

# Searches for New Physics at HERA



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**on behalf  
of the H1 and ZEUS Collaborations**

signature driven:

- events with isolated leptons and missing  $p^T$
- multi lepton events
- general searches

model driven:

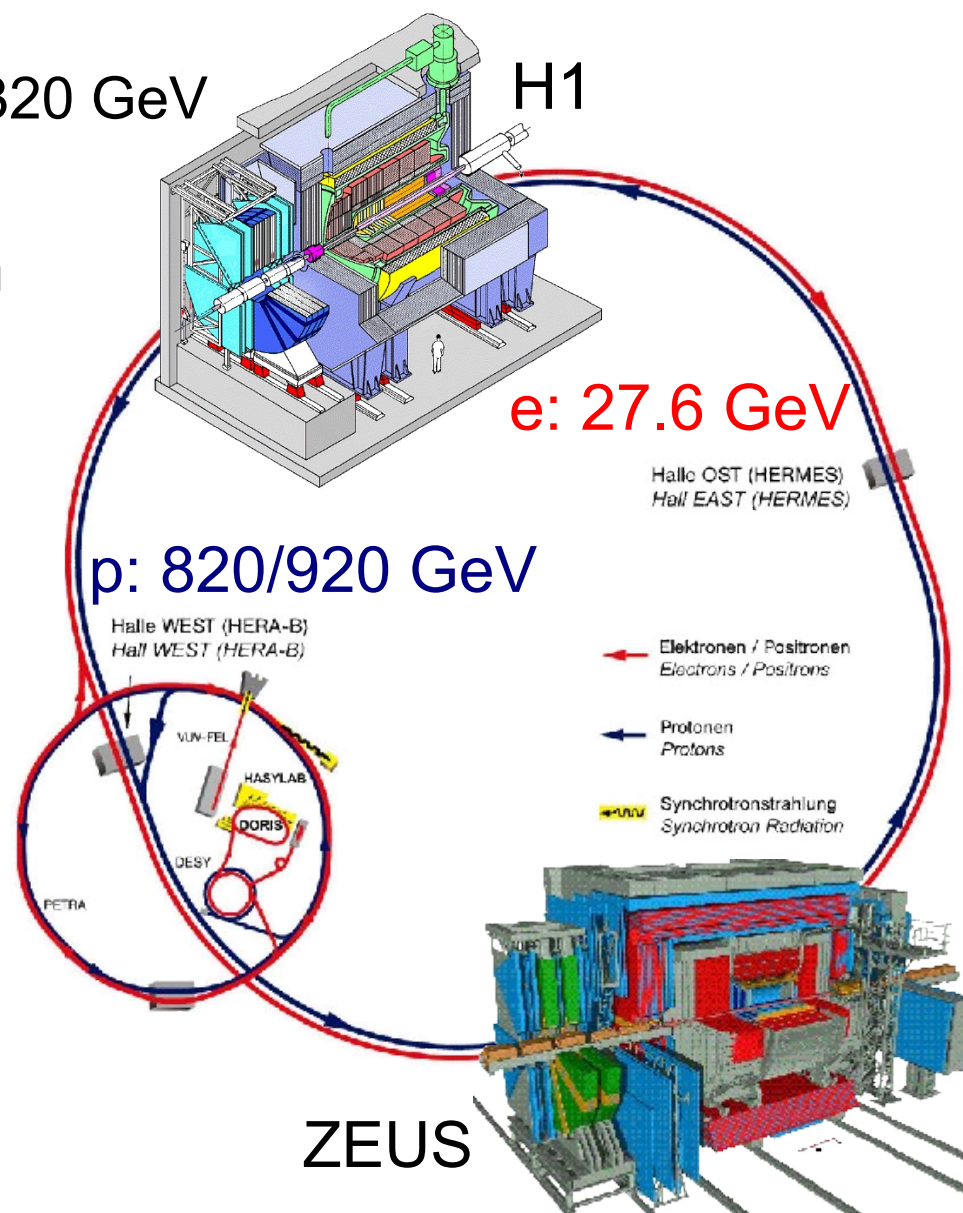
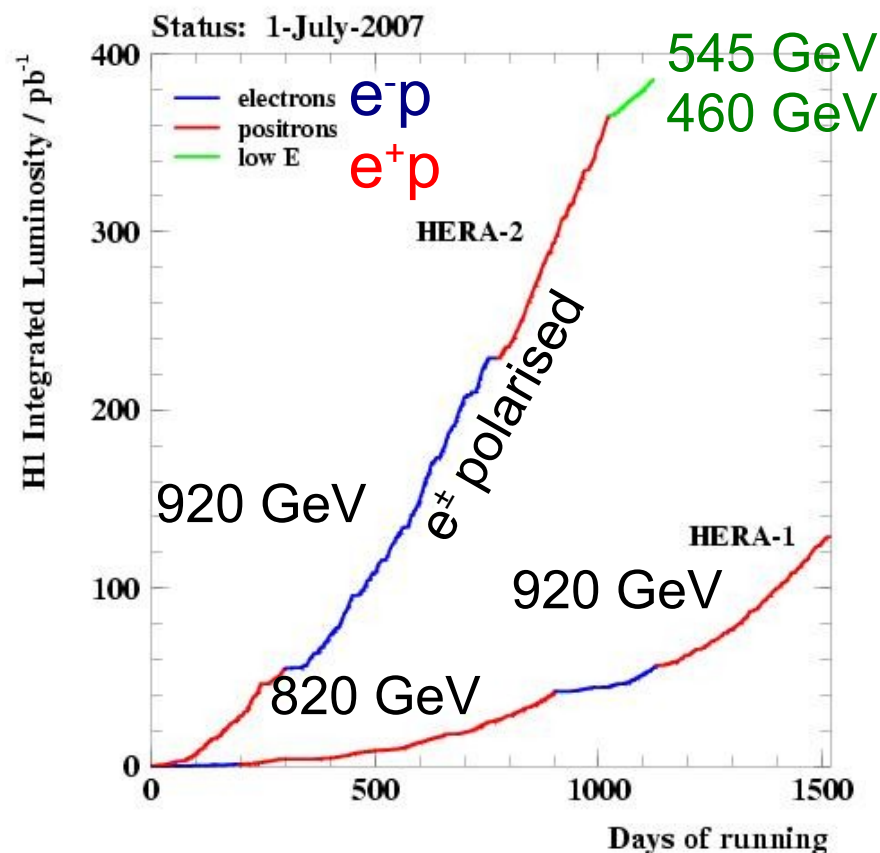
- excited leptons
- leptoquarks
  - lepton flavour violation
- NC DIS: quark radius, heavy leptoquarks

# The HERA Collider

the only ep collider in the world:  $\sqrt{s} = 320$  GeV

running from 1992 – 2007

integrated luminosity H1+ZEUS:  $\approx 1 \text{ fb}^{-1}$

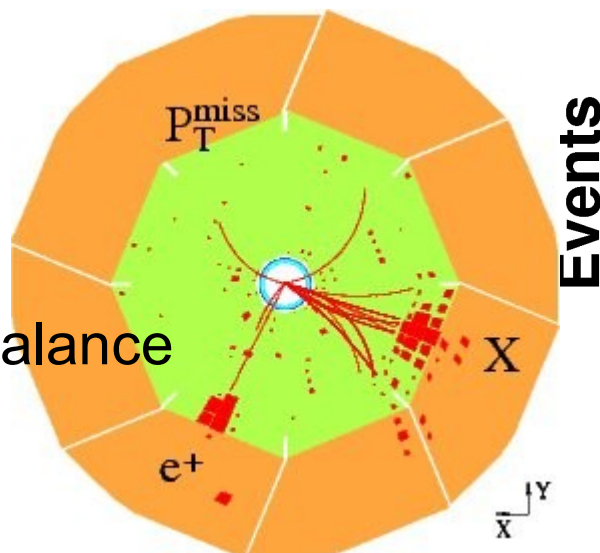




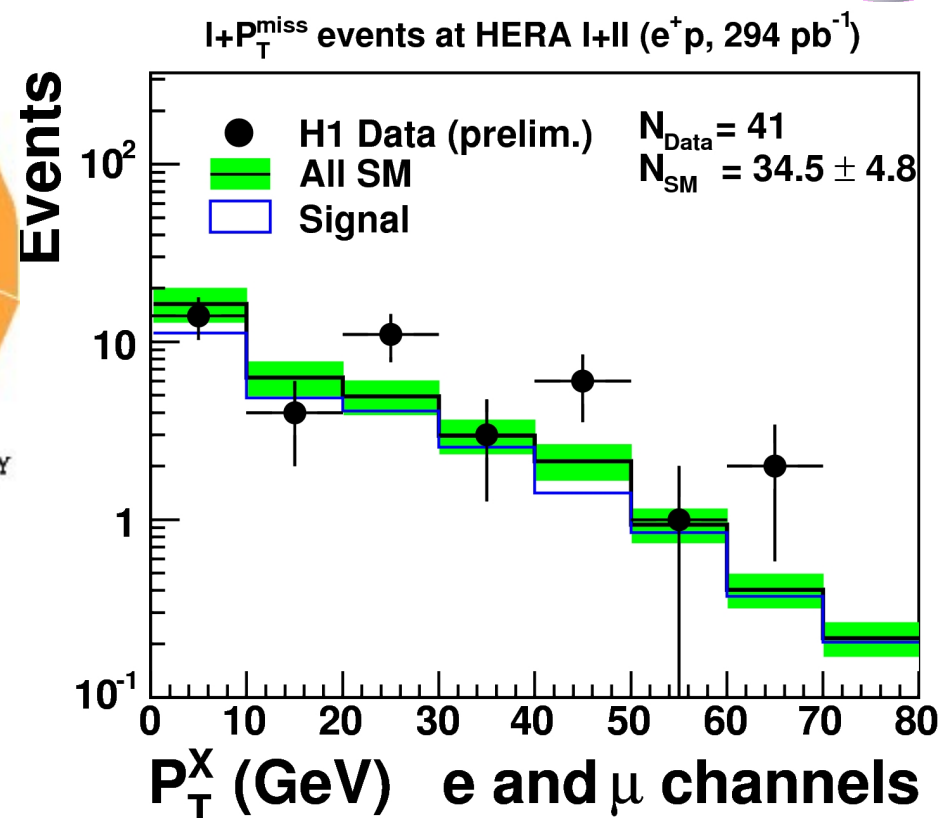
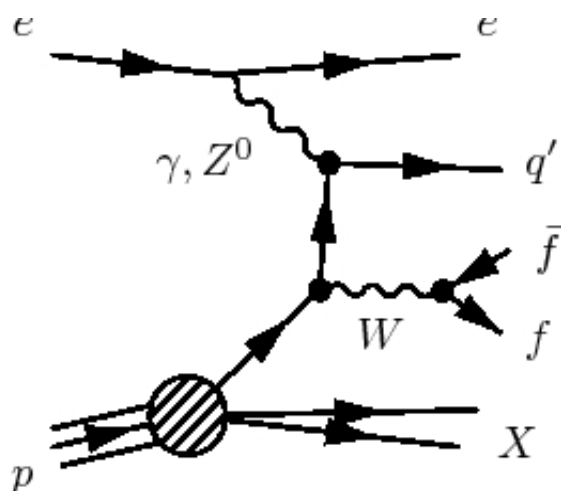
# Isolated Leptons and $p_T^{\text{miss}}$

## event selection

- lepton isolation  
 $P_t^l > 10 \text{ GeV}$ ,
- momentum imbalance  
 $P_T^{\text{miss}} > 12 \text{ GeV}$



Standard Model process:  
single W production



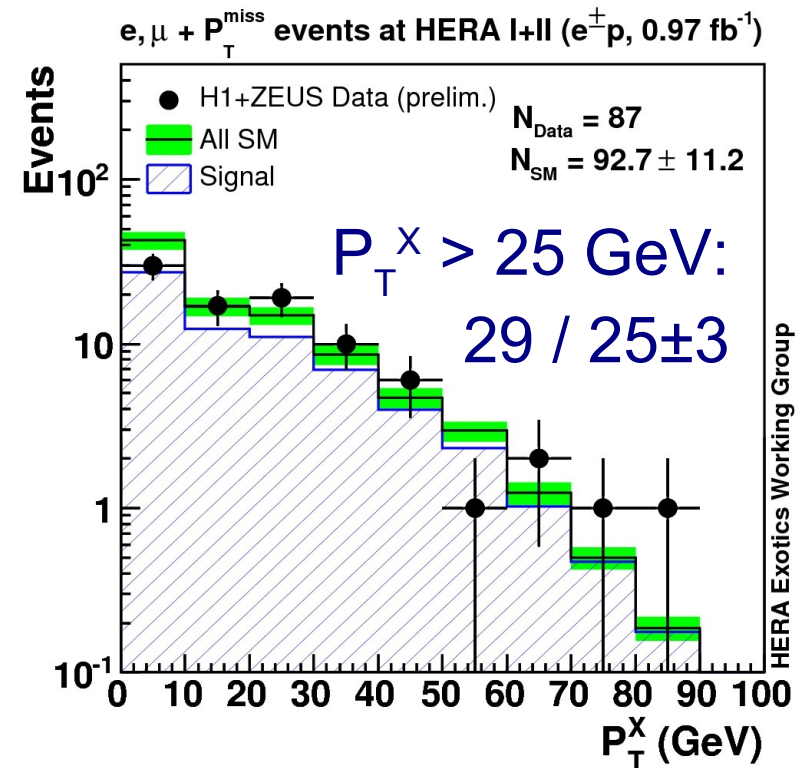
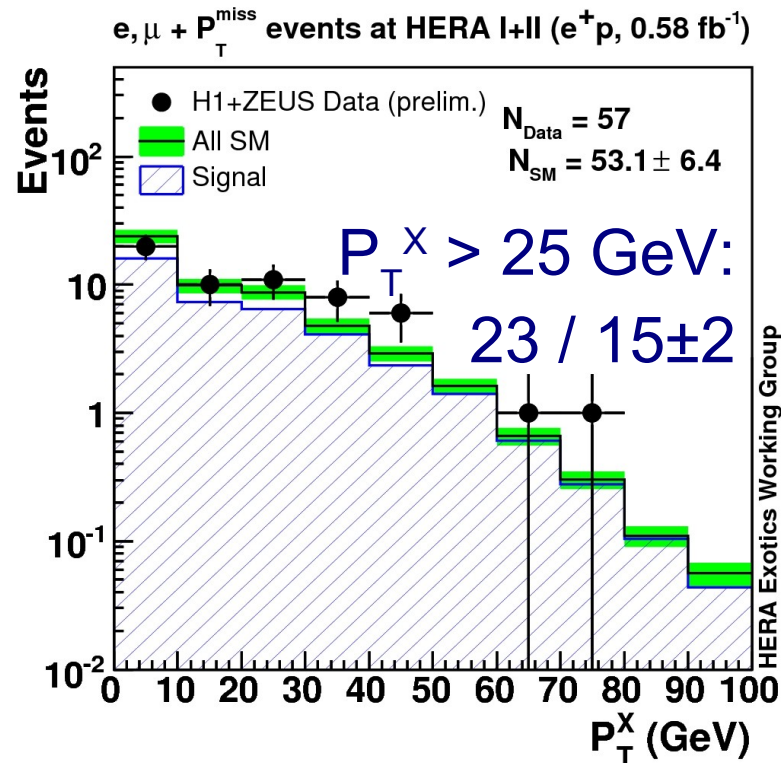
in  $e^+p$  and for  $P_T^X > 25 \text{ GeV}$ :

- H1: 21 events  
for  $9 \pm 1.5$  expected:  $3.0 \sigma$
- ZEUS observe no deviation from SM

# Isolated Leptons and $p_T^{\text{miss}}$



H1 and ZEUS combined in a common phase space



- excess at  $P_T^X > 25 \text{ GeV}$  in the  $e^+p$  data
  - remains with  $1.8 \sigma$ , but is not seen in the total sample (including  $e^-p$  data)
- single  $W$  production has been seen at HERA

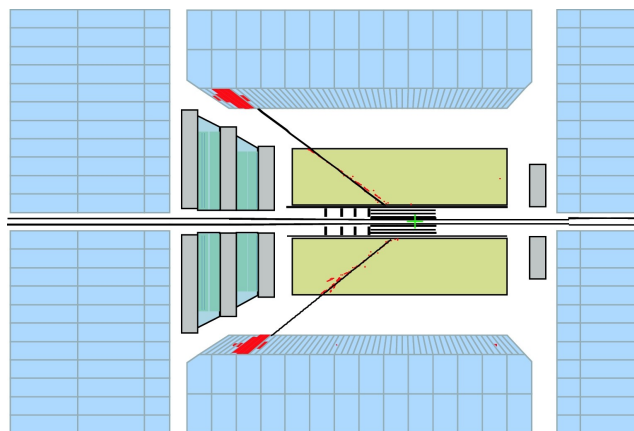
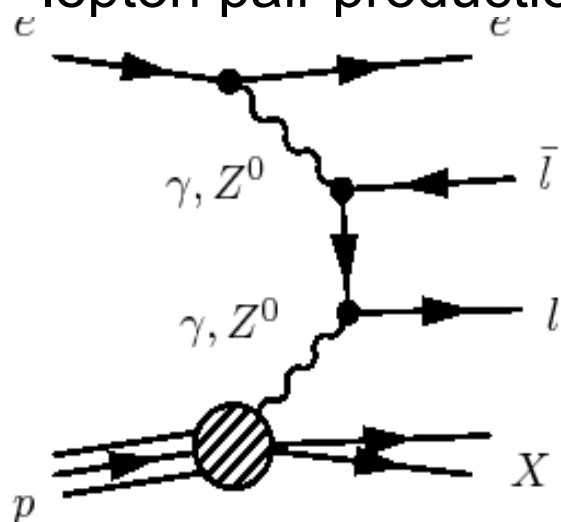


# Multi-Leptons

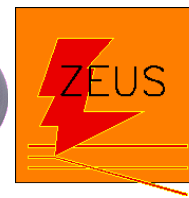
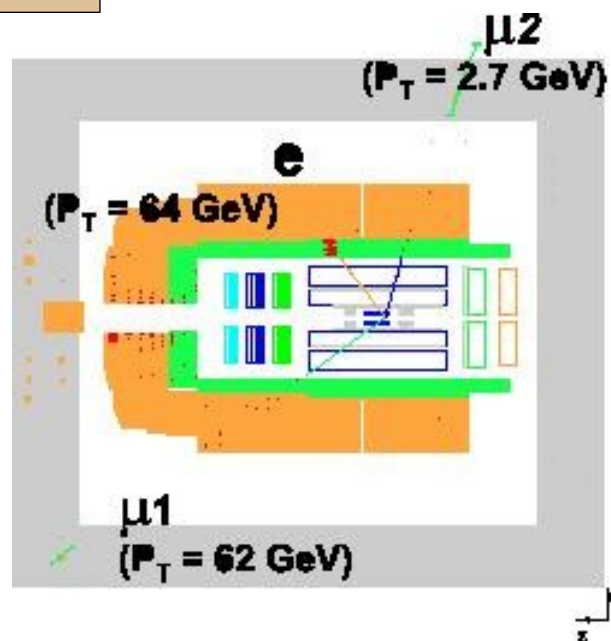
topology:

- $ee$ ,  $eee$
- $e\mu$ ,  $e\mu\mu$ ,  $\mu\mu$  (H1 only)

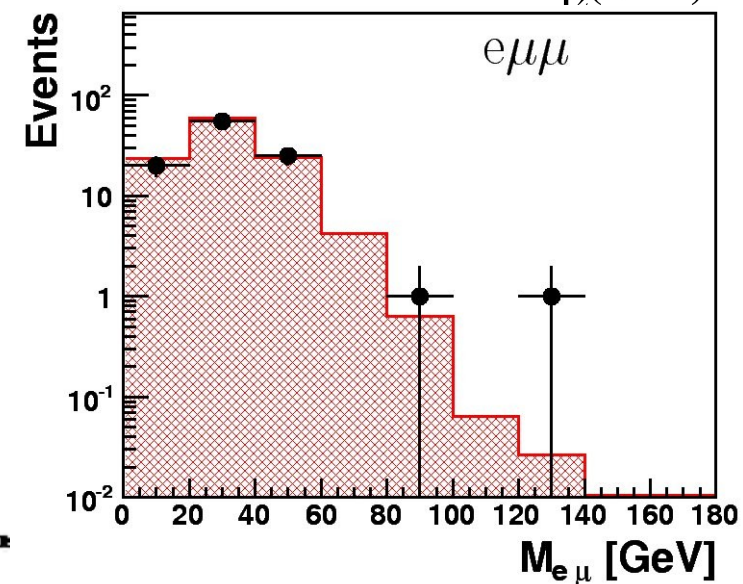
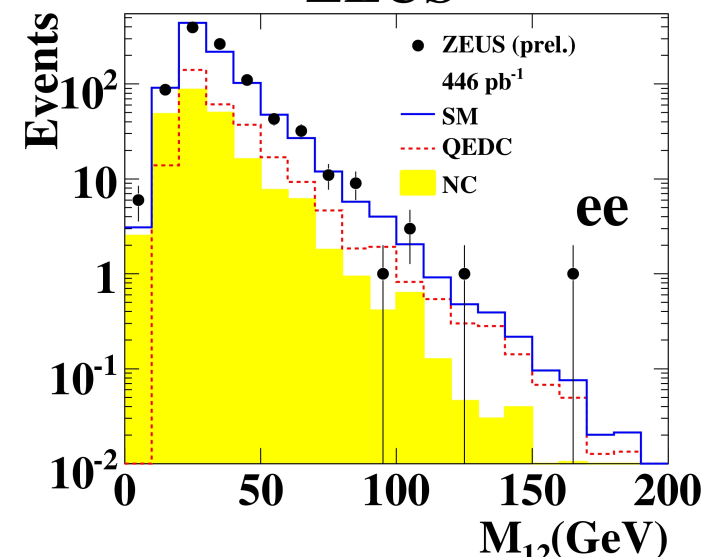
SM process:  
lepton pair production



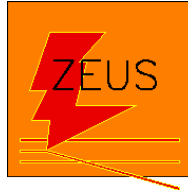
ZR View



ZEUS



# Multi-Leptons

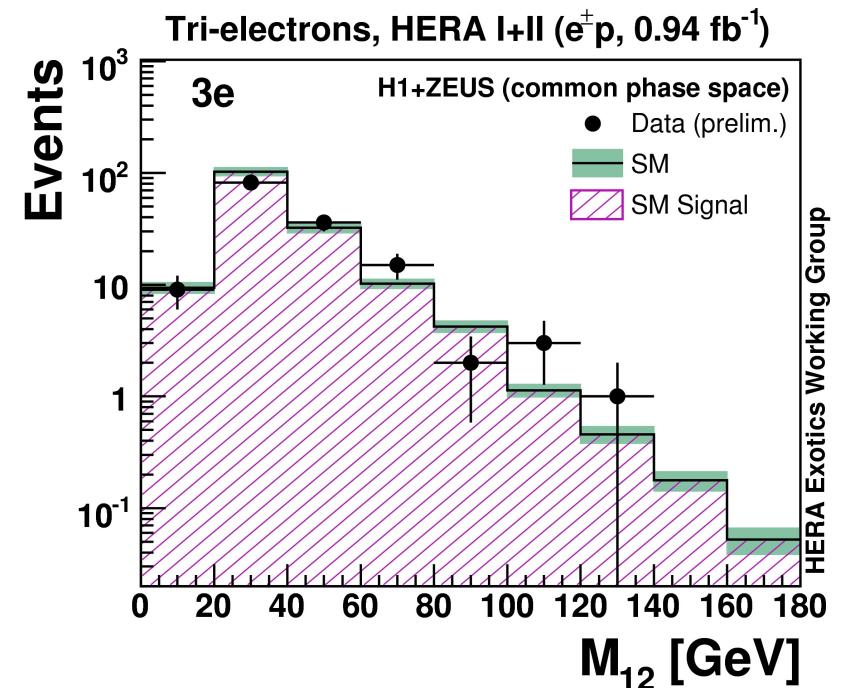
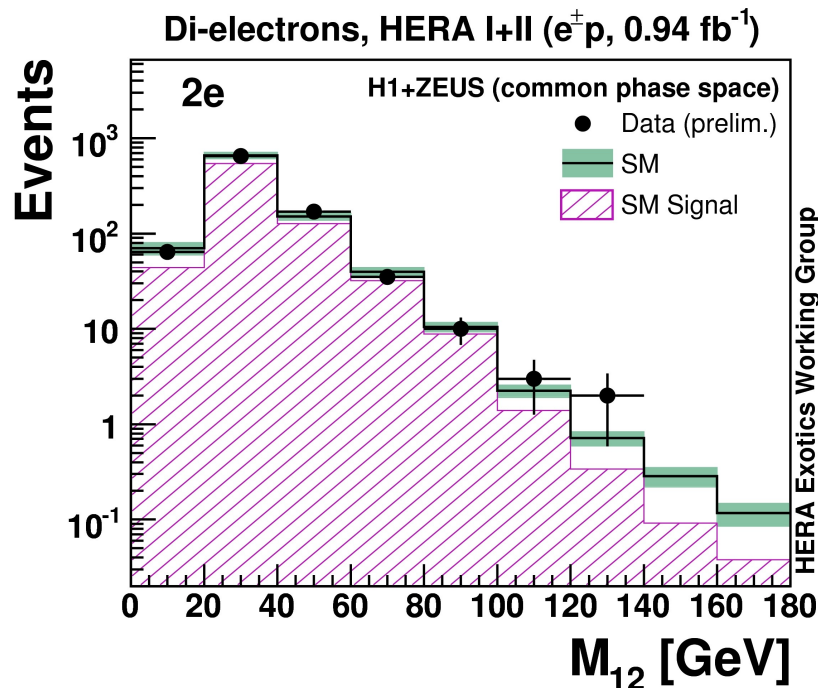


H1 and ZEUS combined  
in common phase space

- overall a good agreement between data and SM
- some interesting events at high masses

$M_{12} > 100 \text{ GeV}$

Selection	data	SM
$e^+p$		
2e	4	$1.97 \pm 0.22$
3e	4	$1.10 \pm 0.12$
$e^-p$		
2e	1	$1.44 \pm 0.15$
3e	0	$0.75 \pm 0.08$





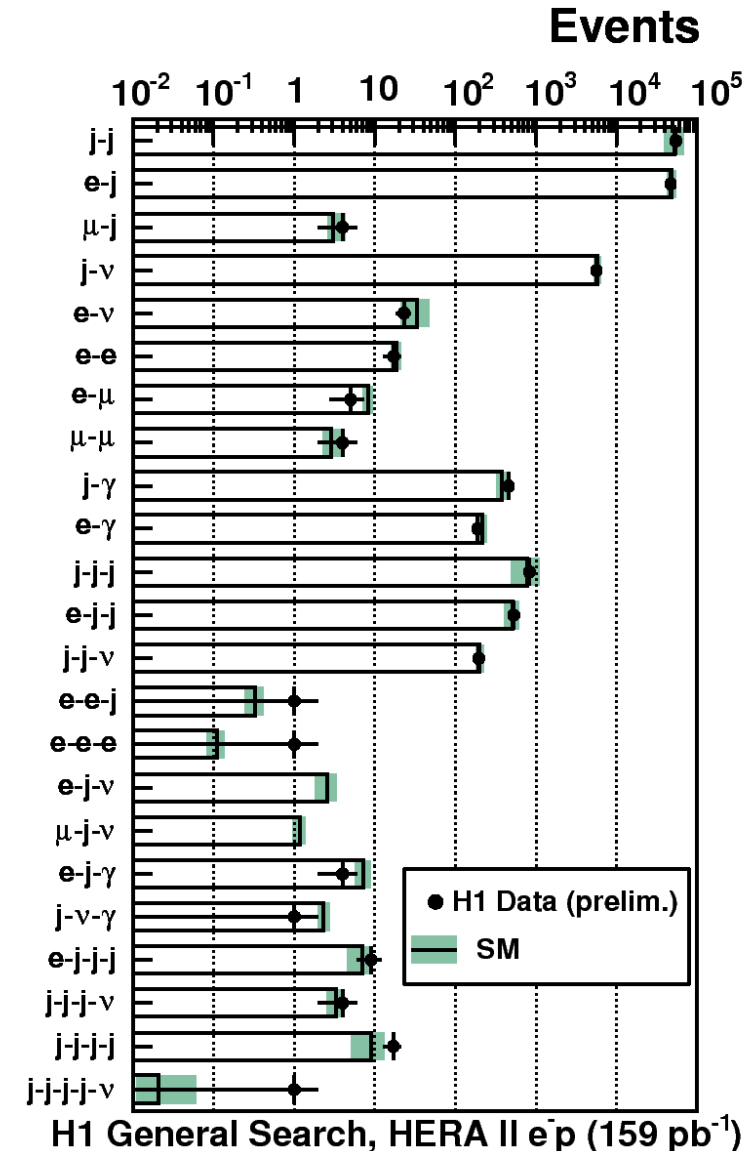
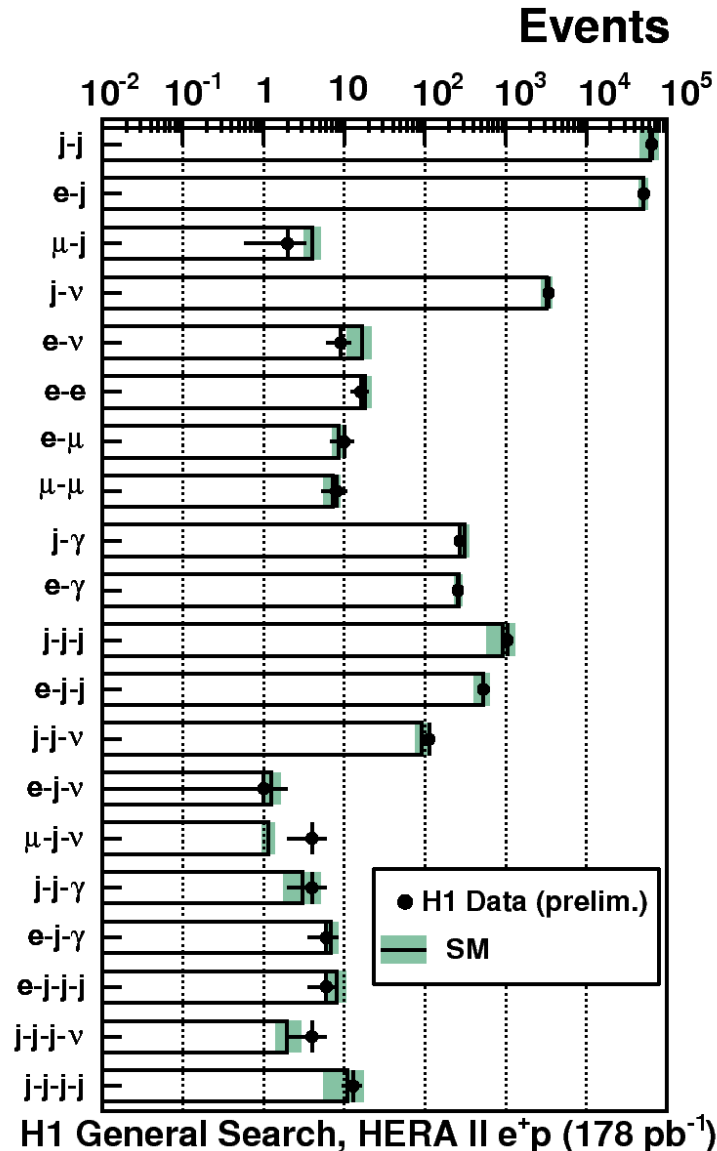
# General Search

all particles

- $P_T > 20\text{GeV}$
- $10^\circ < \theta < 140^\circ$
- $\Delta(\eta\theta) > 1$
- $E - P_z < 75\text{ GeV}$

largest  
fluctuation:  
 $\mu\text{-jet-v}$  →

in most channels  
good agreement  
between data and  
SM

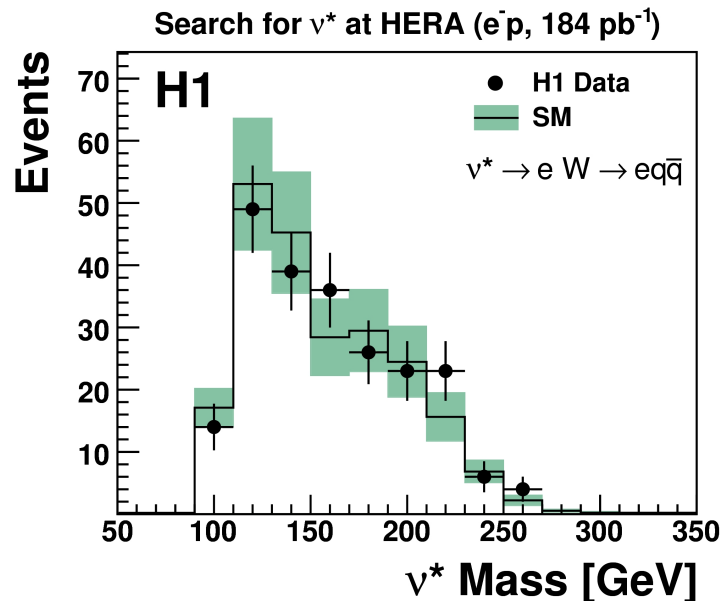
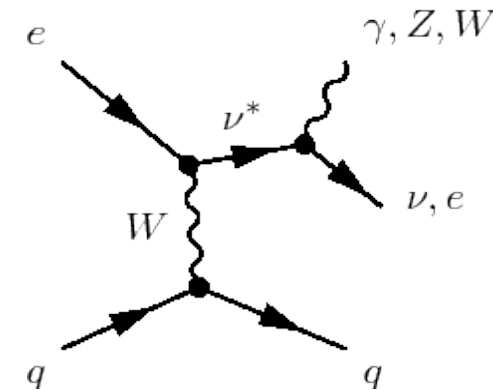




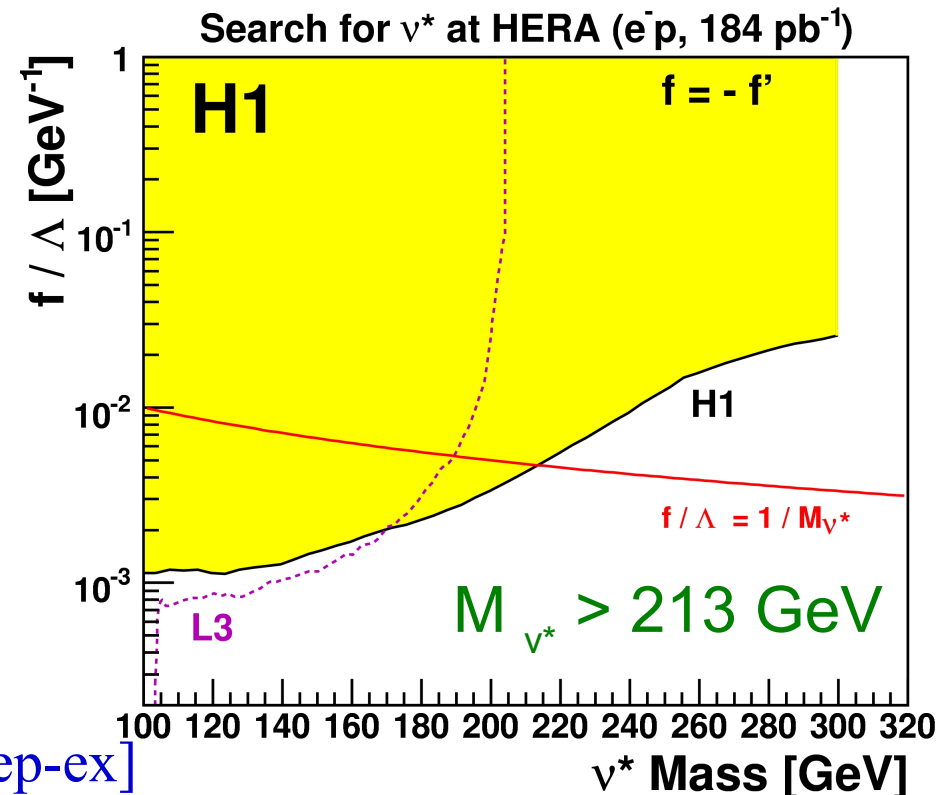
# Excited Neutrinos

$\nu^*$  composite fermion at scale  $\Lambda$   
 cross section proportional to coupling  
 $f$  and  $f'$  (similar to electroweak:  $g$  and  $g'$ )

- data well described by SM prediction:  
 no evidence for excited neutrinos



- nearly coverage of LEP (L3) results
- paper submitted: [arXiv:0802.1858 \[hep-ex\]](https://arxiv.org/abs/0802.1858)



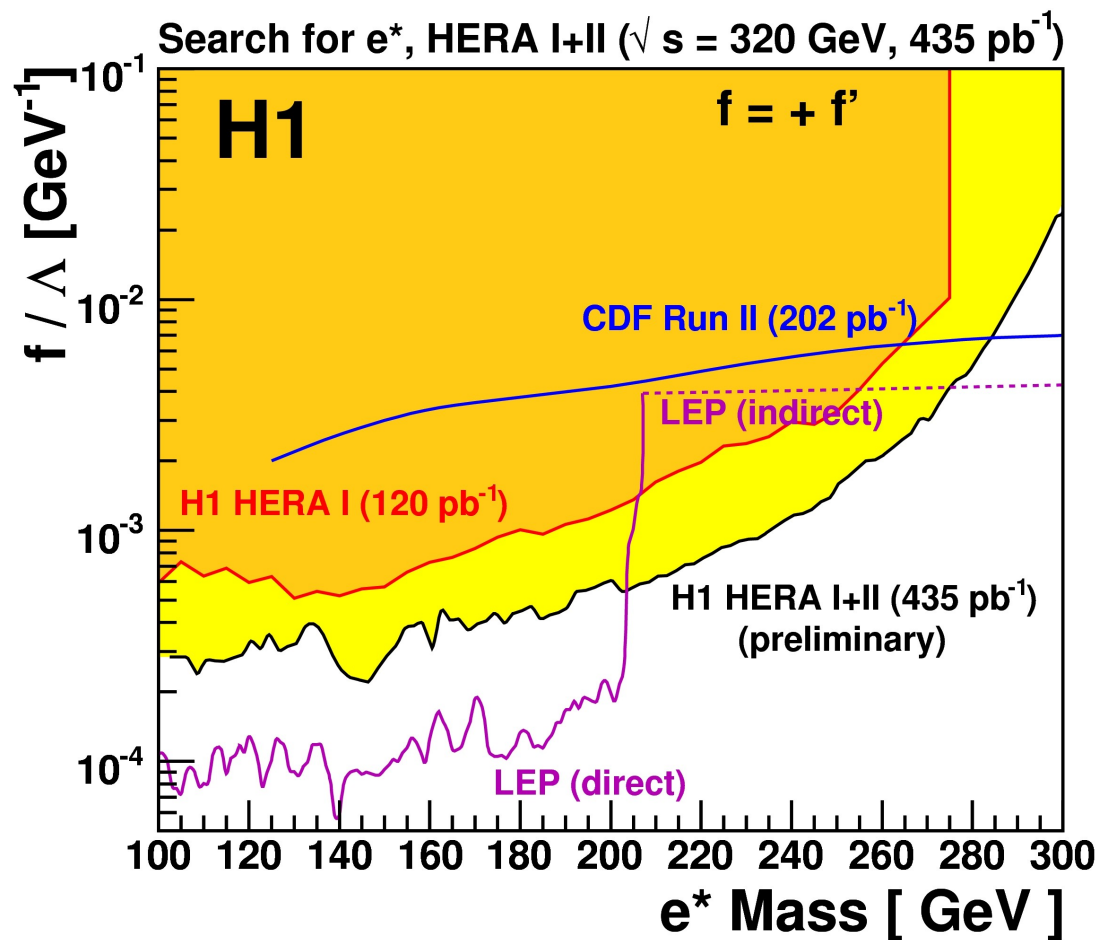
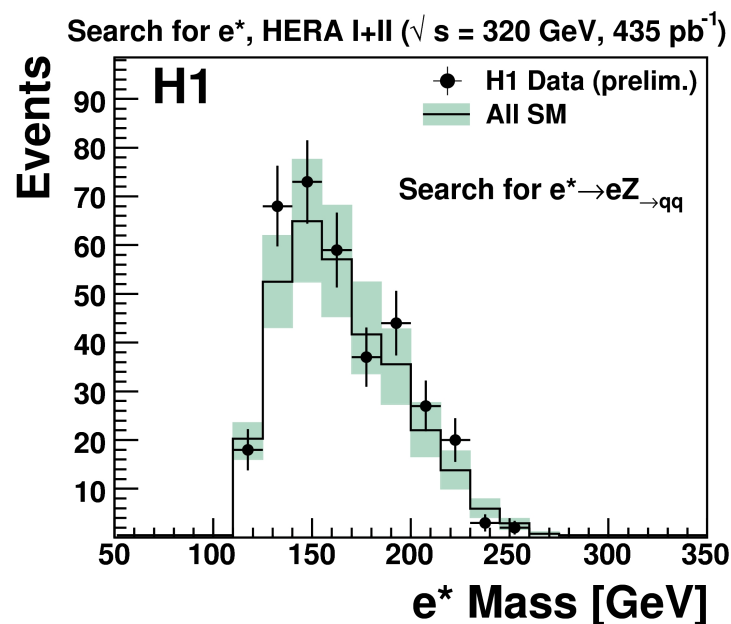
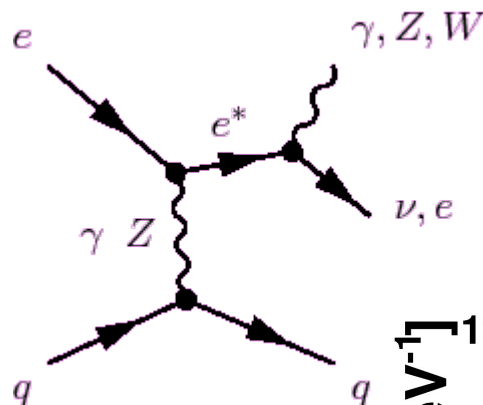




# Excited Electrons

similar process:

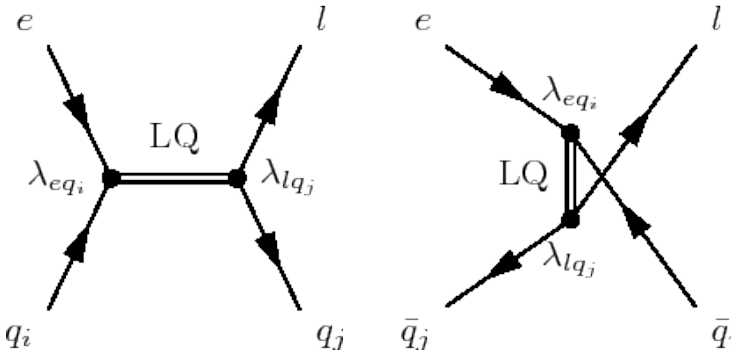
- no evidence for excited electrons
- limits: increase of sensitivity by HERA II data



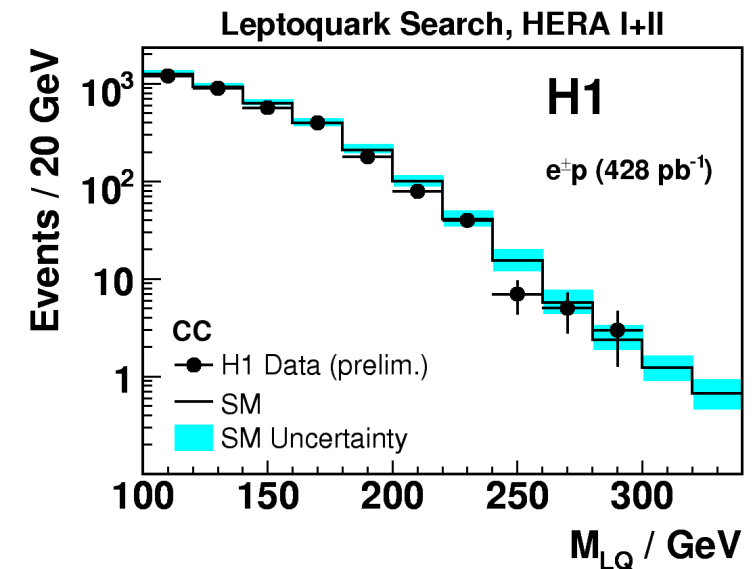
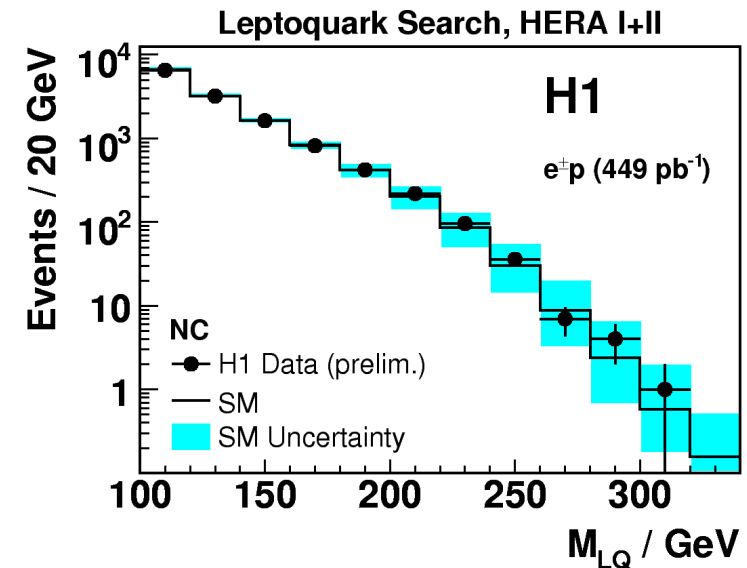


# Leptoquarks

lepton and quark at the same vertex

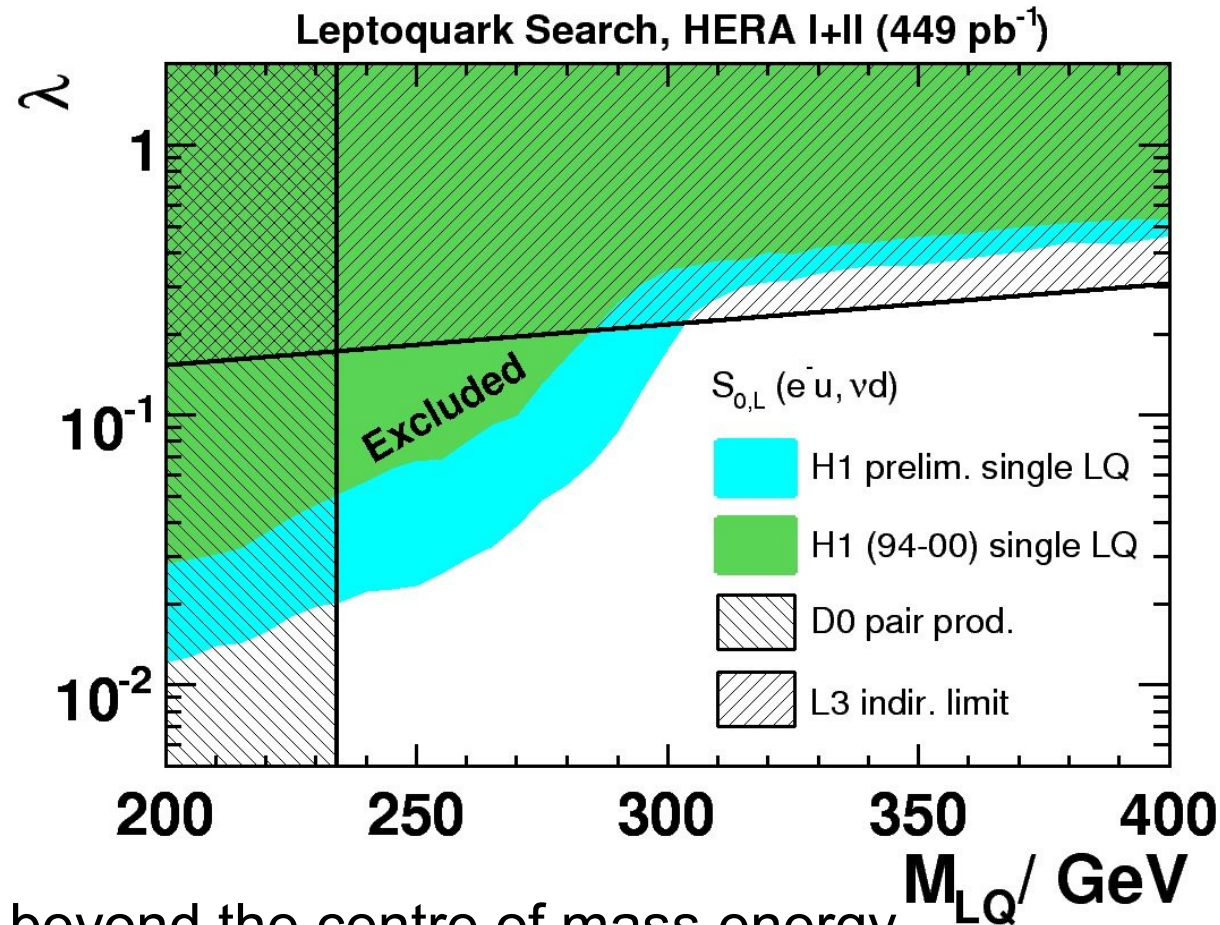


- Buchmüller Rückl Wyler model:
  - $e^+p$ : 7 leptoquarks ( $F=0$ )
  - $e^-p$ : 7 leptoquarks ( $F=2$ )
- first generation LQ (outgoing lepton:  $e, \nu$ )
  - final state similar to NC/CC DIS: interference terms modify cross section
- signal: resonance in mass spectra
- no evidence for a leptoquark





# Leptoquarks



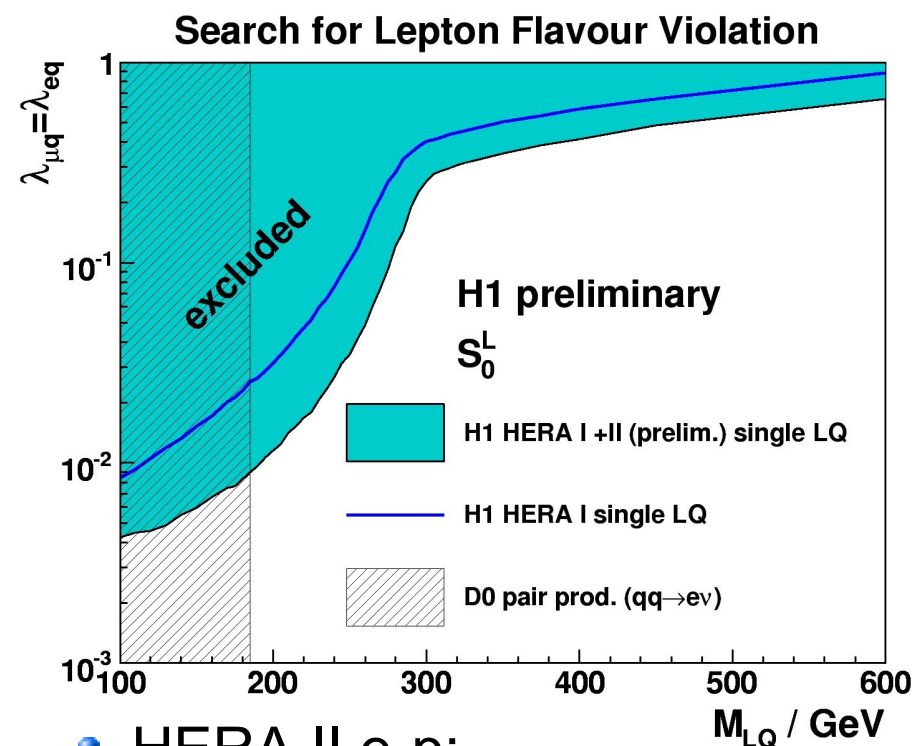
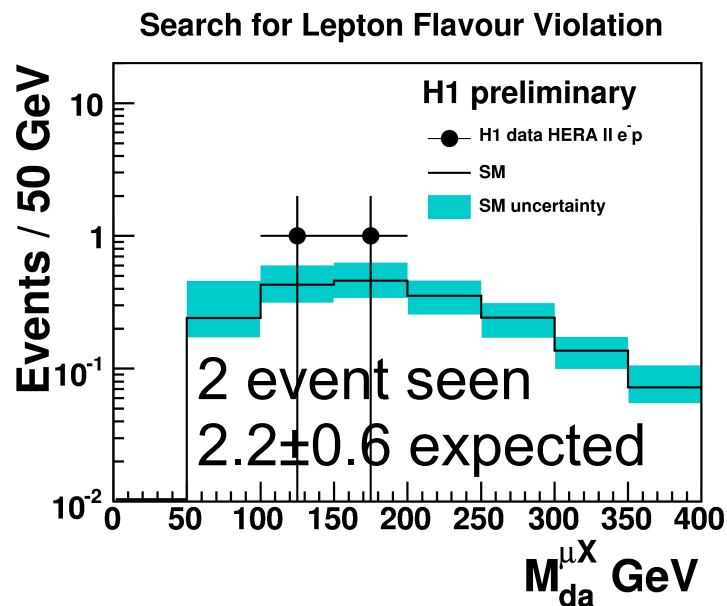
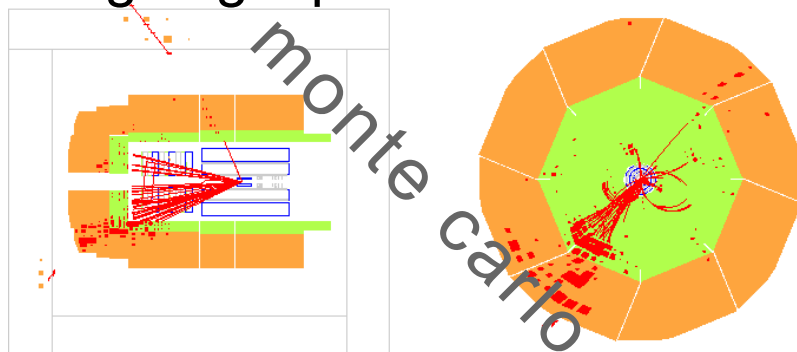
- sensitivity beyond the centre of mass energy due to virtual effect (u channel)
- assuming  $\lambda=0.3$ :  $M_{LQ} > 300 \text{ GeV}$
- better than the OPAL limit



# Lepton Flavour Violation

lepton flavour violation can be mediated by leptoquarks

- outgoing lepton a **muon**/tau instead of an electron



- HERA II e-p:  
10 times more luminosity
- pushing the limit down



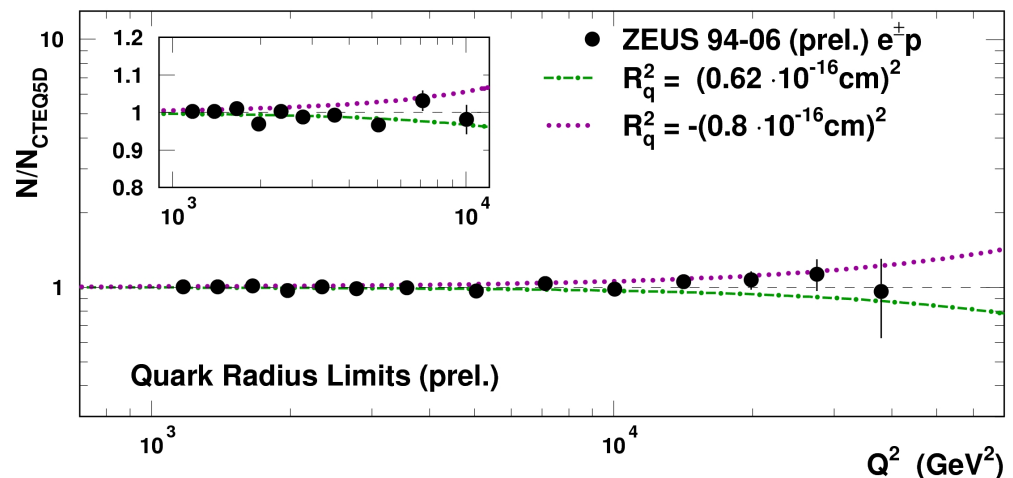
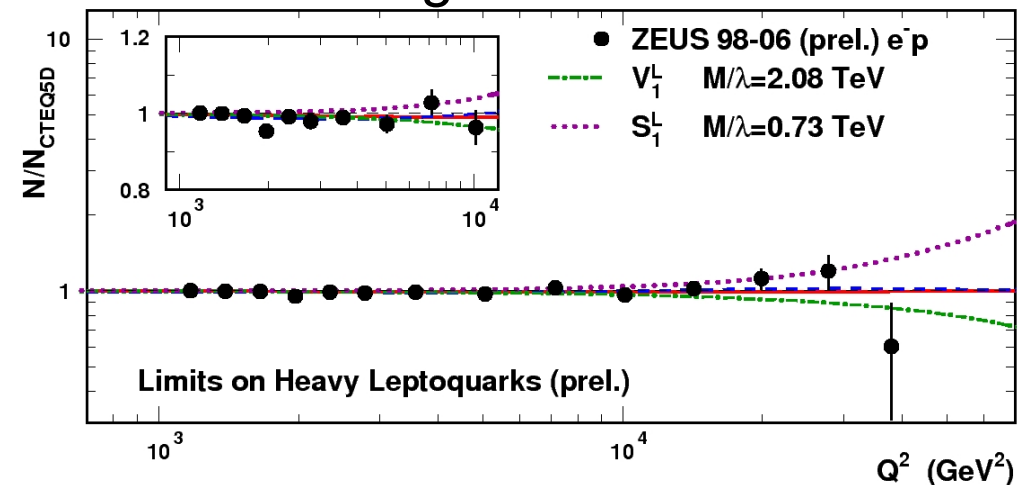
# Contact Interaction

new interaction between electron and quark involving mass scales above centre-of-mass energy can modify cross section at high  $Q^2$

- four-fermion interaction
- heavy leptoquarks
- graviton of extra large dimensions
- finite charge radius of the quark

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{\text{SM}}}{dQ^2} \cdot \left( 1 - \frac{R_q^2}{6} Q^2 \right)$$

- limit:  
below 1/1000 of a proton radius





# Summary

- HERA data taking ended on June 30, 2007  
after 15 years of successful operation  
both experiments together have collected  $\approx 1\text{fb}^{-1}$  of high quantity data
- comprehensive searches for new physics phenomena  
using all data and combining H1 and ZEUS are ongoing
- some interesting excess in rare signatures:  
isolated lepton and multi leptons
- newest limits on various theories:  
excited fermions, leptoquarks, quark radius
- HERA is competitive and unique

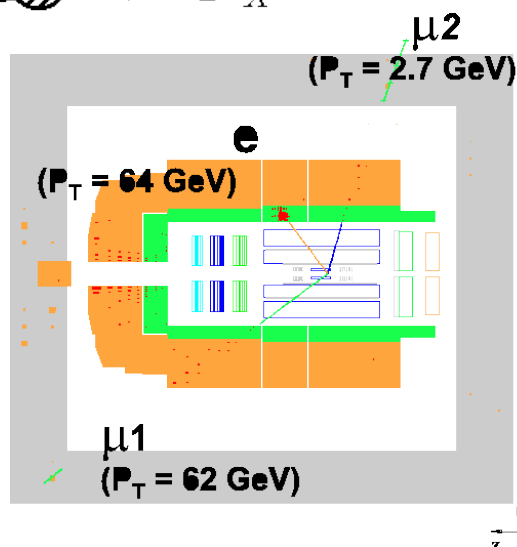
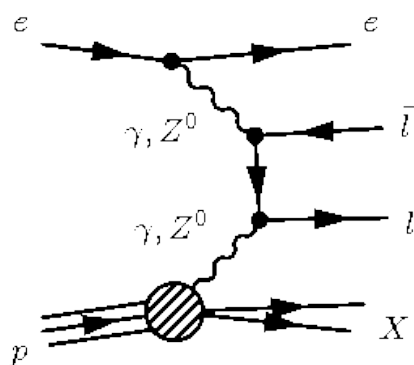
# Backup



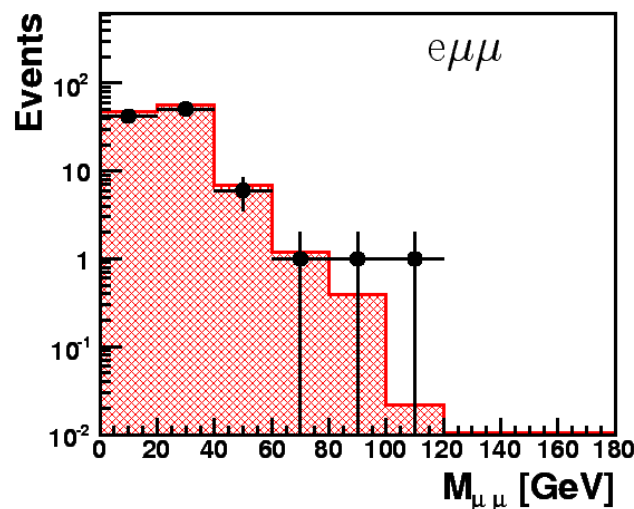
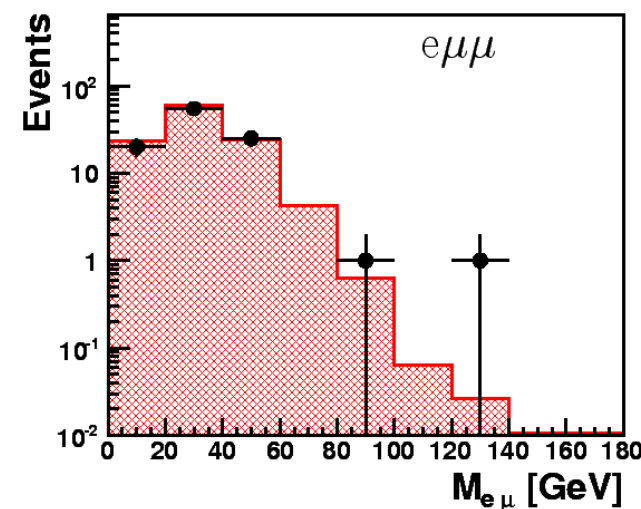
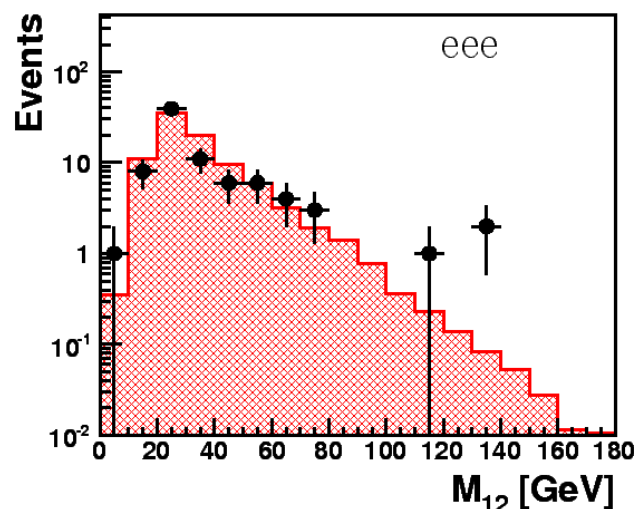
# Multi-Leptons

topology: 2 or 3  $e/\mu$

SM process:  
lepton pair production



H1 Multi-lepton analysis HERA I+II ( $459 \text{ pb}^{-1}$ )

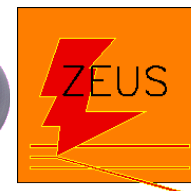


- H1 Data (prelim.)
- ▨ DIS+Compton
- ▨ Pair Production

H1 sees 5 events with  $M_{ij} > 100 \text{ GeV}$

SM expectation: 1.0

# Multi-Leptons



H1+ZEUS Multi-electron analysis HERA I+II ( $0.94 \text{ fb}^{-1}$ , preliminary)

Selection	Data	SM	Pair Production	NC-DIS + Compton
2e	937	$937 \pm 67$	$756 \pm 48$	$181 \pm 39$
3e	148	$161 \pm 10$	$160 \pm 10$	$0.4 \pm 0.01$
All	1085	$1098 \pm 75$	$916 \pm 58$	$182 \pm 39$

H1+ZEUS Multi-electron analysis HERA I+II (preliminary)

$M_{12} > 100 \text{ GeV}$

Selection	Data	SM	Pair Production	NC-DIS + Compton
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$e^+p$  collisions ( $0.56 \text{ fb}^{-1}$ )

2e	4	$1.97 \pm 0.22$	$1.10 \pm 0.21$	$0.87 \pm 0.18$
3e	4	$1.10 \pm 0.12$	$1.10 \pm 0.12$	—

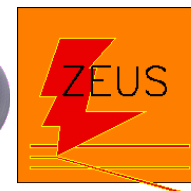
$e^-p$  collisions ( $0.38 \text{ fb}^{-1}$ )

2e	1	$1.44 \pm 0.15$	$0.77 \pm 0.10$	$0.67 \pm 0.12$
3e	0	$0.75 \pm 0.08$	$0.75 \pm 0.08$	—

$e^\pm$  collisions ( $0.94 \text{ fb}^{-1}$ )

2e	5	$3.41 \pm 0.37$	$1.87 \pm 0.25$	$1.54 \pm 0.29$
3e	4	$1.85 \pm 0.24$	$1.85 \pm 0.24$	—

# Isolated Leptons and $p_T^{\text{miss}}$



H1+ZEUS Preliminary $l + P_T^{\text{miss}}$ events at HERA I+II		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2007 $e^+p$ $0.58 \text{ fb}^{-1}$	Full Sample	39 / $41.3 \pm 5.0$ (70%)	18 / $11.8 \pm 1.6$ (85%)	57 / $53.1 \pm 6.4$ (73%)
	$P_T^X > 25 \text{ GeV}$	12 / $7.4 \pm 1.0$ (78%)	11 / $7.2 \pm 1.0$ (85%)	23 / $14.6 \pm 1.9$ (81%)
1998-2006 $e^-p$ $0.39 \text{ fb}^{-1}$	Full Sample	25 / $31.6 \pm 4.1$ (63%)	5 / $8.0 \pm 1.1$ (86%)	30 / $39.6 \pm 5.0$ (68%)
	$P_T^X > 25 \text{ GeV}$	4 / $6.0 \pm 0.8$ (67%)	2 / $4.8 \pm 0.7$ (87%)	6 / $10.6 \pm 1.4$ (76%)
1994-2007 $e^\pm p$ $0.97 \text{ fb}^{-1}$	Full Sample	64 / $72.9 \pm 8.9$ (67%)	23 / $19.9 \pm 2.6$ (85%)	87 / $92.7 \pm 11.2$ (71%)
	$P_T^X > 25 \text{ GeV}$	16 / $13.3 \pm 1.7$ (73%)	13 / $12.0 \pm 1.6$ (86%)	29 / $25.3 \pm 3.2$ (79%)



# W - Polarisation

with isolated lepton analysis the W polarisation can be measured:

- longitudinal  $F_0$ ,
- left handed  $F_-$  and right handed  $F_+$

$$\frac{dN}{d \cos \theta^*} \propto \overbrace{(1 - F_- - F_0)}^{F_+} \cdot \frac{3}{8} (1 + \cos \theta^*)^2 + F_0 \cdot \frac{3}{4} (1 + \cos^2 \theta^*) + F_- \cdot \frac{3}{8} (1 - \cos \theta^*)^2$$

