Search for electroweak SUSY production at CMS

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Motivation

- Most SUSY searches have focused on strong production, which has the largest cross section.

  - Limits on these models probe masses of strongly-interacting particles up to ~1 TeV
  - Similar cross-sections to EWK gaugino’s of 300-400 GeV
- Interesting when squarks and gluino’s are heavy, but EWKinons are light
- Very clean multi-lepton signatures with little hadronic activity

\[ \sigma_{\text{tot}}[\text{pb}]: \text{pp} \rightarrow \text{SUSY} \]

\[ \sqrt{S} = 7 \text{ TeV} \]
Chargino-neutralino production

charged-neutralino production: light sleptons and sneutrinos

- Model naturally gives 3\ell (off-Z) signatures, but can give 2\ell or 3\ell (on-Z) signatures, depending on mass spectrum
  - consider options where taus are preferred
    - final states with hadronic taus are considered

- Dedicated analyses:
  - 3-lepton search
  - same-sign di-lepton analysis (Veto third lepton, fully exclusive)

One missed: SS dileptons
Chargino-neutralino production

Chargino-neutralino production: direct decays to bosons (heavy sleptons)

- Model naturally gives 3ℓ and 3l (on-Z) and 2l (on-Z) + jets signatures

- Dedicated analyses:
  - 3-lepton + M(ll) + MT
  - 2-lepton + di-jet + MET

- Model naturally gives a variety of signatures following the Higgs decay modes
  - Extra handle: Higgs mass

- Dedicated analyses:
  - 1 lepton +b’s
  - SS dileptons
  - trileptons
Other models for direct EWK SUSY production

- Models naturally give $2\ell$ (off-Z) signatures
- Dedicated analysis:
  - opposite-sign di-lepton analysis

- Dedicated analysis for HH decay mode:
  - 4b analysis (SUS-13-022)
- Dedicated analysis for ZZ decay mode:
  - four leptons analysis
  - $Z + $ dijet analysis

\[ \begin{align*}
P_1 & \xrightarrow{\ell} \tilde{l} \xrightarrow{\tilde{\chi}_1^0} \tilde{l} \\
\tilde{\nu} & \xrightarrow{\tilde{\chi}_1^{\mp}} \tilde{\ell} \xrightarrow{\tilde{\chi}_1^0} \ell \\
\end{align*} \]

Slepton pair production

\[ \begin{align*}
P_1 & \xrightarrow{\ell} \tilde{l} \xrightarrow{\tilde{\chi}_1^0} \tilde{l} \\
\tilde{\nu} & \xrightarrow{\tilde{\chi}_1^{\mp}} \tilde{\ell} \xrightarrow{\tilde{\chi}_1^0} \ell \\
\end{align*} \]

Chargino pair production

\[ \begin{align*}
P_1 & \xrightarrow{\ell} \tilde{l} \xrightarrow{\tilde{\chi}_1^0} \tilde{l} \\
\tilde{\nu} & \xrightarrow{\tilde{\chi}_1^{\mp}} \tilde{\ell} \xrightarrow{\tilde{\chi}_1^0} \ell \\
\end{align*} \]

GMSB Higgsino production

\[ \begin{align*}
P_1 & \xrightarrow{\ell} \tilde{l} \xrightarrow{\tilde{\chi}_1^0} \tilde{l} \\
\tilde{\nu} & \xrightarrow{\tilde{\chi}_1^{\mp}} \tilde{\ell} \xrightarrow{\tilde{\chi}_1^0} \ell \\
\end{align*} \]
• **Selection:**
  - Exactly 3 leptons, at most 1 $\tau_{\text{had}}$
  - B-veto to reduce ttbar
  - MET>50 GeV cut to reduce Z+jets
  - MET, $m_T$ and dilepton mass binning
    - dilepton mass bins to reduce Z backgrounds
    - mT bins to reduce W backgrounds

• **Backgrounds:**
  - Data-driven background prediction for non-prompt and misidentified leptons
  - WZ: MC with data-driven corrections to MET
Three lepton analysis

- **Multiple final states:**
  - 3 e/μ, OSSF pair
  - 3 e/μ, no OSSF
  - SS e/μ + τ_{had}
  - OS eμ + τ_{had}

- **Results:**
  - Data consistent with prediction in the full region of phase space

For τ-enriched models

arXiv:hep-ex/1405.7570
Same-Sign dilepton analysis

- Small mass splittings can lead to soft leptons and missing one of the leptons
- Tighter cuts needed because of larger backgrounds

**Selection:**
- Exactly 2 high $p_T$ electrons or muons
- Z veto
- Cut on small hadronic activity or large MET:
  - SR1: MET>200 GeV
  - SR2: jet-veto, 120 GeV<MET<200 GeV

**Backgrounds:**
- Data-driven background prediction for non-prompt and misidentified leptons

**Results:**
- Good agreement between data and prediction

arXiv:hep-ex/1405.7570
Chargino-neutralino production

Charginos $\tilde{\chi}^\pm$ and neutralinos $\tilde{\chi}^0_2$ are produced in $pp \rightarrow \tilde{\chi}^+_1 \tilde{\chi}^0_1$.

$\tilde{\chi}^+_1$ and $\tilde{\chi}^0_2$ are sleptons $\tilde{\ell}$.

$m_{\text{slep}} = x \cdot m_{\chi^+} + (1-x) \cdot m_{\text{LSP}}$

Equal BF to e, $\mu$, $\tau$:
- $x = 0.5$
- $x = 0.05$

Recovered by SS analysis

arXiv:hep-ex/1405.7570
Z+dijet analysis

- **Selection:**
  - Z -> ee or μμ candidate
  - Third lepton veto
  - B veto to suppress ttbar
  - Dijet mass compatible with W boson
  - Use MET bins

- **Backgrounds:**
  - Z+jets MET modeled with γ+jets templates
  - Flavor symmetric backgrounds from eμ

- **Results:**
  - Data well described over several orders of magnitude

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![Graph showing data and backgrounds comparison](image)

*arXiv:hep-ex/1405.7570*
Chargino-neutralino production to WZ

- Complementarity between different analyses:
  - 3l without Z candidate
  - Z+dijet analysis
  - 3l with Z candidate

arXiv:hep-ex/1405.7570
Different Higgs decays according to SM branching fractions – Lead to different final state signatures

Chargino – neutralino production with decay to WH final state

Events in 20 fb⁻¹

Chargino / neutralino mass [GeV]
WH single-lepton

- **Selection:**
  - 1 high $p_T$ e/μ
  - Use kinematic variables to exploit extra MET in event:
    - Cuts on $m_T$, $m_T^{bl}$
    - Different MET bins
  - exactly 2 jets, both b-tagged
  - Look for resonance in $M(bb)$

- **Backgrounds:**
  - Mostly ttbar and W+jets
  - MC with data-driven corrections

- **Results:**
  - No peak visible in mass spectrum

arXiv:hep-ex/1405.7570
WH SS dilepton

**Selection:**
- Exactly 2 same-sign $e/\mu$
- B-veto to suppress ttbar
- 2 or 3 jets
- Extra cuts on MET and different $m_{T2}$ variables to reduce SM backgrounds
- Try to reconstruct visible Higgs mass

**Backgrounds:**
- Data-driven estimates for non-prompt and misidentified leptons
- Prompt SS 2l from MC

**Results:**
- No excess found in $M_{jjj}$ mass spectrum

![Graph showing signal region and results](image_url)

arXiv:hep-ex/1405.7570
WH multi-lepton

Re-interpretation of inclusive multilepton analysis: hep-ex/1404.5801

- **Selection:**
  - 3 or 4$p_T$ leptons; max. 1 $\tau_{had}$
  - Detailed binning:
    - Number of leptons
    - # b-jets
    - MET
    - $H_T$

- **Backgrounds:**
  - MC with data-driven corrections for ttbar, VV
  - Data-driven for Z+jets and $Z\gamma^*$

- **Results:**
  - Focus on regions with low $H_T$ and b-veto
  - No excess visible
Chargino-neutralino production to WH

- Sensitivity up to 200 GeV
- **1l** most powerful
  - SS **2l** and ≥**3l** contribute at low mass

![Graph showing CMS sensitivity limits for chargino-neutralino production](image.png)

arXiv:hep-ex/1405.7570

Pieter Everaerts

EWK SUSY

June 5, 2014
Conclusions

- Wide variety of searches for EWK SUSY
  - No SUSY found
  - Stringent constraints on masses of gauginos
- Probing chargino-neutralino masses up to 200-720 GeV, depending on decay mode

![Graph showing constraints on chargino-neutralino masses](ZOOM)

**ArXiv:** hep-ex/1405.7570
Back-up
Four lepton analysis

**Selection:**
- 4 e/μ or 3e/μ+τ
- Bin in number of opposite-sign same-flavor pairs, dilepton mass and MET
- b-jet veto to suppress ttbar

**Backgrounds:**
- ZZ: MC with data-driven MET corrections
- Data-driven method for non-prompt and misidentified leptons

**Results:**
- No significant excess seen in data vs. prediction

arXiv:hep-ex/1405.7570
Chargino-neutralino production to SM bosons

- Neutralino pair production in gauge-mediated symmetry breaking (GMSB) higgsino model
  - Exclusion in terms of parameter ($\mu$) that controls the masses for Chargino and LSP

\[ m_{\tilde{\chi}^\pm_1} \approx m_{\tilde{\chi}^0_1} \approx \mu \]

Interesting region for naturelness

arXiv:hep-ex/1405.7570
GSMB model (ZZ)

- Cross section of $\chi^0\chi^0$ is suppressed w.r.t. $\chi^\pm\chi^0 \rightarrow$ no sensitivity to models with only $\chi^0\chi^0$ production
- Interpret results using GMSB model with large BF to ZZ+MET

\[ \tilde{\chi}_1^\pm, \tilde{\chi}_0^0 \] nearly mass-degenerate with NLSP: $\chi^\pm \rightarrow \chi^0 + \text{low } p_T \ell\nu / qq$  

$Z$-enriched higgsino NLSP $\rightarrow$ large BF to $Z + G$

- 3 diagrams enhance $\sigma \times \text{BF}$ to ZZ+MET final state

neutralino-neutralino  
chargino-neutralino  
chargino-chargino
**OS dilepton analysis**

**Selection:**
- 2 OS dileptons
  - Separately $e\mu$ and $ee/\mu\mu$
- $B$-veto to suppress $t\bar{t}$
- $MET > 60$ to suppress $Z+jets$
- Fit $MC_{T,Perp}$-spectrum
  - Kinematic endpoint for WW, $t\bar{t}$,...

**Backgrounds:**
- Fit templates from MC and data-driven control regions

**Results:**
- Observed $MC_{T,Perp}$ agrees with prediction

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**Same flavor**

\[ \sqrt{s} = 8 \text{ TeV} \quad L = 19.5 \text{ fb}^{-1} \]

**Signal region**

<table>
<thead>
<tr>
<th>Entries / 10 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^\pm e^\mp / \mu^\pm \mu^\mp$</td>
</tr>
</tbody>
</table>

**arXiv:hep-ex/1405.7570**
Chargino and slepton pair production

Same lepton flavor

Independent lepton flavors

arXiv:hep-ex/1405.7570
\[ M_{CT,\text{Perp}}^2 = m^2(v_a) + m^2(v_b) + 2[E_T(v_a)E_T(v_b) + p_T(v_a) \cdot p_T(v_b)] \]

\[ M_{CT}^{\text{max}} = \frac{m^2(P) - m^2(C)}{m(P)} \]

- Endpoint only holds if PP are back-to-back (no ISR)
- Project visible momentum in direction perpendicular to ISR or other visible upstream objects
  - Implemented as
    \[ \vec{p}_{UP} = -(\vec{p}_{T,\text{miss}} - \vec{p}_{T1} - \vec{p}_{T2}) \]
    \[ M_{CT\perp}^2 = m^2(v_a) + m^2(v_b) + 2[E_{T\perp}(v_a)E_{T\perp}(v_b) + p_{T\perp}(v_a) \cdot p_{T\perp}(v_b)] \]

where

\[ E_{T\perp}(v) = \sqrt{m^2(v) + p_{T\perp}^2(v)} \]

if \( m(v) = 0 \),

\[ M_{CT\perp}^2 = 2p_T(v_1)p_T(v_2) (|\sin \phi_1||\sin \phi_2| + \sin \phi_1 \sin \phi_2) \]

\( \phi_i \) is the angle between \( p_{T\perp}(v_i) \) and \( p_{UP} \)
4b + MET search

- **Selection:**
  - 4-5 jets, of which 3 or more are b-tagged
  - Pair jets into Higgs candidates
    - Minimize difference in invariant masses
  - Cut on MET significance and topological cuts ($\Delta \phi$)
  - Look at average $M_{jj}$

- **Backgrounds:**
  - Estimate from sidebands in mass window and # b-tags

- **Results:**
  - No significant excess seen (max. $\sim 1.5 \sigma$)

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CMS Preliminary, $L = 19.3 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$

**E W K S U S Y**

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**June 5, 2014**

**CMS-PAS-SUS-13-022**
4b + MET search

- **Results:**
  - Slight $\sim 1.5\,\sigma$ excess in 4b region

- **Interpretation:**
  - Small region expected to be excluded close Higgsino mass of 300 GeV, not excluded because of small excess

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CMS Preliminary, $L = 19.3\,\text{fb}^{-1}$, $\sqrt{s} = 8$ TeV

- **SIG region (4b sample):**
  - Data
  - $t\bar{t}$
  - W+jets & single t
  - Z+jets
  - QCD
  - Other

- **σ (pb):**
  - Observed data
  - Expected ± 1 $\sigma_{\exp}$
  - Expected ± 2 $\sigma_{\exp}$
  - Theory prediction
  - Theory uncertainty

- **Higgsino mass $m_{\chi_1^0}$ (GeV):**
  - $m_{\chi_1^0} = m_{\chi_1^-} = m_{\chi_2^0};\, m_{\text{LSP}} = 0$

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**CMS-PAS-SUS-13-022**