SUSY and SUSY breaking Scale

LCWS 00'

Oct. 26th

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** Introduction

** Model predictions for sparticle masses and their relation to SUSY breaking scale/parameters.

** capabilities of an e^+e^- LC ($\sqrt{s} \gtrsim 500$ GeV) for precision measurements of sparticle properties

*** Lessons we can learn about the scale and mechanism of SUSY breaking from these measurements.

** How will LC crucially complement/extend the achievements of LHC

** What would be desired extensions in colliding ptcles./luminosity/energy from the point of view of SUSY investigations?

1] A. Accamando et al, Phys. Rep. 289 (1998) 1; New TESLA TDR

2] Case for 500 GeV e^+e^- linear collider, hep-ph/0007022

3] Web page http://acfahep.kek.jp/

My charge:

To summarize how

1) LC will aid in establishing SUSY as a viable theory

2) LC will help gleen information about the scale and the mechanism of SUSY breaking.

Introduction :

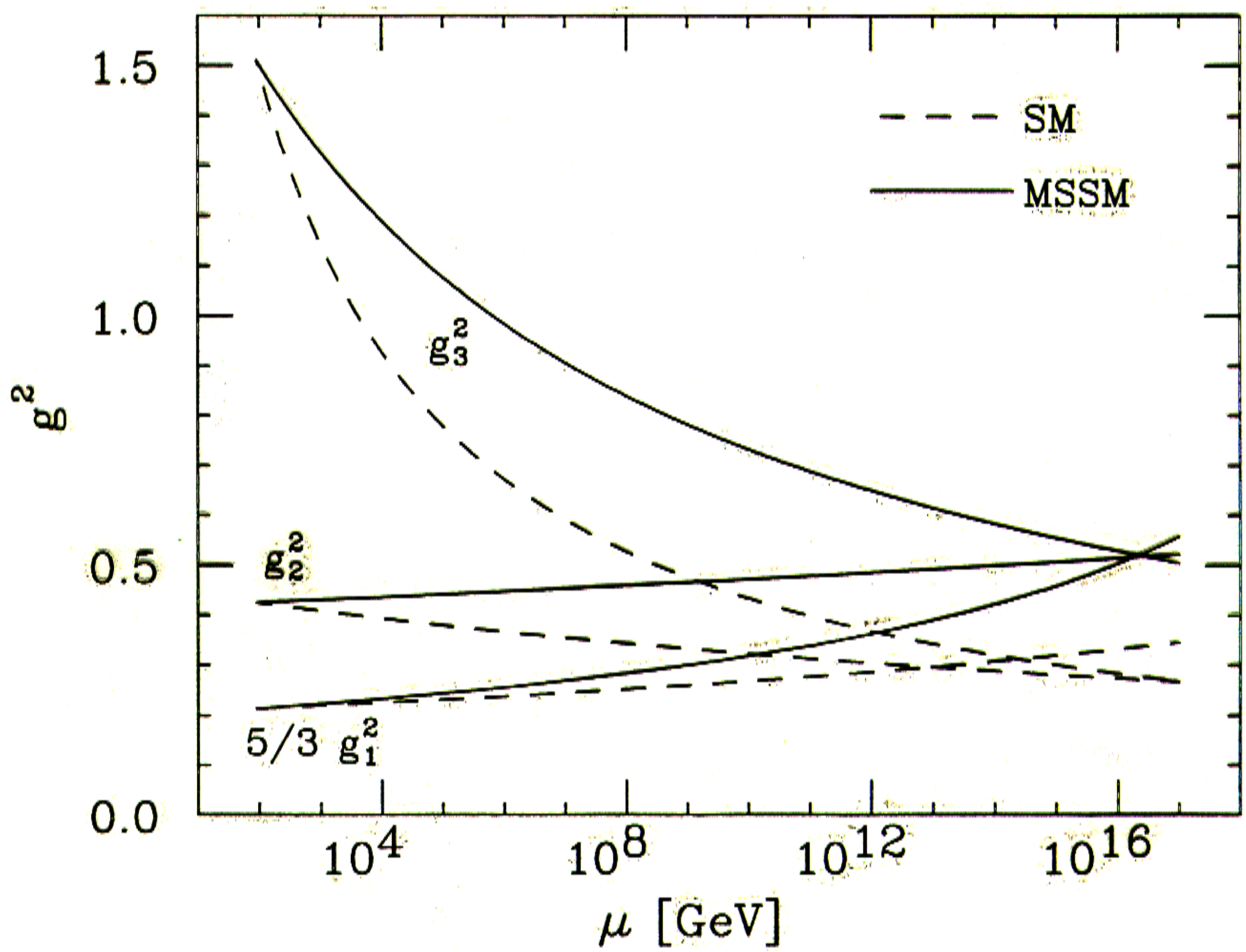
Supersymmetry (SUSY) [TeV scale]

* stabilizes m_h at electroweak scale. The only concrete and worked out solution we have.***

* Provides a natural mechanism for the SSB of EW symmetry.

* Existence of Higgs scalar no longer very special

** Unification of Couplings.



BUT

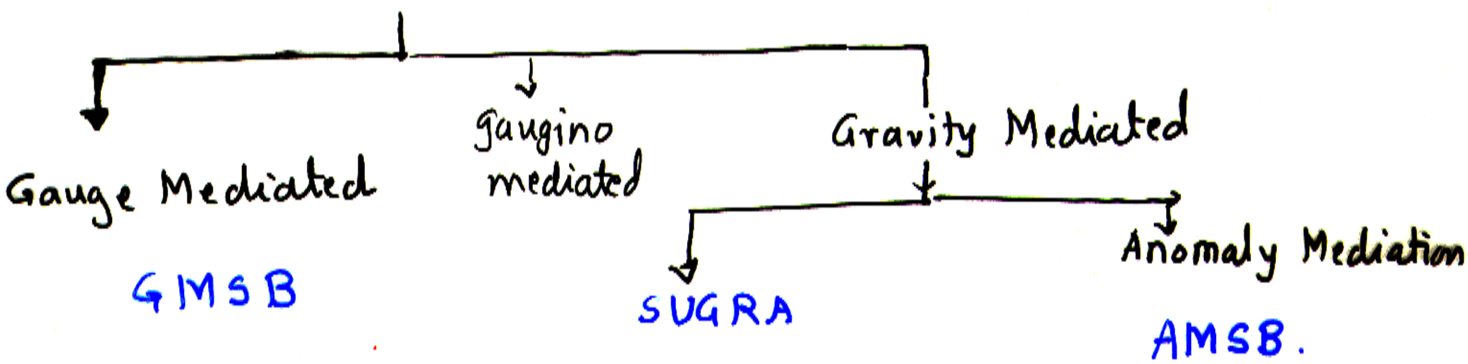
*** Of course ∃ extra dim. then perhaps problem does not exist.

** supersymmetry is broken in real life

** susy breaking not really understood completely

** susy breaking happens in secluded sector.

** Mediation of this breaking to low energy world



(m)SUGRA, (c)MSSM,

** Soft susy breaking parameters at high scale decided by the susy breaking mechanism and its mediation. $10^4\,\mathrm{GeV} < M_{SB} < M_{Pl}$

** sparticle masses at the EW scale (for all sparticles) and couplings (for some of them) depend on this mechanism.

This is the clue provided to us to point to high scale physics

		$m_{\tilde{q}}$	gaugino m	scalar m^2
I	(m) SUGRA (c) MSSM	$\frac{M_{SSB}^2}{\sqrt{3} M_{P\ell}} \sim$ TeV $M_{SSB} \sim 10^{10}-10^{11}$ GeV	$\left(\frac{\alpha_i}{\alpha_2}\right)^2 M_2^2$ Gaugino Unification	$m_0^2 + \sum_i C_i M_i^2$ ↑ RG evolution
II	GMSB	$\left(\frac{\sqrt{F}}{100\,\text{TeV}}\right)^2$ eV	$\left(\frac{\alpha_i}{\alpha_2}\right)^2 M_2^2$	$\sum_i c_i' M_i^2$ ↑ RG evolution
III	AMSB	~ 100 TeV	$\left(\frac{b_i}{b_2}\right)^2 M_2^2$ R.G. inv.	$\sum_i 2 a_i b_i \frac{\alpha_i^2}{\alpha_2^2} M_2^2$ R.G. inv. ↓ minimal cure: addition of M_0^2 at some scale

Weak scale

I, II : $M_1 : M_2 : M_3 = 1 : 2 : 7$

III : $M_1 : M_2 : M_3 = 2.8 : 1 : -8.3$

β_i : β f^ns. for which enter RG# $= \frac{-b_i}{(4\pi)^2} g_i^2$

γ_i: Anom. dim. $= -\frac{a_i}{(4\pi)^2} g_i^2$

(m) SUGRA : $m(\tilde{l}) < m(\tilde{q})$ normally ($m_{\tilde{q}}$: mass of 1/2nd gen. sq.)

mostly $\tilde{\chi}_1^0$: bino ; LSP $\not{E}_T$

$m(\tilde{e}_R) < m(\tilde{l}_L)$

AMSB : $\tilde{\chi}_1^0, \tilde{\chi}_1^+ \approx \tilde{W}_3, \tilde{W}^+$ • Degenerate. Degeneracy lifted only by loop effects.

$\tilde{\chi}_1^0$ LSP

$\Delta M = m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} < 1$ GeV : difft. phenomenology

$\Delta M > 1$ GeV : (m) SUGRA situation

$\tilde{l}_L, \tilde{l}_R$: degenerate.

$\tilde{G}$: LSP $2\times10^{-5} < m_{\tilde{G}} < 1$ keV

GMSB : $\tilde{\chi}_1^0 / \tilde{\tau}_1 / \tilde{e}_R$: candidates for NLSP

decay length: $c\tau\beta\gamma$: 10^{-4} cm. $\longrightarrow$ 10^5 cm.

$$L = c\tau\beta\gamma \propto \frac{1}{(m_{\tilde{\chi}_1^0})^5} (\sqrt{F})^4$$

$$\left.\begin{array}{l} \tilde{\chi}_1^0 \to \tilde{G}\gamma \\ \tilde{\tau}_1 \to \tilde{G}\tau \end{array}\right\} \text{Main decay modes}$$

Leptonic colliders which can study sleptons really crucial.

- SUSY phenomenology in its gory detail looks too complicated. perhaps because we are not looking at things the right way. Important to try and extract ~~is~~ 'model indep' information as far as possible

We need to

(a) find sparticles, establish quantum nos.

(b) check the interactions and establish coupling equalities implied by **supersymmetry**

(c) determine sfermion masses

gaugino - higgsino mixing

gaugino masses

(d) Third generation L - R mixing

μ, soft susy breaking terms. → **physics of SUSY breaking** ← A, μ, $\tan\beta$, soft susy breaking terms

LHC will do part of the —— things.

Promises of LHC to susy enthusiasts:
(Hopes from LHC of susy enthusiasts)

- If susy has been realized by nature, LHC will for sure provide proof for it 'Naturalness'

If theories are 'natural' some sparticles must be accessible at LHC. (Gauginos/higgsinos) ⇐ Barbieri . . . Anderson, ... Feng, Moroi, . . . Allanach, ...

- The strongly interacting heavier sparticles are produced first, lighter sparticles in decays. 'top-down'.
- Rates are very high. Transp. 'discovery of susy not a problem'. Transp.
- Worst background for susy is susy itself.

Very nice analysis methods developed make possible measurement of a variety of sparticle masses but not quantum nos.

- heavier gauginos not acessible.
- Over a large region of parameter space only one higgs (lighter) might be visible. Transp.
- measurements of $m_{\tilde{q}}, m_{\tilde{g}}, m_{\tilde{\chi}^\pm}$ possible with good degree of accuracy. sumarized later
- Possible to get a good idea of eff. susy breaking scale Transp.

1) Accurate information about SUSY breaking scale and mechanism seems generally not easily extractable.

2) Model indep. determination of $m_{\tilde{\chi}^0_1} \approx 10\%$ level.

3) Reach in sleptons limited unless sleptons are produced in decays

4) Analysis and determination of many parameters model dependent. Within a model a high deg. of accuracy. Model indep. analyses have begun. [Paige, Hinchliffe...] look promising .....

5) If $m_{\tilde{l}_R} < m_{\tilde{\chi}^0_2}$, LHC studies may be able to determine all the parameters to predict density of thermal LSP relics. Drees, Nojiri, ...

[Gaugino/Higgsino content of the neutralino $\tilde{\chi}^0_2$ is what one wants to determine.]

This information is also crucial in LHC analyses

LC $\Longrightarrow$ LHC.

Hopes from a linear collider: (SUSY).

A high luminosity machine to make precision measurements of sparticle properties.

BUT

We need $\sqrt{s} > 2m_s + 30 \sim 40$ GeV.

Hope: To build on the results obtained by LHC

a) Determine sparticle masses, mixing to high precision

b) Determine quantum nos. such as spin, hypercharge

c) Measure equality of couplings predicted by SUSY.

d) with (a) + info. from LHC ⟹ info. about SUSY breaking at high scale.

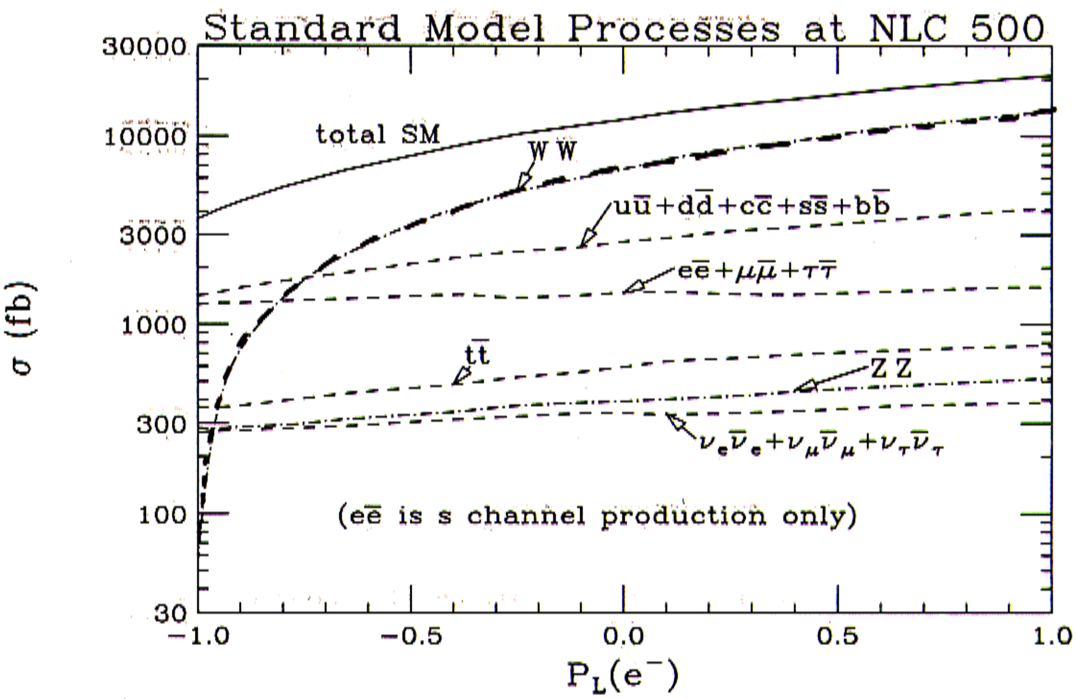
What are the special features which help extra?

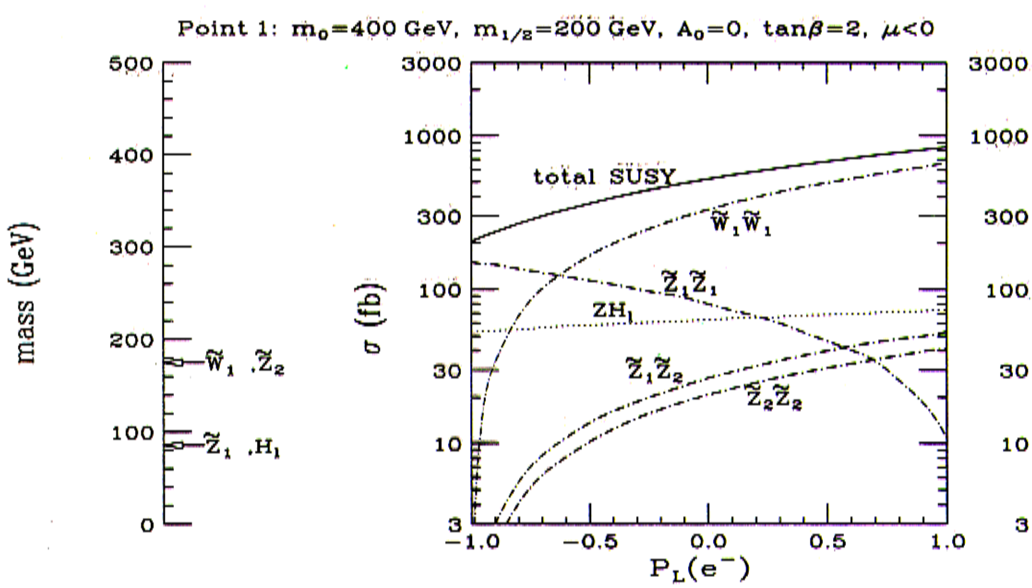
1) Energy can be tuned.: bottom up approach. Start with lightest. Input from LHC will of course help in choices of energy.

2) Use of polarisation: SUSY deals with chiral fermions & their partners. Imp. info. can be projected. WW bkgd. can be killed. useful for (a)

Transp.

3) Running in e^-e^- / $\gamma\gamma$ / $e\gamma$ mode can add to useful information [example later]


Standard Model Processes at NLC 500
total SM
W W
$u\bar{u}+d\bar{d}+c\bar{c}+s\bar{s}+b\bar{b}$
$e\bar{e}+\mu\bar{\mu}+\tau\bar{\tau}$
$t\bar{t}$
Z Z
$\nu_e\bar{\nu}_e+\nu_\mu\bar{\nu}_\mu+\nu_\tau\bar{\nu}_\tau$
($e\bar{e}$ is s channel production only)
σ (fb)
$P_L(e^-)$


Point 1: m_0=400 GeV, $m_{1/2}$=200 GeV, A_0=0, tanβ=2, μ<0
mass (GeV)
$\tilde{W}_1$, $\tilde{Z}_2$
$\tilde{Z}_1$, H_1
σ (fb)
total SUSY
$\tilde{W}_1\tilde{W}_1$
$\tilde{Z}_1\tilde{Z}_1$
ZH_1
$\tilde{Z}_1\tilde{Z}_2$
$\tilde{Z}_2\tilde{Z}_2$
$P_L(e^-)$

What and how well can LC measure?

* A large body of old and new work.

1) K. Fujii, Tsukamoto, ...
2) Pekin, Tata, Murayama
3) Feng, Strassler
4) Feng, Finnel
5) Nojiri, Fujii, Tsukamoto

sleptons
charginos
neutralinos
→ squarks
staus.

1] Kalinowski, Zerwas, Choi ....
2] G. Moortgat-pick, ...
3] Kneur, Moultaka
4] Kraml, Eberl, Majerotto, ...
5] Blair, Martyn.

- some are full fledged MC analyses
- some use only statistical errors
- some use statistical errors + conservative estimates of effeciency
- All use polarisation crucially.
- Use

Examples

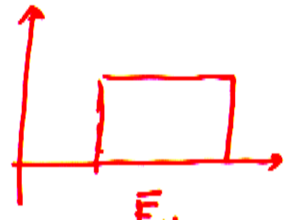
i) Mass determination from end pts.

$$e^+ e^- \to \tilde{\mu}_R \tilde{\mu}_R^*$$

$\tilde{\mu}_R^* \to \tilde{\chi}_1^0 \mu^+$

$\tilde{\mu}_R \to \tilde{\chi}_1^0 \mu^-$

Transp.



TESLA, high luminosity : $\delta m_{\tilde{\mu}_R} \simeq 0.3\%$

ii) Threshold Mass scan

Fermions $\sim \beta$, scalars $\sim \beta^3$

Transp. $\delta m_{\tilde{\mu}_R} \simeq 0.1\%$

$\tilde{\nu}_\tau$: degradation due to detection eff. of τ.

Advantage of threshold scan remarkable in this case.

iii) Study of higher order effects is now state of the art.

Martyn : finite width of $\tilde{\mu}$

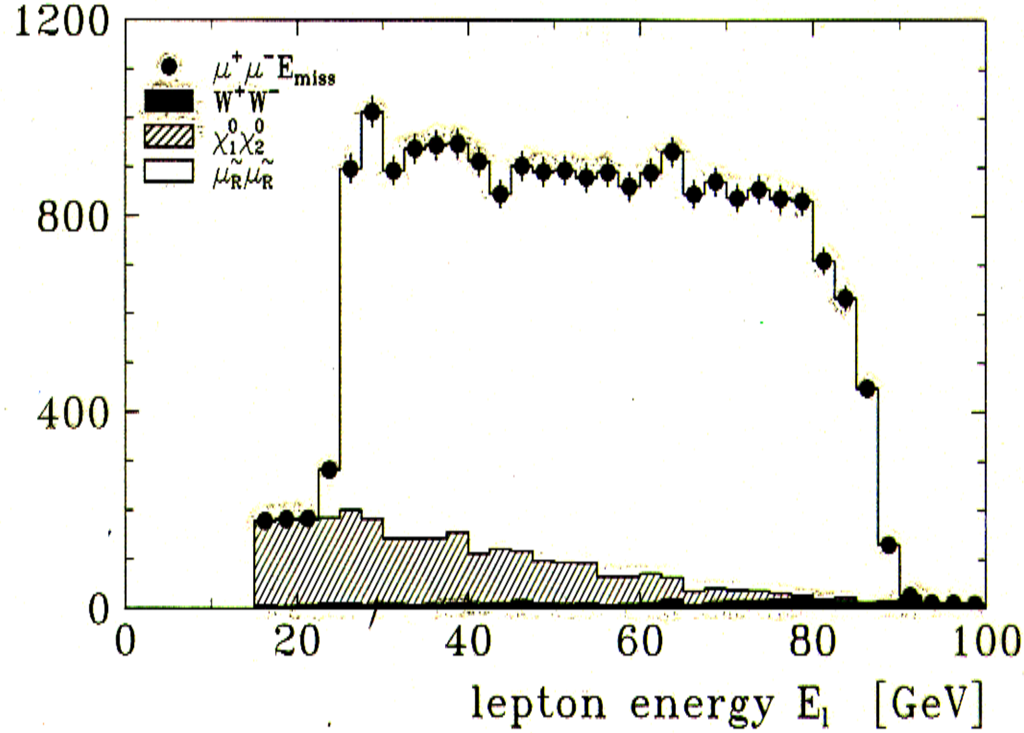
Freitas : full calculation of $e^+e^- \to \mu^+\mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$

Drees, Ebdi, Kraml, R.G : Effect of higher order corrections on $m_{\tilde{q}}$ determination

Transp.

For TESLA : $P_{e^-} = 0.8$, $P_{e^+} = 0.6$, Int. Lum. ~ 500 fb^{-1}/yr.

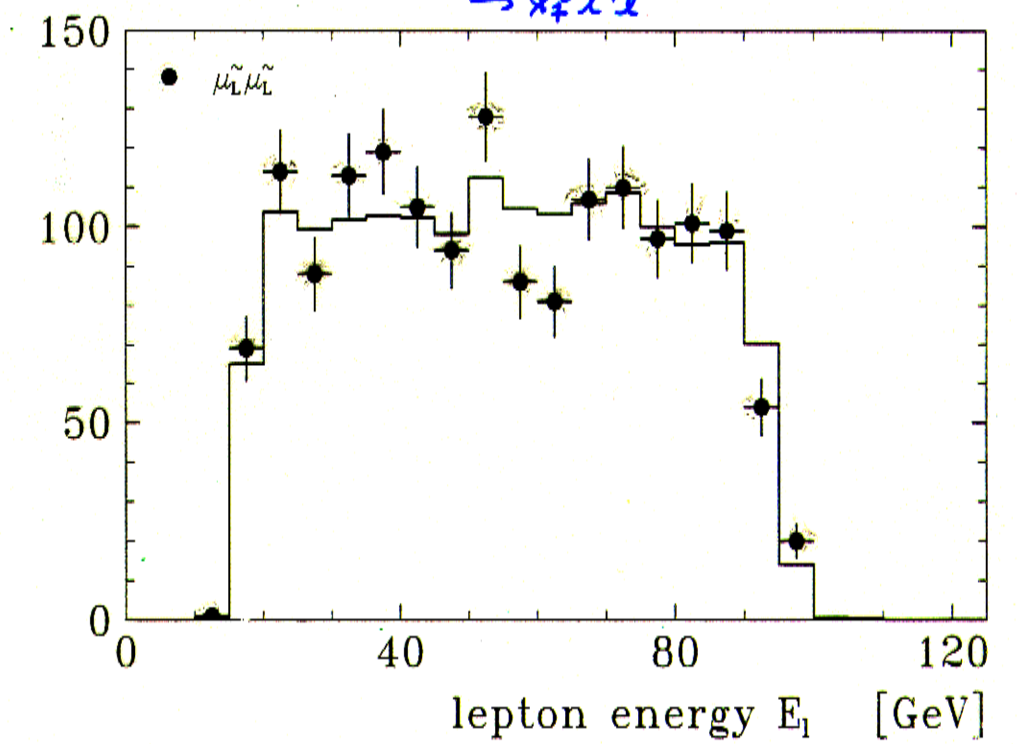
Martyn, Blair



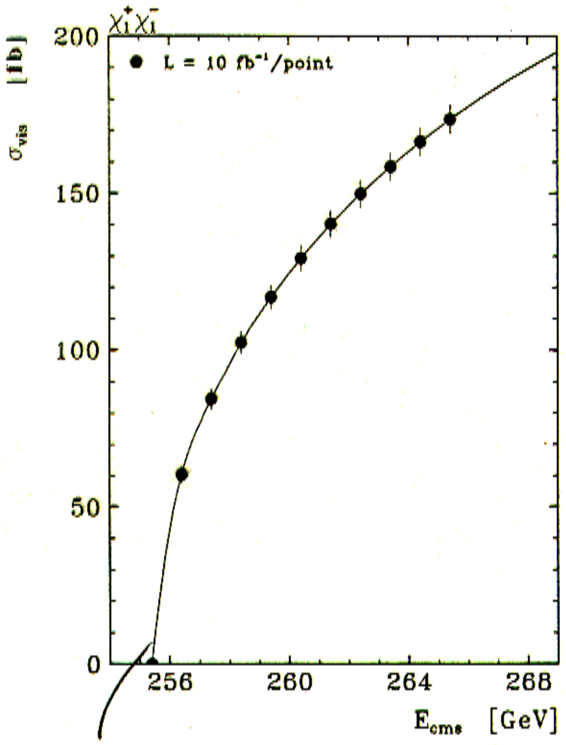
$\tilde{\mu}_L \tilde{\mu}_L^+ \to \mu \tilde{\chi}_2^0 \mu \tilde{\chi}_2^0$

$\hookrightarrow \tilde{\chi}_1^0 l^+ l^-$

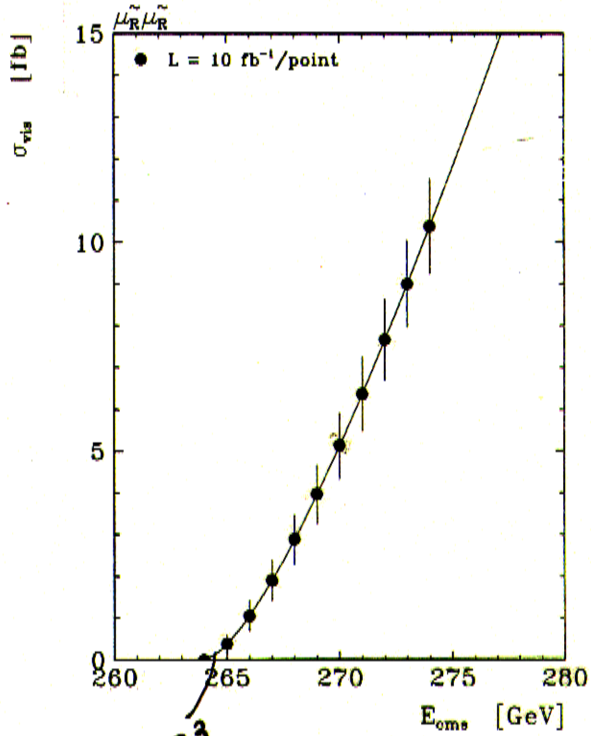
6 lepton final states



Martyn, Blair



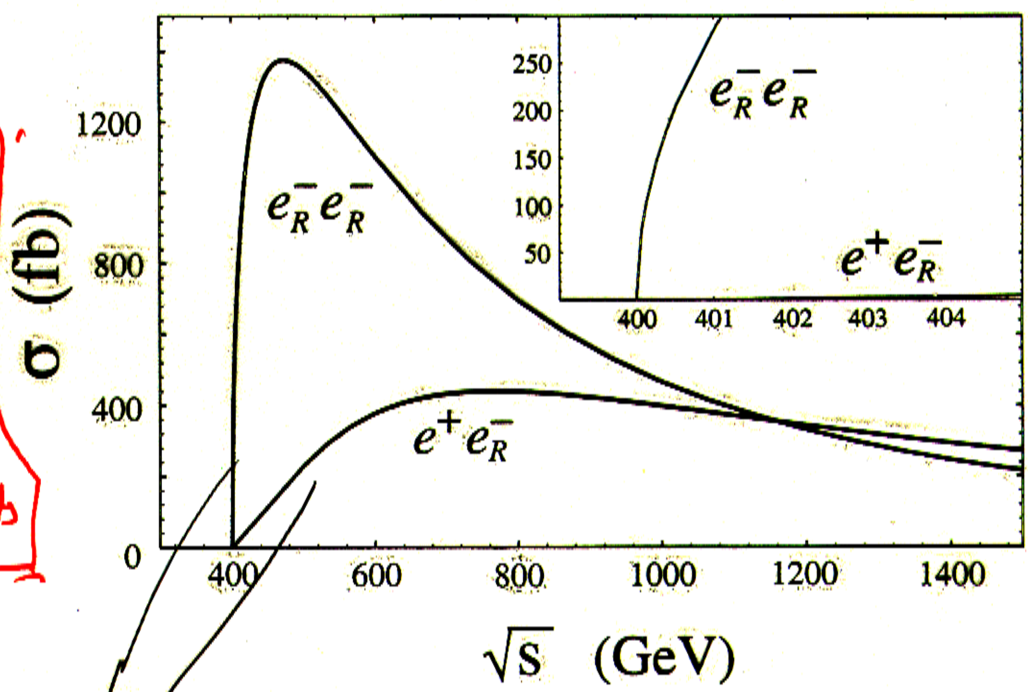
β



β^3

Feng

This fig. does not include Beamstr. effects, ISR effects



$e^+ e_R^- \to \tilde{e}_R^* \tilde{e}_R$

$e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-$

precision for mass measurement ↑ using e^-e^-

Kinematic mass determinations at TESLA

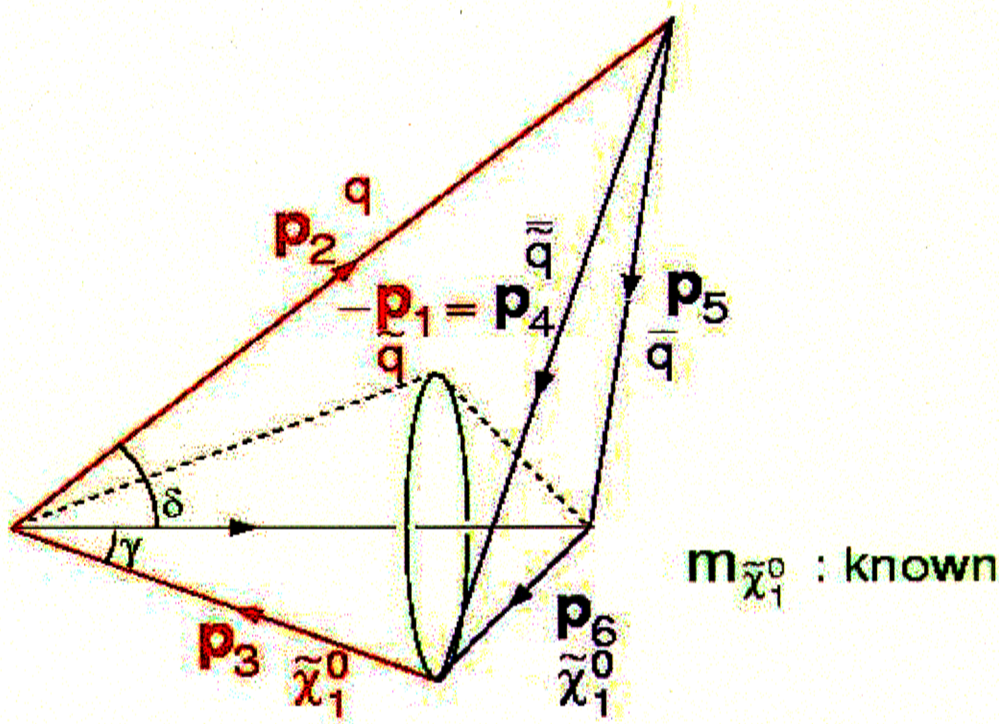
Blair, Martyn

For Threshold scans 10 fb^{-1} per point

Assume universal masses

	δm	m	
$\tilde{\mu}_R$	0.09	132.0	$\Rightarrow m_0, m_{1/2}, \tan\beta$
$\tilde{\mu}_L$	0.4	176.0	
$\tilde{\nu}_\mu$	0.8	160.6	
$\tilde{e}_R$	0.05	132.0	
$\tilde{e}_L$	0.18	176.0	
$\tilde{\nu}_e$	0.07	160.6	
$\tilde{\tau}_1$	0.6	131.0	$\Rightarrow m_0, m_{1/2}, \mu, \tan\beta$
$\tilde{\nu}_\tau$	0.6	160.6	
$\tilde{\chi}_1^\pm$	0.04	127.7	$\Rightarrow M_2, \mu, \tan\beta$
$\tilde{\chi}_2^\pm$	0.25	345.8	
$\tilde{\chi}_1^0$	0.05	71.9	$\Rightarrow M_1, M_2, \mu, \tan\beta$
$\tilde{\chi}_2^0$	0.07	130.3	
$\tilde{\chi}_3^0$	0.30	319.8	
$\tilde{\chi}_4^0$	0.52	348.2	

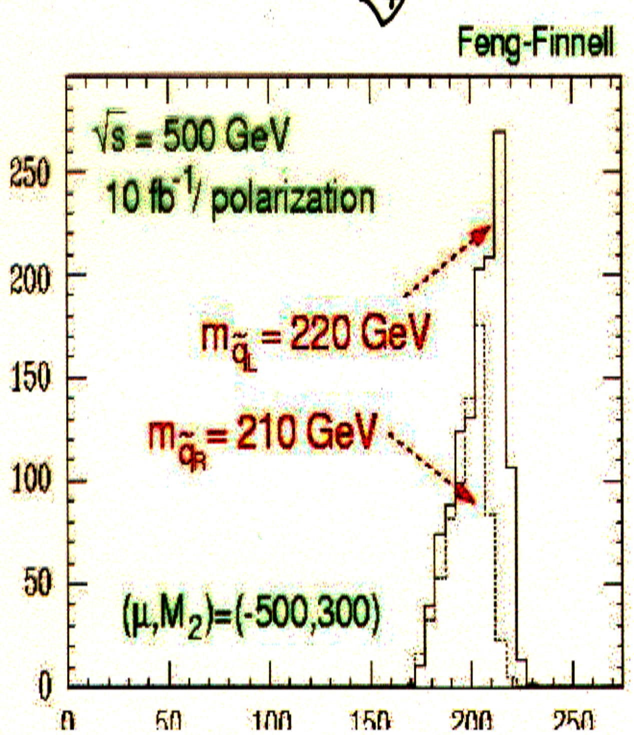
$\tilde{\tau}_2, \ldots$



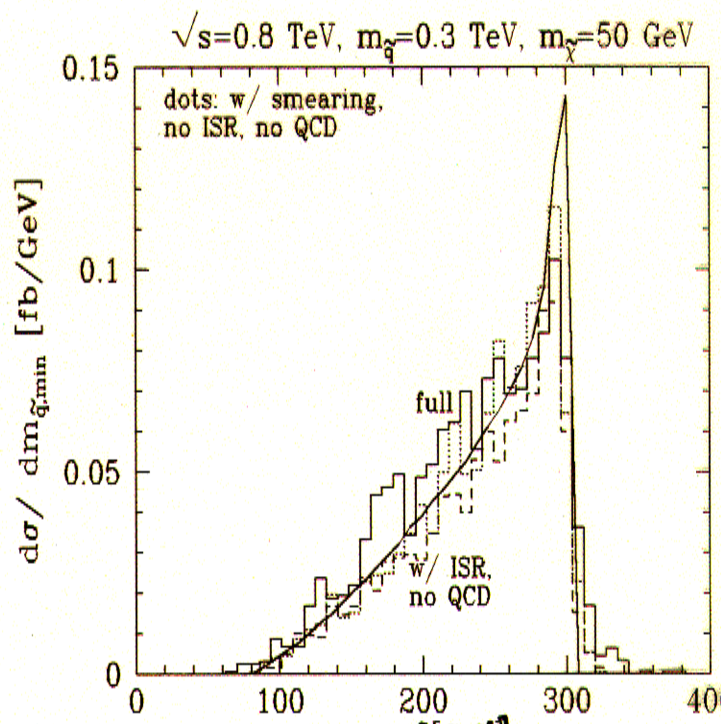
dist^n. in minimum kinematically allowed mass $m_{\tilde{q},min}$ peaks at true $m_{\tilde{q}}$.

⇓

Drees, Godbole, Ebeli, Kraml



→ [GeV]



→ [GeV]

Effect of rad. corrections.

Third generation squarks, sleptons :

Want to determine

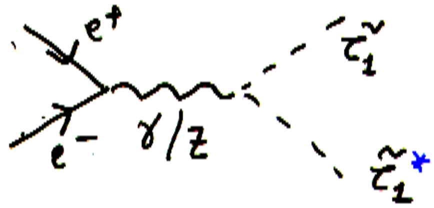
$\theta_{\tilde{t}}, \theta_{\tilde{\tau}}, m_{\tilde{t}_1}, m_{\tilde{\tau}_1}$ ⇒ clue to high scale phys.

$\tilde{\tau}$: (Nojiri)

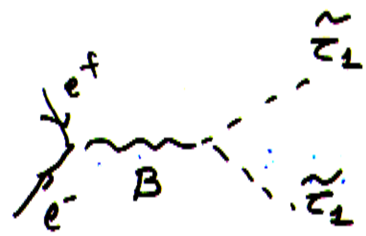
* $\cos\theta_{\tilde{\tau}}$: mixing angle $\tilde{\tau}_1 = \cos\theta_\tau \, \tilde{\tau}_L + \sin\theta_\tau \, \tilde{\tau}_R$

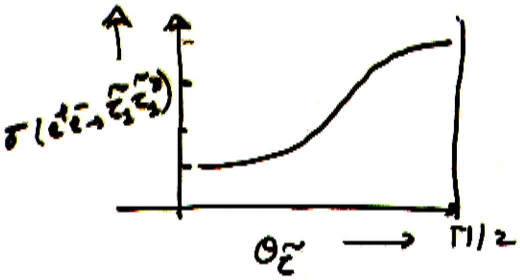
Use polarized beams.

(say) $P_e = 1$



$\xrightarrow[\sqrt{s} \gg m_Z]{P_e = 1}$

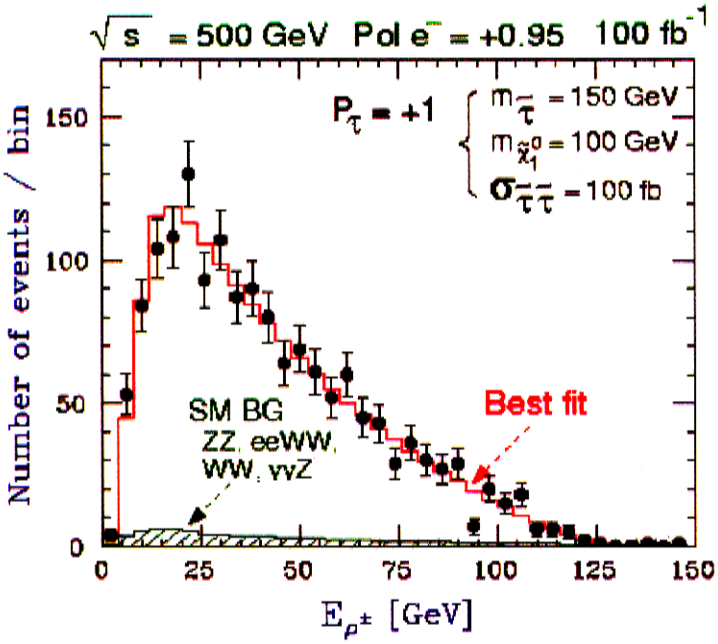


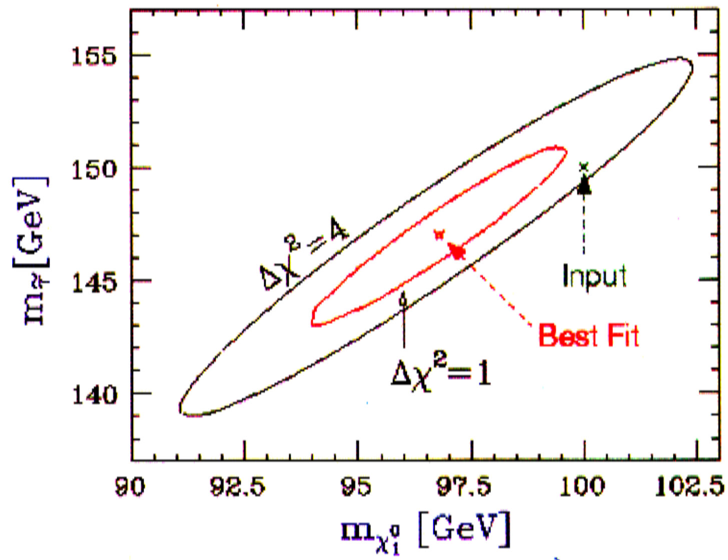


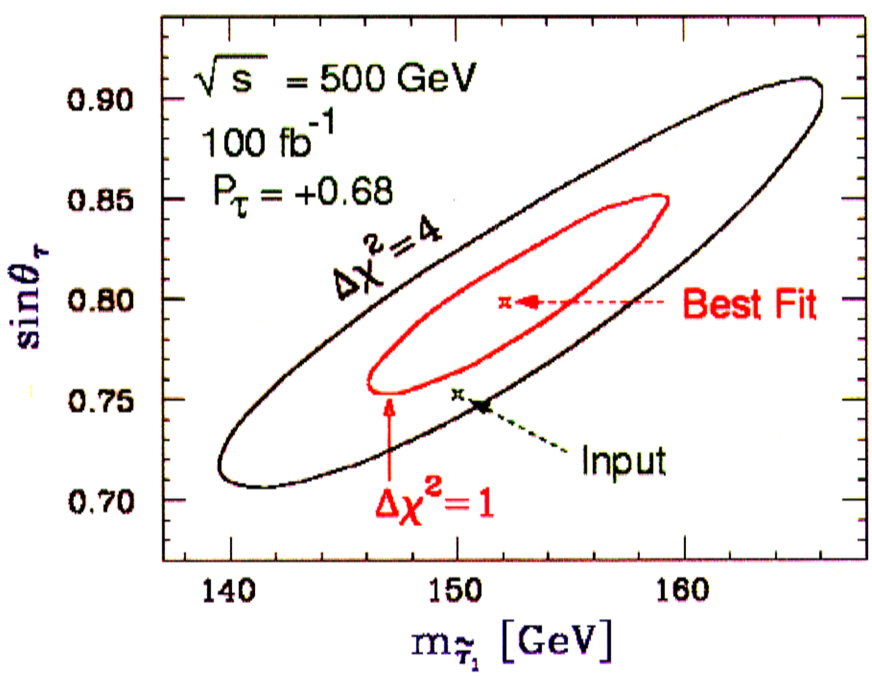
$4\,\sigma(\tilde{\tau}_L) = \sigma(\tilde{\tau}_R)$

* $\tilde{\tau} \to \tau \tilde{\chi}_1^0$

∴ polarisation of τ sensitive to $\tan\beta$.

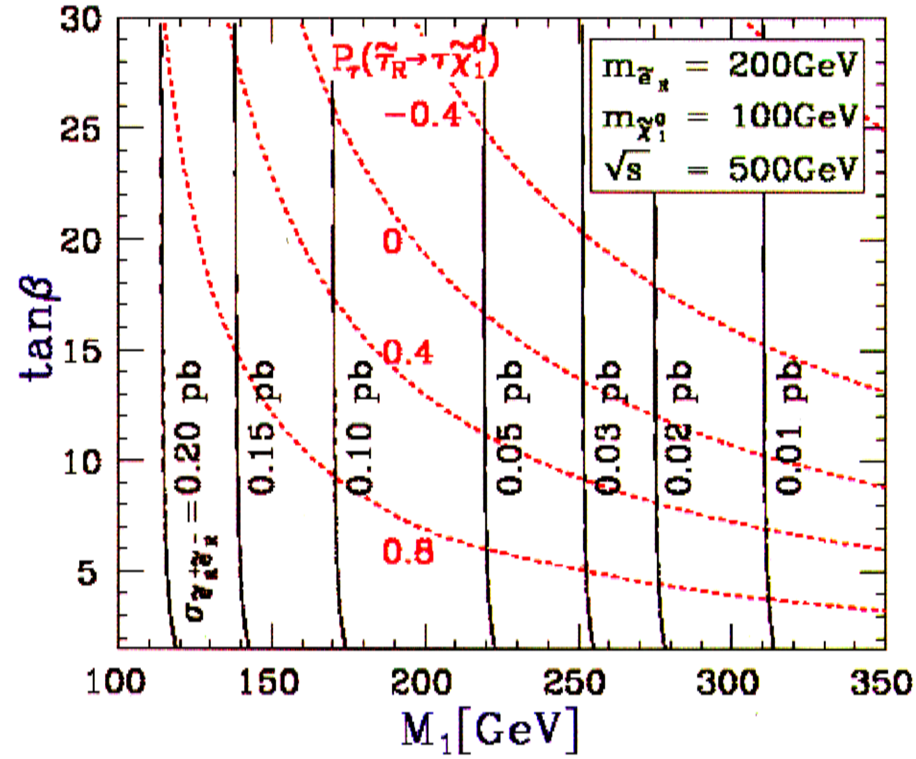


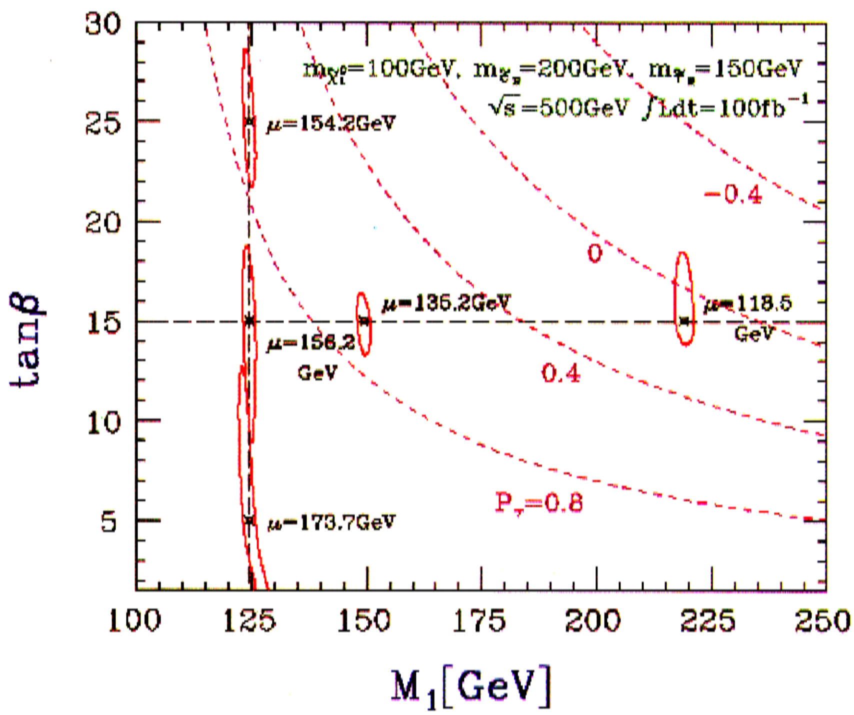


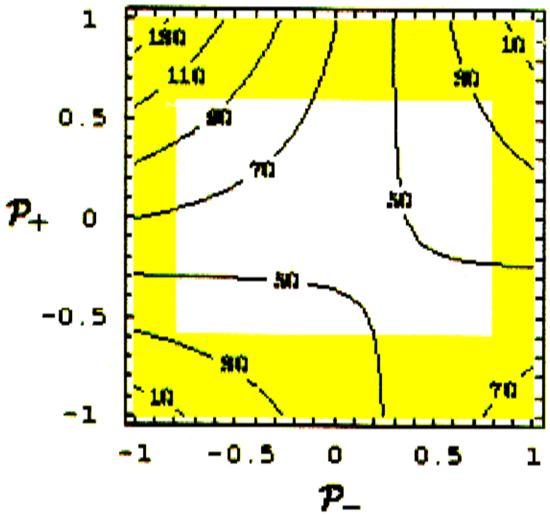


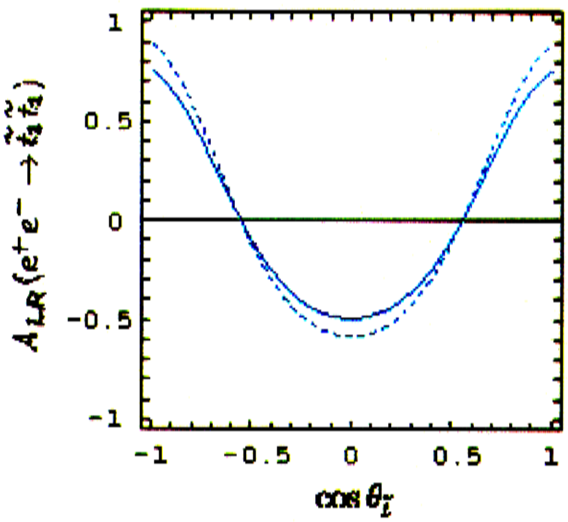
$\Delta(\sin\theta_\tau) < 0.03$ (if one assumes $m_{\tilde{\chi}_1^0}$ known $\Rightarrow \Delta m_{\tilde{\tau}_1}$ ↓)

$\sigma(e^+e^- \to \tilde{e}_R \tilde{e}_R^*)$, $P_\tau(\tilde{\tau} \to \tau \tilde{\chi}_1^0)$



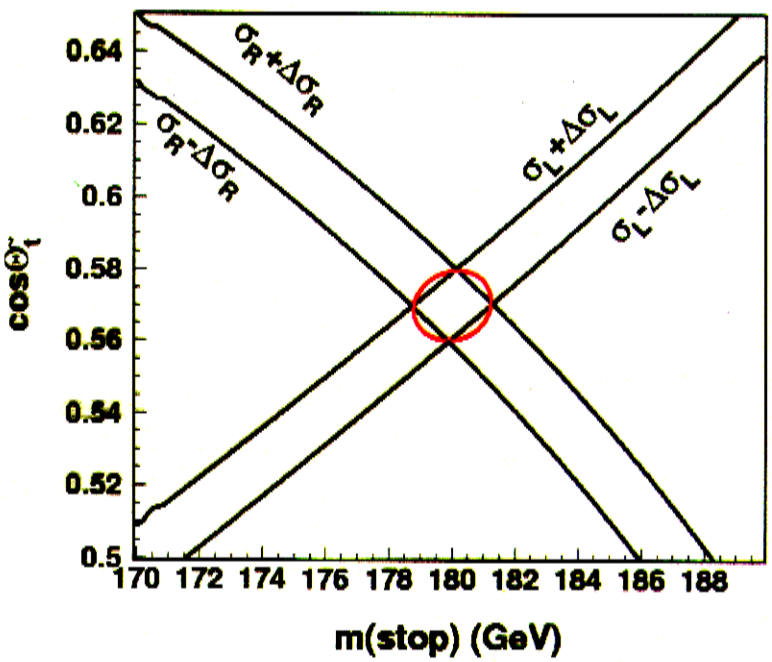






TESLA

stop into c neutralino 80/60 pol



$\Delta(\cos\theta_{\tilde{t}}) = 0.003$
$\Delta(m_{\tilde{t}}) = 0.8$

If $m_{\tilde{t}}$ in this range LHC analysis?

1) Kraml et al

2) A. Sopczak .... MC studies

Quantum no. determination

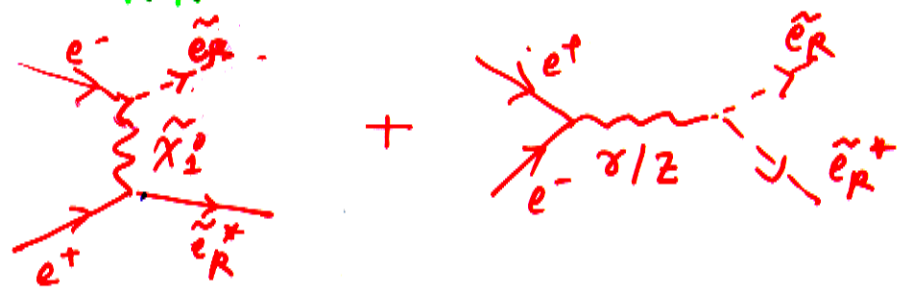
1 : polarization dep. of x-sections.

2. spin 0 of $\tilde{\mu}$ can be inferred by reconstructing angular dist. of $\tilde{\mu}$. (Fujii et al)

3. Equality of couplings :

Nojiri

1) $g_{\tilde{e}_R e_R \tilde{B}} = g_{Bee} = \sqrt{2}\, g \tan\theta_W = g'\sqrt{2} = \sqrt{2} g' Y_B$



$\delta Y_b \simeq 1\%$ (100 fb^{-1})

Fig.

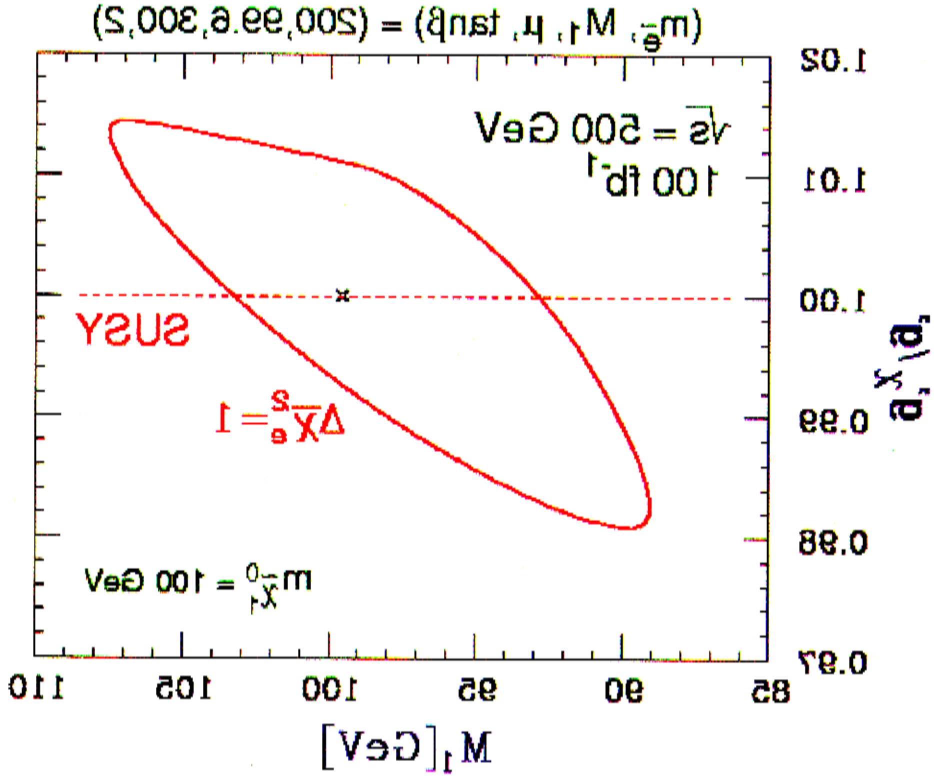
size comparable to the susy oblique corrections to coupling equalities **

** Nojiri, Pierce ... , Feng, Polonsky, ... } get back later.

2) $g_{e\nu W} = g_{e\tilde{\nu}\tilde{W}}$ Test (Choi, Zerwas, ...)

For the point they considered ± .1% test.
1 ab^{-1}

(23)



M. Nojiri, K. Fujii, T. Tsukamoto

$e^+e^- \to \tilde{e}_R \tilde{e}_R^*$

$\frac{d\sigma}{d\cos\theta}(e^+e^- \to \tilde{e}_R^- \tilde{e}_R^+)$ sensitive to M_1

and $g_{\tilde{e}_R \tilde{e}_R B}$.

Higgsino / Gaugino Content

Lightest chargino $\tilde{\chi}_1^+$

Measurements of $m_{\tilde{\chi}_1^+}$, $m_{\tilde{\chi}_1^0}$ and,

$\sigma^{tot}_{\tilde{\chi}_1^+\chi_1^-}$ and (i) Angular correlations among $\tilde{\chi}_1^+$ decay products
(from polarization of $\tilde{\chi}_1^\mp$)

OR (ii) polarized cross-sections σ_R^{11}, σ_L^{11}, $\sigma_{R,L}^{12}$, $\sigma_{R,L}^{22}$

1 ab^{-1} $\Rightarrow$ Determination of $\cos 2\phi_L$, $\cos 2\phi_R$ $\lesssim 1-3\%$

[Choi, Zerwas, Kalinowski, ...]

ϕ_L, ϕ_R : chargino-higgsino mixing angles.

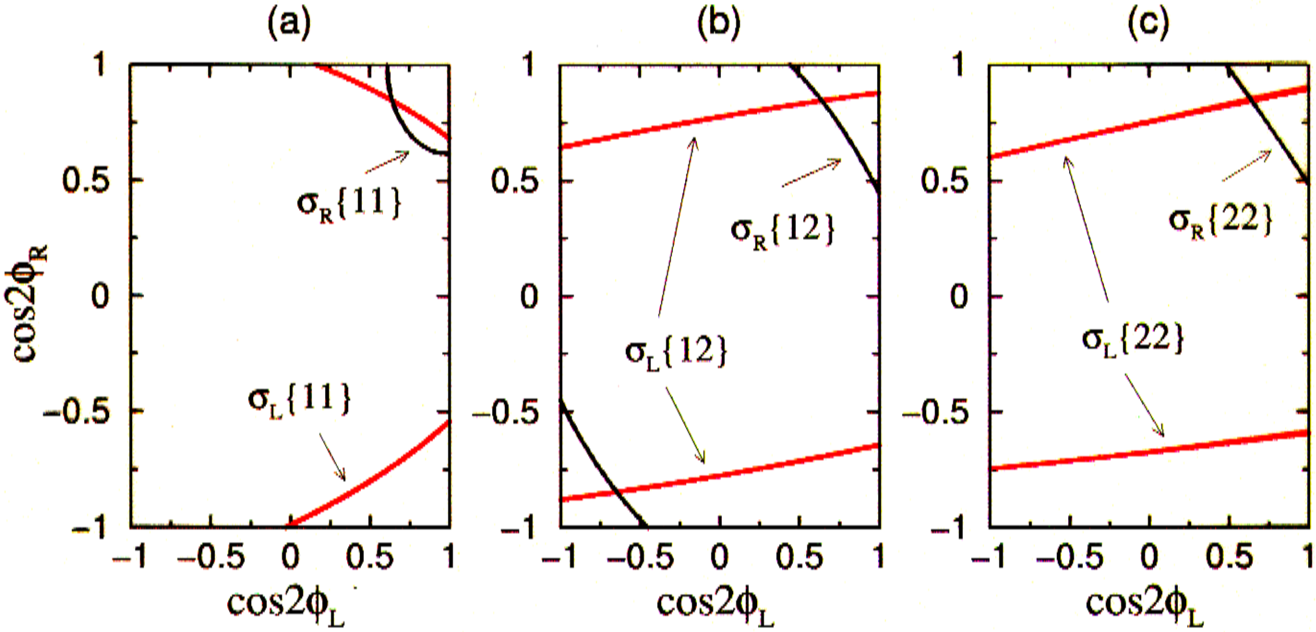
$\Rightarrow$ Reconstruction of $\tan\beta$, M_2, μ.

> Since all the variables are proportional to $\cos 2\beta$ accuracy of $\tan\beta$ determination not so good at high $\tan\beta$

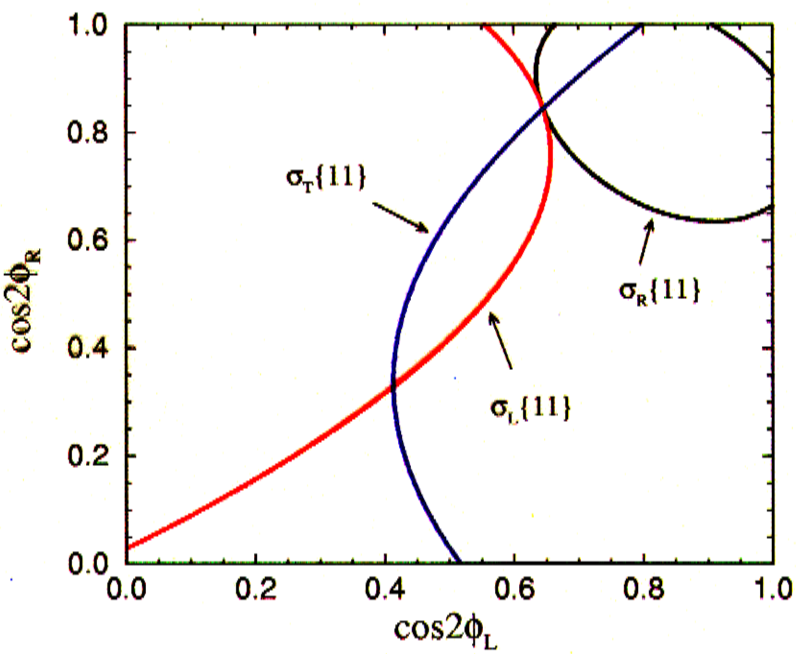
At high $\tan\beta$ $\tilde{\tau}_1$ studies $\Rightarrow$ info. about $\tan\beta$
↳ Nojiri

Higgs sector $\Rightarrow$ $\tan\beta$
↳ Feng ...
Han ...

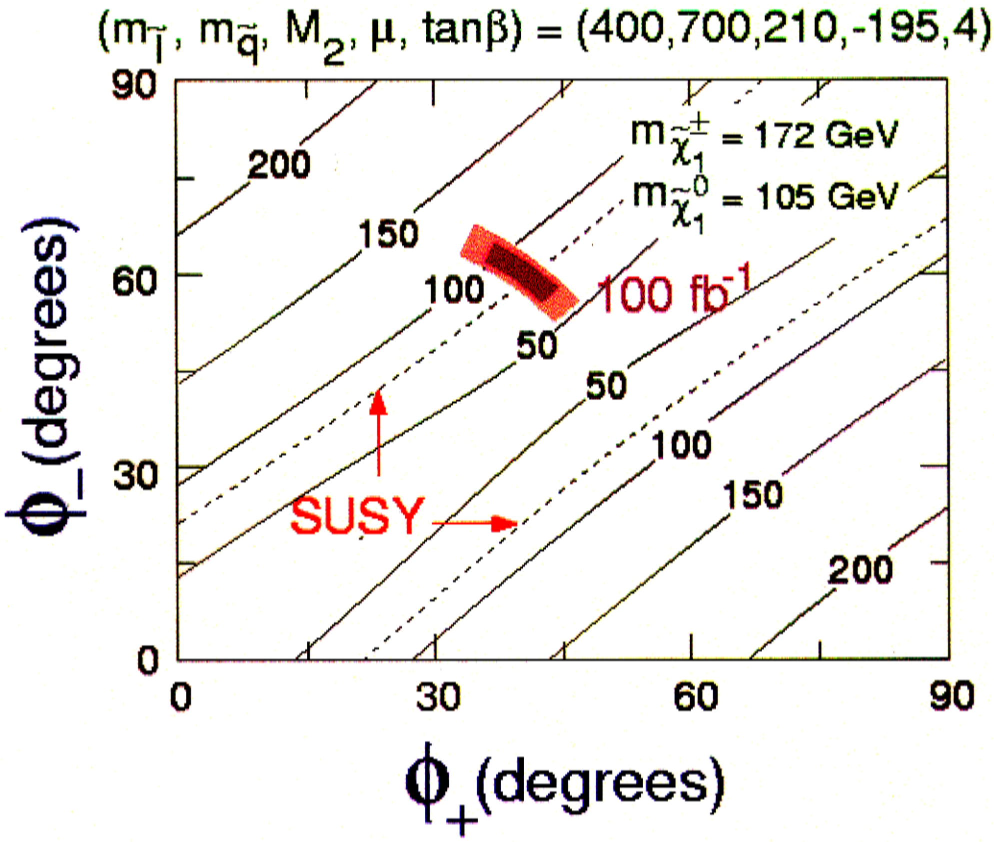
LHC $\rightarrow$ $\tan\beta$



(a)
(b)
(c)
cos2φR
cos2φL
σR{11}
σL{11}
σR{12}
σL{12}
σR{22}
σL{22}



cos2φR
cos2φL
σT{11}
σR{11}
σL{11}



Fujii, Feng, Peskin, Tata.

Similar analytical work done for neutralinos.

(i) possible to extract $M_1, M_2, \mu, \tan\beta$ from measurements
Kneur, Moultaka

(ii) polarization of e^- and e^+ beams can be used to extract information on M_1.
Increase accuracy of the info. G. Moortgat-Pick ....

(iii) studies where $\tilde{\chi}_1^+$, $\tilde{\chi}_1^0$ are almost degenerate
winos; pheno. studies have been preformed. Look very promising

S. Mrenna, J. Gunion.

Probir Roy, D. Ghosh ...

Determination of SUSY breaking scale

+ SUSY breaking parameters at high scale

Two approaches: I] SUSY breaking parameters at high scale $(M_1, M_2, \mu, \tan\beta, m_0) \Longleftrightarrow$ observables $(\sigma_L, \sigma_R, A_{FB}, \cdots)$

1) Feng, Murayama, Fujii, ...
2) Peskin, Murayama, Tata, ...

Transp. → JLC (Top down)

Blair & Moortgn

II] SUSY $(M_1, M_2, \mu, \tan\beta, m_0) \Longleftrightarrow$ physical parameters $(m_{\tilde\chi}, m_{\tilde e}, \cos\theta_{\tilde\chi}, \cos\theta_{\tilde e_i}, \cdots) \Longleftrightarrow$ Observables $(\sigma_L, \sigma_R, A_{FB}, m_{\tilde\chi}, m_{\tilde e} \cdots)$

Top down

As model indep. as possible

Bottom up approach Porod, Zerwas, Blair

To learn about the scale now, use RG eqns.

Use measured sparticle masses, c.sections at EW scale to extract SUSY parameters at EW scale. Try to reconstruct the parameters M_i, $M^2_{scalars}$, ... at high scale.

F   Table.

$$\alpha_i = z_i \alpha_U$$

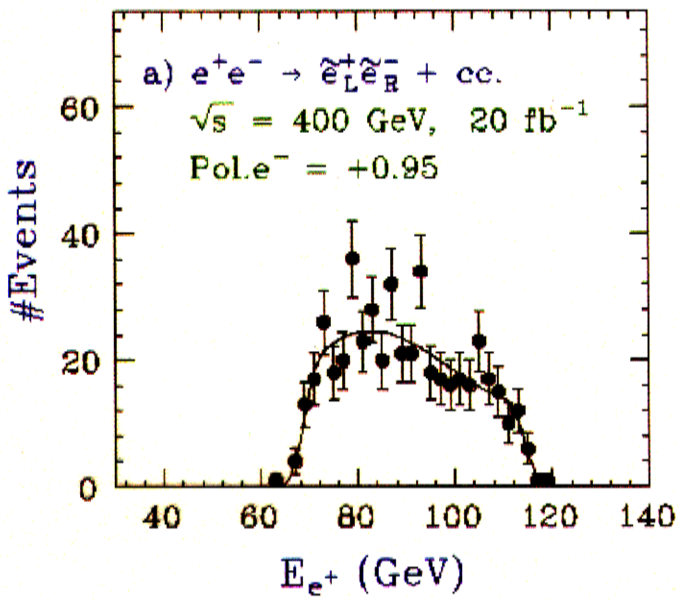
$$M_i = z_i M_{1/2} \quad \text{— gaugino}$$

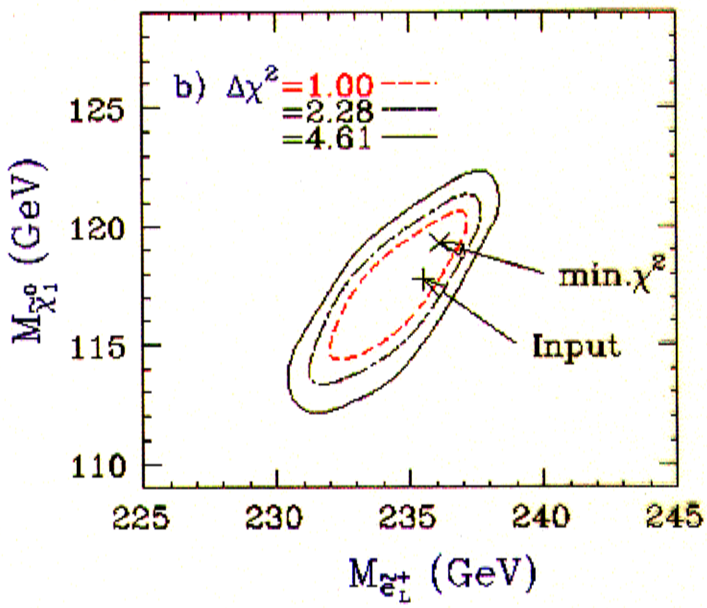
scalars

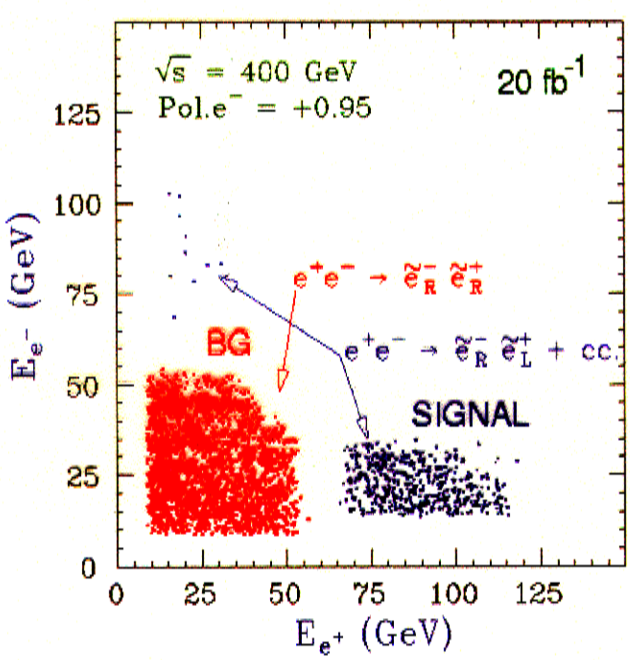
$$M_j^2 = M_0^2 + c_j M_{1/2}^2 + \sum_{\beta=1,2} c'_{j\beta} \Delta M_\beta^2$$

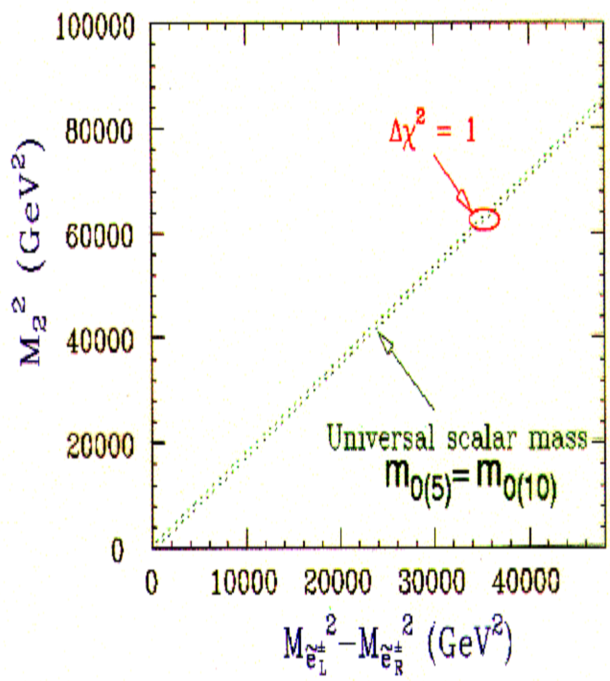
$$A_K = d_K A_0 + d'_K M_{1/2}$$

First two generation scalar/lepton masses & gaugino masses unify nicely. squarks, H_2 have larger errors



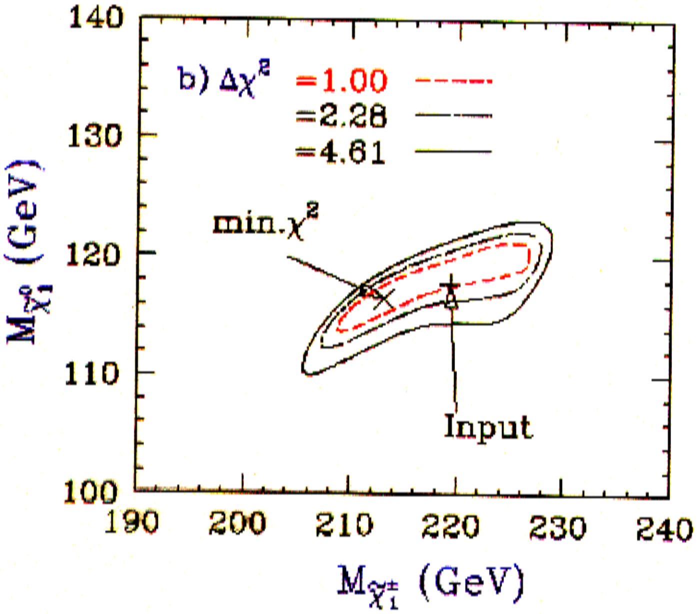


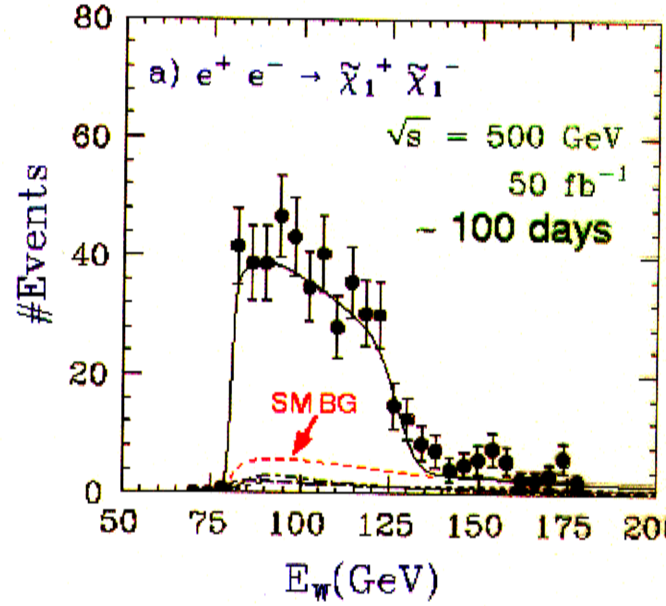


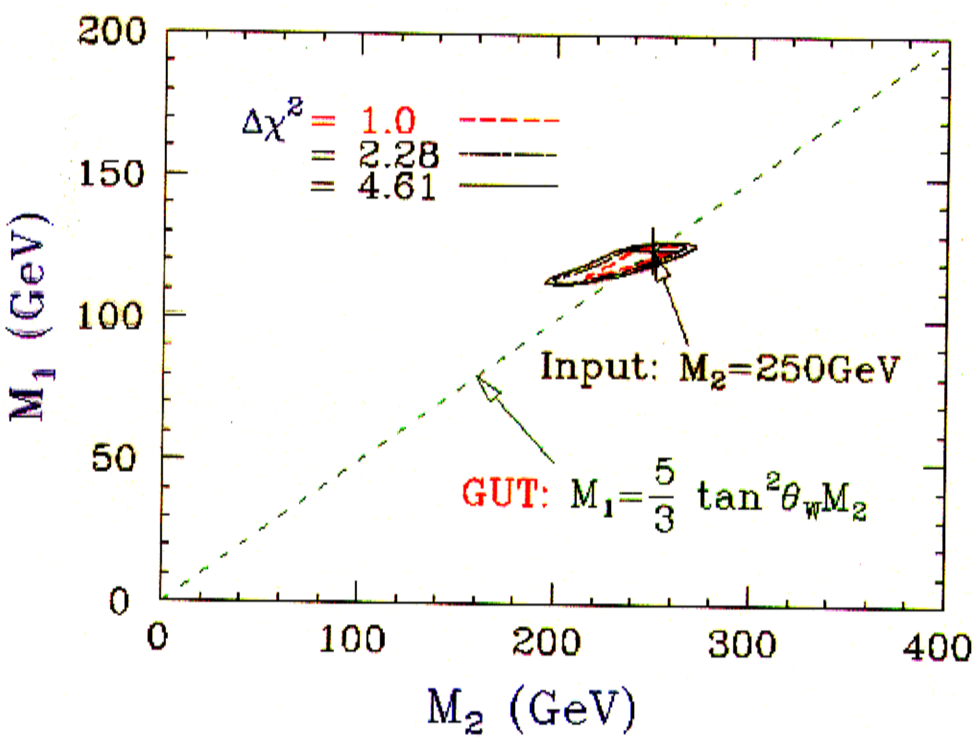


Assuming a universal mass M_0.

one expects. $M^2_{\tilde{e}_L} - M^2_{\tilde{e}_R} = \kappa M^2_{1/2} - \frac{1}{2}(1-4\sin^2\theta_W)\cos 2\beta\, M_Z^2$







$m_{\tilde{\chi}_1^\pm}$, $\sigma_R(\tilde{\chi}_1^\pm)$, angular dist^{n} $\sigma_R(\tilde{e}_R)$, $m_{\tilde{\chi}_1^0}$

Blair, Martyn: Top down approach.

Use all the accurately measured masses from threshold scan.

Assume unification of scalar masses.

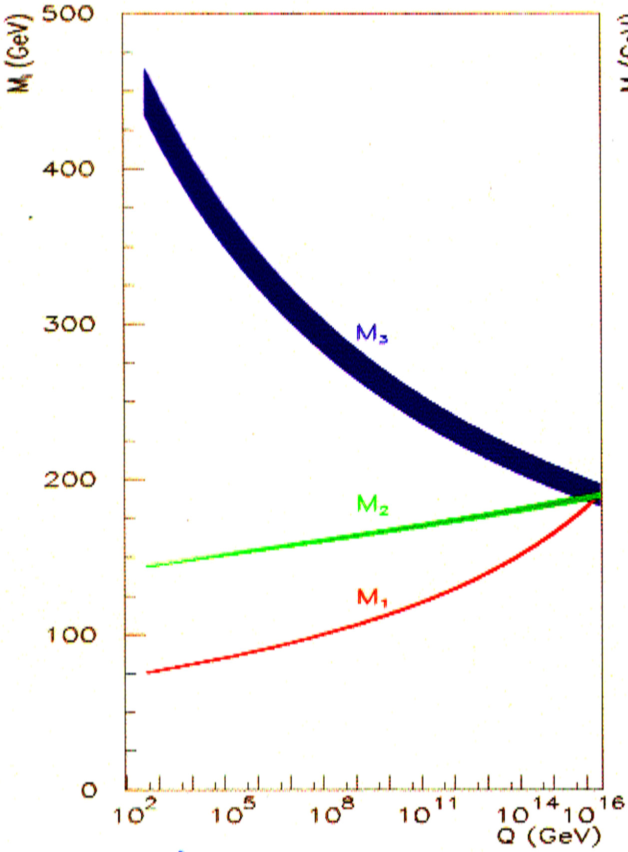
Fit (M_1), M_2, m_0, A_0, $\tan\beta$,

	true value	Error
m_0	100	0.09
$m_{1/2}$	200	0.10
A_0	0	6.3
$\tan\beta$	3	0.02

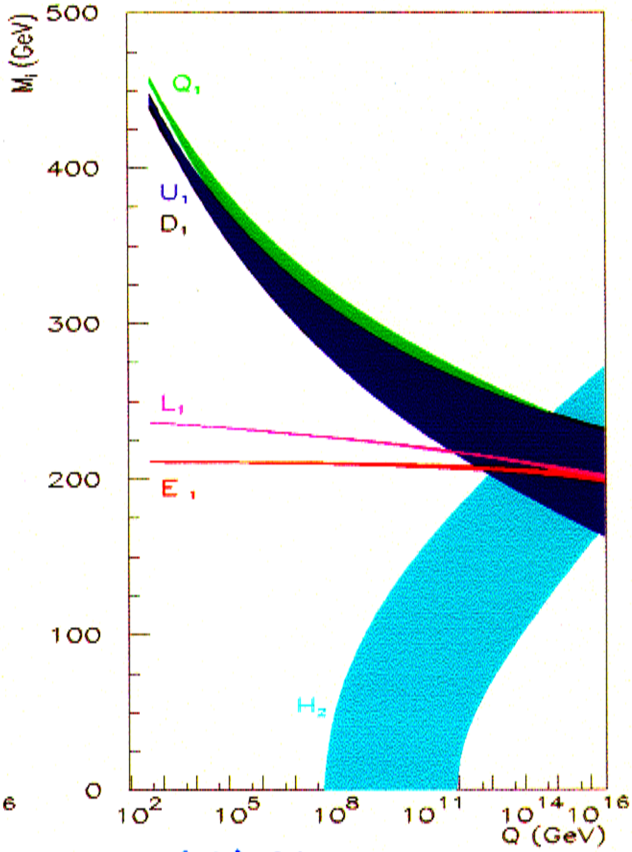
	true value	error
m_0	100	0.09
M_1	200	0.20
M_2	200	0.20
A_0	0	10.3
$\tan\beta$	3	0.04

High luminosity TESLA and (higher energy)
$\sqrt{s} = 500$ GeV

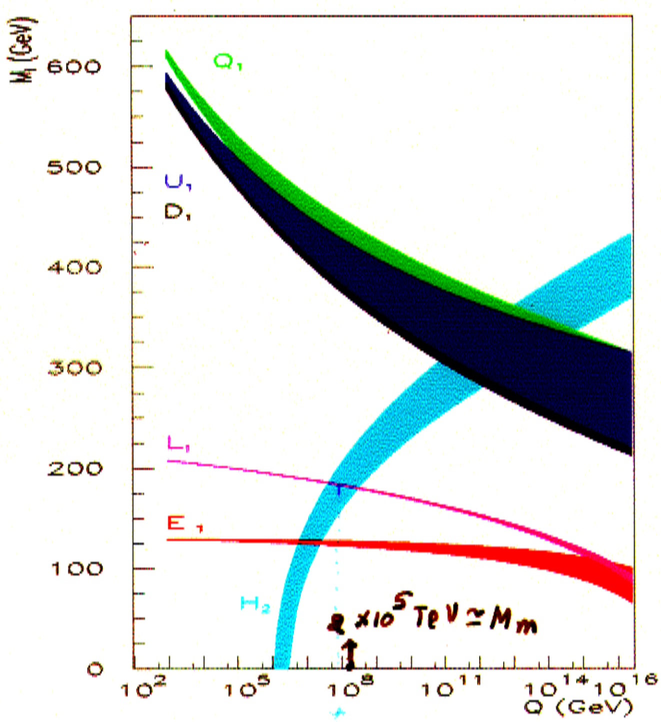
Errors on initial values LC+LHC



(m)SUGRA.



(m) SUGRA. 1 TeV



GMSB

Bottom-up approach:

Possible to determine the soft ~~susy~~ parameters at high scale 'directly' by R.G. evolution.

i) Gaugino masses ⟶

ii) 1st, 2nd generation scalar leptons ⟶
quarks } ⟶ 'larger errors
Higgs }

iii) 3rd generation & A_K : existence of pseudo fixed point increases errors reconstruction of M_0.

High Accuracy possible at LC (TESLA, high luminosity) absolutely essential input to such studies.

Determination of SUSY scale :

Ambrosanio, Blair

GMSB :

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \, \tilde{\chi}_1^0$$

$\tilde{\chi}_1^0 \hookrightarrow \gamma \tilde{G}$

$\tilde{\chi}_1^0 \hookrightarrow \gamma \tilde{G}$

$\hookrightarrow \tilde{G} f \bar{f}$

Fig.

[Use 'charged decays' of $\tilde{\chi}_1^{\pm}$ also]

Delayed decay of $\tilde{\chi}_1^0$ ⇒ nonpointing photon.

1) $\gamma\gamma + \not{E}$ central hard γ's	prompt decay	$\beta\gamma c\tau$ < 1 cm.
2) γ "γ" $\not{E}$ "γ" "γ" $\not{E}$	delayed decays	1 cm < $c\tau$ < 1000 cm
3) $\not{E}$, "γ"		$10 < c\tau < 10^5$

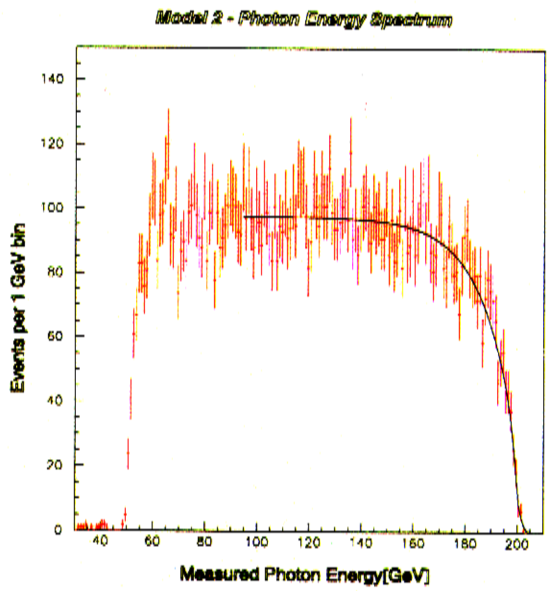
Fig.

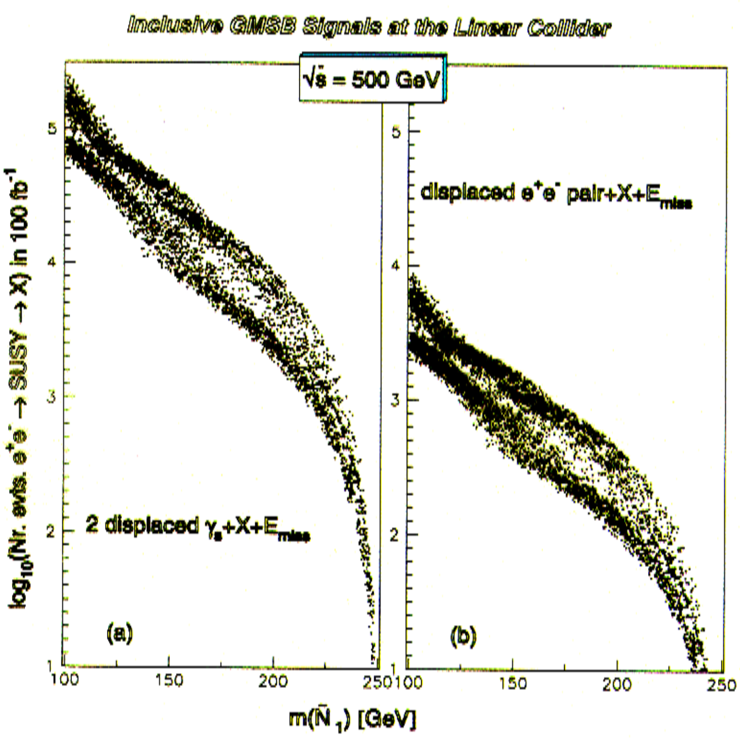
$\tilde{\chi}_1^0$ mass can be measured with E_γ measurement Fig.

Using known value of $m_{\tilde{\chi}_1^0}$, determination of decay length 'λ' on an event by event basis.

Life time can be determined to ~ 10 % over the entire range expected in GMSB models.

$$c\tau \propto \frac{1}{m^5_{\tilde{\chi}_1^0}} \left(\sqrt{F}\right)^4$$


Model 2 - Photon Energy Spectrum
Events per 1 GeV bin
Measured Photon Energy[GeV]


Inclusive GMSB Signals at the Linear Collider
√s = 500 GeV
log10(Nr. evts. e+e- → SUSY → X) in 100 fb-1
2 displaced γs+X+Emiss
(a)
displaced e+e- pair+X+Emiss
(b)
m(Ñ1) [GeV]

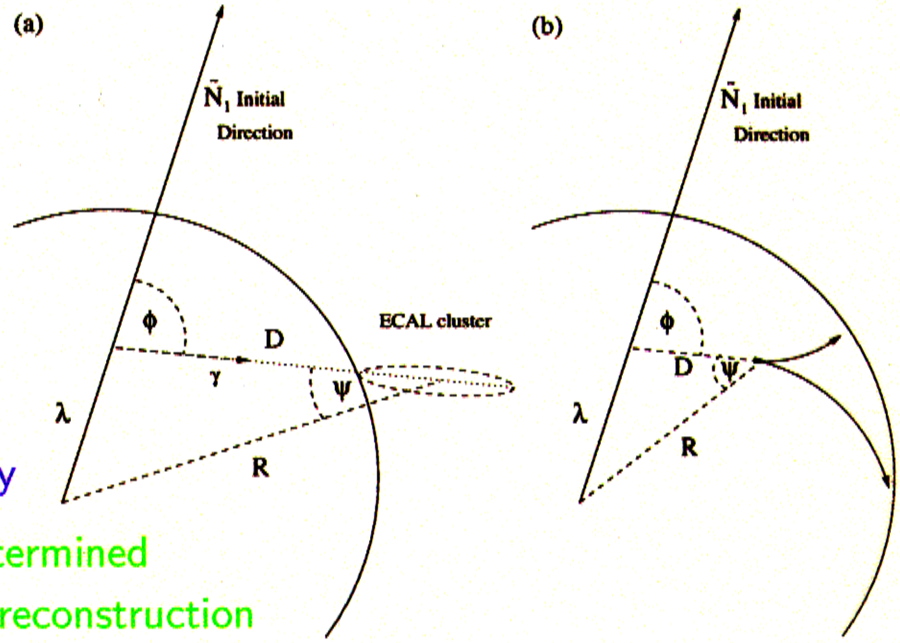
Neutralino NLSP Event Signatures @ LC

⋄ Topology of a $\tilde{N}_1$ decay (one side of each event):

λ = decay length
can be measured
(event-by-event)

ϕ calculated from
measured $m_{\tilde{N}_1}$ and
ECAL shower energy

R and ψ can be determined
from ECAL shower reconstruction
if λ not too small

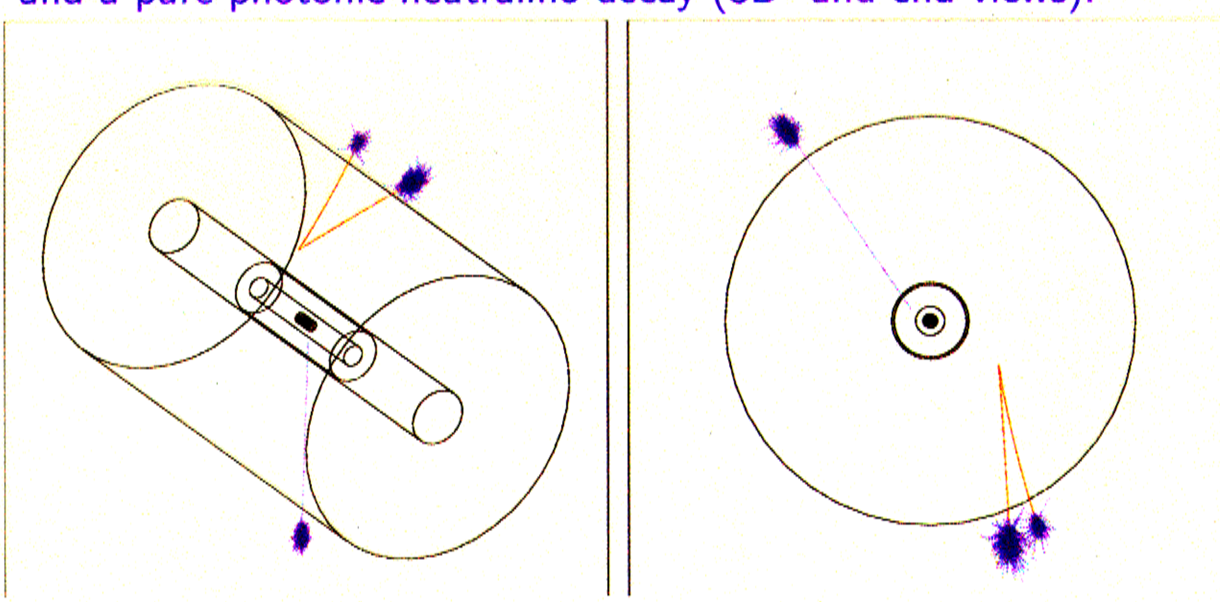


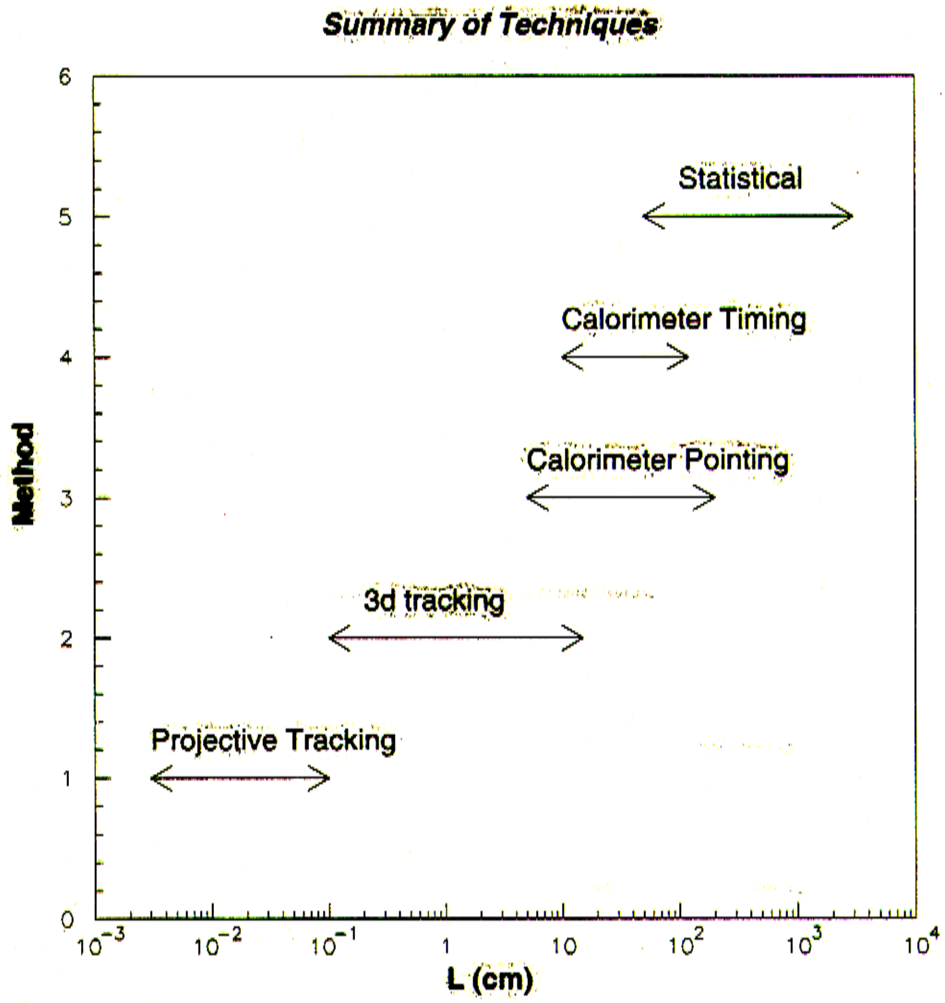
⋆ (a) Pure photonic $\tilde{N}_1$ decay

⋆ (b) γ converts $\to e^+e^-$ $(D \neq 0)$ OR
$\tilde{N}_1 \to$ 3-body "charged decay" $(D = 0)$

$\Longrightarrow$ reconstructed pair's vertex/momentum $\Longrightarrow$ "γ" flight line

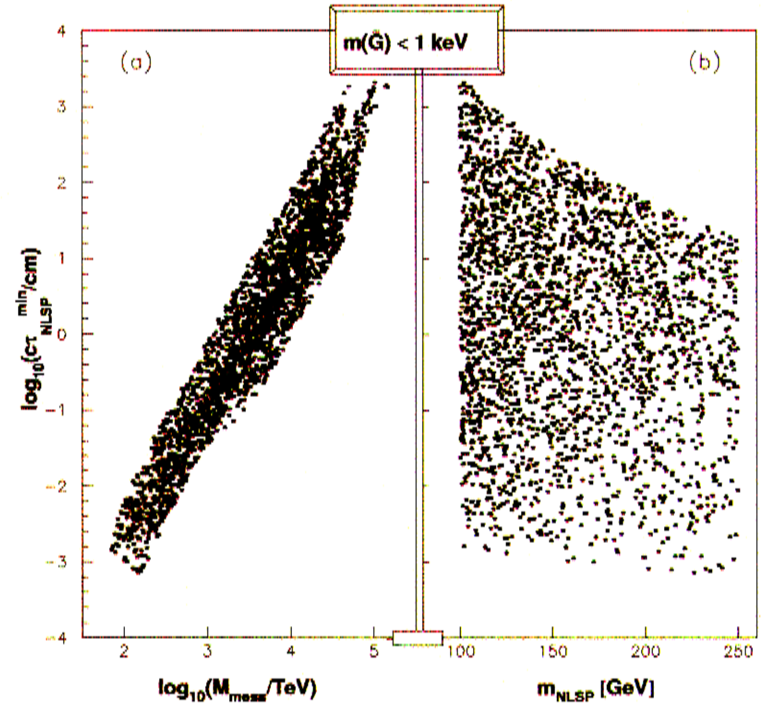
⋆ A fully simulated $e^+e^- \to \tilde{N}_1\tilde{N}_1$ event involving both a "charged" and a pure photonic neutralino decay (3D- and end-views):



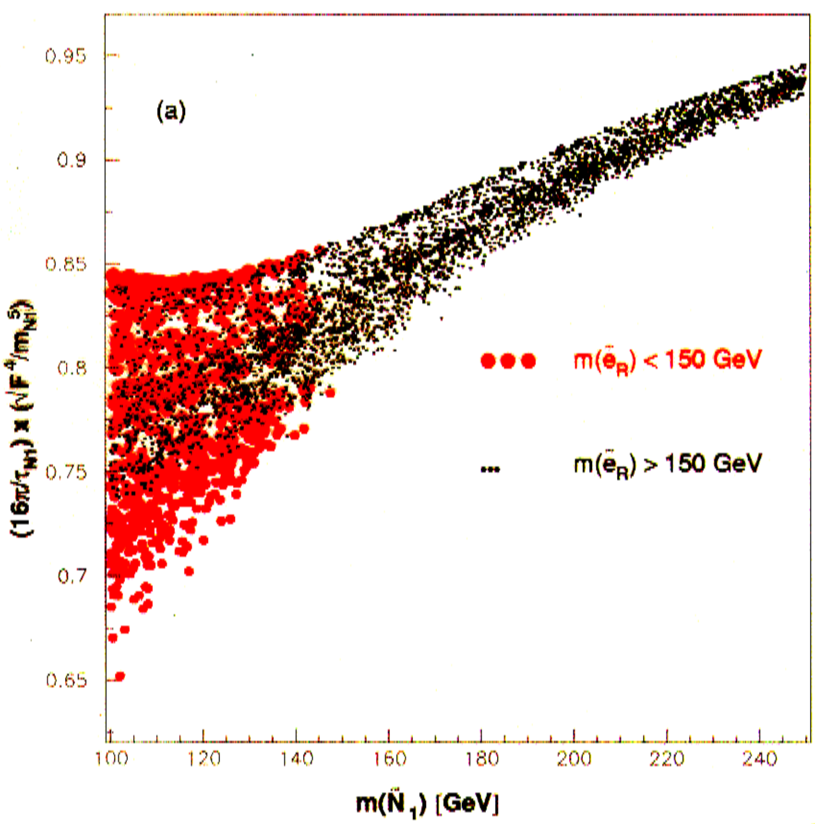


A measurement of L ~~to~~ 10%, is possible over the entire range.

GMSB Models with Neutralino NLSP



Neutralino NLSP Lifetime → $\sqrt{F}$



Information on $m(\tilde{\chi}_1^0)$, $\tau_{\tilde{\chi}_1^0} \Rightarrow \sqrt{F}$

Super Oblique Corrections :

What if squarks are very heavy ?

Can we get a handle on this scale ?

'Super' oblique corrections — Nojiri, Pierce, . . . Feng, Polonsky . . .

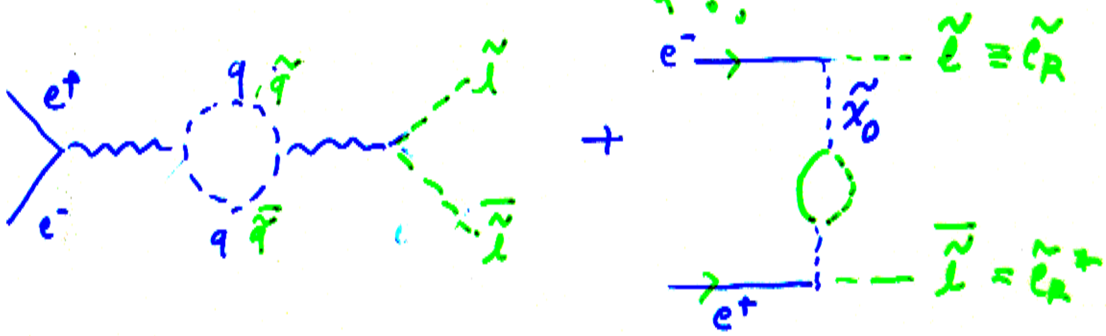
$$g_{ee_R B} = g_{e\tilde{e}_R\tilde{B}} \equiv g_Y \quad \text{'susy'}$$

$$\frac{\delta g_Y}{g_Y} \simeq \frac{11\, g_Y^2}{48\pi^2} \ln\left(\frac{m_{\tilde{Q}}}{m_{\tilde{l}}}\right)$$

* splitting bet. $m_{\tilde{Q}}$ and $m_{\tilde{l}}$ ⟹ corrections.

susy

* corrections even grow with $m_{\tilde{Q}}$!!



$$\frac{m_{\tilde{Q}}}{m_{\tilde{l}}} = 10 \Rightarrow \frac{\delta g_Y}{g_Y} \sim 0.7\%$$

Feng. $e^-e^- \to \tilde{e}_R\tilde{e}_R$

only the 't' channel diagram exists

Measurement of 'super' oblique correction to $\sim 0.15\%$ (using only statistics).

Conclusions :

To get precision information about SUSY, ~~SUSY~~ scale, ~~SUSY~~ mechanism a high, luminosity e^+e^- collider $\sqrt{s} \geq 500$ GeV, upto 1000 GeV will be absolutely essential.

Such a collider can yield model indep., unambiguous information,

'CAN perhaps go a long way towards putting SUSY in text books !!"