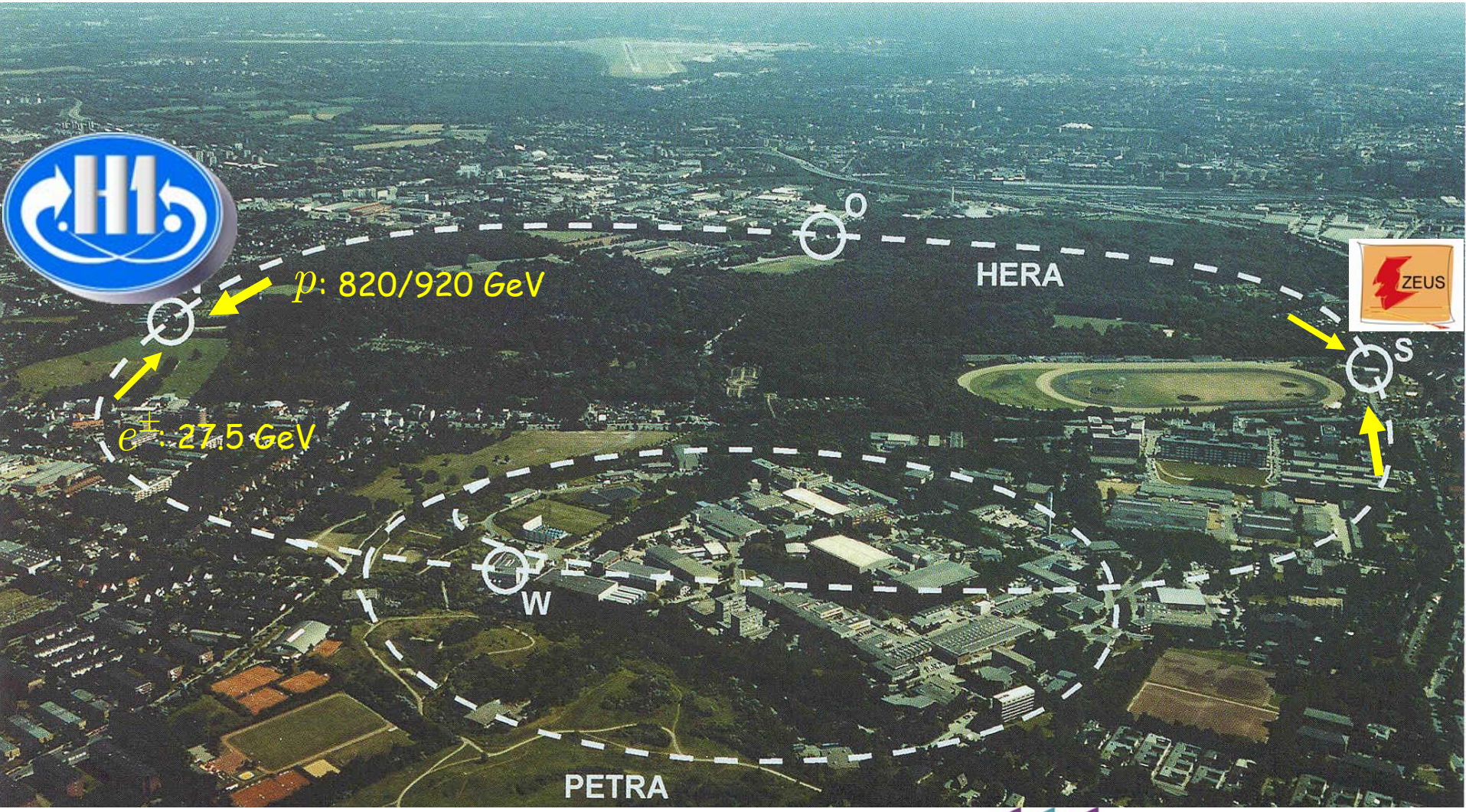
Searches for Excited Fermions at HERA

-- Final Results from H1

Z. Zhang (LAL, Orsay) on behalf of the H1 Collaboration



Introduction

- **HERA:**
  - Unique $e^{\pm}p$ collider of the world (1992-2007)
  - High c.m. energy up to 320GeV for direct searches
  - Integrated luminosity/experiment: ~0.5 fb^{-1}

- **Excited fermions (ν^*, e^* and q^*)**

  Very actively searched for at HERA (& elsewhere):

  8 (H1) + 4 (ZEUS) publications

  of which 3 from H1 based on full HERA data

  ➔ subject of this talk

Motivation & the Model

- 3 family & mass hierarchy ←→ Composite Model of fermions

Excited fermions

- The effective Lagrangian:

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

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

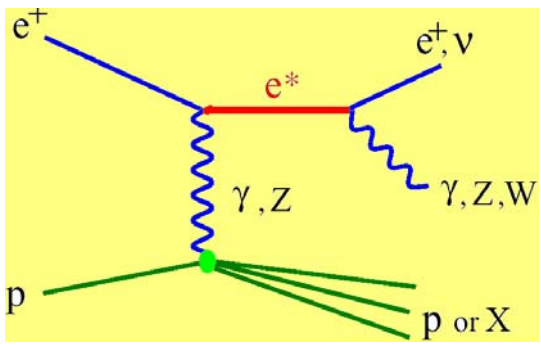
Λ: Compositeness scale

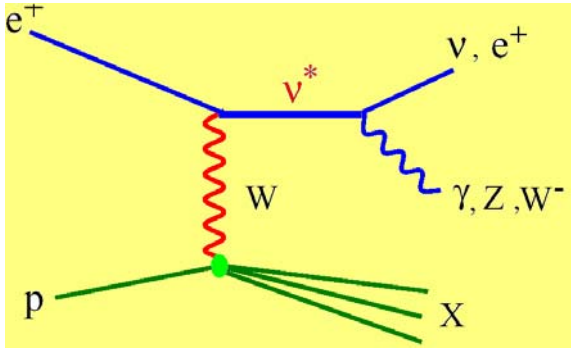
$f,\ f',\ f_s$: relative strength to Z/W, γ, g

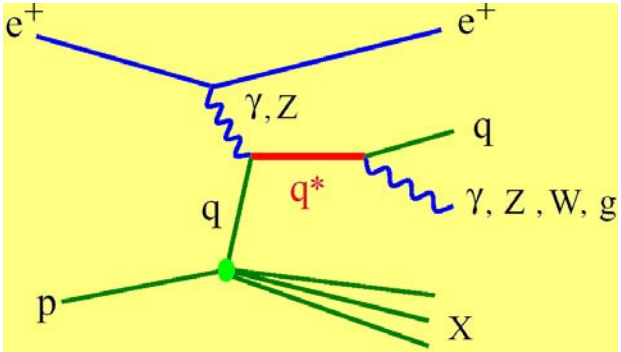
Hagiwara et al., Z. Phys. C 29 (1985) 115; Boudjema et al., Z. Phys. C 57 (1993) 425

Productions and Decays

Excited fermions of 1st generation: singly produced at HERA







Decays to standard fermions and gauge bosons

with $Z \rightarrow ee, \mu\mu, qq$, and $W \rightarrow e\nu_e, \mu\nu_\mu, qq'$

➔ Experimental signature:

isolated lepton(s), γ, missing energy + jets

Excited Neutrinos

H1 Collab., Phys. Lett. B 663 (2008) 382

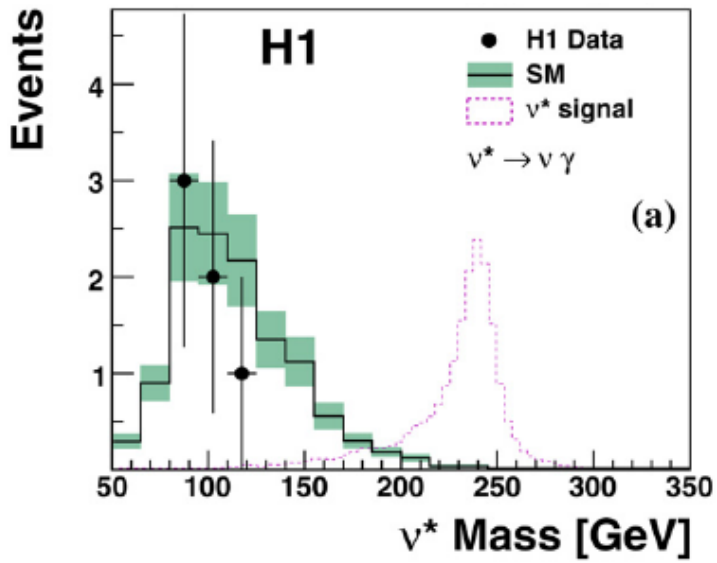
- **Use all HERA-2 e^-p data (184 pb^{-1})**

  (cross section much larger than in e^+p data)

- **Model Assumption:**

  $f=-f'$ or $f=+f'$ (insensitive to f_s)

  ~90%, 85% decay modes investigated



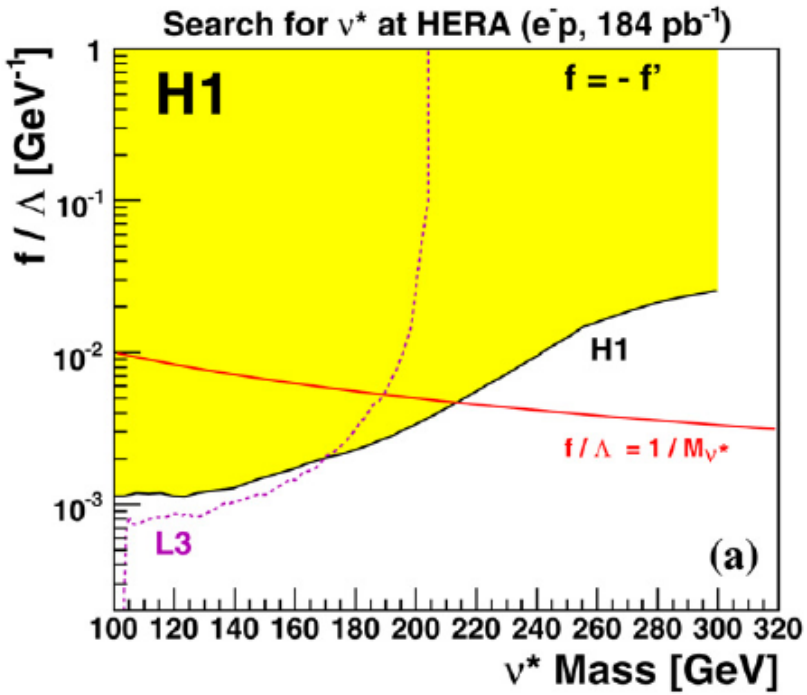
Channel	Data	SM	Signal efficiency [%]
$\nu^* \to \nu\gamma$	7	12.3 ± 3.0	50–55
$\nu^* \to eW \to eq\bar{q}$	220	223 ± 47	40–65
$\nu^* \to eW \to e\nu\mu$	0	0.40 ± 0.05	35
$\nu^* \to eW \to e\nu e$	0	0.7 ± 0.1	45
$\nu^* \to \nu Z \to \nu q\bar{q}$	89	95 ± 21	25–55
$\nu^* \to \nu Z \to \nu ee$	0	0.19 ± 0.05	45

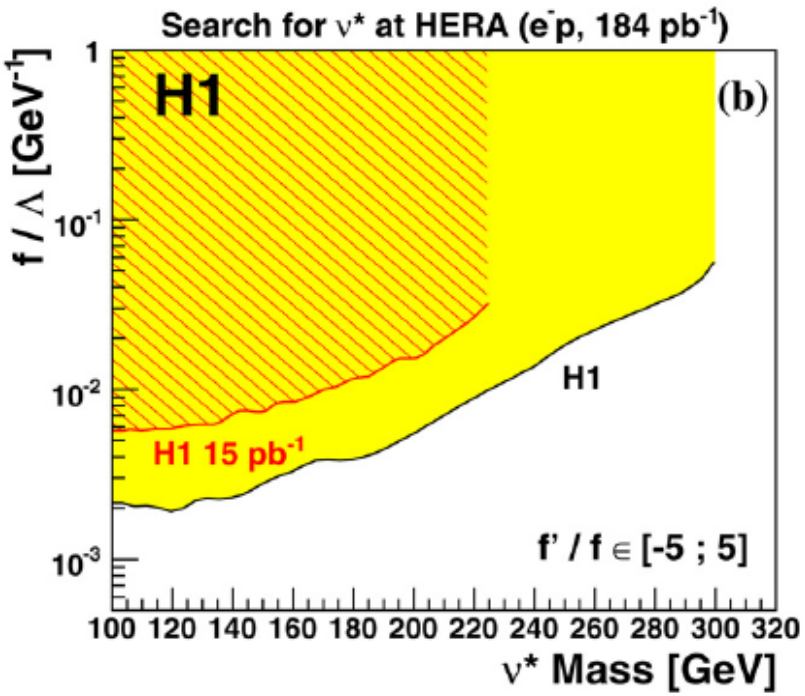
➔ No evidence for ν* found, mass dependent exclusion limits derived

Excited Neutrinos (continued)

H1 Collab., Phys. Lett. B 663 (2008) 382

Limits at 95% CL and all channels combined





- ➔ If $f/\Lambda=1/M_{\nu^*}$, $M_{\nu^*}<213$ excluded
- ➔ Best sensitivity achieved for mass beyond the LEP reach

- ➔ HERA1 limits improved by a factor of 3-4

(scan in f'/f)

Excited Electrons

H1 Collab., Phys. Lett. B 666 (2008) 131

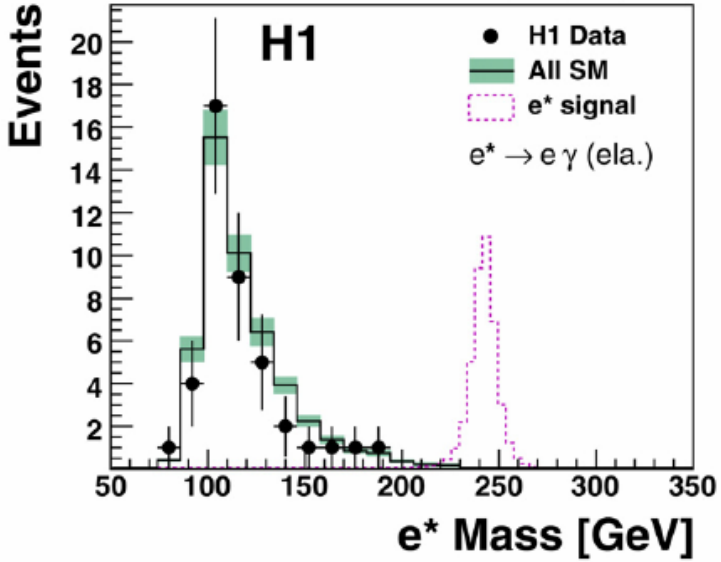
- **Use full HERA data (475 pb^{-1})**

  (Four-fold increase in stat vs. HERA-1)

- **Model Assumption:**

  f=+f′ (cross section small for f=-f′)

  80-90% decay modes investigated



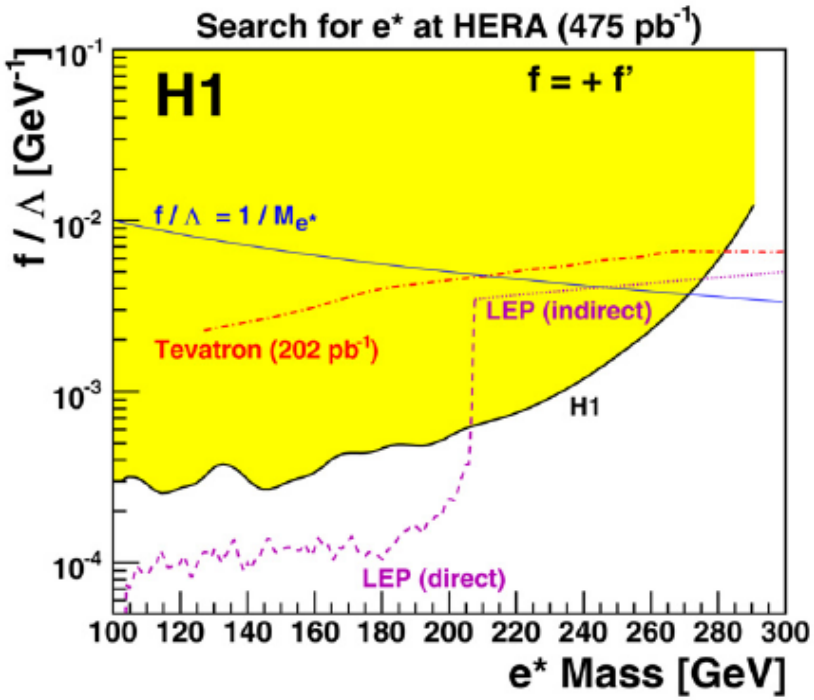
Channel	Data	SM	Signal efficiency [%]
$e^* \to e\gamma$ (ela.)	42	48 ± 4	60–70
$e^* \to e\gamma$ (inel.)	65	65 ± 8	60–70
$e^* \to \nu W \to \nu q\bar{q}$	129	133 ± 32	20–55
$e^* \to \nu W \to \nu e\nu$	4	4.5 ± 0.7	60
$e^* \to eZ \to e\nu\nu$			35
$e^* \to eZ \to eq\bar{q}$	286	277 ± 62	20–55
$e^* \to eZ \to eee$	0	0.72 ± 0.06	60
$e^* \to eZ \to e\mu\mu$	0	0.52 ± 0.05	40–15

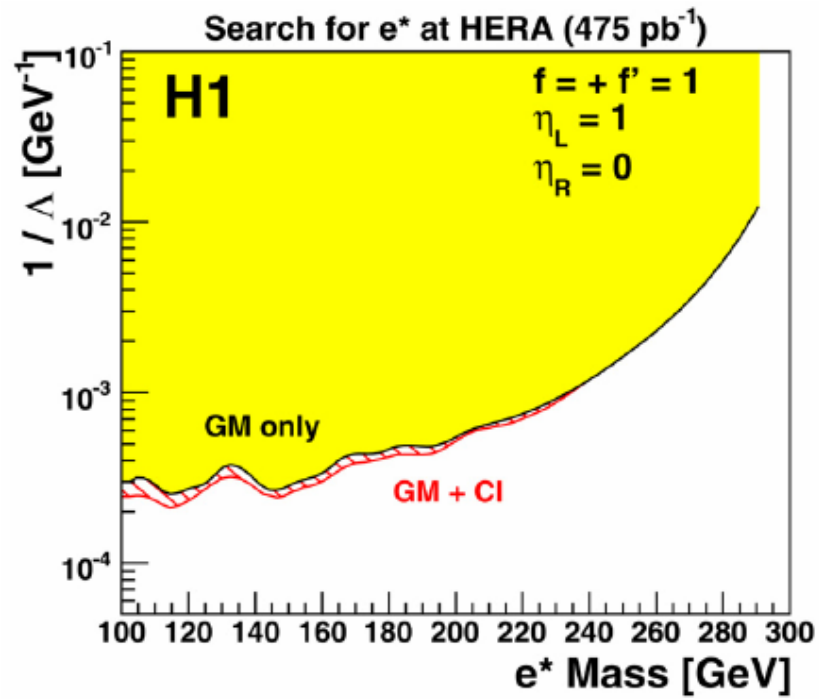
➔ No evidence for e* found, mass dependent exclusion limits derived

Excited Electrons (continued)

H1 Collab., Phys. Lett. B 666 (2008) 131

Limits at 95% CL and all channels combined





➔ If $f/\Lambda=1/M_{e^*}$, $M_{e^*}<272$ excluded

➔ The results extend previously excluded domain at LEP, Tevatron

GM: Gauge Mediated interactions
CI: Contact Interactions

➔ GM interactions dominate

Excited Quarks

H1 Collab., to appear in Phys. Lett. B (June 2009)

- **Use full HERA data (475 pb^{-1})**

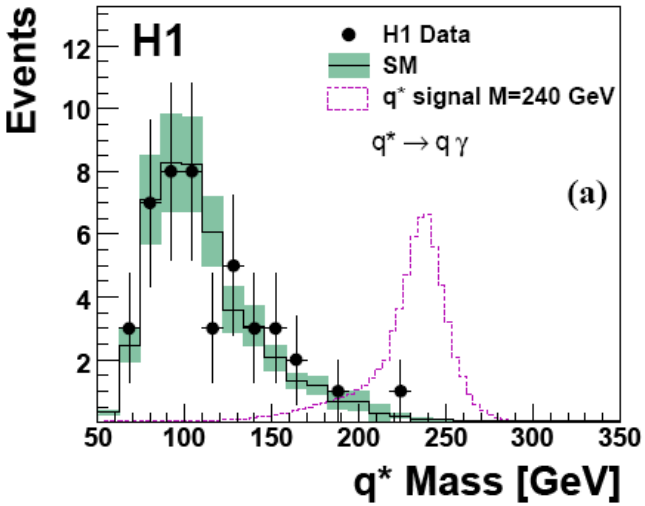
  (12-fold increase in stat vs. prev. results)

- **Model Assumption:**

  f=+f′ (f_s=0 or f_s≠0)

  s, u channels + interference

  (previously only s-channel with NWA considered)



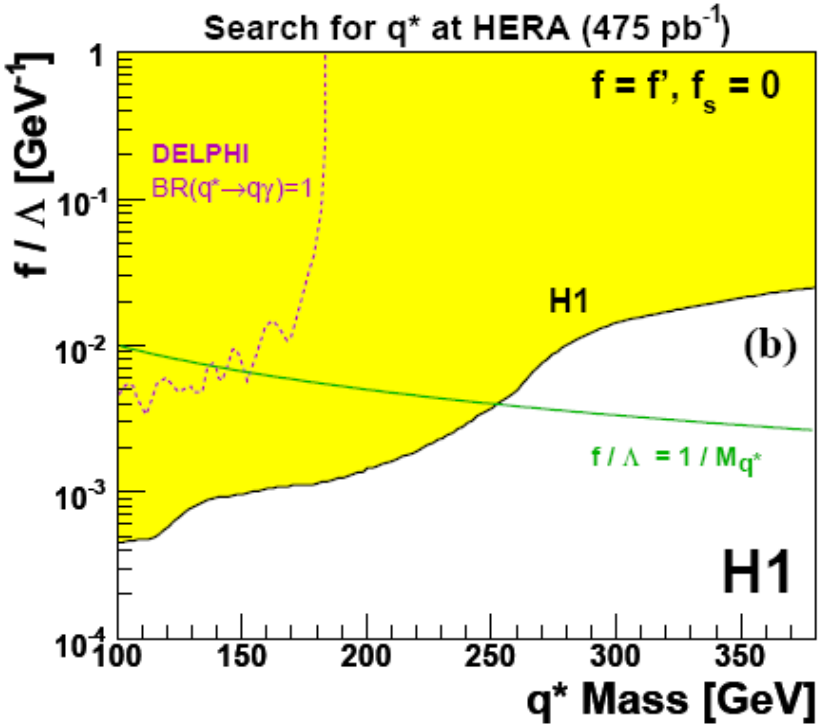
Channel	Data	SM	Signal Efficiency [%]
$q^* \to q\gamma$	44	$46 \pm 4 \pm 7$	35 – 45
$q^* \to qW/Z \to qq\bar{q}$	341	$326 \pm 48 \pm 62$	5 – 55
$q^* \to qW \to qe\nu$	6	$6.0 \pm 0.2 \pm 0.8$	20 – 30
$q^* \to qW \to q\mu\nu$	5	$4.4 \pm 0.2 \pm 0.7$	20 – 40
$q^* \to qZ \to qee$	0	$0.44 \pm 0.06 \pm 0.04$	15 – 30
$q^* \to qZ \to q\mu\mu$	0	$0.87 \pm 0.10 \pm 0.04$	15 – 30

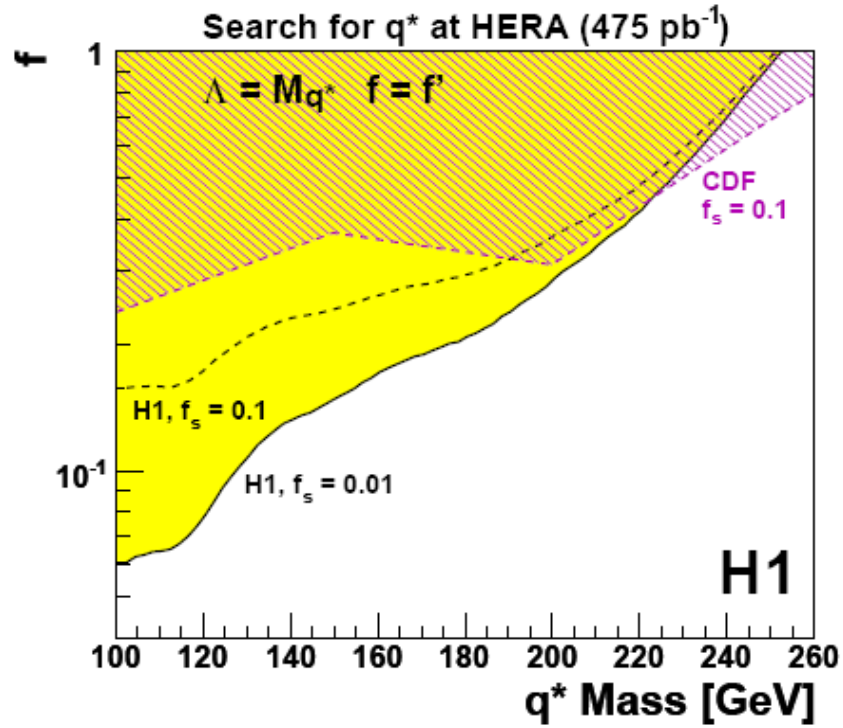
➔ No evidence for q* found, mass dependent exclusion limits derived

Excited Quarks (continued)

H1 Collab., to appear in Phys. Lett. B (June 2009)

Limits at 95% CL and all channels combined





➔ If $f/\Lambda=1/M_{q^*}$, $M_{q^*}<252$ excluded

➔ The results extend
- beyond the kinematical limits
- previously excluded domain at LEP

➔ HERA limits complementary to that of Tevatron for $f_s < f, f'$

Summary

- H1 has given the final word on the searches for f*:

  If $f/\Lambda=1/M_{f^*}$, M_{f^*}<213, 272, 252GeV excluded at 95%CL

  for ν^*, e*, and q*, respectively

- The HERA limits with the full data sample

  - improve significantly previous HERA results

  - extend/compete/complement those at LEP/Tevatron