Search for compressed SUSY in the stau-neutralino coannihilation region with a soft tau lepton and ISR jet

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On behalf of the CMS collaboration

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Outline

1. Standard Model (SM) & connections between Particle Physics, Cosmology, & Dark Matter (DM)
2. Event selection criteria
3. Background estimation strategies
4. Expected background and signal yields in the signal region (SR)
5. Expected limits

The Standard Model and Dark Matter

- We rely on the SM to describe the fundamental particles and their interactions.
- Even so, the SM is inherently *incomplete*. The SM fails to answer many broad questions:
    - matter-antimatter asymmetry in the universe, hierarchy problem, origin of neutrino masses, particle identity of astronomical DM
- From astronomy, we have a measure of the DM relic density in the universe, which has remained relatively constant since “freeze-out.”
    - At “freeze-out,” the DM rates of creation and annihilation went to approximately zero.
- We seek a DM particle with properties that lead to a consistent DM relic density with that measured by astronomers.

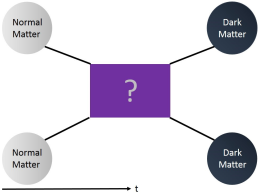


Figure 1: normal matter annihilation to DM

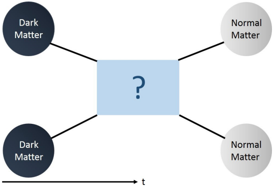


Figure 2: DM reduction to normal matter

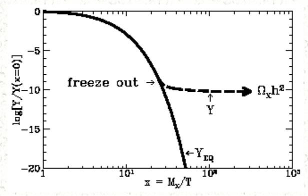
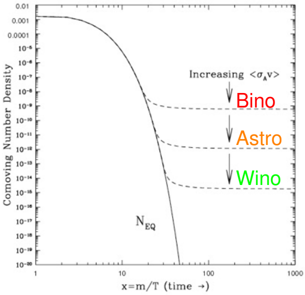


Figure 3: DM relic density over time w/ indication of freeze-out

Particle Physics, Cosmology, and Dark Matter

- To obtain a relic DM density consistent with the measured value by astronomers, stau-neutralino *coannihilation* can be introduced.
    - DM candidate is the lightest neutralino (mostly Bino) from supersymmetry ($\tilde{\chi}_1^0$).
    - We allow the $\tilde{\chi}_1^0$ to coannihilate with the stau ($\tilde{\tau}$), the supersymmetric partner of the tau (τ) lepton. They coannihilate to produce normal matter.
- DM relic density is extremely sensitive to the mass difference between the $\tilde{\tau}$ and $\tilde{\chi}_1^0$.
- Since $\sigma_{CA} \propto e^{-\Delta m}$, where σ_{CA} is the coannihilation cross section and Δm is the mass difference between $\tilde{\tau}$ and $\tilde{\chi}_1^0$, this motivates a search for *compressed spectra* ($\Delta m < 50$ GeV).



Jungman *et al* hep-ph/9506380

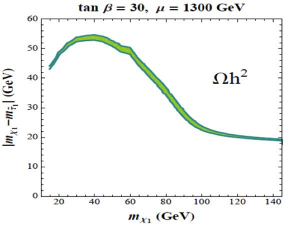


Figure 4: http://arxiv.org/pdf/1205.5842v1.pdf

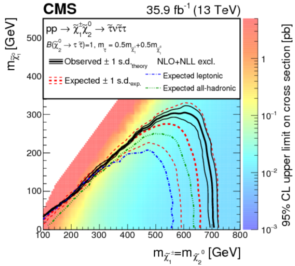
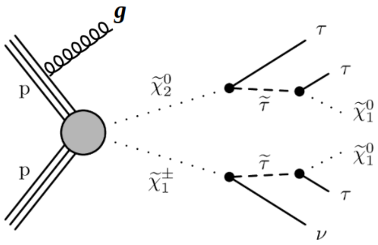


Figure 5: SUS-17-003

Motivating the Event Final State

Pheno: https://doi.org/10.1103/PhysRevD.94.073007



- Event includes multiple τs.
- Since we target compressed mass spectra, mass gaps between supersymmetric particles are small→We have difficulty detecting multiple τs in this event.
- An **initial state radiation (ISR) jet** provides a natural kinematic boost, allowing for easier detection of a **single hadronic tau (τ_h)**.
- Another consequence of small mass gaps between supersymmetric particles is **high missing transverse energy ($\vec{E}_T^{miss}$)** from the neutrinos.

Background Estimation Strategy [1]

$Z(\to \mu\mu) + \mathrm{ISR}$ Control Region

- **We utilize this region to understand the ISR jet efficiency in the SR.**

$$N_{\mathrm{SR}} = \sigma \cdot L_{\mathrm{int}} \cdot \epsilon_{\tau_h} \cdot \epsilon_{E_{\mathrm{T}}^{\mathrm{miss}}} \cdot \boxed{\epsilon_{\mathrm{ISR}}}$$

- **We study the effect of the kinematic boost from the ISR jet on the event by studying $p_T(Z)$ (which is $p_T(\mu^+\mu^-)$).**
- **We derive a series of weights to correct for the mismodeling of the ISR jet in simulation for each event.**

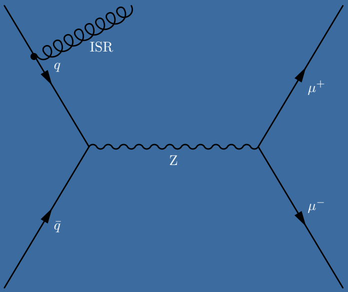


Figure 6: Z+jets with μs

Background Estimation Strategy [2]

$W(\rightarrow \mu\nu) + \mathrm{ISR}$ Validation Region

- **We utilize this region to understand the efficiency for the missing transverse energy in the SR.**

$$N_{\mathrm{SR}} = \sigma \cdot L_{\mathrm{int}} \cdot \epsilon_{\tau_h} \cdot \boxed{\epsilon_{E_{\mathrm{T}}^{\mathrm{miss}}}} \cdot \epsilon_{\mathrm{ISR}}$$

- **We can conclude from this region the following:**
    - **The modeling of the ISR jet activity in MC is understood.**
    - **The ISR weights are correct.**
    - **The $\vec{E}_T^{miss}$ is well modeled after appropriate corrections.**

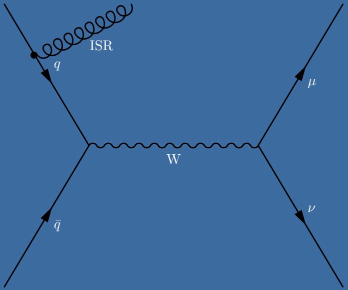


Figure 7: W+jets background

Background Estimation Strategy [3]

$Z(\rightarrow \tau^+\tau^- \rightarrow \tau_h^+\tau_h^-) + \mathrm{ISR}$ Control Region

- **We utilize this region to get a handle on the τ_h identification efficiency ($\epsilon_{\tau_h ID}$) in the SR.**

$$N_{\mathrm{SR}} = \sigma \cdot L_{\mathrm{int}} \cdot \boxed{\epsilon_{\tau_h}} \cdot \epsilon_{E_{\mathrm{T}}^{\mathrm{miss}}} \cdot \epsilon_{\mathrm{ISR}}$$

- **We can conclude from this region that the tau identification efficiency is well understood.**

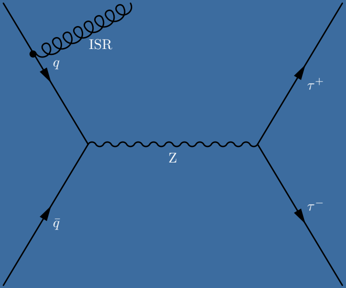


Figure 8: Z+jets with τs

Background Estimation Strategy [4]

$t\bar{t}$ Control Region

- **We construct four regions that differ in b-jet multiplicity, τ_h ID, and number of charged particle tracks for τ_h. We utilize these regions to understand the b-jet modeling in the SR.**

$$N_{\mathrm{SR}} = \sigma \cdot L_{\mathrm{int}} \cdot \epsilon_{\tau_h} \cdot \epsilon_{E_{\mathrm{T}}^{\mathrm{miss}}} \cdot \epsilon_{\mathrm{ISR}} \cdot \boxed{\epsilon_{\mathrm{b-jet}}.}$$

- **We can conclude that the modeling of b-jets in MC is well understood.**

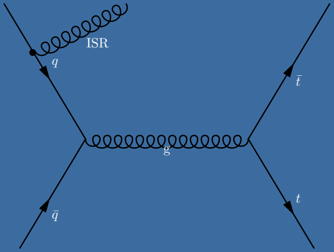


Figure 9: $t\bar{t}$ background

Background Estimation Strategy [5]

QCD Control Region

- **This method allows for the correct normalization and m_T shape for QCD events in the SR using a transfer factor.**
- **The transfer factor is the number of events with a τ_h candidate passing "Tight" divided by the number with a τ_h candidate passing "Loose" but failing "Tight."**
- **The transfer factor is obtained using an additional CR, obtained using $W(\rightarrow \mu\nu)$+"τ_h" events. The τ_h results from a jet misidentified as a τ_h.**

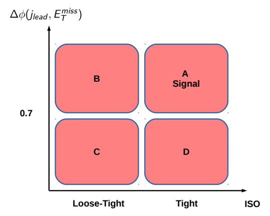


Figure 10: QCD estimation methodology

Expected Background and Signal in the SR

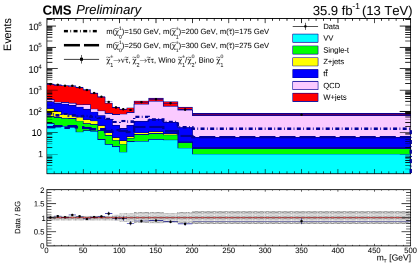


Figure 11: $m_T(\tau_h, \vec{E}_T^{miss})$ unblinded for 2016 data and MC

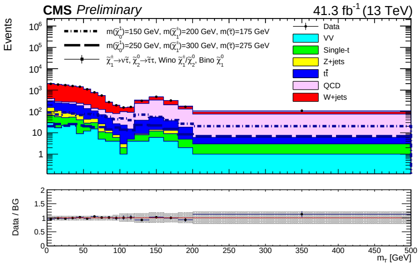


Figure 12: $m_T(\tau_h, \vec{E}_T^{miss})$ unblinded for 2017 data and MC

Observation is consistent with SM prediction. There is no evidence of new physics.

Expected and Observed Limits

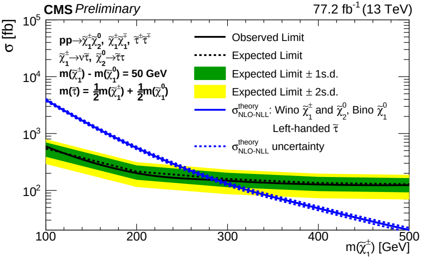
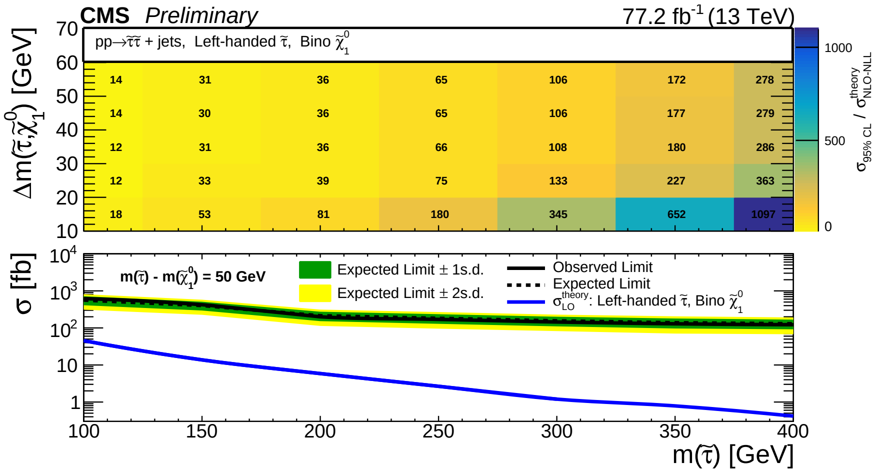


Figure 13: Expected and observed upper limit at the 95% CL on the signal cross-section as a function of $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^\pm}$ w/ 2016 & 2017 data.

We exclude $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ with masses below 290 GeV for $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 50$ GeV, exceeding the sensitivity from other searches in these compressed $\tilde{\tau}$-$\tilde{\chi}_1^0$ regions. Previous bounds from LEP exclude masses below $\sim$ 100 GeV.

- $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ are 100% Wino
- $\tilde{\chi}_1^0$ is 100% Bino
- $m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) = 50$ GeV
- $m(\tilde{\tau}) = \frac{m(\tilde{\chi}_1^\pm) + m(\tilde{\chi}_1^0)}{2}$
- Our signal samples consider "inclusive" $\tilde{\tau}$ production:
  - $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$+jets: ($\sim$ 64.4% of total x-sec)
  - $\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$+jets ($\sim$ 33% of total x-sec)
  - $\tilde{\tau}\tilde{\tau}$+jets ($\sim$ 2% of total x-sec)

Expected and Observed Limits for Direct Stau

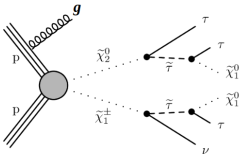


For a $\tilde{\tau}$ mass of 100 GeV, the observed limit is about 10 times the theoretical cross section for $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0) = 25$ GeV.

Summary and Conclusions

- We have completed the analysis with 2016 and 2017 data from the CMS experiment.
- Understanding the modeling of initial state radiation and its correlation with the lepton and $\vec{E}_T^{miss}$ is a key aspect of this search.
- **For a $\tilde{\tau}$ mass of 100 GeV, the observed limit is about 10 times the theoretical cross section for $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0) = 25$ GeV.**
- **We exclude $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ with masses below 290 GeV for $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 50$ GeV.**
- **This exceeds the sensitivity from other stau searches (current bounds are still the LEP bounds for the model we've considered).**
- CADI line for CMS: SUS-19-002

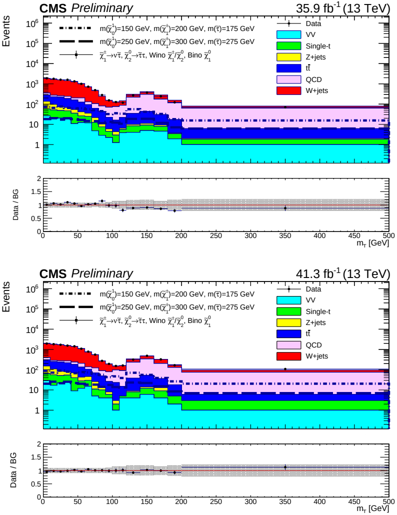
BACKUP SLIDES



Pheno: https://doi.org/10.1103/PhysRevD.94.073007

Event Selection

- Basic Selection and Event Cleaning
  - noise filters, good primary vertex, etc.
  - MET filters
- $\geq$ 1 jet with $p_T(j) > 30$ GeV
  - $|\eta(j)| < 2.4$ & “Loose” (2016) or “Tight” (2017) ID
  - $p_T^{ISR}(j) = p_T^{lead}(j) > 100$ GeV
- jet cross-cleaned with τ_h ($\Delta R(j, \tau_h) > 0.3$)
- $E_T^{miss} > 230$ GeV
  - PFMet with HF and type-1 corrections, MET-v2 in 2017
- $N(\tau_h) == 1$, $20 < p_T(\tau_h) < 40$ GeV, $|\eta(\tau_h)| < 2.1$
- QCD rejection: $|\Delta\phi(j_{lead}, E_T^{miss})| \geq 0.7$
- 1 prong requirement for τ_h + “Tight” MVA isolation
- Veto b-jets: $p_T > 30$ GeV and $|\eta| < 2.4$
- Veto other leptons (“Tight” for μ and “Loose” cut-based for e)
- Trigger: MET trigger ($>$ 99% efficiency w.r.t to our selections)



Top (bottom) is for 2016 (2017) data and MC.

Source	W	DY	$t\bar{t}$	VV	QCD	Signal
Lumi	2.5	2.5	2.5	2.5	–	2.5
μ ID	< 1	< 1	< 1	< 1	–	1
e ID	< 1	< 1	< 1	< 1	–	1
τ_h ID	6	8	9	9	–	9
Trigger	3	3	3	3	–	3
b ID	2	2	7	2	–	2
JES	s	s	s	s	–	s
TES	s	s	s	s	–	s
MMS	< 1	< 1	< 1	< 1	–	< 1
EES	< 1	< 1	< 1	< 1	–	< 1
Pileup	5.0	5.0	5.0	5.0	–	5.0
PDF	4.8	4.2	4.2	3.5	–	6.0
bin-by-bin stat.	s	s	s	s	–	s
Closure+Norm.	2	8	6	–	23	–
ISR	s	s	–	–	–	s
Prefiring	–	–	–	–	–	s
$Ratio^{Tight}_{Loose}$	–	–	–	–	s	–
Gen. Scale	1	1	3.5	–	–	2
Fast Sim.	–	–	–	–	–	s

Systematics values are given in percent. “s” indicates “shape” uncertainties.