Moriond QCD week
18-24 March 2001

Other Searches at LEP

Sylvie Braibant
CERN

On behalf of the LEP experiments

RPV-SUSY

GMSB

Technicolor

Excited leptons

Leptoquarks

Searches Variants

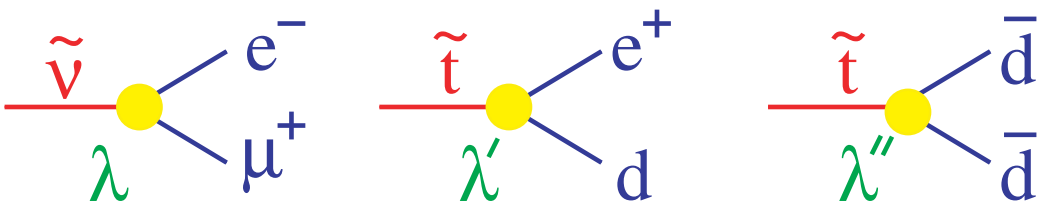
- *R-parity conserving SUSY*
  (LSP stable → missing energy)
  - *Standard SUSY: neutralino LSP*
    (see T. Alderweireld's talk)
  - *GMSB: gravitino LSP $\tilde{G}$*
    - *light G (eV → GeV) with possibly long lifetime of slepton or neutralino NLSP: either $\tilde{\chi}_1^0$ or $\tilde{l}$*
    - *super-light $\tilde{G}$ (μeV)*
- *R-parity violating SUSY (LSP decays to SM particles)*
  - *vast field with very different signatures*
- *Exotics*
  - *Technicolor*
  - *Leptoquarks*
  - *Excited Leptons*

RPV SUSY: Superpotential

$$W = \lambda_{ijk} L_L^i L_L^j \bar{E}_R^k + \lambda'_{ijk} L_L^i Q_L^j \bar{D}_R^k + \lambda''_{ijk} \bar{U}_R^i \bar{D}_R^j \bar{D}_R^k$$

L violation (*bilinear term $\varepsilon_i L_i H_u$ rotated away*)

B violation



L violation B violation

with

L_L:	*lepton doublet superfield*
Q_L:	*quark doublet superfield*
E_R:	*lepton singlet superfield*
D_R:	*down-quark type singlet superfield*
U_R:	*up-quark type singlet superfield*
$\lambda, \lambda', \lambda''$:	*Yukawa couplings*
i, j, k:	*generation indices*

Due to symmetry $i < j$ *for* λ_{ijk}

$j < k$ *for* λ''_{ijk}

$\rightarrow$ *45 (9 + 27 + 9) independent couplings*

RPV SUSY: R-Parity

To avoid L and B violation R-parity is introduced via a discrete multiplicative quantum number in SUSY models

$$R_p = (-1)^{2S+3B+L}$$

S: spin
B: baryon number
L: lepton number

$R_p = 1$ *for SM particles*
$R_p = -1$ *for SUSY particles*

If R_p *is conserved,* $W = 0$

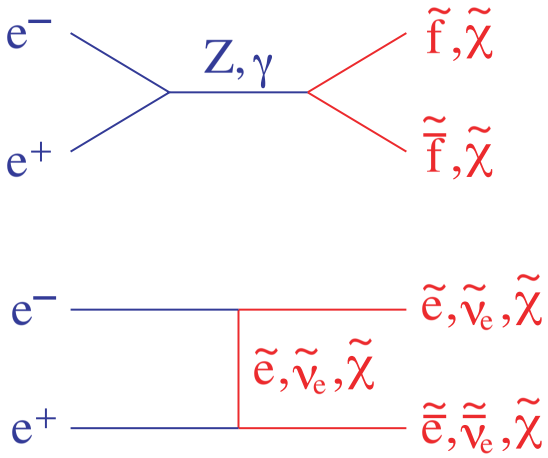
	R_p	$\not{R}_p$
SUSY particles produced in	*pairs*	*pairs or singly*
the LSP	*is stable*	*decays*
experimental signature	E_{miss}	no E_{miss}

Exclusion limits from R_p*-conservation are not valid under* R_p*-violation.*

- *Assumptions*
  - *exactly 1* λ-like *coupling different from 0 at the time*
  - *mean path of flight* < 1 cm $\rightarrow \lambda > 10^{-4}$

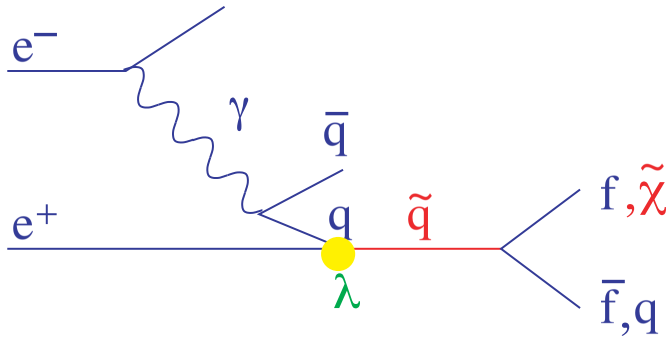
RPV SUSY: Production Mechanisms

Pair -production



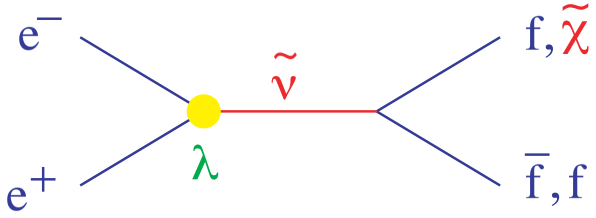
masses up to beam energy

Single production



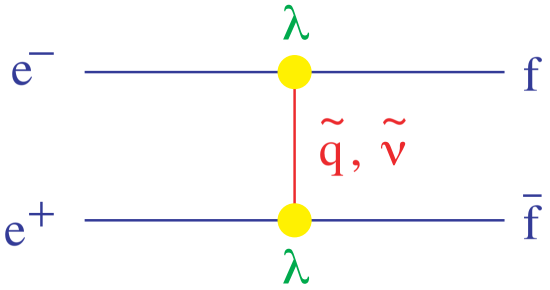
masses up to $\sqrt{s}$

s–channel resonance



masses up to $\sqrt{s}$

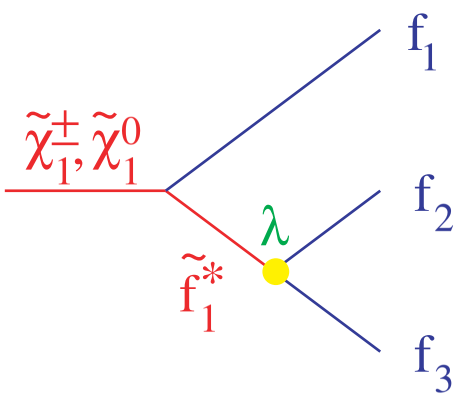
t–channel exchange



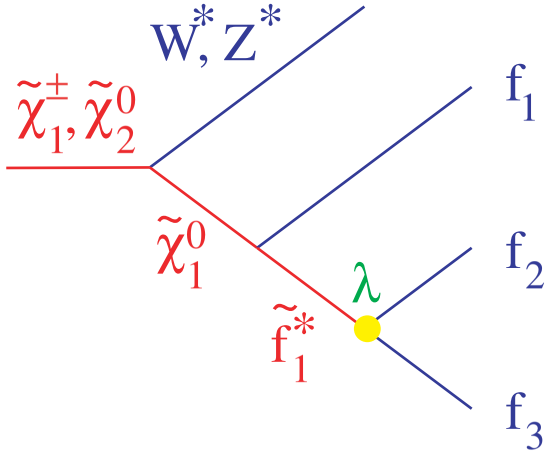
masses up to $2 \times \sqrt{s}$

RPV SUSY:Gaugino Searches

Direct decays



Indirect decays



R_p-*conserving decays*
plus decay products of χ_1^0

Final states from pair-production:

	direct decays	*indirect decays*
gauginos	*6 fermions*	*10 fermions*

Direct decays:

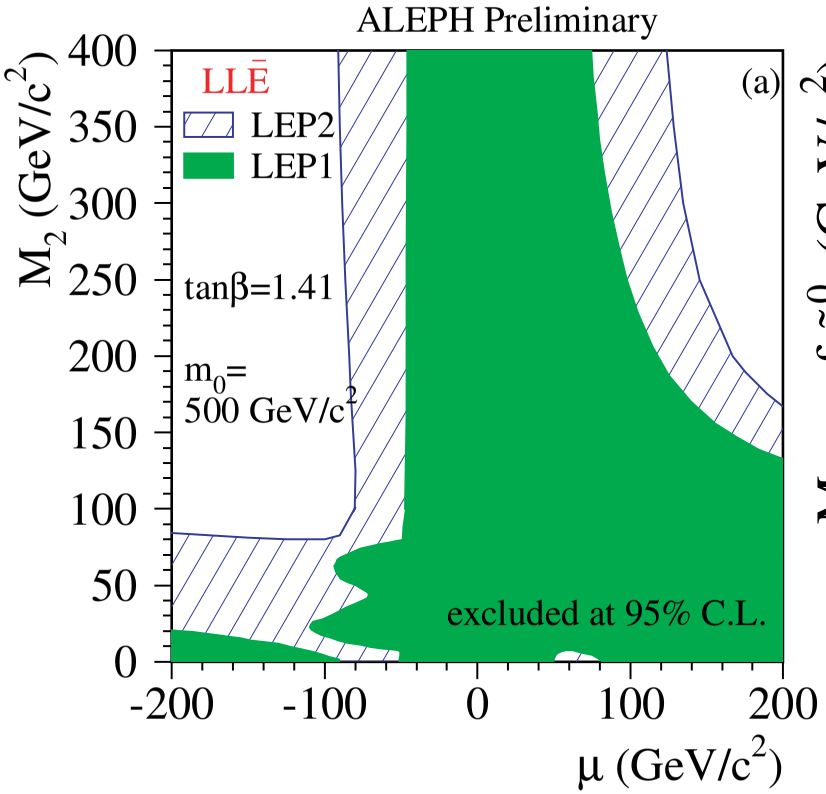
$\chi_1^0\chi_1^0 \rightarrow 4\,l + \not{E}$
$\chi_1^+\chi_1^- \rightarrow 2\,l + \not{E}$
$\chi_1^+\chi_1^- \rightarrow 4\,l + \not{E}$
$\chi_1^+\chi_1^- \rightarrow 6\,l$

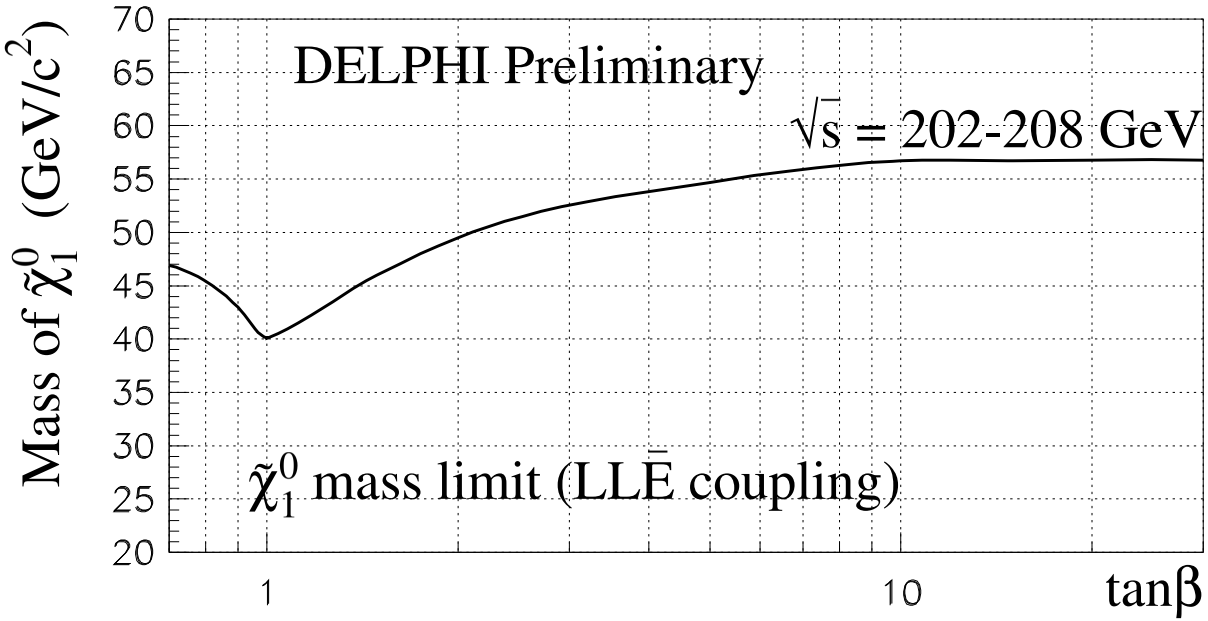
λ

Indirect decays:

$\chi_1^+\chi_1^- \rightarrow WW + 4\,l + \not{E}$

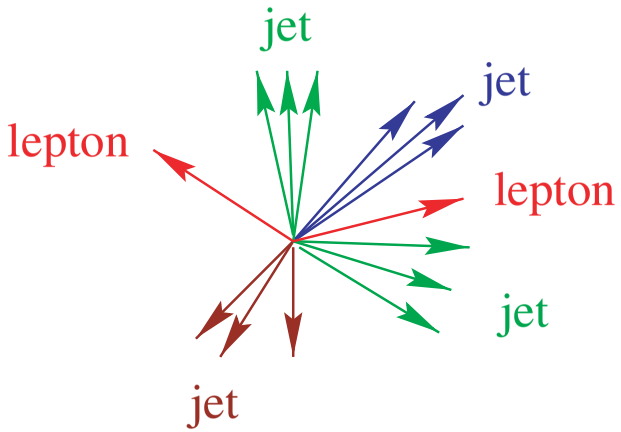
RPV SUSY: Gaugino Searches for λ





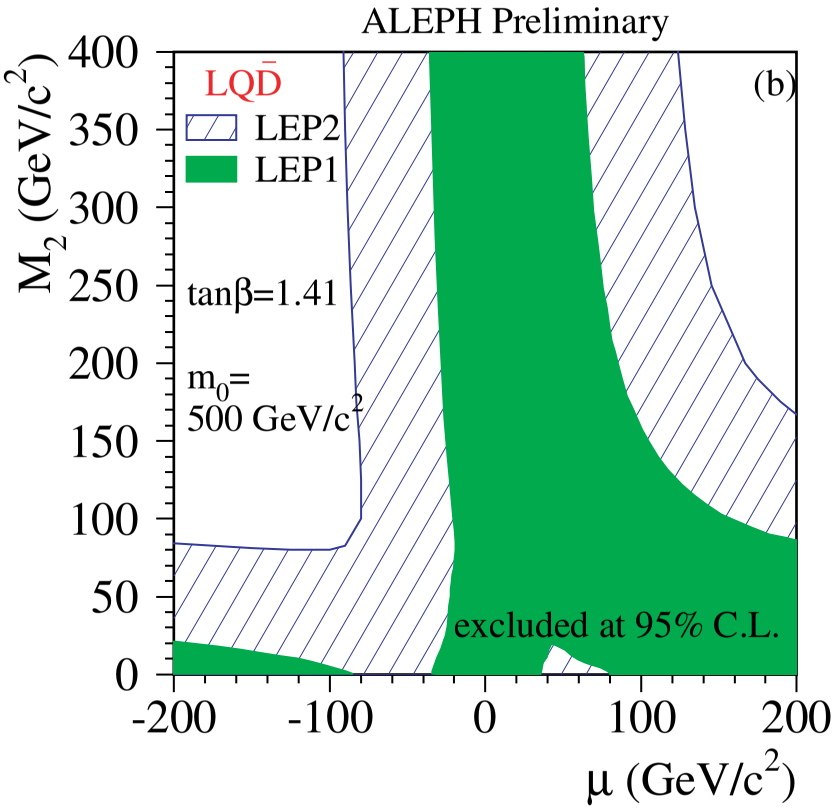
$m_{\tilde{\chi}_1^0} > 40$ GeV

RPV SUSY: Gaugino Searches for λ'



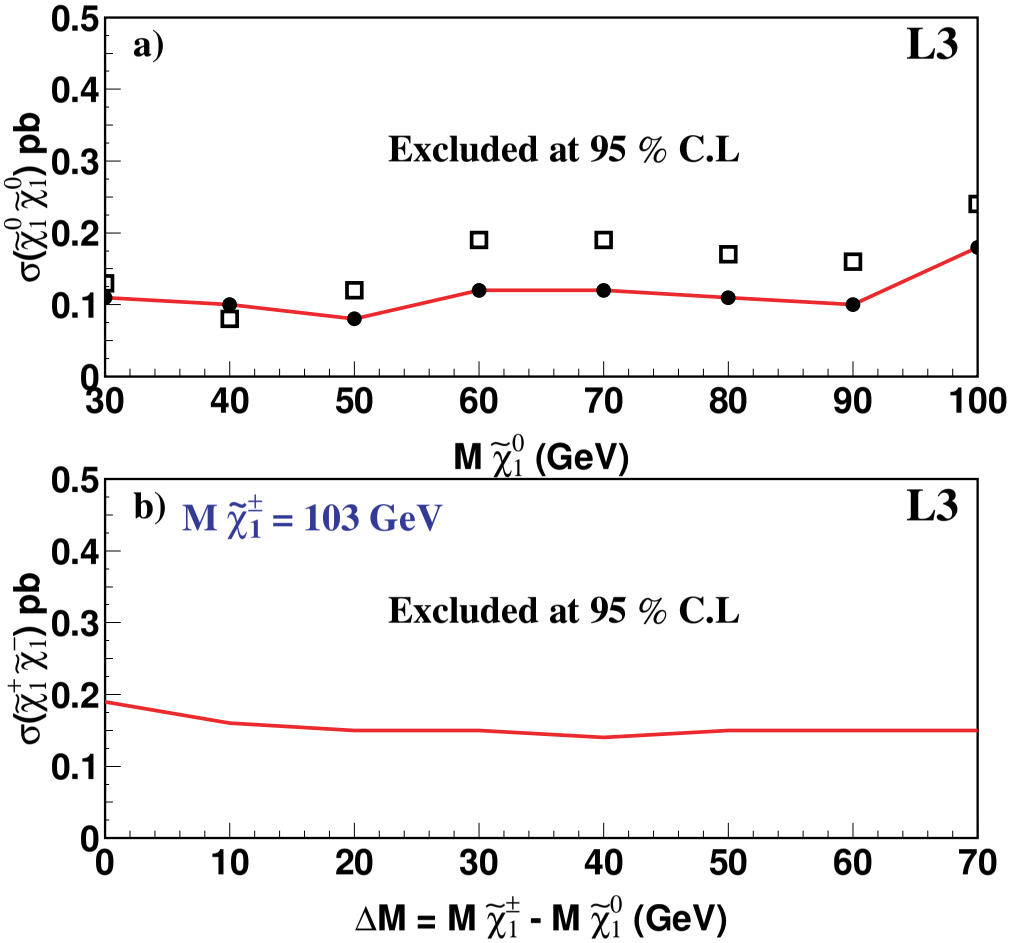
Background from W-pair production and multi-hadronic events

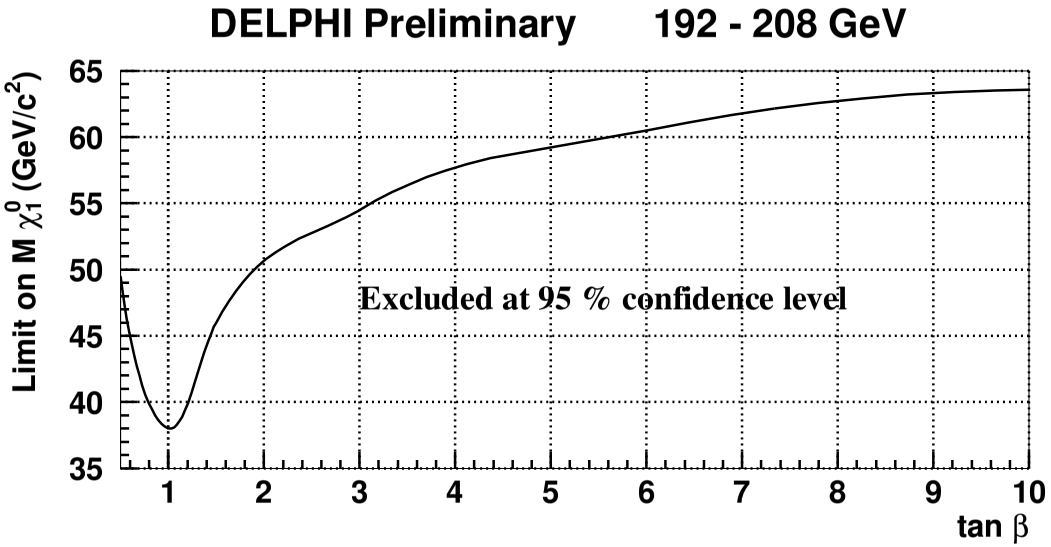
Final states contain many jets and leptons



RPV SUSY: Gaugino Searches for λ''

Final states with up to 10 jets

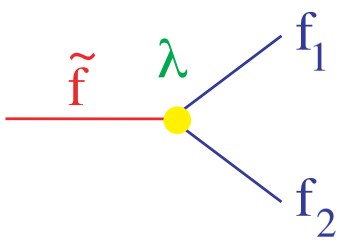




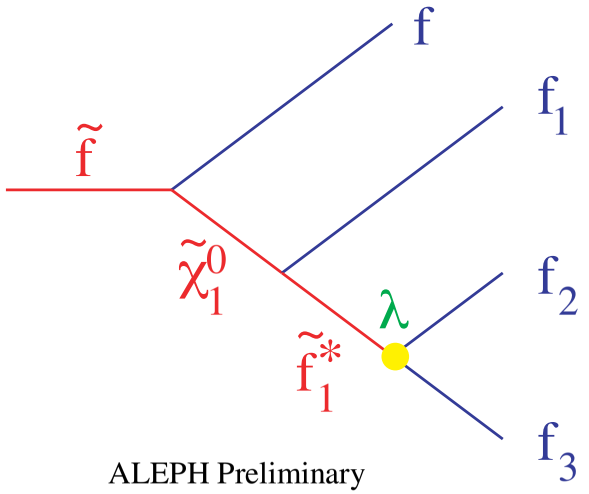
$m_{\tilde{\chi}_1^0} > 38$ GeV

RPV SUSY: Slepton Searches

Direct decays



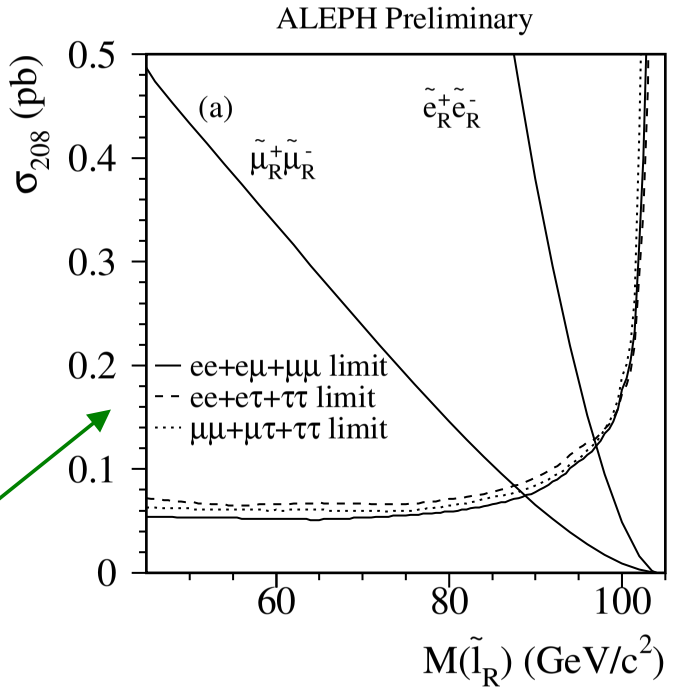
Indirect decays



Final states:

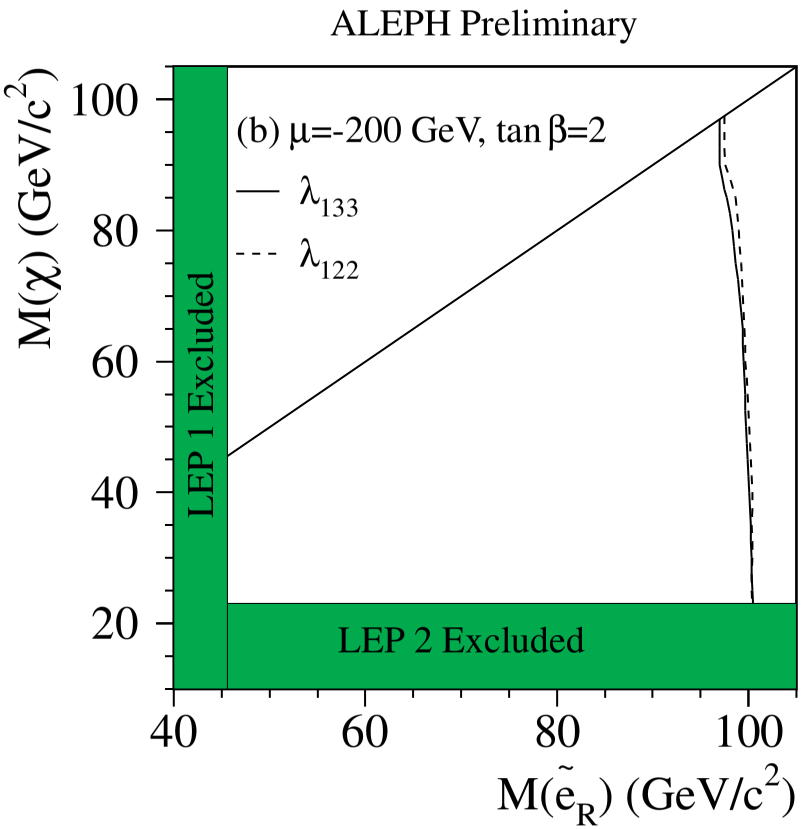
	direct decays	*indirect decays*
λ	*2 ℓ + E̸*	*6 ℓ + E̸*
λ'	*4 jets*	*(2+x) ℓ + 4 jets*
λ''	*–*	*2 ℓ + 6 jets*

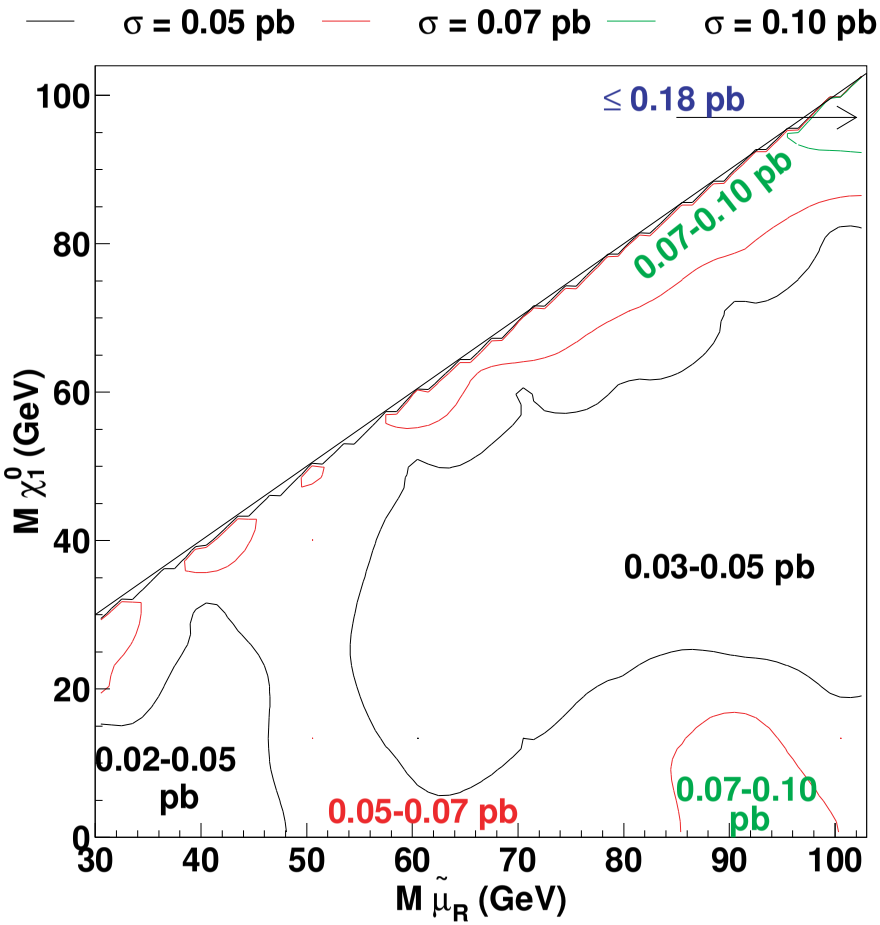
Cross-section limits for 2 ℓ + E̸ final states



RPV SUSY: Slepton Searches - MSSM limits

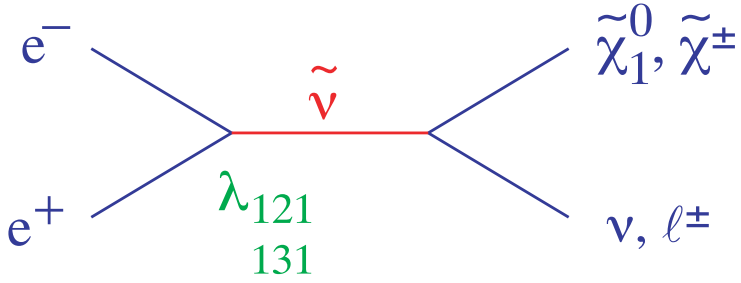
λ λ''

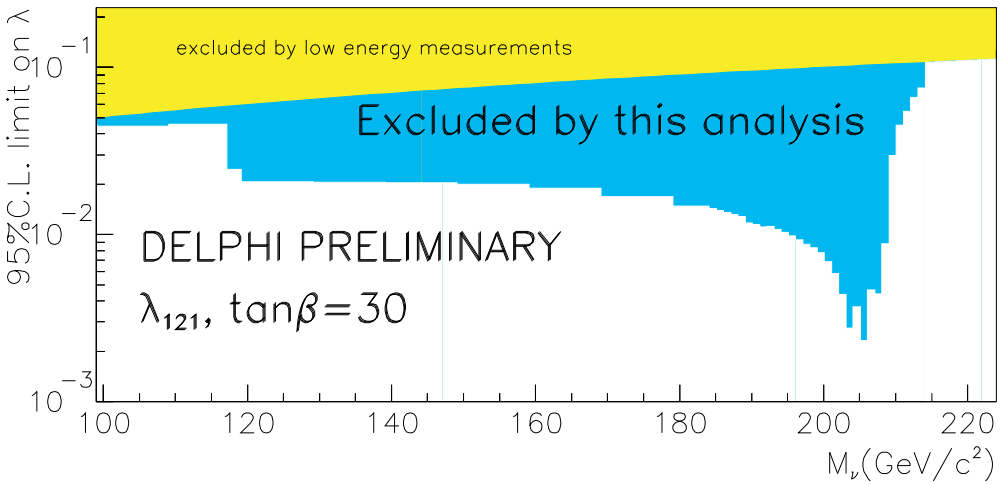


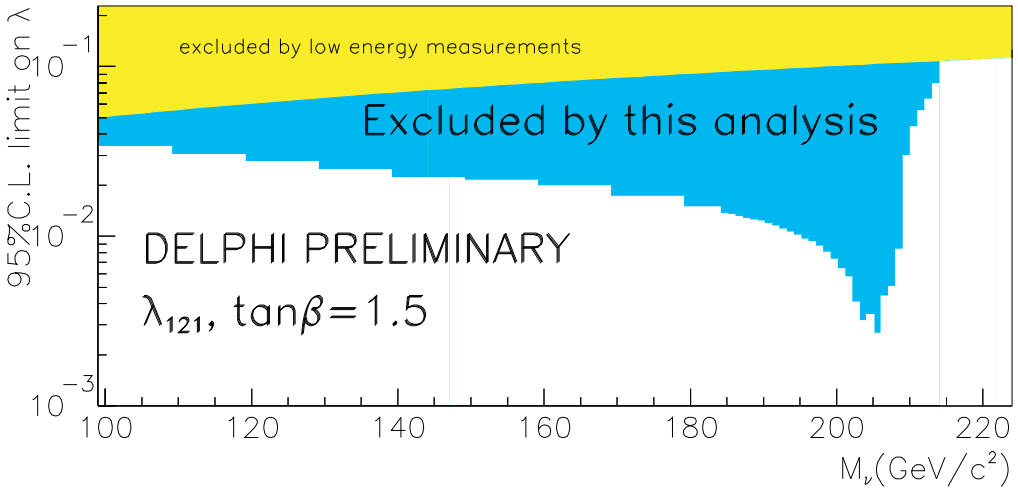


Similar results for squarks, sneutrinos for RPV λ, λ', λ'' decays

RPV SUSY: Sneutrino Searches - Resonant Production







RPV SUSY

- *Searches for R_p-violating production and decay of SUSY particles are complementary to searches with R_p-conservation*

- *Under the assumption of R_p-violation, searches have been performed for gauginos, sleptons, sneutrinos and squarks for all Yukawa couplings λ, λ', λ''*

- *No evidence for SUSY with R_p-violation*

- *Exclusion limits are similar to the R_p-conserving case*

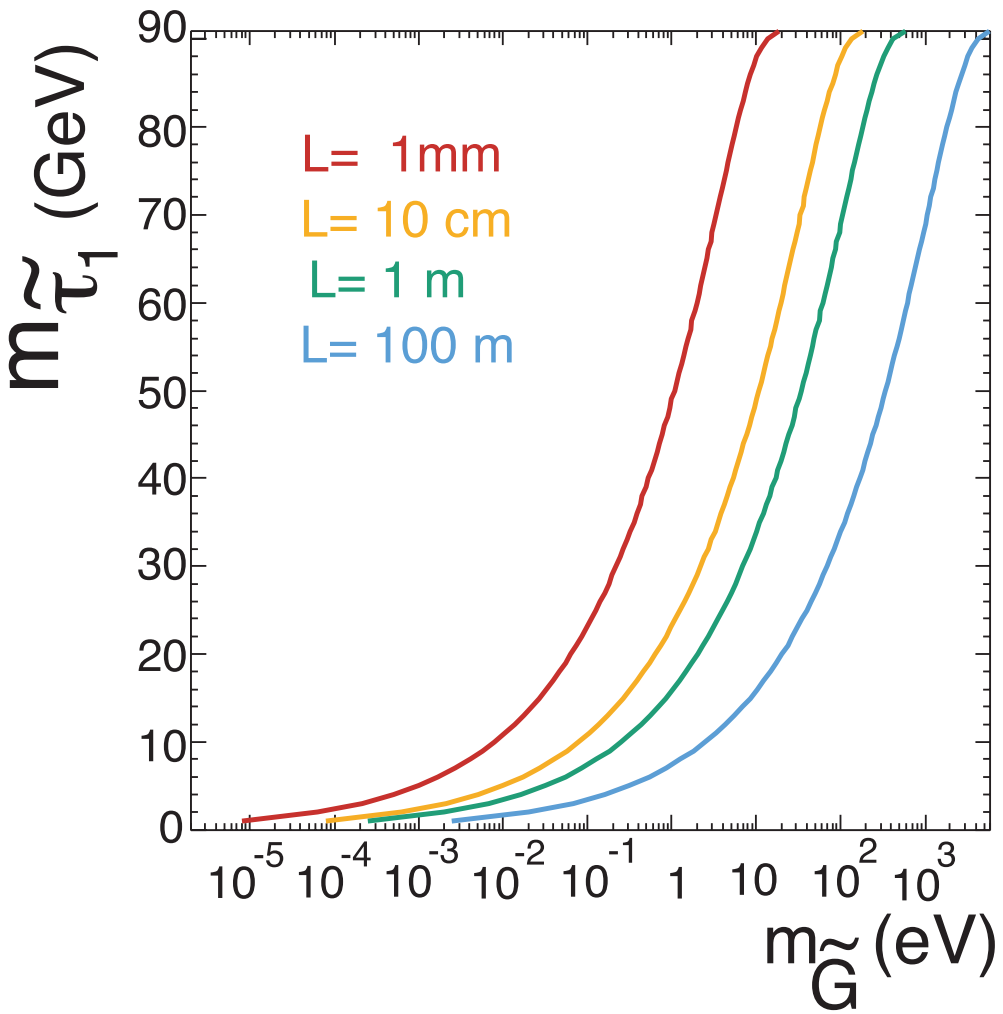
GMSB SUSY Searches: Light Gravitino Scenarios

Very general light gravitino scenarios:

- $\tilde{G}$ is the LSP $m_{\tilde{G}} \leq$ O (KeV).
- $\tilde{\chi}_1^0$ or $\tilde{\tau}_1$ are the NLSPs.
- Decay length of the NLSP depends on $\tilde{G}$ mass and NLSP mass:

$$L_{(\,\mathrm{NLSP}\,)} \sim \sqrt{\frac{E^2}{m_{NLSP}^2} - 1}\left(\frac{\mathrm{GeV}}{m_{NLSP}}\right)^5 \left(\frac{m_{\tilde{G}}}{\mathrm{eV}}\right)^2 \mathrm{cm}$$

Example: $m_{\tilde{\tau}}$ versus $m_{\tilde{G}}$ for various decay lengths $\Longrightarrow$



Wide range of NLSP lifetimes suggests to explore many different final topologies!

GMSB SUSY Searches

Parameters of Minimal Model	
$\sqrt{F}$	SUSY breaking scale (or $m_{\tilde{G}}$)
M	Messenger scale
N	Number of sets of messenger particles
Λ	Sparticle mass scale
$\tan\beta$	Ratio of the vacuum expectation values of the two Higgs doublets
μ	SUSY-conserving Higgs mass parameter

$M_{\tilde{G}} < 1\ \text{GeV} \Rightarrow$ LSP

NLSP

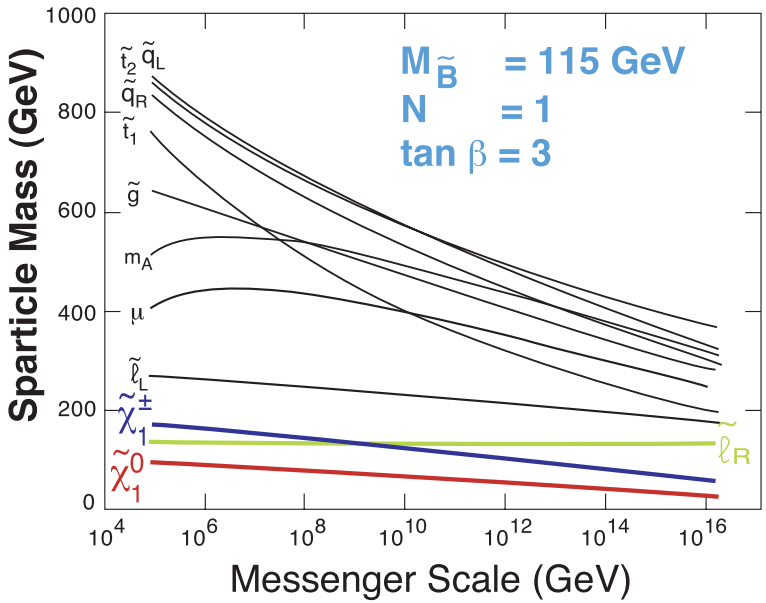
$\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$

$\tilde{\ell}_R^{\pm} \rightarrow \ell^{\pm}\tilde{G}$

NLSP $c\tau =$

$1\,\mu\text{m} - 10^{11}\,\text{km}$

Example GMSB mass spectra
(Dimopoulos *et al.*, hep-ph/9609434):

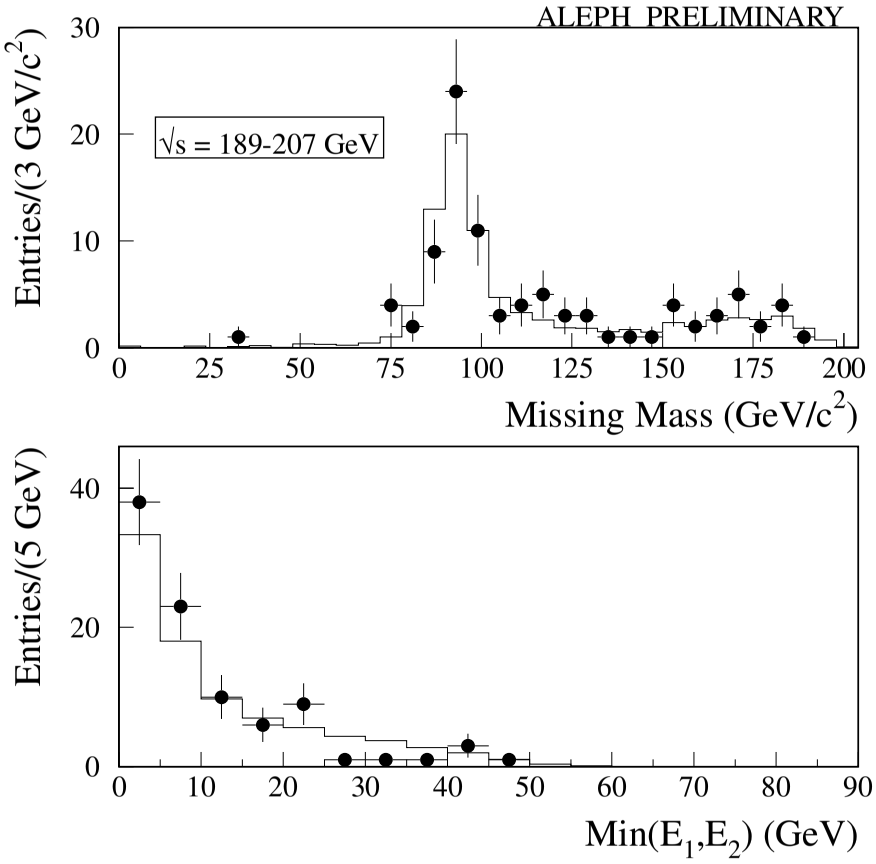


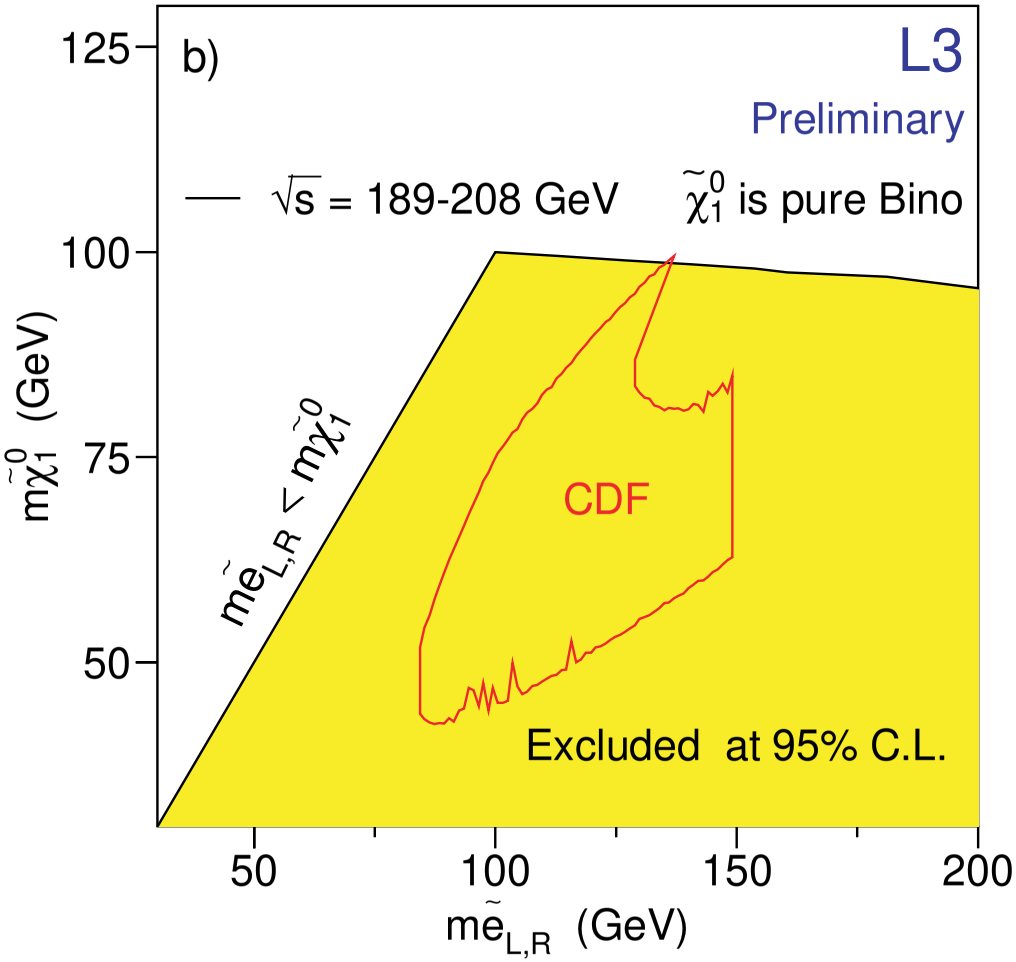
GMSB SUSY Searches: Neutralino NLSP

$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$
$\quad\quad\quad

GMSB SUSY Searches: Neutralino NLSP

Acoplanar photons *Zero Lifetime*

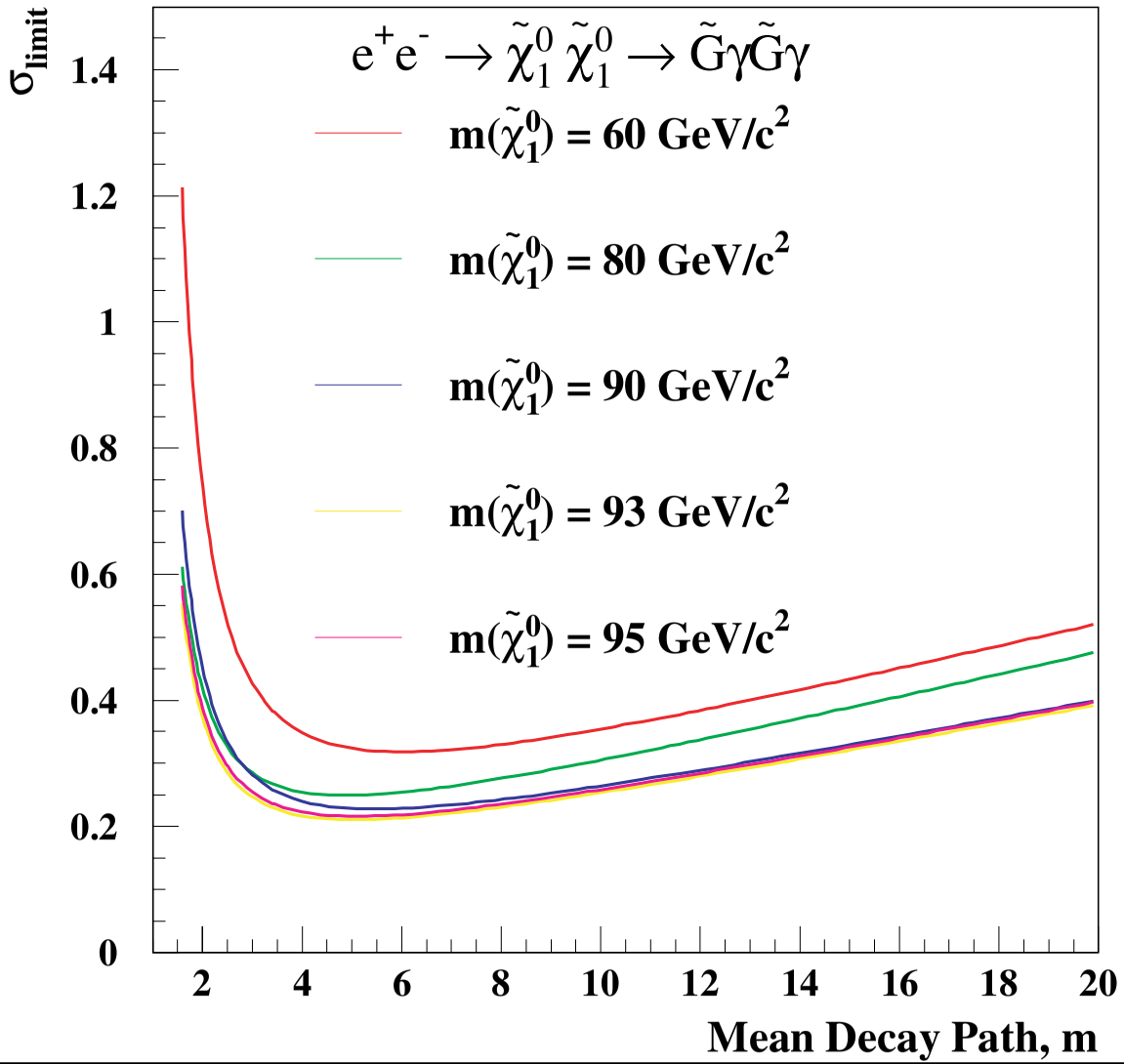




GMSB SUSY Searches: Neutralino NLSP

Non-pointing single photons

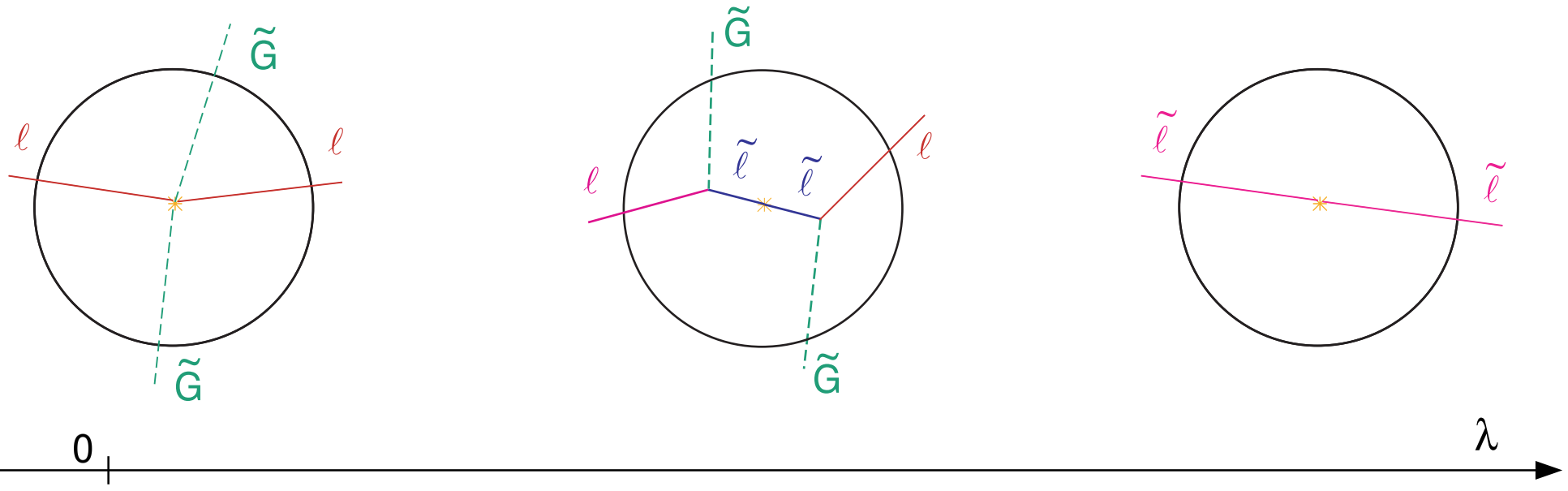
Non-Zero Lifetime



GMSB SUSY Searches: Slepton NLSP

$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow \tilde{G}\,\ell^-$

$\hookrightarrow \tilde{G}\,\ell^+$



Zero Lifetime
Acoplanar leptons

↓

Exclusion plots for Sleptons in gravity-mediated

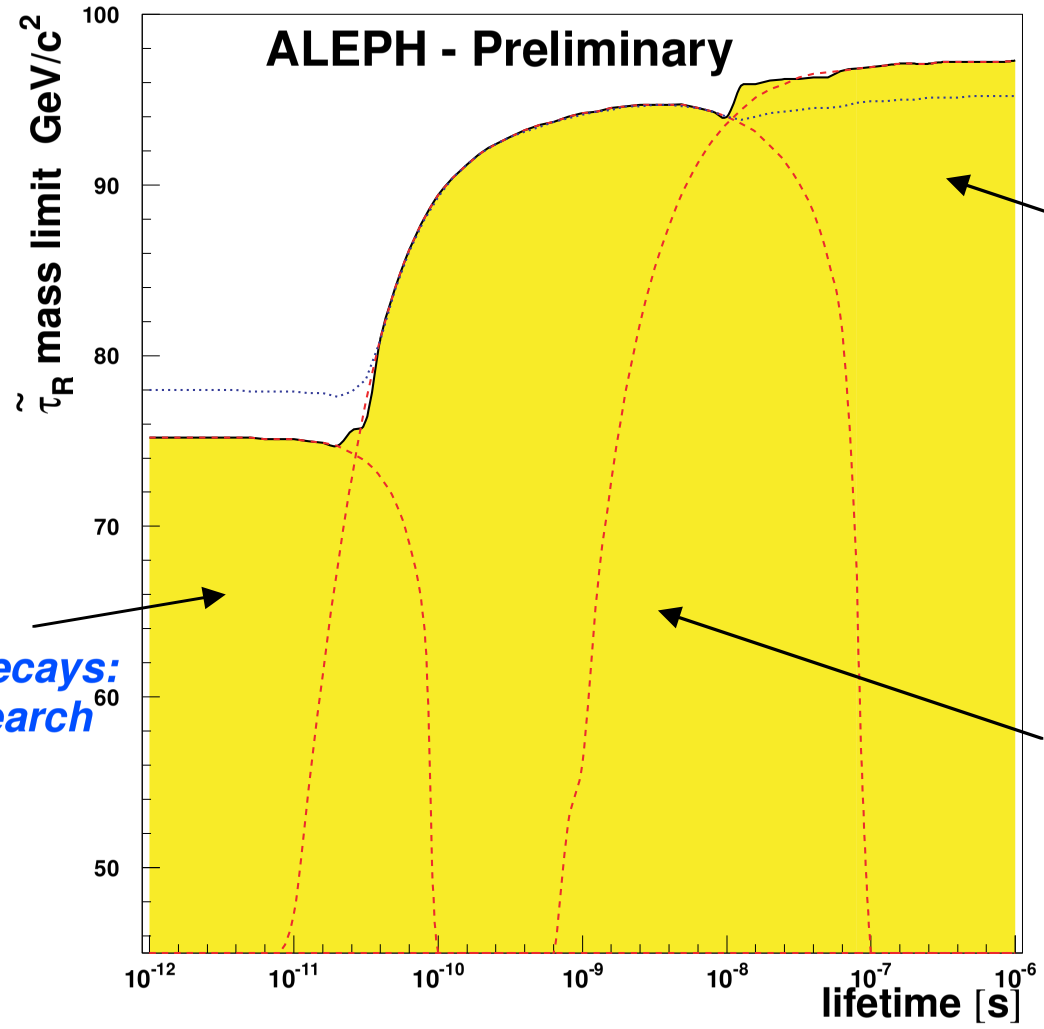
Large IP + kinks

Large IP → Λ*=O(1 mm)-O(40 cm)*
Kinks → Λ*=O(10 cm)-O(2 m)*

Heavy stable charged particles
dE/dx
or
RICH detectors

GMSB SUSY Searches: Slepton NLSP

Combining searches in various regions of $\tilde{l}$ lifetime



Zero lifetime:
Search for prompt decays:
acoplanar lepton search

Long lifetime:
Searches for heavy stable charged particles

Intermediate lifetime
Searches for large impact parameters+
Searches for kinks

GMSB SUSY Searches: Sgoldstino

$e^+e^- \rightarrow \phi\gamma$

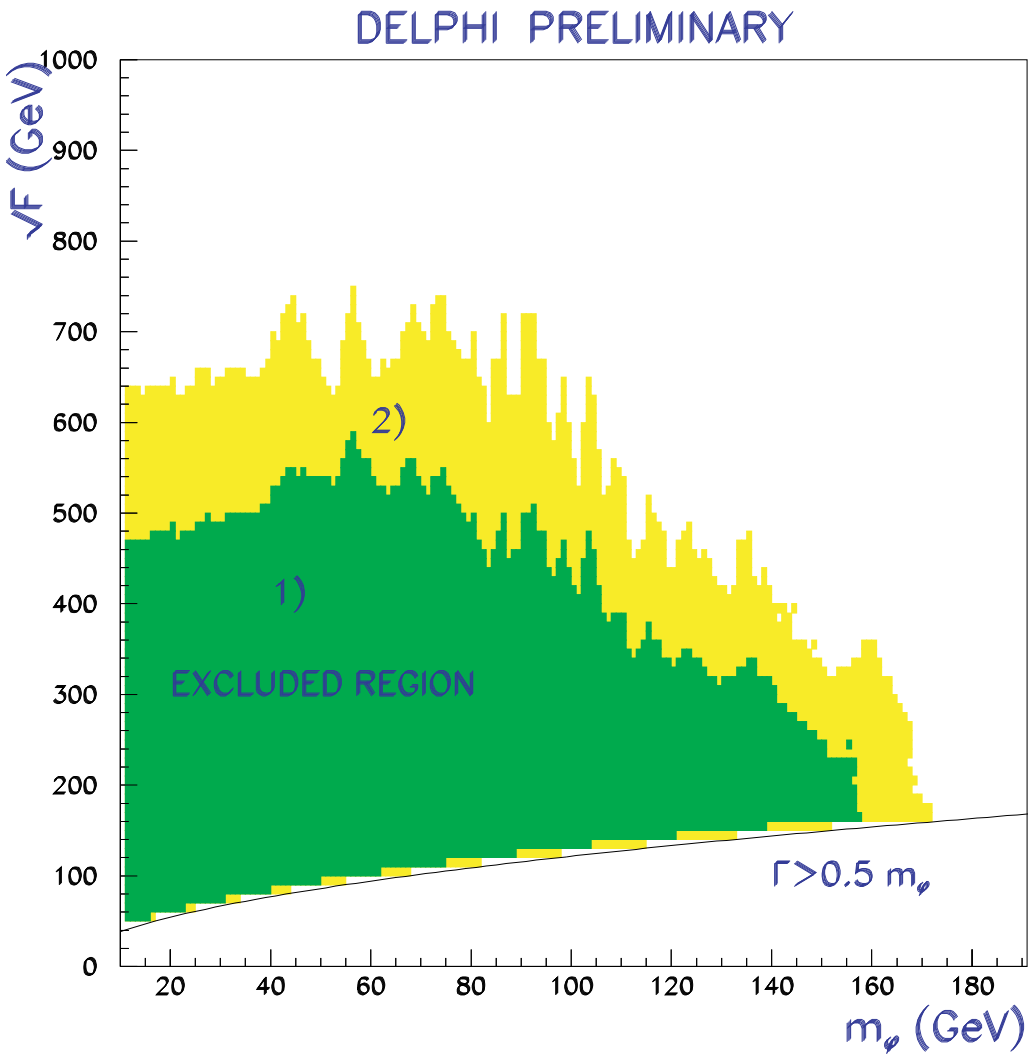
Depends on m_ϕ and $\sqrt{F}$

Most relevant decays:

$\phi \rightarrow \gamma\gamma$ (4-11%)
$\phi \rightarrow gg$ (96-89%)

$$E_\gamma = \frac{s - m_\phi^2}{2\sqrt{s}}$$

	M_1	M_2	M_3
1)	200	300	400
2)	350	350	350



Technicolor

• *Provides a scheme to generate W/Z masses. EW symmetry broken dynamically by strong interactions of gauge bosons.*

• *Introduces new technifermions*

$$\begin{pmatrix} T_V^{\alpha} \\ T_D^{\alpha} \end{pmatrix}$$

which obey a QCD-like

Interaction with an effective scale $\Lambda_{TC} >> \Lambda_{QCD}$

• *At* Λ_{TC} *, TC interation becomes strong* $\rightarrow$ *techniquark condensates replace non zero VEV of Higgs field:*

$$<T\overline{T}> = F_{\pi} \sim 246 \text{ GeV}$$

• *Extensions are worked out to solve problems:*

• *These extensions call for a large number* N_D *of technidoublets* $\rightarrow$ *additional scalar* (π_T, π'_T) *and vector* (ρ_T, ω_T) *mesons which can be light enough to be observed at LEP2.*

Technicolor

$e^+e^- \rightarrow \rho_T \rightarrow f\bar{f}$ *(below WW threshold)*

$e^+e^- \rightarrow \rho_T \rightarrow W^+W^-$ *(above WW threshold)*

$\rho_T \rightarrow W^{\pm}\pi_T^{\pm}, \pi_T^0\gamma$

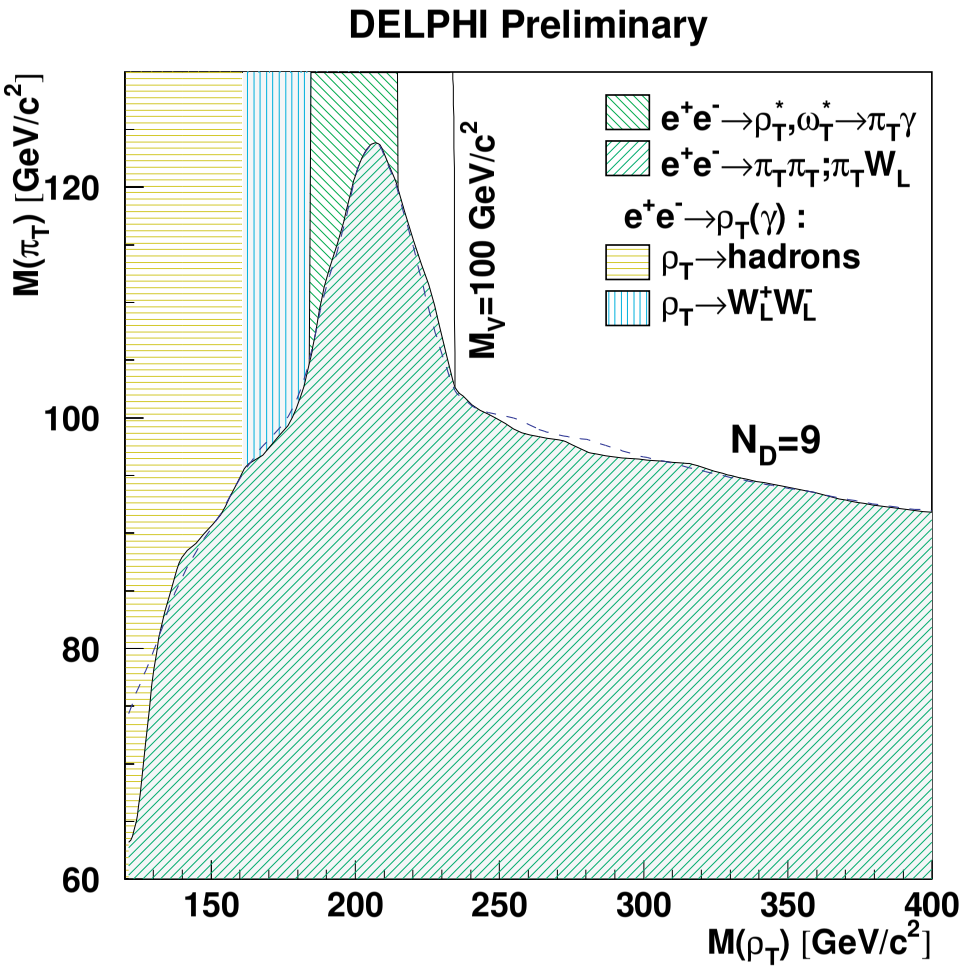
$\rho_T \rightarrow \pi_T\,^-\pi_T^+$

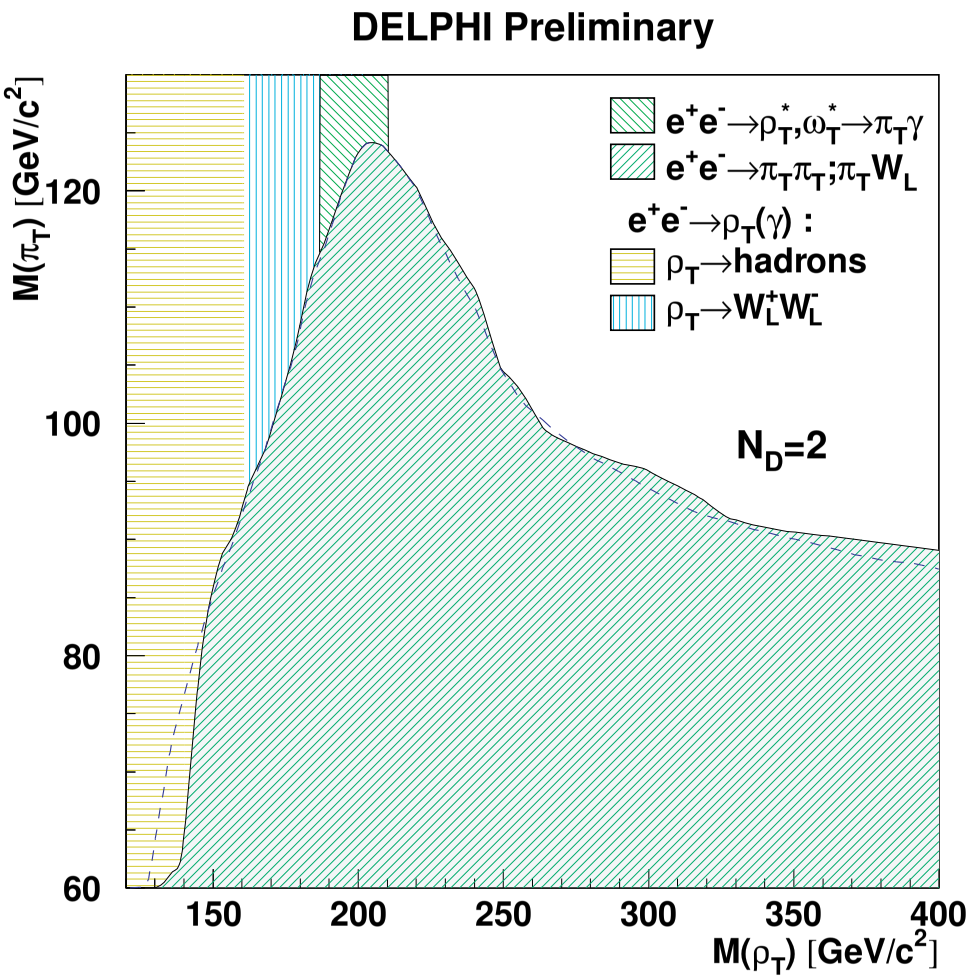
Important decays $\pi_T^+ \rightarrow \bar{b}c, \bar{b}u$

Technicolor

No significant contribution of technicolor production is observed

→ 95% CL exclusion region in the (M_{ρ_T}, M_{π_T}) plane





Excited Leptons

The existence of three families of quarks and leptons is a strong motivation for substructures.

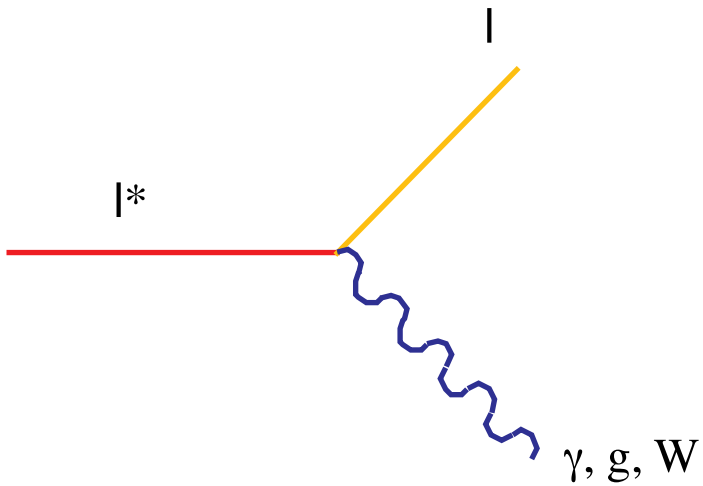
In composite models, quarks, leptons and gauge bosons are composite with an associated energy scale Λ.

At $E_{c.m.} << \Lambda$, one could get manifestations of these new constituents through anomalous decay modes, anomalous electric and magnetic multipoles, excited fermions, leptoquarks and contact terms.

Production

Excited leptons can be pair produced in e^+e^- collisions, $e^+e^- \rightarrow \ell\ell^*$ or singly produced, $e^+e^- \rightarrow \ell\ell^*$.

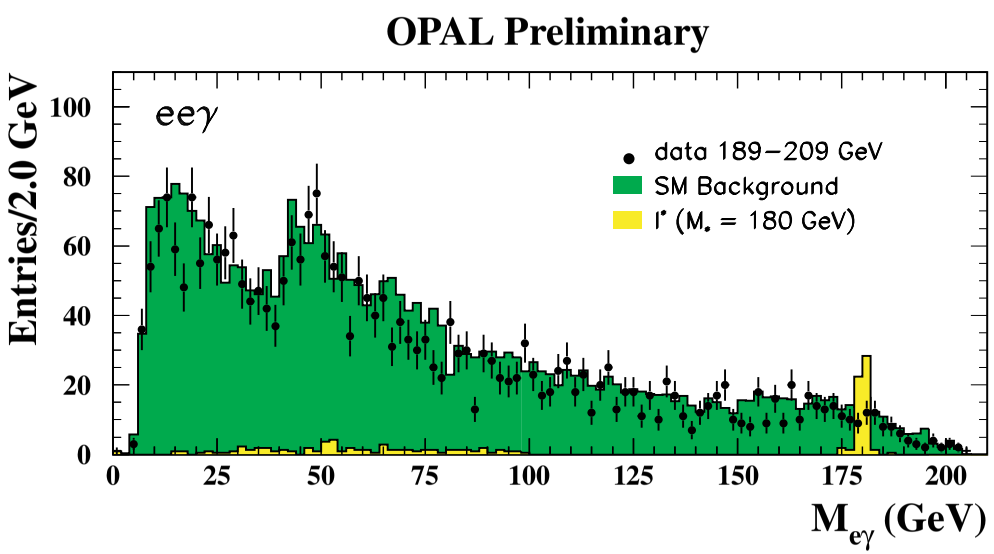
Decay

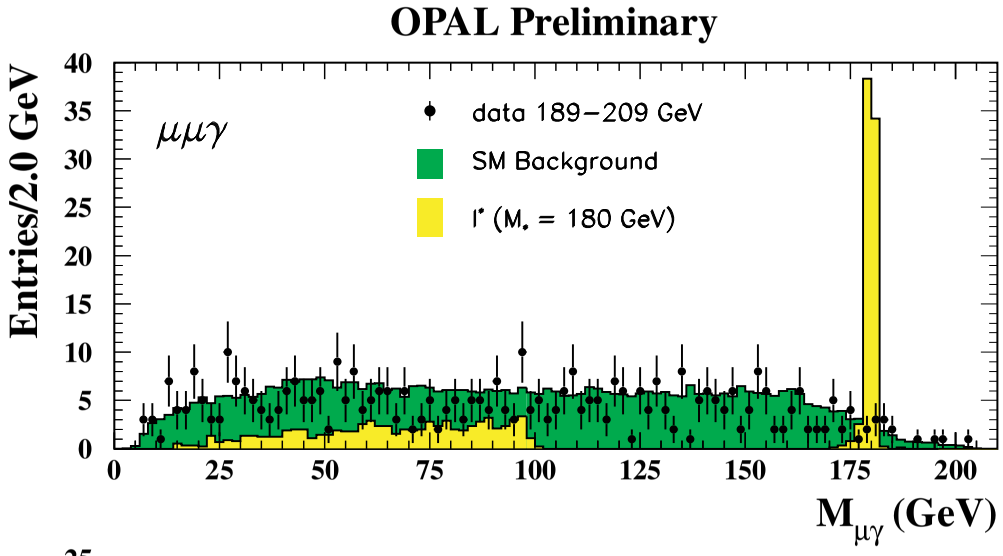


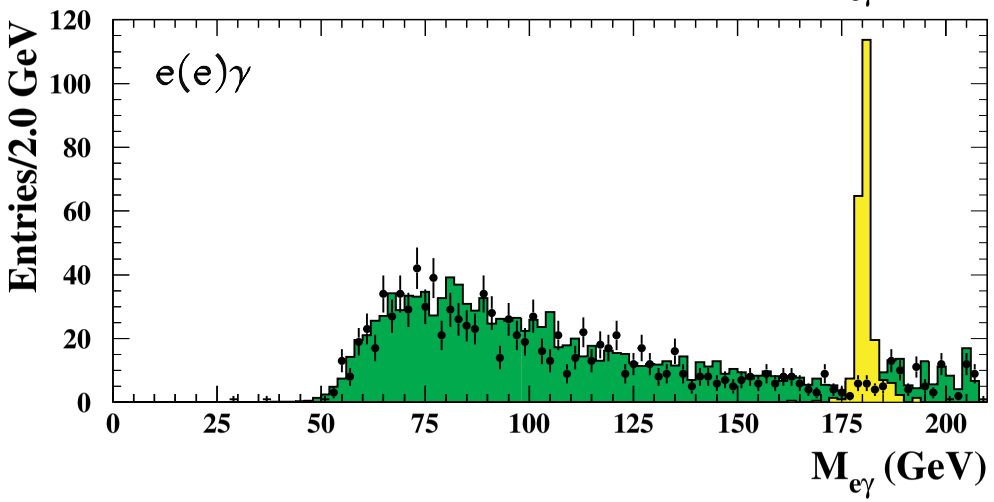
Topologies

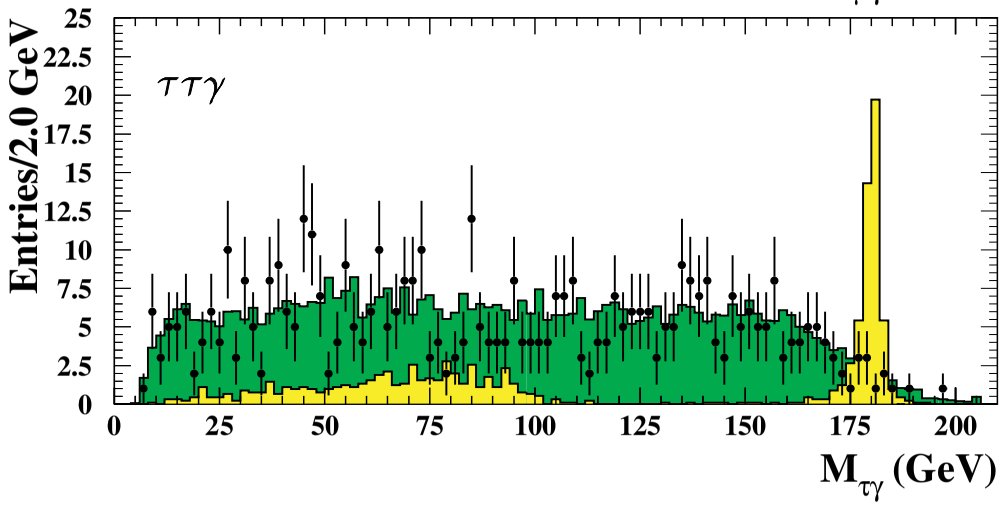
eeγγ, μμγγ, ττγγ, eeWW, ννγγ (pair production)
eeγ, μμγ, ττγ, νeW and ννγ (single production)

Exited Leptons



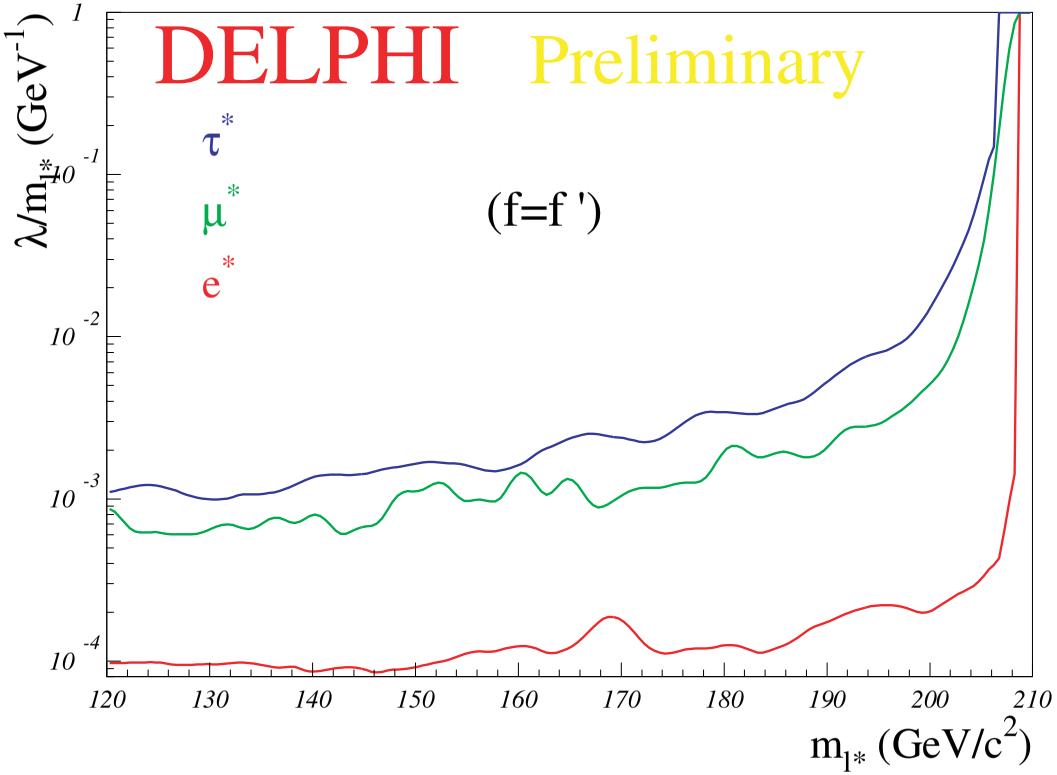


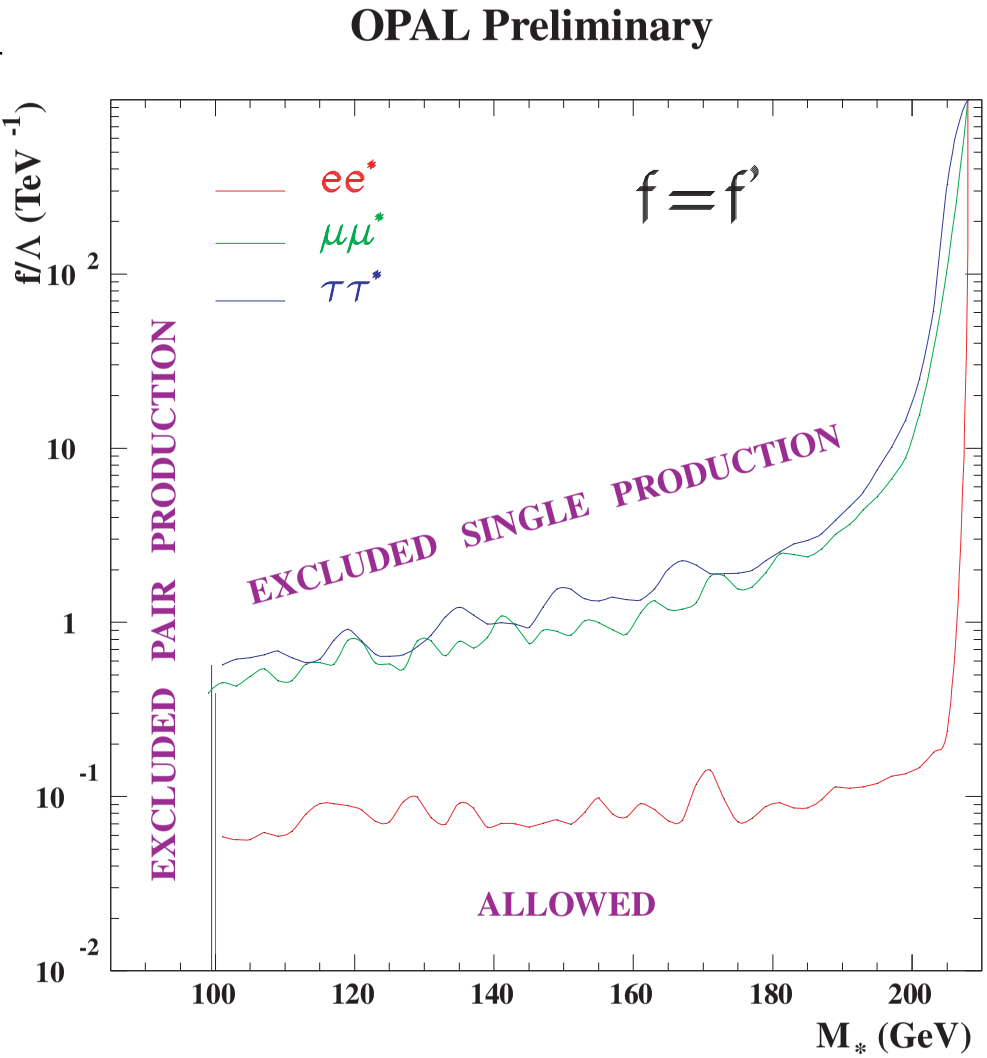




Excited Leptons

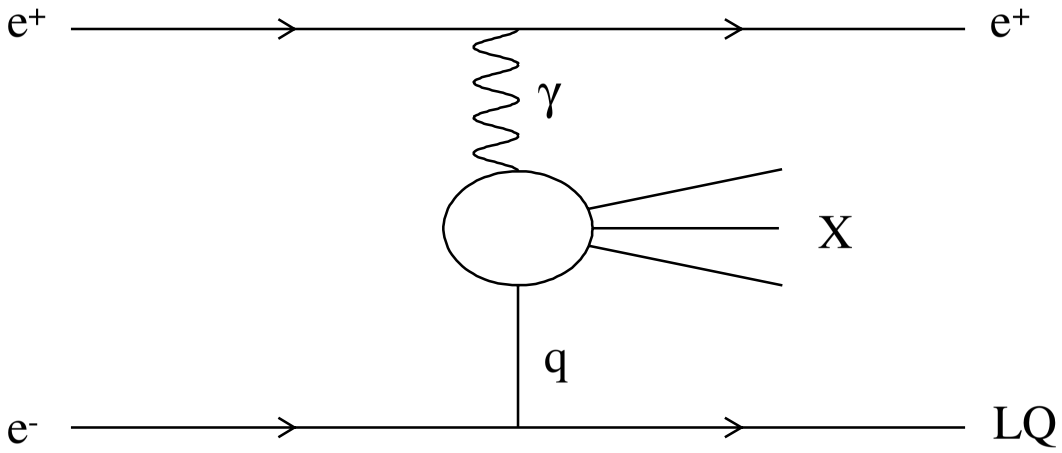
Flavour	95% mass limits (GeV)
e*	102.9
μ*	102.9
τ*	102.8



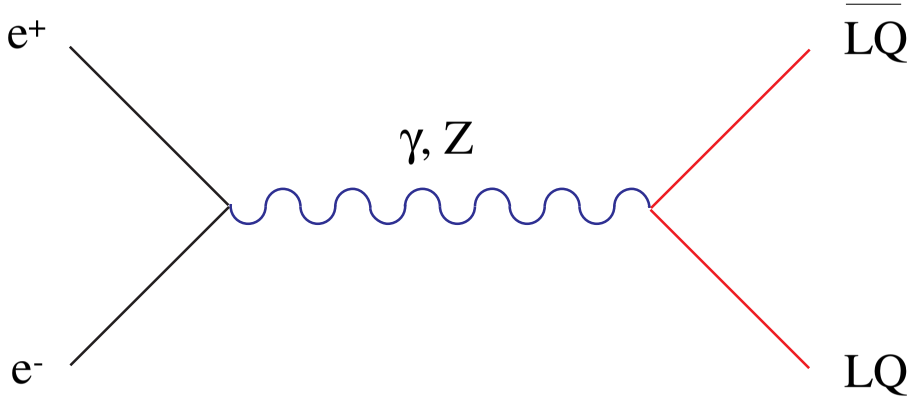


Leptoquarks

Single Production

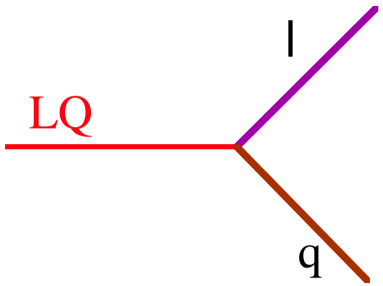


Pair Production

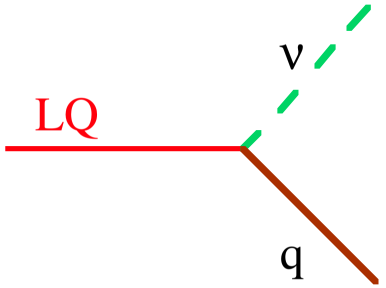


Leptoquarks

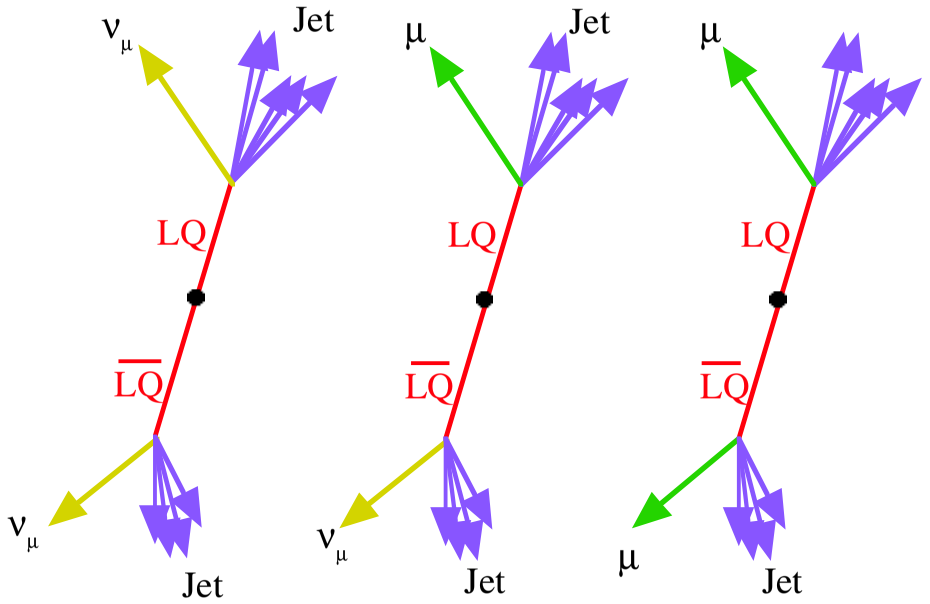
Production



BR = β

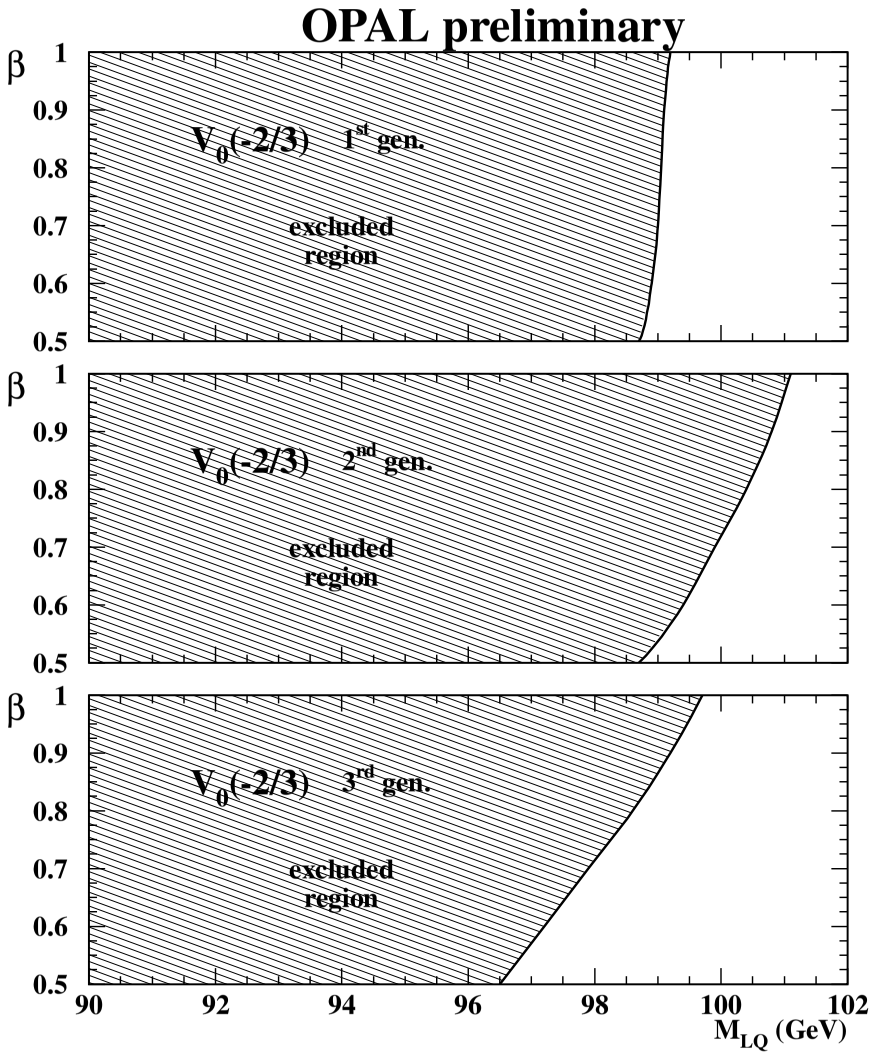


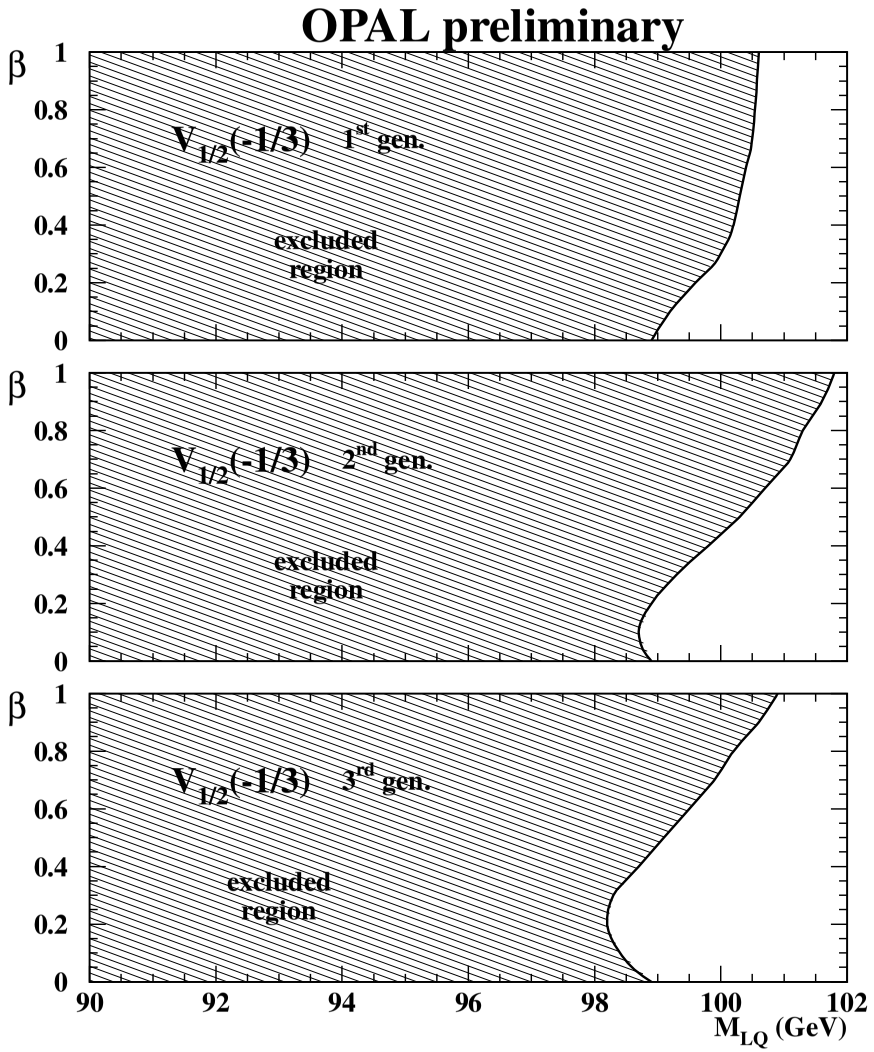
BR = 1 - β



Leptoquarks

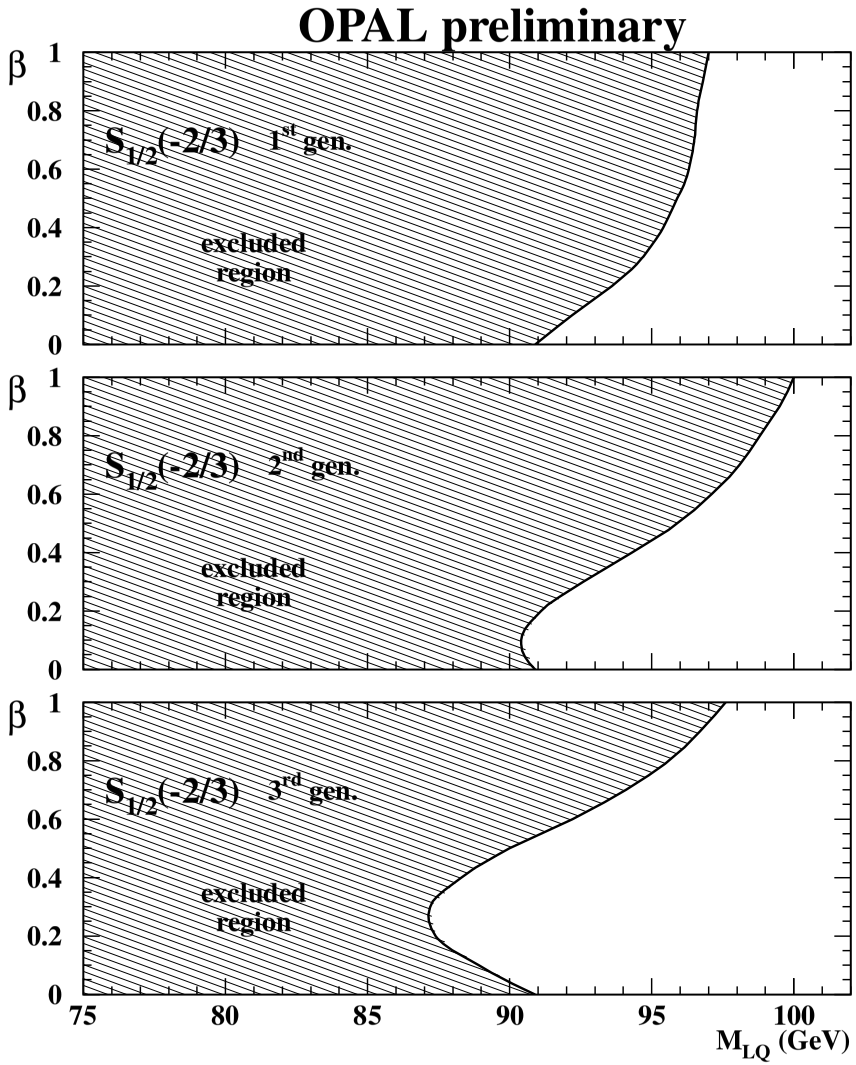
Vector Leptoquarks





Leptoquarks

Scalar Leptoquarks



Conclusions

- *LEP has been a great success until its very end*
- *A broad spectrum of new particle searches have been and are actively pursued… but no indication for Physics beyond the SM*
- *Results are interpreted in various models*
- *Existing limits have been extended:*

  ⇒ *plenty of preliminary results using all the data collected at LEP*

  LEP SUSY working group combining results on:

  GMSB and RPV

  LEP exotica working group starting to combine results on:

  single top, excited leptons, leptoquarks
- *We are working towards FINAL LEP results*
- *Apologies for results which were not shown*
- *Many thanks to my LEP colleagues who helped me to prepare this talk*