DIS 2000

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Lepton Flavor Violation at HERA

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- Introduction
- Analysis
- Limits:
  - $M_{LQ} < \sqrt{s}$ $(\mu,\ \tau)$
  - $M_{LQ} \gg \sqrt{s}$ $(\mu,\ \tau)$
- Outlook

Results of the ZEUS and H1 collaborations

Lepton Flavor

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix}, \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}, \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

In SM processes lepton flavor number individually conserved:

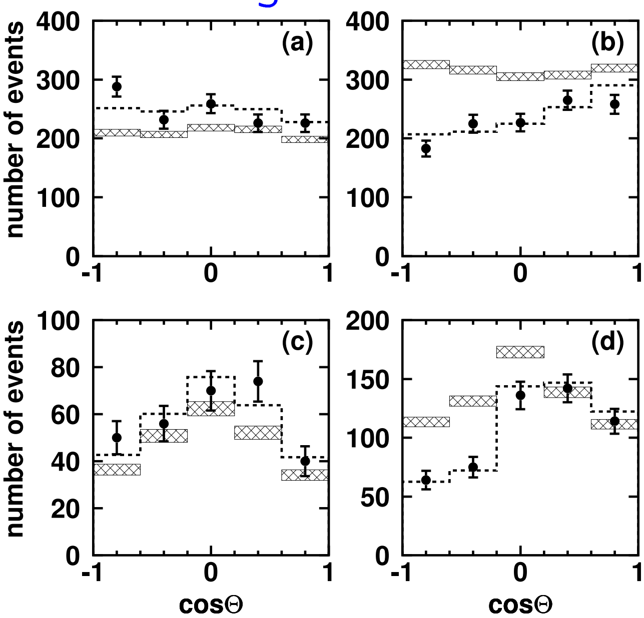
$$N_e = N(e^-) + N(\nu_e) - N(e^+) - N(\bar{\nu}_e)$$
$$N_\mu = N(\mu^-) + N(\nu_\mu) - N(\mu^+) - N(\bar{\nu}_\mu)$$
$$N_\tau = N(\tau^-) + N(\nu_\tau) - N(\tau^+) - N(\bar{\nu}_\tau)$$

Lepton Flavor: book-keeping quantum number:
$\rightsquigarrow$ not in relation with fundamental symmetry

many extensions of SM give LF conservation up

Super-Kamiokande:
Evidence for ν_μ oscillations

Zenith angle distributions



shaded: no ν oscillations:

dashed: $\nu_\mu \leftrightarrow \nu_\tau$ oscillations:

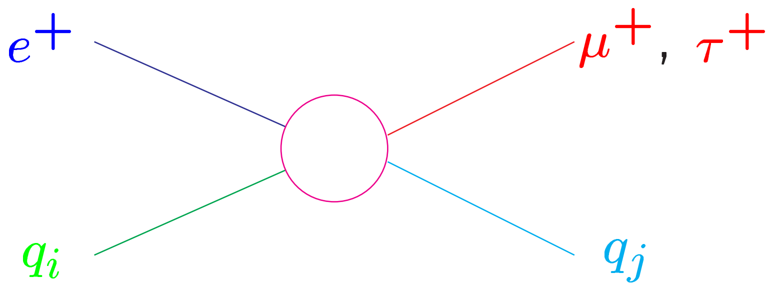
$\sin^2 2\theta = 1.0$,

$\Delta m^2 = 2.2 \cdot 10^{-3}$ eV^2

$\rightsquigarrow$ first observation to Lepton Flavor Violation

Leptoquarks

possible signature of LFV at HERA:



possible process: Leptoquarks (LQ)

LQ's are (hypothetical) particles which couple to both quarks and leptons:

- color triplet bosons
- fractional charge
- non-zero lepton and baryon number

occur in many extensions of SM (GUT's, Technicolor, composite models)

simplest models involving LFV LQ's characterized by 3 parameters:
- LQ mass
- coupling at each lepton-quark-leptoquark vertex

phenomenological ansatz: $\Rightarrow$ 14 LQ-types, classified by their quantum numbers $S_I^{L,R}$, $V_I^{L,R}$

(Buchmüller, Rückl, Wyler, Phys. Lett. B191, 442, 1987)

'fermion number' F $= |L + 3B| =$ 0, 2

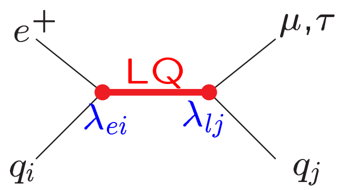
- F=0 (particle - antiparticle)
- F=2 (particle - particle ; antiparticle - antiparticle)

Leptoquarks (cont'd)

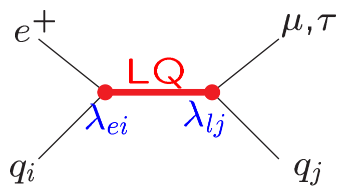
Leptoquarks:

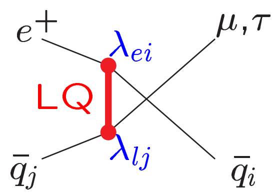
production in s-channel – exchange in u-channel

- $M_{LQ} < \sqrt{s}$: *('low mass LQs')*



- $M_{LQ} \gg \sqrt{s}$: *('high mass LQs')*





$$\sigma \propto (\lambda_{ei} \times \sqrt{BR})^2 q(x_0)$$

$$\sigma \propto \left[\frac{\lambda_{ei}\lambda_{lj}}{M_{LQ}^2}\right]^2$$

narrow resonance in x-distribution, peaked at $x_0 = \frac{M_{LQ}^2}{s}$

generalized four fermion coupling (cf. Fermi coupling constant)

only F=0 LQ's considered

(since e^+p-scattering)

F=0 and F=2 LQ's considered

Data sets

- 1994-1997 e^+p data, $\sqrt{s} = 300$ GeV
- $\underline{\mathcal{L}_{\text{H1}} = 37\, pb^{-1}}$
- search for μq and τq final states

only hadronic τ-decays considered

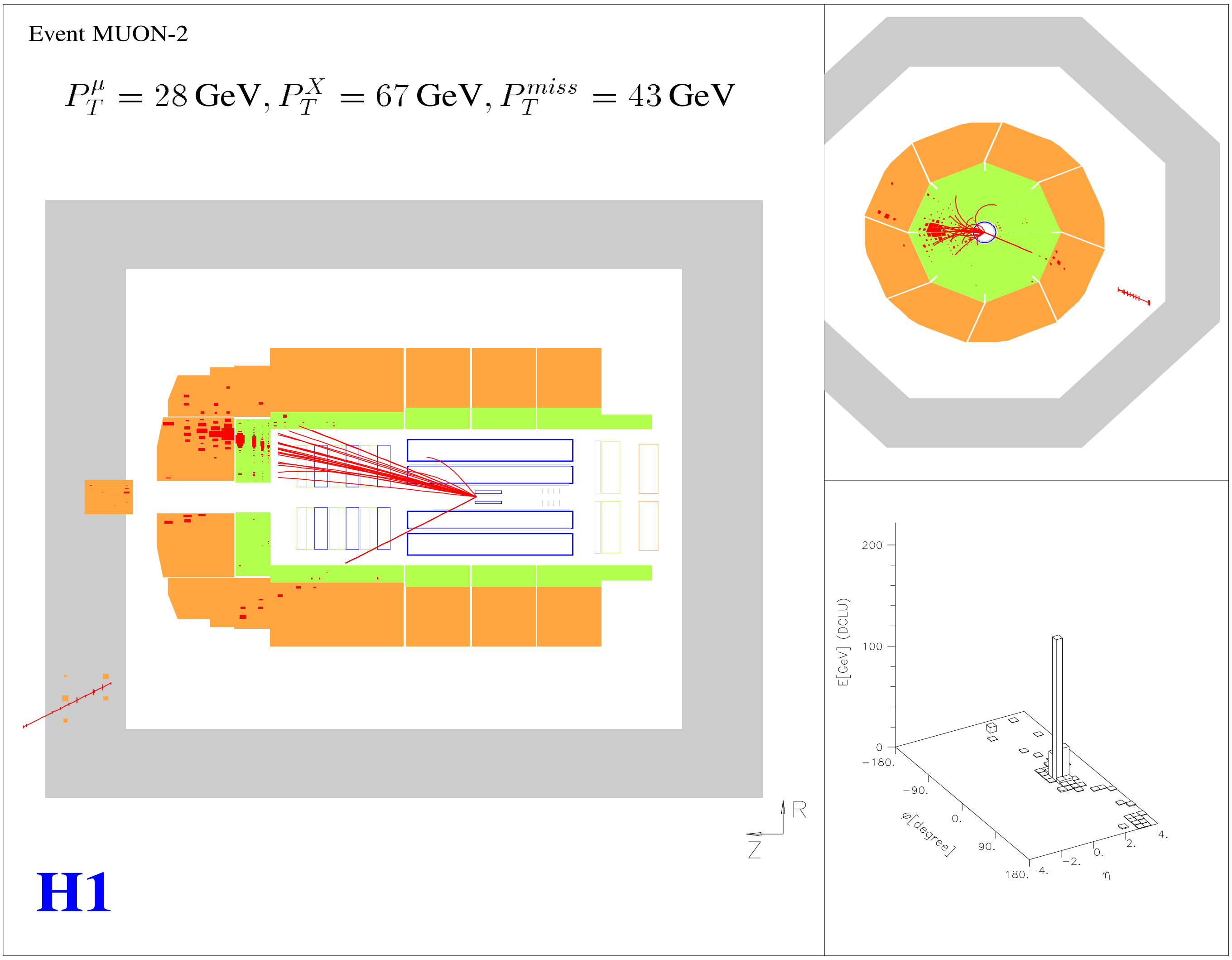
- 1994-1997 e^+p data, $\sqrt{s} = 300$ GeV
- $\underline{\mathcal{L}_{\text{ZEUS}} = 47.7\, pb^{-1}}$
- search for μq and τq final states

all τ-decays considered

Search for $e^+p \to \mu X$

Signature: high-p_t μ instead of electron $\rightsquigarrow \not{P}_t$(cal.)

$$e^+p \to \mu^+ X$$



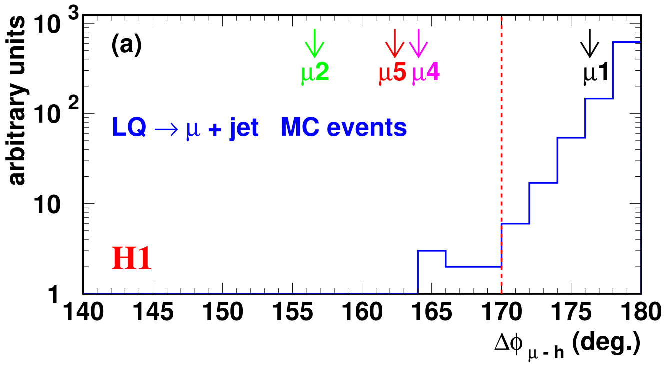
Search strategy (H1):

- CC sample ($Q^2 > 1000\,\mathrm{GeV}^2$, $\not{P}_t > 25\,\mathrm{GeV}$)
- $\exists$ isolated high-p_t μ
- at least one high-p_t jet
- NO electron with $E_t > 5\,\mathrm{GeV}$

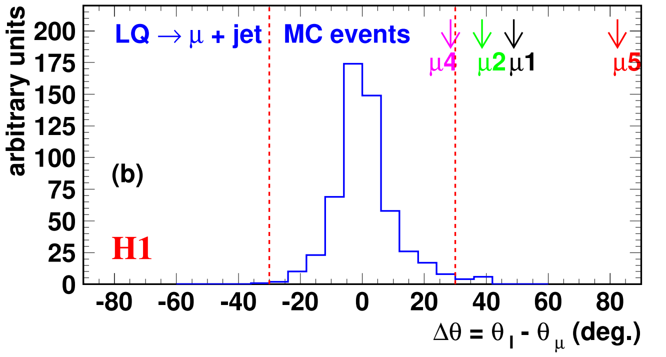
Search for $e^+p \to \mu X$ (cont'd)

4 (μ+*jet*)-events observed (0.6± 0.1 expected)

$\rightsquigarrow$ amongst the high-p_t lepton events



$\Delta\phi(\mu - \text{had.})$



$\Delta\theta = \theta_l - \theta_\mu$

but: NOT compatible with LQ

H1: no LQ $\mu +$jet-candidate

($\epsilon \sim$ 30% $- \sim$ 60% for $M_{LQ} < \sqrt{s}$,

$\epsilon \sim$ 20% $- \sim$ 33% for $M_{LQ} \gg \sqrt{s}$)

ZEUS made similar analysis:

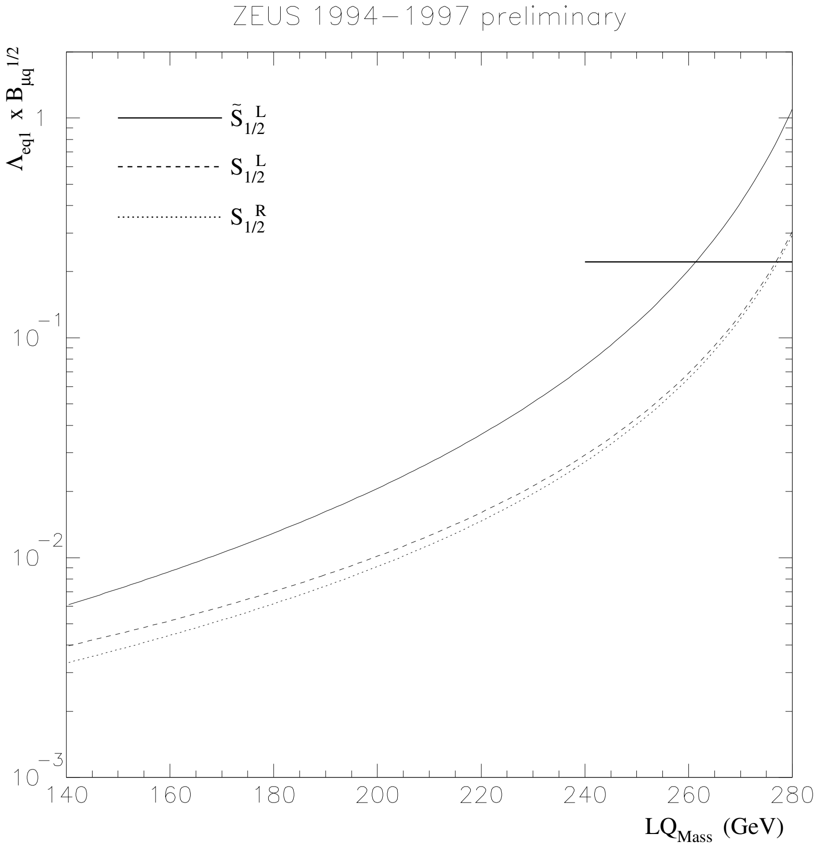
ZEUS: no candidate

no outstanding high-p_t muons...

Search for $e^+p \to \mu X$: Limits on low-mass LQ's

no limits set on low mass LQ's for $e \leftrightarrow \mu$

limits on $\underline{\lambda_{e1} \times \sqrt{BR(LQ \to \tau q)}}$ at 95% C.L.



Assuming $\lambda_{e1} = \sqrt{4\pi\alpha}$ and $BR(LQ \to \mu q) = 50\%$:

LQ type	$\tilde{S}^L_{1/2}$	$S^L_{1/2}$	$S^R_{1/2}$	V^L_0	V^R_0	$\tilde{V}^R_0$	V^L_1
Mass limit [GeV]	262	277	278	264	269	282	285

D0: $M_{LQ} < 200$ GeV for $BR(LQ \to \mu + jet) = 1$ excluded

High-mass LQ's

$M_{LQ} \gg \sqrt{s}$: both s- and u-channels give considerable contributions to σ

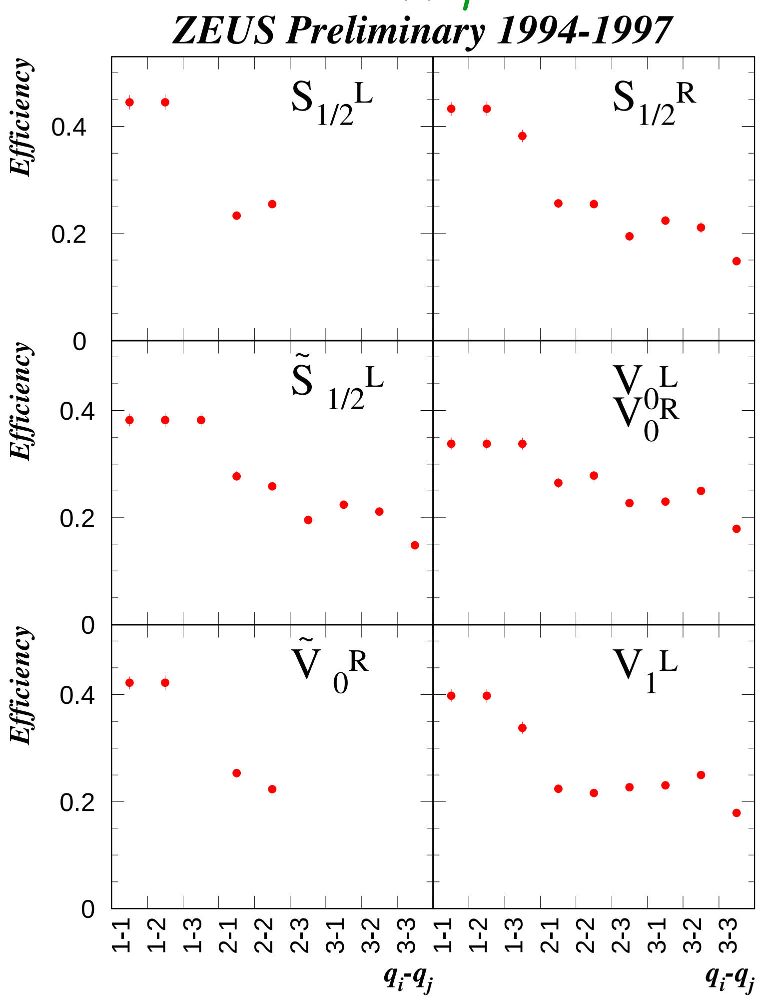
$$\sigma \propto \left[\frac{\lambda_{ei}\lambda_{lj}}{M_{LQ}^2}\right]^2$$

$\rightsquigarrow$ $2 \times 7 \times 3 \times 3 = 126$ cases per final state lepton

H1: assumes $\epsilon(q_i, q_j) = \epsilon(q_1, q_1)$, $\forall(q_i, q_j)$, for given F

ZEUS: efficiency for each different (q_i, q_j)-combination

$e \leftrightarrow \mu$



- valence quarks

$\rightsquigarrow$ high Q^2

$\Rightarrow$ high efficiency

- sea quarks

$\rightsquigarrow$ lowish Q^2, low p_t

$\Rightarrow$ lower efficiency

Limits on $\frac{\lambda_{ei}\lambda_{\mu j}}{M_{LQ}^2}$ in 10^{-4} GeV^{-2} (F=0)

$e \leftrightarrow \mu$

$q_i q_j$	$S^L_{1/2}$	$S^R_{1/2}$	$\tilde{S}^L_{1/2}$	V^L_0	V^R_0	$\tilde{V}^R_0$	V^L_1
1 1	$\mu N \to eN$ $7.6 \cdot 10^{-7}$ 0.019 0.025	$\mu N \to eN$ $2.6 \cdot 10^{-7}$ 0.016 0.021	$\mu N \to eN$ $7.6 \cdot 10^{-7}$ 0.029 0.036	$\mu N \to eN$ $2.6 \cdot 10^{-7}$ 0.019 0.031	$\mu N \to eN$ $2.6 \cdot 10^{-7}$ 0.019 0.031	$\mu N \to eN$ $2.6 \cdot 10^{-7}$ 0.015 0.025	$\mu N \to eN$ $1.1 \cdot 10^{-7}$ 0.007 0.011
1 2	D$\to \mu$ e$^+$ 0.062 $\boxed{\mathbf{0.020}}$ 0.026	K$\to \mu$ e$^+$ $6 \cdot 10^{-7}$ 0.016 0.021	K$\to \mu$ e$^+$ $6 \cdot 10^{-7}$ 0.029 0.036	K$\to \mu$ e$^+$ $3.6 \cdot 10^{-7}$ 0.022 0.034	K$\to \mu$ e$^+$ $3.6 \cdot 10^{-7}$ 0.022 0.034	D$\to \mu$ e$^+$ 0.03 $\boxed{\mathbf{0.016}}$ 0.028	K$\to \mu$ e$^+$ $3.6 \cdot 10^{-7}$ 0.008 0.013
1 3	——	B$\to \mu$ e 0.008 0.030 0.037	B$\to \mu$ e 0.008 0.030 0.037	V_{bu} 0.002 0.026 0.04	B$\to \mu$ e 0.004 0.026 0.04	——	V_{bu} 0.002 0.026 0.04
2 1	D$\to \mu$ e$^+$ 0.062 0.081 0.089	K$\to \mu$ e$^+$ $6 \cdot 10^{-7}$ 0.049 0.055	K$\to \mu$ e$^+$ $6 \cdot 10^{-7}$ 0.060 0.070	K$\to \mu$ e$^+$ $3.6 \cdot 10^{-7}$ 0.027 0.041	K$\to \mu$ e$^+$ $3.6 \cdot 10^{-7}$ 0.027 0.041	D$\to \mu$ e$^+$ 0.03 0.032 0.043	K$\to \mu$ e$^+$ $3.6 \cdot 10^{-7}$ 0.015 0.019
2 2	$\mu \to$e γ $2.5 \cdot 10^{-5}$ 0.108 0.11	$\mu \to$e γ $2.5 \cdot 10^{-5}$ 0.054 0.062	$\boxed{\mathbf{0.067}}$ 0.075	$\mu \to$e γ 0.04 $\boxed{\mathbf{0.032}}$ 0.049	$\mu \to$e γ 0.04 $\boxed{\mathbf{0.032}}$ 0.049	$\mu \to$e γ 0.005 0.050 0.07	$\mu \to$e γ 0.003 0.021 0.03
2 3	——	B$\to \mu$ e K 0.006 0.084 0.084	B$\to \mu$ e K 0.006 0.084 0.084	B$\to \mu$ e K 0.003 0.053 0.078	B$\to \mu$ e K 0.003 0.053 0.078	——	B$\to \mu$ e K 0.003 0.053 0.078
3 1	——	B$\to \mu$ e 0.008 0.090 0.1	B$\to \mu$ e 0.008 0.090 0.1	V_{bu} 0.002 0.031 0.04	B$\to \mu$ e 0.004 0.031 0.04	——	V_{bu} 0.002 0.031 0.04
3 2	——	B$\to \mu$ e K 0.006 0.106 0.11	B$\to \mu$ e K 0.006 0.106 0.11	B$\to \mu$ e K 0.003 0.038 0.05	B$\to \mu$ e K 0.003 0.038 0.05	——	B$\to \mu$ e K 0.003 0.038 0.05
3 3	——	0.157 $\boxed{\mathbf{0.15}}$	0.157 $\boxed{\mathbf{0.15}}$	$\mu \to$ e γ $5.6 \cdot 10^{-4}$ 0.076 0.108	$\mu \to$ e γ $5.6 \cdot 10^{-4}$ 0.076 0.108	——	$\mu \to$ e γ $5.6 \cdot 10^{-4}$ 0.076 0.108

Process with most stringent **indirect** constrained (from H1 publ.)

ZEUS Preliminary 1994-1997: most stringent limit from $\boxed{\textbf{ZEUS}}$

H1 published: most stringent limit from $\boxed{\textbf{H1}}$

Limits on $\frac{\lambda_{ei}\lambda_{\mu j}}{M_{LQ}^2}$ in 10^{-4} GeV^{-2} (F=2)

$e \leftrightarrow \mu$

$q_i q_j$	S_0^L	S_0^R	$\tilde{S}_0^R$	S_1^L	$V_{1/2}^L$	$V_{1/2}^R$	$\tilde{V}_{1/2}^L$
1 1	$\mu N \to eN$ $7.6 \cdot 10^{-7}$ 0.032 0.051	$\mu N \to eN$ $7.6 \cdot 10^{-7}$ 0.032 0.051	$\mu N \to eN$ $7.6 \cdot 10^{-7}$ 0.041 0.061	$\mu N \to eN$ $2.3 \cdot 10^{-7}$ 0.017 0.026	$\mu N \to eN$ $2.6 \cdot 10^{-7}$ 0.015 0.018	$\mu N \to eN$ $1.5 \cdot 10^{-7}$ 0.008 0.010	$\mu N \to eN$ $2.6 \cdot 10^{-7}$ 0.010 0.013
1 2	$K \to \pi\nu\bar{\nu}$ 10^{-5} 0.069 0.091	D$\to \mu$ e$^-$ 0.062 0.069 0.091	K$\to \mu$ e$^-$ $6 \cdot 10^{-7}$ 0.054 0.081	K$\to \mu$ e$^-$ $3.6 \cdot 10^{-7}$ 0.026 0.037	K$\to \mu$ e$^-$ $3.6 \cdot 10^{-7}$ 0.030 0.034	K$\to \mu$ e$^-$ $3.6 \cdot 10^{-7}$ 0.024 0.027	D$\to \mu$ e$^-$ 0.03 0.042 0.044
1 3	V_{ub} 0.004 ——	——	B$\to \mu$e 0.008 0.064 0.086	V_{ub} 0.004 0.031 0.043	B$\to \mu$e 0.004 0.045 0.048	B$\to \mu$e 0.004 0.045 0.048	——
2 1	$K \to \pi\nu\bar{\nu}$ 10^{-5} 0.036 0.055	D$\to \mu$ e$^-$ 0.062 $\boxed{\mathbf{0.036}}$ 0.055	K$\to \mu$ e$^-$ $6 \cdot 10^{-7}$ 0.046 0.066	K$\to \mu$ e$^-$ $3.6 \cdot 10^{-7}$ 0.019 0.029	K$\to \mu$ e$^-$ $3.6 \cdot 10^{-7}$ 0.015 0.018	K$\to \mu$ e$^-$ $3.6 \cdot 10^{-7}$ 0.009 0.011	D$\to \mu$ e$^-$ 0.03 $\boxed{\mathbf{0.010}}$ 0.013
2 2	$\mu \to$e γ $1.1 \cdot 10^{-4}$ 0.108 0.13	$\mu \to$e γ $1.1 \cdot 10^{-4}$ 0.108 0.13	$\mu \to$e γ $4.5 \cdot 10^{-5}$ 0.067 0.095	$\mu \to$e γ $2.2 \cdot 10^{-5}$ 0.033 0.045	$\mu \to$e γ 0.08 $\boxed{\mathbf{0.032}}$ 0.037	$\mu \to$e γ 0.003 0.028 0.030	$\mu \to$e γ 0.003 0.050 0.052
2 3	B$\to l\nu$X 0.04 ——	——	B$\to \mu$e K 0.006 0.084 0.10	B$\to \mu$e K 0.003 0.042 0.052	B$\to \mu$e K 0.003 0.053 0.054	B$\to \mu$e K 0.003 0.053 0.054	——
3 1	V_{ub} 0.004 ——	——	B$\to \mu$e 0.008 0.054 0.077	V_{ub} 0.004 0.027 0.038	B$\to \mu$e 0.004 0.016 0.018	B$\to \mu$e 0.004 0.016 0.018	——
3 2	B$\to l\nu$X 0.04 ——	——	B$\to \mu$e K 0.006 0.106 0.14	B$\to \mu$e K 0.003 0.053 0.068	B$\to \mu$e K 0.003 0.038 0.040	B$\to \mu$e K 0.003 0.038 0.040	——
3 3	——	——	$\mu \to e\gamma$ $4.5 \cdot 10^{-5}$ 0.157 0.17	$\mu \to e\gamma$ $2.2 \cdot 10^{-5}$ 0.079 0.085	$\mu \to e\gamma$ 0.006 0.076 0.068	$\mu \to e\gamma$ 0.006 0.076 0.068	——

Process with most stringent **indirect** constrained (from H1 publ.)

ZEUS Preliminary 1994-1997: most stringent limit from **ZEUS**

H1 published

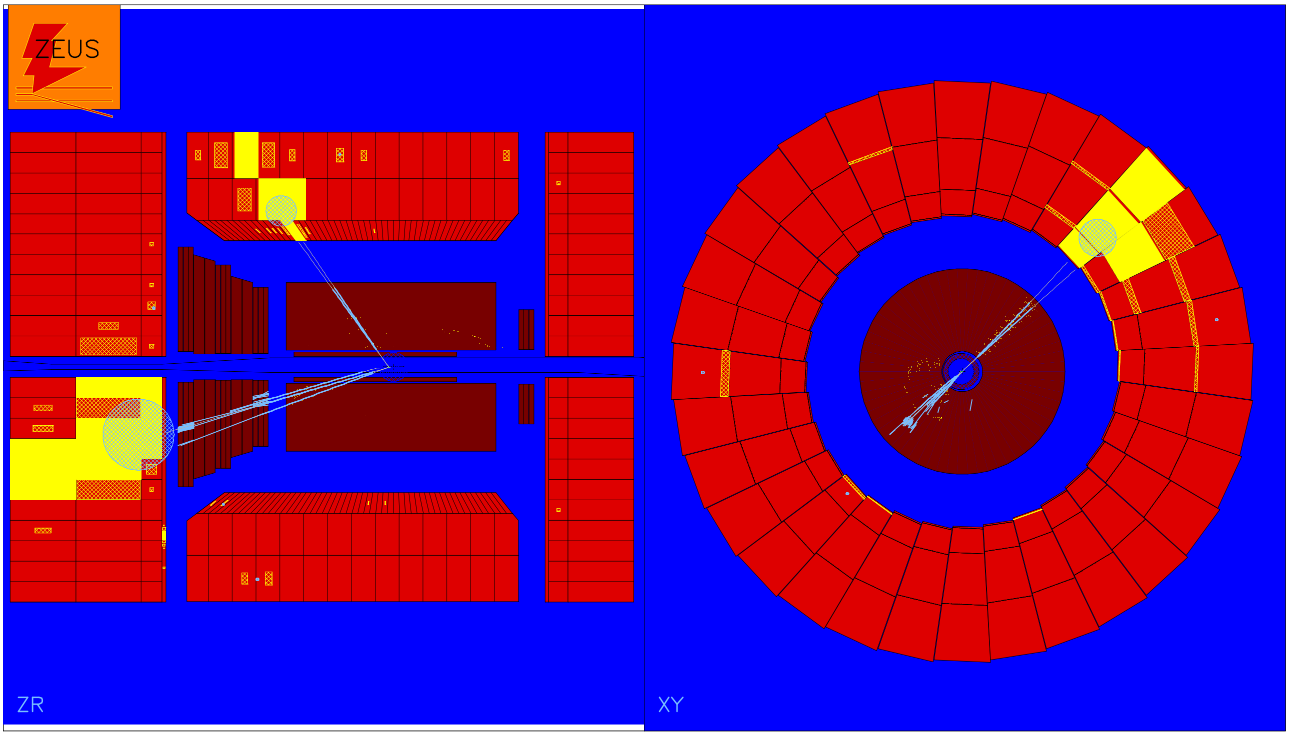
Search for $e^+p \to \tau X$

Signature: high p_t-τ instead of electron, but...

τ decays nearly almost at the vertex

τ^+	$\longrightarrow$	$e^+\nu_e\bar{\nu}_\tau$	17.9	%
τ^+	$\longrightarrow$	$\mu^+\nu_\mu\bar{\nu}_\tau$	17.6	%
τ^+	$\longrightarrow$	$h^+\bar{\nu}_\tau + \geq 0$ neutrals	50.3	%
τ^+	$\longrightarrow$	$2h^+h^-\bar{\nu}_\tau + \geq 0$ neutrals	14.0	%
τ^+	$\longrightarrow$	$\geq 5h^\pm\bar{\nu}_\tau + \geq 0$ neutrals	0.1	%

$\sim 65\%$



Characteristics:

– collimated and low charged multiplicity
– narrow cluster
– 1–3 tracks to this cal deposit

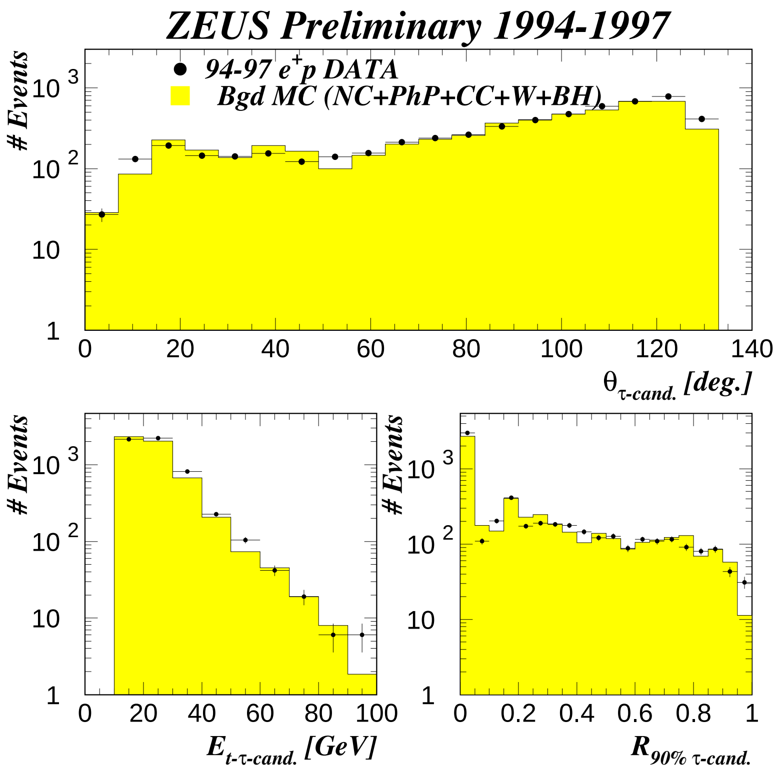
Signature:
- high-p_t e in $\not{P}_t$-direction
- high-p_t μ in $\not{P}_t$-direction
- narrow jet in $\not{P}_t$-direction

Search for $e^+p \to \tau X$

$\tau \to$ hadrons ν

Search strategy (ZEUS):

- Preselection (CC-trigger, low Q^2-NC-rejection)
- $\exists$ 'pencil'-like jet (1-3 tracks to jet, $M_{\text{jet}} < 7$ GeV)



- 'pencil'-like jet:
  - hadronical
  - narrow: 90% of energy within $R(\eta, \phi) = 0.3$
  - $\neq$ NC-DIS electron: use of tracking and calorimeter information

LQ specific cuts

- large $\not{P}_t$ ($\not{P}_t$ >12 GeV)
- at least one high p_t-jet ($P_t > 25$ GeV) & 'τ-jet' ($P_t > 20$ GeV)
- 'τ-jet' aligned in azimuth with $\not{P}_t$

ZEUS: no candidate

Search for $e^+p \to \tau X$

$\tau \to \mu\ \nu\bar{\nu}$, $\tau \to$ e $\nu\bar{\nu}$

Search strategy (ZEUS):

- CC sample ($\not{P}_t > 15$ GeV (e) - $\not{P}_t > 20$ GeV (μ))
- high-p_t e or μ
- at least one high-p_t jet ($p_t > 15$ GeV)
- lepton aligned in azimuth with $\not{P}_t$

ZEUS: no candidate

(Overall τ-selection efficiency $\sim 25\% - \sim 31\%$ for $M_{LQ} < \sqrt{s}$)

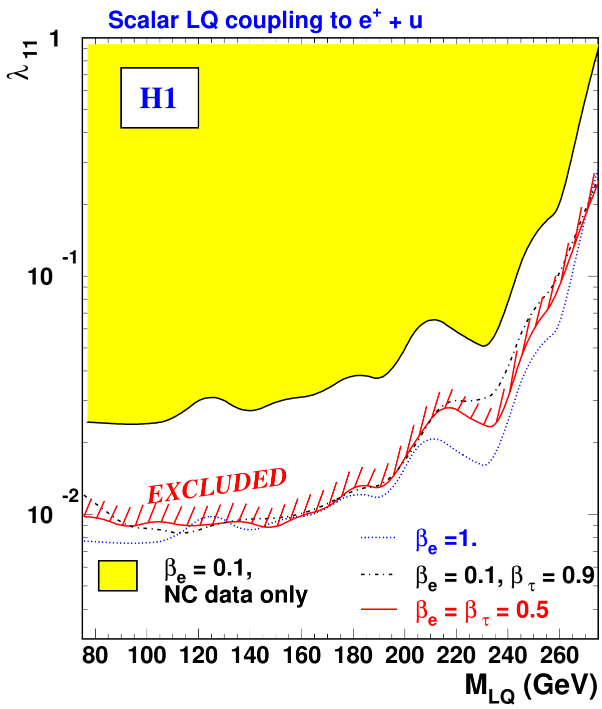
H1 made similar search:

but: hadronic τ decays only

H1: no candidate

Search for $e^+ p \to \tau X$: Limits on low-mass LQ's

both e^+ + jet- and τ^+ + jet- channels combined



95% C.L. mass dependent limits on λ_{11} when fixing β_e and β_τ

for e.m. coupling and $\beta_e + \beta_\tau \sim 1$:

$M_{LQ} < 275$ GeV excluded

CDF: $M_{LQ} < 99$ GeV excluded for $\mathrm{BR}(LQ \to \tau b) = 1$

D0: $M_{LQ} < 94$ GeV excluded for $\mathrm{BR}(LQ \to \nu b) = 1$

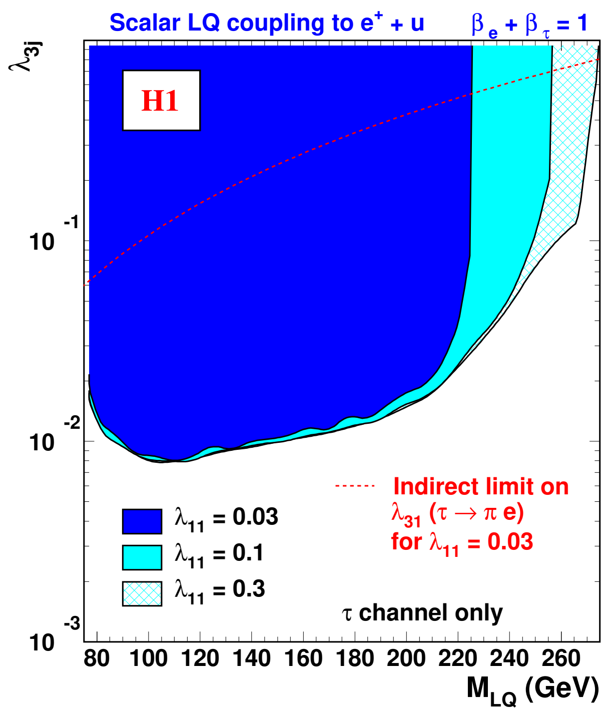
HERA has large discovery potential if β_τ high and β_e low

95% C.L. mass dependent limits on λ_{3j} for different fixed values of λ_{11}

$\rightsquigarrow$ sensitive on λ_{3j} as long as LQ light enough to have a substantial production cross-section via λ_{11}

if $\lambda_{11} = \lambda_{3j} = \sqrt{4\pi\alpha}$:

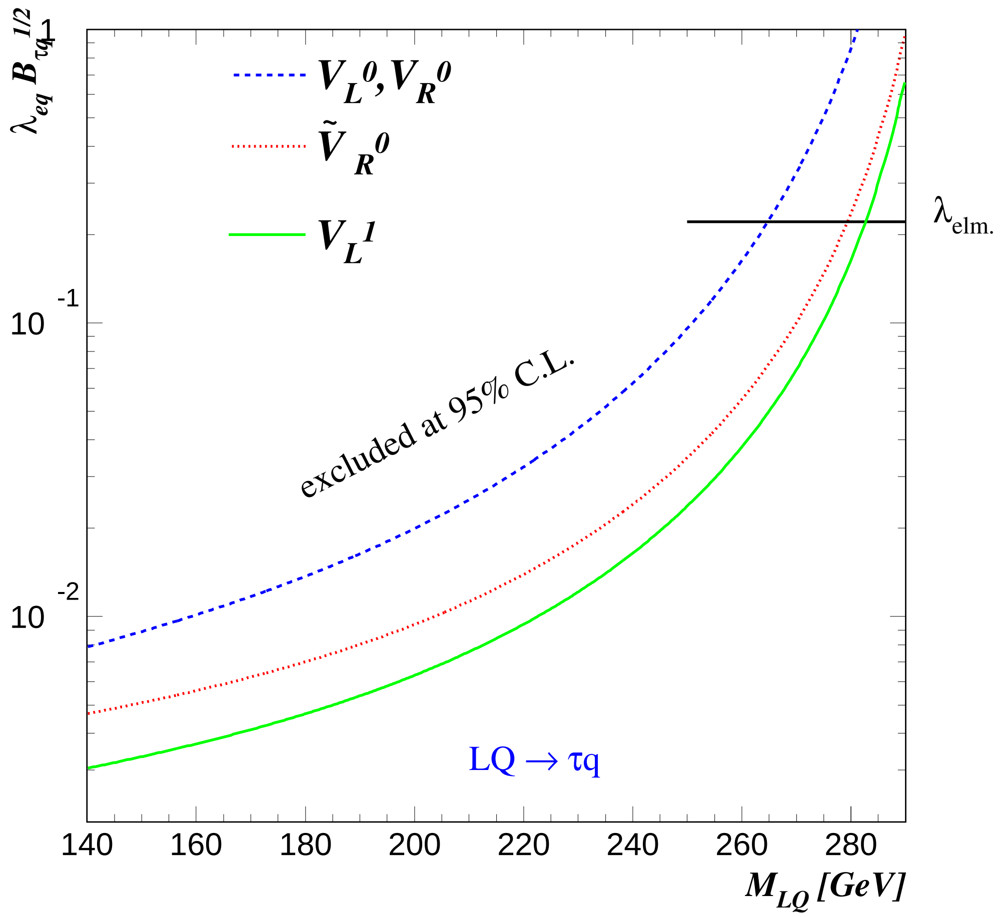
$M_{LQ} < 270$ GeV excluded



Search for $e^+p \to \tau X$: Limits on low-mass LQ's

only τ^+ + jet used to set limits

limits on $\underline{\lambda_{e1} \times \sqrt{BR(LQ \to \tau q)}}$ at 95% C.L.



Assuming $\lambda_{e1} = \sqrt{4\pi\alpha}$ and $BR(LQ \to \tau q) = 50\%$:

LQ type	$\tilde{S}^L_{1/2}$	$S^L_{1/2}$	$S^R_{1/2}$	V^L_0	V^R_0	$\tilde{V}^R_0$	V^L_1
Mass limit [GeV]	259	276	277	260	265	279	283

Limits on $\frac{\lambda_{ei}\lambda_{\tau j}}{M^2_{LQ}}$ in 10^{-4} GeV^{-2} (F=0)

$e \leftrightarrow \tau$

q_iq_j	$S^L_{1/2}$	$S^R_{1/2}$	$\tilde{S}^L_{1/2}$	V^L_0	V^R_0	$\tilde{V}^R_0$	V^L_1
1 1	$\tau \to \pi e$ 0.0032 0.030 0.046	$\tau \to \pi e$ 0.0016 0.025 0.037	$\tau \to \pi e$ 0.0032 0.046 0.062	G_F 0.002 0.033 0.049	$\tau \to \pi e$ 0.0016 0.033 0.049	$\tau \to \pi e$ 0.0016 0.024 0.041	G_F 0.002 0.012 0.019
1 2	$\boxed{0.030}$ 0.047	$\tau \to$K e 0.05 $\boxed{0.025}$ 0.038	$\tau \to$K e 0.05 $\boxed{0.046}$ 0.063	$\tau \to$K e 0.03 0.036 0.053	$\tau \to$K e 0.03 0.036 0.053	$\boxed{0.026}$ 0.045	K $\to \pi\nu\bar{\nu}$ $2.5 \cdot 10^{-6}$ 0.012 0.021
1 3	——	B$\to \tau e$ X 0.08 $\boxed{0.049}$ 0.065	B$\to \tau e$ X 0.08 $\boxed{0.049}$ 0.065	B$\to l\nu$X 0.02 0.044 0.062	B$\to \tau e$ X 0.04 0.044 0.062	——	B$\to l\nu$X 0.02 0.044 0.062
2 1	0.153 $\boxed{0.15}$	$\tau \to$K e 0.05 0.092 0.095	$\tau \to$K e 0.05 0.105 0.12	$\tau \to$K e 0.03 0.049 0.064	$\tau \to$K e 0.03 0.049 0.064	$\boxed{0.061}$ 0.073	K $\to \pi\nu\bar{\nu}$ $2.5 \cdot 10^{-6}$ 0.026 0.032
2 2	$\tau \to e\gamma$ 0.03 0.187 0.18	$\tau \to e\gamma$ 0.02 0.101 0.10	$\boxed{0.120}$ 0.13	$\boxed{0.061}$ 0.076	$\boxed{0.061}$ 0.076	$\boxed{0.102}$ 0.107	$\boxed{0.041}$ 0.044
2 3	——	B$\to \tau e$ X 0.08 0.153 0.14	B$\to \tau e$ X 0.08 0.153 0.14	B$\to l\nu$X 0.02 0.102 0.112	B$\to \tau e$ X 0.04 0.102 0.112	——	B$\to l\nu$X 0.02 0.102 0.112
3 1	——	B$\to \tau e$ X 0.08 0.162 0.16	B$\to \tau e$ X 0.08 0.162 0.16	V_{ub} 0.002 0.052 0.068	B$\to \tau e$ X 0.04 0.052 0.068	——	V_{ub} 0.002 0.052 0.068
3 2	——	B$\to \tau e$ X 0.08 0.202 0.19	B$\to \tau e$ X 0.08 0.202 0.19	B$\to l\nu$X 0.02 0.073 0.083	B$\to \tau e$ X 0.04 0.073 0.083	——	B$\to l\nu$X 0.02 0.073 0.083
3 3	——	0.275 $\boxed{0.23}$	0.275 $\boxed{0.23}$	$\tau \to e\gamma$ 0.51 0.144 $\boxed{0.14}$	$\tau \to e\gamma$ 0.51 0.144 $\boxed{0.14}$	——	0.144 $\boxed{0.14}$

Process with most stringent **indirect** constrained (from H1 publ.)

ZEUS Preliminary 1994-1997: most stringent limit from $\boxed{\textbf{ZEUS}}$

H1 published: most stringent limit from $\boxed{\textbf{H1}}$

Limits on $\frac{\lambda_{ei}\lambda_{\tau j}}{M_{LQ}^2}$ in 10^{-4} GeV^{-2} (F=2)

$e \leftrightarrow \tau$

$q_i q_j$	S_0^L	S_0^R	$\tilde{S}_0^R$	S_1^L	$V_{1/2}^L$	$V_{1/2}^R$	$\tilde{V}_{1/2}^L$
1 1	G_F 0.003 0.053 0.082	$\tau \to \pi e$ 0.0032 0.053 0.082	$\tau \to \pi e$ 0.0032 0.070 0.097	G_F 0.003 0.028 0.042	$\tau \to \pi e$ 0.0016 0.025 0.030	$\tau \to \pi e$ $8 \cdot 10^{-4}$ 0.013 0.018	$\tau \to \pi e$ 0.0016 0.016 0.023
1 2	$K \to \pi\nu\bar{\nu}$ 10^{-5} 0.128 0.146	**0.128** 0.146	$\tau \to$K e 0.05 0.092 0.129	$K \to \pi\nu\bar{\nu}$ 10^{-5} 0.045 0.059	$K \to \pi\nu\bar{\nu}$ $5 \cdot 10^{-6}$ 0.055 0.060	$\tau \to$K e 0.03 0.044 0.048	0.081 **0.078**
1 3	V_{bu} 0.004 ——	——	B$\to \tau e$ X 0.08 0.107 0.138	V_{bu} 0.004 0.053 0.069	B$\to \tau e$ X 0.04 0.083 0.084	B$\to \tau e$ X 0.04 0.083 0.084	——
2 1	$K \to \pi\nu\bar{\nu}$ 10^{-5} 0.058 0.089	**0.058** 0.089	$\tau \to$K e 0.05 0.077 0.106	$K \to \pi\nu\bar{\nu}$ 10^{-5} 0.031 0.046	$K \to \pi\nu\bar{\nu}$ $5 \cdot 10^{-6}$ 0.024 0.031	$\tau \to$K e 0.03 **0.013** 0.018	**0.016** 0.023
2 2	$\tau \to e\gamma$ 0.075 0.180 0.211	$\tau \to e\gamma$ 0.075 0.180 0.211	$\tau \to e\gamma$ 0.045 0.120 0.151	$\tau \to e\gamma$ 0.015 0.059 0.071	**0.063** 0.064	**0.050** 0.053	0.096 **0.091**
2 3	B$\to l\nu$X 0.04 ——	——	B$\to \tau e$ X 0.08 0.155 0.167	B$\to l\nu$X 0.04 0.078 0.083	B$\to \tau e$ X 0.04 0.104 0.095	B$\to \tau e$ X 0.04 0.104 0.095	——
3 1	B$\to l\nu$X 0.04 ——	——	B$\to \tau e$ X 0.08 0.092 0.123	B$\to l\nu$X 0.04 0.046 0.061	B$\to \tau e$ X 0.04 **0.026** 0.031	B$\to \tau e$ X 0.04 **0.026** 0.032	——
3 2	B$\to l\nu$X 0.04 ——	——	B$\to \tau e$ X 0.08 0.202 0.218	B$\to l\nu$X 0.04 0.099 0.109	B$\to \tau e$ X 0.04 0.074 0.071	B$\to \tau e$ X 0.04 0.074 0.071	——
3 3	——	——	$\tau \to e\gamma$ 0.045 0.275 0.272	$\tau \to e\gamma$ 0.015 0.150 0.136	0.139 **0.12**	0.139 **0.12**	——

Process with most stringent **indirect** constrained (from H1 publ.)

ZEUS Preliminary 1994-1997: most stringent limit from **ZEUS**

H1 published: most stringent limit from **H1**

Future of LFV at HERA

1998-1999: e^-p ($E_p = 920$ GeV)
⇝ complementary sensitivity for F=2 LQ's

2000-2001: HERA upgrade

2001-2006: ∼1 fb^{-1} (expected)

⇝ current HERA limits improve by $\sim \sqrt{\frac{1000 pb^{-1}}{50 pb^{-1}}} \sim 4.5$

Limits on $\frac{\lambda_{eq_i}\lambda_{\tau q_j}}{M_{LQ}^2}$ for F=0 LQ's:

$e \leftrightarrow \tau$

$q_i q_j$	$S^L_{1/2}$	$S^R_{1/2}$	$\tilde{S}^L_{1/2}$	V^R_0	V^L_0	$\tilde{V}^R_0$	V^L_1
1 1							
1 2							
1 3	-					-	
2 1							
2 2							
2 3	-					-	
3 1	-					-	
3 2	-					-	
3 3	-					-	

: HERA will set most stringent limit on $\frac{\lambda_{eq_i}\lambda_{\tau q_j}}{M_{LQ}^2}$

: HERA will set most stringent limit on $\frac{\lambda_{eq_i}\lambda_{\tau q_j}}{M_{LQ}^2}$
if limits from rare B-decays do not improve by factor > 2

similar table for F=2 LQ's

Future of LFV at HERA

(cont'd)

$\underline{e \leftrightarrow \mu}$

much stronger constrains from low energy experiments

$\rightsquigarrow$ Distribution of color boxes in table (p.10, 11) will not change...

limits from low energy experminents even expected to improve by $\sim$ 8 for limits from $(\mu - e)$-conversion and from $\mu \to$ e γ (PSI)

Conclusions

- 1994-1997 e^+p H1 and ZEUS data analyzed for lepton flavor violation via LQ's

- NO evidence found for LFV LQ's in the given data sets

- HERA sets limits on resonantly produced LFV LQ's up to $\sim$ 280 GeV

- For $M_{LQ} \gg \sqrt{s}$ HERA sets limits in hitherto unconstrained flavor combinations and improves several existing limits, especially for $e \leftrightarrow \tau$

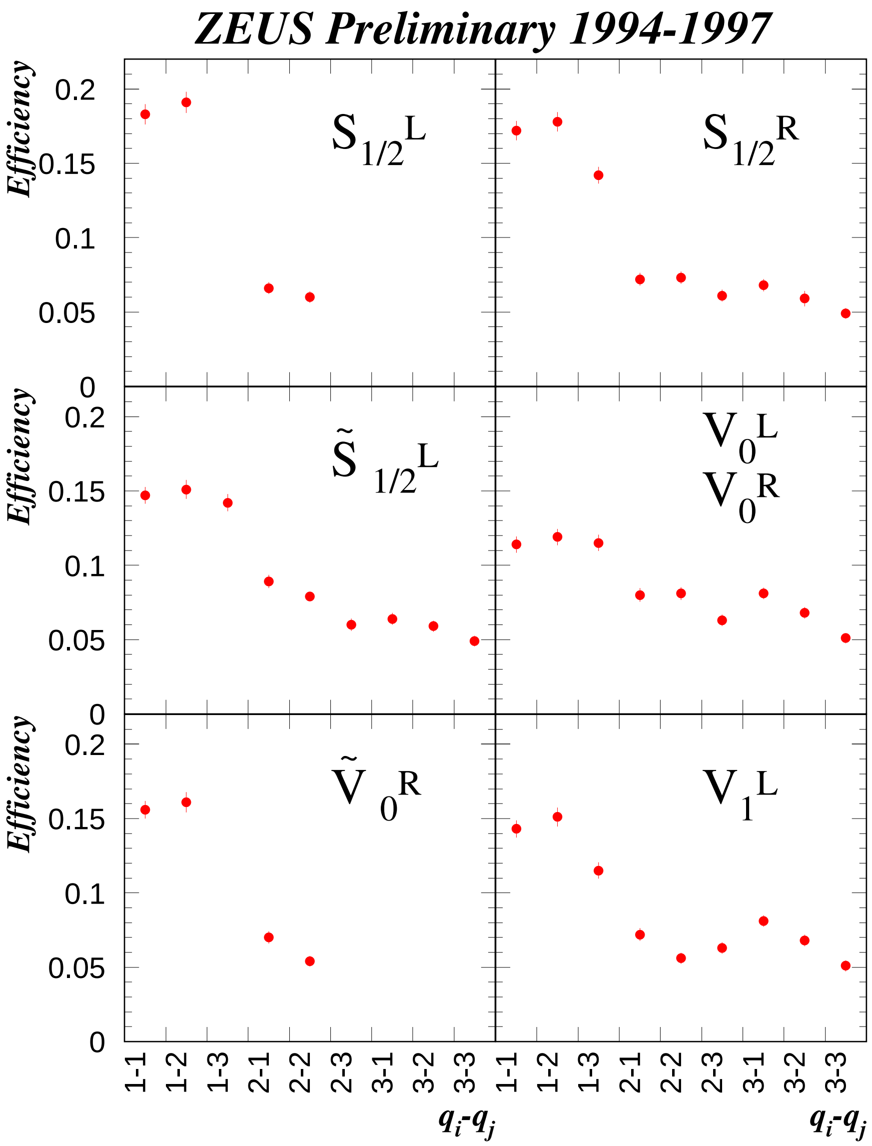
HERA upgrade:

promises improvement of existing limits by a factor $4-5$, unless...

The search continues...

High-mass LQ's - Efficiencies

$e \leftrightarrow \tau$



- valence quarks

$\rightsquigarrow$ high Q^2

$\Rightarrow$ high efficiency

- sea quarks

$\rightsquigarrow$ lowish Q^2, low p_t

$\Rightarrow$ lower efficiency