How to discriminate MSSM and NMSSM? (preliminary)

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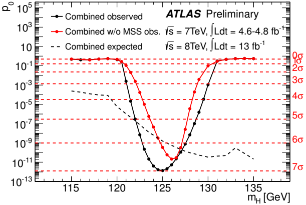
DESY

Outline

- LHC and SUSY
- Strategy to distinguish between MSSM and NMSSM scenarios.
- Example of analysis.
- Conclusions and outlook.

2012 gave us many of results from LHC, in particular:

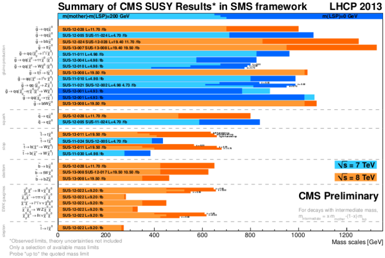


- SM-like Higgs discovery at 125 GeV

  Yes, " We have it! "

- Great performance from LHCb.

BUT



- No direct observation of BSM particles
- SUSY constrained minimal models, ex. cMSSM, etc under pressure.
  see Rachik Soualah's and Lukas Vanelderen's talks
- As well as composite models [Redi, Sanz, de Vries, Weiler '13] , Little Higgs [Reuter, Tonini '12] . . .

SUSY possible scenarios?

SUSY is (still) one of the best in shape solutions. Much parameter regions to explore, both in MSSM and in NMSSM see Sven Heinemeyer's talk. For example

- Heavier neutral scalar option at 125 GeV.
- No lose theorems for NMSSM [Ellwanger et al.] ...

This is particulary the case if we do not assume any SUGRA, GUT or other high energy assumptions.

Also:

- Split SUSY [Wells '03], [Arkani-Hamed & Dimopoulos '04].
- Natural SUSY.
- ...

MSSM vs NMSSM?

In case of SUSY discovery, how to distinguish between MSSM and NMSSM scenarios?

MSSM		($\mathbb{Z}_3$-)NMSSM
$h,\ H,\ A,\ H^{\pm}$: $\tan\beta,\ m_A$		$S_{1,2,3},\ P_{1,2},\ H^{\pm}_{1,2}$: $\tan\beta,\ \lambda,\ x,\ \kappa,\ A_\lambda,\ A_\kappa$
$\tilde{\chi}^{\pm}_1,\ \tilde{\chi}^{\pm}_2$: $M_2,\ \mu,\ \tan\beta$	+ Singlino =	$\tilde{\chi}^{\pm}_1,\ \tilde{\chi}^{\pm}_2$: $M_2,\ \lambda\cdot x,\ \tan\beta$
$\tilde{\chi}^0_{1,2,3,4}$: $M_1,\ M_2,\ \mu,\ \tan\beta$		$\tilde{\chi}^0_{1,2,3,4,5}$: $M_1,\ M_2,\ \lambda,\ x,\ \kappa, \tan\beta$

Often one looks only at the Higgs scalar sector.

What if:

- Higgs spectra are not distinguishable at the LHC and LC?
- Very similar chargino/neutralino spectra?
- Close cross sections?

This is possible for unconstrained scenarios [hep-ph/0502036].

Strategy

- We measure at LHC/LC the light SUSY masses: $m_{\tilde{\chi}^0_{1,2}}$, $m_{\tilde{\chi}^\pm_1}$, $m_{\tilde{\nu}}$, $m_{\tilde{e}_{R,L}}$.
- At the LC:
  - We exploite polarized beams: $P_{e^-} \in [-0.9, +0.9]$, $P_{e^+} \in [-0.6, +0.6]$.
  - We measure $\sigma(e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2)$ and $\sigma(e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1)$ at $\sqrt{s} = 350,\ 500$ GeV.
- The strategy is to:
  - Find MSSM/NMSSM scenarios reproducing the observed spectra and cross sections.
  - Assume experimental uncertainties: $\delta m_{\tilde{\nu}_e}$, $\delta m_{\tilde{e}_L} \sim 1.5\%$; $\delta m_{\tilde{\chi}^\pm_1}$, $\delta m_{\tilde{\chi}^0_1}$, $\delta m_{\tilde{\chi}^0_2} \sim 1\%$.
    Polarization uncertainties give a negligible contribution.
    (rather conservative assumptions)
  - Fit the NMSSM theoretical values to the MSSM parameters M_1, M_2, $\mu, \tan\beta$.
  - Derive heavier MSSM chargino/neutralino masses.
  - Verification at LHC/LC.

Example: SUSY inputs and spectra

Very close lower MSSM/NMSSM spectra possible for unconstrained scenarios, ex: $M_1 > M_2$, contempled also in AMSB.

	M_1	M_2	$\mu/\mu_{eff} = \lambda \cdot x$	$\tan\beta$	κ	λ
MSSM	365	142	360	8		
NMSSM	360	142	457.5	9.6	0.2	0.5

Leading to $m_h = 125$ GeV and

	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$	$m_{\tilde{\chi}_5^0}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_2^\pm}$
MSSM	129	338	366	405		130	382
NMSSM	129	336	366	468	499	131	474

We also take $m_{\tilde{e}_L}$ =240, $m_{\tilde{e}_R}$ =224, $m_{\tilde{\nu}_e}$ =226.

Available production channels:

$\sqrt{s} = 350$ GeV: $\sigma(e^+e^- \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm)$.

$\sqrt{s} = 500$ GeV: $\sigma(e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0)$ and $\sigma(e^+e^- \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm)$.

Example: $\sigma(e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-)$

$\sigma(e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-)$ at $\sqrt{s}$ =350, 500 GeV

$\sqrt{s}$ =350 GeV	MSSM	NMSSM
$P = (0, 0)$	422.2±14.6	427.8±15.2
$P = (-0.9, 0.6)$	1282.7±44.4	1298.5±46.1
$P = (0.9, -0.6)$	17.7±0.6	19.2±0.7

$\sqrt{s}$ =500 GeV	MSSM	NMSSM
$P = (0, 0)$	302.9±3.65	313±3.85
$P = (-0.9, 0.6)$	920.4±10.9	951.4±11.5
$P = (0.9, -0.6)$	12.62±0.22	12.69±0.22
$P = (-0.9, -0.6)$	230.13±2.8	237.9±2.9
$P = (0.9, 0.6)$	48.6±0.7	50.1±0.6

- The statistic error is given by 1 σ at $\int \mathcal{L} = 500$ fb^{-1}.
- $\delta m_{\tilde{\nu}_e}$, $\delta m_{\tilde{e}_L} = 1.5\%$, $\delta m_{\tilde{\chi}_1^\pm}$, $\delta m_{\tilde{\chi}_1^0}$, $\delta m_{\tilde{\chi}_2^0}$ at 1%.
- Relative error on the polarizations: $\Delta P/P = 0.5\%$, negligible.

Example: $\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0)$

$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0)$ at $\sqrt{s}$ =500 GeV:

$\sqrt{s}$ =500 GeV	MSSM	NMSSM
$P=(0,0)$	9.45±1.41	6.05±0.86
$P=(-0.9,0.6)$	28.7±4.3	18.4±2.6
$P=(0.9,-0.6)$	0.40±0.07	0.251±0.042
$P=(-0.9,-0.6)$	7.18±1.08	4.59±0.66
$P=(0.9,0.6)$	1.52±0.23	0.97±0.14

- The statistic error is given by 1 σ at $\int \mathcal{L} = 500\ \text{fb}^{-1}$.
- $\delta m_{\tilde{e}_L} = 1.5\%$, $\delta m_{\tilde{\chi}_1^0}$, $\delta m_{\tilde{\chi}_2^0}$ at 1%.
- Relative error on the polarizations: $\Delta P/P = 0.5\%$, negligible.

MSSM	$\tilde{B}$	$\tilde{W}$	$\tilde{H}_a$	$\tilde{H}_b$
$\tilde{\chi}_1^0$	0.08%	91.8%	2.3%	5.8%
$\tilde{\chi}_2^0$	58.2%	3.8%	22.8%	15.2%
$\tilde{\chi}_3^0$	0.1%	0.96%	38.3%	60.6%
$\tilde{\chi}_4^0$	41.6%	3.41%	36.7%	18.3%

NMSSM	$\tilde{B}$	$\tilde{W}$	$\tilde{H}_a$	$\tilde{H}_b$	$\tilde{S}$
$\tilde{\chi}_1^0$	0.04%	95%	1.1%	3.4%	0.5%
$\tilde{\chi}_2^0$	0.4%	1.9%	11.4%	4.8%	42.6%
$\tilde{\chi}_3^0$	56%	0.2%	1.4%	0.004%	42.3%
$\tilde{\chi}_4^0$	0.1%	0.7%	39.3%	59.2%	0.6%
$\tilde{\chi}_5^0$	4.5%	2.3%	46.7%	32.5%	13.9%

Example: MSSM parameters fit

Using the low spectra masses and $\sigma_{L,R}(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-)$, $\sigma_{L,R}(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0)$ calculated within NMSSM the we perform a χ^2-fit on the MSSM parameters: see Krzysztof's talk

M_1	M_2	μ
349.1±3.7	135.5±0.7	456.4±37.9

Since $\tan\beta$ is unconstrained, it is varied in [1, 60].

- $m_{\tilde{\chi}_3^0} \in [425, 500]$ GeV.
- $m_{\tilde{\chi}_4^0} \in [440, 509]$ GeV.
- $m_{\tilde{\chi}_2^\pm} \in [435, 508]$ GeV.

If we can observe $\tilde{\chi}_3^0$ (through cascades...), we assume an error $\delta m_{\tilde{\chi}_3^0}$ =2%.
We obtain, according to our MSSM and NMSSM original scenario: $m_{\tilde{\chi}_3^0} = 366 \pm 7$ GeV.

Far away by the range of the MSSM fit!!

Example: distinction through neutralino mixing

One should look also at the gaugino/neutralino components of neutralinos:

MSSM fit	$\tilde{B}$	$\tilde{W}$	$\tilde{H}_a$	$\tilde{H}_b$
$\tilde{\chi}_1^0$	0.01%	96%	0.4%	3.6%
$\tilde{\chi}_2^0$	93.8%	0.3%	2.3%	3.6%
$\tilde{\chi}_3^0$	0.1%	0.9%	48.6%	50.4%
$\tilde{\chi}_4^0$	6.1%	2.7%	48.8%	42.3%

NMSSM	$\tilde{B}$	$\tilde{W}$	$\tilde{H}_a$	$\tilde{H}_b$	$\tilde{S}$
$\tilde{\chi}_1^0$	0.04%	95%	1.1%	3.4%	0.5%
$\tilde{\chi}_2^0$	0.4%	1.9%	11.4%	4.8%	42.6%
$\tilde{\chi}_3^0$	56%	0.2%	1.4%	0.004%	42.3%
$\tilde{\chi}_4^0$	0.1%	0.7%	39.3%	59.2%	0.6%
$\tilde{\chi}_5^0$	4.5%	2.3%	46.7%	32.5%	13.9%

Exploit precision LC observables (masses, cross section, Brs . . .).

For ex. gaugino properties can be determined through the hadronic decay modes see Madalina's talk

Conclusions and outlook

- LHC data have severely put under pressure constrained SUSY models, not SUSY. NMSSM is a possibility.
- Unconstrained MSSM and NMSSM scenarios can lead to similar lower spectra and production cross section at LC.
- To understand the underlying model, one can exploit the power of polarized beam at the LC. Measure $\sigma_{L,R}(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0)$ and $\sigma_{L,R}(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-)$.
- Then a fit to the MSSM parameters can allow a search for heavier resonances with an interplay between LHC an the LC, giving a strong discrimination tool.

To do:

- Include other observables to perform the fits and improve the strategy.
- Extend the philosophy to the MSSM scenario. $E(6)$-MSSM?

Thanks!