Search for physics beyond the Standard Model with the ATLAS detector

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 STATUS OF THE STANDARD MODEL (SM)

SM provides a mathematical description of all known particles and their interaction

- All SM cross sections of all SM heavy particles and their combination are measured
- Higgs boson discovered at the LHC in July 2012 (see Alain’s talk for more details)

However, several experimental and theoretical problems exist with the SM:

- **No gravity**
- **Number of generations**
- **Number of bosons**
- **Neutrinos**

- **Matter-antimatter asymmetry**
- **Dark energy**
- **Dark matter**
- **Grand unification?**
The gauge hierarchy problem

Gauge hierarchy problem in the Standard Model:

- Higgs boson couples to all massive particles → EW scale — Planck scale → large quantum correction

\[
(125)^2 = m_H^2 = (m_H^2)_0 - \frac{3G_F}{4\sqrt{2}\pi^2} (4m_t^2) \Lambda_{NP}^2 + \frac{3G_F}{4\sqrt{2}\pi^2} (2m_W^2 + m_Z^2 + m_H^2) \Lambda_{NP}^2
\]

- Large fine-tuning (\(\sim 10^{17}\)) required to accommodate the Higgs boson mass (125 GeV)
Supersymmetry (SUSY) can solve the gauge hierarchy problem:

- SM boson ↔ new fermion; SM fermion ↔ new scalar

\[ m_h^2 = (m_h^2)_0 - \frac{3G_F}{4\sqrt{2}\pi^2} (4m_t^2) \Lambda_{NP}^2 + \frac{3G_F}{4\sqrt{2}\pi^2} (4m_t^2) \Lambda_{NP}^2 + \frac{3G_F}{\sqrt{2}\pi^2} (m_t^2 - m_t^2) \ln(\Lambda_{NP}/m_h) + \ldots \]

\[ \lambda = \sqrt{2}m_t / v \]
\[ \sqrt{2G_F} = v^2 \]

- The SM (positive) and SUSY (negative) corrections cancel exactly: SUSY broken!
A natural SUSY spectrum
Other BSM theories

Other Beyond the Standard Model (BSM) theories:

- Vector like quarks: hypothetical 1/2 spin colored particles (left- and right-handed states have the same coupling)

- Large extra dimensions: $\Lambda_{NP} \rightarrow$ scale of new space-time structure/quantum gravity

- New strong Dynamics: $\Lambda_{NP} \rightarrow$ new strong coupling scale, composite Higgs

$\rightarrow$ Experimental signature: new particles with a mass close to $\Lambda_{NP}$

Can expect several types of final states, including or not:

- Leptons & photons
- Hadrons (resolved or boosted)
- Di-boson resonances
- Missing transverse energy
Search for BSM physics with the ATLAS detector using Run-2 (13 TeV) data:

- Corresponding to an integrated luminosity of $\sim 36 \text{ fb}^{-1}$

- Results from ATLAS Supersymmetry Public Results and Exotics Public Results

- Focus on analyses obtained with full 2015 and 2016 data-sets (& with lot of contributions from Canadian researchers)
SM backgrounds

- tt / t, tt + Z/W,
- di-bosons, V+jets, multi-jets

estimation

Check bkg estimate in validation regions (close to SRs)

Look in signal regions → is there any excess?

Main prompt SM backgrounds: semi – data driven
- using control regions (CRs) kinematically close to SRs → to min. syst. due to SR-CR extrapolation
- estimate the bkg in the signal regions (SRs) relying on MC shape using transfer factors

Minor prompt SM backgrounds: purely MC

Detector background (fakes): fully data – driven
- Using a matrix method
- Jet smearing
- Templates

Set model dependent / independent exclusion limits
- cut & count
- or combined fit using CL$_S$ formalism (using mainly simplified BSM models)

IF NOT
SUSY (simplified) models

Search for SUSY with SRs optimized to maximize the sensitivity to a large # of signal models:

- Final states with $0 \to 4/5$ leptons, many ($b$-) jets, low or high $E_T^{miss}$ (& $\tilde{\chi}_1^0$, the LSP)

(b) 2-step

(c) 2-step

(d) sleptons

(e) 1-step

(f) gtt

(g) gtb

(h) Baryon-nr violating

(i) Baryon-nr violating

(j) Lepton-nr violating

(k) sqsq

(l) sqsq

(m) sqsq

(n) sbsb

(o) stst

(p) stst
Search for SUSY with multi-jets final states

Final states with 0-leptons and $2 \to 6$ jets, CONF-2017-022 or $7 \to 11$ jets, CONF-2017-033

- Key variables: $N_{jets}$, $m_{eff}$ or $H_T$, $E_T^{miss}$, $\Delta \Phi(jet_{1,2,3}, E_T^{miss})_{min} > 0.2 \to 0.8$, etc.
- Main backgrounds: $W/Z+\text{jets}$, $t\bar{t}$, single top, di-boson and multi-jets processes
  - Estimation using dedicated CRs, but for di-boson processes (MC simulations)

- Most significant excesses: $\text{Meff-2j-2100}$ (a significance of 2.14 standard deviations)
Exclusion limits (1-step & 2-step decays)

No significant excess → place limits on sparticles masses using simplified SUSY models:

- Limits obtained also with other final states (blue) → complementary of the ATLAS searches

\[ m(\tilde{\chi}_1^\pm) = \frac{1}{2}(m(\tilde{g}) + m(\tilde{\chi}_1^0)) \]

\[ m(\tilde{\chi}_2^0) = \frac{1}{2}(m(\tilde{g}) + m(\tilde{\chi}_2^0)) \]

<table>
<thead>
<tr>
<th>g → q\bar{q}W_1^0</th>
<th>g → q\bar{q}Z_1^0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-lepton expected</td>
<td>≥ 7-11 jets expected</td>
</tr>
<tr>
<td>0-lepton observed</td>
<td>≥ 7-11 jets observed</td>
</tr>
<tr>
<td>1-lepton expected</td>
<td>SS leptons expected</td>
</tr>
<tr>
<td>1-lepton observed</td>
<td>SS leptons observed</td>
</tr>
</tbody>
</table>

Run 1 expected:
- 0-lepton: ATLAS-CONF-2017-022
- 1-lepton: ATLAS-CONF-2016-054
- 7-11 jets: ATLAS-CONF-2017-033
- SS leptons: ATLAS-CONF-2017-030

Run 1 observed:
- 0-lepton: ATLAS-CONF-2017-022
- 1-lepton: ATLAS-CONF-2016-054
- 7-11 jets: ATLAS-CONF-2017-033
- SS leptons: ATLAS-CONF-2017-030

Run 1:
- ATLAS: arXiv:1507.05525

May 2017
Search for SUSY with 0 or 1 lepton and \( \geq 3 \) \( b \)-jets, ATLAS-CONF-2017-021

- Discovery strategy: cut-and-count SRs targeting compressed, intermediate and boosted reg.
- Exclusion strategy: multi-bin fit across binned orthogonal SRs in \( N_j \) and \( m_{\text{eff}} \)
- Key variables: nr. of leptons and \( (b-) \)jets, \( E_T^{\text{miss}}, m_{\text{eff}}, m_T, M_{\sum} \), \( \Delta \Phi(\text{jet}_{1\rightarrow4}, E_T^{\text{miss}})_{\text{min}} \), etc

- Dominant background: \( t\bar{t} \) pairs with additional high \( p_T \) jets
- \( t\bar{t} \) MC simulations normalized in an 1-lepton CR and extrapolated to VRs and SRs
Final states with multi- \( b \) jets

Results in the signal regions:

- No significant excess found above the predicted background in the SRs

- Gluino masses excluded up to 1.9 TeV → strongest limits among all ATLAS searches
Direct top squark searches

Search for direct top squarks production in events with a Z or Higgs boson, CONF-2017-019

- SRs with at least three leptons plus a $b$-jet (top squark decays via $Z$ bosons)
  - Bkgs: $t\bar{t}Z$, di-boson and “fake”/non-prompt leptons
  - Dominant source of uncertainty: limited statistics

- SRs with one or two leptons and at least four $b$-jets (top squark decays via Higgs bosons)
  - Bkgs: $t\bar{t}$ pair production (>80%)
  - Dominant source of uncertainty: $t\bar{t}$ bkg modeling

- No significant excess in any of the signal regions
- Top squarks masses excluded up to about 800 GeV
Direct top squark searches

Summary of the dedicated ATLAS searches for top squark (stop) pair production

- Several top squark decay modes considered

Top squark masses excluded up to 950 GeV
Several multi-$\ell$ searches available: opposite/same-charge or three leptons, CONF-2017-030

- Same-charge (SS) final states: electron charge flips and fake leptons non-negligible bkgs
- Several signal regions defined with **SS or three leptons**, $(b\bar{b})$-jets, $m_{\text{eff}}$ and $E_{T}^{\text{miss}}$
- One signal region with three leptons of same electric charge (Rpc3LSS1b)
Electroweak searches

Direct searches for charginos and neutralinos in events with two or more leptons (link)

- Here focus on final states with $\geq 2$ opposite-charge hadronic taus (CONF-2017-035)
- No $b$-jets or a tau lepton pair compatible with the $Z$ boson mass
- Key variables: max transverse mass of the taus (min 70 GeV) and $E_T^{\text{miss}}$ (min 110 GeV)
- Main bkgs: multi-jets, $W+\text{jets}$, di-bosons (“fake” or “real” tau candidates)
### ATLAS SUSY Searches* - 95% CL Lower Limits

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<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell$, $\mu$, $\tau$, $\gamma$</th>
<th>Jets</th>
<th>$E_T^{miss}$</th>
<th>$m_{X_{3/2}}$ ($\text{GeV}$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSUGRA/CMSM</td>
<td>$0$ $\mu$, $1$ $\tau$</td>
<td>Yes</td>
<td>$20.3$</td>
<td>$1.86, \text{TeV}$</td>
<td>$1597.05655$</td>
</tr>
<tr>
<td>$\tilde{g} \rightarrow t\bar{t}$</td>
<td>$0$</td>
<td>$2$</td>
<td>$2.02, \text{TeV}$</td>
<td>$1597.05655$</td>
<td></td>
</tr>
<tr>
<td>GGM (bino NLSP)</td>
<td>$\tilde{t}$</td>
<td>$1$</td>
<td>$1.87, \text{TeV}$</td>
<td>$1597.05655$</td>
<td></td>
</tr>
<tr>
<td>GGM (higgsino-bino NLSP)</td>
<td>$\tilde{t}$</td>
<td>$1$</td>
<td>$1.87, \text{TeV}$</td>
<td>$1597.05655$</td>
<td></td>
</tr>
<tr>
<td>GGM (higgsino-NLSP)</td>
<td>$\tilde{t}$</td>
<td>$1$</td>
<td>$1.87, \text{TeV}$</td>
<td>$1597.05655$</td>
<td></td>
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<tr>
<td>Gravitino LSP</td>
<td>$0$</td>
<td>mono-jet</td>
<td>$20.3$</td>
<td>$0.90, \text{TeV}$</td>
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</table>

**Inclusive Searches**

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell$, $\mu$, $\tau$, $\gamma$</th>
<th>Jets</th>
<th>$E_T^{miss}$</th>
<th>$m_{X_{3/2}}$ ($\text{GeV}$)</th>
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<tbody>
<tr>
<td>$\tilde{b}_1$, $\tilde{b}_2$</td>
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<td>$1$</td>
<td>$950, \text{GeV}$</td>
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<td>$\tilde{b}_1$, $\tilde{b}_2$</td>
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<td>$1.10, \text{TeV}$</td>
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</tr>
<tr>
<td>$\tilde{t}_1$, $\tilde{t}_2$</td>
<td>$0$</td>
<td>$2$</td>
<td>$1.10, \text{TeV}$</td>
<td>$1597.05655$</td>
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<tr>
<td>$\tilde{t}_1$, $\tilde{t}_2$</td>
<td>$0$</td>
<td>$4$</td>
<td>$1.10, \text{TeV}$</td>
<td>$1597.05655$</td>
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<tr>
<td>GGM (bino NLSP)</td>
<td>$\tilde{t}$</td>
<td>$1$</td>
<td>$1.10, \text{TeV}$</td>
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<td>GGM (higgsino-bino NLSP)</td>
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**EW Direct**

<table>
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<tr>
<th>Model</th>
<th>$\ell$, $\mu$, $\tau$, $\gamma$</th>
<th>Jets</th>
<th>$E_T^{miss}$</th>
<th>$m_{X_{3/2}}$ ($\text{GeV}$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct $\tilde{H}^+_1$, $\tilde{H}^+_2$, $\tilde{H}^0_1$, $\tilde{H}^0_2$</td>
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<td>$1$</td>
<td>$90-440, \text{GeV}$</td>
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<tr>
<td>Direct $\tilde{H}^0_1$, $\tilde{H}^0_2$, $\tilde{H}^0_3$, $\tilde{H}^0_4$</td>
<td>$0$</td>
<td>$1$</td>
<td>$710, \text{GeV}$</td>
<td>$1597.05655$</td>
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</tbody>
</table>

**Long-lived Third Generation squarks up to 950 GeV**

**Third generation squarks up to 950 GeV**

**Electroweak particles up to 1.2 TeV**

**Long lived gluinos up to 1.6 TeV**

**Long lived electroweak p. up to 500 GeV**

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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, i.e. refs. for the assumptions made.*
**Long lived particles (LLP)**

**LLP final states: LLP arise from small couplings, heavy mediators, etc.**

- Unique signature (lifetimes in the pico to nanoseconds range), usually negligible SM bkg
- Metastable: displaced vertices, \( DV \) O(1-10 mm) or disappearing tracks O(1-100 mm)
  - \( DV, \text{CONF-2017-026} \): \( \geq 1 \) \( DV \) with high mass and high nr. of tracks (\( \geq 5 \)) and \( E_T^\text{miss} \)
- Bkg: hadronic interaction (material veto) and accidental crossing (dominant)

- For \( \tau = 1 \) ns, upper limits on the gluino mass are placed above 2.2 TeV for \( \tilde{\chi}_1^0 \) 100 GeV
**Vector-like top quarks (T)**

Search for vector-like top quarks \( (Q=+\frac{2}{3}|e|) \) with one lepton and \( E_T^{\text{miss}} \) (CONF-2017-015):

- Assuming only couplings to third gen. quarks, targeting \( T\bar{T} \rightarrow Z/W/Ht + X, Z \rightarrow \nu\nu \)
- Pre-selection: \#b-jets (\( \geq 1 \)), \#jets (\( \geq 4 \)), \( E_T^{\text{miss}} (> 300 \text{ GeV}) \), \( \Delta\Phi(j_1,j_2,E_T^{\text{miss}}) (> 4) \)

- Dominant bkgs: semi-leptonic \( t\bar{t} \) events, single top and \( W+\)jets production
- Reduced with requirements on e.g (\( W \)) transverse mass \( m_T \), number of boosted selected top quarks

![Graphs and plots](image-url)
Search for $Z'$ (spin 1) signatures with two opposite-charge lepton pairs (CONF-2017-027):

- $Z'$: predicted by Grand Unified Theories, etc.
- In the Sequential SM (SSM), $Z'$ has same couplings to fermions as the SM $Z$

If new physics, the invariant mass of the lepton pair is a great variable to look at:

- The new heavy resonance, $Z'$, should create a bump
- Non-resonant effects should change the shape of the distribution

Most significant excess at $m_{Z'} = 2.37$ TeV, in the di-electron channel (2.37σ)
But globally much less significant, only $-0.2\sigma$
Heavy bosons ($W'$)

Search for heavy gauge boson resonance (spin 1) with one lepton and $E_T^{miss}$ (CONF-2017-016):

- $W'$: predicted by models with extra-dimensions, little Higgs model, etc.
- In the Sequential SM (SSM), $W'$ has same couplings to fermions as the SM $W$, thus $W' \rightarrow \ell\nu$ or $W' \rightarrow q\bar{q}$
- Key variables: $m_T \rightarrow$ a signal would appear as an excess at high $m_T$
- Main bkgs: $W$, $t\bar{t}$ and single top (“real”, from MC) and multi-jets (“fakes”, from data)

*Most significant excess is at $m_{W'} = 1.1$ TeV in the electron channel ($2.3\sigma$)*
*In the muon channel, at $m_{W'} = 5$ TeV ($1.8\sigma$)*
Searches with di-jets events

Search for heavy resonances decaying to $W$ or $Z$ and a Higgs boson ($VH$) (CONF-2017-018)

- Only $qar{q}^{(')}bar{b}$ final states are considered
- And the high mass region ($m_{VH} > 1$ TeV) where the $V$ and $H$ bosons are highly boosted
- Final states candidates (from each boson) are reconstructed in one single jet: small bkg
- Key variable: mass of the two reconstructed (large-R) jets
- After pre-selection, main bkg (90%) from multi-jets events (taken from data)

The largest excess observed at $m_{JJ} = 3.0$ TeV with a local significance of $3.3\sigma$
- The global significance of this excess is $2.2\sigma$
- Heavy resonances ($Z'$ or $W'$ bosons) excluded up to $\sim 2.5$ TeV
Summary of di-boson resonance searches

*Expected and observed limits on the cross section times branching fraction to $WZ$ for a new heavy vector boson $W'$ at $\sqrt{s} = 13$ TeV. The different limit curves correspond to different decay modes for the $W$ and $Z$ bosons.

$ATLAS$ Preliminary

$\sqrt{s} = 13$ TeV, 13.2-15.5 fb$^{-1}$

95% C.L. exclusion limits

HVT model A $g_v = 1$

Expected

Observed

qqqq

lvqq

llqq

vvqq

$W'$ masses excluded up to 2.4 TeV
Search for dark matter (DM)

DM candidates: stable electrically-neutral particle, weakly interacting with the SM particles

- Direct detection: look directly for the mediator (di-jet resonance)
- Indirect detection: relay on signatures with high $E_T^{miss}$ and a SM particle $X$ (mono-$X = q/g, b/t, \gamma, W/Z/h$)

$\rightarrow$ Today: results of the search for $pp \rightarrow Z' \rightarrow Ah \rightarrow \chi \bar{\chi} b \bar{b}$ signals ($A=$pseudoscalar, CONF-2017-028)

- $E_T^{miss} > 150$ GeV, no isolated leptons and one reconstructed Higgs boson
- Dominant bkgs: $Z(\nu \nu)/Wj$ and $t\bar{t}$

<table>
<thead>
<tr>
<th>Source of uncert.</th>
<th>Impact [%] (a)</th>
<th>(b)</th>
<th>(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V+$jets modeling</td>
<td>5.0</td>
<td>5.7</td>
<td>8.2</td>
</tr>
<tr>
<td>$t\bar{t}$, single-$\tau$ modeling</td>
<td>3.2</td>
<td>3.0</td>
<td>3.9</td>
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<tr>
<td>SM $Vh(bb)$ norm.</td>
<td>2.2</td>
<td>6.9</td>
<td>6.9</td>
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<tr>
<td>Signal modeling</td>
<td>3.9</td>
<td>2.9</td>
<td>2.1</td>
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<td>MC statistics</td>
<td>4.9</td>
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<td>Luminosity</td>
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<td>5.4</td>
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<tr>
<td>$b$-tagging, track jets</td>
<td>1.4</td>
<td>11</td>
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<td>$b$-tagging, calo jets</td>
<td>5.0</td>
<td>3.4</td>
<td>4.7</td>
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<tr>
<td>Jets with $R = 0.4$</td>
<td>1.7</td>
<td>3.8</td>
<td>2.1</td>
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<tr>
<td>Jets with $R = 1.0$</td>
<td>$&lt;0.1$</td>
<td>1.2</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Total systematic 10 21 36
Statistical 6 38 62
Total 12 43 71
Conclusions

- Excellent LHC performance!
- ATLAS has a wide BSM physics program, scrutinizing each corner of the phase space
- As for today, (unfortunately) no evidence of SUSY or other BSM particles
- New limits significantly extend the Run 1 results → check out also the ATLAS public page
- Exciting future in front of us: at the end of the LHC Run-2 expect 120-150 fb$^{-1}$ and by 2035 $\sim$ 3000 fb$^{-1}$ of data!
BACKUP
Search for SUSY with multi-jets final states, 2→6 jets

- Most significant excess across $m_{\text{eff}}$-based SRs occurs in SR Meff-2j-2100 (LHS plot, a significance of 2.14 standard deviations)
- In RJR-based SRs, most significant excess RJR-S1a (RHS plot, 2.22σ)

![Graphs showing data and distributions for ATLAS Preliminary experiments at $\sqrt{s}=13$ TeV, 36.1 fb⁻¹ with m_{eff}(incl.) and H_{P,T,2,1} values.](image)
Search for SUSY with multi-jets final states

Final states with 0-leptons and 7→11 jets

- Discriminants: $E_T^{miss}$ over sqrt of sum of jets $p_T$ ($H_T$), sum of the large-R Jets mass ($M_{\sum J}$)
- Main backgrounds: multi-jets, $t\bar{t}$ and $W+$jets processes
  - Multi-jets: using a data template fit method (LHS plot)
  - $t\bar{t}$ and $W+$jets: MC normalized in dedicated CRs (middle & RHS plots, after norm)

- Very good data-bkg estimation agreement in all CRs/VRs
Search for SUSY with multi-jets final states

Results in the SRs: uncertainties

[Graph showing relative error and uncertainties for different signal regions, labeled with mass thresholds such as $M_{\text{eff}}-2j-1200$, $M_{\text{eff}}-2j-1600$, etc.]

**ATLAS** Preliminary

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

- Total Uncertainty
- MC statistical uncertainty
- CR statistical uncertainty
- Theoretical uncertainty
- Experimental uncertainty
Largest discrepancy from the SM prediction is a deficit in the 9j MJ500 SR (statistical significance around 1.8\(\sigma\))

Similar deficits are observed in other MJ SRs, but the large overlap between these SRs implies that the deficits are strongly correlated
### SUSY particle

<table>
<thead>
<tr>
<th>Chiral supermultiplets</th>
<th>Proper states in interaction term</th>
<th>Proper states in mass term</th>
<th>Sparticles</th>
<th>Proper states in interaction term</th>
<th>Proper states in mass term</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leptons</strong>&lt;br&gt;$S = 1/2$</td>
<td>$\nu_e$, $e_L$&lt;br&gt;$\nu_\mu$, $\mu_L$&lt;br&gt;$\nu_\tau$, $\tau_L$</td>
<td>$e_R$, $\mu_R$, $\tau_R$&lt;br&gt;$\nu_\ell$, $\mu_\ell$, $\tau_\ell$</td>
<td>Sleptons&lt;br&gt;$S = 0$</td>
<td>$\bar{\nu}_e$, $\bar{e}<em>L$&lt;br&gt;$\bar{\nu}</em>\mu$, $\bar{\mu}_L$</td>
<td>$\bar{e}_R$, $\bar{\mu}_R$, $\bar{\tau}<em>R$, $\bar{\nu}</em>\ell$, $\bar{\tau}_L$</td>
</tr>
<tr>
<td><strong>Quarks</strong>&lt;br&gt;$S = 1/2$</td>
<td>$u_L$, $d_L$&lt;br&gt;$c_L$, $s_L$&lt;br&gt;$t_L$, $b_L$</td>
<td>$u_R$, $d_R$, $c_R$, $s_R$, $t_R$, $b_R$</td>
<td>Squarks&lt;br&gt;$S = 0$</td>
<td>$\bar{u}_L$, $\bar{d}_L$&lt;br&gt;$\bar{c}_L$, $\bar{s}_L$&lt;br&gt;$\bar{t}_L$, $\bar{b}_L$</td>
<td>$\bar{u}_R$, $\bar{d}_R$, $\bar{c}_R$, $\bar{s}_R$, $\bar{t}_R$, $\bar{b}_R$</td>
</tr>
<tr>
<td><strong>Gauge Bosons</strong>&lt;br&gt;$S = 1$</td>
<td>$W^\pm$, $W^0$, $B$, $g$</td>
<td>$W^\pm$, $Z^0$, $\gamma$, $g$</td>
<td>Gauginos&lt;br&gt;$S = 1/2$</td>
<td>$\tilde{W}^\pm$, $\tilde{W}^0$, $\tilde{B}$, $\tilde{g}$</td>
<td>Gluino $\tilde{g}$&lt;br&gt;Neutralinos&lt;br&gt;$\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$&lt;br&gt;Charginos&lt;br&gt;$\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^\pm$</td>
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<tr>
<td><strong>Higgs Boson</strong>&lt;br&gt;$S = 0$</td>
<td>$H_u^+$&lt;br&gt;$H_d^0$&lt;br&gt;$H_u^-$</td>
<td>$h^0$, $H^0$, $A^0$, $H^\pm$</td>
<td>Higgsinos&lt;br&gt;$S = 1/2$</td>
<td>$\tilde{H}_u^+$&lt;br&gt;$\tilde{H}_d^0$&lt;br&gt;$\tilde{H}_u^-$</td>
<td>Neutralinos&lt;br&gt;$\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$&lt;br&gt;Charginos&lt;br&gt;$\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^\pm$</td>
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<td><strong>Graviton</strong>&lt;br&gt;$S = 2$</td>
<td>$G$</td>
<td>$G$</td>
<td>Gravitino&lt;br&gt;$S = \frac{3}{2}$</td>
<td>$\tilde{G}$</td>
<td>$\tilde{G}$</td>
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### Standard Model Total Production Cross Section Measurements

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<th>Status</th>
<th>Reference</th>
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<td>May 2017</td>
<td>ATLAS Preliminary Run 1.2 $\sqrt{s} = 7, 8, 13$ TeV</td>
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<td>$t\bar{t}Z$</td>
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</table>

#### Cross-section vs. $\mu_{\text{particle}}$ [GeV]

![Graph showing cross-section vs. particle momentum](image)

- **8 TeV**
- **13-14 TeV**

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**Note:** The graph shows the cross-section of various processes at different energies. The data points are plotted for each process, indicating the theoretical and experimental measurements. The references for the data points are listed in the status column, with ATLAS Preliminary Run 1.2 at $\sqrt{s} = 7, 8, 13$ TeV.