Leptoquark and R-Parity Violating SUSY Processes

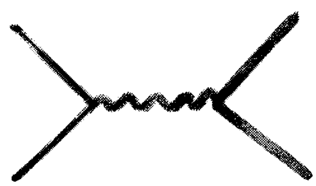
Reinhold Rückl, P6, Sitges, 1-5-99

→ Hewett, Rizzo, Phys. Rep.

LQ Searches at Linear Colliders

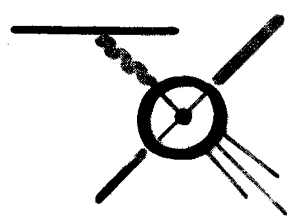
(update of analysis by R. Settles, H. Spiesberger, R.R., DESY 97-123E)

pair production



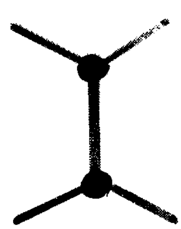
gauge couplings

single production



Yukawa couplings

virtual exchange



Yukawa couplings

others

$\gamma\gamma \to LQ\,\overline{LQ}$

$\gamma e \to LQ\,X$

dominant for small λ

λ

Dondieski, Godfrey (DPF96)

λ

Berger (DPF96); Riemann

Blümlein et al.

DG (DPF96)

Generic Framework

Buchmüller, Wyler, RR

most general Yukawa couplings to lepton-quark pairs

- dimensionless
- SU(3) × SU(2) × U(1) symmetry
- B, L conserving — p decay
- confined to a single family — FCNC
- chiral — $\pi \to l\nu$

additional assumptions usually made

- mass degeneration within a weak isospin multiplet
- only a single multiplet at a time
- decays to SM leptons/quarks only — diff. scenarios { SUSY $\not{R}$, Hewett, Rizzo, ... }

implications

- 2 classes of states with fermion number $\begin{cases} F=0: & l\bar{q} \quad \bar{l}q \\ F=2: & lq \quad \bar{l}\bar{q} \end{cases}$
- correlation between spin and weak isospin
- <u>fixed branching fractions</u> for LQ $\to l^{\pm}$ + jet, ν_l + jet

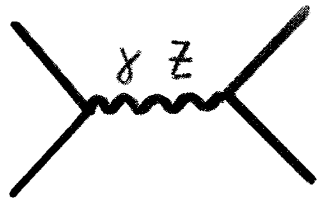
$$B(l^{\pm}j) + B(\nu_l j) = 1 \qquad B(l^{\pm}j) = 0, \tfrac{1}{2}, 1$$

BRW Classification

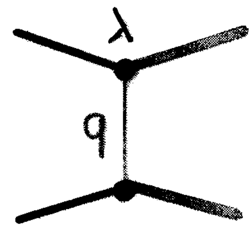
	State	Q	NC	CC	BR $(e^{\pm} j)$	
	S_0	$-1/3$	$e_L u$	$\nu_L d$	$\frac{1}{2}$	
			$e_R u$	—	1	
	$\tilde{S}_0$	$-4/3$	$e_R d$	—	1	Scalar
	S_1	$+2/3$	—	$\nu_L u$	0	
F = 2		$-1/3$	$e_L u$	$\nu_L d$	$\frac{1}{2}$	
		$-4/3$	$e_L d$	—	1	
	$V_{1/2}$	$-1/3$	—	$\nu_L d$	0	
			$e_R u$	—	1	
		$-4/3$	$e_L d$	—	1	Vector
			$e_R d$	—		
	$\tilde{V}_{1/2}$	$+2/3$	—	$\nu_L u$	0	
		$-1/3$	$e_L u$	—	1	
	$S_{1/2}$	$-2/3$	—	$\nu_L \bar{u}$	0	
			$e_R \bar{d}$	—	1	
		$-5/3$	$e_L \bar{u}$	—	1	Scalar
			$e_R \bar{u}$	—		
	$\tilde{S}_{1/2}$	$+1/3$	—	$\nu_L \bar{d}$	0	
F = 0		$-2/3$	$e_L \bar{d}$	—	1	
	V_0	$-2/3$	$e_L \bar{d}$	$\nu_L \bar{u}$	$\frac{1}{2}$	
			$e_R \bar{d}$	—	1	
	$\tilde{V}_0$	$-5/3$	$e_R \bar{u}$	—	1	Vector
	V_1	$+1/3$	—	$\nu_L \bar{d}$	0	
		$-2/3$	$e_L \bar{d}$	$\nu_L \bar{u}$	$\frac{1}{2}$	
		$-5/3$	$e_L \bar{u}$	—	1	

LQ Pair Production and Decay

lowest order production



dominant



small angle, large Yukawa coupling

- $\sqrt{s} = 500$ GeV, $m_{LQ} = 200$ GeV, $\lambda_{L,R} = 0$ including beamstr, ISR $\quad \sigma(S) \cong$ 6 – 150 fb, $\quad \sigma(V) \cong$ 0.2 – 1.8 pb

decays

- first generation LQs $\quad LQ \to eq, \nu_e q \quad (q = u, d)$
- $\lambda_{L,R} < 0.05 \left(\frac{m}{200\ \text{GeV}} \right)$ consistent with exp. bounds

$$\Rightarrow \Gamma_S = \frac{3}{2}\Gamma_V = \frac{1}{16\pi^2} \lambda^2_{L,R}\, m \; < \; 3\ \text{MeV} \left(\frac{m}{200\ \text{GeV}} \right)^3$$

$\Rightarrow$

final states	eejj	eνjj	ννjj
S_0^L, V_0^L	0.25	0.5	0.25
S_0^R, V_0^R	1	--	--
$\tilde{S}_0^R, \tilde{V}_0^R$	1	--	--
S_1^L, V_1^L	(--, 0.25, 1)	(--, 0.5, --)	(1, 0.25, --)
$S_{1/2}^L, V_{1/2}^L$	(--, 1)	--	(1, --)
$S_{1/2}^R, V_{1/2}^R$	(1, 1)	--	--
$\tilde{S}_{1/2}^L, \tilde{V}_{1/2}^L$	(--, 1)	--	(1, --)

MC Simulation

Heyssler, Spiesberger, RR

MC generator **LQPAIR vs. 2.03** Spiesberger

- Lowest order matrix elements
- initial state bremsstrahlung
- beamstrahlung

interface to JETSET for parton shower and hadronization

Sjöstrand et al.

interface to SMEAR vs. 3.02 for detector simulation

Settles, Spiesberger
Wiedenmann

general cuts for event identification

variable	(I) e^+e^- + 2 jets	(II) $e^\pm$ + 2 jets + p^{miss}	(III) 2 jets + p^{miss}
p_T^e	≥ 20 GeV	≥ 20 GeV	≥ 20 GeV veto
p_T^{miss}	≤ 25 GeV	≥ 25 GeV	≥ 25 GeV
E_j	≥ 10 GeV	≥ 10 GeV	--
E_{vis}	$\geq 0.9\sqrt{s}$	$\geq 0.6\sqrt{s}$	--
p_T^j	--	--	≥ 75 GeV
E_{had}	--	≥ 150 GeV	≤ 300 GeV

SM Background

processes

$$e^+e^- \rightarrow WW,\ ZZ \rightarrow l_1\bar{l}_2\ q_3\bar{q}_4$$

$$\rightarrow l_1\bar{l}_2\ q_3\bar{q}_4 \text{ single- and non-resonant}$$

} WPHACT

$$\rightarrow t\bar{t} \rightarrow W^+W^-\ b\bar{b}$$

$$\gamma\gamma \rightarrow 2l\ 2q$$

} PYTHIA

ordering $E_{j_1} > E_{j_2}$

$$|M_{l_1 j_1} - M_{l_2 j_2}| < |M_{l_1 j_2} - M_{l_2 j_1}|$$

additional Cuts

$|M_{l_1 l_2} - M_{Z,W}| \geq 10$ GeV (I), 20 GeV (II,III)

$|M_{j_1 j_2} - M_{Z,W}| \geq 10$ GeV (I), 20 GeV (II,III)

$M_{l_1 l_2}, M_{l_1 j_2}, M_{l_2 j_1} \geq 20$ GeV (I, II)

$M_{j_1 j_2} \leq 400$ GeV (III)

 # background events surviving the cut

$\int dt\,\mathcal{L} = 500\ \text{fb}^{-1}$	$\sqrt{s} = 500$ GeV			$\sqrt{s} = 800$ GeV		
search	I	II	III	I	II	III
# events	325	3750	63425	171	1453	56300

distributions

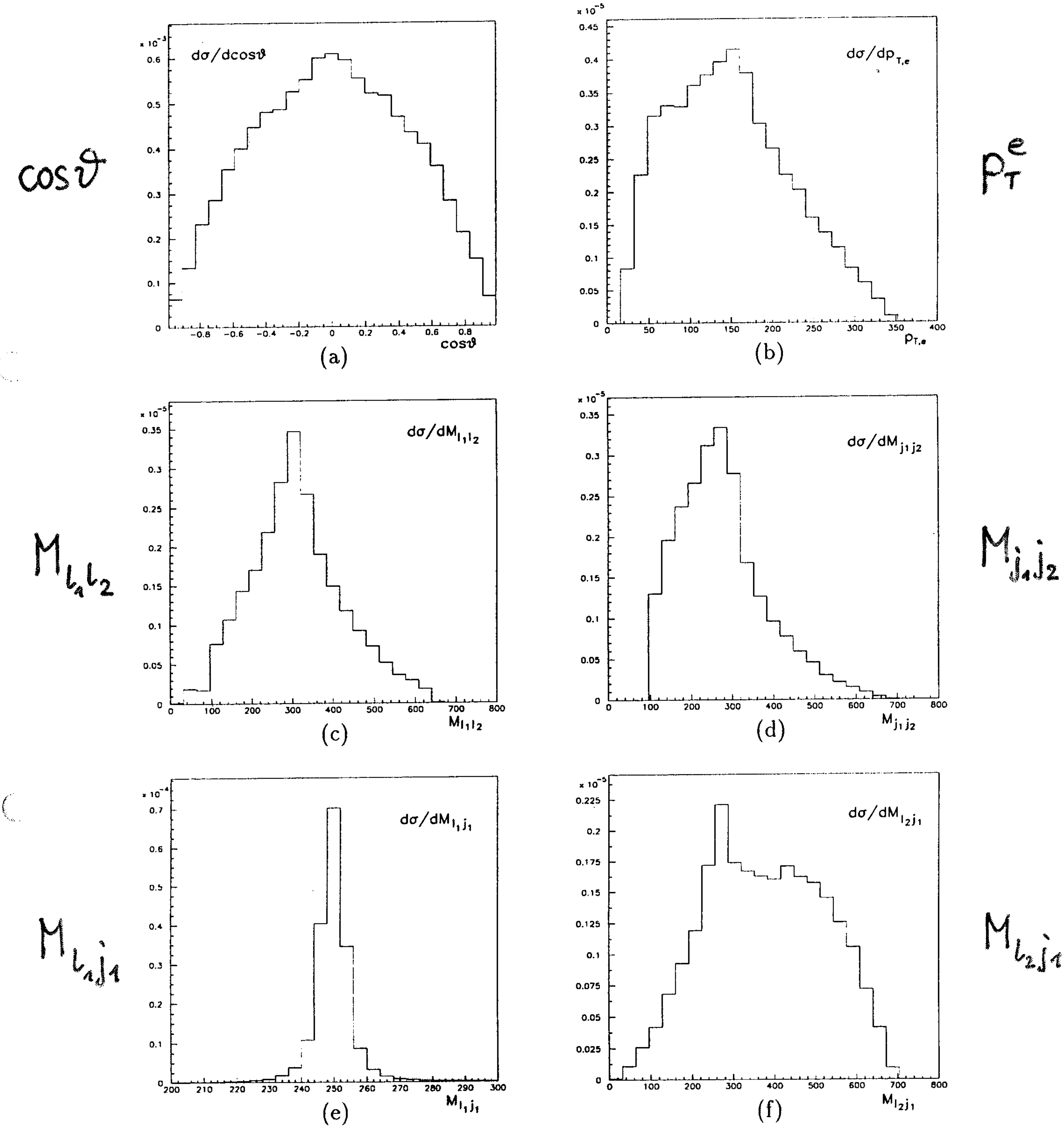


Figure 5: *Event distributions for the process* $e^+e^- \to {}^{-1/3}S_1 + {}^{1/3}\bar{S}_1 \to e^\pm \overset{(-)}{\nu_e}\, jj$ *for* $M = 250$ *GeV at* $\sqrt{s} = 800$ *GeV (search II). Masses are given in GeV and cross sections in pb. The definition of kinematic variables is explained in subsection 3.3.*

Signal Events

 # signal events in e^+e^- + 2 jets

- most/least favourable cases
- medium/high luminosity
- detection efficiency (# events before cuts)

	$e^+e^- \longrightarrow \mathrm{LQ}\,\overline{\mathrm{LQ}} \longrightarrow \ell^+\ell^- + 2$ jets $\lambda_L = 0.01,\ \lambda_R = 0$			
	$\sqrt{s} = 500$ GeV $m_{\mathrm{LQ}} = 230$ GeV		$\sqrt{s} = 800$ GeV $m_{\mathrm{LQ}} = 350$ GeV	
$\int dt\mathcal{L}$	20 fb^{-1}	500 fb^{-1}	50 fb^{-1}	500 fb^{-1}
${}^{-5/3}V_1$	1640 (6063) 27.0%	40004 (151589) 26.4%	4962 (14017) 35.4%	49847 (140177) 35.6%
${}^{-2/3}V_0$	51 (186) 27.4%	1227 (4654) 26.4%	153 (433) 35.3%	1551 (4333) 35.8%
${}^{-4/3}S_1$	173 (630) 27.5%	4221 (15750) 26.8%	499 (1369) 36.4%	4974 (13699) 36.3%
${}^{-1/3}S_0$	1 (6) 16.7%	40 (153) 26.1%	4 (13) 30.8%	48 (134) 35.8%

mass reach requiring $N_{sig} = 5\sqrt{N_{bg}}$

		$\sqrt{s} = 500$ GeV					
$\int dt\mathcal{L}$		(20 fb^{-1})	500 fb^{-1}				
search		I		II		III	
$5\sqrt{N_{bg}}$		(18)	90	(61)	306	(251)	1259
states	B_{eq}	mass reach in GeV					
$^{-1/3}S_0$	$^2/_3$	(202) →	228	(◆)	205	(◇)	◇
	$^1/_2$	(183) →	220	(◆)	208	(◇)	◇
	1	(217)	235	(-)	-	(-)	-
$^{-4/3}\tilde{S}_0$	1	(242)	245	(-)	-	(-)	-
$^{2/3}S_1$	0	(-)	-	(-)	-	(225)	238
$^{-1/3}S_1$	$^1/_2$	(183) →	220	(◆)	208	(◇)	◇
$^{-4/3}S_1$	1	(244)	245	(-)	-	(-)	-
$^{-2/3}S_{1/2}$	$^1/_2$	(230)	241	(221)	236	(179) →	212
	0	(-)	-	(-)	-	(218)	235
	1	(240)	245	(-)	-	(-)	-
$^{-5/3}S_{1/2}$	1	(244)	245	(-)	-	(-)	-
$^{1/3}\tilde{S}_{1/2}$	0	(-)	-	(-)	-	(198) →	214
$^{-2/3}\tilde{S}_{1/2}$	1	(237)	244	(-)	-	(-)	-
$^{-1/3}V_{1/2}$	$^1/_2$	(241)	244	(237)	242	(220)	237
	0	(-)	-	(-)	-	(236)	242
	1	(245)	246	(-)	-	(-)	-
$^{-4/3}V_{1/2}$	1	(247)	247	(-)	-	(-)	-
$^{2/3}\tilde{V}_{1/2}$	0	(-)	-	(-)	-	(236)	242
$^{-1/3}\tilde{V}_{1/2}$	1	(244)	245	(-)	-	(-)	-
$^{-2/3}V_0$	$^2/_3$	(241)	244	(233)	241	(195) →	220
	$^1/_2$	(238)	242	(234)	239	(212)	227
	1	(244)	247	(-)	-	(-)	-
$^{-5/3}\tilde{V}_0$	1	(247)	247	(-)	-	(-)	-
$^{1/3}V_1$	0	(-)	-	(-)	-	(241)	245
$^{-2/3}V_1$	$^1/_2$	(238)	242	(234)	239	(212)	227
$^{-5/3}V_1$	$^1/_2$	(248)	247	(-)	-	(-)	-

scalars

vectors

\- channel not accessible

◇ no sensitivity to masses > 100 GeV

		$\sqrt{s} = 800$ GeV					
$\int dt\mathcal{L}$		(50 fb^{-1}) 500 fb^{-1}					
search		I		II		III	
$5\sqrt{N_{bg}}$		(21)	66	(60)	189	(375)	1186
states	B_{eq}	mass reach in GeV					
$^{-1/3}S_0$	$^2/_3$	(318)	332	(◆)	311	(◇)	◇
	$^1/_2$	(289) →	323	(◆)	309	(◇)	◇
	1	(350)	362	(-)	-	(-)	-
$^{-4/3}\tilde{S}_0$	1	(387)	391	(-)	-	(-)	-
$^{2/3}S_1$	0	(-)	-	(-)	-	(275) →	302
$^{-1/3}S_1$	$^1/_2$	(289) →	323	(◆)	311	(◇)	◇
$^{-4/3}S_1$	1	(389)	396	(-)	-	(-)	-
$^{-2/3}S_{1/2}$	$^1/_2$	(369)	385	(359)	377	(◆)	308
	0	(-)	-	(-)	-	(239) →	287
	1	(384)	294	(-)	-	(-)	-
$^{-5/3}S_{1/2}$	1	(389)	396	(-)	-	(-)	-
$^{1/3}\tilde{S}_{1/2}$	0	(-)	-	(-)	-	(146) →	198
$^{-2/3}\tilde{S}_{1/2}$	1	(379)	396	(-)	-	(-)	-
$^{-1/3}V_{1/2}$	$^1/_2$	(385)	396	(380)	392	(266) →	302
	0	(-)	-	(-)	-	(326)	345
	1	(392)	396	(-)	-	(-)	-
$^{-4/3}V_{1/2}$	1	(395)	395	(-)	-	(-)	-
$^{2/3}\widetilde{V}_{1/2}$	0	(-)	-	(-)	-	(326)	345
$^{-1/3}\widetilde{V}_{1/2}$	1	(390)	392	(-)	-	(-)	-
$^{-2/3}V_0$	$^2/_3$	(385)	392	(373)	389	(200) →	279
	$^1/_2$	(380)	392	(376)	390	(244) →	317
	1	(390)	392	(-)	-	(-)	-
$^{-5/3}\widetilde{V}_0$	1	(396)	397	(-)	-	(-)	-
$^{1/3}V_1$	0	(-)	-	(-)	-	(352)	376
$^{-2/3}V_1$	$^1/_2$	(380)	392	(375)	390	(244) →	317
$^{-5/3}V_1$	$^1/_2$	(396)	395	(-)	-	(-)	-

scalars

vectors

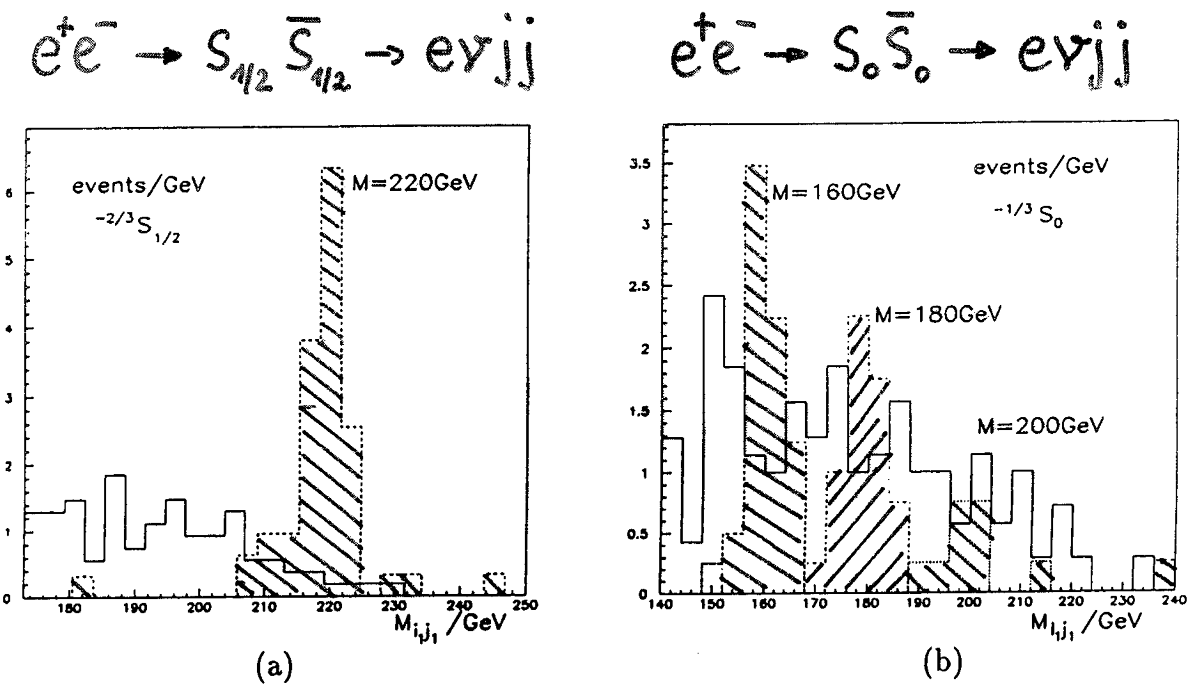
Mass Reach

requiring $N_{signal} \geq 5\sqrt{N_{bg}}$, masses up to $x\frac{\sqrt{s}}{2}$ can be reached

$\sqrt{s} = 500$ GeV	20 fb^{-1}	500 fb^{-1}
Scalar	0.73 - 0.97	0.86 - 0.98
Vector	0.94 - 0.99	0.97 - 0.99
$\sqrt{s} = 800$ GeV	50 fb^{-1}	500 fb^{-1}
Scalar	0.37 - 0.97	0.50 - 0.99
Vector	0.81 - 0.99	0.86 - 0.99

- cuts have to be optimized!
- luminosity not so crucial

mass reconstruction

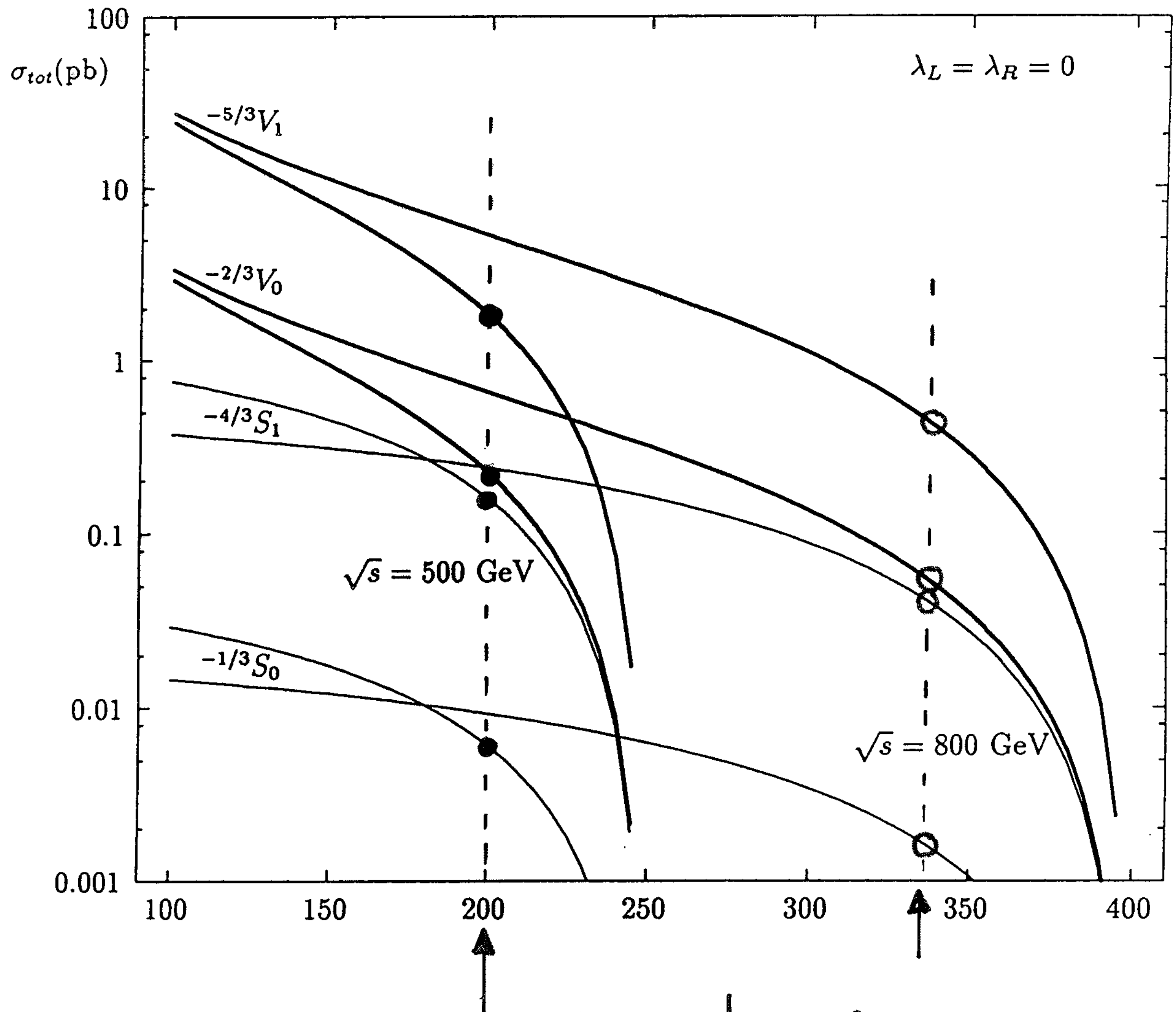


(a) (b)

Figure 6: *Signal and background distributions in the invariant mass* $M_{l_1 j_1}$ *for the channel* $e^{\pm}\nu$*+2jets and* $\sqrt{s} = 500$ *GeV,* $\mathcal{L} = 20\ fb^{-1}$*: (a)* $^{-2/3}S_{1/2}$ *production, (b)* $^{-1/3}S_0$ *production and* $M = 160$ *GeV (dashed),* $M = 180$ *GeV (dash-dotted) and* $M = 200$ *GeV (dotted). The full histograms show the dominant background from* $t\bar{t}$ *production.* $B_{eq} = 0.5$

[redacted] Settles Spiesberger, RR

spin / weak isospin

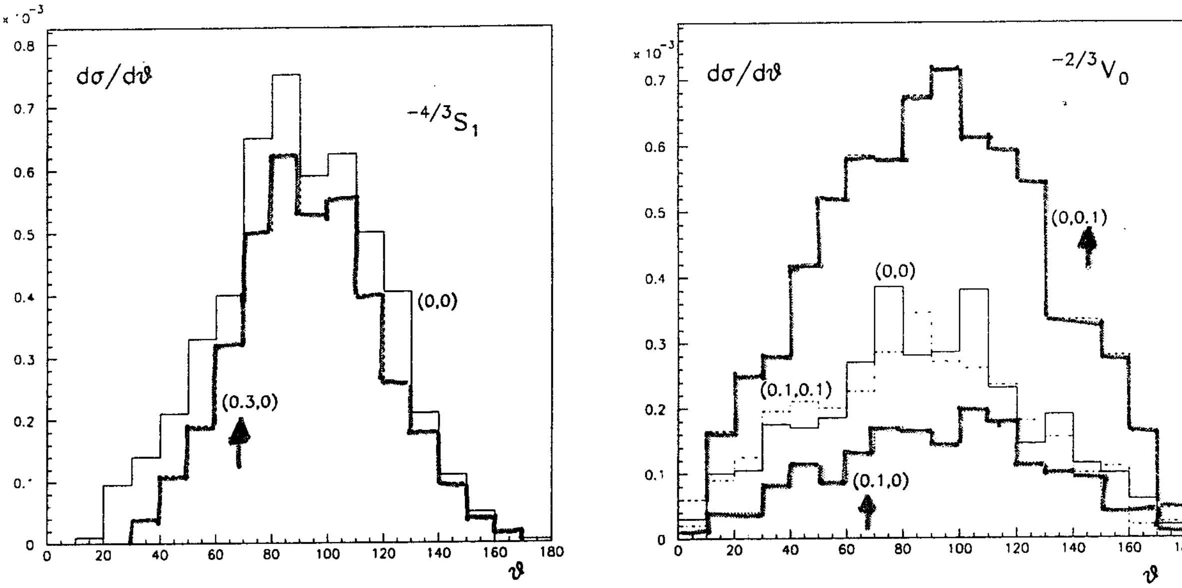


mass known

not possible in $\overset{(-)}{p}p$ and ep searches

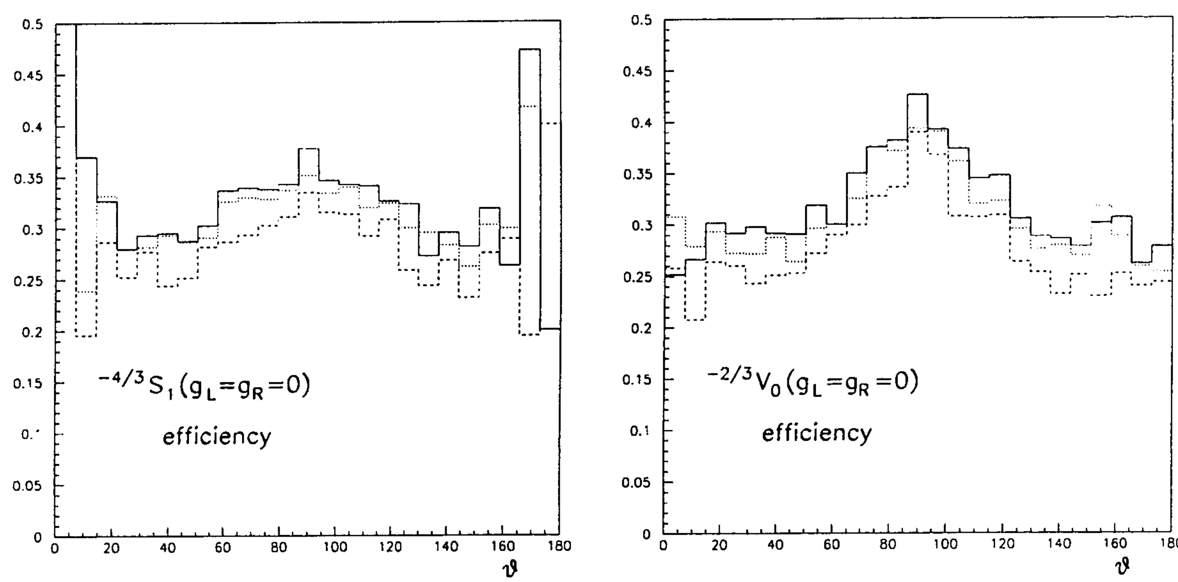
Yukawa coupling

$\lambda_L = 0.09$ $\lambda_{L,R} = 0.03$



(a) (b)

Figure 7: *Angular dependence of the production cross sections for (a)* $^{-4/3}S_1$ *and (b)* $^{-2/3}V_0$ *for various Yukawa couplings* (g_L, g_R) *in units of e* $(M = 300$ *GeV*, $\sqrt{s} = 800$ *GeV*, $\mathcal{L} = 50 fb^{-1}$, *cuts included).*



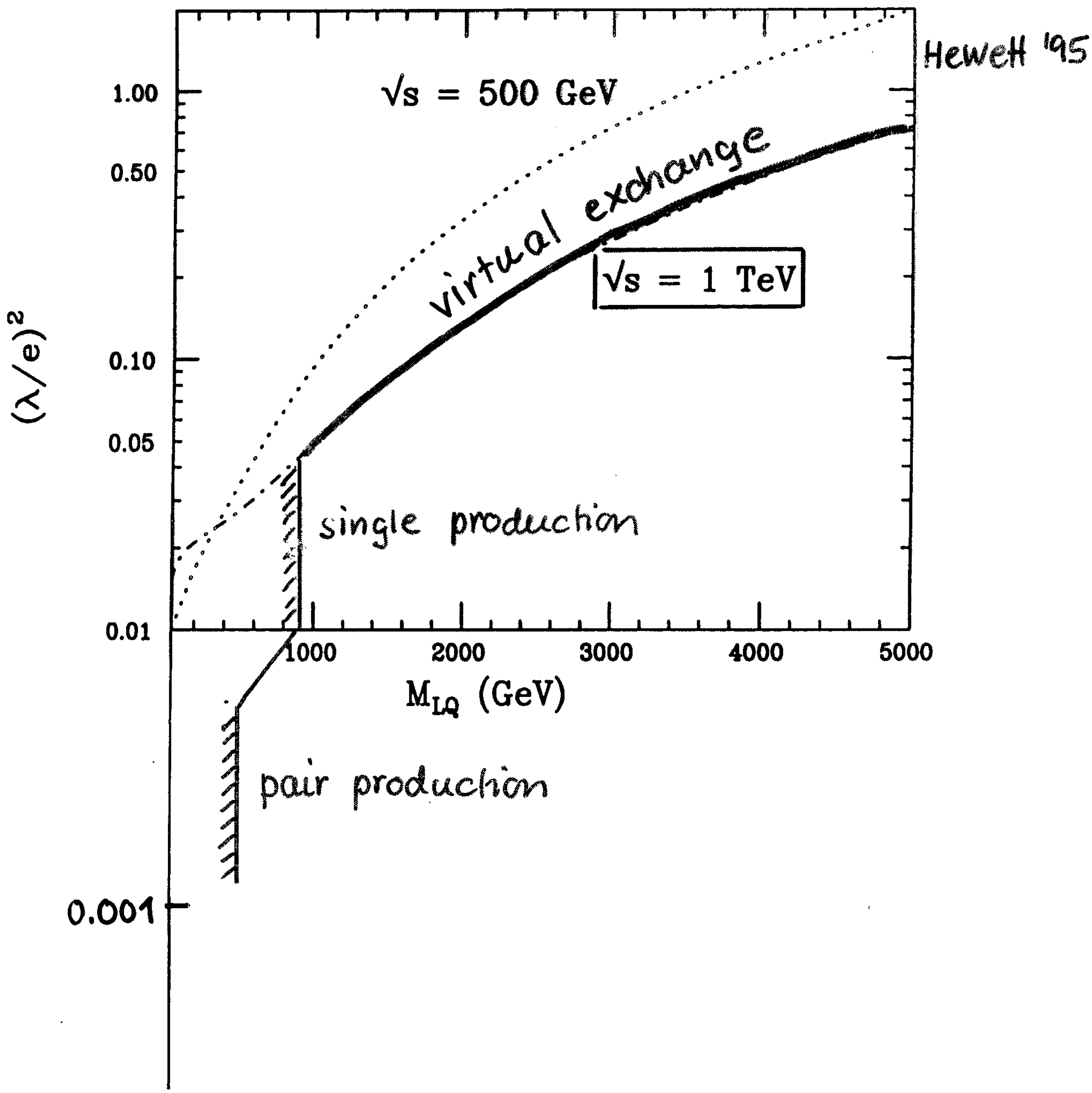
(a) (b)

Figure 8: *Angular dependence of the detection efficiency for a scalar (a) and a vector (b) leptoquark in channel I. The full histogram refers to the 1 TeV detector, the dashed one to a LEP/SLD-type detector. The dotted histogram is obtained with the detector simulation of Ref. [24].*

- requires accurate unfolding of efficiency!

from R. Rücke

summary of LQ searches at e^+e^- Linear Colliders

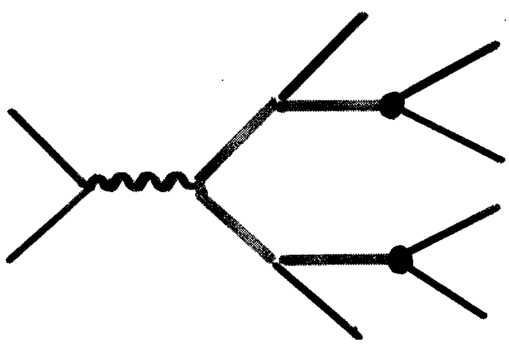


R-Parity Violating Processes at Linear Colliders

(extrapolation of analysis by J. Kalinowski et al. PLB 406 (1997) 314)

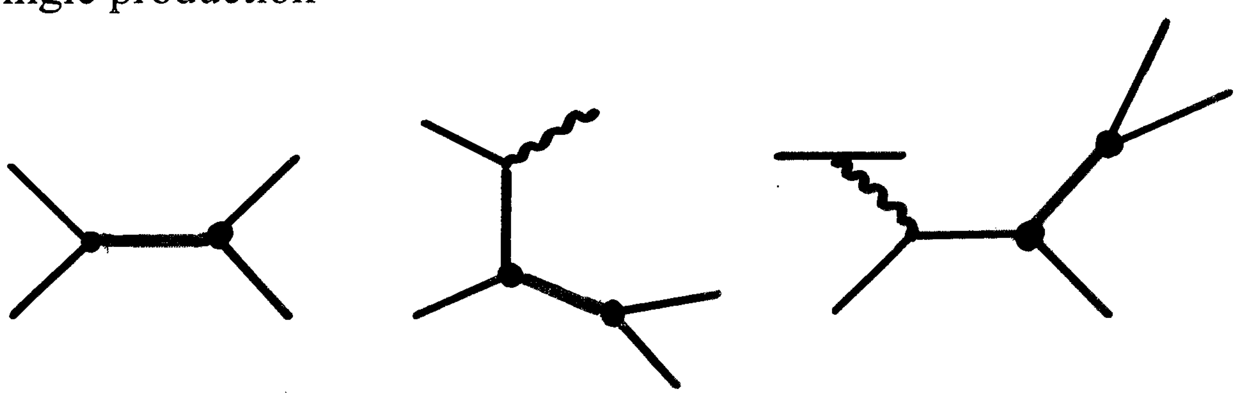
$$W = \ldots + \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

pair production and R-parity violation in decays

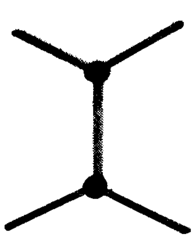


⟶ SUSY WG

single production



virtual exchange



Dimopoulos, Hall
Barger et al., Godbole et al.
Dreiner et al., ...
Chemtop, Moreau; ....

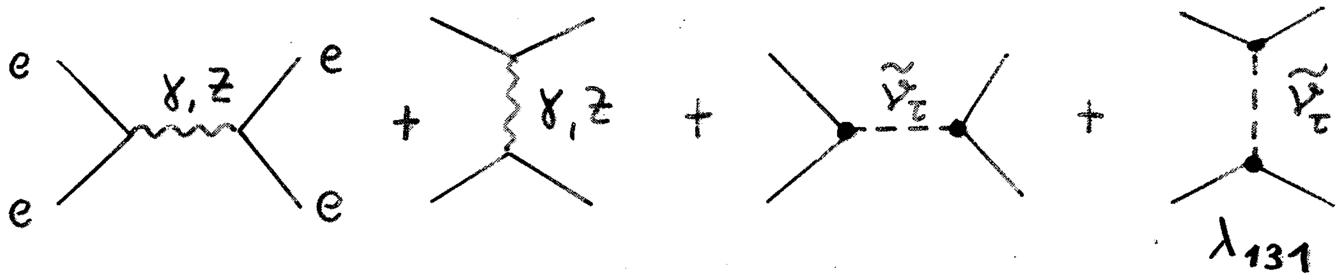
*

$\tilde{v}$

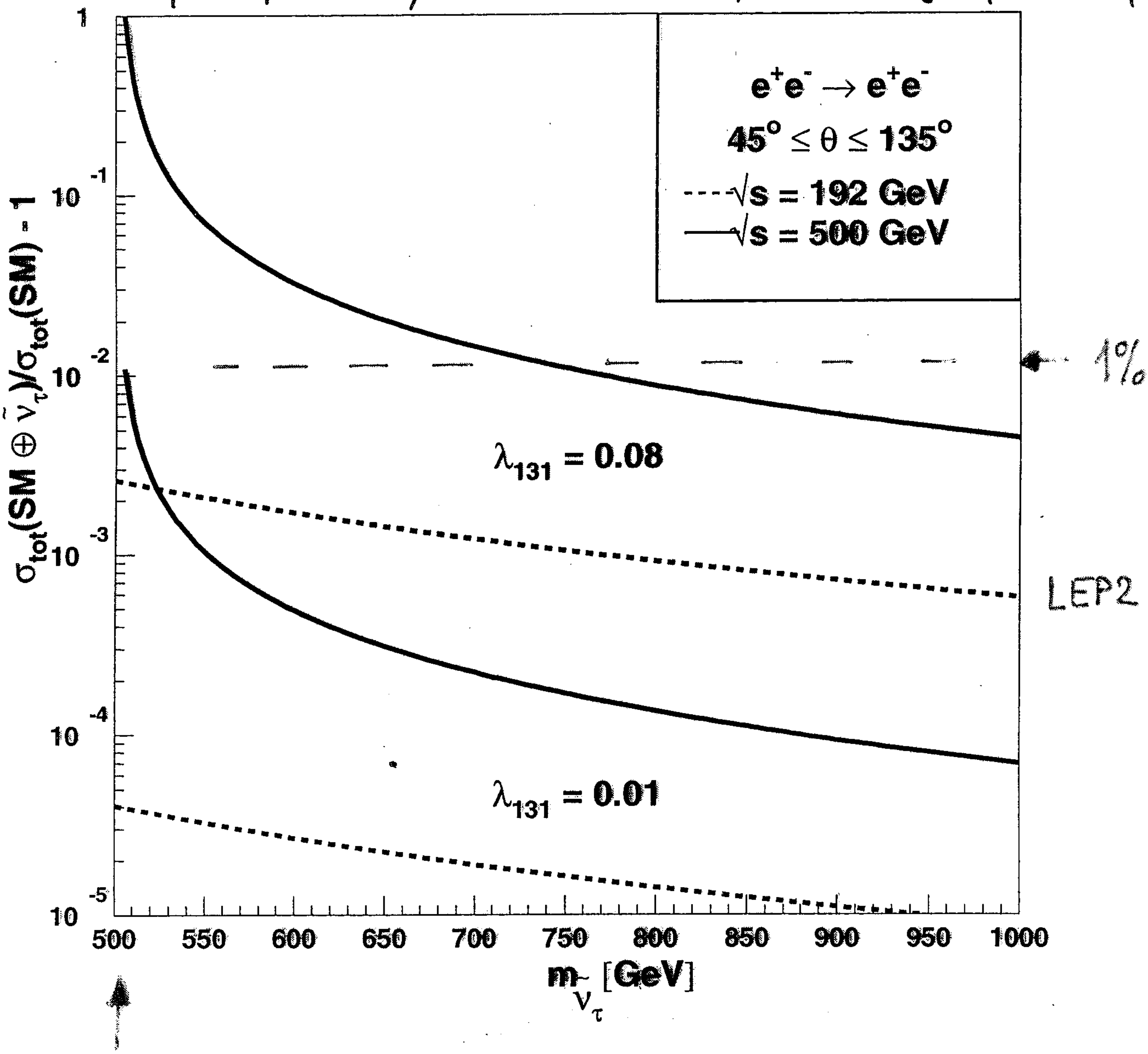
*

$\tilde{v}$

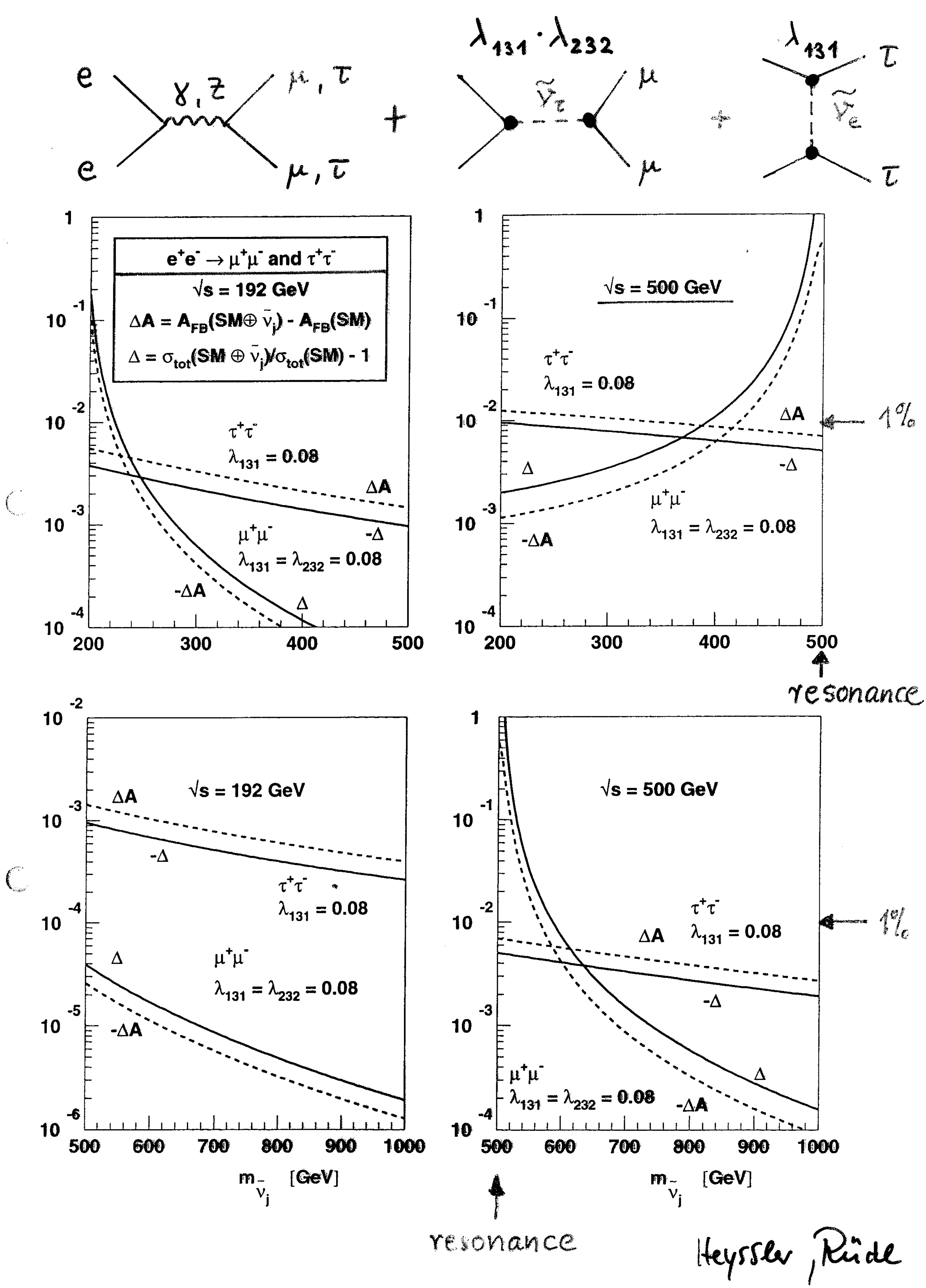
$\not{R}$ MODELS



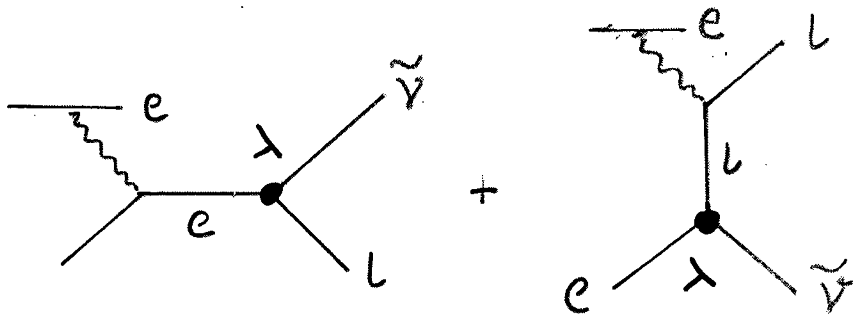
Heyssler, Rüde, see Kalinowski, Spiesberger, Zerwas, Rückl



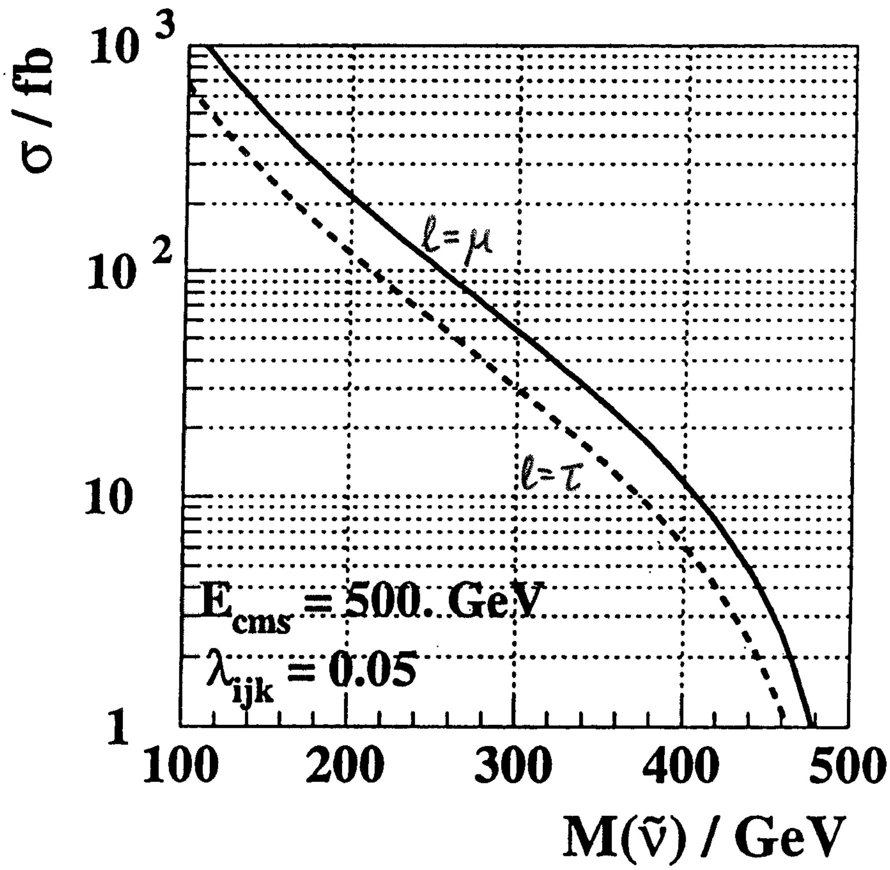
resonance (APV: $\lambda_{131} \lesssim 0.13$)



e
e
γ, Z
μ, τ
μ, τ
+
$\lambda_{131} \cdot \lambda_{232}$
$\tilde{\nu}_\tau$
μ
μ
+
λ_{131}
$\tilde{\nu}_e$
τ
τ
$e^+e^- \to \mu^+\mu^-$ and $\tau^+\tau^-$
$\sqrt{s}$ = 192 GeV
$\Delta A = A_{FB}(SM \oplus \tilde{\nu}_j) - A_{FB}(SM)$
$\Delta = \sigma_{tot}(SM \oplus \tilde{\nu}_j)/\sigma_{tot}(SM) - 1$
$\tau^+\tau^-$
λ_{131} = 0.08
ΔA
-Δ
$\mu^+\mu^-$
$\lambda_{131} = \lambda_{232}$ = 0.08
-ΔA
Δ
$\sqrt{s}$ = 500 GeV
1%
resonance
$\sqrt{s}$ = 192 GeV
$\sqrt{s}$ = 500 GeV
$m_{\tilde{\nu}_j}$ [GeV]
$m_{\tilde{\nu}_j}$ [GeV]
resonance
Heyssler, Rüde



$e^+e^- \to (e)\,\ell\,\tilde{\nu}$ (Dreiner et al.)



reach comparable to single LQ production