Search for supersymmetry with a compressed mass spectrum in events with a soft τ lepton, a highly energetic jet, and large missing transverse momentum in pp collisions at $\sqrt{s}$ =13 TeV at CMS

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The hunt for new physics beyond the standard model at LHC

- Exam -

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In other words

- DIRECT search for the production of SUSY partner of the tau lepton ($\tilde{\tau}$)
- In a scenario where: $\boldsymbol{\Delta m(\tilde{\tau}, \tilde{\chi}_1^0) \leq 50\ \mathrm{GeV}}$
- Performed in 2016 and 2017 data collected by CMS experiment

- SUSY could describe the particle nature of DM and solve the gauge hierarchy problem
- In models with R parity conservation, in order to explain the DM relic abundance observed (WMAP and Plank Collaborations) the annihilation interaction of $\tilde{\chi}_1^0$ with SM particles is not sufficient → model of coannihilation needed: $\tilde{\chi}_1^0$ interacts with SUSY particles and produces SM particles
- The coannihilation xsec is exponentially enhanced by small $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$

$\tilde{\tau}$ particle production

- In pp collisions at the LHC stau production can be:

Direct, in pairs:

$$pp \rightarrow \tilde{\tau}\tilde{\tau}j$$

Indirect, via heavier SUSY particles ($\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$) decays:

$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}j \rightarrow \tilde{\tau}\tilde{\tau}\nu_\tau\nu_\tau j \rightarrow \tau\tilde{\chi}_1^0\tau\tilde{\chi}_1^0\nu_\tau\nu_\tau j$$

$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 j \rightarrow \tilde{\tau}\nu_\tau\tilde{\tau}\tau j \rightarrow \tau\tilde{\chi}_1^0\nu_\tau\tau\tilde{\chi}_1^0\tau j$$

The final state chosen

- In these processes, final states have multiple tau leptons with low p_T → difficult to identify more than 1 tau, especially if leptonic decay (lower BR)
- The analysis requires an extra jet from ISR → exploit the recoil of the ISR jet to detect momentum imbalance and facilitate identification of the low energy τ

Final state: events with exactly 1 tau decaying hadronically and missing transverse momentum recoiling against a high-p_T ISR jet

Analysis selection

Events recorded with a p_T^{miss} trigger

Events selected if:

- $p_T^{miss} > 230$ GeV, where trigger fully efficient
- Exactly 1 τ_h candidate with $|\eta| < 2.1$ and $20 < p_T < 40$GeV
- 1 jet with $p_T > 100$ GeV and $|\eta| < 2.4$
- $|\Delta\phi(j_{ISR}, \vec{p}_T^{miss})| > 0.7$
- Veto on events with b jets or with electrons or muons

Transverse mass is built:

$$m_T(\vec{p}_T^{miss}, \tau_h) = \sqrt{2\, p_T^{miss}\, p_T(\tau_h)(1 - \cos\Delta\phi(\vec{p}_T^{miss}, \tau_h))}$$

Analysis strategy: search for enhancements in the high-m_T part of the spectrum (NON RESONANT SEARCH)

2 different signal benchmarks

Signal SUSY Model 1 (SSM1)

- First set of signal events models $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ and $\tilde{\tau}\tilde{\tau}$ production with up to 2 jets
- This benchmark targets $\tilde{\tau}$ indirect production (since $\tilde{\tau}\tilde{\tau}$ process represents <2% of tot xsec)
- It is motivated by the importance of chargino-neutralino sector in establishing connections between SUSY and DM (provide the correct coannihilation xsec to explain DM relic amount measured)

Signal SUSY Model 2 (SSM2)

- Second set of signal events models the production of $\tilde{\tau}$ pairs up to 2 jets
- This benchmark targets $\tilde{\tau}$ direct production
- It is motivated by possible reinterpretations in other scenarios with $\tilde{\tau}$-like particles (MSSM)

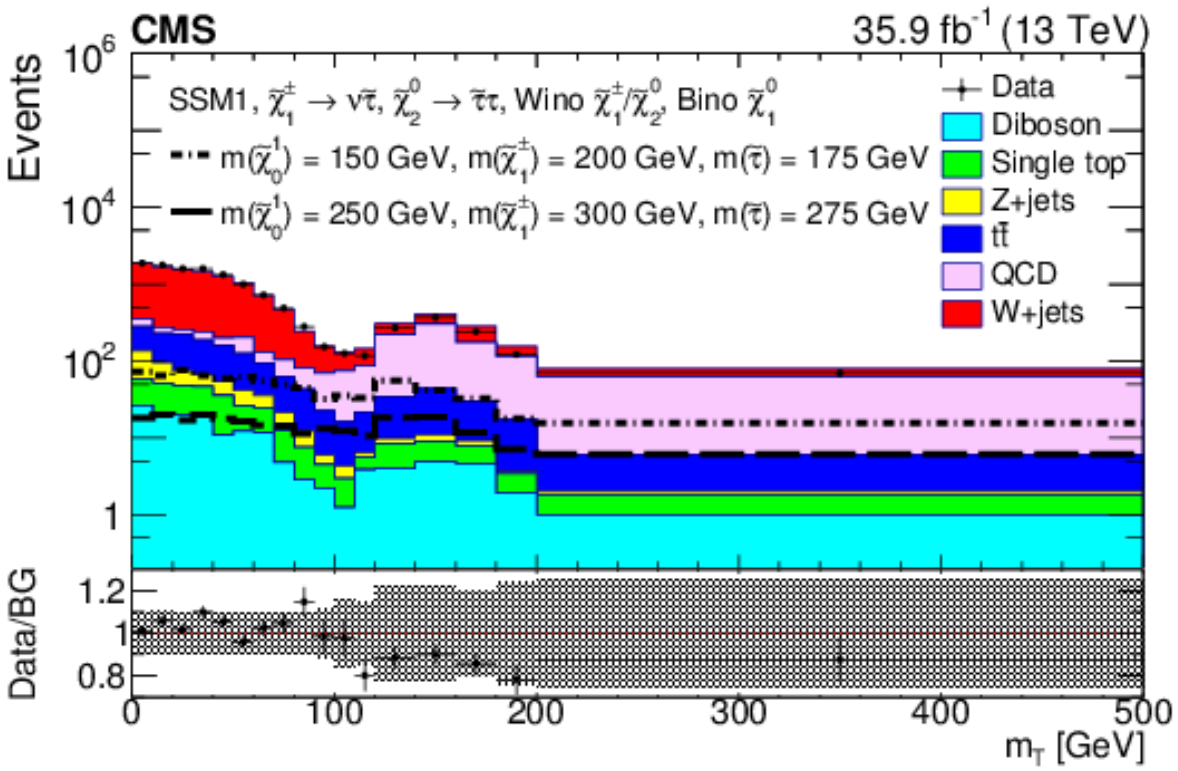
Background sources

- Main background sources are:

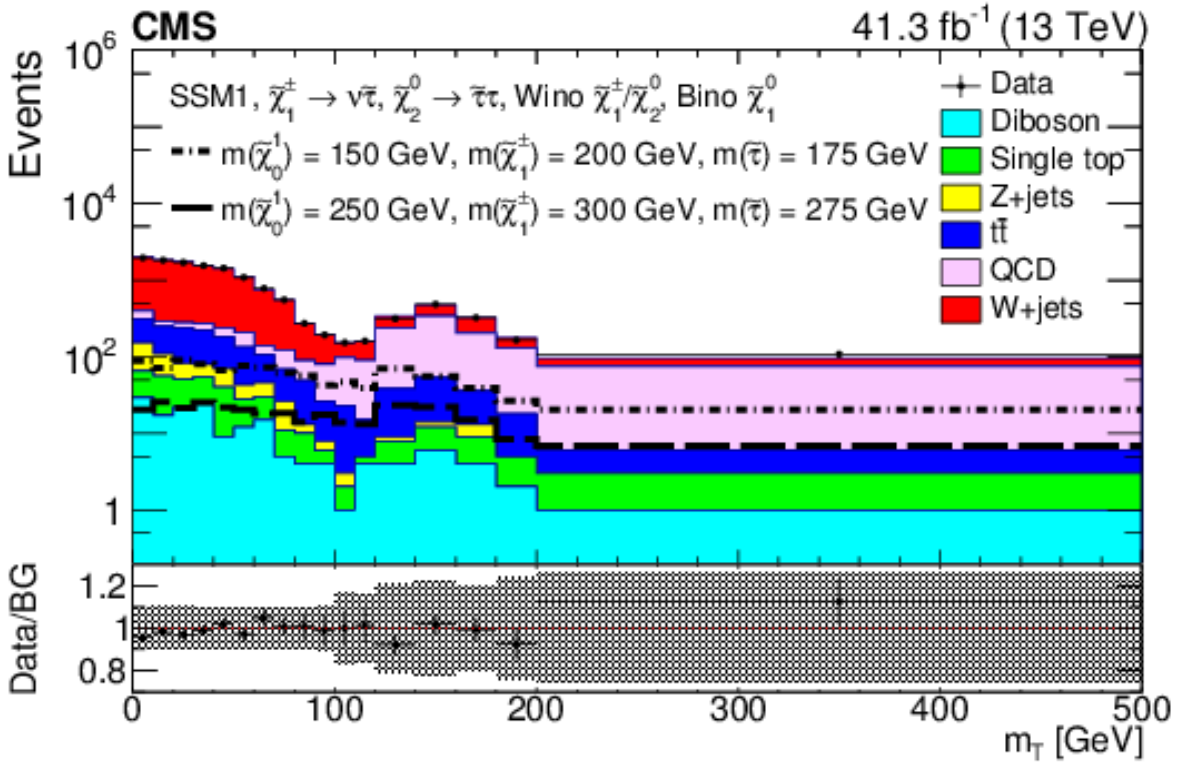
W+jets Z+jets	Events contain genuine τ_h candidates, energetic jets, and p_T^{miss} from neutrinos ➢ Contribution estimated from MC
$t\bar{t}$	Events contain b jets and genuine τ_h candidates ➢ Contribution estimated from MC
QCD multijet	Events contain jets misidentified as τ_h ➢ Contribution estimated from data

Results

- No excess above the SM bkg is observed



2016

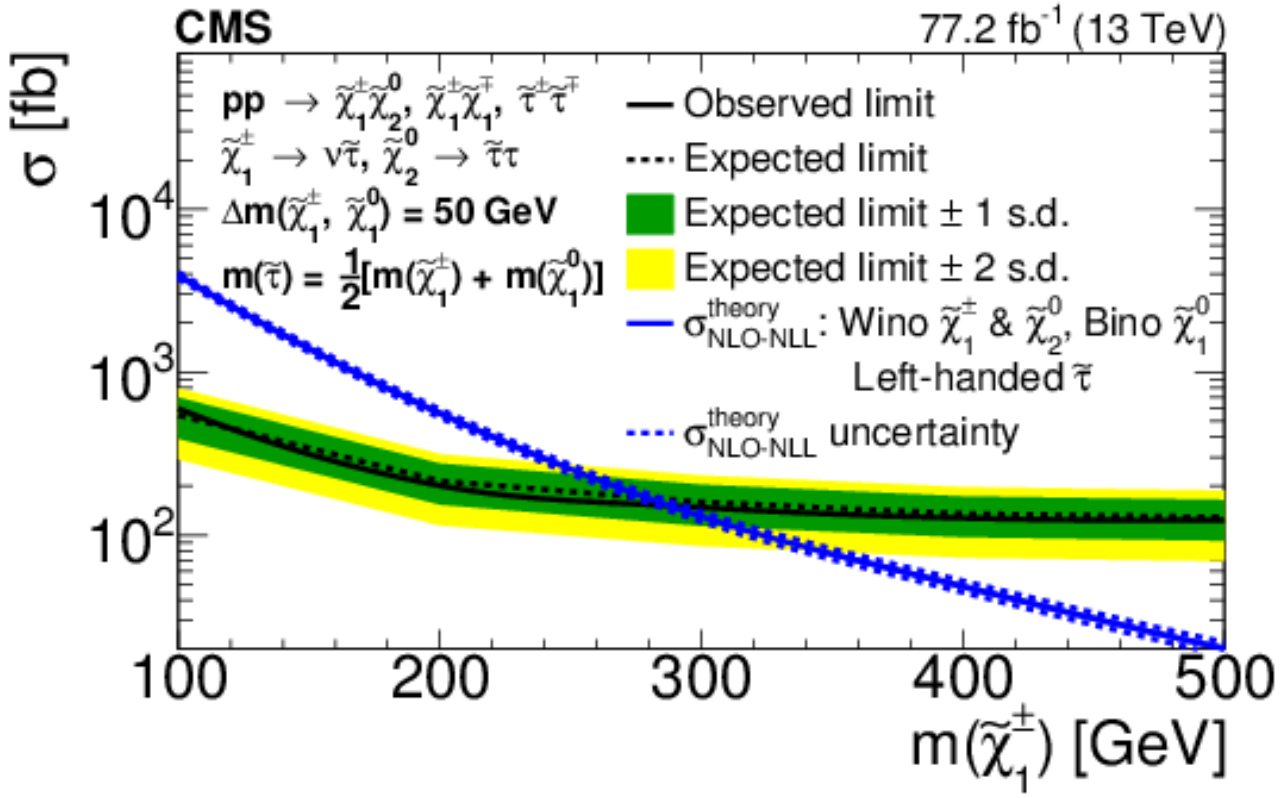


2017

Results

For **SSM1**

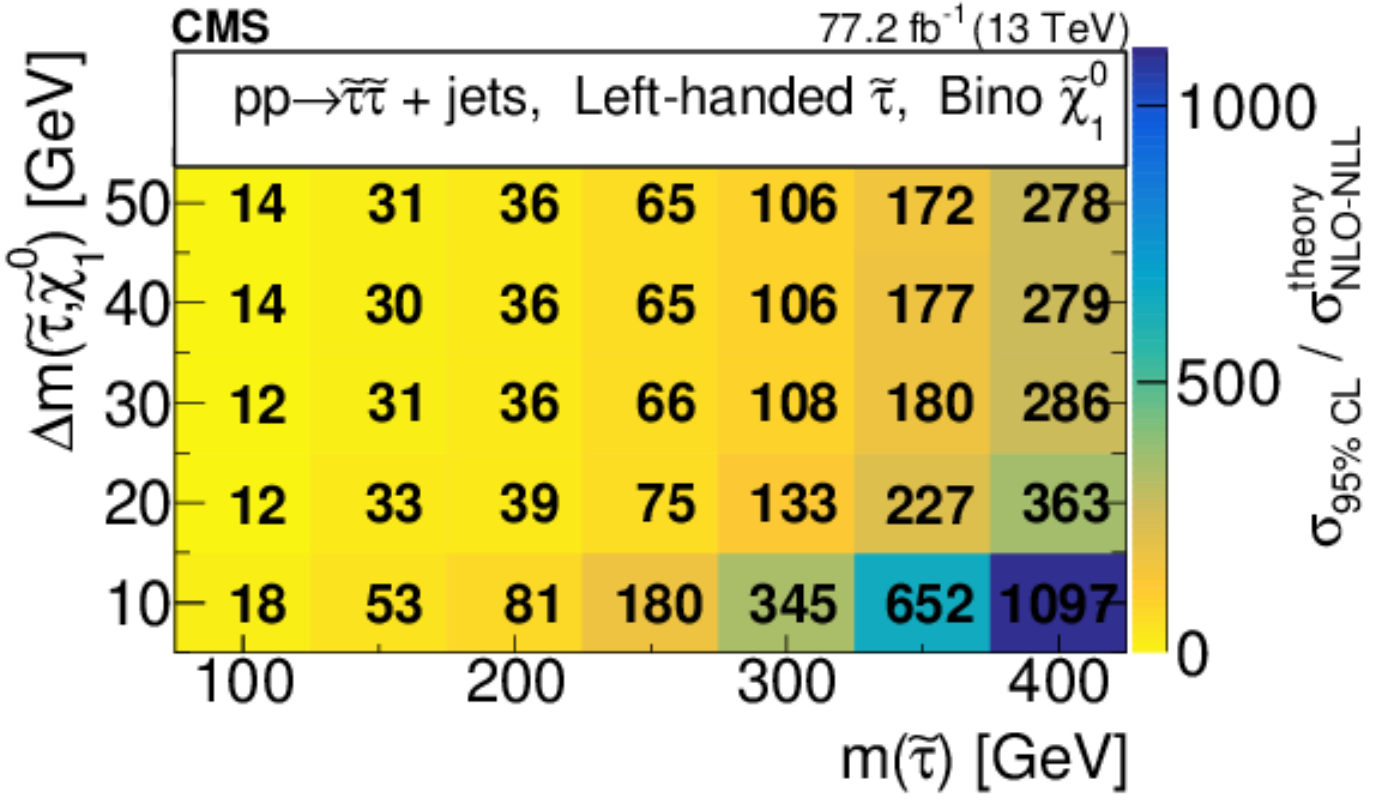
- Upper limit set on the production xsec as a function of $m(\tilde{\chi}_1^{\pm})$ for fixed $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 50$ GeV and $m(\tilde{\tau}) = 0.5\, m(\tilde{\chi}_1^{\pm}) + 0.5\, m(\tilde{\chi}_1^0)$
- Excluded $\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$ with masses < 290 GeV for $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 50$ GeV and $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\tau}) = 25$ GeV



Results

For **SSM2**

- Upper limit set on the production xsec as a function of $m(\tilde{\tau})$ and $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$
- Small production $\tilde{\tau}\tilde{\tau}$ xsec and low signal acceptance make the exclusion scenario challenging



Results from other searches

Searches for $\tilde{\tau}$ and $\tilde{\chi}_1^0/\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ production were performed already at LEP by the 4 experiments [1-4] in slightly different final states (requiring leptons, jets and missing energy in the final state) in a compressed mass spectrum

- Lower limit on the $\tilde{\tau}$ mass were set ($\mathrm{m}(\tilde{\tau}) \gtrsim 80\ \mathrm{GeV}$)
- Lower limit set also on $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ masses for different SUSY hypotheses (some searches exploited ISR photon tag)

1. ALEPH: doi:10.1016/S0370-2693(01)01494-0
2. DELPHI: doi:10.1140/epjc/s2003-01355-5
3. L3: doi:10.1016/j.physletb.2003.10.010
4. OPAL: doi:10.1140/epjc/s2003-01466-y

Results from other searches

At LHC, ATLAS and CMS [1-7] performed searches for $\tilde{\tau}$ and $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ production in compressed mass spectra, exploiting different final states (2 leptons and p_T^{miss}, 2 τ leptons decaying leptonically or leptonically, exploiting the VBF topology)

- Lower limit set also on $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ masses for different SUSY hypotheses but none exceeded LEP measurements
- LEP limits surpassed for the first time by the search presented thanks to ISR-jet tagging

1. CMS: doi:10.1007/JHEP03(2018)160
2. CMS: doi:10.1016/j.physletb.2018.05.062
3. ATLAS: doi:10.1140/epjc/s10052-018-5583-9
4. ATLAS: doi:10.1103/PhysRevD.97.052010
5. CMS: doi:10.1007/JHEP11(2015)189
6. CMS: doi:10.1007/JHEP08(2019)150
7. CMS: arXiv:1907.13179

ISR jet tagging

- The search for direct $\tilde{\tau}$ production with $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0) \leq 50$ GeV is challenging because of the low cross section and the low signal acceptance
- Also, the $\tilde{\tau}$ production processes (direct and indirect) result in final states with multiple τ leptons, but the average p_T is $\Delta m/2$ and therefore below the reconstruction threshold → choice of reconstructing and identifying only one τ_h lepton in the final state
- The ISR jet tagging technique facilitates the detection of momentum imbalance since the p_T^{miss} is searched in the event recoiling against the high-p_T ISR jet
- The ISR jet helps also the identification of the low energy τ lepton decay products
- This technique improved the sensitivity of this analysis w.r.t. previous non-ISR searches

Future prospects

- Many sources of systematic uncertainties:
  - Reconstruction and identification of the low-p_T τ_h
  - Background estimation (especially data-driven multi-jet contribution)
  - Correction factors on ISR jet
- But the sensitivity of this analysis is still dominated by statistical uncertainties
- Perform the analysis with more data will improve the sensitivity:
  - Add 2018 data
  - Perform the analysis with data collected in LHC Run3
  - A future lepton collider will provide a cleaner environment, LEP-like but higher energy and this may improve the analysis sensitivity

Conclusions

- A direct search of SUSY partner of the τ lepton in a compressed mass spectrum was presented
- Data (collected by CMS in 2016 and 2017) do not reveal evidence for new physics
- Limits were set on the production cross section and on $\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$ masses
- The results presented are the first to surpass the LEP bounds thanks to the ISR-jet tagging method
- The sensitivity of the analysis, still statistically dominated, will improve with more data