Displaced Leptons
from Gauge Mediation and Beyond

Jared A. Evans
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Department of Physics
University of Illinois, Urbana-Champaign

CMS 1409.4789
Evans, Shelton – to appear
Motivation for Displaced Leptons

GMSB and $\tilde{\tau}_R$ NLSPs

CMS Displaced $e_\mu$ Search and $\tilde{\tau}_R$

Same-Flavor Displaced Lepton Models

Same-Flavor Displaced Lepton Search for 13 TeV
The LHC Program

The LHC has constrained many new particles in many models:

- MSSM
- $t'/b'$
- UED
- GMSB
- RPV
- Stealth
- 2HDM
- ...

These searches cast a wide net.
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Could be our FIRST pathway to BSM physics!
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Exotic Objects \((pp \rightarrow XX, X \rightarrow o_1 o_2 \text{ or } X \rightarrow o_1 o_2 o_3)\)

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<td>• Focused on pair produced, heavy decays inside the detector</td>
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<td>• Only a selection of searches used, but fairly representative</td>
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<td>• Cavalier about lifetime ranges and triggers; ignoring tops</td>
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<td>• Bold is where searches are really optimized</td>
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Models | Symbol
---|---

Mini-Split

RPV/dRPV

Stealth

Higgs Mixed

Dark Photon

MD Freeze-In Dark Matter

Well-motivated Theoretically

Weak Coverage Experimentally

Evans (UIUC) Displaced Leptons November 13, 2015 5 / 24
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Models Symbol

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**Models**

- Mini-Split: M
- GMSB: G
**Exotic Objects** \((pp \rightarrow XX, X \rightarrow o_1 o_2 \text{ or } X \rightarrow o_1 o_2 o_3)\)

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**Models**

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RPV/dRPV | R
Stealth | S
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Models

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**Models**

- Mini-Split
- GMSB
- RPV/dRPV
- Stealth
- Higgs Mixed
- Dark Photon

**Symbol**

- M
- G
- R
- S
- H
- \(\gamma\)
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MD Freeze-In Dark Matter | D
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Models

- Mini-Split: M
- GMSB: G
- RPV/dRPV: R
- Stealth: S
- Higgs Mixed: H
- Dark Photon: $\gamma$
- MD Freeze-In Dark Matter: D

Symbol

- Well-motivated
- Theoretically

Weak Coverage
- Experimentally
Prompt lepton-based searches:
- Quality criteria drop displaced electrons
- Displaced muons veto events (cosmics)
- Vetoes range from 50 $\mu$m–1 mm

Prompt jets+$E_T$ searches:
- Veto events with leptons
- Definition not always transparent
Displaced Leptons in Prompt Searches

Prompt lepton-based searches:
- Quality criteria drop displaced electrons
- Displaced muons veto events (cosmics)
- Vetoes range from 50 \( \mu \text{m} \)–1 mm

Prompt jets+\( \mathbb{E}_T \) searches:
- Veto events with leptons
- Definition not always transparent

Very dangerous region!

\[
pp \rightarrow \tilde{\ell}^+ \tilde{\ell}^- + X \rightarrow \{\text{displaced muons}\} + X
\]

lives in a prompt search blind spot!

Displaced electrons and taus \( \Rightarrow \) reduced efficiency
Gauge Mediation and $\tilde{\tau}_R$ NLSPs

Lightning Review of Minimal GMSB

$$W \sim X\phi\bar{\phi} + \{\text{MSSM yukawas}\}$$

$$\langle X \rangle = M + \theta^2 F, \quad \Lambda \equiv F/M, \quad \tilde{\Lambda} \equiv \frac{\Lambda}{16\pi^2}$$
Gauge Mediation and $\tilde{\tau}_R$ NLSPs

Lightning Review of Minimal GMSB

\[ W \sim X\phi\tilde{\phi} + \{\text{MSSM yukawas}\} \]

\[ \langle X \rangle = M + \theta^2 F, \quad \Lambda \equiv F/M, \quad \tilde{\Lambda} \equiv \frac{\Lambda}{16\pi^2} \]

\[ M_r \sim N_{\text{eff}} g_r^2 \tilde{\Lambda} \quad \text{A-terms} = 0 \]

\[ m^2_{\text{soft}} \sim 2N_{\text{eff}} C_r g_r^4 \tilde{\Lambda}^2 \quad (C_r \text{ quadratic Casimirs } O(1)) \]
Gauge Mediation and $\tilde{\tau}_R$ NLSPs
Lightning Review of Minimal GMSB

\[ W \sim X\Phi\tilde{\Phi} + \{ \text{MSSM yukawas} \} \]
\[ \langle X \rangle = M + \theta^2 F, \quad \Lambda \equiv F/M, \quad \tilde{\Lambda} \equiv \frac{\Lambda}{16\pi^2} \]

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\[ m^2_{\text{soft}} \sim 2 N_{\text{eff}} C_r g_r^4 \tilde{\Lambda}^2 \quad (C_r \text{ quadratic Casimirs } O(1)) \]

Potential NLSP Masses:

\[ \begin{cases} 
  m_{\tilde{B}} = N_{\text{eff}} g_1^2 \tilde{\Lambda} & N_{\text{eff}} \geq 2 \Rightarrow \tilde{\tau}_R \text{ NLSP} \\
  m_{\tilde{\ell}_R} = \sqrt{\frac{6N_{\text{eff}}}{5}} g_1^2 \tilde{\Lambda} & \text{(or large running)}
\end{cases} \]
GMSB is a very well-motivated source of displaced particles

\[ c_\tau \approx 100 \, \mu m \left( \frac{100 \, \text{GeV}}{m_{\tilde{\tau}}} \right)^5 \left( \frac{\sqrt{F}}{100 \, \text{TeV}} \right)^4 \]

What is $\sqrt{F}$?
GMSB is a very well-motivated source of displaced particles

\[ c_{\tau} \approx 100 \mu m \left( \frac{100 \text{ GeV}}{m_{\tilde{\tau}}} \right)^5 \left( \frac{\sqrt{F}}{100 \text{ TeV}} \right)^4 \]

What is $\sqrt{F}$?

\[ F < M^2; \text{ otherwise arbitrary} \]

\[ c_{\tau} \sim 10 \mu m \left( \frac{100 \text{ GeV}}{m_{\tilde{\tau}}} \right) \left( \frac{M}{\sqrt{F}} \right)^4 \frac{1}{N_{\text{eff}}^2} \]

(minimal GM only)

LHC relevant range: \(100 \mu m \lesssim c_{\tau} \lesssim 1 \text{ m}\)

Measuring \(m_{\tilde{\tau}_R}\) & \(c_{\tau\tilde{\tau}_R}\) probes SUSY breaking!
Gauge Mediation and $\tilde{\tau}_R$ NLSPs

LEP Limits on Slepton NLSPs

**Figure 19:** The observed lower mass limits for pair-produced staus in the stau NLSP (a) and smuons (b), selectrons (c) in the slepton co-NLSP scenario using the direct $\tilde{\tau}^+ + \tilde{\tau}^-$ search. For staus in the slepton co-NLSP scenario the observed and expected lower limit are identical to the limits of the stau in the stau NLSP scenario. The mass limits are valid for a messenger index $N \leq 5$. For the stau NLSP and slepton co-NLSP scenarios, the NLSP mass limits are set by the stau mass limit ($m_{NLSP} > 87.4 \text{ GeV/c}^2$ (a)) and by the smuon mass limit ($m_{NLSP} > 93.7 \text{ GeV/c}^2$ (b)), respectively.

$m_{\tilde{\tau}} > 87 \text{ GeV}$

$m_{\tilde{\mu}} > 94 \text{ GeV}$

OPAL placed the best limits on sleptons of all lifetimes
**Cut Summary of CMS $e\mu$**

**Preselection**

1 OS $e^\pm \mu^\mp$ pair

- $d_\ell > 100 \mu$m
- $p_{T,\ell} > 25$ GeV, $|\eta_\ell| < 2.5$
- Reject $1.44 < |\eta_e| < 1.56$
- $I^{rel,e}_{\Delta R=0.3} < 0.10$, $I^{rel,\mu}_{\Delta R=0.4} < 0.12$
- $\Delta R_{\ell j} > 0.5 \ \forall \text{jets with } p_T > 10$ GeV
- $\Delta R_{e\mu} > 0.5$
- Veto additional leptons
### Cut Summary of CMS $e\mu$

#### Preselection
- 1 OS $e^{\pm}\mu^{\mp}$ pair
- $d_{\ell} > 100 \mu m$
- $p_{T,\ell} > 25$ GeV, $|\eta_{\ell}| < 2.5$
- Reject $1.44 < |\eta_e| < 1.56$
- $I_{\Delta R=0.3}^{rel,e} < 0.10$, $I_{\Delta R=0.4}^{rel,\mu} < 0.12$
- $\Delta R_{e\ell} > 0.5$ for jets with $p_T > 10$ GeV
- $\Delta R_{e\mu} > 0.5$
- Veto additional leptons

![Graph showing SR1, SR2, SR3 regions](image-url)
**Cut Summary of CMS $e\mu$**

**Preselection**

- 1 OS $e^\pm \mu^\mp$ pair
- $d_\ell > 100 \, \mu m$
- $p_T,\ell > 25 \, \text{GeV}, |\eta_\ell| < 2.5$
- Reject $1.44 < |\eta_e| < 1.56$
- $l^{rel,e}_{\Delta R=0.3} < 0.10$, $l^{rel,\mu}_{\Delta R=0.4} < 0.12$
- $\Delta R_{\ell j} > 0.5$ ∀ jets with $p_T > 10 \, \text{GeV}$
- $\Delta R_{e\mu} > 0.5$
- Veto additional leptons

---

**Diagnosis Diagram**

- **SR3**
- **SR2**
- **SR1**

---

**Evans (UIUC)**

Displaced Leptons

November 13, 2015
### Cut Summary of CMS $e\mu$

<table>
<thead>
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<td>$d_\ell &gt; 100 \mu$m</td>
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<td>$p_{T,\ell} &gt; 25$ GeV, $</td>
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<td>Reject $1.44 &lt;</td>
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<tr>
<td>$I^{rel,e}<em>{\Delta R=0.3} &lt; 0.10$, $I^{rel,\mu}</em>{\Delta R=0.4} &lt; 0.12$</td>
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<tr>
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<td>$\Delta R_{e\mu} &gt; 0.5$</td>
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<td><strong>Veto additional leptons</strong></td>
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![Graph showing search regions SR1, SR2, and SR3]
Impact Parameter is *not* the location of parent $b$ and $\tau$ decay products are more collimated
In summary, a search has been performed for new physics with an electron and muon with opposite charges and with a rapidity difference of 0.3 in bins of the electron transverse impact parameter. The observed number of events is consistent with the background expectation. We set limits on several scenarios, including displaced top squark production. The results are interpreted in the context of a displaced supersymmetry model.

**Event Source**

<table>
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<tr>
<th>Event Source</th>
<th>SR1</th>
<th>SR2</th>
<th>SR3</th>
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<tr>
<td>Other EW</td>
<td>0.65 ± 0.13 ± 0.09</td>
<td>(0.89 ± 0.53 ± 0.12) × 10^{-2}</td>
<td>&lt;(89 ± 53 ± 12) × 10^{-4}</td>
</tr>
<tr>
<td>Top quark</td>
<td>0.77 ± 0.04 ± 0.08</td>
<td>(1.25 ± 0.26 ± 0.12) × 10^{-2}</td>
<td>&lt;(2.4 ± 1.3 ± 0.2) × 10^{-4}</td>
</tr>
<tr>
<td>Z→ττ</td>
<td>3.93 ± 0.42 ± 0.39</td>
<td>(0.73 ± 0.73 ± 0.07) × 10^{-2}</td>
<td>&lt;(73 ± 73 ± 7) × 10^{-4}</td>
</tr>
<tr>
<td>HF</td>
<td>12.7 ± 0.2 ± 3.8</td>
<td>(98 ± 6 ± 30) × 10^{-2}</td>
<td>(340 ± 110 ± 100) × 10^{-4}</td>
</tr>
<tr>
<td>Total expected background</td>
<td>18.0 ± 0.5 ± 3.8</td>
<td>1.01 ± 0.06 ± 0.30</td>
<td>0.051 ± 0.015 ± 0.010</td>
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<tr>
<td>Observed</td>
<td>19</td>
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No limits on direct $\tilde{\tau}_R$ production!
No limits on direct \( \tilde{\tau}_R \) production!

But . . . a \( \tilde{\tau}_R \) is not expected in isolation

Near degenerate slepton limits

\[
m_{\tilde{\ell}_R} = m_{\tilde{\mu}_R} = m_{\tilde{\tau}_R} + 10 \text{ GeV}
\]

\[
\tilde{\ell}_R \rightarrow \tilde{\tau}_R + \{\text{soft}\}
\]
No limits on direct $\tilde{\tau}_R$ production!

But . . . a $\tilde{\tau}_R$ is not expected in isolation

Higgsino production limits

$$m_{\tilde{\chi}_1^0} = m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^+}$$

$$\tilde{\chi}_{1,2}^0 \rightarrow \tilde{\tau}_R^\pm \tau^\mp, \quad \tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_R^\pm \nu$$

Limits are very sensitive to $m_{\tilde{\tau}_R}$
No limits on direct $\tilde{\tau}_R$ production!

But . . . a $\tilde{\tau}_R$ is not expected in isolation

Stop production limits

$$m_{\tilde{H}} = m_{\tilde{t}} - 50 \text{ GeV}$$

$$\tilde{t} \rightarrow b\tilde{H}^+ \rightarrow b\nu\tilde{\tau}_R^+$$

Limits are very sensitive to $m_{\tilde{\tau}_R}$
No limits on direct $\tilde{\tau}_R$ production!

But . . . a $\tilde{\tau}_R$ is not expected in isolation

Gluino production limits

\[
m_{\tilde{t}} = m_{\tilde{g}} - 200 \text{ GeV} \\
m_{\tilde{H}} = m_{\tilde{t}} - 50 \text{ GeV}
\]

\[
\tilde{g} \rightarrow \tilde{t}\tilde{t} \rightarrow t\bar{b}\tilde{H}^+ \rightarrow \bar{t}b\nu\tilde{\tau}_R^+
\]

\[
\tilde{g} \rightarrow \tilde{t}^*t \rightarrow t\bar{b}\tilde{H}^- \rightarrow t\bar{b}\bar{\nu}\tilde{\tau}_R^-
\]

Limits are very sensitive to $m_{\tilde{\tau}_R}$
There are several lessons from GMSB $\tilde{\tau}_R$s to improve sensitivity

\[ BR(\tilde{\tau}^+\tilde{\tau}^- \rightarrow e^\pm \mu^{\mp} + X) = 6\% \]
\[ BR(\tilde{\tau}^+\tilde{\tau}^- \rightarrow e^+ e^- + X) = 3\% \]
\[ BR(\tilde{\tau}^+\tilde{\tau}^- \rightarrow \mu^+ \mu^- + X) = 3\% \]

1) Add same-flavor lepton channels
There are several lessons from GMSB $\tilde{\tau}_R$s to improve sensitivity

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1) Add same-flavor lepton channels

$BR(\tilde{\tau}^+\tilde{\tau}^- \rightarrow e^\pm \tau^\mp_h + X) = 23\%$
$BR(\tilde{\tau}^+\tilde{\tau}^- \rightarrow \mu^\pm \tau^\mp_h + X) = 23\%$
$BR(\tilde{\tau}^+\tilde{\tau}^- \rightarrow \tau^\pm_h \tau^\mp_h + X) = 42\%$

2) Include hadronic $\tau_h$s

Experimental feasibility of displaced $\tau_h$s?
Right-handed polarized $\tau$s from $\tilde{\tau}_R$ decays give softer leptons

3) Lower $p_T$ thresholds can capture a lot more signal

Additional triggers – $E_T + \ell\ell$, $E_T$, $\ell\ell\ell$, etc
Search vetoes additional leptons.  
Why?
Search vetoes additional leptons.

Why?

Displaced multilepton background should be very small

(CDF ghost muons???)
Search vetoes additional leptons. Why?

Displaced multilepton background should be very small (CDF ghost muons???)

Gluino & Higgsino model have additional leptons often $\sim (45\%, 30\%)$

If pair-produced object is not charged under lepton number, additional leptons are generic

4) Don’t veto additional leptons
Gluino & Higgsino models have Majorana particles in chain
⇒ same-sign displaced leptons

5) Include same-sign displaced lepton signal regions
Gluino & Higgsino models have Majorana particles in chain
\[ \Rightarrow \text{same-sign displaced leptons} \]

5) Include same-sign displaced lepton signal regions

5') Same-sign possibility fairly generic, be wary of CR contamination

\[ \text{SS}_\ell \text{ can appear in the } \tilde{t} \rightarrow \ell^+ b \text{ benchmark of CMS 1409.4789} \]

Mesino oscillation allows up to 3/8 of events as SS$_\ell$  
Sarid, Thomas – 9909349
CMS Displaced Lepton Search

Potential Improvements?

Disappearing Tracks*

Extend reach in $c_T$?

HSCP

Prompt

$M_{\tilde{t}} = 100$ GeV

$M_{\tilde{t}} = 300$ GeV

$M_{\tilde{t}} = 500$ GeV

Evans (UIUC)

Displaced Leptons

November 13, 2015 18 / 24
CMS Displaced Lepton Search
Potential Improvements?

Disappearing Tracks*

Extend reach in $c_T$?

6) Allow $d_0$ above 2 cm
   (Even just for muons)

$M_{\tilde{\tau}} = 100$ GeV
$M_{\tilde{\tau}} = 300$ GeV
$M_{\tilde{\tau}} = 500$ GeV
CMS Displaced Lepton Search

Potential Improvements?

Disappearing Tracks*

Extend reach in $c_T$?

6) Allow $d_0$ above 2 cm
   (Even just for muons)

7) Relax isolation in high $d_0$ bins
   (Backgrounds are small there)

---

HSCP

Prompt

$M_{\tilde{t}} = 100$ GeV
$M_{\tilde{t}} = 300$ GeV
$M_{\tilde{t}} = 500$ GeV

Evans (UIUC)
Displaced Leptons
November 13, 2015
If \( m_{\tilde{\ell}_R} - m_{\tilde{\tau}_R} \ll 10 \text{ GeV} \) or \( m_{\tilde{B}} \gg m_{\tilde{\tau}_R} \),

then \( \Gamma(\tilde{\ell}_R \rightarrow \ell\tau\tilde{\tau}_R) \ll \Gamma(\tilde{\ell}_R \rightarrow \ell\tilde{G}) \Rightarrow \) Slepton Co-NLSP

Events have displaced \( e^+e^-, \mu^+\mu^-, \) or \( \tau^+\tau^− \)
If $m_{\tilde{\ell}_R} - m_{\tilde{\tau}_R} \ll 10 \text{ GeV}$ or $m_{\tilde{B}} \gg m_{\tilde{\tau}_R}$, then $\Gamma(\tilde{\ell}_R \to \ell \tau \tilde{\tau}_R) \ll \Gamma(\tilde{\ell}_R \to \ell \tilde{G}) \Rightarrow$ Slepton Co-NLSP

Events have displaced $e^+ e^-, \mu^+ \mu^-$, or $\tau^+ \tau^-$

Small splitting can happen for low tan $\beta$

In GGM, $M_1$ and $m^2_{\tilde{E}_R}$ are independent

$\mu^+ \mu^-$ and $e^+ e^-$ searches would be more sensitive to this model
If \( m_{\tilde{\ell}_R} - m_{\tilde{\tau}_R} \ll 10 \text{ GeV} \) \quad \text{or} \quad m_{\tilde{B}} \gg m_{\tilde{\tau}_R}, \)

then \( \Gamma(\tilde{\ell}_R \rightarrow \ell\tau_{\tilde{R}}) \ll \Gamma(\tilde{\ell}_R \rightarrow \ell\tilde{G}) \Rightarrow \text{Slepton Co-NLSP} \)

Events have displaced \( e^+e^-, \mu^+\mu^-, \) or \( \tau^+\tau^- \)

Small splitting can happen for low \( \tan \beta \)

In GGM, \( M_1 \) and \( m_{\tilde{E}_R}^2 \) are independent

\( \mu^+\mu^- \) and \( e^+e^- \) searches would be more sensitive to this model

Can get 100\% \( e^+e^- \) or \( \mu^+\mu^- \) from Extended GMSB: \( W \supset \kappa_i E_i^c \Phi\tilde{\Phi} \)

or Freeze-in of dark matter in matter dominated era: \( \mathcal{L} \supset \lambda_{ij} \phi^{\pm} \ell_i \chi_j \)
RPV can do almost anything
Same-flavor Displaced Lepton Models

$\tilde{\tau}_1$ with $LLE$ RPV

 RPV can do almost anything

$$W = \frac{1}{2} \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2} \lambda''_{ijk} U^c_i D^c_j D^c_k + \mu_i L_i H_u$$

$i, j, k =$ generation indices

$LLE$

$\tilde{\ell}_{L,i}$

$\tilde{\ell}_{L,i}$

$\tilde{\ell}_{R,k}$

$\tilde{\nu}_i$
Same-flavor Displaced Lepton Models

$\tilde{\tau}_1$ with $LLE$ RPV

RPV can do almost anything

$$W = \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c + \mu_i L_i H_u$$

$i, j, k =$ generation indices

$$c_\tau \approx 1 \text{ cm} \left( \frac{10^{-7}}{\lambda_{232}} \right)^2 \left( \frac{100 \text{ GeV}}{m_{\tilde{\tau}}} \right) \sec^2 \theta_{\tilde{\tau}} \quad (\theta_{\tilde{\tau}} = 0 \Rightarrow \tilde{\tau}_1 = \tilde{\tau}_L)$$

$$\lambda_{232} \cos \theta_{\tilde{\tau}} \gg \text{other RPV} \quad \Rightarrow \quad \text{BR}(\tilde{\tau}_1 \rightarrow \mu \nu) \approx 100\%$$

Evans (UIUC) Displaced Leptons November 13, 2015 20 / 24
How can we estimate 13 TeV backgrounds?

1. Use 8 TeV backgrounds to estimate 8 TeV SF backgrounds
2. Rescale backgrounds by $\frac{\sigma(13)}{\sigma(8)}$ (supported by HF MC)
3. Assume displaced $Z \rightarrow e^+e^-/\mu^+\mu^-$ is small or can be controlled
How can we estimate 13 TeV backgrounds?

<table>
<thead>
<tr>
<th>Sample</th>
<th>SR1</th>
<th>SR2</th>
<th>SR3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^\pm \mu^\mp$ 8 TeV (CMS actual)</td>
<td>18.0 ± 3.8</td>
<td>1.01 ± 0.31</td>
<td>0.051 ± 0.018</td>
</tr>
<tr>
<td>$e^\pm \mu^\mp$ 8 TeV (estimate)</td>
<td>19.8 ± 4.1</td>
<td>0.92 ± 0.28</td>
<td>0.055 ± 0.024</td>
</tr>
<tr>
<td>$e^\pm \mu^\mp$ 13 TeV (20 fb$^{-1}$)</td>
<td>34.1 ± 6.5</td>
<td>1.49 ± 0.44</td>
<td>0.086 ± 0.038</td>
</tr>
<tr>
<td>$e^+ e^-$ 13 TeV (20 fb$^{-1}$)</td>
<td>25.2 ± 3.6</td>
<td>1.43 ± 0.33</td>
<td>0.31 ± 0.06</td>
</tr>
<tr>
<td>$\mu^+ \mu^-$ 13 TeV (20 fb$^{-1}$)</td>
<td>13.0 ± 3.1</td>
<td>0.50 ± 0.15</td>
<td>0.012 ± 0.006</td>
</tr>
</tbody>
</table>

1. Use 8 TeV backgrounds to estimate 8 TeV SF backgrounds
2. Rescale backgrounds by $\frac{\sigma^{(13)}}{\sigma^{(8)}}$ (supported by HF MC)
3. Assume displaced $Z \rightarrow e^+ e^-/\mu^+ \mu^-$ is small or can be controlled
Same-Flavor Displaced Lepton Search

13 TeV Same-Flavor Search

$M_{l}$ (GeV) vs. $c\tau$ (cm)

- $\tilde{e}_{R}$
- $\tilde{\mu}_{R}$
- $\tilde{\tau}_{R}$
- $\tilde{\tau}_{R}$ (e$\mu$ only)
\( \tilde{e}^+ \to e^+ \tilde{G} \Rightarrow \) hard leptons
\( \tilde{\mu}^+ \to \mu^+ \tilde{G} \Rightarrow \) hard leptons
\( \tilde{\tau}^+ \to \tau^+ \tilde{G} \Rightarrow \) soft leptons

8) SF search can be improved with higher \( p_T, \ell \), lower background bins
Conclusions

- Displaced $\tilde{\tau}$s from GMSB: well-motivated and weakly constrained
- CMS large impact parameter $e^\pm \mu^\mp$ is not optimized for this signal
- Sensitivity to $\tilde{\tau}_R$ can be improved
  - Add SF$\ell$ bins
  - Add $\tau_h$ bins
  - Lowered $p_T$ thresholds
  - Extend $d_0 > 2$ cm
  - Add SS$\ell$ bins (CR contamination)
  - Allow extra $\ell$s
  - Relax isolation in high $d_0$ bins
  - Add high $p_T,\ell$ bins
- Disappearing track searches should consider this benchmark
- Several models with displaced $ee/\mu\mu$ uncovered at LHC