ECFA / DESY Amsterdam

Special features of SUSY Parameter Determination from e^-e^- Experimentation

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SLEPTON Masses :

$m\,(\tilde{e}_R\,,\ \tilde{e}_L)$

$m\,(\tilde{\mu})$

NEUTRALINO Masses

NEUTRALINO Mass Matrix :

CP - Violating Phases

The greatest challenge for our understanding of Supersymmetry will be our capability to determine a key set of its ~120 parameters:

masses
couplings
phases
mixing parameters ...

Let us start with

$\boxed{\text{SLEPTON MASSES}}$

$\tilde{e}_R, \tilde{e}_L \qquad \tilde{\mu}_R, \tilde{\mu}_L$ ..

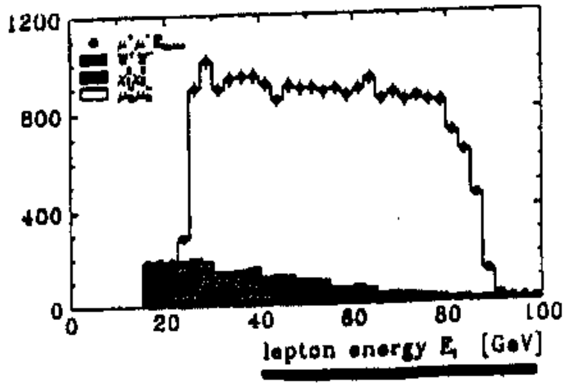
Even if the LHC "finds" them, their precise values will have to be found at the Linear Collider. Try

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

Scalar sleptons decay isotropically in their rest frame

→ flat lepton spectrum
in lab frame

endpoints give slepton, neutralino masses

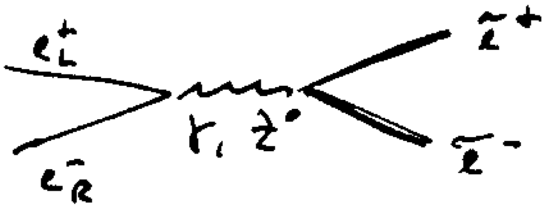


H.U. Martyn

But: More precise: threshold scan of production cross section

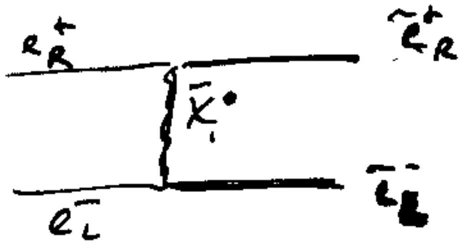
But recall: take selectron case,

expect $m(\tilde{e}_L) > m(\tilde{e}_R)$



$\boxed{\sigma \sim \beta^3}$

angular momentum barrier!

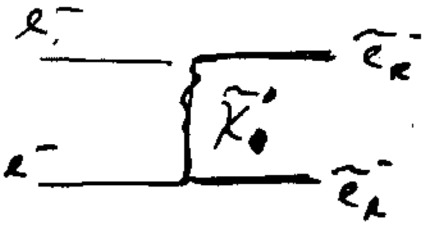


hard-to-remove backgrounds!

But:

If we have **highly polarised** e^-_R, e^-_L beams,

study threshold of
$e^- e^- \to \tilde{e}^-_R \, \tilde{e}^-_R$



$\boxed{\sigma \sim \beta}$ at threshold

STEEP RISE!

and: e^-_L switches off most backgrounds!

$$e^-_R e^+_L \to \tilde{e}^-_R \tilde{e}^+_R \quad : \quad \frac{\pi\alpha^2}{2s}\beta^3 \sin^2\theta \Big|\frac{s}{M_1^2} N_{RR}(t) - (1 + \frac{s_w^2}{c_w^2}\frac{s}{s-m_Z^2})\Big|^2$$

$$e^-_R e^+_L \to \tilde{e}^-_L \tilde{e}^+_L \quad : \quad \frac{\pi\alpha^2}{2s}\beta^3 \sin^2\theta \Big|1 - \frac{\frac{1}{2} - s_w^2}{c_w^2}\frac{s}{s-m_Z^2}\Big|^2$$

$$e^-_R e^+_R \to \tilde{e}^-_R \tilde{e}^+_L \quad : \quad \frac{2\pi\alpha^2}{s}\beta\frac{s}{M_1^2}\big|M_{LR}(t)\big|^2$$

$$e^-_L e^+_L \to \tilde{e}^-_L \tilde{e}^+_R \quad : \quad \frac{2\pi\alpha^2}{s}\beta\frac{s}{M_1^2}\big|M_{LR}(t)\big|^2$$

$$e^-_L e^+_R \to \tilde{e}^-_R \tilde{e}^+_R \quad : \quad \frac{\pi\alpha^2}{2s}\beta^3 \sin^2\theta \Big|1 - \frac{\frac{1}{2} - s_w^2}{c_w^2}\frac{s}{s-m_Z^2}\Big|^2$$

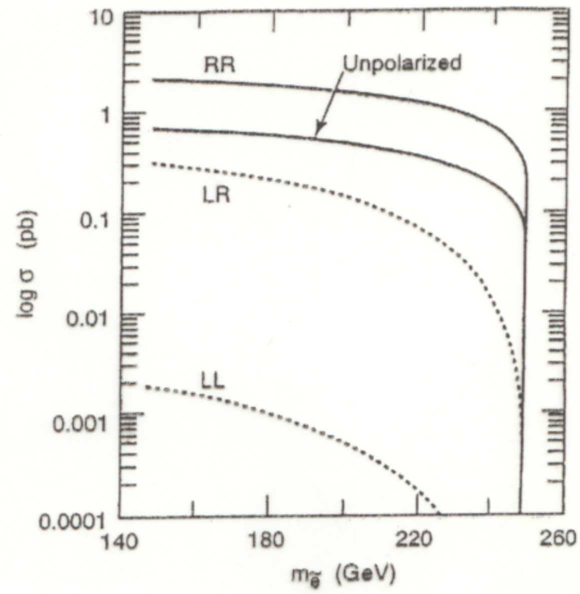
$$e^-_L e^+_R \to \tilde{e}^-_L \tilde{e}^+_L \quad : \quad \frac{\pi\alpha^2}{2s}\beta^3 \sin^2\theta \Big|\frac{s}{M_1^2} N_{LL}(t) - (1 + \frac{(\frac{1}{2} - s_w^2)^2}{c_w^2 s_w^2}\frac{s}{s-m_Z^2})\Big|^2$$

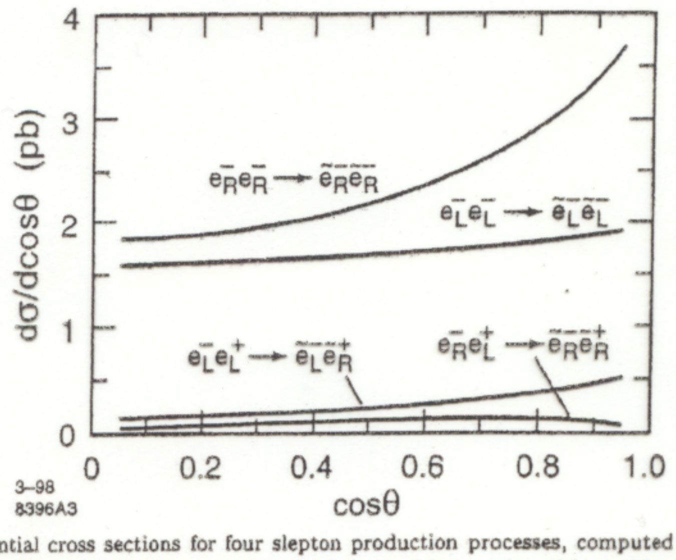
$$e^-_R e^-_R \to \tilde{e}^-_R \tilde{e}^-_R \quad : \quad \frac{2\pi\alpha^2}{s}\beta\frac{s}{M_1^2}\big|M_{RR}(t) + M_{RR}(u)\big|^2$$

$$e^-_L e^-_R \to \tilde{e}^-_L \tilde{e}^-_R \quad : \quad \frac{\pi\alpha^2}{2s}\beta^3 \sin^2\theta \Big|\frac{s}{M_1^2} N_{LR}(t)\Big|^2$$

$$e^-_L e^-_L \to \tilde{e}^-_L \tilde{e}^-_L \quad : \quad \frac{2\pi\alpha^2}{s}\beta\frac{s}{M_1^2}\big|M_{LL}(t) + M_{LL}(u)\big|^2 .$$

The importance of being highly polarized:

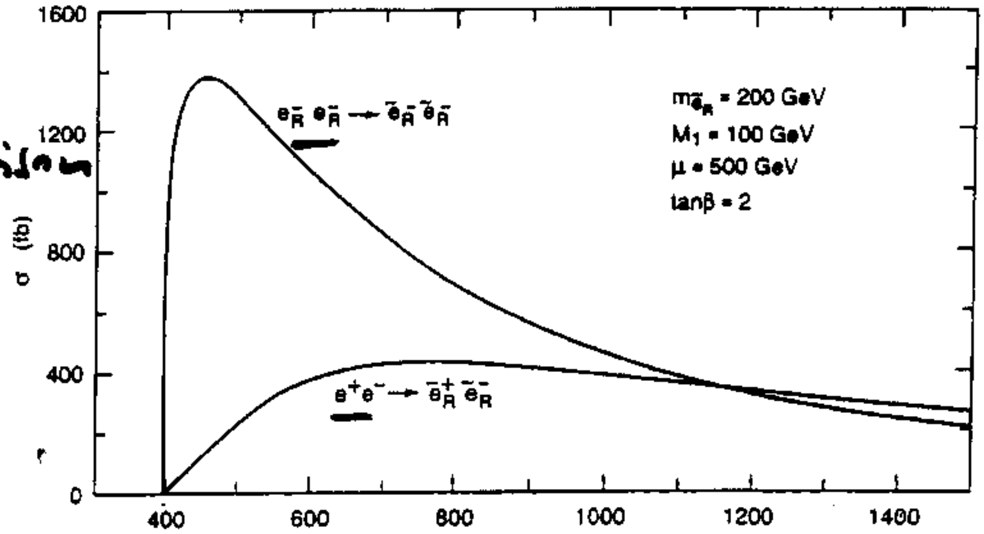




. Differential cross sections for four slepton production processes, computed at a point in the Higgsino region, with $m_2/\mu = -5$ for $\tan\beta = 4$. I have taken $M_1 = 50$, $m(e_R) = 150$, $m(e_L) = 200$, $\sqrt{s} = 500$ GeV.

before $\tilde{e}^-$ width, bremsstrahlung, rad 'cor's

rough comparison of e^+e^- e^-e^-



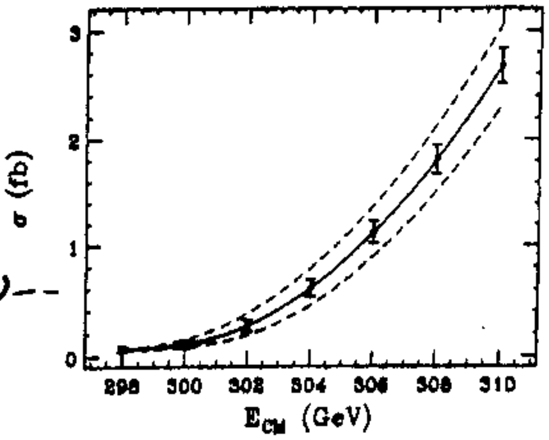
Feng & Peskin compared

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

$P_{e^-} = 0.8$

$\Delta m_{\tilde{e}_R} = \pm 100$ MeV

1 fb^{-1} per point

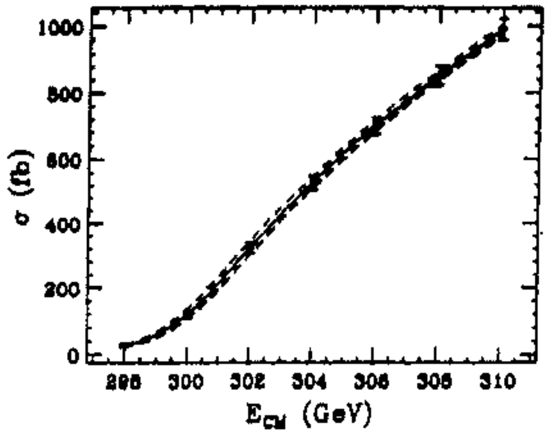


$e^+e^- \to \tilde{e}_R^+ \tilde{e}_R^-$

$P_{e^+} = 0$, $P_{e^-} = 0.8$

$\Delta m_{\tilde{e}_R} = \pm 400$ MeV

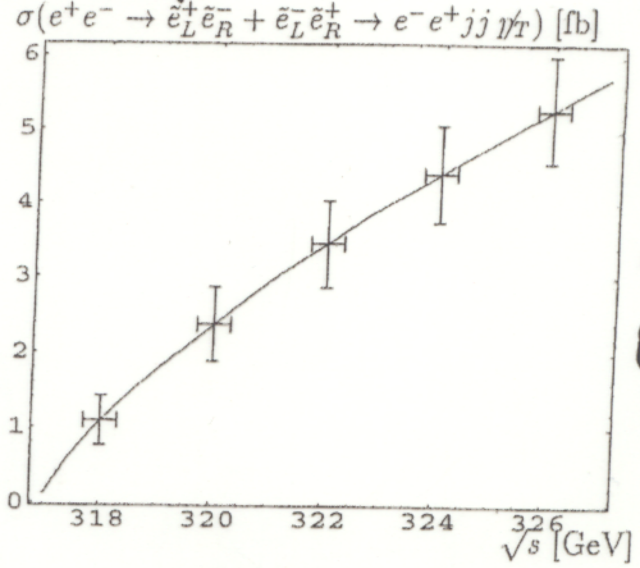
vs. 100 fb^{-1} per point



threshold scan for e^+e^-

note the small slope

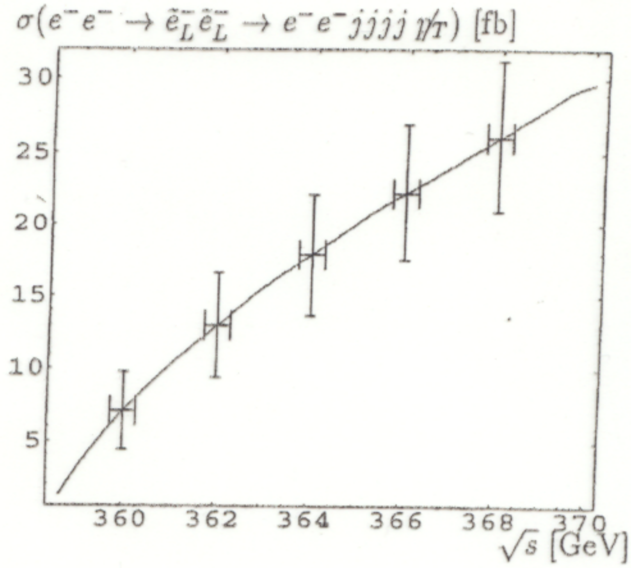
low e^+ pol'n, $m(\tilde{e}_L \neq \tilde{e}_R)$ make for poor threshold quality



Threshold behaviour of the processes $e^+e^- \to \tilde{e}_L^+\tilde{e}_R^- + \tilde{e}_L^-\tilde{e}_R^+ \to e^-e^+jj\ \not{p}_T$ for $P_{e^-} = 0.8$ and $P_{e^+} = 0.6$, $M_2 = 152$ GeV, $\mu = 316$ GeV and $\tan\beta = 3$. ISR corrections and beamstrahlung are included. The error bars show the statistical error for $\mathcal{L} = 10$ fb^{-1}.

... and for e^-e^-

clean signal, well-defined mass resolution!



Threshold behaviour of the process in $e^-e^- \to \tilde{e}_L^-\tilde{e}_L^- \to e^-e^-jjjj\not{p}_T$ for $P_{e_1} = -0.8$ and $P_{e_2} = -0.8$. ISR corrections and beamstrahlung are included. The error bars show the statistical error for $\mathcal{L} = 1$ fb^{-1}.

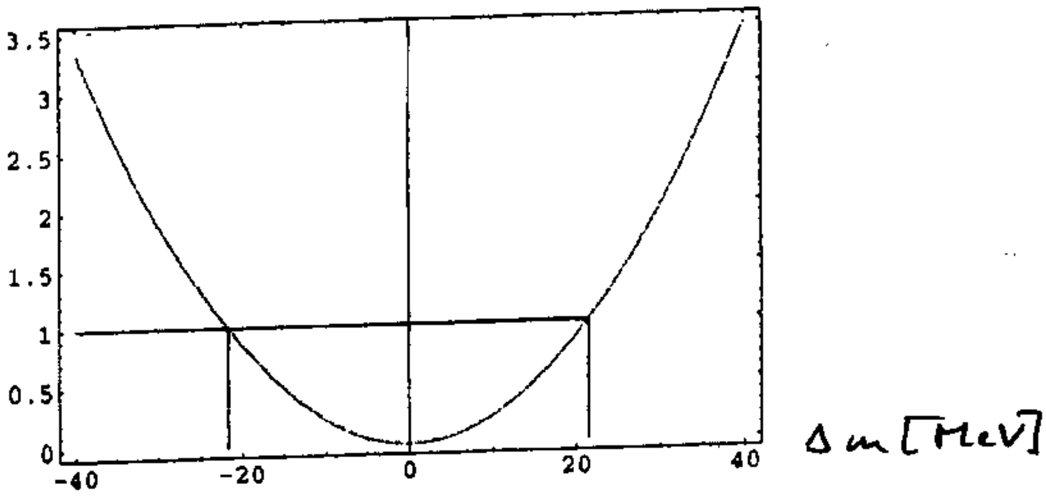
Bločhinger and Mayer, ~~in preparation~~

- calculated the total cross section of

$$e^-e^- \to \tilde{e}^-_{L/R}\tilde{e}^-_{L/R} \to e^-e^-\tilde{\chi}^0_1\tilde{\chi}^0_1$$

[redacted]

- Include ISR and beamstrahlung (use **Pandora**)
- Perform χ^2 fit and find:

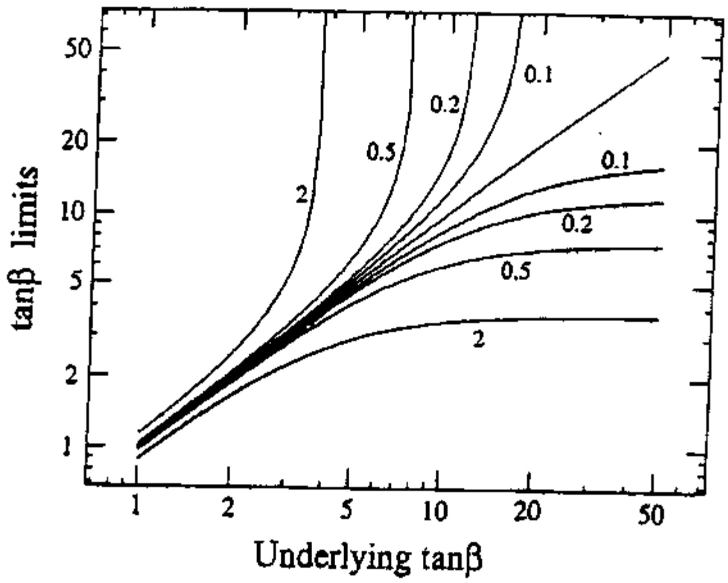


$$\boxed{\Delta m_{\tilde{e}_R} \approx 22 MeV \text{ with } 1\ \mathrm{fb}^{-1}\ .}$$

- For the left selectron an error of 400-500 MeV is feasible (preliminary)

Why do we want such precise information on selectron etc. masses?

ACCESS TO $\boxed{\tan\beta}$



Contours giving the upper and lower limits on $\tan\beta$ for a given underlying $\tan\beta$ and experimental uncertainty in mass difference $\Delta m \equiv m_{\tilde e_L} - m_{\tilde\nu_e}$ as indicated (in GeV), for fixed $m_{\tilde\nu_e} = 200$ GeV.

Recall that, at tree level

$$m^2_{\tilde e_L} - m^2_{\tilde\nu_e} = -M_W^2 \boxed{\cos 2\beta} \;!$$

we measure these   we know this

2^{nd} Generation: Smuon masses

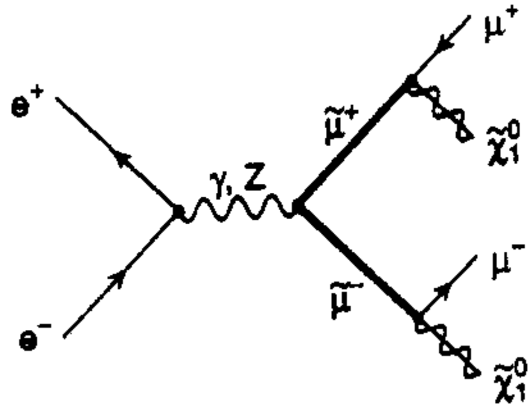
3. [redacted] [redacted] collisions

- s-channel γ, Z exchange
- P-wave $\Rightarrow$ Cross-section $\sim \beta^3$ at threshold
- Restrict to $\tilde{\mu}_R^+ \tilde{\mu}_R^-$ for simplicity
- Dominant decay $\tilde{\mu}_R^- \to \mu^- \tilde{\chi}_1^0$

Choose this final state

[redacted]

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



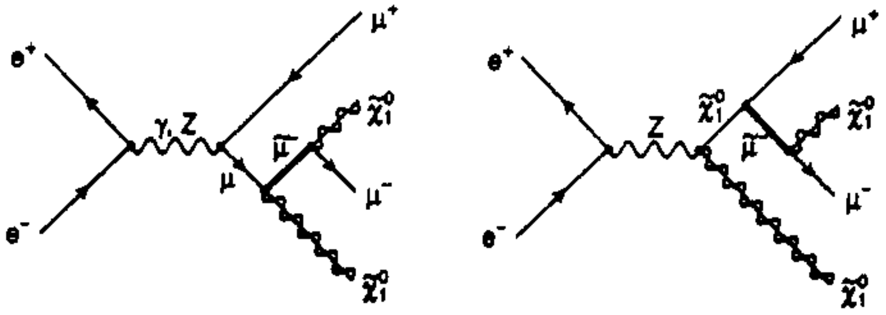
for easy muon detection

Double resonant graph is gauge dependent.

One can get any answer one likes!

Note:

⇒ **Must include singly resonant graphs in signal to give gauge invariant result**



- Include finite width by introducing the complex mass

⇒ [illegible]

- Cannot use double pole approximation at threshold
- Many more singly and non-resonant graphs which are now considered as backgrounds
- Signal and background amplitudes calculated using **Feynarts**
- Adaptive weight optimised Monte Carlo integration over phase space
- ISR included using structure function method
- Beamstrahlung included using **CIRCE**

ATTENTION: Unlike in the Selectron case, We now have large <u>BACKGROUNDS</u>

Backgrounds: [illegible]

[redacted] backgrounds easy to remove:

[<u>Blair, Martyn</u>]

- 1. $e^+e^- \to W^+W^-$, $W \to \mu\nu$
- 2. $e^+e^- \to (\gamma/Z)(\gamma/Z)$, $\gamma/Z \to \mu^+\mu^-$, $\gamma/Z \to \nu\bar{\nu}$

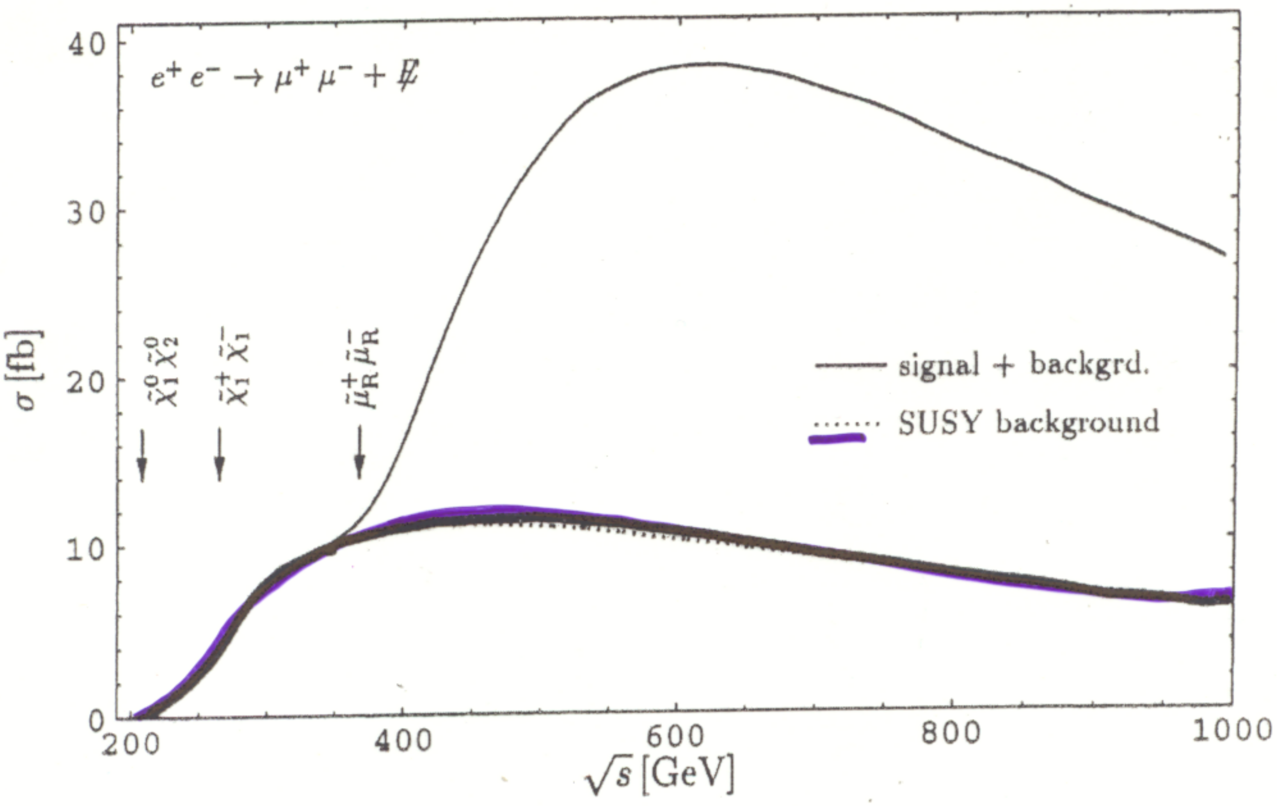
Remove 1: W decay leptons lie approx. in an azimuthal plane.

Remove 2: cut lepton pairs which are:
- collinear
- have invariant mass near the Z mass.

Cuts and detector acceptance $\to$ signal efficiency of 50%

Main SUSY backgrounds:

- $e^+e^- \to \tilde{\chi}_k^0\tilde{\chi}_1^0,\ \tilde{\chi}_k^0 \to \mu^+\mu^-\tilde{\chi}_1^0$
- $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0,\ \tilde{\chi}_2^0 \to \mu^+\mu^-\tilde{\chi}_1^0,\ \tilde{\chi}_2^0 \to \nu\bar{\nu}\tilde{\chi}_1^0$
- $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-,\ \tilde{\chi}_1^\pm \to \tilde{\mu}^\pm\nu_{\tilde{\mu}}\tilde{\chi}_1^0$
- $e^+e^- \to ZZ,\ Z \to \mu^+\mu^-,\ Z \to \tilde{\chi}_1^0\tilde{\chi}_1^0$
- $e^+e^- \to Zh_0/H_0,\ Z \to \mu^+\mu^-,\ h_0/H_0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0$



$\boxed{\text{Conclusions}}$ on $\tilde{e}$'s, $\tilde{\mu}$'s

SELECTRONS

[redacted]

- e^-e^- option much better than e^+e^- for measuring selectron mass
- Negligible backgrounds
- Very accurate mass measurement with little luminosity

SMUONS

[redacted]

- More theoretically challenging
- Must beware of gauge dependence
- Cuts can be devised to remove backgrounds
- Accurate mass measurement looks promising

Must include radiative corrections for per mille accuracy

↑

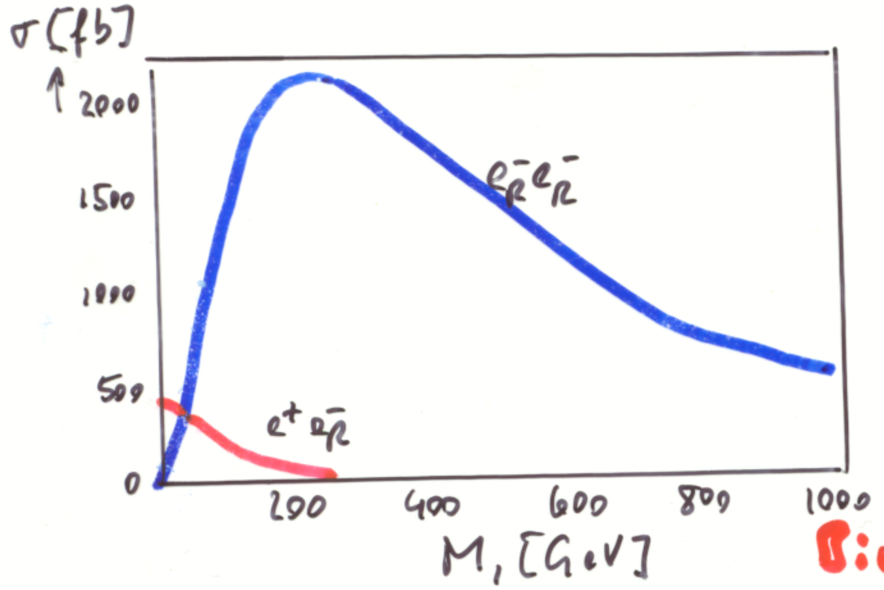
Work on this underway

GAUGINO, NEUTRALINO MASSES

M_1 mass measurement:

recall: $\sigma(e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-) \sim \left|\frac{M_{RR}}{t - M_1^2}\right|^2$

$\sim \frac{1}{M_1^2}$ large M_1



Bino mass

for $\sqrt{s} = 0.5$ TeV

$m_{\tilde{e}_R} = 200$ GeV

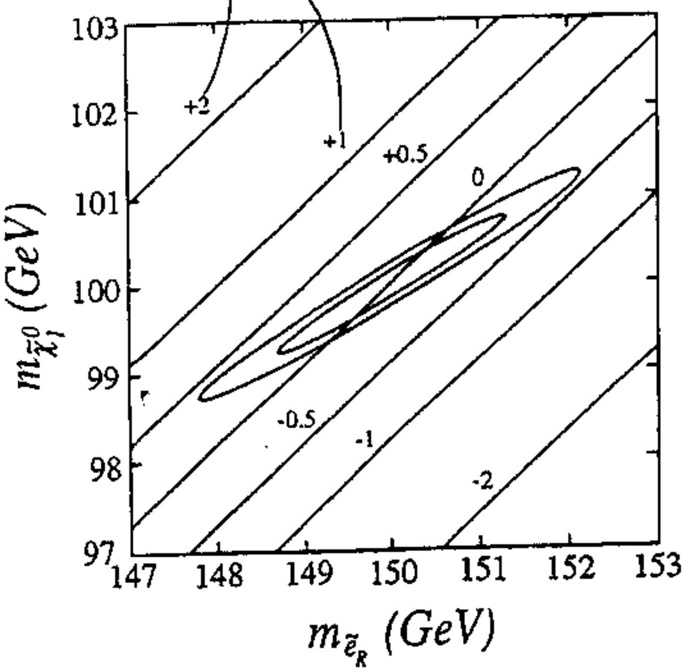
→ take $M_1 = 700$ GeV, find 1σ stat' error from a 100 fb^{-1} high-luminosity measurement $\Delta M_1 \lesssim 2$ GeV !

once M_1 is measured, M_2 can be measured via

$\sigma(e_L^- e_L^- \to \tilde{e}_L^- \tilde{e}_L^-)$

NOTE: SUCH LARGE GAUGINO MASSES (possible in Higgsino region) in gravity mediated models) ARE VERY HARD TO MEASURE ELSEWHERE!

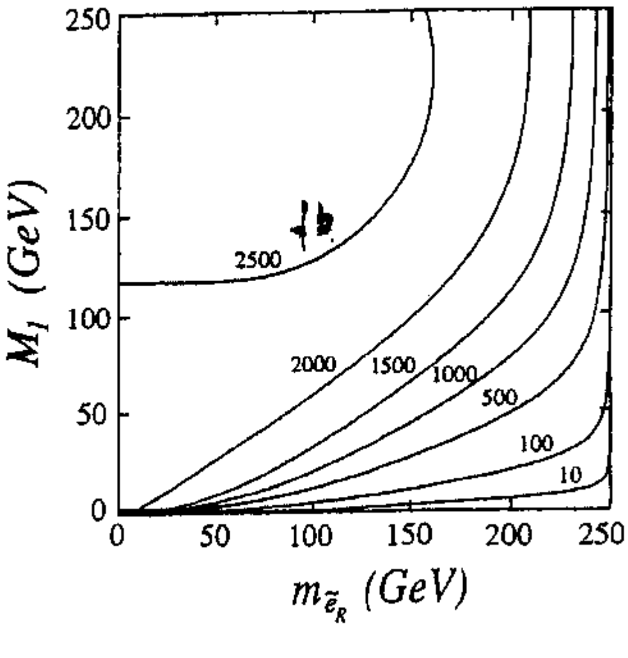
difference in % of σ_R from the central value parameters



Uncertainty ellipses determined by final-state electron energy endpoints at $\sqrt{s} = 0.5$ TeV

assuming $m_{\tilde{e}_R} = 150$ GeV, $m_{\tilde{\chi}_1^0} = 100$ GeV

Measure $\sigma(\tilde{e}_R^- \tilde{e}_R^+)$, find M_1 (or $m_{\tilde{e}_R}$) if not previously known



NEUTRALINO

CP-VIOLATING PHASES ?

1st-order effect possible in $e_L^- e_L^- \to \tilde{e}_L^- \tilde{e}_L^-$

e^+e^- : $\tilde{e}_L^\pm \; \tilde{e}_R^\pm$ requires 2nd order in mixing

e^-e^- : $\tilde{e}_R^- \tilde{e}_R^-$ $\langle BB \rangle$ only : no interference

$\tilde{e}_L^- \tilde{e}_L^-$ $\langle BB \rangle$, $\langle WW \rangle$:

$m_1 m_2^*$ interference

Work by Scott Thomas

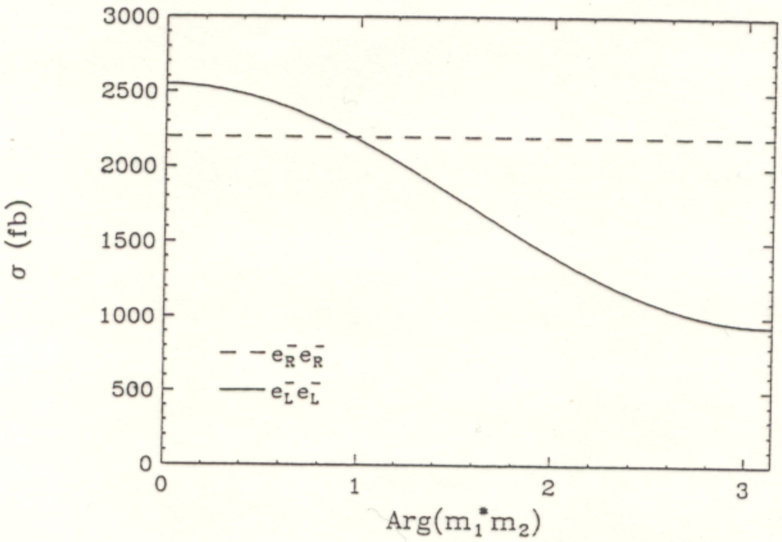
THE NEUTRALINO MASS MATRIX:

CP-VIOLATING PHASES

selectron pair production is sensitive to them

→ total cross-section

CP-Odd Phases in Slepton Pair Production



→ and differential cross-section

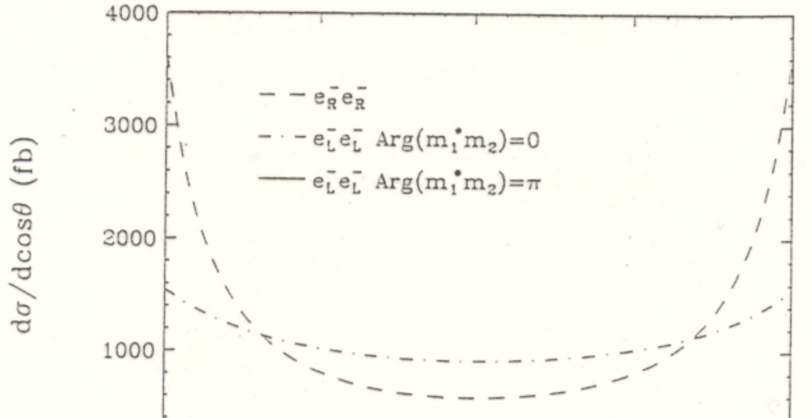


Fig. 3. Differential cross sections for $e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-$ and $e_L^- e_L^- \to \tilde{e}_L^- \tilde{e}_L^-$ in the pure gaugino or Higgsino limit for $\mathrm{Arg}(m_1^* m_2) = 0, \pi$. The parameters are $\sqrt{s} = 500$ GeV, $|m_1| = 150$ GeV, $|m_2| = 300$ GeV, $m_{\tilde{e}_R} = 170$ GeV, and $m_{\tilde{e}_L} = 210$ GeV.

But: mind all parameters!

due to SCOTT THOMAS