

Searches for (non-SUSY) Exotics at HERA

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Unification of Fundamental Interactions*

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on behalf of
the collaborations

H1 and ZEUS



Outline

Latest HERA luminosity harvest

Searches for exotic signatures:

- **Isolated leptons with p_T^{miss}**
- **Multi-lepton events**
- **Multi-jets with p_T^{miss}**



Possible new physics:

- **Anomalous single top via FCNC**
- **Doubly charged Higgs**
- **Excited neutrinos**

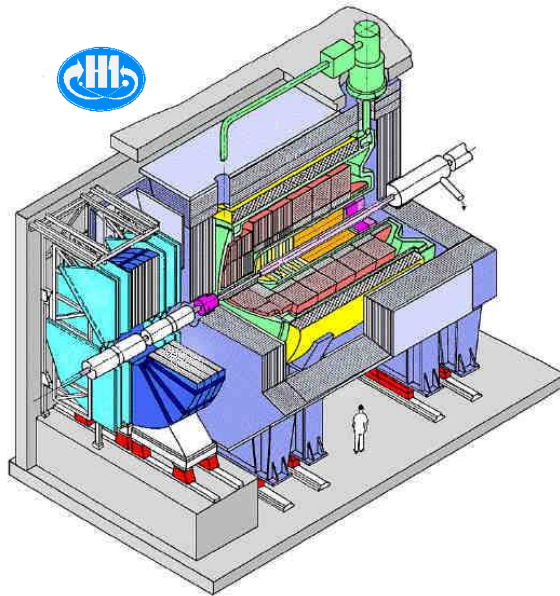
Sorry, there are yet no new HERA results about...

- **Isolated high- p_T μ or τ + jet**
- **Resonances in high- Q^2 NC/CC**

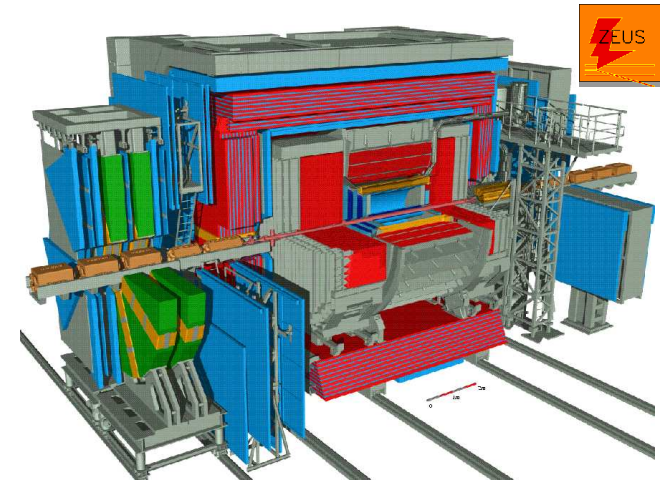
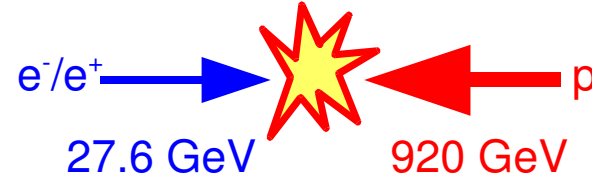


- **Lepton Flavour Violation**
- **Leptoquarks**

HERA with H1 and ZEUS



$$\sqrt{s} = 320 \text{ GeV}$$



**Luminosity seen
by H1 (ZEUS similar):**

HERA I (1994-2000)

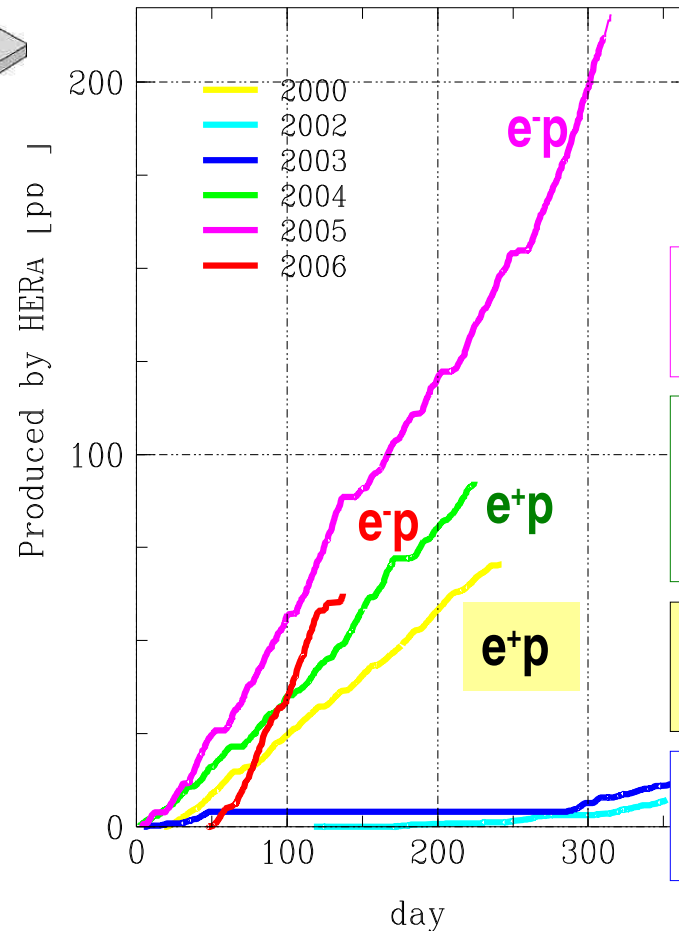
e^+p : $L \sim 115 \text{ pb}^{-1}$

e^-p : $L \sim 15 \text{ pb}^{-1}$

HERA II (2003-now)

e^+p : $L \sim 50 \text{ pb}^{-1}$

e^-p : $L \sim 140 \text{ pb}^{-1}$



2005:
luminosity record

from 2003 on:
longitudinally polarised
lepton beam

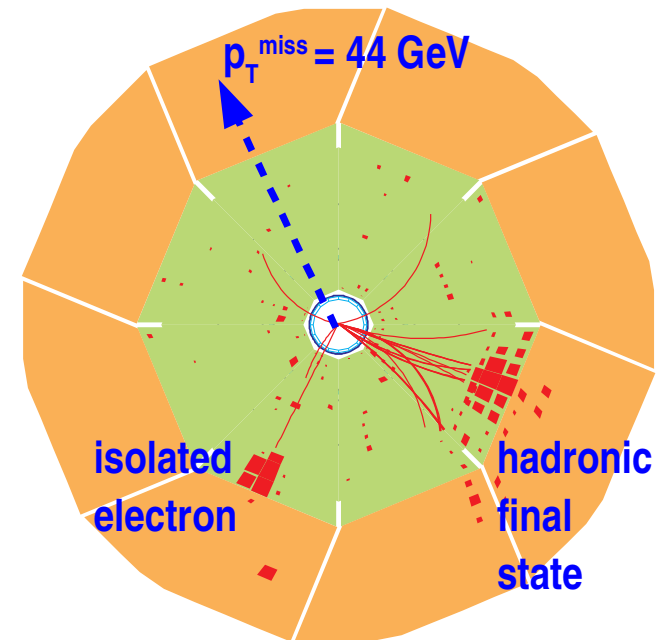
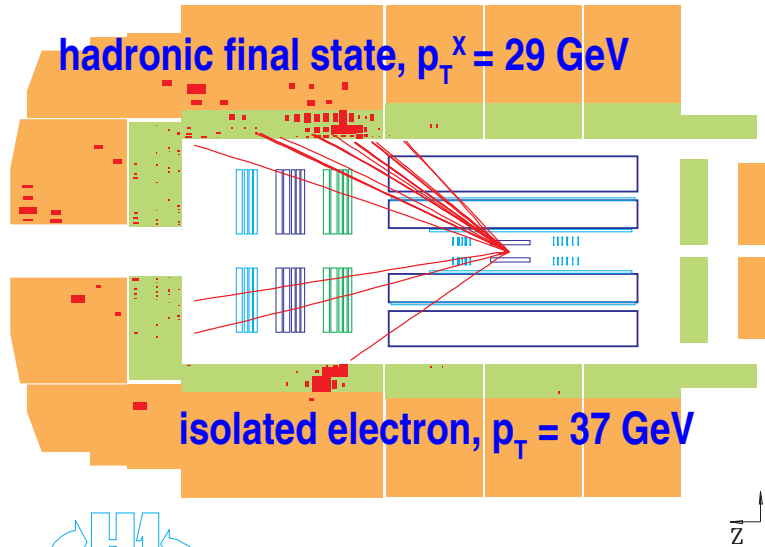
2000:
HERA I ending

2002-03:
HERA II startup

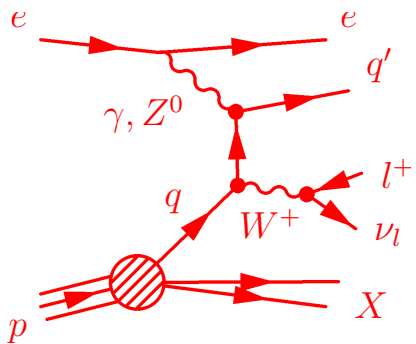
now more than 300 pb^{-1} of data for each experiment!

Isolated leptons and p_T^{miss} (H1)

Excess at high p_T^X !



Dominant SM process: W-Production at $Q^2 \sim 0$ (Photoproduction)



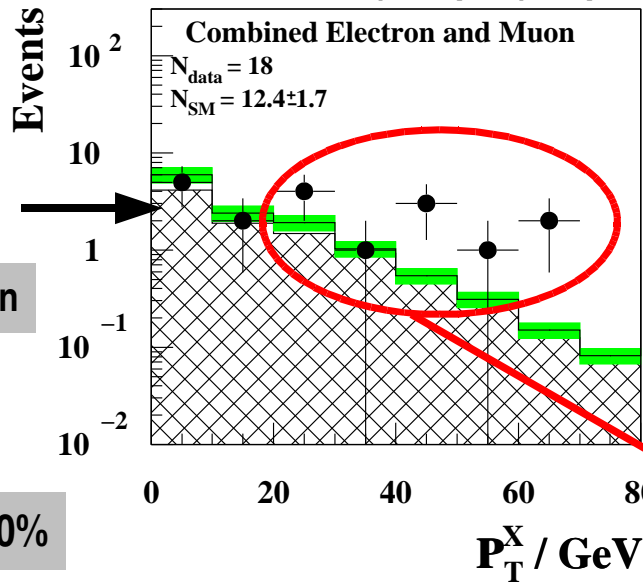
low p_T^X

isol. lepton

p_T^{miss}

$\sigma \sim 1 \text{ pb} \times \text{BR}(W \rightarrow \text{leptons}) \sim 30\%$

HERA I (118 pb^{-1}) e^+p



Phys.Lett. B561 (2003) 241-257

Review to HERA I analysis

(118 pb^{-1} of $e^\pm p$ data):

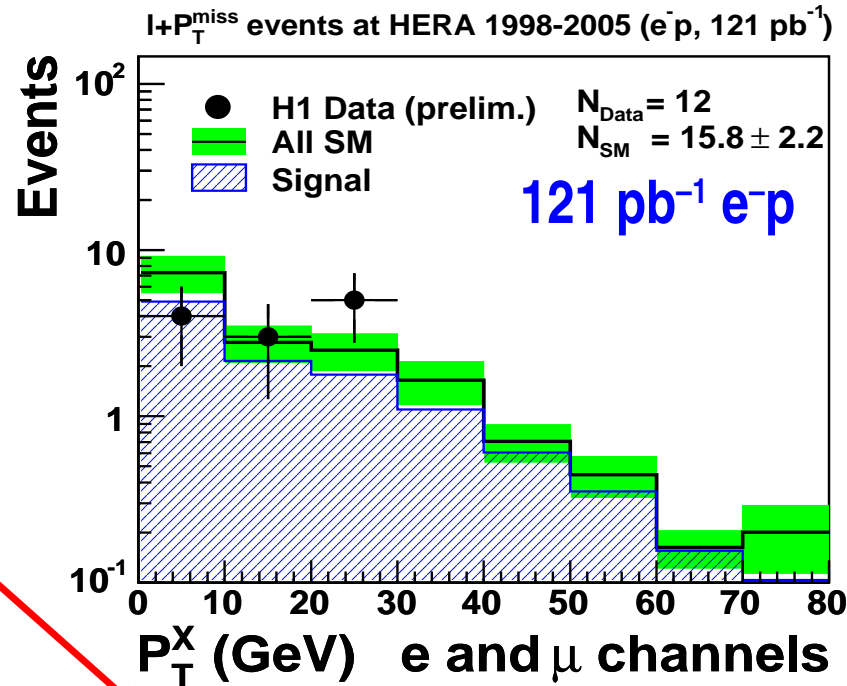
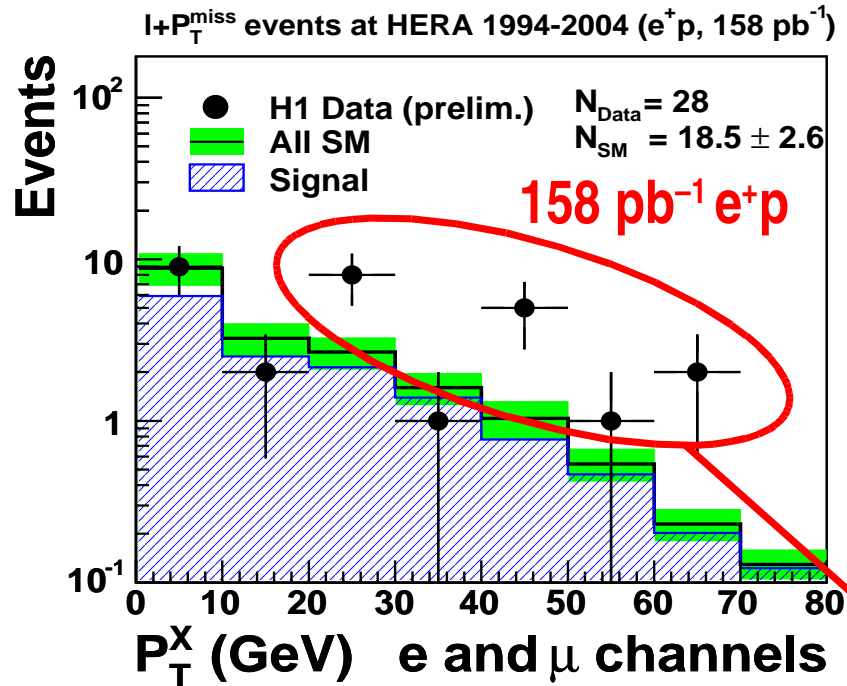
An excess of e^+p data events is observed at large hadronic transverse momentum

($p_T^X > 25 \text{ GeV}$):

$e: 5 / 1.8 \pm 0.3 \quad \mu: 6 / 1.7 \pm 0.3$

Isolated leptons and p_T^{miss} (H1)

Total analysed luminosity from HERA I + II datasets : **279 pb⁻¹**



H1 (prelim.) 279 pb ⁻¹	e channel obs. / exp. (W-cont.)	μ channel obs. / exp. (W-cont.)
Full sample	30 / 27.2 ± 3.8 (68%)	10 / 7.2 ± 1.1 (81%)
$p_T^X > 25$ GeV	11 / 4.7 ± 0.9 (69%)	6 / 4.3 ± 0.7 (78%)
e ⁻ p (121 pb ⁻¹)	2 / 2.4 ± 0.5 (62%)	0 / 2.0 ± 0.3 (76%)
e ⁺ p (158 pb ⁻¹)	9 / 2.3 ± 0.4 (80%)	6 / 2.3 ± 0.4 (78%)

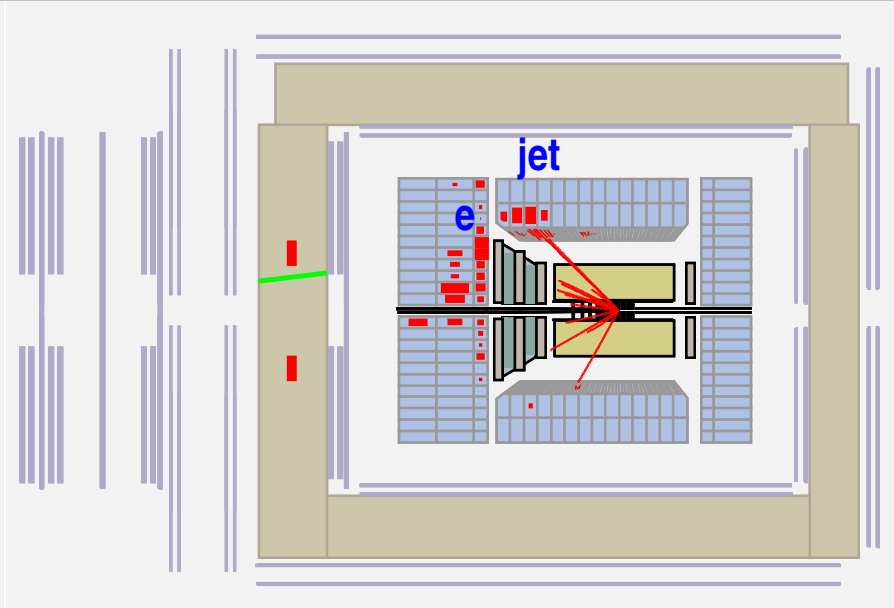
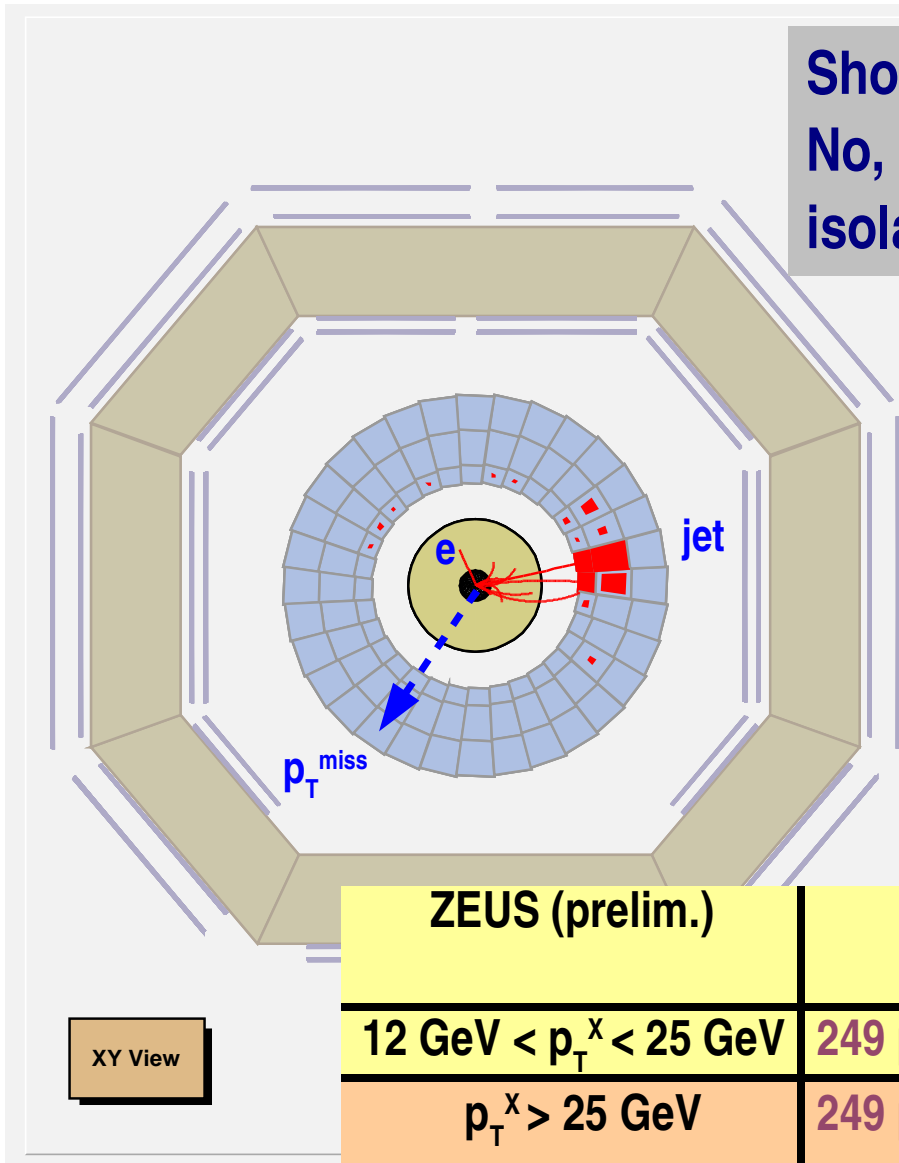
In 279 pb⁻¹ of e[±]p data the excess is observed in **e⁺p data only, not in e⁻p!**

- Does ZEUS see the same?
- Is there a theoretical concept for this? FCNC-top, SUSY?

Isolated leptons and p_T^{miss} (ZEUS)

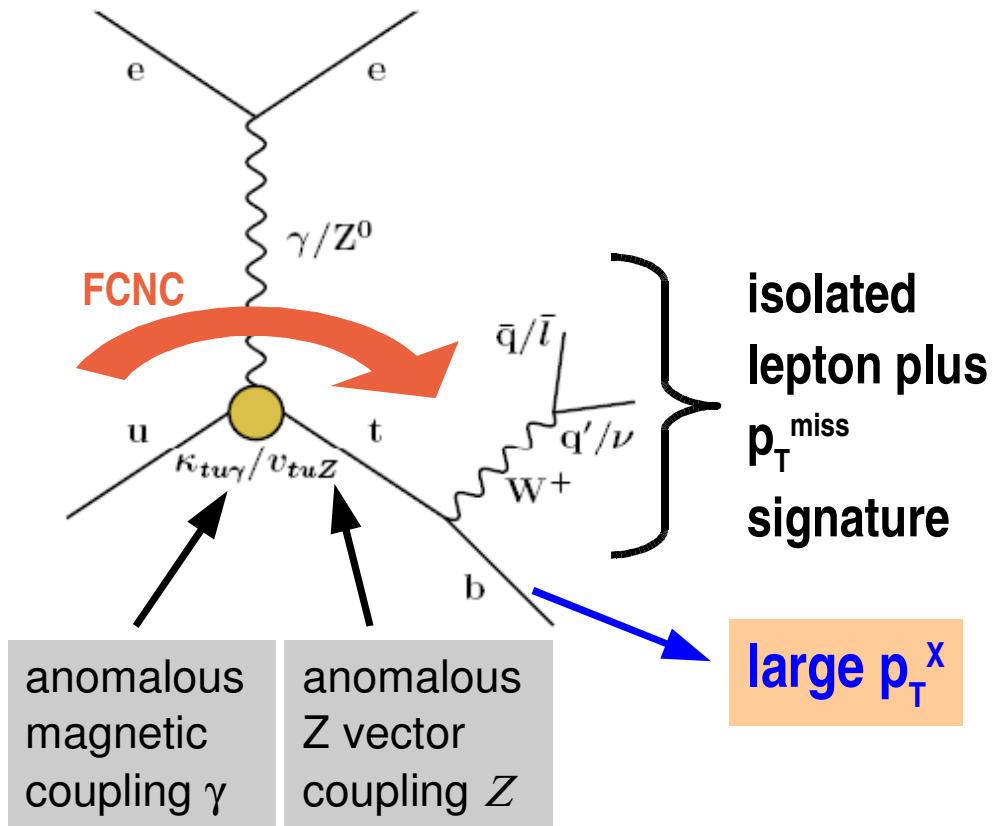
Short answer:

No, ZEUS does not see a significant excess of isolated lepton events in HERA I+II $e^\pm p$ data!



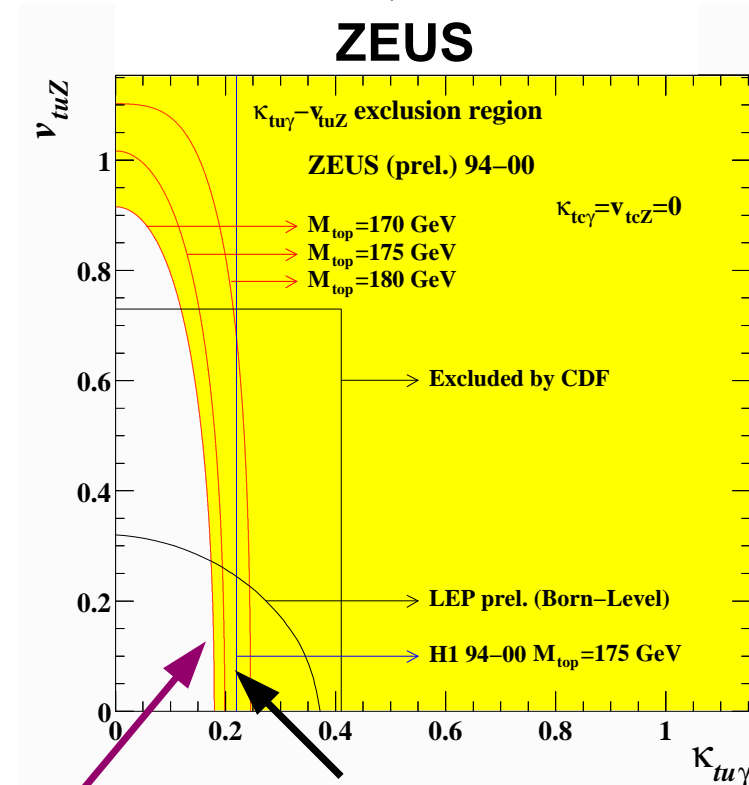
ZEUS (prelim.)	e channel obs. / exp. (W-cont.)	μ channel obs. / exp. (W-cont.)
$12 \text{ GeV} < p_T^x < 25 \text{ GeV}$	249 pb^{-1} : 5 / 3.5 ± 0.4 (58%)	126 pb^{-1} : 2 / 1.4 ± 0.2 (68%)
$p_T^x > 25 \text{ GeV}$	249 pb^{-1} : 4 / 4.4 ± 0.5 (61%)	126 pb^{-1} : 2 / 1.4 ± 0.2 (86%)
e^-p	143 pb^{-1} : 3 / 2.86 ± 0.46 (53%)	126 pb^{-1} : 2 / 1.4 ± 0.2 (86%)
e^+p	106 pb^{-1} : 1 / $1.5^{+0.12}_{-0.13}$ (78%)	—

Anomalous top production via FCNC



Anomalous top production via FCNC may cause observed excess, but it gives no explanation for e^+p/e^-p asymmetry

HERA I analyses have set limits on $\kappa_{tu\gamma}$ and ν_{tuZ}



HERA is competitive!

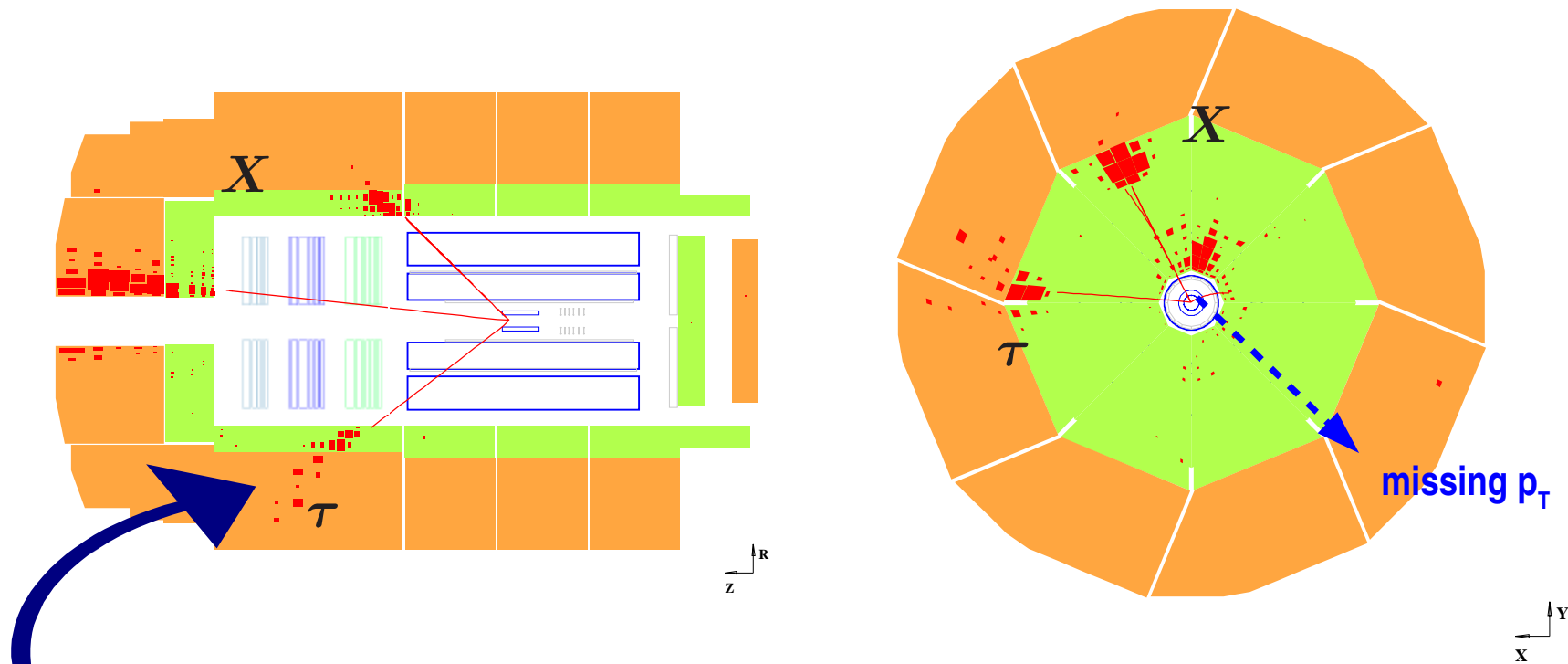
HERA I (117 pb^{-1}):
H1 upper limit
 $\sigma(ep \rightarrow eXt) < 0.55 \text{ pb}$
is weaker than ZEUS limit due to excess!

[Eur.Phys.J. C33 (2004) 9-22]

Isolated tau leptons and p_T^{miss} (H1)

it's very difficult to identify tau leptons at HERA \rightarrow dedicated analysis needed!

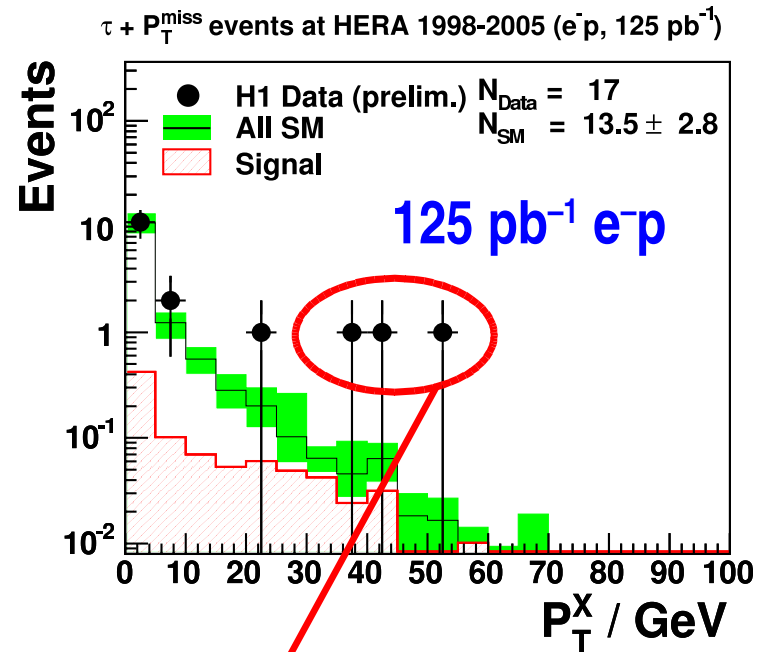
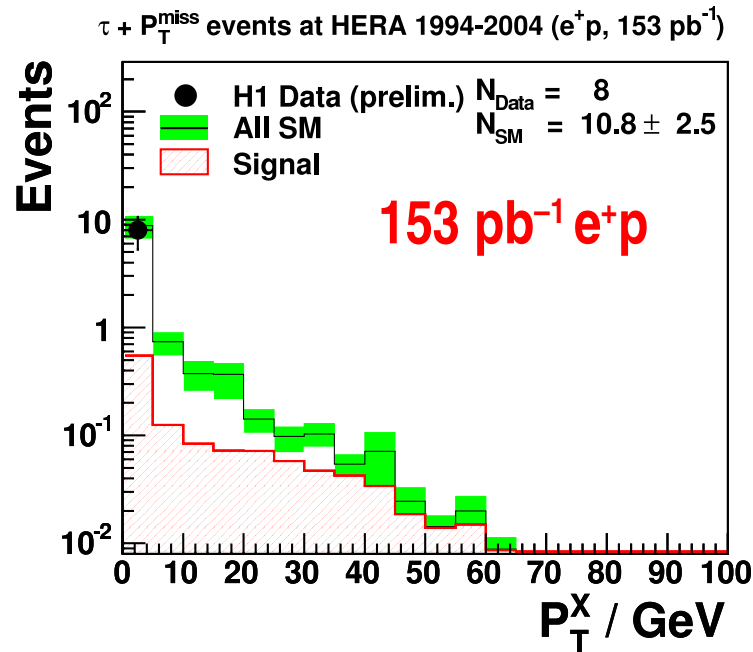
H1 $\tau + P_T^{\text{miss}}$ candidate with large P_T^X



$$P_T^{\text{miss}} = 59 \text{ GeV} \quad P_T^\tau = 14 \text{ GeV} \quad P_T^X = 51 \text{ GeV}$$

Tau-identification (hadronic decays only) based on jets with low track multiplicity and narrow “pencil-like” shape

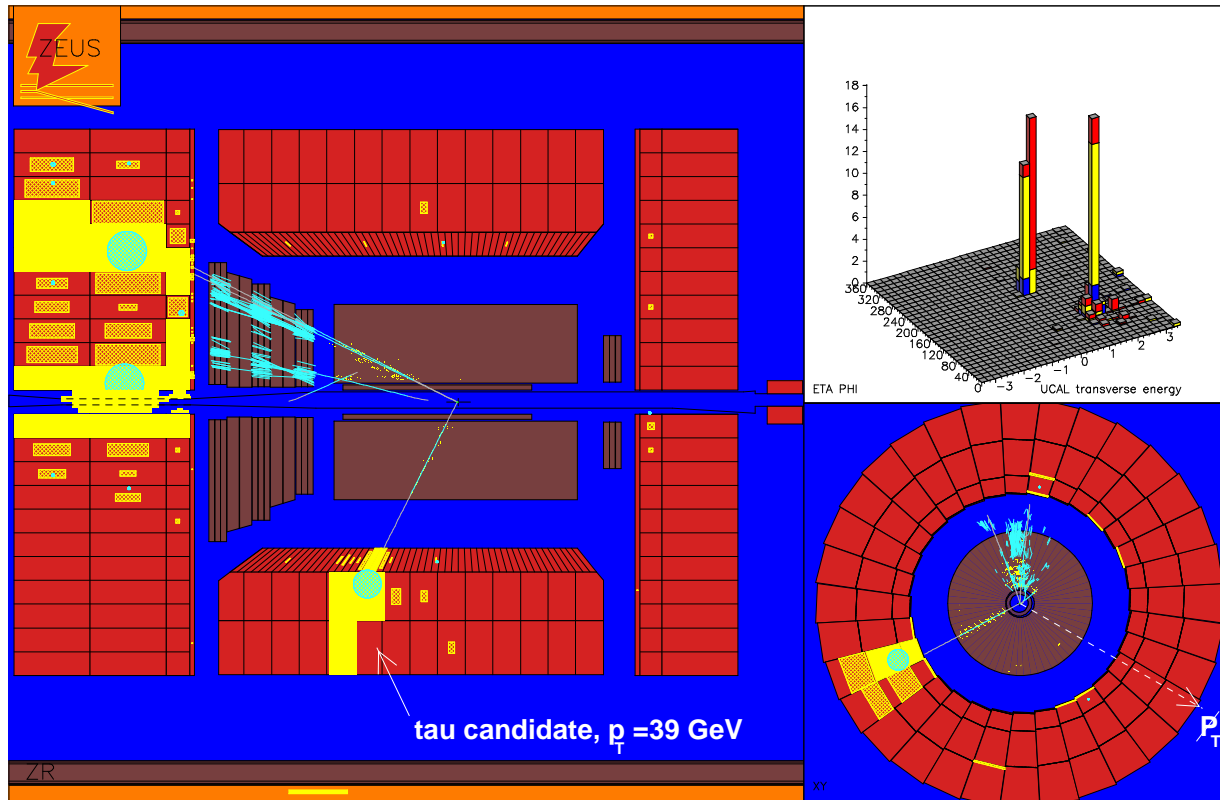
Isolated tau leptons and p_T^{miss} (H1)



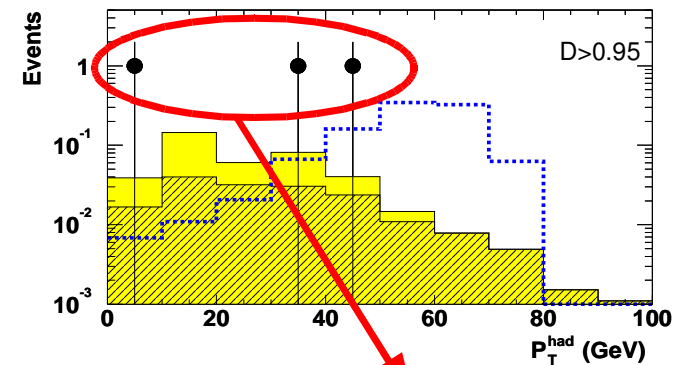
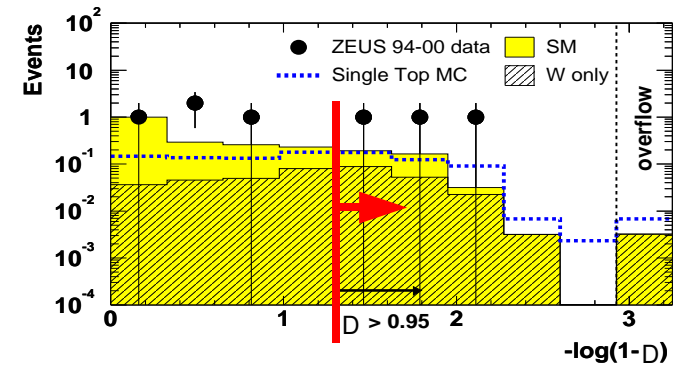
H1 (prelim.) 279 pb^{-1}	$\tau + p_T^{\text{miss}}$ obs. / exp.
Total	25 / 24.2 $^{+4.20}_{-5.80}$
$p_T^X > 25$ GeV	3 / 0.74 $^{+0.19}_{-0.16}$
e^-p (125 pb^{-1})	3 / 0.35 $^{+0.10}_{-0.08}$
e^+p (153 pb^{-1})	0 / 0.40 $^{+0.10}_{-0.10}$

Remarkable events with an isolated tau lepton and p_T^{miss} is observed at high p_T^X in e^-p data!

Isolated tau leptons and p_T^{miss} (ZEUS)



HERA I e^+p data 130 pb^{-1} :



Phys.Lett. B583 (2004) 41-58

Slight excess in the tau channel!
Results from HERA II still to come...

Preselection: 7 / $2.2^{+0.39}_{-0.58}$

D: discriminator variable to separate τ -jets from q-jets

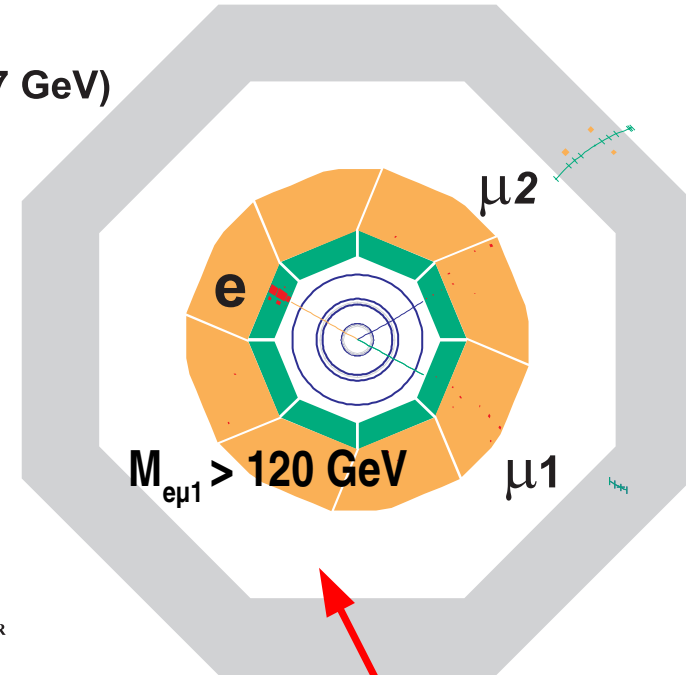
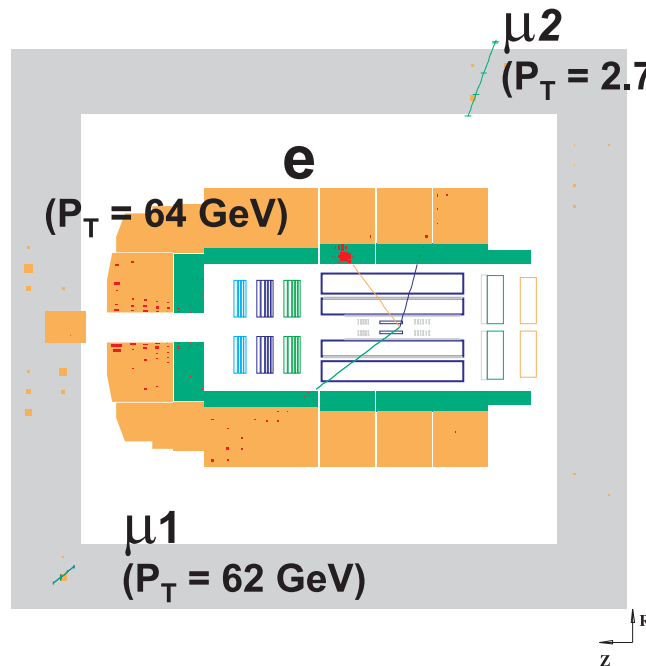
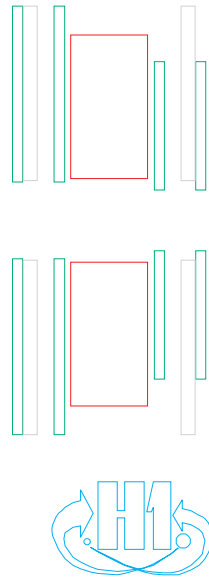
$D > 0.95$: 3 / $0.4^{+0.12}_{-0.13}$

$p_T^X > 25 \text{ GeV}$: 2 / $0.2^{+0.05}_{-0.05}$

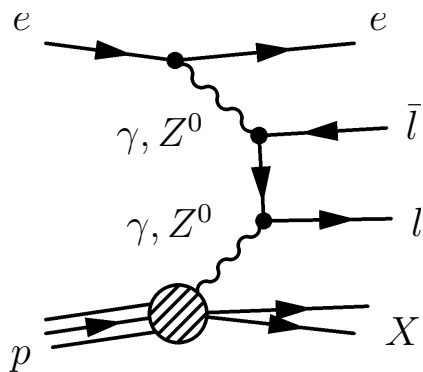
$p_T^X > 40 \text{ GeV}$: 1 / $0.07^{+0.39}_{-0.58}$

Multi-Lepton Events (H1)

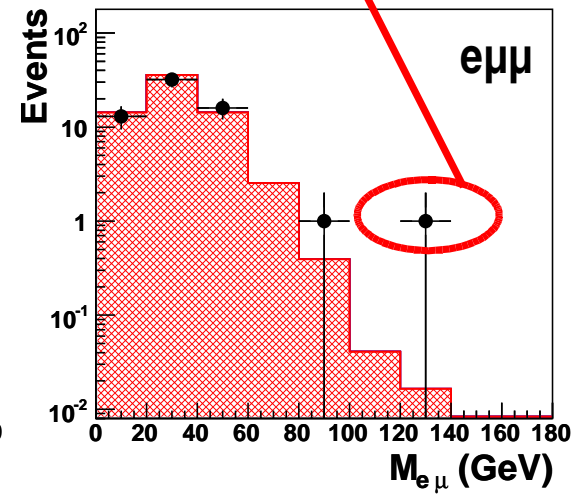
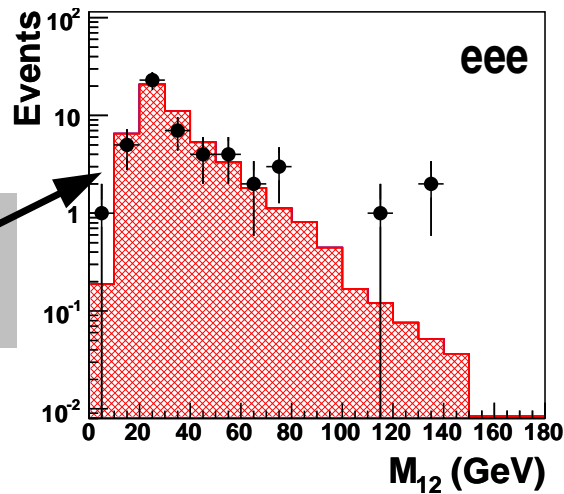
Spectacular multi-lepton events with very high invariant masses are detected!



Dominant SM process is elastic $\gamma\gamma$ scattering



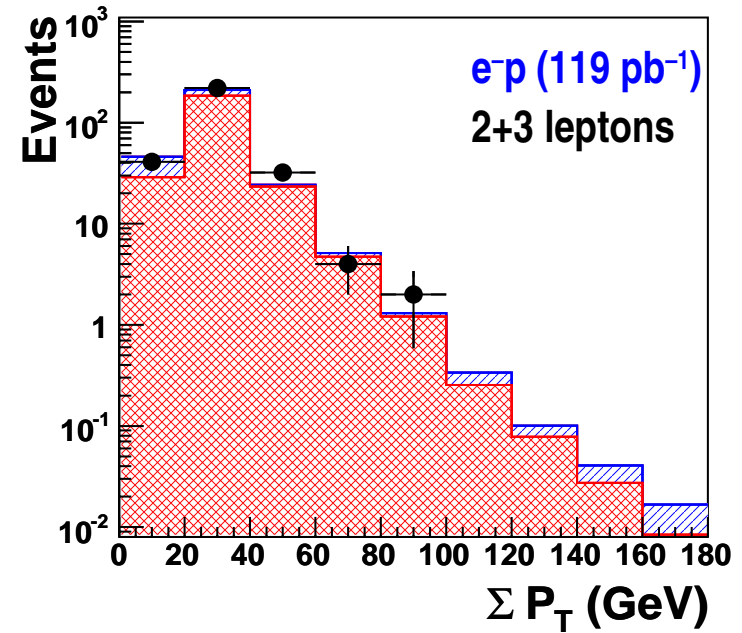
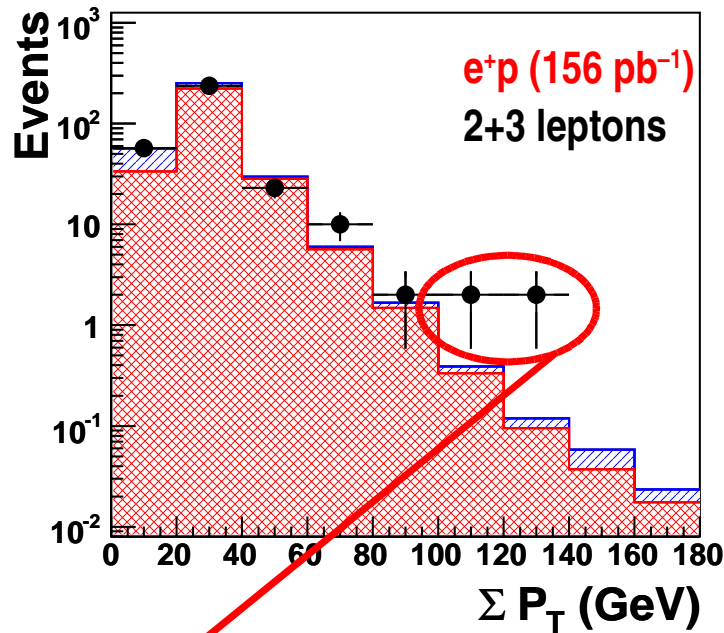
low p_T and
low inv. mass



Multi-Lepton Events (H1)

- H1 Data (prelim.)
- ▨ DIS+Compton
- ▩ Pair Production

Covered analysis topologies:
 2 leptons: ee, μμ, eμ
 3 leptons: eee, eμμ



(Σp_T is the scalar sum of the lepton transverse momenta)

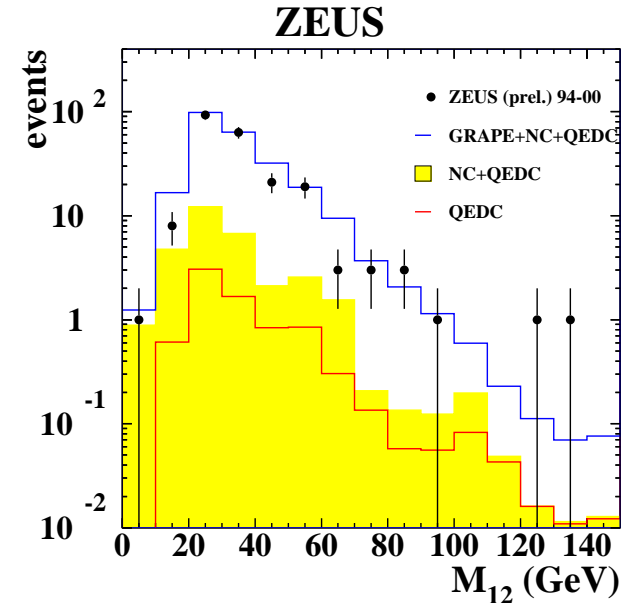
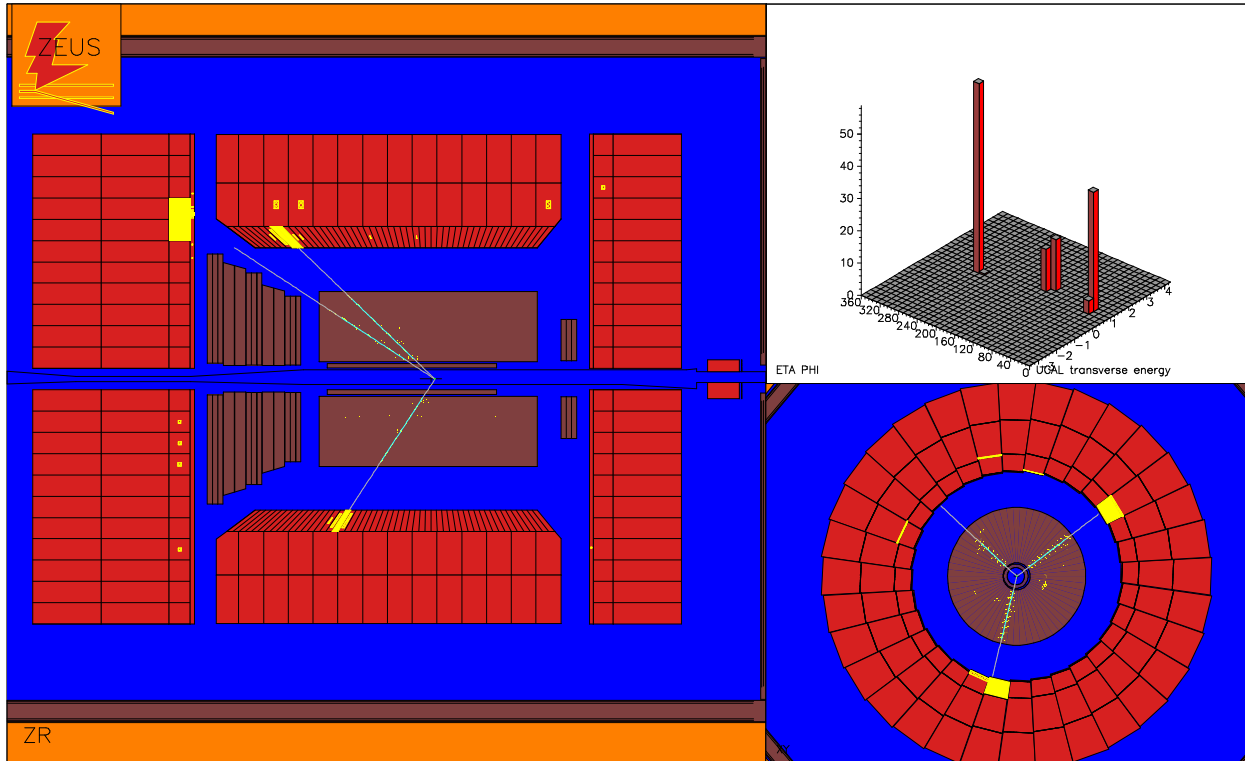
The excess of multi-electron events at high Σp_T is seen in HERA I data. [Eur.Phys.J. C31 (2003) 17-29]

New HERA II data is compatible with SM expectation

	H1 Preliminary 275 pb ⁻¹	
$\Sigma p_T > 100$ GeV	Data	SM
HERA I+II (275 pb ⁻¹)	4	1.1 ± 0.2
e ⁺ p (156 pb ⁻¹)	4	0.6 ± 0.1
e ⁻ p (119 pb ⁻¹)	0	0.5 ± 0.1

Multi-Lepton Events (ZEUS)

eee event in HERA I ...



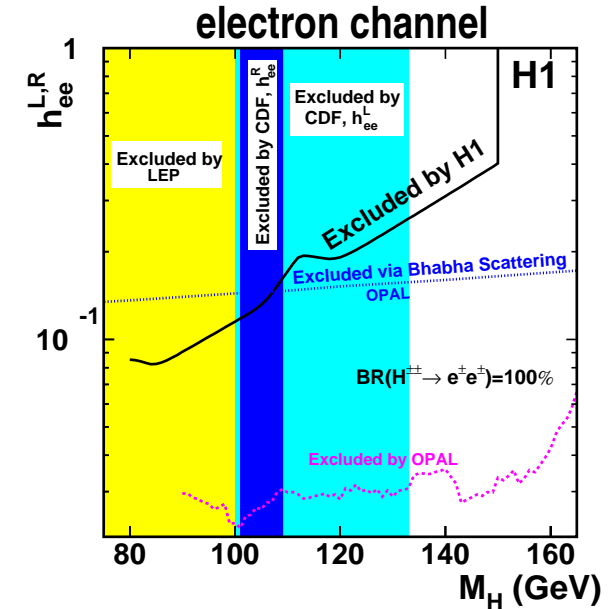
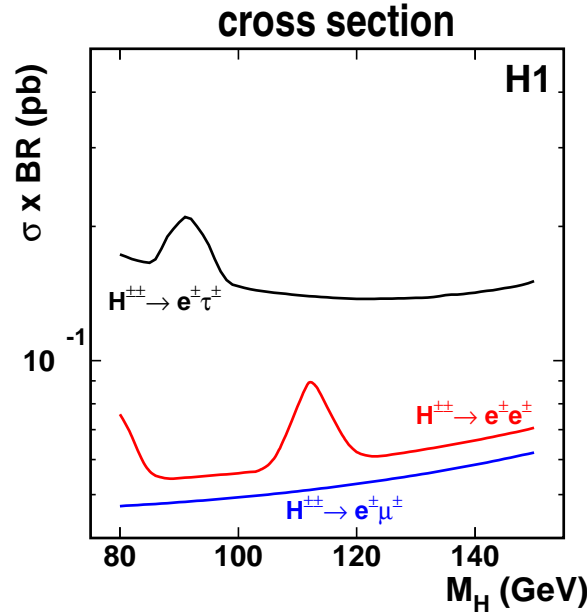
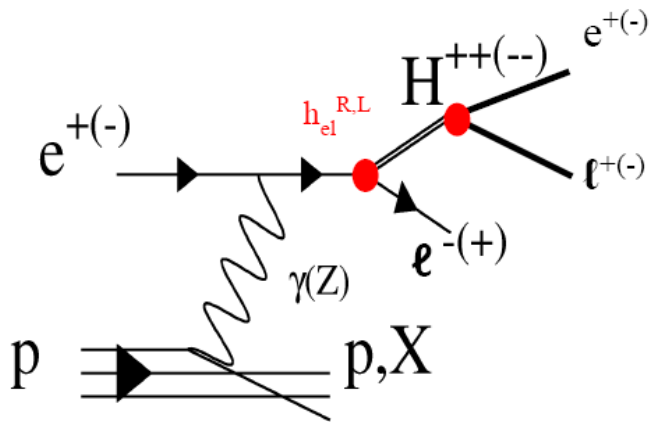
M_{12} : inv. mass of two electrons
with highest inv. mass

HERA I analysis (130 pb^{-1})	events with two or more electrons:	
Type	data	SM
all	217	248.5 ± 3.9
$E_{T,e1} > 30 \text{ GeV}$	8	7.1 ± 0.3
$M_{12} > 100 \text{ GeV}$	2	1.14 ± 0.09

Event yield is
compatible
with SM

Doubly charged Higgs (H1)

Dedicated search for
 ee , $e\mu$ or $e\tau$ pairs with equally
 charged leptons (=beam charge)



HERA I analysis (118 pb⁻¹):

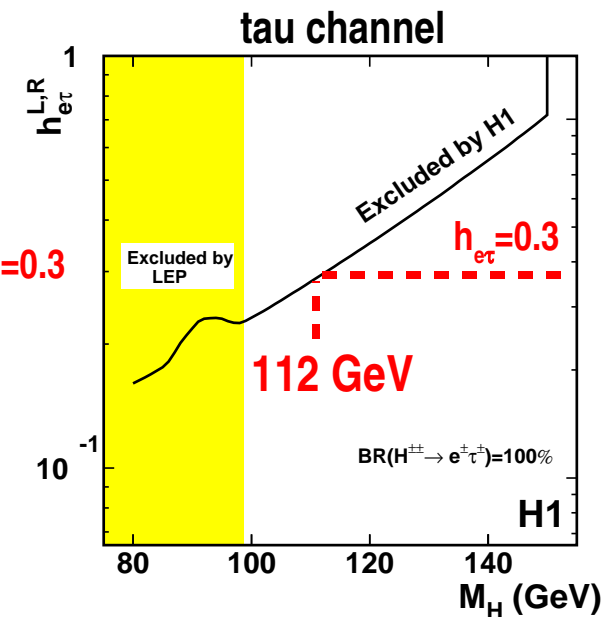
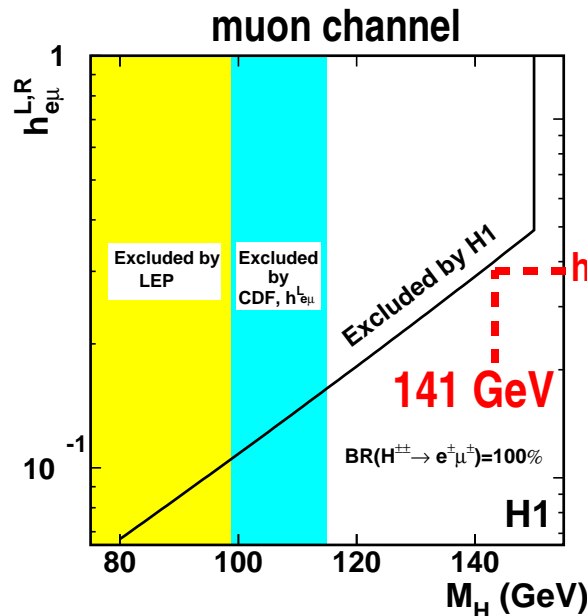
ee : $3 / 2.45 \pm 0.11$

Results: $e\mu$: $1 / 4.12 \pm 0.44$

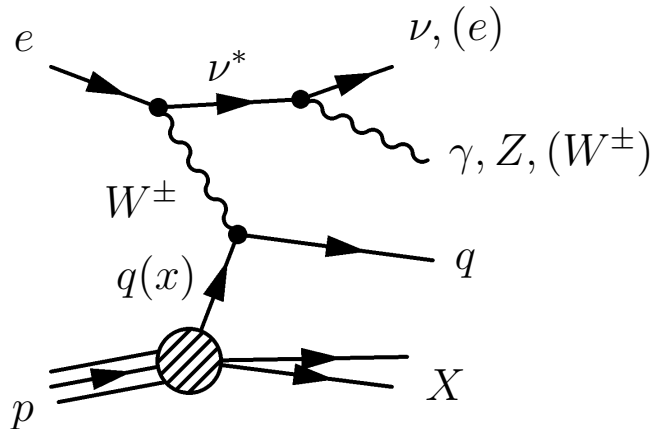
$e\tau$: $1 / 2.07 \pm 0.54$

lower limit on mass of H^{++}
 assuming exclusive coupling
 $h_{e\mu, e\tau} = 0.3$ to $e\mu$ ($e\tau$)
 at **141 GeV (112 GeV)**

[Subm. to Phys.Lett.B, hep-ex/0604027]



Excited neutrinos (H1)



Signature:

- neutral lepton-boson resonance (CC-like)
- extra jets besides ν^* decay products

Feature:

cross sections are $O(10^2)$ larger in e^-p collisions due to favourable valence u-quark and helicity enhancement in CC

$$\mathcal{L}_{\text{int}} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[\underbrace{gf \frac{\tau^a}{2} W_{\mu\nu}^a}_{SU(2)} + \underbrace{g' f' \frac{Y}{2} B_{\mu\nu}}_{U(1)} + \underbrace{g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a}_{SU(3)} \right] F_L \quad \begin{pmatrix} \nu^* \\ e^* \end{pmatrix}$$

Hagiwara et al, ZPC 29 (1985) 115.
Boudjema et al, ZPC 57 (1993) 425.

boson couplings to fermion F and excited fermion F*:

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

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

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

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

$$C_{\gamma e e^*} = -\frac{1}{4} (f + f')$$

→ photon coupling to $\nu\nu^*$ only for $f \neq f'$
photon coupling to ee^* only for $f \neq -f'$

Excited neutrinos (H1)

Analysis reaches 80-90% (~70%) acceptance assuming $f=-f'$ ($f=+f'$) by covering the channels:

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

$\nu^* \rightarrow \nu Z \rightarrow qq'$

$\nu^* \rightarrow e W \rightarrow qq'$

Signature: **photon + p_T^{miss}**

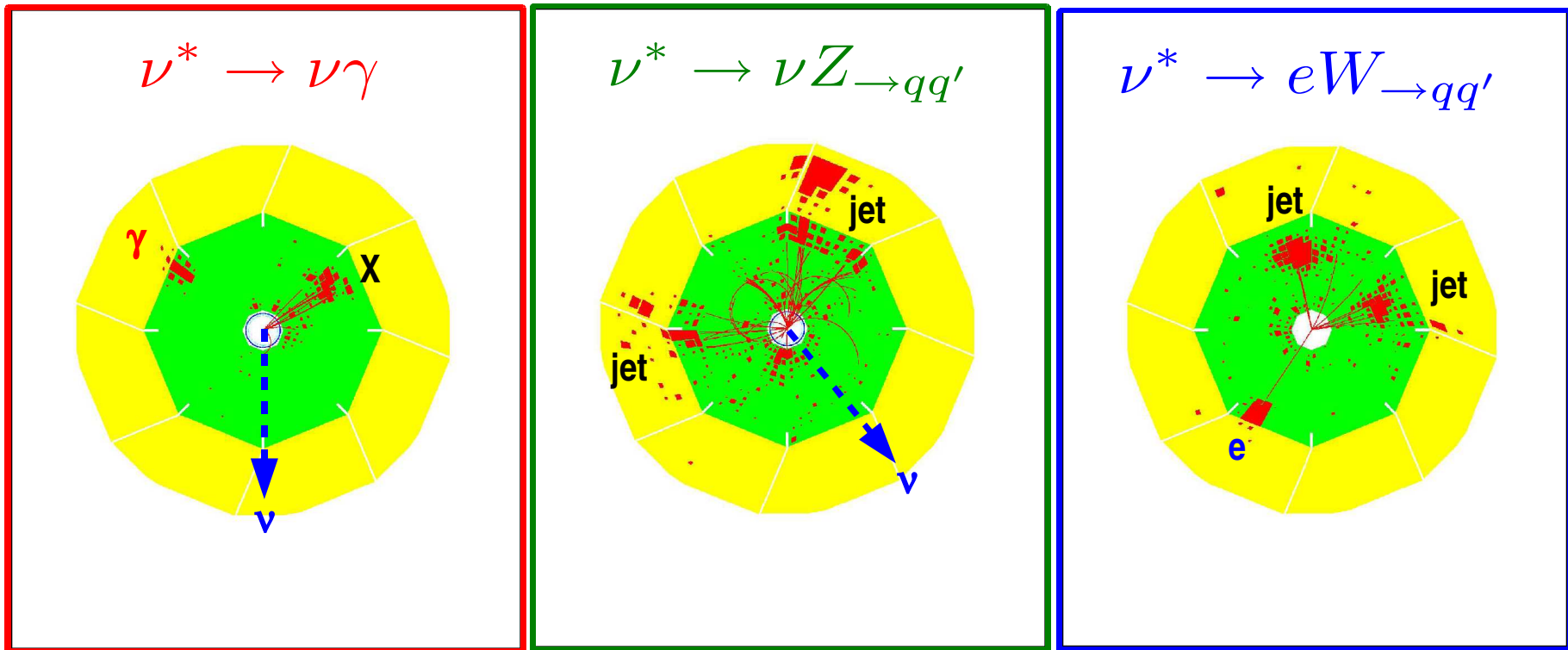
p_T^{miss} + multijet

e + multijet

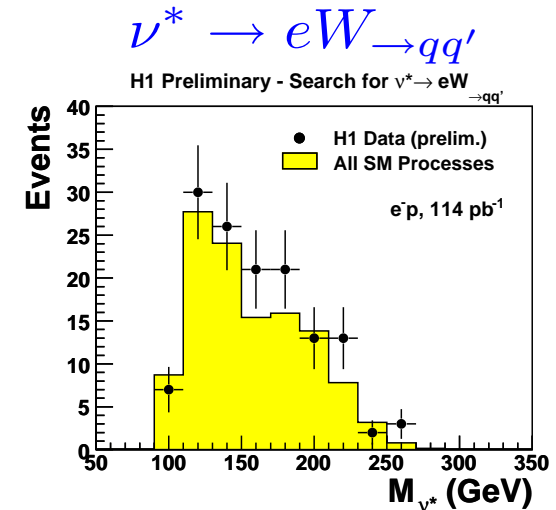
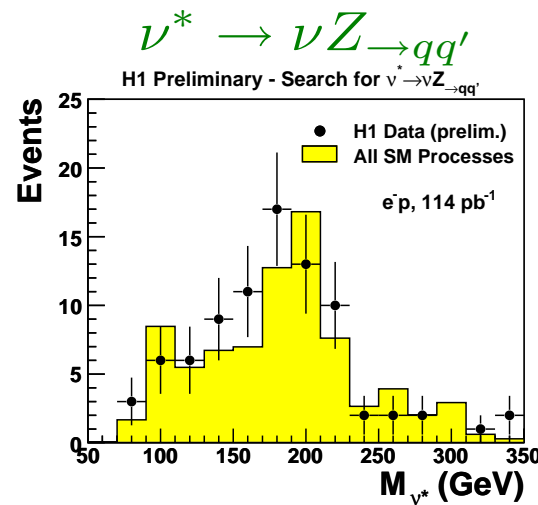
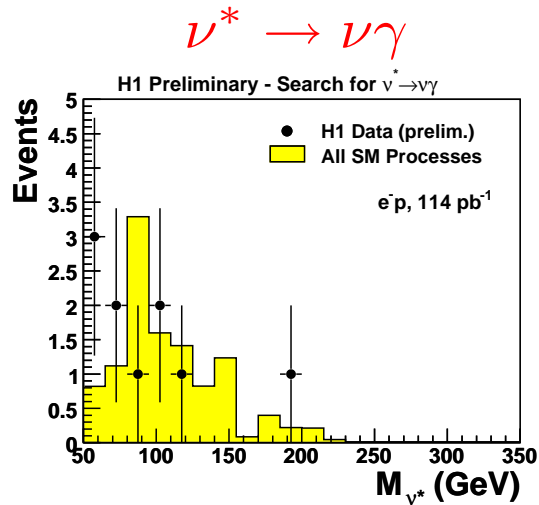
SM Bkg: **radiative CC**

CC (multijet)

NC (multijet)



Excited neutrinos (H1)



data/SM :

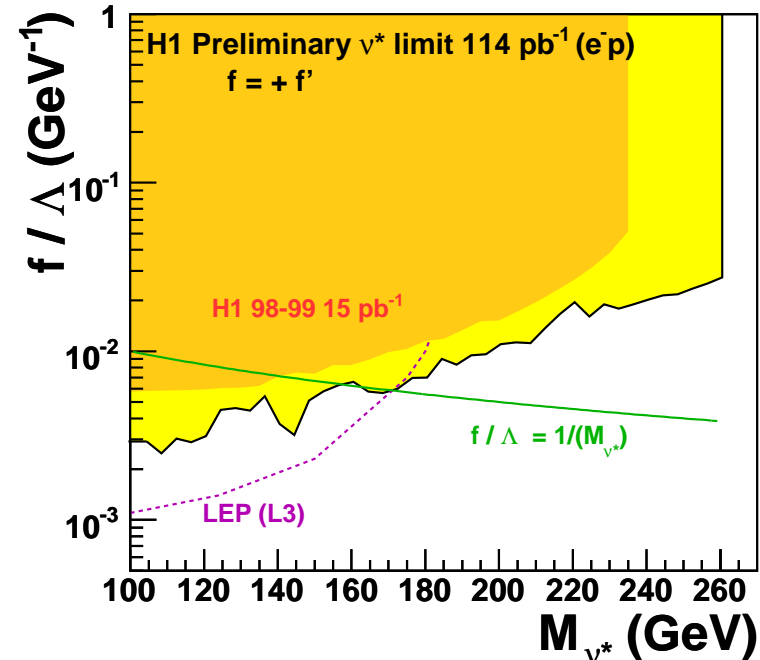
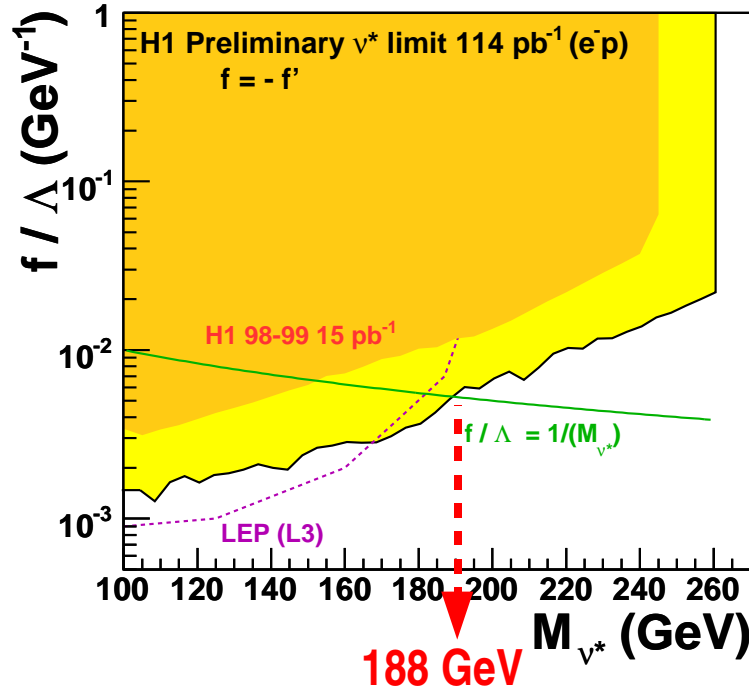
12 / 11.6 ± 2.5

88 / 81 ± 15

136 / 118 ± 22

Extended domain for ν^* production explored!

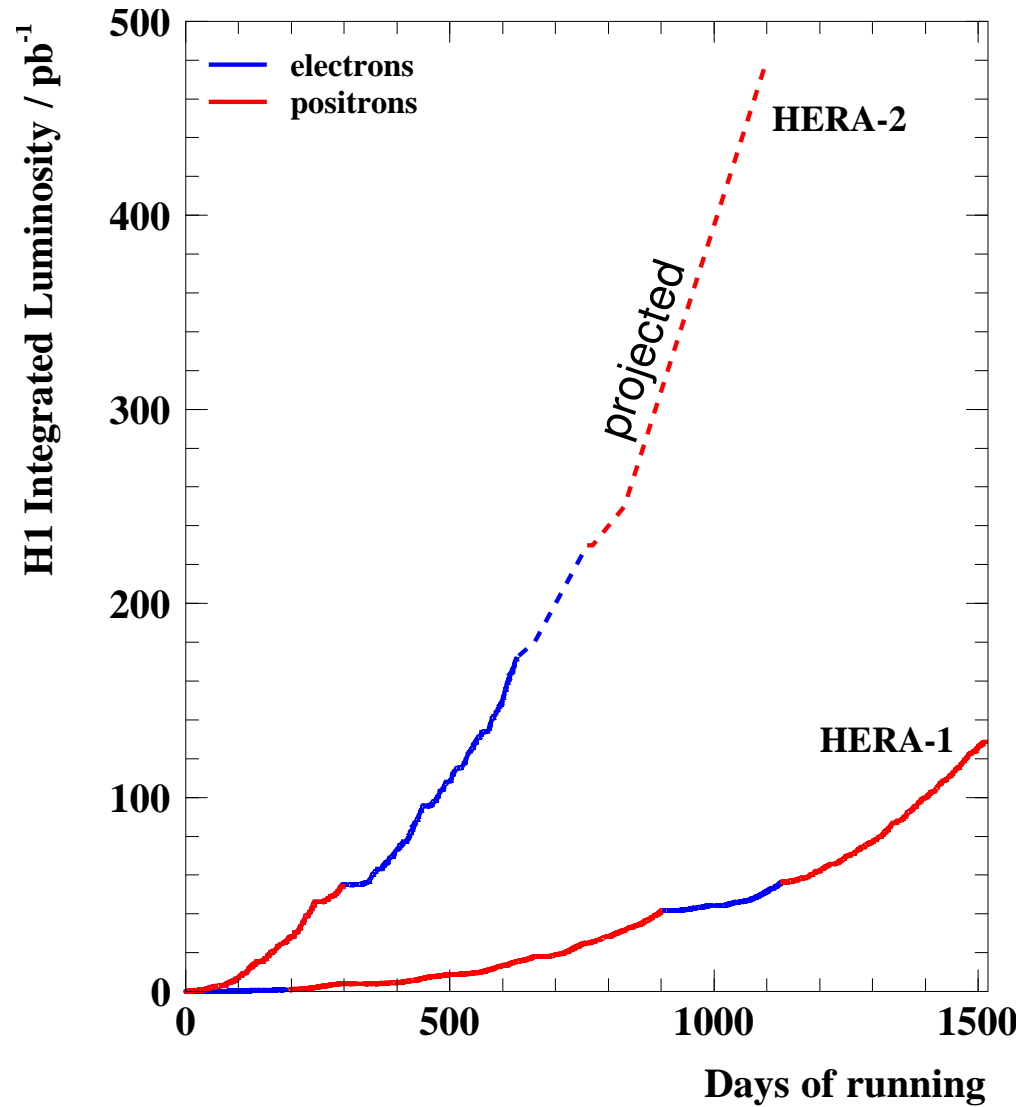
for $f=-f'$ and $f/\Lambda=1/M_{\nu^*}$
 $M_{\nu^*} < 188$ GeV
 excluded



Summary

- **Excess of isolated leptons observed at H1 in old and new e^+p data $\rightarrow e^+p/e^-p$ asymmetry apparent**
- **No such excess at ZEUS**
- **Events with Tau leptons + p_T^{miss} :**
 - Slight excess in both experiments**
- **Remarkable high- p_T multi-lepton events observed**
- **Competitive new limits on doubly-charged Higgs**
- **New domain explored for a possible excited neutrino production and limits extended**

Outlook



watch out for the data
still to come!