Search for Beyond Standard Model (BSM) Higgs bosons

in final states with bottom quarks with the full Run 2 CMS dataset [1].

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Why search for BSM Higgs bosons?

Strong indications the Standard Model (SM) is not complete

An extended Higgs sector can lead to a much richer phenomenology, e.g.:

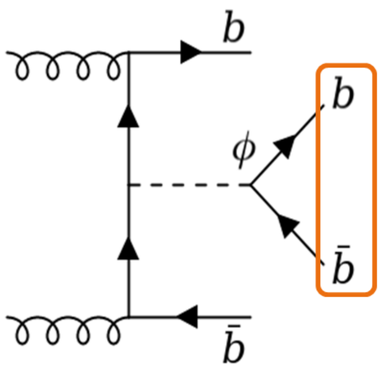
- Two Higgs doublet Models (2HDM)
- Minimal Supersymmetric extension of the SM (MSSM)

2HDM and MSSM feature two complex scalar doublets

- Five physical Higgs bosons: H^+, H^-, A (CP-odd), H, and h (CP-even) $\rightarrow \phi$
- Enhanced coupling to b-quarks in 2HDM in type 2 (MSSM-like sector) and flipped (leptons disfavoured) scenarios

Free parameters (among others)

$\tan\beta$: ratio of v.e.v. of the two doublets
α : mixing angle of the two scalars (2HDM only)
m_A : mass of the CP-odd neutral boson
$cos(\beta-\alpha) \approx 0$: alignment limit, h couplings become SM-like



- **Searching for excess in di-jet mass of the two-leading jets**
- Cross section enhanced by up to $\sim 2tan^2\beta$ in MSSM and 2HDM
- Large multijet background, mainly from QCD
- Partially suppressed background through b-associated production

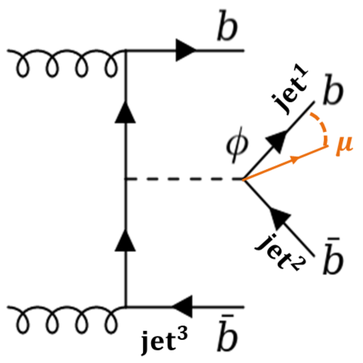
Analysis categories and event selection

2017 and 2018 dataset analyzed and combined with CMS 2016-only results [2]

- **Fully Hadronic (FH) category**, targeting high-masses [300 – 1800] GeV
- **Semi-leptonic (SL) category**, one muon selected within one of the two leading jets to lower jet momentum thresholds, targeting lower masses, [125 – 700] GeV (available only in 2017)

Dedicated triggers:

FH: at least two jets, online b-tagged & **SL**: at least two jets, online b-tagged, a muon within a jet



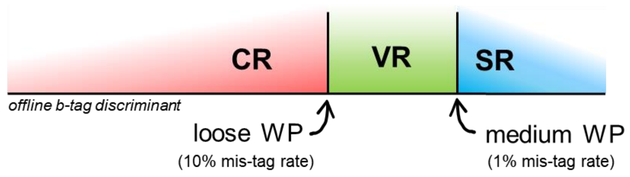
2017 FH: veto events with muon within a jet

Offline selection:

At least three offline b-tagged jets (DeepJet algorithm)

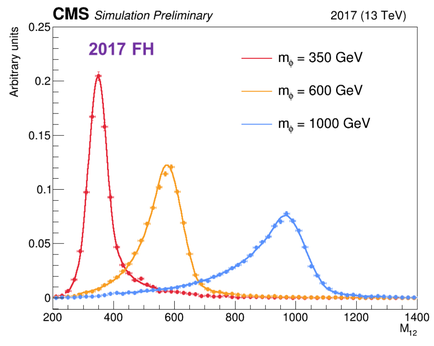
$\mathbf{jet^{1,2}}$: passing the medium WP

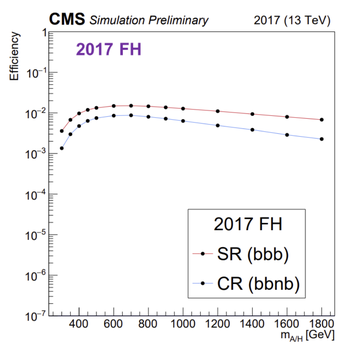
$\mathbf{jet^3}$: used to define the Signal Region (**SR**), a Control Region (**CR**) for background modelling and a Validation Region (**VR**)



Signal Model

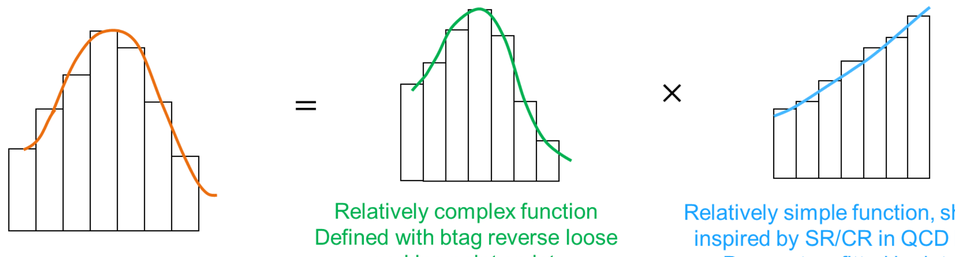
Fourteen mass-points in total per analysis and category, simulated at NLO with POWHEG and PYTHIA 8 generator, parametrized with double-sided crystal ball function





Data-driven background Model

Background in SR = **Data in Control Region (CR)** × **Transfer Factor (TF)**



Relatively complex function
Defined with btag reverse loose working point on jet_3

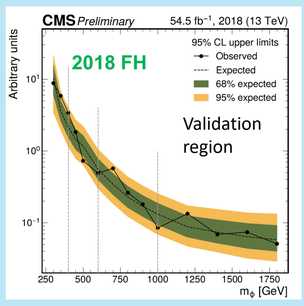
Relatively simple function, shape inspired by SR/CR in QCD MC
Parameters fitted in data

Signal extraction

Simultaneous fit of SR: $\boldsymbol{B_{CR}(m_{12}) \times TF(m_{12}) + S(m_{12})}$ and CR: $\boldsymbol{B_{CR}(m_{12})}$, (where $\boldsymbol{S}$ is the fitted signal)

Validation

- Background modelled as $VR = CR \times TF_{QCD}$, while signal model is directly taken from SR
- Data is consistent with background-only hypothesis in all three analyses
- Successful commissioning of background estimation method and signal extraction



Systematic uncertainties

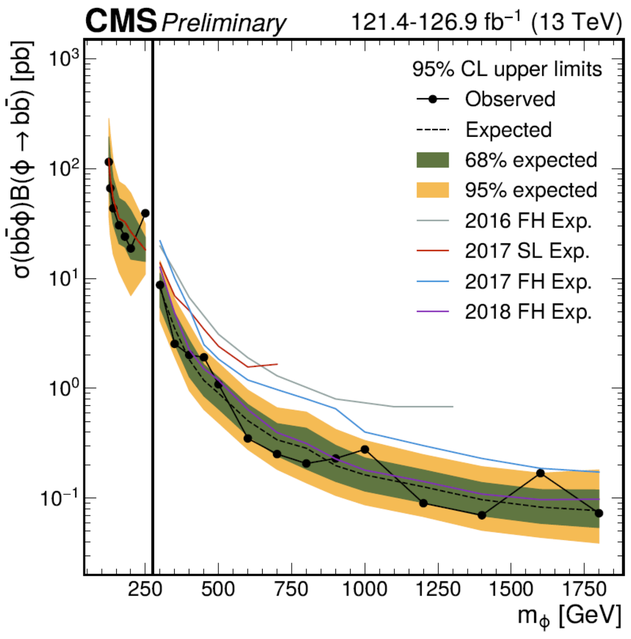
Largest impact on the signal model:

- Online and offline b-tag scale factors (up to 20% effect in the normalization)
- Jet energy scale and resolution (shape-altering and up to 5% normalization)

Largest impact on background model:

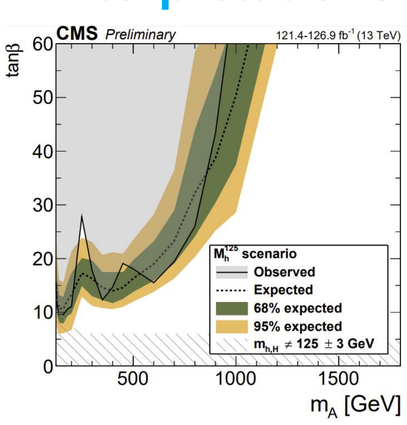
- Uncertainty on TF and CR parameters from the fit
- Uncertainty on choice of TF functional form (discrete profiling)

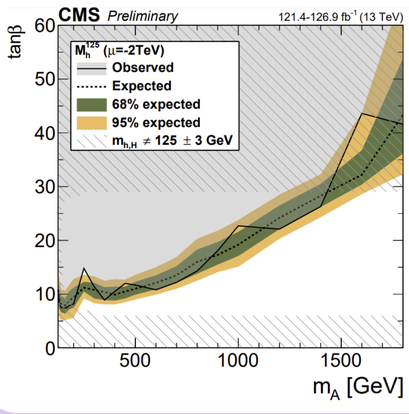
Results and Summary



- Significant improvement achieved with full Run 2 combination
- All mass-points within $\pm 2\sigma$ of expected limit, exception compatible with stat. fluctuations
- **Most stringent limits to date in searches with this final state**

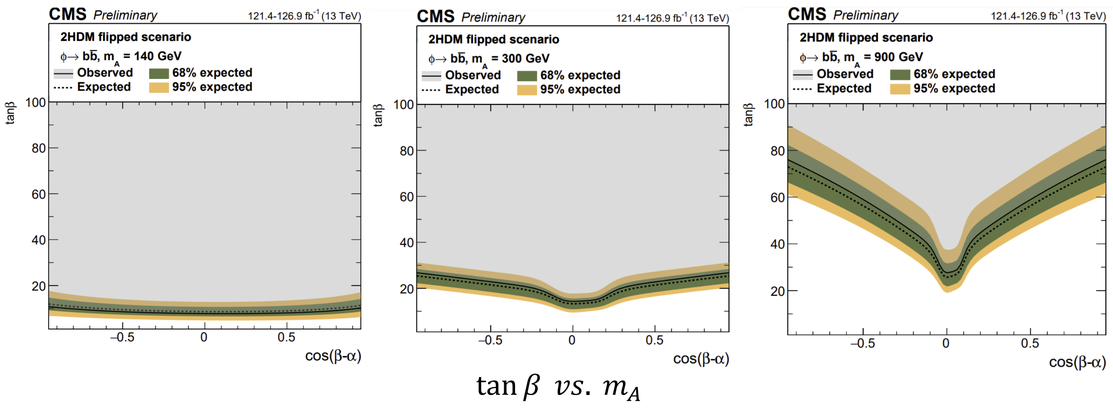
MSSM interpretations



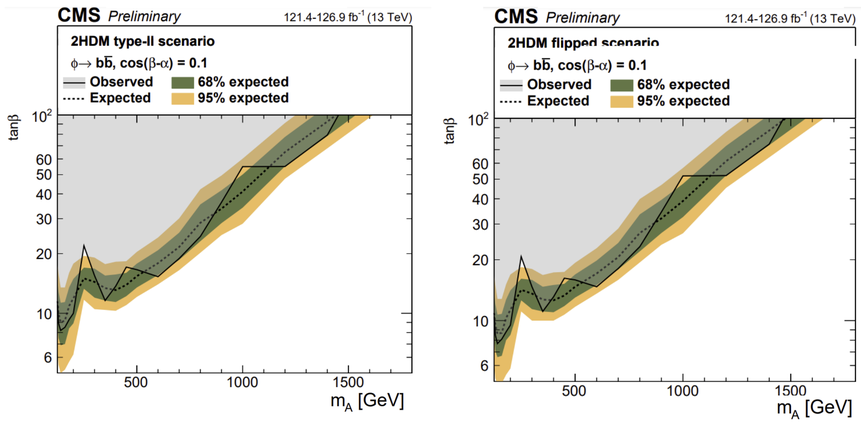


2HDM interpretations

$\tan\beta$ *vs.* $\cos\beta - \alpha$



$\tan\beta$ *vs.* m_A



[1] CMS PAS SUS-24-001
[2] JHEP 08 (2018) 113