Analyses for $\tilde{\mu}_L^+ \tilde{\mu}_L^-$ and $\chi_1^0 \chi_2^0$ in SPS1a'

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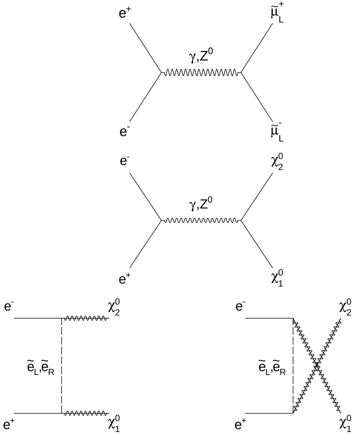
Signal



- Measure $m_{\chi_1^0}, m_{\chi_2^0}, m_{\tilde{\mu}_L}$
- Measure $\sigma \times \mathrm{BR}$
- Disentangle two SUSY production modes
- Test performance of the tracker for precise extraction of kinematics $\rightarrow$ masses
- Test cleanliness of the muon reconstruction
- Test backgrounds from $\gamma\gamma \rightarrow X$ and ISR processes

Process	Cross section at the polarization (e^-,e^+) [fb]		
	(-0.8,0.6)	(-0.8,-0.6)	(-0.8,0)
$e^+e^- \rightarrow \chi_1^0\chi_2^0 \rightarrow \chi_1^0\mu\tilde{\mu}_R \rightarrow \chi_1^0\chi_1^0\mu\mu$	4.2	1.1	2.4
$e^+e^- \rightarrow \tilde{\mu}_L\tilde{\mu}_L \rightarrow \chi_1^0\chi_1^0\mu\mu$	54	18	43

SUSY Backgrounds

Final State	Processes	Cross section [fb]
$\mu\mu\chi_1^0\chi_1^0$	$\tilde{\mu_R}\bar{\tilde{\mu_R}}$	39.77
$\mu\mu\nu_e\nu_e\chi_1^0\chi_1^0$	$\tilde{\mu_L}\bar{\tilde{\mu_L}} \rightarrow \chi_1^0\chi_2^0$ $\chi_2^0\chi_2^0 \rightarrow \mu^\pm\tilde{\mu}^\mp\nu_e\tilde{\nu_{e,L}}$	1.6
$\mu\mu\nu_\mu\nu_\mu\chi_10\chi_1^0$	$\tilde{\mu_L}\bar{\tilde{\mu_L}} \rightarrow \chi_10\mu\nu_{mu}\tilde{\mu_\mu}$ $\chi_2^0\chi_20 \rightarrow \mu^\pm\mu\tilde{R}^\mp\nu_\mu\tilde{\nu_\mu}$ $\tilde{\mu_L}\tilde{\mu_L} \rightarrow \chi_1^0\mu^\pm\chi_1^\mp\nu_\mu$ $\chi_1^\pm\chi_1^\mp \rightarrow \mu\tilde{\nu_\mu}\mu\tilde{\nu_\mu}$	9.29
$\mu\mu\nu_\tau\nu_\tau\chi_1^0\chi_1^0$	$\tilde{\mu_L}\bar{\tilde{\mu_L}} \rightarrow \chi_1^0\chi_2^0$ $\chi_2^0\chi_2^0 \rightarrow \mu\tilde{\mu}\nu_{tau}\nu_\tau$	1.6
$\mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\chi_1^0\chi_1^0$	$\tilde{\tau_1}\tilde{\tau_1}$ $\tilde{\tau_1}\tilde{\tau_1}$	6.1
$\mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\nu_\mu\nu_\mu\chi_1^0\chi_1^0$	$\tilde{\tau_1}\tilde{\tau_2} \rightarrow \chi_1^0\tau\chi_2^0\tau$ $\tilde{\tau_2}\tilde{\tau_2} \rightarrow \chi_1^0\tau\chi_2^0\tau$ $\chi_2^0\chi_2^0 \rightarrow \tau\tilde{\tau}\nu_\mu\tilde{\nu_\mu}$	0.6

- All Background cross-sections at $(P_{e^-}, P_{e^+}) = (-0.8, 0.6)$
- $\tilde{\mu_R}\bar{\tilde{\mu_R}}$ will be one of the highest remaining backgrounds to $\tilde{\mu_L}\bar{\tilde{\mu_L}}$, but the kinematic edges are nicely separated

Backgrounds contd'

Final State	Processes	Cross section [fb]
$\mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\nu_\tau\nu_\tau\chi_1^0\chi_1^0$	$\tilde{\tau}_2\tilde{\tau}_2 \to \chi_1^0\tau\chi_2^0\tau$ $\tau_2\tau_2 \to \chi_1^0\tau\chi_1^\pm\nu_\tau$ $\tau_2\tau_2 \to \chi_1^0\tau\chi_1^\pm\nu_\tau$ $\tau_1\tau_2 \to \tau\chi_1^0\tau\chi_2^0$ $\tilde{\tau}_1\tilde{\tau}_2 \to \tau\chi_1^0\chi_1^\pm\nu_\tau$ $\chi_2^0\chi_2^0 \to \tau\tilde{\tau}\nu_\tau\tilde{\nu_\tau}$ $\chi_1^+\chi_1^- \to \tau\tilde{\nu_\tau}\tau\tilde{\nu_\tau}$ $\chi_1^+\chi_1^- \to \tau\tilde{\nu_\tau}\tilde{\tau}\nu_\tau$	7.4
$\mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\nu_e\nu_e\chi_1^0\chi_1^0$	$\tilde{\tau}_2\tilde{\tau}_2 \to \chi_1^0\chi_1^0\tau\tau$ $\tilde{\tau}_1\tilde{\tau}_2 \to \tau\chi_1^0\tau\chi_2^0$ $\chi_2^0\chi_2^0 \to \tau\tilde{\tau}\nu_e\tilde{\nu_e}$	0.7
$\mu^\pm\mu^\mp\nu_\mu\nu_\tau\nu_\mu\nu_\tau\nu_\mu\nu_\tau\chi_1^0\chi_1^0$	$\chi_1^\pm\chi_1^\mp \to \mu\tilde{\nu_\mu}\tau\tilde{\nu_\tau}$ $\chi_1^\pm\chi_1^\mp \to \mu\tilde{\nu_\mu}\nu_\tau\tilde{\tau}$ $\tilde{\mu_L}\tilde{\mu_L} \to \chi_1^0\mu\chi_1^\pm\nu_\mu$	3.3 3.4 0.35

- In addition, all SM processes with μ, τ and ν are contributing
- Especially ZZ, γZ, WW
- $\gamma\gamma$ not a problem since a cut on $p_\mu > 30$ GeV can be used at this kinematic point (SPS1a' already has low Δm!)

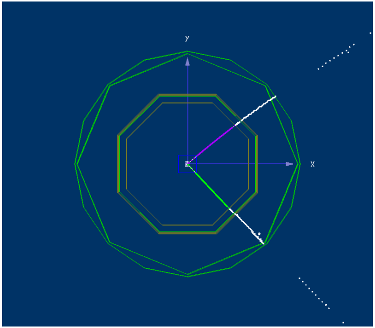
Motivation

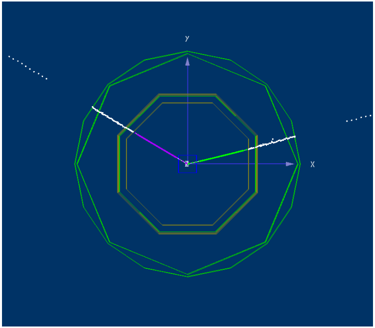
Goals

- Show how precicely we can measure SUSY masses and parameters in the continuum:
  - Can we afford to do threshold scans with several tens of fb^{-1} each for every possible accessible new particle and collect hundreds of fb^{-1} at 350 or 500 GeV in addition? Who knows... So let's better make sure we're good in the continuum, too.
  - That also helps to precicely predict where to do threshold scans.
- Show that we can disentangle dominant and subdominant SUSY decay chains ($\tilde{\mu}_L \bar{\tilde{\mu}}_L$ vs. $\chi_1^0 \chi_2^0$) with the same final state particles and with similar kinematic features
  - This is important because we do not only want to discover something which looks like SUSY, we want to measure precicely all properties (masses, couplimgs) of each particle to show that it is SUSY and how it is broken.

Selection

- Preselection
  - Events with exactly two mip-like tracks in tracker, calorimeters and muon system. Require more than 7 aligned hits in the muon chamber in $\Delta\phi < 2.8^\circ$ and $\Delta\theta < 3.4^\circ$ and match this with a mip-like track in the calorimeter with $\Delta\phi < 11^\circ$ and $\Delta\theta < 11^\circ$





- Beam background is no problem since basically no tracks with $p_T > 30$ GeV are expected from that

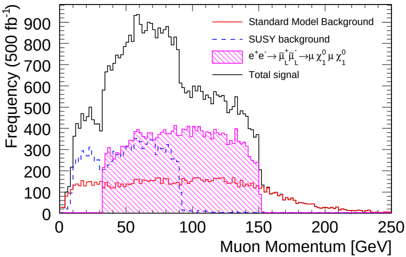
Selection for $e^+e^- \rightarrow \tilde{\mu}_L^+ \tilde{\mu}_L^-$

- $200 < E_{miss} < 430$ GeV. This cut selects the missing energy region of the signal
- The events with $80 < m_{\mu\mu} < 100$ GeV are rejected, in order to exclude the contribution of the di-muon generated from a Z^0 boson
- $m_{\mu\mu} > 30$ GeV, in order to reject the muon pairs originated from a γ.
- $0.1\pi < \theta_\beta < 0.9\pi$ in order to reject the forward and backward-peaked SM background

Selection for $e^+e^- \to \chi_1^0\chi_2^0$

- $0.2 < \theta_\beta < 0.8$. This cut rejects the forward and backward-peaked SM background
- $|\beta| > 0.6$
- $355 < E_{miss} < 395$ GeV for the selection of the high missing energy range
- $p_t > 40\ GeV/c$ for the selection of the high p_t range
- $E_s > 40$ GeV. This cut rejects the di-muon events coming from a γ (SM) and rejects many SUSY background. In particular the background channels with τ in the final state are strongly suppressed.
- Missing mass: exclude $85 < m_{miss} < 100$ GeV to suppress ZZ

Simultaneous Measurement of $m_{\chi_1^0}$ and $m_{\tilde{\mu}_L}$



- Expect kinematic edges at

$$m^2_{\tilde{\mu}_L} = E_s^2 \frac{E_\mu^+ \cdot E_\mu^-}{\left(E_\mu^+ + E_\mu^-\right)^2}$$

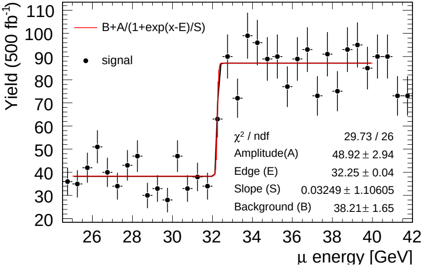
$$m^2_{\chi_1^0} = m^2_{\tilde{\mu}_L} \left(1 - \frac{2\left(E_\mu^+ + E_\mu^-\right)}{E_s}\right)$$

- Use

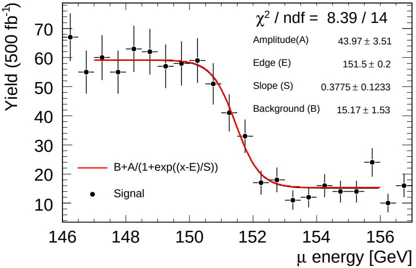
$$f(E|E^+, A, B, S) = B + \frac{A}{1 + e^{-\frac{E - E^+}{S}}}$$

to describe the edges, then calibrate

Simultaneous Measurement of $m_{\chi_1^0}$ and $m_{\tilde{\mu}_L}$

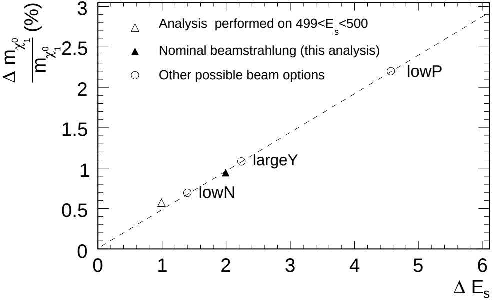


Parameter	Fitted value
A^+	70.32 $\pm$ 6
E^+	150.95 $\pm$ 0.24
S^+	0.67 $\pm$ 0.19
B^+	33.45 $\pm$ 2.10
A^-	71.07 $\pm$ 4.12
E^-	32.55 $\pm$ 0.14
S^-	0.22 $\pm$ 0.01
B^-	69.27 $\pm$ 2.28
$m_{\chi_1^0}$ (Th. 97.71 GeV)	97.55 $\pm$ 1.07 GeV
$m_{\tilde{\mu}_L}$ (Th. 189.86 GeV)	189.87 $\pm$ 0.39 GeV



- Statistical uncertainty of the edge is coming from uncertainty on $E^{\pm}$
- Add syst. error: 0.5 FWHM of the derivative of the fitted function to account for possible misparametrization.

Influence of ΔE_{beam} on $m_{\chi_1^0}$



- The uncertainty strongly depends on the beam energy spread:

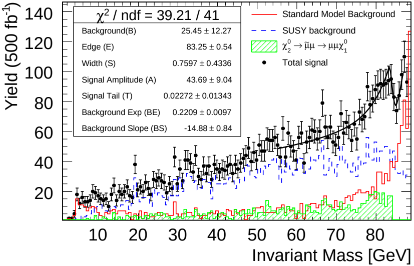
$$\Delta m_{\chi_1^0}(\Delta E_s) = \left(2 \cdot E_s \cdot \left(\frac{E_\mu^+ E_\mu^-}{(E^+ + E^-)^2}\right)\right) \cdot \left(1 - 2 \cdot \frac{(E^+ + E^-)}{E_s} + 2 \cdot E_s \cdot \left(\frac{E^+ E^-}{(E^+ + E^-)^2}\right)\right) \Delta E_s$$

- We could study this much more in detail if we had detailed simulation:

$$\Delta m^2_{\chi_1^0} = \Delta^2_{beamsstrahlung} + \Delta^2_{banana\ effect} + \Delta^2_{beam\ energy} + \Delta^2_{detector}$$

which is not possible in the moment, but it could be very important

Measurement of $m_{\chi_2^0}$



$$m_{\chi_2^0} = \sqrt{\frac{m^2_{\mu\mu}(max) + m^2_{\tilde{\mu}R} \cdot \left(1 - \frac{m^2_{\chi_1^0}}{m^2_{\tilde{\mu}R}}\right)}{\left(1 - \frac{m^2_{\chi_1^0}}{m^2_{\tilde{\mu}R}}\right)}}$$

- Use

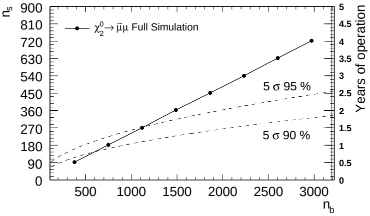
$$f(E) = \underbrace{B + e^{(BE+BS\cdot E)}}_{background} + \begin{cases} A \cdot e^{\frac{(E-E^+)^2}{W^2}} & E \geq E+ \\ \frac{A}{e^{T\cdot E^+}} e^{T\cdot E} & E < E+ \end{cases}$$

to describe the peak.

- With $m_{\tilde{\mu}_R} = 125.3 \pm 0.2$ GeV and $m_{\chi_1^0} = 97.55 \pm 1.07$ GeV:
$m_{\chi_2^0} = 183.50 \pm 1.38$ GeV

Measurement of $\sigma \times \mathrm{BR}$

- $e^+e^- \to \tilde{\mu}_L^+\tilde{\mu}_L^- \to \mu^+\mu^-\chi_1^0\chi_1^0$
  - Using an extended ML fit with the observables
  - mass
  - total transverse momentum of each muon
  - acollinearity of the event
  - take Efficiency and Background from MC
  - Result $\sigma \times \mathrm{BR} = 54.58 \pm 1.35$ fb
- $e^+e^- \to \chi_1^0\chi_2^0 \to \mu^+\mu^-\chi_1^0\chi_1^0$
  - Since kinematic configuration of bg and signal too close: no EML fit.
  - Use simple Poisson statistics to calculate CL
  - Result: 95 % CL of $\sigma \times \mathrm{BR}(e^+e^- \to \chi_1^0\chi_2^0 \to \chi_1^0\tilde{\mu}_R\mu)$ is (3.75,5.57) fb



Summary

- As expected, no differences between ILD and LDC' seen
- Separation of different SUSY signals demonstrated
- Very good precision already without threshold scans
- Dependence on tracking resolution and beam energy spread (Beamsstrahlung + original beam energy spread)
- Documentation ready on ILCILD web page, sample text for LoI underway