SUSY Searches at LEP

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Beyond the Desert
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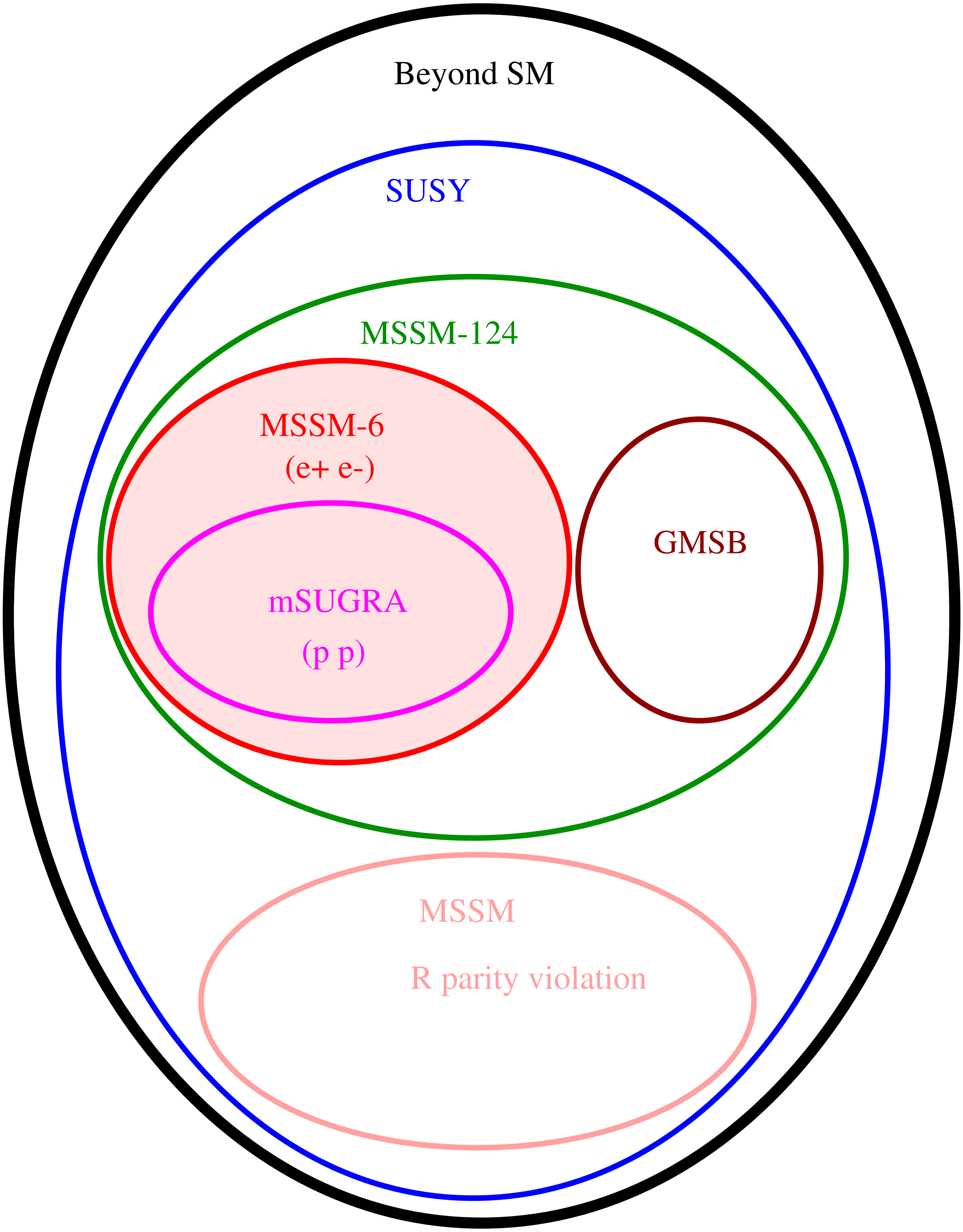
Outline:

- SUSY Framework
- LEP
- Searches:
  - Sneutrino
  - Smuon
  - Stop
  - Charginos
  - Neutralinos
- SUSY Limits

supported by BMBF


Beyond SM
SUSY
MSSM-124
MSSM-6
(e+ e-)
GMSB
mSUGRA
(p p)
MSSM
R parity violation

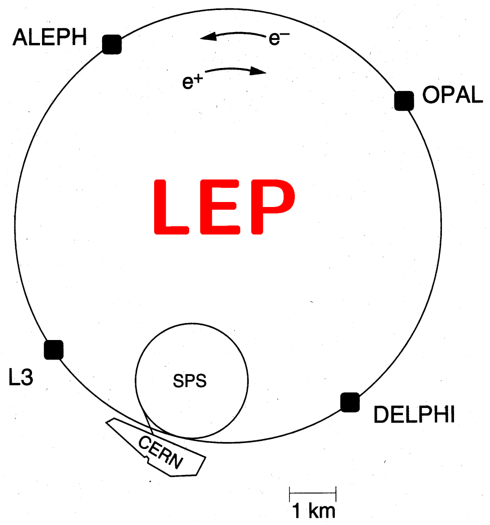
MSSM-6 = CMSSM

Assumptions:
GUT, no CP violation, generation-independence ...
R parity conserved!

Parameters:

- m_0 = Universal scalar mass at GUT scale
  $0 \ \ldots \ \approx 2000\,\mathrm{GeV}$
- $M_2 = SU(2)$ Gaugino mass at electroweak scale
  $0 \ \ldots \ \approx 2000\,\mathrm{GeV}$
- μ = Higgs mass parameter (elw)
  $\approx -2000 \ \ldots \ \approx 2000\,\mathrm{GeV}$
- $\tan\beta$ = ratio of vacuum expectation values (elw)
  $1 \ \ldots \ \approx 50$
- A_0 = Universal trilinear couplings (GUT)
  $0 \ \ldots \ \approx 2000\,\mathrm{GeV}$ (sfermion mixing)
- m_A = Physical mass of CP-odd Higgs
  $0 \ \ldots \ \approx 2000\,\mathrm{GeV}$ (higgs masses)

Additional requirement: LSP (Lightest Susy Particle) has no electromagnetic or strong interaction (cosmology) $\rightarrow \tilde{\chi}, \tilde{\nu}$



LEP 1:

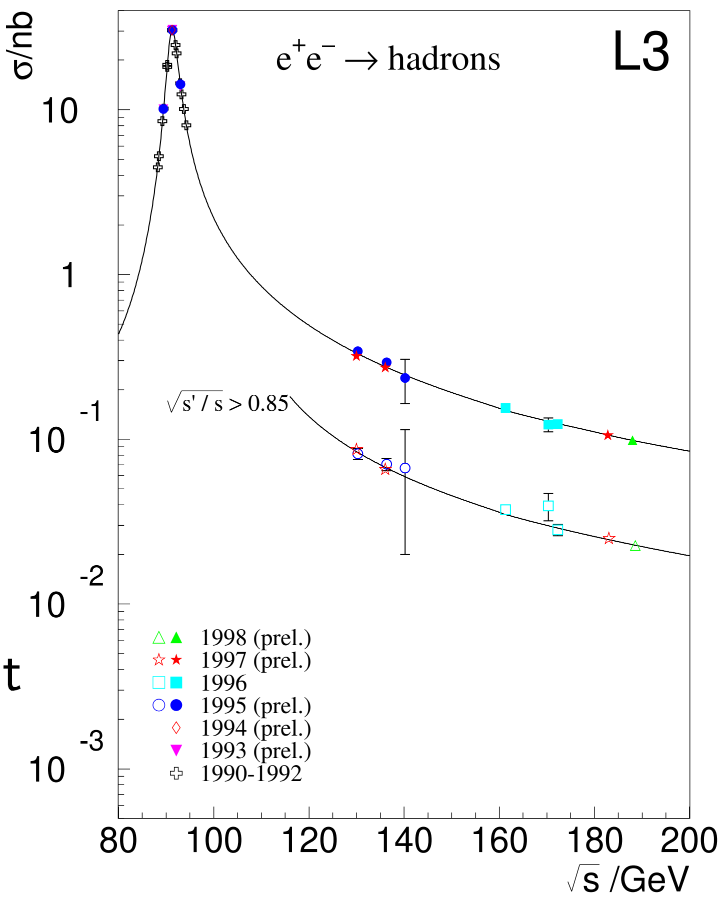
1989 - 1995

$\sqrt{s} \approx 91\,\mathrm{GeV}$

$L = 160\,\mathrm{pb}^{-1}$ / experiment

Advantages:

- Xsection high
- Z (invisible) width: limits independent of decay mode



LEP 2:

1996 - 2000

$\sqrt{s} = 160 - 200\,\mathrm{GeV}$

$L = 260\,\mathrm{pb}^{-1}$ / experiment in 1996-1998

Advantages:

- Center of mass energy large

MSSM-6 Searches at LEP

Squarks $\tilde{u}, \tilde{d}, \tilde{s}, \tilde{c}$ and Gluinos $\tilde{g}$ are heavy $\rightarrow$ Tevatron !

LEP:

- Sneutrino $\tilde{\nu}$
  all three families mass degenerate

- Smuon $\tilde{\mu}$
  representative for $\tilde{e}, \tilde{\mu}, \tilde{\tau}$

- Stop $\tilde{t}$
  representative for $\tilde{b}, \tilde{t}$
  for heavy quarks mixing possibly large and $\tilde{t}_1$ light:

$$\tilde{t}_L \ \ \tilde{t}_R \qquad \rightarrow \qquad \tilde{t}_1 \ \ \tilde{t}_2$$

- Charginos $\chi_1^{\pm} < \chi_2^{\pm}$

- Neutralinos $\chi_1^0 < \chi_2^0 < \chi_3^0 < \chi_4^0$
  χ_1^0 is favorite LSP candidate

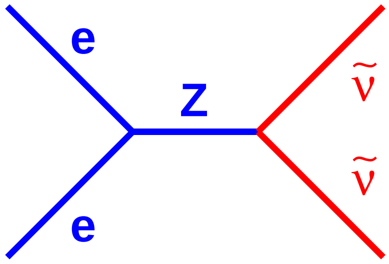
SIGNATURE: Missing energy and momentum

Also: MSSM-Higgs searches at LEP
(see previous talks)

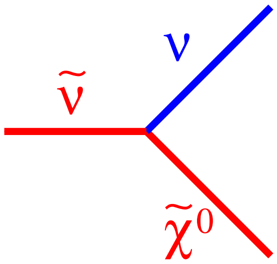
Sneutrino

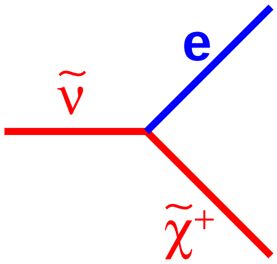
3 families degenerate!

PRODUCTION:



Sneutrino can be stable or might DECAY:





In both cases missing energy in the final state!

Limit from invisible Z width measured at LEP I:

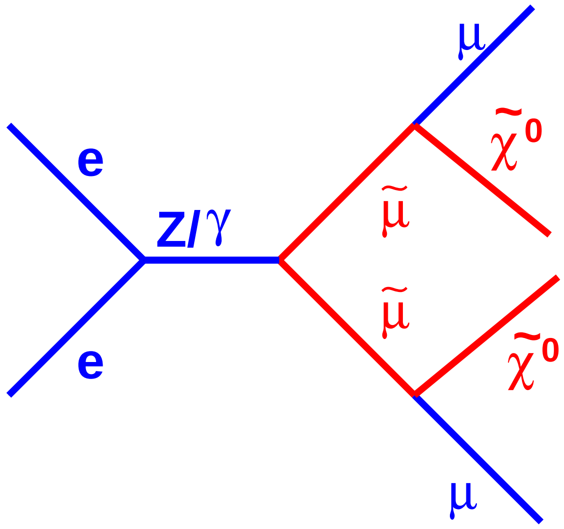
$$\Gamma_{\mathrm{inv}} < 2.8\,\mathrm{MeV} \qquad 95\%\ CL$$

RESULT ('indirect' limit):

$$m > 43\,\mathrm{GeV} \qquad 95\%\ CL$$

Smuon

PRODUCTION and DECAY:



SIGNATURE:

Two acollinear muons

BACKGROUNDS:

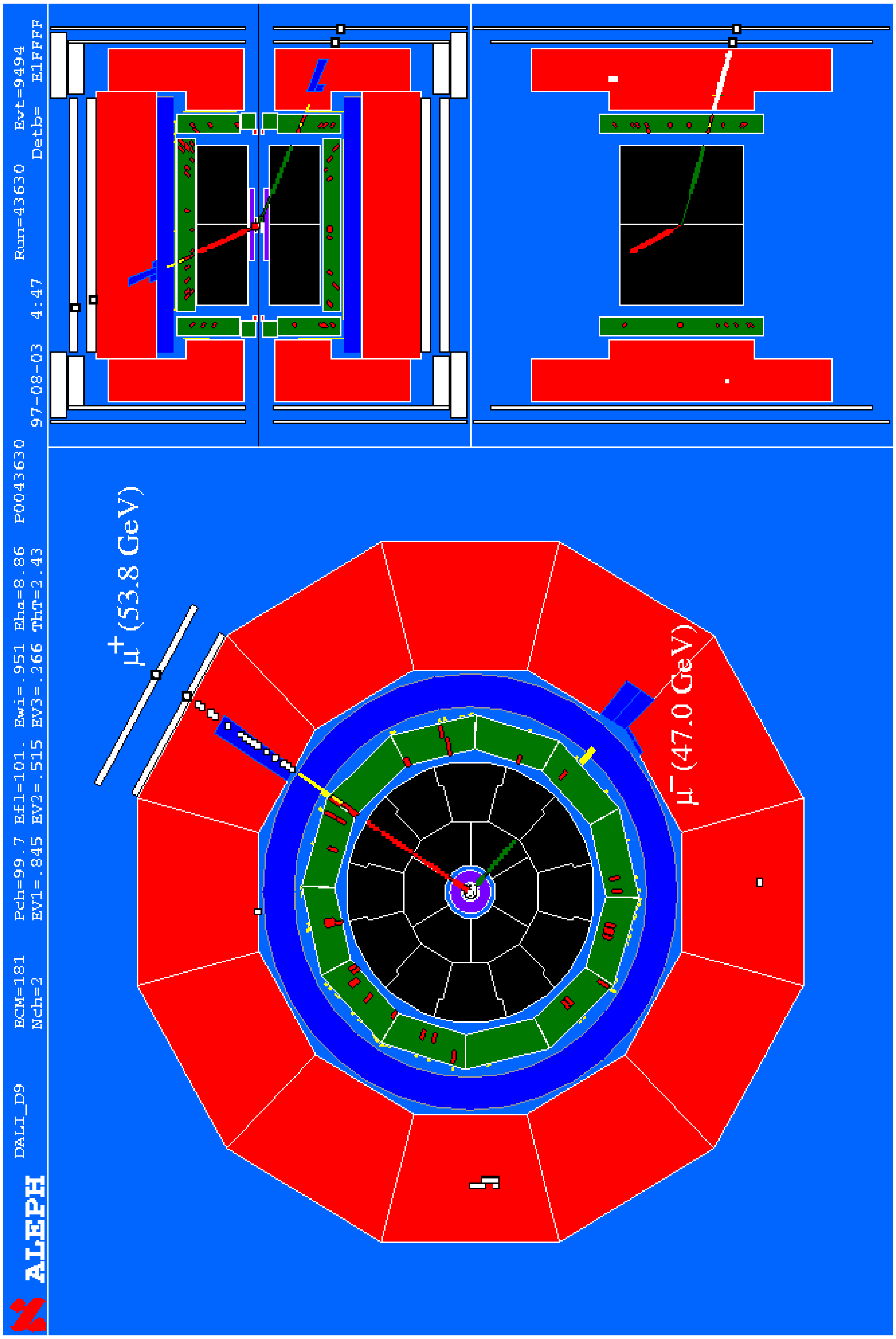
'two photon': $e^+e^-\mu^+\mu^-$, W pairs: W^+W^- ...

REMARKS:

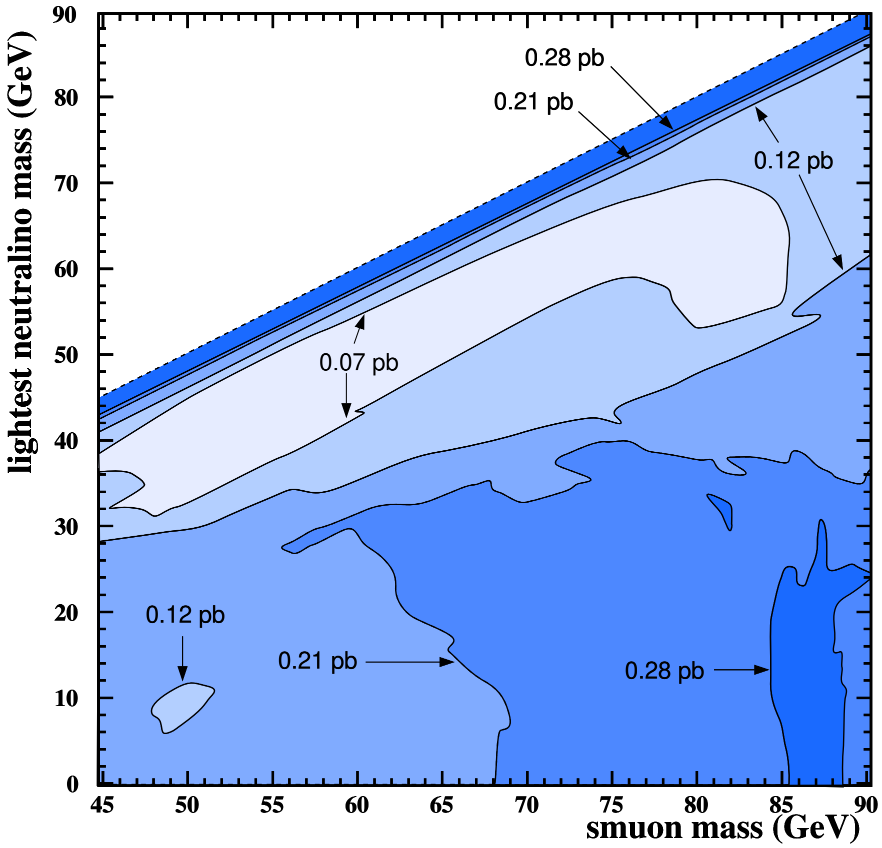
- Visible only if $\Delta m = m(\tilde{\mu}) - m(\tilde{\chi}_1^0) > \mathrm{a\ few\ GeV}$.
- Righthanded sfermions are lighter than lefthanded ones!

No signal found !

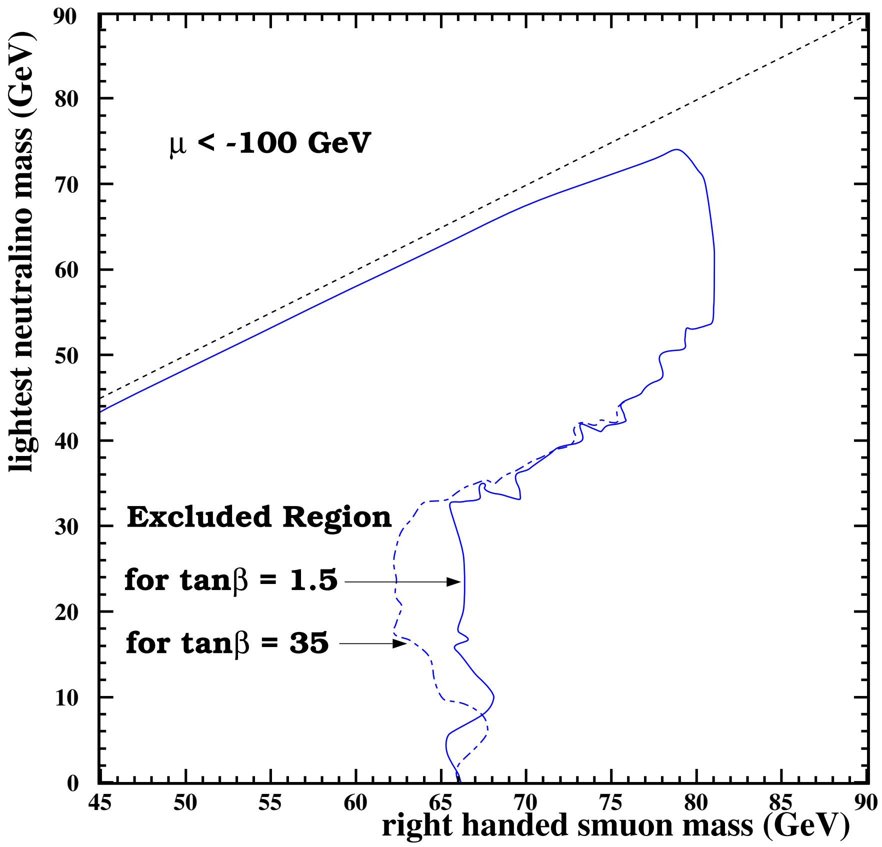
Smuon Candidate (ALEPH, $\sqrt{s}$ =181 GeV)



OPAL



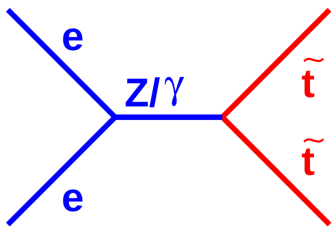
lightest neutralino mass (GeV)
smuon mass (GeV)
0.28 pb
0.21 pb
0.12 pb
0.07 pb
0.12 pb
0.21 pb
0.28 pb



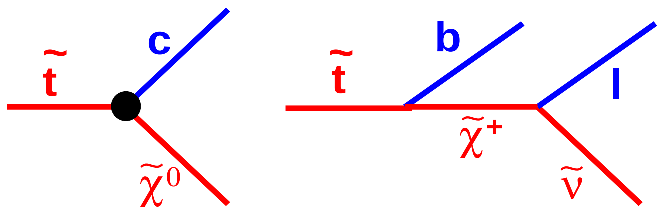
lightest neutralino mass (GeV)
right handed smuon mass (GeV)
μ < -100 GeV
Excluded Region
for tanβ = 1.5
for tanβ = 35

Stop

PRODUCTION:



DECAY:



SIGNATURE:

Two acollinear jets ($+$ leptons)

BACKGROUNDS:

'two photon': $e^+e^-q\,\bar{q}$, '4-fermion': $Z\gamma^*$ ...

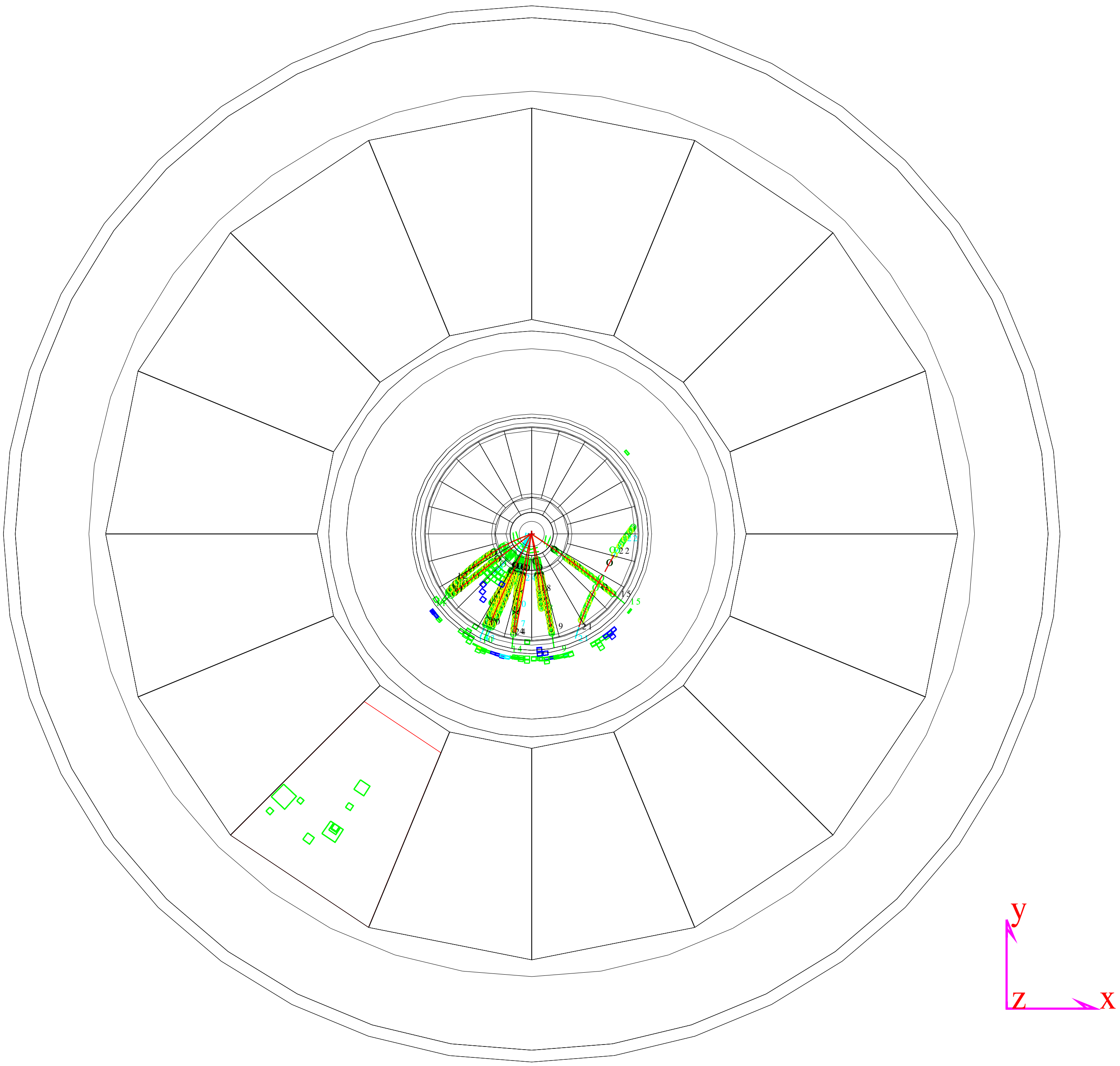
REMARKS:

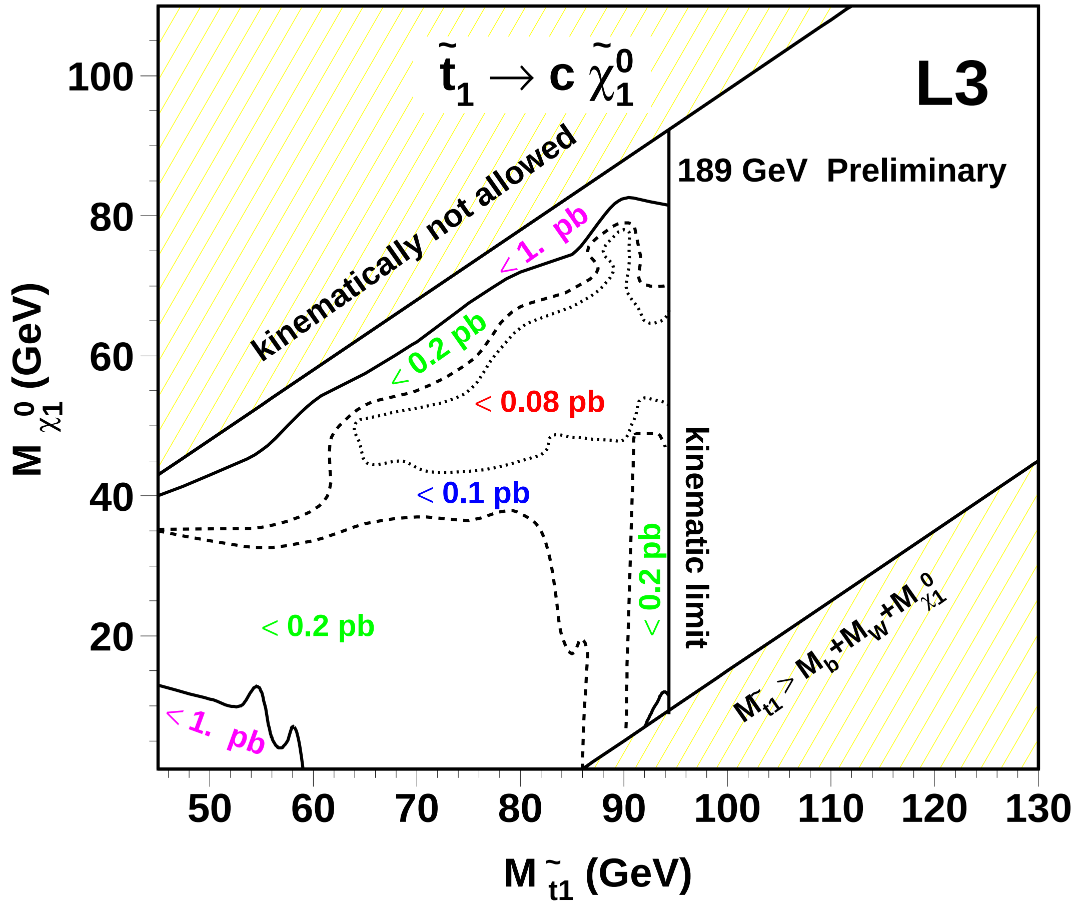
- Visible only if $\Delta m = m(\tilde{t}\,) - m(\tilde{\chi}^0_1\,,\,\tilde{\nu}) >$ a few GeV.
- Mixing: $\tilde{t}_1 = \tilde{t}_L \cos\theta_{LR} + \tilde{t}_R \sin\theta_{LR}$
  influences mass and couplings
  For $\cos\theta_{LR} = 0.57$ NO coupling to Z!

No signal found !

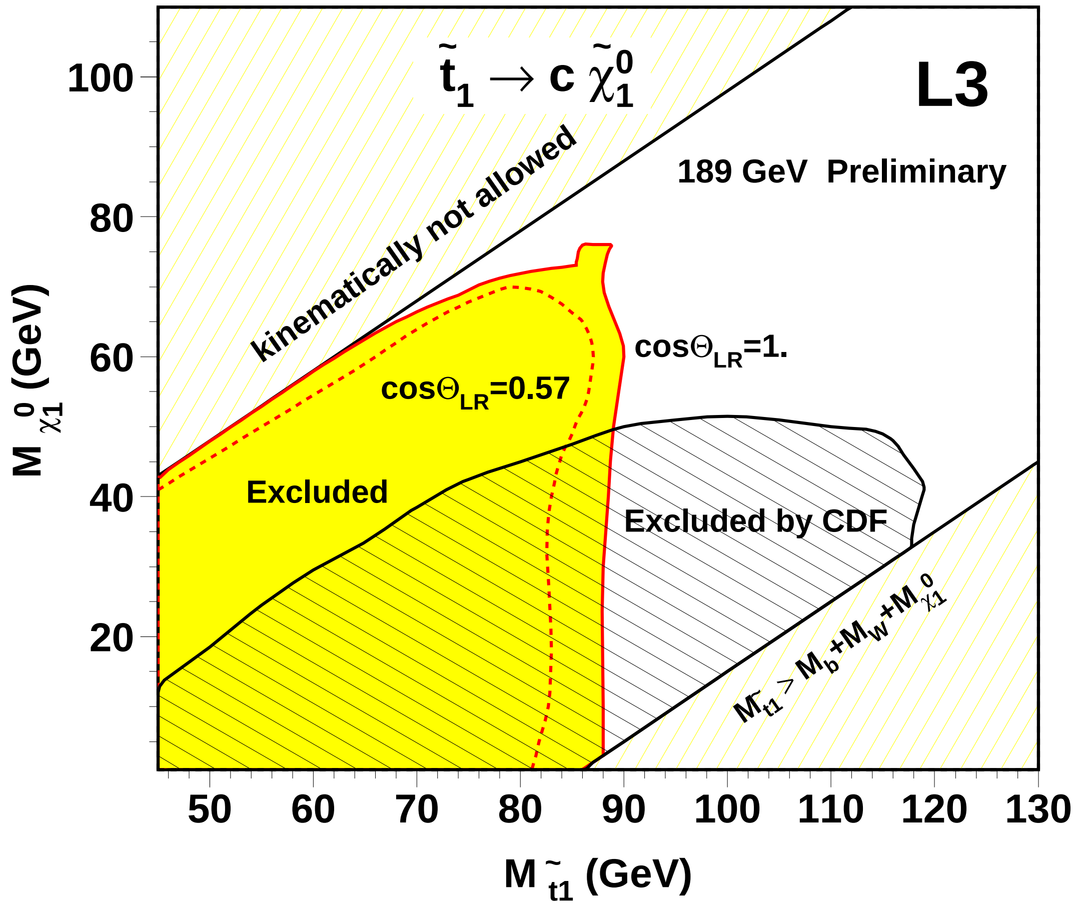
Stop Candidate (L3, $\sqrt{s}$ =183 GeV)

Run # 673109 Event # 3053 Total Energy : 30.64 GeV





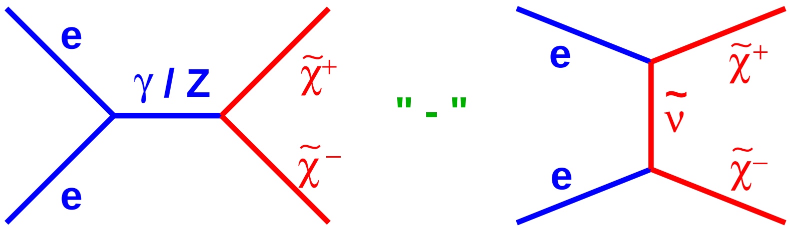
$\tilde{t}_1 \rightarrow c\ \tilde{\chi}^0_1$
L3
189 GeV Preliminary
kinematically not allowed
kinematic limit
< 1. pb
< 0.2 pb
< 0.08 pb
< 0.1 pb
< 0.2 pb
< 0.2 pb
< 1. pb
$M_{\tilde{t}1} > M_b + M_W + M_{\chi 1}^0$
$M_{\chi 1}^{0}$ (GeV)
$M_{\tilde{t}1}$ (GeV)



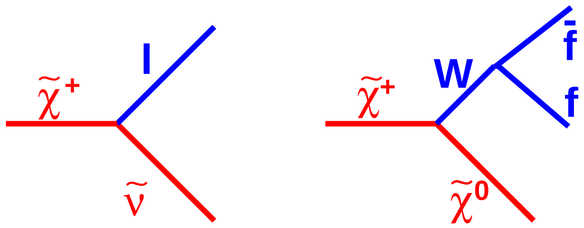
$\tilde{t}_1 \rightarrow c\ \tilde{\chi}^0_1$
L3
189 GeV Preliminary
kinematically not allowed
$\cos\Theta_{LR}$=1.
$\cos\Theta_{LR}$=0.57
Excluded
Excluded by CDF
$M_{\tilde{t}1} > M_b + M_W + M_{\chi 1}^0$
$M_{\chi 1}^{0}$ (GeV)
$M_{\tilde{t}1}$ (GeV)

Chargino

PRODUCTION:



DECAY:



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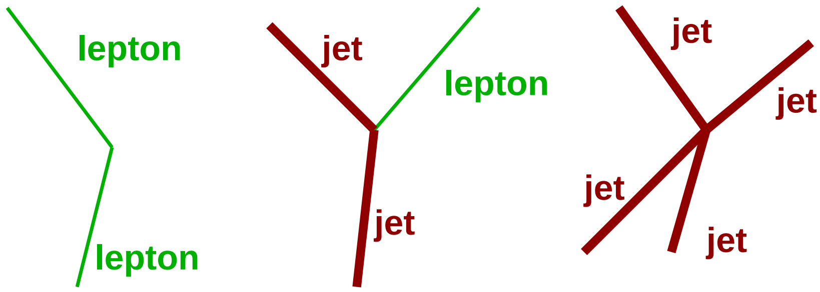


BACKGROUNDS:

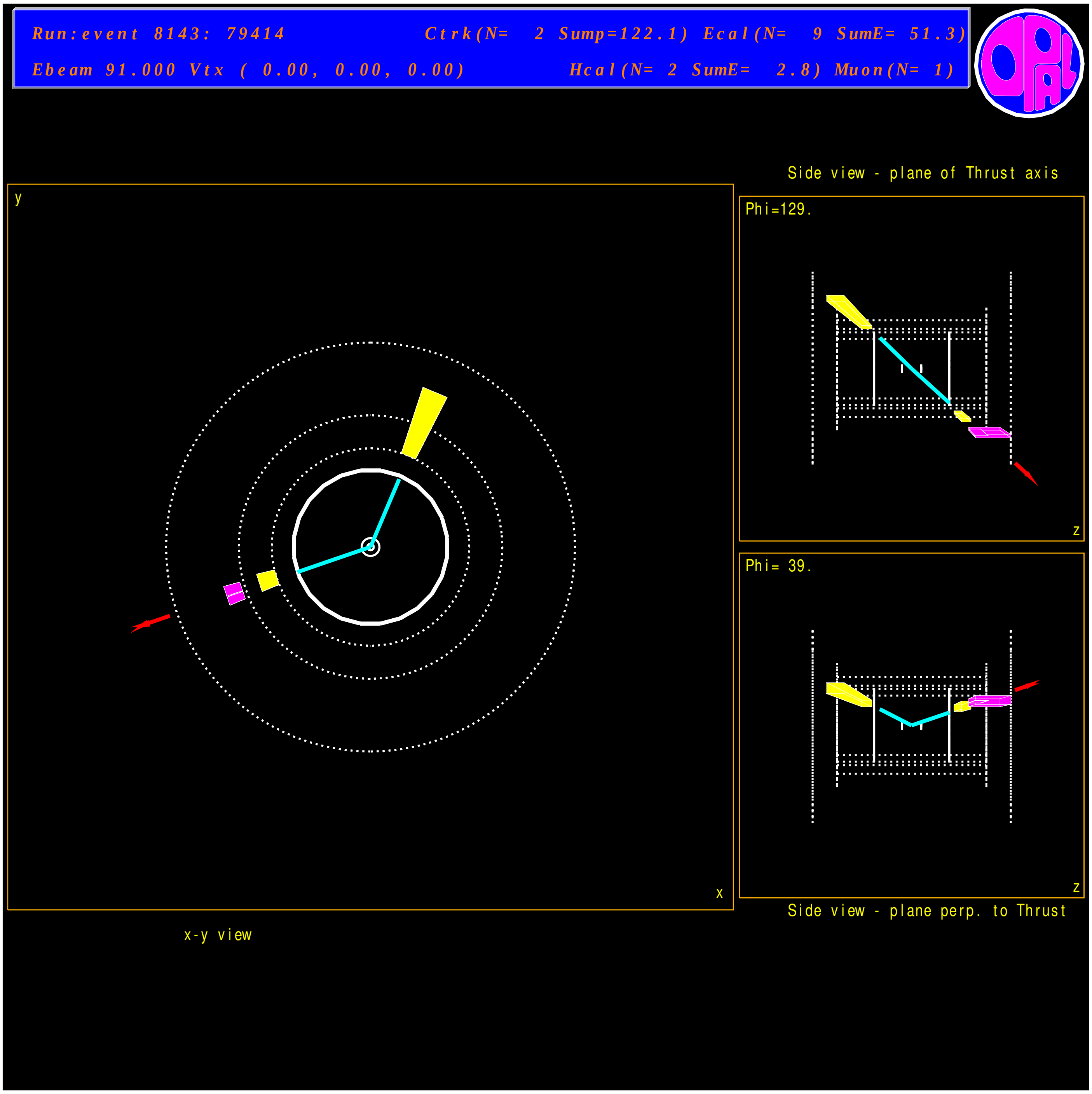
'two photon': $e^+e^- f\,\bar{f}$, '4-fermion': $W^+W^-, Z\gamma^* \ldots$

REMARK:

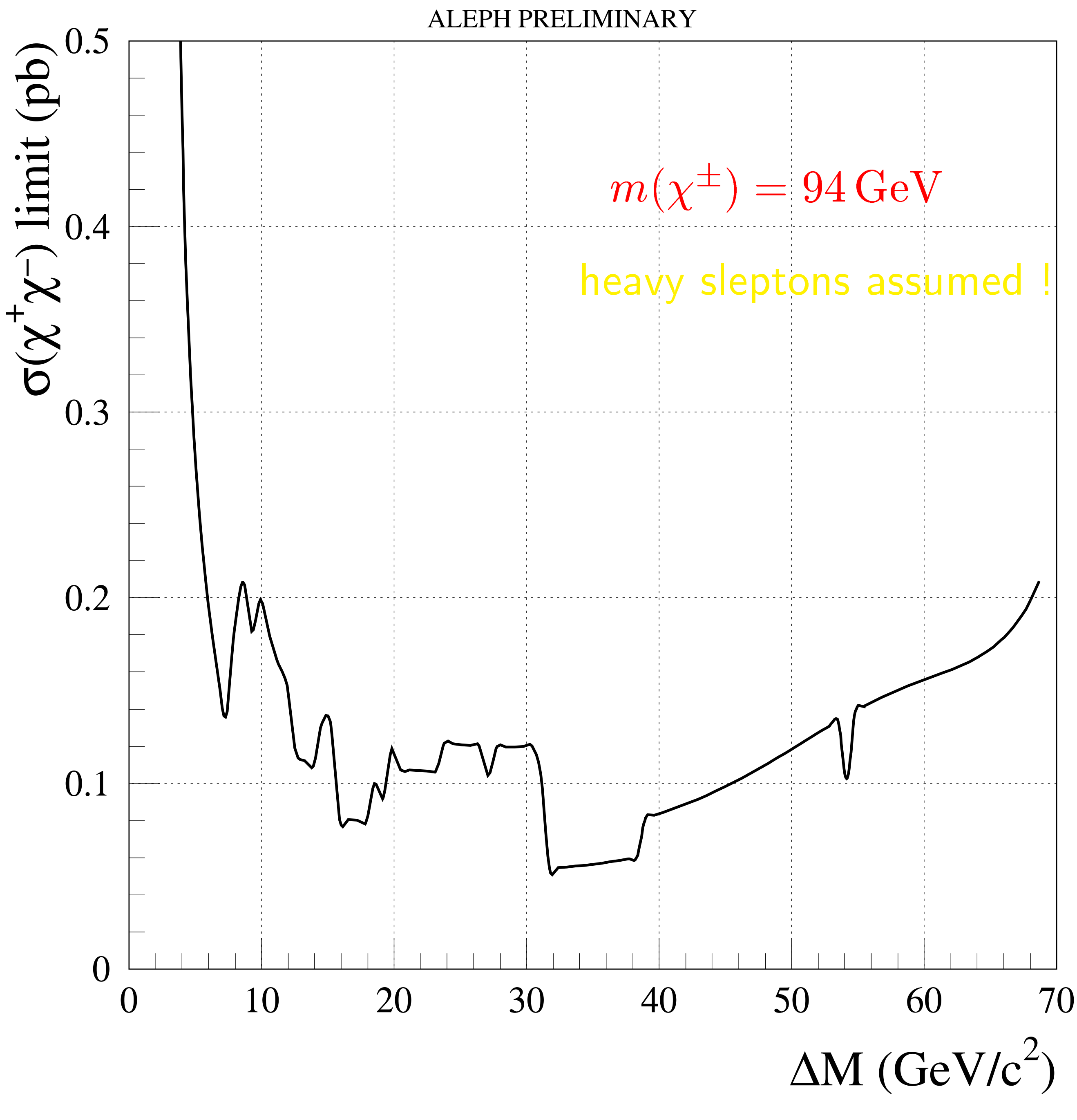
- Visible only if $\Delta m = m(\tilde{\chi}^+) - m(\tilde{\chi}^0_1) >$ a few GeV.

No signal found !

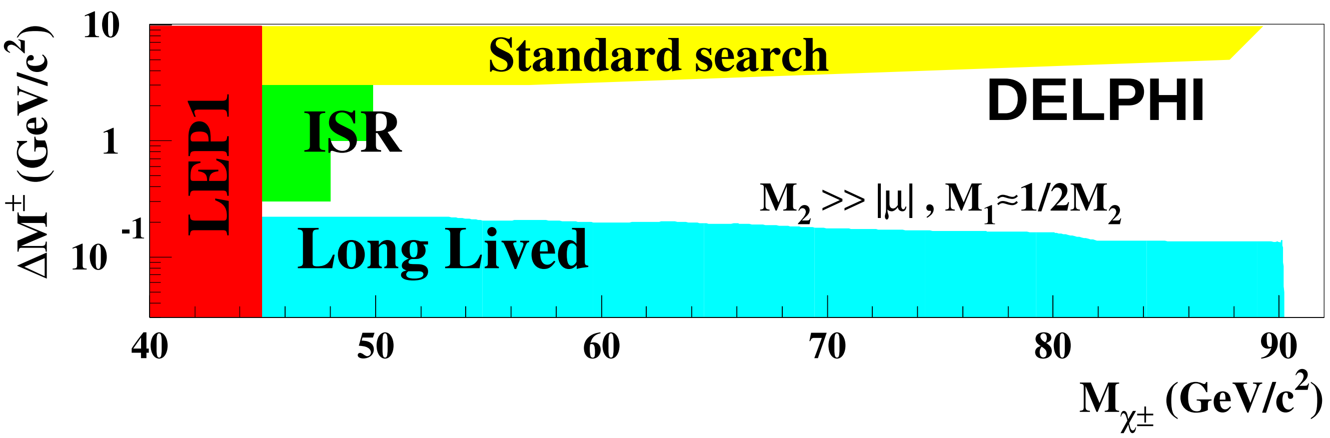
Chargino Candidate (OPAL, $\sqrt{s}$ =182 GeV)



ALEPH, $189\,\mathrm{GeV}$



Chargino Limits for small ΔM



ISR = Initial state radiation: Photon + soft particles

Long Lived = displaced vertex

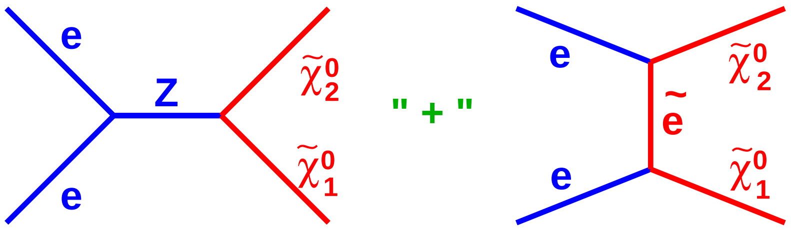
or

stable particle: highly ionizing!

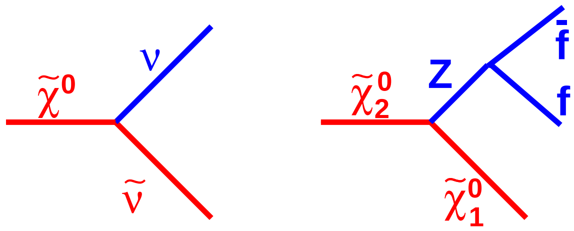
Neutralino

PRODUCTION:

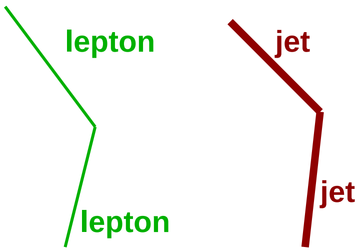
$e^+e^- \to \tilde{\chi}_1^0 \, \tilde{\chi}_1^0$ invisible!



DECAY:



SIGNATURE:



BACKGROUNDS:

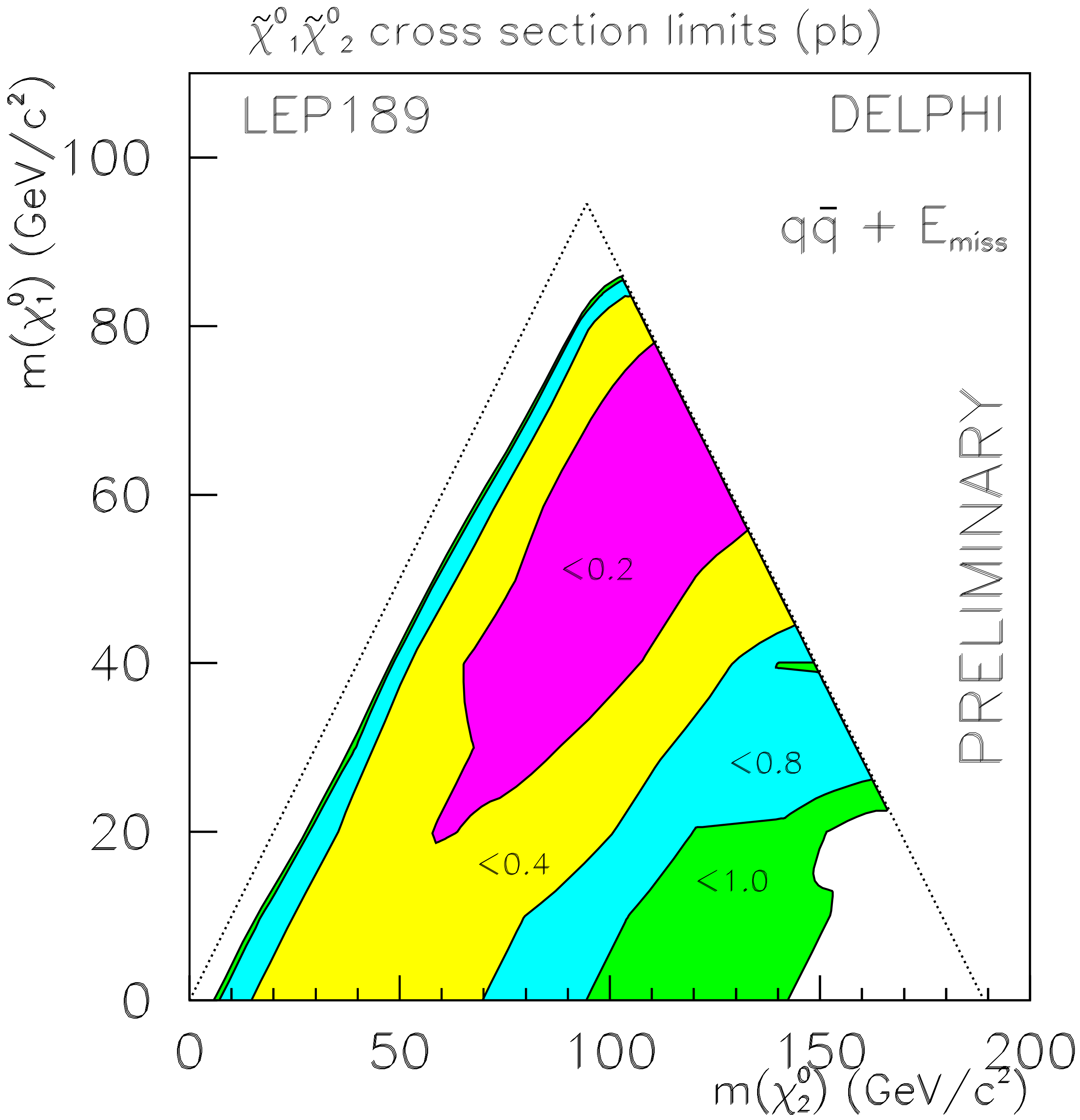
'two photon': $e^+e^- f\,\bar{f}$, '4-fermion': $ZZ, W^+W^- \ldots$

REMARK:

- Visible only if $\Delta m = m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0) >$ a few GeV.

No signal found !

DELPHI, $189\,\mathrm{GeV}$

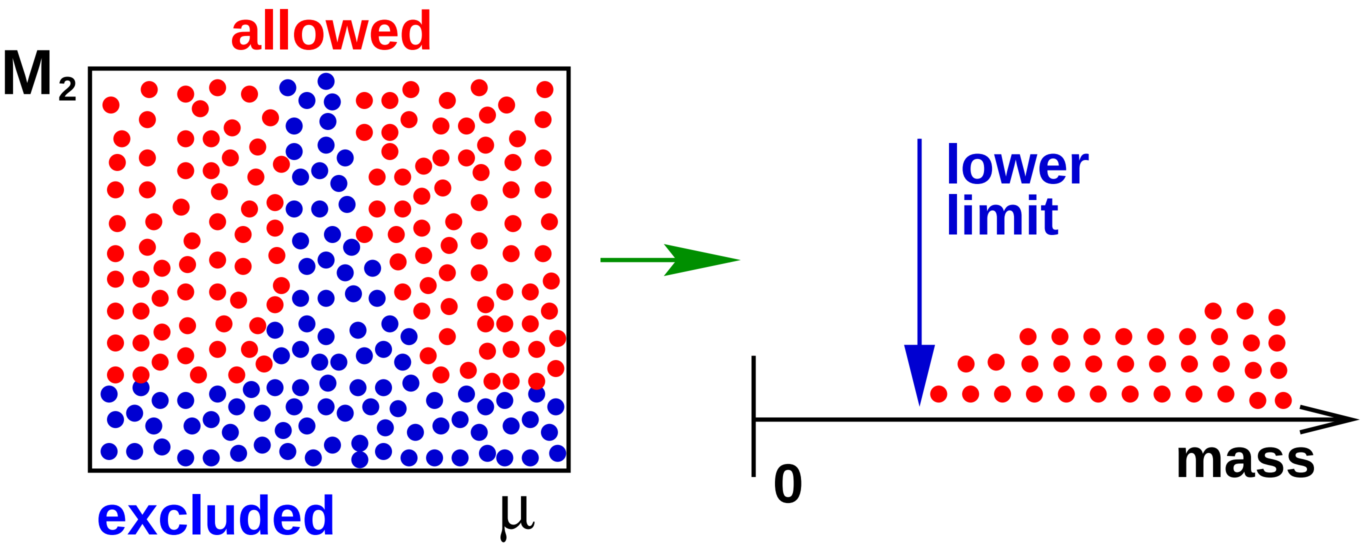


assuming $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + \mathrm{q}\,\bar{\mathrm{q}}$

How to obtain MSSM-6 Limits ?

- Search and calculate experimental limits on xsections, branching fractions . . .

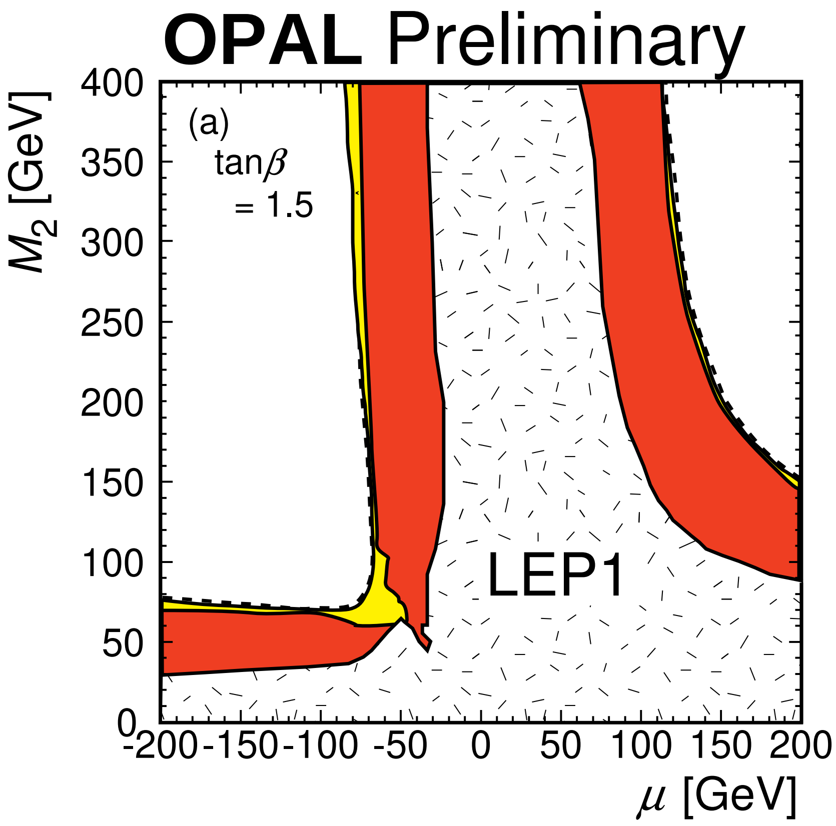
- Calculate excluded SUSY parameter $(M_2, \tan\beta \ldots)$ regions:
  For a given point compare MSSM xsections etc. to the experimental limits.



- Determine sparticle mass limits:
  Scan through allowed subspace of 6-dim SUSY parameter space and calculate mass values
  $\rightarrow$ lower mass limit

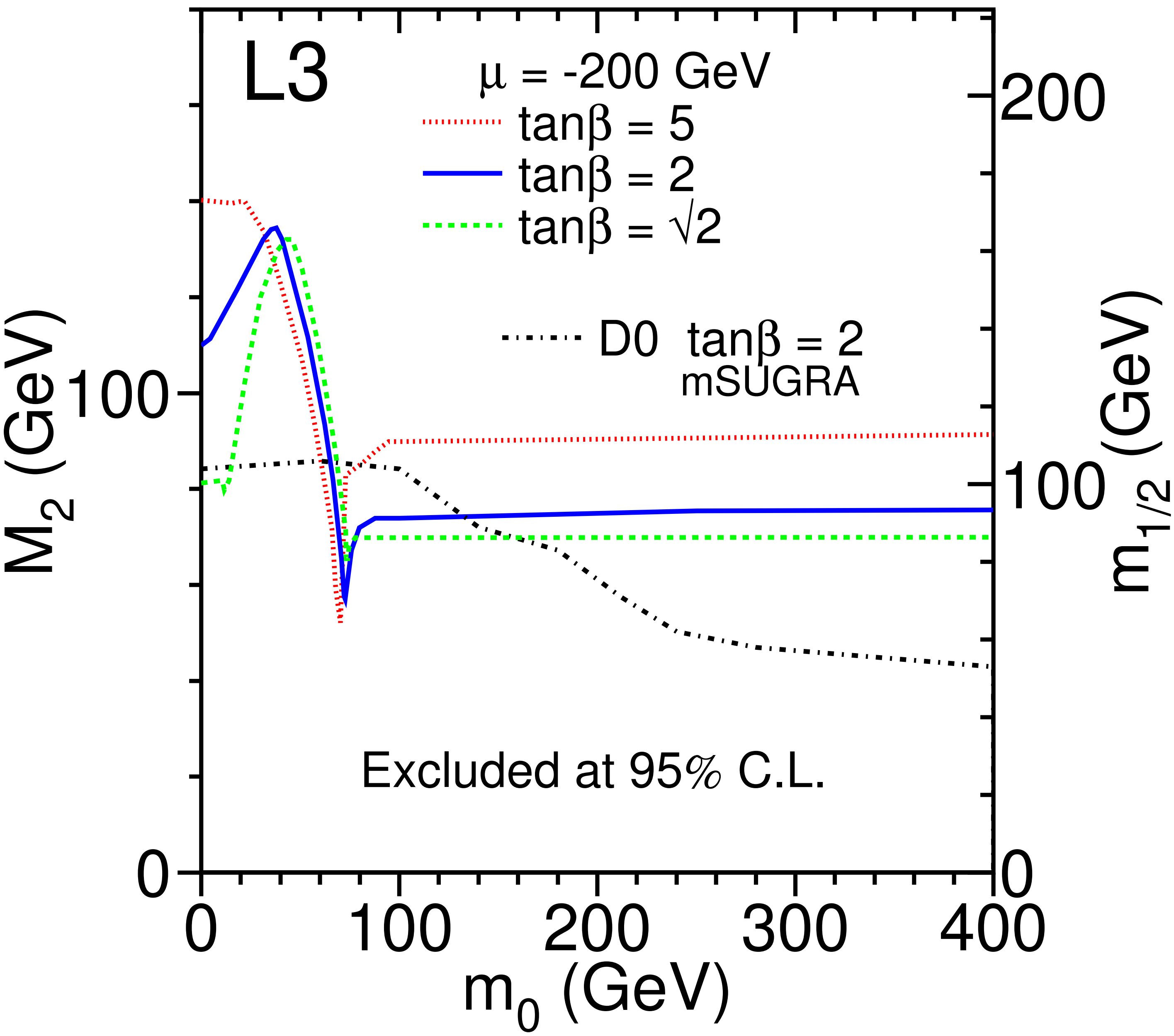
  Note: limit in general better than from direct search in the corresponding channel!

MSSM-6 Limits



$m_0 > 500\,\mathrm{GeV}$ any m_0

MSSM-6 Limits



MSSM-6 Mass Limits

All limits 'unconditional' !, CL $= 95\%$

- Sneutrino $\tilde{\nu}$

$$m > 43\,\mathrm{GeV}$$

- Neutralino χ_1^0

$$m > 32.5\,\mathrm{GeV} \qquad (L3, prel.)$$

- Charged Slepton $\tilde{e}_R, \tilde{\mu}_R, (\tilde{\tau}_R)$

$$m > 41\,\mathrm{GeV}$$

- Chargino $\chi_1^{\pm}$

$$m > 67.7\,\mathrm{GeV} \qquad (L3, prel.)$$

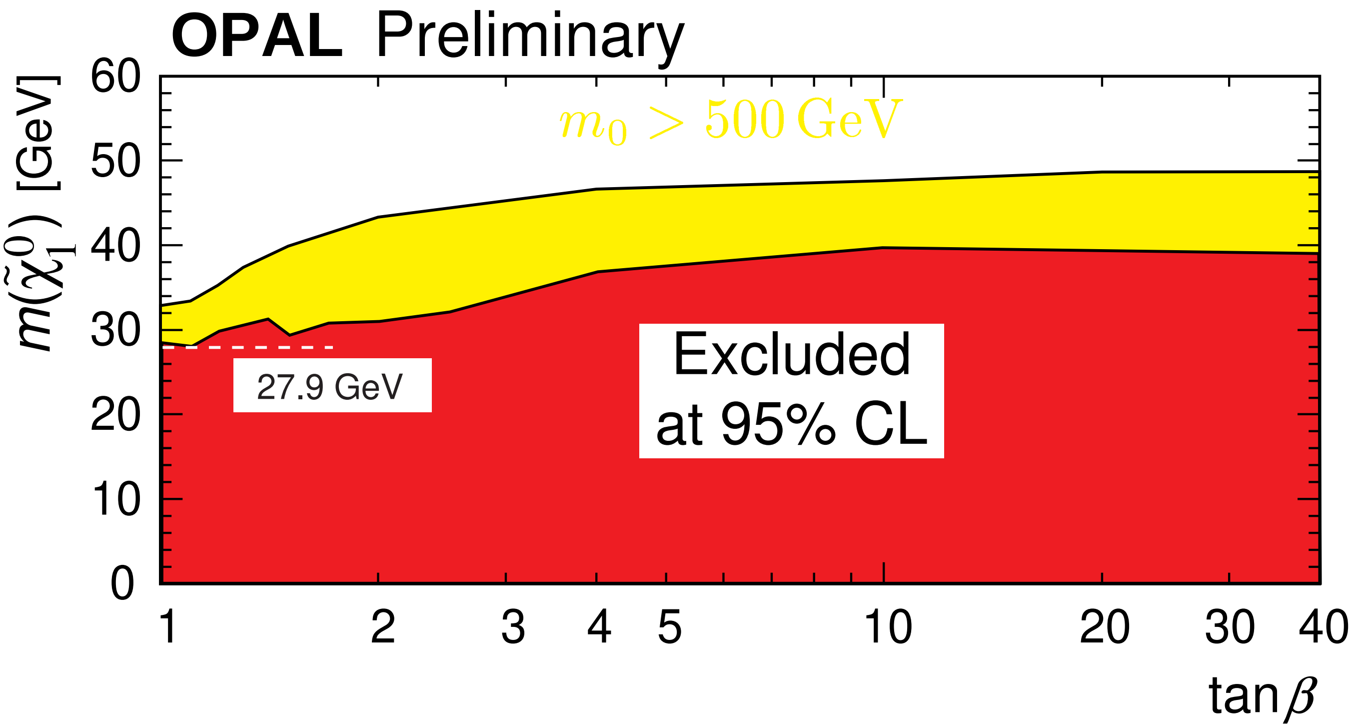
$$\boxed{m(LSP) > 32.5\,\mathrm{GeV}}$$

??? MSSM-6 parameter space fully investigated ????

Preliminary Gaugino Mass Limits

95% CL

Neutralino:



Aleph	32.3 GeV
Delphi	31.2 GeV
L3	32.5 GeV
Opal	27.9 GeV

Chargino ($M_2 < 2\,\mathrm{TeV}$):

L3	67.7 GeV
Opal	65.1 GeV

Conclusions

- SUSY particles have been searched for intensively at LEP I and LEP II
- Nothing was found yet
- Limits on SUSY parameters, sparticle masses and cross sections have been set
  MSSM-6: LSP mass $> 32.5\,\mathrm{GeV}$ (prel.)
- The hunt continues:
  2 more years of data at $\approx 200\,\mathrm{GeV}$ ...