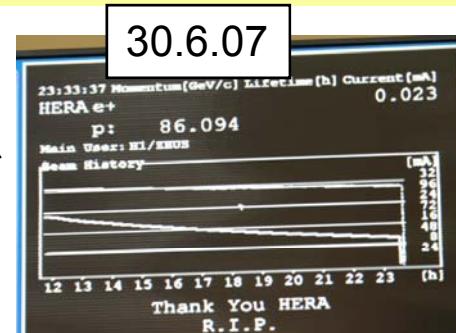
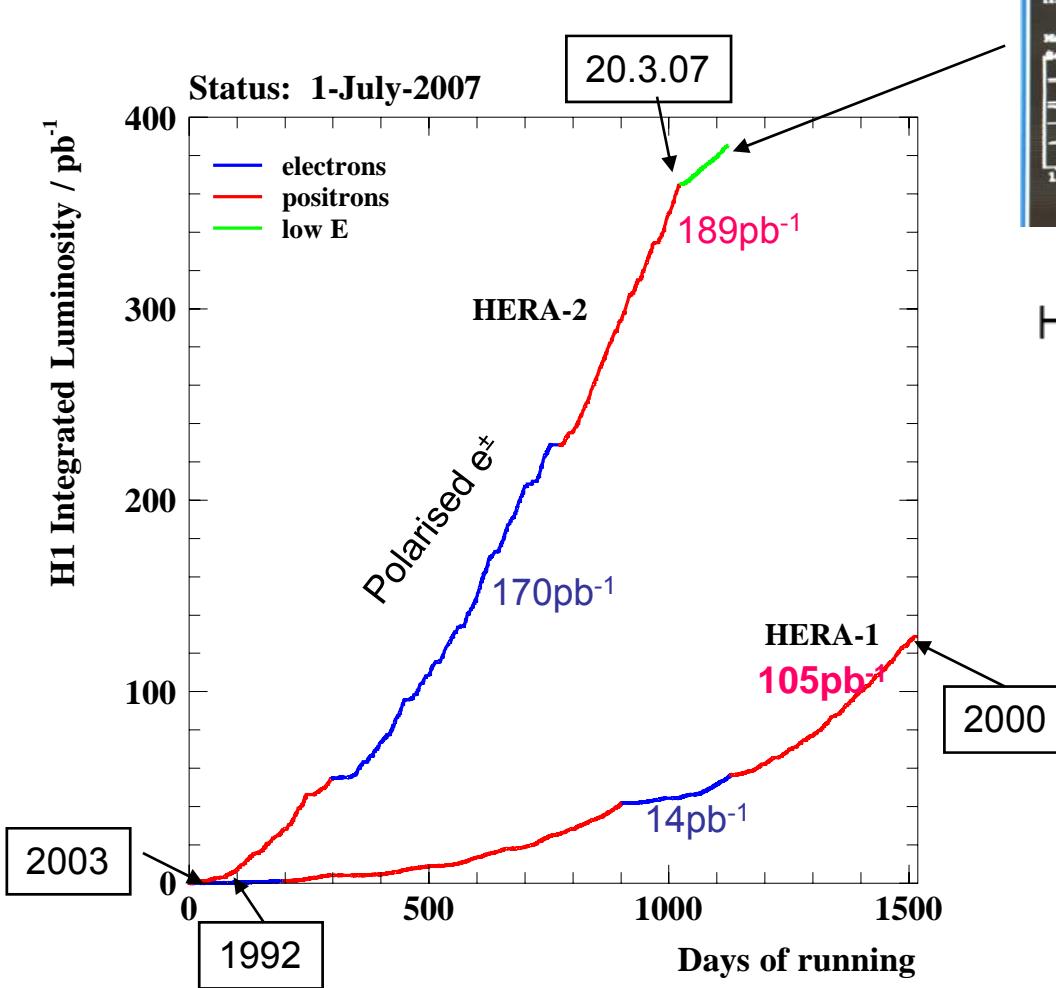


Searches for Isolated Leptons, Multileptons and Leptoquarks at HERA

Judith Katzy (DESY)



HERA



HERA:

318 GeV

$p (920 \text{ GeV})$ $e (27.6 \text{ GeV})$

Total luminosity collected:

H1: 478 pb^{-1}

$294 \text{ pb}^{-1} e^+$

$184 \text{ pb}^{-1} e^-$

Zeus: 492 pb^{-1}

$286 \text{ pb}^{-1} e^+$

$206 \text{ pb}^{-1} e^-$

$\sim 1 \text{ fb}^{-1}$

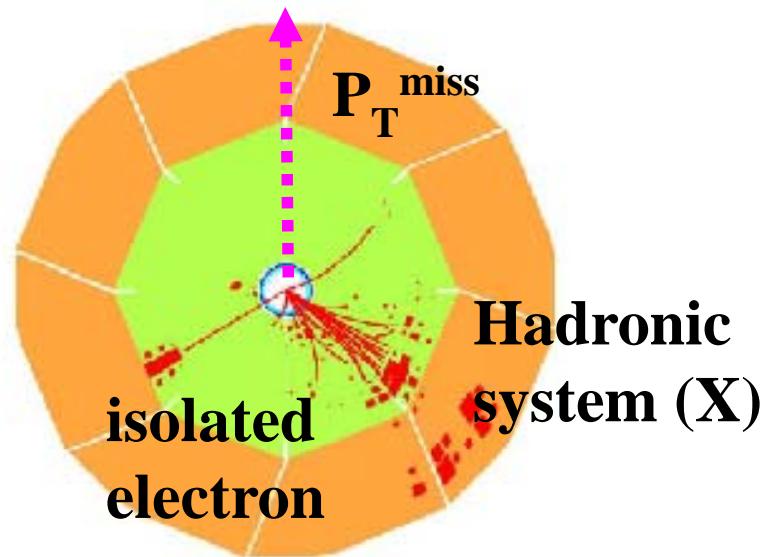
Slide 2

DU1 roughly 0.5 fb-1 per event
combined data set roughly 1 fb-1
roughly 2/3 e+, a little more than 1/3 e-

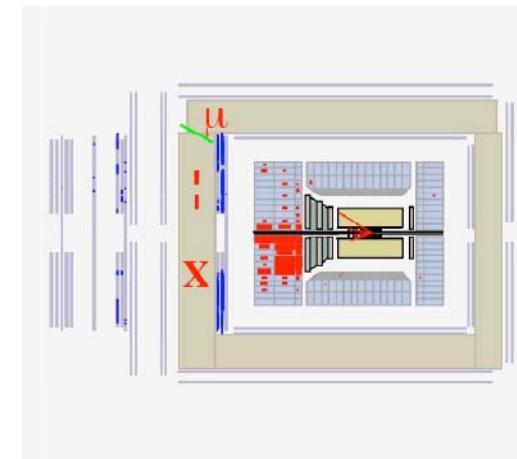
hera1 mainly e+

DESY USER, 7/19/2007

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



HERA I:
H1 observed 11 events at $P_T^X > 25 \text{ GeV}$
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

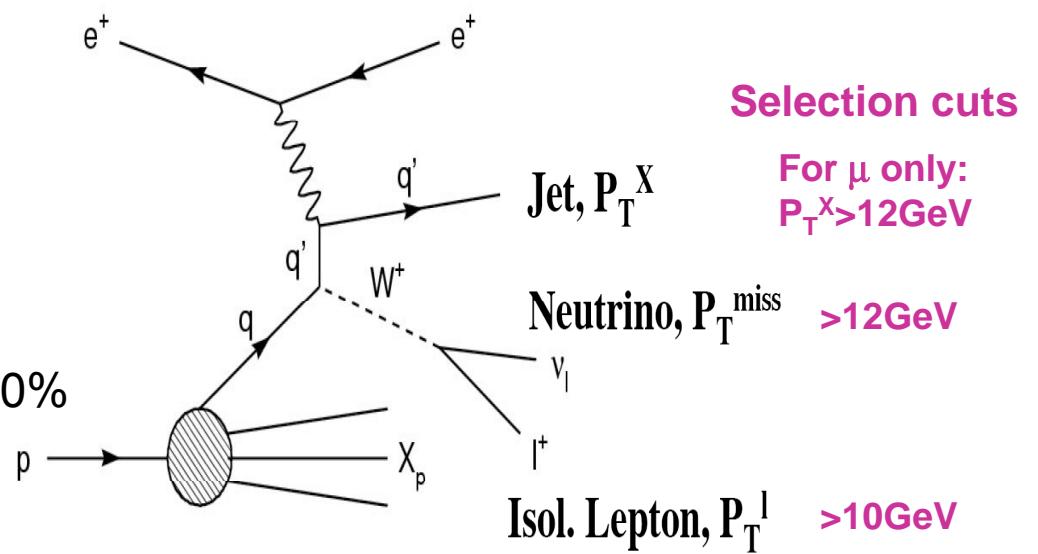
$$\sigma_W \sim 1.3 \text{ pb}^{-1}$$

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)



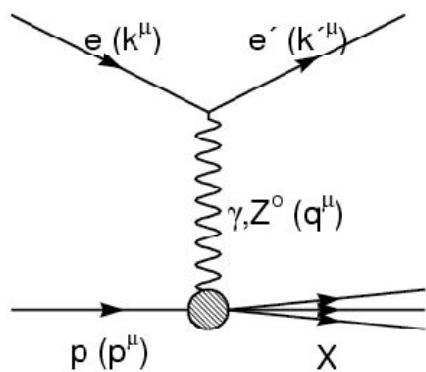
Modelled using EPVEC generator with NLO QCD correction:
Modifies cross section by $\sim 10\%$, reduces theoretical uncertainty to $\sim 15\%$

DU3 photoproduction therefore scattered e undetected
independent on incoming electron charge (e+ and e-)

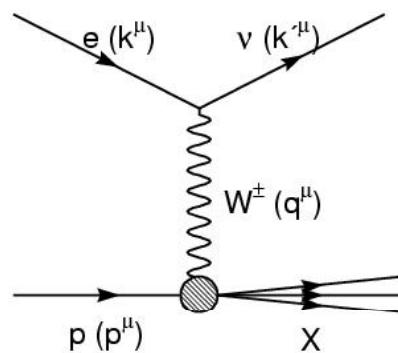
CC W production similar feynman graph only changes: outgoing is nu instead of e, exchanged boson is W instead of gamma
DESY USER, 7/20/2007

Background processes

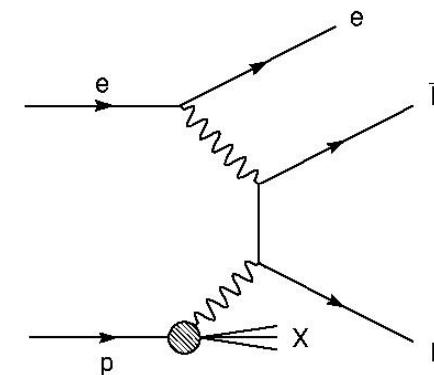
e: Neutral Current



e, μ : Charged Current



μ : Lepton Pair Production



Real electron and
fake P_T^{miss} from
mismeasurement

Misidentified e or μ
and real P_T^{miss}

Real μ and fake P_T^{miss}
from mismeasurement

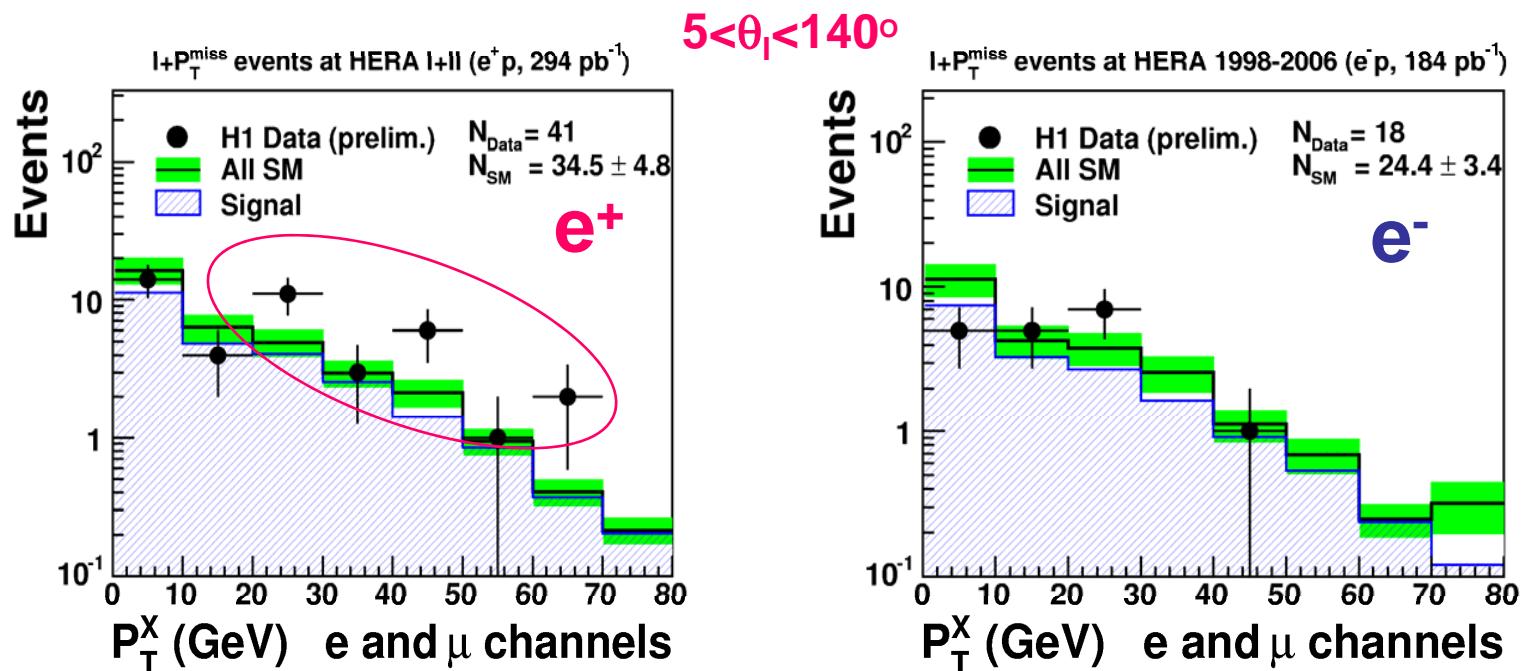
DU14 NC: fake ptmiss due to fluctuations in detector response or lost particles due to limited acceptance

CC: misidentify e or mu from hadronic state or radiated photon

LP in photoproduction: second mu undetected fakes ptmiss

DESY USER, 7/20/2007

H1 isolated leptons



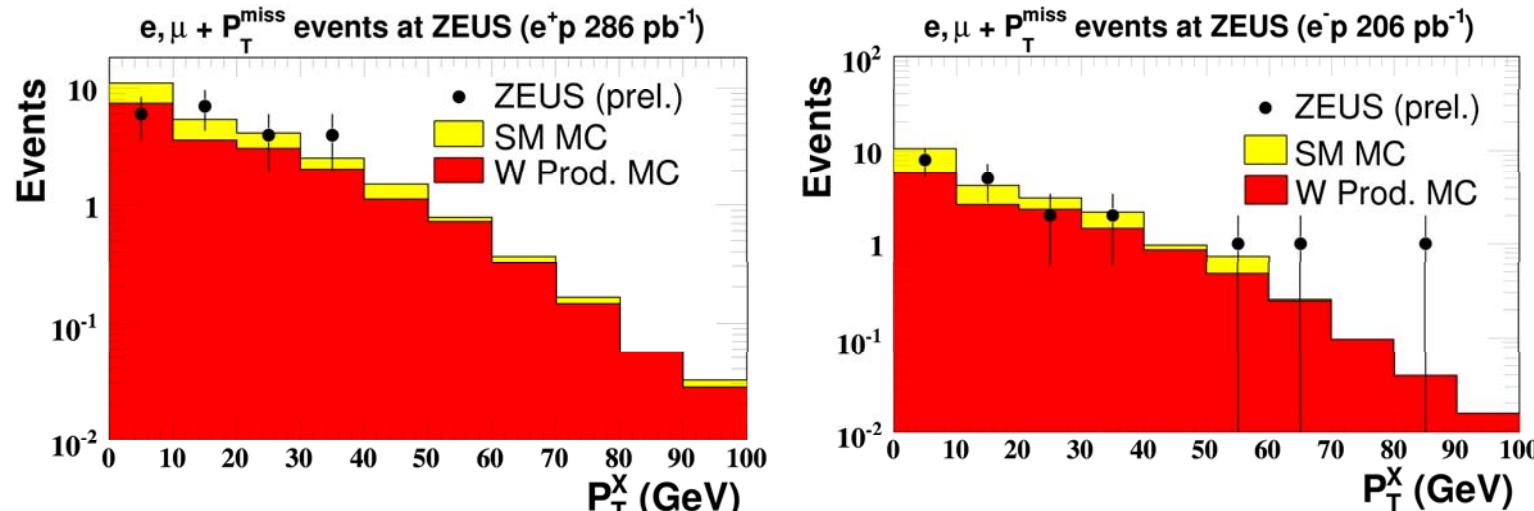
Excess at high p_T^X

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})	$11 / 4.7 \pm 0.9$ (75%)	$10 / 4.2 \pm 0.7$ (85%)	$21 / 8.9 \pm 1.5$ (80%)
$e^- p$ data (184 pb^{-1})	$3 / 3.8 \pm 0.6$ (61%)	$0 / 3.1 \pm 0.5$ (74%)	$3 / 6.9 \pm 1.0$ (67%)

ZEUS isolated leptons

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



41 events observed in 492 pb-1 of data

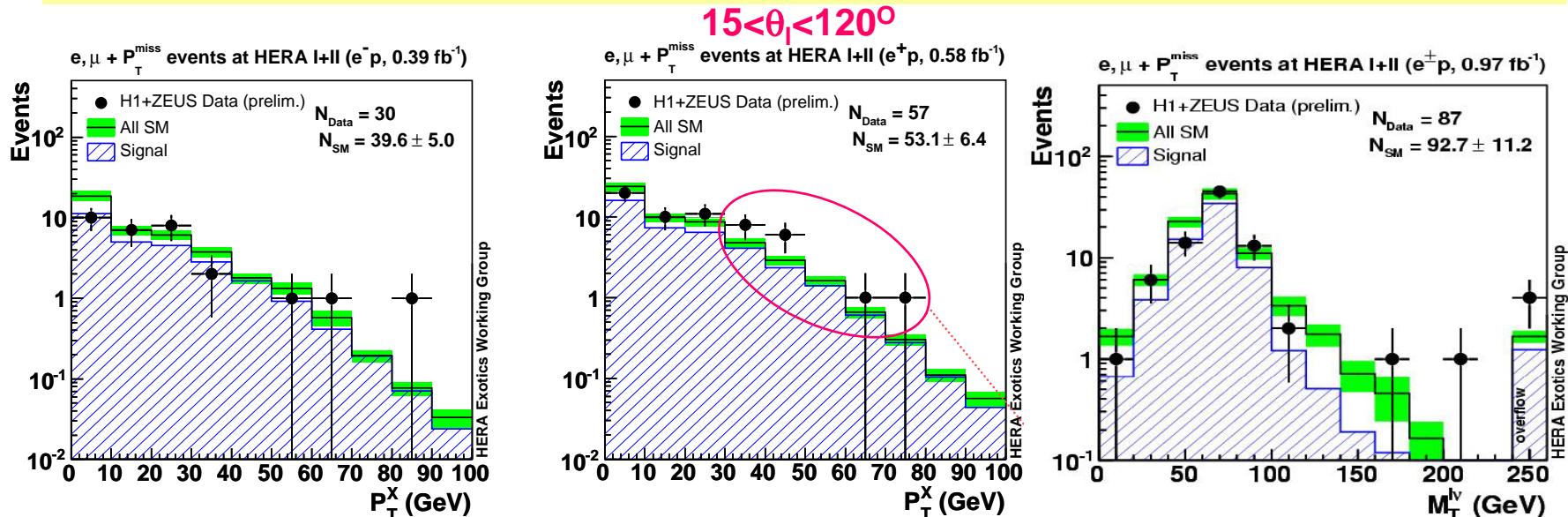
HERA I+II $P_{\text{T}}>25\text{GeV}$	e channel Obs/exp(signal)	μ channel Obs/expt.(signal)
e^+ data	$3/3.9 \pm 0.5(81\%)$	$3/3.6 \pm 0.5(81\%)$
e^- data	$3/3.2 \pm 0.6(69\%)$	$2/2.4 \pm 0.4(85\%)$

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

DU18 e+p data from 1996-2007

H1 acceptance bigger but almost all events from excess are also in the ZEUS acceptance
DESY USER, 7/21/2007

H1 and Zeus combined



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 \pm 0.8 (67%)	2/4.8 \pm 0.7 (87%)	29/25.3 \pm 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

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

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

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

σ_W (pb)	Measured \pm stat \pm sys	SM \pm thesys
\int	$1.23 \pm 0.25 \pm 0.22$	1.31 ± 0.20

Both measured cross sections are in good agreement with the SM

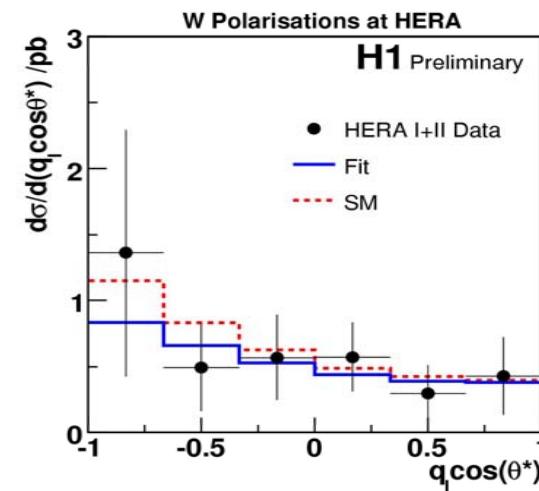
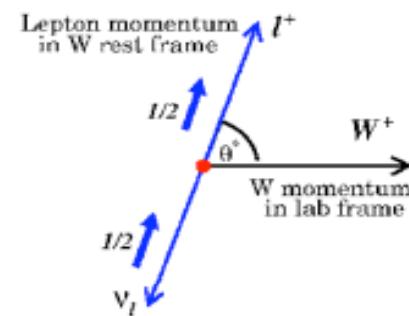
Measurement of W polarisation fraction

$$F_+ = 1 - F_- - F_0$$

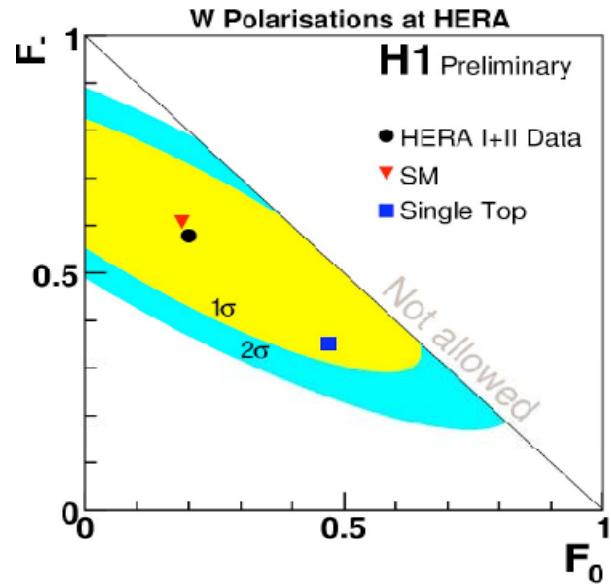
right left longitudinal polarisation fraction

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

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

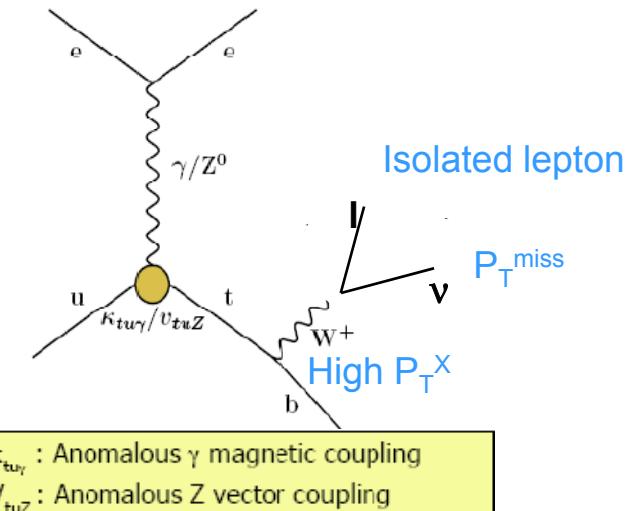
SM single top production $\sigma < 1\text{fb}^{-1}$

Top production via flavor changing NC in BSM

Candidate process for excess

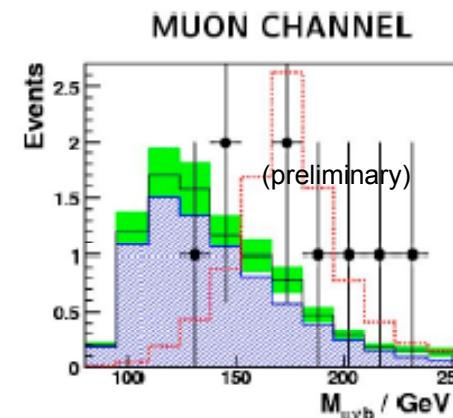
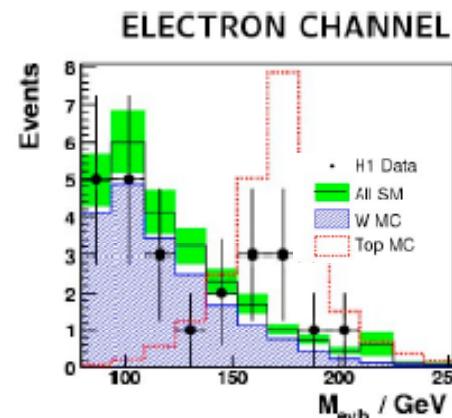
But: same rate for e^+ and e^-

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



24 events selected,
26 events SM prediction

DU8
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:

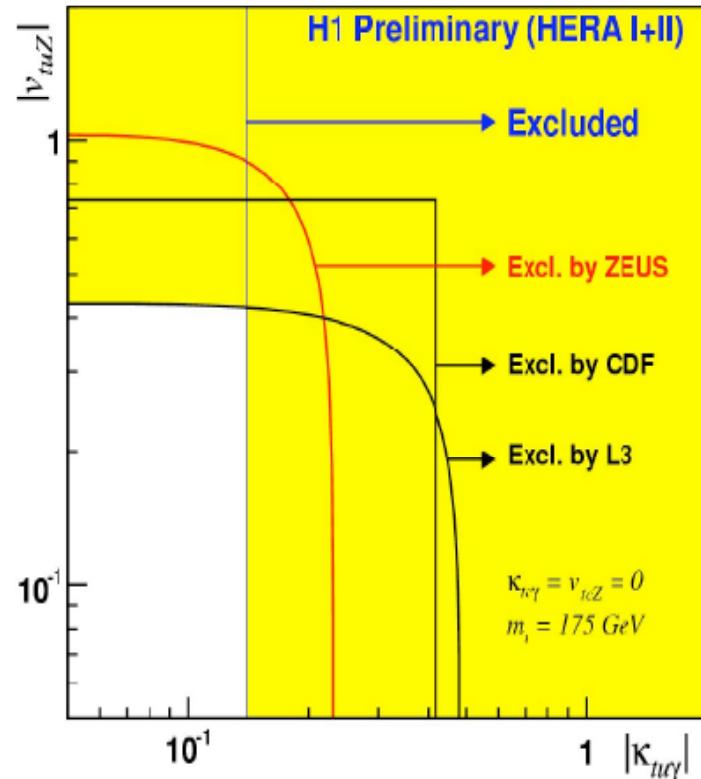
H1: $\sigma(ep \rightarrow etx) < 0.55 \text{ pb}$

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

Upper bound on the anomalous coupling:

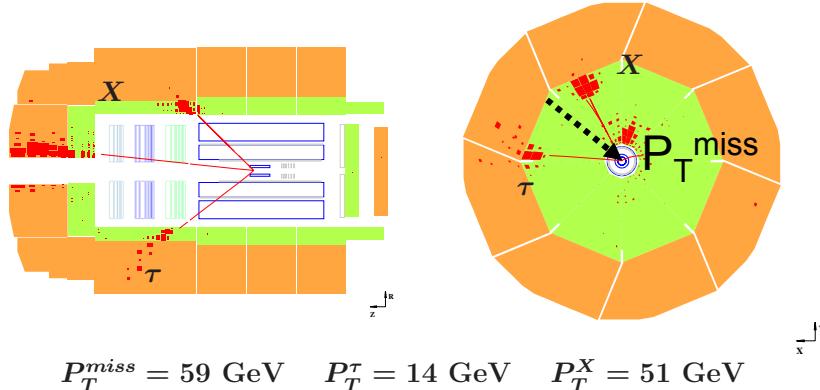
$$|\kappa_{\tau u \gamma}| < 0.14$$

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



Isolated τ leptons + p_T^{miss}

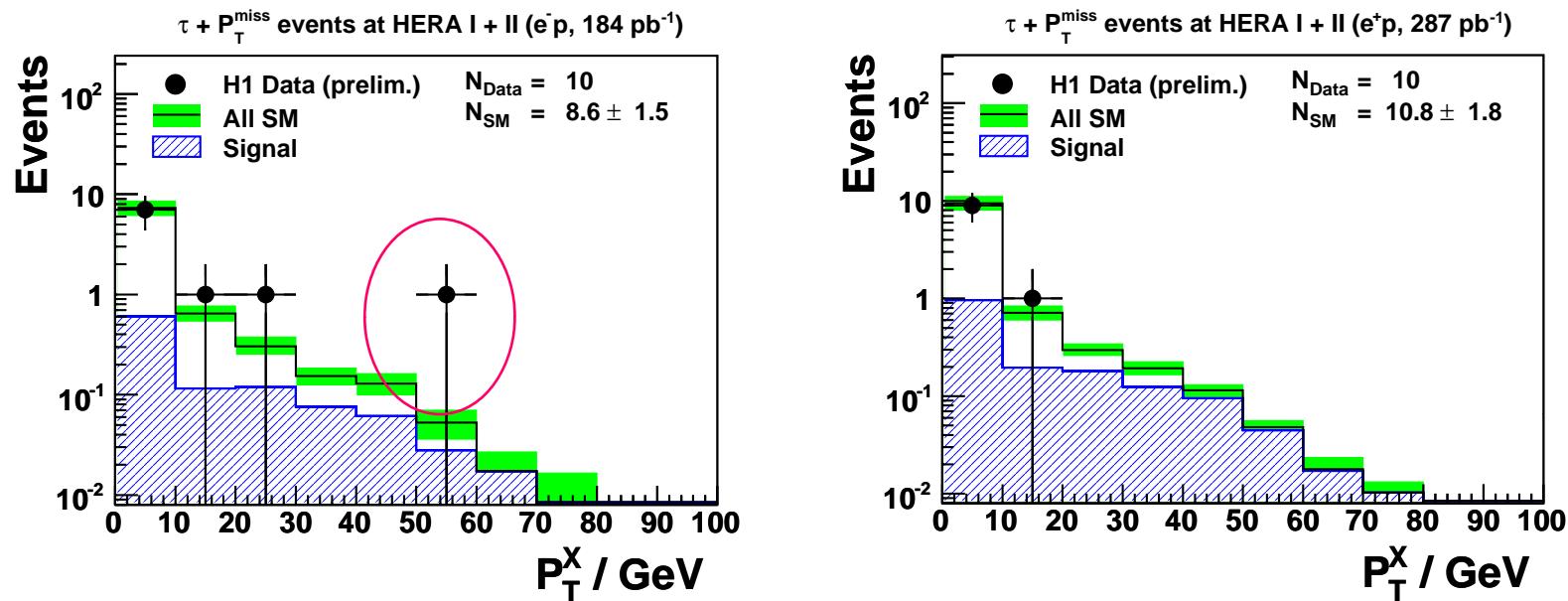
H1 $\tau + p_T^{\text{miss}}$ candidate with large P_T^X



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	$20 / 19.5 \pm 3.2$ (14%)
$P_T^X > 25 \text{ GeV}$	$1 / 0.99 \pm 0.13$ (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**

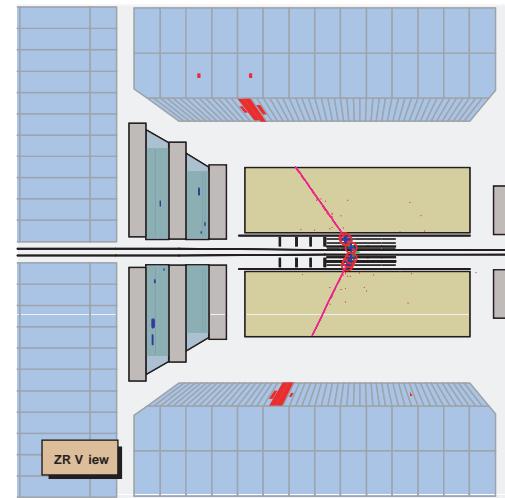
$p_T^{1l} > 10 \text{ GeV}$, $p_T^{2l} > 5 \text{ GeV}$, $20^\circ < \theta < 160^\circ$

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 μ , $\mu\mu$, eeee, e $\mu\mu$



DU9 QED processes well understood - deviations at high mass directly sign of new physics

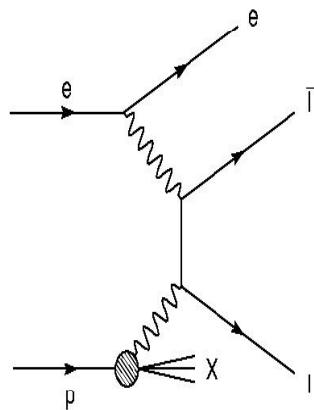
background processes:

NC DIS where part of the hadronic is misidentified as electron

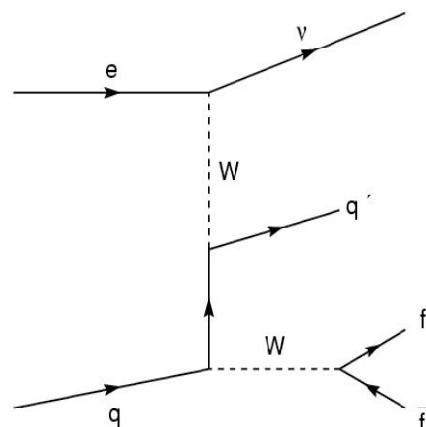
QED Compton with gamma misidentified as e

DESY USER, 7/22/2007

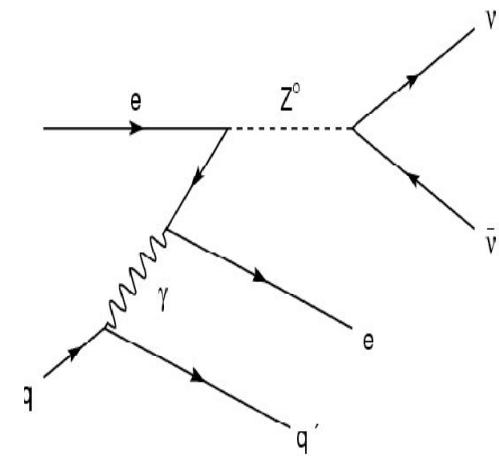
QED processes with multi-lepton final state



$\gamma\gamma$ process dominant



CC W production (7%)



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

DU17 QED processes well understood - deviations at high mass directly sign of new physics

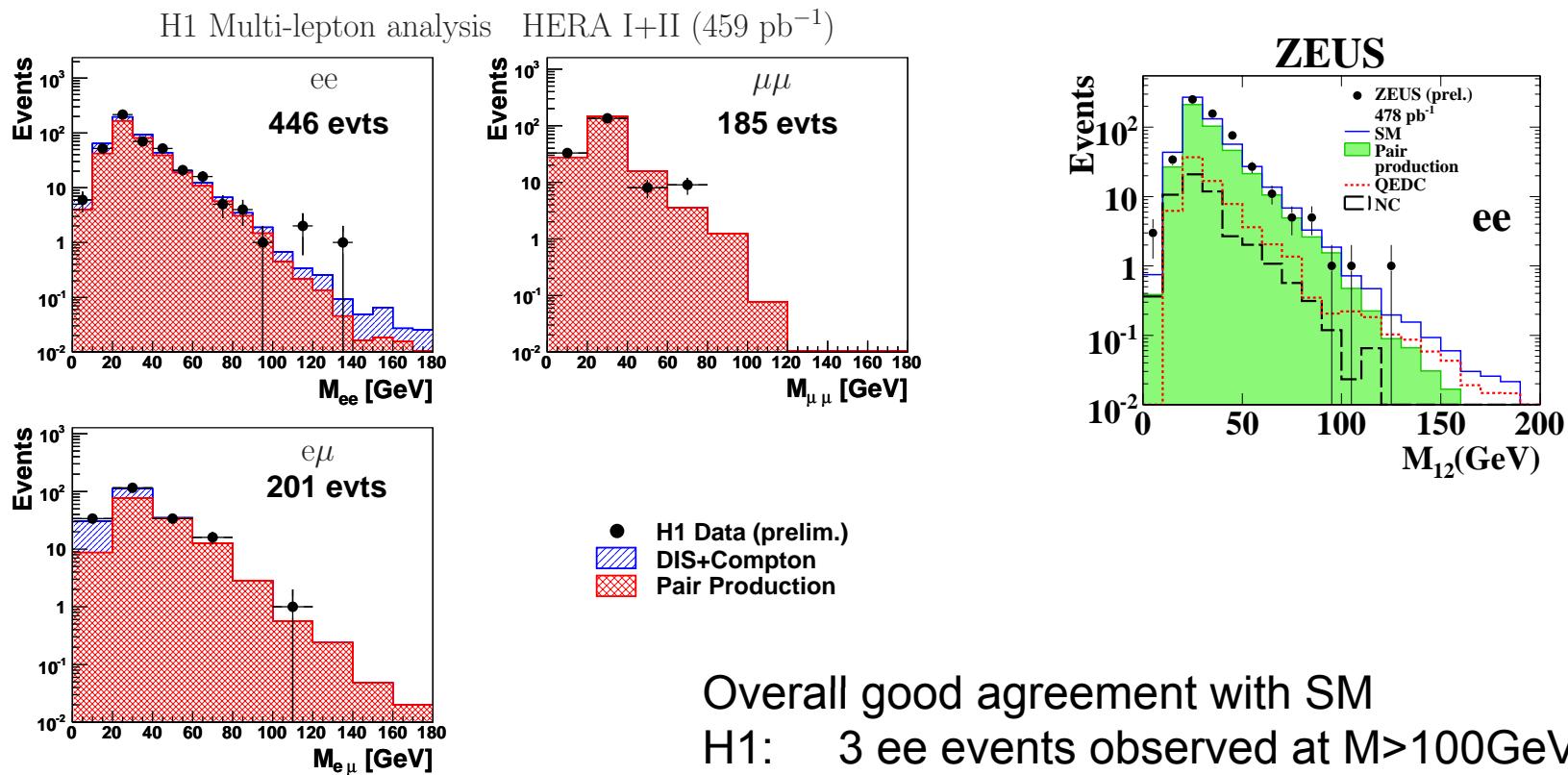
background processes:

NC DIS where part of the hadronic is misidentified as electron

QED Compton with gamma misidentified as e

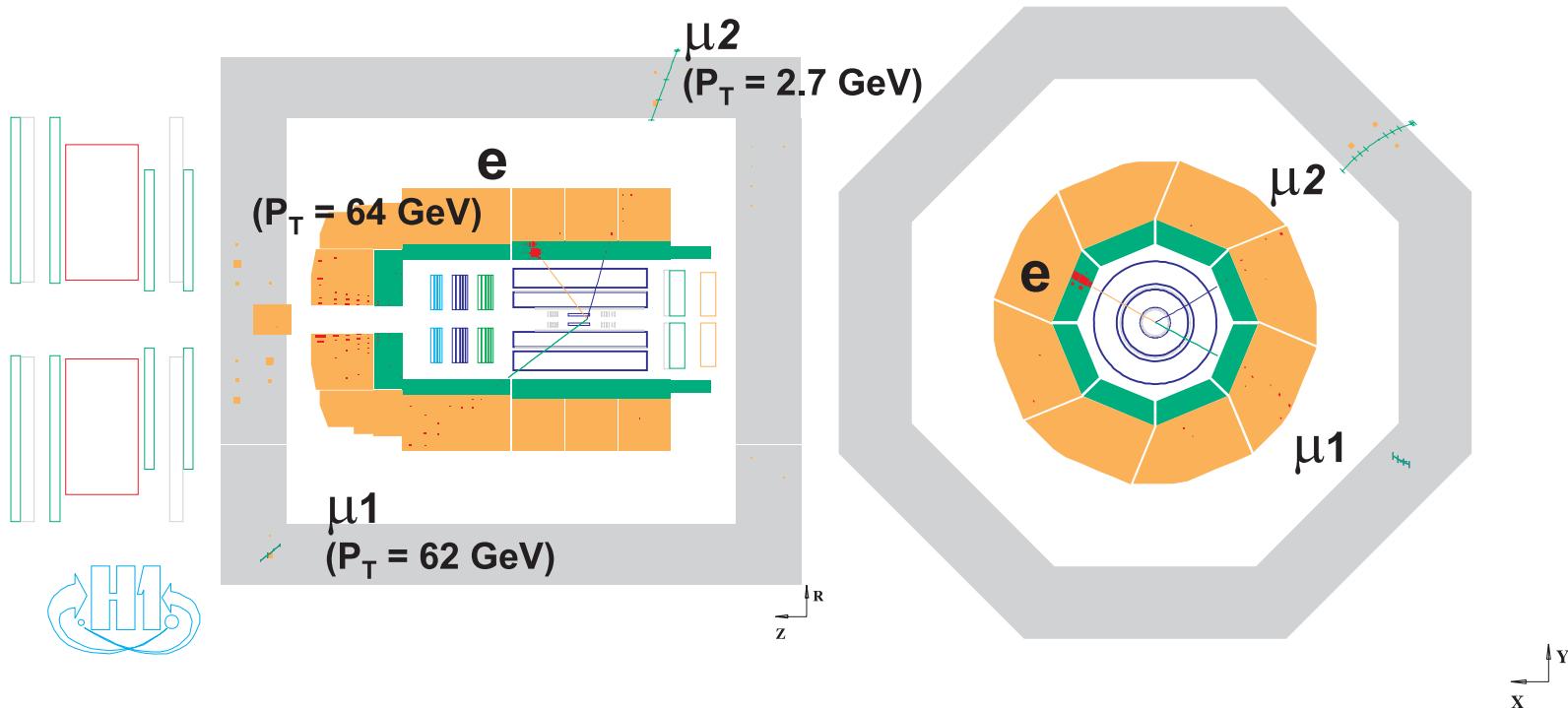
DESY USER, 7/22/2007

2 lepton results



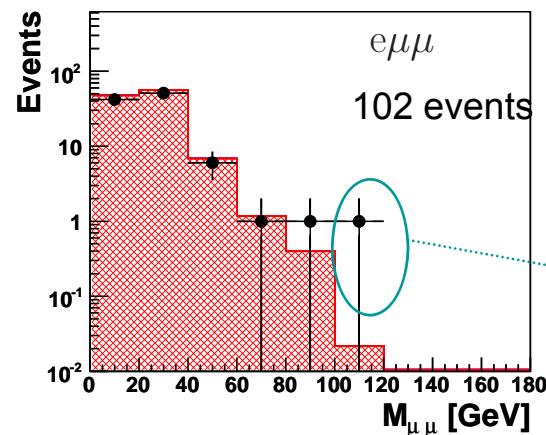
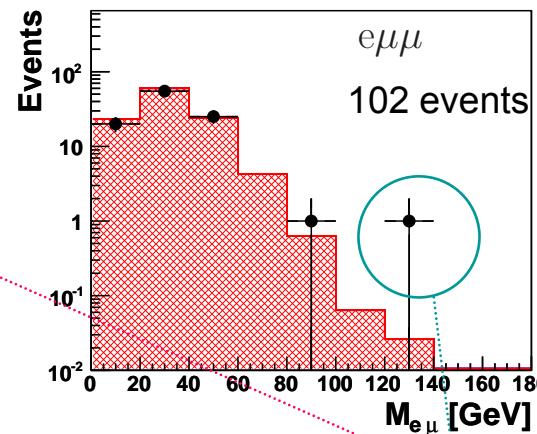
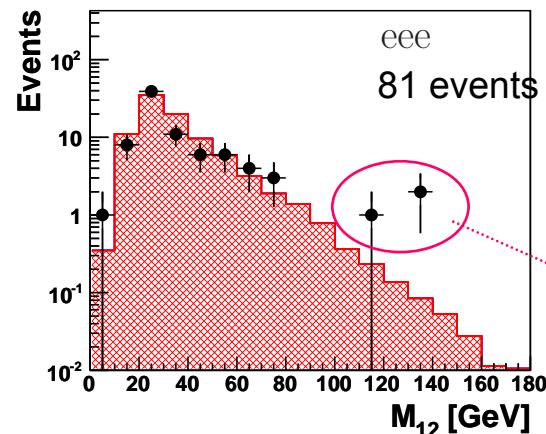
Overall good agreement with SM
H1: 3 ee events observed at $M > 100 \text{ GeV}$
(all hera1 e^+p data)
ZEUS: 2 ee event observed at $M > 100 \text{ GeV}$

3 lepton event



H1 3 lepton results

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



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

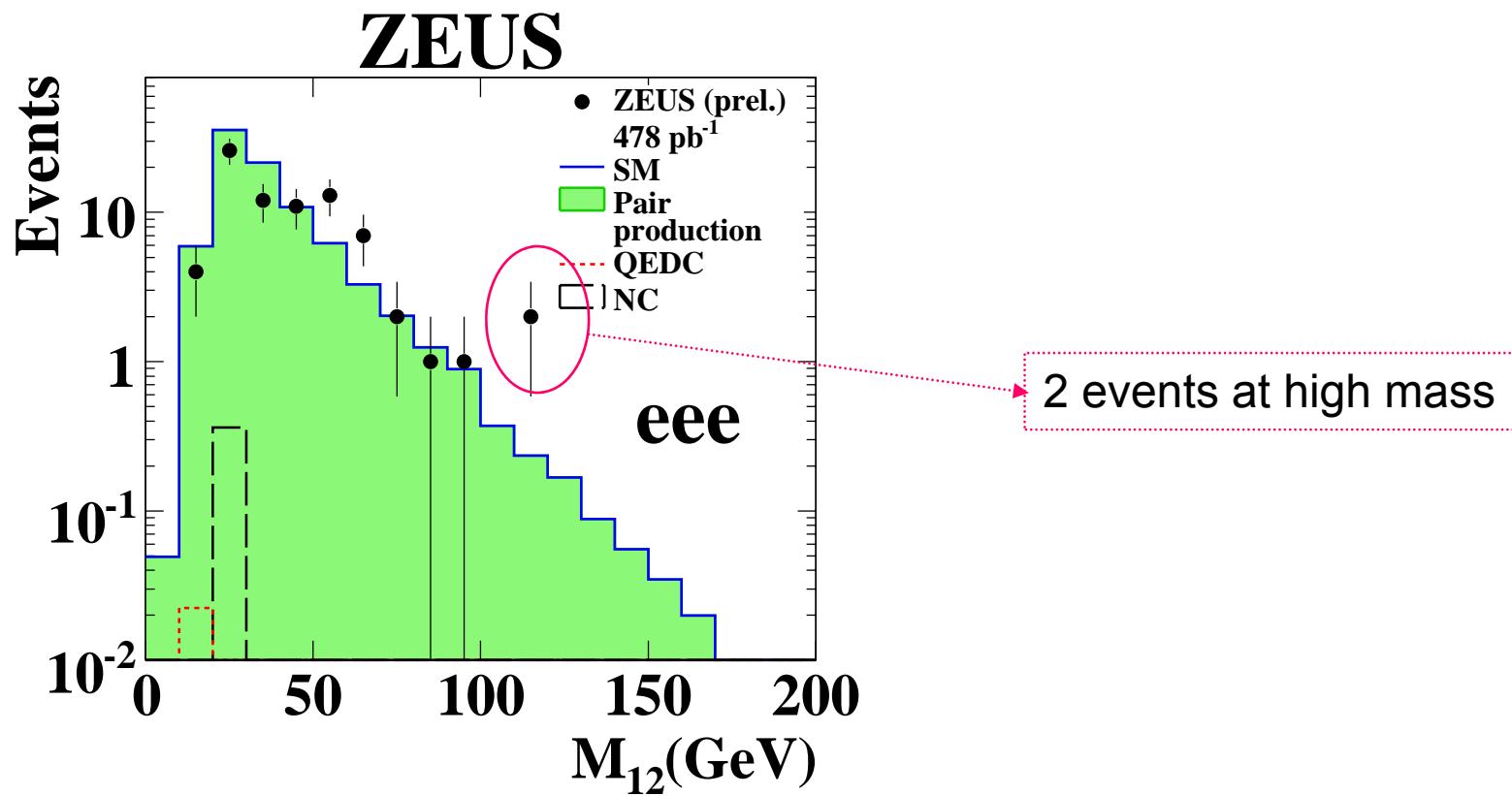
Overall good agreement with SM

Data slightly exceed SM prediction at high mass

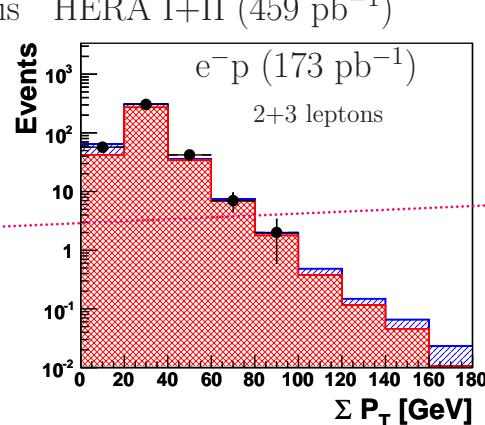
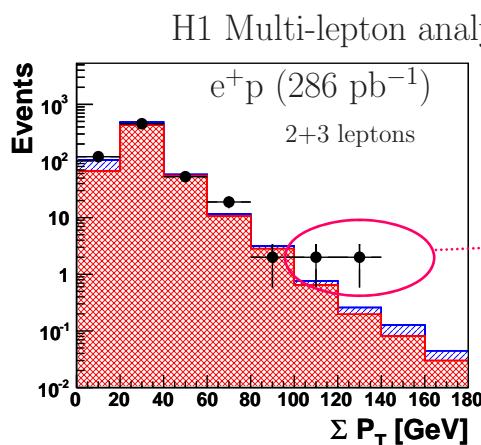
3 eee events
Observed in hera 1 e+p

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

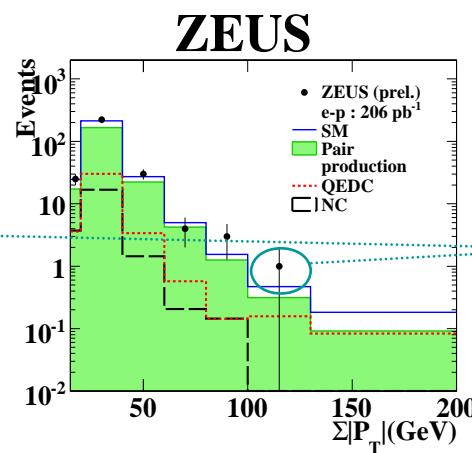
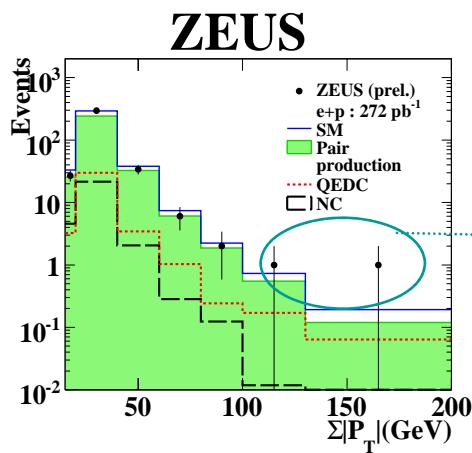
Zeus 3 lepton results



Results on 2+3 leptons

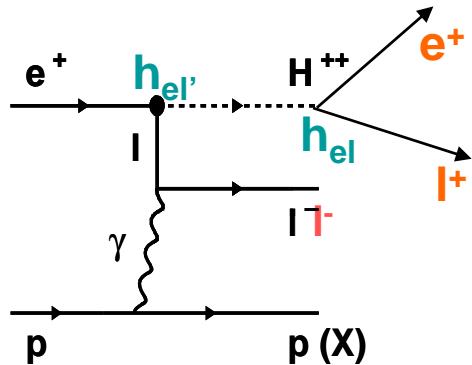


4 events with high ΣP_T
 3 ee events with $M > 100$ GeV
 1 e $\mu\mu$ event with $M_{12} > 100$ GeV
 SM expectation 1.9 ± 0.4



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

H $^{\pm\pm}$ 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, e μ channel, P_T^{miss} cut for τ

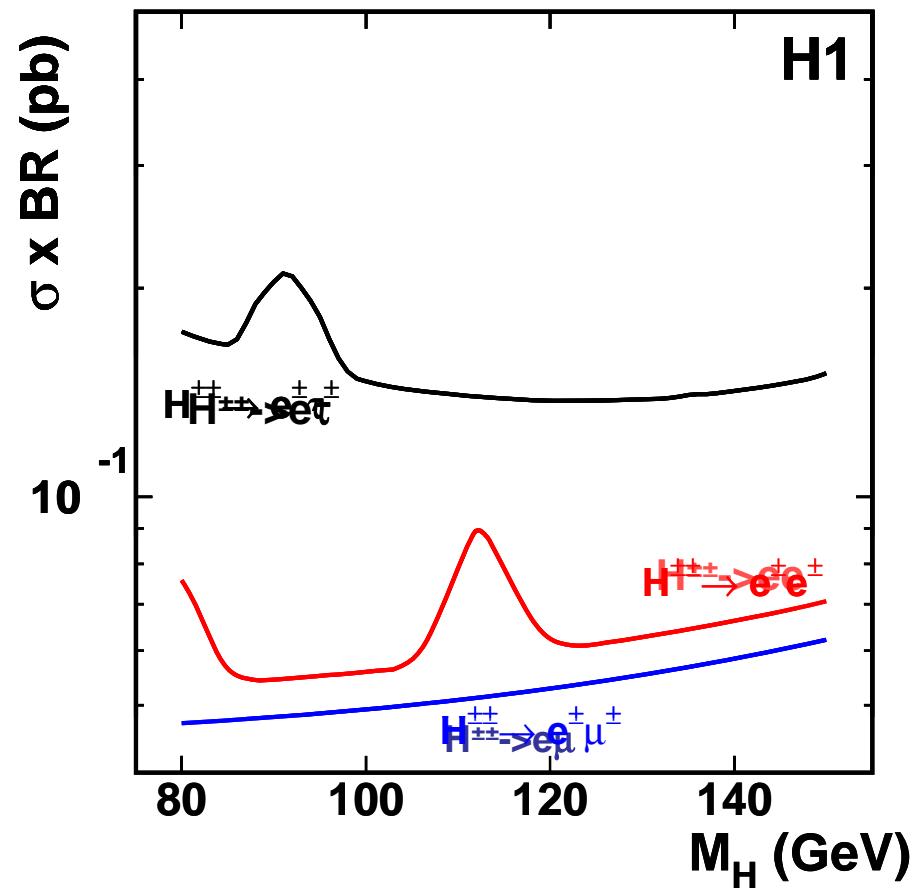
	Events $M_{ll} > 65 \text{ GeV}$	SM
ee	3	2.45 ± 0.11
e μ	1	4.17 ± 0.44
e τ	1	2.1 ± 0.5

DU10

- feynman graph is example
 - 2 more graphs with H⁺⁺ production
 - charge conjugate also exist
 - lepton can be e, mu, tau
 - production might be lepton helicity dependent but here not examined because it's hera1 sample
 - elastic and inelastic p scattering possible
 - signature: 2 same charged leptons with charge of incoming lepton , 1 opposite charge lepton, pt of H decay leptons higher than l-
 - experimental selection: as multilepton analysis
 - 2 highest pt leptons are assigned to H
 - if there charge is measureable must be same as the charge of the incoming lepton
 - background misid jets as lepton in nc dis, converted photon of compton events
 - candidate for explanation of multi-lepton events
 - check mass spectrum 2 highest pt leptons
 - Mee dependent pt cut?

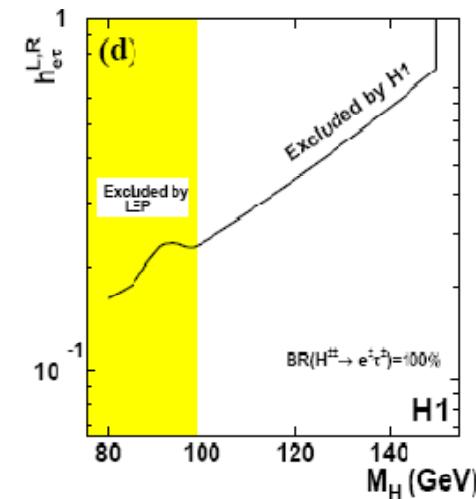
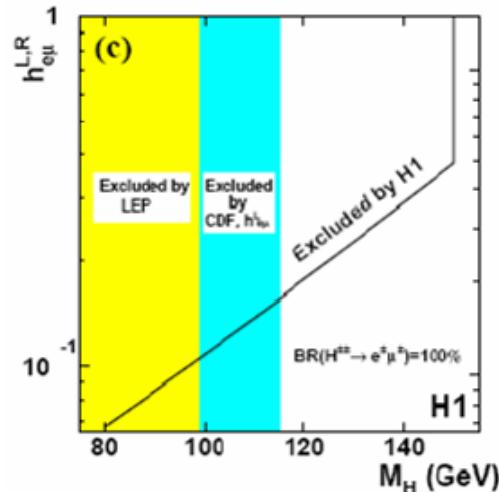
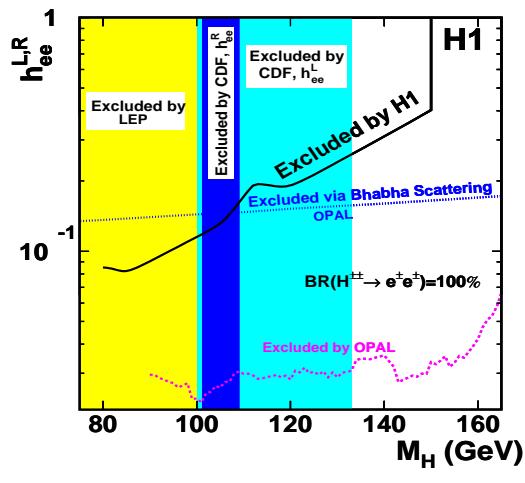
DESY USER, 7/18/2007

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



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

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

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

DU11

set limits for the case that the H^{++} only couples to the channel under investigation i.e. only to ee or only to em or only to et

there are also limits of opal on hee independent of decay mode which can explain why H1 doesn't see anything in the mm and tt channel

DESY USER, 7/18/2007

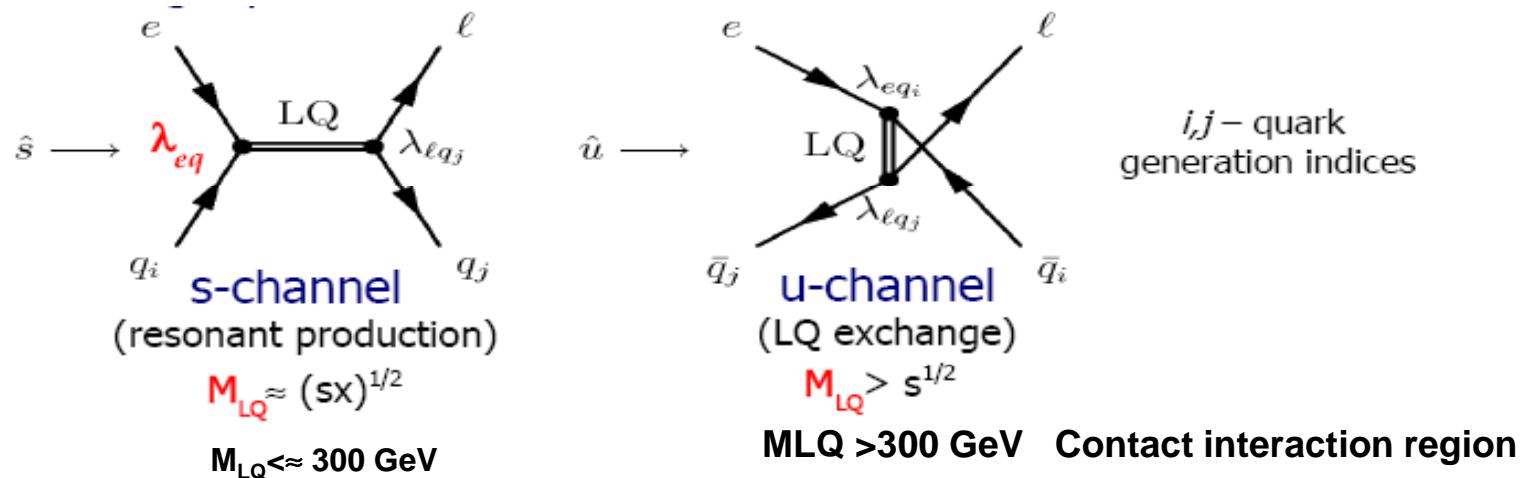
Leptoquarks at HERA

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

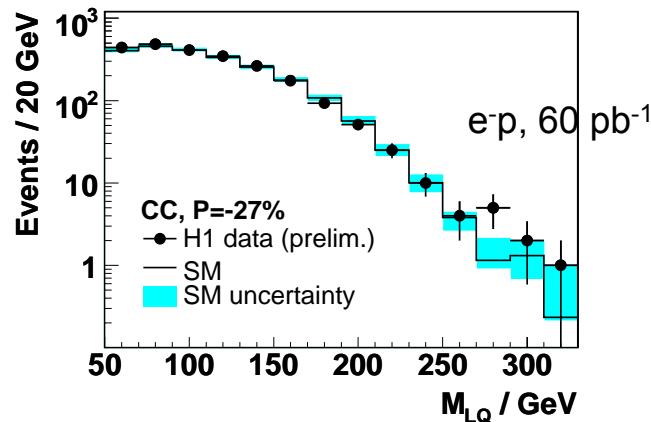
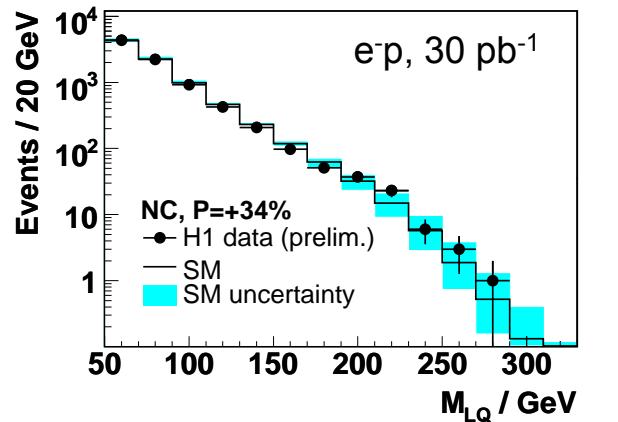
LQ at HERA: single production from incoming particles



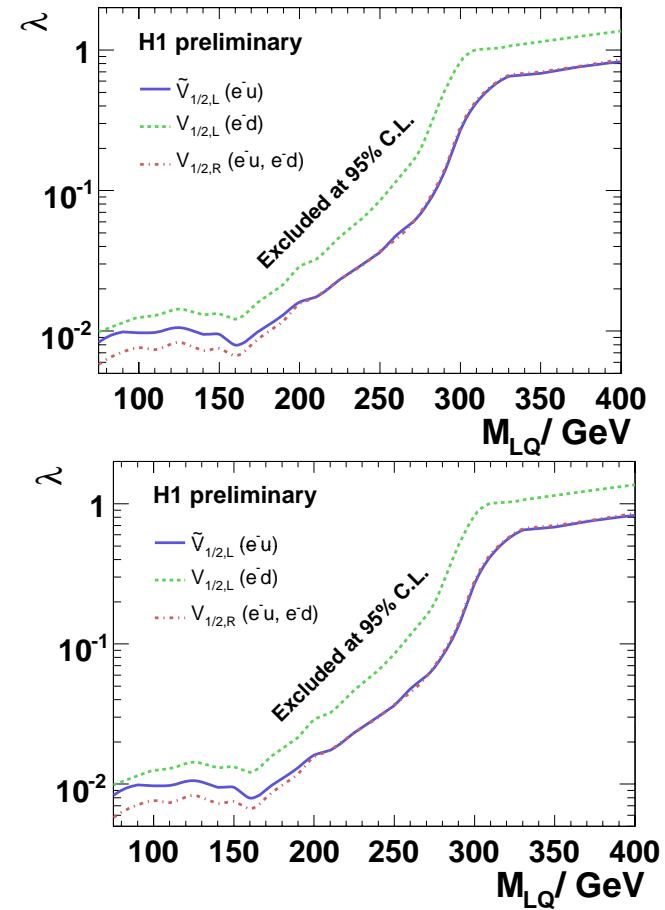
LQ decay lepton flavor conserving (LFC): $LQ \rightarrow eq, vq$
or lepton flavor violating (LFV): $LQ \rightarrow \mu q, \tau q$

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

Limits on 1st generation M_{LQ}



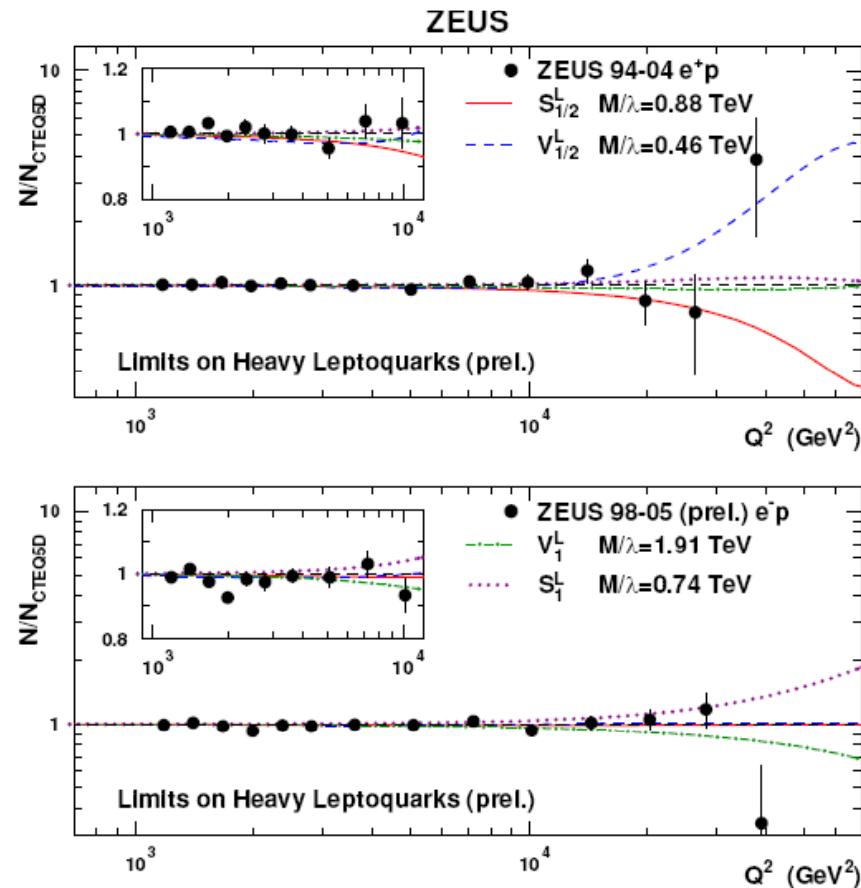
No enhancement
No evidence for LQ signal



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

Heavy Leptoquarks

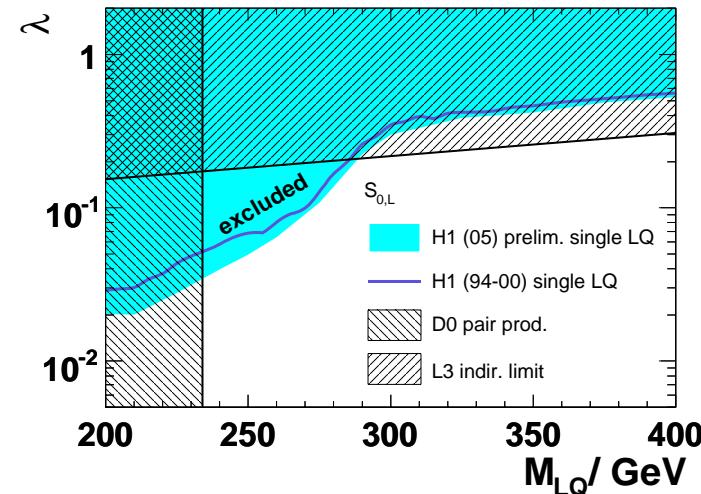
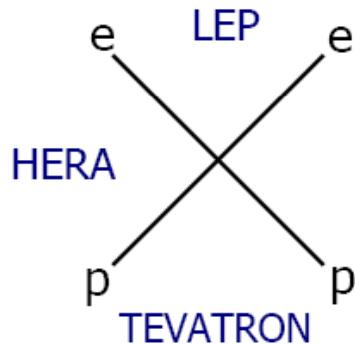
- Possible new interaction between e and q can modify DIS cross section at high Q^2 via virtual effects
- Search for virtual LQ exchange using 4 fermion eeqq contact interaction method
->report by P.Schleper in Alternatives



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

Comparison with LEP and Tevatron

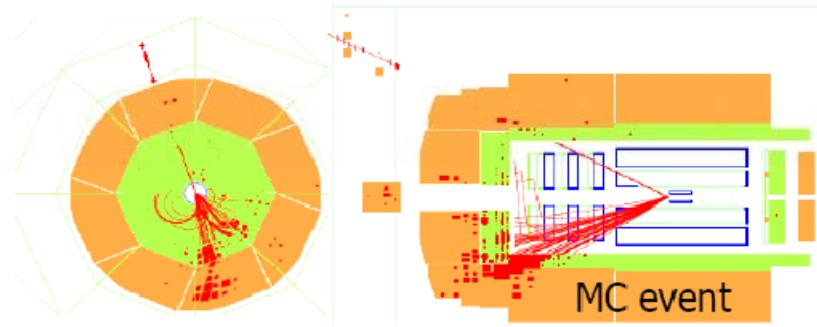
- LEP: contact interaction (indirect constraints from $e^-e^+ \rightarrow q\bar{q}$)
- TEVATRON: pair production (λ independent)
- HERA: single production ($M_{LQ} < 300$ GeV) and contact interaction ($M_{LQ} > 300$ GeV)



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

Limits on LFV Leptoquarks

Signature $e p \rightarrow \mu X$



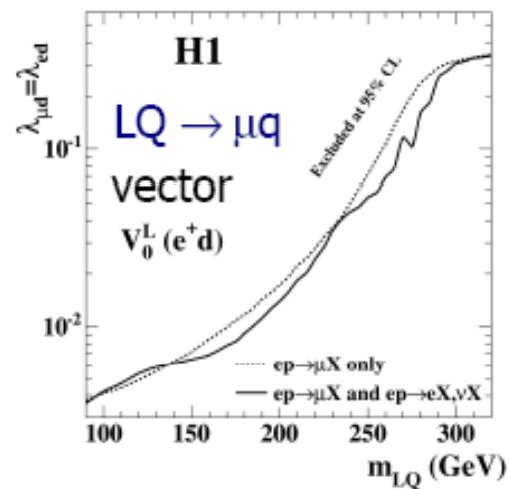
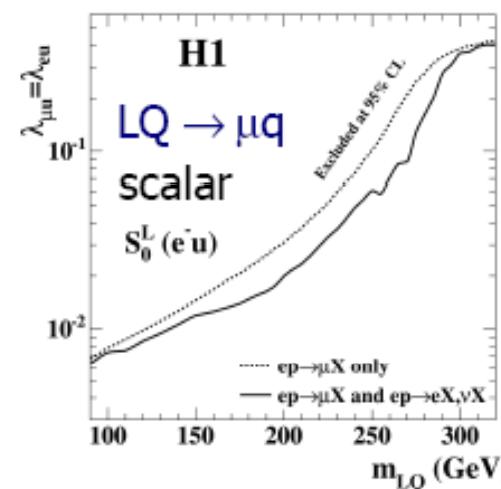
$$\lambda_{eq} = \lambda_{\mu q} \text{ or } \lambda_{eq} = \lambda_{bq}$$

Assume:

No evidence for
Signal found

Low background, good sensitivity

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



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

Summary

- Results for isolated leptons with p_T^{miss} shown for complete hera 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 hera 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^l		> 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_l^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)
$\Delta\phi_{l-X}$	$< 160^\circ$	$< 170^\circ$
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 $M_{\parallel} > 100 \text{ GeV}$

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

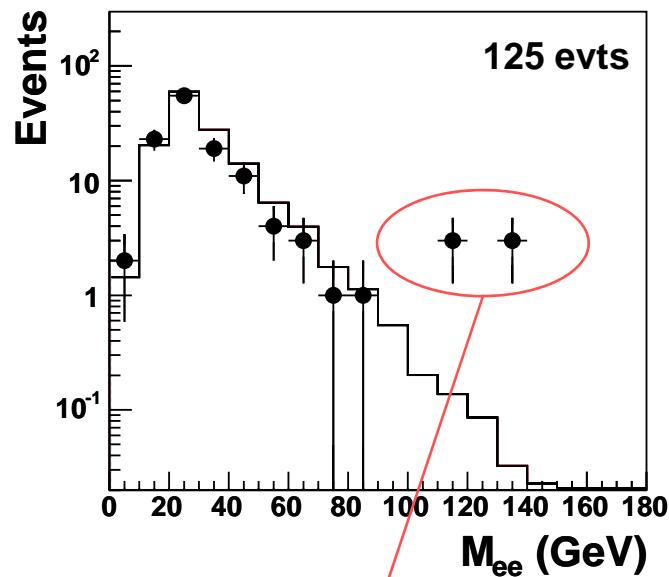
Type	DATA	SM	Pair production	QEDC	NC

e^+p	2e	1	0.9 ± 0.1	0.5 ± 0.1	0.4 ± 0.1
	3e	2	$0.6 - 0.07 + 0.5$	0.6 ± 0.07	< 0.01

e^-p	2e	1	0.8 ± 0.1	0.4 ± 0.04	0.39 ± 0.3
	3e	0	$0.4 - 0.1 + 0.5$	1.0 ± 0.1	< 0.01

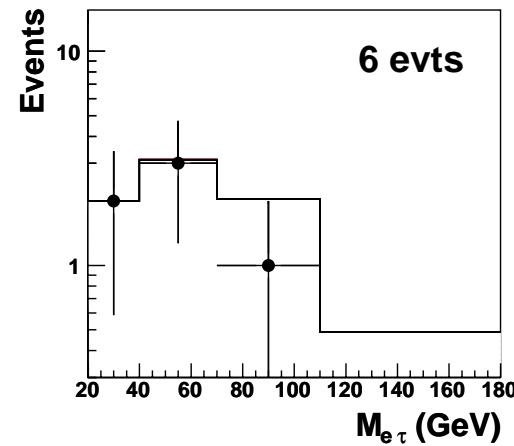
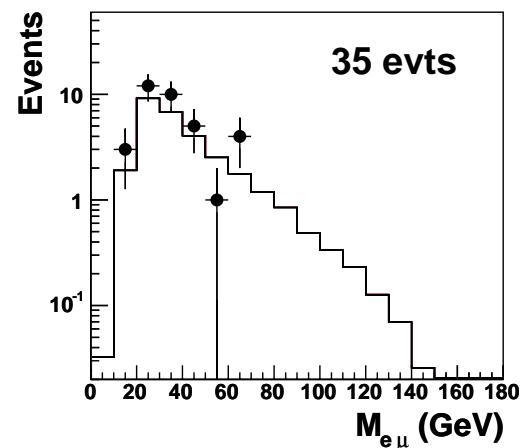
2 lepton mass spectra, $H^{\pm\pm}$ search (backup)

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

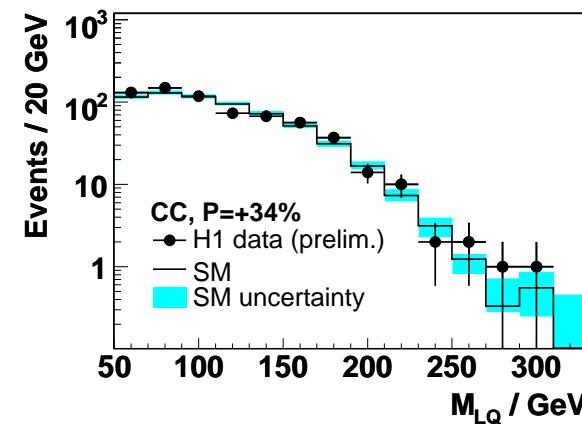
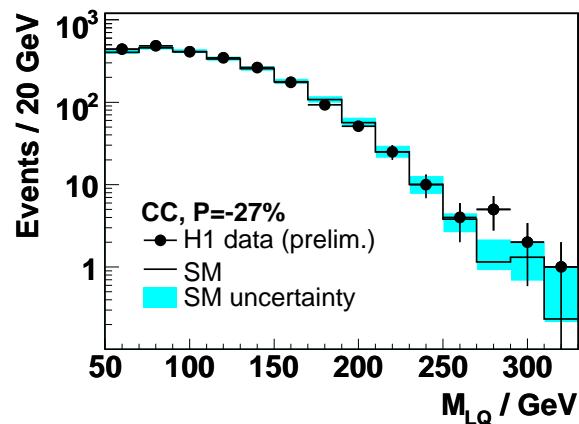
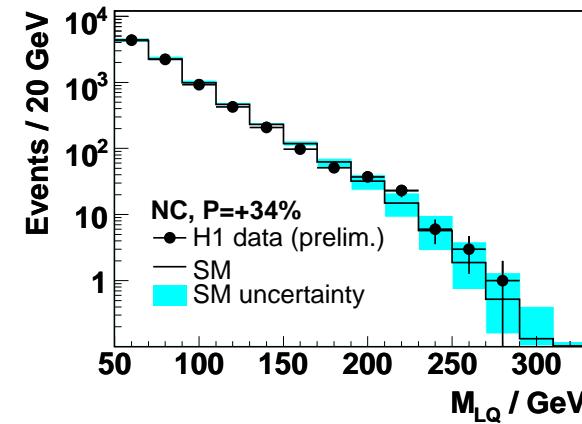
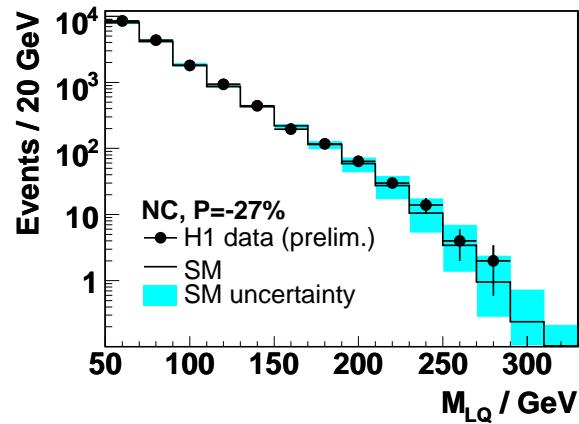


6 evts obs.
 0.53 ± 0.06 expt.

1 event after final selection
(charge+ P_T cuts)

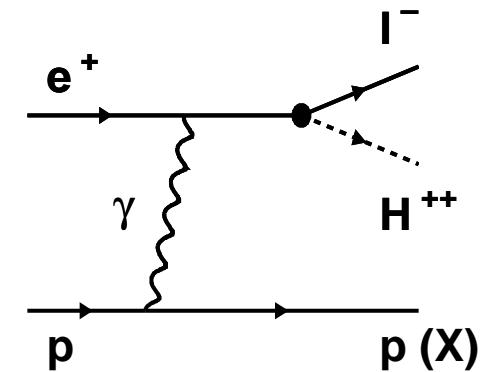
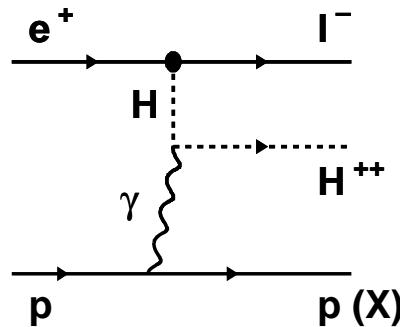
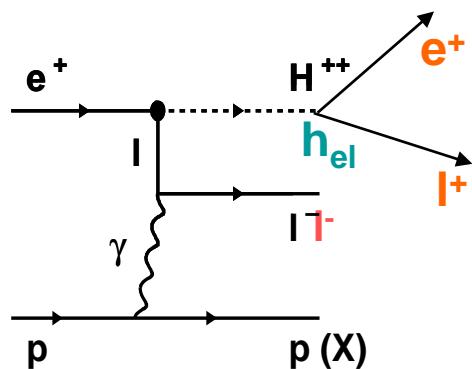


Leptoquark search all mass spectra



$H^{\pm\pm}$ production

H1 HERA I data



DU16

feynman graph is example

- 2 more graphs with H⁺⁺ production
- charge conjugate also exist
- lepton can be e, mu, tau
- production might be lepton helicity dependent but here not examined because it's hera1 sample
- elastic and inelastic p scattering possible
- signature: 2 same charged leptons with charge of incoming lepton , 1 opposite charge lepton, pt of H decay leptons higher than l-
- experimental selection: as multilepton analysis
 - 2 highest pt leptons are assigned to H
 - if there charge is measureable must be same as the charge of the incoming lepton
- background misid jets as lepton in nc dis, converted photon of compton events
- candidate for explanation of multi-lepton events
- check mass spectrum 2 highest pt leptons
- Mee dependent pt cut?

DESY USER, 7/18/2007

CC and NC cross section

