Search for nonresonant Higgs boson pair production in final states with two bottom quarks and two tau leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV

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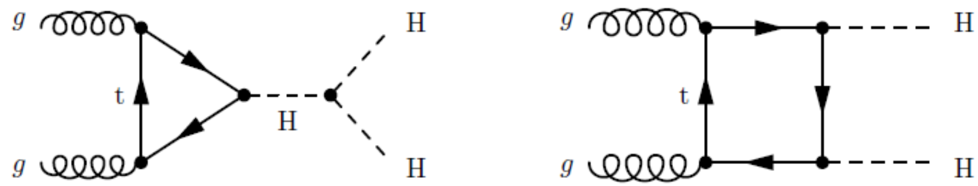
Introduction

HH production:

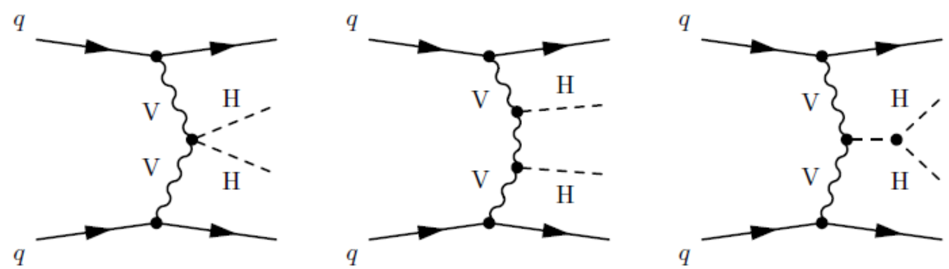
$$\sigma_{ggF}^{HH} = 31.05^{+2.2\%}_{-5.0\%}(scale) \pm 3\,\%(PDF + \alpha_S) \pm 2.6\,\%(m_t)fb$$ NNLO

ggF



$$\sigma_{VBF}^{HH} = 1.726^{+0.03\%}_{-0.04\%}(scale) \pm 2.1\,\%(PDF + \alpha_S)fb$$ next-to-NNLO

VBF



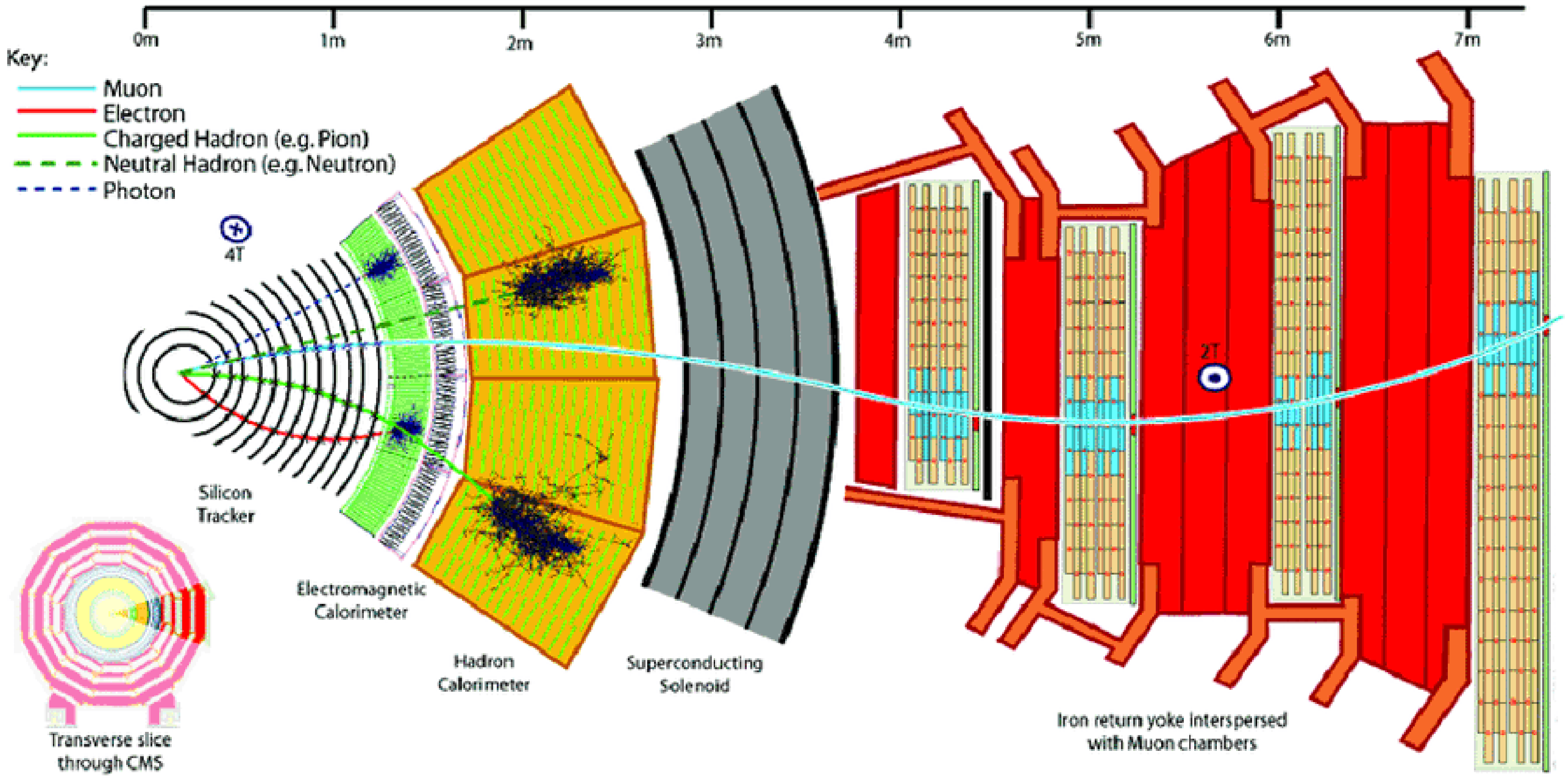
Target process:

$$ggF\ or\ VBF \rightarrow HH \rightarrow b b \underbrace{\tau\tau}$$

$$\tau_h\tau_e,\ \tau_h\tau_\mu,\ \tau_h\tau_h$$

CMS Detector

Data are measured @ CMS, $\sqrt{s} = 13$ TeV, during 2016, 2017, 2018



Selecting events by:

- L1 $\longrightarrow$ 1000 kHz
- HLT $\longrightarrow$ 1 kHz

Methods

1. Data and simulating samples

   MADGRAPH_aMC@NLO, POWHEG

2. Event reconstruction and selection
   - It is based on the PF algorithm ⟶ Identify particles
   - Electrons energy determination
   - Muons reconstruction
   - Classify hadronic decay mode of τ by neutral pions & PF reconstruction

     ⟶ At least one hadronic τ decay should be considered(Table 1)
   - Jets reconstruction through energy deposits in ECAL

3. Event categorization and discriminating variables

   Multi-classification approach enhance the analysis sensitivity

4. Background modelling

   $t\bar{t}$ production, Zγ⟶ ll, QCD multijet events are main backgrounds

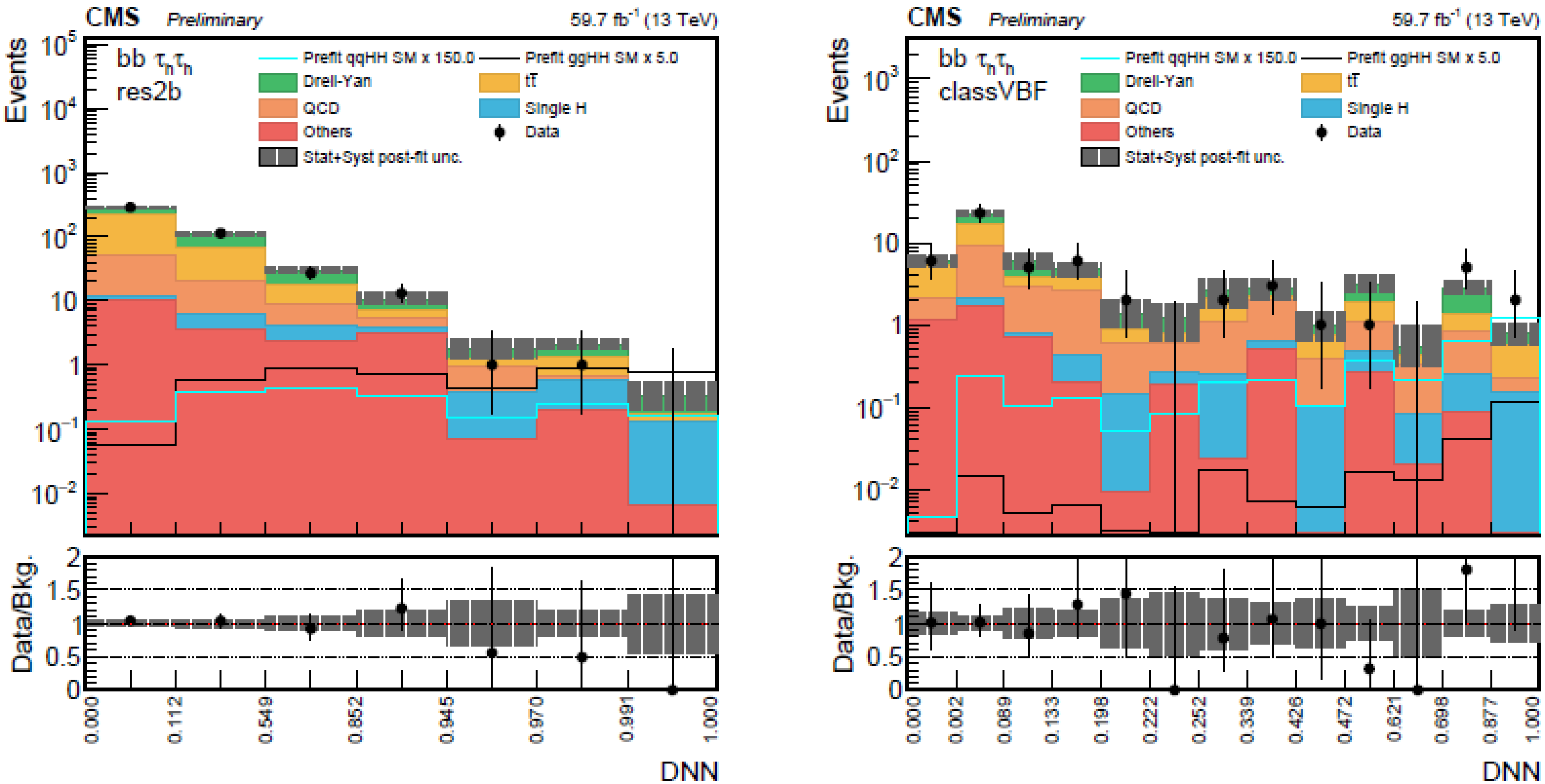
5. Systematic uncertainties

   Normalization and shape uncertainty which affect on total event and event distribution

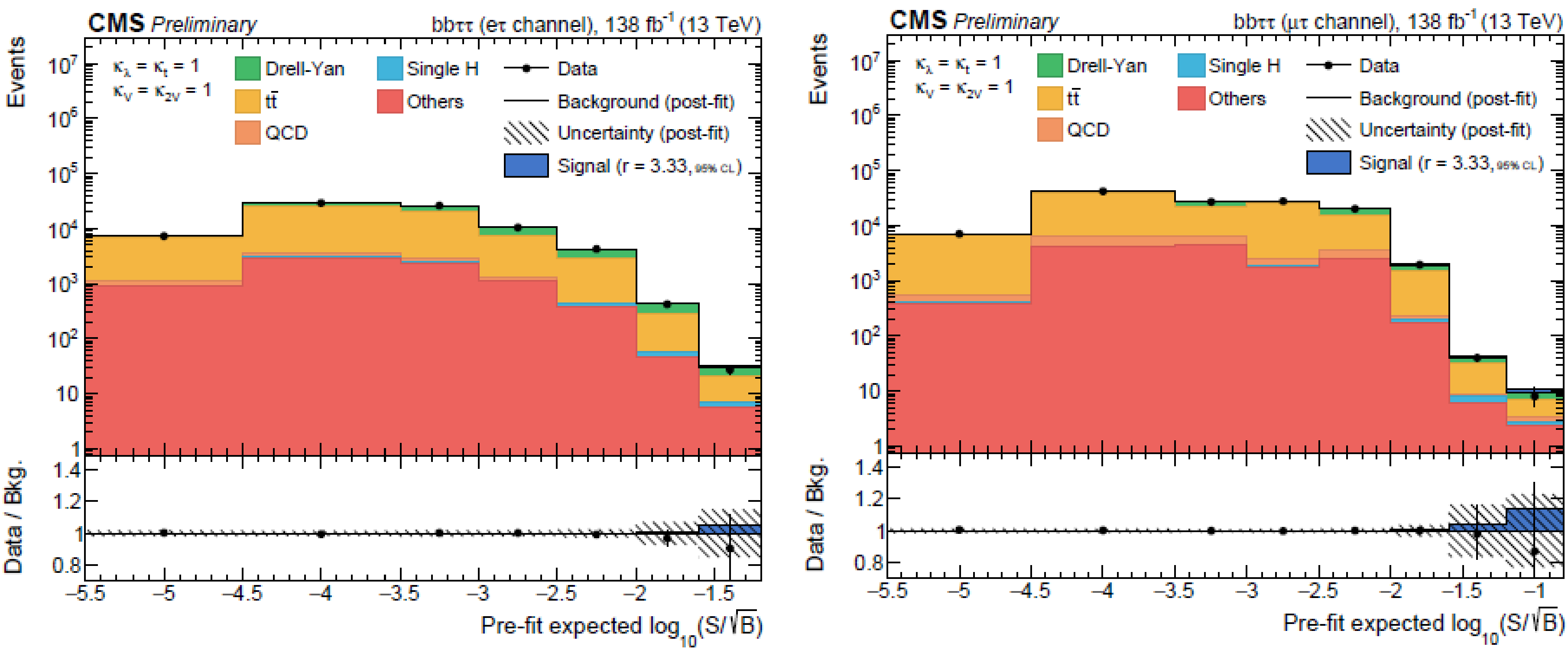
Table 1: Summery of selection applied to the $\tau\tau$ pair

Online p_T trigger thresholds	single-e: $p_T > 25(32)$ GeV, cross-e: $p_T > 24$ GeV single-μ: $p_T > 22(24)$ GeV, cross-μ: $p_T > 19(20)$ GeV di-tau: $p_T > 35$ GeV, di-tau VBF: $p_T > 20$ GeV
Offline p_T thresholds	1 GeV (electrons and muons), 5 GeV (taus)
η thresholds	electrons and muons: $\|\eta\| < 2.1$ tau: $\|\eta\| < 2.1$ (2.3) for di-tau and cross (single) triggers
Lepton ID and Isolation	Tight electron MVA ID+Iso, Tight muon ID and Iso
τ_h isolation ($\tau_e\tau_h$, $\tau_\mu\tau_h$ channels)	Medium DeepTauVsJet Tight DeepTauVsMu Very-loose DeepTauVsEle
τ_h isolation ($\tau_h\tau_h$ channel)	Medium DeepTauVsJet Very-loose DeepTauVsMu Very-very-loose DeepTauVsEle
Distance to PV	$\|d_{xy}\| < 0.045$ cm (electrons and muons only) $\|d_z\| < 0.2$ cm
Pair selections	opposite sign, $\Delta R > 0.5$

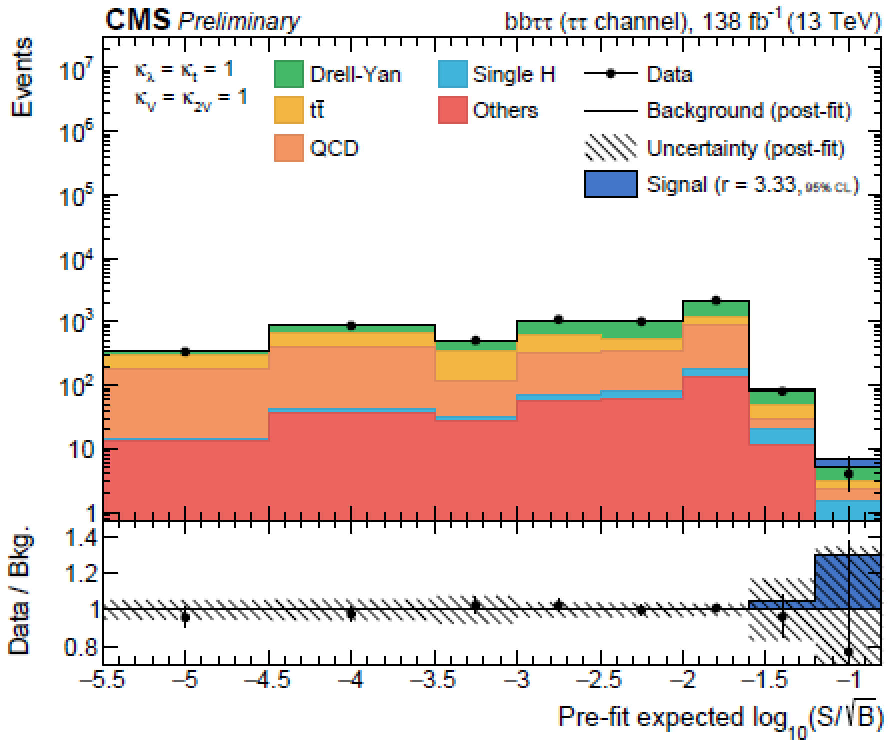
Results



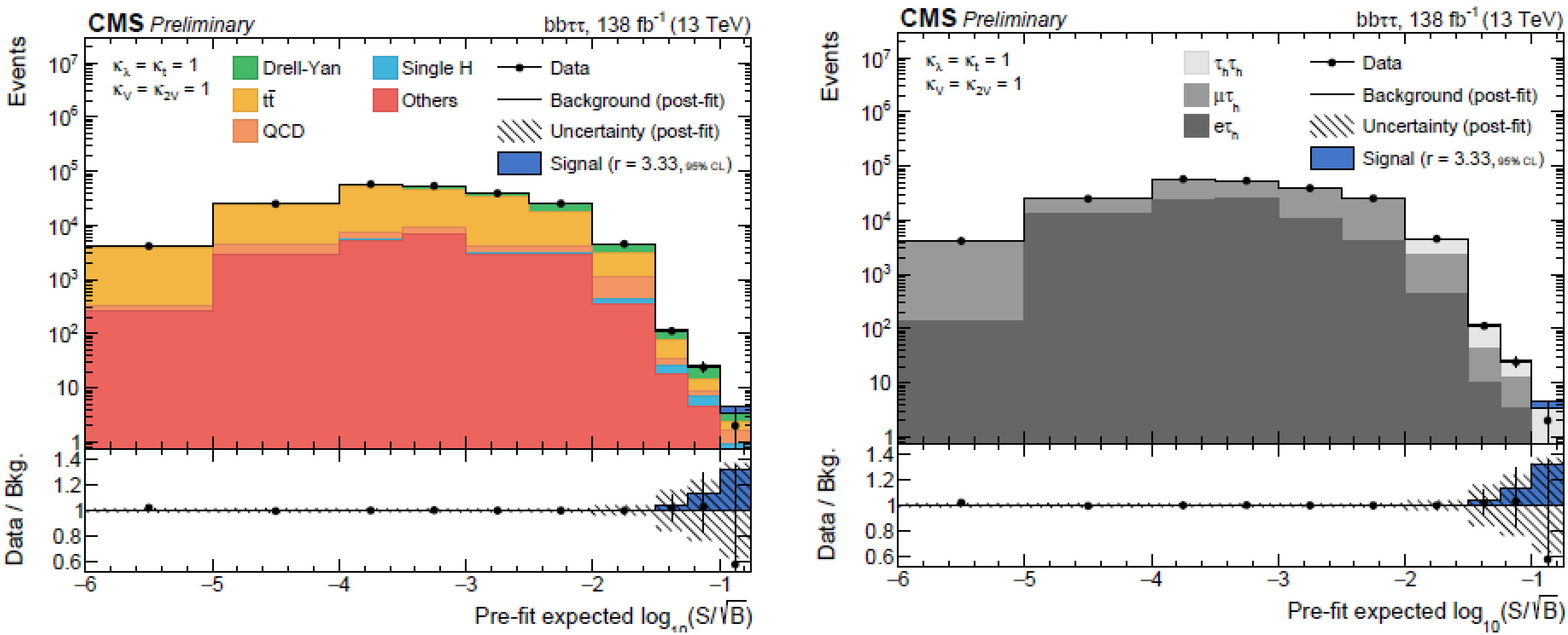
DNN prediction distributions in the $\tau_h\tau_h$ channel in 2018 for the most sensitive category in the ggF (left) and VBF (right) searches. The shaded band in the plots represents the statistical plus systematic uncertainty.



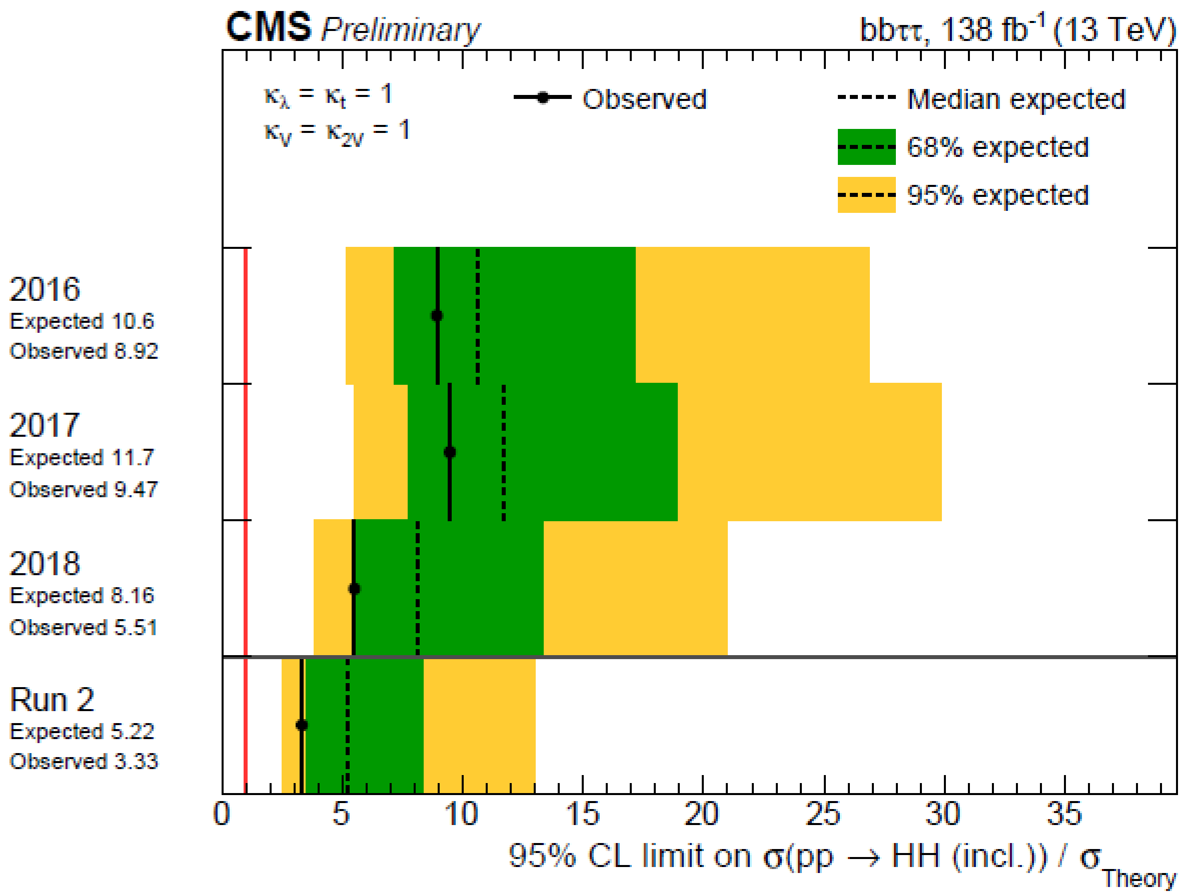
Combination of bins of all postfit distributions, ordered and merged according to their prefit signal-to-background ratio, separately for the $\tau_e\tau_h$ channel (top left), the$\tau_\mu\tau_h$ channel (top right), and $\tau_h\tau_h$ channel (bottom). The ratio also shows the signal scaled to the observed exclusion limit.



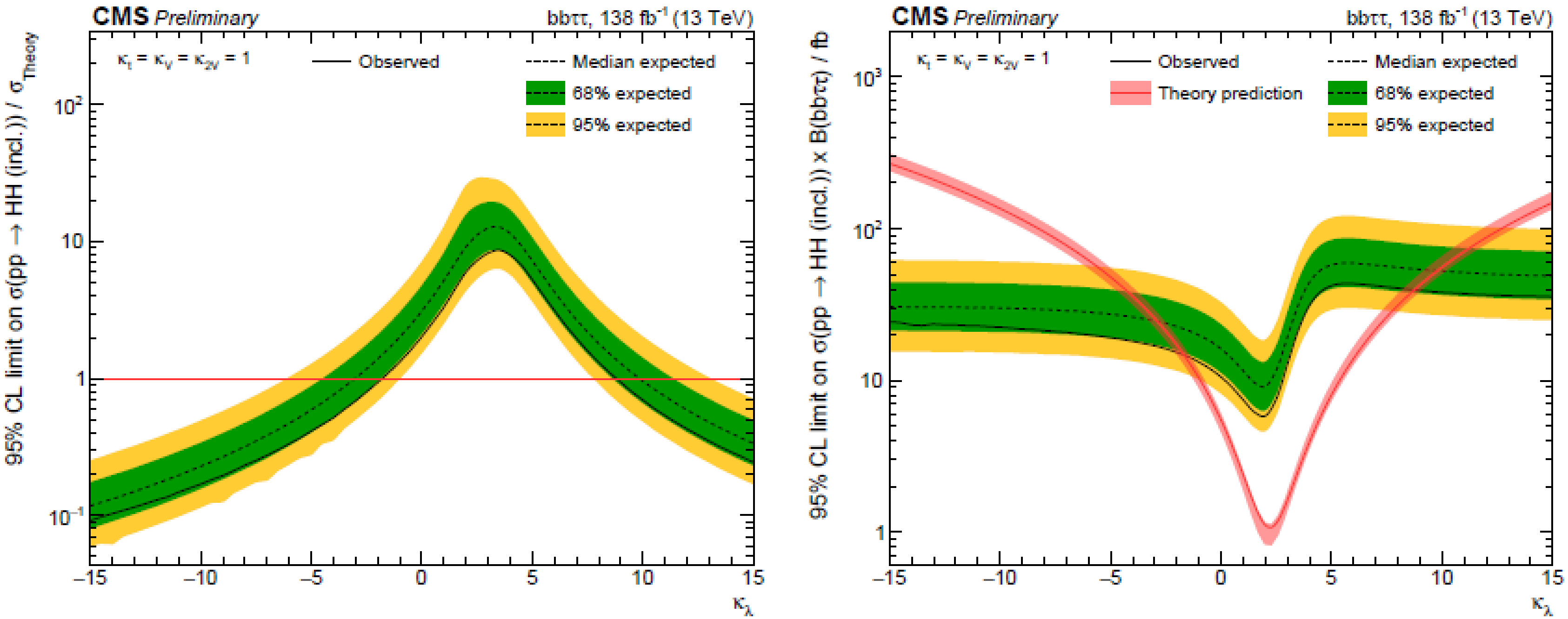
CMS Preliminary
bbττ (ττ channel), 138 fb-1 (13 TeV)
κλ = κt = 1
κV = κ2V = 1
Drell-Yan
tt̄
QCD
Single H
Others
Data
Background (post-fit)
Uncertainty (post-fit)
Signal (r = 3.33, 95% CL)
Events
Data / Bkg.
Pre-fit expected log10(S/√B)



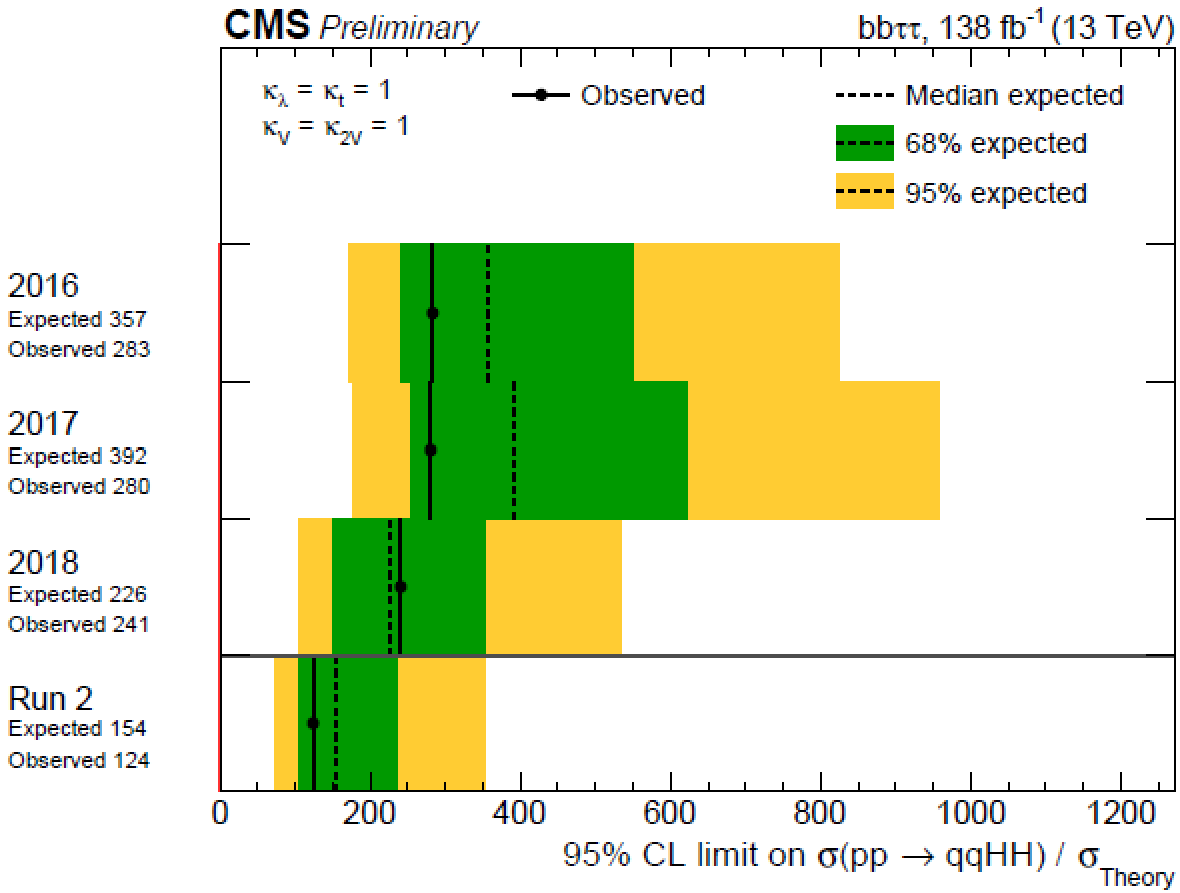
Combination of bins of all postfit distributions, ordered and merged according to their prefit signal-to-background ratio, separately for the background contribution split into physics processes (left), and split into the three considered final state channels (right). The ratio also shows the signal scaled to the observed exclusion limit.



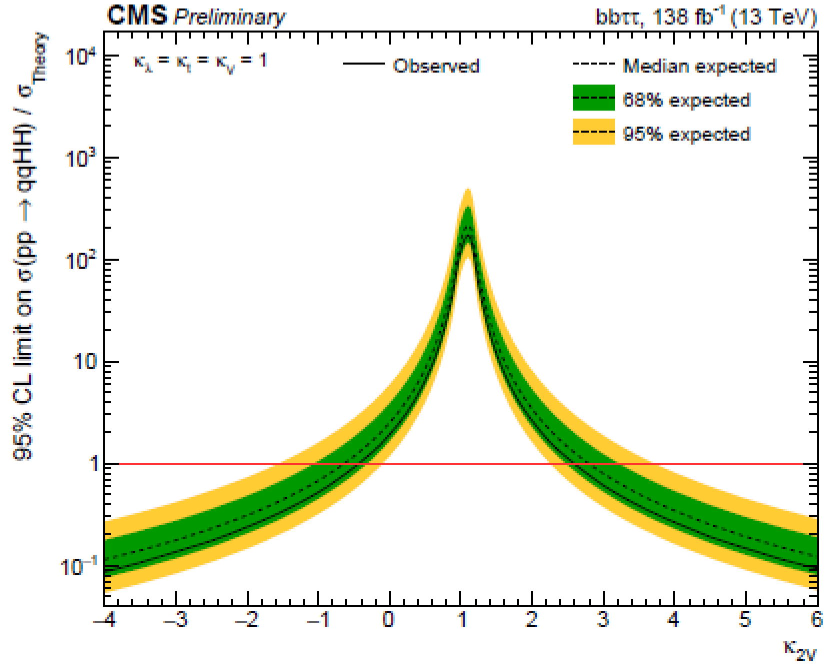
Upper limit on the HH ggF +VBF signal strength at 95% CL for $k_\lambda = 1$, separated into different years and combined for the full Run 2 data set.

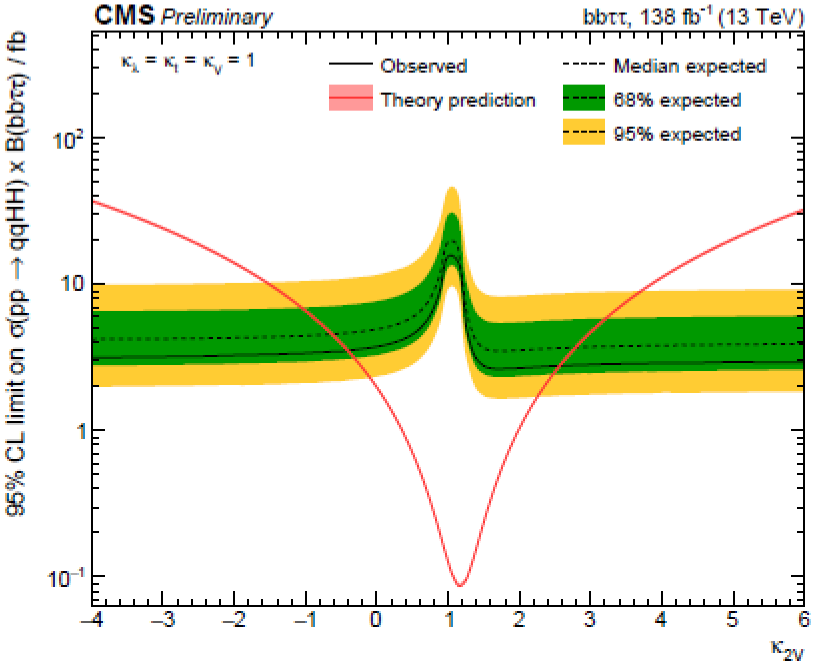


Observed and expected upper limits at 95% CL as a function of k_λ on the HH ggF+VBF signal strength (left) and on the HH ggF +VBF cross section times the bb$\tau\tau$ branching ratio (right). In both cases all other couplings are set to their SM expectation.

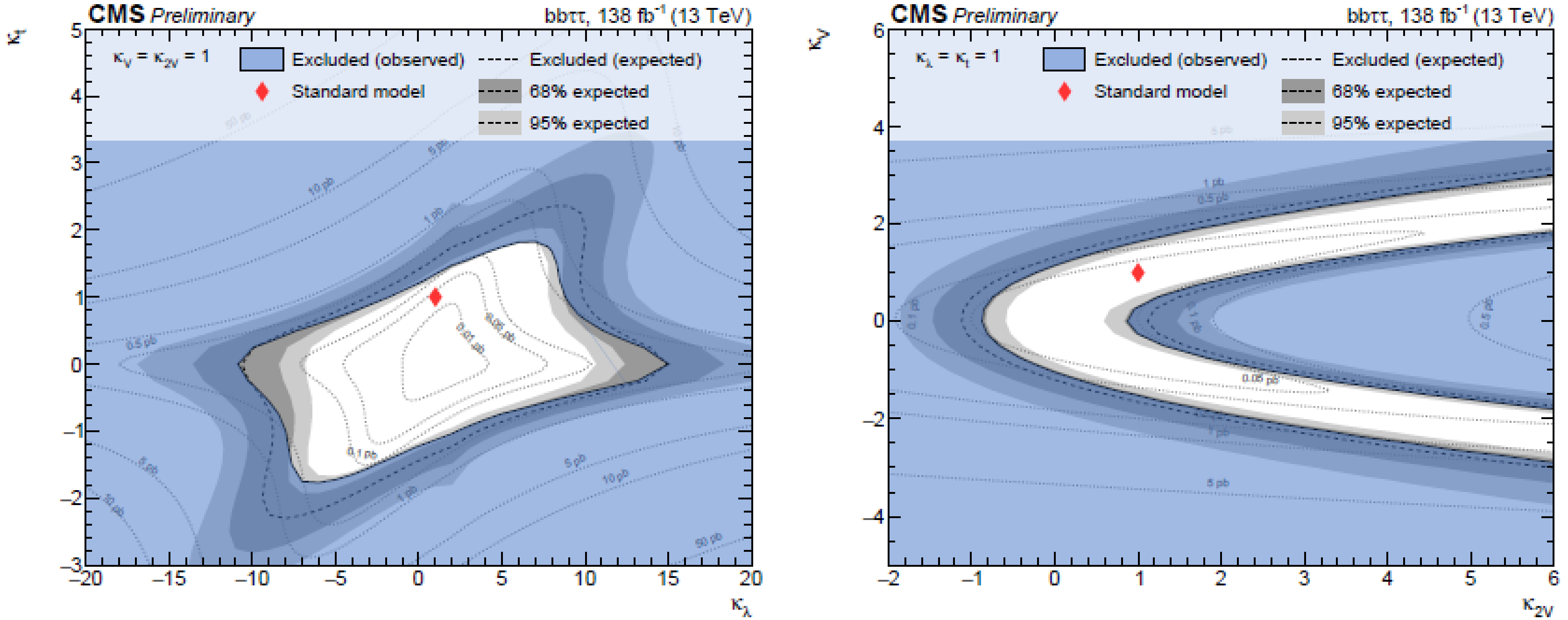


Upper limit on the HH VBF signal strength at 95% CL for $k_{2V} = 1$, separated into different years and combined for the full Run 2 data set.

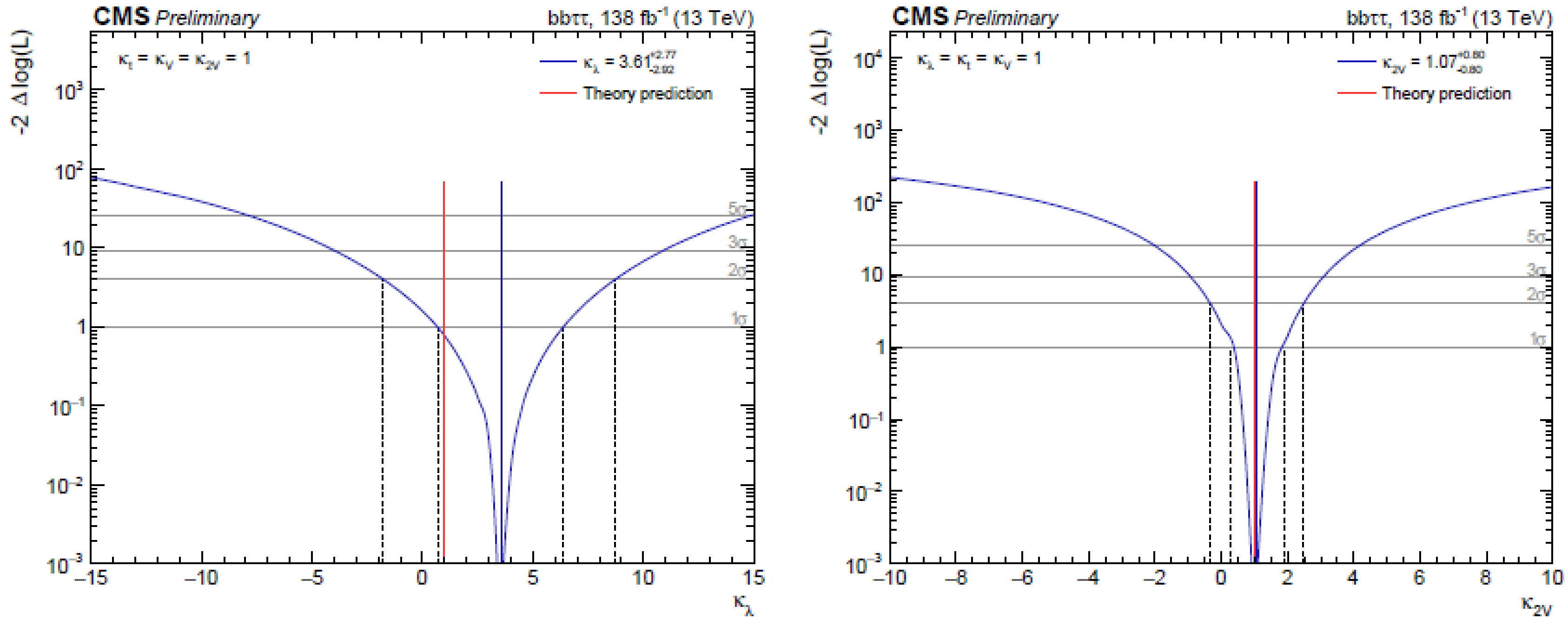




Observed and expected upper limits at 95% CL as a function of k_{2V} on the HH VBF signal strength (left) and on the HH VBF cross section times the bb$\tau\tau$ branching ratio (right). In both cases all other couplings are set to their SM expectation.



Two-dimensional exclusion regions as a function of the k_λ and k_t couplings for the full Run2 combination (left), both k_{2V} and k_V are fixed to unity. Two-dimensional exclusion regions as a function of the k_{2V} and k_V couplings (right), both k_λ and k_t are set to unity. Expected uncertainties on exclusion boundaries are inferred from uncertainty bands of the limit calculation, and are denoted by dark and light grey areas. The blue area marks parameter combinations that are observed to be excluded. For visual guidance, theoretical cross section values are illustrated by thin, labeled contour lines with the SM configuration denoted by a red diamond.



Observed likelihood scan as a function of k_λ (left) and k_{2V} (right) for the full Run 2 combination. The dashed lines show the intersection with threshold values one and four, corresponding to 68% and 95% confidence intervals, respectively.

Summery

- A search for nonresonant Higgs boson pair (HH) production via gluon-gluon fusion and vector boson fusion (VBF) processes in final states with two bottom quarks and two τ leptons was presented.

- This analysis builds up on the improvements made by the CMS Collaboration in the jet and τ lepton identification and reconstruction algorithms. All these techniques enable the achievement of particularly stringent results on the HH production cross sections.

- The observed 95% CL upper limit on HH total production cross section corresponds to 3.3 times the theoretical SM prediction, and the expected limit is 5.2 times the SM prediction. The observed 95% CL upper limit for the VBF HH SM cross section corresponds to 124 times the theoretical SM prediction and the expected limits is about 154 times the SM prediction.

- The observed (expected) 95% CL constraints on k_{λ} and k_{2V}, derived from limits on the HH production cross section times the bb$\tau\tau$ branching ratio, are found to be $1.8 < k_{\lambda} < 8.8$ ($-3 < k_{\lambda} < 9.9$) and $-0.4 < k_{2V} < 2.6$ ($-0.6 < k_{2V} < 2.8$), respectively.

Thanks for Your Consideration