OXFORD 3/21/[illegible]
C.A. HEUSCH

EXPLORING THE NEUTRALINO MASS MATRIX IN e^-e^- SCATTERING

WE HOPE WE CAN LEAVE THE JOB OF FINDING SUSY SIGNALS TO TEV 33 / LHC BUT

ITS VERY LARGE NUMBER OF VITAL PARAMETERS WILL BE MOSTLY OUT OF QUANTITATIVE REACH FOR HADRON MACHINES

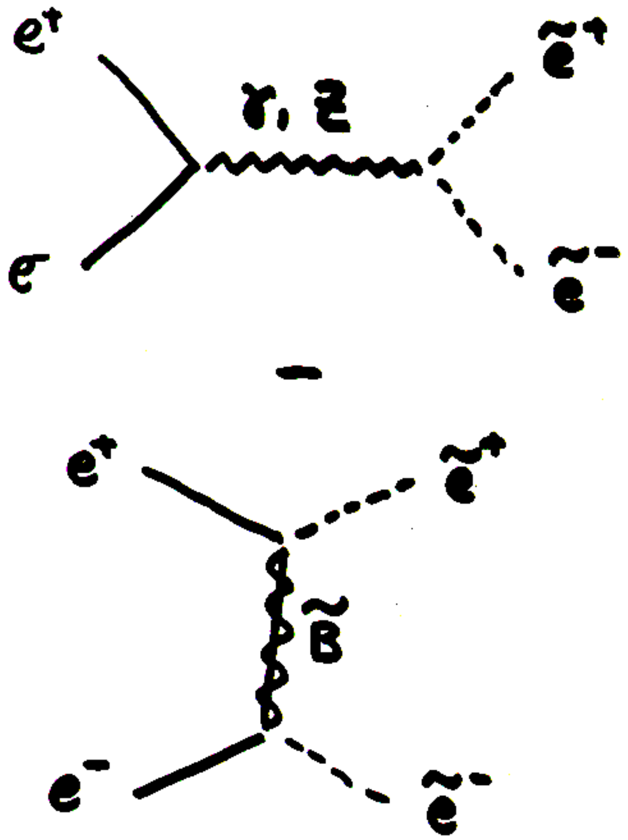
→ THE LINEAR COLLIDER WILL HAVE TO COME TO THE RESCUE

MASSES, COUPLINGS, PHASES

→ the lowest are expected to be
selectrons
gauginos
higgsinos (?)

DO AS WE DID IN THE PAST: e^+e^- ...

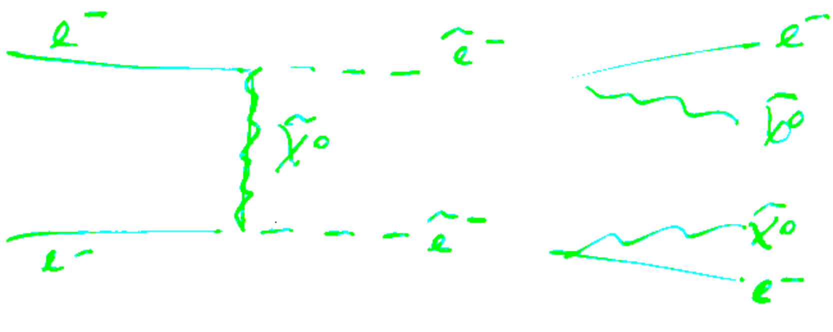
BUT



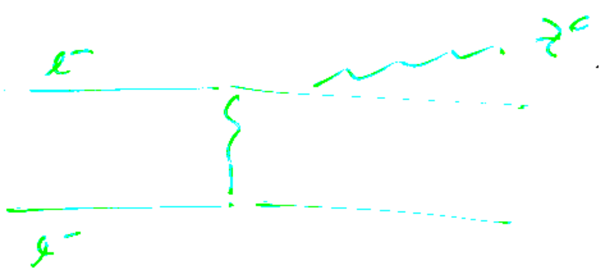
destructive interference

PLENTIFUL BACKGROUNDS

GO TO e^-e^- COLLISIONS:



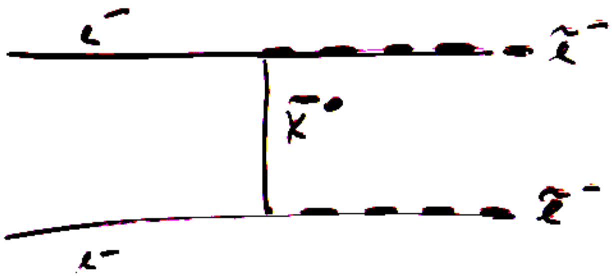
main background:



etc.

HAS CONSIDERABLE ADVANTAGES

The process



occurs via Majorana neutralino exchange

wino } gaugino
bino]
higgsino

ADVANTAGES:

Cross-sections are rel'ly large (~1 R)

strongly polarization-dependent

Final states are

characteristic, detectable

Backgrounds $e^-e^- \to e^-e^-Z^0$ (1)

$\to e^- \nu_e W^-$ (2)

$\hookrightarrow e^- \bar{\nu}_e$

are easily eliminated:

(1) by kinematical cuts on E_e,

(2) by polarization change.

THE IMPORTANCE OF BEING POLARIZED!

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

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

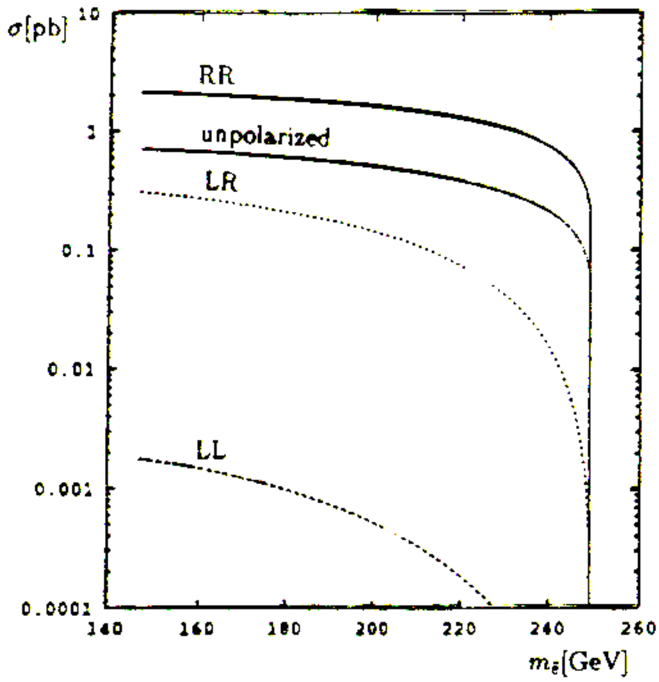


Figure 12: Cross-section of selectron pair production for a given SUSY parameter set, as a function of selectron mass, for different helicity combinations of the incoming e^- beams, at a 500 GeV NLC.

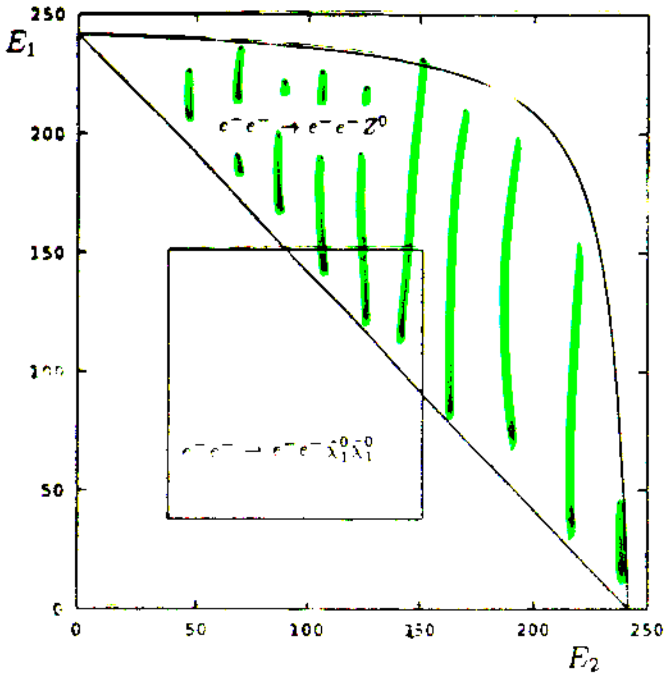


Figure 13: The allowed electron ranges for a pair of 200 GeV selectrons decaying into e^-e^- plus a pair of 100 GeV neutralinos (box) and for the principal background, Z "bremsstrahlung" ($e^-e^- \to e^-e^-Z$). This example illustrates the relative ease with which backgrounds can be removed by cuts on the final-state electrons (from ref. 26).

once understood, the $\tilde{e}^-$ decay

may also become accessible

FIRST OBVIOUS TASK:

$\left.\begin{array}{l}\tilde{e}\\ \tilde{\chi}_1^0\end{array}\right\}$ **MASS MEASUREMENTS**

Recall $\tilde{e}^-$ is a scalar,

BUT RECALLS HELICITY LABEL: $\tilde{e}_L^-$, $\tilde{e}_R^-$

we expect $m(\tilde{e}_L) > m(\tilde{e}_R)$ [most models]

certainly $\neq$

The neutralino masses are not predicted in their hierarchy, a vast parameter space to be explored

if gauginos are lightest, → "gaugino region"

" higgsinos " " → "higgsino region"

of neutralino space

NEUTRALINOS: Higgsino gaugino photino Zino

THE MASS MATRIX

$$\mathbf{m} = \begin{pmatrix} m_1 & 0 & -m_Z s_w \cos\beta & m_Z s_w \sin\beta \\ 0 & m_2 & m_Z c_w \cos\beta & -m_Z c_w \sin\beta \\ -m_Z s_w \cos\beta & m_Z c_w \cos\beta & 0 & -\mu \\ m_Z s_w \sin\beta & -m_Z c_w \sin\beta & -\mu & 0 \end{pmatrix}$$

with $(c_w, s_w) = (\cos\theta_w, \sin\theta_w)$

... AND THE NEUTRALINO FUNCTIONS

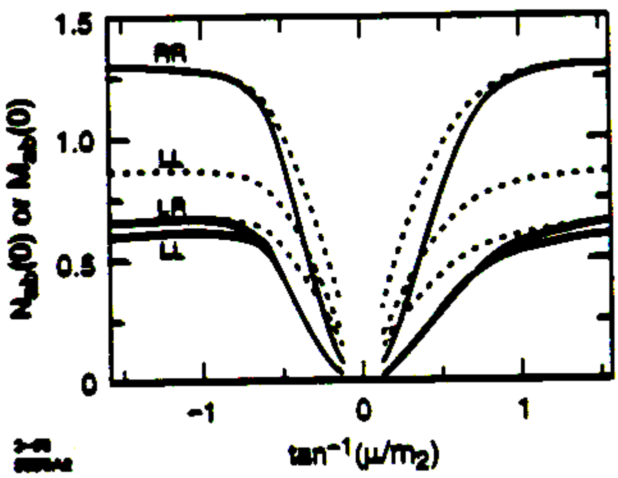
$$V_{Li} = \frac{1}{2c_w} V_{1i} + \frac{1}{2s_w} V_{2i}\,, \qquad V_{Ri} = \frac{1}{c_w} V_{1i}\,.$$

From these objects, we can construct the dimensionless neutralino functions,

$$N_{ab}(t) = \sum_i V_{ai} \frac{M_i^2}{M_i^2 - t} V_{bi}^*$$

$$M_{ab}(t) = \sum_i V_{ai} \frac{M_1 M_i}{M_i^2 - t} V_{bi}\,,$$

FOR A SENSIBLE CHOICE OF PARAMETERS,



The six neutralino functions, evaluated at $t = 0$, displayed as functions of $\tan(\mu/m_2)$, for $\tan\beta = 4$, along the line in parameter space for which the mass of the lightest neutralino is 50 GeV. The functions N_{ab} are drawn as solid lines, the M_{ab} as dotted lines.

SUSY Mass Measurement in $e^-e^- \to \tilde{e}^-\tilde{e}^-$

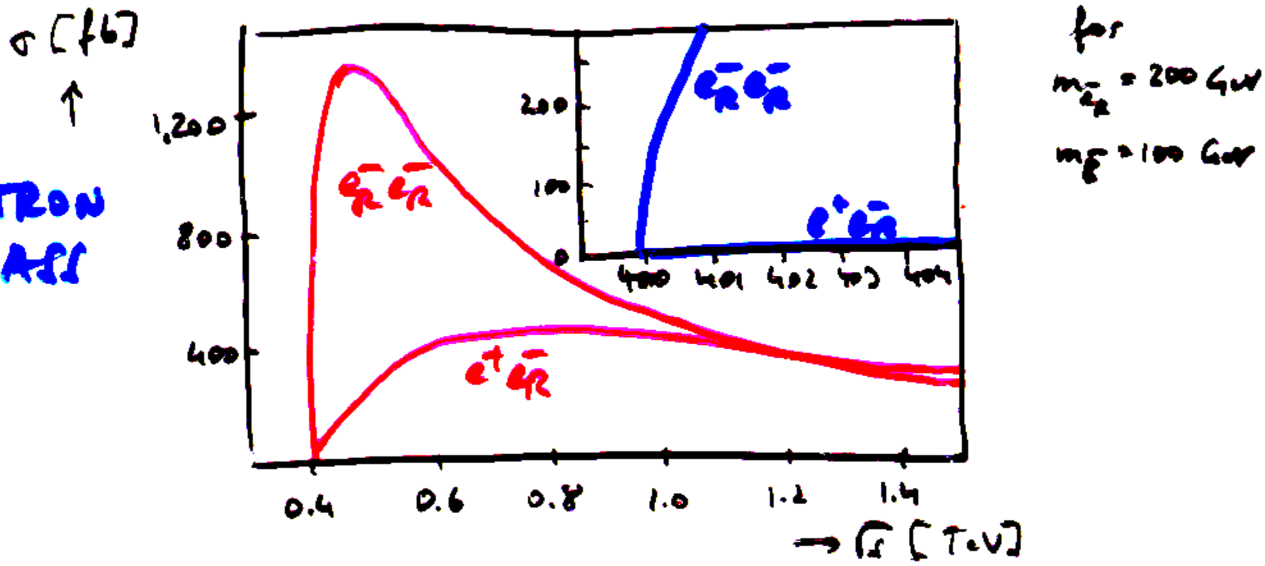
Jonathan Feng, e^-e^- 97

the fermion number-violating process

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

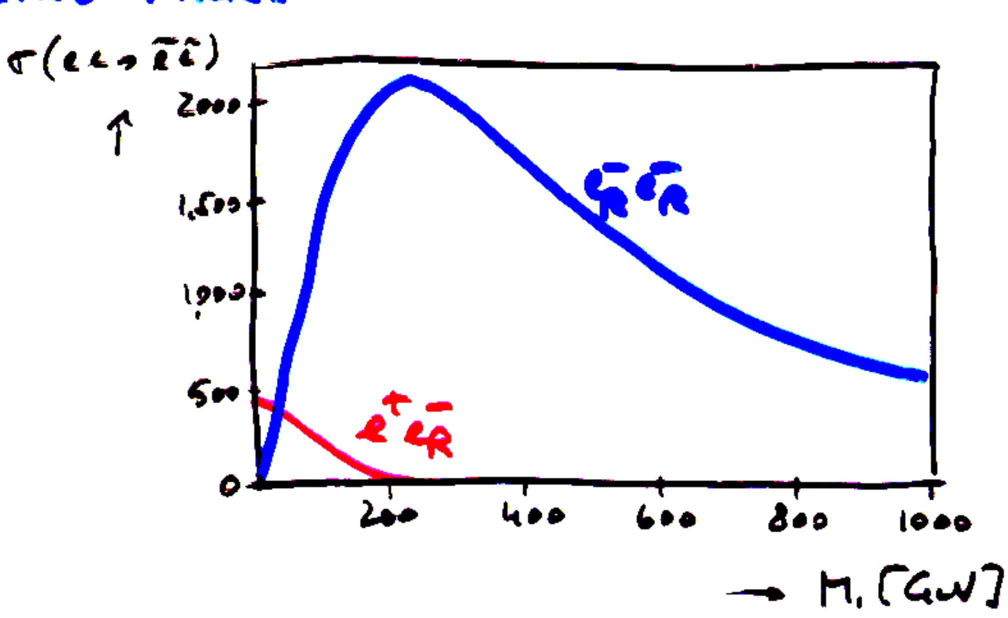
leads to the most precise determinations of $m(\tilde{e}^-)$

SELECTRON MASS



(assume sharp masses, no beamstrahlung)

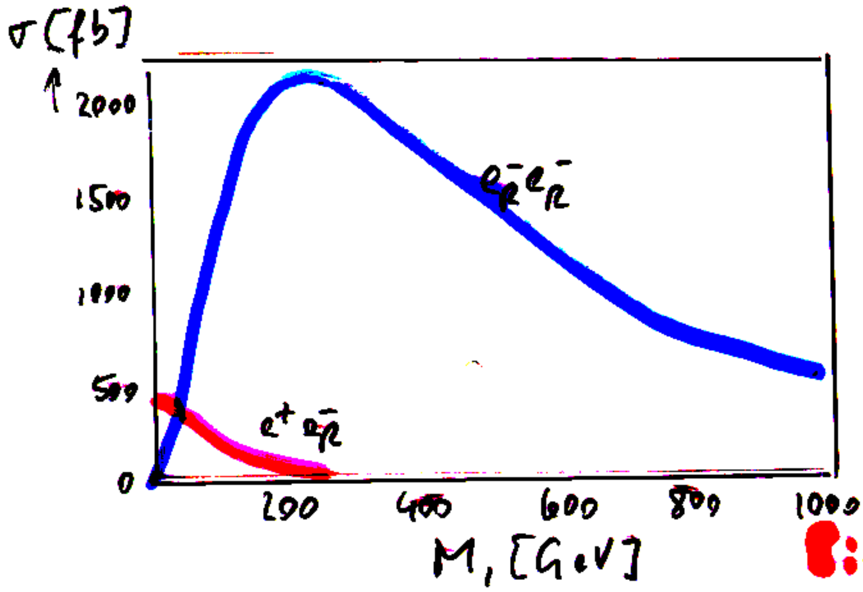
and BINO MASS M_1



M_1 mass measurement:

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

$\sim \frac{1}{M_1^2}$ [illegible] M_1



for $\sqrt{s} = 0.5$ TeV

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

[illegible]

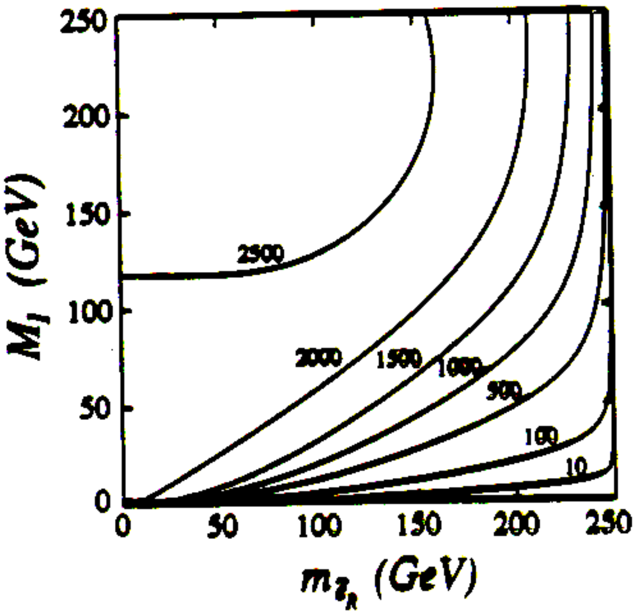
→ take $M_1 = 700$ GeV, find 1σ stat' error from a $100\ fb^{-1}$ high-luminosity measurement $\delta M_1 \lesssim 2$ GeV !

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.

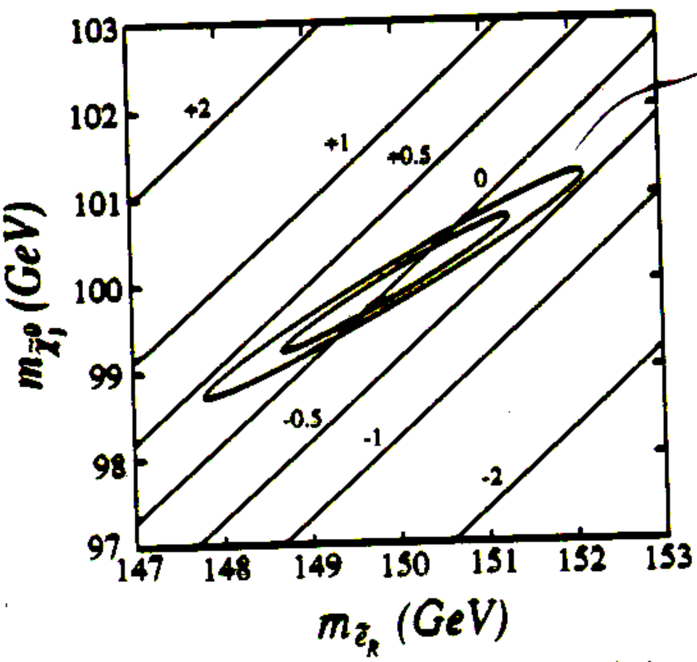
mass determination: $\tilde{e}_R$, M_1



$\sqrt{s} = 500$ GeV

Contours of constant $\sigma_R \equiv \sigma(e^-_R e^-_R \to \tilde{e}^-_R \tilde{e}^-_R)$ in fb in the $(m_{\tilde{e}_R}, M_1)$ plane for $\sqrt{s} = 500$

mass determination: $\tilde{e}_R$, $\tilde{\chi}^0_1$



uncertainty ellipsis $\Delta E = 0.3, 0.5$ GeV

assuming

$m_{\tilde{e}_R} = 150$ GeV

$m_{\tilde{\chi}^0_1} = 100$ GeV,

end point measurement of final-state e

The allowed regions, "uncertainty ellipses," of the $(m_{\tilde{e}_R}, m_{\tilde{\chi}^0_1})$ plane, determined by measurements of the end points of final state electron energy distributions with uncertainties $\Delta E =$ 0.3 GeV and 0.5 GeV. The underlying central values are $(m_{\tilde{e}_R}, m_{\tilde{\chi}^0_1}) = (150$ GeV, 100 GeV), and $\sqrt{s} = 500$ GeV. We also superimpose contours (in percent) of the fractional variation of σ_R with respect to its value at the underlying parameters.

ACCESS TO PHASES

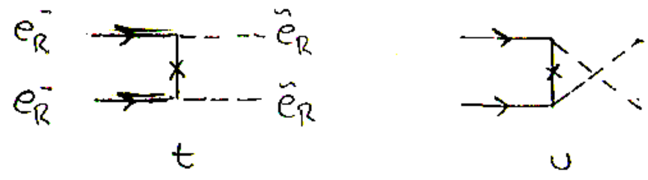
Scott Thomas

$e^- e^-$ 97

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

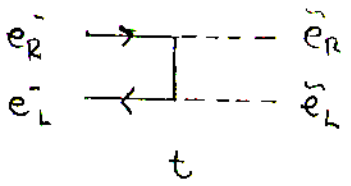
$\tilde{\chi}_i^0$ exchange : (Only b,w components)

RR



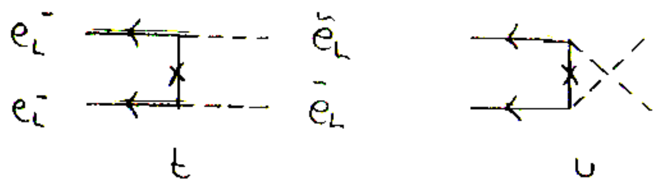
$\Delta X = -2$

RL



$\Delta X = 0$

LL



$\Delta X = 2$

$$V_{Ri} = \frac{1}{\cos\theta_w} V_{1i}$$

$$V_{Li} = \frac{1}{2\cos\theta_w} V_{1i} + \frac{1}{2\sin\theta_w} V_{2i}$$

$$\mathcal{N}_{ab} = \sum_i V_{ai}^* \frac{1}{|m_i|^2 - t} V_{bi}$$

$$\mathcal{M}_{ab} = \sum_i V_{ai} \frac{m_i}{|m_i|^2 - t} V_{bi}$$

Note that $\mathrm{Im}\mathcal{N}_{aa} = 0$.

Cross sections

$$\frac{d\sigma}{dt}(e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-) = \frac{3}{2} R \ |\mathcal{M}_{RR}(t) + \mathcal{M}_{RR}(u)|^2$$

$$\frac{d\sigma}{dt}(e_L^- e_L^- \to \tilde{e}_L^- \tilde{e}_L^-) = \frac{3}{2} R \ |\mathcal{M}_{LL}(t) + \mathcal{M}_{LL}(u)|^2$$

$$\frac{d\sigma}{dt}(e_L^- e_R^- \to \tilde{e}_L^- \tilde{e}_R^-) = 3R \left(\frac{(t - m_{\tilde{e}_L}^2)(m_{\tilde{e}_R}^2 - t)}{s} - t \right) \ |\mathcal{N}_{LR}(t)|^2$$

S. Thomas

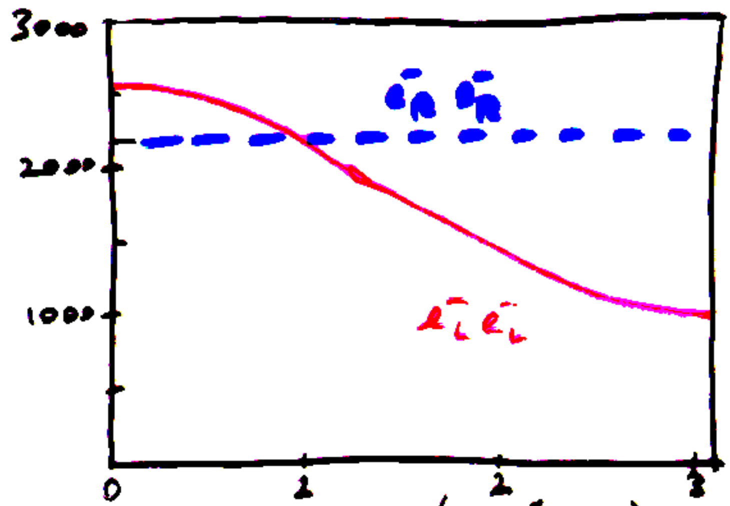
CP violating phases:

phase-dependent interference takes place between different neutralino mass eigenstates in the same channel,

not suppressed well above threshold

TOTAL CROSS SECTION in pure $\left\{\begin{matrix}\text{higgsino}\\ \text{gaugino}\end{matrix}\right\}$ limit:

$\sigma(e^-e^- \to \tilde{e}^-\tilde{e}^-)$ [fb]



$\arg(m_1^* m_2)$

$\sqrt{s} = 0.5$ TeV

$|m_1| = 100$ GeV

$|m_2| = 200$ GeV

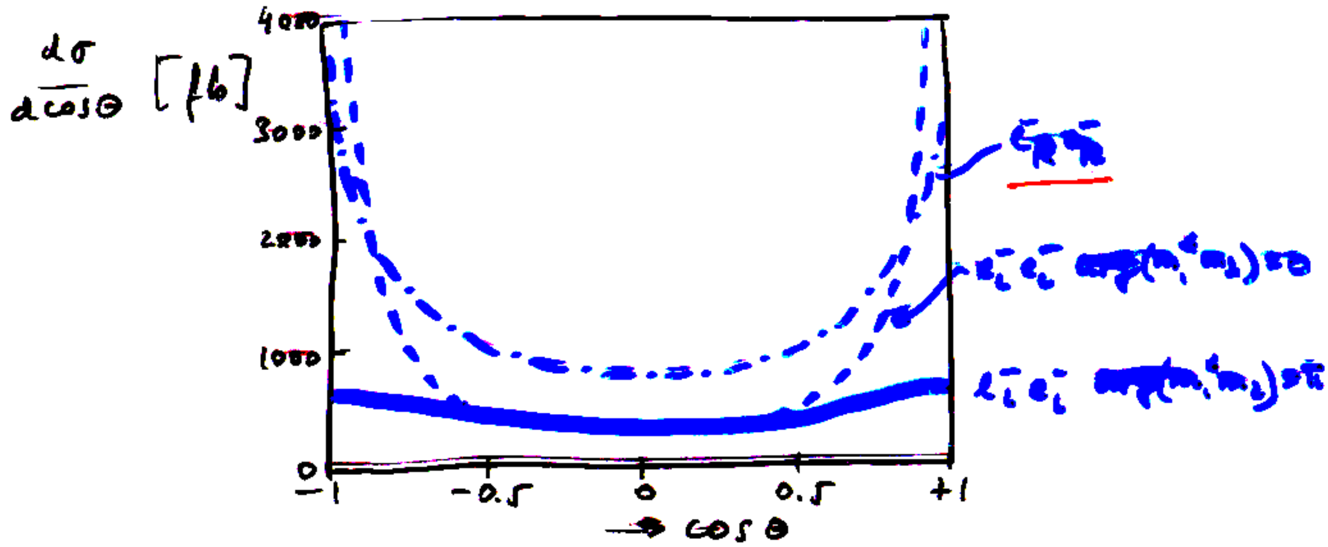
$m_{\tilde{e}_R} = 130$ GeV

$m_{\tilde{e}_L} = 180$ GeV

For comparison, note that

$R(\sqrt{s} = 0.5\ \text{TeV}) = 400$ fb

SENSITIVITY OF SELECTRON PAIR PRODUCTION TO PHASES IN THE MASS MATRIX



$\sqrt{s} = 0.5$ TeV ; masses as above

→ Higgsino or gaugino limit
but features remain similar away from limits.

→ LEFT-HANDED SELECTRON PAIR PRODUCTION IS THE MOST SENSITIVE PROBE OF RELATIVE BINO AND WINO PHASES.

This provides the best chance to measure a CP-odd phase at the L.C.

→ complementary to low-energy electric dipole measurements?

CONCLUSIONS:

- The simplicity of the process $e^- e^- \to \tilde{e}^- \tilde{e}^-$ permits unparalleled access to the parameters that determine the neutralino mass matrix, throughout a large parameter space.

- The precise measurement of $\tilde{e}^-_R$, $\tilde{e}^-_L$ masses is unique by at the basis of these possibilities, unassailable / unattainable by $e^+ e^-$.

- The purity of sample and the suppression of essentially all backgrounds is guaranteed by the easy access to high polarization, helicity flip of incoming electron beams.

- CP violating phases are nowhere as well traced by realistic measurement as in $\tilde{e}^- \tilde{e}^-$ production from $e^- e^-$.

- The high-luminosity scenario guarantees a chance to bring this unique access to SUSY parameters to fruition, further open the door to many other parameters not discussed above ($\tan\beta, \ldots$)