Chargino/Neutralino analysis in SUSY Point 5 scenario with ILD detector

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Thanks to all ILD people for various support.
SUSY chi1/ne2-pair process

Final state: WW/ZZ + DMDM → j jjj + missing

• Analysis key:
  W/Z separation by 2 jet mass
  - High energy reso.

• Observables:
  - Cross sections: 1D/2D fit
  - SUSY masses (χ⁺₁, χ⁰₂ and χ⁰₁)

SUSY parameters:

- m₀ = 206 GeV, m₁/₂ = 293 GeV,
- tan β = 10, A = 0, µ = 375 GeV

- Degenerate
  m(χ⁻⁺₁) = 216.5 GeV, m(χ⁰₂) = 216.7 GeV
  m(χ⁰₁) = 115.7 GeV, Others heavy

- 100 GeV diff.: decays W/Z + LSP
- σ(e⁺e⁻ → χ⁺₁χ⁻₁) = 132.2 fb (>95%)
- σ(e⁺e⁻ → χ₀₂χ₀₂) = 23.3 fb

5.7 times
ILD Analysis framework

ILD_00 detector model
- Vertex: Si pixel (3x2 layers)
- Silicon Tracker: 4 layers
- TPC (main tracker)
- ECAL/HCAL (5mm/3cm pixel)
- Solenoid (3.5Tesla)
- Muon detector

ILD standard MC simulation output
- Mass production on grid
- SM full processes (luminosity: 0.1-50 fb\(^{-1}\))
- SUSY signal: 1000 fb\(^{-1}\)

ILD standard reco. output
- Tracking
- Particle Flow
- Flavor tagging etc.

Analysis code
- An original Marlin processor for kinematic fit and ROOT tree making
- ROOT macros for analysis.
Data Samples

• SUSY point5 signal events generated with whizard (in DESY)
  – 500 fb$^{-1}$ all-SUSY processes in point5
  – Another 500 fb$^{-1}$ $\chi^\pm/\chi^0$ signal events for template

NOTE: $m_W = 79.8$ GeV due to whizard’s problem

• SM events (mass production, ~20M events)
  – 20-50 fb$^{-1}$ ee$\rightarrow$2/4/6-jet(+lepton) events
  – 0.1 fb$^{-1}$ $\gamma\gamma/e\gamma$ events
  – Additional 500 fb$^{-1}$ $\gamma\gamma \rightarrow$ WW events

• All ILD_00 geometry
Cuts for SM suppression

- 4-jet clustering (Durham)
- # Track $\geq 20$
- $100 < E_{\text{vis}} < 300$ GeV
- each $E_{\text{jet}} > 5$ GeV
- $|\cos \theta|_{\text{jet}} < 0.99$
- Kinematic fit converged

BG suppression cuts

- “qqqq + missing”
- each jet has $\geq 2$ tracks
- $|\cos \theta|_{\text{miss}} < 0.8$
- no $> 25$ GeV leptons
- # PFOs/jet $> 3$
- missing mass $> 220$ GeV
- Kinematic fit converged

Likelihood: $\mathcal{L} = (0, 0.6, 1.1)$

<table>
<thead>
<tr>
<th>Cuts</th>
<th>$\tilde{\chi}^+_1 \tilde{\chi}^-_1 \rightarrow \text{hadrons}$</th>
<th>$\tilde{\chi}^0_2 \tilde{\chi}^0_2 \rightarrow \text{hadrons}$</th>
<th>other SUSY</th>
<th>SM $\gamma \gamma$</th>
<th>SM 6f</th>
<th>SM 4f</th>
<th>SM 2f</th>
</tr>
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<tbody>
<tr>
<td>nocut</td>
<td>28529</td>
<td>5488</td>
<td>74650</td>
<td>3.66e+09</td>
<td>521610</td>
<td>1.48e+07</td>
<td>2.14e+07</td>
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<tr>
<td>Total # of tracks $\geq 20$</td>
<td>27897</td>
<td>5449</td>
<td>24305</td>
<td>3.03e+06</td>
<td>495605</td>
<td>6.68e+06</td>
<td>5.33e+06</td>
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<tr>
<td>$100 &lt; E_{\text{vis}} &lt; 300$ GeV</td>
<td>27895</td>
<td>5449</td>
<td>22508</td>
<td>1.06e+06</td>
<td>44394</td>
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<td>1.56e+06</td>
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<td>$E_{\text{jet}} &gt; 5$</td>
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<td>908492</td>
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<td>$</td>
<td>\cos(\theta)_{\text{jets}}</td>
<td>&lt; 0.99$</td>
<td>26560</td>
<td>5240</td>
<td>19200</td>
<td>350364</td>
<td>41098</td>
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<tr>
<td>$\gamma_{34} &gt; 0.001$</td>
<td>26416</td>
<td>5218</td>
<td>15255</td>
<td>202510</td>
<td>38638</td>
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<td>166305</td>
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<td># of tracks $\geq 2$/jets</td>
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<td>9559</td>
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<td>22740</td>
<td>255870</td>
<td>145270</td>
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<td>$</td>
<td>\cos \theta_{\text{miss}}</td>
<td>&lt; 0.99$</td>
<td>25463</td>
<td>5099</td>
<td>9487</td>
<td>25087</td>
<td>22311</td>
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<tr>
<td>$E_{1} &lt; 25$</td>
<td>25123</td>
<td>4981</td>
<td>6463</td>
<td>23133</td>
<td>14407</td>
<td>154927</td>
<td>3534</td>
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<tr>
<td>$N_{\text{PFO}} &gt; 3$</td>
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<td>4975</td>
<td>20144</td>
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<td>529</td>
<td>389</td>
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<tr>
<td>$</td>
<td>\cos \theta_{\text{miss}}</td>
<td>&lt; 0.8$</td>
<td>20139</td>
<td>4079</td>
<td>3186</td>
<td>656</td>
<td>3837</td>
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<tr>
<td>$M_{\text{miss}} &gt; 220$ GeV</td>
<td>20085</td>
<td>4068</td>
<td>4999</td>
<td>626</td>
<td>3649</td>
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</tr>
<tr>
<td>Kin. fit converged</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• MarlinKinFit processor
  – (Essential) free parameters: Energy and opening angle for each jet(-pair)… NDF=6
  – Constraints:
    • Two di-jet masses are the same – 1C fit
    • Two di-jet masses are \( m_W / m_Z \) – 2C fit (W/Z)

• Jet pairing
  – All pairs
  – Best kinematic fit

<table>
<thead>
<tr>
<th>Obs.</th>
<th>KinFit</th>
<th>Pairing</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma ) (1D fit)</td>
<td>1C</td>
<td>KinFit</td>
</tr>
<tr>
<td>( \sigma ) (2D fit)</td>
<td>No</td>
<td>All</td>
</tr>
<tr>
<td>mass</td>
<td>2C</td>
<td>( \chi^2 ) / KinFit</td>
</tr>
</tbody>
</table>
Invariant mass spectrum

- Combination by kinematic fit
- 4f background is small in the signal mass region
- $\chi^+_1 / \chi^0_2$ separation can be seen
Cross section fitting procedure:

- **SM background**
  - 2\textsuperscript{nd} polynomial fitting separately

- **SUSY + SM**
  - Gaussian + BW for each W/Z
  - Width and center value fixed, normalization is the only free parameters
  - SM 2\textsuperscript{nd} polynomial fixed

**Fit result (\sigma resolution):**

- 0.95\% for \(\chi^\pm\), 2.9\% for \(\chi^0_2\).

Resolution is a little worse, but less MC info required than 2D fit.
Cross section – 2D fit (1)

Original distribution

SM background

Procedure

1. Make di-jet-mass-pair distribution with $500\text{fb}^{-1}$ statistics. (left figure)
   - SUSY and SM combined, SM weighted.
   - All combinations are used (3 entries/event)

2. SM background (right figure) is subtracted from the distribution considering statistical fluctuation.
Cross section – 2D fit (2)

Chargino template

Neutralino2 template

Procedure

3. Using another 500 fb\(^{-1}\) \(\chi^\pm/\chi_0^2\) data, template distribution for both \(\chi^\pm\) and \(\chi_0^2\) are produced.

4. Fit the distribution obtained in 2. with 
   \[ c_1 \times \text{(chargino dist)} + c_2 \times \text{(neutralino2 dist)} \]
   (\(c_1\) and \(c_2\) are free parameters)

5. Repeat 10000 times with SUSY and SM fluctuated.
Cross section – 2D fit (3)

Fitted distribution

Residual (data – fit)

Fit result (10000 average)

$c_1 = 99.97 \pm 0.84\%$, $c_2 = 97.50 \pm 2.75\%$

corresponding to (500 fb$^{-1}$)

$\sigma(e^+e^- \rightarrow \chi^+\chi^-) = 124.80 \pm 1.05$ fb$^{-1}$ (MC 124.84)

$\sigma(e^+e^- \rightarrow \chi^0_2\chi^0_2) = 21.90 \pm 0.62$ fb$^{-1}$ (MC 22.46)
W/Z separation for mass fit

Paring by Kinematic fit probability and cut by $\chi^2$ are applied.

\[
\chi^2_W(m_1, m_2) = \frac{(m_1 - m_W)^2 + (m_2 - m_W)^2}{\sigma^2}
\]

\[
\chi^2_Z(m_1, m_2) = \frac{(m_1 - m_Z)^2 + (m_2 - m_Z)^2}{\sigma^2}
\]

- $\chi^2_W < 4$ for $\tilde{\chi}_1^\pm$ mass fit.
- $\chi^2_W > 4$ & $\chi^2_Z < 4$ for $\tilde{\chi}_2^0$ mass fit.

Chargino selection (no SM)

<table>
<thead>
<tr>
<th>Selection</th>
<th>Signal efficiency</th>
<th>Signal purity</th>
<th>SUSY bg</th>
<th>SM bg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chargino</td>
<td>35.9%</td>
<td>83.4%</td>
<td>5.4%</td>
<td>11.2%</td>
</tr>
<tr>
<td>Neutralino</td>
<td>20.4%</td>
<td>53.8%</td>
<td>22.3%</td>
<td>23.8%</td>
</tr>
</tbody>
</table>

Neutralino selection (no SM)
**Procedure**

1. **2C Kinematic fit** (fit di-jet masses to $m_W/m_Z$)
   
   Pair selection by fit probability, selection by $\chi^2$ (prev. slide)

2. Subtract SM background with statistical fluctuation included

3. Fit 100 times with following function to obtain edge position.

\[
f(x; t_{0-1}, b_{0-2}, \sigma_{0-1}, \Gamma) = \int_{t_0}^{t_1} (b_2 t^2 + b_1 t + b_0) V(t - x, \sigma(t), \Gamma) \, dt \quad (7)
\]

\[
\sigma(t; \sigma_0, \sigma_1) = \sigma_0 + \frac{(\sigma_1 - \sigma_0)(t - 80)}{40}.
\]

7-8 parameters (for $\chi^0_2 \, b_2$ is fixed to 0)
Edge positions \((t_0, t_1)\)

- **W lower**: \(80.04 \pm 0.055\) GeV (MC: 79.80 GeV)
- **W higher**: \(131.8 \pm 0.59\) GeV (MC: 132.77 GeV)
- **Z lower**: \(92.68 \pm 0.32\) GeV (MC: 93.09 GeV)
- **Z higher**: \(127.9 \pm 0.74\) GeV (MC: 129.92 GeV)
Edge to mass

• Kinematics are used to interpret edge position to SUSY masses.

PROBLEM: W lower edge is just at $m_W$ thus has no information for SUSY masses!

• We don’t use W lower edge but use other three edges for the mass calculation (3 variables -> 3 masses: $\chi^+_1$, $\chi^0_2$ and $\chi^0_1$)

• Statistical error of the masses is estimated by toy-MC including correlation between masses. (edge positions are independent)
Results and comments

Gaugino masses w/o correction

\[ m(\chi_{1}^{\pm}) = 220.7 \pm 2.8 \text{ GeV} \]
\[ m(\chi_{2}^{0}) = 219.2 \pm 1.1 \text{ GeV} \]
\[ m(\chi_{1}^{0}) = 118.2 \pm 0.85 \text{ GeV} \]

Gaugino masses w/ correction

\[ m(\chi_{1}^{\pm}) = (216.5) \pm 3.1 \text{ GeV} \]
\[ m(\chi_{2}^{0}) = (216.7) \pm 1.0 \text{ GeV} \]
\[ m(\chi_{1}^{0}) = (115.7) \pm 0.82 \text{ GeV} \]

- Edge position can be corrected in real experiment using MC distribution.
  - Upper left: w/o correction
  - Upper right: assumed that the edge position can be perfectly corrected and the error of the edge position is the same as it without correction.

- Point 5 is a very special scenario which cannot use W lower edge, resulting in worse mass resolution (especially for \( \chi_{1}^{+} \)).

Taikan Suehara et al., ALCPG09 in Albuquerque, 30 Sep. 2009  page 16
Summary

• ILD has sufficient power to separate chargino/neutralino events in point5 SUSY.
• $< 1\%$ ($\chi^\pm$) and $2-3\%$ ($\chi^0_2$) pair production cross section resolution is obtained.
• With 2C kinematic fit, $\sim 1$ GeV ($\chi^0_2$) and $\sim 3$ GeV ($\chi^\pm$) mass resolution is obtained.
• Although mass fit includes some conservative assumptions, it should be a good first estimate of real analyses.
  – Of course having a room to improve analysis…
The end