Searches for Excited Fermions in ep collisions

Marie Jacquet

LAL Orsay

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

On behalf of the H1 collaboration

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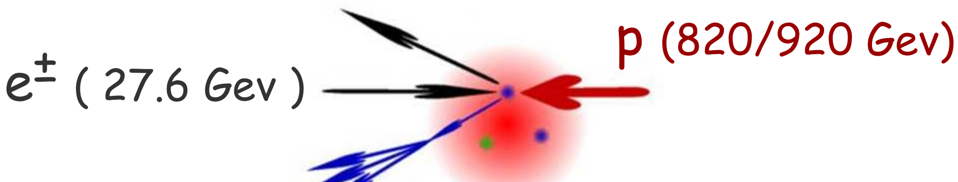
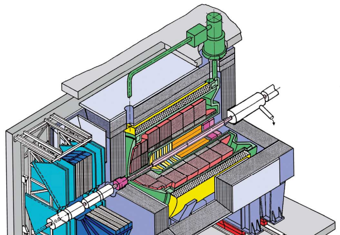
The HERA collider





$\sqrt{s}$ = 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.

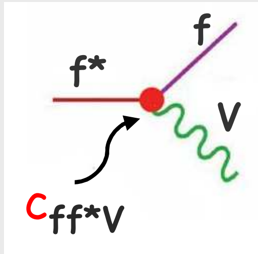
(F.M. renard, Phys. Lett. 116B, 264, 1982)

- The ways to couple fermions and excited fermions :

  Gauge mediated interactions (GM) :

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

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



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

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

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

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \bar{F}^*_R\, \sigma^{\mu\nu} \left[g\, f\, \overset{SU(2)}{\frac{\tau^a}{2}} W^a_{\mu\nu} + g'\, f'\, \overset{U(1)}{\frac{Y}{2}} B_{\mu\nu} + g_s\, f_s\, \frac{\lambda^a}{2} \overset{SU(3)}{G^a_{\mu\nu}} \right] F_L + h.c.$$

scale of the substructure

weight factors parametrizing different scales for the 3 gauge groups

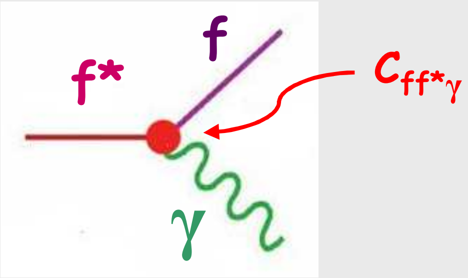
(g, g', g_s : usual weak and strong coupling constants)

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

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

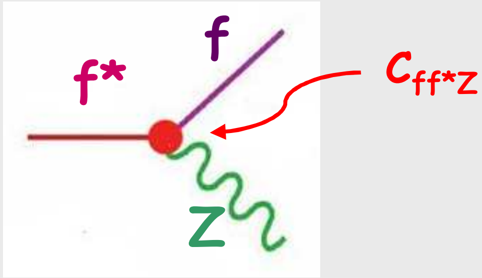
Expression of the Vff* couplings (V = γ,Z,W)

- ff*γ vertex



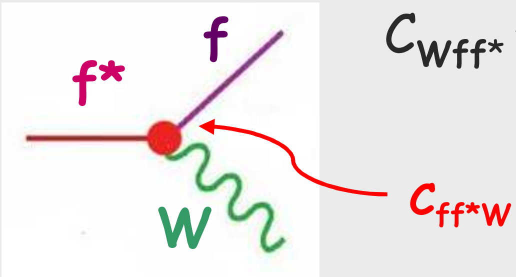
$$C_{\gamma f f^*} = \frac{1}{2}\left(f I_3 + f' \frac{Y}{2}\right)$$

- ff*Z vertex



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

- ff*W vertex



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

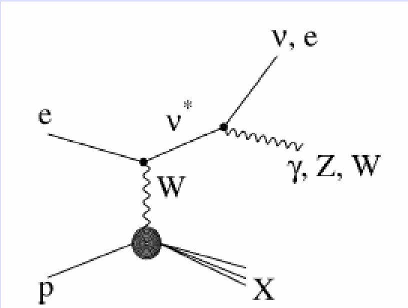
I_3: third isospin component

Y: hypercharge (±1 for ℓ^*)

θ_W: Weinberg angle

Excited fermions : production and decay at ep colliders

ν*



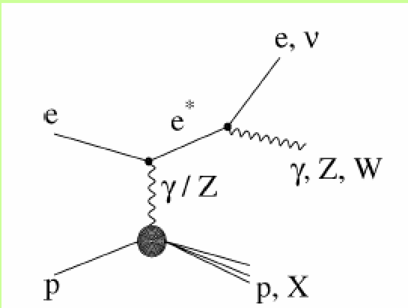
- produced via t-channel W boson exchange

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

("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})

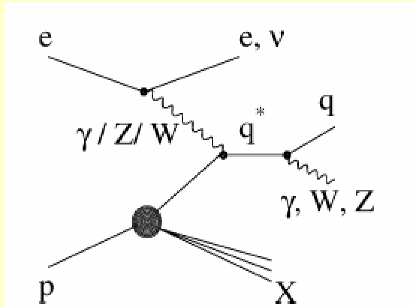
f* de-excitation by emission of γ, Z, W

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})

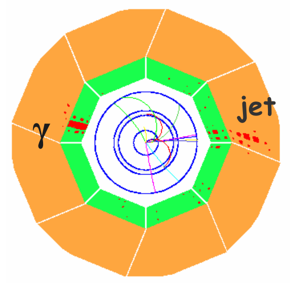
(plan to analyse all the H1 data)

Searches for ν^* with H1

decay | | MC events | results

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

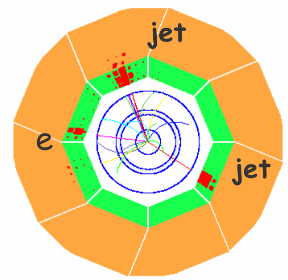
- P_T^{miss} > 20 GeV , 1 γ candidate
- 1 jet with P_T^{jet} >5 GeV
- Reduce CC DIS : P_T^{γ} > 20 GeV



data	SM	sig. ε (%)
7	12.3 ± 3.0	50-55

$\nu^* \to eW$
$\to e\bar{q}q$

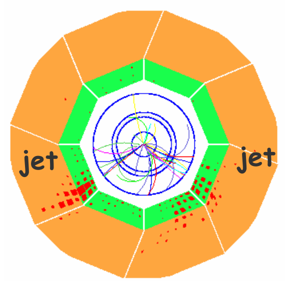
- 1 isolated electron , P_T^{e} >25 GeV
- at least 2 jets, P_T^{jets} > 20,15 GeV
- Reduce NC DIS : W candidate is formed from 2 highest P_T jets



data	SM	sig. ε (%)
220	223 ± 47	40-65

$\nu^* \to \nu Z$
$\to \nu q\bar{q}$

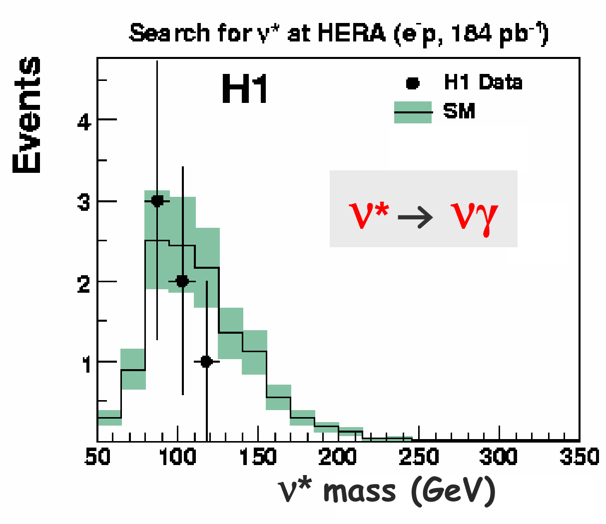
- P_T^{miss} >20 GeV
- at least 2 jets, P_T^{jet} >20,15 GeV
- Reduce CC DIS : Z candidate is formed from 2 highest P_T jets

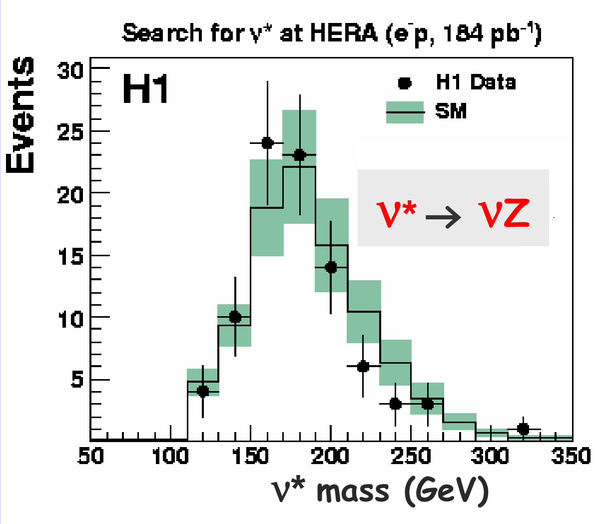


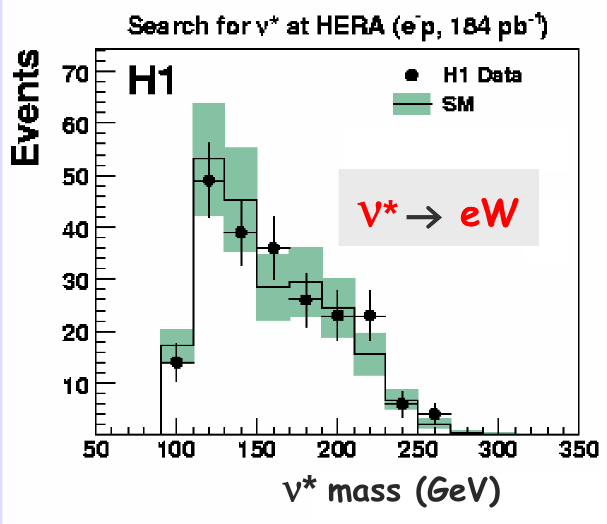
data	SM	sig. ε (%)
89	95 ± 21	25-55

$\nu^* \to \nu Z \to \nu ee$	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)



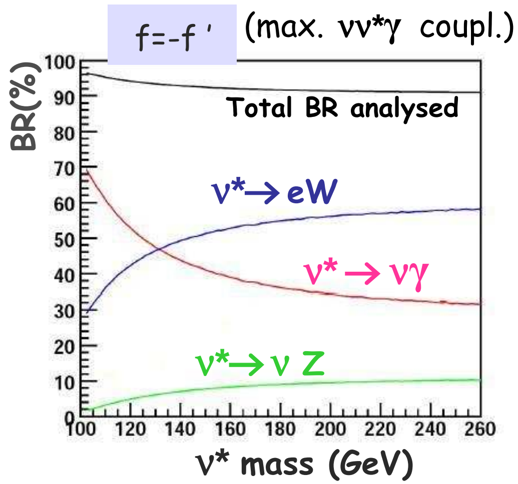


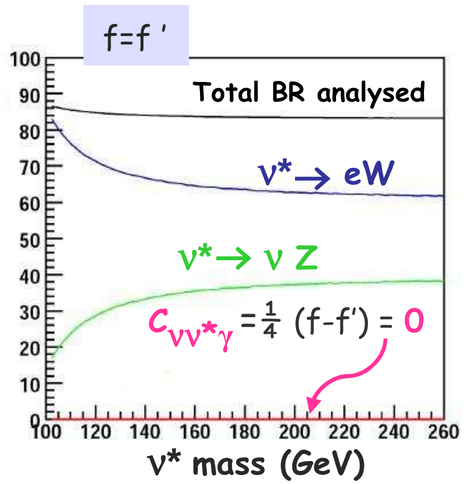


Good agreement data / SM, no resonance observed

ν* branching ratio

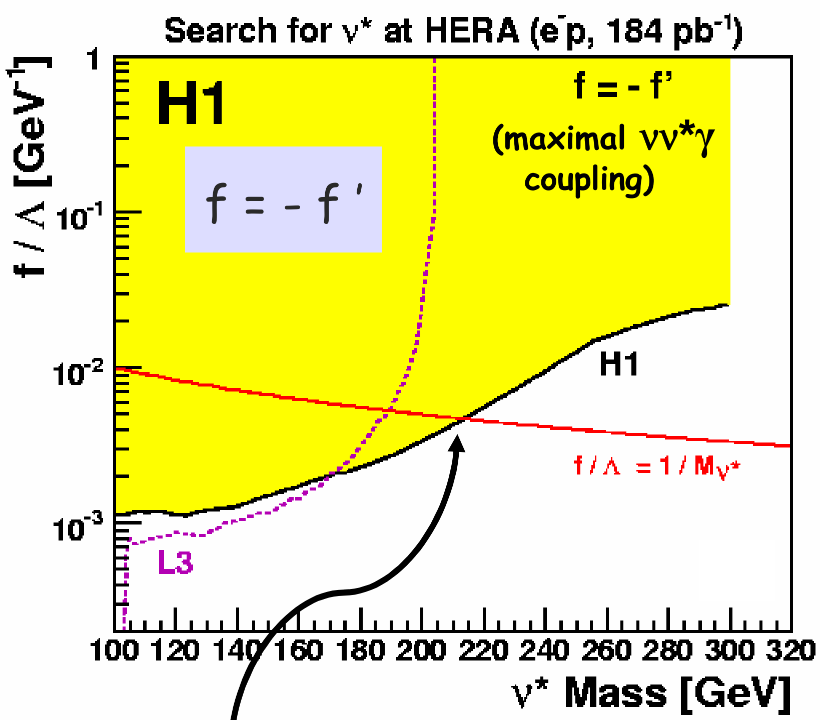
(almost all ν* decay topologies are investigated)

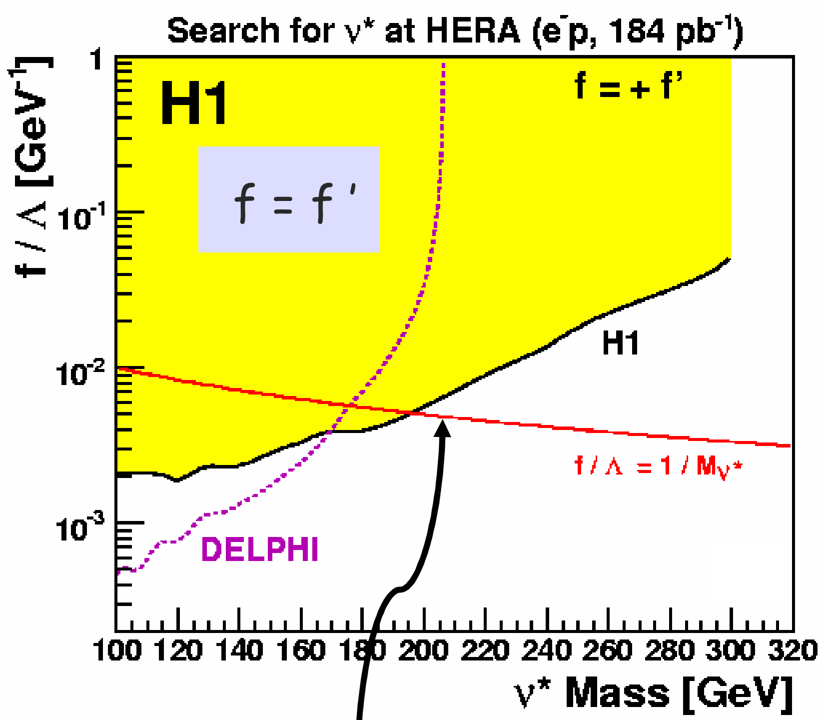




Limits on f/Λ from ν^* production

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





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

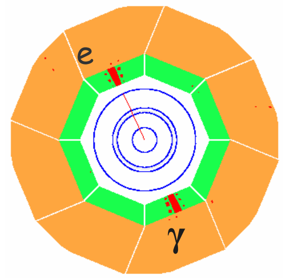
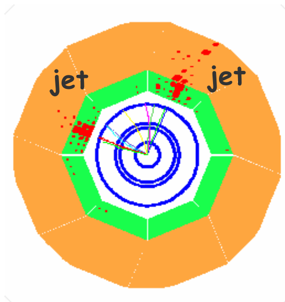
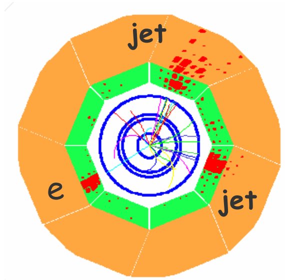
If $f/\Lambda = 1/M_{\nu^*}$ and $f = -f'$

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

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

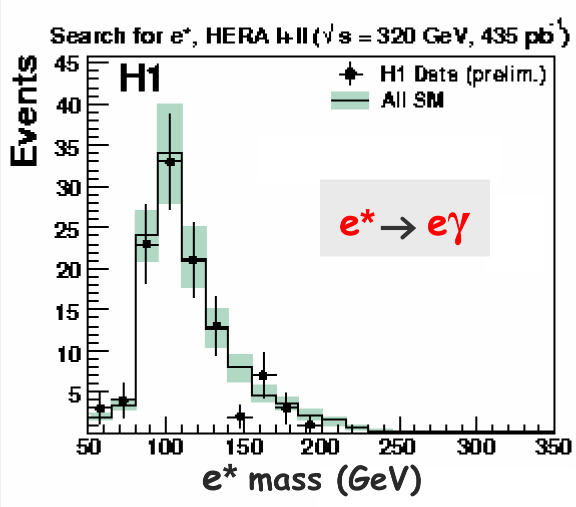
$M_{\nu^*} < 196$ GeV excluded

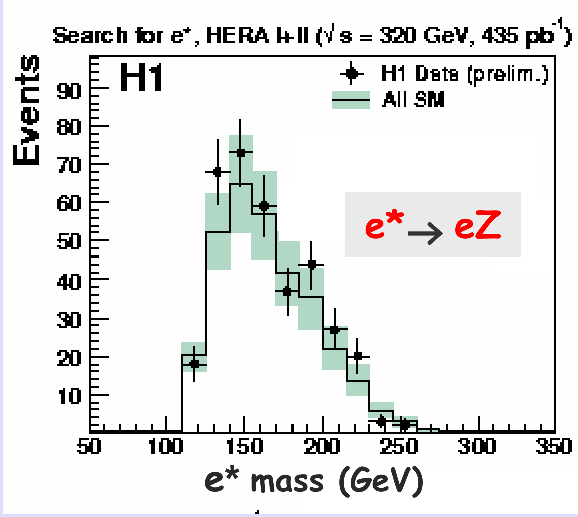
For masses beyond the LEP reach, best sensitivity achieved so far

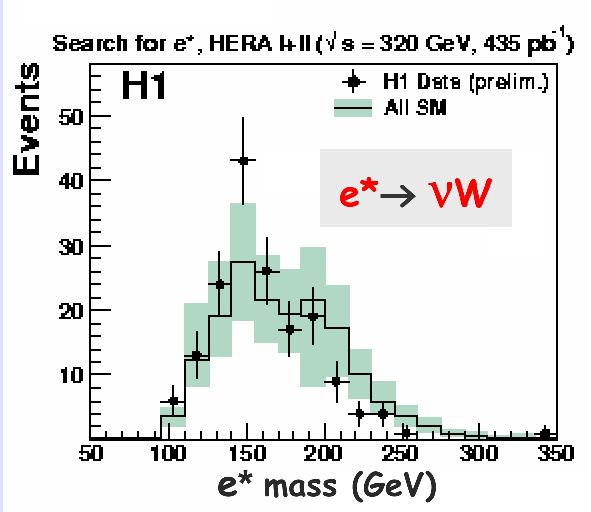
decay	Searches for e* with H1	MC events	results
$e^* \to e\gamma$	• 2 electromagnetic clusters with $P_T > 20,15$ GeV • Reduced QED compton $P_T^{em_1} + P_T^{em_2} > 75$ GeV $E^{em_1} + E^{em_2} > 100$ GeV	 	see below
$e^* \to \nu W$ $\to \nu q\bar{q}$	• P_T^{miss} + 2 jets , same as $\nu^* \to \nu Z \to \nu q\bar{q}$	 	see below
$e^* \to eZ$ $\to eq\bar{q}$	• 1 electron + 2 jets , same as $\nu^* \to eW \to eq\bar{q}$	 	see below

decay	data	SM	sig. ε (%)
$e^* \to e\gamma$	112	125 ± 19	60-70
$e^* \to \nu W \to \nu q\bar{q}$	172	175 ± 39	40
$e^* \to eZ \to eq\bar{q}$	351	318 ± 64	45

Invariant mass distributions in the 3 main channels :



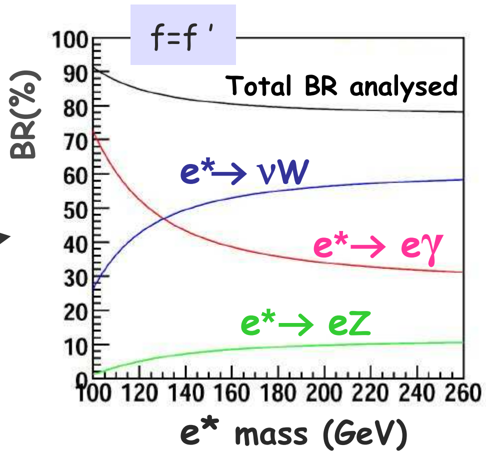




→ Good agreement data / SM, no resonance observed

e* branching ratio

(almost all e* decay topologies are investigated)



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

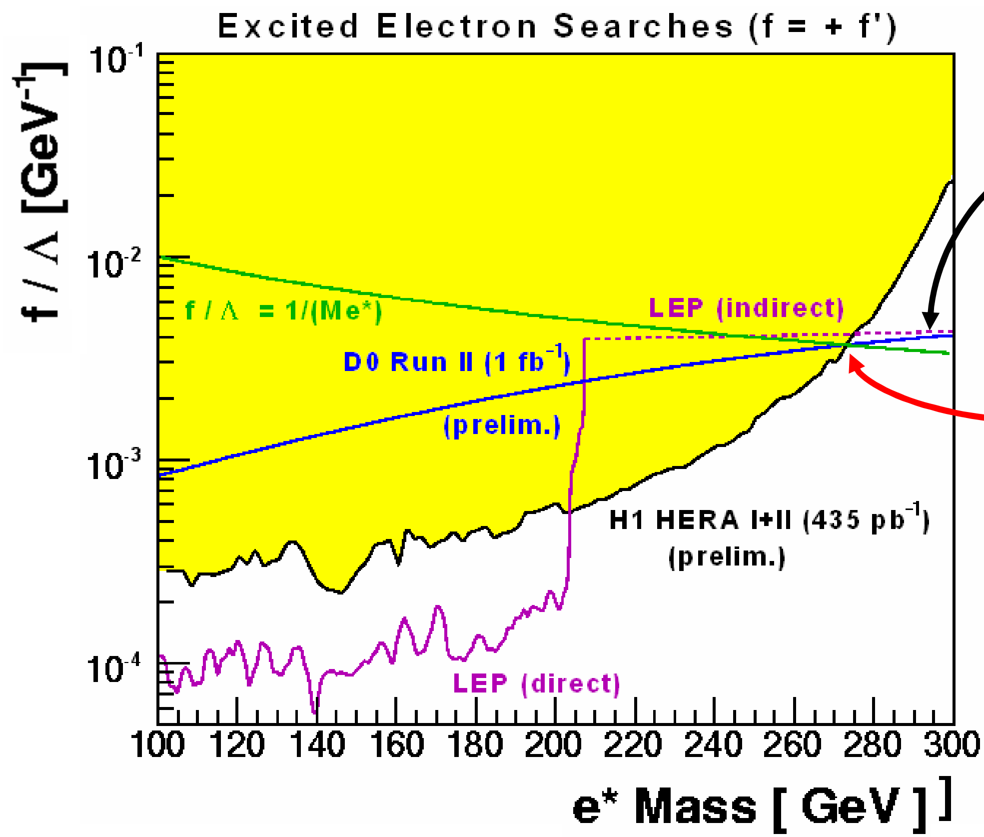
  Cross section very small in that case :

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

  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})

$\left(\begin{array}{c} q\bar{q} \rightarrow \gamma, Z \rightarrow ee^* \\ e^* \rightarrow e\gamma \end{array} \right)$

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