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Search for excited fermions in ep collisions at HERA

Ainas Weber
ZEUS Collaboration
University of Bonn

on behalf of

H1 & ZEUS

- Compositeness
- Excited fermions at HERA
- H1 and ZEUS searches for

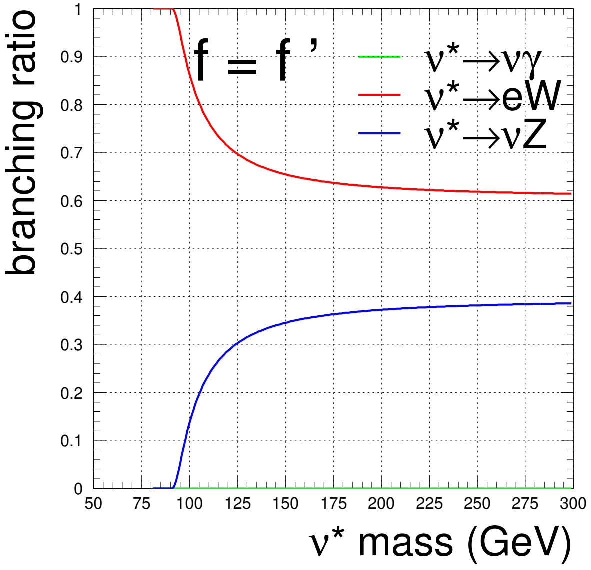
$$\begin{array}{ll} \boldsymbol{e^*} \rightarrow e\gamma & \boldsymbol{\nu^*} \rightarrow \nu\gamma \\ \quad \rightarrow eZ \rightarrow eq\bar{q} & \quad \rightarrow \nu Z \rightarrow \nu q\bar{q} \\ \quad \rightarrow \nu W \rightarrow \nu q\bar{q}' & \quad \rightarrow eW \rightarrow eq\bar{q}' \end{array}$$

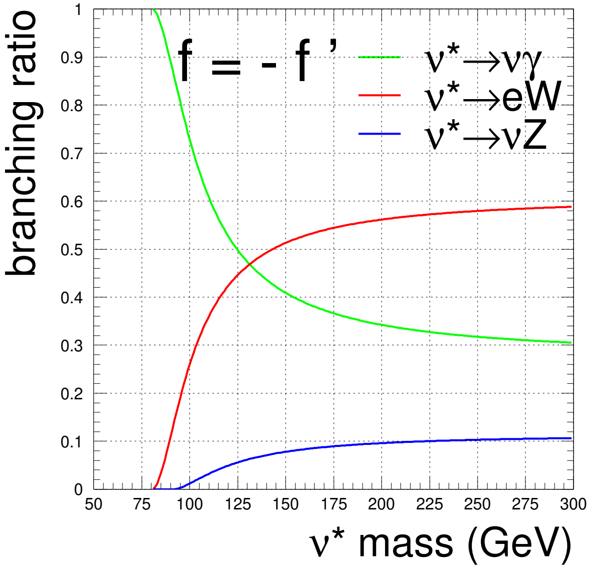
Compositeness and excited fermions

- **Substructure $\Leftrightarrow$ heavy excited states** which couple to fermions and gauge bosons
- Theoretical basis for experimental searches: **phenomenological compositeness model** by **Hagiwara** et al. (1983)
- **Effective Lagrangian**, transitions $F \leftrightarrow F^*$:

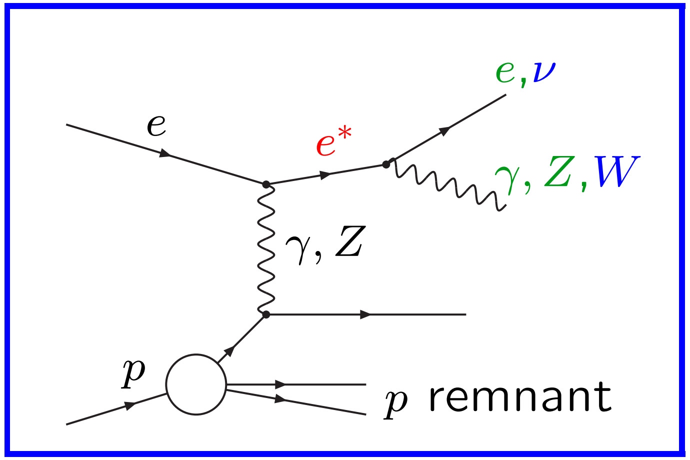
$$\mathcal{L} = \frac{1}{\Lambda}\bar{F}^*_R\sigma^{\mu\nu}\left[g f\frac{\vec{\tau}}{2}\partial_\mu\vec{W}_\nu + g' f'\frac{Y}{2}\partial_\mu B_\nu\right]F_L + \text{h.c.}$$

- **Energy scale** $\Lambda \sim \mathcal{O}(\text{TeV})$
  Weight factors f, f'
- Assumption: $|f| = |f'|$
  $\rightarrow$ branching ratios and production cross-sections



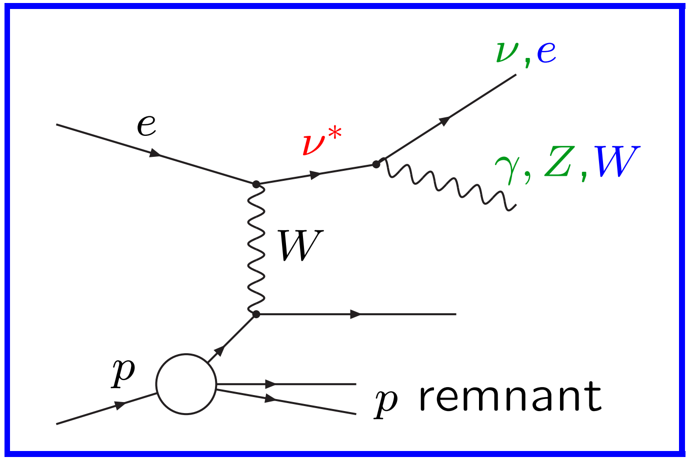


Direct production of excited leptons in ep collisions at HERA



- e^*: production cross-section is independent of lepton charge-sign
- ν^*: due to W exchange, cross section is substantially higher for e^-p than for e^+p

  → e^-p preferred for ν^* search



Data recorded by H1 and ZEUS:

		$\sqrt{s}$[GeV]	$\mathcal{L}$/exp.
1994–1997	e^+p	300	$\approx 40\,\text{pb}^{-1}$
1998–1999	e^-p	318	$\approx 16\,\text{pb}^{-1}$
1999–2000	e^+p	318	$\approx 66\,\text{pb}^{-1}$

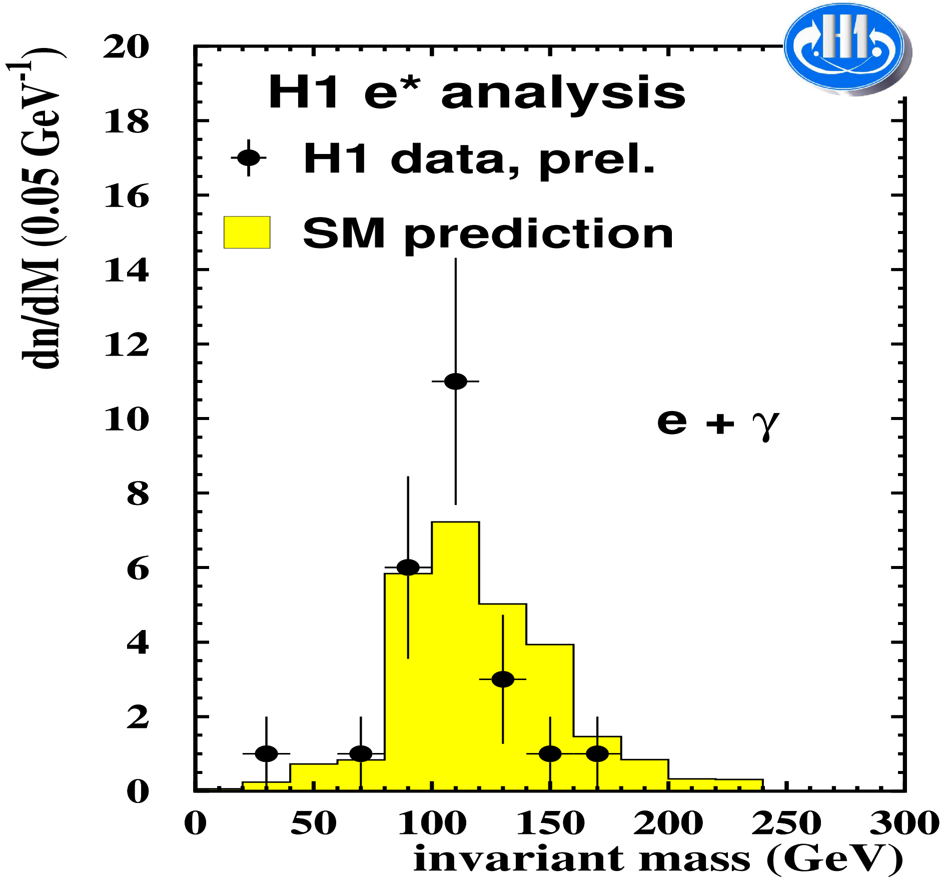
Decay channels analysed

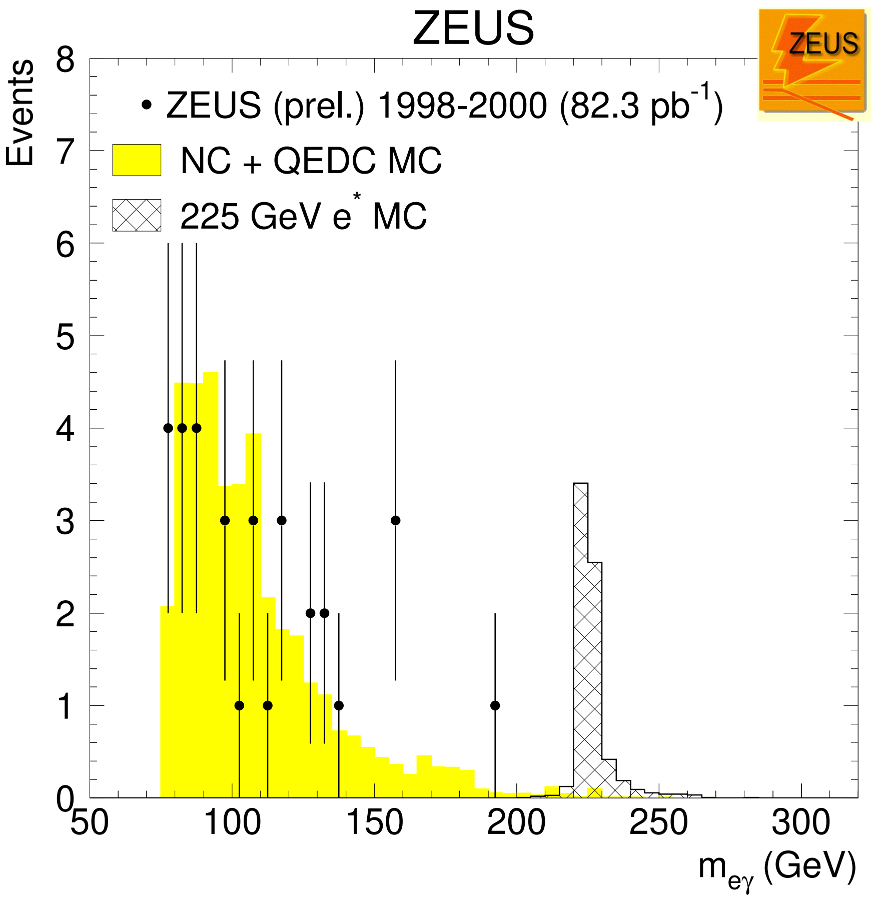
***NC*-like final state:**	
high-energy electron	SM backgrounds:
• $\nu^* \longrightarrow eW \longrightarrow eq\bar{q}'$ • $e^* \longrightarrow eZ \longrightarrow eq\bar{q}$	NC DIS
• $e^* \longrightarrow e\gamma$	NC DIS, QED-Compton (WAB)

***CC*-like final state:**	
final-state $\nu \Rightarrow \not{P}_T$	SM backgrounds:
• $\nu^* \longrightarrow \nu Z \longrightarrow \nu q\bar{q}$ • $e^* \longrightarrow \nu W \longrightarrow \nu q\bar{q}'$	CC DIS, PHP
• $\nu^* \longrightarrow \nu\gamma$	CC DIS

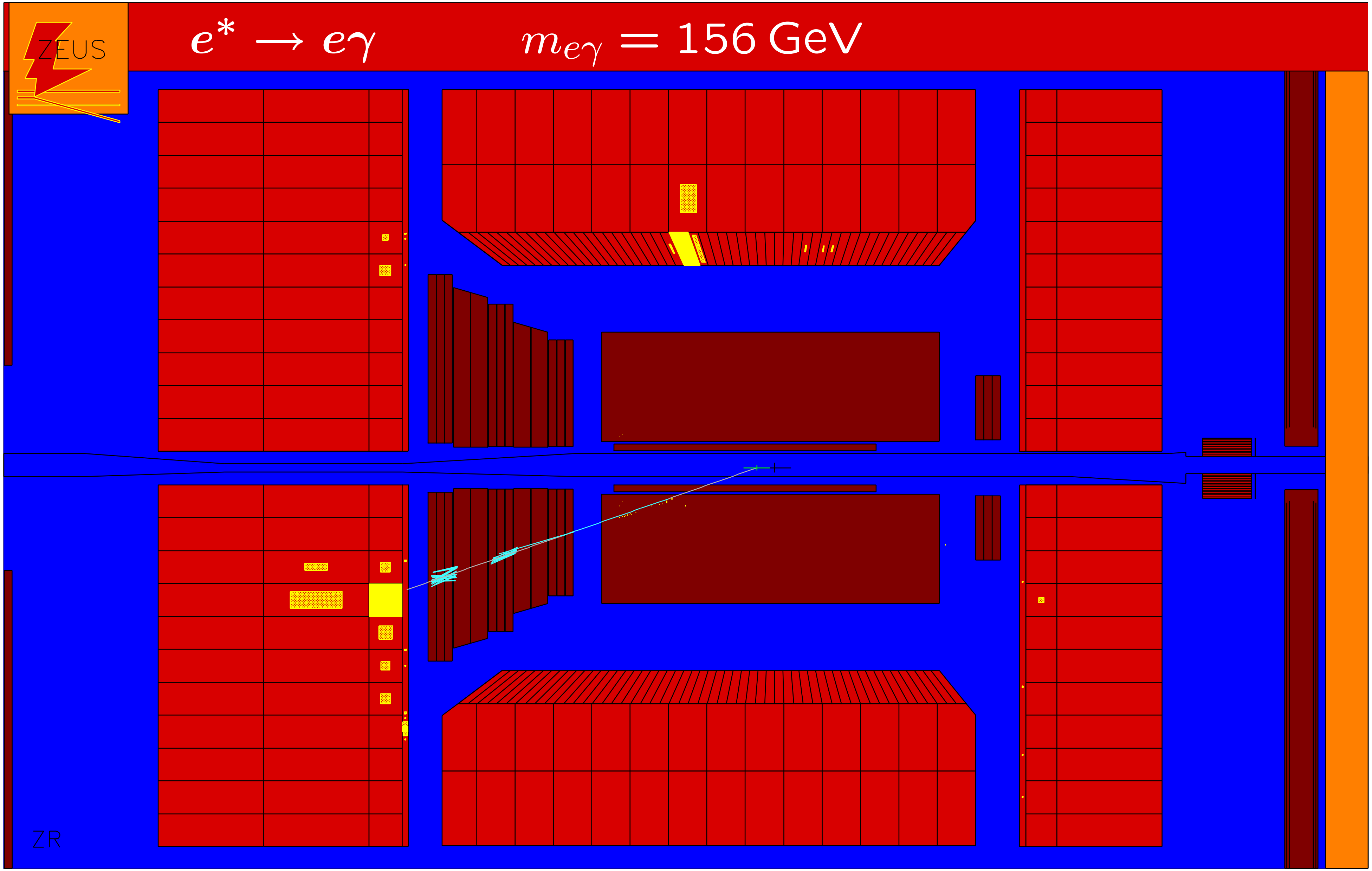
$e^* \longrightarrow e\gamma$: mass spectra

- two isolated electromagnetic clusters with large E_T



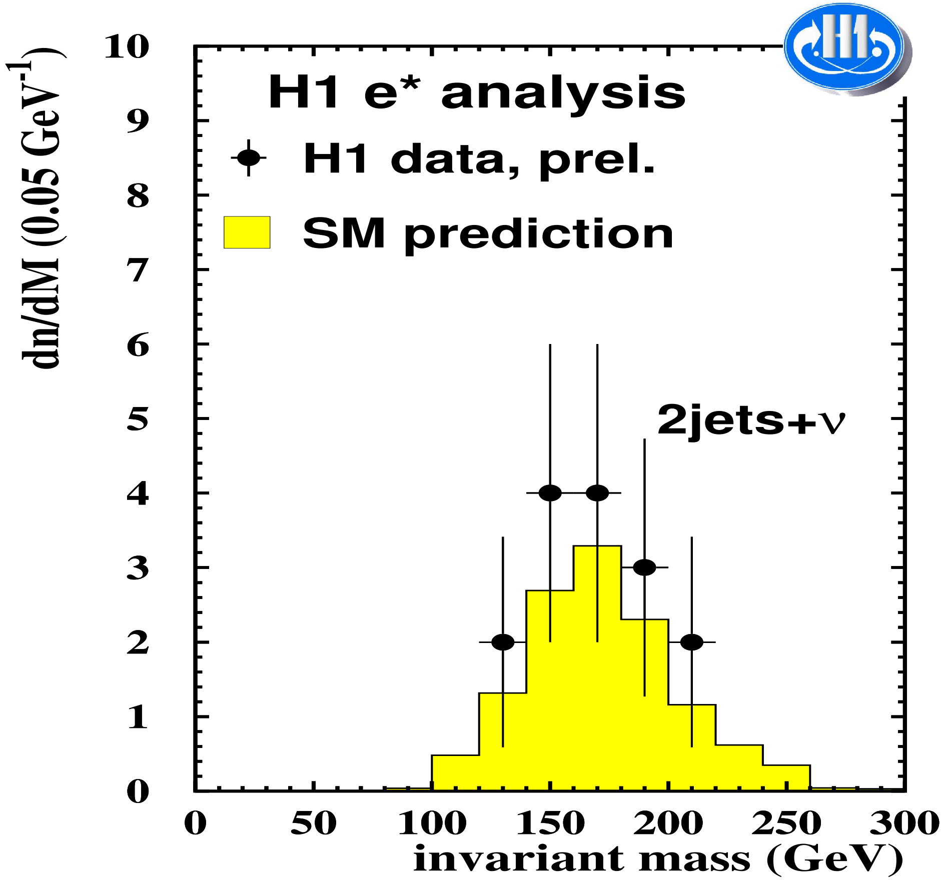


$e^* \rightarrow e\gamma$ $m_{e\gamma} = 156$ GeV

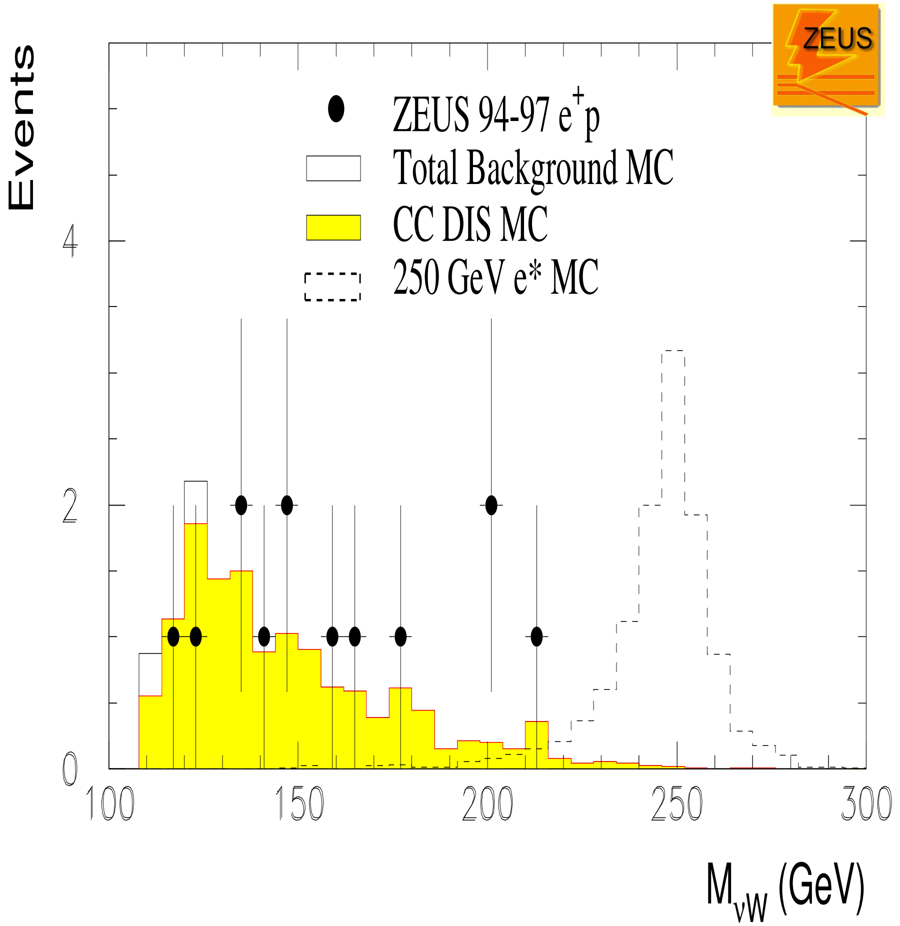


$e^* \to \nu W \to \nu q\bar{q}'$: mass spectra

- at least two jets with large E_T

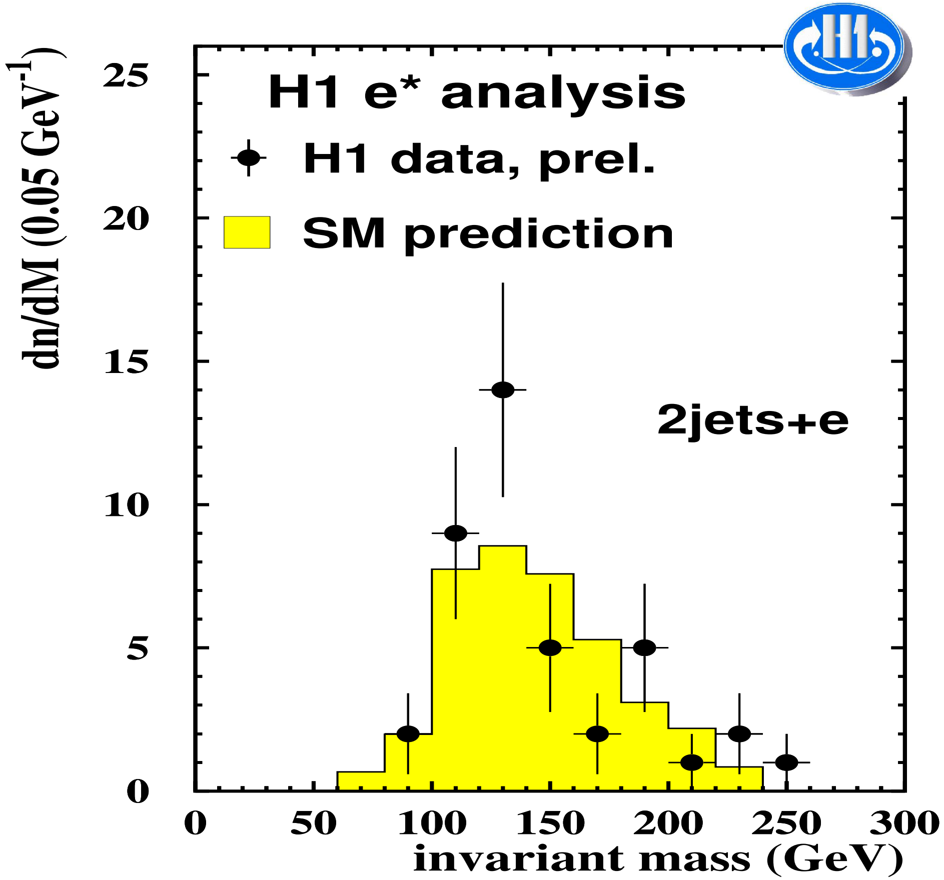


- large $\not{P}_T$

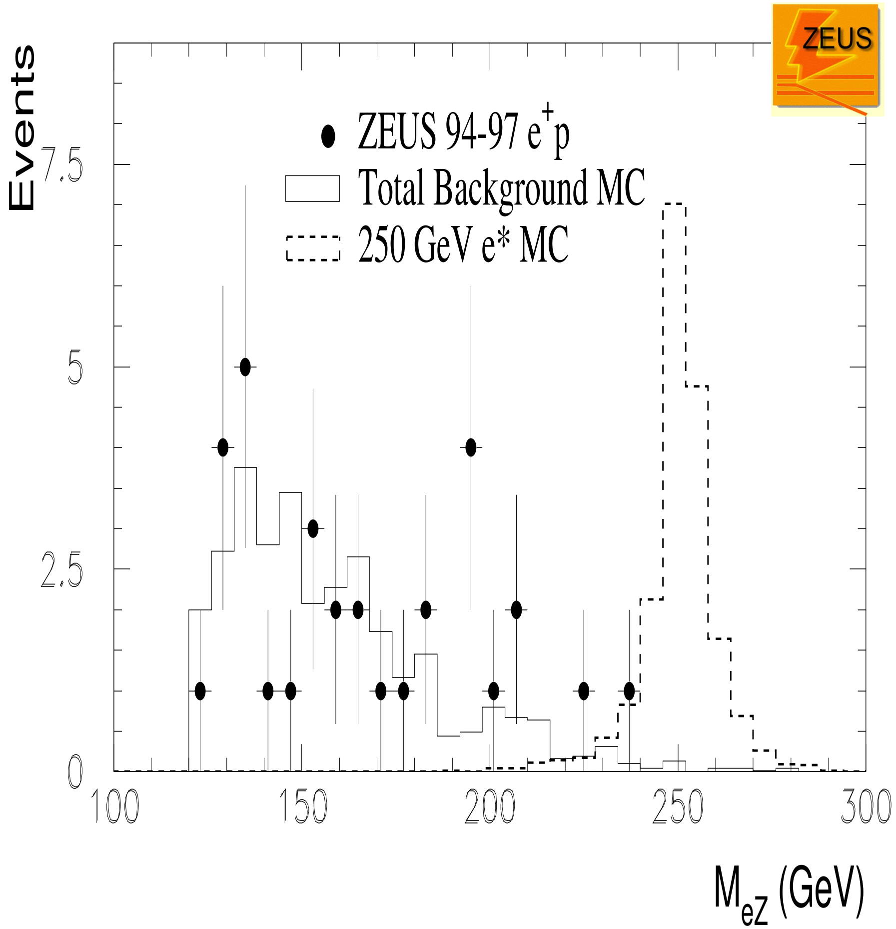


$e^* \longrightarrow eZ \longrightarrow eq\bar{q}$: mass spectra

- at least two jets with large E_T



- high-energy electron



Excited neutrinos

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

- high-energy photon in the forward direction
- large $\not{p}_T$

$\nu^* \rightarrow eq\bar{q}'$ & $\nu^* \rightarrow \nu q\bar{q}$:

- similar final-state topologies as in the respective e^* channels

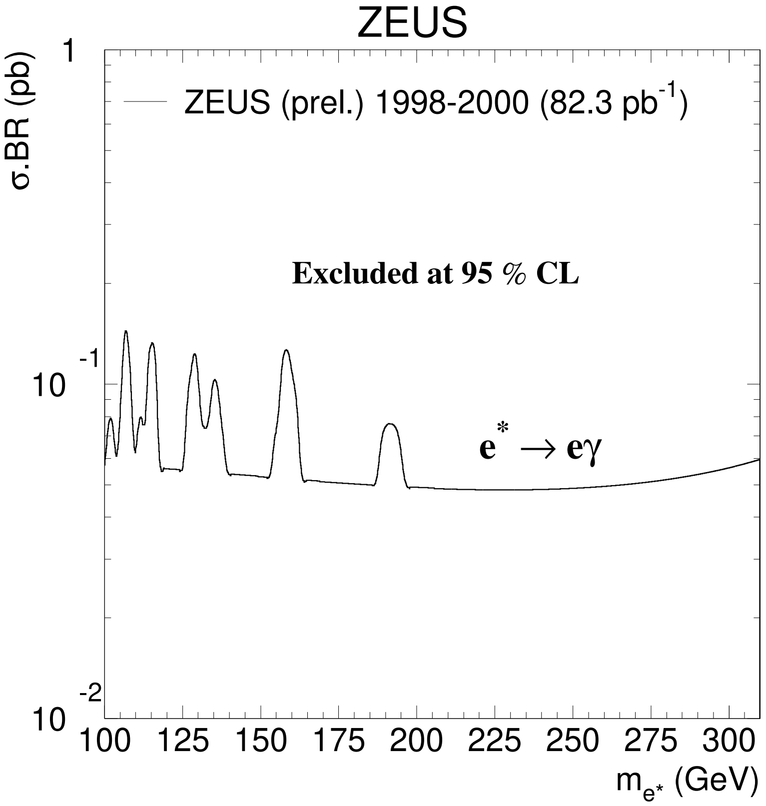
Search results: event numbers

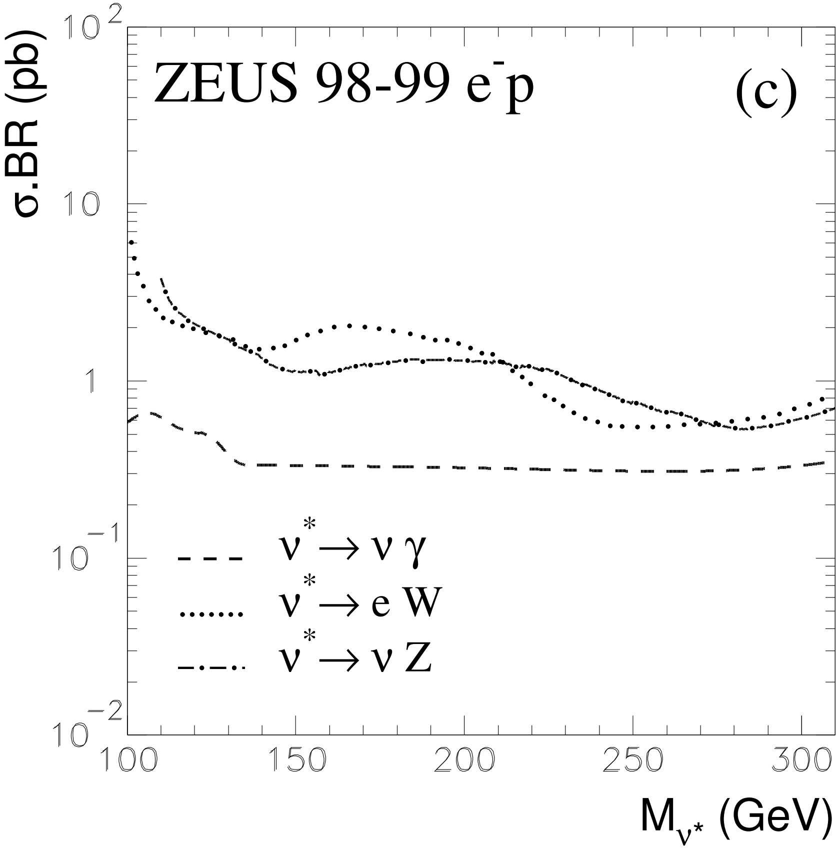
		H1		ZEUS	
decay	sample	data	total bg.	data	total bg.
$e^* \to e\gamma$	94–97	8	7.2±1.0±0.1	18	20.1±1.2
	98–99	4	4.0±0.7±0.2	10	8.7
	99–00	12	15.6±1.7±0.4	22	30.8
$e^* \to \nu q\bar{q}'$	94–97	6	7.1±2.1±2.8	13	13.9±1.1
	98–99	4	5.6±0.4±1.2		
	99–00	31	25.3±1.9±5.5		
$e^* \to eq\bar{q}$	94–97	2	2.4±0.2±0.7	32	32.9±1.1
	98–99	5	3.9±0.2±0.7		
	99–00	8	6.1±0.4±1.5		
$\nu^* \to \nu\gamma$	98–99	2	3.0±0.2±1.2	2	1.5±0.2
$\nu^* \to eq\bar{q}'$	98–99	6	7.0±0.6±1.4	20	15.0±1.3
$\nu^* \to \nu q\bar{q}$	98–99	1	3.7±0.2±0.9	16	13.5±0.6

Good agreement between data and SM background ⇒ exclusion limits

Upper limits on $\sigma \times \mathrm{BR}$

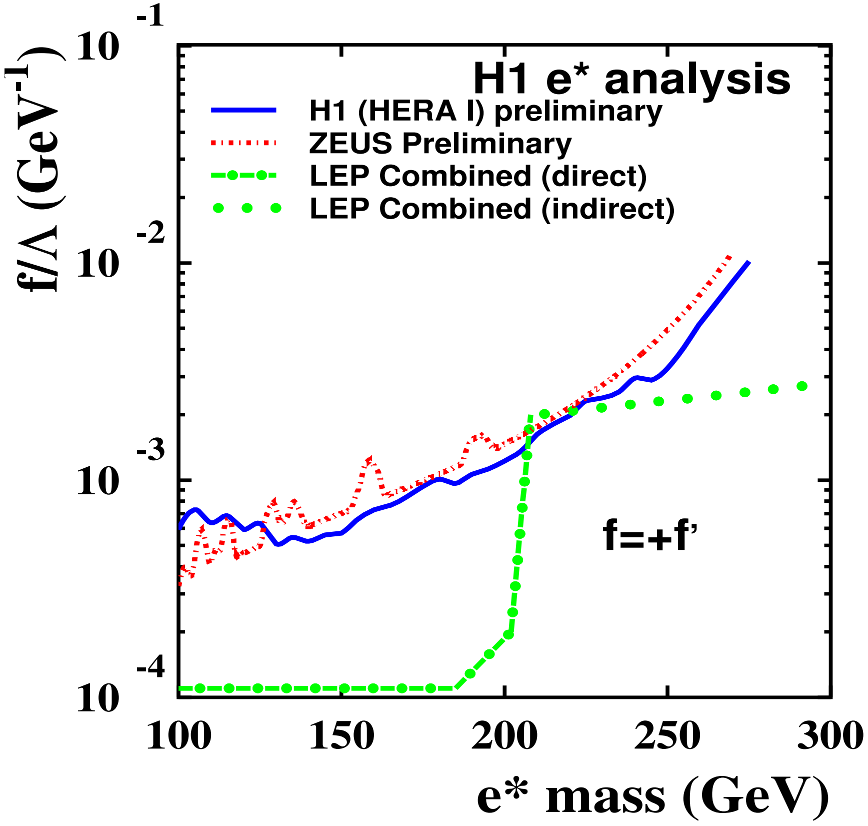
- 95 % confidence level; area above curves is excluded
- limits are model independent, only efficiency from signal MC
- limits for a narrow resonance

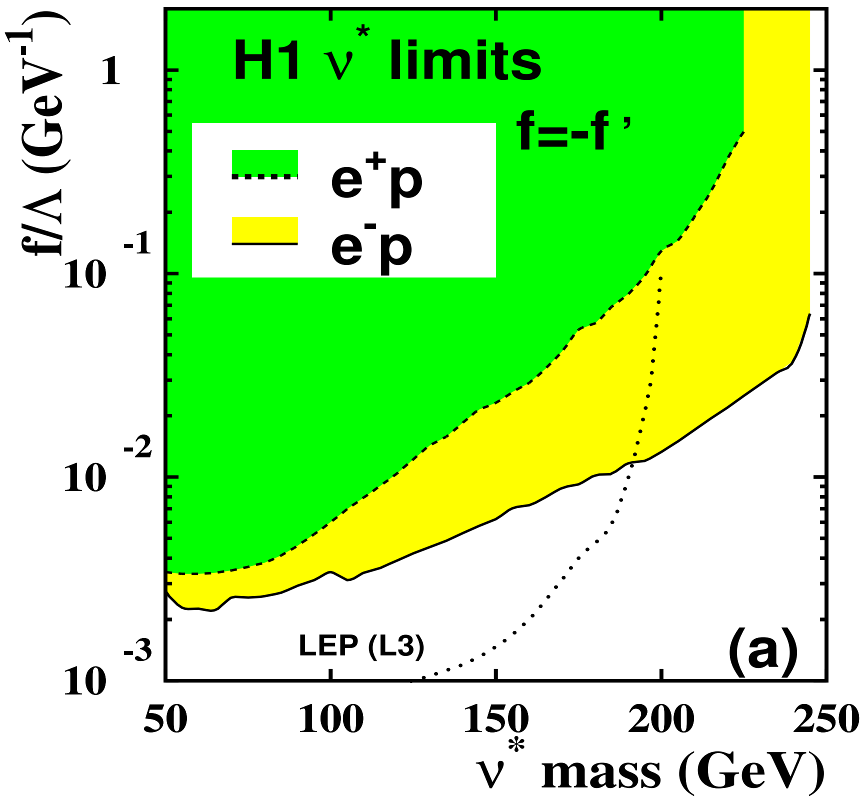




Upper limits on f/Λ (1)

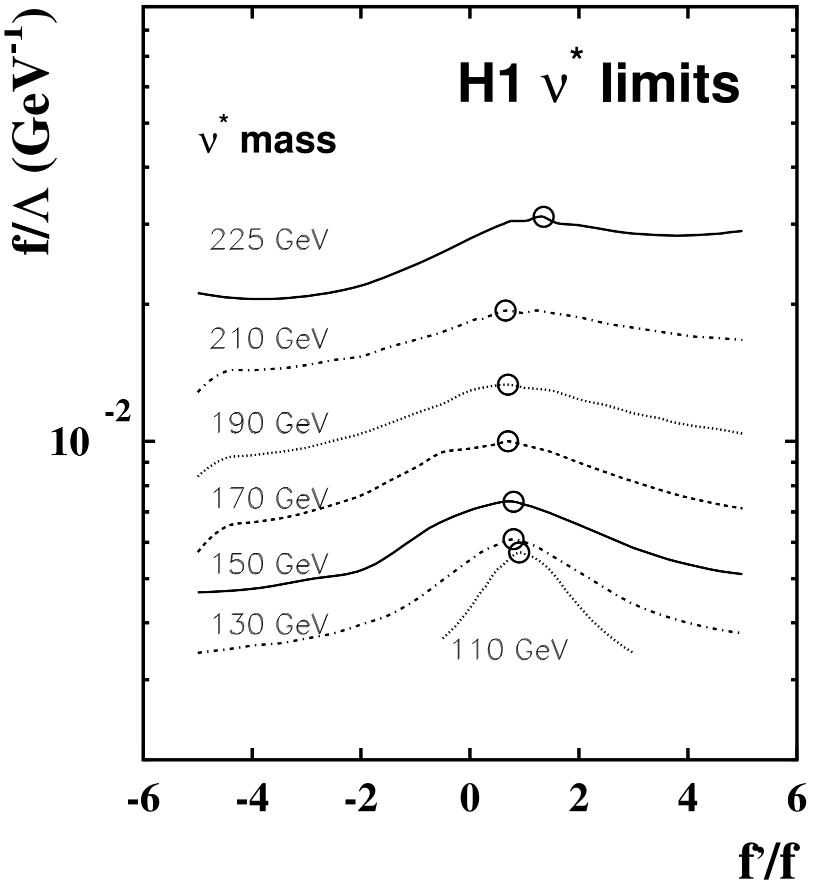
- 95 % confidence level; area above curves is excluded
- limits are model specific (Hagiwara)

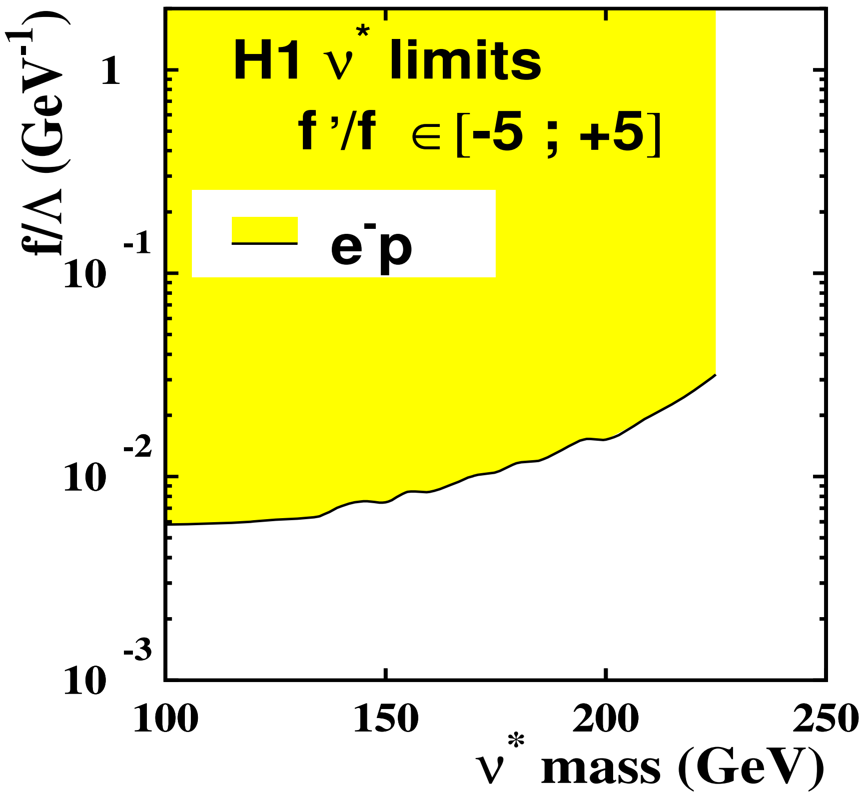




Upper limits on f/Λ (2)

- H1: limits independent of f'/f





Summary and outlook

- **Compositeness** hypothesis: fermion substructure ↔ **heavy excited states**
- **Direct searches** for resonantly produced $\boldsymbol{e^*}$, $\boldsymbol{\nu^*}$ and $\boldsymbol{q^*}$ in ep collisions at HERA
- **Decay channels** recently considered by **H1** and **ZEUS**:

$e^* \to e\gamma$	$\nu^* \to \nu\gamma$
$e^* \to eZ \to eq\bar{q}$	$\nu^* \to \nu Z \to \nu q\bar{q}$
$e^* \to \nu W \to \nu q\bar{q}'$	$\nu^* \to eW \to eq\bar{q}'$

- Complete **HERA I** data analysed
- **No evidence** for any excited fermion found
- **Upper limits** at 95 % C.L. on $\sigma \times$ BR and f/Λ; competitive with LEP results; HERA sets most stringent ν^* limits for high-mass region
- **Future HERA running:**
  increased lumi allows to access higher masses for f/Λ limits;
  ν^* search would benefit significantly from additional e^-p data