Search for beyond the SM Physics

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- Highlights from Hera I
- What at HERA II

BSM searches at HERA I

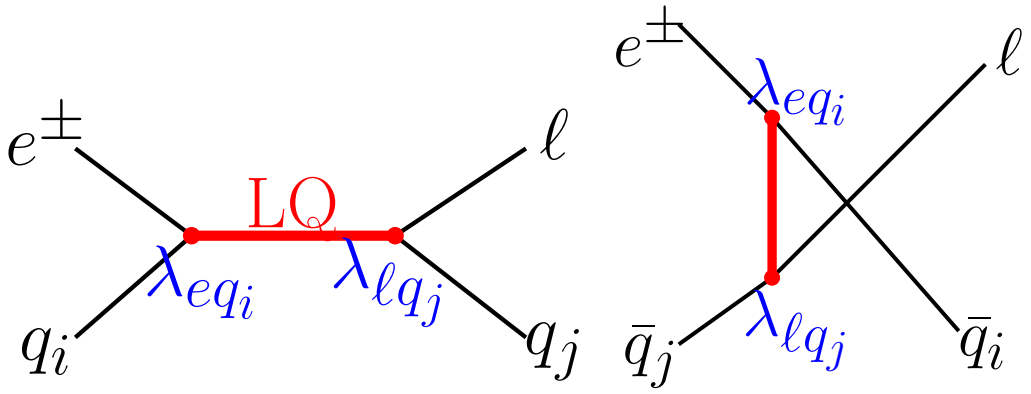
Resonance-type or Contact-Interactions

- Leptoquarks
- Lepton Flavour Violation
- Contact Interactions
- Extra-dimension limit
- Quark Radius limit
- Excited fermions
- SUSY in MSSM R_p conserving model
- SUSY in R_p-violating model

Exclusive final states

- Isolated e, μ, τ and missing p_T
- Single-top limits
- Dielectron, Dimuon events
- Doubly-charged Higgs limits
- General search
- Magnetic Monopole search

Leptoquarks



Scalar or vector color triplet bosons, carrying both L and B.

at HERA BRW model is used:

- L and B conservation; $F = 3B + L = 0, 2$ defined
- either left-handed or right-handed couplings
- 7 scalar and 7 vector leptoquarks
- all 14 decay to eq
- 4 decay to eq and νq

but also more model independent limits are derived

Leptoquark(II)

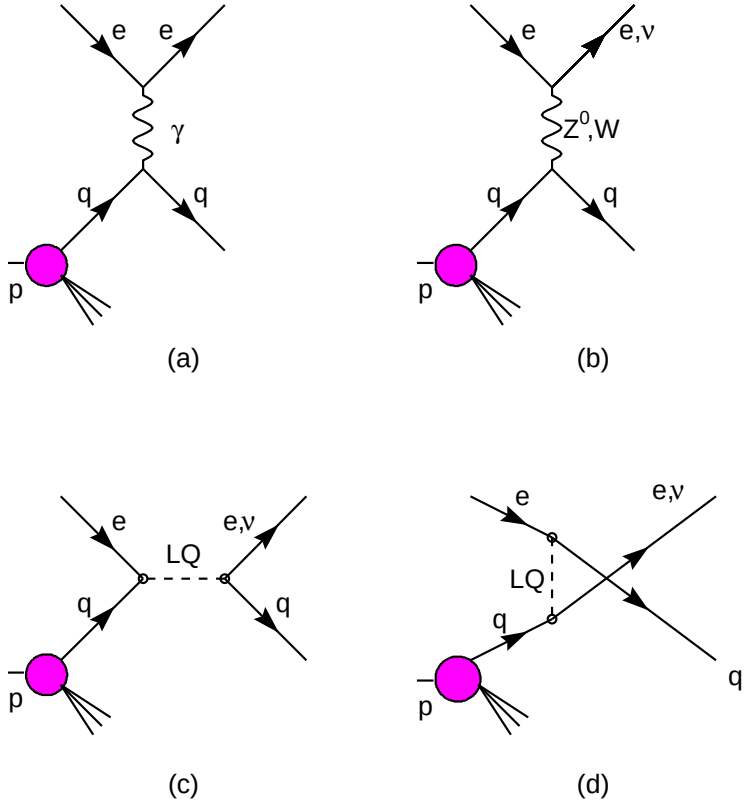
$$\sigma(e^{\pm}q \to e(\nu_e)q) = \sigma_{SM} + \sigma^{INT}_{u/SM} + \sigma^{INT}_{s/SM} + \sigma_u + \sigma_s$$

$M_{LQ} < s$:

- $\sigma_s^{NWA} = (J+1)\frac{\pi\lambda^2}{4s} q(x_0, Q_0^2)$

  $x_0 = \frac{M_{LQ}^2}{s}, Q_0^2 = M_{LQ}^2$

- $y = 1/2(1 - \cos\theta^*)$,
  (θ^*) scattering angle in eq (νq) rest frame
- DIS: $\simeq 1/y^2$; Scalar LQ $\simeq (y)$; Vector LQ $\simeq (1-y)^2$



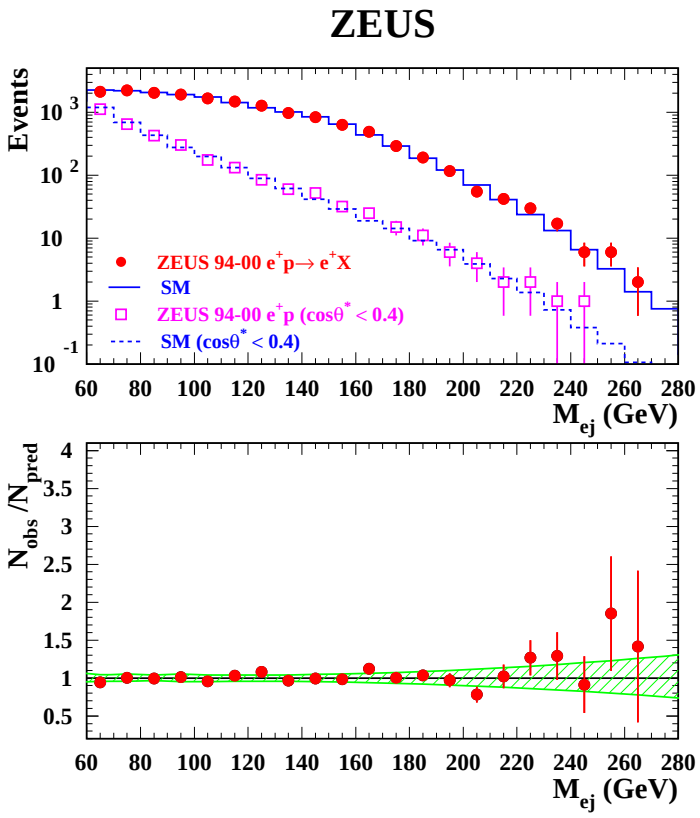
$M_{LQ} > s$:

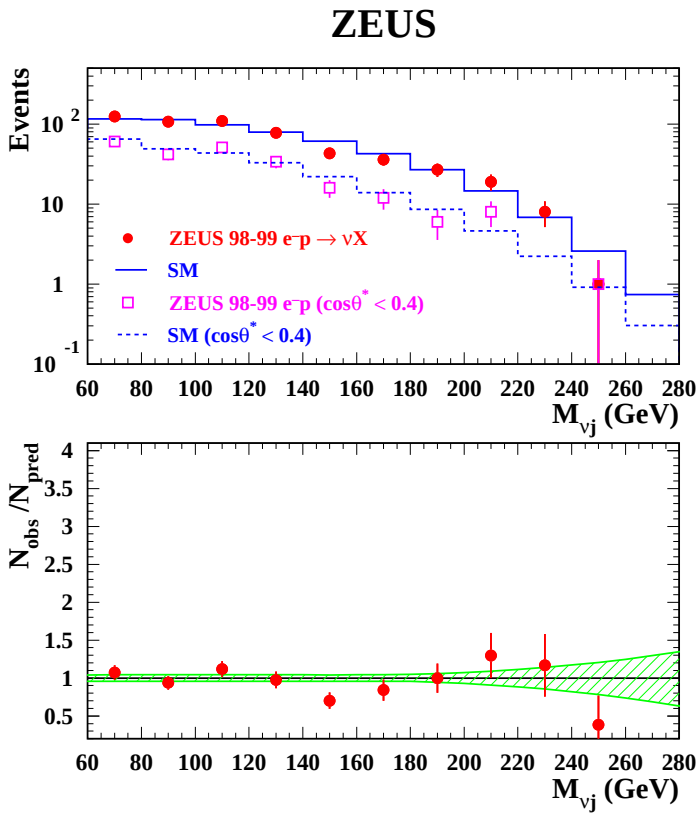
Contact-Interactions term

Leptoquark III

$F = 3B + L$=0 best in e^+p

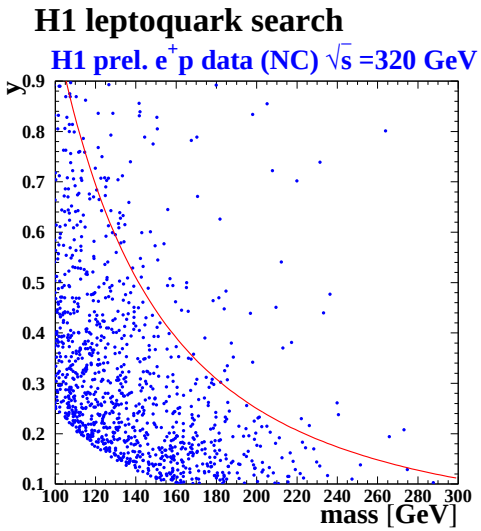
$F = 3B + L$=2 best in e^-p

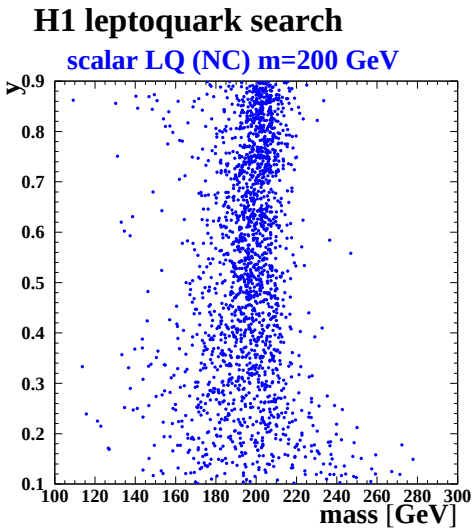


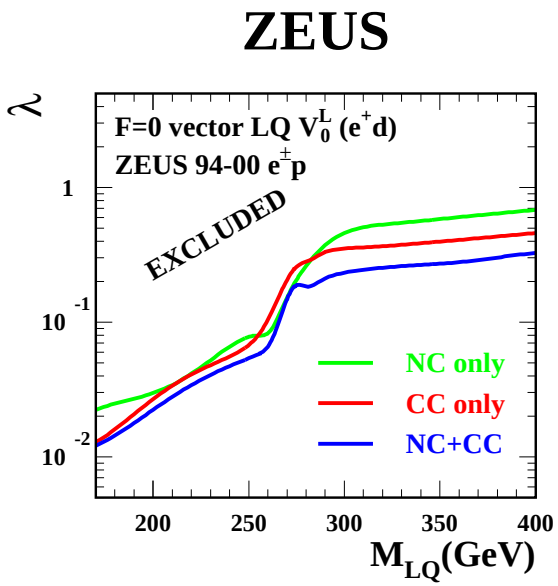


No signal seen by H1 and ZEUS , set limits on LQs production

Leptoquark IV



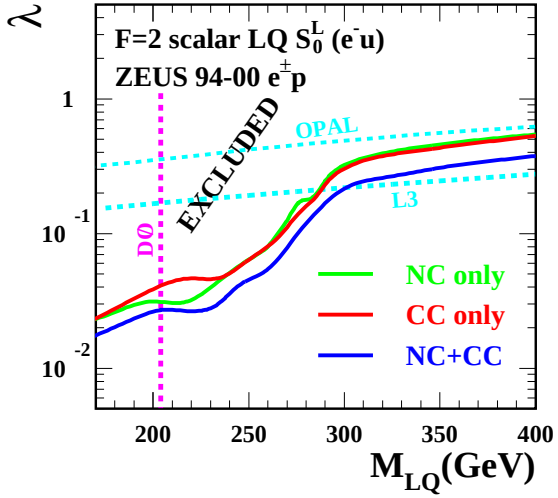




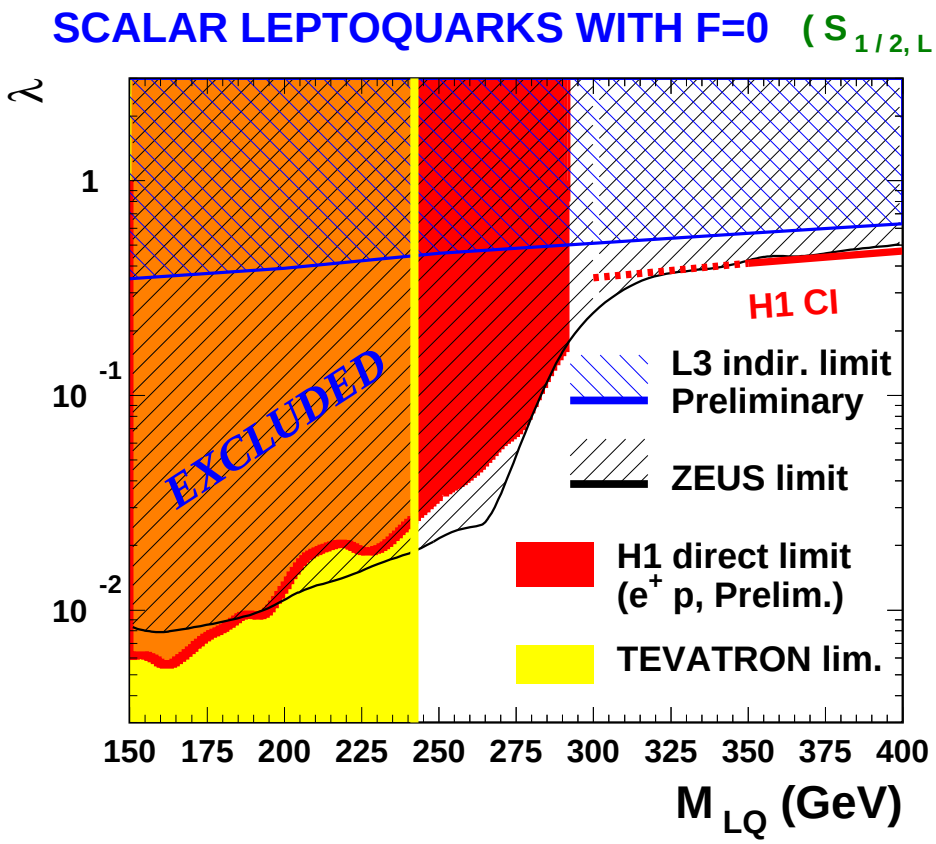
Use 2-dimensional information

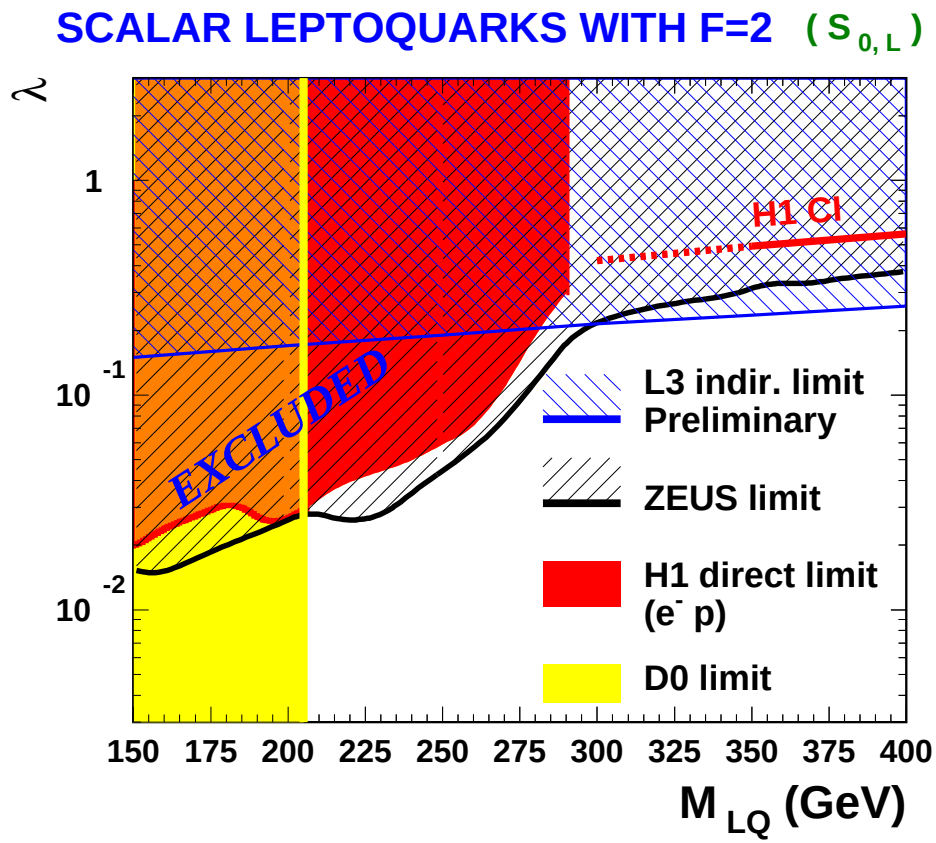
in x-y plane to extract limits

Zeus fits NC+CC together →



Leptoquark V





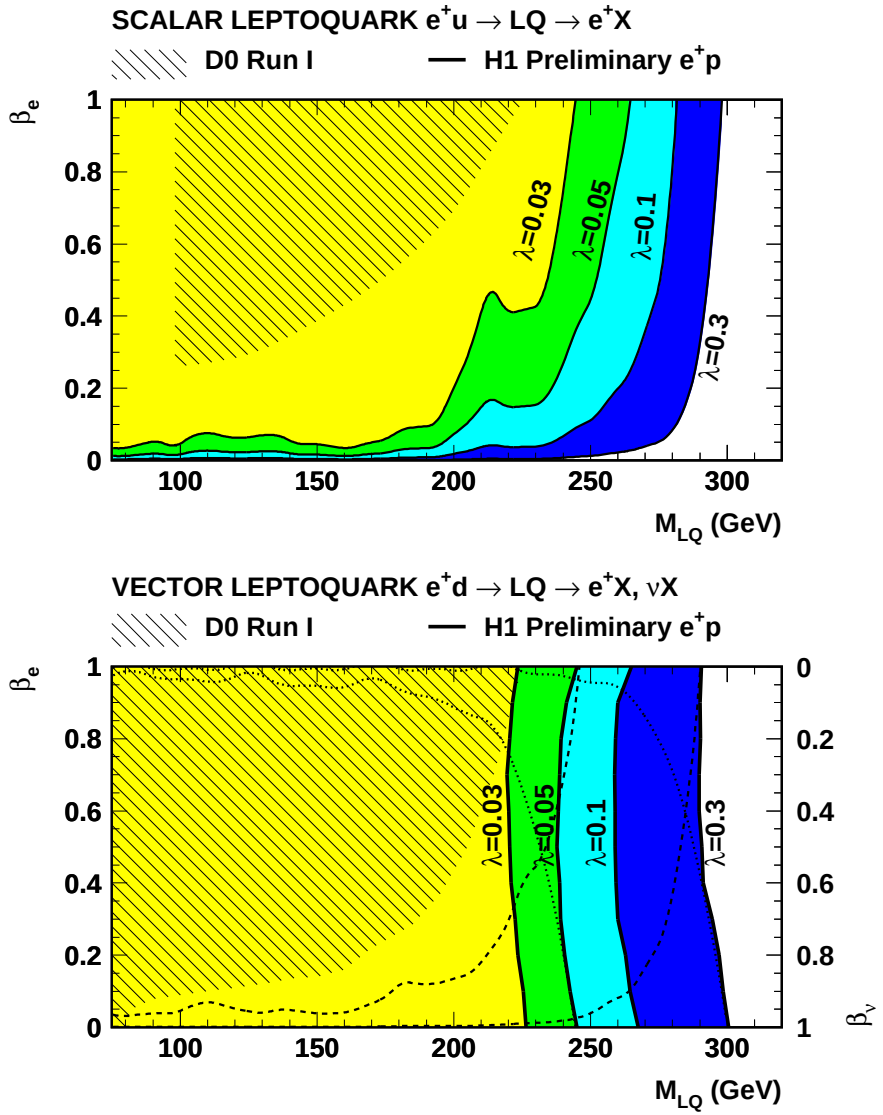
HERA I limits very competitive in the region $230 \div 280\ GeV$

DO RunI+RunII prel. M_{LQ}(scalar)$> 253\ GeV$ for $\beta(LQ \to eq) = 1$

Leptoquark VI

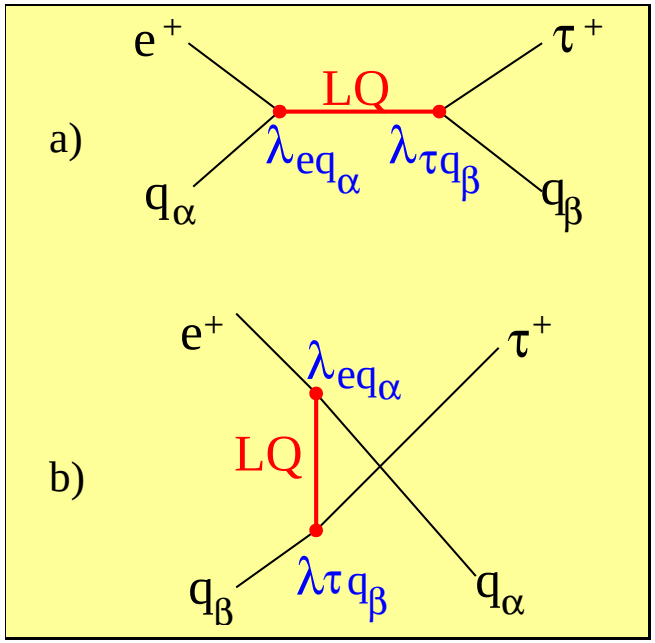
Tevatron limits do not depend on λ, but depend on β

HERA independent of β, still discovery window at low β



Lepton Flavour Violation

- Evidence for neutrino oscillations: do we see oscillation also between leptons?
- Leptoquark and Susy models predict LFV interactions
- Signature: $eq \rightarrow \mu(\tau)q'$, high missing p_T, μ or τ aligned with the missing p_t, small SM background
- also here distinguish between $M_{LQ} < s$ ('peak' expected', high p_T lepton) and $M_{LQ} > s$ (softer p_T lepton)

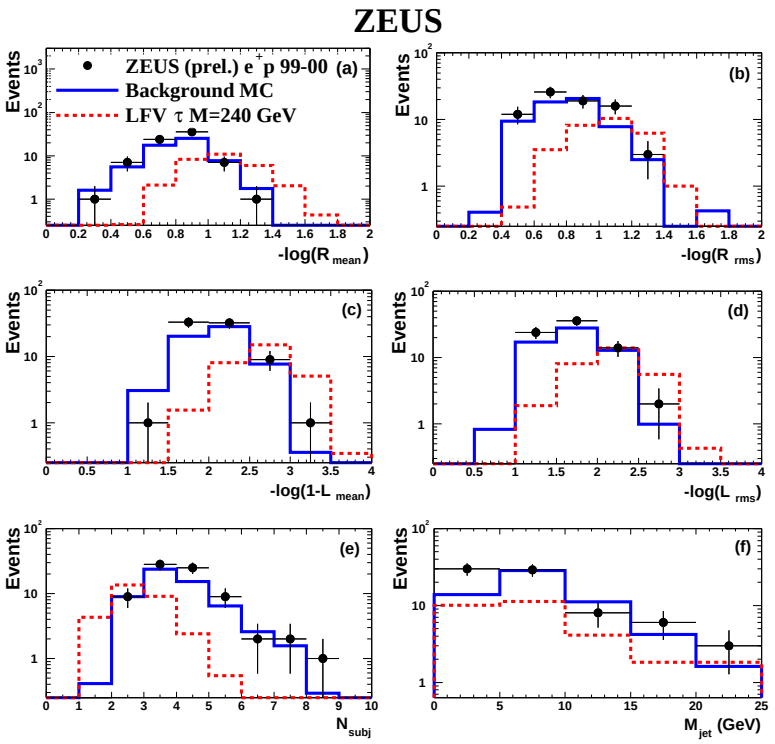


Lepton Flavour Violation II

New results from Zeus on $eq \rightarrow \tau q'$

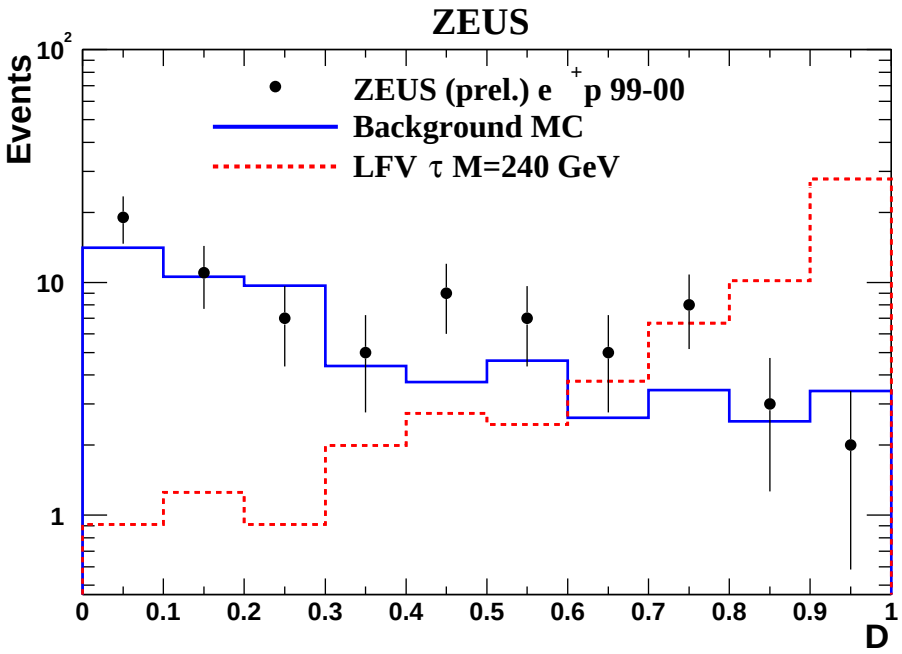
(99-00 e^+p data)

τ-discriminant selection:



$$D = \frac{\rho_{sign}}{\rho_{backg} + \rho_{sign}}$$

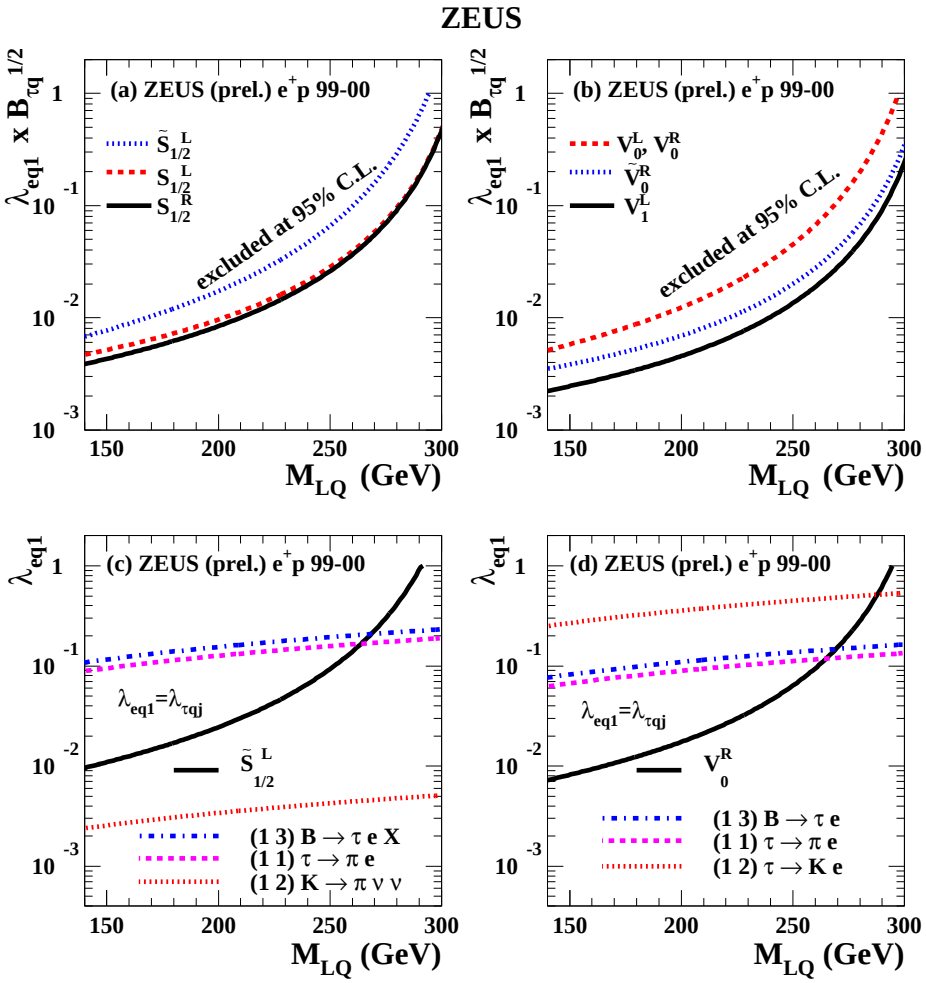
in 6-dimensions, slight increase in effi ciency using this method



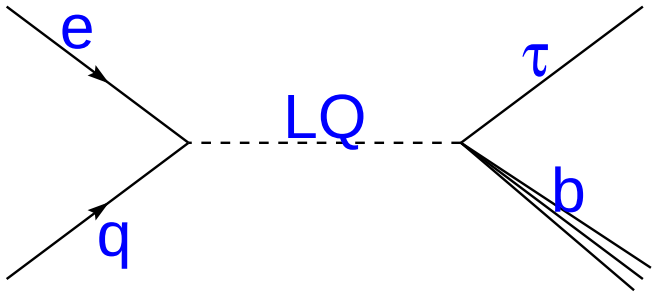
$D \rightarrow 0$ QCD-jets, $D \rightarrow 1$ $\tau-$jets

No events survive the final cuts

Lepton Flavour Violation III



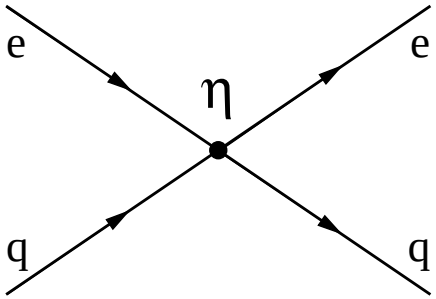
LQs excluded in mass range
$276 \div 299\ GeV$
for $\lambda_{eq} = \lambda_{\tau q} = 0.3$

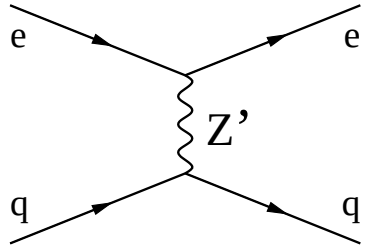


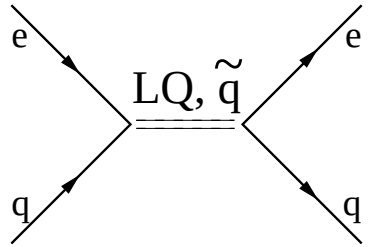
HERA competitive when a heavy quark in the final state is involved

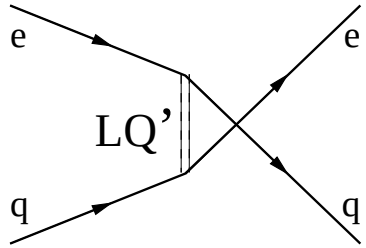
Contact Interactions

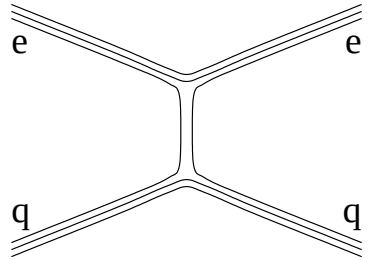
$$\mathcal{L}_{CI} = \sum_{\alpha,\beta=L,R}^{q} \eta_{\alpha\beta}^{eq} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$

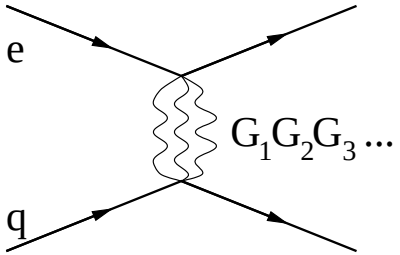


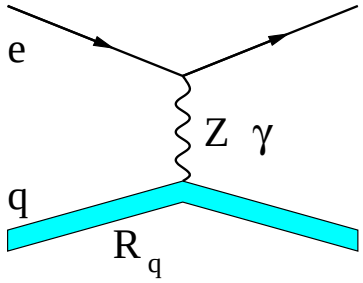










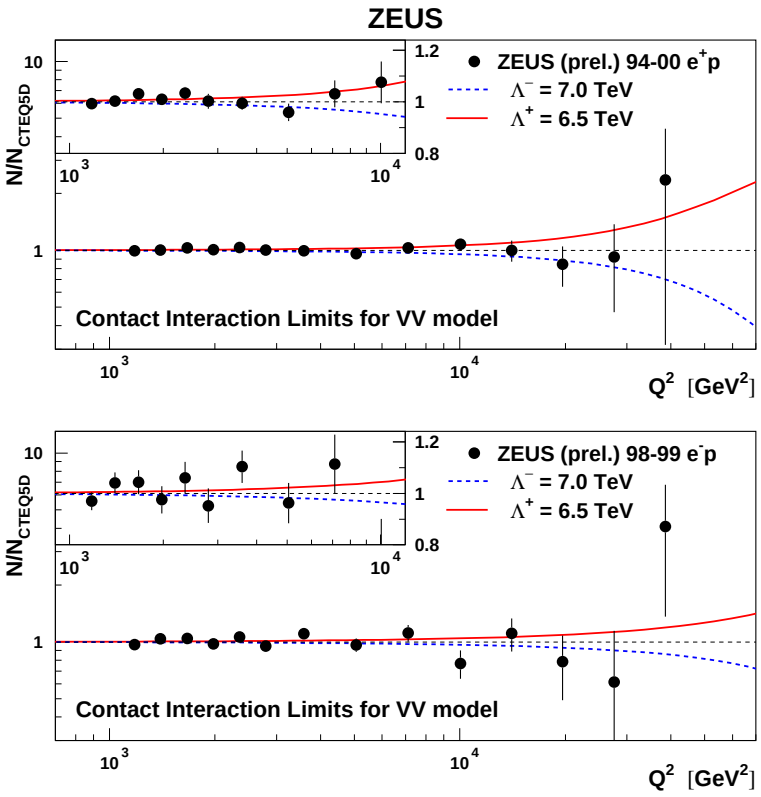


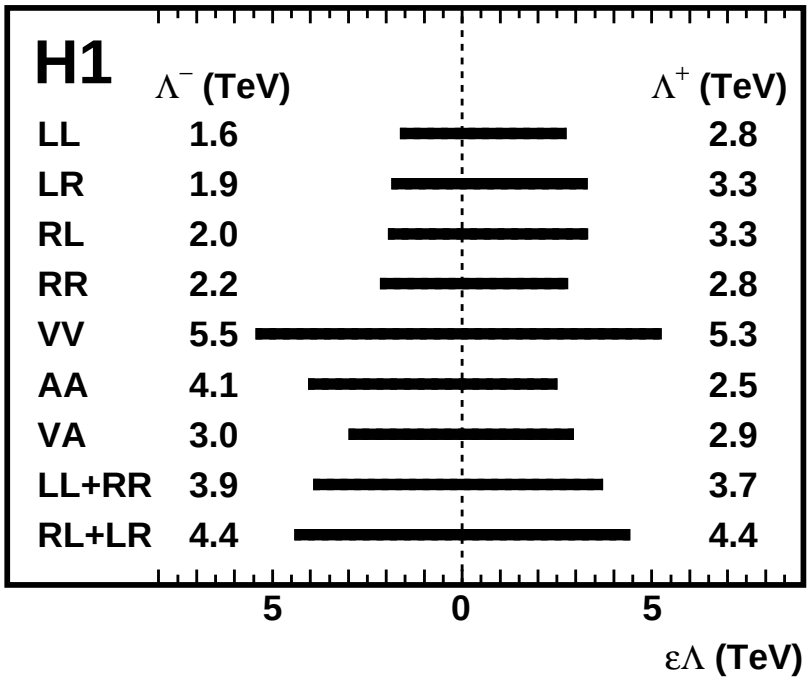
complementary to LEP/Tevatron

- leptoquarks
- General Contact Interactions
- Large Extra-Dimensions
- Quark Radius

Contact Interactions II

$$\eta = \frac{\epsilon \cdot 4\pi}{(\Lambda^2)}$$





Also limits on the quark radius:

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

$$R_q < 1.0 \times 10^{-16}\ cm \text{ (H1)}$$

i.e. $VV \rightarrow \epsilon_{LL} = \epsilon_{LR} = \epsilon_{RL} = \epsilon_{RR} = +1$

Search for R-parity violation SUSY

MSSM model:

$R_p = (-1)^{3B+L+2S}$

=1 for particle, =-1 for sparticle

particle	sparticle
quark	squark ($\tilde{q}$)
charged lepton	slepton($\tilde{e}$,$\tilde{\mu}$,$\tilde{\tau}$)
neutrino	sneutrino ($\tilde{\nu}$)
photon	photino
graviton	gravitino ($\tilde{G}$)
Z^0	zino $\tilde{Z}$
neutral h, A, H	neutral higgsino $H_{1,2}$
charged $H^{\pm}$	charged Higgsino $\tilde{H}^{\pm}$
$W^{\pm}$	wino $\tilde{W}^{\pm}$

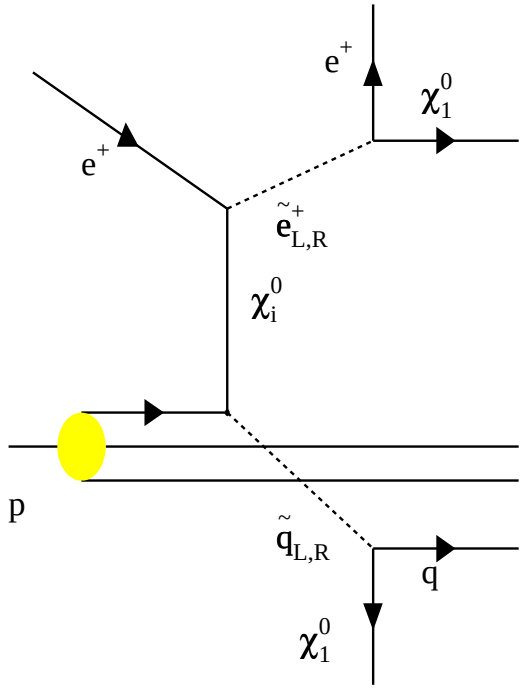
$\tilde{W}^{\pm}, \tilde{H}^{\pm} \rightarrow \chi_1^{\pm}, \chi_2^{\pm}$ charginos

$\tilde{\gamma}, \tilde{Z}, \tilde{H}^0_{1,2} \rightarrow \chi^0_{1,2,3,4}$ neutralinos

μ Higgs mixing parameter

$\tan\beta$ ratio of vev scalar Higgses

R_P conserving at HERA:



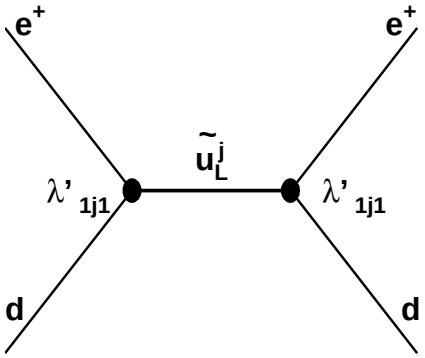
$(M_{\tilde{e}} + M_{\tilde{q}})/2 \geq 77\ GeV$

HERA not competitive

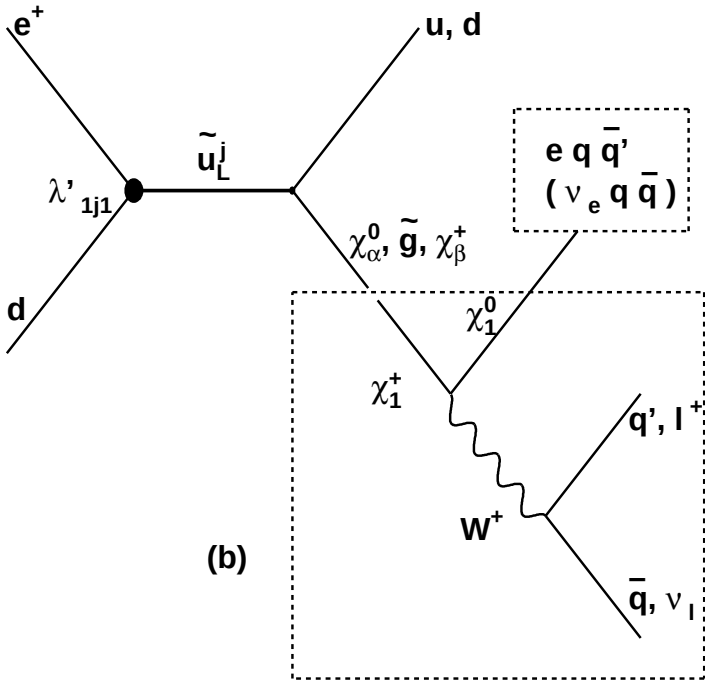
Search for R-parity violation SUSY (II)

R_P-violating lagrangian:

$$\mathcal{L} = \lambda_{ijk} L_i L_j \tilde{E}_k + \lambda'_{ijk} L_i Q_j \tilde{D}_k + \lambda''_{ijk} U_i D_j \tilde{D}_k$$



(a)



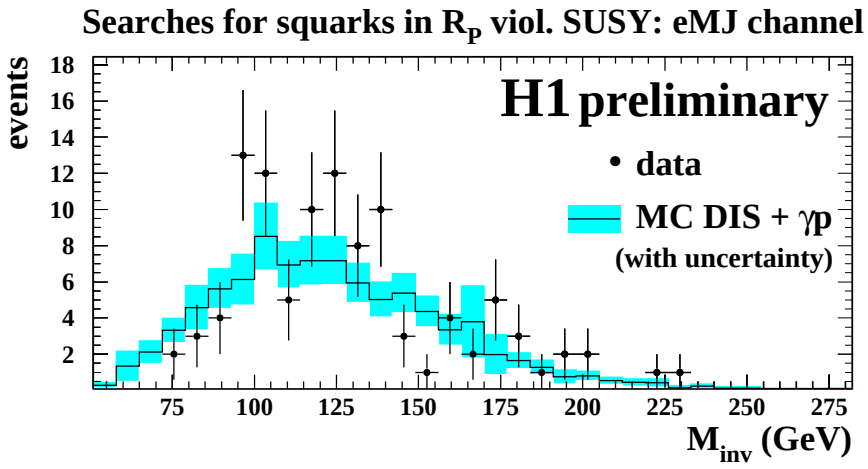
(b)

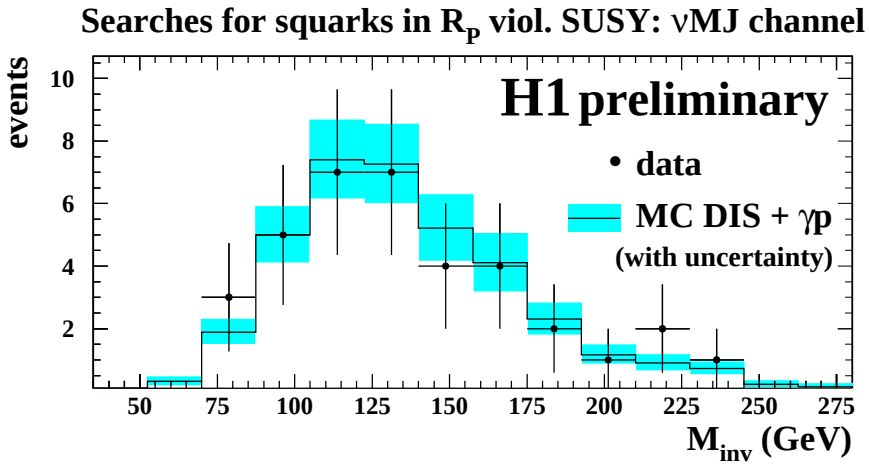
Search for R-parity violation SUSY (III)

Seven different topologies studied by H1 in 98-00 data:

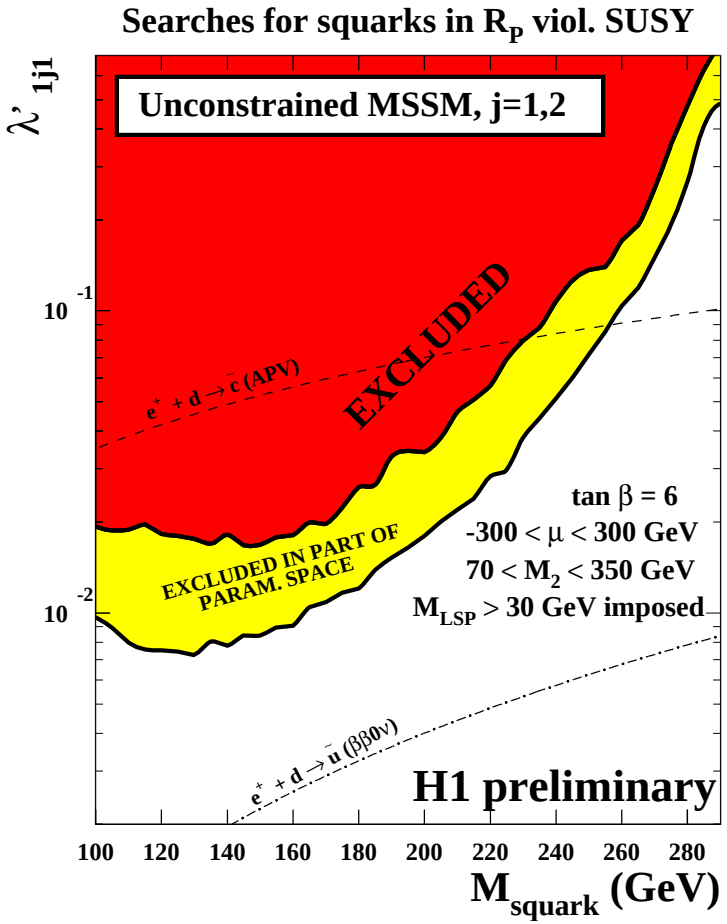
- e, ν + 1 jet (like LQ search)
- $e^{\pm}$ + multijets (also wrong-sign e)
- ν+multijets
- el+multijets
- νl+multijets

No evidence for deviation from SM

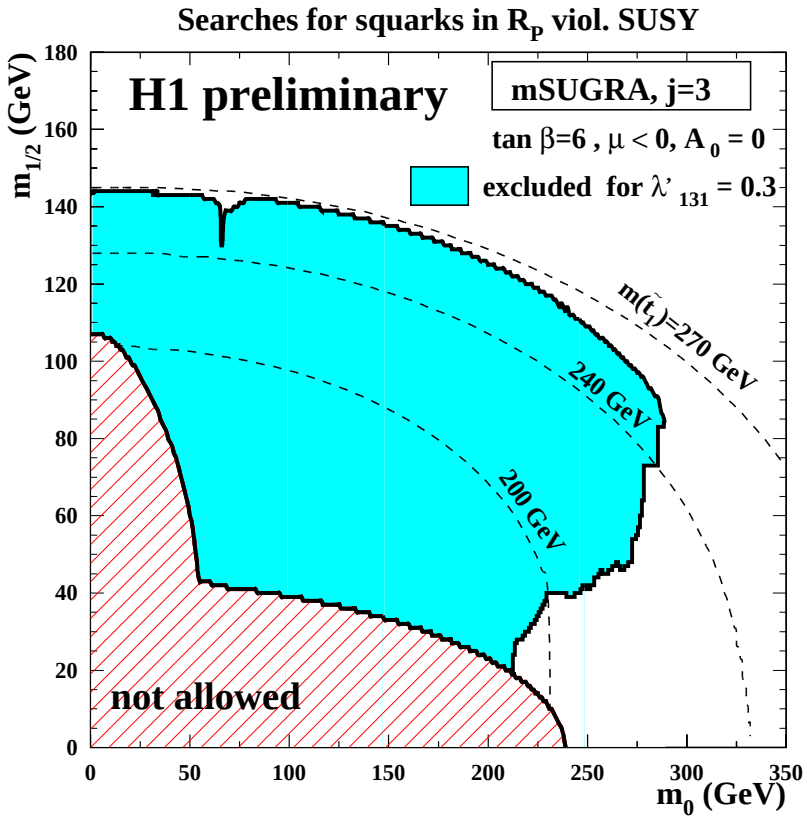




Search for R-parity violation SUSY (IV)



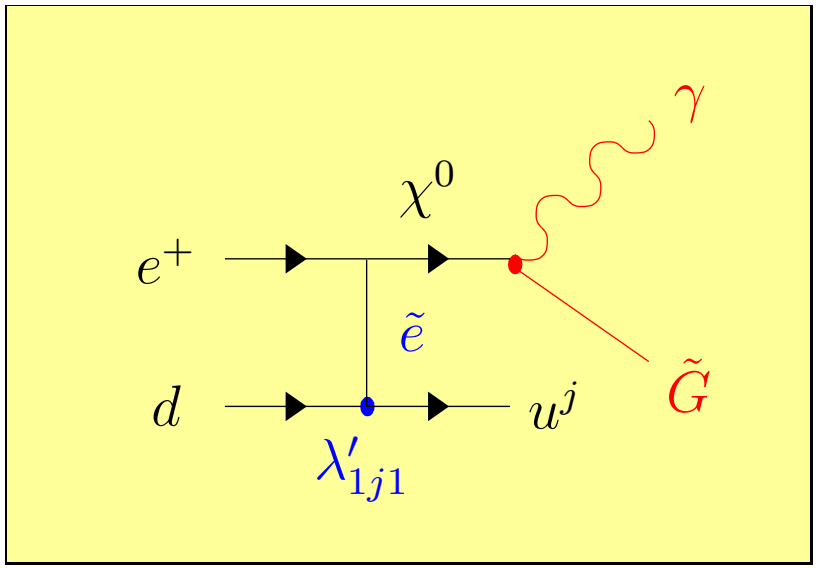
$\tilde{u}_L$,$\tilde{c}_L$ ruled out up to $\simeq$ 240 GeV for $\lambda' = 0.3$



$\tilde{t}_L$ ruled out up to $\simeq$ 270 GeV for $\lambda' = 0.3$

(Tevatron sensitivity Run I 130 GeV, Run II 250 GeV)

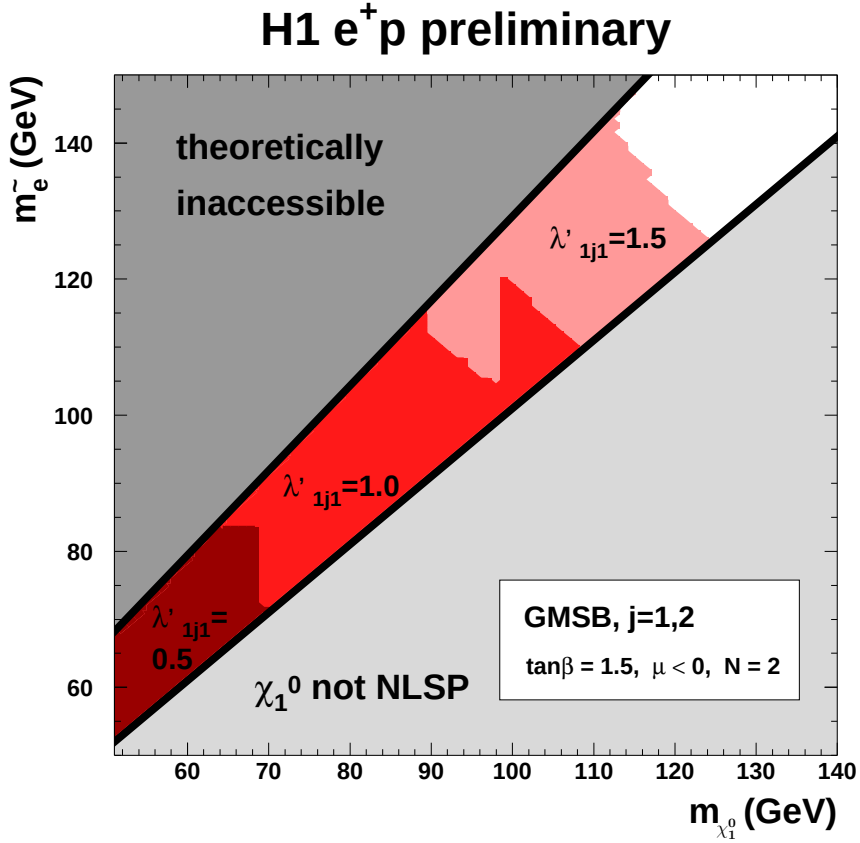
Search for Superlight Gravitinos at HERA



GMSB scenario: $\tilde{G}$ is LSP, χ^0 is NLSP, $m_{\tilde{q}} > m_{\tilde{e}}$

Signature: missing p_T ($> 25\ GeV$), isolated γ ($E_T > 15\ GeV$), 1 event found, 2.55 ± 1.30 expected

Tevatron Run I: 1 $ee\gamma\gamma + p_T$ event

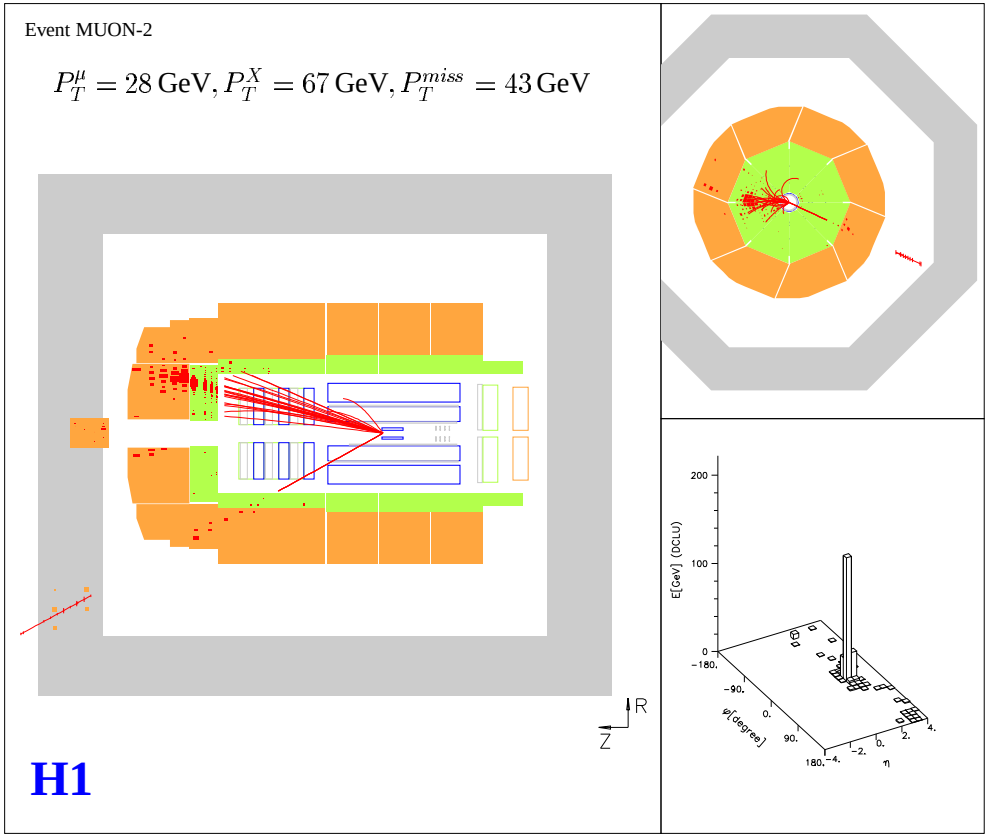


Limits independent of the squark mass

Typical LEP limits are $m_{\chi^0} >\simeq 90\ GeV, m_{\tilde{e}} >\simeq 90\ GeV$

Isolated lepton and missing p_T events at HERA

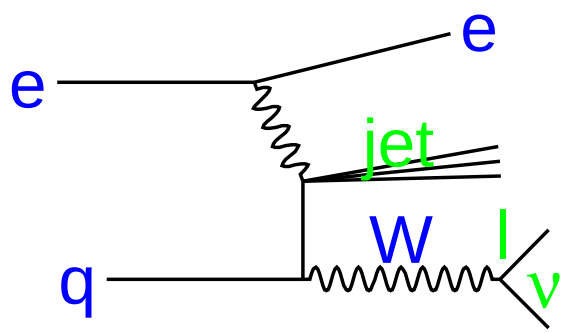
$e^+p \to \mu^+X$



1 isolated lepton (μ,e) ,

with high p_T, p_T^{miss}, jet (p_T^X)

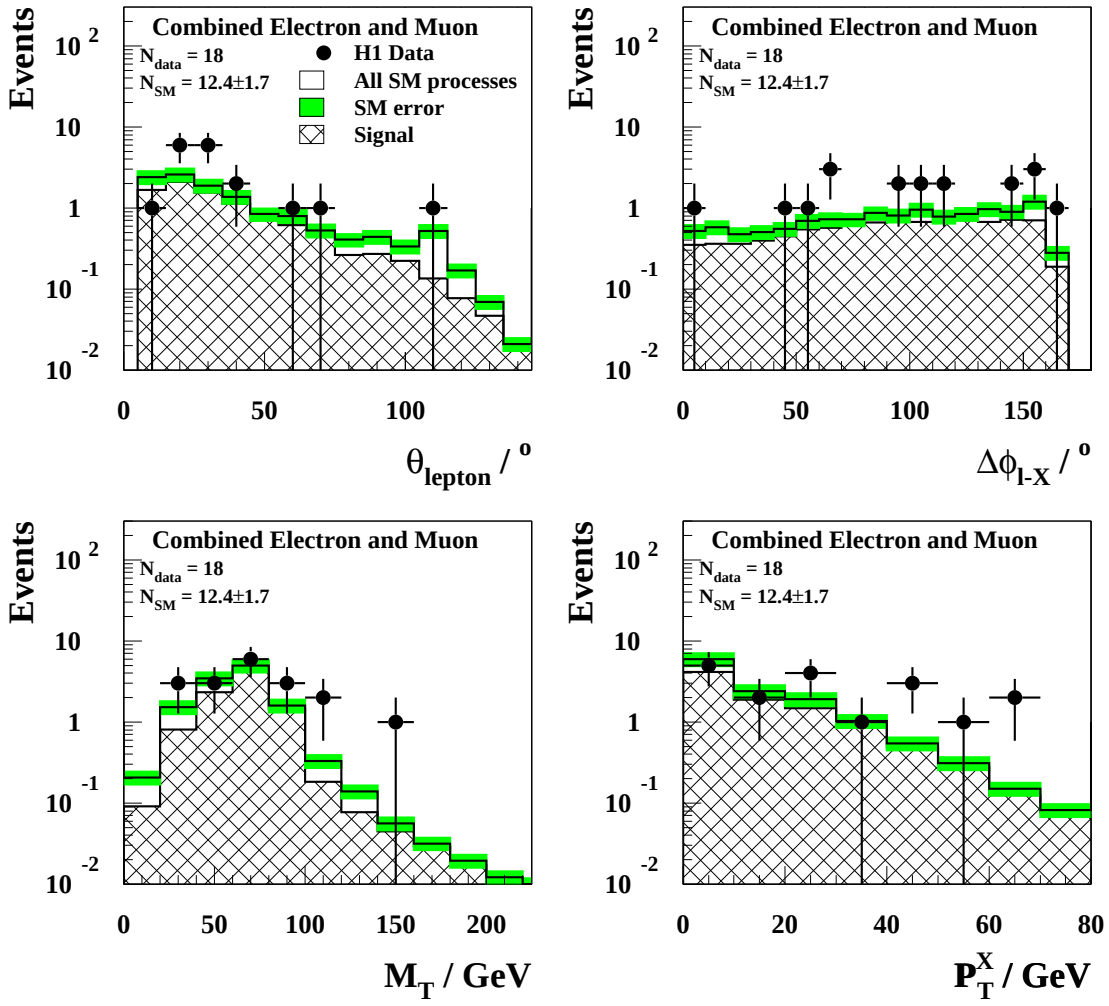
Main SM process:



Spectacular events found by H1 in e^+p data

Isolated lepton (II)

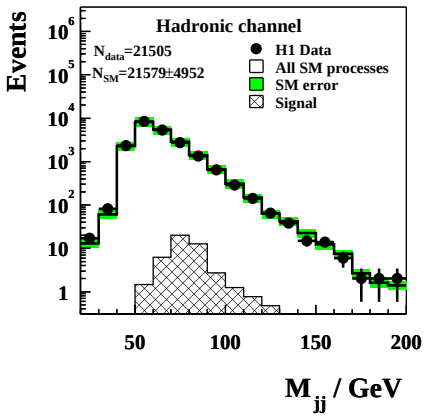
Cuts optimized for W production

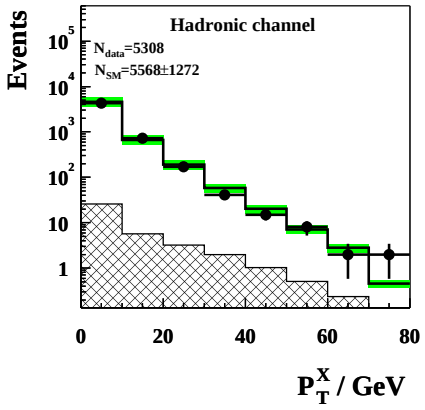


Isolated leptons (III)

H1e^+p $(e+\mu)$	Data	SM	W-only
$p_t^X < 12\ GeV$	5	6.40 ± 0.79	4.45 ± 0.70
$12 < p_t^X < 25\ GeV$	3	3.08 ± 0.43	2.40 ± 0.40
$25 < p_t^X < 40\ GeV$	4	1.83 ± 0.27	1.59 ± 0.26
$p_t^X > 40\ GeV$	6	1.08 ± 0.22	0.96 ± 0.22

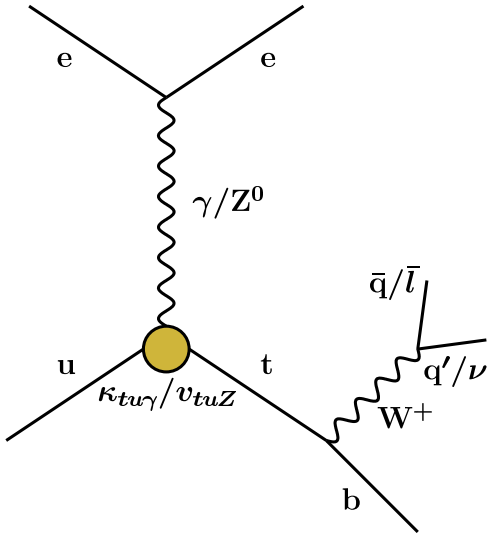
- H1 e^-p data (14 pb^{-1}): 1 e-event (1.69 ± 0.22 dallo SM), 0-μ
- No deviation observed in the hadronic W-production





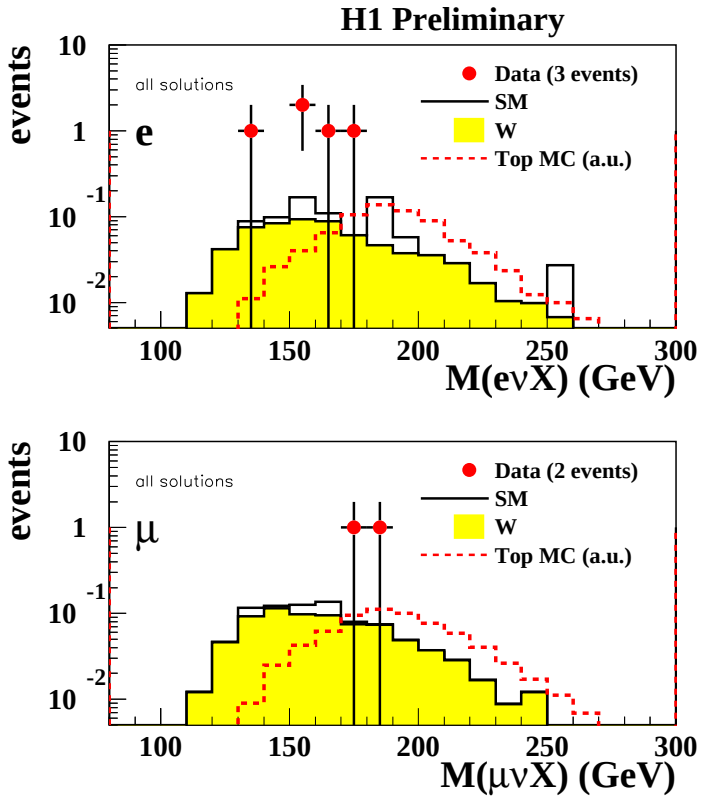
Isolated leptons (IV)

Excess in e^+p collisions, at high p_T^X, is that new physics?:



single-top production with anomalous $k_{tu\gamma}, v_{tuZ}$ FCNC coupling (SM cross-section $1\,fb^{-1}$)

After top-selection cuts: 5 events (3e,2μ) survive (1.77 ± 0.46 expected):



Isolated leptons (V)

ZEUS $e^{\pm}p$ data (130 pb^{-1}) :

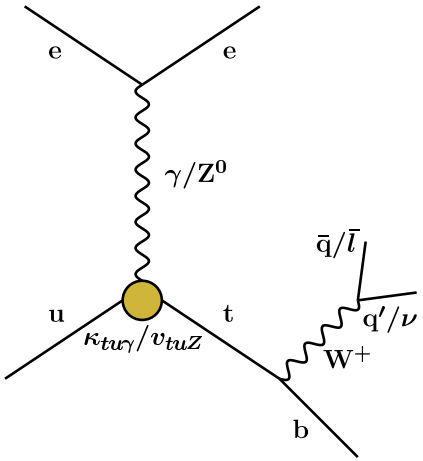
ZEUS	**Electrons** obs./ exp. (W)	**Muons** obs./exp. (W)
Total	$24/20.6^{+1.7}_{-4.6}$ (17%)	$12/11.9^{+0.6}_{-0.7}$ (16%)
$p_T^X > 25\ GeV$	$2/2.90^{+0.59}_{-0.32}$ (45%)	$5/2.75^{+0.21}_{-0.21}$ (50%)
$p_T^X > 40\ GeV$	$0/0.94^{+0.11}_{-0.10}$ (61%)	$0/0.95^{+0.14}_{-0.10}$ (61%)

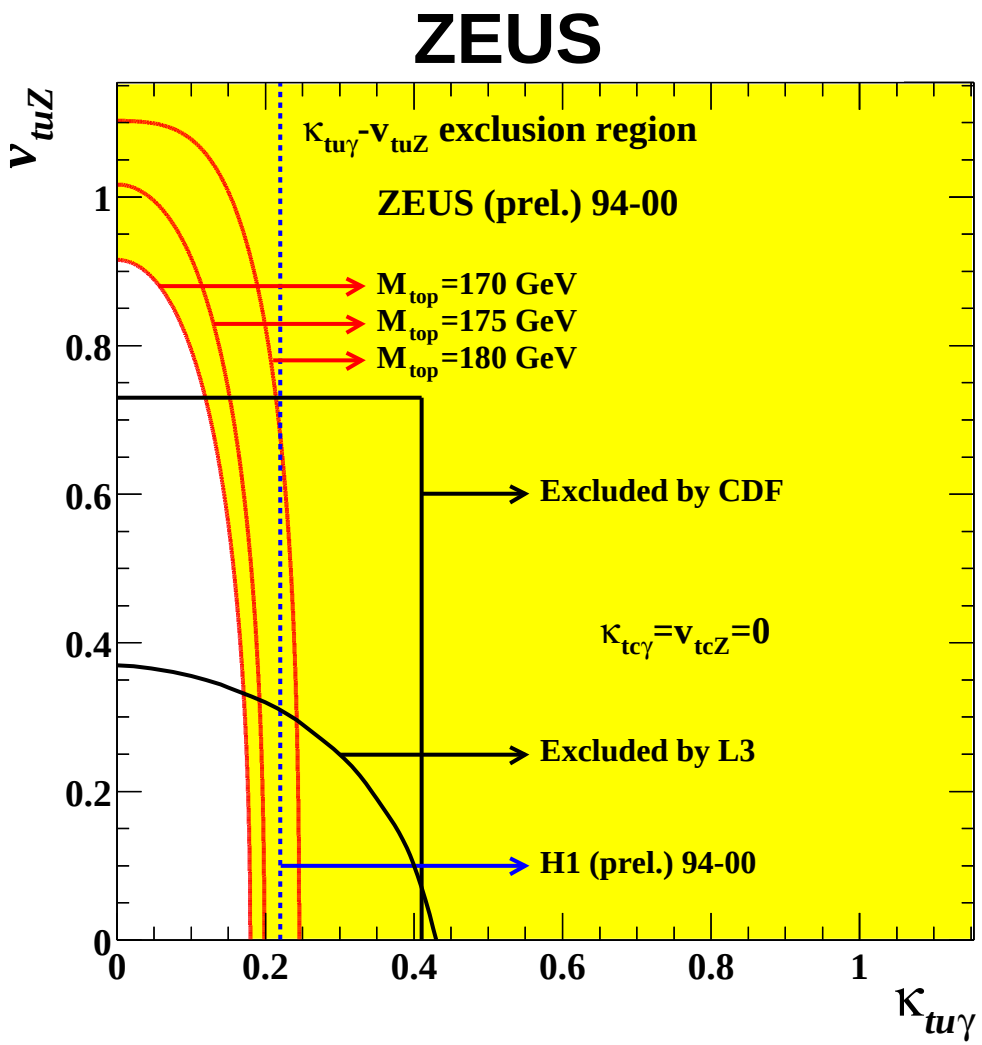
Good agreement seen with the SM

No deviation observed in the W-hadronic channel

Isolated leptons VI

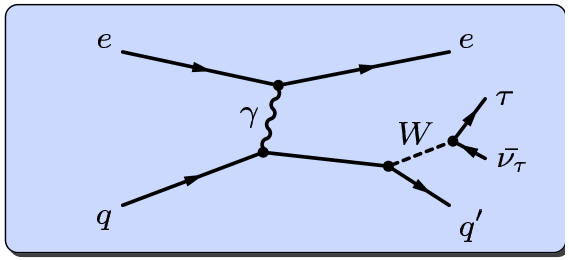
- Limit calculated in NLO for γ-exchange, in LO for γ/Z-exchange
- Zeus effi ciency evaluated also for the Z-exchange
- H1 limit weaker due to the observed excess
- Lagrangian convention differ by $\sqrt{2}$ compared to LEP, consider only u-contribution for LEP

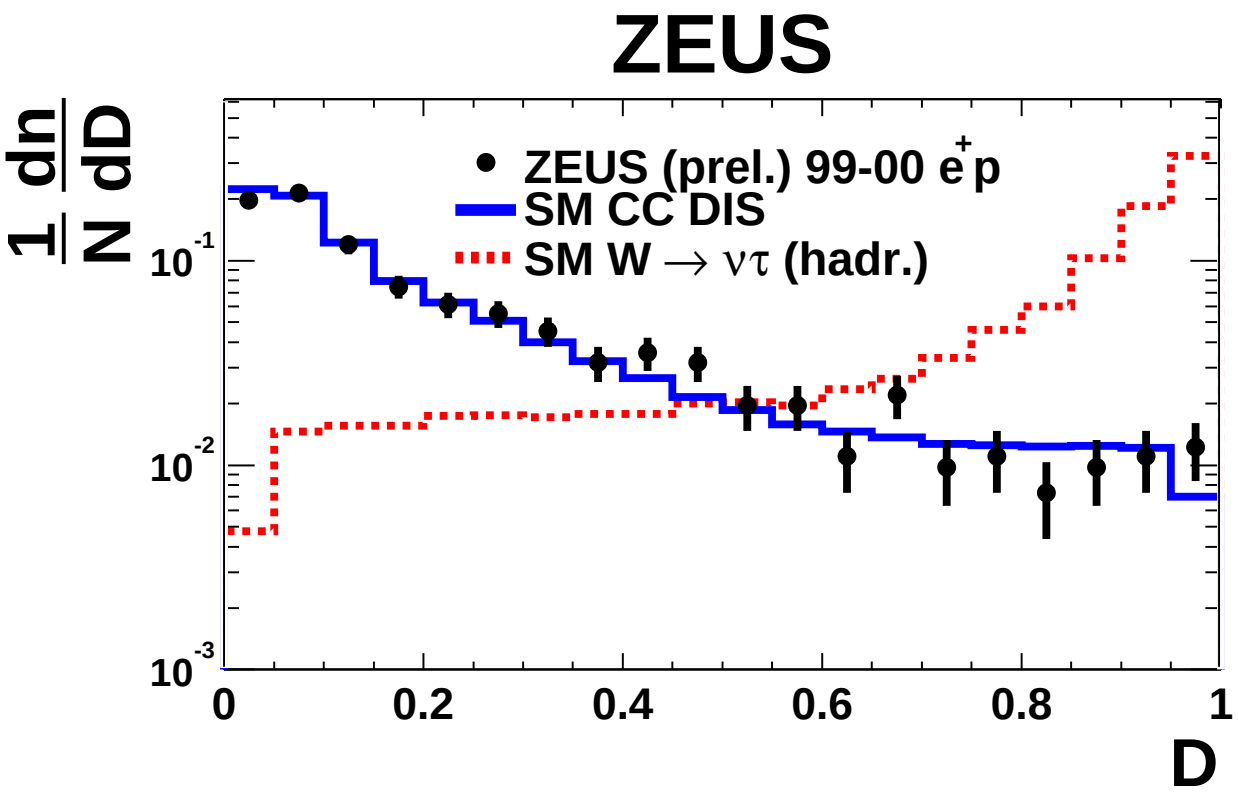




Isolated τ in ZEUS

Previous search extended to the τ (hadronic decay), using the τ-discriminant D





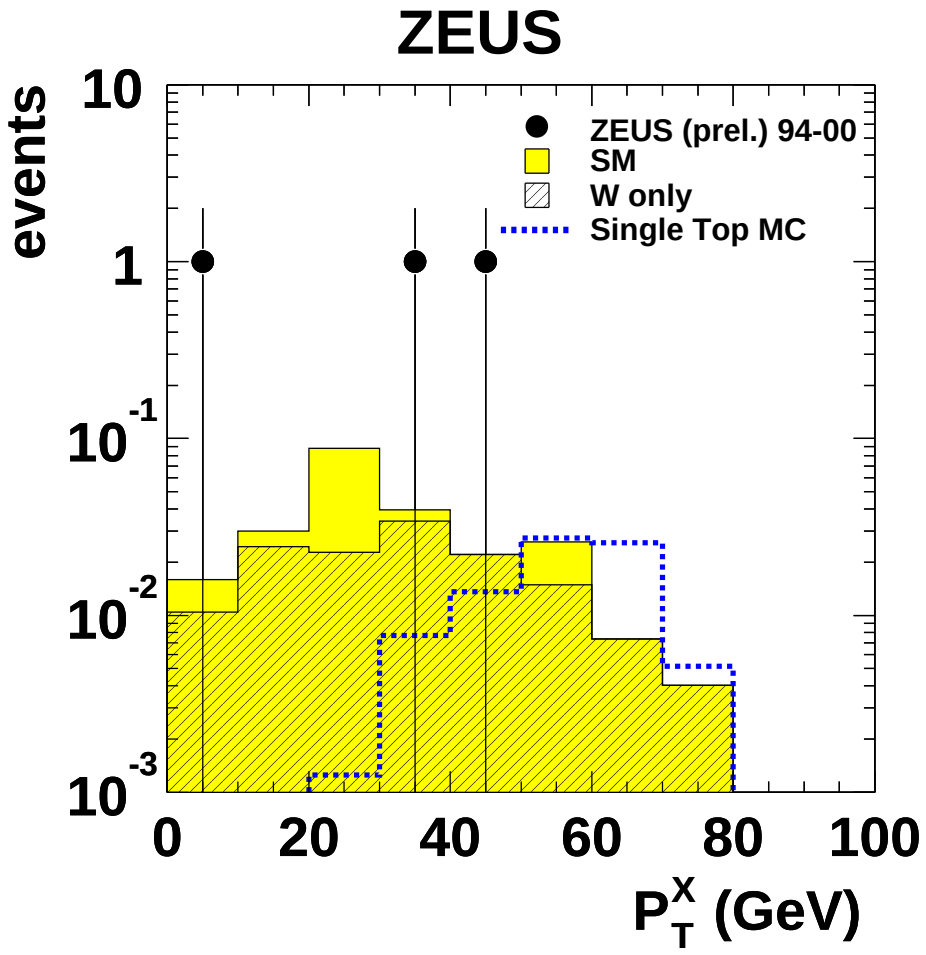
$D \to 0$, CC DIS-jets $D \to 1$, $W \to \nu\tau$-jets

Isolated τ in ZEUS (II)

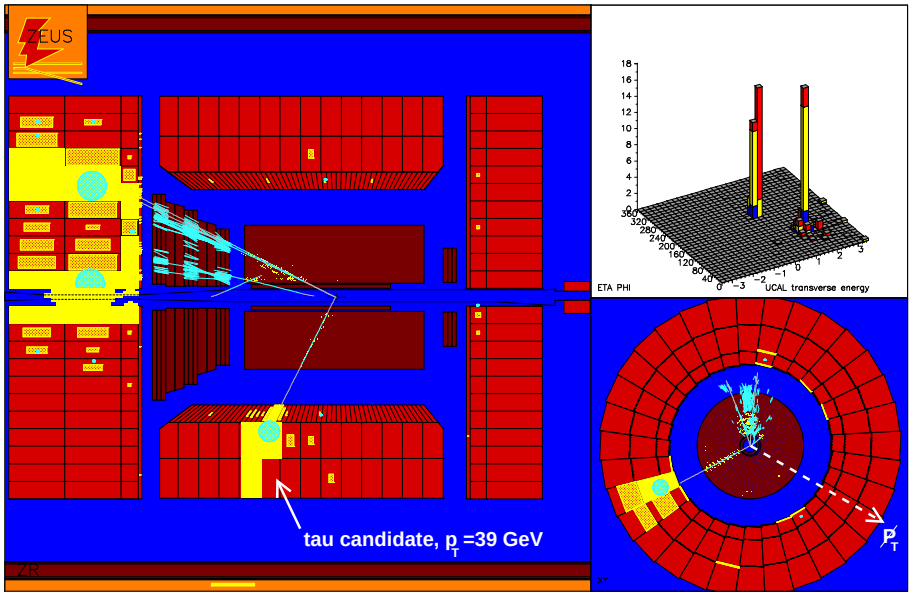
- Standard isolated track + missing p_T selection
- exclude tracks which are either e or μ
- to remaining tracks apply $D > 0.95$

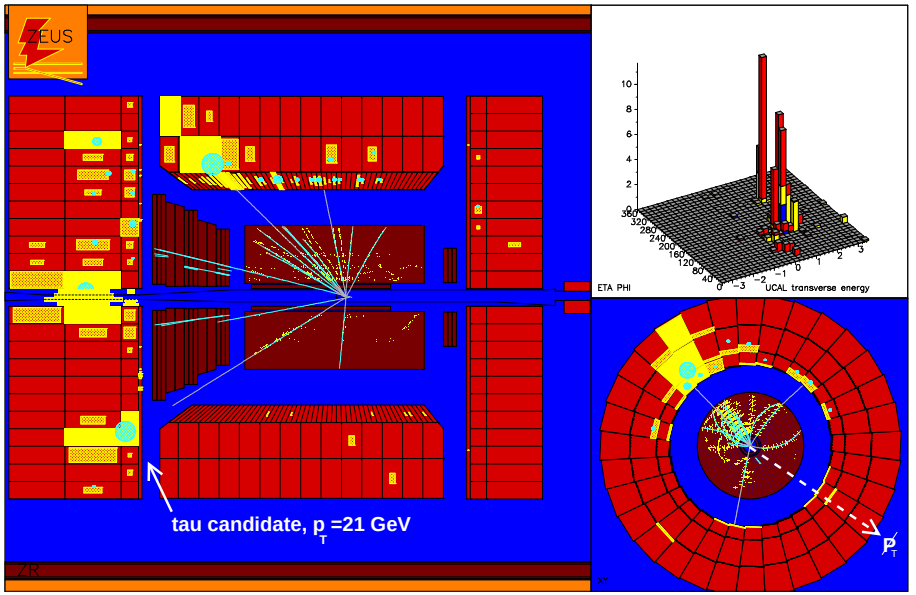
  3 events observed/0.23 ± 0.06 expected
- $p_T^X > 25\ GeV$

  2 events observed/0.12 ± 0.02 expected (Poisson prob=6.4×10^{-3})



Isolated τ in ZEUS (III)





e^+p 1999 data

$p_T^{miss} = 39\ GeV$

$p_T^X = 37\ GeV$

$p_{\tau-jet} = 39\ GeV$

$M_T = 68\ GeV$

e^+p 1999 data

$p_T^{miss} = 37\ GeV$

$p_T^X = 48\ GeV$

$p_{\tau-jet} = 21\ GeV$

$M_T = 32\ GeV$

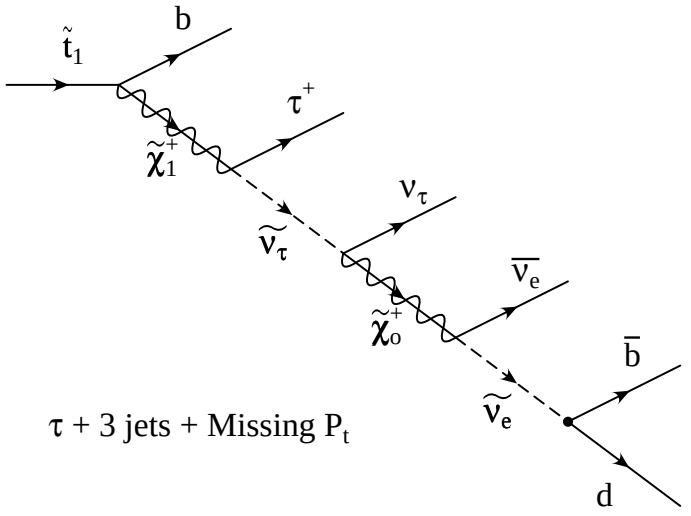
Summary on isolated leptons at HERA I

H1 94-00 e^+p (101.6 pb^{-1})	**Electron** obs./exp.	**Muon** obs./exp.
$p_T^X > 25$ GeV	4 / 1.49	6 / 1.44
$p_T^X > 40$ GeV	3 / 0.54 $\pm$ 0.11	3 / 0.55 $\pm$ 0.12

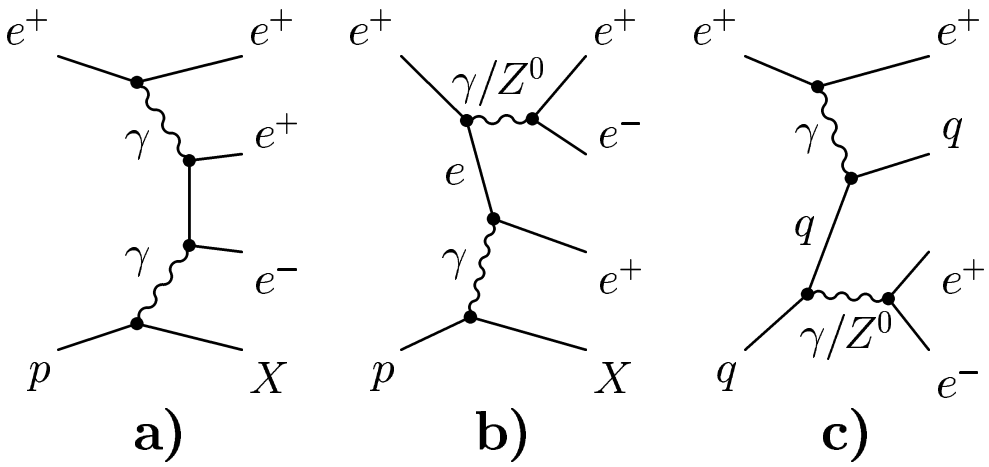
ZEUS preliminary 94-00 $e^\pm$p (130.5 pb^{-1})	**Electron** obs./exp.	**Muon** obs./exp.	**Tau** obs./exp. (W)
$p_T^X > 25$ GeV	2 / 2.90	5 / 2.75	2 / 0.12 $\pm$ 0.02
$p_T^X > 40$ GeV	0 / 0.94	0 / 0.95	1 / 0.06 $\pm$ 0.01

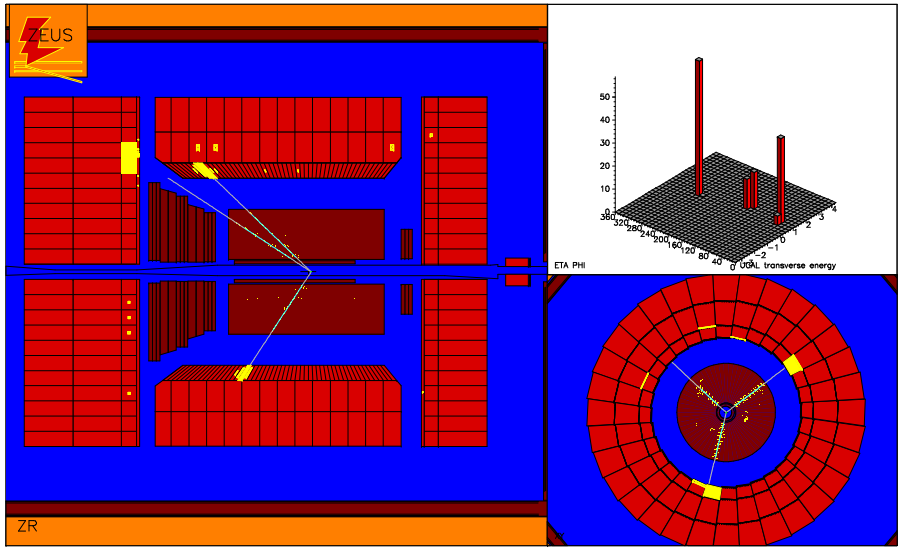
These 2 τ-events are unlikely to be explained by single-top anomalous production, as their cross-section is higher than the excluded cross section of $\sigma(ep \rightarrow etX) < 0.225\ pb(\sqrt{s} = 320\ GeV)$, obtained from the $e/\mu/jet$-channels.

A crazy diagram without a W-decay:



Multi-electron events

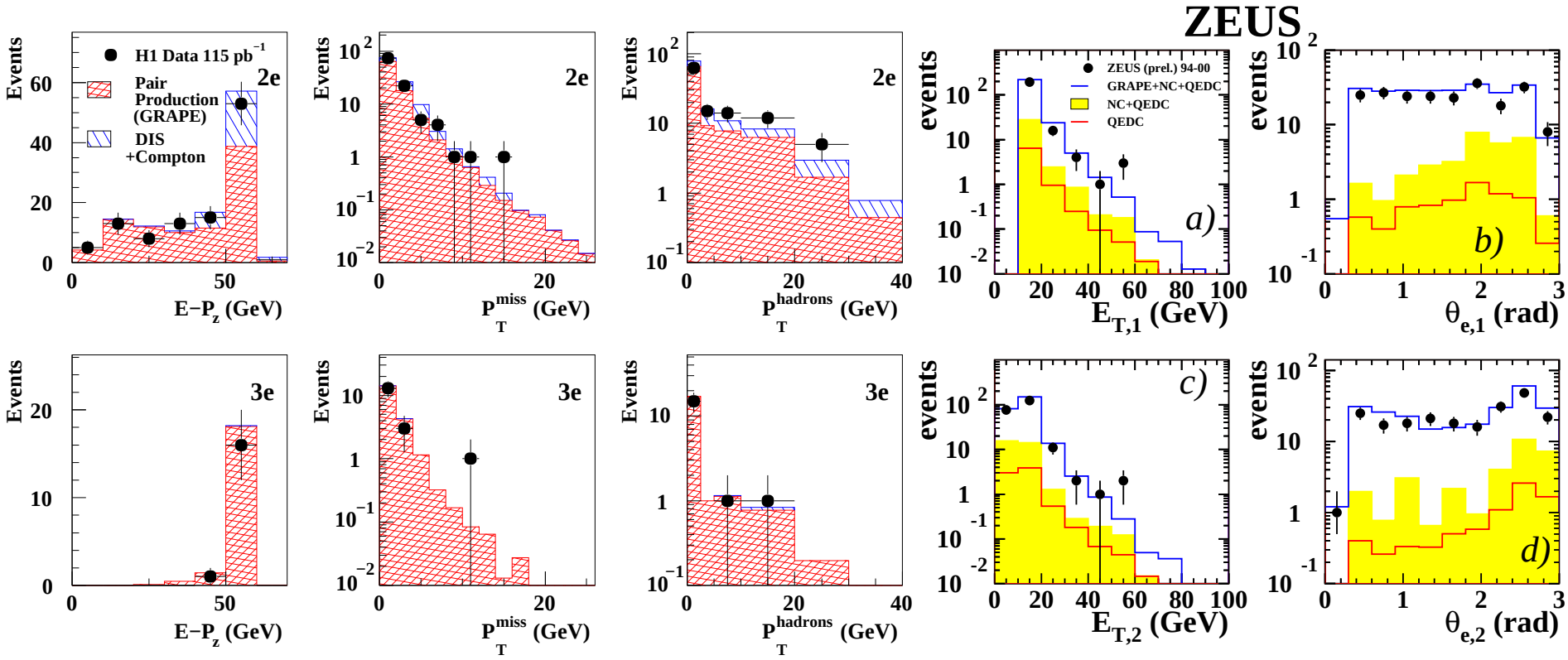




2 central isolated electrons $p_T > 5\ GeV$, at least one with $p_T > 10\ GeV$
($20° < \theta_e < 150°$ H1, $17° < \theta_e < 164°$ ZEUS)

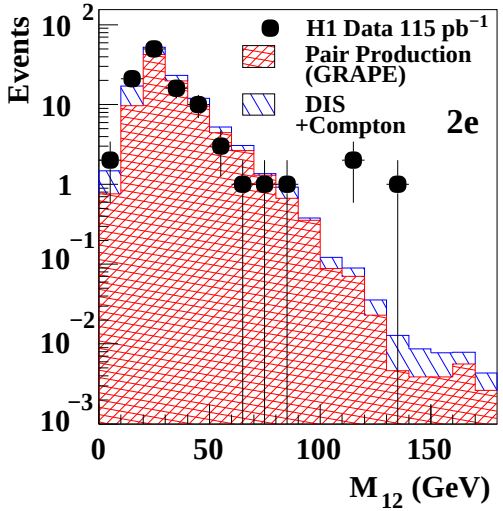
3rd electron in $5° < \theta_e < 175°$ ($E_e > 5\ GeV$ rear, $E_e > 10\ GeV$ forward)

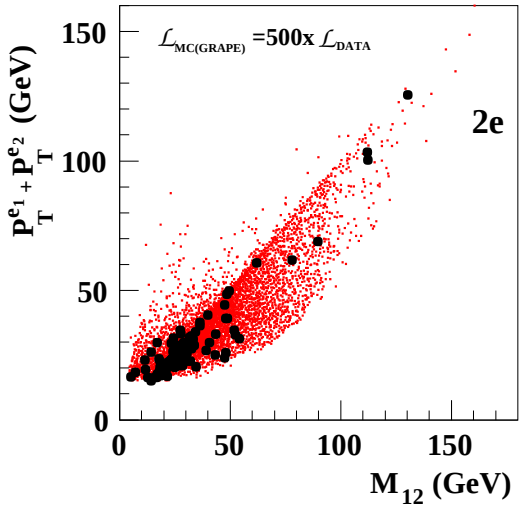
Multi-electron events (II)

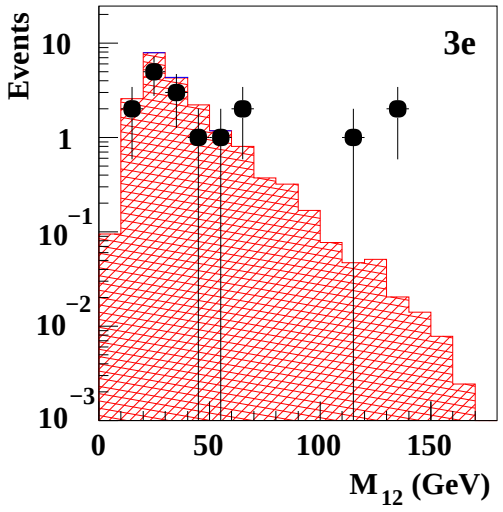


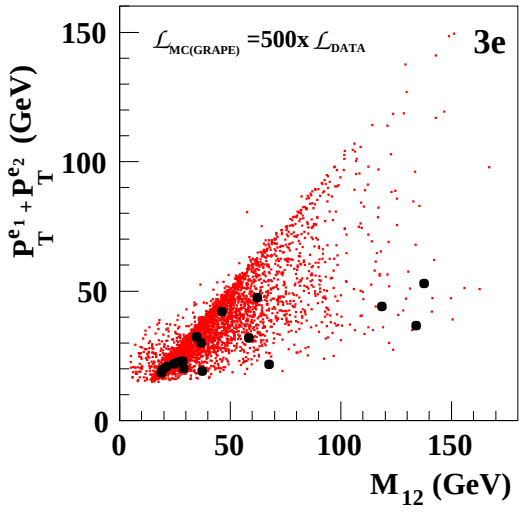
≃ 100 – 200 events selected, in general good agreement with the SM

Multi-electron events (III)









H1 Total

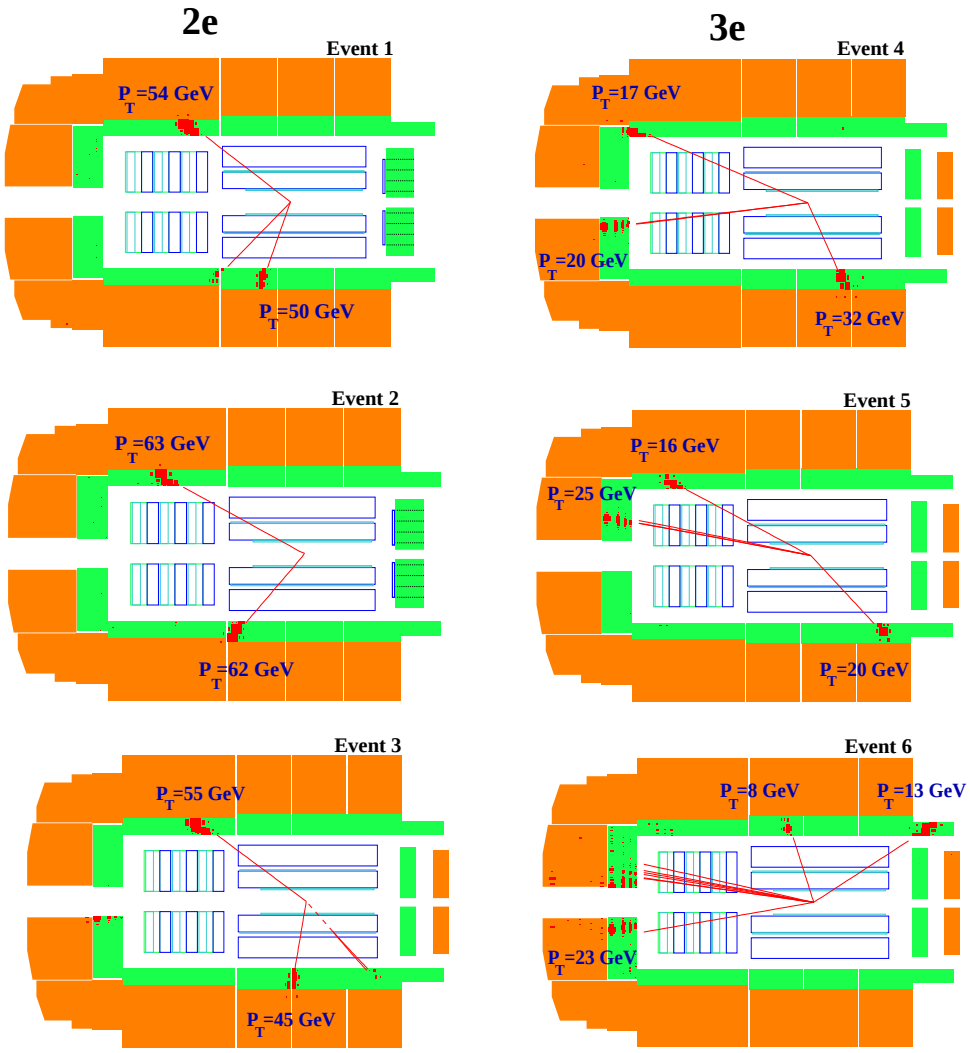
Sample	Data	SM
2 e total	108	117.1 ± 8.6
3 e total	17	20.3 ± 2.1

H1 $M_{12} > 100\ GeV$

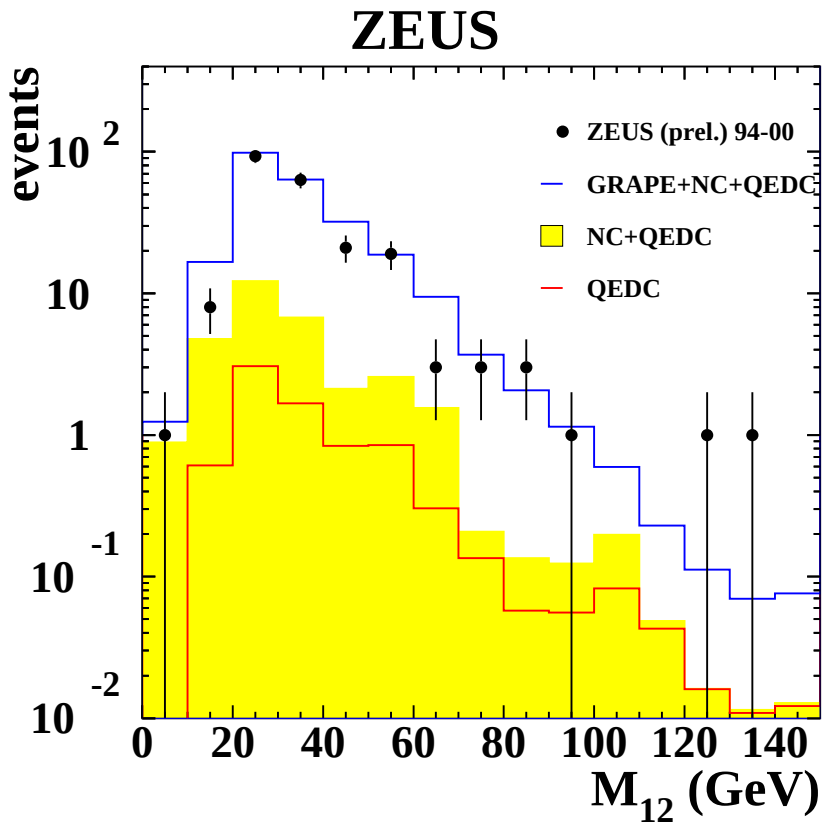
Sample	Data	SM
2 e	3	0.30 ± 0.04
3 e	3	0.23 ± 0.04

6 outstanding events at $M_{12} > 100\ GeV$

Multi-electron events (IV)



Multi-electron events (V)



ZEUS Total

Sample	Data	SM
2 e total	191	213.9 ± 3.9
3 e total	26	34.7 ± 0.5

ZEUS $M_{12} > 100\ GeV$

Sample	Data	SM
2 e	2	0.77 ± 0.08
3 e	0	0.37 ± 0.04

Good agreement with the SM prediction

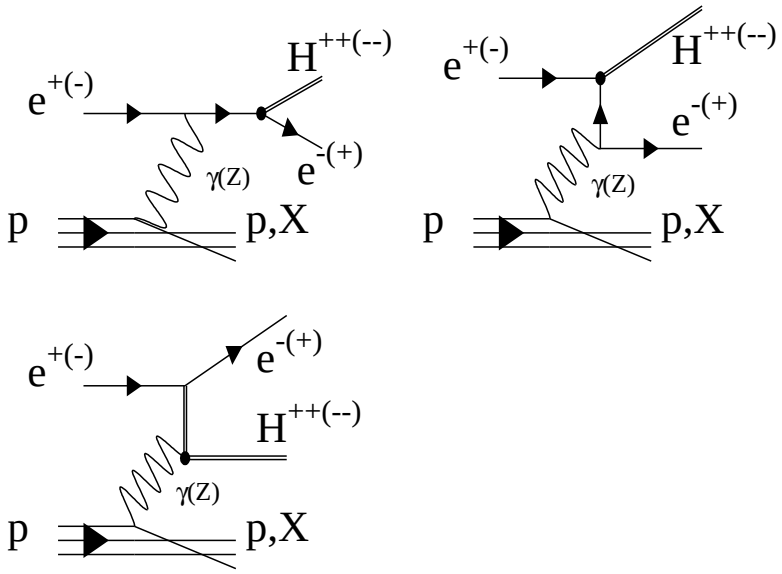
No dimuon event with $M_{12} > 100\ GeV$ observed by H1 and ZEUS

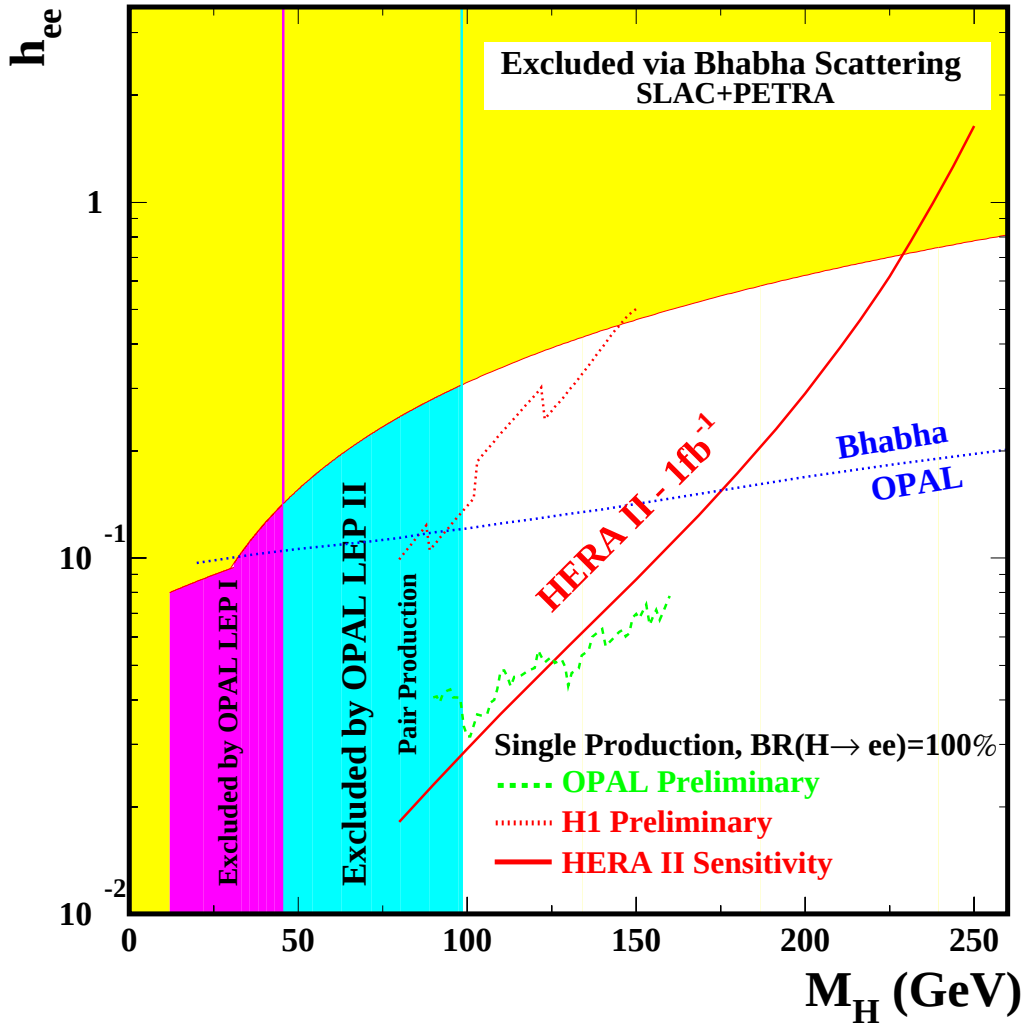
Multi-electron events (VI)

Possible BSM interpretation:

$e^+p \rightarrow e^- H^{++} X, H^{++} \rightarrow l^+l^+$

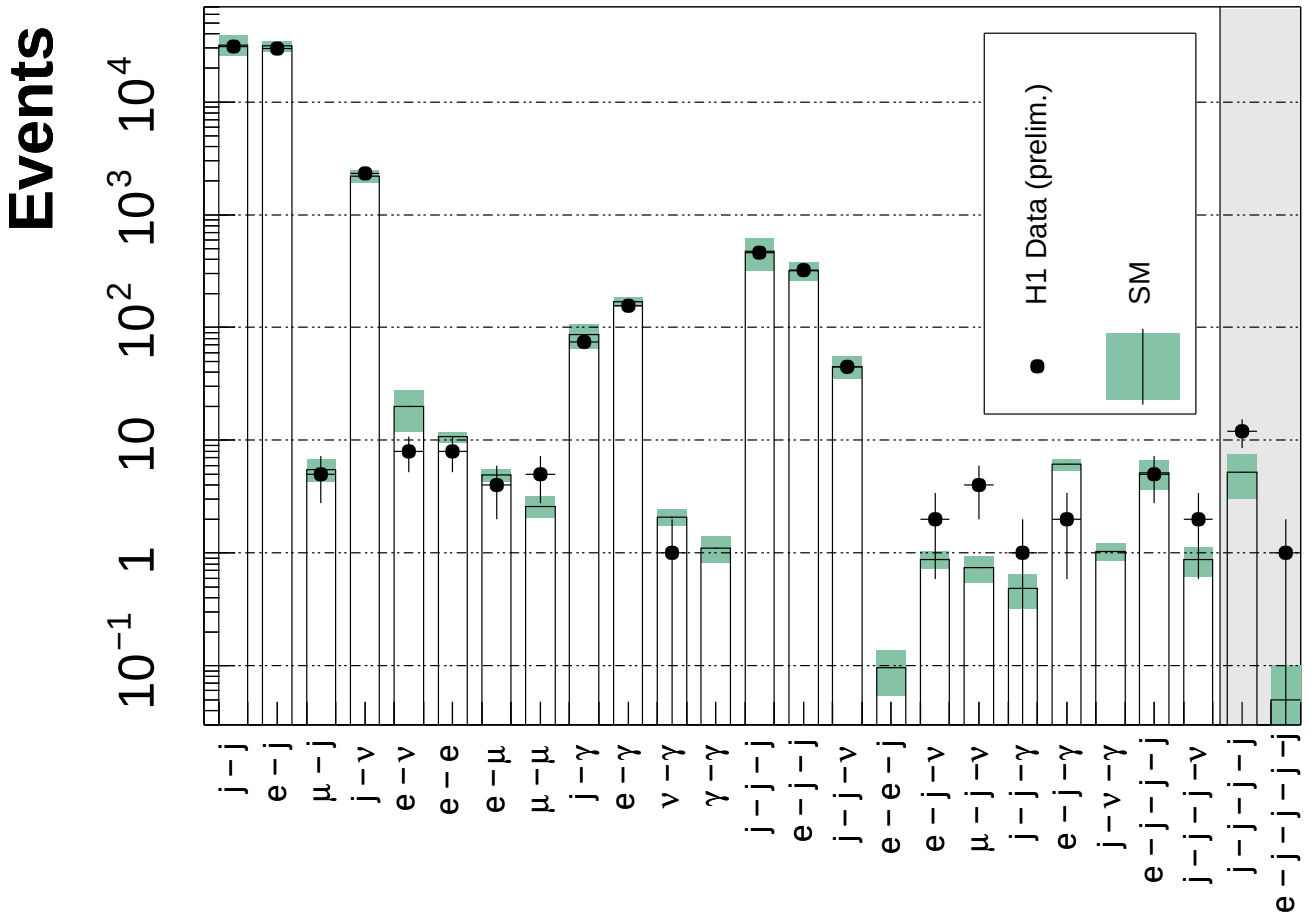
dedicated search by H1: large ($p_t^{e1} + p_t^{e2}$), same-charge leptons, 1 event passes the cuts

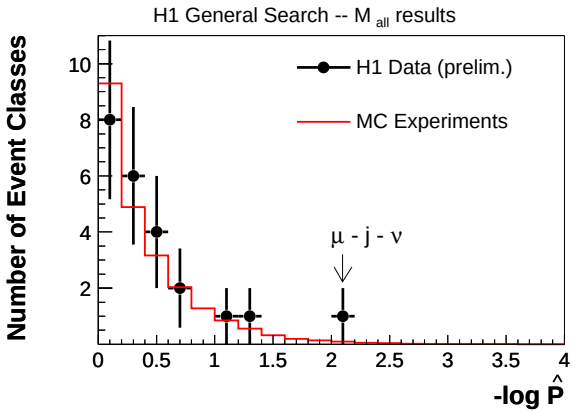


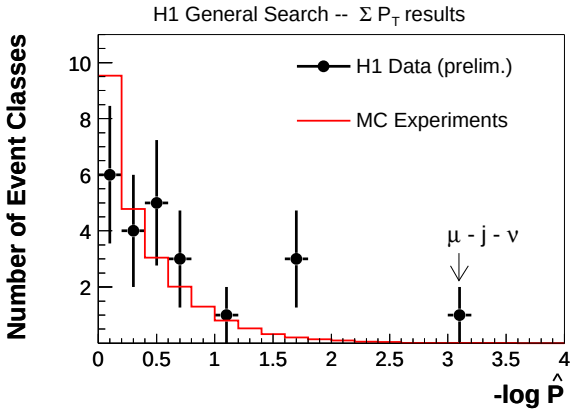


Anything else?

Very nice general search done by H1:







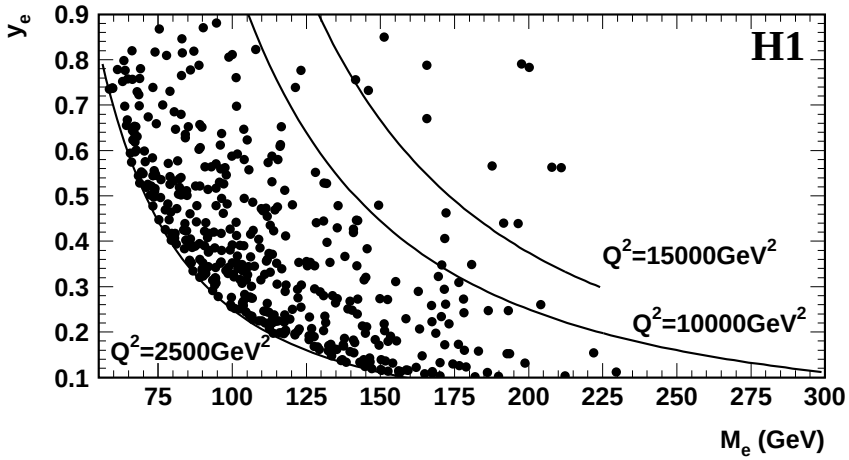
Largest deviation found in $\mu - j - \nu$

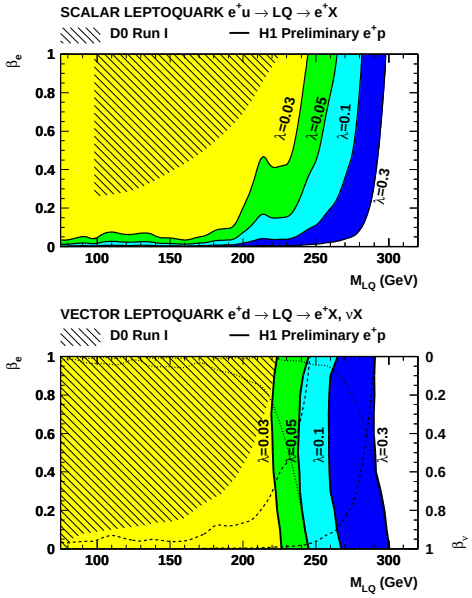
What to do at HERA II

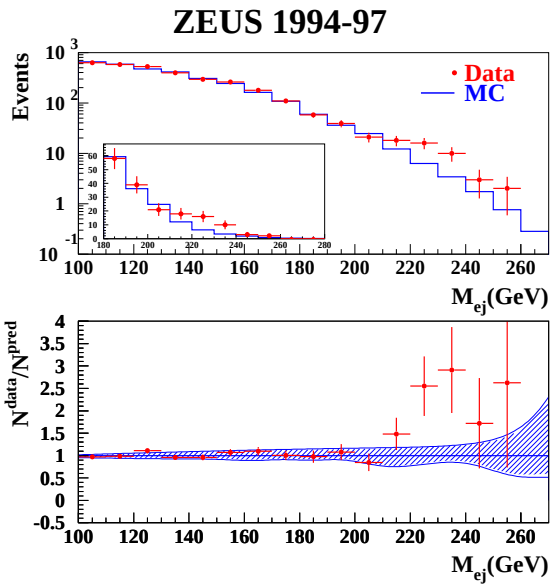
- Competition with Tevatron Run II diffi cult, already very strong limits set on leptoquarks, excited electrons,.., need to concentrate on few key channels
- Remaining puzzles from HERA I (isolated leptons, dilepton events), also and especially in $e^- p$ (only $\simeq 16\ pb^{-1}$ up to now), it will be exciting to look into that
- some examples in the next pages of what we still can do

What to do at HERA II:Leptoquarks

A *must* at HERA:

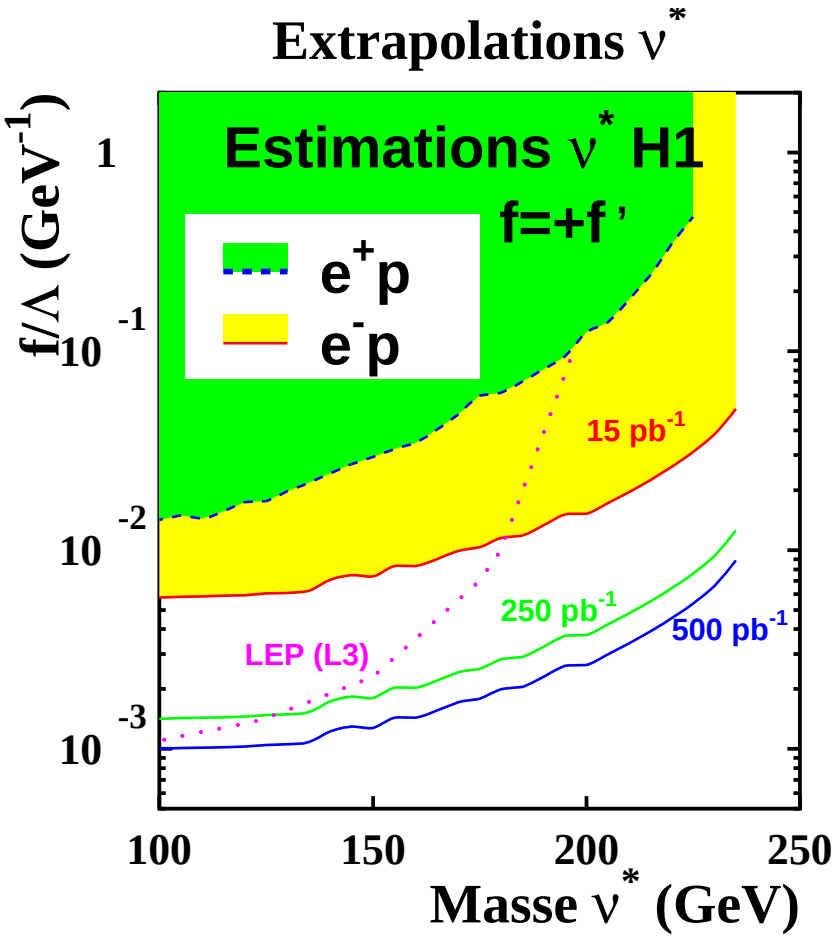


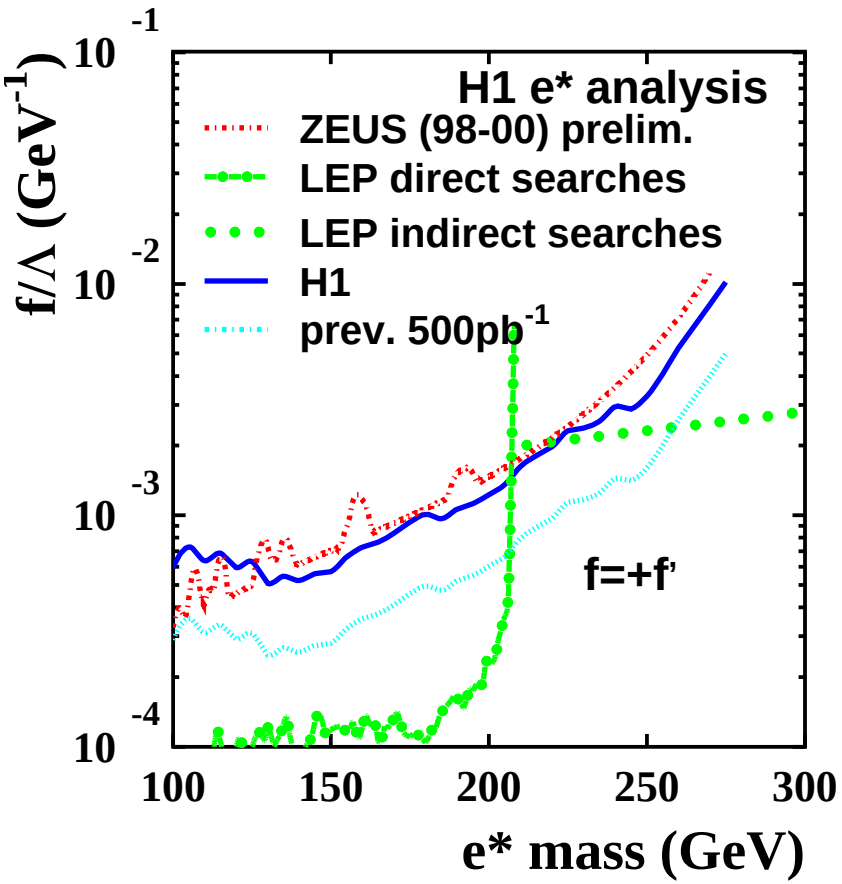




Still very competitive for small branching ratios to eq, important to look in other channels like νq or LFV

What to do at HERA II:Excited fermions

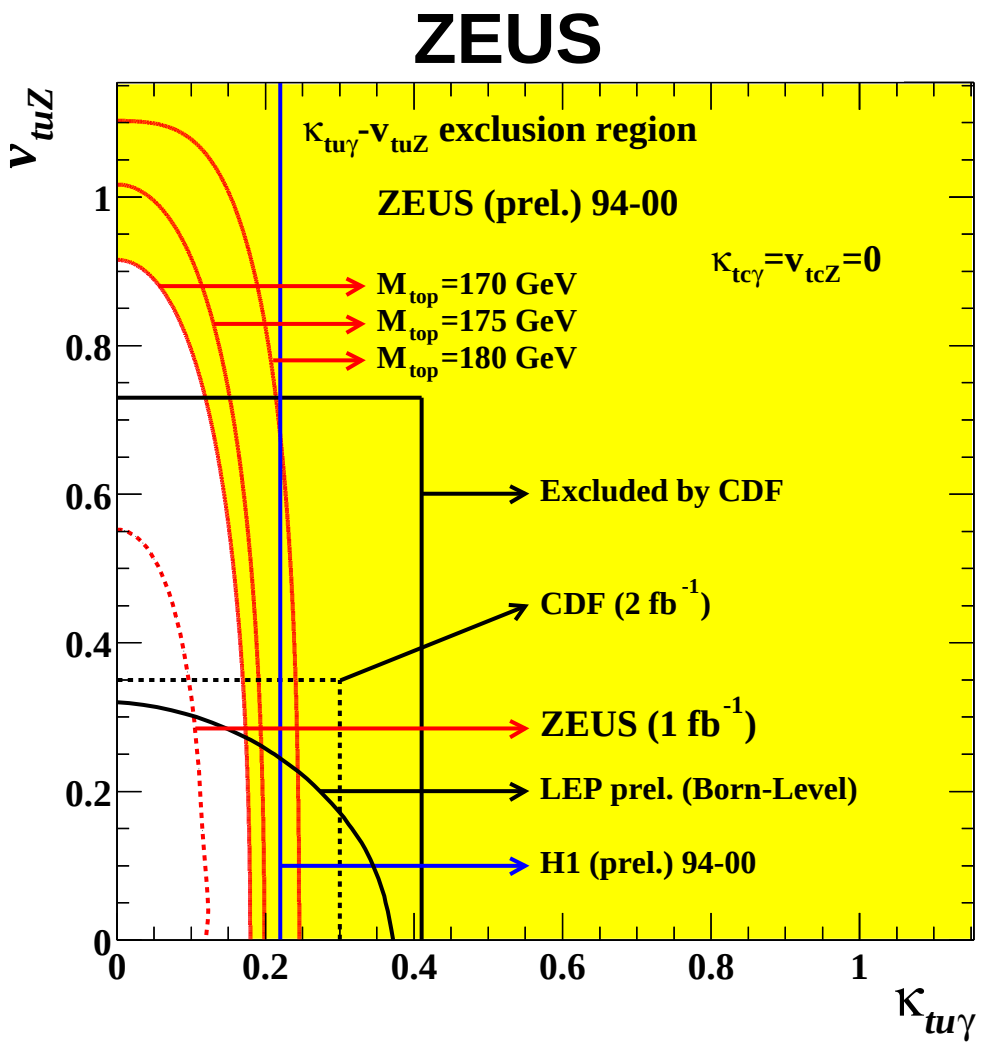




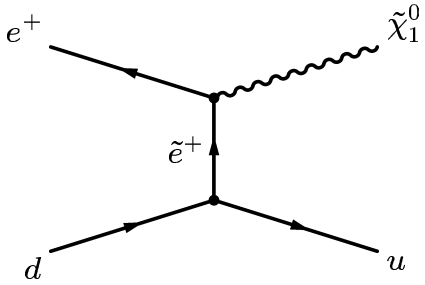
What to do at HERA II:FCNC

Hope to see still deviations from the expectation, but in case

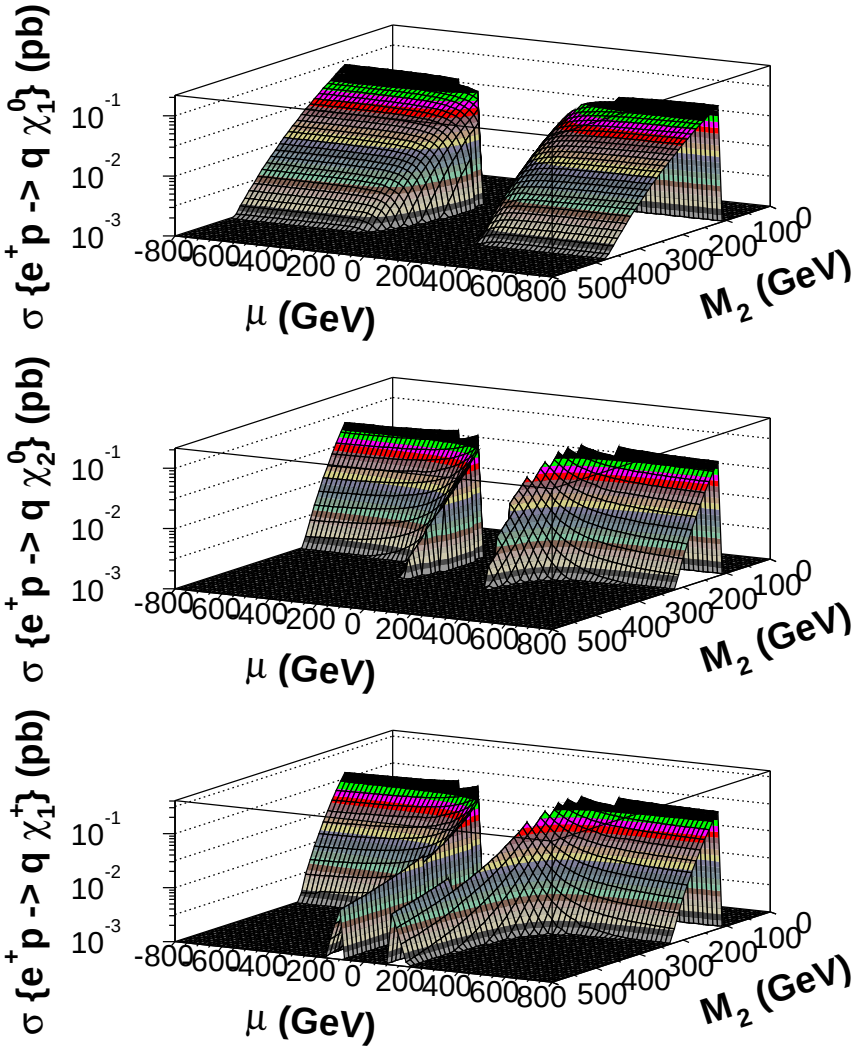
very competitive limits for HERA II



What to do at HERA II:slepton



Cross-section ($\lambda' = 1$ in plots) depends strongly on μ, M_2, but could be $\simeq pb^{-1}$. Signature: wrong sign-electron



Summary

- Both experiments published or are publishing the classic searches (lepto-quarks,contact interactions,...) on all HERA I data.
- Isolated leptons search also finalized by HERA I: excess in e, μ channels from H1, τ channel from ZEUS, results are not easy to explain together, need more statistics.
- Dielectron excess at $M_{12} > 100\ GeV$ observed by H1, not confirmed by ZEUS.
- Still a lot to do in the SUSY R_p searches
- HERA II: $5\times$ more luminosity, better forward tracking, $b-$tagging will help in clarifying last remaining puzzles; competition with Tevatron difficult
- Need a team to combine H1+ZEUS limits and present HERA to the outside world (see LEP experience): manpower and a lot of effort is required though, but not impossible.