Measuring Higgs boson properties in the diphoton channel and simplified template cross sections

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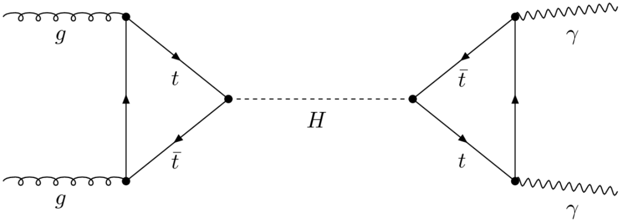
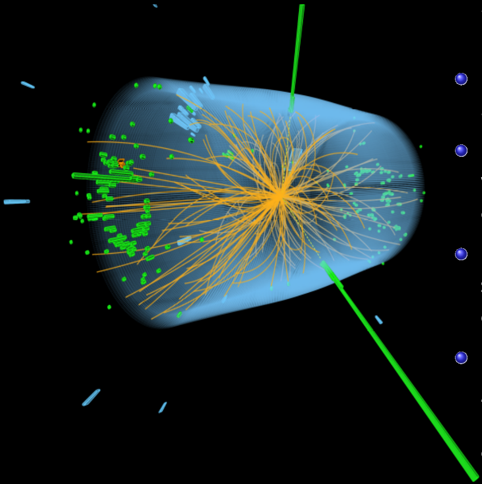
Introduction

- Now entered realm of precision measurements in Higgs (H) sector.
- Ever increasing dataset + improved analysis techniques allow strict tests of SM in terms of Higgs/EWSB parameters.
- So far, all consistent with SM predictions!
- $H \to \gamma\gamma$ played major role in discovery, and now in measurements of H properties, due to precise reconstruction of $m_{\gamma\gamma}$ peak.



Outline

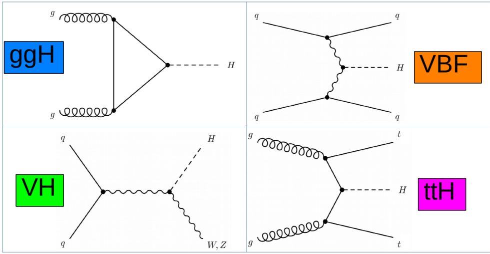


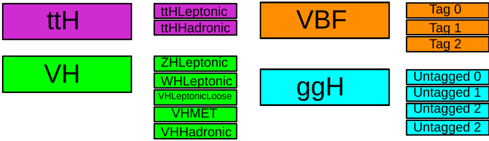
- Analysis performed by CMS [1] on 35.9 fb^{-1} of pp-collision data ($\sqrt{s}$=13TeV).
- Events selected by diphoton triggers (30 and 18 GeV thr.)
- MC simulate signal+background, weighted+calibrated to reproduce distributions in data.
- Methodology: event classification, signal+background modelling, fit to extract POIs
- POIs include signal strengths, $\mu = \sigma_{\text{obs}}/\sigma_{\text{SM}}$ for overall + individual Higgs production modes, and Higgs coupling modifiers

1 CMS PAS HIG-16-040: https://cds.cern.ch/record/2264515

Event classification

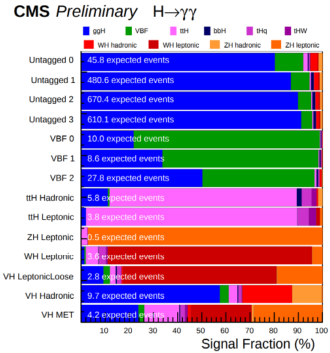
- Events separated targetting production modes, and according the $m_{\gamma\gamma}$ resolution and signal-to-background ratio.
- Improves sensitivity and allows individual signal strength measurements.
- Use the **other reconstructed particles/jets** in an event, satisfy dedicated criteria related to each category.
- Multivariate classifier to separate VBF/ggH according to purity/$m_{\gamma\gamma}$ resolution.

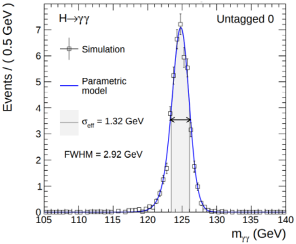




Modelling

- **Signal**: fit $m_{\gamma\gamma}$ peak in each category using simulated events.
- **Background**: extracted from data using discrete profiling method. Treats choice of background function as nuisance parameter by trialing many families of functions.
- **Systematics**: treats uncertainties depending on effect on $m_{\gamma\gamma}$ distribution.

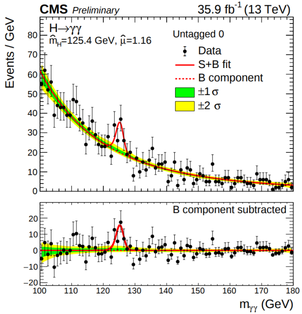


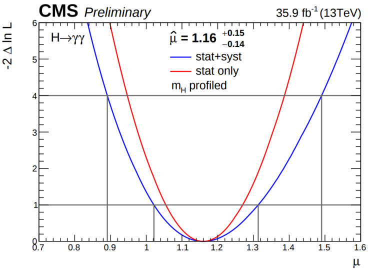


Results

Extracting POIs

- **Simultaneous** fit of signal+background to each category, allowing μ_i and m_H to vary.

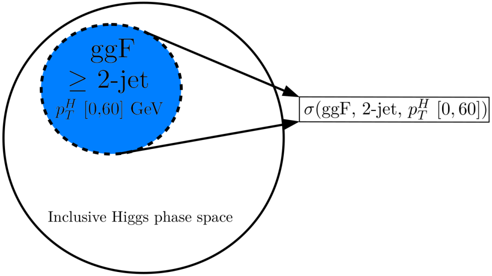




- Likelihood scans to extract best-fit values + uncertainties for signal strengths (also coupling modifiers, see [1]).

Simplified template cross sections (STXS)

- **Issue**: theoretical uncertainties directly folded into measurement stage.



- **Idea**: STXS framework [2]. Measure cross sections instead of signal strengths in fiducial volumes (bins) of inclusive Higgs phase space.
- Maximise experimental sensitivity whilst minimizing theoretical dependencies in measurements.

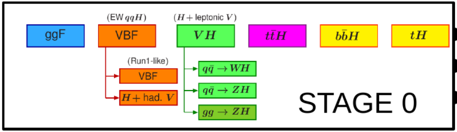
[2] - Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, arXiv:1610.07922 **p457**

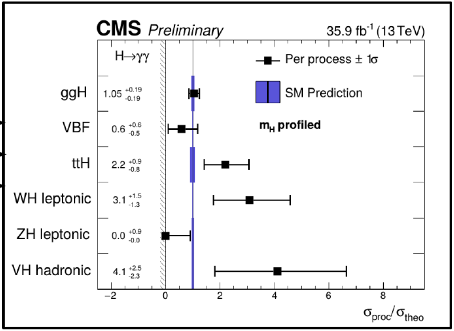
Choosing the "bins"...

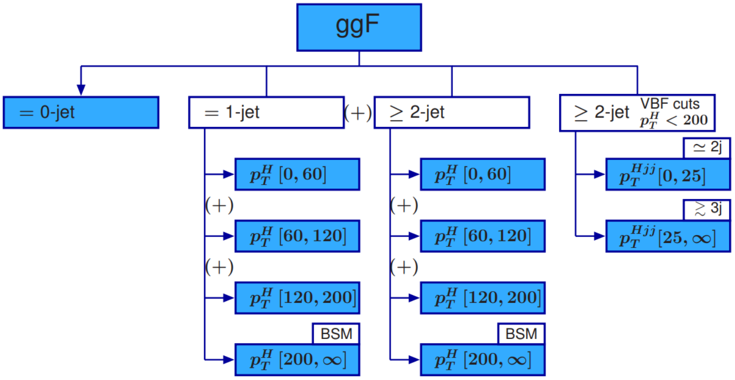
- Require bins to be mutually exclusive regions of phase space.
- Higgs production mechanisms again separated, remove production mode dependencies.
- Bins aligned with experimental cuts to avoid extrapolations into larger regions of phase space.
- Roughly constant experimental acceptance, removes direct dependencies on underlying theory distribution in simulation.
- Theory perspective, isolate bins with largest theory systematics or bins which may have increased sensitivity to BSM enhancements.
- Careful with BDT!

Staging

Framework evolves with increasing statistics, more finely-grained bins.

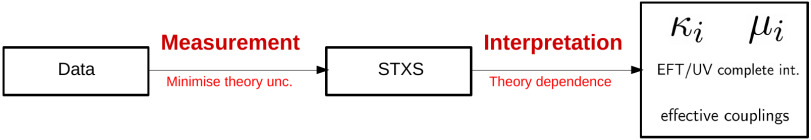






Timescales

- Stage 1 expected to be achieved by end of LHC run 2
- Stage 2 bin definitions TBD after gaining experience from previous stages. Integrate during run 3, fully achieved at HL-LHC.



Ultimate goal: Provide interface between measurement and interpretation

- Minimise theory at measurement stage (shift to interpretation step)
- Finely grained bins provide more info for interpretation
- Measurements remain long term useful.
- Efficient framework for **combinations** across decay channels, and ultimately across collaborations (CMS+ATLAS).

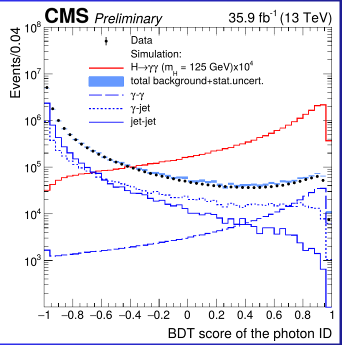
Summary

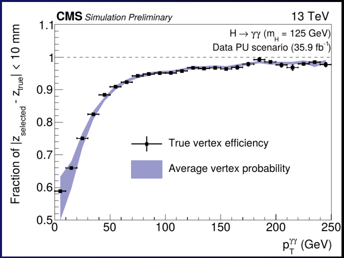
- Presented precision measurements of Higgs boson signal strengths in diphoton channel.
- With ever-increasing data set + improving reconstruction and analysis techniques can precisely test SM in Higgs sector, and learn more about EWSB dynamics.
- However, current analysis folds directly theoretical uncertainties at measurement stage.
- Solution is STXS, provide a natural way to progress Higgs coupling measurements in future!

BACK UP SLIDES

Preselection, vertex and corrections

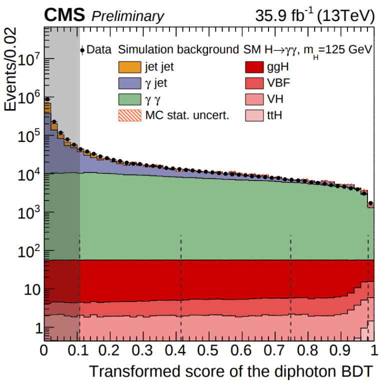
- Photon energy corrections: MV regression, ratio true energy/recon. energy as target. Input shower shapes etc. Also correct energy scale in data/smearing in simulation using $Z \to e^+e^-$ candidates
- Preselection: p_T, isolation, electron veto etc
- Photon ID: BDT score to separate prompt photons from photon candidates
- Vertex scenario: important for resolution of peak, use BDT (input related to recoiling tracks). Fit signal models for each vertex scenario.

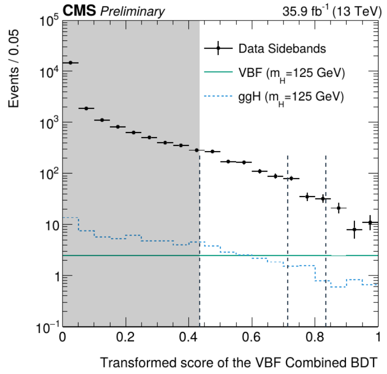




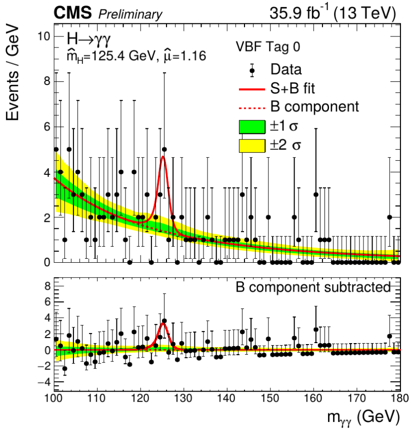
Diphoton BDT and VBF Combined BDT

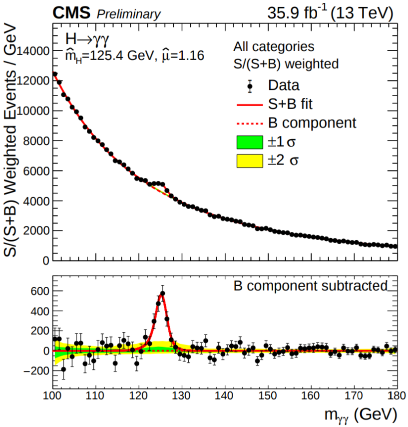
- Diphoton BDT: major ingredient in classification to evaluate resolution. Split ggH according to $m_{\gamma\gamma}$ res. High score for events with photons showing signal like kinematics, good mass resolution and good individual photon ID.
- VBF Combined BDT: separates VBF from ggH. ggH as background. Used to split VBF categories by purity. One input is diphoton BDT score.



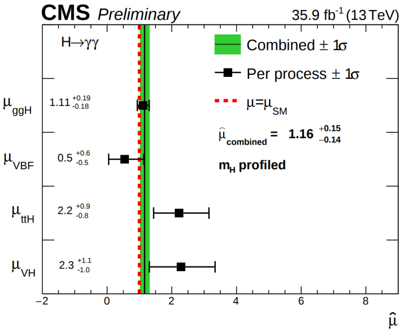


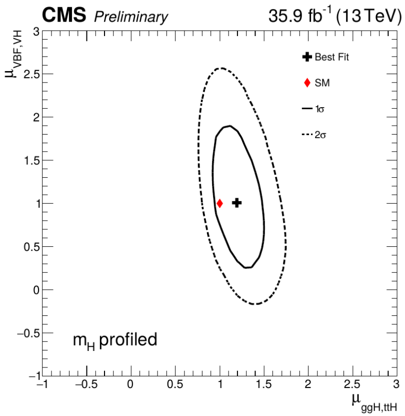
S+B Fits


CMS Preliminary
35.9 fb-1 (13 TeV)
H→γγ
m̂H=125.4 GeV, μ̂=1.16
VBF Tag 0
Data
S+B fit
B component
±1 σ
±2 σ
Events / GeV
B component subtracted
mγγ (GeV)


CMS Preliminary
35.9 fb-1 (13 TeV)
H→γγ
m̂H=125.4 GeV, μ̂=1.16
All categories
S/(S+B) weighted
Data
S+B fit
B component
±1 σ
±2 σ
S/(S+B) Weighted Events / GeV
B component subtracted
mγγ (GeV)

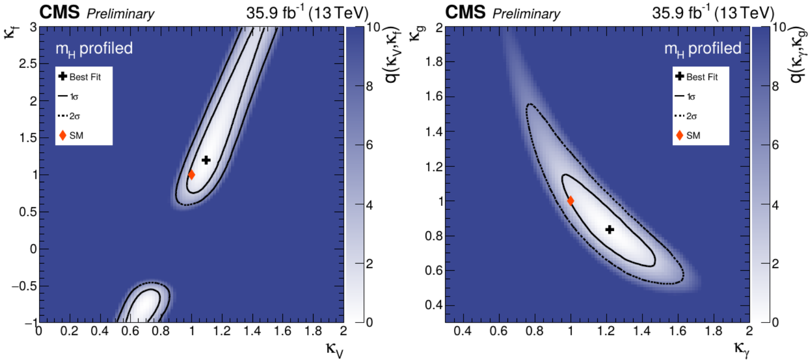
Results: likelihood scans



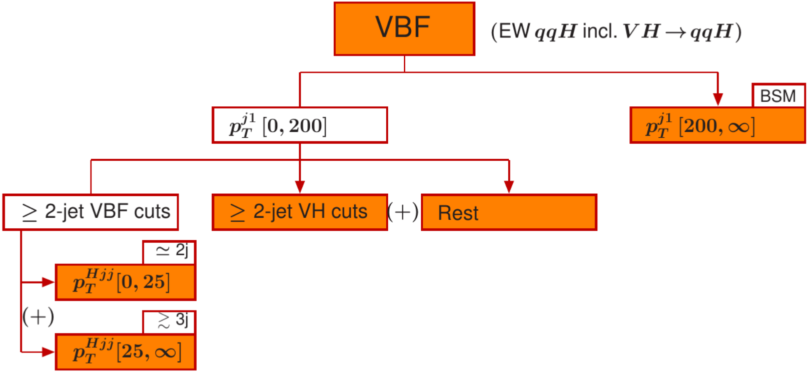


Results: κ analysis

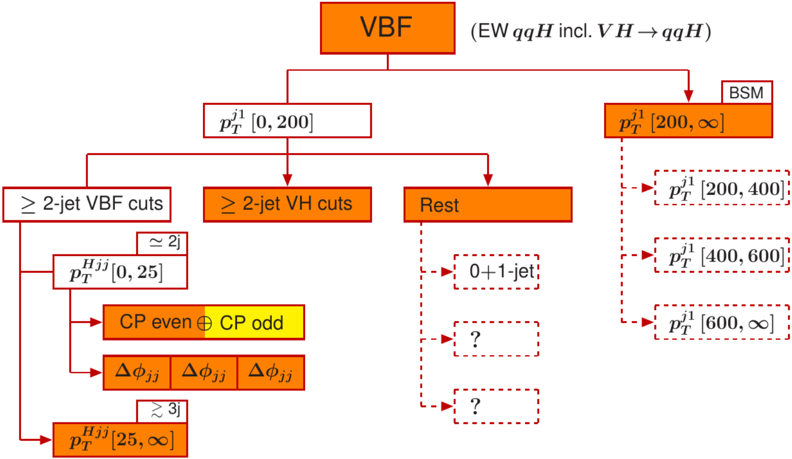
- Interpretation in terms of effective coupling modifiers. Allows couplings to deviate from SM predictions. Highly consistent with SM



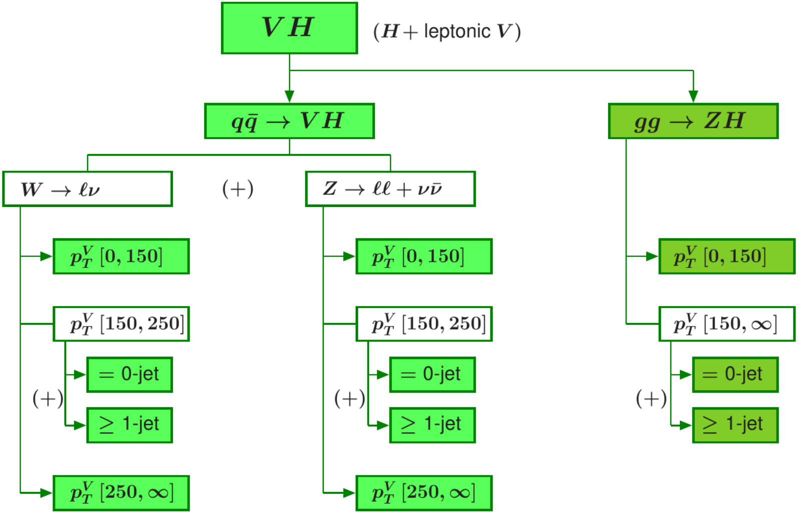
VBF: Stage 1


VBF
(EW qqH incl. $VH \to qqH$)
p_T^{j1} $[0, 200]$
BSM
p_T^{j1} $[200, \infty]$
$\geq$ 2-jet VBF cuts
$\geq$ 2-jet VH cuts
(+)
Rest
$\simeq$ 2j
$p_T^{Hjj}[0, 25]$
(+)
$\gtrsim$ 3j
$p_T^{Hjj}[25, \infty]$

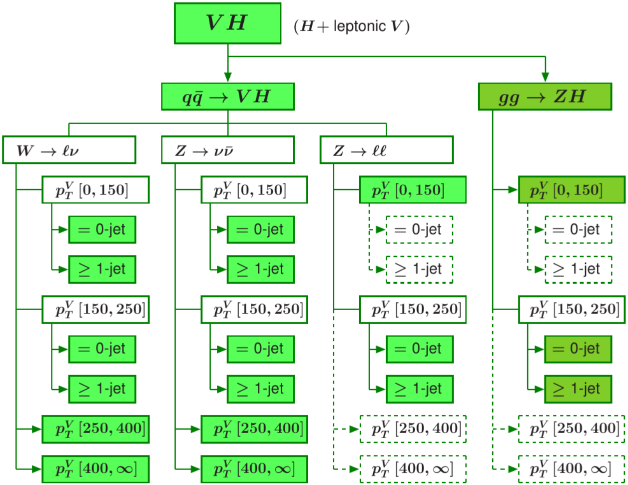
VBF: Stage 2


VBF
(EW qqH incl. $VH \to qqH$)
p_T^{j1} [0, 200]
BSM
p_T^{j1} [200, ∞]
$\geq$ 2-jet VBF cuts
$\geq$ 2-jet VH cuts
Rest
p_T^{j1} [200, 400]
p_T^{j1} [400, 600]
p_T^{j1} [600, ∞]
$\simeq$ 2j
p_T^{Hjj} [0, 25]
0+1-jet
CP even $\oplus$ CP odd
?
$\Delta\phi_{jj}$
$\Delta\phi_{jj}$
$\Delta\phi_{jj}$
?
$\gtrsim$ 3j
p_T^{Hjj} [25, ∞]

VH: Stage 1


VH
$(H +$ leptonic $V)$
$q\bar{q} \to VH$
$gg \to ZH$
$W \to \ell\nu$
$(+)$
$Z \to \ell\ell + \nu\bar{\nu}$
$p_T^V\ [0, 150]$
$p_T^V\ [150, 250]$
$= 0$-jet
$(+)$
≥ 1-jet
$p_T^V\ [250, \infty]$
$p_T^V\ [0, 150]$
$p_T^V\ [150, 250]$
$= 0$-jet
$(+)$
≥ 1-jet
$p_T^V\ [250, \infty]$
$p_T^V\ [0, 150]$
$p_T^V\ [150, \infty]$
$= 0$-jet
$(+)$
≥ 1-jet

VH: Stage 2


VH
($H+$ leptonic V)
$q\bar{q} \to VH$
$gg \to ZH$
$W \to \ell\nu$
$Z \to \nu\bar{\nu}$
$Z \to \ell\ell$
p_T^V $[0, 150]$
$= 0$-jet
≥ 1-jet
p_T^V $[150, 250]$
$= 0$-jet
≥ 1-jet
p_T^V $[250, 400]$
p_T^V $[400, \infty]$