# Excited fermions at H1

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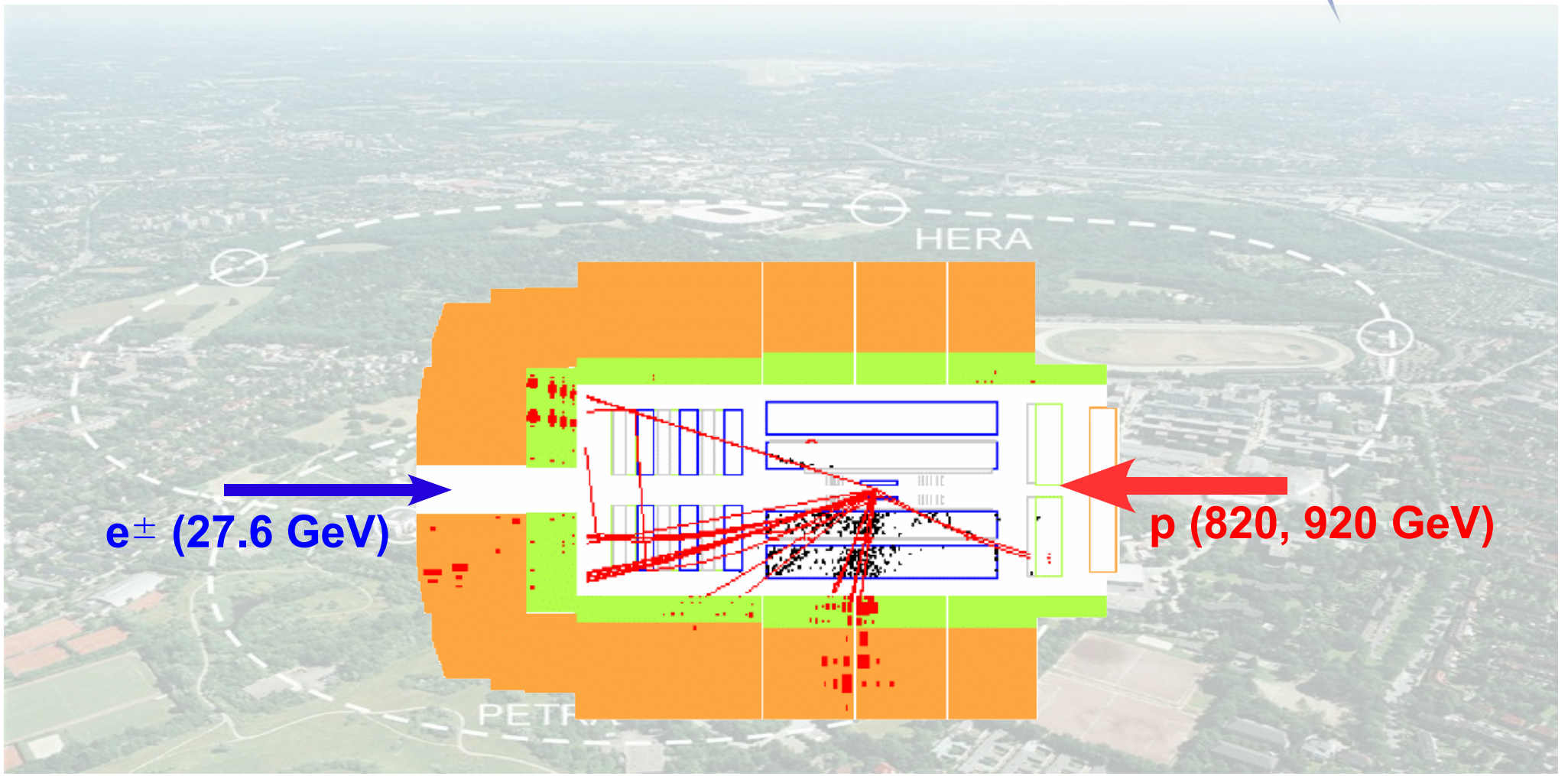
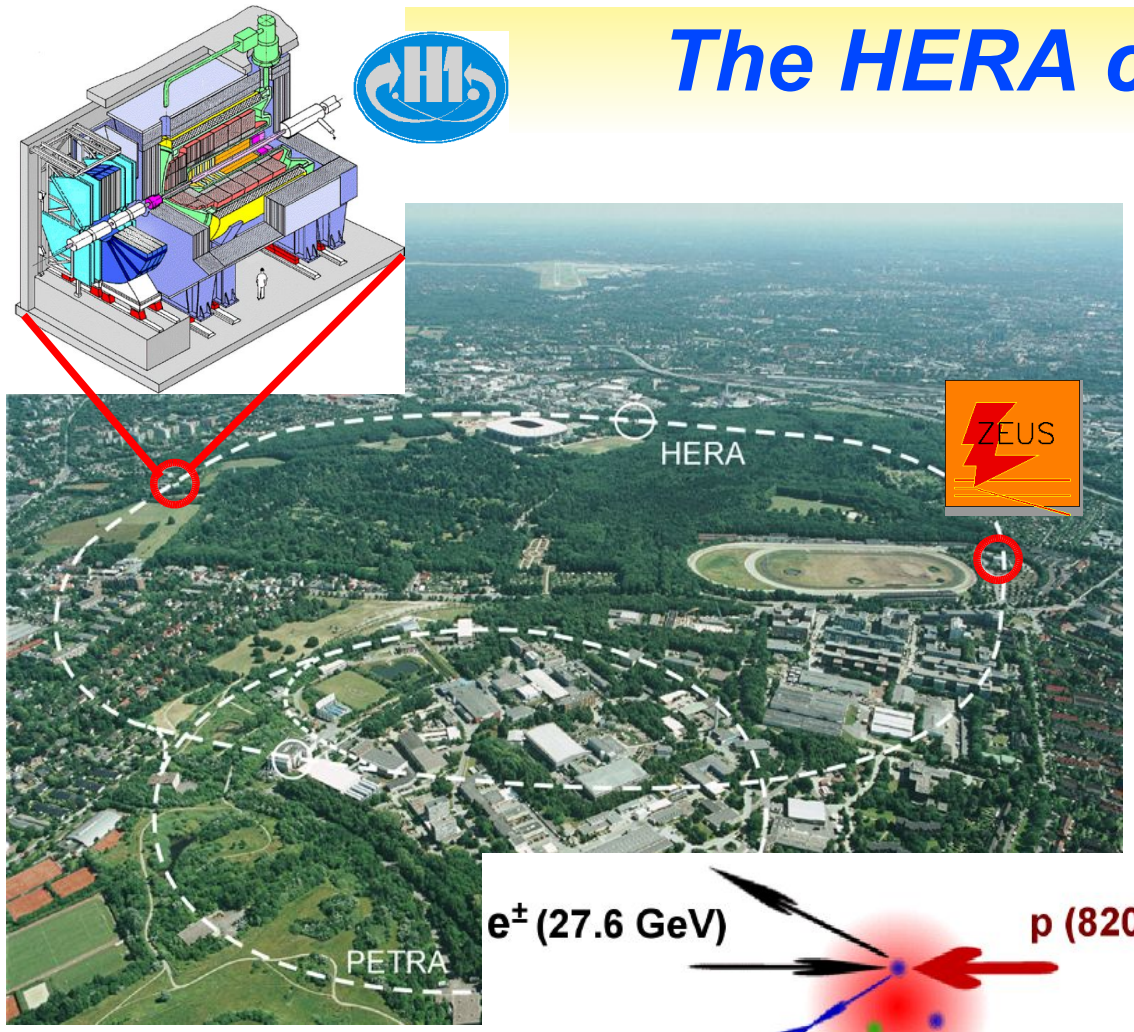
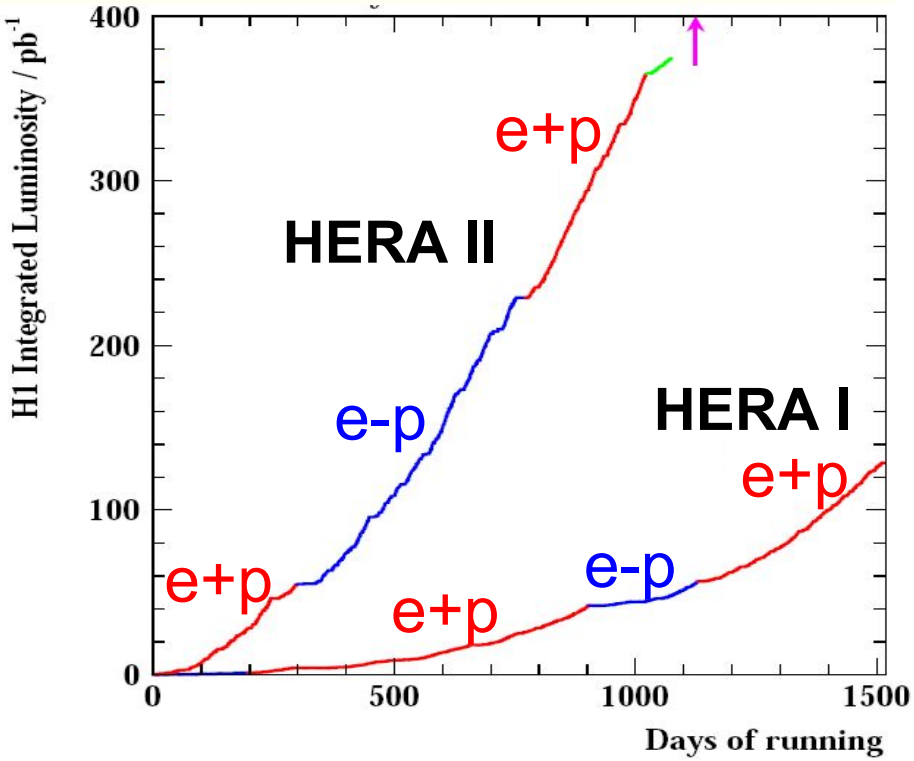
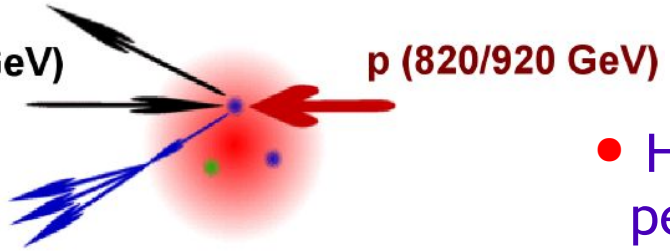
*On behalf of the H1 Collaboration*



# The HERA collider




- HERA I: 1992-2000, ~120 $pb^{-1}$ per experiment
- HERA II: luminosity upgrade and polarised lepton beams

➔ End of $E_{cm}$ = 320 GeV run: March, 20 2007

➘ All HERA I+II data from H1 at $E_{cm}$ = 320 GeV (435 $pb^{-1}$) used here

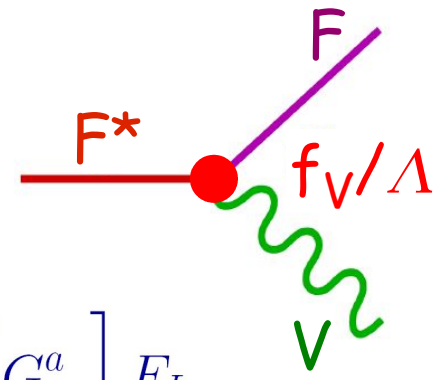
# Excited fermions ...

- Excited states:

  ➔ If found, direct proof of compositness

- Excited fermions F* couple to gauge bosons (F*FV)
- Organised in iso-doublets $(e^*, \nu^*)_{L,R}$

[Hagiwara et al. ZPC 29(1985)115]
[Boudjema et al. ZPC 57(1990)425]




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

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

- Compositness scale $\Lambda$, relative strengh to $\gamma$,Z,g: f, f', fs

- Another approach: contact interactions (suppose common constituents)

$$\mathcal{L}_{CI} \sim \frac{4\pi}{\Lambda^2}\ (\bar{e^*}\gamma^\mu e)\ (\bar{q}\gamma_\mu q)$$

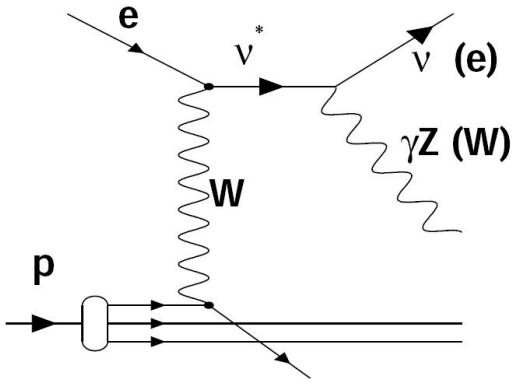
[Baur et al. PRD 42(1990)815]

➔ Same phenomenology, mainly different normalisation

➔ Not considered here

# Excited neutrinos: production and decays

- Produced via t-channel exhange of W boson



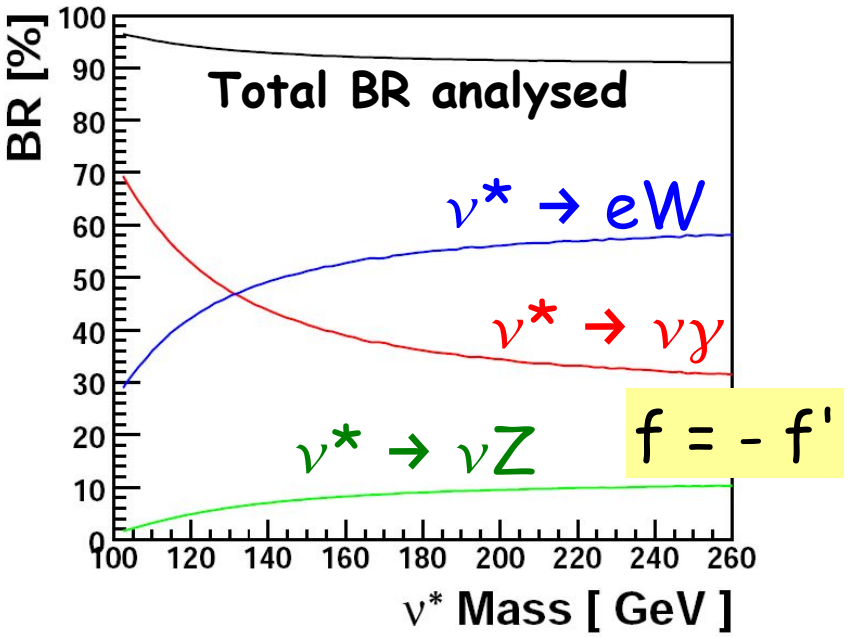

➔ De-excitation by emission of $\gamma$, W, Z

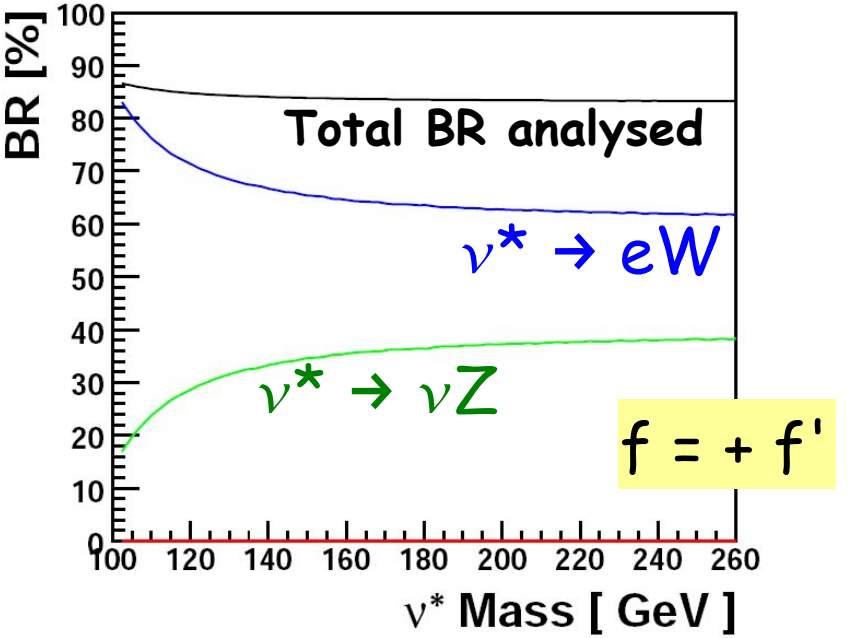
| Decay | Signature | Main SM Background |
|---|---|---|
| $\nu^* \to \nu\gamma$ | $\gamma + P_T^{miss}$ | Radiative CC |
| $\nu^* \to eW_{\hookrightarrow qq}$ | e + 2 jets | NC + 2 jets |
| $\nu^* \to \nu Z_{\hookrightarrow qq}$ | $P_T^{miss}$ + 2 jets | CC + 2 jets |
| $\nu^* \to \nu Z_{\hookrightarrow ee}$ | 2e + $P_T^{miss}$ | NC-DIS |
| $\nu^* \to eW_{\hookrightarrow e\nu}$ | 2e + $P_T^{miss}$ | W production |
| $\nu^* \to eW_{\hookrightarrow \mu\nu}$ | e + $\mu$ + $P_T^{miss}$ | $\mu$-pairs |

➔ Cross section much larger in e-p
(due to favourable valence u-quarks and helicity enhancement)

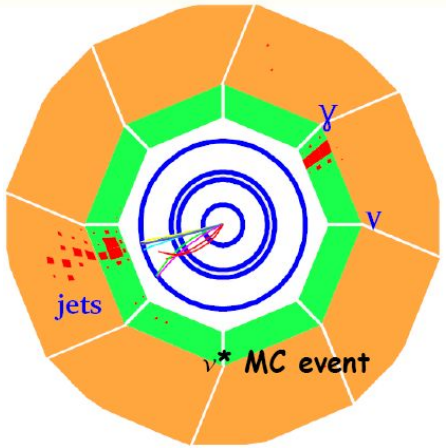
➘ Use only e-p data

➘ Almost all decay channels investigated



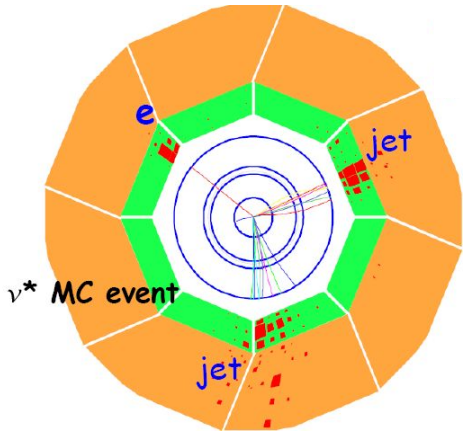
# Search for excited neutrinos




## $\nu^* \rightarrow \nu\gamma$

- $P_T^{miss} > 15$ GeV, $P_T^{jet} > 5$ GeV
- Isolated photon
- Reduce CC DIS:

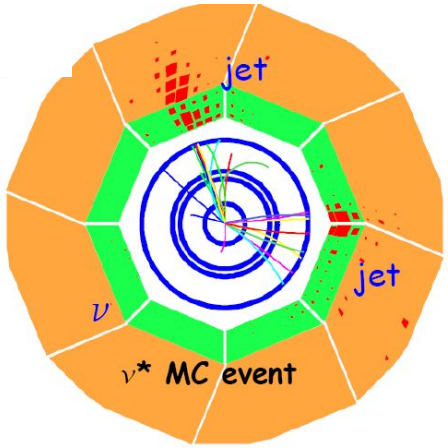
  ➔ $P_T^{\gamma} > 20$ GeV + extra kinematic cuts




## $\nu^* \rightarrow eW$

- 1 electron, $P_T^e > 10$ GeV
- 2 jets, $P_T^{jets} > 20, 15$ GeV
- + cuts to reduce NC DIS

  ➔ W candidate is formed from 2 highest $P_T$ jets




## $\nu^* \rightarrow \nu Z$

- $P_T^{miss} > 12$ GeV
- 2 jets, $P_T^{jets} > 20, 15$ GeV
- + cuts to reduce CC DIS

  ➔ Z candidate is formed from 2 highest $P_T$ jets

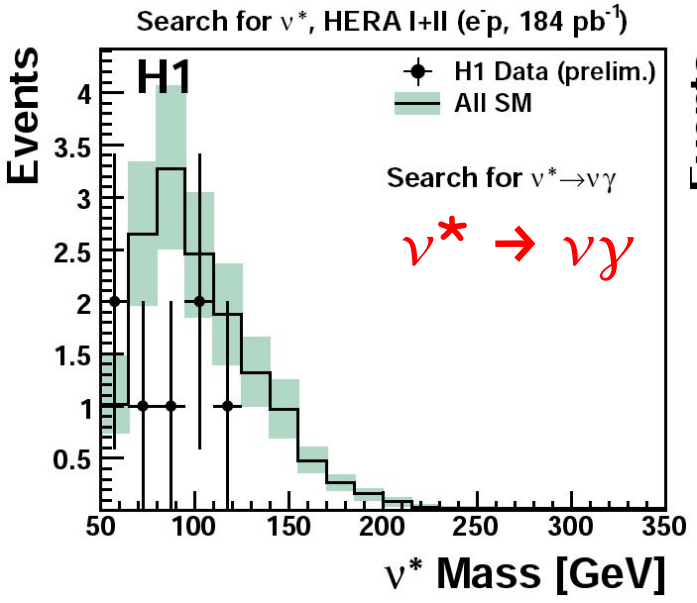
# Search for $\nu^*$: results

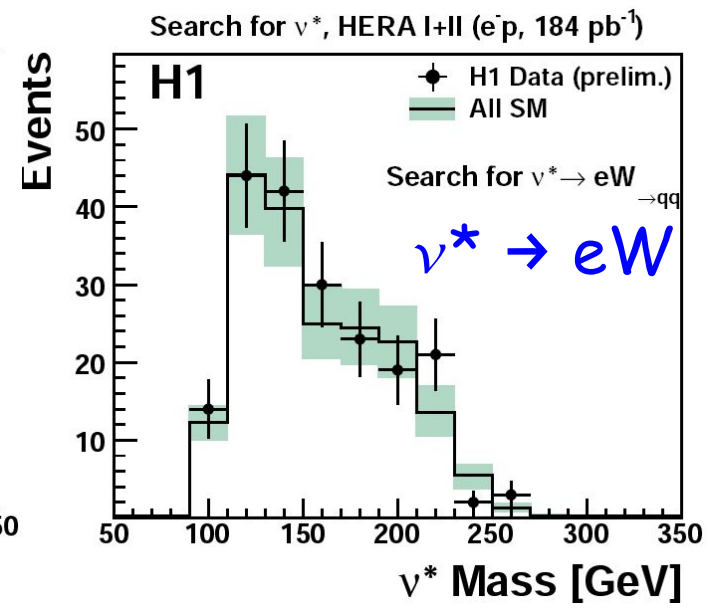
- Total event yields in each channel:

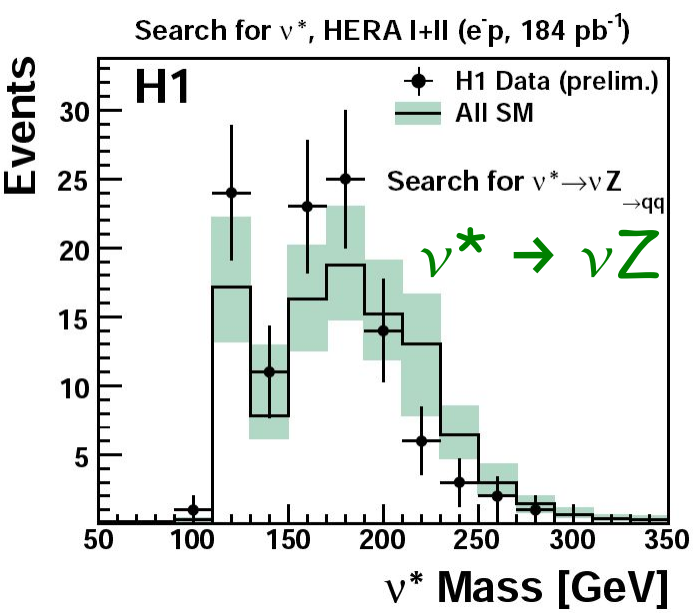
Search for $\nu^*$, HERA I+II ($e^-p$, 184 pb$^{-1}$, preliminary)

| Selection | Data | SM | Efficiency × BR |
|---|---|---|---|
| $\nu^* \to \nu\gamma$ | 9 | $15 \pm 4$ | 50 % |
| $\nu^* \to eW_{\hookrightarrow qq}$ | 198 | $189 \pm 33$ | 30–40 % |
| $\nu^* \to \nu Z_{\hookrightarrow qq}$ | 111 | $102 \pm 24$ | 40 % |
| $\nu^* \to eW_{\hookrightarrow \nu\mu}$ | 0 | $0.54 \pm 0.04$ | 3–4.5 % |
| $\nu^* \to eW_{\hookrightarrow \nu e}$ | 0 | $0.6 \pm 0.3$ | 4–6 % |
| $\nu^* \to \nu Z_{\hookrightarrow ee}$ | 0 | $0.12 \pm 0.04$ | 2 % |

- Invariant mass distributions in 3 main channels:



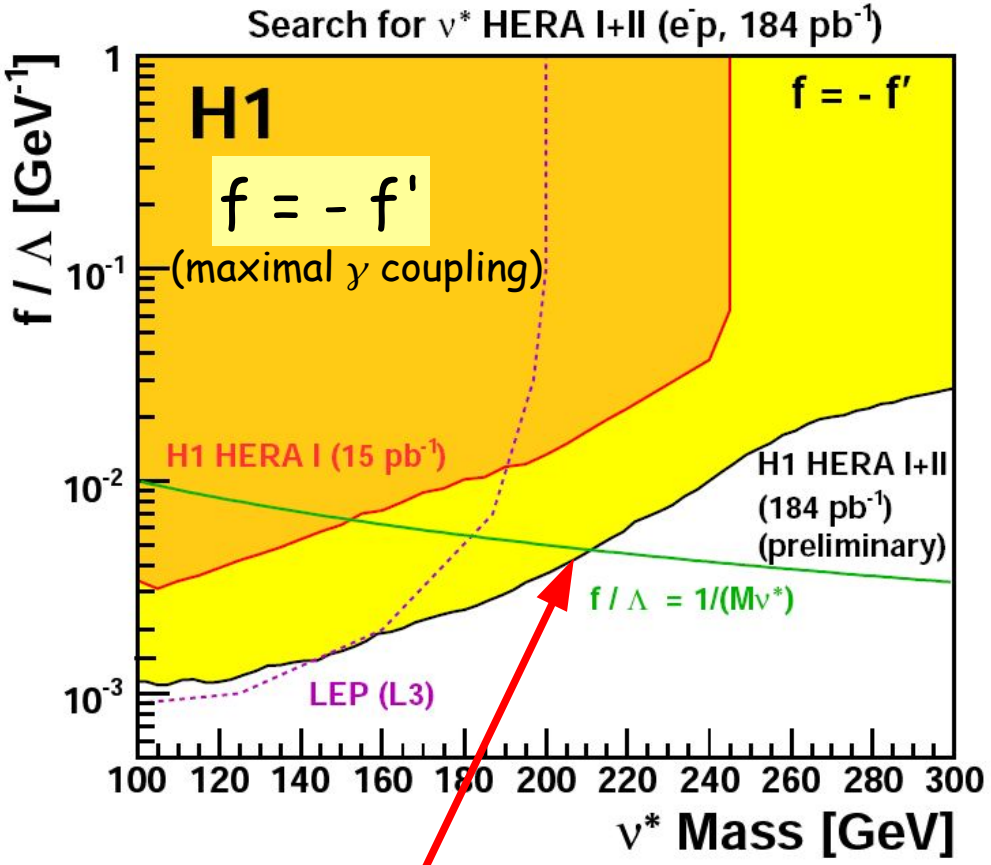



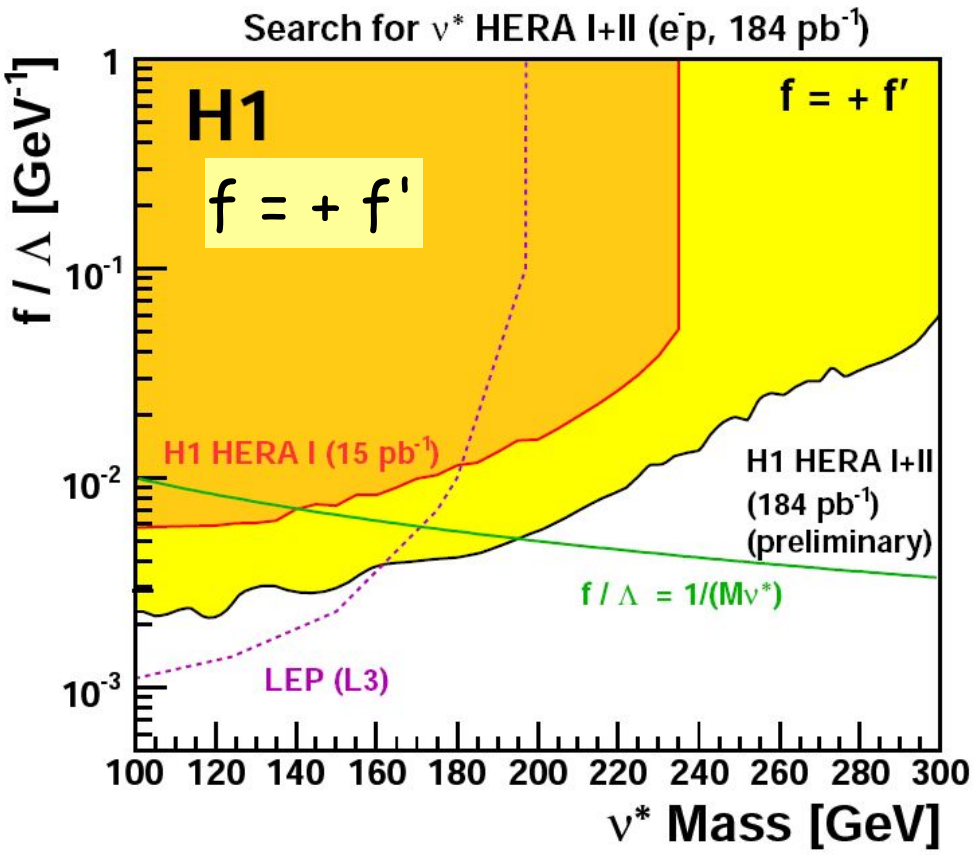




↘ Good agreement with the SM, no resonance observed

# Limits on $\nu^*$ production

- Limits at 95% C.L. derived, all channels combined:



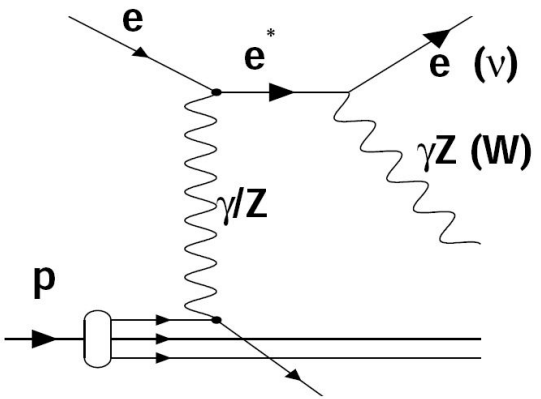

If $f/\Lambda = 1/M\nu^*$ and f=-f' $M\nu^* < 211$ GeV excluded

↘ Large improvement compared to HERA I

↘ For masses beyond the LEP reach:
best sensitivity achieved so far

# Excited electrons: production and decays

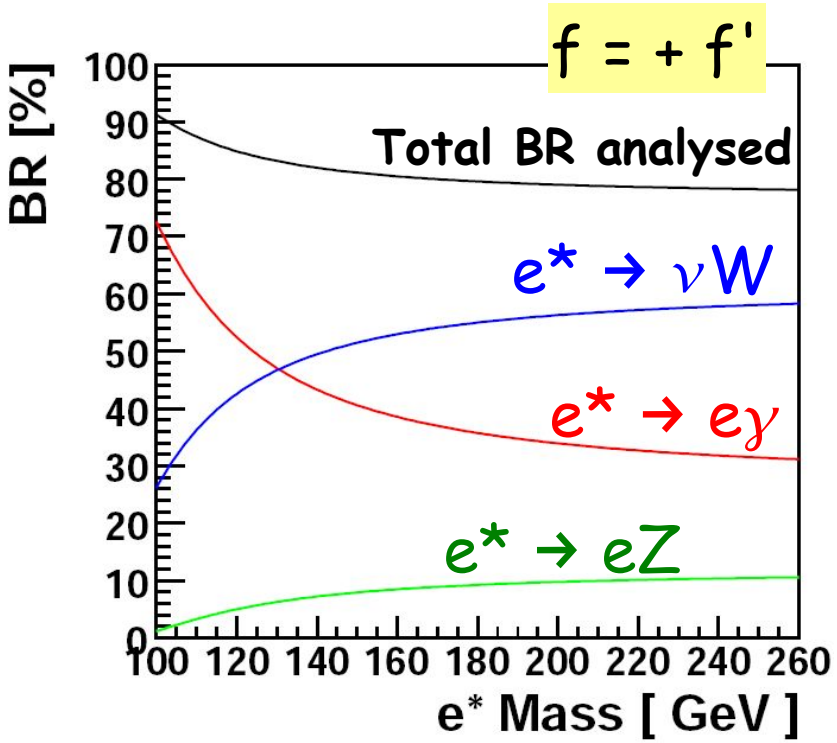
- Produced via t-channel exhange of $\gamma$/Z bosons




➔ De-excitation by emission of $\gamma$, W, Z

➔ Signatures similar to $\nu$*

| Decay | Signature | Main SM Background |
|---|---|---|
| $e^* \to e\gamma$ | e + $\gamma$ | QED-Compton |
| $e^* \to eZ_{\hookrightarrow qq}$ | e + 2 jets | NC + 2 jets |
| $e^* \to \nu W_{\hookrightarrow qq}$ | $P_T^{miss}$ + 2 jets | CC + 2 jets |

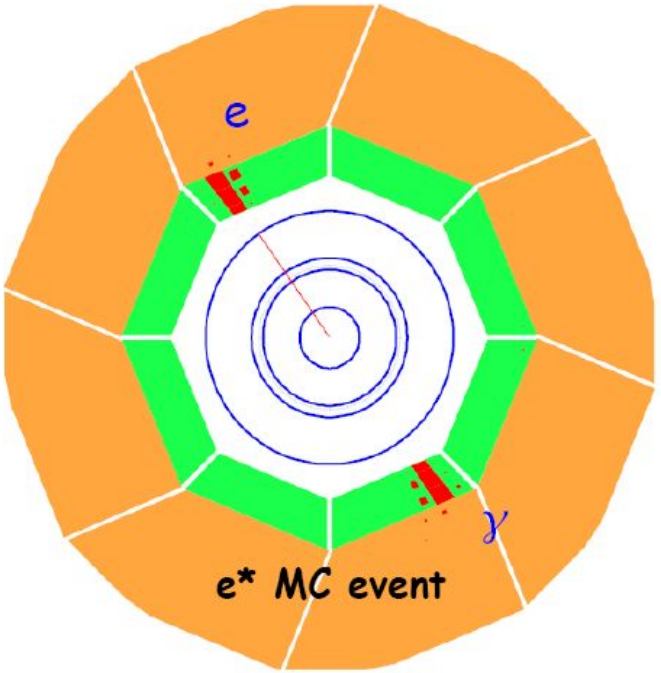



➘ Only hadronic decays of W/Z analysed so far

➔ Very small cross section in case f = -f'

➔ Study only f = + f'

# Search for excited electrons




$e^* \rightarrow e\gamma$

- 2 electromagnetic clusters
- no track associated to the 2nd
- $P_T^e > 20$ GeV, $P_T^\gamma > 15$ GeV
- Reduce QED-Compton background:

  ➔ $P_T^\gamma + P_T^e > 75$ GeV

  ➔ $E^\gamma + E^e > 100$ GeV

$e^* \rightarrow \nu W$ ➔ $P_T^{miss}$ + 2 jets, similar to $\nu^* \rightarrow \nu Z$

$e^* \rightarrow eZ$ ➔ 1 electron + 2 jets, similar to $\nu^* \rightarrow eW$

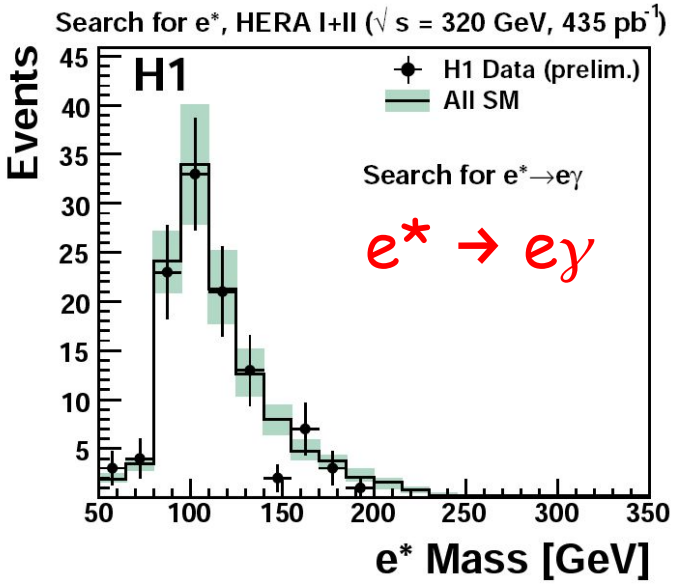
# Search for e*: results

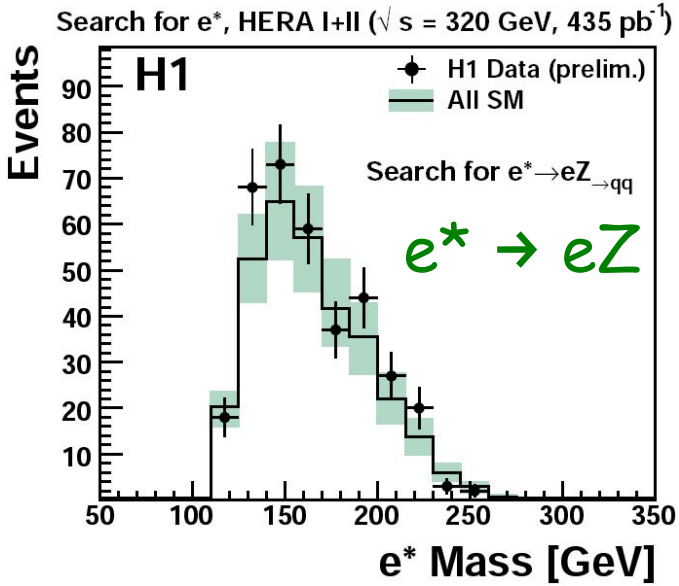
- Total event yields in each channel:

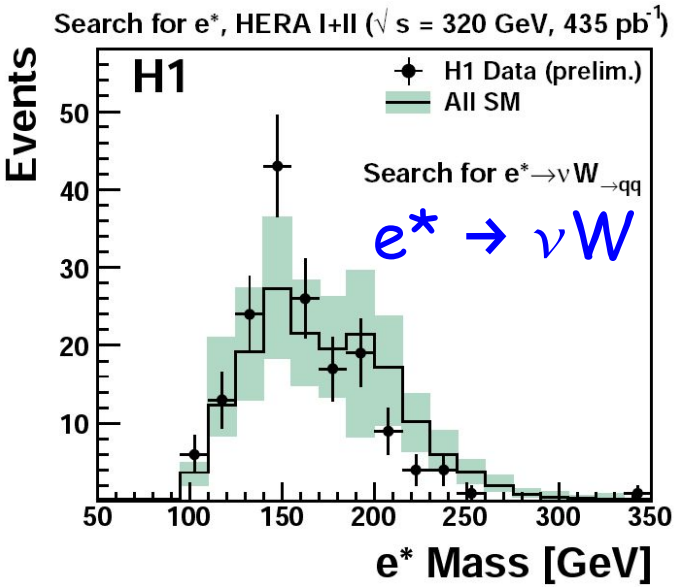
Search for $e^*$ HERA I+II ($\sqrt{s} = 320$ GeV, 435 pb$^{-1}$, preliminary)

| Selection | Data | SM | Efficiency × BR |
|---|---|---|---|
| $e^* \to e\gamma$ | 112 | $125 \pm 19$ | 60–70 % |
| $e^* \to \nu W_{\to qq}$ | 172 | $175 \pm 39$ | $\sim 40$ % |
| $e^* \to e Z_{\to qq}$ | 351 | $318 \pm 64$ | $\sim 45$ % |

- Invariant mass distributions in 3 main channels:



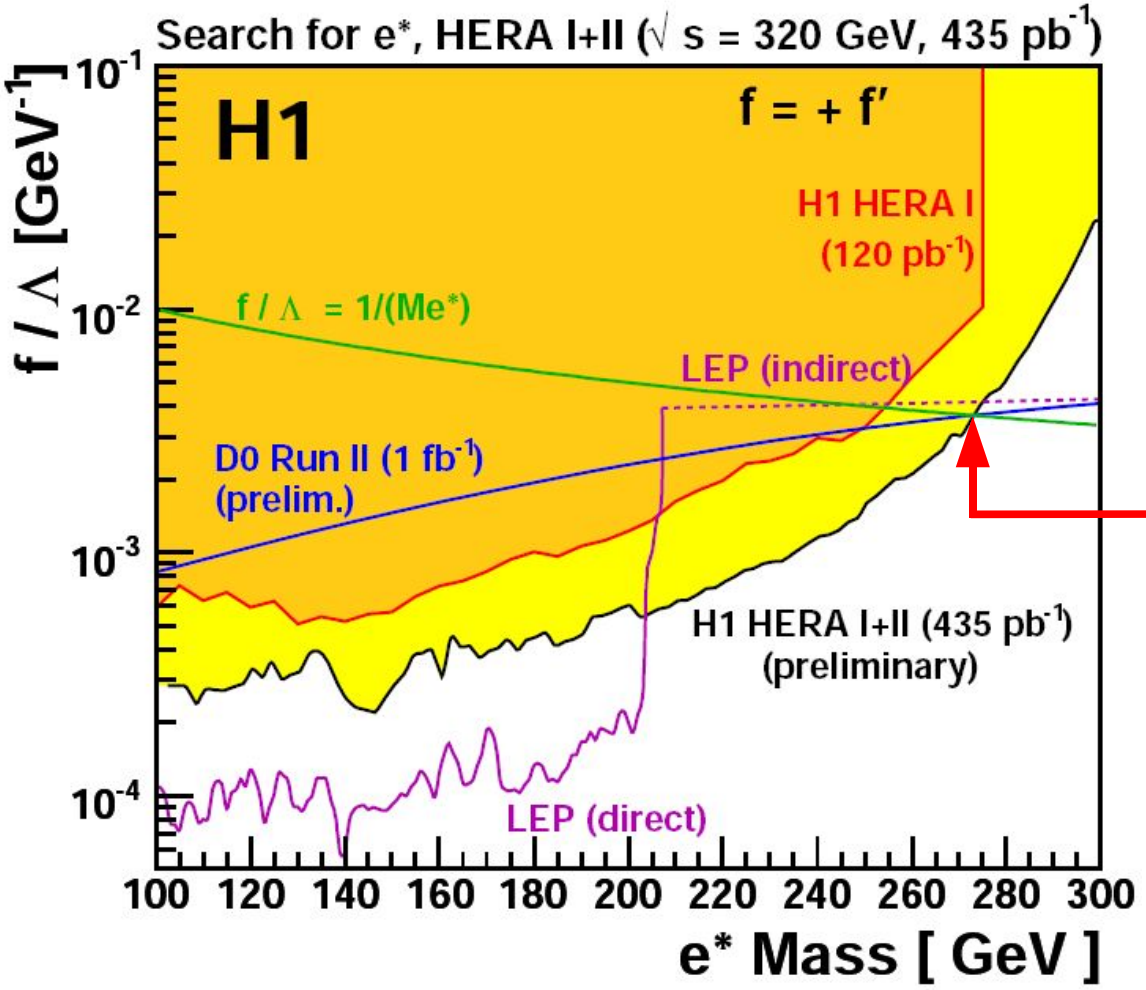




↘ Good agreement with the SM, no resonance observed

# New limit on e* production

- Limit at 95% C.L. derived, all channels combined:




If $f/\Lambda = 1/Me^*$ and $f=+f'$

**$Me^* < 273$ GeV** excluded

↘ A new territory explored

↘ Best sensitivity for intermediate e* masses

# Summary

- All H1 data at $E_{cm}$ = 320 GeV (435 $pb^{-1}$) have been used to look for excited electron and neutrino

  ➔ A new domain explored, but no positive signal found

  ➔ Upper limits are derived:

  - For $\nu^*$: If $f/\Lambda = 1/M\nu^*$ and f=-f' **$M\nu^* < 211$ GeV** excluded
  - For e*: If $f/\Lambda = 1/Me^*$ and f=+f' **$Me^* < 273$ GeV** excluded

  ↘ Presently the most stringent world limits

  ↘ In the mass range $\sqrt{s_{LEP}} = 200 < M_{l^*} < 300$ GeV, HERA has the best sensitivity