Searches for SUSY and Dark Matter from ATLAS and CMS

With an emphasis on Post-EPS results and $t$ final states

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On behalf of ATLAS and CMS

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Theoretical Motivation

Dark Matter

- No particle evidence

Supersymmetry

- Mitigates $t$ corrections to $m_H$
- Provides dark matter
- Also no evidence

Galaxy Cluster MACS J0025.4−1222
Hubble Space Telescope ACS/WFC
Chandra X-ray Observatory

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SUSY + DM, ATLAS + CMS
September 1, 2017 2 / 24
Introduction

Dark Matter: Simplified Models

- Introduce a collection of simplified models
  - Mediators stand in for more complex theories

- Signature is $E_T^{\text{miss}} + \text{associated particles}$
- **Bonus:** we can look for the visible mediator decay products!
- At LHC, grouped into mono-X, di-X searches
SUSY: Less simplified models

- Some are more model based, use SUSY variables
  - $m_{T2}$, $m_{CT}$, etc
  - Used to extract SUSY with multiple DM particles in final state

- Some complicated enough that the signature becomes generic, e.g.
  - Multijet + $E_T^{\text{miss}}$: SUSY-2016-13
  - Multijet: SUS-16-040
Mono-Everything (Photon Shown)

The “Easy” Final States: Mono-$\gamma$, Mono-jet

Mono-$\gamma$ (arXiv:1704.03848)

- Require precise $E_T^{\text{miss}}$, object calibration
- Many interpretations

Monojet (PAS: EXO-16-048)

- $\sqrt{s}=13$ TeV, 36.1 fb$^{-1}$
- $m_{\chi} = 10/700$ GeV
- ATLAS
- CMS Preliminary
- Data / Pred.
Next in Line: Mono Boson

Mono-W/Z
(PAS: B2G-17-005)

Mono-H (arXiv:1707.01302)

- Rely heavily on large-\( R \) “fat” jets
- Include subjet \( b \)-tagging, substructure
Mono Top, Hadronic (PAS: EXO-16-051)

- **Trigger:** $H_T^{\text{miss}} > x \cap E_T^{\text{miss}} > x$
  - $x \in \{90, 100, 110, 120\}$, depending on lumi
- **Veto leptons, extra $b$-jets**
- **One $R = 1.4$ jet passing top selection**
- **Two production modes: resonant and non-resonant**

**ATLAS Result**

- Similar signal model at $\sqrt{s} = 8$ TeV
- Single lepton, $m_T$-based selection
- arXiv:1410.5404
CMS Mono Top: Top Tagger

- Soft Drop Mass 110–210 GeV
- $b$ tagged subjet
- Top BDT:
  - HEPTopTaggerV2
  - $\tau_{32}$
  - 11 ECF ratios
- Similar to ATLAS approach
  - ATLAS-CONF-2017-064

Control Regions

- $t\bar{t}$ ($mu + had$), 6%
- $Z \rightarrow \mu\mu + jets$, 7%
No deviation from standard model

Previous limits on on similar models: $M_\phi \lesssim 700$ GeV
2 \ell \ (ATLAS: \texttt{arXiv:1707.02424}, CMS: \texttt{EXO-16-031})

- Look for bumps on a smooth background
- Rules lots of (simplified) parameter space

- Low mass: both experiments use “trigger scouting” and ISR
SUSY Searches

https://cds.cern.ch/record/2113241
$2\tilde{t} \rightarrow 2\ell + 2b + E_T^\text{miss}$ (arXiv:1708.03247)

- Separate from $t\bar{t}$ by cutting hard on $m_{T2}$ (arXiv:hep-ph/0304226)
- Still leaves “gaps” e.g. where $m_{\tilde{t}} - m_t \approx m_{\tilde{\chi}_1^0}$
Focus on “compressed”: small $\Delta m \equiv m_t \tilde{t}_1 - m_{\tilde{\chi}_1^0}$

Custom SV-based discriminant to identify $b$-jets with $p_T < 20$ GeV
3rd Generation Squark $\rightarrow c, b$ (arXiv:1707.07274)

- Favored when $m_{\tilde{t}} - m_{\tilde{\chi}_1^0} < m_W$
- Use $c$-tagging to identify FCNC $\tilde{t}$ decays

- Similar final state to arXiv:1407.0608
**Summary:** Simplified Mediator \((g_q = 0.25, g_\ell = 0.0)\)
Simplified Mediator \( (g_q = 0.1, g_{\ell}^A = 0.1, g_{\ell}^V = 0.01) \)
In the low energy limit, we can compare to direct detection

\[ \frac{g_X g_q}{Q^2 - M^2} = - \frac{g_X g_q}{M^2} \left( 1 + \frac{Q^2}{M^2} + O \left( \frac{Q^4}{M^4} \right) \right) \approx - \frac{g_X g_q}{M^2} \]
Bonus Exclusions: Mono-$H$

- Showing ATLAS $H \to bb$ (arXiv:1707.01302)
- CMS results in backup
### ATLAS SUSY Searches* - 95% CL Lower Limits

**May 2017**

<table>
<thead>
<tr>
<th>Model</th>
<th>(e, \mu, \tau, \gamma)</th>
<th>Jets</th>
<th>(E_T^{miss})</th>
<th>(\int L dt) (\text{(fb}^{-1}))</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MSUGRA/CMSM</strong></td>
<td>(0-3), (e, \mu, \tau, \gamma)</td>
<td>1-2</td>
<td>0-2 jets</td>
<td>20.3</td>
<td>1.85 TeV</td>
<td>m((\tilde{g})) = 1.85 TeV, m((\tilde{t}_1)) = 900 GeV</td>
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<tr>
<td></td>
<td>(0, \chi^0_1)</td>
<td>0</td>
<td>0</td>
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<td>1502.01518</td>
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<td><strong>Bilinear RPV CMSM</strong></td>
<td>(0-3), (e, \mu, \tau, \gamma)</td>
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*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*
Wrap Up

- No new physics, but...
- Lots of new ways to look for physics
  - Mono-\(X\) searches: Mono-\(t\), Mono-\(H\)
  - Two body decays from simplified DM models
    - Trigger scouting
    - ISR + dijet
- Also many new SUSY searches
- A lot has happened since EPS 2017
BONUS SLIDES
Multijet + Large $R$ Jet

$E_T^{\text{miss}} + \text{jets (new)}$

**ATLAS**

$\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$

- Multijet
- $W \rightarrow l\nu + \text{jets}$
- Data
- Other
- $t\bar{t} \rightarrow q\bar{q}, l\bar{l}$
- Total Background

**Jets, no $E_T^{\text{miss}}$ (new)**

**CMS Preliminary**

- $N_{\text{lep}} = 1$
- $N_{\text{jet}} \geq 8$
- $800 < M_J \leq 1000$ GeV
- $M_{800} < M_b$

- Data
- $t\bar{t}$
- QCD
- $W+\text{jets}$
- Other

Events

Data/Fit

$N_{\text{jet}} \geq 4$
\[ \gamma + E_T^{\text{miss}} + H_T \ (\text{arXiv:1707.06193}) \]

**Graph:**
- Data
- Nongenuine \( p_T^{\text{miss}} \)
- \( \gamma W \)
- \( \gamma t \bar{t} \)
- \( \gamma Z \)
- \( e \rightarrow \gamma \)
- \( T5Wg \) 1600 100
- \( T6gg \) 1750 1650
- Total uncertainty

**Legend:**
- Events / GeV
- 35.9 fb\(^{-1}\) (13 TeV)
- CMS

**Axes:**
- \( p_T^{\text{miss}} \) (GeV)
- Normalization
- Validation
- Data/Pred.
- Bkg. frac.
CMS Mono-$H$

$H \rightarrow \gamma \gamma$ (EXO-16-054)

\[ H \rightarrow bb \]

![Graph showing the CMS 95% C.L. limit on $\sigma_{bb}$ for $m_A=500, 600, 700, 800$ GeV.](image)

- Expected limit
- Observed limit
- ± 1 std. dev.
- ± 2 std. dev.

$2.3 \text{ fb}^{-1} (13 \text{ TeV})$

- CMS $Z \rightarrow \text{DM}+h(2\text{HDM})$
- $h \rightarrow bb + h \rightarrow \gamma \gamma$
- $g_z = 0.8$

$\sigma_{bb}$ vs $m_Z$ [GeV]