Potential of the LHC and LC to Study Degenerate Wino Pairs

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✘ $M_2 \ll M_1, |\mu|$ is "natural" when:

- gaugino masses are dominated by loop corrections
  - ▷ O–II superstring models

    A. Brignole, L.E. Ibanez, and C. Munoz
  - ▷ SUSY–breaking from the conformal anomaly (AMSB)

    G.F. Giudice, M.A. Luty, H. Murayama and R. Rattazzi; L. Randall and R. Sundrum
- SUSY is broken by an F–term that is not an SU(5) singlet

  Snowmass96 Summer Study

✘ LSP and NLSP are Winos with nearly degenerate masses

- Radiative corrections favor $M_{\widetilde{C}_1} - M_{\widetilde{N}_1} > m_\pi$

  S. Mizuta, D. Ng, M. Yamaguchi; A. Papadopoulous, D. Pierce; D. Pierce, J. Bagger, K. Matchev, R.–J. Zhang

See related studies of AMSB-like phenomenology

Gunion, Drees; Gunion, Drees, Chen; Gherghetta, Guidice, Wells; Feng *et al.*; Gunion, SM;

Paige,Wells; Baer, Mizukoshi, Tata

Talk available at:

`http://moose.ucdavis.edu/mrenna/talks/LCsusy.ps`

LEP, Tevatron and NLC expectations

Phenomenology depends critically on mass degeneracy.

- $M_{\widetilde{C}_1} - M_{\widetilde{N}_1} < 1$ GeV can yield quasi-stable charginos, kinks or stubs, or high-impact parameter pions
- $M_{\widetilde{C}_1} - M_{\widetilde{N}_1} \sim 1$ GeV is already considered SUGRA-like for LEP, but will be challenging for hadron colliders
- At a hadron collider, depends also on $\Delta M \equiv M_{\tilde{g}} - M_{\widetilde{N}_1}$

LEP or NLC can probe near kinematic limit

- $\widetilde{C}_1^+ \widetilde{C}_1^-$ if $M_{\widetilde{C}_1} - M_{\widetilde{N}_1} \leq m_\pi$
- $\gamma \widetilde{C}_1^+ \widetilde{C}_1^- \rightarrow \gamma + \not{M}$ +possibly $\widetilde{C}_1 \rightarrow$ soft π ($\gamma\gamma$ background)

Tevatron@10 fb^{-1}

- $\widetilde{C}_1 \widetilde{C}_1 + \widetilde{C}_1 \widetilde{N}_1 \rightarrow$ LHITs/STUBs $M_{\widetilde{C}_1} \sim 450/200$ GeV
- $\gamma + \not{E}_T$, jets+$\not{E}_T$ for $\Delta M \sim 0$ $M_{\widetilde{C}_1} \sim 170$ GeV
- mSUGRA case for ΔM large

☆ For LHC, concentrate on challenging case when chargino decays are not visible

minimal (m)AMSB at the LHC

In mAMSB, mass hierarcy at @ M_{EW} is
$|M_1| : |M_2| : |M_3| \sim 3 : 1 : 7$

Large $\not\!\!E_T$ because $\Delta M = M_{\tilde{g}} - M_{\widetilde{N}_1} \sim .8 M_{\tilde{g}}$

Squarks and Sleptons can be relevant

$$M^2_{\tilde{q}} \simeq M_0^2 + .89 M_3^2$$
$$M^2_{\tilde{\ell}} \simeq M_0^2 - (.03 - .04) M_3^2$$

- **multijet+$\not\!\!E_T$**

$$M_0 \gg M_{\tilde{g}} \; (M_0 = 3\,\text{TeV}) \Rightarrow \widetilde{g} + \widetilde{g}$$
$$M_0 \sim M_{\tilde{g}} \Rightarrow \widetilde{q} + \widetilde{g}$$

- **1(2) Lepton(s)+jets+$\not\!\!E_T$**

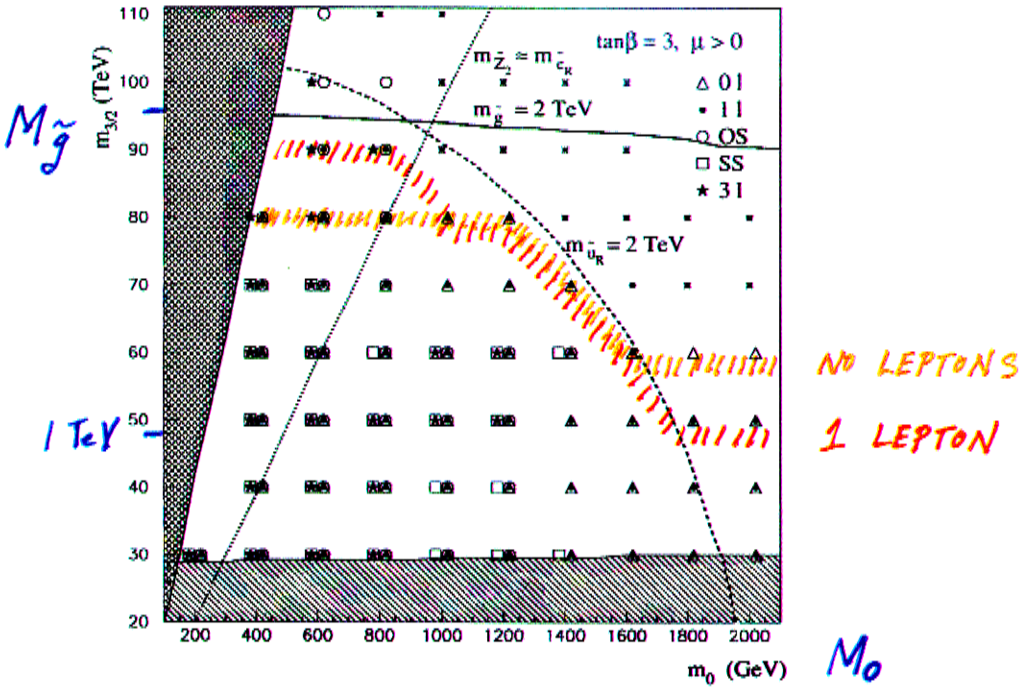
$$\begin{aligned} M_0 \sim M_{\tilde{g}} \Rightarrow &\quad \widetilde{q}_R \to \widetilde{N}_2 q, \quad \widetilde{N}_2 \to W\widetilde{C}_1 \\ M_0 = .4 M_{\tilde{g}} \Rightarrow &\quad \widetilde{q}_R \to \widetilde{N}_2 q, \quad \widetilde{N}_2 \to \widetilde{\ell}\ell \\ M_0 \gg M_{\tilde{g}} \Rightarrow &\quad \widetilde{g} \to t\bar{t}\widetilde{N}_1, \quad t\bar{b}\widetilde{C}_1, \cdots \end{aligned}$$

Discovery convention:

$$\frac{S}{\sqrt{B}} > 5 \quad \frac{S}{B} > \frac{1}{5} \quad N_{\text{ev}} > 5 \; @ 10\,\text{fb}^{-1}$$

LHC Results for 10 fb^{-1}

[hep-ph/0007073], H. Baer, J. K. Mizukoshi and X. Tata



(n) ⇒ number of leptons

mAMSB	ISAJET $M_{\tilde g}$	Our $M_{\tilde g}$
$M_0 = .4 M_{\tilde g}$	2.0 TeV (2)	1.8 (0) 1.7 (1) TeV
$M_0 = M_{\tilde g}$	1.5 TeV (0,1)	1.6 (0) 1.3 (1) TeV
$M_0 \gg M_{\tilde g}$	1.3 TeV (0,1)	1.3 (0) TeV

ΔM	$M_{\tilde g}$ for $M_{\tilde q} \sim 3$ TeV
.5 TeV	1 TeV
.3 TeV	.75—.85 TeV
~ 0	.3—.4 TeV ($\gamma + \not{E}_T$)

LHC Summary

- We analyzed SUSY models with a nearly degenerate $\widetilde{C}_1 - \widetilde{N}_1$ pair
    - ▷ Concentrated on case when chargino decays are invisible
- Similar (but different) results for AMSB as ISAJET group
    - ▷ Looser cuts yield larger backgrounds, but comparable to matrix element results
    - ▷ Our reach in 1 lepton+jets+$\not\!\!E_T$ is lower
- SUSY@LHC may appear only as excesses on tails of SM backgrounds
    - ▷ Need to understand QCD to do this right (for signal and background)
    - ▷ How do you know it is SUSY?
- AMSB mass splitting is large $\Delta M \sim .8 M_{\tilde{g}}$
    - ▷ Smaller ΔM much more challenging $\cdots$ can SUSY remain hidden at LHC?
- Since $M_{\widetilde{C}_1} = 300$ GeV $\Rightarrow M_{\tilde{g}} = 2.1$ TeV, LHC with 10 fb^{-1} does not have the same reach as NLC600 for AMSB, unless M_0 small
    - ▷ NLC600 may not have kinematic reach beyond $\widetilde{C}_1, \widetilde{N}_1$

Lepton Collider Overview

✔ Concentrate on difficult case when scalars are heavy

- $\Delta m_{\tilde{\chi}_1} < m_\pi$

  $\widetilde{C}_1^\pm$ yields a highly–ionizing or disappearing track

  $\widetilde{C}_1^+ \widetilde{C}_1^-$ production will be easily seen

- $\Delta m_{\tilde{\chi}_1} > 2 - 3\,\mathrm{GeV}$

  mSUGRA limit at LEP2

✘ $m_\pi < \Delta m_{\tilde{\chi}_1} < 2 - 3\,\mathrm{GeV}$

$\widetilde{C}_1^\pm \to \widetilde{N}_1 \pi^\pm$ decay yields a soft π track

STUB ($\Delta m_{\tilde{\chi}_1} < 180\,\mathrm{MeV}$) or HIP ($\Delta m_{\tilde{\chi}_1} < 1\,\mathrm{GeV}$)

▷ $\gamma\gamma \to \pi\pi$ background makes direct $\widetilde{C}_1^+ \widetilde{C}_1^-$ unmanageable

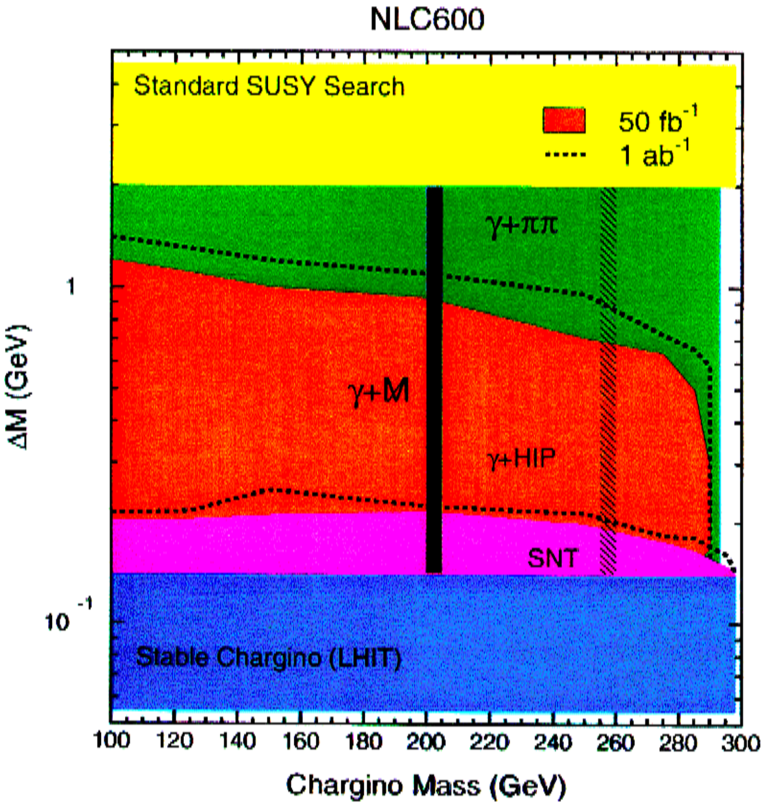
▷ $e^+e^- \to \gamma \widetilde{C}_1^+ \widetilde{C}_1^-$ (with $\nu\bar{\nu}\gamma$ background)

$\gamma + \not{E} + \pi\pi$ signature

$p_T^\gamma > 10\,\mathrm{GeV}, 10^\circ \leq \theta_\gamma \leq 170^\circ$

Disclaimer: We assume background to $\gamma + \pi$(s) signal is small. No decent Monte Carlo programs, but measured background after cuts at LEP2 is negligible, even without requiring a high impact parameter for at least one of the π's.

NLC600 reach for 50 fb^{-1}/1 ab^{-1}



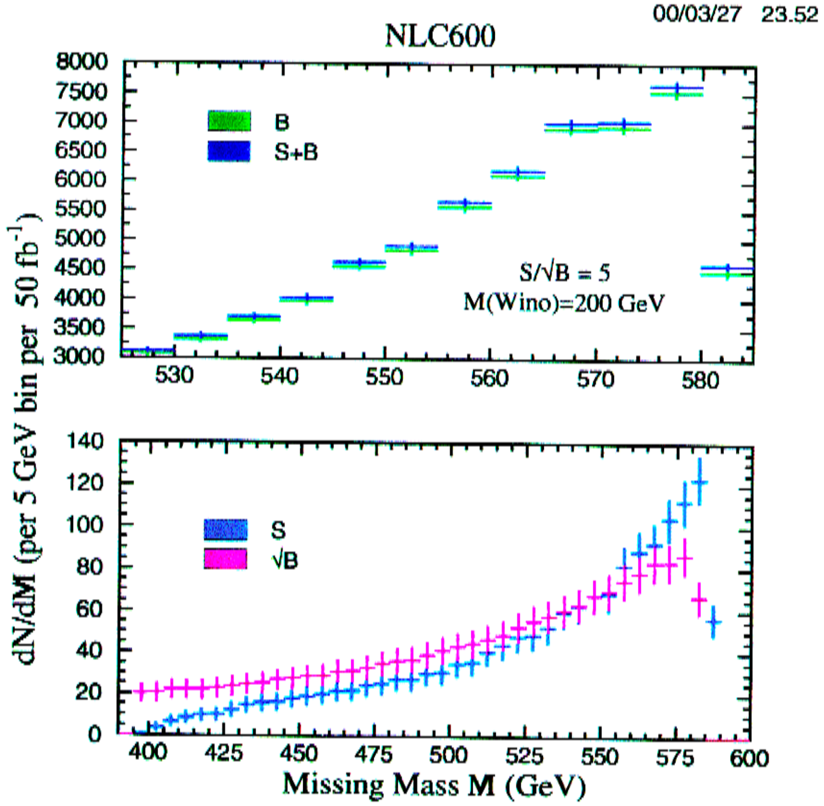
- 10 event min for "background free"
- otherwise $S/\sqrt{B} > 5$, $S/B > 0.02$
- For $200\ \mathrm{MeV} < \Delta m_{\tilde{\chi}_1} < 2\ \mathrm{GeV}$, γ tag is necessary for tagging and reducing background

SNT ⇒ terminating chargino track

HIP ⇒ soft π with significant impact parameter

$\pi\pi$ ⇒ two, soft, acollinear pions

$\not{M}$ Signal from γ+Invisible



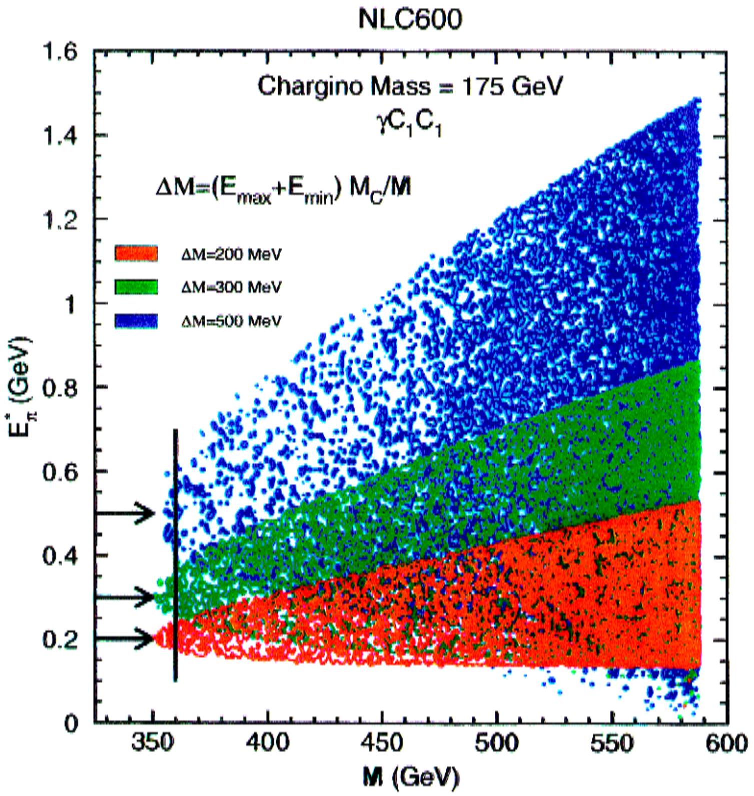
$$S/B = .02 \Rightarrow M_{\tilde{C}_1} = 200 \text{ GeV } (50 \text{ fb}^{-1})$$

$$S/B = .01 \Rightarrow M_{\tilde{C}_1} = 250 \text{ GeV } (180 \text{ fb}^{-1})$$

$m_{\tilde{C}_1^\pm}$ (GeV)	175	250	275
σ (fb)	3.9	2.3	1.4
S/B	0.043	0.025	0.016
L (fb^{-1}) for 5σ	150	435	1140

Table 1: $\gamma + \not{M}$ results for $580 \leq \not{M} \leq 590$ GeV.

Determining $m_{\widetilde{C}_1^\pm}$ and $\Delta m_{\tilde{\chi}_1}$



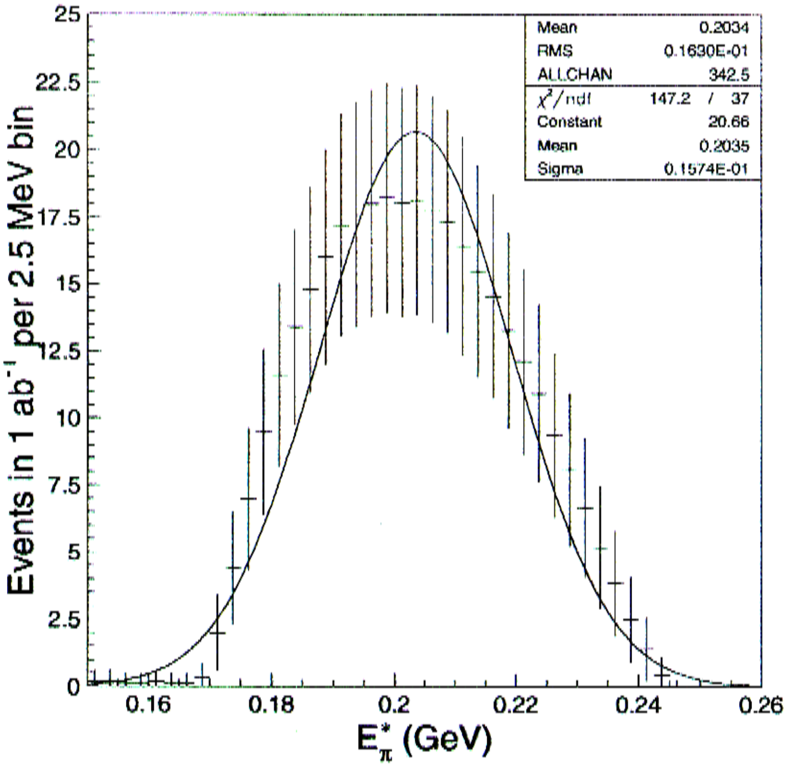
$$\widehat{S}(m_{\widetilde{C}_1^\pm}-\delta m_{\widetilde{C}_1^\pm})-\widehat{S}(m_{\widetilde{C}_1^\pm})=\sqrt{\widehat{S}(m_{\widetilde{C}_1^\pm}-\delta m_{\widetilde{C}_1^\pm})}$$

Find $\delta m_{\widetilde{C}_1^\pm}$ for $50\ \mathrm{fb}^{-1}/1\ \mathrm{ab}^{-1}$

$$m_{\widetilde{C}_1^\pm}\in[150,225]\ \mathrm{GeV}\Rightarrow\delta m_{\widetilde{C}_1^\pm}=1/.2\ \mathrm{GeV}$$

$$m_{\widetilde{C}_1^\pm}\in[250,275]\ \mathrm{GeV}\Rightarrow\delta m_{\widetilde{C}_1^\pm}=0.5/.1\ \mathrm{GeV}$$

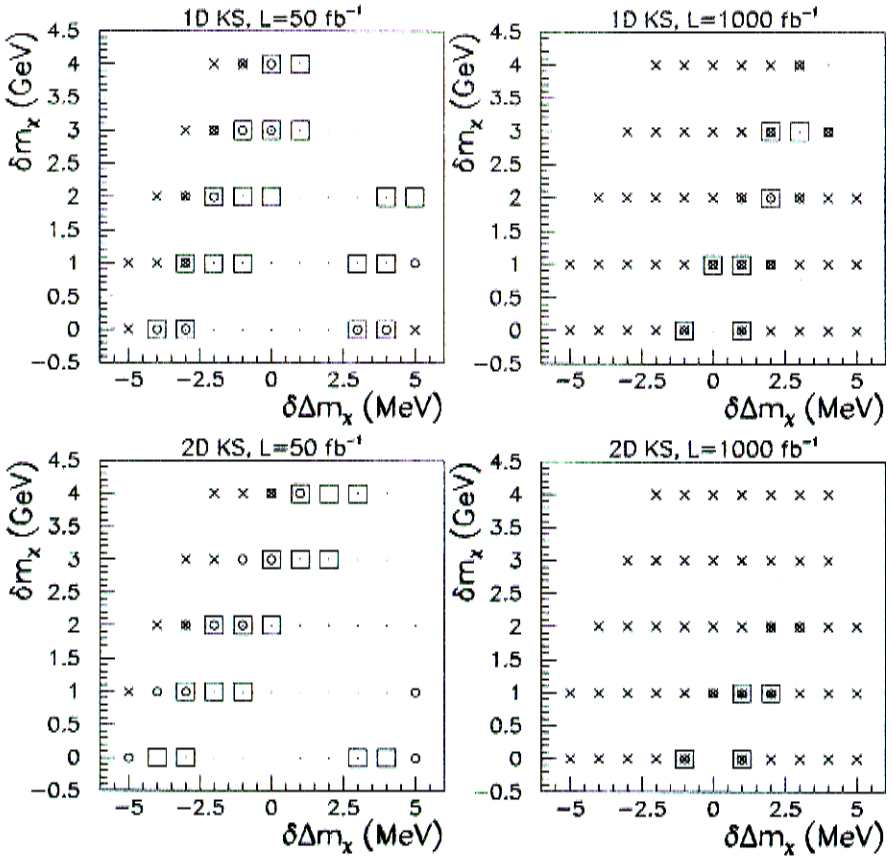
$\Delta m_{\tilde{\chi}_1}$ from Average E_π^* Near Threshold



$\delta \bar{E}_\pi^* = \delta \Delta m_{\tilde{\chi}_1} = \sigma_\pi / \sqrt{N}$ ⇒sub-MeV resolution

Note systematic shift in mean (correctable)

KS Test of Full 1-D or 2-D Distribution



P=probability of compatibility between neighboring points in

$[m_{\tilde{C}_1^\pm}, \Delta m_{\tilde{\chi}_1}]$-space

$\times \Rightarrow P < 0.1$

$\circ \Rightarrow 0.1 < P < 0.3$

❑ $\Rightarrow 0.3 < P < 0.68$

Polarization Dependence

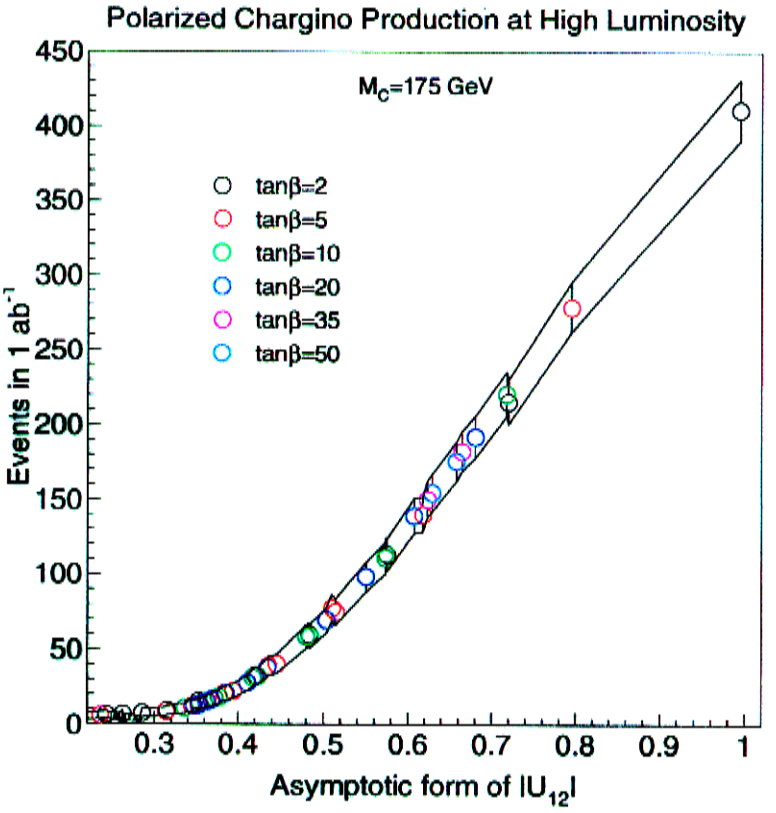
$$Z\widetilde{C}_1^+\widetilde{C}_1^- \propto \frac{ig}{c_W}\gamma^\mu\left(O^L_{11}P_L + O^R_{11}P_R\right)$$

$$O^L_{11} = -c_W^2 + \frac{1}{2}V_{12}^2 \quad O^R_{11} = -c_W^2 + \frac{1}{2}U_{12}^2$$

$$U_{12} = \frac{m_W\sqrt{2}(M_2 c_\beta + \mu s_\beta)}{M_2^2 - \mu^2} \quad (|M_2 \pm \mu| \gg m_Z)$$

By accident ($\sin^2\theta_W = \frac{1}{4}$), σ[Wino pair (+γ)] ~ 0 for e^-_R

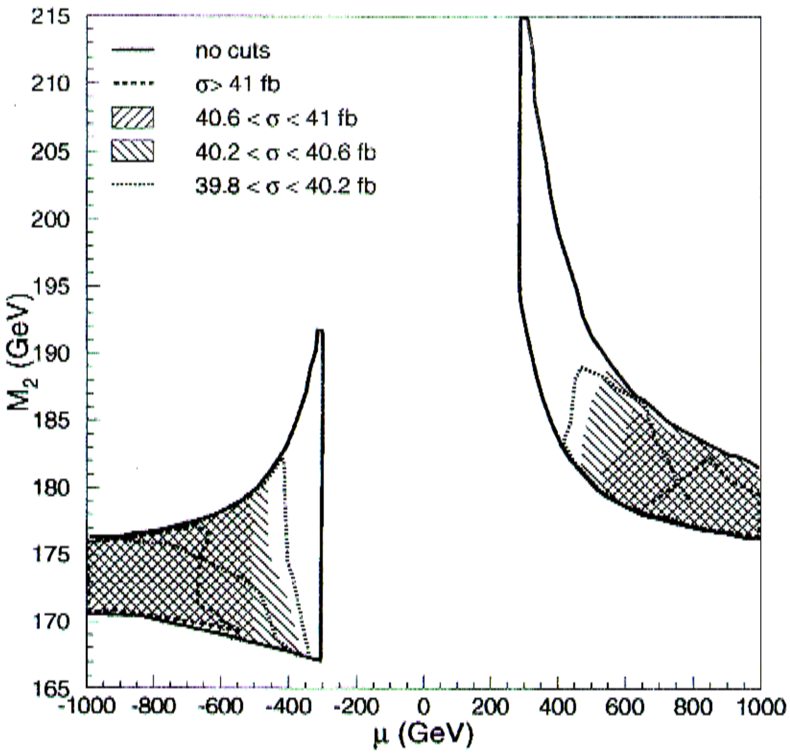
However, polarization can help in **measuring** parameters


Polarized Chargino Production at High Luminosity

Constraining M_2, μ and $\tan\beta$

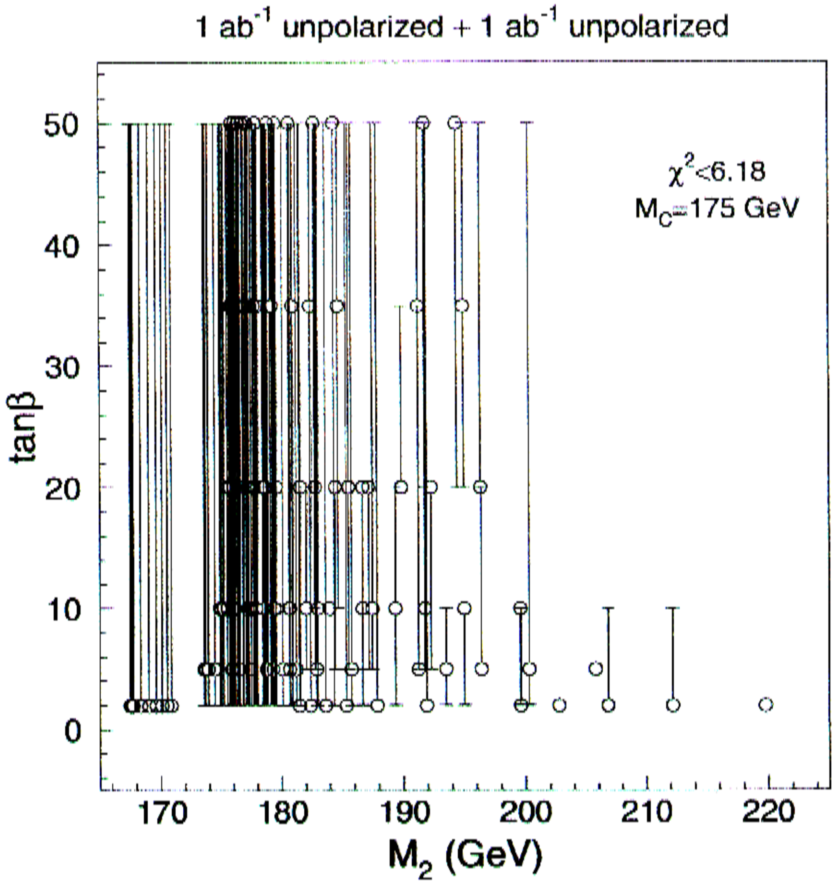
$\gamma\widetilde{C}_1^+\widetilde{C}_1^-$ at an Unpolarized LC

$M_{\widetilde{C}_1} = 175\ \mathrm{GeV}$

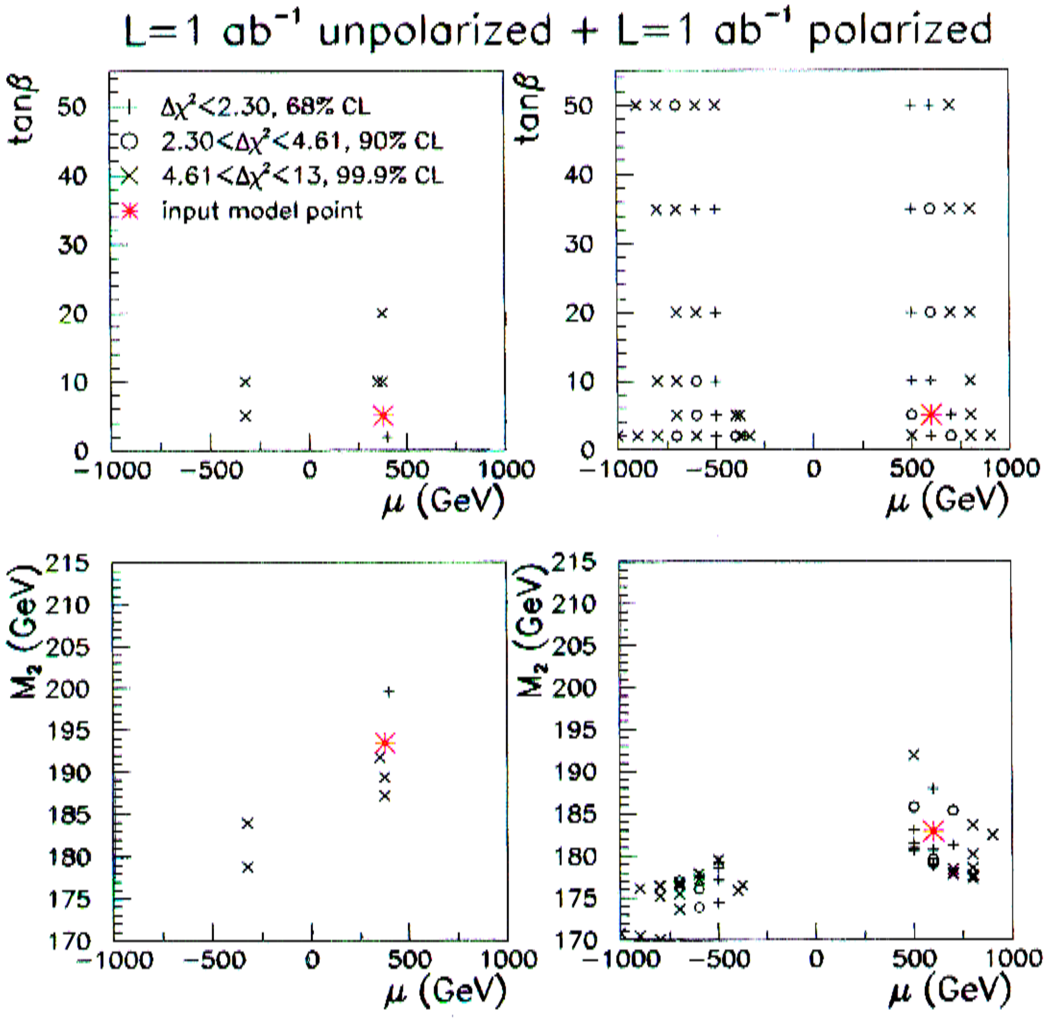


- Small $|\mu|$ measured to $\sim 200\ \mathrm{GeV}$
- Large $|\mu| \Rightarrow M_2 \sim M_{\widetilde{C}_1} \pm 5\ \mathrm{GeV}$
- $\tan\beta$ essentially undetermined
- $\sigma(\sqrt{s})/\sigma(\sqrt{s'}) \sim$ constant

Combination of Polarized and Unpolarized Data is most constraining



- $M_2 - \tan\beta$ points are models
- $\tan\beta$ error bars given by other χ^2-compatible models
- larger $M_2 \Rightarrow$ smaller $|\mu|$


L=1 ab^{-1} unpolarized + L=1 ab^{-1} polarized

LC Summary

✔ LC can easily discover $\widetilde{C}_1^{\pm}$ nearly degenerate with $\widetilde{N}_1$

- $\Delta m_{\tilde{\chi}_1} < m_\pi \Rightarrow$ long-lived heavily ionizing $\widetilde{C}_1^{\pm}$ tracks
- $\Delta m_{\tilde{\chi}_1} \sim 2\ \mathrm{GeV} \Rightarrow$ mSUGRA signals

✔ $200\ \mathrm{MeV} < \Delta m_{\tilde{\chi}_1} < 2\ \mathrm{GeV}$ is the most challenging

✘ $\gamma + \not{E} + \pi\pi$ final state will be the crucial discovery mode

  ✔ LC can measure:

  ▷ $m_{\widetilde{C}_1^{\pm}}$ from M threshold ($< 0.5\%$ error)

  ▷ $\Delta m_{\tilde{\chi}_1}$ from the average soft π energy near threshold (0.5% error)

  ✔ Constraints on M_2, μ and $\tan\beta$

  ▷ best from polarized+unpolarized data

  ▷ Polarized measurements need 1 ab^{-1}

✘ Must understand/control $\gamma\gamma$ backgrounds