W bosons and searches for Beyond SM physics at HERA

Roberto Sacchi–Torino University

Ringberg Workshop "New Trends in HERA Physics 2001"

June 22, 2001

On behalf of H1 and ZEUS

HERA as an e–q collider:

- e–q resonances
  - leptoquarks
  - R–parity violating SUSY
- eeqq Contact Interactions
  - Compositeness
  - Large Extra dimensions,
  - Quark radius
- W and Top search
- excitations: Excited Fermions (not shown)
- Conclusions and Outlook

Leptoquarks–Intro

Carry both Lepton and Baryon numbers

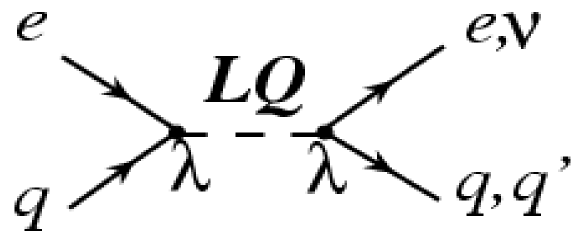
- Fermion Number: F=|3B+L| = 0;2

F=0: couple to e^+q ($e^-\bar{q}$) $\Rightarrow$ best with $\mathbf{e^+p}$ data
F=2: couple to e^-q ($e^+\bar{q}$) $\Rightarrow$ best with $\mathbf{e^-p}$ data

Buchmüller–Rückl–Wyler (**BRW**) Model:

- *SU(3)×SU(2)×U(1)* invariance;
- lepton and baryon number conservation;
- either left– or right–handed couplings;
- isospin multiplets are mass degenerate;

7 scalar and 7 vector LQ species
branching ratio to eq/νq: β=0,½,1



s–channel LO cross section (NWA)

$$\sigma^{NWA} = (J+1)\frac{\pi}{4s}\lambda^2 q\left(\frac{M_{LQ}^2}{s}, M_{LQ}^2\right)$$

(*good approx. for small λ and $M_{LQ}<\sqrt{s}$*)

LQ decay angular distribution

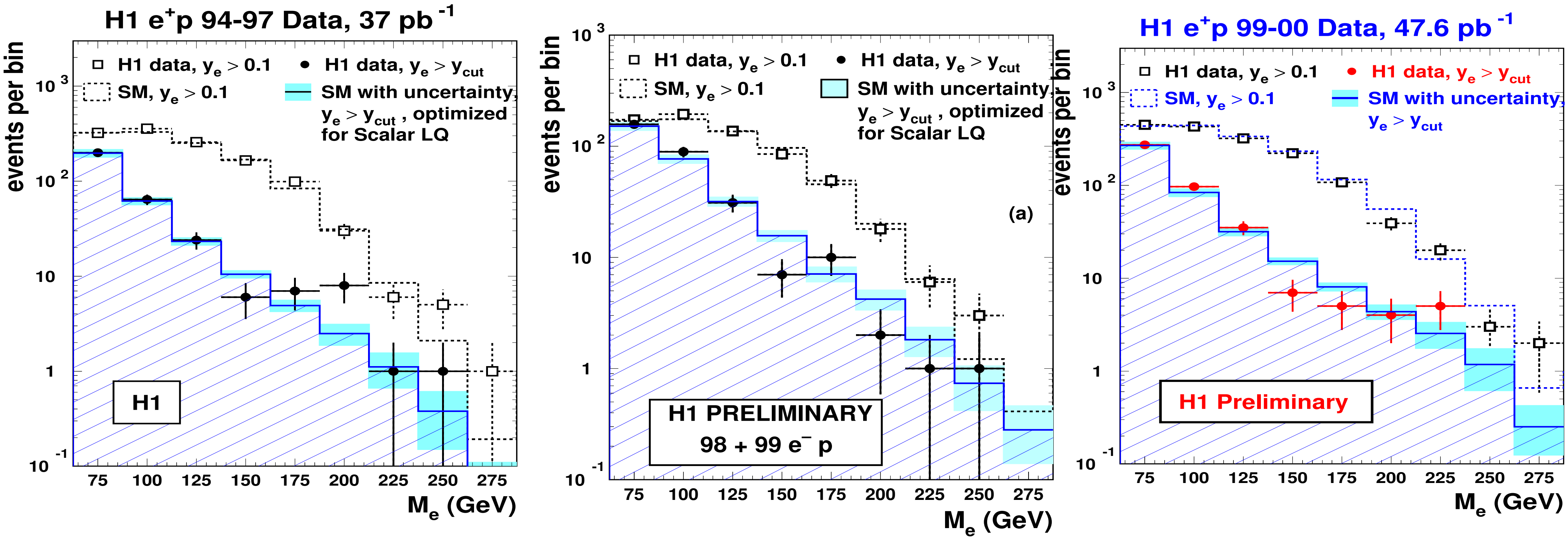
($\cos\theta^*=1-2y$)

flat y	scalar LQ
$(1-y)^2$	vector LQ
$1/y^2$	NC DIS background

$\Rightarrow$ **y cut used to enhance sensitivity**

H1 Leptoquark search

- NC DIS selection: Et(e)>15GeV;
- $0.1<y_e<0.9$, $Q^2>2500$ GeV^2
- Mass reconstruction from e energy/angle (M_e)



Note: High–x high–Q^2 excess of events observed by both ZEUS and H1 in 1994–97 data has not been confirmed with new data!

ZEUS high–Q2 high–x excess ?

ZEUS ⇒

N_{obs} (N_{exp})	1994–97	1998–99	1999–00	1994–96
$Q^2>35000$ GeV^2	2 (0.34)	2 (1.02)	1 (0.53)	2 (0.15)
$x>0.55$, $y>0.25$	4 (1.90)	1 (1.30)	0 (1.60)	4 (0.91)

ZEUS e–jet resonance search

- Require: Et > 60 GeV
  Ee > 25 GeV
  Et(jet) > 15 GeV
- Look at invariant e–jet mass(M_{ej})

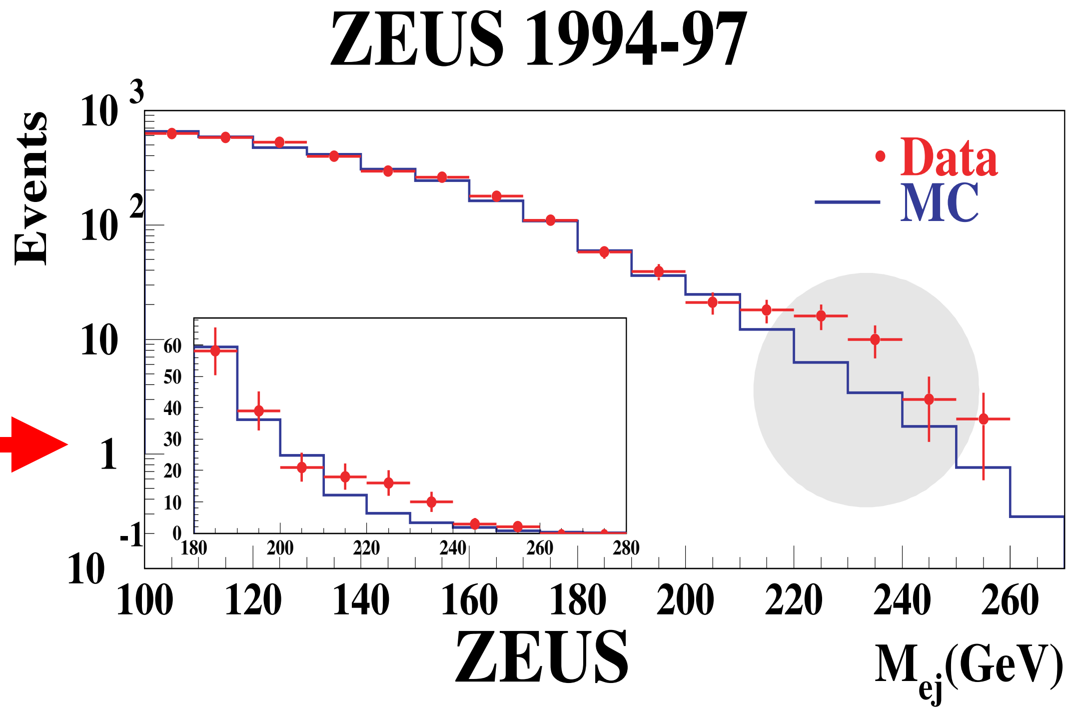
ZEUS 1994–97 e^+p

Excess observed at M>210 GeV:

⇒ 49 events found (24.7±5.6 expected)

⇒ shape of y–distrib. similar to NC

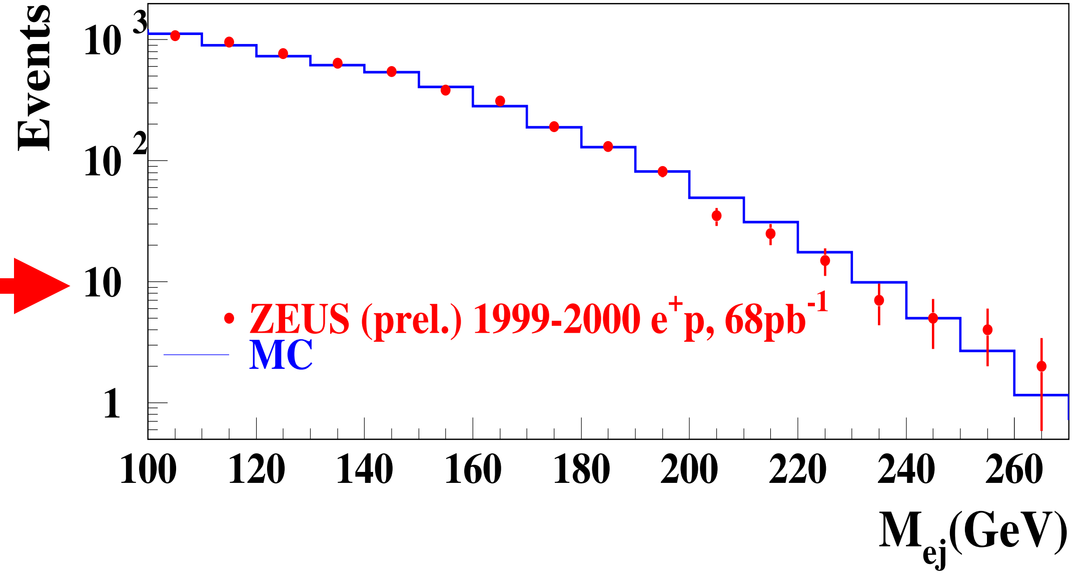
⇒ not statistically compelling...



ZEUS 1999–00 e^+p

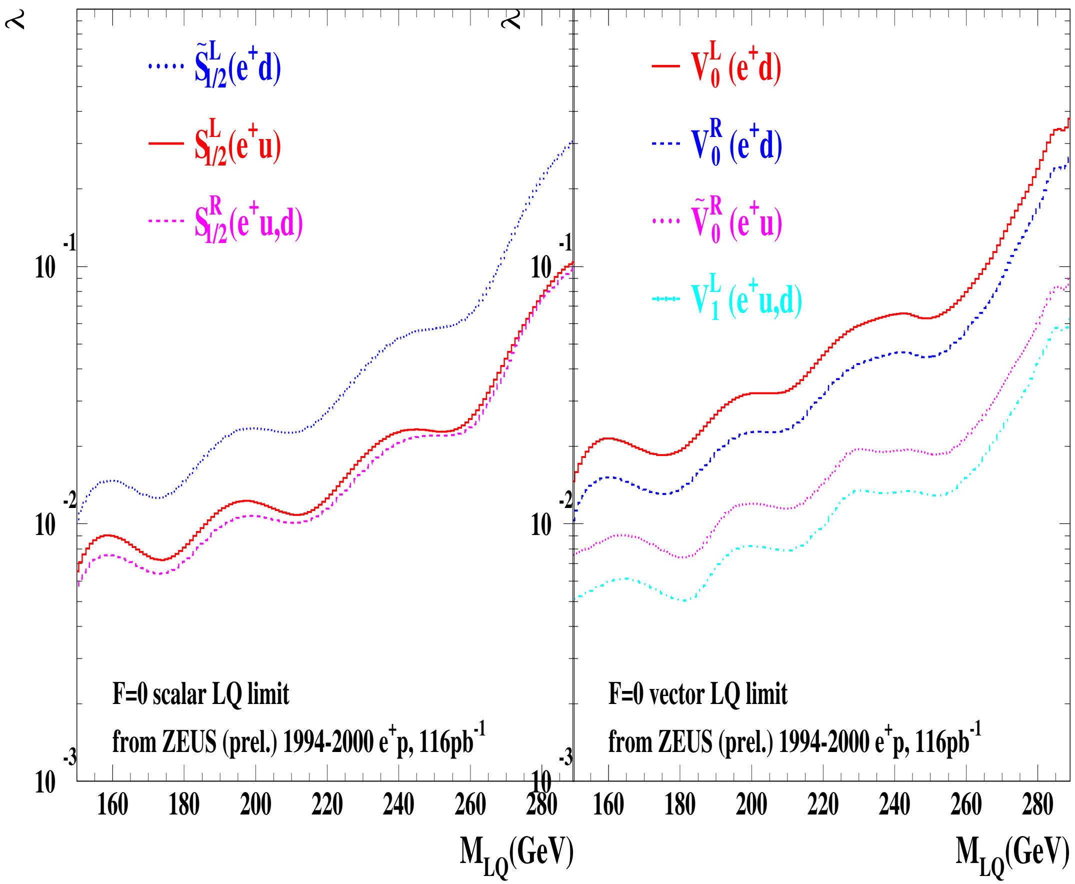
Excess not confirmed

Good agreement with SM NC

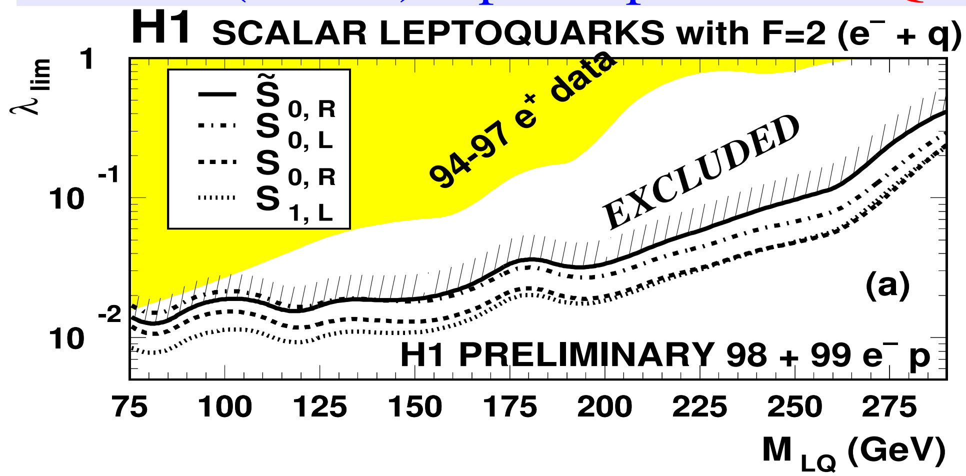


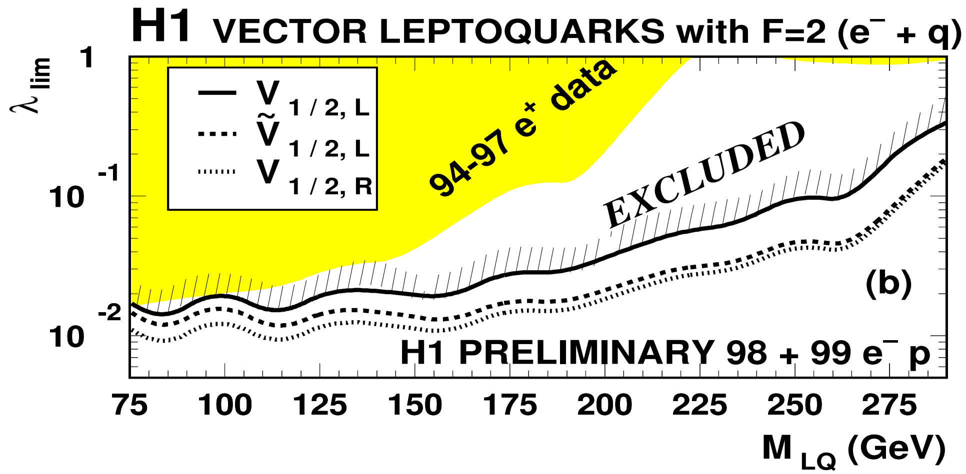
Limits on 1st generation BRW LQs

ZEUS Prel. (94–00) e^+p 116pb^{-1} F=0 LQs



H1 Prel. (98–99) e^-p 14.4pb^{-1} F=2 LQs



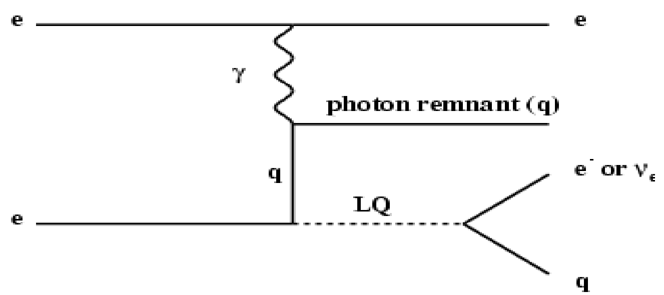


F=2 LQs $\Rightarrow$ Limits up to 290 GeV for λ of EM coupling strenght

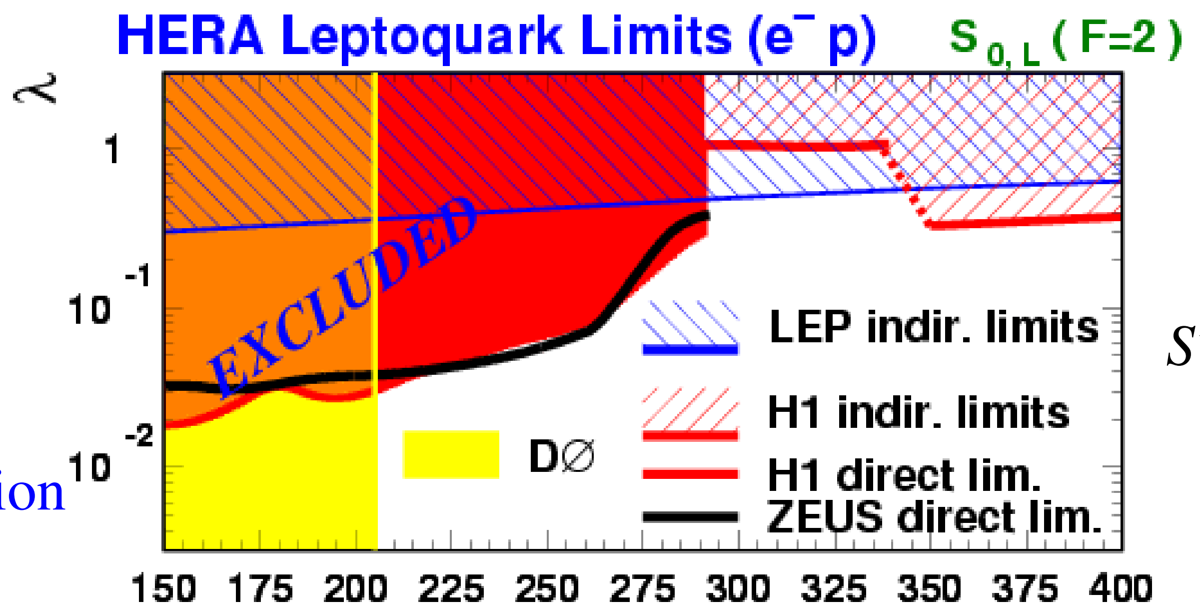
F=0 LQs $\Rightarrow$ Limits up to 275 GeV for 1/100 of EM strenght

Comparison with LEP and TeVatron

LEP:



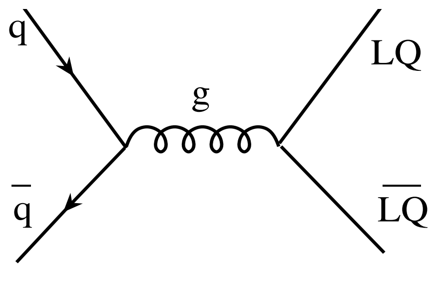
limits shown are from virtual effects to hadronic cross section



$S_0^L \rightarrow (\beta = \frac{1}{2})$

TeVatron:

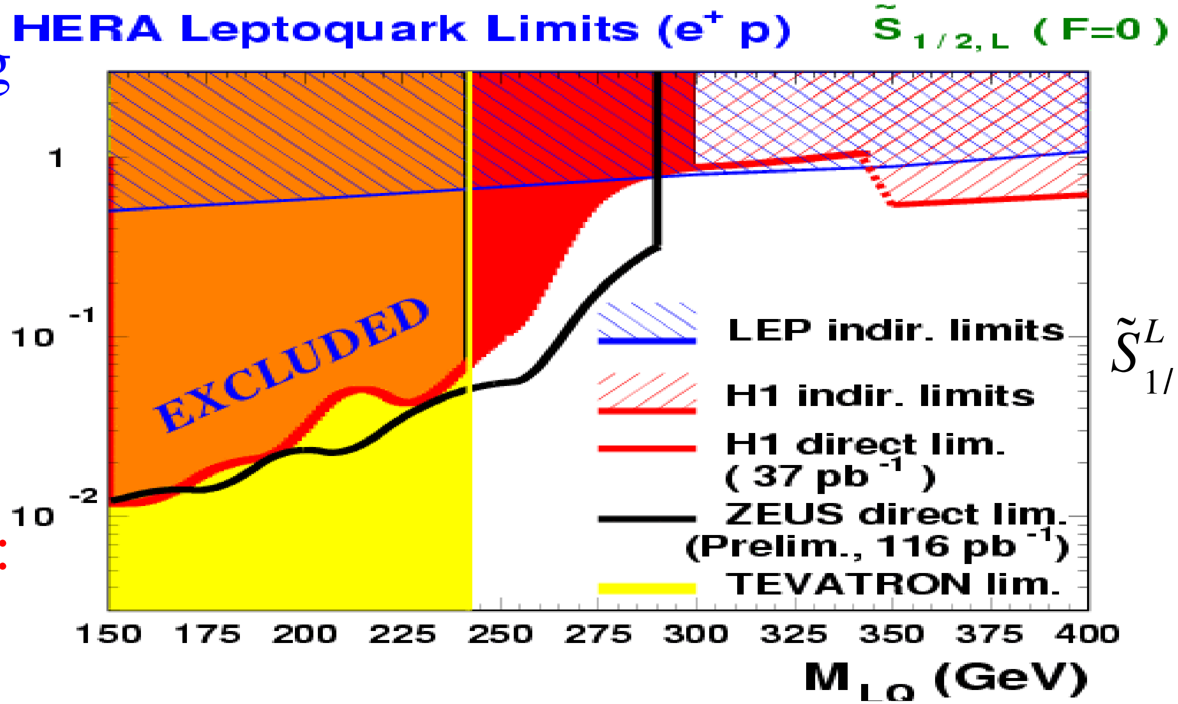
LQs pair produced via strong coupling:



⇒ limits independent of λ

⇒ CDF/D0 combined limits:

M_{LQ}>242 GeV (β=1)



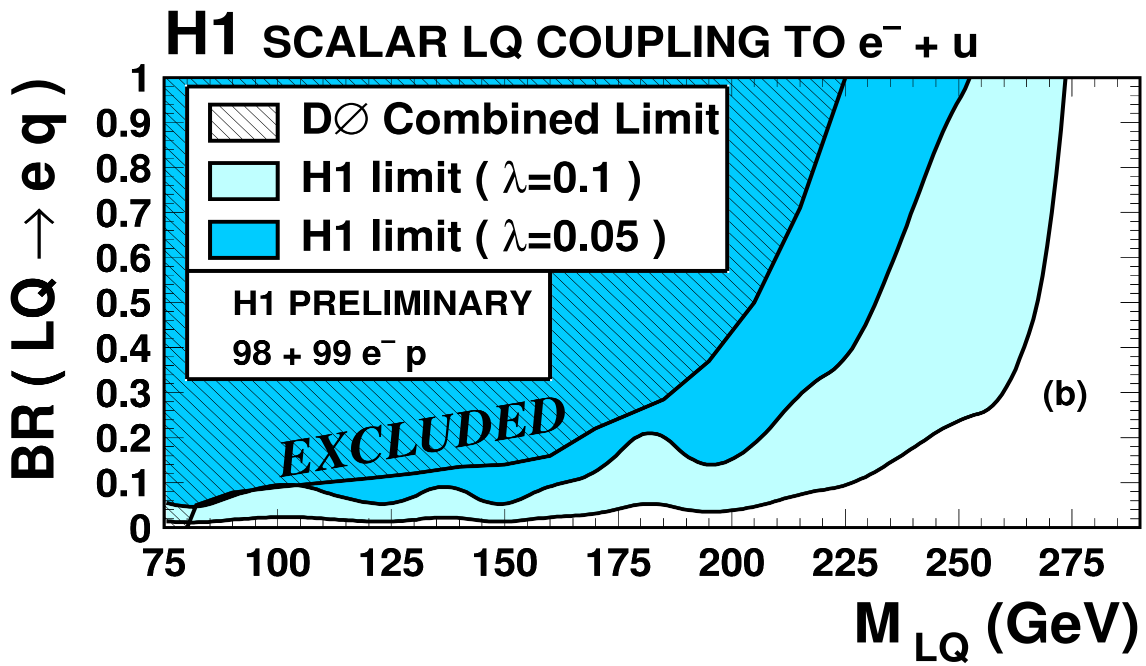
$\tilde{S}_{1/2}^L \rightarrow (\beta = 1)$

General LQ model

BR(LQ→eq) as a function of M_{LQ} at fixed coupling λ

For large λ or small BR(eq)

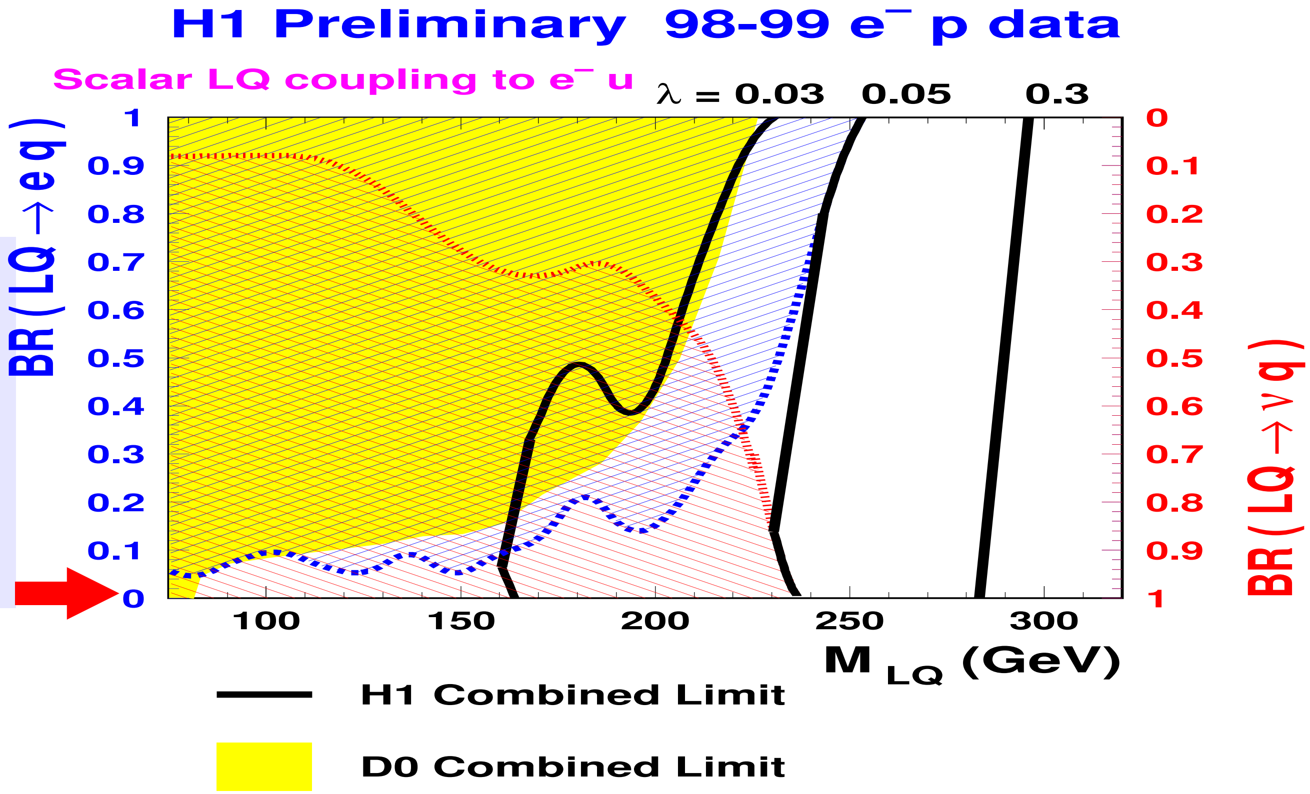
⇒still discovery potential⇐



CC and NC analysis combined to constrain the same resonant state

⇒ BR(LQ→eq)+BR(LQ→νq) =1

⇒ mass limits largely independent of BR

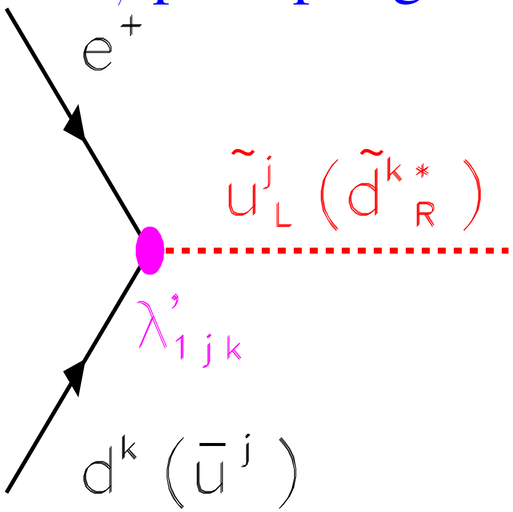


Rp violating SUSY at HERA

$$R_P = (-1)^{3B+L+S} = \begin{Bmatrix} +1\,(SM\ particles) \\ -1\,(SUSY\ partners) \end{Bmatrix}$$ is a multiplicative quantum number

If Rp is not conserved: $\Rightarrow$ squarks can be singly produced;
$\Rightarrow$ LSP can decay to SM particles

The $\not{R}p$ coupling λ'_{ijk} allows for squark production at HERA
(i,j,k = generation indices)



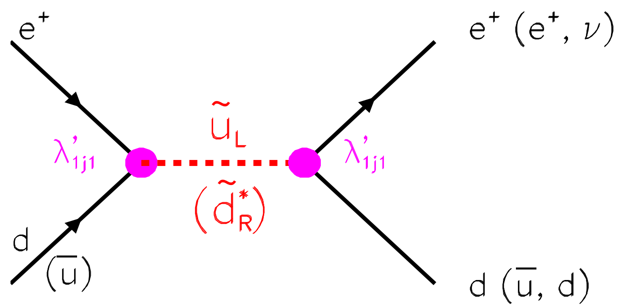
In e^+p collisions $\Rightarrow$ mostly sensitive to λ'_{1j1}

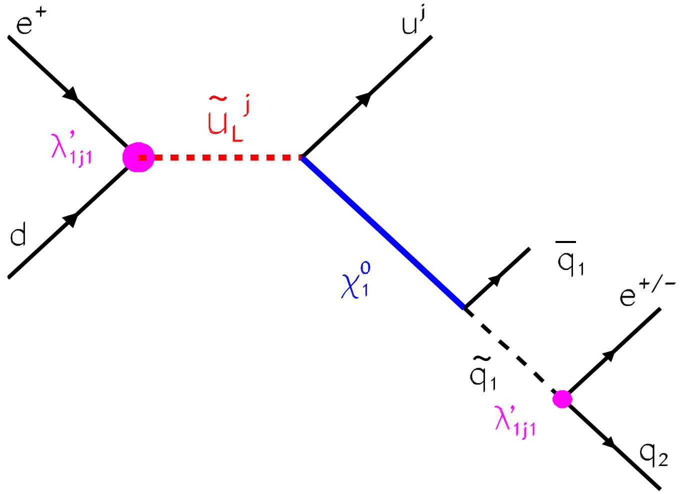
$$e^+ d \rightarrow \tilde{u}, \tilde{c}, \tilde{t}$$

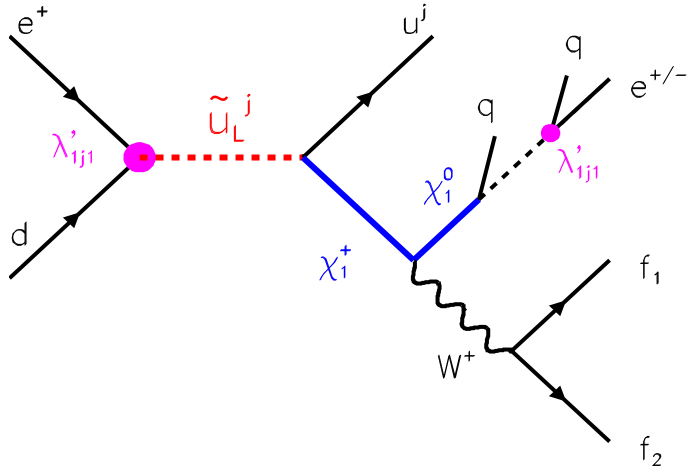
Production cross section (NWA): $\sigma^{NWA}(ep \rightarrow \tilde{u}^J_L) \propto \lambda'^2_{1j1} \cdot d(x = M^2_{\tilde{q}}/s)$

RpV squark decay topologies

LQ–like decays
(ν+q decays disfavoured in e^+p collisions)







Muliti–jet topologies from gauge decays:

⇒cascade decays

⇒hadronic/leptonic W and Z decays

⇒**wrong sign lepton !!**

Events are classified into exclusive distinguishable analysis classes:

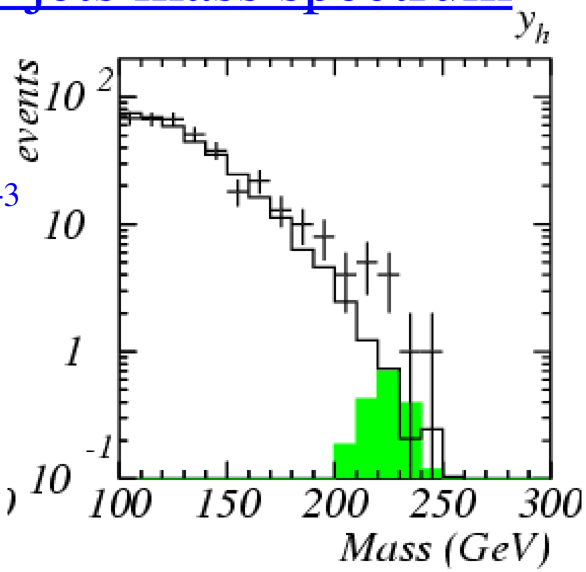
Signature	Decay Process	ZEUS	H1
e^+ + jet	RpV squark decay		
ν + jet	"		
e^+ + multi–jets	Gauge decay		
e^- + multi–jets	"		
ν + multi–jets	"		
e + ℓ + multi–jets	" + cascade		
ν + ℓ + multi–jets	" + cascade		

Branchings depend on M_{squark} and λ' and MSSM parameters M_2, μ, $\tan\beta$

RpV: Examples of mass spectrum

ZEUS ν + multi–jets mass spectrum

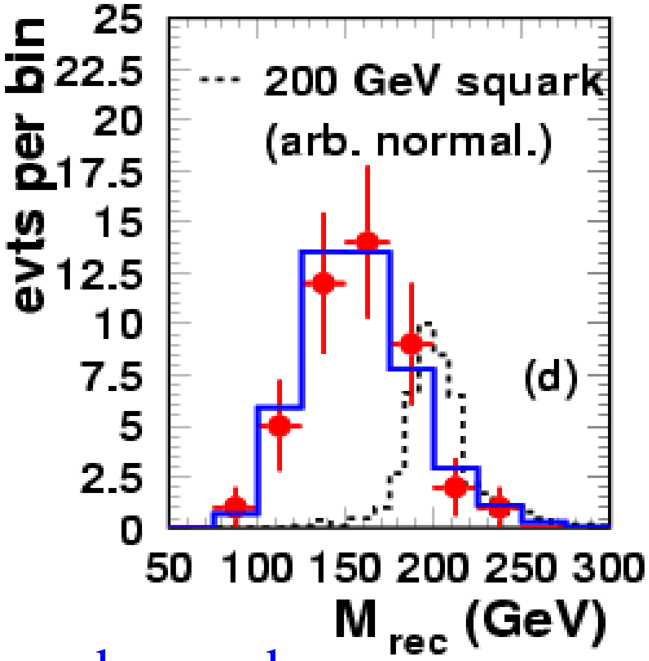
- P_T^{miss}>18 GeV
- No e found
- circularity > 10^{-3}



Excess at M>200 GeV: 15 events (5.1 exp.)
event kin. do not correspond to signal
⇒ currently under investigation

H1 ν + jets + X mass spectrum

- P_T^{miss}>25 GeV
- ≥ 2 high–Et jets
- Et^{jet1}>15 GeV
- θ^{jet1}>10°

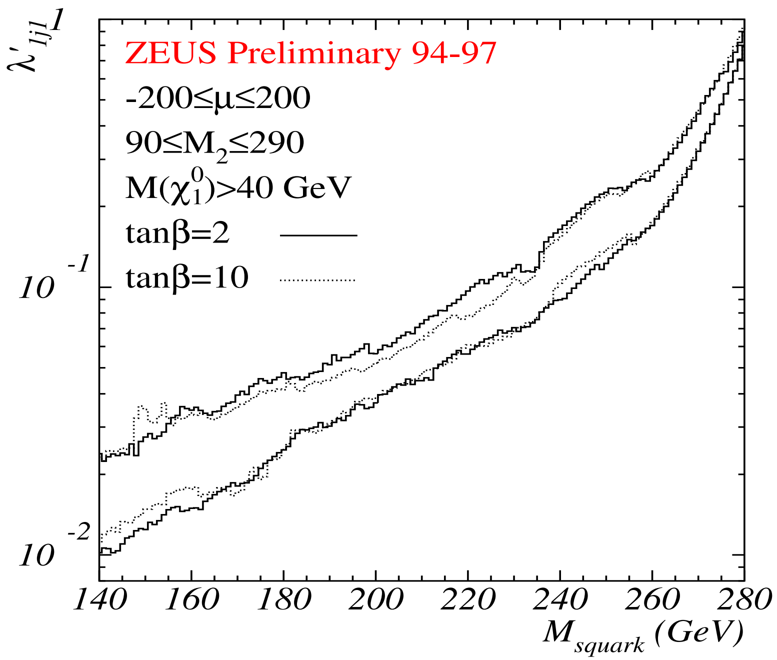


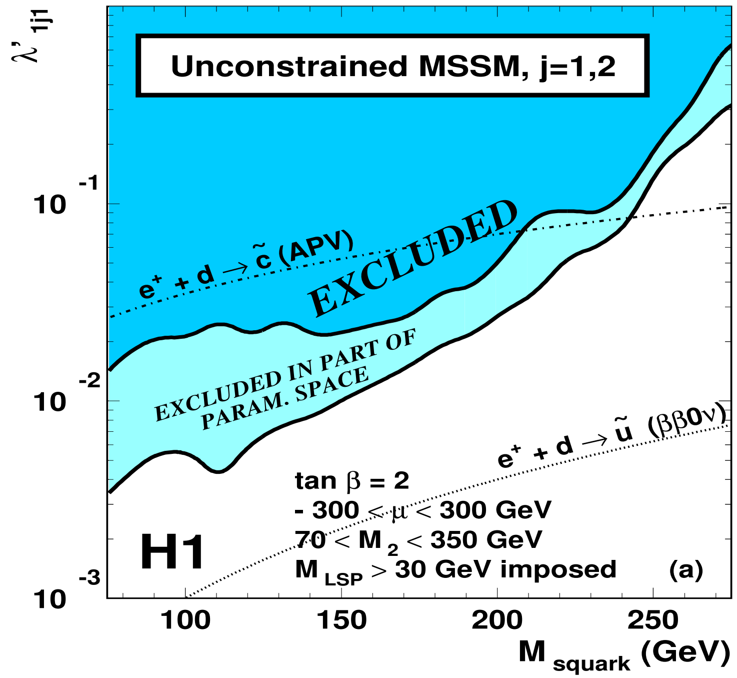
No deviation observed

ZEUS:
- broader selection in each class
- optimized y, circularity and mass cut for each (M_2,μ,tanβ) point.

Unconstrained MSSM

- masses and couplings of χ^0 and $\chi^\pm$ determined form μ, M_2 and $\tan\beta$;
- <u>sfermion masses</u> are free param.; (both squarks and sleptons are mass degenerate)
- μ, M_2 parameter scan performed at fixed $\tan\beta \Rightarrow$ limits in $(\lambda_{1j1}, M_{squark})$ plane.





Note: case j=3 considered separately by H1

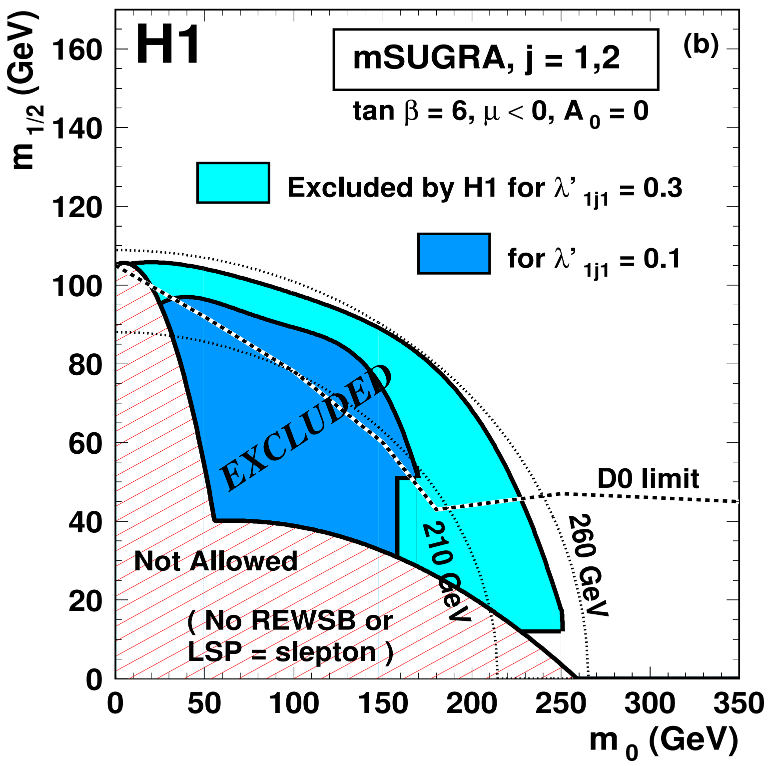
For $\lambda'=0.3$, M_{squark} up to 270 GeV are excluded 95% CL

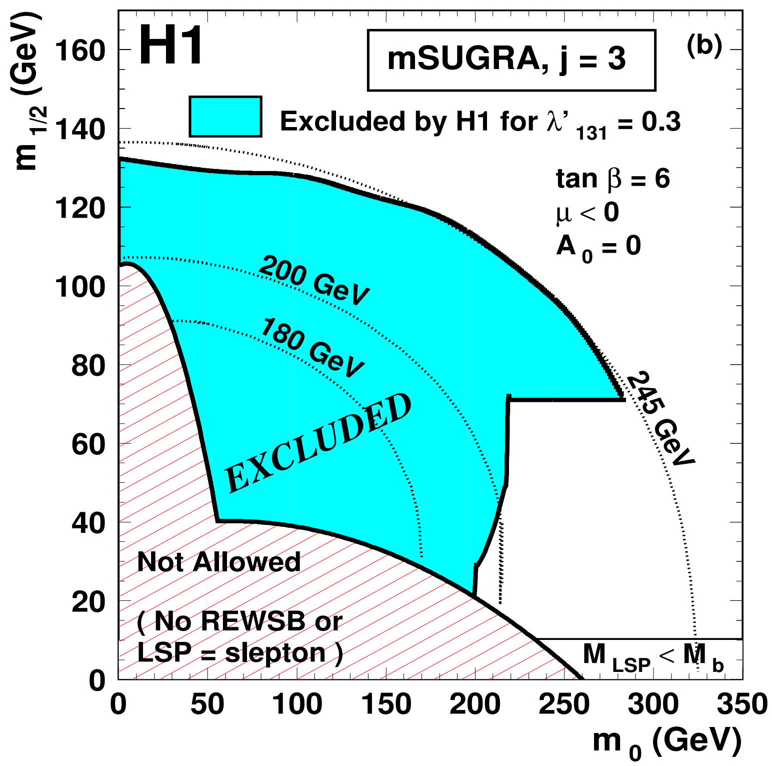
- CDF/D0 limits on scalar LQ naturally eluded (small branching $\tilde{u}^j_L \to eq$)
- Stringent limits on λ'_{111} from neutrinoless $\beta\beta$ decay
- HERA limits comparable or better than APV on λ'_{1j1} for j=2,3

mSUGRA model

Free parameters:

- m_0 and $m_{1/2}$ (common ***sfermion*** and ***gaugino*** masses at GUT scale)
- **sign(μ)**; the assumed symmetry breaking mechanism predicts |μ| from tanβ
- **tanβ** and **A_0** (normally A_0=0)





Note: TeVatron and LEP limits do not depend on λ., but increase tanβ reduces D0 sensitivity

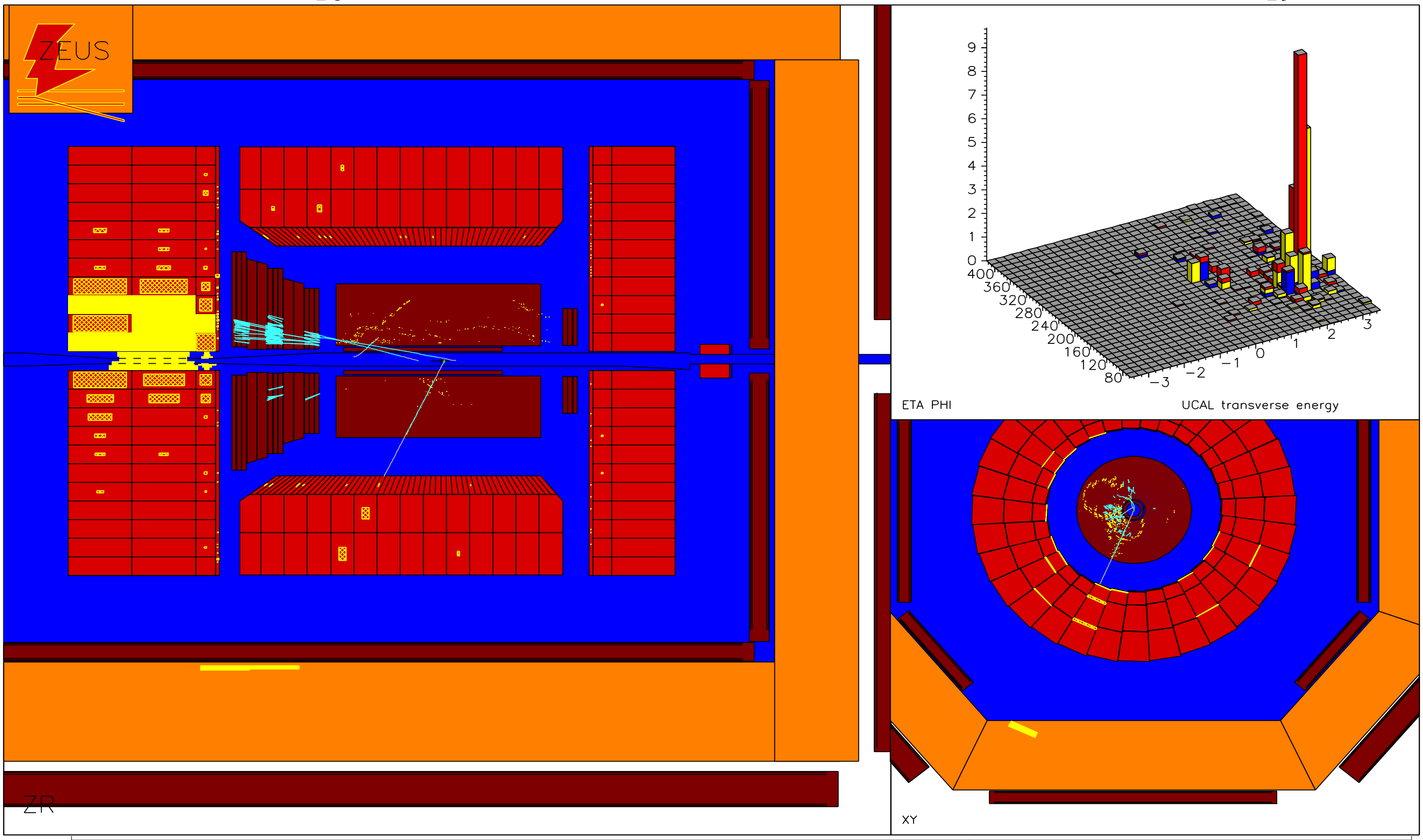
⇒ HERA complementary to TeVatron

⇒ for λ'=0.3, M<260 GeV **nearly fully excluded**

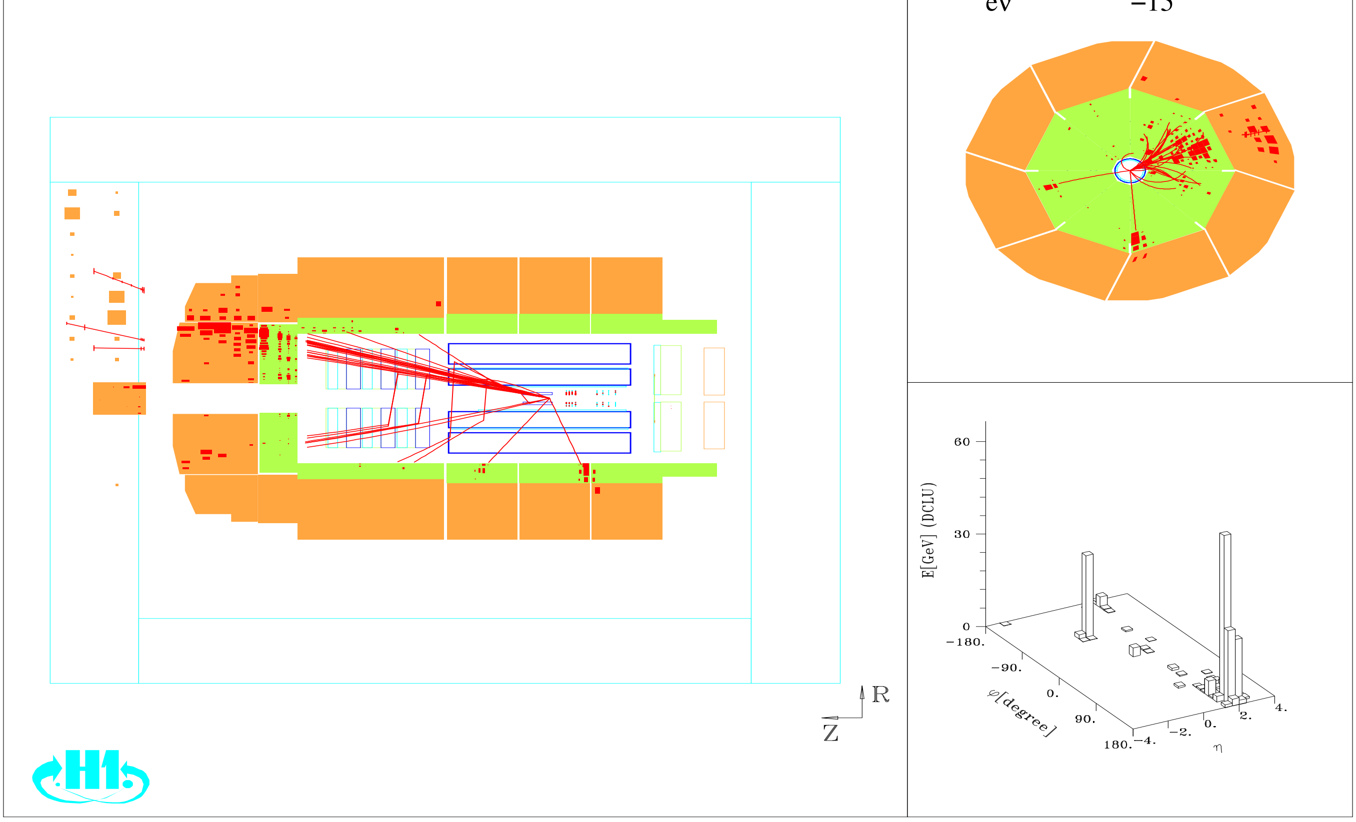
For intermediate values of m_0 LEP sensitivity comparable to HERA (not shown)

High–Pt isolated leptons + missing Pt events

$Pt(\mu^{+})=\mathbf{38}^{+20}_{-10}$ GeV, $Pt^{X}=\mathbf{36}$ GeV, $Pt^{miss}=\mathbf{61}$ GeV, $M_{T}=\mathbf{91}^{+39}_{-19}$ GeV



$Pt(e^{+}) = \mathbf{25}$ GeV, $Pt^{X}=\mathbf{43}$ GeV, $Pt^{miss}=\mathbf{42}$ GeV, $M_{e\nu}=\mathbf{77}^{+22}_{-15}$ GeV

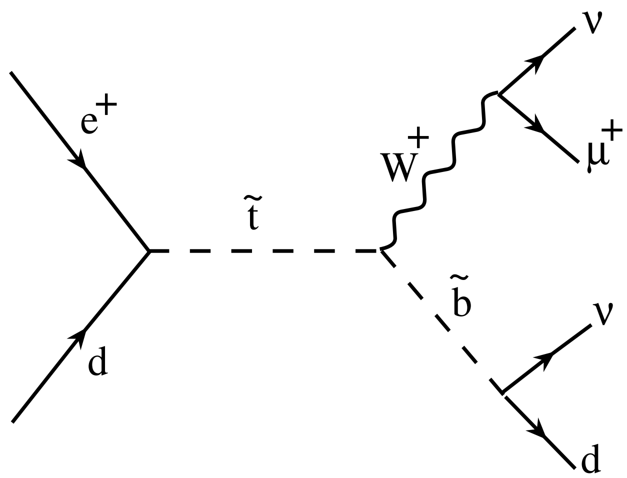


Such topologies are unexpected in SM **W** production

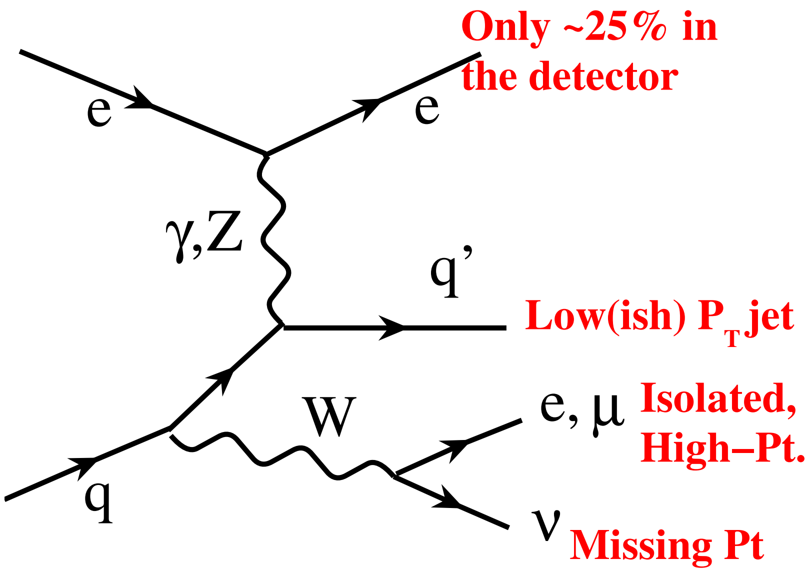
W production at HERA

Non SM W production examples:

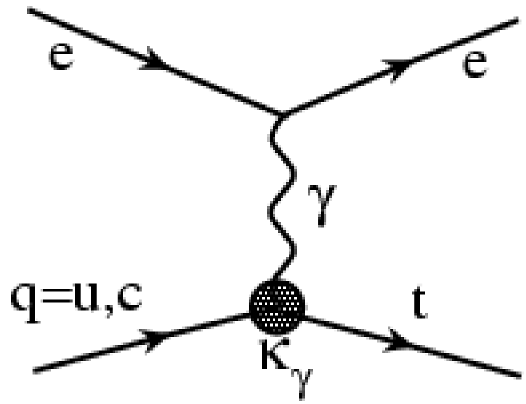
SUSY $\not{R}_p$ stop production



Rare SM process: $\sigma(ep \to eW^{\pm}X) \sim 1\ pb$



FCNC top production with $t \to bW$



Main SM Backgrounds:

- **CC DIS with fake lepton (e.g. FSR γ)**
- **NC DIS with energy mismeasurement**
- **inelastic $\gamma\gamma \to l^+l^-$ if one lepton is missed**

Also: anomalous WWγ coupling

Hi–Pt leptons: H1 analysis

(update of Osaka results: 94–00 data → 115 pb^{-1})

- Main selection cuts (simplified):

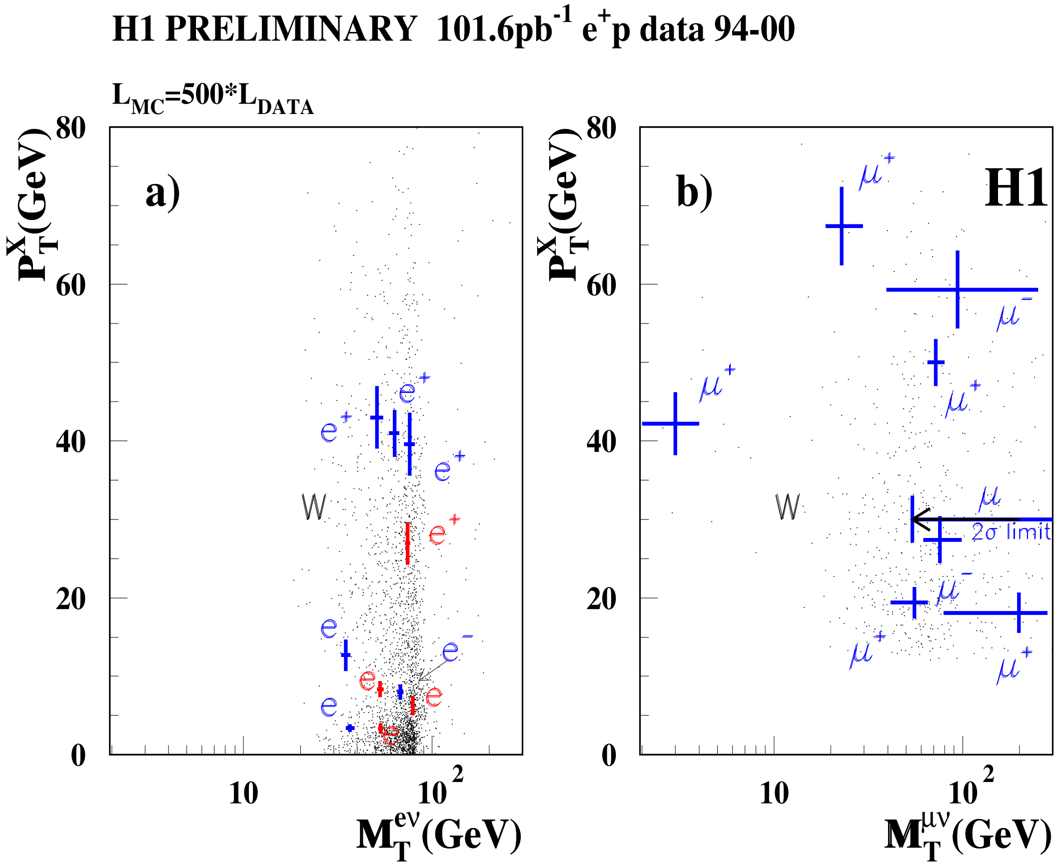
– $P_T^{CAL} > 12$ GeV

– $P_T^{track} > 10$ GeV (~$0.1 < \theta^{track} < 2.5$ rad)

– $D_{jet} > 1.0$, $D_{track} > 0.5$

– $P_T^X > 12$ (only for μ channel)

+ additional topological cuts to enhance W signal over NC, CC and $\gamma\gamma \to \mu\mu$



1994–1997 e^+p data (36.5 pb^{-1}):
Excess ($5\mu^{\pm}$ vs 0.8 exp.) first reported

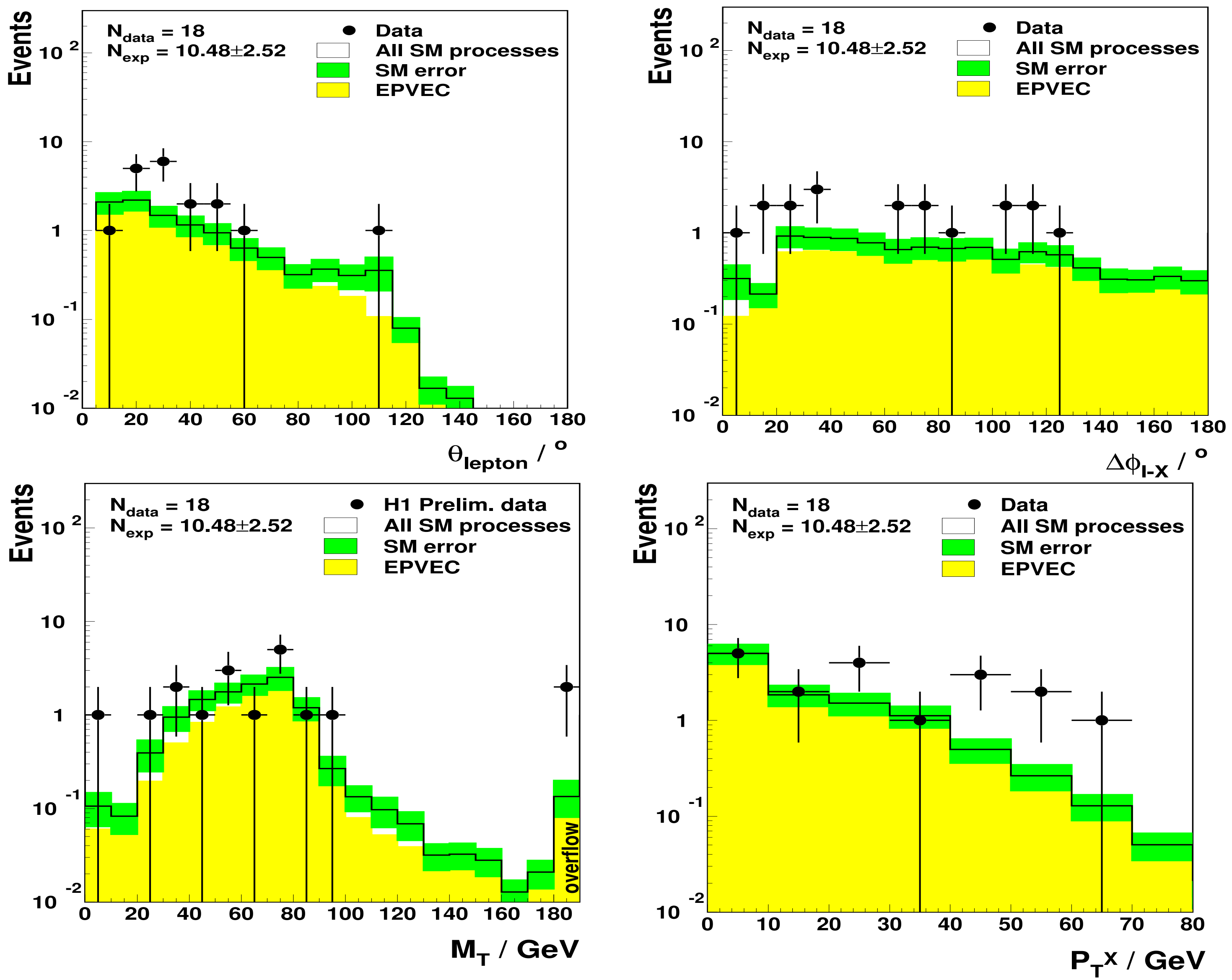
1998–1999 e^-p data (13.6 pb^{-1}):
0 events found(1.8 expected)

- 1994–2000 e^+p data:
Agreement with SM for $P_T^X < 25$ GeV
Excess over SM for $P_T^X > 25$ GeV:
10 events found(2.8 expected)

H1 Preliminary 1994–2000 e+p	Electrons Observed/expected (W)	Muons Observed/expected (W)
$P_T^X > 0$ GeV	10 / 7.9±1.9 (6.1)	—
$P_T^X > 12$ GeV	5 / 2.6±0.7 (2.1)	8 / 2.6±0.7 (2.1)
$P_T^X > 25$ GeV	4 / 1.3±0.3 (1.1)	6 / 1.5±0.4 (1.3)
$P_T^X > 40$ GeV	2 / 0.4±0.1 (0.4)	4 / 0.6±0.2 (0.6)

H1: W candidates (e and μ)

- Electrons and muons combined
- Excess at high P_T^X seen in both electron and muon channels
- Shapes of the other distributions are compatible with the expectations
- Most of the events have $M_T \simeq M_W$

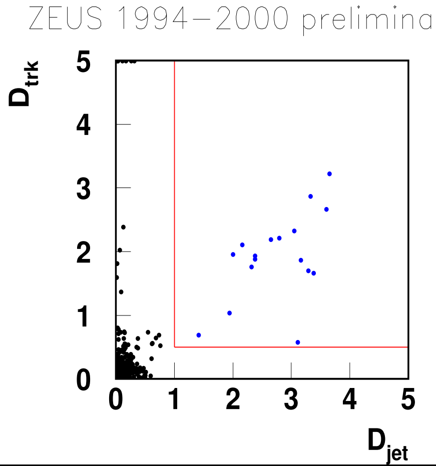


Hi–Pt leptons: ZEUS analysis

(update of Osaka results: 94–00 data→ 130pb^{-1})

Main selection cuts:

- P_T^{CAL}> 20 GeV
- P_T^{track}> 10 GeV (~0.3<θ^{track}<2.0 rad)
- $\Delta\varphi$ > 0.2 (only if e is found)
- ≥ 1 jet with E_T>5 GeV



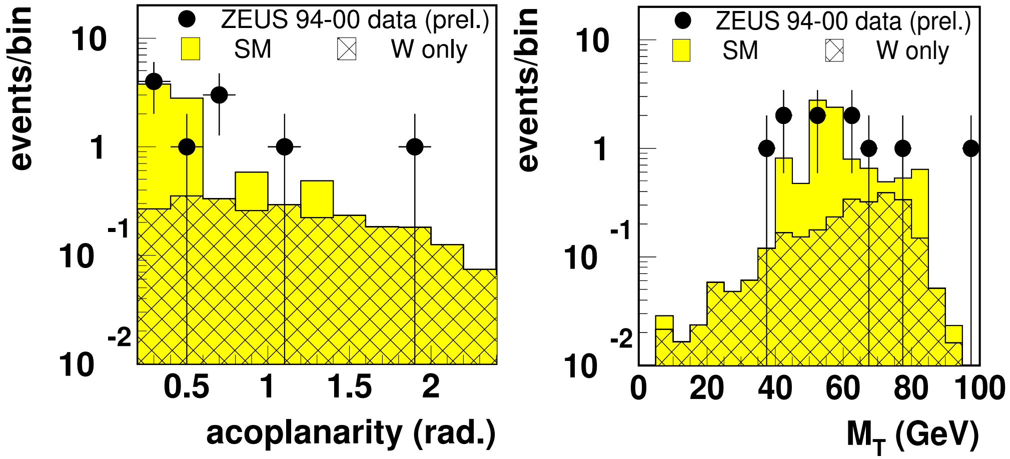
Isloation:

D_{trk} > 0.5

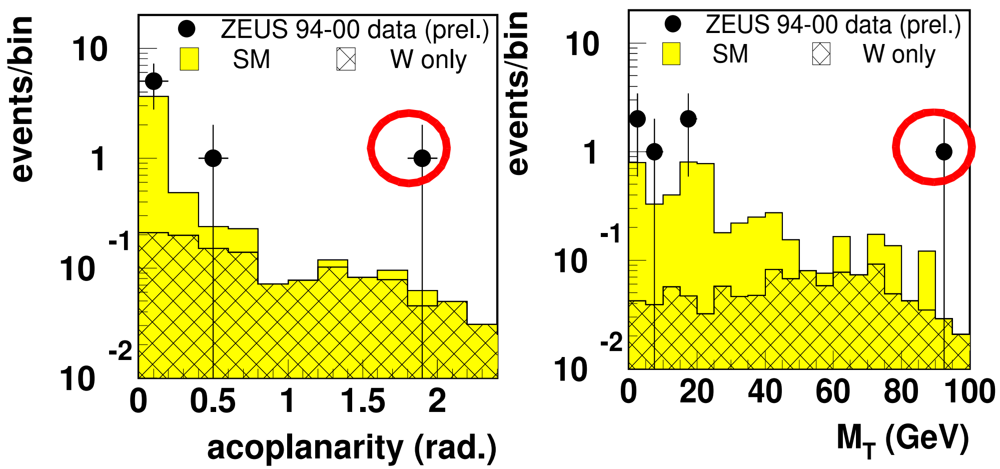
D_{jet} > 1.0

ZEUS Preliminary 1994–2000	**Electrons** Observed/expected (W)	**Muons** Observed/expected (W)
e+p 114 pb^{-1}	7 / 9.9±1.6 (2.4)	7 / 4.6±0.6 (1.1)
e–p 16 pb^{-1}	3 / 1.1± 0.4 (0.3)	0 / 0.8 ± 0.1 (0.2)
Total 130 pb^{-1}	**10 / 11.0±1.6 (2.7)**	**7 / 5.4±0.7 (1.3)**

Electron events



Muon events



Event rate consistend with SM predictions

→ SM <u>not</u> dominated by W (NC, $\gamma\gamma\to\mu\mu$)

→ one outstanding μ event

ZEUS–H1 comparison @ large P_T^X

ZEUS

Enhance W signal over background:
- E–Pz < 45 GeV (only e events)
- Net missing P_T > 12 GeV (only μ events)
- Reject if 2nd muon found

H1

Restrict to ZEUS angular range:
$0.3 < \theta^{track} < 2.0$ rad

(systematic uncertainties included)

ZEUS Preliminary 94–00 e±p 130 pb^{-1}	Electrons Observed/expected (W)	Muons Observed/expected (W)
$P_T^X > 25$ GeV	1 / 1.14±0.06 (1.10)	1 / 1.29±0.16 (0.95)
$P_T^X > 40$ GeV	0 / 0.46±0.03 (0.46)	0 / 0.50±0.08 (0.41)

H1 Preliminary 94–00 e+p 82 pb^{-1}	Electrons Observed/expected (W)	Muons Observed/expected (W)
$P_T^X > 25$ GeV	3 / 0.84±0.22 (0.67)	6 / 0.94±0.26 (0.78)
$P_T^X > 40$ GeV	2 / 0.27±0.08 (0.26)	4 / 0.35±0.10 (0.33)

Conclusions:

- Although 2 experiments have similar sensitivity, ZEUS cannot reproduce the H1 excess.
- Statistical fluctuation (Poisson P~3.10^{-3}) not likely.
- QCD–LO cross section uncertainty ~ 30% (working on NLO..)
- Hadronic/tau W decay attempted → no comparable sensitivity.

→ Can only wait for HERA high–lumi to settle the issue ←

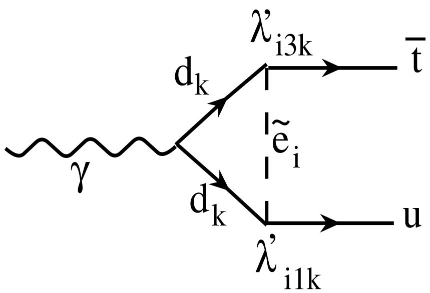
Search for single top production

$t \to b + W \to b + l + \nu$

$\Rightarrow$ large P_T^X from b quark

FCNC coupling is highly suppressed in SM: $\Rightarrow$ beyond SM physics.

e.g. $\not{R}$p SUSY:



ZEUS selection ($W \to l\nu$, 130 pb^{-1}):

Isolated track + Pt^X> 40 GeV

→ ~ 6% top selection efficiency

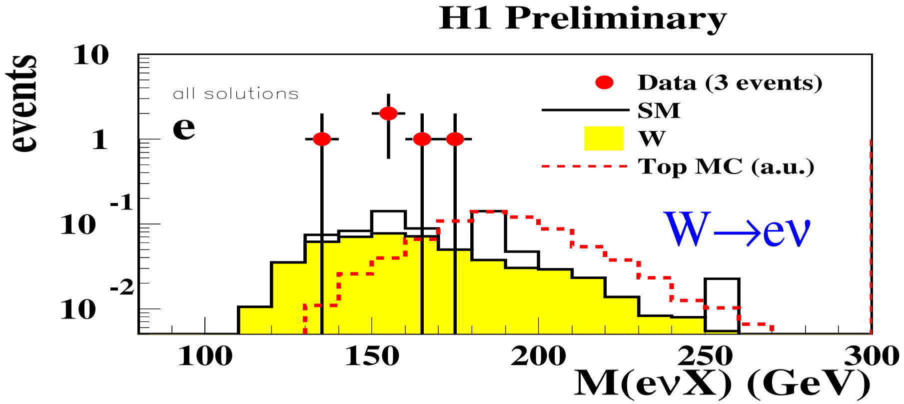
→ **0** events, **1.1** expected

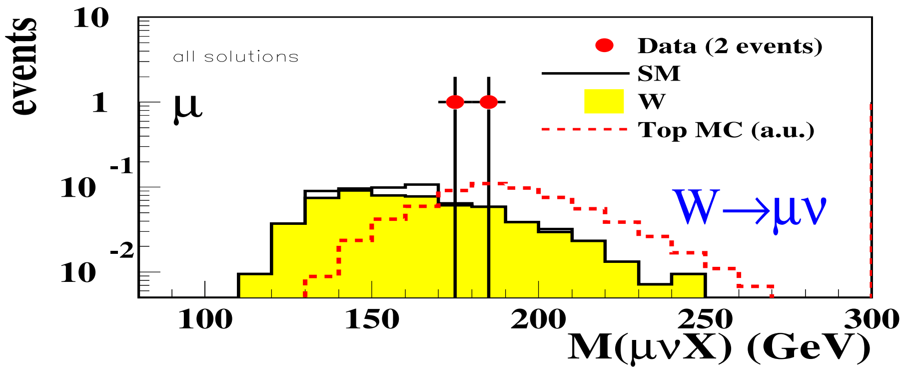
H1 selection ($W \to l\nu$, 84 pb^{-1}):

W selection + Pt^X> 25 GeV+ Pt^{jet}> 25 GeV + Mt> 10 GeV

→ 5 (3e + 2μ) candidates, 1.4±0.5 exp.

→ ~ 40% top selection efficiency





H1 selection ($W \to qq'$, 36 pb^{-1}):

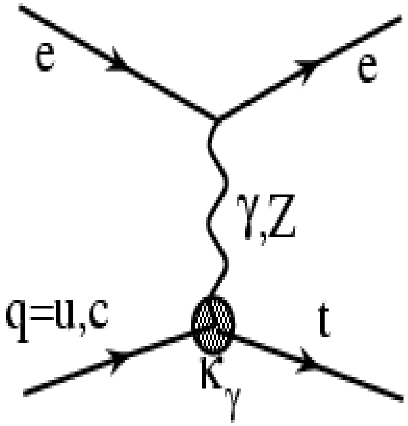
3 jets, Pt> 25,15,10 GeV

→ 10 candidates, 8.3 exp. (large uncer.)

Limits on FCNC t–u–γ coupling

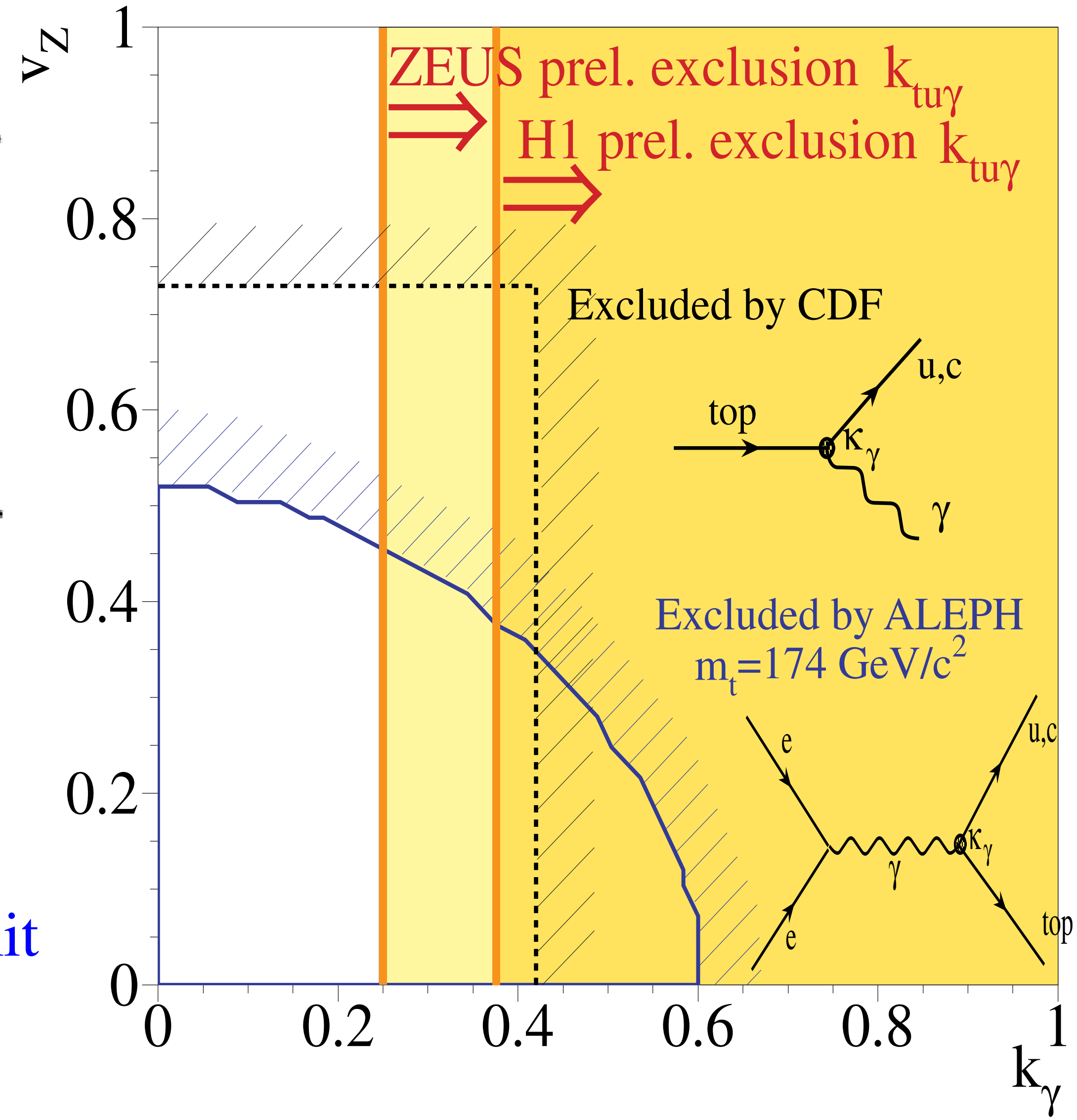
<u>Assumptions</u>:

- t–channel γ exchange dominates
- larger sensitivity for coupling to u–quarks



$$L_{eff} = e e_q \frac{1}{m_{top}} \bar{t}\, \sigma^{\mu\nu} q_\nu \kappa_\gamma u A_\mu$$

⇒limits on $\kappa_{\gamma ut}$ from cross–section limit



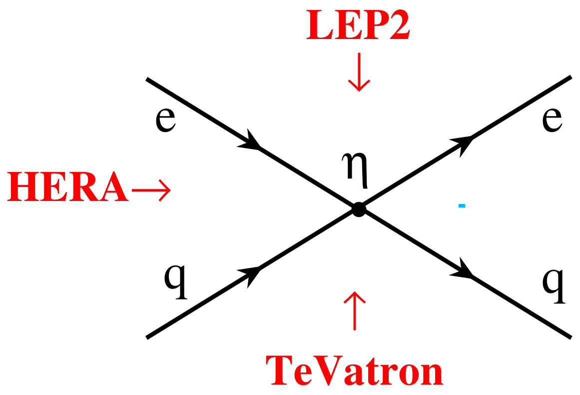
HERA gives the strongest bound on FCNC t–u–γ coupling !

eeqq Contact Interactions

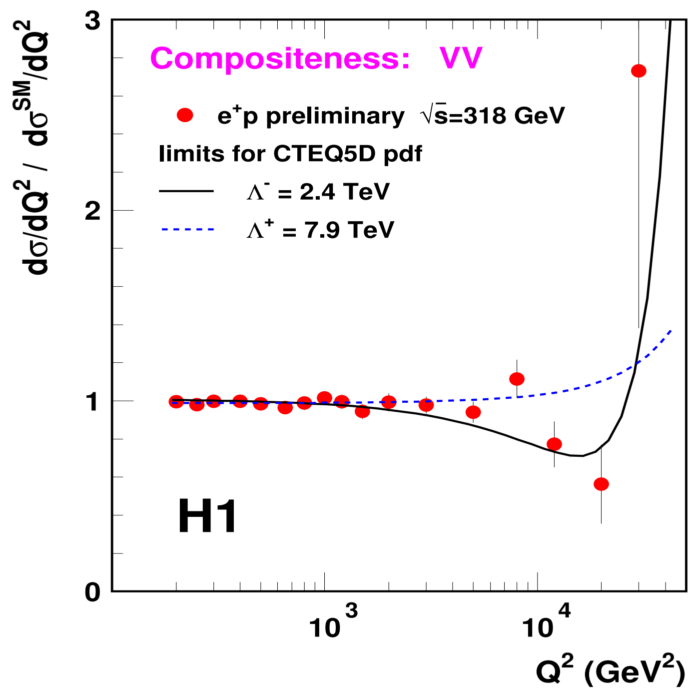
Describes effects of new physics at an effective mass scale $\Lambda \gg \sqrt{s}$

Examples:

- **new heavy bosons**
- **new currents**
- **heavy leptoquarks**
- **compositness**



Models assuming different helicity structures of new interactions can be investigated by looking at deviations from SM in $d\sigma/dQ^2$



Note:

Only vector CI terms considered

$$L_{CI} = \sum_{\alpha,\beta=L,R} \eta^{eq}_{\alpha\beta} (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$

$$\boxed{\eta = \frac{\epsilon \cdot g^2}{\Lambda^2}}$$

Conventionally $g^2 = 4\pi$

$\varepsilon = \pm 1$ ($\rightarrow$ 2 different scenarios)

Compositeness models

Model	η^u_{LL}	η^u_{LR}	η^u_{RL}	η^u_{RR}	η^d_{LL}	η^d_{LR}	η^d_{RL}	η^u_{LL}
LL	$+\eta$				$+\eta$			
LR		$+\eta$				$+\eta$		
RL			$+\eta$				$+\eta$	
RR				$+\eta$				$+\eta$
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$	
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$	
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$
U1	$+\eta$	$-\eta$						
U2	$+\eta$		$+\eta$					
U3	$+\eta$			$+\eta$				
U4		$+\eta$	$+\eta$					
U5		$+\eta$		$+\eta$				
U6			$+\eta$	$-\eta$				

Analysis methods

H1 1994–2000 analysis (97pb^{-1})

- χ^2 fit to NC $d\sigma/dQ^2$ + CI model;
- fit includes statistical and systematic uncetainties + overall normalization;
- PDFs⇒ <u>most conservative</u> results quoted;
- 95% CL limit:

$$\chi^2(\eta) - \chi^2(SM) = 3.84$$

ZEUS 94–00 preliminaries (130 pb^{-1})

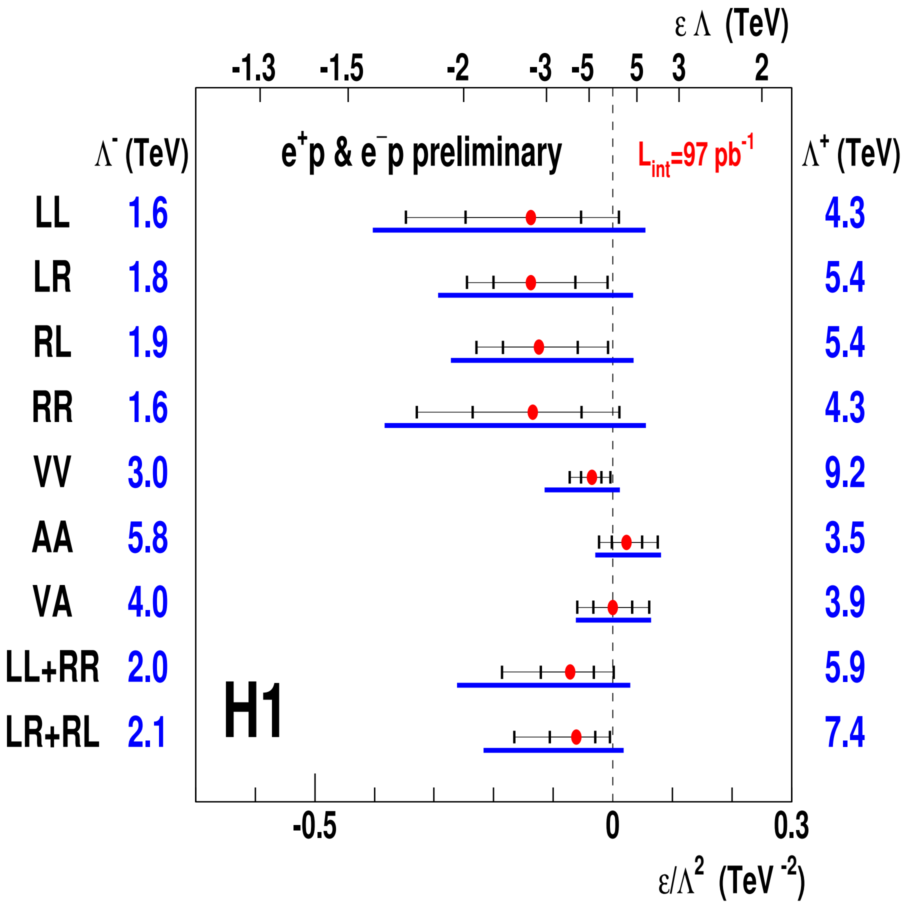
- Log–likelyhood from binned Q^2 distribution
- Limit setting based on "MC experiments"

⇒Normalization uncertainty included in logL function

⇒Other systematic uncertainties varying in MC experiments

Fits to compositeness models

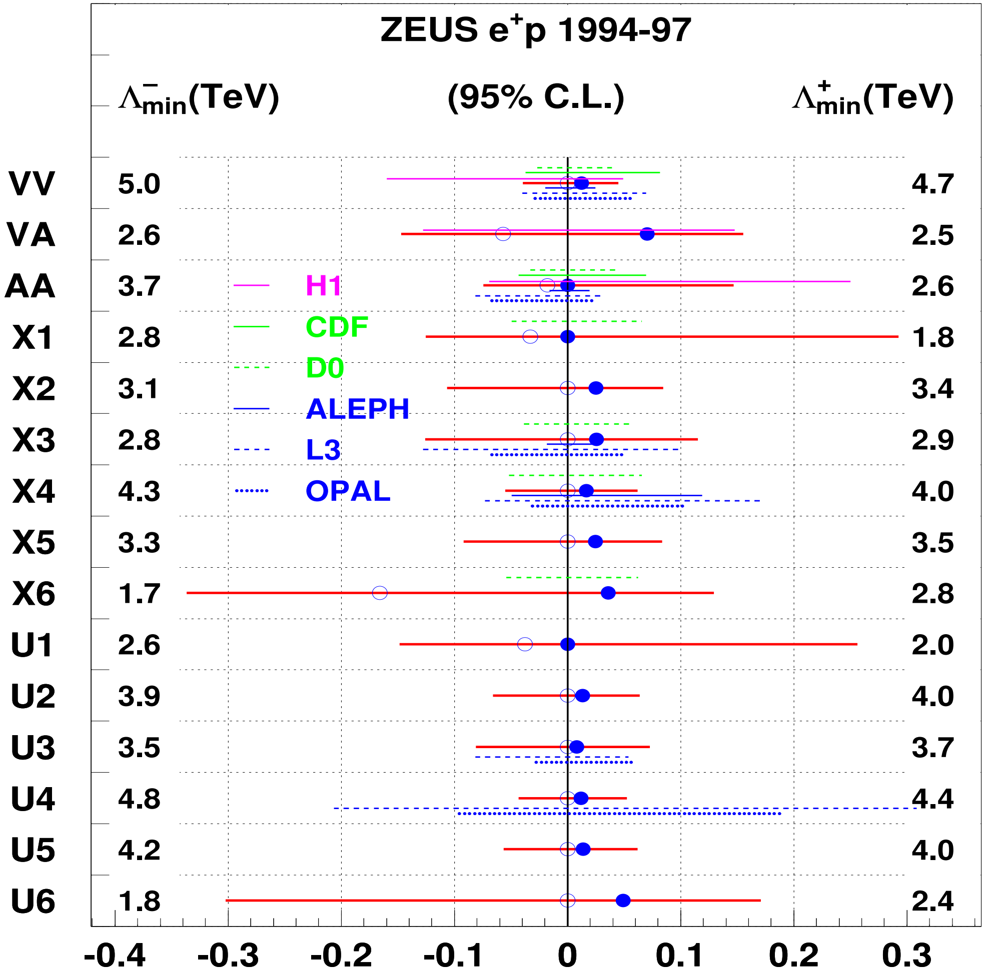
H1 1994–2000 analysis (97pb^{-1})



data slightly undershoots SM at high Q^2
models with negative interference favoured

Λ > 1.6 – 9.2 TeV

ZEUS 1994–97 analysis (47pb^{-1})

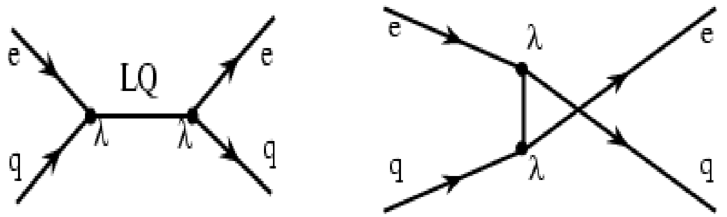


Good agreement with SM

Λ > 1.7 – 6.0 TeV

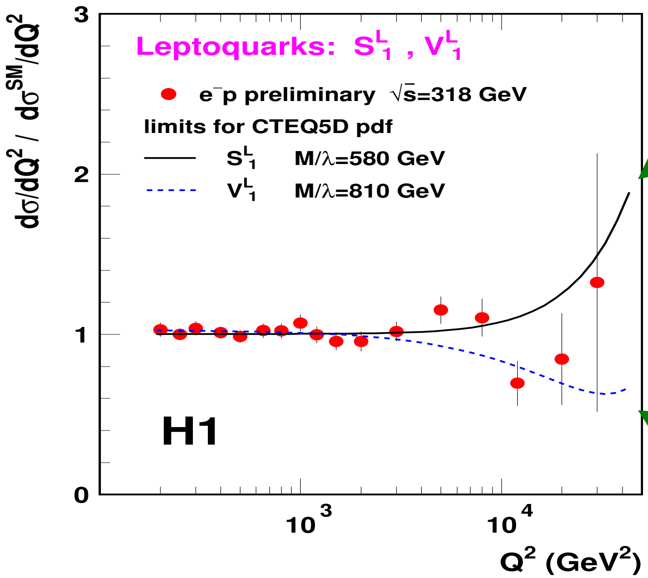
High Mass Leptoquarks ($M_{LQ} \gg \sqrt{s}$)

Both s– and u–channel contribute:



Effective CI coupling: $\eta \propto (\lambda/M_{LQ})^2$

Limits derived for all BRW LQ's



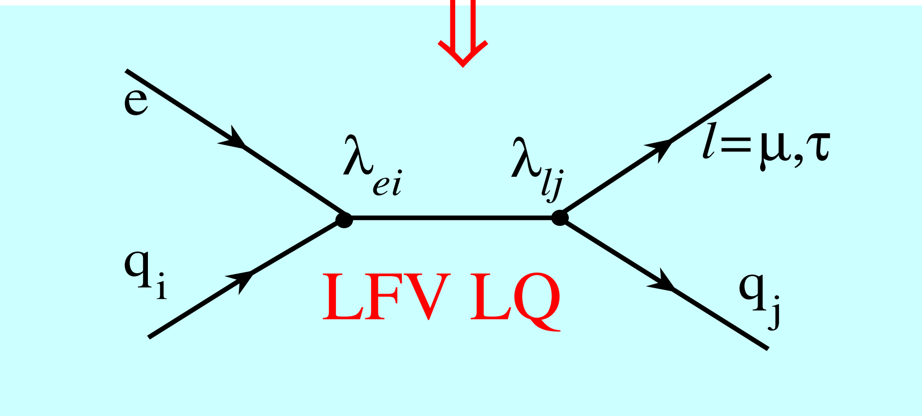
H1 1994–2000 preliminary 95% C.L.

LQ	η^u $(\lambda/M_{LQ})^2$	η^d $(\lambda/M_{LQ})^2$	F	M_{LQ}/λ [GeV]
S_0^L	$\eta_{LL} = +1/2$		2	**1070**
S_0^R	$\eta_{LL} = +1/2$		2	**960**
$\tilde{S}_0^R$		$\eta_{LL} = +1/2$	2	**290**
$S_{1/2}^L$	$\eta_{LL} = -1/2$		0	**380**
$S_{1/2}^R$	$\eta_{LL} = -1/2$	$\eta_{LL} = -1/2$	0	**380**
$\tilde{S}_{1/2}^L$		$\eta_{LL} = -1/2$	0	**650**
S_1^L	$\eta_{LL} = +1/2$	$\eta_{LL} = +1$	2	**690**
V_0^L		$\eta_{LL} = -1$	0	**1030**
V_0^R		$\eta_{LL} = -1$	0	**810**
$\tilde{V}_0^R$	$\eta_{LL} = -1$		0	**530**
$V_{1/2}^L$		$\eta_{LL} = +1$	2	**480**
$V_{1/2}^R$	$\eta_{LL} = +1$	$\eta_{LL} = +1$	2	**1510**
$\tilde{V}_{1/2}^L$	$\eta_{LL} = +1$		2	**1690**
V_1^L	$\eta_{LL} = -2$	$\eta_{LL} = -1$	0	**680**

High Mass LFV Leptoquarks

Non flavor–diagonal LQ: can couple to different quark and lepton generations

⇓



No events found by ZEUS/H1 (1994–97)

For $M_{LQ} \gg \sqrt{s} \Rightarrow$ **CI analysis**

H1 and **ZEUS** limits expressed in (for all generation combinations)

$$\frac{\lambda_{eq_i}\lambda_{lq_j}}{M^2_{LQ}}$$

NOTE: HERA has higher sensitivity than low–enery experiments when heavy quarks are involved

H1 and ZEUS (Prel.) 95% CL limits (10^{-4} GeV^{-2})

$e \leftrightarrow \tau$				$F=0$			
q_iq_j	$S^L_{1/2}$ 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 $e^+(\sqrt{2}u+d)$
1 1	$\tau\to\pi e$ 0.0032 **0.030**	$\tau\to\pi e$ 0.0016 **0.025**	$\tau\to\pi e$ 0.0032 **0.046**	G_F 0.002 **0.033**	$\tau\to\pi e$ 0.0016 **0.033**	$\tau\to\pi e$ 0.0016 **0.024**	G_F 0.002 **0.012**
1 2	*H1:* 0.047 $\boxed{\mathbf{0.030}}$	$\tau\to$K e 0.05 $\boxed{\mathbf{0.025}}$	$\tau\to$K e 0.05 $\boxed{\mathbf{0.046}}$	$\tau\to$K e 0.03 $\boxed{\mathbf{0.036}}$	$\tau\to$K e 0.03 $\boxed{\mathbf{0.036}}$	*H1:* 0.045 $\boxed{\mathbf{0.026}}$	K $\to\pi\nu\bar{\nu}$ $2.5\cdot10^{-6}$ **0.012**
1 3	*	B$\to\tau$e X 0.08 $\boxed{\mathbf{0.049}}$	B$\to\tau$e X 0.08 $\boxed{\mathbf{0.049}}$	B$\to l\nu$X 0.02 **0.044**	B$\to\tau$e X 0.04 $\boxed{\mathbf{0.044}}$	*	B$\to l\nu$X 0.02 **0.044**
2 1	*H1:* 0.15 $\boxed{\mathbf{0.15}}$	$\tau\to$K e 0.05 $\boxed{\mathbf{0.092}}$	$\tau\to$K e 0.05 **0.11**	$\tau\to$K e 0.03 $\boxed{\mathbf{0.049}}$	$\tau\to$K e 0.03 $\boxed{\mathbf{0.049}}$	*H1:* 0.073 $\boxed{\mathbf{0.061}}$	K $\to\pi\nu\bar{\nu}$ $2.5\cdot10^{-6}$ **0.026**
2 2	$\tau\to e\gamma$ 0.03 **0.19**	$\tau\to e\gamma$ 0.02 **0.10**	*H1:* 0.13 $\boxed{\mathbf{0.12}}$	*H1:* 0.076 $\boxed{\mathbf{0.061}}$	*H1:* 0.076 $\boxed{\mathbf{0.061}}$	*H1:* 0.107 $\boxed{\mathbf{0.10}}$	*H1:* 0.044 $\boxed{\mathbf{0.041}}$
2 3	*	B$\to\tau$e X 0.08 $\boxed{\mathbf{0.15}}$	B$\to\tau$e X 0.08 $\boxed{\mathbf{0.15}}$	B$\to l\nu$X 0.02 **0.10**	B$\to\tau$e X 0.04 **0.10**	*	B$\to l\nu$X 0.02 **0.10**
3 1	*	B$\to\tau$e X 0.08 **0.16**	B$\to\tau$e X 0.08 **0.16**	V_{ub} 0.002 **0.052**	B$\to\tau$e X 0.04 $\boxed{\mathbf{0.052}}$	*	V_{ub} 0.002 **0.052**
3 2	*	B$\to\tau$e X 0.08 **0.20**	B$\to\tau$e X 0.08 **0.20**	B$\to l\nu$X 0.02 **0.073**	B$\to\tau$e X 0.04 $\boxed{\mathbf{0.073}}$	*	B$\to l\nu$X 0.02 **0.073**
3 3	*	*H1:* 0.23 $\boxed{\mathbf{0.28}}$	*H1:* 0.23 $\boxed{\mathbf{0.28}}$	$\tau\to e\gamma$ 0.51 **0.14**	$\tau\to e\gamma$ 0.51 **0.14**	*	*H1:* 0.14 $\boxed{\mathbf{0.14}}$

Large Extra Dimensions

Propose n spatial Extra Dimensions (ED) restricted to size R:

→ SM particles confined to 4D brane

→ gravity can propagate in ED

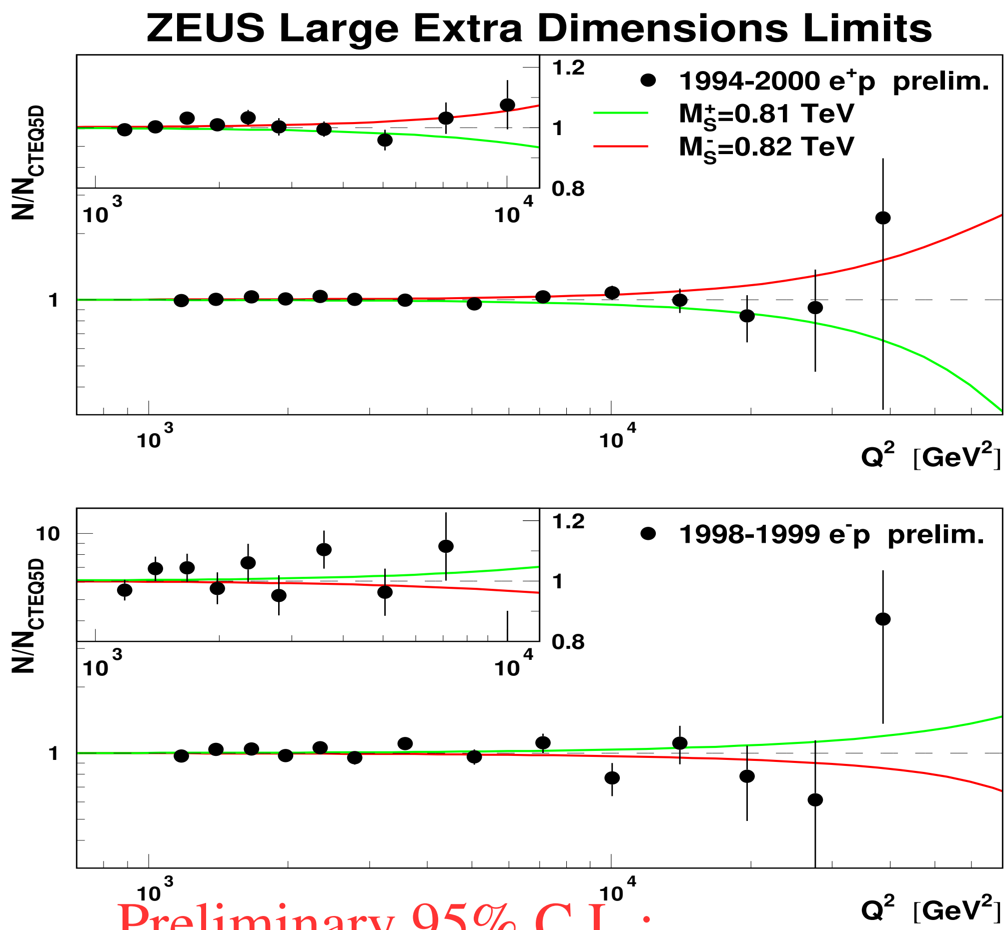
→ new "effective" scale $M_S \sim \mathcal{O}(\text{TeV})$

$$R^n M_S^{n+2} \sim M_P^2 \qquad (M_P^2 \simeq 10^{19} GeV)$$

(n>2 and R≤ 100 μm scenario conceivable)

Kaluza–Klein graviton couples with SM particles with effective CI coupling

$$\eta = \lambda / M_S^4 \qquad (\lambda = \pm 1)$$



Preliminary 95% C.L.:

ZEUS (1994–2000 , $\mathcal{L}$=130 pb^{-1})

$M_S^+ > 0.81$ TeV

$M_S^- > 0.82$ TeV

H1 (1994–2000 , $\mathcal{L}$=97 pb^{-1})

$M_S^+ > 0.63$ TeV

$M_S^- > 0.93$ TeV

Quark Form Factors

Quark substructure

$\Downarrow$

finite size of electroweak charges

Classical approach : **quark form factor**

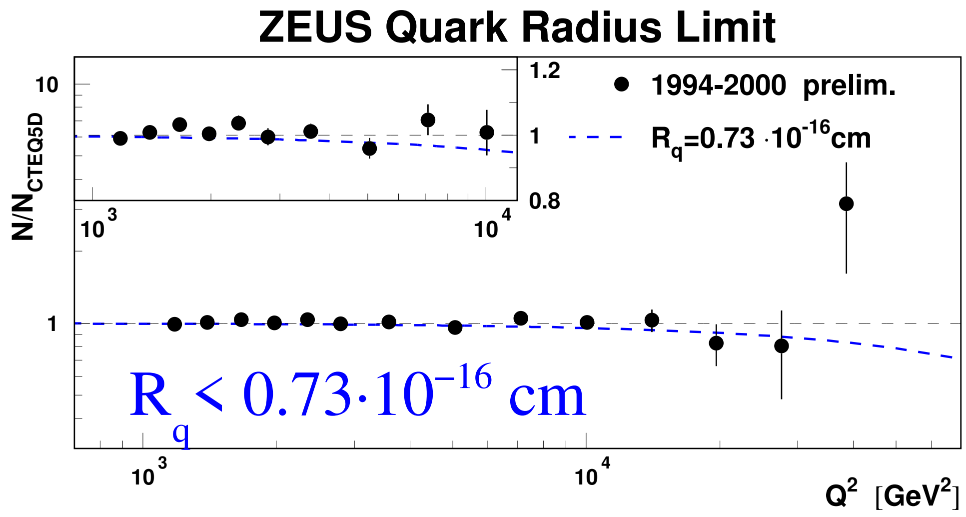
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot \left[1 - \frac{R_q^2}{6} Q^2 \right]$$

where R_q = *rms radius of charge distribution*

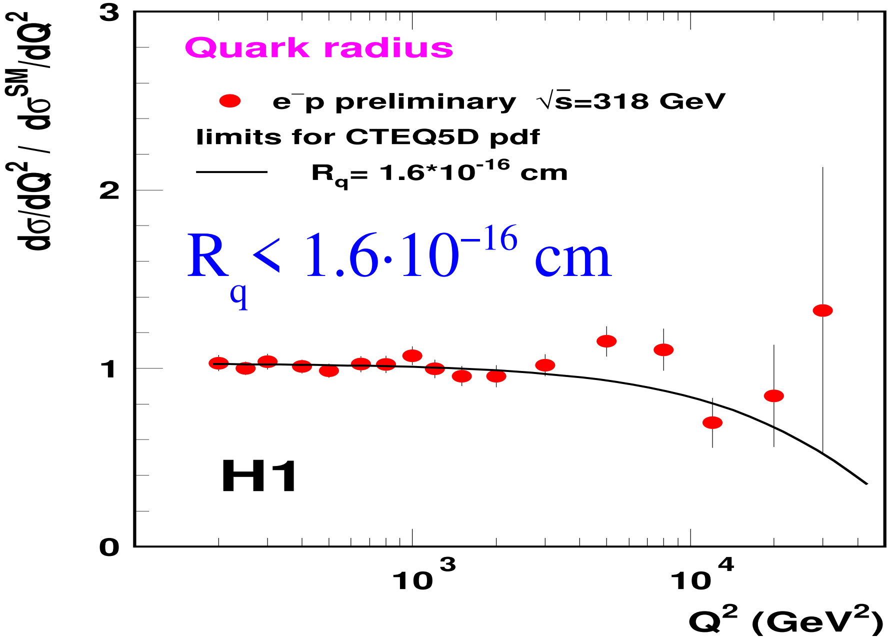
Note:

same dependence for e^+p and e^-p data

Prel. 95% C.L. limits



H1 Quark Radius Limit



Conclusions

- Most of the pre–HERA upgrade data analyzed
  – ~110 pb^{-1} e^+p data and ~15 pb^{-1} e^-p data per experiment
- No <u>clear</u> signals of BSM physics established
  – excesses observed in the past were not confirmed by new data:
    - Mej spectrum (ZEUS 94–97)
    - High–Q^2 high–x (ZEUS/H1 1996)
  – **Intriguing excess of Hi–Pt lepton events (H1)**
    - HERA high–lumi running will help settle the issue !
- Limits on many BSM models presented,

  $\Rightarrow$Comparable sensitivity of TeVatron and LEP was achieved

Outlook

1 fb^{-1} of data till ~2005 with polarized e$^+$/e$^-$ beam:

$\Rightarrow$ better sensitivity in some CI scenarios

$\Rightarrow$ selectively switch off backgrounds

$\Rightarrow$ be prepared for the unexpected !!!

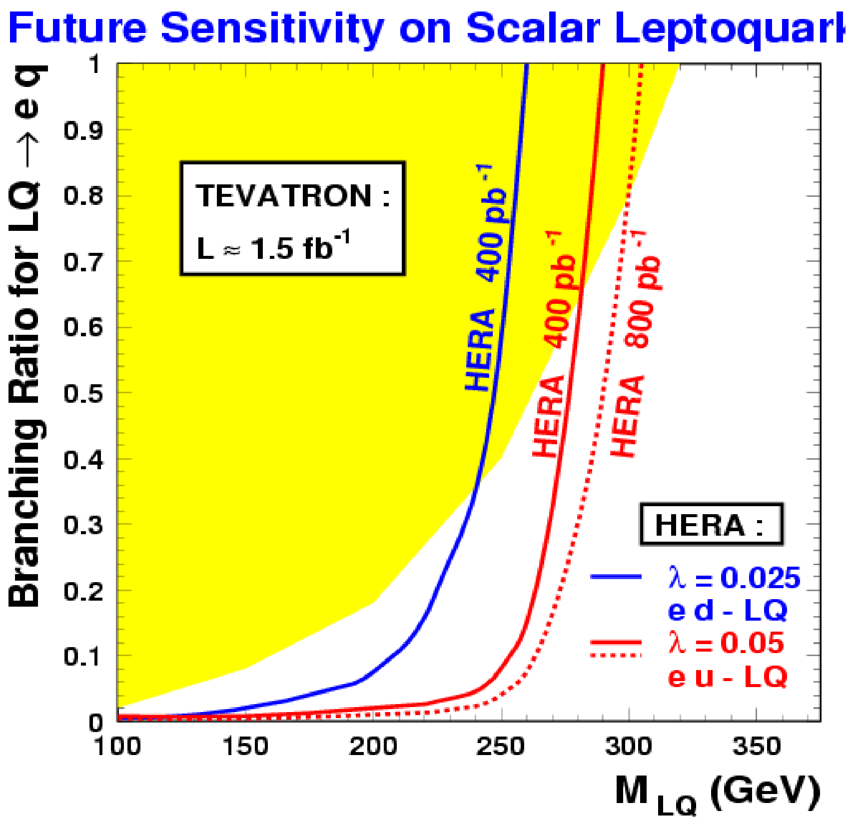
TeVatron Run II should collect 1÷2 fb^{-1} by end of 2002 :

BRW LQs which decay 100% to eq will be probed beyond HERA CM energy:

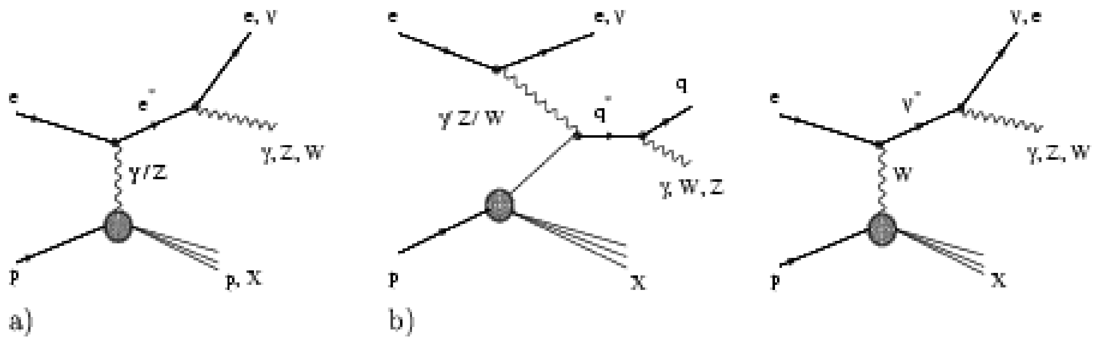
Low decay BR. to eq can still be better probed at HERA

Also, at large λ Yukawa coupling in RpV SUSY or LQ, HERA is still favored

Other models are not probed extensively at TeVatron: F*, LFV, ...



Excited Fermions (brief review)



- Composite fermions –> excited states
- <u>Phenomenological model</u> by Hagiwara–Komamiya–Zeppenfeld:

$$\mathscr{L}_{ff^*} \propto [f \bullet SU(2) + f' \bullet U(1) + f_s \bullet SU(3)]/\Lambda$$

Λ = compositeness scale

f = weight factors associated with the gauge groups

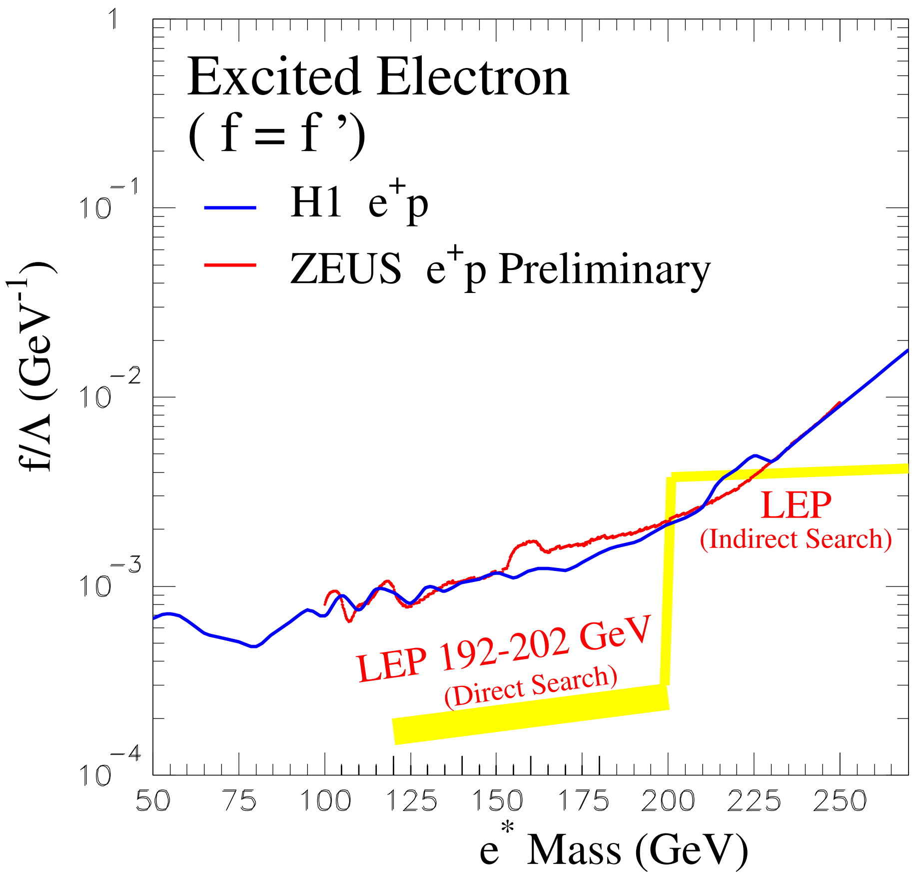
- Relations between f f'and f_s is assumed:

$\Rightarrow$branching ratio fixed

$\Rightarrow$limits on f/Λ

e* limits from ZEUS and H1

95% CL limit on f/Λ:

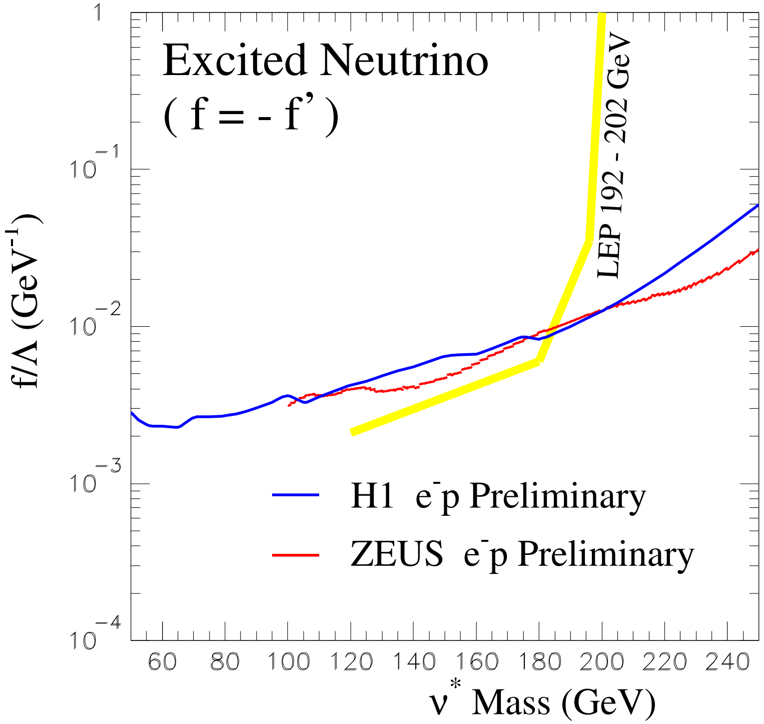


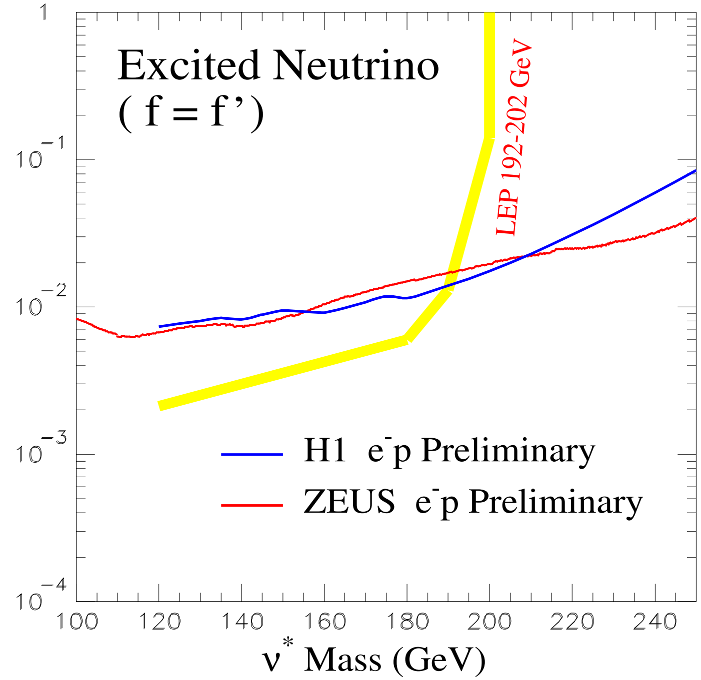
Assuming $f/\Lambda = 1/M_{e^*}$:

M_{e^*}: > 223 GeV (H1) > 229 GeV (ZEUS)

ν* limits from ZEUS and H1

95% CL limit on f/Λ:





<u>Assuming</u> $f/\Lambda=1/M_{\nu*}$:

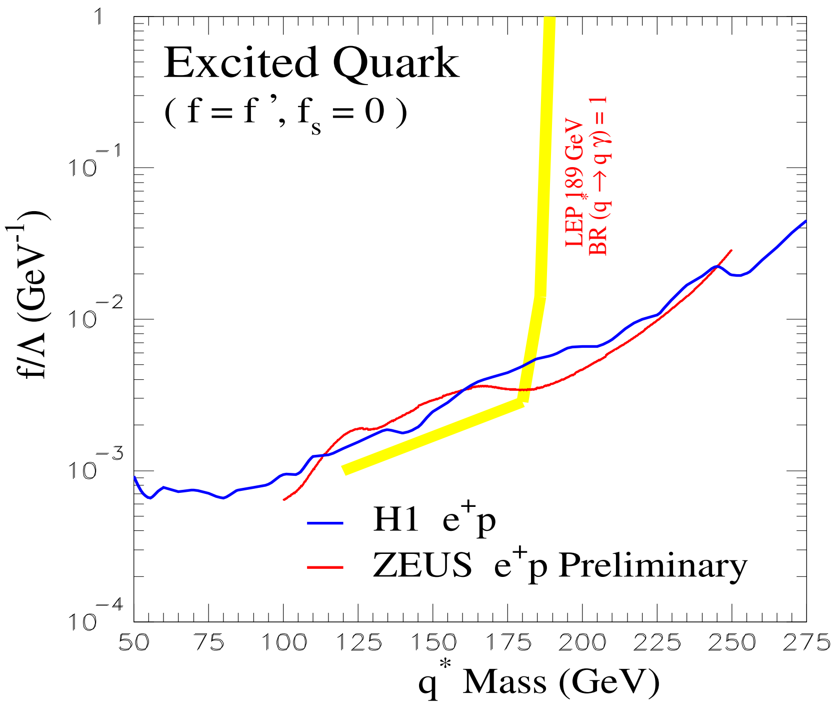
$M_{\nu*}$:> 150 GeV (H1) > 163 GeV (ZEUS)

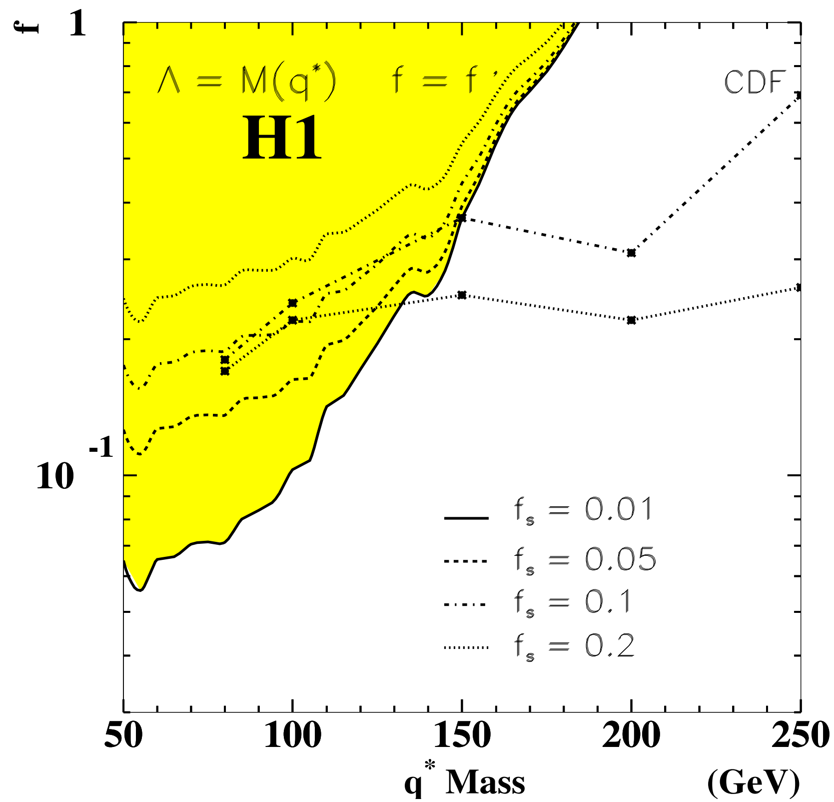
<u>Assuming</u> $f/\Lambda=1/M_{\nu*}$:

$M_{\nu*}$:> 134 GeV (H1) > 133 GeV (ZEUS)

q* limits from ZEUS and H1

95% CL limit on f/Λ:





Assuming $f/\Lambda=1/Mq_*$:

Mq_*:> 188 GeV (H1) > 203 GeV (ZEUS)

Results are complementary to TeVatron !!