

Beyond the Standard Model Physics at HERA



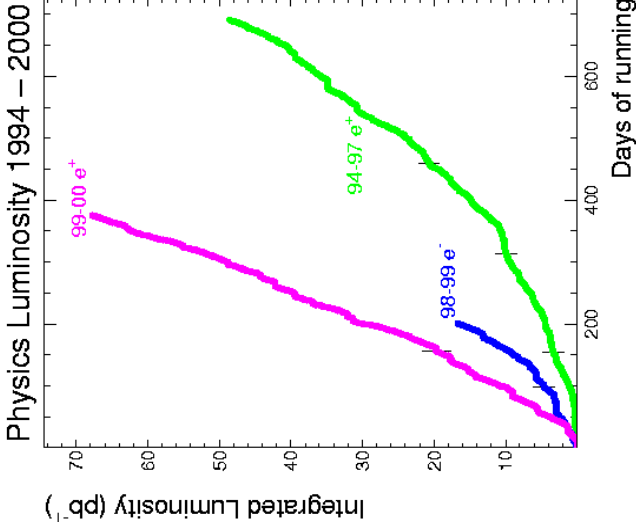
Cristinel

DIACONU

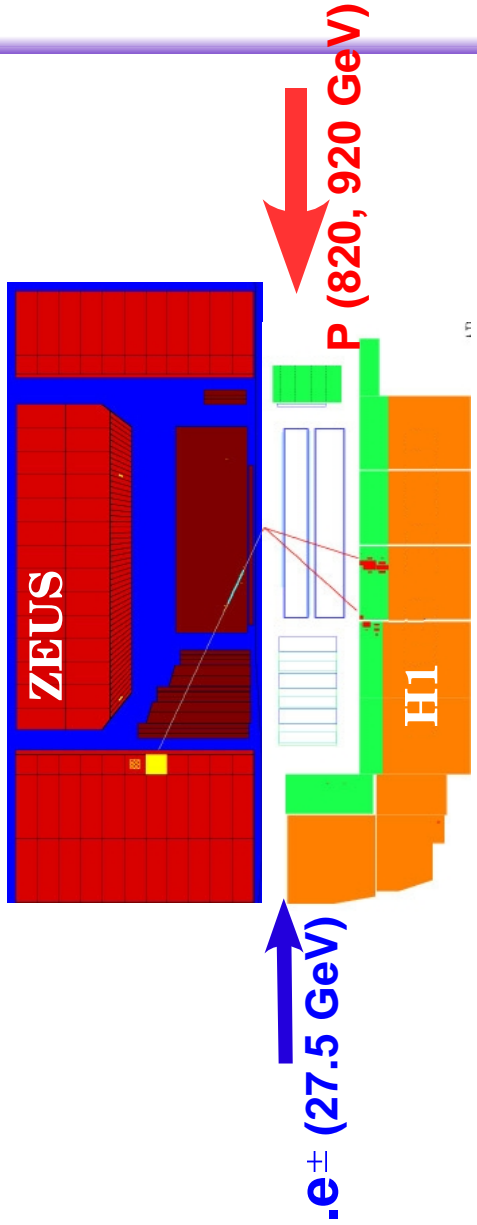
On behalf of H1 and ZEUS collaborations



- Introduction
- "Expected" BSM searches
 - × **LQ, LFV, Rp SUSY, f*, MM**
- Rare SM processes and BSM brainstorming
 - **$l+P_T^{\text{miss}}$** ->
 - Anomalous top production
- Multi-leptons ->
 - **H⁺⁺**
- Conclusion and outlook



HERA



Year	\sqrt{S} (GeV)	Beam	$\int \mathcal{L} \text{ (pb}^{-1}\text{) /expt.}$
94 - 97	301	$e^+ p$	≈ 35
98 - 99	319	$e^- p$	≈ 15
99 - 00	319	$e^+ p$	≈ 70

$L = 2 \times 120 \text{ pb}^{-1}$

Test proton structure $10^{-18} \text{ m} \Rightarrow p_{\text{size}}/1000$

p structure

p flashed with 'weak' light

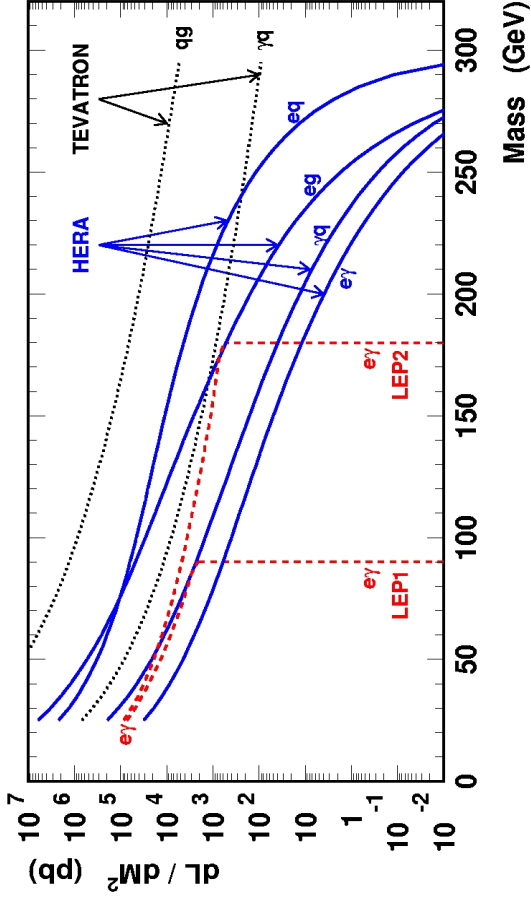
Standard Model constraints

New kinematics/initial state explored

\Rightarrow Beyond SM

HERA II : $1 \text{ fb}^{-1}/\text{expt}$ and e-polarisation -> 2006

BSM Physics at HERA



Search for new physics:

1. flux of ingredients

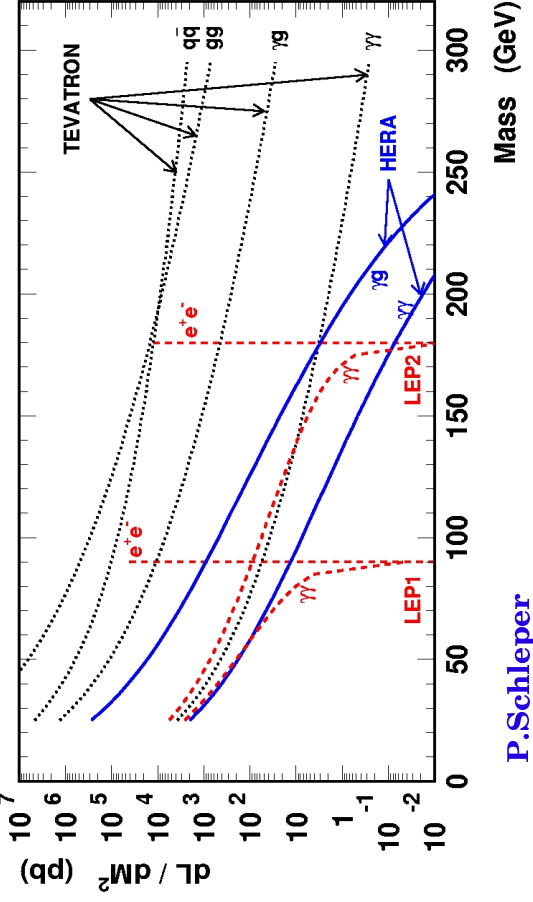
HERA: e^+q collisions at highest Energy/Lumi

2. cross section of the hard process

unknown, allow to compare ee (LEP) qq (Tevatron)

3. SM background (low)

search for unexpected/spectacular events



BSM searches -- Outline

A: Models: LQ, SUSY, f^* , MM, top, $H^{\pm\pm}$

B: High P_T multi-lepton events

-> $l+P_T^{\text{miss}}$

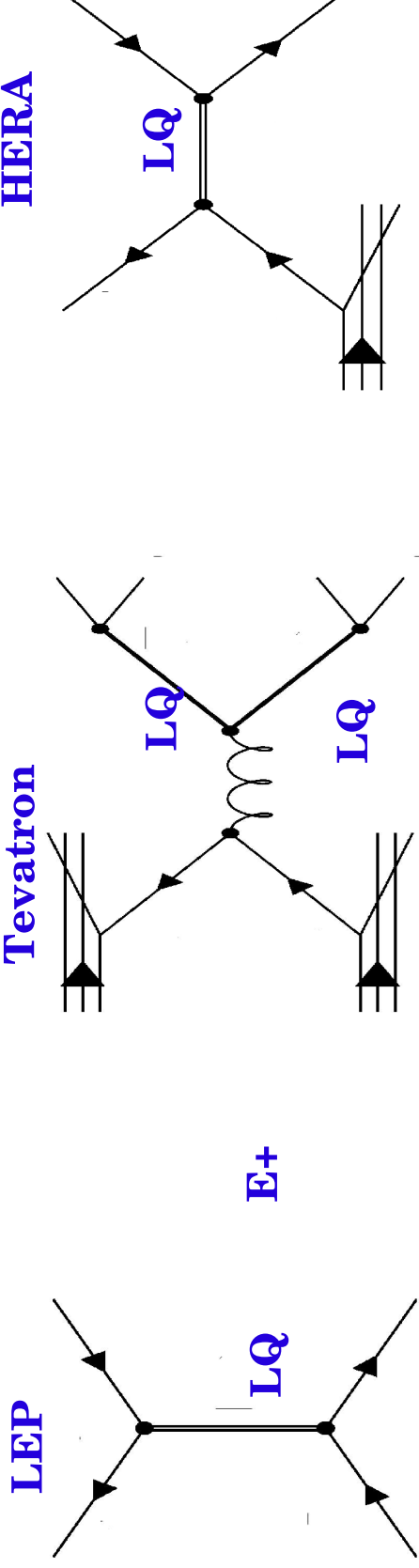
-> multi-e

not shown: LFV, CI, LED, ...

P. Schleper

Lepto-quarks

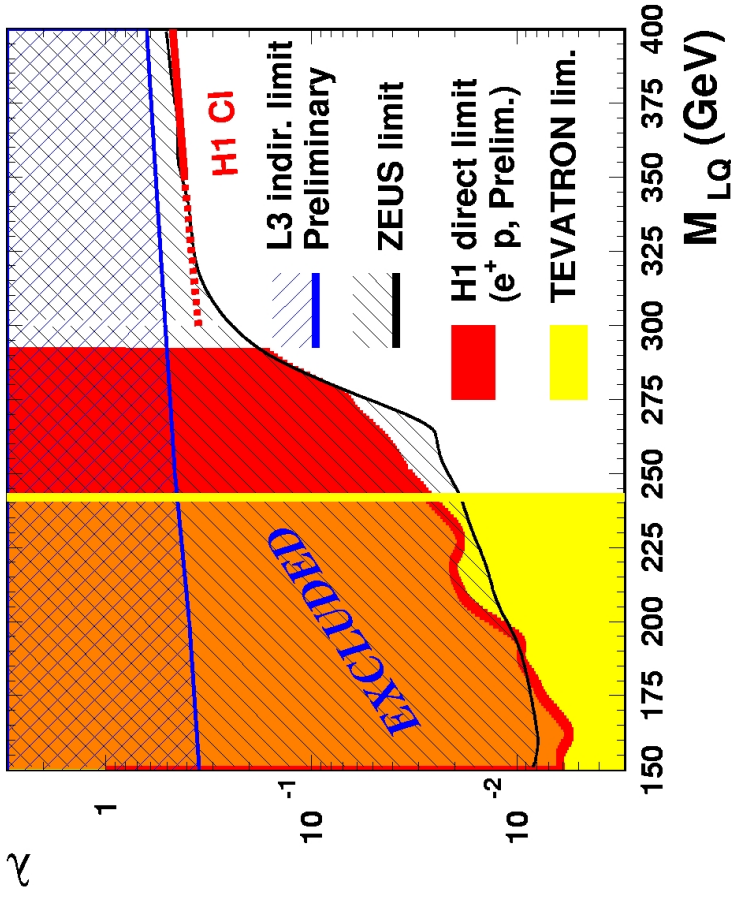
- LQ color triplet bosons
- L and B numbers and fractional Q_{em} , Fermion number $F=3B+L$
 - $e+p \rightarrow F=0$ $e-p \rightarrow F=2$
- Buchmuller-Ruckl-Wyler minimal model
 - $SU(3) \times SU(2) \times U(1)$ invariance
 - LQ couple to chiral fermions : coupling λ
 - 14 species: 7 scalars +7 vectors
 - Branching ratio fixed



- @ HERA : direct lepton-quark collisions, s-channel production
 - Privileged collider for leptoquark searches
 - Production via Yukawa coupling $\sim \lambda^2$

Lepto-quarks

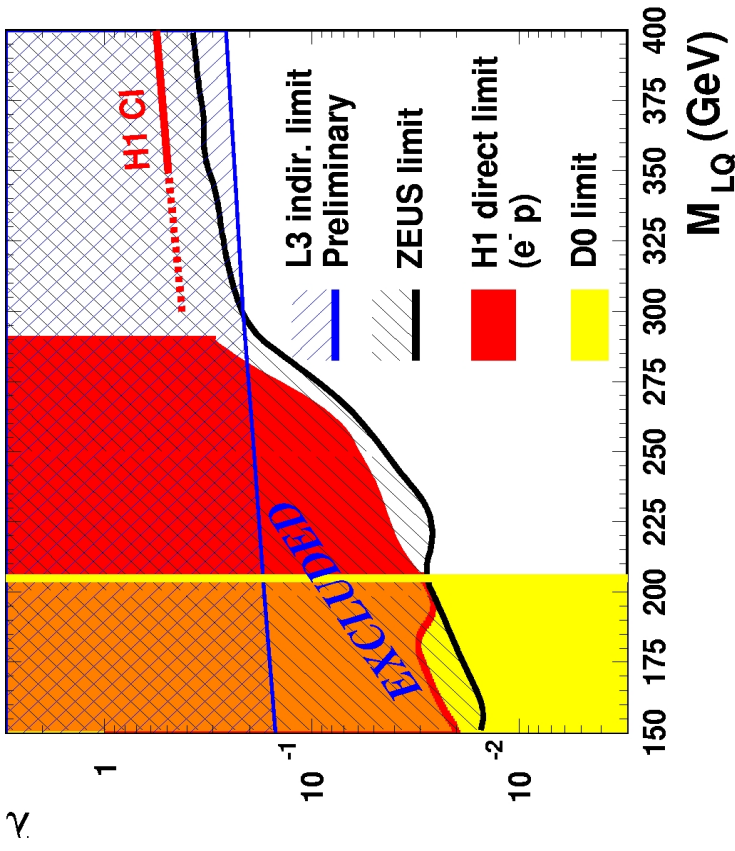
SCALAR LEPTOQUARKS WITH $F=0$ ($S_{1/2,L}$)



e+p $Q_{em} = -2/3$ $\beta_{eq} = 100\%$

Tevatron $M_{LQ} > 245$ GeV
 HERA ($\lambda = 0.1$) $M_{LQ} > 275$ GeV

SCALAR LEPTOQUARKS WITH $F=2$ ($S_{0,L}$)



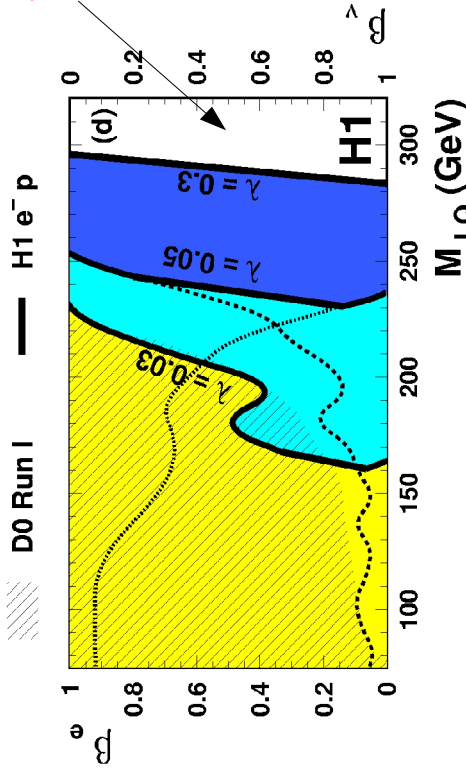
e-p $Q_{em} = -1/3$ $\beta_{eq} = \beta_{\nu q} = 50\%$

Tevatron $M_{LQ} > 204$ GeV
 HERA ($\lambda = 0.1$) $M_{LQ} > 275$ GeV

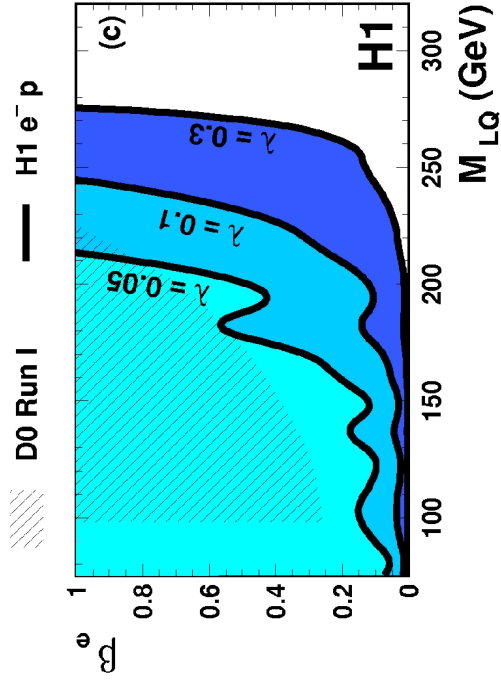
Lepto-Quarks

Non-minimal model: branching fraction free

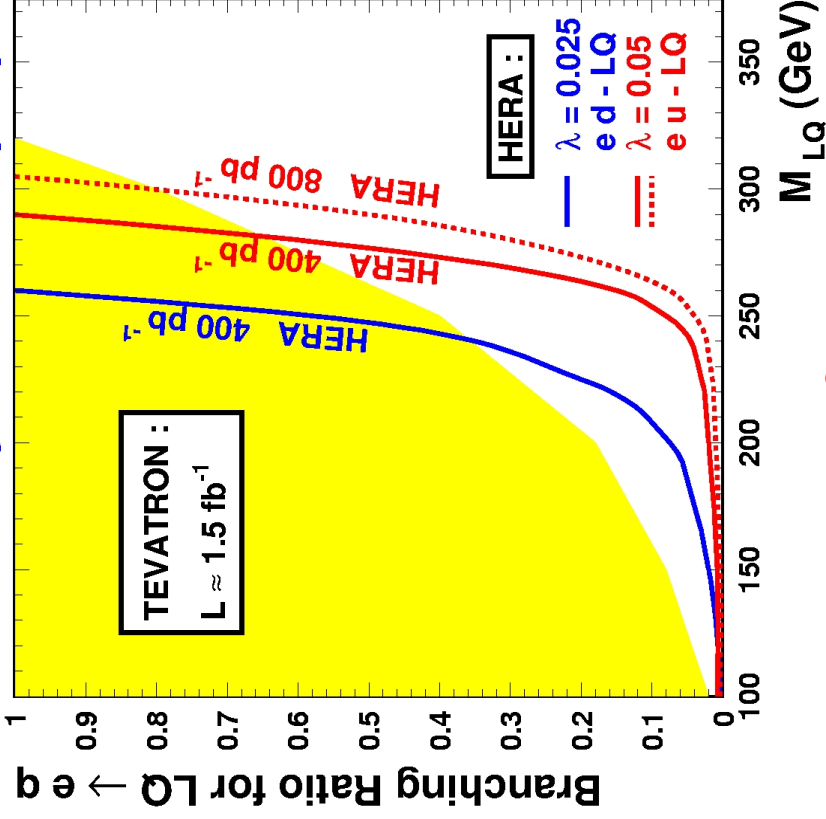
SCALAR LEPTOQUARK $e^- u \rightarrow LQ \rightarrow e^- X, \nu X$



SCALAR LEPTOQUARK $e^- d \rightarrow LQ \rightarrow e^- X$



Future Sensitivity on Scalar Leptoquarks



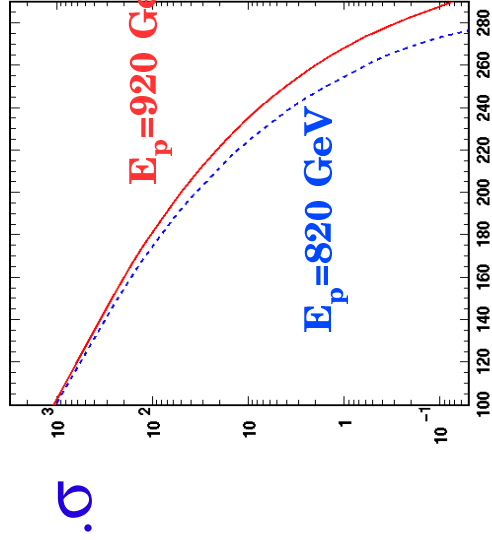
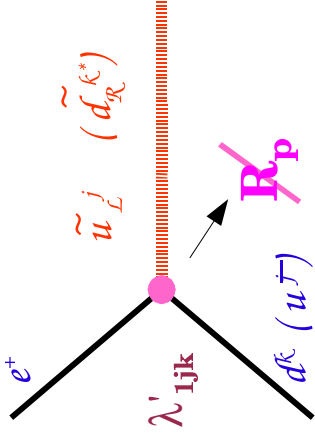
Sensitivity @ low β_e

SUSY in ep collisions

Initial state eq ideally suited to look for

e.g. Squarks in SUSY

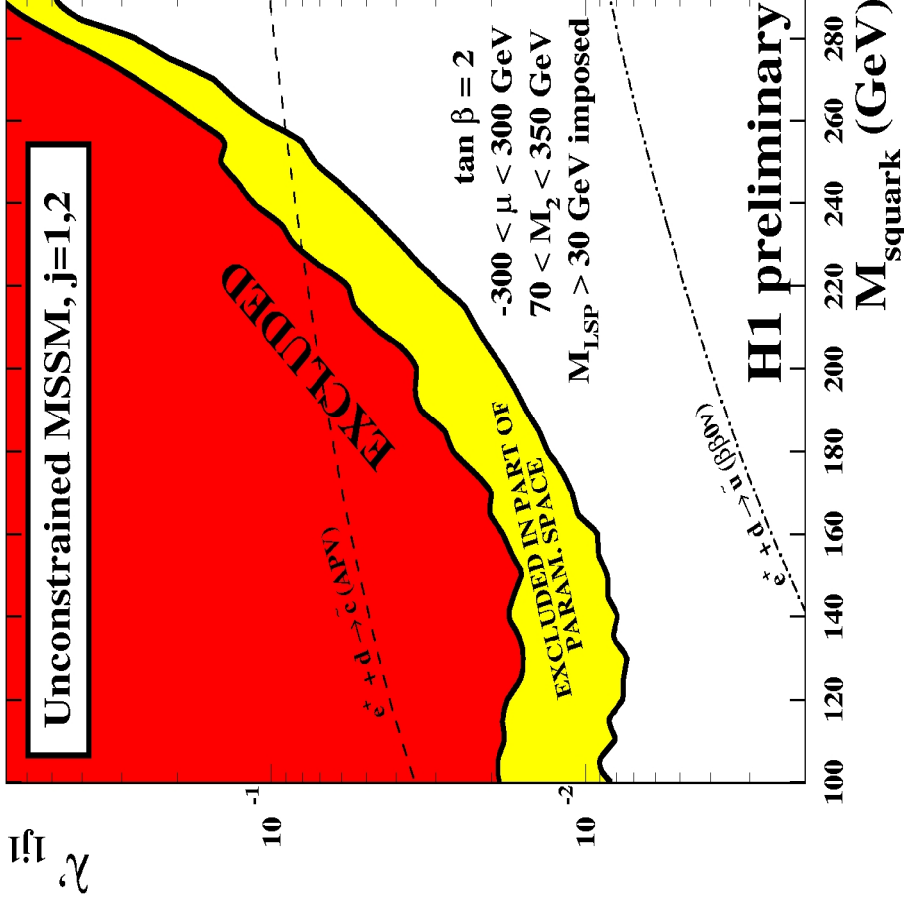
where R-parity is violated via a λ' coupling



$M_{\tilde{q}}$

New preliminary results
for $E_p = 920$ GeV

Searches for squarks in R_p viol. SUSY



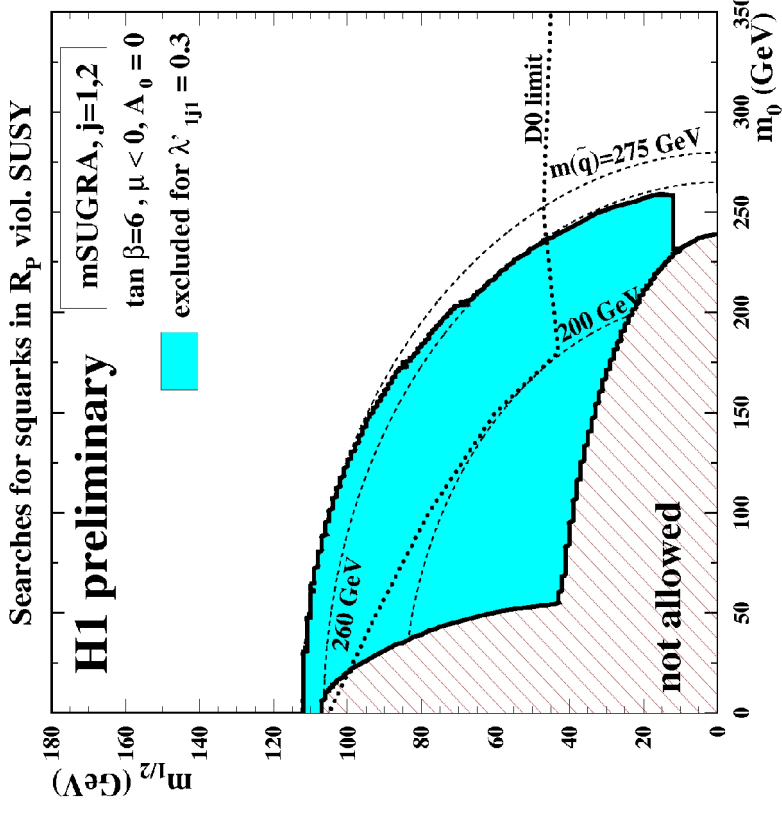
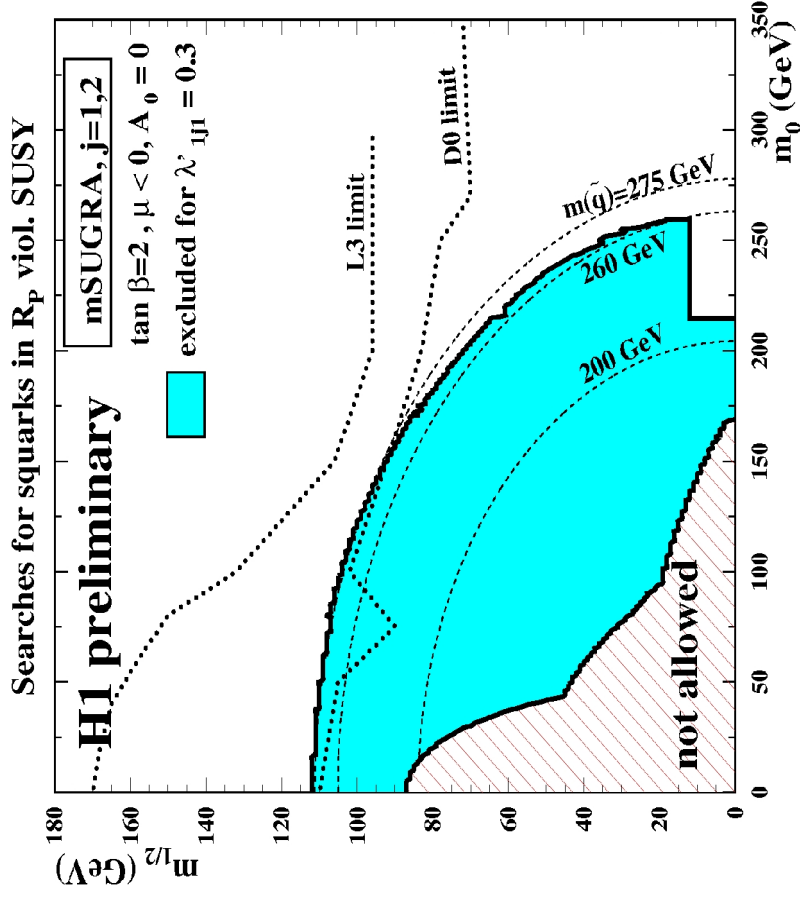
SUSY constraints on MSUGRA

- Sfermion & gaugino masses related via RGE
- m_0 ($m_{1/2}$) = common mass param for scalar (gauginos) at GUT scale
- Assume Radiative Electroweak Symmetry Breaking

For medium $\tan\beta$: H1's sensitivity extends beyond the domain excluded by D0

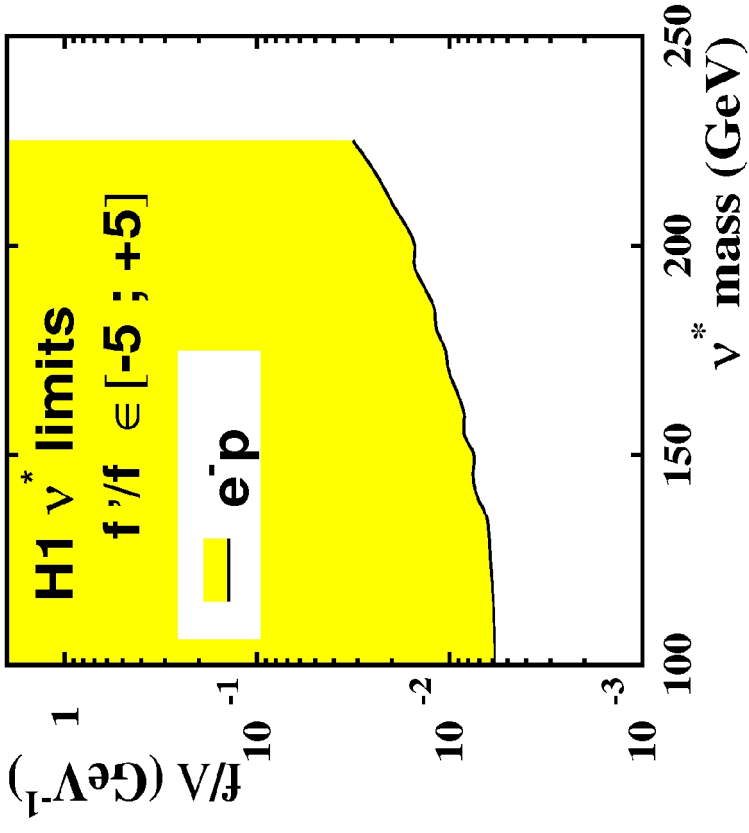
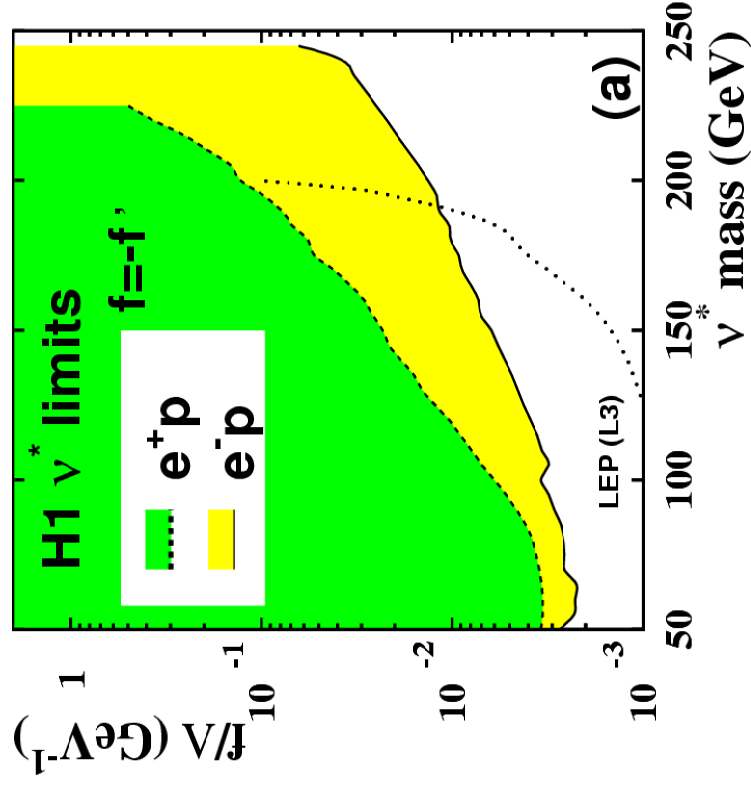
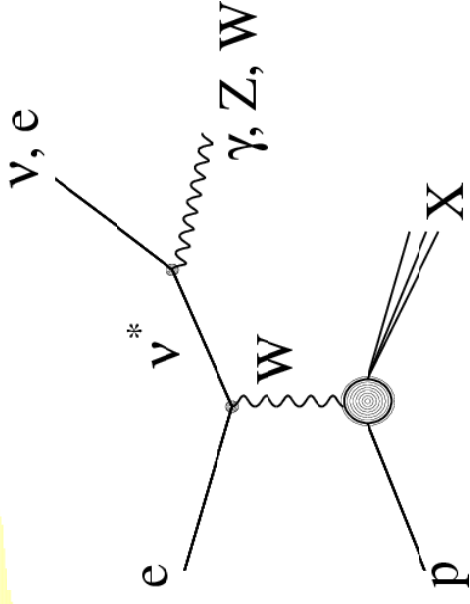
→ **Complementarity.**

However H1 bounds depend on λ' , D0's do not.



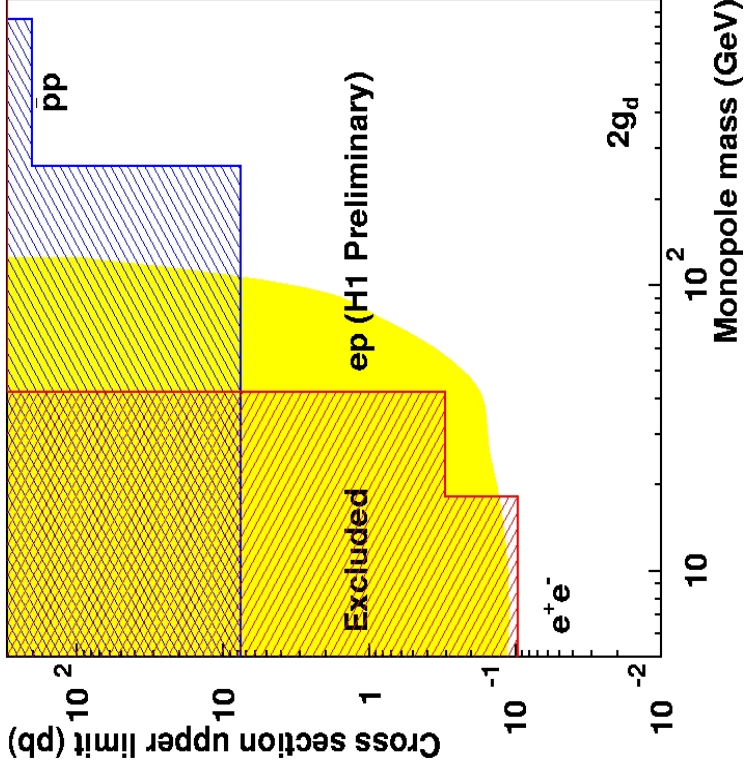
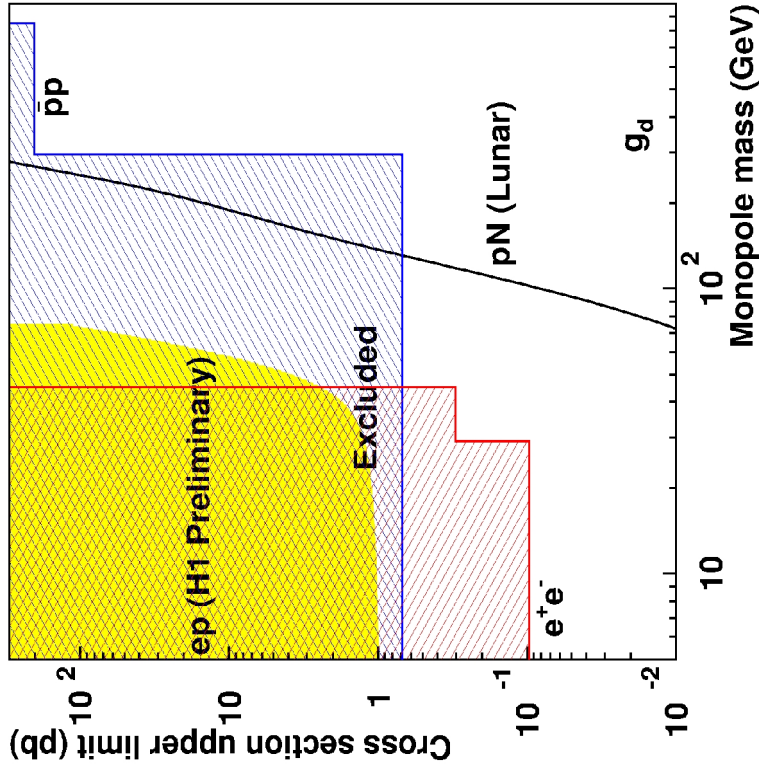
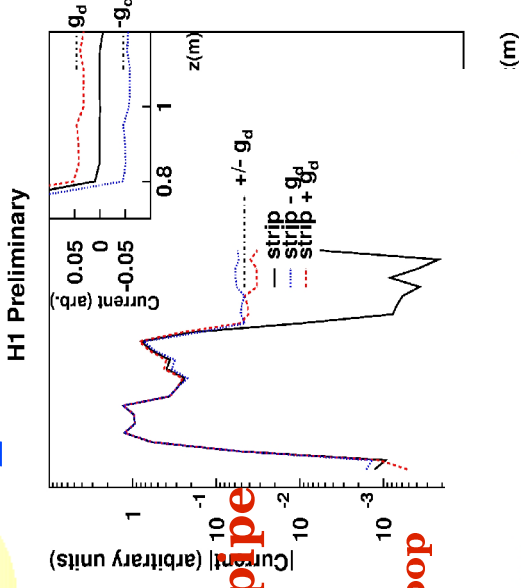
Excited fermions: ν^*

- Compositeness at a scale Λ
- Model respect SM symmetries
- $SU(3) \times SU(2) \times U(1)$
- gauge constants f_s, f_f, f'
- combine in coupling constants
- Search for fermion-boson resonance

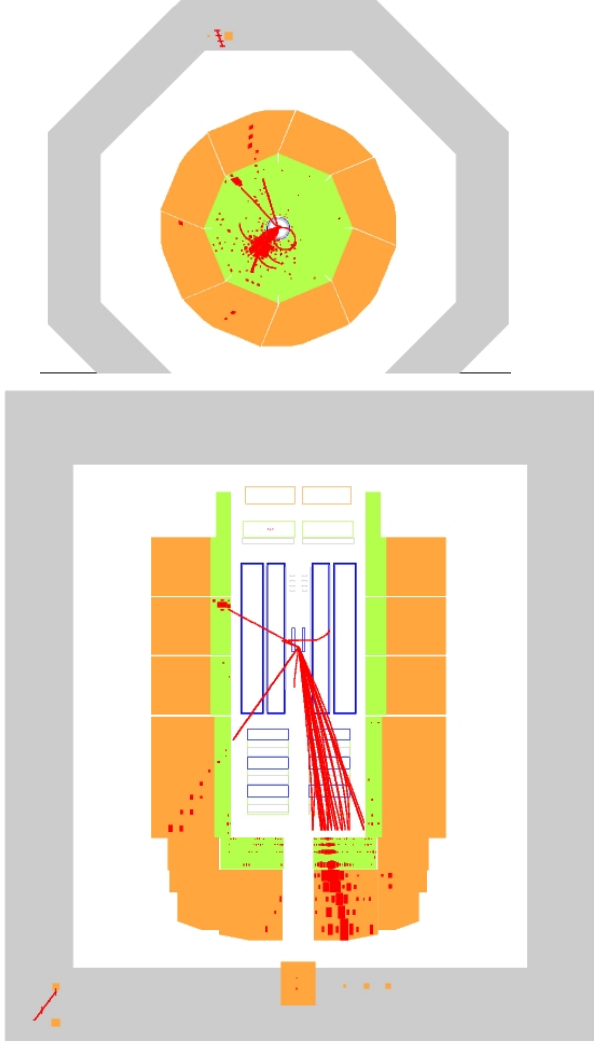


Search for Magnetic Monopoles

**MM: Dirac quantization $eg = nhc/4\pi$
 $ep \rightarrow MM$ (pair production)
 monopoles stopped and trapped in the beam pipe
 (old = 62 pb^{-1}) beam pipe cut in strips
 analyzed with a SQUID ->
 permanent current induced if a monopole pass through the loop**



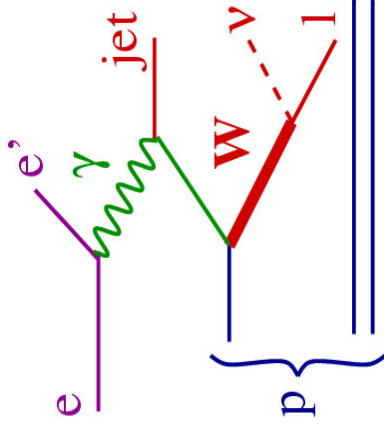
Isolated lepton events with missing P_T



- Hadronic jet
- Missing P_T
- Isolated lepton

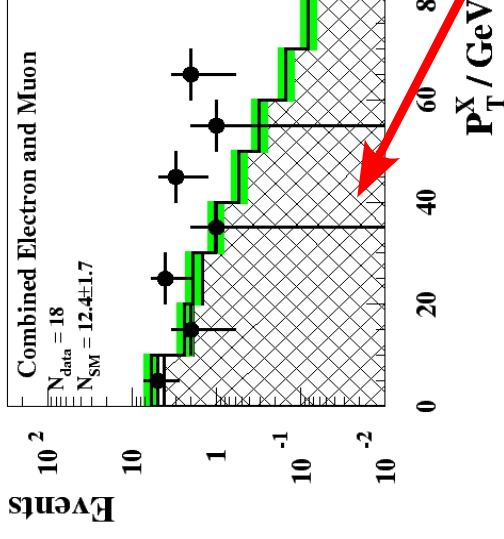
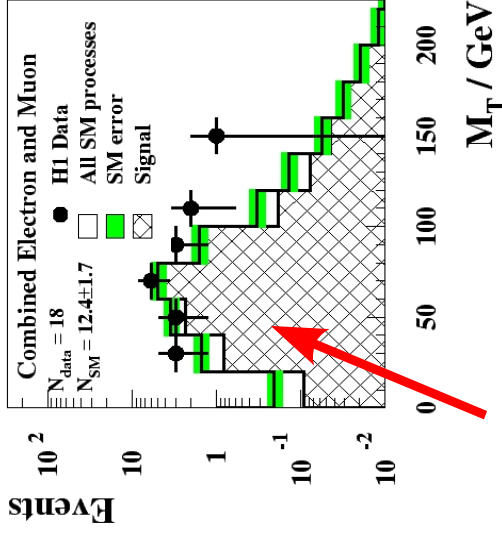


- Dominant SM process: W production
 $\sigma(ep \rightarrow eW^\pm X) \sim 1\text{pb}$
 EPVEC Baur Vermaseren Zeppenfeld + NLO^{QCD} Spira et al.
- H1: further cuts to enhance W component
H1 and ZEUS published results (2003)



Isolated leptons: W production

- **H1: $e + \mu$**

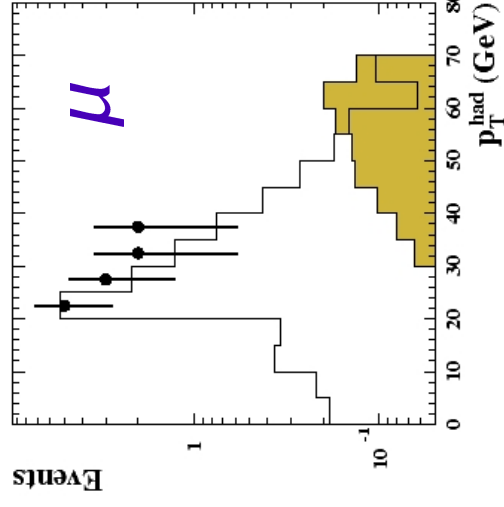
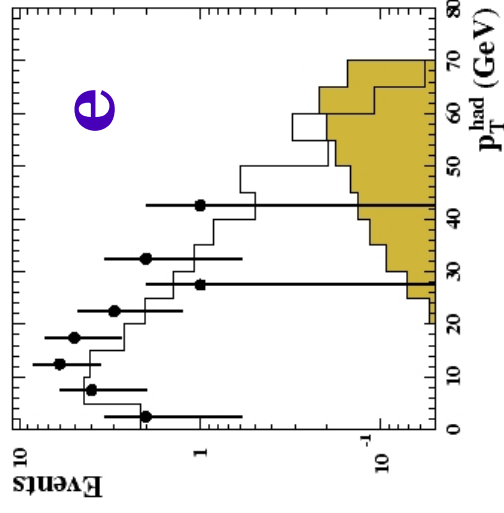


Excess at high P_T^X

Compatible with W hypothesis

- **Zeus:**

- ZEUS 94-00 (130 pb^{-1})
- Standard Model MC
- $ep \rightarrow e\tau X$ MC



Isolated leptons: results at high P_{T^X}

H1	Electrons obs. / exp. (W)	Muons obs. / exp. (W)
$e^+ p$ (101.6 pb ⁻¹)		
$P_{T^X} > 25$ GeV	4 / 1.49 ± 0.25 (83 %)	6 / 1.44 ± 0.26 (89 %)
$P_{T^X} > 40$ GeV	3 / 0.54 ± 0.11 (83 %)	3 / 0.55 ± 0.12 (93 %)

→ Excess at high P_{T^X} in both 94-97 and 99-00 data

→ In $e^- p$ data : 1 e (expect 1.69) and 0μ (0.37)

ZEUS	Electrons obs. / exp. (W)	Muons obs. / exp. (W)
$e^\pm p$ (130 pb ⁻¹)		
$P_{T^X} > 25$ GeV	2 / 2.90 ^{+ 0.59} _{- 0.32} (45 %)	5 / 2.75 ± 0.21 (50 %)
$P_{T^X} > 40$ GeV	0 / 0.94 ^{+ 0.11} _{- 0.10} (61 %)	0 / 0.95 ^{+ 0.14} _{- 0.10} (61 %)

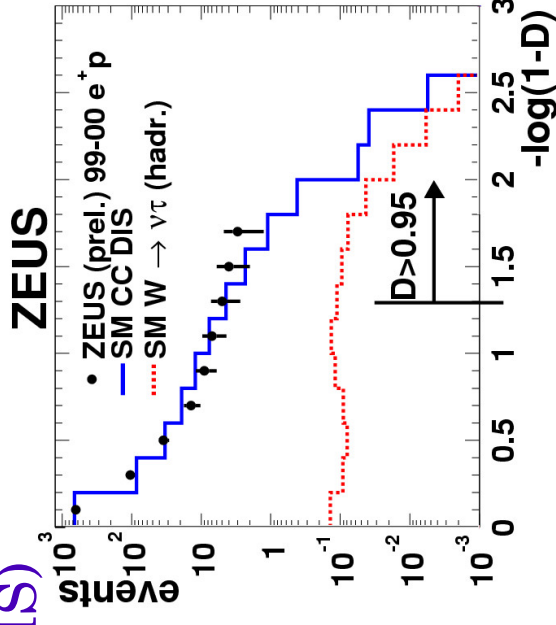
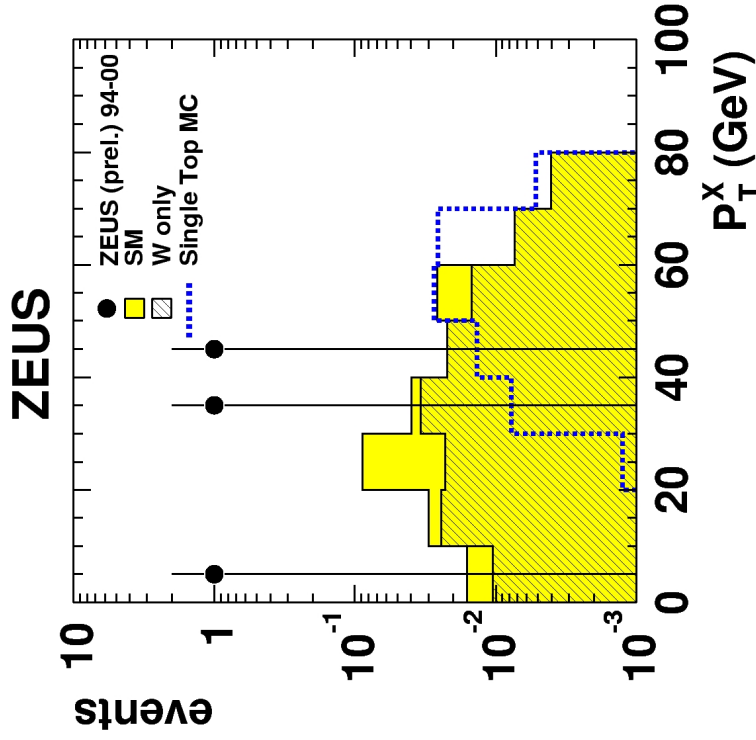
→ Yields consistent with SM prediction

→ **H1: pure W sample**

→ Different observation @ $P_{T^X} > 40$ GeV, low statistics

Isolated leptons: τ decay channel

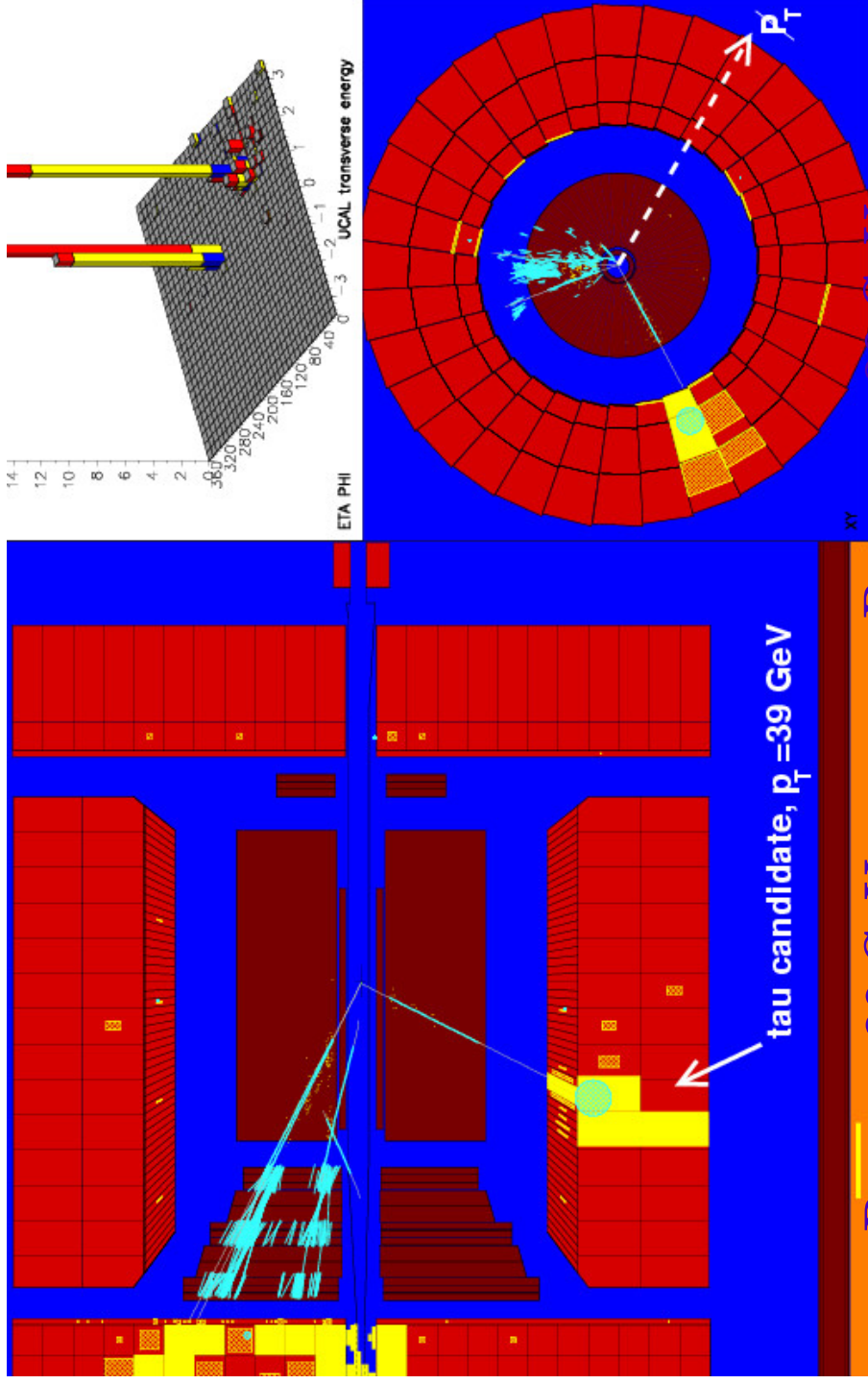
- Isolated high P_T track + pencil-like jet in calo
- Multi-variables technique: discriminate τ hadronic jet (1-prong decay) from QCD jets (CC-DIS)
- 24 % signal efficiency



ZEUS preliminary	Taus
e+p (130.5 pb-1)	obs. / exp. (W)
$P_{T^X} > 25 \text{ GeV}$	2 / 0.12 \pm 0.02 (0.10)
$P_{T^X} > 40 \text{ GeV}$	1 / 0.06 \pm 0.01 (0.05)

→ 2 new τ events at high P_{T^X}

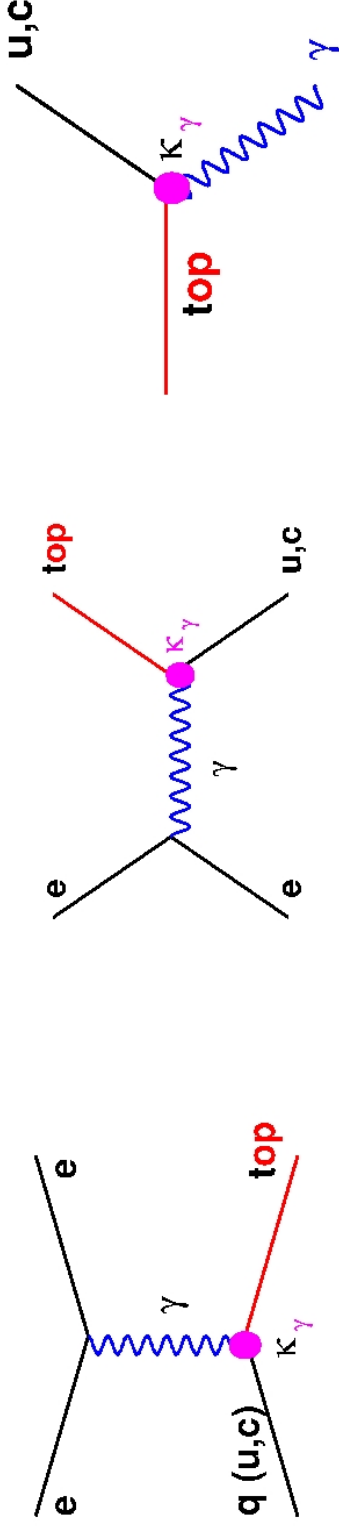
τ candidate



- $P_{T,cal} = 39$ GeV
- $P_{T,\tau} = 37$ GeV
- $P_{T,\tau, jet} = 39$ GeV
- $M_T = 68$ GeV

Single top production at HERA

- Single top production in SM negligible ($< 1 \text{ fb}$)
- production in FCNC process with anomalous κ_γ coupling



HERA

LEP

TEVATRON

- $t \rightarrow b + W \rightarrow$ high $P_{T^X} + 1 \nu$ or $q \bar{q}'$

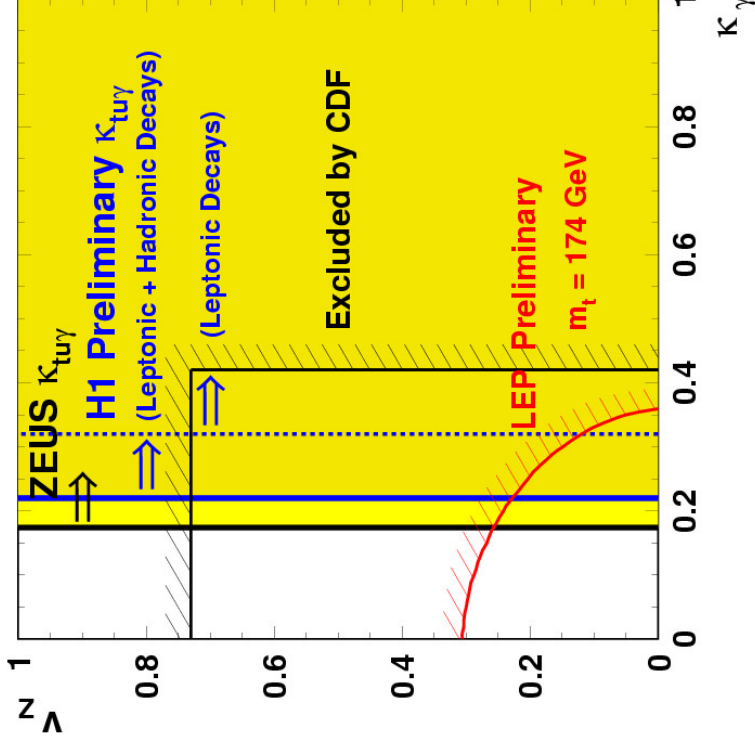
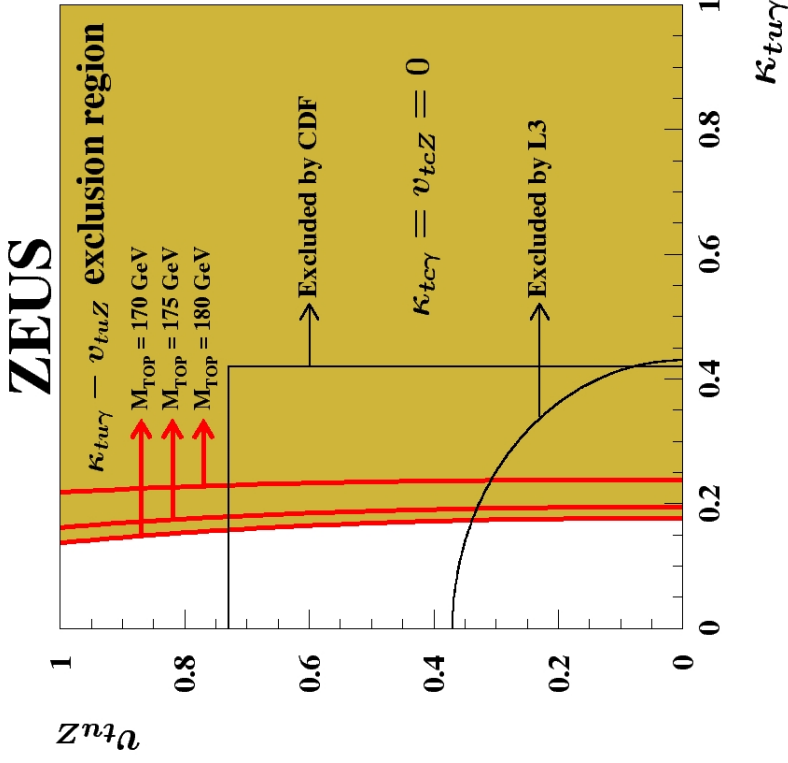
→ Signatures

- Leptonic: $1 + P_{T^{\text{miss}}} + \text{high } P_T \text{ jet}$
- Hadronic: 3 high P_T jets

	Leptonic	Hadronic
HI	5/1.7	14/19.4
ZEUS	0/1.9	14/17.6

No signal --> limits

Exclusion limits on FCNC coupling



(sensitivity to v_{tuZ} ,

LO calculations, NLO are not available)

NLO calculation (Belyaev Kidonakis.)

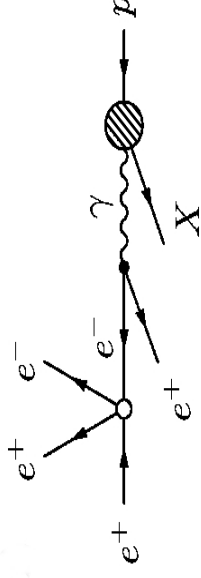
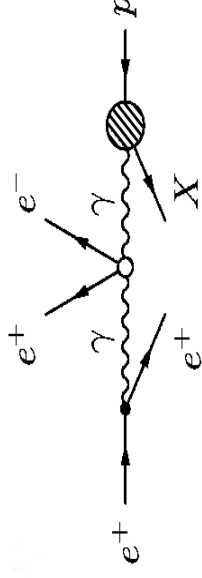
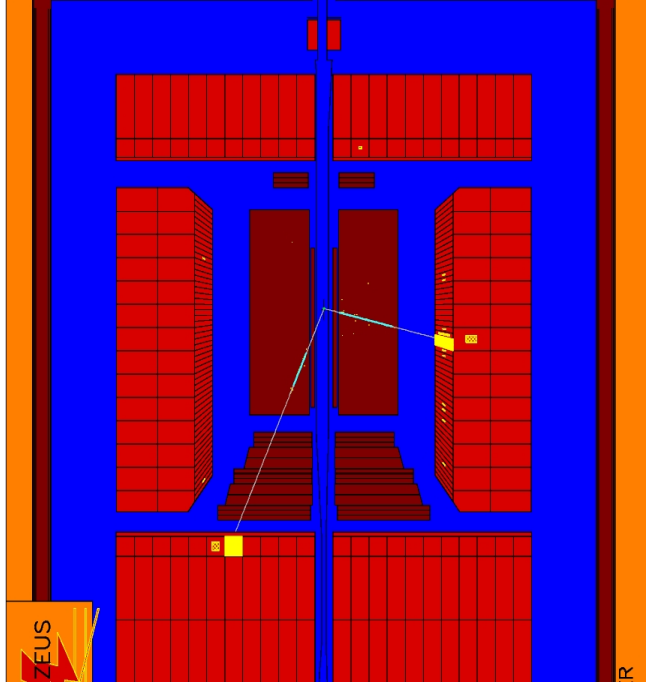
- Sensitivity at HERA on FCNC top production
- Limits (leptonic + hadronic decays):
 $\kappa_{t\gamma} < 0.174$ (ZEUS)
 < 0.22 (H1) (fluctuations in leptonic channel)

Lepton pair production

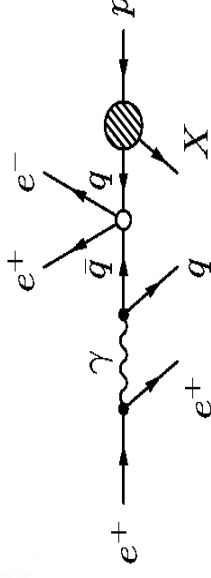
→ e^-e^- or $\mu^-\mu^-$ pairs

Mainly produced in photon-photon collisions

Rare process with spectacular topology



GRAPE (T.Abe)



- Background: fake leptons
 - NC-DIS: fake 2nd electron from radiation or mis-identification
 - Compton: $e\gamma(p) \rightarrow e + \gamma$ (→ fake 2nd e)

Multi-electron selection

- 2 e sample: 2 central isolated electrons

	H1	ZEUS
P_T	$> 10, 5 \text{ GeV}$	$> 10, E > 10 \text{ GeV}$
Lepton polar angle	$20^\circ - 150^\circ$	$17^\circ - 164^\circ$

+ good track associated to e shower

- 3 e sample: any 3rd electron ($5^\circ < \theta < 175^\circ$)
 → no 4 electron events found by H1 or ZEUS

H1 (115 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	105	118.2 ± 12.8	93.3 ± 11.5	25.0 ± 5.5
3 e	16	21.6 ± 3.0	21.5 ± 3.0	0.1 ± 0.0

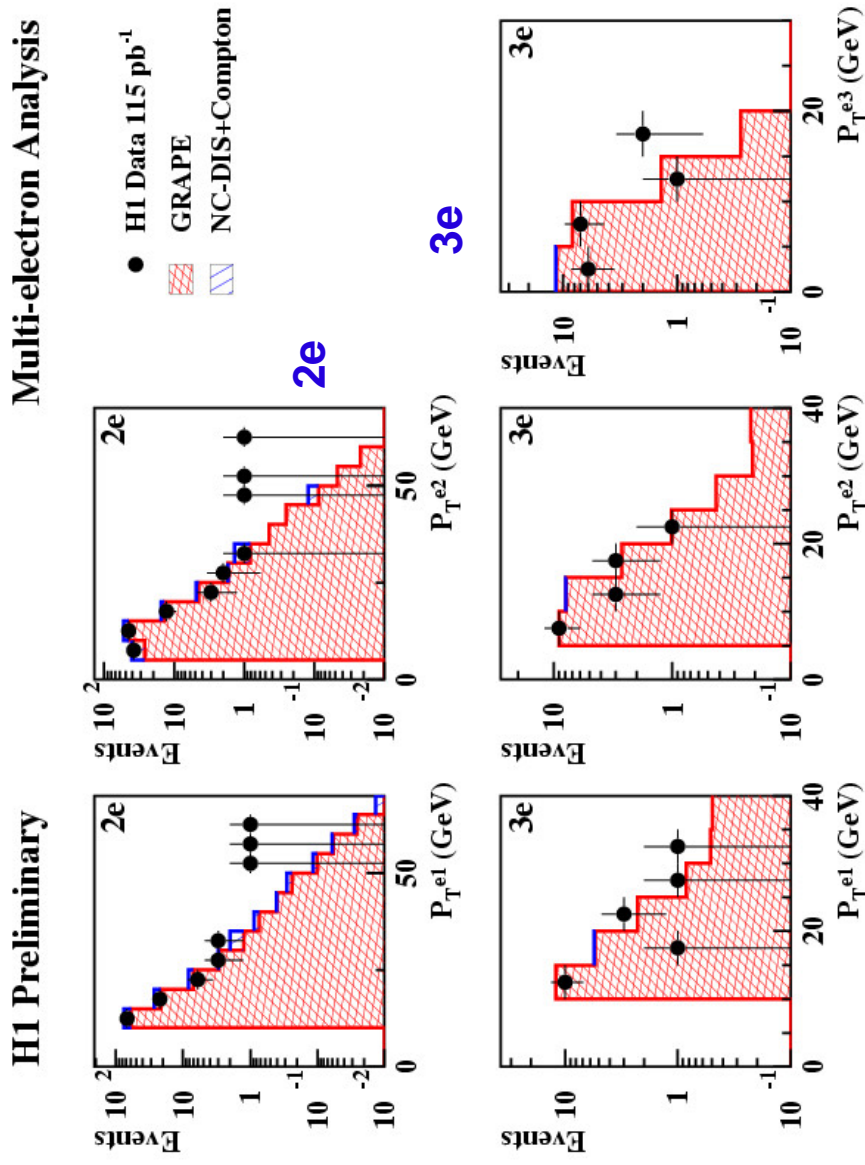
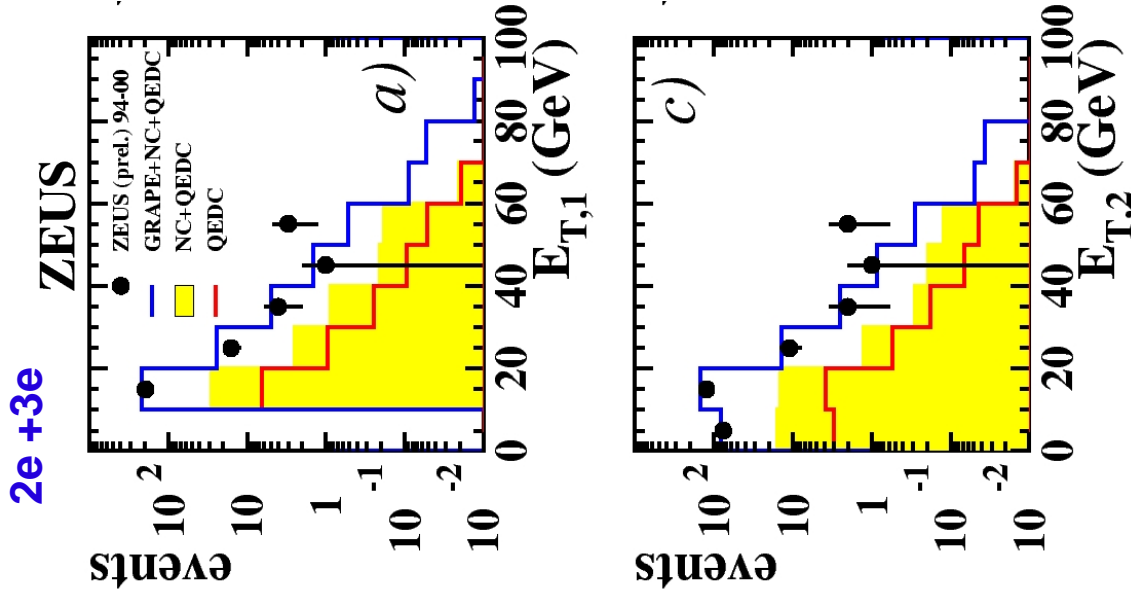
(statistical and systematical errors)

ZEUS (130 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	191	213.9 ± 3.9	182.2 ± 1.2	31.7 ± 3.7
3 e	26	34.7 ± 0.5	34.7 ± 0.5	--

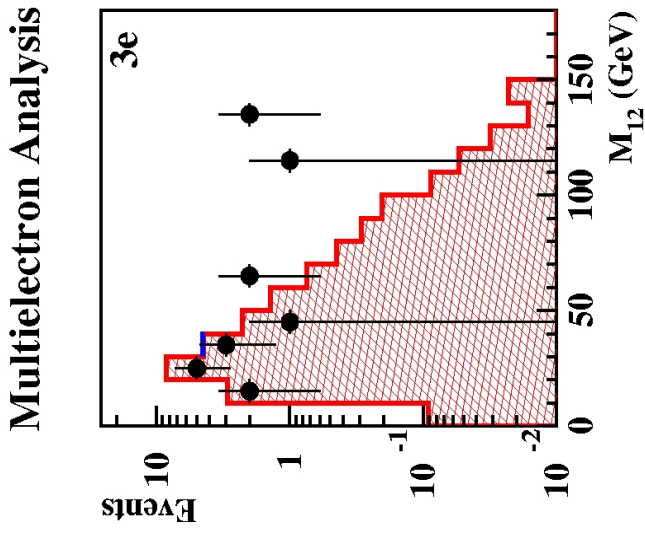
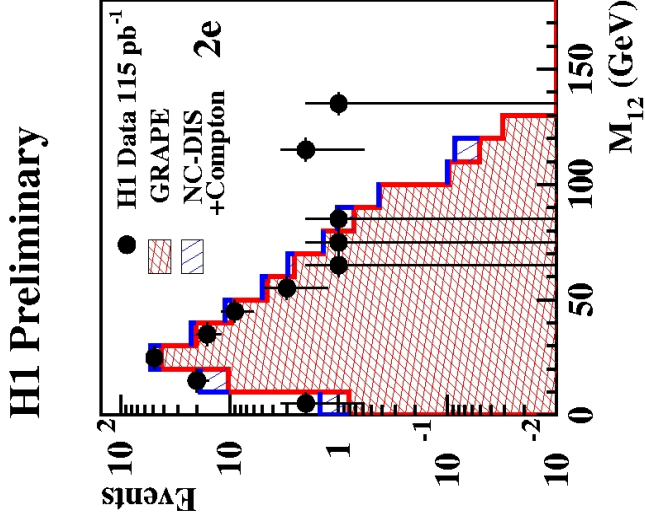
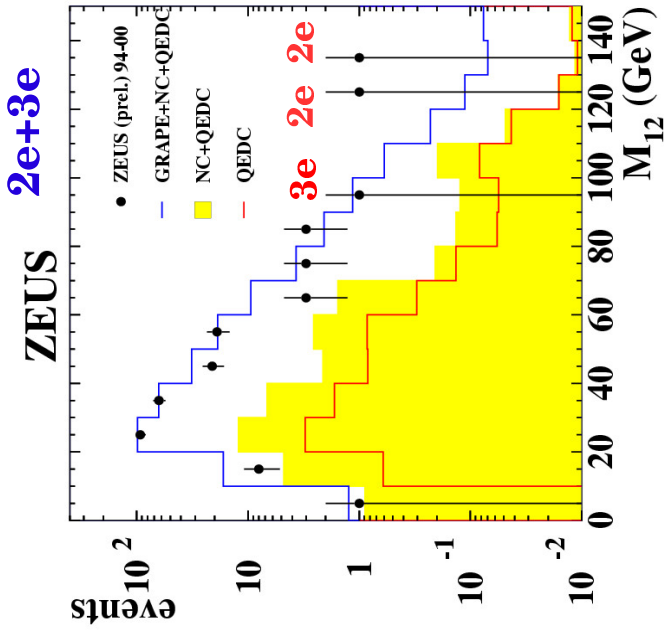
(statistical errors)

Multi-electrons: transverse momenta

- Good overall agreement
- ZEUS: 2 events $P_T > 50$ GeV
- H1: three 2e events $P_T > 50$ GeV



M_{12} mass of the two highest PT electrons



$M_{12} > 100$ GeV

	Data	SM	lepton pairs	NC + Compton
H1(115 pb-1)	3	0.25 ± 0.05	0.21 ± 0.04	0.04 ± 0.03
2e	3	0.23 ± 0.04	0.23 ± 0.04	0.0 ± 0.0

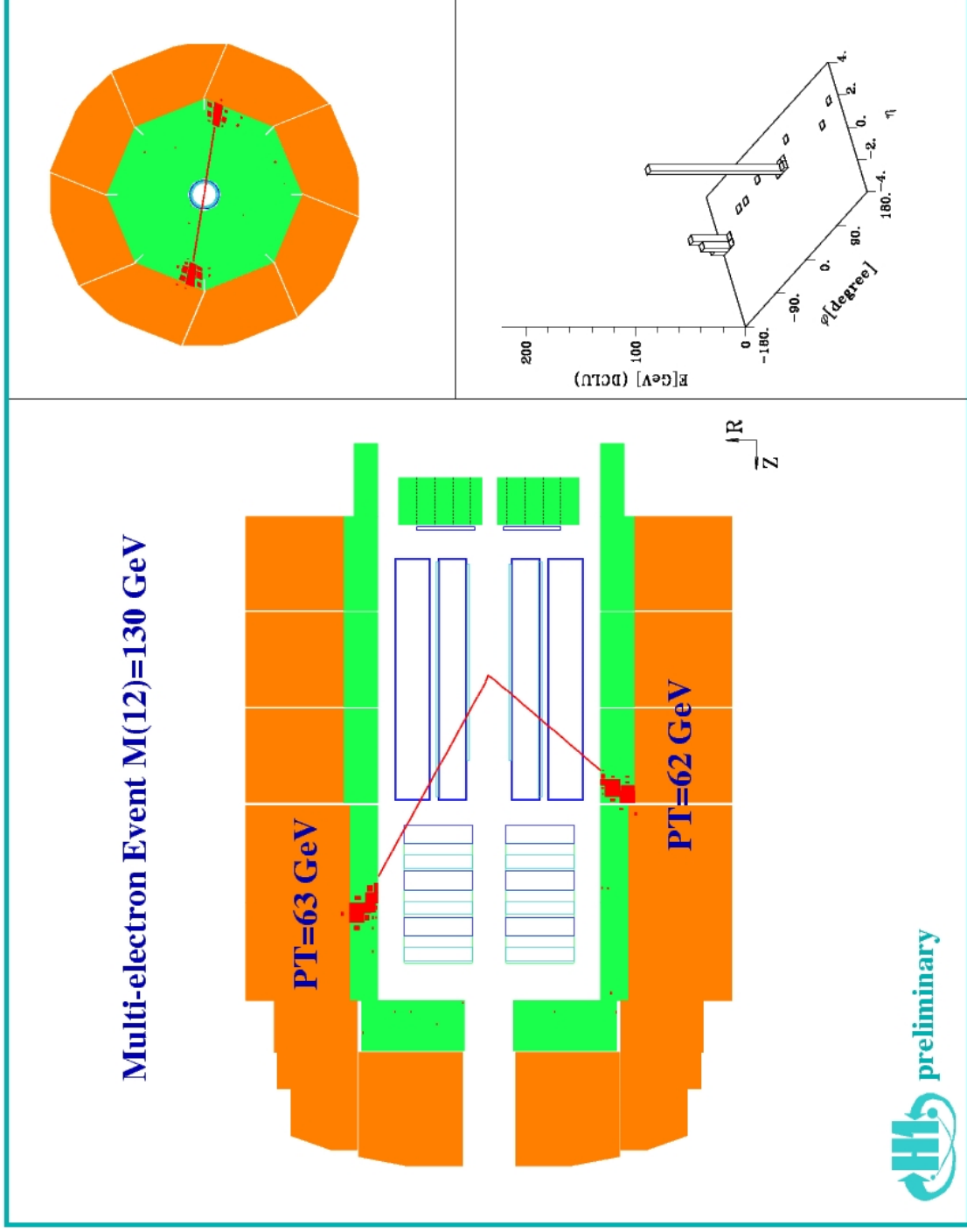
(statistical and systematical errors)

	Data	SM	lepton pairs	NC + Compton
ZEUS(130pb-1)	2	0.77 ± 0.08	0.47 ± 0.05	0.30 ± 0.07
3e	0	0.37 ± 0.04	0.37 ± 0.04	--

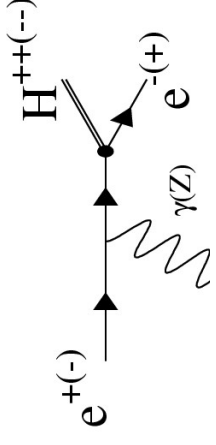
(statistical errors)

(different polar angle domains for H1 / ZEUS)

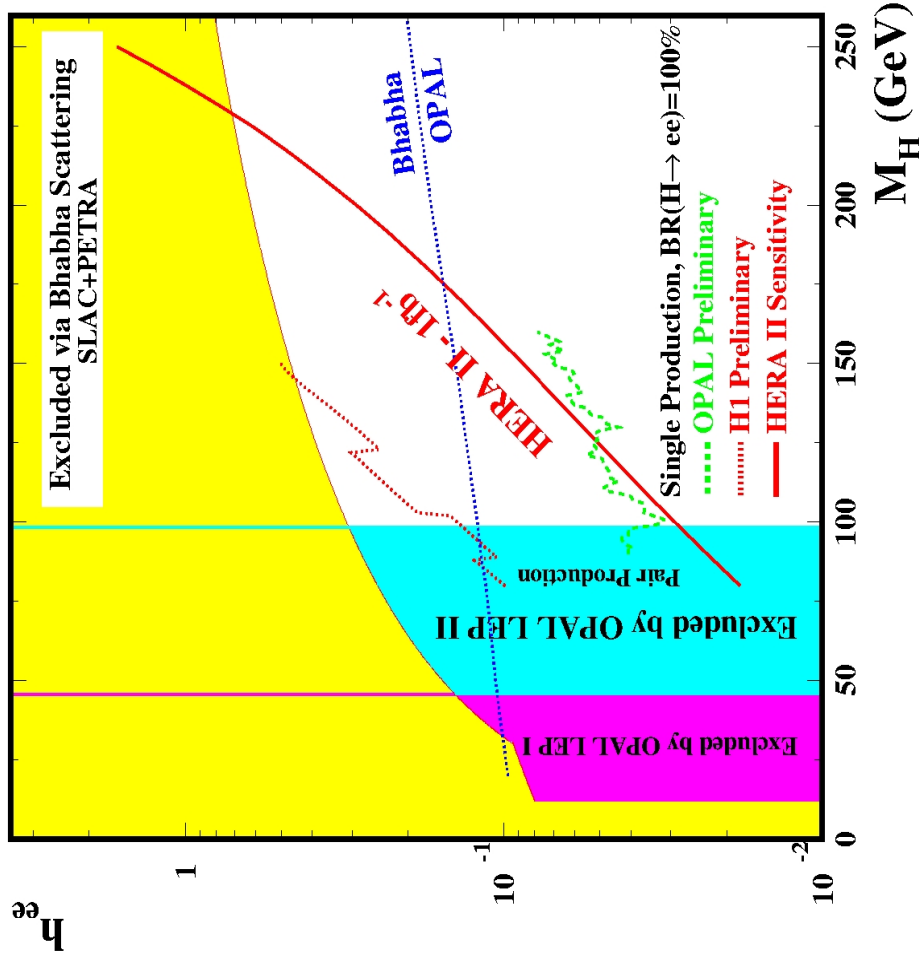
2e event (H1) $M_{12} = 130 \text{ GeV}$



Doubly charged Higgs at HERA ?



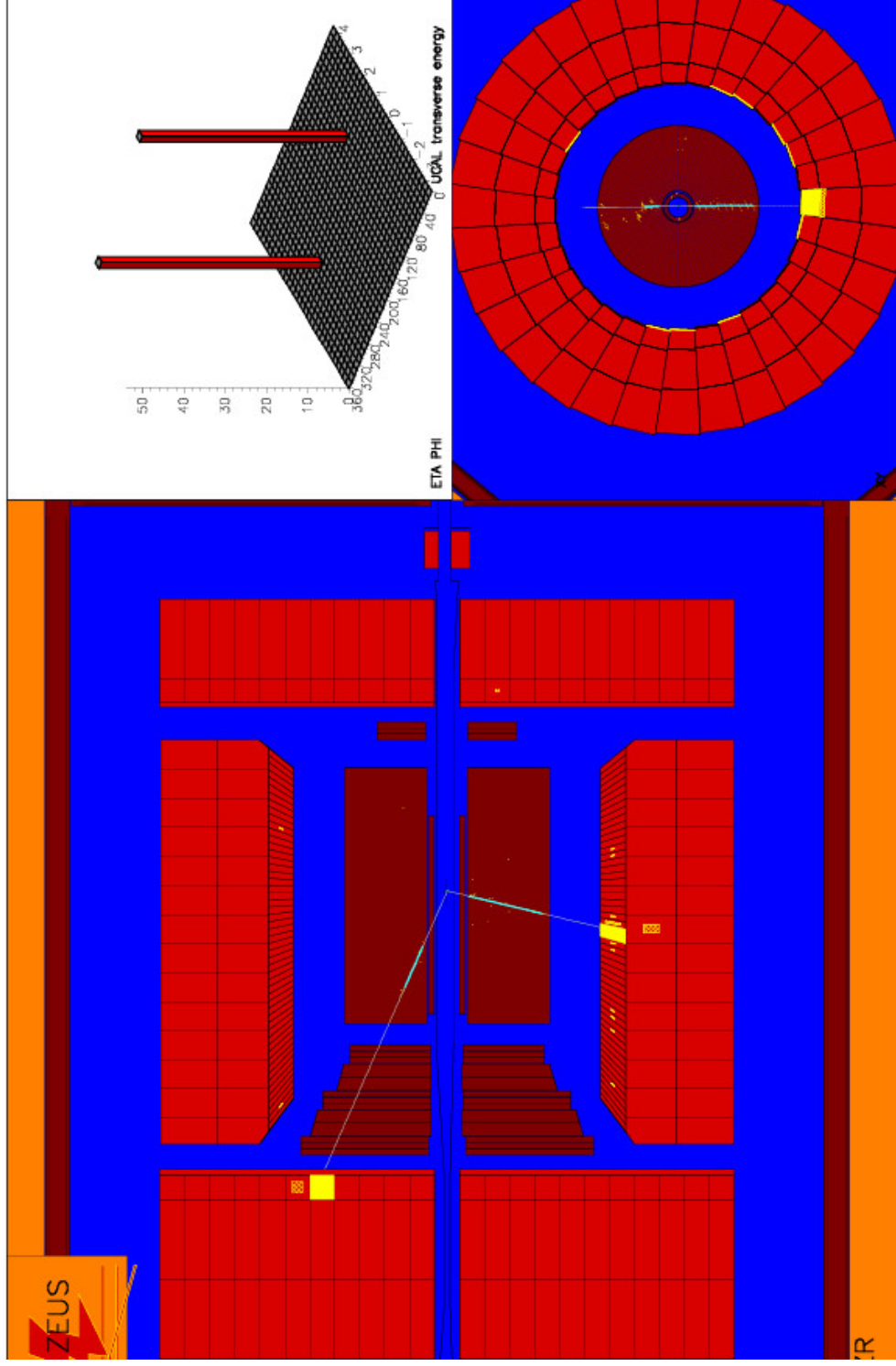
- H^{++} predicted in LR symmetric models
- at HERA : $e^+ p \rightarrow e^- H^{++} X$, $H^{++} \rightarrow l^+ l^+$, sensitivity to h_{ee} coupling
- ➔ H1: on top of multi-electron selection
- ➔ combines e and μ channels
(no multi- μ events @ high mass)
- Only one 2e event fulfils charge requirements
- ➔ Doubly charged Higgs unlikely
- ➔ Strong bounds on Yukawa coupling h_{ee} by OPAL



Conclusions and outlook

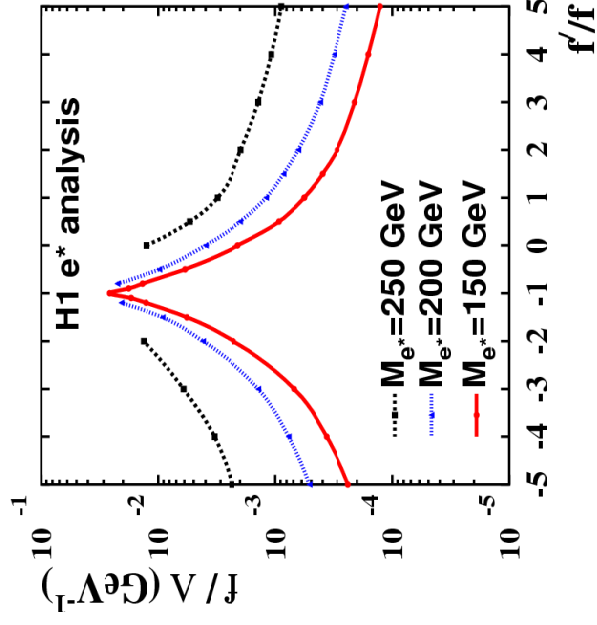
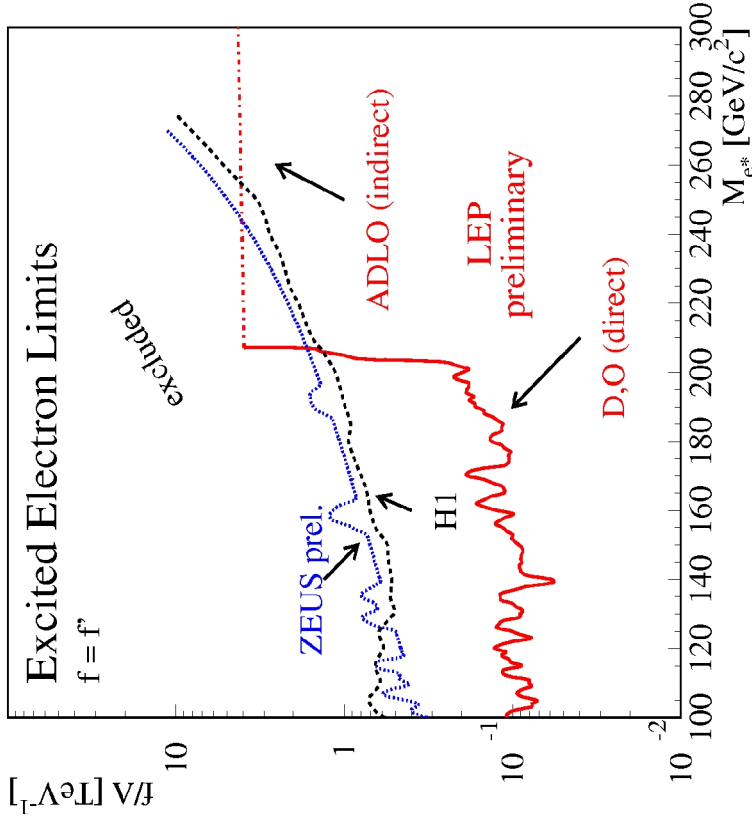
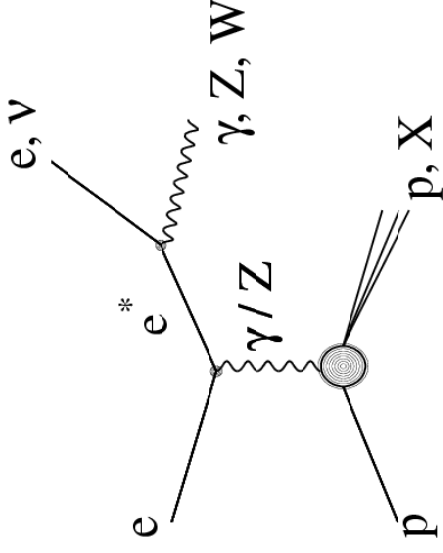
- HERA is a unique facility to search for new physics and test models
 - Shown: LQ, R_pSUSY, f*, Monopoles, Anom.top, H₊₊
 - Not shown: contact interactions, LED, LFV
 - Interesting events with several leptons:
 - H1: Intriguing isolated electron/muon events with missing P_T
 - ZEUS event yields in agreement with SM but ... 2 τ interesting events !
 - Both H1 and ZEUS observe events with 2,3 electrons at high mass (stay tuned...)
- HERA II plan: x10 more luminosity + e polarisation**
- startup difficult
- specific lumi upgrade OK but high background
- problems being solved now :more shielding + vacuum pumps
- hopefully substantial increase in integrated lumi up to 2006

2e event (ZEUS) $M_{12} = 134 \text{ GeV}$



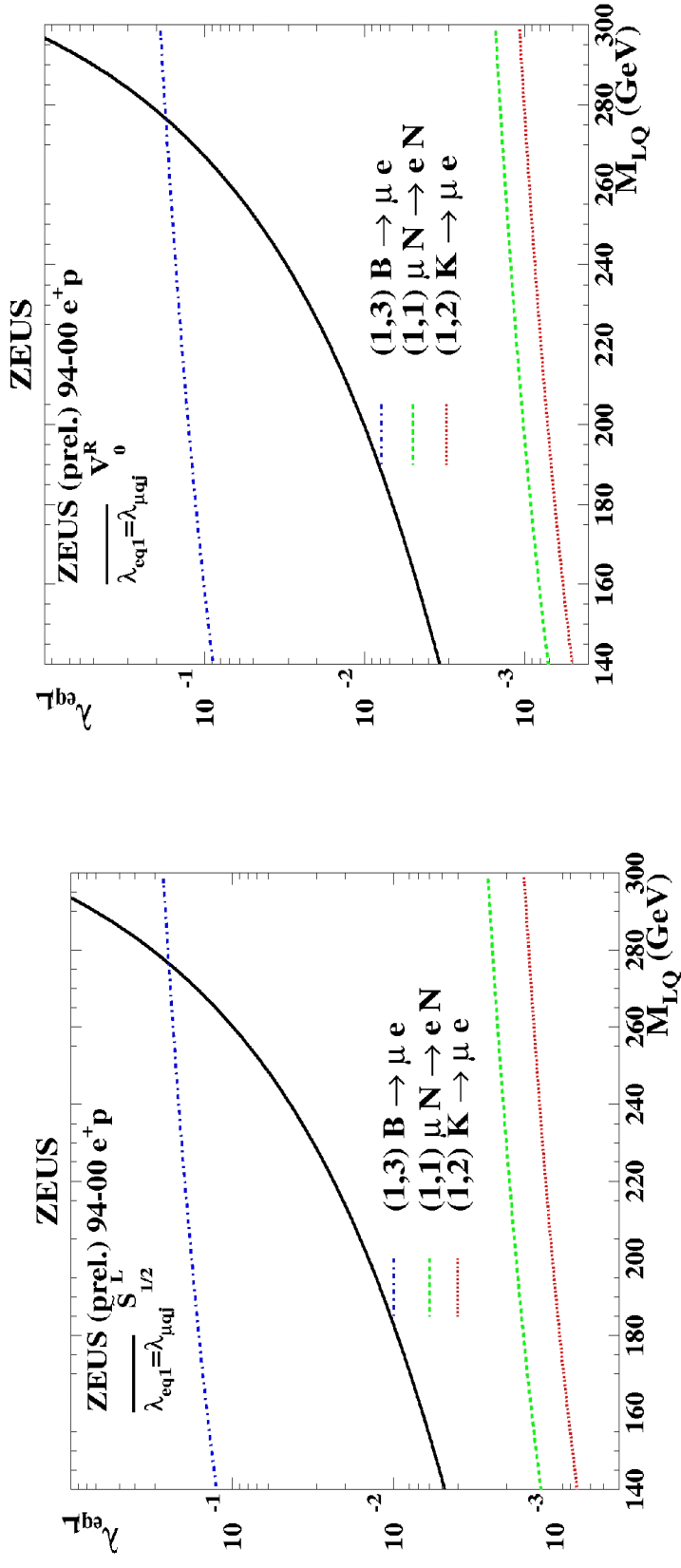
Excited fermions: e^*

- ✓ Compositeness at a scale Λ
- ✓ Model respect SM symmetries
- ✓ $SU(3) \times SU(2) \times U(1)$
- ✓ gauge constants f_s, f_f
- ✓ combine in coupling constants
- ✓ Search for fermion-boson resonance



Lepton Flavour Violation

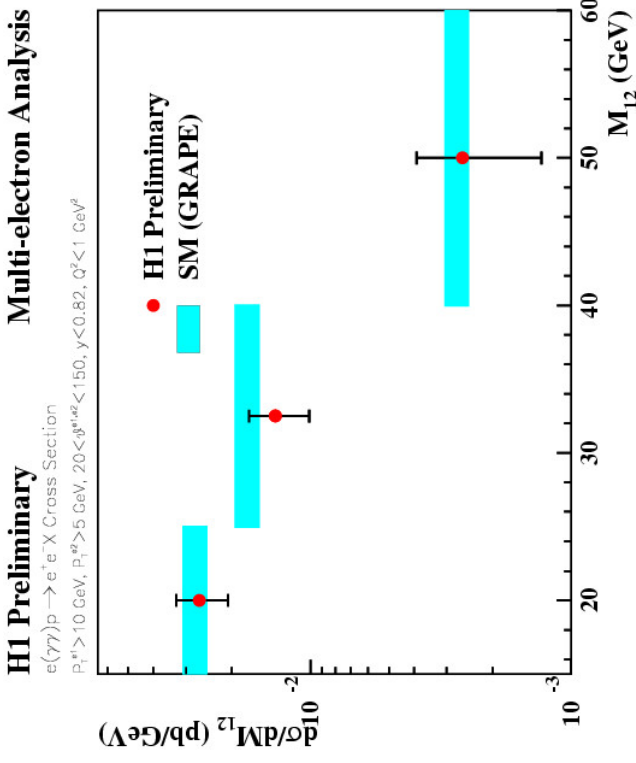
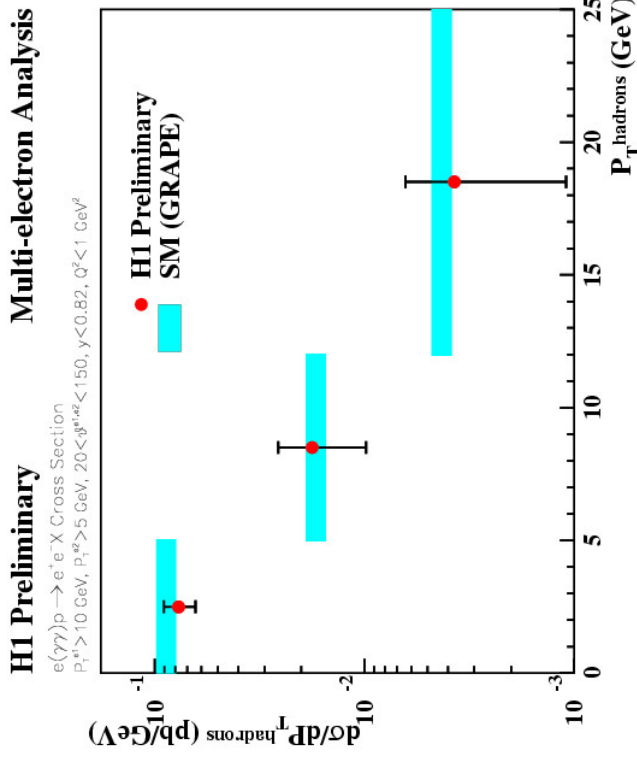
Mediated by leptoquarks that couple to two different generations $e \rightarrow LQ \rightarrow \mu q$



H1: Cross-section measurement

$$\gamma\gamma \rightarrow e^+e^-$$

- 2e sample + E-Pz < 45 GeV, opposite charges, $y < 0.82$, $Q^2 < 1 \text{ GeV}^2$
- data / MC: $41 / 48.3 \pm 6.1$ (1.9 background)

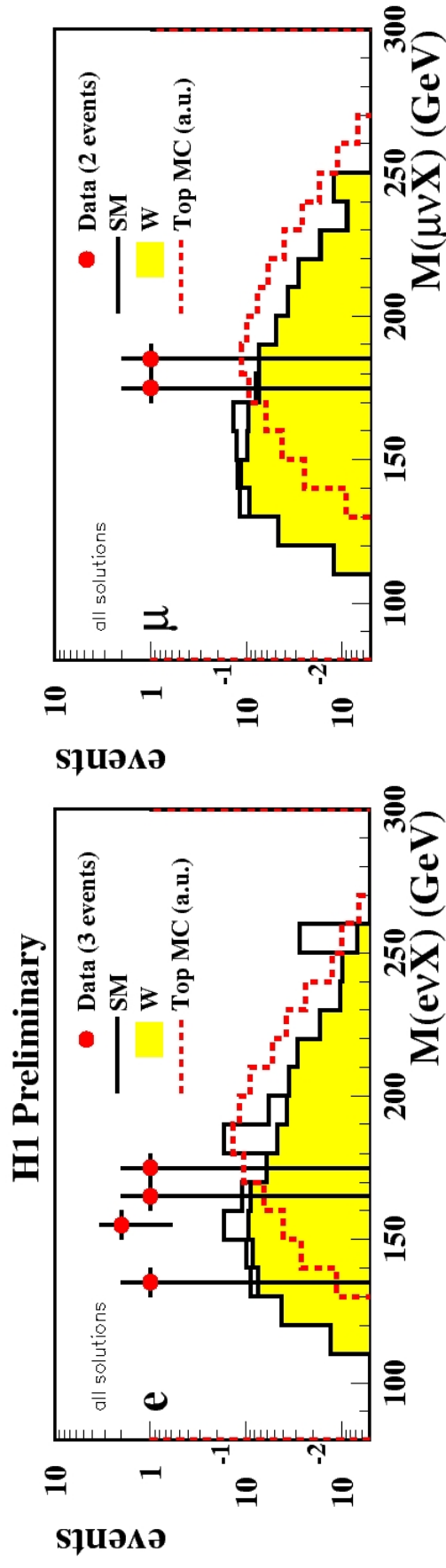


→ Inelastic process well described

→ Good agreement

Semi-leptonic top decays

- $t \rightarrow b W \rightarrow l(e \text{ or } \mu) + \nu$
- **ZEUS : no events $P_{TX} > 40 \text{ GeV}$**
- H1: further cuts to separate top from SM W
 - $P_T^{\text{jet}} > 25 \text{ GeV}$ $M_{T l, \nu} > 10 \text{ GeV}$
 - only + lepton charge

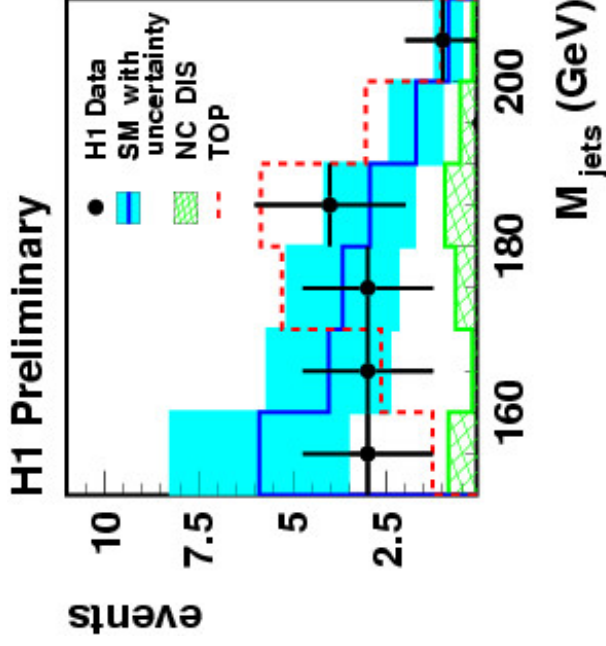
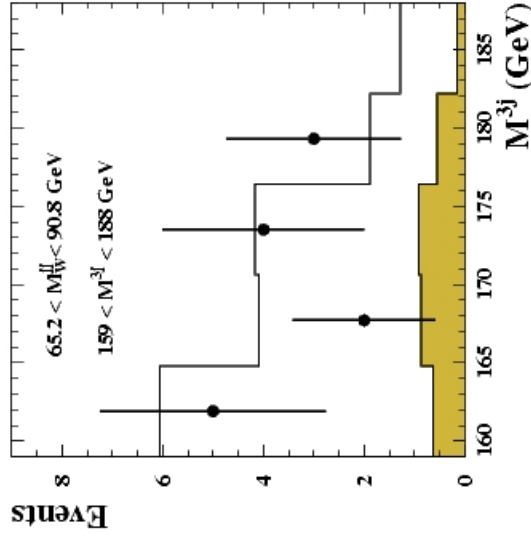


→ **H1: 5 events (3e, 2μ) / 1.77 ± 0.46 expected**

Single top: hadronic decay

- $t \rightarrow bW \rightarrow q\bar{q}' \Rightarrow 3$ high P_T jets

	ZEUS	H1
$P_{T,jet}$	$> 40, 25, 14$	$> 40, 25, 20$
W mass window	$65 < M_{2j} < 91$	$70 < M_{2j} < 90$
top mass window	$159 < M_{3j} < 188$	$150 < M_{3j} < 210$
		+ cut on decay angle (H1)



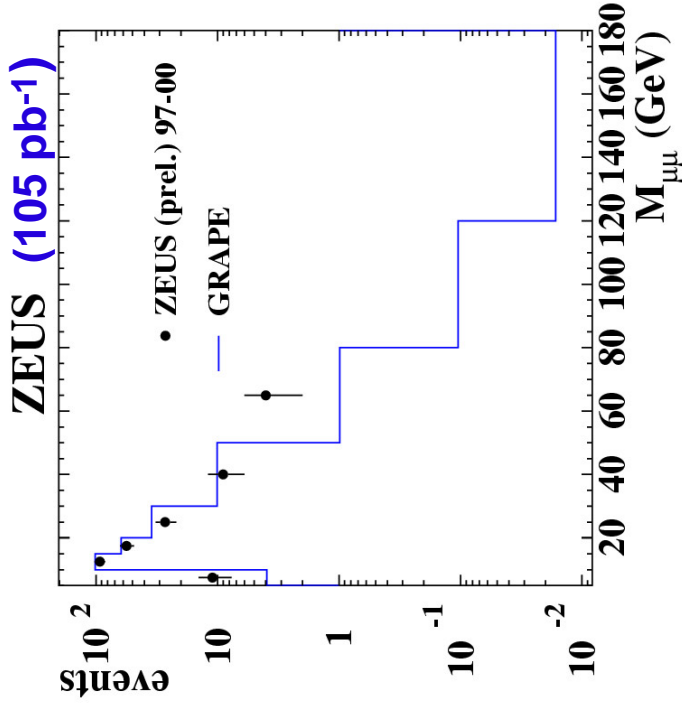
ZEUS	$14 / 17.6^{+2.5}_{-1.5}$
H1 prelim.	$14 / 19.6 \pm 7.8$

- Comparison to semi-leptonic decay (H1):
 - < 5.4 expected (95 % CL) ⇔ 5 observed
 - no contradiction within systematics

Di-muon events

- μ identified in central tracker, calorimeter and external muon chambers ($20^\circ < \theta < 160^\circ$)

- ➔ No μ - μ event observed with $M_{\mu\mu} > 100$ GeV
- ➔ Comparison $2e \leftrightarrow \mu\mu$: 1 $\mu\mu$ expected (H1)



H1: (71 pb⁻¹)

