Searches for Electroweak Production of Supersymmetric Gauginos and Sleptons with the ATLAS Detector
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Introducing Electroweak (EW) SUSY:

- Comparison to “strong production”
- Few phenomenology items
- Search strategies

ATLAS searches based on lepton signatures

- Recent EW SUSY results:
  \[1, 2, 3, 4\) leptons (plus \(E_T\))
- The global picture and the future prospects

LHC Run 1 over from > 1 years

Data may still hide surprises...
Introduction to Electroweak SUSY

SUSY prediction of partners of SM particles at 1 TeV scale still appealing:

- possible solution to “hierarchy problem”
- may hint to gauge coupling unification
- neutral LSP *may* be a Dark Matter candidate

But...

- **strong production** (squarks and gluinos):  
  - was expected to dominate at LHC  
  - exclusion limits already stringent

Characteristics of EW SUSY production:

- rarer because of smaller cross sections  
- charginos ($\tilde{\chi}^\pm$), neutralinos ($\tilde{\chi}^0$), and sleptons ($\tilde{\ell}$) favor leptonic final states  
- signatures with small SM background

Can EW production lead to discover SUSY if squarks/gluiinos are much heavier?
Under some assumptions, all EW SUSY sector is defined by 9 parameters:

- for the *sleptons*: 4 masses \((m_{\tilde{e}_L}^2, m_{\tilde{e}_R}^2, m_{\tilde{\tau}_L}^2, m_{\tilde{\tau}_R}^2)\) plus 1 mixing angle \((\theta_{\tilde{\tau}})\)

- 4 parameters \((M_1, M_2, \mu, \tan \beta)\) of *gauginos/higgsinos* mixing matrices:

\[
\begin{pmatrix}
M_1 & 0 & -c_\beta s_W M_Z & s_\beta s_W M_Z \\
0 & M_2 & c_\beta c_W M_Z & -s_\beta c_W M_Z \\
-c_\beta s_W M_Z & c_\beta c_W M_Z & 0 & -\mu \\
s_\beta s_W M_Z & -s_\beta c_W M_Z & -\mu & 0 \\
\end{pmatrix}
\]

Neutral: Bino, Wino, Higgsino

⇒ 4 Neutralinos \((\tilde{\chi}_1^0 - \tilde{\chi}_4^0)\) or N1-N4 eigenstates

Charged: Wino, Higgsino

⇒ 2 Charginos \((\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm)\) or C1,C2 eigenstates

How to study this?

- Phenomenological constrained MSSM (pMSSM) with lightest \(m_H = 125\) GeV

- Or simplified models:
  - pure states ⇒ no mixing of wino, bino, and higgsinos
  - gluino and squarks masses above TeV scale, decoupled heavy higgses
  - one decay considered each time ⇒ es. \(BR(\tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0) = 100\%\)
Recent ATLAS Searches based on Lepton Signatures

Recipe for a successful SUSY analysis:

- Well defined final state depending on multiplicity of physics objects:
  - light leptons, hadronic \( \tau \) \((\tau^{\text{had}})\), photons, jets, \(b\)-jets, \(E_T\)
  - Common identification criteria within ATLAS SUSY group

- Define kinematic regions (3 possible kind):
  - **SR**  Signal Region with maximal sensitivity to specific models/parameter spaces
  - **VR**  Validation Region dominated by SM backgrounds, used to test analysis robustness
  - **CR**  Control Region in phase space close to SR \(\Rightarrow\) used to help background estimate by extrapolation to SR (systematic uncertainty reduction)

- Background estimate (analysis dependent): fully or partially MC-based for well defined SM processes, completely data-driven for components hard to simulate (e.i. multi-jet or fake lepton ID)

Recent ATLAS results, according to lepton multiplicity:

| 1 lep. + \(b\bar{b}\) + \(E_T\) | ATLAS-CONF-2013-093 | 8-2013 |
| 2 lep. + 2 jets + \(E_T\) | JHEP 05 (2014) 071 | 3-2014 |
| 3 lep. + \(E_T\) + (0 – 2\(\tau^{\text{had}}\)) | JHEP 04 (2014), 169 | 2-2014 |
| 4 lep. + \(E_T\) + (0 – 2\(\tau^{\text{had}}\)) | CERN-PH-EP-2014-074 (PRD submitted) | 5-2014, New! |
| \(2\ \tau^{\text{had}} + E_T\) | ATLAS-CONF-2013-028 (available in backup) | 3-2013 |

See M. Goblirsch contribution
1 Lepton, $E_T$ and $H \rightarrow b\bar{b}$ Analysis

**ATLAS-CONF-2013-093:**
- First analysis exploiting $m_h = 125$ GeV (with $H \rightarrow b\bar{b}$)
- Two SRs optimized for low (high) $\Delta m$ of $\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0$
- Main backgrounds ($t\bar{t}$, $W$+jets) reduced using:
  \[ m_{cT} \approx \sqrt{2p_T^{b1}p_T^{b2}(1 + \cos \phi_{bb})} \]
  mass of pair produced particles with semi-invisible decay

$\Rightarrow$ 95% CL limit on $\sigma_{obs}/\sigma_{theo}$ for $m_{\tilde{\chi}_1^\pm}$ vs $m_{\tilde{\chi}_1^0}$ (C1 vs N1):

\[ m_{bb} \text{ in SRa:} \]

**ATLAS Preliminary**

Expected limit 68% CL
Observed limit ($\pm 1 \sigma_{theo}$)

0 20 40 60 80 100 m_{\tilde{\chi}_1^\pm} [GeV]

Data/SM 0 0.5 1 1.5 2

$\int L \, dt = 20.3 \, fb^{-1}$, $\sqrt{s} = 8$ TeV
SRA+SRB
$\tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow W^+\tilde{\chi}_1^0 h^0\tilde{\chi}_1^0$

**SUSY on WH production**

$\tilde{\chi}_1^\pm$, $m = 130$, 0 GeV
$\tilde{\chi}_1^0$, $m = 225$, 0 GeV
Recent ATLAS Searches based on Lepton Signatures

2 Leptons, $E_T$ (+jets) Analysis

JHEP 05 (2014) 071:

⇒ More complex analysis with 7 SRs specifically optimized:

3 SRs: slepton mediated

1 SRs: WZ mediated

3 SRs: WW mediated

SRs optimization according to:

- Same-Flavor (SF), Different-Flavor (DF) leptons
- use of s-transverse mass:
  \[ m_{T2} = \min_q m_T(\ell_1, q_T), m_T(\ell_2, E_T - q_T) \]
- $m_{T2}$ end-point used to reduce main backgrounds ($t\bar{t}$, WW)
95% Exclusion Limits on Several Models

- **slepton mediated (C1C1)**
  - Observed limit ($\pm 1 \sigma_{\text{obs}}$)
  - Expected limit ($\pm 1 \sigma_{\text{exp}}$)

- **WZ mediated (C1N2)**
  - Observed limit ($\pm 1 \sigma_{\text{obs}}$)
  - Expected limit ($\pm 1 \sigma_{\text{exp}}$)

- **WW mediated (C1C1)**
  - Observed limit ($\pm 1 \sigma_{\text{obs}}$)
  - Expected limit ($\pm 1 \sigma_{\text{exp}}$)

⇒ No excess with respect to SM predictions

- $\Delta m_{\tilde{\chi}^\pm_1} = 200$ GeV improved exclusion with respect to 7 TeV (blue line)
- WZ mediated models difficult for $m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^\pm_1} = m_Z$
- Results interpreted in pMSSM phase space exclusions
Recent ATLAS Searches based on Lepton Signatures

3 Leptons, $\mathbb{E}_T (0 - 2 \tau^{\text{had}})$ Analysis

JHEP 04 (2014), 169:

- Combined use of SF/DF, Opposite Sign (OS), $m_T$ cuts, high $\mathbb{E}_T$, $\Delta \phi_{\ell\ell}$, etc ...

⇒ SR characterized by 20 independent bins targeting $\tilde{\ell}$ and WZ mediated scenarios

⇒ 1 specific SR optimized for $WH$ mediated scenarios

- 3 SRs with 1, or 2 $\tau^{\text{had}}$: 

⇒ improved sensitivity to $\tilde{\tau}$ mediated scenarios

⇒ with relevant fraction of reducible backgrounds

- Relevant background components from rare SM processes such $VVV$ and $t\bar{t}V$

#### Data / SM

- SR with 20 independent bins
- $m_{T2}$ cut on 2 $\tau^{\text{had}}$ SR
Exclusion Results on Target models

- slepton mediated (C1N2)
- WZ mediated (C1N2)
- WH mediated (C1N2)
- \( \tilde{\tau} \) mediated (C1N2)

⇒ No excess with respect to SM predictions

- Very powerful constraint from binned SR: large improvement in challenging WZ mediated region

- Models common to other analysis may be used for combined exclusions
**Combination of $2\ell + \slash E_T$ and $3\ell + \slash E_T$ Analyses**

$$\Delta m \gtrsim 70 \text{ GeV}$$ improved exclusion combining orthogonal SRs!
Recent ATLAS Searches based on Lepton Signatures

4 Leptons, \( \not{E}_T \ (0 - 2 \tau^{had}) \) Analysis - New!

CERN-PH-EP-2014-074 ⇒ targets scenarios with both R-Parity Violation & Conservation

- R-Parity Violating (RPV) SUSY potential:
  \[ W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k \]
  with \( L_i, L_j, \bar{E}_k \) supermultiplets with SM and SUSY fields

- RPV simplified models:
  ⇒ if \( \lambda_{ijk} \neq 0 \), LSP decay \( \tilde{\chi}^0_1 \rightarrow 2\ell + 1\nu \)
  ⇒ lepton-flavor signature depends on \( i, j, k \)
  ⇒ cross section depends by NLSP (4 topologies investigated)

- High multiplicity of objects from RPV cascade, not only leptons

9 SR optimized for RPV or RPC signals:

- SM reduction with SFOS veto, high \( m_{\text{eff}} = \sum_{\text{all obj.}} |p_T| \) and/or high \( \not{E}_T \) (useful for RPC scenarios)
- 6 SRs with 1, 2 \( \tau^{had} \) ⇒ sensitive to all \( \lambda_{ijk} \)
- Boosted topology from light LSP ⇒ lepton isolation corrected for close by tracks
- Rare SM processes (VVV and \( t\bar{t}Z \)) may be source of relevant background fractions

Example of RPV cascade with gluino NLSP:

RPV Up-sides:
⇒ almost un-explored phase space
⇒ clean signature

RPV Down-sides:
⇒ need additional symmetry for \( p^+ \) stability
⇒ no Dark Matter candidate from LSP
Exclusion Results from 4 Leptons, $E_T$ $(0 - 2 \tau^{had})$ Analysis

Examples of $E_T$ and $m_{eff}$ distributions in signal regions with no $\tau^{had}$ and $Z$-veto:

- No excess with respect to SM predictions
- RPC constraints in models with sleptons
- powerful constraints on all $\lambda_{ijk}$ leptonic flavours

$\tilde{\ell}$ mediated RPC (N2N3)

$\lambda_{ijk}$ exclusion, gluino NLSP

$\lambda_{ijk}$ exclusion, Wino NLSP
The ATLAS collaboration presented several recent searches for EW SUSY scenarios characterized by leptons in the final state:

The global picture at the end of Run 1, 2013:

Summary of chargino (C1), neutralino (N1 or N2) exclusion
Conclusions

The ATLAS collaboration presented several recent searches for EW SUSY scenarios characterized by leptons in the final state:

*The global picture now, 2014, same dataset but improved analysis*

Summary of Chargino (C1), neutralino (N1 or N2) exclusion
*(4 lep. result not included yet)*
Prospects

⇒ No surprises yet with current dataset... *what to do next??*
⇒ Keep improving: more advanced analysis techniques, combination of different channels
Prospects

⇒ No surprises yet with current dataset... what to do next??
⇒ Keep improving: more advanced analysis techniques, combination of different channels

Prepare for discovery in Run 2!

THANKS FOR YOUR KIND ATTENTION!
Back Up Slides
$2 \tau^{\text{had}} + \slashed{E}_T$

**ATLAS-CONF-2013-028:**
- Combined use of di-tau trigger and $\slashed{E}_T$ trigger
- SR optimized with OS, $\slashed{E}_T$ and $m_{T^2}$
- Fake-$\tau$ with ABCD method: $\tau_{ID}$ vs $m_{T^2}$
- No excess over SM expectations

**C1N2 via $\tilde{\tau}$ exclusion**

**C1C1 via $\tilde{\tau}$ exclusion**

**OS SR $m_{T^2}$, $b$-veto**

**OS SR $m_{T^2}$**
The Atlas Detector