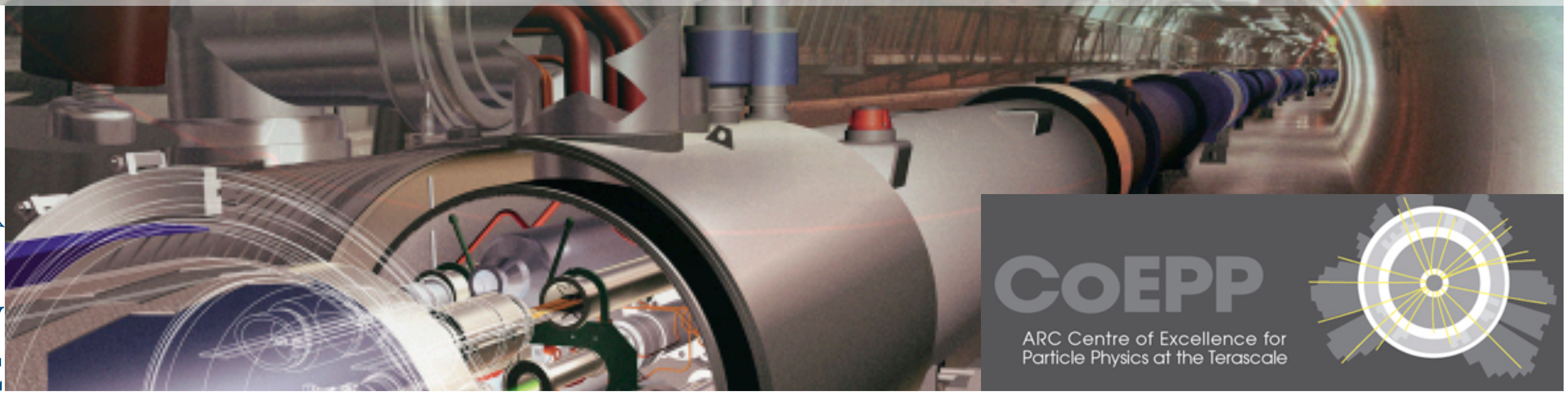
Séminaire – Marseille –27th May 2013

THE HEAVY HIGGS SEARCHES FROM STANDARD MODEL TO BEYOND

Sara Diglio

The University of Melbourne



THE UNIVERSITY OF MELBOURNE

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

4th July 2012

CERN PRESS RELEASE : 4TH JULY 2012

CERN EXPERIMENTS OBSERVE PARTICLE CONSISTENT WITH LONG-SOUGHT HIGGS BOSON

Geneva, 4 July 2012. At a seminar held at CERN* today as a curtain raiser to the year's major particle physics conference, **ICHEP2012 in Melbourne**, the **ATLAS and CMS experiments** presented their latest preliminary results in the search for the long sought Higgs particle. **Both experiments observe a new particle in the mass region around 125-126 GeV**

The next step will be to determine the precise nature of the particle and its significance for our understanding of the universe.

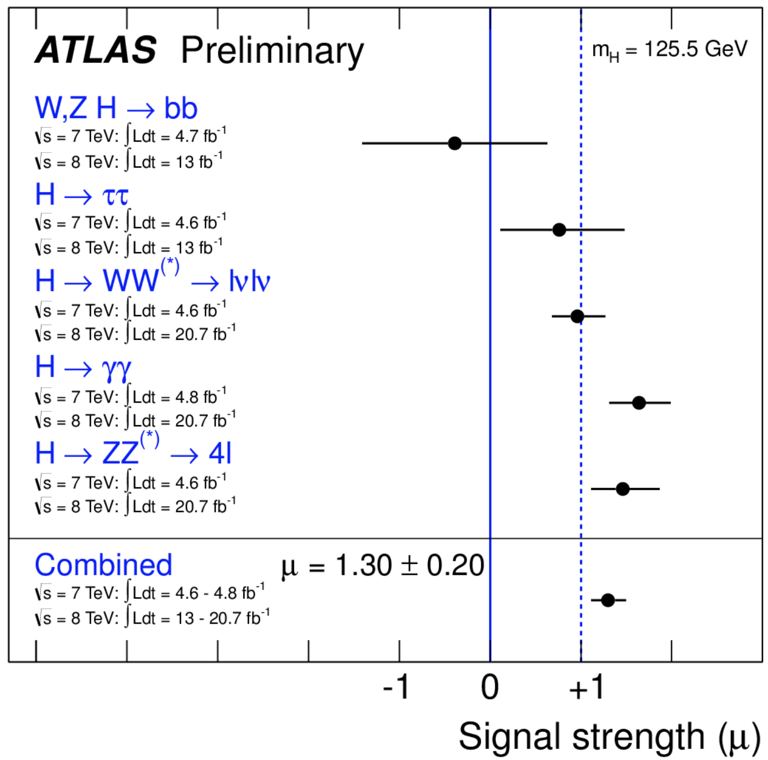
Are its properties as expected for the long-sought Higgs boson, the final missing ingredient in the Standard Model of particle physics? Or is it something more exotic?

OUTLINE

- Testing the Nature of the Higgs boson
- Why Heavy Higgs searches?
- BSM benchmark: 125 GeV Higgs + real singlet
- Status and plan of the search
- Conclusions

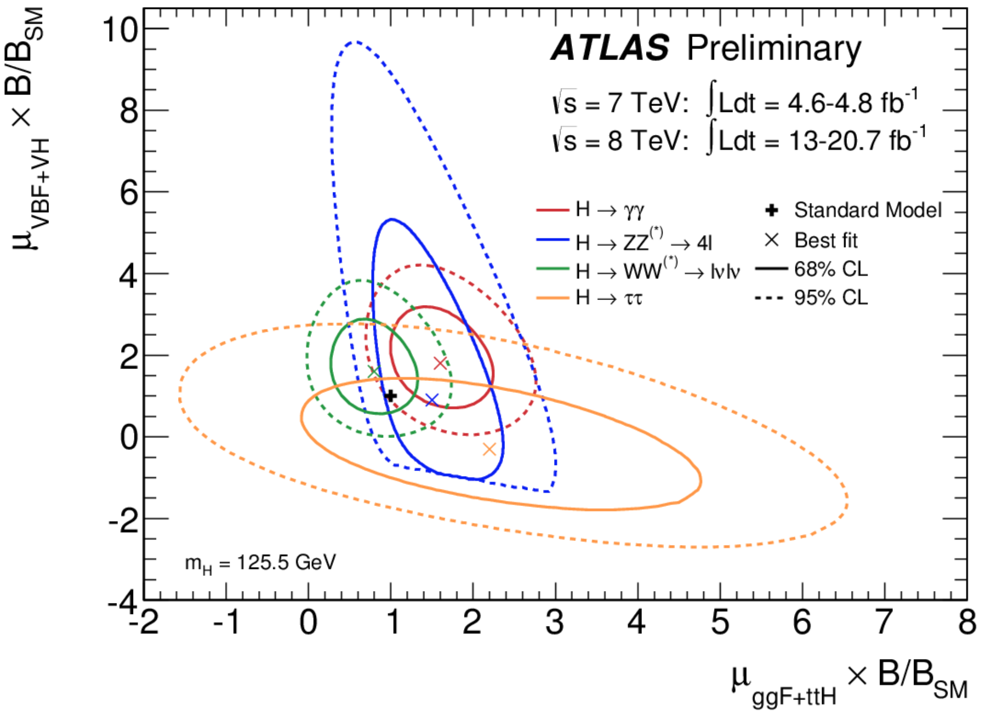
Testing the Nature of the Higgs boson wrt SM

- Overall compatibility



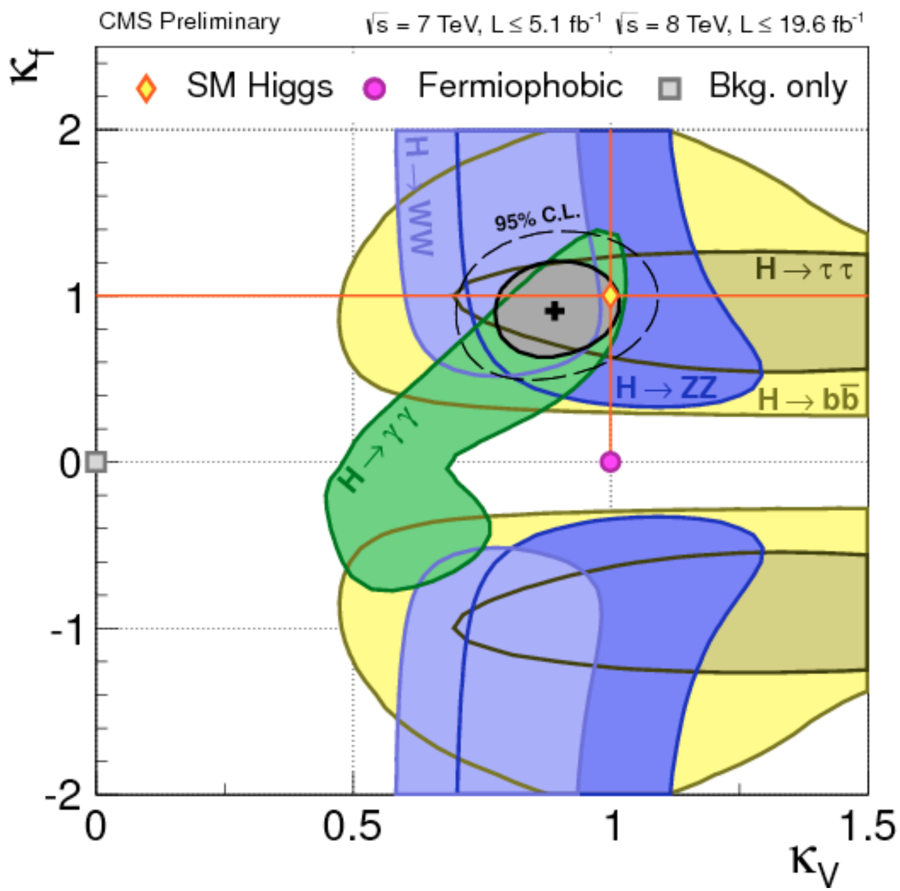
Testing the Nature of the Higgs boson wrt SM

- Overall compatibility
- Production modes



Testing the Nature of the Higgs boson wrt SM

- Overall compatibility
- Production modes
- Global fit on Couplings



Testing the Nature of the Higgs boson wrt SM

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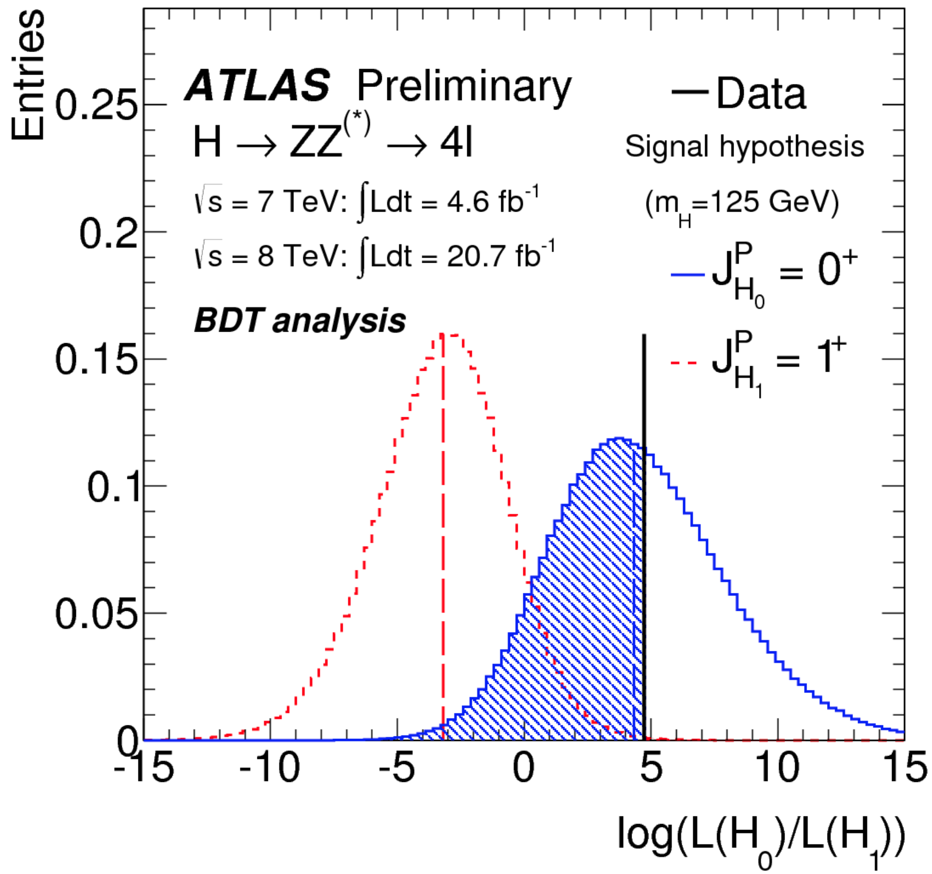
- Spin 0, mostly CP+



SINCE THE 4TH JULY 2012 …

Testing the Nature of the Higgs boson wrt SM

- Overall compatibility
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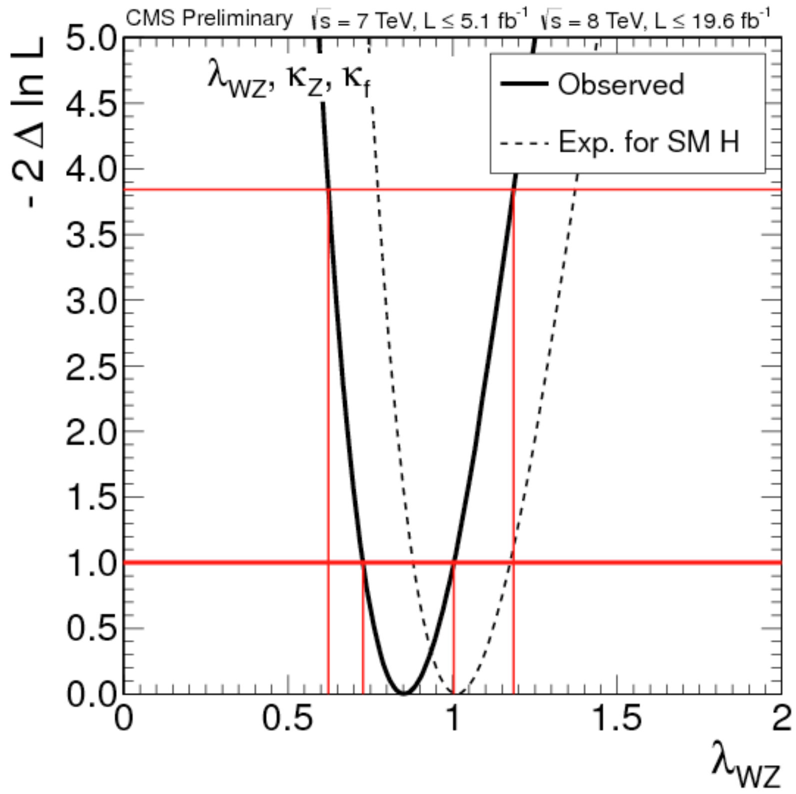
- Spin 0, mostly CP+
- Custodial W/Z symmetry

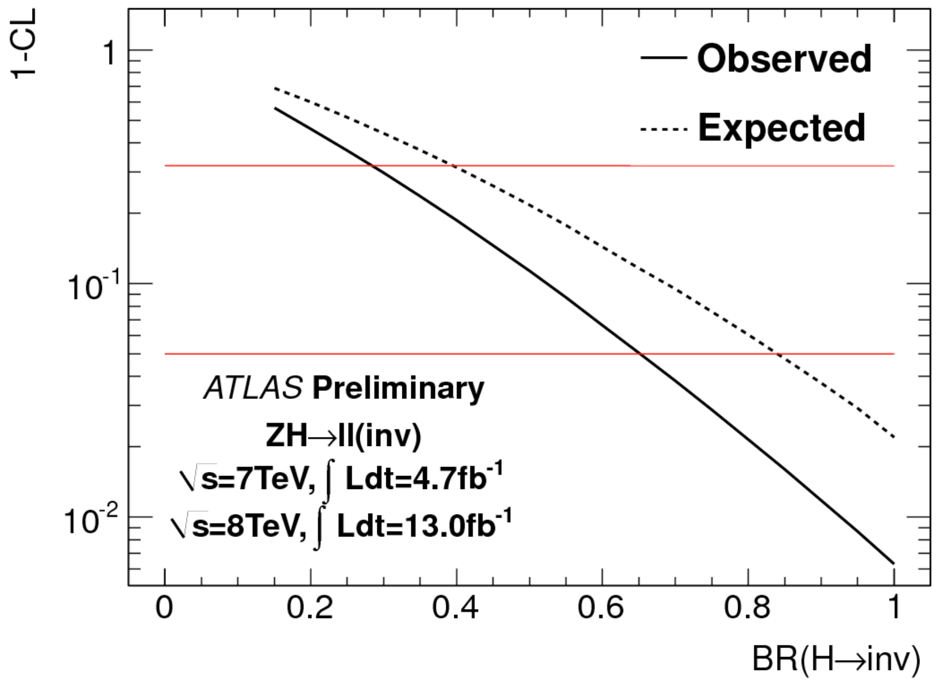


$$\frac{m_W}{m_Z \cos\theta_W} = 1 \quad \Rightarrow \quad \lambda_{WZ} = \frac{c_W}{c_Z} = 1$$

Testing the Nature of the Higgs boson wrt SM

- Overall compatibility
- Production modes
- Global fit on Couplings
- Spin 0, mostly CP+
- Custodial W/Z symmetry
- There are no new light states to which the Higgs boson can decay

→ Invisible width=0



BR(H→inv) < 0.6 @ 95% CL

Testing the Nature of the Higgs boson wrt SM

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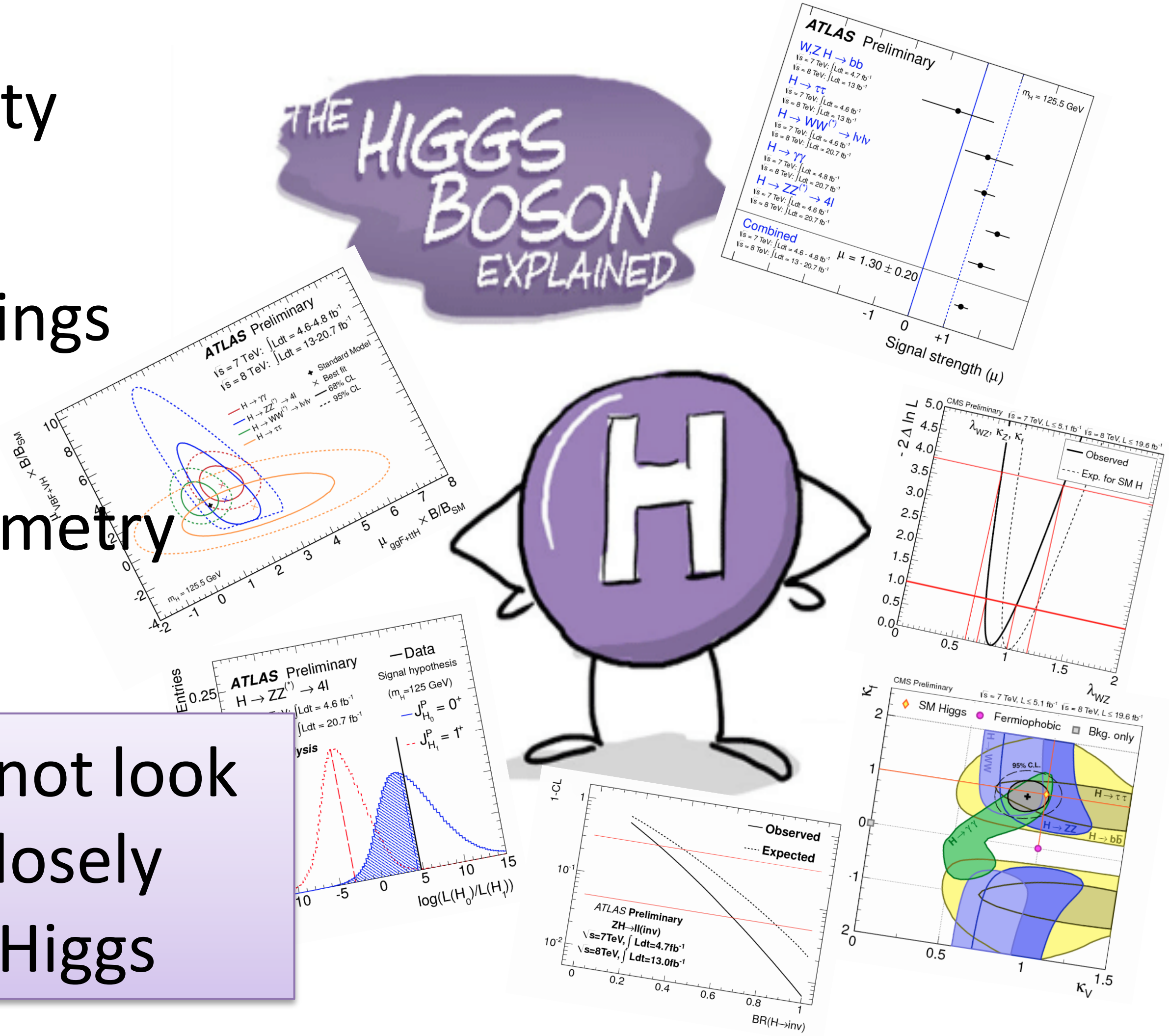
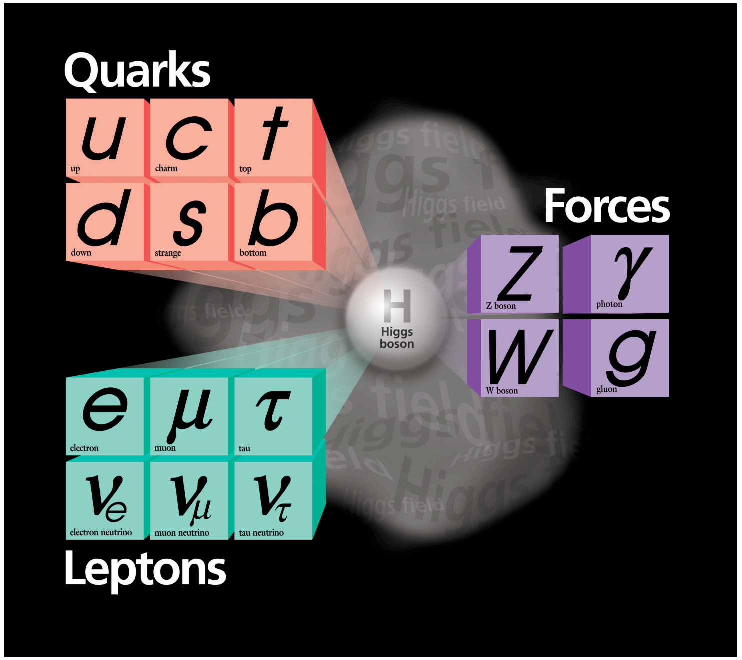
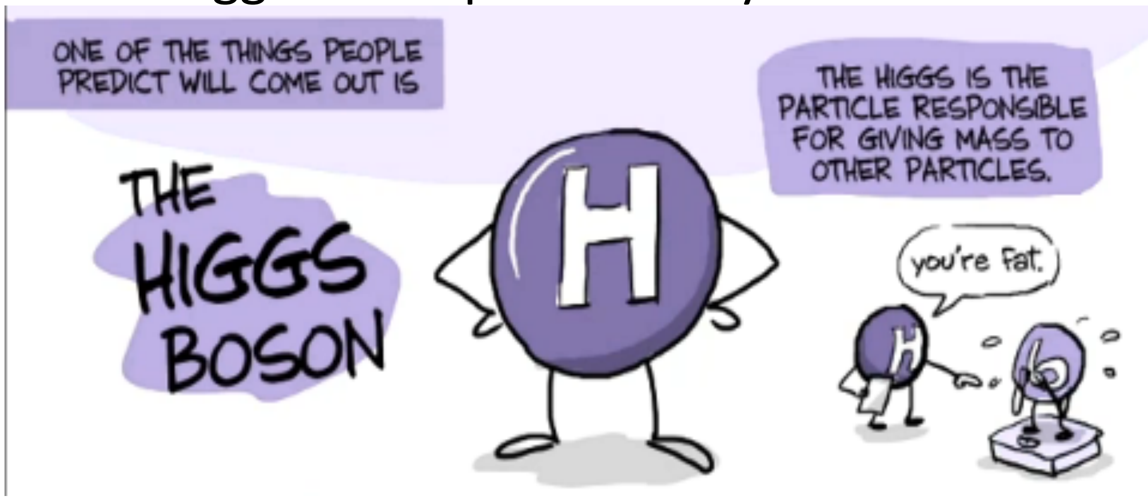


The new boson does not look an impostor ← it closely resembles the SM Higgs

‘THE’ HIGGS BOSON?

- According to the current results the 125 GeV discovered particle closely resembles the Higgs boson predicted by the S

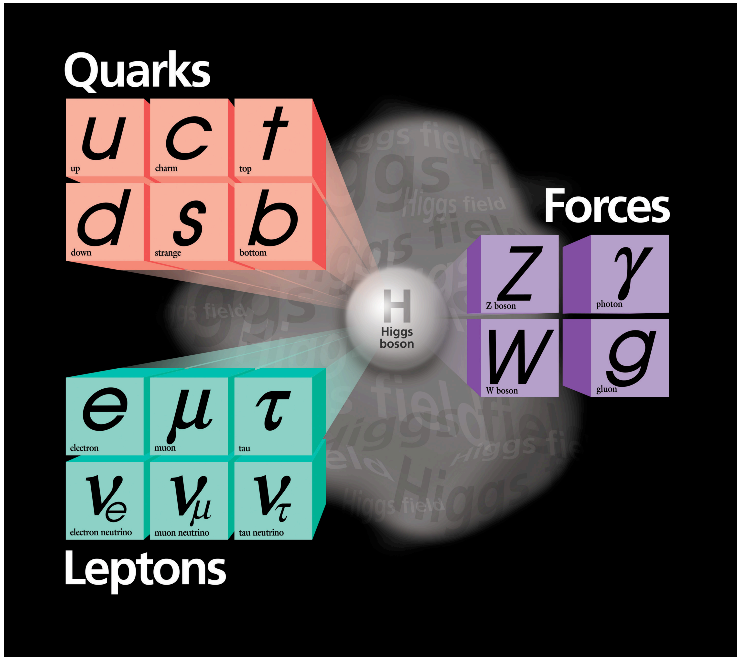




OPEN QUESTIONS :

- Is it fully responsible for the generation of the masses of other SM particles ?
- Or is it part of a more extended sector with **more ‘Higgs-like’ particles**?

‘A’ HIGGS BOSON?



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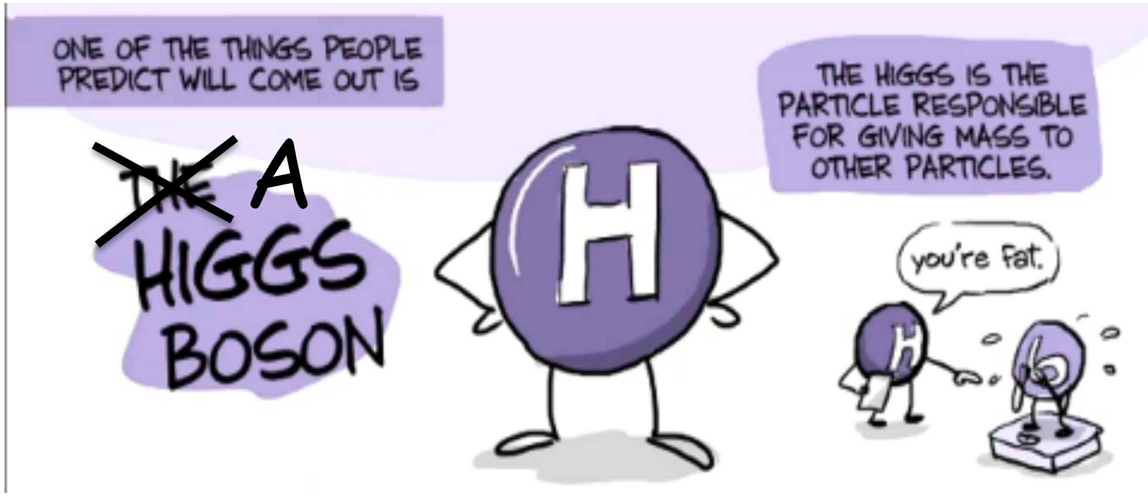

OPEN QUESTIONS :

‘The’ or ‘A’ Higgs boson?

- Is it fully responsible for the generation of the masses of other SM particles ?
- Or is it part of a more extended sector with **more ‘Higgs-like’ particles**?

Need to investigate
Beyond SM scenarios

BSM SCENARIO

Is a completely model independent analysis possible?
→ **NOT enough data yet to have a model independent conclusion**

Even with a few reasonable assumptions

- spin-0 + CP-even
- custodial W/Z symmetry
- No FCNC

Relations imposed by unitarity

$V_L V_L \to V_L V_L$	$c_V^2 + c_V'^2 = 1$
$V_L V_L \to f\bar{f}$	$c_V c_F + c_V' c_F' = 1$

still the parameter space is large →**need to consider benchmark models**

The SM is one specific point in the wide parameter space allowed by more generic benchmark models → reinterpretation of SM results

Strategies developed for SM searches will be extended to Beyond SM (BSM) 'SM-like'

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I will focus on a generic BSM benchmark which:

- **is consistent with ~125 GeV observation**
- contains a **second heavier Higgs-like state**
- is compatible with EW precision data

125 GeV Higgs + Real Singlet

C. Grojean, K. Kumar, H. E. Logan et al.

Model discussion and strategy building within the Heavy Higgs and BSM LHC HXS WG

HEAVY HIGGS AND BSM LHC HXS WG

- New joint effort between LHC experimental and theory communities
- **The main scope is to provide theoretical guidelines in common between ATLAS and CMS to**
  - characterize properly the heavy Higgs in the SM case
  - define general benchmarks to reinterpret SM searches/ signatures in BSM scenarios

We started looking into the most basic/general BSM scenarios from a general point of view

125 GeV Higgs + Real Singlet

Contacts: ATLAS: K. Peters**, SD**
CMS : M. Kadastik, S. Bolognesi
TH : M.Muehlleitner, H.Logan

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsBSM

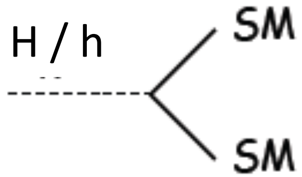
125 GeV Higgs + real singlet

Two resonances with couplings rescaled wrt to SM

- h125 (h) coupling = C × SM
- Heavy Higgs (H) coupling= C' × SM

By C. Grojean, K. Kumar, H. E. Logan

universal rescaling of Higgs couplings



$$\sqrt{\mu}\, g_{hXX}^{SM}$$

$$c_V^2 + c_V'^2 = 1 \qquad c_V = c_F = \sqrt{\mu}$$

125 GeV Higgs + Real Singlet

Two resonances with couplings rescaled wrt to SM

- h125 (h) coupling = C × SM
- Heavy Higgs (H) coupling= C' × SM

- **Unitarization**

  $C'^2 + C^2 = 1$, ie $C' = \cos\theta$, $C = \sin\theta$

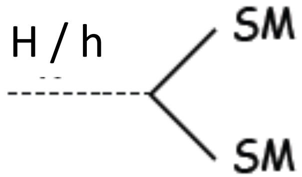
- Heavy Higgs **width and cross-section directly rescaled by $C'^2 = \cos^2\theta$**
  - $\mu_H' = C'^2$
  - $\Gamma_H' = C'^2 \times \Gamma_H^{SM}$

Free parameter $C'^2 \rightarrow \Gamma_H'$

2 free parameters: M_H and Γ_H'

By C. Grojean, K. Kumar, H. E. Logan

universal rescaling of Higgs couplings



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  - $\Gamma_H' = C'^2 \times \Gamma_H^{SM}$

  Free parameter $C'^2 \rightarrow \Gamma_H'$

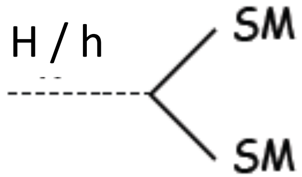
- **H coupling** constrained by the measured **h**

  Signal strength(Moriond 2013):
  - $\mu_{hATLAS} = 1.3 \pm 0.2$
  - $\mu_{hCMS} = 0.88 \pm 0.21$

2 free parameters:
M_H and Γ_H'

By C. Grojean, K. Kumar, H. E. Logan

universal rescaling of Higgs couplings



$$\sqrt{\mu}\, g_{hXX}^{SM}$$

$$c_V^2 + c_V'^2 = 1 \qquad c_V = c_F = \sqrt{\mu}$$

Taking the uncertainty to be Gaussian, these correspond to a **2σ** lower bound on μ and hence an upper bound of C'^2 of

$\mu_{hATLAS} > 0.9 \rightarrow \mu' = C'^2 < 0.1 \rightarrow$ **very narrow Γ_H'**

$\mu_{hCMS} > 0.41 \rightarrow \mu' = C'^2 < 0.46$

125 GeV Higgs + Real Singlet

What if **H->h h decay** (+ new unknown decays) ?

- Coupling of h125 (h) = C × SM
- Coupling of heavy Higgs (H) ~ C' × SM
- **Unitarization**

  $C'^2 + C^2 = 1$, ie $C' = \cos\theta$, $C = \sin\theta$
- considering **H->h h decay**

  (+ new unknown decays)

→1 additional free parameter (BR_{new})

- Heavy Higgs search in **2 parameters space for each mH hypotesis**

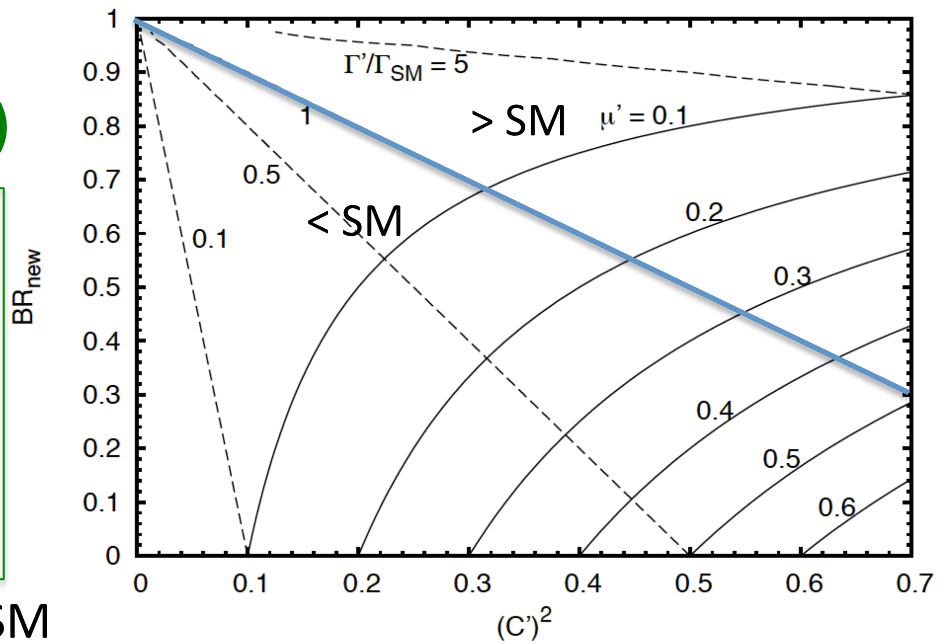
$$\mu' = C'^2(1 - \mathrm{BR}_{new})$$
$$\Gamma'_{tot} = \frac{C'^2}{(1 - \mathrm{BR}_{new})}\Gamma_{\mathrm{SM}}.$$

SM Limit
C'^2 → ($1-BR_{new}$)

- width may be narrower or larger than SM

3 free parameters:
M_H, Γ_H', BR_{new}

$$c_V^2 + c_V'^2 = 1 \qquad c_V = c_F = \sqrt{\mu}$$

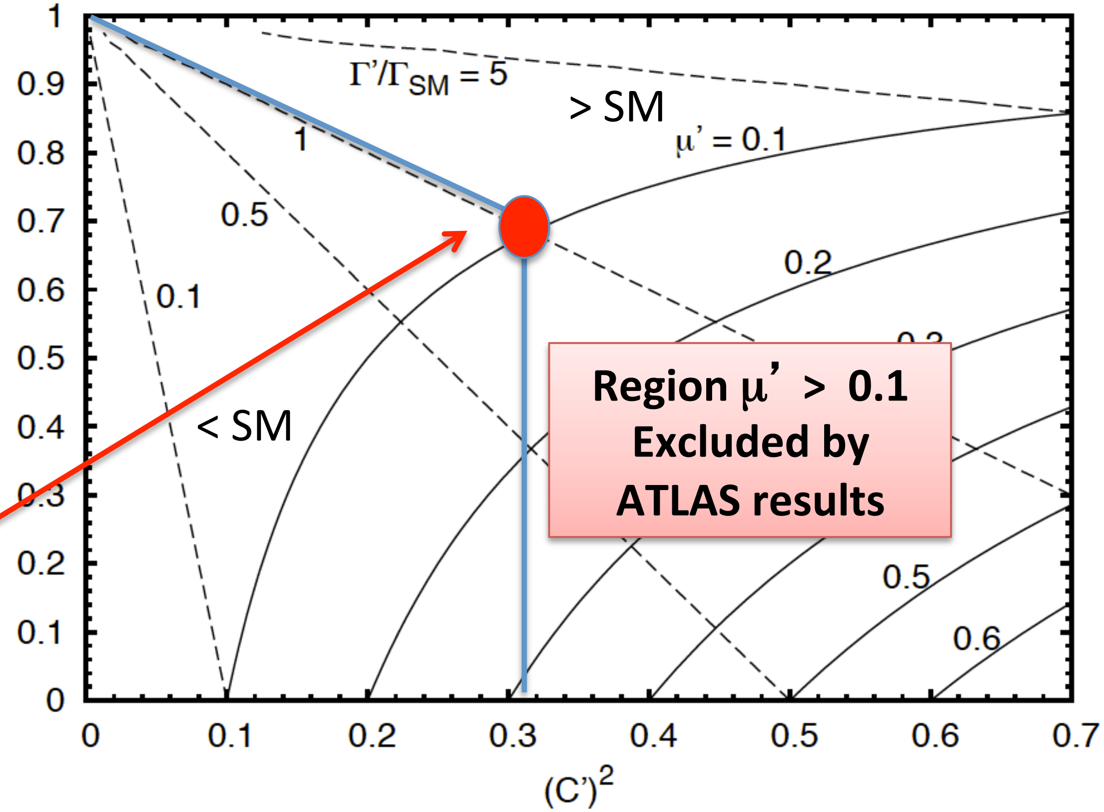


125 GeV Higgs + real singlet

H constrained by h

From signal strength presented at Moriond 2013:

- μ_{ATLAS} = 1.3±0.2
- μ_{CMS} = 0.88±0.21



Taking the uncertainty to be Gaussian → 2σ lower bound on μ and hence an upper bound on μ'

μ_{HATLAS} > 0.9 → μ' < 0.1

μ_{HCMS} > 0.41 → μ' < 0.46

125 GeV Higgs + real singlet –Strategy-

- **Scan on M'_H vs Γ'_H (vs BR_{new})**

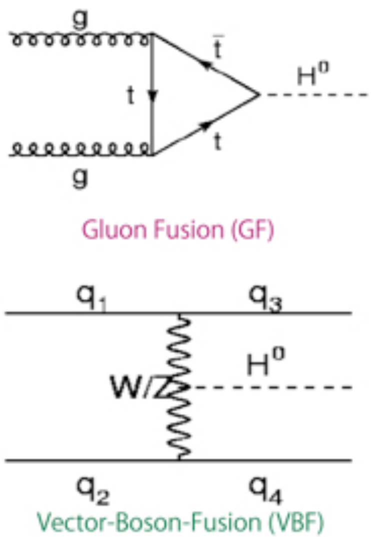
  NB scanning over Γ_H is equivalent to scan over C'

- ***Starting from SM: $\Gamma'_H = \Gamma_{SM}$***

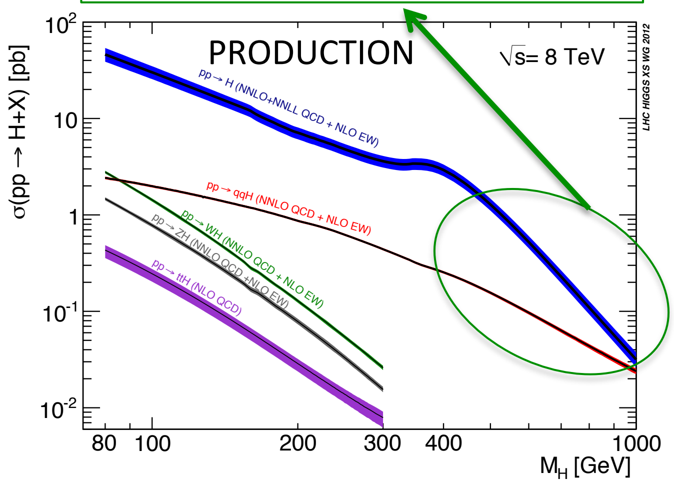
- Exploring the full available parameter space
  - Extend tool and techniques developed for SM search
    - Using same SM MC signal samples by rescaling them to account for width-change related effects

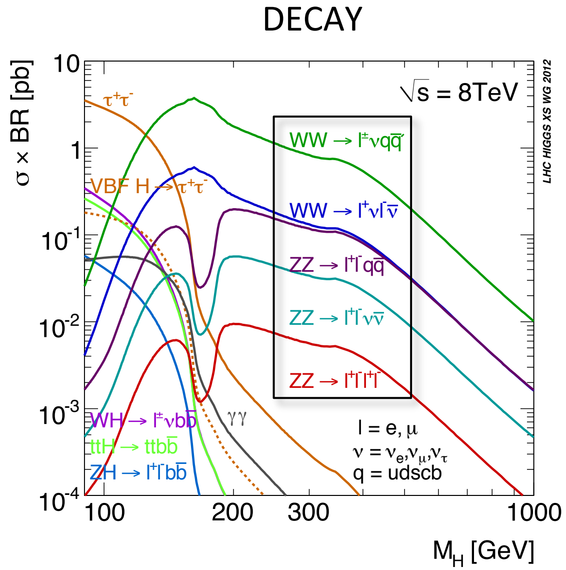
THE STANDARD MODEL CASE

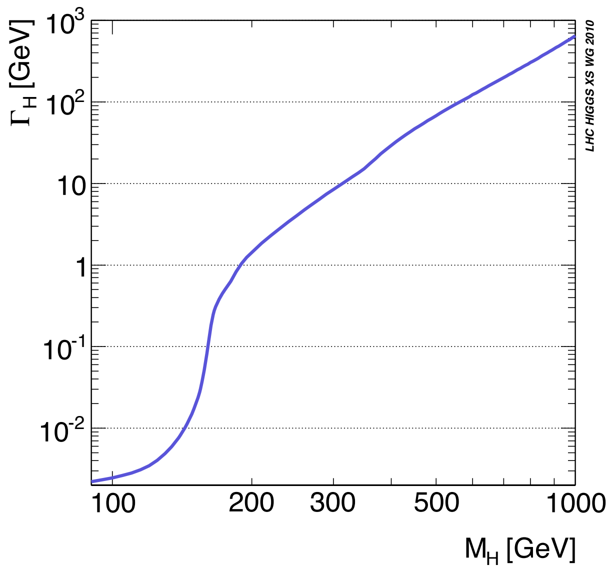
THEORETICAL ISSUES RELATED TO HIGH MASS



ggF and **VBF** comparable







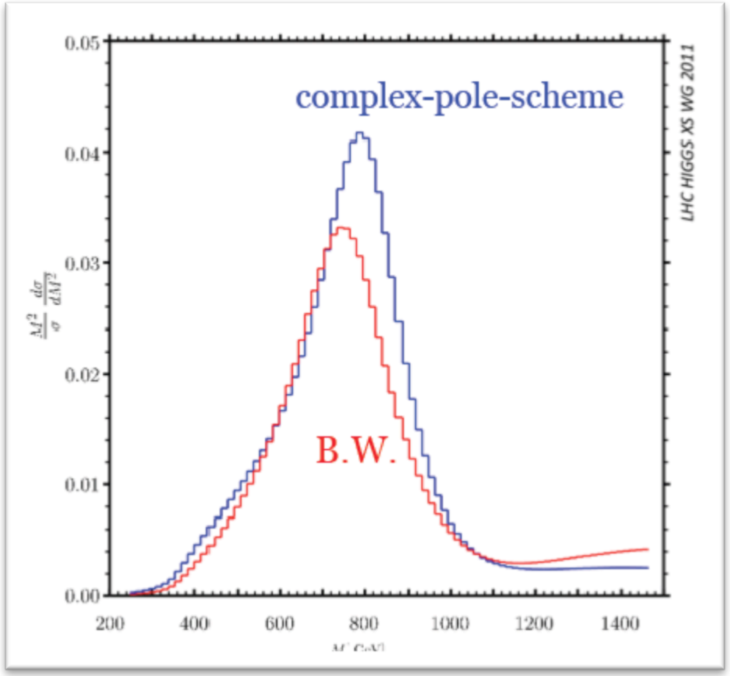
With the increasing of the Higgs mass ($m_H \geq 400$ GeV) we must account for:

- Lineshape effect → Higgs propagator
- Signal-continuum Background interference effect

These effects can be neglected for $\Gamma_H \ll m_H$

Lineshape effect: Higgs propagator

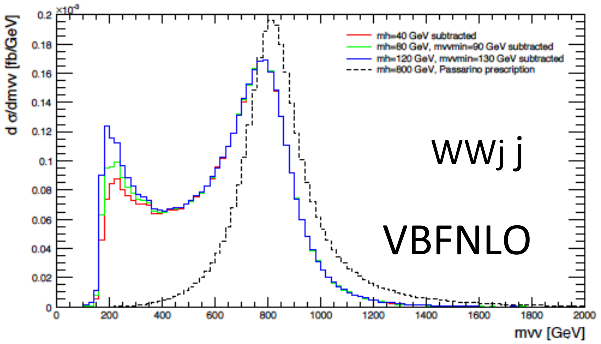
$$\delta\left(\hat{s}-M_H^2\right) \rightarrow \begin{cases} \frac{1}{\pi}\frac{M_H\Gamma_H}{\left(\hat{s}-M_H^2\right)^2+\left(M_H\Gamma_H\right)^2} & \text{Fixed width} \\ \frac{1}{\pi}\frac{\hat{s}\Gamma_H/M_H}{\left(\hat{s}-M_H^2\right)^2+\left(\hat{s}\Gamma_H/M_H\right)^2} & \text{Running width} \end{cases}$$



- The propagator affects both
  - the total X sec
  - the mass shape
- The effect increase with the increasing of m_H
- The BW propagator is **NOT valid** anymore in the **heavy mass region** (m_H>400 GeV) → **The correct propagator is a complex function**
- Possible solution: **COMPLEX POLE SCHEME (CPS)** → **It has been implemented in PowHeg signal samples for 400≤m_H≤1000 GeV**

SIG-BKG INTERFERENCE EFFECT

Vector Boson Fusion

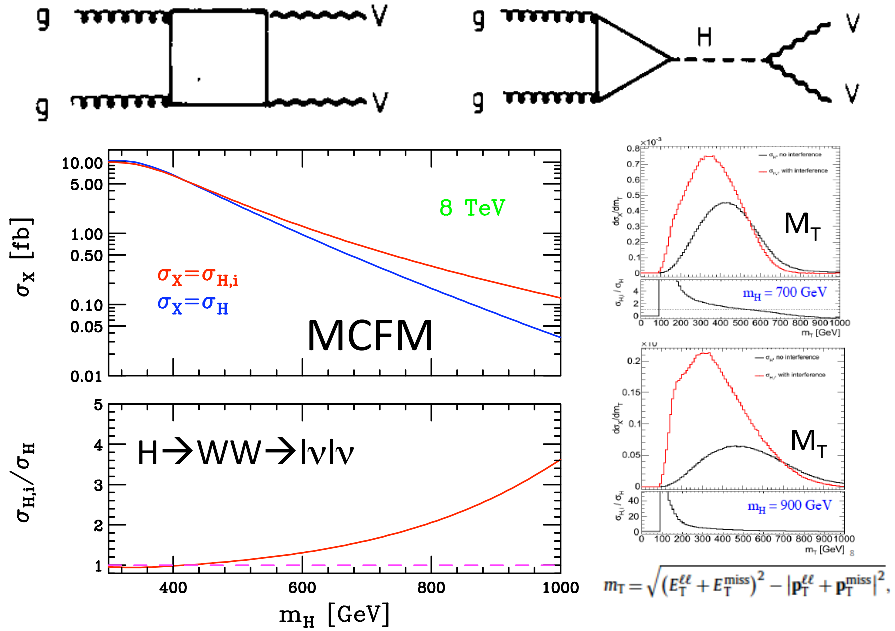


Some light-Higgs mass dependence in threshold region around m_{VV} = 200 ⇒ eliminate by cuts

- Define $S = \int d\Phi |\mathcal{M}_B + \mathcal{M}_H(m_H)|^2 - B$ where $B = \int d\Phi |\mathcal{M}_B + \mathcal{M}_h(m_h)|^2$
- Integrate over suitable mass range $[m_H - \Gamma_1, m_H + \Gamma_2]$
- ⇒ S and B well defined and do not violate unitarity
- **Interference is NOT included in PowHeg CPS samples:**

→ Need to correct MC signal samples using other MCs (VBFNLO) with I_{LO}

Gluon gluon fusion



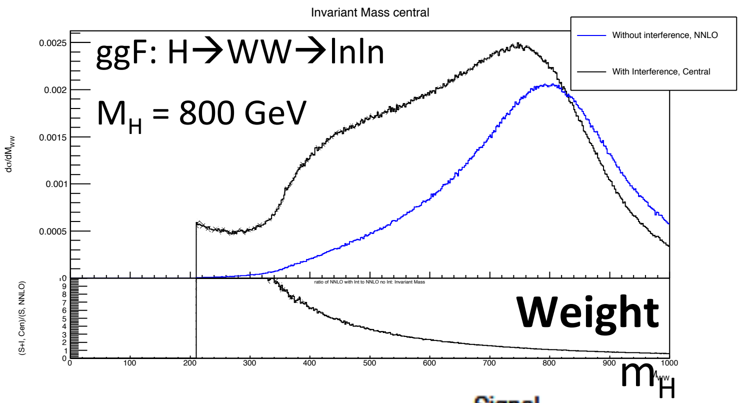
- The interference affects both the total X sec and distributions
- Effect increase with the increasing of m_H
- **Interference is NOT included in PowHeg CPS samples:**

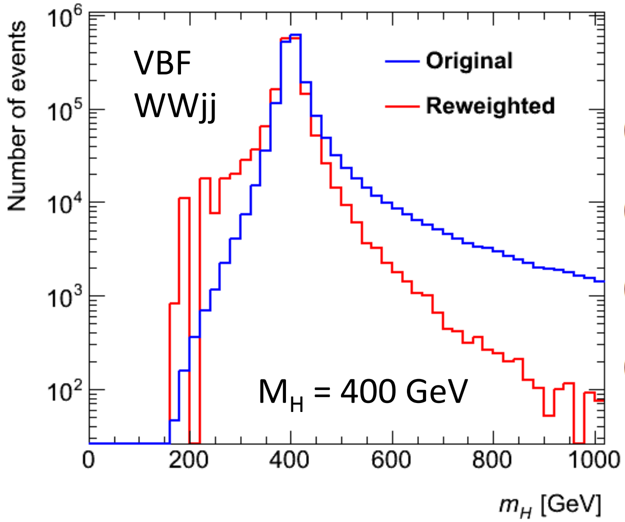
→ Need to rescale MC signal samples using other MCs (MCFM or gg2VV) with I_{LO}

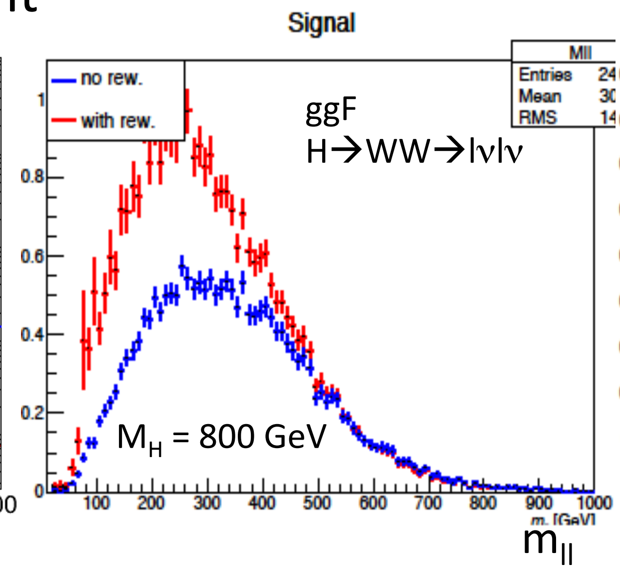
INTERFERENCE RESCALING TOOLS

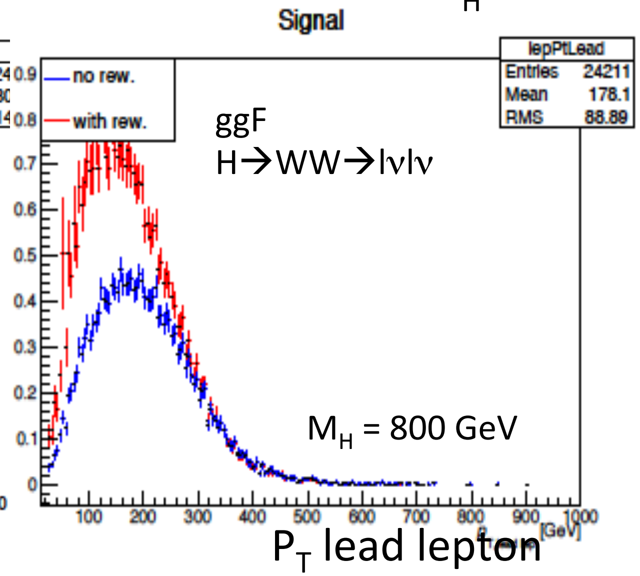
Different tools (depending from the final states) developed to reweight the MC signal samples to account for the interference effect

- **Weight** calculated as the ratio between m_H distribution with and without the interference effect
- Rescale MC signal samples on an event by event weight







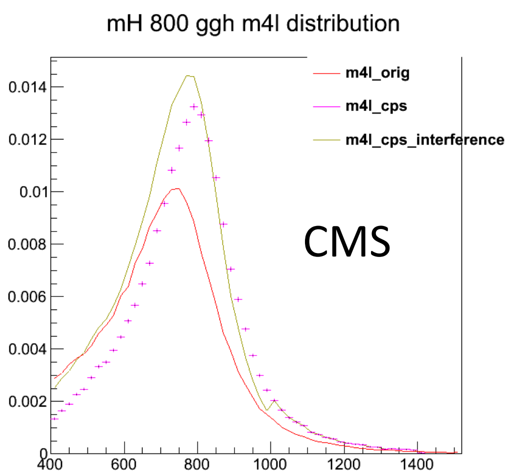


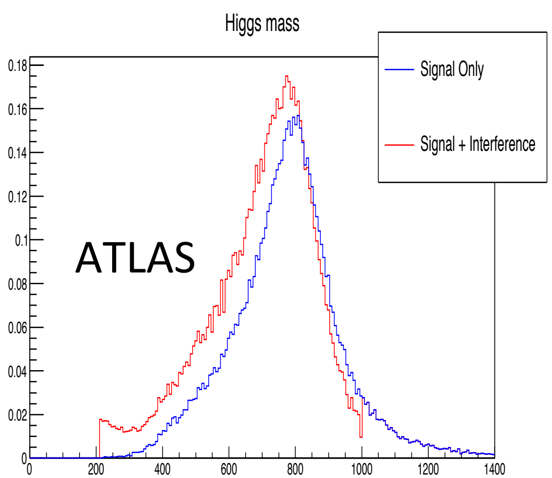
COMPARISON ATLAS-CMS

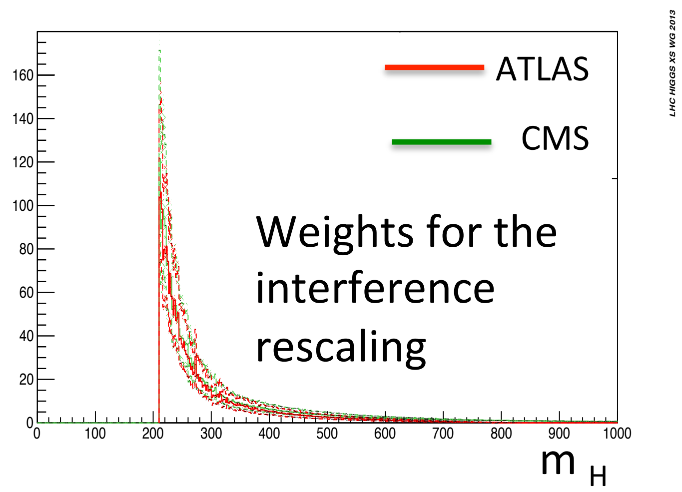
The benchmark choice and strategy to perform the analysis is discussed/developed within the

'High mass and BSM' LHC HXS WG

- Joint ATLAS-CMS effort to develop tools for a correct treatment of the the theoretical issues according to theorists prescriptions



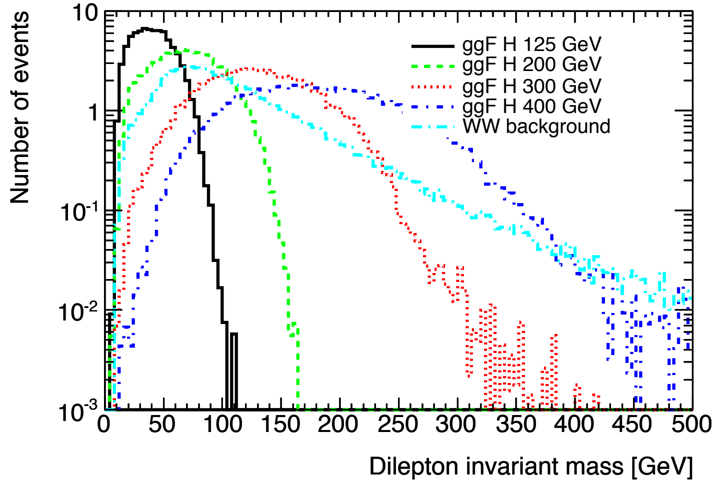




EXPERIMENTAL ISSUES RELATED TO HIGH MASS

- **Different event topology**
  - Larger m_H →
    - →more difficult to disentangle signal from dominant bkg
    - →study variables correlations
    - Re-optimization of Signal Region (SR*)
    - Re-optimization of Control Regions (CR**)

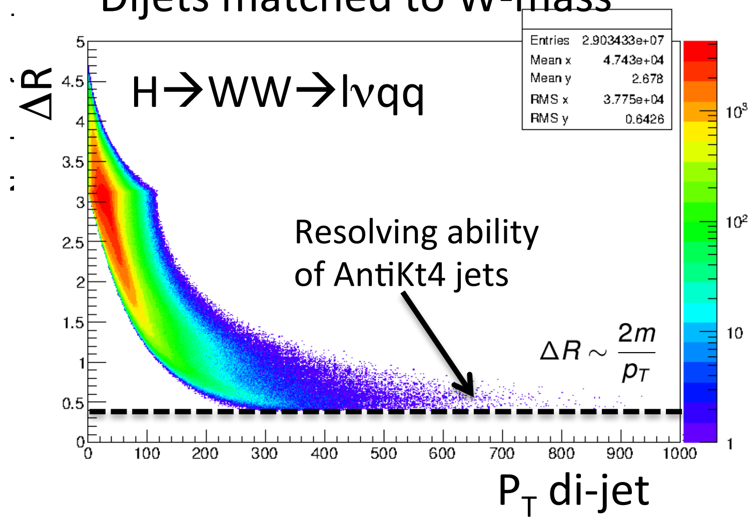
H→WW→lνlν



- **Jet merging**
  - Larger m_H →
    - → larger boost to V (W or Z) : larger p^V_T
    - → ΔR of V decay products gets smaller:
    - → **Lost ability to resolve jets with ΔR < 0.4**
    - Possible solution under investigation:

      Fat Jets + jet substructure techniques

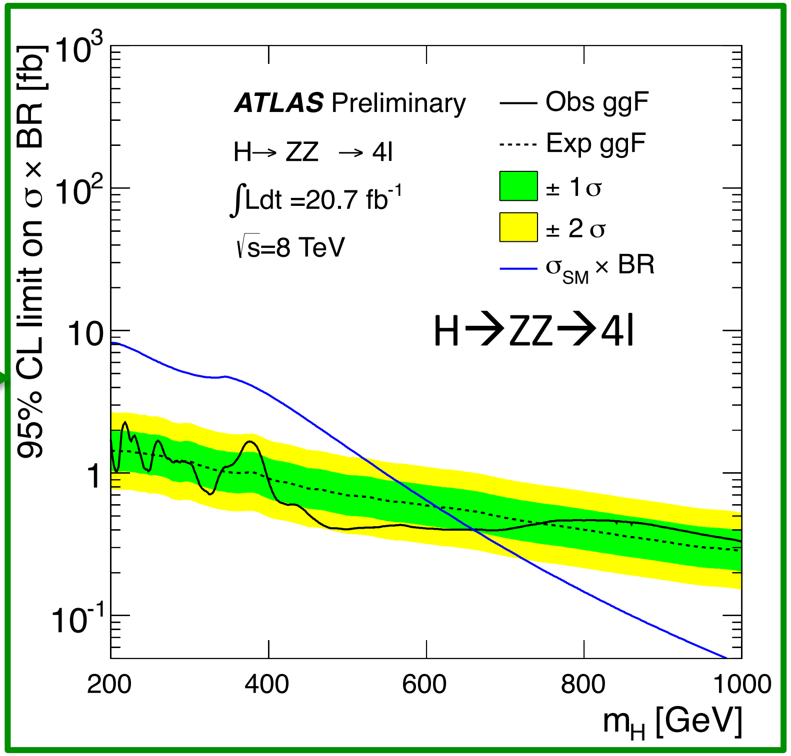
Dijets matched to W-mass

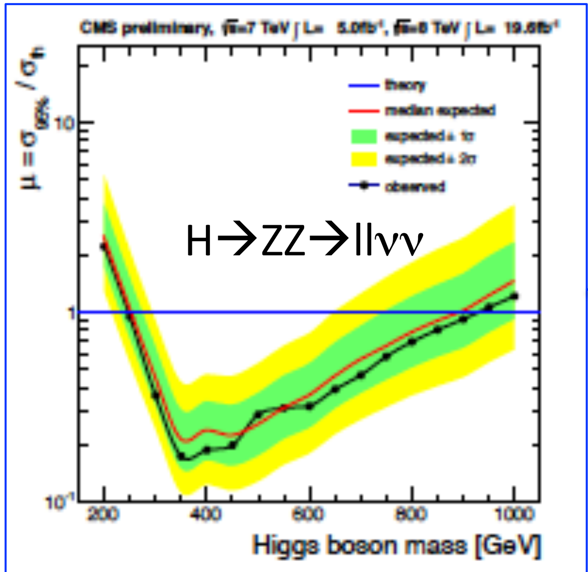


*SR: region where the signal is enhanced wrt bkg **CR: bkg region where the contamination of the signal is negligible

SM RESULTS: INTERPRETATION

BSM interpretation: σ x BR





SM interpretation
σ / σ_{SM}

Advantage of BSM interpretation
Every model (compatible with the generic assumptions made to perform the analysis) can extract its own limit by including the correspondent theory prediction curves into the plane

SM RESULTS: INTERPRETATION

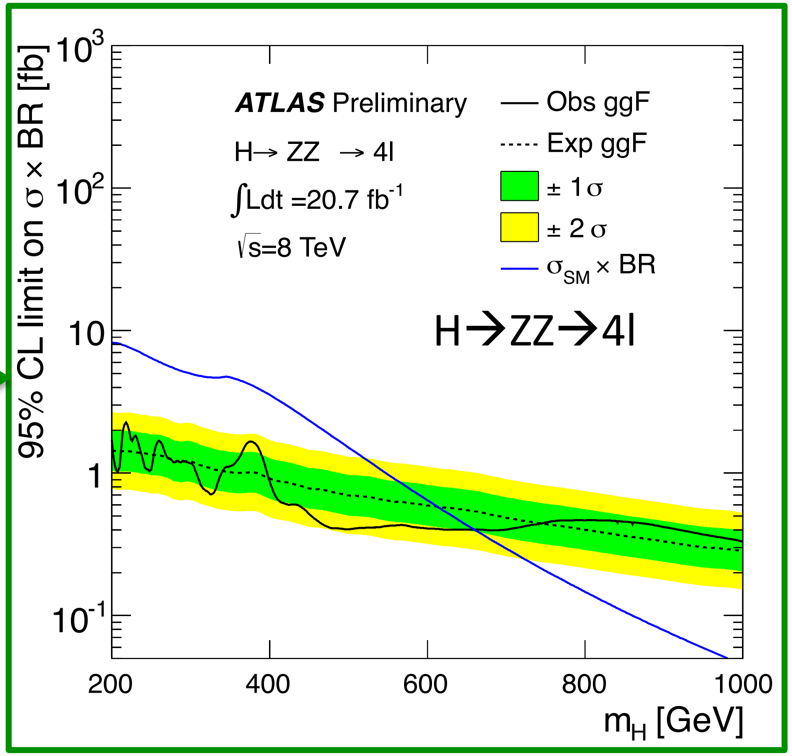
BSM interpretation: σ* BR

ATLAS plans for the near future
Extend searches in ggF and VBF up to 1 TeV in the following channels:

- $H \rightarrow WW \rightarrow l\nu l\nu$ *
- $H \rightarrow WW \rightarrow l\nu qq$
- $H \rightarrow ZZ \rightarrow llqq$
- $H \rightarrow ZZ \rightarrow 2l2\nu$

I am coordinating the common theoretical issues for all the channels

* The one I am working on



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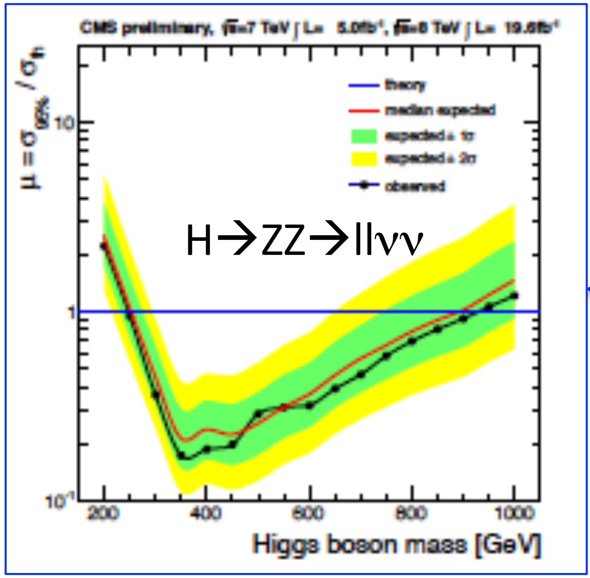


Advantage of BSM interpretation
Every model (compatible with the generic assumptions made to perform the analysis) can extract its own limit by including the correspondent theory prediction curves into the plane

BEYOND THE STANDARD MODEL REGION $\Gamma_H \neq \Gamma_{SM}$

WHAT WE LEARNED FROM SM SEARCHES

In the high mass region we have to deal with new theoretical and experimental issues

- Theoretical
  - Higgs lineshape propagator
  - Interference between signal and continuum bkg
- Experimental
  - Different topology
  - Jet merging

All the analysis techniques and tools developed for SM will be used for BSM

What we learned from SM searches

A lot of work has been done from both theoretical and experimental side to perform the analysis in the high mass region

- Theoretical
  - Higgs lineshape propagator
    - The correct propagator is a complex function (CPS)
    - Breit-Wigner (BW) approximation used in the low mass region is not valid
    - → CPS implemented in new PowHeg MC
  - Interference between signal and continuum bkg
    - Bigger effect for larger Γ_H
    - Need to reweight PowHeg MC samples to account for the effect

      → estimation by using MC which include I_{LO} : MCFM and gg2VV
- Experimental
  - Different topology
    - Re-optimization of Signal and Control Regions
  - Jet merging
    - Increase vector transverse momentum→ lost the ability to resolve jets with $\Delta R < 0.4$
    - Ability recovered by using Fat jets and substructure techniques

All the analysis techniques and tools developed for SM will be used for BSM

H constrained by h

From signal strength presented at Moriond 2013:

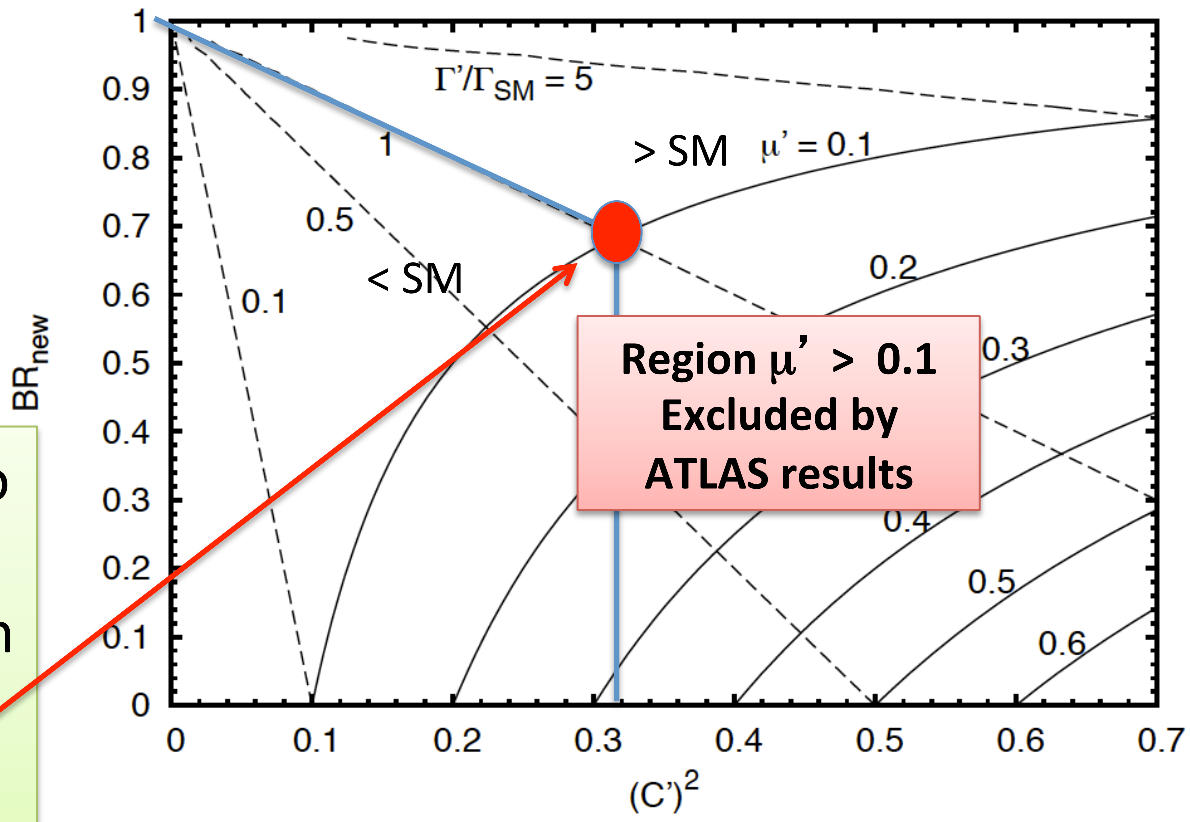
- μ_{ATLAS} = **1.3±0.2**
- μ_{CMS} = **0.88±0.21**

$$\mu' = C'^2(1 - \mathrm{BR}_{new})$$
$$\Gamma'_{tot} = \frac{C'^2}{(1 - \mathrm{BR}_{new})}\Gamma_{SM}.$$

Taking the uncertainty to be Gaussian→ **2σ** lower bound on μ and hence an upper bound on **μ'**

$\mu_{HATLAS} > 0.9$ → **μ' < 0.1**

$\mu_{HCMS} > 0.41$ → μ' **< 0.46**



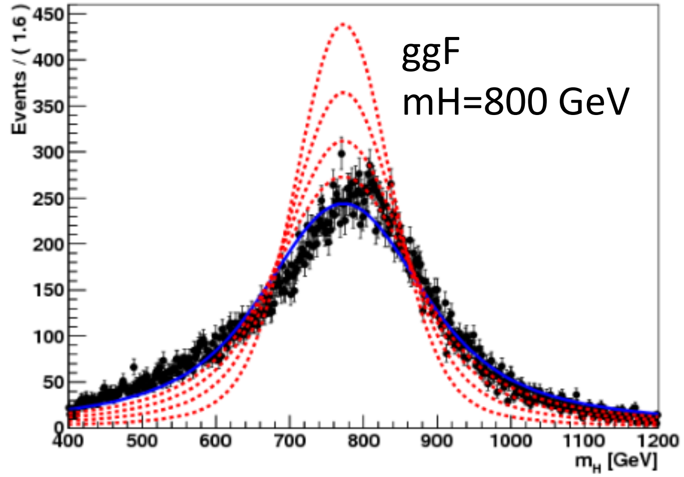
FROM SM TO BSM

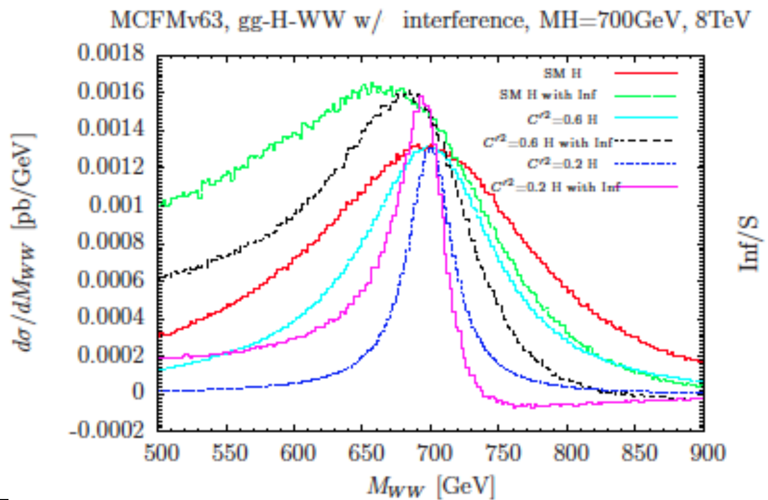
Goal: reweight the heavy Higgs width Γ'_H
by some factor $\Gamma'_H = K' \times \Gamma_{SM}$ where $K' = (C'^2/(1-BR_{new}))$

Common strategy ATLAS-CMS

1. **Rescaling the width of SM PowHeg signal samples**
   - Generate a set of weights from a fit for ggF and VBF
   - Multiply the fitted width by a factor
   - Keep normalisation

2. **Scaling for the signal-continuum bkg interference effects**
   - **Weights obtained by running MCFM and gg2VV which have the benchmark implemented→ bigger effect for larger Γ'_H**





TOWARDS RESULTS…

ATLAS approach

- Extend SM searches up to 1 TeV
- Reinterpretation in the BSM contest
- Start exploring the parameters space region for $\Gamma'_H < \Gamma_{SM}$ assuming no decay of the new scalar into new particles(BR_{new} =0) constraining the parameters space by using current measurement: $\mu_{ATLAS} = 1.3 \pm 0.2$
- Extend to all the available parameters space by scanning over M'_H vs Γ'_H vs BR_{new}

CMS approach

- Extend SM searches up to 1 TeV
- Reinterpretation in the BSM contest
- Start exploring the parameters space region for $\Gamma'_H < \Gamma_{SM}$ assuming no decay of the new scalar into new particles(BR_{new} =0) regardless of constraints from existing data
- Extend to all the available parameters space by scanning over M'_H vs Γ'_H vs BR_{new}

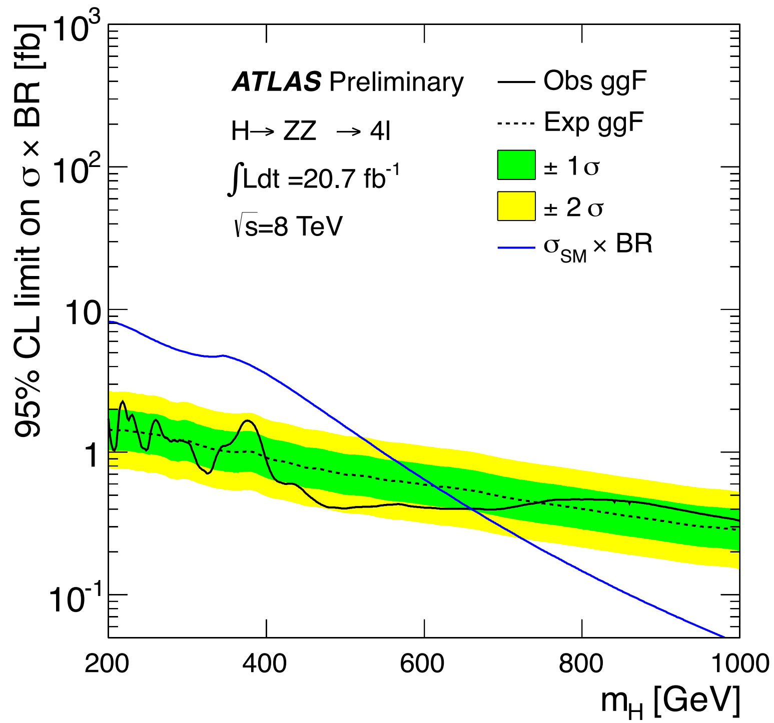
RESULTS

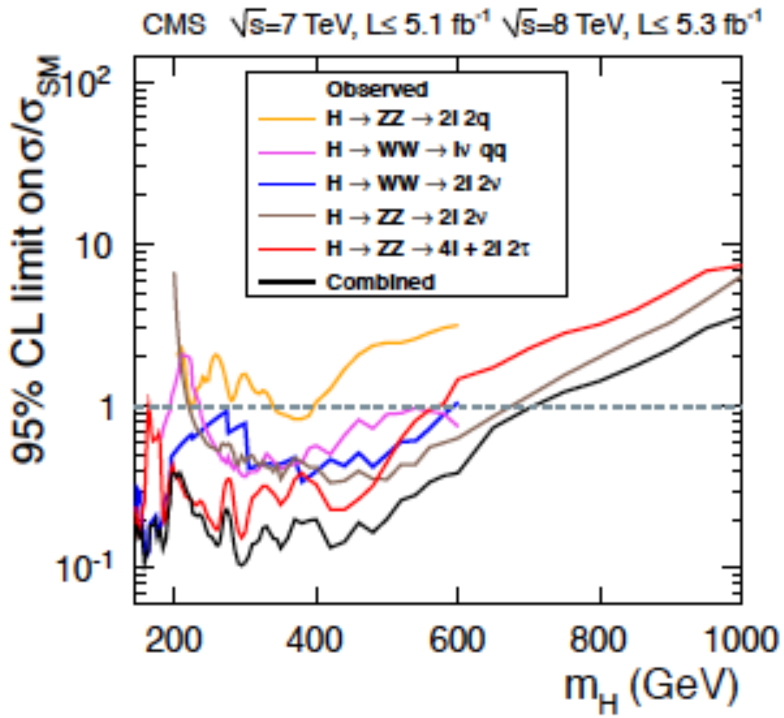
ATLAS approach

- Extend SM searches up to 1 TeV
- Reinterpretation in the BSM contest

CMS approach

- Extend SM searches up to 1 TeV





RESULTS

ATLAS approach

- Start exploring the parameters space region for $\Gamma'_H < \Gamma_{SM}$ assuming no decay of the new scalar into new particles(**BR_{new} =0**) constraining the parameters space by using current measurement: $\mu_{ATLAS} = 1.3 \pm 0.2$

Almost excluded by ATLAS results

$\mu_H' = C'^2$

$\Gamma_H' = C'^2 \times \Gamma_H^{SM}$

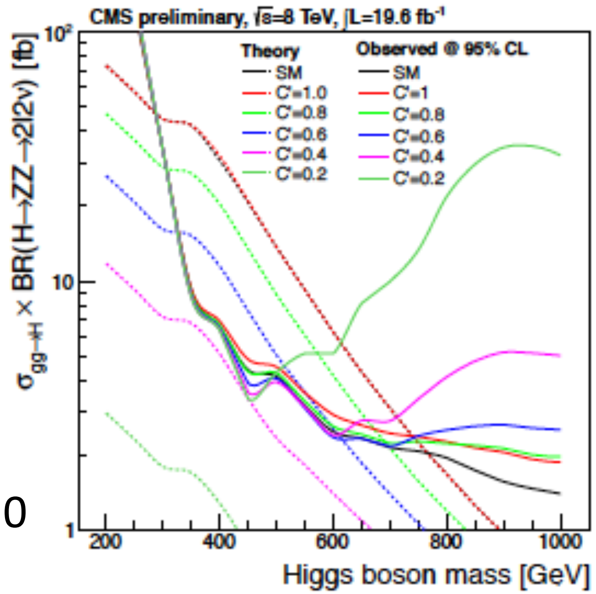
Taking the uncertainty to be Gaussian
→ **2**σ lower bound on μ and hence an upper bound of C'^2 of

$$\mu_{HATLAS} > 0.9 \rightarrow \mu' = C'^2 < 0.1$$

CMS approach

- Start exploring the parameters space region for $\Gamma'_H < \Gamma_{SM}$ assuming no decay of the new scalar into new particles(**BR_{new} =0**) regardless of constraints from existing data

$H \rightarrow ZZ \rightarrow 2l2\nu$



scan over the range $0.2 \leq C' \leq 1.0$

FUTURE PLANS

ATLAS approach

- Extend to all the available parameters space by scanning over M'_H vs Γ'_H vs BR_{new}

CMS approach

- Extend to all the available parameters space by scanning over M'_H vs Γ'_H vs BR_{new}

Extend searches in ggF and VBF up to 1 TeV in all the relevant channels in the high mass region

- $H \rightarrow WW \rightarrow l\nu l\nu$
- $H \rightarrow WW \rightarrow l\nu qq$
- $H \rightarrow ZZ \rightarrow 4l$
- $H \rightarrow ZZ \rightarrow llqq$
- $H \rightarrow ZZ \rightarrow 2l2\nu$

CONCLUSIONS

- **The discovery era has just started…**
- Experimental measurements confirm the nature of the ~125 GeV particle looks more and more consistent with the Standard Model Higgs boson
- The SM is only one specific point in the wide parameter space allowed by more generic Beyond the Standard Model benchmarks consistent with observations
- Experimental communities are interested in BSM – 'SM-like' scenarios : **125 GeV + real singlet is a generic and very promising model**
- A lot of progresses have been reached thanks to the *joint effort of theory and experimental (ATLAS and CMS) communities*
- Ready to extend and improve searches in to explore the full parameter space → results will come soon!

BACKUP

125 GeV Higgs + real singlet (I)

The most general gauge-invariant potential can be written as [588, 589]

$$V = \lambda\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)^2 + \frac{1}{2}M^2 s^2 + \lambda_1 s^4 + \lambda_2 s^2\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right) + \mu_1 s^3 + \mu_2 s\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right), \quad (315)$$

where s is the real singlet scalar and in the unitary gauge the SM Higgs doublet can be written as

$$\Phi = \begin{pmatrix} 0 \\ (\phi + v)/\sqrt{2} \end{pmatrix} \quad (316)$$

with $v \simeq 246$ GeV. We have already used the freedom to shift the value of s so that s does not get a vacuum expectation value. As a result, M^2 must be chosen positive in Eq.eq:potential.

To prevent the potential from being unbounded from below, the quartic couplings must satisfy the conditions:

$$\lambda > 0, \qquad \lambda_1 > 0, \qquad \lambda_2 > -2\sqrt{\lambda\lambda_1}. \quad (317)$$

The trilinear couplings μ_1 and μ_2 can have either sign.

$$V_2 = \lambda v^2\phi^2 + \frac{1}{2}M^2 s^2 + \mu_2 v\,\phi s. \quad (318)$$

In particular, the mixing between ϕ and the singlet field s is controlled by the coupling μ_2. The mass eigenvalues are then given by

$$M^2_{h_1,h_2} = \lambda v^2 + \frac{1}{2}M^2 \mp \sqrt{\left(\lambda v^2 - \frac{1}{2}M^2\right)^2 + \mu_2^2 v^2}\,, \quad (319)$$

125 GeV Higgs + real singlet (II)

where we have defined the mass eigenstates h_1, h_2 as

$$\begin{aligned} h_1 &= \phi \cos\theta - s \sin\theta \\ h_2 &= \phi \sin\theta + s \cos\theta, \end{aligned} \tag{320}$$

with the mixing angle θ which can be written as

$$\tan 2\theta = \frac{-\mu_2 v}{\lambda v^2 - \frac{1}{2}M^2} \,. \tag{321}$$

In order to find the domain of θ we can rewrite the masses as follows:

$$M^2_{h_1,h_2} = \left(\lambda v^2 + \frac{1}{2}M^2\right) \mp \left(\frac{1}{2}M^2 - \lambda v^2\right) \sec 2\theta \tag{322}$$

If we require h_1 to be the lighter mass eigenstate and choose $M^2 > 2\lambda v^2$, then $\sec 2\theta > 0$, and hence $\theta \in (-\frac{\pi}{4}, \frac{\pi}{4})$.

Note that in the notation of Eqs.eq:ccouplg1,eq:cprimecouplg1 we have in particular

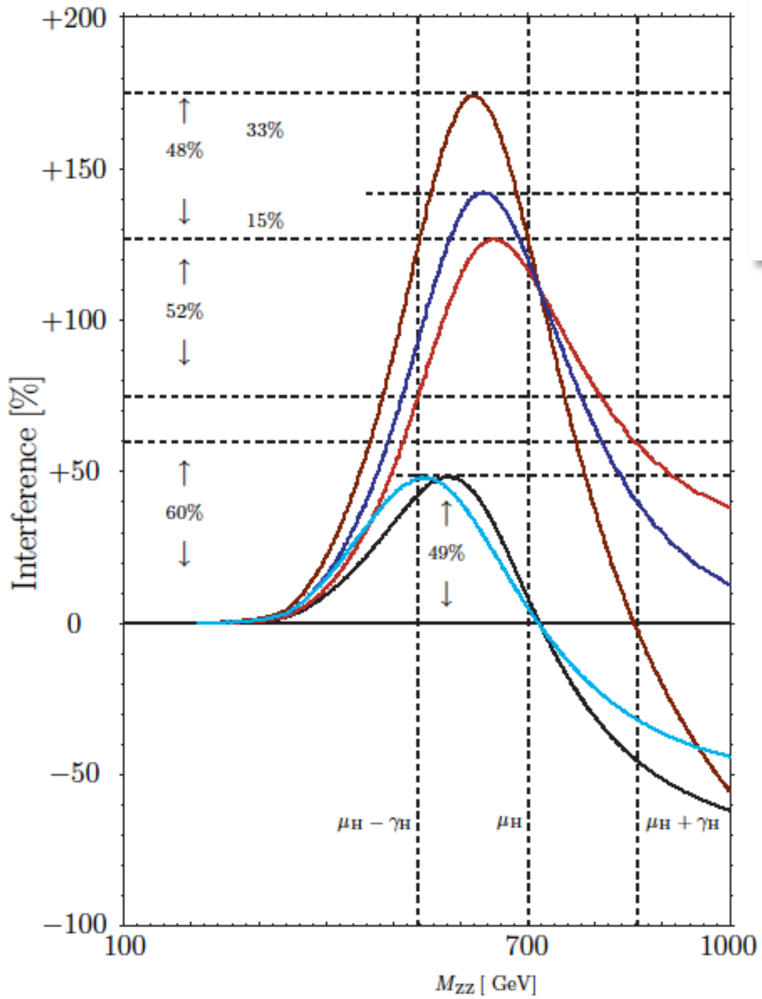
$$C \equiv C_V = C_f = \cos\theta \tag{323}$$

$$C' \equiv C'_V = C'_f = \sin\theta \,. \tag{324}$$

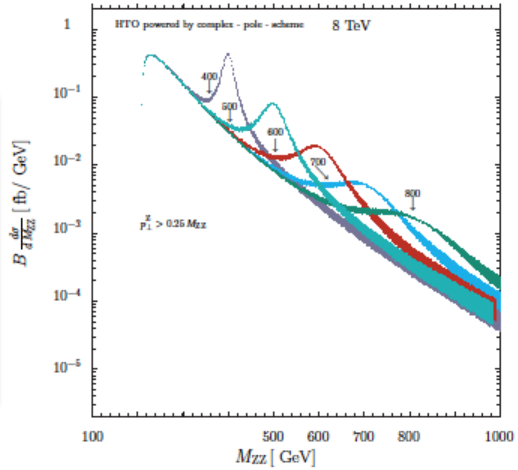
GGF INTERFERENCE RESCALING LO → NNLO

How does the interference scale from LO to NNLO?

→ Our ignorance is transferred in the uncertainties →



A reweighting procedure to rescale MC samples for the interference effect has been set up, based on invariant mass



LO
- S+B (LO)
- S+B+I (LO)

NNLO
- multiplicative (S+I)*K +B
- additive (S*K) + I + B

  } **UNCERTAINTY BAND**

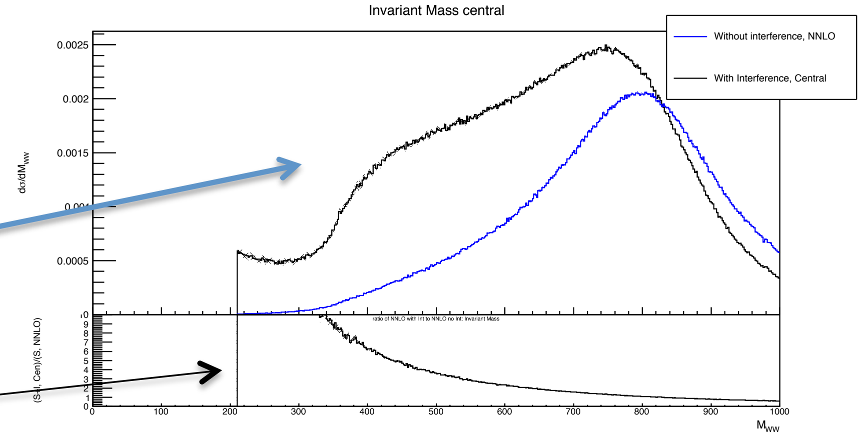
- intermediate: **CENTRAL VALUE**
  S*K + I*K' + B

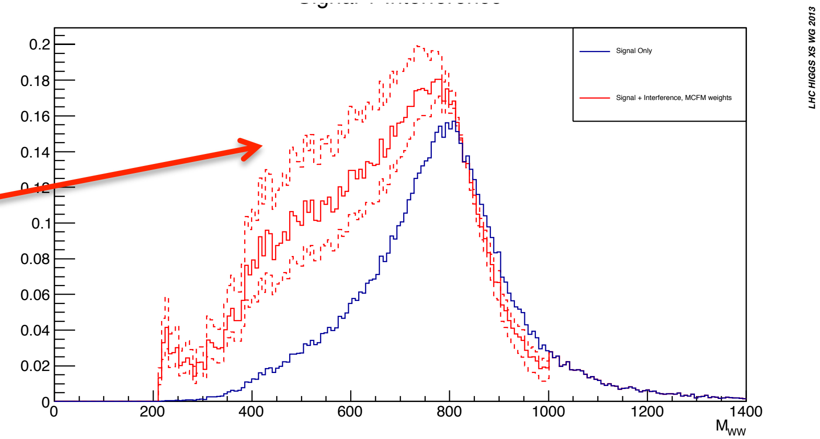
where $\mathbf{K = S_{NNLO}/S_{LO}}$ while K' just include gg initiated diagrams

GGF: Interference Reweighting

By Thor Taylor

- Use of MCFM on PowHeg CPS
- Generate S and S+I samples at LO with MCFM
- Use Passarino's K-factors and scaling scheme to get S and S+I at NNLO
- **w= (S+I, central)/(S, NNLO)**
- Reweight PowHeg CPS signal S +I = S(PowHeg)*w
- Include additive and multiplicative weights for the uncertainties:
  - w_add= (S+I, additive)/(S, NNLO)
  - w_mult= (S+I, multiplicative)/(S, NNLO)





INTERFERENCE RESCALING PROCEDURE

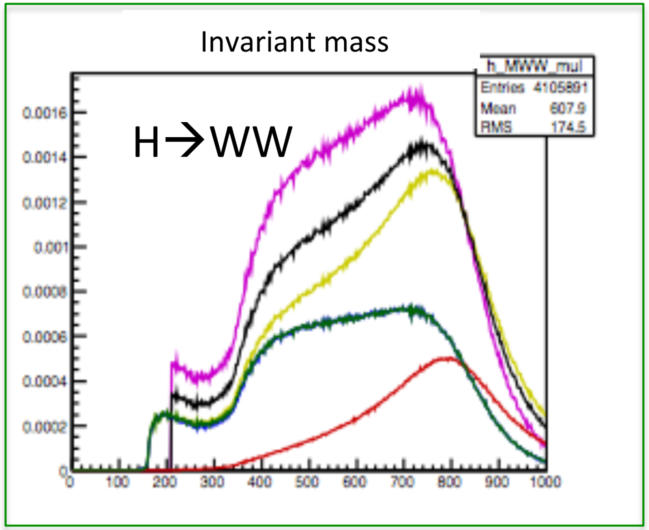
Is the reweighting on the mass shape enough to catch the distortion of kinematics due to interference ?

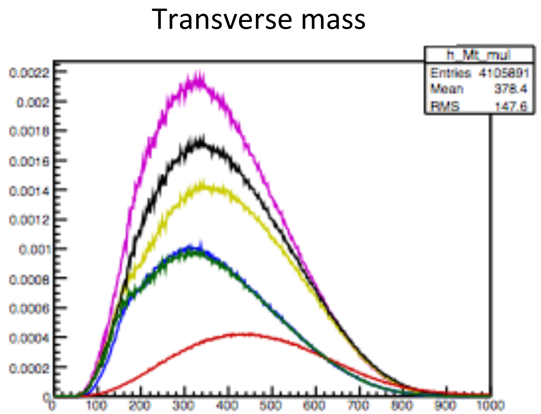
- Without interference
- With Interference
- Reweighted

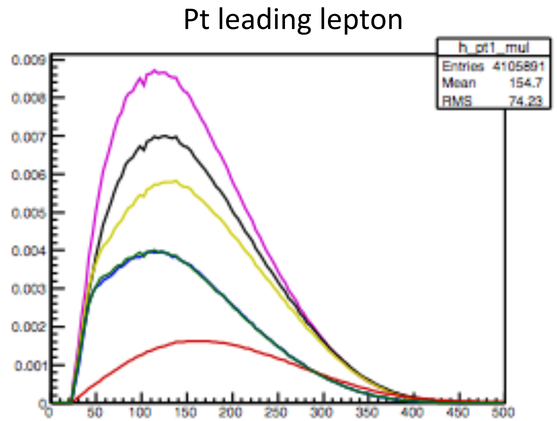
} MCFM generated - LO

- Additive
- Multiplicative
- Intermediate

} MCFM reweighted- NNLO





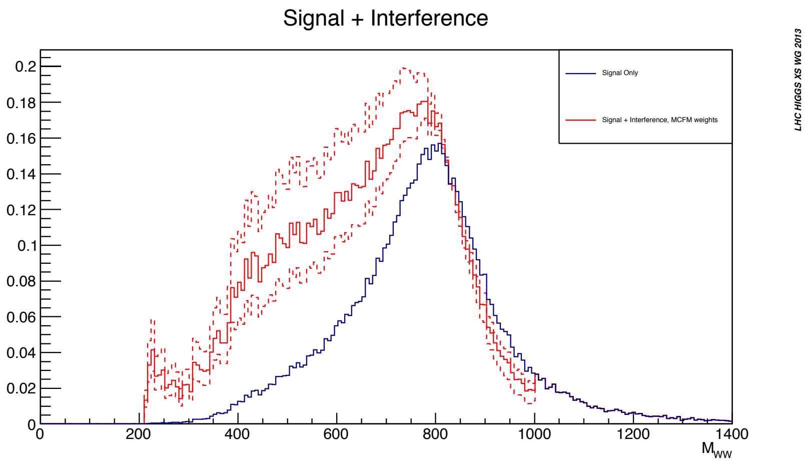


Yes!

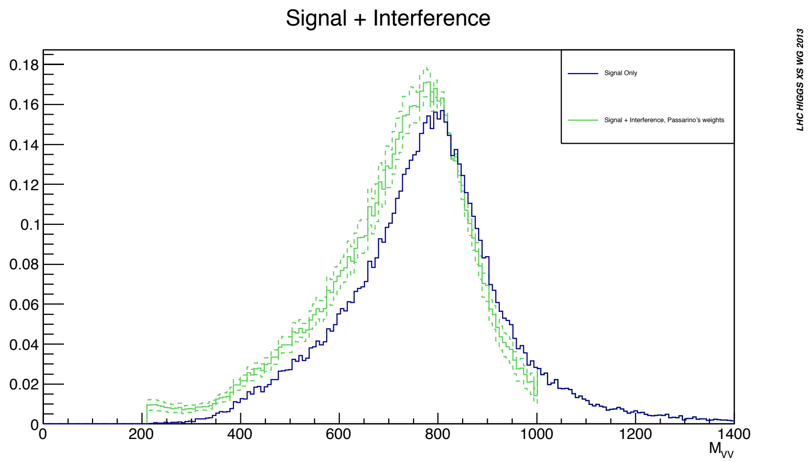
We can reweight our MC samples to account for the signal-background interference effect and the LO→NNLO effect

INTERFERENCE RESCALING TOOLS

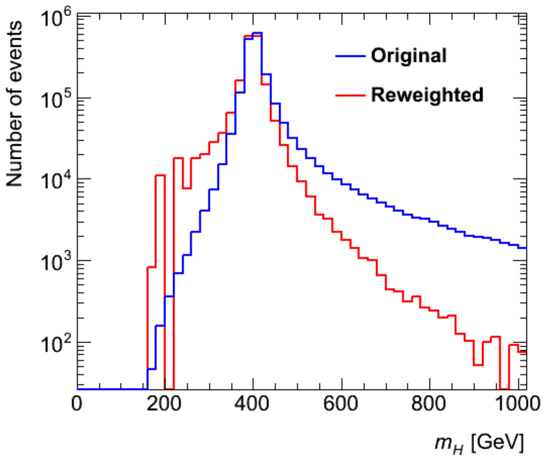
- ggF : H→WW



- ggF : H→ZZ



- VBF: qqH→WWjj

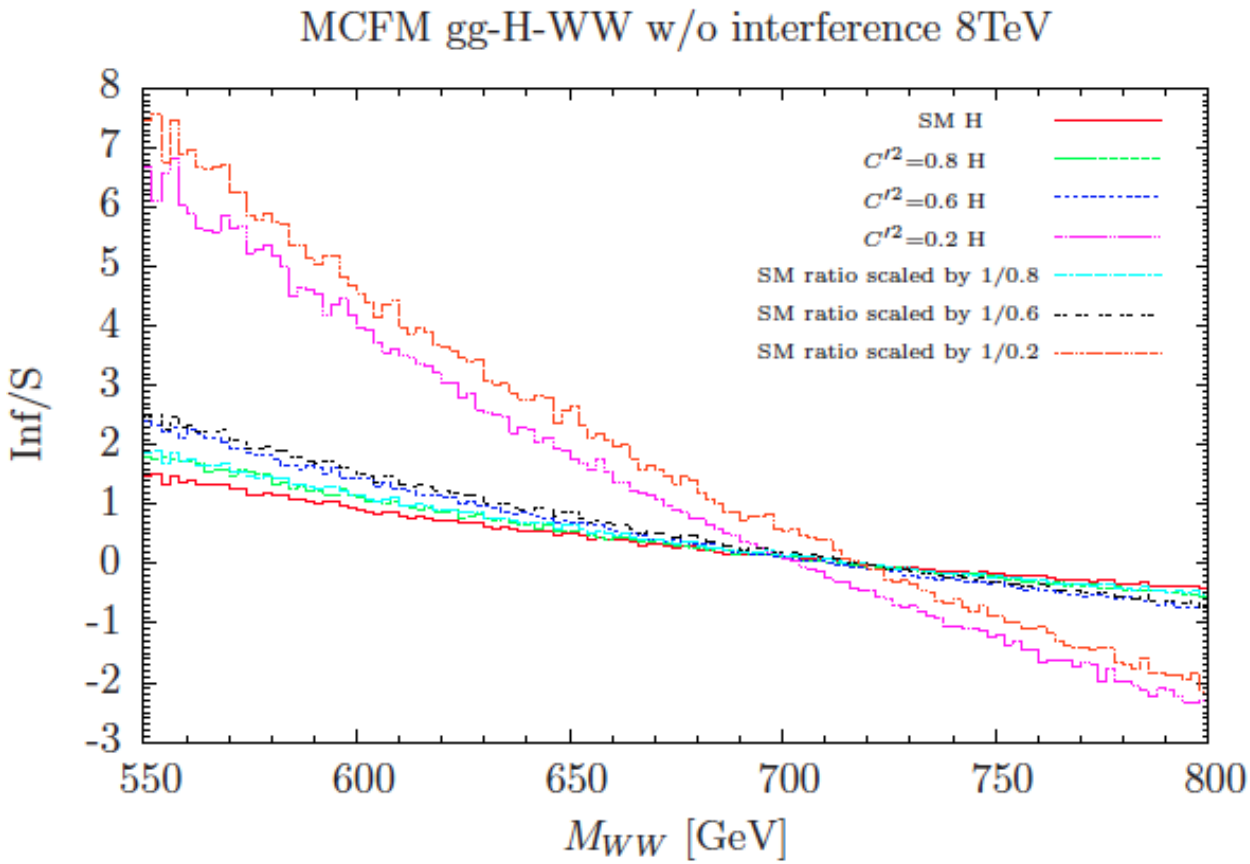


- VBF: qqH→ZZjj
  - NOT available yet
  - Asked VBFNLO authors to develop the same tool for ZZ final state → under development

INTERFERENCE RESCALING TOOLS

- ggF : H→WW
  - Weights at LO extracted by running MCFM
  - Rescaling from LO→NNLO and associate uncertainties according to Passarino's prescription and K factors
- ggF : H→ZZ
  - Weights at NNLO extracted provided by Passarino (4l) / extracted from gg2VV (2l2n)
  - Associate uncertainties according to Passarino's prescription and K factors
- VBF: qqH→WWjj
  - Weights at LO extracted by running REPOLO (REweighting POwheg events at LO) based on VBFNLO
  - Uncertainty must be estimated by comparing distributions obtained via REPOLO and by running VBFNLO
- VBF: qqH→ZZjj
  - <u>NOT available yet</u>
  - Asked REPOLO authors to develop the same tool for ZZ final state → under development

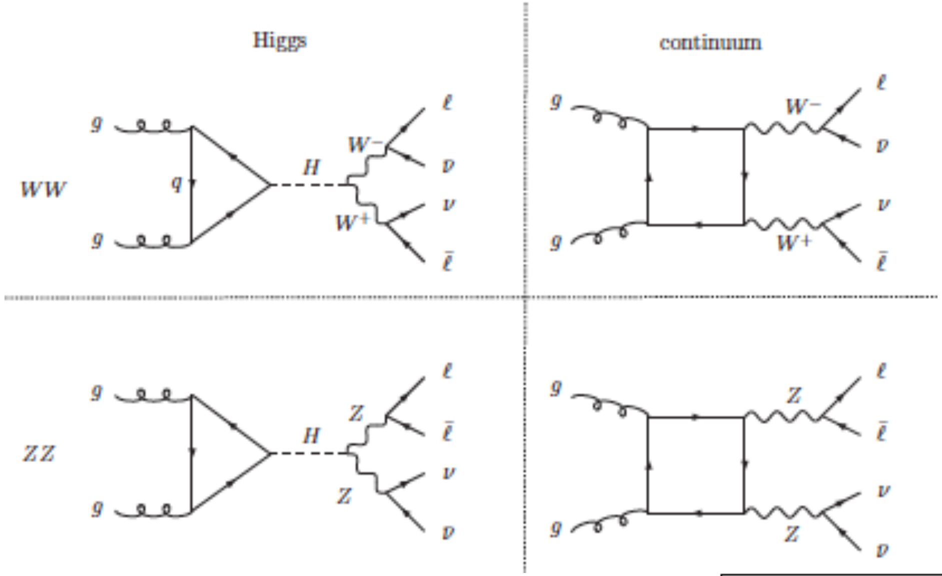
INTERFERENCE IN BSM



- Can we scale the SM interference effects by $1/C'^2$?
- Scaling SM interference contribution shows similar trend but not perfect agreement → associate a conservative 100% uncertainty for the BSM reweighting

WW/ZZ INTERFERENCE IN GG → H → ZZ → 2L2N

Same flavor final state interference between continuum WW and ZZ



Relative measures for interference effect

$S+B$-inspired measure:

$$R_1 := \frac{\sigma(|\mathcal{M}_{\mathrm{H}} + \mathcal{M}_{\mathrm{cont}}|^2)}{\sigma(|\mathcal{M}_{\mathrm{H}}|^2) + \sigma(|\mathcal{M}_{\mathrm{cont}}|^2)}$$

$S/\sqrt{B}$-inspired measure:

$$R_2 := \frac{\sigma(|\mathcal{M}_{\mathrm{H}}|^2 + 2\,\mathrm{Re}(\mathcal{M}_{\mathrm{H}}\mathcal{M}^*_{\mathrm{cont}}))}{\sigma(|\mathcal{M}_{\mathrm{H}}|^2)}$$

	$gg\ (\to H) \to WW/ZZ \to \ell\bar{\nu}_\ell\bar{\ell}\nu_\ell$				
	σ [fb], pp, $\sqrt{s} = 8$ TeV, $M_H = 600$ GeV			interference	
process	H_{offshell}	cont	$\lvert H_{\mathrm{ofs}}$+cont$\rvert^2$	R_1	R_2
$gg\ (\to H) \to ZZ$	0.2175(8)	0.0834(2)	0.3150(8)	1.047(4)	1.065(6)
$gg\ (\to H) \to WW/ZZ$	0.2220(8)	0.1020(2)	0.3406(8)	1.051(4)	1.075(6)

Continuum interference between qq→WW and qq→ZZ is negligible:
arXiv: 1107.5051

	$gg\ (\to H) \to WW/ZZ \to \ell\bar{\nu}_\ell\bar{\ell}\nu_\ell$				
	σ [fb], pp, $\sqrt{s} = 8$ TeV, $M_H = 1000$ GeV			interference	
process	H_{offshell}	cont	$\lvert H_{\mathrm{ofs}}$+cont$\rvert^2$	R_1	R_2
$gg\ (\to H) \to ZZ$	0.01265(5)	0.0687(2)	0.0927(2)	1.140(3)	1.90(2)
$gg\ (\to H) \to WW/ZZ$	0.01278(5)	0.0846(3)	0.1090(2)	1.119(3)	1.91(3)

To be included in the
H→ZZ→2l2n final state

N.Kauer

$H \to ZZ$ search cuts: $|M_{\ell\bar{\ell}} - M_Z| < 15$ GeV, $\not{E}_T > 110$ GeV, $M_T > 325$ GeV

$M_T = \sqrt{(M_{T,\ell\ell} + \not{M}_T)^2 - (\mathbf{p}_{T,\ell\ell} + \not{\mathbf{p}}_T)^2}$ with $\not{M}_T = \sqrt{\not{p}_T^2 + M_{\ell\ell}^2}$, other as above

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CMS RESULTS

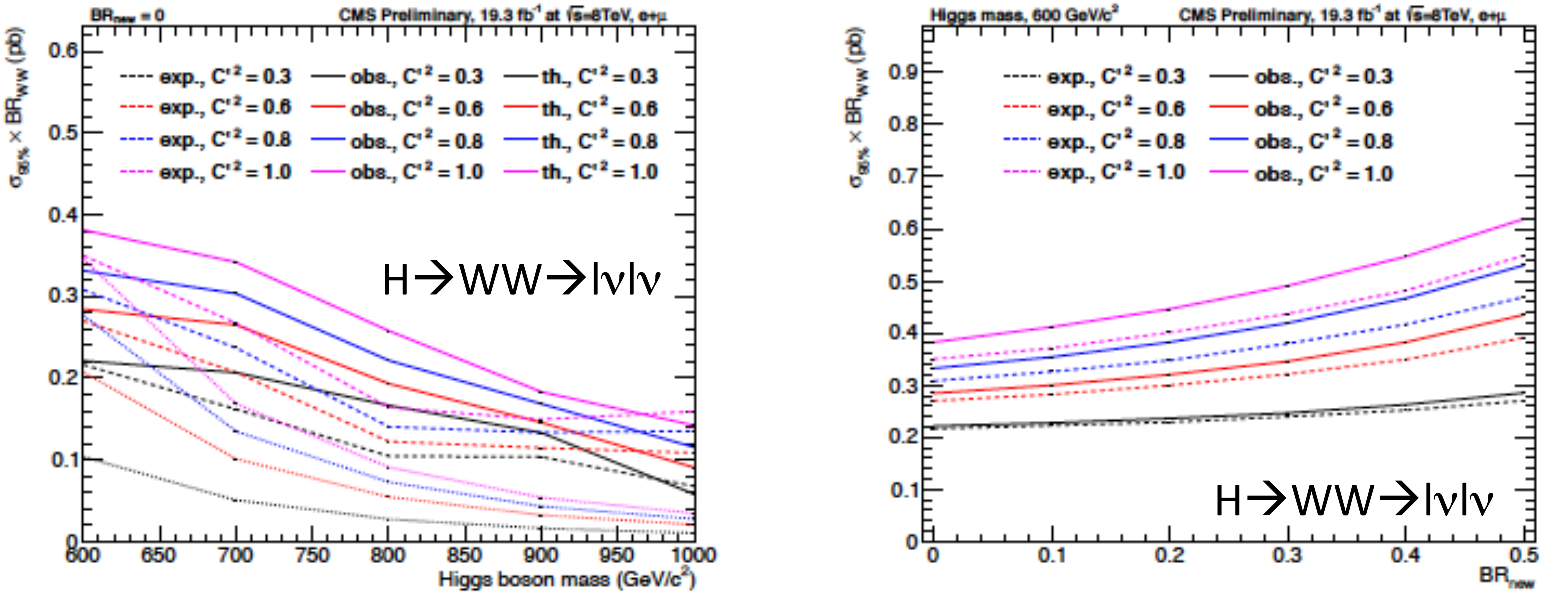
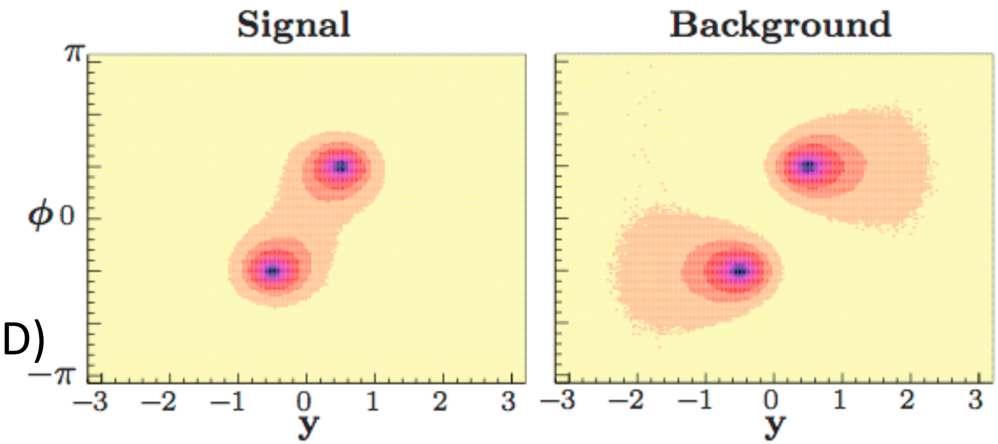


Figure 7: On the left, BSM exclusion limits for a signal mass hypothesis of 600 GeV as a function of mass for various values of C'^2 where $BR_{new} = 0$. On the right, BSM exclusion limits for a signal mass hypothesis of 600 GeV as a function of BR_{new} for various values of C'^2 where $m_H = 600\,\mathrm{GeV}$.

- BSM interpretation limits
- Performed in the region $\Gamma_H' \leq \Gamma_{SM}$
- **No constraints from existing data** taken into account: scan over the range 0.3 ≤ C' ≤ 1.0
- **Only gluon gluon fusion**

Experimental Issues related to High mass

- At higher Higgs mass (higher W pT) we need:
  - Ability to resolve jets with dR < 0.4 → fat jet container
    - J → 1.0 Anti-Kt
- Including a simple wider jet algo will help with our signal acceptance
  - May not help reduce background
  - Wider jet area → more area for pileup + other unrelated energy
- The Answer? Jet substructure techniques!
  - Attempts to separate color singlets from color octets: discriminate jets coming from a hadronically decaying W boson from QCD jets originating from quarks and gluons.
  - Looking into jet substructure also introduces new discriminating variables
    - N-subjetiness (reject top)
    - Jet sphericity (W+jets + other QCD)



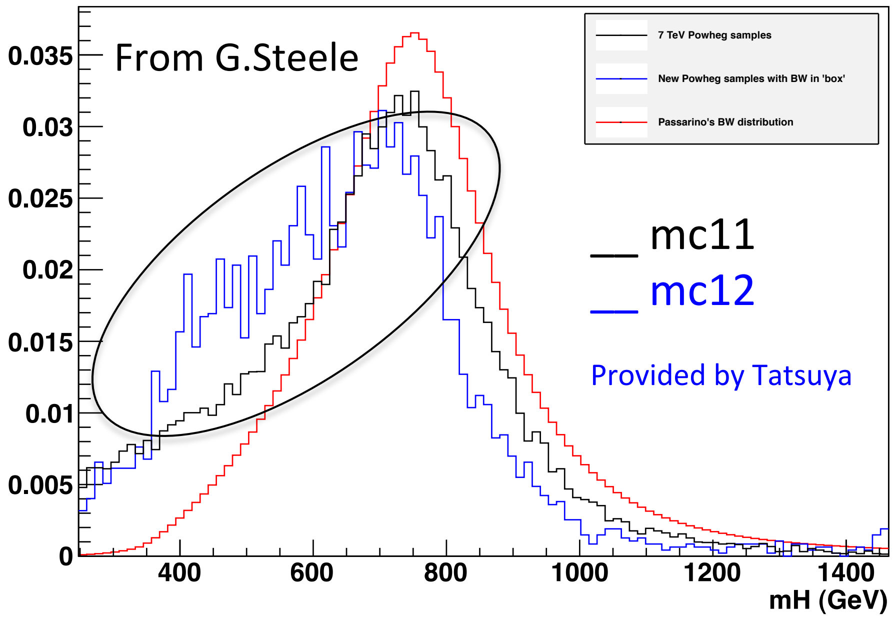
POWHEG BOX GENERATION

It has been verified that the CPS works properly,

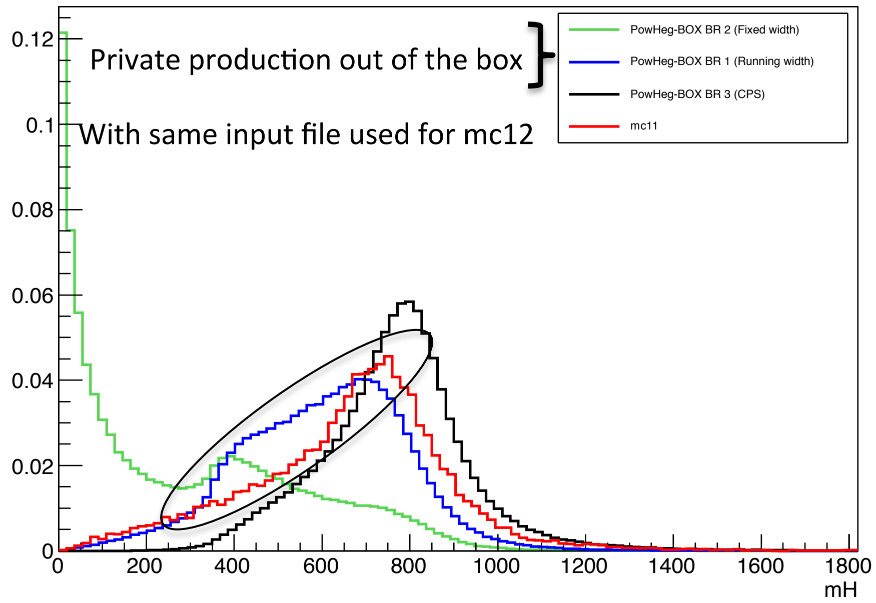
while there are some problems with the BW lineshape

in the high mass region

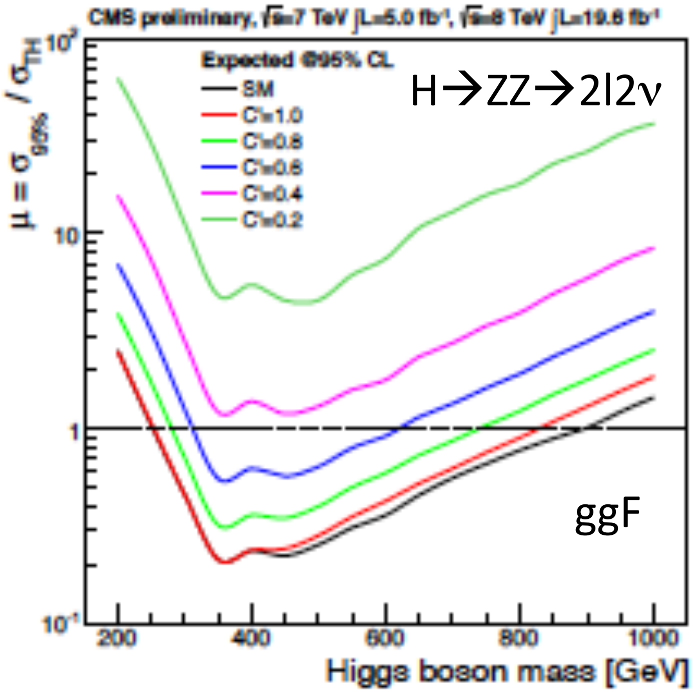
Powheg vs Passarino BW distribution mH = 800 GeV

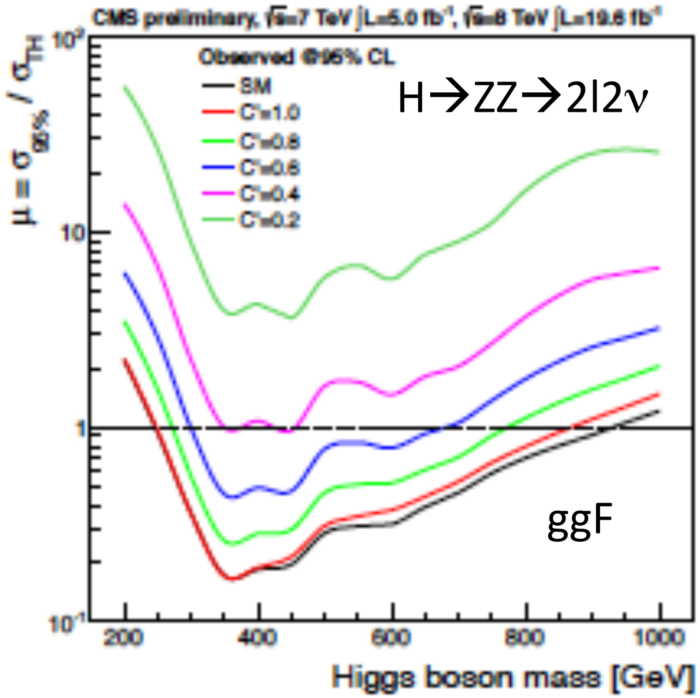


7 TeV - mH 800 GeV



CMS RESULTS





- Reference benchmarks σ_{TH}: SM and **125 GeV Higgs + real singlet**
- Performed in the region $\Gamma_H' \leq \Gamma_{SM}$
- **No constraints from existing data** taken into account: scan over the range $0.2 \leq C' \leq 1.0$
- Assuming **no decay of the new scalar into new particles**: $BR_{new} = 0$

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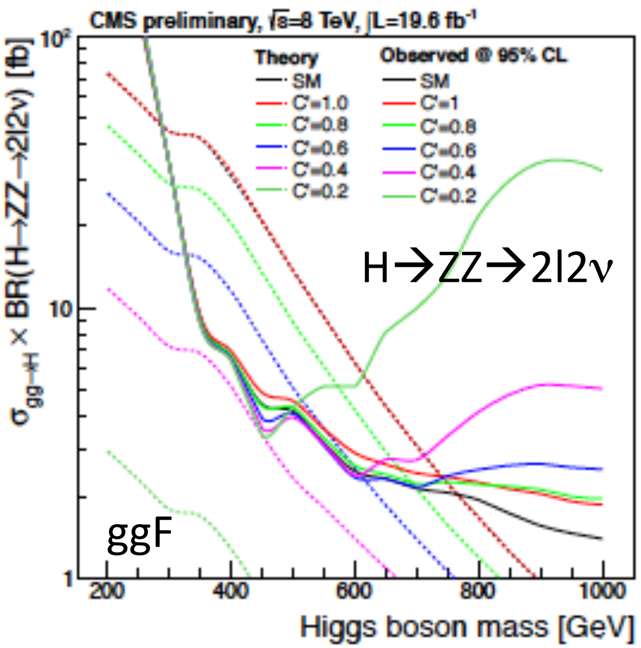
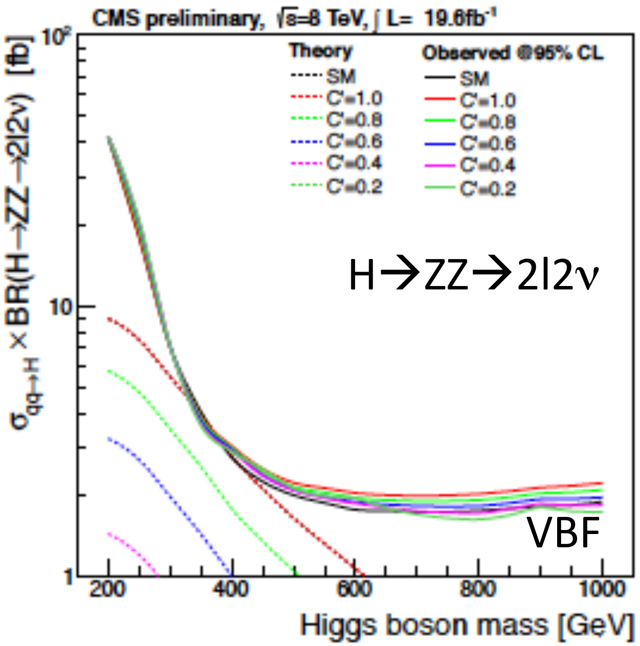
CMS RESULTS





- BSM interpretation limits
  (including SM and 125 GeV Higgs + real singlet curves)
- Performed in the region $\Gamma_H' \leq \Gamma_{SM}$
- **No constraints from existing data** taken into account: scan over the range $0.2 \leq C' \leq 1.0$
- **Assuming no decay of the new scalar into new particles**: $BR_{new} = 0$
- **VBF channels DO NOT account for interference effect**

EXPERIMENTAL ISSUES RELATED TO HIGH MASS