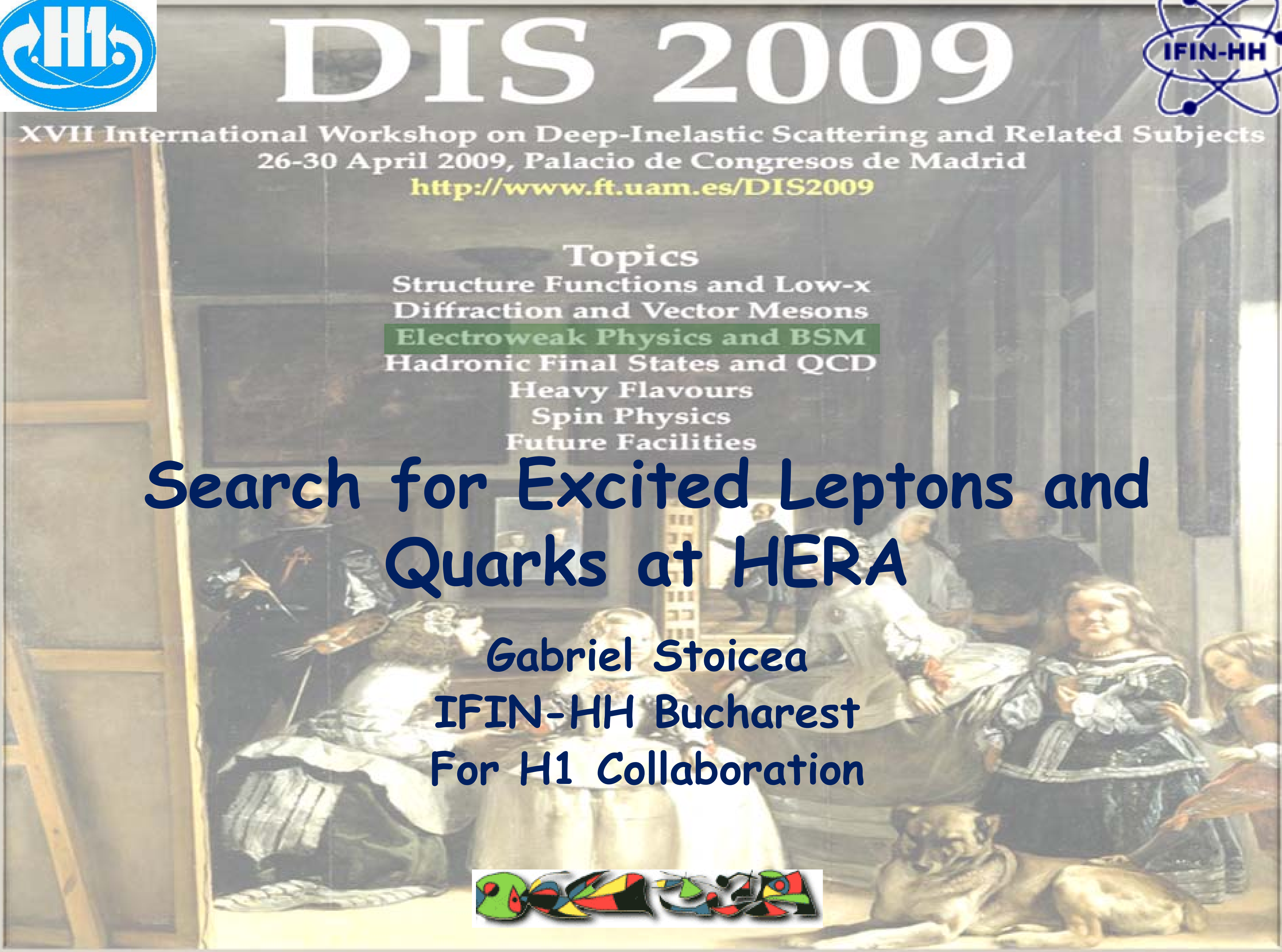
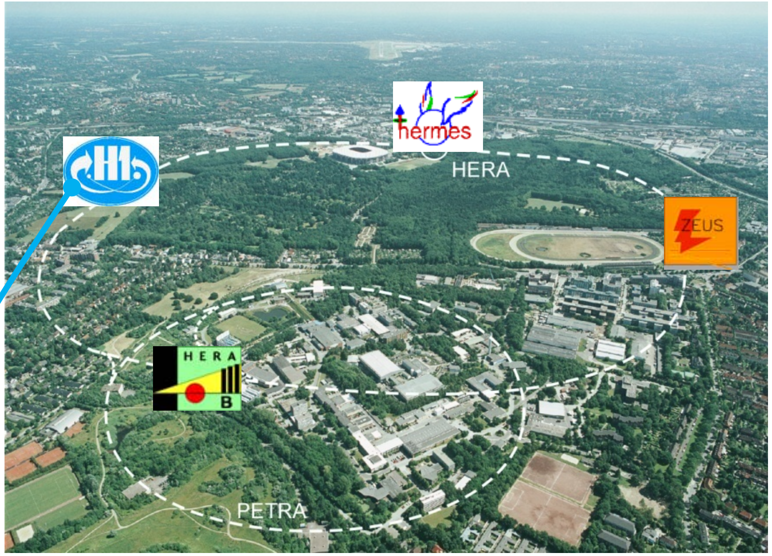
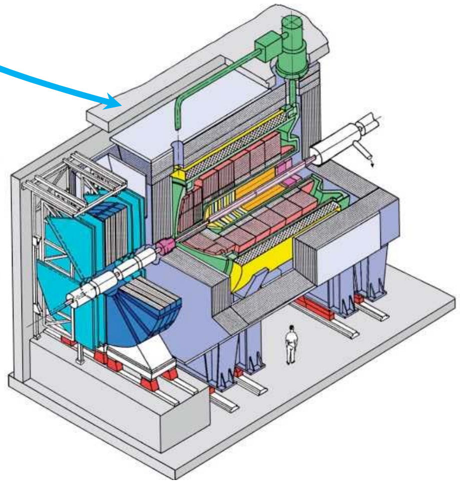


Search for Excited Leptons and Quarks at HERA

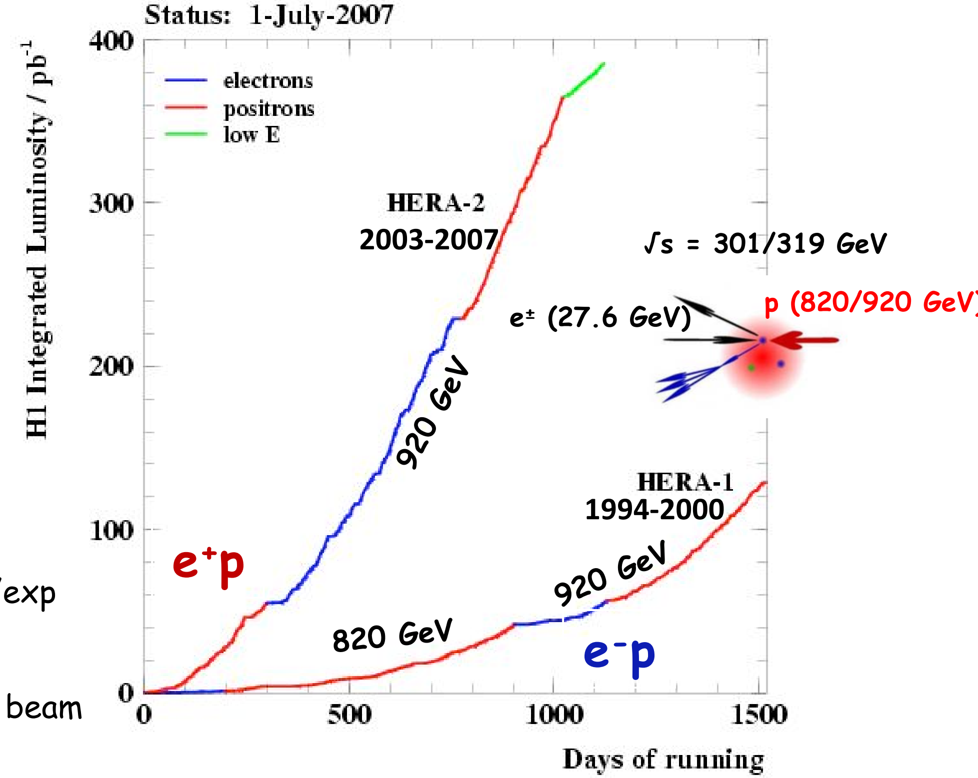
Gabriel Stoicea
IFIN-HH Bucharest
For H1 Collaboration

H1 and HERA 1994-2007





HERA I : 120 pb^{-1} /exp
HERA II :
o Lumi upgrade
o Polarised leptons beam



- H1 detector at HERA, asymmetric design
- Large increase in data from HERA II and polarised $e^{\pm}p$ data
- Final H1 dataset: $e^{-}p$: 184 pb^{-1} ; $e^{\pm}p$: 475 pb^{-1}
- <u>Presented here</u>: **Excited Leptons and Quarks**

Excited fermion states generalities

Basic elements of the gauge mediated theory

- Excited fermion states should be a signal for substructure at a characteristic scale $O(\Lambda)$
(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.
- The ways to couple fermions and excited fermions :

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

→ Gauge mediated interactions (GM) :

- f^* can carry different spin/isospin values
  Assume that f^* have spin 1/2 - isospin 1/2 and are organised in left/right weak doublet → $F^*_{L,R} = (\nu^*_e, e^*)_{L,R}$ (Kuhn & Zerwas, Phys. Lett B 147,189,1984)
- Lagrangian should respect a chiral symmetry
  → Only right-handed part of F^* involved in fF^*V couplings
- Interactions described in a SU(2)XU(1) invariant form

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

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

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

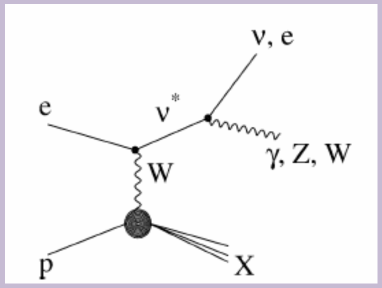
(K.Hagiwara et al., ZPC 29, 115, 1985)

→ or Contact interactions – considered for e*: see later (U.Baur et al, Phys. Rev 42, 815, 1990)

Excited fermions : production and decay at ep colliders

ν*

Phys.Lett.B663:382-389,2008



o produced via t-channel W boson exchange

$\sigma(e^-p)/\sigma(e^+p)$ ~ 100, M_{ν^*}=200 GeV

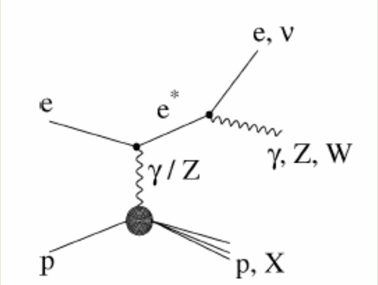
("charged current" like production)

H1 analysis : use all e^-p data (184 pb^{-1})

similar signatures for e* and ν*

e*

Phys.Lett.B666:131-139,2008



o produced via t-channel γ/Z bosons exchange

o contact interactions

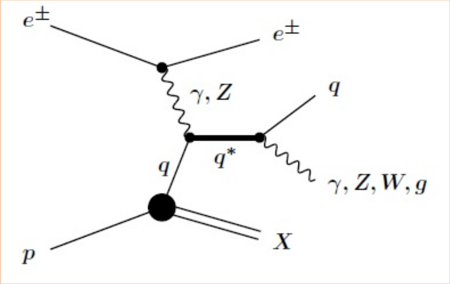
H1 analysis : use all $e^{\pm}p$ data (475 pb^{-1})

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

q*

New results - To be submitted to Phys.Lett.B

Under the assumption:
f_s = 0, (assumed for all f* here)
f = f'
(q* prod. via qg = 0)
(q* decay into qg = 0)



o q* produced via t-channel γ/Z bosons exchange

Results complementary to the q* searches performed at the Tevatron ($f_s \neq 0$).
The effect of non-zero values of f_s is also studied.

H1 analysis: use all $e^{\pm}p$ data (475 pb^{-1})

Searches for q* with H1 ($e^{\pm}p$, 475 pb^{-1})

channel

$q^* \rightarrow q\gamma$

- 1 isolated electromagnetic cluster with P_T^{γ} > 35 GeV
- at least 1 jet with P_T^{jet} > 20 GeV
- Reduced NC-DIS: no other isolated electron with E_e > 10 GeV in LAr

$q^* \rightarrow qW/Z \rightarrow qqq$

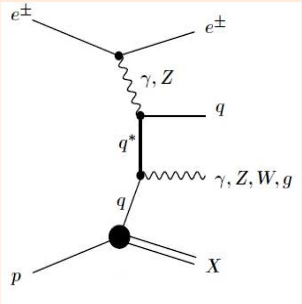
- at least 3 jets with P_T^{jets} > 50, 30, 15 GeV
- Reduced multi-jet photoproduction : highest P_T jet is not associated to the W or Z candidate

$q^* \rightarrow qW \rightarrow qe\nu$ ▪ P_T^{miss} + e + jet   bkg : NC-DIS and photoproduction

$q^* \rightarrow qW \rightarrow q\mu\nu$ ▪ P_T^{miss} + μ + jet   bkg : SM W production

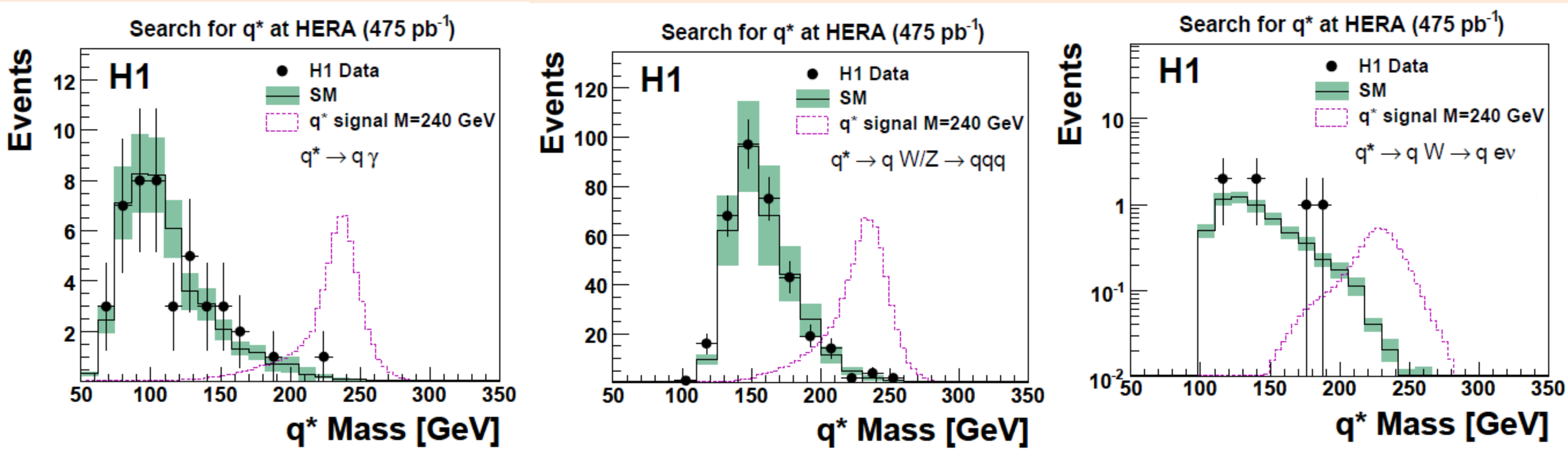
$q^* \rightarrow qZ \rightarrow qee$ ▪ jet + 2e   bkg : e - pairs

$q^* \rightarrow qZ \rightarrow q\mu\mu$ ▪ jet + 2μ bkg : μ - pairs

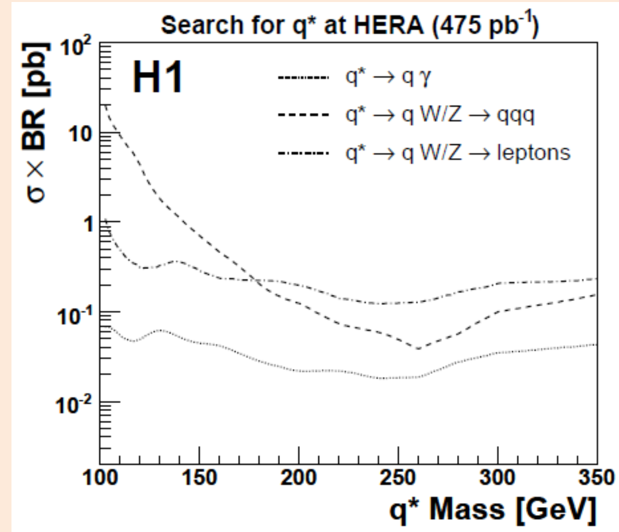


o u-channel included for the exchange of excited quarks
Non-negligible cross section for the high q* masses and low values of Λ.

Searches for q* with H1 ($e^{\pm}p$, 475 pb^{-1})



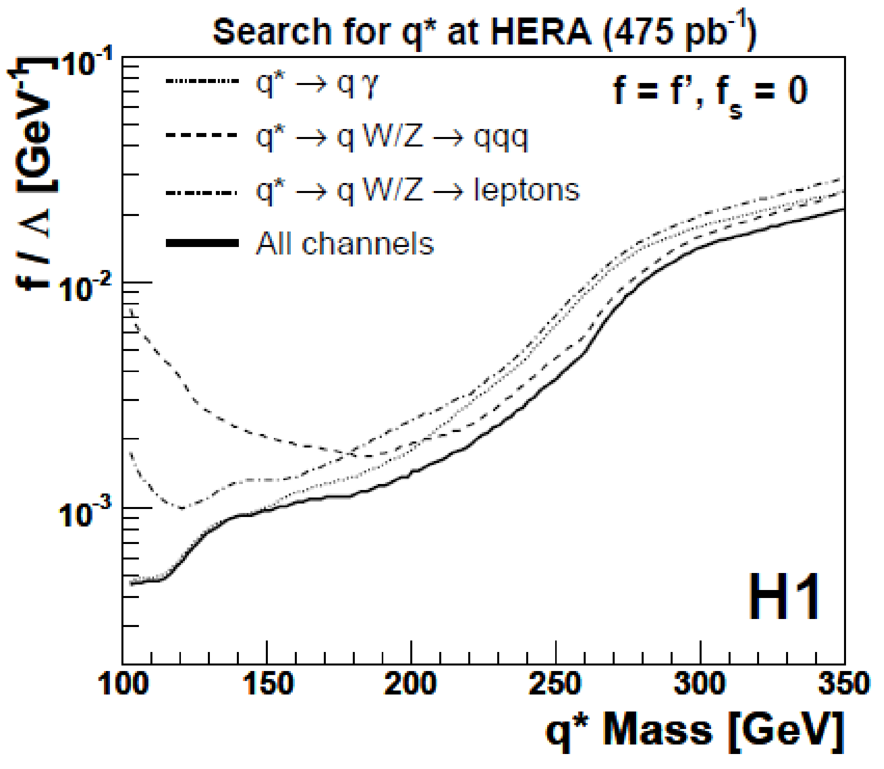
H1 Search for q^* at HERA (475 pb^{-1})			
Channel	Data	SM	Signal Efficiency [%]
$q^* \to q\gamma$	44	46 ± 8	35 – 45
$q^* \to qW/Z \to q\bar{q}$	341	326 ± 78	5 – 55
$q^* \to qW \to qe\nu$	6	6.0 ± 0.8	20 – 30
$q^* \to qW \to q\mu\nu$	5	4.4 ± 0.7	20 – 40
$q^* \to qZ \to qee$	0	0.44 ± 0.08	15 – 30
$q^* \to qZ \to q\mu\mu$	0	0.87 ± 0.11	15 – 30

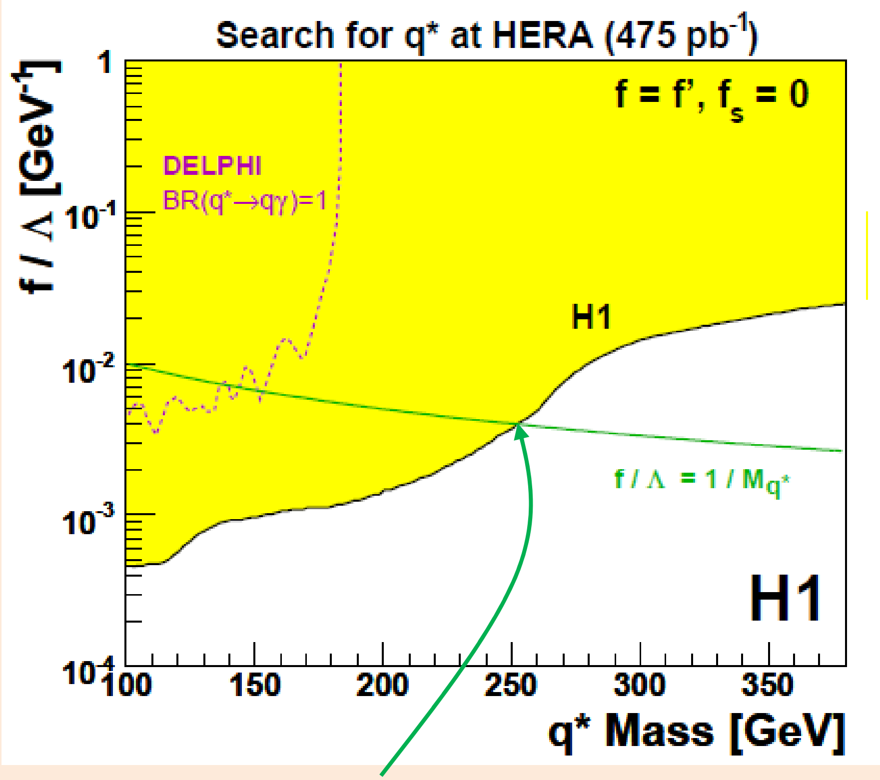


- Good agreement with the SM and no resonance observed in mass spectra
- Derive limits @ 95% C.L. on f/Λ as a function of M_{q^*} for all channels combined
- Conventional assumptions:
  - $f_s = 0$ (no s interactions)
  - f,f' comparable; only examine f = +f'

Limits on f/Λ from q* production

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





M_{q*} < 252 GeV excluded for $f/\Lambda = 1/M_{q*}$

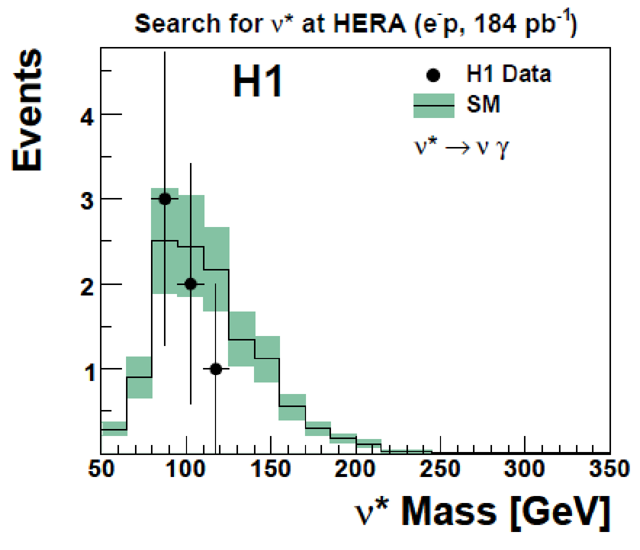
- Limit driven by q* → qγ at low mass, W/Z decays contribute at higher masses
- Limits greatly improved with respect to HERA I limit

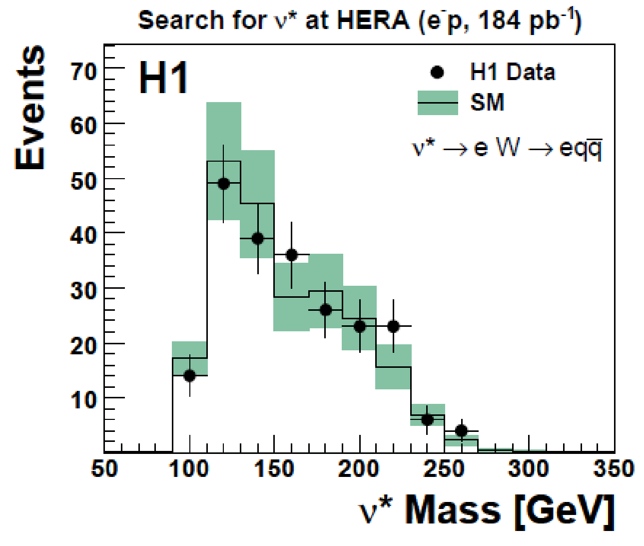
HERA: Best sensitivity for masses beyond the LEP reach

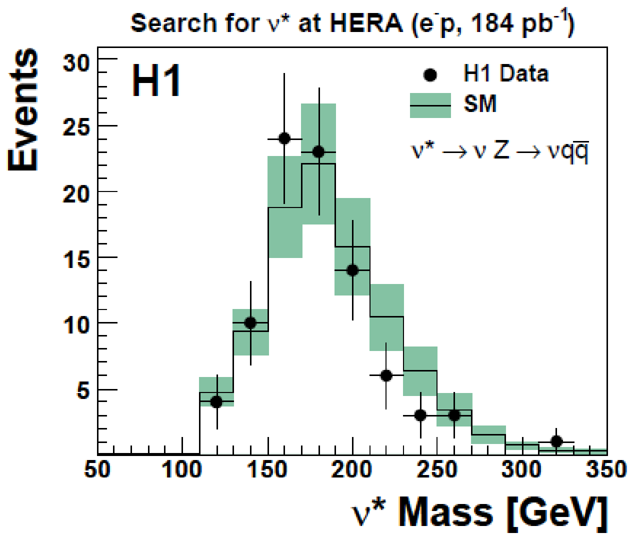
Searches for ν* with H1 (e^-p, 184 pb^{-1})

Search for ν^* at HERA (e^-p, 184 pb^{-1})

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



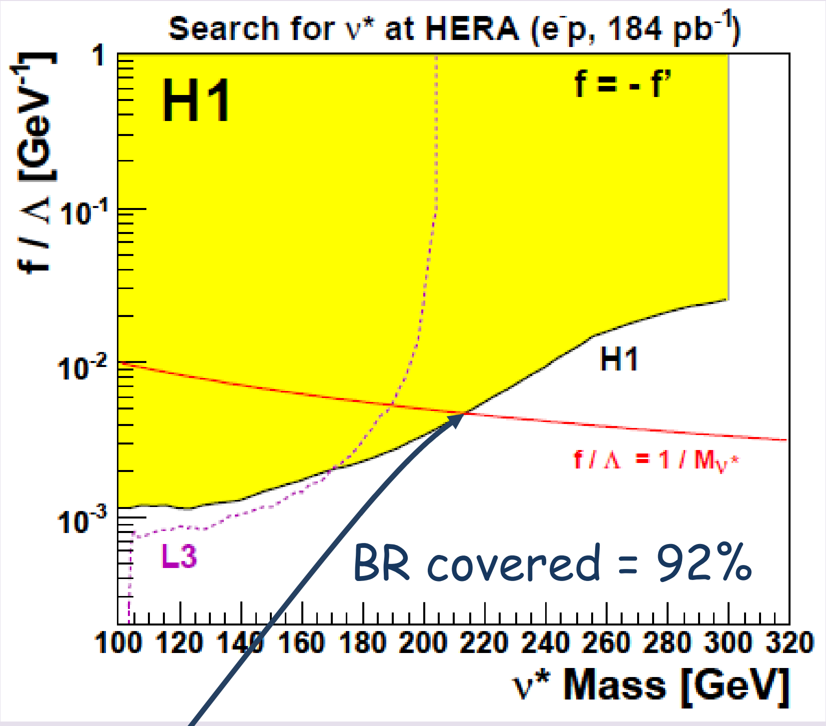


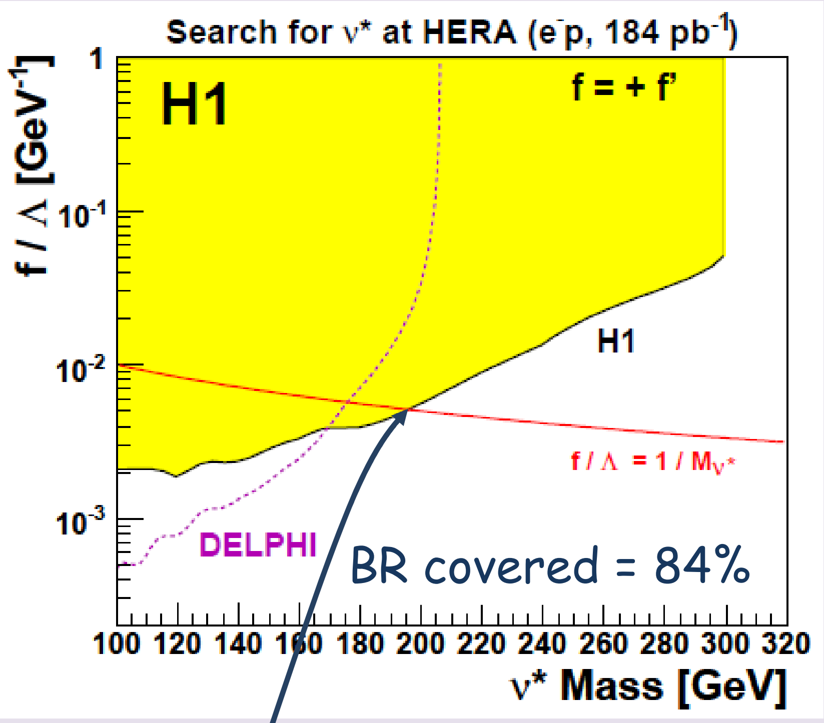


- Good agreement with the SM and no resonance observed in mass spectra
- Derive limits @ 95% C.L. on f/Λ as a function of M_{ν^*} for channels combined
- Conventional assumptions:
- – ν* is insensitive to f_s (=0)
- – f,f' comparable; examine f = -f' or f = +f'

Limits on f/Λ from ν* production

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





$M_{\nu^*} < 213$ GeV excluded for $f/\Lambda = 1/M_{\nu^*}$

Limit driven by $\nu^* \to \nu\gamma$ at low mass,
$\nu^* \to eW$ contributes for M > 200 GeV

$M_{\nu^*} < 196$ GeV excluded for $f/\Lambda = 1/M_{\nu^*}$

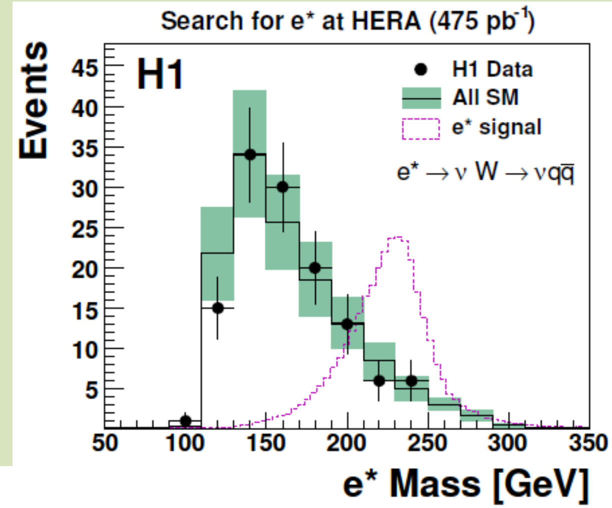
Limit mainly driven by $\nu^* \to eW$
($\nu^* \to \nu\gamma$ forbidden for f = +f')

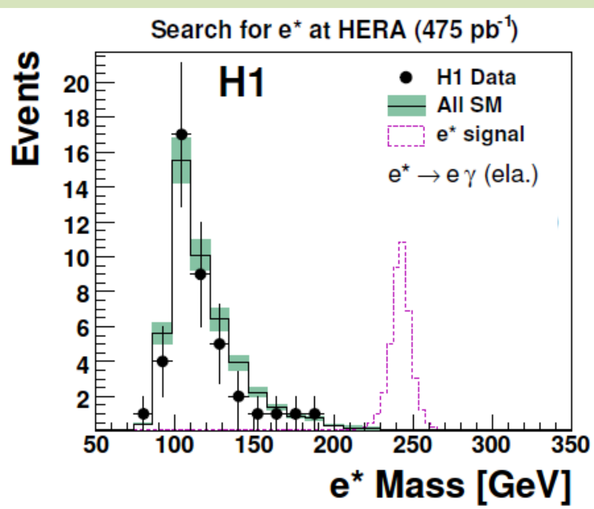
HERA: Best sensitivity for masses beyond the LEP reach

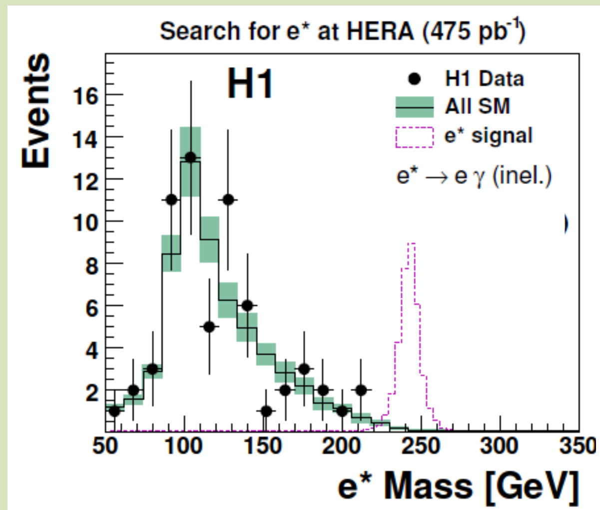
Searches for e* with H1 ($e^{\pm}p$, 475 pb^{-1})

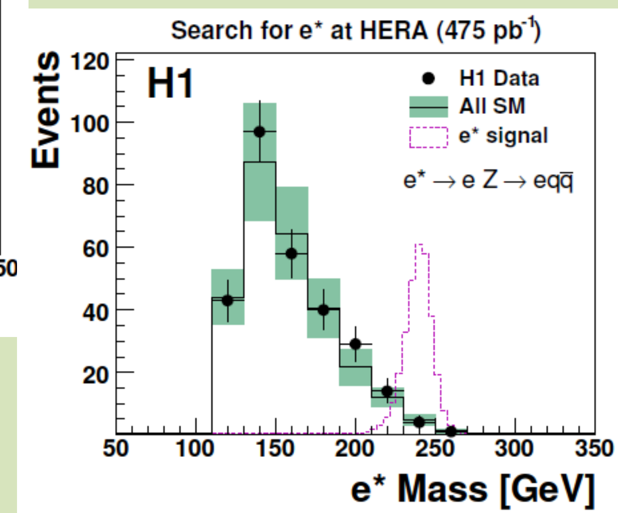
Search for e^* at HERA (475 pb^{-1})

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





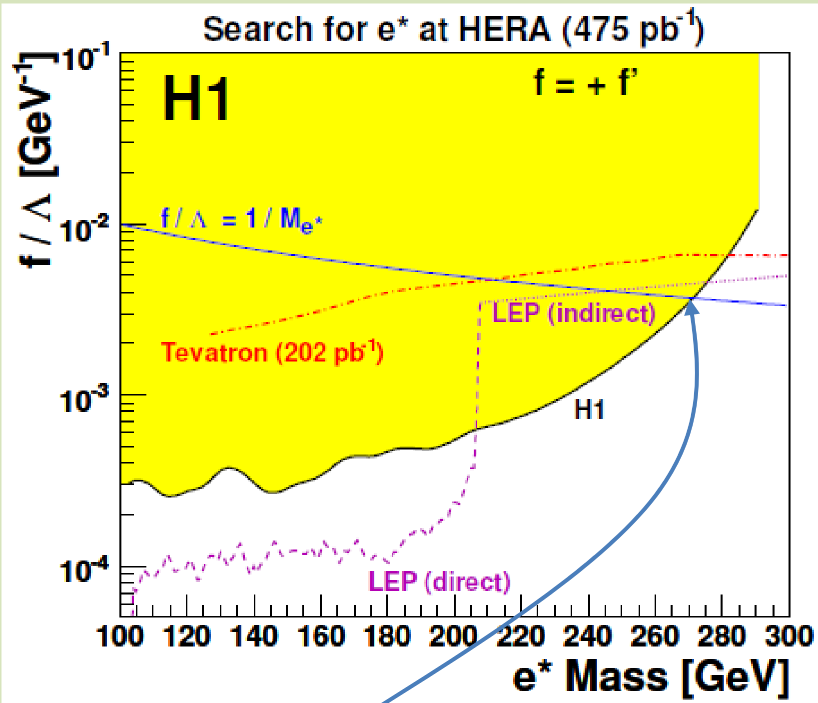


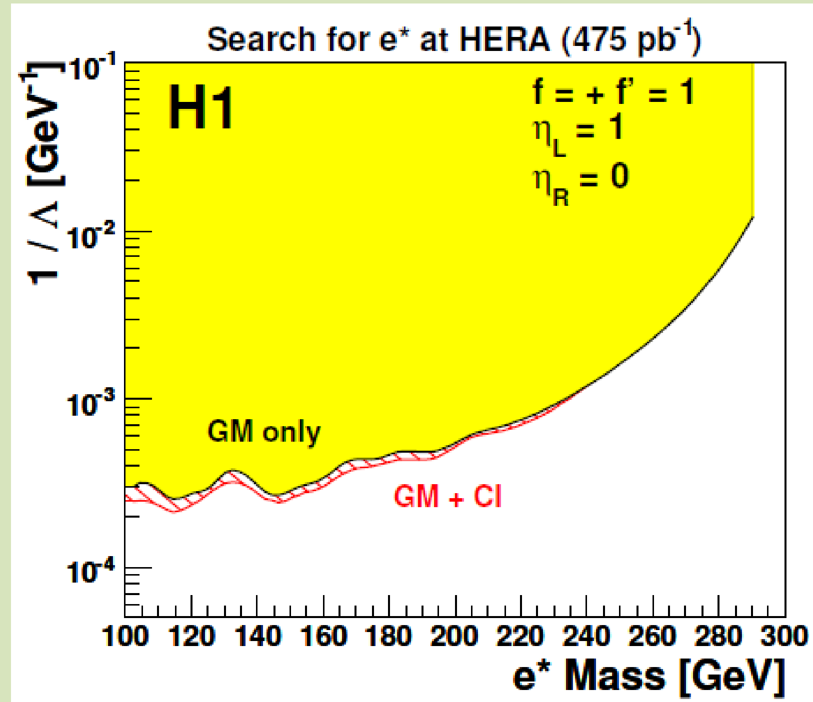


- Good agreement with the SM and no resonance observed in mass spectra
- Derive limits @ 95% C.L. on f/Λ as a function of M_{e^*} for channels combined
- Conventional assumptions:
  - e* is insensitive to fs (=0)
  - f = +f' only ($e^* \to e\gamma$, high BR, forbidden for f = -f')

Limits on f/Λ from e* production

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



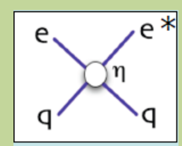


M_{e^*} < 272 GeV excluded for f/Λ = 1/M_{e^*}
Limit driven by e* → eγ at low mass, e* → νW contributes at higher masses
Results from LEP (OPAL, DELPHI) and from CDF (e* within GM model) also shown

HERA: Best sensitivity in the intermediate e* mass range

- In addition to the GM interactions, a CI model can be used to describe the f ↔ f* transitions, described by:

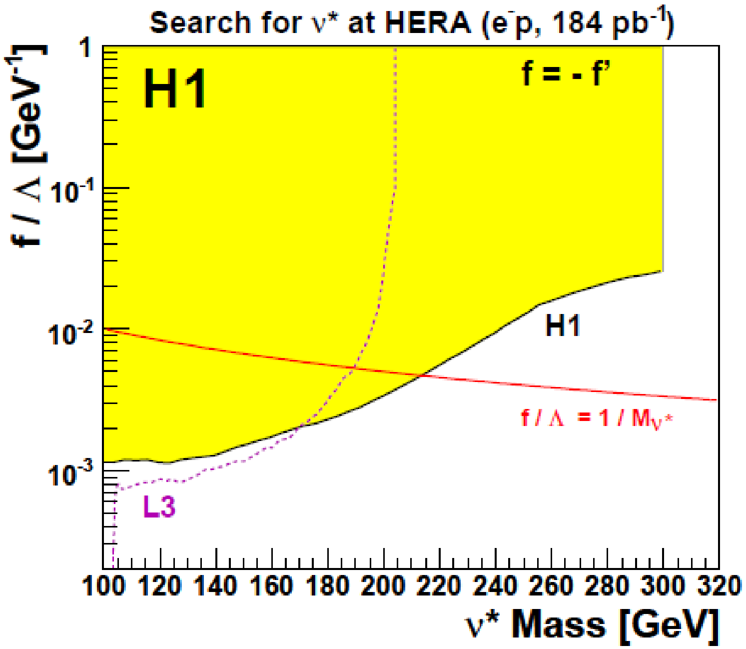
$$\mathcal{L}_{CI} = \frac{4\pi}{2\Lambda^2} j^{\mu} j_{\mu}$$

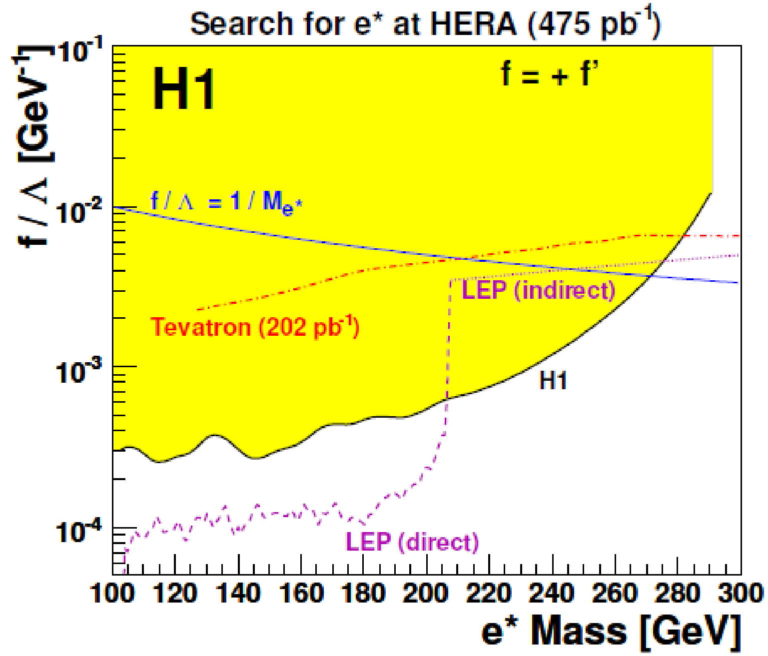


with left-handed fermion currents.
- Total e* production cross section is the sum of the cross sections σ_{GM+CI}
- For simplicity, set f = +f' = 1, fixing the relative strength of the GM and CI components and use only GM e* decays (> 95% of total here)

- For a given mass, CI contribution decreases for increasing Λ
- For e* masses below 250 GeV, the additional contribution of CI to e* production changes the limit by a factor 1.15 → 1.2

Summary – for 200 GeV < M_{f*} < 300 GeV, HERA has the best sensitivity





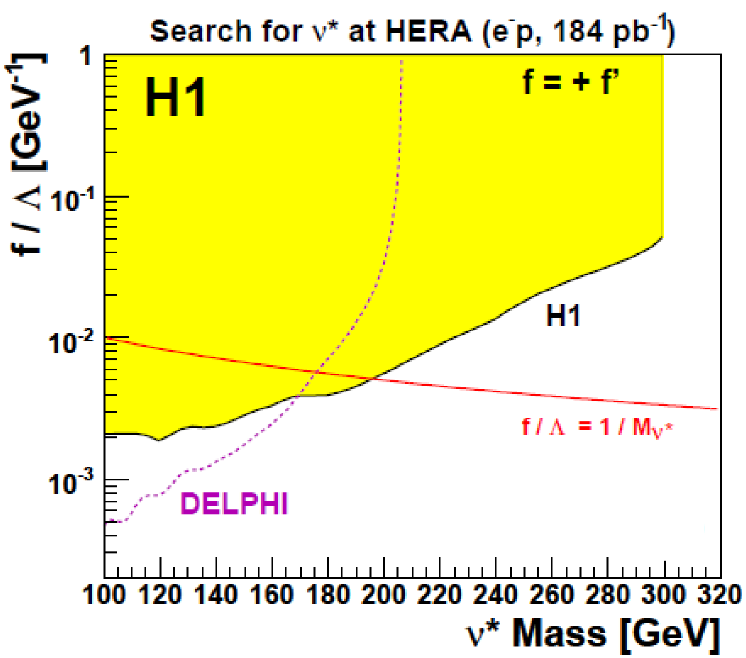
All the H1 data at E_{cm}= 301, 319 GeV have been used :

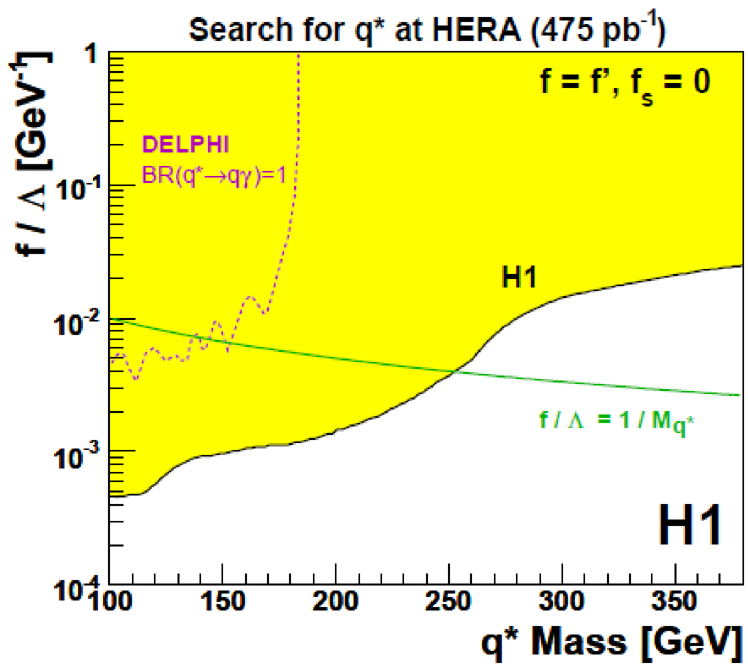
✓ e^-p : 184 pb^{-1} excited neutrino (published)

✓ $e^{\pm}p$: 475 pb^{-1} excited electrons (published) and excited quarks (to be published)

No signal found and improved upper limits have been derived :

For ν* : $M_{\nu*}$ < 213 GeV excluded
For e* : M_{e*} < 272 GeV excluded
For q* : M_{q*} < 252 GeV excluded

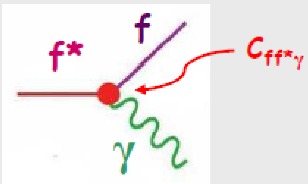




Back-up slides

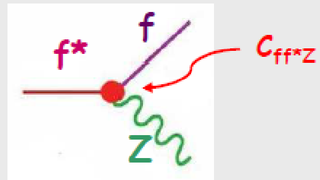
Expression of the Vff* couplings (V = γ,Z,W)

- ff*γ vertex



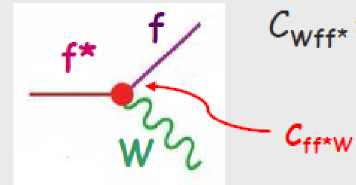
$C_{\gamma f f^*} = \frac{1}{2}(fI_3 + f'\frac{Y}{2})$

- ff*Z vertex



$C_{Zff^*} = \frac{1}{2}(fI_3 \cot\theta_W - f'\frac{Y}{2}\tan\theta_W)$

- ff*W vertex



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

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

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

I_3: third isospin component

Y: hypercharge (±1 for ℓ^*)

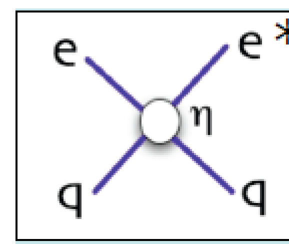
θ_W: Weinberg angle

e* Limits including the CI Production Model

- In addition to the GM interactions, a CI model can be used to describe the f ↔ f* transitions, described by:

$$\mathcal{L}_{CI} = \frac{4\pi}{2\Lambda^2} j^\mu j_\mu$$ with $j_\mu = \eta_L \bar{F}_L^* \gamma_\mu F_L + \eta'_L \bar{F}_L \gamma_\mu F_L + \eta''_L \bar{F}_L^* \gamma_\mu F_L^* + h.c. + (L \to R)$

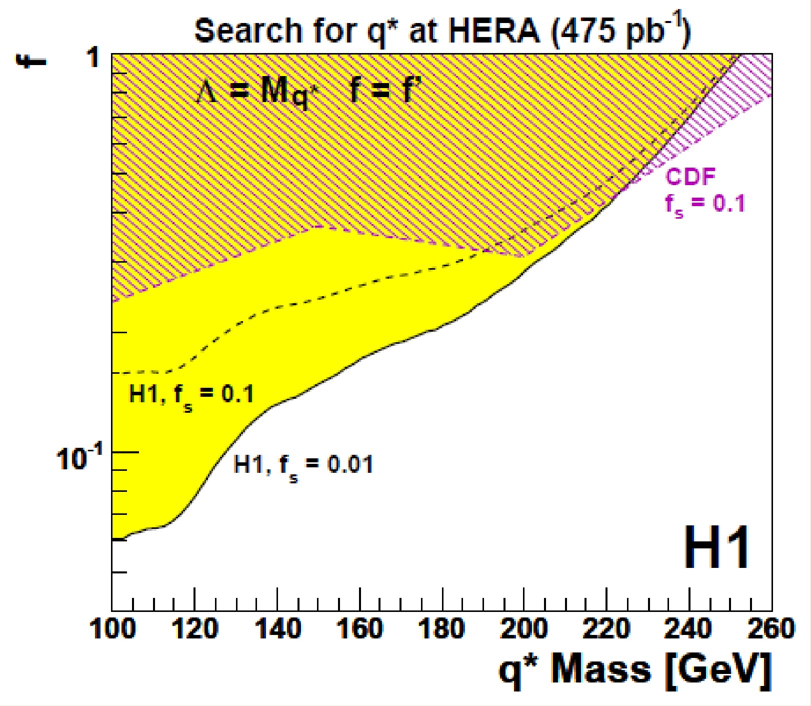
with left-handed fermion currents.



- Total e* production cross section is the sum of the cross sections σ_{GM+CI}
- For simplicity, set f = +f' = 1, fixing the relative strength of the GM and CI components and use only GM e* decays (> 95% of total here)

Limits on f/Λ from q* production

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



- $f = f'$, $\Lambda = M_{q*}$
- this limit is derived using $\gamma/Z/W$ decay channels of q*

For $f_s < 0.1$ and for $M_{q*} < 190$ GeV, the present analysis probes a domain not excluded by Tevatron experiments