Search for Excited Fermions at HERA

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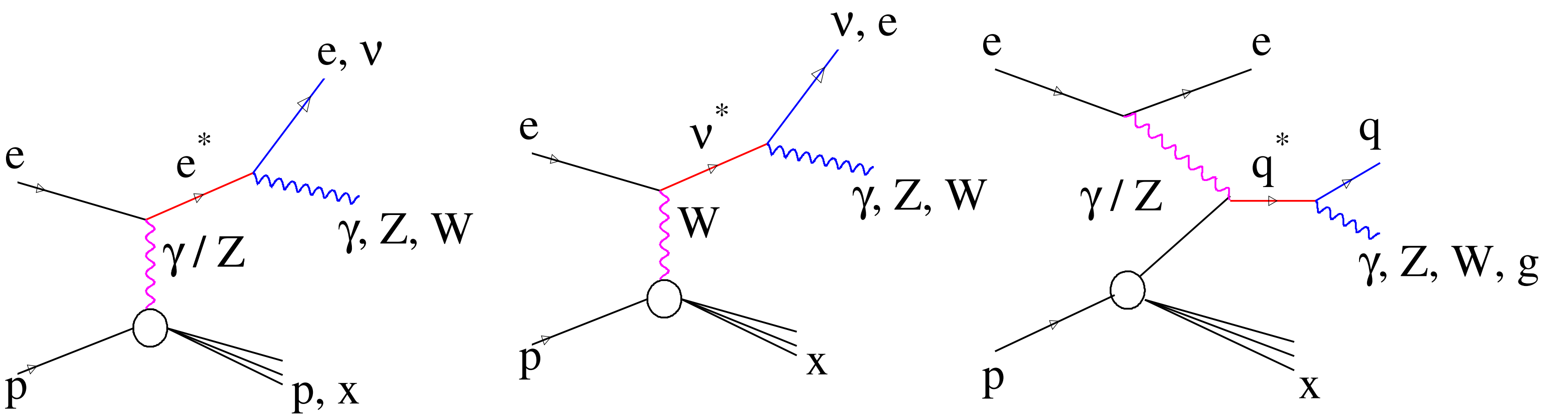
Representing the H1 and ZEUS Collaborations

- *Introduction*
- *Search for Excited Electrons*
- *Search for Excited Neutrinos*
- *Search for Excited Quarks*
- *Summary*

Compositeness ⇒ Excited Fermion



Phenomenological Model

$$F^* \to F + V$$
$$\hookrightarrow q\,\bar{q}\,', l\,\bar{l}\,'$$
$$(V = \gamma,\ Z,\ W)$$

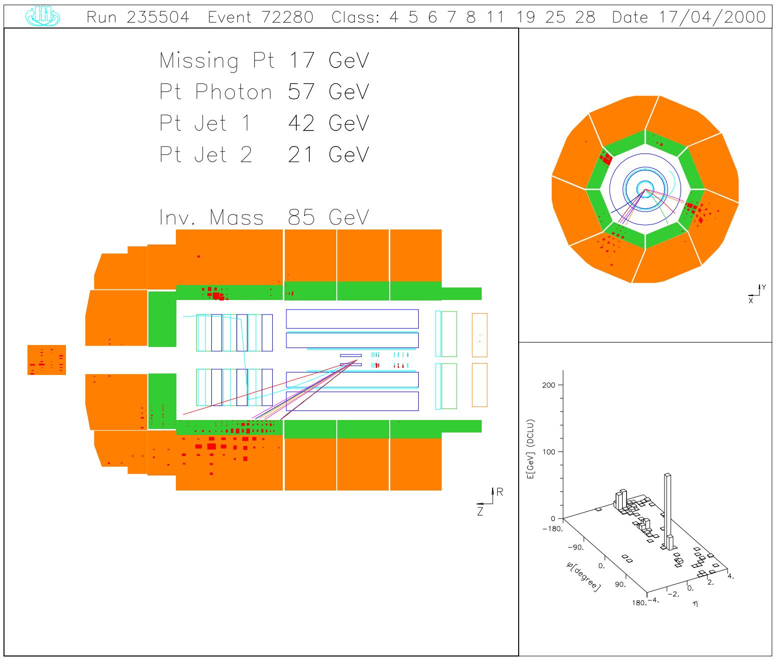
$$\mathcal{L}_{F^*F} = \frac{1}{\Lambda}\bar{F}^*_R\left[\,f\cdot \underset{W}{SU(2)} + f'\cdot \underset{Y}{U(1)} + f_s\cdot \underset{C}{SU(3)}\,\right]F_L$$

Compositeness Scale : $\Lambda \sim \mathcal{O}(\text{TeV})$
Free Parameters : $f, f', f_s \sim \mathcal{O}(1)$

$$\sigma(ep \to F^*X) \sim (\frac{f}{\Lambda})^2,\ \ (\frac{f'}{\Lambda})^2,\ \ (\frac{f_s}{\Lambda})^2$$

e^+p **data**	e^-p **data**
$\sqrt{s} = 300$ GeV	$\sqrt{s} = 318$ GeV
$\mathcal{L} = 38$ pb^{-1}	$\mathcal{L} = 17$ pb^{-1}
e^*, ν^*, q^*	ν^*

Event Displays

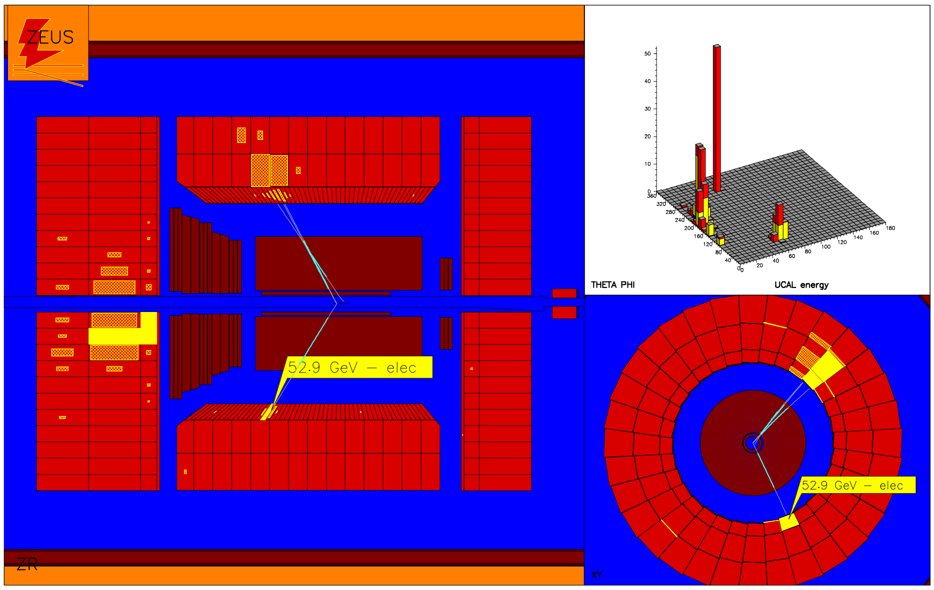


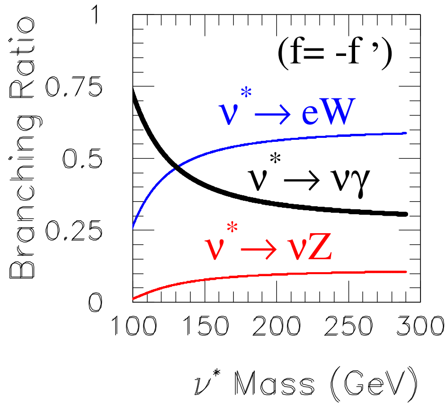
H1

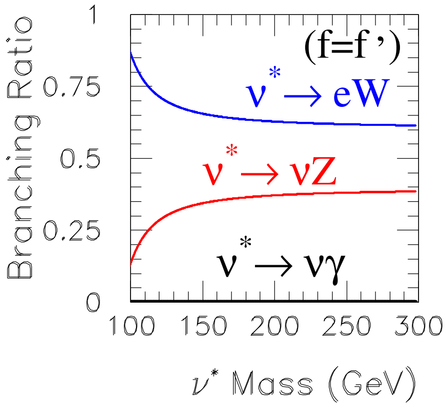
$\nu^* \to \nu\gamma$
candidate

ZEUS

$q^* \to qW \to qe\nu$
candidate







Channel	Topology	Studied by
Excited Electron		
$e^* \to e\gamma$	$e + \gamma +$ high E_t	ZEUS, H1
$e^* \to eZ \to eq\bar{q}$	$e +$ 2 jets	ZEUS, H1
$e^* \to eZ \to ee^+e^-$	3 $e +$ high E_t	H1
$e^* \to eZ \to e\nu\bar{\nu}$	$e+$ high $\not{P}_t$	H1
$e^* \to eZ \to e\mu\bar{\mu}$	$e+$ 2 μ	H1
$e^* \to \nu W \to \nu q'\bar{q}$	high $\not{P}_t$ + 2 jets	ZEUS, H1
Excited Neutrino		
$\nu^* \to \nu\gamma$	$\gamma +$ high $\not{P}_t$	ZEUS, H1
$\nu^* \to eW \to e\nu e$	2 $e +$ high $\not{P}_t$	H1
$\nu^* \to eW \to eq'\bar{q}$	high $\not{P}_t$ + 2 jets	ZEUS, H1
$\nu^* \to eW \to e\mu\nu$	$e + \mu +$ high $\not{P}_t$	H1
$\nu^* \to \nu Z \to \nu q\bar{q}$	high $\not{P}_t$ + 2 jets	ZEUS, H1
$\nu^* \to \nu Z \to \nu ee$	2 $e+$ high $\not{P}_t$	H1
Excited Quark		
$q^* \to q\gamma$	$\gamma +$ jet	ZEUS, H1
$q^* \to qZ \to qq'\bar{q}'$	3 jets	H1
$q^* \to qZ \to qee$	2 $e +$ jet	H1
$q^* \to qZ \to q\mu\bar{\mu}$	2 $\mu +$ high $\not{P}_t$	H1
$q^* \to qW \to q\nu e$	$e +$ jet + high $\not{P}_t$	ZEUS, H1
$q^* \to qW \to qq'\bar{q}$	3 jets	H1
$q^* \to qW \to q\mu\nu$	$\mu +$ jet + high $\not{P}_t$	H1

Search For Excited Electron

Signature of main channels

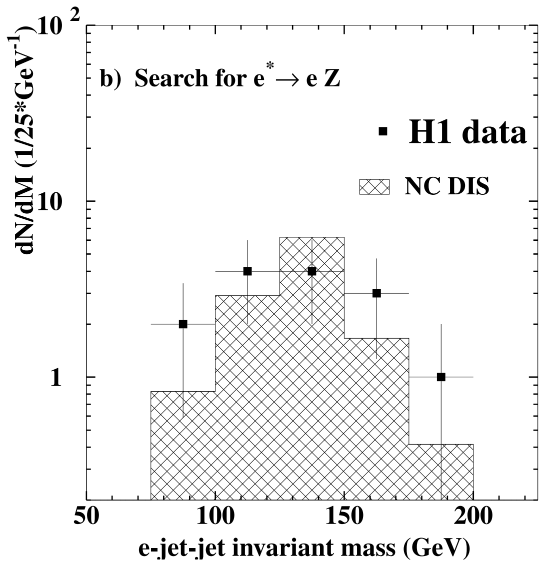
▷ $e^* \to e\gamma$:	1 electron + 1 photon (high E_t)
▷ $e^* \to \nu W \to \nu q'\bar{q}$:	high $\not{P}_t$ + 2 high E_t jets (with mass $\sim M_W$)
▷ $e^* \to eZ \to eq\bar{q}$:	1 electron + 2 high E_t jets (with mass $\sim M_Z$)

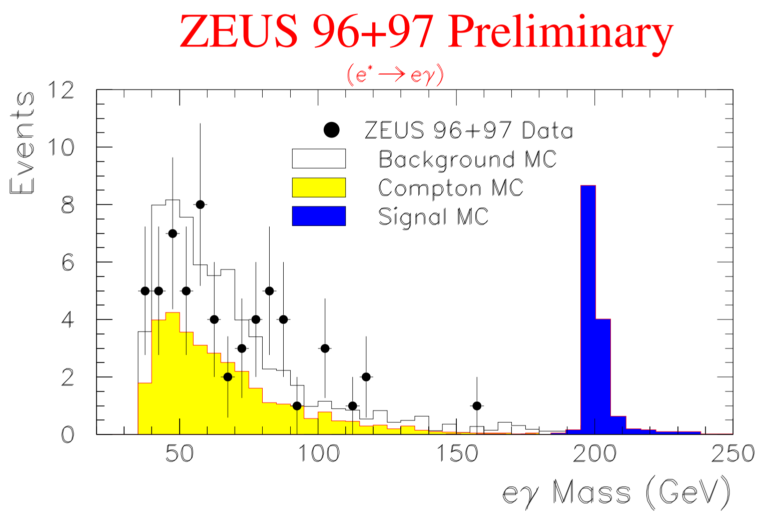
H1

Channel	Events	Background
$e^* \to e\gamma$ (Elas)	53	52.5 ± 1.5
$e^* \to e\gamma$ (Inel)	68	77.4 ± 8.2
$e^* \to eZ_{\to ee}$	1	0.9 ± 0.4
$e^* \to eZ_{\to \mu\bar{\mu}}$	0	0.35 ± 0.05
$e^* \to eZ_{\to \mu\bar{\mu}}$	1	2.7 ± 0.4
$e^* \to eZ_{\to q\bar{q}}$	14	12.3 ± 3.4
$e^* \to \nu W_{\to q'\bar{q}}$	3	3.3 ± 0.6

ZEUS

Channel	Events	Background
$e^* \to e\gamma$	60	68 ± 2
$e^* \to eZ_{\to q\bar{q}}$	29	26.7 ± 0.9
$e^* \to \nu W_{\to q'\bar{q}}$	12	14.3 ± 0.9

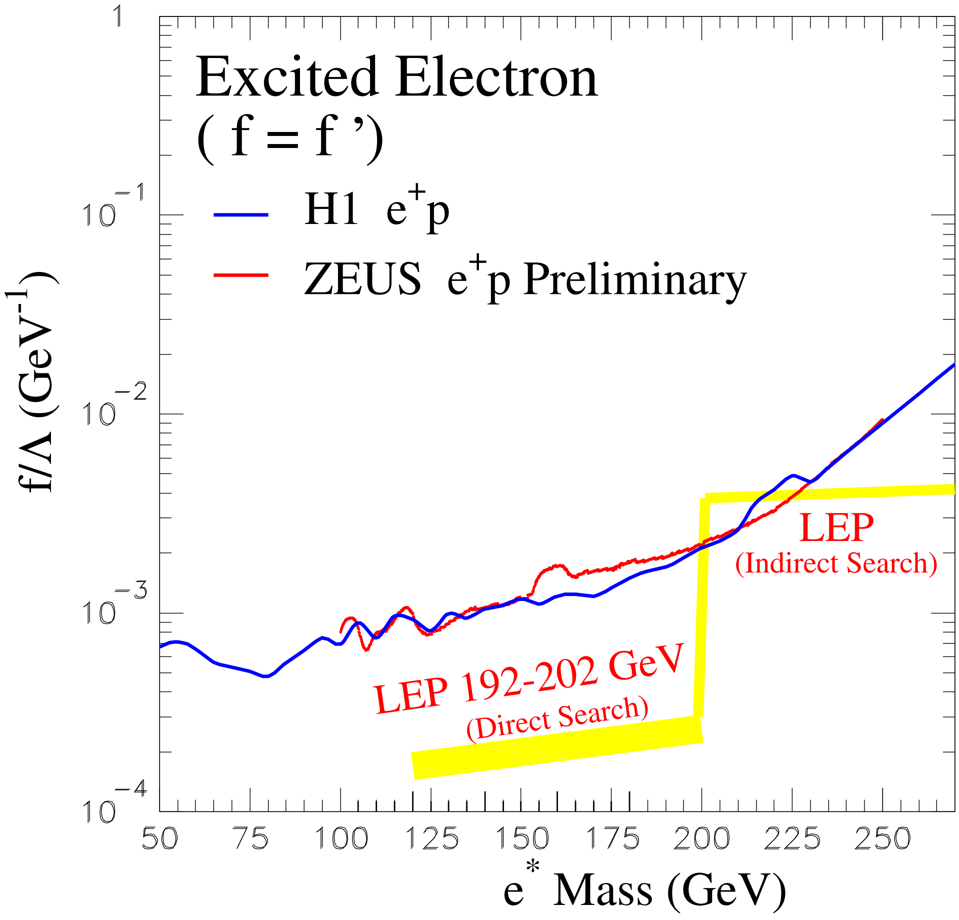




HERA Excited Electron Limits
$(f = f')$

No evidence for e^* production

95% C.L. Limits on f/Λ



H1	ZEUS
Assuming $f/\Lambda = 1/M_{e^*}$ $50 < M_{e^*} < 223$ GeV are excluded.	Assuming $f/\Lambda = 1/M_{e^*}$ $100 < M_{e^*} < 229$ GeV are excluded.

Search For Excited Neutrino

Signature of main channels

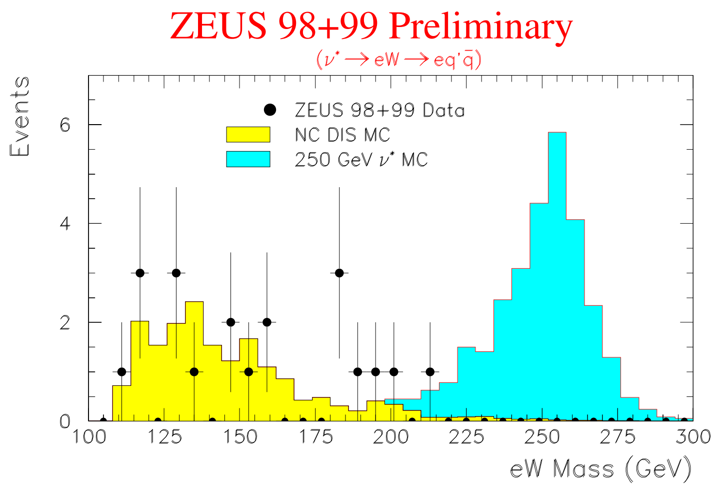
▷ $\nu^* \to \nu\gamma$:	1 photon + high $\not{P}_t$
▷ $\nu^* \to eW \to eq'\bar{q}$:	1 electron + 2 high E_t jets (with mass $\sim M_W$)
▷ $\nu^* \to \nu Z \to \nu q\bar{q}$:	high $\not{P}_t$ + 2 high E_t jets (with mass $\sim M_Z$)

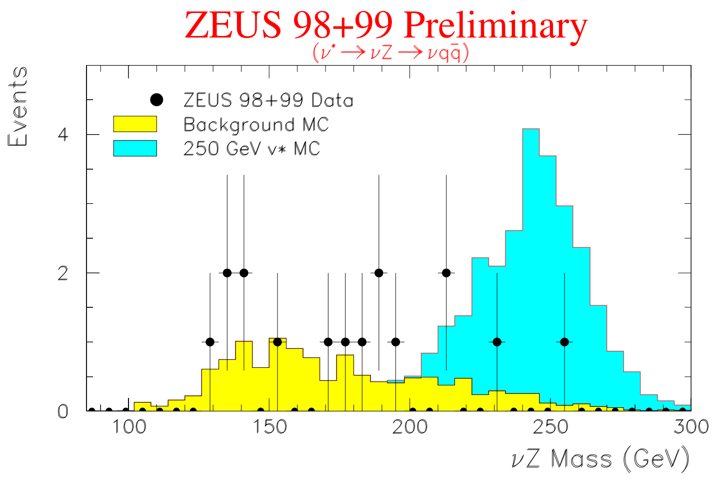
H1

Channel	Events	Background
$\nu^* \to \nu\gamma$	2	$2.56 \pm 0.17 \pm 1.20$
$\nu^* \to eW_{\to q'\bar{q}}$	4	$7.74 \pm 1.38 \pm 1.63$

ZEUS

Channel	Events	Background
$\nu^* \to \nu\gamma$	2	1.8 ± 0.2
$\nu^* \to eW_{\to q'\bar{q}}$	20	15.0 ± 1.5
$\nu^* \to \nu Z_{\to q\bar{q}}$	16	12.3 ± 0.6

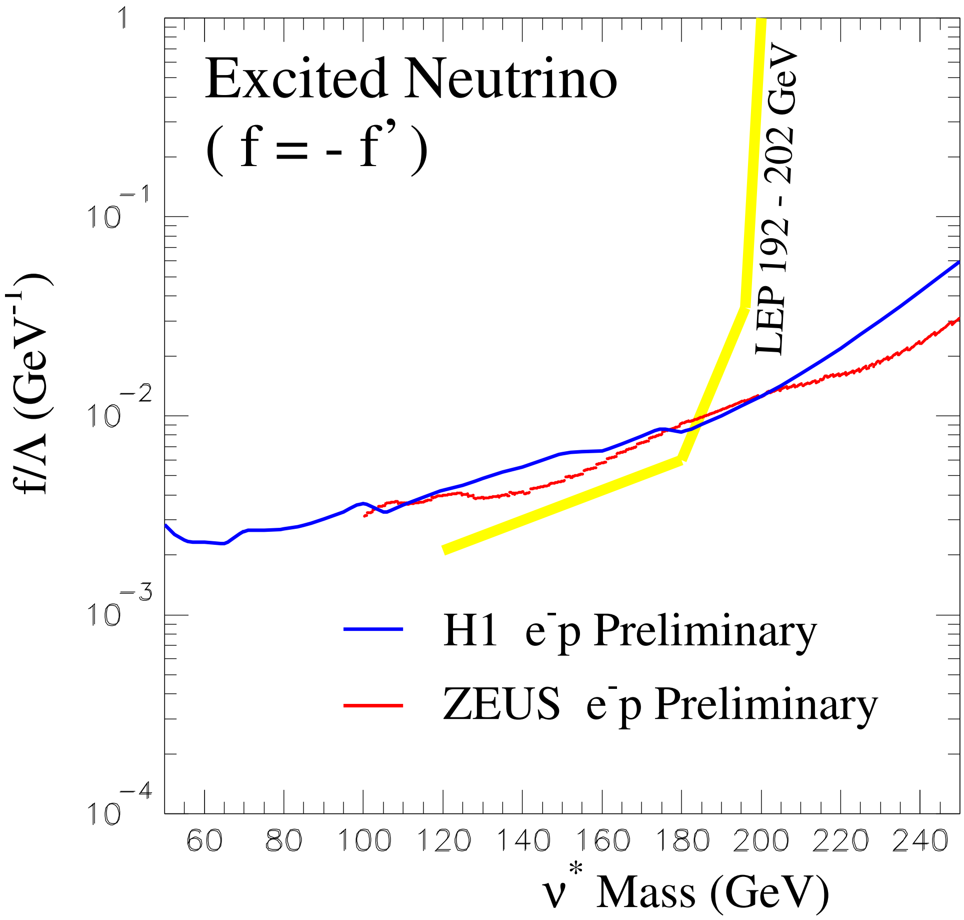




HERA Excited Neutrino Limits
$(f = -f')$

No evidence for ν^* production

95% C.L. Limits on f/Λ

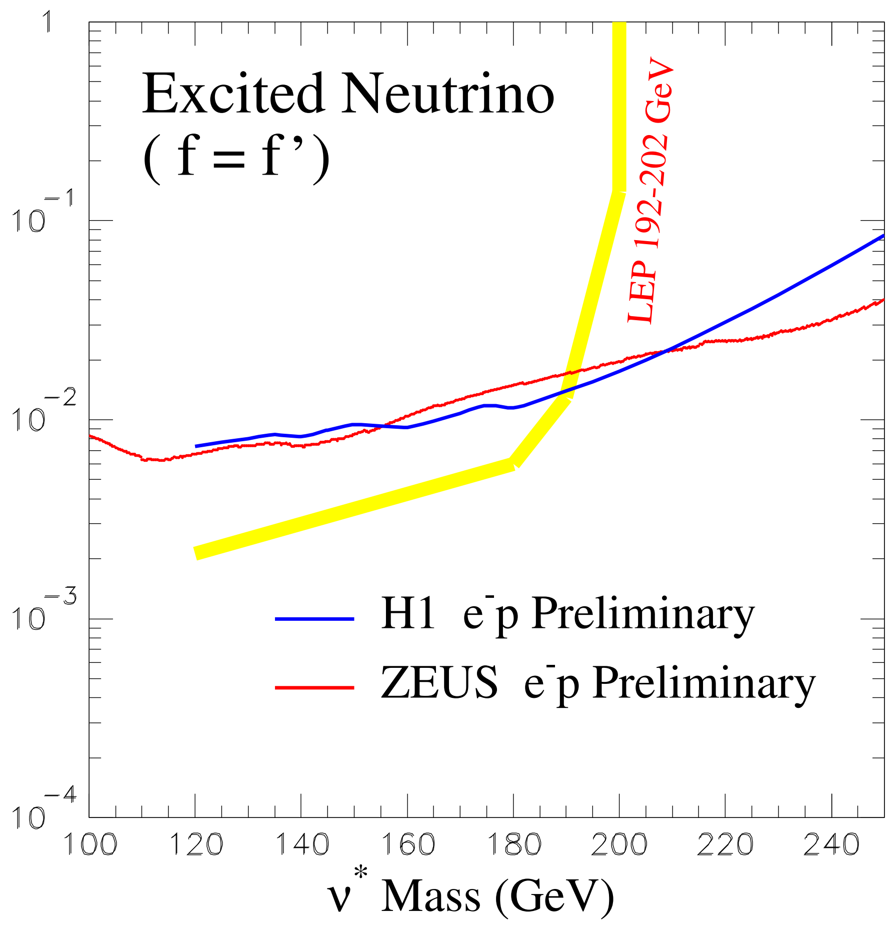


H1	ZEUS
Assuming $f/\Lambda = 1/M_{\nu^*}$ $50 < M_{\nu^*} < 150$ GeV are excluded.	Assuming $f/\Lambda = 1/M_{\nu^*}$ $100 < M_{\nu^*} < 163$ GeV are excluded.

HERA Excited Neutrino Limits
$(f = f' : \nu^* \to \nu\gamma$ forbidden$)$

No evidence for ν^* production

95% C.L. Limits on f/Λ



H1	ZEUS
Assuming $f/\Lambda = 1/M_{\nu^*}$ $110 < M_{\nu^*} < 134$ GeV are excluded.	Assuming $f/\Lambda = 1/M_{\nu^*}$ $100 < M_{\nu^*} < 133$ GeV are excluded.

Search For Excited Quark

Signature of main channels

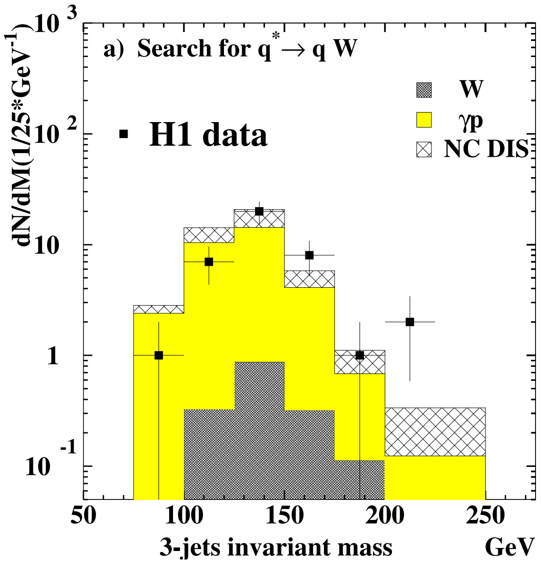
- $q^* \to q\gamma$: 1 photon + 1 jet
- $q^* \to qW \to qq'\bar{q}''$: 3 high E_t jets
- $q^* \to qW \to qe\nu$: 1 electron + high $\not{P}_t$ + 1 jet
- $q^* \to qZ \to qq'\bar{q}'$: 3 high E_t jets

H1

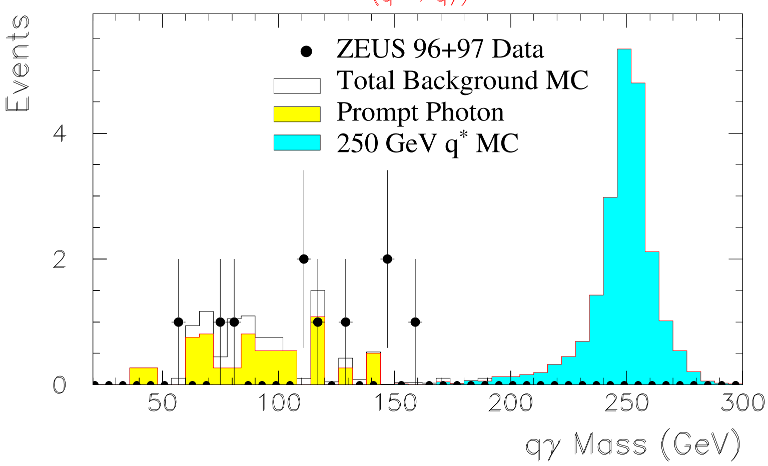
Channel	Events	Background
$q^* \to q\gamma$	35	36 ± 5
$q^* \to qZ_{\to ee}$	0	0.65 ± 0.53
$q^* \to qZ_{\to \mu\bar{\mu}}$	0	0.35 ± 0.05
$q^* \to qZ_{\to q\bar{q}}$	32	25.3 ± 9.1
$q^* \to qW_{\to e\nu}$	1	1.10 ± 0.35
$q^* \to qW_{\to \mu\nu}$	3	0.41 ± 0.03
$q^* \to qW_{\to q'\bar{q}}$	39	45.3 ± 17.3

ZEUS

Channel	Events	Background
$q^* \to q\gamma$	10	15.3 ± 1.5
$q^* \to qW_{\to e\nu}$	3	3.3 ± 0.5



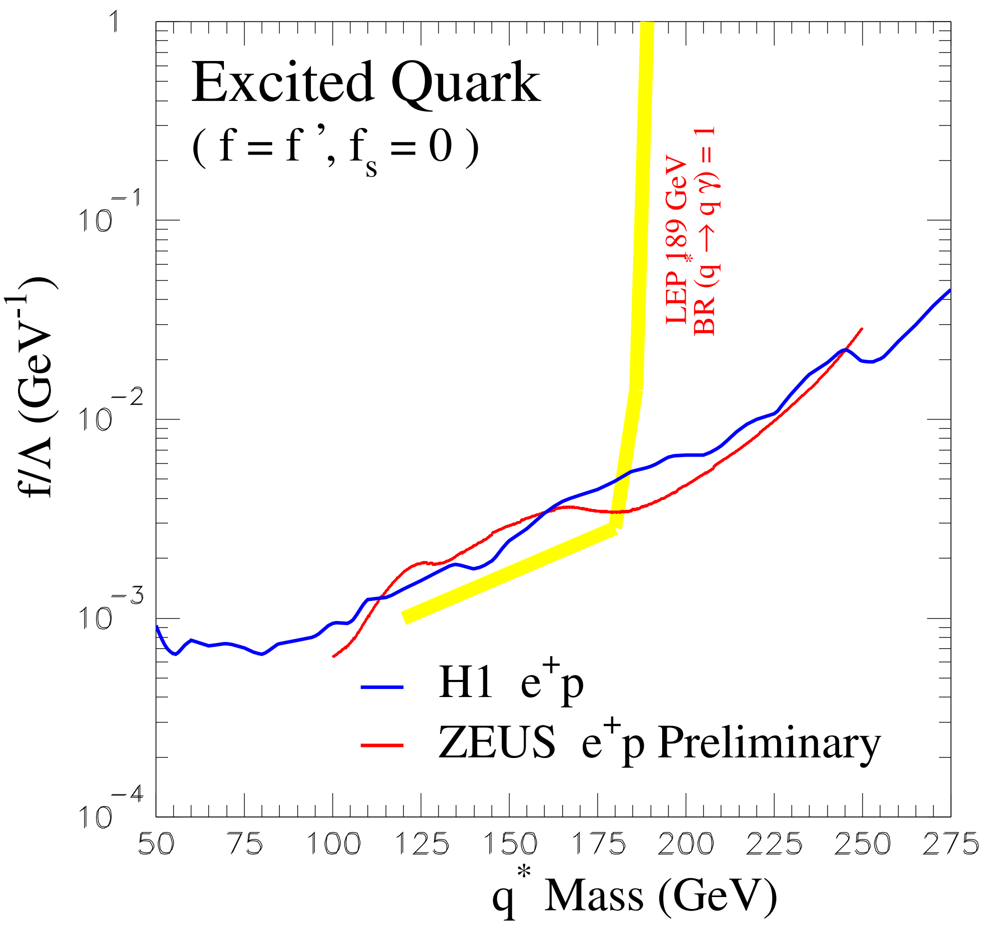
ZEUS 96+97 Preliminary
($q^* \to q\gamma$)



HERA Excited Quark Limits
$(f = f', f_s = 0)$

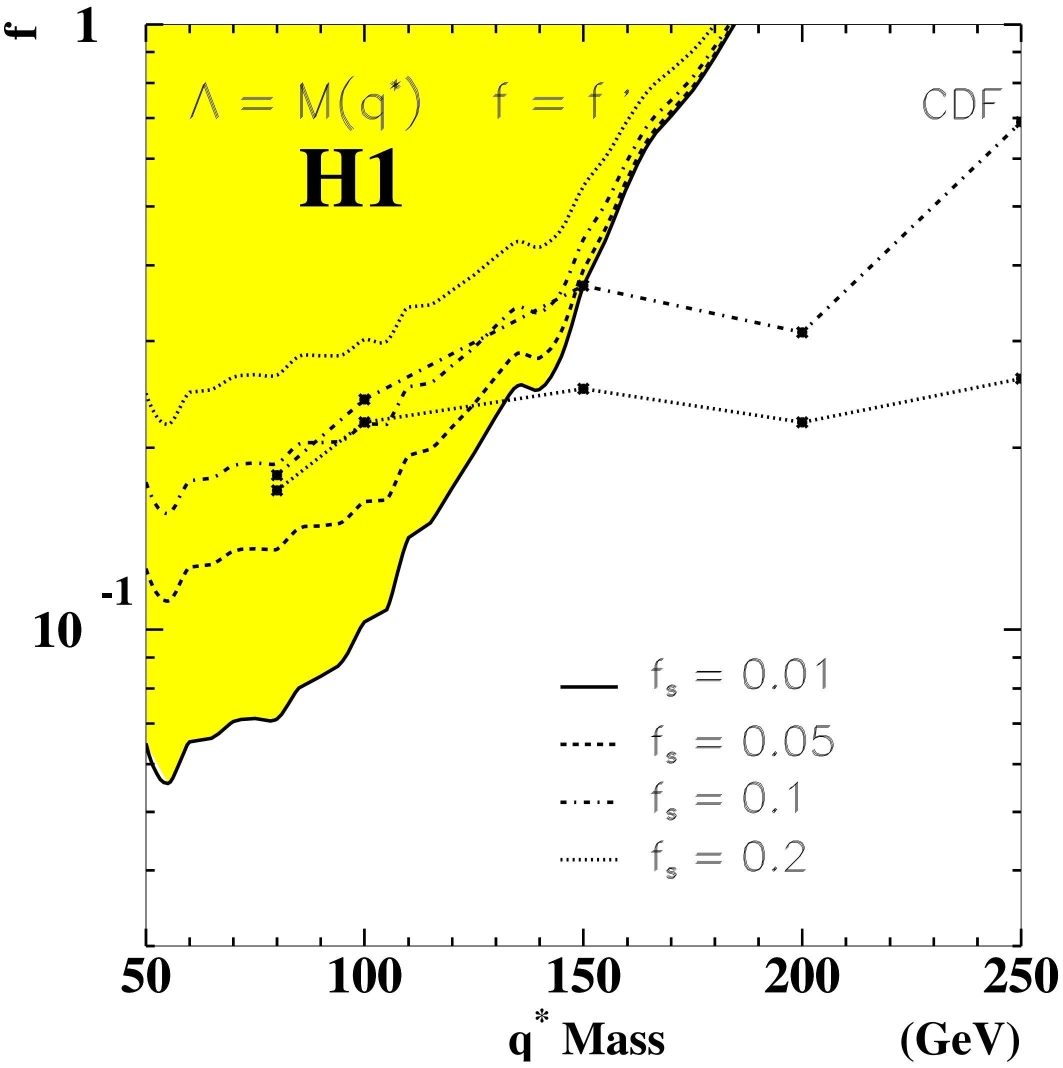
No evidence for q^* production

95% C.L. Limits on f/Λ



H1	ZEUS
Assuming $f/\Lambda = 1/M_{q^*}$ $50 < M_{q^*} < 188$ GeV are excluded.	Assuming $f/\Lambda = 1/M_{q^*}$ $100 < M_{q^*} < 203$ GeV are excluded.

95% C.L. Limits on f
(Assuming $f = f'$ and $\Lambda = M_{q^*}$)



For $f_s < 0.1$
HERA is more competitive than Tevatron

Summary

- Searches for excited fermions have been performed by the H1/ZEUS collaborations using e^+p and e^-p data.
- No evidence for excited fermion production is found.
- e^-p data (despite smaller luminosity) has larger potential for ν^* due to much higher σ.
- HERA extends limits beyond the reach of other colliders.
- e^* and ν^* explored well beyond LEP limits.
- q^* complements Tevatron for EW q^* production and HERA is more competitive than Tevatron for $f_s < 0.1$.
- 2001-2006 upgraded HERA data (~ 1 fb^{-1}) will bring much extended discovery potential (especially for ν^*).