Distinctive NMSSM scenarios at the LHC: an implementation in Isajet

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(based on current work done in collaboration with Ana Teixeira)

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- In the superpartner sector:
  New singlino $\Rightarrow$ 1 extra neutralino (possibly pure singlino)

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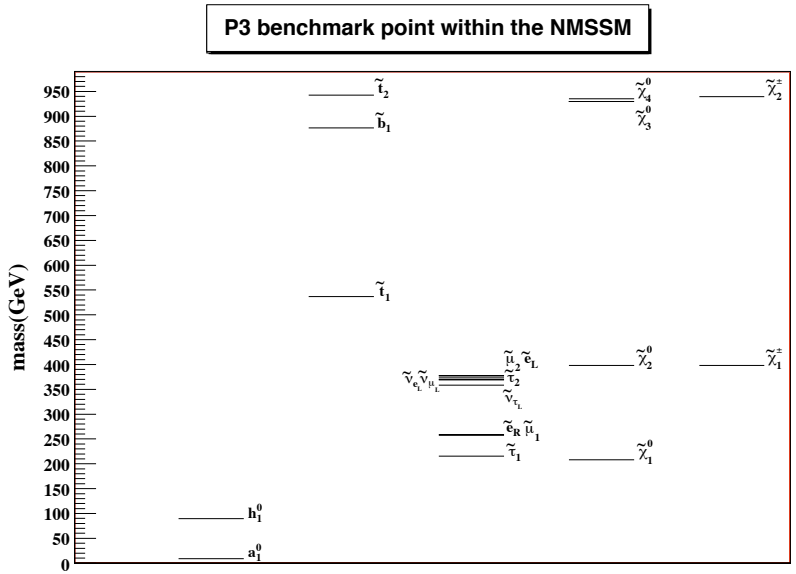

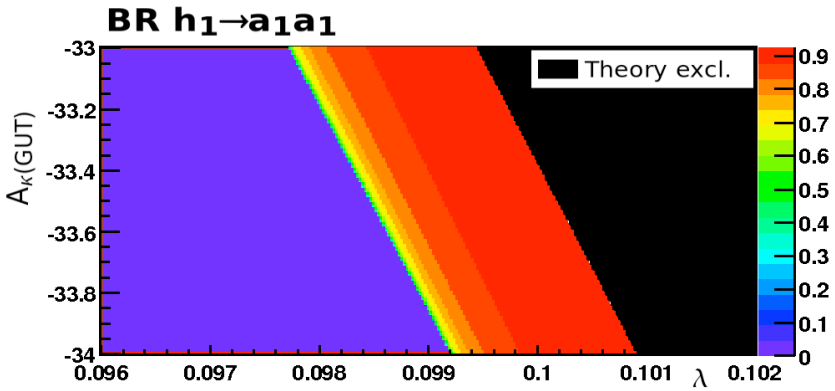

(A. Djouadi et *al.* [arXiv:0801.4321 [hep-ph]])

$BR(h_1^0 \longrightarrow a_1^0 a_1^0)$ almost 100%

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1. $\tilde{\tau}_1$ NLSP + $\tilde{\chi}_1^0$ singlino-like with $(m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1}) << m_{\tilde{\chi}_1}, m_{\tilde{\tau}_1}$: $\tilde{\tau}_1 \rightarrow \tau + \tilde{\chi}_1^0$ slow rate

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Example: cNMSSM

Isajet is a fortran code which may work on various operating systems (SUN, Linux-oriented, MacOS X, etc...)

- Compilation issues: f77/g77/ifort compilers needed, make, etc..
- Use CERN libraries ⇒ beware of your lib version !
- 2 executables ISAJET and ISASUSY to use (we have modified ISASUSY)

Structure of Isajet: parton showering, beam jets

Isajet: a Monte Carlo event generator 3 steps

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- Hard-event generation with matrix elements and QCD radiative corrections (initial final states)
- Independent parton fragmentation into hadrons, decay of short-lived particles ($\tau < 10^{-12}$ s)
- Jet clustering

(H. Baer, F.E. Paige, S.D. Protopopescu and X. Tata [http://www.hep.fsu.edu/ isajet/isajet779.ps])

Structure of Isajet: parton showering, beam jets

Parton fragmentation: Monte Carlo algorithm with independent fragmentation ansatz of Field and Feynman

$q_i - \bar{q}_i$ pairs generated from quark/gluon q/g
probability related to q_i flavor (randomly from g)
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Jet clustering: Abramovskii, Kanchelli and Gribov model (not entering into details)

Structure of Isajet: hard event and model implementation

- Hard event: use of the fortran code IsaSusy for spectrum and decay chains

  One subroutine per calculation ⇒ "sort of" modularity
  cost: each coupling has to be defined very often
  (no common blocks for such quantities...)

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- MSSM is fully implemented in Isajet within a spectrum generator with RGEs

  Our goal: modify this specific part to implement NMSSM

SUSY conventions in Isajet

Code conventions in Isajet do not follow SLHA (alas..)

$\Rightarrow$ dictionnary required !

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Examples:

- Sign of μ: $\texttt{XMU} = -\mu_{literature}$
- Neutralino basis $(-\tilde{h}_u, -\tilde{h}_d, \tilde{\lambda}_2, \tilde{\lambda}_1)$ in Isajet $\Rightarrow$ reverse order
- Chargino matrices and angles:

$$U = \begin{pmatrix} -\sin(\texttt{GAMMAL}) & -\cos(\texttt{GAMMAL}) \\ -\texttt{THX} * \cos(\texttt{GAMMAL}) & \texttt{THX} * \sin(\texttt{GAMMAL}) \end{pmatrix}$$

Mass matrices modification and spectrum interface

To implement NMSSM, three main requirements:

1. modify the neutralino matrix
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Spectrum generated (NMSPEC) and experimental constraints verified within NMSSMTOOLS suite

(U. Ellwanger, J.F. Gunion and C. Hugonie [arXiv:hep-ph/0406215], U. Ellwanger and C. Hugonie [arXiv:hep-ph/0612134])

We have created an interface between Isajet and NMSSMTOOLS: low energy **Isajet spectrum/input** defined by **NMSPEC output**

Modifying the couplings - new decays

New states in Higgs and higgsino sectors
$\Rightarrow$ new mixing coefficients $\Rightarrow$ couplings have to change

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All modified decays have been cross-checked

- NMHDECAY for Higgs decays
- SusyHit through decoupling regime for neutralinos and charginos

Cross-check is so far in good agreement ($0.5 - 1$ % level)

Modifying the couplings - new decays

1. Higgs decays: nearly all Higgs couplings modified
   e.g. $h_i a_j a_k$, $h_i \chi_j \chi_k$, $a_i \chi_j^{\pm} \chi_k^{\pm}$, etc..

   New decays have been implemented, such as $h_1^0 \to a_1^0 a_1^0$
   Sleptons/Squarks-Higgs remain to be done

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2. Neutralino/chargino decays:
   $\tilde{\chi}_i^{\pm} \to \tilde{\chi}_j^0 W^{\pm}$, $\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 Z$, $\tilde{\chi}_i^{\pm} \to \tilde{\nu} l$, etc.. modified
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3. Slepton/Squark decays into Higgs/neutralino remain to be modified

Some preliminaries numerical results

SUSYHIT decay width outputs

```
chi+_2 --> chi+_1 Z  0.596383318E+00

chi+_2 --> chi0_1 W+ 0.160872552E+00

chi+_2 --> chi+_1 h   0.419970527E+00
```

Some preliminaries numerical results

SUSYHIT decay width outputs
ISAJET decay width outputs

```
chi+_2 --> chi+_1 Z  0.596383318E+00

W2SS+  --> W1SS+ Z0 0.59941E+00

chi+_2 --> chi0_1 W+ 0.160872552E+00

W2SS+  --> Z1SS W+   0.15995E+00

chi+_2 --> chi+_1 h   0.419970527E+00

W2SS+  --> W1SS+ HL0 0.41678E+00
```

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NMHDECAY decay width outputs

```
H_1 --> A_1 A_1  3.06557910E-02

H_2 --> H_1 H_1  4.43256512E-03

H_2 --> A_1 Z   8.85711751E-01

A_2 --> neu_1 neu_1 5.53305165E-03
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HL0 --> HA0 HA0 3.0660E-02

H_2 --> H_1 H_1  4.43256512E-03

HH0 --> HL0 HL0 4.4482E-03

H_2 --> A_1 Z   8.85711751E-01

HH0 --> HA0 Z0 8.8556E-01

A_2 --> neu_1 neu_1 5.53305165E-03

HA20 --> Z1SS Z1SS 5.5523E-03
```
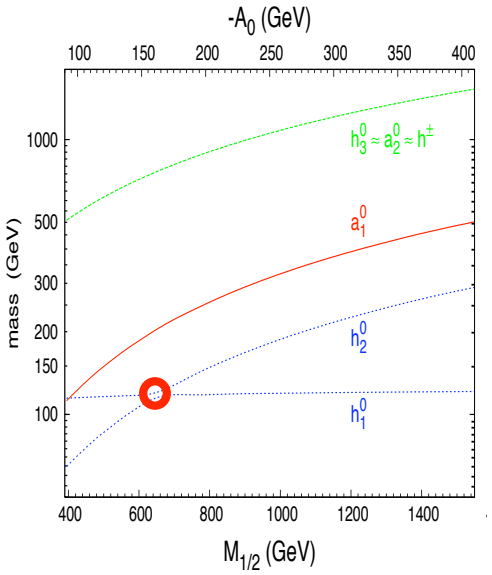

An application of Isajet

We can study GUT-like scenarios with NMSPEC-generated spectrum within Isajet, a low-energy program

Interesting example: the strong mixing regime in cNMSSM



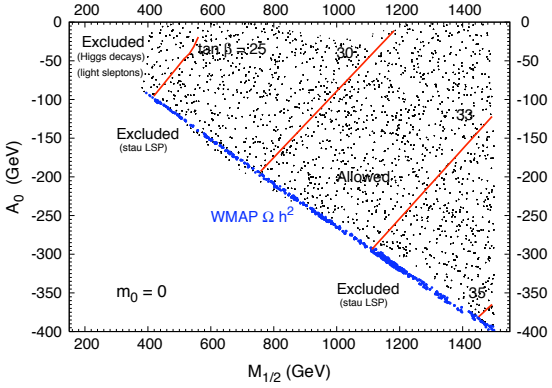
Two reasons of interest:

- cNMSSM actually described by a single parameter
- strong mixing regime ⇒ striking differences with MSSM possibily appear at maximum

(A. Djouadi, U. Ellwanger and A. Teixeira, [arXiv:0803.0253v1 [hep-ph]])

An application of Isajet

1. Theoretical appealing reason: parameter space described by a single parameter



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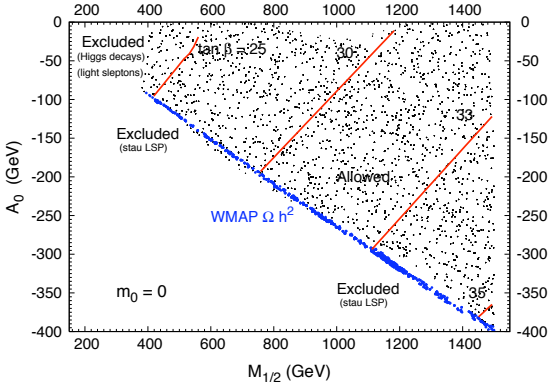

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2. Experimental aspects of strong mixing regime:
   - Generic within cNMSSM: displaced vertices ($\tilde{\tau}_1$ long-lived), unconventional decays
   - Particular aspect: strong doublet-singlet mixing
     $\Rightarrow$ modification of SM-like Higgs couplings with singlet effect possibly visible at maximum

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- Already implemented: Higgs decays (apart from sparticle final states), nearly all neutralino decays, spectrum interface

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- Lots to be done, especially cross section computation and sfermion decays