

23-3-99

Plenary Review Susy wg

Part I

H-U Martyn

- mSUGRA model studies
- $\tilde{E}\tilde{E}$ production
- GMSB studies
- e^-e^- option

H-U Martyn

A Sopczak et al

G Blair

C Hensch

Part II

W Majerotto

- R_p violating Susy
- $\chi^+\chi^-$ production
- $\chi^0\chi^0$ production
- $\tilde{E}\tilde{E}$ production

M Besaeson, G Leoreanu

J Kalinowski et al

G Krontget-Pick

S Kraml

- Talks at Sitges

- Future tasklist

Supersymmetric Particle Spectrum

particle	spin	SUSY partner	spin	mixed states
leptons ℓ	1/2	sleptons $\tilde{\ell}$	0	
quarks q	1/2	squarks \tilde{q}	0	
gluon g	1	gluino \tilde{g}	1/2	
bosons γ, Z, W	1	gauginos $\tilde{\gamma}, \tilde{Z}, \tilde{W}$	1/2	$\chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0$
Higgs h, A, H	0	higgsinos $\tilde{h}, \tilde{A}, \tilde{H}$	1/2	χ_1^\pm, χ_2^\pm

▷ mSUGRA – 5 parameters specify particle sector

$$\text{LSP} = \chi_1^0$$

• mSUGRA scenario I (S Ambrosanio, G Blair, P Zerwas)

$$m_0 = 100 \text{ GeV}$$

$$M_{1/2} = 200 \text{ GeV}$$

$$A_0 = 0 \text{ GeV}$$

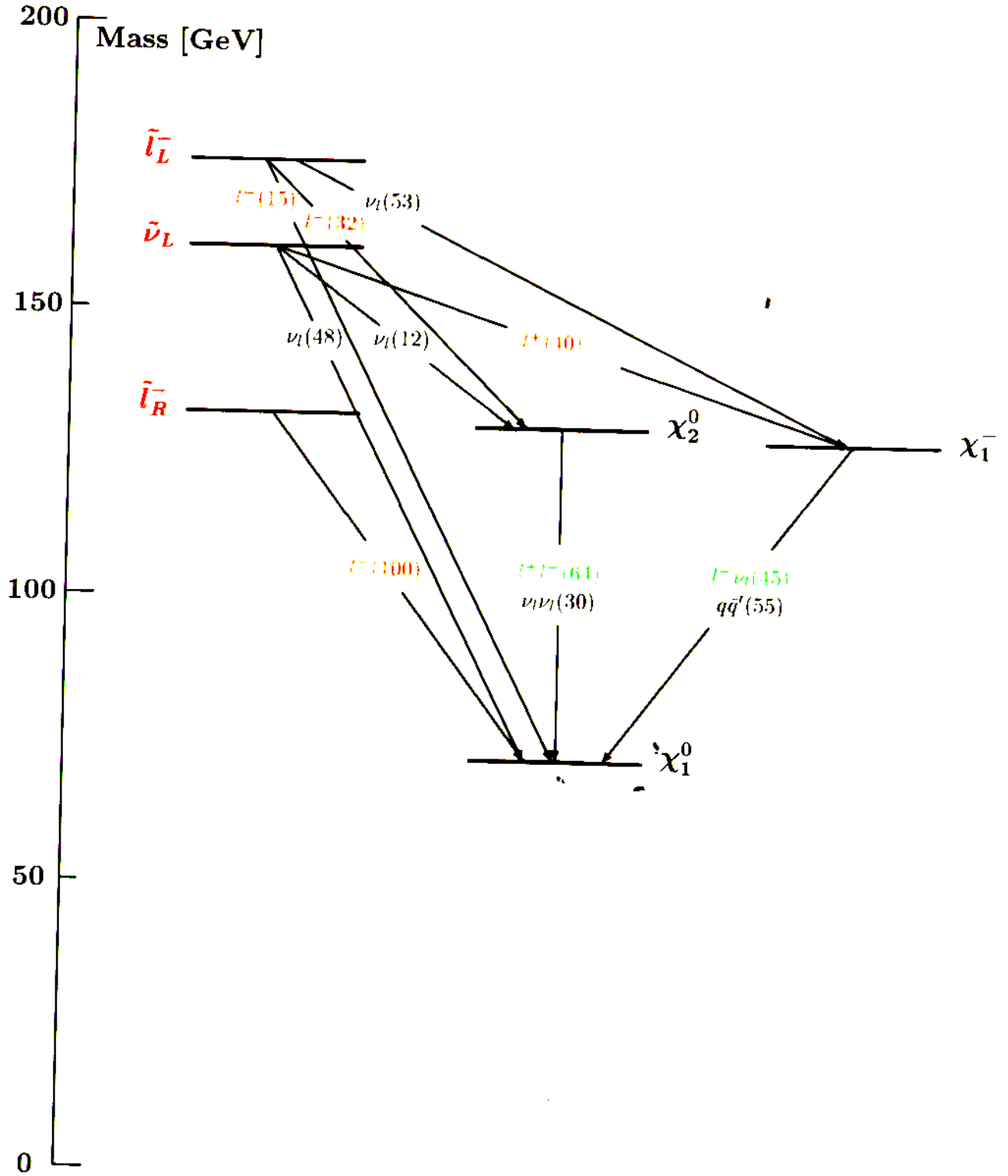
$$\tan \beta = 3$$

$$\text{sign } \mu > 0$$

Scalar Lepton Decays

mSUGRA scenario I

$m_0 = 100 \text{ GeV}$, $M_{1/2} = 200 \text{ GeV}$, $A_0 = 0$, $\tan\beta = 3$, $\text{sign}(\mu) > 0$



$\tilde{l}'s$ & $\chi's$ at $\sqrt{s} = 500$ GeV

$$e^+e^- \rightarrow l^+l^- E_{miss}$$

▷ Search scalar muons $e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\chi^0 \mu^-\chi^0$

topology	$\mu^+ \mu^-$ pair + nothing else in detector
radiative γ veto	$E_\gamma < 5$ GeV $ \cos \theta_\gamma < 0.985$
lepton	2.5 GeV $< E_l < 0.45 \sqrt{s}$ $ \cos \theta_l < 0.90$
one lepton	$Q_l \cos \theta_l < 0.65$
trans. momentum	$ \vec{p}_\perp > 10$ GeV
miss. momentum	$ \cos \theta_{\vec{p}_{miss}} < 0.90$ veto ISR
di-lepton & recoil	$m_{recoil} + 0.4 m_{ll} > 0.6 \sqrt{s}$
thrust axis	$ \cos \theta_T < 0.85$

• Flat lepton energy spectrum of two-body decay

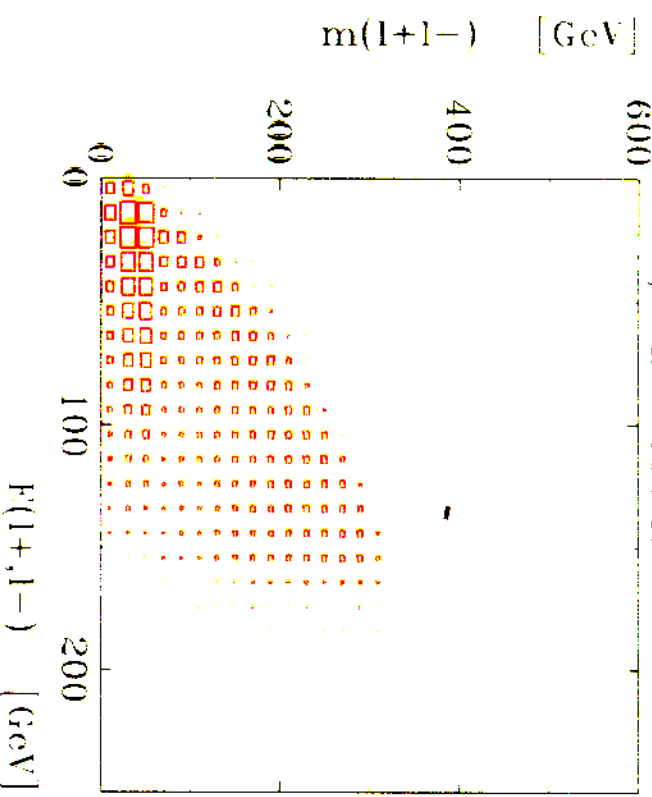
$$E_{max, min} = \frac{m_{\tilde{l}}}{2} \left(1 - \frac{m_\chi^2}{m_{\tilde{l}}^2} \right) \gamma (1 \pm \beta)$$

$$m_{\tilde{l}} = \frac{\sqrt{s}}{E_{min} + E_{max}} \sqrt{E_{min} \cdot E_{max}}$$

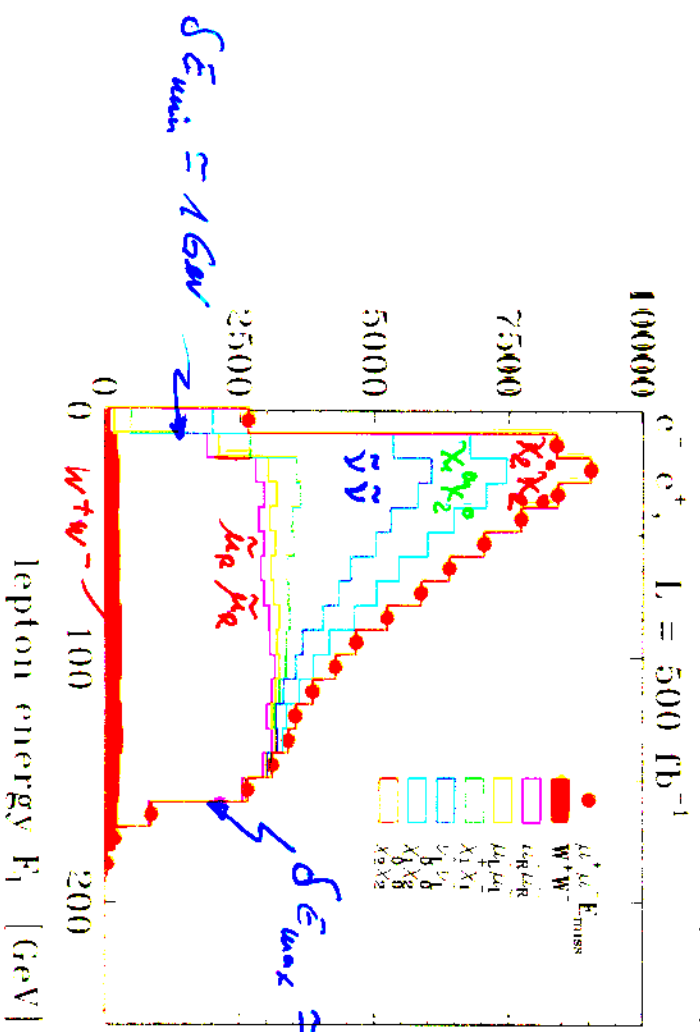
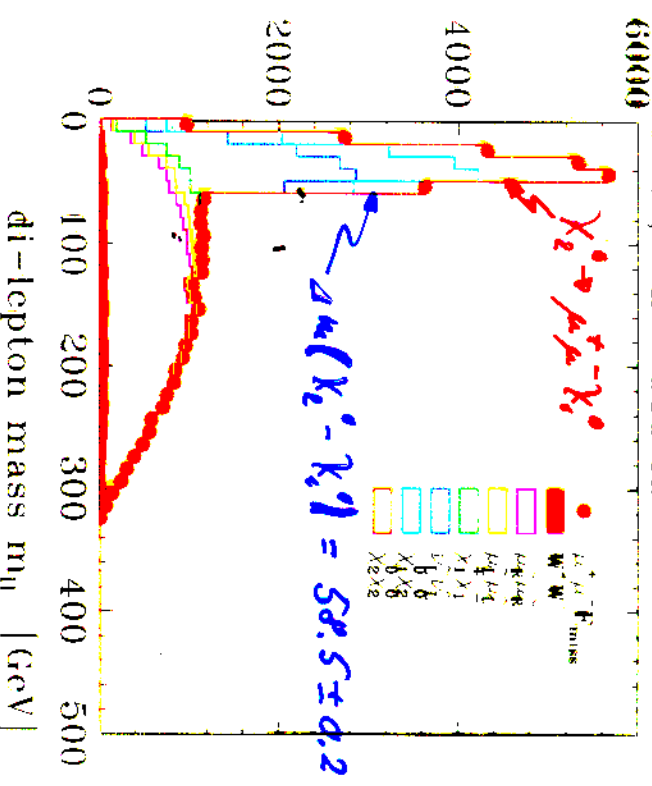
$$m_\chi = m_{\tilde{l}} \sqrt{1 - \frac{E_{min} + E_{max}}{\sqrt{s}/2}}$$

$$\delta m \simeq \frac{m}{2} \left\{ \frac{\delta E_{min}}{E_{min}} \oplus \frac{\delta E_{max}}{E_{max}} \right\}$$

Look - $e^+e^- \rightarrow \mu^+\mu^- F_{miss}$
 $e^+e^-, L = 500 \text{ fb}^{-1}$



$F_{miss} = 500 \text{ GeV}, L = 500 \text{ pb}^{-1}$
 $e^+e^-, L = 500 \text{ fb}^{-1}$



$m_{\tilde{\chi}_0} = 132 \pm 5.5 \text{ GeV}$
 $m_{\tilde{\chi}_1} = 72 \pm 3 \text{ GeV}$

• SUSY signals $\mu^+ \mu^- E_{miss}$ at $\sqrt{s} = 500$ GeV

reaction	$e^- e^+$		$e_R^- e^+$	$e_L^- e^+$	$e_R^- e_L^+$	$e_L^- e_R^+$
	σ [fb]	$\sigma_{\mu\mu}$	$\sigma_{\mu\mu}$	$\sigma_{\mu\mu}$	$\sigma_{\mu\mu}$	$\sigma_{\mu\mu}$
$\tilde{\mu}_R^+ \tilde{\mu}_R^-$	64.2	40.1	61.8	19.2	97.0	24.9
$\tilde{\mu}_L^+ \tilde{\mu}_L^-$	39.2	2.4	1.1	3.7	1.3	5.9
$\tilde{\nu}_L \tilde{\nu}_L$	985	15.5	13.6	17.5	20.0	24.5
$\chi_1^+ \chi_1^-$	311	3.8	0.6	7.0	0.3	11.2
$\chi_1^0 \chi_2^0$	83.9	10.7	7.1	14.3	10.0	22.3
$\chi_2^0 \chi_2^0$	151	11.5	1.8	21.0	0.8	33.6
$W^+ W^-$	7690	4.0	0.6	7.6	0.3	11.9
$\gamma/Z \rightarrow \mu^+ \mu^-$	1090	< 0.04				
$e^+ e^- \mu^+ \mu^-$	$\sim 10^6$	< 0.1				

▷ Important: choice of correct **POLARISATION !!**

(i) gain in signal/background

(ii) gain in rate up to $\sim 2.5 - 3$ wrt unpolarised beams

• Luminosity per year at $\sqrt{s} = 500$ GeV

$$\mathcal{L}(e_L^- e_R^+) = \mathcal{L}(e_R^- e_L^+) = 250 \text{ fb}^{-1}$$

$$\mathcal{P}(e^-) = \pm 85\%$$

$$\mathcal{P}(e^+) = \pm 60\%$$

Scalar Lepton Production

$$e^+e^- \rightarrow \tilde{l}_L^+ \tilde{l}_L^- \rightarrow 6l^\pm$$

$$e^+e^- \rightarrow \tilde{\mu}_L^+ \tilde{\mu}_L^-$$

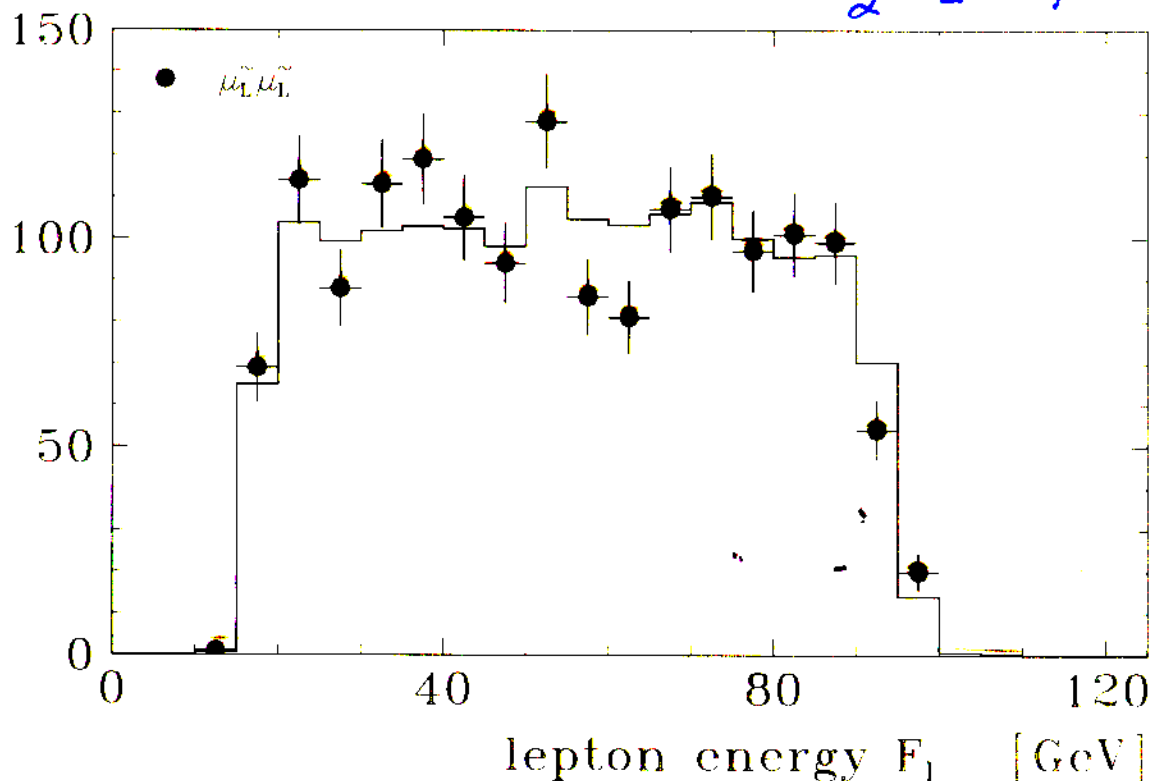
$$\rightarrow \mu^+ \chi_2^0 \mu^- \chi_2^0 \quad Br = 0.32^2$$

$$\chi_2^0 \rightarrow l^+ l^- \chi_1^0 \quad Br(l = e, \mu, \tau) = 0.64$$

$$\sigma(e_L^- e_R^+) \mathcal{B} = 4.0 \text{ fb} \quad \text{at } \sqrt{s} = 500 \text{ GeV}$$

$\Rightarrow m_{\tilde{\mu}_L}$ and $m_{\chi_2^0}$ from E_μ spectrum

auto-subtraction of cascade decays $\chi_2^0 \rightarrow l^+ l^- \chi_1^0$



$$m_{\tilde{\mu}_L} = 176.0 \pm 0.3 \text{ GeV}$$

$$m_{\chi_2^0} = 130.5 \pm 0.2 \text{ GeV}$$

$\Rightarrow \text{Note: } \sigma(e_L^- e_R^+ \rightarrow \tilde{e}_L^+ \tilde{e}_L^-) \mathcal{B} = 13.6 \text{ fb}$

Scalar Lepton Production

$$e^+e^- \rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$$

$$e^+e^- \rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$$

$$\rightarrow \mu^+ \chi_1^0 \mu^- \chi_1^0$$

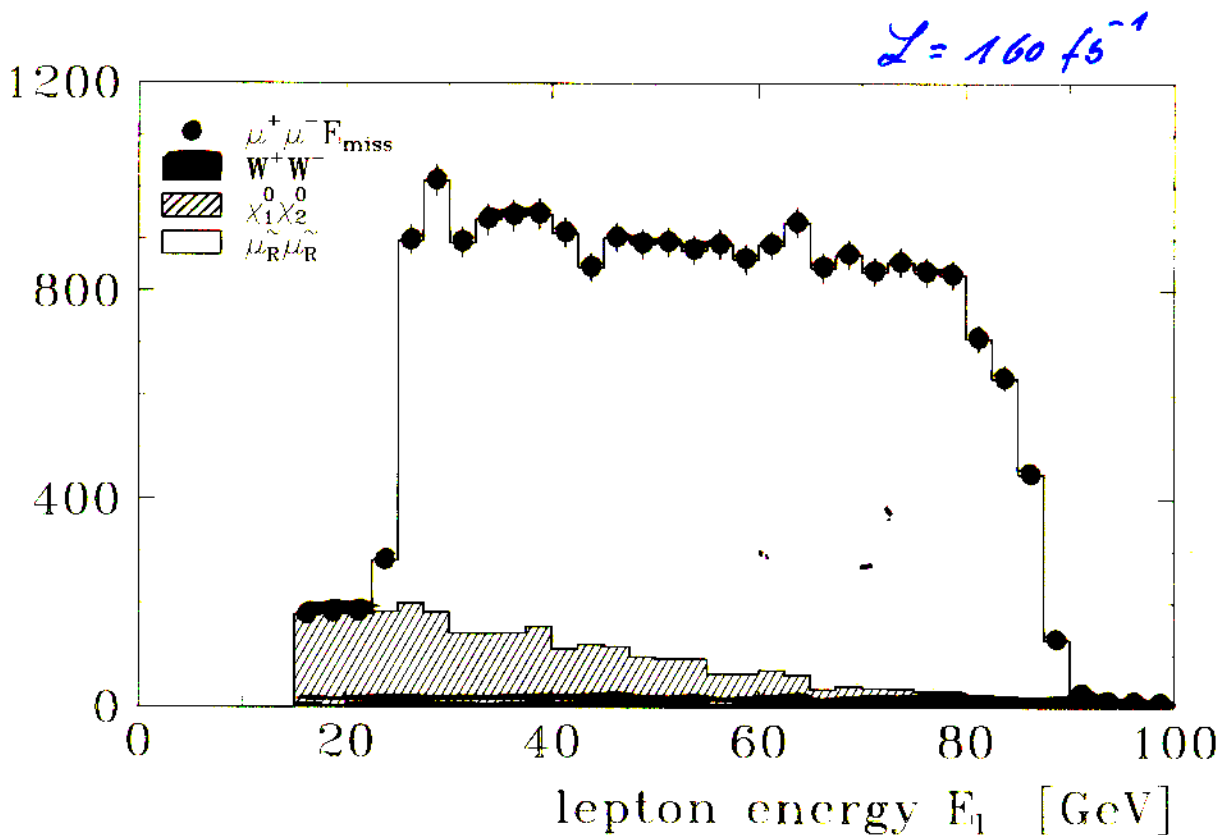
$$\sigma(e_R^- e_L^+) \mathcal{B} = 89.5 \text{ fb} \quad \text{at } \sqrt{s} = 320 \text{ GeV}$$

Backgrounds:

$$\chi_1^0 \chi_2^0 \sim 10\%, \text{ controllable}$$

$$W^+ W^- \text{ negligible}$$

$\Rightarrow m_{\tilde{\mu}_R}$ and $m_{\chi_1^0}$ from E_μ spectrum



$$m_{\tilde{\mu}_R} = 132.0 \pm 0.3 \text{ GeV}$$

$$m_{\chi_1^0} = 71.9 \pm 0.2 \text{ GeV}$$

Chargino Production

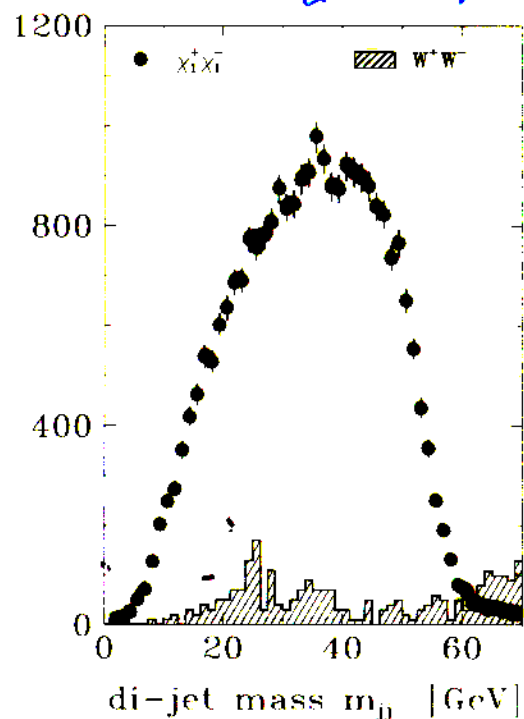
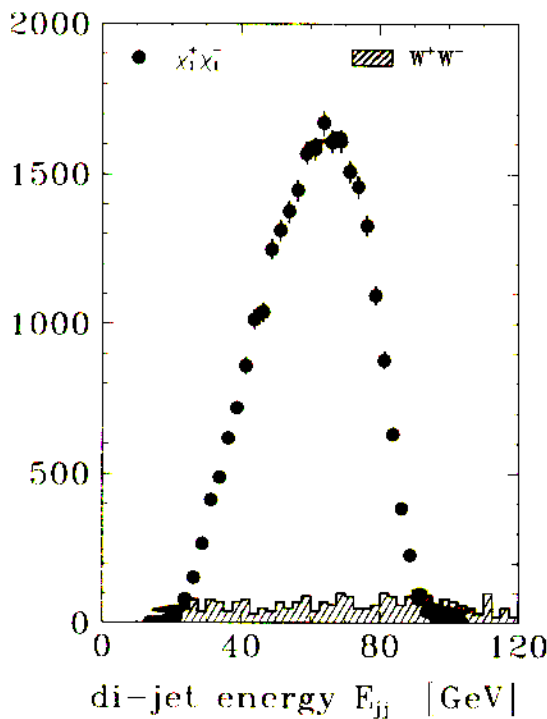
$$e^+e^- \rightarrow \chi_1^+ \chi_1^-$$

$$\begin{aligned}
 e^+e^- &\rightarrow \chi_1^+ \chi_1^- \\
 &\rightarrow l^\pm \nu \chi_1^0 q\bar{q}' \chi_1^0 \quad Br = 2 \cdot 0.45 \cdot 0.55 \\
 \sigma(e_L^- e_R^+) \mathcal{B} &= 330 \text{ fb} \quad \text{at } \sqrt{s} = 320 \text{ GeV}
 \end{aligned}$$

Background:

$$W^+W^- < 10\%$$

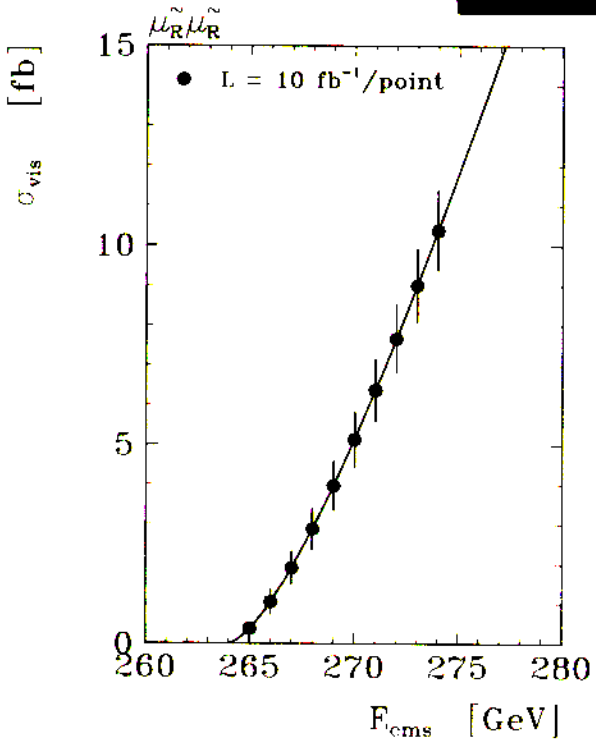
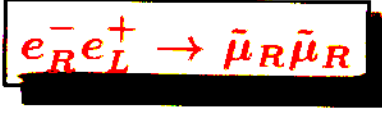
$\Rightarrow m_{\chi_1^\pm}$ and $m_{\chi_1^0}$ from di-jet energy and mass spectra



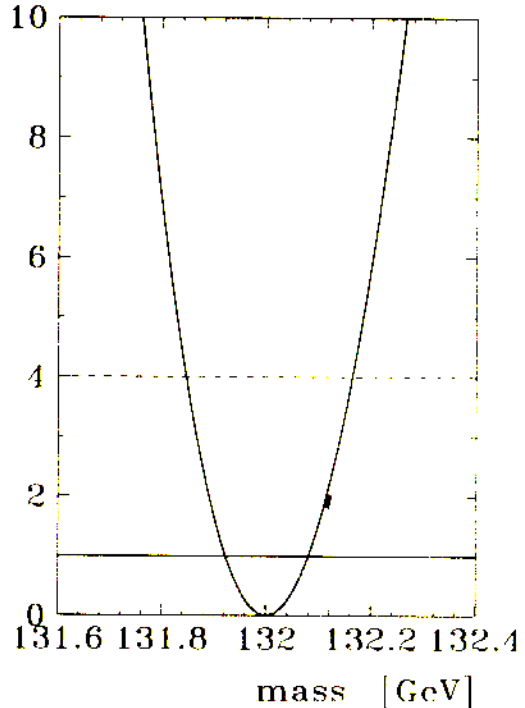
$$m_{\chi_1^\pm} = 127.7 \pm 0.2 \text{ GeV}$$

$$\Delta m(\chi_1^\pm - \chi_1^0) = 55.8 \pm 0.15$$

Threshold Scans



$\Delta \chi^2$

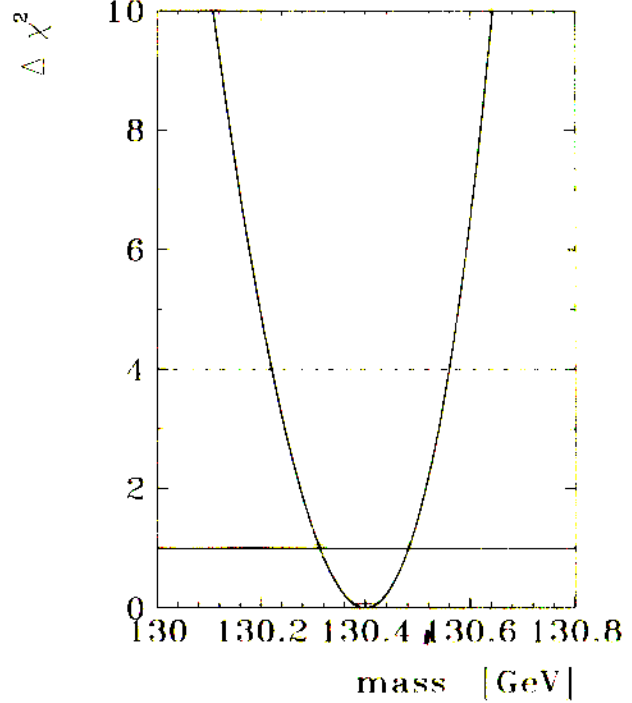
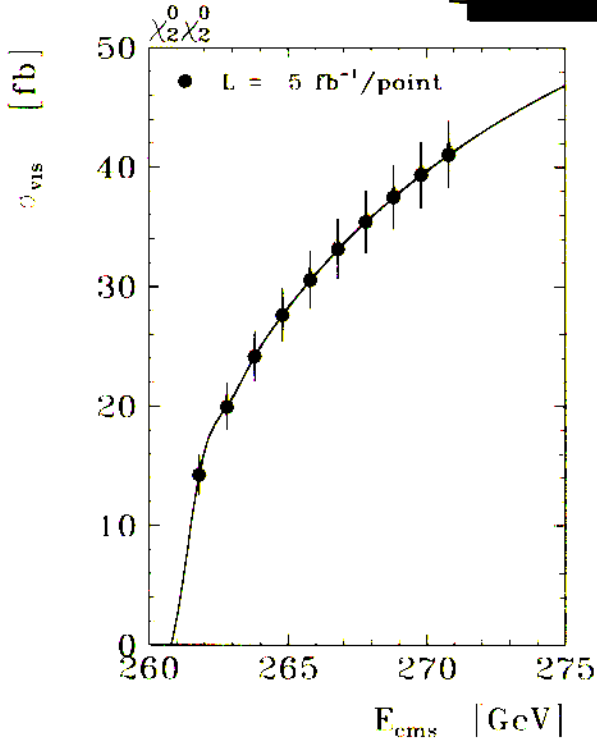


$m_{\tilde{\mu}_R} = 132.0 \pm 0.08 \text{ GeV}$

$\mathcal{L} = 100 \text{ fb}^{-1}/10 \text{ pt}$

$\sigma \sim \beta^3$

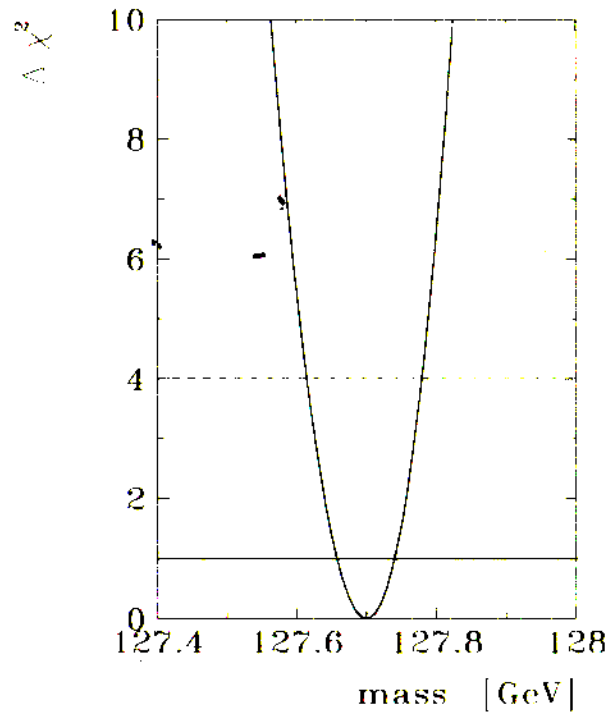
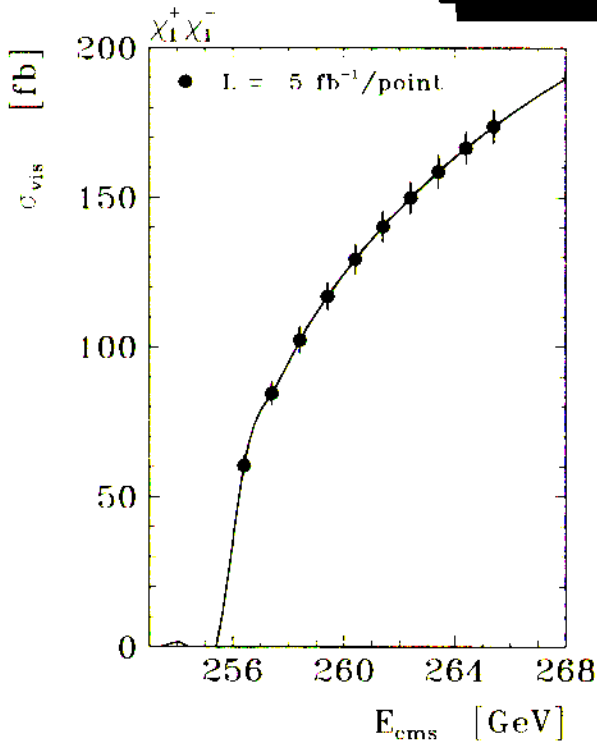
2 monoenergetic μ 's



$$m_{\chi_2^0} = 130.4 \pm 0.08 \text{ GeV}$$

$$\mathcal{L} = 50 \text{ fb}^{-1} / 10 \text{ pt}$$

$\sigma \sim \beta$



$$m_{\chi_1^\pm} = 127.7 \pm 0.05 \text{ GeV}$$

$$\mathcal{L} = 50 \text{ fb}^{-1} / 10 \text{ pt}$$

$\tilde{t}\tilde{t}$ production

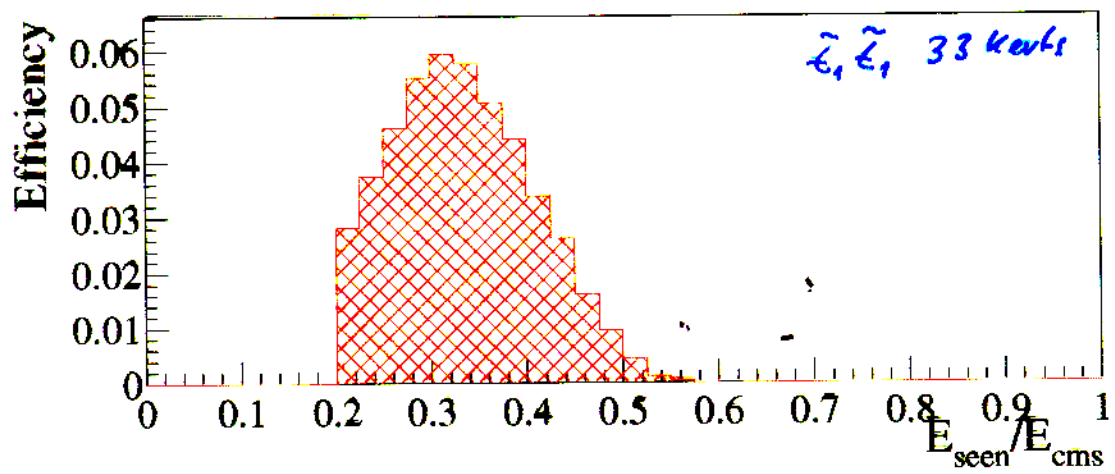
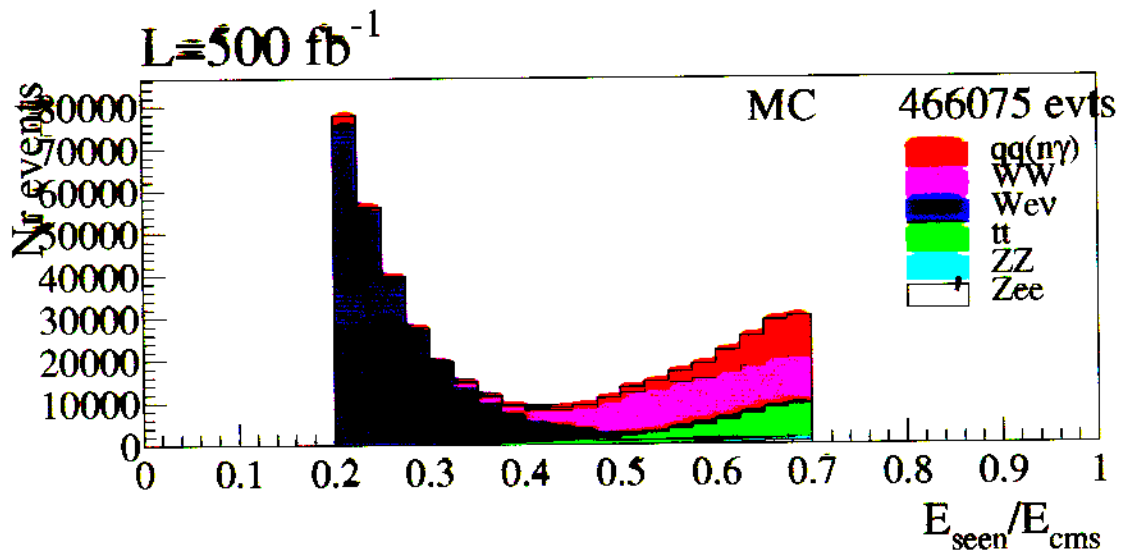
$$\tilde{t}_1 = \tilde{t}_L \cos\theta + \tilde{t}_R \sin\theta$$

$$\tilde{t}_2 = -\tilde{t}_L \sin\theta + \tilde{t}_R \cos\theta \quad m(\tilde{t}_1) < m(\tilde{t}_2)$$

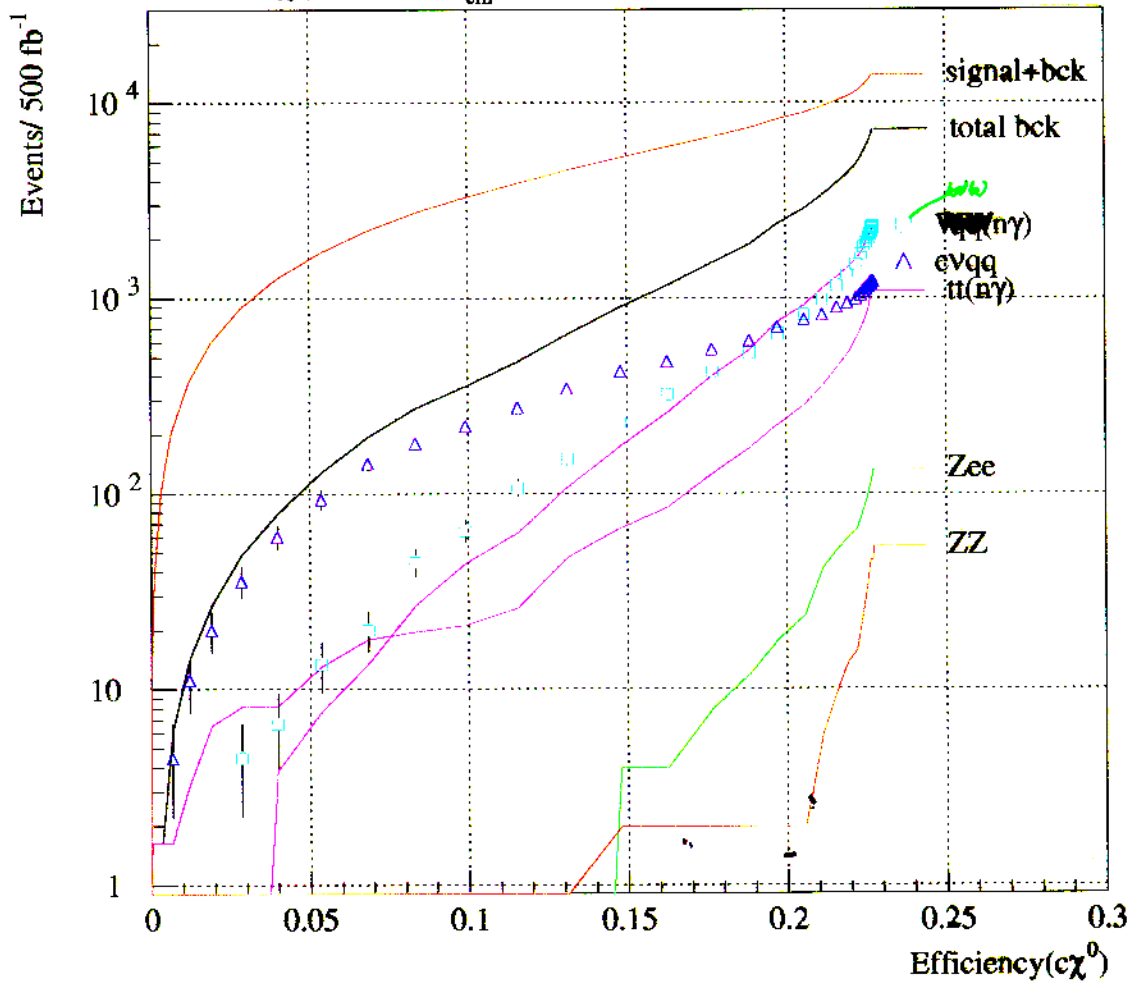
choice: $m_{\tilde{t}_1} = 180 \text{ GeV}$ $\cos\theta = 0.57$ min x-section
 $\mathcal{L} = 500 \text{ fb}^{-1}$ at $\sqrt{s} = 500 \text{ GeV}$

decay model $\tilde{t}_1 \rightarrow e \chi_1^0$
 $\rightarrow b \chi_1^\pm$ still under study

- huge SM background, $\sigma_{b\tilde{t}_1} \sim 60 \text{ fb}$
- current event topology
- apply iterative discriminant analysis using many variables $\Sigma \approx 1290$
- get mass & mixing angle from $\sigma_L(\tilde{e}_L e^t)$ and $\sigma_R(\tilde{e}_R e^t)$



STOP($c\chi^0$) $\sigma=59$ fb, $E_{cm}=500$ GeV, e^- NO POLARIZATION



Results and Conclusions

- 500 fb⁻¹ simulated: 16 mio events.
- Rerun after Frascati to fix small problems.
- More precise xsections (most important $We\nu$)
- L- and R-polarized cross sections in the IDA.
- Large sensitivity improvement with LEP2 knowledge.
- Errors on cross section for L- and R-polarized:

Polarization	Efficiency	Background	Cross section(fb)
L-polarized	12%	650	61.2 ± 0.9
unpolarized	12%	400	59.1 ± 0.9
R-polarized	12%	240	57.1 ± 1.0

- only 2% stat. err.
- \implies sys. err. : beamstrah., luminosity, ...
- \implies theoretical precision
- \implies Mass and mixing angle determination
- \implies Determination of soft-breaking parameters

Introduction:

One option for breaking SUSY is via Gauge Mediated interactions GMSB.

The essential phenomenological consequences are:

- ◇ The gravitino is very light (few eV): $\tilde{G} = \text{LSP}!$

$$m_{3/2} = m_{\tilde{G}} = \frac{F}{\sqrt{3}M_P} \simeq \left(\frac{\sqrt{F}}{100 \text{ TeV}} \right)^2 2.37 \text{ eV},$$

- ◇ We consider the case where the NLSP is the neutralino, \tilde{N}_1 .

- ◇ \tilde{N}_1 is unstable. We consider the main cases:

$$\begin{aligned} \tilde{N}_1 &\rightarrow \gamma \tilde{G} && \text{displaced } \gamma \\ &&& \text{time delayed } \gamma \\ \tilde{N}_1 &\rightarrow Z^0 \tilde{G} \\ \tilde{N}_1 &\rightarrow f \bar{f} \tilde{G} && \text{few \%} \end{aligned} \left. \vphantom{\begin{aligned} \tilde{N}_1 &\rightarrow \gamma \tilde{G} \\ \tilde{N}_1 &\rightarrow Z^0 \tilde{G} \\ \tilde{N}_1 &\rightarrow f \bar{f} \tilde{G} \end{aligned}} \right\} 2^{\text{nd}} \text{ vertex}$$

- ◇ The \tilde{N}_1 lifetimes and branching have been calculated (S.A.) and included in a modified version of SUSYGEN, including the correct q^2 distributions for the decay to $f \bar{f} \tilde{G}$.

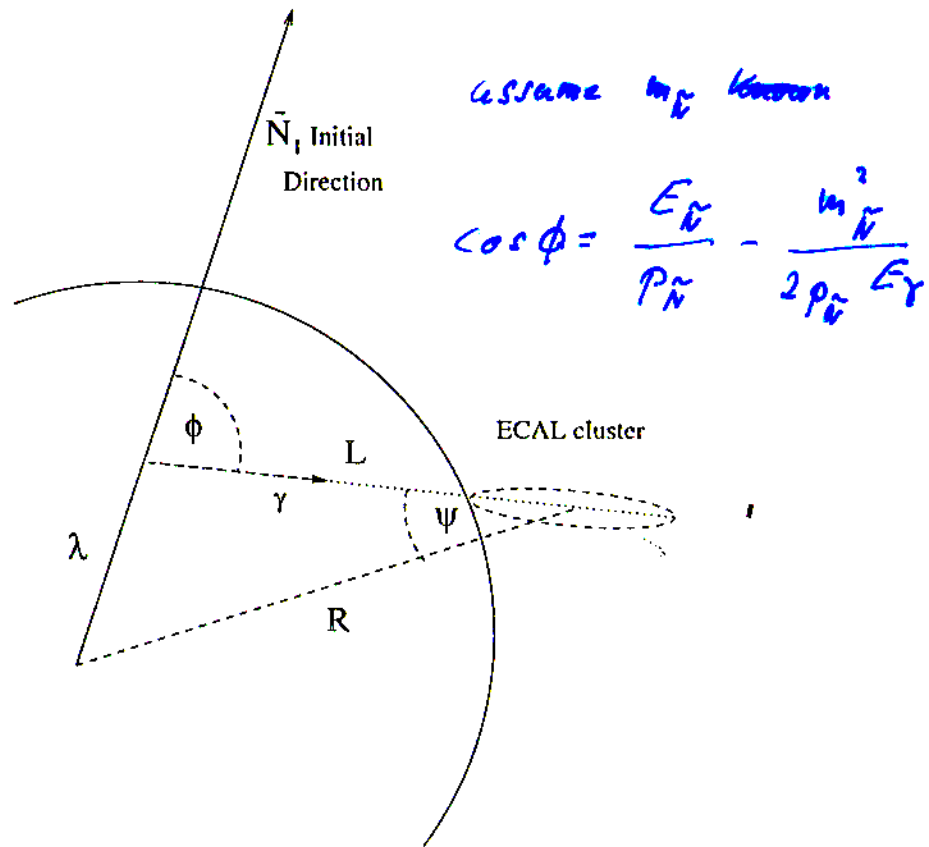
- ◇ We consider models containing a range of masses between 100 GeV and 200 GeV for the \tilde{N}_1 . Presented here are:

Model #1: $M_{\text{mess}} = 161 \text{ TeV}$; $N_{\text{mess}} = 1$; $\Lambda = 76 \text{ TeV}$;
 $\tan \beta = 3$; with $M_{\tilde{N}_1} = 100 \text{ GeV}$

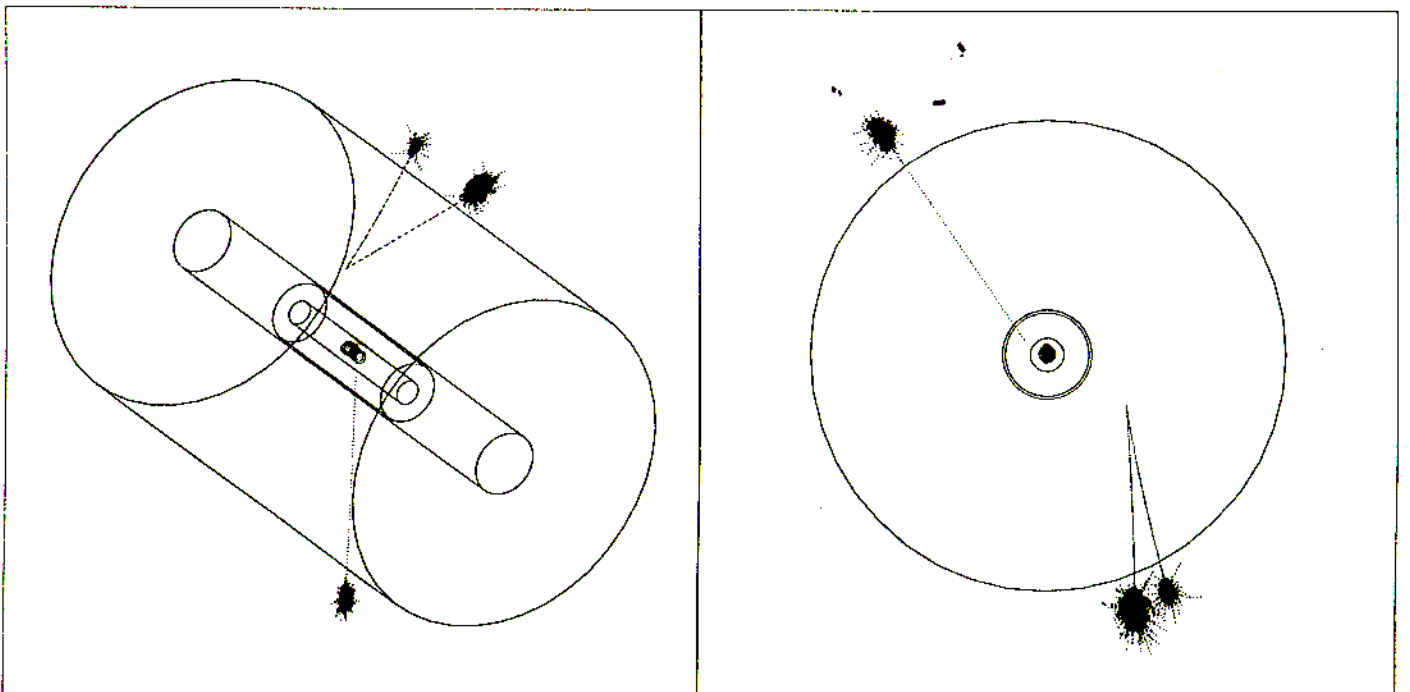
Model #2: $M_{\text{mess}} = 309 \text{ TeV}$; $N_{\text{mess}} = 1$; $\Lambda = 146 \text{ TeV}$;
 $\tan \beta = 3.5$; $\mu > 0$ with $M_{\tilde{N}_1} = 200 \text{ GeV}$

Event Signatures

The general event topology can be described as:



A fully simulated event involving both a "charged" and a photonic neutralino decay (3D- and end-view):



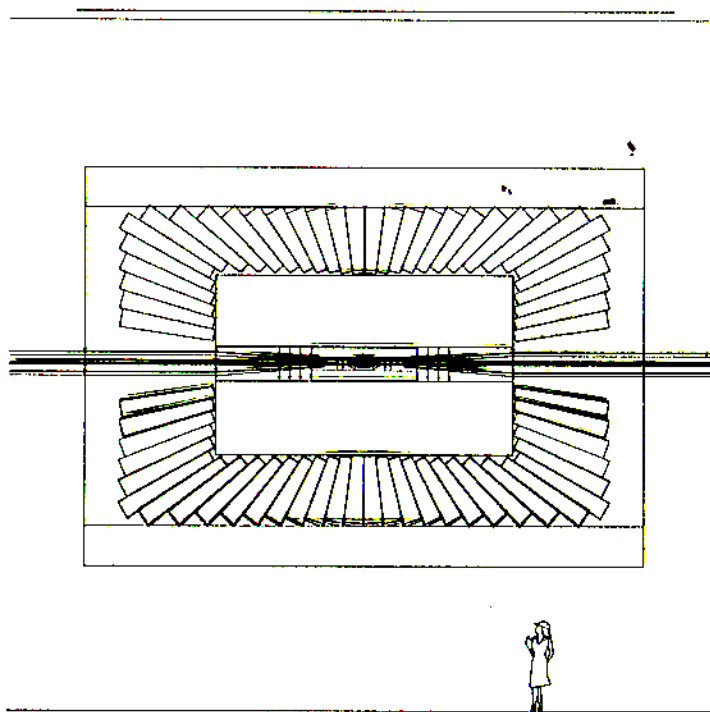
Simulation using BRAHMS

BRAHMS, was used for detector simulation.

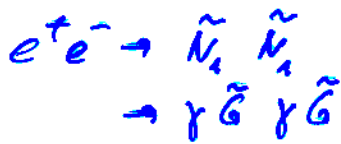
Full shower simulation was not employed. Instead the following parameters were used when particles hit the calorimeter:

Angular Coverage	$ \cos \theta < 0.95$
Barrel r - Dimensions (cm)	$172 < r < 210$
Endcap z -Dimensions (cm)	$280 < z < 330$
Energy Resolution (%)	$10.3/\sqrt{E \text{ GeV}} + 0.6$
Spatial Resolution (cm)	$4/\sqrt{E \text{ GeV}} + 2$
Angular Pointing Resolution (mrad)	$50/\sqrt{E \text{ GeV}}$
Time Resolution (ns)	$2/\sqrt{E \text{ GeV}} + 0.5$

The full material of the CDR inner detector was included and hits in tracking detectors used to reconstruct tracks in the case of charged decays, or conversions.

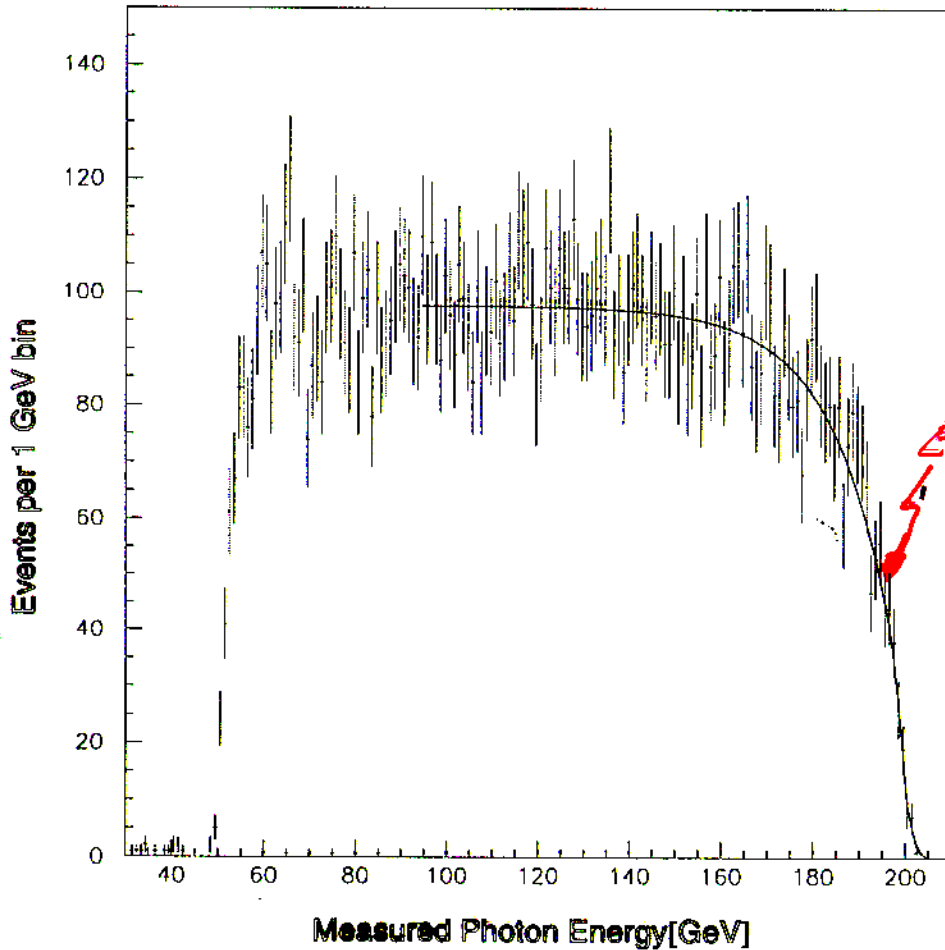


Photon Energy Spectrum :



$$E_{\gamma}^{\max} = \frac{1}{4} (\sqrt{s} \pm \sqrt{s - 4m_{\tilde{G}}^2})$$

Model 2 - Photon Energy Spectrum



$$m_{\tilde{N}_1} = 199.7 \pm 0.3 \text{ GeV}$$

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The plot includes ISR, beamstrahlung and calorimeter resolution.

Statistics corresponds to 200 fb⁻¹.

The fit is to the phenomenological function (where Freq is the cumulative normal distribution):

$$\frac{1}{n_0} \frac{dn}{dE} = 0.788 - 0.716 \exp\left(\frac{E - E_{\gamma}^{\max}}{13.5}\right) - 0.0722 \exp\left(\frac{E - E_{\gamma}^{\max}}{6.06}\right) + 0.212 \text{ Freq}\left(\frac{E - E_{\gamma}^{\max}}{1.87}\right)$$

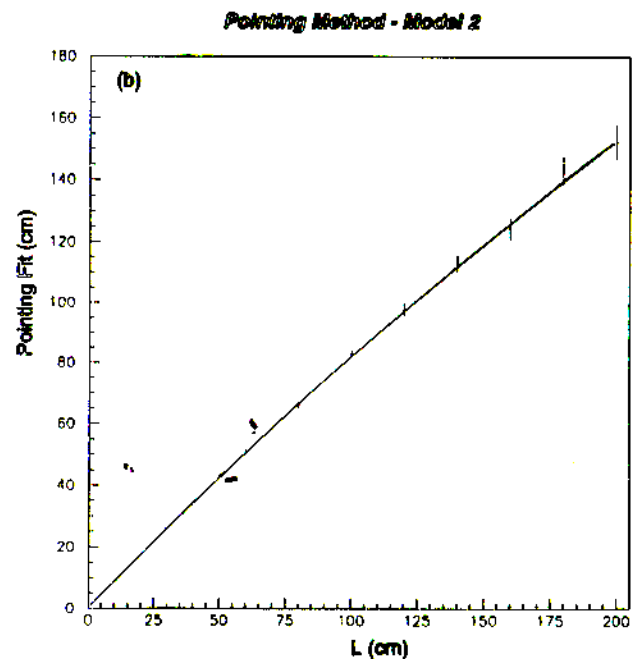
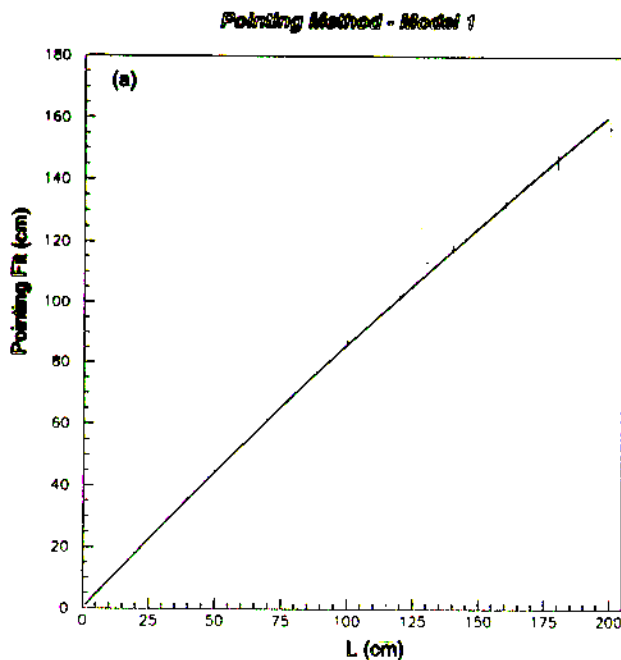
Calorimeter Pointing Method:

Using the angle ψ obtained from the ECAL shower development, together with ϕ from the ECAL energy provides a value of λ .

- ◇ We use and angular ψ resolution of $50 \text{ mrad}/\sqrt{E}$ as a benchmark.
$$\delta\psi = \frac{50 \text{ mrad}}{\sqrt{E}}$$
- ◇ All photons (usually 2 per event) can be used, so statistics are not a problem for the regions of interest.
- ◇ ISR is included and affects the slope of the plots.

Model #1

Model #2



The lines show the effect of a $\pm 100 \text{ MeV}$ shift on $m_{\tilde{N}_1}$; there is clearly no significant dependence.

Conclusion: the calorimeter pointing method is excellent for $5\text{cm} < L < 2 \text{ m}$, with statistical error of order 1-5% over the region of interest.

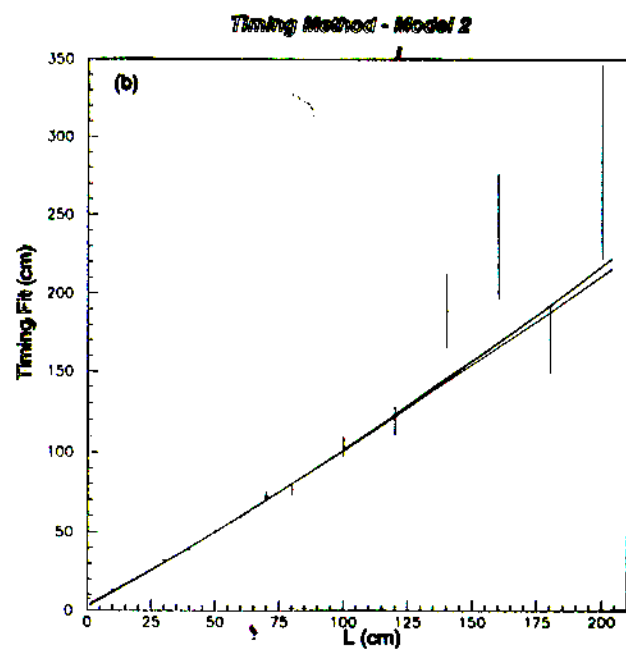
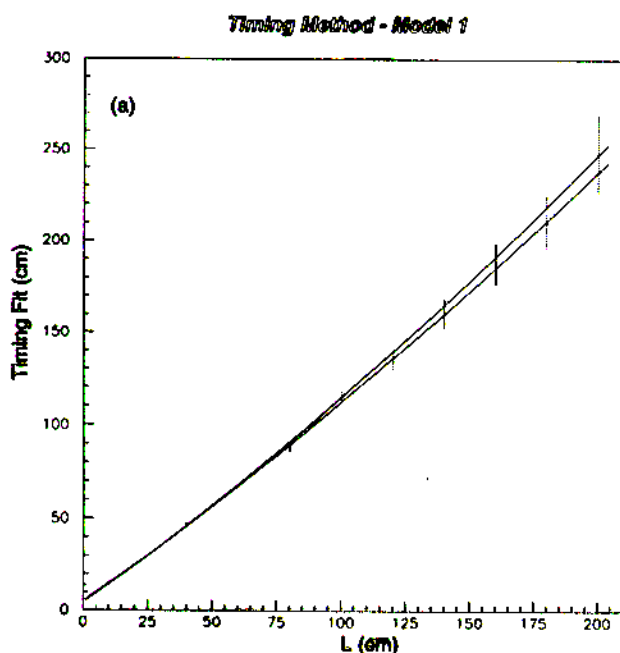
Calorimeter Timing Method:

Using timing information from the ECAL, together with ϕ from the ECAL energy means that λ can be usually obtained up to a quadratic ambiguity.

- ◇ We use timing resolution of approximately 0.5 ns as a benchmark.
- ◇ ISR is included and affects the slope of the plots.

Model #1

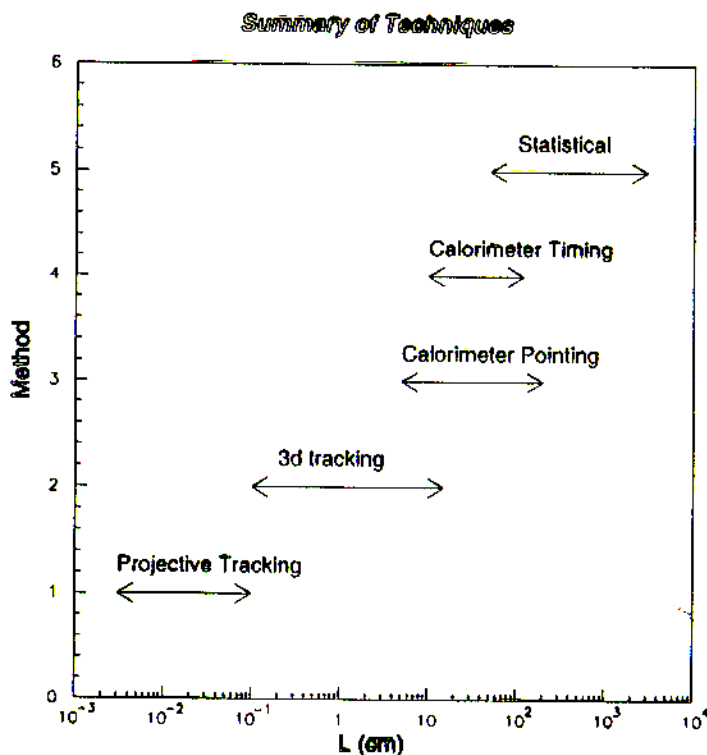
Model #2



The lines show the effect of a ± 100 MeV shift on $m_{\tilde{N}_1}$; there is clearly no major dependence.

- ◇ The calorimeter timing method is relevant for $10\text{cm} < L < 120\text{ cm}$
- ◇ The method is not as precise as the pointing method.
- ◇ Timing is essential for background suppression (cosmics, beam related...) so should be available, regardless of its use in an L measurement.

Conclusions:



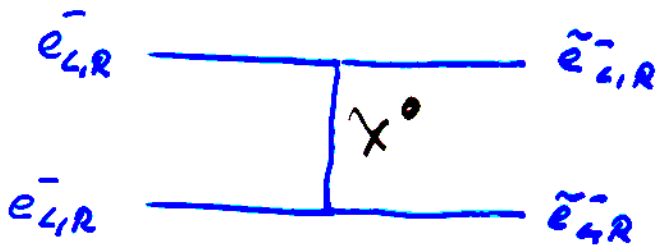
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- TESLA/CDR detector are ideally suited for GMSB searches.
- The study has been performed for a representative set of models.
- There is redundancy over most of the L measurement range.
- The LC allows a choice of thresholds and \dot{E} - p constraints for λ .
- $\beta\gamma$ can be tuned to optimise σ vs $\beta\gamma$. Typically a factor of $2-3^{\pm 1}$ can be thus obtained at the end points.
- NLSP lifetimes could be measured to approximately 10% or better throughout the range:

$$\sim 10\text{microns} < c\tau < \sim 50\text{m}$$

- The study has assumed 200 fb^{-1} - any reduction in $\int \mathcal{L}$ will eat away at the ends of the $c\tau$ -reach. High luminosity is important.

e^-e^- option



$$\tilde{e}^- \rightarrow e^- \gamma^0$$

advantages/interest

- both beams high polarisation
- high m_τ sensitivity at threshold $\sigma \sim \beta$
- access to neutralino mass matrix in t -channel exchange

Gain wrt e^+e^- running not yet quantified
needs to be studied