Searches for leptoquarks, squarks in $R\!\!\!/_P$ SUSY, and excited fermions at HERA

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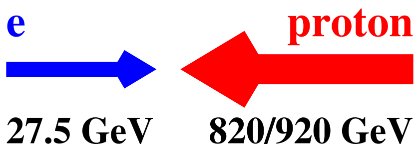
On behalf of

H1 ZEUS

- Introduction
- Leptoquarks
- Squarks in $R\!\!\!/_P$ SUSY
- Excited fermions
- Summary and outlook

Introduction to HERA

HERA: Unique ep collider

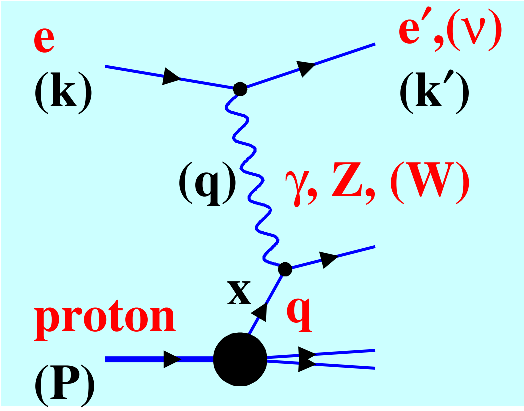


year	collision	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})/exp
1994-1997	e^+p	300	~ 40
1998-1999	e^-p	320	~ 15
1999-2000	e^+p	320	~ 70

Main standard model processes and kinematics:

Neutral Current (NC)
Charged Current (CC)
interactions $\longrightarrow$

Major backgrounds for direct searches

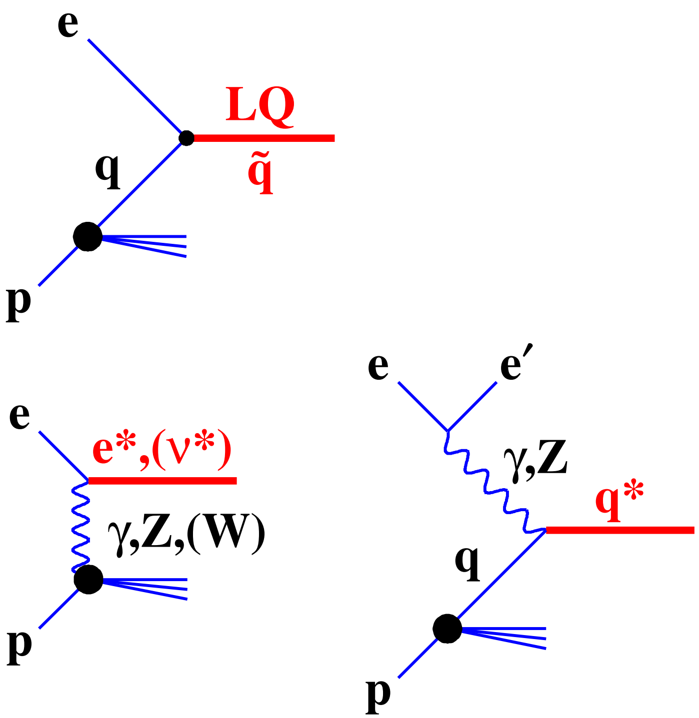


$$Q^2 = -(k-k')^2 = -q^2$$
$$x = \frac{Q^2}{2(P \cdot q)}$$
$$y = \frac{Q^2}{sx}$$
$$M = \sqrt{sx}$$

Search for New Physics at HERA

Direct production of resonances for mass $< \sqrt{s}$ (this talk)

- Leptoquarks (LQs)
  (eq) bound states in various theories beyonds SM
- Squarks ($\tilde{q}$) in $\not{R}_P$ SUSY
  Supersymmetric (SUSY) partners of quarks
- Excited fermions (e^*, ν^*, q^*)
  Substructure of SM fermions



Indirect search (contact interactions) for mass $> \sqrt{s}$ (→ Zarnecki)

Search for leptoquarks

Leptoquarks (LQs):

Scalar and vector
color triplet bosons
carry L and B numbers
$\Rightarrow$ Fermion number
$F = 3B + L = 0, 2$

Production cross section:

(e.g. for s-channel)

unknown Yukawa couplings

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

known parton densities

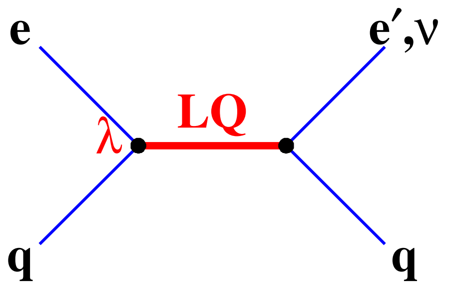
Decays (Final states: NC, CC-like):

Generic models

$BR(\mathrm{LQ} \to lq)$, $BR(\mathrm{LQ} \to \nu q)$
free parameters

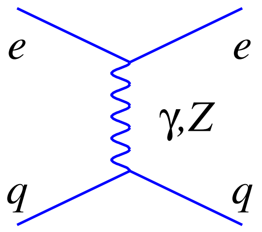
Buchmüller-Rückl-Wyler (BRW) model

7 scalars, 7 vectors
$BR_{eq} = 1, 1/2$, $BR_{\nu q} = 0, 1/2$



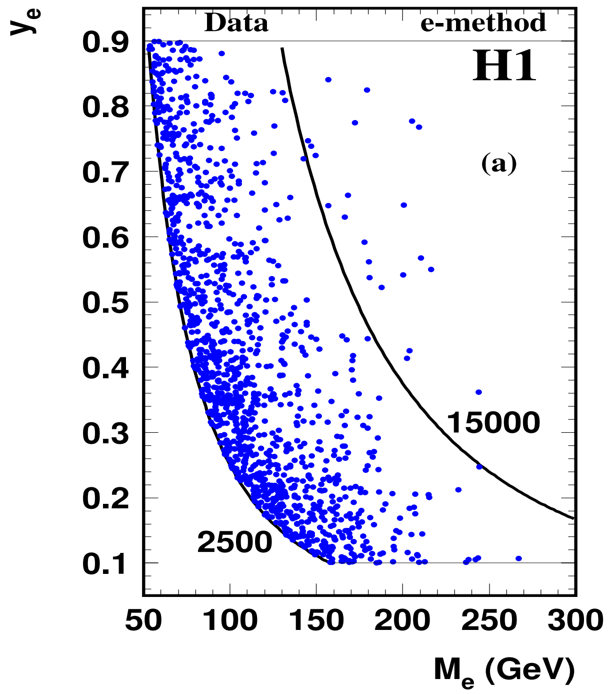
Scalar LQs versus NC DIS

NC DIS



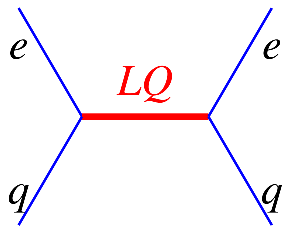
$$\frac{d\sigma}{dy} \sim \frac{1}{y^2}$$

H1 data 94-97



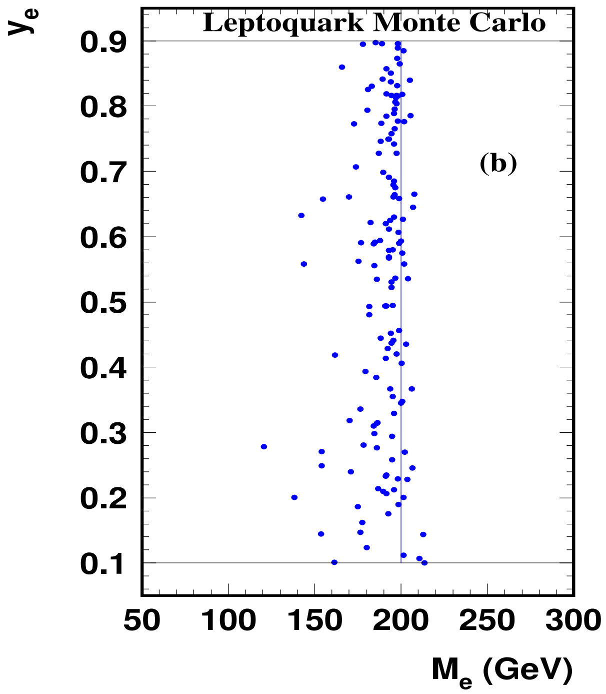
Scalar LQs:

(or $\tilde{q}$ in $\not{R}_P$ SUSY)



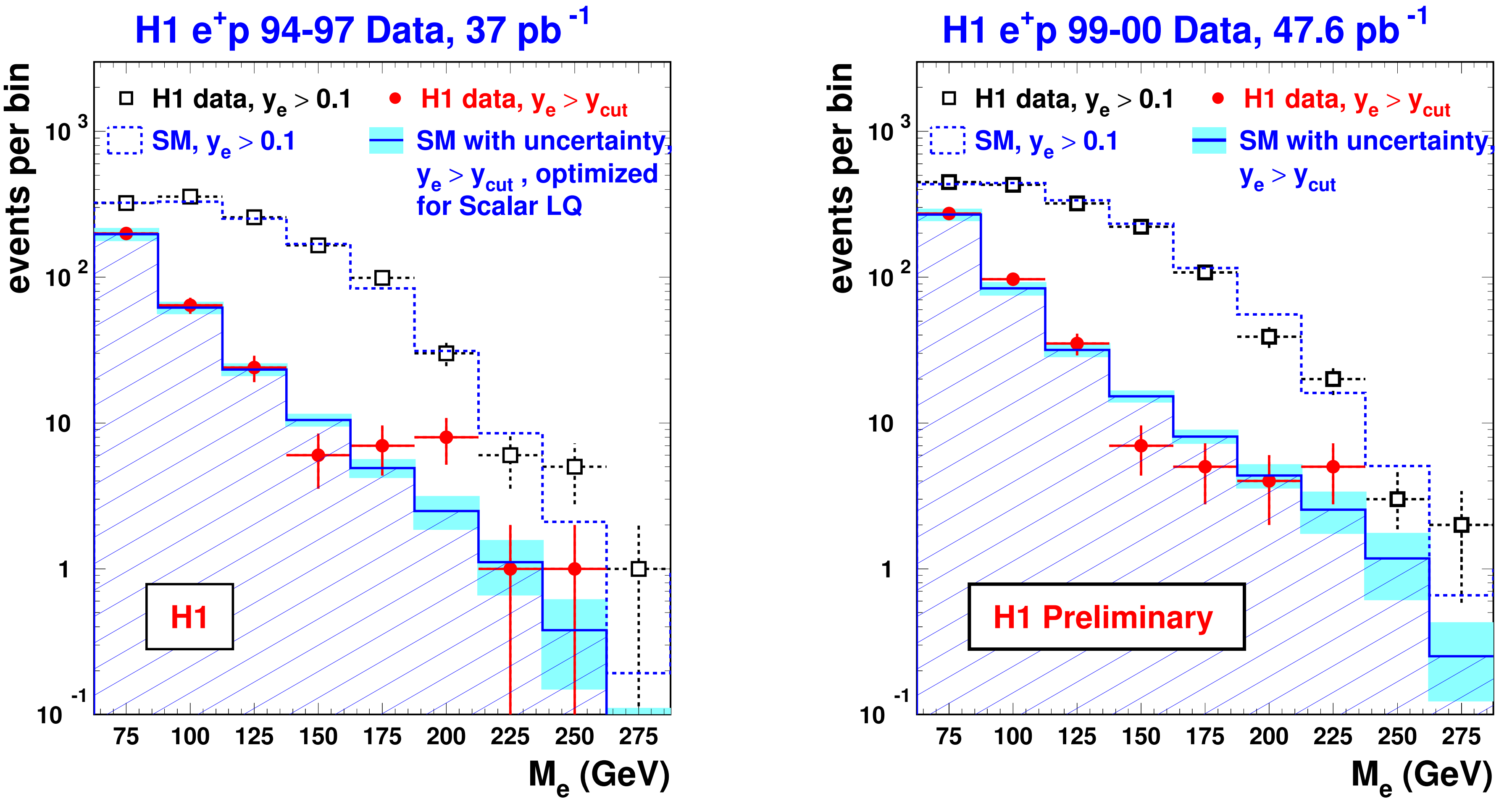
$$\left.\frac{d\sigma}{dy}\right|_{\text{scalar}} \rightarrow \text{flat}$$

Monte carlo



$\Rightarrow$ **Same final states but different y (angular) distributions**

Mass distribution: Excess or Fluctuation?



⇒ Excess in old data not confirmed by new data (also for ZEUS)

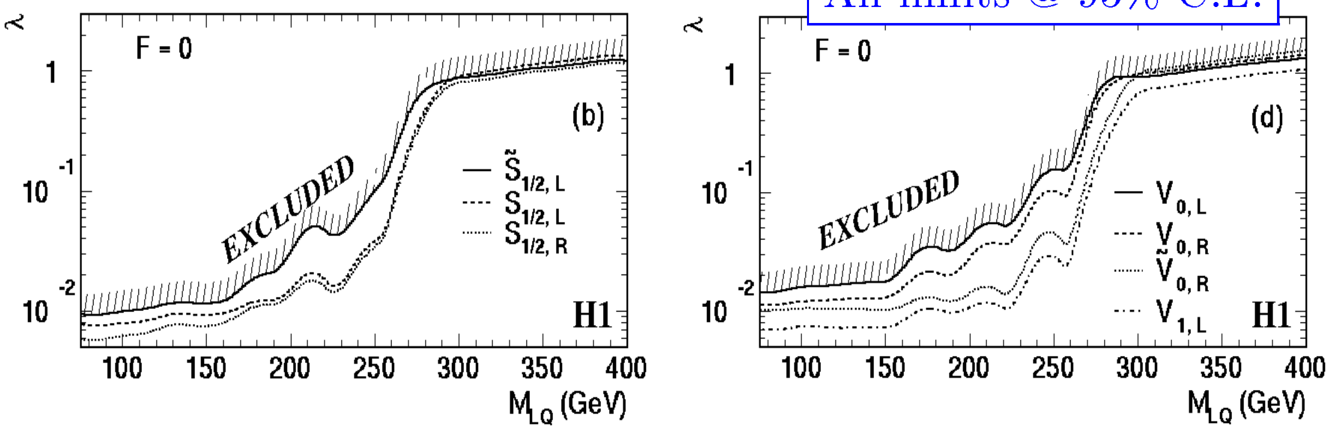
⇒ Proceed to derive limits on the LQ couplings λ and masses

Constraints on 1st generation LQs in BRW model

All limits @ 95% C.L.

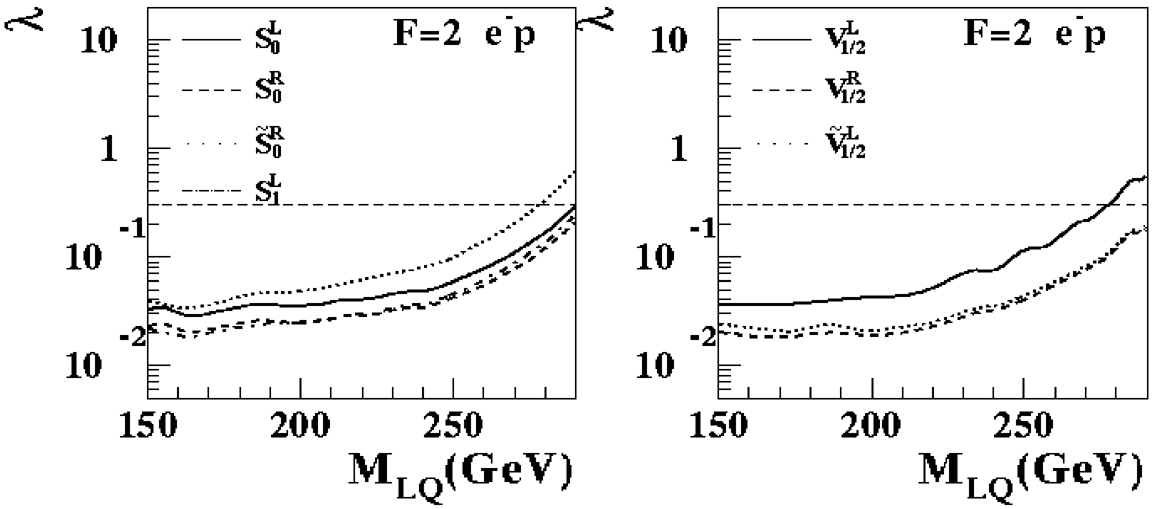
H1 e^+p ($\sqrt{s} = 300$):
(94-97) $\longrightarrow$
$F = 0$: e^+q ($F = 2$: $e^+\overline{q}$)

For $\lambda = \sqrt{4\pi\alpha_{\rm em}} = 0.3$,
$M_{\rm LQ}$ up to 284 GeV excl.



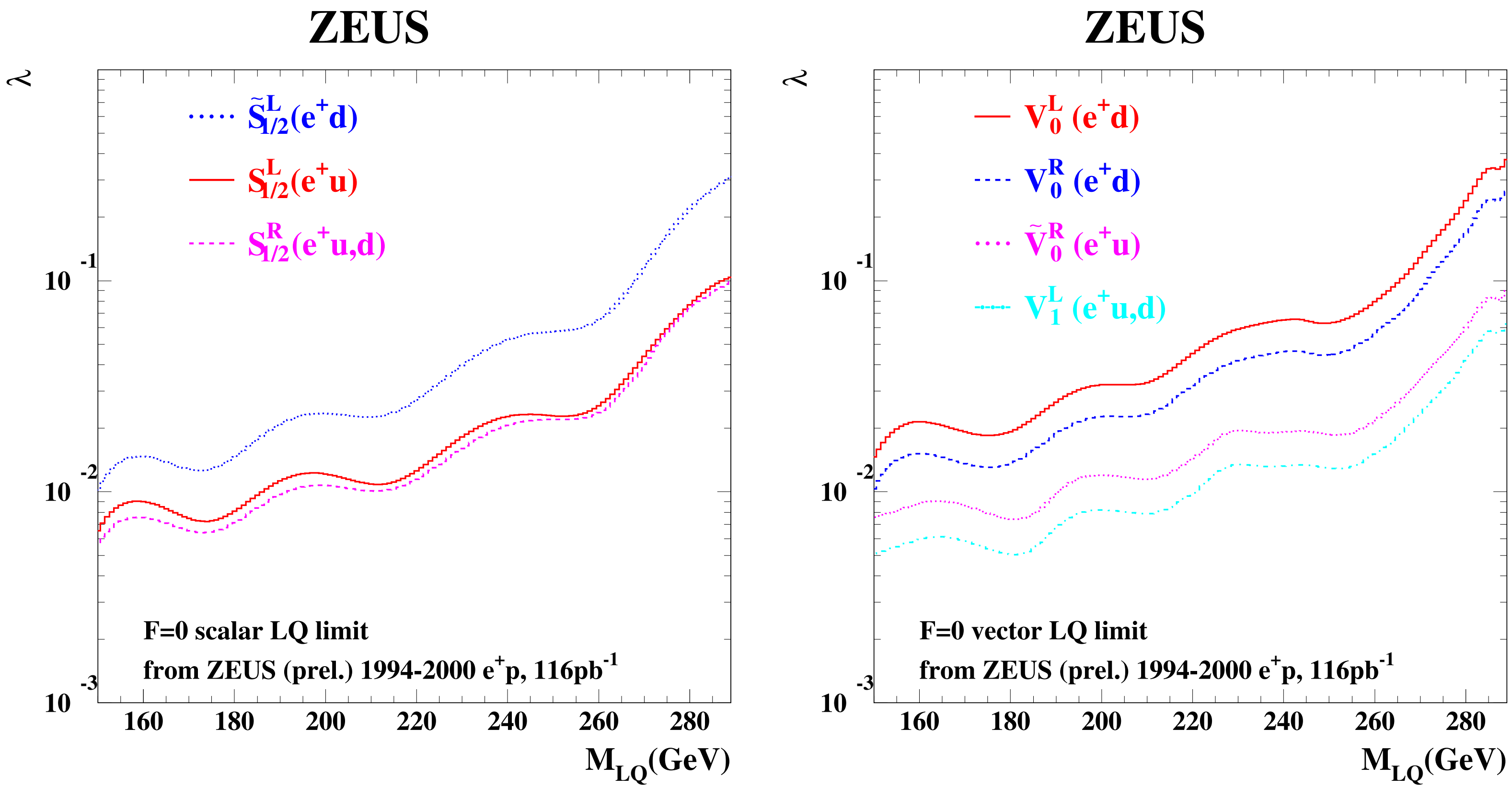
ZEUS e^-p ($\sqrt{s} = 320$):
(98-99 preliminary)$\longrightarrow$
$F = 2$: e^-q ($F = 0$: $e^-\overline{q}$)

For $\lambda = 0.3$,
$M_{\rm LQ}$ up to 290 GeV excluded



$\Rightarrow$ $e^\pm$ probing different LQs
$\Rightarrow$ higher $\sqrt{s}$ $\rightarrow$ better limit at ~ 290 GeV
$\Rightarrow$ H1 limits $> \sqrt{s}$ by considering u-channel exchange, interference with NC

New preliminary results: combined 1994-2000 e^+p data



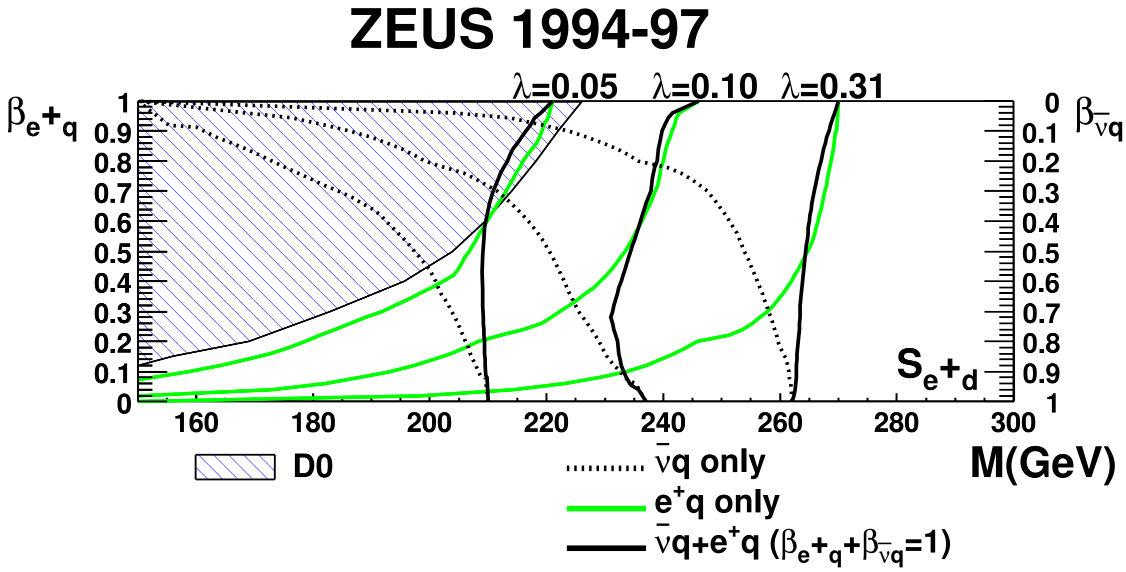
For $\lambda = 0.03$ (i.e. a coupling 100 times smaller than α_{em})

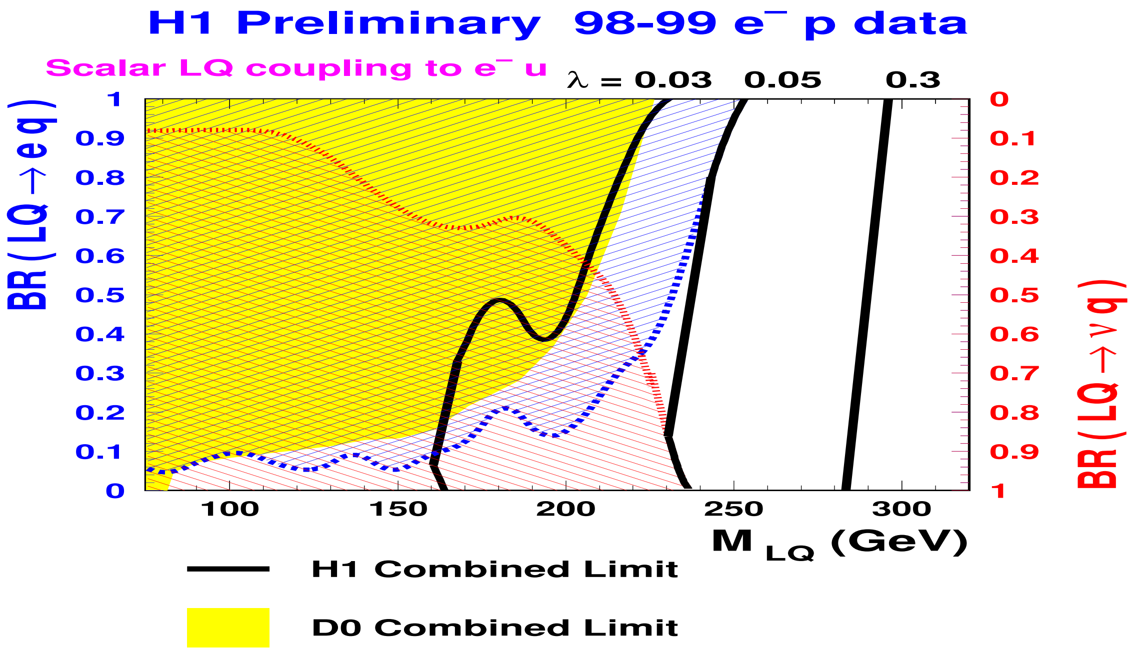
1994-2000 combined: M_{LQ} up to 275 GeV excluded

Improved by 25 GeV with respect to 1994-1997 alone

Constraints in generic models

In generic models, BR_{eq} and $BR_{\nu q}$ not fixed

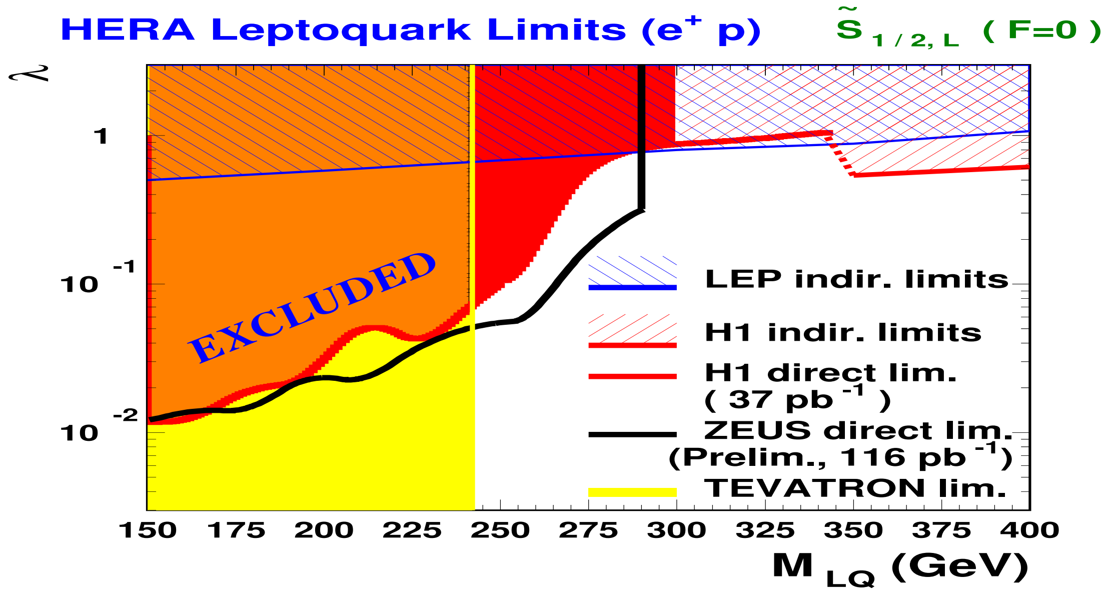


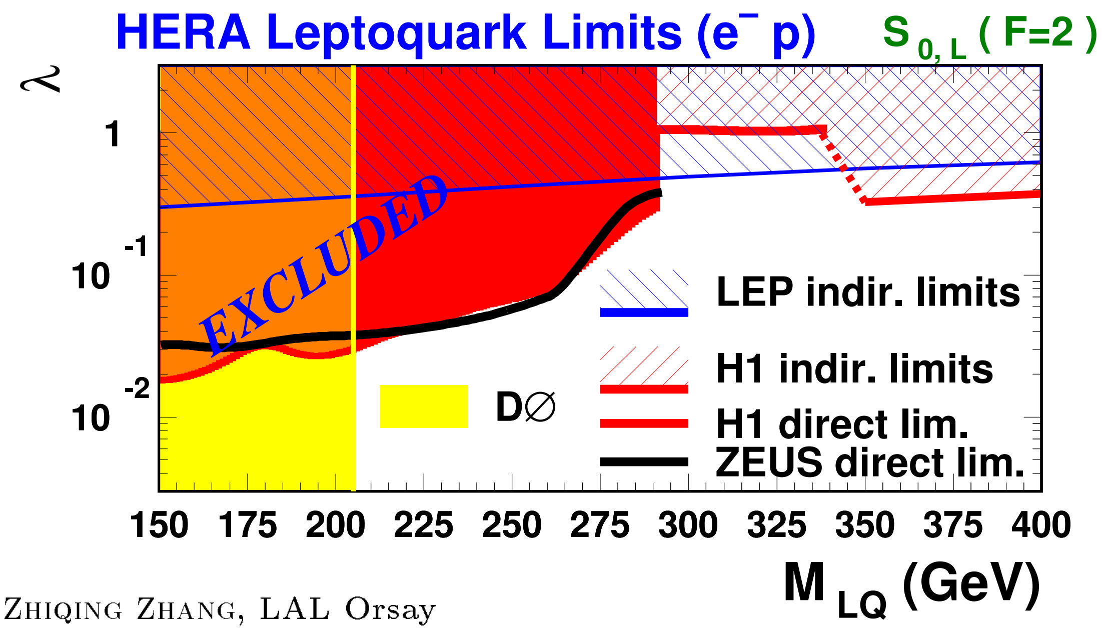


⇒ Combined mass limits largely independent of BR_{eq} or $BR_{\nu q}$

⇒ Higher sensitivity at high masses with e^-p due to the increase in $\sqrt{s}$ and $u > d$

Comparison with LEP and Tevatron





(In BRW model)

LEP:

Virtual effects to hadronic cross section

Tevatron:

LQ pair produced via strong coupling

Limits independent of λ

HERA:

Both direct & indirect limits

Stringent limits for intermediate mass range

Higher sensitivity when $\sqrt{s} \nearrow$

Search for squarks in $\not{R}_P$ SUSY

R-parity, a multiplicative quantum number:

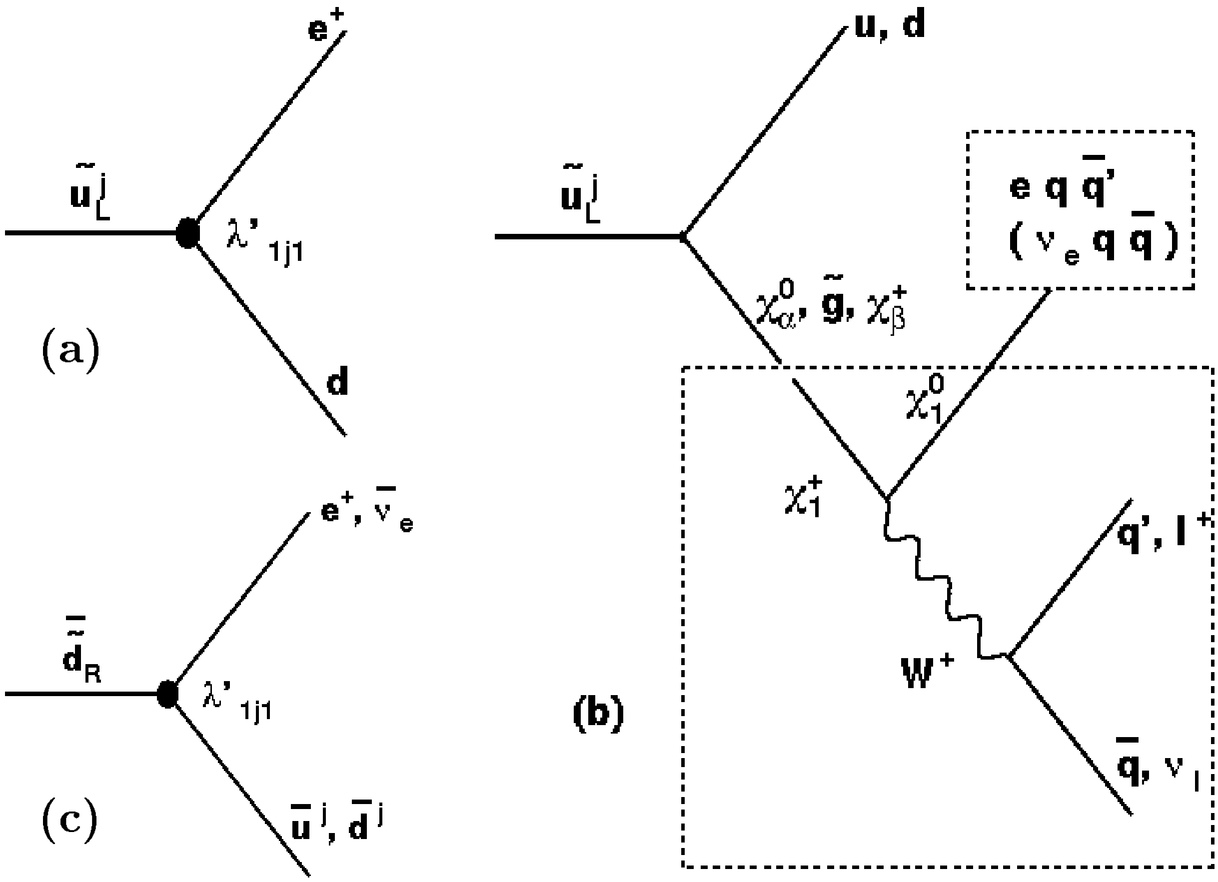
$$R_P = (-1)^{3B+L+S} = \begin{cases} +1 & \text{(SM particles)} \\ -1 & \text{(SUSY particles)} \end{cases}$$

$\not{R}_P$ terms in SUSY superpotential:

$$\mathcal{W}_{\not{R}_P} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

HERA e, p beams $\rightarrow$ well suited for $\lambda' \neq 0$

LSP unstable $\rightarrow$ $\not{R}_P$ and gauge **decays:**



$\Downarrow$ $\Downarrow$

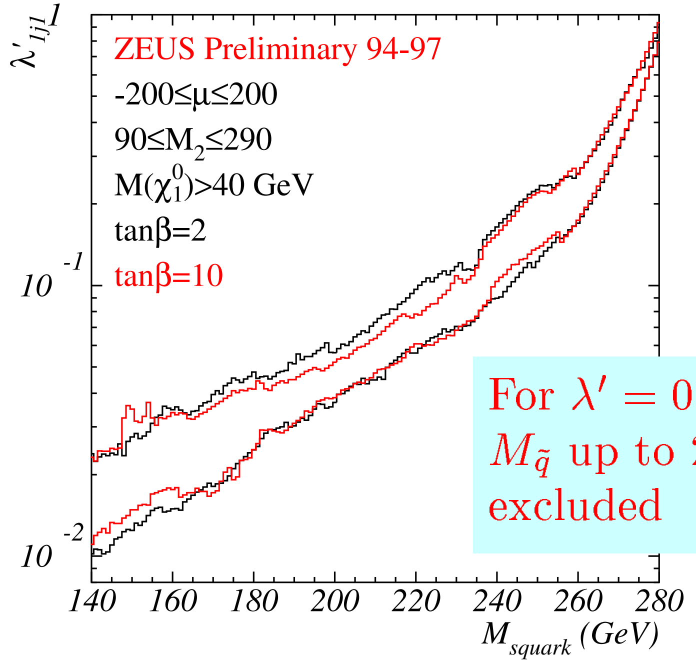
Final states: LQ-like l+multijets

Limits in unconstrained MSSM

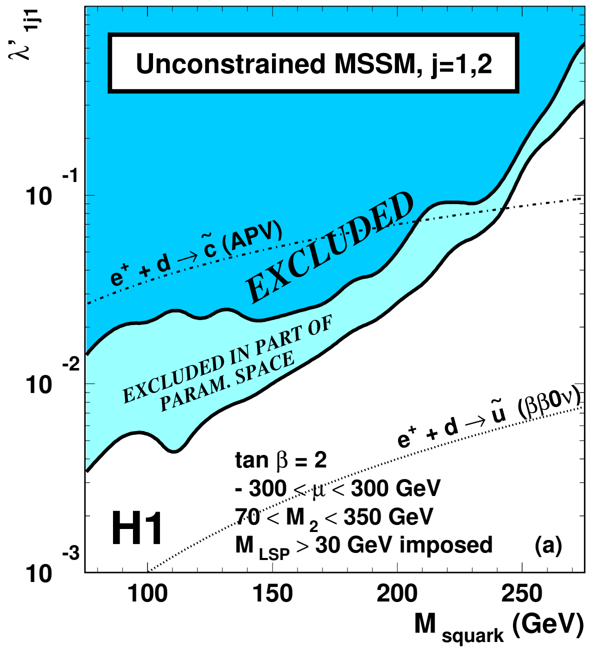
Minimal Supersymmetric Standard Model

Masses and couplings of χ's depend on $\mu, M_2, \tan\beta$

Sfermions mass: free parameters, assumed to be degenerate



For $\lambda' = 0.3$,
$M_{\tilde q}$ up to 270 GeV
excluded



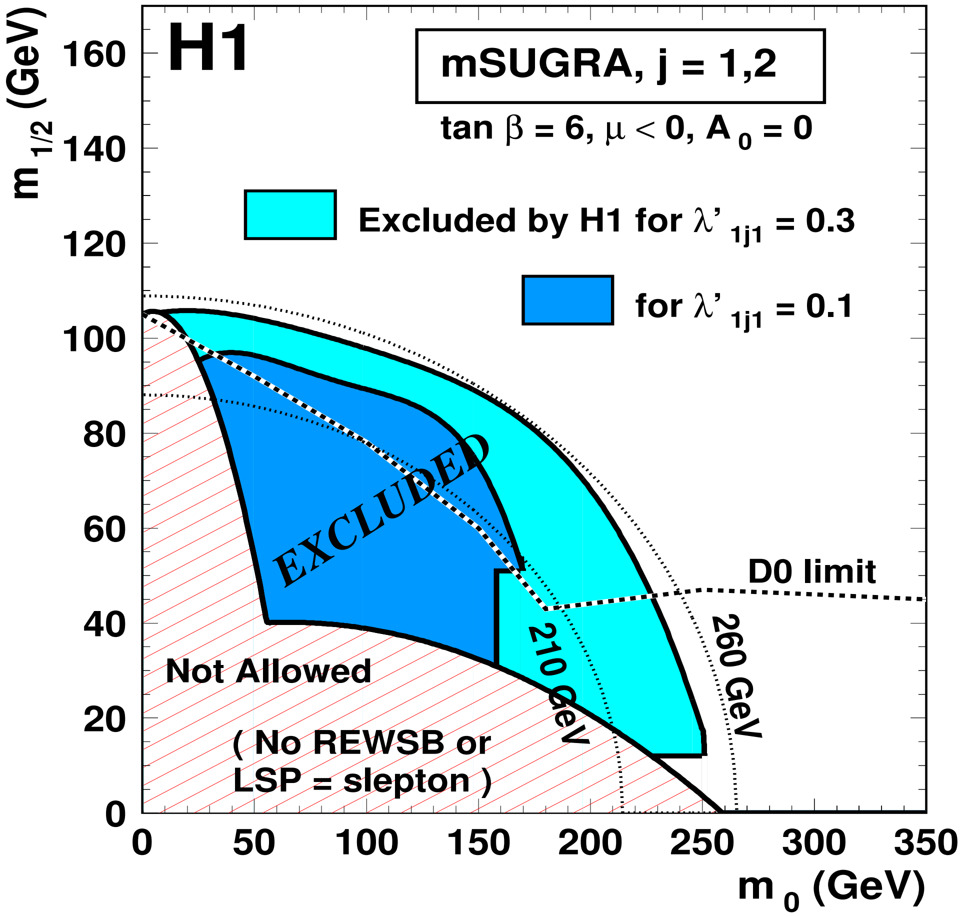
Comparison with indirect limits:

- Better limit on λ'_{111} from $e^+ + d \to \tilde u(\beta\beta 0\nu)$ (Atomic Parity Violation)
- HERA limits better (up to ~ 3) on λ'_{121}, λ'_{131} for $M_{\tilde q} \lesssim 240\,\mathrm{GeV}$ than APV

Constraints, comparison in mSUGRA

minimal SUperGRAvity

Only 5 free parameters: $m_0, m_{1/2}, \tan\beta, \mathrm{sign}(\mu), A_0$



Comparison with Tevatron/LEP:

- Tevatron/LEP limits independent of λ'
- Tevatron: search with di-lepton, limits degrade (smaller BR) for large $\tan\beta$
- LEP direct search limited to $M_{\tilde{q}} \lesssim E_e \sim 100\,\mathrm{GeV}$
- LEP combined searches for χ's and sleptons: comparable/slightly better than HERA limits

Search for excited fermions f^*s

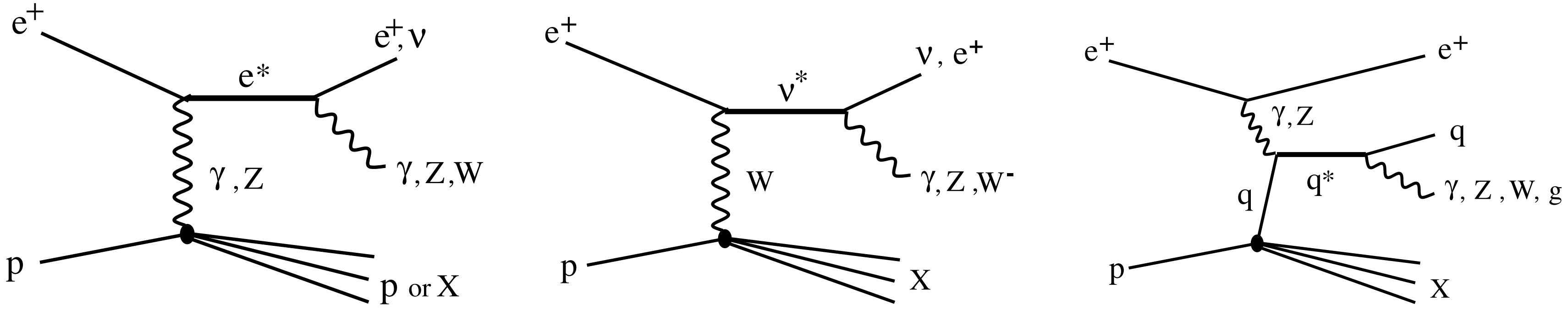
Observation of f^*s $\Longleftrightarrow$ Direct evidence for substruture

Effective Lagrangian for the considered f^*s (spin 1/2, isospin 1/2):

$$L_{\text{eff}} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L + h.c.$$

Λ: compositeness scale; f, f', f_s: relative coupling parameters

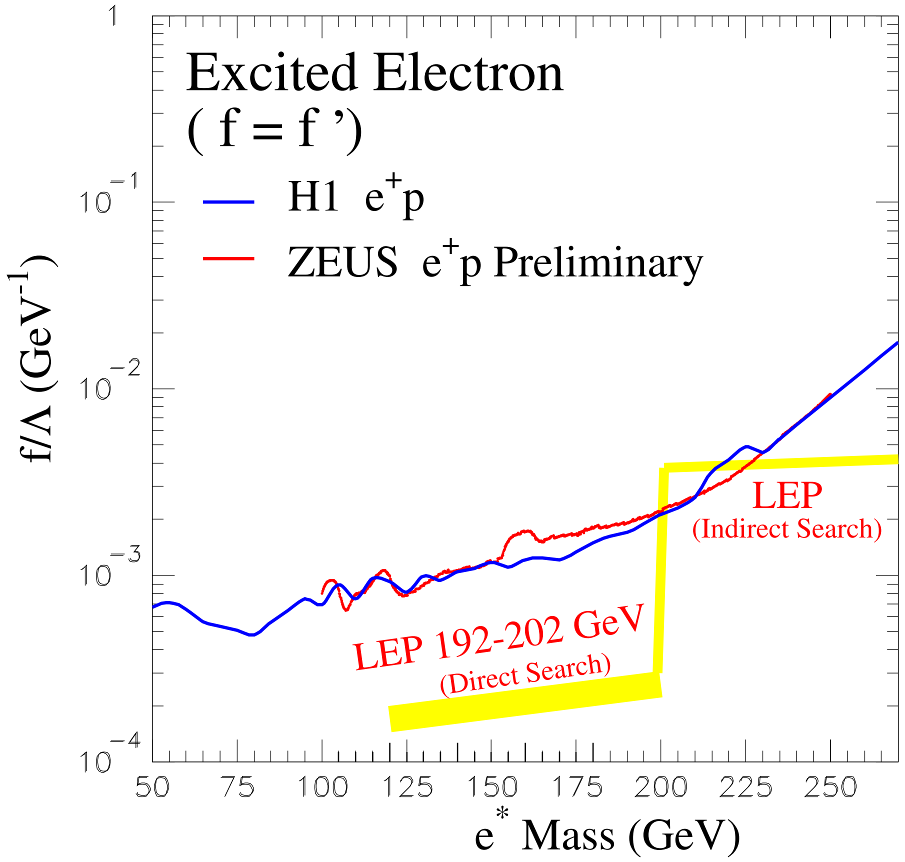
Production and decays:



e^* has elastic contribution; $W, Z \rightarrow$ hadrons, leptons

Constraints and comparison for e^*

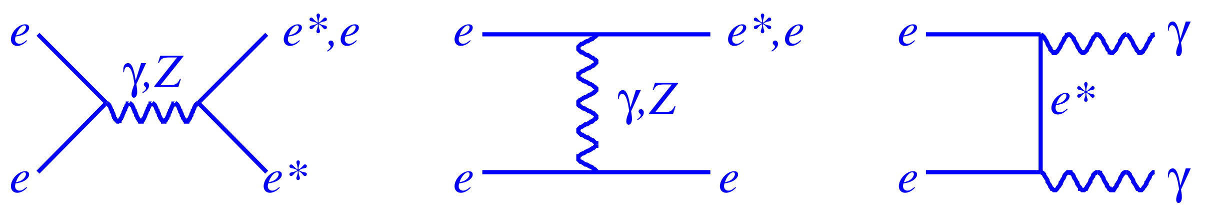
HERA direct search at $\sqrt{s} = 300\,\mathrm{GeV}$:



If $f/\Lambda = 1/M_{e^*}$, $M_{e^*} < 229\,\mathrm{GeV}$ excluded

Comparison with LEP:

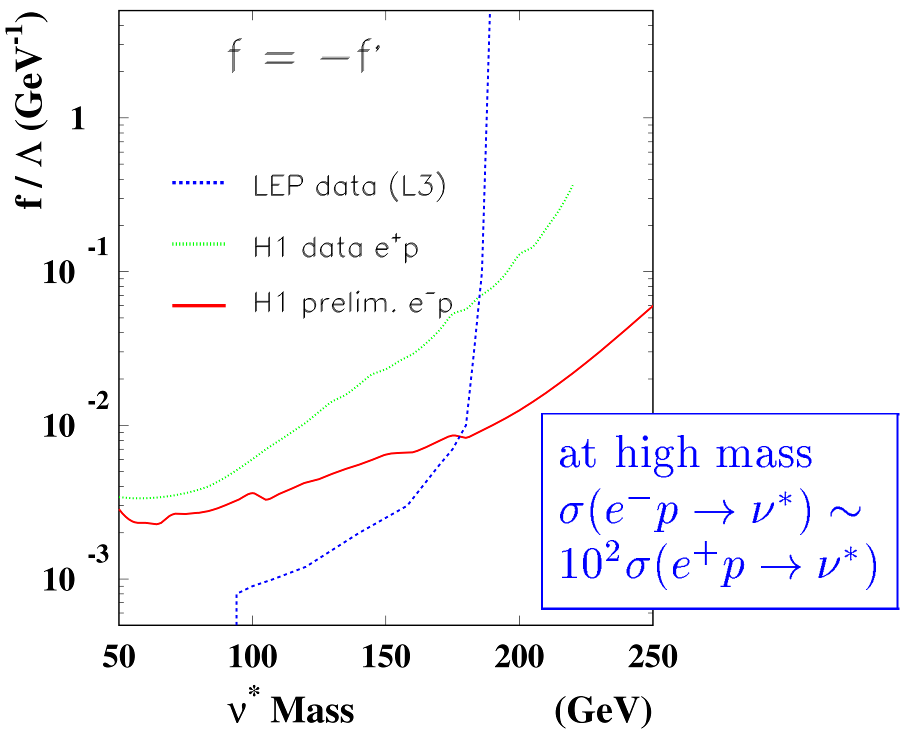
Direct search — Indir. search



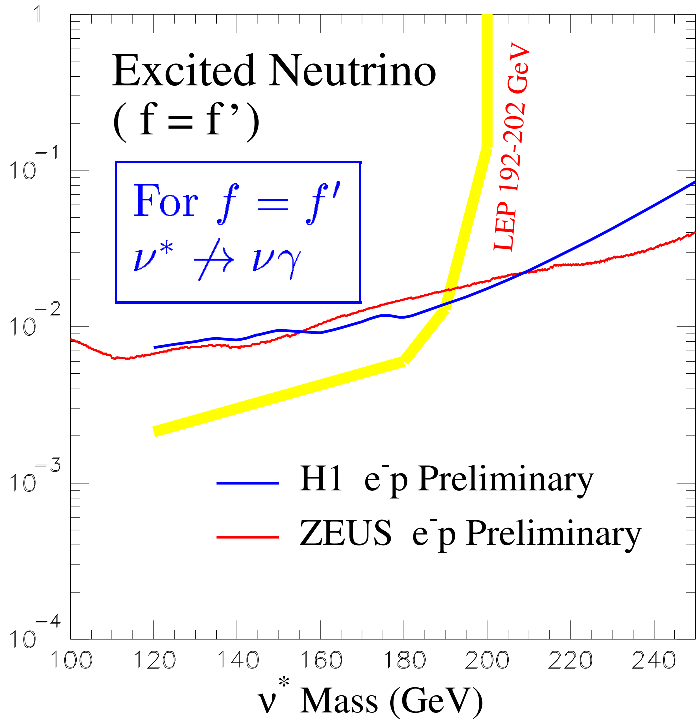
pair: $M_{e^*} < E_e$ — single: $M_{e^*} < \sqrt{s}$ — virtual: $M_{e^*} > \sqrt{s}$

Constraints and comparison for ν^*

H1: $e^+, \sqrt{s} = 300, \mathcal{L} = 37\,\mathrm{pb}^{-1}$ versus
$e^-, \sqrt{s} = 320, \mathcal{L} = 16\,\mathrm{pb}^{-1}$



HERA versus LEP

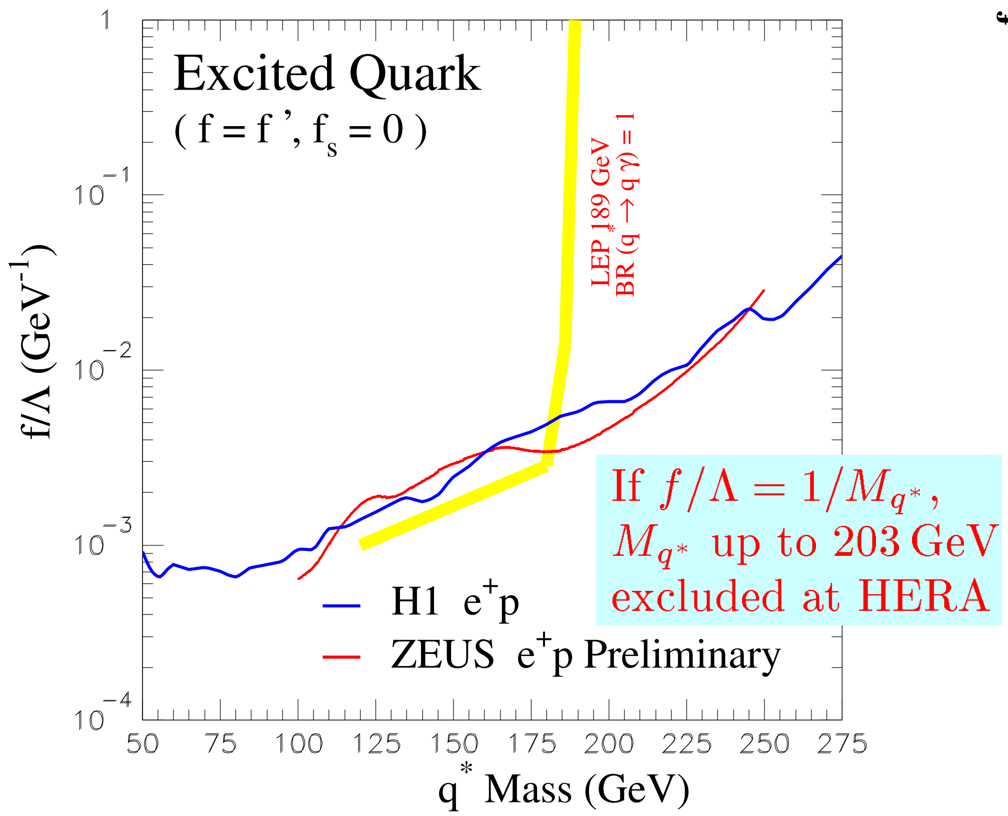


If $f/\Lambda = 1/M_{\nu^*}$,
$M_{\nu^*} < 114\,\mathrm{GeV}$ $(e^+ p)$ excluded
$M_{\nu^*} < 150\,\mathrm{GeV}$ $(e^- p)$ excluded

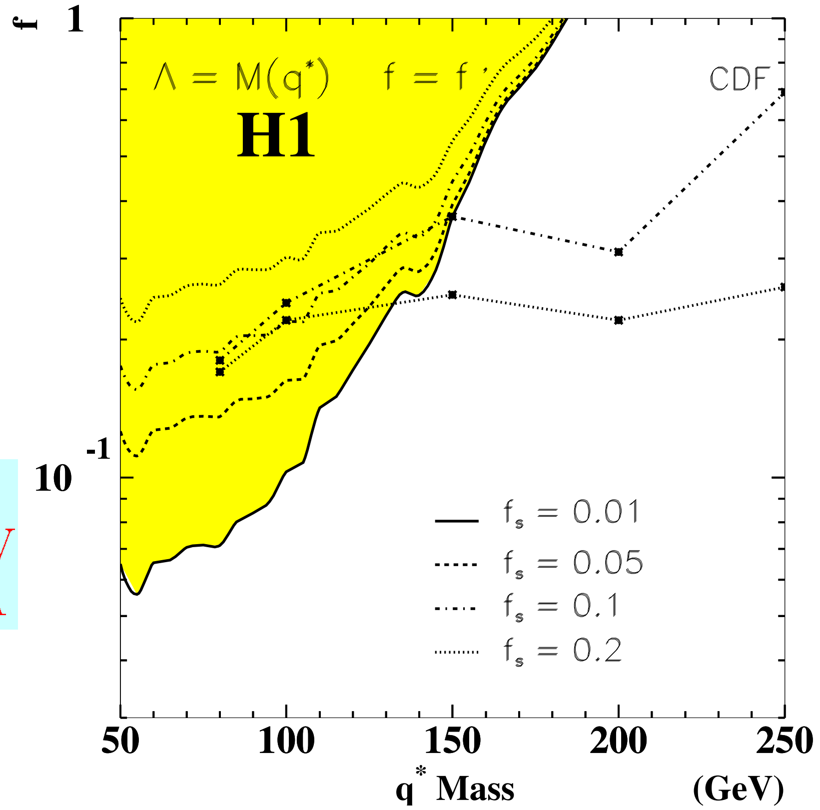
$\Rightarrow$ Above $\sim 190\,\mathrm{GeV}$, HERA extends LEP

Constraints and comparison for q^*

HERA versus LEP



H1 versus CDF



HERA limits extend LEP at high M_{q^*}
LEP limits apply for $\mathrm{BR}(q^* \to q\gamma) = 1$

HERA best sensitivity when $f_s \searrow$
Tevatron best sensitivity when $f_s \nearrow$

Summary

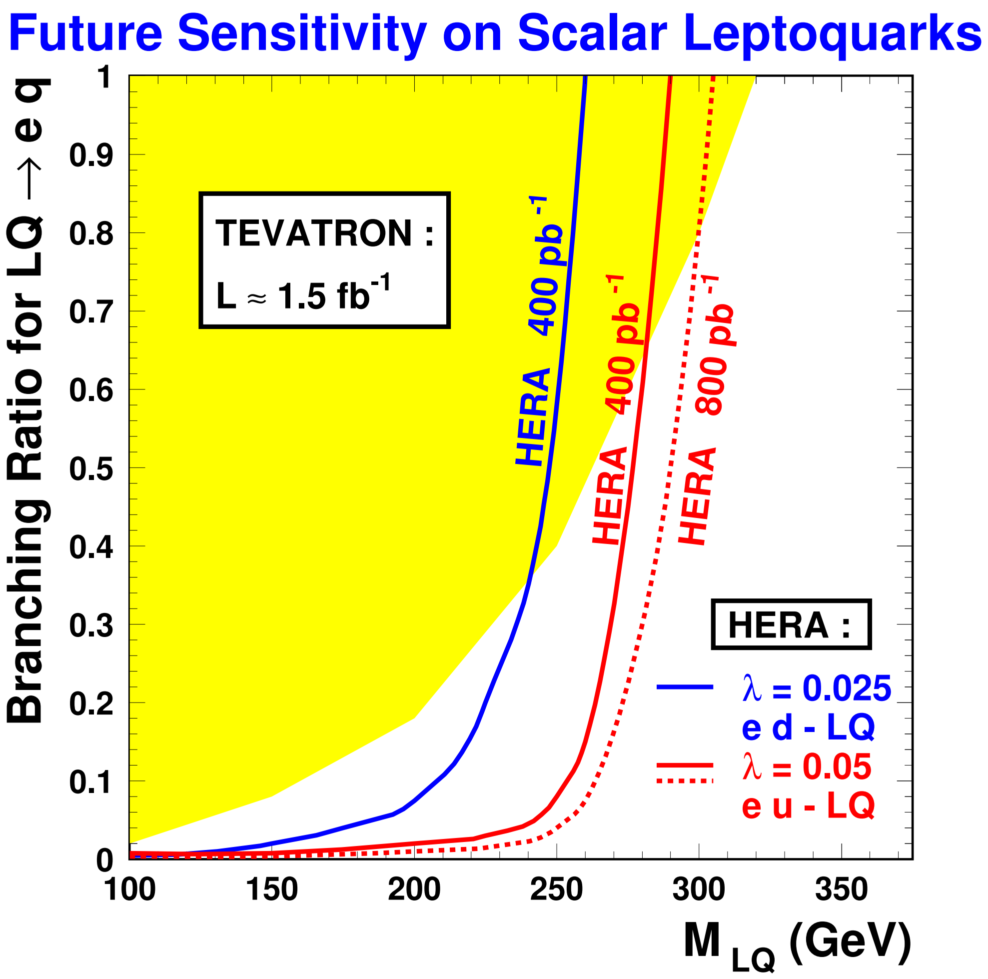
- Resonance productions of new particles (leptoquarks, squarks in $R\!\!\!/_P$ SUSY, excited fermions) have been extensively searched for at HERA
- No evidence for these new particles has been found so far
- Stringent limits on couplings and masses have been derived

Search	Couplings	$e^+p(\sqrt{s}=300)$	$e^-p(\sqrt{s}=320)$	$e^+p(\sqrt{s}=320)$
LQs $(F=0)$	$\lambda=0.3$	$>284\,\mathrm{GeV}$		
	$\lambda=0.03$	$>250\,\mathrm{GeV}$		$>275\,\mathrm{GeV}$
LQs $(F=2)$	$\lambda=0.3$		$>290\,\mathrm{GeV}$	
$\tilde{q}$ uncon. MSSM	$\lambda'=0.3$	$>270\,\mathrm{GeV}$		
$\tilde{q}$ mSUGRA	$\lambda'=0.3$	$>260\,\mathrm{GeV}$		
e^*	$f=f'$	$>229\,\mathrm{GeV}$		
ν^*	$f=-f'$	$>114\,\mathrm{GeV}$	$>150\,\mathrm{GeV}$	
q^*	$f=f', f_s=0$	$>203\,\mathrm{GeV}$		

- The limits are competitive/complementary to those derived from LEP, Tevatron, and/or low energy experiments

Outlook

- At HERA II there are still open windows for discovery
- If no direct observation of new particles, stringent limits are expected to complement the Tevatron:



⇒ Looking forward to an exciting future at HERA with 5 times more lumi and upgraded H1 and ZEUS detectors