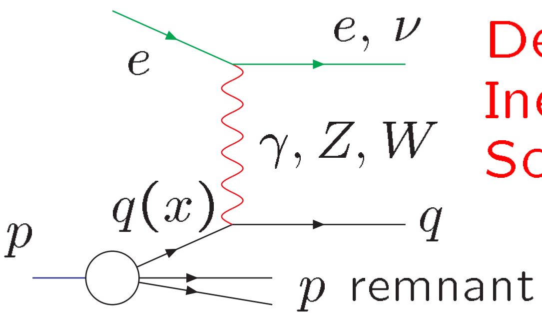
Searches for SUSY at HERA

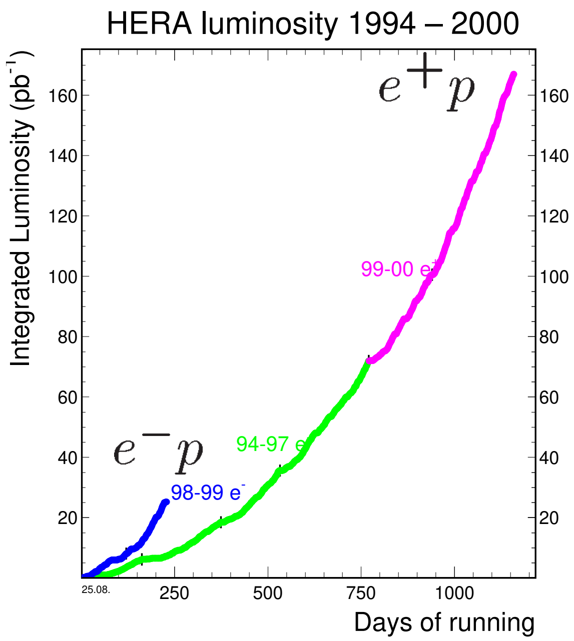
Nichol Brümmer
Ohio State University

- $\rightarrow$ HERA
- $\rightarrow$ Leptoquarks coupling to $e^{\pm}q$
- $\rightarrow$ Lepton Flavour Violation
- $\rightarrow$ Contact Interactions, large extra dimensions
- $\rightarrow$ Excited Fermions
- $\rightarrow$ Squarks in $\not{R}_P$ MSSM at HERA
- $\rightarrow$ High p_T leptons: W production, single top
- $\rightarrow$ Conclusions

DATA samples from HERA



Deep Inelastic Scattering

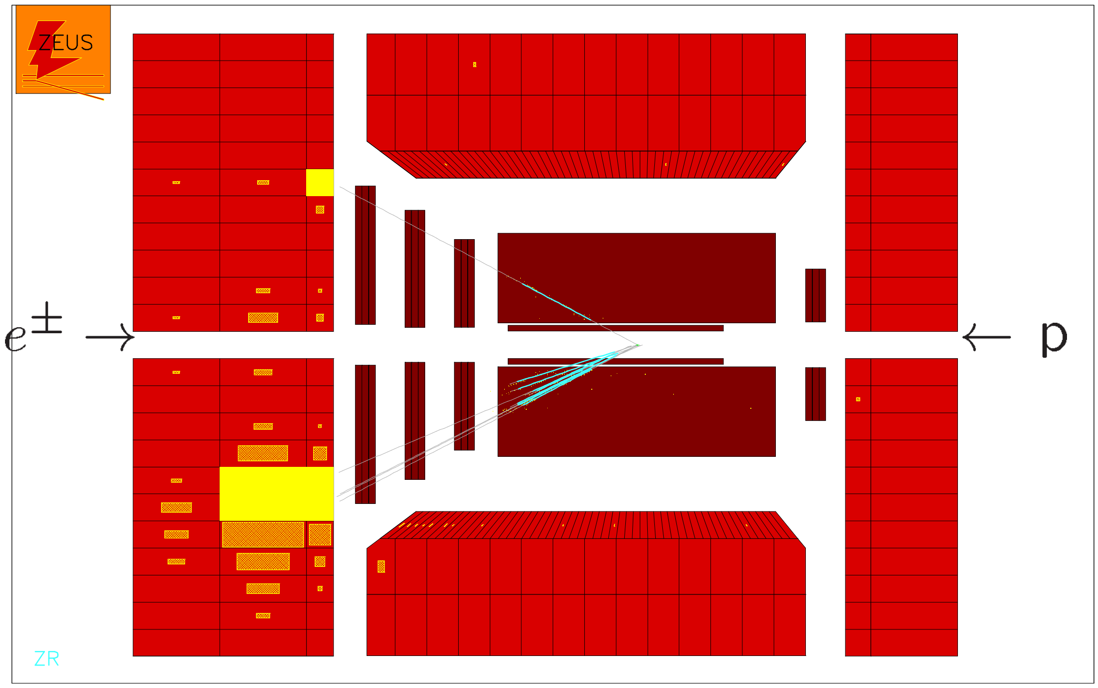


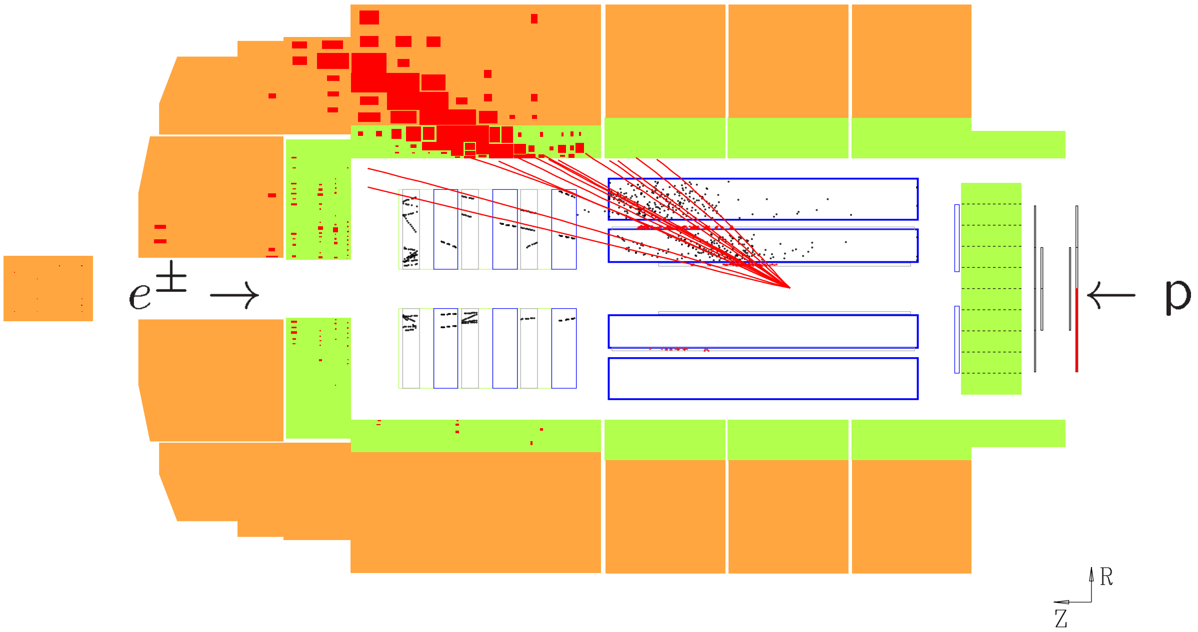
$Q^2 =$ (4 momentum transfer)^2
$x =$ parton momentum fraction
$y = (1 + \cos\theta^*)/2$
$M = \sqrt{xs}$
$Q^2 = xys$

$E_e^{\text{beam}} = 27.5$ GeV

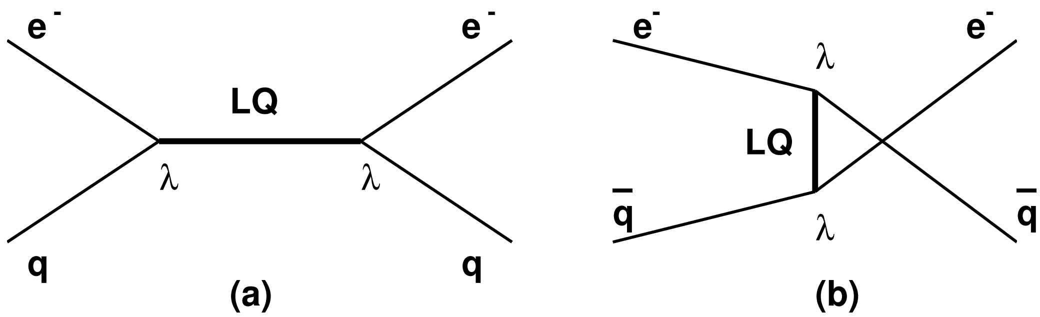
	E_p^{beam} (GeV)	$\sqrt{s}$ (GeV)	ZEUS (pb^{-1})	H1 (pb^{-1})
1993–1994 e^-p	820	300	1	1
1994–1997 e^+p	820	300	48	37
1998–1999 e^-p	920	318	16	15
1999–2000 e^+p	920	318	68	56

ZEUS NC DIS, H1 CC DIS





Leptoquarks coupling to $e^{\pm}p$



- $e^{+}p$ data are sensitive to $F = 0$ LQs
- $e^{-}p$ data are sensitive to $F = 2$ LQs
- 2×7 multiplets of $SU(3) \times SU(2) \times U(1)$

Buchmüller, Rückl, Wyler

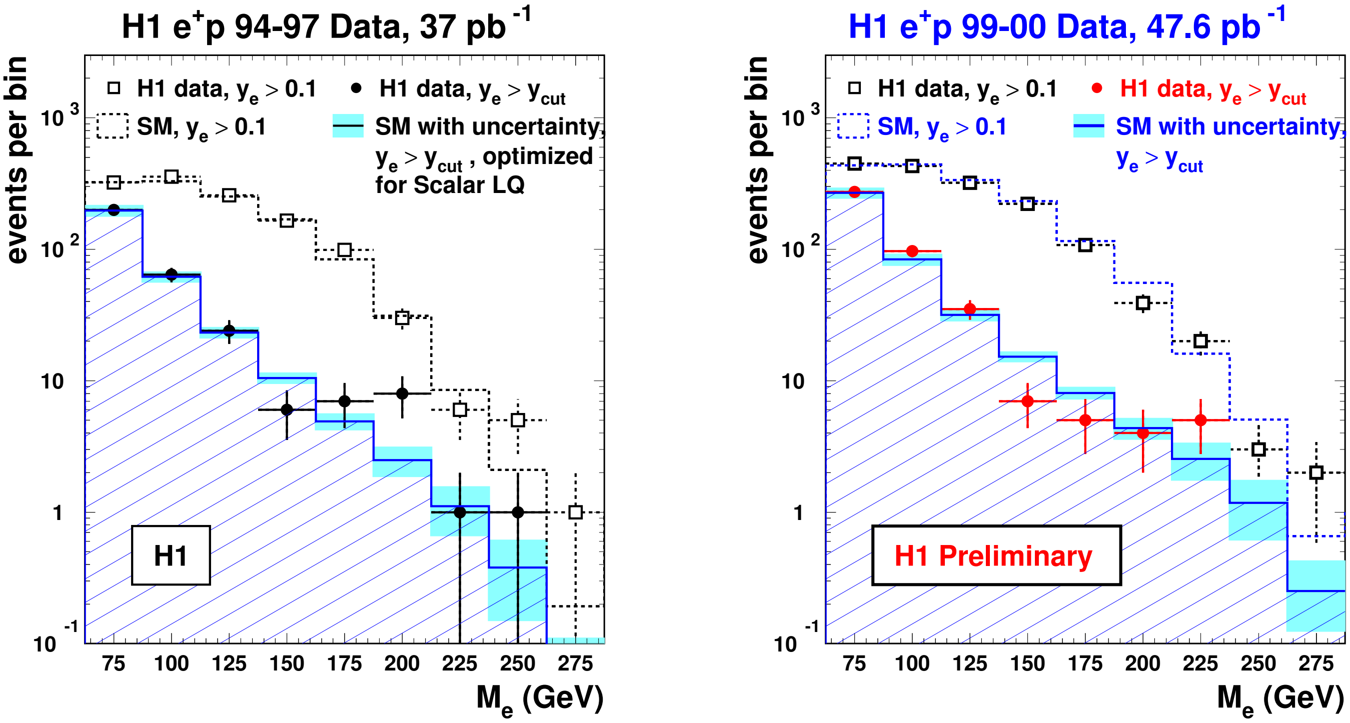
$F = 0, 2$ Scalars, Vectors, labeled by isospin and lepton helicity.

- Narrow-width approximation:
  $\sigma(e^{-}p \to LQ) = (\pi/4s)\lambda^2 \; q|_{x=M_{LQ}^2/s}$

- Start with high-Q^2 NC DIS events
- Apply optimized cut $y > y_{\mathrm{cut}}(M_e)$
  NC DIS: $\sigma \sim 1/y^2$
  Scalar LQ decays isotropically in $y = (1 - \cos\theta^*)/2$
  Vector LQs $\sigma \sim (1 + \cos\theta^*)^2 = (1 - y)^2$
- Search resonance in e-jet mass, $M = \sqrt{sx}$

Latest 1999–2000 e^+p data

H1: Mass Spectrum before and after
optimized cuts on $y = (1 - \cos\theta^*)/2$

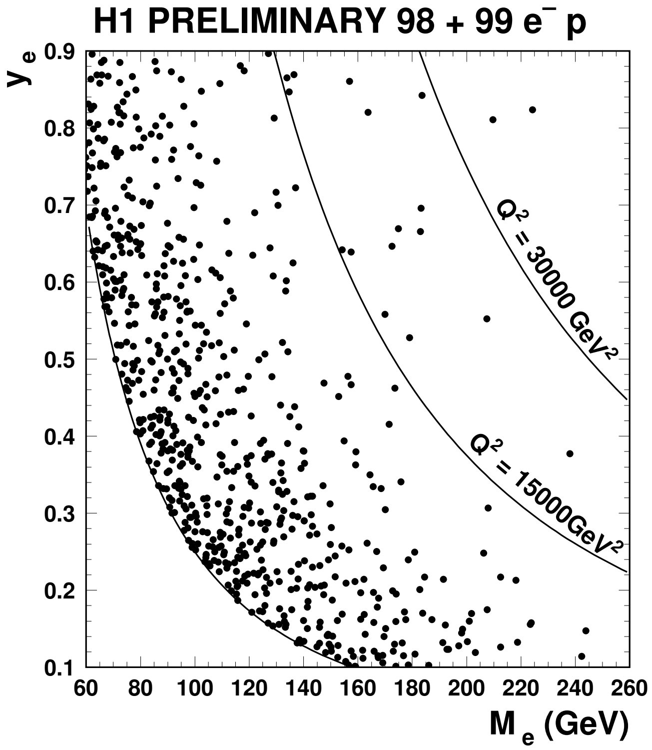


94-97: excess | 99-00: agreement

ZEUS: comparison 96 excess

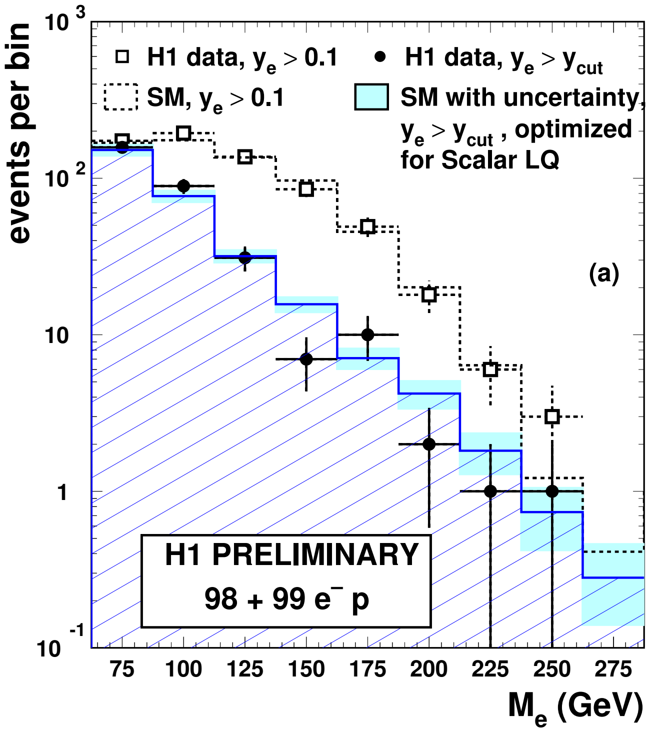
Period	$\int Ldt$ (pb⁻1)	$\sqrt{s}$ (GeV)	$Q^2 > 35000$ ZEUS	SM	$x > 0.55$, $y > 0.25$ ZEUS	SM
94-97 e^+p	47.7	300	2	0.34	4	1.9
98-99 e^-p	16.2	318	2	1.02	1	1.3
99-00.. e^+p	39.2	318	1	0.53	0	1.6

$F = 2$ Leptoquarks in e^-p data

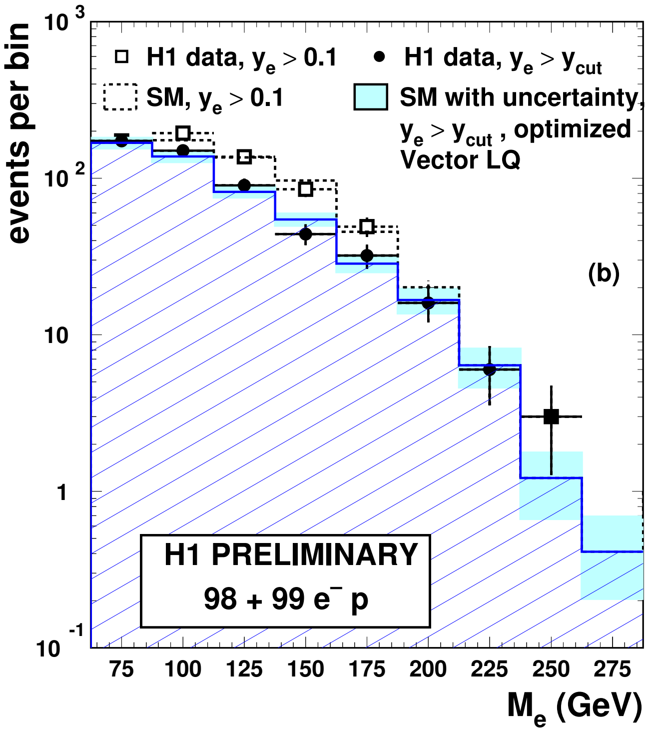


Scatter plot of y_e vs. M_e with contours of $Q^2 =$ $2500, 15000, 30000\,\mathrm{GeV}^2$.

Mass Spectrum before and after optimized y cuts.

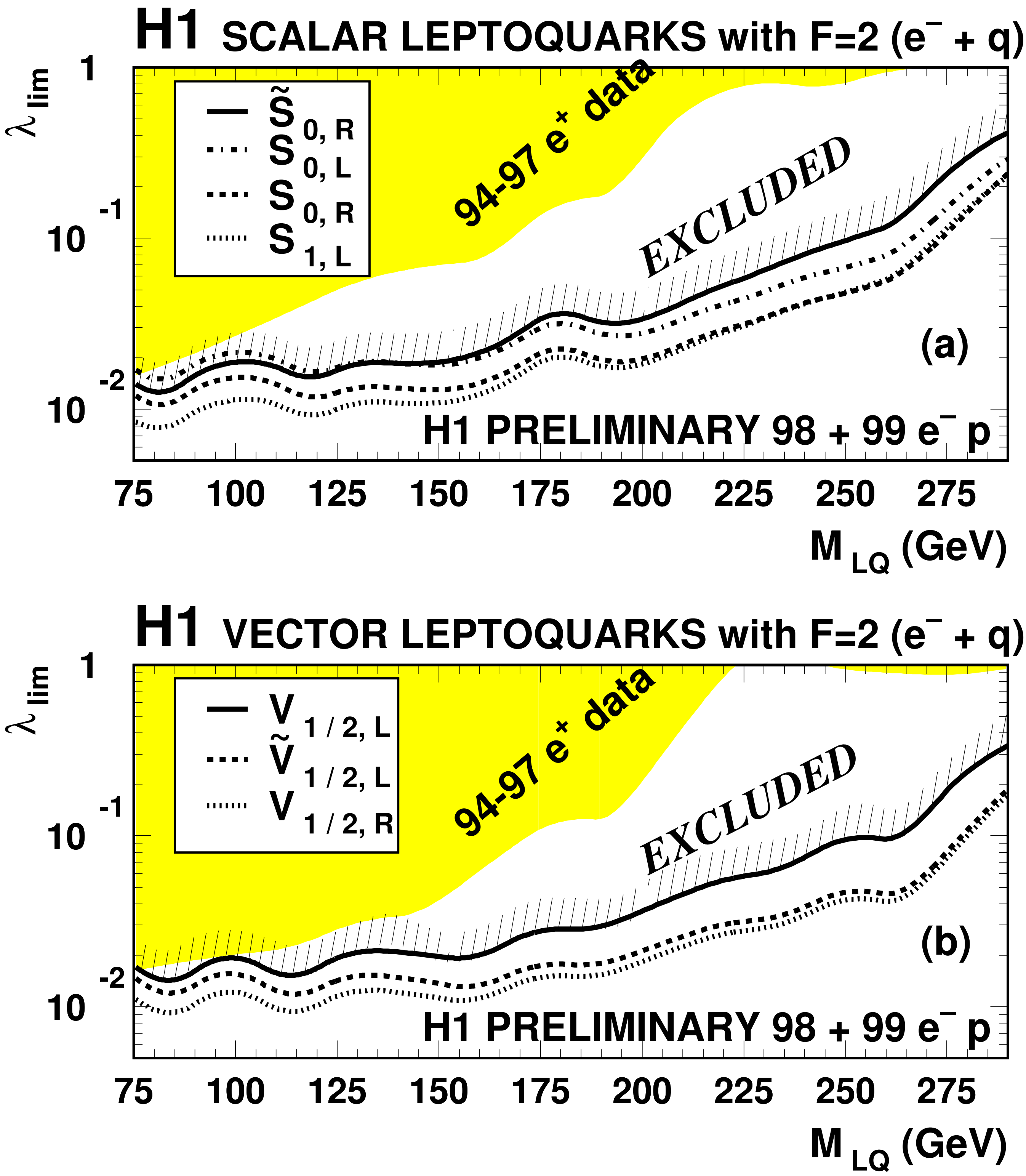


Scalar

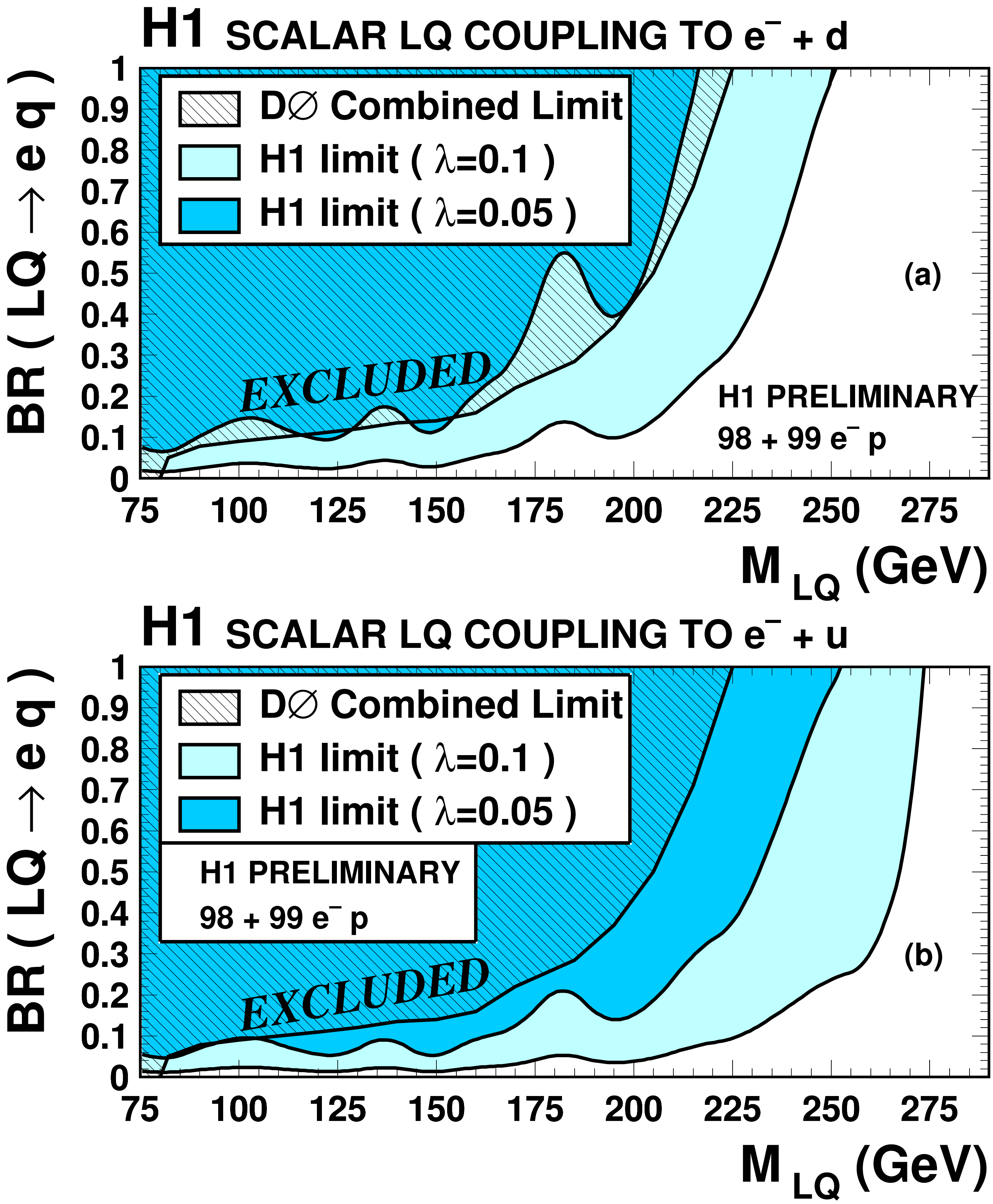


Vector

Limits on $F = 2$ Leptoquarks

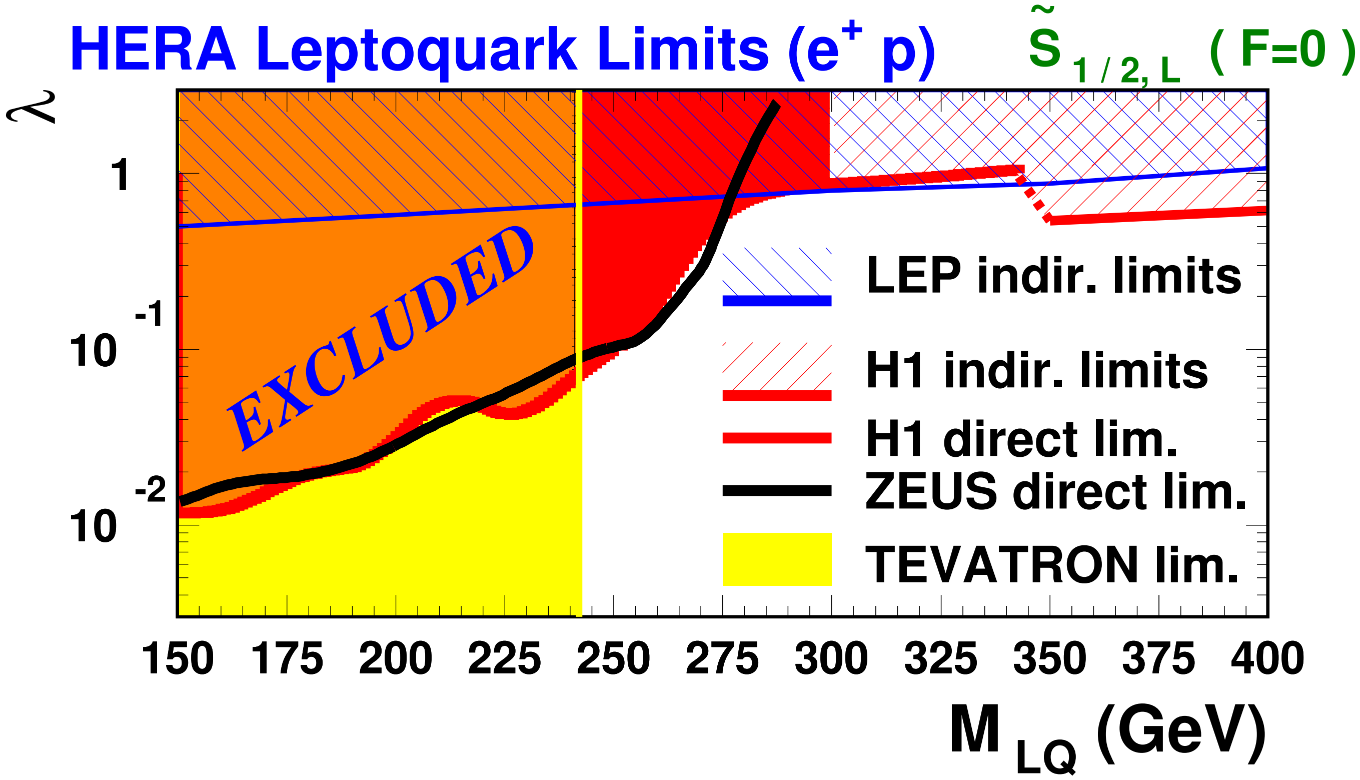


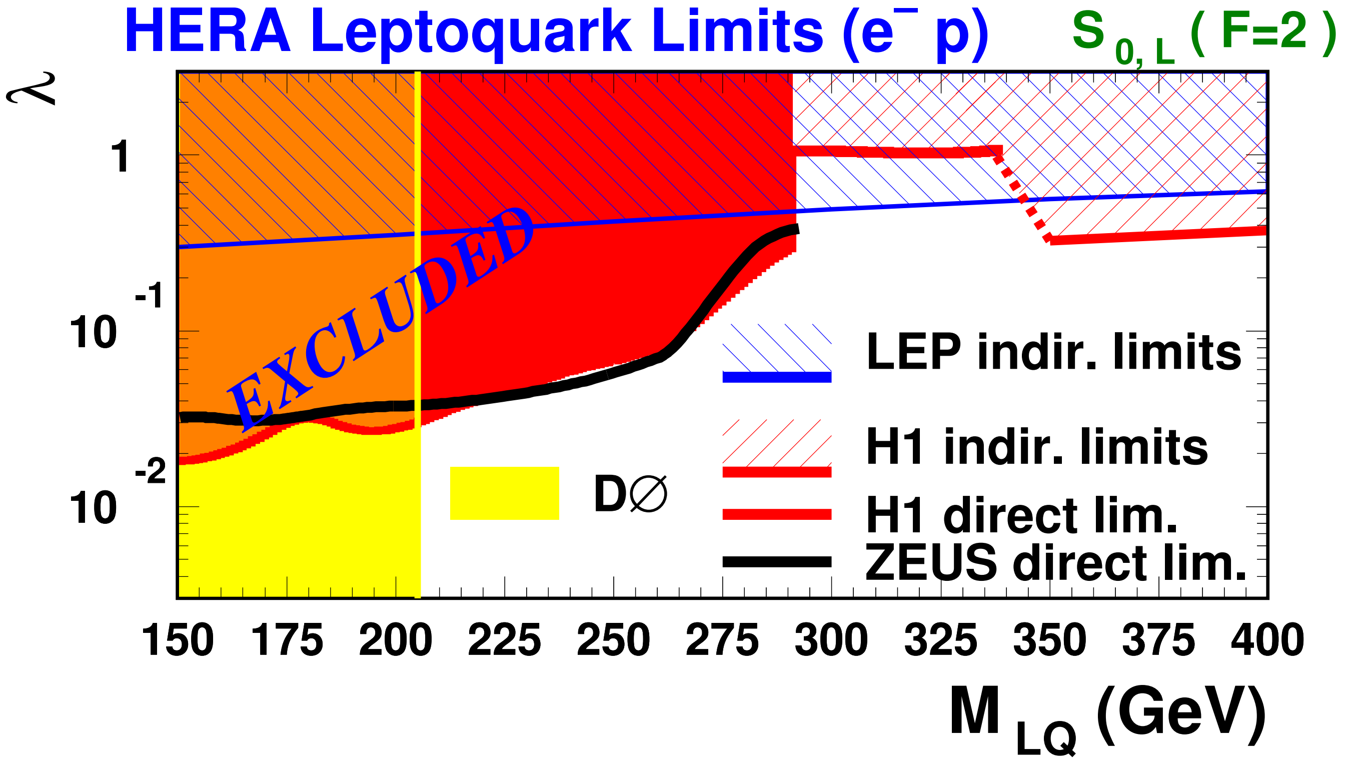
Comparison with TEVATRON



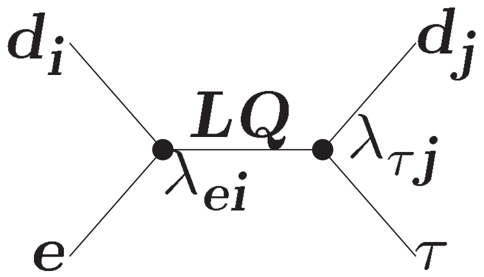
Limits on branching ratio of $LQ \to eq$ for $\lambda = 0.05, 0.1$

Comparison with $p\bar{p}$, e^+e^-





Lepton Flavor Violation



→ Spectacular and clean signature for new physics.
- Use 1994-1997 e^+p data. $\sqrt{s} = 300$ GeV^2.
  $\mathcal{L}_{\rm H1} = 37\,\mathrm{pb}^{-1}$, $\mathcal{L}_{\rm ZEUS} = 48\,\mathrm{pb}^{-1}$.

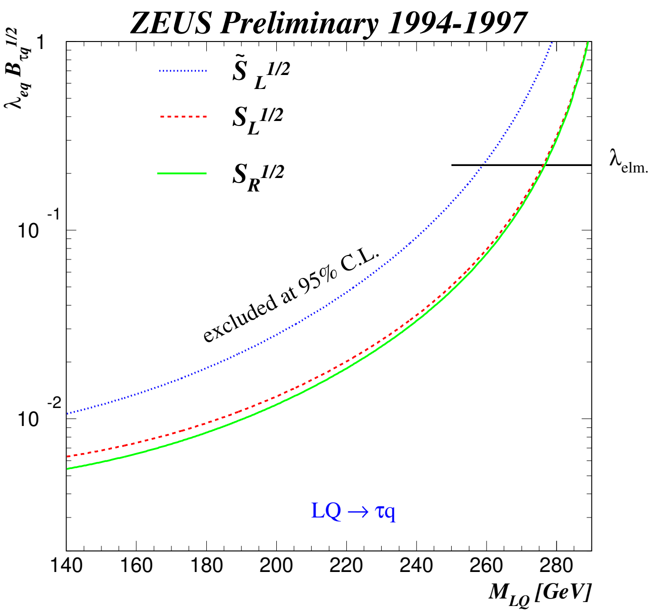
→ Search for μq and τq final states.:
- missing P_t in the calorimeter.
- isolated high P_t lepton, aligned with missing P_t.
- high P_t jet.

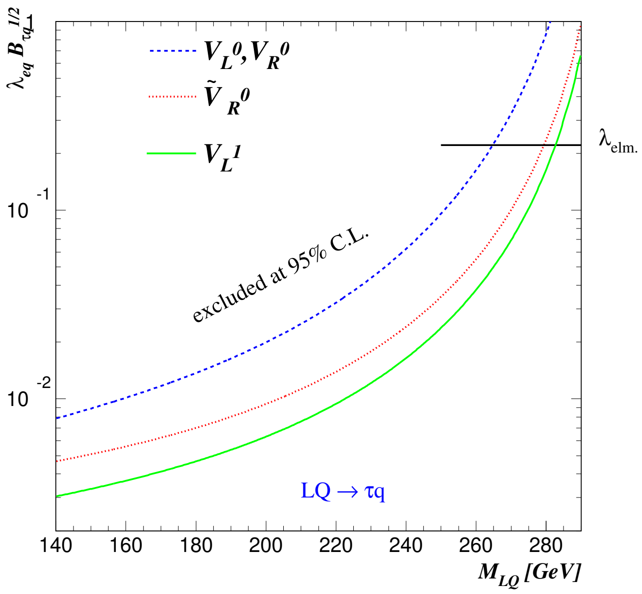
→ τ identification:
- $\tau \to e\nu_e\nu_\tau$ or $\mu\nu_\mu\nu_\tau$: require high P_t e or μ.
- $\tau \to \nu_\tau$+hadrons (ZEUS only):
  Require narrow jet, 1–3 tracks, $M_{jet} < 7$ GeV

→ Neither ZEUS nor H1 found any candidates.
- Set limits on $\lambda_{eq}\sqrt{B_{\ell q}}$ vs. LQ mass.
- For $M_{lq} > \sqrt{s}$, treat as a contact interaction with

$$\sigma \sim \left[\frac{\lambda_{ei}\lambda_{\ell j}}{M_{lq}^2}\right]^2$$

ZEUS Limits on $e^+q \to LQ \to \tau q$





$\lambda_{eq}\sqrt{B_{\tau q}}$ for scalar LQ $\qquad$ $\lambda_{eq}\sqrt{B_{\tau q}}$ for vector LQs.

ZEUS limits for $e^+q \to \mu q$ have also been shown.
H1 has published similar limits for both $e^+q \to \mu q$ and $e^+q \to \tau q$.

Limits on $e \to \tau$ Lepton Flavor Violation $(F = 0)$

Limits on $\lambda_{ei}\lambda_{\tau j}/M^2_{lq}$ in units of 10^{-4} GeV^2

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 $\boxed{0.14}$

Blue=best indirect limit, Red=ZEUS Preliminary, Green=H1.

Limits on $e \to \tau$ Lepton Flavor Violation $(F = 2)$

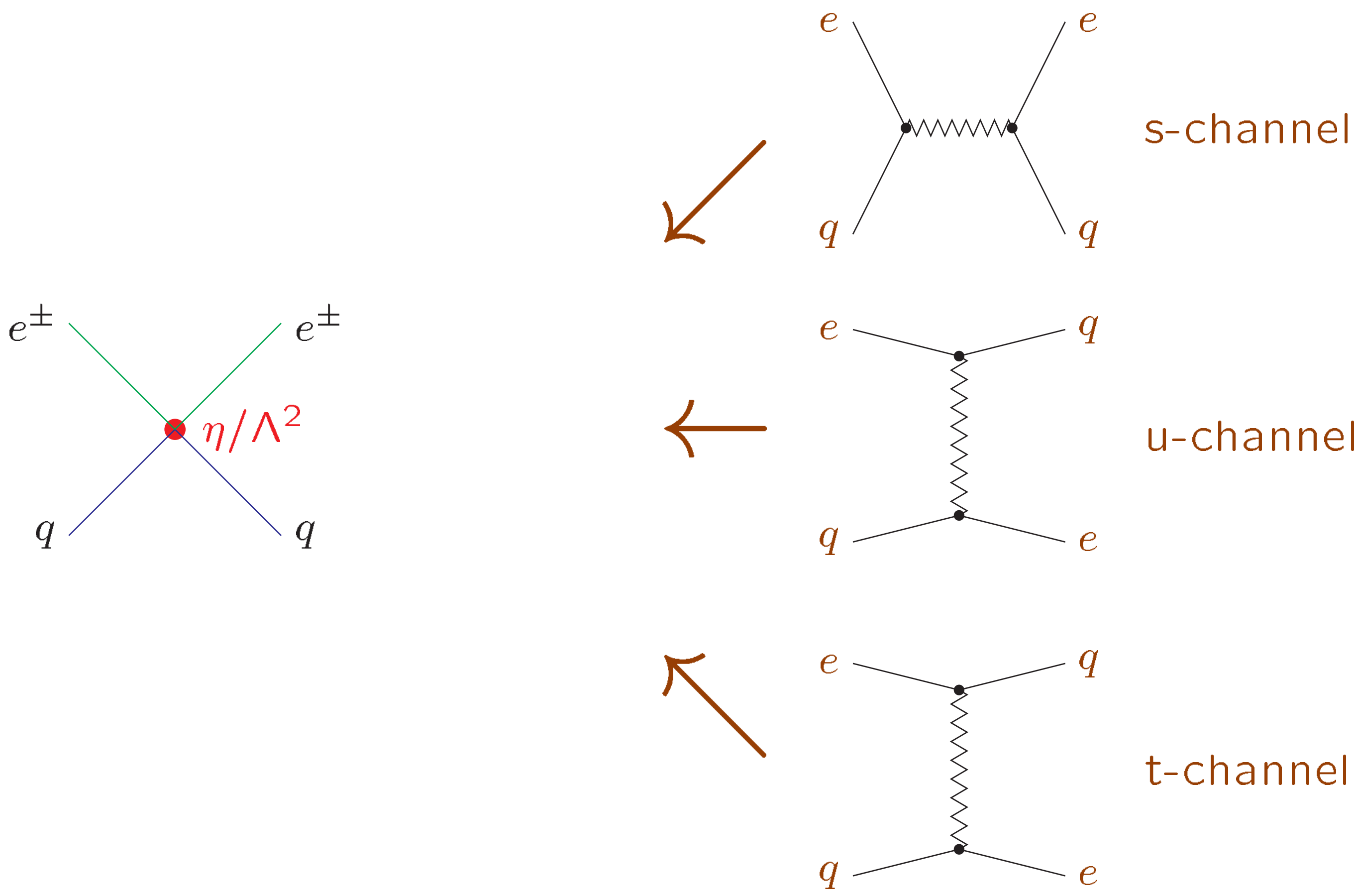
Limits on $\lambda_{ei}\lambda_{\tau j}/M_{lq}^2$ in units of 10^{-4} GeV^2

$q_i q_j$	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	$\boxed{\mathbf{0.128}}$ 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 $\boxed{\mathbf{0.078}}$
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	$\boxed{\mathbf{0.058}}$ 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 $\boxed{\mathbf{0.013}}$ 0.018	$\boxed{\mathbf{0.016}}$ 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	$\boxed{\mathbf{0.063}}$ 0.064	$\boxed{\mathbf{0.050}}$ 0.053	0.096 $\boxed{\mathbf{0.091}}$
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 $\boxed{\mathbf{0.026}}$ 0.031	B$\to \tau e$ X 0.04 $\boxed{\mathbf{0.026}}$ 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 $\boxed{\mathbf{0.12}}$	0.139 $\boxed{\mathbf{0.12}}$	——

Blue=best indirect limit, Red=ZEUS Preliminary, Green=H1.

Contact Interactions

e.g. Leptoquarks, Z', W', GUTs, technicolor, compositeness, etc.



$$\mathcal{L}_{eff} = \frac{g^2}{\Lambda^2} \cdot \sum_{\substack{a,b=L,R \\ q=u,d}} \eta^q_{ab} (\bar{e}_a \gamma^\mu e_a)(\bar{q}_b \gamma_\mu q_b)$$

$\rightarrow$ Pion decay $\Rightarrow$ limits on scalar/tensor couplings
$\rightarrow$ Consider only combinations of chiral vector terms
$\rightarrow$ Effective Graviton exchange considered separately

Contact Interaction Scenarios

CI scenarios = linear combinations of η_{ab}^{q}

CI	η^u_{LL}	η^u_{LR}	η^u_{RL}	η^u_{RR}	η^d_{LL}	η^d_{LR}	η^d_{RL}	η^d_{RR}	studied by
VV	+	+	+	+	+	+	+	+	ZEUS,H1
AA	+	−	−	+	+	−	−	+	
VA	+	−	+	−	+	−	+	−	
X1	+	−	0	0	+	−	0	0	ZEUS
X2	+	0	+	0	+	0	+	0	
X3	+	0	0	+	+	0	0	+	
X4	0	+	+	0	0	+	+	0	
X5	0	+	0	+	0	+	0	+	
X6	0	0	+	−	0	0	+	−	
U5	0	+	0	+	0	0	0	0	ZEUS
U1	+	−	0	0	0	0	0	0	
U4	0	+	+	0	0	0	0	0	
LL	+	0	0	0	+	0	0	0	H1
LR	0	+	0	0	0	+	0	0	
RL	0	0	+	0	0	0	+	0	
RR	0	0	0	+	0	0	0	+	

→ H1 also considers all 14 LQ-scenario's

→ Marginal effect if including s, c, b, t

Restrictions:

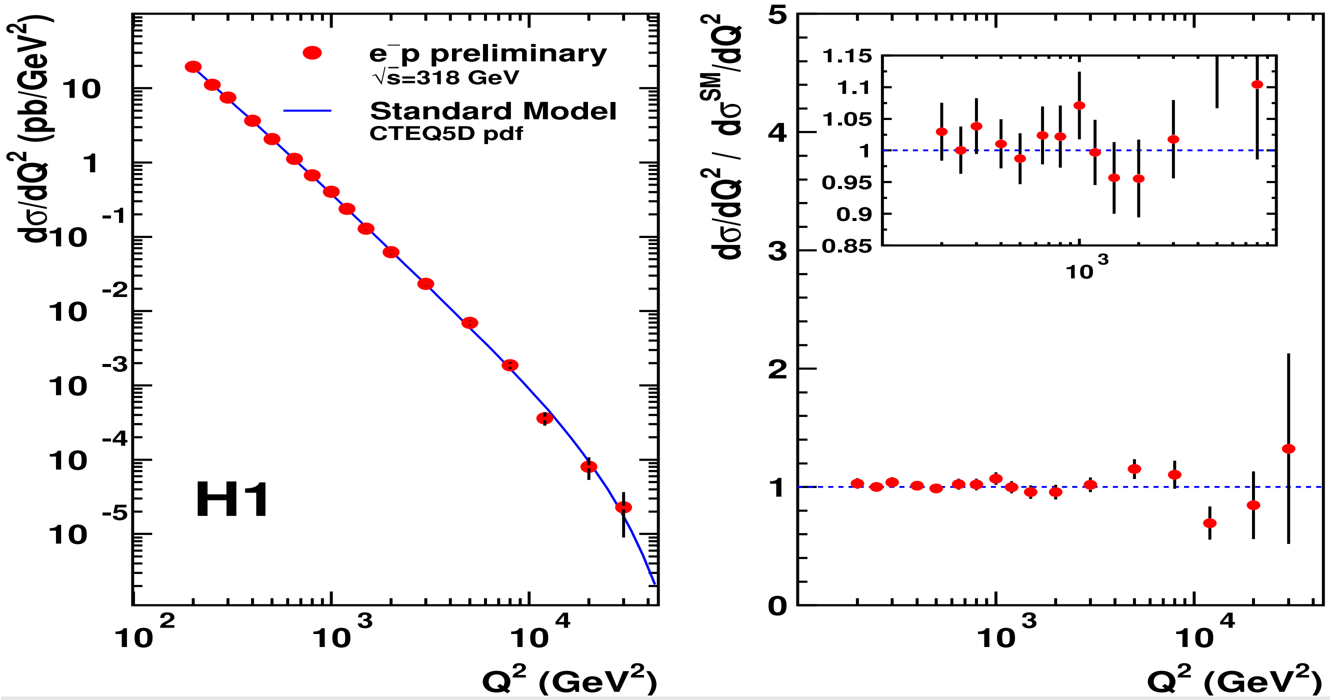
- Severe limits from Atomic Parity Violation for all scenarios having

$$\eta_{LL} + \eta_{LR} - \eta_{RL} - \eta_{RR} \neq 0$$

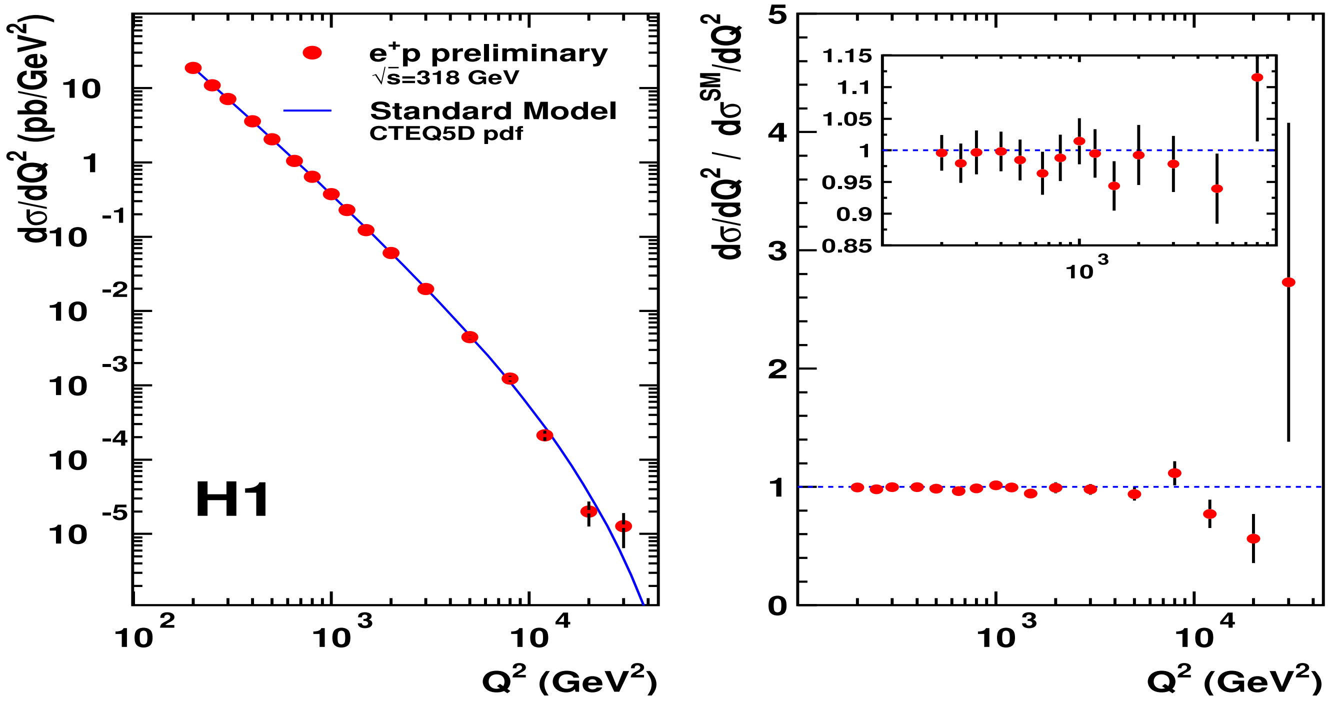
→ ... but recently: $\Delta Q_W^{Cs} \equiv Q_W^{meas} - Q_W^{SM} = 1.13 \pm 0.46$

- $SU(2)_L \times U(1)_R \Rightarrow \eta^u_{ab} = \eta^d_{ab}$ (not U1–U5)

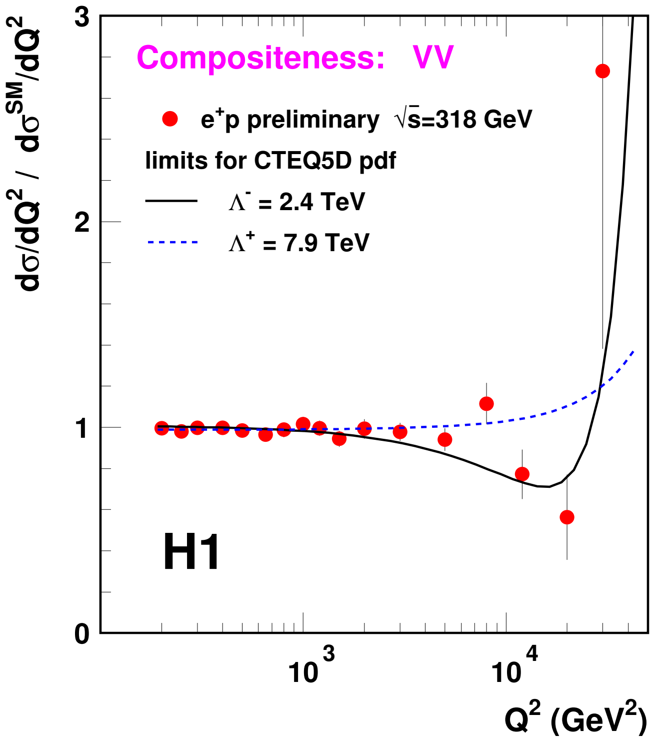
H1 98-99 15.2 pb^{-1} e^-p data

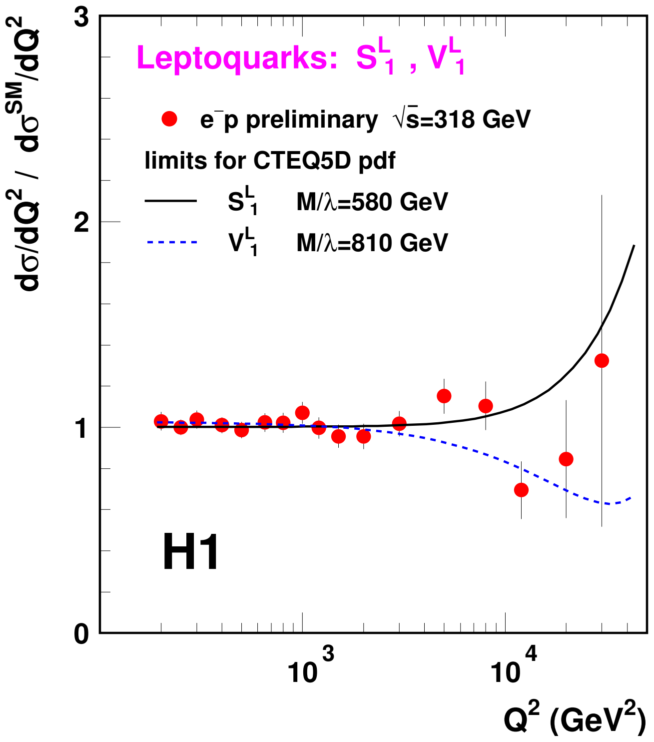


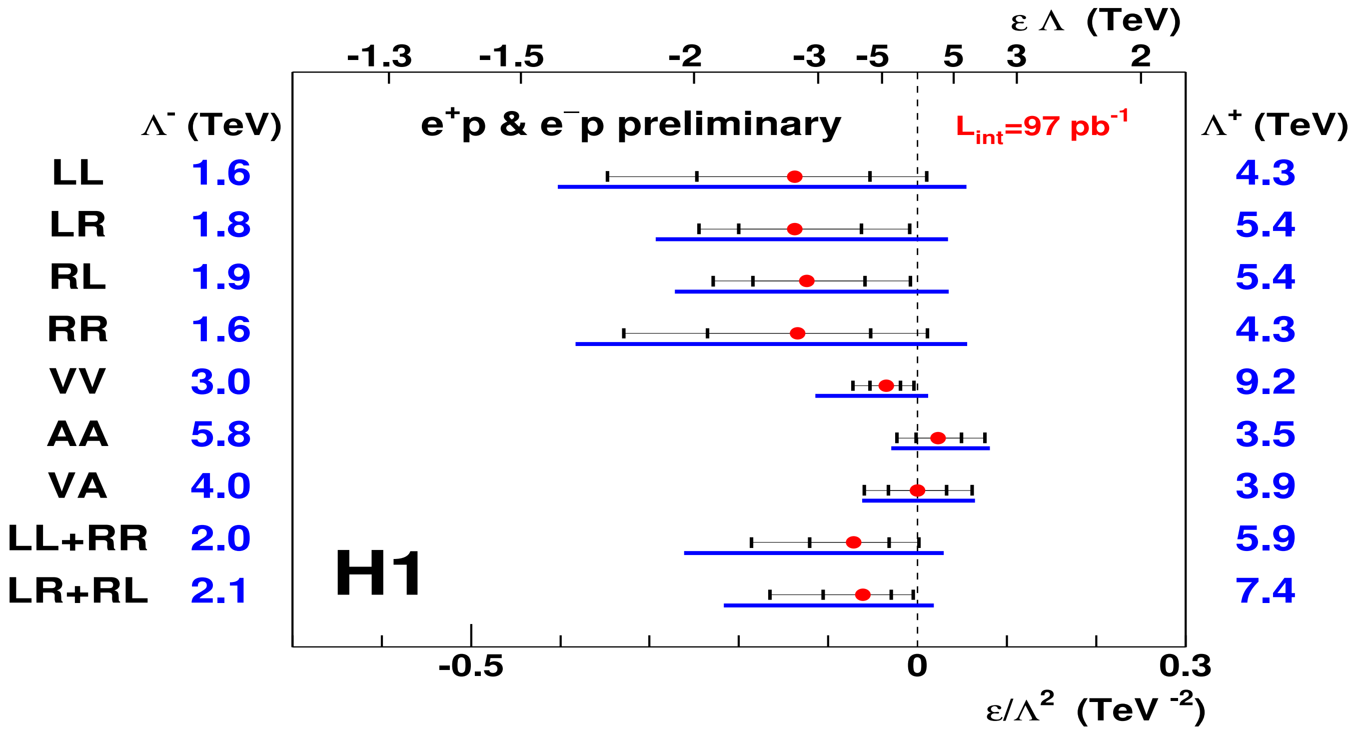
H1 99-00 45.9 pb^{-1} e^+p data



New H1 Contact Term analysis

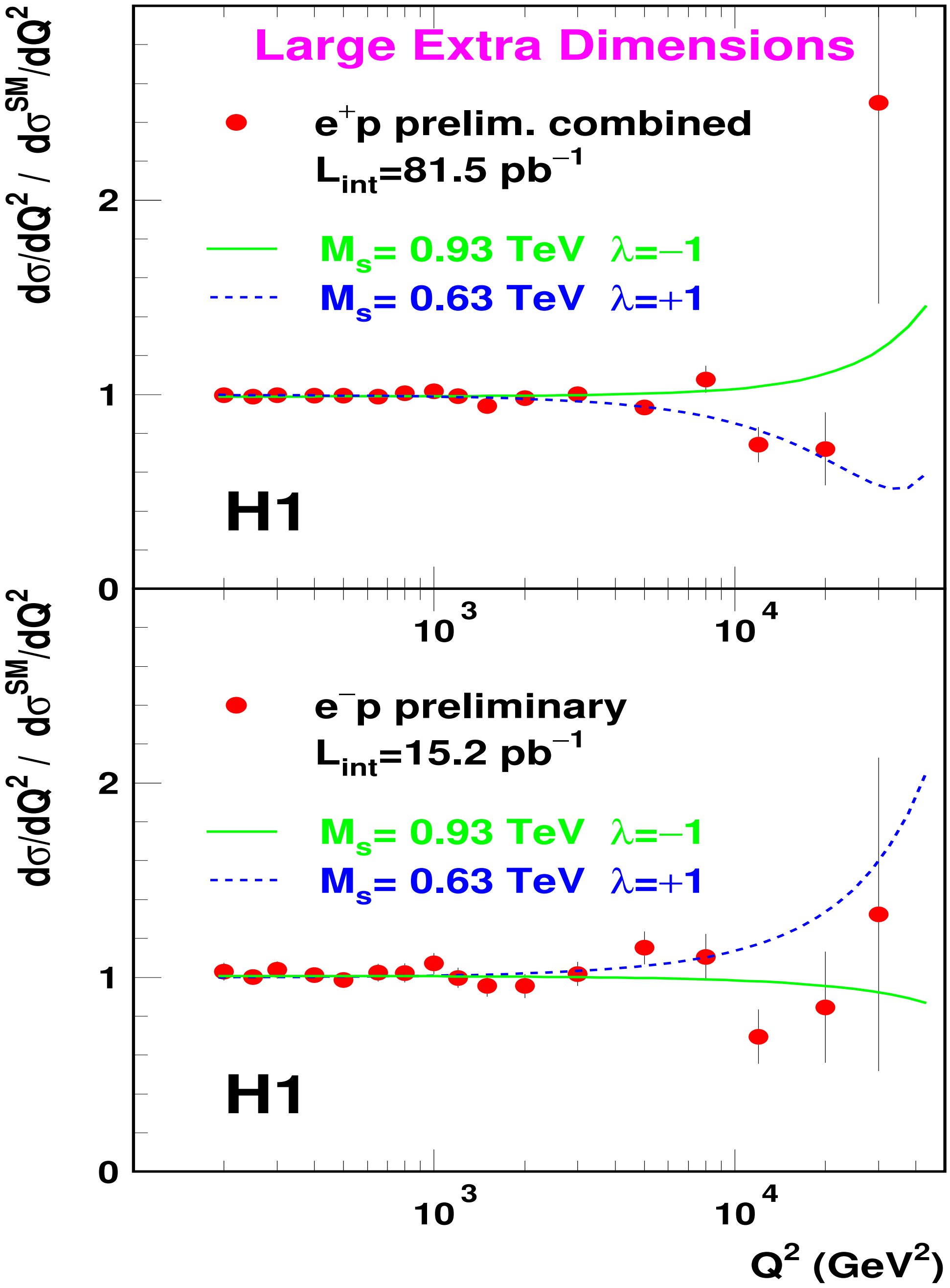




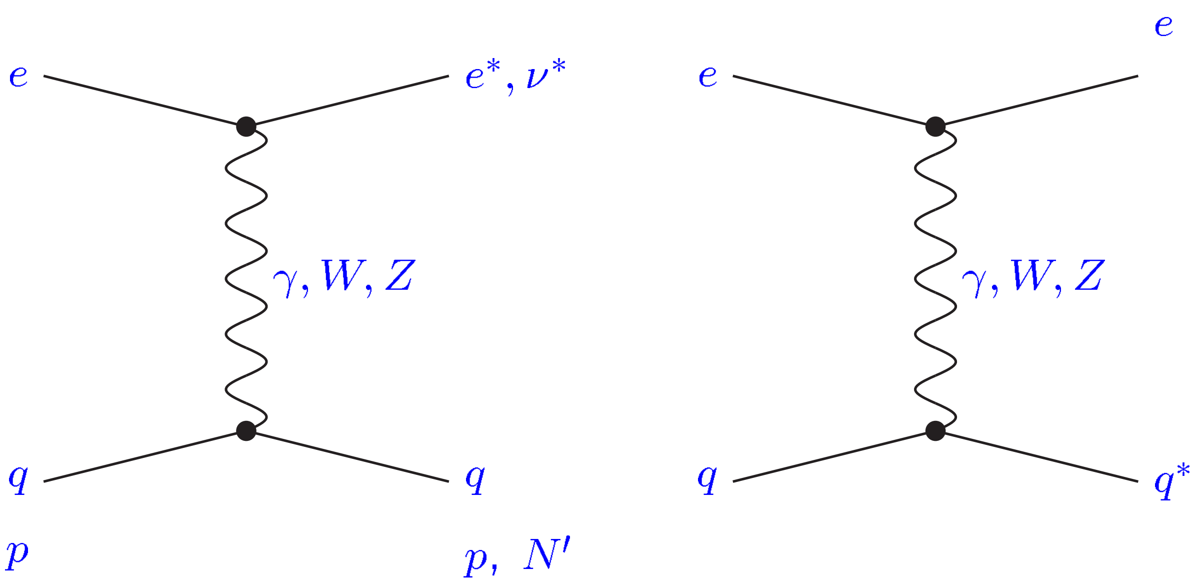


Large Extra Dimensions

- String theory can have large ($\lesssim$1mm) extra dimensions
- SM particles are confined to usual 4 dimensions
- Graviton propagates in extra dimensions $\Rightarrow$
  Kaluza-Klein tower of massive particles
- At HERA: $\sim eeqq$, $eegg$ contact interactions
- Coupling strength $\pm\Lambda^{-4}$



Compositeness: Excited Fermions



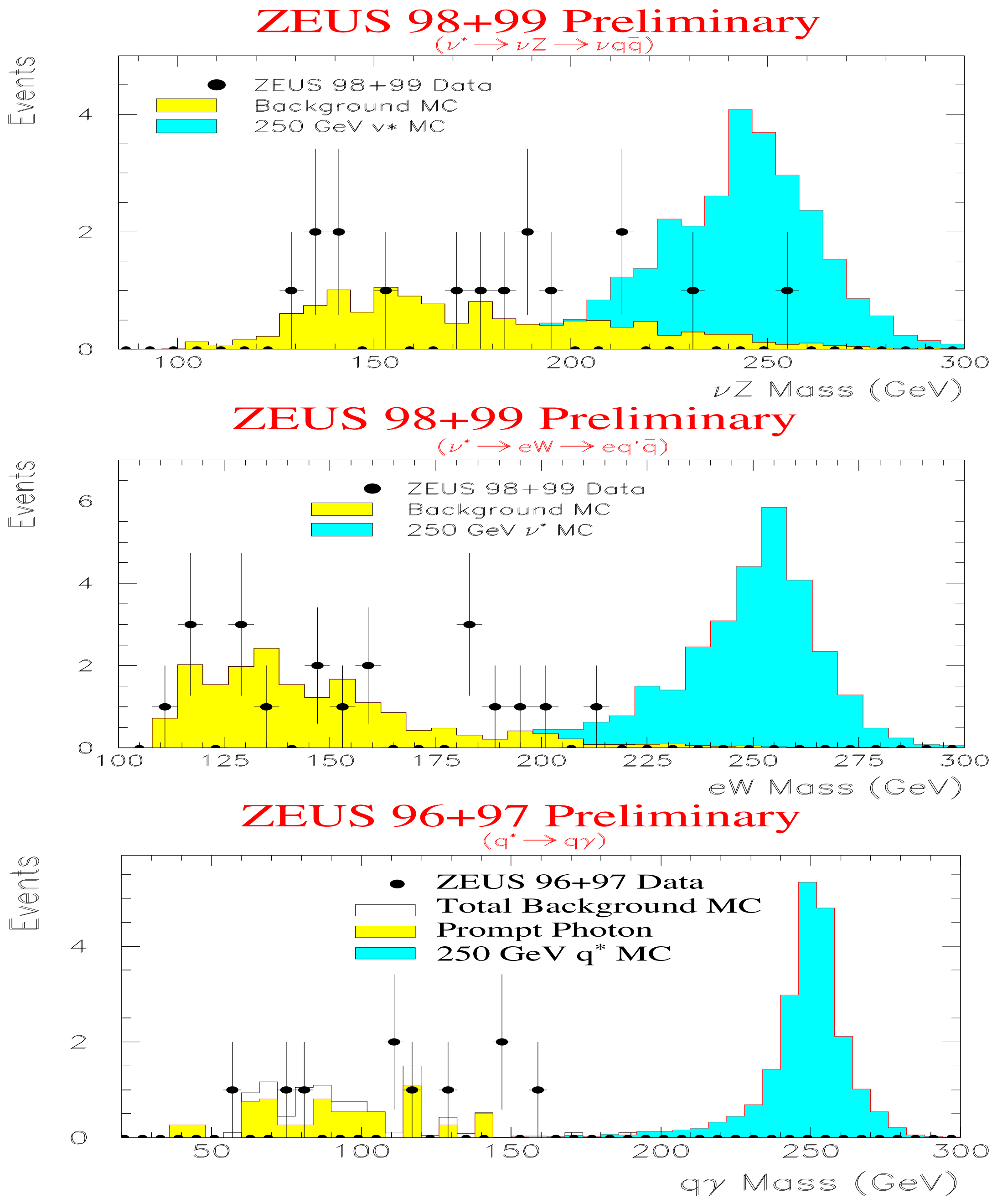
Phenomenological model:

$$\mathcal{L}_{\text{int}} = \frac{1}{2\Lambda} \bar{F}^*_R \sigma^{\mu\nu} \left[g f \frac{\tau^a}{2} W^a_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G^a_{\mu\nu} \right] F_L + \text{h.c.}$$

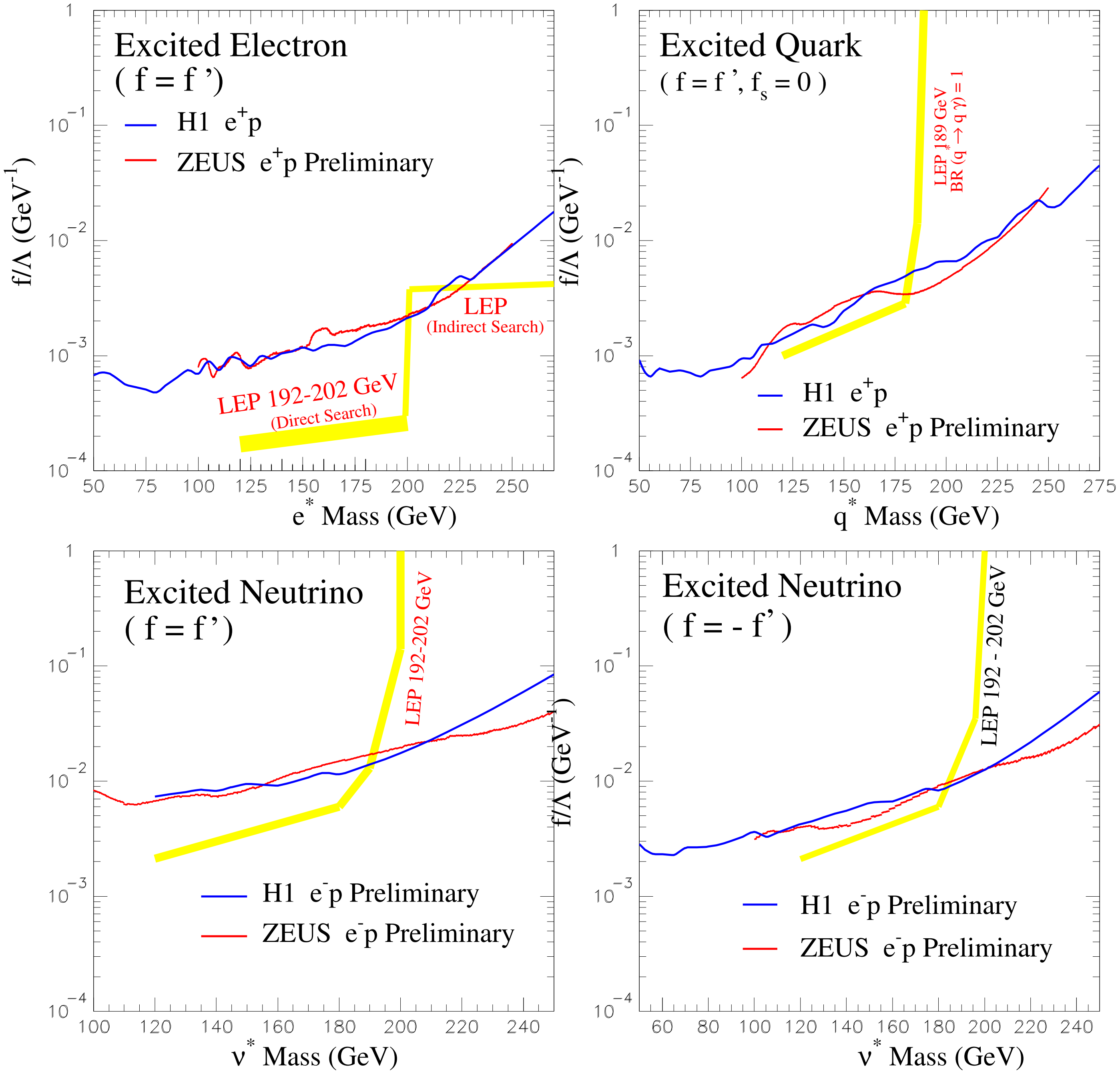
(Hagiwara, Komamiya, Zeppenfeld)

- clean signals, good acceptance, low backgrounds
- e^* production $\sim$ half elastic: $e + p \to e^* + p$
- QED Compton: irreduceable background for $e^* \to e\gamma$
- no significant excess found
  $\Rightarrow$ cross section limits
  $\Rightarrow$ limits on coupling $\times$ Branching Ratio

Mass distribution of candidates



Limits on Excited Fermion couplings



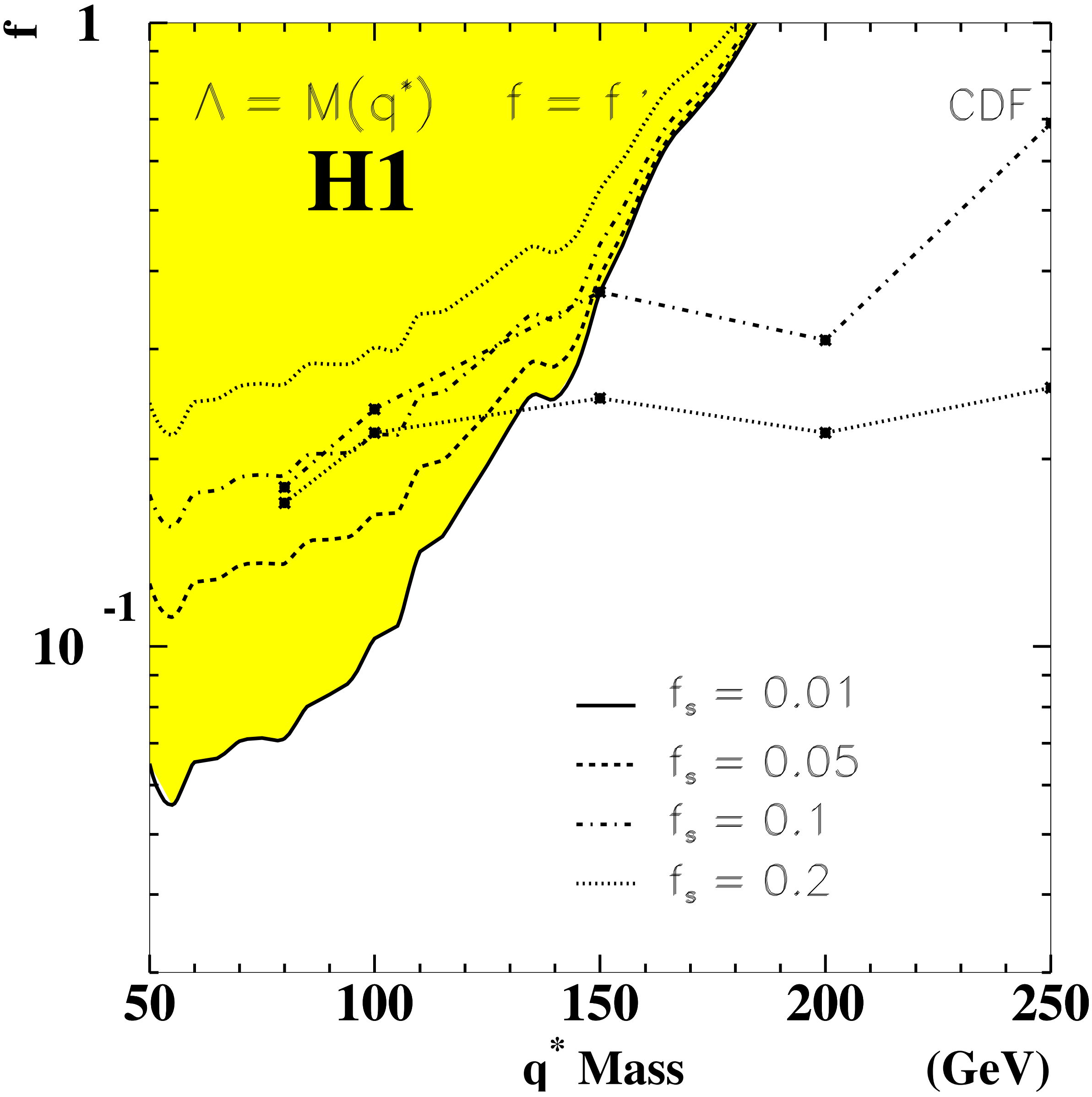
→ $F/\Lambda = 1/M^* \Rightarrow$

- $M_{e^*} > 229$ GeV
- $M_{q^*} > 203$ GeV if $f_s = 0$
- $M_{\nu^*} > 134$ (163) GeV if $f = f'$ ($f = -f'$).

Comparison with Tevatron for q^*

95% C.L Limits on f

Assuming $f = f'$ and $\Lambda = M_{q^*}$



For $f_s < 0.1$, HERA limits on q^* are complementary to Tevatron

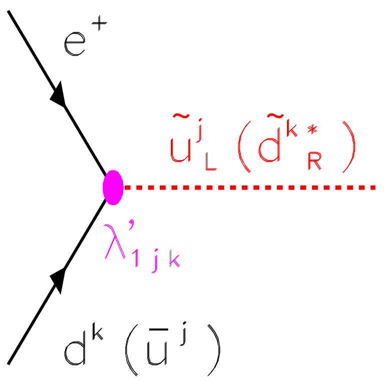
R_P violating MSSM at HERA

- $R_P = (-1)^{3B+L+2S}$ particles $\leftrightarrow$ sparticles
- $\not{R}_P \rightarrow$ single sparticle production
  decay of LSP
- General MSSM with R_P violation:

$$W_{SUSY} = W_{MSSM} + W_{\not{R}_P}$$
$$W_{\not{R}_P} = \tfrac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \tfrac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- The term with λ'_{ijk} is relevant for ep:

$$W_{LQD} = \lambda'_{ijk} \Big[-\tilde{e}^i_L u^j_L \bar{d}^k_R - e^i_L \tilde{u}^j_L \bar{d}^k_R - (\bar{e}^i_L)^c u^j_L (\tilde{d}^k_R)^* + \tilde{\nu}^i_L d^j_L \bar{d}^k_R + \nu^i_L \tilde{d}^j_L \bar{d}^k_R + (\bar{\nu}^i_L)^c d^j_L (\tilde{d}^k_R)^* \Big]$$



production $\not{R}_P$:

e^+p mainly λ'_{1j1}: $e^+ d^k \rightarrow \tilde{u}^j_L$

e^-p mainly λ'_{11k}: $e^- u^j \rightarrow (\overline{\tilde{d}^{k*}_R})$

decays both $\not{R}_P$ and Gauge:

$\tilde{u}^j_L \rightarrow e^+ d^k_L,\ u^j_L \tilde{\chi}^0_i,\ d^j_L \tilde{\chi}^+, \ldots$

$\overline{\tilde{d}^{j*}_R} \rightarrow e^- u^k_L,\ \bar{\nu} d^k_R,\ d^j_R \tilde{\chi}^0_i, \ldots$

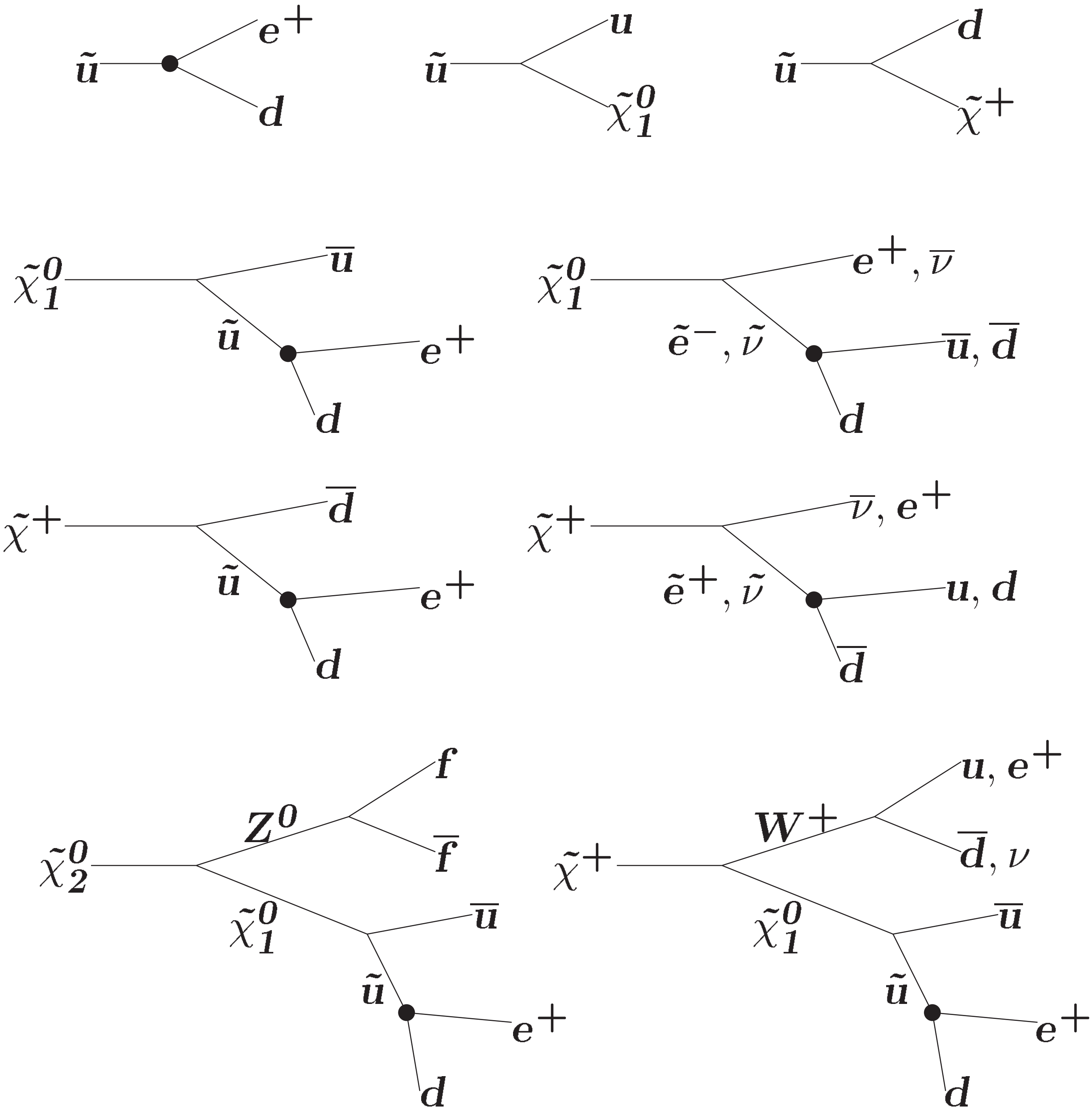
MSSM parameters: μ, $\tan\beta$, M_1, M_2, M_3 ...

Narrow Width Approximation:

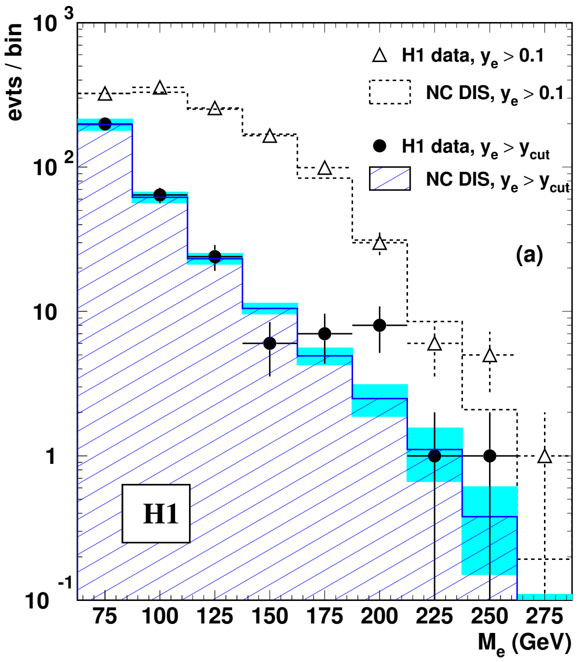
$$\sigma(e^+p \rightarrow \tilde{u}^j) = \pi/(4s)(\lambda'_{1jk})^2\, d^k \Big|_{x=M^2/s}$$

Examples of $\tilde{u}$ decays

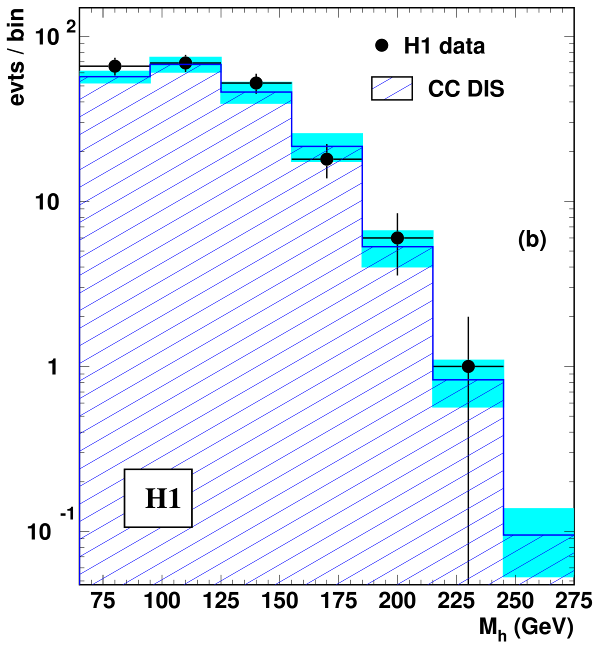
$\bullet = \lambda'_{111}$ $\not{R}_P$-coupling



H1 leptoquark-like: e^+q, νq



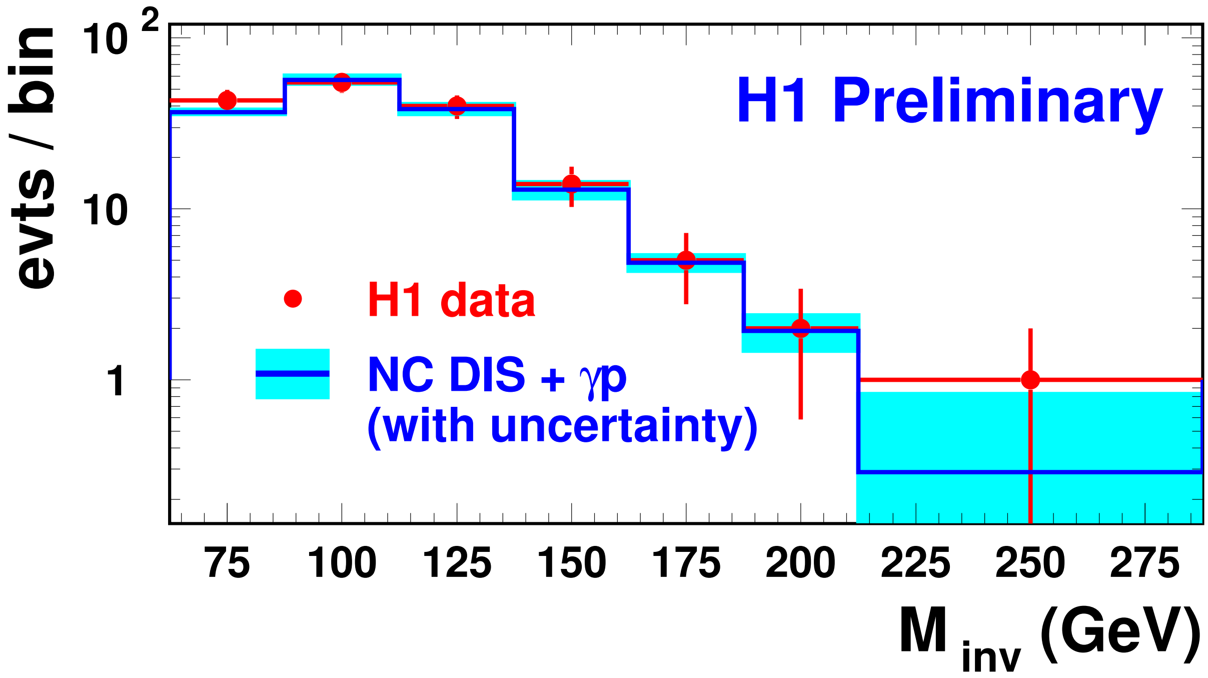
e^+q topology



νq topology

- → Reduce NC-DIS with cut $y_e > y_{cut}(M)$
- → Known 'HERA-Leptoquark-excess' still visible, but less significant
- → Massive νq final state well described by CC-DIS
- → νq final state not considered in limits on $\tilde{u}$, $\tilde{c}$

H1: $e^+ q\bar{q}$, $e^+ q\bar{q}q\bar{q}$



→ 160 events observed

→ 152.6 ± 13.4 events expected from SM.

→ Mass distributions of DATA and SM agree.

H1,ZEUS: $e^- q\bar{q}$, $e^- q\bar{q}q\bar{q}$

→ Wrong charge electron: no SM background.

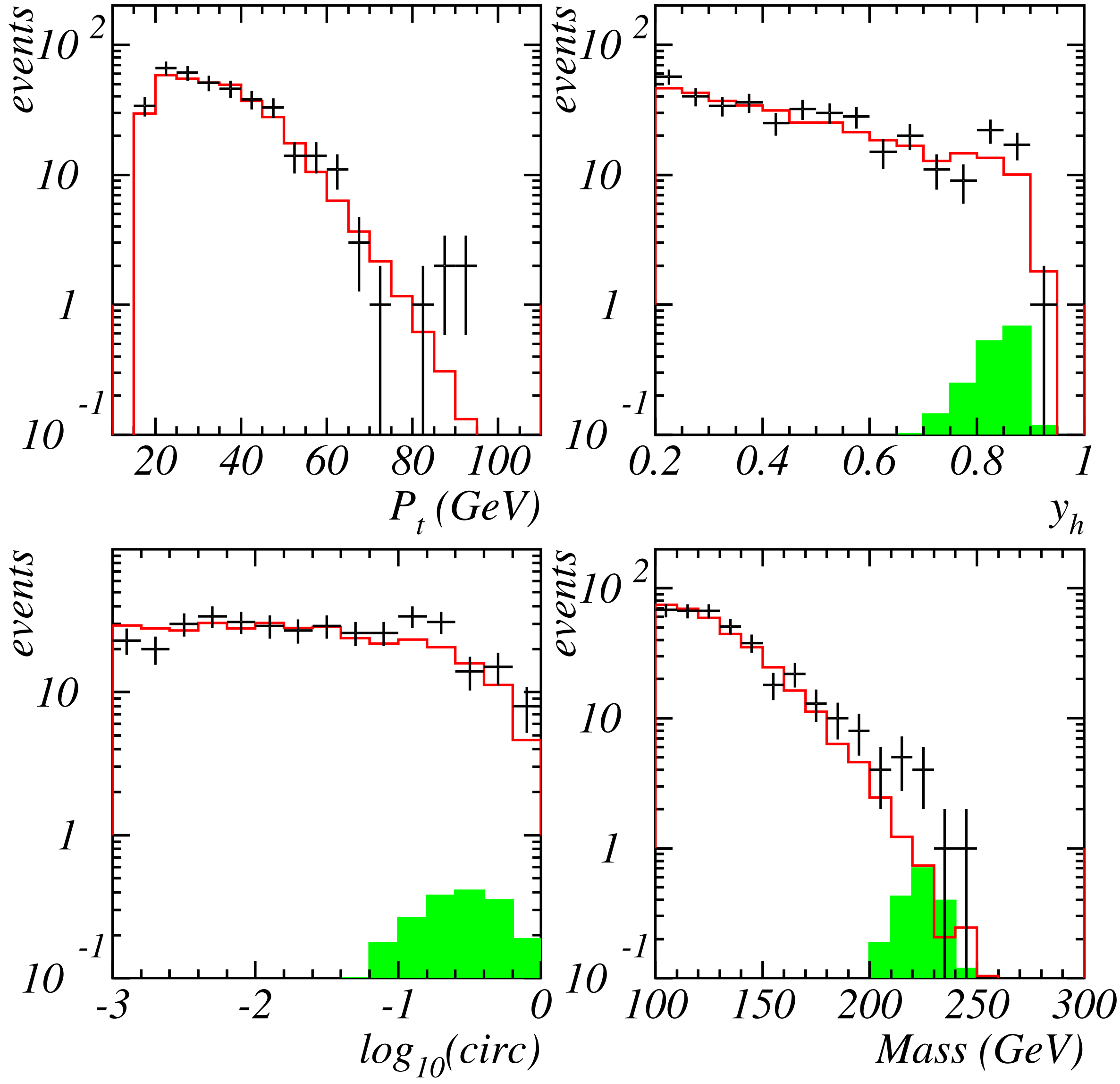
→ No event found in ZEUS or H1 data.

→ SM expectation is 1.3±0.3 (H1) and 0.26 (ZEUS).

ZEUS: $\nu q\bar{q}$, $\nu q\bar{q}q\bar{q}$

Reconstructed Mass > 100 GeV

- Shaded green: signal for a 220 GeV squark
- circularity: 2 dim version of sphericity

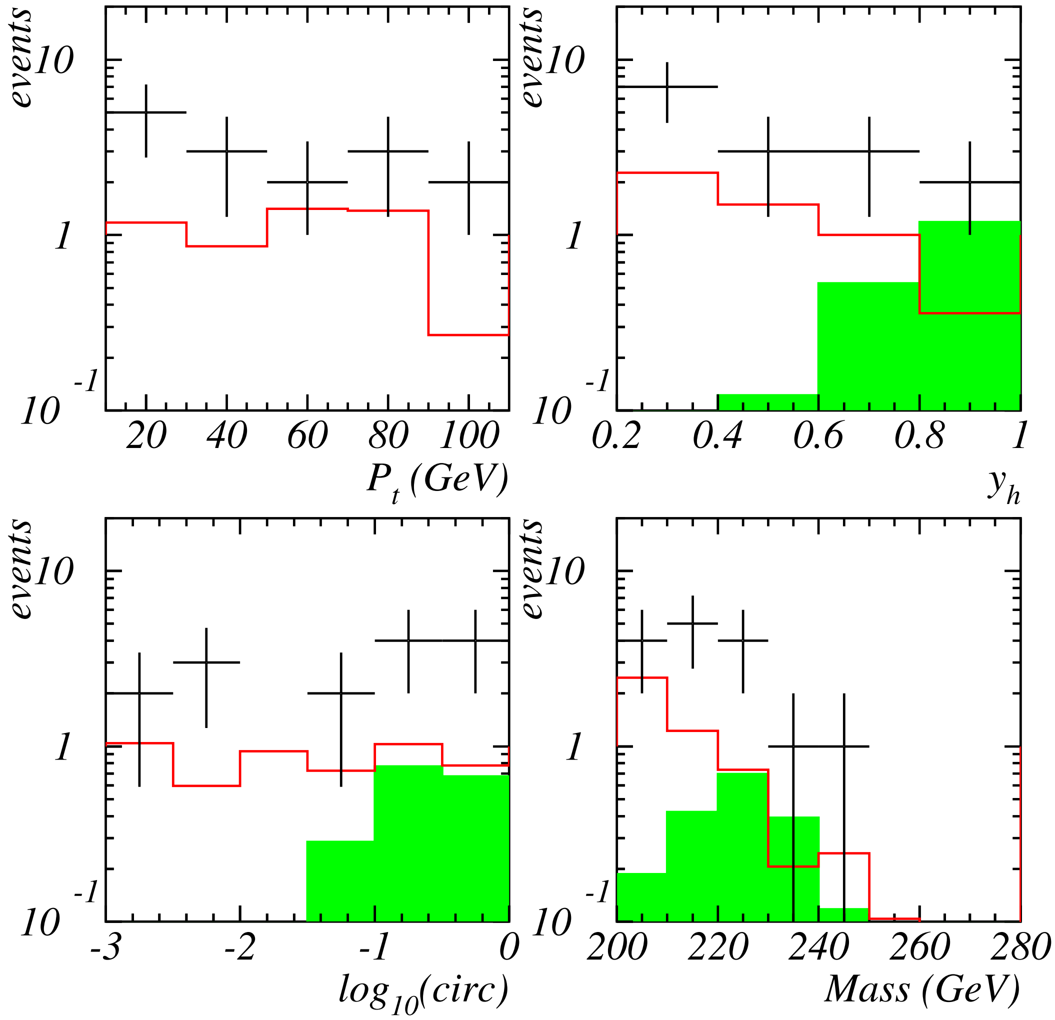


$\rightarrow$ Some excess of data over CC DIS at high mass

ZEUS: $\nu q q \bar{q}$, $\nu q q \bar{q} q \bar{q}$

Reconstructed Mass > 200 GeV

- Shaded green: signal for a 220 GeV squark



→ Excess not like that of a SUSY signal

→ Uncertainties on proton density at high x: valence d, sea quarks, gluons (CTEQ4)

→ H1: data agrees with Standard Model

No SUSY signal observed $\Rightarrow$
95% C.L. Upper Limits on λ'_{1j1}

$\rightarrow$ Intricate book-keeping:

- Many channels per final state topology
- Branching ratios $\leftarrow$ SUSY parameters
- Monte Carlo samples $\rightarrow$ efficiency estimates

Need combination of all important channels:

$\rightarrow$ High efficiency for all μ, M_2, $\tan\beta$ considered

$\rightarrow$ Scan over SUSY-parameters μ, M_2, $\tan\beta$

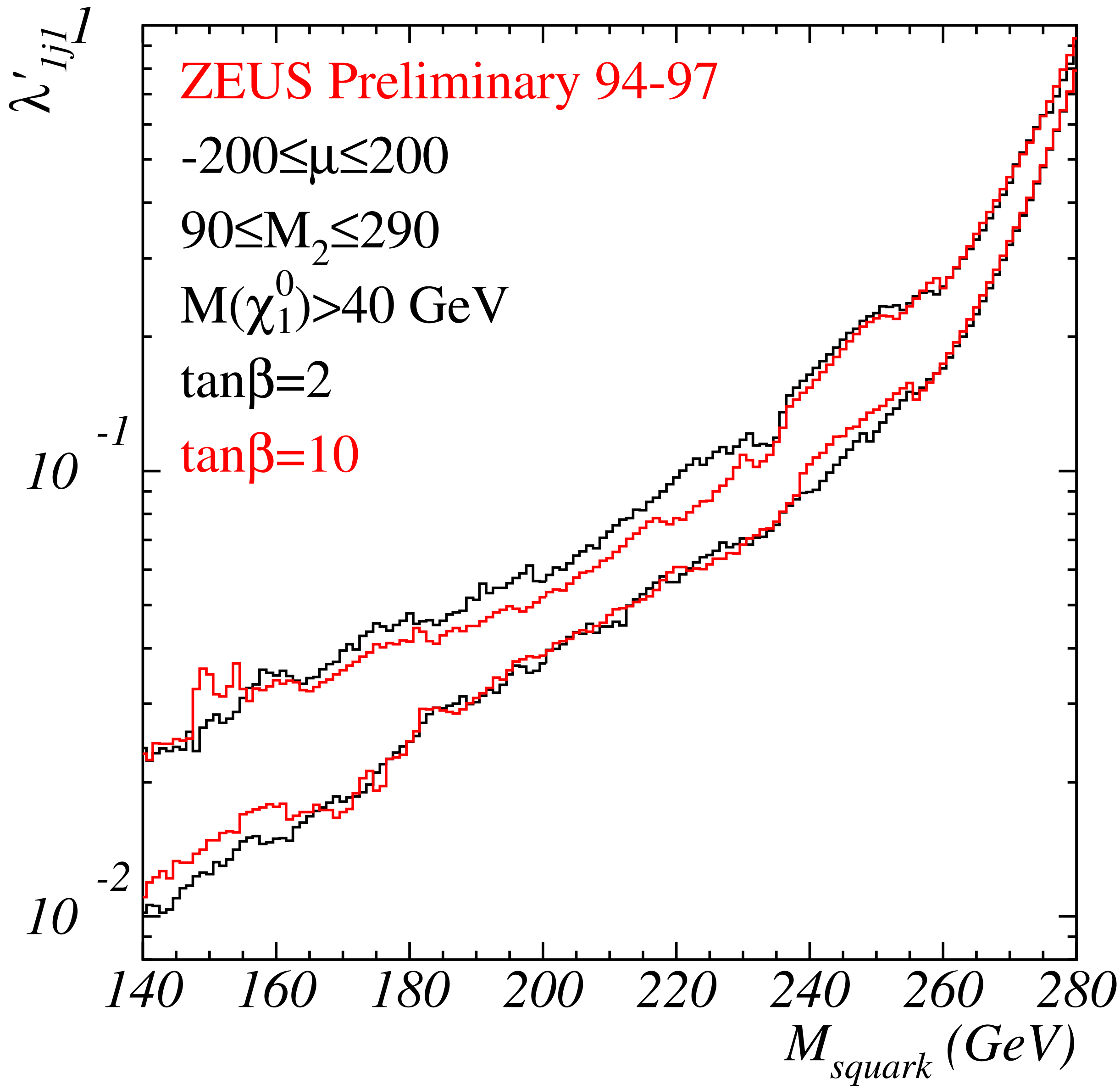
$\rightarrow$ Limits for large range of SUSY-models

ZEUS limits on λ'_{1j1} vs $M_{\tilde{q}}$ for large SUSY parameter range

→ M(sleptons) = M(squarks) = $M_{\tilde{q}}$

→ Vary μ, M_2 over large range for $\tan\beta = 2,\ 10$

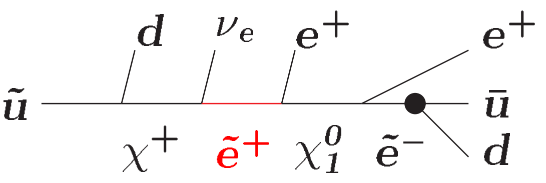
→ lowest, highest 95% CL Limits on λ_{ijk} vs $M_{\tilde{u}^j}$



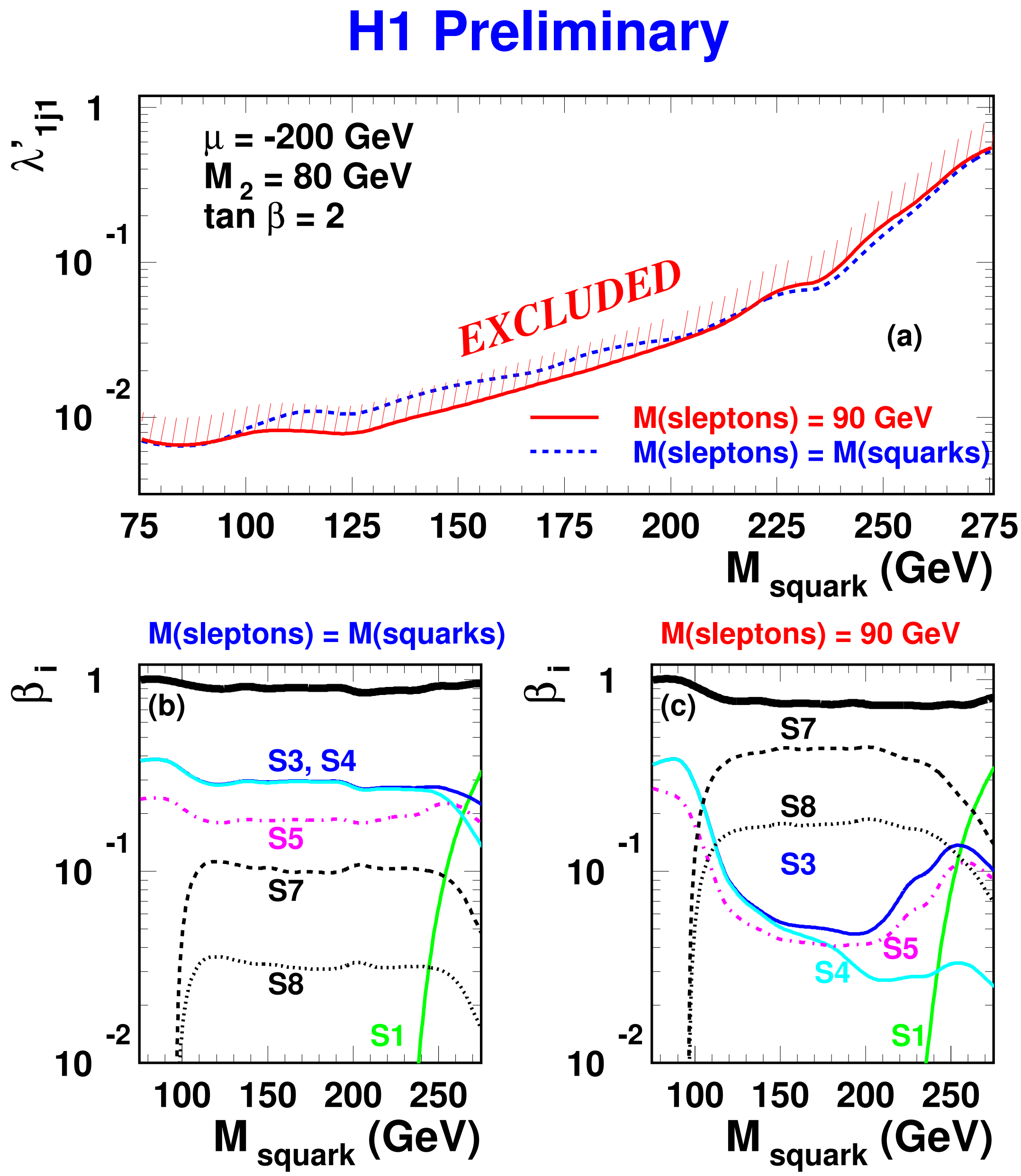
→ No strong variation of limits with μ, M_2, $\tan\beta$

H1 limits for M(sleptons) = 90 GeV

$\rightarrow$ enhanced topology: e, e or μ, $\not{P}_T$, jets



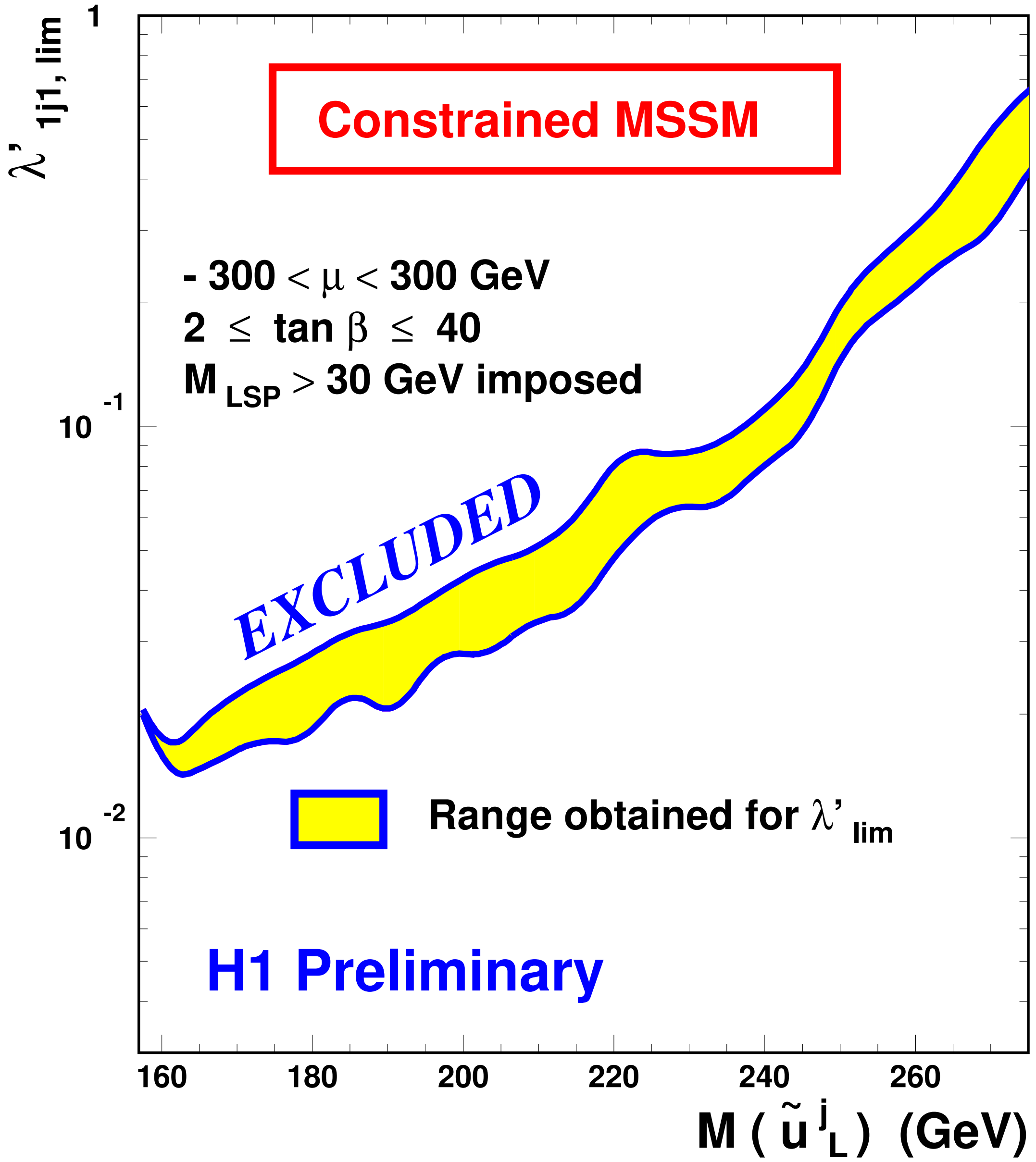
important when
low M(slepton)=90 GeV
and photino-like χ_1^0



Sfermion masses $= m_0$ at GUT scale

→ Evolve masses down to electroweak scale

→ Reduced M_2 range depends on M(squark), $\tan\beta$



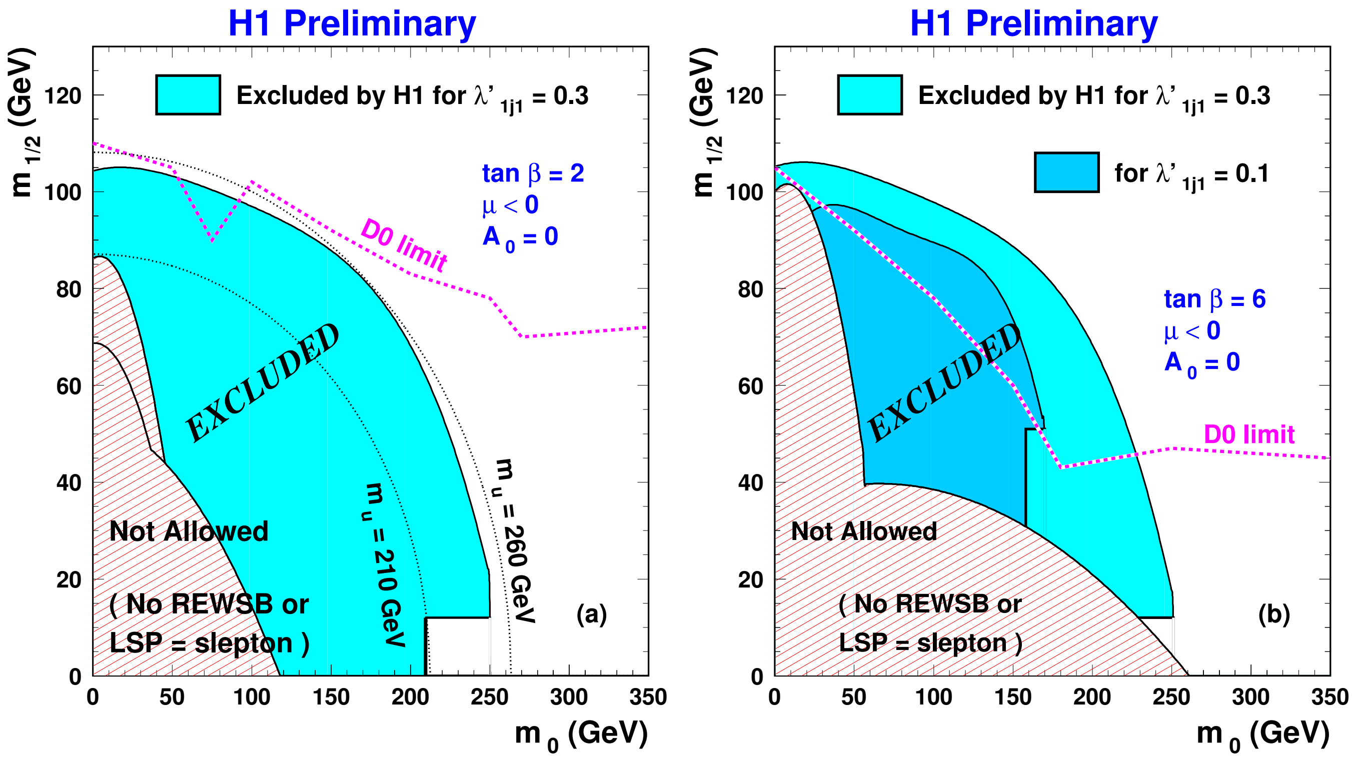
→ Limits extend beyond CDF, D0 limits when branching ratio to eq is small

mSUGRA model

→ Radiative Electroweak Symmetry Breaking

→ Two mass parameters: m_0, $m_{1/2}$

→ Also $|\mu|$ is predicted from $\tan\beta$

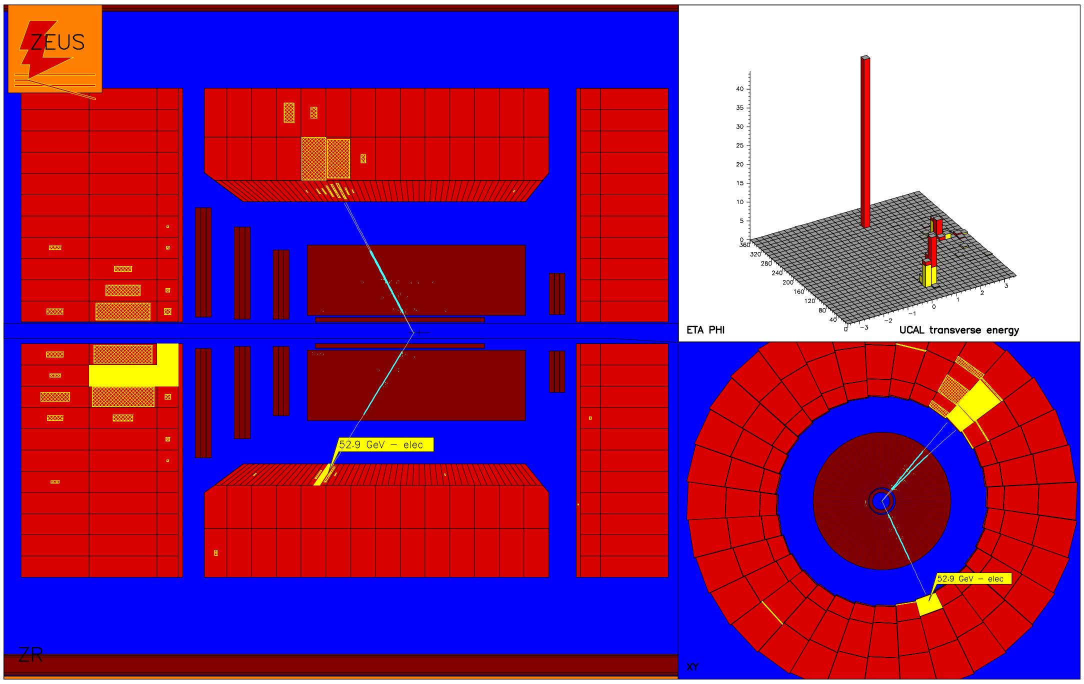


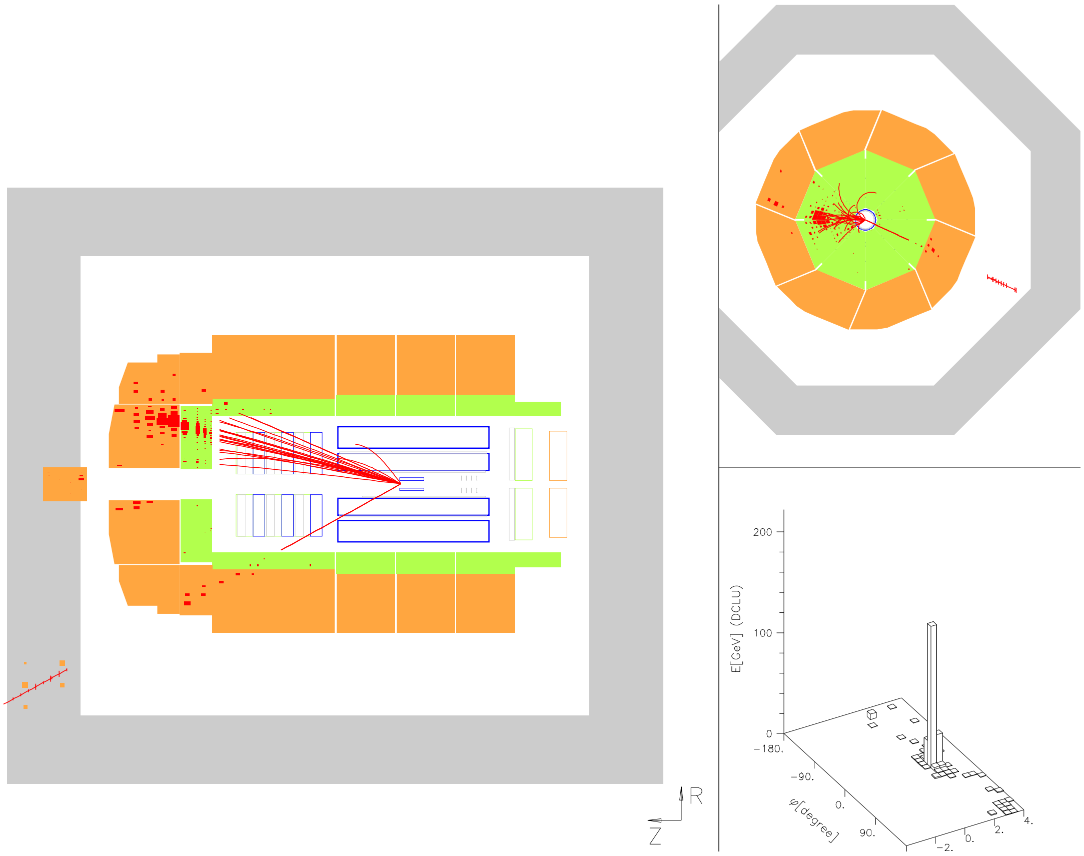
→ complementary to D0 search

→ TEVATRON limits are independent of λ'

Isolated Lepton +

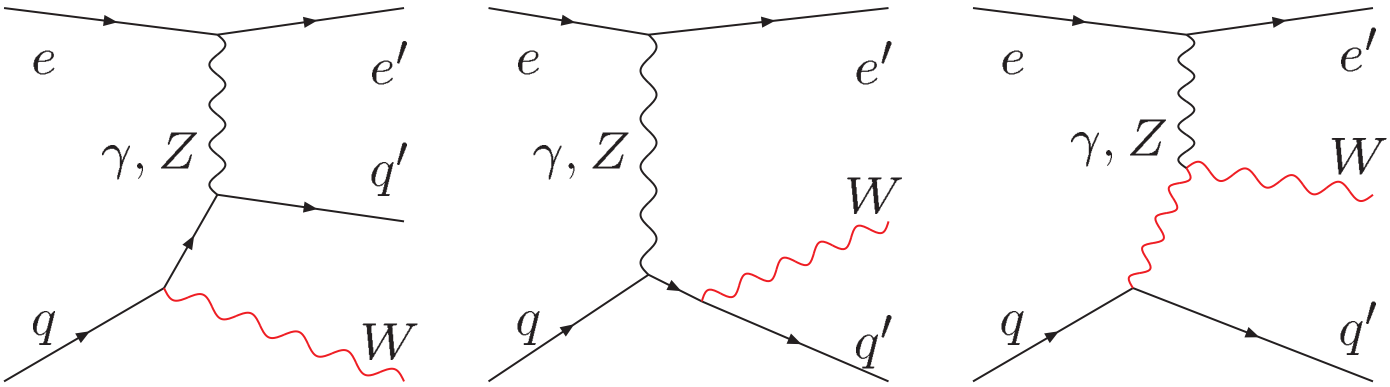
Missing Pt





$\rightarrow$ Standard Model W production?

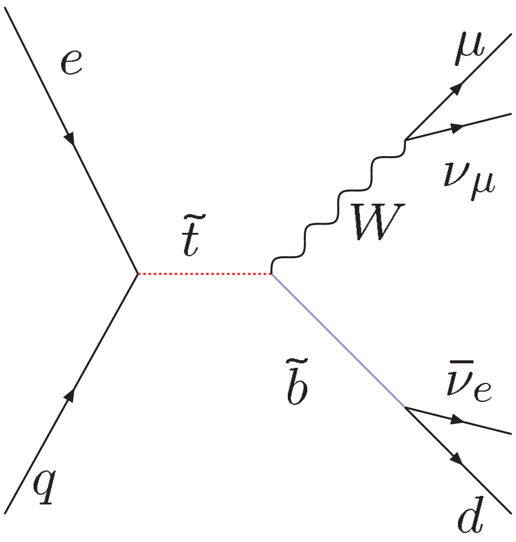
Standard Model W Production

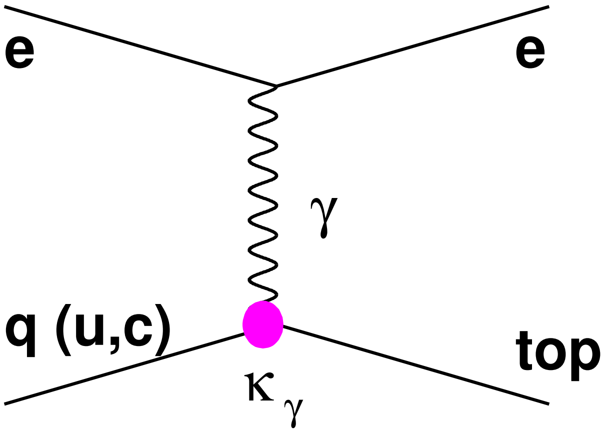


Standard Model Backgrounds:

- NC DIS with missing P_T from mismeasurement
- CC DIS with (fake) isolated lepton
- $ep \to \ell^+\ell^- X$ via inelastic $\gamma\gamma \to \ell^+\ell^-$

Non-Standard Model examples:





SUSY: $\not{R}_P$ stop

Flavour Changing Neutral Current: $\kappa_{\gamma,ut}$

Isolated Lepton events

→ Selection (simplified):

- Isolated track with $P_T > 10$ GeV: e or μ
- Missing P_T, $P_T^X > 25$ GeV
- Acoplanar lepton and jet
- No second isolated muon with $P_T > 1$ GeV

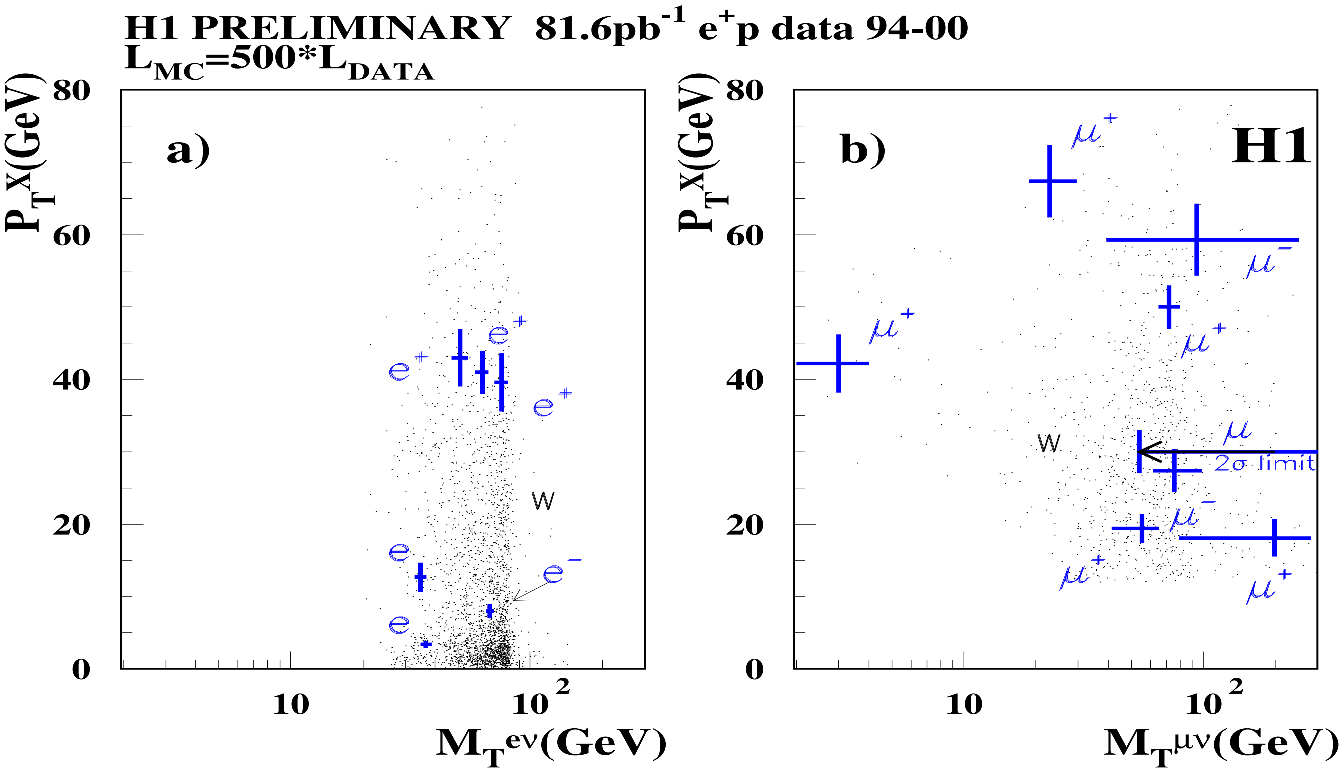
H1: $13.6\,\mathrm{pb}^{-1}$ e^-p, $81.6\,\mathrm{pb}^{-1}$ e^+p

P_T^X	electron events			muon events		
GeV	#	SM	W	#	SM	W
> 25	3	0.84 ± 0.22	0.67	6	0.94 ± 0.26	0.78
> 40	2	0.27 ± 0.08	0.26	4	0.35 ± 0.10	0.33

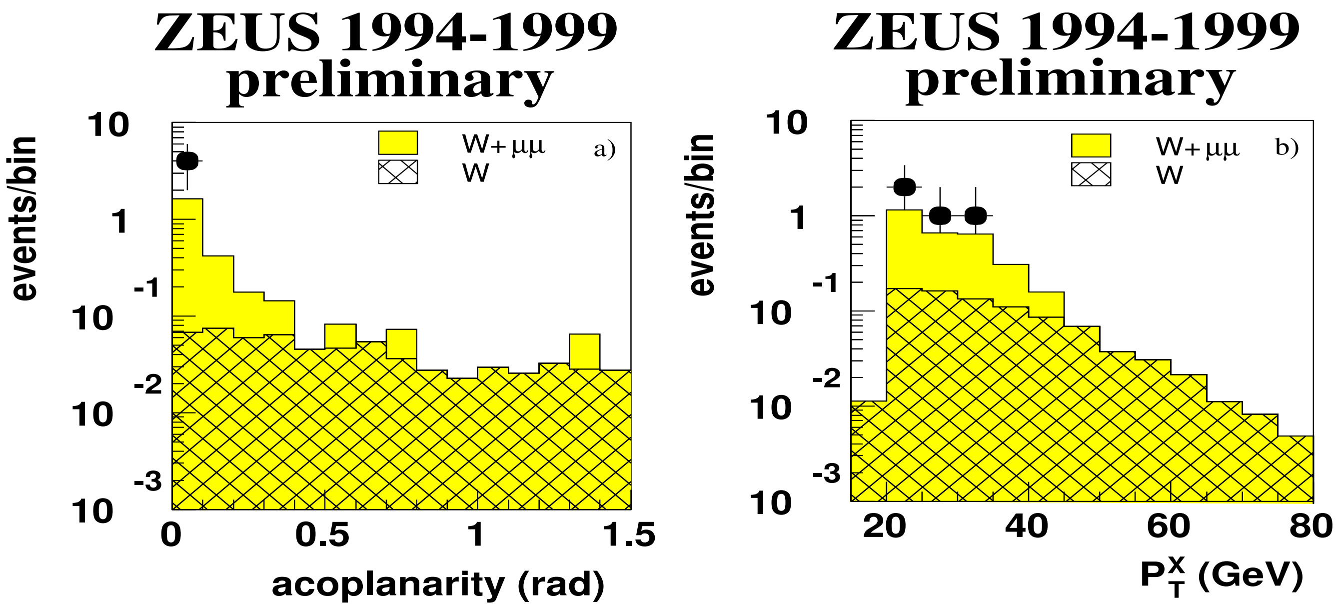
ZEUS: $82\,\mathrm{pb}^{-1}$ of e^+p and e^-p

P_T^X	electron events			muon events		
GeV	#	SM	W	#	SM	W
> 25	1	0.78 ± 0.04	0.74	0	0.82 ± 0.10	0.66
> 40	0	0.27 ± 0.02	0.27	0	0.32 ± 0.03	0.28

Isolated Lepton + Missing P_t Events (1994-2000)

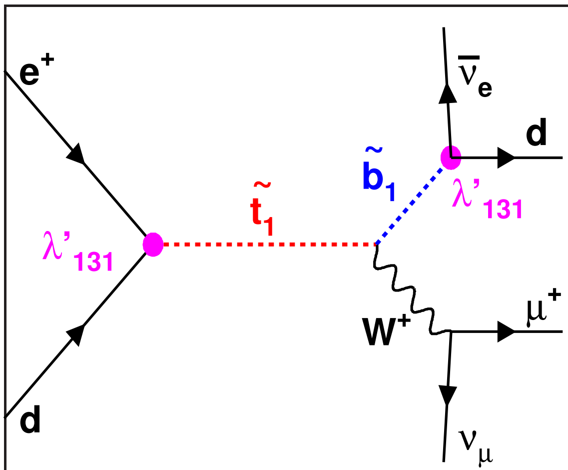


Several H1 μ events have very large hadronic P_T (P_T^X)



ZEUS μ events are consistent with expected background.

H1 1999: $\tilde{t} \to \tilde{b} + W$ no explanation



Model : $\not{R}_P$ SUSY, $\lambda'_{131} \neq 0$

Assumptions :
$\tilde{b}_1$ is the LSP
$M_{\tilde{b}_1} < M_{\tilde{t}_1} < M_{\chi_1^+}$

cf T.Kon et al

Existing limits $\Rightarrow$ $M_{\tilde{b}_1} \gtrsim 90$ GeV, real W $\Rightarrow$ $M_{\tilde{t}_1} \gtrsim 180$ GeV
Only decay mode for $\tilde{b}_1$: $\tilde{b}_1 \to d\bar{\nu}_e$
Original theoretical motivation: "explain"
HERA high Q^2 NC DIS and high p_T lepton events

- $W \to e\nu$: 1 event in H1 (e^-)
- $W \to \mu\nu$: 4 events in H1 (2 μ^+, 1 μ^-, 1 $\mu^\pm$)
  $\mu^- e^+$ event fails selection due to e^+
- $W \to had.$: demand $P_{T,miss} > 25$ GeV, $P_{T,jet,1,2} > 25$ GeV

$\boxed{N_{had,obs} = 3 \text{ evts}, \; N_{had,SM} = 4.7 \pm 0.7 \text{ evts (CC DIS)}}$

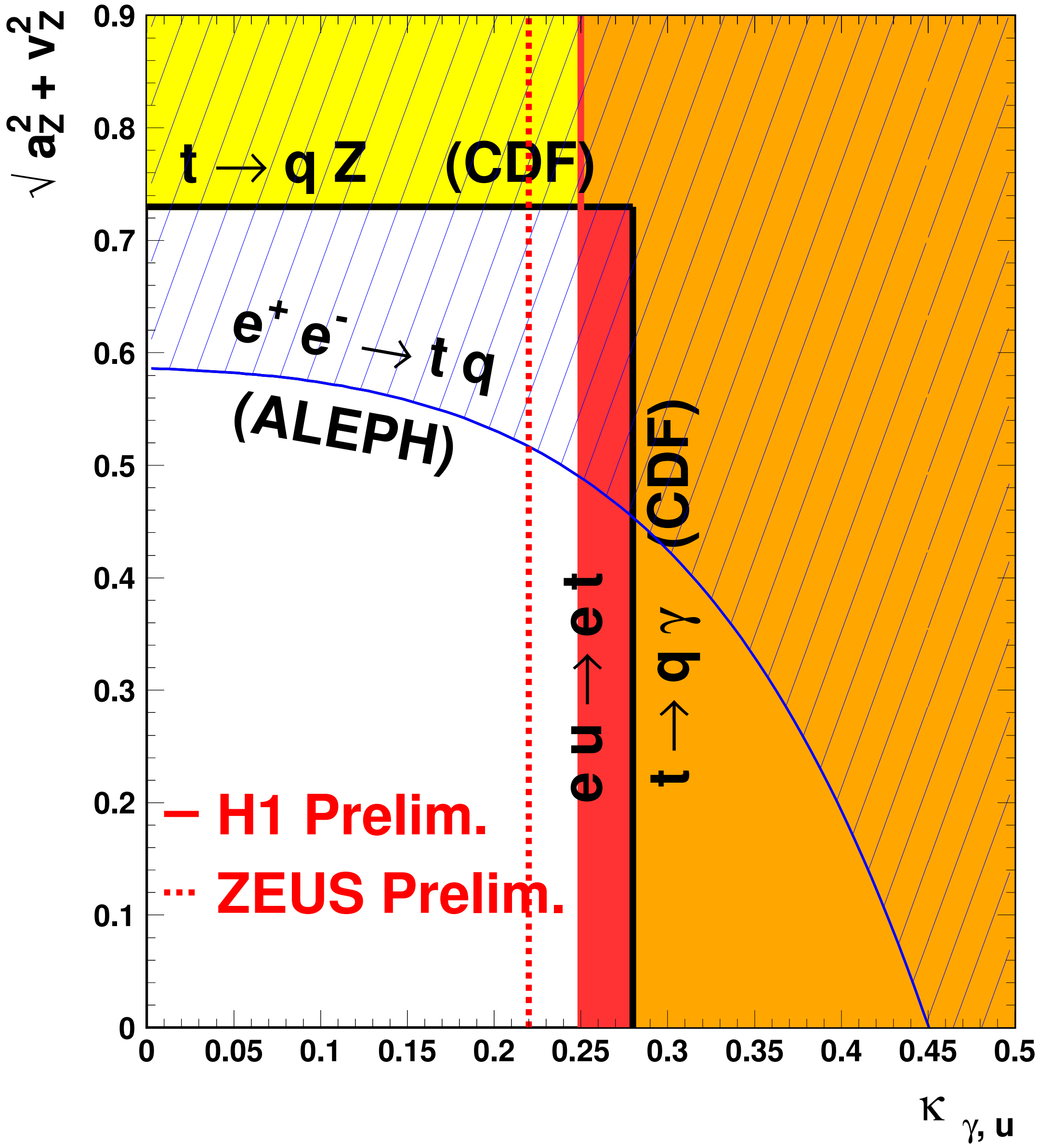
No excess had. channel $\Rightarrow$ Cannot "explain" μ events

Quantitatively, for $M_{\tilde{t}} \sim 200$ GeV, $M_{\tilde{b}} \sim 100$ GeV:
- efficiencies: $\varepsilon(W \to had.) \simeq \varepsilon(W \to \mu\nu) \simeq 50\%$
- SM: $BR(W \to \mu\nu) = \mathbf{0.15} \cdot BR(W \to had.)$

$\to$ Upper limit on additional μ events from $\tilde{b}W$:
$N_{obs,\tilde{b}W}(W \to \mu) < 0.36$ at 90% C.L

Search for single top production

- → Anomalous $tu\gamma$ coupling $\kappa_{tu\gamma}$
- H1 limit $\kappa_{tu\gamma} < 0.25$ from $t \to$ 3jet
- ... does not yet rule out this explanation of H1 events
- ZEUS limit $\kappa_{tu\gamma} < 0.22$ from $t \to$ jet + lepton + $P_{T,miss}$



Conclusions

- → HERA complementary to LEP, Tevatron
- → HERA excess of 1996: going, going, nearly gone ...
- → Leptoquarks: new analyses with $e^- p$ data
- → Lepton Flavour Violation: several world-best limits
- → Contact Interactions: e^+ and e^- complementary
  New H1 limits on scale Λ in the range 2–9 TeV
- → Large extra dimensions: $\Lambda > 0.63$ (0.93) TeV ($\lambda = \pm 1$)
- → Excited Fermions: limits to LEP, Tevatron
- → Squarks: all-purpose HERA search
  $M_{\tilde{q}} \gtrsim 265$ GeV for $\lambda_{1j1} = 0.3$
- → High P_T Leptons: some intriguing H1 events
- → Single top production: $\kappa_{tu\gamma} < 0.22$

- → HERA switched OFF for Upgrade of HERA, ZEUS, H1
- → ... time for interesting data analyses ...
- → Restart september 2001