Non-Resonant Di-Higgs

Work towards measuring the Higgs self coupling

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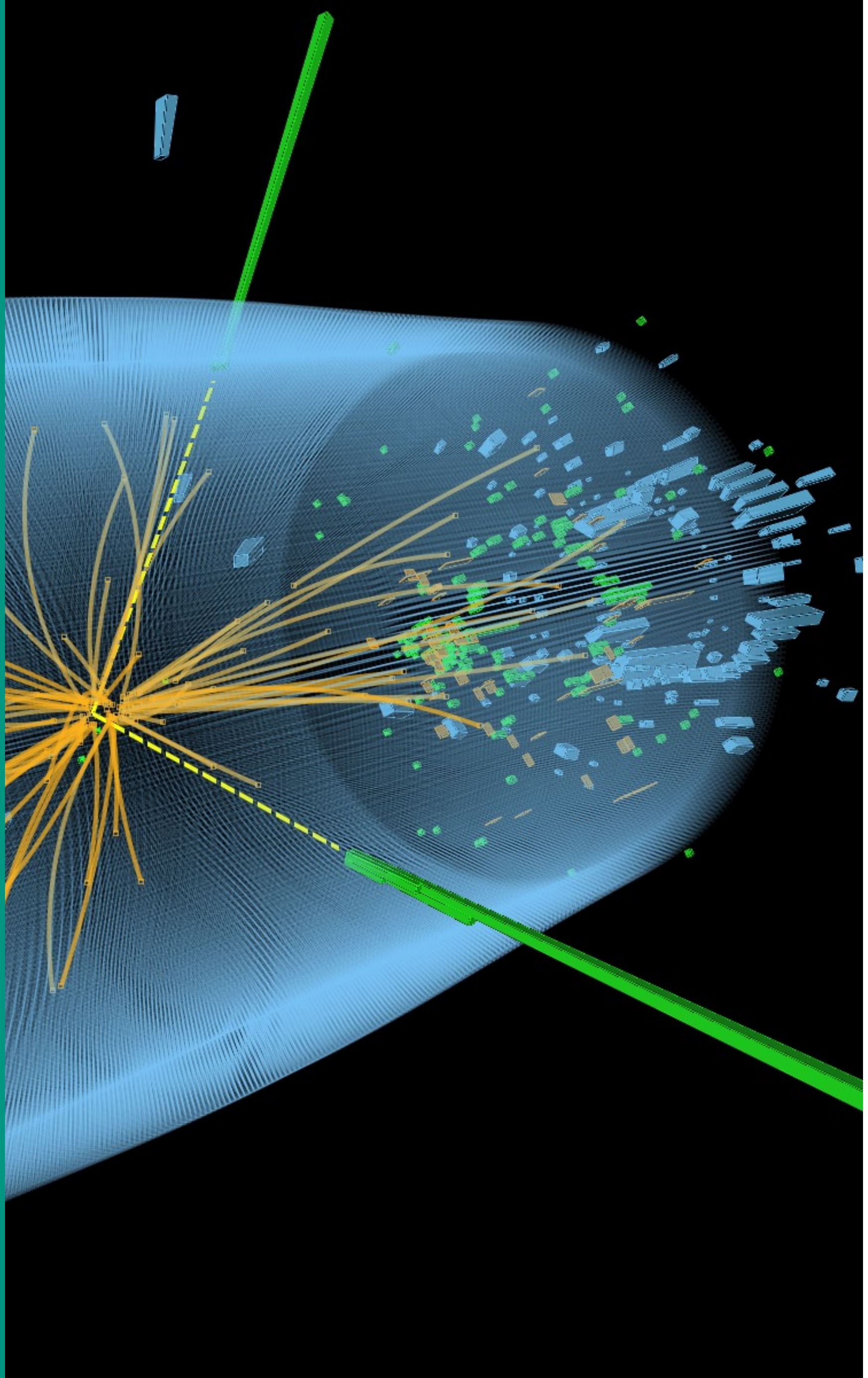
Bad Honnef, 03.09.2026



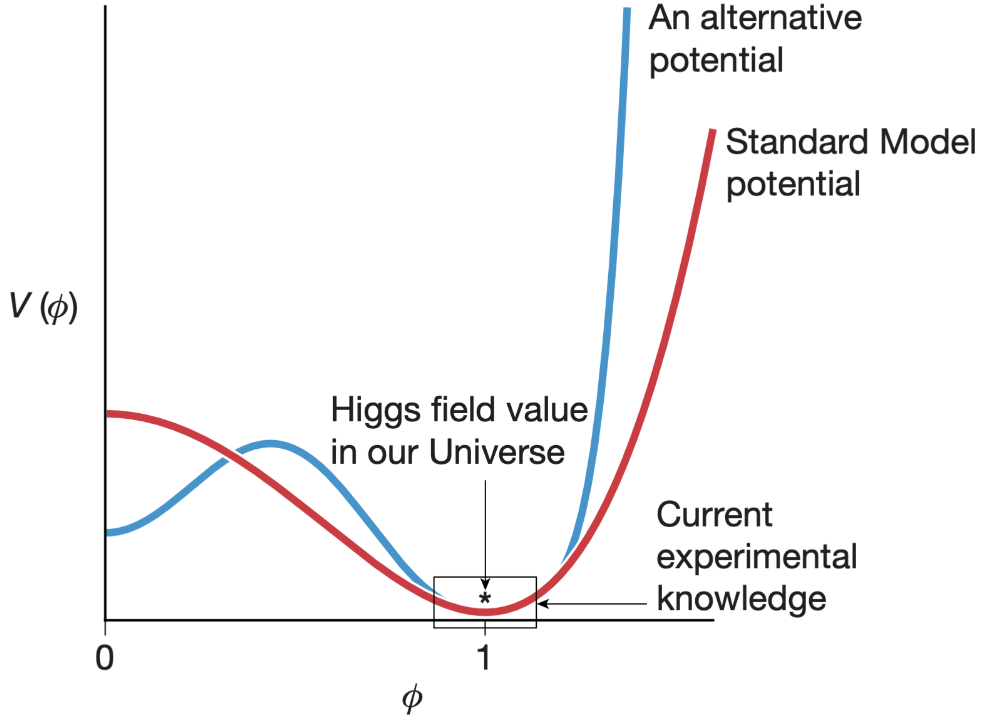
https://cms.cern/

Motivation for non-resonant Di-Higgs

- Probing the Higgs self-coupling
- Improve experimental constraints on the Higgs self-coupling
- Many BSM models predict enhanced production rates

- Starting to explore non-resonant Di-Higgs production in the HH $\rightarrow bb\tau\tau$ final state at KIT

- This analysis is based on CMS 2018 data



Potential energy density V(ϕ) associated with the Higgs field ϕ, as a function of the value of ϕ.
https://doi.org/10.1038/s41586-022-04899-4

Non-Resonant Di-Higgs

Processes

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Processes

NN Training

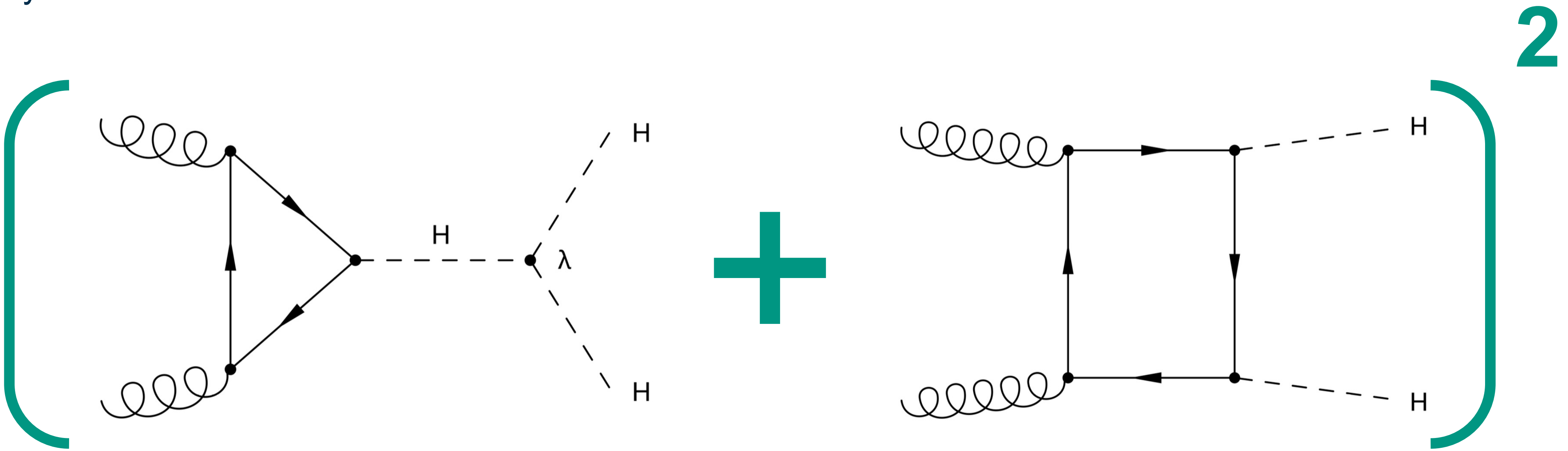
Result

Signal Processes

$$\sigma^{\mathrm{SM}}(gg \to HH) = 31.1^{+6\%}_{-23\%} \pm 3\% \ (\mathrm{PDF}+\alpha_s) \ \mathrm{fb} \quad (\mathrm{NNLO})$$

$$\sigma^{\mathrm{SM}}(gg \to H) = 48.5^{+4.6\%}_{-6.7\%} \pm 3.2\% \ (\mathrm{PDF}+\alpha_s) \ \mathrm{pb} \quad (\mathrm{N^3LO})$$

→ Different by a factor ≈ 1500



Destructive Interference

Signal Processes

- Branching fraction ≈ 7.3 %

- b quarks reconstructed as b-tagged jets
- Considered $\tau\tau$ final states
  - Full-hadronic final state ($\tau_h\tau_h$)
    - ➕ Highest branching fraction
    - ➖ Larger QCD multijet background and higher τ_h trigger thresholds
  - Semi-leptonic final states: ($e\tau_h$ & $\mu\tau_h$)
    - ➕ Efficient e / μ triggers
    - ➖ Strong $t\bar{t}$ background and more challenging $m_{\tau\tau}$ reconstruction

HH final states [1]

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

$\tau\tau$ final states [2]

Final state	Branching fraction [%]
$\tau_\mathrm{h}\tau_\mathrm{h}$	42.0
$\mathrm{e}\tau_\mathrm{h}$	23.1
$\mu\tau_\mathrm{h}$	22.5
$\mathrm{e}\mu$	6.2
ee	3.2
$\mu\mu$	3.0

87.6 %

[1]: DOI:10.3390/sym14020260
[2]: https://pdg.lbl.gov Accessed on March 2nd.

Object Selection

Kinematic selection requirements

ML-based τ_h identification [1]

- choose two tau candidates with oposite charge and the highest p_T

ML-based identification of b-quark induced jets [2]

- One b-tagged jet must pass the medium working point
- The second b-jet is selected as the one with the highest b-tag discriminant

Lepton vetos

- Reject events with other electrons or muons

[1] DeepTau v2.5 arXiv:2511.05468

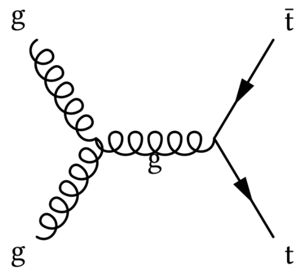
[2] DeepJet arXiv:2008.10519

Background Processes

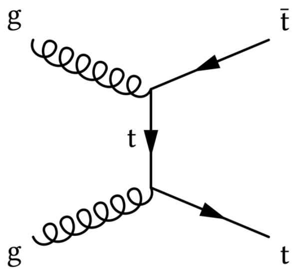
Simulated backgrounds:

- Top quark pair ($t\bar{t}$)
- Drell-Yan ($Z \to ll$)
- Diboson
- Single t
- Others like Single Higgs and Triboson

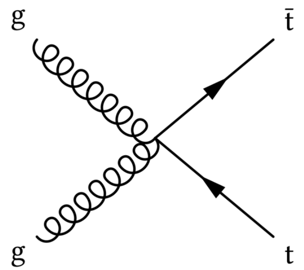
Data-driven estimation of QCD multijet production



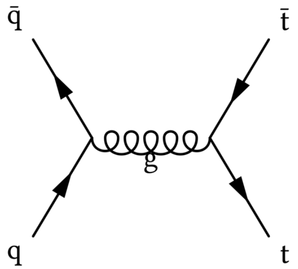
(a) $gg \longrightarrow t\bar{t}$ (s-channel gluon).



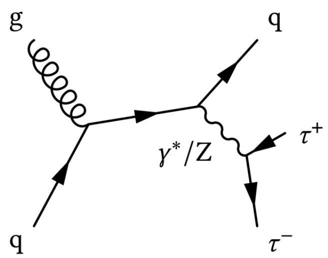
(b) $gg \longrightarrow t\bar{t}$ (t-channel top exchange).



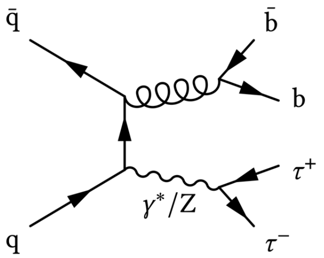
(c) $gg \longrightarrow t\bar{t}$ (u-channel top exchange).



(d) $q\bar{q} \longrightarrow t\bar{t}$ (s-channel gluon).



(a) Compton process: $qg \rightarrow Zq$ with $Z \rightarrow \tau^+\tau^-$.



(b) $Z+b\bar{b}$ from gluon splitting: $q\bar{q} \rightarrow Zg$, $g \rightarrow b\bar{b}$.

Background Processes

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- Top quark pair ($t\bar{t}$)
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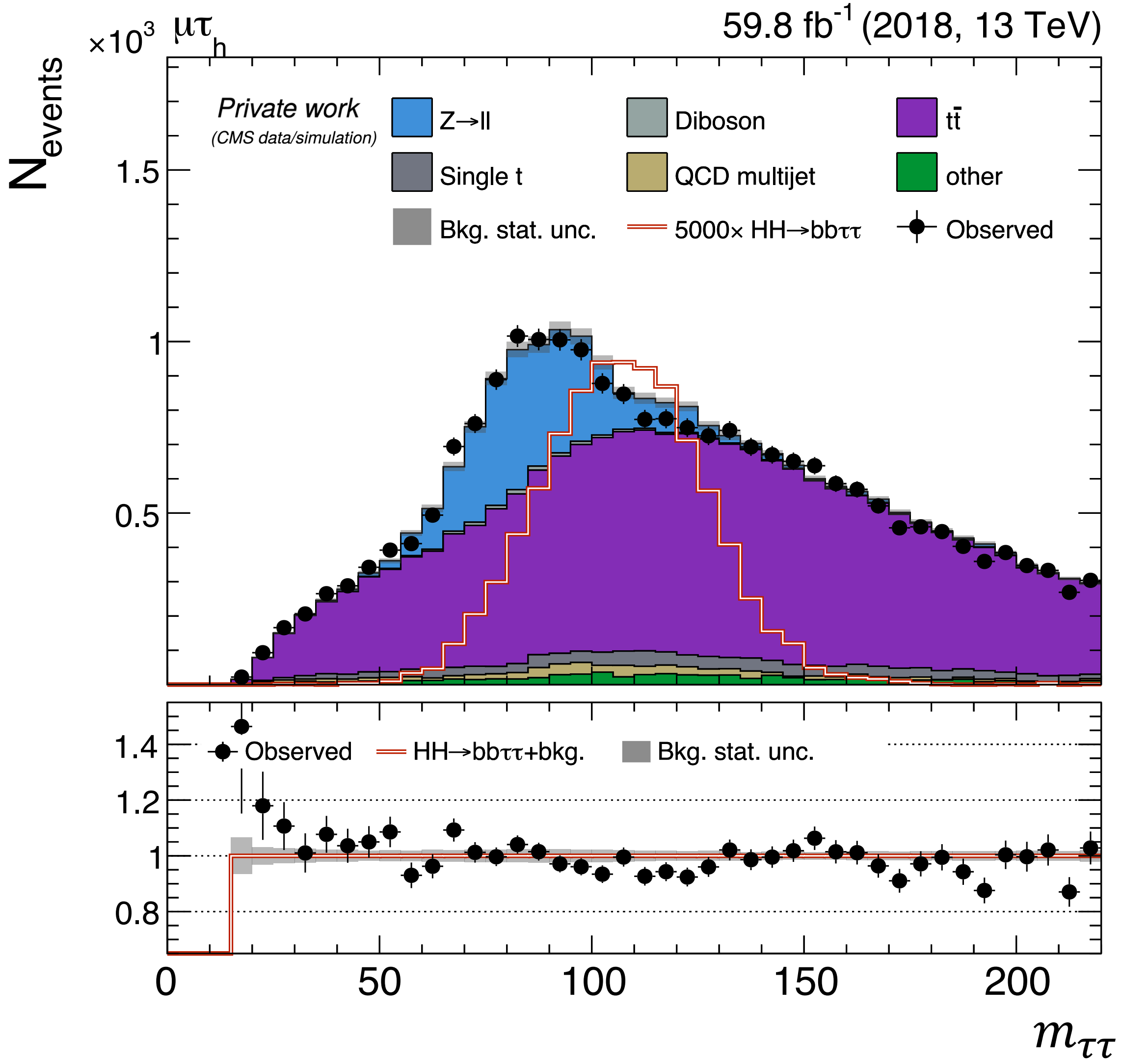
- Others like Single Higgs and Triboson

Data-driven estimation of QCD multijet production



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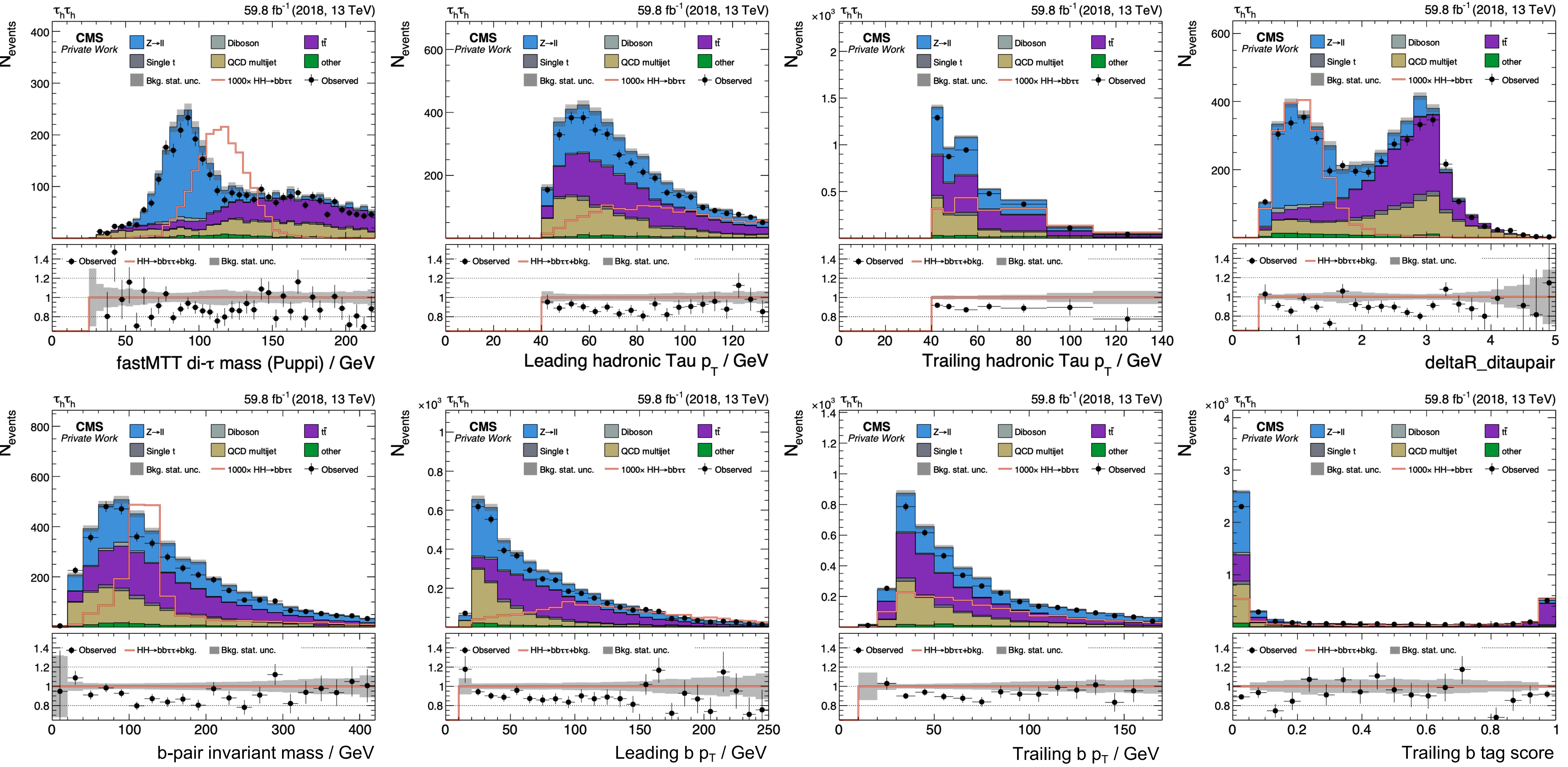
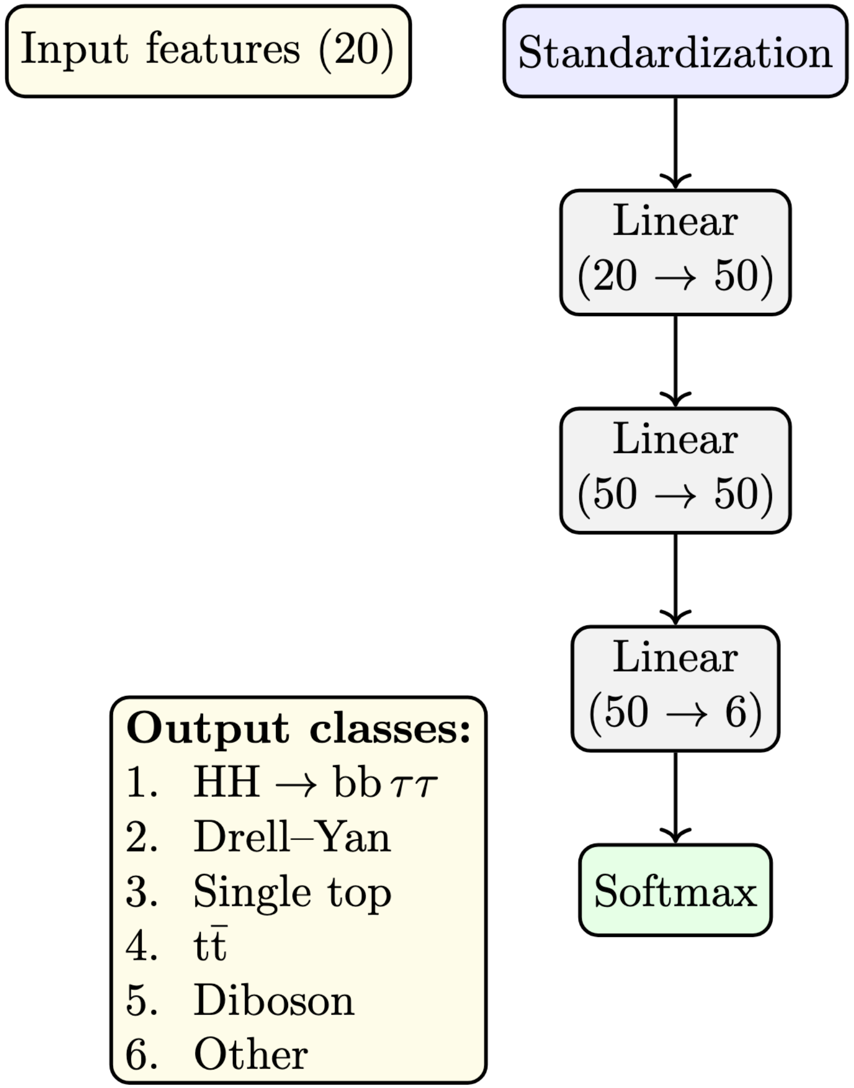
Cut based analysis?

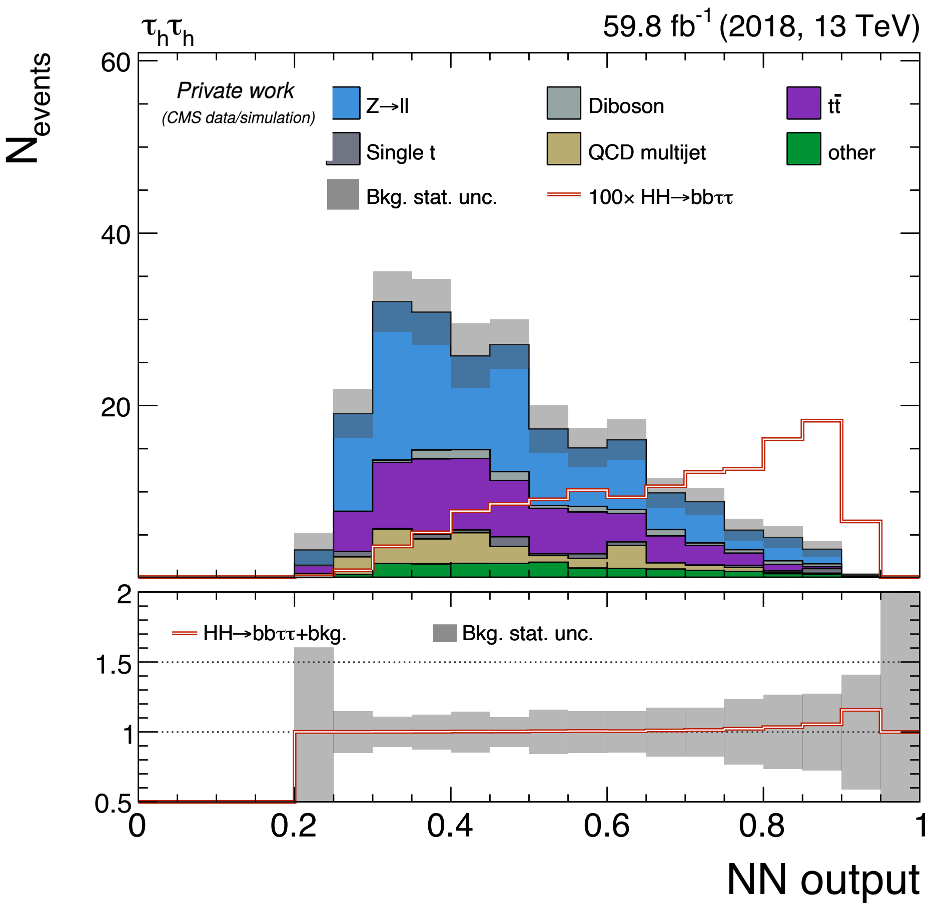


NN Training

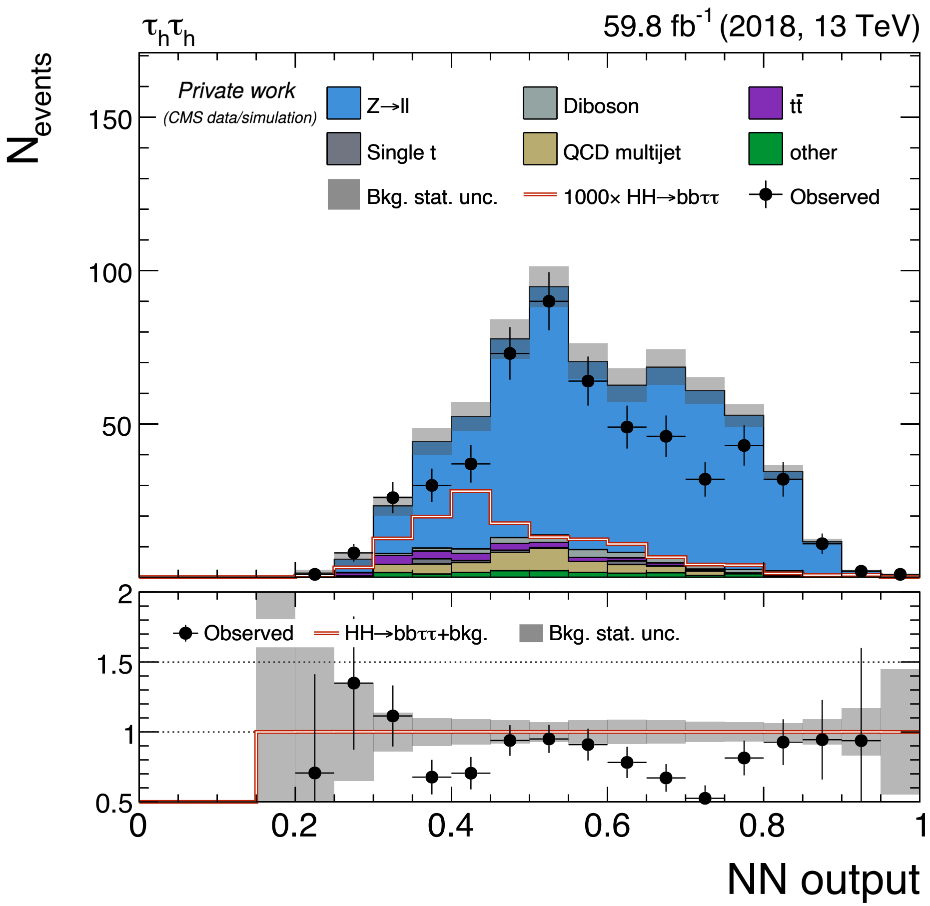
- Multiclass classification
- Cross Entropy Loss function
- Single parameter update per epoch
- L2 regularization and Dropout
- Balancing weights by the number of simulated events



Analysis categories - Examples



Signal category with blinded data



Drell-Yan category

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Processes

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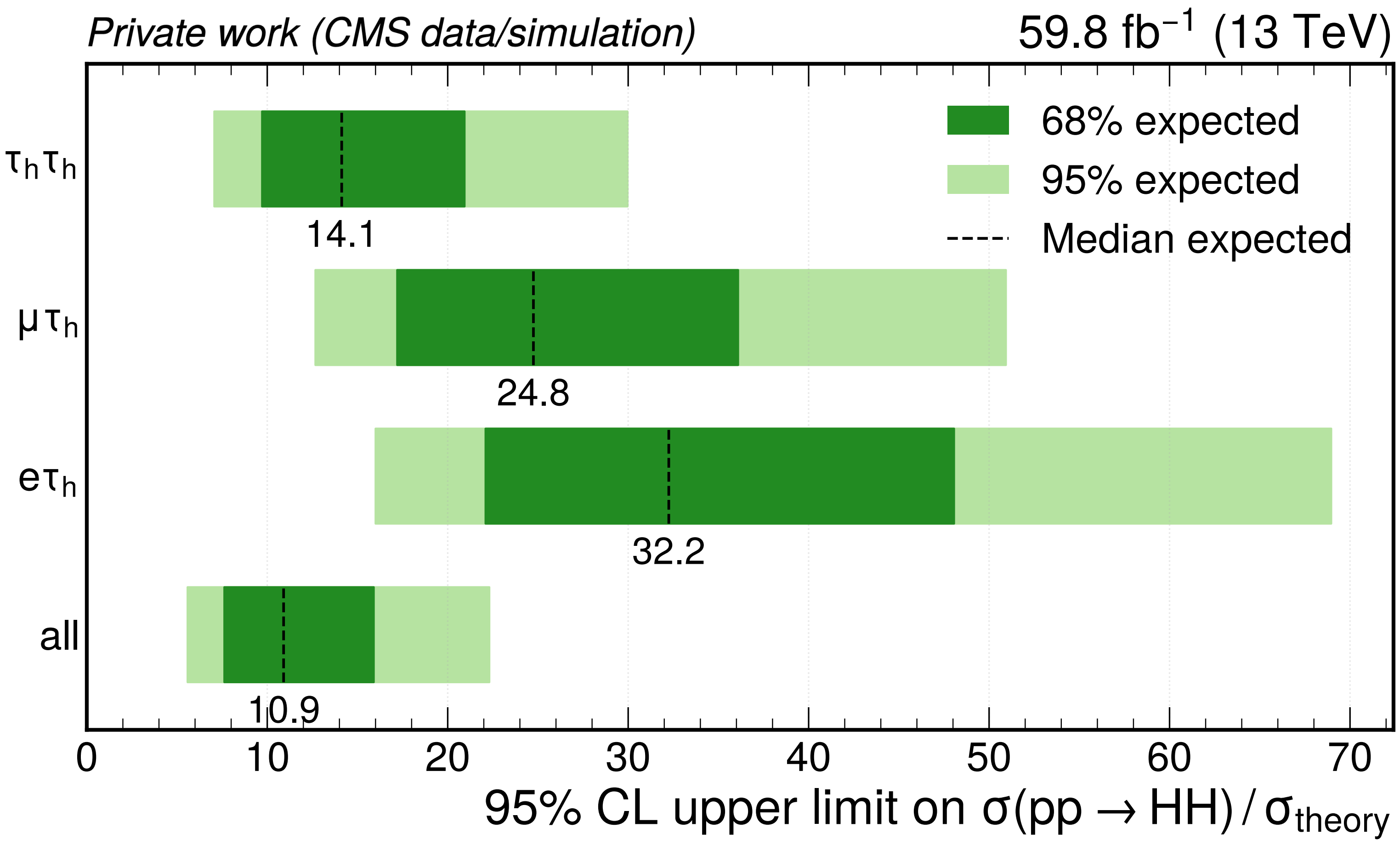
Result snapshot



To be compared with the previous publication by CMS [1]: **8.2** 95% CL upper limit

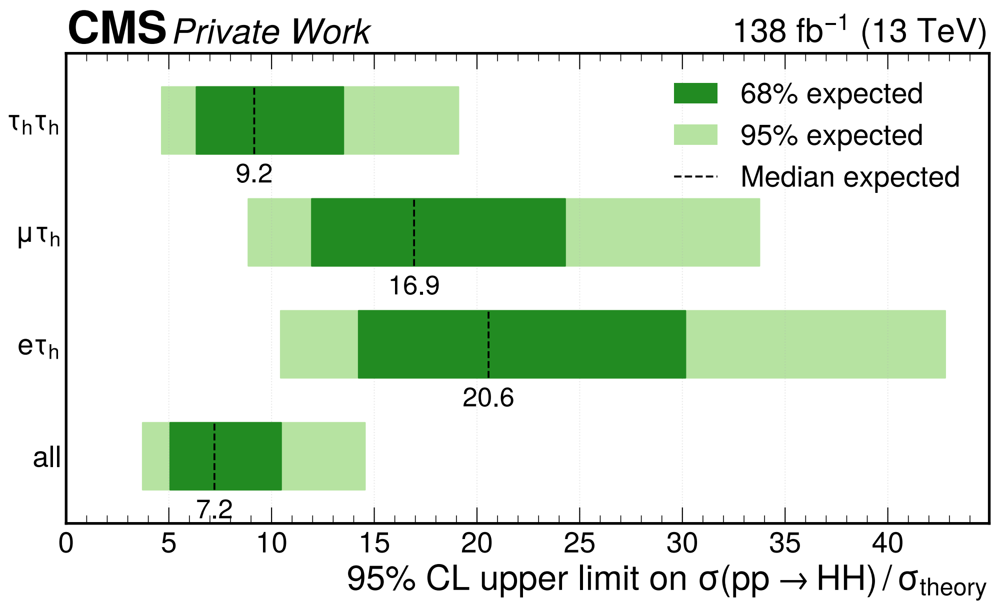
[1] arXiv:2206.09401

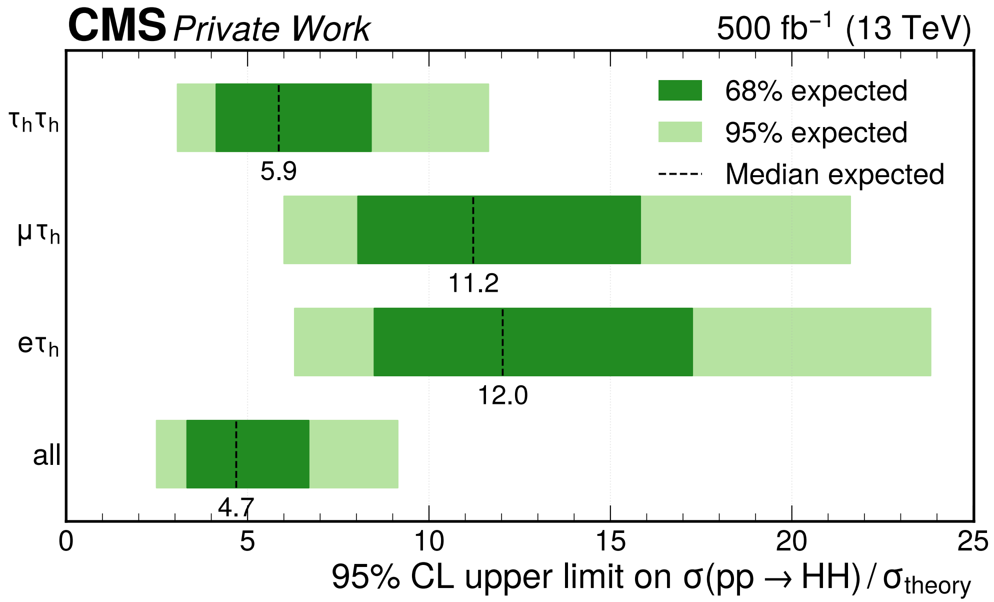
Conclusion

- Complete HH → bb$\tau\tau$ (resolved) analysis in $\tau_h\tau_h, \mu\tau_h, e\tau_h$ final states based on 2018 UL data by the CMS Collaboration
- Good data understanding achieved

Further improvements:

- Expand to full Run 2 and Run 3 data
- Improve modelling of backgrounds
- Work on improved sensitivity





Object Selection

Object selection

Kinematic requirements

Channel	Object	p_T [GeV]	$\lvert\eta\rvert$	$\lvert d_z\rvert$ [cm]	$\lvert d_{xy}\rvert$ [cm]	$I_\mathrm{rel}^{e/\mu}$	m_T [GeV]
$e\tau_\mathrm{h}$	e	> 33	< 2.1	< 0.2	< 0.045	< 0.15	< 70
	τ_h	> 30	< 2.3	< 0.2			
$\mu\tau_\mathrm{h}$	μ	> 25	< 2.1	< 0.2	< 0.045	< 0.15	< 70
	τ_h	> 30	< 2.3	< 0.2			
$\tau_\mathrm{h}\tau_\mathrm{h}$	τ_h (each)	> 40	< 2.1	< 0.2			

p_T transverse momentum
$\lvert\eta\rvert$ pseudo rapidity
d impact parameter
I_rel relative isolation
m_T transverse mass

Channel	Object	vsEle	vsMu	vsJet
$e\tau_\mathrm{h}$	τ_h	`Tight`	`VLoose`	`Medium`
$\mu\tau_\mathrm{h}$	τ_h	`VVLoose`	`Tight`	`Medium`
$\tau_\mathrm{h}\tau_\mathrm{h}$	τ_h (each)	`VVLoose`	`VLoose`	`Medium`

NN Input Parameter

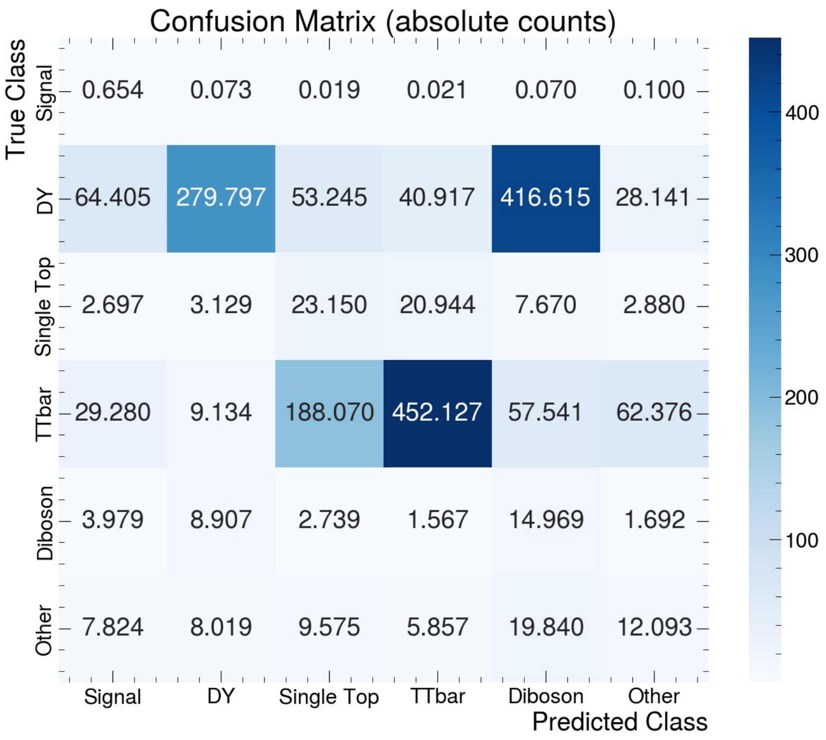
NN Input Parameter

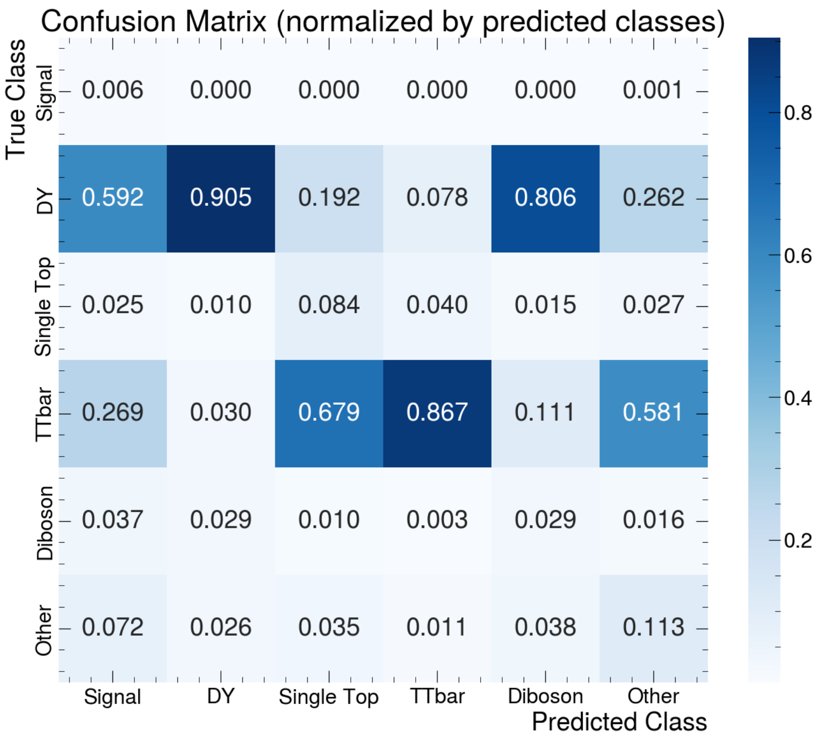
Variable	Description
m_{inv}^{jj}	Invariant mass of the two hardest jets; expected to peak near m_{H}.
$m_{\text{inv}}^{\text{b}\bar{\text{b}}}$	Invariant mass of the two b-tagged jets; highly correlated with m_{inv}^{jj}.
$m_{\tau\tau}^{\text{FastMTT}}$	Reconstructed $\tau^+\tau^-$ mass using FastMTT (Sec. 5.6) to account for neutrinos in the τ decays.
$m_{\tau\tau}^{\text{CollApprox}}$	Reconstructed $\tau^+\tau^-$ mass using the collinear $m_{\tau\tau}$ approximation.
m_{vis}	Invariant mass of the visible decay products of the $\tau^+\tau^-$-system.
m_T^{tot}	Total transverse mass, which is the sum of the transverse masses of all final state particles.
$\Delta R_{\text{b}\bar{\text{b}}}$, $\Delta R_{\tau\tau}$	Angular separations capturing the production kinematics.
$p_{\text{T}}^{j,1}$, $p_{\text{T}}^{j,2}$	Transverse momenta (p_T) of the leading and subleading jet.
$p_{\text{T}}^{\text{bpair},1}$	p_{T} of the leading b-tagged jet; highly correlated with $p_{\text{T},1}^{j}$.
$p_{\text{T}}^{\text{dijet}}$	Combined p_{T} of the two hardest jets.
$p_{\text{T}}^{\text{bpair,dijet}}$	Combined p_{T} of the b-jet pair; highly correlated with $p_{\text{T}}^{\text{dijet}}$.
p_{T}^{1}	p_{T} of the electron, muon or the p_{T}-leading τ_{h}.
$p_{\text{T}}^{\text{FastMTT}}$	p_T of the $\tau^+\tau^-$ system reconstructed with FastMTT to account for neutrinos in the τ decays.
$p_{\text{T}}^{\text{vis}}$	p_{T} of the visible decay products of the $\tau^+\tau^-$-system.
n_{btag}	Number of b-tagged jets.
n_{jets}	Number of reconstructed jets.
btag^1, btag^2	DeepJet discriminants of the selected candidate jet to form the $\text{b}\bar{\text{b}}$ pair.

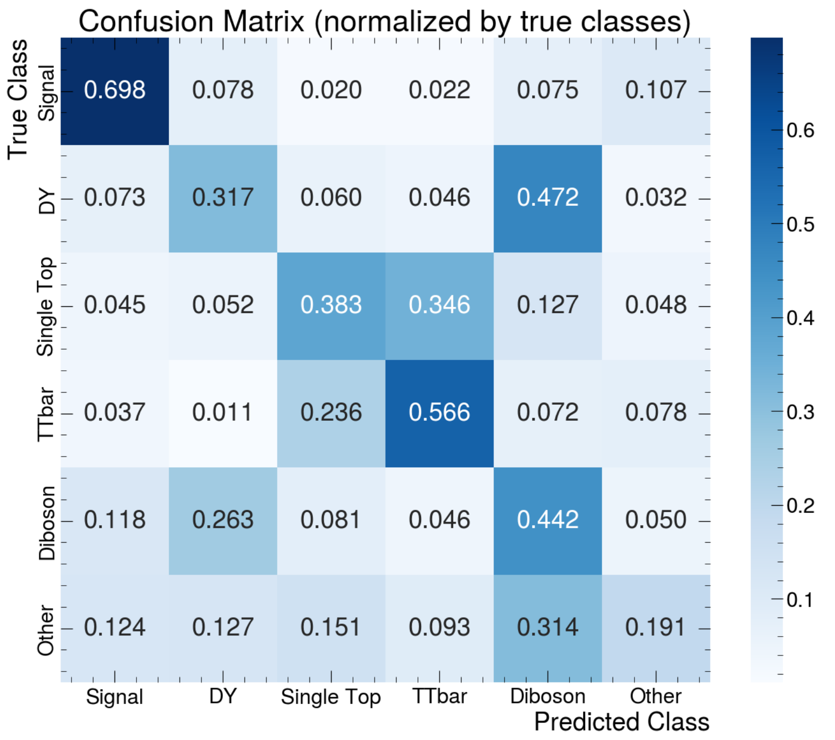
Confusion Matrices

$\tau_h \tau_h$ final state

Equal balancing by simulated events

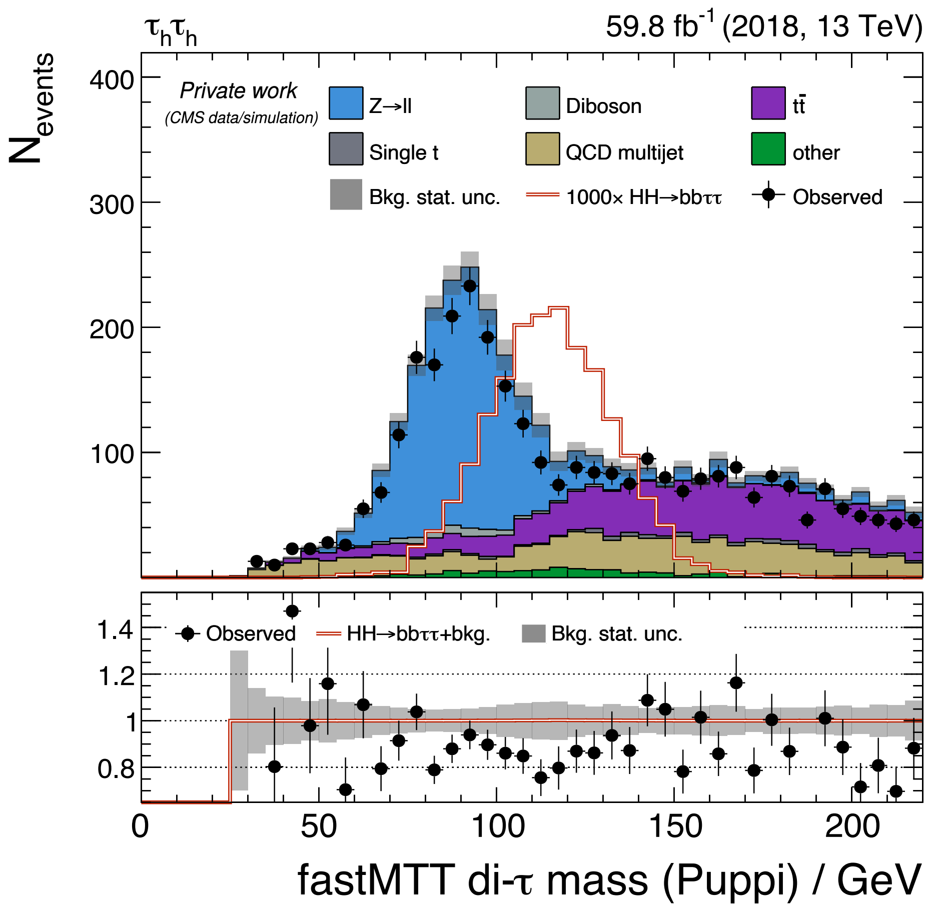


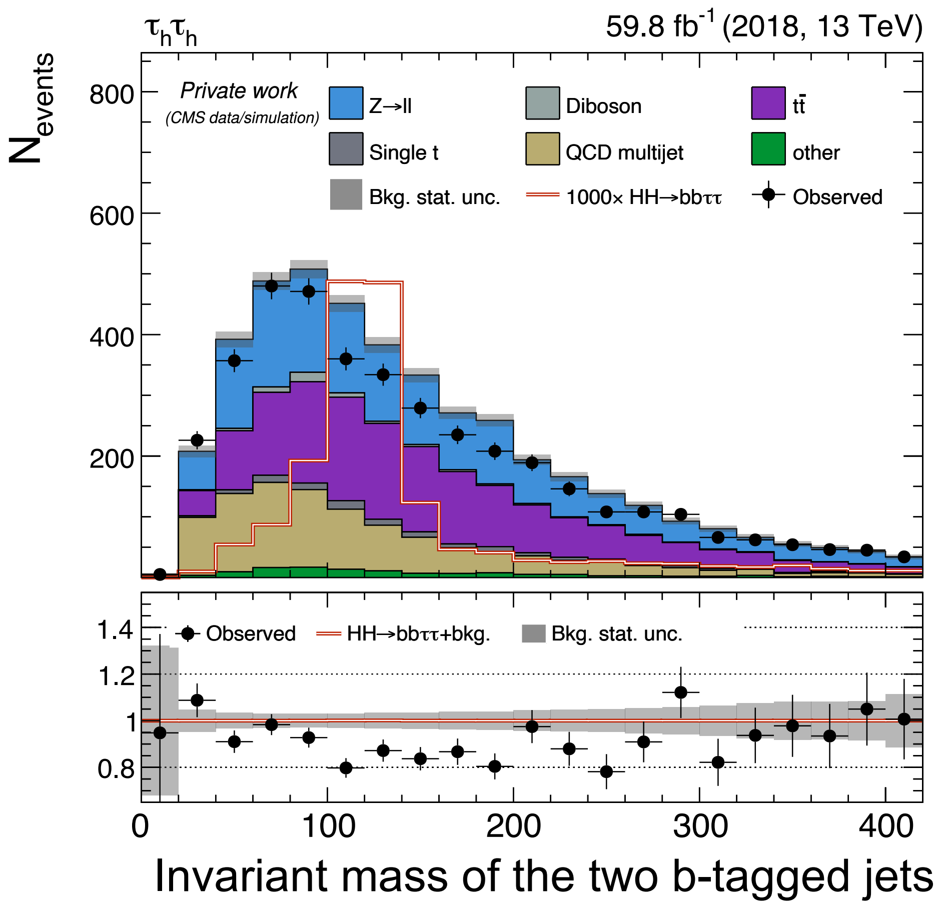




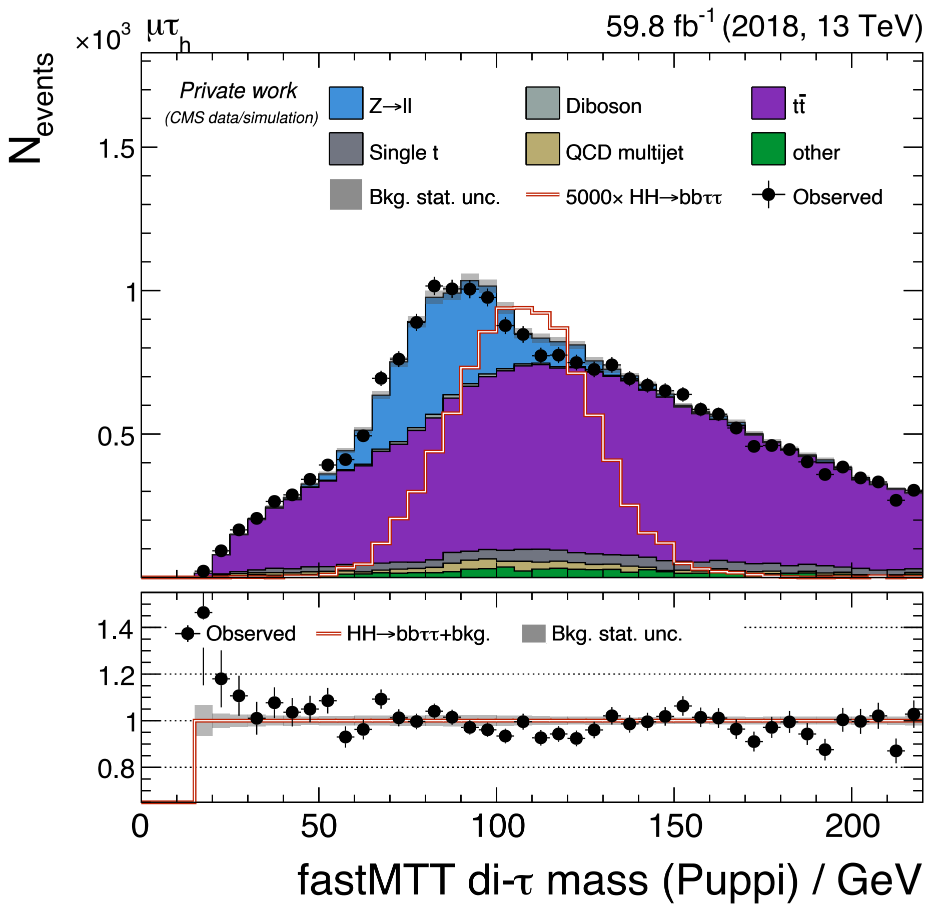
Control Plots

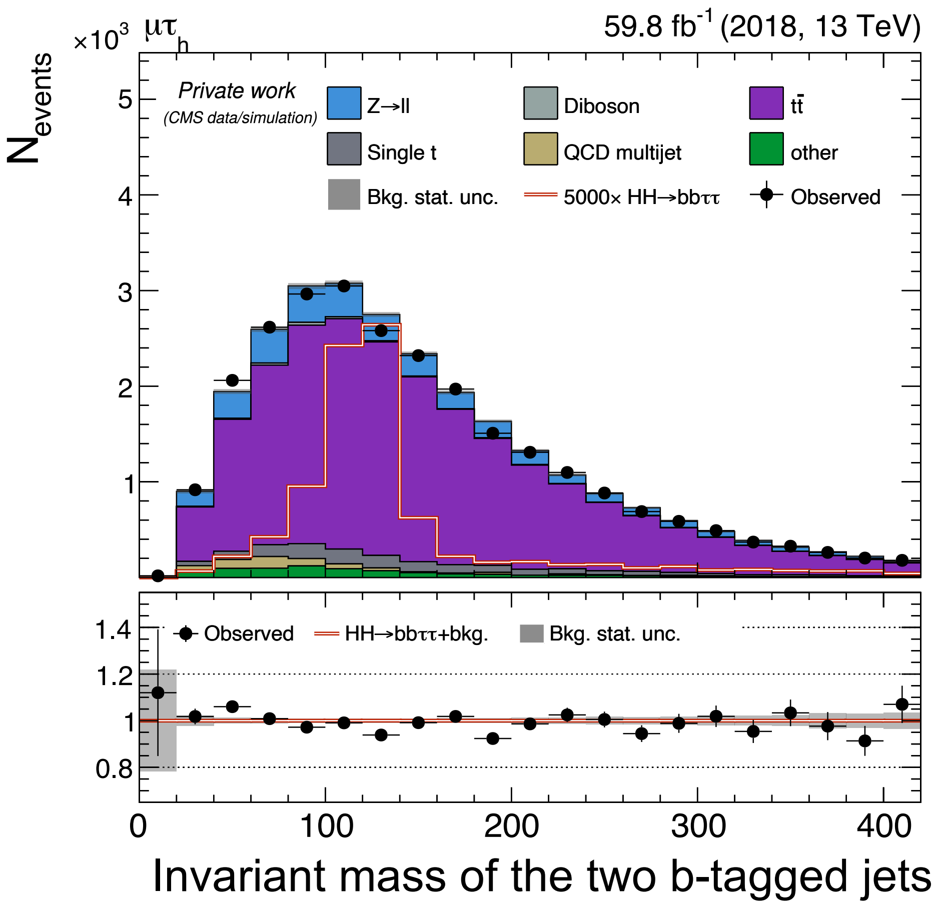
Control Plots - $\tau_h\tau_h$



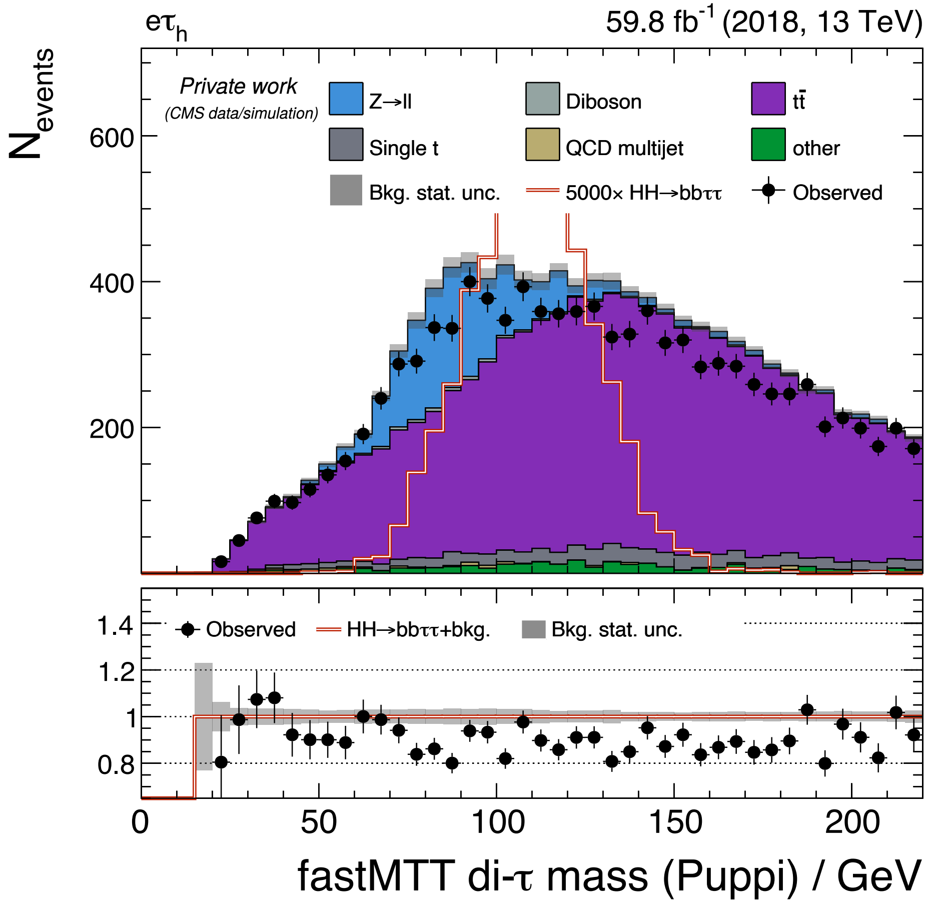


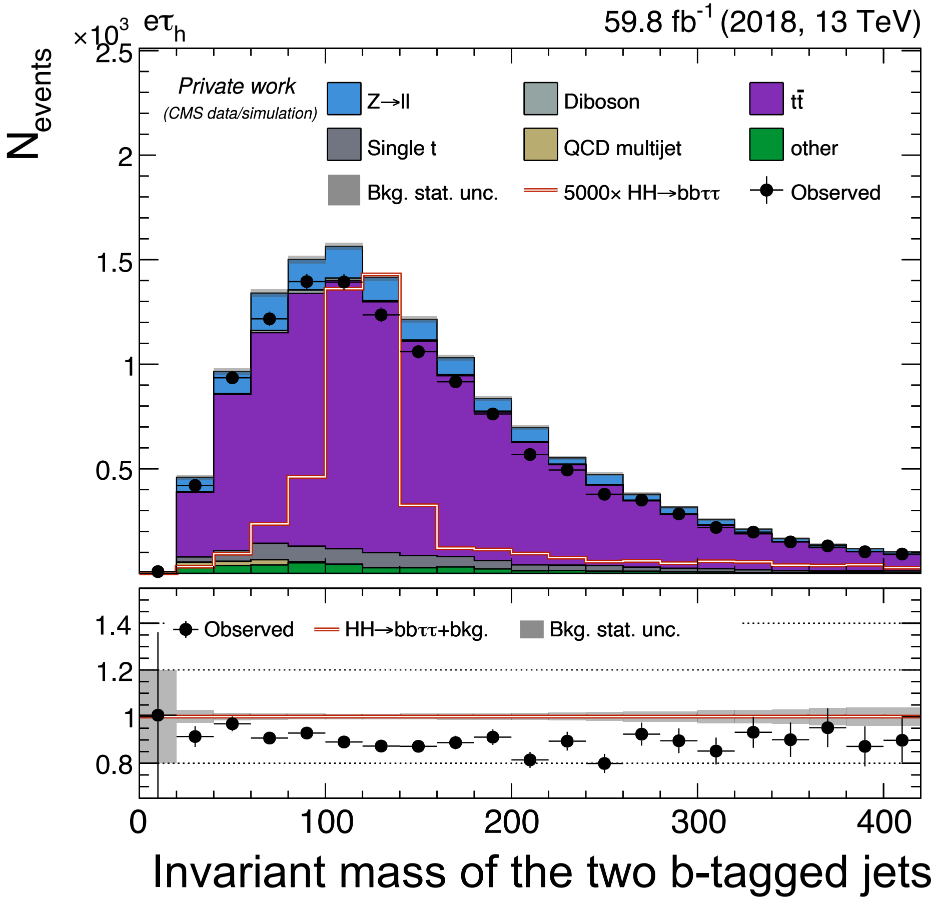
Control Plots - $\mu\tau_h$





Control Plots - $e\tau_h$





Systematic uncertainties

Systematic uncertainties

Nuisance	Processes	Channels	Size (up/down)
eff_e	all	et	1.02
eff_m	all	mt	1.02
eff_t_vsLep	all	et,mt	1.01
eff_t_vsLep	all	tt	1.02
eff_t_vsJet†	all	et,mt	1.02
eff_t_vsJet†	all	tt	1.04
lumi_13TeV	all	all	1.025
htt_vvXsec	diboson	all	1.05
htt_stXsec	single t	all	1.05
htt_tjXsec	$t\bar{t}$	all	1.06
htt_wjXsec	W	all	1.04
htt_zjXsec	DY	all	1.02
QCDNorm	QCD	et, mt	1.108
QCDNorm	QCD	tt	1.216
QCDscale_ttH, pdf_ttH, alphaS_ttH	ttH	all	(1.058/0.908), 1.030, 1.020
QCDscale_ggH, pdf_ggH, alphaS_ggH	ggH	all	1.039, 1.019, 1.026
QCDscale_qqH, pdf_qqH, alphaS_qqH	qqH	all	(1.004/0.997), 1.021, 1.005
QCDscale_VH, pdf_VH, alphaS_VH	VH(WH+ZH)	all	(1.038/0.970), 1.017, 1.009
QCDscale_HH	signal	all	(1.022/0.950)
PDF_alphas_HH	signal	all	1.030
mtop_HH	signal	all	1.026
BR_h_bb	signal	all	(1.0125/0.9873)
BR_h_tautau	signal	all	1.0165

ABCD Method

ABCD Method

For QCD multijet production estimation

Region	**Charge**	$\tau_{h,1}$ **isolation**	$\tau_{h,2}$ **isolation**
A (target)	OS ($q_1 q_2 < 0$)	Iso	Iso
B (shape)	OS ($q_1 q_2 < 0$)	Iso	Anti-Iso
C (norm)	SS ($q_1 q_2 > 0$)	Iso	Iso
D (norm)	SS ($q_1 q_2 > 0$)	Iso	Anti-Iso