FCNC and LFV at HERA

SUSY 2002 – Hamburg – 20.06.2002

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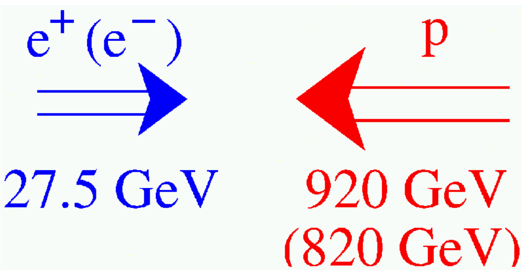
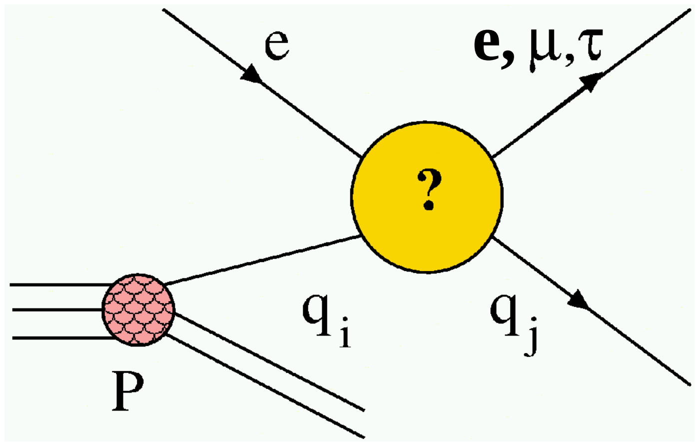
On behalf of:

- Isolated Leptons
- Flavour Changing Neutral Currents
- Lepton Flavour Violation
- Summary/Outlook



$\sqrt{s} = 320\,GeV\ (300\,GeV)$

$L \approx 120\ pb^{-1}$ / experiment

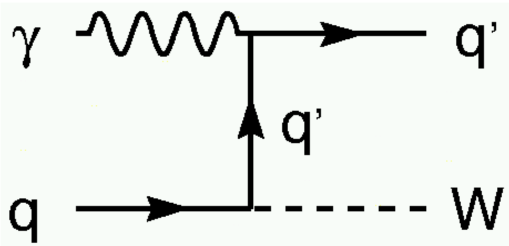


Events with Isolated Leptons

Search for: $e\,p \rightarrow e\,X\,l\,\nu$

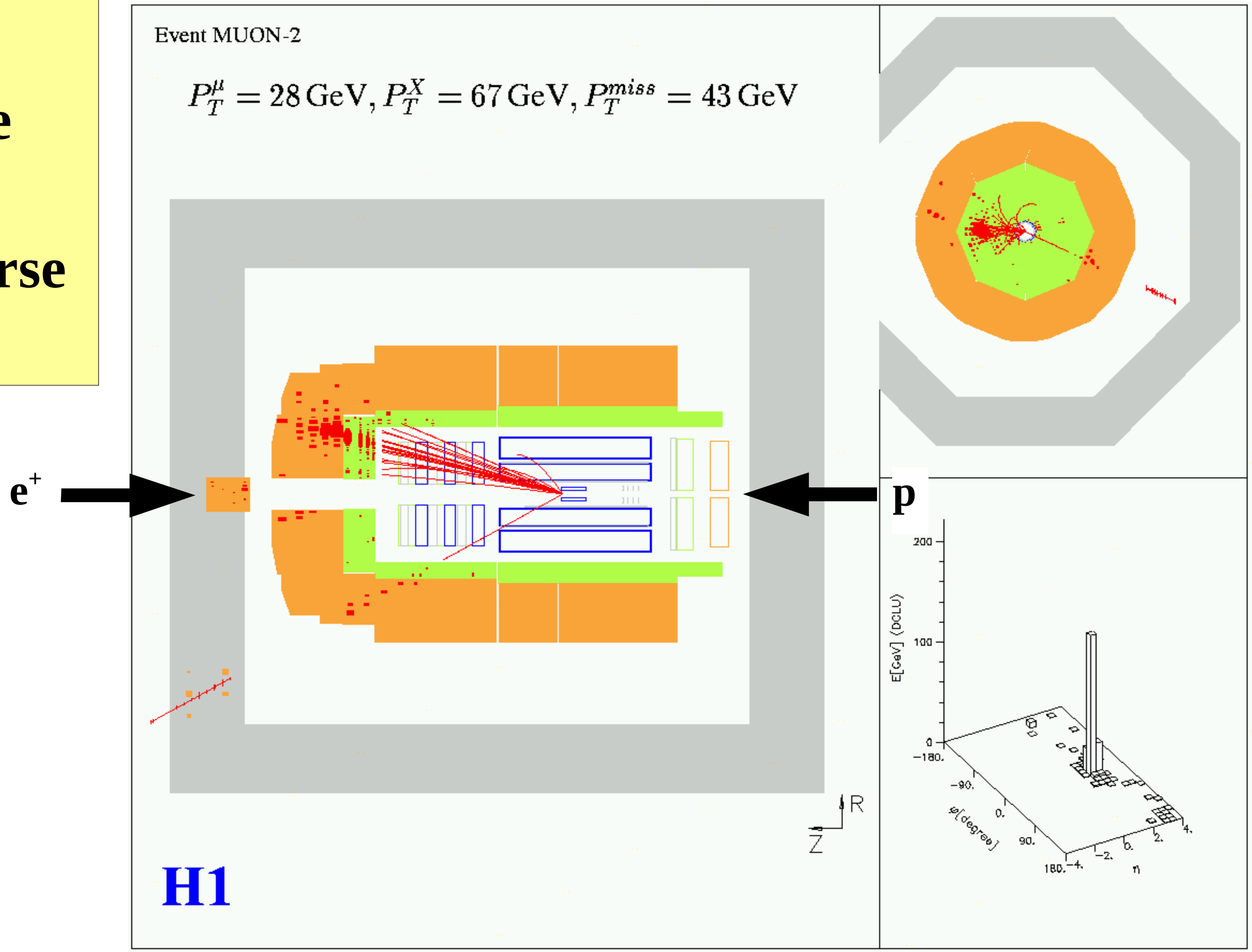
Signature:
- **isolated lepton**
- **large missing transverse momentum p_T^{miss}**
- **(large hadronic transverse momentum p_T^X)**

Main background:
W production, e.g.:

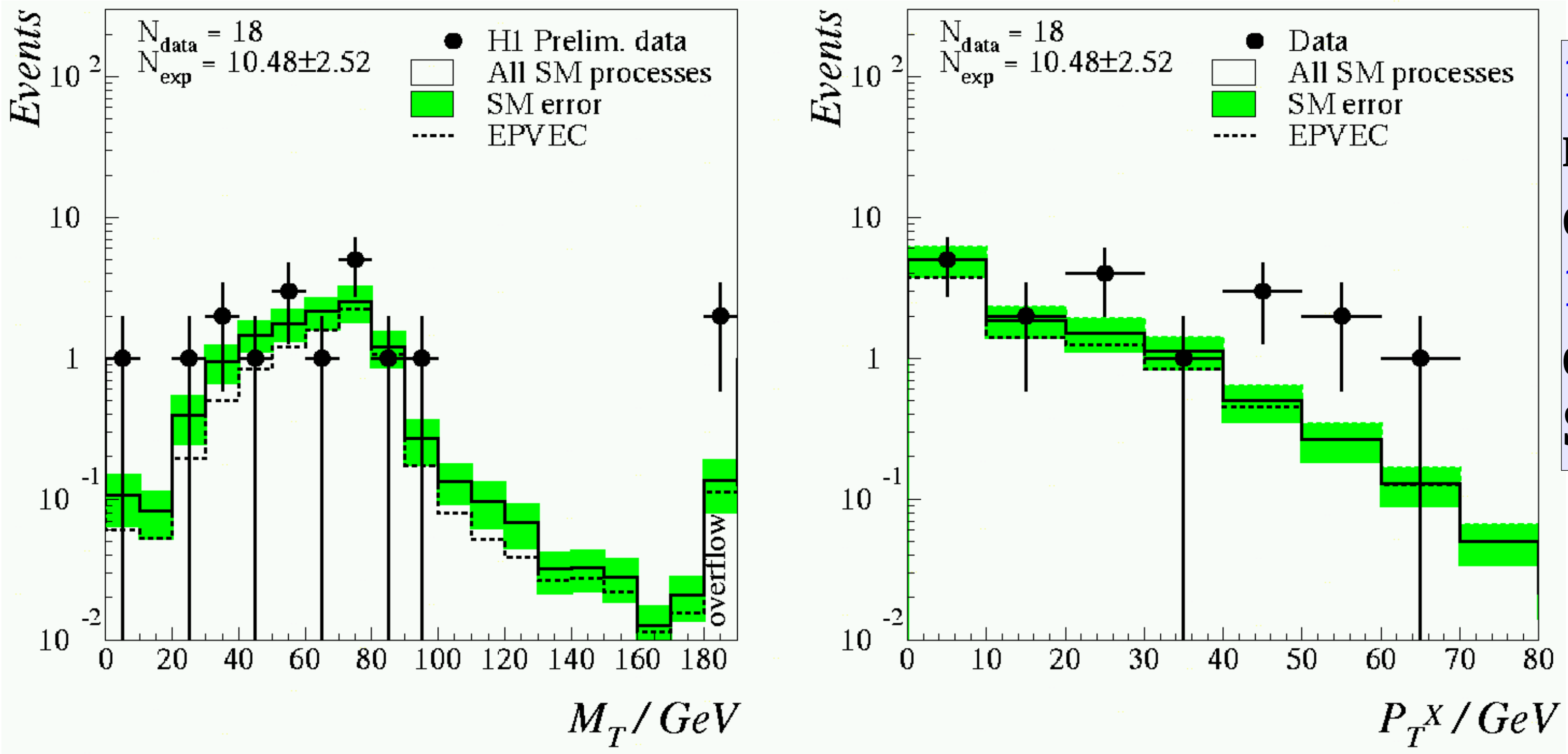


$$\sigma(ep \rightarrow eW^{\pm}X) \approx 1pb$$

H1 candidate event:



H1 Isolated Leptons



18 electron and muon events observed, 10.5 ±2.5 expected from SM

H1 preliminary 94-00 e^+p (101.6 pb^{-1})	Electron Obs./expected (W)	Muon Obs./expected (W)	combined Obs./exp.
$p_T^X > 25$ GeV	$4/1.29 \pm 0.33$ (1.05)	$6/1.54 \pm 0.41$ (1.29)	$10/2.8 \pm 0.7$
$p_T^X > 40$ GeV	$2/0.41 \pm 0.12$ (0.40)	$4/0.58 \pm 0.16$ (0.53)	$6/1.0 \pm 0.3$

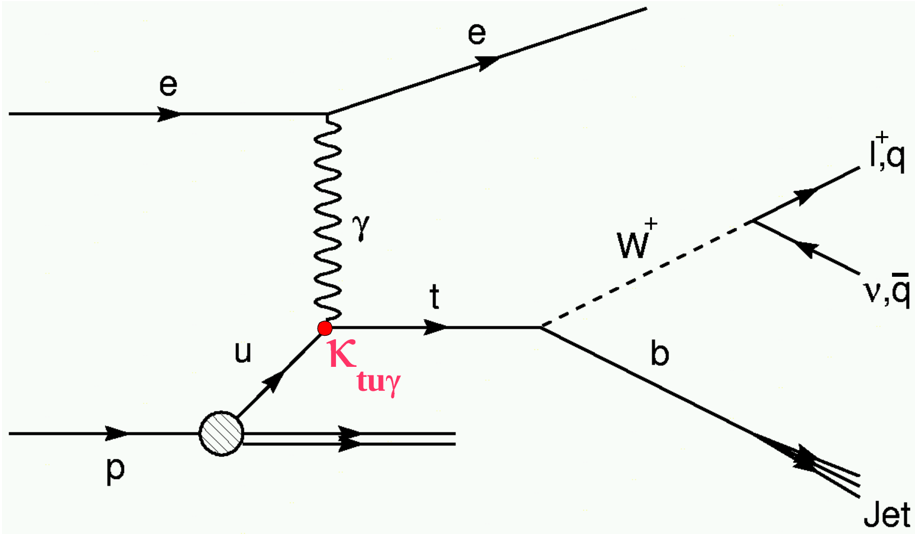
- **Excess of isolated lepton events above SM prediction.**
- **Events have large hadronic momenta.**

Single Top Quark Production at HERA

- $ep \rightarrow etX$ in the SM only through loops, GIM suppressed
  $\Rightarrow$ negligible cross section (~1fb)

- Possible production mechanism through **Flavour Changing Neutral Currents (FCNC)**
- Predicted by SM extensions

→ Effective anomalous coupling $\kappa_{tu\gamma}$
  - Z_0 exchange suppressed
  - u quark dominates at high x



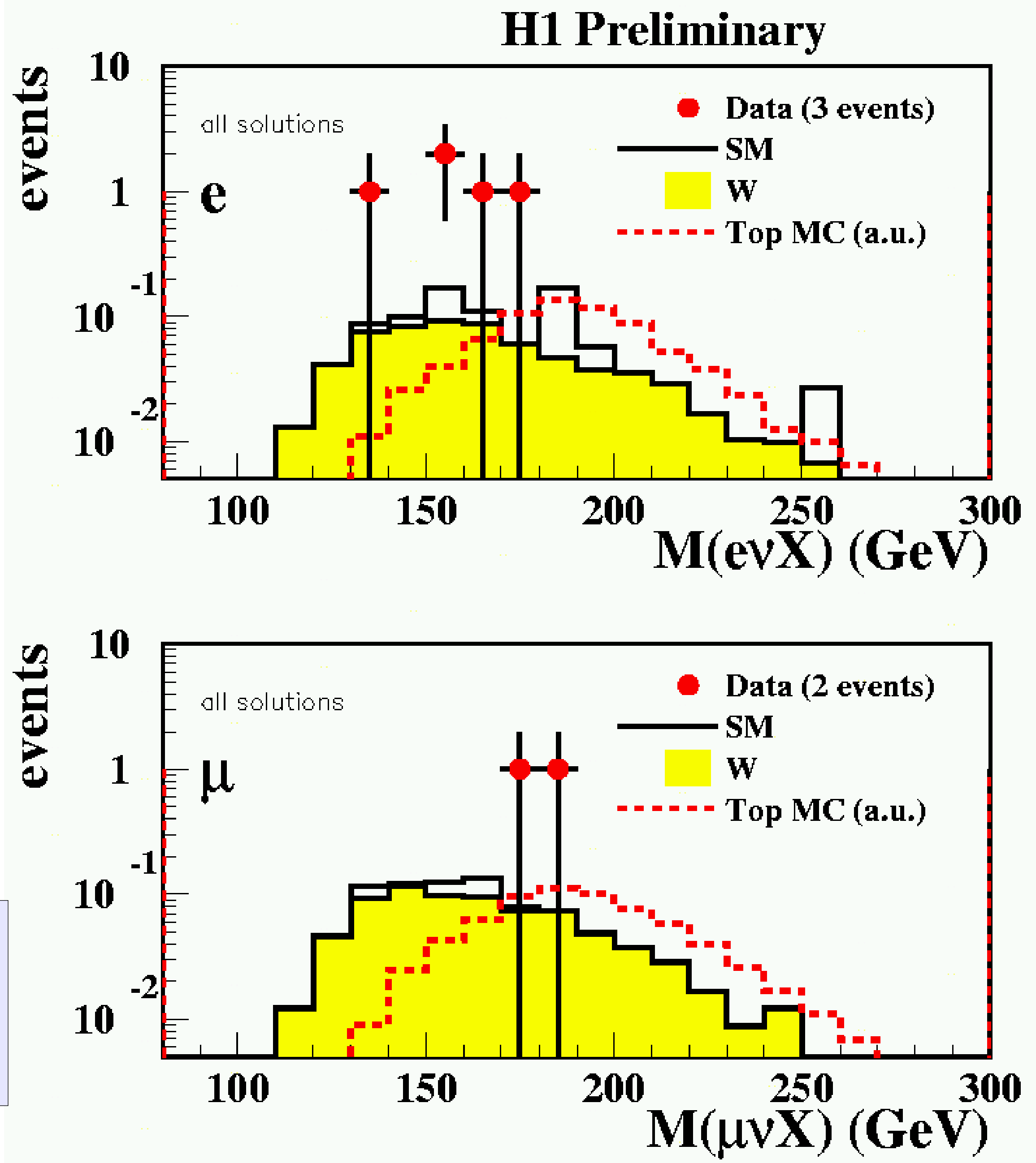
- Top quark decays to Wb
- W decays into lepton+neutrino (30%) or into hadrons (70%).

H1 Final Top Selection

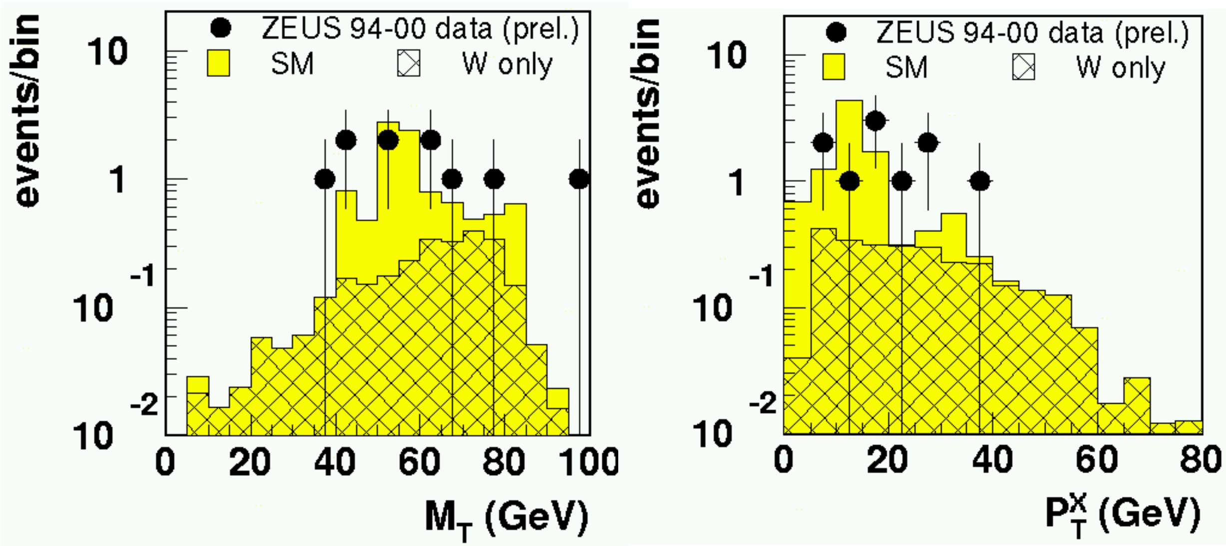
require:
- positively charged isolated lepton
- p_T^X>25 GeV (35 GeV)
- $M_T^{l\nu}$>10 GeV

- 3 electron and 2 muon events compatible with single top production.
- 1.8±0.29 events expected from background (mainly W production).

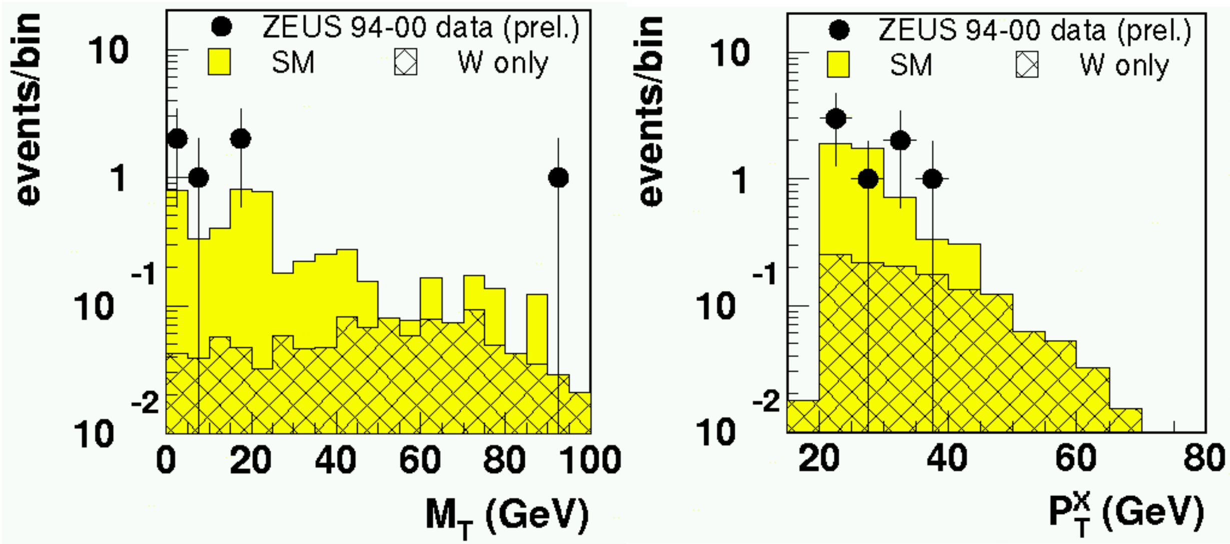
- Top mass reconstructed as invariant mass of l-v-jet, using kinematic constraints



ZEUS Isolated Leptons + Single Top



Electrons: 10 events observed,
11.0 ±1.6 expected from SM (mainly NC DIS)



Muons: 7 events observed,
5.4 ± 0.7 exp. from SM (mainly muon pair prod.)

- **No excess** above SM expectation observed.
- **Distribution** of kinematic variables is compatible with SM prediction.

After final top selection cuts:

ZEUS preliminary 94-00 $e^{\pm}p$ $(130\ \mathrm{pb}^{-1})$	Electron Obs./expected (W)
$p_T^X > 25$ GeV	$1/1.14 \pm 0.06\ (1.10)$
$p_T^X > 40$ GeV	$0/0.46 \pm 0.03\ (0.46)$

ZEUS preliminary 94-00 $e^{\pm}p$ $(130\ \mathrm{pb}^{-1})$	Muon Obs./expected (W)
$p_T^X > 25$ GeV	$1/1.29 \pm 0.16\ (0.95)$
$p_T^X > 40$ GeV	$0/0.50 \pm 0.08\ (0.41)$

→ **No candidates for Single Top Production**

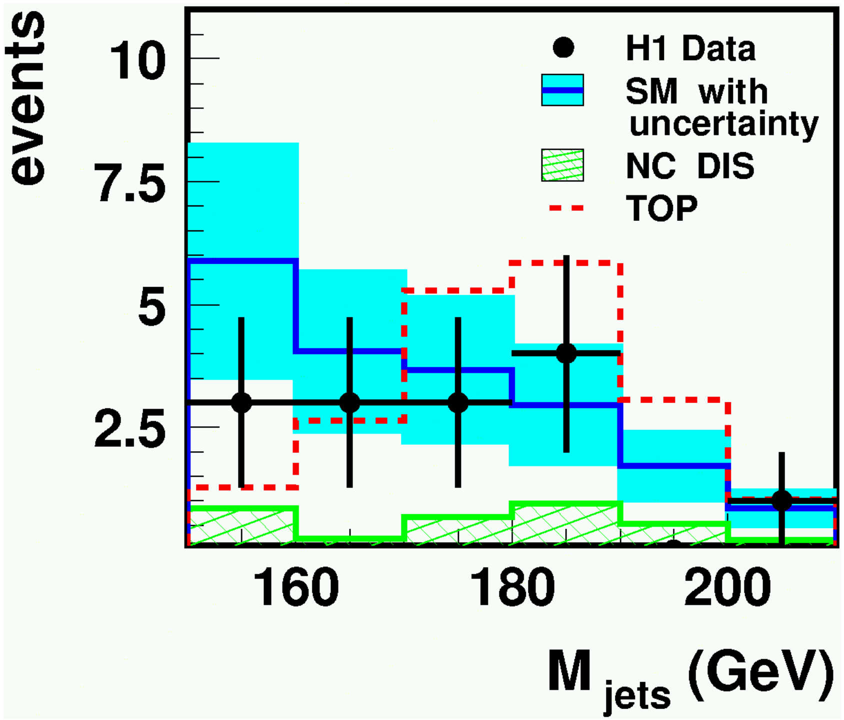
Single Top Quark Production - Hadronic Channel

Search for: $e\,u \rightarrow e\,t \rightarrow e\,b\,W \rightarrow e\,b\,q\,\bar{q}$

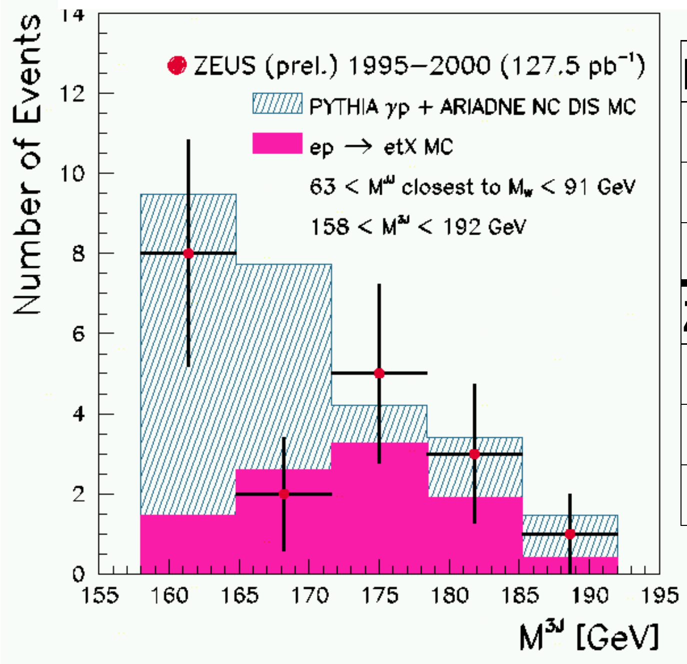
Signature: 3 jet events with $M^{jj} \approx M_W$ and $M^{3j} \approx M_{top}$.

Background: $\gamma p \rightarrow$ 3 jet QCD processes.

H1 1994-2000 data, L=115.2 pb^{-1}



ZEUS 1995-2000 data, L=127.5 pb^{-1}

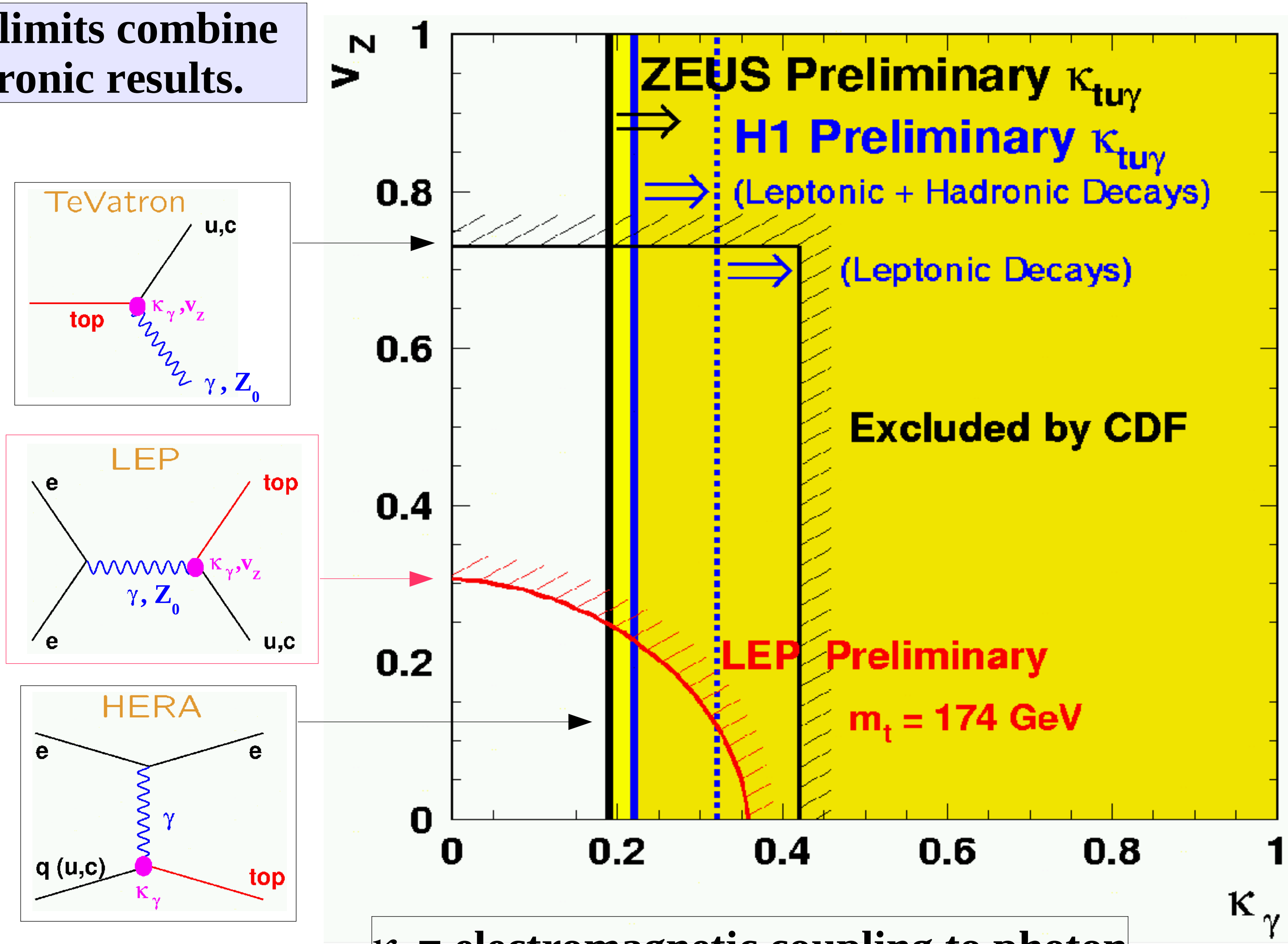


H1 94-00	After Top Cuts
Data	14
SM	19.6+-7.8
Efficiency	27%
ZEUS 95-00	
Data	19
SM	20.0
Efficiency	31%

- **No excess above SM prediction in both experiments.**
- **Sensitivity lower with respect to leptonic channel.**

Exclusion Limits on FCNC

ZEUS and H1 limits combine Leptonic+Hadronic results.



HERA is competitive with LEP and TeVatron for κ_γ.

κ_γ = electromagnetic coupling to photon

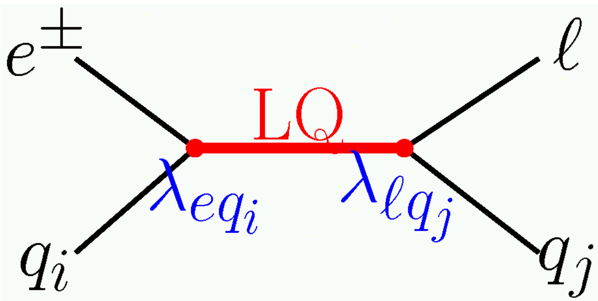
v_Z = vector coupling to Z_0

Lepton Flavour Violation

- Extensions of the Standard Model allow LFV (Leptoquark models, R-parity violating SUSY, ...)
- HERA is an ideal place to search for both, $e^{\pm}\rightarrow\mu$ and $e^{\pm}\rightarrow\tau$.
- Quantitative description: LQs coupling to different generations.

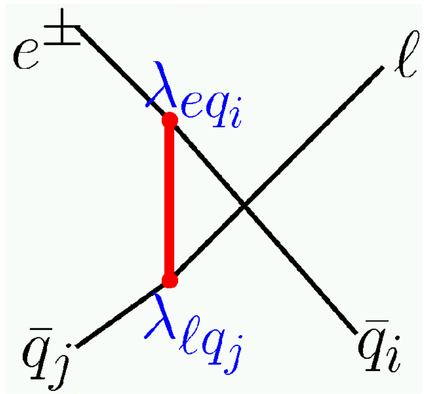
➔ Buchmüller-Rückl-Wyler model:
14 LQ types with Fermion number 0, 2 (F=L+3B)

Narrow Width Approximation for Low Mass LQs ($M_{LQ}<\sqrt{s}$)



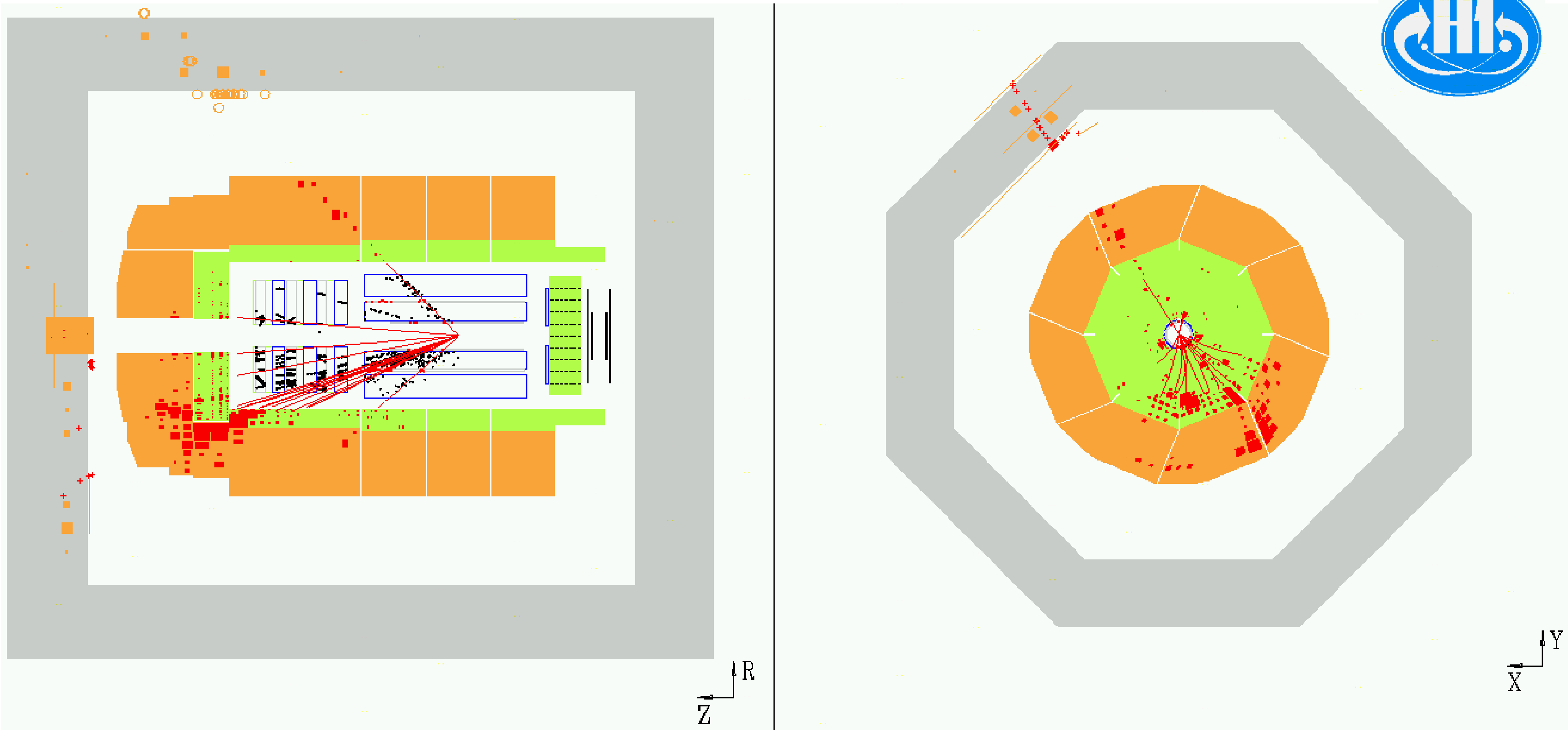
Signature:
- Isolated μ or τ with high p_T
- Peak in the l-jet mass spectrum
- l and jet back-to-back
- only F=0 LQs considered (interaction with valence quark for e^+p)

High Mass Approximation ($M_{LQ}>>\sqrt{s}$)



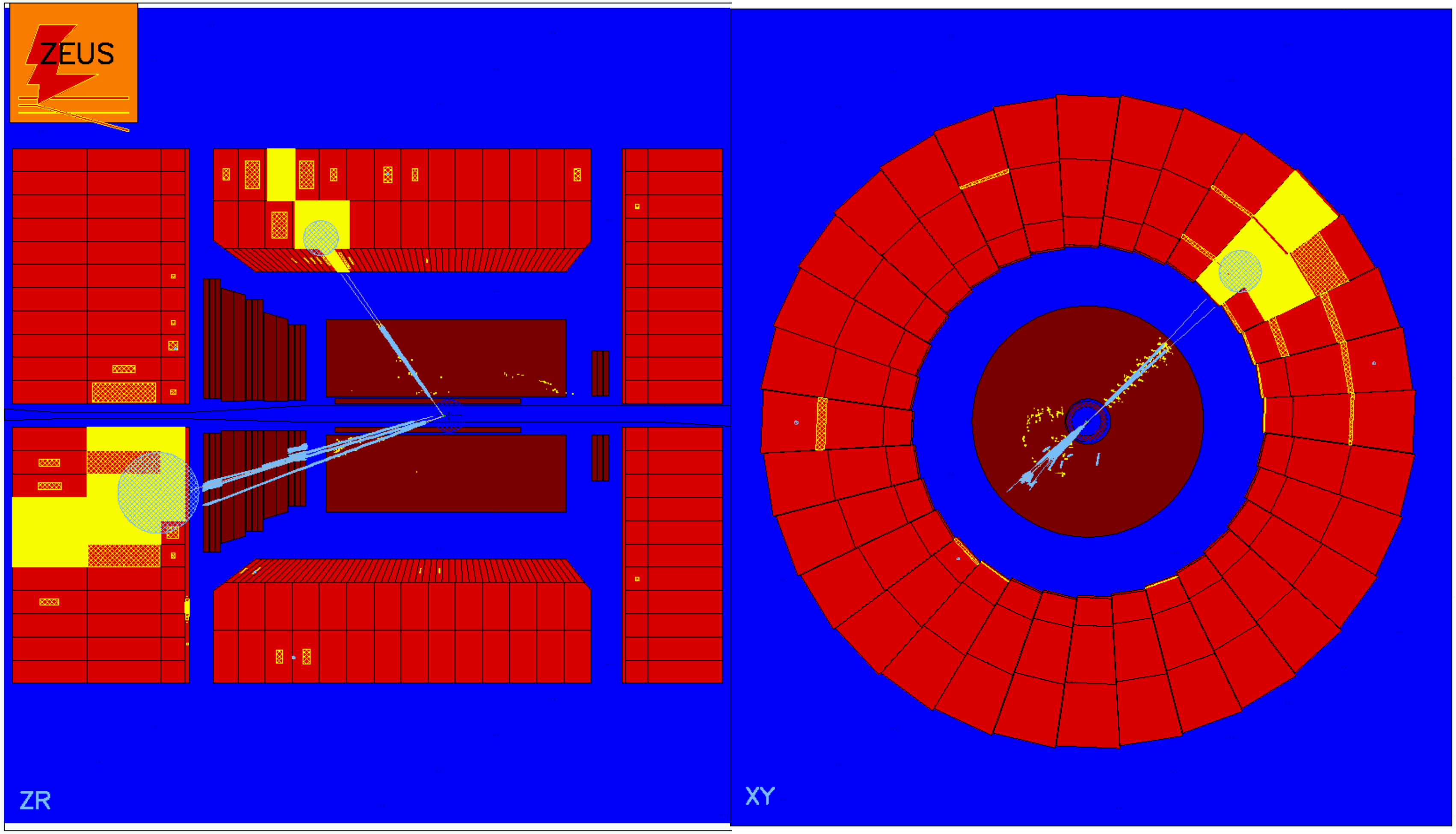
Signature:
- Isolated μ or τ with softer p_T spectrum
- Both F=0 and F=2 LQs are considered

LFV μ Channel Signature



- Isolated μ in the missing p_T direction
- Small SM background
- High selection efficiency (~40%-60% for low mass LQs)

LFV τ Channel Signature



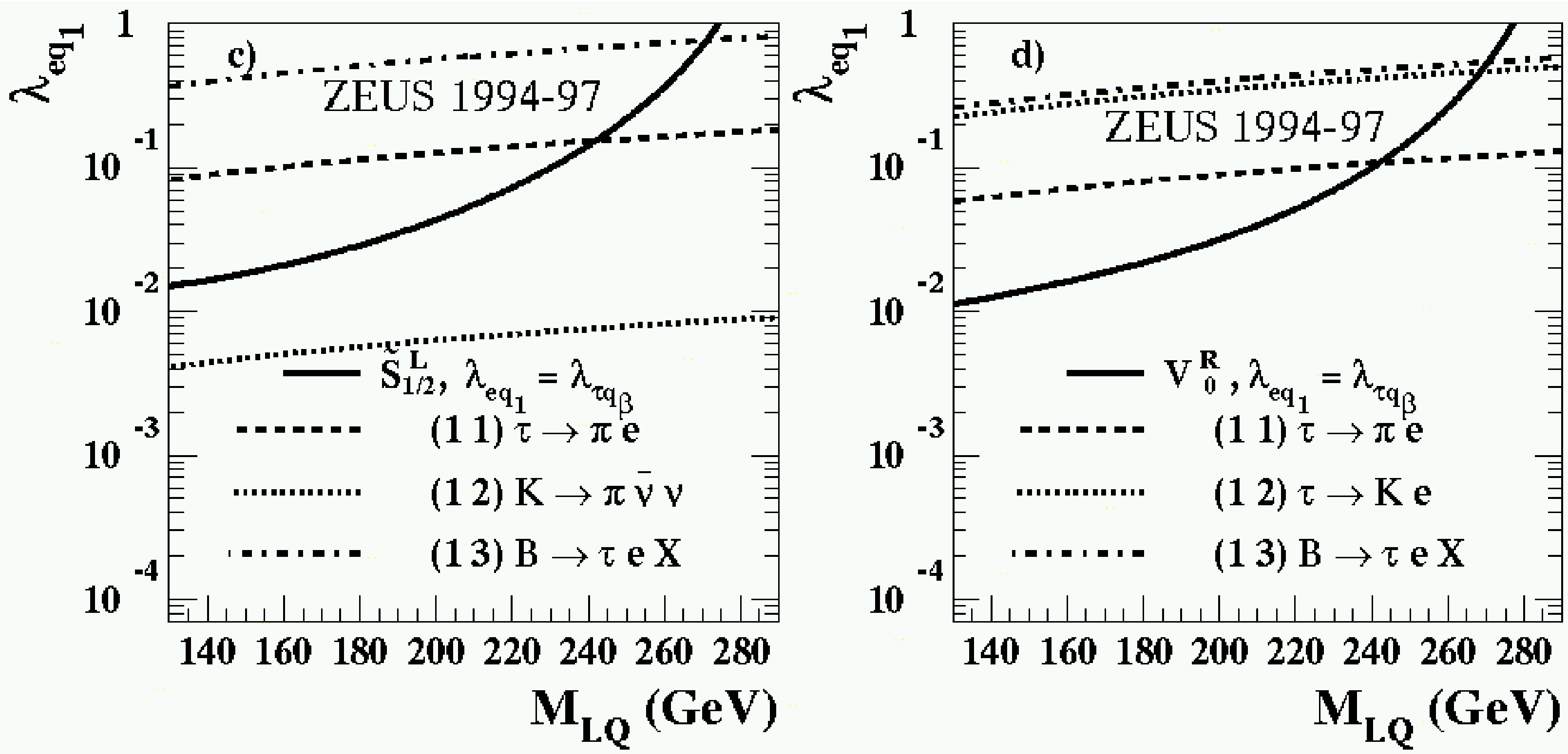
Simulated event,
$m_{LQ} = 200\,GeV$

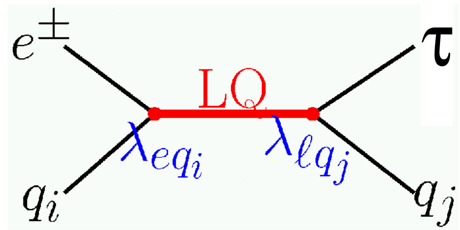
$\tau^{+} \rightarrow K^{+}\pi^{0}\ \overline{\nu}_{\tau}$

- **High p_T isolated e or μ in the missing p_T direction**
- **Narrow jet with 1-3 tracks, pointing into the missing p_T direction**
- **Low SM background**
- **Selection efficiency ~25%-30%**

Search for e+p→τX: Low Mass Limits

No LFV events found in both experiments.
- **Set limits on characteristic Yukawa couplings**





$$\sigma^{NWA} \propto \lambda^2_{eq_1} \beta_{\tau\, qj}$$

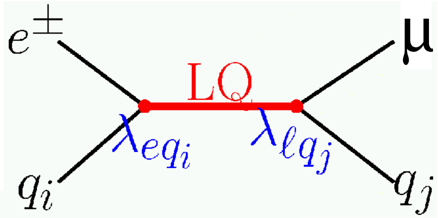
$\lambda_{eq1} = \lambda_{lqj} = 0.3$ →

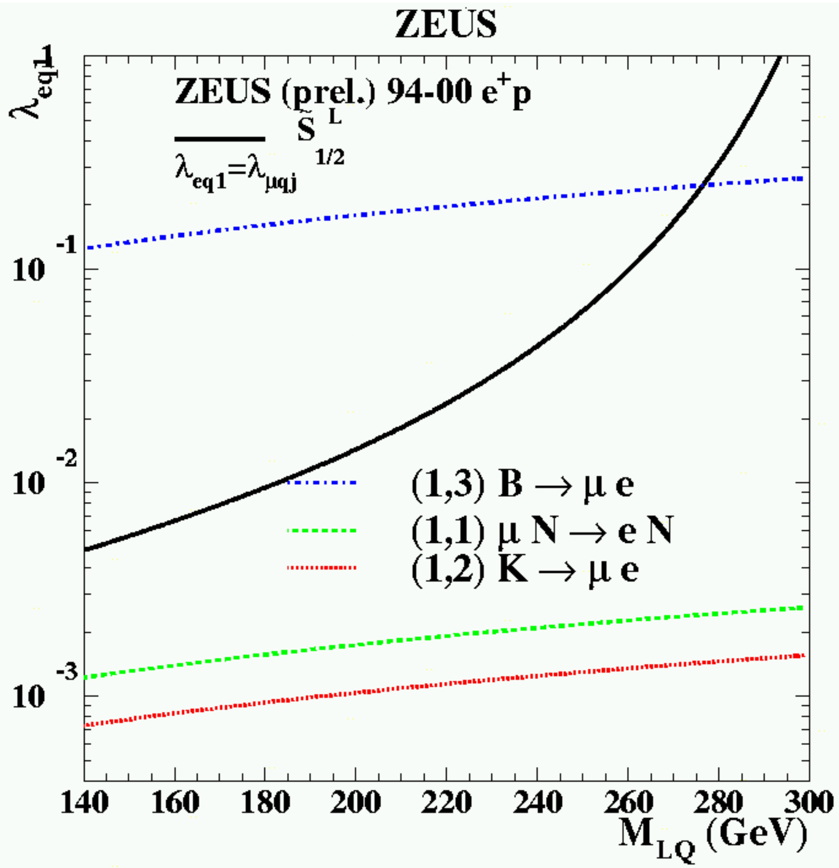
LQ type	$S^L_{1/2}$	$S^R_{1/2}$	$\tilde{S}^L_{1/2}$
Mass limits (GeV)	275	276	258

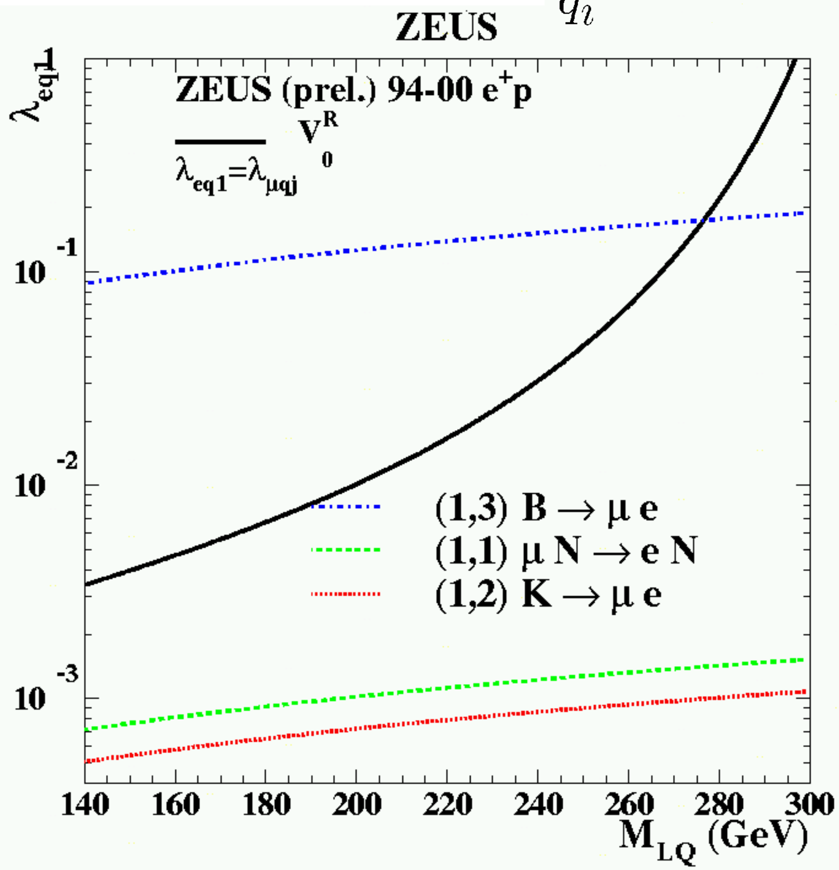
Similar results obtained by H1.

→ HERA improves limits from low energy experiments.

Search for e+p→μX: Low Mass limits







Lower mass limit at 95% C.L by assuming $\lambda_{eq1} = 0.3$

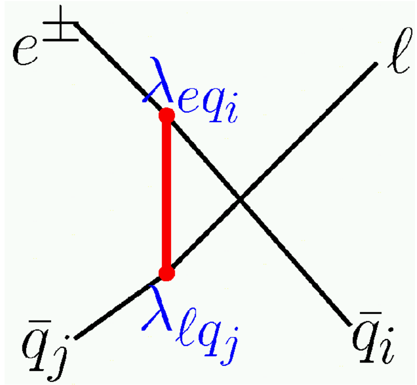
LQ type	$S^L_{1/2}$	$S^R_{1/2}$	$\tilde{S}^L_{1/2}$	V^L_0	V^R_0	$\tilde{V}^L_0$	V^L_1
Mass limits (GeV)	296	296	280	279	284	298	301

HERA limits competitive, if 3rd quark generation is involved.

Search for e+p→μX, e+p→τX: high mass limits

- contact interaction cross section for $M_{LQ} >> \sqrt{s}$:

$$\sigma^{HMA}(\lambda, M_{LQ}) \propto \left[\frac{\lambda_{eq_i}\lambda_{lq_j}}{M_{LQ}^2}\right]^2$$



- selection efficiency independent of M_{LQ}, but varies with quark generation

- New preliminary results from ZEUS using all data (94-00).

- limits for higher generation quarks improved.

Search for e+p→μX: high mass limits

$F=0$	Zeus Preliminary (94-00 combined limits)						$\frac{\lambda_{eq_i}\lambda_{\mu q_j}}{M^2_{LQ}}$ (TeV^{-2})
$q_i q_j$	$S^L_{1/2}$ $e^-\bar{u}$ 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	$\mu N\to eN$ 7.6×10^{-5} 1.1	$\mu N\to eN$ 2.6×10^{-5} 0.9	$\mu N\to eN$ 7.6×10^{-5} 1.6	$\mu N\to eN$ 2.6×10^{-5} 1.0	$\mu N\to eN$ 2.6×10^{-5} 1.0	$\mu N\to eN$ 2.6×10^{-5} 0.8	$\mu N\to eN$ 1.1×10^{-5} 0.4
1 2	$D\to\mu\bar{e}$ 4 **1.2**	$K\to\mu\bar{e}$ 2.7×10^{-5} 1.0	$K\to\mu\bar{e}$ 2.7×10^{-5} 1.7	$K\to\mu\bar{e}$ 1.3×10^{-5} 1.2	$K\to\mu\bar{e}$ $.3\times10^{-5}$ 1.2	$D\to\mu\bar{e}$ 2 **1.0**	$K\to\mu\bar{e}$ 1.3×10^{-5} 0.5
1 3	*	$B\to\mu\bar{e}$ 0.8 1.8	$B\to\mu\bar{e}$ 0.8 1.8	V_{ub} 0.2 1.5	$B\to\mu\bar{e}$ 0.4 1.5	*	V_{ub} 0.2 1.5
2 1	$D\to\mu\bar{e}$ 4 **3.6**	$K\to\mu\bar{e}$ 2.7×10^{-5} 2.4	$K\to\mu\bar{e}$ 2.7×10^{-5} 3.2	$K\to\mu\bar{e}$ 1.3×10^{-5} 1.3	$K\to\mu\bar{e}$ 1.3×10^{-5} 1.3	$D\to\mu\bar{e}$ 2 **1.3**	$K\to\mu\bar{e}$ 1.3×10^{-5} 0.6
2 2	$\mu\to3e$ 5×10^{-3} 5.8	$\mu\to3e$ 7.3×10^{-3} 3.1	$\mu\to3e$ 1.6×10^{-2} 3.8	$\mu\to3e$ 8×10^{-3} 1.9	$\mu\to3e$ 8×10^{-3} 1.9	$\mu\to3e$ 2.5×10^{-3} 2.9	$\mu\to3e$ 1.5×10^{-3} 1.2
2 3	*	$B\to\bar{\mu}eK$ 0.6 4.4	$B\to\bar{\mu}eK$ 0.6 4.4	$B\to\bar{\mu}eK$ 0.3 2.9	$B\to\bar{\mu}eK$ 0.3 2.9	*	$B\to\bar{\mu}eK$ 0.3 2.9
3 1	*	$B\to\mu\bar{e}$ 0.8 4.3	$B\to\mu\bar{e}$ 0.8 4.3	V_{ub} 0.2 1.4	$B\to\mu\bar{e}$ 0.4 1.4	*	V_{ub} 0.2 1.4
3 2	*	$B\to\bar{\mu}eK$ 0.6 5.8	$B\to\bar{\mu}eK$ 0.6 5.8	$B\to\bar{\mu}eK$ 0.3 2.2	$B\to\bar{\mu}eK$ 0.3 2.2	*	$B\to\bar{\mu}eK$ 0.3 2.2
3 3	*	$\mu\to3e$ 7.3×10^{-3} 7.7	$\mu\to3e$ 1.6×10^{-2} 7.7	$\mu\to3e$ 8×10^{-3} 3.9	$\mu\to3e$ 8×10^{-3} 3.9	*	$\mu\to3e$ 1.5×10^{-3} 3.9

Search for e+p→τX: high mass limits

$e \to \tau$ ZEUS 94-97 $F = 0$							
$\alpha\beta$	$S^L_{1/2}$ e^+u_α	$S^R_{1/2}$ $e^+(u+d)_\alpha$	$\tilde{S}^L_{1/2}$ e^+d_α	V^L_0 e^+d_α	V^R_0 e^+d_α	$\tilde{V}^R_0$ e^+u_α	V^L_1 $e^+(\sqrt{2}u+d)_\alpha$
1 1	$\tau \to \pi e$ 0.4 3.0	$\tau \to \pi e$ 0.2 2.5	$\tau \to \pi e$ 0.4 4.6	G_F 0.2 3.3	$\tau \to \pi e$ 0.2 3.3	$\tau \to \pi e$ 0.2 2.4	G_F 0.2 1.2
1 2	**3.1**	$\tau \to Ke$ 5 **2.5**	$K \to \pi\nu\bar{\nu}$ 10^{-3} 4.7	$\tau \to Ke$ 3 3.7	$\tau \to Ke$ 3 3.7	**2.7**	$K \to \pi\nu\bar{\nu}$ 2.5×10^{-4} 1.3
1 3	*	$B \to \tau\bar{e}X$ 8 **5.1**	$B \to \tau\bar{e}X$ 8 **5.1**	$B \to l\nu X$ 2 4.6	$B \to \tau\bar{e}X$ 4 4.6	*	$B \to l\nu X$ 2 4.6
2 1	**16**	$\tau \to Ke$ 5 9.2	$K \to \pi\nu\bar{\nu}$ 10^{-3} 12	$\tau \to Ke$ 3 4.9	$\tau \to Ke$ 3 4.9	**6.2**	$K \to \pi\nu\bar{\nu}$ 2.5×10^{-4} 2.6
2 2	$\tau \to ee\bar{e}$ 20 **20**	$\tau \to ee\bar{e}$ 30 **11**	$\tau \to ee\bar{e}$ 66 **12**	$\tau \to ee\bar{e}$ 33 **6.2**	$\tau \to ee\bar{e}$ 33 **6.2**	$\tau \to ee\bar{e}$ 10 11	$\tau \to ee\bar{e}$ 6.1 **4.3**
2 3	*	$B \to \tau\bar{e}X$ 8 16	$B \to \tau\bar{e}X$ 8 16	$B \to l\nu X$ 2 12	$B \to \tau\bar{e}X$ 4 12	*	$B \to l\nu X$ 2 12
3 1	*	$B \to \tau\bar{e}X$ 8 17	$B \to \tau\bar{e}X$ 8 17	V_{ub} 0.2 5.4	$B \to \tau\bar{e}X$ 4 5.4	*	V_{ub} 0.2 5.4
3 2	*	$B \to \tau\bar{e}X$ 8 22	$B \to \tau\bar{e}X$ 8 22	$B \to l\nu X$ 2 7.6	$B \to \tau\bar{e}X$ 4 7.6	*	$B \to l\nu X$ 2 7.6
3 3	*	$\tau \to ee\bar{e}$ 30 **30**	$\tau \to ee\bar{e}$ 66 **30**	$\tau \to ee\bar{e}$ 33 **15**	$\tau \to ee\bar{e}$ 33 **15**	*	$\tau \to ee\bar{e}$ 6.1 15

$e \to \tau$ ZEUS 94-97 $\lvert F \rvert = 2$							
$\alpha\beta$	S^L_0 $e^+\bar{u}_\alpha$	S^R_0 $e^+\bar{u}_\alpha$	$\tilde{S}^R_0$ $e^+\bar{d}_\alpha$	S^L_1 $e^+(\bar{u}+\sqrt{2}\bar{d})_\alpha$	$V^L_{1/2}$ $e^+\bar{d}_\alpha$	$V^R_{1/2}$ $e^+(\bar{u}+\bar{d})_\alpha$	$\tilde{V}^L_{1/2}$ $e^+\bar{u}_\alpha$
1 1	G_F 0.3 5.4	$\tau \to \pi e$ 0.4 5.4	$\tau \to \pi e$ 0.4 7.1	G_F 0.3 2.8	$\tau \to \pi e$ 0.2 2.6	$\tau \to \pi e$ 0.1 1.3	$\tau \to \pi e$ 0.2 1.7
1 2	$K \to \pi\nu\bar{\nu}$ 10^{-3} 14	**14**	$\tau \to Ke$ 5 9.3	$K \to \pi\nu\bar{\nu}$ 10^{-3} 4.6	$K \to \pi\nu\bar{\nu}$ 5×10^{-4} 5.5	$\tau \to Ke$ 3 4.5	**8.2**
1 3	V_{ub} 0.4 *	*	$B \to \tau\bar{e}X$ 8 12	V_{ub} 0.4 5.5	$B \to \tau\bar{e}X$ 4 8.4	$B \to \tau\bar{e}X$ 4 8.4	*
2 1	$K \to \pi\nu\bar{\nu}$ 10^{-3} 5.9	**5.9**	$\tau \to Ke$ 5 7.8	$K \to \pi\nu\bar{\nu}$ 10^{-3} 3.2	$K \to \pi\nu\bar{\nu}$ 5×10^{-4} 2.5	$\tau \to Ke$ 3 **1.3**	**1.6**
2 2	$\tau \to ee\bar{e}$ 20 **19**	$\tau \to ee\bar{e}$ 20 **19**	$\tau \to ee\bar{e}$ 66 **13**	$\tau \to ee\bar{e}$ 55 **6.2**	$\tau \to ee\bar{e}$ 33 **6.5**	$\tau \to ee\bar{e}$ 15 **5.2**	$\tau \to ee\bar{e}$ 10 **9.7**
2 3	$B \to l\nu X$ 4 *	*	$B \to \tau\bar{e}X$ 8 17	$B \to l\nu X$ 4 8.1	$B \to \tau\bar{e}X$ 4 11	$B \to \tau\bar{e}X$ 4 11	*
3 1	$B \to l\nu X$ 4 *	*	$B \to \tau\bar{e}X$ 8 9.3	$B \to l\nu X$ 4 4.7	$B \to \tau\bar{e}X$ 4 **2.6**	$B \to \tau\bar{e}X$ 4 **2.6**	*
3 2	$B \to l\nu X$ 4 *	*	$B \to \tau\bar{e}X$ 8 21	$B \to l\nu X$ 4 10.2	$B \to \tau\bar{e}X$ 4 7.6	$B \to \tau\bar{e}X$ 4 7.6	*
3 3	*	*	$\tau \to ee\bar{e}$ 66 **30**	$\tau \to ee\bar{e}$ 55 **16**	$\tau \to ee\bar{e}$ 33 **15**	$\tau \to ee\bar{e}$ 15 **15**	*

Summary and Outlook

- Searches for Single Top Production in the leptonic and hadronic decay channel of the W performed by H1 and ZEUS.
  - Excess of events at H1 in the leptonic channel, which are compatible with single top quark production:
    H1: 5 events observed, 1.8 exp. from BG
    ZEUS: 0 events observed, 1.0 exp. from BG
- No excess in the hadronic channel for both experiments.

- H1 and ZEUS have searched for LFV interactions in both, the μ and τ channel.
  - No LFV events found at HERA up to now.
  - Limits competitive with low energy experiments, e.g. up to M_{LQ} > 282 (τ) and 301 GeV (μ) for λ=0.3, NWA.

- Waiting for data from HERA II:
  - 10 times higher luminosity $\rightarrow$ up to 3 times higher sensitivity to couplings for both searches
  - improved detectors, in particular forward tracking