luminosity

  e^-p data help to improve limits

CI Limits on $1/\Lambda^2$ in Compositeness Models



abstract 12-0158



abstract 12-0228

- no evidence for CI signal
- resulting limits are in the range 1.7-6.2 TeV depending on chiral structure of model

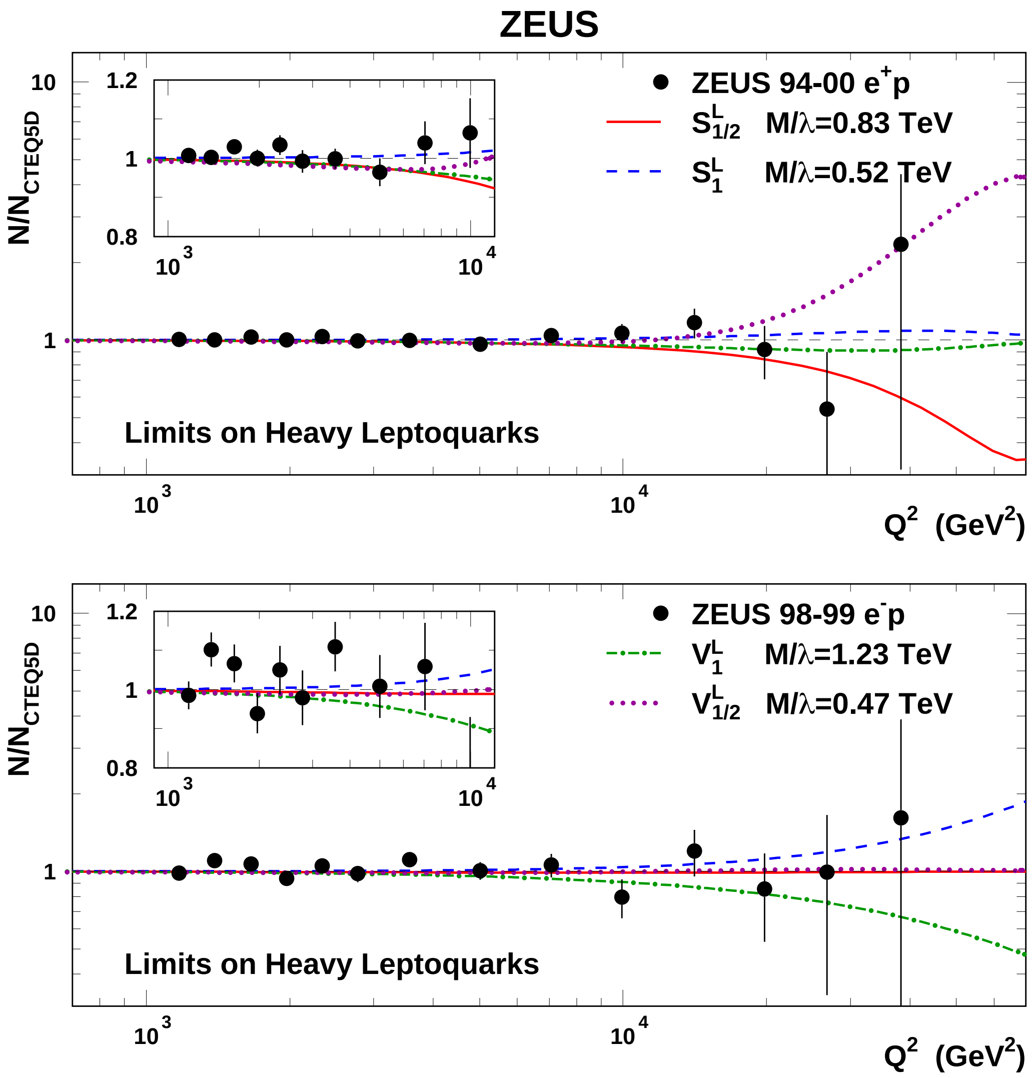
Comparison with other Experiments

		ZEUS		H1		D0		CDF		ALEPH		L3		OPAL	
Model	Coupling structure $[\epsilon_{LL},\epsilon_{LR},\epsilon_{RL},\epsilon_{RR}]$	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
LL	$[+1,\ 0,\ 0,\ 0]$	1.7	2.7	1.6	2.8	4.2	3.3	3.7	2.5	6.2	5.4	2.8	4.2	3.1	5.5
LR	$[\ 0,+1,\ 0,\ 0]$	2.4	3.6	1.9	3.3	3.6	3.4	3.3	2.8	3.3	3.0	3.5	3.3	4.4	3.8
RL	$[\ 0,\ 0,+1,\ 0]$	2.7	3.5	2.0	3.3	3.7	3.3	3.2	2.9	4.0	2.4	4.6	2.5	6.4	2.7
RR	$[\ 0,\ 0,\ 0,+1]$	1.8	2.7	2.2	2.8	4.0	3.3	3.6	2.6	4.4	3.9	3.8	3.1	4.9	3.5
VV	$[+1,+1,+1,+1]$	6.2	5.4	5.5	5.3	6.1	4.9	5.2	3.5	7.1	6.4	5.5	4.2	7.2	4.7
AA	$[+1,-1,-1,+1]$	4.7	4.4	4.1	2.5	5.5	4.7	4.8	3.8	7.9	7.2	3.8	6.1	4.2	8.1
VA	$[+1,-1,+1,-1]$	3.3	3.2	3.0	2.9										
X1	$[+1,-1,\ 0,\ 0]$	3.6	2.6			4.5	3.9								
X2	$[+1,\ 0,+1,\ 0]$	3.9	4.0												
X3	$[+1,\ 0,\ 0,+1]$	3.7	3.6	3.9	3.7	5.1	4.2			7.4	6.7	3.7	4.4	4.4	5.4
X4	$[\ 0,+1,+1,\ 0]$	5.1	4.8	4.4	4.4	4.4	3.9			4.5	2.9	5.2	3.1	7.1	3.4
X5	$[\ 0,+1,\ 0,+1]$	4.0	4.0												
X6	$[\ 0,\ 0,+1,-1]$	2.5	3.5			4.3	4.0								
U1	$[+1,-1,\ 0,\ 0]^{eu}$	3.8	3.6												
U2	$[+1,\ 0,+1,\ 0]^{eu}$	5.0	4.2												
U3	$[+1,\ 0,\ 0,+1]^{eu}$	5.0	4.1									5.2	9.2		
U4	$[\ 0,+1,+1,\ 0]^{eu}$	5.8	4.8									3.2	2.3		
U5	$[\ 0,+1,\ 0,+1]^{eu}$	5.2	4.3												
U6	$[\ 0,\ 0,+1,-1]^{eu}$	2.8	3.4												

limits comparable to those obtained at LEP & TeVatron

Search for Leptoquarks in CI: $M_{LQ} >> \sqrt{s}$

- Leptoquarks appear in many extentions of Standard Model
  - color triplet bosons (scalars or vectors)
  - carry both L and B numbers
  - fractional charge
- Classification in Buchmüller-Rückl-Wyler model
  - dimensionless chiral couplings invariant under SU(3)xSU(2)xU(1)
  - 14 LQ-types (7 scalar, 7 vector)
  - conserved fermion number $F = L+3B = 0, \pm 2$
- at HERA (coupling to valence quarks):
  - $e^+p \rightarrow LQ\ (F=0)$
  - $e^-p \rightarrow LQ\ (F=2)$



Comparison of Limits on M_{LQ}/λ_{LQ}

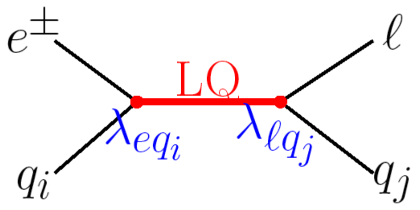
Model	Coupling Structure	M_{LQ}/λ_{LQ} [TeV] ZEUS	H1	L3	OPAL
S_0^L	$a_{LL}^{eu} = +\frac{1}{2}$	0.61	0.71	1.40	0.98
S_0^R	$a_{RR}^{eu} = +\frac{1}{2}$	0.56	0.64	0.30	0.30
$\tilde{S}_0^R$	$a_{RR}^{ed} = +\frac{1}{2}$	0.27	0.33	0.58	0.80
$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	0.83	0.85	0.54	0.74
$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.53	0.37		0.86
$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	0.43	0.43	0.42	0.48
S_1^L	$a_{LL}^{ed} = +1,\ a_{LL}^{eu} = +\frac{1}{2}$	0.52	0.49		
V_0^L	$a_{LL}^{ed} = -1$	0.55	0.73	1.83	1.27
V_0^R	$a_{RR}^{ed} = -1$	0.47	0.58	0.51	0.54
$\tilde{V}_0^R$	$a_{RR}^{eu} = -1$	0.87	0.99	1.02	1.44
$V_{1/2}^L$	$a_{LR}^{ed} = +1$	0.47	0.42	0.71	0.90
$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	0.99	0.95		0.71
$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	1.06	1.02	0.54	0.59
V_1^L	$a_{LL}^{ed} = -1,\ a_{LL}^{eu} = -2$	1.23	1.36		

- depending on LQ type HERA limits are in the range 0.3-1.4 TeV
- for 50% of all LQs best limits come from H1 or ZEUS

Lepton Flavour Violation

- Neutrino oscillation → Lepton Flavour is not conserved
- Charged leptons: very stringent limits from rare decays, especially for e ⇔ μ
- At HERA LFV can be mediated by LQs if they couple to different generations

Low mass $M_{LQ} < \sqrt{s}$

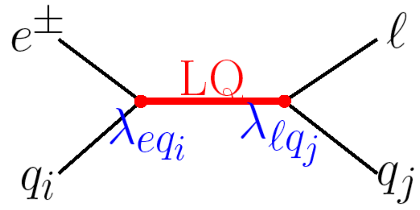


s-channel

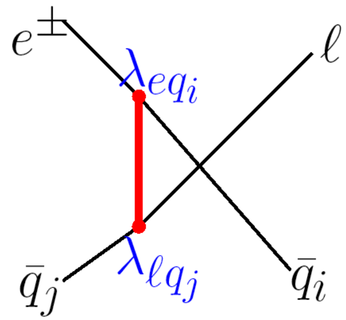
Narrow Width Approximation:

$$\sigma^{NWA} \propto \lambda^2_{eq_i} \beta_{lq_j}$$

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



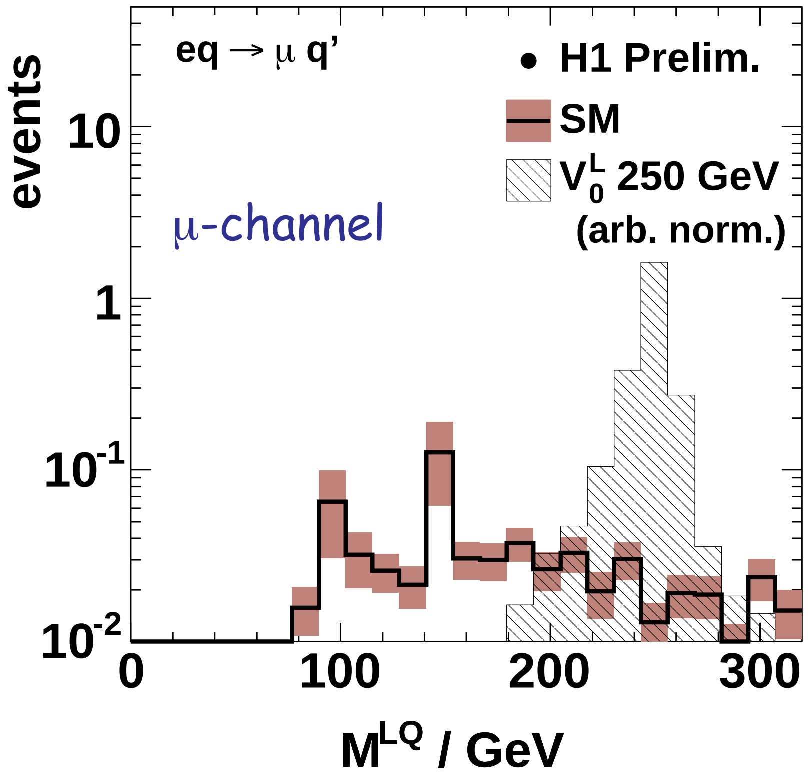
s-channel



u-channel

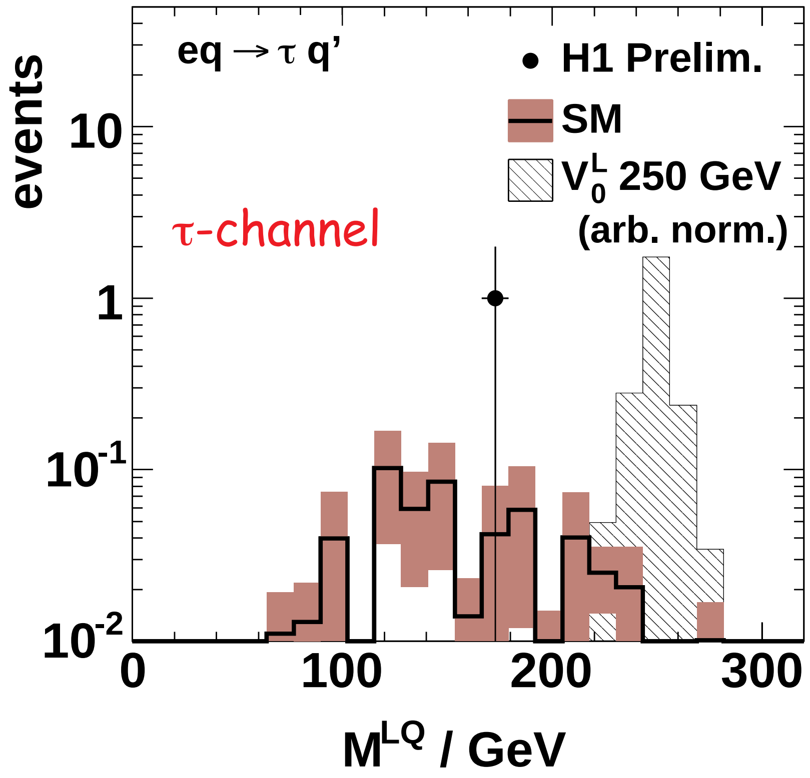
$$\sigma^{HMA} \propto \left(\frac{\lambda_{eq_i} \lambda_{eq_j}}{M^2_{LQ}}\right)^2$$

H1 Search for $e^+p \to \mu X$ and $e^+p \to \tau X$



- one isolated μ
- back to back to jet in φ
- $p_T^{Calo} > 25$ GeV

abstract 12-0766



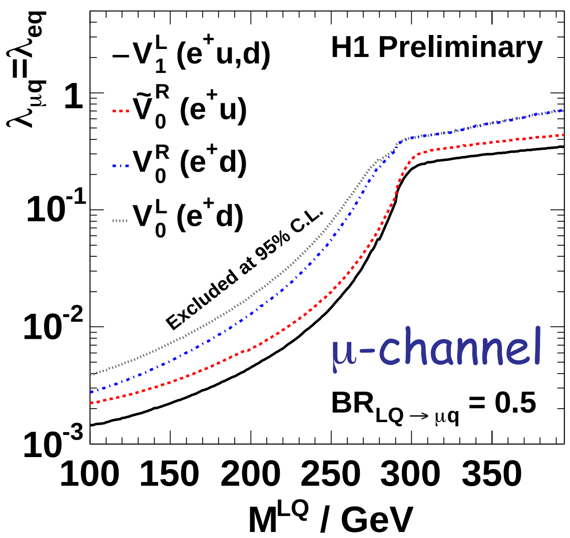
- hadronic τ decays
  → pencil-like jet
- 2nd jet, no e/μ in event
- $p_T^{miss} > 20$ GeV || τ–jet

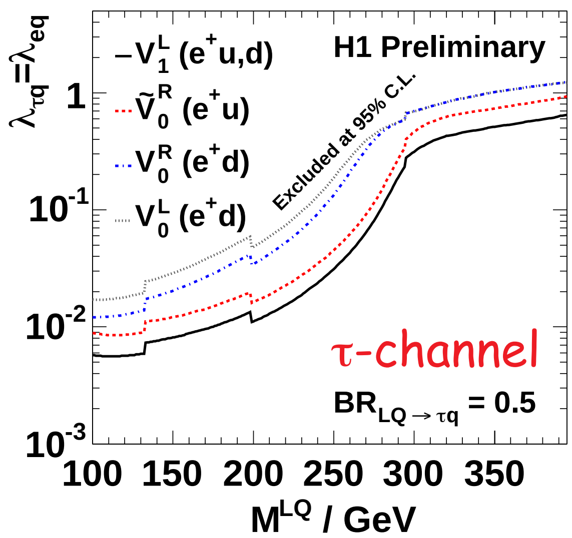
L = 66.5 pb^{-1}

	LQ → μ+q	LQ → τ+q
Data	0	1
Total SM	0.74 ± 0.25	0.56 ± 0.16

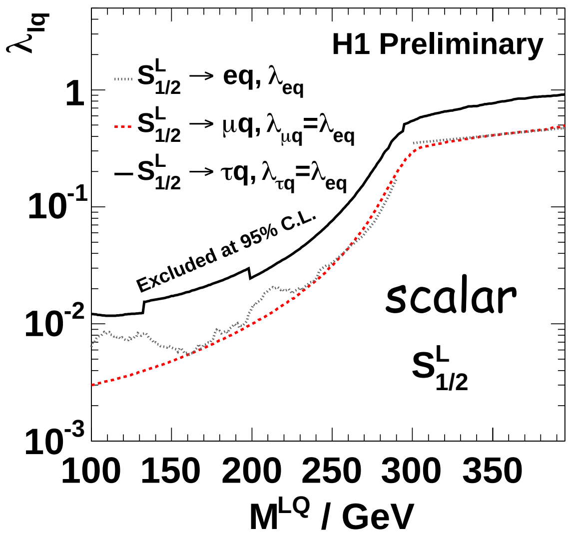
H1 Limits on Coupling Constants

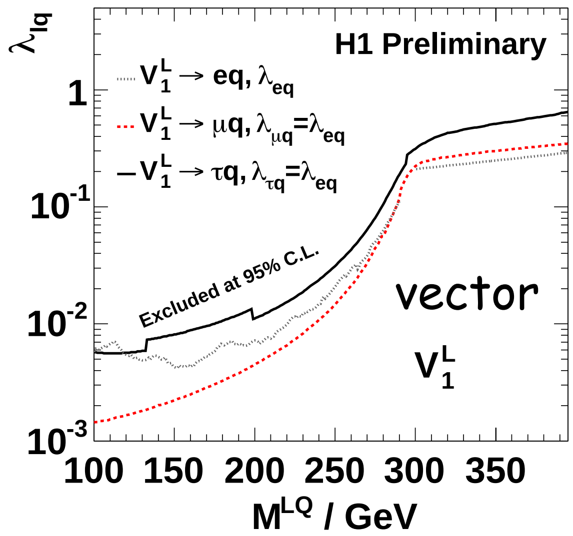
Example for Vector LQs





- sensitivity drops towards high masses due to steeply falling quark distributions
- some sensitivity extending beyond kinematic limit due to finite width of LQ
- at high masses limits connect to CI limits

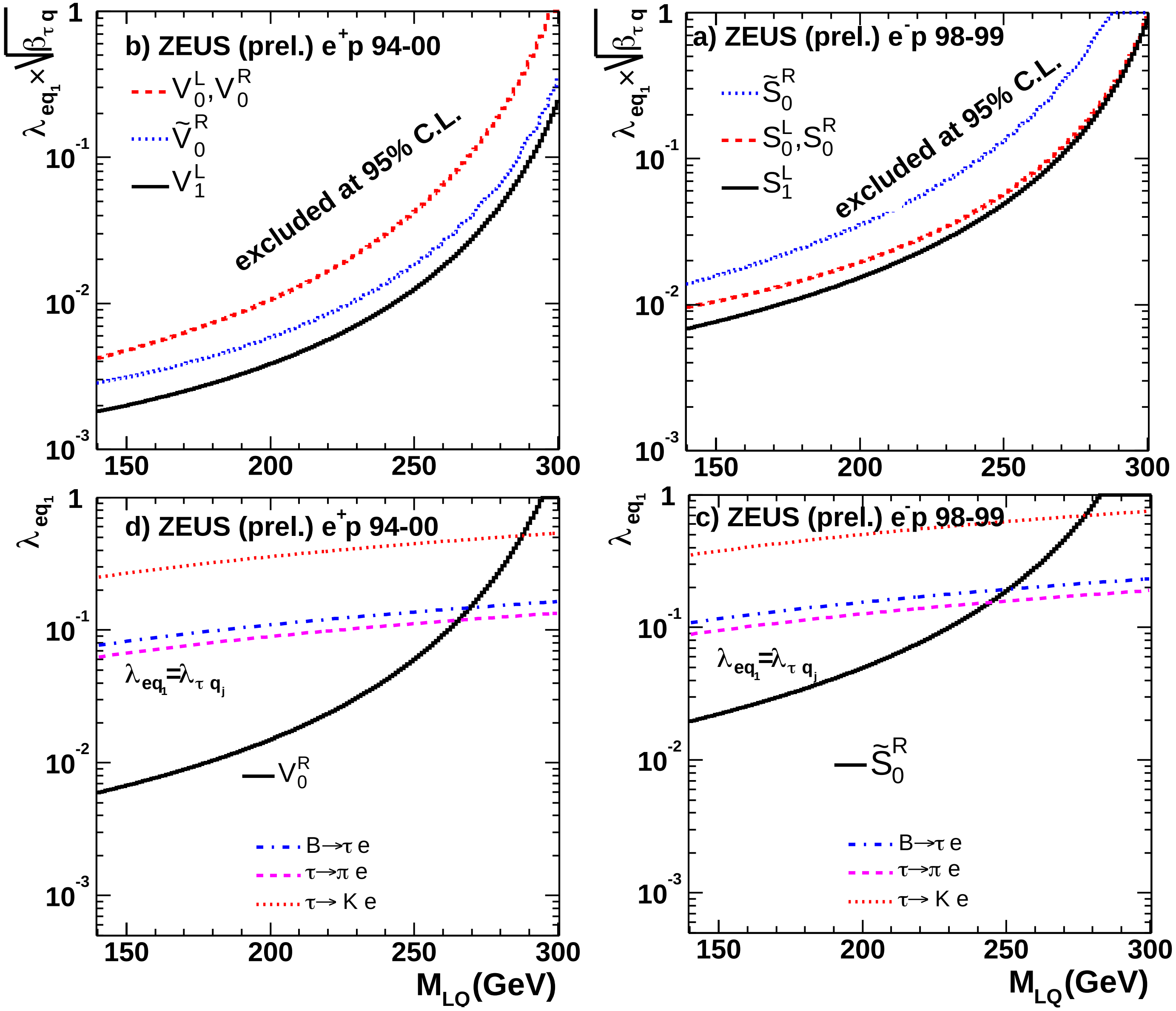




- LQ coupling to all 3 generations studied
- best sensitivity for μq channel because
  - low background
  - high selection efficiency

ZEUS Limits on Coupling for τ-Channel

F=0 (vector) F=2 (scalar)



abstract 12-0255

Similar analysis from ZEUS

L = 112/16.7 pb^{-1}

	LQ → μ+q	LQ → τ+q
Data	**0**	**0**
Total SM	**0.86 ± 0.15**	**1.7 ± 0.4**

- ZEUS τ-limits more stringent than those from rare B, K, τ decays for LQ masses below 250-270 GeV
- for coupling of elmag. strenght [λ=0.03] M_{LQ} > 250-280 GeV

High Mass Leptoquark Limits $M_{LQ} >> \sqrt{s}$

$e \to \tau$ ZEUS (prel.) $e^{\pm}p$ 94-00 $F = 0$

e	τ	$S^L_{1/2}$ $e^-\bar{u}$ e^+u	$S^R_{1/2}$ $e^-(\bar{u}+\bar{d})$ $e^+(u+d)$	$\tilde{S}^L_{1/2}$ $e^-\bar{d}$ e^+d	V^L_0 $e^-\bar{d}$ e^+d	V^R_0 $e^-\bar{d}$ e^+d	$\tilde{V}^R_0$ $e^-\bar{u}$ e^+u	V^L_1 $e^-(\sqrt{2}\bar{u}+\bar{d})$ $e^+(\sqrt{2}u+d)$
1	1	$\tau \to \pi e$ 0.4 **1.7**	$\tau \to \pi e$ 0.2 **1.4**	$\tau \to \pi e$ 0.4 **2.6**	$\tau \to \pi e$ 0.2 **1.7**	$\tau \to \pi e$ 0.2 **1.7**	$\tau \to \pi e$ 0.2 **1.2**	$\tau \to \pi e$ 0.06 **0.6**
1	2	**1.8**	$\tau \to Ke$ 6.3 **1.5**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **2.8**	$\tau \to Ke$ 3.2 **2.1**	$\tau \to Ke$ 3.2 **2.1**	**1.5**	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **0.7**
1	3	*	$B \to \tau\bar{e}$ 0.6 **3.0**	$B \to \tau\bar{e}$ 0.6 **3.1**	$B \to \tau\bar{e}$ 0.3 **2.5**	$B \to \tau\bar{e}$ 0.3 **2.5**	*	$B \to \tau\bar{e}$ 0.3 **2.5**
2	1	**6.1**	$\tau \to Ke$ 6.3 **4.1**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **5.2**	$\tau \to Ke$ 3.2 **2.3**	$\tau \to Ke$ 3.2 **2.3**	**2.2**	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **1.0**
2	2	$\tau \to 3e$ 5 **10**	$\tau \to 3e$ 8 **5.5**	$\tau \to 3e$ 17 **6.5**	$\tau \to 3e$ 9 **3.4**	$\tau \to 3e$ 9 **3.4**	$\tau \to 3e$ 3 **5.5**	$\tau \to 3e$ 1.6 **2.1**
2	3	*	$B \to \tau\bar{e}X$ 14 **8.0**	$B \to \tau\bar{e}X$ 14 **7.7**	$B \to \tau\bar{e}X$ 7.2 **5.4**	$B \to \tau\bar{e}X$ 7.2 **5.4**	*	$B \to \tau\bar{e}X$ 7.2 **5.4**
3	1	*	$B \to \tau\bar{e}$ 0.6 **7.9**	$B \to \tau\bar{e}$ 0.6 **7.3**	V_{ub} 0.12 **2.6**	$B \to \tau\bar{e}$ 0.3 **2.6**	*	V_{ub} 0.12 **2.6**
3	2	*	$B \to \tau\bar{e}X$ 14 **11**	$B \to \tau\bar{e}X$ 14 **10**	$B \to \tau\bar{e}X$ 7.2 **4.2**	$B \to \tau\bar{e}X$ 7.2 **4.2**	*	$B \to \tau\bar{e}X$ 7.2 **4.2**
3	3	*	$\tau \to 3e$ 8 **15**	$\tau \to 3e$ 17 **14**	$\tau \to 3e$ 9 **8.2**	$\tau \to 3e$ 9 **8.2**	*	$\tau \to 3e$ 1.6 **8.2**

At high masses $\sigma \propto \left(\frac{\lambda_{eq_\alpha}\lambda_{lq_\beta}}{M^2_{LQ}}\right)^2$

- table shows 95% CL limits on $\lambda_{eq_\alpha}\lambda_{lq_\beta}/M^2_{LQ}$ for $eq_a \to \tau q_\beta$ in the case F=0
- limits from rare decays included for comparison
- ZEUS limit shown in third line
- 2.3 indicates best limit coming from ZEUS

Summary and Outlook

New results from H1 and ZEUS based on ~130 pb^{-1} of HERA I data:

- no evidence for Contact Interaction signals
  $\Rightarrow$ limits from HERA for
  - compositeness scales Λ > 1.7-6.2 TeV
  - LQ masses M_{LQ}/λ > 0.3-1.4 TeV
- limits set on LFV LQs
  - searches for LQ coupling to e, μ, τ
  - LQ mass limits for λ=0.03 M_{LQ} > 250-280 GeV

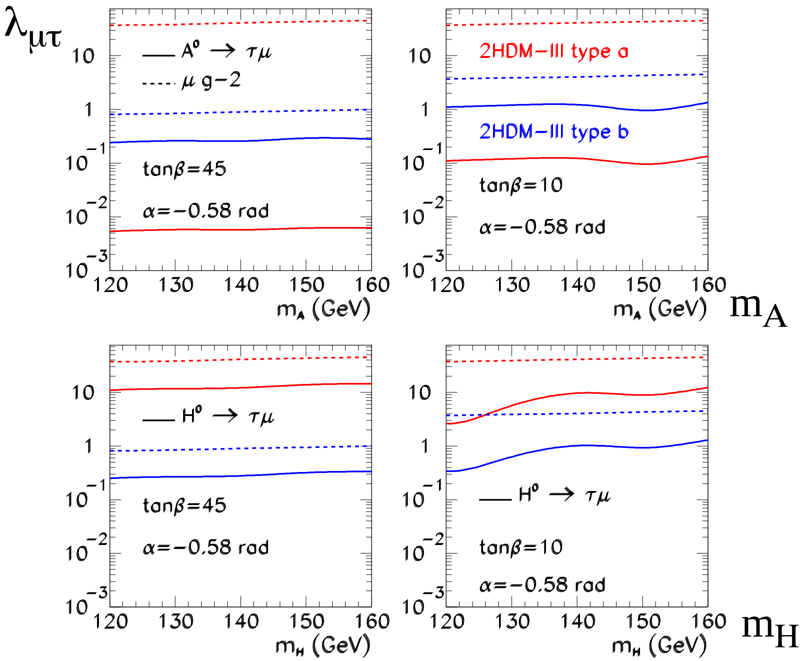
HERA II

- expect ~700pb^{-1} per experiment until 2007
- approximately equal sharing between
  - e^+p and e^-p
  - left- and righthanded polarised leptons

Further in the future:

- LFV channels studied for initial low luminosity phase of LHC (10-100 fb^{-1}):
  - $\tau \rightarrow \mu\mu\bar{\mu}$
  - $\tau \rightarrow \mu\gamma$
  - $\chi_2^o \rightarrow \chi_1^o \tau\mu$
  - $H^o / A^o \rightarrow \tau\mu$

abstract 12-0258



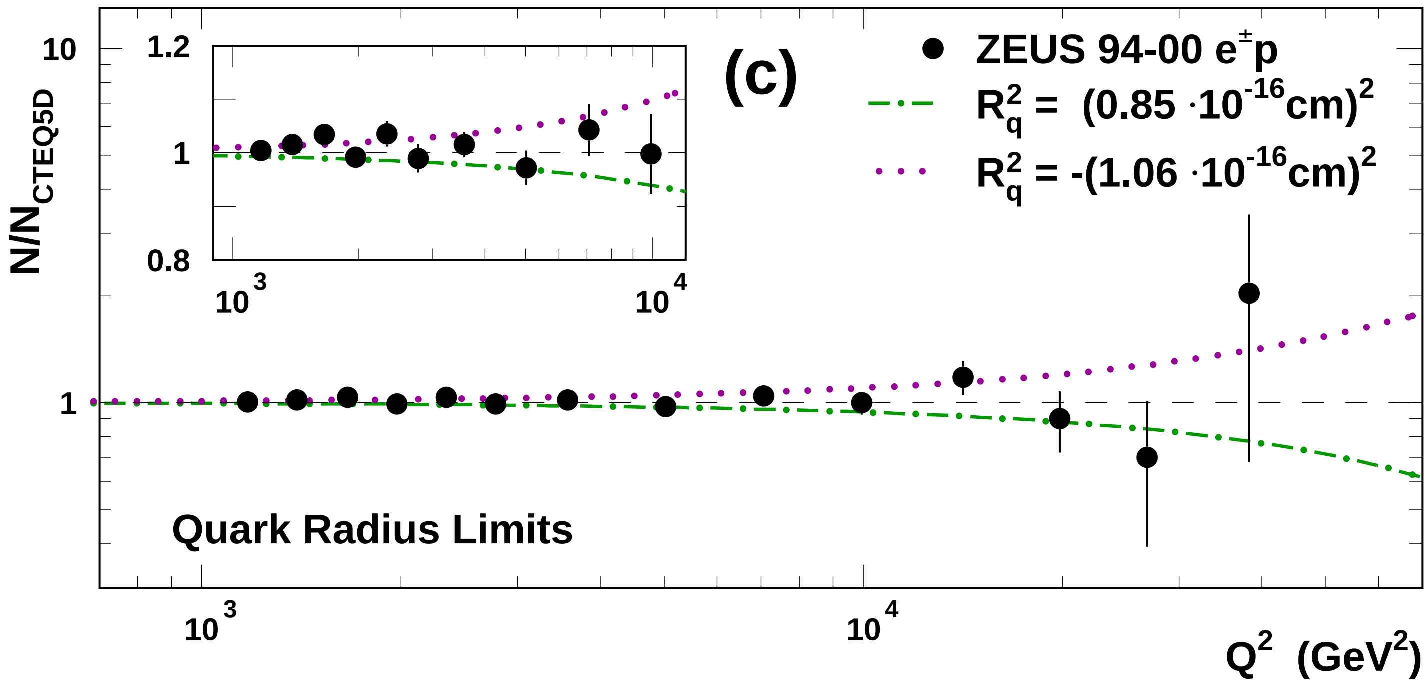
Backup Slides

Limit on Quark Radius

- Introduce tform factors for non point-like electron and quark:

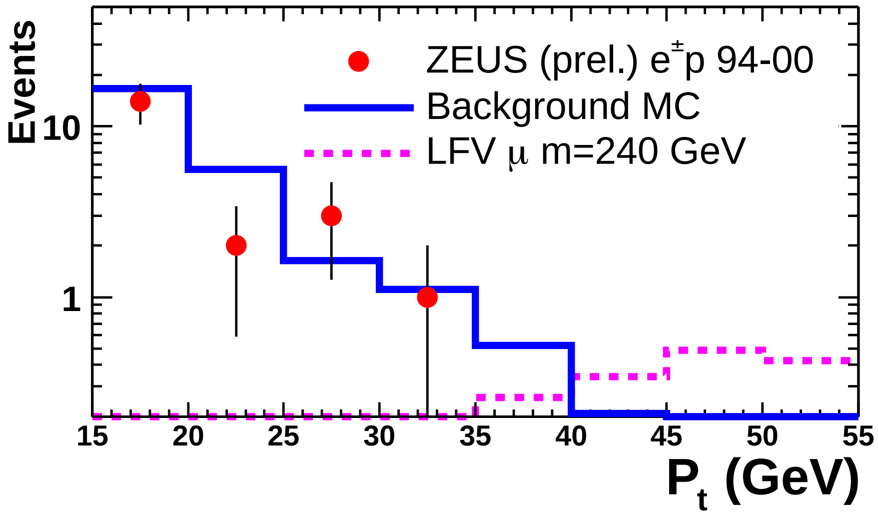
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2)\, f_q^2(Q^2)\ , \quad f_{e,q} = 1 - \frac{R_{e,q}^2}{6} Q^2$$

- Assume point-like electron: $f_e \equiv 1$

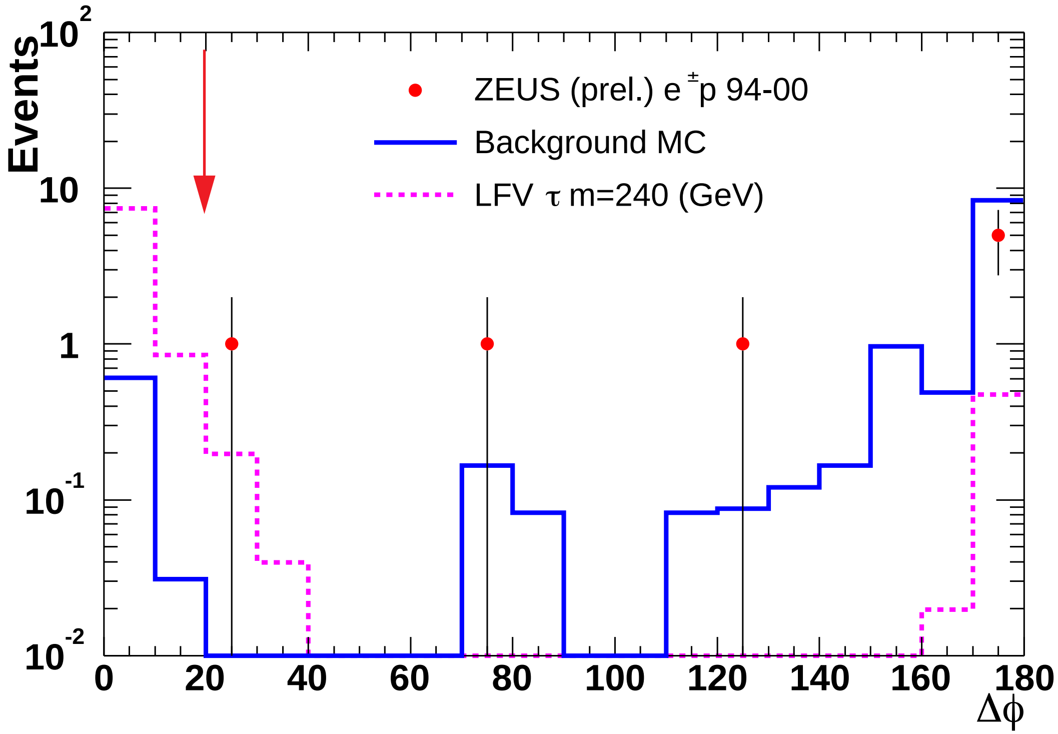


ZEUS Search for $e^+p \to \mu X$ and $e^+p \to \tau X$: $M_{LQ} < \sqrt{s}$

μ-channel



τ-channel



- one isolated μ
- $p_t > 20$ GeV

- no event found after final selection
- SM expectation: 0.86±0.15

- leptonic τ decays
- multivariate τ id. for hadronic decays
- $p_t^{miss} > 15$ GeV || to τ in φ

- no event found after final selection
- SM expectation: 1.7±0.4