Experimental SUSY Program at Linear e^+e^- Colliders

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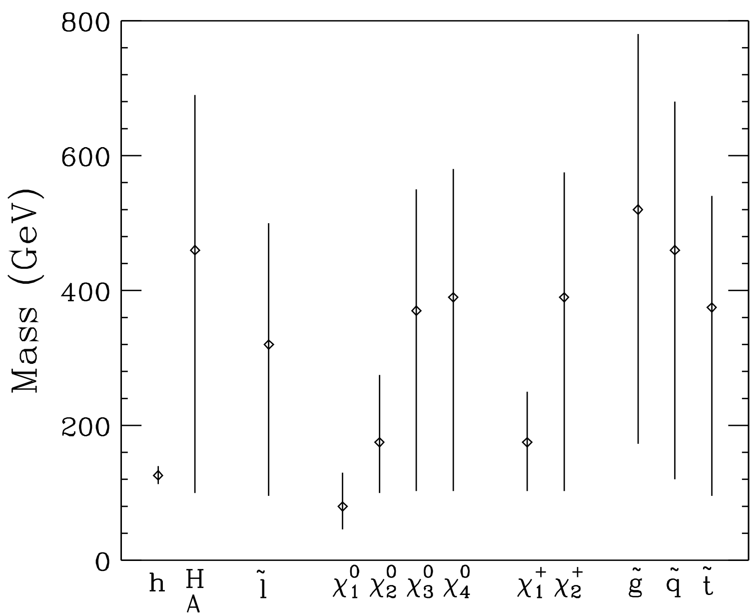
- **Introduction**
- **Experimental Aspects of LC's for SUSY**
- **Measurement of Masses, Cross Sections, Properties**
- **Alternative SSB signatures**
- **Extrapolation to high scales**
- **Conclusion**

Introduction

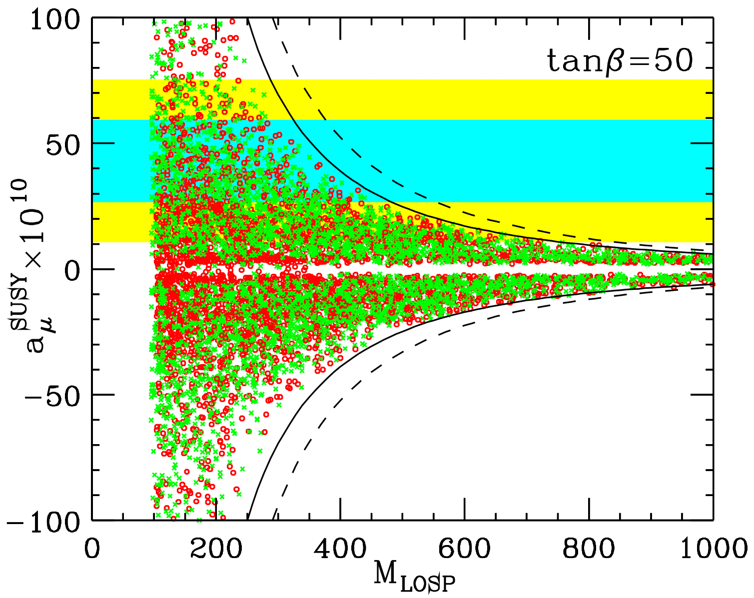
- Low scale supersymmetry gold plated candidate for new physics
- $\longrightarrow$ hierarchy problem solved
- $\longrightarrow$ clear path to grand unification
- $\longrightarrow$ Planck scale models naturally are suspersymmetric

Excellent chance to see SUSY partners at early (500 GeV) stage of LC project

”naturalness”



experimental hints, e.g. $(g-2)_\mu$



Supersymmetry - LC program

- **Precision measurement of the properties of the accessible part of spectrum:**

  $\longrightarrow$ **Sleptons**

  $\longrightarrow$ **Gauginos**

  $\longrightarrow$ **Scalar top quarks**

  $\longrightarrow$ **SUSY nature of Higgs(es)**

- **Ensure sensitivity in various SSB scenarios (mSUGRA,GMBS,AMSB)**

  $\longrightarrow$ **lifetime, kinks, long-lived particles, non-pointing photons**

- **Finally: what's going on at the GUT scale?**

  $\longrightarrow$ **SUSY-RGE's tell the truth!**

Experimental Aspects

- Beam Polarisation: ($\longrightarrow$ G. Moortgat-Pick)
  - control large WW background
  - distentangle states
- mass measurement from spectra
  - excellent tracking/calorimeter resolution
- threshold scans
  - control beam energy/spread, beamstrahlung
- Missing energy signals
  - hermeticity down to low angles
- lifetime:
  - charged secondaries: secondary vertices, energy loss measurement
  - neutral secondaries: highly granular calorimeter as ’photon vertex detector’

Sleptons

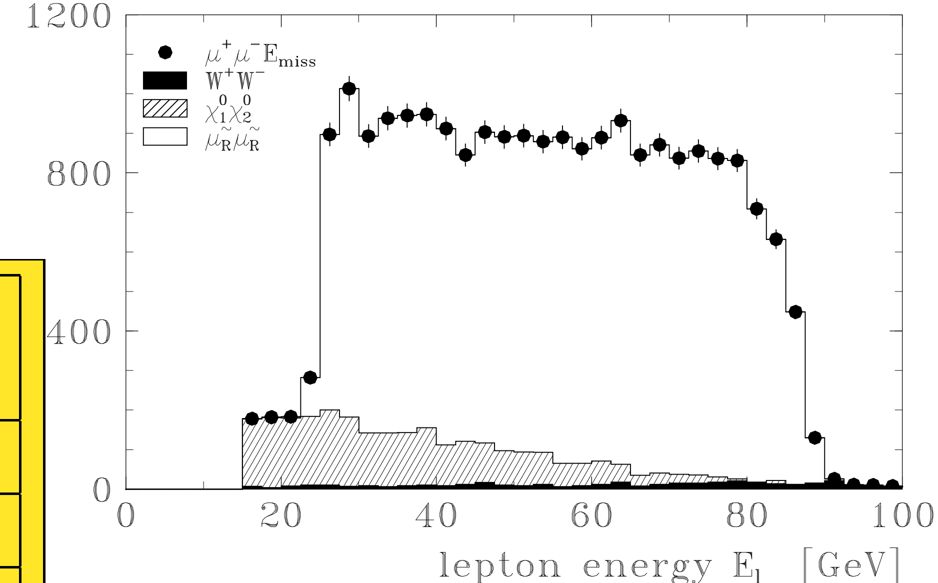
e.g. $e^+e^- \rightarrow \tilde{\mu}_R\tilde{\mu}_R$
$\rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$

large rates

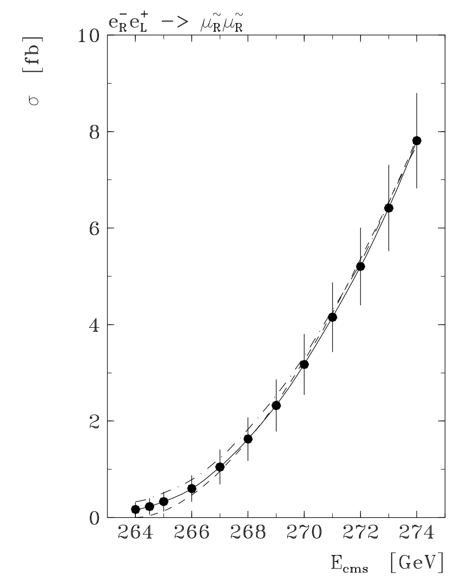
tiny background (mainly SUSY)

slepton	m GeV	Δ m$_{cont}$ GeV	Δ m$_{scan}$ GeV
$\tilde{\mu}_R$	132.0	0.3	0.09
$\tilde{\mu}_L$	176.0	0.3	0.4
$\tilde{\nu}_\mu$	160.6	0.2	0.8
$\tilde{e}_R$	132.0	0.2	0.05
$\tilde{e}_L$	176.0	0.3	0.18
$\tilde{\nu}_e$	160.6	0.2	0.07
$\tilde{\tau}_1$	131.0		0.6
$\tilde{\tau}_2$	177.0		0.6
$\tilde{\nu}_\tau$	160.6		0.6

Masses of $\tilde{\chi}_1^0$ and $\tilde{\mu}$ from kinematic edges:



Masses from threshold scan ($10\ fb^{-1}$ /point):



Gauginos - Mass

Charginos:

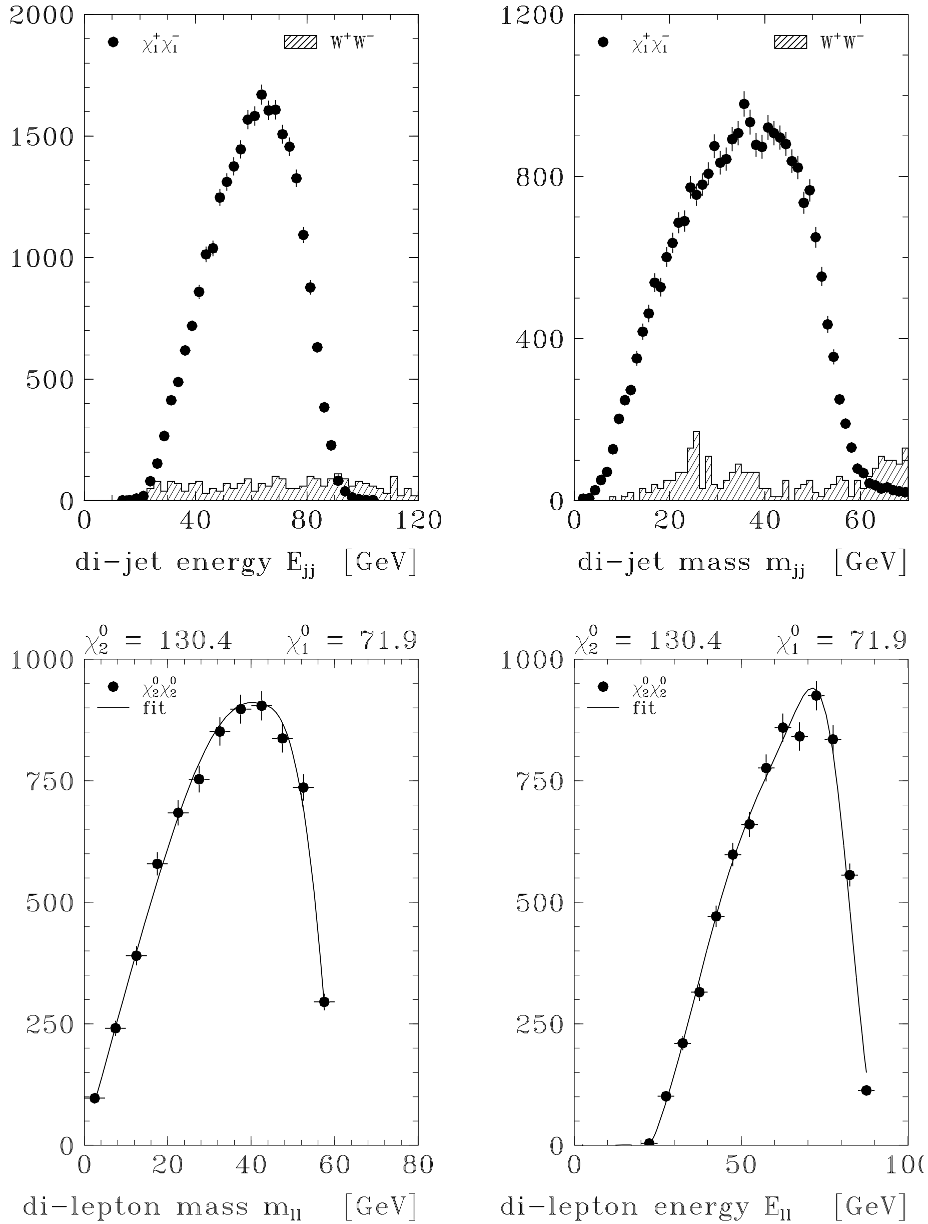
e.g. $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$

$\to 4jets + \tilde{\chi}_1^0\tilde{\chi}_1^0$

Neutralinos:

e.g. $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0$

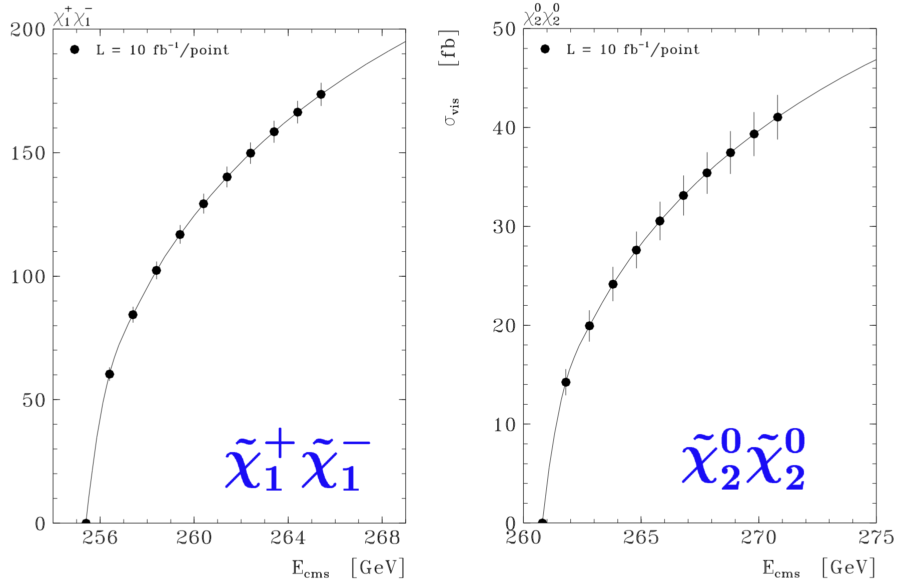
$\to 4\ell + \tilde{\chi}_1^0\tilde{\chi}_1^0$



Gauginos - Mass Scan

or from

threshold scan:



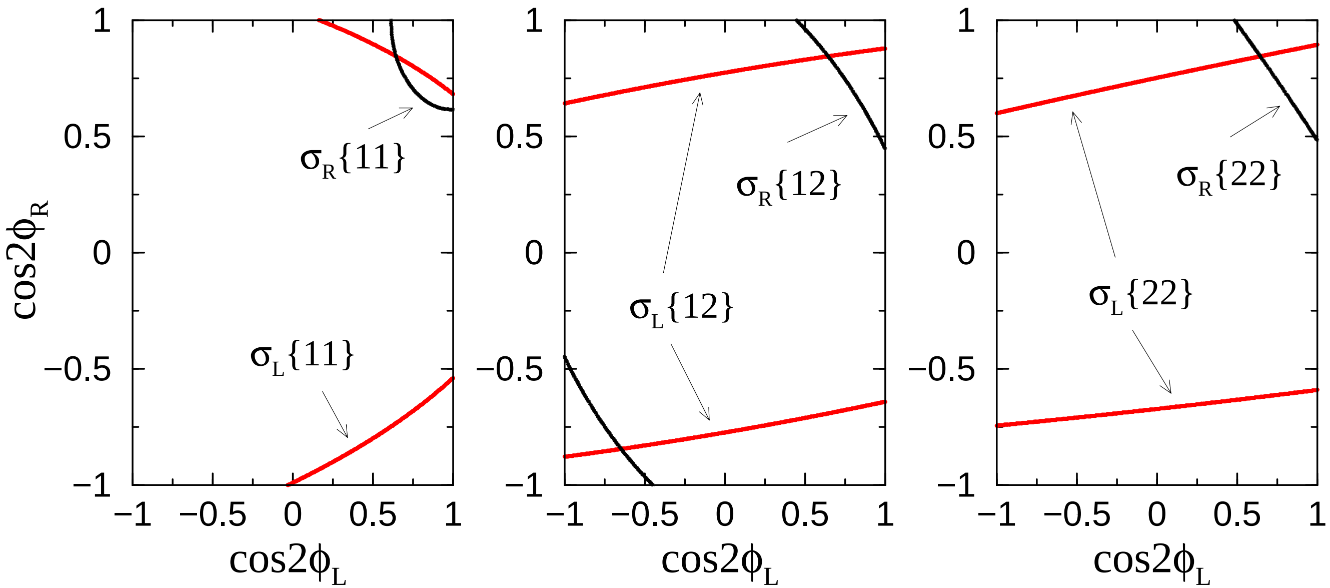
gaugino	m GeV	Δ m_c GeV	Δ m_s GeV
$\tilde{\chi}_1^\pm$	127.7	0.2	0.04
$\tilde{\chi}_2^\pm$	345.8		0.25
$\tilde{\chi}_1^0$	71.9	0.1	0.05
$\tilde{\chi}_2^0$	130.3	0.3	0.07
$\tilde{\chi}_3^0$	319.8		0.30
$\tilde{\chi}_4^0$	348.2		0.52

Chargino - Properties

Disentangle Wino/Higgsino admixture of Charginos:

$$\mathcal{M}_C = \begin{pmatrix} M_2 & \sqrt{2}\, m_W \cos\beta \\ \sqrt{2}\, m_W \sin\beta & \mu \end{pmatrix} \Rightarrow \text{2 mixing angles } \Phi_R, \Phi_L$$

μ, M_2 and (moderate) $\tan\beta$ can be uniquely determined with polarisation:



	input 1	fit	input 2	fit
M_2	152 GeV	152 $\pm$ 1.8 GeV	150 GeV	150 $\pm$ 1.2 GeV
μ	316 GeV	316 $\pm$ 0.9 GeV	263 GeV	263 $\pm$ 0.7 GeV
$\tan\beta$	3	3 $\pm$ 0.7	30	$>$ 20

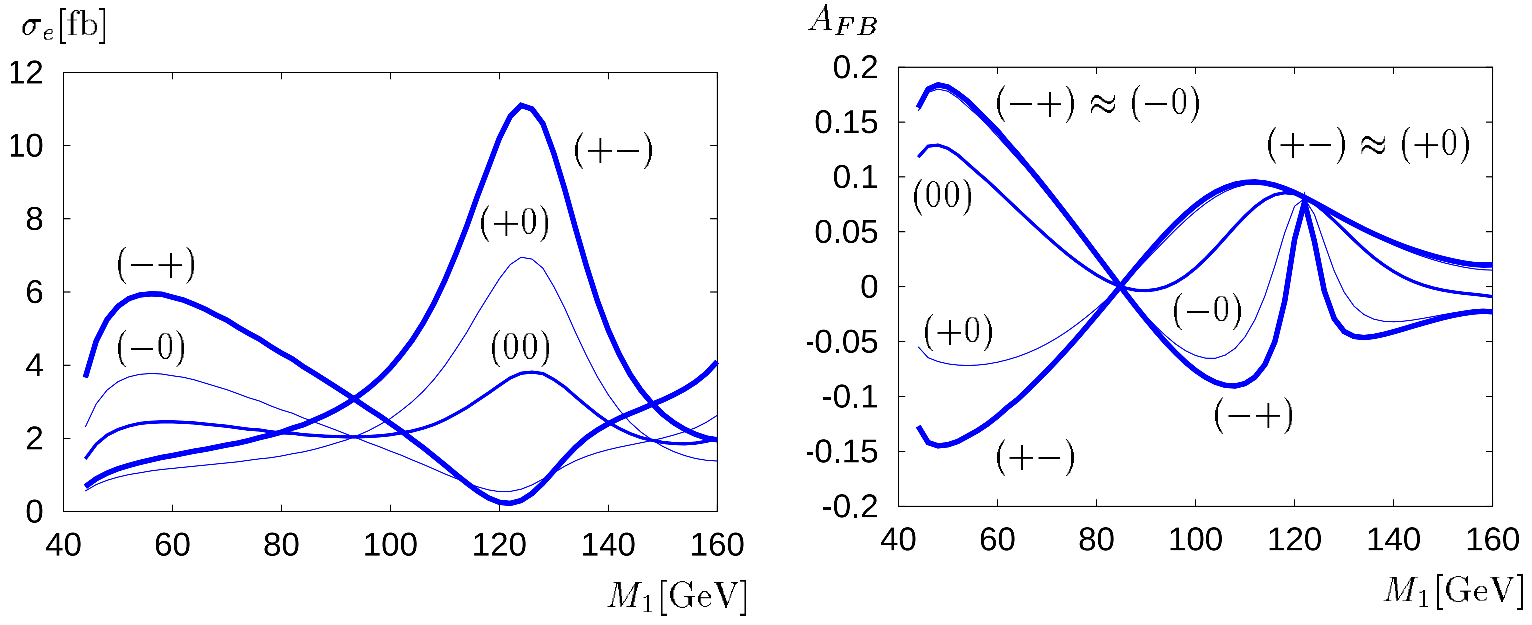
Neutralino - Properties

Neutralino system depends also on M_1 (in addition to M_2, μ, $\tan\beta$)

Exploit spin correlation in two lepton final state from

$e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_1 \to \ell^+\ell^-\tilde{\chi}^0_1\tilde{\chi}^0_1$

beam polarisation essential!



	input 1	fit	input 2	fit
M_1	78.7 GeV	78.7 $\pm$ 0.7 GeV	78.0 GeV	78.0 $\pm$ 0.4 GeV

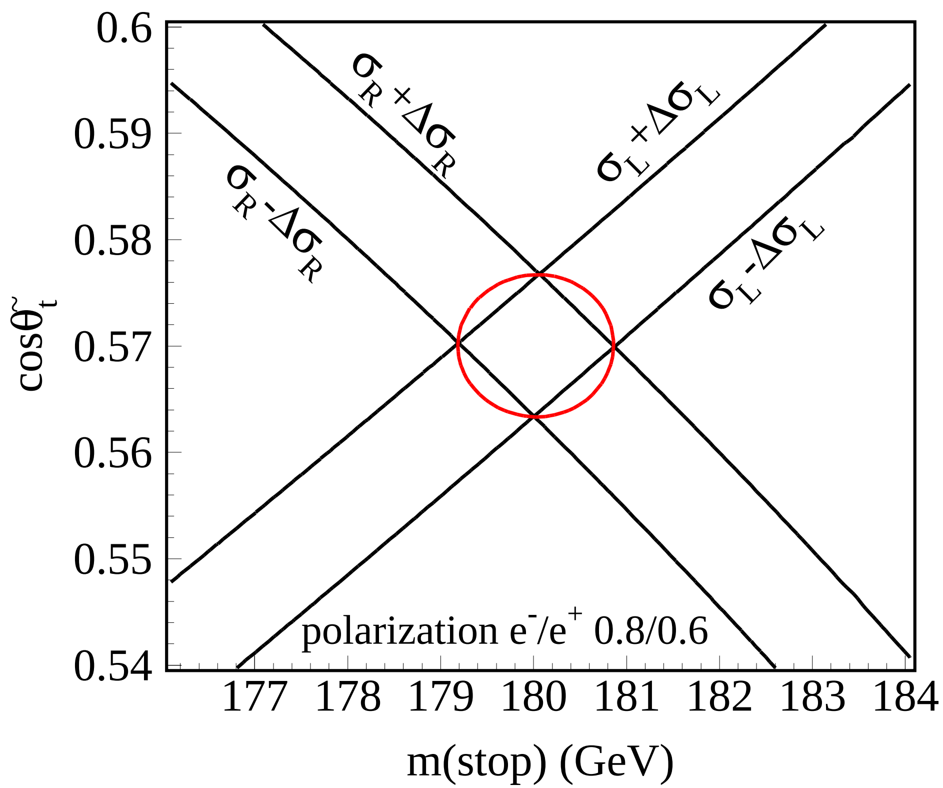
Scalar Top

Large mixing of $\tilde{t}_R$ and $\tilde{t}_L$ $\Rightarrow$ large mass splitting possible

$e^+e^- \to \tilde{t}_1\tilde{t}_1$ with $\tilde{t}_1 \to \tilde{\chi}_1^0 c$ and $\tilde{t}_1 \to \tilde{\chi}_1^+ b$ studied.

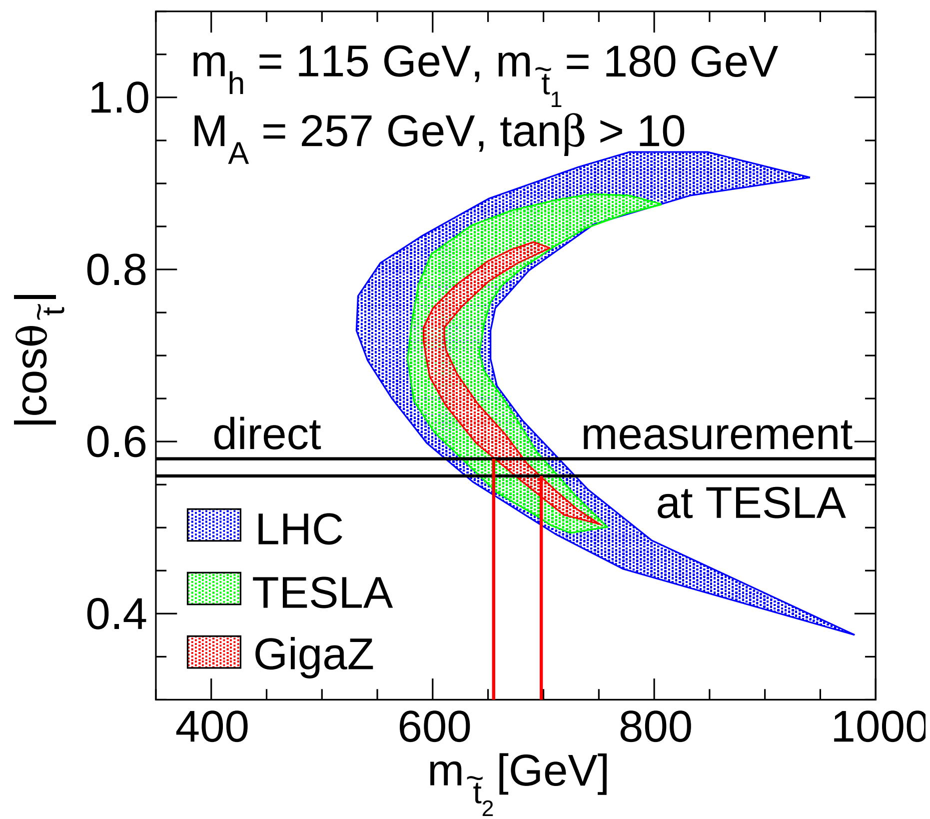
LR-asymmetry provides

Mass and mixing angle:



Precision measurements of EW observables

yield $m_{\tilde{t}_2}$ or provide consistency check:



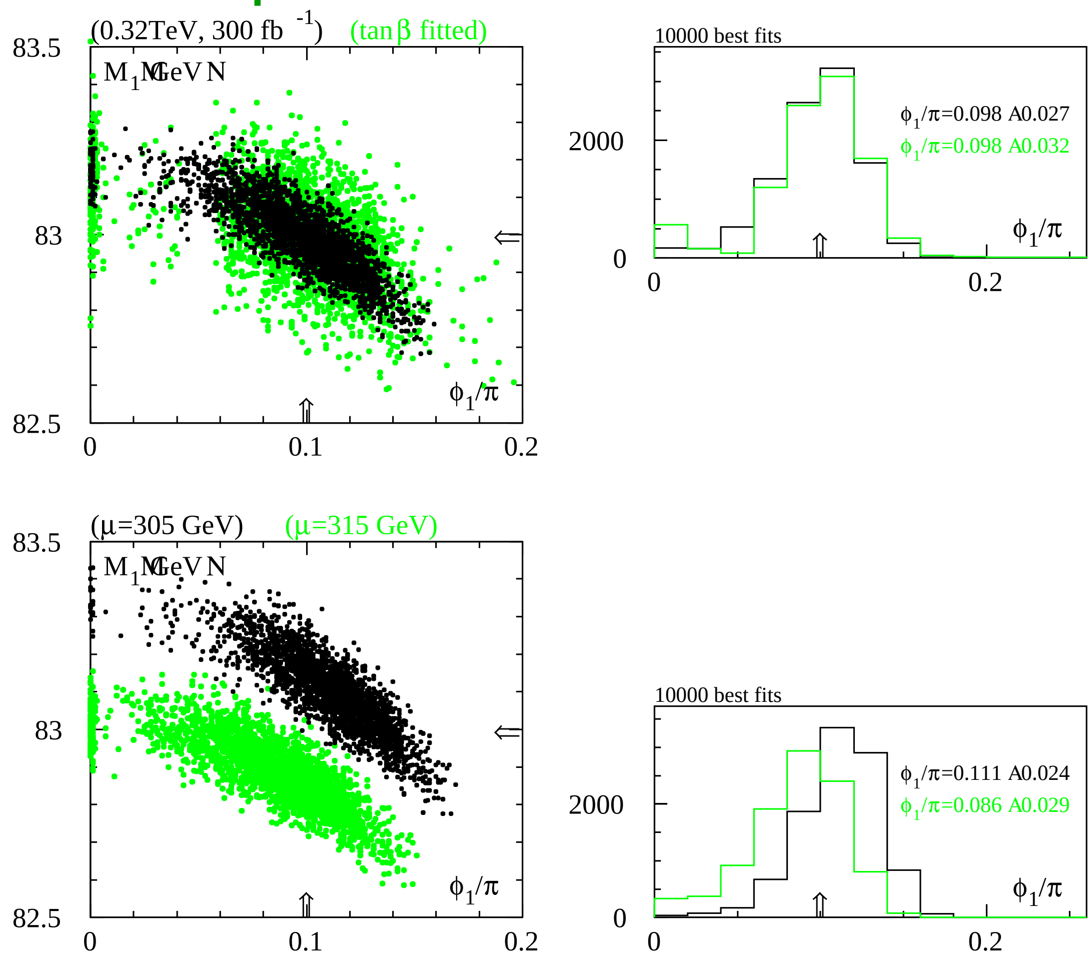
CP Violation

SUSY mass parameters may be complex $\Rightarrow$ CP-violationg phases:

$$\mu = |\mu| e^{i\phi_\mu}, M_1 = |M_1| e^{i\phi_1}$$

Phases affect various observables: $\sigma(\tilde{\chi}^0_1\tilde{\chi}^0_2)$, BR($\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 e^+ e^-$), $m_{\tilde{\chi}^0_1}$ etc.

$\longrightarrow$ extract size and phases from simultaneous fit:

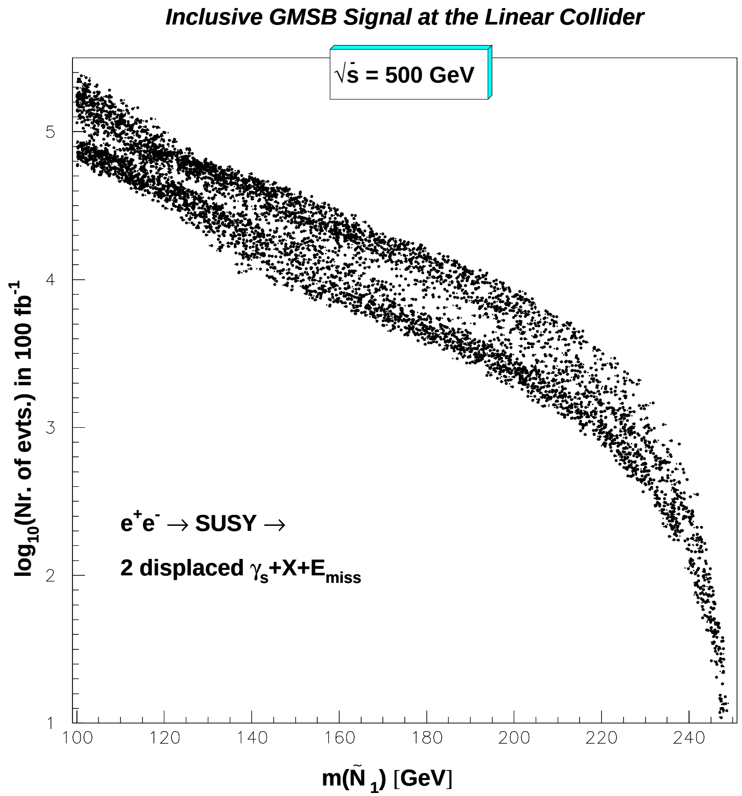


Special Signatures: GMSB

Various SUSY breaking scenarios (may) have different experimental signatures

Gauge mediated SUSY breaking (GMSB) with $\tilde{\chi}^0_1$ NLSP typically leads to delayed $\tilde{\chi}^0_1 \to \tilde{G}\gamma$ decays with displaced photons

$\Rightarrow$ demanding signature for calorimetry!



Large inclusive rate

various techniques:

sensitivity for

30μm $< c\tau <$ 40 m

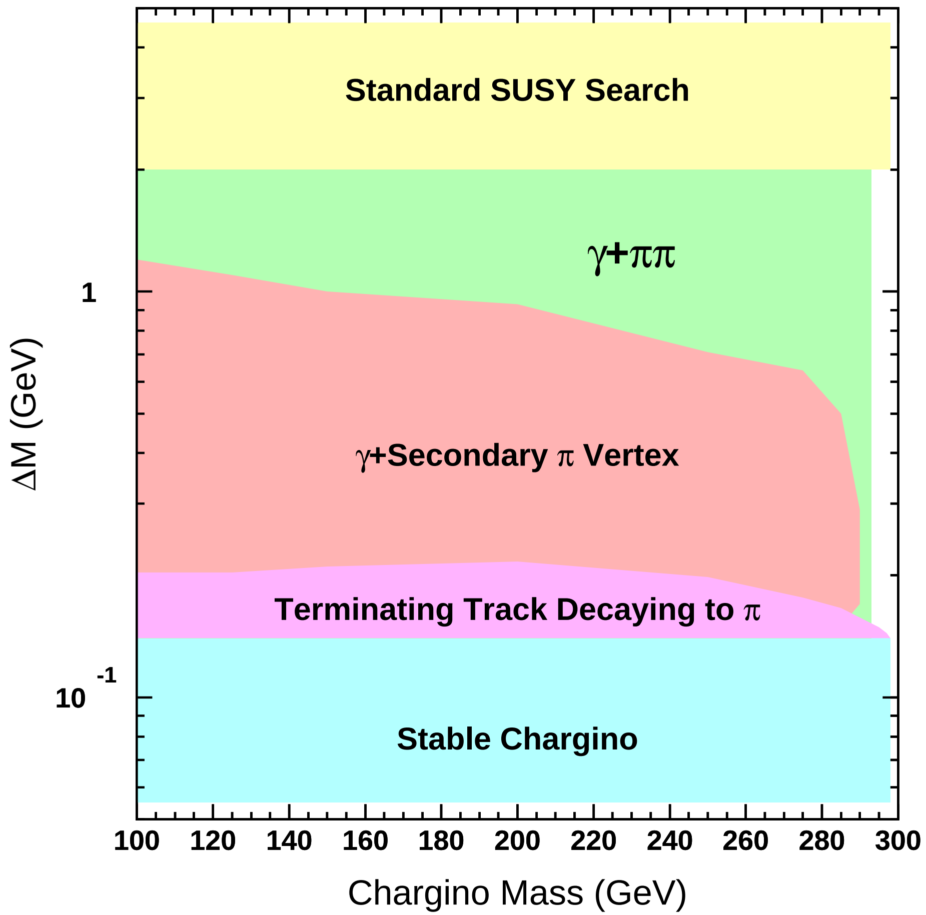
Special Signatures: AMSB

In Anomaly Mediated SUSY Breaking (AMSB) typically:

$\Delta M = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ **very small**

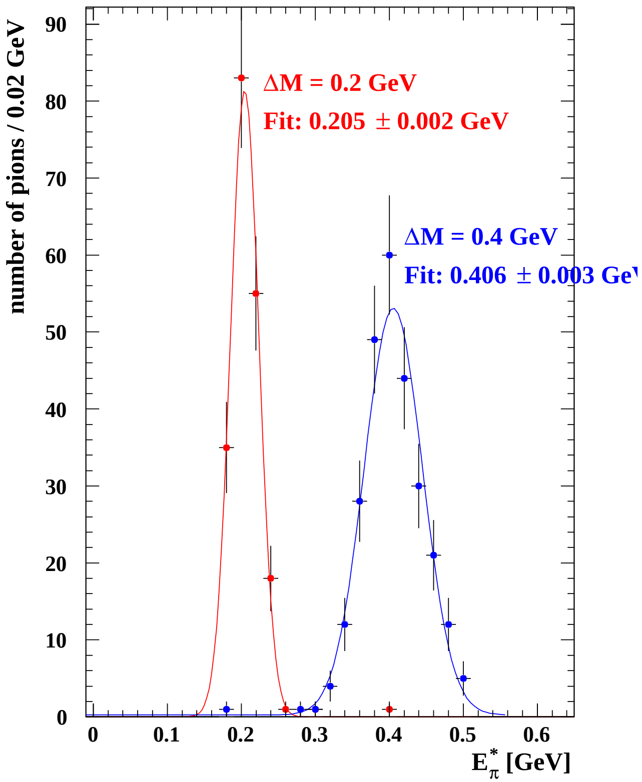
$\Rightarrow$ **various signatures and methods:**

E_{cm}=600 GeV, L=50 fb^{-1}



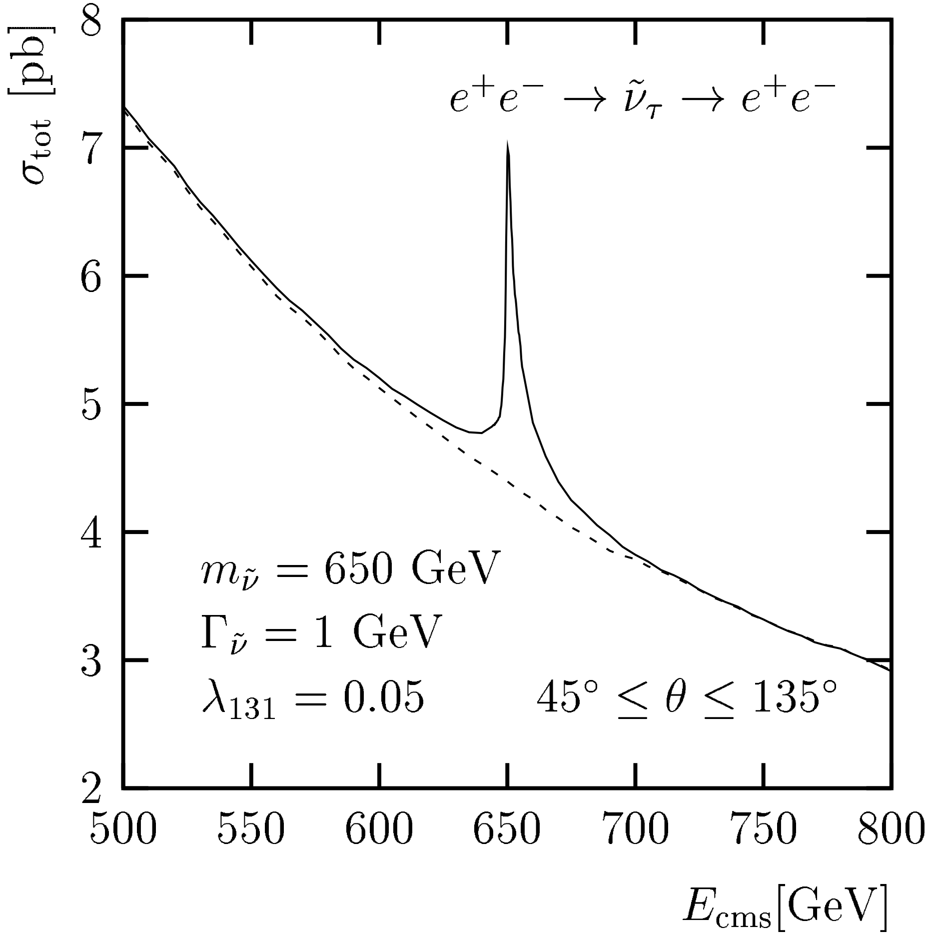
Example:

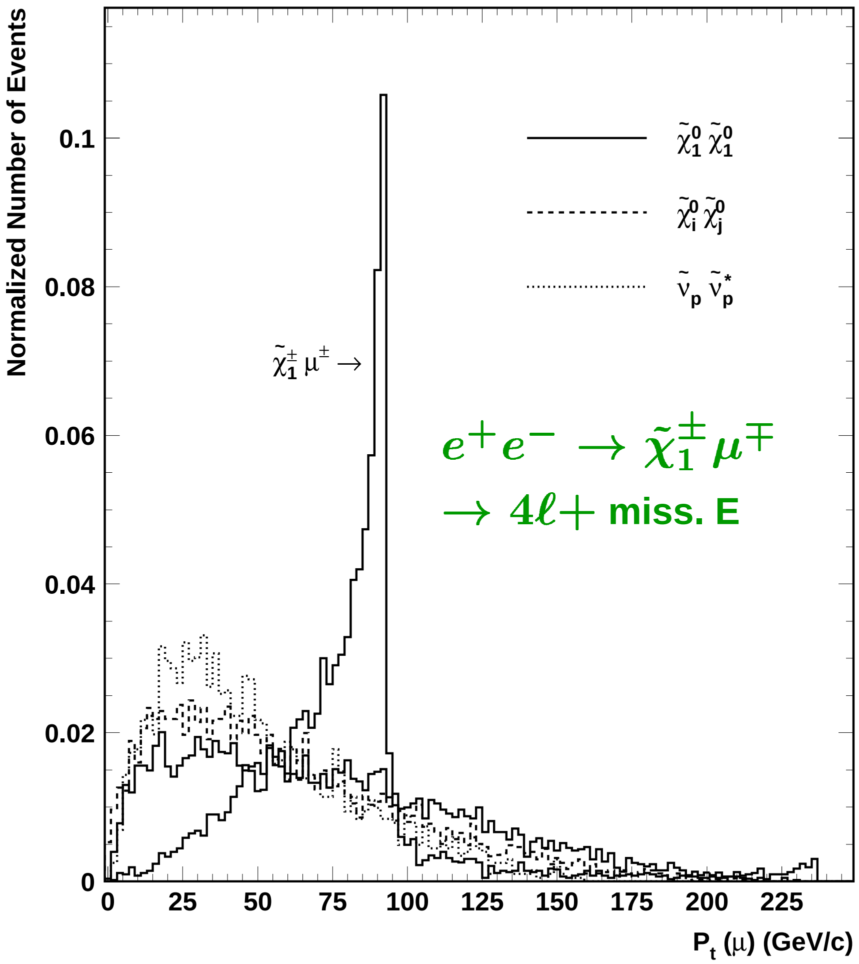
Measure ΔM with high accuracy using $\pi^\pm$ spectrum from $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + \pi^\pm$



R-Paritiy violation

R–Parity violation may provide spectacular signatures!





$e^+e^- \to \tilde{\chi}^\pm_1 \mu^\mp$

$\to 4\ell +$ **miss. E**

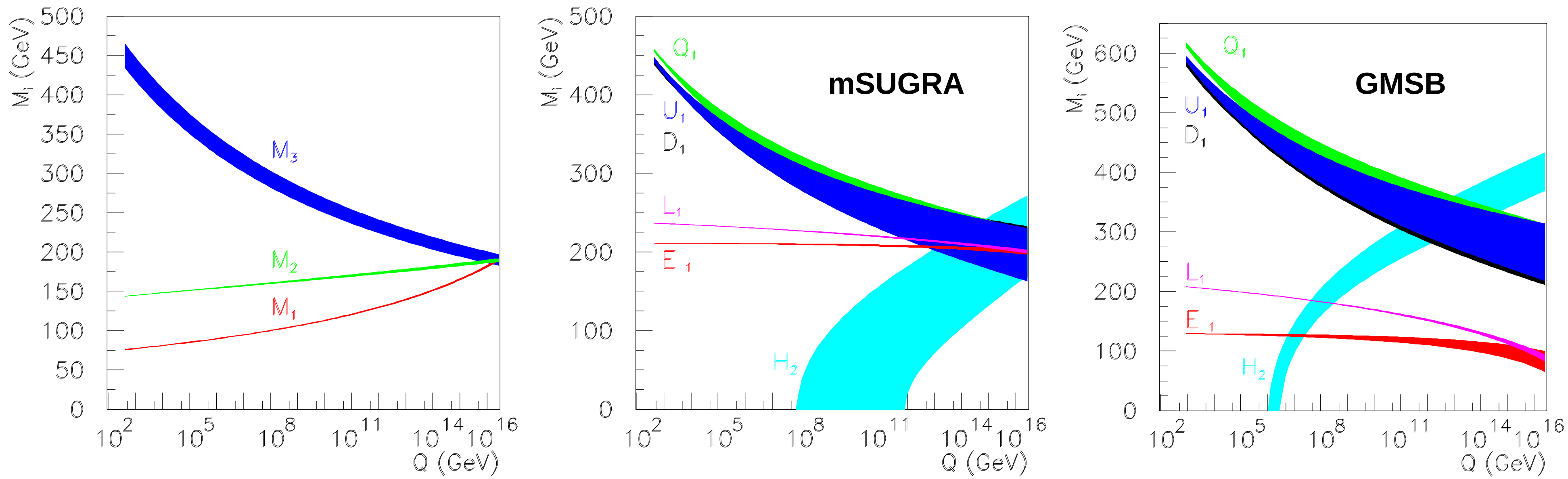
Extrapolation to High Scales

What can be learned from the measured parameters?

Bottom up approach: $\longrightarrow$ G. Blair

Reconstruct the mass parameters at the EW scale (with errors)

Evolve those parameters to high scale through RGE's



High Precision provides information about energy scales far beyond $\sqrt{s}$ of the machine.

Summary

- Accessible part of SUSY spectrum (sleptons,gauginos,stop) can be studied in great detail
- All masses precisely measurable (o(50 - 600) MeV)
- Fundamental SUSY parameters can be extracted with high precision
- Sensitivity in all studied non-standard SUSY scenarios (including phases)
- Extrapolation to high scales to learn about SUSY breaking / unification is possible