Recasting Searches for Exotic Detector Objects

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Evans, Shelton – arXiv:1601.01326

This Talk

What are Exotic Detector Objects?

Long-lived NLSP Staus from Gauge Mediation

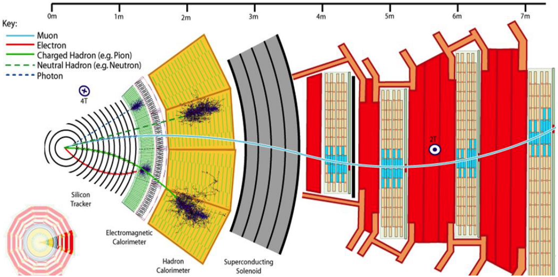
Summary of Relevant Exotic Detector Object Searches

Details of How to Recast These Searches

Comments on Recasting These Searches

What are Standard Detector Objects?

	Object	**Very Rough Identification Criteria**
1)	Photon	Hard, isolated EM calo deposit, $E_{tracks} \ll E_{calo}$
2)	Electron	Hard, isolated EM calo deposit, $E_{track} \sim E_{calo}$
3)	Muon	Hard, isolated track through muon chamber
4)	Jet	Other hard calo/track/particle clusters
a)	Tau	Single or 3-prong hard, isolated track(s)
b)	*b*-jet	Secondary vertex, looks *b*-ish
5)	$\vec{\not{E}}_T$	$-\sum \vec{p}_T$



What are Exotic Detector Objects?

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Loaded words: track, isolated, hard, cluster, vertex, *b*-ish ...

Exotic detector objects have properties that allow them to be distinguished from these standard objects

Two basic classes: Direct & Indirect

What are Exotic Detector Objects?

Direct vs Indirect

Direct

Observe the object itself

Examples

Disappearing tracks

Heavy, stable, charged particles

Magnetic monopoles

R-hadrons

Quirks

...

Indirect

Observe atypical SM decay products

Collimated particles fail isolation

Non-isolated leptons/photons

Photon or lepton jets

Particles that decay in flight

Long lifetime from an approximate symmetry in the low energy theory

High dimension operators
High mass scale
Small couplings

The Problem

Constraints on Long-lived Staus

1. GMSB is a very well-motivated source of long-lived particles
   - Lifetime of NLSP can vary from $c\tau \sim 10\mu$m to detector stable
2. Theory prejudice likes right-handed stau NLSP
3. **Signature:** Charged particle moves $\mathcal{O}(c\tau)$ through detector
   - Displaced decay as $\tilde{\tau}_R \to \tau \tilde{G}$
4. Prompt searches veto large impact parameter leptons

GOAL: Assess constraints on non-prompt NLSP $\tilde{\tau}_R$

- Long lifetime: Heavy, stable, charged particles
- Decay in tracker: Disappearing tracks (Kinked tracks)
- Decay $\lesssim$ beam pipe: Leptons with large impact parameter

Relevant LHC search: HSCP

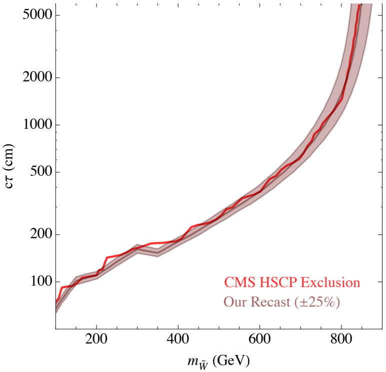
CMS 1305.0491

At long lifetime: $c\tau_{\tilde{\tau}} \gtrsim$ 1m $\Rightarrow$ heavy, detector-stable, charged particle

CMS HSCP search 1305.0491 (expect similar from ATLAS 1411.6795)

Cuts

Central:	$\|\eta\| < 2.4$
Hard:	$p_T > 70$ GeV
Isolated:	$\sum p_{T,\Delta R<0.3}^{trks} < 50$ GeV $I_{\Delta R<0.3}^{calo,track} < 0.3$
Slow:	$1/\beta > 1.225$
Large dE/dx:	see 1305.0491



(see next talk by Jan Heisig)

Efficiency maps provided: 1502.02522

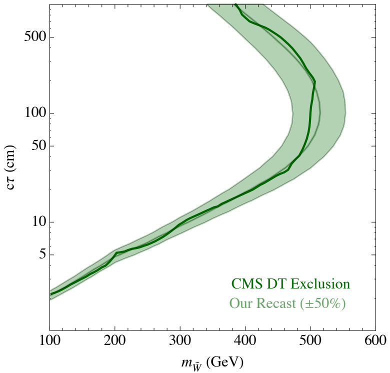
Relevant LHC search: Disappearing Tracks

CMS 1411.6006

At slightly shorter lifetimes: 30 cm $\lesssim c\tau_{\tilde{\tau}} \lesssim$ 3 m $\Rightarrow$ disappearing tracks

Cuts

A hard jet:	$p_T > 110$ GeV, $\lvert\eta\rvert < 2.4$
Missing energy:	$\not{E}_T > 100$ GeV
Hard track stub:	$p_T > 50$ GeV Few outer tracker hits
Particular eta:	$1.85 < \lvert\eta\rvert < 2.1$ $0.35 < \lvert\eta\rvert < 1.42$ or $\lvert\eta\rvert < 0.15$
Isolated:	$E^{calo}_{\Delta R<0.5} < 10$ GeV $I^{trks,track}_{\Delta R<0.3} < 0.05$



Simple efficiency map provided 1411.6006

Relevant LHC search: Disappearing Tracks

ATLAS 1310.3675

At slightly shorter lifetimes: 20 cm $\lesssim c\tau_{\tilde{\tau}} \lesssim$ 2 m $\Rightarrow$ disappearing tracks

Cuts

A hard jet: $p_T > 90$ GeV, $|\eta| < 2.5$

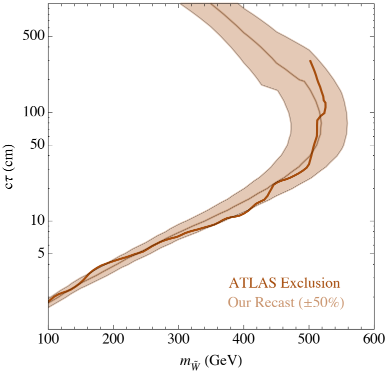
Missing energy: $\not{E}_T > 90$ GeV

Hard track stub: $p_T > 75$ GeV
highest p_T track in event
$<$ 5 hits in TRT

Eta: $0.1 < |\eta| < 1.9$

Isolated: $I^{trks,track}_{\Delta R<0.4} < 0.04$
$\Delta R_{jt} > 0.4 \forall p_{T,j} > 45$ GeV

Veto leptons: es, μs, & μ chamber tracks $>$ 10 GeV

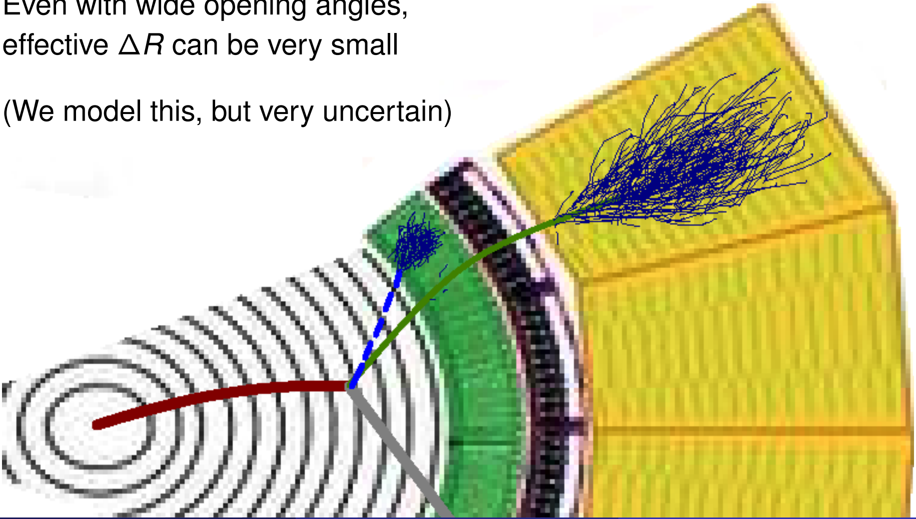


No efficiency map provided

Isolation requirements are hard on long-lived staus

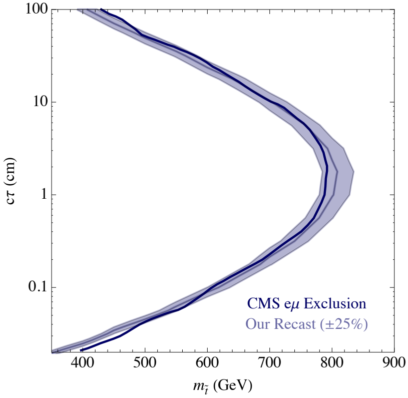
Even with wide opening angles,
effective ΔR can be very small

(We model this, but very uncertain)



At short lifetimes: 100 μm $\lesssim c\tau_{\tilde{\tau}} \lesssim$ 3 cm $\Rightarrow$ displaced 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, $\lvert\eta_\ell\rvert < 2.5$
Reject $1.44 < \lvert\eta_e\rvert < 1.56$
$I^{calo,e}_{\Delta R<0.3} < 0.10$, $I^{calo,\mu}_{\Delta R<0.4} < 0.12$
$\Delta R_{\ell j} > 0.5\ \forall$ jets with $p_T > 10$ GeV
$\Delta R_{e\mu} > 0.5$
$v_{T,\tilde{\ell}} < 4$ cm, $v_{z,\tilde{\ell}} < 30$ cm
Veto additional leptons

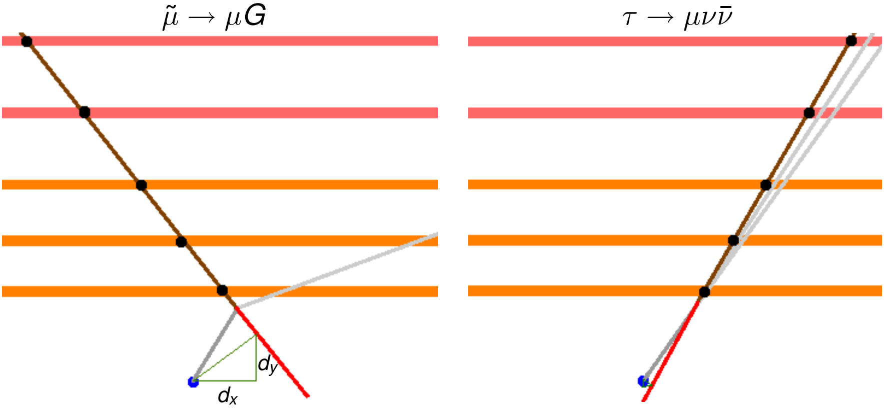


Extensive recasting details provided!

https://twiki.cern.ch/twiki/bin/view/CMSPublic/DisplacedSusyParametrisationStudyForUser

Relevant LHC search: CMS Displaced $e\mu$ (1409.4789)

Impact Parameter



Impact Parameter is *not* the location of parent

b and τ decay products are more collimated

Details of Recasting

Monte Carlo

1. Generated production LHE events in MadGraph5
   - Direct stau, $\tilde{H}$, $\tilde{t}$, and $\tilde{g}$ production considered
   - $pp \to X + \tilde{\tau}_R\tilde{\tau}_R + n_j j$
   - CMS displaced $e\mu$ search: no matching
   - Disappearing Tracks & HSCP: $n_j = 0$ or 1
2. Joined with $\tilde{\tau}_R$ decay LHE files made with MadGraph5
   - CMS displaced $e\mu$ search: $\tilde{\tau}_R \to \ell\nu\bar{\nu}\tilde{\chi}^0_1$ using TauDecay
   - Disappearing Tracks & HSCP: $\tilde{\tau}_R \to \tau\tilde{\chi}^0_1$
3. Wrote Pythia8 code to:
   - Shower events in stream (matched to up one jet for DT & HSCP)
   - Cluster jets with FastJet & smear jet energy
   - Locate $\tilde{\tau}_R$ and link to decay products (via $\tilde{\tau}_R$ event record id)
   - Output file with γs, jets, ℓs, τ_hs, $\tilde{\tau}_R$s, and $\not{E}_T$ (p_T, η, ϕ, iso, etc)
   - ℓs & τ_hs may be tagged as coming from a particular $\tilde{\tau}_R$

Details of Recasting
CMS HSCP & displaced $e\mu$

HSCP: followed the detailed instructions in 1502.02522

- Really great efficiency maps! ("tracker + time-of-flight" SR)
- Assigned $c\tau$ dependent weight
- Removed all leptons that came from a $\tilde{\tau}$
- Reduced jet p_T if $\tilde{\tau}$ daughter τ_h overlapped with jet
- Apply (lax) charged track isolation requirement

CMS $e\mu$: followed https://twiki.cern.ch/twiki/bin/view/CMSPublic/DisplacedSusyParametrisationStudyForUser

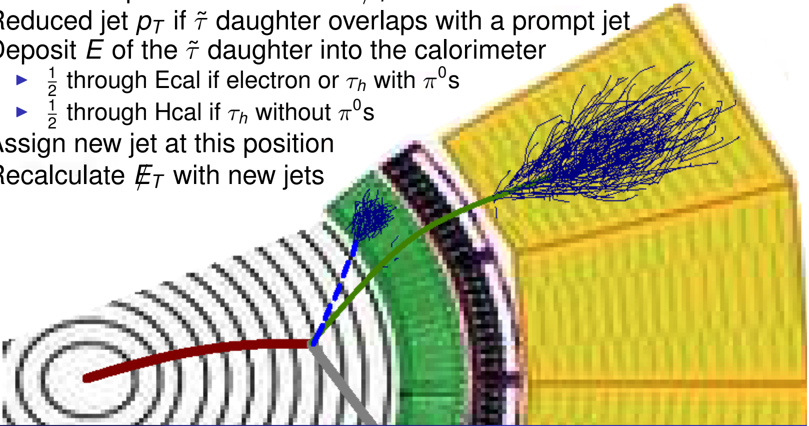
- Used only $pp \to X + \tilde{\tau}_R^+ \tilde{\tau}_R^- \to X + e^+ \mu^- \tilde{G}\tilde{G}\nu\nu\bar{\nu}\bar{\nu}$ events
- Use kinematics and displacement of $\tilde{\tau}$ to find impact parameter
- Assigned $c\tau$ dependent weight to fall in signal regions
  - Note: $c\tau_\tau = 87\mu$m was neglected in finding weight (small effect)

Details of Recasting

Disappearing Tracks (part 1)

Disappearing tracks (both ATLAS and CMS):

- Construct $d_{\tilde{\tau}_1}$ vs $d_{\tilde{\tau}_2}$ grid of 10 cm radial displacements
- Assign $c\tau$ dependent weight for $\tilde{\tau}$ to have decayed within that bin
- Relocate $\tilde{\tau}$ decay products to originate from the center of that bin
  1. Remove displaced muons from $\not{E}_T$ determination
  2. Reduced jet p_T if $\tilde{\tau}$ daughter overlaps with a prompt jet
  3. Deposit E of the $\tilde{\tau}$ daughter into the calorimeter
     - $\frac{1}{2}$ through Ecal if electron or τ_h with π^0s
     - $\frac{1}{2}$ through Hcal if τ_h without π^0s
  4. Assign new jet at this position
  5. Recalculate $\not{E}_T$ with new jets



Details of Recasting

Disappearing Tracks (part 2)

CMS disappearing tracks: used efficiency map in 1411.6006 appendix

- AMSB wino sample removed η cuts from eff map (factor of 1.5)
- Apply strict $E^{calo}_{\Delta R<0.5} < 10$ GeV isolation

ATLAS disappearing tracks: no efficiency map available

- Discard every event with a muon
- Discard staus that survive well into the muon chamber
- Made an efficiency map based on the propagation through TRT
  - (Experimented with several options – had a minimal impact)
- Require that track is the hardest in the event
  - Harder than other stau if it survives more than 30 cm
- Apply isolation $\Delta R_{jt} > 0.4 \; \forall \; p_{T,j} > 45$ GeV

Recast Limits on $\tilde{\tau}_R$

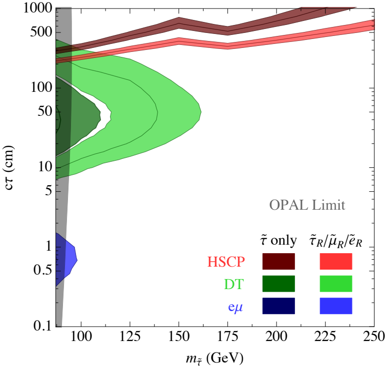
Only HSCP limits on direct $\tilde{\tau}_R$ production!

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

Near degenerate slepton limits

$$m_{\tilde{e}_R} = m_{\tilde{\mu}_R} = m_{\tilde{\tau}_R} + 10 \text{ GeV}$$

$$\tilde{\ell}_R \rightarrow \tilde{\tau}_R + \{\text{soft}\}$$



(Better limit from both disappearing track searches shown)

Recast Limits on $\tilde{\tau}_R$

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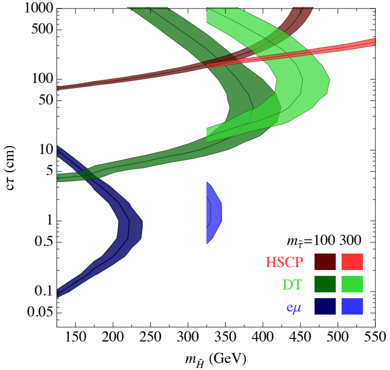
Higgsino production limits

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

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



(Better limit from both disappearing track searches shown)

Limits are very sensitive to $m_{\tilde{\tau}_R}$

Recast Limits on $\tilde{\tau}_R$

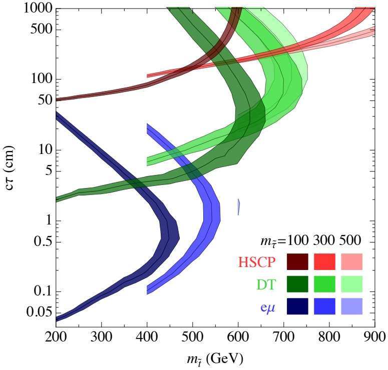
Only HSCP limits on direct $\tilde{\tau}_R$ production!

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

<u>Stop production limits</u>

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

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



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Limits are very sensitive to $m_{\tilde{\tau}_R}$

Recast Limits on $\tilde{\tau}_R$

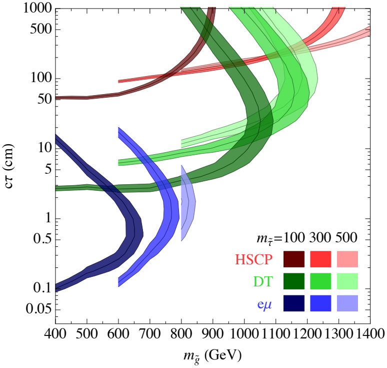
Only HSCP limits on direct $\tilde{\tau}_R$ production!

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

<u>Gluino production limits</u>

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

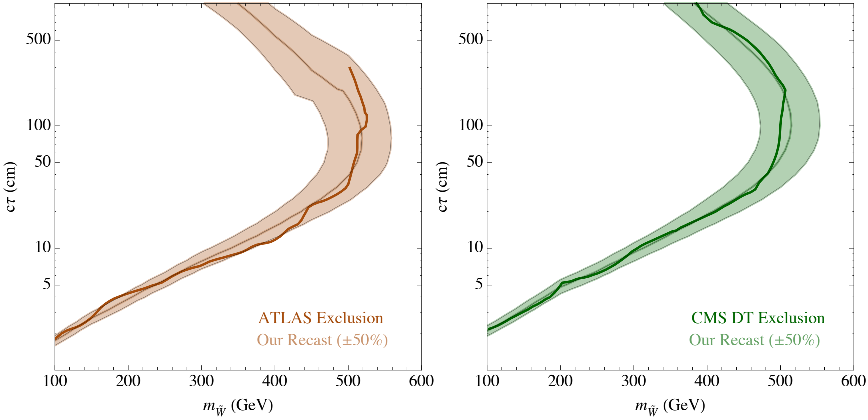
$$\tilde{g} \to \tilde{t}\bar{t} \to \bar{t}b\tilde{H}^+ \to \bar{t}b\nu\tilde{\tau}_R^+$$
$$\tilde{g} \to \tilde{t}^* t \to t\bar{b}\tilde{H}^- \to t\bar{b}\bar{\nu}\tilde{\tau}_R^-$$



(Better limit from both disappearing track searches shown)

Limits are very sensitive to $m_{\tilde{\tau}_R}$

Efficiency maps and recasting instructions are an *essential* facet to all searches for exotic detector objects



Clear information about applying the search beyond the benchmark

are valuable for recasting to new scenarios

(Admittedly, tricky to assess in advance)