

# Latest Results on Higgs production and decay @CMS

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## Outline



- Introduction
- Higgs profile @ LHC Run 1
- New results @ 13 TeV CMS Run 2
  - Boson channels:  $H \rightarrow ZZ_4I$ ,  $H \rightarrow \gamma\gamma$  and  $H \rightarrow WW \rightarrow 2I_{2V}$
  - Higgs production associated with top quarks
  - VBF H(bb)
- More results
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/ PhysicsResultsHIG

More detail on RUN I Higgs properties covered by Marcello Fanti Rare decays by Liang Li and BSM Higgs searches by Li Yuan DiHiggs by Martino Dall'Osso



## **Higgs Production**





The first extended running period of the LHC at Vs=7 and 8 TeV brought the anticipated discovery of the Higgs boson by the CMS and ATLAS collaborations



## Higgs Decays at 125 GeV







## Higgs Profile @ LHC Run 1







## Higgs Profile @ LHC Run 1







## Higgs Profile @ LHC Run 1





## Higgs boson in Run 2



- LHC restarted in 2015 with a collision energy of 13 TeV and 25 ns bunch spacing
  - Increased sensitivity to tails of differential distributions and BSM
  - Increased sensitivity to large partonic center-of-mass (e.g. ttH production)
- Run 2 dataset ~22 fb<sup>-1</sup>in 2016
  - Already produced more Higgs bosons than in Run 1
- Most analyses follow closely methods and strategies developed during Run 1



1 1 1 1 AUG 1 Sep 1 Oct 1 NOV

Date (UTC)

1 Dec

, May

2 Jun







- Very small branching fraction (~0.2%)
- Clean final state with two isolated high p<sub>T</sub> photons and good resolution
- Narrow peak over falling background
  - Main backgrounds γγ and γ-jet
- Production modes probed
  - ggF, VBF, ttH
- Analysis strategy:
  - Events categorized into classes (S/B, mass resolution, additional particles) to improve the analysis sensitivity
  - Extraction of signal through fit of di-photon invariant mass spectrum in each category









### **Fiducial cross section**

- Different event categorization:
  3 mass resolution categories
- Event yields corrected for detector inefficiency and resolution
- Minimal dependence on theoretical modeling

$$\hat{\sigma}_{fid} = 69^{+16}_{-22} (\text{stat.})^{+8}_{-6} (\text{syst.}) \text{fb}$$

SM exp. (a)125.09 GeV:  $\sigma_{fid}^{th.} = 73.8 \pm 3.8 {\rm fb}$ 

 Good agreement between data and theory







7/29/16





#### Consistency tests: signal strengths and couplings



ggH,ttH

q(k<sub>V</sub>,k<sub>f</sub>)

8

-6

-4

-2

2



## H→ZZ→4I



- Golden channel at LHC
  - Two pairs of same flavor, opposite sign, isolated leptons
  - Large S/B, excellent resolution
  - Narrow peak over a flat background
- All main production modes probed: ggF, VBF, VH, ttH
  - Now have 6 cats (diff. from Run 1)
- Extraction of signal through fit of m<sub>4</sub>, together with various kinematics discriminants which enhance the signal purity of different production modes

#### The Higgs boson rediscovered: 6.20@125.09 GeV









- Fiducial volume defined to closely match reconstruction level
- Maximum likelihood fit to the inclusive m<sub>41</sub> distribution
- $\sigma_{\text{fid.}} = 2.29^{+0.74}_{-0.64} (\text{stat.})^{+0.30}_{-0.23} (\text{sys.})^{+0.01}_{-0.05} (\text{model dep.}) \text{ fb}$ SM expectation:  $\sigma_{\text{fid.}}^{\text{SM}} = 2.53 \pm 0.13 \text{ fb}$
- Differential cross section for p<sub>T</sub>(H) and N(jets)





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## H→ZZ→4I







 $H \rightarrow ZZ \rightarrow 4I$ 



## Consistency tests: signal strengths and couplings











## $H \rightarrow WW \rightarrow 2I2v$





- WW is one of the Higgs decays with larger BR
- Final state contains
  Neutrinos → impossible reconstruct an invariant mass spectrum
- With a reasonable level of som irreducible backgrounds
- Main background composition varies w.r.t. number of jets
  - o jets: WW, W+jets
  - **1 jet**: WW, Top
- 2D observables:  $m_{\parallel} \& m_{T}^{H}$



For 125 GeV Higgs Observed (expected) significance: 0.7 (2.0)  $\sigma$  Observed  $\mu$  = 0.3 +/- 0.5





- Probing the top-Higgs Yukawa coupling at LHC
  - via gluon fusion cross section, assuming no BSM particles running in the loop
  - directly at tree level, via associated productions



- $\sigma$  for ttH has the largest boost going from 8 to 13 TeV among the 5 main Higgs production modes ( $\sigma_{\rm ttH}$  ~510 fb@13 TeV)
- Challenging due to the presence of additional jets and leptons from top decay
- Searches for ttH in CMS
  - ttH( $\rightarrow$ bb), ttH(multilepton); ttH( $\rightarrow\gamma\gamma$ ) included in H $\gamma\gamma$  analysis



## ttH(→bb)



- High cross section x BR, but complex multi-jet final state with large background
  - Main bkg: tt+heavy flavor production
- Events categorized according to amount of leptons, jets, b-jets
- Reduce tt+jets using kinematic variables and Matrix Element Method





## ttH in multi-lepton final states





- Events with at least 2 loose or 1 medium b-tagged jets categorized into
  - two same-sign leptons + 4 jets
  - at least three leptons (with Z veto) + 2 jets
- Main backgrounds
  - **irreducible**: ttV (from MC), di-boson (validated in data)
  - **reducible**: non-prompt leptons in tt events and charge mis-ID, datadriven



## **Kinematic discrimination**



- Building separate BDT discriminators to improve discrimination against tt and ttV events
  - Jet multiplicity, lepton/jet angular separation, MET, lepton pT
  - Also matrix element weights for ttH and ttV hypotheses used in 3l





## ttH signal extraction



• The signal is extracted via a 2-dimensional fit to the BDT discriminators







## • Results with 2015 + 2016 data

Category	Obs. limit	Exp. limit $\pm 1\sigma$	Best fit $\mu \pm 1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}{}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}{}_{-0.4}$	$2.0^{+0.8}$ $_{-0.7}$



#### Observed (expected) significance: 3.2 (1.7) $\sigma$



## tH(→bb)



- Tiny SM production cross section: (~80 fb@ 13 TeV)
  - Diagrams are interfering in SM
  - While it's constructive for inverted top coupling  $k_{top}=-1$





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# VBF H(bb)



- VBF H→bb more difficult to exploit than VH signature for H→bb but larger production cross section
  - Forward jets are used to trigger and discriminate against multi-jet background
  - Signal extracted via a fit to the m<sub>bb</sub> spectrum





CMS	Upper limit x SM (expected)	Signal strength µ
Run 1	5.5 (2.5)	<b>2.8</b> <sup>+1.6</sup> <sub>-1.4</sub>
Run 2+	1 3.4 (2.3)	1.3 <sup>+1.2</sup> -1.1



## Summary



- Exploration of the new energy regime of 13 TeV has just started
- The Higgs boson has been rediscovered and several measurements performed
- No significant deviation from the Standard model from this first look
- 10x more data to come by end of 2018
- Looking forwards to much more precise measurements of the Higgs sector, stay tuned !





## Thanks !





#### Part of CMS Collaboration with >4400 collaborators from >200 institutions