MSSM benchmarks
with
realistic gaugino-higgsino mixing

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The Gaugino-Higgsino Sector

Charged winos and higgsinos mix into \textbf{charginos}:

\[
\left\{ \left( \tilde{W}^- \right), \left( \tilde{H}^- \right) \right\} \xrightarrow{\text{EWSB}} \left\{ \left( \chi^-_1 \chi^-_2 \right) \right\}.
\]

The neutral bino, wino and higgsinos mix into \textbf{neutralinos}:

\[
\begin{pmatrix}
\tilde{B} & \tilde{W}_3^0 & \tilde{H}_1^0 & \tilde{H}_2^0
\end{pmatrix}^T \xrightarrow{\text{EWSB}} \begin{pmatrix}
\chi_1^0 & \chi_2^0 & \chi_3^0 & \chi_4^0
\end{pmatrix}^T.
\]

All masses and couplings in this sector and with the SM depend on (only) four MSSM parameters:

\[
\{ \mathcal{W}_{\text{MSSM}}, \mu, \tan \beta, M_1, M_2 \}\]

if squarks are decoupled \((m_{\tilde{q}} \gtrsim 1.5 \text{ TeV})\) also cross-sections!
The Minimal Approach

"Dare to be Naive." - R. Buckminster Fuller

Method to obtain MSSM benchmarks, e.g. mass spectra and mixing matrices:

- **set** a no-mixing spectrum with:

1. **bino LSP and** $M_1 < M_2$: ($\mu \to \infty$)
   
   \[
   \begin{align*}
   M_{\chi^0_1} &= M_1 \\
   M_{\chi^\pm_2} &= M_2 \\
   \end{align*}
   \]
   \[\Rightarrow U = \nu = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \quad \mathcal{N} = \begin{pmatrix} 1 & 0 & 0 & 0 \\
   0 & 1 & 0 & 0 \\
   0 & 0 & 0 & 0 \\
   0 & 0 & 0 & 0 \end{pmatrix}\]

2. **wino LSP and** $M_1 > M_2$: ($\mu \to \infty$)
   
   \[
   \begin{align*}
   M_{\chi^0_2} &= M_1 \\
   M_{\chi^\pm_1} &= M_2 \\
   \end{align*}
   \]
   \[\Rightarrow U = \nu = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \quad \mathcal{N} = \begin{pmatrix} 0 & 1 & 0 & 0 \\
   1 & 0 & 0 & 0 \\
   0 & 0 & 0 & 0 \\
   0 & 0 & 0 & 0 \end{pmatrix}\]

3. **triplet of Higgsino LSPs**: ($\{M_1, M_2\} \to \infty$)
   
   \[
   \begin{align*}
   M_{\chi^0_1} &= M_{\chi^\pm_1} = M_{\chi^0_2} = \mu \\
   \end{align*}
   \]
   \[\Rightarrow U = \nu = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \quad \mathcal{N} = \begin{pmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \mp \frac{1}{\sqrt{2}} \\
   0 & 0 & \frac{1}{\sqrt{2}} & + \frac{1}{\sqrt{2}} \\
   0 & 0 & 0 & 0 \\
   0 & 0 & 0 & 0 \end{pmatrix}\]

Applicability for three scenarios, two regions in parameter space.
A Next-To-Minimal Approach

"To improve is to change, so to be perfect is to have changed often.” - W. Churchill

Our proposed method to obtain MSSM benchmarks:

1. **scan** for MSSM parameters \{\mu, \tan \beta, M_1, M_2\}
2. **compute** spectrum and mixing matrices, e.g. diagonalise matrices
3. **select** or **discard** benchmark by comparison with selection criteria

Applicability in (much) larger region of MSSM parameter space
Case-Study:

Higgsino-like benchmarks with equidistant mass-splitting

\[ M_{\chi_1^0} = M_{\chi_1^\pm} - \frac{\Delta M_{21}}{2} \quad \text{and} \quad M_{\chi_2^0} = M_{\chi_1^\pm} + \frac{\Delta M_{21}}{2} \]

Definition of search-grid for \( \sim 10000 \) benchmarks:

<table>
<thead>
<tr>
<th>Physical mass (splitting)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Grid spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{\chi_1^\pm} )</td>
<td>90 GeV</td>
<td>400 GeV</td>
<td>3.1 GeV</td>
</tr>
<tr>
<td>( \Delta M_{21} )</td>
<td>1 GeV</td>
<td>100 GeV</td>
<td>1 GeV</td>
</tr>
</tbody>
</table>

Benchmark selection:

\[
\begin{align*}
&d_1 \Delta M_{\chi_1^\pm} = \delta M_{\chi_1^\pm} \\
&d_2 \Delta (\Delta M_{21}) = 2\delta (M_{\chi_2^0} - M_{\chi_1^\pm}) \\
&d_3 \Delta (\Delta M_{21}) = 2\delta (M_{\chi_1^\pm} - M_{\chi_1^0})
\end{align*}
\]

\[ \Rightarrow \text{score} = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2}{3}} < 0.1 \quad \text{acceptable} \]

Additional reweight to find maximum higgsino content of \( \{ \chi_1^0, \chi_2^0, \chi_1^\pm \} \):

\[ \text{score}_{\text{new}} \frac{f_{\text{old}}}{f_{\text{new}}} < \text{score}_{\text{old}} \]
Scan Results: Benchmark Properties

higgsino content

fine-tuning

$M_W$

$M_Z \cdot \sqrt{c_W^2 s_W^2}$

$\mu > 0$

$\mu < 0$

no benchmarks found

$10^5$ benchmarks available

1 benchmark

$\Delta M_{31}$ (GeV)

$\Delta M_{21}$ (GeV)

$M_{X_1}$ (GeV)

$M_{X_1}$ (GeV)

$\Delta M_{21}$ (GeV)

$\Delta M_{31}$ (GeV)

$M_{X_1}$ (GeV)

$M_{X_1}$ (GeV)

$\mu > 0$

$\mu < 0$
Scan Results: Benchmark Parameters ($\mu > 0$)

where: $\epsilon_{\mu}^{95\%} \in [-0.09, 0.08]$
Conclusion

"A Conclusion is the place where you get tired of thinking." - A. Bloch

- minimal approach has only limited applicability
- (our) next-to-minimal approach has much wider applicability
- MSSM parameter space is constrained more directly
- our approach is feasible in finding benchmarks

Questions

"Better to ask a question than to remain ignorant." - proverb

maybe later? → mpasunder@uni-muenster.de
DM relic density

\[
\mu > 0
\]

\[
\mu < 0
\]

using MicroMegas
Direct Detection

\[ \mu > 0 \]

\[ \mu < 0 \]

using MicrOMEGAS