

# Search for excited fermions at HERA



On behalf on the H1 and ZEUS  
collaborations



- Compositeness model
- Investigated topologies
- Search for  $e^*$ ,  $\nu^*$ ,  $q^*$
- Conclusion

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# Excited fermions models

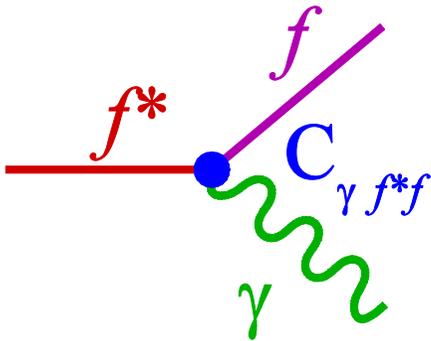
- Compositeness models are aimed to explain the **number of families** in SM. If fermions have a **substructure**  $\rightarrow$  They can be observed in **excited states**.
- Effective lagrangian proposed by K. Hagiwara, S. Komamiya, and D. Zeppenfeld (**Z. Phys. C29 p115 (1985)**):

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

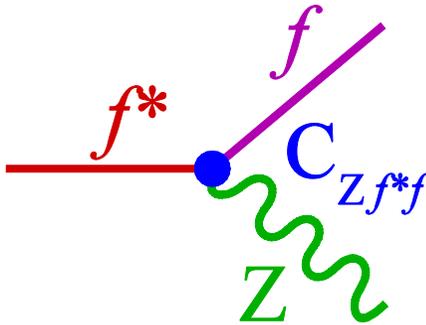
- Right and left-handed components of the excited form weak isodoublets
  - Field-strength tensors associated to gauge fields SU(2), U(1) and SU(3)
  - SM couplings
  - Coupling strength between  $f^*$  and bosons from SU(2), U(1) and SU(3)
  - Compositeness scale
- **BR of excited fermions** depend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

# Gauge group weights $f, f'$ and $f_s$

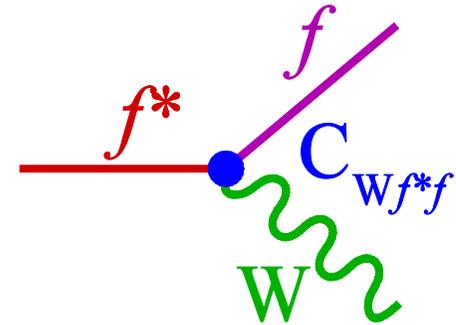
•  $\gamma f^* f$  vertex:



•  $Z f^* f$  vertex:



•  $W f^* f$  vertex:



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

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

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

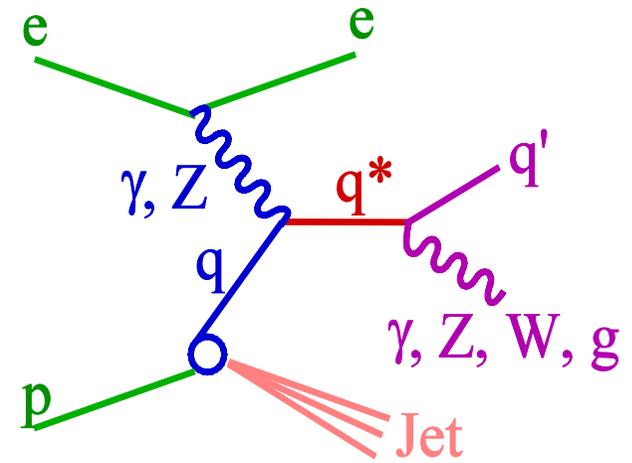
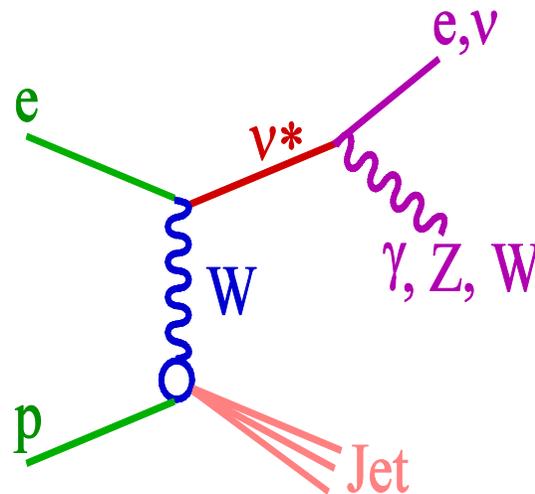
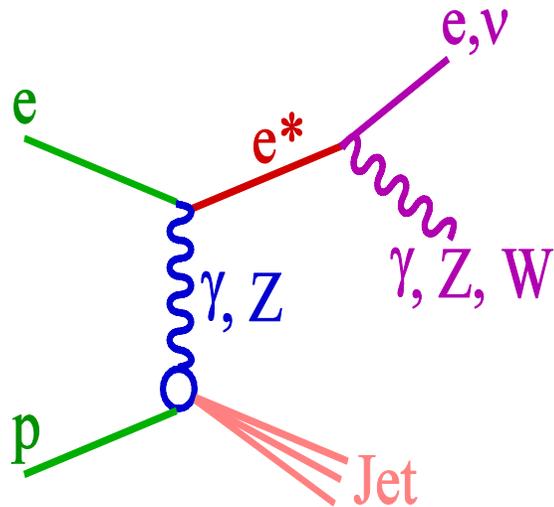
- $I_3$ : third component of isospin
- $Y$ : hypercharge
- $\theta_W$ : Weinberg angle

- 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

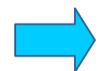
- ➔ Search for excited electrons, neutrinos and quarks:  $e^*$ ,  $\nu^*$ ,  $q^*$
- ➔ Fermions de-excitation by emission of  $\gamma$ ,  $Z^0$  or  $W^\pm$ :



➔ 3 excited fermions  $\times$  3 gauge bosons.

$e^*$   $\nu^*$   $q^*$

$\gamma$   $Z$   $W$



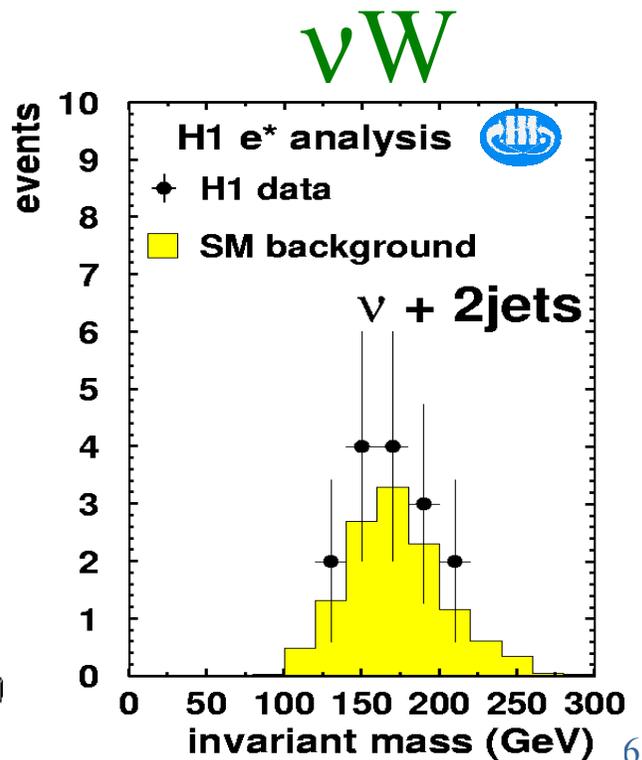
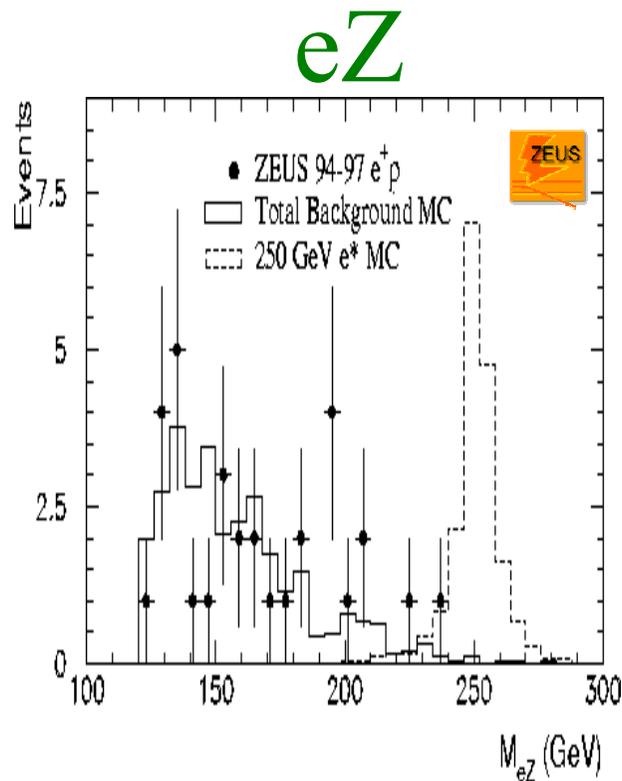
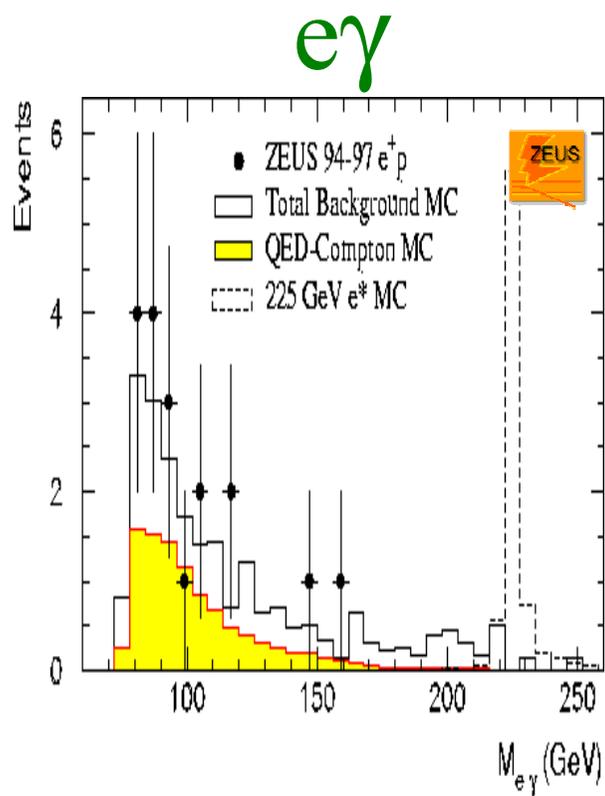
- 9 channels.
- More sub-channels to investigate due to Z and W various decays.

# H1 and ZEUS luminosities

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

# Search for excited electrons

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



# Number of events in excited electron search

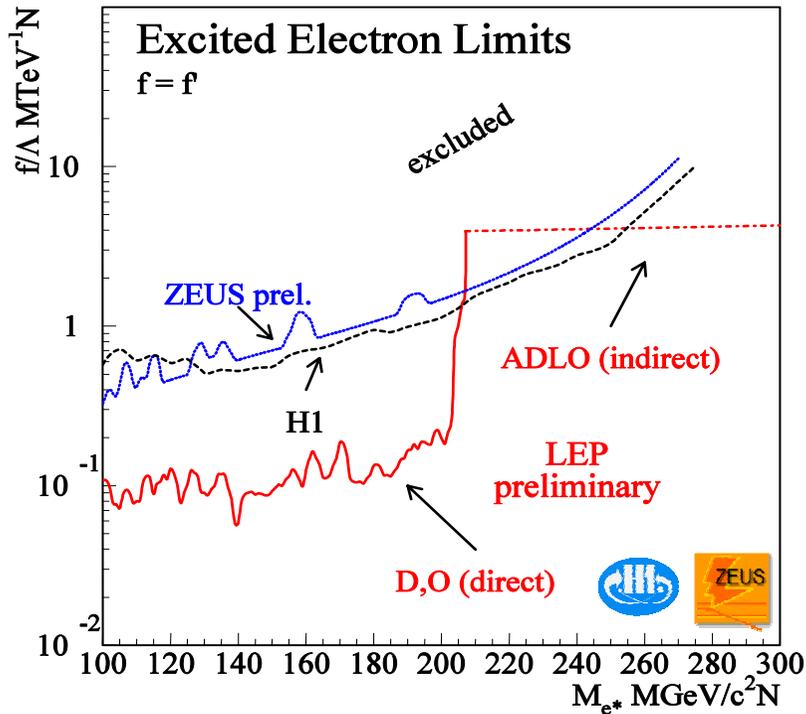
	Sample	H1		ZEUS	
		Data	SM expectation	Data	SM expectation
$e^* \rightarrow e + \gamma$	94-97	8	$7.2 \pm 1.0 \pm 0.1$	18	$20.1 \pm 1.2$
	98-99	4	$4.0 \pm 0.7 \pm 0.2$	10	8.7
	99-00	12	$15.6 \pm 1.7 \pm 0.4$	22	30.8
$e^* \rightarrow e + Z$	94-97	6	$7.1 \pm 2.1 \pm 2.8$	13	$13.9 \pm 1.1$
	98-99	4	$5.6 \pm 0.4 \pm 1.2$		
	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	$32.9 \pm 1.1$
	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  $f/\Lambda$  are derived.

# Limits on excited electrons

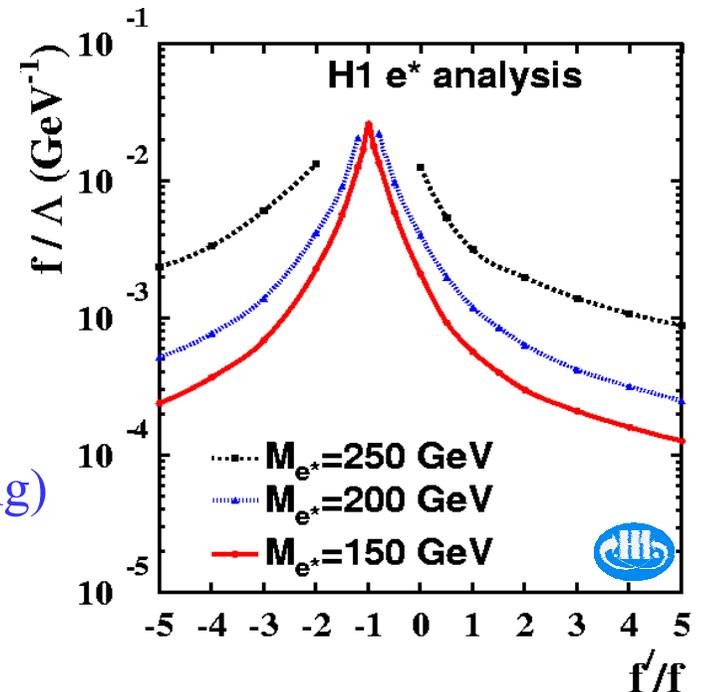


➔ H1 and ZEUS limits extend the excluded region to higher masses than reached in previous direct searches of LEP-II.

More general limits on  $f/\Lambda$  as a function of  $f'/f$ :

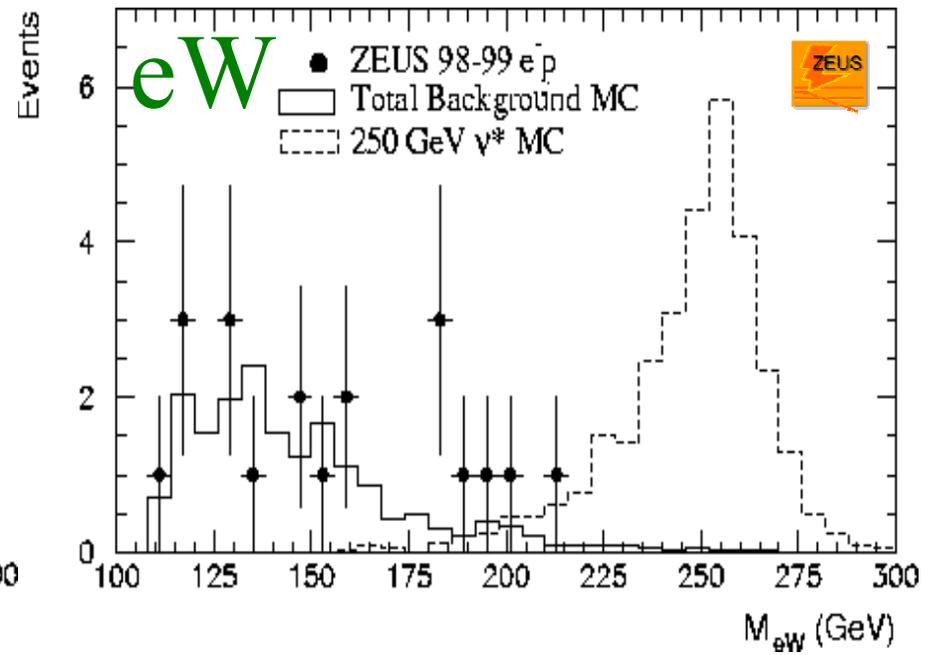
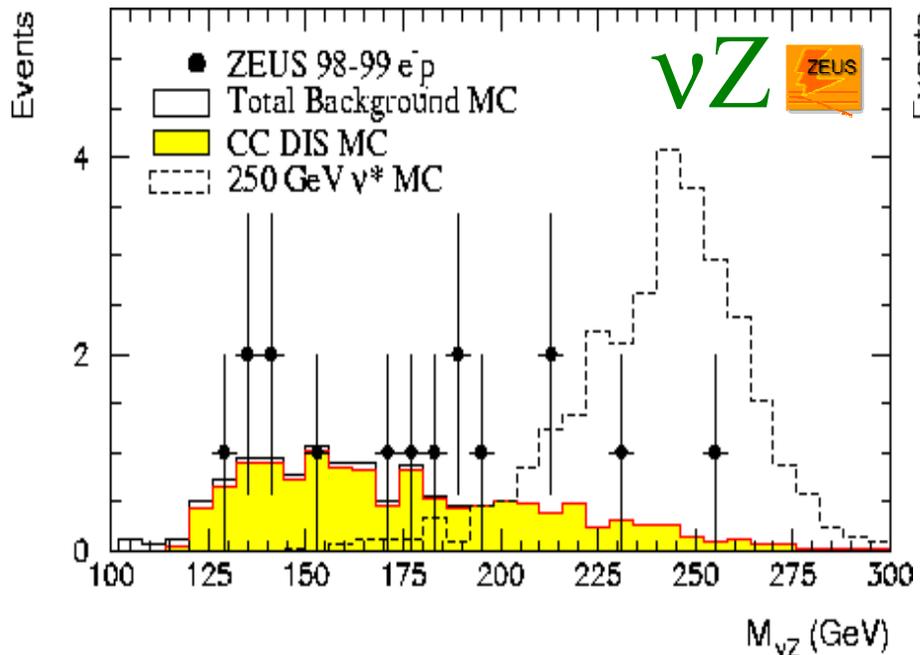
- for  $f = f'$ : main contribution from  $e^* \rightarrow e + \gamma$
- for  $f = -f'$ : only  $e^* \rightarrow e + Z$  (vanishing EM coupling)

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



# 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

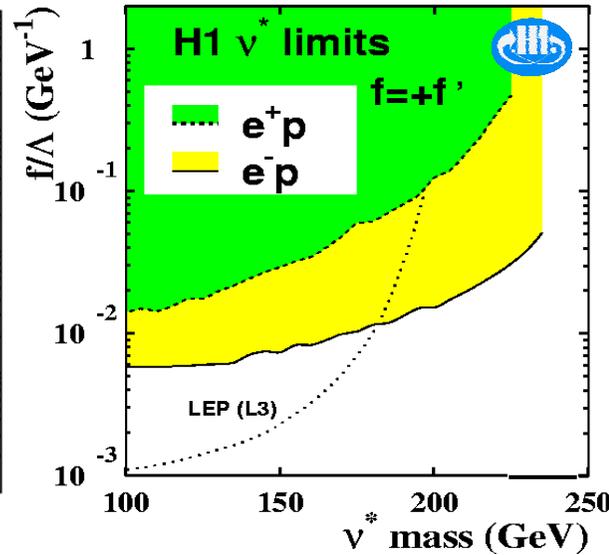
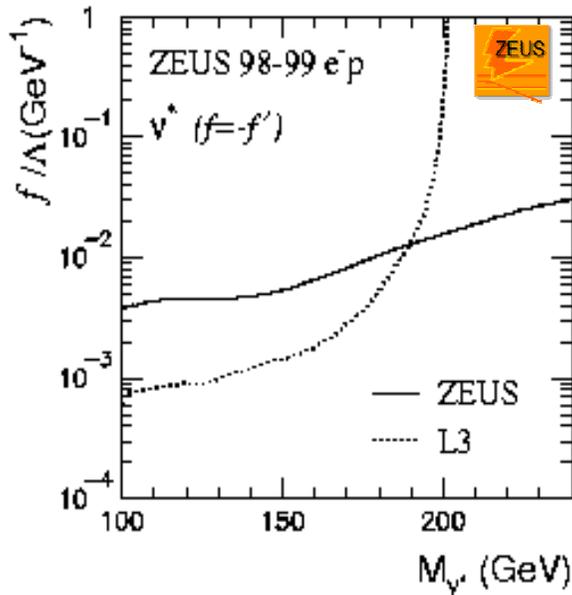
	H1		ZEUS	
	Data	SM expectation	Data	SM expectation
$\nu^* \rightarrow \nu + \gamma$	2	$3.0 \pm 0.2 \pm 1.2$	2	$1.5 \pm 0.2$
$\nu^* \rightarrow \nu + Z$	6	$7.0 \pm 0.6 \pm 1.4$	16	$13.5 \pm 0.6$
$\nu^* \rightarrow e + W$	1	$3.7 \pm 0.2 \pm 0.9$	20	$15.0 \pm 1.3$

- In all channels, for both experiments:

Good agreement between number of observed and expected events.

➡ Upper limits at 95 % CL on the coupling  $f/\Lambda$  are derived.

# Limits on excited neutrinos

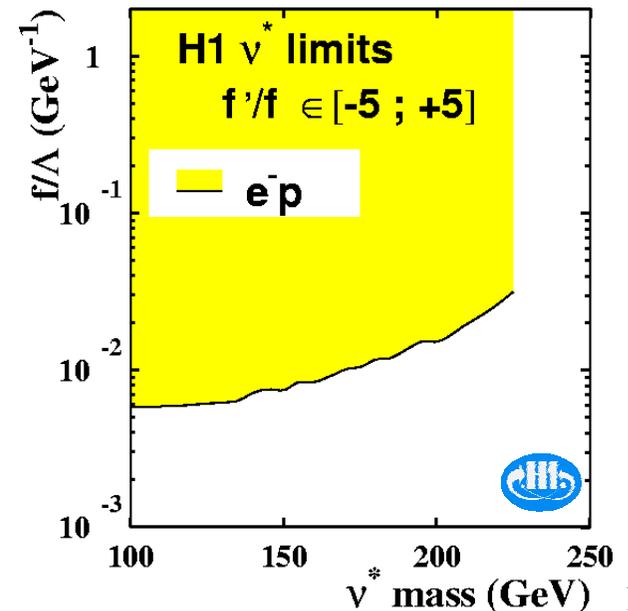
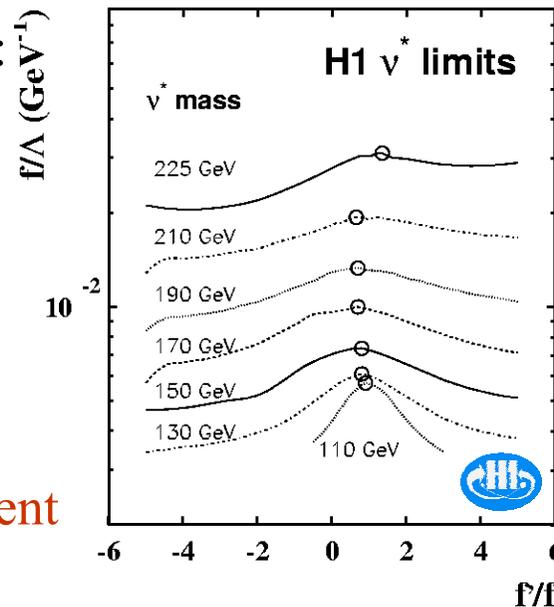


➡ HERA limits more stringent at high masses beyond the kinematic reach of LEP-II.

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  $M_{\nu^*}$ .

➡ Limits on  $f/\Lambda$  independent of  $f/f'$  are obtained.



# Search for excited quarks

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

- 3 channels:

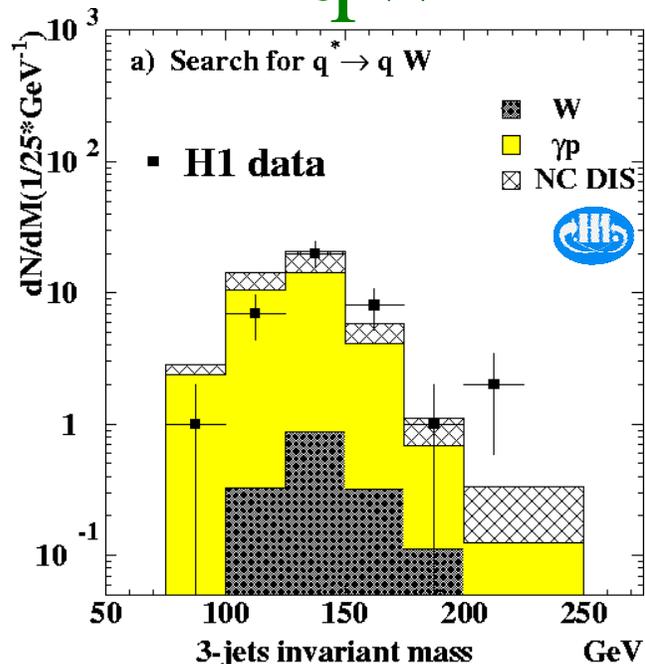
- $q^* \rightarrow q + \gamma$   $\rightarrow$  Jet + photon.

- $q^* \rightarrow q + Z$  then  $Z \rightarrow ll, q\bar{q}$   $\rightarrow$  Jet + 2 leptons or 3 jets

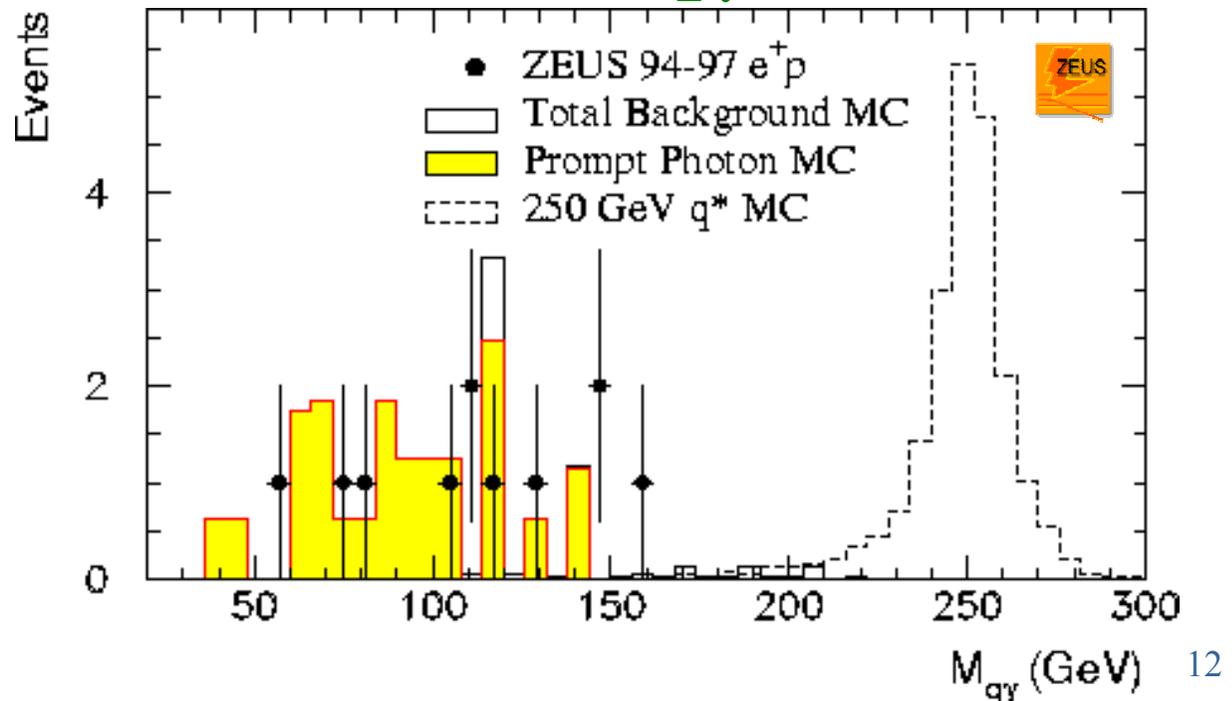
- $q^* \rightarrow q + W$  then  $W \rightarrow lv, q\bar{q}'$   $\rightarrow$  Jet + lepton +  $P_T^{\text{miss}}$  or 3 jets

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

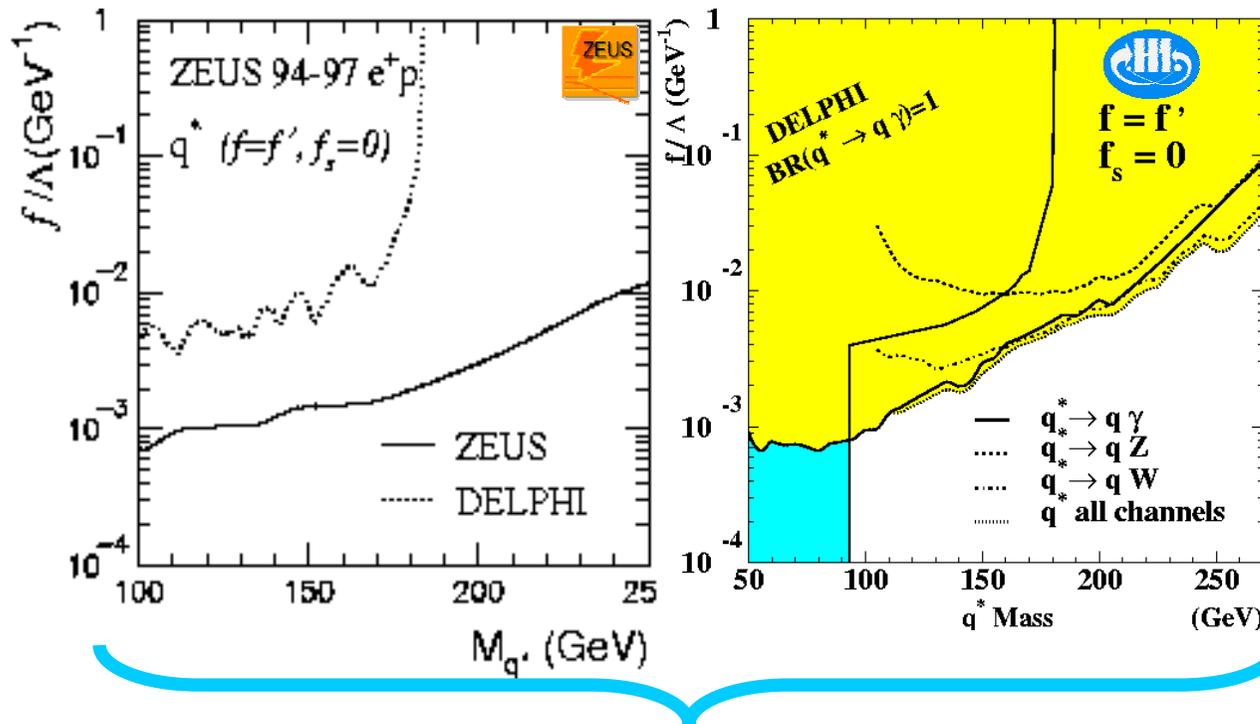
- In all channels:

Good agreement between number of observed and expected events.

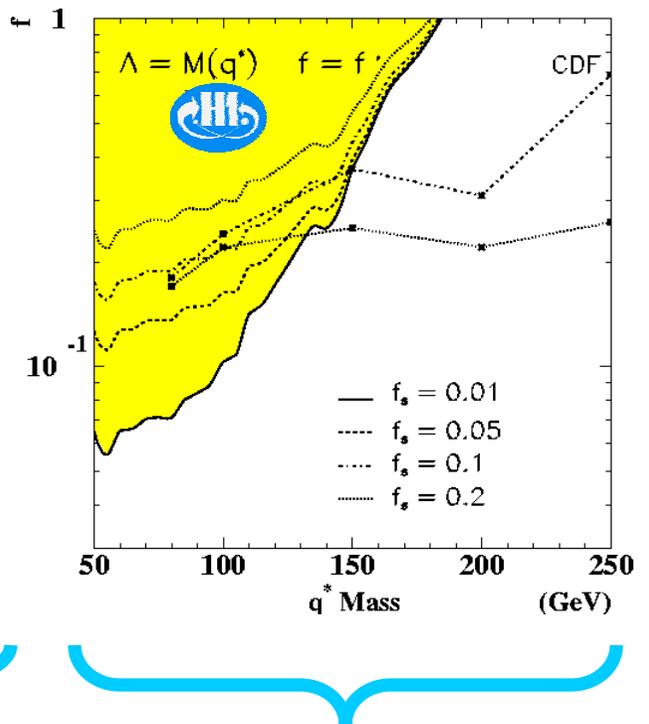
➡ Upper limits at 95 % CL on the coupling  $f/\Lambda$  are derived.

# Limits on excited quarks

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



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



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

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.
    - $\nu^*$ : 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  $1 \text{ fb}^{-1}$  is expected.  
Increased statistics will allow to access higher masses for  $f/\Lambda$  limits, especially for excited neutrinos if more  $e\text{-}p$  data are collected.