Searches for Gauge Mediated SUSY Breaking at LEP

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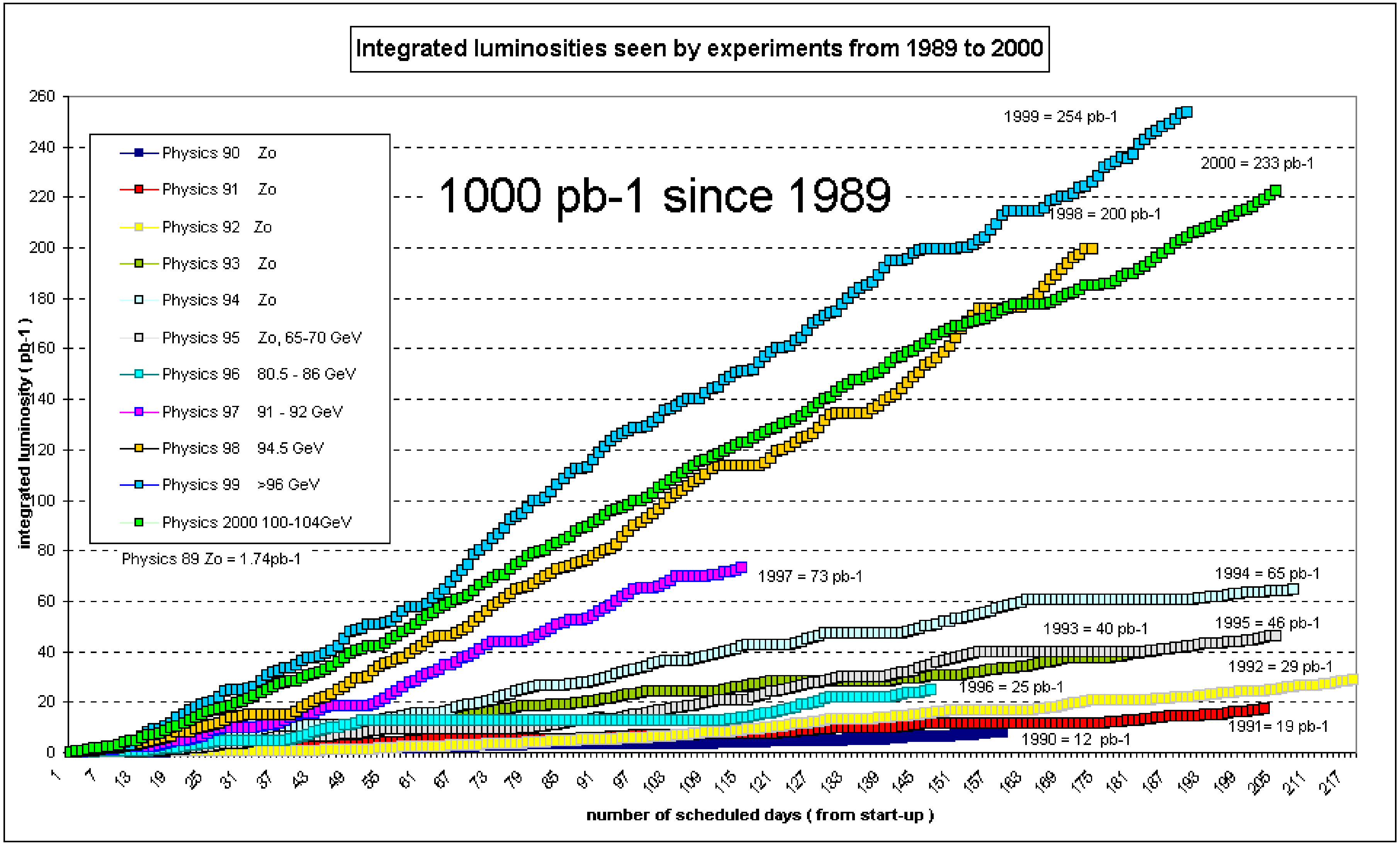
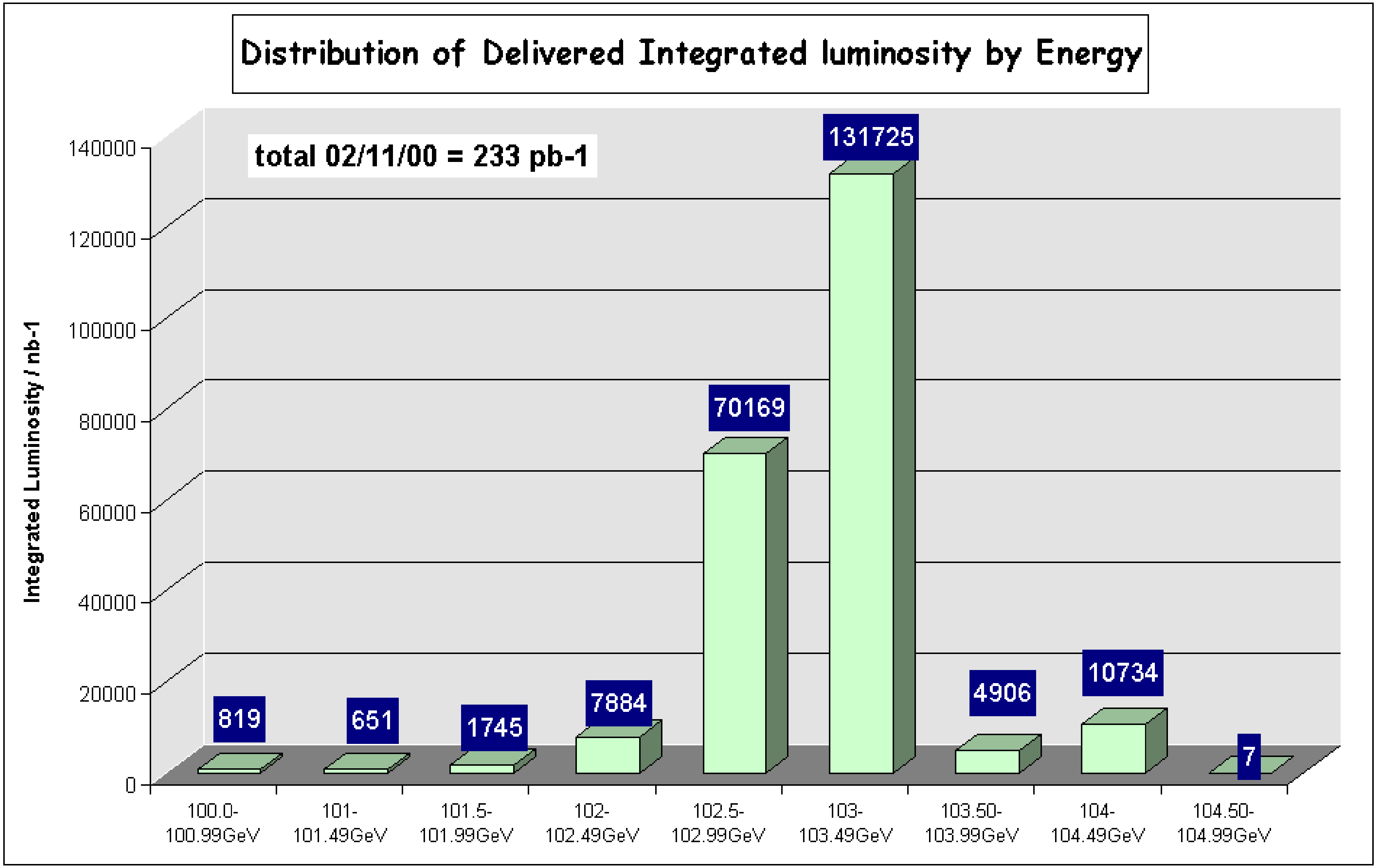
- ▷ Introduction
- ▷ Searches for: – topologies with a neutralino NLSP
  – topologies with a slepton NLSP
- ▷ Interpretations
- ▷ Summary

All limits are at 95% confidence level.

The LEP Dataset





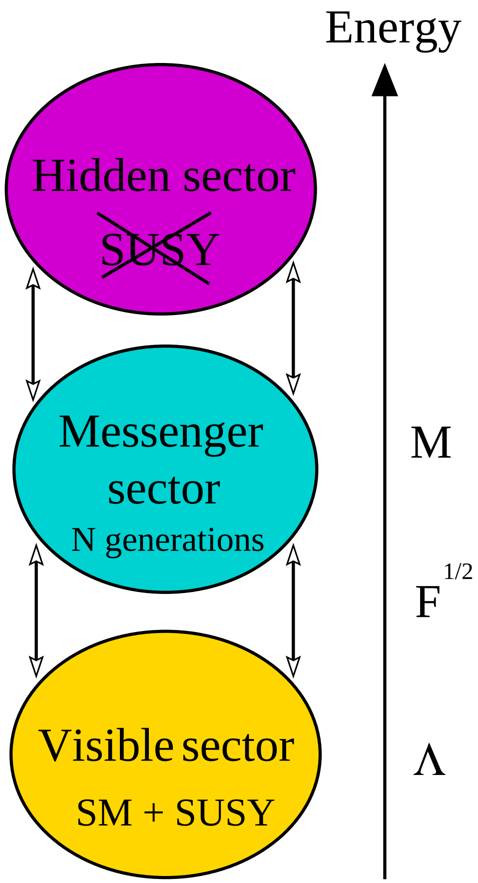
Distribution of Delivered Integrated luminosity by Energy
total 02/11/00 = 233 pb-1
Integrated Luminosity / nb-1
0
20000
40000
60000
80000
100000
120000
140000
819
651
1745
7884
70169
131725
4906
10734
7
100.0-
100.99GeV
101-
101.49GeV
101.5-
101.99GeV
102-
102.49GeV
102.5-
102.99GeV
103-
103.49GeV
103.50-
103.99GeV
104-
104.49GeV
104.50-
104.99GeV

Introduction

SUSY particles are not degenerate with Standard Model particles $\Rightarrow$ SUSY is *broken* ...

... either via *gravity* $\longrightarrow$ supergravity (SUGRA)

... or via the Standard Model *gauge interactions* $\longrightarrow$ **G**auge **M**ediated **S**USY **B**reaking



Advantage of GMSB: gauge interactions are flavour–blind $\Rightarrow$ no FCNC

Six new parameters in the minimal GMSB model:

Λ	SUSY particle mass scale
M	Messenger particle mass scale
N	Messenger index
$\sqrt{F}$	SUSY breaking scale
$\tan\beta$	Ratio of Higgs vacuum expectation values
$sign(\mu)$	Sign of Higgs sector mixing parameter

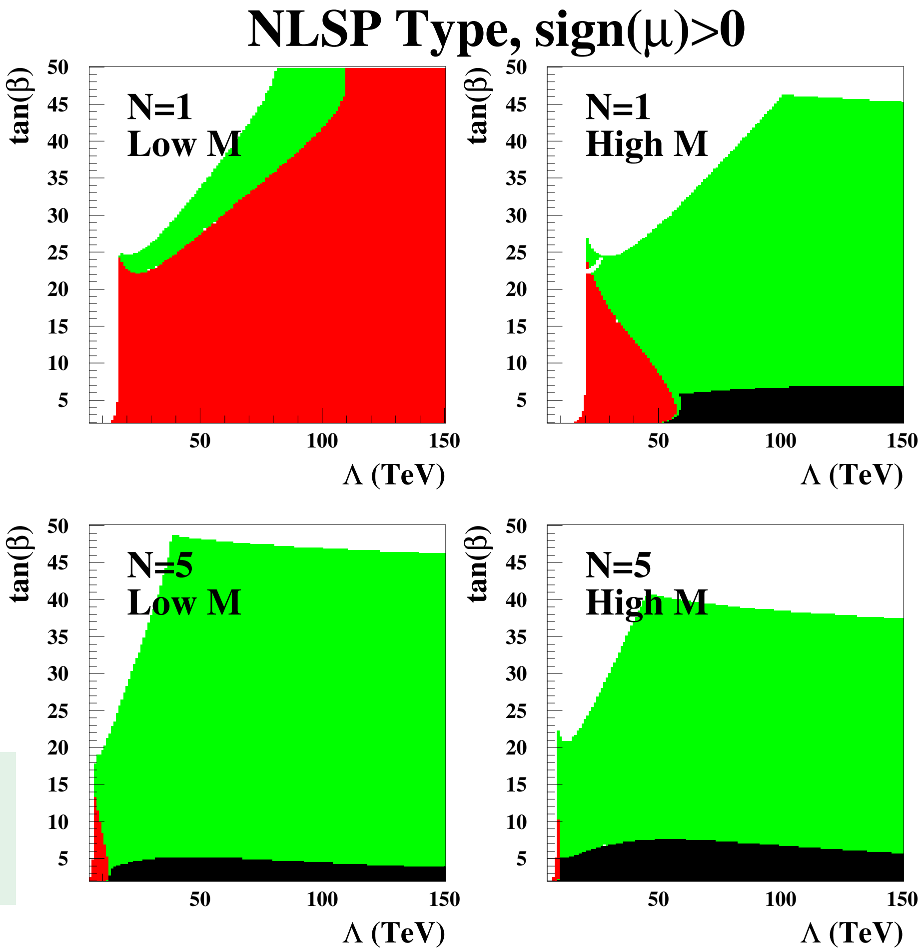
GMSB Phenomenology:

SUSY breaking scale $\sqrt{F} \ll 10^{11}$ GeV and $m_{\tilde{G}} \simeq 2.5(\frac{\sqrt{F}}{100\ \text{TeV}})^2$ eV $\longrightarrow$ gravitino $\tilde{\text{G}}$ is LSP

(LSP = Lightest SUSY Particle)

NLSP (next–to LSP) can be:

- the neutralino: $\tilde{\chi}^0_1 \longrightarrow \gamma\tilde{\text{G}}$
- the lighter stau: $\tilde{\tau}_1 \longrightarrow \tau\tilde{\text{G}}$
- all sleptons ("co–NLSP"): $\tilde{\ell}_R \longrightarrow \ell\tilde{\text{G}}$



(OPAL GMSB scan)

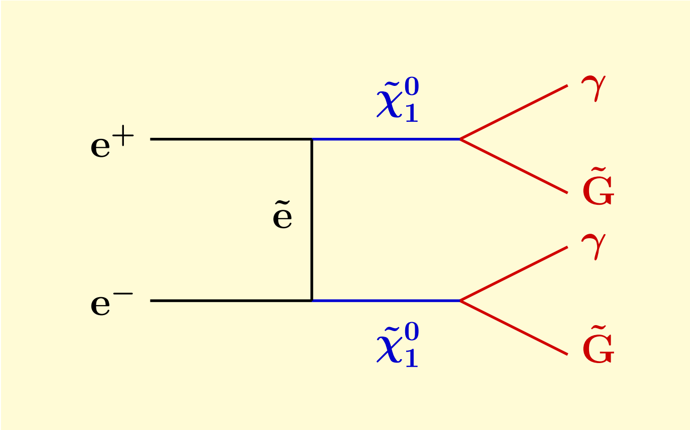
The **NLSP decay length** can be *macroscopic:*

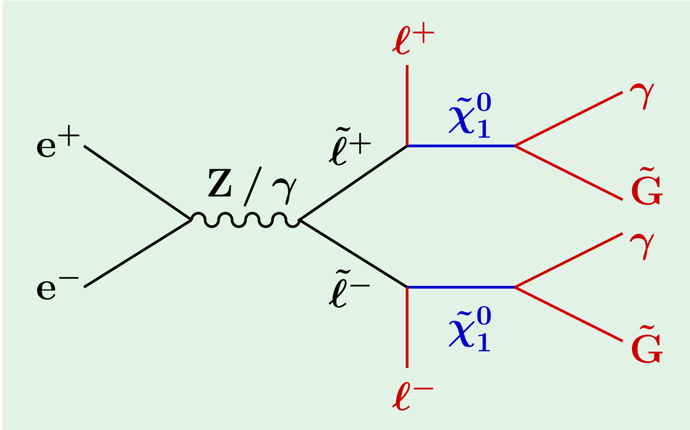
$$c\tau \simeq \frac{0.01}{\kappa_\gamma}\left(\frac{100\text{GeV}}{m_{\text{NLSP}}}\right)^5\left(\frac{\sqrt{F}}{100\text{TeV}}\right)^4 \text{ cm}$$

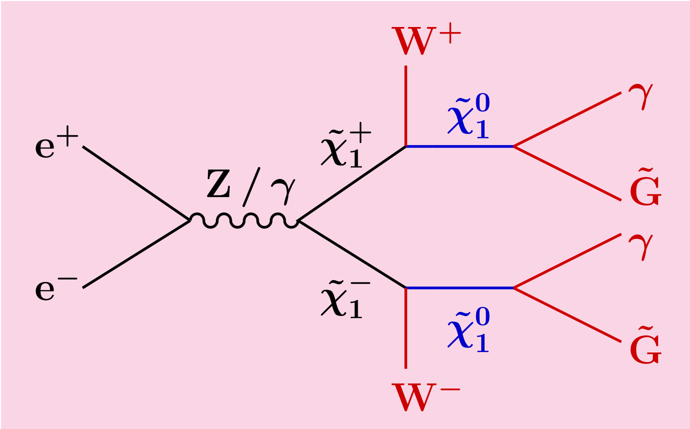
(κ_γ = photino component of the $\tilde{\chi}^0_1$; $\kappa_\gamma = 1$ for $\tilde{l}$)

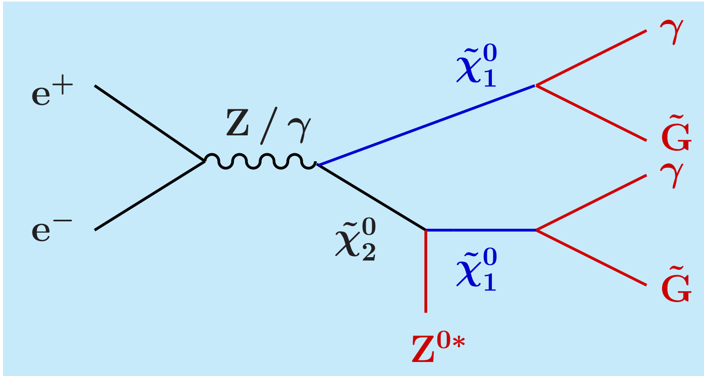
$\Rightarrow$ Expect a variety of challenging topologies depending on the NLSP type and its lifetime!

Topologies in the Neutralino NLSP Scenario:



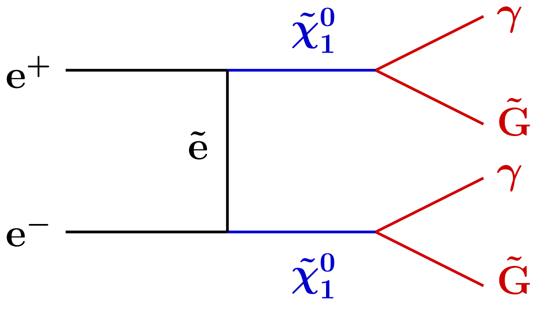




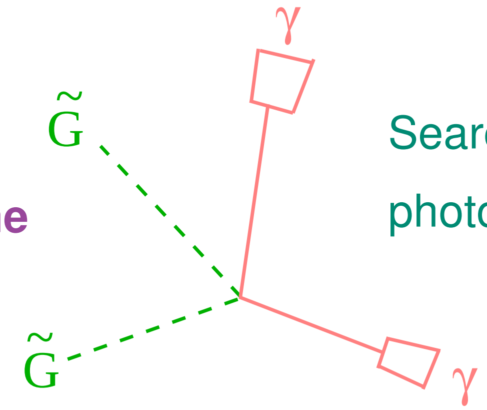


- ▷ **Prompt neutralino decays: photons +** $\not\!\!E$ (+ leptons / jets)
- ▷ **Intermediate neutralino lifetime: non–pointing photons +** $\not\!\!E$ (+ leptons / jets)
- ▷ **Stable neutralinos:** invisible (or leptons / jets + $\not\!\!E$)

Search for Acoplanar Photons

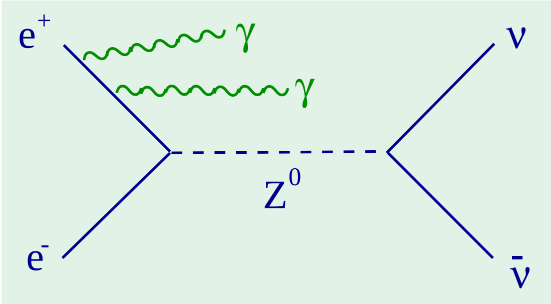


Zero lifetime $\Longrightarrow$

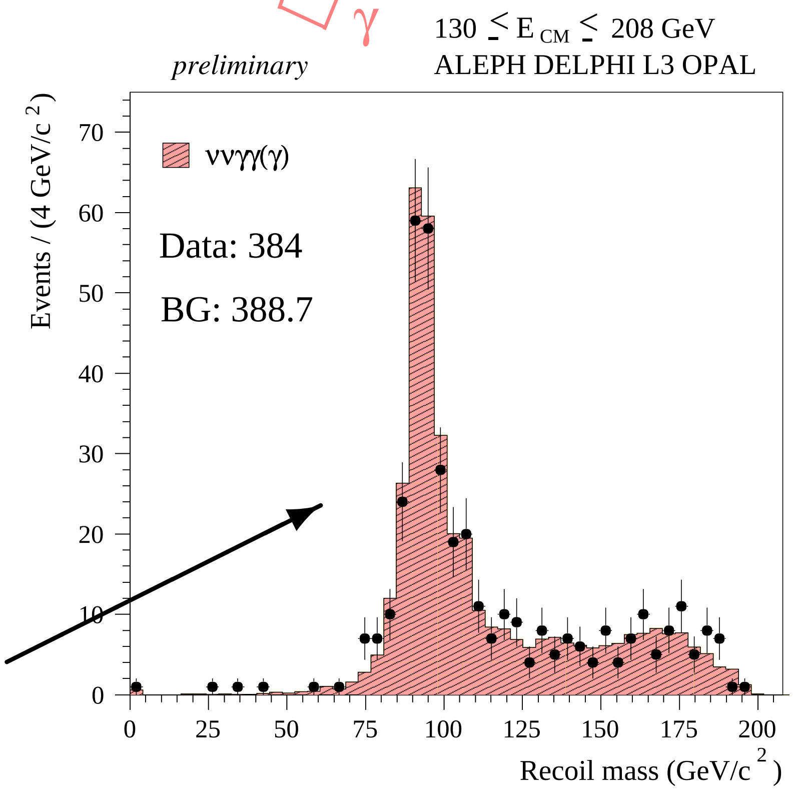


Search for two high–energetic photons and missing p_T

Irreducible background:

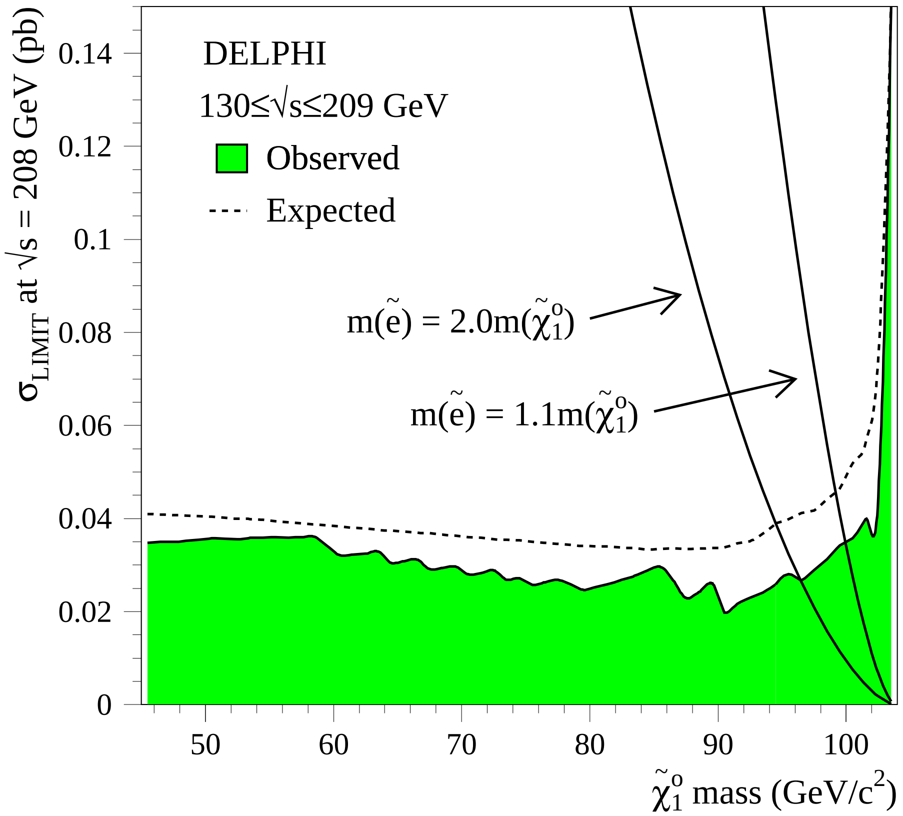


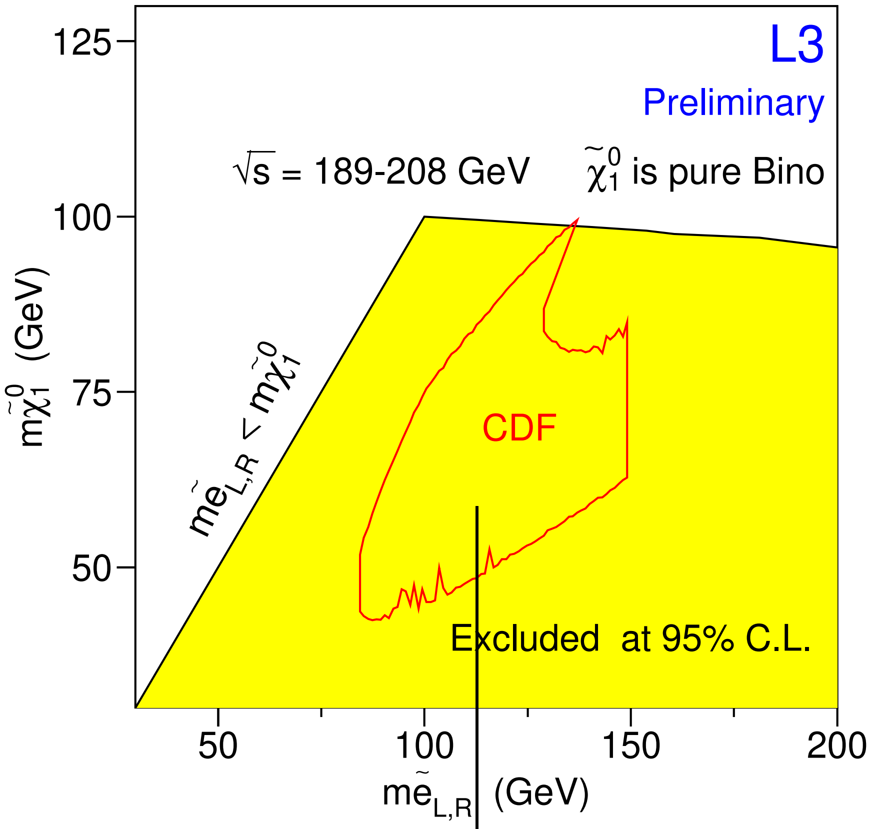
Discriminant: recoil mass against the $\gamma\gamma$ system



No excess over BG expectation

$\longrightarrow$ **cross–section limits:**





$M_{\tilde\chi_1^0} > 96$ GeV for $M_{\tilde{e}_R} = 2.0 M_{\tilde\chi_1^0} \approx M_{\tilde{e}_L}$

$\Rightarrow$ GMSB interpretation of the famous

$\mathrm{ee}\gamma\gamma\ \not{E}_\mathrm{T}$ event from CDF excluded!

$(\tilde{e}^+\tilde{e}^- \longrightarrow \tilde\chi_1^0\tilde\chi_1^0 e^+e^- \longrightarrow \gamma\gamma\tilde{G}\tilde{G}e^+e^-)$

Neutralinos with Intermediate Lifetimes

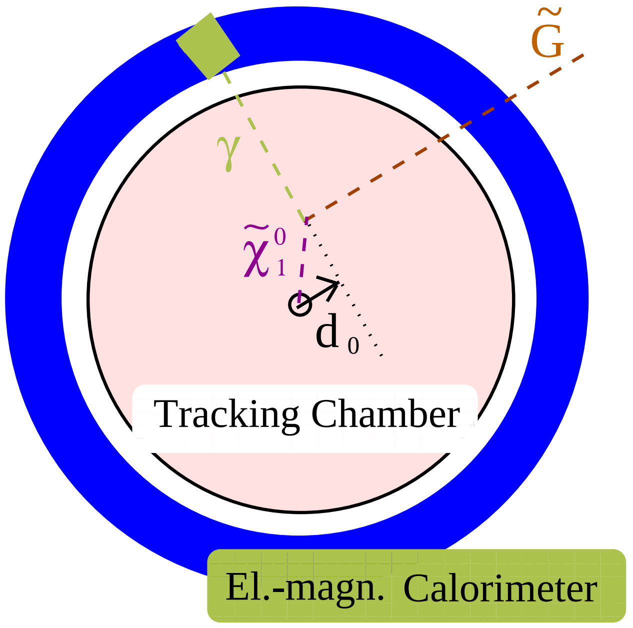
For **longer** neutralino lifetimes: photons do not point to the primary vertex

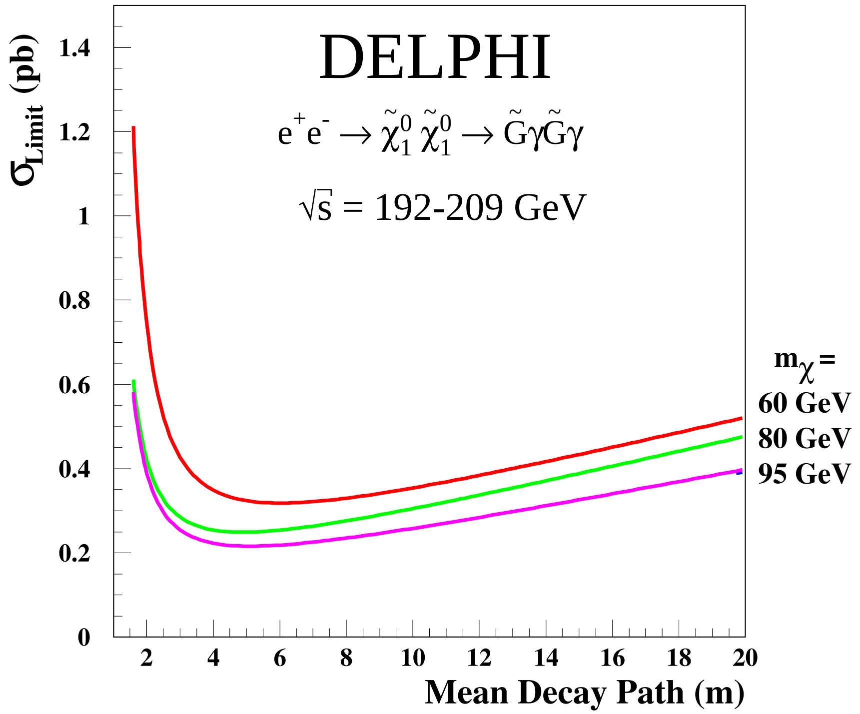
$\longrightarrow$ search for *single* photons with large impact parameters ($d_0 > 40$ cm)

$\longrightarrow$ high *calorimeter granularity* allows to reconstruct impact parameter

ALEPH, 189–209 GeV: 2 obs. / 1.0 exp.

DELPHI, 130–209 GeV: 16 obs. / 14.6 exp.



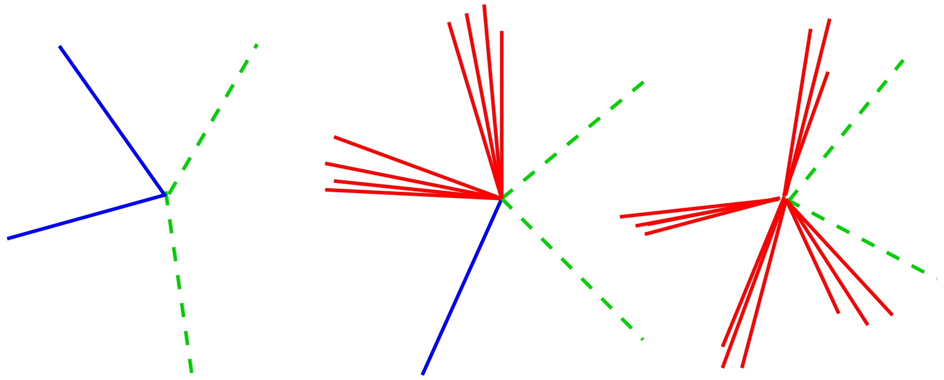


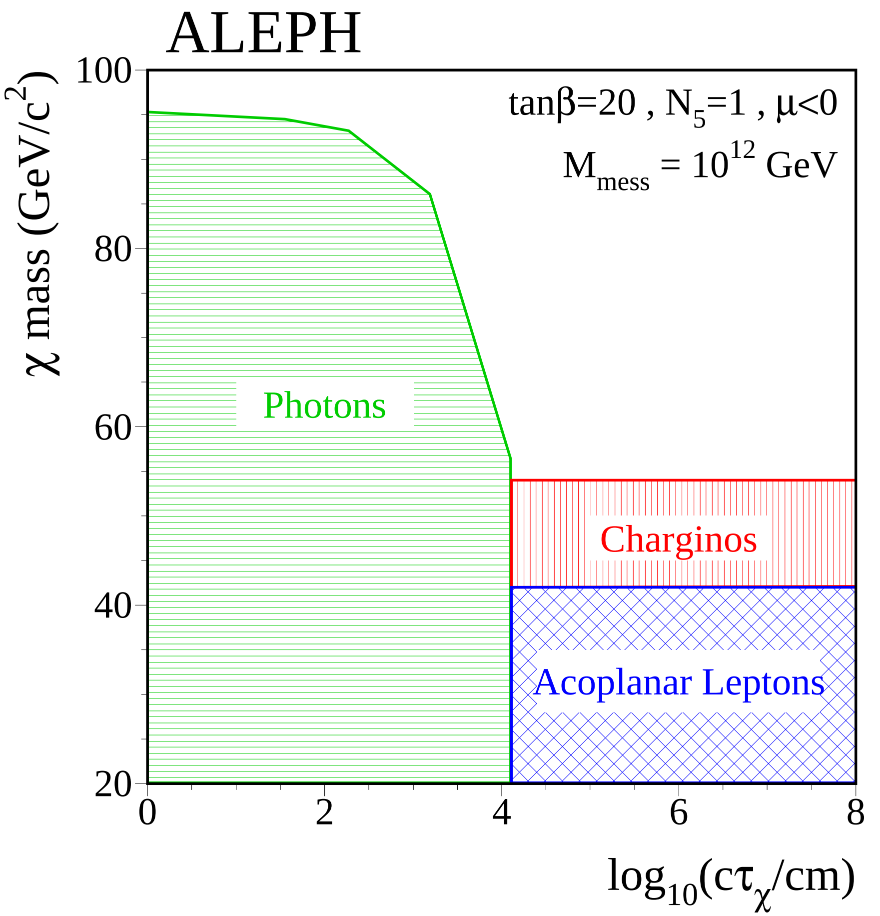
Main BG: cosmic ray events & detector noise

Search for Long–Lived Neutralinos

$\tilde{\chi}_1^0$ stable $\Rightarrow \mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$ is invisible $\Rightarrow$ indirect production used to constrain M$(\tilde{\chi}_1^0)$

- ▷ $\mathbf{e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow \ell^+\tilde{\chi}_1^0\,\ell^-\tilde{\chi}_1^0}$
- ▷ $\mathbf{e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W^{+*}\tilde{\chi}_1^0\,W^{-*}\tilde{\chi}_1^0}$





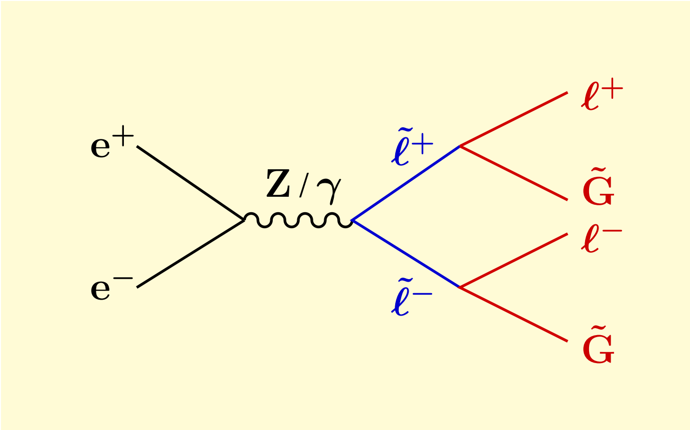
$\rightarrow$ SUGRA ($\tilde{\chi}_1^0$ is LSP) searches can be used

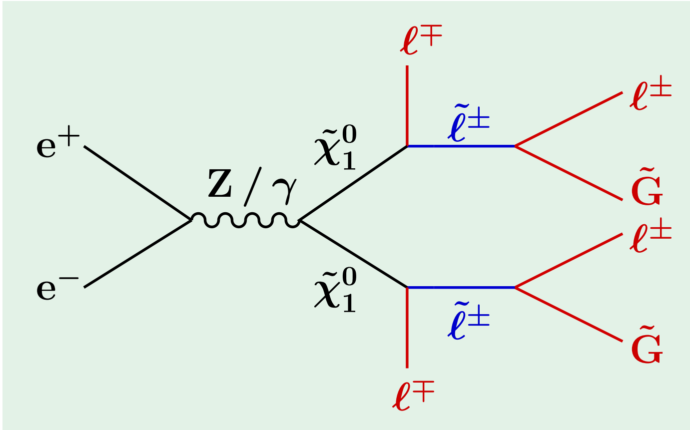
$\Rightarrow$ M$(\tilde{\chi}_1^0) > 54$ GeV for all lifetimes

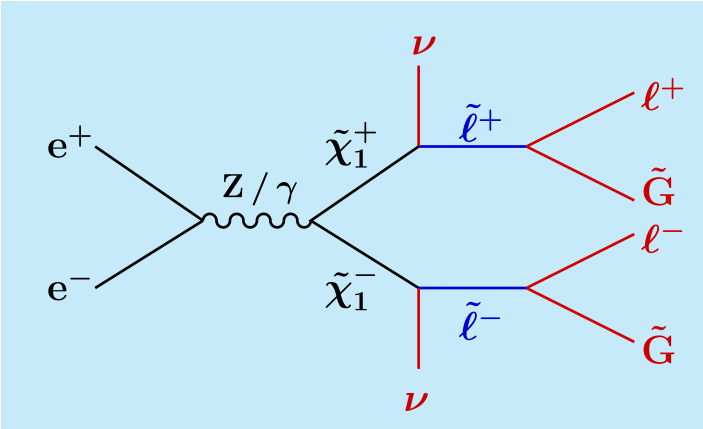
$(N = 1, \tan\beta = 3, \Lambda = 39$ TeV, $M = 10^{10}$ GeV)

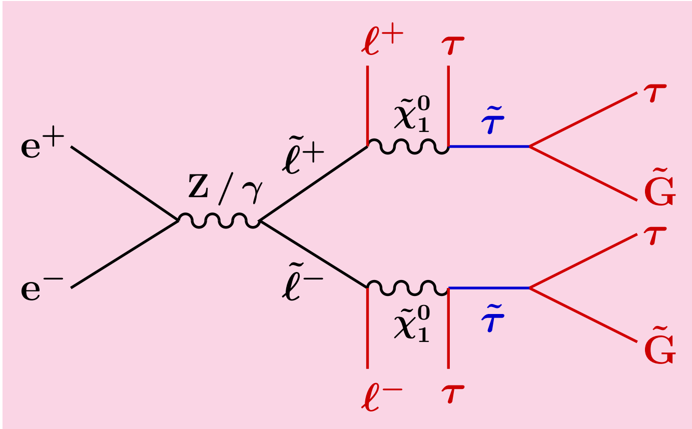
(theoretical framework: Ambrosanio, Kribs, Martin)

Topologies in the Slepton NLSP Scenario:



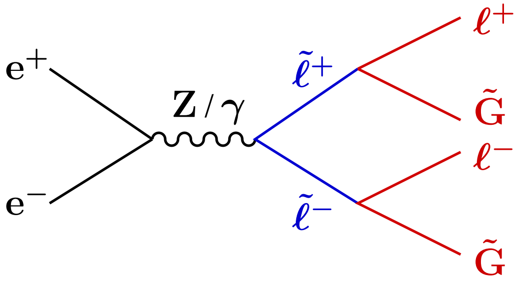




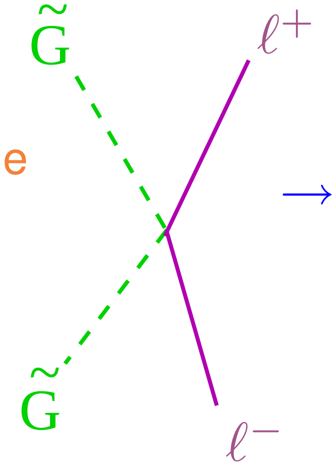


- **Prompt slepton decays:** 2 / 4 / 6 leptons + $\not{E}$
- **Intermediate slepton lifetime:** tracks with large impact parameters / kinks (+ 2 / 4 leptons)
- **Stable sleptons:** sleptons (+ 2 / 4 leptons)

Search for Acoplanar Leptons

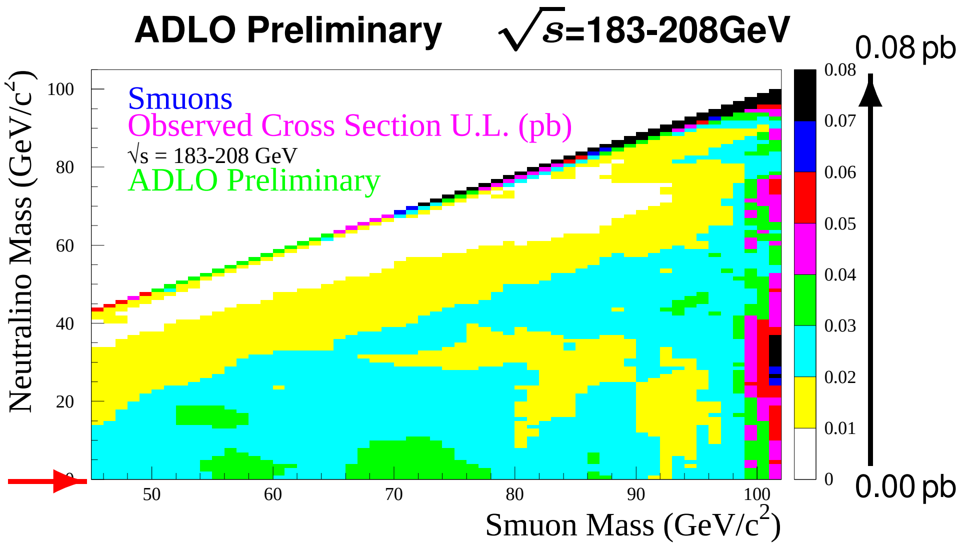


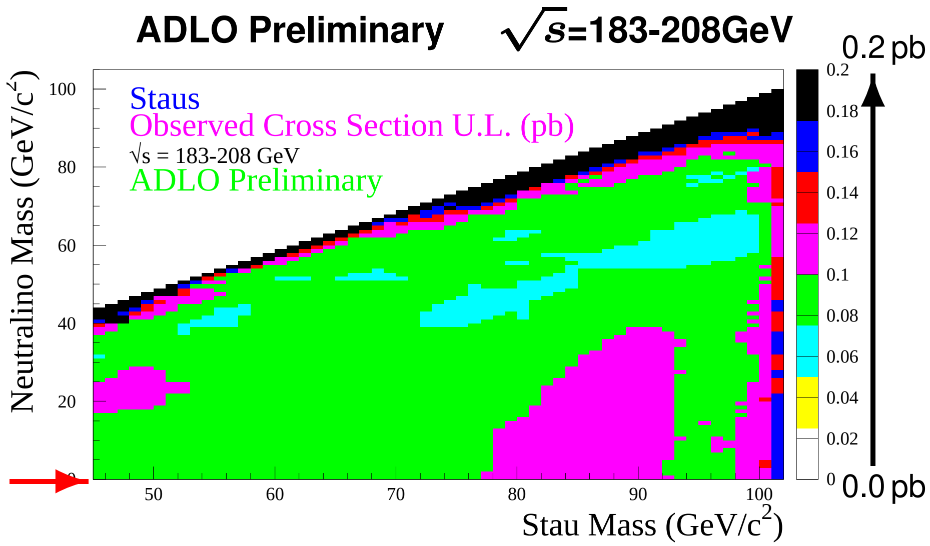
zero lifetime $\Longrightarrow$



$\rightarrow$ mSUGRA sleptons with $M_{\tilde\chi_1^0} = 0$

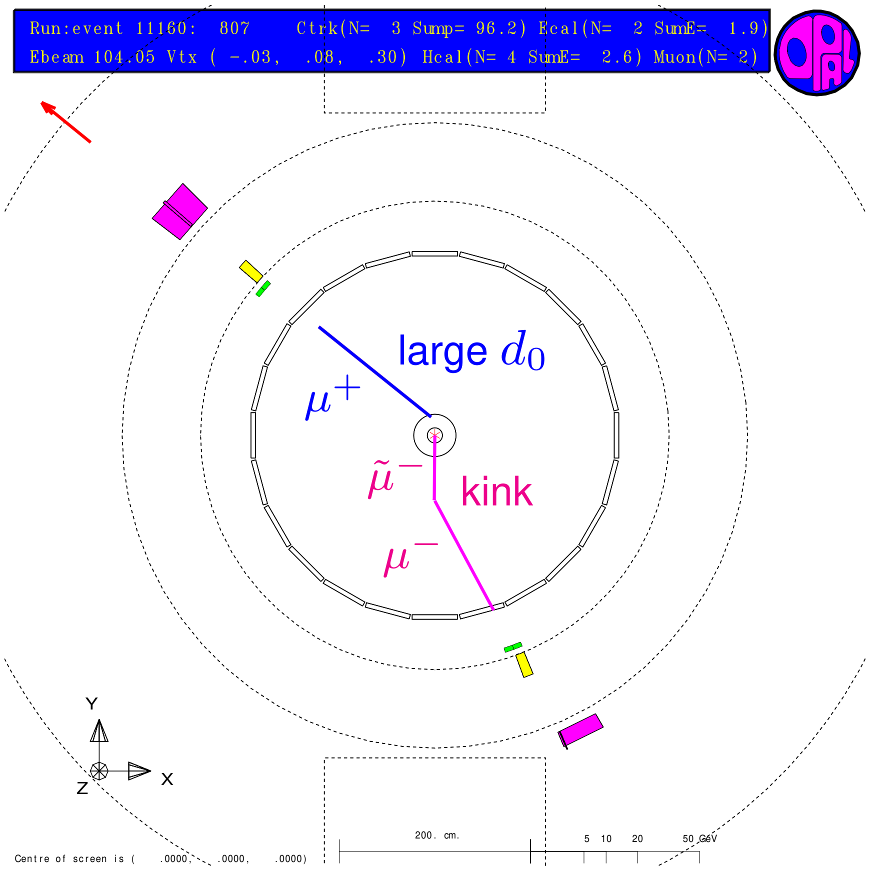
$(\tilde\ell_R^+\tilde\ell_R^- \rightarrow \ell^+\tilde\chi_1^0\,\ell^-\tilde\chi_1^0)$





Search for Sleptons with Intermediate Lifetime

A *simulated* $\tilde{\mu}^+\tilde{\mu}^-$ event:



If the slepton decays

– before reaching the tracking chamber:

$\longrightarrow$ *tracks with large impact parameters (d_0)*

– in the tracking chamber:

$\longrightarrow$ *tracks with kinks*

BG: – cosmic ray events

– hadronic interaction with detector material

– beam related BG

Large d_0 + kinks, 189–209 GeV:

A: 1 obs. / 1.1 exp.

D: 9 obs. / 7.4 exp.

O: 2 obs. / 2.8 exp. ($\tilde{e}$, $\tilde{\mu}$)

7 obs. / 4.4 exp. ($\tilde{\tau}$)

Search for Long–Lived Sleptons

Pair–produced sleptons decay outside detector

$\longrightarrow$ two back–to–back tracks with

– anomalous high or low ionization energy loss (dE/dx)

– no calorimeter signals (”heavy muons”)

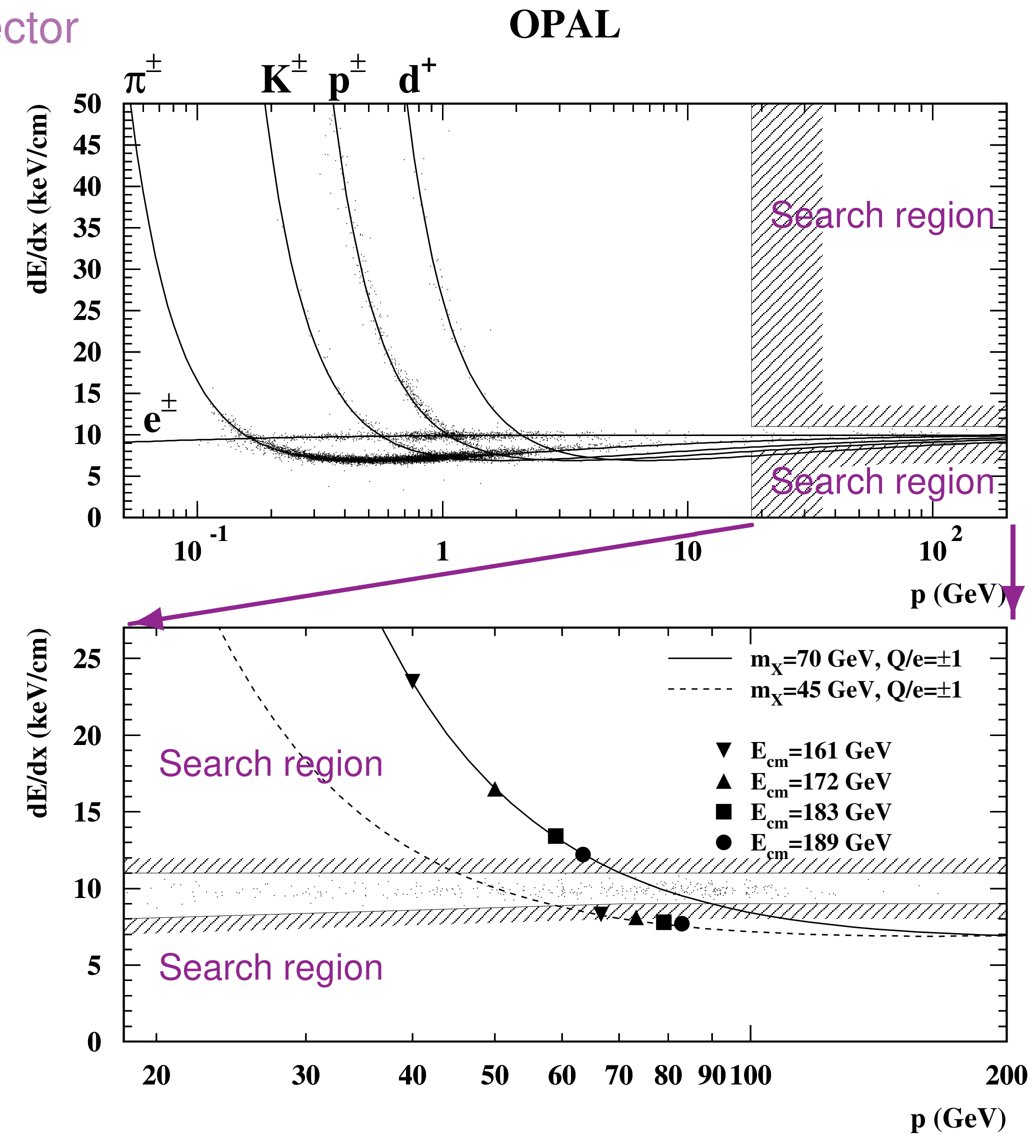
SM background–free &
very high efficiency (OPAL $>$ 90%)

$\sqrt{s} = 189 - 209$ GeV:

ALEPH: 1 obs. / 2.3 exp.

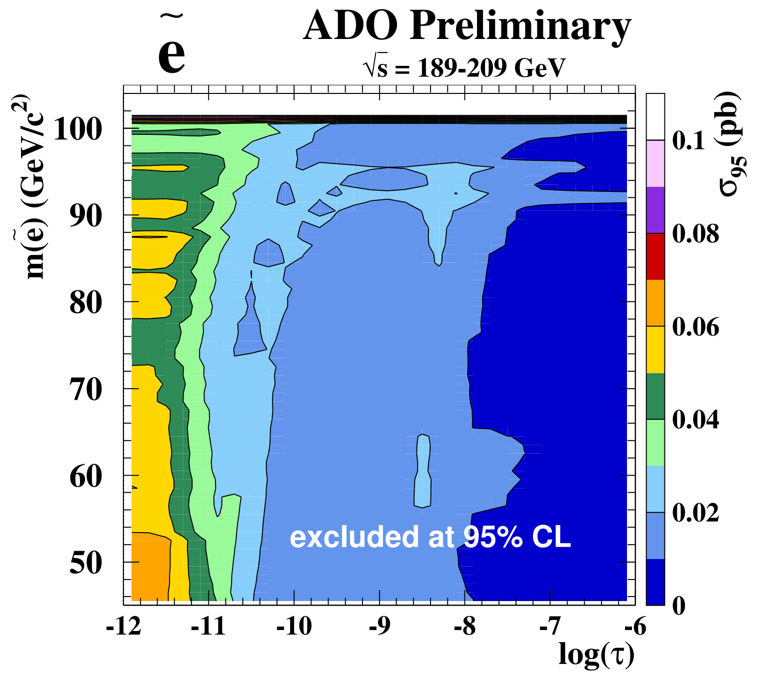
DELPHI: 1 obs. / 2.7 exp.

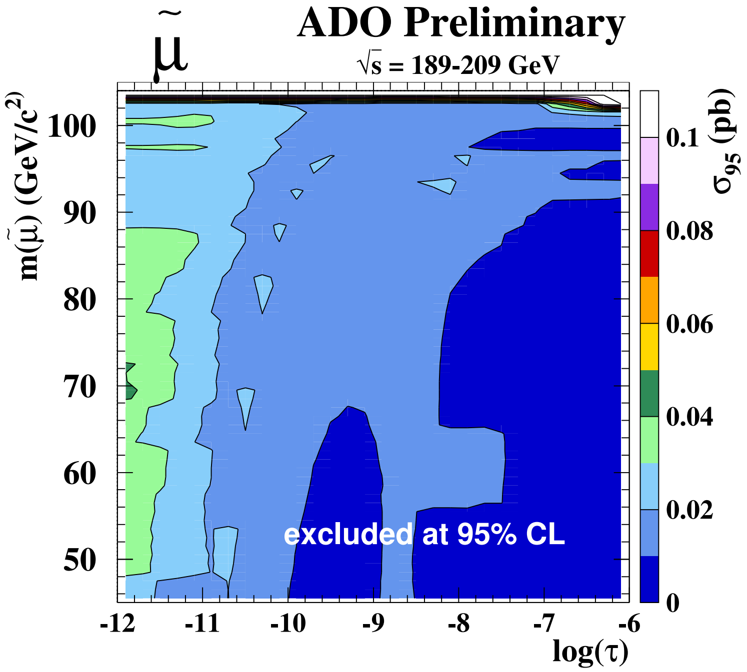
OPAL: 1 obs. / 0.6 exp.

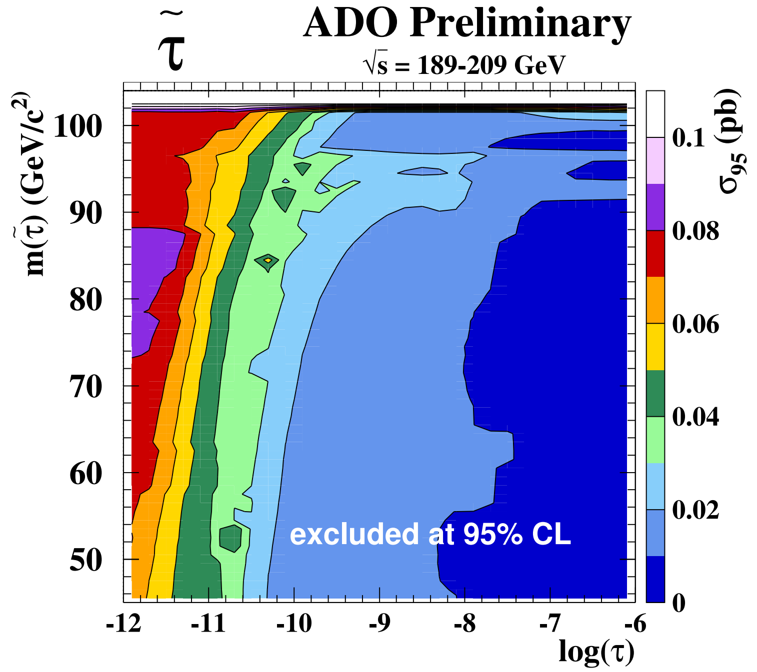


Combination of all lifetimes:

Cross–section limits





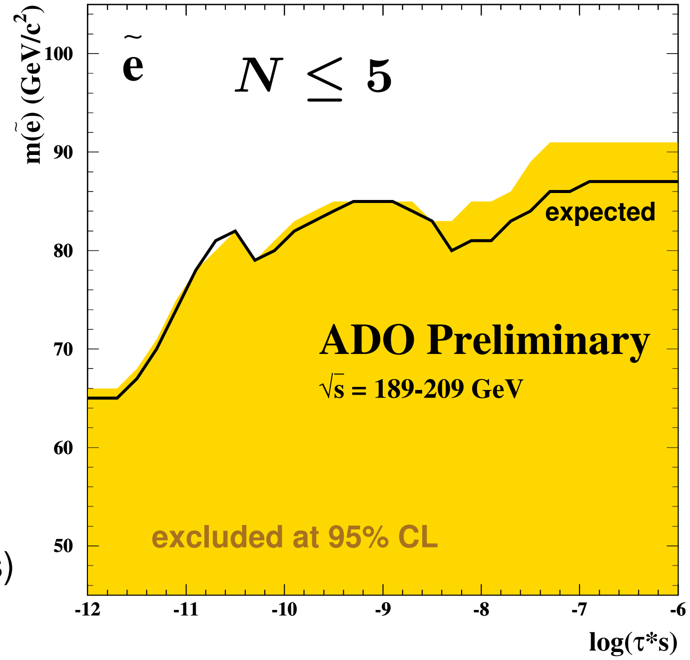


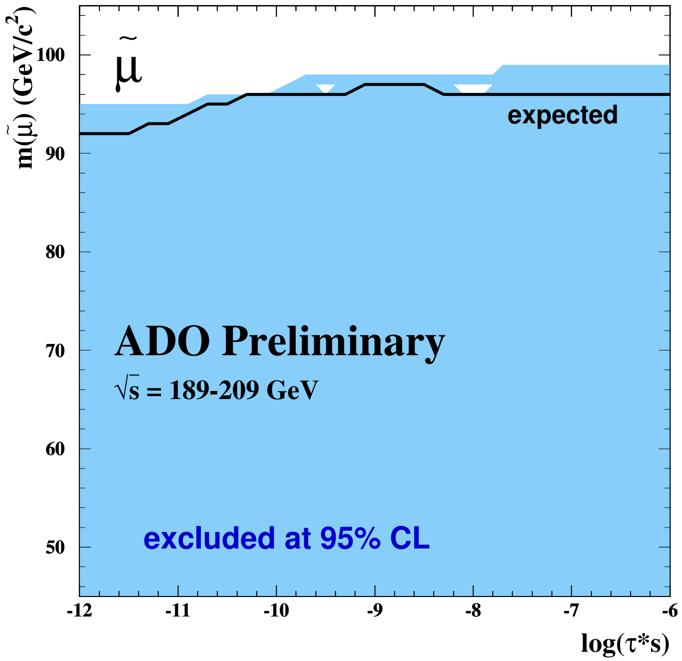
Combination of all lifetimes:

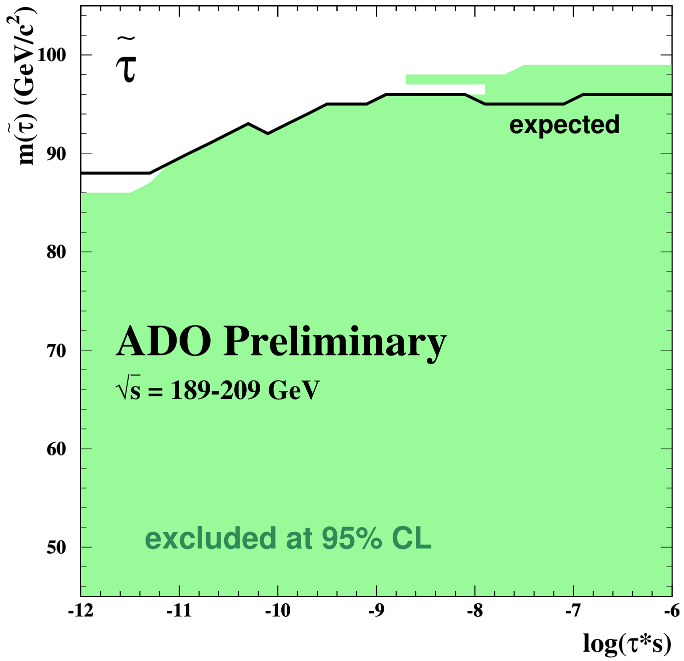
Slepton mass limits

$M_{\tilde{e}} > 66.0$ GeV
$M_{\tilde{\mu}} > 95.2$ GeV
$M_{\tilde{\tau}} > 86.1$ GeV

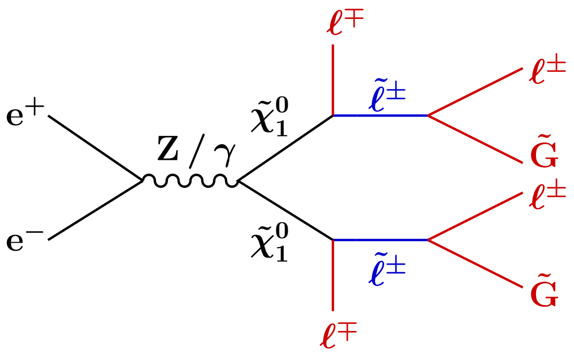
(exp. cross–sections based on Dimopoulos, Thomas, Wells)







$\tilde{\chi}_1^0\tilde{\chi}_1^0$ Production with a $\tilde{\ell}$ NLSP

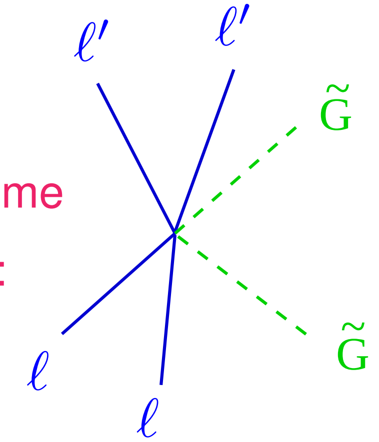


→ stau NLSP: $\tilde{\tau}\tilde{\tau}$

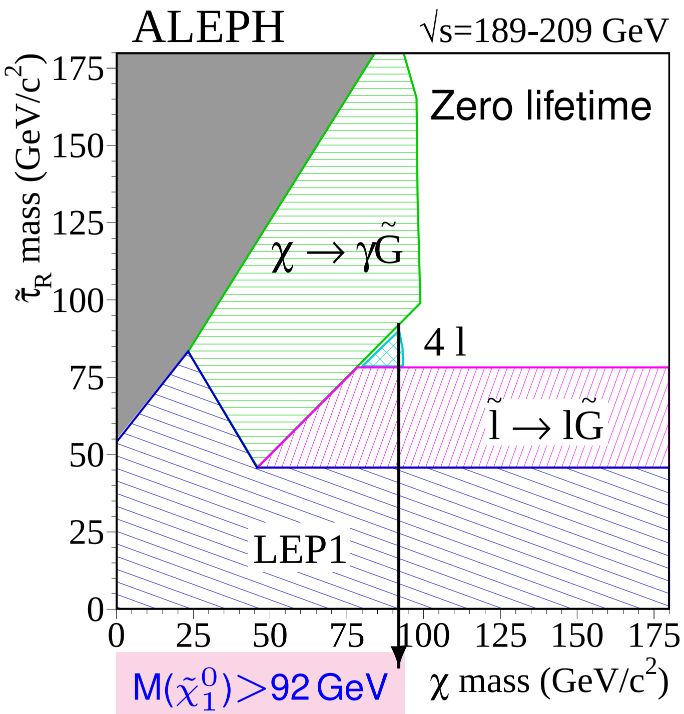
→ slepton co–NLSP:

$\tilde{e}\tilde{e}, \tilde{\mu}\tilde{\mu}, \tilde{\tau}\tilde{\tau}, \tilde{e}\tilde{\mu}, \tilde{e}\tilde{\tau}, \tilde{\mu}\tilde{\tau}$

zero lifetime topology:



... but also large d_0 & kinks!



M($\tilde{\chi}_1^0$)>92 GeV

E.g. $\tilde{\tau}\tilde{\tau}$, 189–209 GeV:

4 leptons + $\not{E}$:
A: 22 obs. / 16.5 exp.
D: 15 obs. / 11.6 exp.
O: 5 obs. / 5.0 exp.

Large d_0 and kinks:
A: 5 obs. / 5.3 exp.
O: 5 obs. / 5.4 exp.

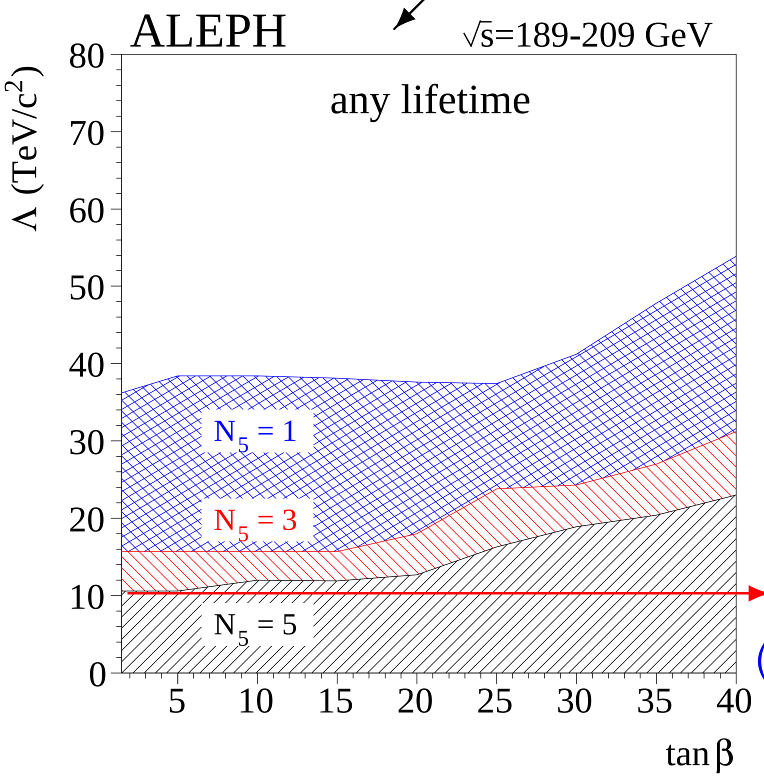
Interpretations in the Minimal GMSB Model

Scan the

GMSB parameters, e.g.:

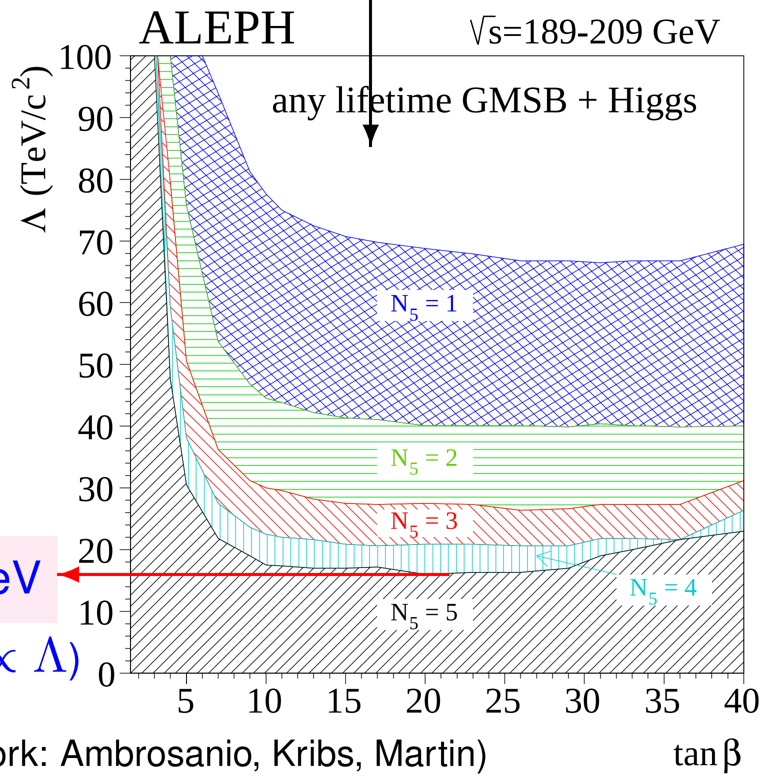
$$1 \leq N \leq 5$$
$$1.5 \leq \tan\beta \leq 40$$
$$10\ \text{TeV} \leq M \leq 10^9\ \text{TeV}$$
$$sign(\mu) = \pm 1$$
$$1\ \text{TeV} \leq \Lambda \leq min(\sqrt{F}, M)$$

Use MSSM Higgs exclusion in $M_h - \sin^2(\beta - \alpha)$ plane



$\Lambda > 10\,(16)$ TeV

(sparticle masses $\propto \Lambda$)



(theoretical framework: Ambrosanio, Kribs, Martin)

Summary

Searches have been performed at LEP for (almost) all topologies predicted within the minimal GMSB model.

No evidence for GMSB has been found at LEP.

Constraints on the GMSB parameter space have been substantially improved by the LEP results.

More results expected: final analyses of all experiments, final LEP combinations, even new channels.

We hope for exciting results from the Tevatron & LHC!