Searches Beyond Standard Model at Existing Colliders

Discovery Prospects at HERA_{II} and Tevatron_{II}

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Outline:

- **Introduction: why bother ?**
- **Leptoquarks, Technicolor, L Flavor Violation, $\not{R}_p$-SUSY, Right-handed W Currents, FCNCs, Doubly Charged Higgs, Bileptons, q^*'s and e^*'s, Contact Interactions, Extra Dimensions, ...**
- **Summary**

Foreword

Assignment (from Achim Geiser):

- $\lesssim$ 25 min. talk
- " ... **not** ... meant to be ... **a complete review of all** .... **topics concerned** ..."
- " ... **focus on new, controversial topics** and/or **topics of particular interest** ..."
- " ... in order to **stimulate discussions** and **give some ideas on how to proceed** with further analysis ..."

Why bother in general ?

- Almost no undisputable evidence for physics beyond the Standard Model has been found since $\sim$ 25 years (except in the ν sector ...)

But:

- 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_{Ia}	$e^\pm p$	300 GeV	$\mathcal{O}(1\text{ pb}^{-1})$	1992-93
HERA_{Ib}	$e^\pm p$	$\lesssim$ 320 GeV	$\mathcal{O}(100\text{ pb}^{-1}) \otimes 2$	1994-00
Tevatron_{Ia}	$p\bar{p}$	1.8 TeV	$\mathcal{O}(10\text{ pb}^{-1})$	1987-89
Tevatron_{Ib}	$p\bar{p}$	1.8 TeV	$\mathcal{O}(100\text{ pb}^{-1}) \otimes 2$	1992-96
HERA_{II}	$e^\pm_{L,R}p$	$\sim$ 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 ? ...

Why bother at HERA ?

Well ... consider possible answers to some of the fundamental questions raised above :

How do particle acquire masses ?

Elementary Higgs $\Rightarrow$ SM
EW symmetry breaking "natural" $\Rightarrow$ Supersymmetry
(HERA $\leftrightarrow$ $\not{R}_p$-SUSY Yukawa Sector, FCNCs)
Dynamic EW symmetry breaking $\Rightarrow$ Technicolor
(HERA $\leftrightarrow$ color triplet bound states of technifermions, FCNCs)

How to "explain" the symmetry between L and Q sectors ?
How to incorporate massive neutrinos ?

Leptoquarks
(HERA $\leftrightarrow$ Scalar and vector LQs, LFVs ...)
Extension of the electroweak sector:
(HERA $\leftrightarrow$ Doubly charged Higgs, Bileptons ...

How to "explain" the threefold "replica" of fermion generations ?

Composite leptons ? Composite Quarks ?
(HERA $\leftrightarrow$ excited states of leptons and quarks, FCNCs)

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. ...

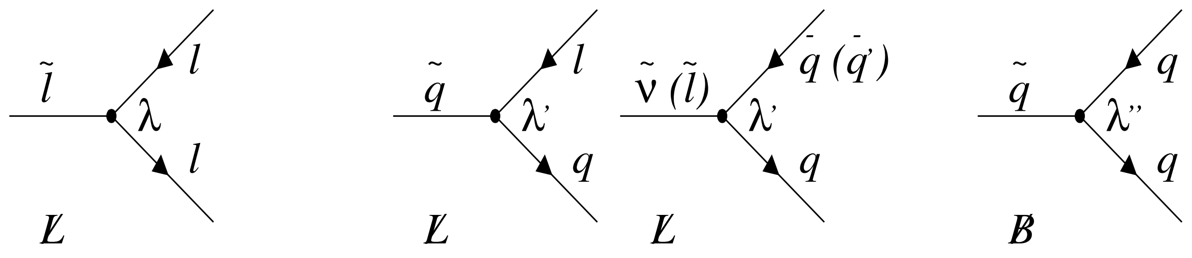
R-Parity Violating SUSY

- 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 supersymmetric matter

  A non-vanishing $\not R_p$ Yukawa coupling could be revealed through new and distinct decay modes of sparticles $\leftrightarrow$ indirect sensitivity to λ, λ' or λ'' at LEP 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}	$\tilde{\nu}_\mu, \tilde{\nu}_\tau$	$l_i^+ l_k^- \rightarrow \tilde{\nu}_j$	$i = k = 1\,,\ j = 2, 3$
$p\bar{p}$	λ'_{ijk}	$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	$d_k \bar{d}_j \rightarrow \tilde{\nu}_i$	$i, j, k = 1, \ldots, 3$
		$\tilde{e}, \tilde{\mu}, \tilde{\tau}$	$u_j \bar{d}_k \rightarrow \tilde{l}_{iL}$	$i, k = 1, \ldots, 3\,,\ j = 1, \ldots, 2$
	λ''_{ijk}	$\tilde{d}, \tilde{s}, \tilde{b}$	$\bar{u}_i \bar{d}_j \rightarrow \tilde{d}_k$	$i, j, k = 1, \ldots, 3\,,\ j \neq k$
		$\tilde{u}, \tilde{c}, \tilde{t}$	$\bar{d}_j \bar{d}_k \rightarrow \tilde{u}_i$	$i, j, k = 1, \ldots, 3\,,\ j \neq k$
ep	λ'_{1jk}	$\tilde{d}_R, \tilde{s}_R, \tilde{b}_R$	$l_1^- u_j \rightarrow \tilde{d}_{kR}$	$j = 1, 2$
	λ'_{1jk}	$\tilde{u}_L, \tilde{c}_L, \tilde{t}_L$	$l_1^+ d_k \rightarrow \tilde{u}_{jL}$	$i, j, k = 1, \ldots, 3$

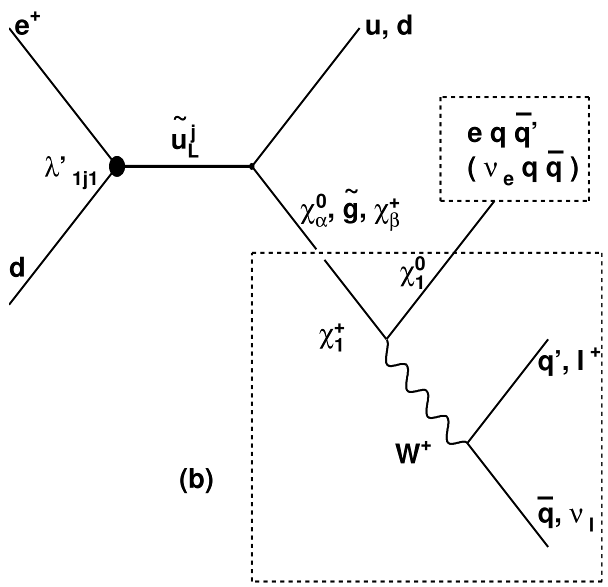
UTTERLY UNAVOIDABLE CONSTRAINTS ON SPARTICLE MASSES			
Sparticle Type	**Model**	**95% CL** M_{low} **Limits** (in GeV)	**Applicability**
Gauginos-Higgsinos (EW sector)			
$\tilde{\chi}_i^0$	MSSM	37	$i=1$; $\forall(\tan\beta, m_0)$; LSP $\equiv \tilde{\chi}_1^0$; GUT rel.
	$R\!\!\!/_p$-SUSY	35-40	$\mathrm{LL\bar{E}}$, $\mathrm{\bar{U}\bar{D}\bar{D}}$; $\forall$ MSSM
		30	$\mathrm{LQ\bar{D}}$; $\forall$ MSSM
	GMSB	77	LSP/NLSP $\equiv \tilde{G}/\tilde{\chi}_1^0$; $\beta(\tilde{\chi}_1^0 \to \gamma\tilde{G}) = 100\%$
		91	$\tilde{G}$ is LSP, $\tilde{\tau}_1$ is NLSP; $M_{\tilde{G}} < 1$ eV
$\tilde{\chi}_i^\pm$	MSSM	72	$i=1$; $\forall(\tan\beta, m_0)$; LSP $\equiv \tilde{\chi}_1^0$; GUT rel.
	$R\!\!\!/_p$-SUSY	103	$\mathrm{LL\bar{E}}$, $\mathrm{\bar{U}\bar{D}\bar{D}}$; $\forall$ MSSM
		100	$\mathrm{LQ\bar{D}}$; $\forall$ MSSM
	GMSB	150	LSP/NLSP $\equiv \tilde{G}/\tilde{\chi}_1^0$; $\beta(\tilde{\chi}_1^0 \to \gamma\tilde{G}) = 100\%$
		95	LSP/NLSP $\equiv \tilde{G}/\tilde{\tau}_1$; $\forall M_{\tilde{G}}$
Gauginos (Strong sector)			
$\tilde{g}$	mSUGRA	190	jets + $E\!\!\!/_T$ final states
		180	dilepton final states
Sfermions			
$\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$	MSSM	92 / 85 / 68	$\tilde{l}_R$; $\Delta M_{\tilde{l}\tilde{\chi}} > 10$ GeV $\tilde{l} \to l\tilde{\chi}_1^0$; $\forall$ mixing
$\tilde{e}$	$R\!\!\!/_p$-SUSY	69-96	$\mathrm{LL\bar{E}}$, $\mathrm{LQ\bar{D}}$, $\mathrm{\bar{U}\bar{D}\bar{D}}$; $\tilde{l}_R$ pair prod.; $\forall$ MSSM
$\tilde{\mu}$, $\tilde{\tau}$		61-87	$\mathrm{LL\bar{E}}$, $\mathrm{LQ\bar{D}}$, $\mathrm{\bar{U}\bar{D}\bar{D}}$; $\tilde{l}_R$ pair prod.; $\forall$ MSSM
	GMSB	77	$\tilde{\tau}_1$; $\tilde{G}$ is LSP, $\tilde{\tau}_1$ is NLSP; $\forall M_{\tilde{G}}$
$\tilde{\nu}$	MSSM	43	
	$R\!\!\!/_p$-SUSY	84-99	$\mathrm{LL\bar{E}}$, $\mathrm{LQ\bar{D}}$, $\mathrm{\bar{U}\bar{D}\bar{D}}$; $\tilde{\nu}_e$ pair prod.; $\forall$ MSSM
		64-83	$\mathrm{LL\bar{E}}$, $\mathrm{LQ\bar{D}}$, $\mathrm{\bar{U}\bar{D}\bar{D}}$; $\tilde{\nu}_{\mu,\tau}$ pair prod.; $\forall$ MSSM
$\tilde{q}$	MSSM	260	jets + $E\!\!\!/_T$ final states
		230	dilepton final states
$\tilde{t}_1$	MSSM	88	$\tilde{t}_1 \to c\tilde{\chi}_1^0$; $M_{\tilde{\chi}_1^0} < 1/2 M_{\tilde{t}}$; $\forall\theta_{mix}$
		138	$\tilde{t}_1 \to bl\tilde{\nu}$; $M_{\tilde{\nu}} < 1/2 M_{\tilde{t}}$; $\forall\theta_{mix}$
		90-91	$\tilde{t}_1 \to c\tilde{\chi}_1^0, bl\tilde{\nu}$; $\Delta M_{\tilde{t}_1\tilde{\chi}} > 7$ GeV; $\forall\theta_{mix}$

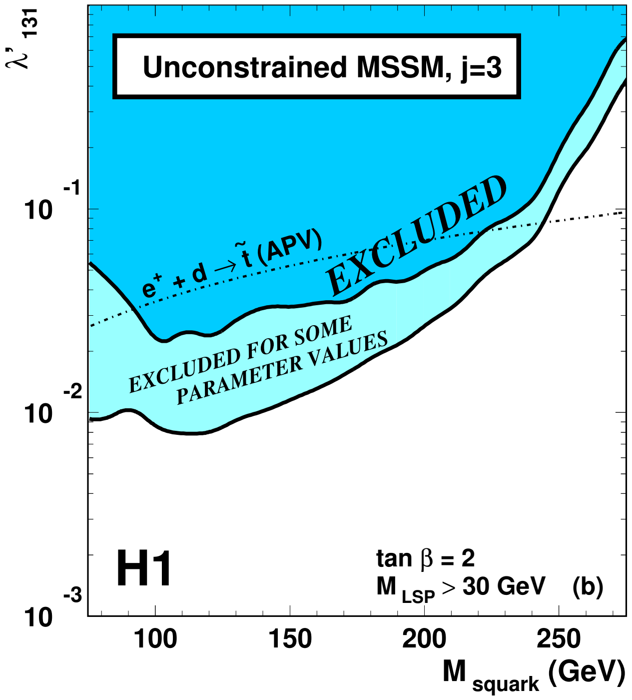
Experimental ressources: LEP$_I$ and LEP$_{II}$; Tevatron

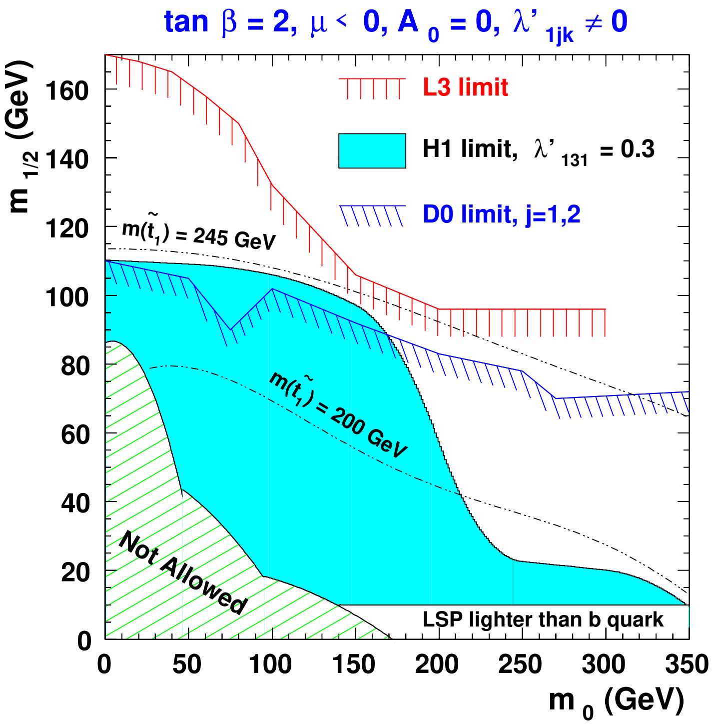
Search for $\not{R}_p$-SUSY at HERA

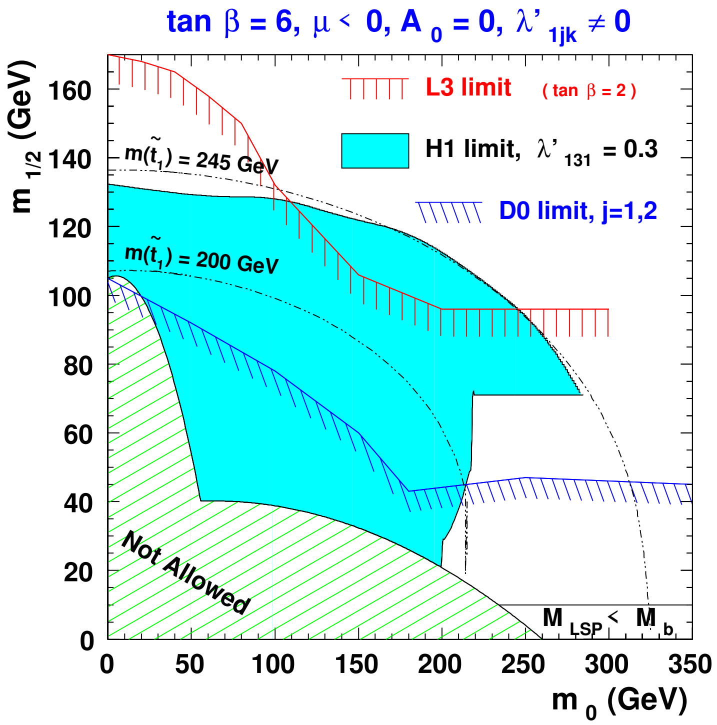
(snapshot)

- SUSY could be discovered through λ' at HERA !
- 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 $\tilde{t}$)









$\not{R}_p$-SUSY: The Case of the Stop

- $\tilde{t} \leftrightarrow$ special role in SUSY !? e.g. influence on Higgs phenomenology !?

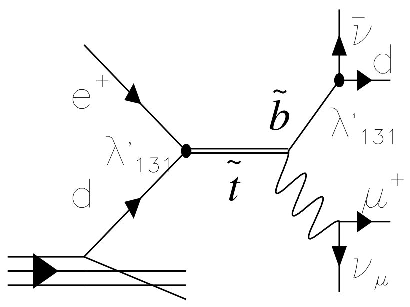
$$M \simeq \begin{pmatrix} m^2_{\tilde{f}_L} & am_f \\ am_f & m^2_{\tilde{f}_R} \end{pmatrix} \leftrightarrow \text{Mass mixing important for } \tilde{t}\,,\, \tilde{b}\ !$$

- $\tilde{t}_1$ could be the lightest squarks and lighter than top !

eigenval. $\leftrightarrow m^2_{\tilde{t}_1,\tilde{t}_2} = \frac{1}{2}(m^2_{\tilde{t}_L} + m^2_{\tilde{t}_R} \mp \sqrt{(m^2_{\tilde{t}_L} - m^2_{\tilde{t}_R})^2 + 4a^2m^2_t})$

- More modest constraints from LEP (θ_t dependent) and Tevatron for a single type of squark ! (otherwise, SUSY partners of light quarks are expected to be almost mass degenerate e.g. in mSUGRA)

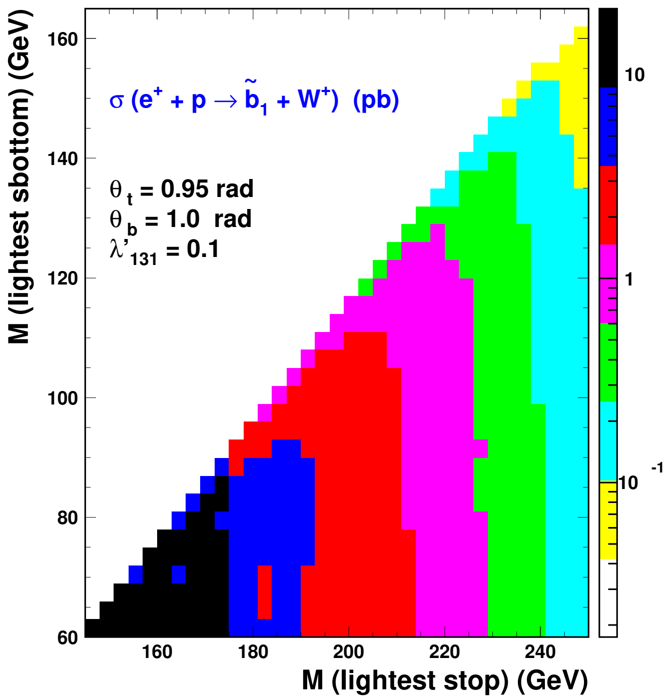
- Specific (outstanding) event topologies must be considered in a significant fraction of the parameter space



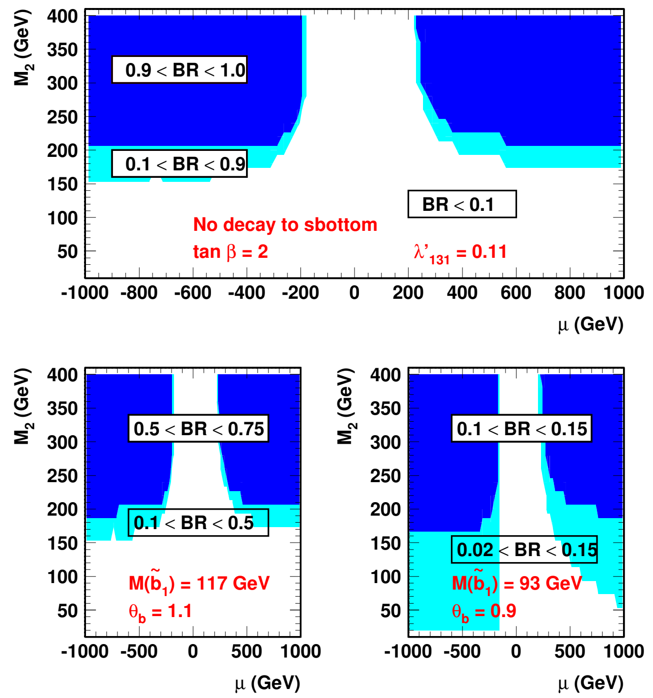
- Possibly significant rates both in $\tilde{t}_1 \to \tilde{b}_1 + W$ and $\tilde{t}_1 \to ed$
- $\tilde{t}_1 \to \tilde{b}_1 + W \Rightarrow$ outstanding event topologies: $l^{\pm} + jet + \not{P}_T$

$\not{R}_p$-SUSY: The Case of the Stop

E. Perez, "SUSY-98" (Oxford) & "Tools for SUSY 99" (Lyon)



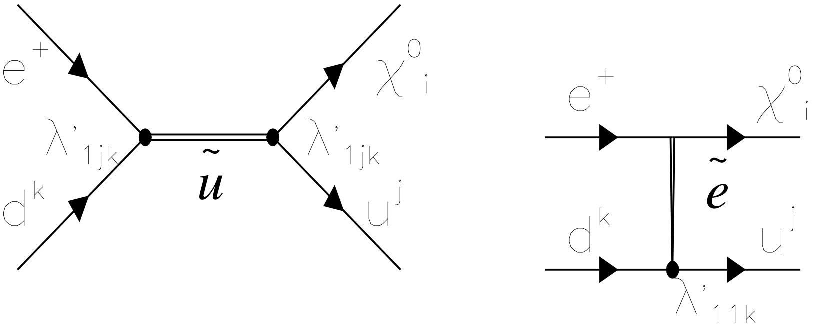
- e.g. $\lambda'_{131} = 0.1$, $\tan\beta = 5 \Rightarrow$ cross-section $\sigma \lesssim 1$ pb for $M_{\tilde{t}_1} \gtrsim 220$ GeV , $M_{\tilde{b}_1} \gtrsim 120$ GeV
- Observing only a few outstanding events with $l^{\pm} + jet + \not{P}_T$ for luminosities $\mathcal{L} = \mathcal{O}(100)$ pb^{-1} is possible in accessible $M_{\tilde{t}_1}$ range



- Large M_2 and high $|\mu|$
  $\Rightarrow$ heavy χ^0, χ^+
  $\Rightarrow \beta(\tilde{t}_1 \to \tilde{b}_1 + W)$
  varies slowly **and**
  $\beta(\tilde{b}_1 \to \bar{\nu}_e + d) \simeq 1$
- Final states:
  $l^{\pm} + jet + \not{P}_T$
  and
  $multijets + \not{P}_T$

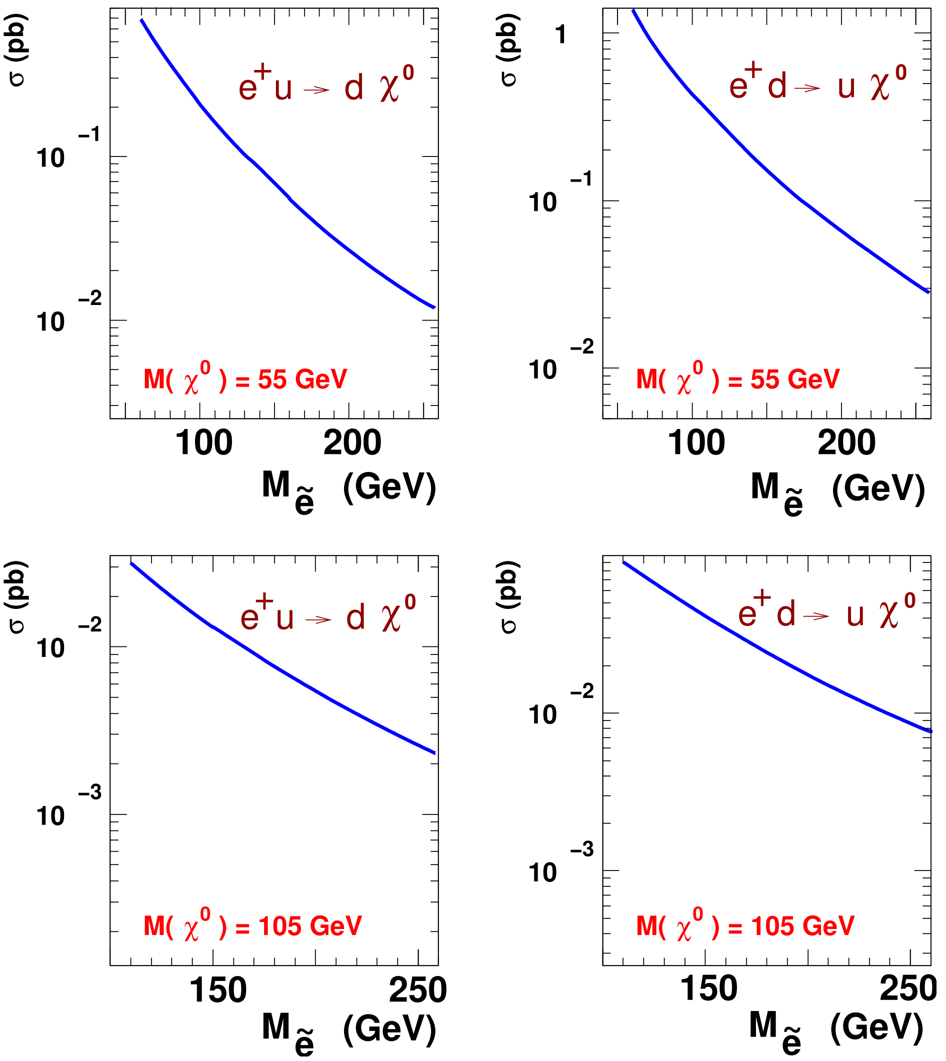
$\not{R}_p$-SUSY without Squarks at HERA

- If $M_{\tilde{q}} \gg M_{\tilde{l}}$ (or if Tevatron pushes $M_{\tilde{q}}$ beyond direct HERA reach) λ' couplings can still be probed at HERA via $\tilde{l}$ exchange !



- The search for $\tilde{l}^{\pm}$ in $\not{R}_p$-SUSY can be extended at HERA far beyond the reach of LEP$_{II}$!

E. Perez, "Tool 99" (Lyon) e.g. $\lambda' = 0.5$, $\tan\beta = 1$, $\chi^0 \sim \tilde{\gamma}$:



"Aide-mémoire" on $\not{R}_p$-SUSY

• Rather complete and exhaustive search for resonant $\tilde{q}$ production via λ' followed by direct ($\not{R}_p$) or indirect (initiated by gauge coupling) decays have been carried using $\mathcal{O}(100)$ pb^{-1} of e^+p data by H1 and ZEUS experiments.

• The combined $e^{\pm}p$ analysis allowing to establish the best λ' $vs.$ $M_{\tilde{q}}$ constraints involving λ'_{11k} (mainly from e^-p data) or λ'_{1j1} (mainly from e^+p data) remains to be completed.

• Specific analysis for superpartners of heavy quarks must be performed to take into account possibly large contribution in outstanding decay topologogies (e.g. $\tilde{t}_1 \rightarrow \tilde{b}_1 + W$ leading to events with $l^{\pm} + jet + \not{P}_T$).

• Sleptons in $\not{R}_p$-SUSY theories can be searched beyond the reach of LEP$_{II}$ independently from the coloured sparticle sector !

Flavour Changing Neutral Currents

• FCNCs are absent at tree level in the Standard Model
Neutral Currents are flavour diagional

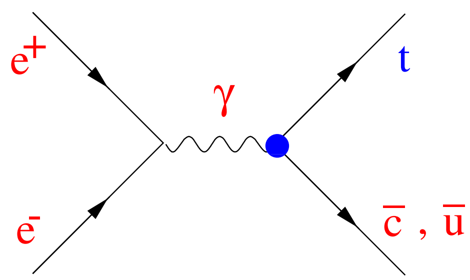
• FCNCs appear "naturally" (but strongly suppressed !) at one-loop level due to CKM mixing

• In some specific models, FCNC processes in the top sector receive a large contribution beyond the Standard Model rates:

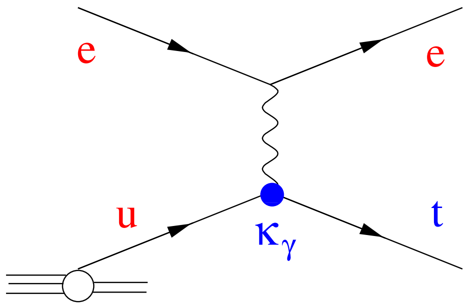
Theory	$\beta(t \to c\gamma, cZ^0)$
Standard Model	$\sim 10^{-13} - 10^{-12}$
Two Higgs Doublet	$\sim 10^{-9} - 10^{-8}$
Supersymmetry	$\sim 10^{-8} - 10^{-6}$
Multiple Higgs Doublet	$\sim 10^{-6} - 10^{-5}$
Quark Singlets	$\sim 10^{-2}$
Composite top quark	$\sim 10^{-2}$
R-Parity Violating SUSY	$\gtrsim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

• Because of it's large mass, the top could be an ideally sentitive to physics beyond the Standard Model

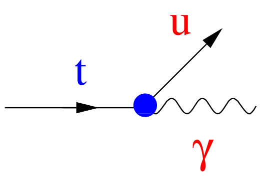
LEP



HERA

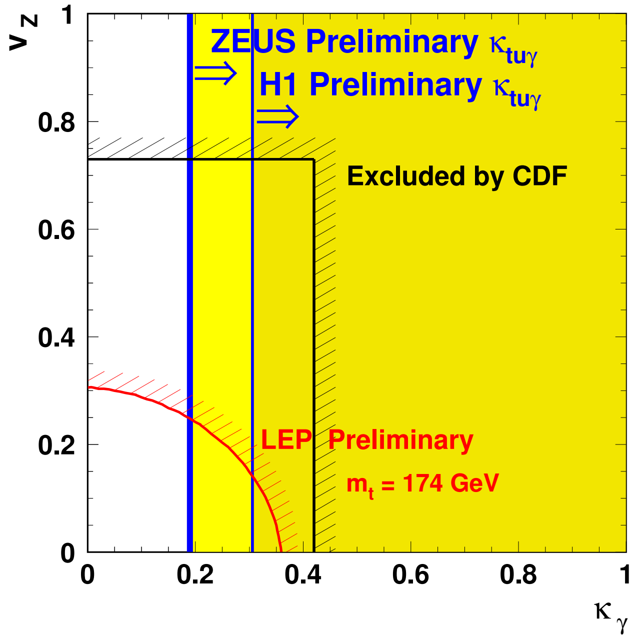


Tevatron

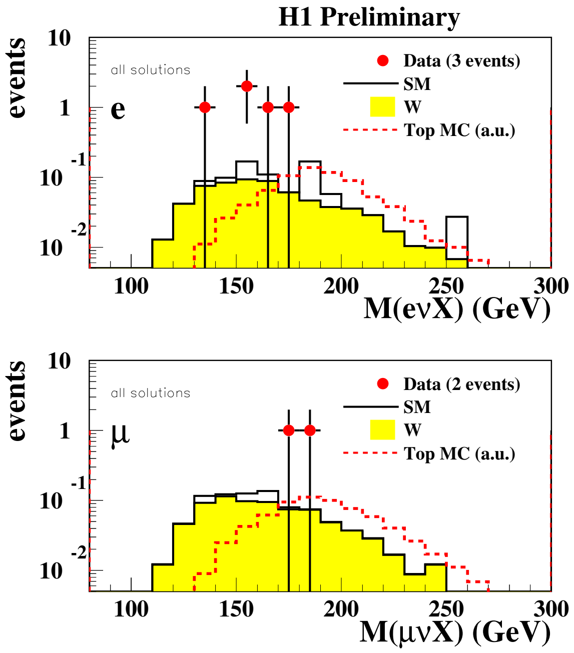


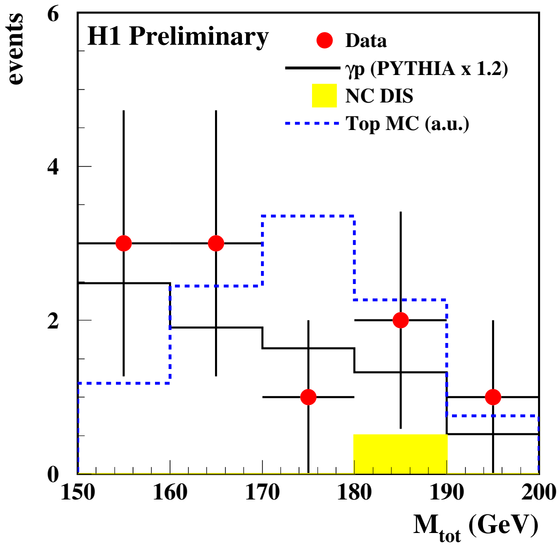
Search for FCNCs at HERA

(snapshot)



H1 limits weaker: excess of high P_T lepton (e and μ) top-like events !





EPS 2001: $e^{\pm} + p$ Obs. 5 Exp. 0.88 ± 0.2 $P_T^x > 25$ GeV

Not contradicted (nor confirmed!) by $bq\bar{q}'$ search

"Aide-mémoire" on FCNCs at HERA

• Possible FCNC $t - u - \gamma$ couplings of the top quark can be probed at HERA at a sensitivity competitive with other colliders.

• Single top production at HERA would lead to striking event topologies similar to those of $l^{\pm} + jet + \not{P}_T$ events already observed.

Doubly Charged Higgs Bosons

- **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.*).

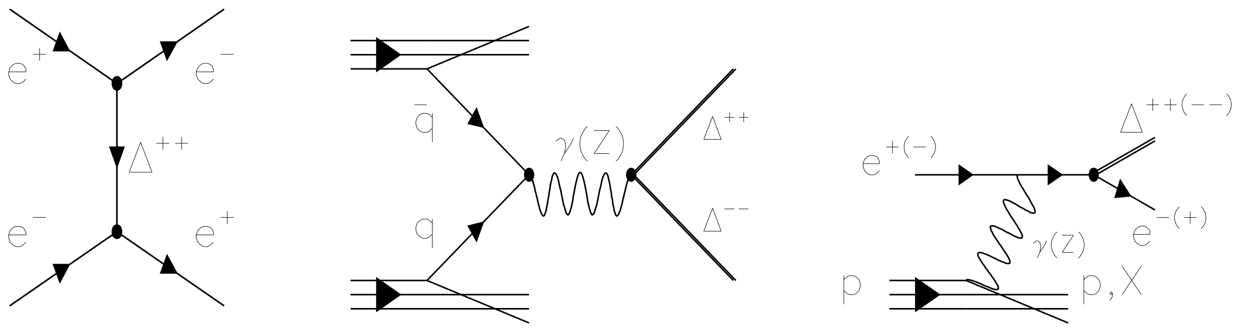
- There $\exists$ strong motivations for light $\Delta^{\pm\pm}$ in SUSY models incorporating $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- SUSY L-R models $\Rightarrow$

  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. $e^+p \rightarrow e^-\Delta^{++}X$; $\Delta^{++} \rightarrow l^+l^+$

$\Rightarrow$ striking three lepton event topologies !

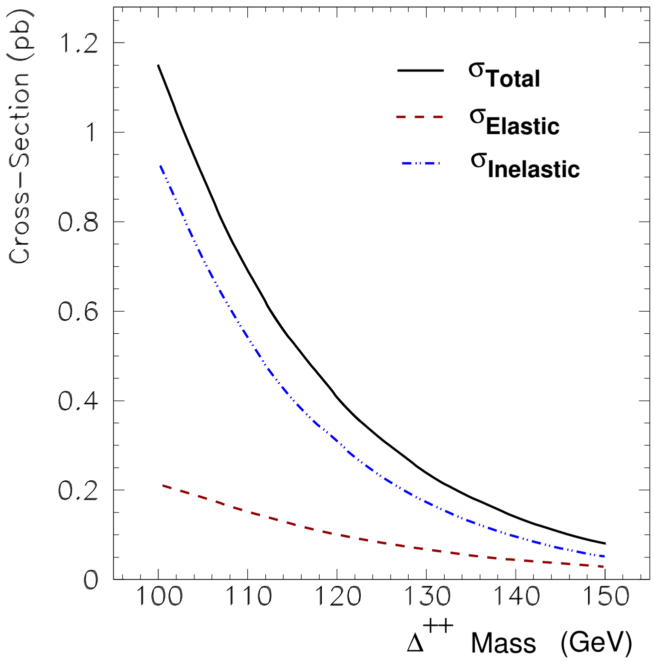
Note: ∘ Bosonic decays $\Delta^{--} \rightarrow \Delta^- W_R^-$; $\Delta^-\Delta^-$ likely to be closed or disallowed.

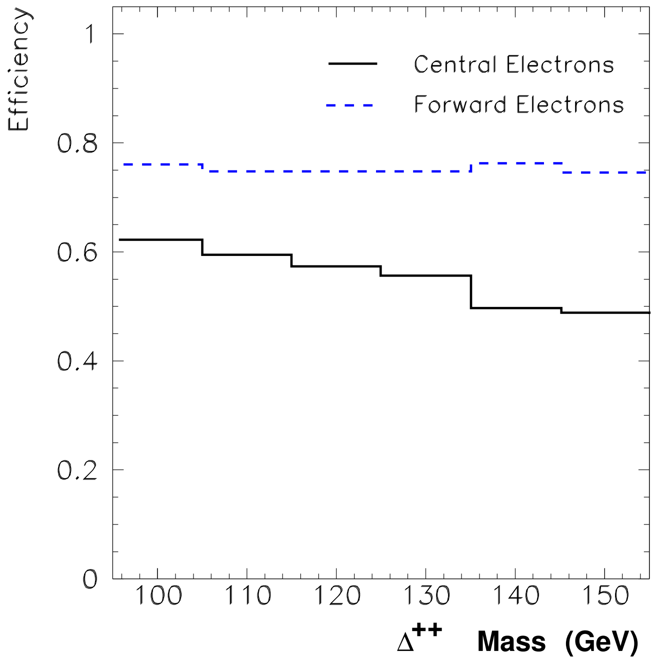
∘ Direct couplings to quarks forbidden by Q conservation

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

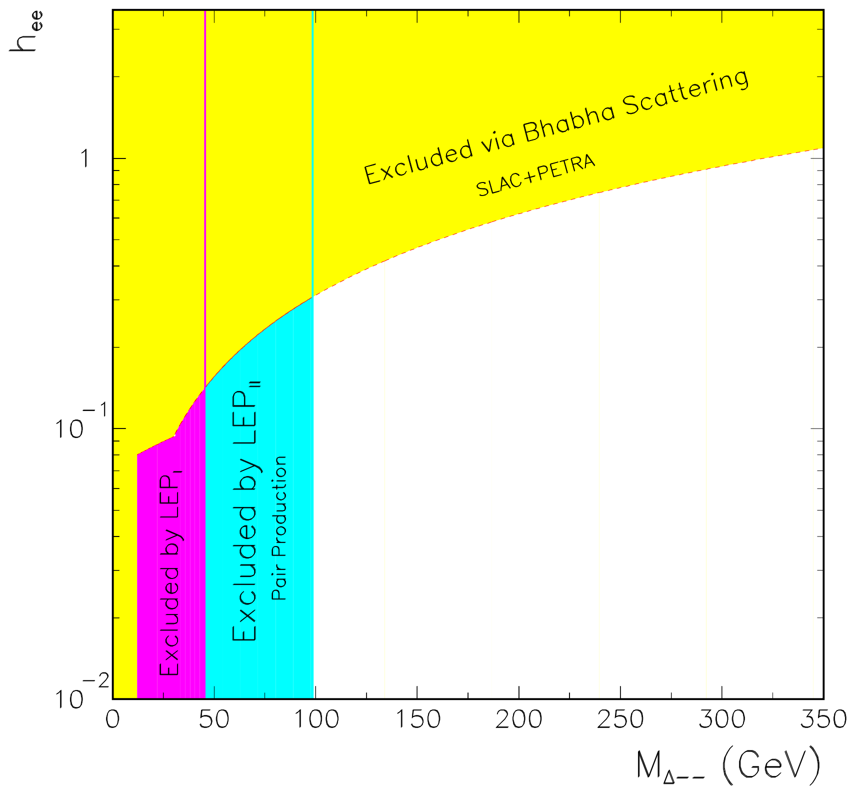
(snapshot)

B. Olivier et al., PYTHIA + COMHEP





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



- $M = 100$ GeV

  $\sigma_{tot} = 1.15$ pb

  $\epsilon = 63\%$

  $2\text{"}e\text{"}/3\text{"}e\text{"} = 50\%$

- $M = 150$ GeV

  $\sigma_{tot} = 0.08$ pb

  $\epsilon = 49\%$

  $2\text{"}e\text{"}/3\text{"}e\text{"} = 44\%$

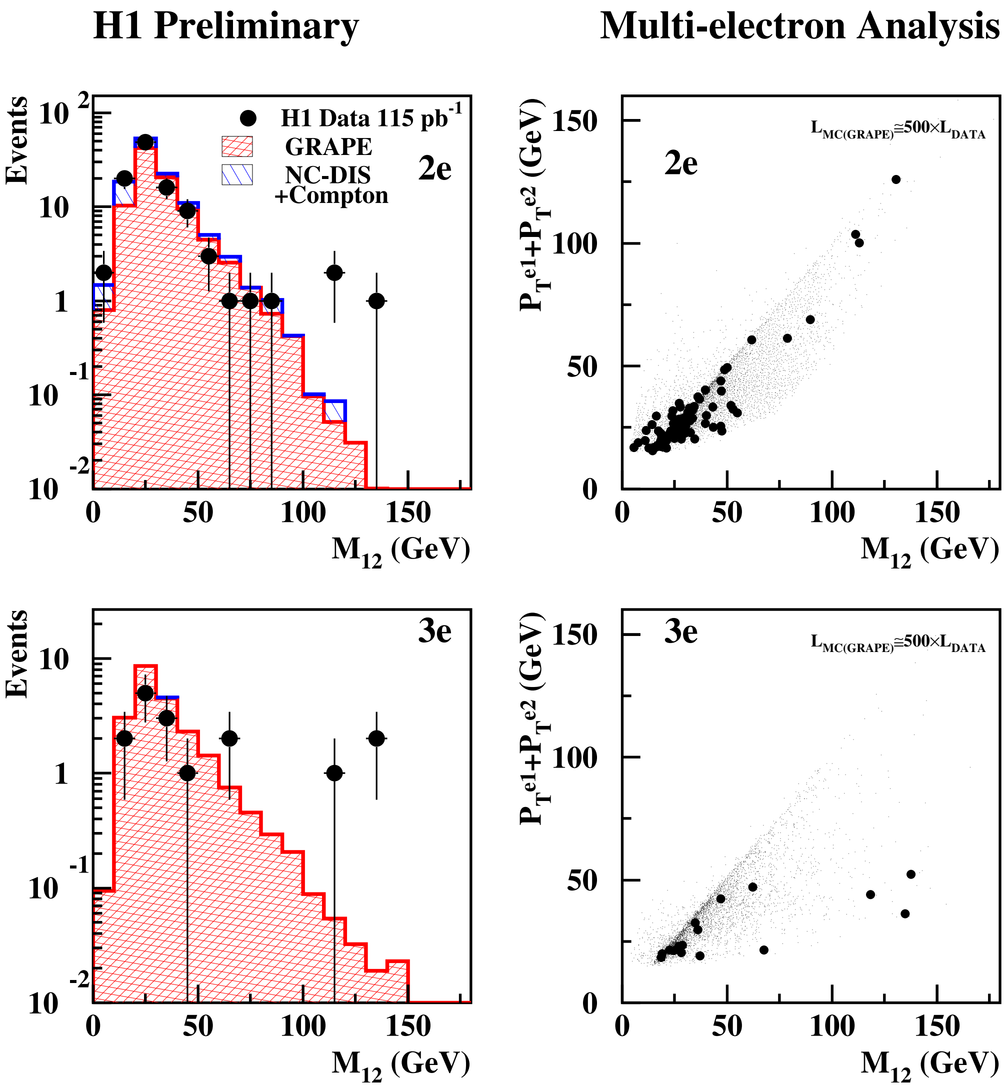
$\exists$ Exhaustive review of constraints (Bileptons): F. Cuypers, S. Davidson (1998) q

Outstanding Multi-electron Topologies at HERA

H1 Preliminary 115 pb^{-1}

(snapshot)

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



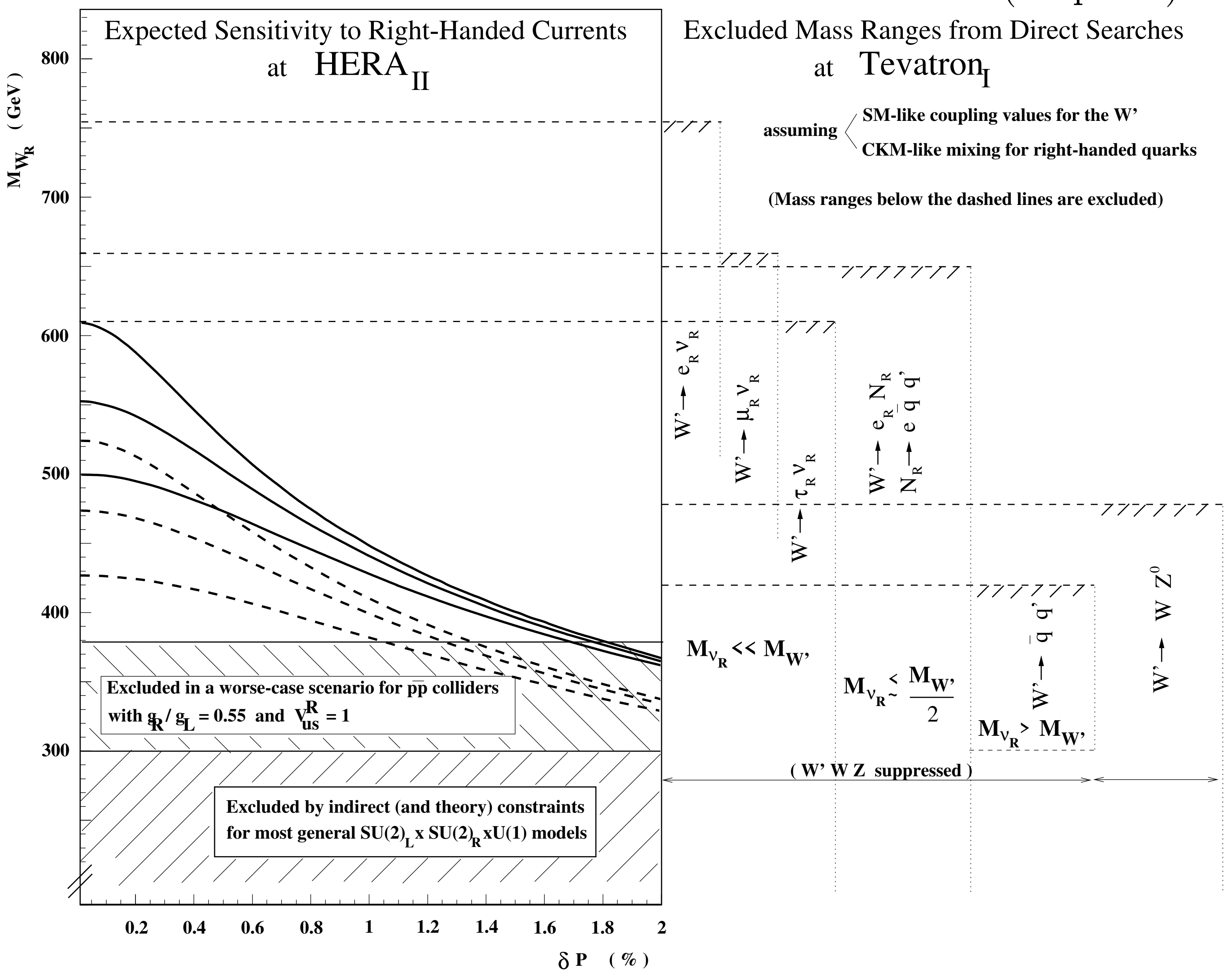
”Aide-mémoire” on Doubly Charged Higgs

• HERA allows to search for doubly charged higgs bosons in an extended range of mass and couplings.

• Three-lepton events with outstanding topologies similar to those observed at HERA could be expected from processes like
$e^+p \rightarrow e^-\Delta^{++}X\,;\,\Delta^{++} \rightarrow l^+l^+$

Right-Handed Weak Currents at HERA ?

(snapshot)



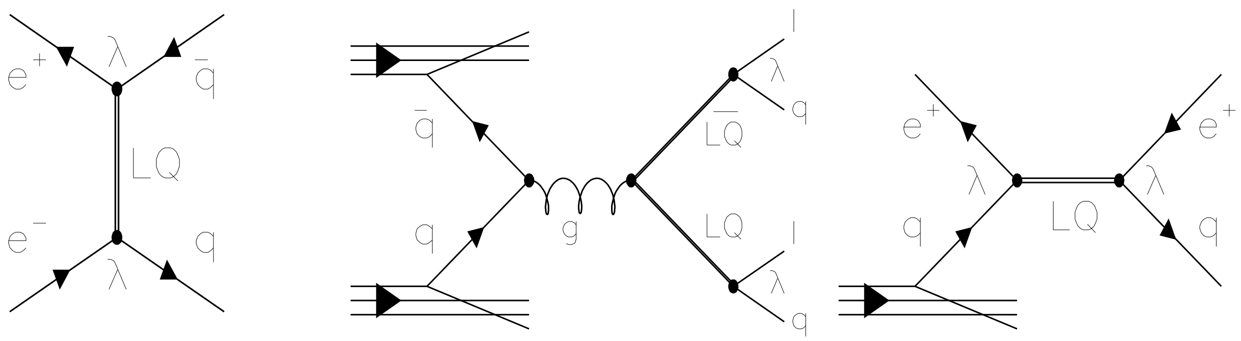
Note: Tevatron constraints depend on:

- g_r coupling of W' — production cross-section
- $L - R$ mixing angle ξ — rel. contribution of $W' \to W Z^0$
- Mass and nature of ν_R's
- "CKM" mixing matrix for q_R's — affects prod. via $\bar{u}d$ or $\bar{d}u$!

Leptoquarks

- LQs "explain" the essential connection between the L and Q sectors
  e.g. relationship between q and l EW charges exactly cancel triangle anomalies in the SM
- 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: "explain" symmetry between l and q sectors
  SUPERSTRING-"inspired" E_6 models
  TECHNICOLOR-like theories: alternative (?) to the higgs ?
  COMPOSITENES-like theories: "explain" the 3 generations

At Colliders:



At HERA: ∘ LQ interaction interferes with SM boson exchange
∘ $e^-p \to S_0\,;\ \tilde{S}_0\,;\ S_1 \qquad e^+p \to \bar{S}_{1/2}\,;\ \bar{\tilde{S}}_{1/2}$
∘ l angular spectra distinct from standard DIS
∘ All LQ types can be distinguished through $e^{\pm}_{L,R}$!

At Tevatron: ∘ Best sensitivity for $\beta_{eq} \to 1$

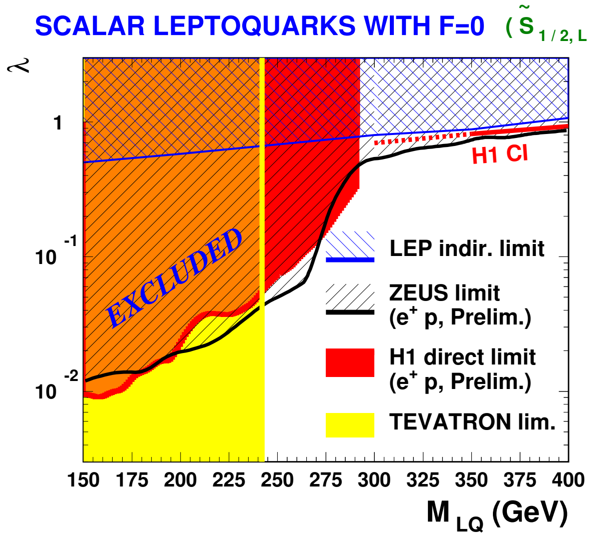
Search for Leptoquarks at HERA

(snapshot)

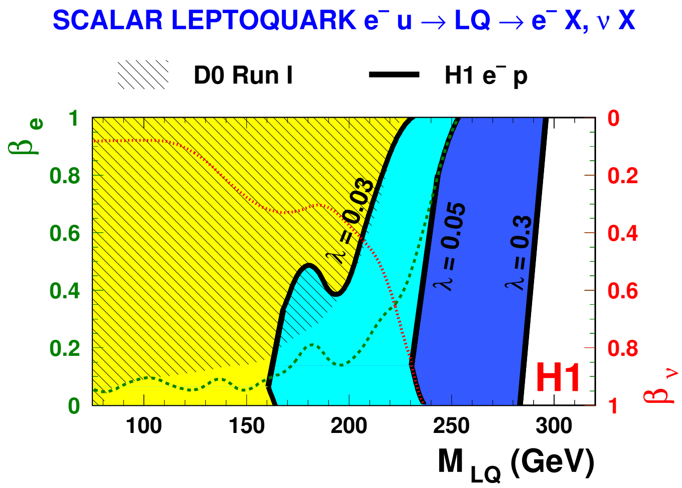
- Büchmuller-Rückl-Wyler LQ types for "minimal" models $\leftrightarrow$ assume (chiral) couplings invariant under SM gauge interactions; interactions **only** with SM fermions and gauge bosons; etc.

$\Rightarrow$ 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} even for 1^{rst} generation leptoquarks

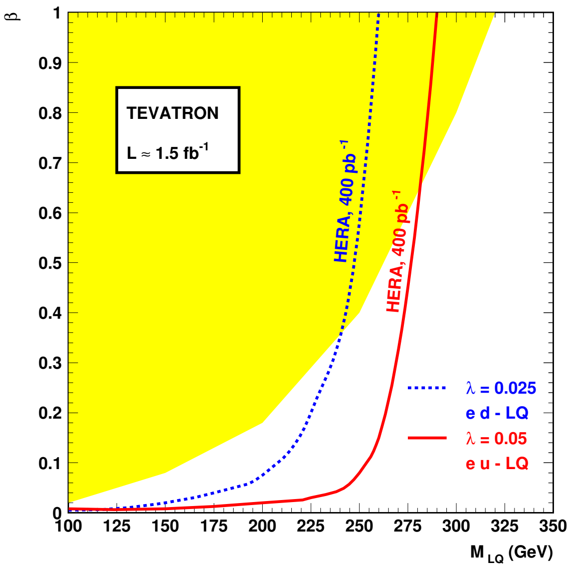


Leptoquark prospects at HERA

(snapshot)

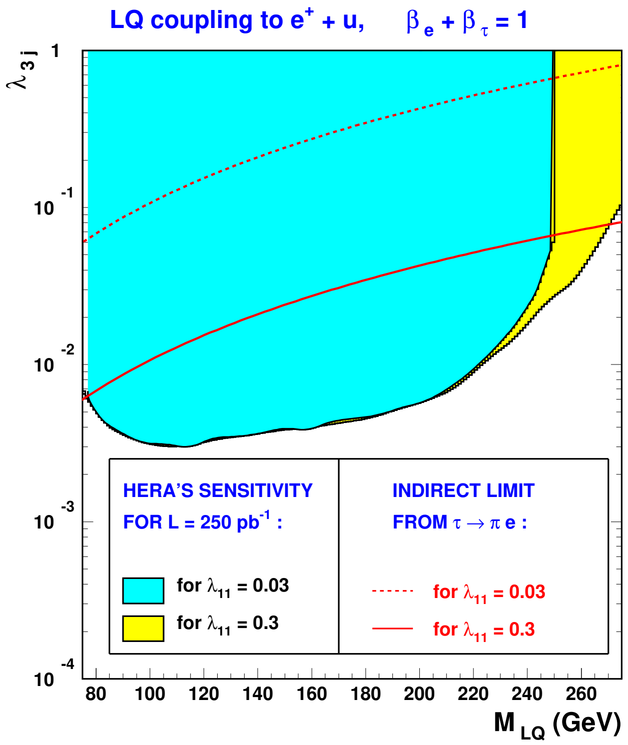
- Best cases at HERA are for LQs in non-minimal minimal models (non-standard decays allowed $\leftrightarrow$ arbitrary β_{eq})

  with $\beta_{eq} \ll 1$



- Unique sensitivity and striking signal for LFV at HERA through (e.g.) s-, t- or u-channel exchange of new bosons

  e.g. LQ with mixed $\lambda_{eq_i} \times \lambda_{\tau q_j}$ couplings



"Aide-mémoire" on Leptoquarks

• Rather complete and exhaustive search for NC-like and CC-like LQ signal combining $\mathcal{O}(10)$ pb^{-1} of e^-p data (most sensitive to $F=2$ types) and $\mathcal{O}(100)$ pb^{-1} of e^+p data (most sensitive to $F=0$ types) have been performed.

Final HERA$_I$ results from H1 and ZEUS remain to be published for minimal BRW types and in non-minimal models

• Further progress would best profit from 1) increased $e^{\pm}p$ luminosities; 2) increased $\sqrt{s}_{ep}$ (unfortunately not envisaged). Polarisation brings only a slight improvement of the signal-to-background ratio for specific types of leptoquarks (e.g. S_R type) and is thus only crucial ounce a discovery has been made.

• Direct and indirect searches have been performed for LFV processes possibly mediated by leptoquarks

Final HERA$_I$ results from H1 and ZEUS remain to be published.

• Indirect constraints must be revisited.

Summary

- 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$_{II}$

- Avoiding/escaping stringent existing constraints (e.g. from colliders) $\rightarrow$ somehow renders surviving theories beyond Standard Model less predictive/falsifiable ? (e.g. extended walking technicolour, compositeness, non-minimal SUSY, etc.)

- There $\exists$ **no** firm prediction for a discovery within the reach of HERA$_{II}$ (no BSM theory would otherwise become largely falsified !)
  BUT
  There do $\exists$ possibly exciting new physics which could lead to acceptable and striking signal at HERA (leptoquarks, LFV, composite fermions, FCNCs, $\not{R}_p$-SUSY, doubly charged Higgs, Bileptons, contact interactions, extra-dimensions ....

- Theorists/phenomenologists as well as machine support is needed to guarantee that no opportunity will have been missed by H1 and ZEUS !
  New physics may be within reach at pre-LHC colliders ... or it may not.