Searches for New Physics at HERA

Nick Malden
Manchester University

for the H1 and ZEUS Collaborations

THE UNIVERSITY of MANCHESTER

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What's the talk about?

Introduction to HERA & Looking for New Physics at HERA

Leptoquarks

Contact Interactions & Large Extra Dimensions

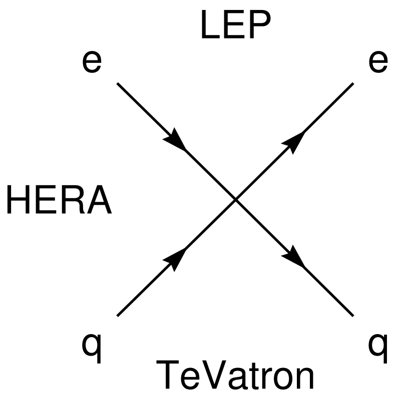
R_P violating SUSY

Excited fermions & Multi-electron production

Isolated Leptons and Missing P_T & Single Top

Conclusions and Outlook

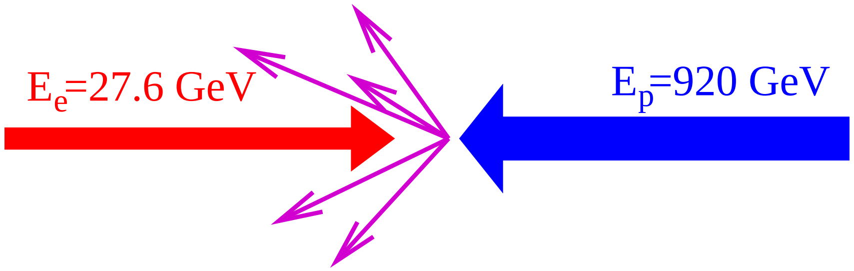
Introduction to HERA

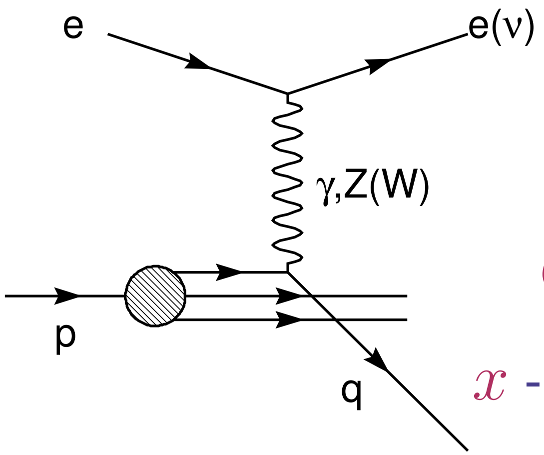


HERA ep collider can uniquely look for

new physics in eq interactions

CoM Energy $\sqrt{s}$= 320 GeV





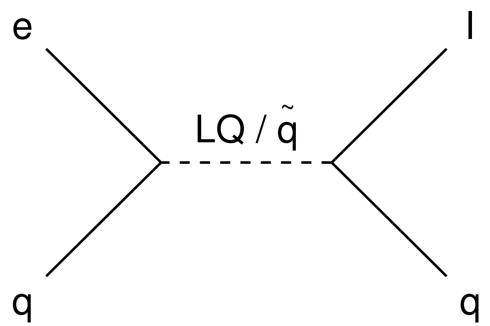
DIS Kinematics:

Q^2 - the four momentum transfer of the $\gamma/Z^o/W^\pm$

x - the struck quark's fraction of the proton's momentum

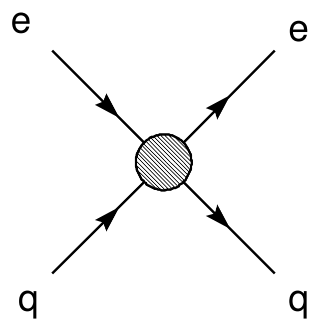
y - the inelasticity $\longrightarrow$ polar angle of scattered lepton

New Physics at HERA



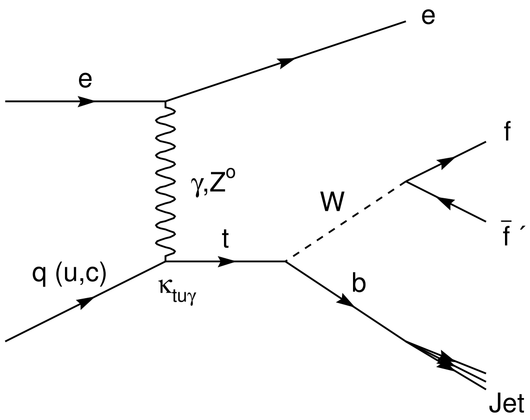
eq resonances – brief fusion of e and q to form

Leptoquark or R_p-violating squark



Contact interactions – generic coupling model to

probe scales (masses and dimensions) beyond COM



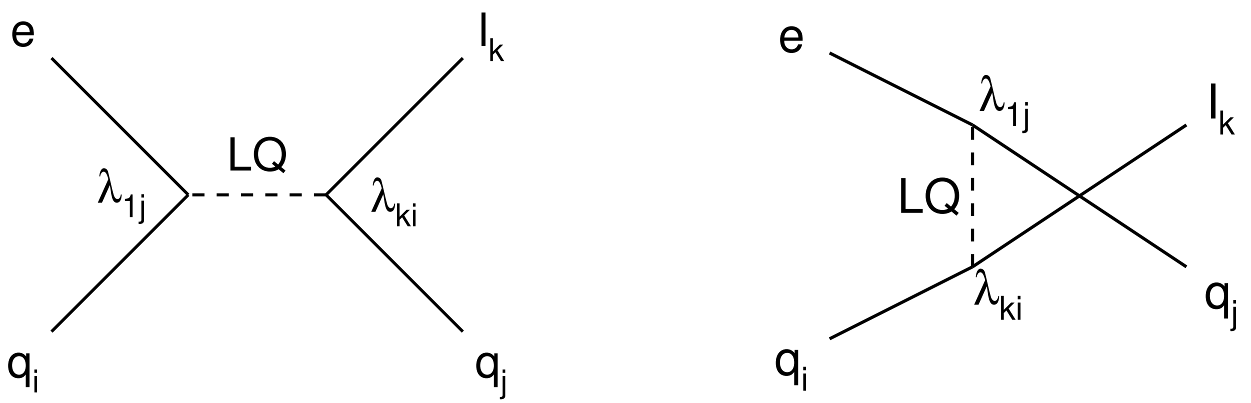
Exclusive final states – rare topologies

– exotic particles or decay modes

e.g. FCNC single top

Leptoquarks

- Quarks and Leptons are both point-like fermions – Clear symmetry between the families (3 x 2) – proton and electron carry same electric charge (to 1 part in 10^{21})
- Is there a higher symmetry? $\longrightarrow$ Leptoquarks (LQs) with B and $L \neq 0$



s channel $\qquad$ u channel

- LQs are part of many GUTs which appeal to higher symmetries – SU(5) or SU(15)
- Buchmüller-Rückl-Wyler (BRW) model predicts 14 LQs (7 scalar & 7 Vector) – $F = 0$ for $e^+ + q$ & $F = 2$ for $e^- + q$
- Yukawa coupling λ_{ij}. BRs fixed – β_{eq}=$1,\frac{1}{2}$ and $\beta_{\nu q}$=$0,\frac{1}{2}$

Leptoquarks – Resonance search

Separate from DIS data:

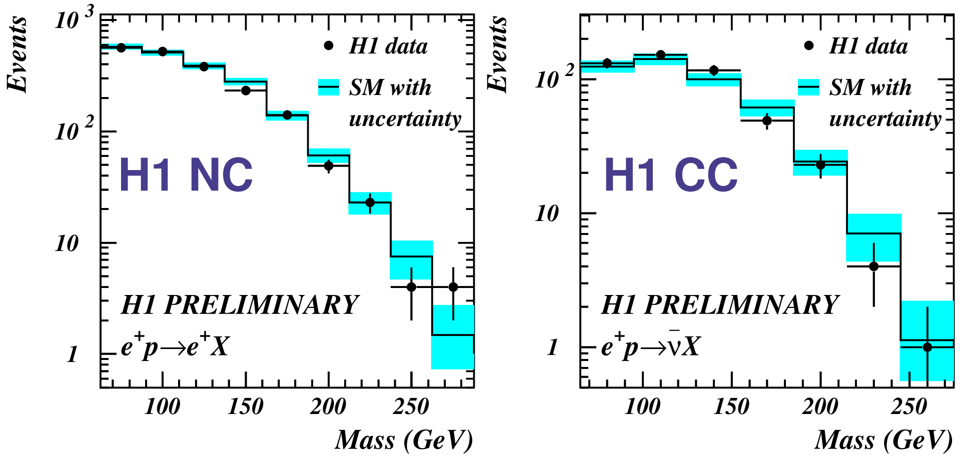
Scalar LQs produced flat in y

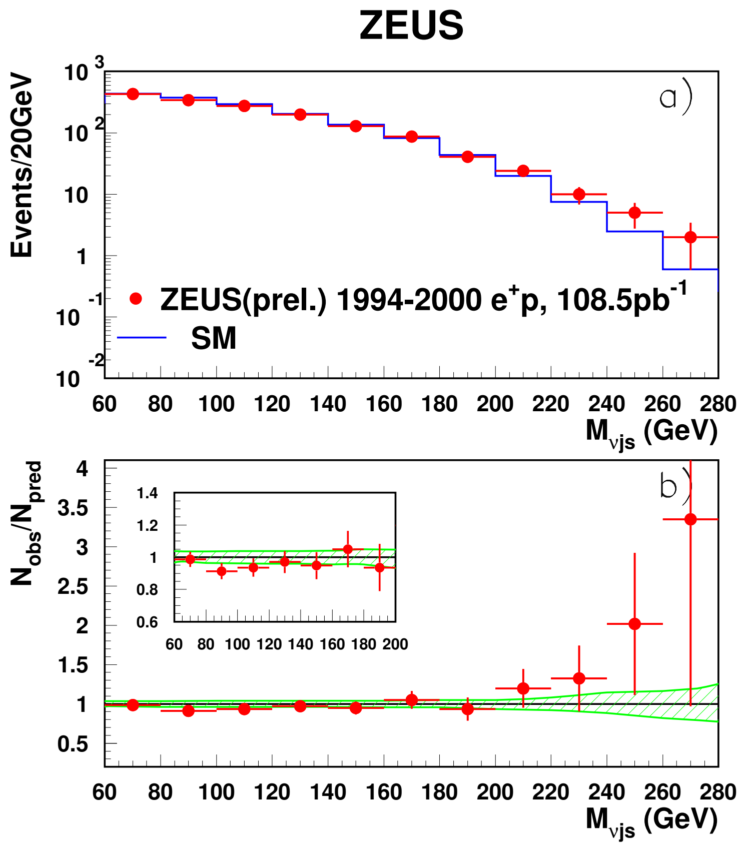
Vector LQs produced $\propto (1-y)^2$

NC DIS $\propto \frac{1}{y^2}$

Recall y relates to the scattered lepton polar angle

$y = \frac{1}{2}(1 + \cos\theta^*)$

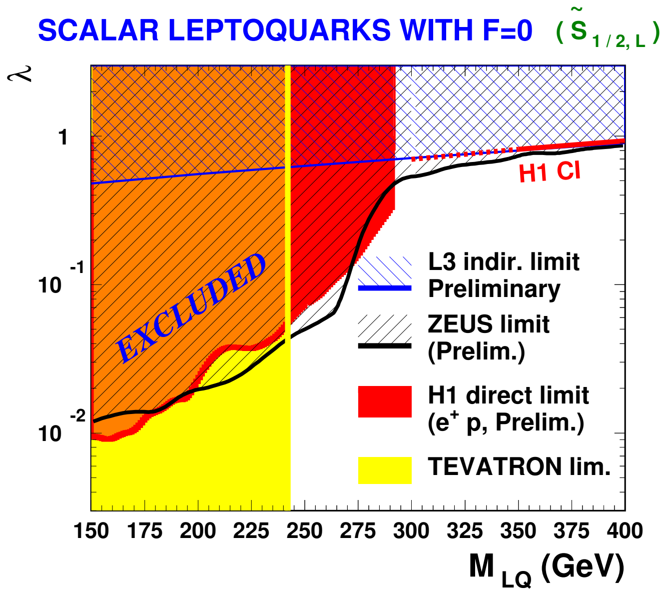


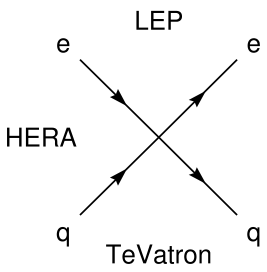


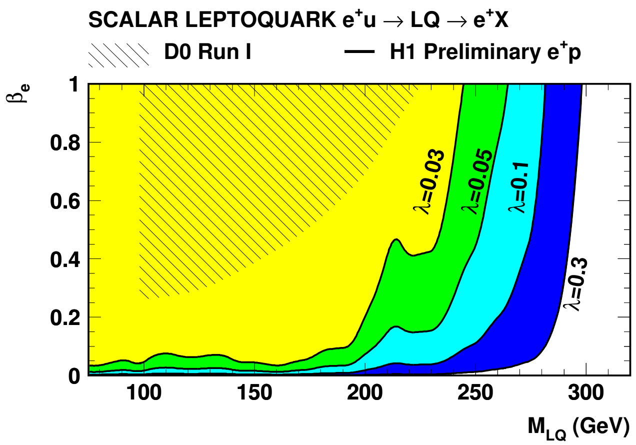
ZEUS High Q^2 CC data

- Good agreement with SM $\longrightarrow$ derive mass & coupling exclusion limits

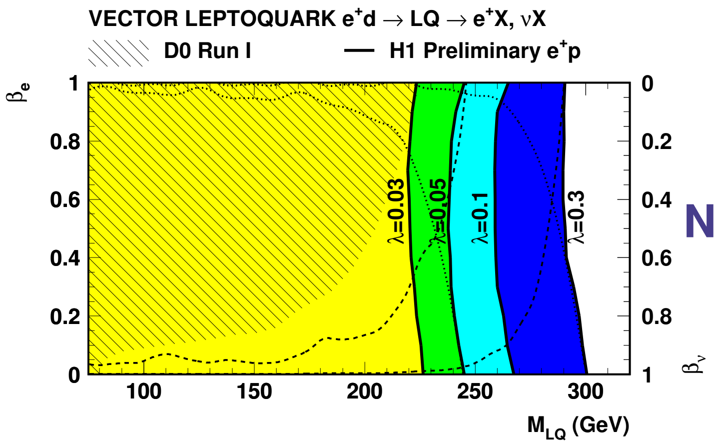
Leptoquarks – Mass and coupling Limits







H1 NC



H1 NC+CC

Recall.....

TeVatron : pair production - independent of λ

LEP : virtual effects in $e^+e^- \longrightarrow$ hadrons

– strongly dependent on λ

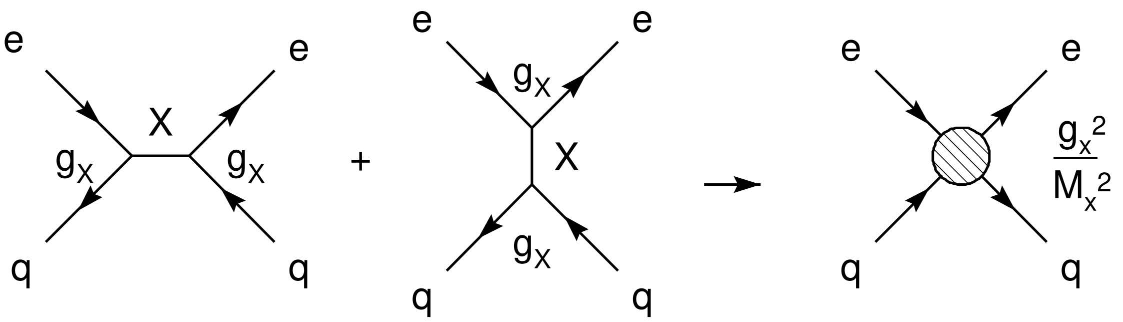
More general model – β free – various λ

NC+CC data – if $\beta(eq) + \beta(\nu q) = 1$

limits almost independent of β

Contact Interactions

- For very heavy particles ($M_X >> \sqrt{s}$) parameterise a coupling for exchanges which will interfere with "regular" HERA exchanges (γ,Z^o & $W^{\pm}$) :



Examine high Q^2 data – highest energies & smallest dist's

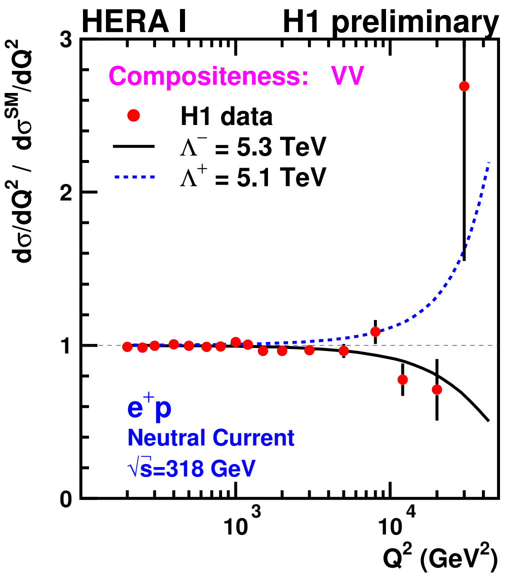
No significant deviations from SM seen (upwards or

downwards dependent on the sign of the interference term)

General CI model depends on chirality (LL,LR,VV...)

Also set limits on quark radius (finite radius has same

effect as Λ^-) $\rightarrow R_q < 0.73\text{x}10^{-18}$ m (ZEUS 95% C.L.)



Large Extra Dimensions

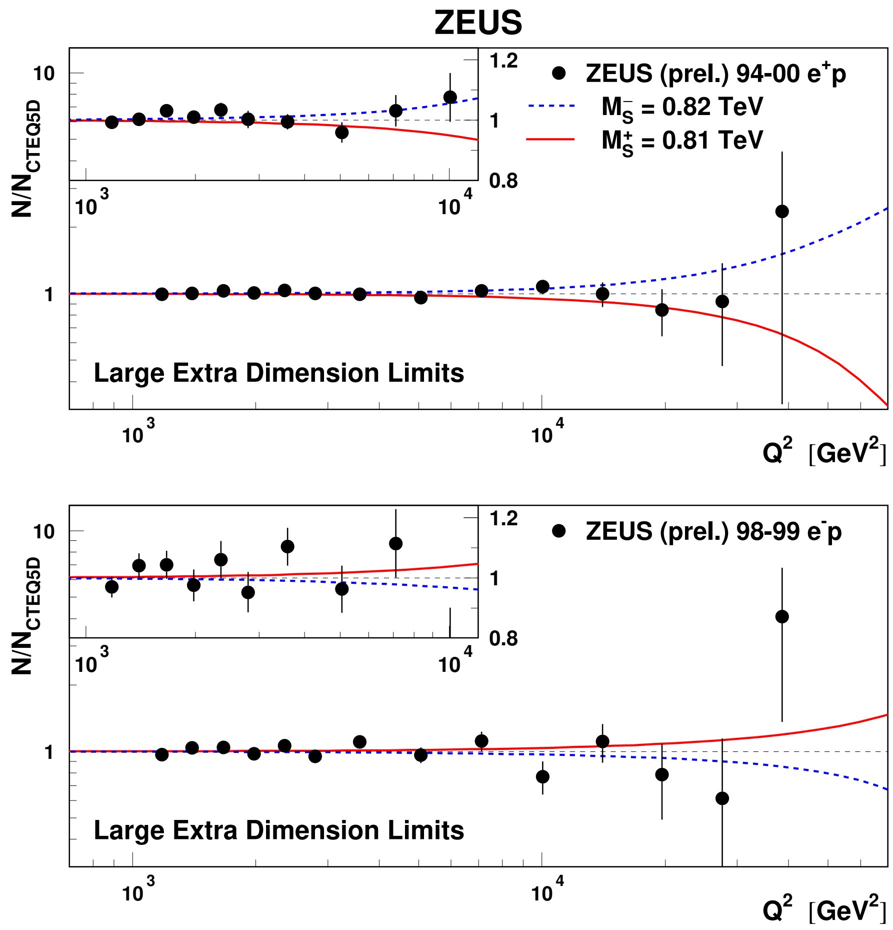
- Arkani-Hamed, Dimopoulos and Dvali suggest SM particles propagate in 4-D but gravitons propagate in (4+n)-D. Extra dimensions are curled-up within size $R \sim 1/M_s$
- Virtual Kaluza-Klein graviton exchange interferes with γ, Z exchange – affects $eq \to lq'$ rate

Set limits on the mass scale M_s

$\pm$ for positive/negative interference

HERA$_I$ limits on M_s (95% CL) :

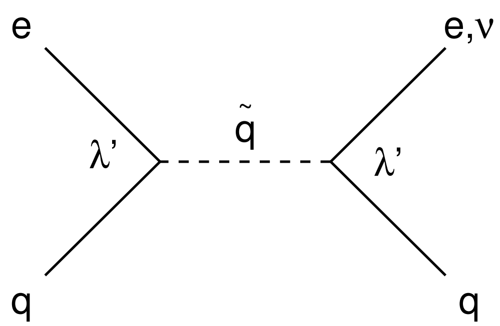
λ	H1	ZEUS
$+1$	0.83 TeV	0.81 TeV
-1	0.79 TeV	0.82 TeV



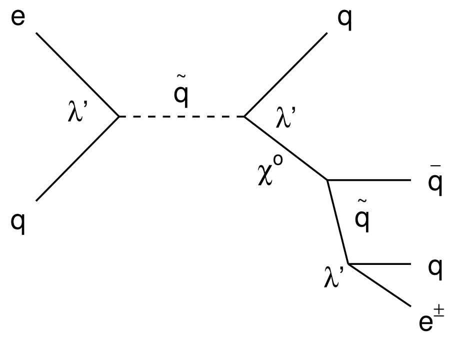
R-parity violating SUSY

- $R_P = (-1)^{L+3B+2S}$ is "even" (=1) for all known particles – is "odd" (=-1) for their supersymmetric partners

- Its violation $\Rightarrow$ SUSY particles can be singly produced and the LSP not stable



LQ-like

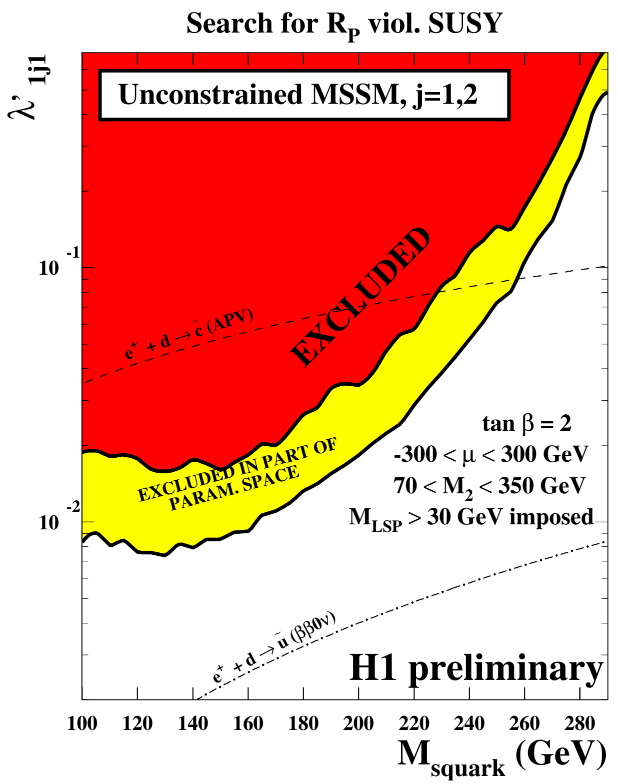


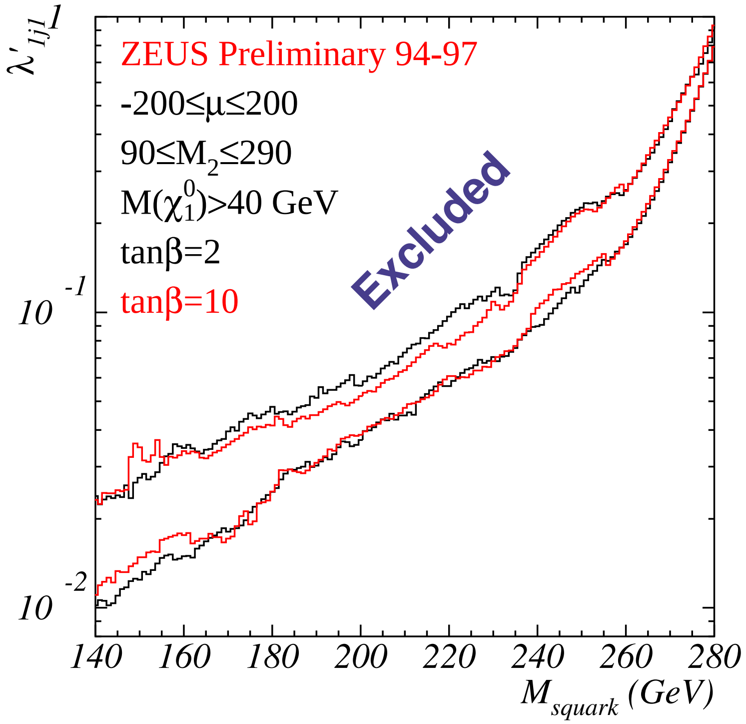
Cascade decays

- Search for resonant particle production. Cascade decays leading to "wrong" sign leptons give background free channels

- No excess seen in all channels $\longrightarrow$ set exclusion limits for unconstrained MSSM (squark mass independent of μ, M_2 & $\tan\beta$) and for mSUGRA

R-parity violating SUSY – MSSM



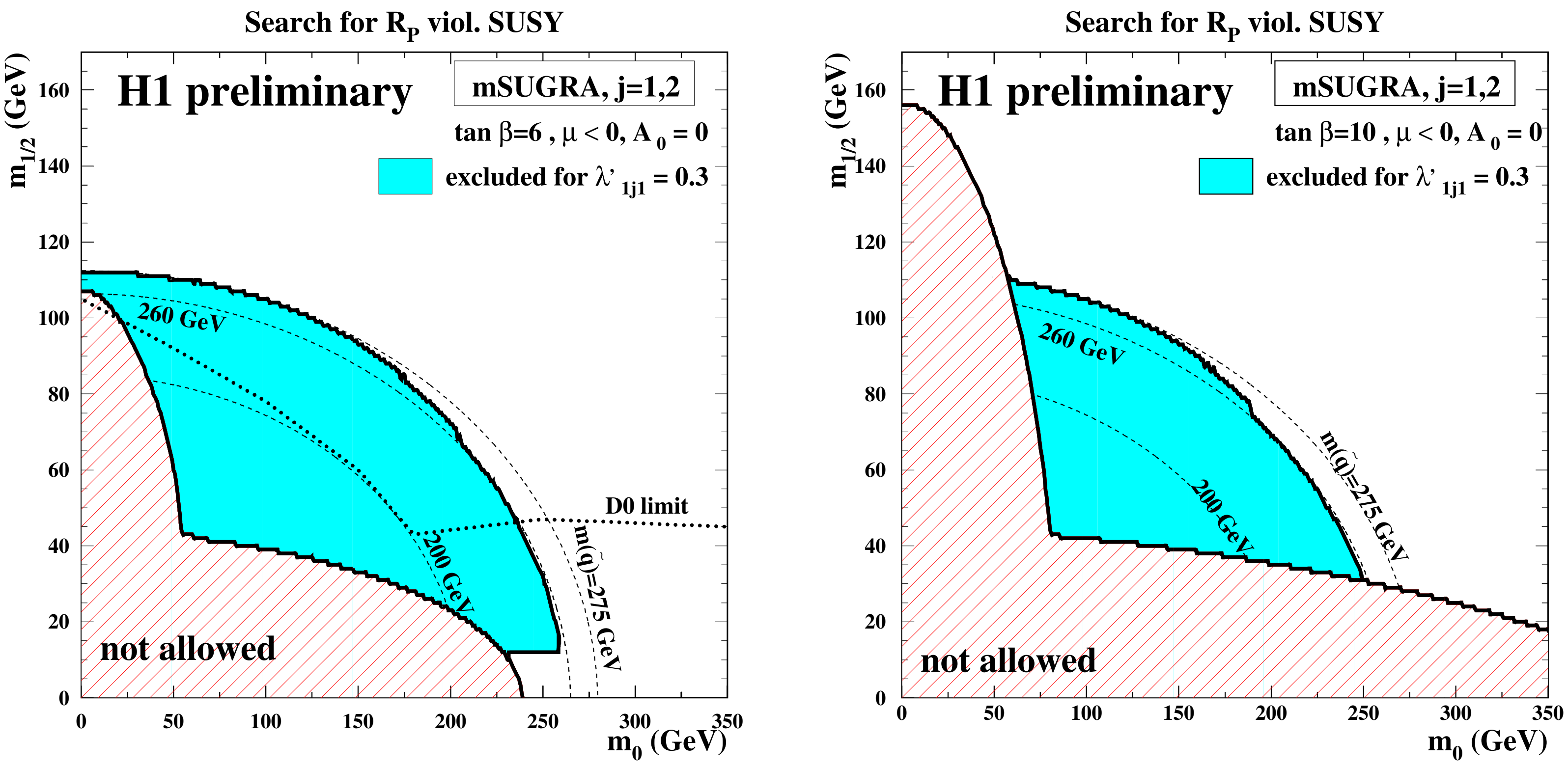


H1 Preliminary 99-00 data

ZEUS Preliminary 94-97 data

- Minimal SuperSymmetric Model (MSSM) – free variation of μ, M_2 & $\tan\beta$.
- Band shows squark mass vs coupling changing with variation of these parameters.

R-parity violating SUSY – mSUGRA

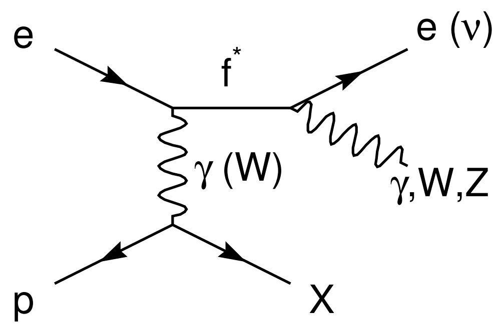


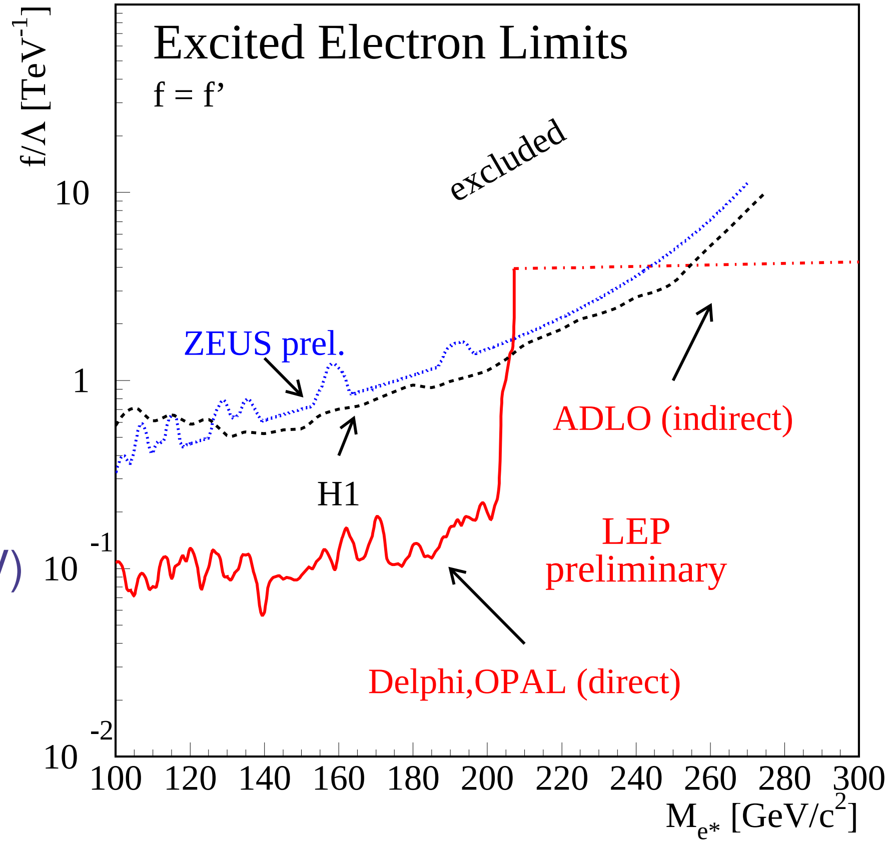
H1 Preliminary 99-00 data

- Minimal SuperGravity Model (mSUGRA) – constrained by (amongst others)
  - m_0 (universal mass parameter for sfermions at GUT scale)
  - assumption that EW symmetry breaking driven by radiative corrections

Excited fermions

- Fermion compositeness $\longrightarrow$ excited states f^*
- States described by Langrangian proposed by Hagiwara *et al.*:
  $L \propto \frac{1}{\Lambda}(f \bullet \mathrm{SU}(2)) + f' \bullet \mathrm{U}(1)) + f_s \bullet \mathrm{SU}(3))$
- Λ – Compositeness scale & f, f', f_s – gauge group weights





HERA has access above LEP 2 energy (202 GeV)

Below this QED predicts cross-section

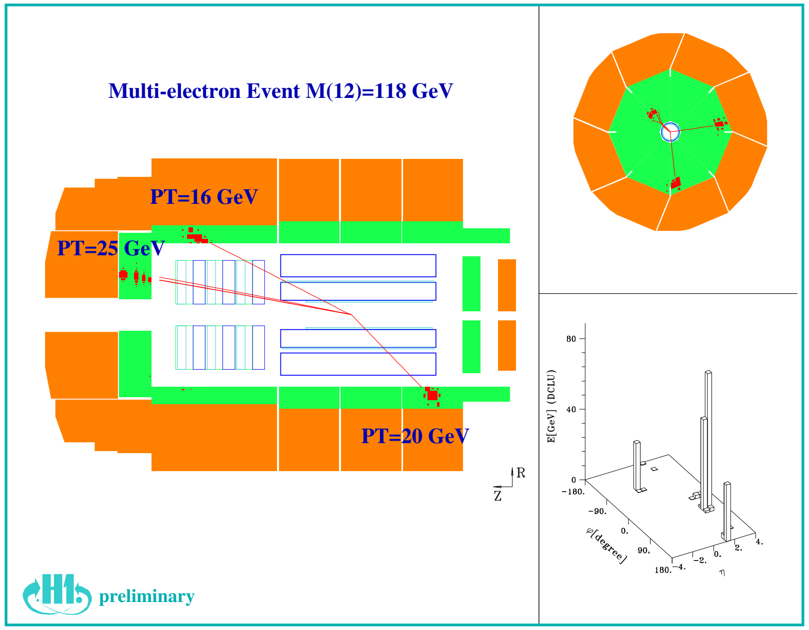
very precisely

Multi-electron production

- Search for multi-electron topologies
- SM expectation from QED processes
  - well calculated $\gamma\gamma \rightarrow e^+e^-$
- Interesting to look at large $M_{ee(e)}$

Agreement over full mass range:

e.g. H1 : 105 *cf.* 118.2 $\pm$ 12.8 ($>$2 e)

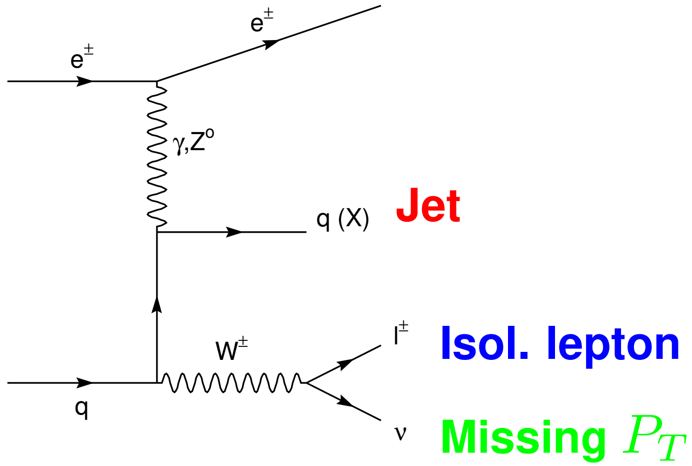


H1 Preliminary 115 pb^{-1}	DATA	SM
2e selection – $M(12) > 100$	3	0.25 ± 0.05
3e selection – $M(12) > 100$	3	0.23 ± 0.04

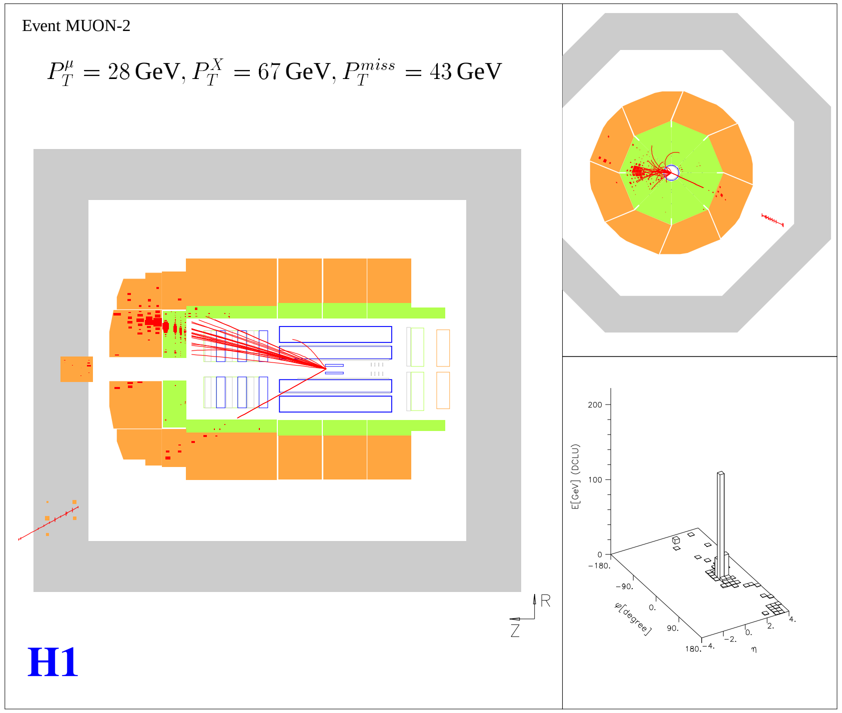
ZEUS Preliminary 130 pb^{-1}	DATA	SM
2e selection – $M(12) > 100$	2	1.14 ± 0.09

Isolated leptons and missing P_T – H1 Excess

- H1 observe an excess of events with a high P_T isolated lepton and missing P_T (hep-ex/0301030)



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



- Only significant contribution to this signal comes from SM is W production with leptonic decay, particularly at high P_T^X (hard hadronic system) – small (3%) contribution from Z decay
- NLO SM W calculations now available – QCD corrections – Diener *et al.* (hep-ph/0203269)

Isolated leptons and missing P_T – H1 Excess

- H1 e^+p data (105 pb^{-1}) from 1994-2000 – 10 electron & 8 muon combined :

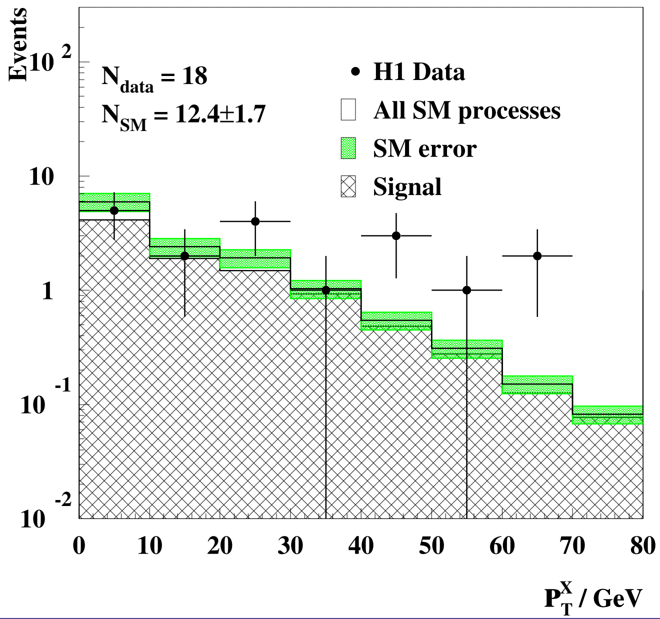
Electron and Muon	H1 Data	SM expect'n	SM Signal	Other SM processes
$P_T^X < 12$ GeV	5	6.40 ± 0.79	4.45 ± 0.70	1.95 ± 0.36
$12 < P_T^X < 25$ GeV	3	3.08 ± 0.43	2.40 ± 0.40	0.68 ± 0.14
$25 < P_T^X < 40$ GeV	4	1.83 ± 0.27	1.59 ± 0.26	0.24 ± 0.06
$P_T^X > 40$ GeV	6	1.08 ± 0.22	0.96 ± 0.22	0.12 ± 0.04

Greatest discrepancy at large P_T^X where background is very small

H1 e^-p data (14 pb^{-1}) :

– one electron event for 1.69 ± 0.22 expected

(0 muon for 0.37 ± 0.06 exp.)



Isolated leptons and missing P_T – ZEUS results

ZEUS data ep ($\sqrt{s}$) $\mathcal{L}$	Electrons Observed/exp'd (W)	Muons Observed/exp'd (W)
e^+p (300 GeV) 48 pb^{-1}	4 / $7.3^{+0.8}_{-2.1}$	0 / $4.2^{+0.4}_{-0.3}$
e^-p (318 GeV) 17 pb^{-1}	7 / $3.2^{+0.6}_{-1.0}$	1 / $2.1^{+0.2}_{-0.2}$
e^+p (318 GeV) 66 pb^{-1}	13 / $10.1^{+0.9}_{-1.9}$	11 / $5.6^{+0.4}_{-0.4}$
Total 130 pb^{-1}	24 / $20.6^{+1.7}_{-4.6}$ (17%)	12 / $11.9^{+0.6}_{-0.7}$ (16%)

Looser selection than H1

Event rate consistent with SM prediction

ZEUS have also presented results for the tau channel ($\longrightarrow$ 1 prong decay)

Final selection isolating W component:

ZEUS preliminary 94-00 $e^{\pm}p$ 130 pb^{-1}	Electrons Observed/exp'd (W)	Muons Observed/exp'd (W)	Taus Observed/exp'd (W)
$P_T^X > 25$ GeV	2 / $2.90^{+0.59}_{-0.32}$ (45%)	5 / $2.75^{+0.21}_{-0.21}$ (50%)	2 / 0.12 $\pm$ 0.02 (83%)
$P_T^X > 40$ GeV	0 / $0.94^{+0.11}_{-0.10}$ (61%)	0 / $0.95^{+0.14}_{-0.10}$ (61%)	1 / 0.06 $\pm$ 0.01 (83%)

H1 electron / muon excess is not seen, although the taus look interesting...

Anomalous (FCNC) single top production

Isolated lepton, missing p_T and hard jet also

the signature for $t \rightarrow bW \rightarrow bl\nu$

Also look at hadronic W decays

SM exp'n negligible due to FCNC vertex $\kappa_{\gamma ut}$

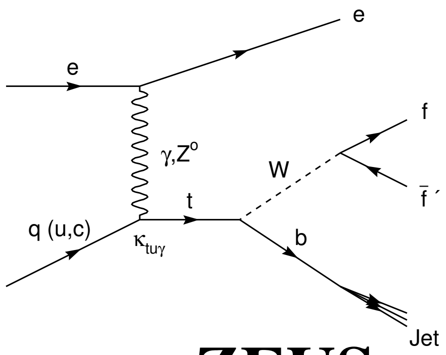
HERA very sensitive to this coupling ($\kappa_{\gamma ut}$)

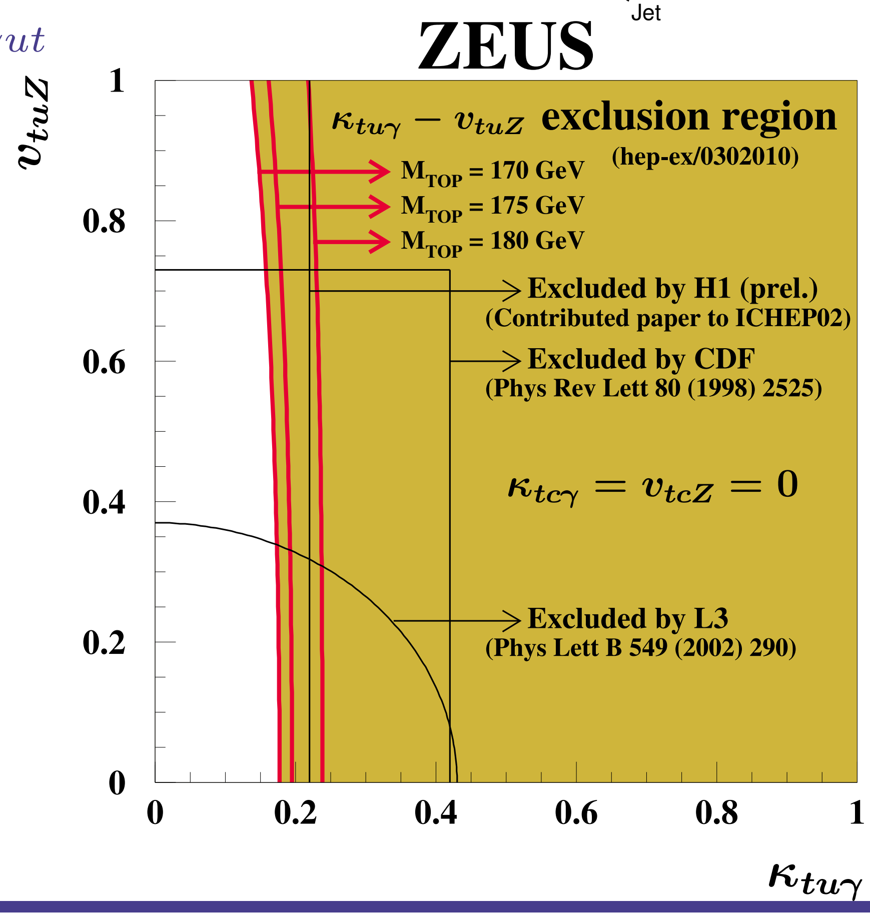
– slight sensitivity to κ_{Zut}

LEP : $e^+e^- \rightarrow \gamma, Z \rightarrow tu$

TeVatron : rare top decays $t \rightarrow \gamma q, Zq$

H1 isolated leptons separate H1 / ZEUS limits





Conclusions and Outlook

The HERA experiments have unique access to potential BSM scenarios

Exclusion limits have been set for LQs (BRW), Contact Interactions, LEDs (ADD), R_P–violating SUSY (MSSM & mSUGRA) and excited fermions

Intriguing isolated lepton results. Keenly await new data for both H1 and ZEUS

HERA II data will extend the search potential for H1 & ZEUS
and improve limits set on new physics models