Search for supersymmetric partner of top quark pair production in a di-τ final state with CMS detector
(DHEP Annual Review Meeting 2022)

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Why SUSY

- Standard Model (SM) of high-energy physics is a remarkably successful theory, supported by the experimental results.
- However SM fails to explain several observations:
  - ➔ Dark matter and dark energy
  - ➔ Matter-antimatter asymmetry
  - ➔ Naturalness and Higgs mass etc.

- Supersymmetry tries to answer the shortcomings of SM by introducing a bosonic supersymmetric partner (superpartner) for each fermion (and vice-versa), the superpartner having the same quantum numbers, other than spin, as its SM partner.

- The present analysis is based on minimal supersymmetric standard model (MSSM) that contains the SM particles, their SUSY partners and two Higgs doublet.

$$H_u = (H^+_u, H^0_u) \text{ and } H_d = (H^0_d, H^-_d)$$

- The parameter $\tan\beta$ is defined by

$$\tan\beta = v_u/v_d$$

Where v_u and v_d are the VEV corresponding to H^0_u and H^0_d respectively

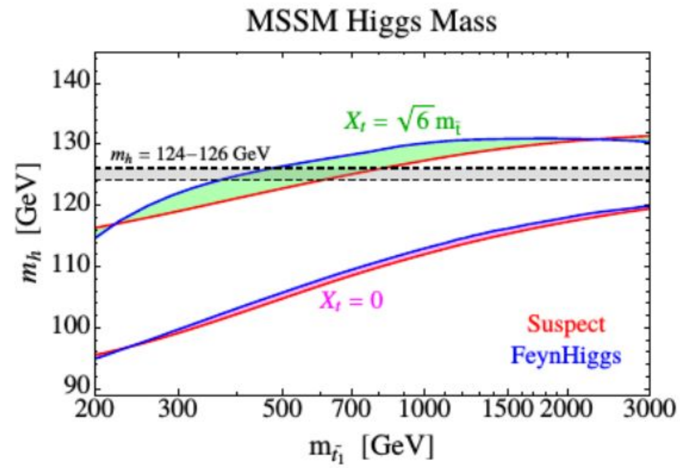
Why top squark search

- The MSSM has 5 higgs boson: *h, H, A, $H^\pm$*.
- The tree level CP even *h* receives substantial mass correction involving top squark loop:

$$m_h = m_z|cos2\beta| + \frac{3m_t^4}{2\pi^2 v^2 sin^2\beta}[log\frac{m_s^2}{m_t^2} + \frac{X_t^2}{2m_s^2}(1 - \frac{X_t^2}{6m_s^2})] \qquad X_t = A_t - \mu cot\beta$$

$$m_s = \sqrt{m_{\tilde{t}1} m_{\tilde{t}_2}}$$

- *h* is the **SM like higgs boson** with m_h=125.38 ± 0.11 (stat) ± 0.08 (syst) GeV [Ref: Physics Letters B 805 (2020) 135425]
- The discovery of higgs boson constrains the lighter stop mass stringently.
- For maximal mixing scenario, to get a higgs boson of mass ~125 GeV, the lighter stop mass is required to be ~500 GeV which is interesting in the LHC scenario.



Signal Channel

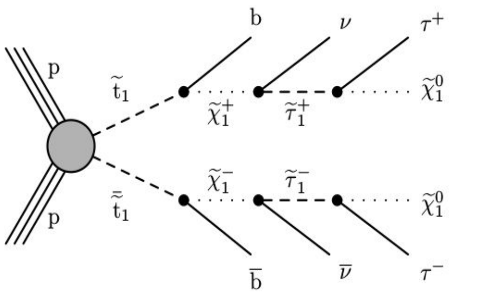


Diagram 1

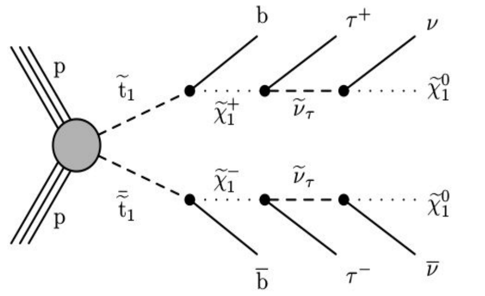


Diagram 2

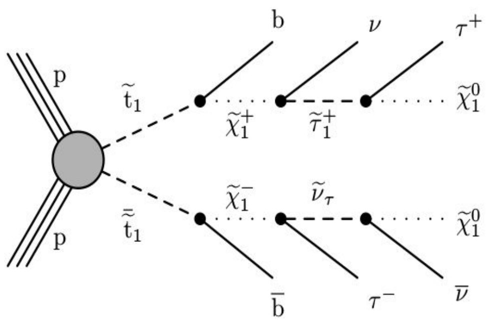


Diagram 3

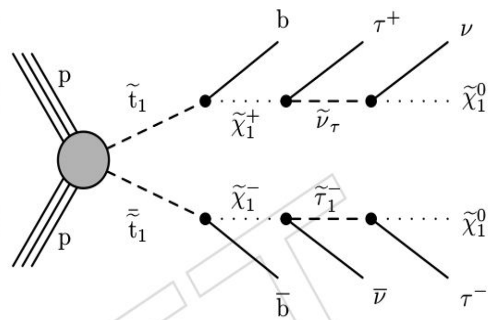


Diagram 4

Our decay chain is:

$$\tilde{\chi}_1^\pm \to \tilde{\tau}_1^\pm \nu_\tau \to \tau^\pm \nu_\tau \tilde{\chi}_1^0$$

or

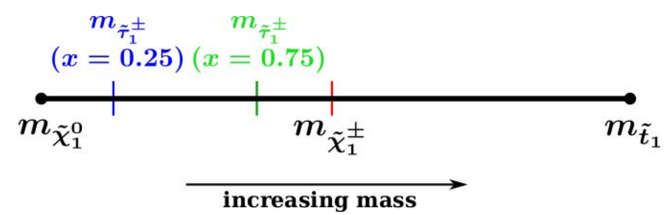
$$\tilde{\chi}_1^\pm \to \tau^\pm \tilde{\nu}_\tau \to \tau^\pm \nu_\tau \tilde{\chi}_1^0$$

Mass Relations:

$$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 0.5(m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0})$$

$$m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} = x[m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}]$$

Assuming $m_{\tilde{\tau}_1} = m_{\tilde{\nu}_\tau}$ with x=[0.25, 0.5, 0.75]



- **The first two diagrams are competing.** For a given stop and LSP mass:
  - x = 0.25: The slepton is closer to the LSP. So the first diagram produces softer taus, and second harder.
  - x = 0.75: The slepton is closer to the chargino. So the first diagram produces harder taus, and second softer.
  - x = 0.5: Both the diagrams behave similarly.

- Both hadronic and semileptonic decays of tau lepton is considered in this analysis

Why τ-Lepton Final State

- Chargino/neutralino are admixture of gaugino and higgsino like components:

$$\tilde{\chi}_i^{\pm} = C_{1i}\tilde{W}^{\pm} + C_{2i}\tilde{H}^{\pm}$$

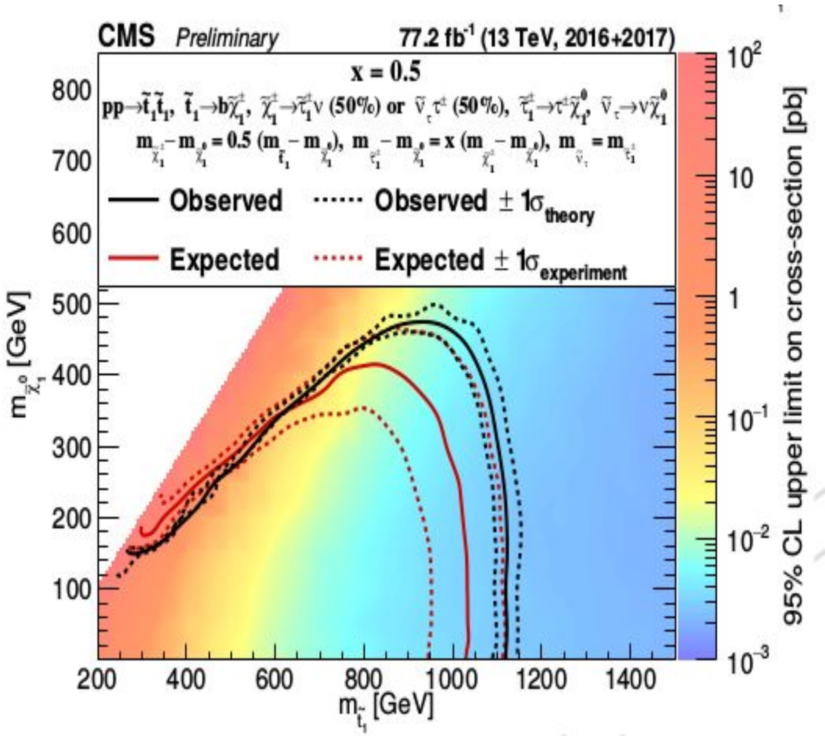
$$\tilde{\chi}_i^{0} = N_{1i}\tilde{\gamma} + N_{2i}\tilde{Z} + N_{3i}\tilde{H}_1^{0} + N_{4i}\tilde{H}_2^{0}$$

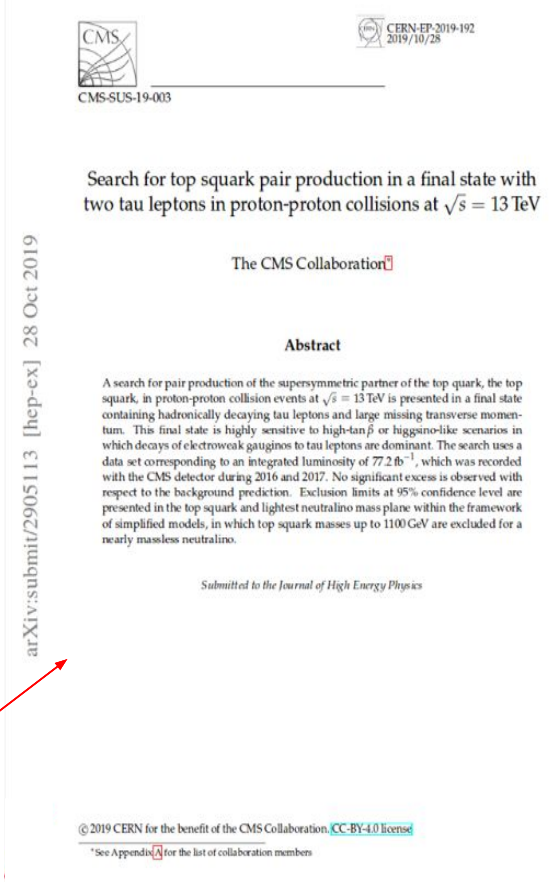
- In a higgsino like scenario:

$|C_{2i}|^2 >> |C_{1i}|^2$ and $|N_{3i}|^2 + |N_{4i}|^2 >> |N_{1i}|^2 + |N_{2i}|^2$

- $\tan\beta >> 1$ implies $(1/\cos\beta) >> 1$.
- The higgsino component of chargino/neutralino couples to sleptons with a strength $\propto (m_l/\cos\beta)$.
- In high $\tan\beta$ region and higgsino like scenario, the chargino/neutralino most often decays to τ lepton as $m_\tau >> m_e$ and m_μ .
  - ➔ In such SUSY cascade decay, we have lot of τ-lepton in the final state

Previous Analysis result (di-τ_h final state)





CMS-SUS-19-003

CERN-EP-2019-192
2019/10/28

arXiv:submit/2905113 [hep-ex] 28 Oct 2019

Search for top squark pair production in a final state with two tau leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

Abstract

A search for pair production of the supersymmetric partner of the top quark, the top squark, in proton-proton collision events at $\sqrt{s} = 13$ TeV is presented in a final state containing hadronically decaying tau leptons and large missing transverse momentum. This final state is highly sensitive to high-$\tan\beta$ or higgsino-like scenarios in which decays of electroweak gauginos to tau leptons are dominant. The search uses a data set corresponding to an integrated luminosity of 77.2 fb^{-1}, which was recorded with the CMS detector during 2016 and 2017. No significant excess is observed with respect to the background prediction. Exclusion limits at 95% confidence level are presented in the top squark and lightest neutralino mass plane within the framework of simplified models, in which top squark masses up to 1100 GeV are excluded for a nearly massless neutralino.

Submitted to the Journal of High Energy Physics

*See Appendix A for the list of collaboration members

The analysis result in di-τ_h final state (2016+2017) is already published in JHEP (hep-ex 1910.12932)

DOI 10.1007/JHEP02(2020)015

CMS-SUS-19-003

Top squark mass up to ~1100 GeV are excluded for a nearly massless neutralino

Main backgrounds

The analysis is performed for total 138fb^{-1} of data collected in full Run-2 by CMS detector

- The main background contributions are coming from:
  - ➔ $t\bar{t}$ (831.76 pb),
  - ➔ Associated production of single top (ST) with a W-boson (35.6 pb)
  - ➔ Fake background coming from jet misidentified as τ_h
  - ➔ DY+jets (5343 pb),

- Other small contributions are coming from
  - ➔ W+jets, WH, ZH,
  - ➔ WW, WZ, ZZ,
  - ➔ TTZ, TTW,
  - ➔ t-channel single top production

Top squark pair production cross-section for different top squark mass

m_{Stop}(GeV)	Xsection(pb)
200	75.5
500	0.609
800	0.033
1000	0.0068

- Generator level matching has been performed for prompt τ_h in case of MC to ensure that it is non fake

Search Variables

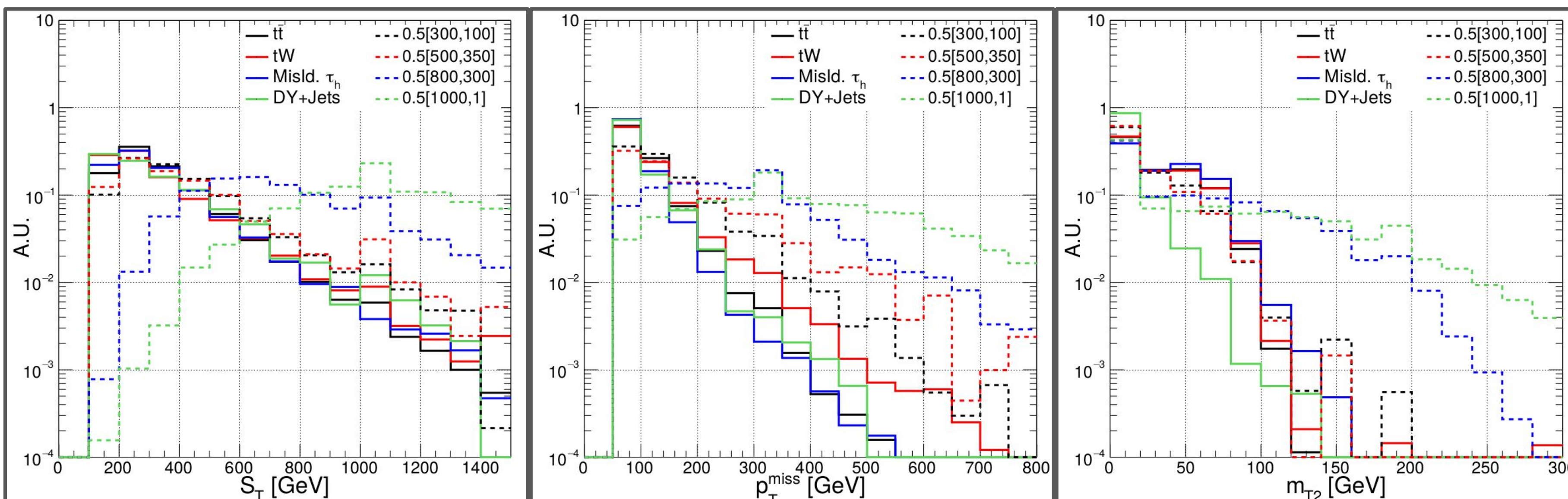
Our main search variables are:

- MET: Sensitive to the kinematics of the neutralino and neutrino
- $m_{T2}(\ell, \tau_h, \text{MET})$ or $m_{T2}(\tau_h, \tau_h, \text{MET})$: Sensitive to the chargino mass

$$m_{T2}(vis1, vis2, MET) = \min_{\vec{p}_T^{\,inv1} + \vec{p}_T^{\,inv2} = \vec{\not{p}}_T} \left[\max\{m_T^2(\vec{p}_T^{\,vis1}, \vec{p}_T^{\,inv1}), m_T^2(\vec{p}_T^{\,vis2}, \vec{p}_T^{\,inv2})\}\right]$$

$$m_T^2(\vec{p}_T^{\,vis1}, \vec{p}_T^{\,inv1}) = m_{vis1}^2 + m_{inv1}^2 + 2(E_T^{vis1} E_T^{inv1} - \vec{p}_T^{\,vis1} \cdot \vec{p}_T^{\,inv1})$$

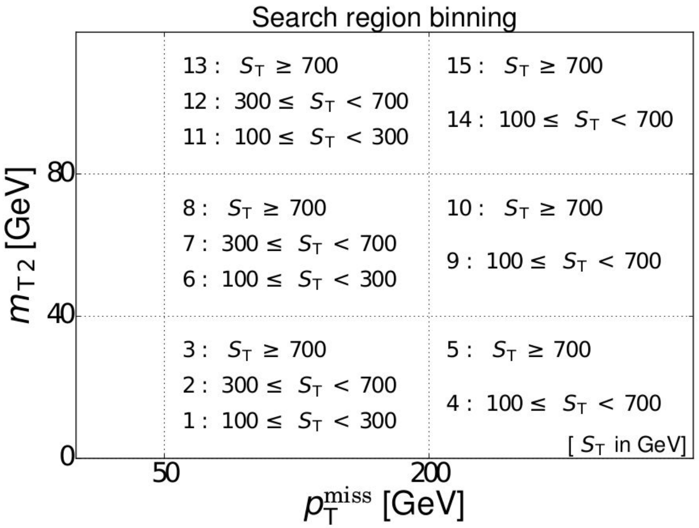
- S_T (scalar p_T sum of all visible objects): Sensitive to to the total mass of the system (top squark mass)



Selection region event selection and SR selection

Event Selection ($\ell\tau_h$-category)

- Exactly one muon (electron) passing medium (tight) id WP for $\mu\tau_h$ ($e\tau_h$) category
- Exactly one τ_h passing tight iso WP and $\Delta R(\mu/e, \tau_h)>0.5$
- The muon (electron) and τ_h should be of opposite sign
- Veto events if there is any extra lepton passing p_T > 15 GeV and $|\eta|$ <2.4
- $N_{b\text{-jet(Medium)}} \geq 1$
- $\Delta R(\mu/e, \text{jet})>0.5$ and $\Delta R(\tau_h, \text{jet})>0.5$
- MET > 50 GeV
- S_T > 100 GeV (scalar p_T sum of all visible objects)



$t\bar{t}$ estimate: Methodology

Ref: CMS-EXO-17-016, SUS-19-003

- The goal is to correct the prediction of $t\bar{t}$ MC yield in the signal region by deriving a correction factor in a $t\bar{t}$ enriched control region (CR)
- We determined the scale factor in **e-μ** control region which is highly pure in $t\bar{t}$ (~ 90%)
  - The purity, p, is defined as,

$$p = \frac{CR^{t\bar{t}\ MC}}{CR^{all\ MC}}$$

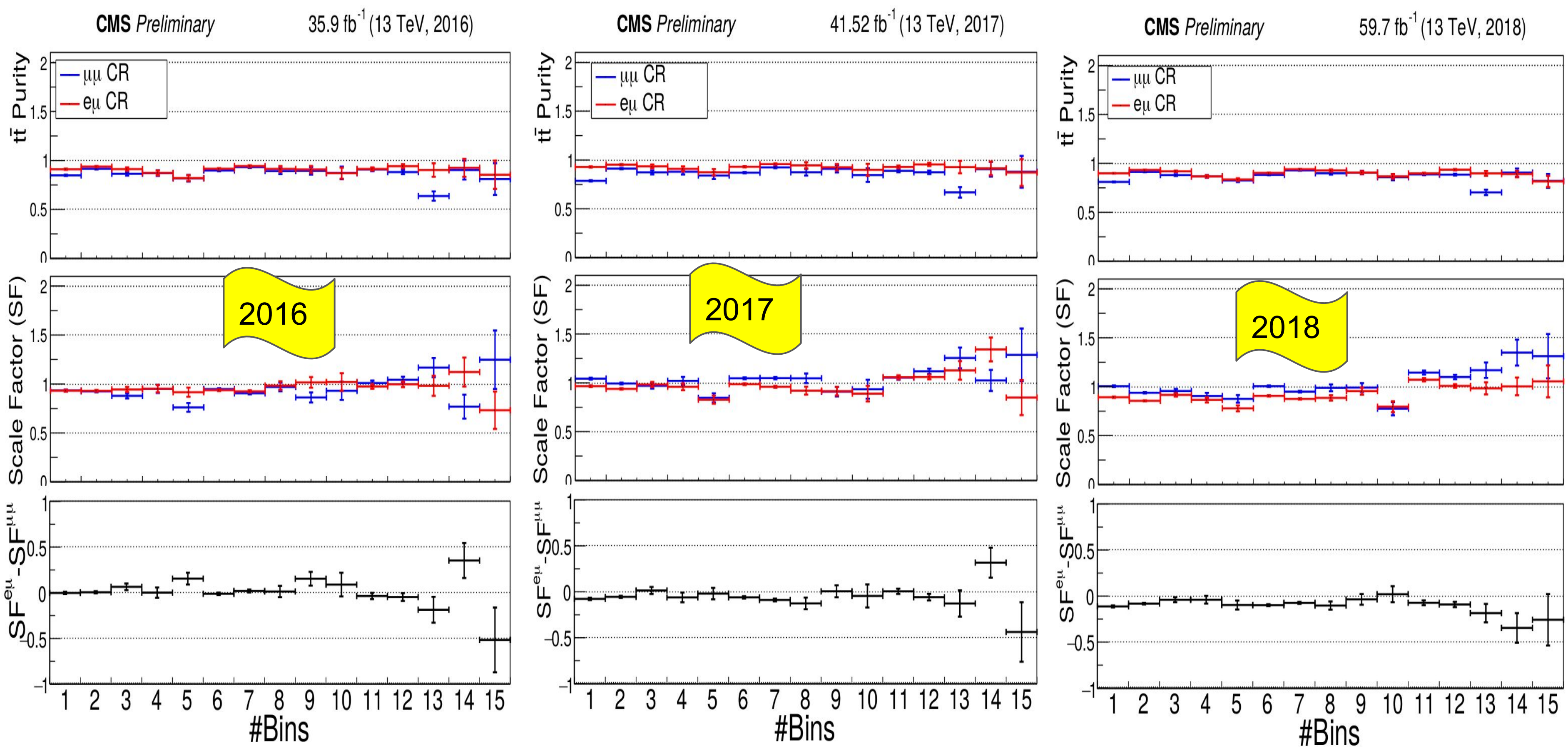
  - For a given bin i, the scale factor is defined as,

$$SF_i = \frac{N^{e\mu\ \mathrm{CR}}_{i,\mathrm{data}}}{N^{e\mu\ \mathrm{CR}}_{i,\mathrm{MC}}}$$

- Repeated the same exercise in di-μ control region also
- The di-μ CR gives an opportunity to cross check our results. This measurement is also useful to check any dependence on lepton flavour
- The difference $SF^{e\mu}$-$SF^{\mu\mu}$ is taken as systematic on the SF
- The corrected $t\bar{t}$ yield in simulation in each region of the SR is then obtained as

$$N^{\mathrm{SR}}_{i,\mathrm{corr}\ t\bar{t}} = N^{\mathrm{SR}}_{i,t\bar{t}\ \mathrm{MC}} SF_i = \frac{N^{e\mu\ \mathrm{CR}}_{i,\mathrm{data}} N^{\mathrm{SR}}_{i,t\bar{t}\ \mathrm{MC}}}{N^{e\mu\ \mathrm{CR}}_{i,\mathrm{MC}}}$$

SFs, Purity and Systematic Unc.



To reduce the effect of statistical fluctuations, bins [14, 15] in the CR have been merged to obtain the same SF for both the bins.

Jet to τ_h Fake Background Estimation(Semileptonic): Methodology

The main steps for jet to τ_h fake background estimation are:

- ❑ First find a control region (CR) orthogonal to signal region where there is no real τ_h but there is jet.
- ❑ Find the jet to τ_h fake rate in this CR.
- ❑ Validate the fake rate in another validation region, orthogonal to both the CR and SR.
- ❑ If the fake estimation is found to work in the validation region, use it to determine fake background in the SR.

CR For Fake Rate Determination (Semileptonic channels)

Ref: SUS-17-002

- Fake rate is estimated in a data driven method in a W+jets enriched region
- The fake rate is determined using the following formula:

$$R = \frac{N^{CR}_{data}(\tau,Tight) - N^{CR}_{\text{MC w/o W+jets}}(\tau,Tight)}{N^{CR}_{data}(\tau,VLoose\&!Tight) - N^{CR}_{\text{MC w/o W+jets}}(\tau,VLoose\&!Tight)}$$

- The fake contribution is then determined in the signal region using the following formula:

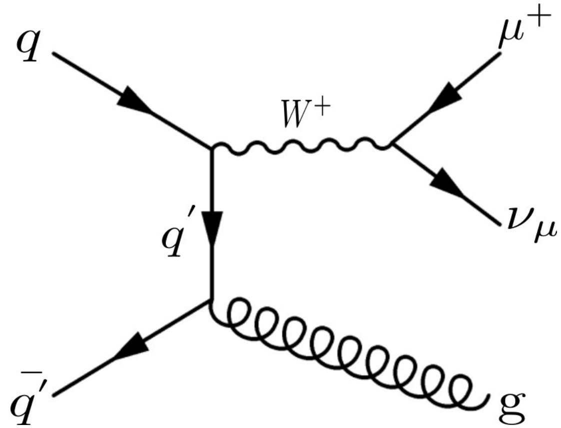
$$N^{SR}(jets \to \tau) = R[N^{SR}_{data}(\tau_{VL\&!T}) - N^{SR}_{MC}(\tau_{VL\&!T\&GenMatched})]$$

Purity of W+Jets is ≃83 %

- Fake rates were validated in a DY+Jets enriched region and good closure is observed

Event Selection:

- Exactly one muon passing tight identification and at least one τ_h candidate passing VLoose isolation WP.
- Veto events with extra lepton passing $p_T > 15$ GeV and $|\eta|<2.4$.
- $60<M_T$ (transverse mass of μ and MET)<120
- $0 < N_{jet(non\text{-}tagged)} < 3$.
- MET > 50 GeV.
- $N_{b\text{-}jet} = 0$ (This selection makes this CR orthogonal to our signal region where we require at least one b-jet passing medium WP of DeepJet algorithm).



Fake rates(R) (Semileptonic channels)

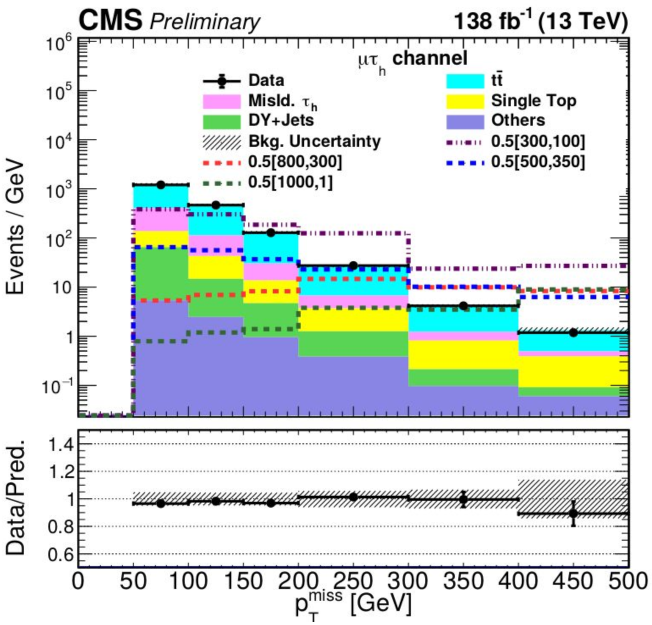
2016	$30 \le p_T < 40$	$40 \le p_T < 70$	$70 \le p_T < 150$	$p_T \ge 150$
$0 \le \|\eta\| < 1.44$	0.20(±0.004)	0.18(±0.005)	0.18(±0.009)	0.30(±0.040)
$1.44 \le \|\eta\| < 2.3$	0.15(±0.005)	0.15(±0.007)	0.15(±0.013)	0.18(±0.049)

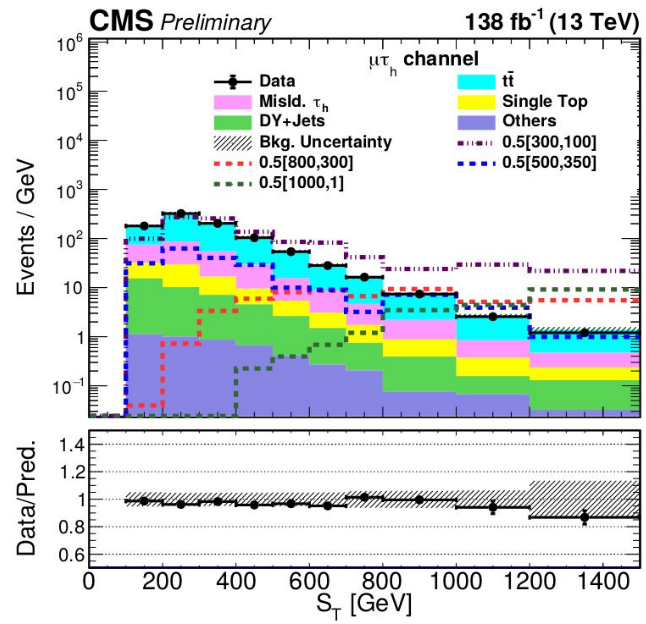
2017	$30 \le p_T < 40$	$40 \le p_T < 70$	$70 \le p_T < 150$	$p_T \ge 150$
$0 \le \|\eta\| < 1.44$	0.21(±0.004)	0.21(±0.005)	0.21(±0.009)	0.30(±0.041)
$1.44 \le \|\eta\| < 2.3$	0.17(±0.005)	0.18(±0.007)	0.15(±0.014)	0.26(±0.065)

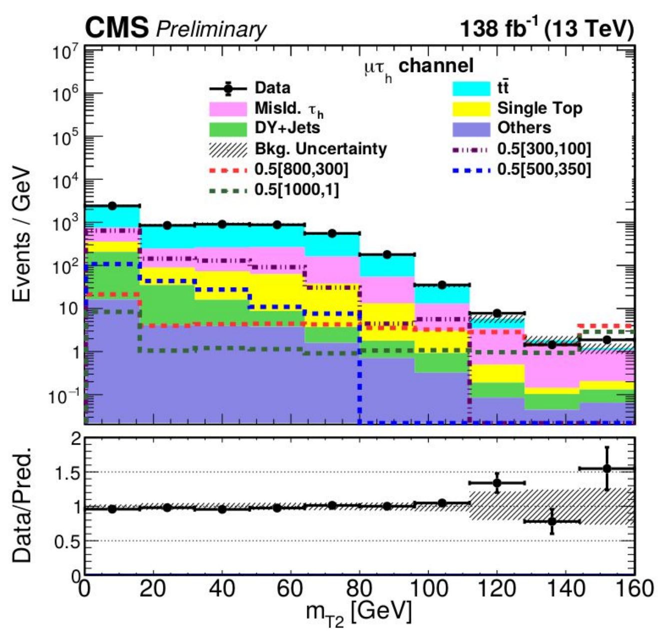
2018	$30 \le p_T < 40$	$40 \le p_T < 70$	$70 \le p_T < 150$	$p_T \ge 150$
$0 \le \|\eta\| < 1.44$	0.20(±0.003)	0.20(±0.005)	0.21(±0.004)	0.29(±0.033)
$1.44 \le \|\eta\| < 2.3$	0.18(±0.004)	0.16(±0.006)	0.17(±0.012)	0.36(±0.063)

The error indicates the statistical error only

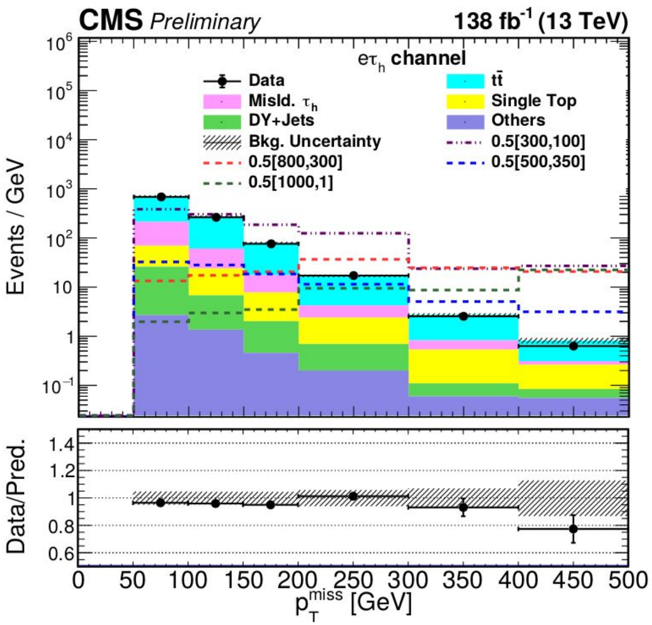
SR search variables Data-MC comparison (Full Run2)

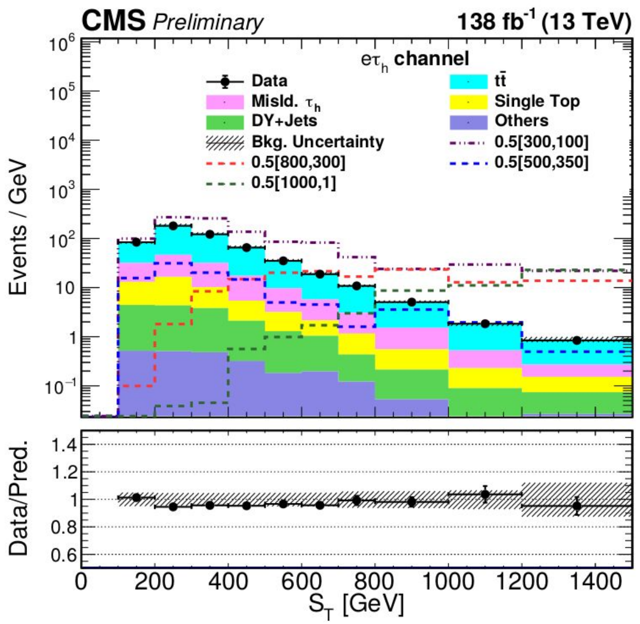


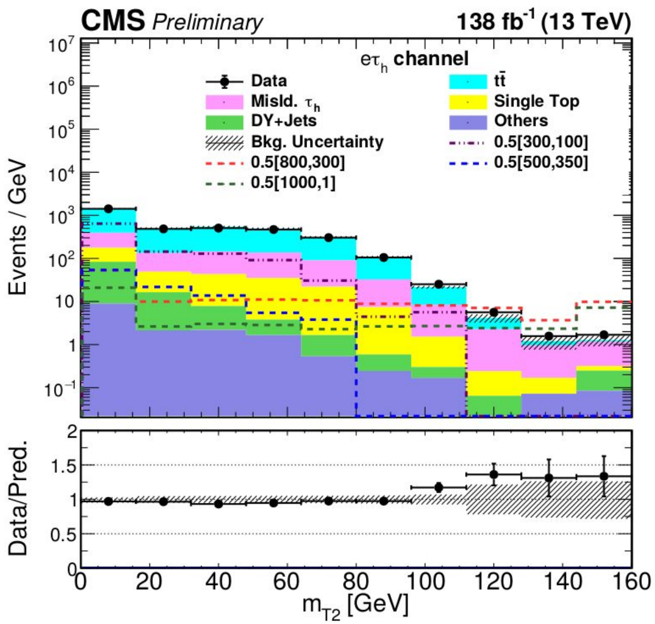




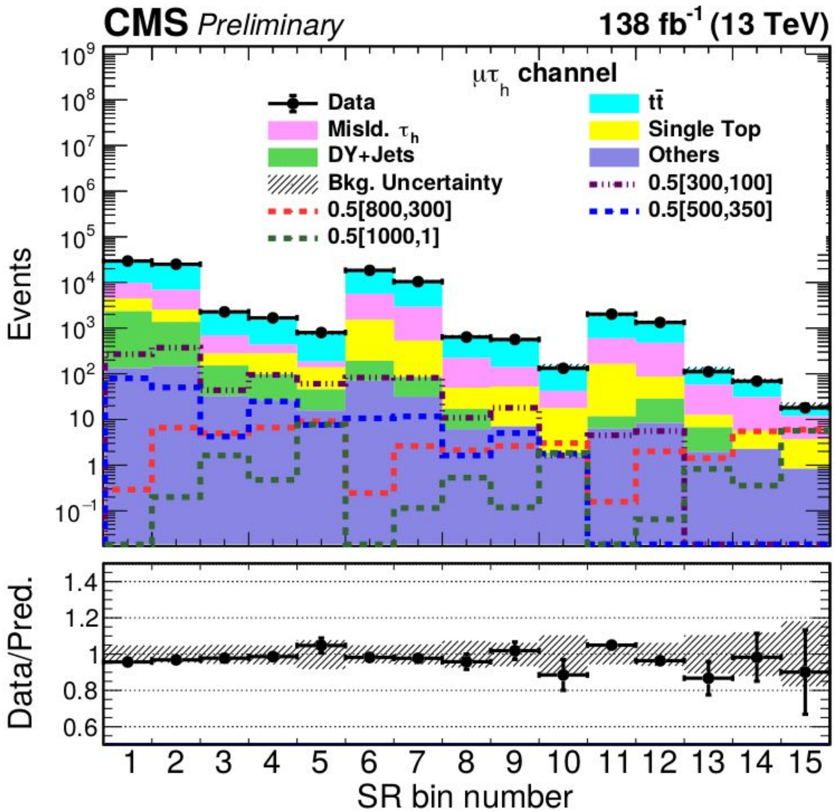
SR search variables Data-MC comparison (Full Run2)

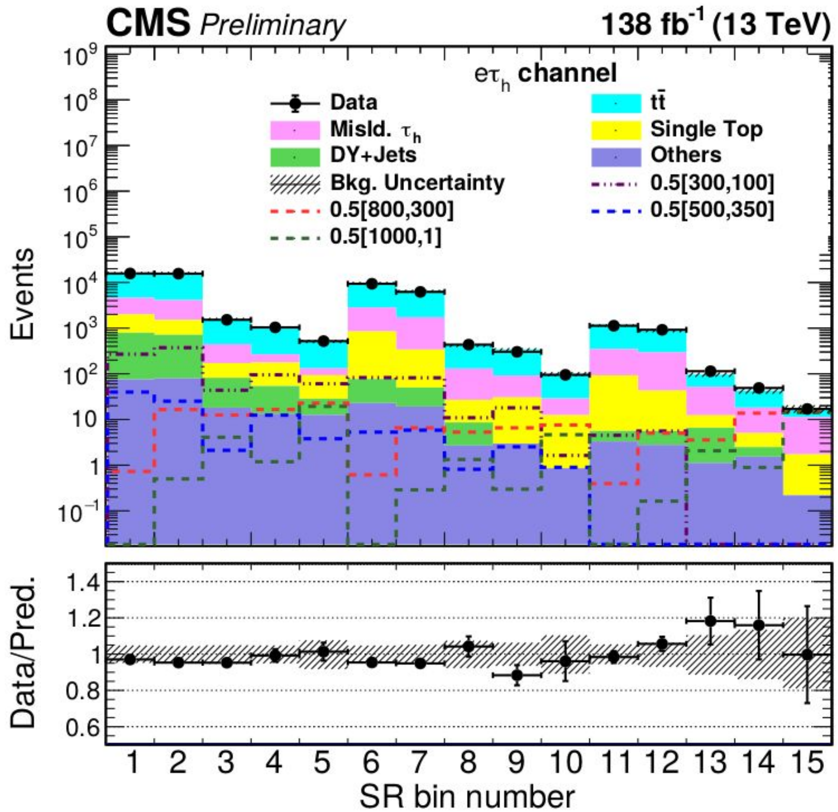




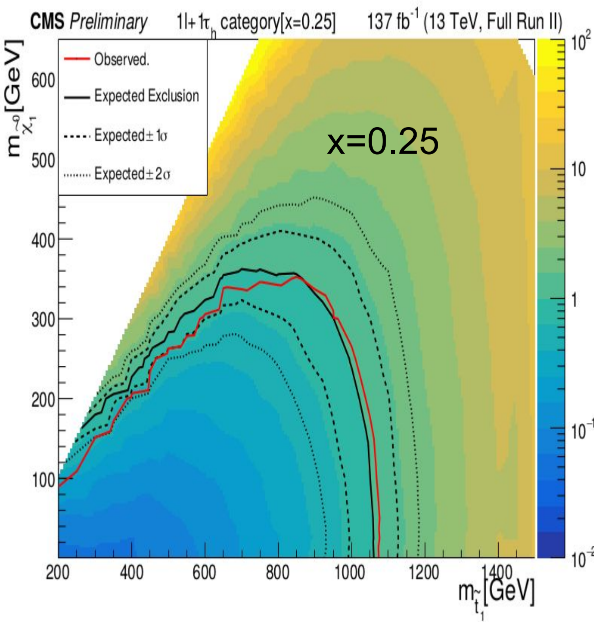


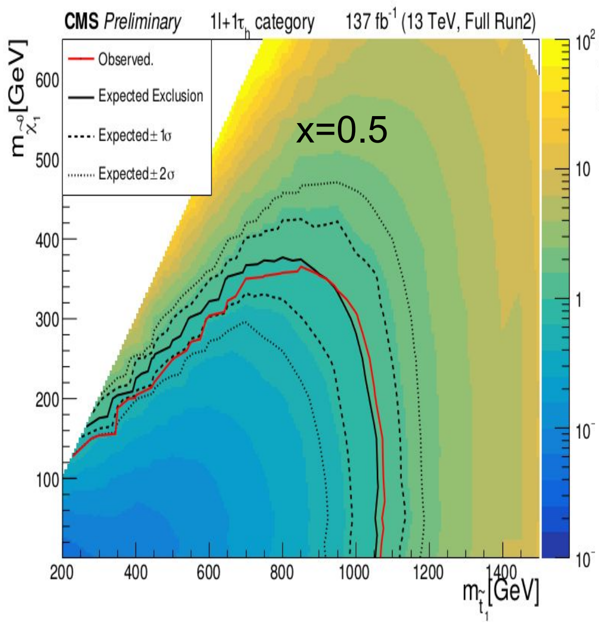
Signal region Data-MC comparison (bin-wise) (Full Run2)

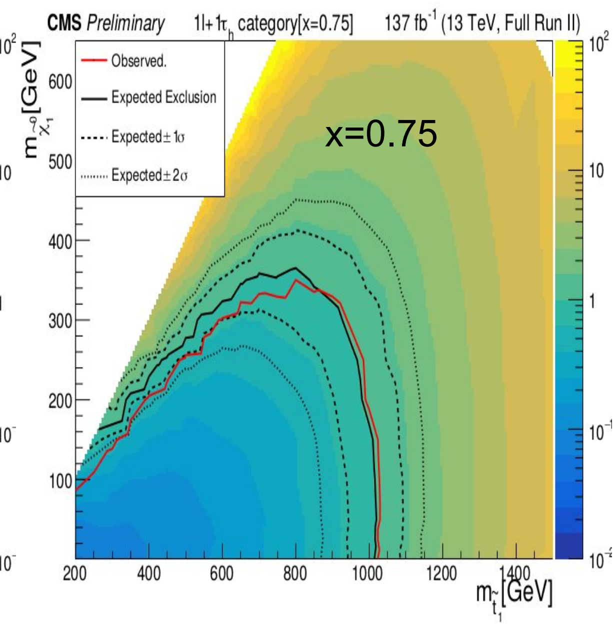




$\mu\tau_h$ + $e\tau_h$ combined exclusion (Full Run 2)



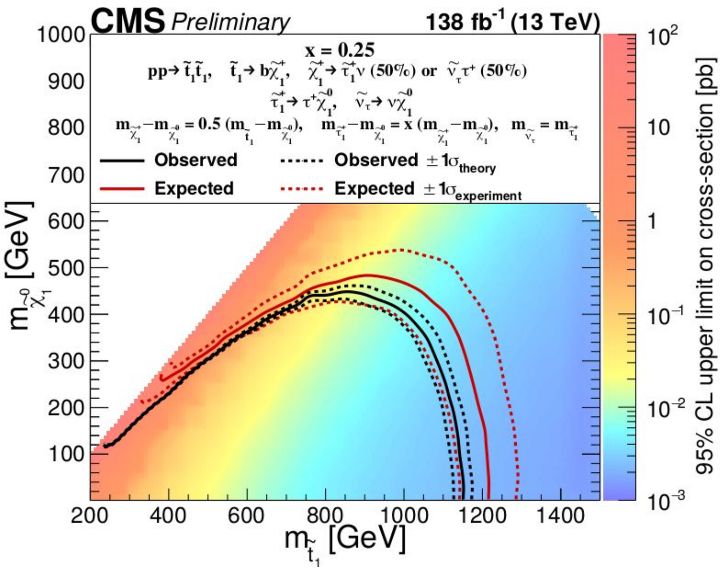


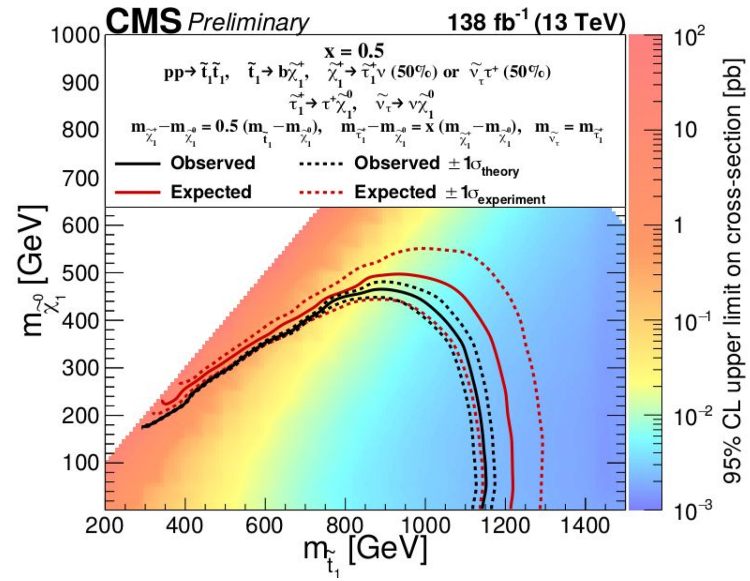


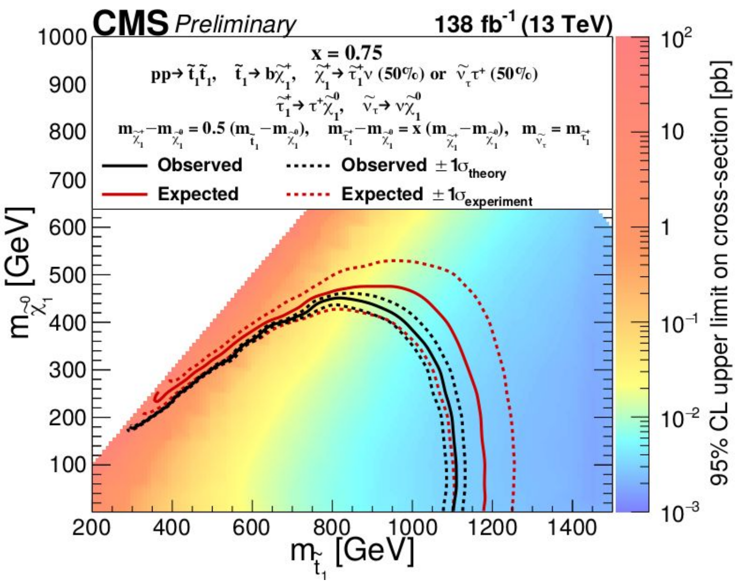
$$\mu = \frac{N_{data} - N_{bkg}}{N_{sig}}$$

- Top squark mass upto 1050 GeV is excluded for nearly mass less neutralino
- Neutralino mass upto 360 GeV is excluded for 850 GeV top squark mass

$\mu\tau_h + e\tau_h + \tau_h\tau_h$ combined exclusion (Full Run 2)







- ❑ Top squark mass upto 1140 GeV is excluded for nearly mass lep neutralino
- ❑ Neutralino mass upto 500 GeV is excluded for 950 GeV top squark mass

Summary

- Top squark search in di-tau semileptonic channel is presented.
- Top squark mass upto 1050 GeV is excluded for nearly mass lep neutralino.
- Combination of semileptonic and fully hadronic channels exclude top squark mass upto 1140 GeV for nearly mass lep neutralino.

Thank you

Back up

Object Selection

μ-Selection:

- Medium (tight) identification WP in SR (tau fake rate estimation)
- Impact parameters: $|d_{xy}|<0.045$ cm and $|d_z|<0.2$ cm
- Medium WP of Δβ corrected isolation
- p_T > 28 GeV and $|\eta|<2.4$

e-Selection:

- Tight identification
- Missing hit in inner tracker should not exceed 1
- Conversion veto is applied
- Impact parameters: $|d_{xy}|<0.045$ cm and $|d_z|<0.2$ cm
- Tight WP of Δβ corrected isolation
- p_T > 30(36) GeV for era 2016(2017,2018) and $|\eta|<2.1$

Missing Energy (MET):

Type-I PF MET

τ_h-Candidate Selection:

- Decay Mode (1 and 3 prong decays)
- Deep tau against jet Tight (VLoose) WP in SR (tau fake rate estimation)
- μ-Fake Check: Deep tau against mu Tight WP
- e-Fake Check: Deep tau against e Loose WP
- p_T > 30 GeV and $|\eta|<2.3$ (for $\ell\tau_h$ channels)
- p_T > 40 GeV and $|\eta|<2.1$ (for di-τ_h channels)

Jet Selection:

- p_T > 25 GeV and $|\eta|<2.4$(for $\ell\tau_h$ channels)
- p_T > 20 GeV and $|\eta|<2.4$(for di-τ_h channels)

b-jet Selection:

- Deep Jet medium WP

Background overview

- The largest prompt contribution is coming from tt (and tW for $\ell\tau_h$) as it's topology is similar to our signal process. We derived scale factors from tt enriched CR

- The other major background contribution in the sensitive bins is from fake taus (mostly from semi-leptonic $t\bar{t}$ events). The fake bkg is estimated in a data driven way.

- The DY background is taken from MC with Z -p_T reweighting applied.

- All other bkgs are estimated from simulations with all the corrections and scale-factors applied

Applied Corrections and SFs:

- ❑ Trigger SF
- ❑ Tau Id SF
- ❑ b-tagging SF
- ❑ Lepton iso-id SF
- ❑ Jet Energy Correction (JEC)
- ❑ Jet Energy Resolution (JER)
- ❑ PU re-weighting
- ❑ Tau energy scale
- ❑ FastSim MET, lepton and τ_h correction (for signal only)

$t\bar{t}$ +tW estimate: CR event selections

Ref: CMS-EXO-17-016, SUS-19-003

Event Selection:

e-μ CR:

- Trigger: **e-μ** cross trigger
- Exactly one muon passing medium id WP and exactly one electron passing tight id WP and of opposite sign

di-μ CR:

- Trigger: **Single muon** trigger
- Exactly two muon passing medium id WP and of opposite sign

Common selection criteria for both CRs:

- Veto events with 60< $M_{e\mu}$ /$M_{\mu\mu}$ <120 to reduce DY events
- Veto events that contain at least one tight τ_h or any extra lepton
- $N_{b\text{-jet(Medium)}}$ ≥1
- MET > 50 GeV
- S_T>100 (Scalar p_T sum of all leptons and jets)

Validation of the $t\bar{t}$ SF method

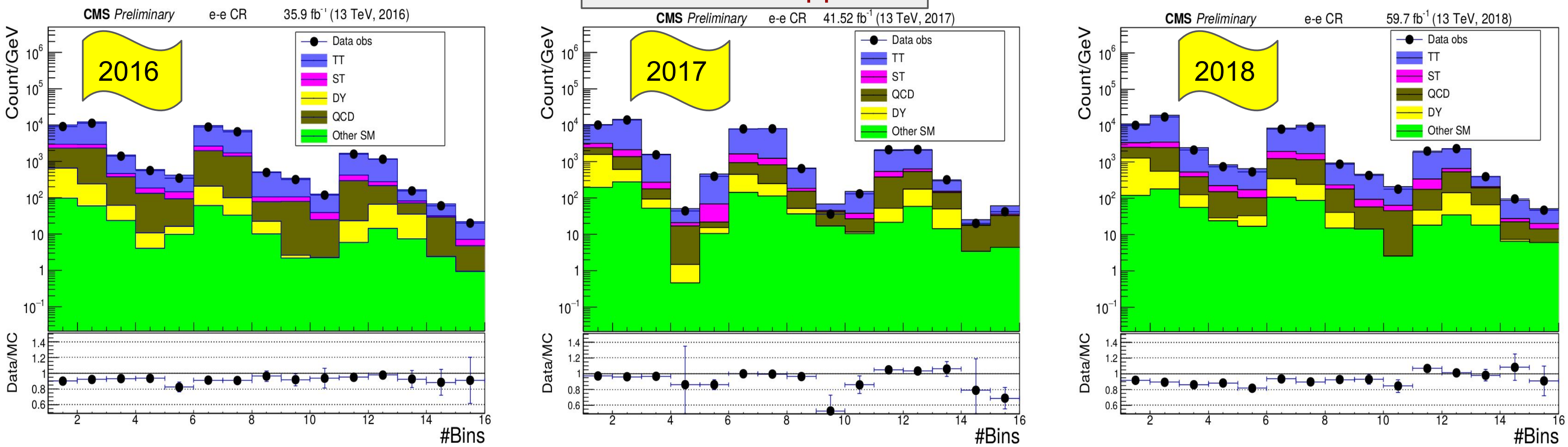
For the validation we selected a $t\bar{t}$ enriched region with di-electron final state

Event Selection:

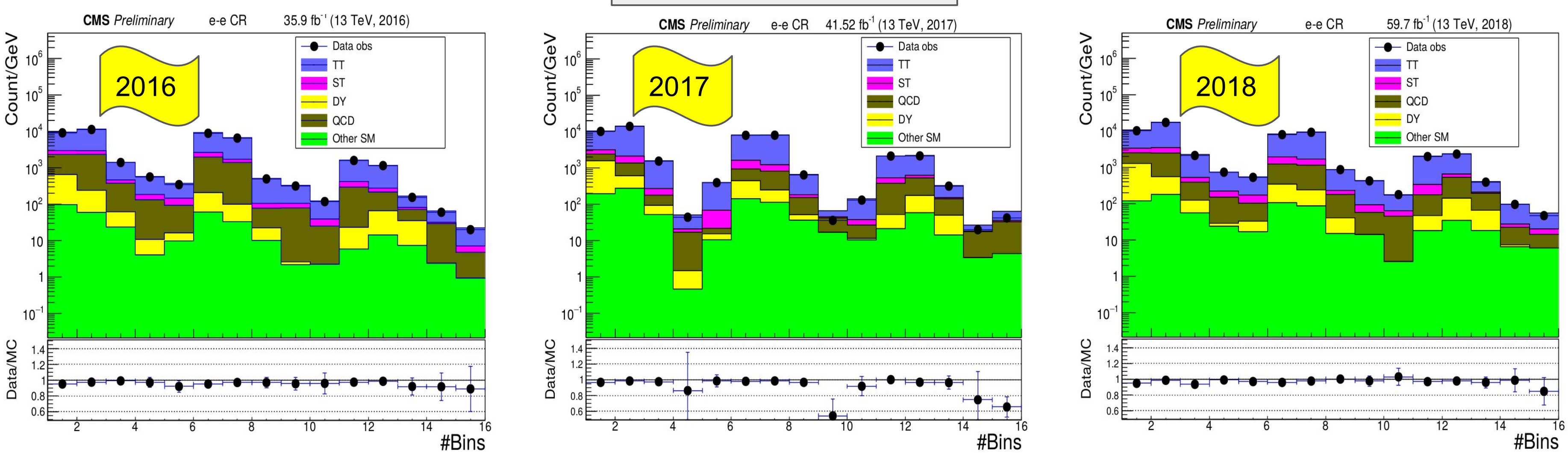
- Trigger: **Single electron** trigger
- Exactly two electron passing tight id and iso WP and of opposite sign
- Veto events with $60<M_{ee}<120$ to reduce DY events
- Veto events that contain at least one tight τ_h or any extra lepton
- $N_{b\text{-jet(Medium)}} \geq 1$
- MET > 50 GeV
- S_T>100 (Scalar p_T sum of all visible objects)

Validation plots for the $t\bar{t}$ SF method

Before SFs applied

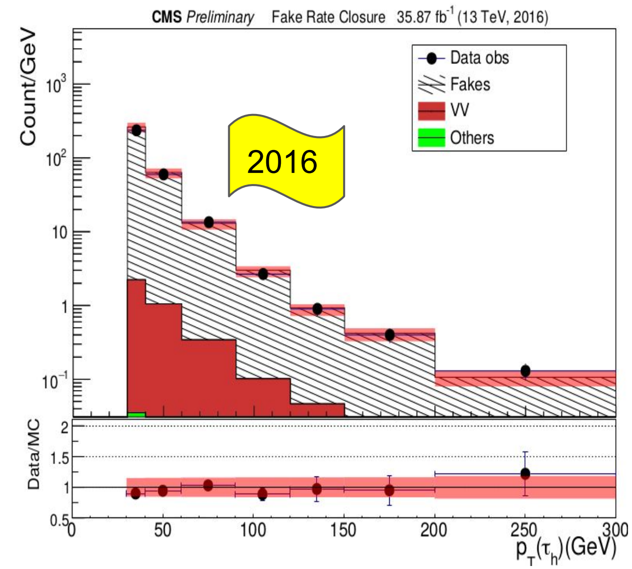


After SFs applied



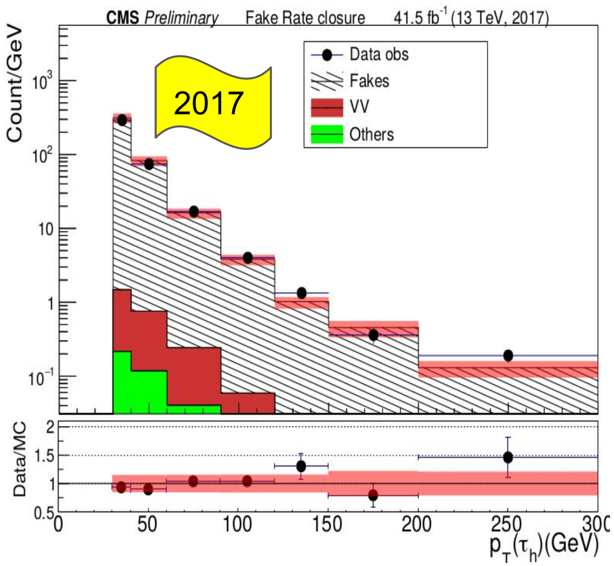
After the SFs applied, the Data-MC agreement is getting better

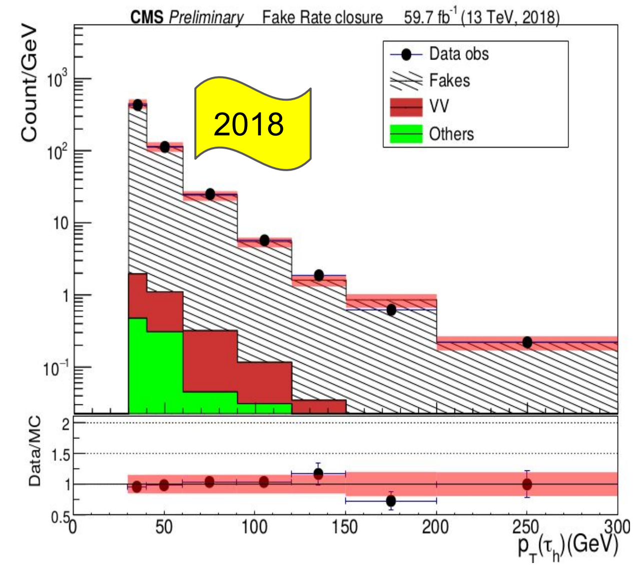
Closure test of fake estimation



- For validation of the fake rate a DY+jet enriched region (orthogonal to SR) is selected with:
  - Exactly two tight muons and 70<$M_{\mu\mu}$<110.
  - Exactly one τ_h candidate(supposed to be coming from jet faking as τ_h)
  - MET<50 GeV.
- Closure plots for the p_T of τ_h is shown for 2016, 2017 and 2018 and reasonably good closure is obtained.

More closure plots are in back up





- The Fake rate is also evaluated in a QCD enriched region and the difference is found to be 15% which is added as an extra uncertainty
- W+jets-> consists more quark jets, QCD-> consists more gluon jets
- The difference accounts for the parton flavor dependence of the FRs (more details are in the backup)

Systematics(1)

- μ, e, τ_h FastSim SF: Derived from tt̄ MC (in the backup). The statistical uncertainty is propagated.
- τ_h ID-iso: From https://twiki.cern.ch/twiki/bin/view/CMS/TauIDRecommendation13TeV.
- τ_h ES: From https://twiki.cern.ch/twiki/bin/view/CMS/TauIDRecommendation13TeV.
- JEC: From https://twiki.cern.ch/twiki/bin/view/CMS/JECDataMC.
- JER: From https://twiki.cern.ch/twiki/bin/viewauth/CMS/JetResolution.
- QCD scale: The combination of μ_R and μ_F that gives the maximum variation is used. Refer https://indico.cern.ch/event/515356/contributions/2180624/attachments/1278947/1898943/SMHTauTau.pdf.
- b-tagging: The efficiency in MC is corrected using the event weight reweighting method from https://twiki.cern.ch/twiki/bin/view/CMS/BTagSFMethods.
- tt̄ SF: The difference between the SFs derived in the eμ and μμ regions (added in quadrature with the statistical uncertainty) is propagated.
- Z-p_T reweighting: The size of the correction is propagated as the uncertainty. Corrections taken from HTT: https://github.com/danielwinterbottom/CorrectionsWorkspace/tree/ic_embed.

Systematics(2)

- ➔ τ_h fake-rate (parton flavor): A flat ±15% uncertainty on the fake-rate is used.
- ➔ Luminosity: From https://twiki.cern.ch/twiki/bin/viewauth/CMS/SUSRecommendationsRun2Legacy.
- ➔ Pileup: The minimum bias cross section is varied by ±2.5%. Refer https://cds.cern.ch/record/2647118/files/CR2018_328.pdf.
- ➔ MET unclustered energy: The uncertainty due to the variation of the unclustered component in MET https://twiki.cern.ch/twiki/bin/view/CMSPublic/WorkBookMetAnalysis.
- ➔ Signal cross-section: From https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections13TeVstopsbottom.
- ➔ FastSim MET correction: the signal yields are corrected as $\text{yield}_{\text{nominal}} = (\text{yield}_{\text{gen-MET}} + \text{yield}_{\text{reco-MET}})/2$. The error on the corrected yield is obtained as, $\Delta\text{yield} = \pm|\,\text{yield}_{\text{nominal}} - \text{yield}_{\text{reco-MET}}\,|$.

N.B. The systematics on the $t\bar{t}$ background whose source is not τ_h identification/reconstruction, cancel out. This is because the variations in SR $t\bar{t}$ and $CR_i^{\text{all MC}}$ due to those sources cancel out (refer to $t\bar{t}$ SF slides).

Systematics for $\mu\tau_h$ channel (Full Run 2)

Uncertainty source	x = 0.5 [300,100]	x = 0.5 [500,350]	x=0.5 [800,300]	x=0.5 [1000,1]	$t\bar{t}$	Single Top	DY+Others	MisId. τ_h
Signal cross-section	± 6.9%	± 7.5%	± 9.5%	± 11%	—	—	—	—
FASTSIM p_T^{miss} resolution	± 1.6%	± 1.6%	± 0.3	±0.1%	—	—	—	—
τ_h FASTSIM/GEANT4	± 0.7%	± 0.7%	± 0.9%	± 1.3%	—	—	—	—
μ FASTSIM/GEANT4	± 1.7%	± 1.4%	± 2.9%	3.1%	—	—	—	—
JER	+0.6%	+0.3%	< 0.1%	+0.1%	-	+0.3%	+4.2%	+0.1%
	-0.1%	-0.5%	< 0.1%	< 0.1%	—	-0.1%	-1.5%	-0.4%
2018 m_{T2} uncertainty	—	—	—	—	< 0.1%	< 0.1%	< 0.1%	< 0.1%
JEC	+0.1%	+0.2%	< 0.1%	+0.1%	—	0.6%	+4.7%	+0.4%
	-0.3%	-0.5%	< 0.1%	-0.1%	—	-0.7%	-3.0%	-0.4%
μ_R and μ_F scales	0.5%	+0.8%	+0.2%	+0.2%	—	4.2%	+4.0%	+4.9%
	-0.5%	-0.8%	-0.3%	-0.3%	—	-4.0%	-5.1%	-5.1%
τ_h Id-iso	+3.2%	+3.2%	+3.2%	+3.2%	+3.1%	+3.1%	3.1%	+1.6%
	-3.9%	-3.8%	-4.1%	-4.1%	-3.8%	-3.9%	-3.6%	-1.3%
Pileup	+0.6%	+0.1%	+0.3	+0.4%	—	+0.7%	+0.4%	+0.2%
	-0.6%	-0.1%	-0.3	-0.4%	—	-0.7%	-0.4%	-0.2%
p_T^{miss} Unclustered energy	< 0.1%	< 0.1%	+0.1%	< 0.1%	—	0.7%	+5.0%	0.2%
	< 0.1%	0.1%	< 0.1%	-0.1%	—	-1.2%	-3.2%	-0.3%
b-tagging	< 0.1%	± 0.1	± 0.14	± 0.4%	—	± 2.0%	± 5.3%	± 0.7%
2017 p_T^{miss} uncertainty	—	—	—	—	< 0.1%	< 0.1%	< 0.1%	< 0.1%
τ_h energy scale	-0.6%	-0.05%	-0.3%	< 0.1%	+0.1%	+0.1%	+2.5%	+0.1%
	-0.1%	-0.6%	-0.1%	< 0.1%	-0.1%	-0.1%	-3.8%	-0.1%
trigger	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
$t\bar{t}$ SF	—	—	—	—	± 3.8%	± 3.9%	—	—
τ_h fake rate (parton flavour)	—	—	—	—	—	—	—	± 15%

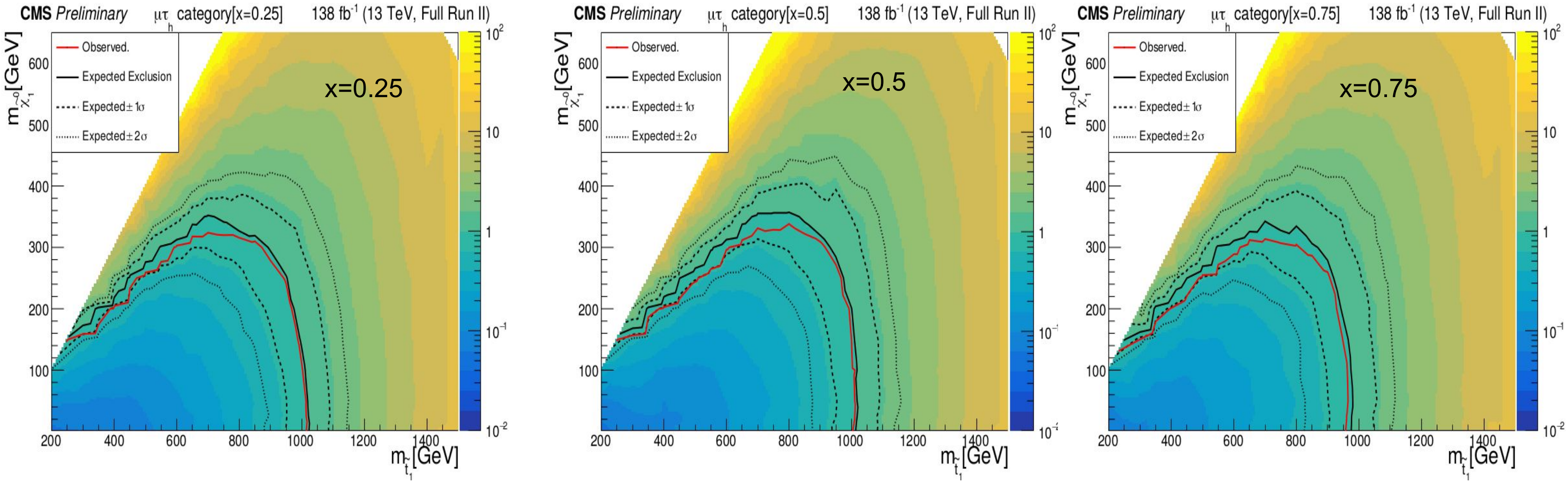
- ➔ These values are the weighted (by the yields in the respective bins) averages of the relative uncertainties in the different search regions
- ➔ For the asymmetric uncertainties, the upper (lower) entry is the uncertainty due to the upward (downward) variation
- ➔ The numbers in square brackets in the heading indicate the top squark and LSP masses in GeV, respectively

Systematics for eτ_h channel (Full Run 2)

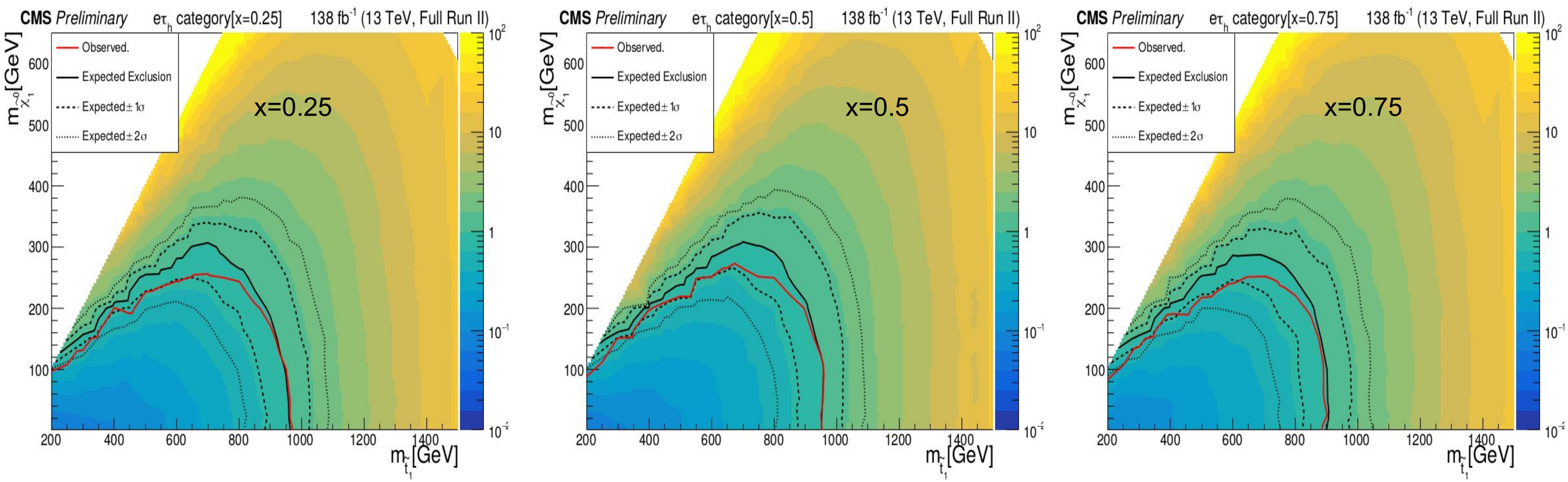
Uncertainty source	x = 0.5 [300,100]	x = 0.5 [500,350]	x=0.5 [800,300]	x=0.5 [1000,1]	$t\bar{t}$	Single Top	DY+Others	MisId. τ_h
Signal cross-section	± 6.9%	± 7.5%	± 9.5%	±11% —	—	—	—	
FastSim p_T^{miss} resolution	± 0.6%	± 0.5%	< 0.1%	< 0.1%	—	—	—	—
τ_h FastSim/FullSim	± 0.9%	± 0.8%	± 1.1%	± 1.6%	—	—	—	—
e FastSim/FullSim	± 1.7%	± 1.4%	± 3.1%	± 3.1%	—	—	—	—
JER	0.1%	0.2%	< 0.1%	+0.1%	—	+0.5%	+2.5%	+0.1%
	-0.4%	-1.5%	-0.1%	+0.1%	—	-0.2%	+0.3%	-0.4%
2018 m_{T2} uncertainty	-	-	-	-	< 0.1%	< 0.1%	< 0.1%	< 0.1%
JEC	0.2%	-0.2%	0.1%	+0.1%	—	0.6%	+3.2%	+0.4%
	-0.2%	-0.3%	-0.1	-0.1%	—	-0.9%	-2.0%	-0.4%
QCD scale	0.5%	1.02%	0.5%	+0.3%	—	4.1%	3.2%	5.5%
	-0.4%	-1.1%	-0.5%	-0.4%	—	4.0%	-4.6%	-5.5%
τ_h Id-iso	+3.2%	+3.2%	3.2%	+3.2%	+3.1%	+3.1%	3.1%	+1.7%
	-3.9%	-4.3%	-4.1%	-4.1%	-3.7%	-3.9%	-3.7%	-1.4%
Pileup	+0.2%	+0.7%	0.4%	+0.4%	—	+0.8%	+0.1%	+0.3%
	-0.1%	0.7%	-0.1%	-0.4%	—	-0.8%	-0.1%	-0.3%
p_T^{miss} Unclustered energy	+0.6%	+0.8%	+0.2%	< 0.1%	—	+0.8%	+3.6%	+0.2%
	-0.4%	-0.7%	-0.2%	0.1%	—	-0.8%	-1.9%	-0.4%
b-tagging	± 0.1%	<0.1%	± 0.2	± 0.5%	—	± 2.0%	± 4.9%	± 0.8%
2017 p_T^{miss} uncertainty	—	—	—	—	< 0.1%	< 0.1%	< 0.1%	< 0.1%
trigger	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
τ_h energy scale	-0.6%	-0.1%	-0.1%	< 0.1%	< 0.1%	+0.1%	1.5%	< 0.1%
	-0.7%	0.4%	-0.1%	< 0.1%	< 0.1%	-0.1%	-3.4%	
$t\bar{t}$ SF	—	—	—	—	± 3.8%	± 4.0%	—	—
τ_h fake rate (parton flavour)	—	—	—	—	—	—	—	± 15%

Exclusion (Full Run 2)

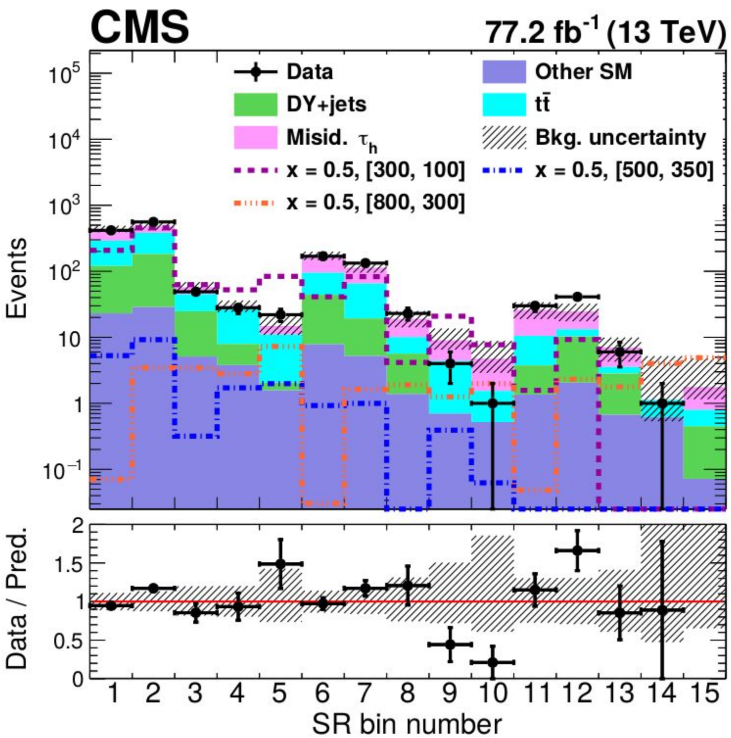
$\mu\tau_h$ category

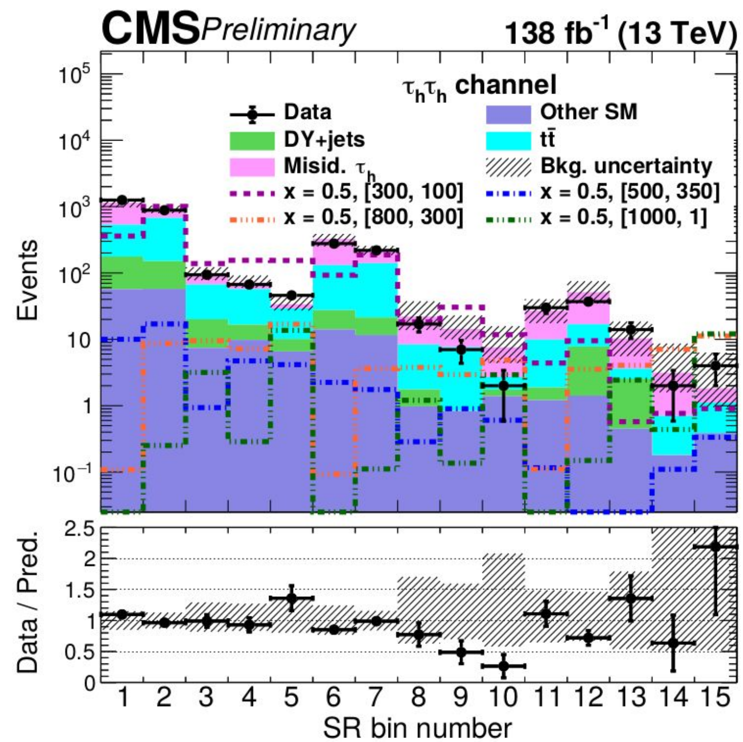


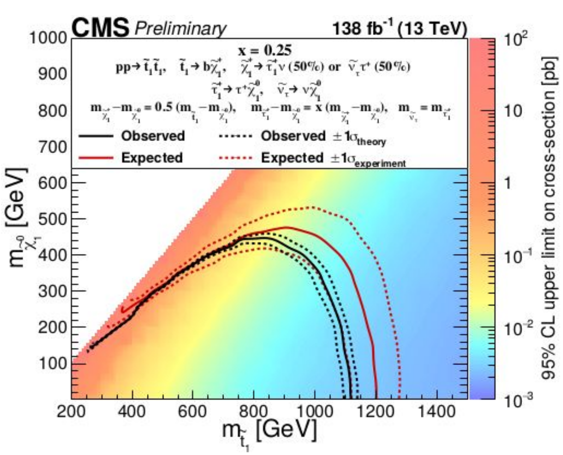
$e\tau_h$ category

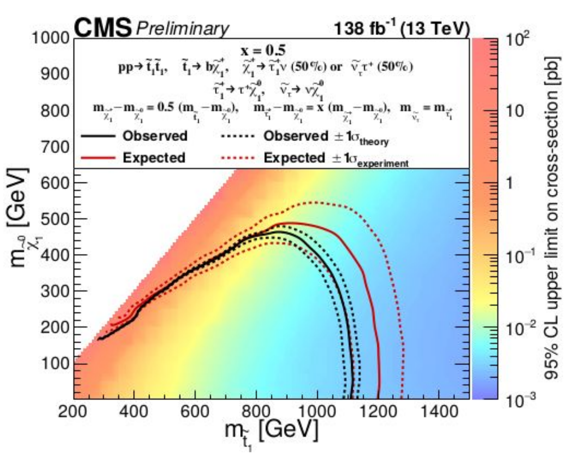


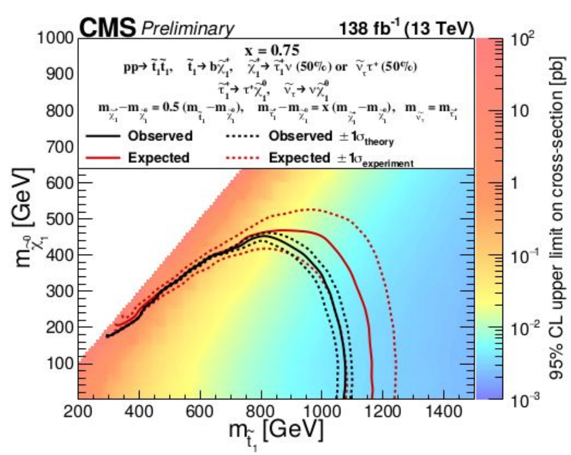
$\tau_h \tau_h$ Results











MSSM Particle spectra

Name	Superfield	Spin-0	Spin-1/2	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
Quarks, Squarks	Q_L	$(\tilde{u} \quad \tilde{d})_L$	$(u \quad d)_L$	3	2	1/6
(×3 familes)	U_R	$\tilde{u}_R$	u_R	$\bar{3}$	1	−2/3
	D_R	$\tilde{d}_R$	d_R	$\bar{3}$	1	1/3
Leptons, Sleptons	L_L	$(\tilde{\nu} \quad \tilde{e})_L$	$(\nu \quad e)_L$	+1	+2	−1/2
(×3 familes)	E_R	$\tilde{e}_R$	e_R	1	1	1
Higgs, Higgsinos	H_u	$(H_u^+ \quad H_u^0)$	$(\tilde{H}_u^+ \quad \tilde{H}_u^0)$	1	2	1/2
	H_d	$(H_d^0 \quad H_d^-)$	$(\tilde{H}_d^0 \quad \tilde{H}_d^-)$	1	2	−1/2

Name	Spin-1/2	Spin-1	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
Gluon, Gluino	$\tilde{g}$	g	8	1	0
W bosons, Winos	$\widetilde{W}^{\pm} \quad \widetilde{W}^0$	$W^{\pm} \quad W^0$	1	3	0
B bosons, Binos	$\widetilde{B}^0$	B^0	1	1	0

SR Yields (Full Run 2)

SR Bin	Tot Bkg.	Data
1	$16222.2^{+68.8+657.9}_{-68.8-675.2}$	15744
2	$16374.3^{+65.1+598.3}_{-65.1-658.0}$	15605
3	$1601.4^{+19.8+64.1}_{-19.8-73.2}$	1524
4	$1047.6^{+16.5+46.0}_{-16.5-49.1}$	1039
5	$514.3^{+11.1+37.7}_{-11.1-40.8}$	520
6	$9824.8^{+49.4+350.5}_{-49.4-381.7}$	9372
7	$6559.3^{+38.9+262.8}_{-38.9-296.0}$	6222
8	$418.0^{+9.8+24.5}_{-9.8-26.5}$	435
9	$343.1^{+8.8+17.6}_{-8.8-18.4}$	303
10	$99.1^{+4.8+8.9}_{-4.8-9.4}$	95
11	$1149.8^{+16.8+43.3}_{-16.8-47.4}$	1131
12	$872.6^{+14.5+37.4}_{-14.5-46.0}$	921
13	$96.7^{+5.4+6.5}_{-5.4-7.0}$	114
14	$42.5^{+3.3+4.3}_{-3.3-4.5}$	49
15	$17.1^{+1.9+2.7}_{-1.9-2.5}$	17
Total	$55182.9^{+120.1+997.4}_{-120.1-1066.4}$	53122

1e+1τ_h category

SR Bin	Tot Bkg.	Data
1	$30800.6^{+103.9+1232.3}_{-103.9-1266.6}$	29475
2	$25860.8^{+85.0+942.5}_{-85.0-1017.3}$	25055
3	$2323.1^{+24.8+97.1}_{-24.8-105.9}$	2273
4	$1700.2^{+22.8+74.7}_{-22.8-99.2}$	1678
5	$763.5^{+13.5+58.1}_{-13.5-61.6}$	800
6	$18752.4^{+69.0+662.9}_{-69.0-723.4}$	18412
7	$10685.4^{+50.9+438.3}_{-50.9-477.4}$	10441
8	$665.9^{+12.8+39.7}_{-12.8-40.6}$	638
9	$554.5^{+12.0+30.0}_{-12.0-32.8}$	565
10	$149.1^{+6.0+14.3}_{-6.0-14.3}$	132
11	$1931.3^{+22.2+71.5}_{-22.2-84.8}$	2027
12	$1383.2^{+19.1+62.0}_{-19.1-66.0}$	1333
13	$127.9^{+6.1+10.3}_{-6.1-10.3}$	111
14	$70.2^{+4.2+6.6}_{-4.2-6.6}$	69
15	$20.0^{+2.1+3.0}_{-2.1-2.8}$	18
Total	$95869.8^{+167.4+1718.6}_{-167.4-1831.8}$	93072

1μ+1τ_h category