Scrutinizing H(125) using Z→ll events with high E_T^{miss}

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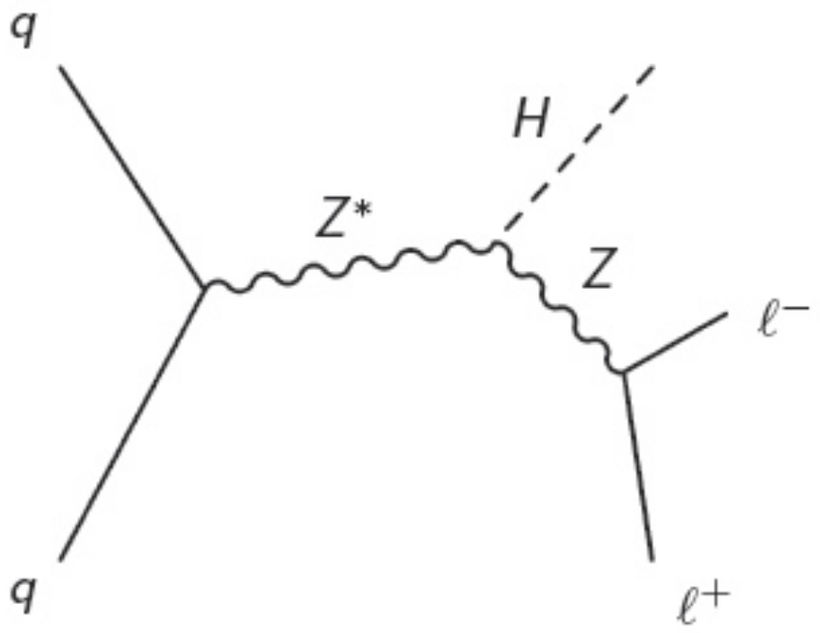
Introduction

- ZZ→2l2nu is a powerful channel in searching for high mass Higgs-like particle (Loic's talk)
  - Good understanding of data, backgrounds, systematics
  - Will continue high mass searching at 13 TeV
- Other physics reach of this channel? Can it tell us something about the newfound Higgs (125)?
  - Invisible decay of Higgs, ZH→2l+MET
  - Bounding Higgs width using off-shell production

Higgs invisible decay

- Many BSM theories predict invisible final states of the Higgs decay
- Indirect result from visible decays allows for as larger as 64% Higgs decay branching ratio to undetected final states at 95% CL (assuming couplings to vector bosons bound by SM, CMS-HIG-13-005)
- Direct searches rely on associated production modes (Vector boson Fusion, VH, H+1j), where the Higgs recoils a visible system

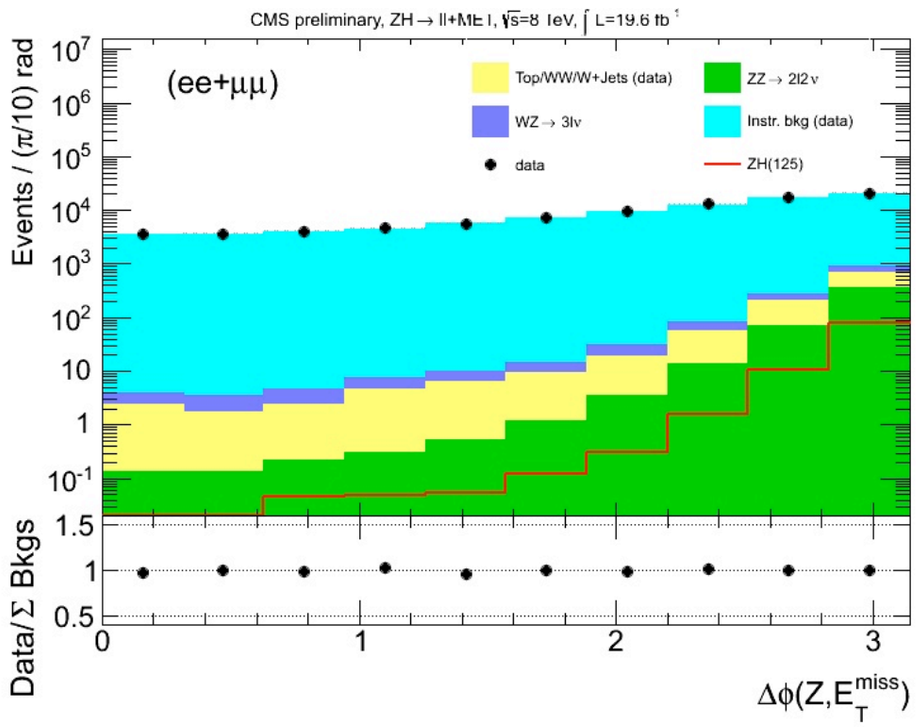


ZH(Z→ll), very clear topology
di-lepton balances E_T^{miss}

Event selection

CMS-HIG-13-018

- To select Z→ee or μμ events
  - Oppositely-charged, isolated e or μ, with p_T > 20 GeV each, and di-lepton invariant mass within ±15GeV of Z boson mass
- To remove Drell-Yan (instrumental background)
  - E_T^{miss} > 110 GeV
  - Δϕ > 2.6
  - $|E_T^{miss}-p_T\_Z|/p_T\_Z < 0.2$
- Reject event with extra lepton or jet (to reduce WZ, top backgrounds)

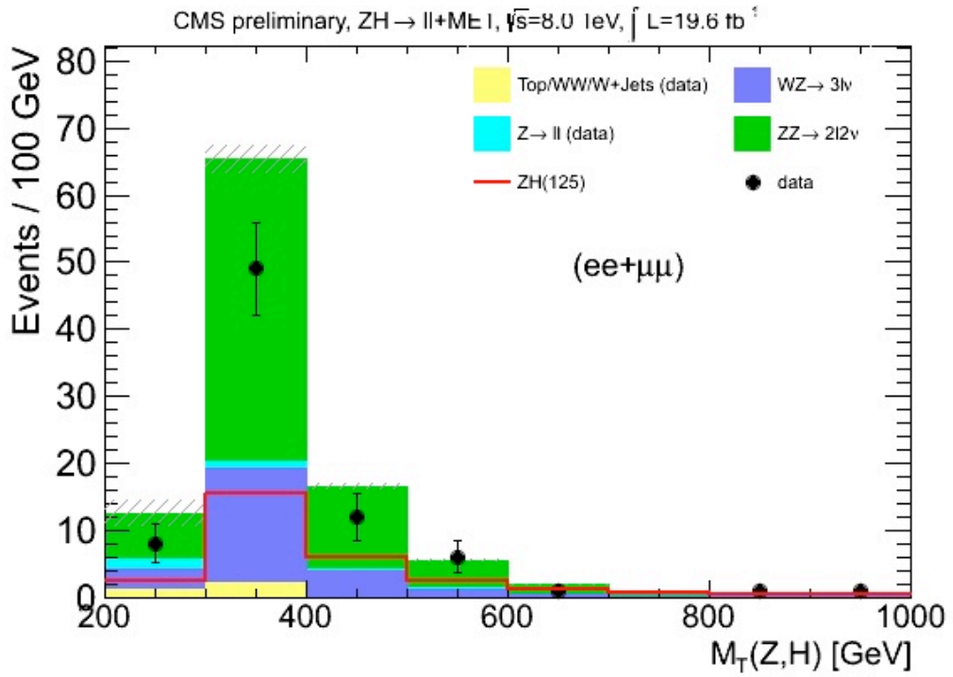


DY has much higher cross section than the signal;
Fake E_T^{miss} due to mis-measurement;
Reduced by very tight E_T^{miss} cut and Z/E_T^{miss} balance cut

Signal extraction

$$m_{\mathrm{T}}^2 = \left[\sqrt{(p_{\mathrm{T}}^{\ell\ell})^2 + (m_{\ell\ell})^2} + \sqrt{(E_{\mathrm{T,PF}}^{\mathrm{miss}})^2 + (m_{\ell\ell})^2}\right]^2 - \left[\vec{p}_{\mathrm{T}}^{\,\ell\ell} + \vec{E}_{\mathrm{T,PF}}^{\mathrm{miss}}\right]^2$$

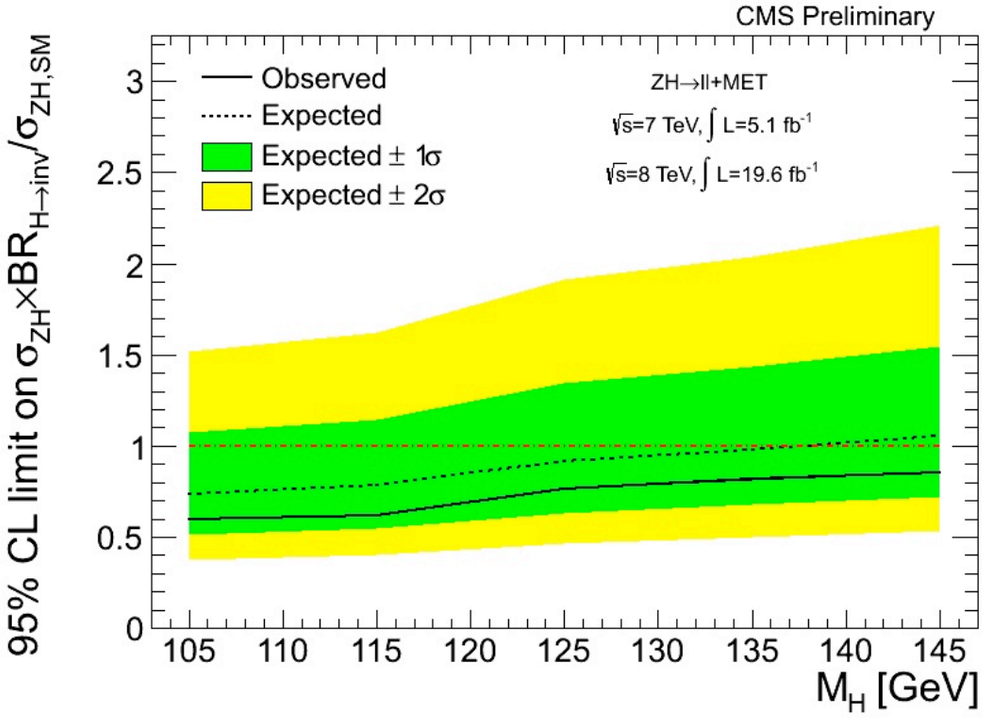
- After event selections, DY/Top/WW are negligible. Remains are ZZ/WZ
- Perform a shape-based analysis to make full use of residually kinematic discrimination of ZH signal and irreducible backgrounds
- Main systematics are theoretical uncertainties (PDF, QCD scales) of ZH and ZZ/WZ, 8~9%
- Still statistics driven at this stage

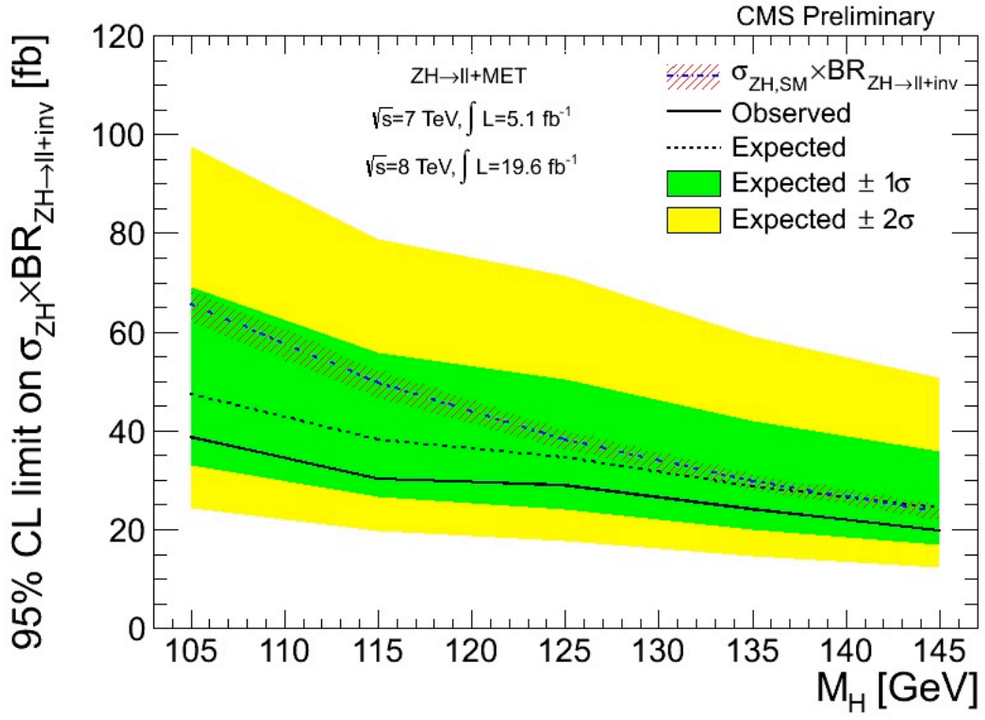


ZZ/WZ are irreducible, and have slightly lower p_T_Z and E_T^{miss} than signal on average;
A transverse mass is defined to further discriminate signal and ZZ/WZ

Result

- Full 2011 and 2012 data: 5/fb @ 7 TeV + 20/fb @ 8 TeV
- For a 125 GeV Higgs, the observed (expected) upper limit on BR→invisible is 75(91)% at 95% C.L.
- Limits at other mass points constrain additional Higgs-like particles with exotic decay modes

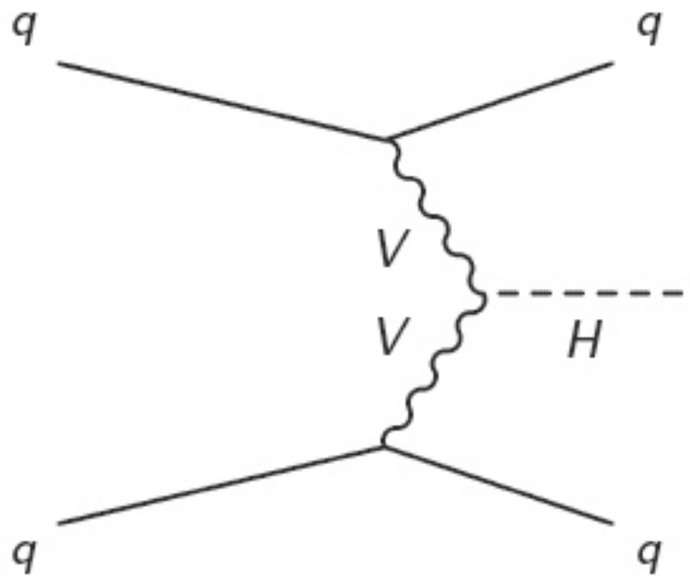




Combined with VBF channel

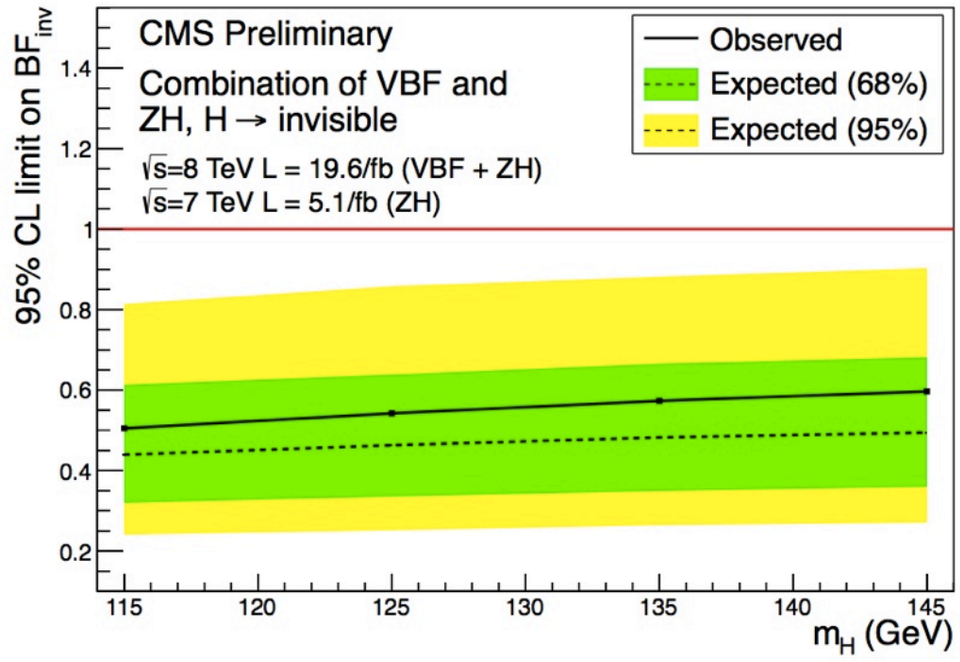
- A pair of forward/backward jets, with large invariant mass, well separated in rapidity
- Large cross section; also larger backgrounds

CMS-HIG-13-013



Preliminary combination of VBF and ZH

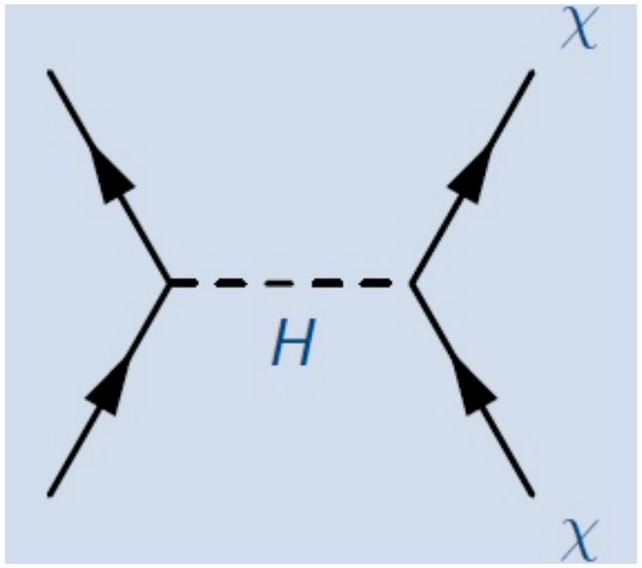
Observed(expected) upper limit on BR→invisible is 54(46)% at 125 GeV

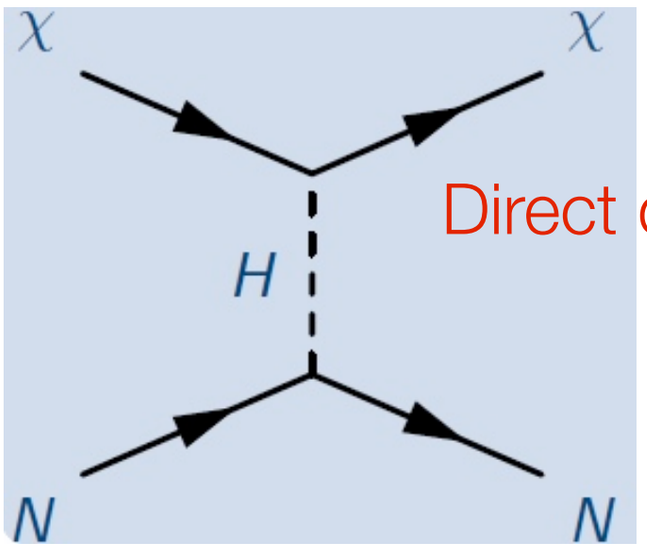


Higgs invisible decay → Higgs portal to dark matter

- Higgs portal: a hidden sector can provide stable dark matter particles with couplings to the Higgs sector of SM
  - Higgs becomes the key mediator in the DM scattering and annihilation process, providing connection between Higgs invisible decay study at LHC with direct DM detection

LHC





Direct detection

If the dark matter candidate has a mass below m_H/2, the upper limit on Higgs invisible decay BR can constrain Higgs-DM coupling; then translated to the DM-nucleon elastic cross sections

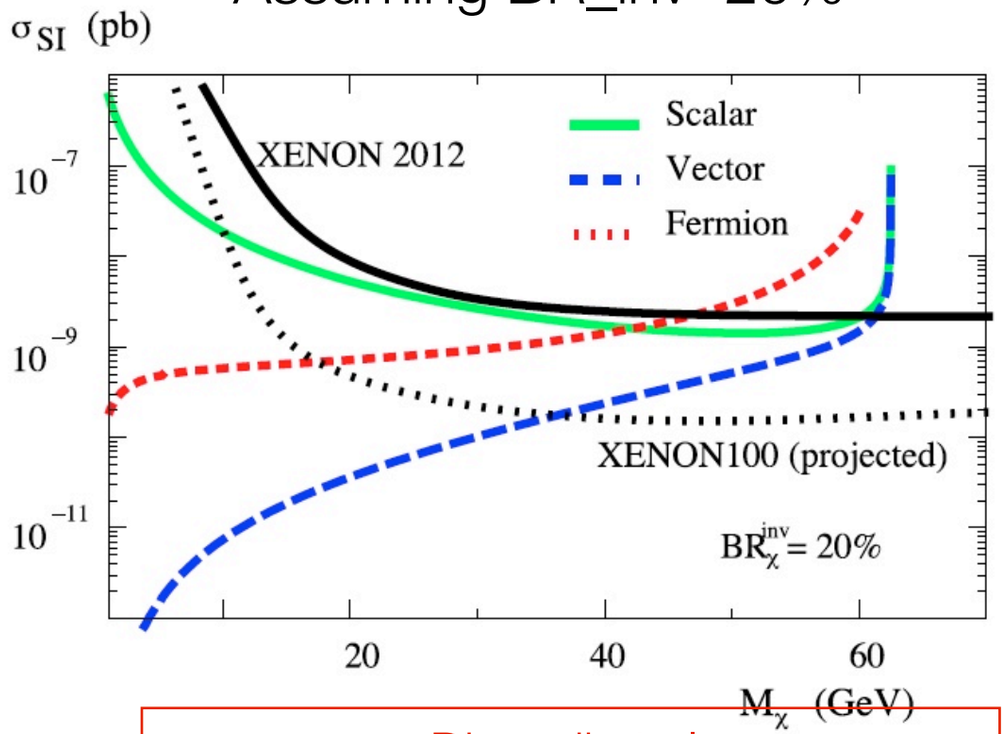
Three spin scenarios are considered for DM particles: scalar, vector, Majorana fermion

$$\sigma^{SI}_{S-N} = \frac{4\Gamma(H \to inv)}{m_H^3 v^2 \beta} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}$$

$$\sigma^{SI}_{V-N} = \frac{16\Gamma(H \to inv) M_\chi^4}{m_H^3 v^2 \beta (m_H^4 - 4M_\chi^2 m_H^2 + 12M_\chi^4)} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}$$

$$\sigma^{SI}_{f-N} = \frac{8\Gamma(H \to inv) M_\chi^2}{m_H^5 v^2 \beta^3} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}.$$

Assuming BR_inv=20%



Djouadi et al.
Phys. Let. B 709 (2012) 6569
Eur. Phys. J. C (2013) 73:2455

CMS will include DM interpretation in the Higgs invisible decay combination paper

Bounding Higgs width using off-shell production

Caola & Melnikov, 1307.4935
Campbell et al, 1311.3589

Narrow-width approximation

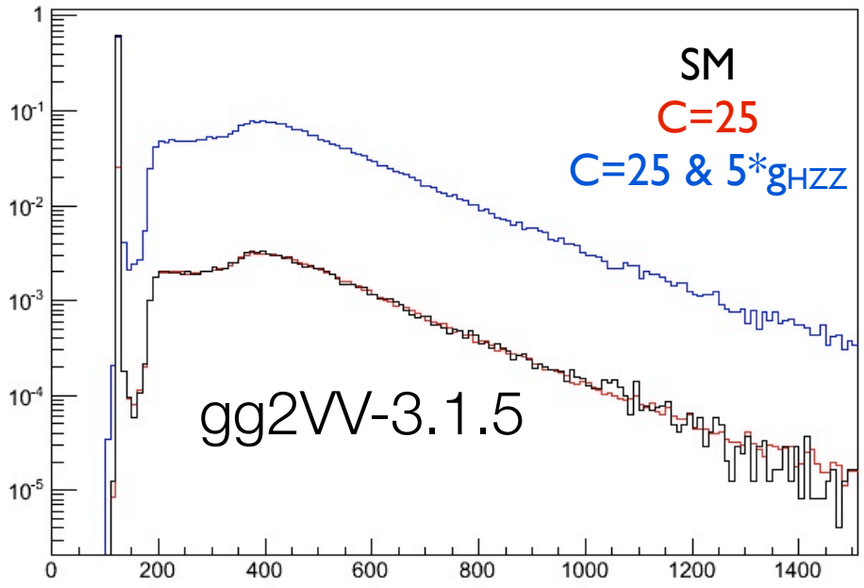
$$\sigma_{i\to H\to f} \sim \frac{g_i^2 g_f^2}{\Gamma_H}$$

Cross section maintains constant if simultaneous scaling numerator and denominator by C

$$\frac{\mathrm{d}\sigma_{pp\to H\to ZZ}}{\mathrm{d}M_{4l}^2} \sim \frac{g_{Hgg}^2 g_{HZZ}^2}{(M_{4l}^2 - m_H^2)^2 + m_H^2\Gamma_H^2}.$$

Complete off-shell treatment

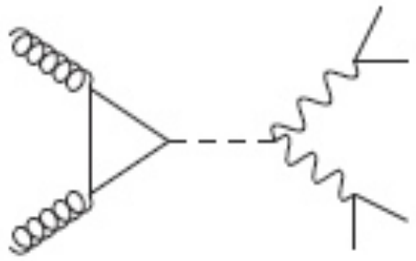
C=Γ/Γ_SM

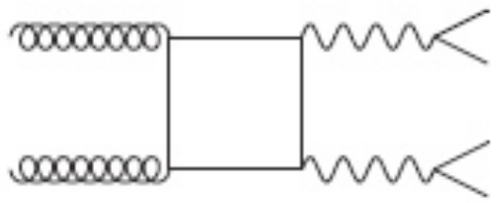


On-shell production proportional to couplings, and inversely proportional to C.
Off-shell production proportional to couplings, independent on C.

Measuring off-shell production gives upper limit on coupling and hence the Higgs width

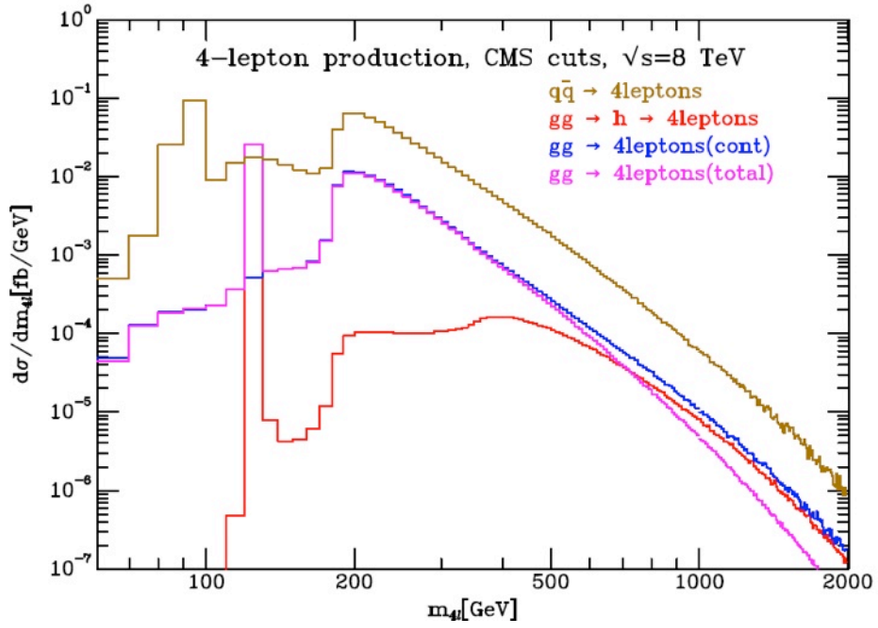
Interference is expected with box-diagram (~10% ZZ production)



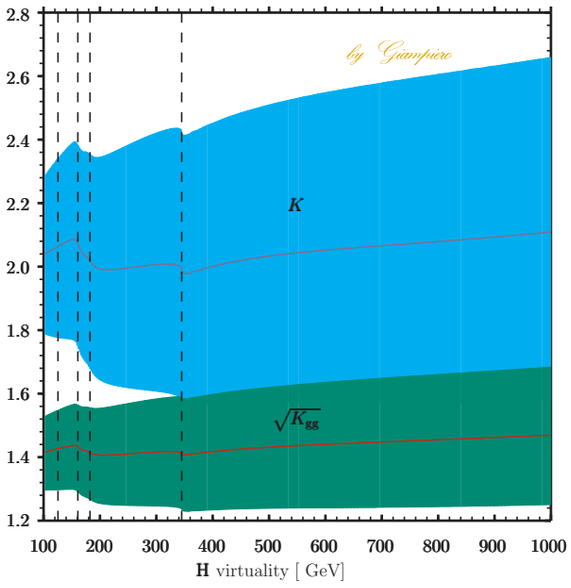


In H→4l channel, by counting 4l events in high mass region, Γ/Γ_SM could be constrained to < 20~50

Caola & Melnikov, 1307.4935
Campbell et al, 1311.3589

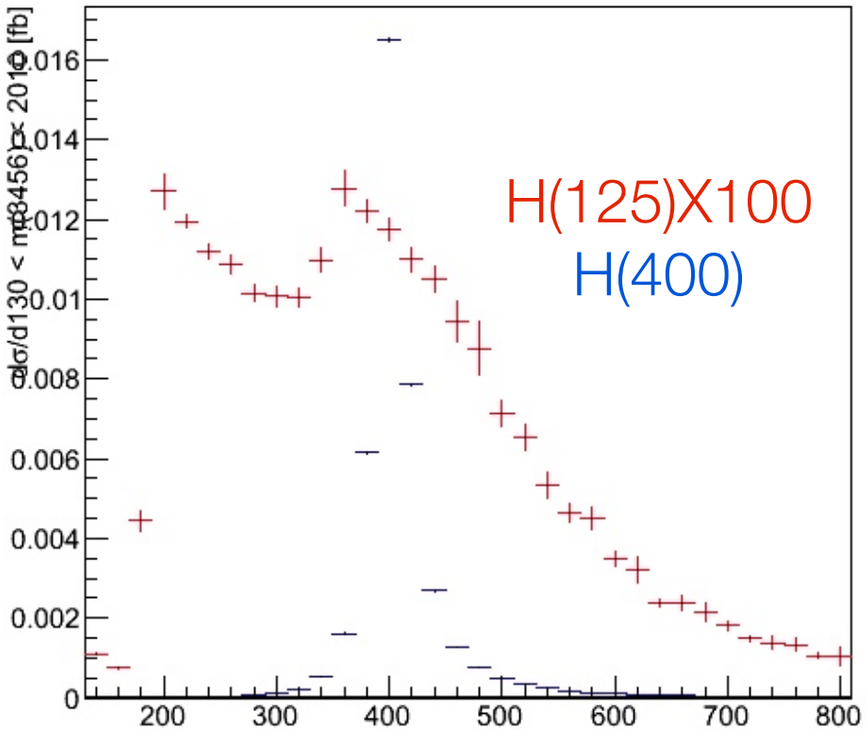


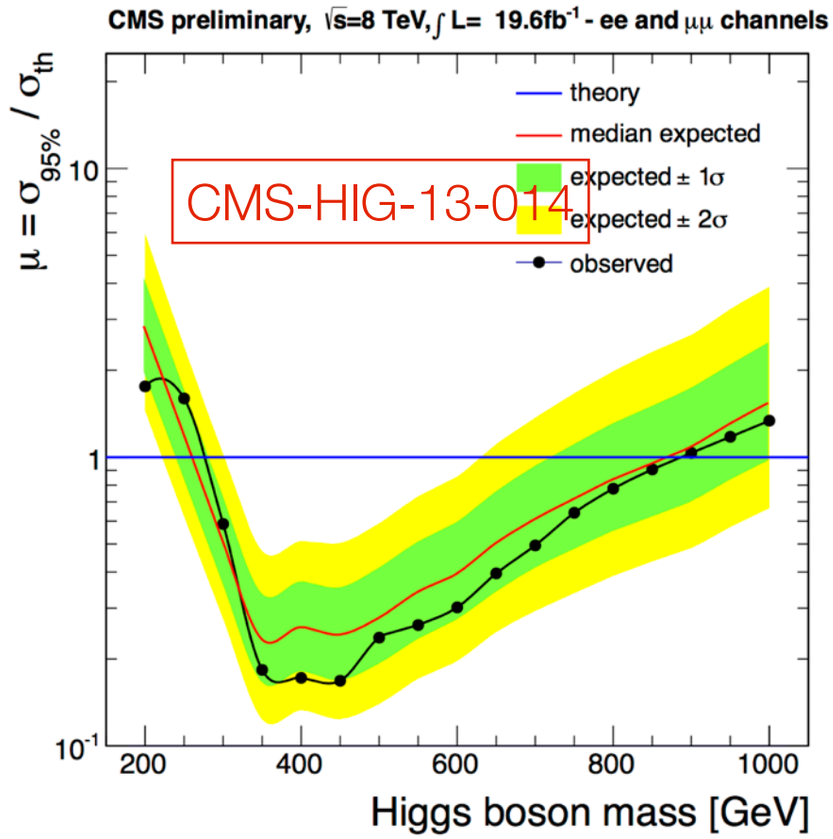
Passarino, 1312.2397



Residual theoretical uncertainty
NNLO K factors for LO signal
sqrt(K_{gg}) for to LO interference

Sensitivity of 2l2nu channel



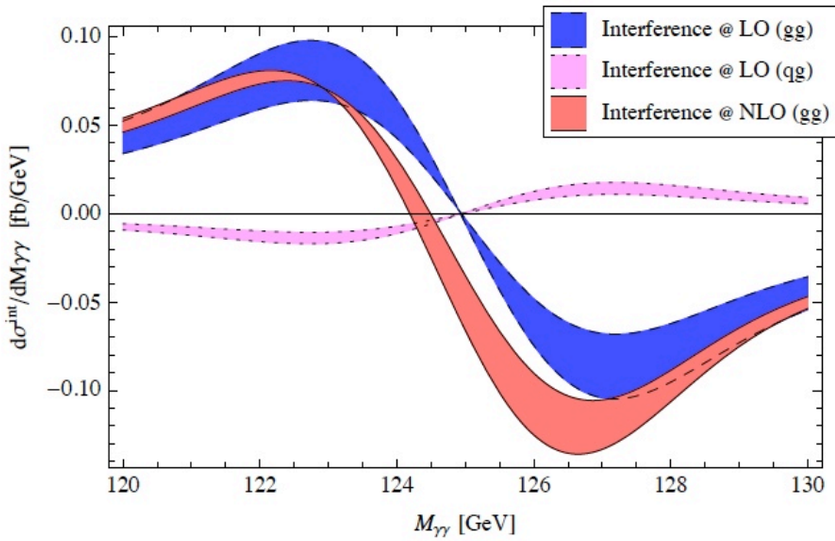


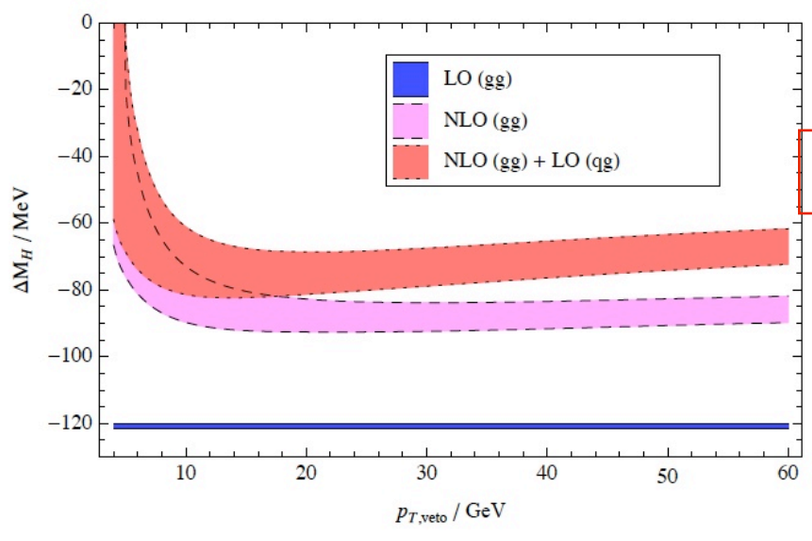
Sensitivity in heavy Higgs search

So far only ggH is used; is VBF also helpful in Higgs width study?
Theoretical input needed

Other methods of width bounding

- Direct measurement: Higgs width convoluted with resolution, Γ/Γ_SM<~1000 (e.g. CMS-HIG-13-016, H→γγ)
- Mass shift measurement in H→γγ: Signal-background interference, Γ/Γ_SM <~200 (Δm~1GeV)





Dixon & Li, 1305.3854

H→ZZ off-shell and interference are computed at LO;
would be helpful to have prediction with additional parton

Summary

- Z→2l events with high E_T^{miss} are used to study Higgs coupling and width
  - Setting upper limit on Higgs decay BR→invisible to be 75%
  - Could bound Higgs width to be smaller than 20~50 times SM width
- ZZ→2l2nu was thought to be only sensitive to heavy Higgs search; LHC was thought to be not able to determine Higgs width to a good level, and have not much to do with dark matter ...
  - These are good examples of interaction between theorists and experimentalists
  - We welcome new ideas!