Searches for Excited Fermions in ep collisions

Marie Jacquet

LAL Orsay

On behalf of the H1 collaboration

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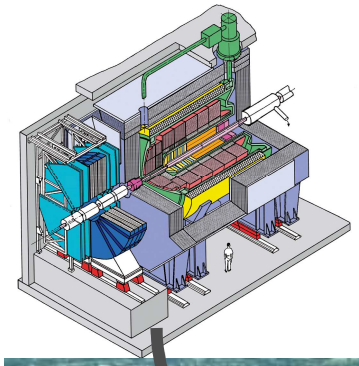
The HERA collider



$\sqrt{s}$ = 300,320 GeV

HERA I : 1992-2000
(120 pb^{-1} per experiment)

HERA II :

- Lumi upgrade
- Polarised leptons beams

All HERA I+II data : ○ $e^{-}p$: 184 pb^{-1} ○ $e^{\pm}p$: 475 pb^{-1}

Excited fermion states generalities

- Excited fermion states should be a signal for substructure at a characteristic scale $\mathcal{O}(\Lambda)$ (Actual experimental constraints lead to a scale $\Lambda > \sim 1$ TeV)

- If known quarks and leptons are composite they should be considered, as the ground state to a rich spectrum of excited states

- Composite models of fermions :

  should explain the threefold "replica" of fermion generation

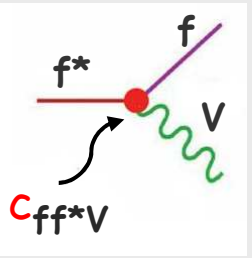
  should be possible alternatives to the conventional SM description of EW symmetry breaking.

- The ways to couple fermions and excited fermions :

  Gauge mediated interactions (GM) :

  $f^* \longleftrightarrow f$ transitions described by an effective lagrangian :

$$\mathcal{L}^{GM}_{eff} = \sum_{V=\gamma,Z,W} \frac{e}{\Lambda} \bar{f}^* \sigma^{\mu\nu} (c_{Vf^*f} - d_{Vf^*f} \gamma_5) f \partial_\mu V_\nu + h.c.$$



  or Contact interactions (not considered here, an H1 paper in preparation)

  (U.Baur et al, Phys. Rev 42, 815, 1990)

(F.M. renard, Phys. Lett. 116B, 264, 1982)

Basic elements of the gauge mediated theory

- f* can carry different spin/isospin values (Kuhn & Zerwas, Phys. Lett B 147,189,1984)

  Assume that f* have spin $\frac{1}{2}$ - isospin $\frac{1}{2}$ and are organised in left/right weak doublet → $F^*_{L,R} = \left(\nu^*_e, e^*\right)_{L,R}$

- Lagrangian should respect a chiral symetry

  → Only right-handed part of F* involved in fF*V couplings

- Interactions described in a SU(2)XU(1) invariant form

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} F^*_R \bar{\sigma}_R^{\mu\nu} \left(g f \frac{\tau^a}{2} W^a_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G^a_{\mu\nu} \right) F_L + \text{h.c.}$$

SU(2) U(1) SU(3)

scale of the substructure

weight factors parametrizing different scales for the 3 gauge groups

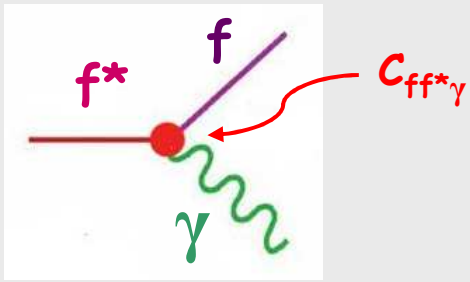
(g, g', g_s : usual weak and strong coupling constants)

$W_{\mu\nu}$, $B_{\mu\nu}$, $G_{\mu\nu}$: filed-strength tensors

(K.Hagiwara et al., ZPC 29, 115, 1985)

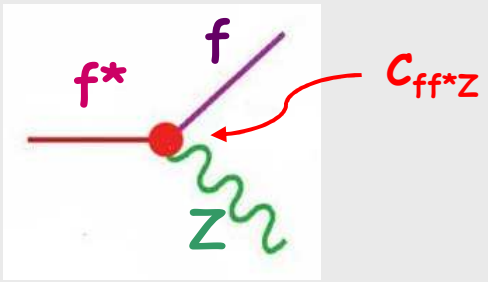
Expression of the Vff* couplings (V = γ,Z,W)

ff*γ vertex



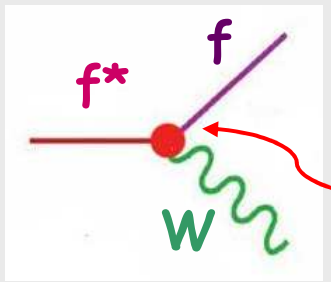
$$C_{\gamma ff^*} = \frac{1}{2}\left(fI_3 + f'\frac{Y}{2}\right)$$

ff*Z vertex



$$C_{Zff^*} = \frac{1}{2}\left(fI_3 \cot\theta_W - f'\frac{Y}{2}\tan\theta_W\right)$$

ff*W vertex



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

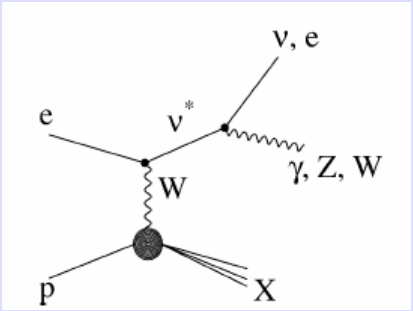
I_3: third isospin component

Y: hypercharge (±1 for ℓ^*)

θ_W: Weinberg angle

Excited fermions : production and decay at ep colliders

ν^*



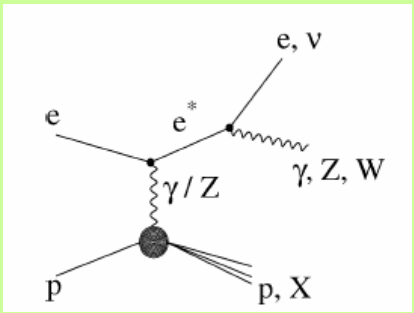
- produced via t-channel W boson exchange

$\sigma(e^-p)/\sigma(e^+p) \sim 100$

("charged current" like production)

H1 analysis : use all e^-p data (184 pb^{-1})

e^*



- produced via t-channel γ/Z bosons exchange

H1 analysis : use (almost) all $e^{\pm}p$ data (435 pb^{-1})

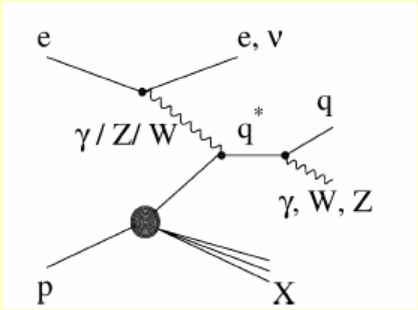
f* de-excitation by emission of γ, Z, W

q^*

Under the assumption $f_s = 0$

(q^* prod. via $qg = 0$)
(q^* decay into $qg = 0$)

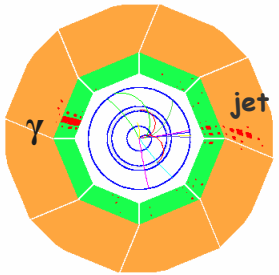
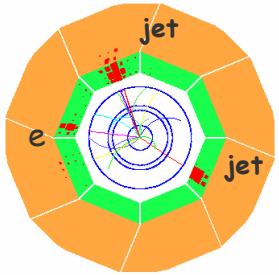
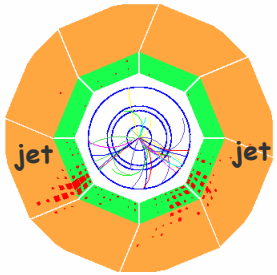
- q^* produced via t-channel γ/Z/W bosons exchange



H1 analysis on e^+p data (37 pb^{-1})

(plan to analyse all the H1 data)

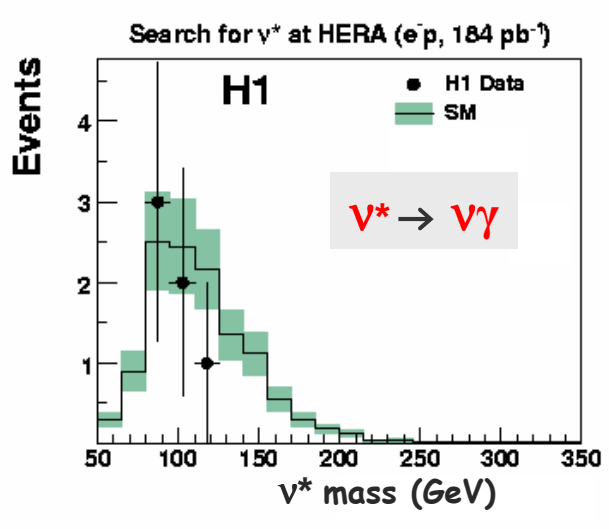
Searches for ν* with H1

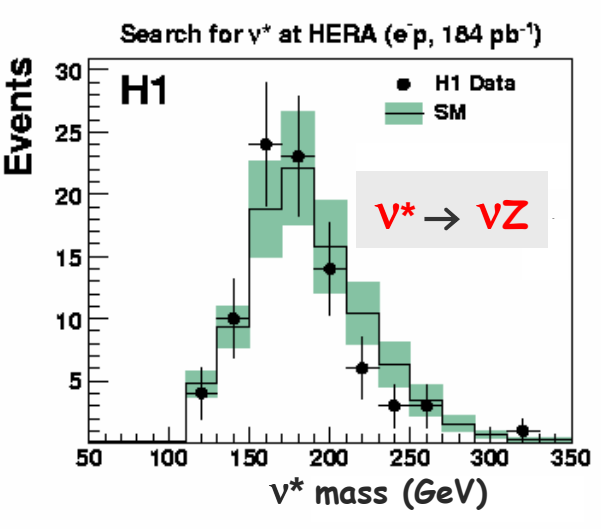
decay		MC events	results
$\nu^* \to \nu\gamma$	• P_T^{miss} > 20 GeV , 1 γ candidate • 1 jet with P_T^{jet} >5 GeV • Reduce CC DIS : P_T^{γ} > 20 GeV		data: 7 — SM: 12.3 ± 3.0 — sig. ε (%): 50-55
$\nu^* \to eW$ $\to e\bar{q}q$	• 1 isolated electron , P_T^e >25 GeV • at least 2 jets, P_T^{jets} > 20,15 GeV • Reduce NC DIS : W candidate is formed from 2 highest P_T jets		data: 220 — SM: 223 ± 47 — sig. ε (%): 40-65
$\nu^* \to \nu Z$ $\to \nu q\bar{q}$	• P_T^{miss} >20 GeV • at least 2 jets, P_T^{jet} >20,15 GeV • Reduce CC DIS : Z candidate is formed from 2 highest P_T jets		data: 89 — SM: 95 ± 21 — sig. ε (%): 25-55

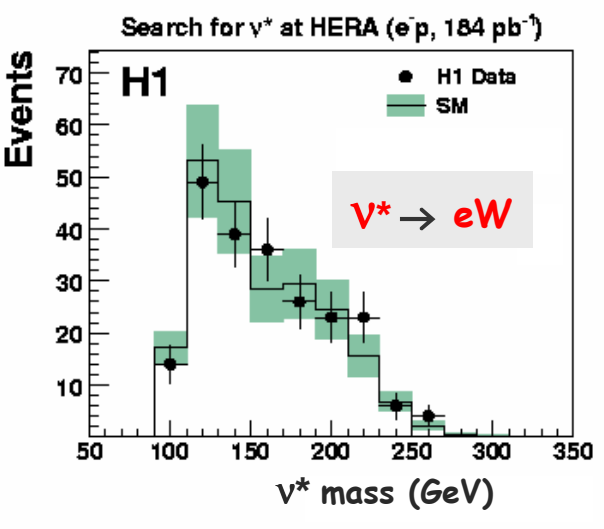
$\nu^* \to \nu Z \to \nu ee$	P_T^{miss} + 2e	bkg : NC - DIS	0	0.19 ± 0.05	45
$\nu^* \to eW \to ee\nu$	P_T^{miss} + 2e	bkg : W production	0	0.70 ± 0.10	45
$\nu^* \to eW \to e\mu\nu$	P_T^{miss} + e + μ	bkg : μ-pairs	0	0.40 ± 0.05	35

Invariant mass distributions in the 3 main channels :

(Submitted to Phys. Lett. B, DESY 08-009)





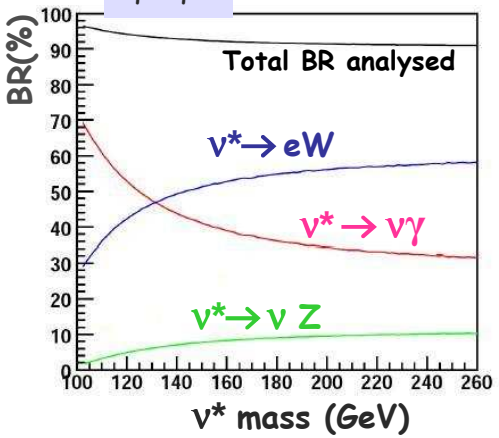


→ Good agreement data / SM, no resonance observed

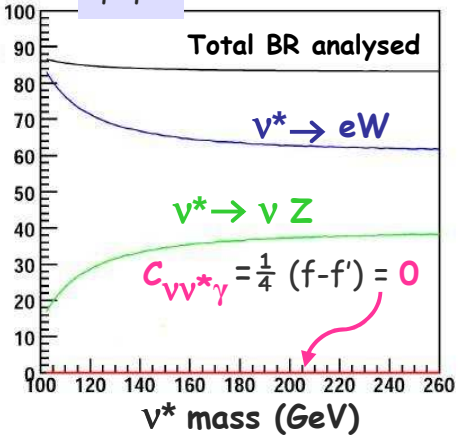
ν* branching ratio

(almost all ν* decay topologies are investigated)

f=-f ' (max. νν*γ coupl.)

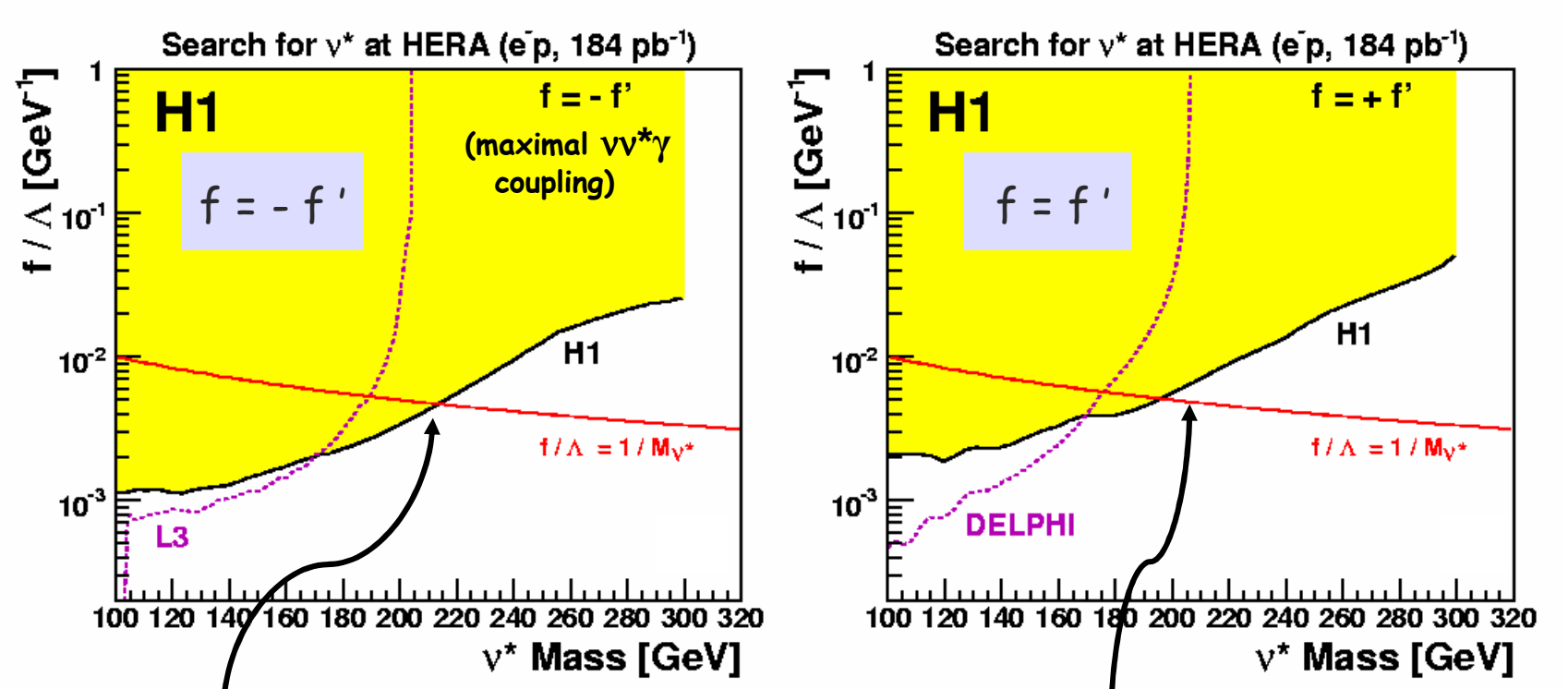


f=f '



Limits on f/Λ from ν^* production

Limits at 95% C.L. on f/Λ from all channels combined



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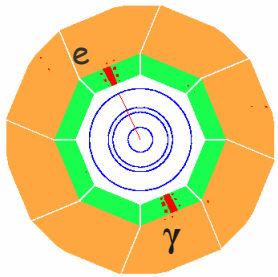
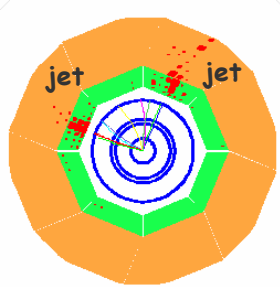
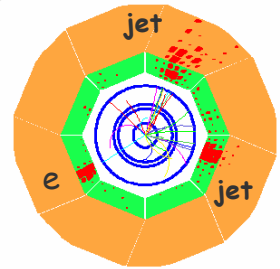
If $f/\Lambda = 1/M_{\nu^*}$ and $f = -f'$

$M_{\nu^*} < 213$ GeV excluded

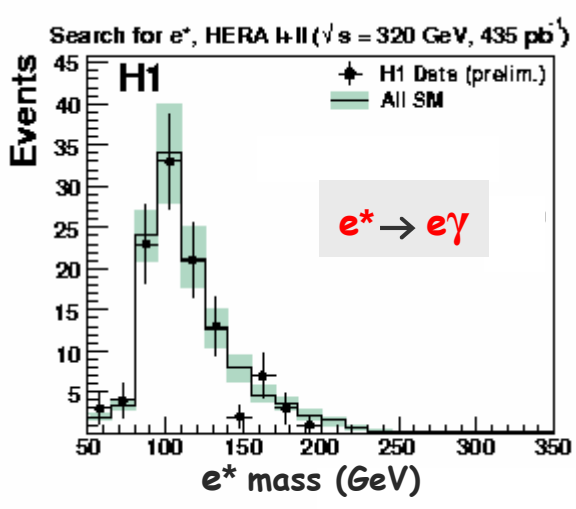
If $f/\Lambda = 1/M_{\nu^*}$ and $f = +f'$

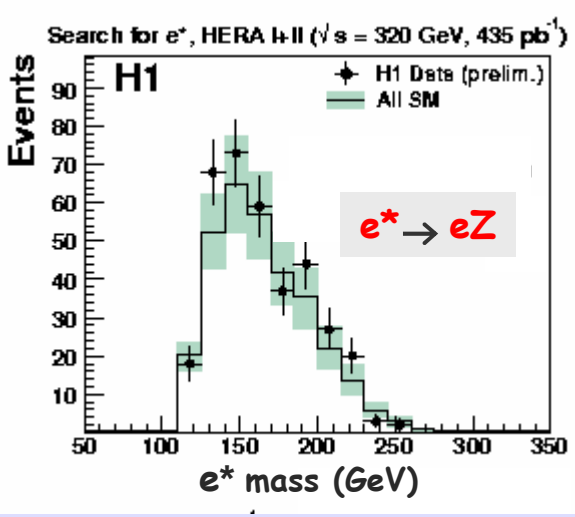
$M_{\nu^*} < 196$ GeV excluded

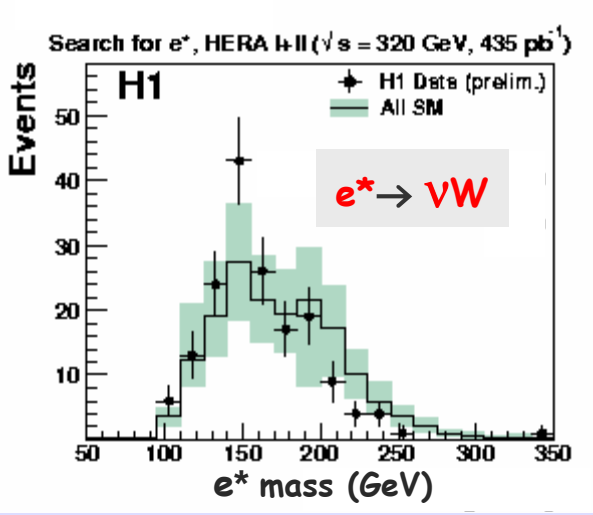
For masses beyond the LEP reach, best sensitivity achieved so far

decay	Searches for e* with H1	MC events	results
$e^* \rightarrow e\gamma$	• 2 electromagnetic clusters with P_T > 20,15 GeV • Reduced QED compton $P_T^{em_1} + P_T^{em_2} > 75$ GeV $E^{em_1} + E^{em_2} > 100$ GeV		data 112 SM 125 ± 19 sig. ε (%) 60-70
$e^* \rightarrow \nu W$ $\rightarrow \nu q\bar{q}$	• P_T^{miss} + 2 jets , same as $\nu^* \rightarrow \nu Z \rightarrow \nu q\bar{q}$		data 172 SM 175 ± 39 sig. ε (%) 40
$e^* \rightarrow eZ$ $\rightarrow eq\bar{q}$	• 1 electron + 2 jets , same as $\nu^* \rightarrow eW \rightarrow eq\bar{q}$		data 351 SM 318 ± 64 sig. ε (%) 45

Invariant mass distributions in the 3 main channels :



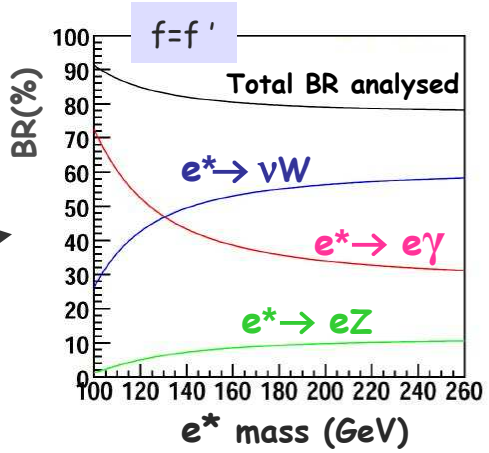




Good agreement data / SM, no resonance observed

e* branching ratio

(almost all e* decay topologies are investigated)



- $C_{ee^*\gamma} = \frac{1}{4}(f + f') = 0$ for $f = -f'$

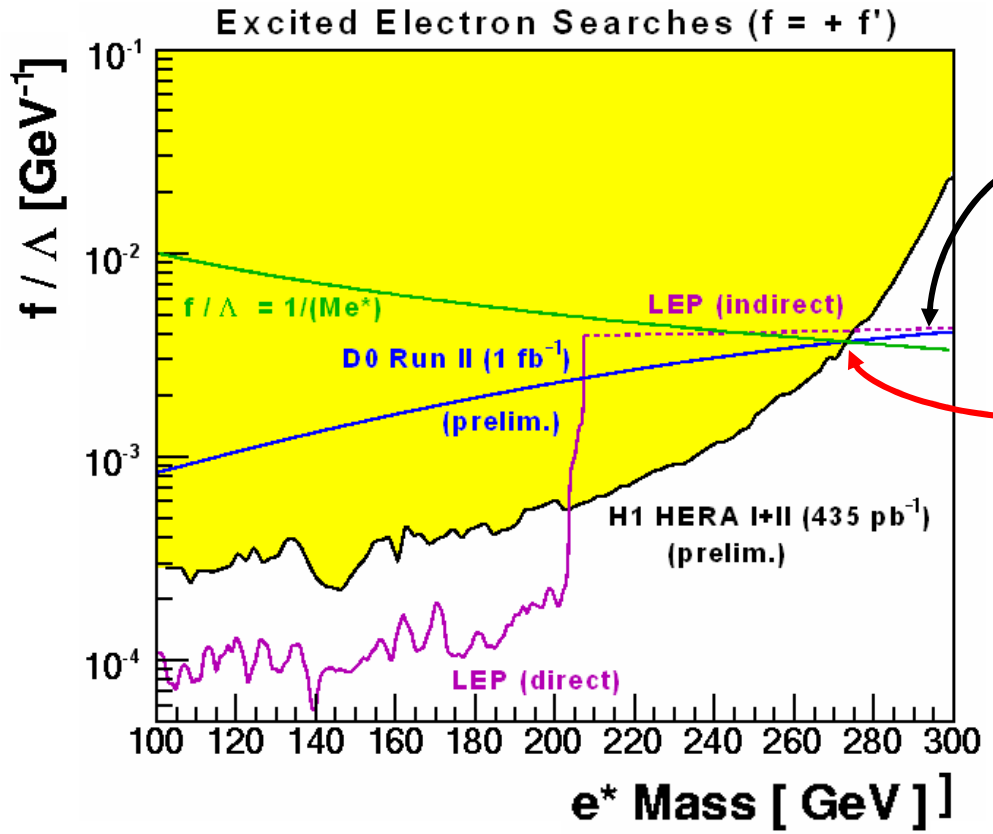
  Cross section very small in that case :

  at $M_{e^*} = 200$ GeV $\begin{cases} \sigma_{(f=+f')} = 7.3 \times 10^{-3}\ pb^{-1} \\ \sigma_{(f=-f')} = 7.8 \times 10^{-6}\ pb^{-1} \end{cases}$

  Only the case f = +f ' will be studied

Limits on f/Λ from e* production

Limits at 95% C.L. from all channels combined



e* D0 (1 fb^{-1})

$qq \to \gamma, Z \to ee^*$

$e^* \to e\gamma$

If : $f/\Lambda = 1/M_{e^*}$ and $f = +f'$

$M_{e^*} < 273$ GeV excluded

Best sensitivity achieved for intermediate e* mass ranges

(e* at HERA have a unique sensitivity up to $M_{e^*} \sim 300$ GeV and $f/\Lambda \sim 10^{-3}$ GeV^{-1})

Summary

All the H1 data at E_{cm}= 300, 320 GeV have been used :

- e^-p : 184 pb^{-1} to look for excited neutrino (published)
- $e^{\pm}p$: 435 pb^{-1} to look for excited electrons (preliminary)

No signal found and upper limits have been derived :

For e^* : if $f/\Lambda = 1/M_{e^*}$ and $f = +f'$, $M_{e^*} < 273$ GeV excluded

For ν^* : if $f/\Lambda = 1/M_{\nu^*}$ and $f = -f'$, $M_{\nu^*} < 213$ GeV excluded

In the mass range 200 GeV < M_{ℓ^*} < 300 GeV,

HERA has the best sensitivity