Search for SUSY with R-parity violation at LEP

- Introduction on R-parity violation
- Searches at LEP
  - Pair production
  - Single sneutrino production
  - Single top production
  - Spontaneous R-Parity violation
- Conclusions

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MSSM Lagrangian

Super fields = H1,H2,Q,L,U,D,E

$$\mathcal{L} = 1/16\,\Sigma_S\,\bar{D}^2 D^2(\psi_S^{\dagger}\psi_S) \qquad \text{Matter}$$

$$-1/16 D^2 tr(\mathcal{W}_i^{\alpha}\mathcal{W}_{i\,\alpha}) + hc \qquad \text{Gauge}$$

$$+1/4(D^2 W(\psi) + \bar{D}^2 W(\bar{\psi})) \qquad \text{Yukawa}$$

With the superpotential :

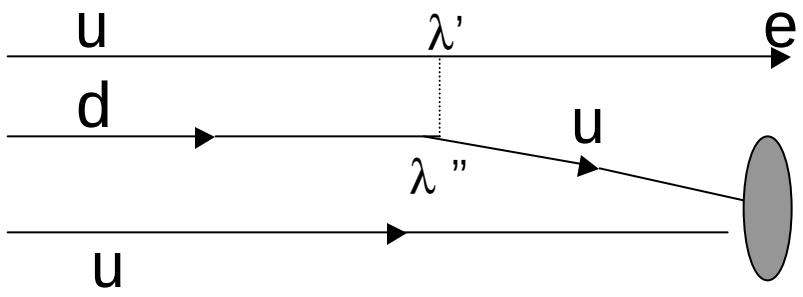
$$W(\psi) = \mu H_1 H_2 + \lambda_e L H_1 \bar{E} + \lambda_d Q H_1 \bar{D} + \lambda_u d Q H_2 \bar{U} + m L H_2 + \lambda L L \bar{E} + \lambda^{'} L Q \bar{D} + \lambda^{''} \bar{U}\bar{D}\bar{D}$$

R-Parity

- 3 terms of superpotential break B or L

$$\lambda_{ijk} L_i L_j \bar{E}_i + \lambda'_{ijk} L_i Q_j \bar{D}_i + \lambda''_{ijk} U_i \bar{D}_j \bar{D}_i$$

- Experimental problem :
  - ex : Proton decay



- Solution : A new symmetry (multiplicative)

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

Introduction: R-parity Violation

- $\lambda_{ij<k}$ LLE + λ'_{ijk} LQD+ $\lambda''_{ij<k}$ UDD
  9 + 27 + 9 = 45 coupling constants
- R_p conserved => $\lambda = \lambda' = \lambda'' = 0$
- Experiments => Limits on λ, λ', λ'' (or their product)

$\lambda'_{11k} * \lambda''_{11k} < 10^{-22}$	proton decay
$\lambda < 10^{-3}$ to 10^{-1}	with $\lambda_{133} < 0.003$ limit on ν_e mass
$\lambda' < 10^{-2}$ to 10^{-1}	with $\lambda'_{111} < 4.10^{-4}$ neutrinoless beta decay
$\lambda'' < 1$ (!)	except $\lambda''_{112} < 10^{-6}$ nucleon double decay

==> There is a lot of room for R-parity violation

Introduction: The constraint MSSM with $\not{R}_P$

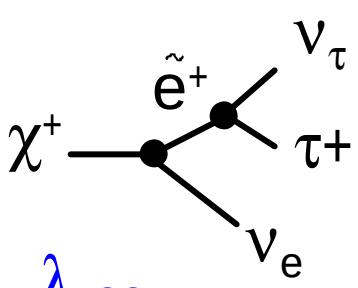
Gauginos	M_i	gauginos masses @ GUT scale
		$M_1:M_2:M_3=\alpha_1:\alpha_2:\alpha_3$
Sfermions	mo	sfermions masses @ GUT scale
Higgs	tanβ	tanβ = <H2>/<H1>
Higgsinos	μ	higgsinos masses

Mixing parameters in squark sector : A_u, A_d

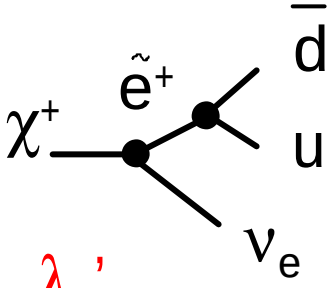
Hence 4/6 parameters + 45 λ couplings
(45 ... but just one not zero at the same time)

Introduction: Direct and indirect decays

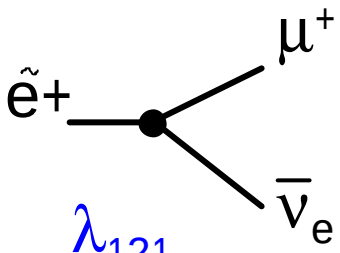
Direct



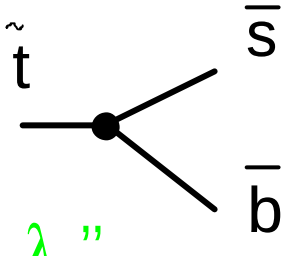
λ_{133}



λ'_{111}

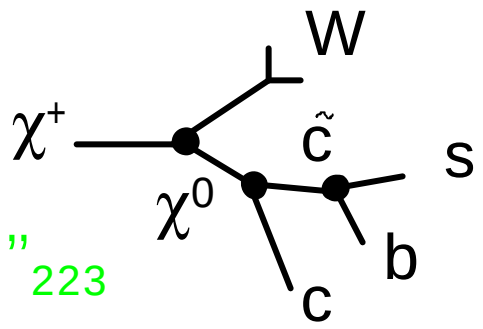


λ_{121}

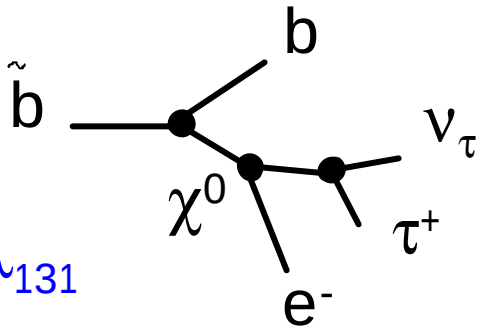


λ''_{323}

Indirect



λ''_{223}



λ_{131}

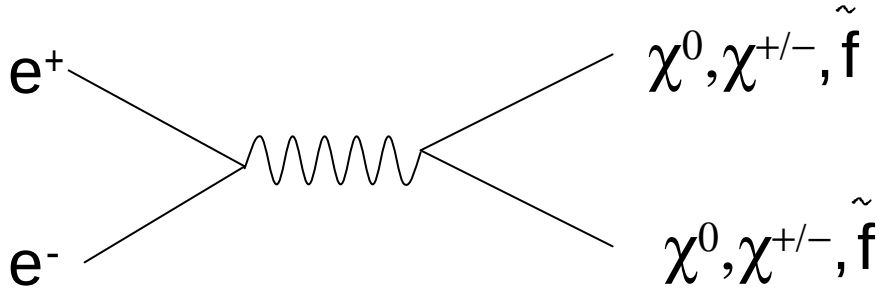
LLE, LQD and UDD

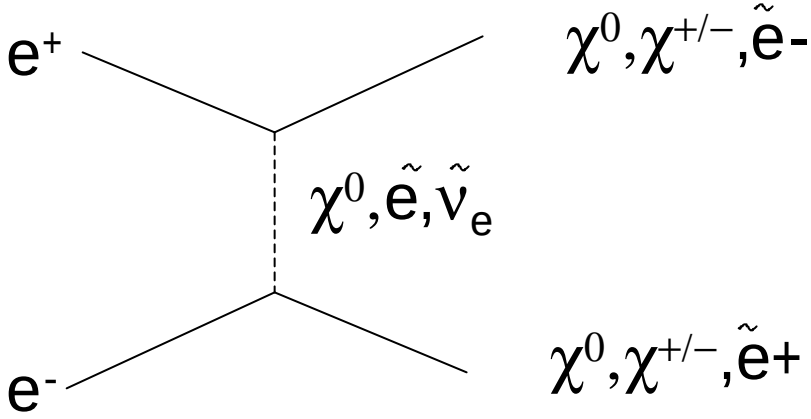
Searches at LEP collider

- Pair production: main production mode at LEP
- Single production: σ proportional to λ^n coupling
  - Single sneutrino resonant production
  - Single sneutrino photoproduction
  - Single top production
- General assumptions:
  - Decay with no displaced vertices $\longrightarrow$ $\lambda > [10^{-4} - 10^{-6}]$
  - Only one λ is none zero.
- Data:
  - all integrated luminosity from 189 to 208 GeV is used in most results presented

Pair Production

- This is the 'R_p conserved' production mode, it doesn't involve ~~R_p~~ couplings



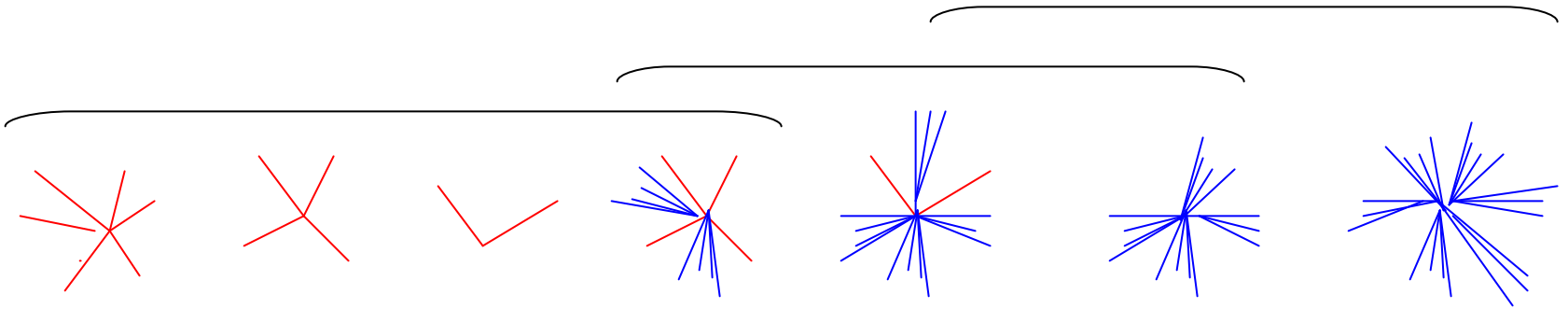


Interference for small e,ν_e masses

Pair production: Topologies, summary ...

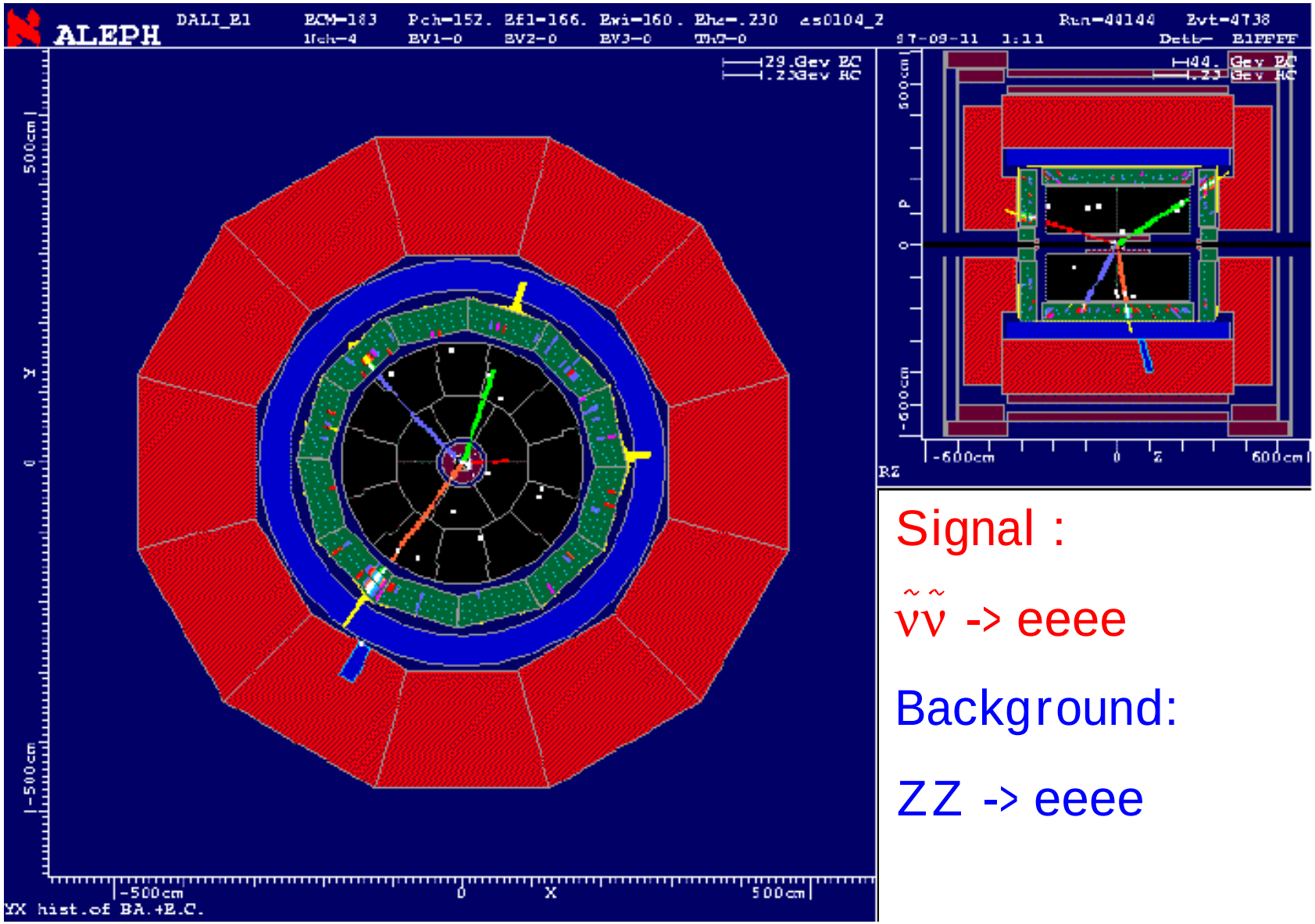
LLE LQD UDD

Many leptons Jets and leptons Many jets



6 leptons 4 leptons 2 leptons leptons and jets 4 jets 6jets or plus

Pair Production: 4 electrons candidate (LLE)



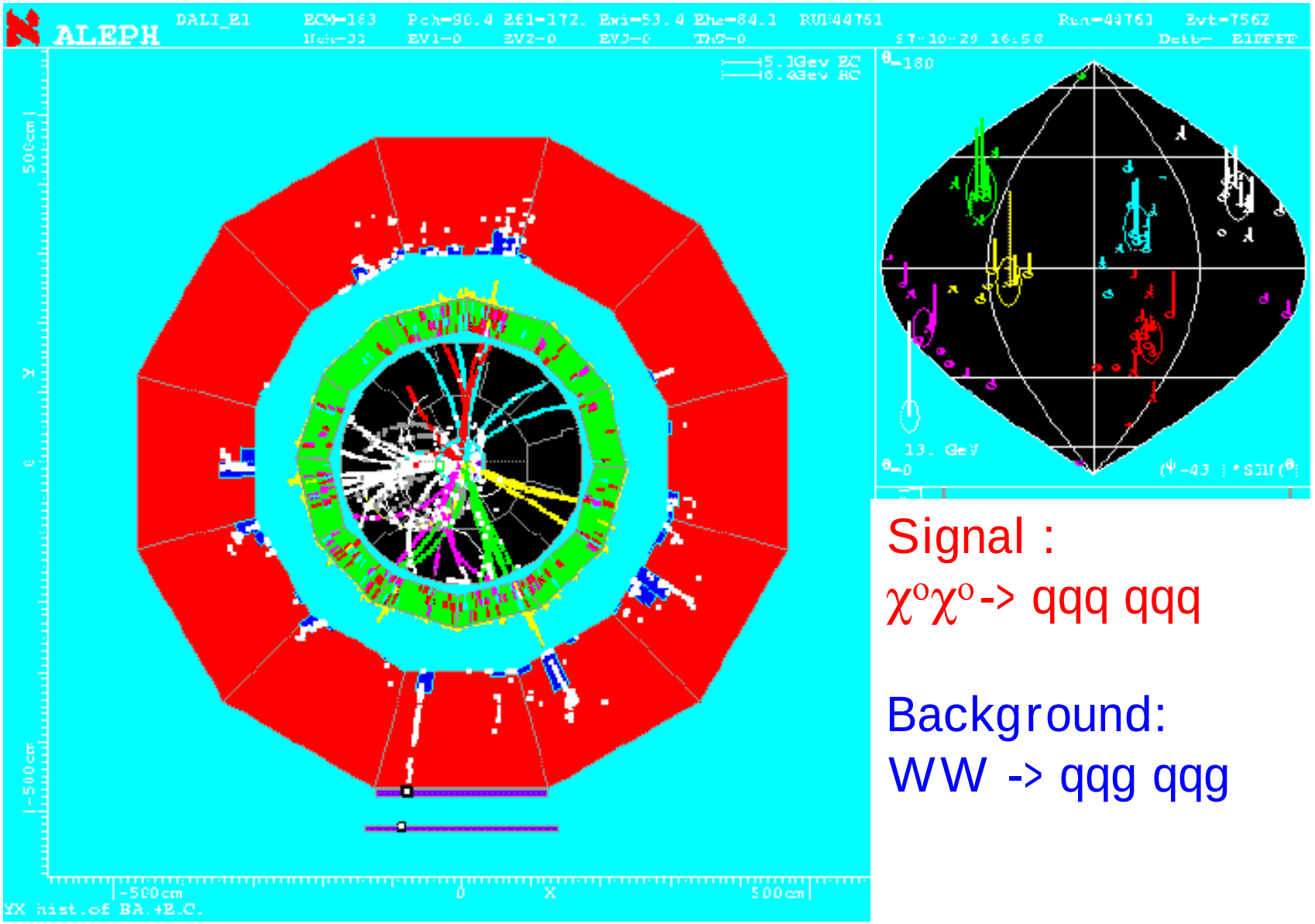
Signal :

$\tilde{\nu}\tilde{\nu}$ -> eeee

Background:

ZZ -> eeee

Pair production: 6 jets candidate (UDD)



Signal :

$\chi^o\chi^o$ -> qqq qqq

Background:

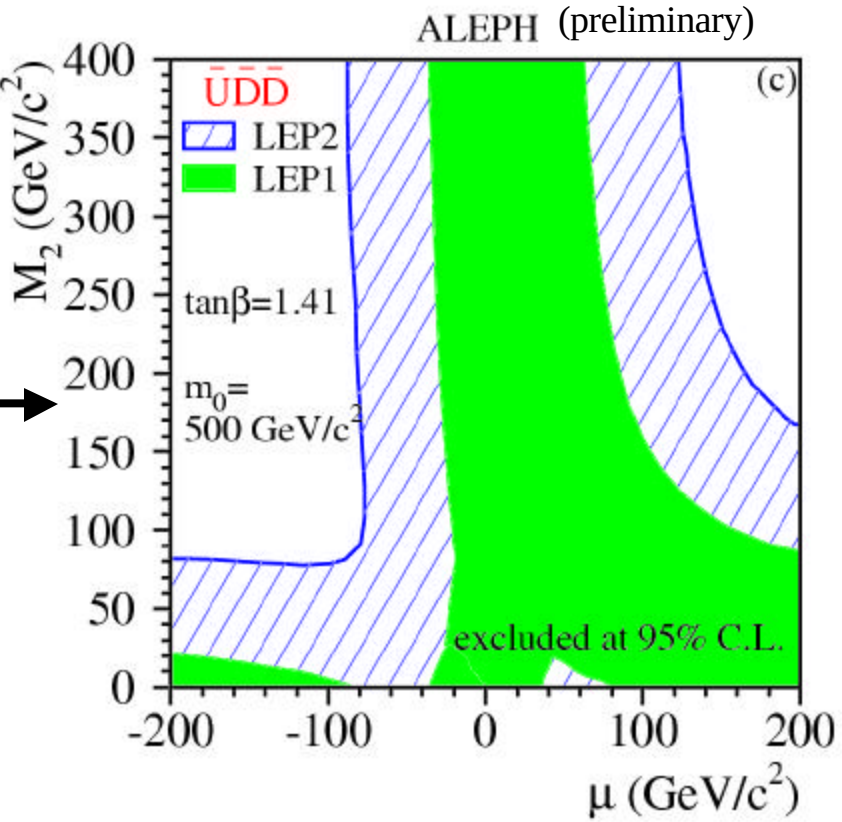
WW -> qqq qqq

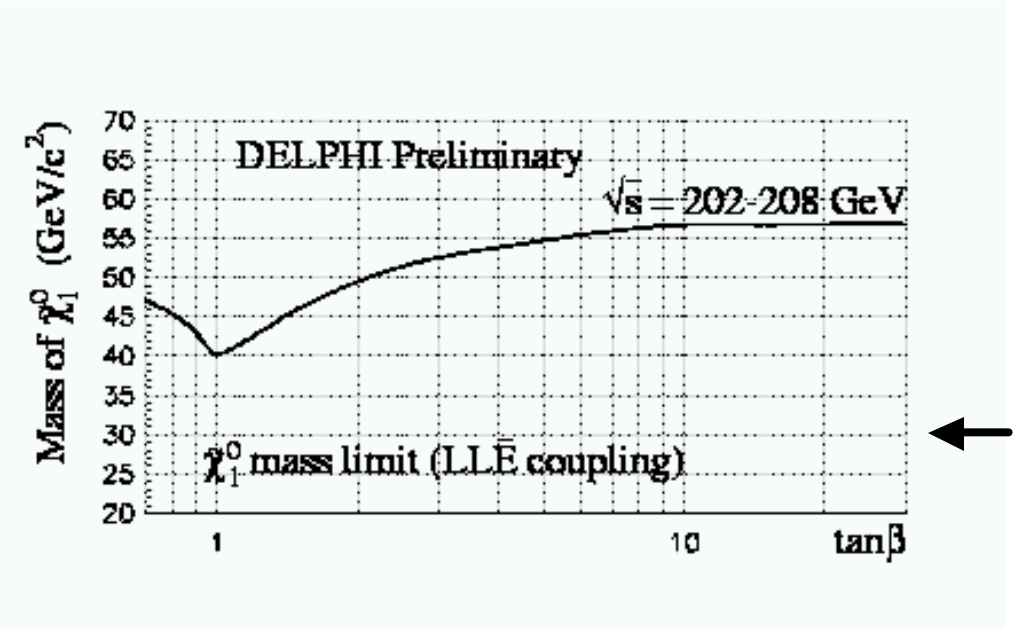
Pair production: Results

- Many selections have been applied covering topologies from 6 lepton to 10 jet events
- Nices candidates found , but no significant excesses
- Limits at 95 % CL are then given, in the framework of CMSSM

Pair production: Limits for χ^0 et $\chi^{+/-}$

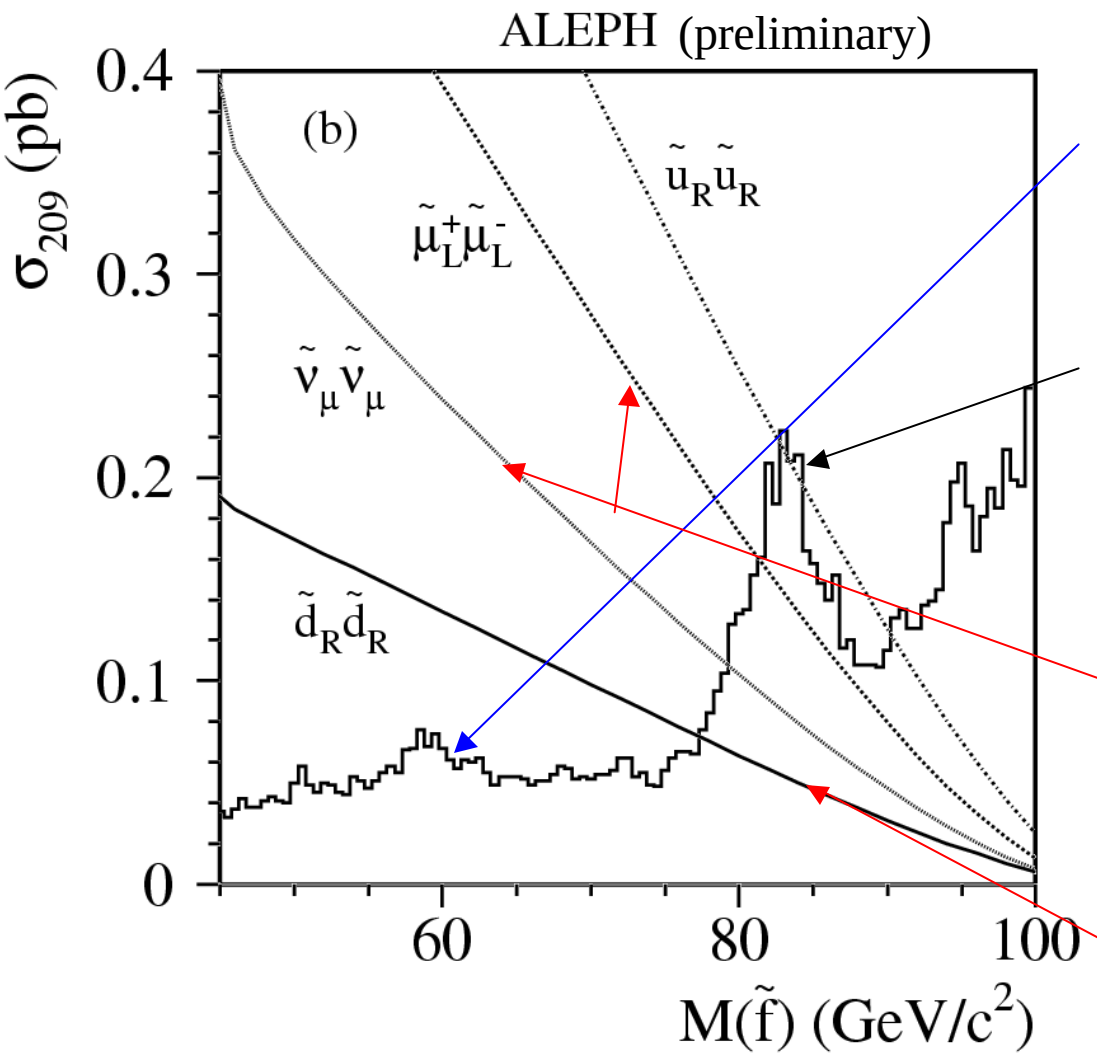
Kinematical limit reached for $\chi^{+/-}$ (for LLE, LQD and UDD)





$M\chi^0 > 40, 38$ GeV (LLE, UDD)
Independently of CMSSM parameters

Pair production: Limits from '4 jets' analysis



From 4 jets background, we extract the maximum cross section of a signal

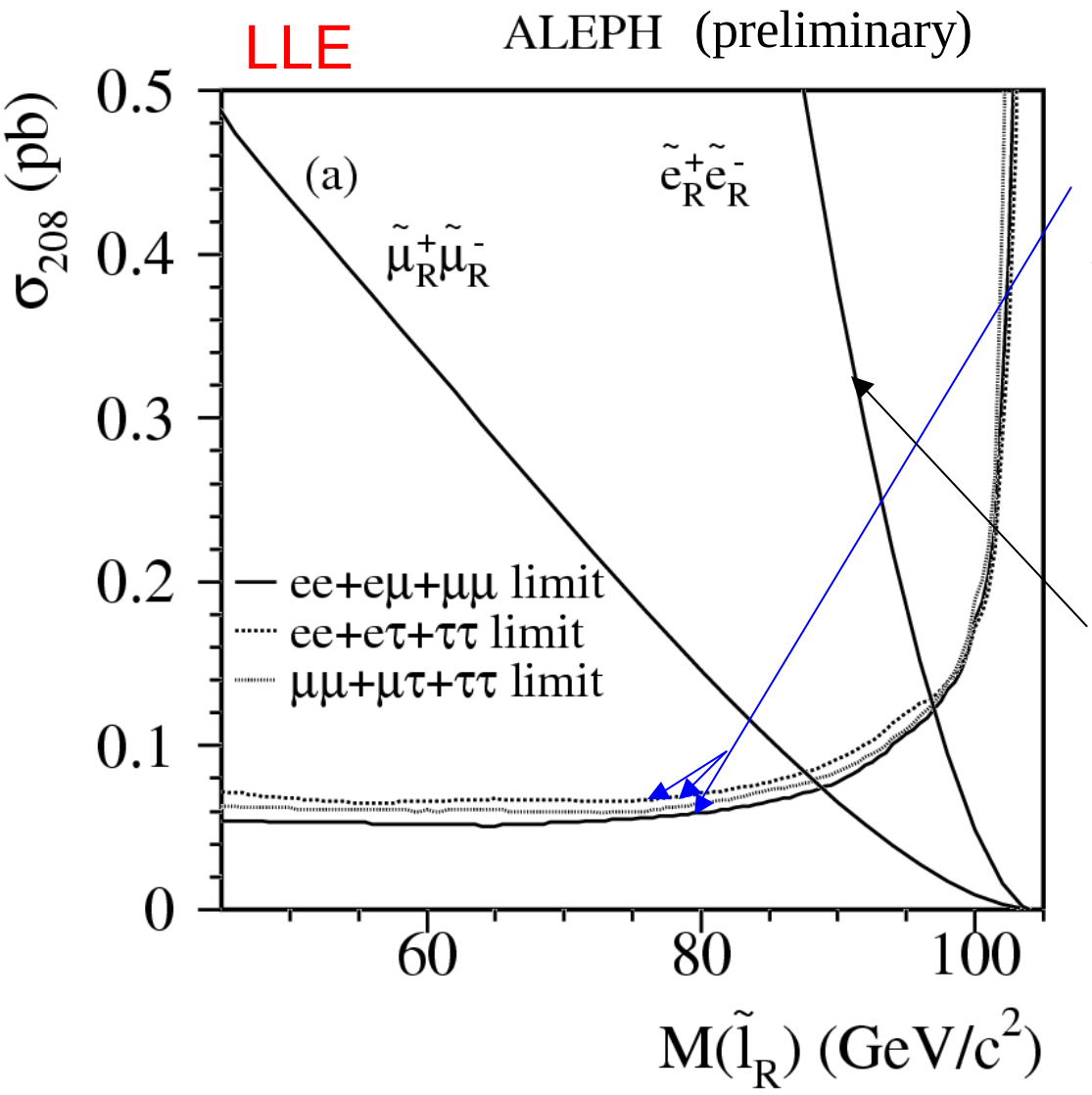
4 jets from W^+W^-

Expected cross section:

LQD : $\tilde{\mu},\tilde{\nu}$ → q q

UDD: $\tilde{d}$ → q q

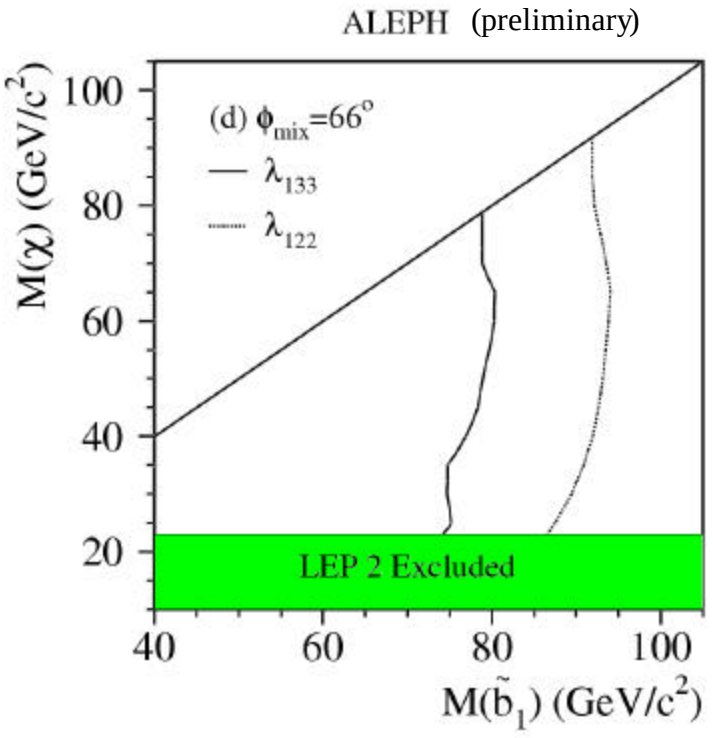
Pair production: Sleptons limits (direct decay)

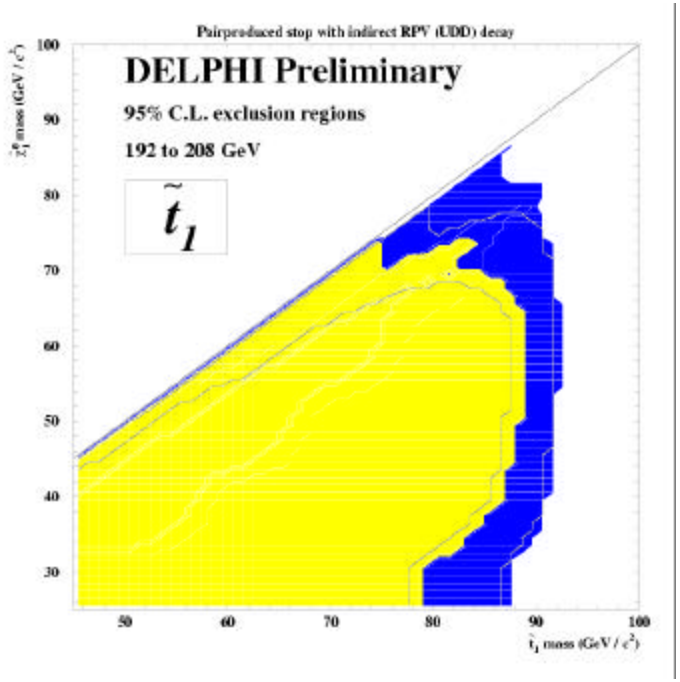


2 leptons in the final state : with lepton type =(1,2) (1,3) (2,3)

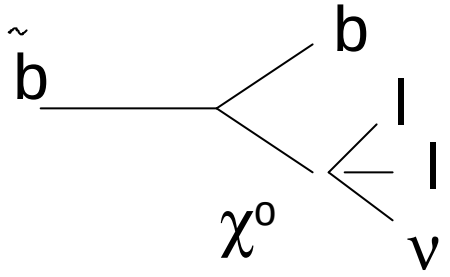
Cross section =f(m_l)

Pair production: Squarks limits (indirect decay)

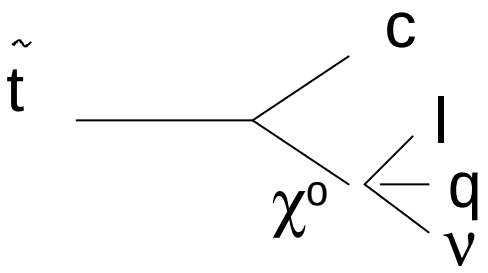




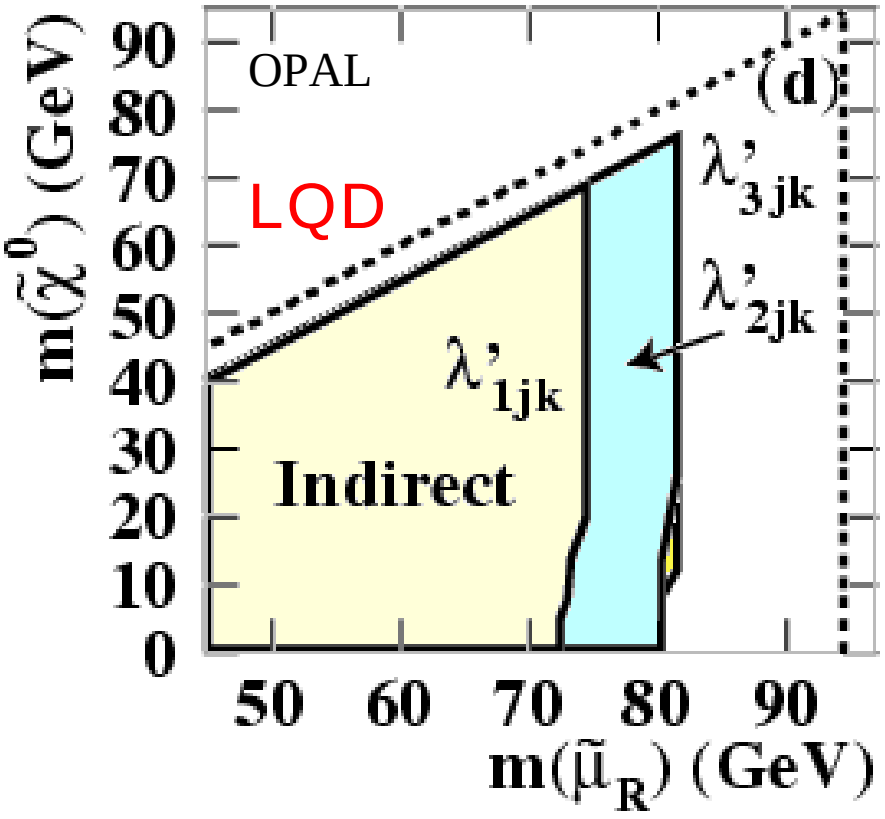
$\tilde{b}$ indirect decay LLE:

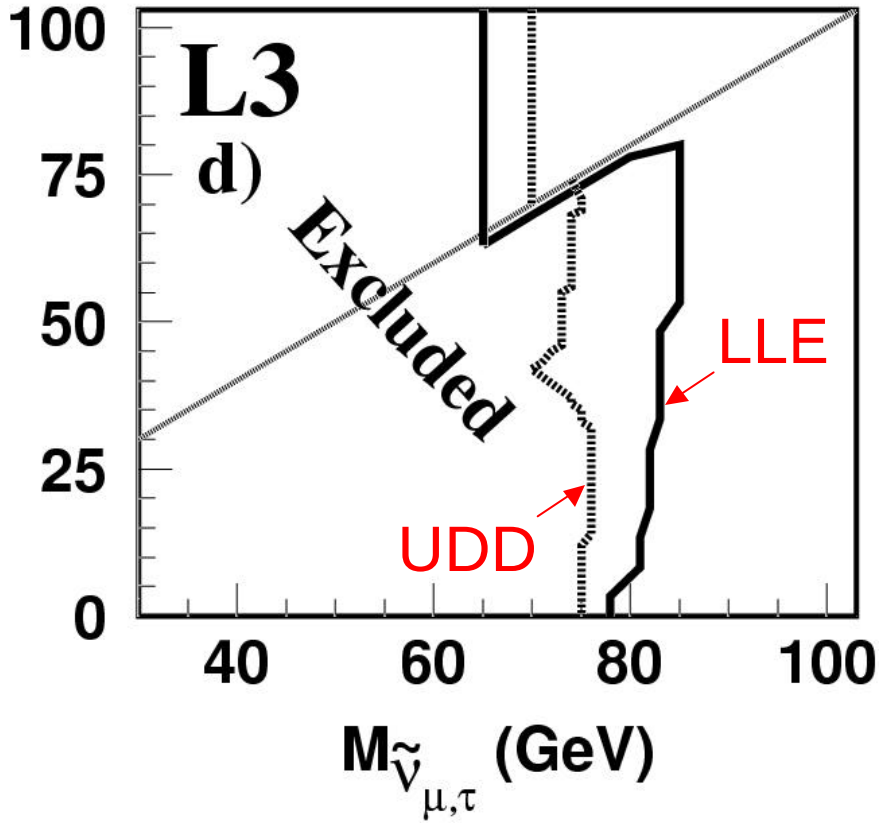


$\tilde{t}$ indirect decay LQD:

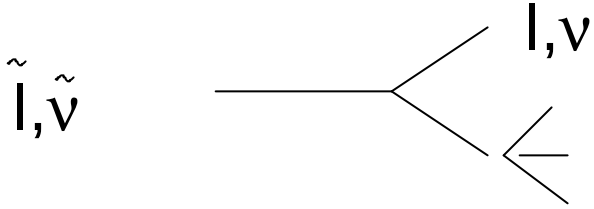


Pair production: Slepton/Sneutrino limits (indirect decay)





sneutrino and selectrons limits , indirect decay via LLE, LQD or UDD:



2 leptons, lepton +jets or 3 jets

Pair production: Results in numbers

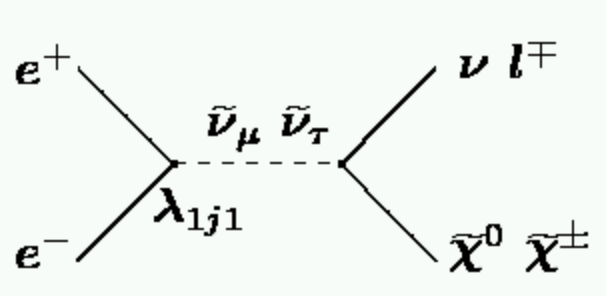
- Summary of absolute mass limits (GeV) of sparticules (Best results from the 4 LEP experiments without combination)

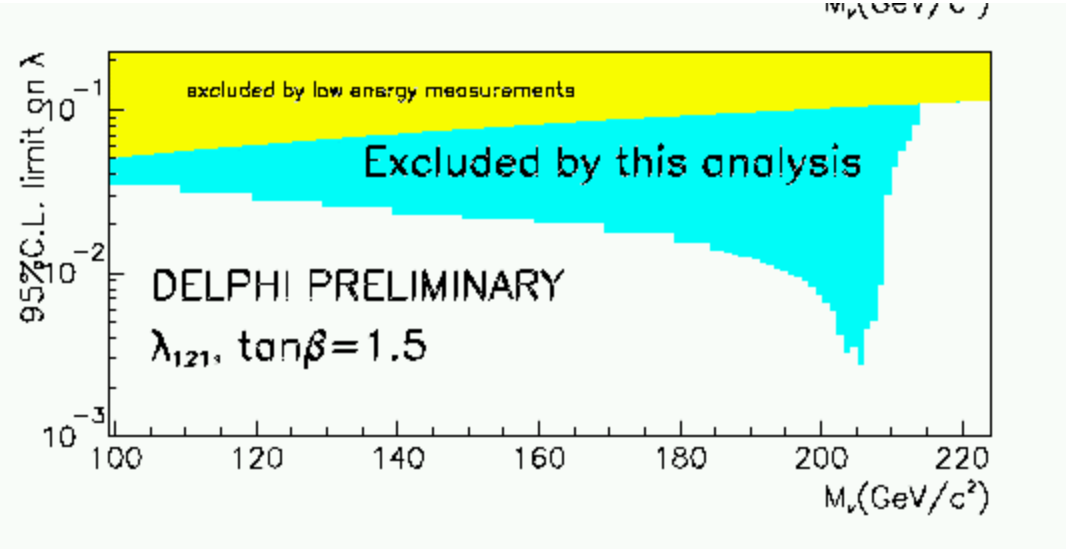
	LLE/LQD/UDD
χ^0	30 GeV
χ^{+-}	103 GeV
$\tilde{l}$	81 GeV
$\tilde{\nu}$	65 GeV
$\tilde{t},\tilde{b}$	75 GeV

Single sneutrino resonant production

- 3 analysis depending on sneutrino decay:
  - $\nu\chi$: 2λ +E
  - $l\chi$: 2(4)l +E (direct decay)
  - $l\chi$: 2(4)l + 2j +E

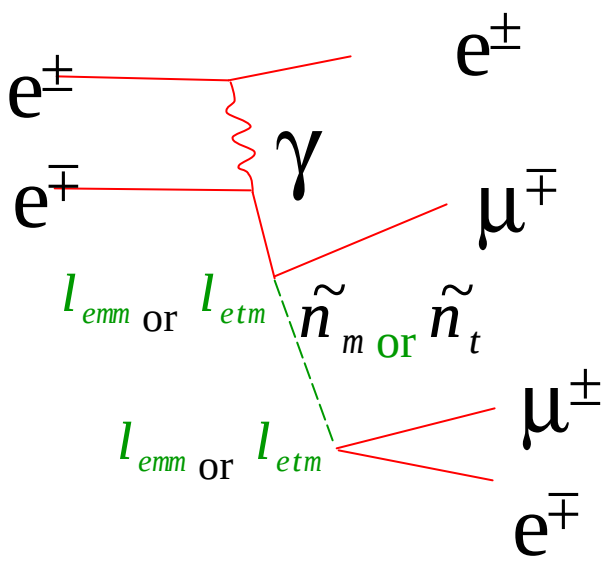
→ upper limits on λ_{121} and λ_{131}

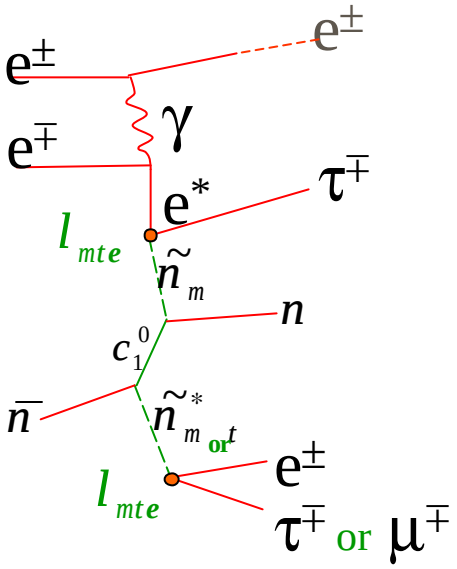




Single sneutrino photoproduction

- Direct decay and Indirect decay

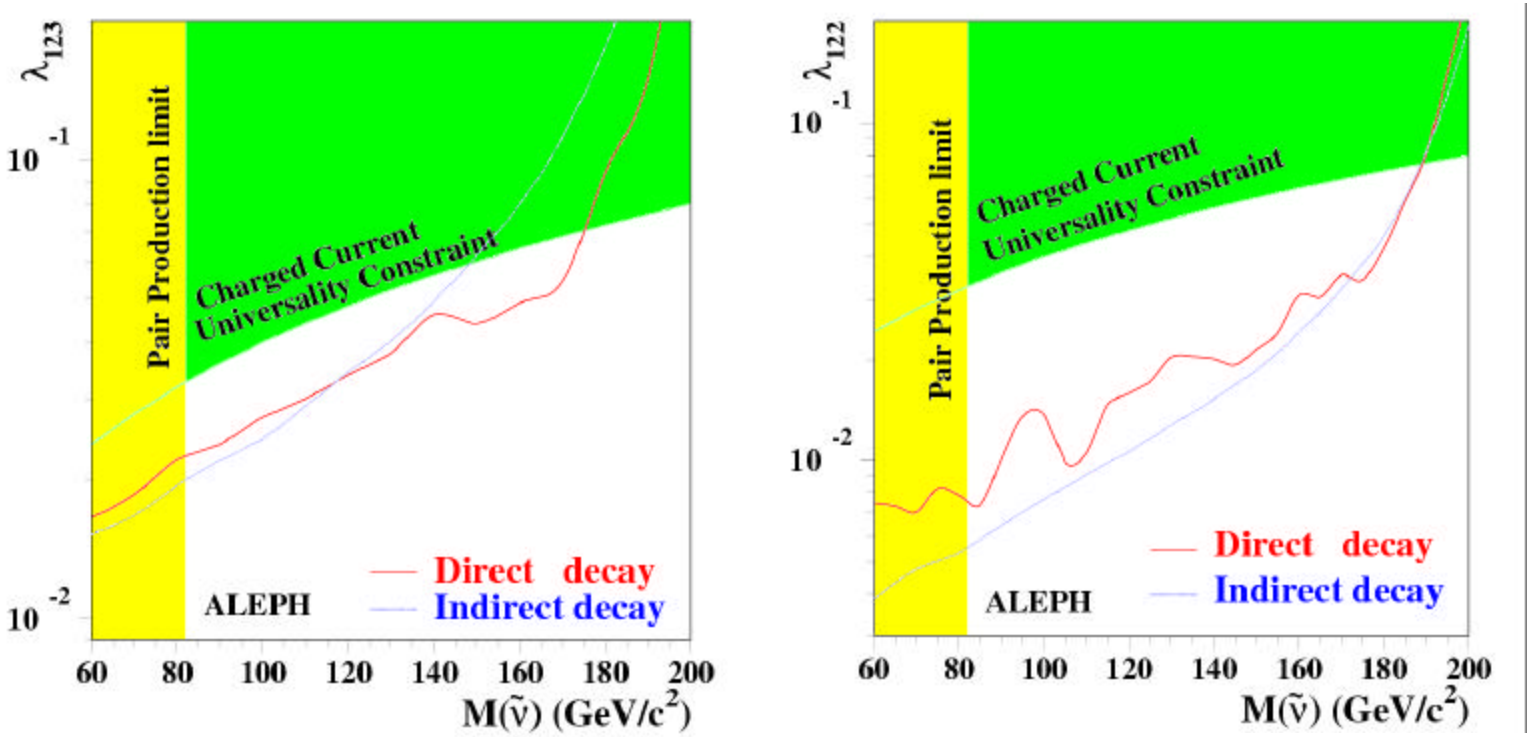




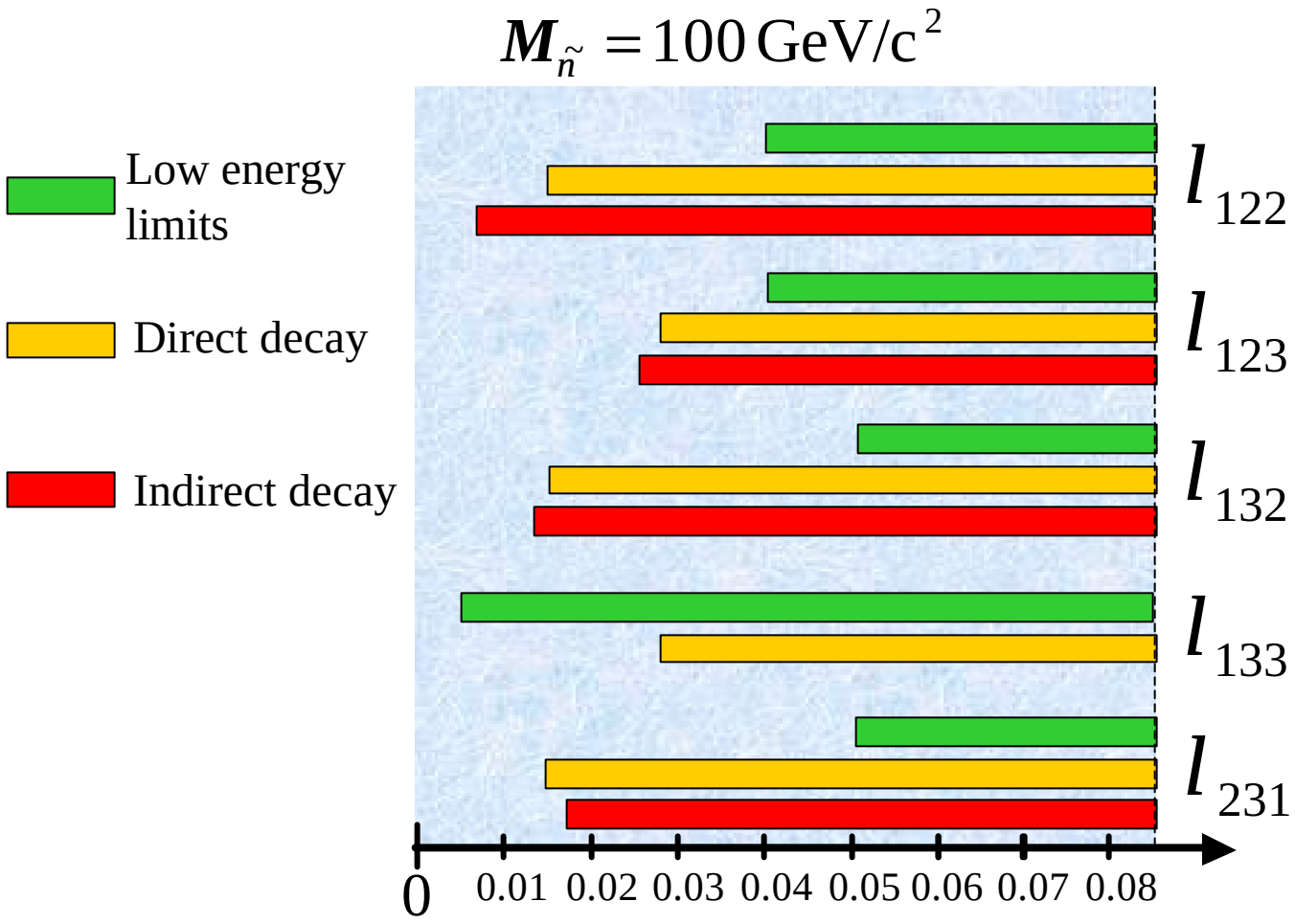
- Selection for identified leptons and missing energy, using invariant mass of lepton pairs

Single sneutrino photoproduction: Results

- No excess found => limits for Direct and Indirect decays



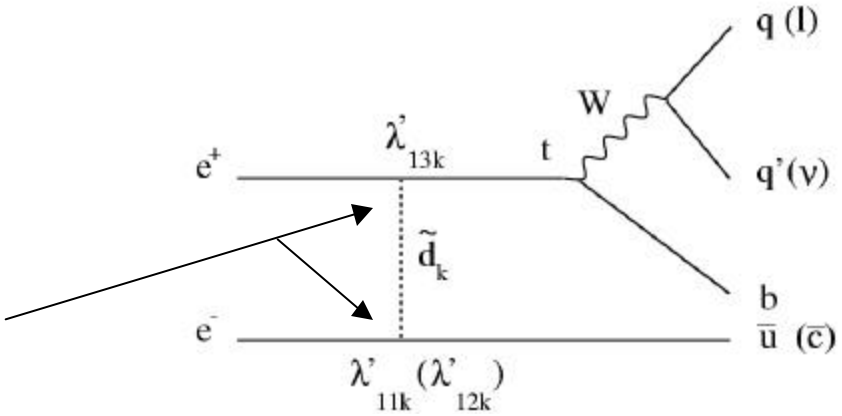
Single sneutrino photoproduction: Limits



Single top production

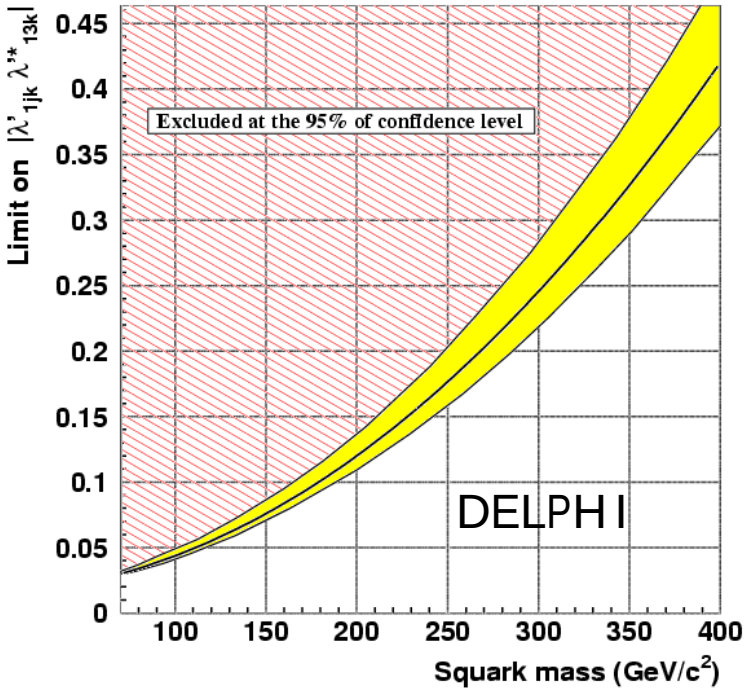
Highly suppressed within The Standard Model

The production mode involves 2 λ couplings



Unsucessful search of hadronic and semi-leptonic channels leads to :

$\sigma(e^+e^- \rightarrow t\bar{u} \text{ or } t\bar{c}) < 0.11$ pb



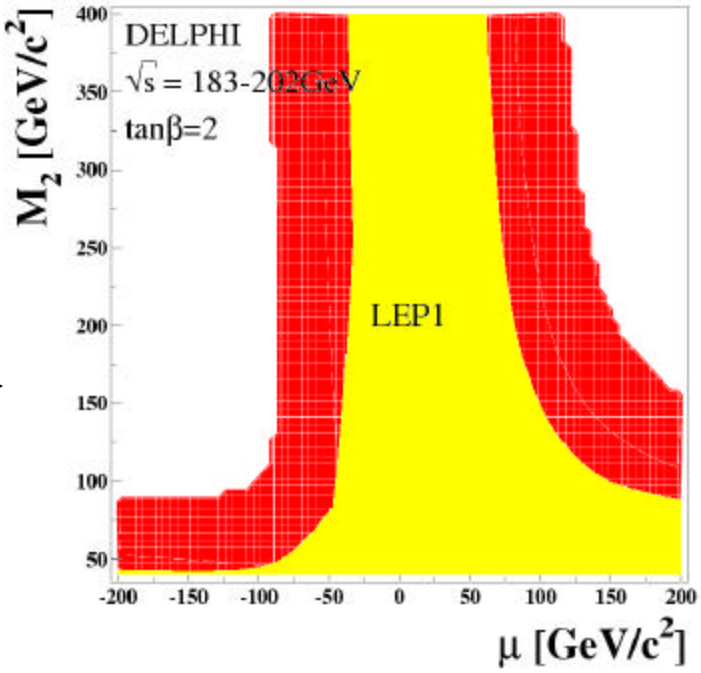
Spontaneous breaking R-Parity violating

- Spontaneous breaking of R-Parity =>
  - New boson: the Majoron J
  - New decay for the chargino : $\tilde{\chi}^{\pm} \longrightarrow \tau^{\pm} J$

- The search for τ + missing energy signatures found no signal

  => $m\chi > 100.9$ GeV

  and



Conclusions

- For pair production:
  - sfermions and gauginos not found !

  => absolute mass limits on sparticles around 80 +/- 20 GeV
  - The limits reach the level of the R-parity conserved ones

- For single production:
  - Limits on sneutrino up to 200 GeV and on squarks of 400 GeV have been reached

- Independently of $\not{R}_p$ search, this is a very good test of Standard Model with a very broad range of final states.