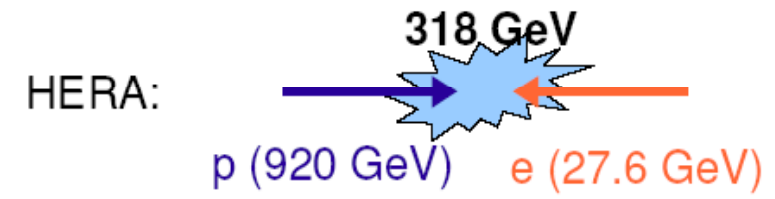
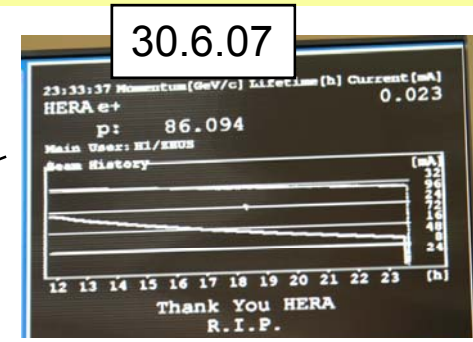
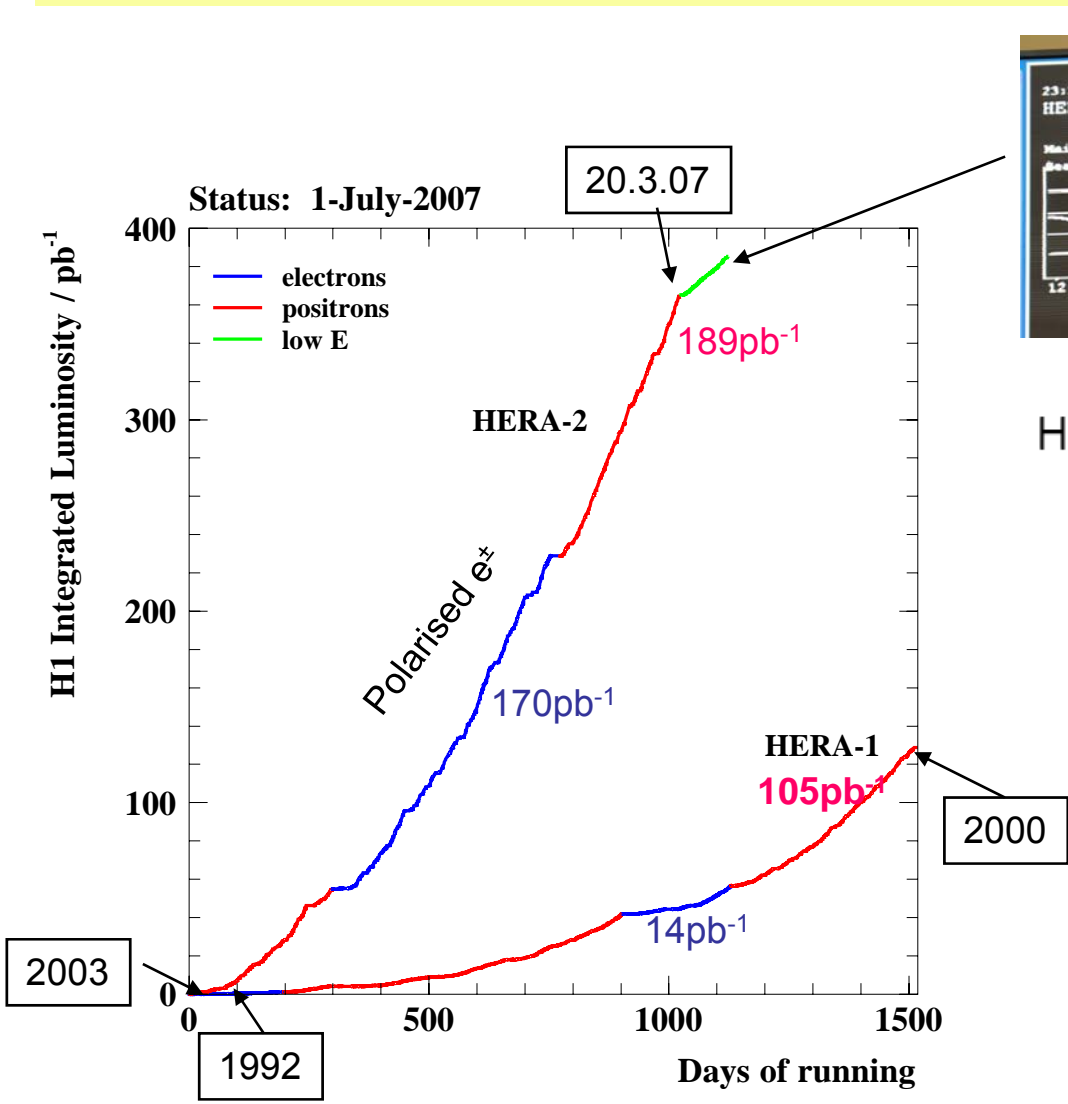


Searches for Isolated Leptons, Multileptons and Leptoquarks at HERA

Judith Katzy (DESY)



HERA



Total luminosity collected:

H1: **478 pb^{-1}**

294 pb^{-1} e^+

184 pb^{-1} e^-

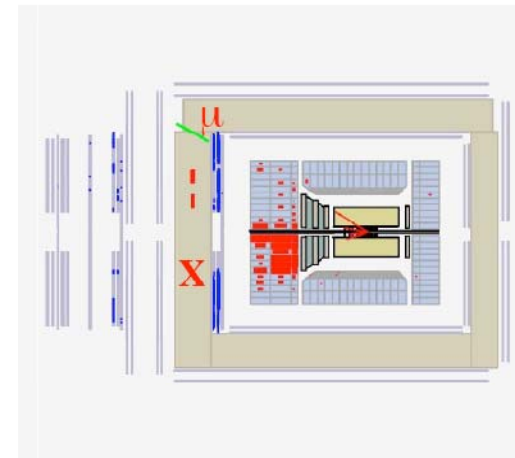
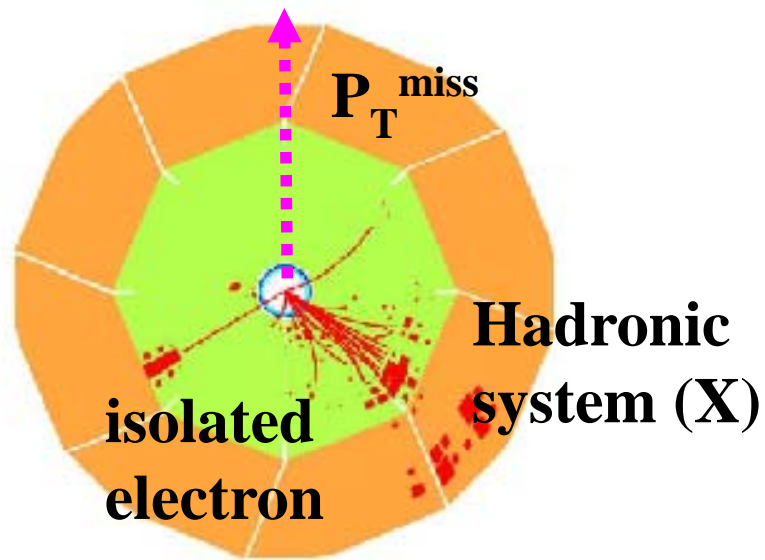
Zeus: **492 pb^{-1}**

286 pb^{-1} e^+

206 pb^{-1} e^-

$\sim 1 fb^{-1}$

Events with isolated e or μ and P_T^{miss}



HERA I:
H1 observed 11 events at $P_T^X > 25$ GeV
at SM expectation 3.5 ± 0.6

ZEUS in agreement with
SM expectation

Both experiments performed search in complete HERA data set

Standardmodel prediction

Real W production in photoproduction
with W decay into leptons
main process for this event topology
Hadronic system with typically low p_T^X

$$\sigma_W \sim 1.3 \text{ pb}^{-1}$$

W decay branching ratio into e or μ $\sim 20\%$

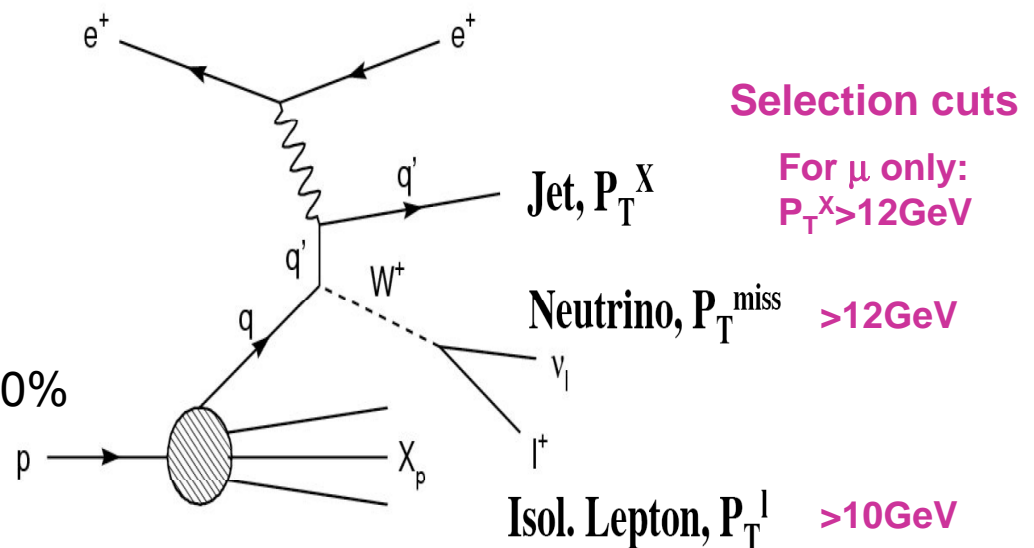
Other signal processes:

CC W production $\sim 7\%$

Cabbibo-Parisi Z0 production $\sim 3\%$ (only e channel)

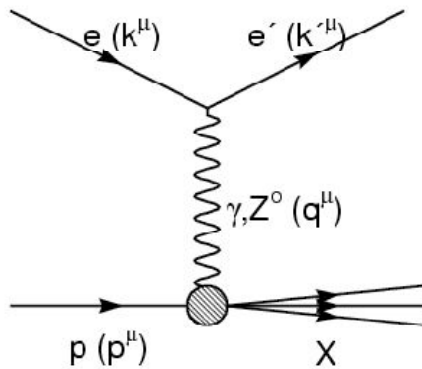
Modelled using EPVEC generator with NLO QCD correction:

Modifies cross section by $\sim 10\%$, reduces theoretical uncertainty to $\sim 15\%$



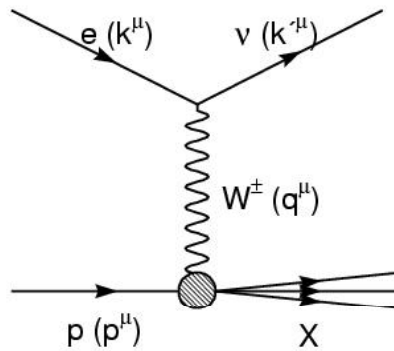
Background processes

e: Neutral Current



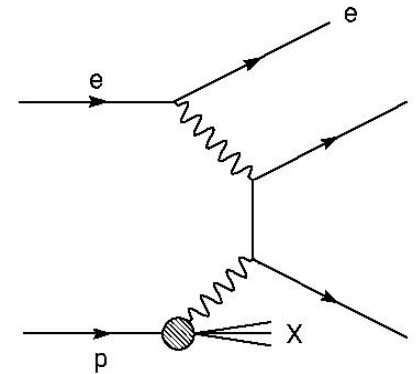
Real electron and fake P_T^{miss} from mismeasurement

e, μ : Charged Current



Misidentified e or μ and real P_T^{miss}

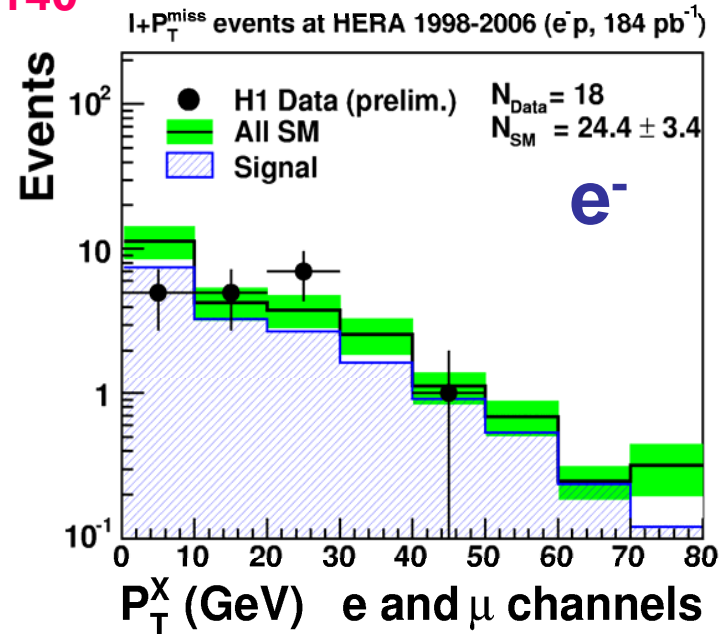
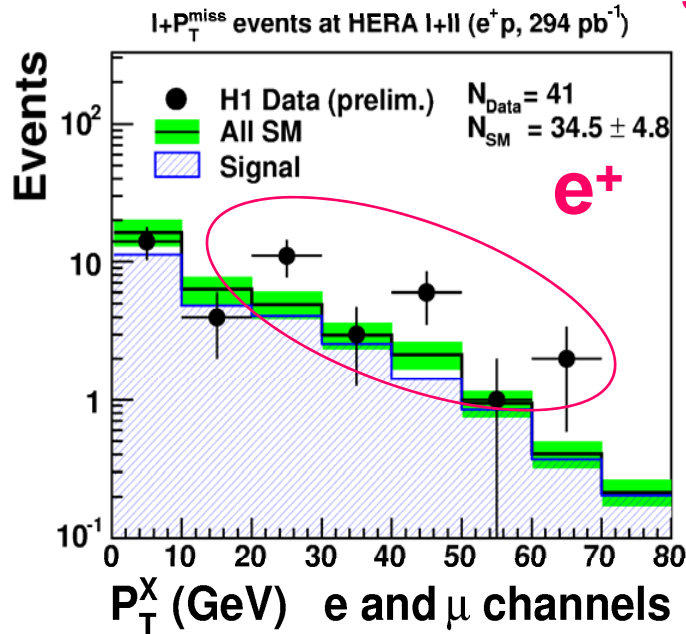
μ : Lepton Pair Production



Real μ and fake P_T^{miss} from mismeasurement

H1 isolated leptons

$5 < \theta_l < 140^\circ$



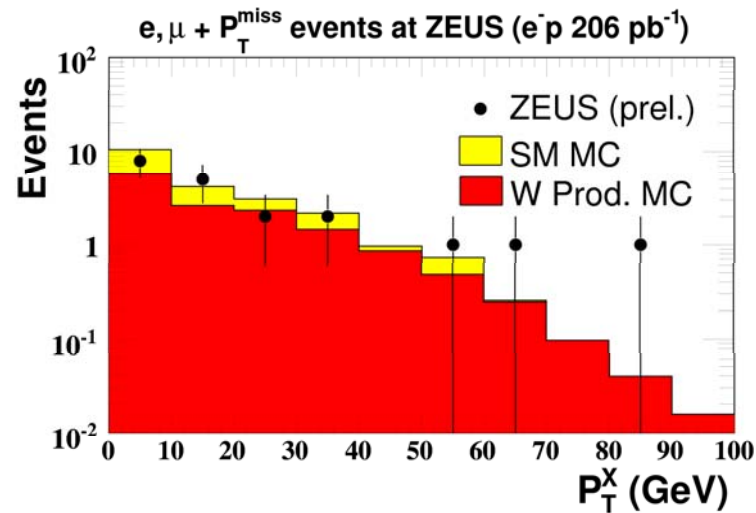
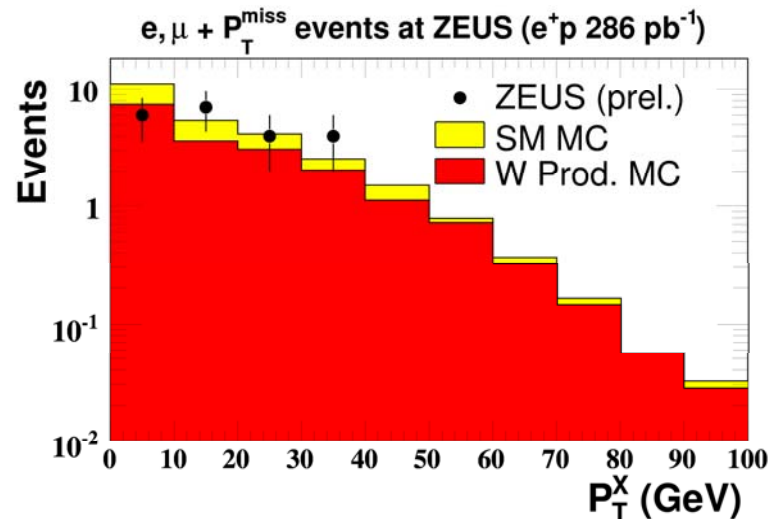
Excess at high p_T^X

Agreement with SM

H1 HERA I+II $P_T^X > 25 \text{ GeV}$	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
e^+p data (294 pb^{-1})	11 / 4.7 ± 0.9 (75%)	10 / 4.2 ± 0.7 (85%)	21 / 8.9 ± 1.5 (80%)
e^-p data (184 pb^{-1})	3 / 3.8 ± 0.6 (61%)	0 / 3.1 ± 0.5 (74%)	3 / 6.9 ± 1.0 (67%)

ZEUS isolated leptons

$15^\circ < \theta_l < 120^\circ$



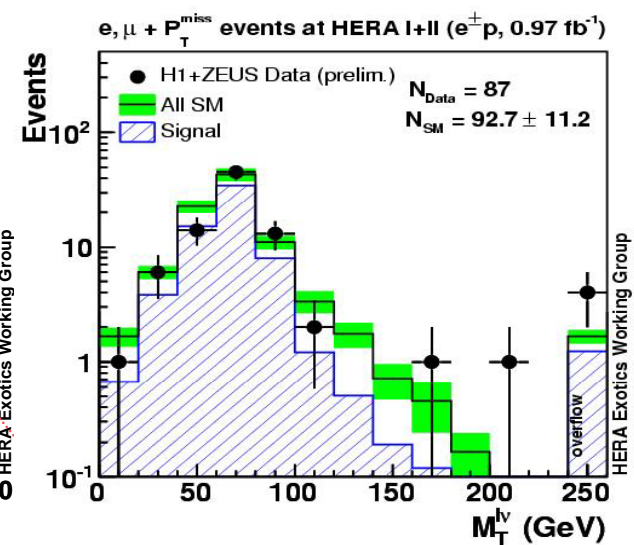
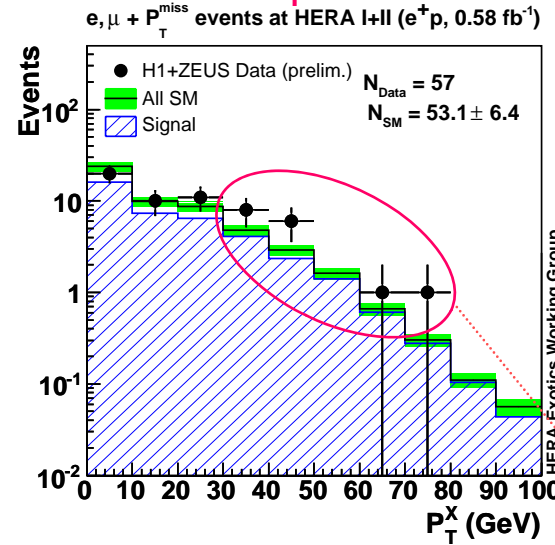
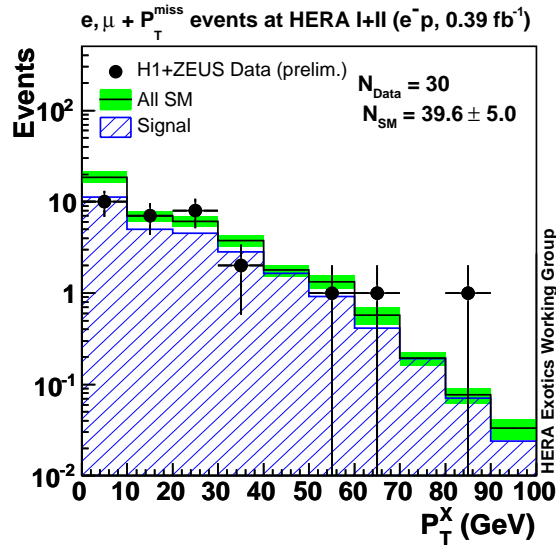
41 events observed in 492 pb-1 of data

HERA I+II P _T >25GeV	e channel Obs/exp(signal)	μ channel Obs/expt.(signal)
e ⁺ data	3/3.9 ±0.5(81%)	3/3.6±0.5(81%)
e ⁻ data	3/3.2±0.6(69%)	2/2.4±0.4(85%)

Good agreement between data and Standard Model for both data sets
No Excess seen at high P_T^X as seen by H1

H1 and Zeus combined

$15 < \theta_l < 120^\circ$



87/92.7 \pm 11.2 events with isolated leptons and P_T^{miss} observed in 0.97 fb^{-1}

H1+ZEUS HERA I+II $P_T^X > 25 \text{ GeV}$	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
e^+p data (0.58 fb^{-1})	12 / 7.4 ± 1.0 (70%)	11 / 7.2 ± 1.0 (85%)	23 / 14.6 ± 1.9 (81%)
e^-p data (0.39 fb^{-1})	4 / 6.0 ± 0.8 (67%)	2 / 4.8 ± 0.7 (87%)	6 / 10.6 ± 1.4 (76%)
$e^+ + e^-$ data (0.97 fb^{-1})	4/ 6.0 ± 0.8 (67%)	2/ 4.8 ± 0.7 (87%)	29/ 25.3 ± 3.2 (79%)

Excess in e^+ data has significance of 1.8σ based on data of both experiments
(2.9σ H1 data only)

Cross section measurements

H1 data only

$$\sigma_{IsoLep} = \frac{N_d - N_{bg}^{MC}}{\mathcal{L}\epsilon} \quad \epsilon = \frac{N_{rec}^{MC}}{N_{gen}^{MC}}$$

$\sigma_{IsoLep}(\text{pb})$	Measured \pm stat \pm sys	SM \pm thesys
\int	0.24 \pm 0.05 \pm 0.05	0.26 \pm 0.04

branching ratio $W \rightarrow e, \mu$ $\sim 21\%$
subtract Z^0 processes

$\sigma_W(\text{pb})$	Measured \pm stat \pm sys	SM \pm thesys
\int	1.23 \pm 0.25 \pm 0.22	1.31 \pm 0.20

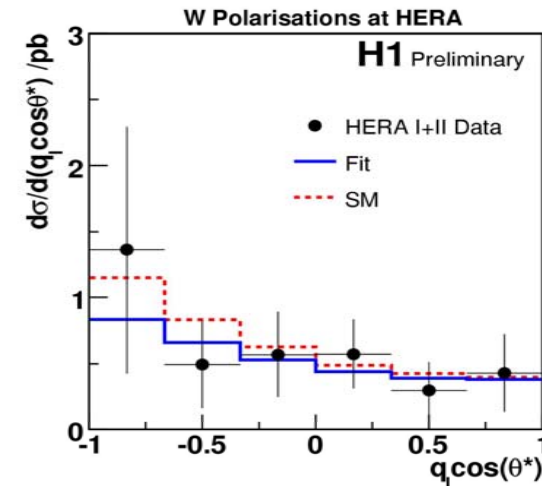
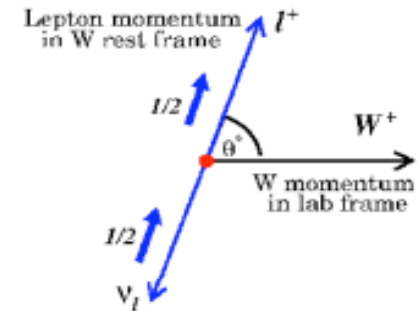
Both measured cross sections are in good agreement with the SM

Measurement of W polarisation fraction

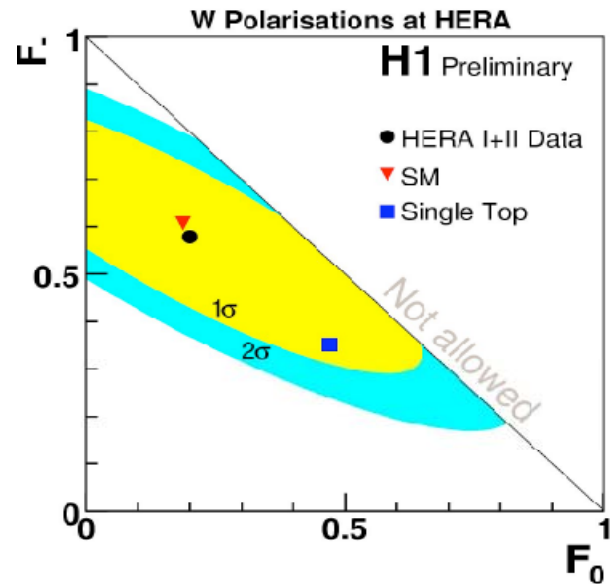
$F_+ = 1 - F_- - F_0$
 right left longitudinal polarisation fraction

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

Fit H1 measured cross section to $dN/d\cos\theta^*$ and extract F_0 and F_- simultaneously



W polarisation fraction



Good agreement with the SM found compatible with Single top production within 1σ

Single parameter fit (other parameter at SM value)

	HERA I+II data	SM
F_+	$0.58 \pm 0.15(\text{stat}) \pm 0.12(\text{sys})$	$0.61 \pm 0.01(\text{stat})$
F_0	$0.15 \pm 0.21(\text{stat}) \pm 0.09(\text{sys})$	$0.19 \pm 0.01(\text{stat})$

Anomalous single top production

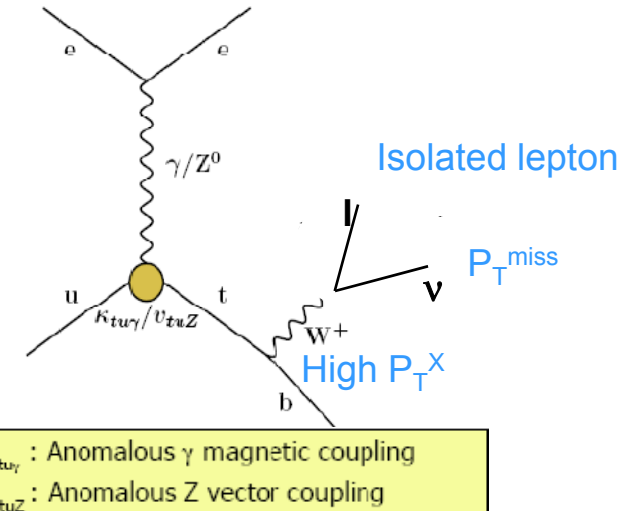
SM single top production $\sigma < 1 \text{ fb}^{-1}$

Top production via flavor changing NC in BSM

Candidate process for excess

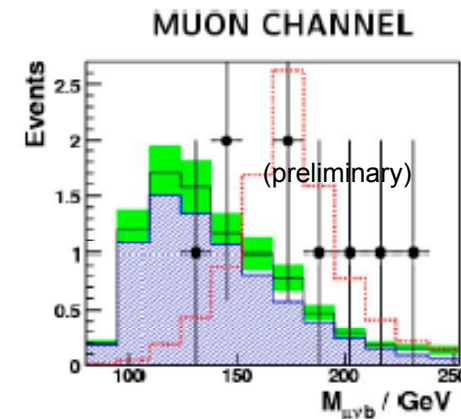
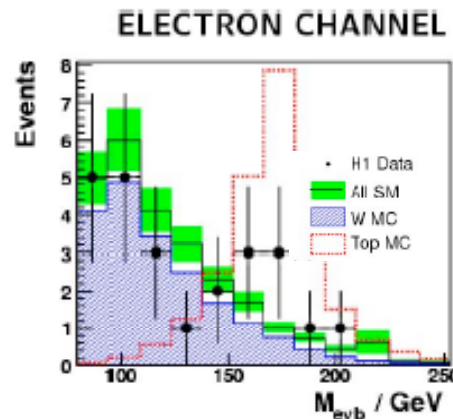
But: same rate for e^+ and e^-

Search for FCNC based on isolated lepton events of HERAI+II
 additional good top quark reconstruction and positive lepton charge requirement (if possible)



24 events selected, DU8
 26 events SM prediction

No significant signal found
 using multi variant analysis



DU8

previous (hera1) analysis also considered hadronic W decays

DESY USER, 7/21/2007

Single top results

Limits on FCNC cross section derived using maximum likelihood:

$$\sigma(ep \rightarrow etX) < 0.16 \text{ (95\% CL)}$$

HERA 1 results:

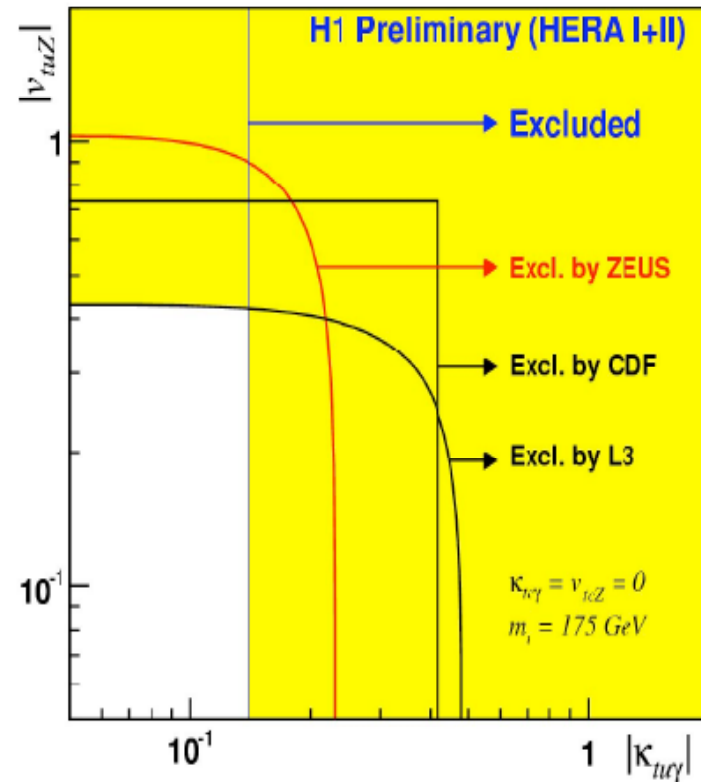
$$\text{H1: } \sigma(ep \rightarrow etx) < 0.55 \text{ pb}$$

$$\text{Zeus: } \sigma(ep \rightarrow etX) < 0.23 \text{ pb}$$

Upper bound on the anomalous coupling:

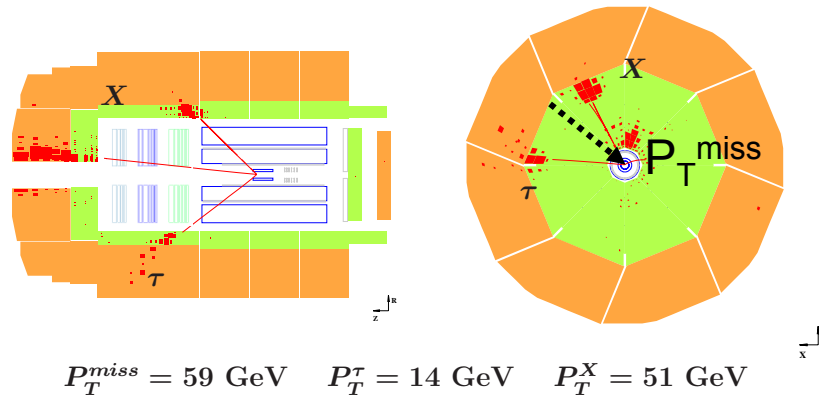
$$\kappa_{\tau u \gamma} < 0.14$$

New limit extends into region of phase space uncovered by other colliders



Isolated τ leptons + p_T^{miss}

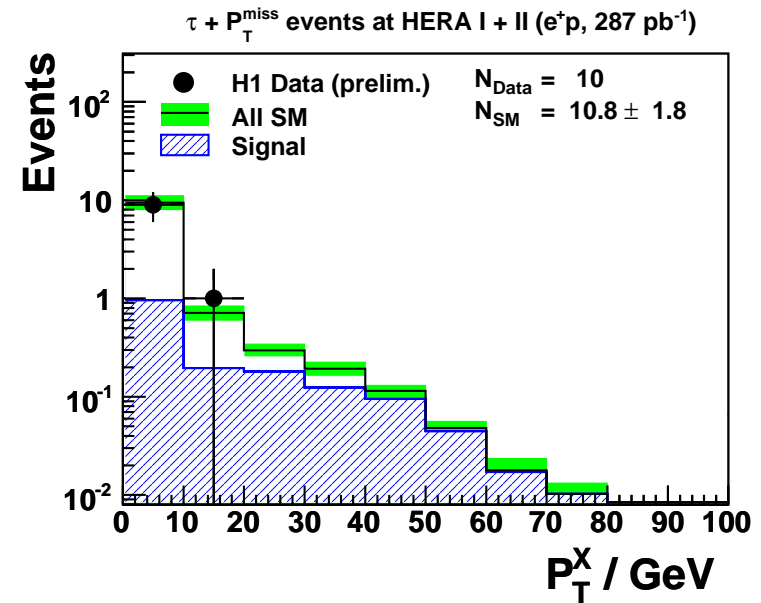
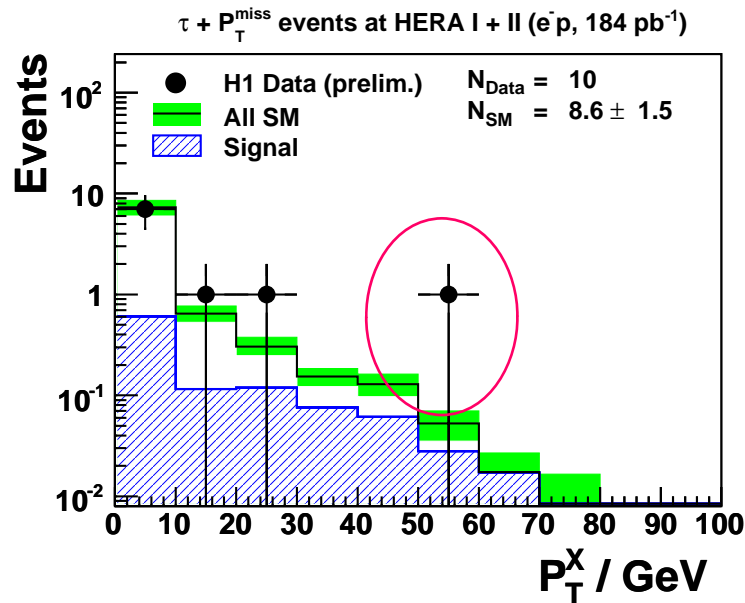
H1 $\tau + P_T^{\text{miss}}$ candidate with large P_T^X



Look for events with P_T^{miss} and a narrow hadronic jet in complete HERA data set

- 45% of τ decay into 1 charged particle (“1-prong-decay”) giving a narrow, pencil like jet
- main (and large!) background CC events with narrow jets
- complementary results to those in electron and muon channel
- enhanced τ production above SM predicted by some R_p violating SUSY models
- HERA I data ZEUS observed 3 events over SM expectation 0.4 ± 0.12 ,
2 events at $P_T^X > 25 \text{ GeV}$, SM expectation 0.2 ± 0.05

τ results



H1 $e^\pm p$ data HERA I+II (471 pb^{-1})	τ channel obs. / exp. (signal)
Full sample	20 / 19.5 ± 3.2 (14%)
$P_T^X > 25$ GeV	1 / 0.99 ± 0.13 (63%)

20 events observed

Good agreement with the SM prediction for e^+ and e^- data set

Only 1 event at high P_T^X – in the e^-p data!

Dominated by background processes – only 14% signal (other channels up to 85%)

Multi-Leptons

**Search for topologies with
2 or 3 high p_T leptons**

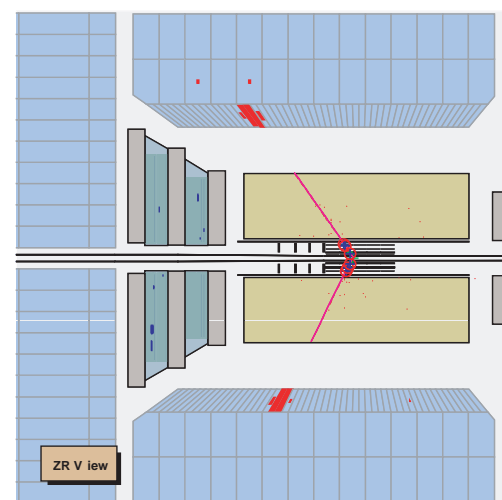
$p_T^{1l} > 10\text{GeV}$, $p_T^{2l} > 5\text{GeV}$, $20^\circ < \theta < 160^\circ$

Third lepton:

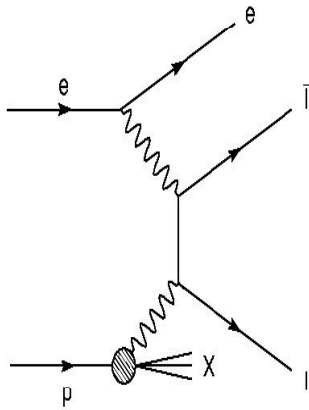
$E_e > 5\text{GeV}$ or $p_T^\mu > 2\text{GeV}$, $5^\circ < \theta < 175^\circ$

ZEUS: ee , eee

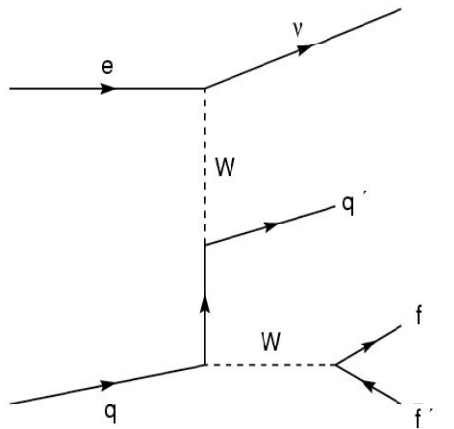
H1: ee , $e\mu$, $\mu\mu$, eee , $e\mu\mu$



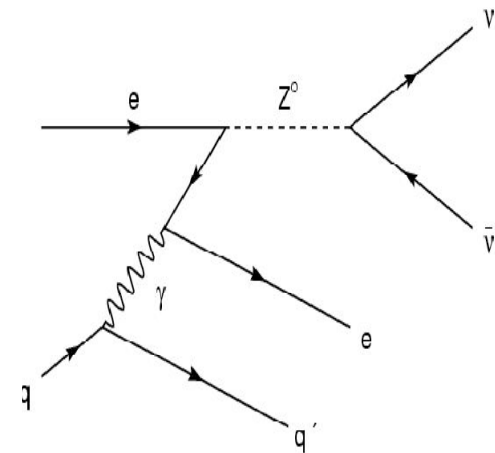
QED processes with multi-lepton final state



$\gamma\gamma$ process dominant



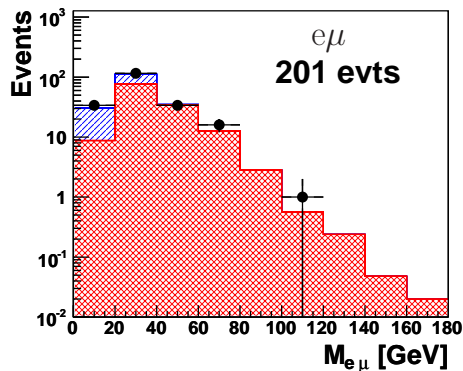
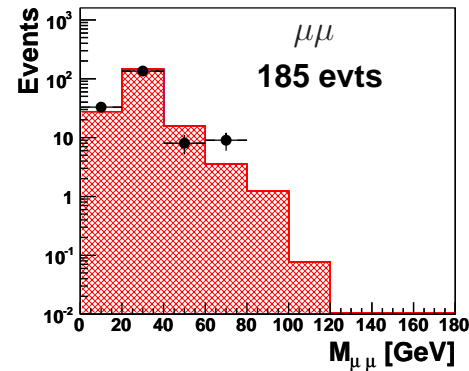
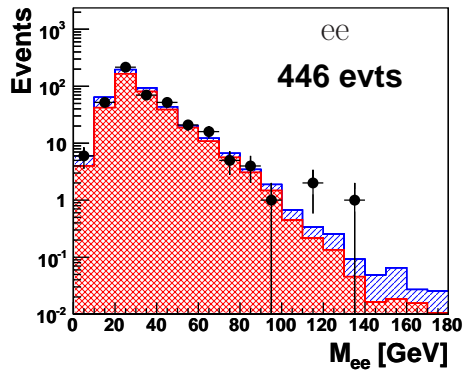
CC W production (7%)



Cabbibo-Parisi Z0 production
~3%, only in electron channel

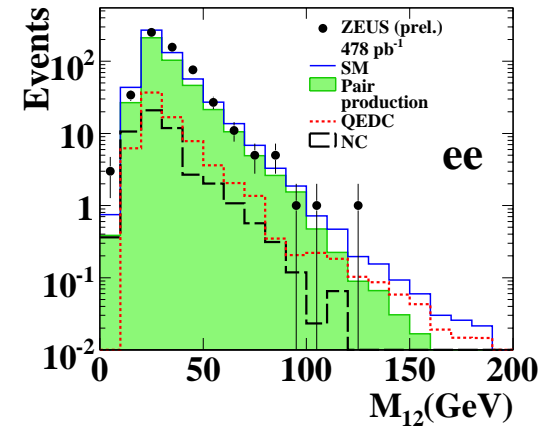
2 lepton results

H1 Multi-lepton analysis HERA I+II (459 pb⁻¹)



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

ZEUS

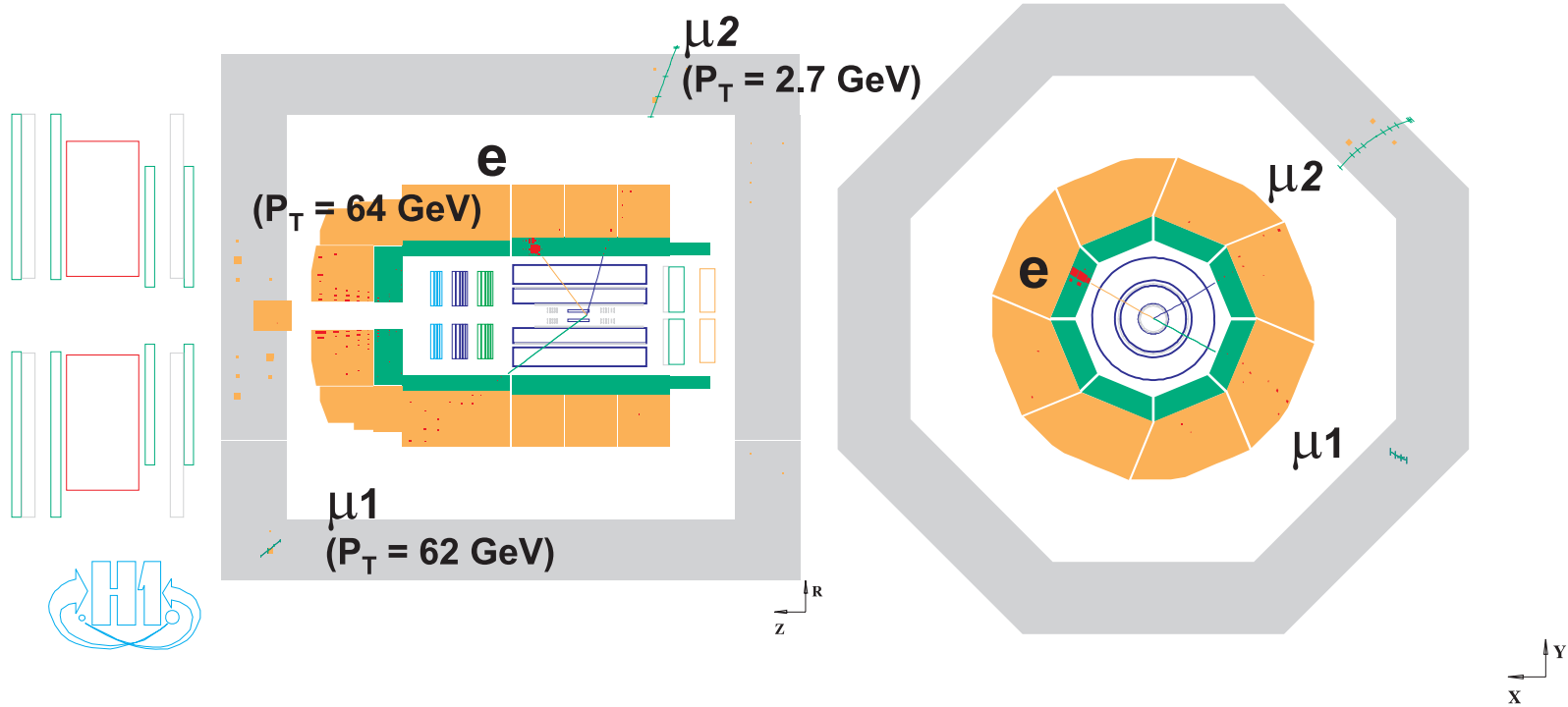


Overall good agreement with SM

H1: 3 ee events observed at $M > 100 \text{ GeV}$
 (all hera1 e⁺p data)

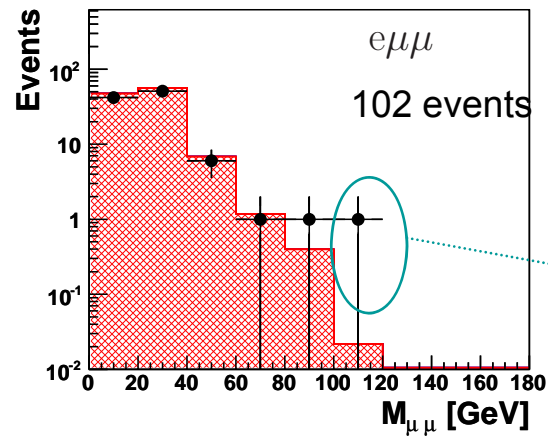
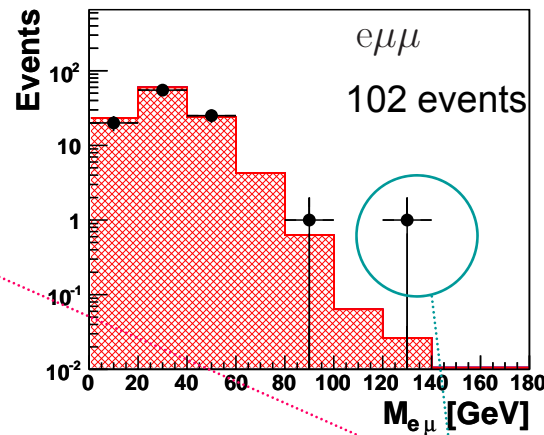
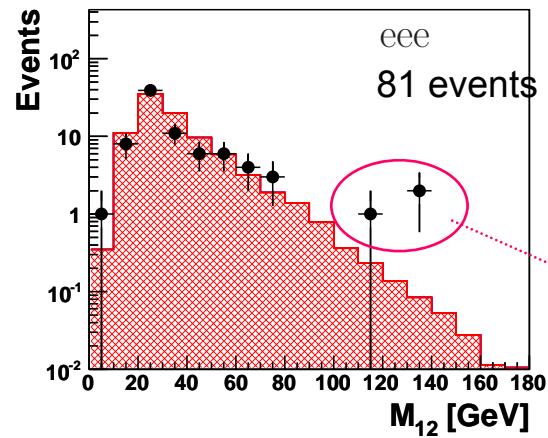
ZEUS: 2 ee event observed at $M > 100 \text{ GeV}$

3 lepton event



H1 3 lepton results

H1 Multi-lepton analysis HERA I+II (459 pb⁻¹)



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

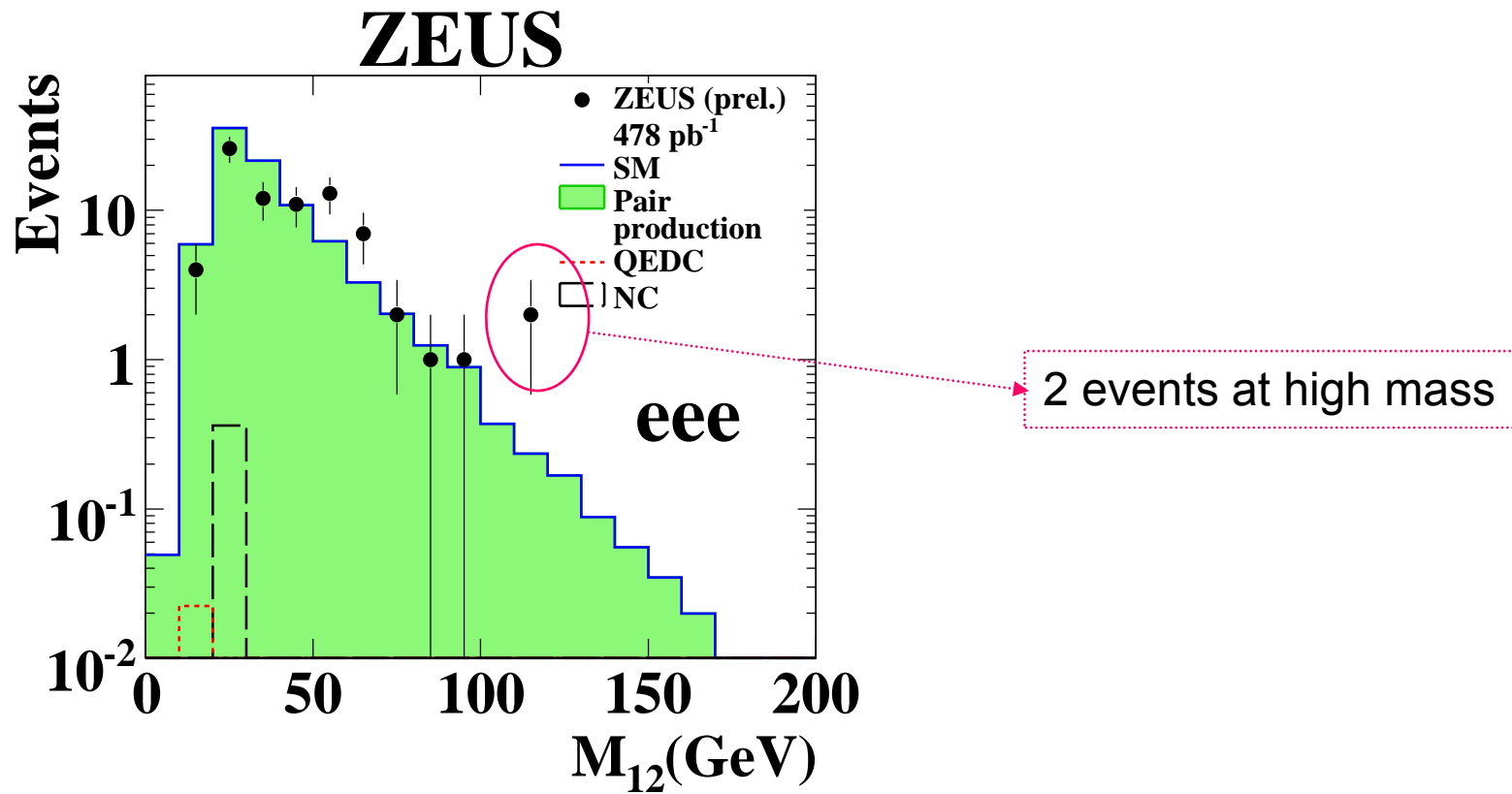
Overall good agreement with SM

Data slightly exceed SM prediction at high mass

3 eee events
Observed in hera 1 e⁺p

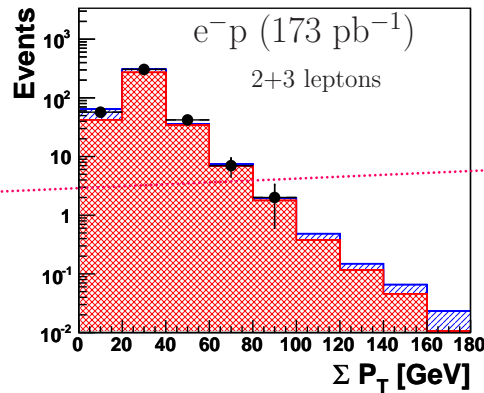
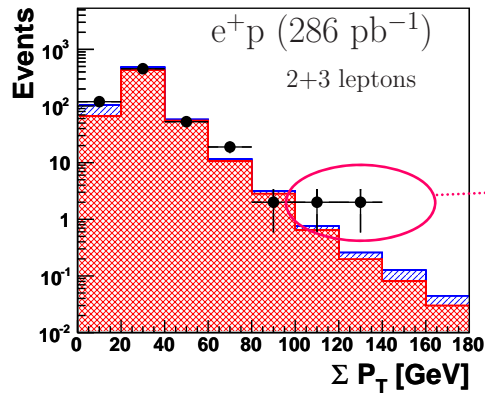
2 $e\mu\mu$ events observed in
Hera 2 e⁺p

Zeus 3 lepton results



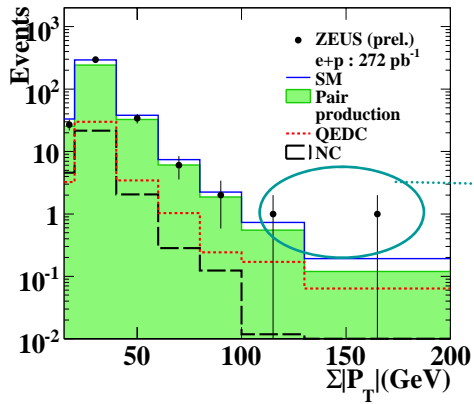
Results on 2+3 leptons

H1 Multi-lepton analysis HERA I+II (459 pb⁻¹)

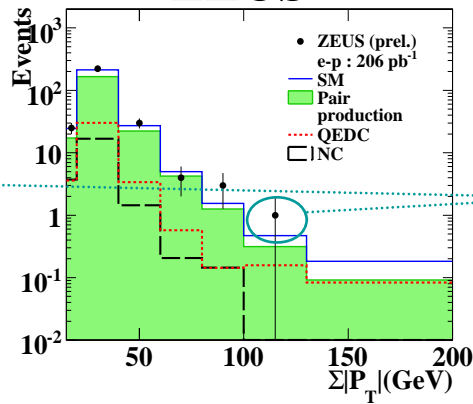


4 events with high ΣP_T
 3 ee events with $M > 100$ GeV
 1 $e\mu\mu$ event with $M_{12} > 100$ GeV
 SM expectation 1.9 ± 0.4

ZEUS

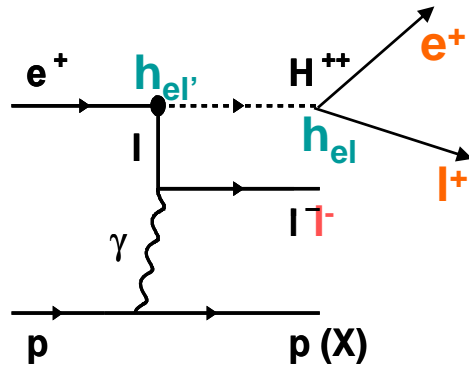


ZEUS



3 events with high ΣP_T
 SM expectation $1.58^{+0.16}_{-0.12}$

H^{±±} search



H1 HERA I data

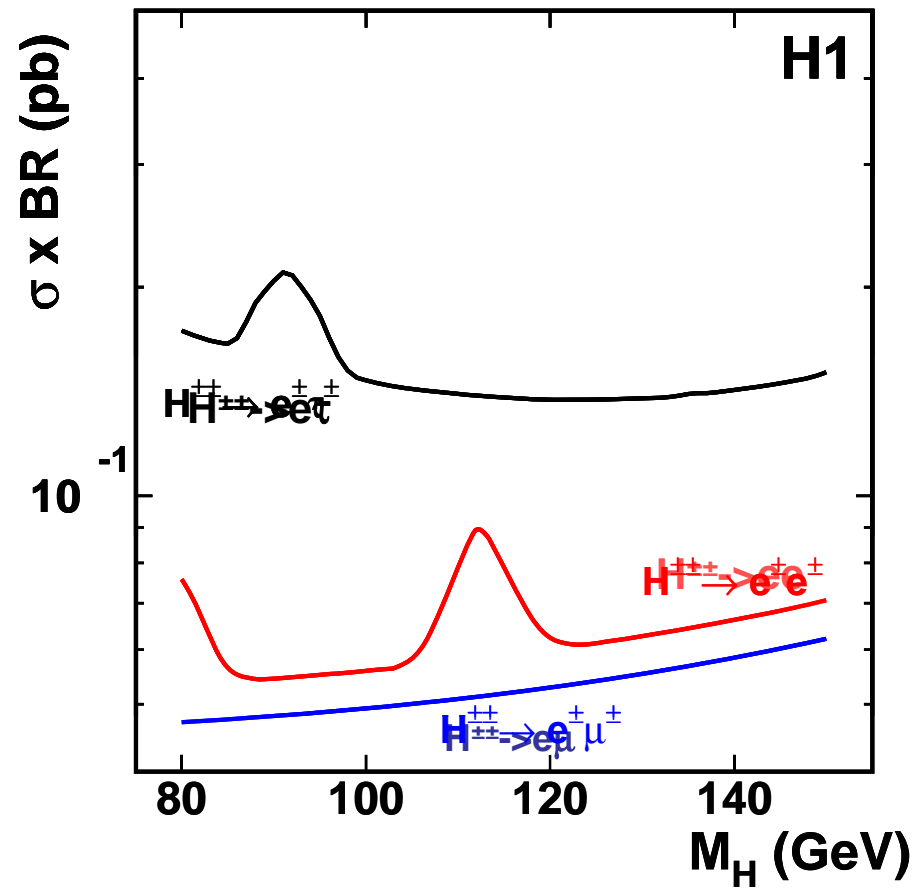
H^{±±}/H^{±±} exists in some left-right symmetric extensions to SM and SUSY models

Search for resonances in mass spectra of multi lepton sample

Additional charge and P_T cut for ee, eμ channel, P_T^{miss} cut for eτ

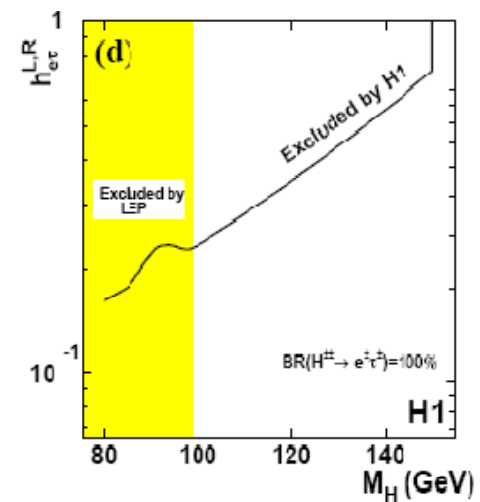
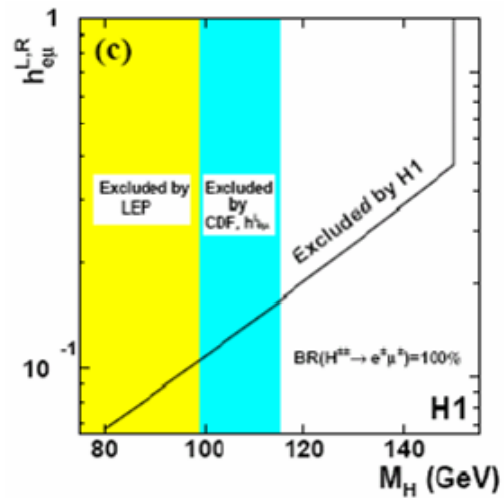
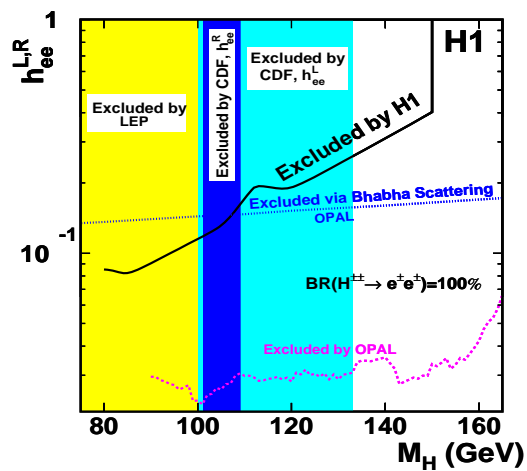
	Events M _{ll} >65GeV	SM
ee	3	2.45±0.11
eμ	1	4.17±0.44
eτ	1	2.1±0.5

Limit on $H^{\pm\pm}$ cross section



Best sensitivity for $H^{\pm\pm} \rightarrow e\mu$: $\sigma_{H^{\pm\pm} \rightarrow e\mu} < 0.05 \text{ pb}$

Limits on $H^{\pm\pm}$ mass



H1 sets most stringent limits on M_H for $H^{\pm\pm}$ coupling to $e\mu$ and $e\tau$ at coupling of electromagnetic strength:

$$h_{e\mu} = 0.3 \quad M_H > 141 \text{ GeV}$$

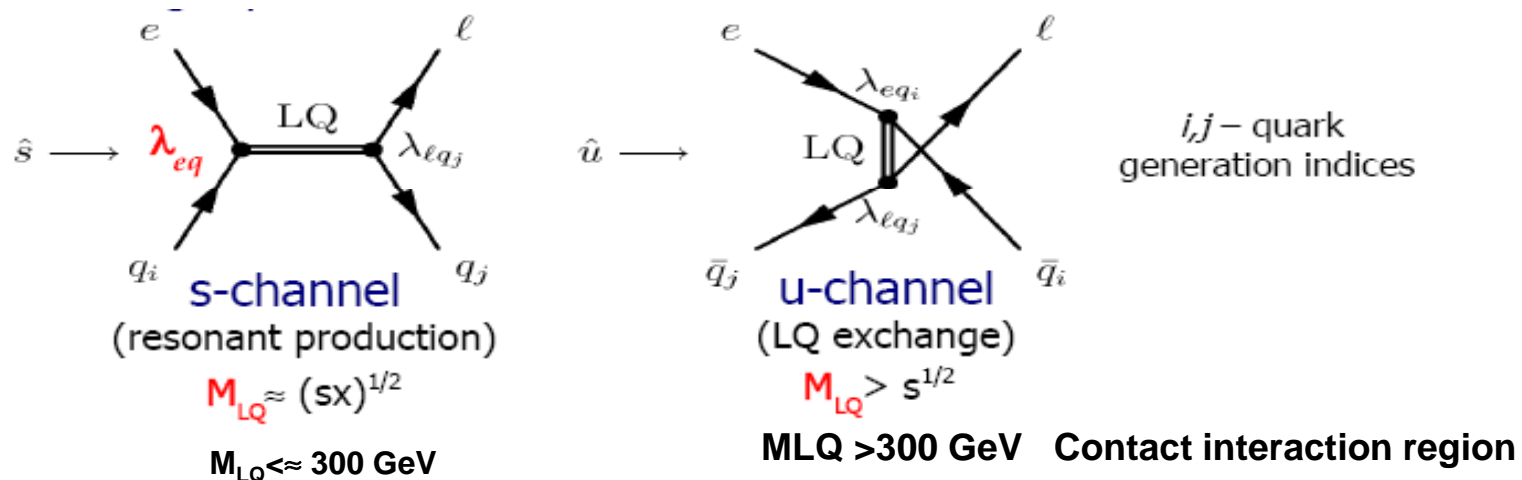
$$h_{e\tau} = 0.3 \quad M_H > 112 \text{ GeV}$$

Leptoquarks at HERA

Leptoquarks: color triplet boson with leptonic and baryonic quantum number:
 Fermion number: $F=L+3B$ $F=2$ (e-p) $F=0$ (se+p)

Buchmüller-Rückl-Wyler (BRW) model: LQ classified into 14 types (7 vector, 7 scalar) depending on spin, isospin, chirality

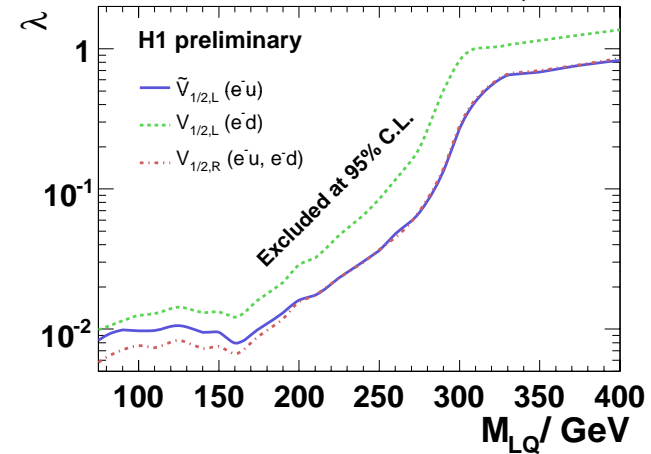
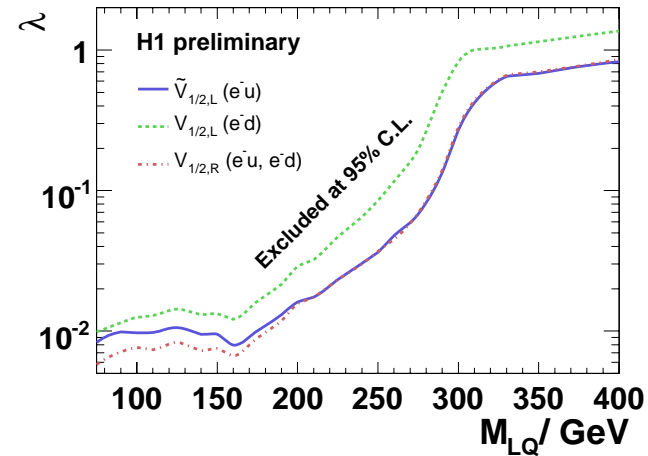
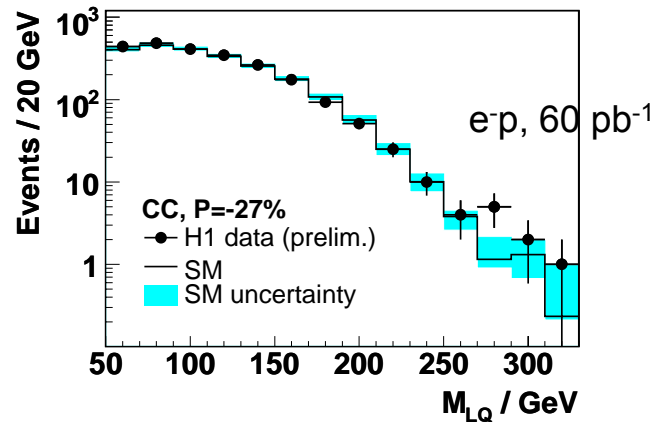
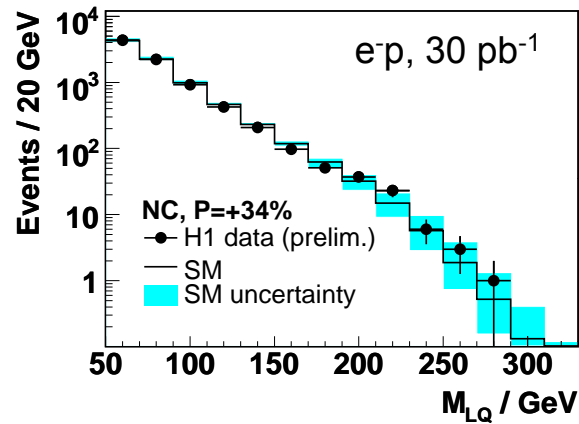
LQ at HERA: single production from incoming particles



LQ decay lepton flavor conserving (LFC): $LQ \rightarrow e q, \nu q$
 or lepton flavor violating (LFV): $LQ \rightarrow \mu q, \tau q$

H1 and ZEUS search for LQ in inclusive NC and CC event sample of 2004/05 data

Limits on 1st generation M_{LQ}

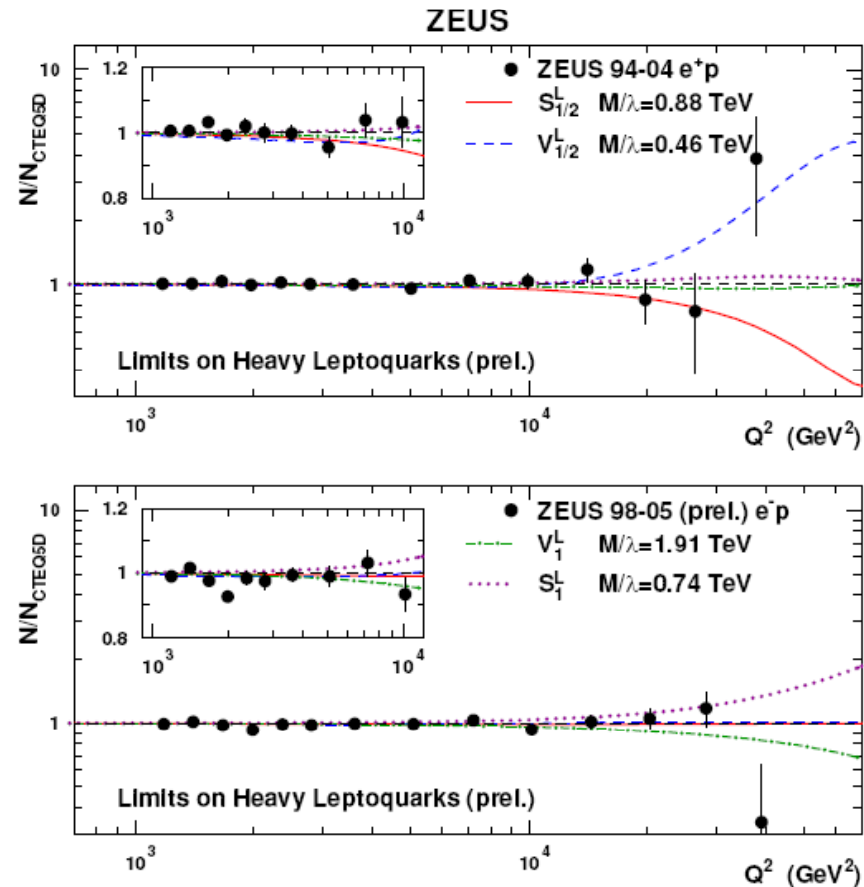


No enhancement
 No evidence for LQ signal

At $\lambda \sim 0.3$ exclude $M_{LQ} > 276-304$ GeV

Heavy Leptoquarks

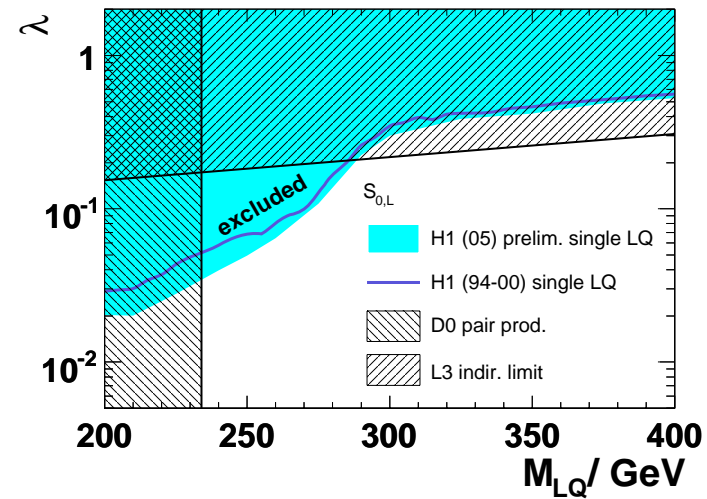
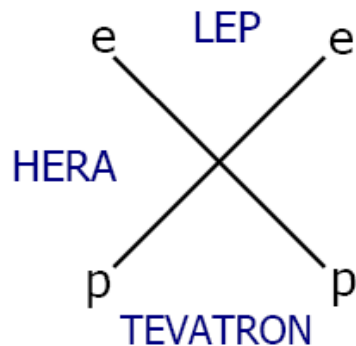
- Possible new interaction between e and q can modify DIS cross section at high Q^2 via virtual effects
- Search for virtual LQ exchange using 4 fermion eeqq contact interaction method
->report by P.Schleper in Alternatives



Lower limits on M_{LQ}/λ derived for all LQ
 $M_{\text{LQ}} \gg 300$ excluded for all LQ for $\lambda \sim 1$

Comparison with LEP and Tevatron

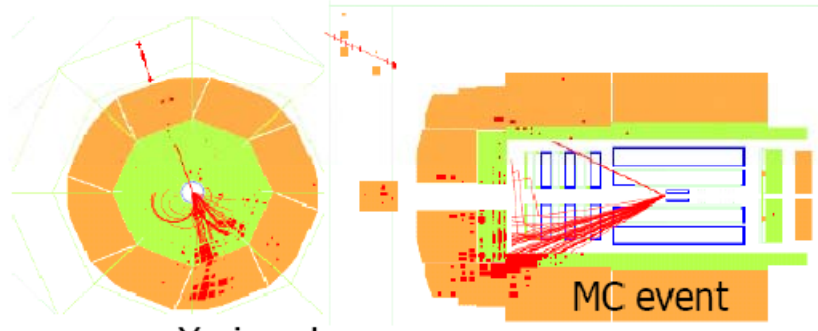
- **LEP**: contact interaction (indirect constraints from $e^-e^+ \rightarrow q\bar{q}$)
- **TEVATRON**: pair production (λ independent)
- **HERA**: single production ($M_{LQ} < 300$ GeV) and contact interaction ($M_{LQ} > 300$ GeV)



~ factor 2 more lumi to be added using full HERA II data

Limits on LFV Leptoquarks

Signature $ep \rightarrow \mu X$



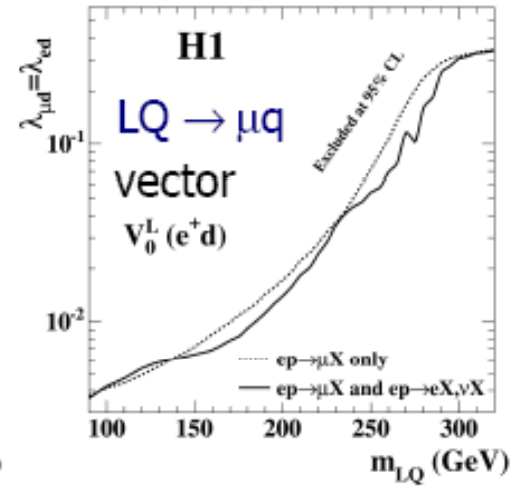
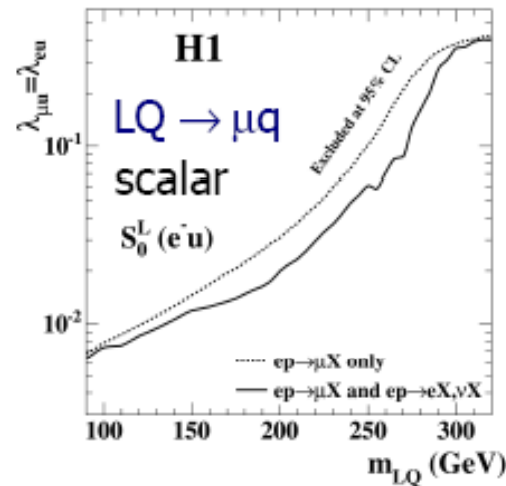
Low background, good sensitivity

Typical selection:
Back-to-back topology,
 $P_{T, \text{calo}} > 20 \text{ GeV}$

$$\lambda_{eq} = \lambda_{\eta q'} \text{ or } \lambda_{eq} = \lambda_{\tau q}$$

Assume:

No evidence for
Signal found




Exclude $M_{LQ} > 300 \text{ GeV}$ for $\lambda \sim 0.3$

Summary

- Results for isolated leptons with p_T^{miss} shown for complete heras data sample and for the first time with h1+zeus combination $\sim 1\text{fb}^{-1}$:
 - In e+p data: H1 observed 21 events where 8.9 were expected in complete data and even stronger signal in e+p data
 - ZEUS observed 6 events where 7.4 expected
- All HERA data analysed by H1 and ZEUS multi-lepton events
 - At high ΣP_T H1 observes 4 events, expectation is 1.9 ± 0.4
ZEUS observes 3 events, expectation is $1.58^{+0.12}_{-0.16}$
 - Combined results expected soon
- Limits for LQ updated – improvement with full heras data sample to come

extras


Isolated lepton event selection

Variable	Electron	Muon
θ_1	$5^\circ < \theta_1 < 140^\circ$ (H1), $15^\circ < \theta_1 < 120^\circ$ (ZEUS)	
P_T^1	> 10 GeV	
P_T^{calo}	> 12 GeV	
P_T^{miss}	> 12 GeV	
P_T^X	-	> 12 GeV
D_{jet}	> 1.0	
D_{track}	> 0.5 for $\theta_e \geq 45^\circ$	> 0.5
ζ_1^2	> 5000 GeV ² for $P_T^{\text{calo}} < 25$ GeV	-
V_{ap}/V_p	< 0.5 (< 0.15 for $P_T^e < 25$ GeV)	< 0.5 (< 0.15 for $P_T^{\text{calo}} < 25$ GeV)
$\Delta\phi_{1-X}$	$< 160^\circ$	$< 170^\circ$
δ_{miss}	> 5 GeV 	-
# isolated μ	0	1

} Analysis phase space selection.
H1: extended polar angle range

} Isolation of lepton

} Cuts designed to reduce SM background, whilst preserving large signal purity

 H1: only if one e candidate is detected, with the same charge as the beam lepton

Multi-lepton event yields at $M_{ll} > 100 \text{ GeV}$

H1 preliminary HERA I+II

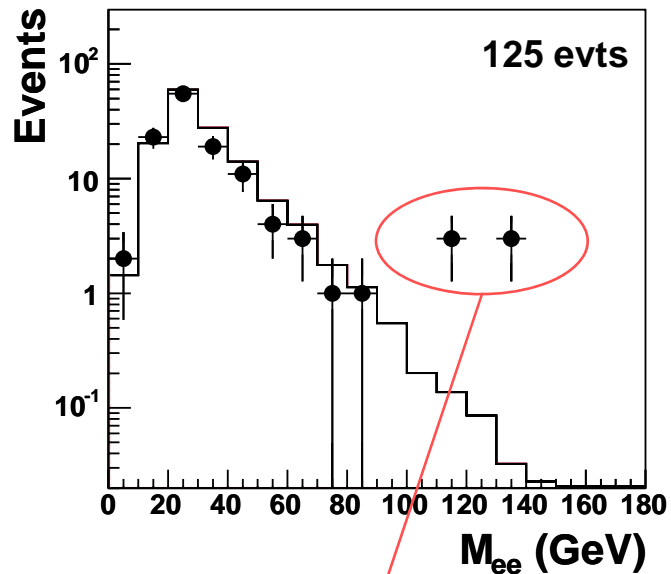
	Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (286 pb ⁻¹)					
e^+p	$ee M_{12} > 100 \text{ GeV}$	3	1.0 ± 0.2	0.6 ± 0.2	0.4 ± 0.1
	$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.06 ± 0.03	0.06 ± 0.03	—
	$e\mu M_{e\mu} > 100 \text{ GeV}$	1	0.53 ± 0.05	0.53 ± 0.05	—
	$eee M_{12} > 100 \text{ GeV}$	3	0.6 ± 0.1	0.6 ± 0.1	—
	$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	1	0.04 ± 0.02	0.04 ± 0.02	—
	$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	1	0.007 ± 0.005	0.007 ± 0.005	—
e^-p collisions (173 pb ⁻¹)					
e^-p	$ee M_{12} > 100 \text{ GeV}$	0	0.55 ± 0.1	0.3 ± 0.1	0.25 ± 0.07
	$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.03 ± 0.02	0.03 ± 0.02	—
	$e\mu M_{e\mu} > 100 \text{ GeV}$	0	0.3 ± 0.05	0.3 ± 0.05	—
	$eee M_{12} > 100 \text{ GeV}$	0	0.32 ± 0.06	0.32 ± 0.06	—
	$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	0	0.04 ± 0.01	0.04 ± 0.01	—
	$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.006 ± 0.004	0.006 ± 0.004	—

ZEUS preliminary HERA I+II

	Type	DATA	SM	Pair production	QEDC	NC
e^+p	2e	1	0.9 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.07 ± 0.03
	3e	2	$0.6 - 0.07 + 0.5$	0.6 ± 0.07	< 0.01	< 0.5
e^-p	2e	1	0.8 ± 0.1	0.4 ± 0.04	0.39 ± 0.3	0.04 ± 0.01
	3e	0	$0.4 - 0.1 + 0.5$	1.0 ± 0.1	< 0.01	< 0.5

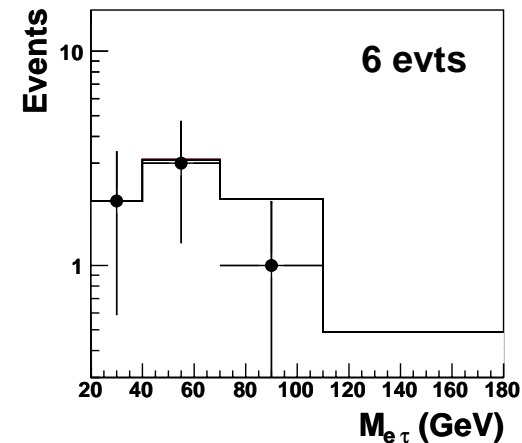
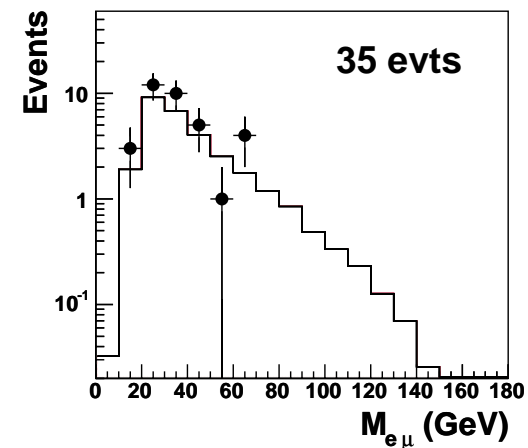
2 lepton mass spectra, $H^{\pm\pm}$ search (backup)

H1 HERA I data, $H^{\pm\pm}$ preselection

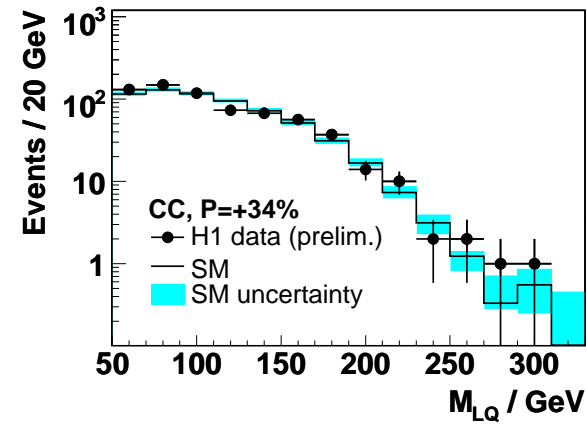
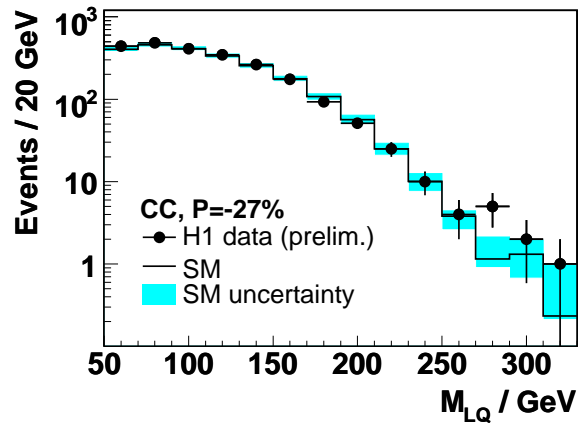
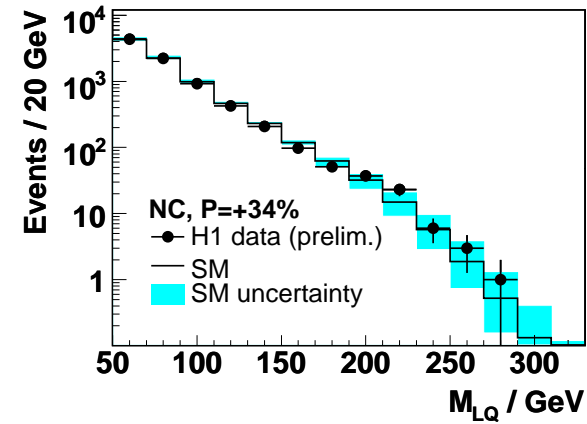
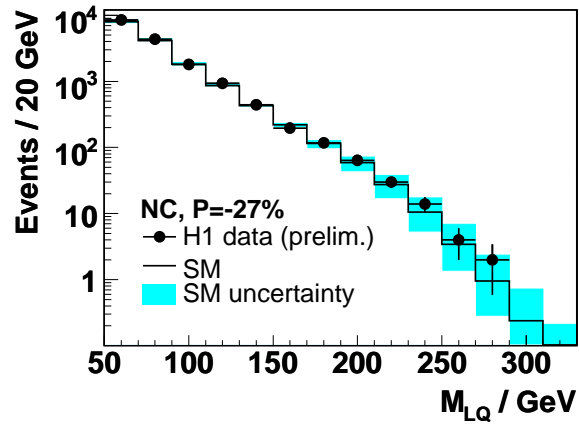


6 evts obs.
 0.53 ± 0.06 expt.

1 event after final selection
(charge+ P_T cuts)

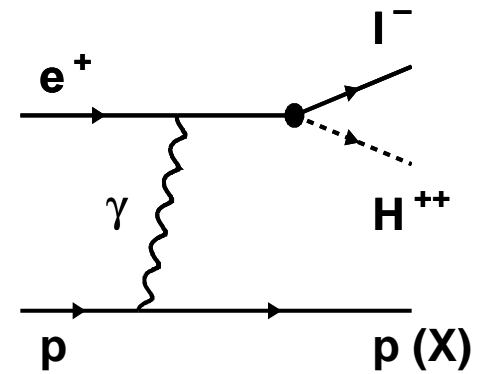
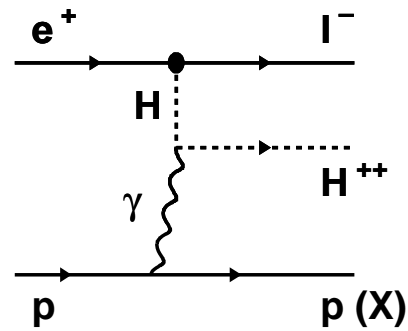
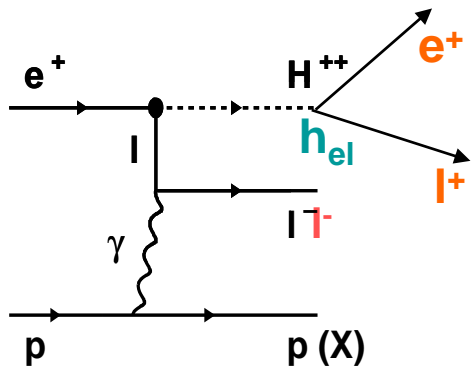


Leptoquark search all mass spectra



$H^{\pm\pm}$ production

H1 HERA I data



CC and NC cross section

