Combined Susy analyses at LHC/LC: Mass predictions $\leftrightarrow$ Parameter determination

Gudrid Moortgat-Pick (IPPP Durham)

in collaboration with

K. Desch, J. Kalinowski, M. Nojiri, G. Polesello

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La Thuile, 'EW Moriond meeting 2004', 23/02/2004

- Motivation
- Strategy
  $\longrightarrow$ LC analysis: prediction of heavy particles
  $\longrightarrow$ LHC analysis: measurement and feed-back to LC
- Application: numerical example SPS1a
  $\longrightarrow$ including realistic simulated errors for the observables
- Conclusions

Motivation: Why LHC/LC studies?

- LHC and LC physics is complementary in many respects

$\Rightarrow$ Mutual benefits for physics program of both machines expected:
a) What is the benefit if both machines are interpreted simultaneously?
b) What do we learn more, if both machines have overlapping running time? ('cover more physics space'?)

- LHC: start $\geq$ 2007, expected to run for O(20) years

- LC: $\geq$ 2015(?), starting with $\sqrt{s} = 500$ GeV$\rightarrow\sim$ 1 GeV

- LHC/LC study group: world–wide working group, started in 2002

$\rightarrow$ collaborative effort of Hadron collider and Linear collider communities

Synergy of LHC/LC in Susy Searches

- This talk: a 'prototype' example for new physics searches (Susy as an example), where simultaneous running of LHC+LC is very important!

  - Key points:

    LC: analysis of non-coloured light particle sector
    $\rightarrow$ prediction (!) of heavier states
    $\Rightarrow$ 'Telling the LHC, where to look!'

    LHC: prediction leads to increase of statistical sensitivity!
    test of a fixed hypotheses instead of many mass hypotheses
    ($\rightarrow$ 'look elsewhere effect')
    LC prediction might be crucial for statistically marginal signals!
    e.g. leads to measurement and identification(!) of heavier states
    $\Rightarrow$ 'Feeding back to LC analysis'

  - Important consistency tests of the new physics (NP) model at an early stage! ($\rightarrow$ outline for future analysis strategies)

Supersymmetry (very short)

- one of the best motivated extensions of the Standard Model (SM)

- Susy transformations:

$$
\begin{array}{lcl}
[e,\mu,\tau]_{L,R} & \leftrightarrow & [\tilde{e},\tilde{\mu},\tilde{\tau}]_{L,R} \\
[\gamma, Z^0, W^{\pm}, g] & \leftrightarrow & [\tilde{\gamma}, \tilde{Z}, \tilde{W}, \tilde{g}] \\
[H_1, H_2] & \leftrightarrow & [\tilde{H}_1, \tilde{H}_2]
\end{array}
$$

- since $m_p \neq m_{\tilde{p}} \Rightarrow$ Susy is broken

$\rightarrow$ leads to a large amount of new free parameters
(MSSM $\sim$ 105 parameters!)

$\rightarrow$ assumptions about Susy breaking mechanism leads to
GUT assumptions and parameter reduction:
m(inimal)SUGRA: 5, mGMSB: 5, mAMSB: 4 parameters

- particular demanding searches for new physics

$\rightarrow$ tasks for experiments: detection as well as
determination 'without' model assumptions!

Susy searches in combined LHC/LC analyses

Case study: take Susy scenario SPS1a (mSUGRA like)

(But without imposing any GUT or breaking scheme assumptions!)

- quite favourable point for LHC and LC
- ATLAS and CMS studies exist

  $\rightarrow$ LHC: dominant $\tilde{g}$,$\tilde{q}$ production; other states from cascade decays
- However, mass reconstruction difficult at LHC: complicated decay chains, e.g. $\tilde{q}_L \rightarrow q\tilde{\chi}^0_2 \rightarrow \ell^{\pm}_2 \tilde{\ell}^{\mp}_R \rightarrow \ell^{\mp}_1 \tilde{\chi}^0_1$, to some extent also heavy gauginos
- most promising: dilepton edges,

  however strong dependence on lightest Susy particle (here: $m_{\tilde{\chi}^0_1}$)

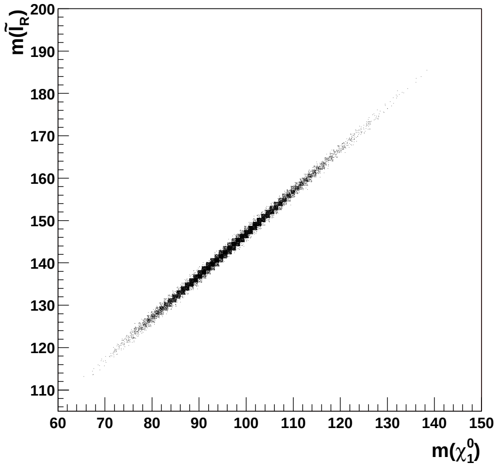
Idea:

$\Rightarrow$ Optimal use of both machines!

LHC analysis with LC input: mass of $\tilde{\chi}_1^0$

Reconstruction of the states in decay chain requires precise knowledge of LSP $\tilde{\chi}_1^0$ mass:

$m_{\tilde{\ell}_R}$



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

$\Rightarrow$ Precision measurement of m_{LSP} leads to significant improvement in determination of $\tilde{\ell}$, $\tilde{q}$ and $\tilde{g}$ masses at the LHC

• joint fit of various kinematic 'edges' yields an overconstrained system

$\longrightarrow$ but assumptions about particle identities

$\Rightarrow$ consistency tests from LC analysis very desirable...

Application example for LHC/LC hand-in-hand analysis

LC analysis:

- use only production of $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$, $\tilde{\chi}^+_1$ up to $\sqrt{s} = 500$ GeV for

$\rightarrow$ determine the fundamental parameters M_1, M_2, μ, $\tan\beta = v_2/v_1$

$\rightarrow$ prediction for $\tilde{\chi}^0_3$, $\tilde{\chi}^0_4$, $\tilde{\chi}^\pm_2$

Procedure:

- Chargino mixing matrix depends on M_2, μ, $\tan\beta$
  diagonalised via two mixing angles $\cos 2\Phi_L$, $\cos 2\Phi_R$
  $\rightarrow$ observables: masses and cross sections (depend also on $m_{\tilde{\nu}}$!)

- Neutralino mixing matrix depends on M_2, μ, $\tan\beta$ and M_1
  $\rightarrow$ observables: masses and cross sections (depend also on $m_{\tilde{e}_L}$, $m_{\tilde{e}_R}$)

- determination of these parameters including
  simulated errors for the scenario SPS1a ($\tan\beta = 10$)!
  $\rightarrow$ combination of analytical step-by-step and fit procedure

Step I: analysis at LC@500 GeV for SPS1a

- taking into account only light particles

$\rightarrow$ simulation of determination of light masses (U. Martyn, M. Ball):

	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{e}_R$	$\tilde{e}_L$	$\tilde{\nu}_e$
mass	176.03	378.50	96.17	176.59	358.81	377.87	143.0	202.1	186.0
error	0.55		0.05	1.2			0.05	0.2	0.7

- $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$: $\sigma_{L,R}(\tilde{\chi}_1^+\tilde{\chi}_1^-) = f(\cos 2\Phi_L, \cos 2\Phi_R, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\nu}_e})$

  with polarised beams $P_{e^-} = \pm 80\%$, $P_{e^+} = \mp 60\%$

$\sqrt{s} = 400$ GeV	$\sqrt{s} = 500$ GeV
$\sigma_L = 215$ fb $\quad \sigma_R = 6$ fb	$\sigma_L = 504$ fb $\quad \sigma_R = 15$ fb

$\Rightarrow$ magnitude of errors ($\int \mathcal{L} = 100$ fb^{-1} for each configuration):

δ_{stat}	up to	$\sim 4\%$
$\delta_{P(e^\pm)}$	$\ll$	1% (σ_L) and $< 2\%$ (σ_R) , where $\Delta P(e^\pm)/P(e^\pm) = 0.5\%$
$\delta_{m_{\tilde{\chi}_1^\pm}}$	up to	$\sim 3\%$
$\delta_{m_{\tilde{\nu}}}$	$\ll$	1%

Step I: analysis at LC@500 GeV for SPS1a, cont.

- $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2,\ \tilde{\chi}^0_2\tilde{\chi}^0_2$: $\sigma_{L,R}(\tilde{\chi}^0_i\tilde{\chi}^0_j) = f(\cos 2\Phi_L, \cos 2\Phi_R, m_{\tilde{\chi}^\pm_1}, m_{\tilde{\chi}^0_1}, m_{\tilde{e}_{L,R}})$
  with polarised beams $P_{e^-} = \pm 80\%$, $P_{e^+} = \mp 60\%$

	$\sqrt{s} = 400$ GeV		$\sqrt{s} = 500$ GeV	
$\tilde{\chi}^0_1\tilde{\chi}^0_2$	$\sigma_L = 148$ fb	$\sigma_R = 20$ fb	$\sigma_L = 168$ fb	$\sigma_R = 21$ fb
$\tilde{\chi}^0_2\tilde{\chi}^0_2$	$\sigma_L = 86$ fb	$\sigma_R = 2$ fb	$\sigma_L = 217$ fb	$\sigma_R = 6$ fb

$\Rightarrow$ magnitude of errors ($\int \mathcal{L} = 100$ fb^{-1} for each configuration):

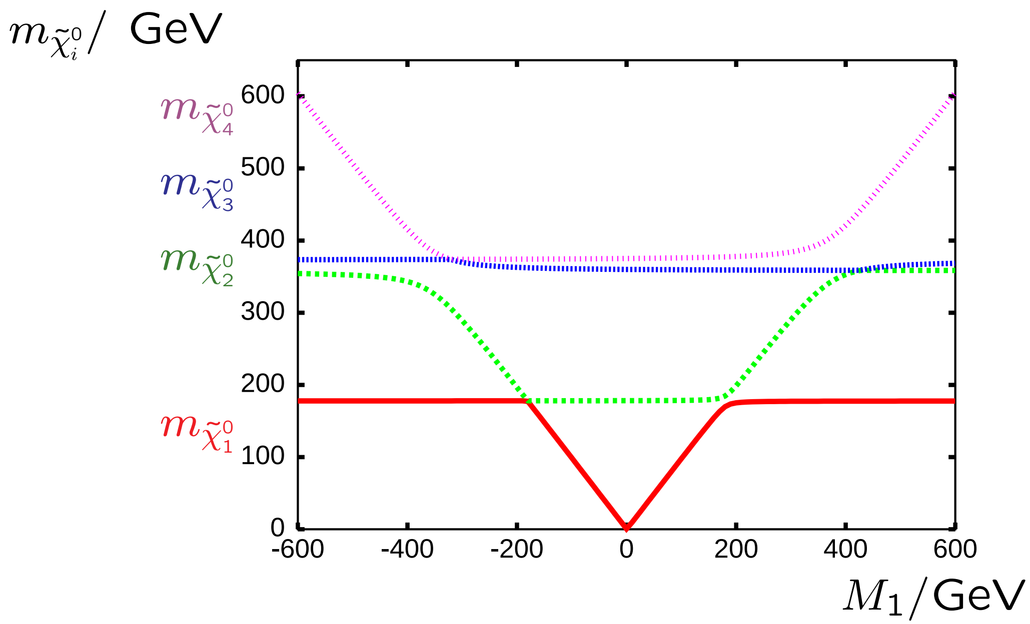
δ_{stat}	up to	$\sim 2\%$ (σ_L) and $\sim 8-16\%$ (σ_R)
$\delta_{P(e^\pm)}$	up to	$\ll 1\%$ (σ_L) and $< 2\%$ (σ_R) , where $\Delta P(e^\pm)/P(e^\pm) = 0.5\%$
$\delta m_{\tilde{\chi}^\pm_1}$	up to	$\sim 2\%$
$\delta m_{\tilde{e}_L}$	up to	0.2%
$\delta m_{\tilde{e}_R}$	up to	0.1%

- light particle production: statistical error and error due to $m_{\tilde{\chi}^\pm_1}$ dominating

One side remark: are neutralino cross section needed?

In principle: only M_1 needed from neutralino sector

Often assumed: M_1 can be derived from $m_{\tilde{\chi}^0_1}\ldots$ That is not true!



- other possibility: characteristic equation for $m^2_{\tilde{\chi}^0_i}$: quadratic in M_1

$\rightarrow$ theoretically only two masses needed, in principle,...

$\Rightarrow$ cross sections needed for unique solution!

Step I: analysis at LC@500 GeV for SPS1a, cont.

Results from the 3-parameter fit of this analytically based procedure:

SPS1a scenario (all masses in GeV)							
	M_1	M_2	μ	$\tan\beta$	$m_{\tilde{\chi}_2^\pm}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$
theo	99.1	192.7	352.4	10	378.5	358.8	377.9
LC_{500}	Susy parameters				Resulting Predictions		
	99.1 ± 0.2	192.7 ± 0.6	352.8 ± 8.9	10.3 ± 1.5	378.8 ± 7.8	359.2 ± 8.6	378.2 ± 8.1

$\Rightarrow$ quite accurate predictions for the LHC analysis!

What's going on at the LHC?

Mass Measurement at the LHC: cascade decays

Search for heavy neutralinos at the LHC:

main decay chains for $\tilde{\chi}^0_4$ + background → very tricky analysis!

- $\tilde{\chi}^0_4(q) \to \tilde{\ell}^{\pm}_R(\ell^{\mp}) \to \tilde{\chi}^0_1 \ell^{\pm}$
- $\tilde{\chi}^0_4(q) \to \tilde{\ell}^{\pm}_L(\ell^{\mp}) \to \tilde{\chi}^0_1 \ell^{\pm}$ or $\tilde{\chi}^0_2 \ell^{\pm}$
- $\tilde{\chi}^{\pm}_2(q') \to \tilde{\nu}_{\ell}(\ell^{\pm}) \to \tilde{\chi}^{\pm}_1 \ell^{\mp}$

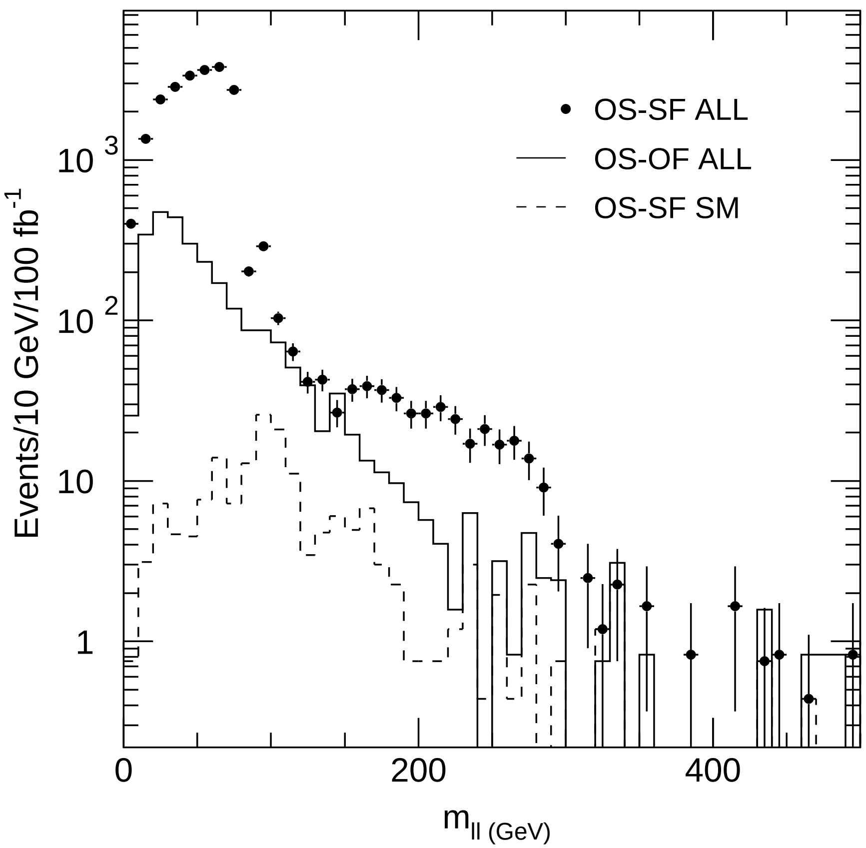
⇒ $m_{\tilde{\chi}^0_4}$ edge challenging!

in combination with invariant masses:

⇒ OS-SF signal derivable

with $\delta(m) \pm 5.1$ GeV

G. Polesello '04



Step 2 – combined analysis with LHC/LC(500)

LC output: 'Telling the LHC, where to look!'
Prediction of the heavier $m_{\tilde{\chi}^0_4} = 378.2 \pm 8.1$ GeV

feed in LHC analysis:

a) using precisely measured light particles $m_{\tilde{\chi}^0_1}$, $m_{\tilde{\chi}^\pm_1}$, $m_{\tilde{e}_{L,R}}$, $m_{\tilde{\nu}}$

b) increase of statistical sensitivity due to LC prediction
('look elsewhere effect')
$\rightarrow$ might be crucial for such stat. marginally signals!

leads to LHC output:

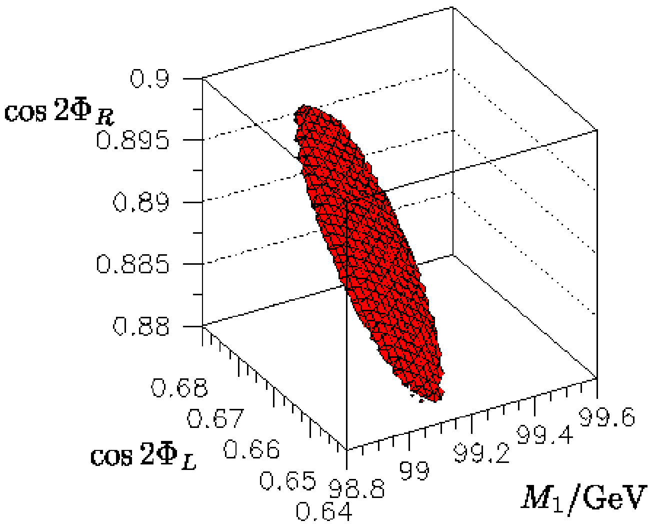
a) precise measurement of $m_{\tilde{\chi}^0_2}$:
$\Rightarrow \delta(m_{\tilde{\chi}^0_2}) = 0.08$ GeV!

b) '$\tilde{\chi}^0_4$' story:
now clear identification of $\tilde{\chi}^0_4$ edge followed by a precise measurements
$\Rightarrow m_{\tilde{\chi}^0_4} = 377.87 \pm 2.23$ GeV

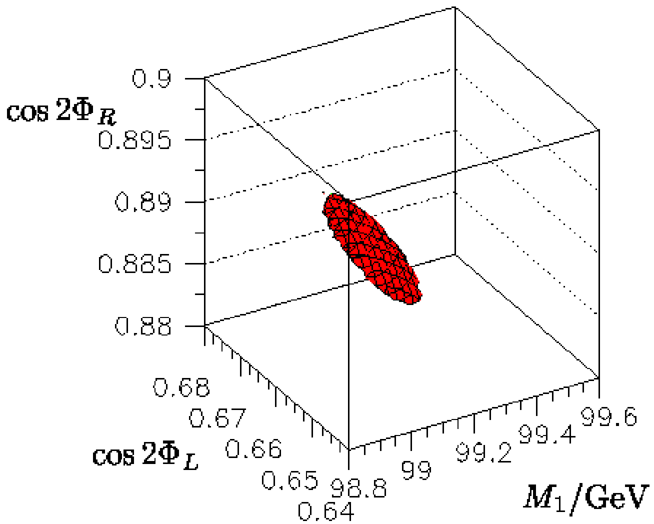
$\Rightarrow$ important model check with LC prediction!
$\Rightarrow$ feeding back precise mass measurements to LC analysis

Step 2 – combined analysis withLHC/LC(500),cont.

LC_{500} only



LHC+LC_{500} combined



	M_1	M_2	μ	$\tan\beta$
theo	99.1	192.7	352.4	10
LC_{500}	99.1 ± 0.2	192.7 ± 0.6	352.8 ± 8.9	10.3 ± 1.5
LHC+LC_{500}	99.1 ± 0.1	192.7 ± 0.3	352.4 ± 2.1	10.2 ± 0.6

$\Rightarrow$ precise results, without assuming a specific breaking scheme!

Conclusions: Promising 'hand-in-hand' LHC/LC procedures!

- Susy (as an example for tricky new physics searches) greatly benefits from synergy of combined LHC and LC analyses

- LHC: edges of heavier non-coloured states quite tricky
  suppose, there is statistically marginal signal right at the LC prediction

$\Rightarrow$ optimised search at the LHC

$\Rightarrow$ clear identification and precise measurement possible or possible LHC upgrades: call for more luminosity (?), ...

- LHC/LC combined analysis: precise ('loop level') Susy parameter determination without assuming a specific Susy breaking scheme!

- LC prediction is prototype example for LHC/LC synergy effects

$\rightarrow$ Outlook: study of 'more difficult' scenarios for both machines

- further examples: LHC/LC study group report ($\geq$ 400 pages!)

$\rightarrow$ LHC/LC webpage: http://www.ippp.dur.ac.uk/~georg/lhclc

Some more details: Errors in $\sigma_{L,R}(\tilde{\chi}^0_i\tilde{\chi}^0_j)$, cont.

Remark: simulation for unpolarised beams (M. Ball@K. Desch)

- efficiency 25%

$\rightarrow$ 'scaling' the stat. error for the polarised case with

  - the same efficiency
  - $\delta\sigma/\sigma = \sqrt{S+B}/S$

- uncertainty in background processes: adding $\delta\sigma_{bg}$

  (respectively to their relative contribution)

What's about $\tilde{\chi}^0_2\tilde{\chi}^0_2$ production?

- no simulation exists so far
- 'multiple' τ's in the final state
- but quite 'background save'

$\Rightarrow$ estimate efficiency of 15%