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Searches for direct production of charginos and neutralinos in final states with tau leptons at LHC

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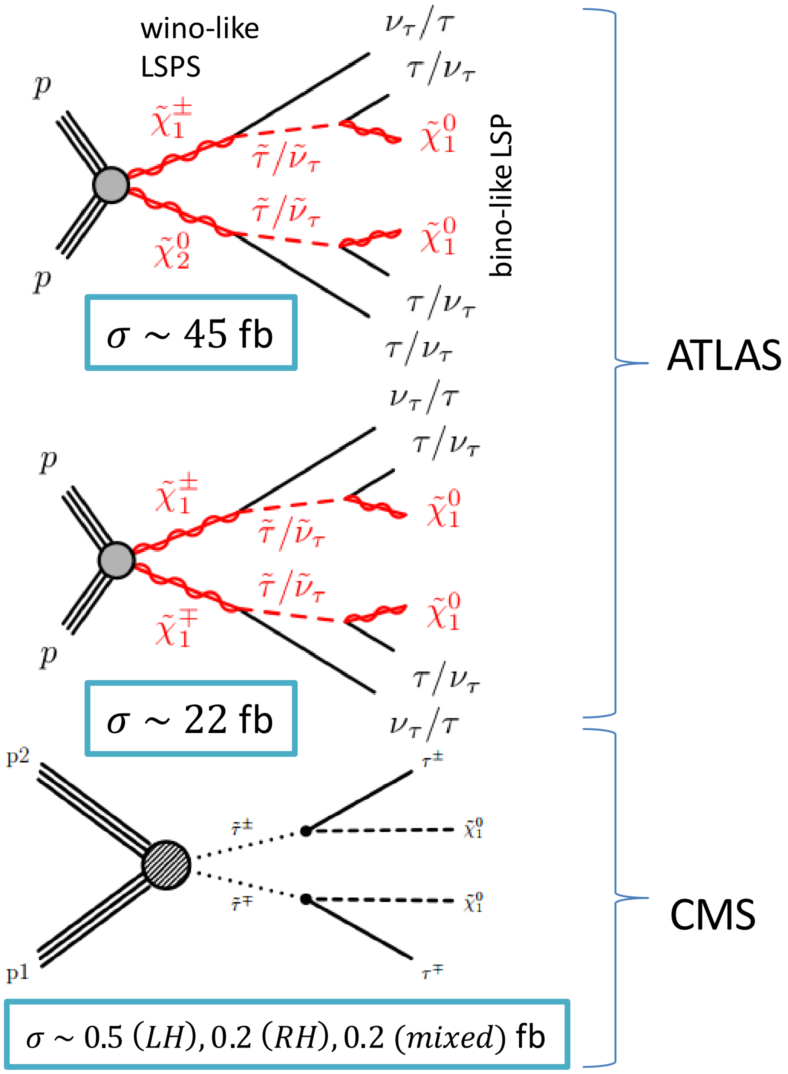


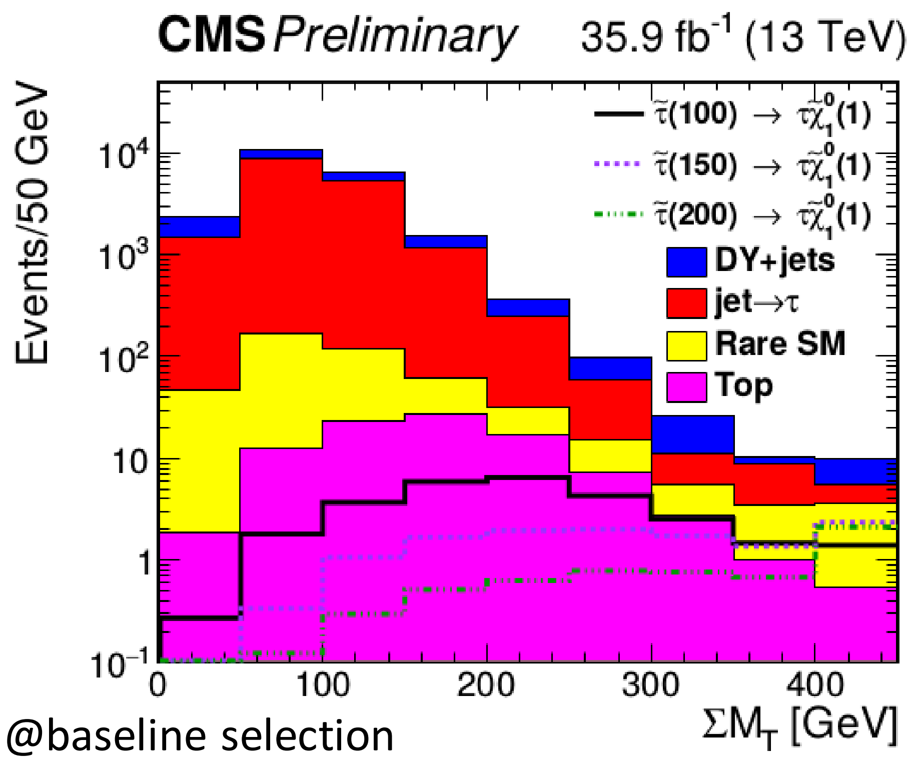
Motivation

- In thermal cosmology scenarios with a bino LSP, the annihilation cross section of DM particles would be too small, leading to an overabundance of DM compared to the current constraints from cosmological measurements.
- The existence of another, nearly mass-degenerate, SUSY particle that could co-annihilate with the DM particle would improve agreement significantly,
- Light staus could play role in co-annihilation of neutralinos (*m~𝒪(100) GeV*) leading to a DM relic density consistent with cosmological observations.

CMS: search for direct staus

- $\tau_{had}\,\tau_{had}$ final states
- hadronic di-τ trigger
- b-jet veto
- $\Delta\phi(\tau_{had}, \tau_{had})$ to suppress SM processes
- Require large $\sum M_T$ for the 2 τ_{had} candidates

$$M_{\mathrm{T}}(\mathrm{q}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) \equiv \sqrt{2E_{\mathrm{T,q}}E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi)}$$



@baseline selection

CMS: selection cont'd

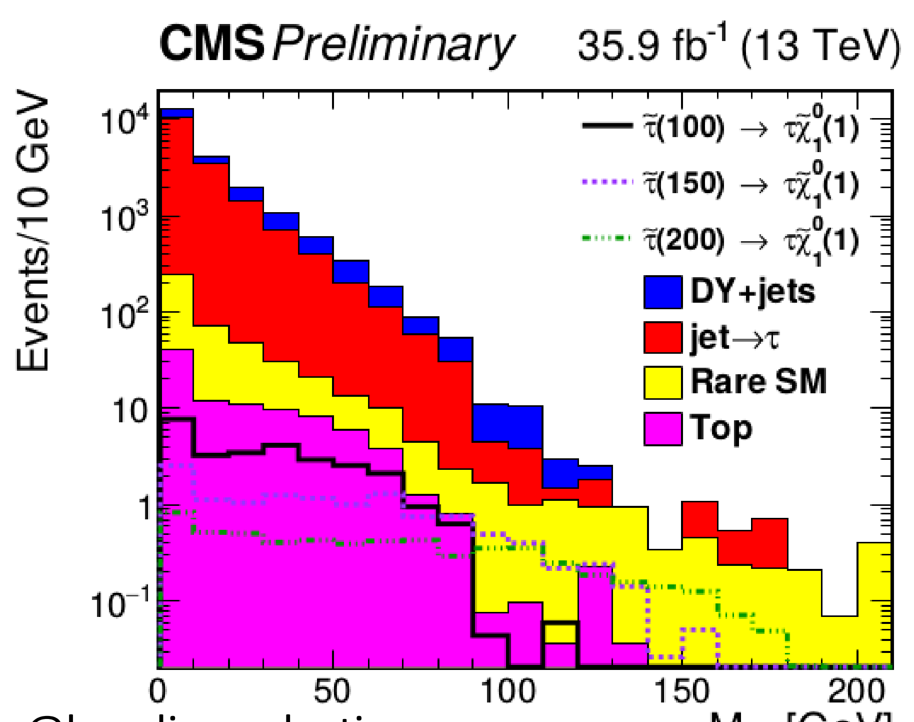
Reconstruct the "transverse mass" to get a handle on the stau mass

$$M_{T2} = \min_{\vec{p}_T^{X(1)} + \vec{p}_T^{X(2)} = \vec{p}_T^{miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

scan on unknowns

a known constrain

and eventually reduce the SM backgrounds for heavy staus.



@baseline selection

CMS: search regions

- Exclusively defined
- **SR1:** large M_{T2} and $\Delta\varphi(\tau,\tau)$
- **SR2:** intermediate M_{T2}, $\Delta\varphi(\tau,\tau)$ and E_T^{miss} but large $\sum M_T$
- **SR3:** intermediate M_{T2}, $\Delta\varphi(\tau,\tau)$ and $\sum M_T$ but large E_T^{miss}

Enhance sensitivity for…

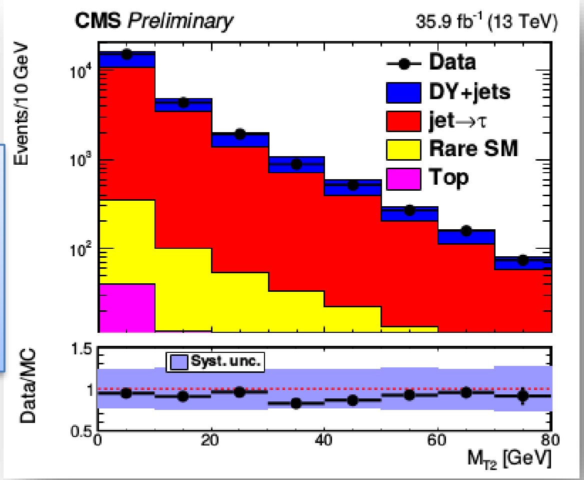
signal models with larger stau masses

signal models with smaller stau masses

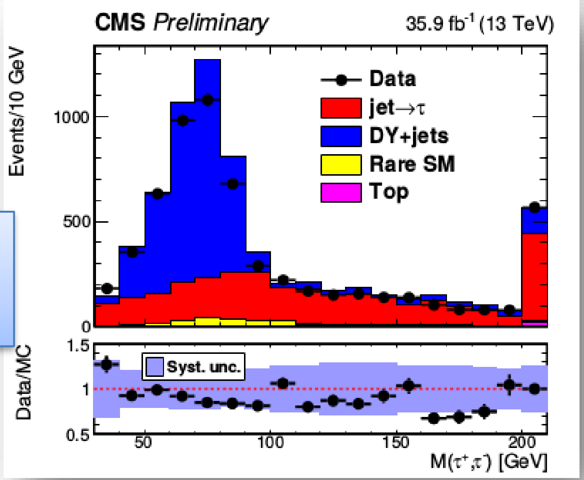
CMS: background estimate

- Main source: Non-prompt and misidentified τ_{had}
- Dominant background: QCD multijet and W+jets processes
- Estimated using data-driven methods – control regions depleted of each background type (SS/Isolated τ-pairs)
- Second main background: Drell-Yan process, estimated from data-corrected simulation

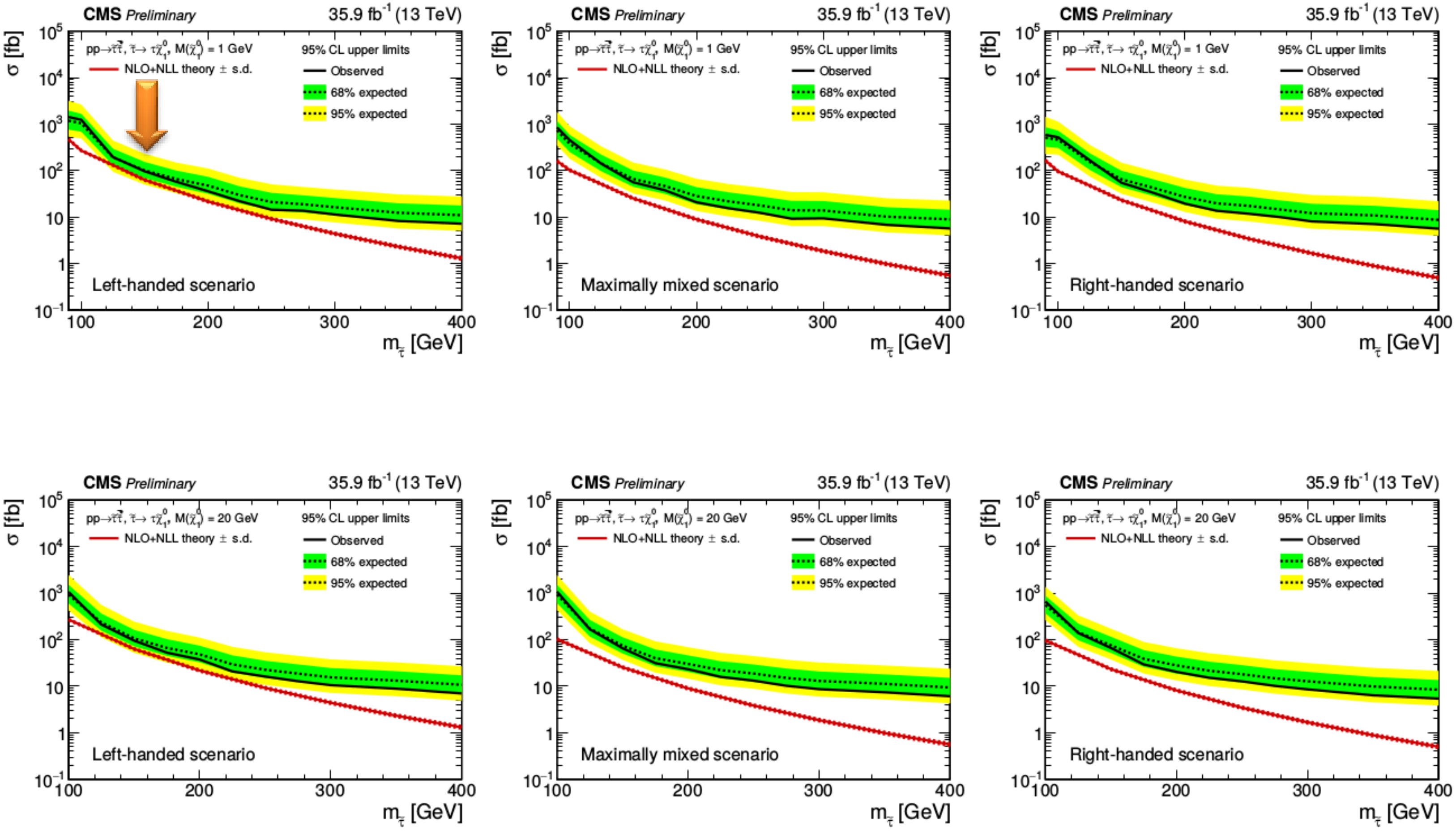
τ fake rate closure (M_{T2}, $\sum M_T$ cuts inverted)



DY modeling (μμ events)



CMS: results



For a left-handed stau m=125 GeV decaying to a massless LSP (1 GeV):

observed limit = 1.5 x σ^{exp}_{signal}

ATLAS: search strategy

- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ production with $\tilde{\chi}_1^0$ being a pure Bino and $\tilde{\tau}_1$ a pure $\tilde{\tau}_{\mathrm{L}}$
- Target events with all-hadronic τ decays
- 2 signal regions based on m_{T2} and E_T^{miss}
- Cover regions with Δm($\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$) $\gtrsim$ 200 GeV
- Main background: QCD multijets from a matrix method (ABCD)

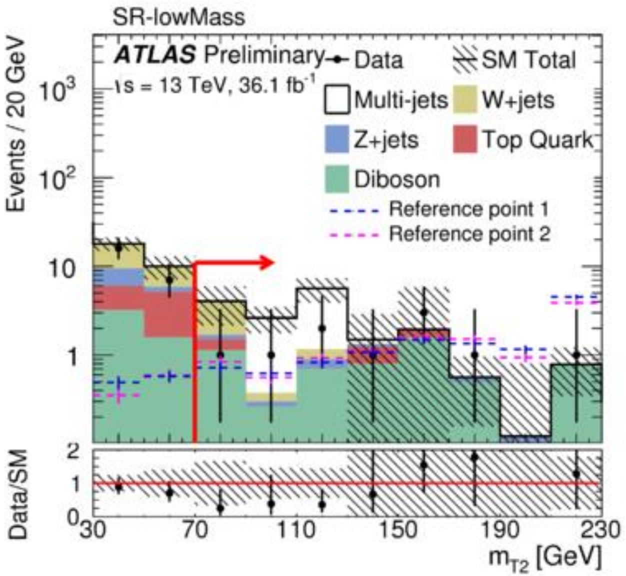
SR "low-mass"

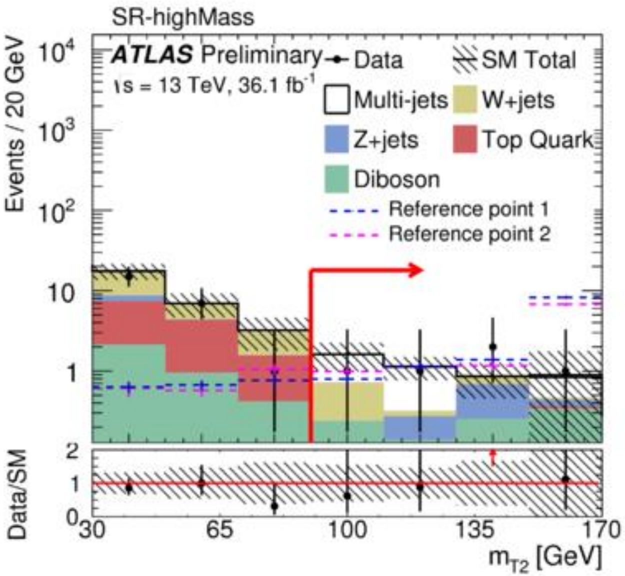
- Di-τ hadronic + E_T^{miss} trigger
- large m_{T2} and E_T^{miss}

SR "high-mass"

- Di-τ hadronic asymmetric trigger
- large m_{T2} and E_T^{miss}
- high m(τ_1, τ_2)

ATLAS: Distributions in signal regions





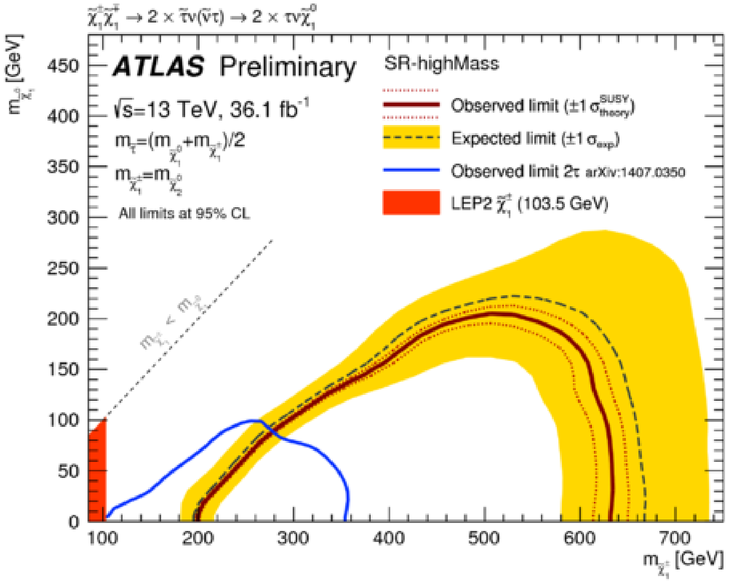
---- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ production with m(C1, N2) = 600 GeV

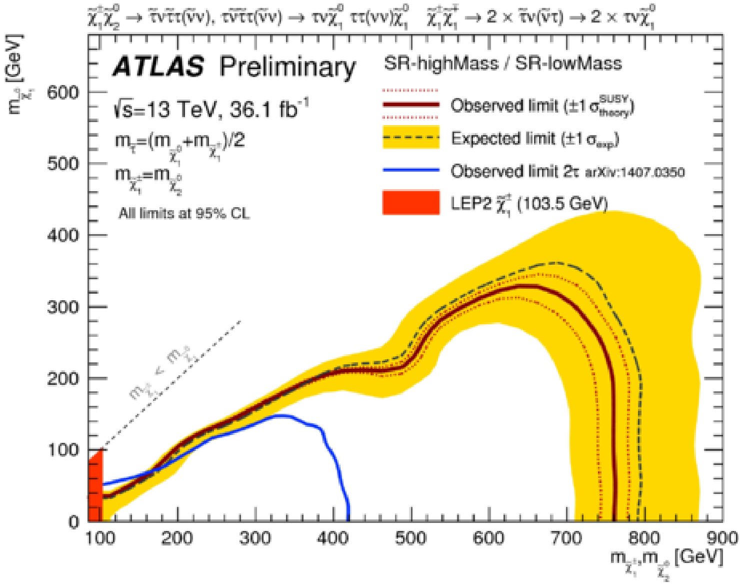
---- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ production with m(C1) = 600 GeV + $\tilde{\chi}_1^{0}$ is massless

m_{T2} in the “low-mass” signal region

m_{T2} in the “high-mass” signal region

ATLAS: Exclusion Contours





Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ search:

$\tilde{\chi}_1^{\pm}$ masses excluded up to 630 GeV for massless $\tilde{\chi}_1^{0}$

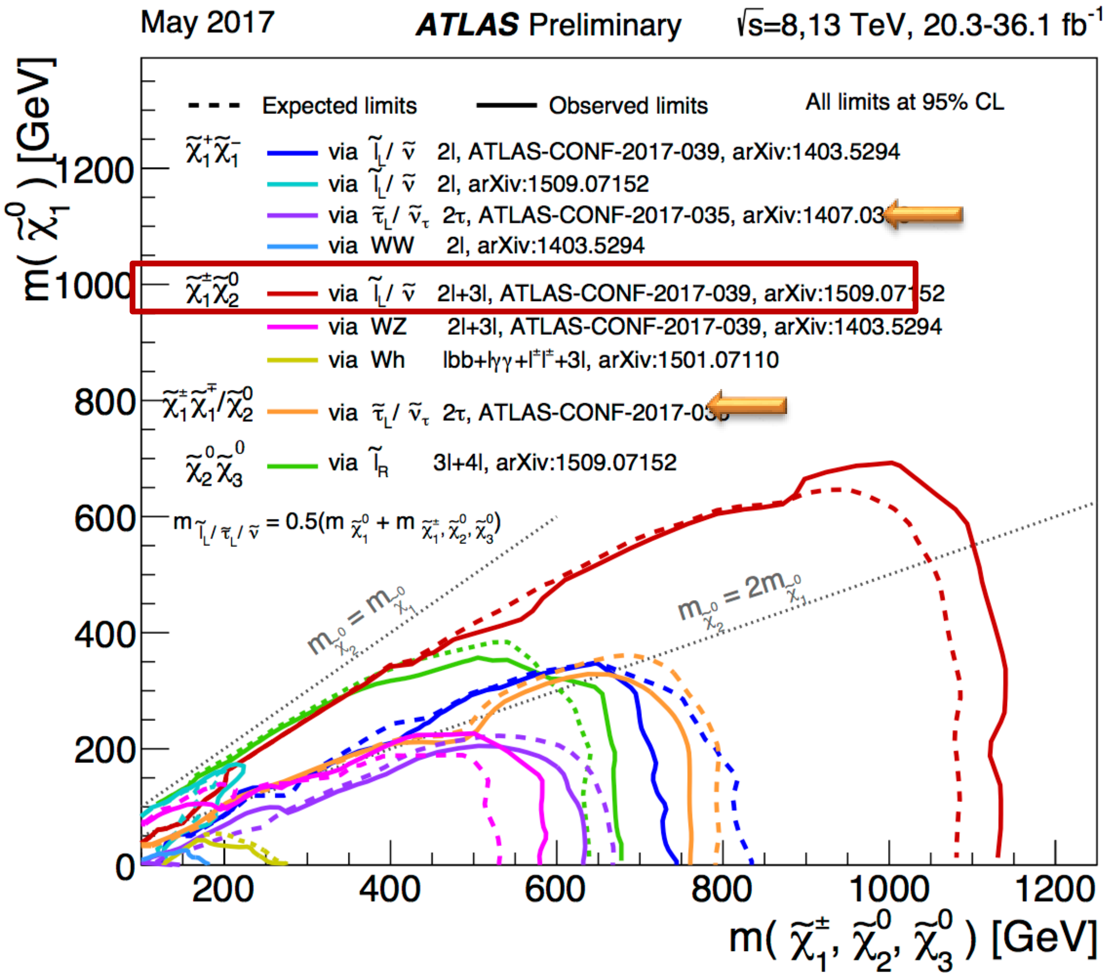
Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ combined:

$\tilde{\chi}_1^{\pm}$ /$\tilde{\chi}_2^{0}$ masses excluded up to 760 GeV for massless $\tilde{\chi}_1^{0}$

→Limits significantly extend previous LEP, ATLAS and CMS results in the high $\tilde{\chi}_1^{\pm}$ mass region

ATLAS: Exclusions Landscape

- 95% CL exclusion limits on $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, and $\tilde{\chi}_2^{0}\tilde{\chi}_3^{0}$ production with either SM-boson-mediated or slepton-mediated decays
- As a function of the $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^{0}$, $\tilde{\chi}_3^{0}$ and $\tilde{\chi}_1^{0}$ masses
- The production cross-section is for *pure wino* $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, and *pure higgsino* $\tilde{\chi}_2^{0}\tilde{\chi}_3^{0}$
- ---, --- : analyses involving $\tilde{\tau}$'s



Synopsis

- Search for Supersymmetry in final states involving hadronic taus
- No significant excess is observed in any of the signal regions in both experiments
- Interpretations as limits on the production of (in)direct stau pairs in the context of simplified models

- The CMS analysis is most sensitive to the direct production of left-handed staus.

- ATLAS is excluding the production of chargino pairs and mass-degenerate charginos & NLSP neutralinos with masses up to 760 GeV.

References

- Search for pair production of tau sleptons in √s=13 TeV pp collisions in the all-hadronic final state, CMS Collaboration, CMS-PAS-SUS-17-003
- Search for the direct production of charginos and neutralinos in final states with tau leptons in √s= 13 TeV pp collisions with the ATLAS detector, ATLAS-CONF-2017-035

BACKUP

ATLAS

Stau searches

→ Mass of lightest 3rd-generation sparticles, $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$should be ~$\mathcal{O}$(100 GeV)

- arguments suggested by Naturalness to protect m_H from quadratically divergent quantum corrections

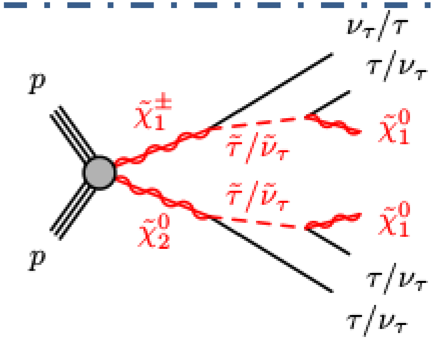
→ Models with light $\tilde{\tau}$ are consistent with current matter data from cosmological observations

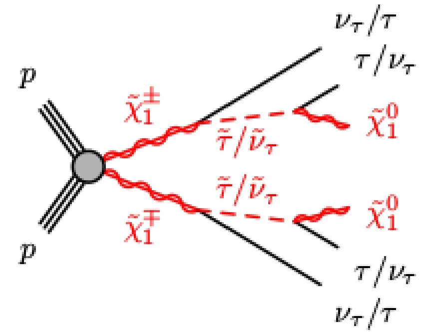
→ In the context of pMSSM, EW production of direct $\tilde{\tau}$'s becomes dominant if $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$are heavy ($\tilde{\chi}_1^0$ is bino-like):

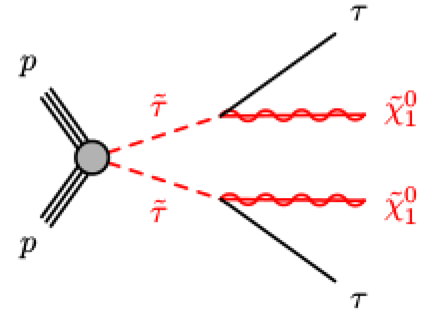
$$
\begin{aligned}
\sigma(\tilde{\tau}_L) &\sim 270 \rightarrow 0.5 \text{ fb} \\
\sigma(\tilde{\tau}_R) &\sim 97 \rightarrow 0.2 \text{ fb} \\
m_{\tilde{\tau}} &\sim 100 \rightarrow 500 \text{ GeV}
\end{aligned}
$$

Simplified model with stau mixing

$$\tilde{\tau}_1 = \tilde{\tau}_R,\ \tilde{\tau}_2 = \tilde{\tau}_L$$







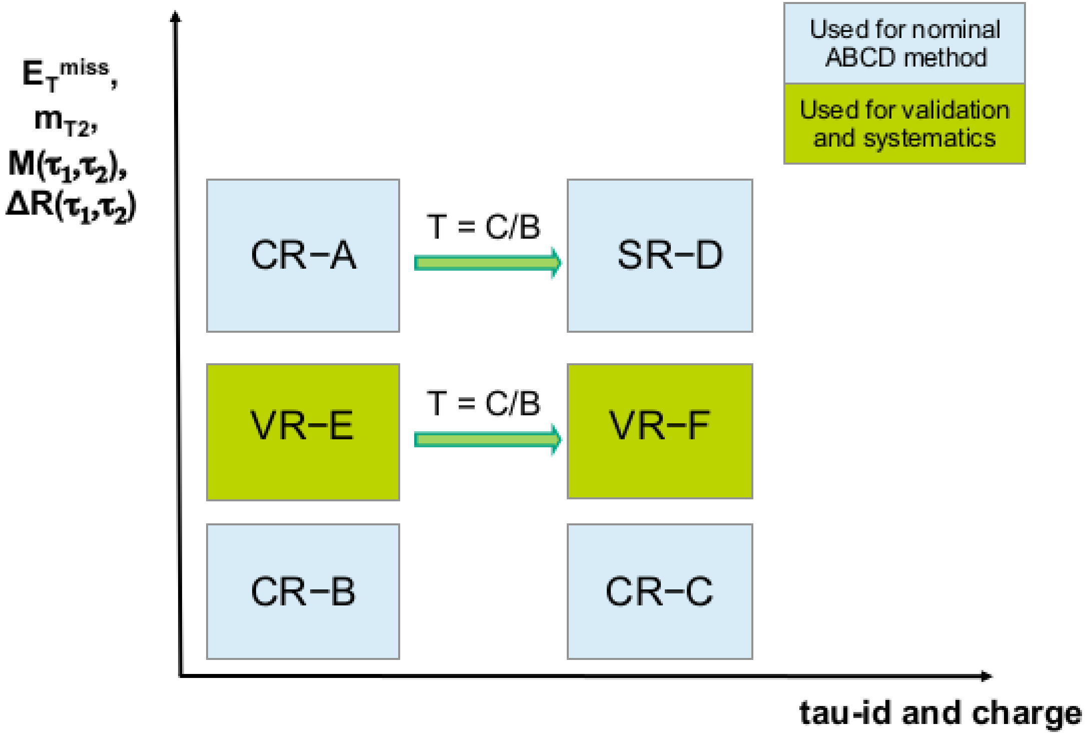
Signal Regions

SR-lowMass	SR-highMass	
at least one opposite sign tau pair		
b-jet veto		
Z-veto		
at least two medium tau candidates	at least one medium and one tight tau candidates	
	$m(\tau_1, \tau_2) > 110$ GeV	
$m_{\mathrm{T2}} > 70$ GeV	$m_{\mathrm{T2}} > 90$ GeV	
di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	asymmetric di-tau trigger
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 110$ GeV
$p_{\mathrm{T},\tau_1} > 50$ GeV	$p_{\mathrm{T},\tau_1} > 80$ GeV	$p_{\mathrm{T},\tau_1} > 95$ GeV
$p_{\mathrm{T},\tau_2} > 40$ GeV	$p_{\mathrm{T},\tau_2} > 40$ GeV	$p_{\mathrm{T},\tau_2} > 65$ GeV

- SR-lowMass (SR-highMass) to cover signal models where the mass difference between the C1/N1 is smaller (larger) than 200 GeV.
- In SR-lowMass, only the di-tau+E T miss trigger is used
- In SR-highMass events are selected with the di-tau+E T miss trigger or by the asymmetric di-tau trigger

Background estimate

- CR-B and CR-C, events are recorded using a di-tau trigger
- multi-jet events in the control and validation regions is estimated from data after subtraction
- of other SM contributions estimated from MC simulation
- CR-B and VR-E more than 86 % of the events come from multi-jet production
- CR-A and CR-C the multi-jet purity is larger than 47 % and 68 %, respectively
- The signal contamination in CR-A for both SRs ranges from a few percent to 30–50 % for a few signal models, and it is taken into account in the simultaneous fit



ABCD Definitions

CR-A	SR-D (SR-lowMass)
di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	
≥ 2 loose tau leptons (SS)	≥ 2 medium tau leptons (OS)
$m(\tau_1, \tau_2) < 250$ GeV	
$\Delta R(\tau_1, \tau_2) > 1.5$	
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV
$m_{\mathrm{T2}} > 70$ GeV	$m_{\mathrm{T2}} > 70$ GeV
VR-E	**VR-F**
di-tau trigger	
≥ 2 loose tau leptons (SS)	≥ 2 medium tau leptons (OS)
$m(\tau_1, \tau_2) < 250$ GeV	
$\Delta R(\tau_1, \tau_2) > 1.5$	
$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV
$50 < m_{\mathrm{T2}} < 70$ GeV	$50 < m_{\mathrm{T2}} < 70$ GeV
CR-B	**CR-C**
di-tau trigger	
≥ 2 loose tau leptons (SS)	≥ 2 medium tau leptons (OS)
$m(\tau_1, \tau_2) < 250$ GeV	
$\Delta R(\tau_1, \tau_2) > 1.5$	
$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV
$20 < m_{\mathrm{T2}} < 50$ GeV	$20 < m_{\mathrm{T2}} < 50$ GeV

CR-A	SR-D (SR-highMass)
di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ or asymmetric di-tau trigger	
≥ 2 loose tau leptons (OS)	≥ 2 medium tau leptons (OS)
< 1 medium 1 tight tau leptons	≥ 1 tight tau lepton
$\Delta R(\tau_1, \tau_2) > 1.8$	
$E_{\mathrm{T}}^{\mathrm{miss}} > 110$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 110$ GeV
$m_{\mathrm{T2}} > 90$ GeV	$m_{\mathrm{T2}} > 90$ GeV
VR-E	**VR-F**
di-tau or asymmetric di-tau trigger	
≥ 2 loose tau leptons (OS)	≥ 2 medium tau leptons (OS)
< 1 medium 1 tight tau leptons	≥ 1 tight tau lepton
$\Delta R(\tau_1, \tau_2) > 1.8$	
$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV
$60 < m_{\mathrm{T2}} < 90$ GeV	$60 < m_{\mathrm{T2}} < 90$ GeV
CR-B	**CR-C**
di-tau or asymmetric di-tau trigger	
≥ 2 loose tau leptons (OS)	≥ 2 medium tau leptons (OS)
< 1 medium 1 tight tau leptons	≥ 1 tight tau
$\Delta R(\tau_1, \tau_2) > 1.8$	
$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV
$10 < m_{\mathrm{T2}} < 60$ GeV	$10 < m_{\mathrm{T2}} < 60$ GeV

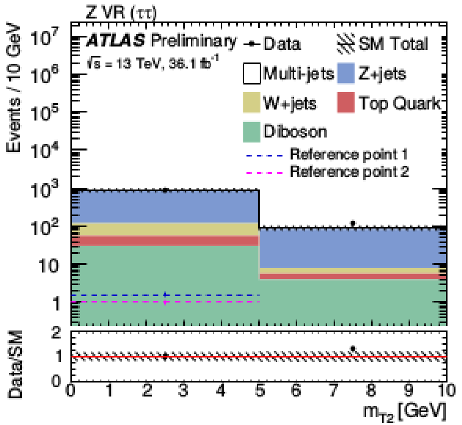
Z and Top Validation Regions

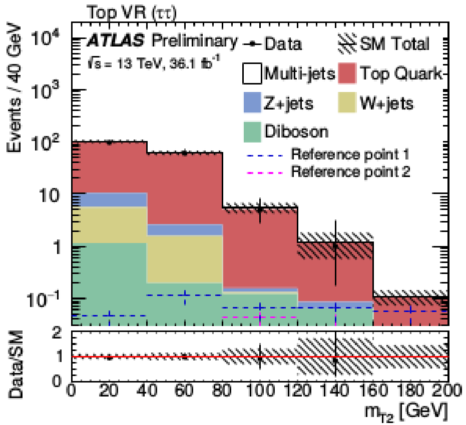
Z-VR	Top-VR
at least one opposite sign tau lepton pair	
tau $p_T > 50, 40$ GeV	
$E_T^{miss} > 60$ GeV	
at least two medium tau leptons	at least one medium and one loose tau lepton
b-jet veto	at least 1 b-jet
$m_{T2} < 10$ GeV	$m_{T2} > 10$ GeV
	m_{CT} top-tagged

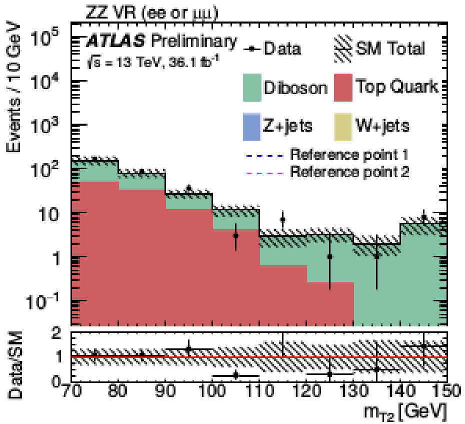
WW and ZZ Validation regions

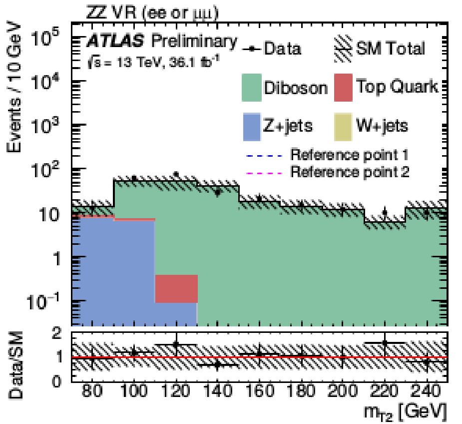
WW-VR	ZZ-VR
one opposite sign lepton pair	
$\mu\ p_{\mathrm{T}}$ >30 GeV, $e\ p_{\mathrm{T}} >$ 40 GeV	
jet veto	
$m_{\ell\ell} >$ 50 GeV	
$E_{\mathrm{T}}^{\mathrm{miss}}$ >50 GeV	
$m_{T\mu} >$ 100 GeV	
$m_{\mathrm{T2}} >$ 70 GeV	
two isolated leptons (e or μ) with different flavor	two isolated leptons (e or μ) with same flavor
m_{CT} top tag veto	$\Delta R(\ell, \ell) < 1.5$
	$\|m_{\ell\ell} - m_Z\| <$ 15 GeV

VR Distributions









CMS

Systematic Uncertainties

Uncertainty	Signal	Non-prompt/misID	Drell-Yan	Top	Rare SM
Tau Efficiency	11%	5%	10%	10%	10%
Iso extrap. non-prompt τ_h	–	28–35	–	–	–
Correlations non-prompt τ_h	–	8–13%	–	–	–
Tau energy scale	2–12%	–	22–34%	9–18%	7–18%
Jet energy scale	1–5%	–	12–20%	1–5%	4–10%
Jet energy resolution	1–4%	–	29–61%	3–10%	11–31%
Unclustered energy	0–3%	–	12–17%	4–5%	3–10%
B–tagging	0.5–1%	–	2–3%	11–20%	1–2%
Drell-Yan mass & p_T	–	–	18–21%	–	–
Background cross sections	–	–	20%	20%	20%
Fast versus full simulation	1–30%	–	–	–	–

Limits at 0.95 CLs

	SR1	SR2	SR3
Non-prompt and misidentified taus	$0.68\ ^{+0.90}_{-0.68}$	2.49 ± 1.83	<1.24
Drell-Yan background	$0.80^{+0.97}_{-0.80}$	< 0.71	< 0.71
Top-quark related background	$0.02^{+0.03}_{-0.02}$	0.73 ± 0.31	1.76 ± 0.68
Rare SM processes	0.72 ± 0.38	0.20 ± 0.15	$0.20 \pm\ ^{+0.25}_{-0.20}$
Total background	$\mathbf{2.22}^{+1.37}_{-1.12}$	$\mathbf{4.35}^{+1.75}_{-1.53}$	$\mathbf{3.70}^{+1.52}_{-1.08}$
Left (150,1)	1.25 ± 0.40	2.91 ± 0.59	1.53 ± 0.33
Right (150,1)	1.09 ± 0.26	1.27 ± 0.20	0.74 ± 0.17
Mixed (150,1)	1.04 ± 0.22	1.39 ± 0.27	0.92 ± 0.15
Observed	**0**	**5**	**2**