Search for supersymmetry with compressed mass spectra or decays via Higgs bosons at CMS

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on behalf of the CMS Collaboration
PART I
Compressed Spectra
Why Compressed?

❖ compressed spectra
  ✦ mass splitting:
    \[
    + \text{MASS(„INCOMING“ SUSY PARTICLE)} - \text{MASS(„OUTGING“ SUSY PARTICLE)} = \text{MASS SPLITTING } =: \Delta M
    \]
  ✦ parameter space with small $\Delta m$ is called „compressed“ (determines possible decay modes)

❖ experimentally challenging - particles with low transverse momentum („soft“) produced in decay
  ✦ …and soft particles are hard to detect (at the LHC)
  ✦ initial state radiation (ISR) is relevant (boosts the system and produces large missing transverse energy (MET))

❖ relic density of compressed models expected to be consistent with cosmological observations [*]

❖ also we haven’t found SUSY yet in uncompressed spectra, maybe it first pops up in the compressed models?

❖ will discuss compressed spectra in colored (stop particles) and electroweak SUSY (charginos)
  ✦ note: there are dedicated CMS talks on stop and electroweak searches later today and tomorrow!

Cosmology Reference:

Compressed SUSY Searches

2-BODY DECAY (FCNC)

fully hadronic searches
CMS-PAS-SUS-16-032
CMS-PAS-SUS-16-036
CMS-PAS-SUS-16-049

4-BODY DECAY VIA OFF-SHELL $W$

dedicated stop searches
CMS-PAS-SUS-16-049
CMS-PAS-SUS-16-052

CHARGINO-MEDIATED DECAY WITH OFF-SHELL $W$

specialized searches
CMS-PAS-SUS-16-048
CMS-PAS-SUS-16-049
CMS-PAS-SUS-16-052

ELECTROWEAK SCENARIO

leptonic searches
CMS-PAS-SUS-16-048
CMS-PAS-SUS-17-004
Stop-Pair Production

IN THIS TALK

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Talk by Indara later today
Search for FCNC SUSY

- search with **two c-tagged jets**
  - 2 jets ($p_T > 30$ GeV) from $c\bar{c} + \text{MET}$
  - dominant bkg: $Z\rightarrow\nu\nu, W+\text{Jets}, t\bar{t}$, single $t$
  - strategy: search for shape difference in combination of variables ($\text{MET}, H_T, N_c\text{-jets}, \ldots$)
  - 23 search categories for FCNC model

- inclusive search with the $M_{T2}$ variable (for more details see Myriam’s talk)
  - $M_{T2} = \min \left( \frac{p_T^{\text{miss}}(1)}{p_T^{\text{miss}}(1) + p_T^{\text{miss}}(2)}, \frac{p_T^{\text{miss}}(2)}{p_T^{\text{miss}}(1) + p_T^{\text{miss}}(2)} \right) \max \left( M_T^{(1)}, M_T^{(2)} \right)$
  - $M_{T2}$ provides great sig-bkg discriminator
  - require $\geq 2$ light flavor jets and significant $H_T$
  - dominant bkg: $Z\rightarrow\nu\nu, W+\text{Jets}, t\bar{t}$, QCD multijet
Inclusive Stop-Pair Production Search

- hadronic final states for multiple decay modes of the stop pair
  - covering the broad range of parameter space (from compressed to uncompressed)
- for compressed region with $\Delta M < M_W$: select at least 2 jets with $p_T > 20$ GeV
  - jets can be b-tagged but $M_T(b\text{-jet}) < M_t$ (reject any $t$ or $W$ candidate)
- require also one ISR jet (light flavor (udsg), $p_T > 200$ GeV, back-to-back with MET)
- dominant background (data-driven estimation)
  - if b’s are involved: „lost lepton“ ($t\bar{t}, W+\text{Jets, } t\bar{t}+W$, single $t$
    - leptonic decay, but lepton fails acceptance or is reconstructed as a jet
  - if b’s are not involved: $Z \to \nu\nu$ ($Z+\text{Jets, } t\bar{t}+Z$)
- 53 low-$\Delta M$ regions for compressed spectra
  - categorization in $N_j, N_b, N_{SV}, p_T(\text{ISR-jet}), p_T(b\text{-jet}), \text{MET}$
Soft B-Tagging

- the lower $\Delta M$, the less energy is available in the compressed case to produce a jet
  - jet-$p_T$ threshold at 20 GeV - will miss all the soft stuff
- in order to recover signal selection efficiency (and improve bkg rejection), deploy soft b-tagging algorithm in addition to "default" b-tagged jets
  - collect all secondary vertices (SV) in the event
  - Inclusive Vertex Finder (IVF) algorithm based on impact parameter variables
  - SV: select low $p_T$ tracks and no "default" jet associated to it
- higher MET (in case of ISR boost) will more significantly displace b hadrons
- 20% selection efficiency at 3% mistag rate
Results and Interpretations

**Chargino-mediated decay**

**4-body decay**
Search with 1 Soft Lepton

- dedicated search for stop-decay via $W$ and $b$
  - exactly one electron ($p_T > 5$ GeV) or muon ($p_T > 3.5$ GeV)
- compressed means small $\Delta M$:
  - signal leptons will be quite soft - hence, require $p_T < 30$ GeV
  - also, expect ISR jet with $p_T > 100$ GeV
- expect MET $> 200$ GeV and $H_T > 300$ GeV
- $\Delta \phi$(jet1,jet2) $< 2.5$ rad - suppresses dijet and multijet background
  - remaining background is dominated by $W$+Jets and $t\bar{t}$
  - estimate from simulation + normalization from control regions ($lep-p_T>30GeV$)
- two set of regions: for very low $\Delta M$ and higher $\Delta M$
  - lepton-$p_T$ spectrum depends on $\Delta M$ - use optimized lep-$p_T$ bins (3.5-5-12-20-30)
  - expect shape difference between signal and background in $M_T(l,MET)$ and MET

for more details have a look at Mateusz’s poster!
Soft Opposite-Sign Dilepton Search

- soft leptons from off-shell bosons
  - two (soft) leptons of opposite-sign same-flavor (Z) + \( W_{\text{hadronic}} \)
- electroweakinos considered mixing of gauginos
  - Higgsino spectrum expected to be compressed
  - this search manages the connection between colored and electroweak natural SUSY
- \( \mu(e) p_T \) between 3.5 (5) and 35 GeV
  - dedicated ID and trigger strategy
  - \( \text{MET} \geq 125 \text{ GeV} \) possible in \( \mu\mu \) case
- lepton aligned with MET in signal (\( M_T(l,\text{MET}) < 70 \text{ GeV} \) for EWK case)
- minimum \( M_T \) against boosted Drell-Yan\( \rightarrow \tau\tau \) and b-jet veto against \( t\bar{t} \)
- reject mis-identified leptons (e.g. from jets) is the key challenge
- shape difference in \( M_\ll \) (EWK scenario) or \( \text{lep-}p_T \) (strong scenario) and MET
Results and Interpretations

STOP-PRODUCTION SCENARIO

bins in lep-p_T and MET

ELECTROWEAK SCENARIO

bins in M_{ll} and MET
Electroweak Scenario - the „WZ Corridor“

- chargino-neutralino production also probed in other analyses, namely the inclusive multilepton search
  - covering broad region of parameter space (small to large ΔM)
- significant loss in sensitivity at ΔM ~ M_z („WZ corridor“)
  - signal has M_z available to produce W or Z boson
  - hence, signal is very similar to SM WZ process
- but signal is a bit different
  - due to mass constraint from chargino / neutralino signal rarely has M_\perp > 105 GeV
  - in case of an ISR boost (high values of H_T), MET and M_T(lep3,MET) are larger for signal than for bkg due to the presence of the LSPs
Results and Interpretation

- finer granularity binning in $75 < M_{ll} < 105$ GeV region via additional $H_T$ bins (0-100-200-$\infty$)
  - limit improvement $\sim 50$ GeV along the WZ corridor
- quite impressive (combined) CMS exclusion in compressed scenarios for electroweak model
  - for more details see Mia’s talk tomorrow
PART II
Decays via Higgs Bosons
SUSY Analyses with Higgses at CMS

- electroweakino particles are mixing of gauginos
  - typically expect Higgsino spectrum to be compressed
- two ways Higgs can occur in EWK SUSY
  - Wino NLSP and Bino LSP - e.g. WH-signature
  - GMSB scenario with Higgsino NLSP and Gravitino LSP
- today, discuss one GMSB analysis in detail: HH→4b signature

Wino scenario

Higgsino scenario

SPOILER ALERT!

CHECK OUT MIA’S TALK TOMORROW!
4b + Missing Energy Search

- **GMSB scenario, HH→bbbb + MET in final state**
- **MET > 150 GeV and 4-5 jets with \( p_T > 25 \) GeV**
- **veto additional leptons and tracks (reduces tt\( \bar{\tau} \))**
- **veto light flavor jets aligned with missing energy (reduces QCD)**
- **categorize 3b and 4b events in bins of missing energy**
  - 2b category serve as control region for irreducible bkg
- **irreducible bkg has 2 real b’s, but additional mis-tagged jets**
  - dominant process is single-lepton ttbar, also DY(inv) + jets
  - lepton fails acceptance (fails selection or is not reconstructed)
- **improved b-tagging algorithm using deep neural networks (DNN)**
  - +20% efficiency at 0.1% mistag rate

**DNN References:**
4b + Missing Energy Search - Results

- strategy
  - reconstruct two $H \rightarrow bb$ candidates from 4 jets with the highest $b$-tag score (3 pairs of candidates)
  - select the pair of $H$ candidates that minimizes $\Delta m_H = m_{H1} - m_{H2}$
  - use $\langle m \rangle$ for signal extraction (uncorrelated with number of $b$-tags)
  - data-driven ABCD method: use shape in 2b control region to predict shape in 3b and 4b regions

- exclusion between 230 and 770 GeV in GMSB model
Summary and Outlook

- **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 a huge variety of topologies, both for colored SUSY and EWK SUSY.

- **development and optimization of key analysis tools** allows probing of very compressed regions:
  - Soft b-tagging recovers signal efficiency below jet-pT threshold
  - Dedicated and trigger strategy for opposite-sign lepton pairs allows going down to 3.5 GeV in momentum.

- **challenging new physics in decays with Higgs bosons**
  - Remember, we found this one only 5 years ago!

- **no hint for new physics observed**, large regions of parameter space were excluded.

- **work to cover even more topologies and probe even larger regions of parameter space**
  - As particle physicists like to say: stay tuned!
Check out other CMS SUSY Contributions!

- Myriam Schönenberger: *Searches for supersymmetry via strong production in fully hadronic final states at CMS* (Thursday 15:00)

- Christian Schomakers: *Searches for supersymmetry via strong production in events with one or more leptons at CMS* (Thursday 15:30)

- Indara Silva: *Searches for production of third generation squarks at CMS* (Thursday 17:30)

- Miaoyuan Liu: *Search for electroweak production of supersymmetry at CMS* (Friday 14:45)

- Marc Weinberg: *Search for supersymmetry in events with photons at CMS* (Friday 15:15)

- Mateusz Zarucki: *Search for Supersymmetry with a Highly Compressed Mass Spectrum in the Single Soft Lepton Channel with the CMS Experiment at the LHC* (Poster)

- me: *Search for EWK Production of SUSY in Final States with Multiple Leptons at the CMS Experiment at the CERN LHC* (Poster)
End
References


References


[CMS-PAS-SUS-16-052] CMS Collaboration, *Search for supersymmetry in events with at least one soft lepton, low jet multiplicity, and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV.*
References


Appendix
The CMS Detector

- excellent muon system, tracking and EM energy resolution give good particle identification
- ideally suited for search for new physics in final states with little hadronic activity (as for EWK SUSY)