Search for Supersymmetry at CMS in Events with Large Jet Multiplicity and Low Missing Transverse Momentum at $\sqrt{s} = 13$ TeV

Christopher Madrid
Baylor University
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SUS-19-004 Team

Chris Madrid, Jay Dittmann, Kenichi Hatakeyama (Baylor)
Owen Long (UC Riverside)
Aron Soha, Jim Hirschauer (FNAL)
Josh Hiltbrand, Jeremy Mans, Nadja Strobbe (University of Minnesota)
Kelvin Mei, Christopher Tully (Princeton)
Motivation

- Inspired by lack of evidence of new physics in searches that require missing transverse momentum (MET)
- Two possible models that satisfy this: **RPV** and **Stealth SUSY**
- Both model’s signature contains two top quarks, 6 additional jets, and low additional missing transverse momentum
- Largest irreducible background is \( t\bar{t} + \text{jets} (~85\%) \)
Signal Models: RPV SUSY

- Stop production to neutralino and a top
- R-parity violation allows the neutralino to decay to light jets through the UDD coupling

- Largely unexplored in the regime of low mass stops (thin solid line shows $m_{\tilde{t}} - m_{\tilde{\chi}^0} = 100 \text{ GeV}$)

arXiv:1209.0764
Signal Models: Stealth SUSY

- Stop production to a singlino, gluon, and top
- Introduces a stealth sector: collection of fields with suppressed coupling to SUSY breaking sector
- Minimal stealth sector: singlet state and singlino superpartner ($S, \tilde{S}$)
- Particles/superpartners mass is degenerate in this sector
- Gravitino has low $p_T$ and mass of 1 GeV in this search

- Our model assumes singlino mass of 100 GeV
- Limits do not extend beyond $m_\tilde{t} = 200-250$ GeV

arXiv:1512.05781
Analysis Strategy

• Main distinguishing feature of the signal is **high jet multiplicity**

• High jet multiplicity is hard to model, so we want to rely on data for background prediction

• Decided to do a fit of the Njet spectrum for $t\bar{t} + \text{jets}$ (other backgrounds taken from MC)

• From theory: ratios of $N_{j+1}/N_j$ can be described by two components
  • a constant at high Njets (“staircase”)
  • a falling function at lower Njets (“Poisson”)

• Ideally, fit Njets shape in a dedicated control region, and use it as a template in the signal region. Unfortunately, a signal-free control region is hard to construct

* A different fit function analogous to this one is used in the analysis because the parameters were highly correlated
No Control Region

- Use a variable that discriminates signal vs. background that is uncorrelated with Njets.
- Divide events into 4 regions for which background events have the same Njets shape.
- Do simultaneous fit to all regions with most background-enriched region “D1” acting as the control region for the most signal-enriched region “D4”.
- The first reasonable variable attempts gave poor performance or were too correlated with Njets.

![Diagram showing the division of Njets and discriminative variable regions.](image-url)
MVA

- Used a **Neural Network(classifier)** with **Gradient Reversal (GR)** to create a discriminating variable
- **GR** adds an extra term to the loss function of the training such that it penalizes the NN if it utilizes any information from that classification layer

\[ L_{tot} = L_{class.} - \lambda L_{GR} \]

- This allowed us to remove Njet correlation while training at the cost of some performance

\[ t\bar{t} - \text{No GR} \quad \text{vs} \quad t\bar{t} - \text{With GR} \]
MVA Performance

- Good overall discrimination; best for highest mass model
- Bin edges defined to give best sensitivity

Note: all Njets combined
Total Fit to MC

• Now that we have a discriminating variable uncorrelated with Njets to bin in, we can perform the fit.

• Background only fit to pseudodata (made up of MC)

• D1 has the most events and is mostly background (low MVA score)

• D4 has the fewest events, but is mostly signal.

Fit setup works well
Signal Injection Test

- Inject signal (Stealth model with stop mass 650 GeV) with 1x nominal cross section into the pseudodata

D3 and D4
background-only
Clear pulls visible

D3 and D4
Signal+Background
Much better pulls
Best fit $r: 1.09 \pm 0.32$

Should be able to see a signal if it is there
Expected Limits (pseudodata)

- Our expected limits for the RPV model is around $m_\tilde{t} = 700$ GeV, whereas for the SYY mode, it is around $m_\tilde{t} = 900$ GeV.
Conclusions

• We are excited to present a new analysis focused on a high jet multiplicity, low missing transverse energy region of phase space.

• There were many challenges to the analysis, but using novel machine learning techniques, like gradient reversal, in combination with existing physics tools, we were able to improve on signal sensitivity.

• Signal injection test gives us confidence that if there is a signal we can find it.

• Please look forward to hearing about our full Run 2 results.
MVA Inputs
Systematics

• For ttbar, the only effects that matter are those affecting the relative Njets shape between MVA bins
• An overall shape difference will be absorbed by the fit, as long as the Njet ratios are smoothly falling or constant
• No good control region is available to do these checks, so derive them from MC variations
• Derive systematic uncertainty as double ratio: 
  \((\text{Njets in MVA bin } Di / \text{Average Njets shape})_{\text{systematic}} / (\text{Njets in MVA bin } Di / \text{Average Njets shape})_{\text{no-systematic}}\)
to avoid double counting the shape differences present in the nominal case
• Nominal shape differences taken into account separately
• For event weight based systematics, derive the size of the uncertainty directly from Njets distributions
JEC/JER Systematics

- JEC/JER can cause bin migrations, both between Njets bins and between MVA bins.
- To avoid large impact from statistical fluctuations in the tail, do a background-only fit to derive the overall and per-MVA bin Njets shape, before computing the double ratio.

Take largest of Up/Down as symmetric uncertainty.