Searches for electroweak SUSY production at CMS

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July 7, 2017
on behalf of the CMS Collaboration
Electroweak SUSY

- Searches for SUSY partners of the electroweak sector.
  - The partners of the SM electroweak bosons mix to form mass eigenstates: chargino and neutralinos.
- Naturalness: gaugino mass is of the order of $H$ boson mass.

\[
\begin{align*}
\tilde{\chi}_1^0 & \quad \tilde{\chi}_2^+ , \tilde{\chi}_2^0 \quad \tilde{\chi}_3^0 , \tilde{\chi}_4^0 \quad \tilde{H} \quad \text{(higgsino)} \\
\tilde{\chi}_1^+ , \tilde{\chi}_2^0 & \quad \tilde{W} \quad \text{(wino)} \\
\tilde{\chi}_1^0 & \quad \tilde{B} \quad \text{(bino)} \quad \text{“U(1)”} \\
& \quad \tilde{G} \quad \text{(gravitino)}
\end{align*}
\]

Appears in GMSB/GGM models, mass $\sim$keV

GMSB = Gauge Mediated SUSY Breaking
GGM = General Gauge Mediation
Electroweak Production of SUSY

- Less constrained by experimental results due to low production cross section for the same SUSY particle mass.
- 35.9 fb-1 proton-proton collision data collected with the CMS detector during 2016 provides unique opportunities to probe SUSY EKW production.
- Performed analyses exploring a large variety of signatures:
  - Will focus on decays through bosons.
  - New! Analyses combination.
  - New! Stau search.
Decays via bosons

- In R-parity conserved models, result in di-boson (W/Z/h/γ) associated with missing transverse momentum (Etmiss)
  - Results in a final state of WH/WZ in Wino Models.

- In GMSB model, mass degenerate \( \tilde{\chi}^\pm_1, \tilde{\chi}^0_2, \text{ and } \tilde{\chi}^0_1 \)
  - Enhanced pair production of \( \tilde{\chi}^0_1 \tilde{\chi}^0_1 \)
  - Also produce a signature of diboson+missingEt.
  - Results in a final state of ZZ/HZ/HH in higgino models.
Experimental signatures: diboson+MET

- Diboson decay results in different signatures
  - $1\ell + 2$ $b$-tagged jets
  - $4\ b$ $b$-tagged jets
  - Opposite-sign dilepton
  - Inclusive multilepton
  - Soft opposite-sign dilepton
  - $H \rightarrow \gamma\gamma$

- Analyses combined to reach best sensitivities for each decay topology

<table>
<thead>
<tr>
<th>Search</th>
<th>WZ</th>
<th>WH</th>
<th>ZZ</th>
<th>ZH</th>
<th>HH</th>
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<td>$H(\gamma\gamma)$</td>
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Experimental signatures: diboson+MET

- Diboson decay results in different signatures
  - 1L + 2 bTagged jets
  - 4 b Tagged jets
  - Opposite-sign dilepton
  - Inclusive multilepton
  - Soft opposite-sign dilepton
  - H->γγ
  - See dedicated talks for other analyses.
  - Constantin: compressed
  - Marc: final states with photons

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Experimental searches

This search [34] selects events with exactly one charged lepton (e or µ), exactly two b jets, and large \( p_{\text{miss}} \) to target the WH topology. The invariant mass of the two b jets is required to be consistent with the mass of the H boson. Kinematic variables are used to suppress backgrounds.

Note: The table shows which searches are used in the interpretation for each of the topologies introduced in Section 3. The selections for all searches were checked to be mutually exclusive, such that each event in data is accepted by at most a single bin in a single search. No significant deviations from the SM predictions were observed in these searches.
Multilepton Search

- Inclusive search not tied to specific SUSY scenario, many decay topologies result in a multi-lepton final state.

- Event categorization:
  - 2 leptons same-sign, trilepton, multilepton
  - presence / invariant mass ($M_{ll}$) of OSSF pairs (~ $Z$-resonances)
  - Other kinematic variables: $E_T^{miss}$, $M_T$
  - Total of 158 search bins

- Dedicated poster will be presented next Monday by Constantin.

- Will show the combination results today.
Single-Lepton (e or µ) + bb Search

- **Higgs Mass**
- **Endpoint for 1L TTbar**

**Plot:**

- CMS Simulation 35.9 fb\(^{-1}\) (13 TeV)
- **Events/10 GeV**
  - 2L top quark
  - 1L top quark
  - W+HF
  - W+LF
  - W+Z(bb)
  - Rare

- **M_{bb} [GeV]**
  - m_{\tilde{\chi}^\pm}\times(350,100)\times50
  - m_{\tilde{\chi}^0}\times(250,1)\times50
  - m_{\tilde{\chi}^-}\times(500,1)\times50
  - m_{\tilde{\chi}^0}\times(225,75)\times50

- **Events/25 GeV**
  - 2L top quark
  - 1L top quark
  - W+HF
  - W+LF
  - W+Z(bb)
  - Rare

- **M_T [GeV]**
  - m_{\tilde{\chi}^\pm}\times(350,100)\times50
  - m_{\tilde{\chi}^0}\times(250,1)\times50
  - m_{\tilde{\chi}^-}\times(500,1)\times50
  - m_{\tilde{\chi}^0}\times(225,75)\times50

**Analysis:**

- Targeted search for WH production.
  - Large branching fraction of H→bb

- Require exactly 1L + two bTagged jets
  - Higgs mass peak, endpoint type of variables for background suppression

- Cut and count analysis with two exclusive signal regions binned in MET 125-200 and 200-∞ GeV.
Single-Lepton (e or \( \mu \)) + \( bb \) Search

- Robust background estimations using control regions in data.
  - 2L Control region to validate overall TTbar modeling.
  - bjet-vetoed Control region to validate Mt shape and tail modeling.
  - Main background 2L TTbar controlled in higgs mass side band.
Electroweakino combination results — WH

CMS

35.9 fb$^{-1}$ (13 TeV)

$pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0, \tilde{\chi}_1^\pm \rightarrow W^\pm \tilde{\chi}_1^0, \tilde{\chi}_2^0 \rightarrow H \tilde{\chi}_1^0$

NLO + NLL exclusion

- Observed limit, ±1 s.d.\text{theory}
- Expected limit, +1 s.d.\text{theory}
- (-1 s.d.\text{exp., no exclusion})

$I\!L + bb$ only

95\% CL upper limit on $\sigma$ [pb]
Electroweakino combination results — WH

- 8 TeV exclusion: ~200 GeV, huge improvement!
- SUS-16-043: IL +bb,
  - sensitive in the bulk of the phase space
- SUS-16-039: multilepton
  - sensitive in compressed region.
- Combined limit bridges the gap in the mass plane.
Opposite-Sign Dilepton Search

- Require 2 opposite-sign same flavor (OSSF) leptons to tag leptonic Z decay.
- Require at least 2 jets from the other boson and large EtMiss from LSP/gravitino.
- Sensitive to models with at least one Z boson.
Opposite-Sign Dilepton Search

Backgrounds:

- **Z+jets:**
  - ETmiss from jet mismeasurement
  - Predicted using γ+jets events in data.

- **Flavor symmetric:**
  - Processes with two W bosons, ttbar
  - \(N(\text{ee}+\mu\mu) = N(\text{e}\mu+\mu\text{e})\)

- **Other backgrounds:**
  - Small, taken from MC.
  - WZ/ZZ validated in CRs.
Electroweakino combination results - WZ

- **SUS-16-039**: Multilepton
- **SUS-16-034**: OS 2L
- **SUS-16-048**: Soft-2lepton (see talk, add link)
Decays via bosons

- **In R-parity conserved models**, result in di-boson (W/Z/h/γ) associated with missing transverse momentum (Etmiss)

- **In GMSB model**, mass degenerate \( \tilde{\chi}_1^\pm, \tilde{\chi}_2^0, \) and \( \tilde{\chi}_1^0 \)
  - Enhanced pair production of \( \tilde{\chi}_1^0 \tilde{\chi}_1^0 \)
  - Also produce a signature of diboson+missingEt.
Electroweakino combination results - HH/ZZ/HZ

- **M(gravitino) = 1 GeV.**
- **SUS-16-034: OS 2L**
- **SUS-16-044: HH->4b +MET**
- **SUS-16-039: Multilepton**
- **SUS-16-045: 2 photon+MET**
Stau search in all hadronic final state

- Started looking at slepton direct production
- Search for two hadronically decaying Taus with large MET.
- The results are interpreted as upper limits on the cross section for tau slepton pair production in different helicity scenarios
Summary

❖ Excellent performance of LHC in 2016 provided CMS with enough data to search for new physics in yet unprobed regions of phase space.

❖ Extensive search program performed at CMS covering an extensive variety of topologies. Only had time to cover some of them today.
  ✦ Focused on decays via bosons today, see backup and poster for decays via sleptons.
  ✦ Branching ratio dependent limits for wino models.

❖ No hint for new physics observed, large regions of phase space were excluded. Analysis results combined to reach best exclusion sensitivity.
  ✦ Significant improvement compared to 8 TeV results.

❖ LHC delivering more pp data in 2017 - stay tuned!
Decays, with Sleptons

- Decay via SLeptons when sleptons are lighter.
- Signature: Leptons+MET
  - Large branching fraction to leptons.
  - Sensitivity dominated by multilepton analysis.

\[
\begin{align*}
\tilde{\chi}_1^{\pm} & \rightarrow \ell^\pm + \nu, \\
\tilde{\chi}_1^0 & \rightarrow \ell^+ \ell^-, \\
\tilde{\chi}_2^0 & \rightarrow \ell^+ + \nu
\end{align*}
\]
Inclusive Multilepton Search - Limits

CMS Preliminary

35.9 fb⁻¹ (13 TeV)

pp → \tilde{\chi}_{1,2}^0 \rightarrow ℓνℓ

BR(\tilde{\chi}_2^0 \rightarrow ℓν)=0.5, m_ℓ = 0.5m_\tilde{\chi} + 0.5m_\tilde{\chi}

-Observed ± 1σ theory
-NLO-NLL excl.

Expected ± 1σ

95% CL upper limit on cross section [pb]

light slepton scenario

flavor-democratic decays

CMS

35.9 fb⁻¹ (13 TeV)

pp → \tilde{\chi}_{1,2}^0 \rightarrow ℓνττ

BR(\tilde{\chi}_2^0 \rightarrow ℓντ)=1, m_ℓ = 0.5m_\tilde{\chi} + 0.5m_\tilde{\chi}

-Observed ± 1σ theory
-NLO-NLL excl.

Expected ± 1σ

95% CL upper limit on cross section [pb]

light stau scenario

decays to taus

Extension of exclusion limit with respect to 8TeV searches up to TeV range
Electroweakino combination results —WZ/WH

Interpretation with mixed decay scenario:

- 50% WH, 50% WZ
Electroweakino combination results — higgsinos

CMS Preliminary

$\text{Br}(\chi_1^0 \rightarrow \text{H+G})$

$35.9 \text{ fb}^{-1} (13 \text{ TeV})$

cross section scenario 2

$m_{\chi_2^0} \approx m_{\chi_1^0} \approx m_{\tilde{\chi}_1^0}$

$m_{\tilde{G}} = 1 \text{ GeV}$

- Observed $\pm 1 \sigma_{\text{theo.}}$
- Expected $\pm 1 \sigma_{\text{exp.}}$
- Expected $\pm 2 \sigma_{\text{exp.}}$