Higgs boson decays into b and c quarks with the CMS experiment

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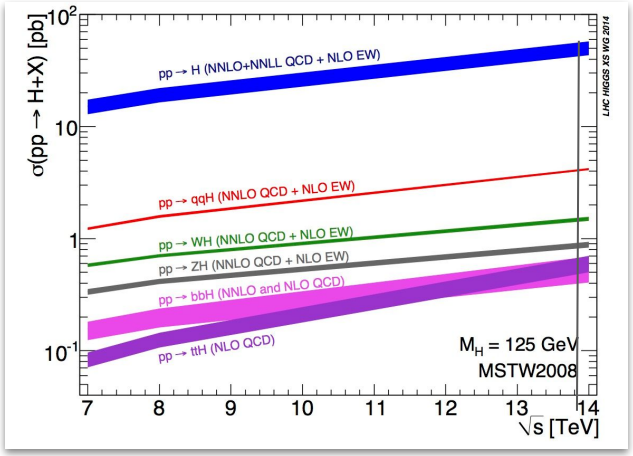
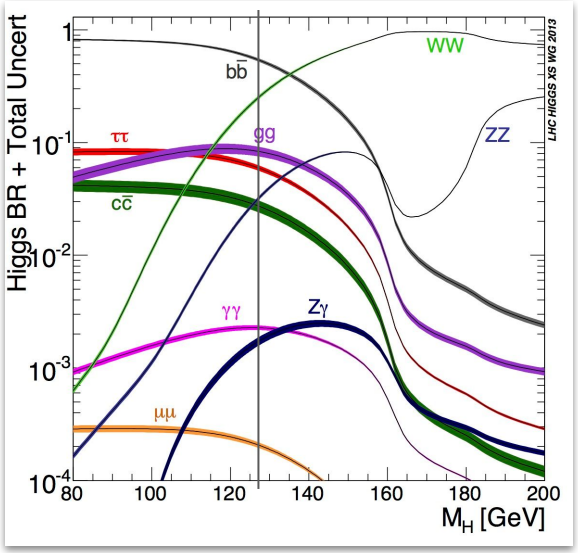
on behalf of the CMS collaboration

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

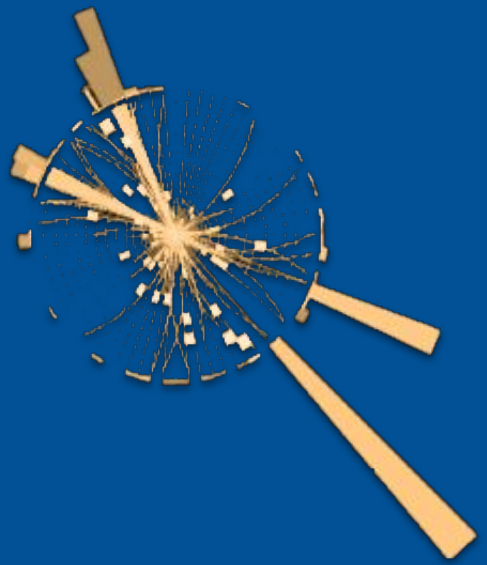
Introduction

- Higgs boson discovered 2012
- Higgs precision measurement and properties has been the focus since
- Full Run 2 data brings new challenges, needs new ideas
- In this talk:
  - VH (H→ $b\bar{b}$)
  - VH (H→ $c\bar{c}$)
  - Highly boosted Higgs (H→$b\bar{b}$)





VH ($H \to b\bar{b}$)
L=77.2 fb^{-1}@13 TeV



VH ($H \rightarrow b\bar{b}$)

Analysis strategy

- 3 channels are considered:
  - 0-lepton ($Z \rightarrow \nu\nu$)
  - 1-lepton ($W \rightarrow l\nu$)
  - 2-lepton ($Z \rightarrow ll$)
- Orthogonal control regions (CR):
  - $t\bar{t}$
  - V+HF(heavy flavor)
  - V+LF (lighter flavors)
- Multi-category DNN in V+HF CR
- DNN for signal classification and extraction

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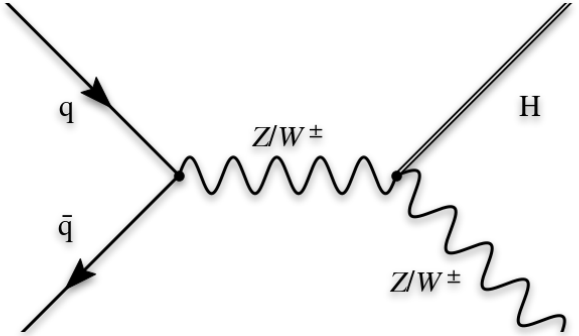
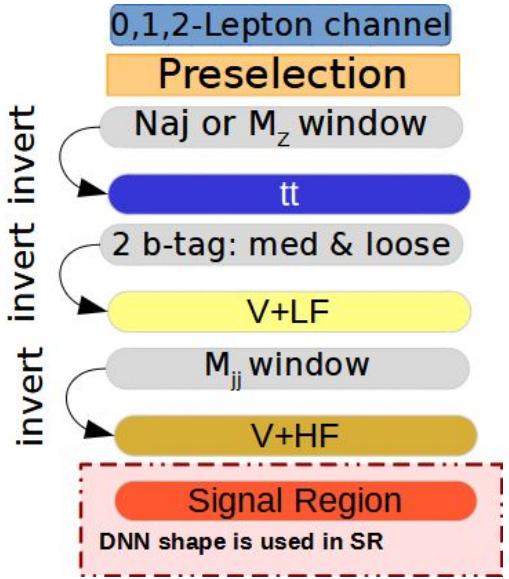


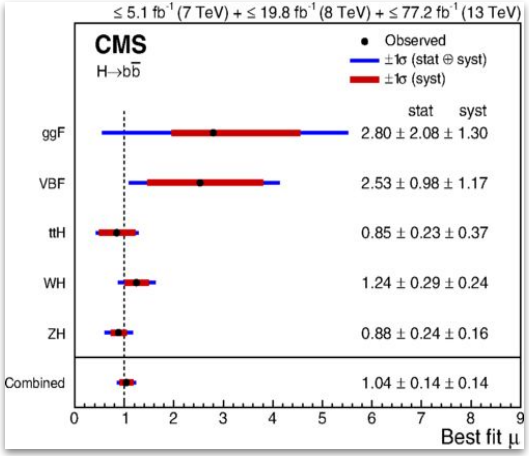


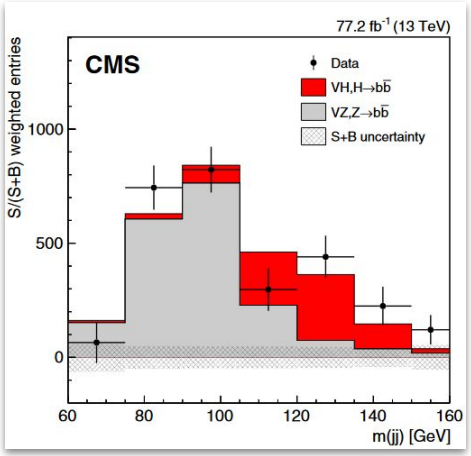
VH ($H \to b\bar{b}$)

Results

- Combination of Run 1 and partial Run 2 data of CMS
- In agreement with SM
- Combined with other production channels
- Observation of H decaying to b-quarks
- Full Run 2 and STXS analysis on the way

Phys. Rev. Lett. 121, 121801





Data set	Significance (σ) Expected	Observed	Signal strength
2017			
0-lepton	1.9	1.3	0.73 ± 0.65
1-lepton	1.8	2.6	1.32 ± 0.55
2-lepton	1.9	1.9	1.05 ± 0.59
Combined	3.1	3.3	1.08 ± 0.34
Run 2	4.2	4.4	1.06 ± 0.26
Run 1 + run 2	4.9	4.8	1.01 ± 0.22

VH ($H \rightarrow c\bar{c}$)
L= 35.9 fb^{-1} @13 TeV

VH (H→$c\bar{c}$)

Analysis strategy

- Probing Higgs decays to 2nd gen. Fermions
- 3-channels: 0-lepton (Z→***νν***) , 1-lepton (W→l***ν***), 2-lepton (Z→ll)
- Resolved and boosted topologies
- CRs for the background normalization in resolved and multivariate methods in boosted
- Main challenge, controlling the c-quark and light-quark against the b-quark background

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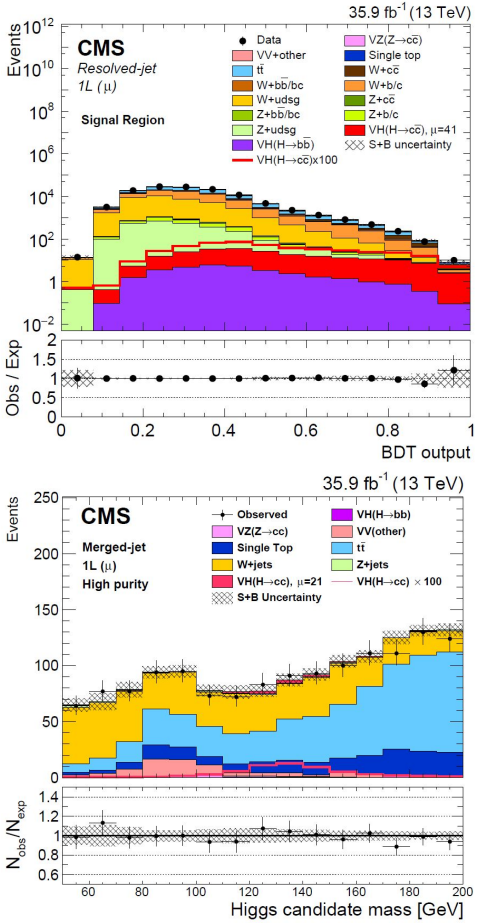

VH (H→$c\bar{c}$) resolved

Analysis strategy

- DeepCSV provides three discriminants
- P(B) used directly for b-tagging
- P(C) and P(L) used for c-tagging From P(L), P(C) and P(B)
  - CvsL = P(C) / [P(C) + P(L)]
  - CvsB = P(C) / [P(C) + P(B)]
- Using BDTs for signal extraction

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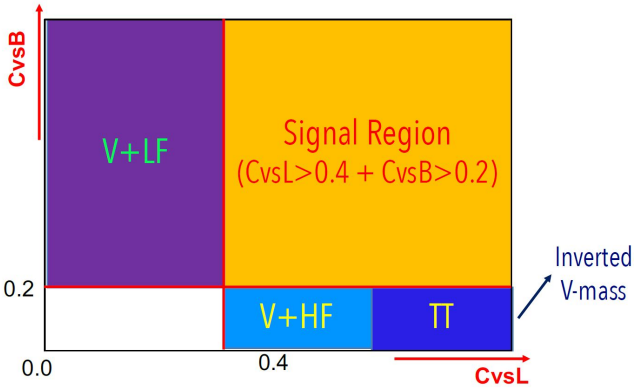

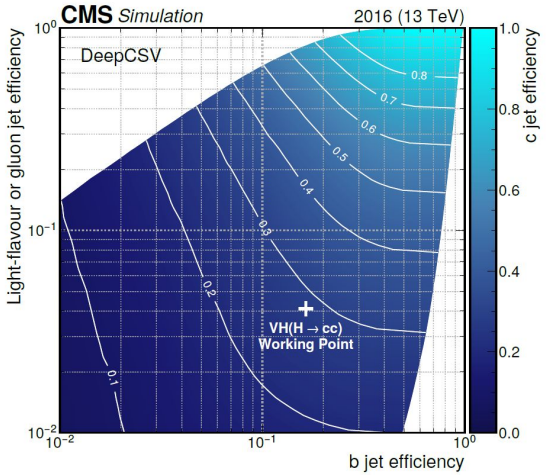

VH (H→$c\bar{c}$) boosted

Analysis strategy

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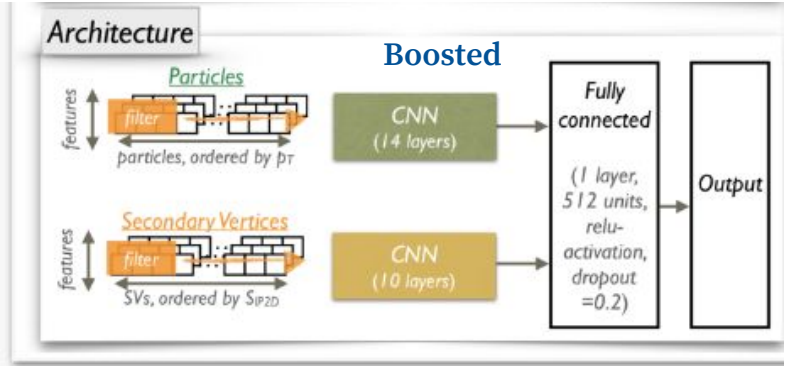
- Using AK15 jets in boosted analysis
- Multicategory multivariate analysis tools in boosted analysis
- Signal is extracted via a binned maximum likelihood fit to the soft-drop mass



CERN-CMS-DP-2020-002

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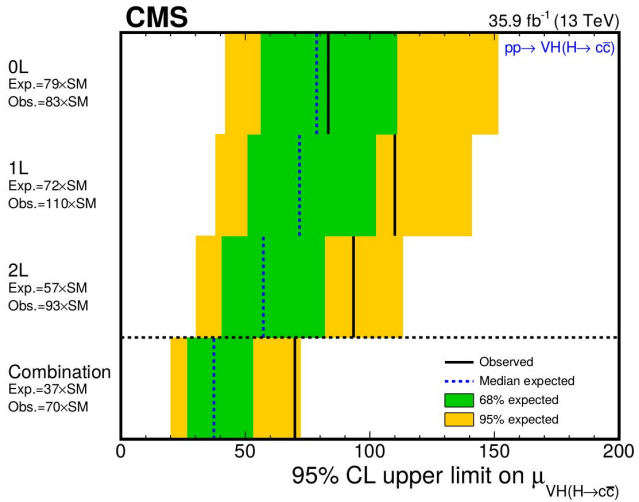
VH ($H \to c\bar{c}$)

Results

- Inclusive resolved and boosted analysis
- Combined to improve accuracy
- Consistent with SM
- Full Run 2 analysis underway

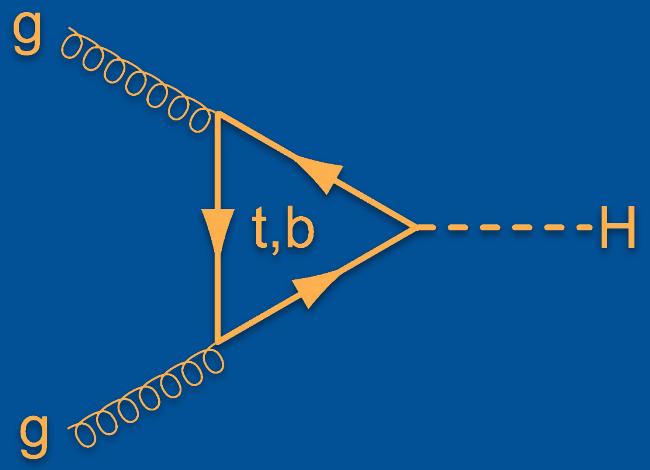
Combination



	Resolved-jet (inclusive)				Merged-jet (inclusive)			
	0L	1L	2L	All channels	0L	1L	2L	All channels
Expected UL	84^{+35}_{-24}	79^{+34}_{-23}	59^{+25}_{-17}	38^{+16}_{-11}	81^{+39}_{-24}	88^{+43}_{-27}	90^{+48}_{-29}	49^{+24}_{-15}
Observed UL	66	120	116	75	74	120	76	71

values w.r.t SM

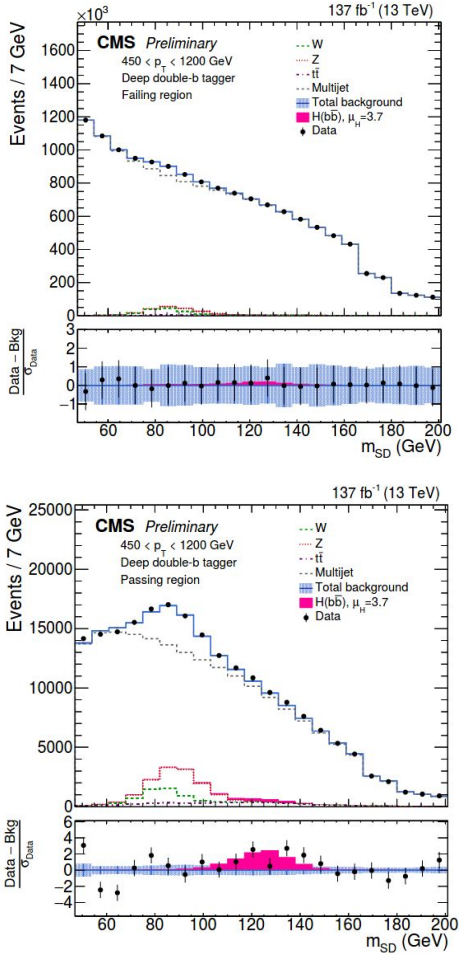
Boosted Higgs ($H \to b\bar{b}$)
L= 137 fb^{-1} @13 TeV



Boosted H($H \to b\bar{b}$)

Analysis strategy

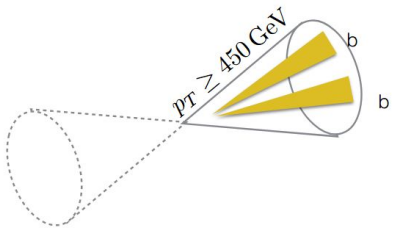
- Full Run2
- Boosted Higgs decays to bb
- Jet substructure and novel b-tagging to reject QCD
- The W and Z boson resonances used to constraint systematic unc.
- 2x improvement compared to previous CMS result
  - Increased integrated luminosity
  - Improved b tagging
  - Smaller theoretical uncertainties.

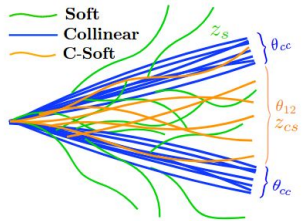


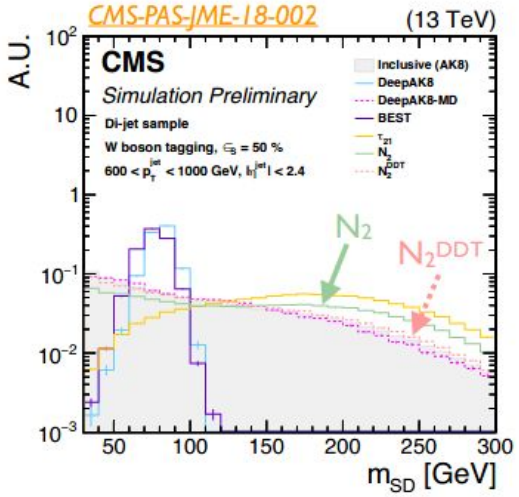
Boosted H(H→$b\bar{b}$)

Analysis strategy

- N_2 :
  - Generalized energy correlation functions [JHEP 1612 (2016) 153] for 2-prong (W/Z/H) tagging
- N_2^{DDT}:
  - Mass-decorrelated version of N2 using the DDT (Designed Decorrelated Tagger [JHEP 1605 (2016) 156]) method
  - Reduces mass sculpting and systematic uncertainties







Boosted H(H→$b\bar{b}$)

Results

- $\mu_H = 3.68 \pm 1.20(\text{stat})^{+0.63}_{-0.66}(\text{syst})^{+0.81}_{-0.46}(\text{theo})$ w.r.t SM

- 2.54 σ significance excess where the expectation is 0.71

- Unfolded differential cross-section as function of Higgs boson p_T

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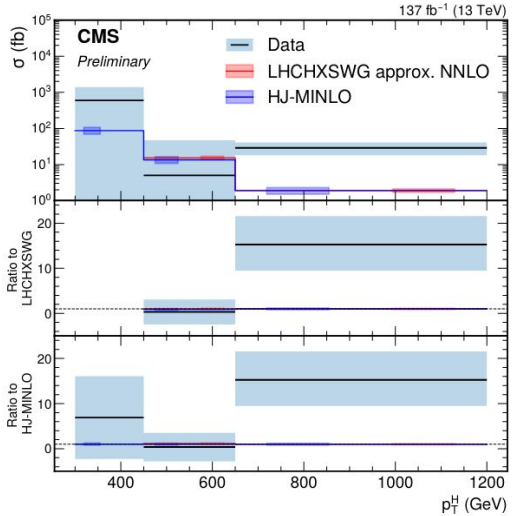

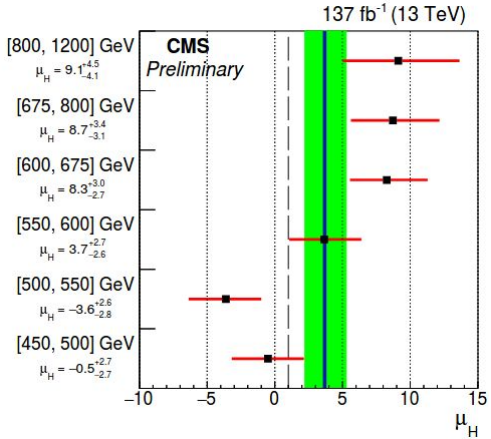

Summary

Summary

- Looked at Higgs associated production and inclusive highly boosted Higgs analyses in decays to b,c-quarks
- The beyond expected results achieved is the outcome of efforts in many branches
  - Accurate, smart and physics aware b-tagging
  - Using new computing and analysis technologies
  - Quantity and quality of data which has never matched before in the history of HEP
- Partial Run 2 analyses reported will update with full data, so stay tuned!

Back up

A decorrelation procedure is further applied to avoid distorting the jet mass distribution when a selection based on N_2 is made. We design a transformation from N_2 to N_2^{DDT}, where DDT stands for "designed decorrelated tagger" [15]. The transformation is defined as a function of the dimensionless scaling variable $\rho = \ln(m_{\mathrm{SD}}^2/p_{\mathrm{T}}^2)$ and the jet p_{T}:

$$N_2^{\mathrm{DDT}}(\rho, p_{\mathrm{T}}) = N_2(\rho, p_{\mathrm{T}}) - N_2^{(X\%)}(\rho, p_{\mathrm{T}}) \,, \tag{12}$$

where $N_2^{(X\%)}$ is the X percentile of the N_2 distribution in simulated QCD events. This ensures that the selection $N_2^{\mathrm{DDT}} < 0$ yields a constant QCD background efficiency of $X\%$ across the mass and p_{T} range considered with no loss in performance. The value $X = 5$ is used throughout this note, following the choice in [76]. The distributions of the N_2 and N_2^{DDT} in signal and background jets are shown in Fig. 6. Signal jets populate smaller values, whereas background jets have larger values. The N_2 DDT is used for V tagging with p_{T} in excess of 500 GeV in the search for light dijet resonances [76].