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Search for excited leptons at HERA

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On behalf of the H1 Collaboration

Excited leptons: Phenomena

If energy scale: $\Lambda \geq 1$ TeV

↓

Leptons could be made of smaller constituents (ex: excited leptons)

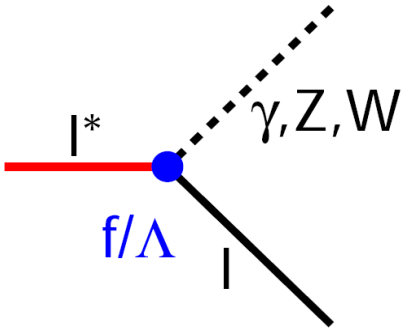
↓

Compositeness Model could explain it

- Basics of the phenomenological model
  - Excited leptons (l*) are considered as spin=1/2 & isospin=1/2 particles
  - Generally assume $\begin{pmatrix} \nu_\ell^* \\ \ell^* \end{pmatrix}_L \begin{pmatrix} \nu_\ell^* \\ \ell^* \end{pmatrix}_R$
  - Excited leptons couple to gauge bosons (ll*V) (Gauge Mediated Interaction)

$$\mathcal{L}_{\ell\ell^* V} = \frac{1}{2\Lambda}\bar{\ell}^* \sigma^{\mu\nu} \left[g f \frac{\boldsymbol{\tau}}{2} \mathbf{W}_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} \right] \ell_L$$

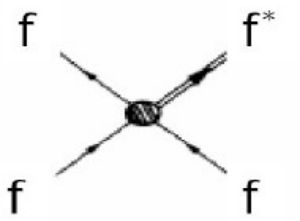
Λ: compositeness scale; f, f': weight factors



- Another approach: couplings of excited leptons to quark and leptons via Contact Interactions

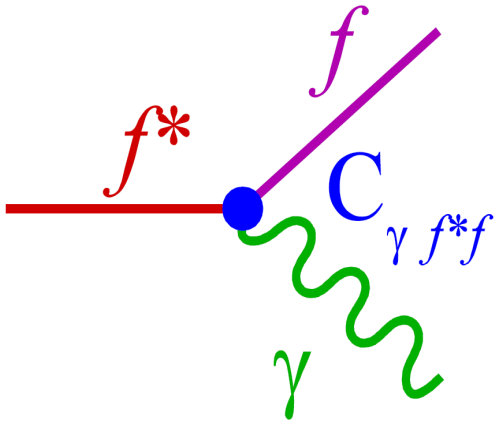
$$\mathcal{L} \alpha \frac{4\pi}{\Lambda^2} (\bar{e^*} \gamma^\mu e)(\bar{q} \gamma_\mu q)$$

- similar phenomena
- mainly differs from GM by a normalisation factor
- not considered in following results



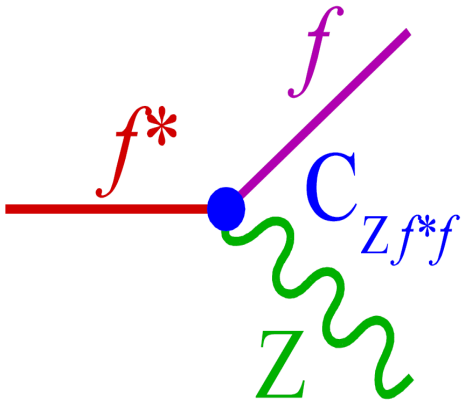
Gauge group weights: *f* & *f'*

- f*fγ vertex



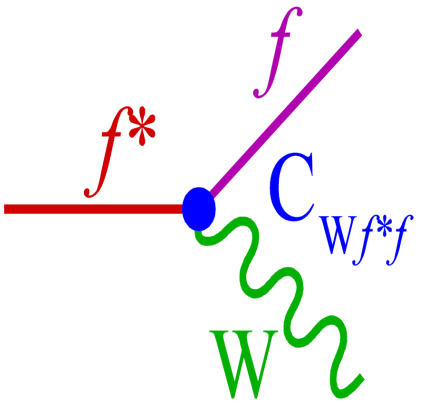
$$C_{\gamma f^* f} = \frac{1}{2}\left(f\, I_3 + f' \frac{Y}{2}\right)$$

- f*fZ vertex



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

- f*fW vertex



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

- I_3 : third component of isospin
- Y: hypercharge (Y=±1 for l*)
- θ_W: Weinberg angle

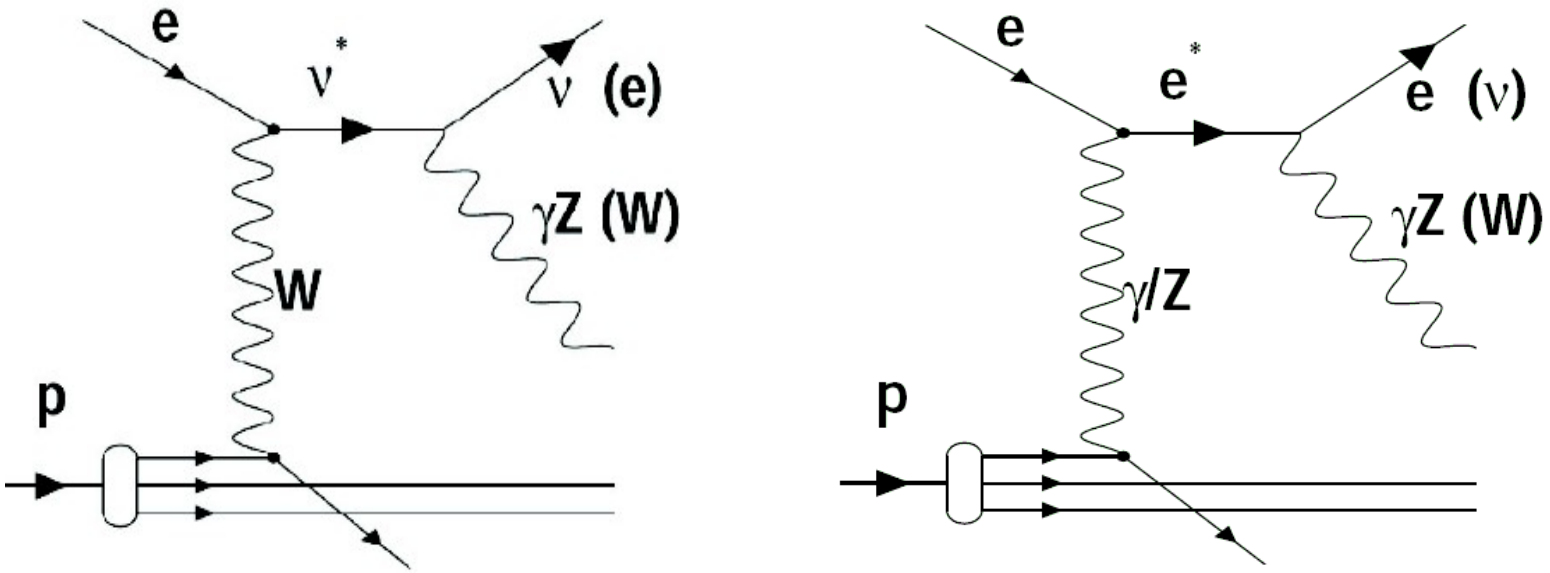
$$C_{\gamma\nu\nu*} = \frac{1}{4}(f - f') = 0|_{f=f'}$$

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

↳ The search for leptons de-excitations gives informations on compositeness coupling

Excited leptons in ep collision

- Production of excited leptons (e*, ν*) via t-channel γ(Z) or W exchange
- Leptons de-excitation by emission of γ, Z^0 or $W^{\pm}$
  - Then, more sub-channels to investigate due to Z and W various decays



↳ We have similar signatures for e* and ν*

Data samples

- Data samples taken by the H1 experiment used in this search for excited leptons

HERA periods/Collisions	$\mathscr{L}(pb^{-1})$	
HERA-I (e^-p)	14.2	published
HERA-I (e^+p)	66.6	published
HERA-II (e^-p)	170.1	new data set
HERA-II (e^+p)	184	new data set
Total	184.3 (e^-p)	→ Used to look for ν^*
	250.6 (e^+p)	
	434.9 $(e^\pm p)$	→ Used to look for e*

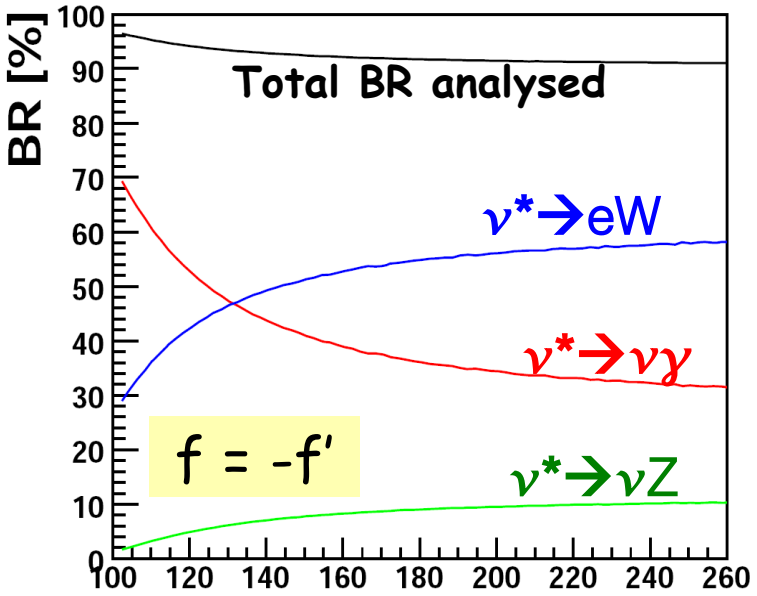
Note: for ν^*, $\sigma(e^-p)/\sigma(e^+p) \sim 100$
due to favourable valence u-quarks and helicity enhancement

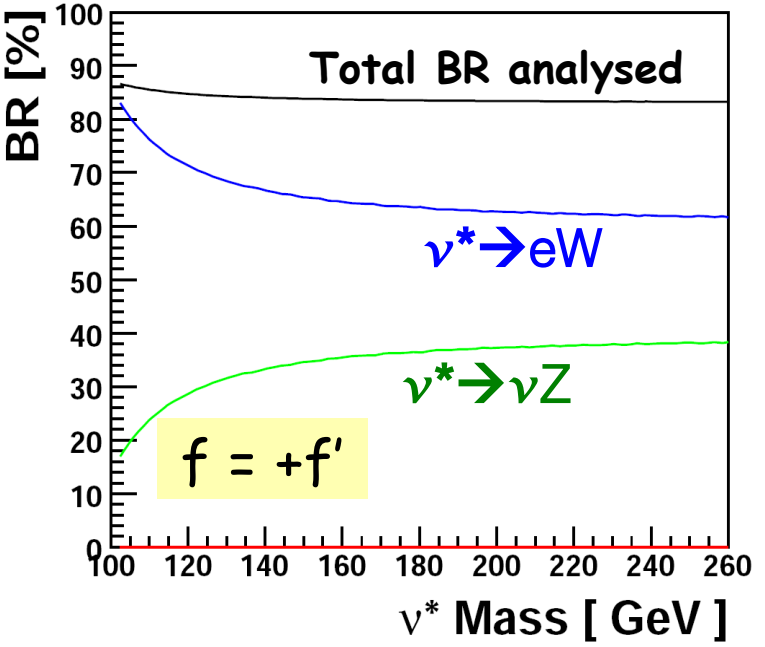
↳ Using full HERA I+II data set at $\sqrt{s}$ = 320 GeV

Excited neutrinos search

- Almost all ν^* decay topologies are investigated

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

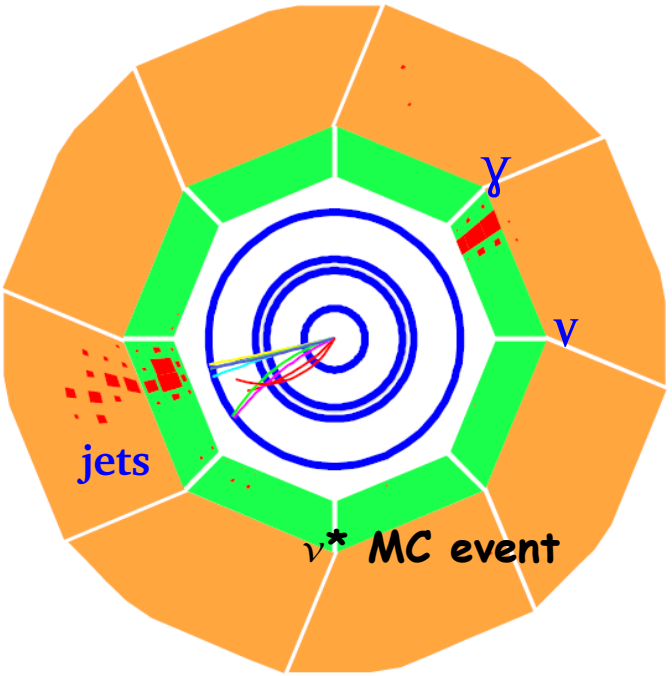




Search for ν^*: radiative decay

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

- Radiative CC DIS
  - Isolated electromagentic deposit
  - No track associated
  - $P^{miss}_T > 15$ GeV
  - Reduce main background (CC) :
    - $P^{\gamma}_T > 20$ GeV
    - E-Pz > 45 GeV or $P^{\gamma}_T > 40$ GeV



Search for ν^*: multi-jets decay

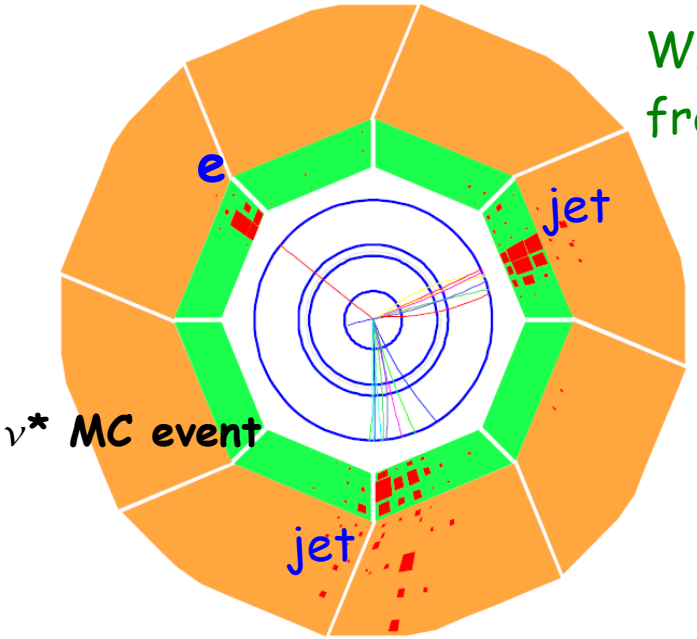
$\nu^* \rightarrow eW$

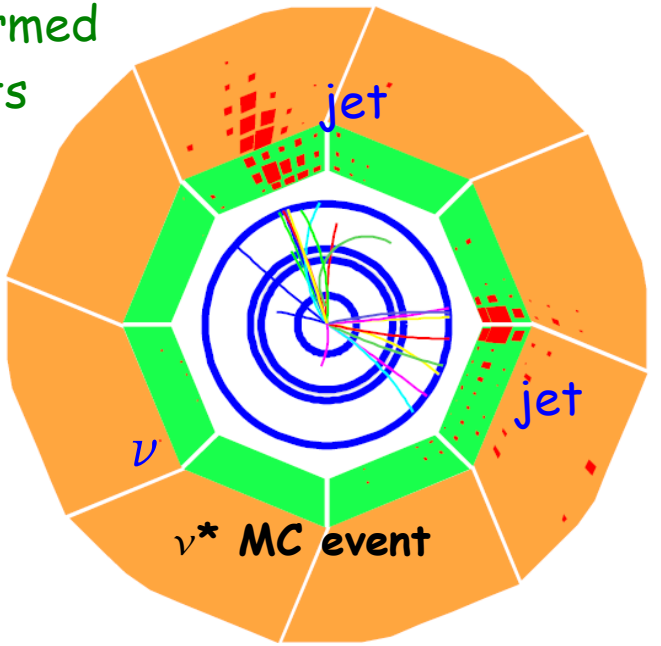
- NC DIS + 2jets
  - $P_T^{e} > 10$ GeV
  - $P_T^{jet1,2} > 20,15$ GeV
  - Reduce NC:
    - $Q^2_e > 2500$ if $P_t^{e} < 25$ GeV

$\nu^* \rightarrow \nu Z$

- CC DIS + 2jets
  - $P_T^{jet1,2} > 20,15$ GeV
  - $P_T^{miss} > 15$ GeV
  - Reduce CC, γP:
    - E-Pz> 25 GeV or $P_T^{miss} > 50$ GeV
    - Vap/Vp > 0.1

W/Z candidate is formed from 2 highest P_T jets



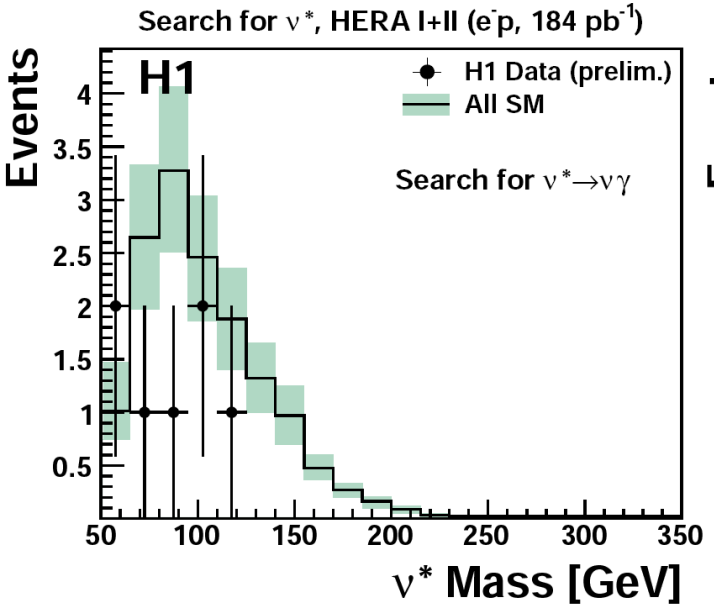


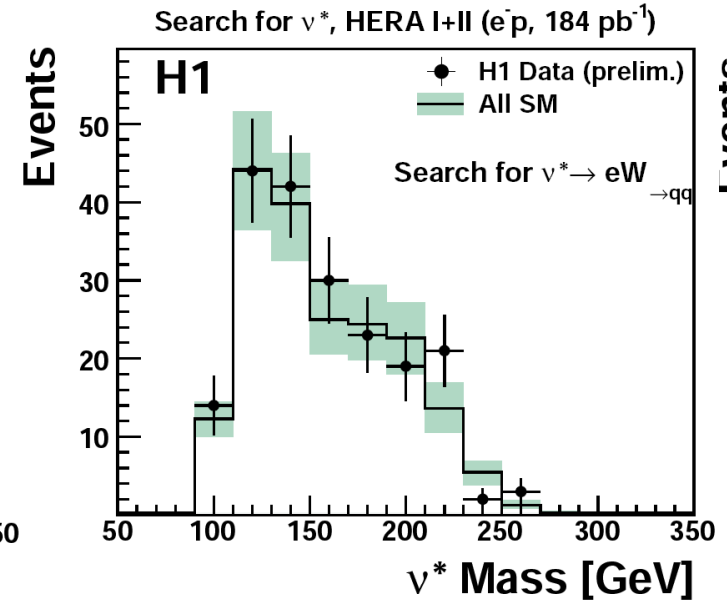
Results for ν^*

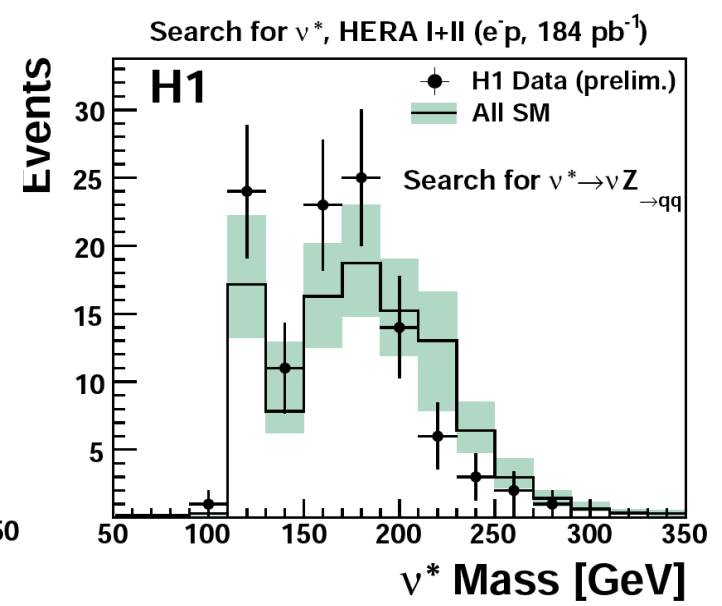
- The observed and expected numbers:

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

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





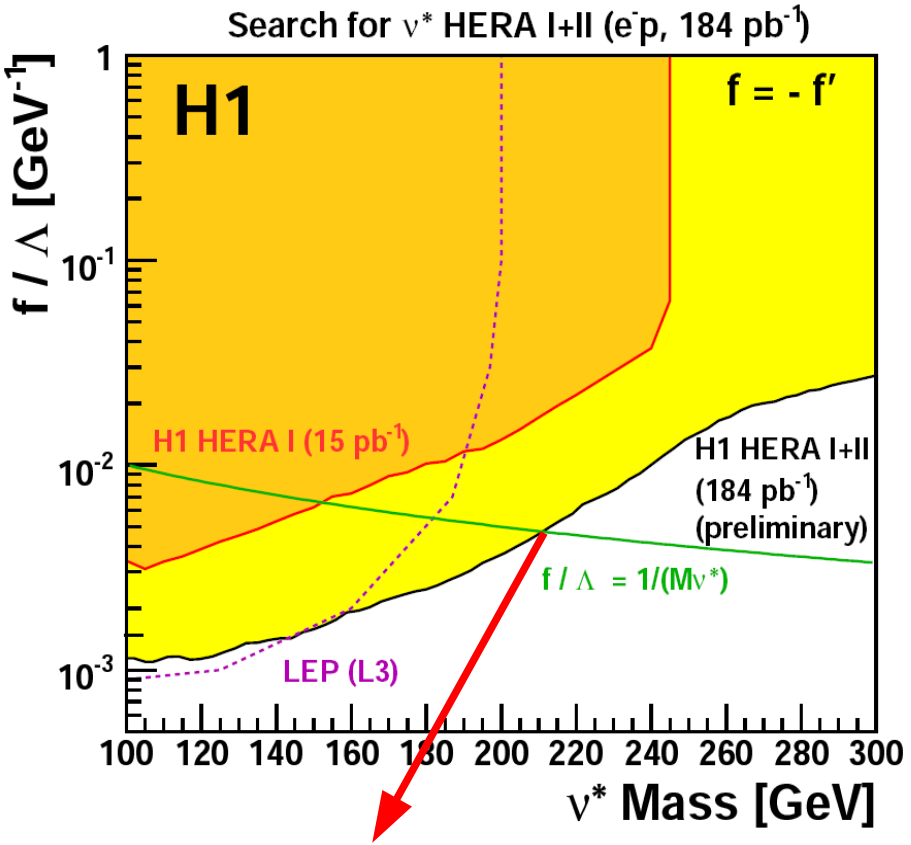


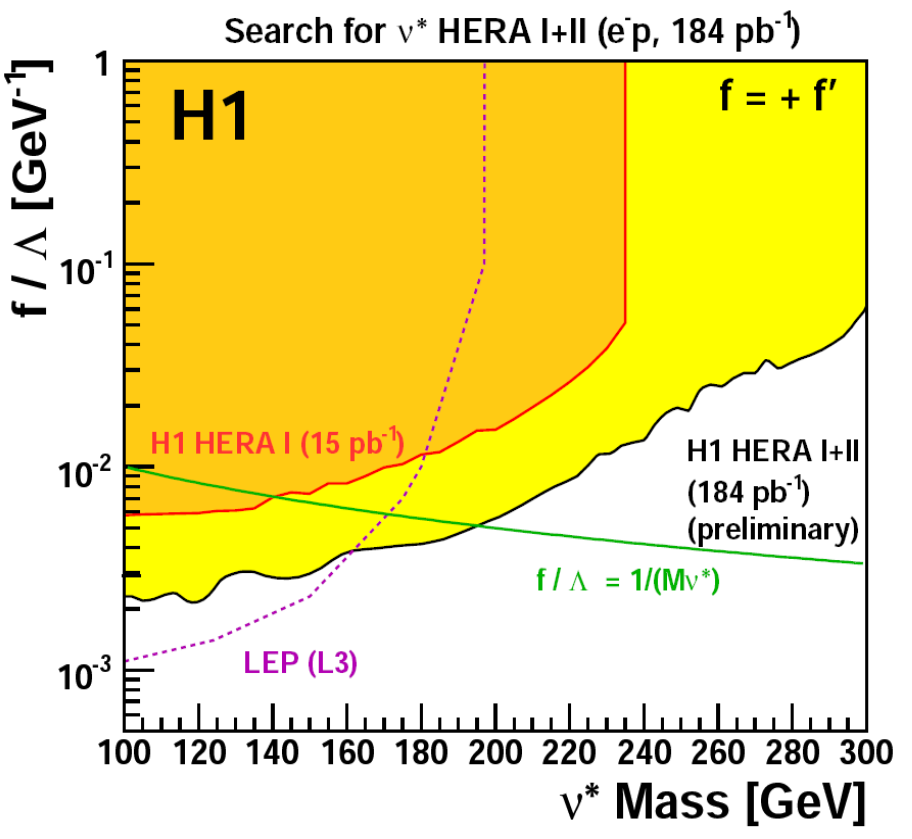
↳ In all channels: good agreement between data and SM prediction

↳ No significant deviation from the SM prediction => exclusion regions (f/Λ, M_{ν^*})

New domain explored

- 95% C.L. exclusion limits:





↳ For f = -f′ and $f/\Lambda = 1/M_{\nu^*}$: $M_{\nu^*} < 211$ GeV are excluded

↳ the new H1 limits greatly extend the previous searched domains at HERA

↳ better sensitivity at HERA for ν^* with masses beyond the LEP reach

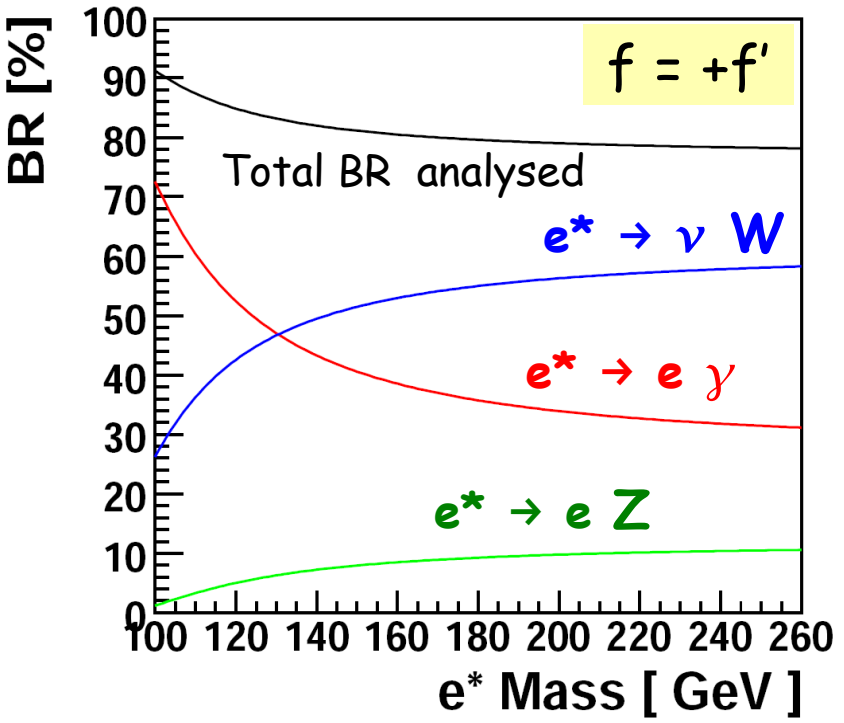
Excited electrons search

(Note: the leptonic decay W/Z not yet consider here)

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

- If f = -f' ☞ $C_{\gamma e^* e}$ = 0 : the cross section in this case is very small

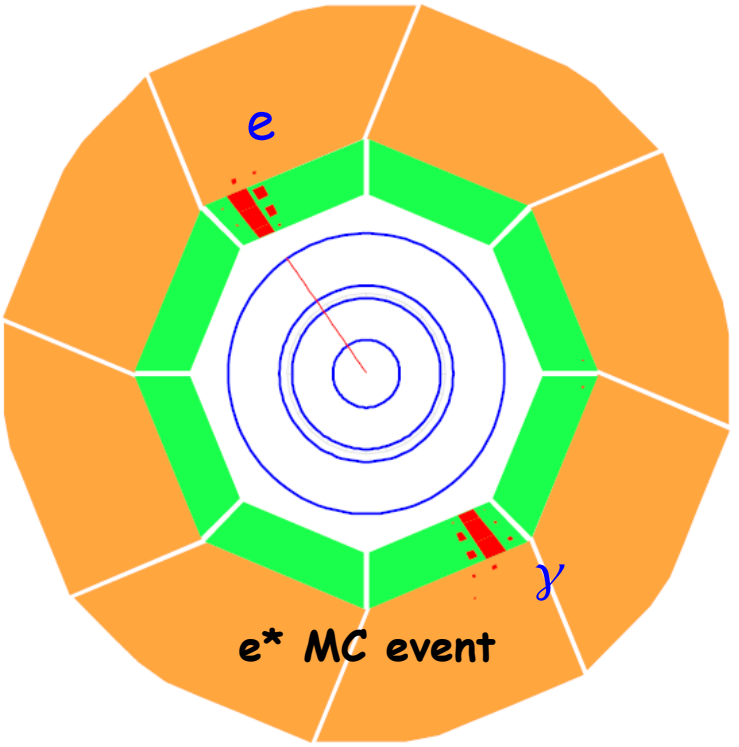
↳ Study only the case *f = +f'*



Search for e*: radiative decay

$e^* \rightarrow e\,\gamma$

- Radiative topology
  - At least two isolated em. deposits
    - $P^{e,\gamma}_T > 20,15$ GeV
    - No track associated to 2nd em. cluster
  - Reduce Comptons :
    - $P^e_T + P^\gamma_T > 75$ GeV
    - $E^e + E^\gamma > 100$ GeV



Search for e*: multi-jets decay

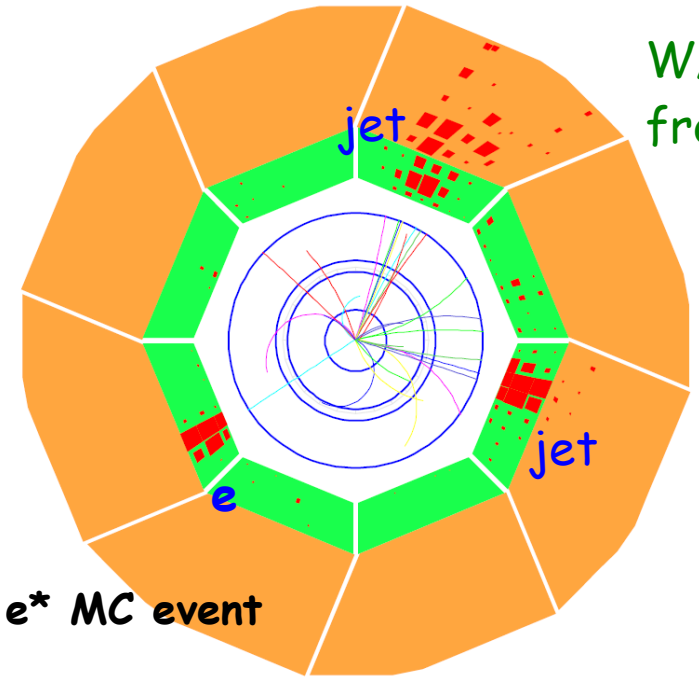
$e^* \rightarrow e\,Z$

- NC DIS + 2jets
- $P^e_T > 20$ GeV
- $P_T^{jet1,2} > 20,15$ GeV
- Reduce NC:
  - $M_{jj} > M_Z - 15$ GeV if $P^e_T < 65$ GeV
  - $\theta^{jet1} < 80$ degrees

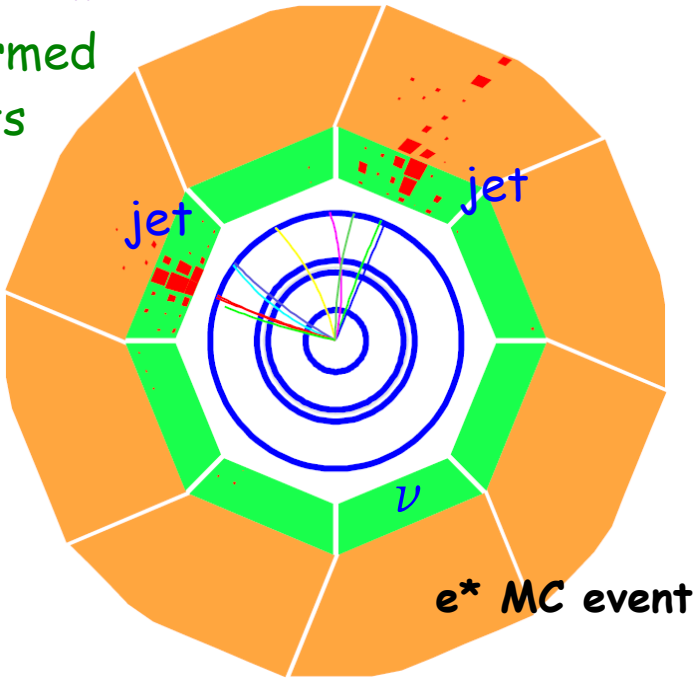
$e^* \rightarrow \nu\,W$

- CC DIS + 2jets
- $P_T^{jet1,2} > 20,15$ GeV
- $P_T^{miss} > 15$ GeV
- Reduce CC, γP:
  - Vap/Vp < 0.3
  - $M_{jj} > M_W - 15$ GeV if $E^{miss} < 65$ GeV

W/Z candidate is formed from 2 highest P_T jets



e* MC event

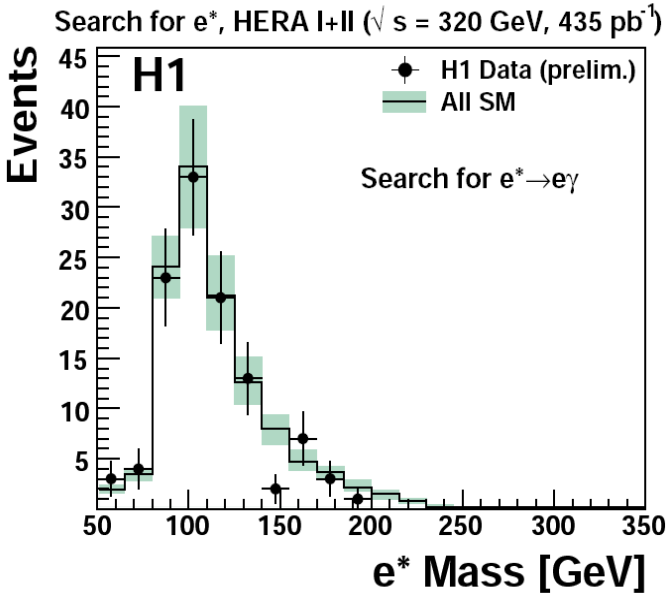


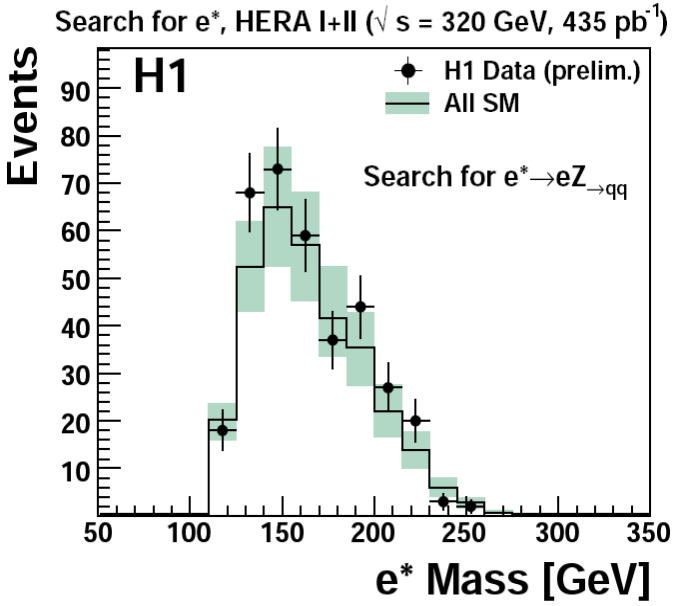
e* MC event

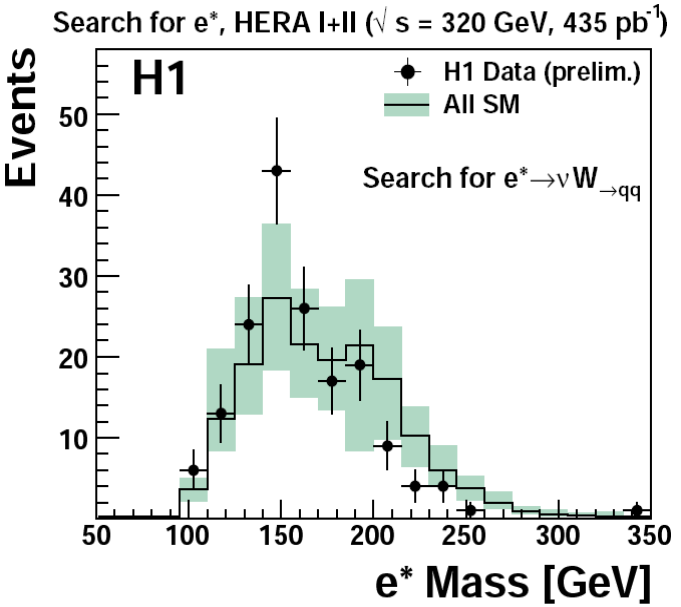
Results summary for e*

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

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





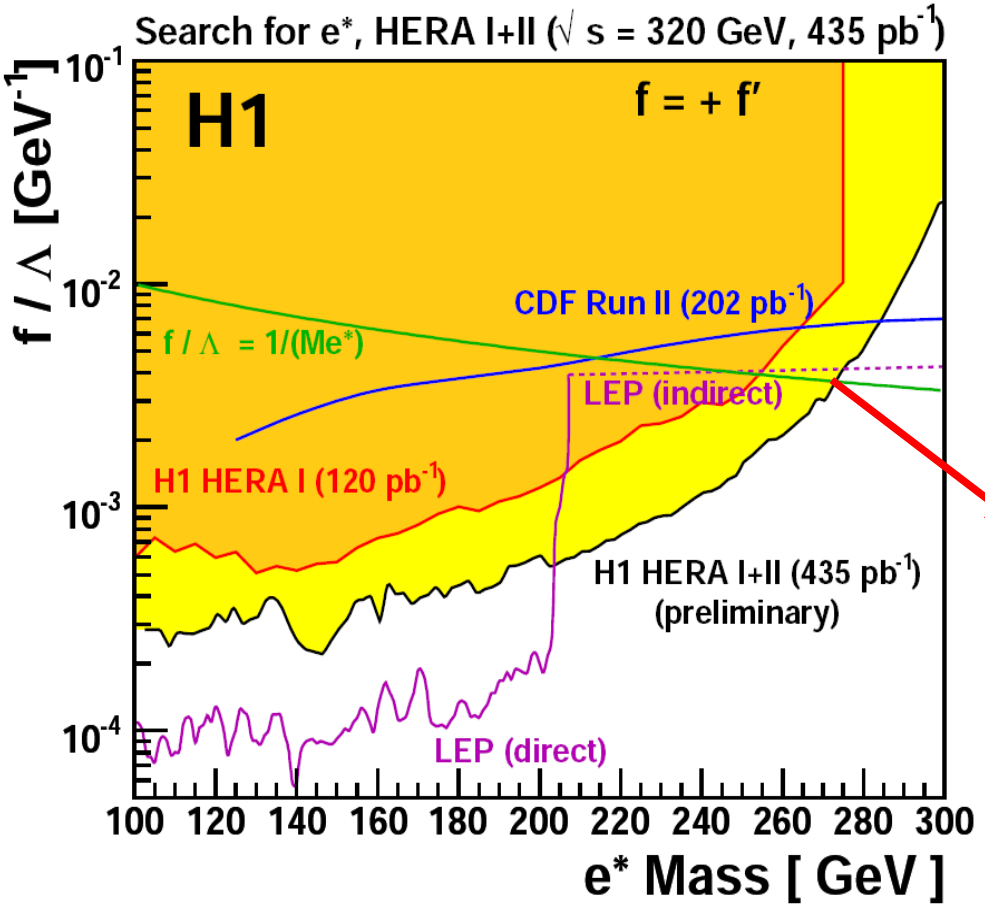


↳ In all channels: good agreement between data and SM prediction

↳No significant deviation from the SM prediction => exclusion regions (f/Λ, M_{e^*})

New domain explored for e*

- 95% C.L. exclusion limits:



↳ New domain explored.
The combined limit is dominated by the limit of the decay e*->eγ

↳ if $f/\Lambda = 1/M_{e^*}$: $M_{e^*} < 273$ GeV are excluded

↳ At high mass: new H1 limit are more stringent than present LEP or Tevatron results

Conclusion

- The search for excited leptons (e*, ν*) in the full $e^{\pm}p$ HERA I+II data collected by the H1 at $\sqrt{s}$ = 320 GeV has been presented

  - Almost all decay channels investigated
  - In all channels: Data and SM predictions in good agreement

- No evidence of excited leptons has been found

  → Upper limits at 95% C.L. are derived

  - For ν*: M_{ν^*} < 211 GeV are excluded (f=-f' & $f/\Lambda=1/M_{\nu^*}$)
  - For e*: M_{e^*} < 273 GeV are excluded (f=+f' & $f/\Lambda=1/M_{e^*}$)

  - Presently the most stringent world limits on high masses e* and ν*