Searches for Supersymmetry with tau leptons at CMS

Valentina Dutta

on behalf of the CMS Collaboration
Introduction

SUSY (still) well motivated as a theory of physics beyond the Standard Model

Rich phenomenology depending on mass hierarchy, allowed decay modes, nature of lightest supersymmetric particle (LSP)

- Many places to look
- Current constraints (usually) based on simplified models, need to be aware of assumptions
SUSY with taus

*SUSY may be more hidden than we hoped but could still be accessed at the LHC with more data!*

Staus could be the key, light $\tilde{\tau}$ well motivated in many models

- **Direct production**: challenging because of small cross sections
- **Indirect production**: decay chains of heavier SUSY particles

**Final states with tau leptons**

- $\tau$ spin-1/2
- $\tilde{\tau}$ spin-0

Light stau coannihilation with bino LSP (small $\Delta m$) could account for observed DM relic density

---

Cross section vs mass

- stau-anti-stau
- gluino-gluino
- squark-anti-squark
- stop-anti-stop
- electroweakino

---

Griest, Seckel '91
Strategy

Mainly focus on **hadronic** tau decay mode (65% BR, fewer neutrinos in final state), **leptonic** decay modes also considered for some searches

- **Particle-flow** reconstruction (charged hadrons, photons from $\pi^0$ decays) key to $\tau_h$ identification
- **Isolation** an important handle to reject fakes: *new approaches using DNNs*

### Misidentified $\tau_h$ background
From other hadronic jets estimated using data-driven techniques

- Extrapolation from relaxed (“loose”) to full (“tight”) isolation

### SUSY vs SM discrimination
Using **mass-related observables**, exploit $p_T^{\text{miss}}$ from LSPs

**e/\mu + v_e/\mu v_\tau**

or

**hadrons + v_\tau**
Hadronic tau isolation

Evolution of techniques: cut-based → MVA (BDT) → DNN, significant boost in sensitivity with each advancement

**DNN approach** for $\tau_h$ isolation brings $\sim 2x$ reduction in fake rate with respect to BDT

- Convolutional neural network using features of particles in tau isolation cone (**low-level** inputs)
- Average CNN score with BDT score (**high-level** inputs)
Hadronic tau isolation

Evolution of techniques: cut-based → MVA (BDT) → DNN, significant boost in sensitivity with each advancement

**DNN approach** for $\tau_h$ isolation brings $\sim 2x$ reduction in fake rate with respect to BDT

- Convolutional neural network using features of particles in tau isolation cone (**low-level** inputs)
- Average CNN score with BDT score (**high-level** inputs)
- Extensive validation in data with $Z \rightarrow \tau\tau$
Direct stau pair production

**Selection:** \(\tau^+\tau^- (\tau_h\tau_h, \mu\tau_h, e\tau_h)\) final states, DNN-based isolation for \(\tau_h\tau_h\)

**Search strategy:** categorize events using \(N(\text{jets})\), mass-related observables for \(\tau_h\tau_h\), BDT shape analysis for \(e\tau_h, \mu\tau_h\)

\(m_{T2}\): Kinematic endpoint given by \(m(X) \rightarrow \text{minimize} \ m_T(p, q)\) solutions over possible \(p_T^{\text{miss}}\) partitions.
Direct stau pair production

$\tilde{\tau}_L\tilde{\tau}_L + \tilde{\tau}_R\tilde{\tau}_R$ production

$\tilde{\tau}_L\tilde{\tau}_L$ production

$\tilde{\tau}_L\tilde{\tau}_L + \tilde{\tau}_R\tilde{\tau}_R$: superpartners of left-/right-handed leptons. Different couplings $\rightarrow \sim 3x$ smaller cross section for $\tilde{\tau}_R\tilde{\tau}_R$ vs $\tilde{\tau}_L\tilde{\tau}_L$ of same mass

Exclusion up to $m(\tilde{\tau}) = 150$ GeV for $\sim$massless $\tilde{\chi}_1^0$

Pushing past LEP stau limits for the first time at the LHC!

$\sim$massless $\tilde{\chi}_1^0$

CMS

$77.2 \text{ fb}^{-1} (13 \text{ TeV})$

Strongest limit at $m(\tilde{\tau}) = 125$ GeV for $\sim$massless $\tilde{\chi}_1^0$

Submitted to Eur. Phys. J. C
Chargino/neutralino → stau

Decays via $\tilde{\tau}$ or tau-sneutrino ($\tilde{\nu}_\tau$) → same final state either way

Selection: $\tau^+\tau^-$ ($\tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$, $e\mu$ final states)

Search strategy: categorize events using $p_T^{\text{miss}}$, $m_T$, $\Sigma m_T$ ($m_T(\tau_1) + m_T(\tau_2)$), also $N(\text{jet})$ for $\mu\tau_h$, $e\tau_h$, $e\mu$

JHEP 11 (2018) 151
Chargino/neutralino → stau

Assume $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0)$, $m(\tilde{\tau}) = 0.5[m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0)]$

Small $\Delta m$ challenging

Exclusion up to $m(\tilde{\chi}_1^{\pm}) = 700$ GeV for ~massless $\tilde{\chi}_1^0$

Exclusion up to $m(\tilde{\chi}_1^{\pm}) = 630$ GeV for ~massless $\tilde{\chi}_1^0$
Stop → stau

Charginos in stop decay chains
decay via $\tilde{\tau}$ or $\tilde{\nu}_\tau$

*Sensitive to Higgsino-like scenarios*

**Selection:** $\tau_h\tau_h + 2b + p_T^{miss}$

**Search strategy:** categorize events using $p_T^{miss}$, $m_{T2}$, $H_T$

CMS-PAS-SUS-19-003

**Search strategy**

```
CMS Preliminary  77.2 fb⁻¹ (13 TeV, 2016+2017)

<table>
<thead>
<tr>
<th>$p_T^{miss}$</th>
<th>Events / GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>10</td>
</tr>
<tr>
<td>Other SM</td>
<td>100</td>
</tr>
<tr>
<td>tt</td>
<td>1000</td>
</tr>
<tr>
<td>Fake</td>
<td>10000</td>
</tr>
<tr>
<td>Bkg. uncertainty</td>
<td>100000</td>
</tr>
</tbody>
</table>

$\tau_h\tau_h + 2b$
```
Stop → stau

\[ m(\tilde{t}) \]
\[ m(\tilde{\chi}_1^{\pm}) \]
\[ m(\tilde{\tau}/\tilde{\nu}) \]
\[ m(\tilde{\chi}_1^0) \]

Exclusion up to \( m(\tilde{t}) = 1100 \text{ GeV} \)
Outlook

Searches targeting staus a critical but challenging avenue to explore: starting to make inroads using new and powerful tools, data-driven background estimation techniques

With more data, we should be able to explore substantial new territory where new physics could be hiding

New physics??
Sensitivity for staus at HL-LHC

Significant region of $\tilde{\tau}$-LSP mass plane can be explored with 3000 fb$^{-1}$, upgraded detectors
Performance can be improved with dedicated techniques