

# Rp-violating SUSY and Exotics at HERA

Yves Sirois

LLR Ecole Polytechnique IN2P3-CNRS

Palaiseau

## Outline:

- Introduction:
- Searches and discovery prospects:

## Covered (partly):

Leptoquarks,  $R_p$ -SUSY, FCNCs,  
Doubly Charged Higgs, Contact Interactions,  
Extra Dimensions

## Uncovered (mostly):

$L$ -Flavour Violation, Technicolour,  
 $R_p$  conserving SUSY,  $W_R$  Currents,  
Bileptons, Excited fermions, ...

- Summary

# Introduction<sup>(1)</sup>

(1) Why bother in general ?

- Although remarkably confirmed (e.g. at colliders), the SM remains unsatisfactory (# arbitrary parameters; partial "unification", etc.)
- Fundamental questions remain to be answered :
  - How do particle acquire masses ?
  - How to "explain" the symmetry between  $L$  and  $Q$  sectors
  - How to "explain" the threefold "replica" of fermion generations ?
- There  $\exists$  a **strong** prejudice (more or less a necessity) for new physics "close to" EW unification scale
  - SUSY matter  $\lesssim \mathcal{O}(1 \text{ TeV})$  ?    String scale  $\lesssim \mathcal{O}(10 \text{ TeV})$  ?
- Scales from 1 to 10 TeV are being or will be best probed in "complementary" collider facilities:

Collider	Beams	$\sqrt{s}$	$\int \mathcal{L} dt$	Years
LEP <sub>I</sub>	$e^+e^-$	$M_Z$	$\sim 160 \text{ pb}^{-1} \otimes 4$	1989-95
LEP <sub>II</sub>	$e^+e^-$	$> 2 \times M_W$	$\sim 700 \text{ pb}^{-1} \otimes 4$	1996-00
HERA <sub>I</sub>	$e^\pm p$	$\lesssim 320 \text{ GeV}$	$\mathcal{O}(100 \text{ pb}^{-1}) \otimes 2$	1994-00
Tevatron <sub>I</sub>	$p\bar{p}$	1.8 TeV	$\mathcal{O}(100 \text{ pb}^{-1}) \otimes 2$	1992-96
HERA <sub>II</sub>	$e_{L,R}^\pm p$	$\sim 320 \text{ GeV}$	$\sim 1 \text{ fb}^{-1} \otimes 2$ ?	2002-06
Tevatron <sub>IIa</sub>	$p\bar{p}$	2.0 TeV	$\sim 3 \text{ fb}^{-1} \otimes 2$ ?	2002-06 ?

Tevatron<sub>IIb</sub> (?)  $\gtrsim 2007$ , LHC  $\gtrsim 2007$  ?, TESLA LC ?  $\gtrsim 2012$  ? ...

(1) Why bother at HERA ?

HERA<sub>I</sub> (1994-00):  $e^\pm p$   $E_e = 27.5$  GeV  $E_p = 820$  to  $920$  GeV  
 $\sqrt{s_{ep}} = 300$  to  $318$  GeV  $\mathcal{L} \sim \mathcal{O}(100)$  pb<sup>-1</sup> × 2

HERA<sub>II</sub> (2002-06):  $e_{L,R}^\pm p$   $E_e = 27.6$  GeV  $E_p \gtrsim 920$  GeV  
 $\sqrt{s_{ep}} \gtrsim 320$  GeV  $\mathcal{L} \sim \mathcal{O}(1)$  fb<sup>-1</sup> × 2

Two general purpose experiments: H1 and ZEUS

**Standard Model physics:** proton structure, EW couplings,  
 QCD dynamics

**Beyond the Standard Model:**

HERA<sub>II</sub> provides a complementary window on:

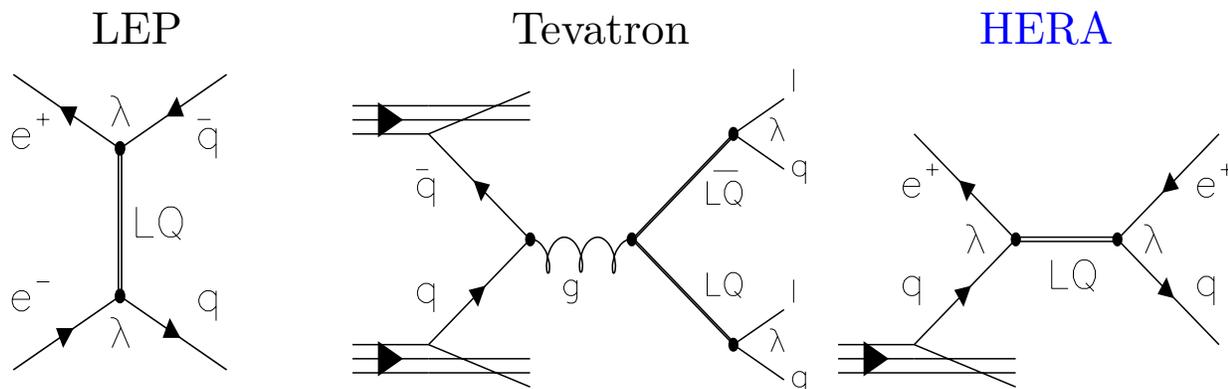
- Physics of theories addressing the hierarchy problem  
 ( $R_p$  Yukawa sector of SUSY; Technicolour, Virtual  $G$  exchange ...)
  - Physics of new theories pertinent for the apparent structure  
 and symmetries of matter  
 (leptoquarks, SM extensions, LFV, FCNCs)
  - Models relevant for the threefold "replica" of fermions  
 (excited fermions, Contact Interactions)
- Admittedly, considering existing constraints and current knowledge,  
 HERA<sub>II</sub> will have essentially nothing to say on extra  $Z$ 's; sparticles  
 and Higgses in MSSM, mSUGRA, GMSB or AMSB theories...;  
 anomalous TGB vertices; etc. ...

# Leptoquarks at Colliders

- LQs are colour triplet bosons (scalars S or vectors V) carrying L and B numbers and fractional  $Q_{em}$
- LQs appear naturally in:
  - GUT-like theories, Superstring-“inspired”  $E_6$  models,
  - Technicolour-like theories, Compositeness models
- Büchmuller-Rückl-Wyler LQ “minimal” model  $\leftrightarrow$ 
  - assume (chiral) couplings invariant under SM gauge interactions;
  - interactions **only** with SM fermions and gauge bosons; etc.
- $\Rightarrow$  Scalars and Vectors each forming 5 Isospin families:
 

F=2	$(S_{0,R}, S_{0,L}), \tilde{S}_{0,R}, S_{1,L}$	$(V_{1/2,R}, V_{1/2,L}), \tilde{V}_{1/2,L}$
F=0	$S_{1/2,L}, (\tilde{S}_{1/2,L}, \tilde{S}_{1/2,R})$	$V_{0,L}, \tilde{V}_{0,R}, V_{1,L}$
- Non-minimal models: non-standard decays allowed  $\leftrightarrow$ 
  - arbitrary  $\beta_{eq}$  for 1<sup>rst</sup> generation leptoquarks
  - e.g. LQ with LFV couplings; e.g.  $\tilde{u}_L \leftrightarrow \tilde{S}_{1/2,L}$   $\tilde{d}_R \leftrightarrow S_{0,L}$

At various colliders:



- At HERA:  $\circ e^-p \rightarrow S_0; \tilde{S}_0; S_1$   $e^+p \rightarrow \bar{S}_{1/2}; \tilde{\bar{S}}_{1/2}$
- $\circ$  All LQ types can be distinguished through  $e_{L,R}^\pm$

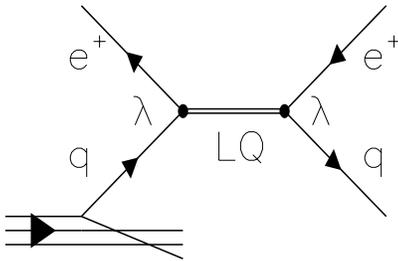
# Search for Leptoquarks at HERA

Previously published:  $F = 0$   $e^+p$ ;  $\mathcal{L} \simeq 37 \text{ pb}^{-1}$  H1 Collab. EPJ C11 (1999) 447

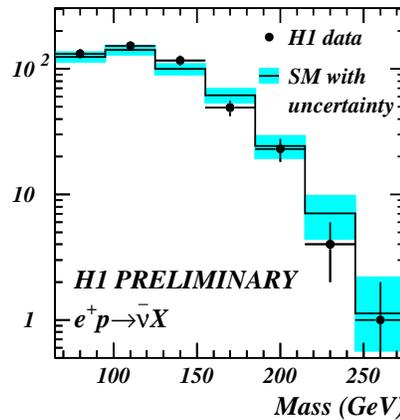
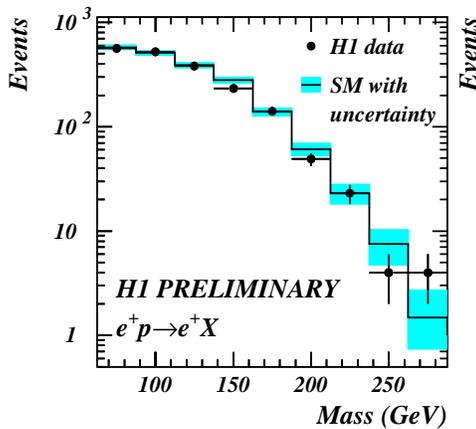
$F = 2$   $e^-p$ ;  $\mathcal{L} \simeq 15 \text{ pb}^{-1}$  H1 Collab. PLB 523 (2001) 234

$F = 0$   $e^+p$ ;  $\mathcal{L} \simeq 48 \text{ pb}^{-1}$  ZEUS Collab. EPJ C16 (2000) 253

PRD 63 (2001) 052002

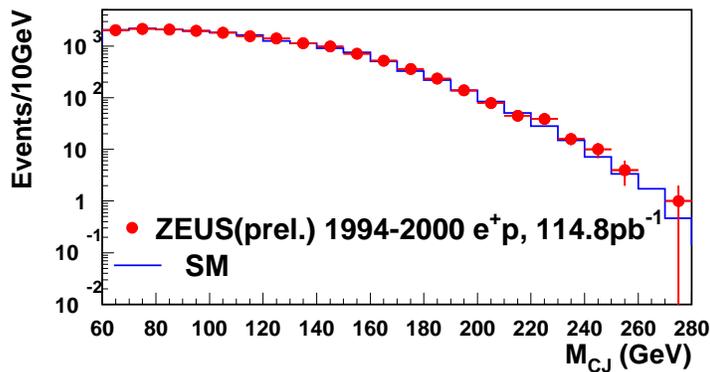


- LQ interaction interferes with SM boson  $t$ -channel exchange
- Background reduction:  $\cos(\theta_e^*)$  spectra distinct from SM DIS



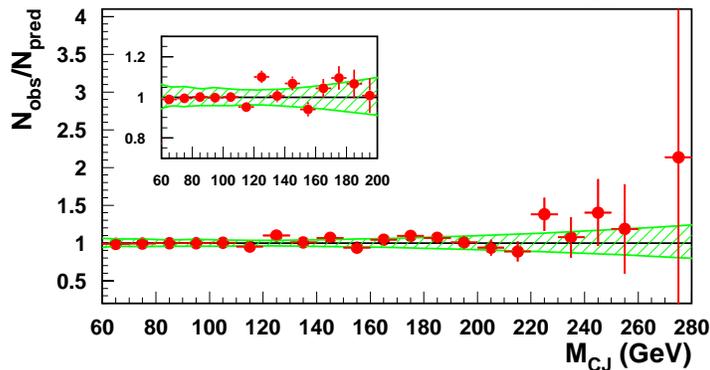
NEW (prelim. DIS 2002)

H1 use all  $e^\pm p$  data



NEW (prelim. DIS 2002)

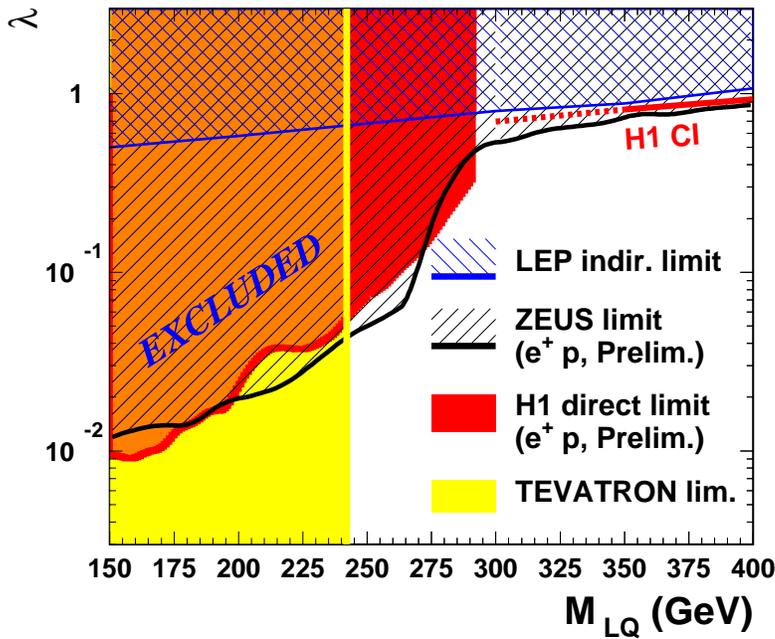
ZEUS use all  $e^\pm p$  data



No deviation from SM expectation !

# Search for Leptoquarks at HERA

## SCALAR LEPTOQUARKS WITH F=0 ( $\tilde{s}_{1/2,L}$ )



$e^+p$

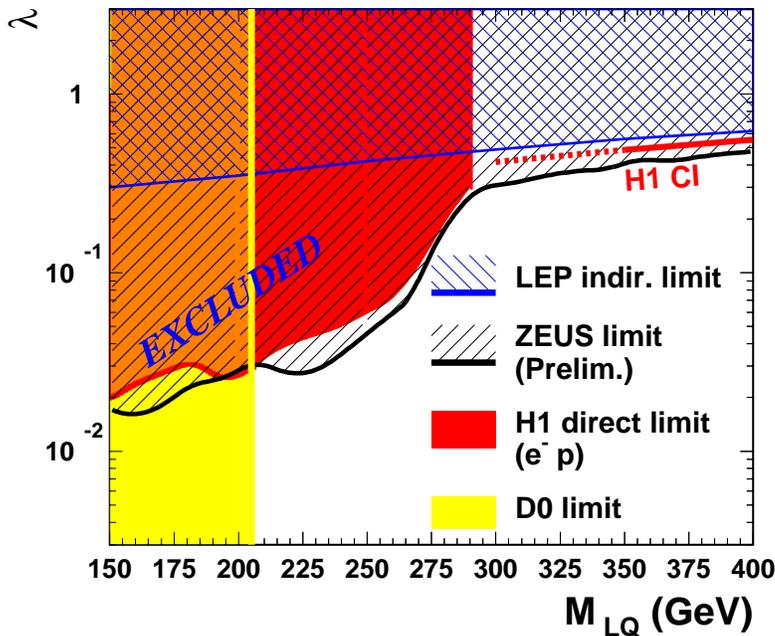
$$Q_{em} = -2/3 \quad \beta_{eq} = 100\%$$

Tevatron:  $M \gtrsim 245$  GeV

HERA: ( $\lambda = 0.3$ )  $M \gtrsim 290$  GeV

( $\lambda = 0.1$ )  $M \gtrsim 270$  GeV

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



$e^-p$

$$\beta_{eq} = \beta_{\nu q} = 50\%$$

Sensitivity  $\uparrow$  by combining

NC-like and CC-like events

Tevatron:  $M \gtrsim 204$  GeV

HERA: ( $\lambda = 0.3$ )  $M \gtrsim 300$  GeV

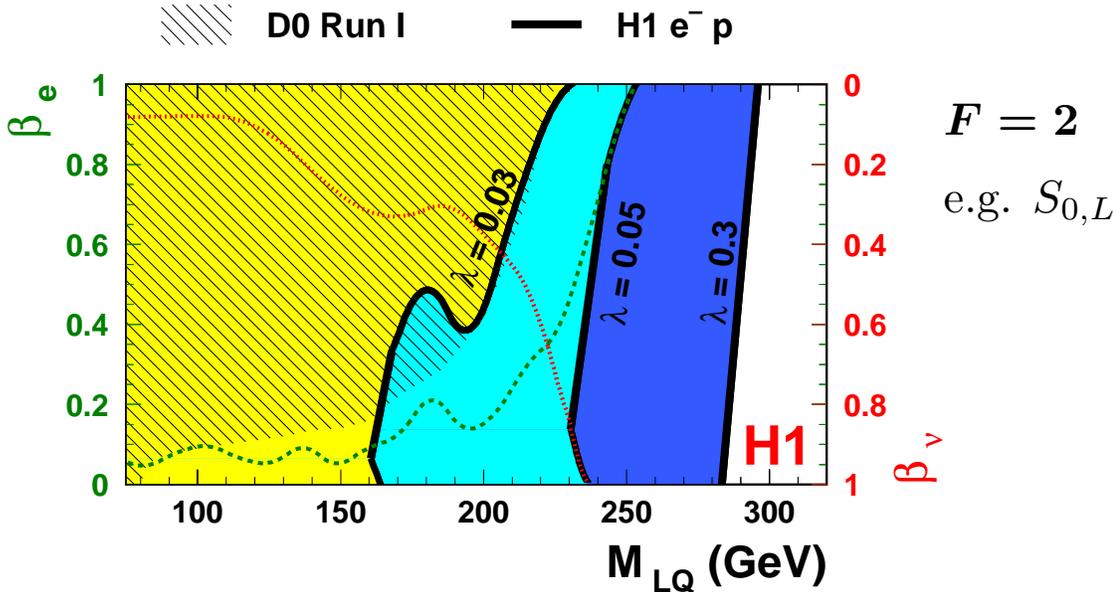
( $\lambda = 0.1$ )  $M \gtrsim 270$  GeV

Recall:  $M < \sqrt{s} \quad \lambda \ll 1 \Rightarrow \sigma \propto \lambda^2$

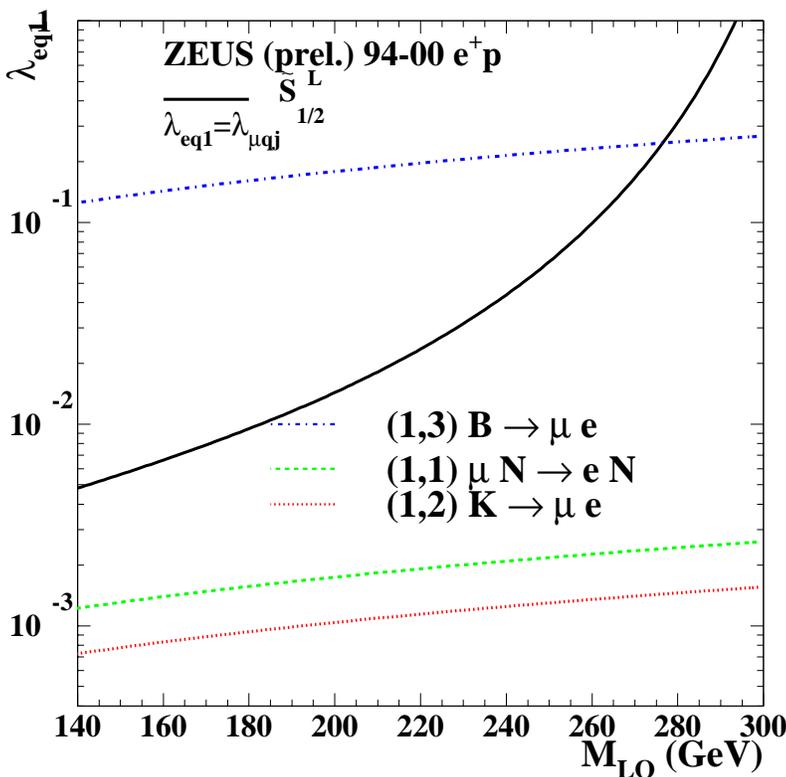
$M \gg \sqrt{s} \Rightarrow \sigma \propto \lambda^4$

# Search for Leptoquarks at HERA

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



- At Tevatron:  $\circ$  Best sensitivity for  $\beta_{eq} \rightarrow 1$
- Best cases at HERA are for LQs in non-minimal minimal models (non-standard decays allowed  $\leftrightarrow$  arbitrary  $\beta_{eq}$ ) with  $\beta_{eq} \ll 1$



- Unique sensitivity and striking signal for LFV at HERA possible through  $s$ -,  $t$ - or  $u$ -channel exchange of new  $eq$  bosons with mixed  $\lambda_{eq_i} \times \lambda_{\mu q_j}$  or  $\lambda_{eq_i} \times \lambda_{\tau q_j}$  (see || session talk by D. Danheim)

$M \gtrsim 280$  GeV for  $\lambda_{eq_1} = 0.3$

- Problem of hierarchy between EW and Planck scale  $\leftrightarrow$  possibly finds solutions in theories with extra dimensions
- There  $\exists$  many viable  $4 + n$  dimensional scenarios

e.g. ADD = Arkani-Hamed, Dimopoulos, Dvali PLB 429 (1998) 263;

RS = Randall, Sundrum PRL 83 (1999) 3370

Various scenarios  $\Leftrightarrow$  model dependent effects at HEP colliders

- ADD scenario: SM particles in 4d  $\leftrightarrow$  gravitons in  $(4+n)d$

$$M_p^2 = R^n M_s^{2+n} \quad n \geq 2 \quad M_p \sim 10^{19} \text{ GeV}$$

$R$  = size of the  $n$  compact extra dimensions

$M_s$  = gravitational scale in  $4 + n$  dimensions

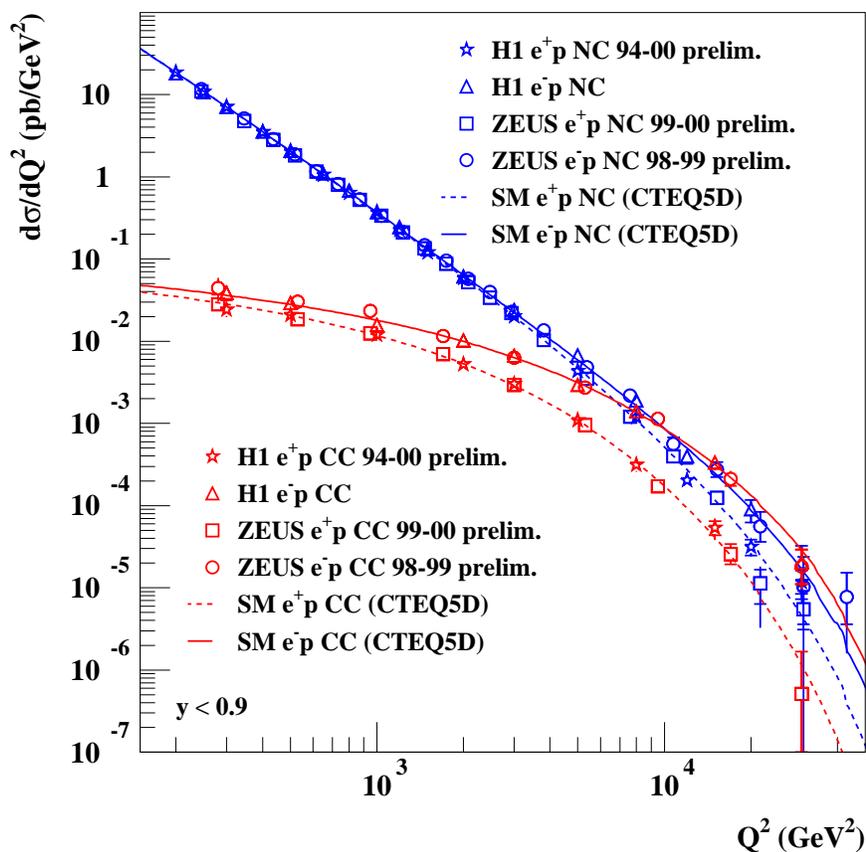
$\Rightarrow$  “tower” of massive Kaluza-Klein excitation states !

$\Rightarrow$  virtual “graviton” exchange interferes with  $\gamma, Z$  exchange

with an effective (contact interaction) coupling  $\eta_G = \lambda/M_s^4$

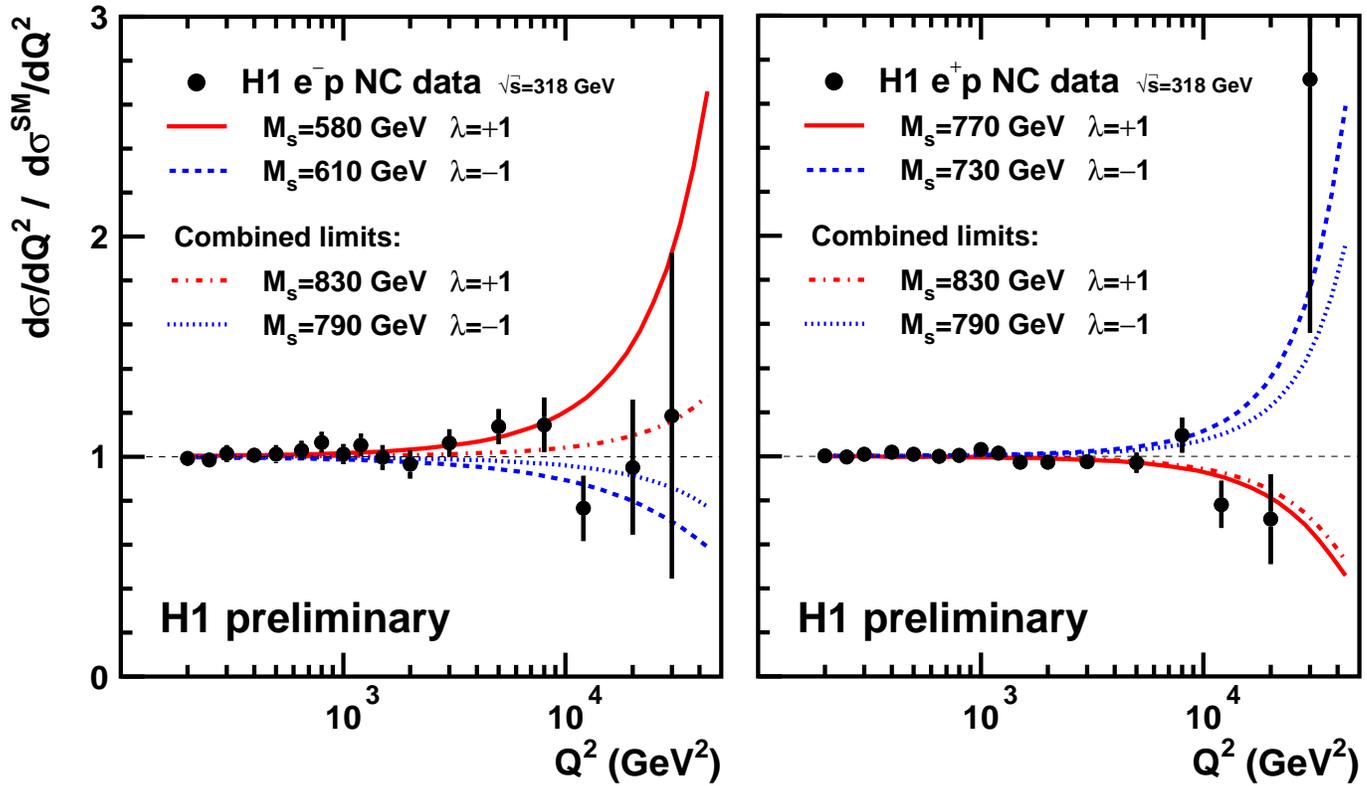
- Observable effects in  $e^+e^- \rightarrow f\bar{f}$ ,  $q\bar{q} \rightarrow l\bar{l}$ ,  $eq \rightarrow lq'$

e.g. Expect deviations from SM in high  $Q^2$  DIS scattering at HERA:



NEW: Using all available  $e^\pm p$  data:

H1 prelim.- Val. d'Aoste 2002      ZEUS prelim. - EPS HEP 2001



HERA<sub>I</sub>, Tevatron<sub>I</sub> and LEP<sub>II</sub> results:

95% CL limit on $M_S$ [TeV]					
$\lambda$	H1	ZEUS	CDF <sup>a</sup>	D0 <sup>b</sup>	LEP Combined <sup>c</sup>
+1	0.83	0.81	0.96	1.21	1.26
-1	0.79	0.82	0.94	1.13	0.96

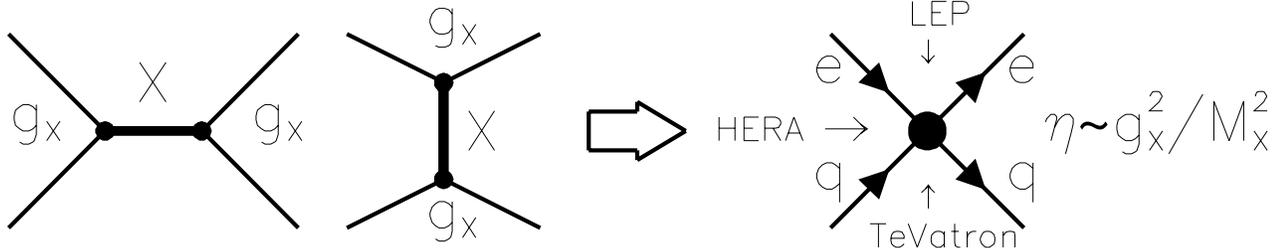
Results conversion from Hewett (H) to Giudice, Rattazi, Wells (GRW) formalism via  $M_{GRW}^4 = (\pi/2)M_H^4$

<sup>a</sup> J. Carlson, APS Meeting (May 2001)      <sup>b</sup> D0 Collab., PRL 86 (2001) 1156

<sup>c</sup> From D. Bourilkov, A+D+L+O experiments for LEP<sub>II</sub>  $\sqrt{s}$  up to 189 GeV

# Contact Interactions

- Interference of (very) heavy bosonic particle  $X$  with SM fields in virtual exchange  $\leftrightarrow$  for  $M_X \gg \sqrt{s}$  the  $s$ -,  $t$ - or  $u$ - channel propagators contract to pointlike **four fermion** CI with eff. coupling  $\eta$  [ $mass^{-2}$ ]



$$\mathcal{L}_{CI} = \sum_{q=u,d} \eta_{LL}^q (\bar{e}_L \gamma_\mu e_L) (\bar{q}_L \gamma^\mu q_L) + \eta_{LR}^q (\bar{e}_L \gamma_\mu e_L) (\bar{q}_R \gamma^\mu q_R) + \eta_{RL}^q (\bar{e}_R \gamma_\mu e_R) (\bar{q}_L \gamma^\mu q_L) + \eta_{RR}^q (\bar{e}_R \gamma_\mu e_R) (\bar{q}_R \gamma^\mu q_R)$$

$$\eta_{ij} \equiv \pm \epsilon g^2 / \Lambda_{ij}^2 \quad i, j = R, L$$

$$g = \text{coupling strength} = 4\pi; \quad \Lambda_{ij} \text{ scale} \equiv M_X$$

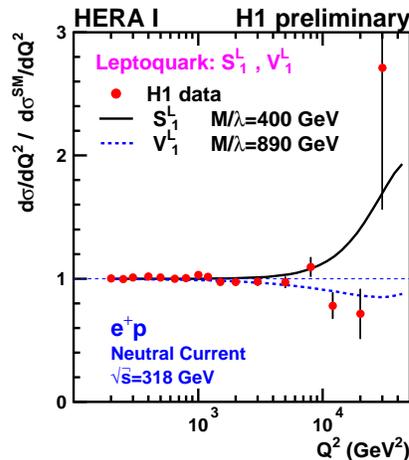
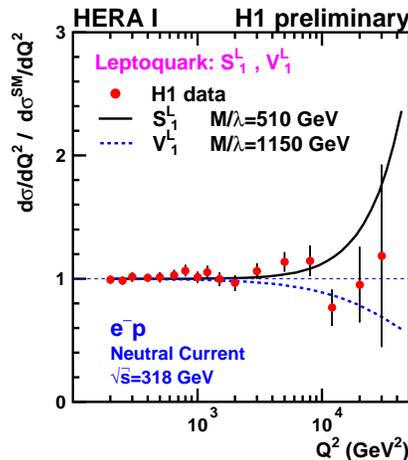
$$\text{APV requires } \eta_{LL}^q + \eta_{LR}^q - \eta_{RL}^q - \eta_{RR}^q = 0$$

- Various vector and axial vector combinations can be considered e.g. Parity conserving Compositeness models with  $q$  universality:

$$VV = LL + LR + RL + RR \quad AA = LL - LR - RL + RR \quad \dots$$

e.g. BRW Leptoquark models (specific chiral couplings to  $e - q$  pairs:

$$S_1^L \Rightarrow \epsilon_{LL}^d = 2 \times \epsilon_{LL}^u = +1$$



Note: HERA results now profit from distinct sensitivity to  $e^-p$  and  $e^+p$  data

# Search for Contact Interactions at HERA

All available  $e^\pm p$  data: [H1 prelim.- Val. d'Aoste 2002](#) [ZEUS prelim. - EPS HEP 2001](#)

[ Recent collider review in [M. Kuze](#), [Y. Sirois](#) PPNP (2002) ]

Compositeness models:

95% CL limit [TeV]	H1		ZEUS		CDF		DØ	
Coupling structure								
Model [ $\epsilon_{LL}, \epsilon_{LR}, \epsilon_{RL}, \epsilon_{RR}$ ]	$\Lambda^-$	$\Lambda^+$	$\Lambda^-$	$\Lambda^+$	$\Lambda^-$	$\Lambda^+$	$\Lambda^-$	$\Lambda^+$
VV [ +1, +1, +1, +1 ]	5.4	5.1	7.0	6.5	5.2	3.5	6.1	4.9
AA [ +1, -1, -1, +1 ]	3.9	2.5	5.3	4.6	4.8	3.8	5.5	4.7
VA [ +1, -1, +1, -1 ]	2.9	2.9	3.4	3.3				

Leptoquark models:

95% CL limit $M_{LQ}/\lambda_{LQ}$ [GeV]						
Model	Coupling Structure	H1	ZEUS	ALEPH	L3	OPAL
$S_0^L$	$\epsilon_{LL}^u = +\frac{1}{2}$	720	750	640	1240	640
$S_0^R$	$\epsilon_{RR}^u = +\frac{1}{2}$	670	690		960	
$\tilde{S}_0^R$	$\epsilon_{LL}^d = +\frac{1}{2}$	330	310	220	260	590
$S_{1/2}^L$	$\epsilon_{LR}^u = -\frac{1}{2}$	870	910	-	180	460
$S_{1/2}^R$	$\epsilon_{RL}^d = \epsilon_{RL}^u = -\frac{1}{2}$	370	690		350	630
$\tilde{S}_{1/2}^L$	$\epsilon_{LR}^d = -\frac{1}{2}$	430	500			370
$S_1^L$	$\epsilon_{LL}^d = 2 \cdot \epsilon_{LL}^u = +1$	480	550	770	640	930

Recall:  $S_0^L \sim \tilde{d}_R$   $\tilde{S}_{1/2}^L \sim \tilde{u}_L$

For  $\lambda = 1$  some LQs excluded up to  $\sim 900$  GeV for scalars  
( $\sim 1.4$  TeV for vectors)

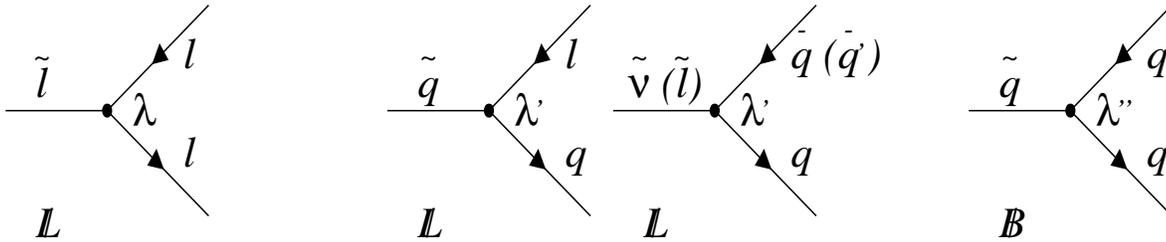
# R-Parity Violating SUSY

- The General Superpotential:

$$W = W_{MSSM} + W_{R_p} \quad R_p = (-1)^{3B+L+2S} \leftrightarrow +1 \text{ for particles; } -1 \text{ for Sparticles}$$

$$W_{R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

$ijk$  for generation; superfield:  $L, Q$  doublets;  $E, D, U$  singlets



Proton stability  $\Rightarrow \lambda' \times \lambda'' = 0$  sufficient.

Main consequences at colliders of a non-vanishing  $\lambda, \lambda'$  or  $\lambda''$ :

- Fundamental instability of SUSY matter  $\Rightarrow$  new/distinct decay modes
- indirect sensitivity to  $\lambda, \lambda'$  or  $\lambda''$  or  $\lambda''$  from sparticle pair production.
- Extended discovery reach in specific cases:

Resonant Production of Sfermions at Colliders			
Collider	Coupling	Sfermion	Elementary Process
$e^+e^-$	$\lambda_{1j1}$	$\tilde{\nu}_\mu, \tilde{\nu}_\tau$	$l_i^+ l_k^- \rightarrow \tilde{\nu}_j \quad i = k = 1, j = 2, 3$
$p\bar{p}$	$\lambda'_{ijk}$	$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	$d_k \bar{d}_j \rightarrow \tilde{\nu}_i \quad i, j, k = 1, \dots, 3$
		$\tilde{e}, \tilde{\mu}, \tilde{\tau}$	$u_j \bar{d}_k \rightarrow \tilde{l}_{iL} \quad i, k = 1, \dots, 3, j = 1, \dots, 2$
	$\lambda''_{ijk}$	$\tilde{d}, \tilde{s}, \tilde{b}$	$\bar{u}_i \bar{d}_j \rightarrow \tilde{d}_k \quad i, j, k = 1, \dots, 3, j \neq k$
		$\tilde{u}, \tilde{c}, \tilde{t}$	$\bar{d}_j \bar{d}_k \rightarrow \tilde{u}_i \quad i, j, k = 1, \dots, 3, j \neq k$
$ep$	$\lambda'_{1jk}$	$\tilde{d}_R, \tilde{s}_R, \tilde{b}_R$	$l_1^- u_j \rightarrow \tilde{d}_{kR} \quad j = 1, 2$
	$\lambda'_{1jk}$	$\tilde{u}_L, \tilde{c}_L, \tilde{t}_L$	$l_1^+ d_k \rightarrow \tilde{u}_{jL} \quad i, j, k = 1, \dots, 3$

- Best discovery reach for SUSY at HERA = single  $\tilde{q}$  prod. through  $\lambda'$ !

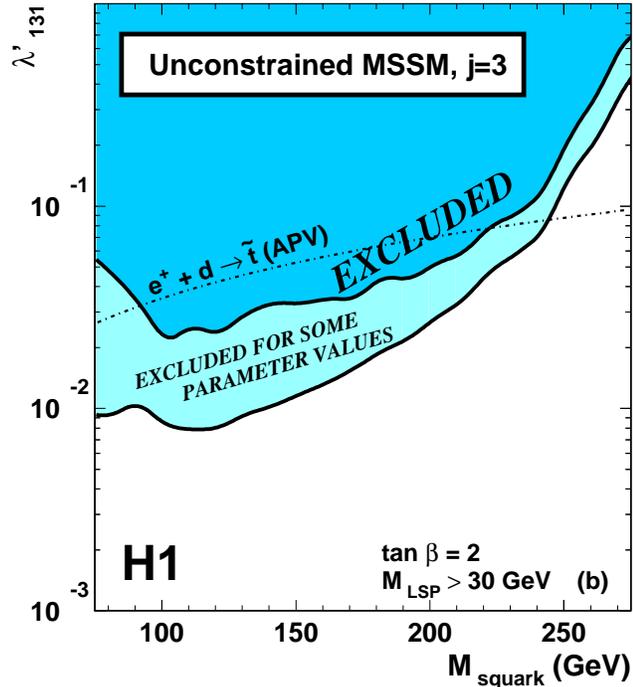
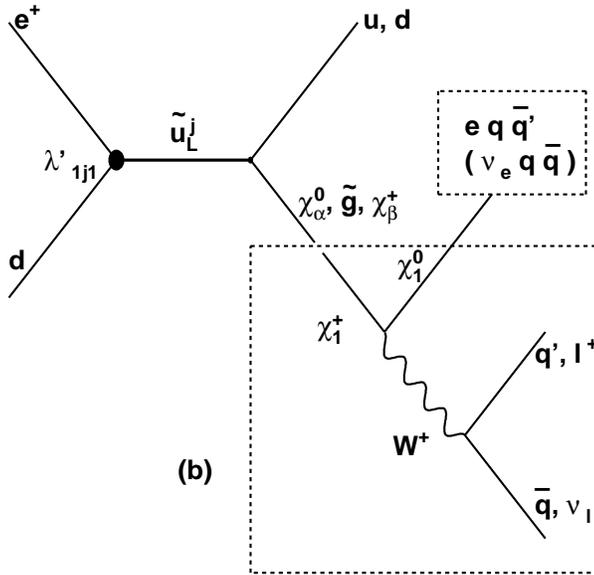
# Search for $R_p$ -SUSY at HERA

$\tilde{q}$  single production: H1 EPJ C20 (2001) 4 ZEUS prelim. ICHEP (Osaka) 2000

- Different kinds of  $\tilde{q}$  produced dominantly for  $e^\pm$

$$e^- p \leftrightarrow \lambda'_{11k} \text{ and } \tilde{d}_{R\text{-like}} \tilde{q} \quad e^+ p \leftrightarrow \lambda'_{1j1} \text{ and } \tilde{u}_{L\text{-like}} \tilde{q} \text{ (e.g. the } \tilde{t}\text{)}$$

$$-300 < \mu < 300 \text{ GeV} \quad 70 < M_2 < 350 \text{ GeV}$$

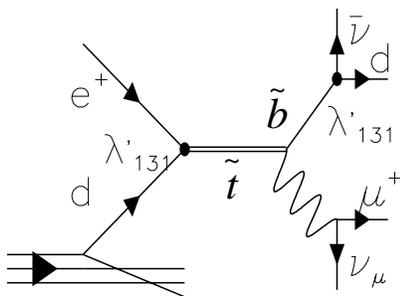


$$M_{\tilde{q}} \gtrsim 260 \text{ GeV for } \lambda'_{1j3} = 0.3$$

Sensitivity beyond indirect limits

Widely model independent

- The special case of the  $\tilde{t}$



- Possibly significant rates both in

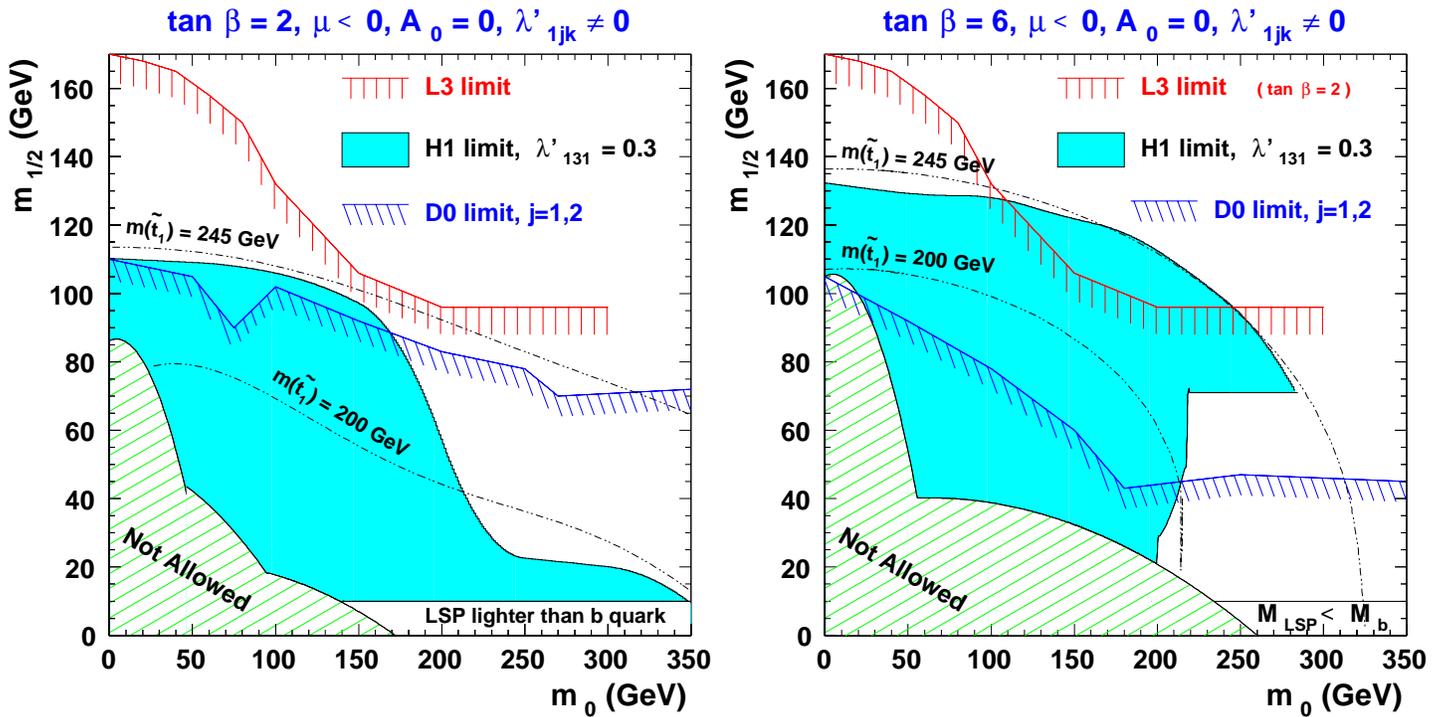
$$\tilde{t}_1 \rightarrow \tilde{b}_1 + W \text{ and } \tilde{t}_1 \rightarrow ed$$

- $\tilde{t}_1 \rightarrow \tilde{b}_1 + W \Rightarrow$  outstanding event topologies:  $l^\pm + jet + \cancel{E}_T$

E. Perez, SUSY 98 & Tools for SUSY 99

# Search for $R_p$ -SUSY at HERA

$\tilde{q}$  single production: H1 EPJ C20 (2001) 4 ZEUS prelim. ICHEP (Osaka) 2000



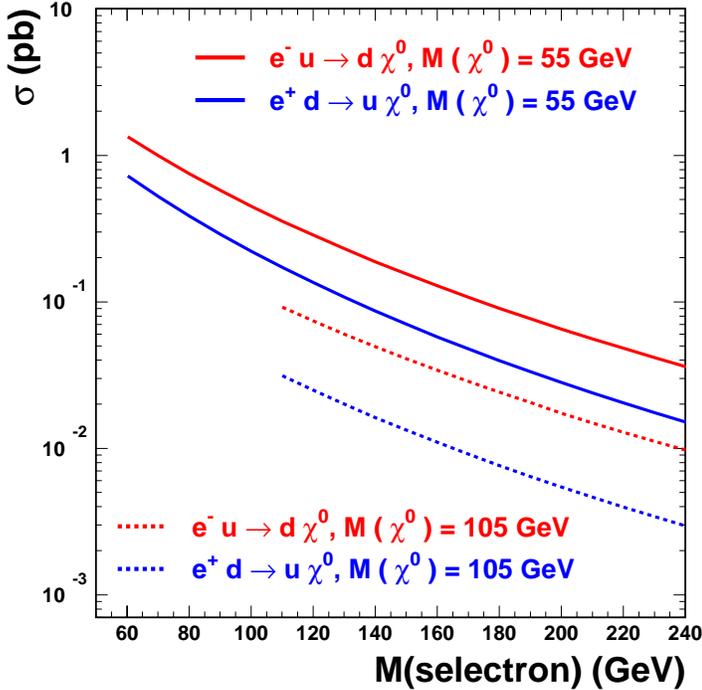
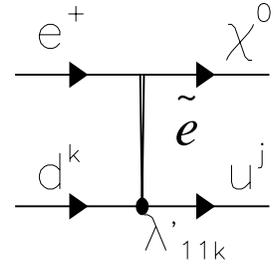
$m_0$  ( $m_{1/2}$ ) = common scalar (gaugino) mass at GUT scale

"Not Allowed"  $\equiv$  No radiative EW symmetry breaking or **LSP = slepton**

- Best sensitivity at HERA towards larger  $\tan \beta$  relative to Tevatron ( $\chi_1^0$  zino-like  $\Rightarrow$  decay in  $e^\pm q \bar{q}'$  suppressed)
- HERA Limits at larger  $\tan \beta \sim$  follow isomass curve

- If  $M_{\tilde{q}} \gg M_{\tilde{l}} \leftrightarrow \lambda'$  can still be probed via  $\tilde{l}$  exchange !

Also  $\tilde{\chi}^+$  production via  $\tilde{\nu}$  exchange



$$R_p + \text{MSSM/mSUGRA} \Rightarrow \chi_1^0 \rightarrow e^\pm q \bar{q}'$$

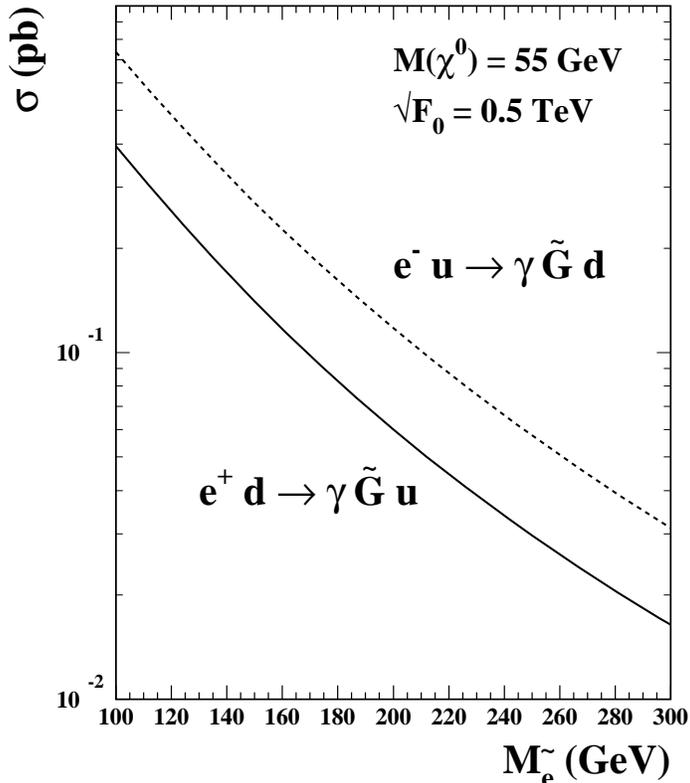
E. Perez, "Tool 99" (Lyon)

$\chi_1^0$  search can be extended for  $\tilde{l}^\pm$  beyond LEP<sub>II</sub> reach

Cross-sections here assumes:

$$\lambda' = 0.5 \quad \tan \beta = 1$$

$$\chi^0 \sim \tilde{\gamma}$$



$$R_p + \text{GMSB} \Rightarrow \chi_1^0 \rightarrow \gamma \bar{G}$$

Ch. Schwanenberger (2002)

GMSB: Sensitive to  $(\lambda', \sqrt{F_0})$

$\tilde{l}$  masses  $100 < M_{\tilde{l}} < 300$  GeV

Cross-sections here assumes:

$$\sqrt{F_0} = 0.5 \text{ TeV} \quad \tan \beta = 1$$

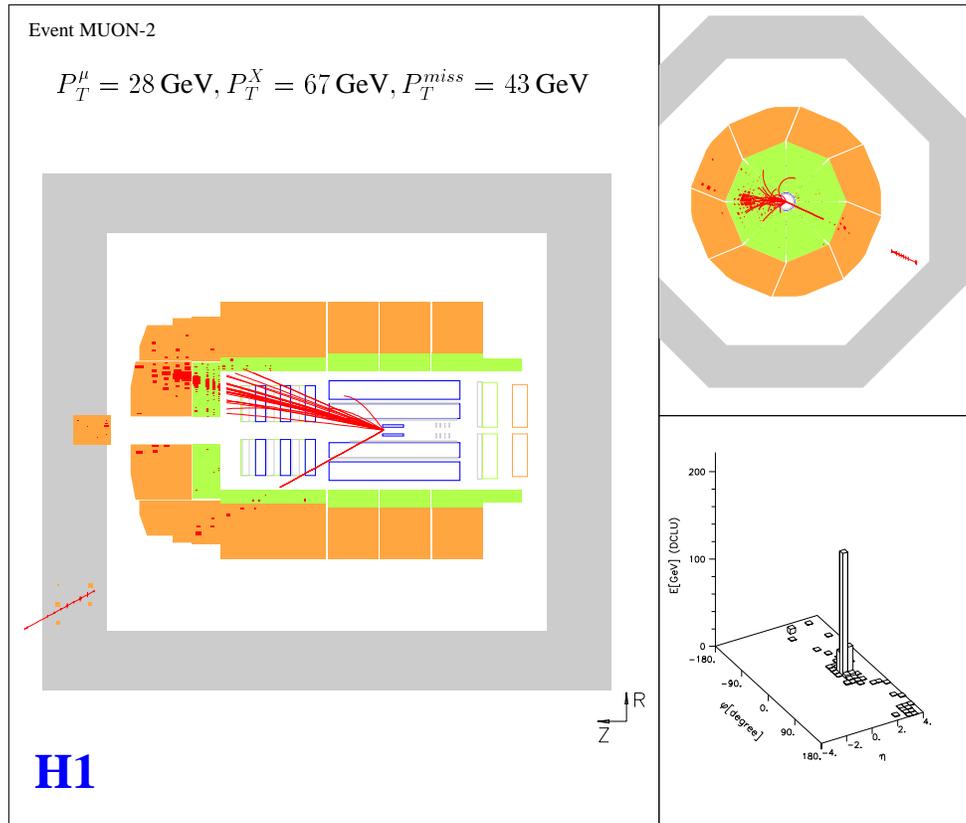
$$(\mu, M_1, M_2) = (-60, 50, 80) \text{ GeV}$$

$$M_{\tilde{G}} = F_0 / \sqrt{3} M_P$$

$$\sqrt{F_0} = \text{fund. scale of SUSY breaking}$$

# Outstanding Isolated Lepton Topologies at HERA ?

Reminder:



	$P_T^X > 0 \text{ GeV}$	$P_T^X > 40 \text{ GeV}$
<b>H1 selection:</b>	18	6
SM expectation:	$10.5 \pm 2.5$	$1.0 \pm 0.3$
<b>ZEUS selection:</b>	10	0
SM expectation:	$11.0 \pm 1.6$	-

Recall:  $R_p + \text{MSSM} : e^+d \rightarrow \tilde{t}_1 \rightarrow \tilde{b}W^+ ; \tilde{b} \rightarrow \bar{\nu}d \quad W^+ \rightarrow l^+\nu$

$R_p + \text{GMSB} : e^+d \rightarrow u\chi^+ ; \chi^+ \rightarrow \tilde{G}W^+ ; W^+ \rightarrow l^+\nu$

...

**top FCNC** :  $e^\pm u \rightarrow et ; t \rightarrow bW^\pm ; W^+ \rightarrow l^+\nu$

...

# Flavour Changing Neutral Currents

- FCNCs are absent at tree level in the Standard Model

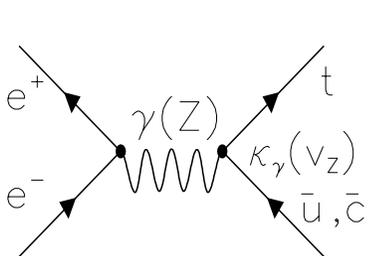
Neutral Currents are flavour diagonal

- FCNCs appear "naturally" (but strongly suppressed !) at one-loop level due to CKM mixing
- In some specific models, FCNC processes in the top sector receive a large contribution beyond the Standard Model rates:

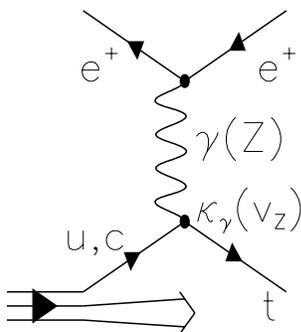
Theory	$\beta(t \rightarrow c\gamma, cZ^0)$
Standard Model	$\sim 10^{-13} - 10^{-12}$
Two Higgs Doublet	$\sim 10^{-9} - 10^{-8}$
Supersymmetry	$\sim 10^{-8} - 10^{-6}$
Multiple Higgs Doublet	$\sim 10^{-6} - 10^{-5}$
Quark Singlets	$\sim 10^{-2}$
Composite top quark	$\sim 10^{-2}$
R-Parity Violating SUSY	$\gtrsim 10^{-2}???$

- Because of its large mass, the top could be an ideally sensitive to physics beyond the Standard Model

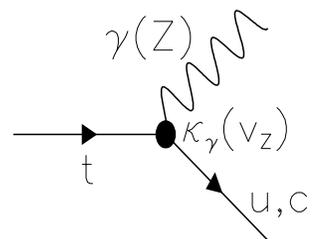
LEP



HERA



Tevatron



# Search for FCNCs at HERA

All available  $e^\pm p$  data;  $ep \rightarrow etX$ ;  $t \rightarrow bW$ ; leptonic and hadronic  $W$  decays

H1 prelim.- EPS HEP 2001 + DIS 2002

ZEUS prelim. - EPS HEP 2001

- Single top searches at HERA originally motivated by the finding of outstanding events with "isolated  $l +$  large  $\cancel{P}_T +$  high  $P_T$  jet"

(H1 excess not confirmed by ZEUS)

e.g.  $e$ -channel

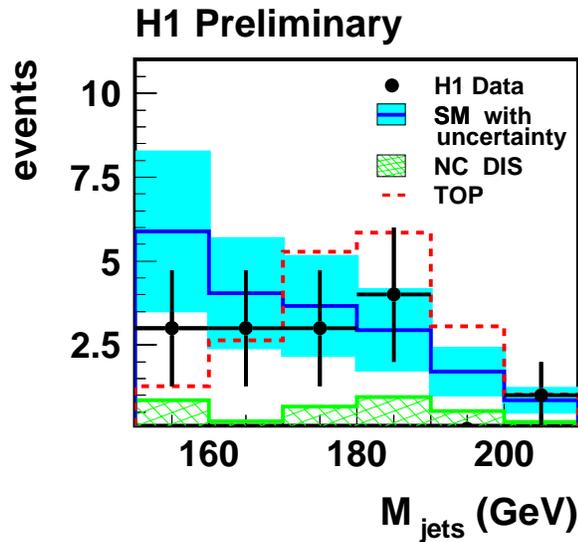
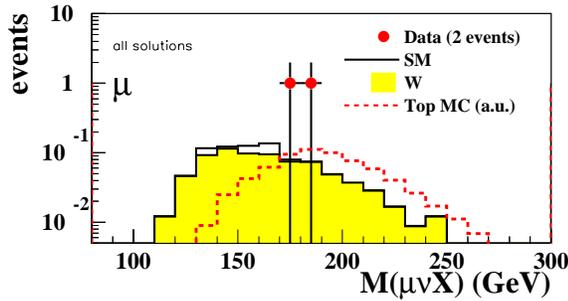
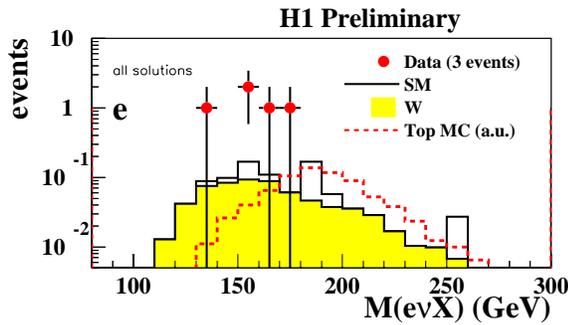
$$P_T^X > 25 \text{ GeV} \quad P_T^{jet} > 25 \text{ GeV}$$

$$M_T^{e\nu} > 10 \text{ GeV} \quad \epsilon \sim 40\%$$

had.-channel

$$P_T^{jet} > 40, 25, 20 \text{ GeV}$$

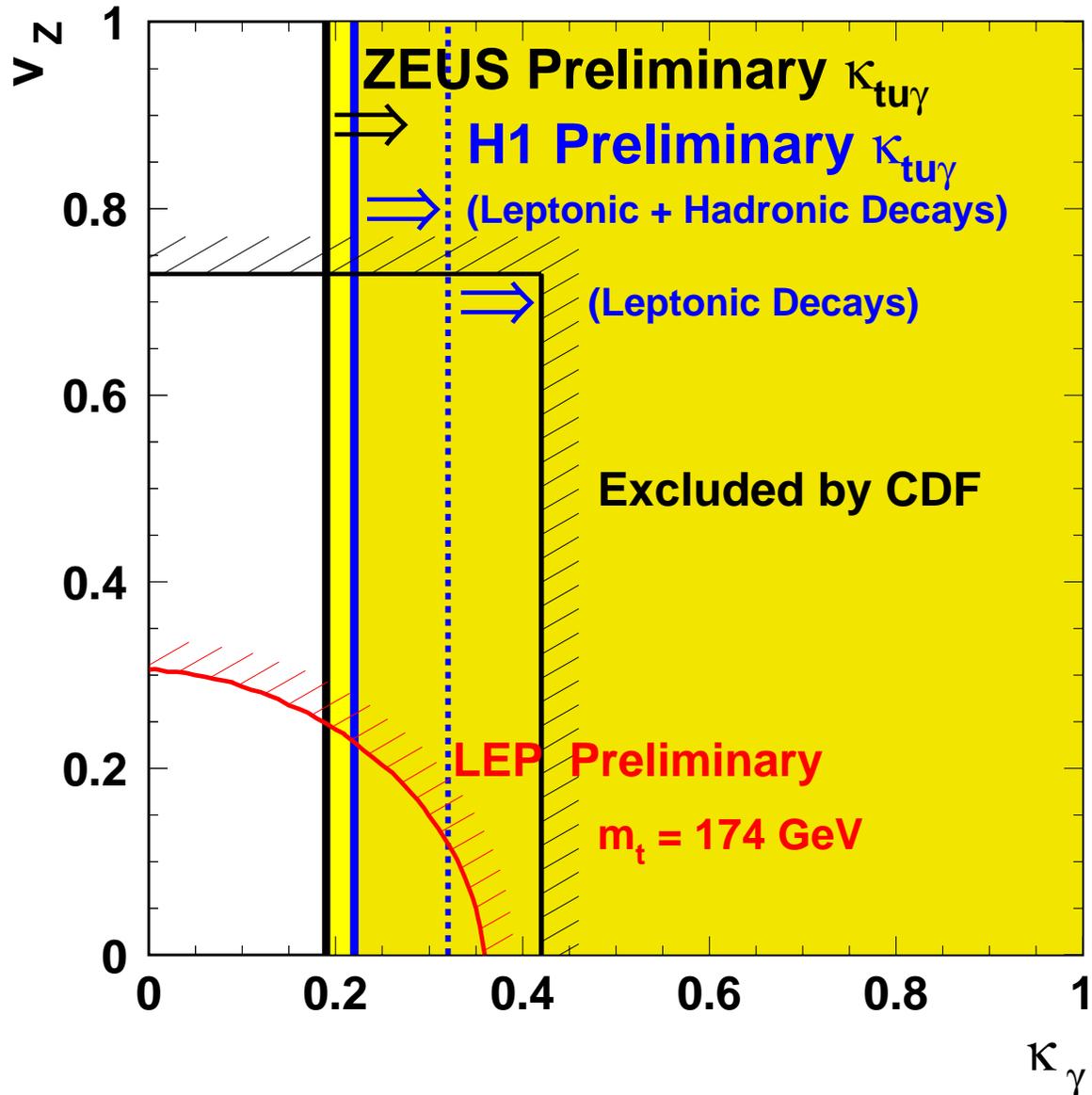
$$\epsilon \sim 30\%$$



	$e$ -channel	$\mu$ -channel	had.-channel
<b>H1 top selection:</b>	3	2	14
SM expectation:	$0.75 \pm 0.18$	$0.77 \pm 0.21$	$19.6 \pm 7.8$
Top efficiency:	37%	45%	27%
<b>ZEUS top selection:</b>	1	1	19
SM expectation:	$1.14 \pm 0.06$	$1.29 \pm 0.16$	$\sim 20$
Top efficiency:		$\sim 21\%$	

# Search for FCNCs at HERA

- Sensitivity at HERA comparable/complementary to that of LEP<sub>II</sub> and Tevatron<sub>I</sub> (... but ADLO combination using full LEP<sub>II</sub> data still to come !)



- HERA exclusion at 95% CL:

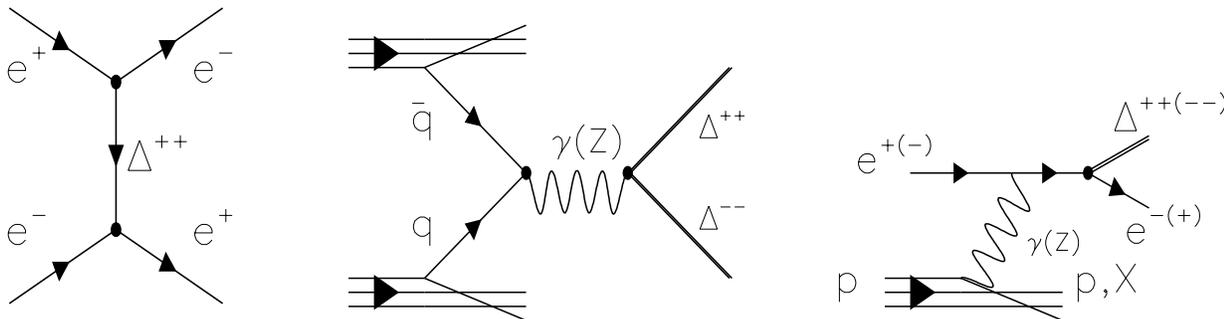
$$\kappa_{t\gamma} < 0.22 \text{ (H1)} \quad \kappa_{t\gamma} < 0.19 \text{ (ZEUS)}$$

# Doubly Charged Higgs Bosons

M. Kuze, Y. Sirois, PPNP Review (2002)

- **Doubly charged scalar particles  $\Delta^{\pm\pm}$**  appear in various models relying on an extension of the EW symmetries beyond SM
  - Gauged  $U(1)_{B-L}$  (*Pati-Salam* unification of color and lepton numbers);
  - Left-Right symmetric models (*Mohapatra et al., Cvetič et al., Huitu et al.*);
  - Higgs triplet models (*Georgi et al., Gunion et al.*).
- There  $\exists$  strong motivations for light  $\Delta^{\pm\pm}$  in SUSY models incorporating  $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- **SUSY L-R models  $\Rightarrow$** 
  - Two Higgs triplets  $(\Delta^0, \Delta^-, \Delta^{--})_{L \text{ or } R}$  acting solely in the leptonic sector ! Do not couple to ordinary fermion masses !
  - Appear alongside with sparticles, additional  $W'^{\pm}$  and  $Z'$  bosons;
  - Heavy Majorana neutrino  $N_R^i$  for each generation  $i$ , ...

At Colliders:

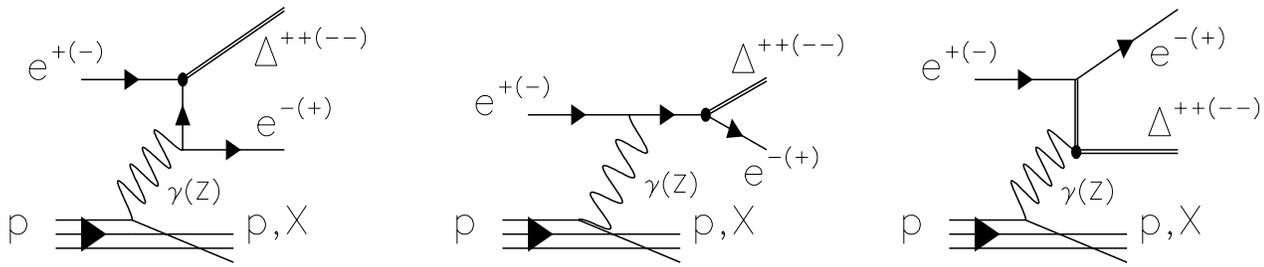


At HERA: e.g.  $e^+p \rightarrow e^- \Delta^{++} X$ ;  $\Delta^{++} \rightarrow l^+ l^+$   
 $\Rightarrow$  striking three lepton event topologies !

Note:  $\circ$  Bosonic decays  $\Delta^{--} \rightarrow \Delta^- W_R^-$ ;  $\Delta^- \Delta^-$  likely to be closed or disallowed.

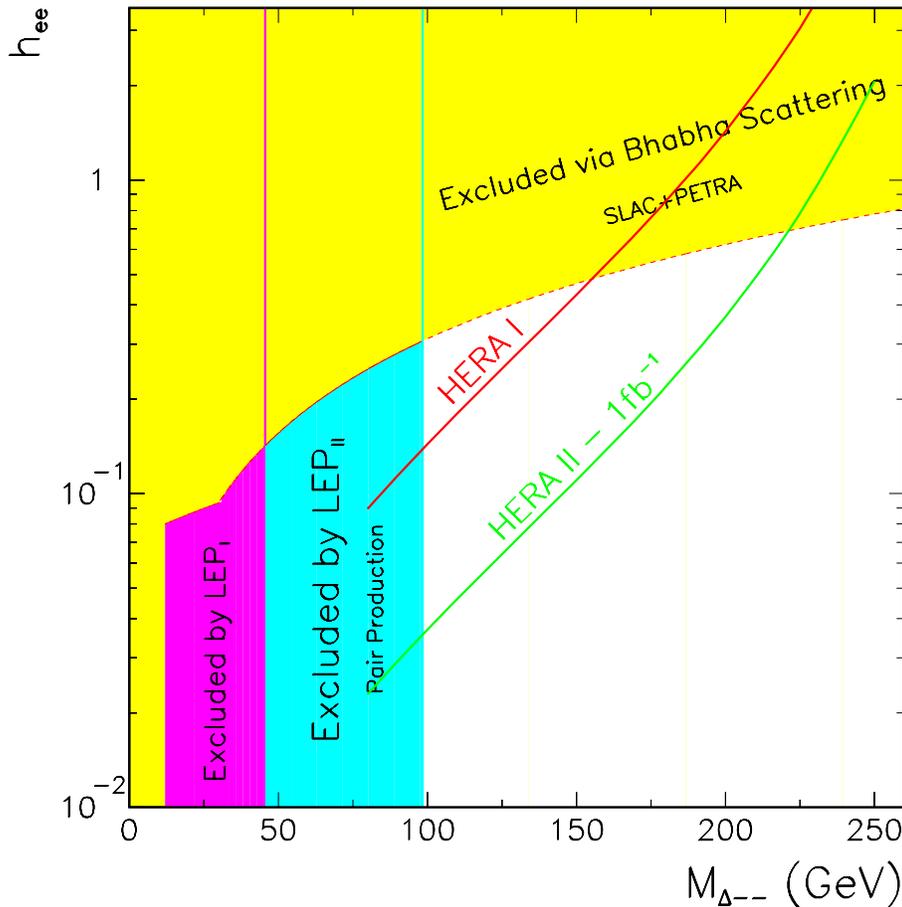
$\circ$  Direct couplings to quarks forbidden by  $Q$  conservation

# $\Delta^{\pm\pm}$ prospects at HERA



HERA Simulation using PYTHIA + COMPHEP (B. Olivier et al., H1 Collab.)

- Expect: (2/3) "elastic" and (1/3) "inelastic" contributions
- For  $M_{\Delta} \gtrsim 100$  GeV: in  $\lesssim 50\%$  cases 1  $e$  lost + 2  $e$  in  $20 \lesssim \theta \lesssim 150^\circ$   
 $\epsilon_{tot} \simeq 40\%$  to  $70\%$  to reconstruct the  $\Delta^{\pm\pm}$



HERA prospects assume:

No signal

Negligible background

$\beta(\Delta^{++} \rightarrow e^+e^+) = 100\%$

HERA<sub>I</sub>  $\epsilon_{tot} = 40\%$  (ct)

HERA<sub>II</sub>  $\epsilon_{tot} = 70\%$  (ct+fw)

⇓

For  $h_{ee} = 0.3$ :

$M_{\Delta} \lesssim 130$  GeV (HERA<sub>I</sub>)

$M_{\Delta} \lesssim 190$  GeV (HERA<sub>II</sub>)

Note:  $\exists$  Exhaustive review of constraints (Bileptons): F. Cuyper, S. Davidson (1998)

# Outstanding Multi-leptons at HERA

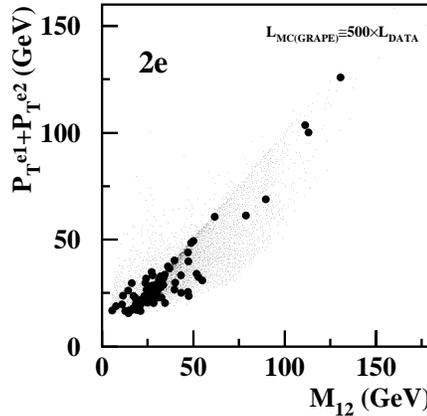
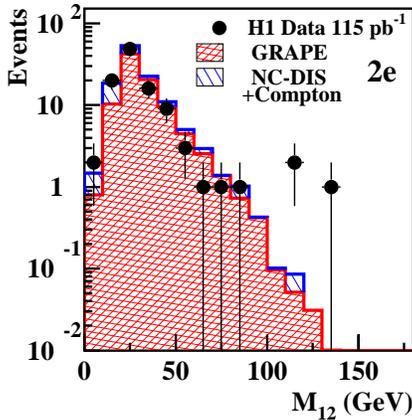
Electrons  $115 \text{ pb}^{-1} e^\pm p$  data (H1 Collab. preliminary DIS 2002)

Muons  $70 \text{ pb}^{-1} e^\pm p$  data (H1 Collab. preliminary DIS 2002)

- SM background: elastic+inelastic  $\gamma(e) - \gamma(p)$  collisions  
+ Cabbibo-Parisi ( $el$  reaction following  $\gamma(p) \rightarrow l^+l^-$ )

H1 Preliminary

Multi-electron Analysis



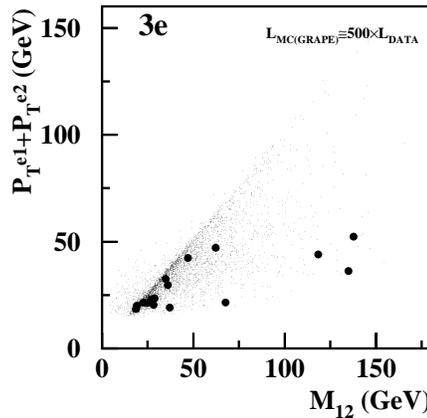
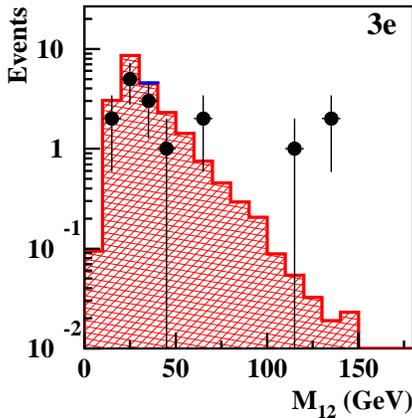
Analysis requires

$\geq 2$  central "e"

$[20 < \theta_e \lesssim 150^\circ]$

$P_T(e) > 5, 10 \text{ GeV}$

3<sup>rd</sup> "e" unrestricted



- Results at high masses:

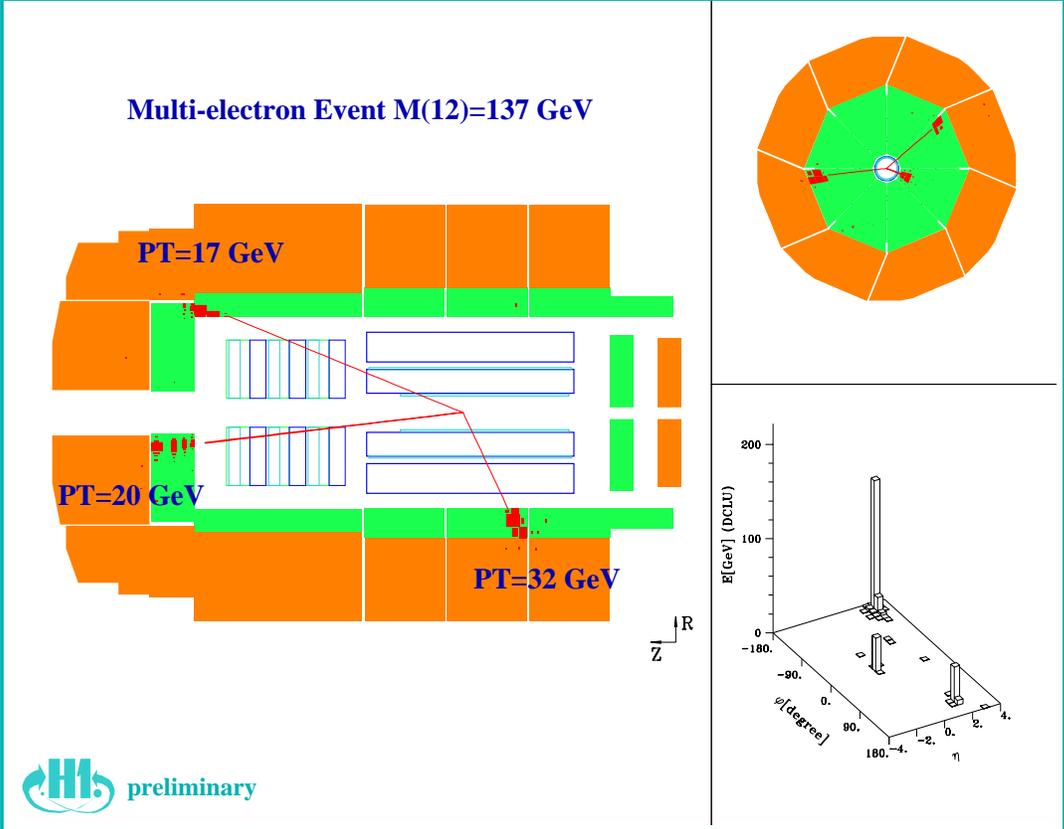
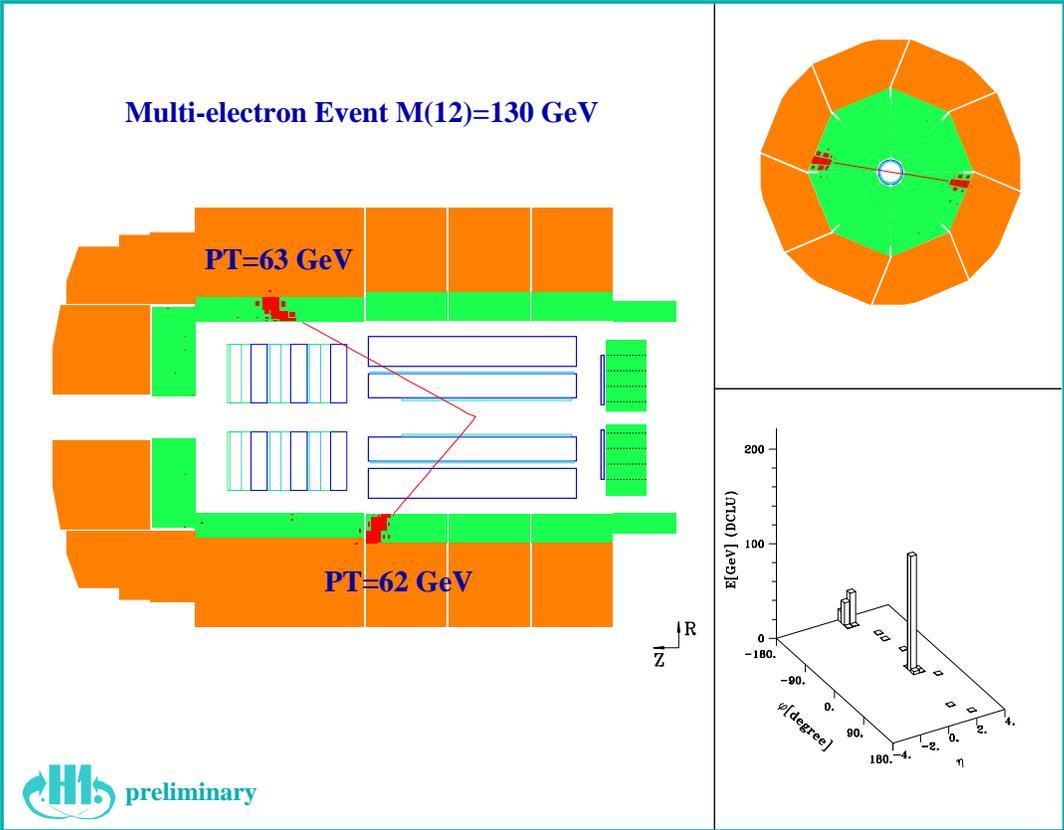
Selection	H1 DATA	SM
Visible 2e $M(12) > 100$	3	$0.25 \pm 0.05$
Visible 3e $M(12) > 100$	3	$0.23 \pm 0.04$

No  $\mu\mu$  events seen with  $M_{\mu\mu} > 100 \text{ GeV}$ ;

Three "2e" events  $\leftrightarrow 3 \times \mathcal{L}\epsilon(\mu\mu)/\mathcal{L}\epsilon(ee) \simeq 1\mu\mu$  event

# Outstanding Multi-leptons at HERA

(snapshot)



There do  $\exists$  possibly exciting new physics which could lead to acceptable and striking signals at HERA (leptoquarks, LFV, composite fermions, FCNCs,  $R_p$ -SUSY, doubly charged Higgs, Bileptons, contact interactions, extra-dimensions ...)

- Rather exhaustive searches have been performed at HERA<sub>I</sub> using or combining  $e^-p$  data [ $\mathcal{O}(10) \text{ pb}^{-1}$ ] and  $e^+p$  data [ $\mathcal{O}(100) \text{ pb}^{-1}$ ]
- Outstanding event topologies possible (beyond  $\exists$  constraints) from (e.g.)  $R_p$ -SUSY:  $\tilde{t}_1 \rightarrow \tilde{b}_1 + W$  ;  $W \rightarrow l\nu$   
 $t$ -channel slepton exchange  
FCNCs in top sector:  $eu \rightarrow et$  ;  $t \rightarrow Wb...$   
Doubly charged Higgses:  $e^+p \rightarrow e^- \Delta^{++} X$  ;  $\Delta^{++} \rightarrow l^+l^+$
- The upgraded HERA and Tevatron Colliders will offer ( $\geq 2002$ ) complementary sensitivity to new physics coupling to  $e - q$  pairs (leptoquarks, LFV, composite fermions, FCNCs,  $R_p$ -SUSY etc.) in a mass range beyond the reach of LEP<sub>II</sub>
- The discovery reach at HERA<sub>II</sub> can profit mainly from:  
 $\uparrow \mathcal{L}(e^\pm p)$  [ $\mathcal{O}(1) \text{ fb}^{-1} \times 2$ ]     $\uparrow \sqrt{s}_{ep}$  [330 GeV] maybe possible  
Disentangling an eventual signal at HERA<sub>II</sub> can profit from:  
 $e_{L,R}^\pm$  beam  $\leftrightarrow$  slightly improved signal/background  
 $\leftrightarrow$  distinguish quantum numbers