HERA H1 ZEUS

Searches and Discovery Prospects at HERA

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Outline:

- **Introduction: why bother ?**
- **Beyond Standard Model at HERA:**

  Main Topics of Interest:

  Leptoquarks, Gravitons in Extra Dimensions, Contact Interactions, L-Flavour Violation, $\not{R}_p$-SUSY, Doubly Charged Higgs, FCNCs

  Other Topics of Interest :

  Excited fermions, Bileptons, Technicolour, W_R Currents, R_p conserving SUSY, ...
- **Summary**

Introduction$^{(1)}$

(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$_I$	e^+e^-	M_Z	$\sim 160\text{ pb}^{-1} \otimes 4$	1989-95
LEP$_{II}$	e^+e^-	$> 2 \times M_W$	$\sim 700\text{ pb}^{-1} \otimes 4$	1996-00
HERA$_I$	$e^\pm p$	$\lesssim 320$ GeV	$\mathcal{O}(100\text{ pb}^{-1}) \otimes 2$	1994-00
Tevatron$_I$	$p\bar{p}$	1.8 TeV	$\mathcal{O}(100\text{ pb}^{-1}) \otimes 2$	1992-96
HERA$_{II}$	$e^\pm_{L,R}p$	~ 320 GeV	$\sim 1\text{ fb}^{-1} \otimes 2$?	2002-06
Tevatron$_{IIa}$	$p\bar{p}$	2.0 TeV	$\sim 3\text{ fb}^{-1} \otimes 2$?	2002-06 ?

Tevatron$_{IIb}$ (?) $\gtrsim$2007, LHC $\gtrsim$2007 ?, TESLA LC ? $\gtrsim$2012 ? ...

Introduction$^{(2)}$

(1) Why bother at HERA ?

HERA$_I$ (1994-00): $e^{\pm}p$ $E_e = 27.5$ GeV $Ep = 820$ to 920 GeV
$\sqrt{s_{ep}} = 300$ to 318 GeV $\mathcal{L} \sim \mathcal{O}(100)$ pb$^{-1} \times 2$

HERA$_{II}$ (2002-06): $e^{\pm}_{L,R}p$ $E_e = 27.6$ GeV $Ep \gtrsim 920$ GeV
$\sqrt{s_{ep}} \gtrsim 320$ GeV $\mathcal{L} \sim \mathcal{O}(1)$ fb$^{-1} \times 2$

Two general purpose experiments: H1 and ZEUS

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

Beyond the Standard Model:

HERA$_{II}$ 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)

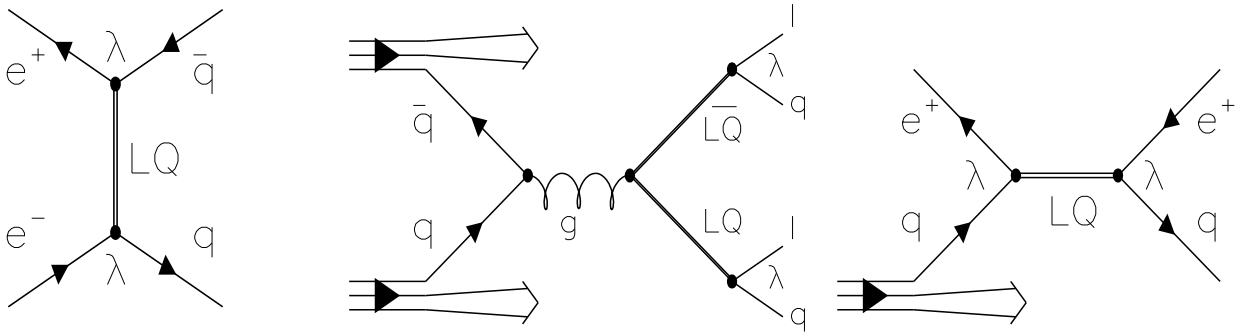
◦ Admittedly, considering existing constraints and current knowledge, HERA$_{II}$ will have essentially nothing to say on extra Z's; sparticles and Higgses in MSSM, mSUGRA, GMSB or AMSB theories...; anomalous TGB vertices; etc. ...

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 β_{eq} for 1^{rst} 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:

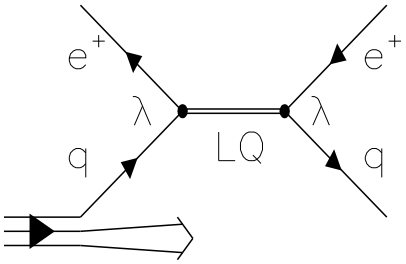
LEP Tevatron HERA



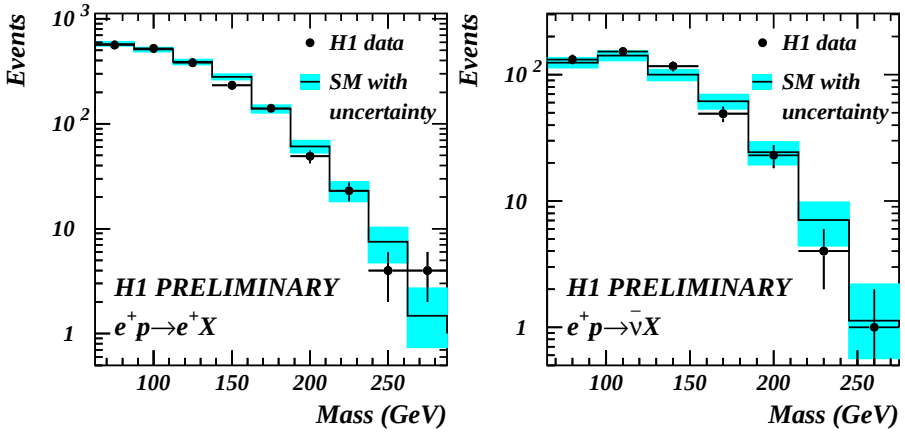
At HERA: ∘ $e^- p \to S_0\,;\ \tilde{S}_0\,;\ S_1$ $e^+ p \to \bar{S}_{1/2}\,;\ \bar{\tilde{S}}_{1/2}$
∘ All LQ types can be distinguished through $e^{\pm}_{L,R}$

Search for Leptoquarks at HERA

Previously published:
- $F = 0$ e^+p; $\mathcal{L} \simeq 37$ pb^{-1} H1 Collab. EPJ C11 (1999) 447
- $F = 2$ e^-p; $\mathcal{L} \simeq 15$ pb^{-1} H1 Collab. PLB 523 (2001) 234
- $F = 0$ e^+p; $\mathcal{L} \simeq 48$ pb^{-1} ZEUS Collab. EPJ C16 (2000) 253 PRD 63 (2001) 052002



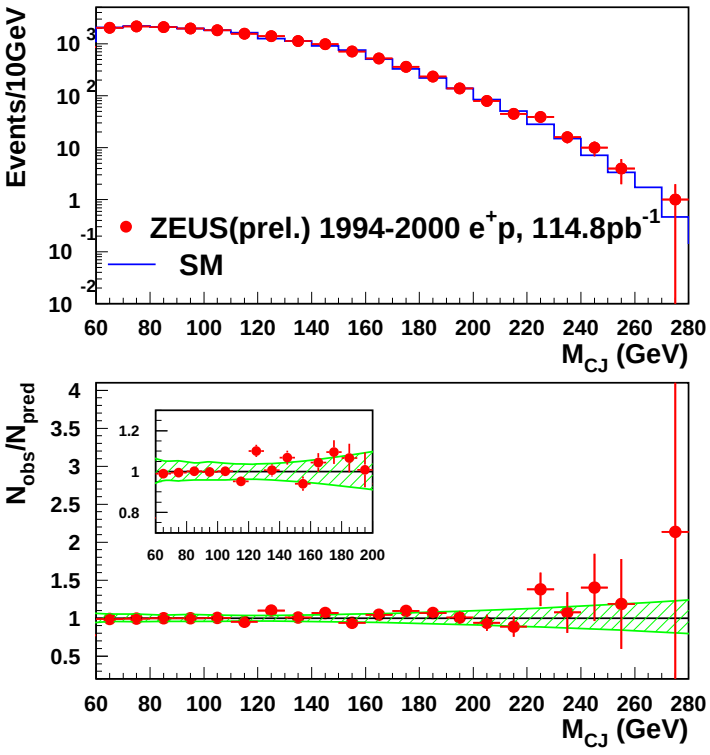
- LQ interaction interferes with with SM boson t-channel exchange
- Background reduction: $\cos(\theta^*_e)$ spectra distinct from SM DIS



NEW

Paper # 1027 ICHEP 2002

H1 combines all $e^{\pm}p$ data



NEW

Paper # 907 ICHEP 2002

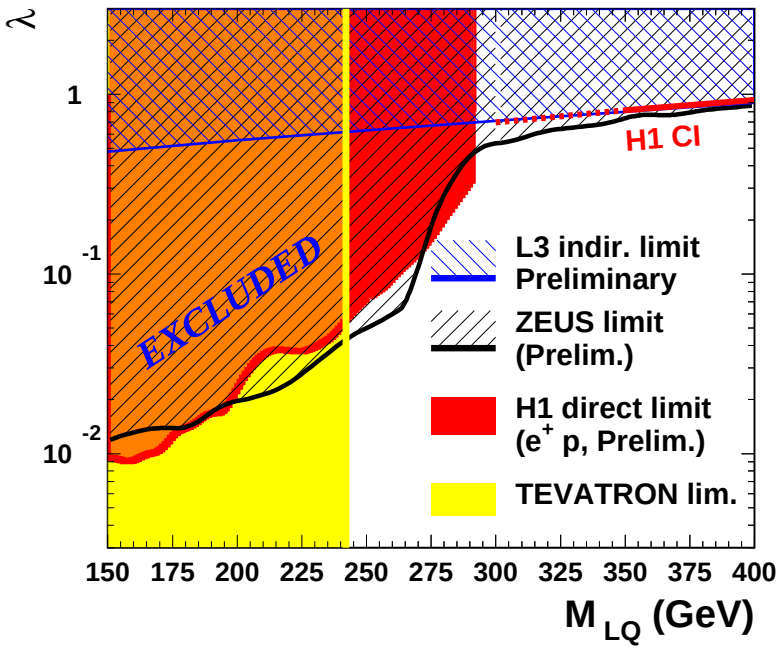
ZEUS combines all $e^{\pm}p$ data

No deviation from SM expectation !

Search for Leptoquarks at HERA

ZEUS paper #907 and H1 paper # 1027 ICHEP 2002 Minimal BRW Model

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



e^+p

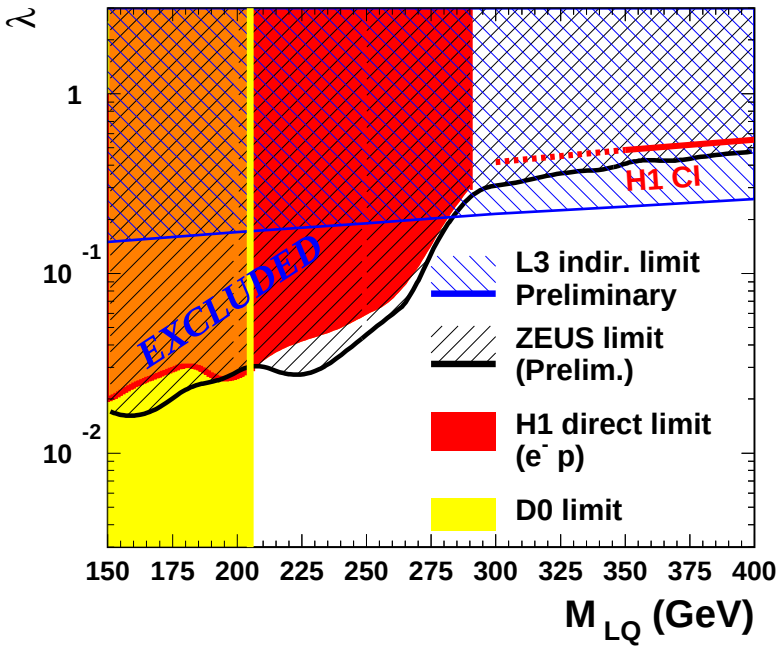
$Q_{em} = -2/3$ $\beta_{eq} = 100\%$

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 ↑ 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

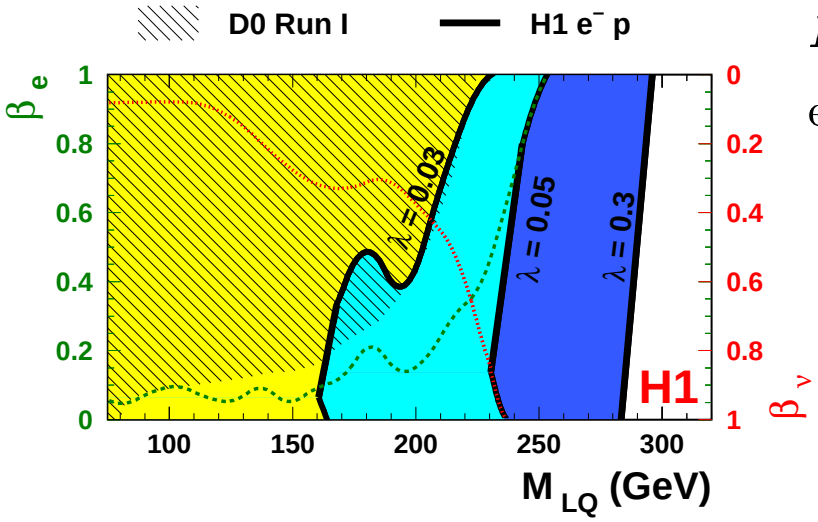
Recall: $M < \sqrt{s}$ $\lambda \ll 1 \Rightarrow \sigma \propto \lambda^2$

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

Search for Leptoquarks at HERA

ZEUS paper #907 and H1 paper # 1027 ICHEP 2002 Non-minimal models

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



$F = 2$

e.g. $S_{0,L}$

Partial Listing for SCALARS (from M. K., Y. S. PPNP 2002)

COLLIDER CONSTRAINTS on 1^{st} GENERATION LEPTOQUARKS					
β_e	Lower Limits at 95%CL			Assumptions	Experiment
	any λ_{lq}	$\lambda_{lq} \geq 0.1$	$\lambda_{lq} \geq 0.3$		
1	242	-	-	$p\bar{p} \to eeqq + X$	CDF⊕DØ
	-	282	298	$e^+u \to LQ^{F=0} \to eq$	H1
	-	276	295	$e^-u \to LQ^{F=2} \to eq$	ZEUS
	-	246	270	$e^+d \to LQ^{F=0} \to eq$	ZEUS
	-	243	276	$e^-d \to LQ^{F=2} \to eq$	H1
1/2	204	-	-	$p\bar{p} \to e\nu(ee)(\nu\nu)qq + X$	DØ
	-	275	292	$e^+u \to LQ^{F=0} \to eq$	H1
	-	271	294	$e^-u \to LQ^{F=2} \to eq, \nu q$	ZEUS
	-	235	265	$e^+d \to LQ^{F=0} \to eq, \nu q$	ZEUS
	-	230	270	$e^-d \to LQ^{F=2} \to eq$	H1
0	98	-	-	$p\bar{p} \to \nu\nu qq + X$	DØ
	-	237	262	$e^+d \to LQ^{F=0} \to \nu q$	ZEUS
	-	262	282	$e^-u \to LQ^{F=2} \to \nu q$	H1

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

Extra Dimensions at Colliders

- 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

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

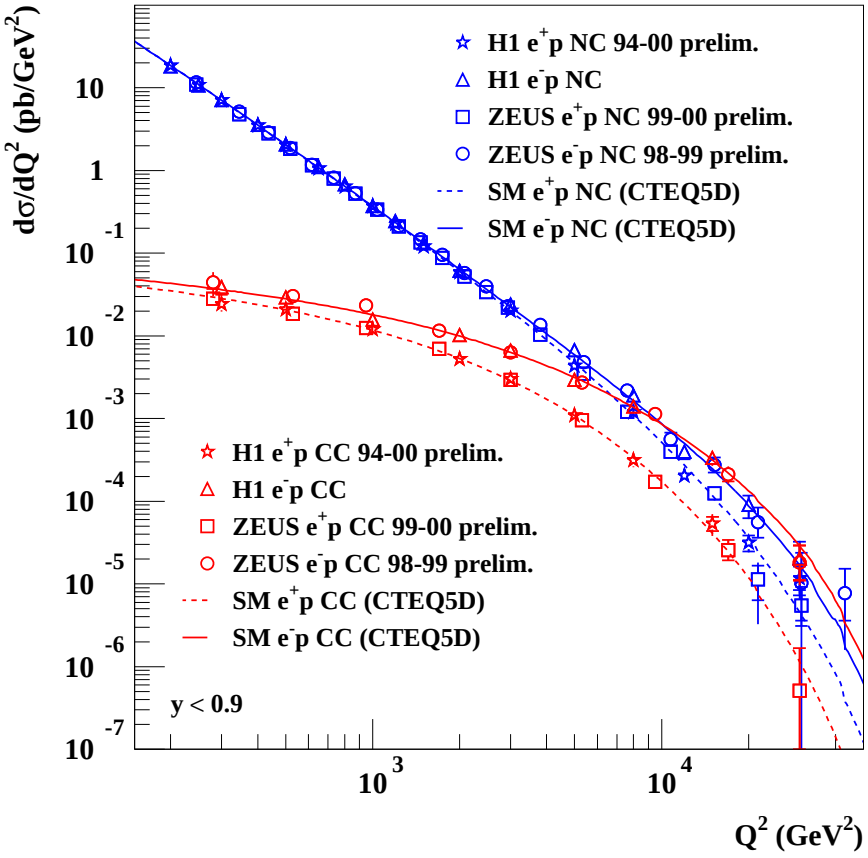
  R = size of the n compact extra dimensions

  M_S = gravitional scale in $4+n$ dimensions

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

  $\Rightarrow$ virtual "graviton" exchange interferes with γ, Z exhange with an effective (contact interaction) coupling $\eta_G = \lambda/M_S^4$
- Observable effects in $e^+e^- \to f\bar{f}$, $\quad q\bar{q} \to l\bar{l}$, $\quad eq \to lq'$

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

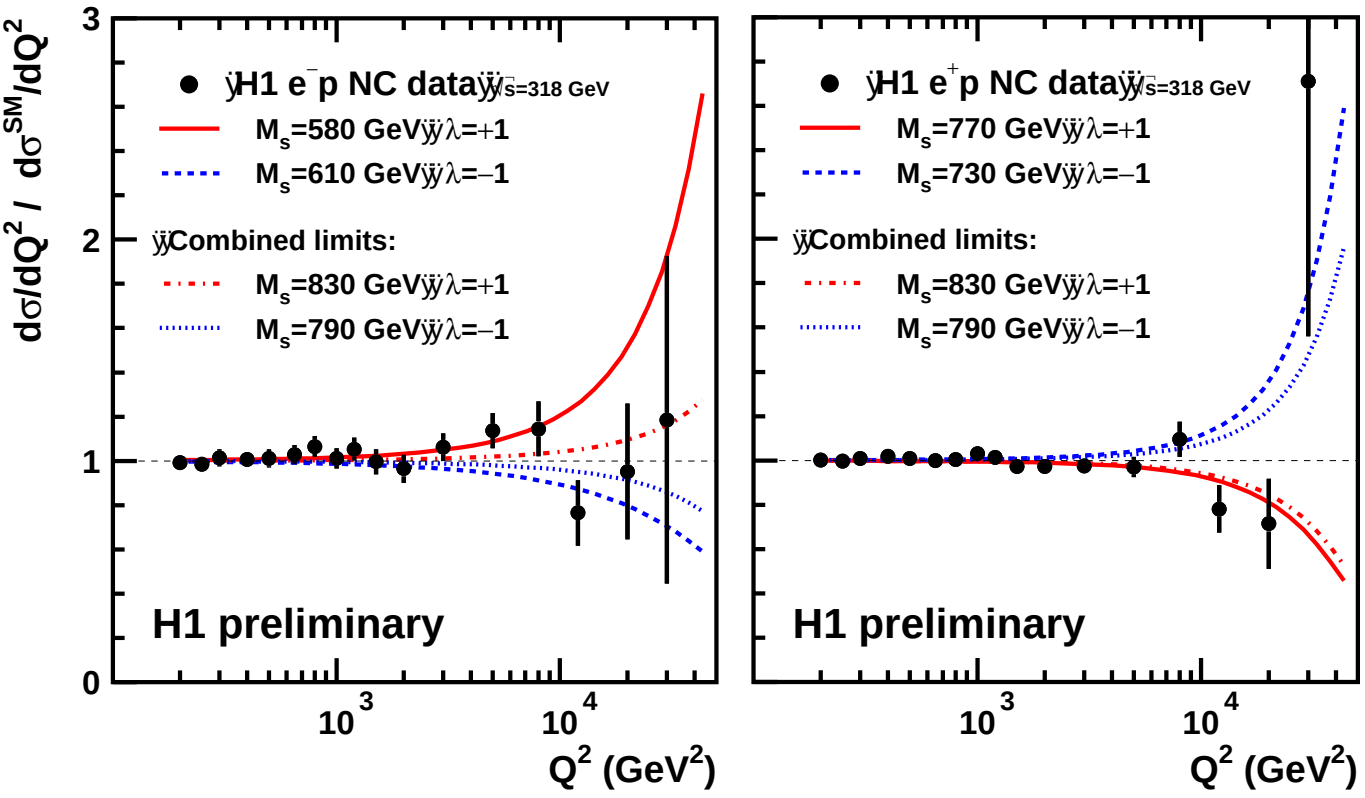


Search for Extra Dimensions at HERA

Published: H1 Collab. PLB 479 (2000) 358

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

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



HERA$_I$, Tevatron$_I$ and LEP$_{II}$ results:

95% CL limit on M_S [TeV]					
λ	H1	ZEUS	CDF[a]	D0[b]	LEP Combined[c]
+1	0.83	0.81	0.96	1.21	1.26
-1	0.79	0.82	0.94	1.13	0.96

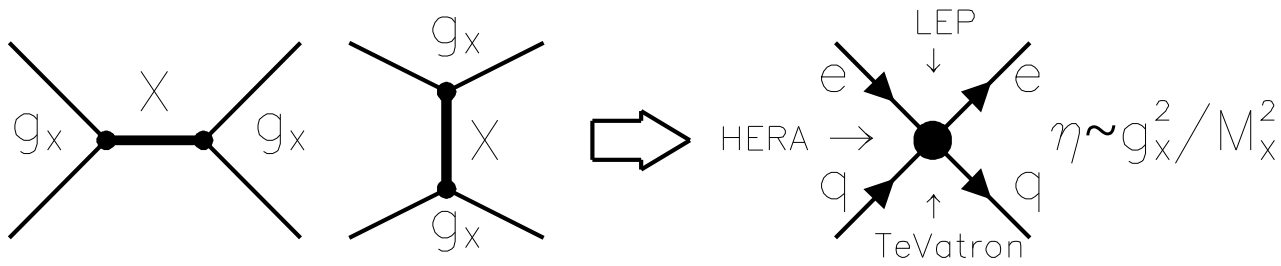
Results conversion from Hewett (H) to Giudice, Rattazi, Wells (GRW) formalism via $M^4_{GRW} = (\pi/2)M^4_H$

[a] J. Carlson, APS Meeting (May 2001) [b] DØ Collab., PRL 86 (2001) 1156

[c] From D. Bourilkov, A+D+L+O experiments for LEP$_{II}$ $\sqrt{s}$ 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 η $[mass^{-2}]$



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

$\eta_{ij} \equiv \pm\epsilon g^2/\Lambda^2_{ij} \qquad i,j = R,L$
g = coupling strength $= 4\pi$; $\quad \Lambda_{ij} scale \equiv M_x$
APV requires $\eta^q_{LL} + \eta^q_{LR} - \eta^q_{RL} - \eta^q_{RR} = 0$

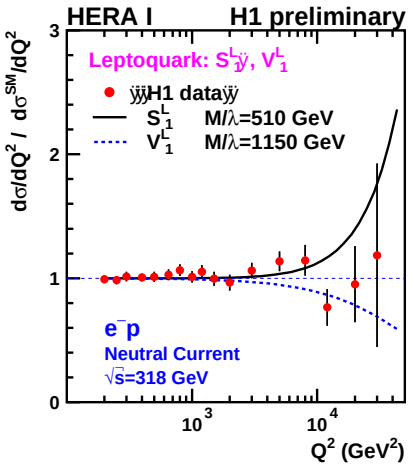
- Various vector and axial vector combinations can be considered

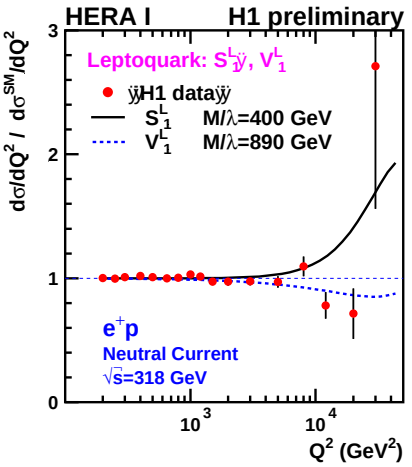
e.g. Parity conserving Compositeness models with q universality:

VV= LL + LR +RL + RR AA= LL- LR - RL + RR ...

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

$S_1^L \Rightarrow \epsilon^d_{LL} = 2 \times \epsilon^u_{LL} = +1$





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 $[\epsilon_{LL},\epsilon_{LR},\epsilon_{RL},\epsilon_{RR}]$	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
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}/λ_{LQ} [GeV]						
Model	Coupling Structure	H1	ZEUS	ALEPH	L3	OPAL
$S_\circ^L$	$\epsilon^u_{LL} = +\frac{1}{2}$	720	750	640	1240	640
$S_\circ^R$	$\epsilon^u_{RR} = +\frac{1}{2}$	670	690		960	
$\tilde{S}_\circ^R$	$\epsilon^d_{LL} = +\frac{1}{2}$	330	310	220	260	590
$S_{1/2}^L$	$\epsilon^u_{LR} = -\frac{1}{2}$	870	910	-	180	460
$S_{1/2}^R$	$\epsilon^d_{RL} = \epsilon^u_{RL} = -\frac{1}{2}$	370	690		350	630
$\tilde{S}_{1/2}^L$	$\epsilon^d_{LR} = -\frac{1}{2}$	430	500			370
S_1^L	$\epsilon^d_{LL} = 2 \cdot \epsilon^u_{LL} = +1$	480	550	770	640	930

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

For $\lambda = 1$ some LQs excluded up to ~ 900 GeV for scalars

(~ 1.4 TeV for vectors)

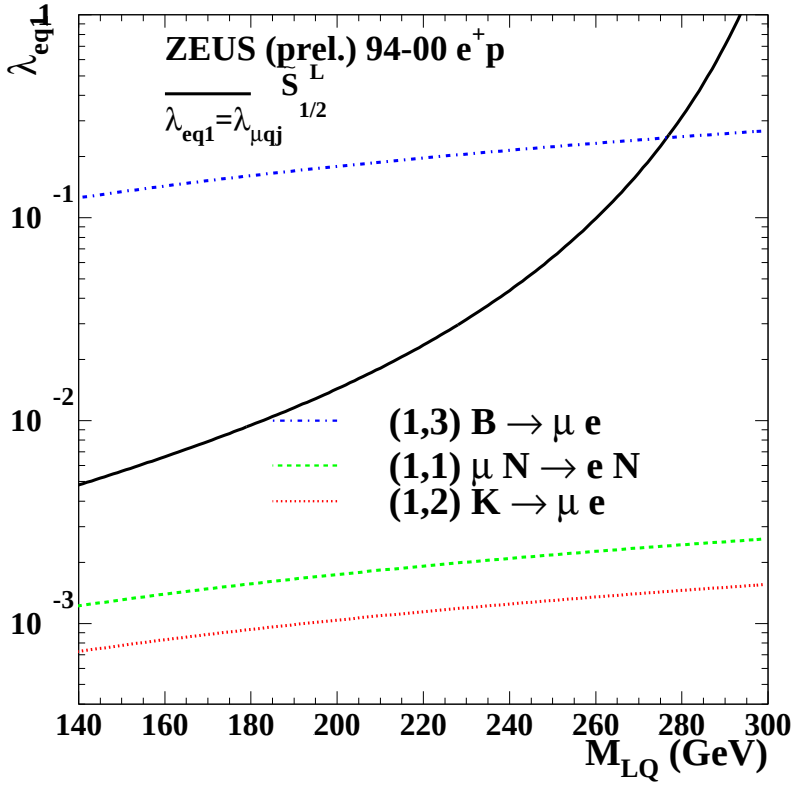
Lepton Flavor Violation at HERA

H1 Eur. Phys. J. C11 (1999) 447
ZEUS paper #906 ICHEP 2002

- Lepton Flavour is conserved in all interactions of the SM
- The **reason** why individual L_e, L_μ and L_τ should be exactly conserved in nature is **unknown**

  Strong evidence already for LFV but only in neutrino sector
- Extensive searches have been carried in dedicated experiments

  (μ nuclear capture, rare or forbidden μ, τ, K, B or D decays)



- ***ep* colliders**

  ⇓

  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 $\lambda_{eq_i} \times \lambda_{\tau q_j}$

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

- LFV in virtual leptoquark exchange for $M_{LQ} \gg \sqrt{s}$

  (cross-section $\propto \lambda_{eq_\alpha}\lambda_{\tau q_\beta}/M^2_{LQ}$)

  e.g. Upper limits for $e \to \tau$ transitions better than most stringent indirect bounds from rare and forbidden decays for about 1/3 of all possible coupling products

  (best for HERA when involving 2^{nd} or 3^{rd} generation quarks)

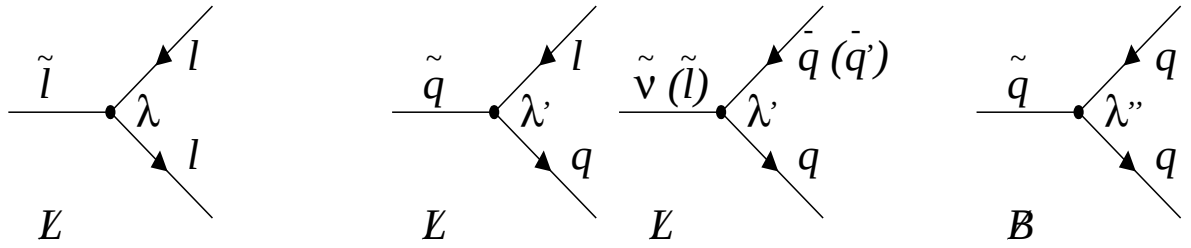
R-Parity Violating SUSY

- The General Superpotential:

$$W = W_{MSSM} + W_{\not R_p} \qquad R_p = (-1)^{3B+L+2S} \leftrightarrow +1 \text{ for particles; } -1 \text{ for Sparticles}$$

$$W_{\not R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}k$$

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 λ, λ' or λ'':

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

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

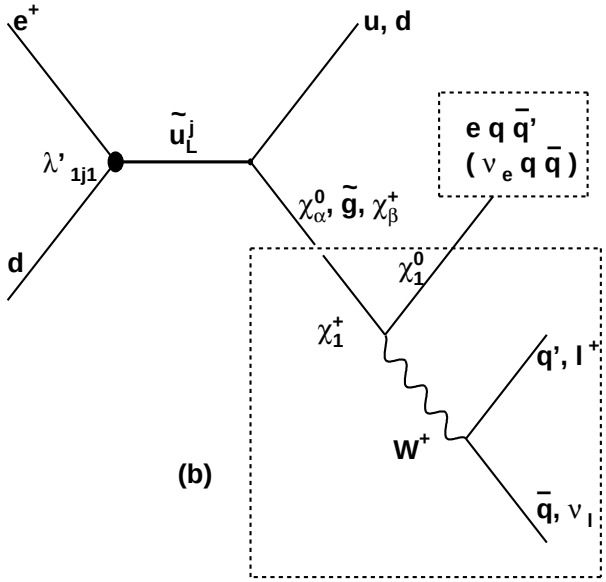
- Best discovery reach for SUSY at HERA = single $\tilde{q}$ prod. through λ'!

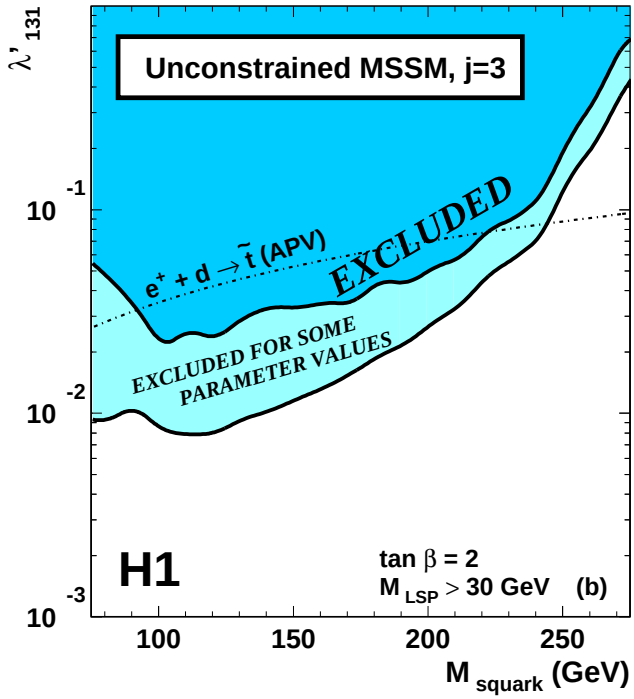
Search for $\not{R}_p$-SUSY at HERA

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

- Different kinds of $\tilde{q}$ produced dominantly for $e^{\pm}$
  $e^- p \leftrightarrow \lambda'_{11k}$ and $\tilde{d}_R$-like $\tilde{q}$ $\quad e^+ p \leftrightarrow \lambda'_{1j1}$ and $\tilde{u}_L$-like $\tilde{q}$ (e.g. the $\tilde{t}$)

$-300 < \mu < 300$ GeV $\quad 70 < M_2 < 350$ GeV





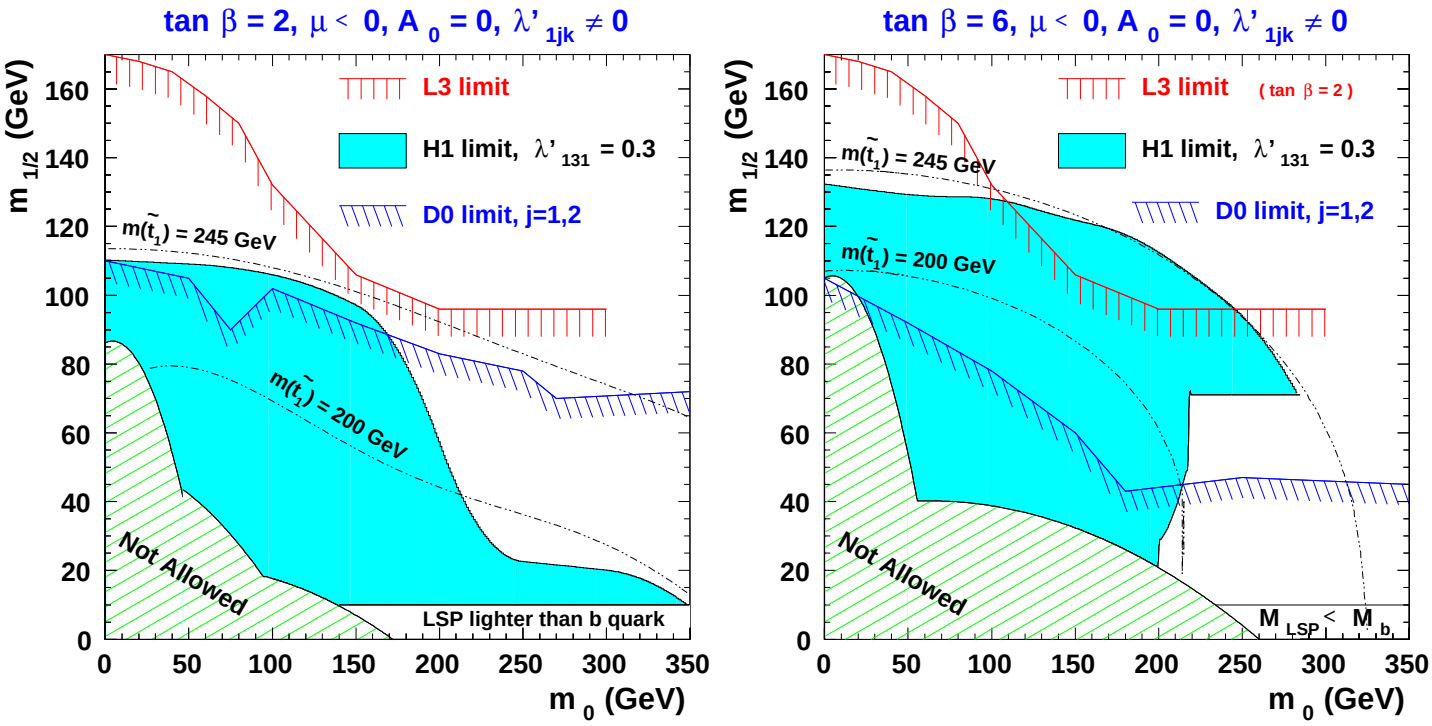
$M_{\tilde{q}} \gtrsim 260$ GeV for $\lambda'_{1j3} = 0.3$

Sensitivity = widely model independent ... and beyond indirect limits

- The special case of the $\tilde{t}$: possibly significant rates both in
  $\tilde{t}_1 \to \tilde{b}_1 + W$ and $\tilde{t}_1 \to ed$ (E. Perez, SUSY 98 & Tools for SUSY 99)
  $\Rightarrow$ possibly outstanding event topologies: $l^{\pm} + jet + \not{P}_T$ (E. Gallo's talk)
- If $M_{\tilde{q}} \gg M_{\tilde{l}}$ the λ'_{11k} can still be probed
  via $\tilde{\chi}^0$ associated production ($\tilde{l}$ exchange)
  or $\tilde{\chi}^{\pm}$ associated production ($\tilde{\nu}$ exchange)
  (E. Perez, Tools for SUSY 99)(Ch. Schanenberger (2002)

Search for $\not{R}_p$-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
  (χ_1^0 zino-like $\Rightarrow$ decay in $e^{\pm}q\bar{q}'$ suppressed)
- HERA Limits at larger $\tan\beta$ $\sim$ follow isomass curve

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., Cvetic et al., Huitu et al.*);

  Higgs triplet models (*Georgi et al., Gunion et al.*).

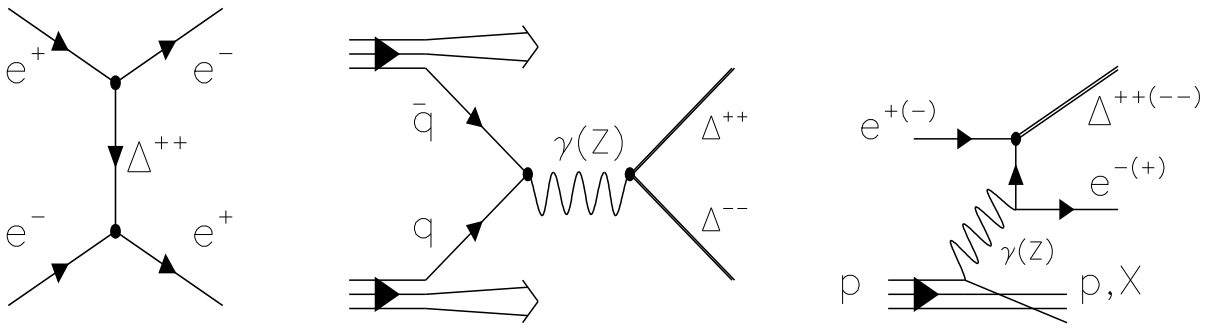
- There $\exists$ strong motivations for light $\Delta^{\pm\pm}$ in SUSY models incorporating $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

- SUSY L-R models $\Rightarrow$
  Two Higgs triplets $(\Delta^0, \Delta^-, \Delta^{--})_{L\,or\,R}$ **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. $e^+p \to e^-\Delta^{++}X$; $\Delta^{++} \to l^+l^+$

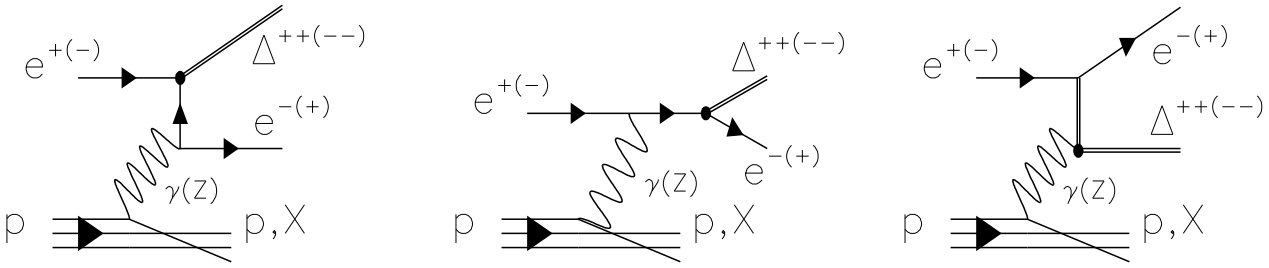
$\Rightarrow$ striking three lepton event topologies !

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

◦ Direct couplings to quarks forbidden by Q conservation

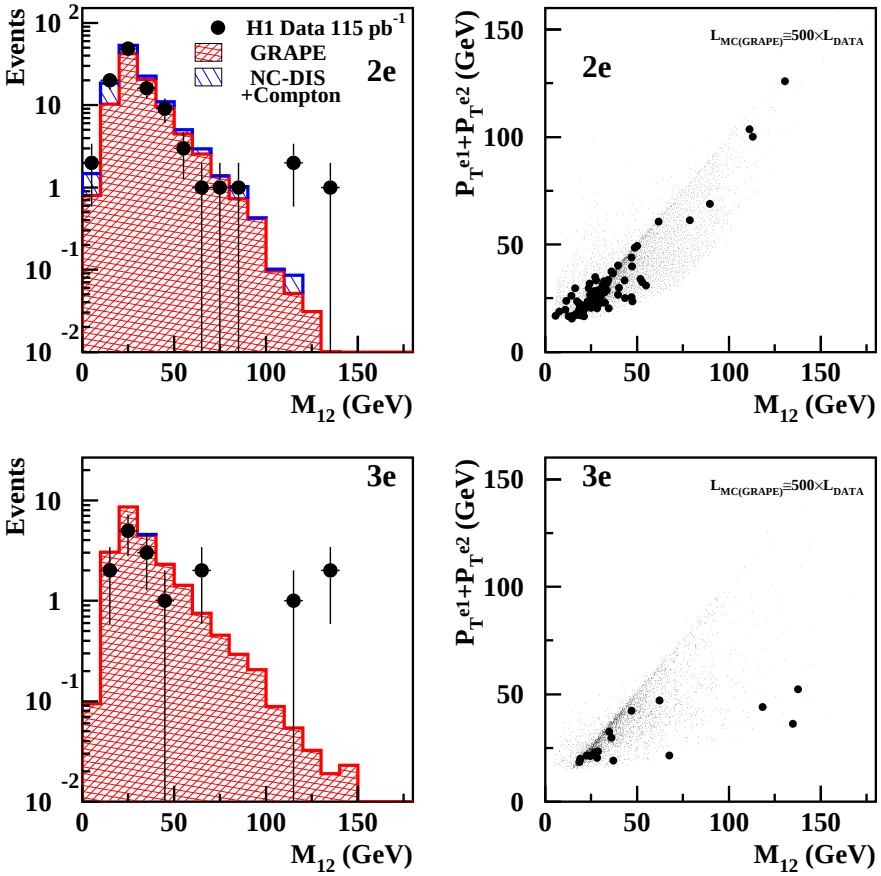
$\Delta^{\pm\pm}$ Search at HERA

H1 paper # 1020 ICHEP 2002



- 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 $20 \lesssim \theta \lesssim 150°$
  $\epsilon_{tot} \simeq 40\%$ to 70% to reconstruct the $\Delta^{\pm\pm}$

H1 Preliminary **Multi-electron Analysis**



Analysis requires

≥ 2 central "e"

$\left[20 < \theta_e \lesssim 150°\right]$

$P_T(e) > 5, 10$ GeV

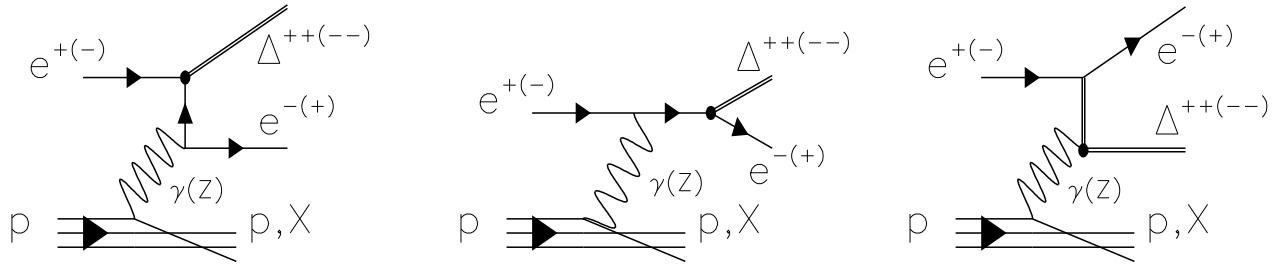
3^{rd} "e" unrestricted

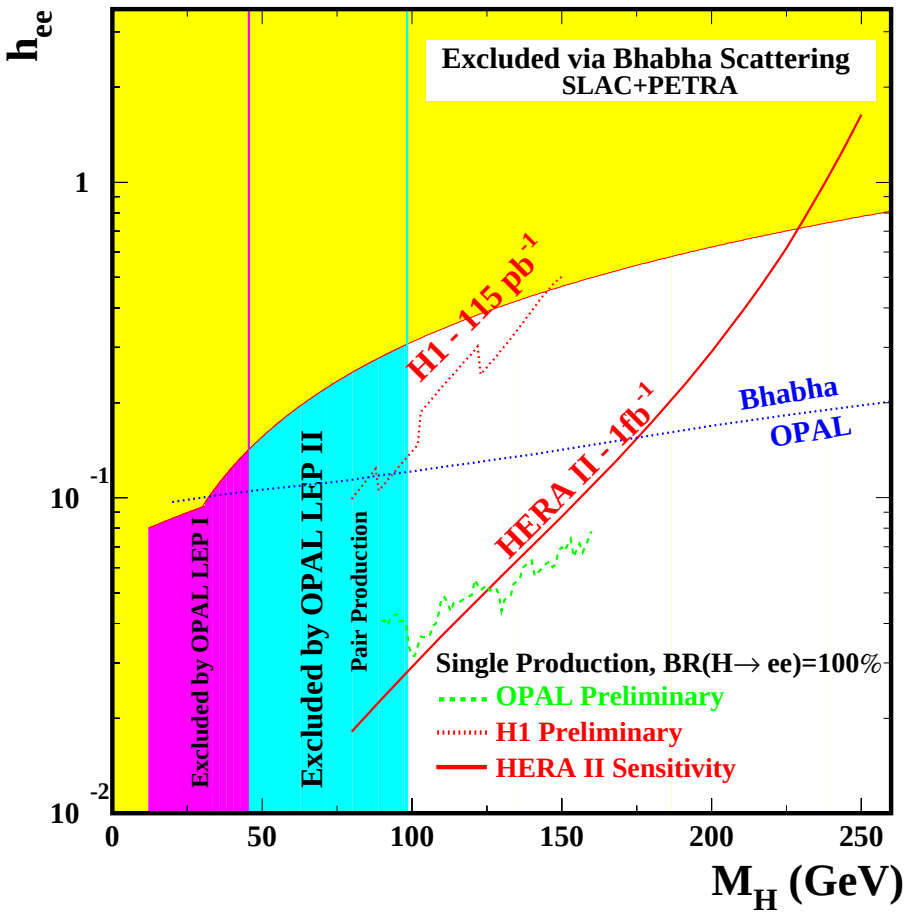
- Specific $\Delta^{\pm\pm}$ selection: M_H dependent cut on $P_T^{e1} + P_T^{e2}$
  No wrong sign tracks from $\Delta^{\pm\pm}$ decay

Only one "2e" event survives at $M_\Delta > 100$ GeV

$\Delta^{\pm\pm}$ Search at HERA

H1 paper # 1020 ICHEP 2002





For $h_{ee} = 0.3$:

$M_\Delta \lesssim 130$ GeV (HERA$_I$)

HERA$_{II}$ prospects:

Assume no signal

Negligible background

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

HERA$_{II}$ $\epsilon_{tot} = 70\%$ (ct+fw)

$\Downarrow$

For $h_{ee} = 0.3$:

$M_\Delta \lesssim 190$ GeV (HERA$_{II}$)

- Sensitivity at HERA$_{II}$ to h_{ee} values below indirect constraints and above LEP direct searches for M_Δ up to $\simeq 175$ GeV

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

Other Topics of Interest at HERA

Snapshot

Flavour **C**hanging **N**eutral **C**urrents (top sector):

- FCNCs absent at tree level in the Standard Model (Neutral Currents are flavour diagonal; FCNCs appear "naturally" but strongly suppressed (!) only at one-loop level due to CKM mixing
- In some specific BSM models, large contributions to FCNC processes possible in the top sector (Multiple Higgs Doublets, Composite top quark, R-Parity Violating SUSY, ...)
- HERA experiments sensitive to $\kappa_{tu\gamma} \lesssim 0.2$ via $ep \to etX$; $t \to bW$ Outstanding event topologies; $\Rightarrow$ E. Gallo's talk

Recent: ZEUS EPS HEP 2001 and H1 EPS HEP 2001 + paper # 1024 ICHEP 2002

Excited Fermions

- Family "replica" over three generations $\Rightarrow$ composite quarks and leptons ? Possibility to create e^*, q^* excited states ?

Recent: ZEUS paper # 912 and H1 paper # 1025+1026 ICHEP 2002

Bileptons

- Interesting phenomenology to be studied at HERA for e.g. vector bileptons $(X^{\pm\pm}, X^{\pm})$ (gauge bosons in 3-3-1 models)

Right-Handed Currents

- Sensitivity at HERA$_{II}$ beyond Tevatron$_I$ ... but only in case of maximal g_R/g_L + very peculiar mass-mixing matrix in right-handed sector (e.g. setting $V_{us}^R = 1$) + highest luminosities + best precision on highest possible lepton beam polarization level !

Exoticas

Summary

There do $\exists$ possibly exciting new physics which could lead to acceptable and striking signals at HERA (leptoquarks, LFV, composite fermions, FCNCs, $\not{R}_p$-SUSY, doubly charged Higgs, Bileptons, contact interactions, extra-dimensions ....

- Rather exhaustive searches have been performed at HERA$_I$ using or combining e^-p data [$\mathcal{O}(10)$ pb^{-1}] and e^+p data [$\mathcal{O}(100)$ pb^{-1}]

- Outstanding event topologies possible (beyond $\exists$ constraints) from (e.g.)
  $\not{R}_p$-SUSY: $\tilde{t}_1 \to \tilde{b}_1 + W$; $W \to l\nu$
  t-channel slepton exchange
  FCNCs in top sector: $eu \to et$; $t \to Wb$...
  Doubly charged Higgses: $e^+p \to e^-\Delta^{++}X$; $\Delta^{++} \to l^+l^+$

- 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, $\not{R}_p$-SUSY etc.) in a mass range beyond the reach of LEP$_{II}$

- The discovery reach at HERA$_{II}$ can profit mainly from:
  $\uparrow \mathcal{L}(e^\pm p)$ [$\mathcal{O}(1)$ fb^{-1} $\times$ 2] $\uparrow \sqrt{s}_{ep}$ [330 GeV] maybe possible
  Disantangling an eventual signal at HERA$_{II}$ can profit from:
  $e^\pm_{L,R}$ beam $\leftrightarrow$ slightly improved signal/background
  $\leftrightarrow$ distinguish quantum numbers