

# Exclusive Searches at HERA

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42<sup>nd</sup> Rencontres De Moriond  
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On behalf of the ZEUS and H1 Collaborations

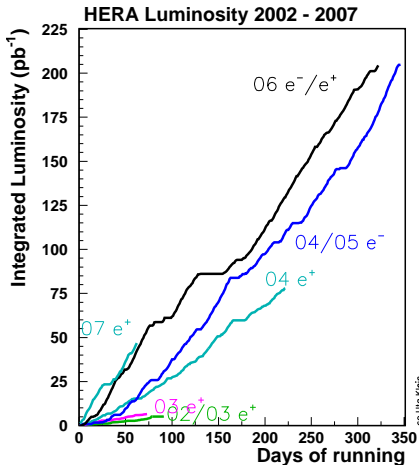
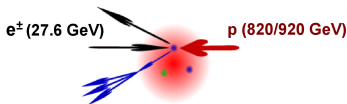


- 1 Introduction
- 2 Model Dependent Searches
- 3 Model Independent Searches
- 4 Summary & Outlook



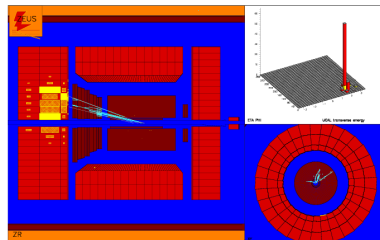
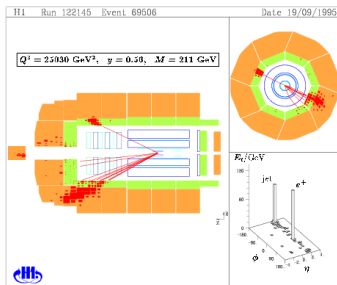


At HERA  $e^\pm$  are collided with protons at the interaction points of H1 and ZEUS with  $\sqrt{s} \approx 320$  GeV



HERA I: ZEUS  $\mathcal{L} \sim 130 \text{ pb}^{-1}$   
HERA II: ZEUS  $\mathcal{L} \sim 300 \text{ pb}^{-1}$





## H1

- Liquid Argon Calorimeter
- Optimised for precision measurement of the scattered lepton

## ZEUS

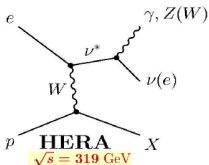
- Depleted Uranium Calorimeter
- Optimised for precision measurement of the hadronic final state



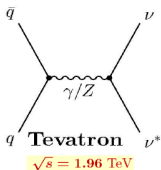
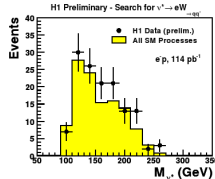
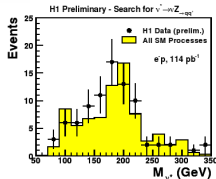
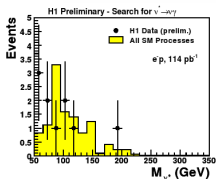
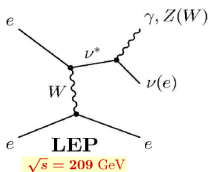
Several ways to search for BSM physics at HERA:

- Searches for new currents affecting DIS processes:
  - Charged Current DIS
  - Neutral Current DIS
  - See Stefan Schmitt's talk
- Model dependent searches for new particles:
  - HERA is not an annihilation machine  $\rightarrow$  the cross section for pair producing heavy new particles is small
  - Single particle production is usually investigated
  - Limits depend on coupling of new particle to SM ones  $\rightarrow$  no absolute mass limits
- Model Independent Searches for new physics:
  - Study SM processes with a low cross-section
  - Investigate all possible final states, compare data to SM expectation



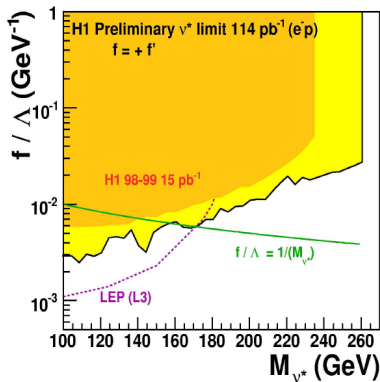
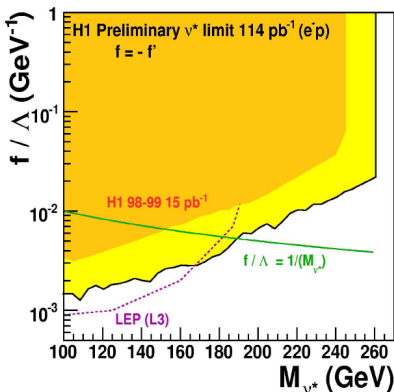


- Discovery of  $\nu^*$  would be direct proof of compositeness
- At HERA  $\nu^*$  are produced in CC like interactions
- Extra jets in the event besides  $\nu^*$  decay products



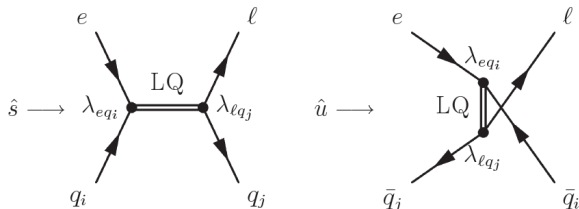
- Cross section much larger in  $e^- p$  ( $\mathcal{O}(10^2)$ ) due to  $u$ -quarks and helicity enhancement (like CC)
- 04-5 HERA data have  $\mathcal{O}(10)$  more  $e^- p$  lumi





- $f = -f' \rightarrow$  maximal photon coupling,  $\Lambda =$  compositeness scale

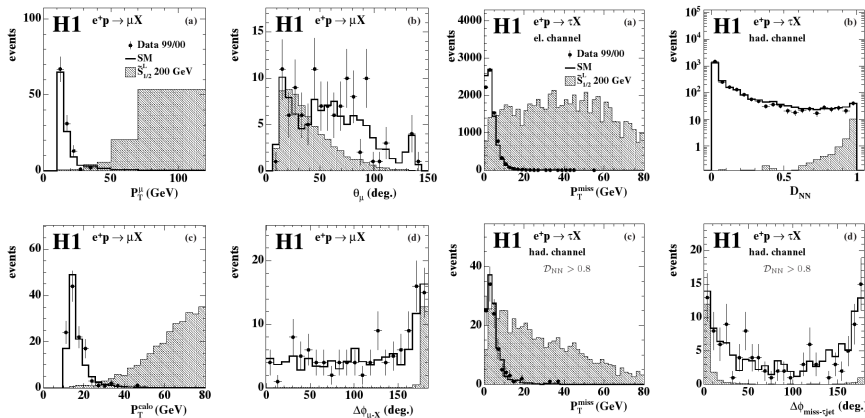




- Particle interactions in the SM conserve lepton flavour
- No underlying symmetry supports this
- LFV has been observed in neutrino measurements
- Possible mechanism leptoquark exchange



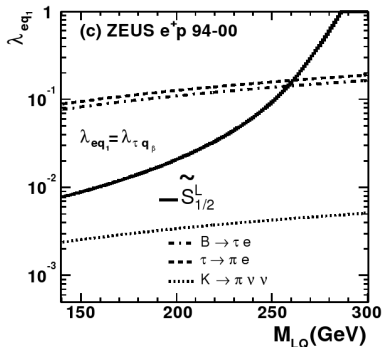
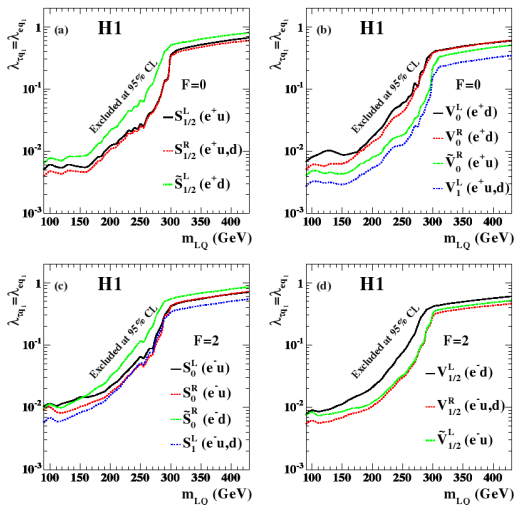




■ No evidence for LFV observed

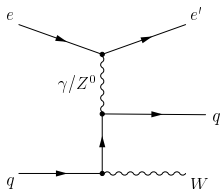


## H1 Search for lepton flavour violation



- Limits set on 14 different lepton flavour violating LQs





High  $P_T$  Isolated leptons in events with large missing  $P_T$  are the signature of many BSM processes at HERA

SM source at HERA is Single  $W$  production:  
At HERA  $\sigma(W \text{ production}) \approx 1.1 \text{ pb}$

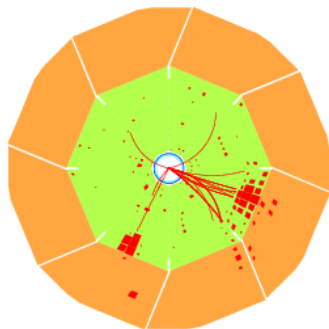
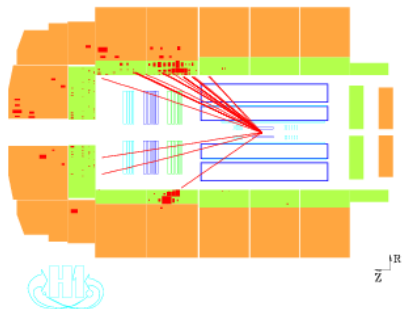
NC DIS	CC DIS	Dilepton production
Genuine electron and fake $P_T^{\text{miss}}$ due to mismeasurement	misidentified lepton and genuine $P_T^{\text{miss}}$	Genuine $\mu$ and fake $P_T^{\text{miss}}$ due to mismeasurement



# Example e Event

Introduction  
Model Dependent  
**Model Independent**  
Summary & Outlook

Isolated Leptons in Events with Large Missing  $P_T$   
Multi-lepton Events  
Generic Search

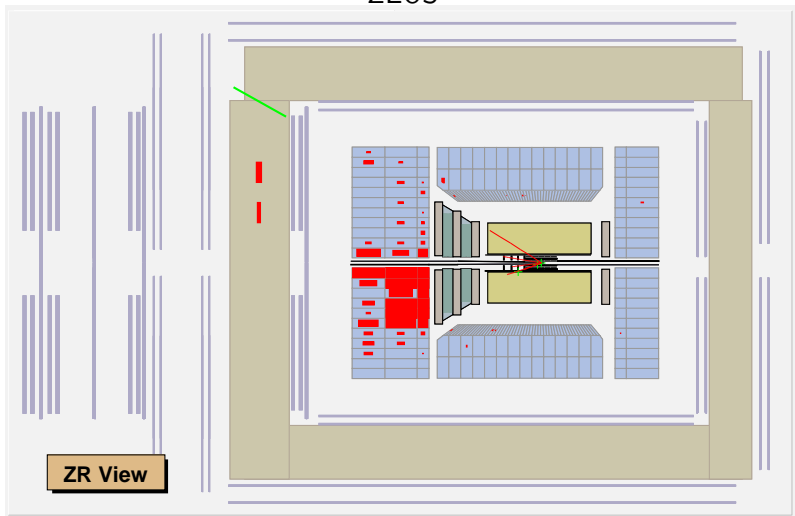


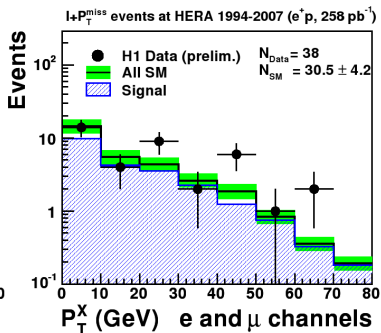
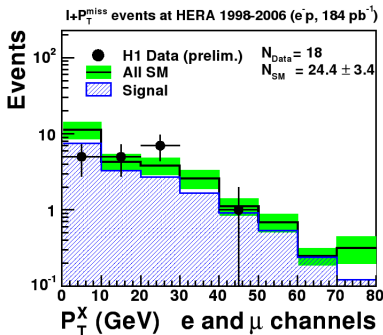
# Example $\mu$ Event

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## ZEUS

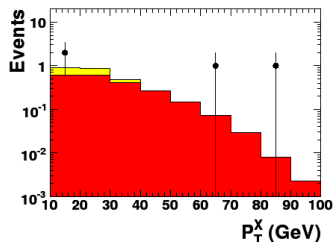
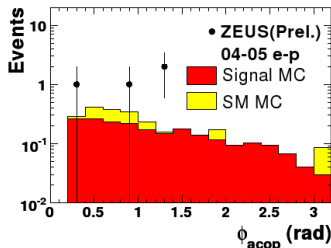




H1 Preliminary $P_T^X > 25$ GeV	$e$ channel obs./exp. (signal)	$\mu$ channel obs./exp. (signal)	$e$ and $\mu$ obs./exp. (signal)
$e^+p$ 258 $\text{pb}^{-1}$	10/4.1 $\pm$ 0.8 (75%)	8/3.7 $\pm$ 0.6 (85%)	18/7.8 $\pm$ 1.3 (80%)
$e^-p$ 184 $\text{pb}^{-1}$	3/3.8 $\pm$ 0.6 (61%)	0/3.1 $\pm$ 0.5(74%)	3/6.9 $\pm$ 1.0 (67%)

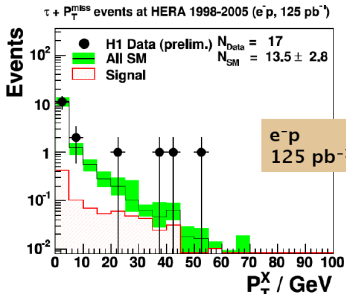
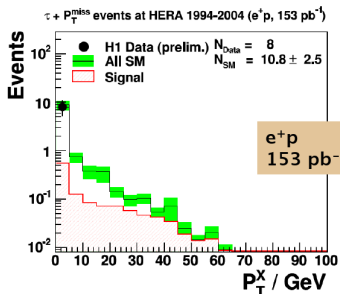


Isolated $e$ candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) 98-06 $e^- p$ (204 $\text{pb}^{-1}$ )	6/2.9 $\pm$ 0.5 (56%)	5/3.8 $\pm$ 0.6 (55%)
ZEUS (prel.) 96-06 $e^+ p$ (228 $\text{pb}^{-1}$ )	4/2.8 $\pm$ 0.5 (63%)	1/3.2 $\pm$ 0.4 (75%)
ZEUS (prel.) 96-06 $e^\pm p$ (432 $\text{pb}^{-1}$ )	10/5.7 $\pm$ 0.7 (60%)	6/7.0 $\pm$ 0.7 (64%)



Isolated $\mu$ candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) 98-06 $e^- p$ (204 $\text{pb}^{-1}$ )	2/2.2 $\pm$ 0.3 (68%)	2/2.2 $\pm$ 0.3 (86%)
ZEUS (prel.) 96-06 $e^+ p$ (228 $\text{pb}^{-1}$ )	3/2.6 $\pm$ 0.5 (68%)	3/3.1 $\pm$ 0.5 (80%)
ZEUS (prel.) 96-06 $e^\pm p$ (432 $\text{pb}^{-1}$ )	5/4.8 $\pm$ 0.5 (68%)	5/5.3 $\pm$ 0.6 (82%)





H1 Preliminary		H1 Data	Total SM expectation	SM signal (W)	Other SM Processes
94-04 $e^+p$ 153 $\text{pb}^{-1}$	Total	8	$10.6 \pm 2.9$	$1.1 \pm 0.23$	$9.5 \pm 2.9$
	$P_T^X > 25$ GeV	0	$0.40 \pm 0.10$	$0.24 \pm 0.05$	$0.15 \pm 0.09$
98-05 $e^-p$ 125 $\text{pb}^{-1}$	Total	17	$13.5 \pm 2.6$	$0.9 \pm 0.15$	$12.6 \pm 2.6$
	$P_T^X > 25$ GeV	3	$0.35 \pm 0.09$	$0.19 \pm 0.03$	$0.16 \pm 0.09$



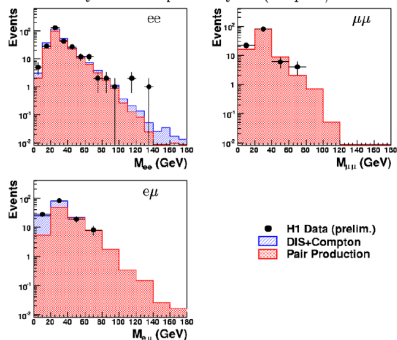


# Multi-lepton Events

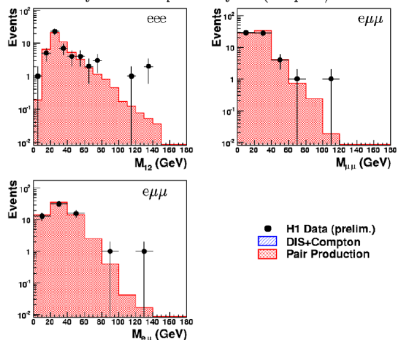
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Model Independent  
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Multi-lepton Events  
Generic Search

H1 Preliminary Multi-lepton analysis ( $275 \text{ pb}^{-1}$ )



H1 Preliminary Multi-lepton analysis ( $275 \text{ pb}^{-1}$ )



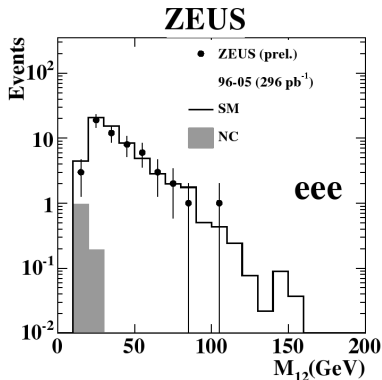
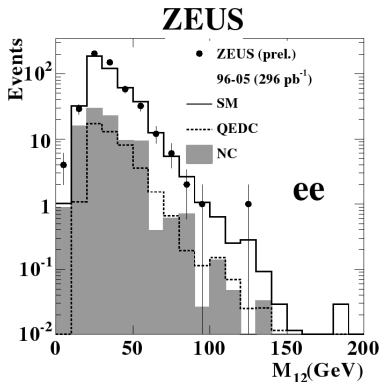
in  $ee$  channel, for  $M_{12} > 100 \text{ GeV}$   $3/0.44 \pm 0.10$  events observed  
 in  $eee$  channel, for  $M_{12} > 100 \text{ GeV}$   $3/0.29 \pm 0.06$  events observed  
 no significant excess in other channels



# Multi-lepton Events

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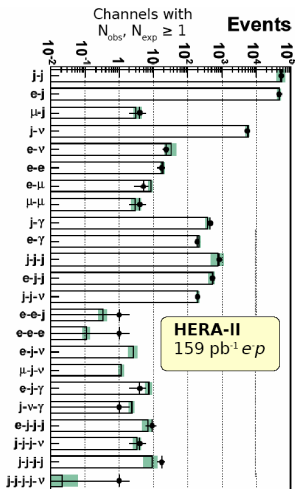
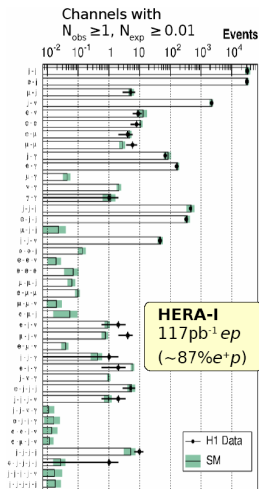
Isolated Leptons in Events with Large Missing  $P_T$   
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in ee channel, for  $M_{12} > 100$  GeV 1/1.5 events observed

in eee channel, for  $M_{12} > 100$  GeV 0/0.29 events observed





- H1 performed a generic search in final states with  $\geq 2$  high  $P_T$  objects:
  - $e, \mu, \text{jets}, \gamma, \nu$
  - $P_T > 20 \text{ GeV}$
  - $10^\circ < \theta < 140^\circ$
- Classify by final state
- SM predictions for all HERA processes
- Good agreement of event yields with SM expectation for most classes



- New limits on parameter space of many BSM models have been set by the HERA experiments
- Intriguing excesses over the Standard Model remain in high  $P_T$  lepton searches
- In many cases H1 and ZEUS provide the world's best limits
- Experiments have each collected close to  $0.5 \text{ fb}^{-1}$  luminosity which is being analysed now



# Back Up

Isolated Lepton Sensitivity  
NFV Leptoquarks  
SUSY  
Multi-lepton events &  $H^{++}$

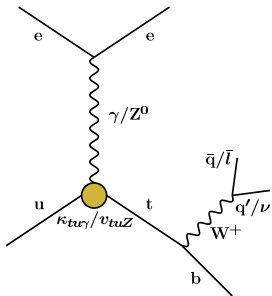
Back up slides follow



# Sensitivity to Isolated Leptons

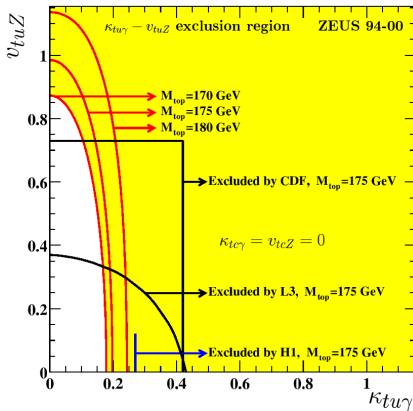
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BSM candidate for excess of high  $P_T$  isolated leptons at large  $P_T^X$  is single top production via anomalous FCNC



LEP and TeVatron are sensitive to these couplings too

## ZEUS

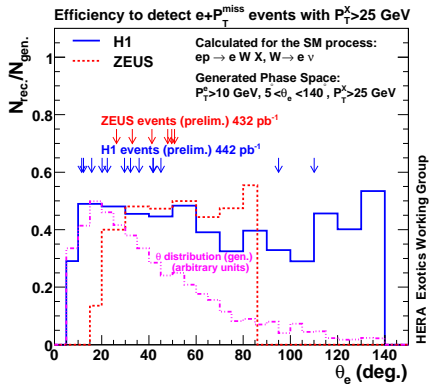
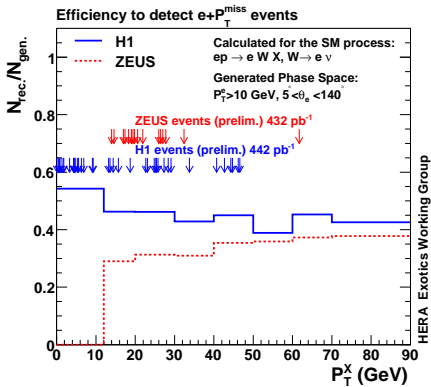


H1 excess compatible with FCNC limits from L3 & CDF



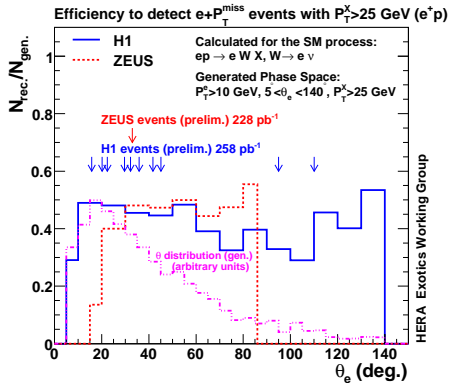
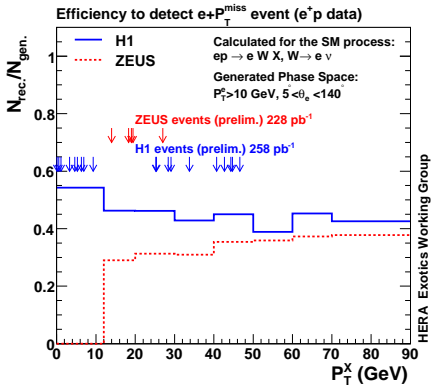
# Efficiency Comparison

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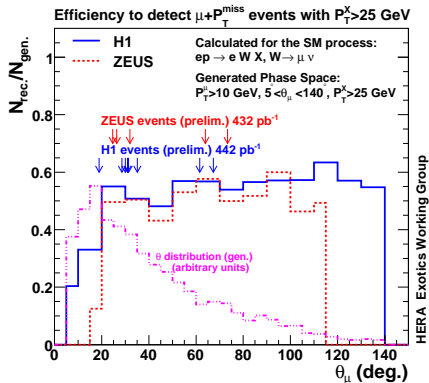
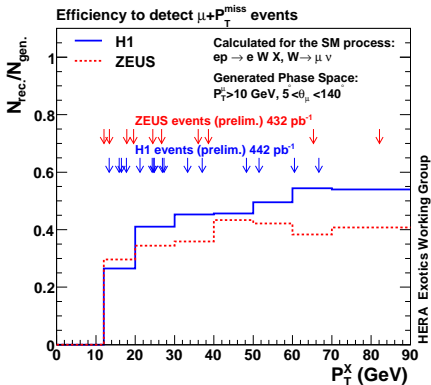
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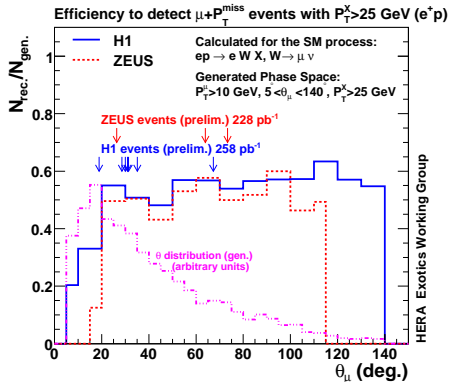
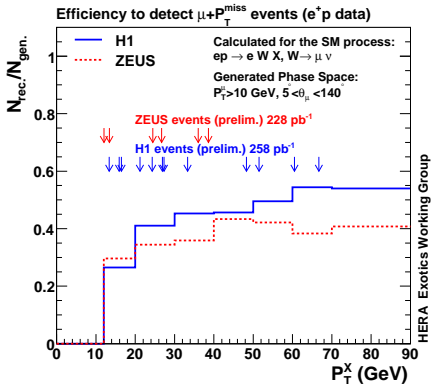
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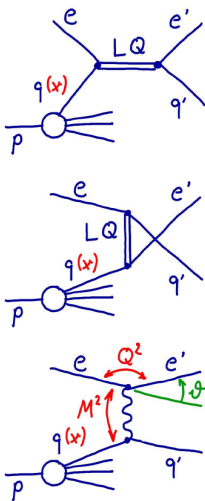
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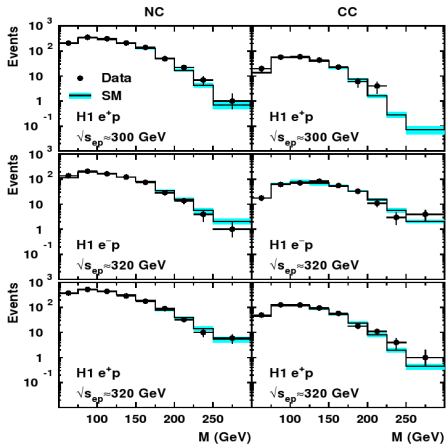
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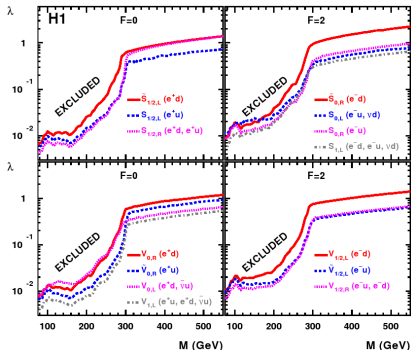


- Leptoquarks appear in many SM extensions e.g; compositeness, technicolour
- Connect Lepton and Quark sectors
- **Scalar** or **Vector** colour triplet bosons
- Carry both **L** & **B**, have fractional EM charge
- Classified by Buchmüller, Ruckl and Wyler according to their quantum numbers
  - LQs couple only to SM fermions and bosons
  - pure chiral couplings
  - family diagonal couplings
- HERA can produce Leptoquarks resonantly in s-channel
- signature one jet, one  $e/\nu$





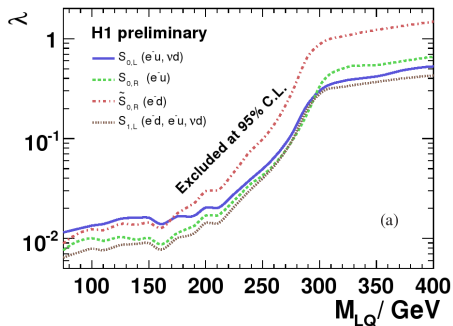
$37 \text{ pb}^{-1} (e^+ p, \sqrt{s} \approx 300 \text{ GeV})$   
 $15 \text{ pb}^{-1} (e^- p, \sqrt{s} \approx 320 \text{ GeV})$   
 $65 \text{ pb}^{-1} (e^+ p, \sqrt{s} \approx 320 \text{ GeV})$



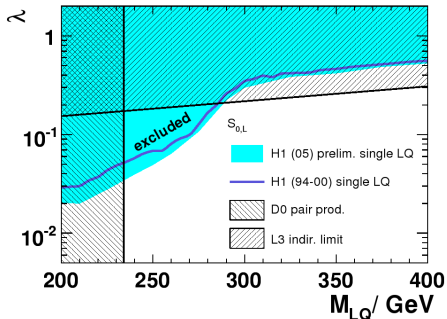
- No sign of Leptoquarks - limits on 14 types of LQ set

- new  $e^- p$  data can improve F=2 limits significantly





- No sign of Leptoquarks - limits on 14 types of LQ set

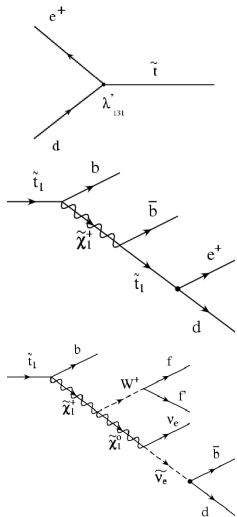


- Main improvement at low masses where production is resonant

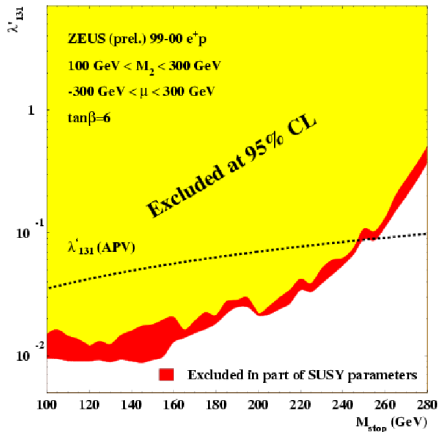


# $R_p$ Violating SUSY - light $\tilde{t}$

Isolated Lepton Sensitivity  
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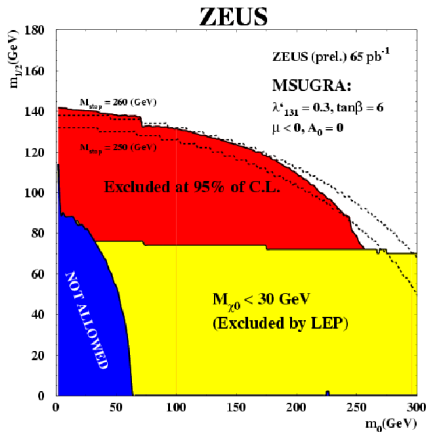
## ZEUS



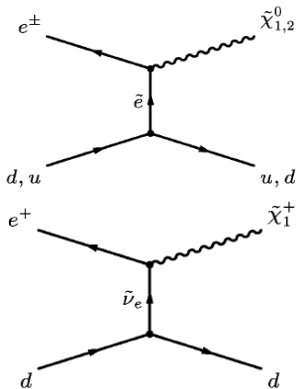
■  $\lambda_{131}$ , direct RPV coupling



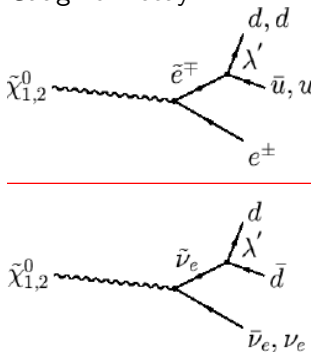
- Limits made for mSUGRA scenario
- Red: Excluded at 95% C.L.
- Yellow: Already excluded by LEP
- Blue: forbidden region



## Gaungino Production:



## Gaungino Decay:



(MSSM, mSUGRA)

### NC-like events

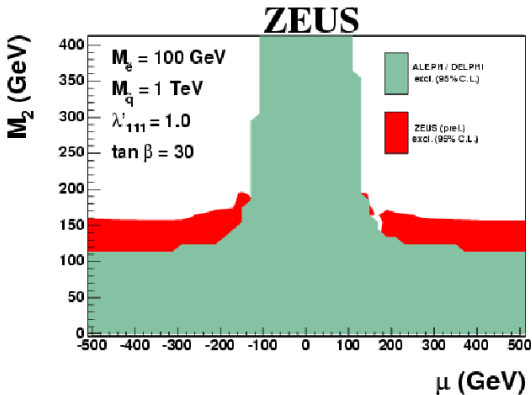
- Electron
- Multiple Jets

### CC-like events

- Neutrino
- Multiple Jets





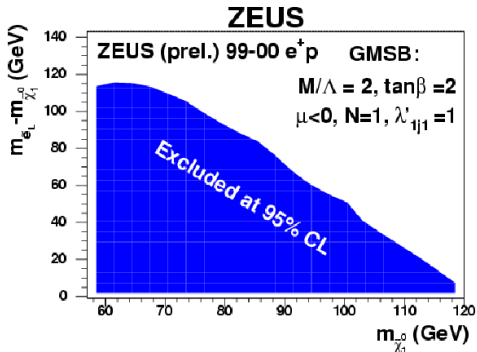
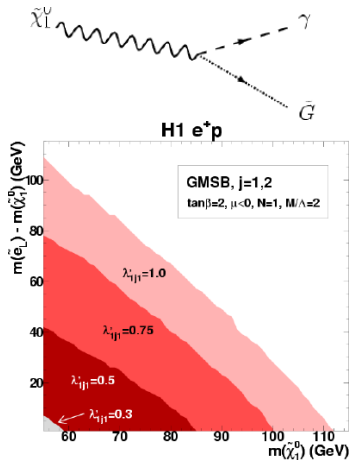


- limits in  $\mu, M^2$  plane compared to LEP



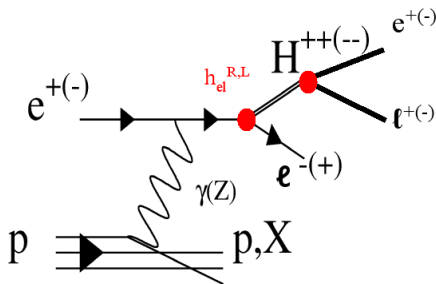
# Gravitino Search

Isolated Lepton Sensitivity  
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- H1 and ZEUS have compatible limits in GMSB





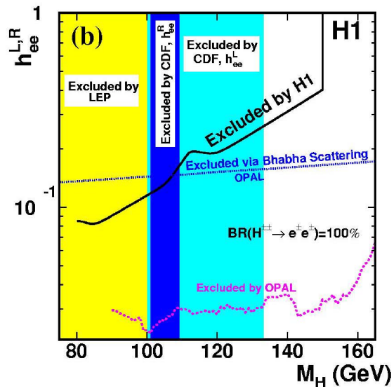
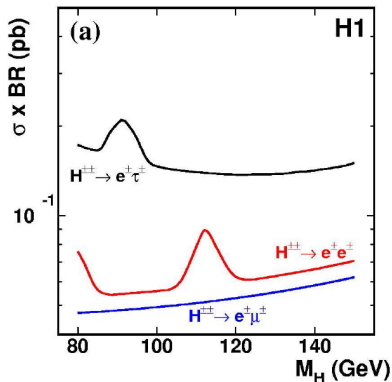
Look for  $ee, e\mu$  or  $e\tau$  pairs of high  $-P_T$  leptons with like charge.  
For  $M_{el} > 65$  GeV':

- $3/2.45 \pm 0.11$   $ee$  candidates
- $1/4.17 \pm 0.44$   $e\mu$  candidates
- $1/2.07 \pm 0.54$   $e\tau$  candidates



# Multi-lepton Events & $H^{++}$

Isolated Lepton Sensitivity  
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 SUSY  
 Multi-lepton events &  $H^{++}$

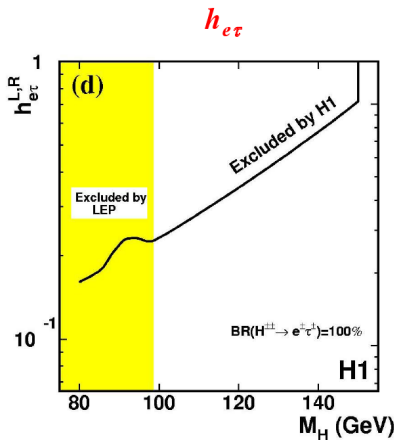
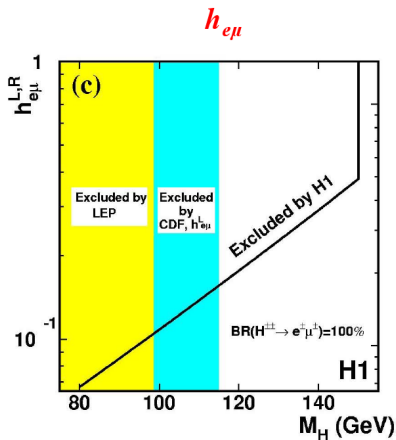


Confirms that excess is unlikely to come from  $H^{++}$



# Multi-lepton Events & $H^{++}$

Isolated Lepton Sensitivity  
 NFV Leptoquarks  
 SUSY  
 Multi-lepton events &  $H^{++}$



H1 limits extend the excluded regions

