SUSY Searches in VBF topology and mu+VBF Trigger Performance in CMS

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on behalf of the SUSY VBF team

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Outline

• Electroweak SUSY Searches
• Searches with Compressed Spectra
• Searches with VBF Tagging
• VBF Trigger Challenges
• 2017 Trigger Performance
• Summary and Outlook
Charginos/neutralinos are expected to be among the lightest SUSY particles (LSP)

- Natural SUSY: Light stops and gauginos/higgsinos to cancel divergences in higgs mass
- LHC limits place $m_{\tilde{g}, \tilde{q}} > 1$ TeV
- If the masses of the gluinos and squarks are large, direct production of charginos/neutralinos/sleptons may dominate the SUSY production at the LHC

Charginos/neutralinos decaying via sleptons/sneutrinos, gauge bosons or higgs can lead to high lepton multiplicity → Comprehensive searches

- High discovery potential, but challenging due to small cross section

- Searches for compressed EWK SUSY → Intensive searches at the LHC

- Challenging detector signatures: low MET and soft decay products
EWK SUSY Searches at CMS

Number of leptons

Interpretation: simplified SUSY models

- 2L SS/3/3+: Inclusive multilepton search to improve sensitivity for various models in uncharged territory (H→WW, ZZ or ττ)
- SUS-16-039 also is sensitive to models with gravitino LSP
- SUS-16-048 also has interpretations in non-simplified models
Simplified Models

• Simplified Models: Used for SUSY searches, taking essential features from viable models
  
  • Target production of charginos (C1), neutralinos (N1,N2) and sleptons
  
  • Assumed 100% BR, parameterized in terms of sparticle masses
  
  • Fixed decay chain considered for signal optimization in searches
  
  • A crucial parameter dictating the sensitivity: $\Delta m = m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}$

• Results also interpreted in phenomenological models for broad range of applicability of the searches
Compressed Spectra Searches

- Light N1 ≈ mass degenerate with C1,N2 (compressed scenarios) is well motivated theoretically

- Naturalness-inspired models motivate light higgsino-like N1 and small mass splitting with C1,N2

- Also connected to cosmologically favored relic dark matter density

- Result in low-momentum decay products → experimentally challenging as they are difficult to trigger on and reconstruct
Advantages of VBF topology selection

- VBF tagging jets
- Broad enhancements in MET
- Compressed scenarios
- Free from trigger bias
- Direct probing EW sector, complementary

VBF + MET topology: MET from forward jets
VBF Channels at CMS

- Three categories:
  - Large mass gap
    → 2 leptons, MET and jets
  - Compressed mass gap
    → 1 soft lepton, MET/jets
  - Very compressed mass gap
    → MET and jets

- 8 TeV channels → 0L & 2L:
  - $\mu\mu jj$, $e\mu jj$, $\mu\tau_{hjj}$, $\tau_h\tau_{hjj}$ (OS and LS)
  - invisible channel (SUSY DM)

- 13 TeV channels adding 1L
  to enhance sensitivity to extremely compressed-mass spectra
  - $\tau_h jj$, $\mu jj$, $ejj$ + invisible channels
VBF based search (2L) vs. Multi-lepton search

JHEP11 (2015) 189
EPJC 74 (2014) 3036

95% CL on EWKino mass of 170 GeV for compressed mass spectrum → unique limits on tau dominated scenario
Comparison to 13 TeV

Summary of CMS exclusion limits for scenarios where SUSY particles are produced via electroweak interactions.

→ Limit comparable to 13 TeV result!
VBF Trigger Challenges

- For 2016 operation, the L1 seeds in the VBF HLT path
  - Neither satisfy VBF nor include HF
- From the middle of 2017, the L1 VBF seeds developed
  - Provide better sensitivity to compressed spectra SUSY
- From the end of 2017, several challenges affecting L1T rates
  - Huge rates and PU dependence from jets in $2.65 < |\eta| < 3.0$ region (trigger tower 28) affecting VBF trig: higher cuts for forward jets
- For 2018 operation, soft mu + VBF is work in progress

- We did not look at the soft-lepton channels with 8 TeV
- For 13 TeV, we focus on single soft-lepton channels due to difficulty to reconstruct multiple leptons in compressed spectra (higher acceptance/sensitivity than dilepton channels)
## Dataset and Selection

- Latest JSON (38.7 fb⁻¹) Cert_294927-306462_13TeV
- No VBF trigger in Run2017 A and B (4.3 fb⁻¹)
- VBF trigger has been performing well since Run2017 C

### HLT_Mu8_TrkIsoVVL_DiPFJet40_DEta3p5_MJJ750_HTT300_PFMETNoMu60

### Central Selections

<table>
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<th>Trigger</th>
<th>SingleMu</th>
<th>HLT_IsoMu27</th>
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<tbody>
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<td>Muon</td>
<td>( p_T ) and ( \eta )</td>
<td>( p_T(\mu) &gt; 30 \text{ GeV},</td>
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<td>Id and Iso</td>
<td>Tight, ( l_{\text{rel}} &lt; 0.15 )</td>
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<td></td>
<td>( N_\mu )</td>
<td>( \geq 1 )</td>
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<tr>
<td>Jets</td>
<td>( p_T ) and ( \eta )</td>
<td>( p_T(j) &gt; 120 \text{ (50) GeV},</td>
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<tr>
<td></td>
<td>( N_{\text{tightJets}} )</td>
<td>( \geq 2 )</td>
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<tr>
<td></td>
<td>HT ((p_T &gt; 30 \text{ GeV},</td>
<td>\eta</td>
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<tr>
<td>MET</td>
<td>( E_{T}^{\text{miss}} ) (no ( \mu ))</td>
<td>&gt; 150 GeV</td>
</tr>
<tr>
<td><strong>VBF Selections</strong></td>
<td>( \eta_1 \cdot \eta_2 &lt; 0, \Delta\eta(j,j) &gt; 3.6 ) and ( M_{jj} &gt; 1000 \text{ GeV} )</td>
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</tbody>
</table>
2017 Trigger Performance

CMS Preliminary

- 98.4% at MET > 150 GeV for 2017 data
  → Significant improvement compared to 2016

- Possible to lower MET cut (250 → 150 GeV: signal eff increased twice)

- Trigger performance is very good and stable over eras
  → Checked with total integrated luminosity (not shown in this talk)
Trigger Performance (con’t)

M$_{jj}$  HT  Sub leading jet p$_{T}$

- 98.4 % at MET > 150 GeV for 2017 data
  → Significant improvement compared to 2016

← Possible to lower MET cut (250 → 150 GeV: signal eff increased twice)

- Trigger performance is very good and stable over eras
  → Checked with total integrated luminosity (not shown in this talk)
• If gluinos/squarks are too heavy, electroweak SUSY may be the dominant SUSY production mechanism at the LHC.

• Presented final electroweak SUSY results at 8 TeV with emphasis on compressed spectra.


• Electroweak SUSY searches will profit from higher luminosity in Run 2 and the VBF triggers developed for better sensitivity.
backup
EWK SUSY Searches at CMS

Gravitino LSP

0 lepton searches
SUS-16-044

1 lepton searches
SUS-16-043

Soft Opposite-sign dilepton
SUS-16-048

Same-sign dilepton
SUS-16-039

Multilepton search $\geq 3$ leptons

$\tilde{\chi}_0^0 \approx \tilde{\chi}_1^\pm \approx \tilde{\chi}_2^0, m_{\tilde{G}} = 1$ GeV
(degenerate Higgsinos with Gravitino as LSP)

SUS-16-039 also sensitive to GMSB model
with higgsino pair production: Gravitino LSP

Minsuk Kim (KNU)
Improvement in Sensitivity

- With full 2016 dataset of 35.9 fb⁻¹, got finally access to new territories, even to light-degenerate-Higgsinos
- Exclusion of charginos and neutralinos pushed up to more than 1.1 TeV
- Limits increased in 3L channel (C1N2 production with light sleptons)

**8 TeV** + 300 GeV → **early 13 TeV** + 100 GeV → **13 TeV**

Summer16, reproduced Run 1 EWKino

Thanks to more lumi and new idea
L1 VBF Seeds

- L1 seeds of mu+VBF triggers for two Runs at different luminosity
  - Run 299368: rate = 2.4 Hz at L~1.4e34 (1.4 Hz expected at L~2e34)
  - Run 300742: rate = 3.3 Hz at L~1.6e34 (need to check at L~1.8e34)

<table>
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</table>

- HF seeds implemented in 2017:
  - two jets with $p_T > 100$ and 35, and a pair of jets with $p_T > 35$ and $M_{jj} > 620$ GeV

- Mu+VBF trigger:
  HLT_Mu8_TrkIsoVVL_DiPFJet40_DEta3p5_MJJ750_HTT300_PFMETNoMu60
Analysis Strategy

- VBF topology → distinctive experimental signature
  - MET + jj + lepton(s)

- Uses $M(j_1,j_2)$ as variable of interest, reflecting the possible presence of a signal in the distribution tails

- Necessitates understanding of
  - Electron/muon/tau ID and MET/jets
  - Trigger efficiencies
  - Backgrounds: DY→ττ, non-prompt(W+jets), ttbar dilepton, VV(WW)

Cut optimization done by using significance: basic cuts → VBF → MET
8 TeV Result: Leptonic Channel

One of first SUSY searches with VBF signature

- Observed 95% limits on EWKino mass
  - For the fixed stau mass: 170 GeV with $\Delta M=50$ GeV and 280 GeV with $M(N_1)=0$ GeV
    → unique limits on tau dominated scenario (next page)
  - For the averaged stau mass: 300 GeV with $M(N_1)=0$ GeV
    → comparable w.r.t multi-lepton searches (backup)