Search for additional neutral MSSM Higgs bosons in the di-tau final state

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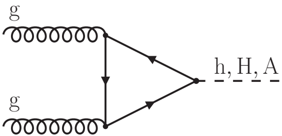
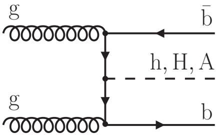
Higgs Sector in the MSSM

- The Higgs sector in MSSM equivalent to 2HDM.
- Predicts 5 Higgs bosons
  - 2 charged bosons $H^{\pm}$
  - Three neutral bosons $\underbrace{h, H, A}_{\phi}$
- At tree level MSSM can be described by 2 free parameters $\rightarrow$ chosen to be m_A and $\tan\beta = {}^{v_u}/_{v_d}$.
- Coupling to down-type fermions enhanced by $\tan\beta$





	g_{VV}/g_{VV}^{SM}	g_{uu}/g_{uu}^{SM}	g_{dd}/g_{dd}^{SM}
A	–	$\gamma_5 \cot\beta$	$\gamma_5 \tan\beta$
H	0	$\cot\beta$	$\tan\beta$
h	1	1	1

Introduction

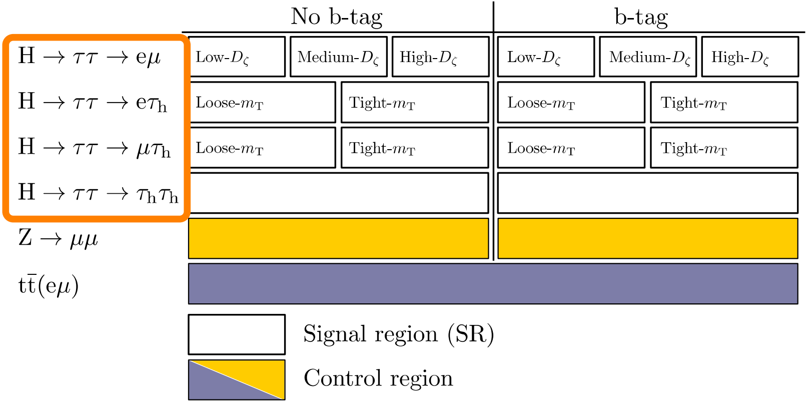
- Analysis is performed in the di-tau final state.

- New results are based on full data collected in 2016 corresponding to 35.9 fb^{-1}.

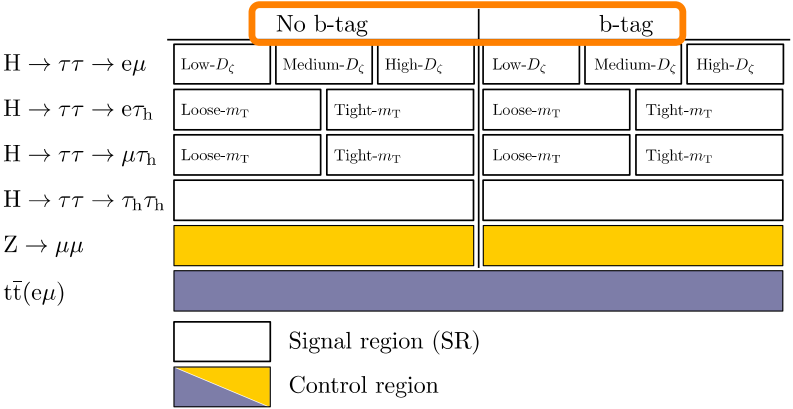
- Major changes with respect to previous analysis on 12.9 fb^{-1}@13 TeV data:
  - Increased sensitivity due to more complex event categorization.
  - Signal modeling at NLO accuracy.
  - Maximally data-driven background estimation for jets misidentified as hadronic tau decays.

Categorization

- Split into channels depending on τ decay.
  - Leptonic: τ to e/μ
  - Hadronic: τ to τ_h

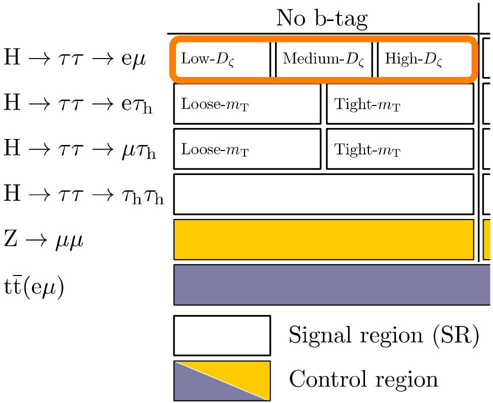


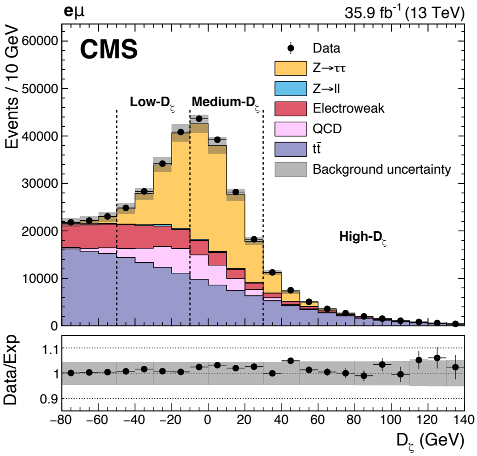
- Split into b-tag and no-btag categories to target b-associate production modes and production via gluon fusion.



Categorization

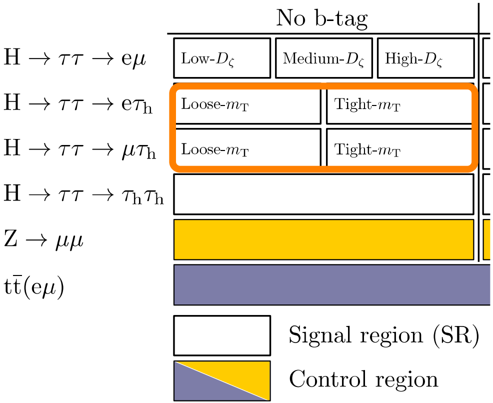
- Takes into account change in S/B ratio especially for high mass signal.

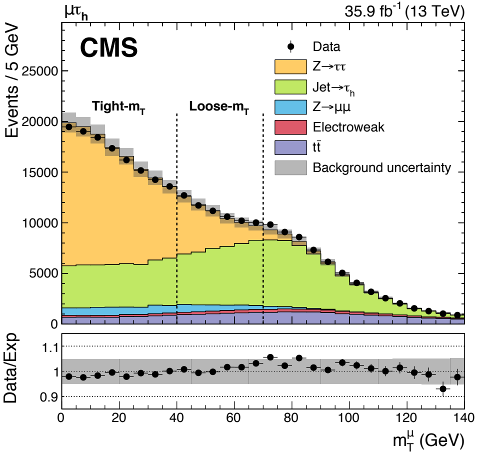




Categorization

- Loose-m_T region increases signal acceptance for high m_T events → "tail-catcher" for high mass signal.



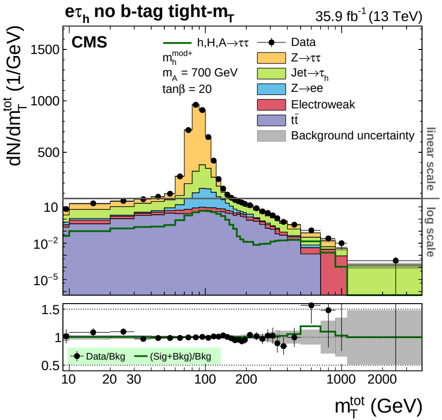


Background estimation

- jet $\rightarrow \tau_h$ fake backgrounds are estimated from data in eτ, $\mu\tau$ and $\tau\tau$ $\rightarrow$ fake factor method.
- QCD background in eμ channel estimated from data.
- Backgrounds from non-jet fakes are estimated using simulation $\rightarrow$ Dominant backgrounds with real hadronic taus are normalized in control regions.

Background process	Misidentification	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$
$H \rightarrow \tau\tau$ (SM)		MC	MC	MC	MC
$Z \rightarrow \tau\tau$		MC†	MC†	MC†	MC†
$Z \rightarrow \ell\ell$	$\ell \rightarrow \tau_h$	MC	MC	MC	MC
	Jet $\rightarrow \tau_h$		F_F	F_F	F_F
Diboson+single t	$\tau/\ell \rightarrow \tau_h$	MC	MC	MC	MC
	Jet $\rightarrow \tau_h$		F_F	F_F	F_F
$t\bar{t}$	$\tau/\ell \rightarrow \tau_h$	MC†	MC†	MC†	MC†
	Jet $\rightarrow \tau_h$		F_F	F_F	F_F
W+jets	Jet $\rightarrow \tau_h$	MC	F_F	F_F	F_F
QCD multijet production	Jet $\rightarrow \tau_h$	CR	F_F	F_F	F_F

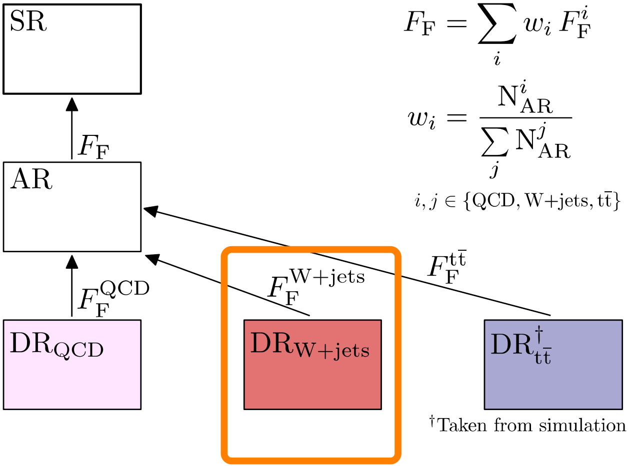
† Normalization from control region in data.



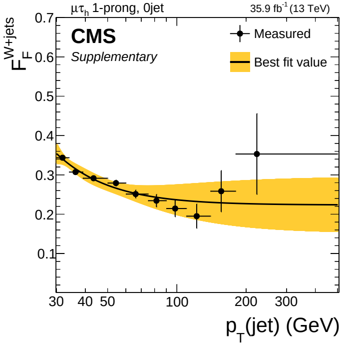
$$F_{\mathrm{F}} = \sum_i w_i \, F_{\mathrm{F}}^i$$

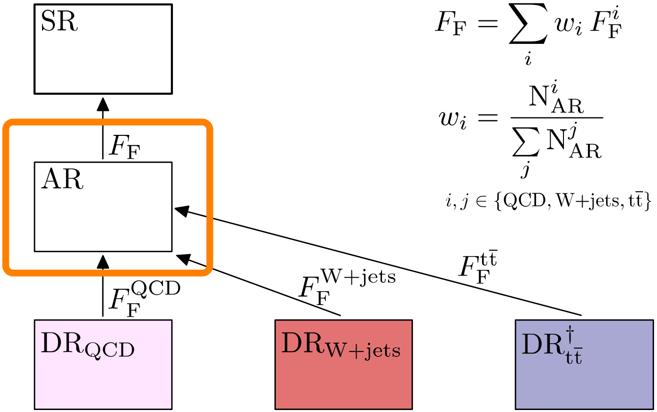
$$w_i = \frac{\mathrm{N}_{\mathrm{AR}}^i}{\sum_j \mathrm{N}_{\mathrm{AR}}^j}$$

$$i, j \in \{\mathrm{QCD}, \mathrm{W{+}jets}, \mathrm{t\bar{t}}\}$$



Measure ratio of isolated taus to taus with inverted isolation in determination regions (DR)





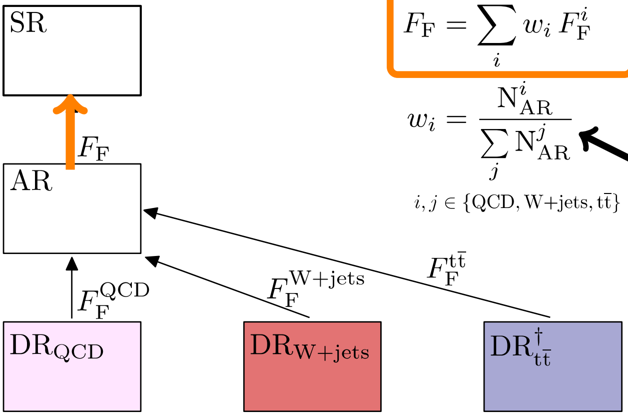
$$F_F = \sum_i w_i \, F_F^i$$

$$w_i = \frac{N_{AR}^i}{\sum_j N_{AR}^j}$$

$$i, j \in \{QCD, W{+}jets, t\bar{t}\}$$

†Taken from simulation

Define application region (AR) that differs from the signal region only by having inverted tau isolation



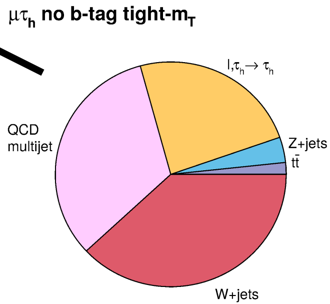
$$F_{\mathrm{F}} = \sum_i w_i \, F_{\mathrm{F}}^i$$

$$w_i = \frac{\mathrm{N}^i_{\mathrm{AR}}}{\sum_j \mathrm{N}^j_{\mathrm{AR}}}$$

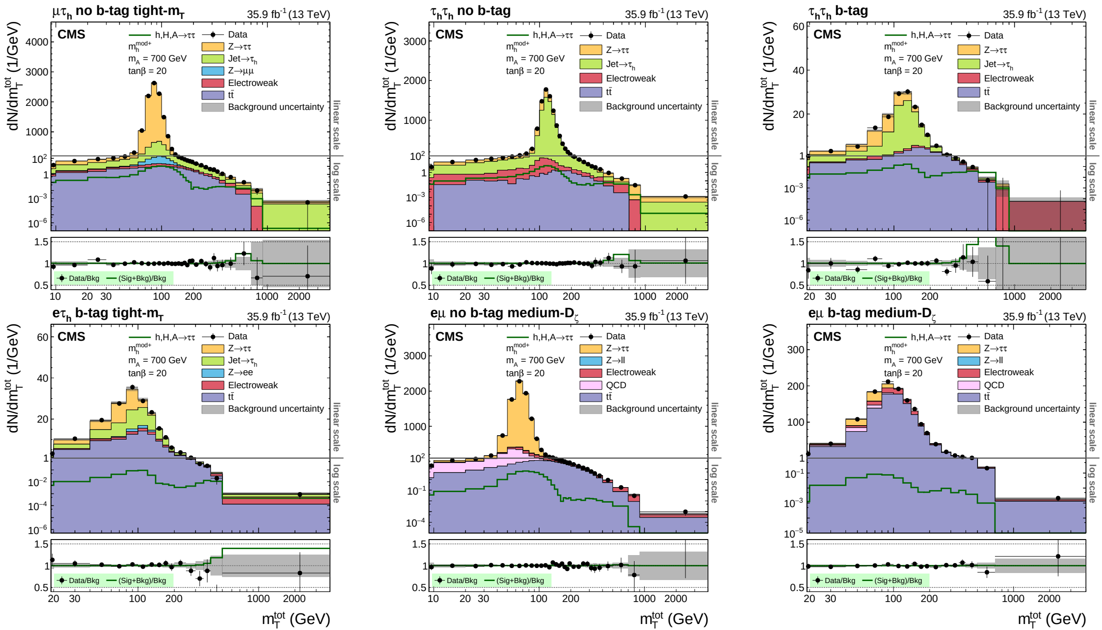
$$i, j \in \{\mathrm{QCD}, \mathrm{W{+}jets}, \mathrm{t\bar{t}}\}$$

†Taken from simulation

Apply fake-factor to events in AR to estimate background in SR

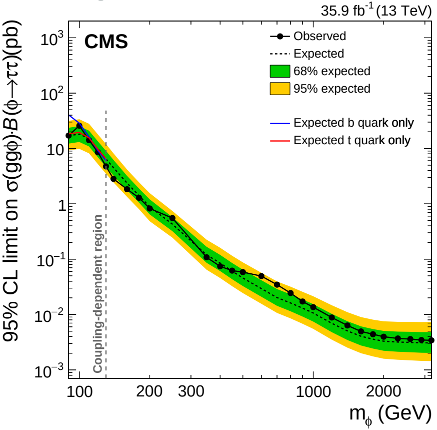


Distributions of Final Discriminator

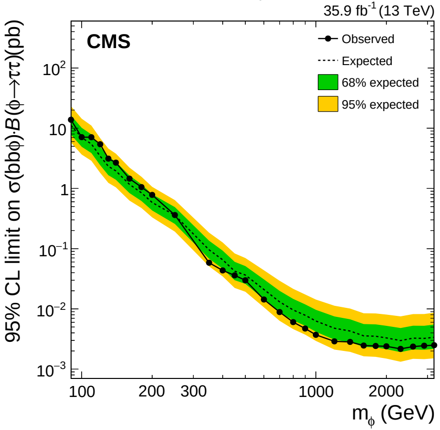


- No deviations beyond 2 sigma found.

gluon fusion



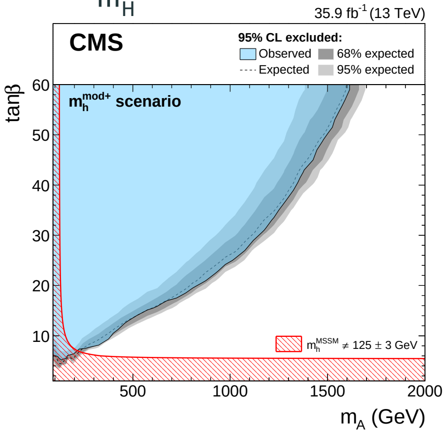
b-associate production



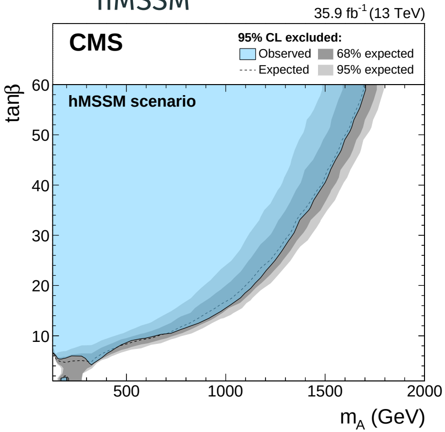
MSSM limits

- Exclusion contours in predefined benchmark models.
- Parameter space explored down to $\tan\beta \gtrsim 6$ for $m_A \lesssim 250$ GeV and up to $m_A = 1600$ GeV.

m_H^{mod+}

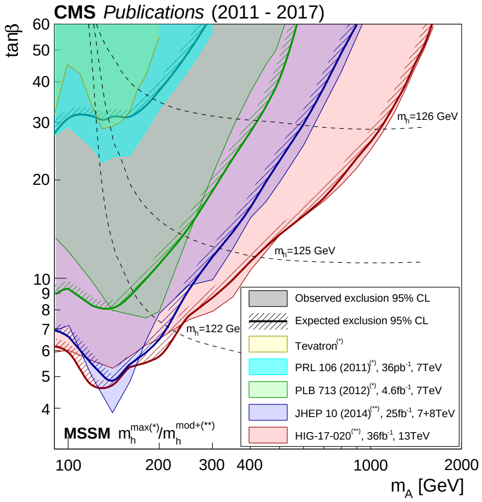


hMSSM



Summary

- Presented results for additional neutral MSSM Higgs bosons in the di-tau final state.
  - Submitted to JHEP (arXiv:1803.06553v1).
- Analysis extends explored parameter space for models of more complex Higgs sector significantly.
- Signal modeling with NLO accuracy.
- Improved background estimation techniques for jet $\rightarrow \tau_h$ fake backgrounds.



Thank you!

Signal Modeling

- Gluon fusion samples with LO accuracy but re-weighted $p_T(H)$ distribution to NLO.
  - p_T distribution depends on $m_A - \tan\beta \rightarrow$ Take this into account for re-weighting.

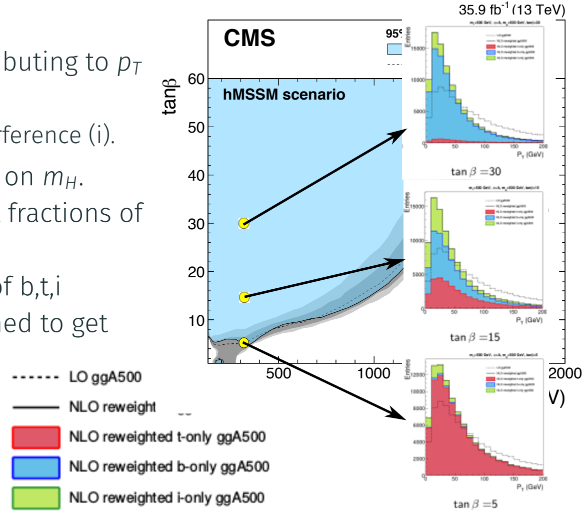
$\rightarrow$ Dissentangle different processes contributing to p_T distribution.

- top-only (t), bottom-only (b) and interference (i).

$\rightarrow$ In 2HDMs p_T distribution depends only on m_H.

$\rightarrow$ $\tan\beta$ dependence arises from different fractions of b,t,i sub-processes.

$\rightarrow$ For each $\tan\beta$ point relative fractions of b,t,i contributions are computed and summed to get overall p_T distributions.



$$D_\zeta = P_\zeta - 1.85 P_\zeta^{vis}$$

$$\text{with } P_\zeta = (\vec{P}_{T,1}^{vis} + \vec{P}_{T,2}^{vis} + \vec{P}_T^{\text{mis}}) \frac{\vec{\zeta}}{|\vec{\zeta}|}$$

$$\text{and } P_\zeta^{vis} = (\vec{P}_{T,1}^{vis} + \vec{P}_{T,2}^{vis}) \frac{\vec{\zeta}}{|\vec{\zeta}|}$$