Distinguishing the NMSSM and the MSSM at the ILC using Fittino

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- What are General Supersymmetry/MSSM/SPSla'/NMSSM?
- SUSY Breaking, mass mixing matrix and mass spectra
- MSSM/SPSla'/NMSSM mimic points
- What is Fittino and what does it do?
- Fittino fits and MSSM/NMSSM truth plots

MSSM/SPSla'

General SUSY has > 100 parameters. However observation severly constrains these

Restrictions

- $BR(\mu \to e\lambda) \to 0$ implies off diagonal elements of slepton mass matrices ->0
- $K^0 \leftrightarrow \overline{K^0}$ CP violation in kaon system restricts mixing of first and second generation squarks

MSSM-22 Parameter Set

- Gaugino masses M_1, M_2, M_3
- 1,2nd Gen mass ($\tilde{e}_L, \tilde{e}_R, \tilde{u}_L, \tilde{u}_R, \tilde{d}_R$)
- 3rd Gen mass ($\tilde{\tau}_1, \tilde{\tau}_2, \tilde{t}_1, \tilde{t}_2, \tilde{B}_R$)
- M_A , μ , $\tan\beta$
- Trilinear ($A_e, A_u, A_d, A_\tau, A_t, A_B$)

Soft SUSY Breaking universality

- All soft SUSY Breaking parameters are real
- Sfermion Mass matrices diagonal
- Trilinear couplings $\propto$ Yukawa couplings

SPA/SPSla' points

- An agreed set of parameters and conventions
- Consistent with experimental data
- Particle masses are fairly light in order to be testable at LHC/ILC

NMSSM - theoretical

Mu Problem

- μ is the mass term of the two Higgs doublets, H_u, H_d
- It is a free parameter and has dimensions of mass.
- Phenomenologically, μ must be of the order of the SUSY/EW Breaking mass scale (~250 GeV)

Naturalness

Terms which appear in the Lagrangian should have units the order of the scale at which the effective theory breaks down – the Plank scale (~10^{19} GeV)

so....NMSSM

- Introduce an additional scalar field $\tilde{S}$ to which the Higgs's couple and is subject itself to symmetry Breaking (i.e. move higgs higgsino mass term from the superpotential to the soft susy Breaking Lagrangian)
- Additional singlet/singlino Superfield $\tilde{S}$
- Mu term replaced By trilinear fields

$$\mu \hat{H}_1 \hat{H}_2 \rightarrow \lambda \hat{H}_1 \hat{H}_2 \hat{S} + \frac{\kappa}{3} \hat{S}^3$$

$$\mu eff = \lambda \langle \hat{S} \rangle$$

- 2 extra Higgs: scalar: H^1 H^2 H^3
  psuedoscalar: A^1 A^2
  charged $H^{\pm}$
- 1 extra neutralino χ^0_1 ,χ^0_2 ,χ^0_3 ,χ^0_4,χ^0_5

Obtaining observables: Chargino mass mixing

MSSM

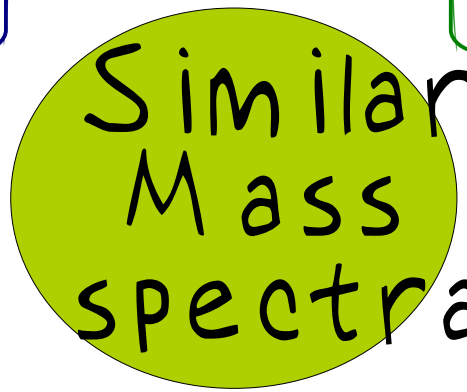
mix $(\tilde{H}_u^+, \tilde{H}_d^-)$ with $(\tilde{B}, \tilde{W}^3)$

$$\begin{pmatrix} M_2 & \sqrt{2}\, M_W s_\beta \\ \sqrt{2}\, M_W c_\beta & \mu \end{pmatrix}$$

NMSSM

mix $(\tilde{H}_u^+, \tilde{H}_d^-)$ with $(\tilde{B}, \tilde{W}^3)$

$$\begin{pmatrix} M_2 & \sqrt{2}\, M_W s_\beta \\ \sqrt{2}\, M_W c_\beta & \mu_{eff} \end{pmatrix}$$



- Solve characteristic equations to get Parameters -> masses
- Neutralino sector mixes $(\tilde{H}_u^+, \tilde{H}_d^-, \tilde{S})$ with $(\tilde{B}, \tilde{W}^3)$ for NMSSM
- Use a Spectrum calculator like Spheno to get all masses and all cross-sections for a particular model (MSSM or NMSSM)
- Are there indistinguishable sets of observables?

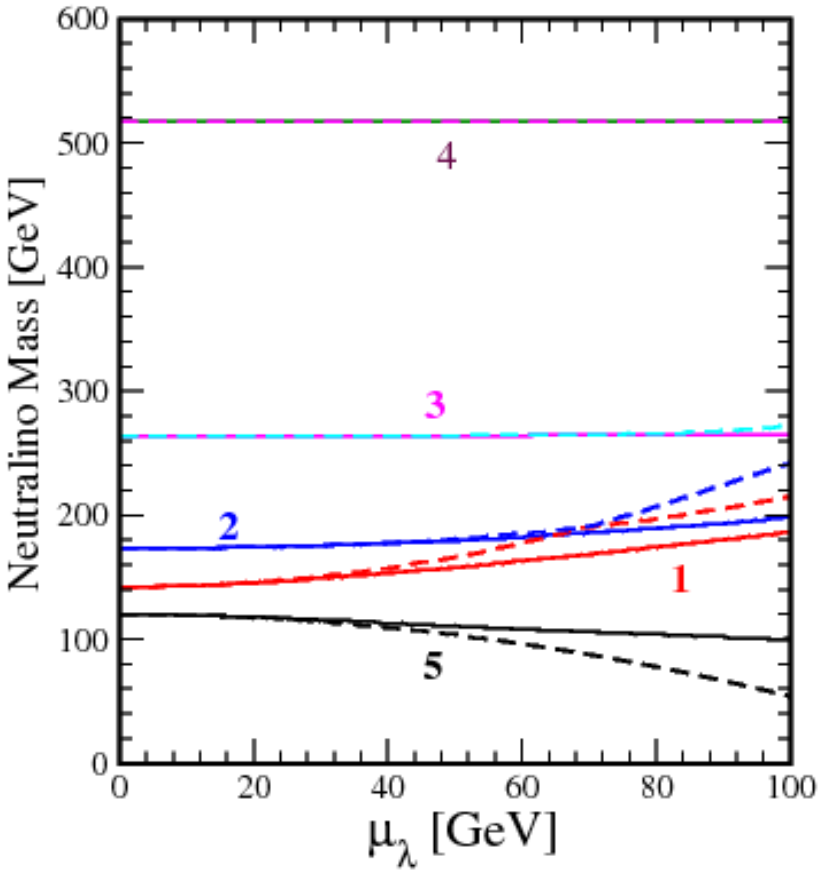
NMSSM – neutralino sector

mix $(\tilde{H}_u^0, \tilde{H}_d^0, \tilde{S})$ *with* $(\tilde{B}, \tilde{W}^3)$

$$\begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ & & 0 & -\mu_{\rm eff} & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & 2\kappa s + 2\mu' \end{pmatrix}$$

Decoupling limit

- For the coupling between S and H_1, H_2 to vanish $\lambda \to 0$
- But $\lambda\langle S\rangle$ is the effective mu term so $\langle S\rangle \to \infty$
- $\langle S\rangle$ scales as $1/\kappa$ so $\kappa \to 0$
- However $\kappa\langle S\rangle$ ($\propto$ mass of χ^0_5) is still free to vary



- χ^0_5 can be the LSP!
- Displaced vertices are possible
- Do not allow this for mimic points study

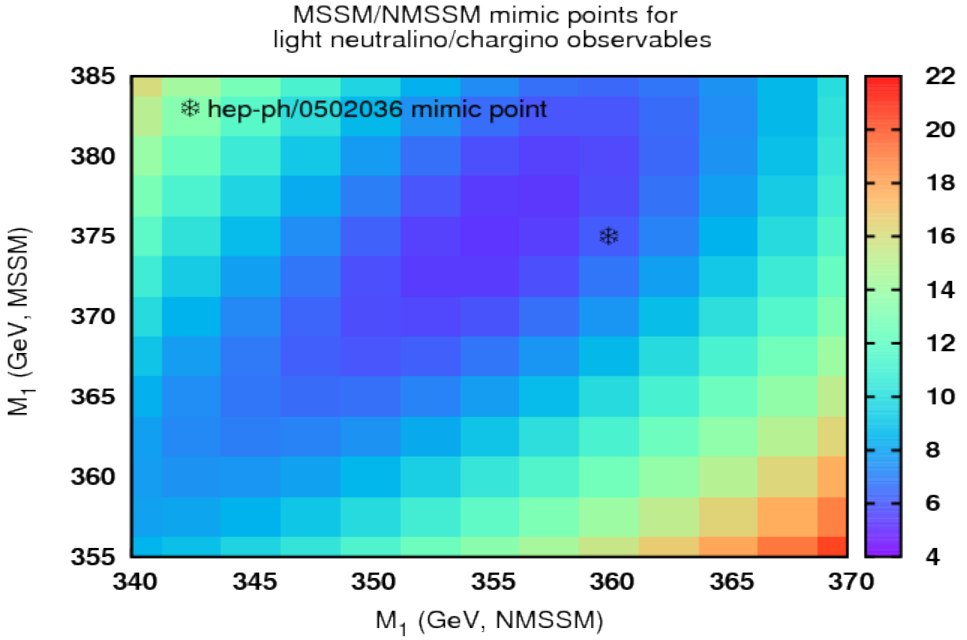
A "difficult" ILC NMSSM/MSSM point

Moortgat-Pick, Hesselbach, Franke & Fraas hep-ph/0502036 (ILC study)

	MSSM	NMSSM
M_1	375 GeV	360 GeV
M_2	152 GeV	147 GeV
tanβ	8	10
μ	360 GeV	-
μ_{eff}	-	457.5 GeV
κ	-	0.2
Mass($\tilde{\chi}_1^0$)	138 GeV	138 GeV
Mass($\tilde{\chi}_2^0$)	344 GeV	337 GeV
Mass($\tilde{\chi}_1^\pm$)	139 GeV	139 GeV
Mass($\tilde{e}_L$)	240 GeV	240 GeV
Mass($\tilde{e}_R$)	220 GeV	220 GeV
Mass($\tilde{\nu}_e$)	226 GeV	226 GeV

Define a distance function:

$$D_{NM} = \sqrt{\sum \left(m_{\chi_1^0}^{NMSSM} - m_{\chi_1^0}^{MSSM}\right)^2 + \left(m_{\chi_1^\pm}^{NMSSM} - m_{\chi_1^\pm}^{MSSM}\right)^2}$$



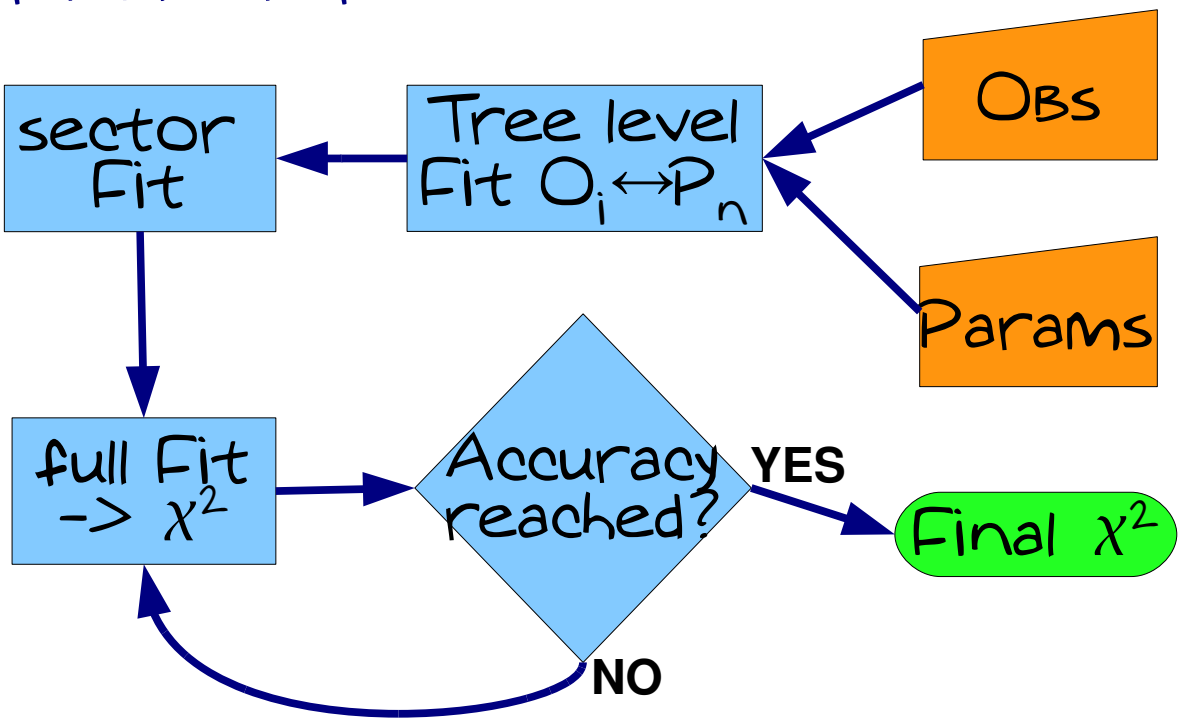
At the ILC cannot distinguish NMSSM/MSSM (at this Par point)

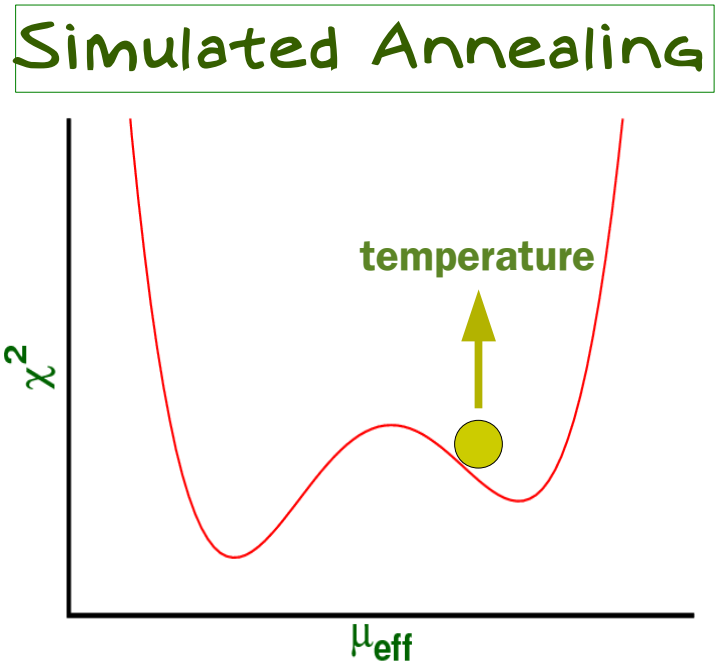
For s=400,500 GeV x-sects

Need s=650 GeV x-sects

Enter, Fittino

- Fit a set of observables (masses, xs, Br, decay widths) to parameters (M_1,M_2,μ,tan β) within a SUSY model (MSSM,NMSSM)
- If Obs (O_1,O_2,....,O_n) and Params (P_1,P_2,....,P_m), then $O_i = F(P_1,P_2,....,P_m)$.
- Fits can be done at tree level (rough) and then with loops
- Calculate χ^2 for the fit of Obs to Params – n-dimensional surface in parameter space





Fittino NMSSM/MSSM fit

Schema:

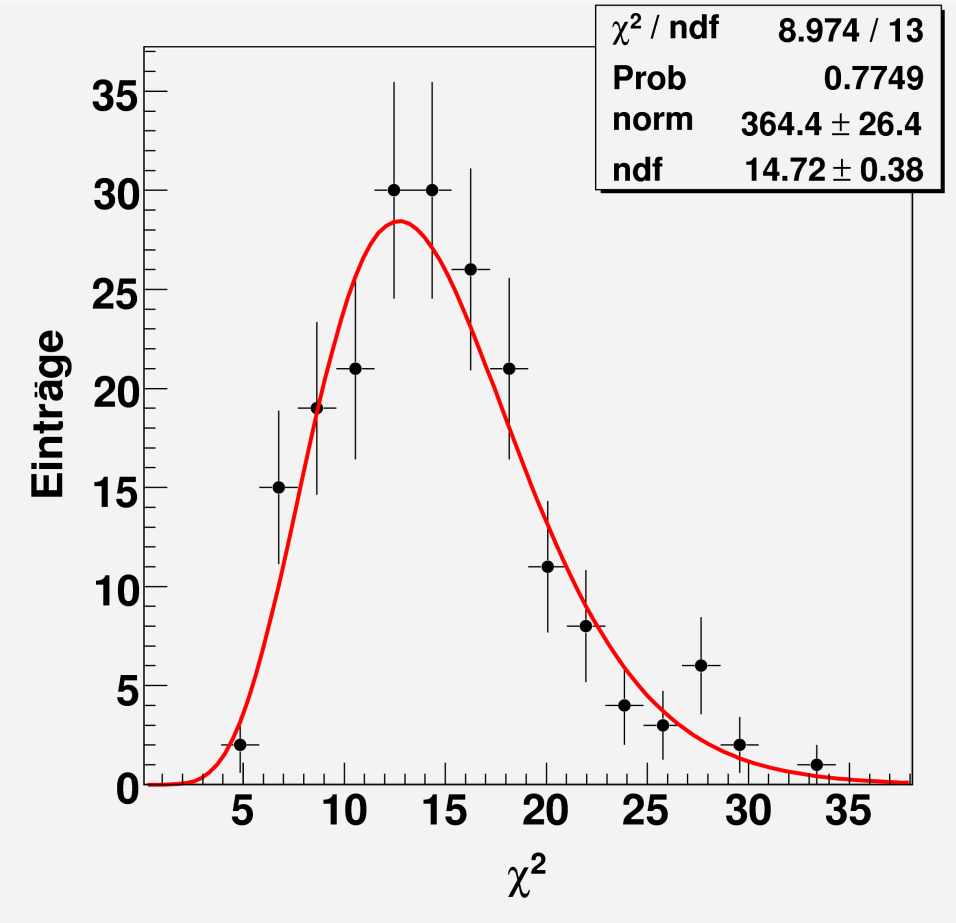
- Choose the "difficult" hep-ph/050236 NMSSM/MSSM point
- For model-specific parameters, μ (MSSM) and λ, κ, μeff (NMSSM) – **fix λ, κ and fit μ and μeff.**

So both NMSSM and MSSM fit to 22 parameters

- Fit the $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$, $\tilde{\chi}^\pm_1$, $\tilde{e}_L$, $\tilde{e}_R$, $\tilde{\nu}_L$ masses. Fix other masses
- Other observables $\sigma(e^+e^- \to \chi^{0,\pm}_{\text{light}})$ at 400,500&650 GeV, polarised
- Check NMSSM obs->NMSSM params fit with "toy fits" (obs smeared within their errors

NMSSM ↔ NMSSM

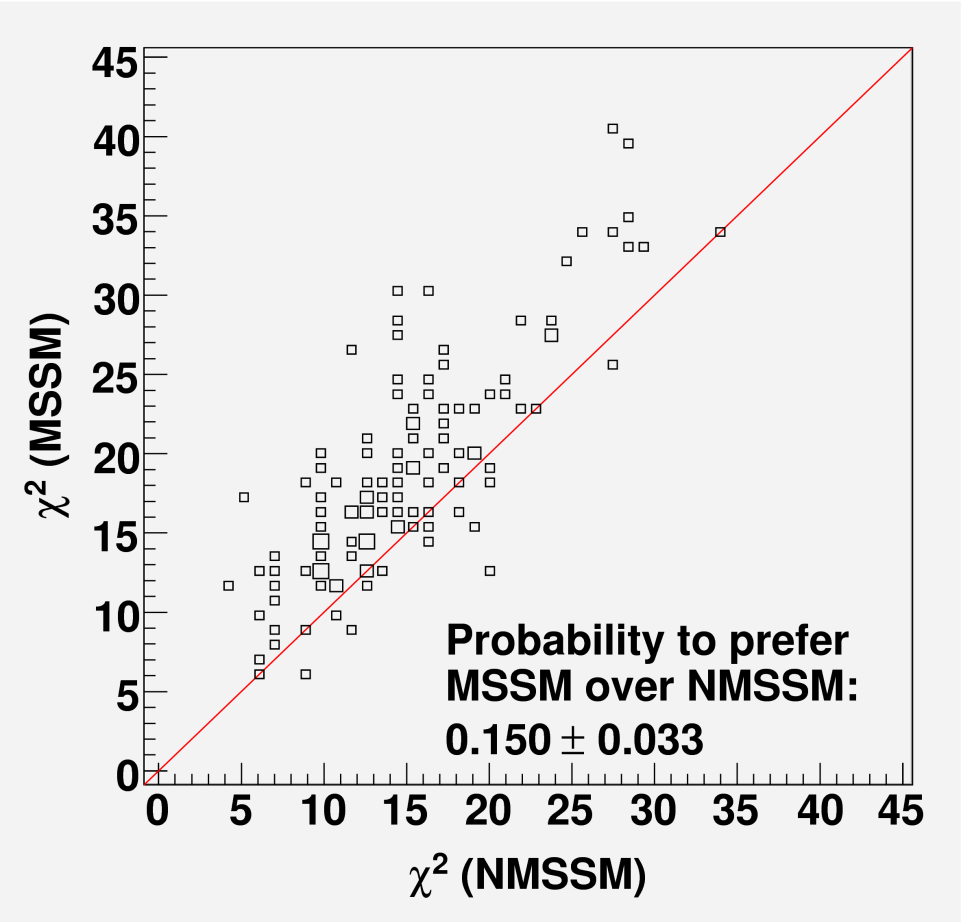
Params - Obs = 15



NMSSM/MSSM χ^2 correlation

$s^{0.5}$ = 400,500 GeV
Polarised&Unpolarised Beams
250 Toyfits

$s^{0.5}$ = 400,500,650 GeV
Polarised&Unpolarised Beams
250 Toyfits



MSSM(Param) <-> NMSSM(Obs)

# Job	chisq	TanBeta	M1
11	4027.256477	24.8969	509.551
14	4025.688755	23.1517	510.37
01	4043.016866	23.1182	510.046
27	3695.092157	25.6162	514.124
43	3923.791504	25.5593	375.707

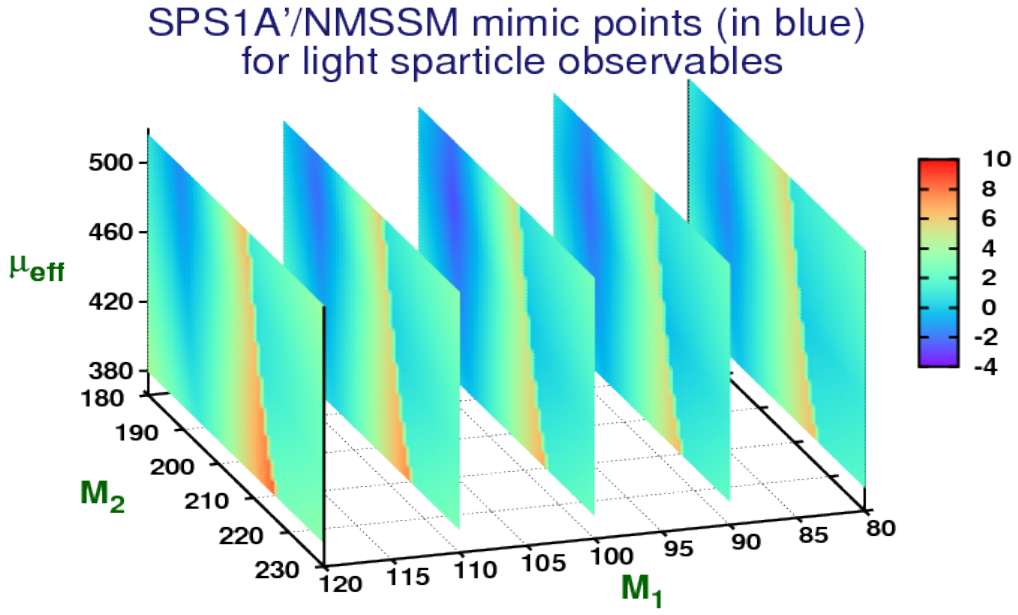
NMSSM/SPSla' mimic points

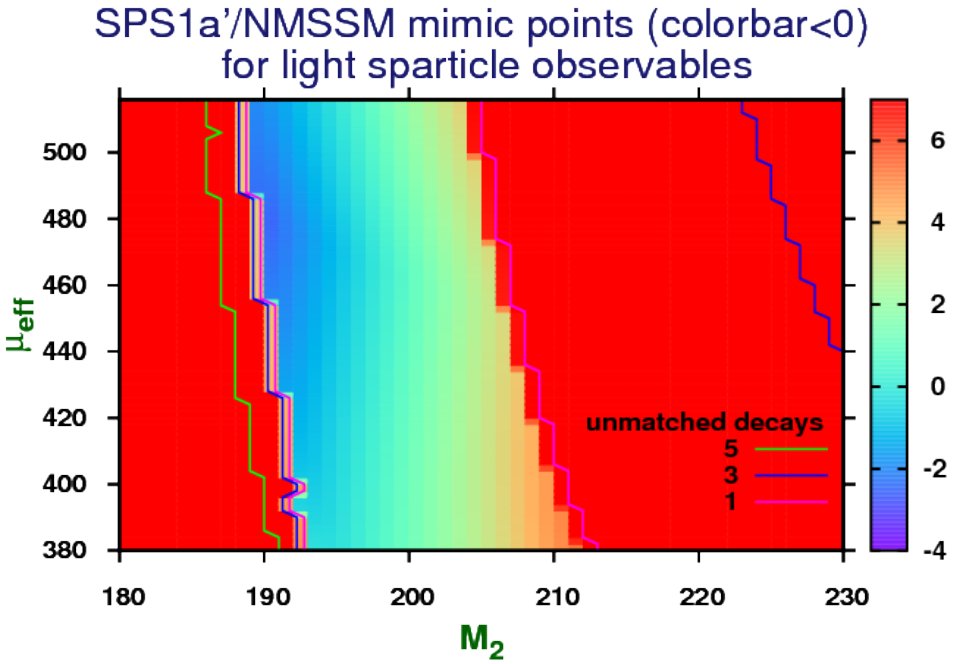
SPSla' point is a fixed parameter set

M_1	M_2	M_3	tanβ	μ
103.3 GeV	193.2 GeV	571.7 GeV	10.0	396.0

Within the mimic points we look for parameter regions which have the same set of decays:

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





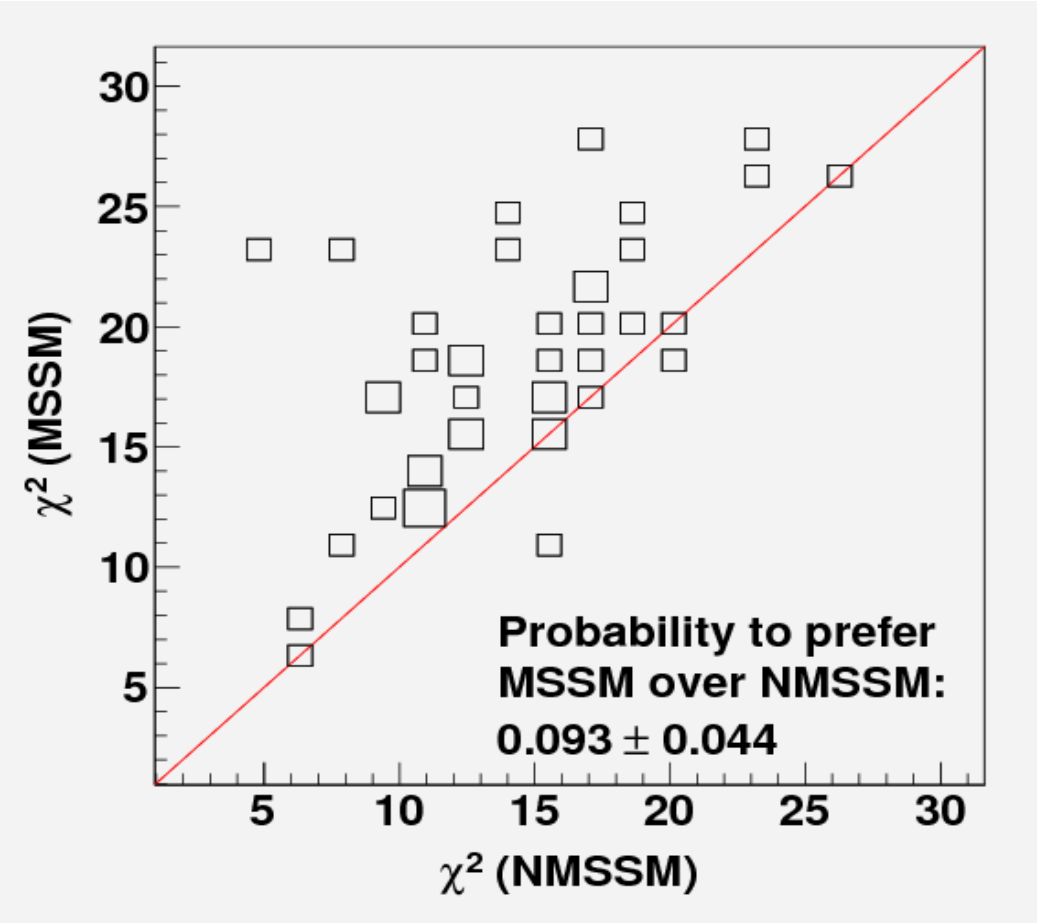
Resolving SPSla'/NMSSM mimic points

ILD Optimisation at SPSla'

DESY FLC Stau study (arXiv:0908.0876v1)

- Full Mokka simulation with ILD detector
- 500 fb^{-1} , $s^{0.5}$ = 500 GeV
- $\tilde{\tau}_1$ is the NLSP
- $m(\tilde{\tau}_1) = 107.69 \pm 0.06 \pm 1.1 \Delta m(LSP)$
- $m(\tilde{\tau}_2) = 183 \pm 11 \pm 18 \Delta m(LSP)$

SPSla'/NMSSM χ^2 correlation



Repeat at lower integrated luminosity to put contour around the mimic areas

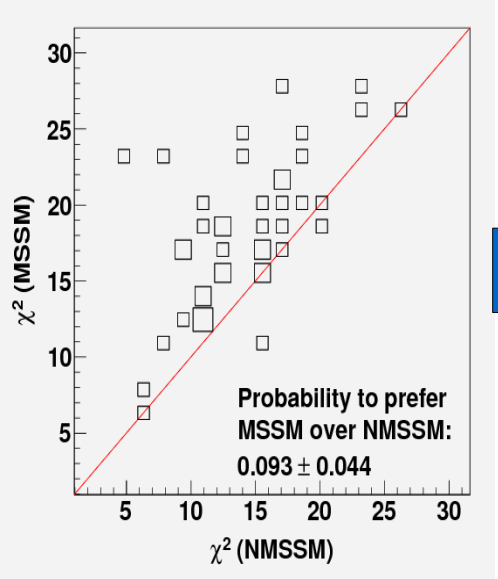
The ultimate challenge: the limit NMSSM→MSSM

MSSM is a subset of the NMSSM

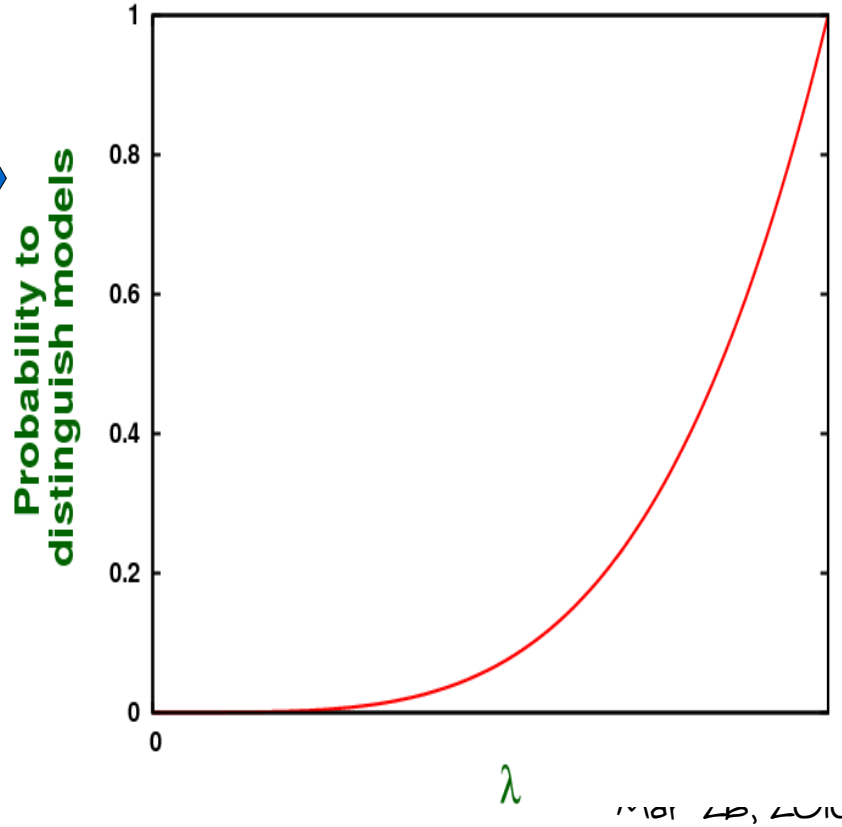
Conditions for MSSM≡NMSSM:

- $\kappa=0$, $\lambda\to 0$, $\langle S\rangle\to\infty$, fixed μ_{eff}

Generate NMSSM/MSSM correlation plot at each λ,<S> point



Obtain a 'truth plot' i.e. find how well Fittino can distinguish models in the limit NMSSM→MSSM



Summary/Ongoing work

(1) NMSSM is an extension of the MSSM introducing an additional scalar field in order to solve the "mu problem"

(2) Analysis of the MSSM and NMSSM mass mixing matrices suggest similar mass spectra of the light sparticles

(3) Defined a distance function between light sparticle observables in MSSM/NMSSM and then do parameter scans using Spheno to find "n-D mimic volumes" in parameter space

(4) Run Fittino at the mimic points with additional obervables in order to reduce the show the extent to which the mimic points can be distinguished

(5) The hep-ph/0502036 NMSSM/MSSM mimic point is already discriminated with observables at $s^{0.5}$=400,500 GeV using Fittino

(6) Introduce more realistic experimental errors on observables at the SPSla' point, using ILD optimisation studies

Backup

General Supersymmetry

$$Q\,|\text{boson}\rangle = |\text{fermion}\rangle \;;\; Q\,|\text{fermion}\rangle = |\text{boson}\rangle$$

Supermultiplets of Super partners

- L – left handed (s)fermions
- E – right handed (s)fermions
- Q – left handed (s)Quarks
- U – right handed up (s)Quarks
- D - right handed down (s)Quarks
- $H_{u,d}$ – 2 Higgs multiplets
- B – U(1) Boson/Bino
- W – SU(2) Bosons/winos
- G – SU(3) Gluons/Gluino

SUSY symmetry Breaking

We can parametrise the susy Breaking Lagrangian By requiring no new Quadratic divergences

$$L_{soft} = -\tfrac{1}{2}\left(M_1 \tilde{B}\tilde{B} + M_2 \tilde{W}\tilde{W} + M_3 \tilde{g}\tilde{g}\right) + \ldots$$

Higgs sector

2 complex doublets ->8 dof

3 dof $W^{\pm}, Z^{0}$; 5 dof $h^{0}, H^{0}, H^{\pm}, A^{0}$

3 Parameters: m_{A^0}, Mass mixing parameter μ and $\tan\beta = v_d/v_u$

Example Fittino run

Input observables with real/expected errors

```
##########################################
###          Fittino example input file    ###
###          for MSSM parameters fit       ###
##########################################

massNeutralino1          97.7642 GeV +-  0.05 GeV # +-  0.4 GeV
massNeutralino2          184.346 GeV +-  0.08 GeV # +-  1.2 GeV
massNeutralino3         -404.141 GeV +-  4.0  GeV # +-  1.1 GeV
massNeutralino4        417.049 GeV +-  2.3  GeV # +-  1.1 GeV
massChargino1        184.133 GeV +-  0.55 GeV # +-  1.0 GeV
massChargino2        418.502 GeV +-  3.0  GeV # +-  3.4 GeV
```

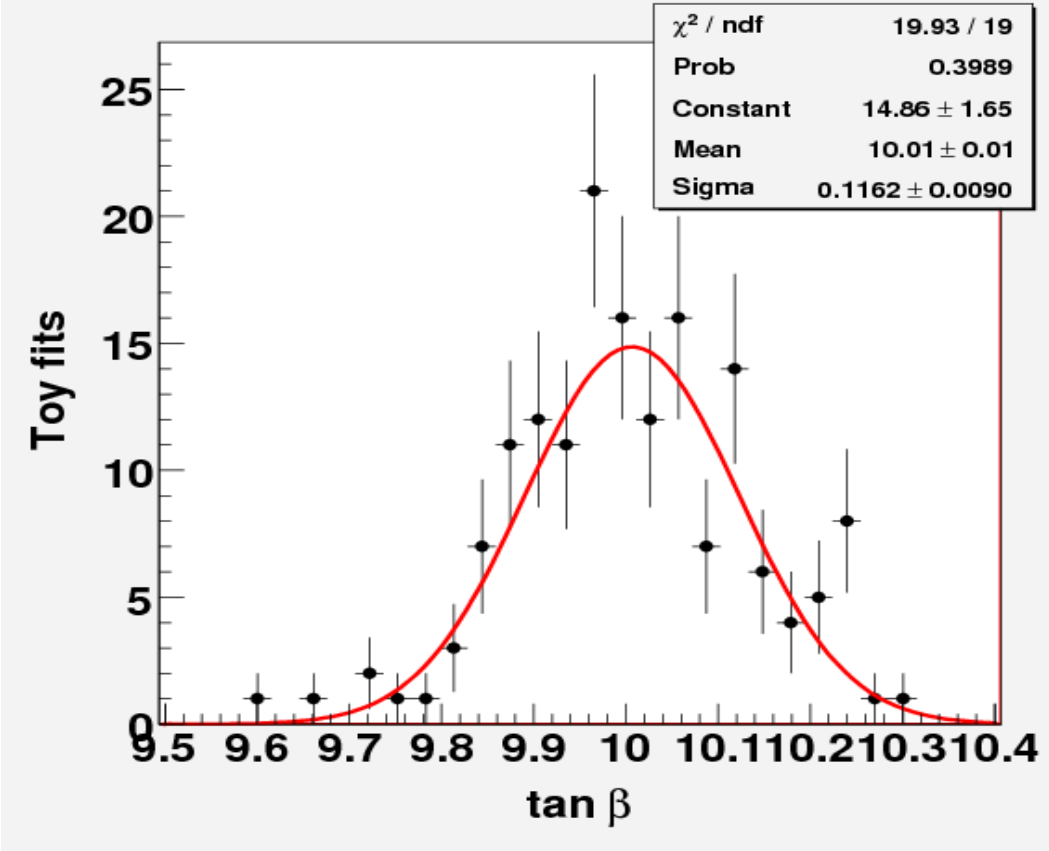
Chose the SUSY model and Input some parameters

```
# fit parameters
##################################

fitModel     MSSM

fitParameter  TanBeta      10.0 +- 1
fitParameter  Mu          4.00391601E+02 GeV
fitParameter  Xtau        -4449.2464     GeV
fitParameter  MSelectronR  1.15601432E+02 GeV
```

- Run once and get a χ^2 for one "toy fit"
- Smear starting value of observables within their errors and get n toy fits



Neutralino mass mixing

MSSM

mix $(\tilde{H}_u^0, \tilde{H}_d^0)$ *with* $(\tilde{B}, \tilde{W}^3)$

$$\begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} \\ & & 0 & -\mu_{\rm eff} \\ & & & 0 \end{pmatrix}$$

NMSSM

mix $(\tilde{H}_u^0, \tilde{H}_d^0, \tilde{S})$ *with* $(\tilde{B}, \tilde{W}^3)$

$$\begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ & & 0 & -\mu_{\rm eff} & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & 2\kappa s + 2\mu' \end{pmatrix}$$