Searches for Gauge Mediated SUSY Breaking Signatures at LEP2

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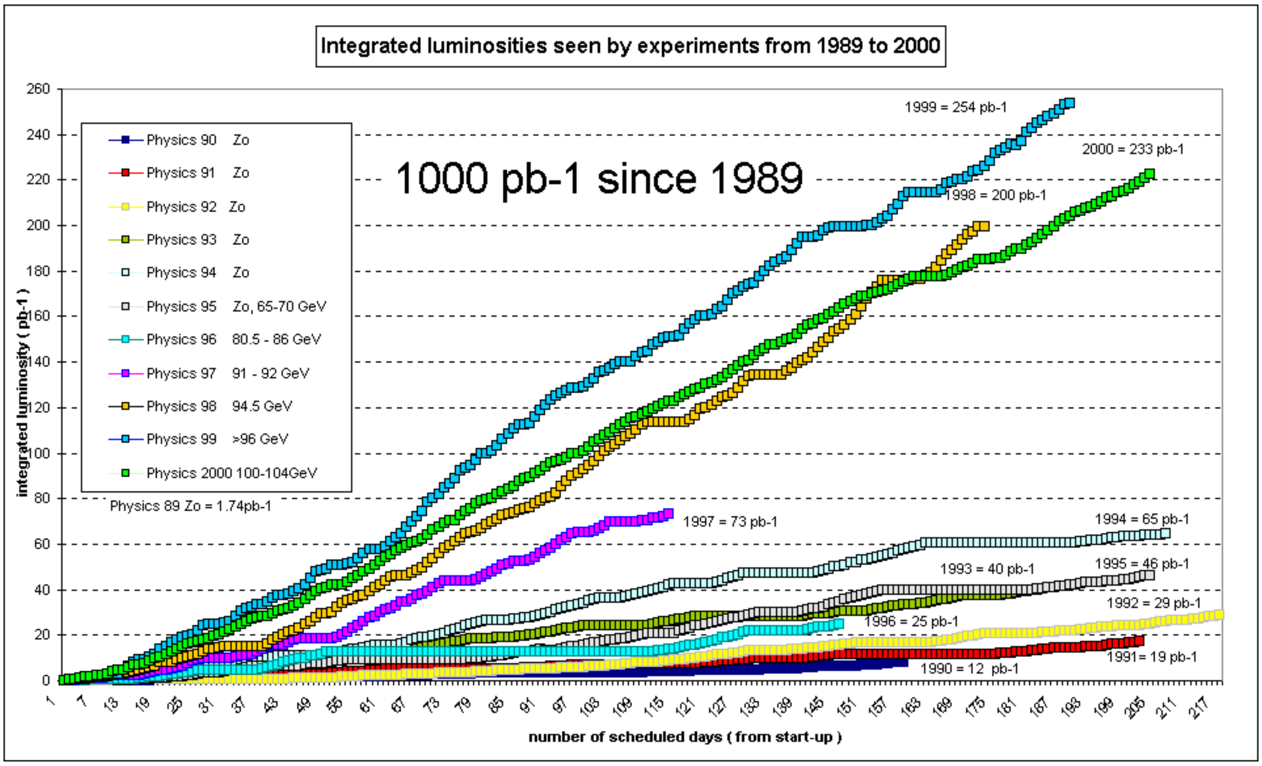
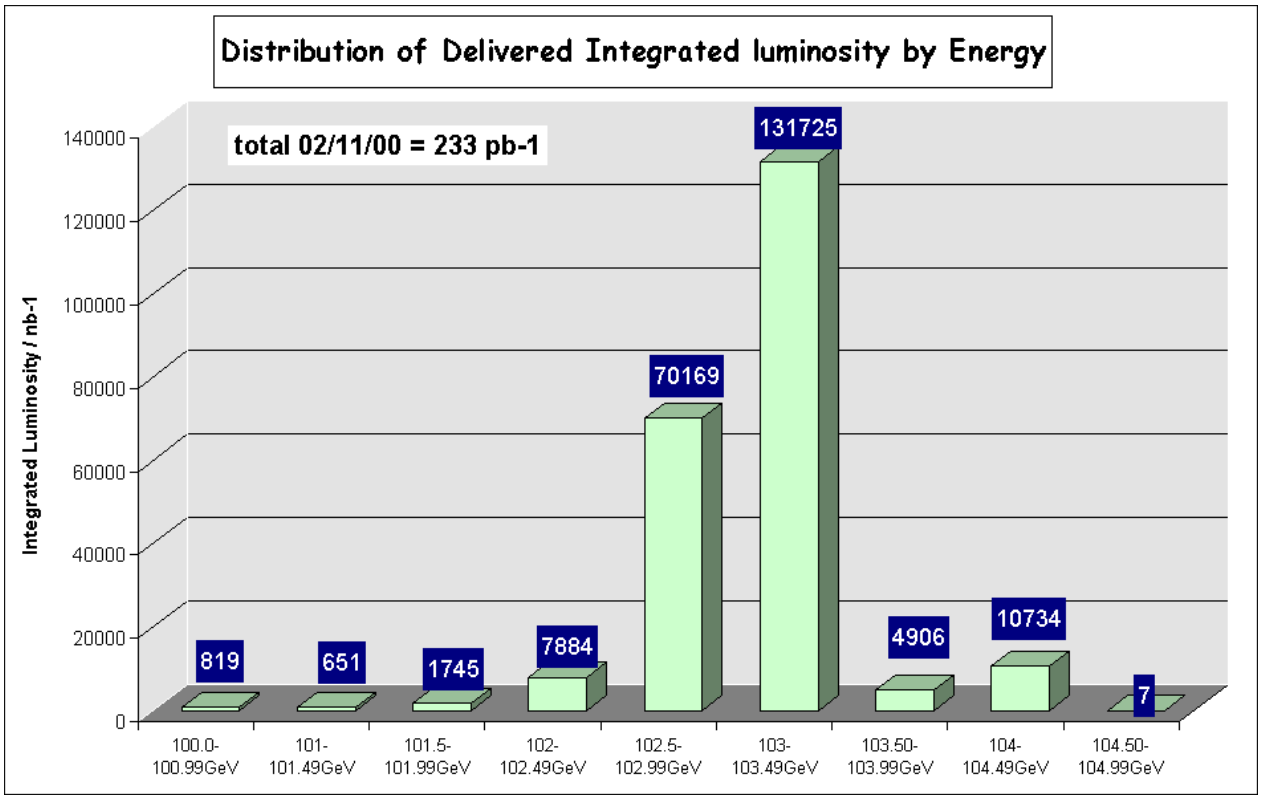
- Introduction to GMSB
  - Gravitino LSP
- Search Results for:
  - Neutralino NLSP Scenario
  - Slepton NLSP Scenario
- Interpretations
- Summary

The LEP Dataset





Introduction to GMSB

SUSY not discovered yet $\Rightarrow$ SUSY is a broken symmetry

But: **the breaking mechanism is unknown.**

Via gravity (SUGRA):
Large FCNC

Via gauge interactions:
Flavour-blind $\longrightarrow$ No FCNC!

$\Rightarrow$ **Gauge Mediated Supersymmetry Breaking:**

SUSY is broken in a hidden sector, which couples to a messenger sector, which in turn couples to the visible sector of known Standard Model– and SUSY–particles.

Only six new parameters in the minimal GMSB model:

$\sqrt{F}$	SUSY breaking scale
Λ	SUSY particle mass scale
M	Messenger particle mass scale
N	Number of sets of messenger particles
$\tan\beta$	Ratio of Higgs vacuum expectation values
Sign(μ)	Sign of Higgs sector mixing parameter

GMSB Phenomenology

The **Gravitino mass** depends on SUSY breaking scale $\sqrt{F}$:

$$m_{\tilde{G}} \simeq 2.5(\sqrt{F}\ /\ 100\ \text{TeV})^2\ \text{eV} \ \rightsquigarrow\ m_{\tilde{G}} < 1\ \text{GeV}$$

$\Rightarrow$ the $\tilde{G}$ is the LSP

Two possible **NLSP's:**
- the slepton $\tilde{l}_R$
- the lightest Neutralino $\tilde{\chi}_1^0$

The NLSP decay mode determines the experimental topology:

$\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$ $\Rightarrow$ **Photons** and $\not{E}$

$\tilde{l}_R \rightarrow l \tilde{G}$ $\Rightarrow$ **Leptons** and $\not{E}$

The **NLSP lifetime** can be sizeable:

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

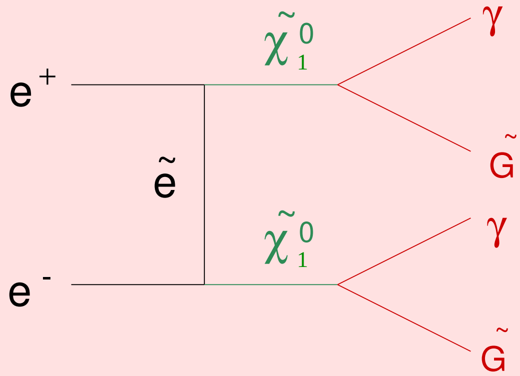
($\kappa_\gamma =$ Photino component of the $\tilde{\chi}_1^0 = 1$ for $\tilde{l}$)

$\rightsquigarrow 1\mu\text{m} <$ decay length $< 10^{11}$ km!

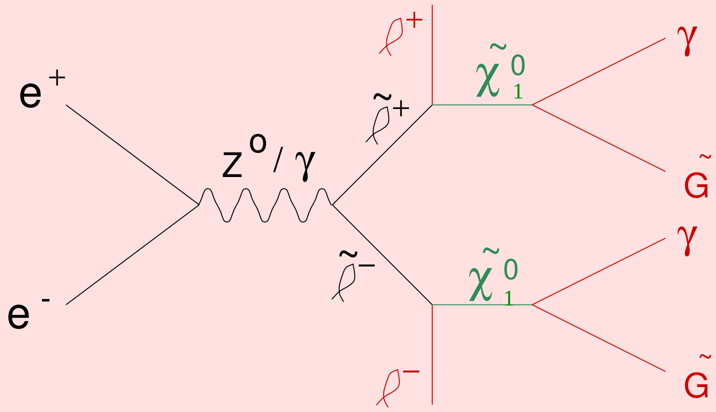
$\Rightarrow$ Need to search for a great variety of different signatures depending on the NLSP type and its lifetime!

The Neutralino NLSP Scenario

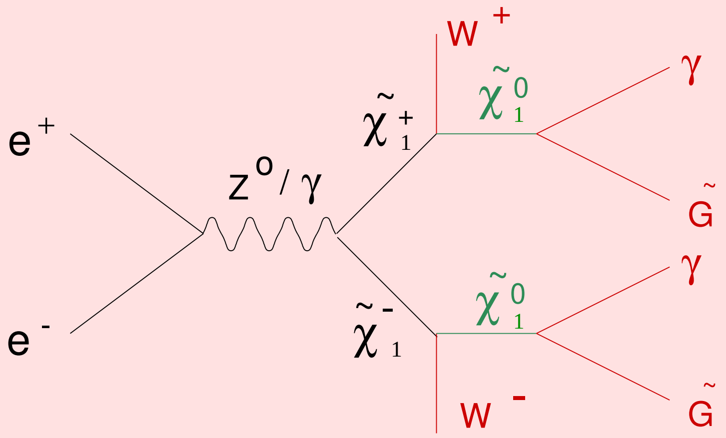
$c\tau \sim 0$:	$\gamma\gamma + \not{E}_T$
$0 < c\tau < \infty$:	$\gamma + \not{E}_T$
$c\tau = \infty$:	Invisible



$c\tau \sim 0$:	$\gamma\gamma\ \ell^-\ell^+ + \not{E}_T$
$0 < c\tau < \infty$:	$\gamma\ \ell^-\ell^+ + \not{E}_T$
$c\tau = \infty$:	$\ell^-\ell^+ + \not{E}_T$



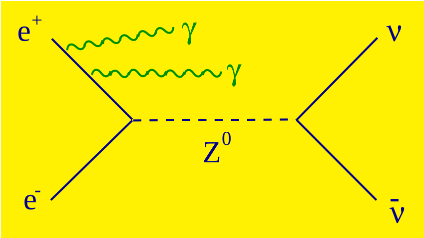
$c\tau \sim 0$:	$\gamma\gamma$ jets / $\ell^\pm + \not{E}_T$
$0 < c\tau < \infty$:	γ jets / $\ell^\pm + \not{E}_T$
$c\tau = \infty$:	jets / $\ell^\pm + \not{E}_T$



Prompt $\tilde{\chi}_1^0$: Acoplanar Photons

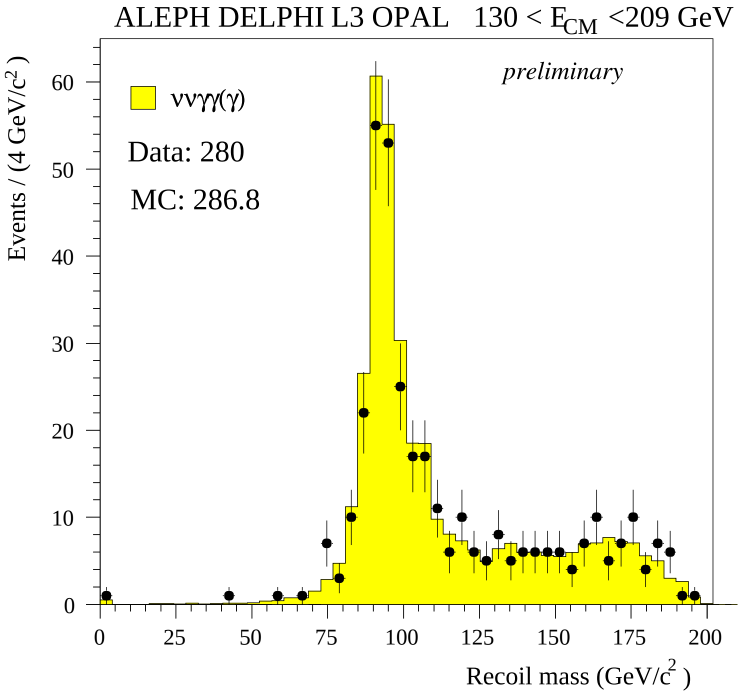
$e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \gamma\gamma\tilde{G}\tilde{G} \Rightarrow$ Search for 2 high-momentum photons and significant $\not{E}$

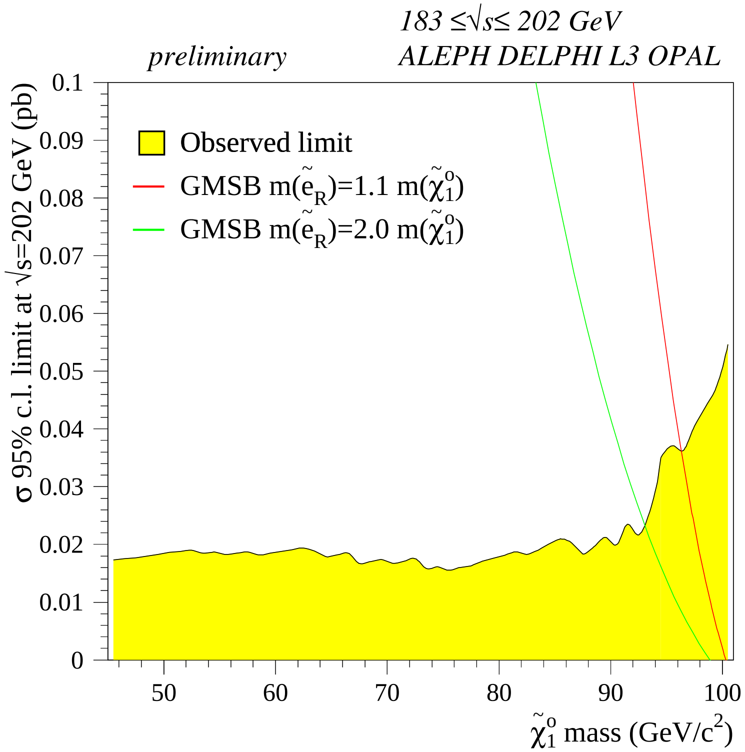
Main Standard Model Background:



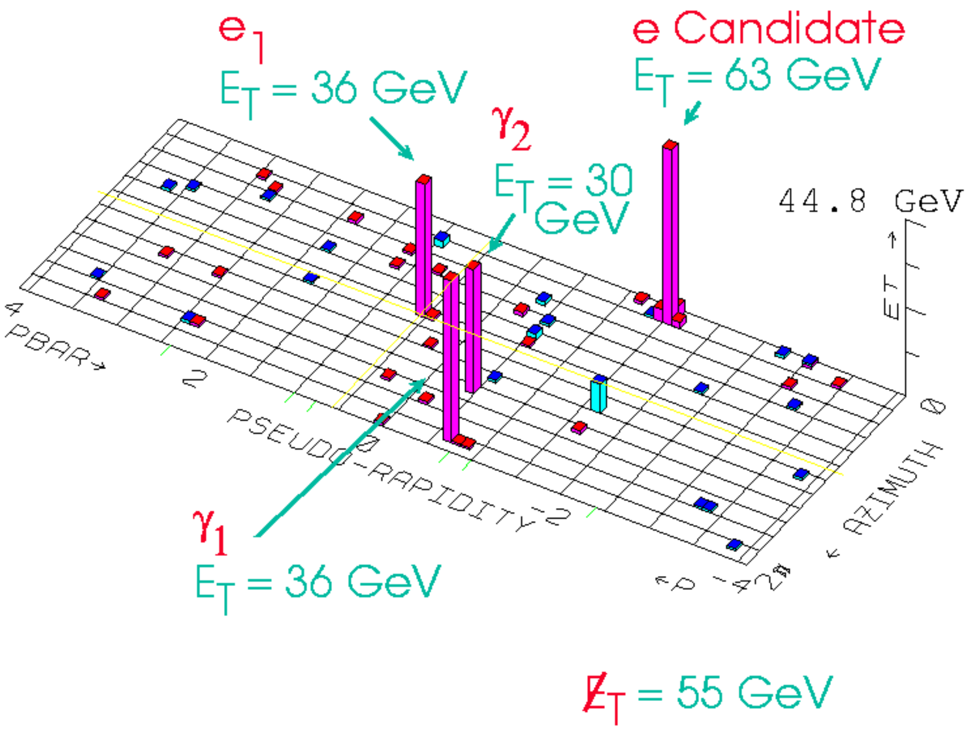
Discriminant:

Recoil mass against the photonic system:



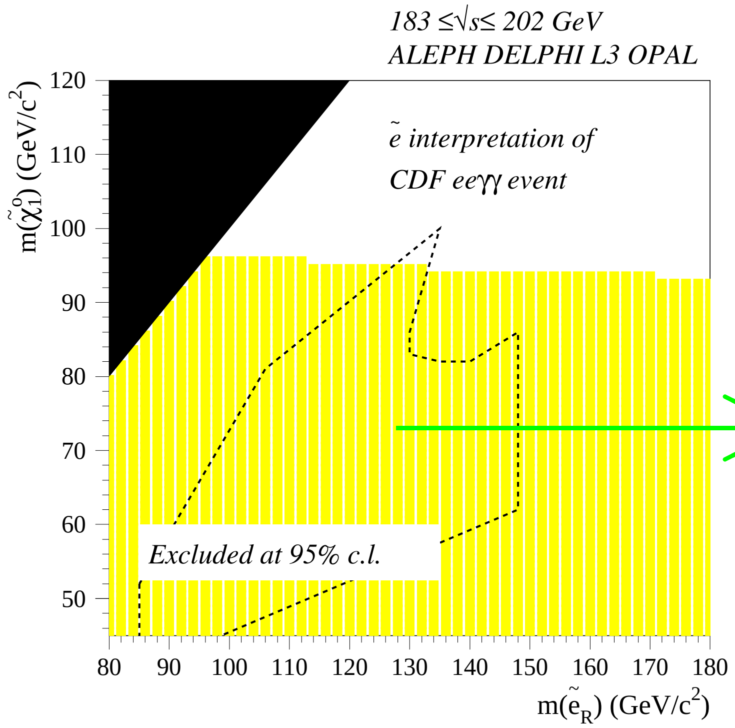


Remember the CDF event?



Interpretation: **CDF:** $\tilde{e}^+\tilde{e}^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- \rightarrow \gamma\gamma\tilde{G}\tilde{G}e^+e^-$

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



CDF region is almost completely excluded!

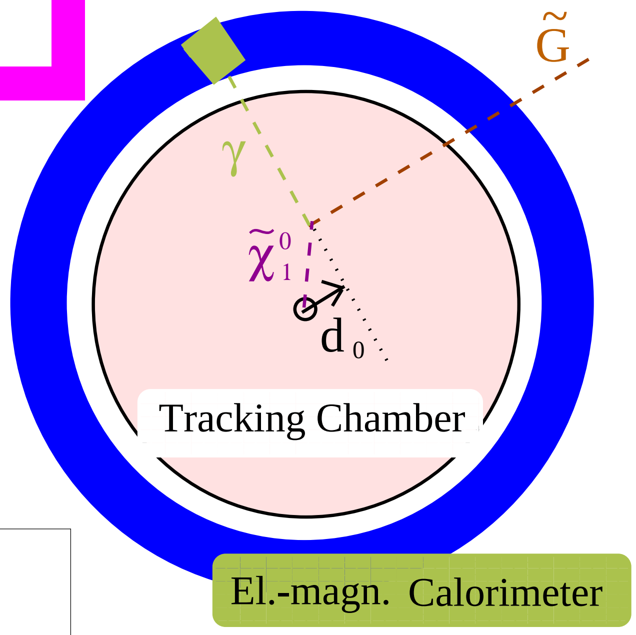
Finite $\tilde{\chi}^0_1$ Lifetime

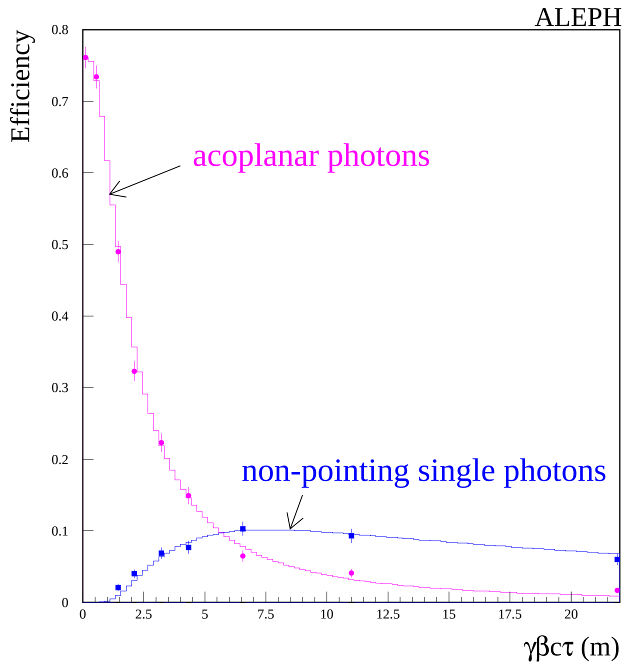
Neutralino(s) decay in the detector

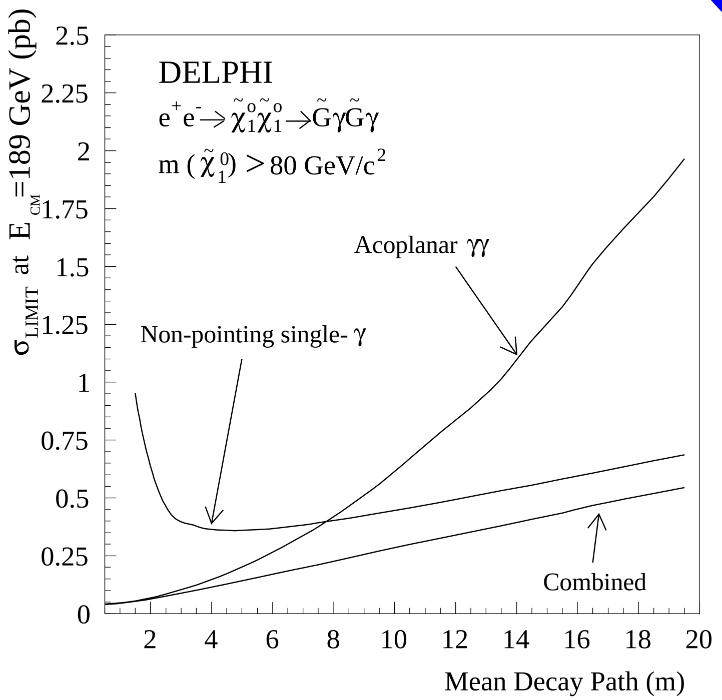
$\longrightarrow$ search for single photon which does not point to the vertex:

◇ Impact parameter from shape of electromagnetic shower $\Rightarrow$

Need high granularity in the electromagnetic calorimeter.





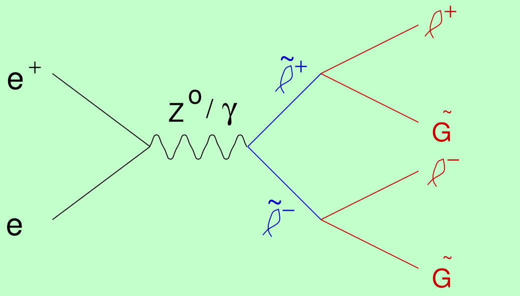


Results @ 189 GeV:

ALEPH: 0 / 0.8
DELPHI: 4 / 5.2

The Slepton NLSP Scenario

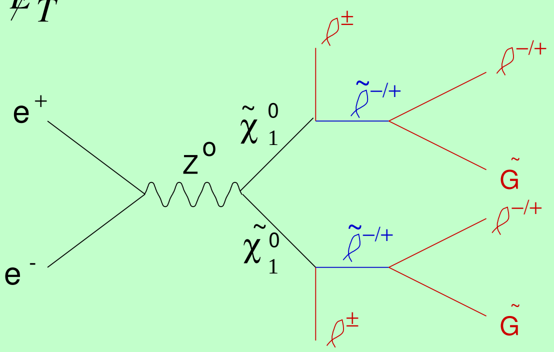
$c\tau \sim 0$:	$\ell^-\ell^+ + \not{E}_T$
$0 < c\tau < \infty$:	2 Kinked Tracks $+ \not{E}_T$
$c\tau = \infty$:	2 Stable Charged



$c\tau \sim 0$: $\ell^+\ell^-\ell'^+\ell'^- + \not{E}_T$

$0 < c\tau < \infty$: $2\ \ell^\pm$ + 2 Kinked Tracks $+ \not{E}_T$

$c\tau = \infty$: $2\ \ell^\pm$ + 2 Stable Charged

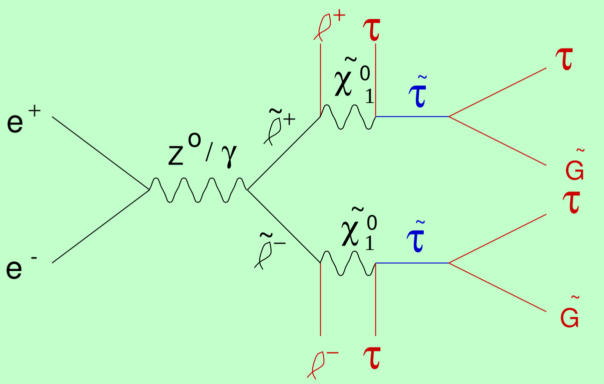


$c\tau \sim 0$: $\tau^{+/-}\ \tau^{+/-}$ + ($\ell^{+/-}\tau^{-/+}\ \ \ell^{+/-}\tau^{-/+}$) $+ \not{E}_T$

$0 < c\tau < \infty$: 2 Kinked Tracks + ($\ell^{+/-}\tau^{-/+}\ \ \ell^{+/-}\tau^{-/+}$) $+ \not{E}_T$

$c\tau = \infty$: 2 Stable Charged + ($\ell^{+/-}\tau^{-/+}\ \ \ell^{+/-}\tau^{-/+}$) $+ \not{E}_T$

Only for $\tilde{\tau}$ NLSP Scenario



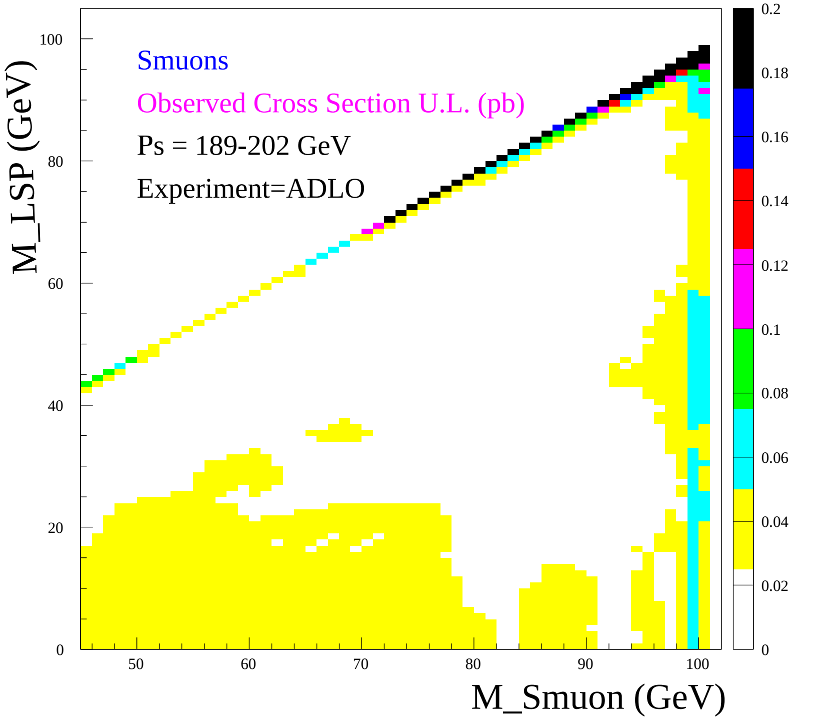
Prompt $\tilde{l}$: Acoplanar Leptons

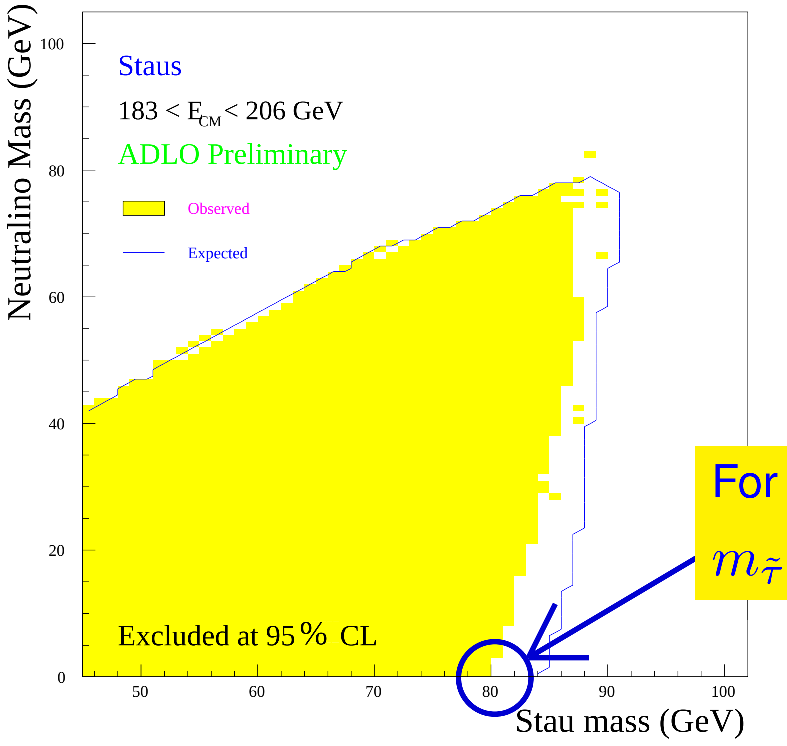
$e^+e^- \rightarrow \tilde{l}^+_R \tilde{l}^-_R \rightarrow l^+\tilde{G} l^-\tilde{G}$

$\Rightarrow$ Topology identical to $\tilde{l}^+_R \tilde{l}^-_R \rightarrow l^+\tilde{\chi}^0_1 l^-\tilde{\chi}^0_1$ with $m_{\tilde{\chi}^0_1} \approx 0$ in the cMSSM

⋆ Search for two identified leptons and missing Energy.

⋆ No excess over background expectation





For $m_{\tilde{\chi}^0_1} \approx 0$:

$m_{\tilde{\tau}} > 80$ GeV

Medium-Lived $\tilde{l}$: Large Impact Parameters or Kinks

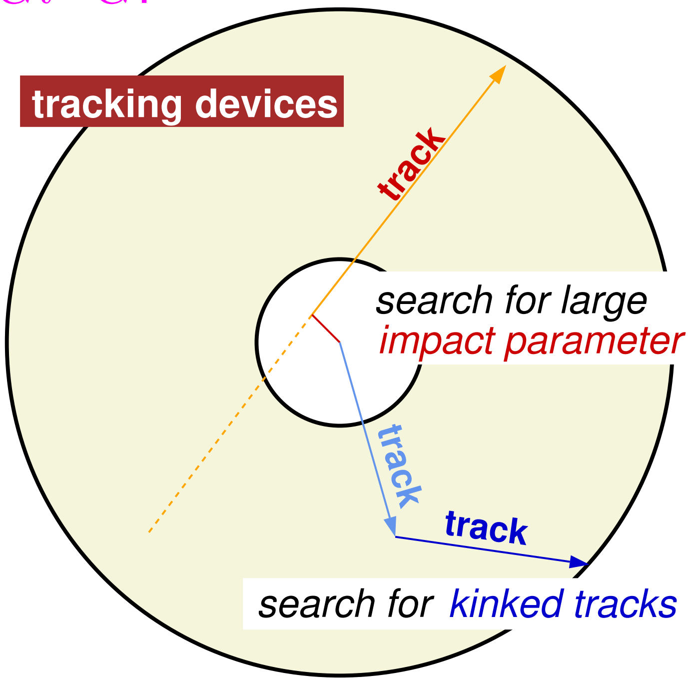
Search for medium-lived $\tilde{l}$ in channel $e^+e^- \rightarrow \tilde{l}^+\tilde{l}^- \rightarrow l^+\tilde{G}l^-\tilde{G}$:

◇ Slepton decays before reaching the tracking device

$\Rightarrow$ track with a large impact parameter (I.P.)

◇ Slepton decays in the tracking chamber

$\Rightarrow$ kinked track or secondary vertex (hadronic τ)



Main background sources:

◇ 2-photon events

◇ cosmic muons,

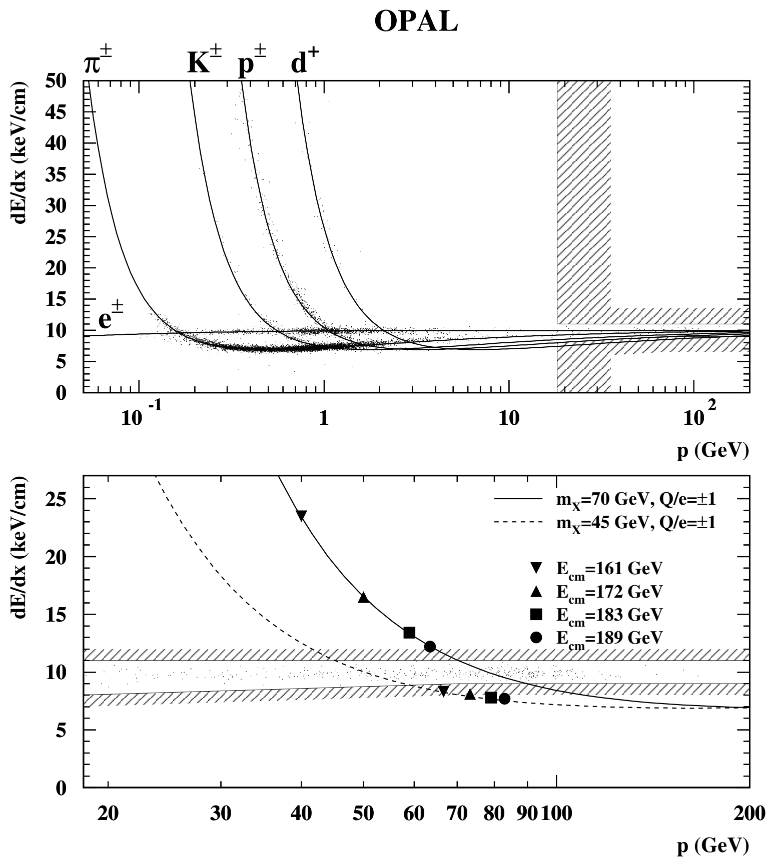
◇ hadronic interactions in/with the beam pipe or the detector, ...

Results @ 189 GeV:

ALEPH (Kinks+I.P.):	1 / 0.9
DELPHI (Kinks+I.P.):	5 / 5.9
OPAL (Kinks):	0 / 0.4

Long-Lived $\tilde{l}$: Anomalous dE/dx

- ⋆ Two back-to-back tracks with anomalous high/low ionization loss (dE/dx)
- ⋆ Weakly interacting particles $\Rightarrow$ No signal in the calorimeters and the RICH (DELPHI)
- ⋆ High efficiency (e.g. OPAL $\approx 95\%$) & very low background

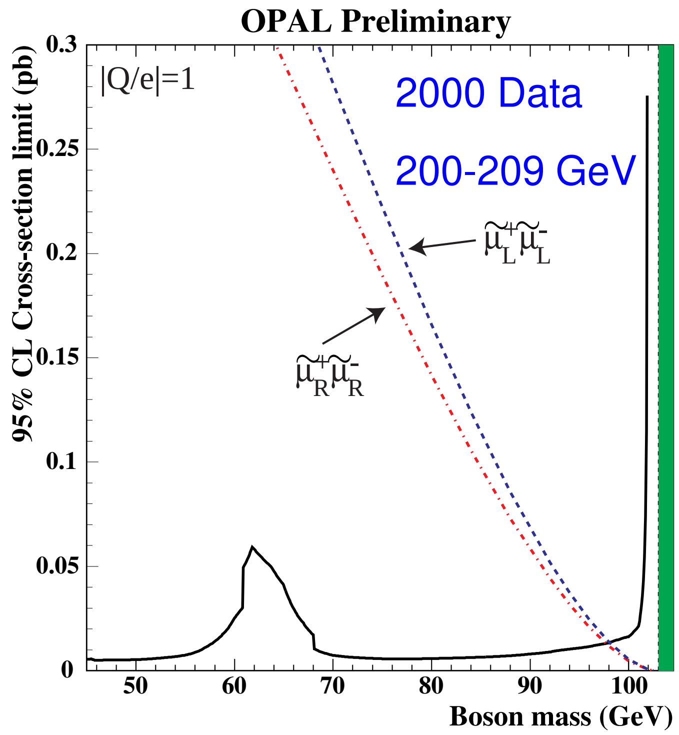


Results @ 189 GeV:

ALEPH: 0 / 0.9

DELPHI: 1 / 1.0

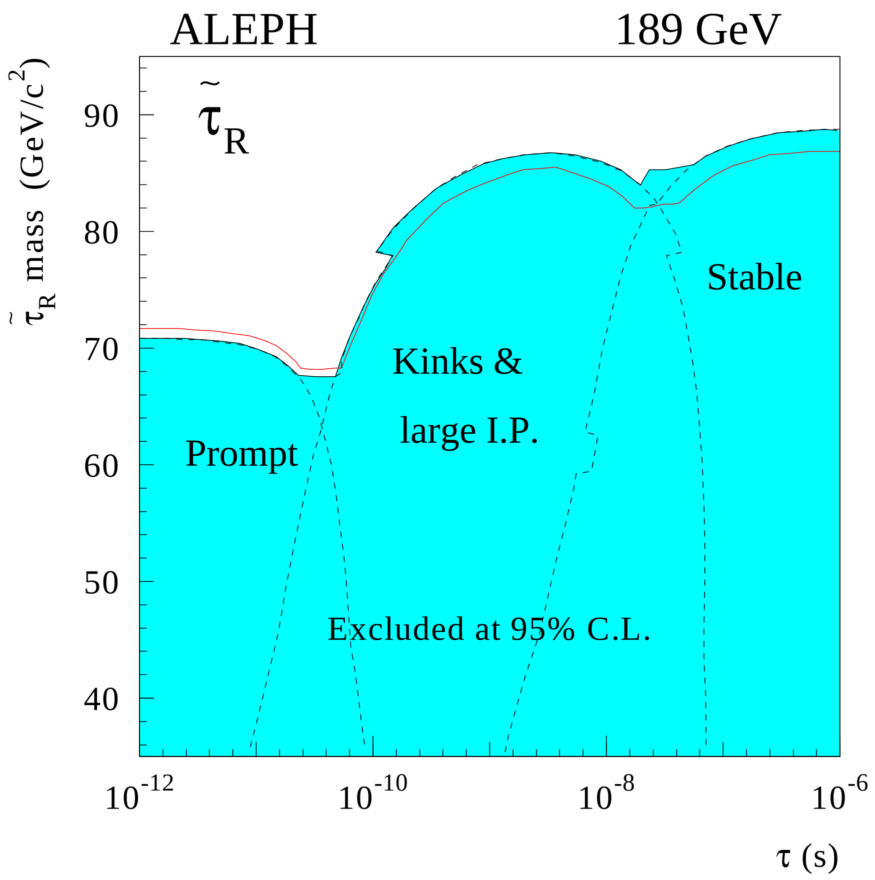
OPAL: 1 / 0.1



Combine results for prompt, medium- and long-lived Sleptons

$\longrightarrow$ Lifetime independent limits on the Slepton masses:

Stau NLSP:



Expected limit

$m_{\tilde{\tau}_R}, m_{\tilde{\tau}_1} > 67$ GeV (ALEPH, 189 GeV)

$m_{\tilde{\tau}_R} > 75$ GeV (DELPHI, 130 – 202 GeV)

Slepton co-NLSP:

$m_{\tilde{l}_R} > 85$ GeV (ALEPH, 189 GeV)

80 GeV (DELPHI, 130 – 202 GeV)

Interpretations

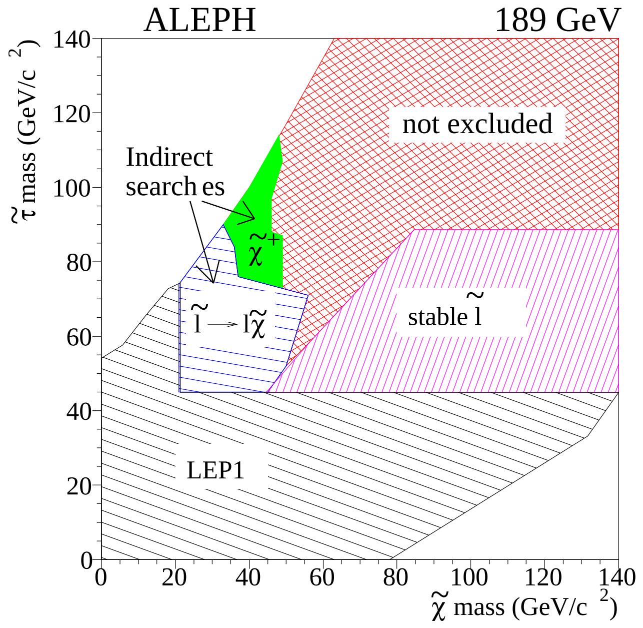
⋆ Perform a scan over the parameter space $\xrightarrow{\text{e.g.}}$

$10\ \text{TeV} < M < 10^9\ \text{TeV}$
$1\ \text{TeV} < \Lambda < \min(\sqrt{F}, M)$
$1.3 < \tan\beta < 38$
$1 < N < 5$
$\text{sign}(\mu) = \pm 1$

⋆ Variation of $\sqrt{F}$ according to the considered lifetime

⋆ General lifetime independent NLSP mass limit $\longrightarrow$

Long NLSP lifetime gives lowest limit:



Combination of:

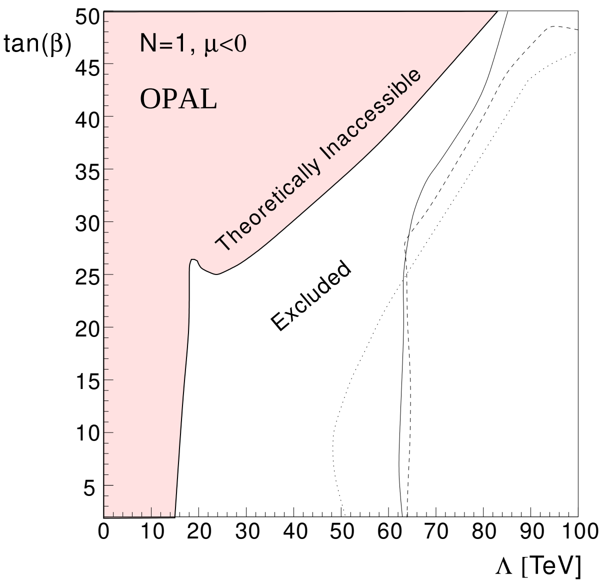
- ○ all lifetimes
- ○ all topologies
- ○ LEP1 searches
- ○ indirect limits for stable $\tilde{\chi}_1^0$

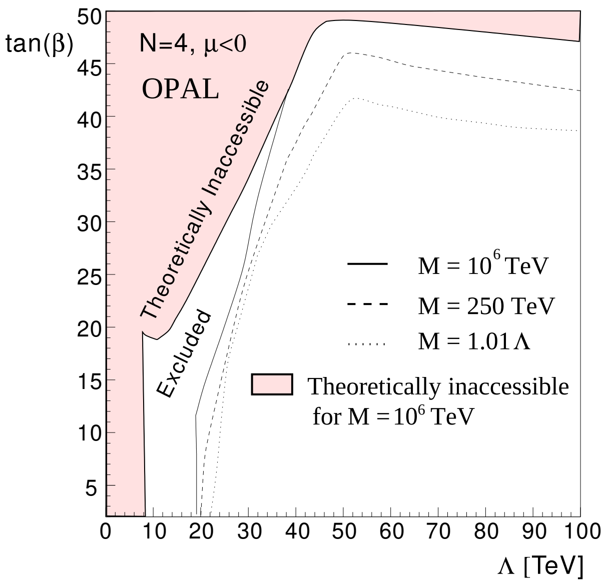
$\Rightarrow$ $M_{\text{NLSP}} > 45$ GeV

Particularly interesting: Mass scale of the SUSY particles Λ

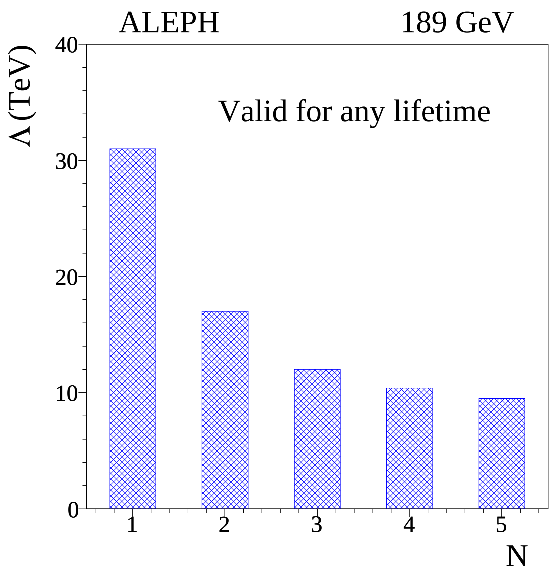
(Gaugino masses $\propto \Lambda$, scalar SUSY particle masses $\propto \Lambda^2$)

Exclusion regions in the Λ vs. $\tan\beta$ plane for 189 GeV, zero-lifetime, $\mu < 0$, and different N and M:





$\Rightarrow$ Λ limit depends strongly on N:



$$\Lambda > 9 \text{ TeV} \rightsquigarrow M_{\tilde{G}} > 2 \cdot 10^{-2} \text{eV}$$

(ALEPH, 189 GeV)

Summary

No hint for GMSB found at LEP.

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

More results still to come: final analyses of the individual experiments as well as LEP combined results.

We are looking forward to hopefully exciting results from the Tevatron and the LHC.