Drell-Yan $Z' \rightarrow \tau\tau$

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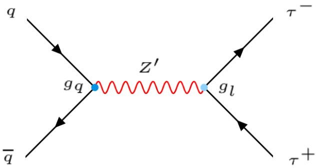
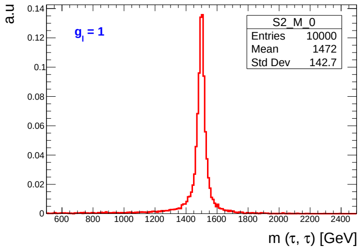
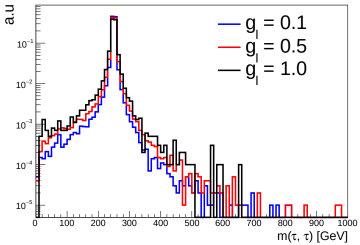
Signal samples

In this analysis we consider $Z' \rightarrow \tau_\mu \tau_h$, $Z' \rightarrow \tau_e \tau_h$ and $Z' \rightarrow \tau_h \tau_h$







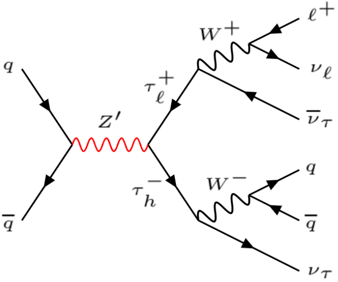
The relevant parameters for the MC signal samples are:

- **Masses:** 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3500, 4000 GeV.
- **Couplings to light and heavy fermions** ($g_l = g_h$): 0.1, 0.5, 1.0, 6.0,16.
- **Coupling to vector bosons**: suppressed.
- All the signal samples have been recently produced.

Signal Region Selection Criteria for $Z' \to \tau_\ell \tau_h$

The selection criteria for $Z' \to \tau_\ell \tau_h$ are listed below:

Trigger ($\tau_\mu \tau_h$)	HLT_IsoMu24 (2016), HLT_IsoMu27 (2017,2018)	
Trigger ($\tau_e \tau_h$)	HLT_Ele27_WPTight_Gsf (2016), HLT_Ele35_WPTight_Gsf (2017,2018)	
$\ell = \mu$ or e	$N(\ell)$	$= 1$
	ID	Tight
	$p_T(\mu/e)$	(35/55) GeV
	$\lvert\eta(\ell)\rvert$	< 2.1
	Relative Isolation (μ)	< 0.15
Tau	$N(\tau_h)$	$= 1$
	$p_T(\tau_h)$	> 20 GeV
	$\lvert\eta(\tau_h)\rvert$	< 2.1
	DeepTauID Isolation*	Tight
	Prongs	1 or 3 hp
$\ell - \tau$ pair	$Q(\ell)Q(\tau)$	< 0 (OS)
	$\cos \Delta\phi(\ell, \tau_h)$	< -0.98
b-jets**	$N(b\text{-jets})$	$= 0$
leading ℓ	$\cos \Delta\phi(p_T^{\text{lead-}\ell}, E_T^{miss})$	< -0.95
	$m_T(p_T^{\text{lead-}\ell}, E_T^{miss})$	> 150 GeV
Dijet veto	$N(jet^\dagger\ pairs)$ passing VBF‡	=0



Orthogonal to the VBF Z' analysis

* TauIDAlgorithm: Tau_idDeepTau2017v2p1

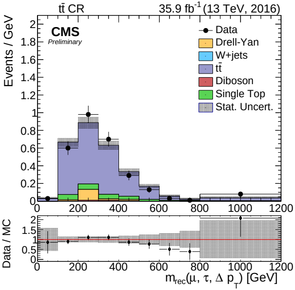
** b-jet: $p_T > 30$, $|\eta| < 2.4$ GeV with CSV medium (2016), DeepCSV tight (2017), DeepF tight (2018)

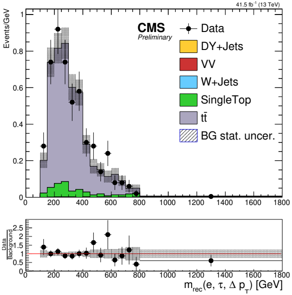
†Jets: $p_T > 30$, $|\eta| < 5$ GeV with Loose ID (2016), Tight ID (2017,2018)

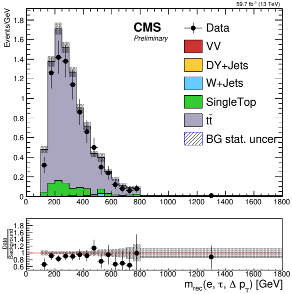
‡VBF events: $|\eta(jj)| < 3.8$, $m(jj) > 300$ GeV

$t\bar{t}$ Control Regions for $Z' \to \tau_\mu\tau_h$ and $Z' \to \tau_e\tau_h$

- To obtain the $t\bar{t}$ CR we require $N(b\text{-jets}) \geq 1$.
- The $t\bar{t}$ distributions for $\tau_\mu\tau_h$ (left) and $\tau_e\tau_h$ (center and right) have the scale factor applied.







Process	Events (2016)
W+jets	0.0 ± 0.0
Drell-Yan	16.5 ± 4.9
$t\bar{t}$	231.1 ± 8.6
SingleTop	24.9 ± 2.1
Diboson	2.9 ± 0.6
TotalBack.	275.5 ± 10.2
Data	285
Purity	84%
Scale Factor	1.04 ± 0.10

Process	Events (2017)
W+jets	0.5 ± 0.3
Drell-Yan	0.4 ± 0.1
ttbar	225.4 ± 9.4
SingleTop	23.3 ± 2.1
Diboson	0.5 ± 0.3
Total Back.	250.1 ± 9.6
Data	253
Purity	90%
Scale Factor	1.01 ± 0.09

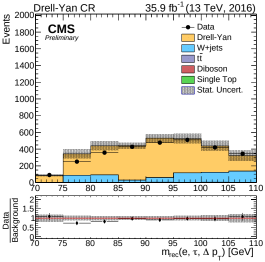
Process	Events (2018)
W+jets	2.2 ± 1.5
Drell-Yan	1.2 ± 0.3
ttbar	436.5 ± 6.0
SingleTop	41.0 ± 3.3
Diboson	0.7 ± 0.2
Total Back.	481.6 ± 7.0
Data	429
Purity	91%
Scale Factor	0.88 ± 0.07

$$\boxed{N_{SR}^{t\bar{t}} = SF \cdot N_{SR}^{MC}}$$

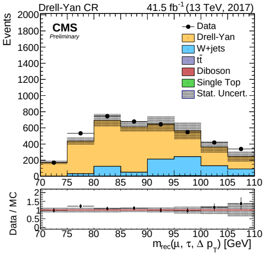
Drell-Yan Control Regions for $Z' \to \tau_e\tau_h$ and $Z' \to \tau_\mu\tau_h$

To obtain the Drell-Yan CR for the $\tau_l\tau_h$ channels we require the following cuts:

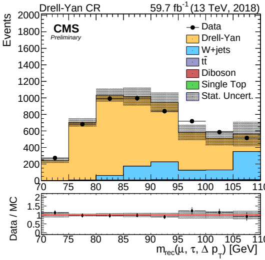
$$m_T(p_T^{\text{lead-}\ell}, E_T^{miss}) < 150 \text{ GeV}$$
$$70 < m_{rec}(\ell, \tau_h, \Delta p_T) < 110 \text{ GeV}$$



Process	Events (2016)
W+jets	626.4 $\pm$ 123.0
Drell-Yan	2388.3 $\pm$ 59.3
ttbar	5.7 $\pm$ 1.5
SingleTop	1.3 $\pm$ 0.5
Diboson	10.0 $\pm$ 1.3
Total Back.	3031.7 $\pm$ 136.6
Data	2892
Purity	79%
Scale Factor	0.94 $\pm$0.07



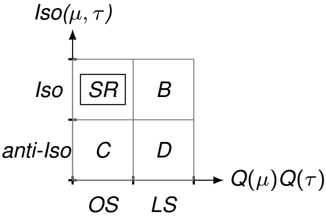
Process	Events (2017)
W+jets	846.1$\pm$180.8
Drell-Yan	3526.1$\pm$100.0
$t\bar{t}$	16.5$\pm$1.0
SingleTop	3.2$\pm$0.8
Diboson	21.5$\pm$2.2
TotalBack.	4413.5$\pm$206.7
Data	4077
Purity	80%
Scale Factor	0.90 $\pm$0.07

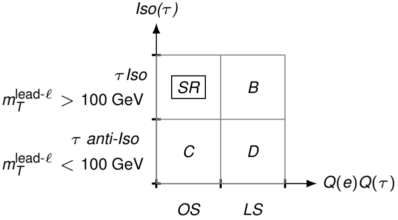


Process	Events (2018)
W+jets	1015.6$\pm$240.1
Drell-Yan	5586.6$\pm$147.8
$t\bar{t}$	22.0$\pm$1.5
SingleTop	5.8$\pm$1.2
Diboson	24.2$\pm$1.5
TotalBack.	6654.2$\pm$281.9
Data	5600
Purity	84%
Scale Factor	0.81 $\pm$0.06

- For 2017 and 2018 for the $\tau_e\tau_h$ channel we cannot obtain a DY CR since $p_T(e) > 55$ GeV.

We estimate QCD in a data-driven way for the $\tau_l \tau_h$ channels using the ABCD method.

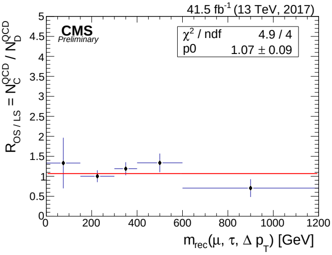


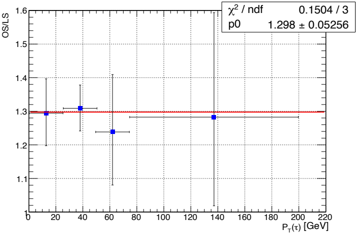


$$N^{QCD}_{SR} = R_{OS/LS} \cdot (N^{\text{Data}}_{B} - N^{\text{non-QCD MC}}_{B})_{LS}$$

where

$$R_{OS/LS} = \frac{(N^{\text{Data}}_{C} - N^{\text{non-QCD MC}}_{C})_{OS}}{(N^{\text{Data}}_{D} - N^{\text{non-QCD MC}}_{D})_{LS}}$$

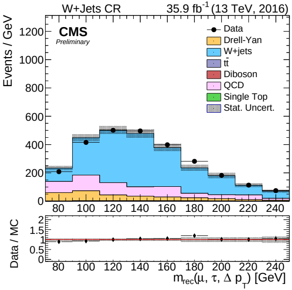




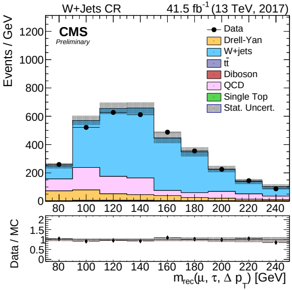
W+jets Control Region for $Z' \to \tau_\mu \tau_h$

Using the following kinematic cuts a control region for W+Jets has been obtained :

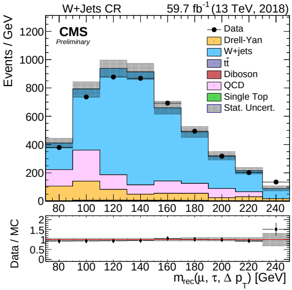
$m_T(p_T^{\text{lead-}\ell}, E_T^{miss}) < 150$ GeV
$m_{rec}(\mu, \tau_h, \Delta p_T) < 250$ GeV
τ anti-Isolation



Process	Events (2016)
Purity	63%
Scale Factor	0.88 $\pm$0.05



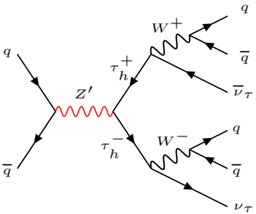
Process	Events (2017)
Purity	70%
Scale Factor	0.98 $\pm$0.06



Process	Events (2018)
Purity	73%
Scale Factor	0.96 $\pm$0.05

$$\boxed{N_{SR}^{W+Jets} = SF \cdot N_{SR}^{MC}}$$

Signal Region Selection Criteria for $Z' \to \tau_h \tau_h$

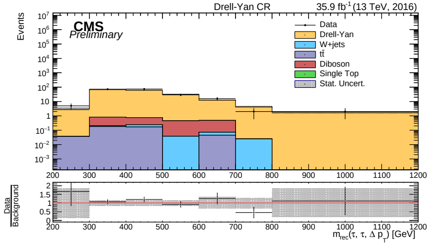


Trigger ($\tau_h\tau_h$)	HLT_DoubleMediumIsoPFTau	
Tau	$N(\tau_h, \tau_h)$	≥ 1
	$N(\tau_h)$	$= 2$
	$p_T(\tau_h)$	> 70 GeV
	$\lvert\eta(\tau_h)\rvert$	< 2.1
	DeepTauID Isolation*	Tight
	Prongs	1 or 2 or 3 hp
	$Q(\tau_1)Q(\tau_2)$	< 0 (OS)
b-jets**	$N(b\text{-jets})$	$= 0$
Topological Selections	$\cos \Delta\phi(\tau_1, \tau_2)$	< -0.95
	$\lvert \cos \Delta\phi(p_T^{\text{lead-}\tau}, E_T^{miss}) \rvert$	> 0.90
	E_T^{miss}	> 30 GeV

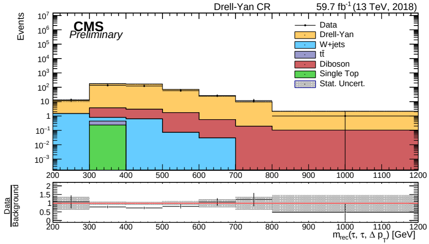
Drell-Yan control region cuts:

Baseline Cuts	Value
$N(\tau)$	=2
$m(\tau, \tau)$	[0, 100] GeV
E_T^{miss}	< 30 GeV

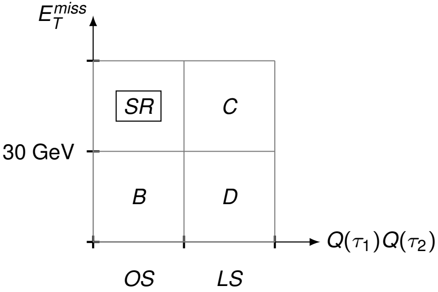
Reconstructed invariant mass for 2016.

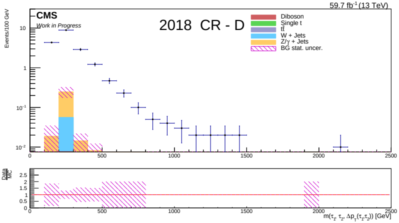


Reconstructed invariant mass for 2018.

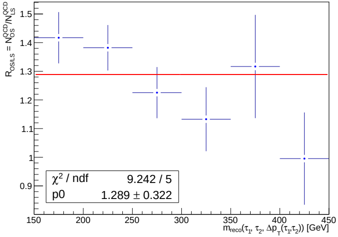


We estimate QCD in a data-driven way for the $\tau_h\tau_h$ channel using the ABCD method.





$$N_{SR}^{QCD} = R_{OS/LS} \cdot (N_B^{\text{Data}} - N_B^{\text{non-QCD MC}})_{LS}$$



The transfer factor ($R_{OS/LS}$) from LS to OS CRs is defined as

$$R_{OS/LS} = \frac{(N_B^{\text{Data}} - N_B^{\text{non-QCD MC}})_{OS}}{(N_D^{\text{Data}} - N_D^{\text{non-QCD MC}})_{LS}}$$

QCD data-driven estimation done for the three years.

Summary

- We have optimized our selection criteria for best signal significance.
- **We have implemented the DeepTau ID algorithm as requested.**
- **The background estimation for all channels is 90% completed.**
- The work on the three different channels has been documented in the analysis note AN-20-134 (AN-20-134 link here) and it has been sent to the conveners.
- We have a dedicated Twiki page for the analysis. (Twiki link here)
- **All the signal samples were produced.**
- We expect to converge with the analysis before Moriond 2021.

Backup Slides

Appendix A: Data and MC samples

DATA SAMPLES

Muon:	/SingleMuon/Run*_*Nano25Oct2019*/NANOAOD *2016(B to H), *2017(B to F), *2018(A to D)
Electron:	/SingleElectron/Run*_*Nano25Oct2019*/NANOAOD *2016(B to H), *2017(B to F)
Tau:	/Tau/Run*_*Nano25Oct2019*/NANOAOD *2016(B to H), *2017(B to F), *2018(A to D)

MC SAMPLES (Nano25Oct2019 for 2016, 2017 & 2018)

Drell-Yan	DY+Jets HT-Binned (MG aMCatNLO MLM)
W+Jets	W+Jets HT-Binned (MG aMCatNLO MLM)
$t\bar{t}$	TT Semi-leptonic, Di-leptonic and Hadronic (PowhegV2 & Pythia8)
Single top	Single top (top/antitop 4f/5f inclusiveDecays) (PowhegV2 & MadSpin)
Diboson	WZ, ZZ, WW (Pythia8)

Appendix C: Deep Tau ID Efficiencies

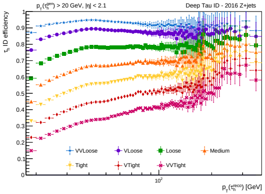


Figure: 2016 Deep Tau ID Efficiencies for Z+Jets

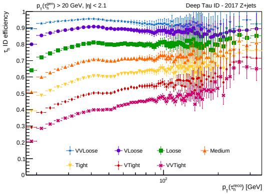


Figure: 2017 Deep Tau ID Efficiencies for Z+Jets

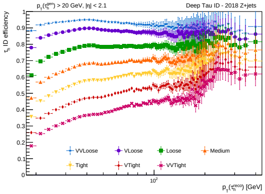
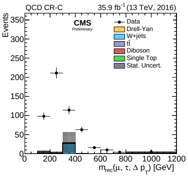


Figure: 2018 Deep Tau ID Efficiencies for Z+Jets

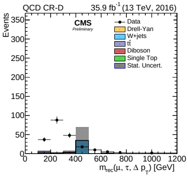
- We compare here the Deep Tau ID Efficiencies for the three years in question (2016, 2017, and 2018) as a function of $p_T(\tau_h^{reco})$ for the various isolations used in this analysis (ranging from VVLoose to VVTight).
- These plots demonstrate a significant improvement in the tracking system after the pixel upgrade for years 2017 and 2018. This could partly explain why QCD is the dominant background in 2016 whereas DY+Jets is the dominant background in more recent years for this channel: particularly at low p_T, there is improved Tau ID Efficiency for 2017 and 2018, which could lead to fewer QCD events than in 2016.

QCD for $Z' \to \tau_\mu \tau_h$ and $Z' \to \tau_e \tau_h$- Transfer Factors

$\tau_\mu \tau_h$



(a) CR-C



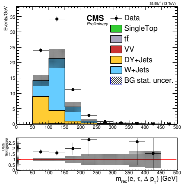
(b) CR-D

CR	Events	Background	QCD Purity
B	392	17.7 ± 6.4	95%
C	352	37.6 ± 27.8	89%
D	211	48.6 ± 34.8	78%

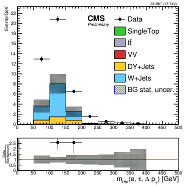
- The transfer factor obtained for the $\tau_\mu \tau_h$ is

$$\mathrm{R}_{OS/LS} = \frac{N^{QCD}_{C,OS}}{N^{QCD}_{D,LS}} = 1.44 \pm 0.19$$

$\tau_e \tau_h$



(a) CR-C



(b) CR-D

CR	Events	Background	QCD Purity
B	1357	662.3 ± 105.0	51%
C	3684	2191.2 ± 184.5	41%
D	2143	724 ± 116.1	62%

- The transfer factor obtained for the $\tau_e \tau_h$ is

$$\mathrm{R}_{OS/LS} = \frac{N^{QCD}_{C,OS}}{N^{QCD}_{D,LS}} = 1.10 \pm 0.18$$