Searches for MSSM Higgs bosons with CMS

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Higgs Sector in the MSSM

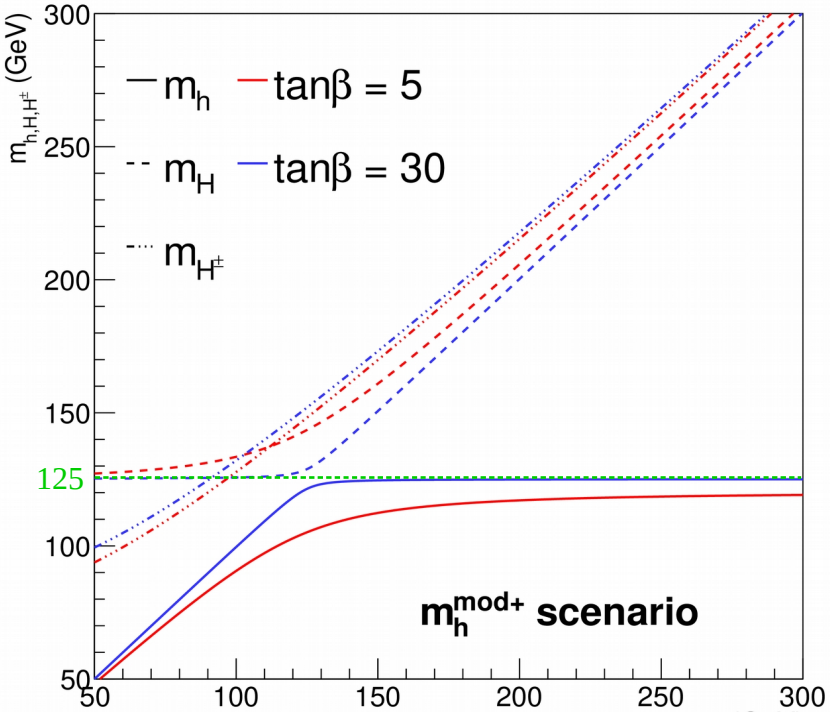
Higgs Sector in the MSSM

- The MSSM is a special Two Higgs Doublet Model
  - 5 Higgs bosons predicted (2 charged: $H^{\pm}$; 3 Neutral: h, H, A)

ϕ

- Stringent mass requirements at tree level

Two free parameters: $m_A, \tan\beta = v_u/v_d$



Created using Feynhiggs 2.13

MSSM Higgs Boson searches by CMS

- Searches for charged Higgs bosons
  - $H^{\pm} \rightarrow W^{\pm}Z$, 2.3+12.9 1/fb @ 13 TeV, PRL 119 (2017) 141802
  - $H^{\pm} \rightarrow \tau\nu_{\tau}$, 12.9 1/fb @ 13 TeV, CMS-PAS-HIG-16-031
- Searches for neutral Higgs bosons
  - A/H/h $\rightarrow \mu\mu$, 5.1 1/fb @ 7 TeV + 19.3 1/fb @ 8 TeV, PLB 752 (2016) 221
  - A/H $\rightarrow$ bb, 4.9 1/fb @ 7 TeV + 19.7 1/fb @ 8 TeV, JHEP 11 (2015) 071
  - A/H/h $\rightarrow \tau\tau$, 35.9 1/fb @ 13 TeV, CMS-PAS-HIG-17-020

Searches for Charged MSSM Higgs Bosons

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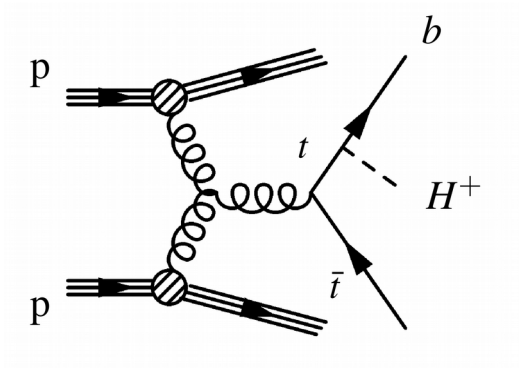
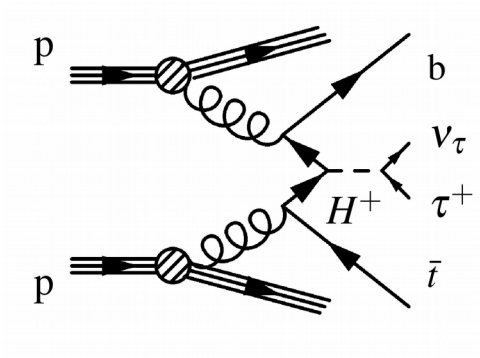
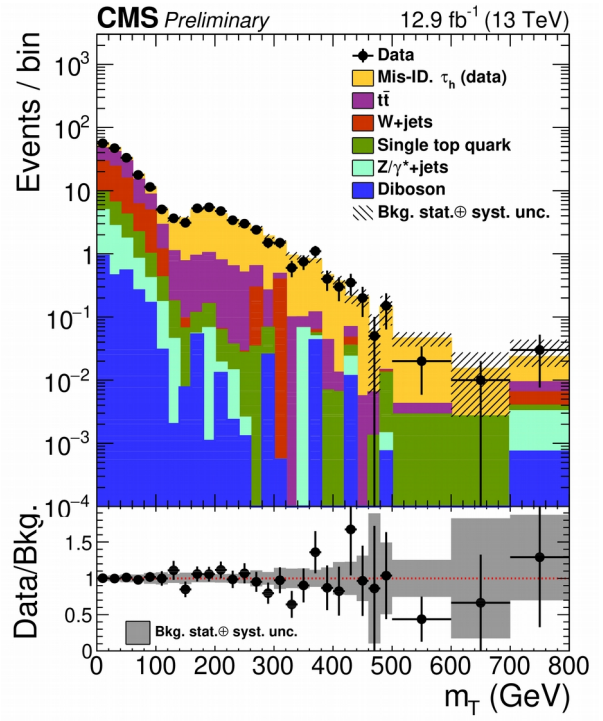






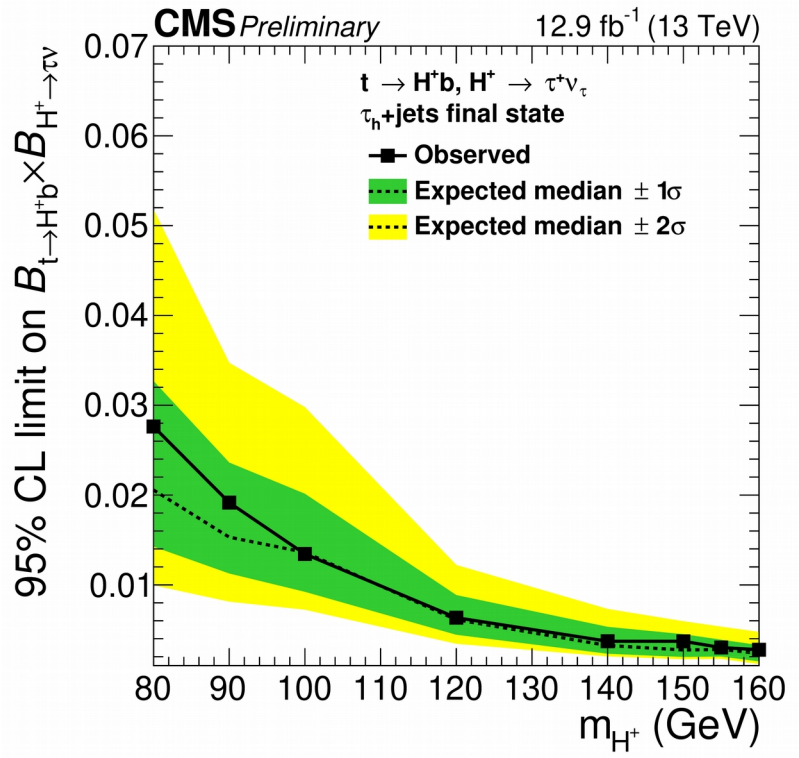
- Studied final state $\mathrm{H}^{\pm} \rightarrow \tau\nu_\tau$ (12.9 1/fb)
- Search is performed for two mass scenarios

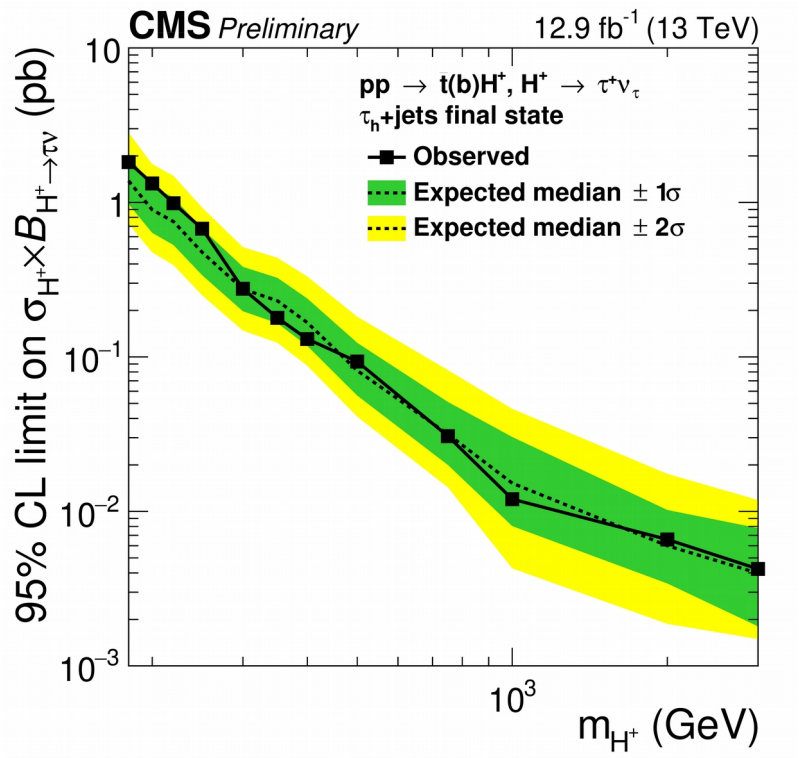
  $\mathrm{m_{H^{\pm}}} < m_\mathrm{t} - m_\mathrm{b}$, $\mathrm{pp} \rightarrow H^{\pm}W^{\mp}b\bar{b}$

  $\mathrm{m_{H^{\pm}}} > m_\mathrm{t} - m_\mathrm{b}$, $\mathrm{pp} \rightarrow tbH^{\pm}$
- The distribution of the transverse mass is studied

CMS-PAS-HIG-16-031

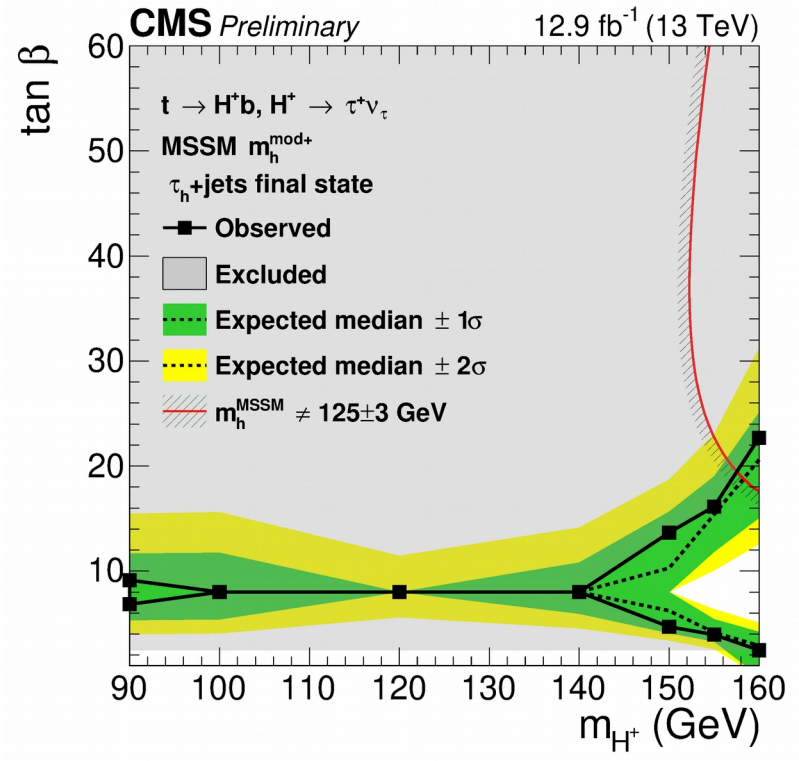
Searches for Charged MSSM Higgs Bosons

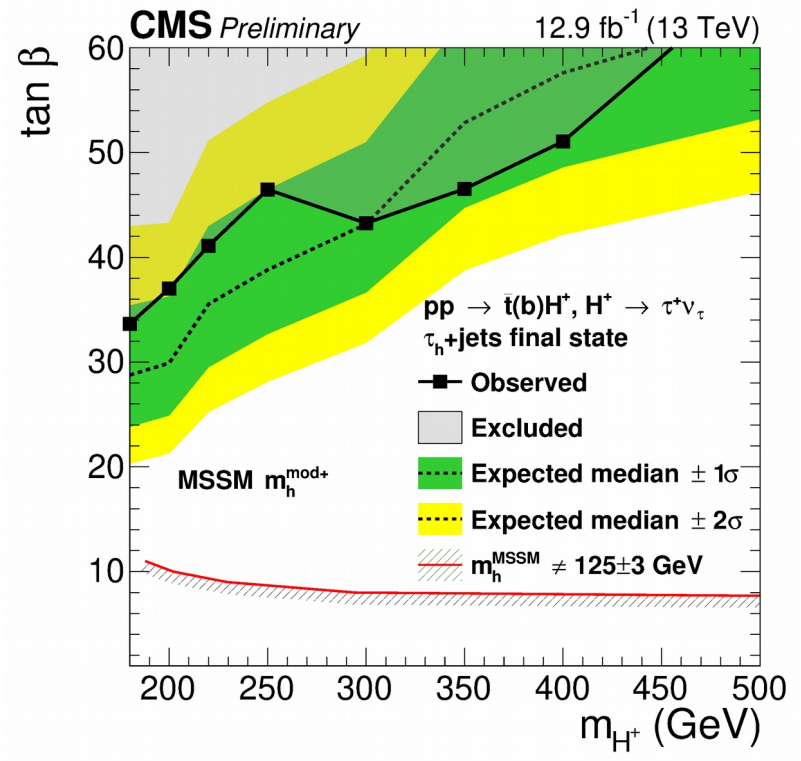




- Exclusion limits are derived as
  - Model independent exclusion limits
- No excess is observed

Searches for Charged MSSM Higgs Bosons





- Exclusion limits are derived as
  - Model independent exclusion limits
  - Exclusion limits in the MSSM m_h^{mod+} scenario
- No excess is observed

Search for Neutral MSSM Higgs Bosons

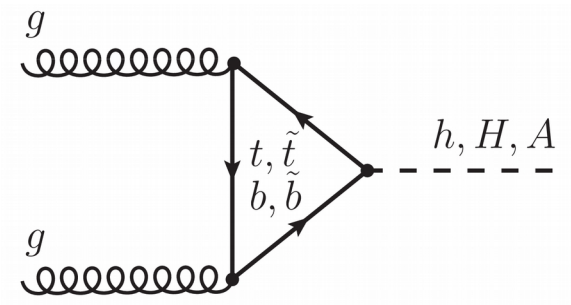
Neutral Higgs Bosons in the MSSM

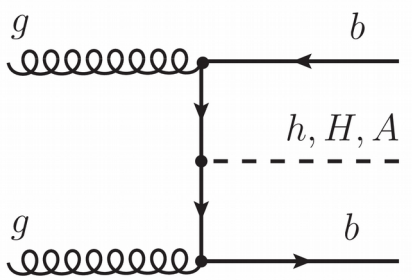
- In the “decoupling limit” $m_A \gg m_Z$
  - Coupling to down-type fermions enhanced by tanβ

	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

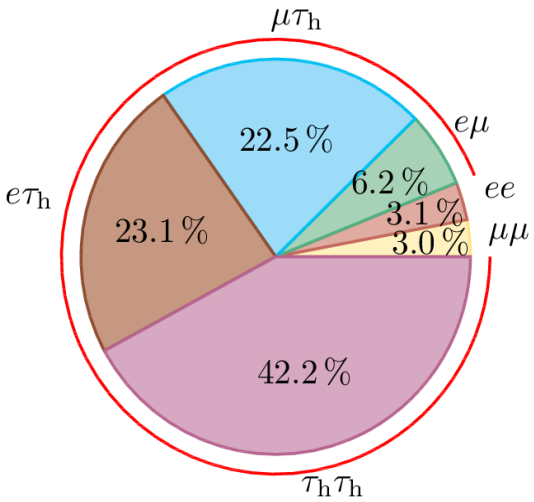
Coupling to τ-leptons

- Production modes





Search in the di-tau Final State



Kinematic selection

final state	first lepton	second lepton
$e\mu$ [(1)]	p_T^e>13 GeV, $\lvert\eta^e\rvert$<2.5	p_T^μ >10 GeV, $\lvert\eta^\mu\rvert$<2.4
$e\tau_h$	p_T^e>26 GeV, $\lvert\eta^e\rvert$<2.1	$p_T^{\tau_h}$>30 GeV, $\lvert\eta^{\tau_h}\rvert$<2.3
$\mu\tau_h$	p_T^μ>23 GeV, $\lvert\eta^\mu\rvert$<2.1	$p_T^{\tau_h}$>30 GeV, $\lvert\eta^{\tau_h}\rvert$<2.3
$\tau_h\tau_h$	$p_T(\tau_h) > 40$ GeV, $\lvert\eta(\tau_h)\rvert < 2.1$	

(1) $p_T > 24$ GeV on the higher p_T trigger match (see text).

- New result on full 2016 dataset corresponding to 35.9 1/fb
- Major changes with respect to previous analyses
  - New method for estimating background from jets misidentified as hadronic tau-decays
  - Introduced full differential NLO description for signal processes

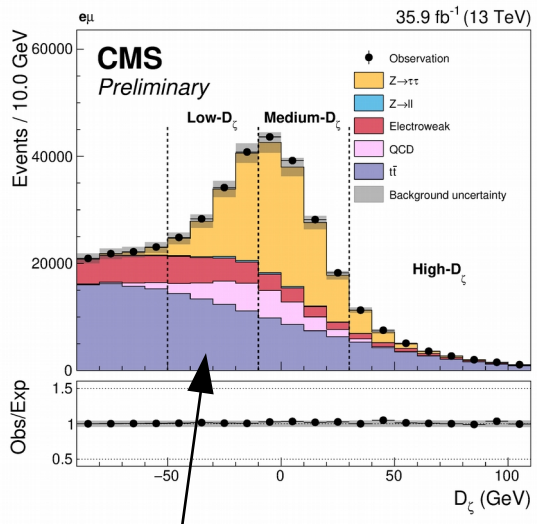
Background processes

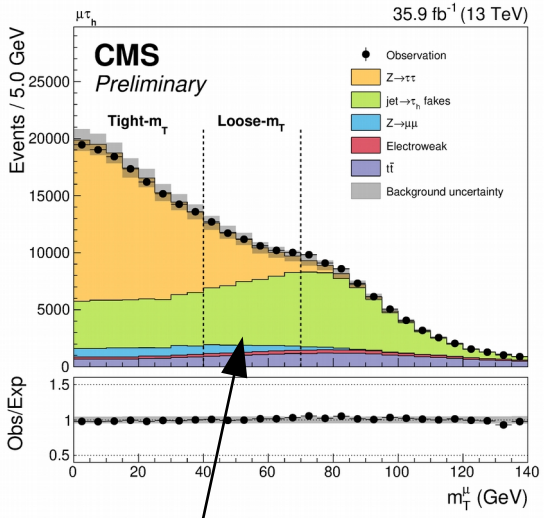
background process	misidentification	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$
$Z \to \tau\tau$		MC†	MC†	MC†	MC†
$Z \to \ell\ell$	$\ell \to \tau_h$	MC	MC	MC	MC
	jet $\to \tau_h$		FF	FF	FF
Diboson+single top	$\tau/\ell \to \tau_h$	MC	MC	MC	MC
	jet $\to \tau_h$		FF	FF	FF
$t\bar{t}$	$\tau/\ell \to \tau_h$	MC†	MC†	MC†	MC†
	jet $\to \tau_h$		FF	FF	FF
W+jets	jet $\to \tau_h$	MC	FF	FF	FF
QCD	jet $\to \tau_h$	CR	FF	FF	FF

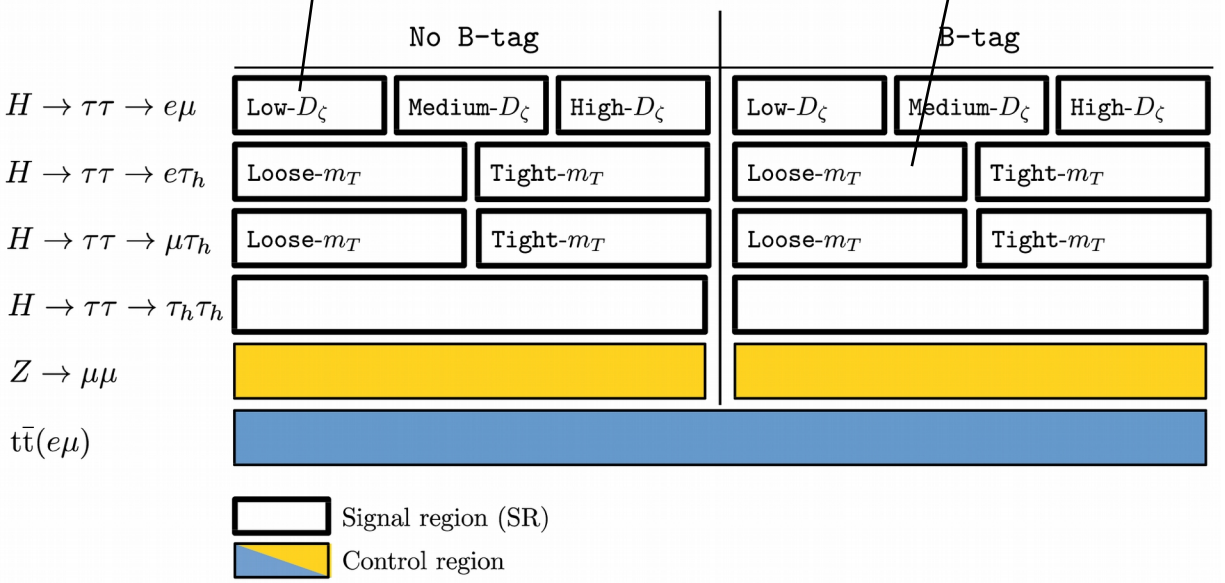
† Normalization from control region in data.

Categorization

- Analysis performed in 16 signal categories
  - Chosen to optimize sensitivity
- 3 control regions included in the fit
  - Constraining $Z \rightarrow \tau\tau$ and $t\bar{t}$





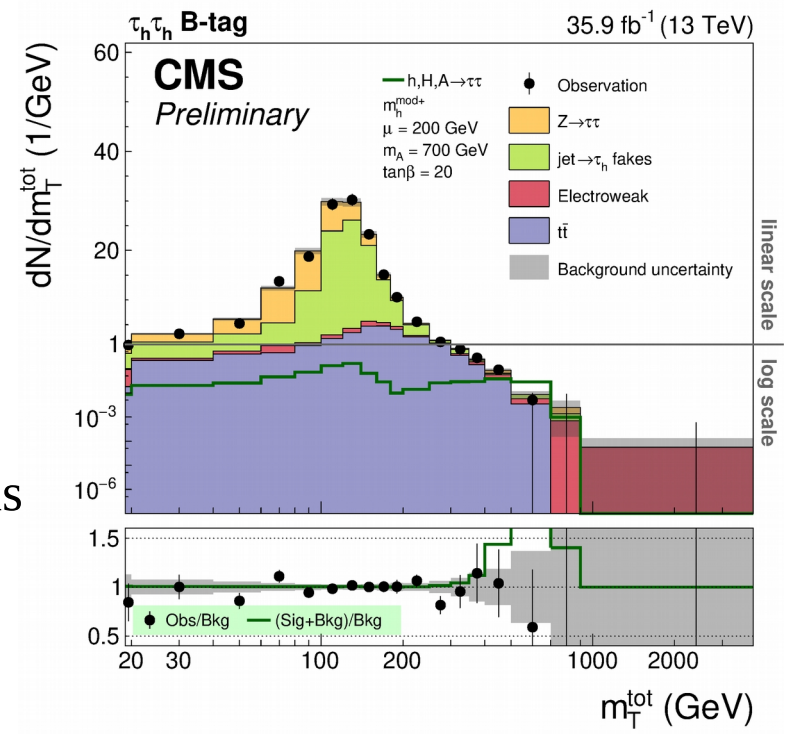


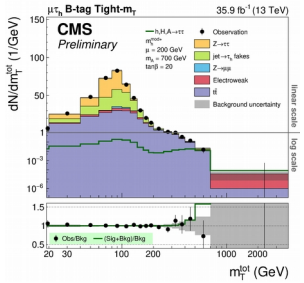
Spectrum of the Final Discriminator

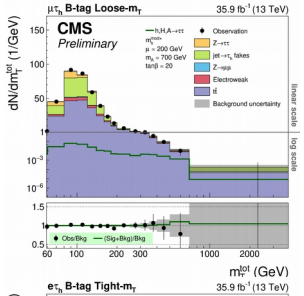
- Using total transverse mass as final discriminator

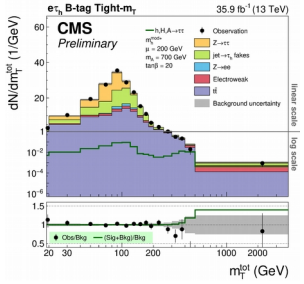
$$m_T^{tot} = \sqrt{m_T^2(\not{E}_T, l_1) + m_T^2(\not{E}_T, l_2) + m_T^2(l_1, l_2)}$$

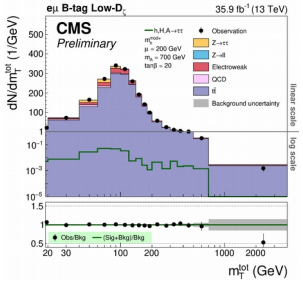
- Good agreement between expectation and observation in all categories
- Large fraction of backgrounds estimated using data driven methods

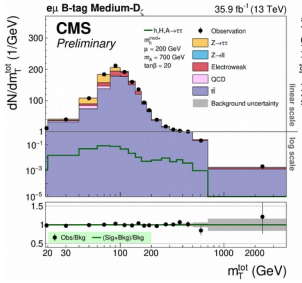


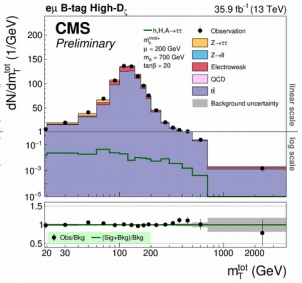


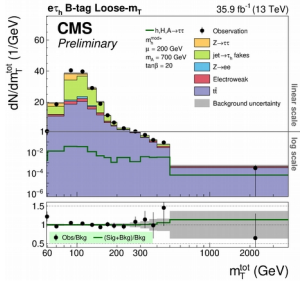






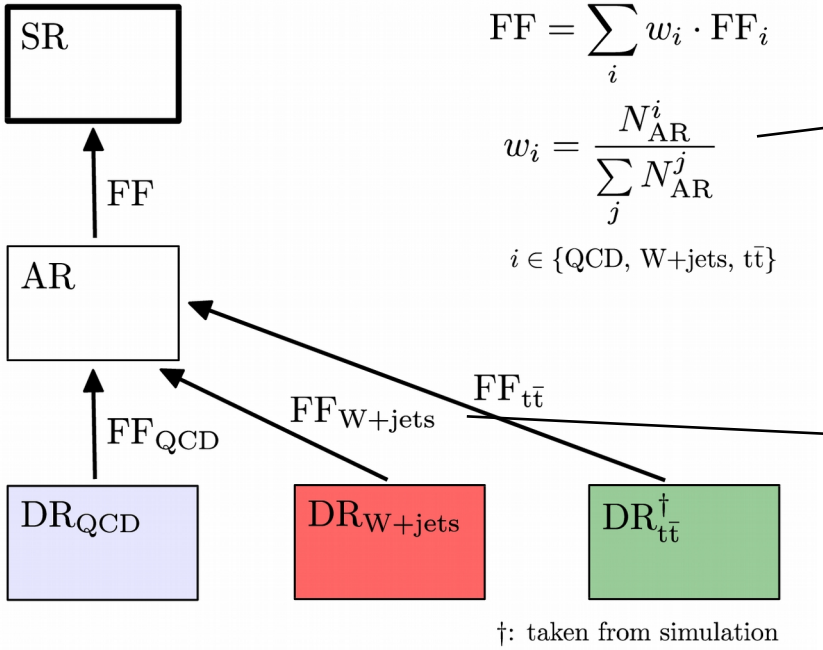






The Fake Factor Method

- Estimation of background from misidentified jets based on anti-isolated region
  - Extrapolate from application region (AR) to signal region (SR) using fake factors (FF)

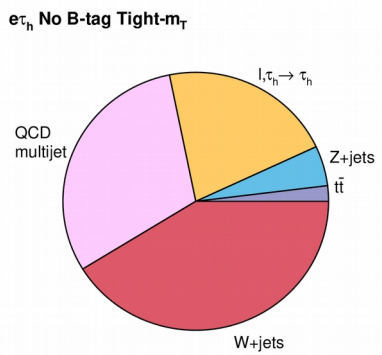


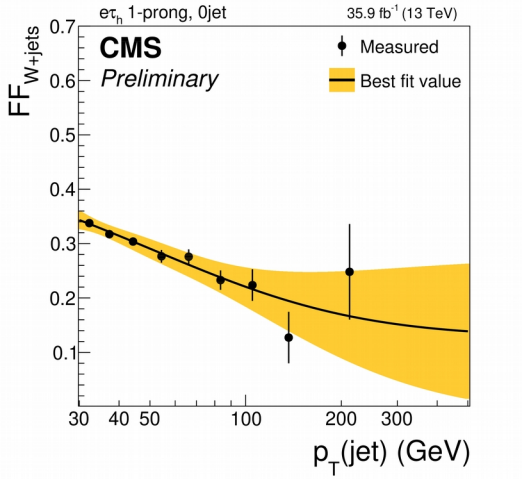
$$\mathrm{FF} = \sum_i w_i \cdot \mathrm{FF}_i$$

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

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

†: taken from simulation

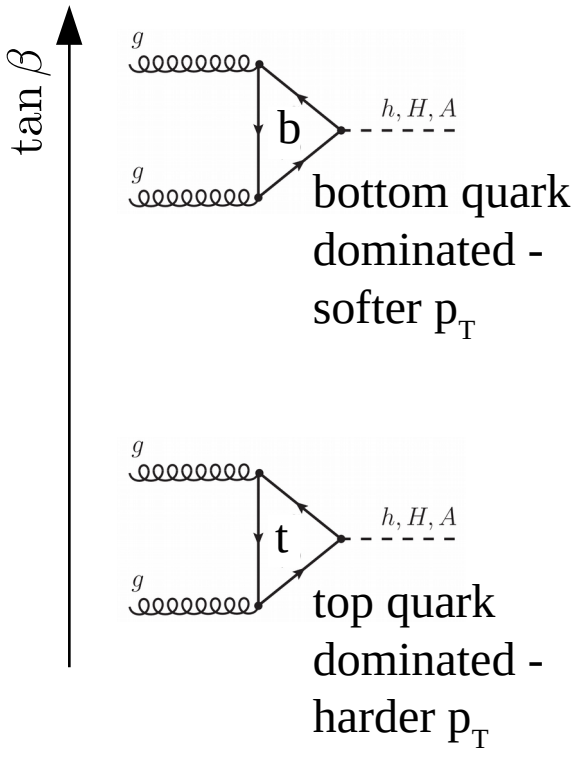


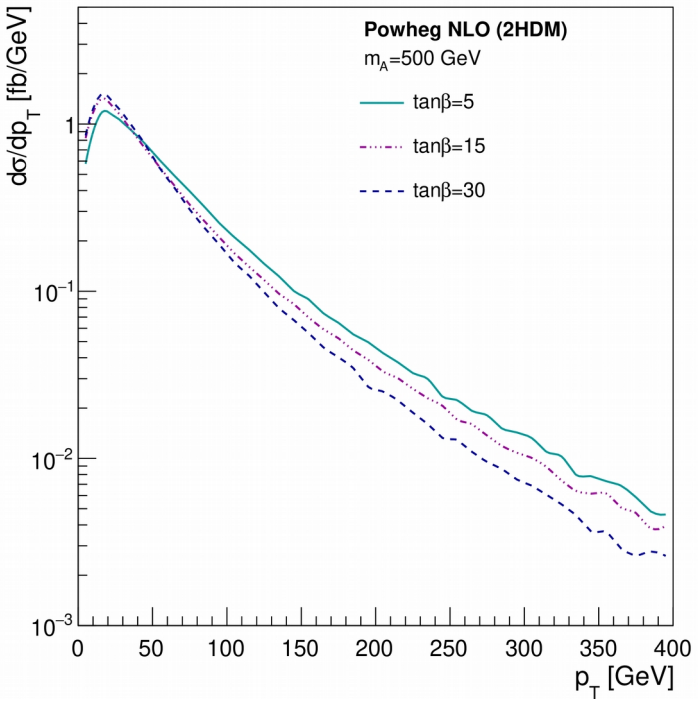


Signal Modeling

- Introduced full differential NLO description for signal processes
  - For $gg \to bb\phi$: generation of samples using aMC@NLO
  - For $gg \to \phi$: multiscale problem → dedicated method required

Emanuele Bagnashi et al
arXiv:1505.00735 [hep-ph]





Changing p_T distributions lead to changing signal acceptances

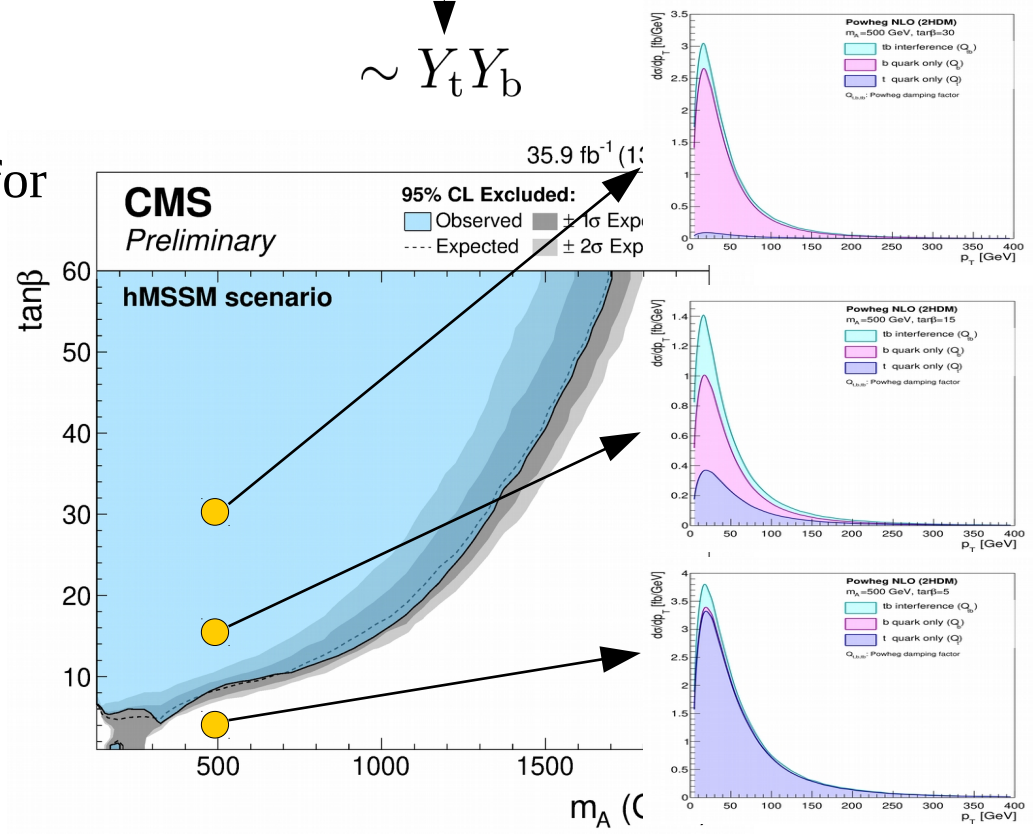
Signal Modeling for Gluon-Fusion

- Decompose cross section into top-only, bottom-only and interference term

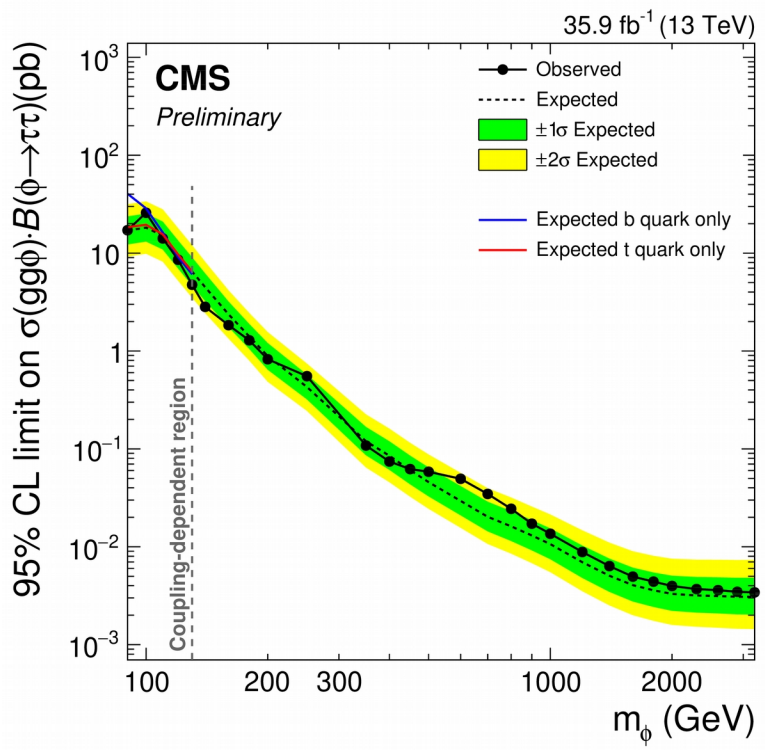
$$\sigma_{\mathrm{tot}} = \sigma^{t}_{\mathrm{MSSM}}(Q_t) + \sigma^{b}_{\mathrm{MSSM}}(Q_b) + \left[\sigma^{t+b}_{\mathrm{MSSM}}(Q_{tb}) - \sigma^{t}_{\mathrm{MSSM}}(Q_{tb}) - \sigma^{b}_{\mathrm{MSSM}}(Q_{tb})\right]$$

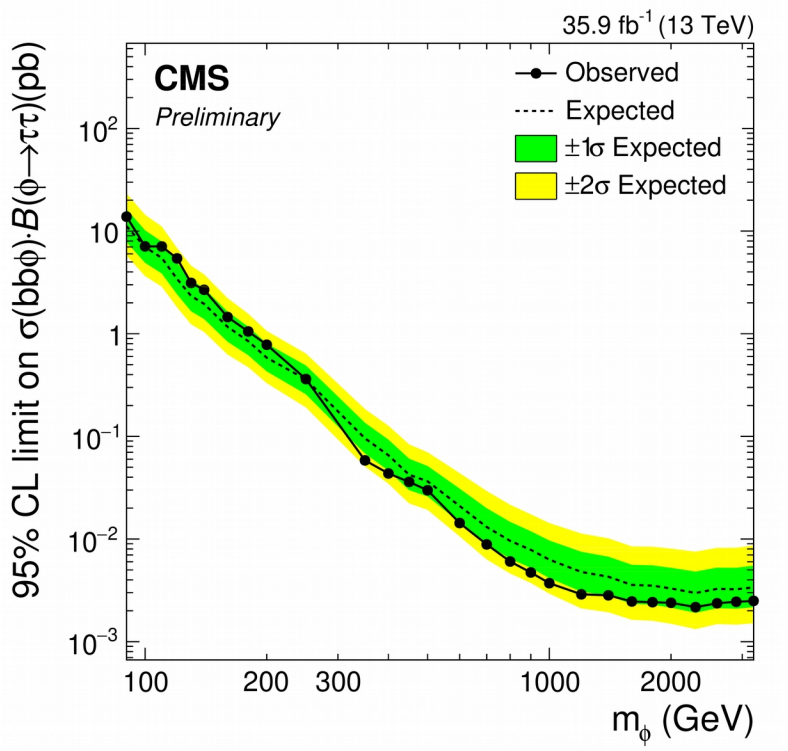
$$\sim Y_{\mathrm{t}}^2 \qquad \sim Y_{\mathrm{b}}^2 \qquad \sim Y_{\mathrm{t}} Y_{\mathrm{b}}$$

- Generate individual distribution for a reference point in the 2HDM
  - Reweight distribution to different parameter point
  - Worked out with E. Bagnaschi and S. Liebler in the frame of the LHCHXSWG-3



Results in the di-tau Final State





- Determined model independent exclusion limits for $gg \rightarrow \phi$ and $gg \rightarrow bb\phi$
  - Assuming narrow width approximation
- No excess observed
- Provide 3D-likelihoodscans to allow for more sophisticated re-interpretations

CMS-PAS-HIG-17-020

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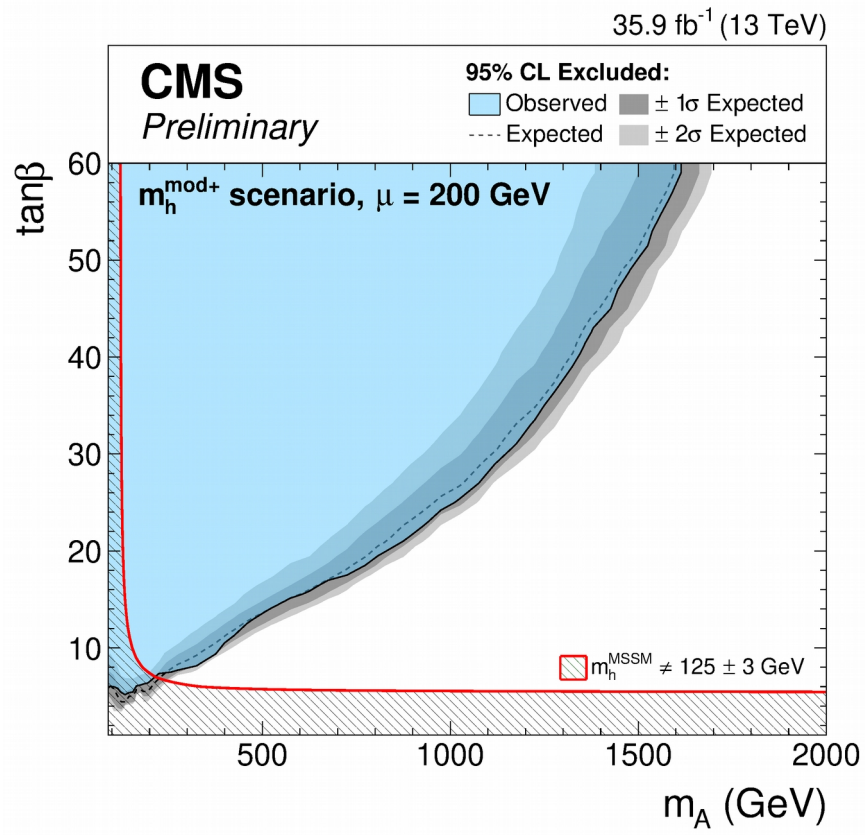
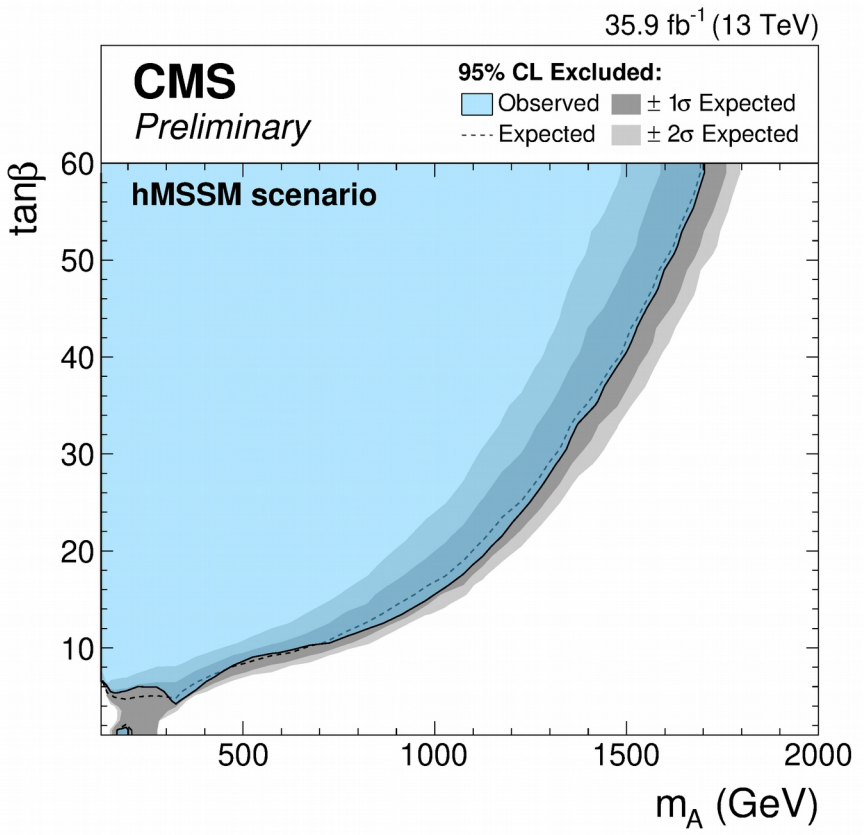


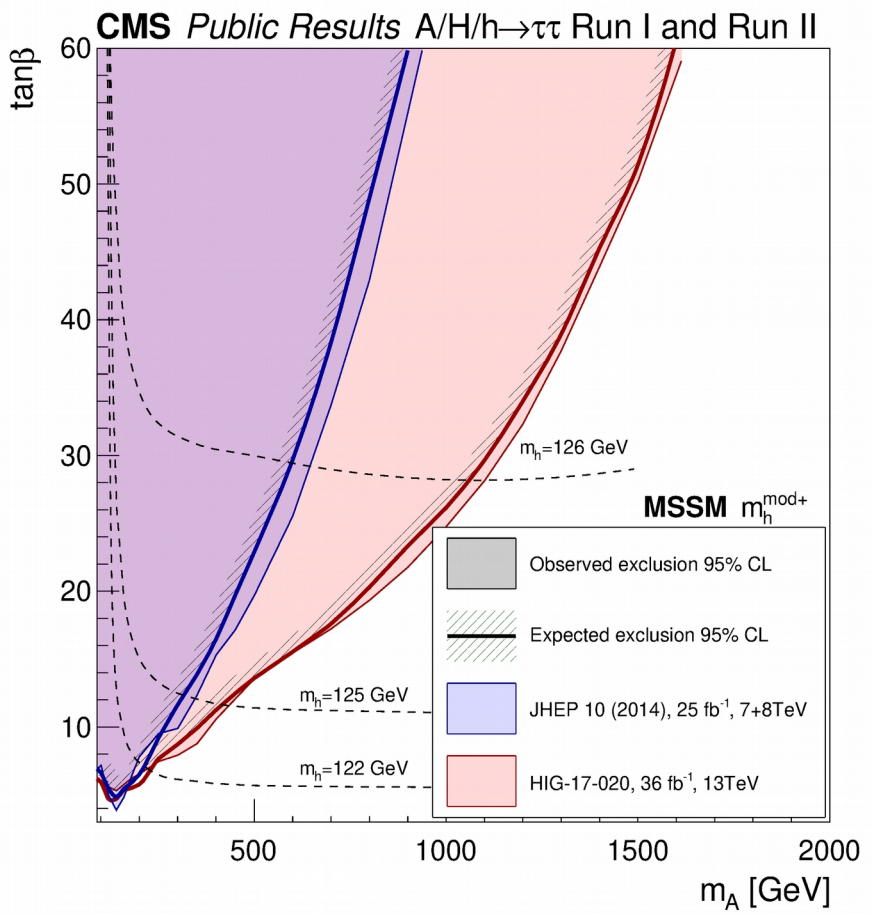


- Exclusion limits in predefined MSSM benchmark scenarios
- Excluded parameters down to tanβ~6 and up to m_A~1600 GeV

Summary

- Results for searches for charged Higgs bosons by CMS on 13 TeV data have been shown
- New results based on 35.9 fb^{-1} of data recorded in 2016 at 13 TeV have just been released for the di-tau channel
  - Improved background estimation techniques
  - Novel approach for modeling the gluon-fusion signal at NLO
  - Significantly improved reach compared to previous analyses

Thank you for your attention



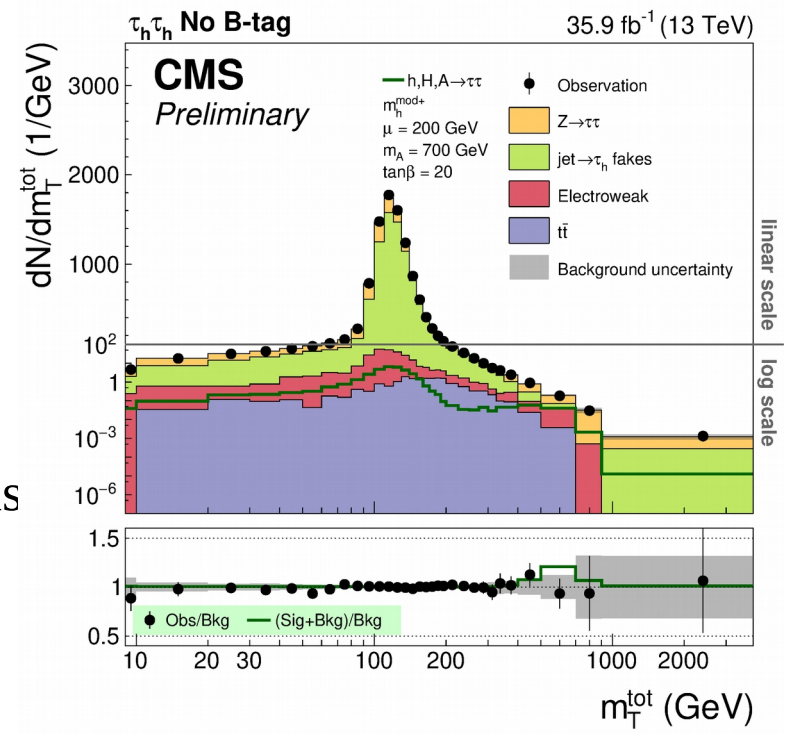
Backup

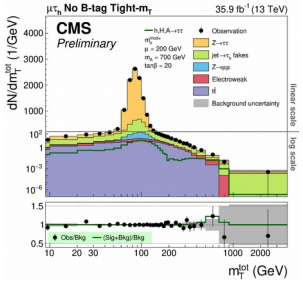
Spectrum of the Final Discriminator

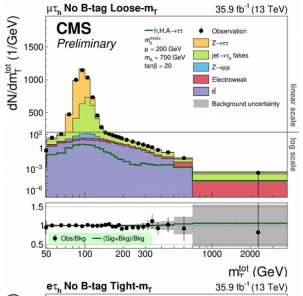
- Using total transverse mass as final discriminator

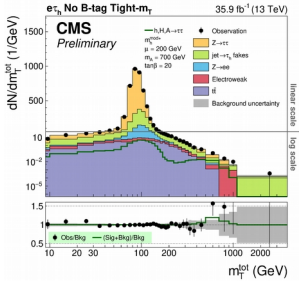
$$m_T^{tot} = \sqrt{m_T^2(\not{E}_T, l_1) + m_T^2(\not{E}_T, l_2) + m_T^2(l_1, l_2)}$$

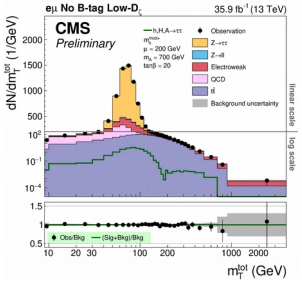
- Good agreement between expectation and observation in all categories
- Large fraction of backgrounds estimated using data driven methods

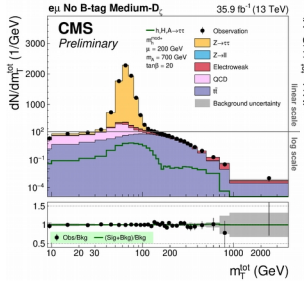


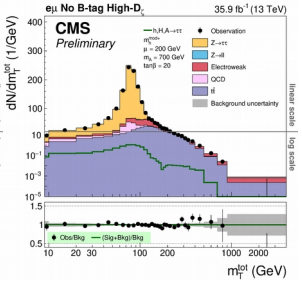


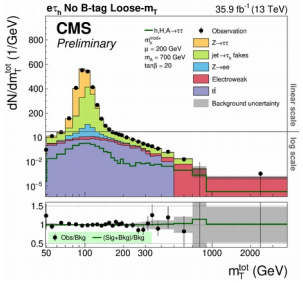






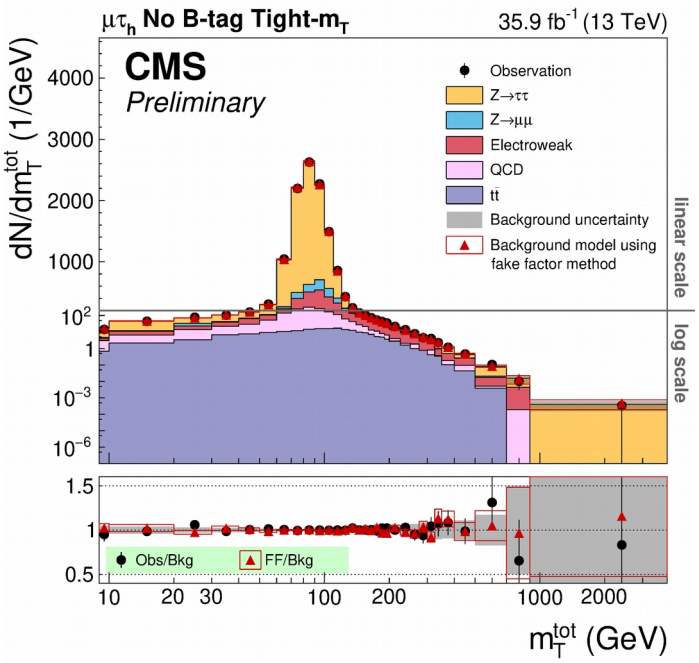


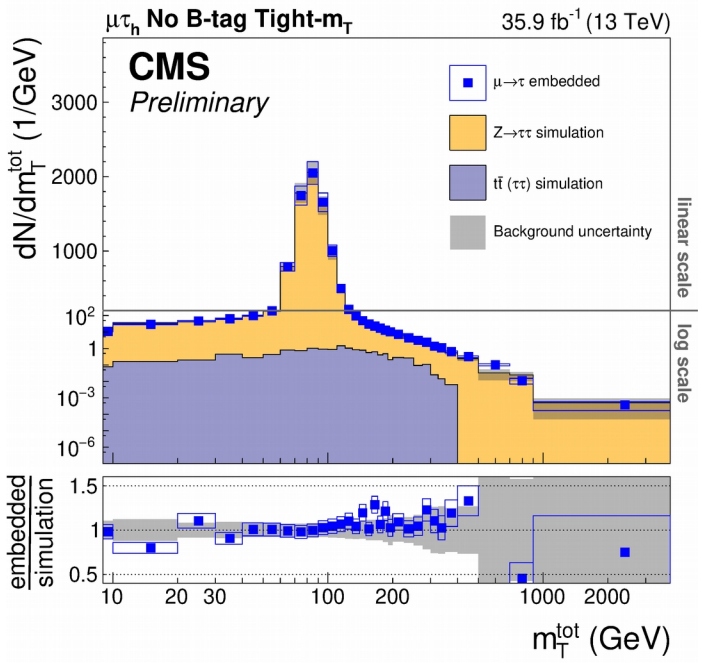




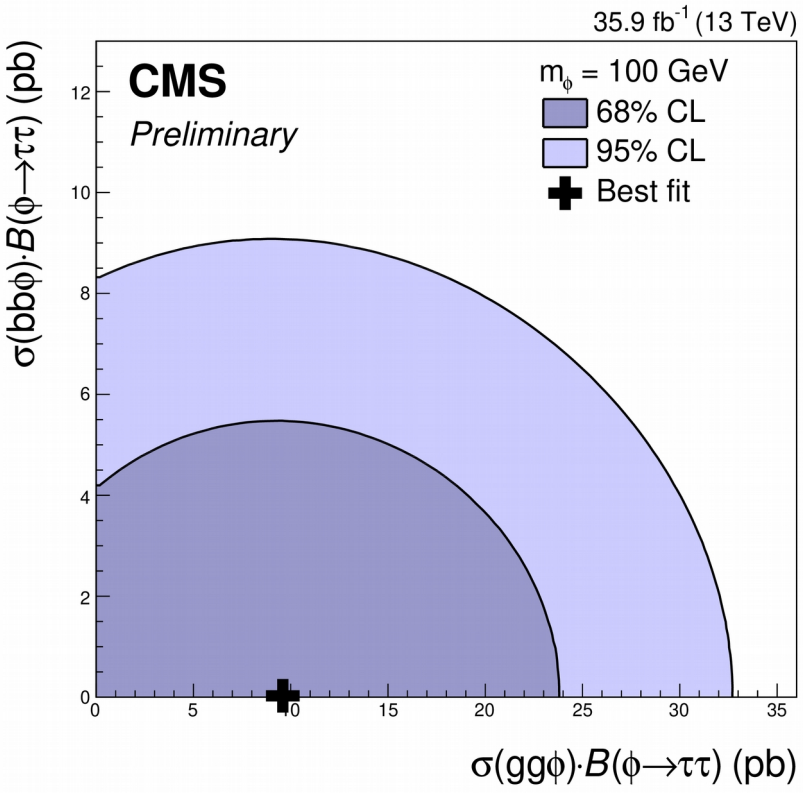
Validation of Background Estimation Techniques

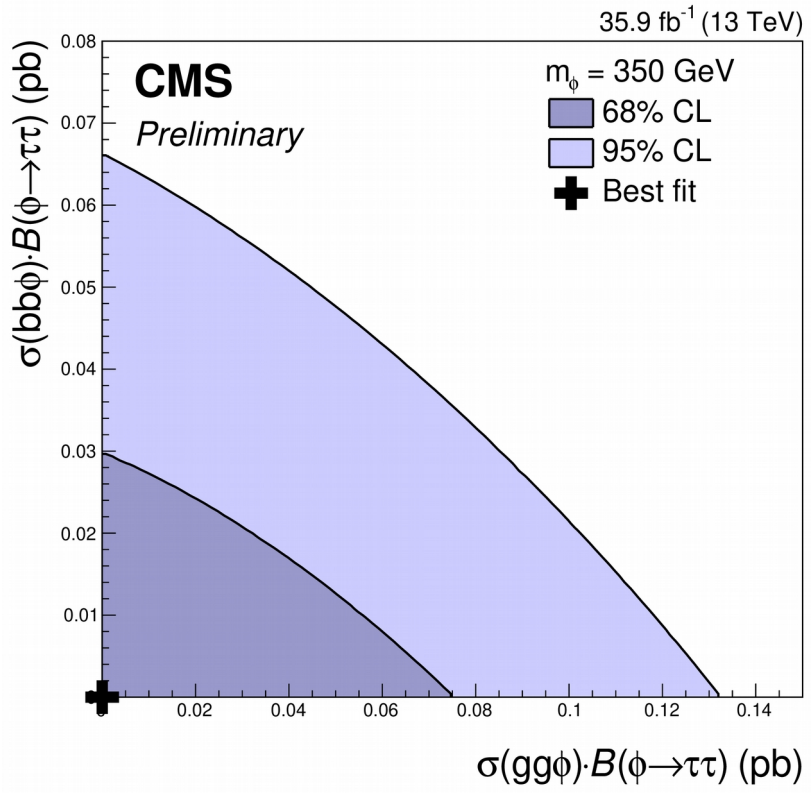
- Background estimation methods extensively checked
  - Fake factor method cross-checked with previous method to estimate W+jets
  - Estimation of $Z \rightarrow \tau\tau$ cross-checked with data-driven estimation method





Results in the di-tau Final State





- Also provide 3D likelihood-scans
  - $\sigma \times BR(gg \to \phi)$, $\sigma \times BR(gg \to bb\phi)$, m_ϕ, ~4.5 million points in total
- Allows for more sophisticated re-interpretations arXiv:1507.06706 [hep-ph]

The Variable D_ζ

$$P_\zeta = P_\zeta^{\mathrm{miss}} - 0.85 P_\zeta^{vis}$$