Inclusive searches for squarks and gluinos with the ATLAS detector
SUPERSYMMETRY IN ATLAS

ATLAS SUSY Searches* - 95% CL Lower Limits

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<th>Model</th>
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<th>Mass limit</th>
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Inclusive Searches

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**Strategy ATLAS SUSY group: cover a wide range of final states and processes**

A. Koutsman

**updated for EPS**
A large number of posters presenting more details
OVERVIEW

• Motivation inclusive searches:
  • SUSY predicts existence of new colored particles
  • If present at TeV-scale, “high discovery potential” at LHC
    • Benchmark for LHC/ATLAS performance
  • R-parity conserving (RPC) models:
    • LSP stable (dark matter candidate)
    • Many energetic decay products:
      • multiple jets
      • large missing ET (MET)
      • possibly lepton(s)
        • hard: $p_T(\text{lep}) \geq 25$ GeV
        • soft: $p_T(\text{lep}) < 25$ GeV

• Focus (on newest results) on inclusive RPC SUSY strong production searches:
  • 1-2 leptons + 3-6 jets + MET: ATLAS-CONF-2013-062
  • 0 leptons + 2-6 jets + MET: ATLAS-CONF-2013-047
  • 0 leptons + 7-10 jets + MET: ATLAS-CONF-2013-054

• All ATLAS SUSY public results AtlasPublic/SupersymmetryPublicResults

• Outline of this talk:
  • Analyses + Backgrounds + Signal Regions
  • Results
  • Interpretation
ANALYSES
+
BACKGROUNDs
+
SIGNAL REGIONS
**BACKGROUND - 0L + 2-6J + MET**

- **MET + jets**: “high discovery potential” of strong production SUSY at hadron collider
- Very powerful, even in busy LHC environment
- Main discriminating variables: MET + effective mass $m_{\text{eff}}$
- 0-lepton analysis focus: short/medium/long decay chains
- Five inclusive channels based on jet multiplicity - 2 / 3 / 4 / 5 / 6 jets + lepton veto
  - optimized for squark or gluino pair (or mixed) production
- Up to three **signal regions (SR)** per channel, based on tighter $m_{\text{eff}}$ (details in backup)

\[ m_{\text{eff}} \equiv \sum_{i=1}^{n} |p_{T}^{(i)}| + E_{T}^{\text{miss}} \]

- Irreducible dominant backgrounds estimated with **Combined Fit Method**:
  1. **Bkg-only fit**: Normalize Monte Carlo (MC) to data in simultaneous fit of control regions (CR)
  2. Include systematic experimental/theoretical uncertainties as nuisance parameters
  3. **Exclusion fit**: Signal model can be included in signal/control regions for exclusion
  - Used in all discussed analyses

**ATLAS-CONF-2013-047**

**Poster**: Valerio Consorti
BACKGROUND - 0L + 7-10J + MET

- What if SUSY mass/decay spectrum more complex?
- **0-lepton + multijets** analysis targets very long decay chains

- Multijet production - QCD, ttbar/W+jets/Z+jets fully hadronic - estimated with a dedicated **data-driven** method, based on the observation that:
  - MET resolution proportional to $\sqrt{HT}$ in jet dominated events
    $\Rightarrow$ MET/$\sqrt{HT}$ ~ independent of jet multiplicity
  - HT = scalar sum of pT of all jets with pT > 40 GeV
  - stochastic variations in measured jet energies

  ➞ Use lower jet multiplicity to retrieve MET/$\sqrt{HT}$ shape from data
  ➞ Use lower MET/$\sqrt{HT}$ to normalize background to data

- **Signal regions** defined by:
  - MET/$\sqrt{HT}$ > 4 $\sqrt{GeV}$
  - jet multiplicity 7 / 8 / 9 / ≥10 jets
  - pT(jet) > 50 (80) GeV

- **ATLAS Preliminary**
  - Data 2012 ($\sqrt{s} = 8$ TeV)
  - No b-jets

- **7 jets control region**
• Trigger / detectors / world not perfect \(\rightarrow\) leptons help in LHC environment
• Leptonic final state cleaner, easier to trigger, but rare (W/Z/slepion in decay chain)
• Leptonic analyses target different decay modes, rejected by 0-lepton analyses

• Extra variables help distinguish backgrounds from signal:
  • Transverse Mass MT (using angular information):
    \[
    m_T = \sqrt{2 \cdot p_T^\ell \cdot E_T^{miss} \cdot (1 - \cos(\Delta \phi(\vec{\ell}, \vec{E}_T^{miss})))}.
    \]

• Hard 1 lepton (electron or muon) **signal regions**, \(p_T(\text{lep}) > 25\text{ GeV}\) defined as:
  • 3 / 5 / 6 jets + high MT + high MET + high meff

• Control regions in leptonic searches typically:
  • At lower MET/MT
  • Subdivided into b-tagged (ttbar enriched) and b-vetoed (W+jets enriched) regions

**Poster:** Jeanette Lorenz

---

**Background - Hard 1L + 3-6J + MET**

- Extra variables help distinguish backgrounds from signal:
  - Transverse Mass \(MT\) (using angular information):
    \[
    m_T = \sqrt{2 \cdot p_T^\ell \cdot E_T^{miss} \cdot (1 - \cos(\Delta \phi(\vec{\ell}, \vec{E}_T^{miss})))}.
    \]

- Hard 1 lepton (electron or muon) **signal regions**, \(p_T(\text{lep}) > 25\text{ GeV}\) defined as:
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- Control regions in leptonic searches typically:
  - At lower MET/MT
  - Subdivided into b-tagged (ttbar enriched) and b-vetoed (W+jets enriched) regions

**Poster:** Jeanette Lorenz
BACKGROUND - **SOFT 1L + 2-5J + MET**

- What if SUSY is not “simple” strong production?
- In **compressed** SUSY spectra, leptons in decay chain expected to be soft
  - Fully compressed spectrum: small $\Delta M$
  - Compressed chargino/neutralino sector: small $m$
- Soft 1 lepton **signal regions**
  $6[\mu](10[e]) < p_T(lep) < 25 \text{ GeV}$:
  - 3 jets / 5 jets + high MET + high MT
  - Complimentary to hard 1-lepton $\rightarrow$ “hard-to-reach” diagonal
- Experimentally challenging $\rightarrow$ need hard **ISR jet**:
  - Trigger signal (MET trigger)
  - Boost fully compressed spectra

---

**Leading jet**

**Soft-lepton**

**mET**
RESULTS
RESULTS - 0 LEPTON

- No significant excess in any signal region (details in back up)
- Data and estimated backgrounds used to set **model-independent limits** on visible BSM cross section
  - No signal model used, in contrast to model interpretations (next)
  - $\sigma_{\text{vis}} < 0.12$ fb
    - $\sigma_{\text{vis}} = \sigma_{\text{BSM}} \times \text{Acceptance} \times \text{efficiency}$

**0L+2-6J+MET**

**5 jets CR/SR**

**0L+7-10J+MET**

**≥10 jets CR/SR**
RESULTS - 1 LEPTON

- No significant excess in any signal region *(details in back up)*
- Data and estimated backgrounds used to set *model-independent limits* on visible BSM cross section
  - $\sigma(\text{vis}) < 0.15$ fb

**soft 1-lepton**

5 jets SR

**hard 1-lepton**

6 jets electron SR

**1/2L+2-6J+MET**
INTERPRETATIONS
• “Higgs-aware” MSUGRA/CMSSM plane
• Gluino masses below ~1.35 TeV excluded for all squark masses
SIMP. MODELS: GLUINO VIA CHARGINO

0L+2-6j+MET

0L+7-10j+MET

1/2L+2-6j+MET
SIMP. MODELS: SQUARK VIA CHARGINO

**0L+2-6J+MET**

Simplified model, $\tilde{q} \tilde{q} \rightarrow q \tilde{q} \tilde{\chi}^\pm_1 \tilde{\chi}^0_1 \rightarrow q \tilde{q} W^+ W^+ \tilde{\chi}^0_1$

- **ATLAS** Preliminary
- Observed limit ($\pm 1 \sigma_{\text{SUSY}}$)
- Expected limit ($\pm 1 \sigma_{\text{exp}}$)

\[
\int L \, dt = 20.3 \text{ fb}^{-1}, \, \sqrt{s}=8 \text{ TeV}
\]

- $m(\tilde{\chi}^0_1) = (m(\tilde{q}) + m(\text{LSP}))/2$
- 0-lepton combined

**1/2L+2-6J+MET**

- **squared lepton**

---

**ATLAS** Preliminary

\[
\text{Observed limit (soft lepton)}
\]

- $q \tilde{q} \rightarrow qW W \tilde{\chi}^0_1$, $x=1/2$

\[
\int L \, dt = 20.3 \text{ fb}^{-1}, \, \sqrt{s}=8 \text{ TeV}
\]

- All limits at 95% CL

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A. Koutsman  
Inclusive SUSY searches  - EPSHEP 2013

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SIMP. MODELS: VIA CHARGINO/NETRALINO2

1/2L+2-6J+MET

ATLAS Preliminary

hard 1-lepton + jets + $E_T^{miss}$

L dt = 20.3 fb$^{-1}$, $\sqrt{s}$=8 TeV

Observed limit (±1σ$_{\text{SUSY}}$)

Expected limit (±1σ$_{\text{exp}}$)

All limits at 95% CL

$\tilde{g}\tilde{g}$ decays via WWZ: $\tilde{g}\tilde{g} \rightarrow qqqq_\pm \tilde{\chi}^\pm_1 \rightarrow qqqqWZW\tilde{\chi}^0_1\tilde{\chi}^0_1$

0L+7-10J+MET

7 TeV

8 TeV

ATLAS Preliminary

$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qqWZ\tilde{\chi}^0_1; m(\tilde{\chi}^0_1)=[m(\tilde{g})+m(\tilde{\chi}^0_1)]/2, m(\tilde{\chi}^0_2)=[m(\tilde{\chi}^0_1)+m(\tilde{\chi}^0_2)]/2$

---

A. Koutsman

Inclusive SUSY searches - EPSHEP 2013

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SUMMARY

- LHC and ATLAS very powerful pairing in search for SUSY
- Unfortunately no sign of supersymmetric phenomena yet
- Excluding gluinos (squarks) with masses up to ~1.3 (0.75) TeV in studied models
- Model-independent limits on visible cross section for BSM physics as low as 0.12 fb

### ATLAS SUSY Searches* - 95% CL Lower Limits

#### Status: EPS 2013

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<th>Jets</th>
<th>$E_{\text{miss}}^T$</th>
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<td>GGM (bino N LSP)</td>
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#### Next steps:

- Finalize all ongoing 8 TeV analyses on full 2012 dataset
- Move forward to produce combined 0L + 1L + 2L + ... exclusions by full statistical analyses combination
- 13-14 TeV: the big next step in mass reach for inclusive searches for squarks and gluinos (fingers crossed)
Los Roques, Venezuela
June 2013
BACK UP
SIMPLIFIED MODELS: DIRECT PRODUCTION

**ATLAS Preliminary**

- ***Observed limit (±1 σ_{exp})***
- ***Expected limit (±1 σ_{exp})***

**squark pair**

- **0L+2-6J+MET**
- **7 TeV**
- **8 TeV**

**squark gluino**

- **7 TeV**
- **8 TeV**

**ATLAS Preliminary**

- **Observed limit (±1 σ_{exp})**
- **Expected limit (±1 σ_{exp})**

A. Koutsman
Inclusive SUSY searches - EPSHEP 2013
- Limits in 1-step (intermediate chargino) gluino pair production simplified models
- Same decay, different grid: new variable $X$ defined as
  - mass splitting ratio

$$X = \frac{m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)}{m(g) - m(\tilde{\chi}_1^0)}$$

**Figure 10**: 95% CL exclusion curve for the simplified gluino–stop (on-shell) model, where the gluino decays as $\tilde{g}!\tilde{\chi}_1^\pm + \bar{t}$ and the stop as $\tilde{t}!\tilde{\chi}_1^0$. With $m(\tilde{\chi}_1^0) = 60$ GeV. Other details as in Fig. 9.

**Figure 11**: 95% CL exclusion curve for the simplified gluino–squark (via $\tilde{\chi}_1^\pm$) model, for the two versions on the model; fixed $x = 1/2$, where $x = (m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)) / (m(\tilde{g}) - m(\tilde{\chi}_1^0))$, and varying $\tilde{\chi}_1^0$ mass on the left, and $\tilde{\chi}_1^0$ mass fixed to 60 GeV and varying $x$ on the right. Other details as in Fig. 9.
SIMP. MODELS: SQUARK - GRID-X

- Limits in 1-step (intermediate chargino) squark pair production simplified models
- Same decay, different grid: new variable $X$ defined as
  \[ X = \frac{m(\tilde{\chi}^0) - m(\tilde{\chi}^0_1)}{m(\tilde{t}) - m(\tilde{\chi}^0_1)} \]

\[0L+2-6J+MET\]

\[1/2L+2-6J+MET\]
MINIMAL UED

- Limits in minimal Universal Extra Dimensions (mUED)
- Signal region: 2 soft muons + 2 jets + high MET + high MT + Z-veto
- Comparable expected limits, but observed limit worse for 2L because of slight excess

**0L+2-6J+MET**

**1/2L+2-6J+MET**

**Figure 5:** (Left) First KK particle mass spectrum for $R=900$ GeV and $\Lambda = 10$. (Right) One of examples decays which provides OSSF di-lepton in the final state.

**Figure 6:** The mass difference between KK-gluon and KK-photon (left) and the total production cross-section (right) as a function of the compactification radius $R$. 

6.3 Systematic uncertainties

Several systematic uncertainties impact the prediction of the expected signal contributions. These uncertainties are discussed in the next sections.

6.3.1 Scale and PDF uncertainties on the cross section

For each model presented in this section, the signal cross section is calculated to next-to-leading or-der in the strong coupling constant, adding the resummation of soft gluon emission at next-to-leading-logarithmic accuracy (NLO + NLL) [35, 41–44]. The nominal cross section and the uncertainty are taken from an envelope of cross section predictions using different PDF sets and factorisation and renormalisation scales, as described in Ref. [45].

There are different theoretical uncertainties considered, that have an impact on the calculated cross section:
SIMP. MODELS: GLUINO VIA SLEPTON

ATLAS Preliminary

ATLAS-CONF-2013-007
Discussed by David Côté on gluino-mediated 3rd gen.

1/2L+2-6J+MET

gluino pair

2L Same Sign+0-3 b-jets+MET
SIMP. MODELS: SQUARK VIA SLEPTON

ATLAS Preliminary

\[ \int L \frac{dt}{dt} = 20.3 \text{ fb}^{-1}, \, 1s=8 \text{ TeV} \]

- Observed limit (±1 \sigma_{\text{theory}})
- Expected limit (±1 \sigma_{\text{exp}})

All limits at 95% CL

Numbers give 95% CL excluded model cross sections [pb]

\[ \tilde{q}\tilde{q} \text{ decays via sleptons/sneutrinos: } \tilde{q}\tilde{q} \rightarrow \text{qq}(\llll)\llll \tilde{\chi}_1^0 \tilde{\chi}_1^0 + \text{neutrinos} \]

ATLAS-CONF-2013-007

Discussed by David Côté on gluino-mediated 3rd gen.

1/2L+2-6J+MET

Squark pair

2L Same Sign+0-3 b-jets+MET
COMBINED FIT METHOD

- Combined Fit Method:
  1) Take shape of variable (MET,MT) distributions from Monte Carlo
  2) Combine all backgrounds in a likelihood model with free normalization parameters for dominant backgrounds
  3) Select signal-free control regions and fit model to data
  4) Extrapolate to signal regions using MC shape and fitted normalizations
  5) Systematic experimental/theoretical uncertainties included as Gaussian constraints
  6) Systematics can be constrained if enough information in fit → “profiling”
  7) MC statistical uncertainties can be included as Poisson errors
  8) Signal can be included in signal regions for exclusion
  9) Shape information (binned fit) easily added for better discriminating power
  10) Statistically independent validation regions used to cross check SM predictions/extrapolation with data

- Combining all useful information into a global Likelihood:

\[ L(n|s, b, \theta) = P_S \times P_W \times P_T \times C_{Syst}, \]

- \( n \) = number of observed events
- \( s \) = SUSY signal to be tested
- \( b \) = background normalization parameters, shared between all fit regions
- \( \theta \) = systematic uncertainties, treated as nuisance parameters with a Gaussian constraint
- \( P_S \) (\( W,T \)) = (Poisson) probability density functions (pdfs) for event counts in signal/control regions
- \( C_{Syst} \) = constraints on systematic uncertainties, proper treatment of correlations
- Simultaneous fit of multiple control (+signal) regions normalizes the backgrounds (and signal)
SIGNAL REGIONS 1L + 2-6J + MET

- Hard 1 lepton signal regions, \( p_T(\text{lep}) > 25 \text{ GeV} \):
  - 3 jets / 5 jets / 6 jets + high MET + high MT
    + high Meff

- Soft 1 lepton signal regions, \( 6[\mu](10[e]) < p_T(\text{lep}) < 25 \text{ GeV} \):
  - 3 jets / 5 jets + high MET + high MT
  - Soft 2 muons signal region (target mUED):
    - high MET + high MT + Z-veto

<table>
<thead>
<tr>
<th>inclusive (binned) hard single-lepton</th>
<th>3-jet</th>
<th>5-jet</th>
<th>6-jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_f )</td>
<td>1 (electron or muon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( p_T^1(\text{GeV}) )</td>
<td>( &gt; 25 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( p_{T,\text{add. jet}}^1(\text{GeV}) )</td>
<td>( &lt; 10 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( N_{\text{jet}} )</td>
<td>( \geq 3 )</td>
<td>( \geq 5 )</td>
<td>( \geq 6 )</td>
</tr>
<tr>
<td>( p_{T,\text{jet}}(\text{GeV}) )</td>
<td>( &gt; 80, 80, 30 )</td>
<td>( &gt; 80, 50, 40, 40, 40 )</td>
<td>( &gt; 80, 50, 40, 40, 40, 40 )</td>
</tr>
<tr>
<td>( p_{T,\text{add. jets}}(\text{GeV}) )</td>
<td>( &lt; 40 )</td>
<td>( &lt; 40 )</td>
<td></td>
</tr>
<tr>
<td>( E_T^\text{miss} (\text{GeV}) )</td>
<td>( &gt; 500 (300) )</td>
<td>( &gt; 300 )</td>
<td>( &gt; 350 (250) )</td>
</tr>
<tr>
<td>( m_T (\text{GeV}) )</td>
<td>( &gt; 150 )</td>
<td>( &gt; 200 (150) )</td>
<td>( &gt; 150 )</td>
</tr>
<tr>
<td>( E_T/ m^\text{eff}_\text{incl} )</td>
<td>( &gt; 0.3 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( m^\text{eff}_\text{incl} (\text{GeV}) )</td>
<td>( &gt; 1400 (800) )</td>
<td></td>
<td>( &gt; 600 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>soft single-lepton</th>
<th>3-jet</th>
<th>5-jet</th>
<th>2-jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_f )</td>
<td>1 (electron or muon)</td>
<td></td>
<td>2 (muons)</td>
</tr>
<tr>
<td>( p_T^1(\text{GeV}) )</td>
<td>[10,25] (electron), [6,25] (muon)</td>
<td>[6,25]</td>
<td></td>
</tr>
<tr>
<td>( p_{T,\text{add. jet}}^1(\text{GeV}) )</td>
<td>( &lt; 7 ) (electron), ( &lt; 6 ) (muon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( m_{\mu\mu} (\text{GeV}) )</td>
<td></td>
<td></td>
<td>( &gt; 15 ) and (</td>
</tr>
<tr>
<td>( N_{\text{jet}} )</td>
<td>[3,4]</td>
<td>( \geq 5 )</td>
<td>( \geq 2 )</td>
</tr>
<tr>
<td>( p_{T,\text{leading jet}}(\text{GeV}) )</td>
<td>( &gt; 180 )</td>
<td></td>
<td>( &gt; 70 )</td>
</tr>
<tr>
<td>( p_{T,\text{subleading jets}}(\text{GeV}) )</td>
<td></td>
<td>( &gt; 25 )</td>
<td></td>
</tr>
<tr>
<td>( N_{b-tag} )</td>
<td></td>
<td></td>
<td>( 0 )</td>
</tr>
<tr>
<td>( E_T^\text{miss} (\text{GeV}) )</td>
<td>( &gt; 400 )</td>
<td>( &gt; 300 )</td>
<td>( &gt; 170 )</td>
</tr>
<tr>
<td>( m_T (\text{GeV}) )</td>
<td></td>
<td>( &gt; 100 )</td>
<td>( &gt; 80 )</td>
</tr>
<tr>
<td>( E_T/ m^\text{incl}_\text{eff} )</td>
<td>( &gt; 0.3 )</td>
<td></td>
<td>( &gt; 0.3 )</td>
</tr>
<tr>
<td>( \Delta R_{\text{min}(jet, } \ell) )</td>
<td>( &gt; 1.0 )</td>
<td></td>
<td>( &gt; 1.0 )</td>
</tr>
</tbody>
</table>
• Five inclusive channels based on jet multiplicity - 2-6 jets - optimized for squark/gluino pair (mixed) production
  • Up to three signal regions for each channel based on tighter meff cuts
  → TOTAL: 10 signal regions (SR)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>A (2-jets)</th>
<th>B (3-jets)</th>
<th>C (4-jets)</th>
<th>D (5-jets)</th>
<th>E (6-jets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T^{\text{miss}}$ [GeV] &gt;</td>
<td>160</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_T(j_1)$ [GeV] &gt;</td>
<td></td>
<td>130</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_T(j_2)$ [GeV] &gt;</td>
<td></td>
<td></td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_T(j_3)$ [GeV] &gt;</td>
<td>–</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>$p_T(j_4)$ [GeV] &gt;</td>
<td>–</td>
<td>–</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>$p_T(j_5)$ [GeV] &gt;</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>$p_T(j_6)$ [GeV] &gt;</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>60</td>
</tr>
<tr>
<td>$</td>
<td>\Delta#phi(jet_i,E_T^{\text{miss}})</td>
<td>_{\text{min}} &gt;$</td>
<td>0.4 ($i = 1,2,3$), 0.2 ($p_T &gt; 40$ GeV jets)</td>
<td>0.4 ($i = 1,2$)</td>
<td>0.2 ($p_T &gt; 40$ GeV jets)</td>
</tr>
</tbody>
</table>

$E_T^{\text{miss}}/m_{\text{eff}}(N_j) >$ | 0.2 | – | 0.3 | 0.4 | 0.25 | 0.25 | 0.2 | 0.15 | 0.2 | 0.25 |

$m_{\text{eff}}(\text{incl.})$ [GeV] > | 1000 | 1600 | 1800 | 2200 | 1200 | 2200 | 1600 | 1000 | 1200 | 1500 |

• Signal regions defined by:
  • jet multiplicity (7 - ≥10 jets)
    • b-tagged jet multiplicity
    • $M_{J\Sigma}$ = mass of large-radius jet
  • $\text{MET}/\sqrt{\text{HT}} > 4 \sqrt{\text{GeV}}$
  → TOTAL 19 signal regions
LARGE-RADIUS JET MASS

- Highy boosted particles expected to form large-radius (‘composite’) massive jets
- Form large radius (R=1.0) anti-kt jets from nominal R=0.4 jets
- \( M_{\Sigma} \) = sum of the masses of composite jets:
  \[
  M_{\Sigma}^J \equiv \sum_{j} m_j^{R=1.0}
  \]
  - \( pT(R=1.0 \text{ jet}) > 100 \text{ GeV} \)
  - \(|\text{eta} (R=1.0 \text{ jet})| < 1.5 \)

- **Signal regions** defined for two \( M_{\Sigma} \) thresholds:
  - \( M_{\Sigma} > 340 \text{ GeV} \)
  - \( M_{\Sigma} > 420 \text{ GeV} \)
  - jet multiplicity - 8 / 9 / \( \geq 10 \) jets - \( pT(\text{jet}) > 50 \text{ GeV} \)
## RESULTS

- No significant excess in any signal region
- Data and estimated backgrounds used to set model-independent limits on visible BSM cross section

### Signal Region

<table>
<thead>
<tr>
<th>Signal region</th>
<th>D</th>
<th>E-tight</th>
</tr>
</thead>
<tbody>
<tr>
<td>jets</td>
<td>5-jet</td>
<td>6-jet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Signal Region

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>A-loose</th>
<th>A-medium</th>
<th>B-medium</th>
<th>B-tight</th>
<th>C-medium</th>
<th>C-tight</th>
</tr>
</thead>
<tbody>
<tr>
<td>jets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Signal Region

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>70pb</th>
<th>850pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>b-jets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others before fit</td>
<td>0.8 ± 0.2</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Multi-jets</td>
<td>0.2 ± 0.4</td>
<td>0.2 ± 0.4</td>
</tr>
<tr>
<td>N_{j} tagged (0.2)</td>
<td>0.7 ± 0.2</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>N_{j} not tagged</td>
<td>0.7 ± 0.2</td>
<td>0.7 ± 0.2</td>
</tr>
</tbody>
</table>

### Signal Region

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>70pb</th>
<th>850pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>b-jets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others before fit</td>
<td>0.8 ± 0.2</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Multi-jets</td>
<td>0.2 ± 0.4</td>
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</tr>
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<td>N_{j} tagged (0.2)</td>
<td>0.7 ± 0.2</td>
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</tr>
<tr>
<td>N_{j} not tagged</td>
<td>0.7 ± 0.2</td>
<td>0.7 ± 0.2</td>
</tr>
</tbody>
</table>
RESULTS - TRIMMED

- No significant excess in any signal region (too much to discuss now)
- Data and estimated backgrounds used to set model-independent limits on visible BSM cross section
  - No signal model used, in contrast to model interpretations (next)
  - $\sigma(\text{vis}) < 0.12$ fb (range between 0.12 - 66.07 fb)
    - $\sigma(\text{vis}) = \sigma(\text{BSM}) \times \text{Acceptance} \times \text{efficiency}$
  - $p_0 = p(s=0) = p$-value of background-only hypothesis

### Table 14: Background fit results for the soft single-lepton and soft dimuon channels

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>A-loose</th>
<th>A-medium</th>
<th>B-medium</th>
<th>B-tight</th>
<th>C-medium</th>
<th>C-tight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total bkg</td>
<td>4700 $\pm$ 500</td>
<td>122 $\pm$ 18</td>
<td>33 $\pm$ 7</td>
<td>2.4 $\pm$ 1.4</td>
<td>210 $\pm$ 40</td>
<td>1.6 $\pm$ 1.4</td>
</tr>
<tr>
<td>(expected) $\mu_{0}^{F}$ [fb]</td>
<td>66.07</td>
<td>2.52</td>
<td>0.73</td>
<td>0.33</td>
<td>4.00</td>
<td>0.12</td>
</tr>
<tr>
<td>$p_{0}^{Z_{\omega}}$ (Z_{\omega})</td>
<td>0.45 (0.1)</td>
<td>0.27 (0.6)</td>
<td>0.50 (0.0)</td>
<td>0.34 (0.4)</td>
<td>0.34 (0.4)</td>
<td>0.50 (0.0)</td>
</tr>
<tr>
<td>Total events after fit</td>
<td>75 $\pm$ 19</td>
<td>45 $\pm$ 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\text{BSM, max}} \cdot A \cdot \epsilon$ (obs) [fb]</td>
<td>1.7</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_{0}$</td>
<td>0.60</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 15: Background fit results for the binned hard single-lepton channel

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>3-jet</th>
<th>5-jet</th>
<th>6-jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>muon</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>electron</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>muon</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fitted background events</td>
<td>3.9 $\pm$ 1.0</td>
<td>2.7 $\pm$ 0.9</td>
<td>3.6 $\pm$ 1.0</td>
</tr>
<tr>
<td>Fitted others</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Multi-jets</td>
<td>1.0</td>
<td>0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

- Also presented are the 95% CL upper limits on the visible cross-section ($\sigma(\text{vis})$) and the number of signal events ($\mu_{0}^{\text{obs}}$).