Search for supersymmetry with τ leptons in the CMS experiment

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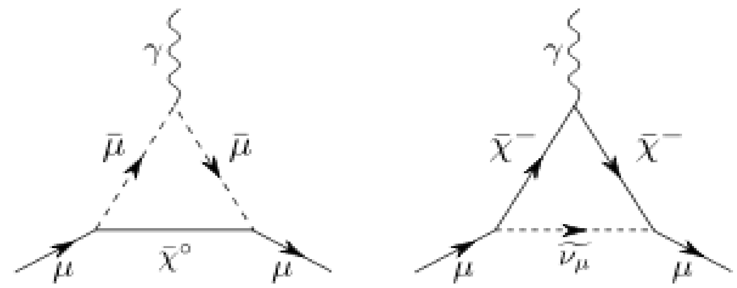
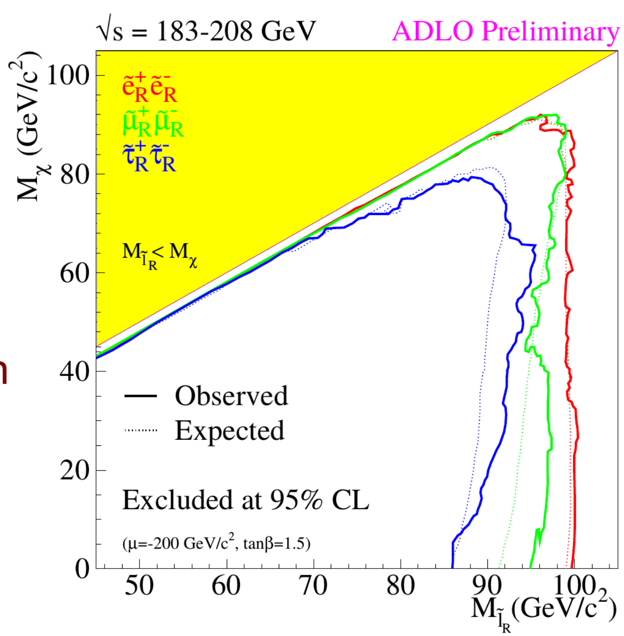
LHC discussion on SUSY, November 19, 2018

Introduction

- LSP co-annihilation with light stau could bring the neutralino relic density to the observed value
- SUSY can explain ~3σ deviation of muon g – 2 from SM prediction → light electroweak sector
- Likelihood analysis of experimental constraints predicts light staus arXiv:1710.11091v2

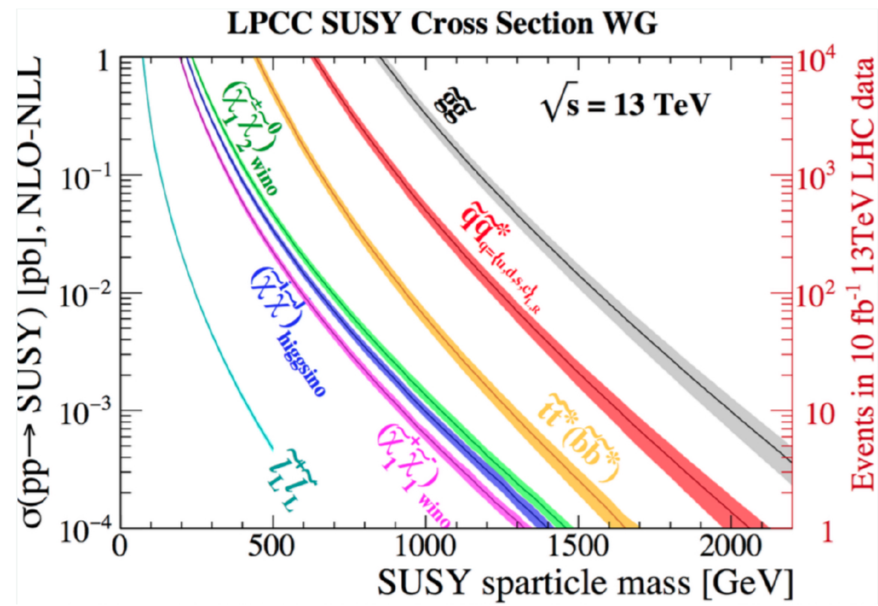


LEP results



LEP put strong limits on slepton masses

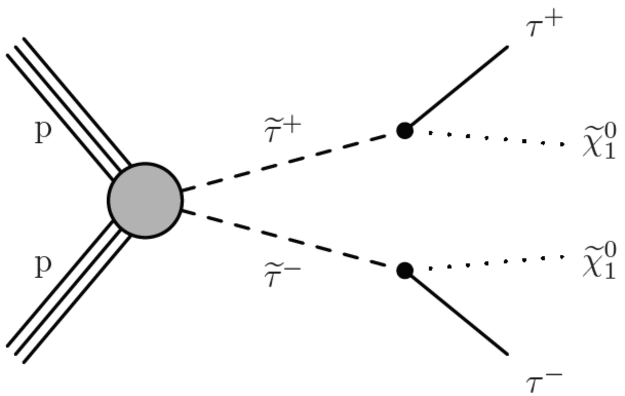
LHC SUSY Cross Section



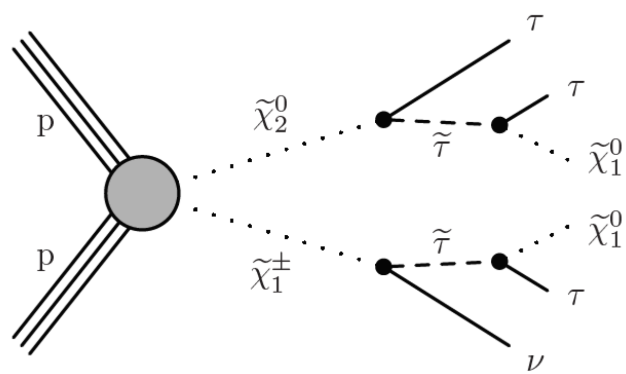
Small slepton cross section makes analysis challenging!

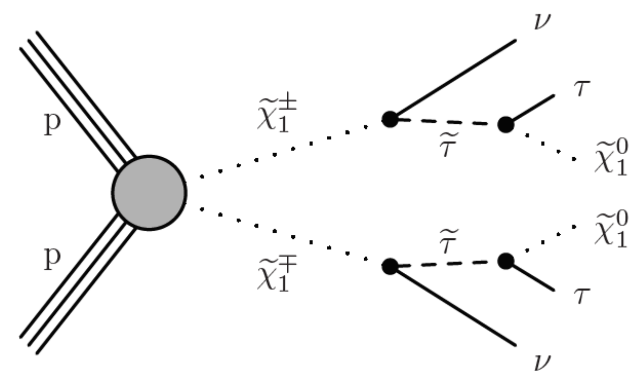
Models and topologies

Direct production



Indirect production





Experimental signature

- Missing transverse energy depends on the model parameters
- Small number of jets and no b-tagged jets

Channel	Signature	$\mathcal{BR}$
$0-\ell$	$2\tau_h + \not{E}_T$	$0.65^2 = 0.42$
$1-\ell$	$\tau_\ell\tau_h + \not{E}_T$	$2\times(0.35\cdot 0.65) = 0.46$
$2-\ell$	$2\tau_\ell + \not{E}_T$	$0.35^2 = 0.12$

Covered by SUS-17-003
$\tau_h\tau_h$

Covered by SUS-17-002
$\mu\tau_h$, $e\tau_h$, $e\mu$

Search variables

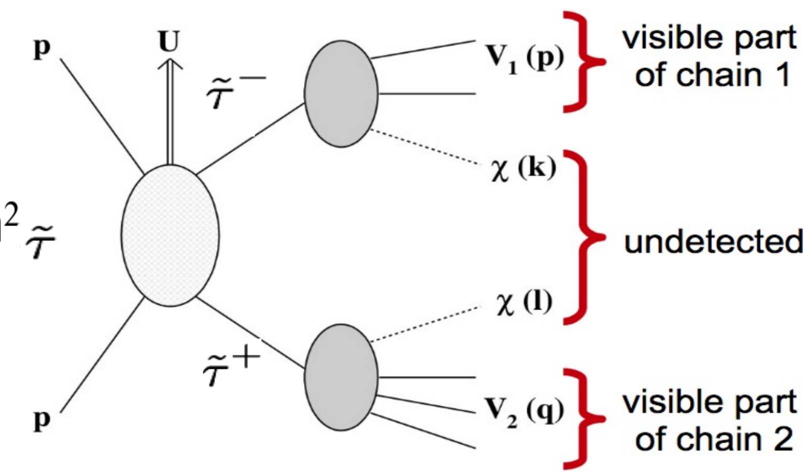
- E_{Tmiss} – missing transverse energy
- M_{T2} – “stransverse” mass

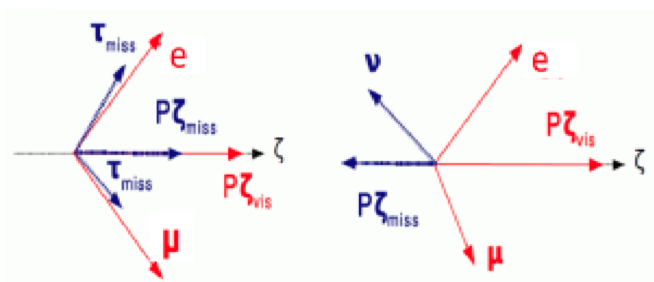
$$M_{T2}^2 = \min_{\vec{k}_T+\vec{l}_T=\text{tot miss }\vec{p}_T} \left\{ \max\left[M_T^2(\text{chain 1}), M_T^2(\text{chain 2}) \right] \right\} \leq m^2_{\tilde{\tau}}$$

- Sum M_T

$$\Sigma M_T = M_T(\ell_1, \vec{p}_T^{\,\text{miss}}) + M_T(\ell_2, \vec{p}_T^{\,\text{miss}})$$

- D_ζ – Discriminant used in legacy Higgs searches





$$D_\zeta = P_{\zeta,\text{mis}} - \alpha \cdot P_{\zeta,\text{vis}}$$

$$P_{\zeta,\text{mis}} = \vec{p}_{T,\text{mis}} \cdot \vec{\zeta}, \quad P_{\zeta,\text{vis}} = (\vec{p}_{T,e} + \vec{p}_{T,\mu}) \cdot \vec{\zeta}$$

ζ – bisector between the direction of the muon

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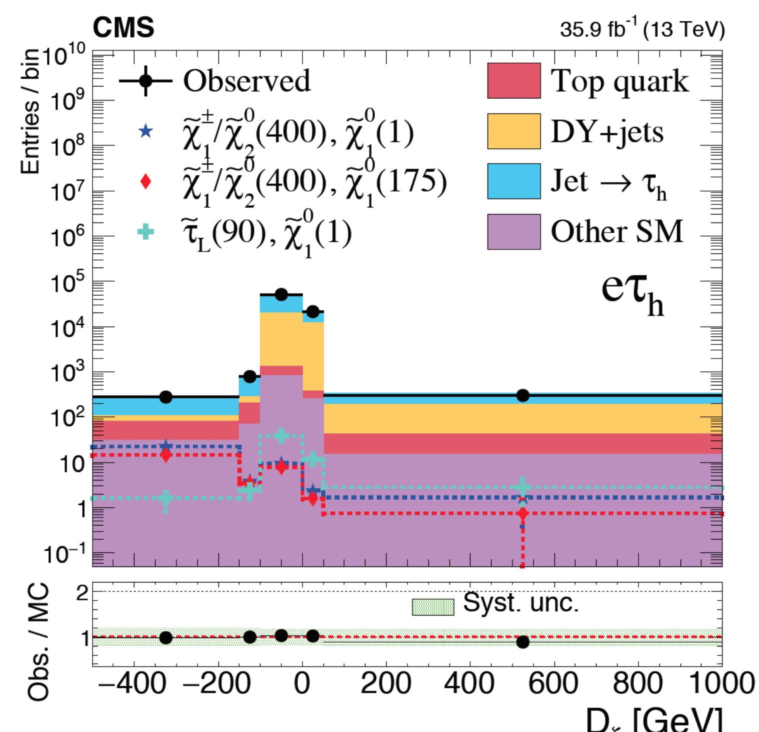


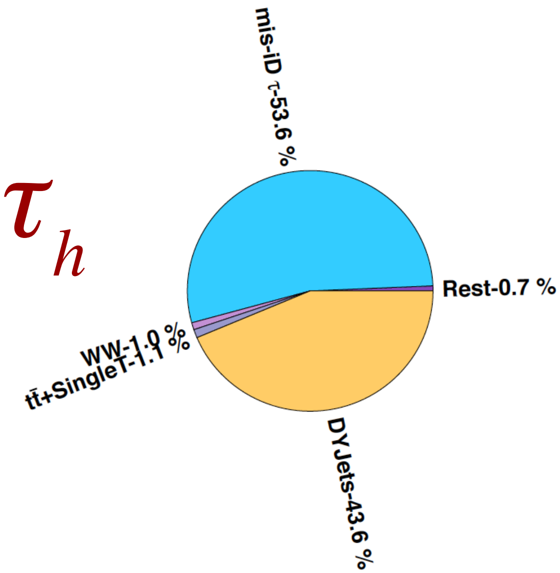
Search strategy $\mu\tau_h$, $e\tau_h$, $e\mu$

SUS-17-002

Selection (36 /fb of Run 2 2016 data)

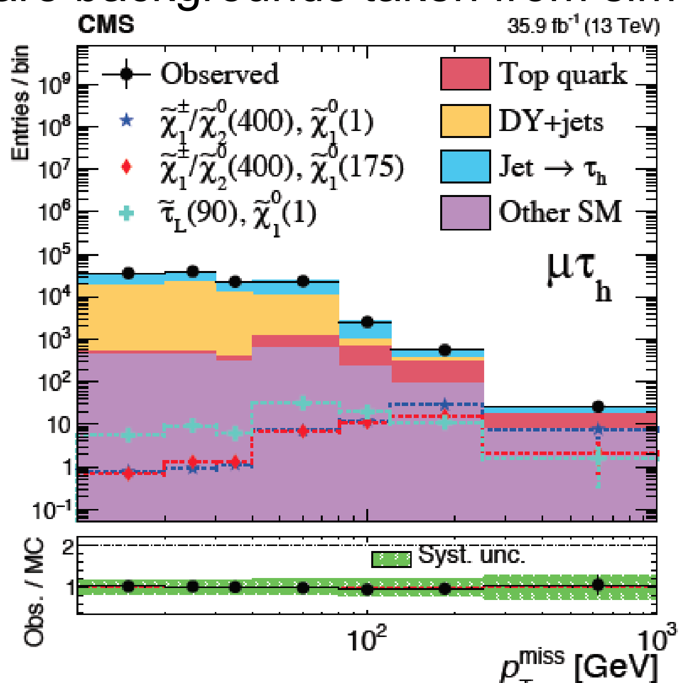
- Opposite charge pair of identified isolated leptons
- No additional leptons
- only 0 or 1 jet and no jets originating from bottom quarks

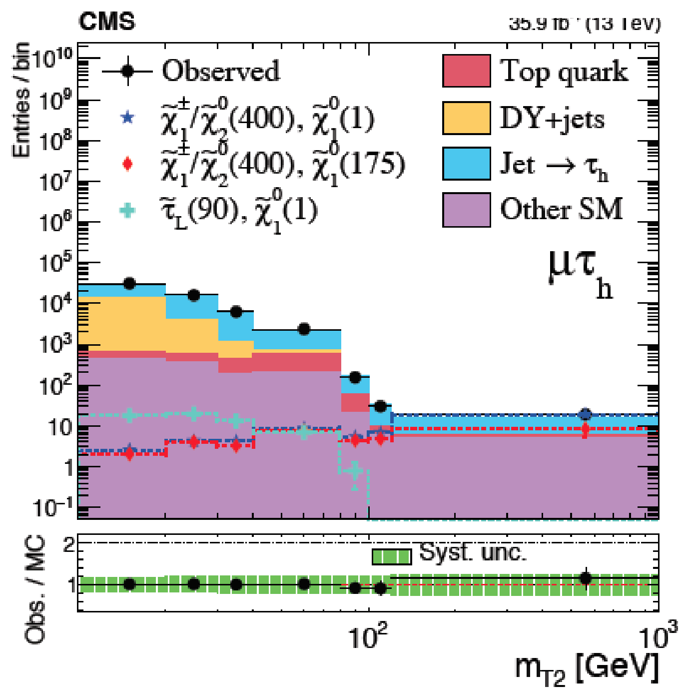
$\mu\tau_h$



Background estimation

- Z+jets and top pair production: corrected shape is taken from MC and normalization from orthogonal CRs
- Jets misidentified as τh: shape is estimated from CR and transfer factor is calculated as a ratio of yields in orthogonal CRs
- Other rare backgrounds taken from simulation

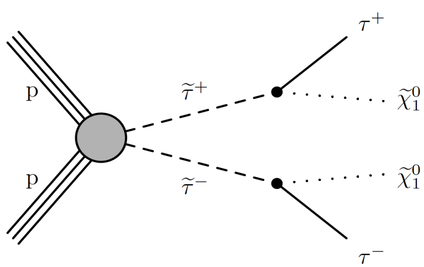


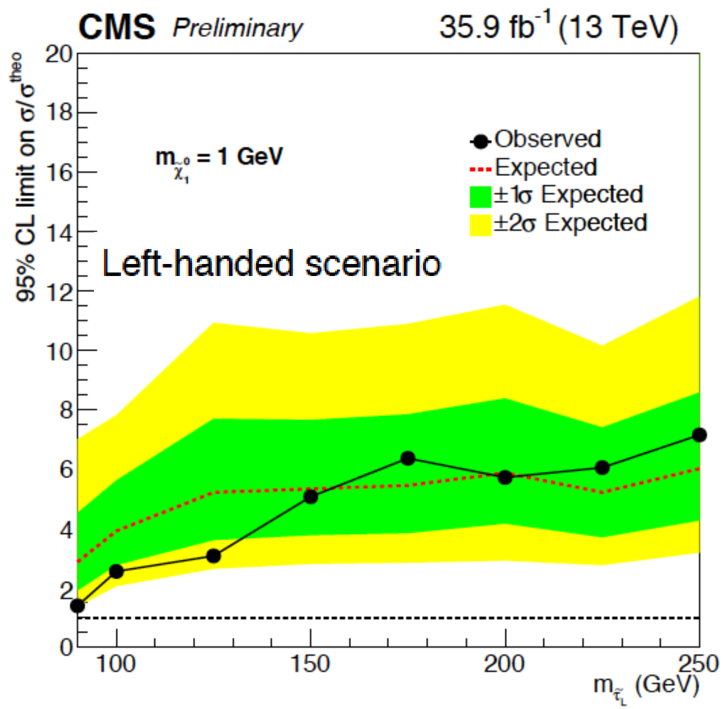


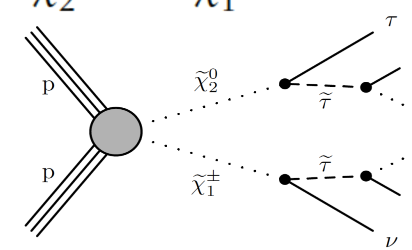
Interpretation $\mu\tau_h$, $e\tau_h$, $e\mu$

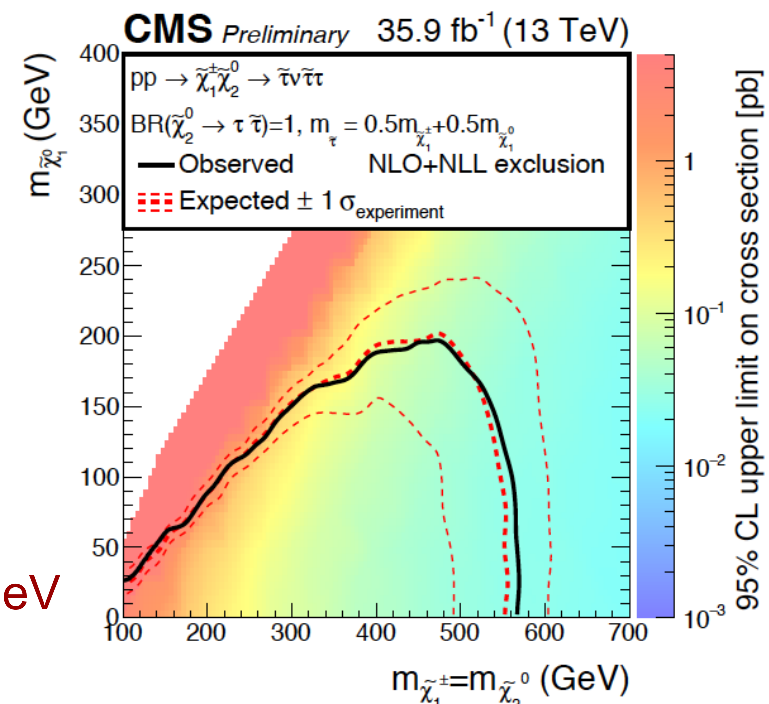
For cut based approach 132 search bins are defined with kinematic variables and jet multiplicity.

For chargino-neutralino (C1N2) interpretation $m_{\tilde{\tau}} = m_{\tilde{\chi}_1^0} + x(m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$









- No significant deviation in any signal region
- Exclude N2 and C1 decaying through staus below 560 GeV for ~ massless LSP
- Direct stau production not yet excluded due to low cross section
- For left-handed stau of around 90 GeV and a massless LSP we exclude 1.5 times the expected SUSY cross-section

CMS-PAS-SUS-17-002, https://cds.cern.ch/record/2297162

Search strategy $\tau_h \tau_h$

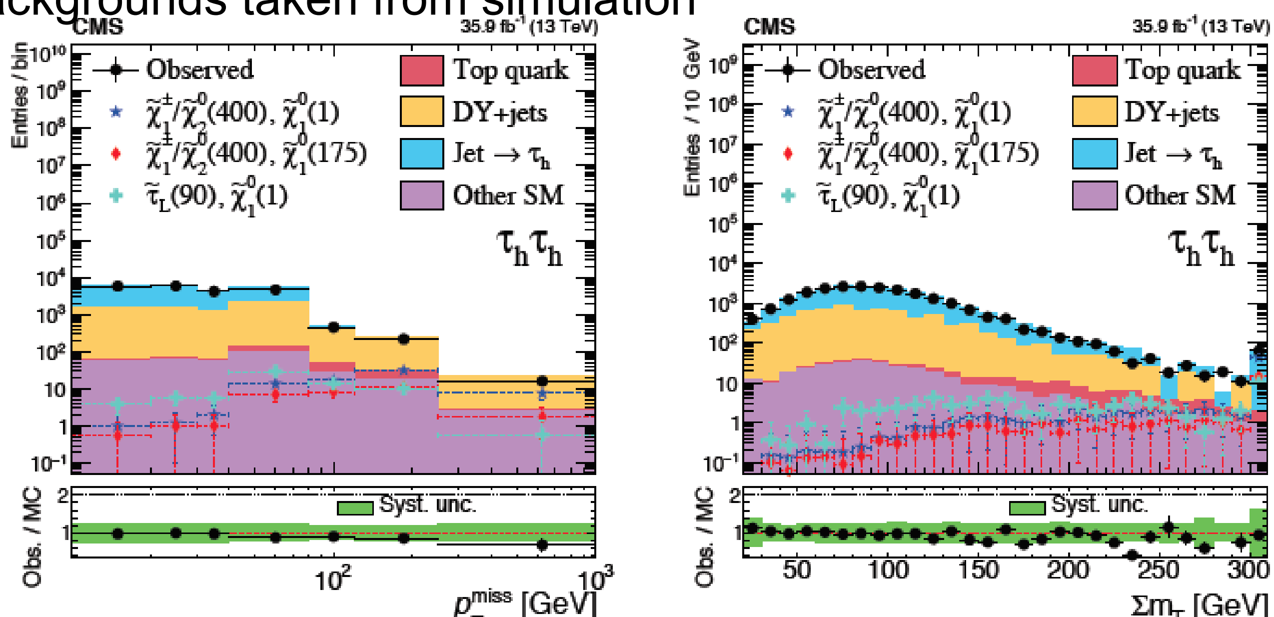
SUS-17-003

Selection (36 /fb of Run 2 2016 data)

- Opposite charge pair of identified hadronically decaying taus
- No additional leptons
- no jets originating from bottom quarks

Background estimation

- Z+jets: Check DY mass and pT spectrum in dimuon CR and correct the simulation for any discrepancies
- QCD, W+Jets: Background if jet fakes tau - fake rate derived in the same sign data events and parameterized as function of pT and decay mode
- Other rare backgrounds taken from simulation



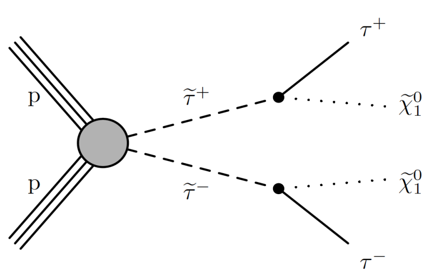
Interpretation $\tau_h \tau_h$

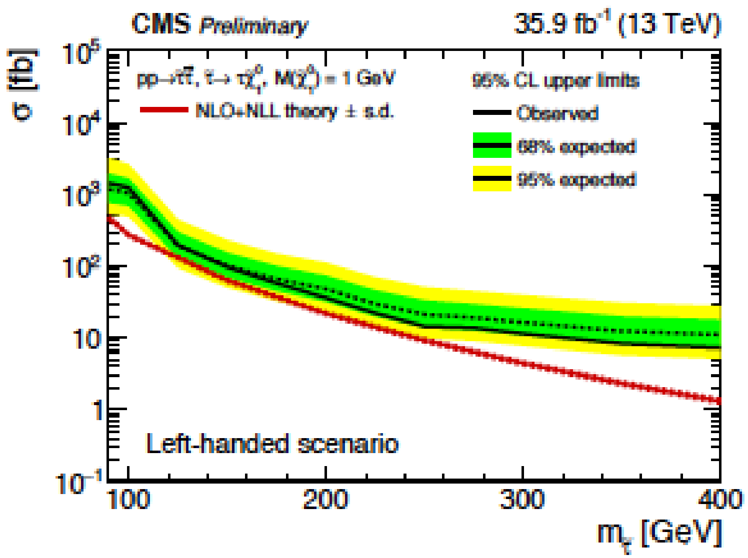
SUS-17-003

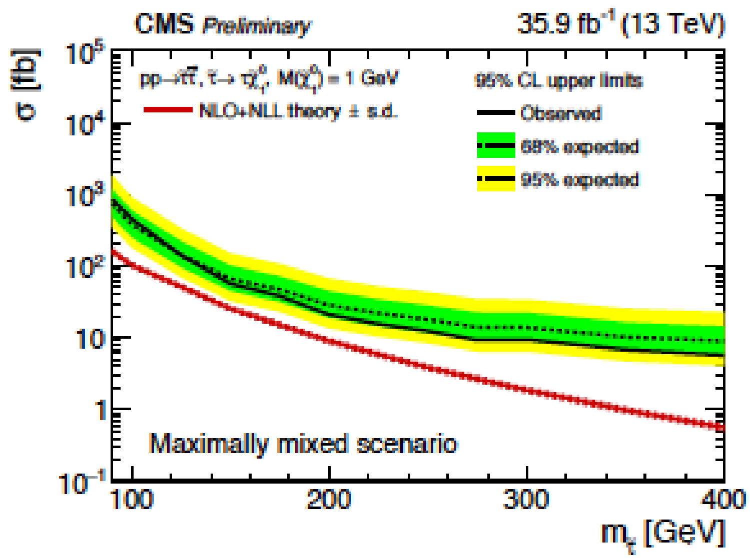
low mass | **high mass**

SR:

low mass	high mass	high mass
$40\,\mathrm{GeV} < M_{T2} < 90\,\mathrm{GeV}$	$40\,\mathrm{GeV} < M_{T2} < 90\,\mathrm{GeV}$	$M_{T2} > 90\,\mathrm{GeV}$
$\Sigma M_T > 350\,\mathrm{GeV}$	$300\,\mathrm{GeV} < \Sigma M_T < 350\,\mathrm{GeV}$	$\lvert\Delta\phi(l_1,l_2)\rvert > 1.5$
$E_T^{miss} > 50\,\mathrm{GeV}$	$E_T^{miss} > 50\,\mathrm{GeV}$	
$\lvert\Delta\phi(l_1,l_2)\rvert > 1.5$	$\lvert\Delta\phi(l_1,l_2)\rvert > 1.5$	



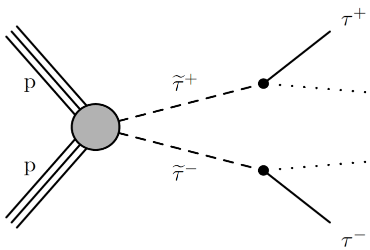


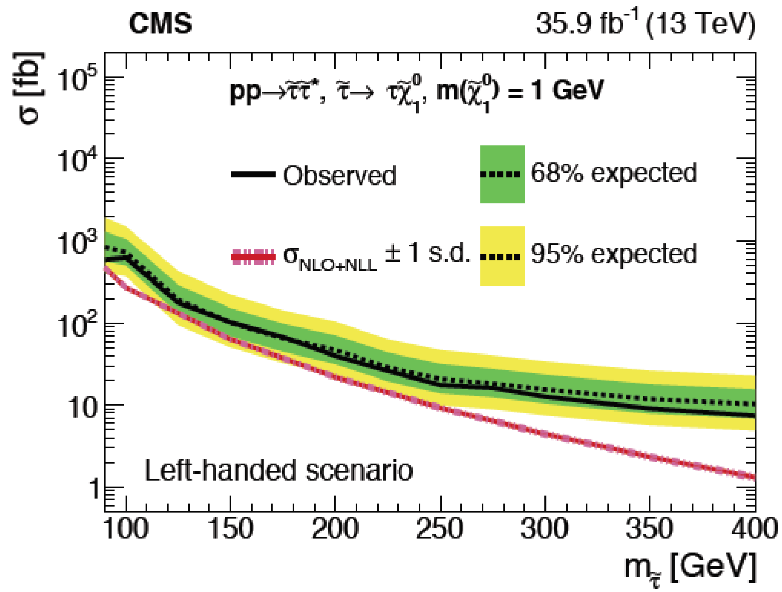


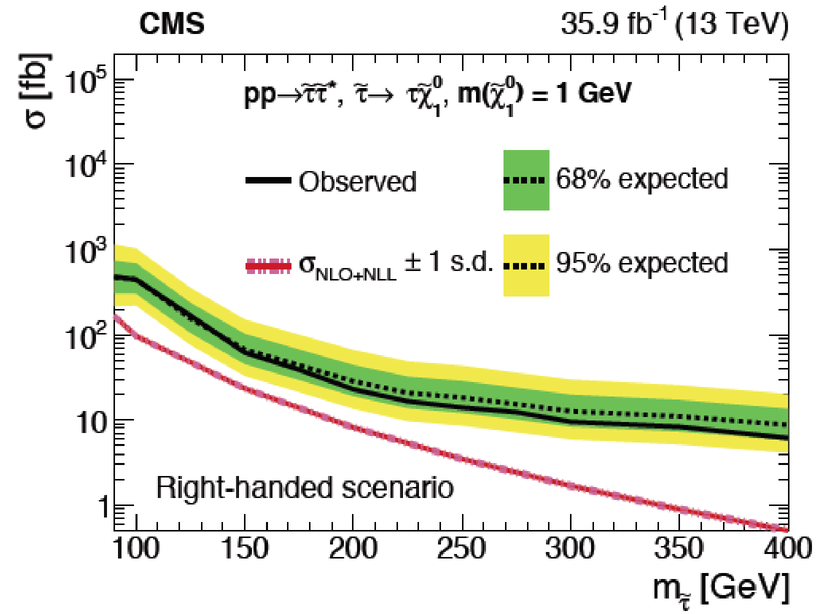
- No significant deviation in any signal region
- Direct stau production not yet excluded due to low cross section
- For left-handed stau of around 150 GeV and a massless LSP we exclude 1.5 times the expected SUSY cross-section

CMS-PAS-SUS-17-003, https://cds.cern.ch/record/2273395

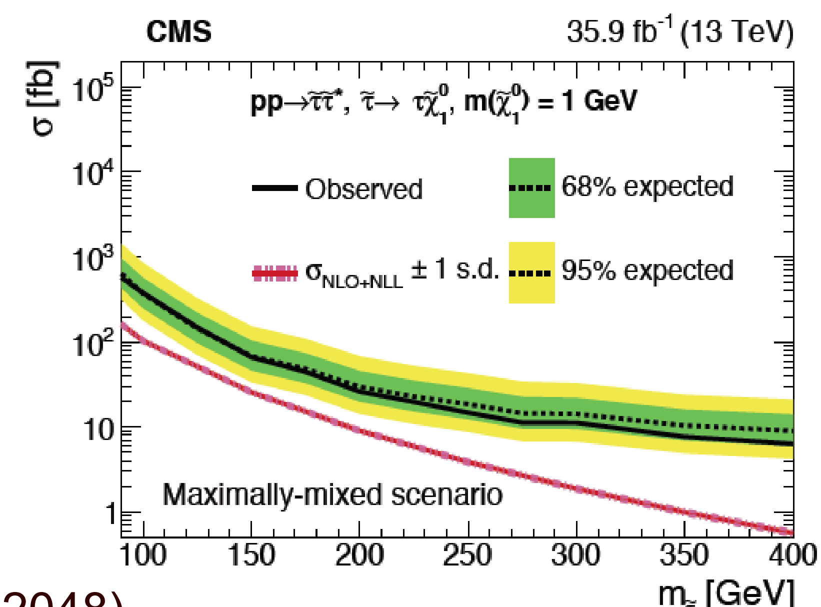
Combination $\tau_h \tau_h$ and $\mu\tau_h$, $e\tau_h$, $e\mu$



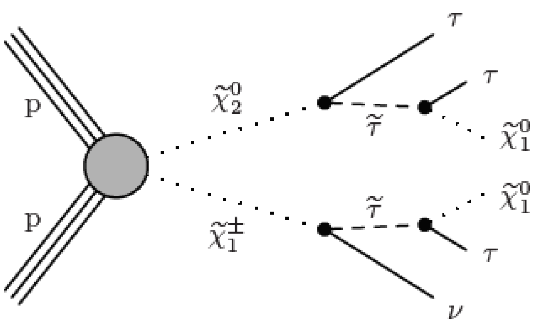


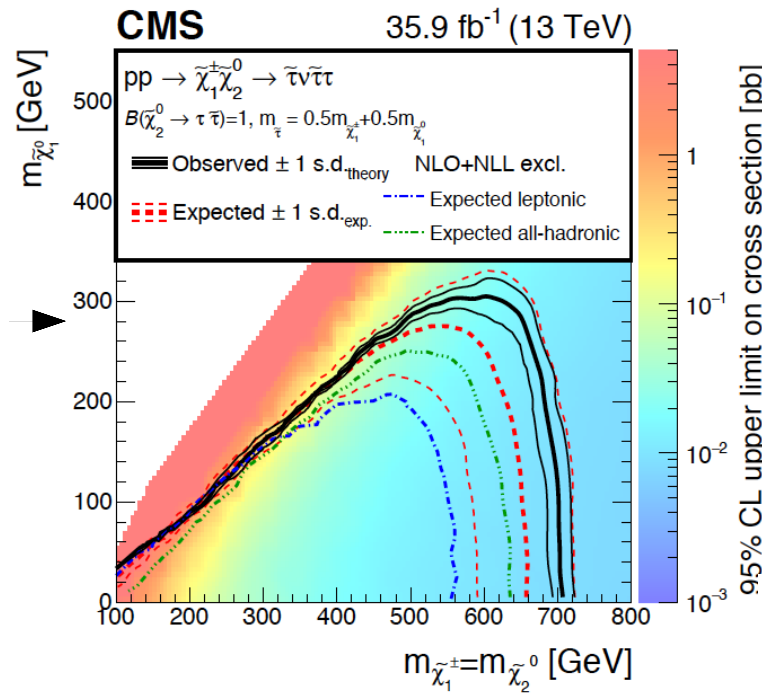


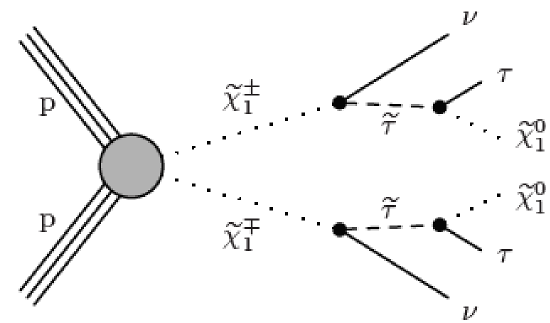
- For direct stau production we use three different stau "chiral states":
  - a purely left-handed stau
  - a purely right-handed stau
  - maximal mixing between the right- and left-handed eigenstates
- Direct stau production not yet excluded due to lov cross section with 2016 data
- Accepted by JHEP (arXiv 1807.02048)

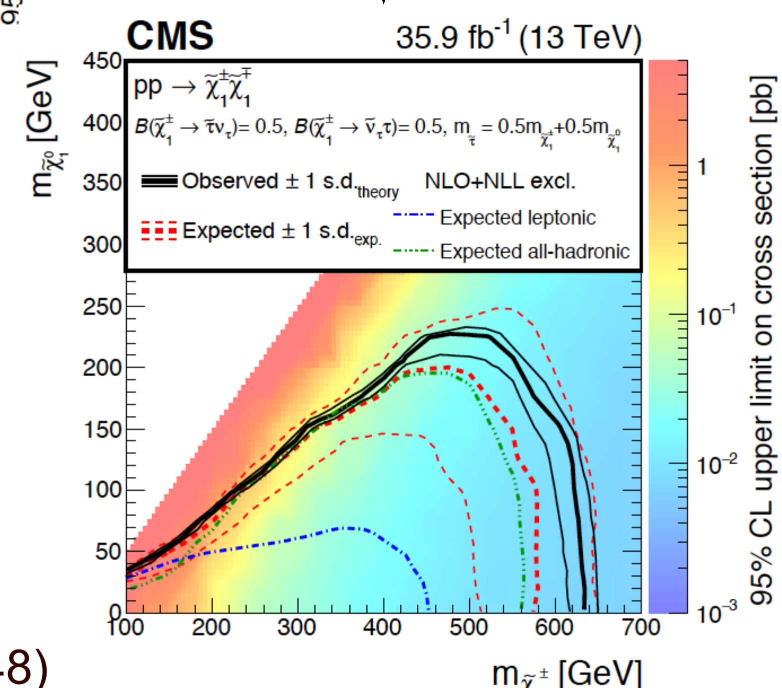


Combination $\tau_h\tau_h$ and $\mu\tau_h$, $e\tau_h$, $e\mu$









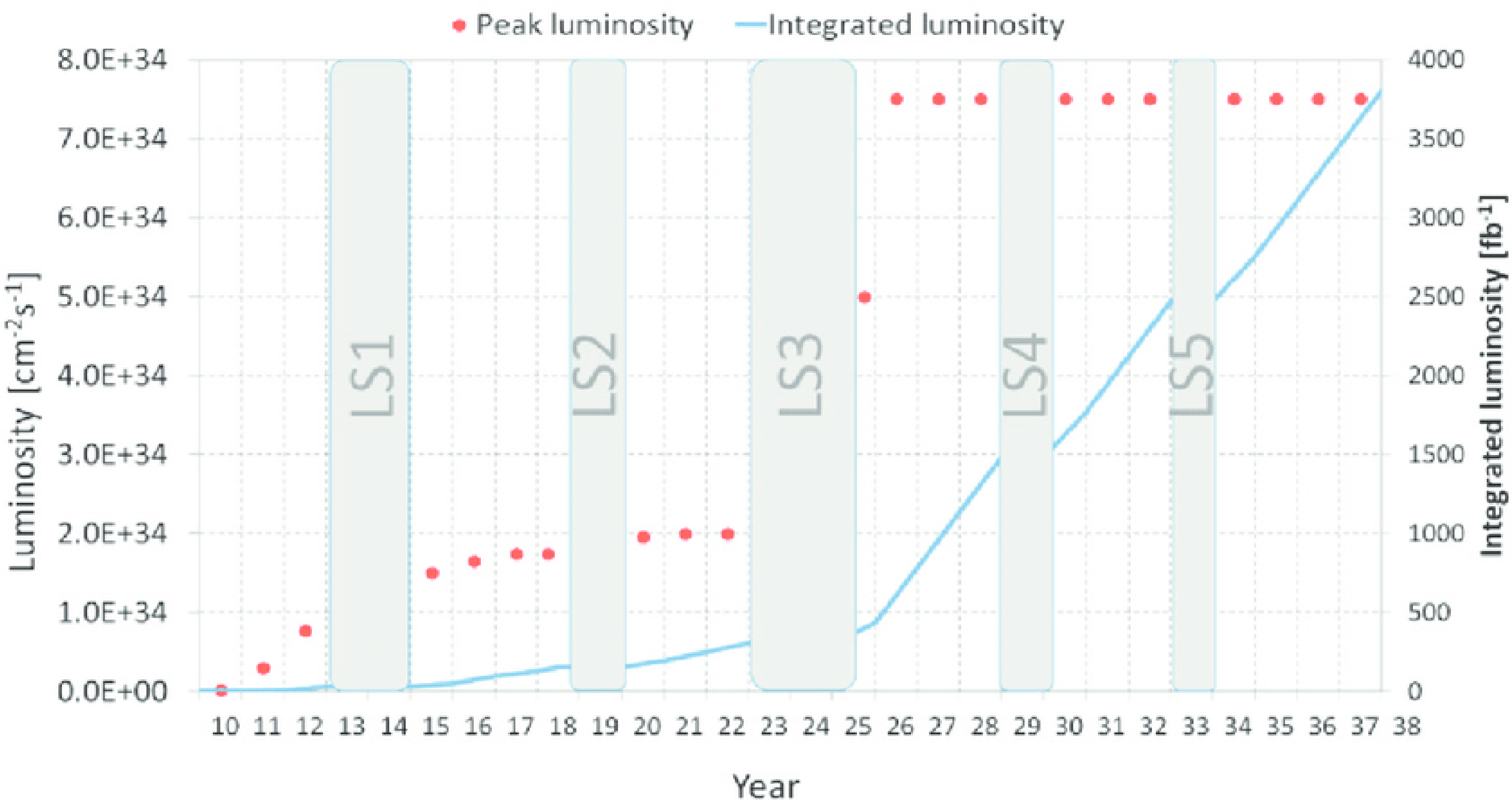
- Stau mass is an average value between the mass of the parent sparticles and LSP.
- For chargino pair production equal branching fractions are assumed for each of the two possible chargino decay chains.
- For chargino-neutralino production we set chargino mass to be equal to neutralino mass.

Accepted by JHEP (arXiv: 1807.02048)

High Luminosity LHC stau search

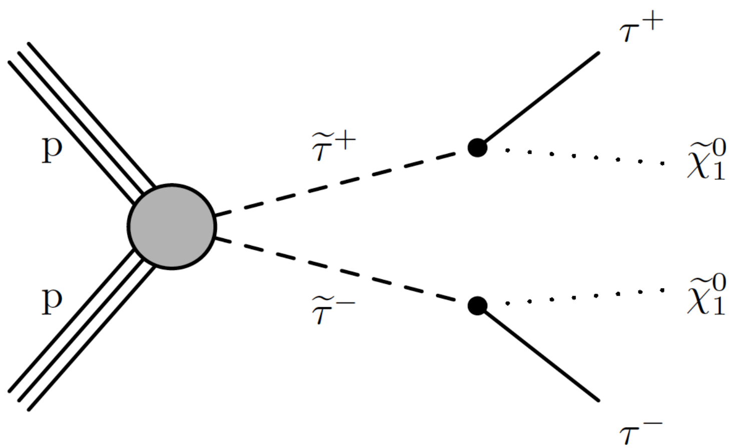
FTR-18-010

- Increase in energy (14 TeV) and tremendous increase in luminosity (3 ab^{-1}) will dramatically improve sensitivity to light stau SUSY scenarios



Technical details

FTR-18-010



We are targeting direct stau production with final state with MET and two tau decaying in different channels

τ_h

Channel	Signature	$\mathcal{BR}$
$0-\ell$	$2\tau_h+\not{E}_T$	$0.65^2 = 0.42$
$1-\ell$	$\tau_\ell\tau_h+\not{E}_T$	$2\times(0.35\cdot 0.65) = 0.46$
$2-\ell$	$2\tau_\ell+\not{E}_T$	$0.35^2 = 0.12$

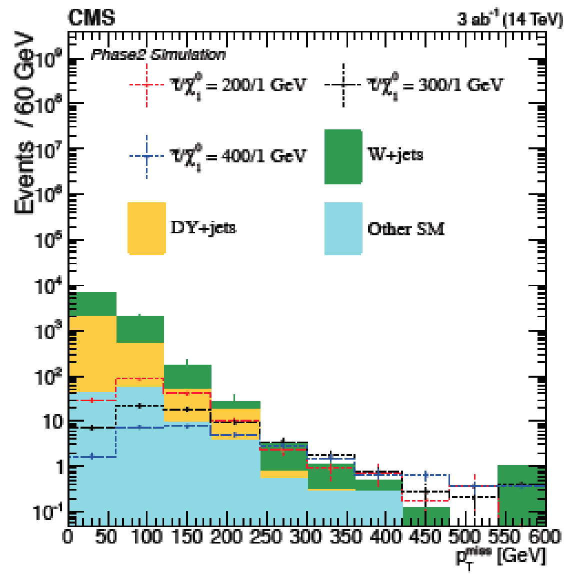
$l\tau_h$

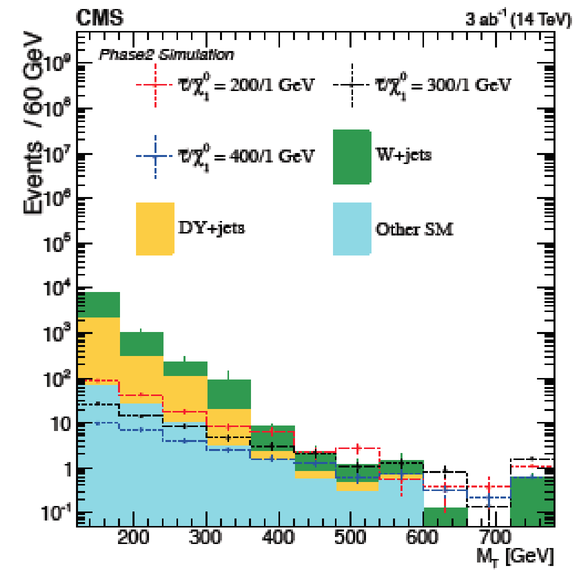
- Selection of oppositely charged tau
- Main backgrounds are jet faking tau from Wjet and genuine hadronic tau from DY
- To imitate full-sim tau reconstruction all PUPPI jets are selected and matched to generator level taus. Matched jets are multiplied by the tau ID efficiency, unmatched are multiplied by the fake rate
- The Delphes simulation of the CMS Phase 2 detector is used

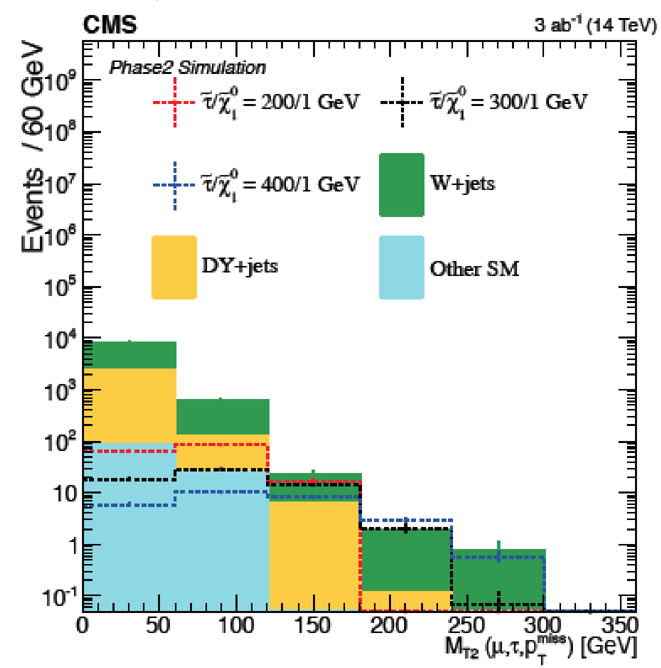
Search region variables

$\mu\tau_h$

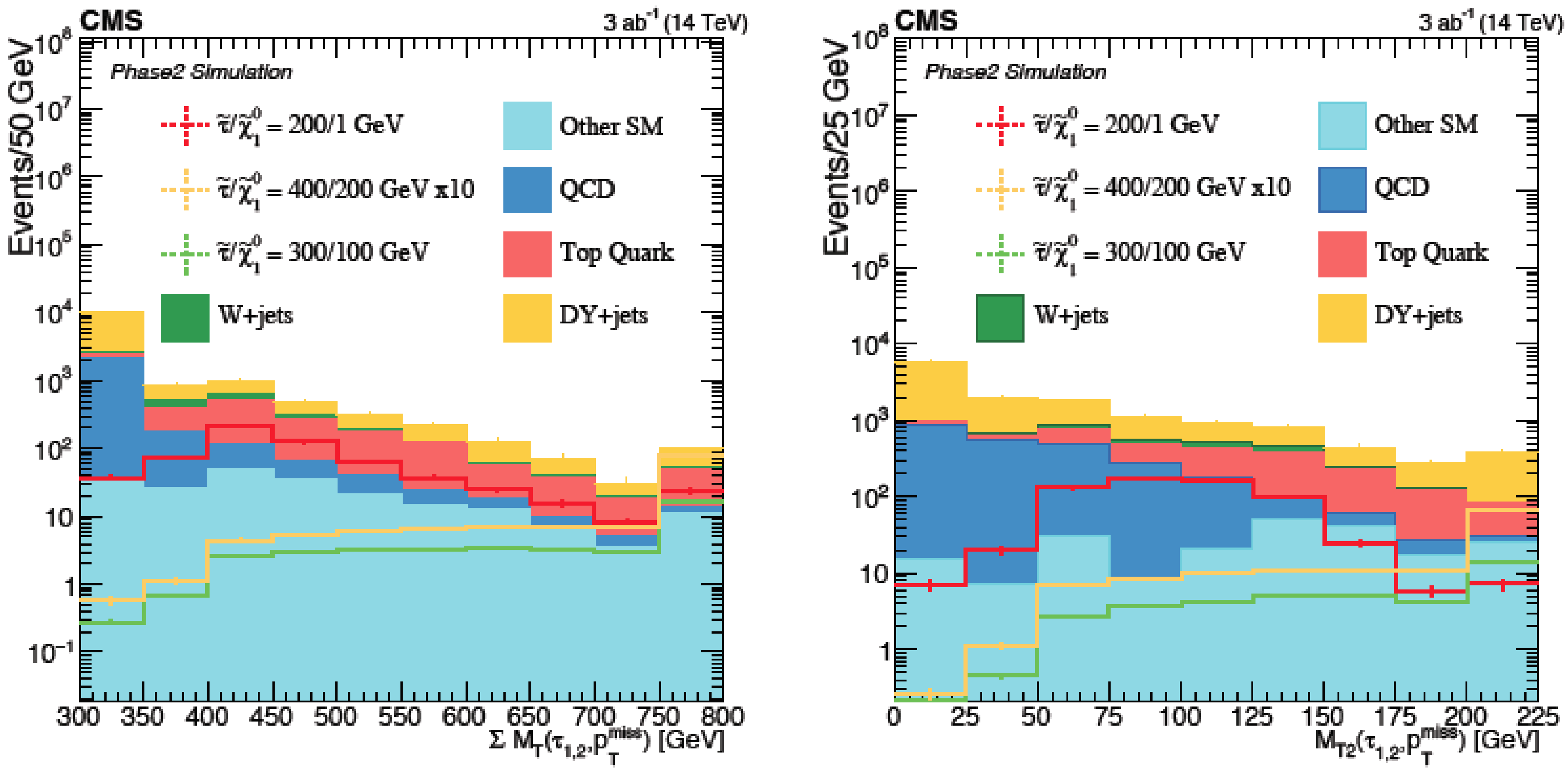
- Search region variables distributions are after baseline selection
- Stau signal is scaled with mass-degenerate scenario
- Other SM corresponds to QCD , top, diboson and triboson production processes







Search region variables $\tau_h \tau_h$

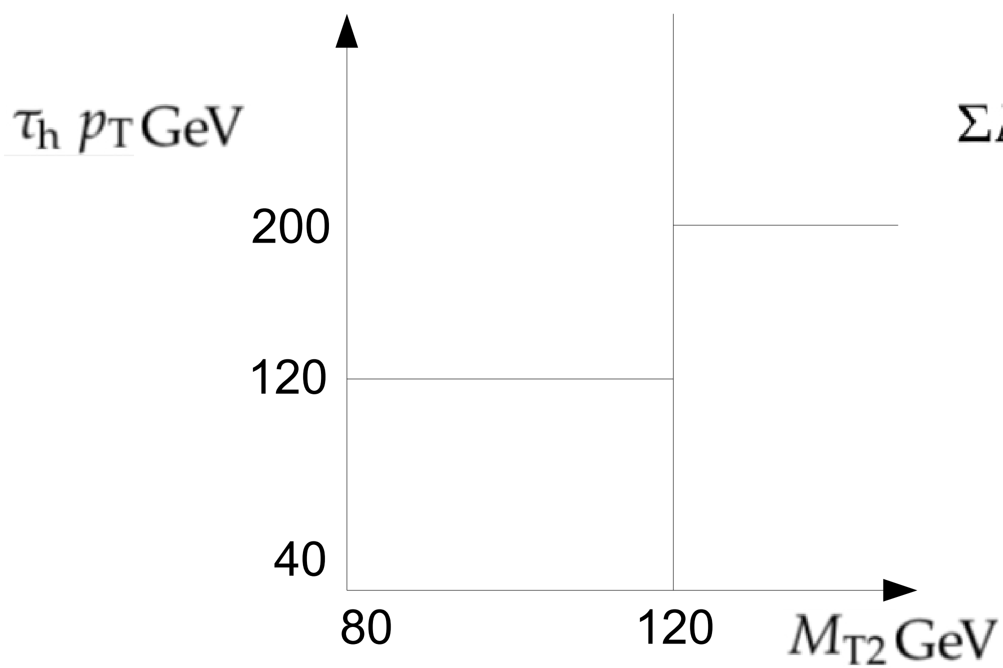


- Other SM corresponds to diboson and triboson production processes

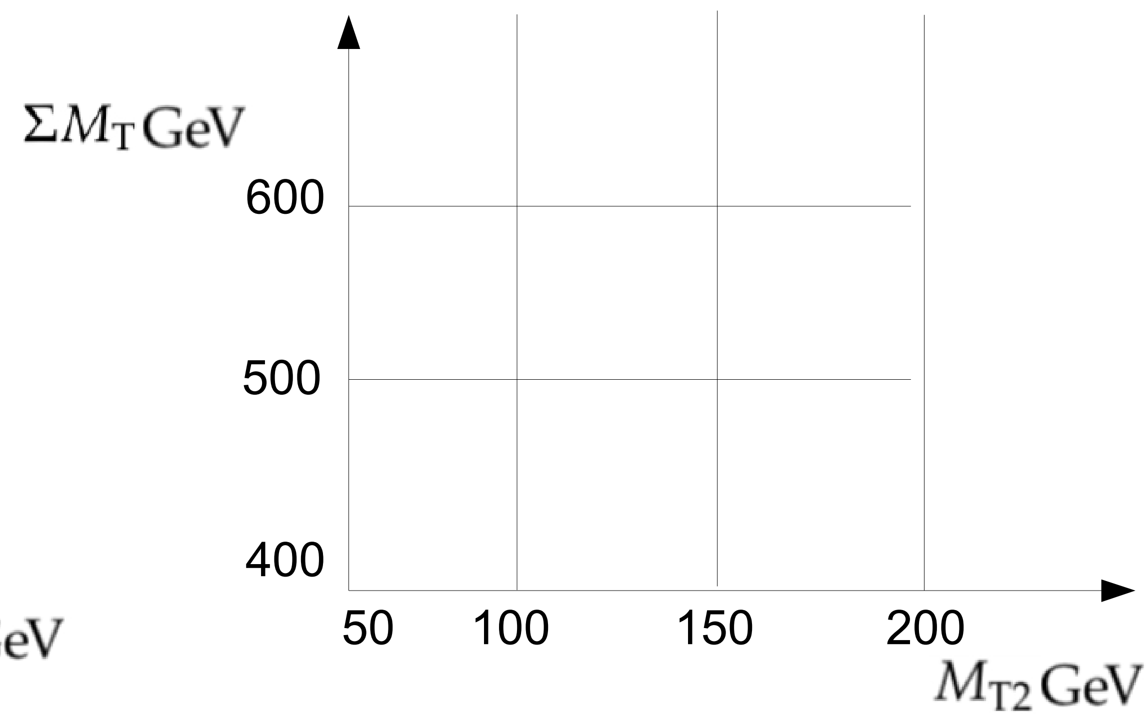
Search region definition

FTR-18-010

Search regions for $l\tau_h$



Search regions for $\tau_h\tau_h$

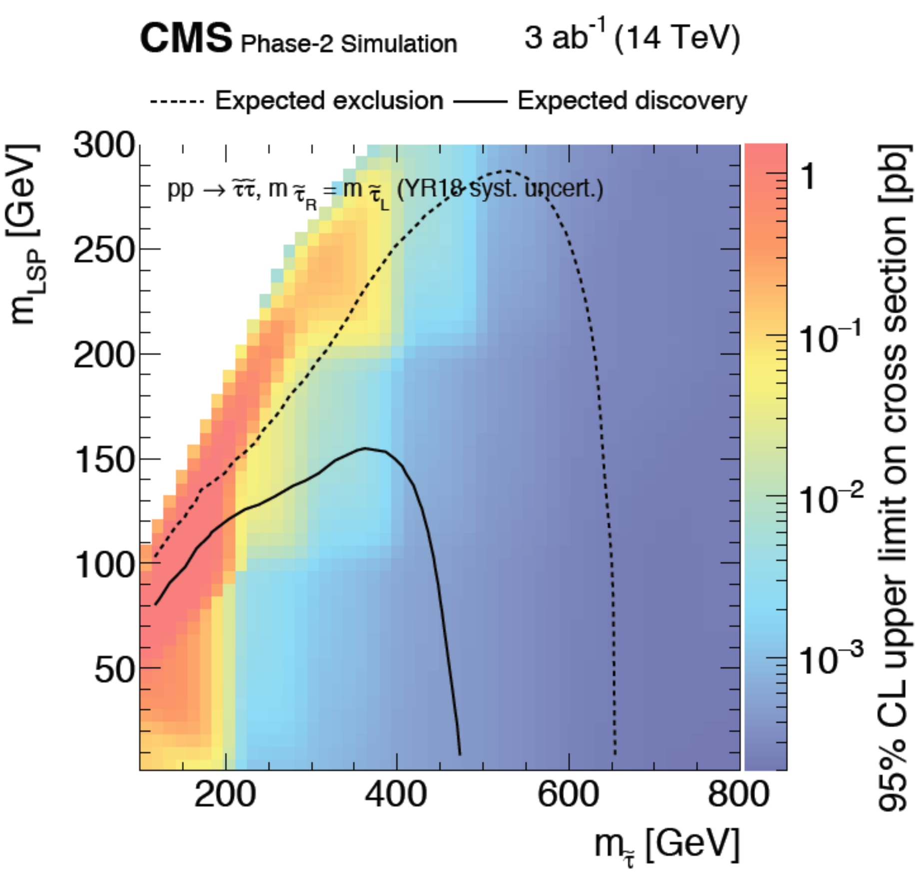


Additional binning in number of jets

Interpretation

FTR-18-010

The results are interpreted as a 95% CL upper limit on the maximally-mixed stau scenario, under the assumption of a degenerate left and right-handed stau cross-section



- The stau analysis has sensitivity for discovery (exclusion) to "Degenerate" stau production w/ a massless lsp for stau masses of 470 (650) GeV

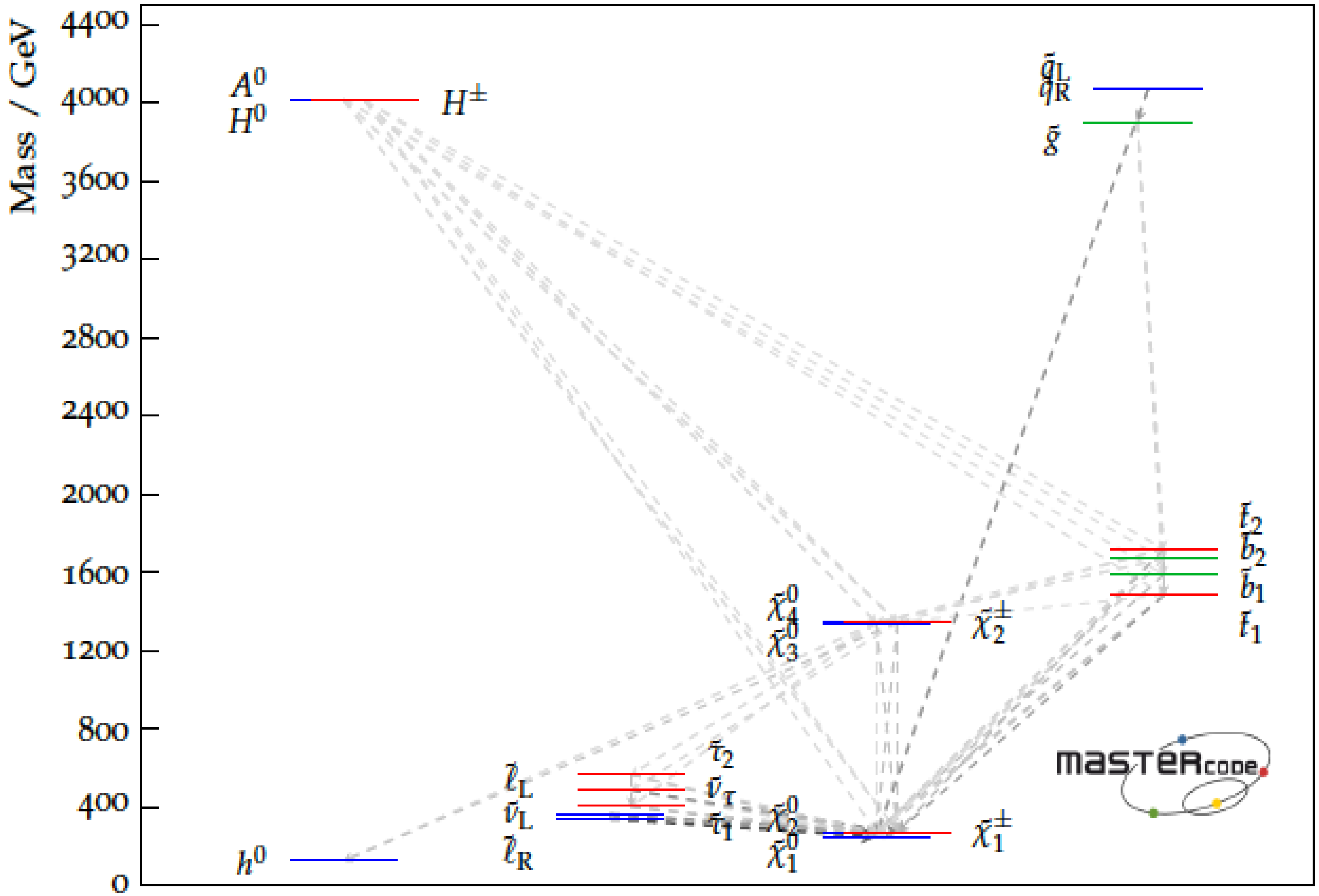
Conclusion

- Run 2 analysis with 2016 data in leptonic channel has a good sensitivity to indirect stau production but not yet sensitive to direct scenario (PAS SUS-17-002)
- Combination with full-hadronic channel (paper SUS-17-003, arxiv 1807.02048) increases sensitivity and brings it on edge of exclusion for several low mass stau points
- Currently, we are working on improvement of analysis techniques and combination 2016 with 2017 data
- Future is bright: HL-LHC projection shows sensitivity to wide range of stau/LSP parameters

Stay tuned!

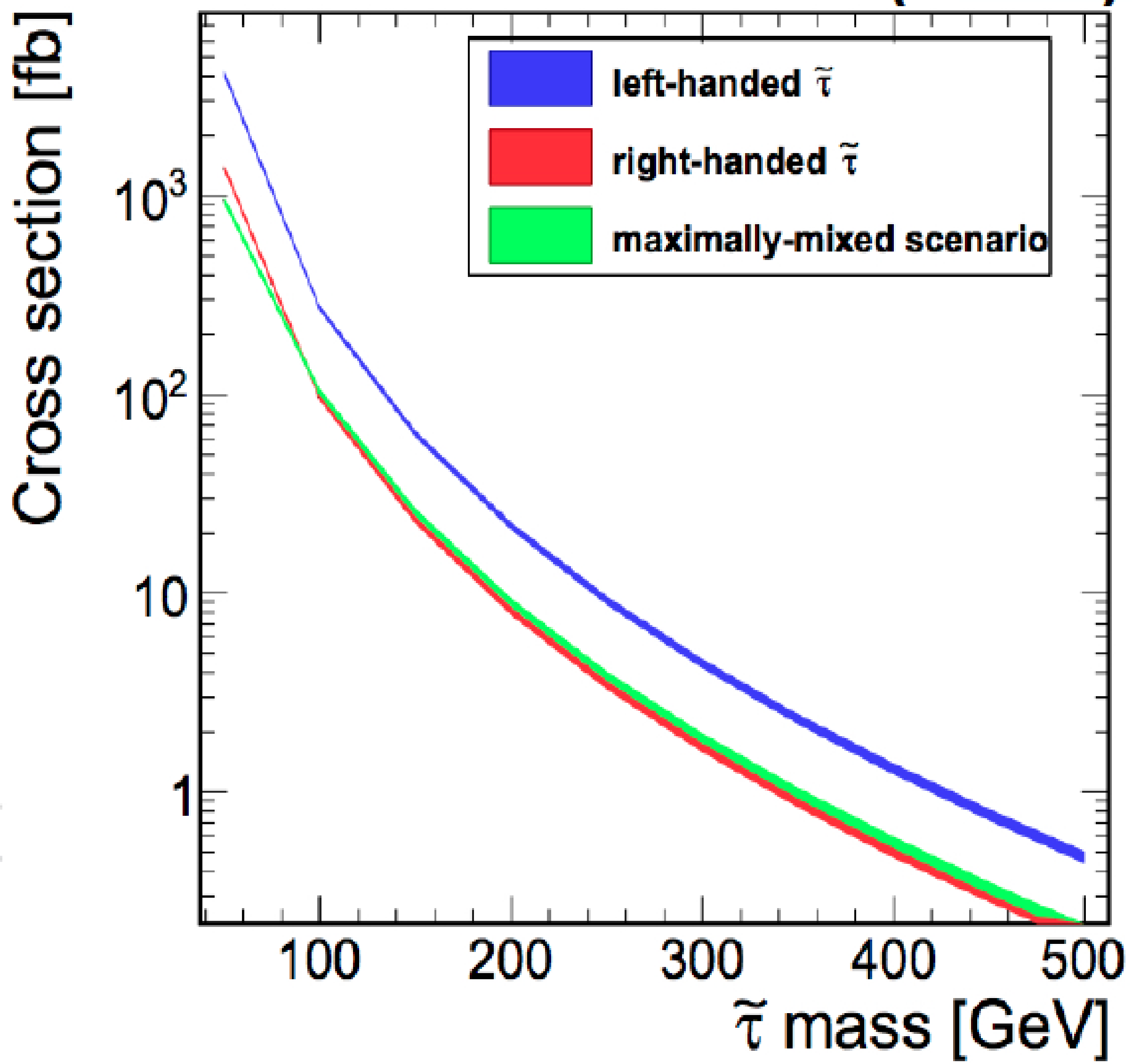
Backup

Likelihood analysis



arXiv:1710.11091
v2

Based on arXiv:hep-ph/1310.2621 (13 TeV)



Search bins

Bin name	p_T^{miss} [GeV]	M_{T2} [GeV]	$D\zeta$ [GeV]	n_{jet}
$p_T^{miss}{}_A M_{T2A} D\zeta_{B-}$	<40	<40	<-100	0
$p_T^{miss}{}_A M_{T2B+} D\zeta_{A+}$		>40	>-500	
$p_T^{miss}{}_B M_{T2A} D\zeta_{B-}$	[40,80]	<40	<-100	
$p_T^{miss}{}_B M_{T2A} D\zeta_{E}$			>50	
$p_T^{miss}{}_B M_{T2B} D\zeta_{B-}$		[40,80]	<-100	
$p_T^{miss}{}_B M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_B M_{T2C+} D\zeta_{A+}$		>80	>-500	
$p_T^{miss}{}_C M_{T2A} D\zeta_{B-}$	[80,120]	<40	<-100	
$p_T^{miss}{}_C M_{T2A} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_C M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_C M_{T2B} D\zeta_{A+}$			>-150	
$p_T^{miss}{}_C M_{T2B+} D\zeta_{A+}$		>80	>-500	
$p_T^{miss}{}_D M_{T2A} D\zeta_{B-}$	[120,250]	<40	<-100	
$p_T^{miss}{}_D M_{T2A} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B}$			[-150,-100]	
$p_T^{miss}{}_D M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2C} D\zeta_{A+}$		[80,100]	>-500	
$p_T^{miss}{}_D M_{T2D} D\zeta_{A+}$		[100,120]	>-500	
$p_T^{miss}{}_D M_{T2E} D\zeta_{A+}$		>120	>-500	
$p_T^{miss}{}_E M_{T2A+} D\zeta_{A+}$	>250	>0	>-500	

Bin name	p_T^{miss} [GeV]	M_{T2} [GeV]	$D\zeta$ [GeV]	n_{jet}
$p_T^{miss}{}_A M_{T2A} D\zeta_{B-}$	<40	<40	<-150	1
$p_T^{miss}{}_A M_{T2A} D\zeta_{B}$			[-150,100]	
$p_T^{miss}{}_A M_{T2A} D\zeta_{D+}$			>0	
$p_T^{miss}{}_A M_{T2A+} D\zeta_{A+}$		>40	>-500	
$p_T^{miss}{}_B M_{T2A} D\zeta_{B-}$	[40,80]		<-100	
$p_T^{miss}{}_B M_{T2A} D\zeta_{E}$		<40	>50	
$p_T^{miss}{}_B M_{T2B} D\zeta_{B-}$		[40,80]	<-100	
$p_T^{miss}{}_B M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_B M_{T2B+} D\zeta_{A+}$		>80	>-500	
$p_T^{miss}{}_C M_{T2A} D\zeta_{B-}$	[80,120]	<40	<-100	
$p_T^{miss}{}_C M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_C M_{T2B} D\zeta_{A+}$			>-150	
$p_T^{miss}{}_C M_{T2CD} D\zeta_{A+}$		[80,120]	>-500	
$p_T^{miss}{}_C M_{T2E} D\zeta_{A+}$		>120	>-500	
$p_T^{miss}{}_D M_{T2A} D\zeta_{B-}$	[120,250]	<40	<-150	
$p_T^{miss}{}_D M_{T2A} D\zeta_{B}$			[-150,-100]	
$p_T^{miss}{}_D M_{T2A} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B}$			[-150,-100]	
$p_T^{miss}{}_D M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2C} D\zeta_{A+}$		[80,100]	>-500	
$p_T^{miss}{}_D M_{T2D} D\zeta_{A+}$		[80,120]	>-500	
$p_T^{miss}{}_D M_{T2E} D\zeta_{A+}$		>120	>-500	
$p_T^{miss}{}_E M_{T2C+} D\zeta_{A+}$	>250	>80	>-500	

Table 9: Definition of combined search bins to be used for easier reinterpretation of the results.

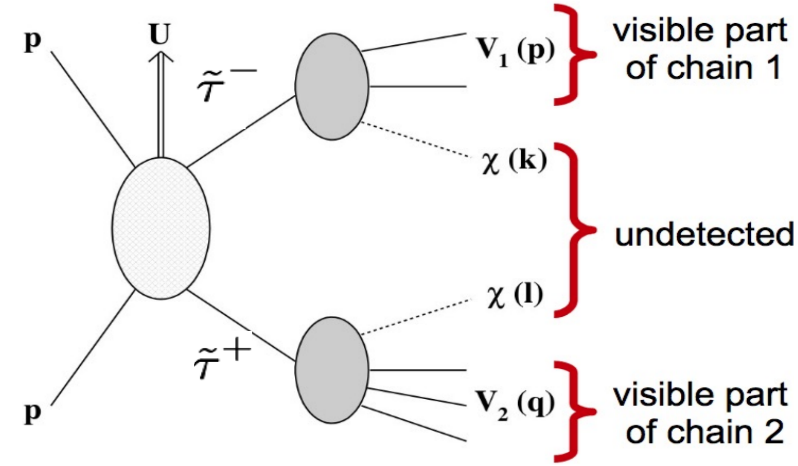
n_{jet}	p_T^{miss}	M_{T2}	Bkg ($e\tau_h$)	Obs. ($e\tau_h$)	Bkg ($\mu\tau_h$)	Obs ($\mu\tau_h$)	Bkg ($e\mu$)	Obs ($e\mu$)
0	> 120 GeV	> 120 GeV	$4.9 \pm 1.5 \pm 1.9$	4	$5.8 \pm 1.8 \pm 2.7$	7.0	$6.8 \pm 2.2 \pm 2.7$	6
1	> 120 GeV	> 100 GeV	$10.8 \pm 2.1 \pm 2.5$	9	$14.4 \pm 2.5 \pm 3.1$	14	$9.7 \pm 2.4 \pm 3.0$	6
1	> 250 GeV	> 80 GeV	$1.6 \pm 0.9 \pm 1.2$	0	$1.5 \pm 0.9 \pm 1.1$	1	$3.3 \pm 2.0 \pm 2.3$	1

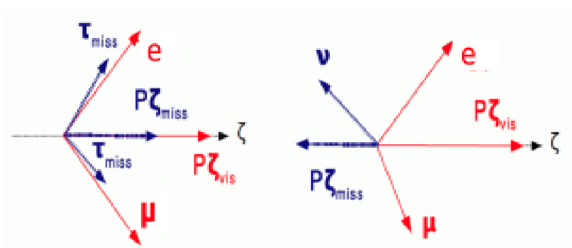
Search variables $\mu\tau_h, e\tau_h, e\mu$

- E_{Tmiss} – missing transverse energy
- M_{T2} – "stransverse" mass

$$M_{T2}^2 = \min_{\vec{k}_T+\vec{l}_T=\text{tot miss }\vec{p}_T} \left\{ \max\left[M_T^2(\text{chain }1), M_T^2(\text{chain }2) \right] \right\} \leq m^2_{\tilde{\tau}}$$

- D_ζ – Discriminant used in legacy Higgs searches



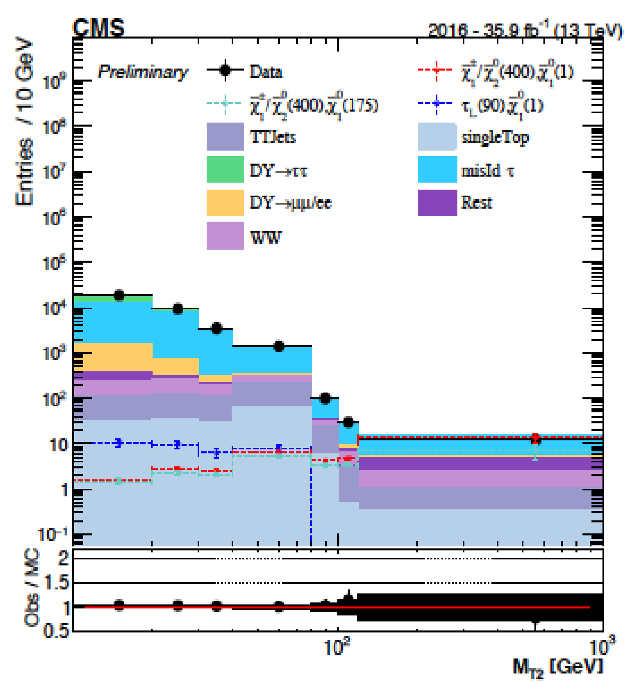


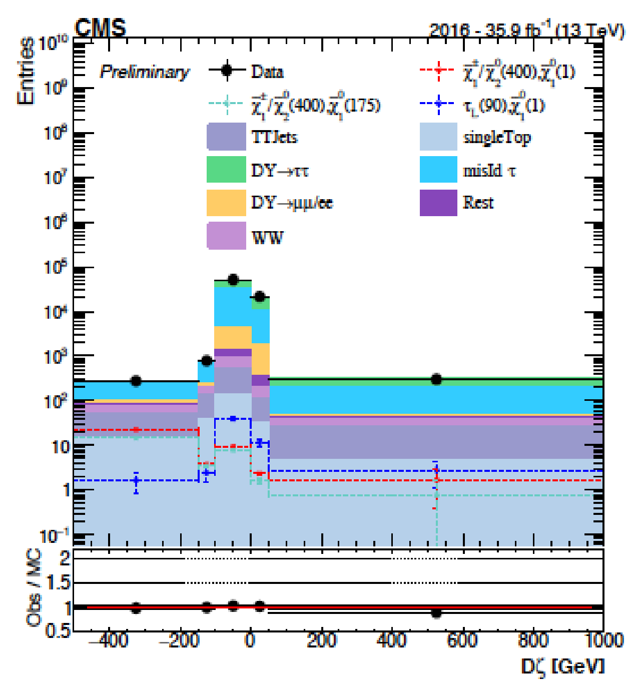
$$D_\zeta = P_{\zeta,\text{mis}} - \alpha \cdot P_{\zeta,\text{vis}}$$

$$P_{\zeta,\text{mis}} = \vec{p}_{T,\text{mis}} \cdot \vec{\zeta}, \quad P_{\zeta,\text{vis}} = (\vec{p}_{T,e} + \vec{p}_{T,\mu}) \cdot \vec{\zeta}$$

ζ – bisector between the direction of the electron and that of the muon

α = 0.85 (optimized value)





Search bins

Bin name	p_T^{miss} [GeV]	M_{T2} [GeV]	$D\zeta$ [GeV]	n_{jet}
$p_T^{miss}{}_A M_{T2A} D\zeta_{B-}$	<40	<40	<-100	0
$p_T^{miss}{}_A M_{T2B+} D\zeta_{A+}$		>40	>-500	
$p_T^{miss}{}_B M_{T2A} D\zeta_{B-}$	[40,80]	<40	<-100	
$p_T^{miss}{}_B M_{T2A} D\zeta_{E}$			>50	
$p_T^{miss}{}_B M_{T2B} D\zeta_{B-}$		[40,80]	<-100	
$p_T^{miss}{}_B M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_B M_{T2C+} D\zeta_{A+}$		>80	>-500	
$p_T^{miss}{}_C M_{T2A} D\zeta_{B-}$	[80,120]	<40	<-100	
$p_T^{miss}{}_C M_{T2A} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_C M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_C M_{T2B} D\zeta_{A+}$			>-150	
$p_T^{miss}{}_C M_{T2B+} D\zeta_{A+}$		>80	>-500	
$p_T^{miss}{}_D M_{T2A} D\zeta_{B-}$	[120,250]	<40	<-100	
$p_T^{miss}{}_D M_{T2A} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B}$			[-150,-100]	
$p_T^{miss}{}_D M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2C} D\zeta_{A+}$		[80,100]	>-500	
$p_T^{miss}{}_D M_{T2D} D\zeta_{A+}$		[100,120]	>-500	
$p_T^{miss}{}_D M_{T2E} D\zeta_{A+}$		>120	>-500	
$p_T^{miss}{}_E M_{T2A+} D\zeta_{A+}$	>250	>0	>-500	

Bin name	p_T^{miss} [GeV]	M_{T2} [GeV]	$D\zeta$ [GeV]	n_{jet}
$p_T^{miss}{}_A M_{T2A} D\zeta_{B-}$	<40	<40	<-150	1
$p_T^{miss}{}_A M_{T2A} D\zeta_{B}$			[-150,100]	
$p_T^{miss}{}_A M_{T2A} D\zeta_{D+}$			>0	
$p_T^{miss}{}_A M_{T2A+} D\zeta_{A+}$		>40	>-500	
$p_T^{miss}{}_B M_{T2A} D\zeta_{B-}$	[40,80]		<-100	
$p_T^{miss}{}_B M_{T2A} D\zeta_{E}$		<40	>50	
$p_T^{miss}{}_B M_{T2B} D\zeta_{B-}$		[40,80]	<-100	
$p_T^{miss}{}_B M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_B M_{T2B+} D\zeta_{A+}$		>80	>-500	
$p_T^{miss}{}_C M_{T2A} D\zeta_{B-}$	[80,120]	<40	<-100	
$p_T^{miss}{}_C M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_C M_{T2B} D\zeta_{A+}$			>-150	
$p_T^{miss}{}_C M_{T2CD} D\zeta_{A+}$		[80,120]	>-500	
$p_T^{miss}{}_C M_{T2E} D\zeta_{A+}$		>120	>-500	
$p_T^{miss}{}_D M_{T2A} D\zeta_{B-}$	[120,250]	<40	<-150	
$p_T^{miss}{}_D M_{T2A} D\zeta_{B}$			[-150,-100]	
$p_T^{miss}{}_D M_{T2A} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B-}$		[40,80]	<-150	
$p_T^{miss}{}_D M_{T2B} D\zeta_{B}$			[-150,-100]	
$p_T^{miss}{}_D M_{T2B} D\zeta_{C+}$			>-100	
$p_T^{miss}{}_D M_{T2C} D\zeta_{A+}$		[80,100]	>-500	
$p_T^{miss}{}_D M_{T2D} D\zeta_{A+}$		[80,120]	>-500	
$p_T^{miss}{}_D M_{T2E} D\zeta_{A+}$		>120	>-500	
$p_T^{miss}{}_E M_{T2C+} D\zeta_{A+}$	>250	>80	>-500	

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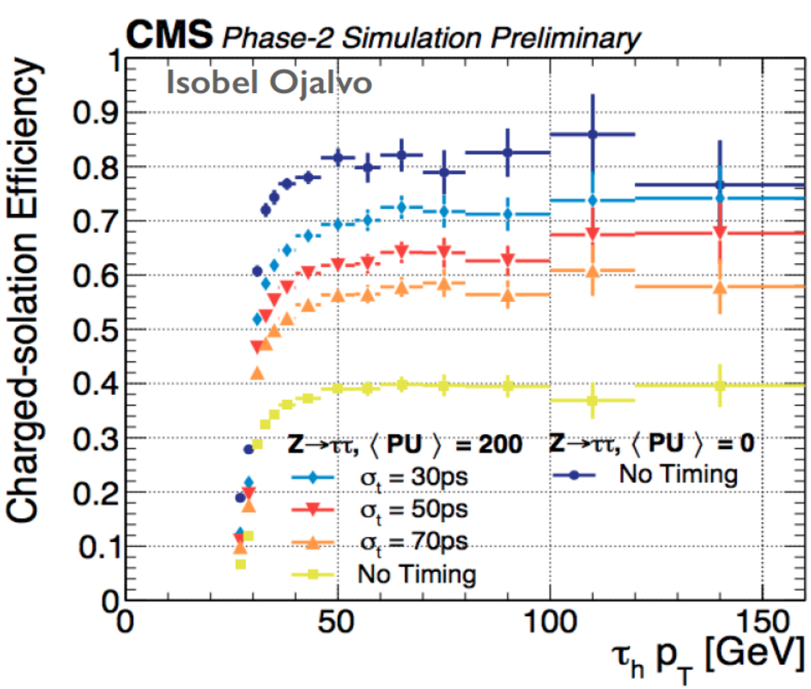
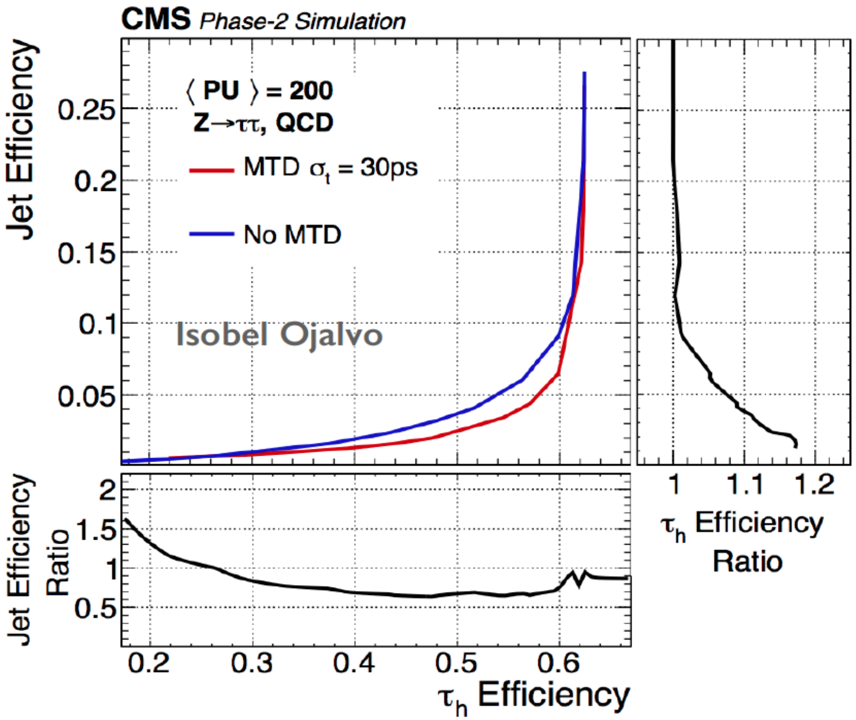
Taus

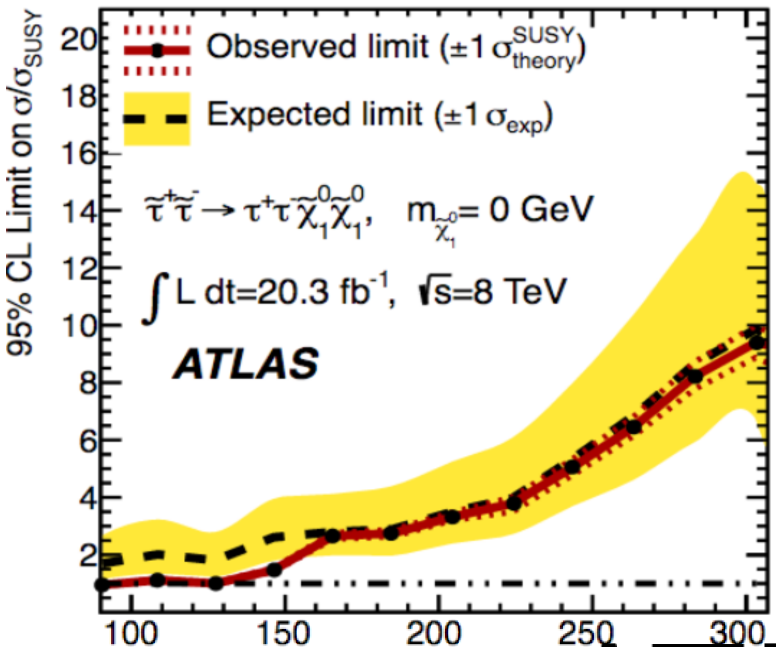
- Main background for fulhadronic channel is double jet faking tau background and for semileptonic channel it is a tau pair production (DY) and single jet faking tau background
- Additional timing detector sensitive to minimum ionizing particles (MIPs) between the tracker and the electromagnetic calorimeters improve the tau charged isolation performance
- Tau ID "Fixed-Strip" algorithm is used





From Atlas

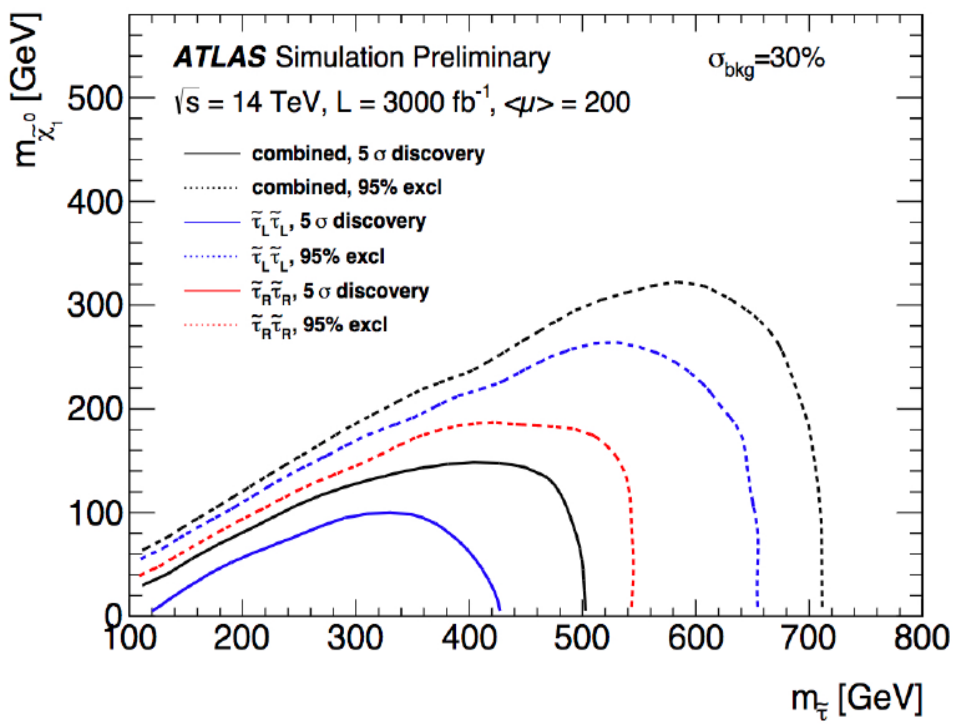
LHC Run1 results



ATLAS (arxiv:1407.0350)

Projection

ATL-PHYS-PUB-2016-021



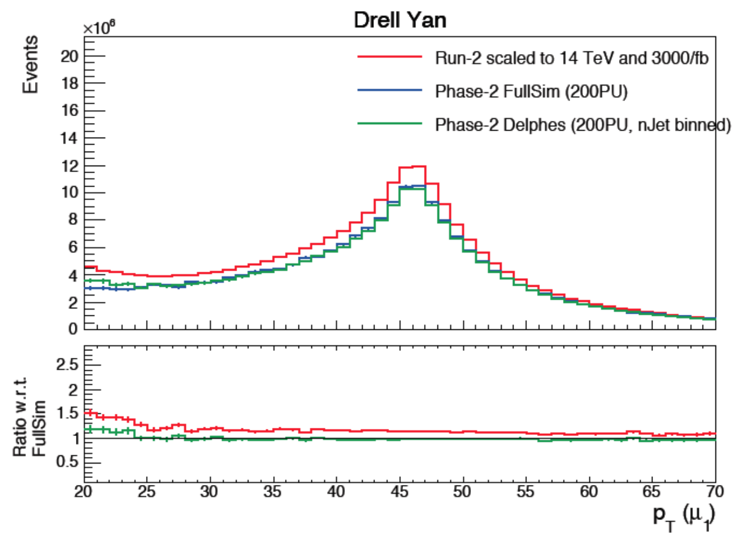
- For direct stau production left-handed, right-handed and degenerate stau production are Considered
- Run 1 analysis from ATLAS excluded degenerate production for a single scenario (stau mass of 109 GeV and a massless LSP)
- No any public increase in sensitivity with 2016 Data
- In 2016 a preliminary result for HL-LHC Stau sensitivity was released from ATLAS (single bin analysis and flat 30% systematic uncertainty)

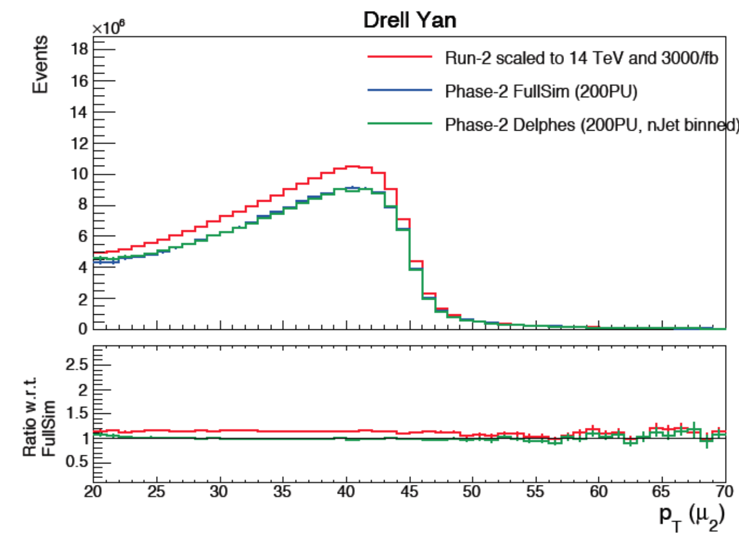
Dynamic event weighting

Dynamic event weighting is applied to imitate Full-Sim tau reconstruction

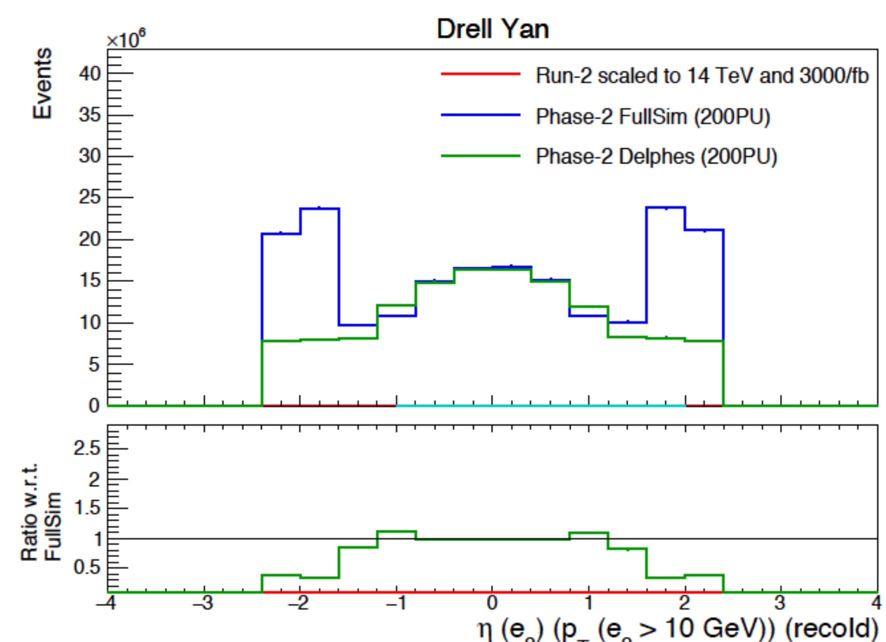
- Gen-matching is attempted on the only PUPPI jet in the event
  - Successful matching: event is multiplied by tau efficiency 32% (from Tu POG)
  - Unsuccessful matching: event is multiplied by jet to tau fake rate. Fake rate is provided by Tau POG and scaled by 1/3 to project MVA improvements
- Dynamic event weighting significantly reduces event weight and therefore the statistical uncertainty

Lepton validation





- Muons and electrons were validated in Drell Yan process decaying leptonically.
  - Muons: good agreement is observed and no SF are needed
  - Electrons: good agreement is observed in barrel (no SF). In endcap SF is used.



Tau ID

Current suggestion how to use the new parametrizations for Delphes, the parametrizations are applied to hadronically decaying taus (efficiency) and jets (fakes). The efficiency and fake definitions for full sim are also shown.

The efficiency is flat with pt with values shown in the table for 9 working points

The fake vs pt parametrization should be applied with fake factor as multiplicative factor for correspondent WP

If (not recommended) somebody wants to explore the eta shape of fakes, one takes the barrel WP and use product of pt and eta fake parametrizations.
This may only make sense is you really go to 2.8 in eta and want to explore performance between 2.3 and 2.8, otherwise you don't need it

Your upper cut on eta should be 2.8, your lower cut on pt should be 20

The MVA if it was there would improve the fake by factor of 3 / 2 for 21/(32 or 54) WPs. This can be used as addition multiplicative factors on fakes 1/3 , 1/2

<table>
<tr><td>Working points</td><td>WP_21</td><td>WP_32</td><td>WP_54</td></tr>
<tr><td>Efficiency (%)</td><td>32</td><td>45</td><td>62</td></tr>
<tr><td></td><td colspan="3">|eta|<3.0 & p_T (20-200)GeV</td></tr>
<tr><td>Fake Rate (%)</td><td>0.25</td><td>0.49</td><td>1.18</td></tr>
<tr><td>Fake Factor</td><td>1.00</td><td>1.96</td><td>4.72</td></tr>
<tr><td></td><td colspan="3">|eta|<2.3 & p_T (20-200)GeV</td></tr>
<tr><td>Fake Rate (%)</td><td>0.23</td><td>0.45</td><td>1.10</td></tr>
<tr><td>Fake Factor</td><td>0.92</td><td>1.80</td><td>4.40</td></tr>
<tr><td></td><td colspan="3">|eta|<1.4 & p_T (20-200)GeV</td></tr>
<tr><td>Fake Rate (%)</td><td>0.22</td><td>0.41</td><td>0.99</td></tr>
<tr><td>Fake Factor</td><td>0.88</td><td>1.64</td><td>3.96</td></tr>
<tr><td colspan="4">FakeRate parametrization factor vs pt (absolute):</td></tr>
<tr><td colspan="4">{-8.33753e-03+1.48065e-03*x-3.23176e-05*x**2+2.91151e-07*x**3-1.20285e-09*</td></tr>
<tr><td colspan="4">x**4+1.88459e-12*x**5)*0.25*(x<190)+0.00058*(x>190) }</td></tr>
<tr><td colspan="4">FakeRate parametrization factor vs eta (relative to barrel):</td></tr>
<tr><td colspan="4">{1.84916*(x-1.4)*(x>1.95)+1*(x<1.95)}</td></tr>
<tr><td colspan="4">Efficiency: num/denom</td></tr>
<tr><td colspan="4">Denom.: GenTauPt>20 & |genTauEta| < (3.0 or 2.3 or 1.4)</td></tr>
<tr><td colspan="4">Num.: TauPt > 20 & genTauMatch ==1 & tauDiscriminatorByDMFinding ==1 & WP's & Denom.</td></tr>
<tr><td colspan="4">Fake Rate: num / denom</td></tr>
<tr><td colspan="4">Denom.: jetPt>20 & |jetEta| < (3.0 or 2.3 or 1.4) & genJetMatch ==1</td></tr>
<tr><td colspan="4">Num.: TauPt > 20 & tauDiscriminatorByDMFinding==1 & WP's & Denom.</td></tr>
<tr><td colspan="4">WP_21</td></tr>
<tr><td colspan="4">CombineIso<2 (|eta|<1.4) || CombineIso<1 (|eat|>1.4)</td></tr>
<tr><td colspan="4">WP_32</td></tr>
<tr><td colspan="4">CombineIso<3 (|eta|<1.4) || CombineIso<2 (|eat|>1.4)</td></tr>
<tr><td colspan="4">WP_54</td></tr>
<tr><td colspan="4">CombineIso<2 (|eta|<1.4) || CombineIso<1 (|eat|>1.4)</td></tr>
<tr><td colspan="4">CombineIso</td></tr>
<tr><td colspan="4">{chargedIso(dR<0.5&|dz|<0.15&pt>0.5) + 0.2*max(0, neutralIso(dR<0.3&pt>1) – 5)}</td></tr>
</table>

Fake rate above comes from cut-based isolation approach. An mva is expected to improve performance by a factor of 3.
Tau working point 32 is chosen.

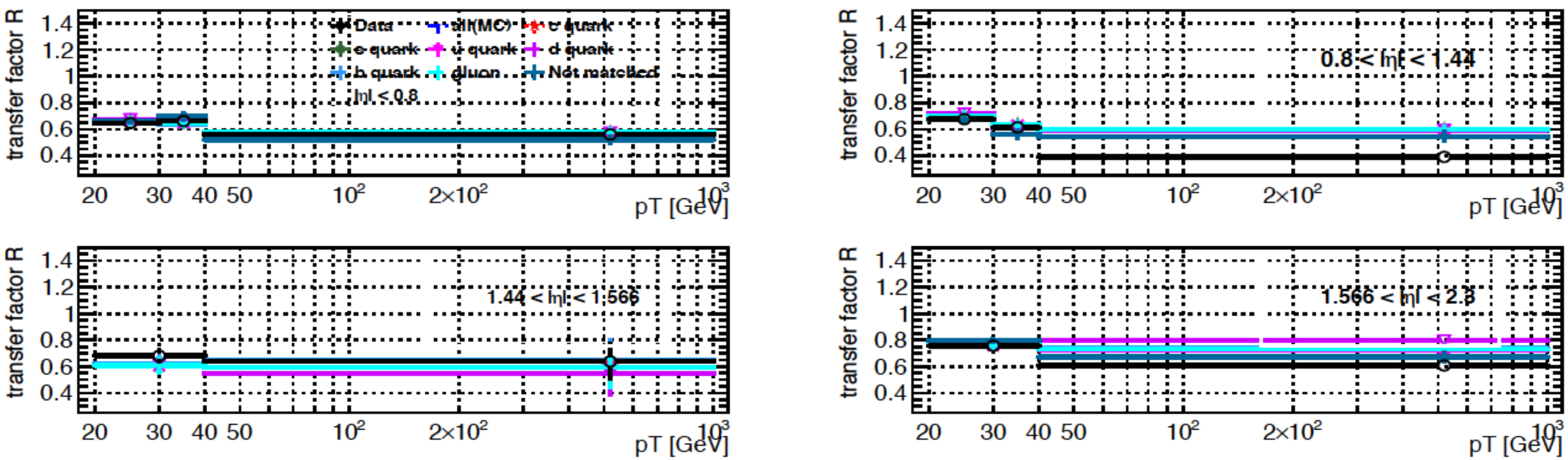
Jet Faking tau bkg

- In $1-\ell$ channels, main background comes from misId-τ
- Use *Tight-to-Lose* method to estimate it
  - Apply nominal event selection but now invert the M_T-mass window, i.e. require $60\ \mathrm{GeV} < \mathrm{M_T} < 120\ \mathrm{GeV}$
  - Further increase purity of W+jets: $\Delta\Phi(W, \mathrm{j_0}) > 2.5$, $0 < n_{\mathrm{jet}} < 3$, $p_T^{miss} > 40\ \mathrm{GeV}$
  - Results are parametrized in $(|\eta|, \mathrm{P_T})$ bins

The Transfer Factor (R) is estimated after subtracting first all non-W+jets MC with prompt-τ ($\approx 18\%$)

$$R = \frac{N^{\mathrm{CS}}_{\mathrm{data}}(\tau, T) - N^{\mathrm{CS}}_{\mathrm{MC\ w/o\ W+jets}}(\tau, T)}{N^{\mathrm{CS}}_{\mathrm{data}}(\tau, L\&!T) - N^{\mathrm{CS}}_{\mathrm{MC\ w/o\ W+jets}}(\tau, L\&!T)}$$

Parametrized results in ($|\eta|$,P_T) bins for Transfer Factor R



PAS

(η,P_T)	20-30GeV	30-40GeV	>40GeV
$\|\eta\| < 0.8$	0.74 ±0.07	0.66 ±0.01	0.56 ±0.02
$0.8 < \|\eta\| < 1.44$	0.68 ±0.01	0.61 ±0.01	0.39 ±0.03
$1.44 < \|\eta\| < 1.566$	0.68 ±0.03		0.64 ±0.08
$1.566 < \|\eta\| < 2.3$	0.59 ±0.02		0.61 ±0.01

Finally, misId-τ shape is estimated from a sideband region defined by SR cuts, but requiring the τ candidate to be $L\&!T$

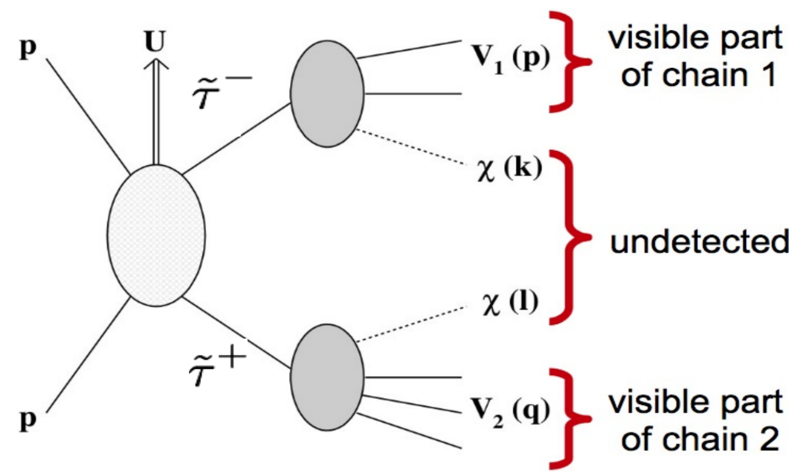
$$N^{SR}(\text{jets} \rightarrow \tau_{\text{tight\_iso}}) = R \cdot [N^{SR}_{\text{data}}(\tau_{\text{L\&!T}}) - N^{SR}_{\text{MC}}(\tau_{\text{L\&!T\&matched\_to\_gen}})]$$

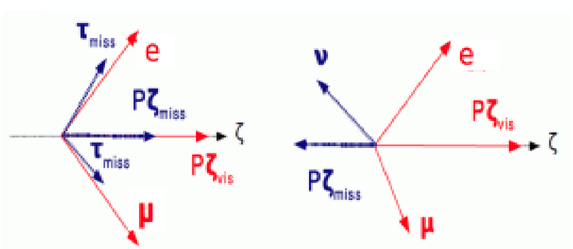
Search variables $\mu\tau_h, e\tau_h, e\mu$

- E_{Tmiss} – missing transverse energy
- M_{T2} – "stransverse" mass

$$M_{T2}^2 = \min_{\vec{k}_T + \vec{l}_T = \mathrm{tot\ miss}\ \vec{p}_T} \left\{ \max\left[M_T^2(\mathrm{chain}\ 1), M_T^2(\mathrm{chain}\ 2) \right] \right\} \leq m^2_{\tilde{\tau}}$$

- D_ζ – Discriminant used in legacy Higgs searches





$$D_\zeta = P_{\zeta,\mathrm{mis}} - \alpha \cdot P_{\zeta,\mathrm{vis}}$$

$$P_{\zeta,\mathrm{mis}} = \vec{p}_{\mathrm{T,mis}} \cdot \vec{\zeta}, \quad P_{\zeta,\mathrm{vis}} = (\vec{p}_{\mathrm{T,e}} + \vec{p}_{\mathrm{T},\mu}) \cdot \vec{\zeta}$$

ζ – bisector between the direction of the electron and that of the muon

α = 0.85 (optimized value)