New Particle Searches at HERA

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Representing the ZEUS and H1 Collaborations

- Leptoquarks
- Contact Interactions
- Lepton Flavor Violation
- R-Parity Violating SUSY
- Isolated Leptons
- Search for $\mathbf{ep} \to \mathbf{tX}$
- Excited Fermions

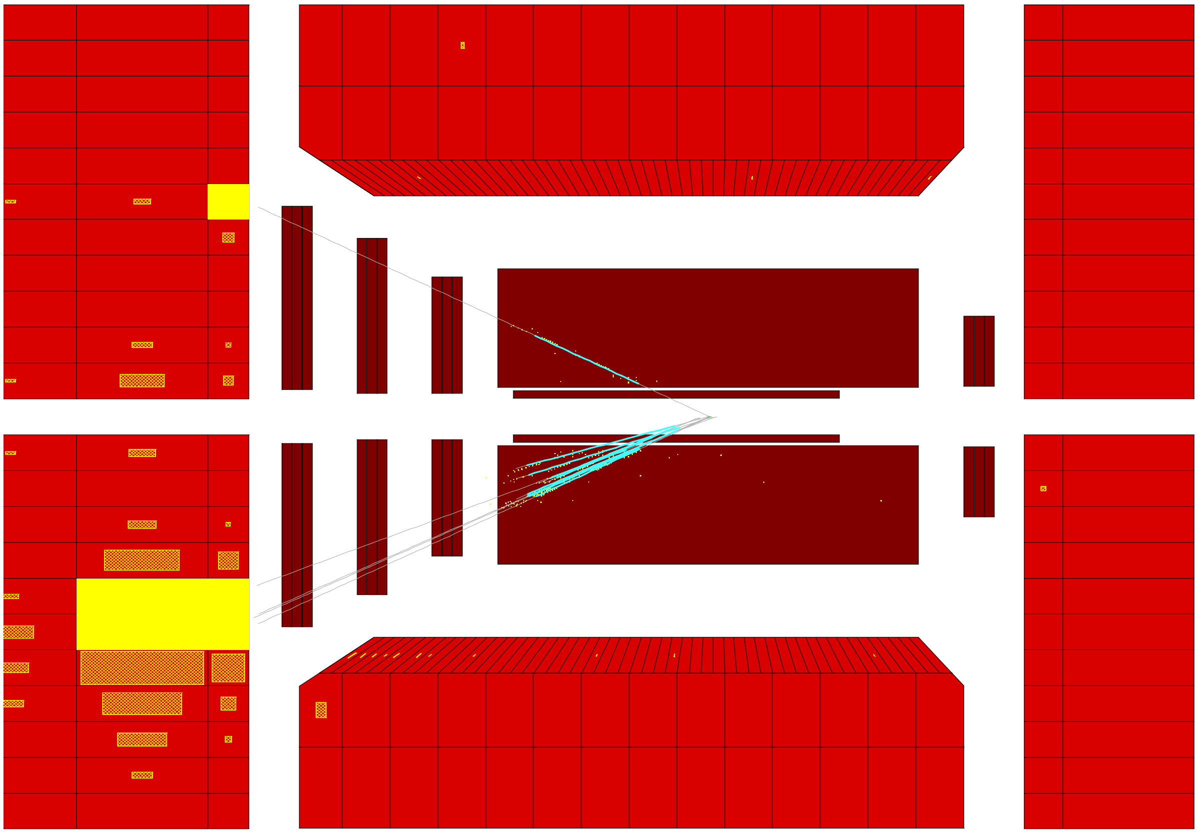
Data Sets

$$E_e = 27.5\,\mathrm{GeV}$$

$$E_p = \begin{cases} 820\,\mathrm{GeV} & \text{until 1997} \\ 920\,\mathrm{GeV} & \text{from 1998} \end{cases}$$

run period	e charge	$\sqrt{s}$	$\int dt\mathcal{L}$ H1	$\int dt\mathcal{L}$ ZEUS
1994-1997	e^+	300 GeV	37 pb^{-1}	48 pb^{-1}
1998-1999	e^-	318 GeV	14 pb^{-1}	17 pb^{-1}
1999-2000	e^+	318 GeV	65 pb^{-1}	66 pb^{-1}

ZEUS Detector



Uranium-Scintillator Calorimeter

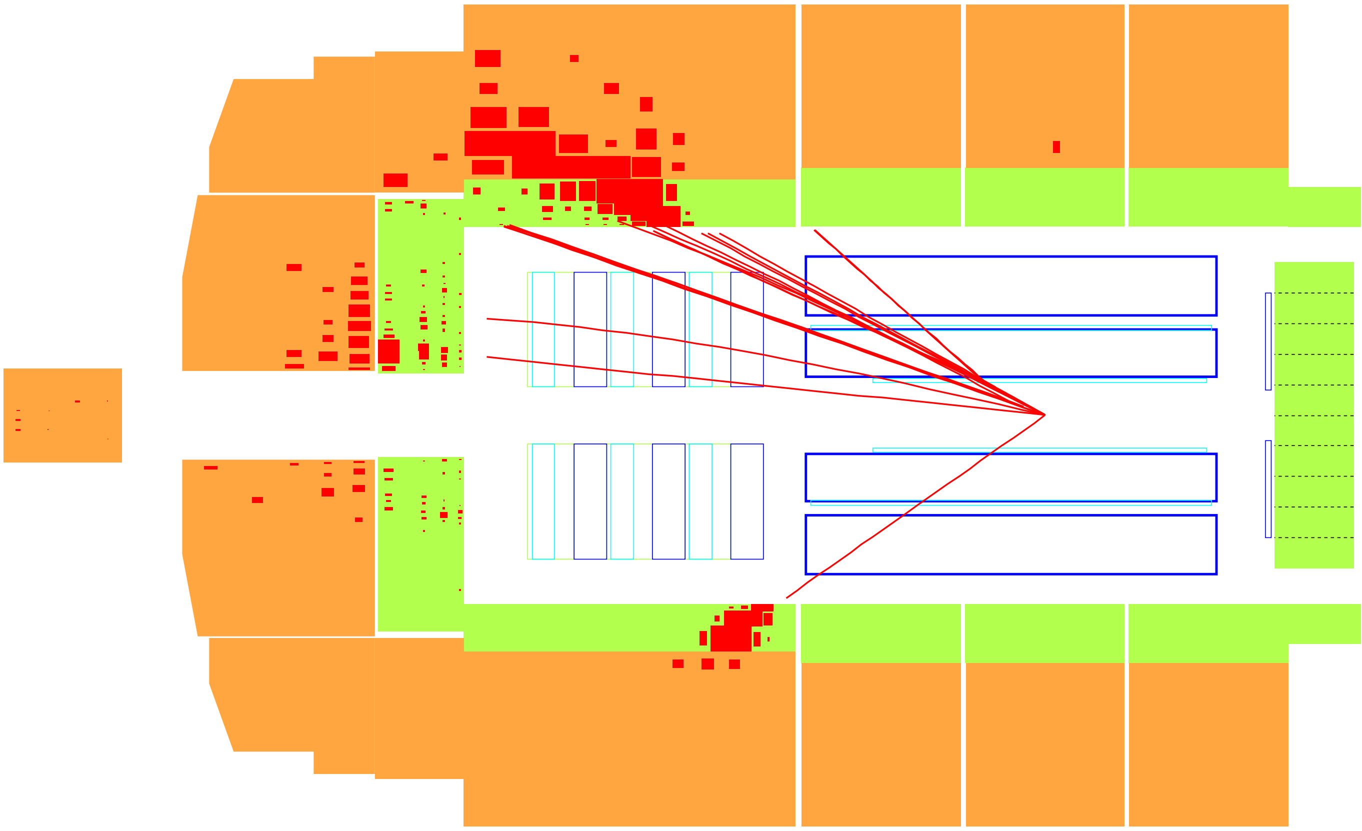
6000 Cells, each read out by 2 PMTs

σ_{θ_e} = 5 mrad

$\sigma/\sqrt{E}$ (e) = 18 %

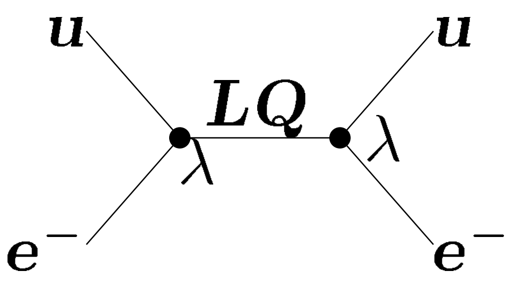
$\sigma/\sqrt{E}$ (had) = 35 %

H1 Detector



Liquid Argon Calorimeter
44000 Cells
σ_{θ_e} = 2-5 mrad
$\sigma/\sqrt{E}$ (e) = 12 %
$\sigma/\sqrt{E}$ (had) = 50 %

Leptoquarks



- Color triplet boson with spin zero or one
- Dimensionless chiral coupling(s) λ_L or λ_R are $SU(3) \times SU(2) \times U(1)$ invariant.
- For $M_{\mathrm{LQ}} < \sqrt{s}$, LQ is produced as s-channel resonance at $x = {M_{\mathrm{LQ}}}^2/s$.
- Partial width $\sim \lambda^2/M_{\mathrm{LQ}}$.
- Scalar LQs decay isotropically $\rightarrow$ uniform in $\cos\theta^*$, y
- Vector LQs decay $\sim (1+\cos\theta^*)^2 \sim (1-y)^2$
- $F=2$ (couples to e^-q or $e^+\bar{q}$):
  4 scalars: $S_0^L, S_0^R, \tilde{S}_0^R, S_1^L$
  3 vectors: $V_{1/2}^L, V_{1/2}^R, \tilde{V}_{1/2}^L$
- $F=0$ (couples to e^+q or $e^-\bar{q}$):
  3 scalars: $S_{1/2}^L, S_{1/2}^R, \tilde{S}_{1/2}^L$
  4 vectors: $V_0^L, V_0^R, \tilde{V}_0^R, V_1^L$.
  labeled by weak isospin and lepton helicity.

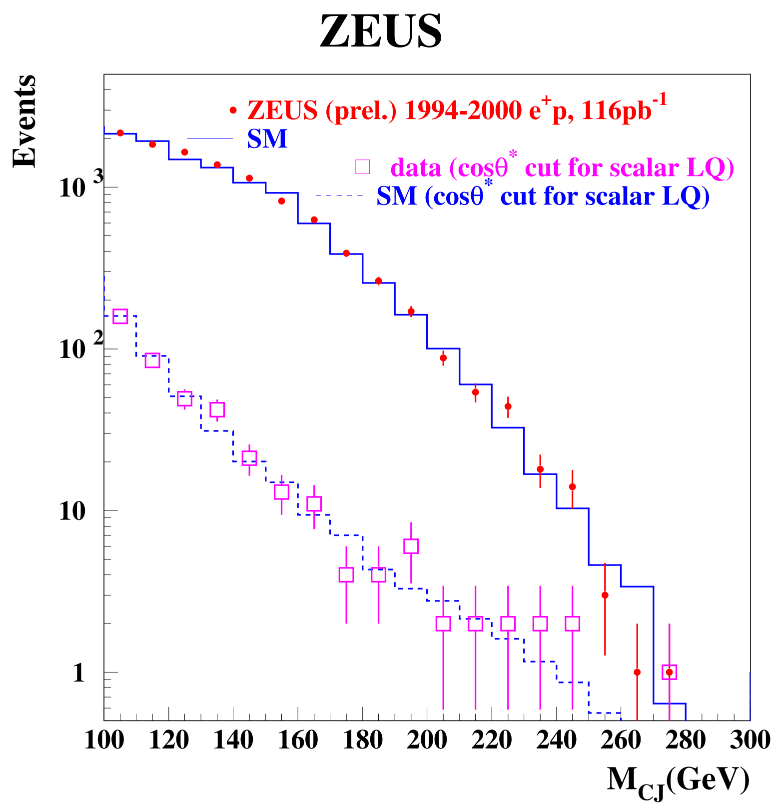
Leptoquarks with $M_{\mathrm{LQ}} < \sqrt{s}$

- Narrow-width approximation:

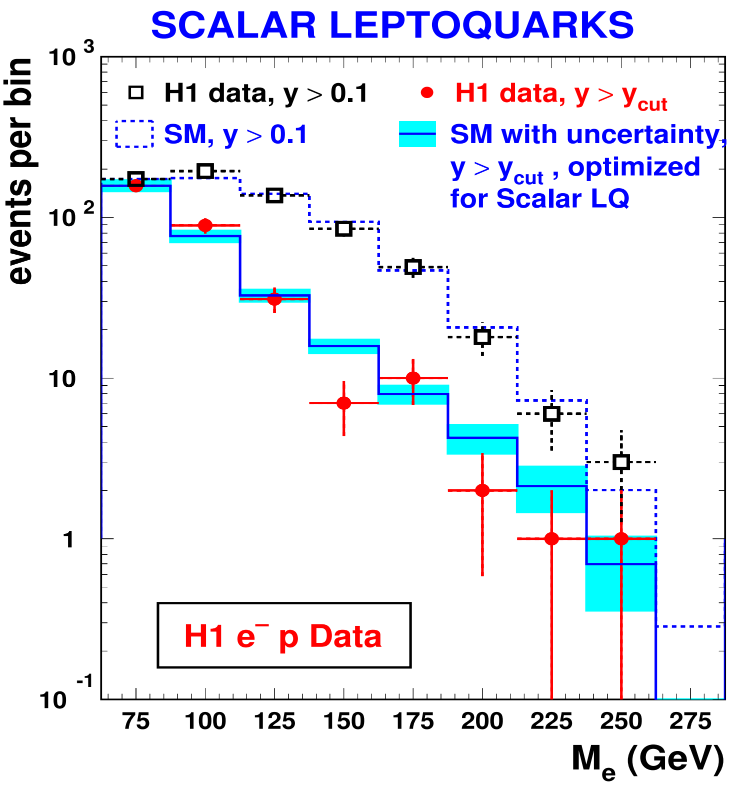
$$\sigma(ep \to LQ) = (\pi/4s)\lambda^2 q(M_{\tilde{q}}{}^2/s) \times \begin{cases} 1 \text{ spin zero} \\ 2 \text{ spin one} \end{cases}$$

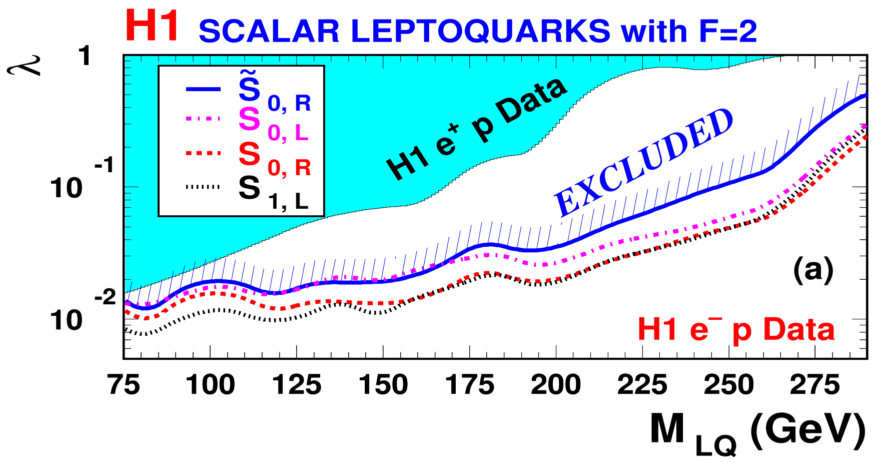
- Search for a narrow resonance in e+jet mass

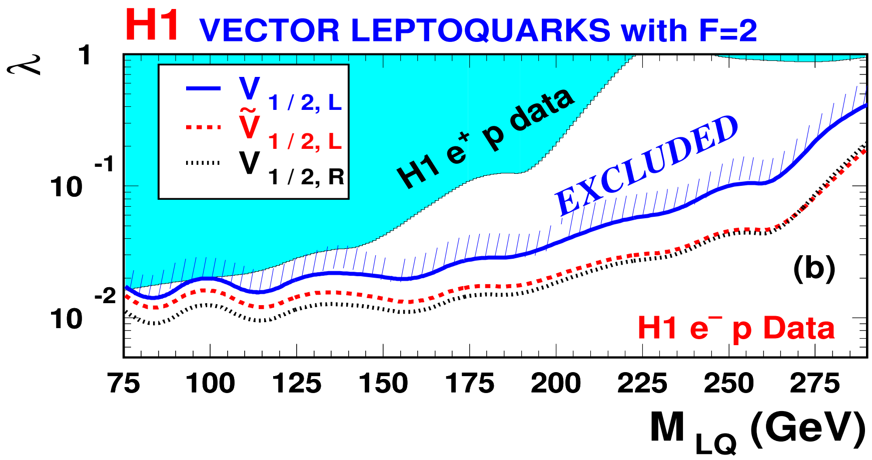
- $y =$ fraction of $E - P_z$ transferred from beam e to hadronic final state discriminates LQ from NC-DIS ($\sim 1/y^2$).

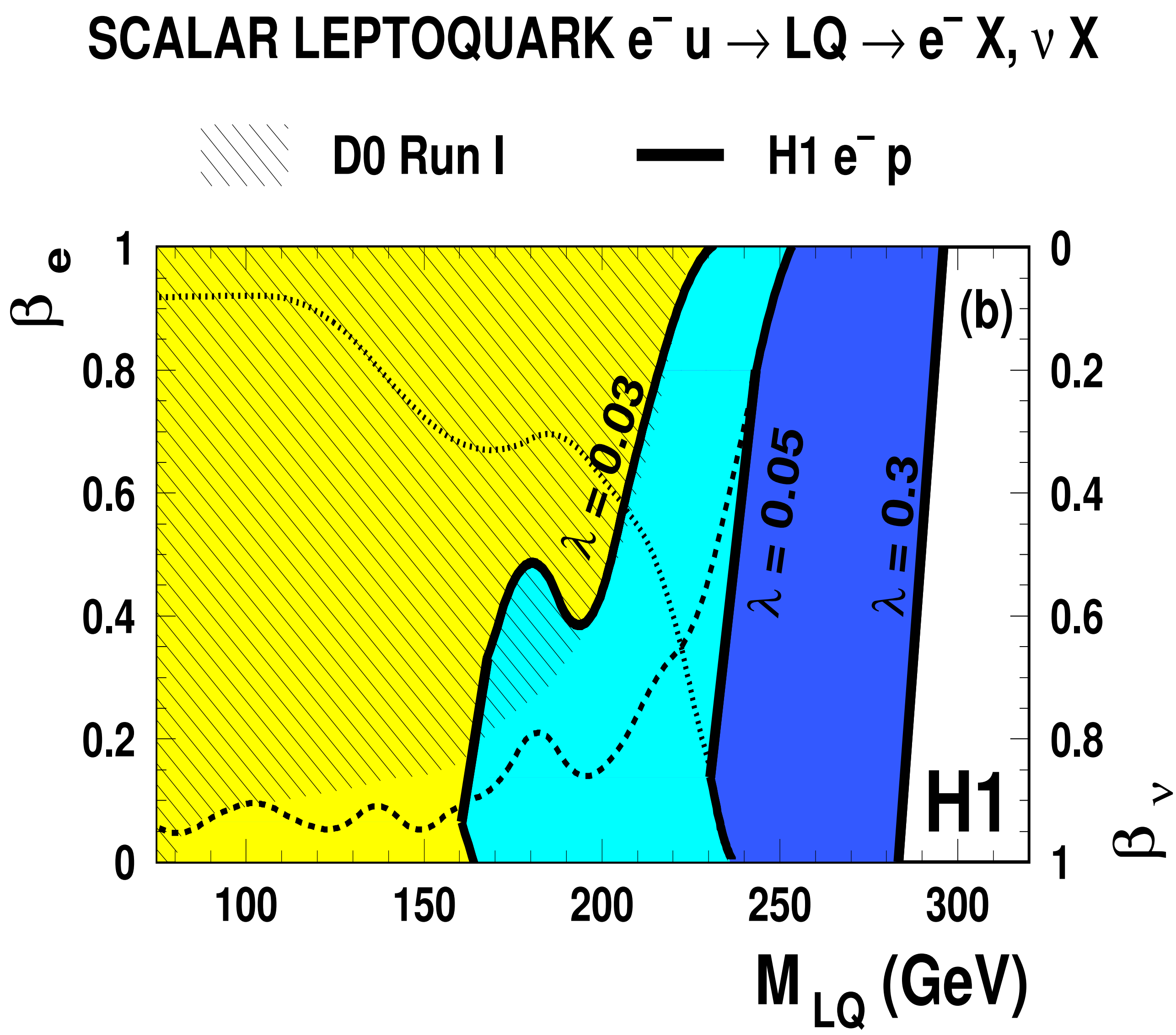


e-jet mass spectrum before and after optimized cut $y > y_{\mathrm{cut}}(M_{\mathrm{LQ}})$


SCALAR LEPTOQUARKS
events per bin
H1 data, y > 0.1
H1 data, y > y_cut
SM, y > 0.1
SM with uncertainty, y > y_cut , optimized for Scalar LQ
H1 e⁻ p Data
M_e (GeV)


H1 SCALAR LEPTOQUARKS with F=2
λ
S̃ 0, R
S 0, L
S 0, R
S 1, L
H1 e⁺ p Data
EXCLUDED
(a)
H1 e⁻ p Data
M LQ (GeV)

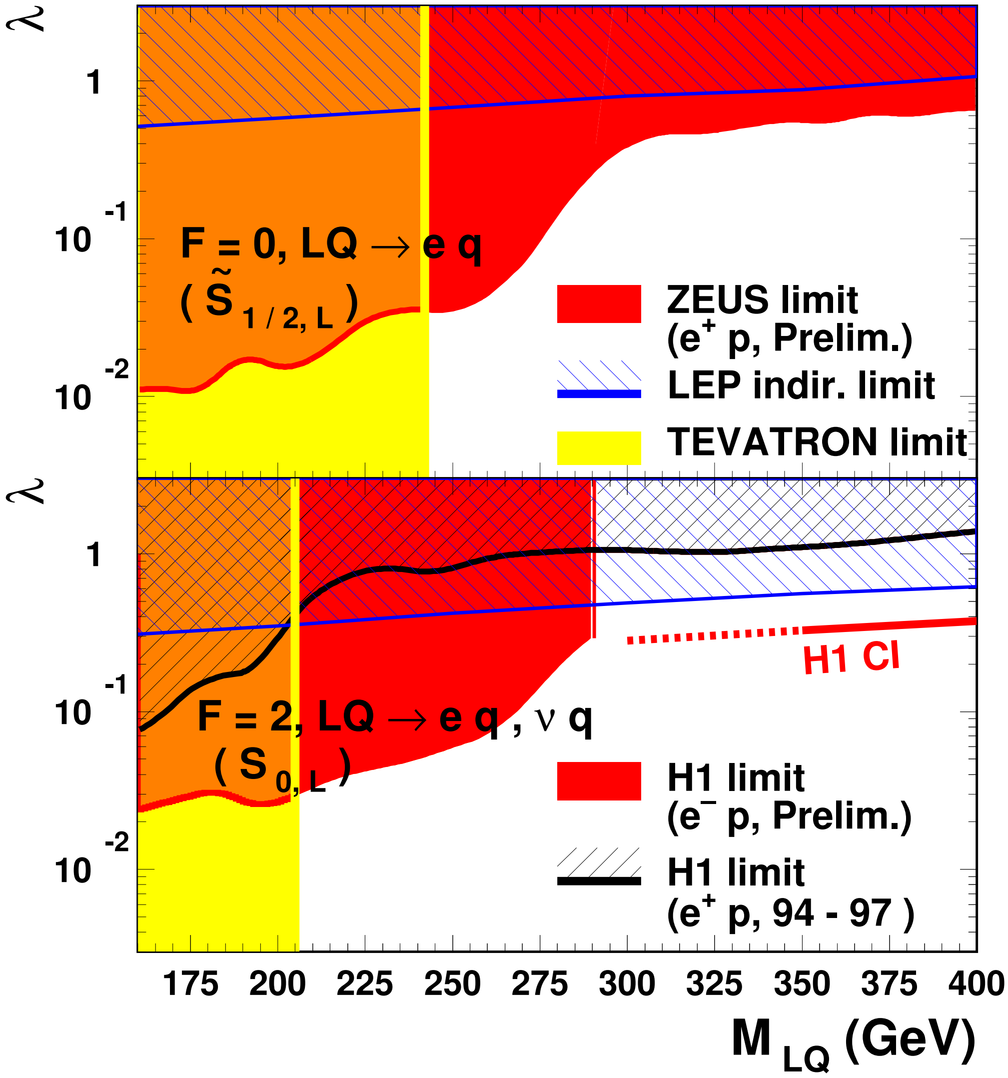

H1 VECTOR LEPTOQUARKS with F=2
λ
V 1 / 2, L
Ṽ 1 / 2, L
V 1 / 2, R
H1 e⁺ p data
EXCLUDED
(b)
H1 e⁻ p Data
M LQ (GeV)



Tevatron sensitivity for eq decays is $>>$ than for νq
HERA eq and νq sensitivities are roughly equal

For $M_{\rm LQ} > \sqrt{s}$, both s– and u–channel contribute.

Constraints on Scalar Leptoquarks



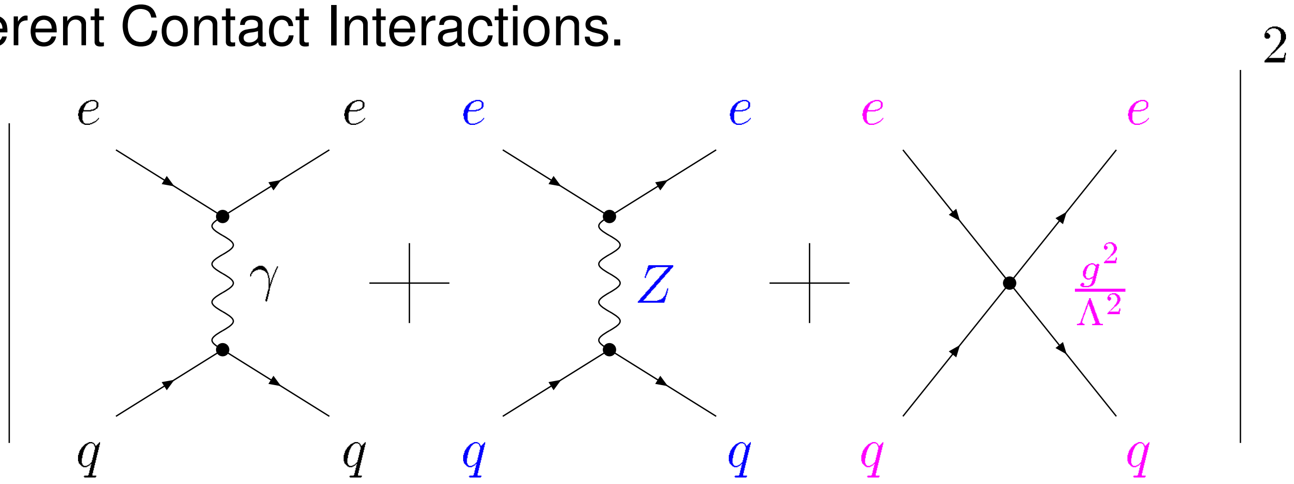
Limits for $M_{LQ} > \sqrt{s}$ derived from likelihood fit to $M_{LQ}, \cos\theta^*$ distribution. Use full LQ cross section including LQ-NC interference.

Contact Interactions

$$\mathcal{L} = \frac{g^2}{\Lambda^2} \sum_{q=u,d} \sum_{\alpha=L,R} \sum_{\beta=L,R} \eta^{eq}_{\alpha\beta} (\overline{e}_\alpha \gamma^\mu e_\alpha)(\overline{q}_\beta \gamma_\mu q_\beta)$$

$g^2 = 4\pi$ $\qquad\qquad$ $|\eta^{eq}_{\alpha\beta}| = 0$ or 1

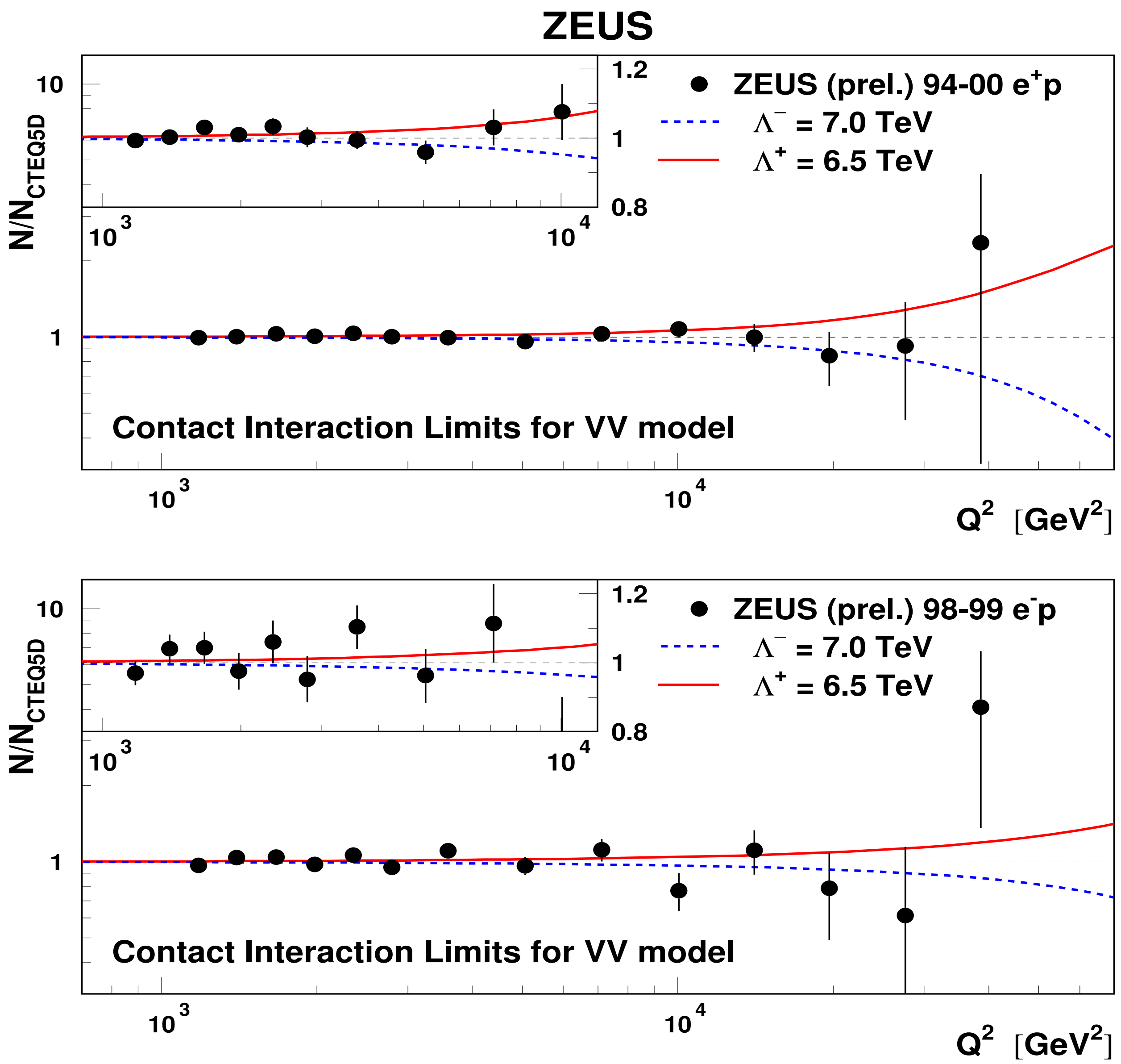
Different combinations of $\eta_{LL}, \eta_{LR}, \eta_{RL}, \eta_{RR}$ yield different Contact Interactions.



$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \quad \left\{(1+(1-y)^2)F_2 \mp (1-(1-y)^2)xF_3\right\}$$

$$\begin{aligned} F_2(x,Q^2) &= \frac{1}{2}\sum_f xq_f^+ \left\{(V_f^L)^2 + (V_f^R)^2 + (A_f^L)^2 + (A_f^R)^2\right\} \\ xF_3(x,Q^2) &= \sum_f xq_f^- \left\{V_f^L A_f^R - V_f^R A_f^L\right\} \\ q_f^{\pm}(x,Q^2) &= q_f(x,Q^2) \pm \overline{q}_f(x,Q^2) \end{aligned}$$

$$\begin{aligned} V_f^L &= e_f \quad -(v_e + a_e)v_f P_Z(Q^2) + \frac{Q^2}{8\pi\alpha}\frac{g^2}{\Lambda^2}(\eta_{LL} + \eta_{LR}) \\ V_f^R &= e_f \quad -(v_e - a_e)v_f P_Z(Q^2) + \frac{Q^2}{8\pi\alpha}\frac{g^2}{\Lambda^2}(\eta_{RL} + \eta_{RR}) \\ A_f^L &= \quad -(v_e + a_e)a_f P_Z(Q^2) + \frac{Q^2}{8\pi\alpha}\frac{g^2}{\Lambda^2}(\eta_{LL} - \eta_{LR}) \\ A_f^R &= \quad -(v_e - a_e)a_f P_Z(Q^2) + \frac{Q^2}{8\pi\alpha}\frac{g^2}{\Lambda^2}(\eta_{RL} - \eta_{RR}) \\ P_Z &= \frac{1}{4\sin^2\theta_W \cos^2\theta_W}\left(\frac{Q^2}{Q^2 + M_Z^2}\right) \end{aligned}$$



Curves show excluded models (95% CL).
ZEUS, H1 both use entire data set (e^- and e^+).

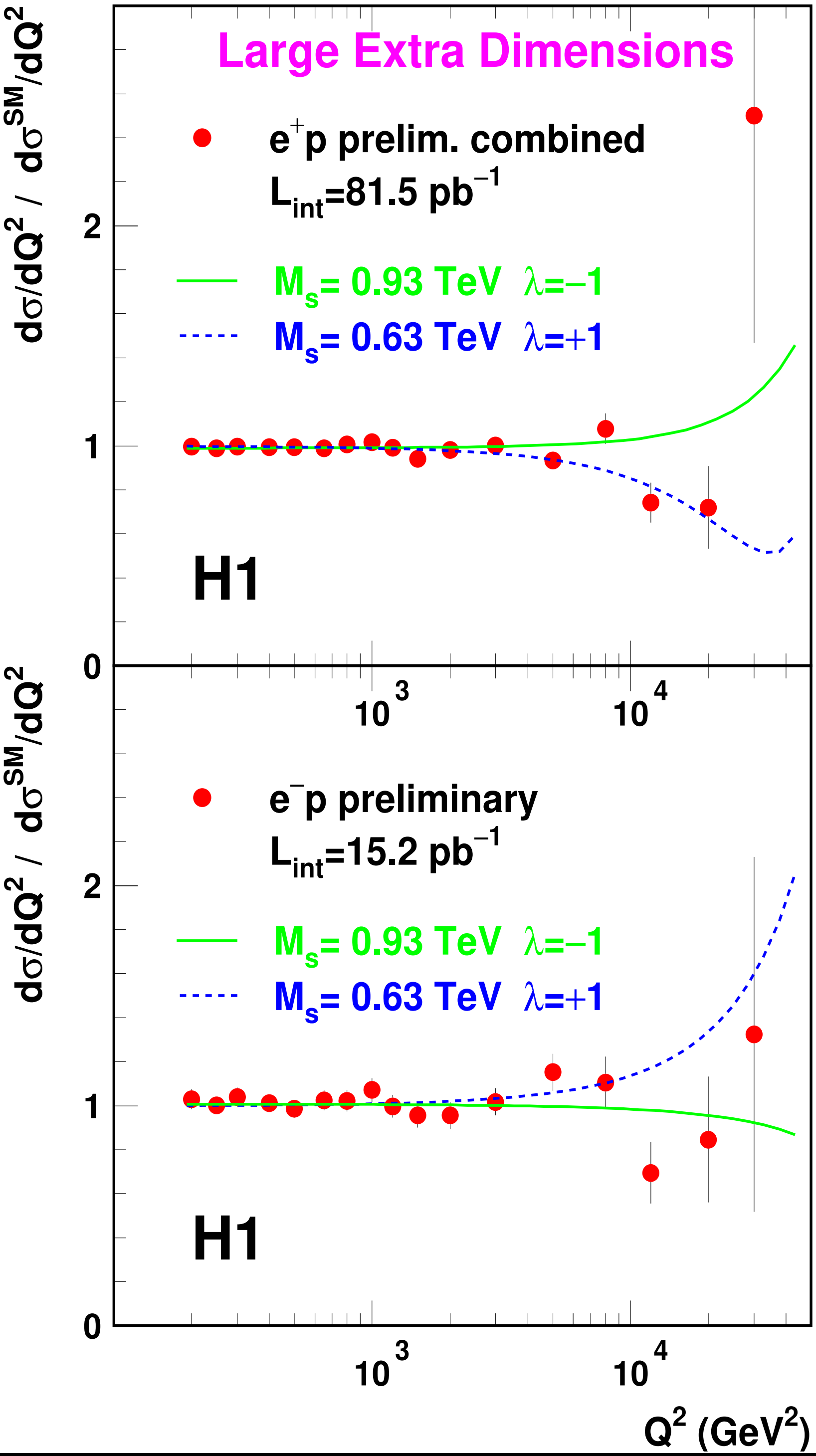
Limits on $\Lambda^{\pm}$ (TeV) for various models.

Model	Coupling structure η^{eq}_{LL}	η^{eq}_{LR}	η^{eq}_{RL}	η^{eq}_{RR}	ZEUS Λ^-	ZEUS Λ^+	H1 Λ^-	H1 Λ^+
VV	+1	+1	+1	+1	7.0	6.5	9.2	3.0
AA	+1	-1	-1	+1	5.3	4.6	5.4	1.8
VA	+1	-1	+1	-1	3.4	3.3	3.9	4.0
LL	+1				-	-	4.3	1.6
LR		+1			-	-	5.4	1.8
RL			+1		-	-	5.4	1.9
RR				+1	-	-	4.3	1.6
X1	+1	-1			4.0	2.7	-	-
X2	+1		+1		4.7	4.7	-	-
X3	+1			+1	4.3	4.2	-	-
X4		+1	+1		5.6	5.6	-	-
X5		+1		+1	4.8	4.8	-	-
X6			+1	-1	2.6	3.9	-	-

Heavy leptoquarks look like contact interactions
e.g. S_0^L corresponds to $\eta^{eu}_{LL} = +\frac{1}{2}$

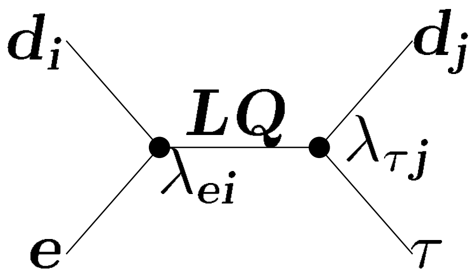
95% C.L. limits on S_0^L: $M_{\rm LQ}/\lambda > \begin{cases} 1.07\ \mathrm{TeV} & \mathrm{H1} \\ 0.75\ \mathrm{TeV} & \mathrm{ZEUS} \end{cases}$

For different LQ species, lower limits on $M_{\rm LQ}/\lambda$ range from 0.3 TeV to 1.7 TeV



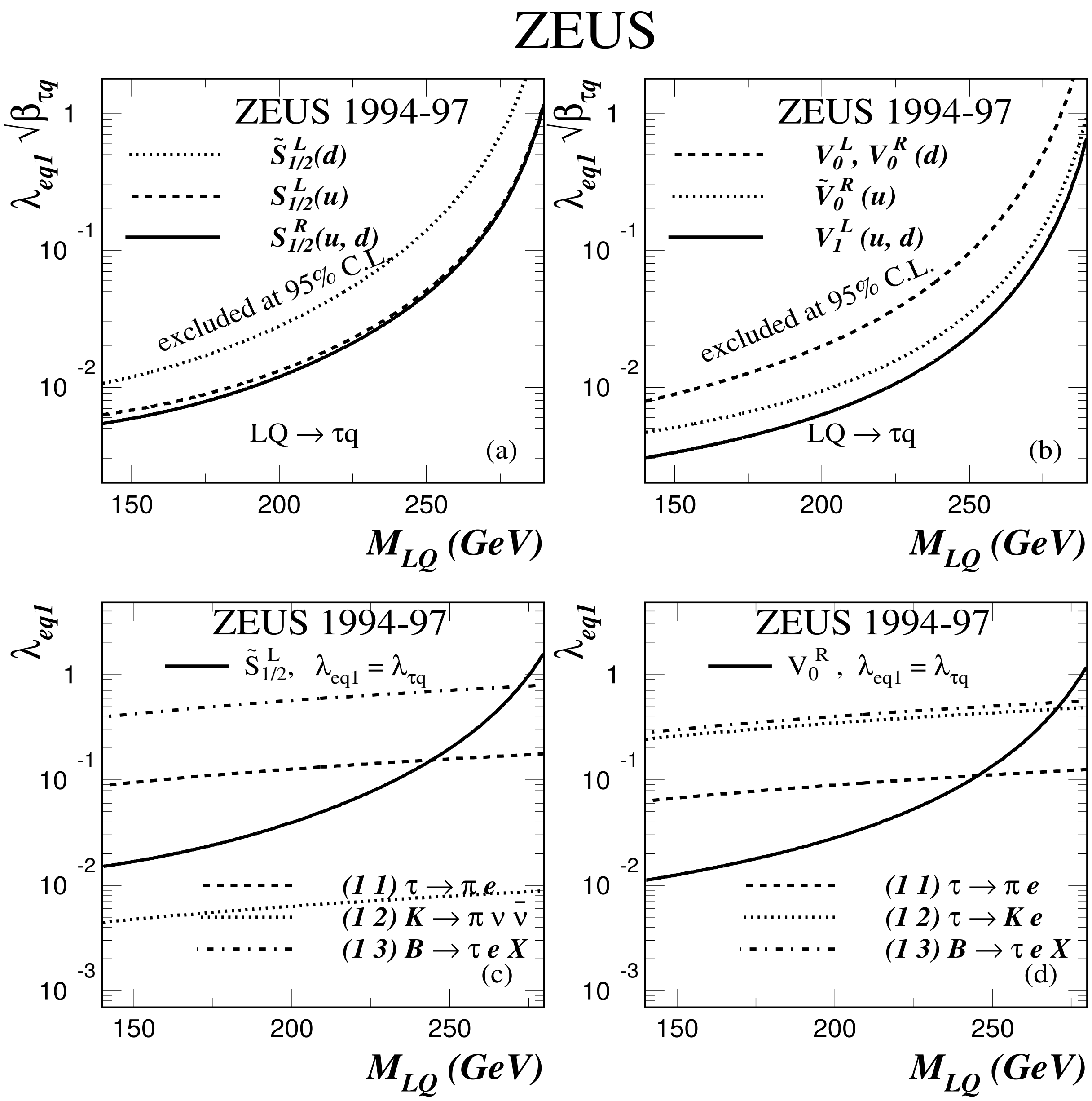
If δ compact dimensions $(R \sim 1\text{mm} = 5 \times 10^{12}\text{GeV}^{-1})$,
$\Rightarrow$ Gravitational interactions with scale M_S
$M_S^{1+\delta/2} \sim R^{-\delta/2} M_P$, where $(M_P = 1.2 \times 10^{19}\text{GeV})$
$\Rightarrow M_S \sim 1\,\text{TeV}$

Lepton Flavor Violation



- Use 1994-1997 e^+p data. $\sqrt{s} = 300$ GeV^2.
  $\mathcal{L}_{\mathrm{H1}} = 37$ pb^{-1}, $\mathcal{L}_{\mathrm{ZEUS}} = 48$ pb^{-1}.
- Search for μq and τq final states.
- Require isolated high P_t lepton, opposite high P_t jet.
- Both ZEUS and H1 observed no candidates.
- Set limits on $\lambda_{eq}\sqrt{B_{\ell q}}$ vs. LQ mass.
- For $M_{lq} > \sqrt{s}$, treat as a contact interaction with

$$\sigma \sim \left[\frac{\lambda_{eq_\alpha}\lambda_{\ell q_\beta}}{M_{lq}^2}\right]^2$$



Coupling limits for Scalar Leptoquarks decaying to τq

Top: Limits on the $\lambda_{eq}\sqrt{B_{\tau q}}$.

Bottom: Limits on the λ_{eq}.

ZEUS preliminary 1994-1999 (64.4 pb^{-1})

$e \to \mu$ $F = 0$

$\alpha\beta$	$S^L_{1/2}$ e^+u	$S^R_{1/2}$ $e^+(u+d)$	$\tilde{S}^L_{1/2}$ e^+d	V^L_0 e^+d	V^R_0 e^+d	$\tilde{V}^R_0$ e^+u	V^L_1 $e^+(\sqrt{2}u+d)$
11	$\mu N \to eN$ 7.6×10^{-5} **1.8**	$\mu N \to eN$ 2.6×10^{-5} **1.5**	$\mu N \to eN$ 7.6×10^{-5} **2.6**	$\mu N \to eN$ 2.6×10^{-5} **1.5**	$\mu N \to eN$ 2.6×10^{-5} **1.5**	$\mu N \to eN$ 2.6×10^{-5} **1.1**	$\mu N \to eN$ 1.1×10^{-5} **0.5**
12	$D \to \mu\bar{e}$ 4 $\boxed{\mathbf{2.0}}$	$K \to \mu\bar{e}$ 2.7×10^{-5} **1.6**	$K \to \mu\bar{e}$ 2.7×10^{-5} **2.7**	$K \to \mu\bar{e}$ 1.3×10^{-5} **2.0**	$K \to \mu\bar{e}$ 1.3×10^{-5} **2.0**	$D \to \mu\bar{e}$ 2 $\boxed{\mathbf{1.6}}$	$K \to \mu\bar{e}$ 1.3×10^{-5} **0.8**
13	*	$B \to \mu\bar{e}$ 0.8 **2.8**	$B \to \mu\bar{e}$ 0.8 **2.8**	V_{ub} 0.2 **2.4**	$B \to \mu\bar{e}$ 0.4 **2.4**	*	V_{ub} 0.2 **2.4**
21	$D \to \mu\bar{e}$ 4 **4.4**	$K \to \mu\bar{e}$ 2.7×10^{-5} **3.2**	$K \to \mu\bar{e}$ 2.7×10^{-5} **4.6**	$K \to \mu\bar{e}$ 1.3×10^{-5} **1.8**	$K \to \mu\bar{e}$ 1.3×10^{-5} **1.8**	$D \to \mu\bar{e}$ 2 $\boxed{\mathbf{1.5}}$	$K \to \mu\bar{e}$ 1.3×10^{-5} **0.7**
22	$\mu \to ee\bar{e}$ 5×10^{-3} **9.2**	$\mu \to ee\bar{e}$ 7.3×10^{-3} **4.7**	$\mu \to ee\bar{e}$ 1.6×10^{-2} **5.7**	$\mu \to ee\bar{e}$ 8×10^{-3} **2.8**	$\mu \to ee\bar{e}$ 8×10^{-3} **2.8**	$\mu \to ee\bar{e}$ 2.5×10^{-3} **4.4**	$\mu \to ee\bar{e}$ 1.5×10^{-3} **1.8**
23	*	$B \to \bar{\mu}eK$ 0.6 **6.9**	$B \to \bar{\mu}eK$ 0.6 **6.9**	$B \to \bar{\mu}eK$ 0.3 **4.5**	$B \to \bar{\mu}eK$ 0.3 **4.5**	*	$B \to \bar{\mu}eK$ 0.3 **4.5**
31	*	$B \to \mu\bar{e}$ 0.8 **6.0**	$B \to \mu\bar{e}$ 0.8 **6.0**	V_{ub} 0.2 **2.0**	$B \to \mu\bar{e}$ 0.4 **2.0**	*	V_{ub} 0.2 **2.0**
32	*	$B \to \bar{\mu}eK$ 0.6 **9.3**	$B \to \bar{\mu}eK$ 0.6 **9.3**	$B \to \bar{\mu}eK$ 0.3 **3.3**	$B \to \bar{\mu}eK$ 0.3 **3.3**	*	$B \to \bar{\mu}eK$ 0.3 **3.3**
33	*	$\mu \to ee\bar{e}$ 7.3×10^{-3} **13**	$\mu \to ee\bar{e}$ 1.6×10^{-2} **13**	$\mu \to ee\bar{e}$ 8×10^{-3} **6.5**	$\mu \to ee\bar{e}$ 8×10^{-3} **6.5**	*	$\mu \to ee\bar{e}$ 1.5×10^{-3} **6.5**

Upper limits on $\dfrac{\lambda_{eq_\alpha}\lambda_{\mu q_\beta}}{M^2_{LQ}}$

α, β=Generations of quarks which couple to e, μ

ZEUS preliminary 1994-1997 (47.7 pb^{-1})

$e \to \tau$ $F = 0$

$\alpha\beta$	$S^L_{1/2}$ e^+u	$S^R_{1/2}$ $e^+(u+d)$	$\tilde{S}^L_{1/2}$ e^+d	V^L_0 e^+d	V^R_0 e^+d	$\tilde{V}^R_0$ e^+u	V^L_1 $e^+(\sqrt{2}u+d)$
11	$\tau \to \pi e$ 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**
12	**3.0**	$\tau \to Ke$ 5 **2.5**	$K \to \pi\nu\bar{\nu}$ 10^{-3} **4.6**	$\tau \to Ke$ 3 **3.6**	$\tau \to Ke$ 3 **3.6**	**2.6**	$K \to \pi\nu\bar{\nu}$ 2.5×10^{-4} **1.2**
13	*	$B \to \tau\bar{e}X$ 8 **4.9**	$B \to \tau\bar{e}X$ 8 **4.9**	$B \to l\nu X$ 2 **4.4**	$B \to \tau\bar{e}X$ 4 **4.4**	*	$B \to l\nu X$ 2 **4.4**
21	**15**	$\tau \to Ke$ 5 **9.2**	$K \to \pi\nu\bar{\nu}$ 10^{-3} **11**	$\tau \to Ke$ 3 **4.9**	$\tau \to Ke$ 3 **4.9**	**6.1**	$K \to \pi\nu\bar{\nu}$ 2.5×10^{-4} **2.6**
22	$\tau \to ee\bar{e}$ 20 **19**	$\tau \to ee\bar{e}$ 30 **10**	$\tau \to ee\bar{e}$ 66 **12**	$\tau \to ee\bar{e}$ 33 **6.1**	$\tau \to ee\bar{e}$ 33 **6.1**	$\tau \to ee\bar{e}$ 10 **10**	$\tau \to ee\bar{e}$ 6.1 **4.1**
23	*	$B \to \tau\bar{e}X$ 8 **15**	$B \to \tau\bar{e}X$ 8 **15**	$B \to l\nu X$ 2 **10**	$B \to \tau\bar{e}X$ 4 **10**	*	$B \to l\nu X$ 2 **10**
31	*	$B \to \tau\bar{e}X$ 8 **16**	$B \to \tau\bar{e}X$ 8 **16**	V_{ub} 0.2 **5.2**	$B \to \tau\bar{e}X$ 4 **5.2**	*	V_{ub} 0.2 **5.2**
32	*	$B \to \tau\bar{e}X$ 8 **20**	$B \to \tau\bar{e}X$ 8 **20**	$B \to l\nu X$ 2 **7.3**	$B \to \tau\bar{e}X$ 4 **7.3**	*	$B \to l\nu X$ 2 **7.3**
33	*	$\tau \to ee\bar{e}$ 30 **28**	$\tau \to ee\bar{e}$ 66 **28**	$\tau \to ee\bar{e}$ 33 **14**	$\tau \to ee\bar{e}$ 33 **14**	*	$\tau \to ee\bar{e}$ 6.1 **14**

$$\text{Upper limits on } \frac{\lambda_{eq_\alpha}\lambda_{\tau q_\beta}}{M^2_{LQ}}$$

α, β=Generations of quarks which couple to e, τ

R-Parity Violating Supersymmetry

$R_p = (-1)^{3B+L+2S} = 1$ for particles, -1 for sparticles

(B =baryon number, L =lepton number, S = spin).

R_p violation $\Rightarrow$ sparticles can decay to particles.

R_p violating term of SUSY superpotential:

$$W_{\not R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

L, Q=	L-handed lepton, quark doublet superfields.
$\overline{E}, \overline{D}, \overline{U}$=	R-handed charged lepton, d and u-type quark singlet superfields.
i, j, k=	generation indices.

Expand $\lambda'_{ijk} L_i Q_j \bar{D}_k$:

$$\lambda'_{ijk} \quad [\quad -\tilde{e}^i_L u^j_L \overline{d}^k_R - e^i_L \tilde{u}^j_L \overline{d}^k_R - (\overline{e}^i_L)^c u^j_L (\tilde{d}^k_R)^*$$
$$+\tilde{\nu}^i_L d^j_L \overline{d}^k_R + \nu^i_L \tilde{d}^j_L \overline{d}^k_R + (\overline{\nu}^i_L)^c d^j_L (\tilde{d}^k_R)^*] + \text{h. c.}$$

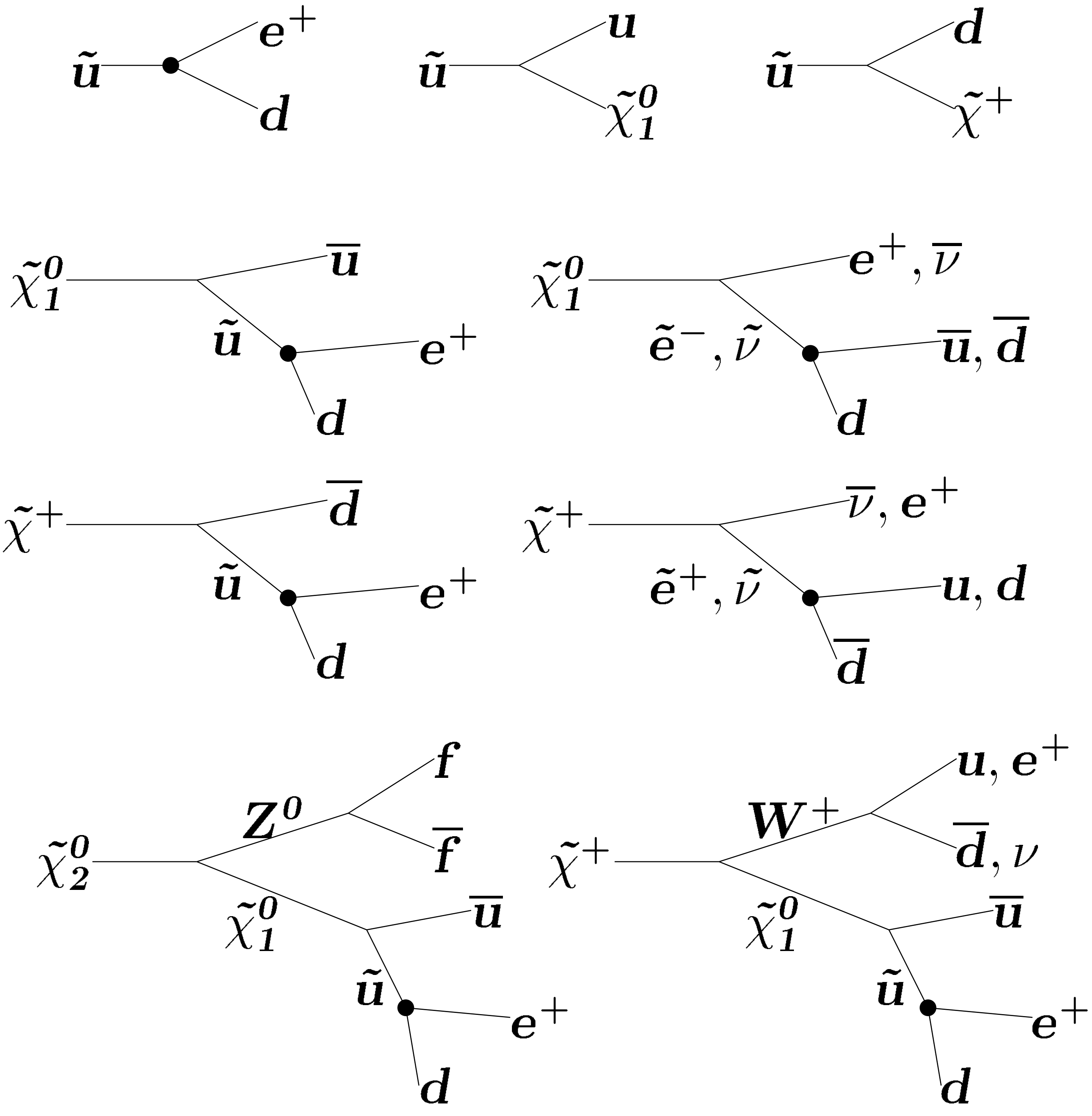
In ep collisions $e^+ d^k \rightarrow \tilde{u}^j$ and $e^- u^j \rightarrow \tilde{d}^k$ occur.

Narrow-width approximation:

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

(here d^k is the parton density for down type quarks)

Strong limits on λ'_{111} from $dd \rightarrow u u e^- e^-$.



$\tilde{\chi}^0$ decays equally likely to $e^+\bar{u}d$ and $e^-u\bar{d}$

$e^- + \text{jets}$ final states have ~ 0 background

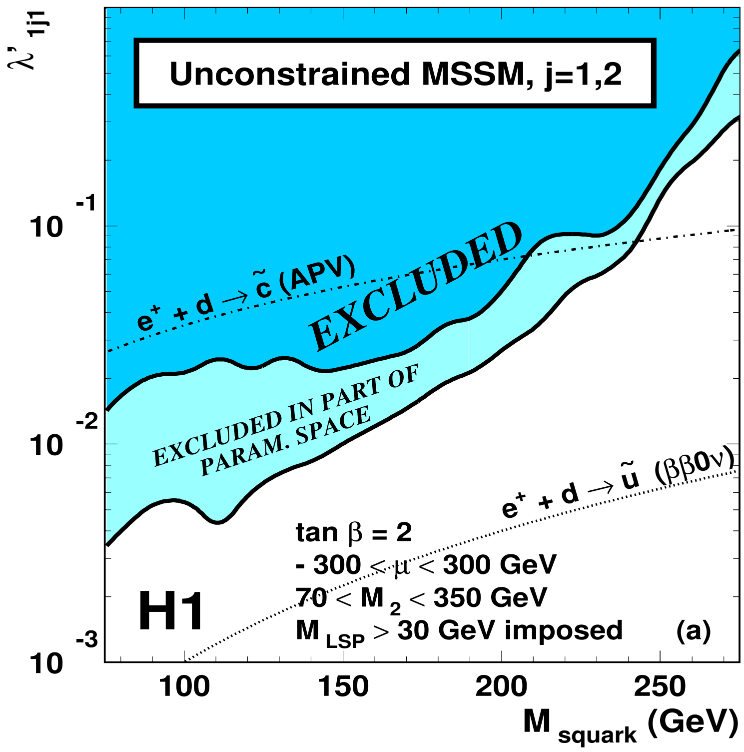
RPV SUSY analysis covers many different final states

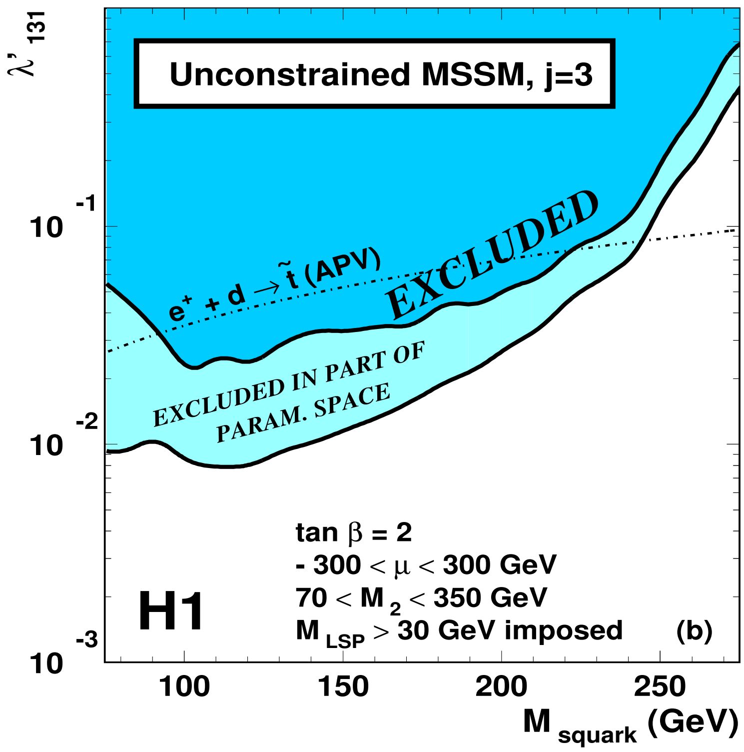
decay	ZEUS	H1
$\tilde{q} \to e^+ q'$	•	•
$\tilde{d} \to \nu + d$		•
$\tilde{q} \to e^+ q\bar{q}$	•	•
$\tilde{q} \to e^- q\bar{q}$	•	•
$\tilde{q} \to \nu q\bar{q}$	•	•
$\tilde{q} \to e^+ q\bar{q}q\bar{q}$	•	•
$\tilde{q} \to e^- q\bar{q}q\bar{q}$	•	•
$\tilde{q} \to \nu q\bar{q}q\bar{q}$	•	•
$\tilde{q} \to e^+ q\bar{q}\ell^+\ell^-$		•
$\tilde{q} \to e^- q\bar{q}\ell^+\ell^-$		•
$\tilde{q} \to \nu q\bar{q}\ell^+\ell^-$		•
$\tilde{q} \to e^+ q\bar{q}\ell\bar{\nu}_\ell$		•
$\tilde{q} \to e^- q\bar{q}\ell\bar{\nu}_\ell$		•
$\tilde{q} \to \nu q\bar{q}\ell\bar{\nu}_\ell$		•

Not included:

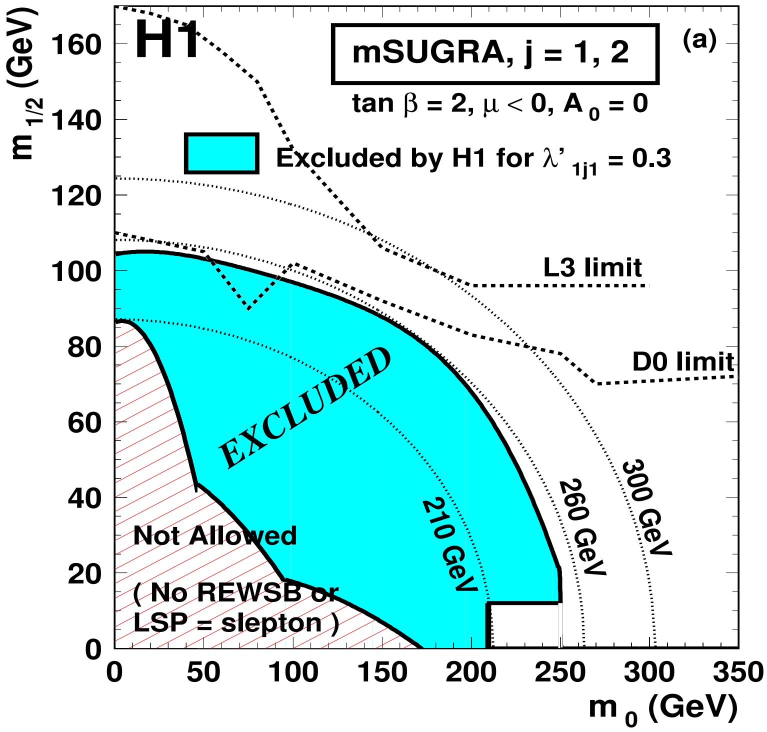
- Decays involving $\chi_3^0, \chi_4^0, \chi_2^+$
- Decays with a final state Higgs.
- Decays with final state top.

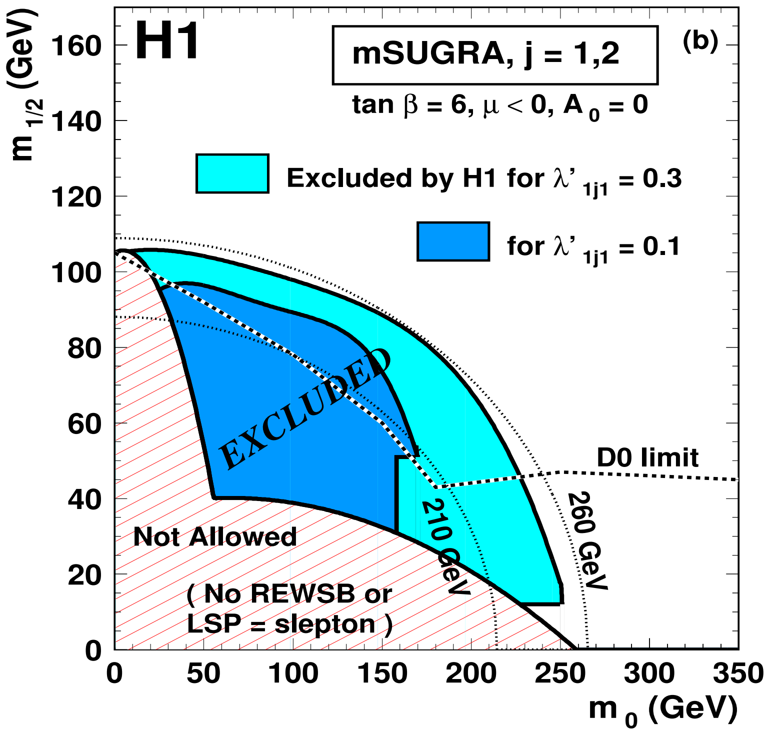
Scan over SUSY parameters μ and M_2





SUGRA model: Sparticle masses, branching ratios determined by $m_0, m_{1/2}, \tan\beta, \mathrm{sign}(\mu)$.





Events with Isolated Leptons and $\not{P}_t$

Standard Model sources

- $ep \to WX$ followed by $W \to \ell\nu$
- NC DIS ($ep \to eX \not{P}_t$)
- $ep \to \ell^+\ell^- X$ via inelastic $\gamma\gamma \to \ell^+\ell^-$

Event Selection

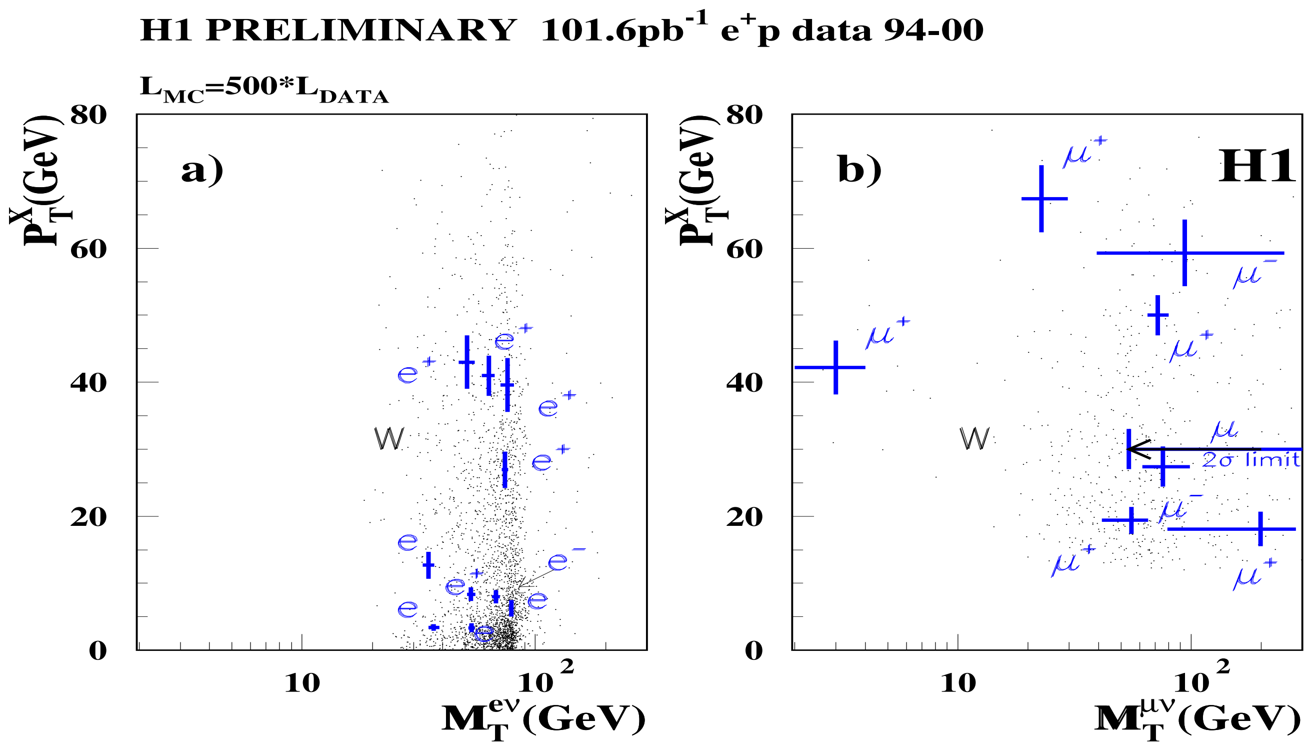
cut	H1	ZEUS
$P_t^{\mathrm{cal}} >$	12 GeV	20 GeV
$P_t^{\mathrm{track}} >$	10 GeV	10 GeV
Track polar angle	$5^\circ < \theta_{\mathrm{track}} < 145^\circ$	$17^\circ < \theta_{\mathrm{track}} < 115^\circ$
$\eta\phi$ isolation from nearest jet $\eta\phi$ isolation from nearest track	$D_{\mathrm{jet}} > 1$ $D_{\mathrm{track}} > 0.5$	$D_{\mathrm{jet}} > 1$ $D_{\mathrm{track}} > 0.5$
Reject if additional μ	Yes	No
$P_t^X >$	12 GeV	5 GeV
Acoplanarity $\ell X >$	$20^\circ (e)$, $10^\circ (\mu)$	11.5°

Number of events ($e+\mu$) passing cuts

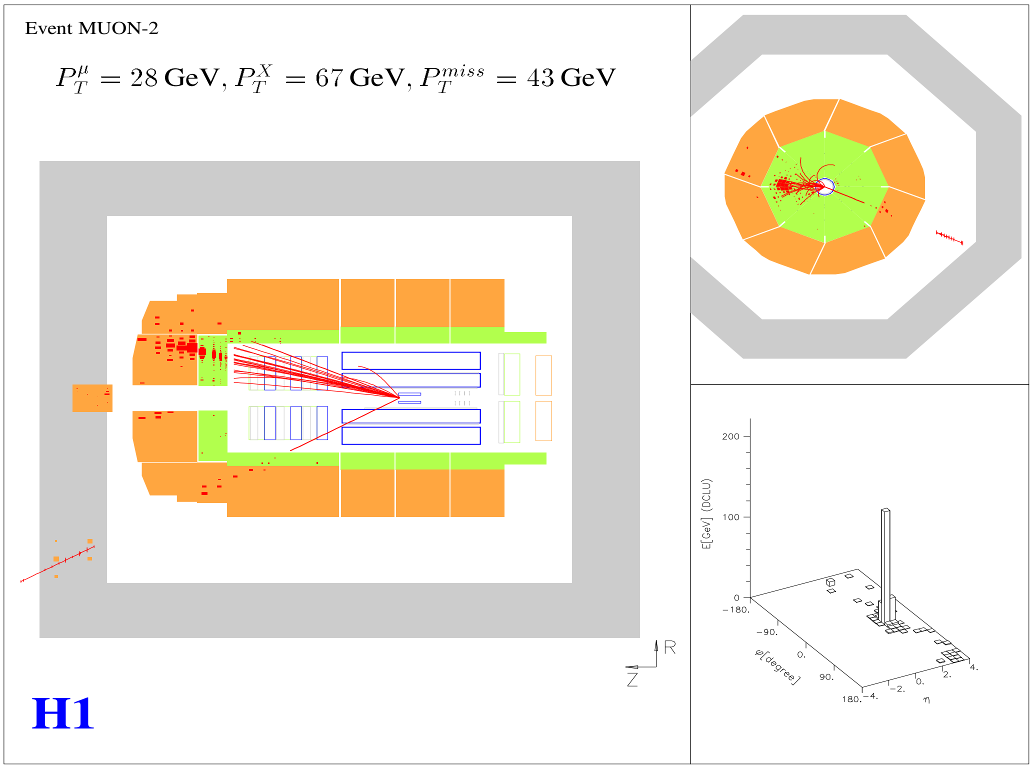
	H1 (115 pb^{-1})			ZEUS (130 pb^{-1})		
	Observed	Expected	W	Observed	Expected	W
	$5+8=13$	5.1 ± 1.3	4.2	$10+7=17$	16.4 ± 2.3	4.0
$P_t^X > 25$ GeV	$4+6=10$	2.8 ± 0.7	2.3	$1+1=2$	2.4 ± 0.2	2.0
$P_t^X > 40$ GeV	$2+4=6$	1.0 ± 0.3	0.9	0	1.0 ± 0.1	0.9

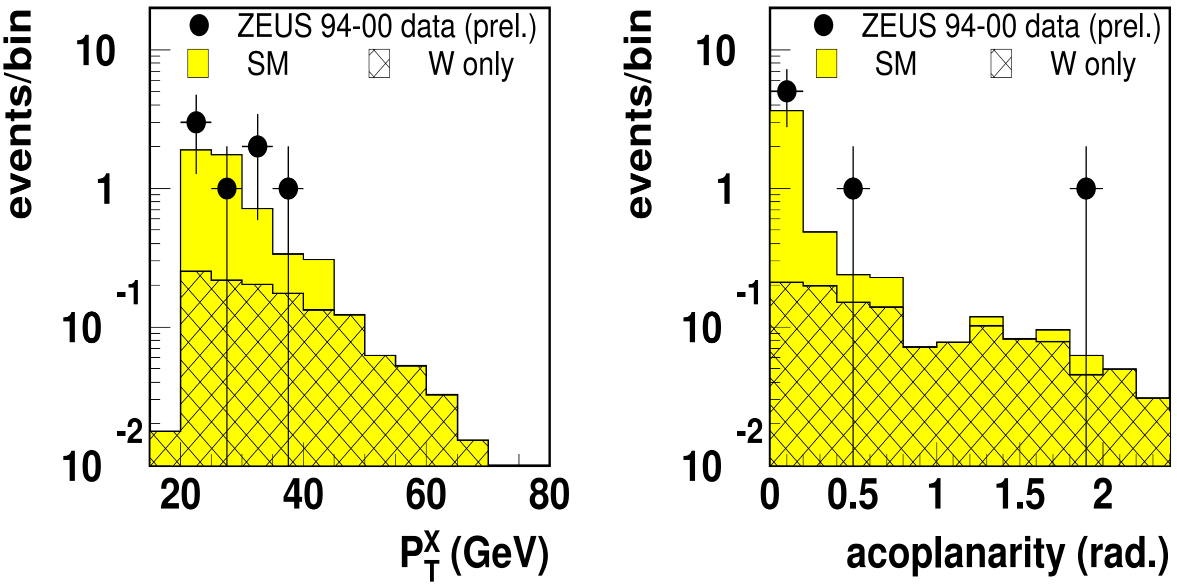
H1 sees an excess at high P_t^X

W Monte Carlo is LO QCD

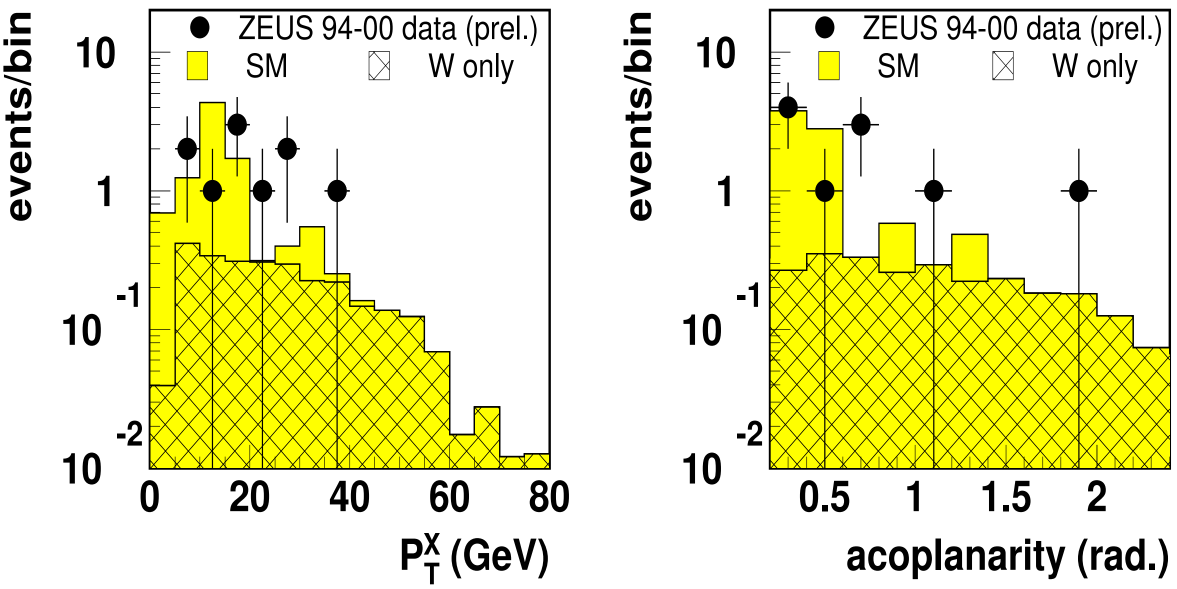

H1 PRELIMINARY 101.6pb-1 e+p data 94-00
LMC=500*LDATA
a)
b)
H1
W
W
e+
e−
μ+
μ−
μ
2σ limit
PTX(GeV)
MTeν(GeV)
MTμν(GeV)
10
10 2
0
20
40
60
80

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


Event MUON-2
$P_T^\mu = 28\,\mathrm{GeV}, P_T^X = 67\,\mathrm{GeV}, P_T^{miss} = 43\,\mathrm{GeV}$
H1
R
Z
E[GeV] (DCLU)
φ[degree]
η



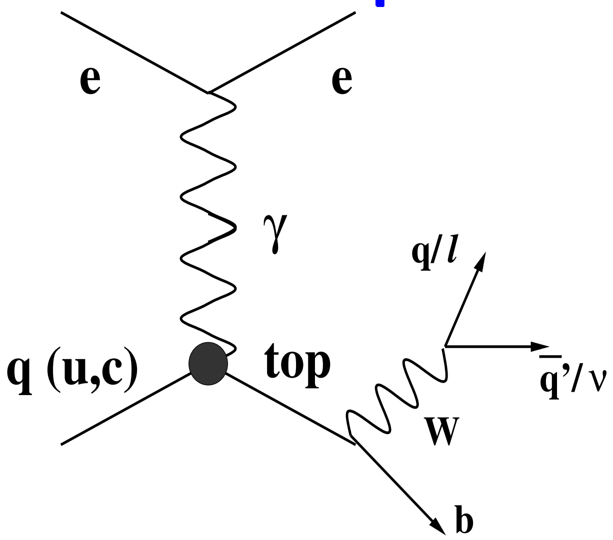
ZEUS μ data



ZEUS e data

ZEUS data is consistent with expected background.

Search for ep $\to$ tX



Leptonic selections are applied to isolated lepton sample.

ZEUS

- $E - P_Z < 45\,\mathrm{GeV}$ (e only)
- $\not{P}_t(\mu + \mathrm{had}) > 12\,\mathrm{GeV}$ (μ only)
- $P_t^X > 40\,\mathrm{GeV}$

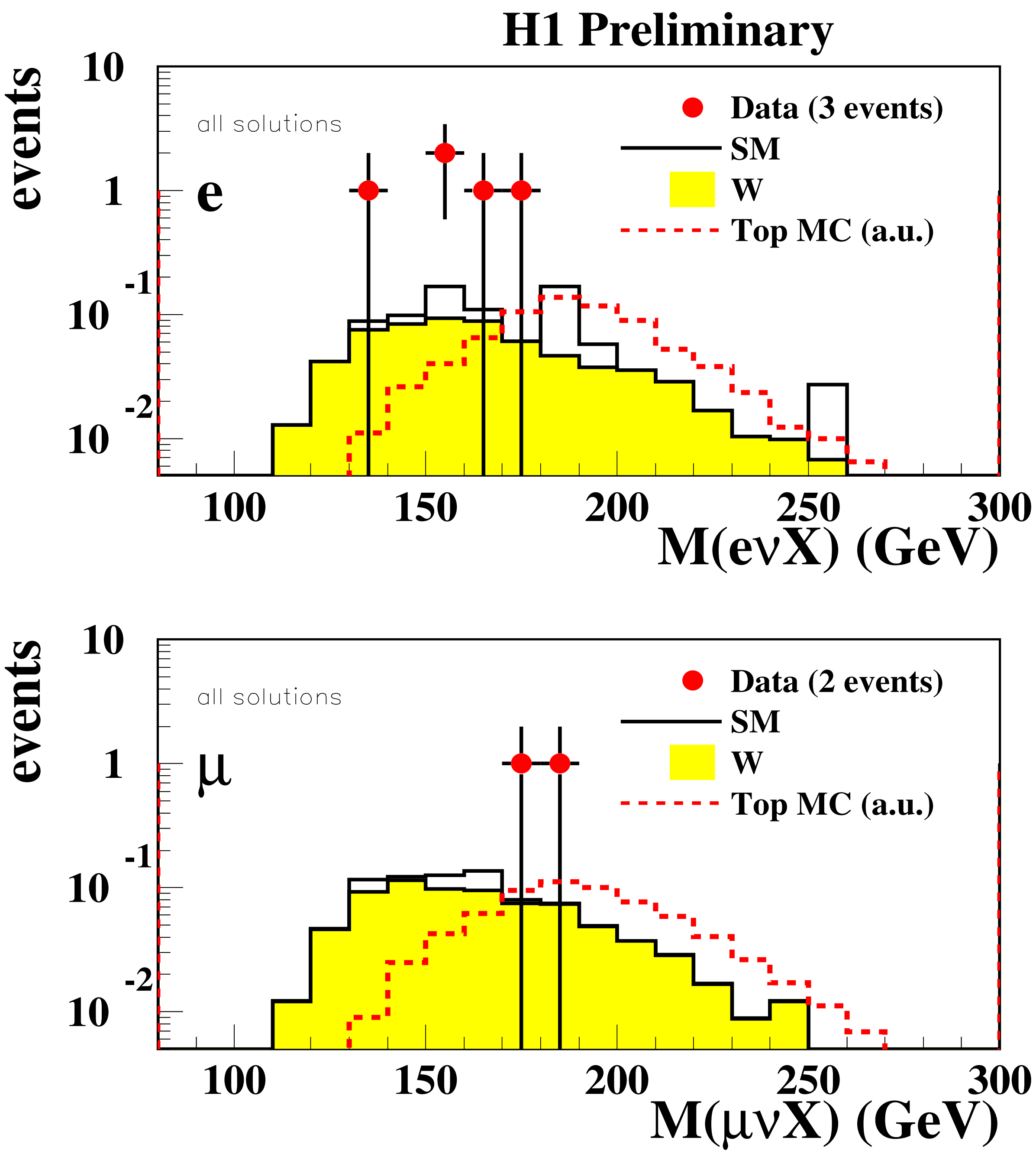
no events pass, 0.96 expected, efficiency$(e + \mu) = 5.5\%$

H1

- $P_t^X > 25\,\mathrm{GeV}$
- a jet with $P_t^{\mathrm{jet}} > 25\,\mathrm{GeV}$ (35 GeV if $\theta_{\mathrm{jet}} < 35^\circ$)
- $M_T^{\ell\nu} > 10\,\mathrm{GeV}$
- lepton must have positive charge

3 e events pass, 0.8 expected, efficiency$= 4.0\%$
2 μ events pass, 0.8 expected, efficiency$=4.8\%$

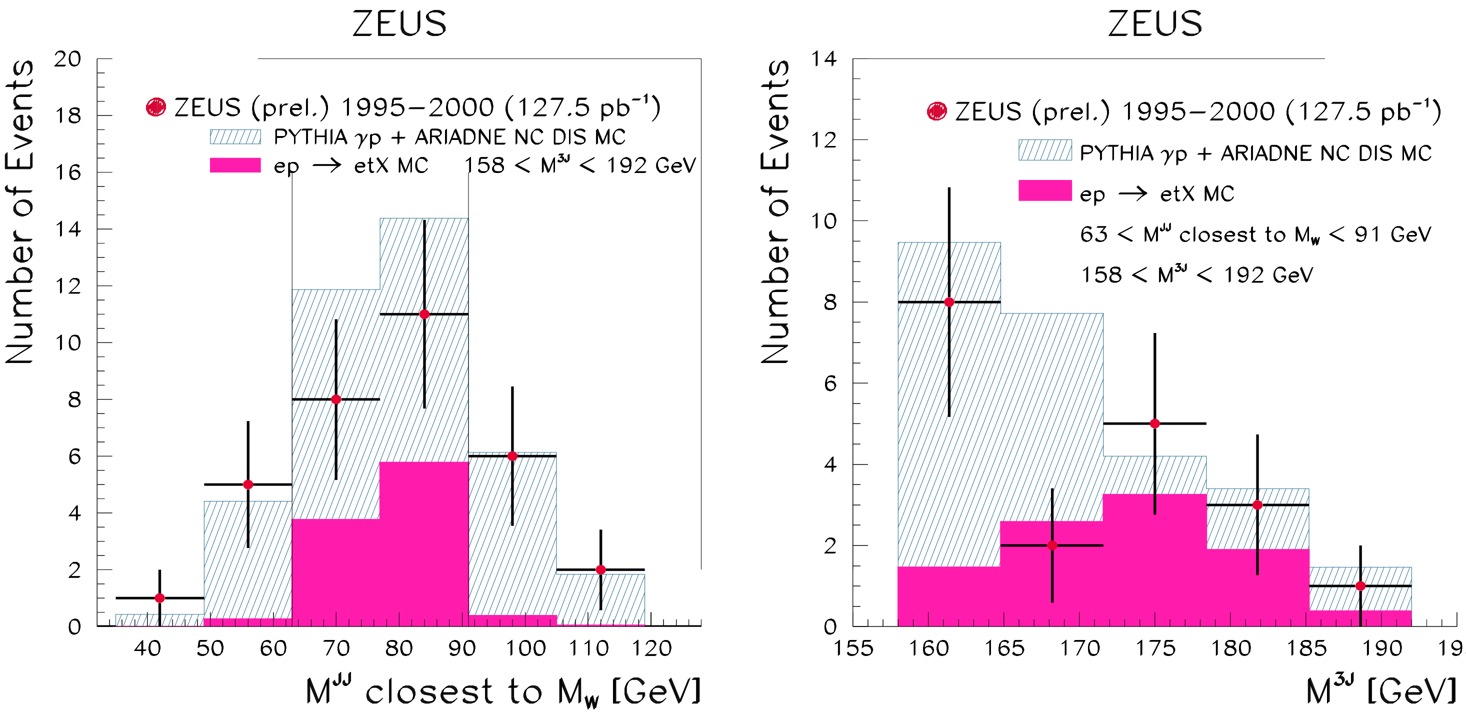
efficiencies include $BR(W \to \ell\bar{\nu}_\ell)$


H1 Preliminary
events
all solutions
e
Data (3 events)
SM
W
Top MC (a.u.)
M(eνX) (GeV)
events
all solutions
μ
Data (2 events)
SM
W
Top MC (a.u.)
M(μνX) (GeV)

ZEUS Hadronic selection ($\mathcal{L} = 127.5\,\text{pb}^{-1}$)

- 3 jets with $-1 < \eta^{\text{jet}} < 2.5$
- $E_T^{\text{jet}} > 40, 25, 14\,\text{GeV}$
- $0.16 < y_{JB} < 0.95$
- Veto NC DIS
- $63\,\text{GeV} < M^{JJ} < 91\,\text{GeV}$
- $158\,\text{GeV} < M^{3J} < 192\,\text{GeV}$

19 events remain, 20.0 expected, efficiency $= 31\%$ of all top decays

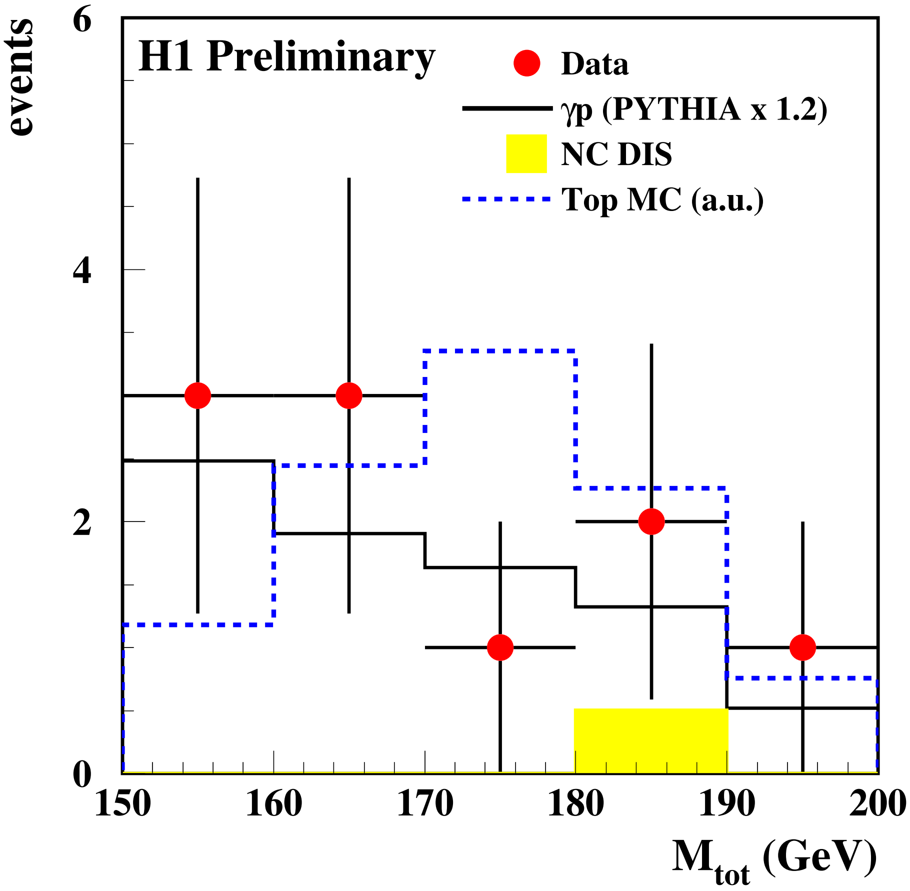


γp background normalized to data with $M^{3J} < 158$ GeV

H1 Hadronic selection ($\mathcal{L} = 36.5\,\mathrm{pb}^{-1}$)

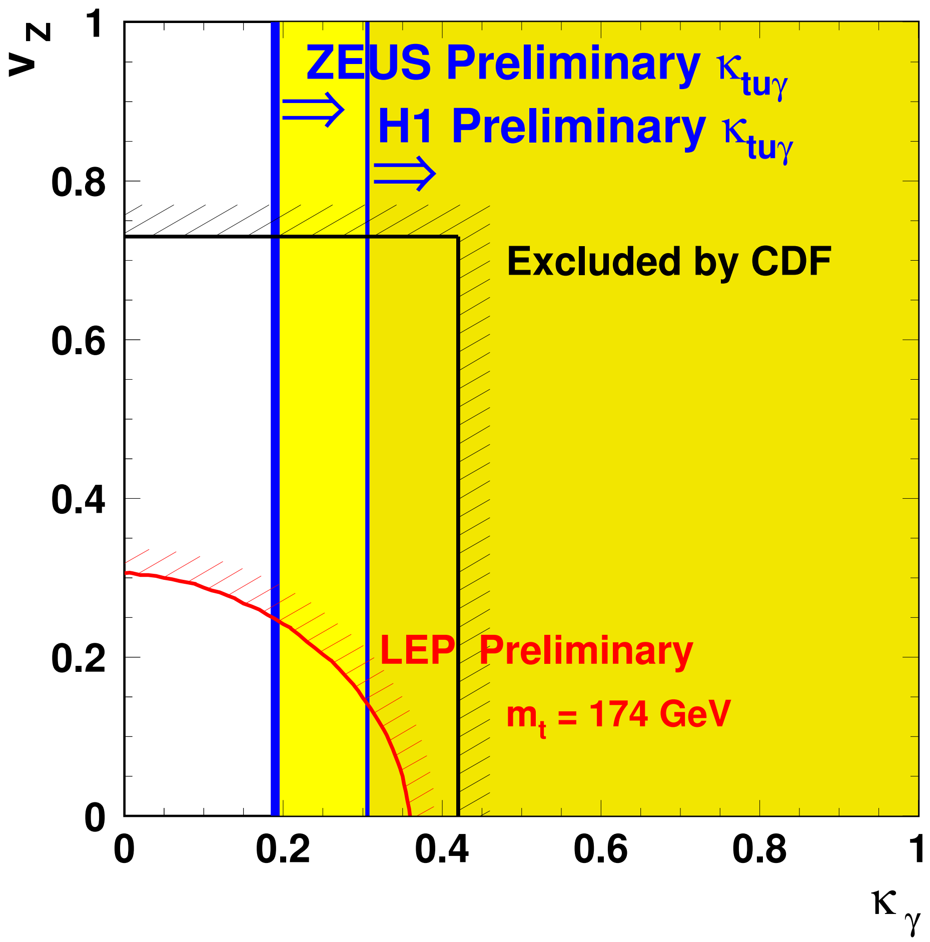
- 3 jets with $E_T^{\mathrm{jet}} > 25, 15, 10\,\mathrm{GeV}$
- $E_t > 120\,\mathrm{GeV}$
- Veto NC DIS
- $70\,\mathrm{GeV} < M^{JJ} < 90\,\mathrm{GeV}$
- $150\,\mathrm{GeV} < M^{3J} < 198\,\mathrm{GeV}$

10 events remain, $8.3^{+4.2}_{-1.9}(\mathrm{exp}) \pm 4.2(\mathrm{the})$ expected
efficiency $= 21\%$ of all top decays



ZEUS Lepton + hadron channels $\rightarrow$ 95% CL limit
$\sigma(ep \rightarrow etX) < 0.25\,\mathrm{pb}(\sqrt{s} = 320\,\mathrm{GeV})$
Limit on anomalous FCNC coupling: $\kappa_{tu\gamma} < 0.19$

H1 Lepton + hadron channels $\rightarrow$ 95% CL limit
$\sigma(ep \rightarrow etX) < 0.87\,\mathrm{pb}(\sqrt{s} = 320\,\mathrm{GeV})$
Limit on anomalous FCNC coupling: $\kappa_{tu\gamma} < 0.305$

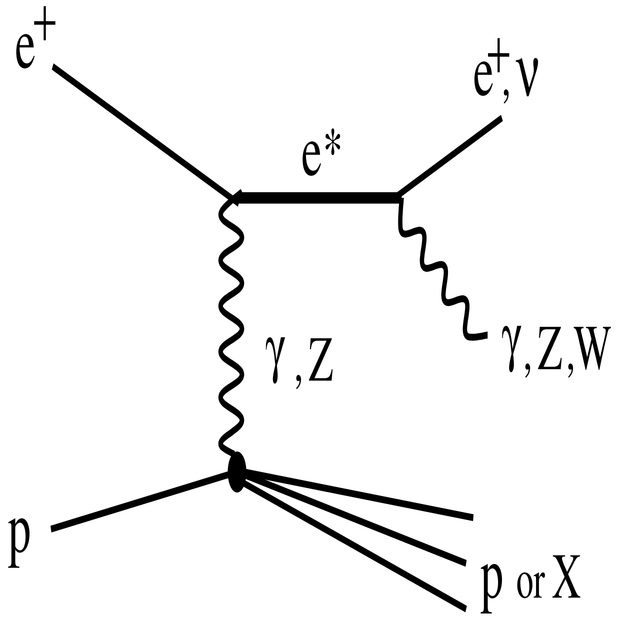


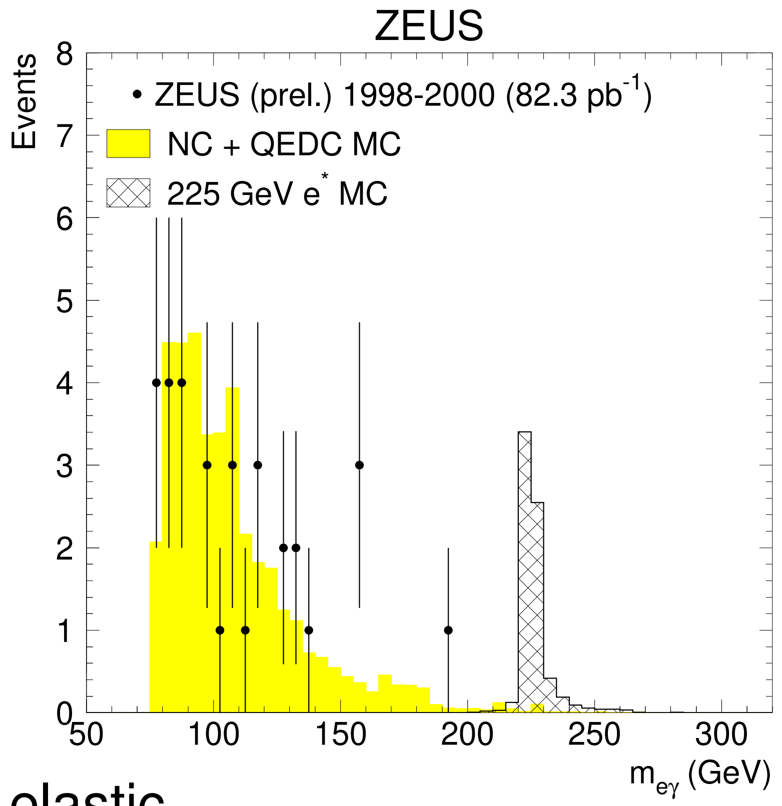
Excited Fermions

If fermions are composite, then excited states are expected

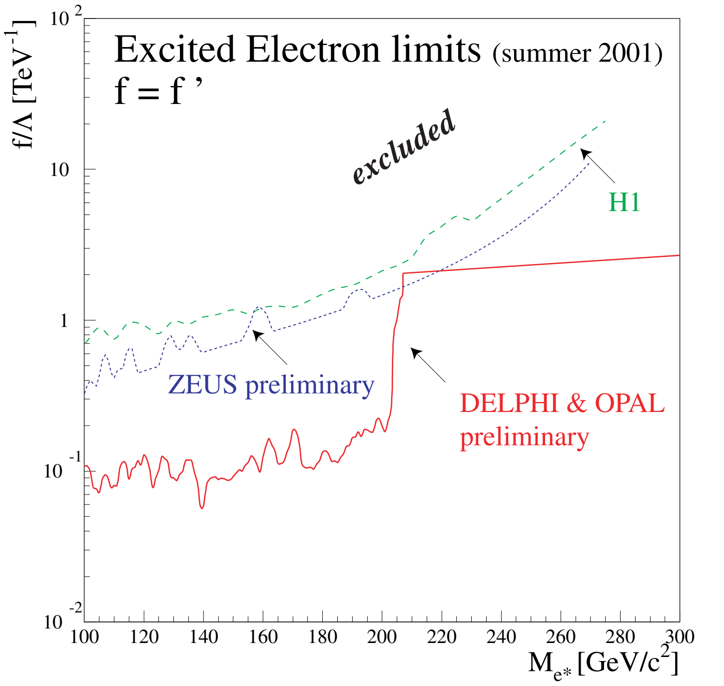
$$\mathcal{L} = \frac{1}{2\Lambda}\bar{F}^*_R \sigma^{\mu\nu}\left[g f \frac{\tau^a}{2} W^a_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G^a_{\mu\nu}\right] F_L + h.c.$$

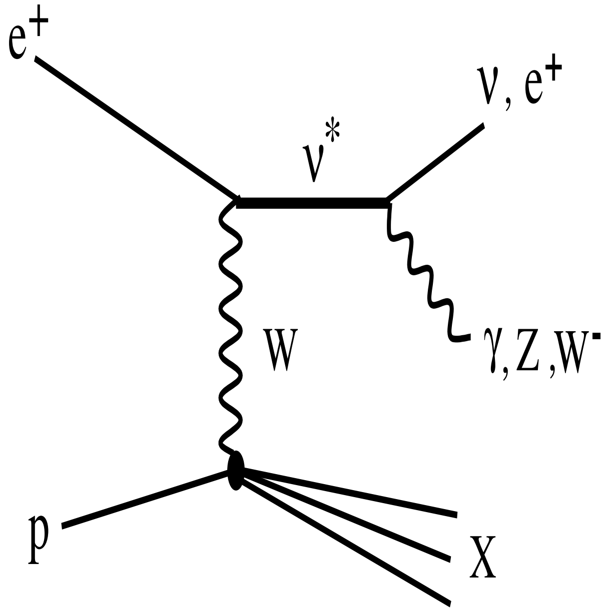
- Magnetic coupling between fermion weak-isodoublet F_L and excited fermions F^*_R
- f, f', f_s are weight factors for Standard Model gauge fields.
- $\Lambda =$ the compositeness scale



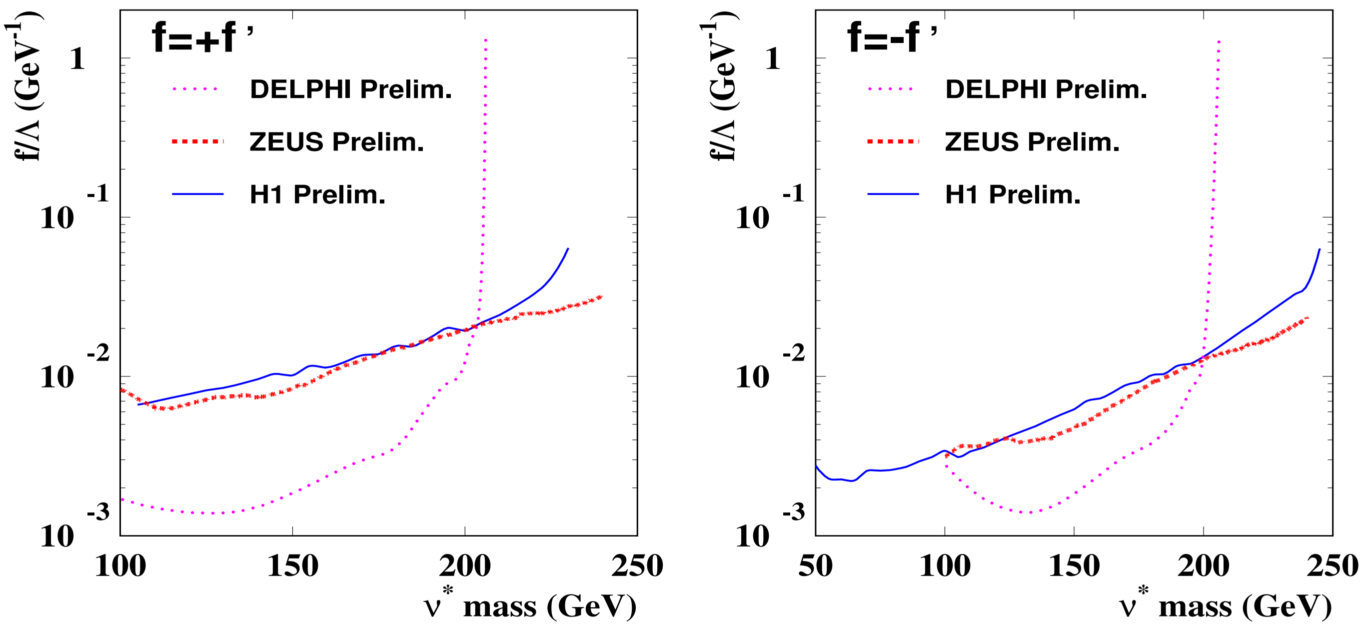


$\sim 50\%$ of e^* production is elastic.
Decay to $e\gamma \sim f + f'$





Decay to $\nu\gamma \sim f - f'$



Conclusions

- HERA is sensitive to LQ, $\tilde{q}$, f^* production with masses < 300 GeV if coupling is high enough.
- More massive states can be detected via virtual effects.
- Most searches use > 100 pb^{-1}data sets.

Outlook

- HERA has been upgraded to increase $\mathcal{L}$ by $4\times$.
- Detector upgrades for H1 and ZEUS (μ-vertex detector).
- New run starting in October.
- Expect 1 fb^{-1} by 2005.