



Search for excited fermions at HERA



On behalf on the H1 and ZEUS
collaborations



- Compositeness model
- Investigated topologies
- Search for e^* , ν^* , q^*
- Conclusion

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Excited fermions models

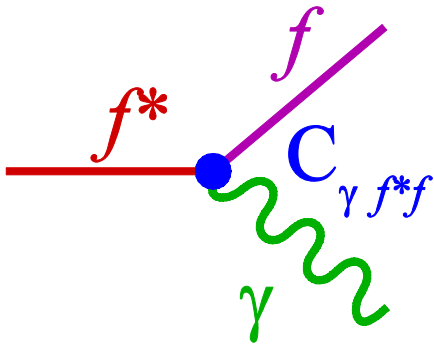
- Compositeness models are aimed to explain the **number of families** in SM. If fermions have a **substructure** \rightarrow They can be observed in **excited states**.
- Effective lagrangian proposed by K. Hagiwara, S. Komamiya, and D. Zeppenfeld (**Z. Phys. C29 p115 (1985)**):

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

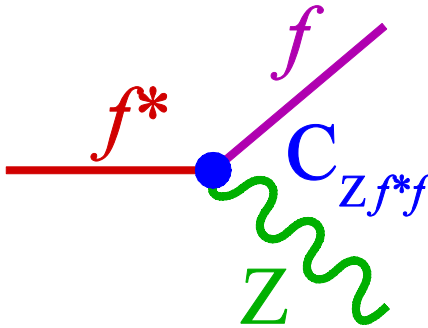
- Right and left-handed components of the excited form weak isodoublets
 - Field-strength tensors associated to gauge fields SU(2), U(1) and SU(3)
 - SM couplings
 - Coupling strength between f^* and bosons from SU(2), U(1) and SU(3)
 - Compositeness scale
- **BR of excited fermions** depend on form factors f, f' and f_s , and on compositeness scale Λ .

Gauge group weights f, f' and f_s

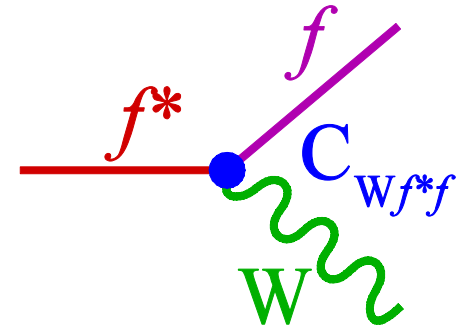
• $\gamma f^* f$ vertex:



• $Z f^* f$ vertex:



• $W f^* f$ vertex:



$$C_{\gamma f^* f} = \frac{1}{2} \left(f I_3 + f' \frac{Y}{2} \right)$$

$$C_{Z f^* f} = \frac{1}{2} \left(f I_3 \cot \theta_W - f' \frac{Y}{2} \tan \theta_W \right)$$

$$C_{W f^* f} = \frac{f}{2\sqrt{2} \sin \theta_W}$$

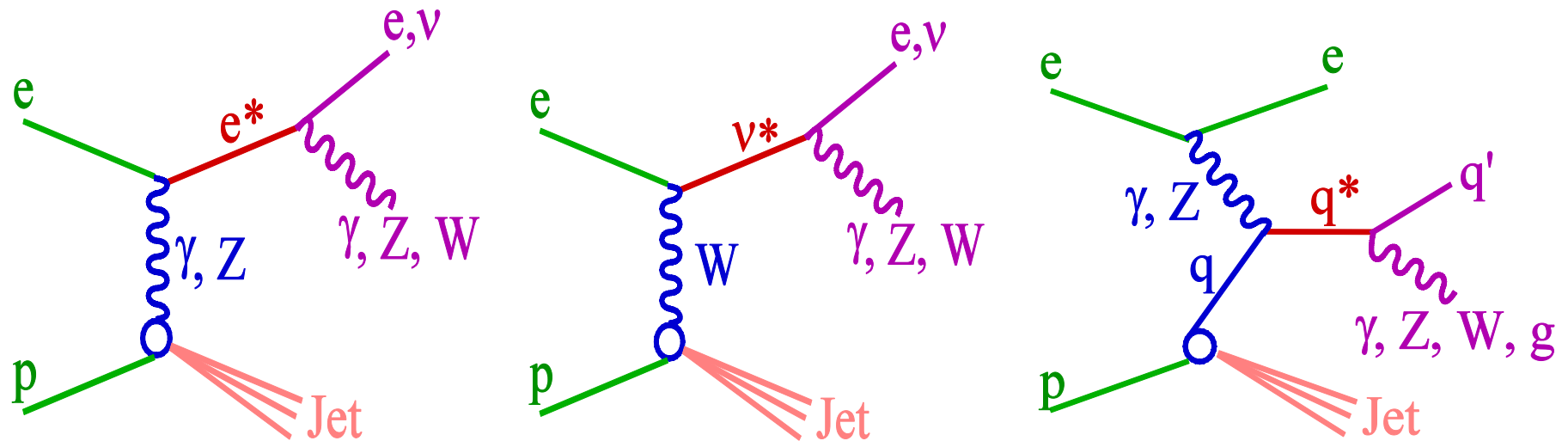
- I_3 : third component of isospin
- Y : hypercharge
- θ_W : Weinberg angle

- If $f = -f'$ $\Rightarrow C_{\gamma e^* e} = 0$
- If $f = f'$ $\Rightarrow C_{\gamma W^* \nu} = 0$

\Rightarrow The search for fermion de-excitations gives informations on compositeness couplings.

De-excitation of excited fermions

- ➔ Search for excited electrons, neutrinos and quarks: e^* , ν^* , q^*
- ➔ Fermions de-excitation by emission of γ , Z^0 or W^\pm :





- ➔ 3 excited fermions \times 3 gauge bosons.

e^* ν^* q^*

γ Z W

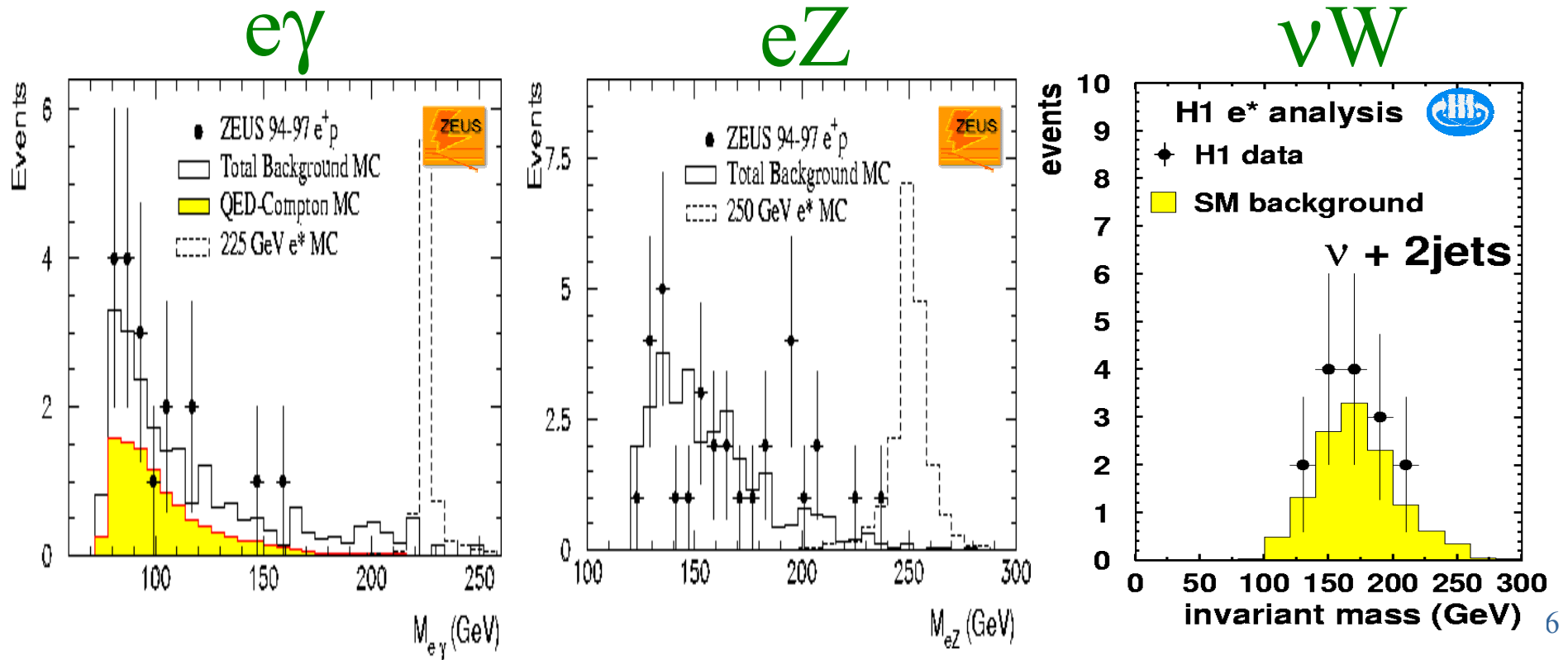
- ➔ • 9 channels.
- More sub-channels to investigate due to Z and W various decays.

H1 and ZEUS luminosities

HERA-I periods	Collisions	\sqrt{s} (GeV)	\mathcal{L} (pb ⁻¹) 	\mathcal{L} (pb ⁻¹) 
94-97	e ⁺ p	300	37	47.7
98-99	e ⁻ p	318	15	16.4
99-00	e ⁺ p	318	68	65.9
Total	e [±] p	-	120	130

Search for excited electrons

- $e^\pm p$ data, with $\sqrt{s} = 300$ and 318 GeV.
- 3 channels:
 - $e^* \rightarrow e + \gamma$ \rightarrow Electron + photon
 - $e^* \rightarrow e + Z$ then $Z \rightarrow q\bar{q}$ \rightarrow Electron + 2 jets
 - $e^* \rightarrow \nu + W$ then $W \rightarrow q\bar{q}$ \rightarrow $E_T^{\text{miss}} + 2$ jets
- Mass distributions:



Number of events in excited electron search

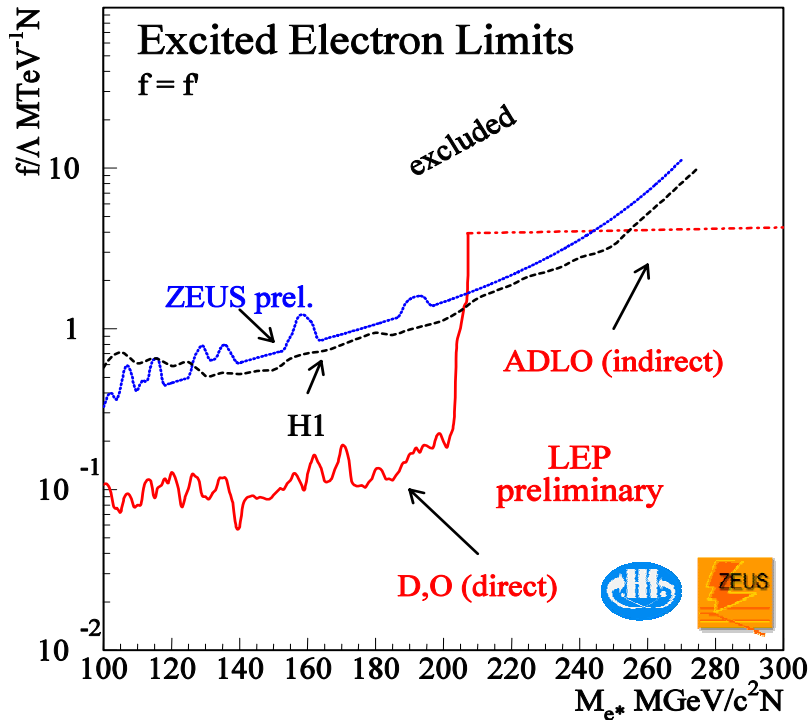
	Sample	H1		ZEUS	
		Data	SM expectation	Data	SM expectation
$e^* \rightarrow e + \gamma$	94-97	8	$7.2 \pm 1.0 \pm 0.1$	18	20.1 ± 1.2
	98-99	4	$4.0 \pm 0.7 \pm 0.2$	10	8.7
	99-00	12	$15.6 \pm 1.7 \pm 0.4$	22	30.8
$e^* \rightarrow e + Z$	94-97	6	$7.1 \pm 2.1 \pm 2.8$	13	13.9 ± 1.1
	98-99	4	$5.6 \pm 0.4 \pm 1.2$		
	99-00	31	$25.3 \pm 1.9 \pm 5.5$		
$e^* \rightarrow \nu + W$	94-97	2	$2.4 \pm 0.2 \pm 0.7$	32	32.9 ± 1.1
	98-99	5	$3.9 \pm 0.2 \pm 0.7$		
	99-00	8	$6.1 \pm 0.4 \pm 1.5$		

- In all channels:

Good agreement between number of observed and expected events.

➡ Upper limits at 95 % CL on the coupling f/Λ are derived.

Limits on excited electrons

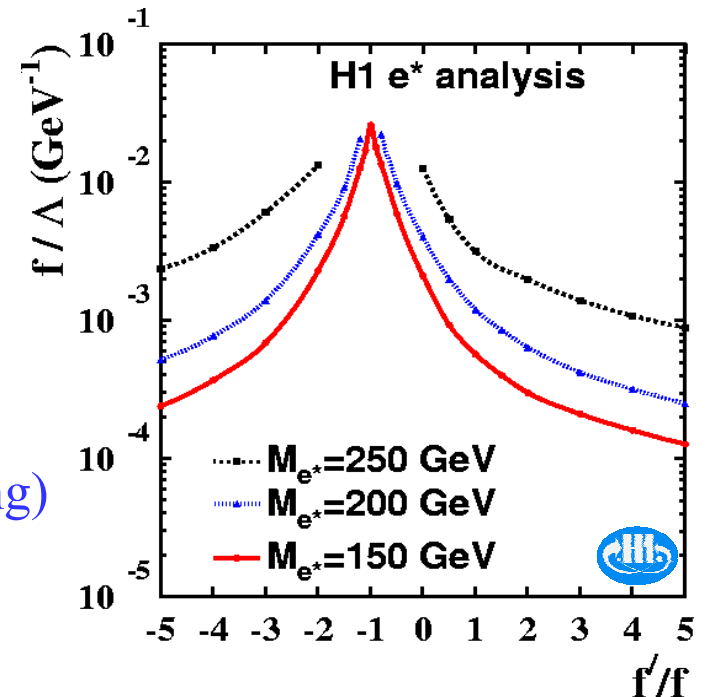


➔ H1 and ZEUS limits extend the excluded region to higher masses than reached in previous direct searches of LEP-II.

More general limits on f/Λ as a function of f'/f :

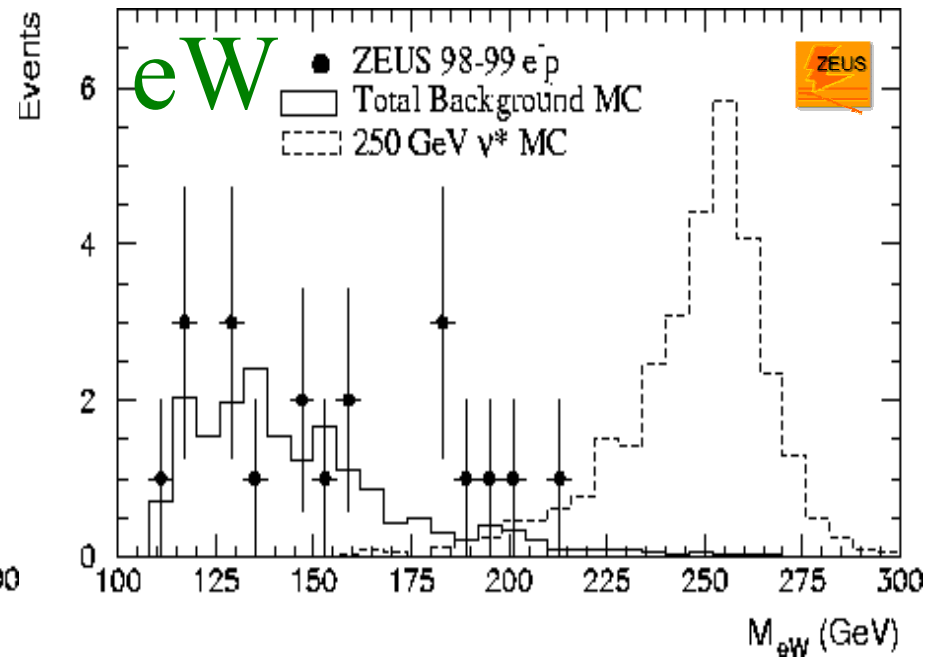
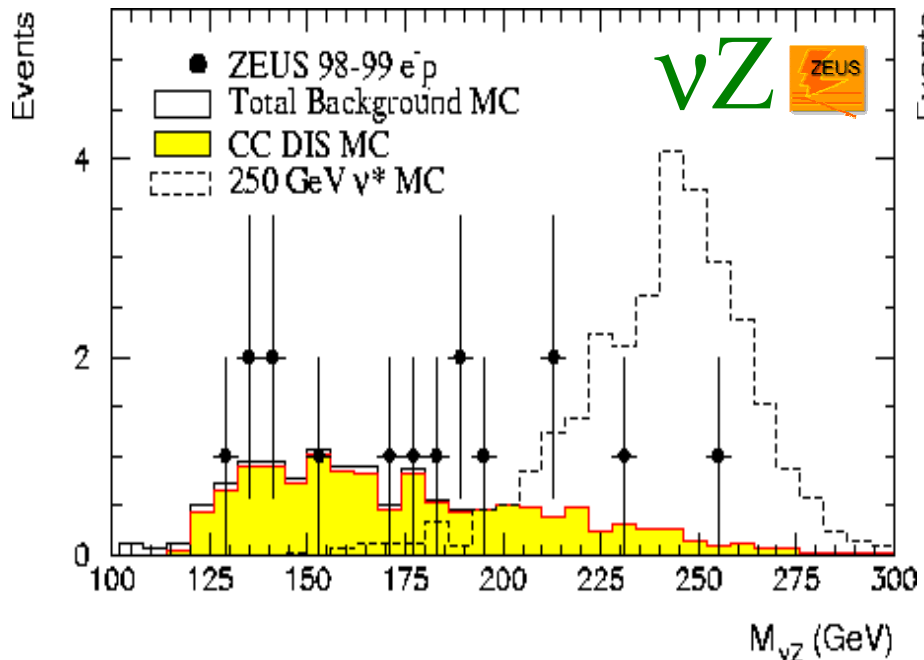
- for $f = f'$: main contribution from $e^* \rightarrow e + \gamma$
- for $f = -f'$: only $e^* \rightarrow e + Z$ (vanishing EM coupling)

➔ $\sigma_{e^*}(f = -f') \ll \sigma_{e^*}(f = f')$



Search for excited neutrinos

- e^-p data with $\sqrt{s} = 318$ GeV
indeed $\sigma(\nu^*)_{e-p} / \sigma(\nu^*)_{e+p}$ of the order of 100
- 3 channels:
 - $\nu^* \rightarrow \nu + \gamma$ $\Rightarrow E_T^{\text{miss}} + \text{photon.}$
 - $\nu^* \rightarrow \nu + Z$ then $Z \rightarrow q\bar{q}$ $\Rightarrow E_T^{\text{miss}} + 2 \text{ jets}$
 - $\nu^* \rightarrow e + W$ then $W \rightarrow q\bar{q}'$ $\Rightarrow \text{Electron} + 2 \text{ jets}$
- Mass distributions:



Number of events in excited neutrino search

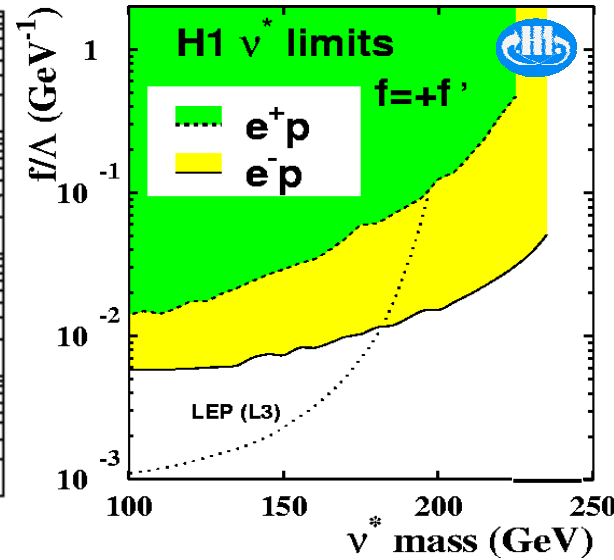
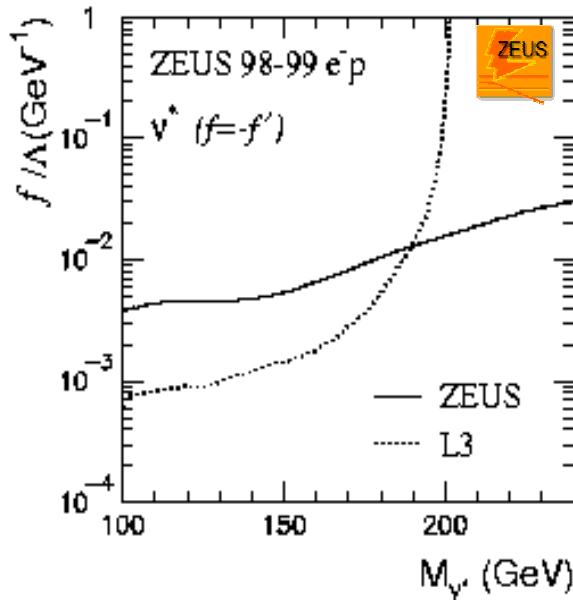
	H1		ZEUS	
	Data	SM expectation	Data	SM expectation
$\nu^* \rightarrow \nu + \gamma$	2	$3.0 \pm 0.2 \pm 1.2$	2	1.5 ± 0.2
$\nu^* \rightarrow \nu + Z$	6	$7.0 \pm 0.6 \pm 1.4$	16	13.5 ± 0.6
$\nu^* \rightarrow e + W$	1	$3.7 \pm 0.2 \pm 0.9$	20	15.0 ± 1.3

- In all channels, for both experiments:

Good agreement between number of observed and expected events.

➡ Upper limits at 95 % CL on the coupling f/Λ are derived.

Limits on excited neutrinos

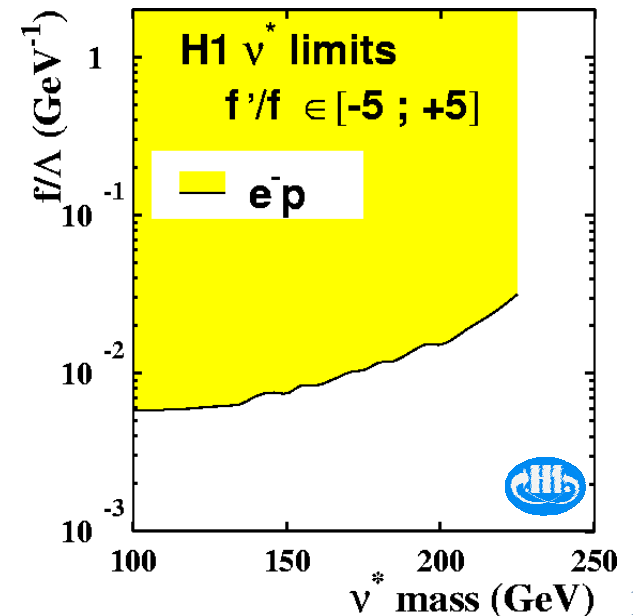
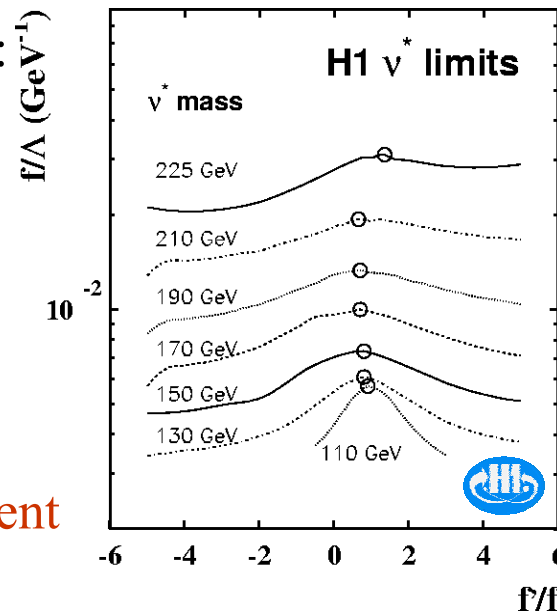


➔ HERA limits more stringent at high masses beyond the kinematic reach of LEP-II.

Less Model-dependent limits:

- The arbitrary ratio f/f' is considered.
- Limits are calculated in the range $-5 < f/f' < 5$.
- The point of worst limit is chosen for each M_{ν^*} .

➔ Limits on f/Λ independent of f/f' are obtained.



Search for excited quarks

- e^+p data with $\sqrt{s} = 300$ GeV

- 3 channels:

- $q^* \rightarrow q + \gamma$

→ Jet + photon.

- $q^* \rightarrow q + Z$ then $Z \rightarrow ll, q\bar{q}$

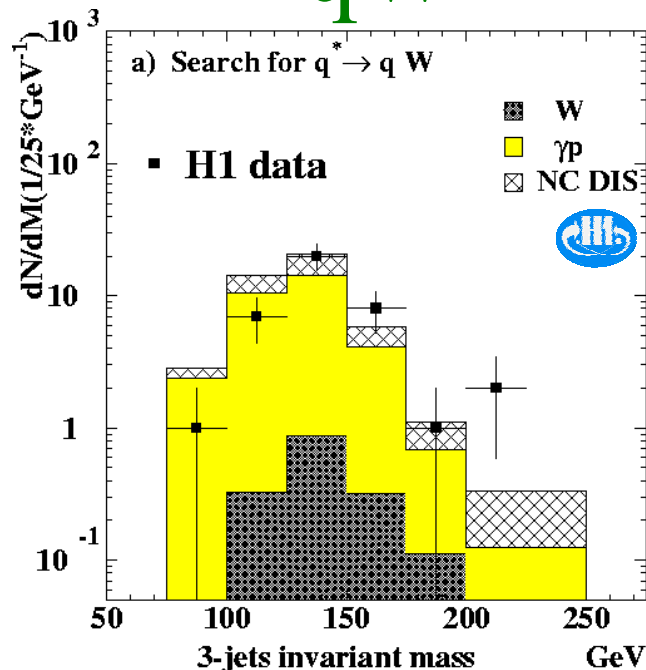
→ Jet + 2 leptons or 3 jets

- $q^* \rightarrow q + W$ then $W \rightarrow lv, q\bar{q}'$

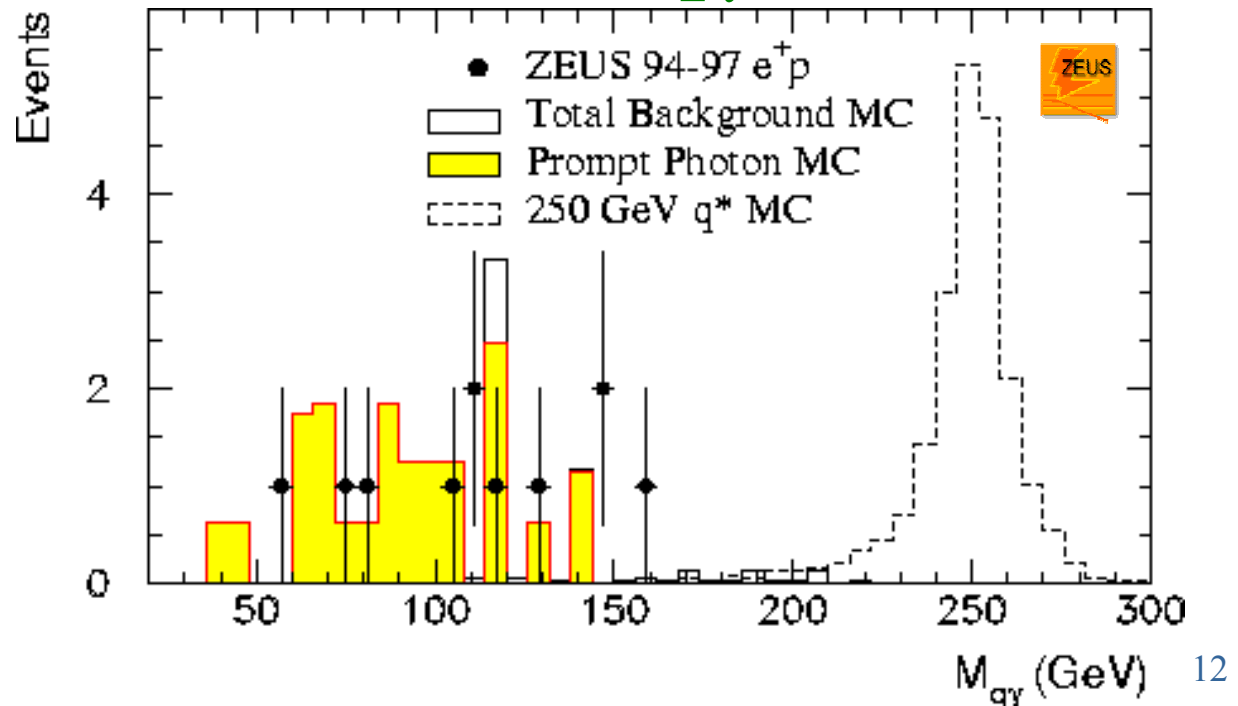
→ Jet + lepton + P_T^{miss} or 3 jets

- Mass distributions:

qW



$q\gamma$



Number of events in excited quark search

	H1		ZEUS	
	Data	SM expectation	Data	SM expectation
$q^* \rightarrow q + \gamma$	35	36 ± 5	11	19.0 ± 1.9
$q^* \rightarrow q + Z_{\rightarrow ee}$	0	0.65 ± 0.53		
$q^* \rightarrow q + Z_{\rightarrow \mu\mu}$	0	0.35 ± 0.05		
$q^* \rightarrow q + Z_{\rightarrow qq}$	32	25.3 ± 9.1		
$q^* \rightarrow q + W_{\rightarrow ev}$	1	1.10 ± 0.35	4	4.1 ± 0.6
$q^* \rightarrow q + W_{\rightarrow \mu\nu}$	3	0.41 ± 0.03		
$q^* \rightarrow q + W_{\rightarrow qq}$	39	45.3 ± 17.3		

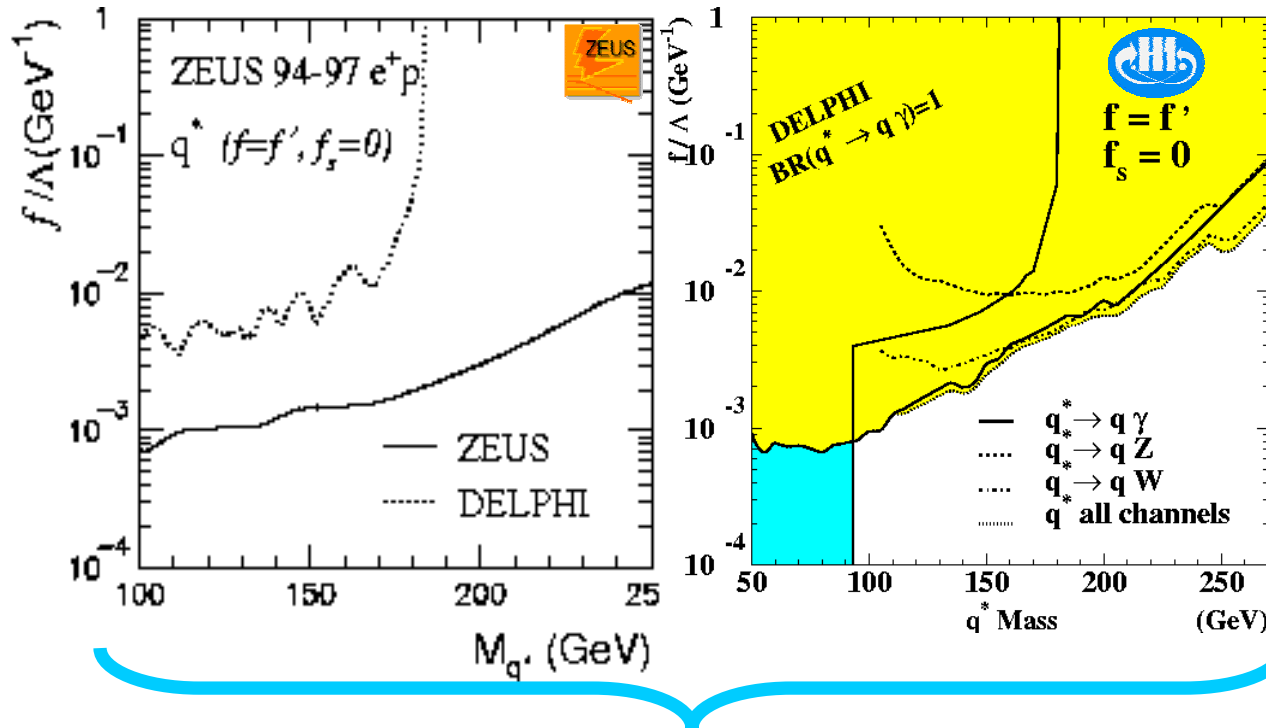
- In all channels:

Good agreement between number of observed and expected events.

➡ Upper limits at 95 % CL on the coupling f/Λ are derived.

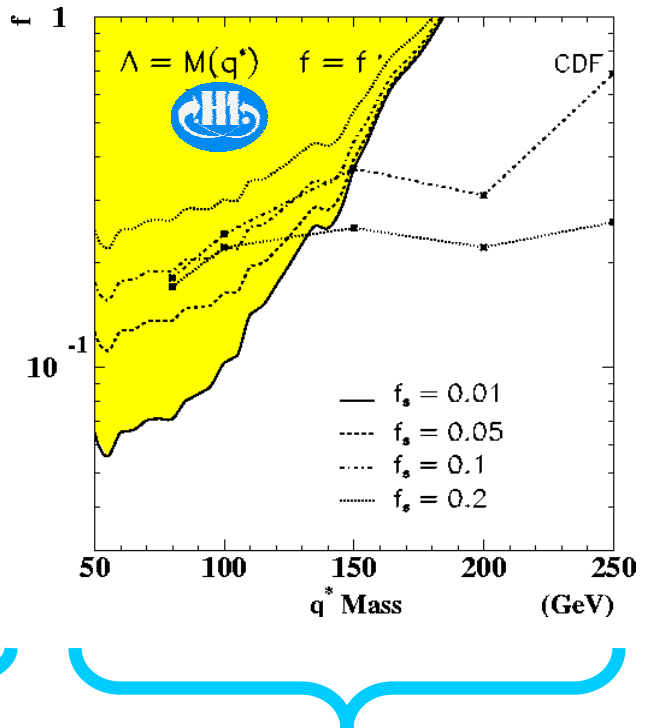
Limits on excited quarks

- Assuming $f=f'$ and $f_s=0$:
(no sensitivity to q^* production by a gluon exchange)



ZEUS and H1 limits extend the excluded region to higher masses than reached in DELPHI (e^+e^- collisions).

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



H1 is more sensitive than CDF ($p\bar{p}$ collisions) at small f_s .

Conclusion and outlook

- The search for excited fermion in the full HERA-I data set has been presented.
- No evidence of excited fermions has been found.
 - ➡ Upper limits at 95% CL are derived:
 - e^* : exclusion region extended beyond LEP \sqrt{s} for direct searches.
 - ν^* : more stringent limits than LEP around its \sqrt{s} .
 - q^* : more sensitive than Tevatron at small values of f_s .
- Future HERA-II data: luminosity of 1 fb^{-1} is expected.
Increased statistics will allow to access higher masses for f/Λ limits, especially for excited neutrinos if more $e\text{-}p$ data are collected.