Strong SUSY production

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This talk: searches for **gluinos** and 1st-2nd generation squarks.

**R-parity conserved**: sparticles pair-produced, LSP stable and DM candidate.
Squarks and gluinos

SUSY partners regulate Higgs mass radiative corrections.

Naturalness favours light stop, gluino and Higgsino.

Gluinos and squarks have largest cross sections, hope they show up at LHC!
Finding Wally in 2 dimensions is already tough. What about finding SUSY in 105 dimensions?
Simplified models

- **Simplified SUSY mass spectrum**, representative of certain parameter space.
- Design **analyses targeting all possible models**.
- **Comprehensive scans** (e.g. pMSSM) provide more generic constraints on SUSY.

### Gluino pairs: $\geq 4$ jets + MET + $X$

### Squark pairs: $\geq 2$ jets + MET + $X$

**MET in all RPC signatures!**
Using MET to find SUSY

**MET trigger rate**

*ATLAS* Trigger Operations

Data 2016 / 2017, $\sqrt{s} = 13$ TeV

- HLT_xe110_mht_L1XE50
- HLT_xe110_pufit_L1XE50

**anti-$k_t$ jets w/ JES**

pileup $E_T$ density fitted from low-$E_T$ towers assuming $\sum E_T = 0$ within resolution

**MET trigger resolution**

*ATLAS* Preliminary

Data 2017

$\sqrt{s} = 13$ TeV, 1.3 fb$^{-1}$

$W\rightarrow \mu

- L1_XE50
- HLT_xe110_pufit_L1XE50
- HLT_xe110_mht_L1XE50

**Lot of care in removing noise:**

- calorimeter electronics noise, missing readout
- beam background: structure in $\phi$
- poorly measured high-$p_T$ muons

**Offline MET**

CMS dijet

- Data
- Data with no cleaning
- Top quark
- W($\nu$)jets
- Z($\nu\nu$)jets
- QCD multijet

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

• **0L + jets + MET**

• **0-1L + b-jets + MET**

• **2L SS / 3L + jets + MET**

• **τ + jets + MET**

• **γγ + MET**
**Signal regions binned** in $N_{\text{jet}}, N_{\text{bjet}}, H_T,$

- $M_{T2}$ when $\geq 2$ jets
- jet $p_T$ when 1 jet

\[ M_{T2} = \min \left[ \max(m_T^{1\chi_1}, m_T^{2\chi_2}) \right] \leq M \]
\[ p_T^{\chi_1} + p_T^{\chi_2} = p_T^{\text{miss}} \]

- **$W(\ell\nu)$ and $t\bar{t}$ with lost $\ell$:**
  1$\ell$ data, 1$\ell \rightarrow 0\ell$ from MC
- **$Z(\nu\nu)$+jets:**
  $Z(\ell\ell)$+jets data, $Z(\ell\ell) \rightarrow Z(\nu\nu)$ from MC
- **multijet:** from data, “rebalance and smear” method

- no $e, \mu, \text{charged PF candidate}$
- large $p_T^{\text{miss}}, H_T^{\text{miss}}, H_T, \text{jet } p_T$
36 fb$^{-1}$ limits improved by
- 100-300 GeV on $m_{\tilde{g}}, m_{\tilde{q}}$
- 100-250 GeV on $m_{\tilde{\chi}_1^0}$
0-1L, ≥4 jets with ≥ 3 b-jets. Main bkg: t\bar{t} + jets.

**Discriminants:**

- \( m_{\text{eff}} = \sum_i p_T^{\text{jet}_i} + \sum_j p_T^{\ell_j} + E_T^{\text{miss}} \)

- \( m_T(\ell, \text{MET}) \): suppress W(\ell\nu) and semilep t\bar{t}

- \( m_T(\text{b-jet}_i, \text{MET}) \leq m_t \) for semilep t\bar{t}

- \( M_j^\Sigma \): sum of masses of \( \leq 4 \) large-R jets (boosted top)

0L and 1L SRs binned in \( N_{\text{jet}} \) and \( m_{\text{eff}} \).
0-1L + b-jets + MET: results

2.3σ excess in 36 fb⁻¹ dataset not confirmed 😞

Limits on gluino mass at fixed LSP mass when varying BR(\tilde{g})

\[ B(\tilde{g} \rightarrow t\bar{t}\chi_1^0) + B(\tilde{g} \rightarrow b\bar{b}\chi_1^0) + B(\tilde{g} \rightarrow t\bar{b}\chi_1^0) = 100\% \]
Limits on Gtt model for on-shell $\tilde{t}$. 

Limits weakens when $m_{\tilde{t}} \approx m_{g\tilde{t}}$ or $m_{\tilde{t}} \approx m_{\tilde{\chi}_1^0}$. 

**ATLAS** Preliminary

\[ \sqrt{s}=13 \text{ TeV}, 79.8 \text{ fb}^{-1} \]

Gtt, $m(\tilde{g})=2.1$ TeV, $m(\tilde{\chi}_1^0)=600$ GeV

- NLO+NLL $g\tilde{g}$ prod. $\pm \sigma$
- Observed limit
- Expected limit
- Observed off-shell stop
- Expected off-shell stop

All limits at 95% CL

Lower $\Delta\phi(j,\text{MET})$

Lower $m_T^{b\text{jet}}$

Lower $M_j^{\Sigma}$

$\tilde{m}(\tilde{t})$ [GeV]
≥2 same-sign ℓ, ≥2 jets.
Trigger: ℓℓ or ℓℓ + HT.

168 SRs binned in $p_T^\ell$, $p_T^{miss}$, N_{jet}, N_{bjet}, HT, m_T^{min}$

Backgrounds:
- prompt $\ell^\pm \ell^\pm$ from MC:
  WZ, $W^\pm W^\pm$, $t\bar{t}W/Z/h$, X+γ
- non-prompt $\ell^\pm \ell^\pm$ from data, “matrix method”: proba. for loose true/fake ℓ to pass tight ID.
- $e^\pm$ with misreconstructed charge:
  OS data + charge flip rate from MC, charge-flip SF from Z(ee) data.
Largest excess: 2.6σ. Set limits on:

- $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$
- $\tilde{g} \rightarrow t\bar{t} \rightarrow t\bar{t}\tilde{\chi}_1^0$ with $\Delta m(t, \tilde{\chi}_1^0) = m_t$
\[ m_{\tilde{\chi}^\pm_1} = 0.5(m_{\tilde{g}} + m_{\tilde{\chi}^0_1}) \]

\[ m_{\tilde{\chi}^\pm_1} = m_{\tilde{\chi}^0_1} + 20 \text{ GeV} \]
$\geq 2$ same-sign $\ell$, $\geq 2$ jets.
Trigger: $\ell\ell$ or MET.

Similar background estimate as CMS:
- prompt $\ell^{\pm}\ell^{\pm}$ from MC
- $e^{\pm}$ with charge flip: OS data + charge flip rate.
  BDT to reject charge-flipped electrons.
  $|\eta_e|<2$: flip rate larger at high $|\eta|$, more material.
- non-prompt $\ell^{\pm}\ell^{\pm}$ from data, matrix method.
  Charge-flip background subtracted from data.
\( \tilde{g} \tilde{g} \) production, \( \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0; m(\tilde{\chi}_1^\pm) = (m(\tilde{g}) + m(\tilde{\chi}_1^0))/2, m(\tilde{\chi}_2^0) = (m(\tilde{\chi}_1^+) + m(\tilde{\chi}_1^-))/2 \)

\[ \sqrt{s} = 13 \text{ TeV}, \ 139 \text{ fb}^{-1} \]

All limits at 95\% CL

**ATLAS** Preliminary

- **Expected Limit** (\( \pm 1 \sigma_{\text{exp}} \))
- **Observed Limit** (\( \pm 1 \sigma_{\text{SUSY}}^{\text{theory}} \))

SS/3L obs. 36 fb\(^{-1}\)

[arXiv:1706.03731]
**$\tau + \text{jets} + \text{MET}$**

**MET trigger.**

**1$\tau$ channel**
- $m_T^\tau$: suppress $W(\tau\nu)$ and $t\bar{t}$
- MET

**2$\tau$ channel**
- $H_T$
- $m_T^{\tau_1} + m_T^{\tau_2}$: suppress high-$p_T$ $Z(\tau\tau)$

NEW: used in multi-bin SR

$W$, $t\bar{t}$, $Z(\tau\tau)$, $Z(\nu\nu)$ fitted to data in CRs.
Gluino pairs decaying via $\tilde{\tau}$.

Light $\tilde{\tau}$ could help regulate $\Omega_{DM}$ (coannihilation).
Gauge-Mediated SUSY Breaking model.

Dominant strong processes at high $\Lambda$ (SUSY breaking scale): squark pairs, squark-gluino.
**γγ + MET**

General Gauge Mediated SUSY breaking model.

Diphoton trigger + $m_{γγ}$.

CR: MET < 100 GeV.
SR: MET > 100 GeV, 6 bins.

Backgrounds:

- **Multijet**: data with fake photons ($f$) failing isolation or shower shape criteria; $N_{γγ}/N_f$ fitted in CR, extrapolated to SR

- **W(εν)γ** with ε faking γ: from εγ data $f_{ε→γ}$ from $m_{ee}$ and $m_{εγ}$ peaks in data

- **Z(νν)γγ** from MC
**γγ + MET: results**

The CMS experiment with 35.9 fb⁻¹ (13 TeV) data presents a plot showing the 95% CL upper limit on the cross section for the processes:

- $pp \rightarrow \tilde{g} \tilde{g} \rightarrow q \bar{q} \tilde{\chi}^0_1, \tilde{\chi}^0_1 \rightarrow \gamma \tilde{G}$, NLO+NLL

The plot is divided into two sections:

1. **Left Section**:
   - $m_{\tilde{g}}$ vs $m_{\tilde{\chi}^0_1}$ with observed and expected cross sections.
   - The 95% CL upper limit is indicated.

2. **Right Section**:
   - $m_{\tilde{q}}$ vs $m_{\tilde{\chi}^0_1}$ with observed and expected cross sections.
   - The 95% CL upper limit is indicated.

The diagrams illustrate the scattering processes at the LHC, with initial states $p, \bar{q}$, and final states $q, \tilde{\chi}^0_1, \tilde{G}$.
Summary

Presented latest searches for $\tilde{g}$ and $\tilde{q}$ at ATLAS and CMS.

First results with full Run-2 dataset (137-139 fb$^{-1}$)!

No evidence for SUSY signal yet.

Limits on $m_{\tilde{g}}, m_{\tilde{q}}, m_{\tilde{\chi}_1^0}$ improved by 100-300 GeV w.r.t. 2016 results.

Stay tuned for more SUSY results!

ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

THANKS!

Coming next:
EW (S. Zambito), 3rd gen $\tilde{q}$ (I. Suarez) and RPV (K. Mei) SUSY searches.
Backup
Use data events from $H_T$ triggers.

1. **“Rebalance”** hard-scattering jets such that $p_{T,reb}^{miss} \approx 0$

   $$ L = \prod_{i=1}^{n} P(p_{T,i}^{reco} | p_{T,i}^{reb}) \times G \left( \frac{p_{T,reb,x}^{miss}}{\sigma_{T}^{soft}} \right) \times G \left( \frac{p_{T,reb,y}^{miss}}{\sigma_{T}^{soft}} \right) $$

   Jet response

2. **Smear** rebalanced jets according to jet resolution

- **Multijet-enriched CRs**

**MET resolution**

$\approx 20$ GeV (min bias)