Higgs couplings to bosons and fermions

Giacomo Ortona (LLR) for the CMS collaboration

Co-funded by the Horizon 2020 Framework Programme of the European Union

Outline

Introduction

Higgs coupling to bosons
- HZZ
- HWW
- Hγγ

Higgs coupling to fermions
- Hbb
- Hττ
- Hμμ

Combination of Higgs couplings

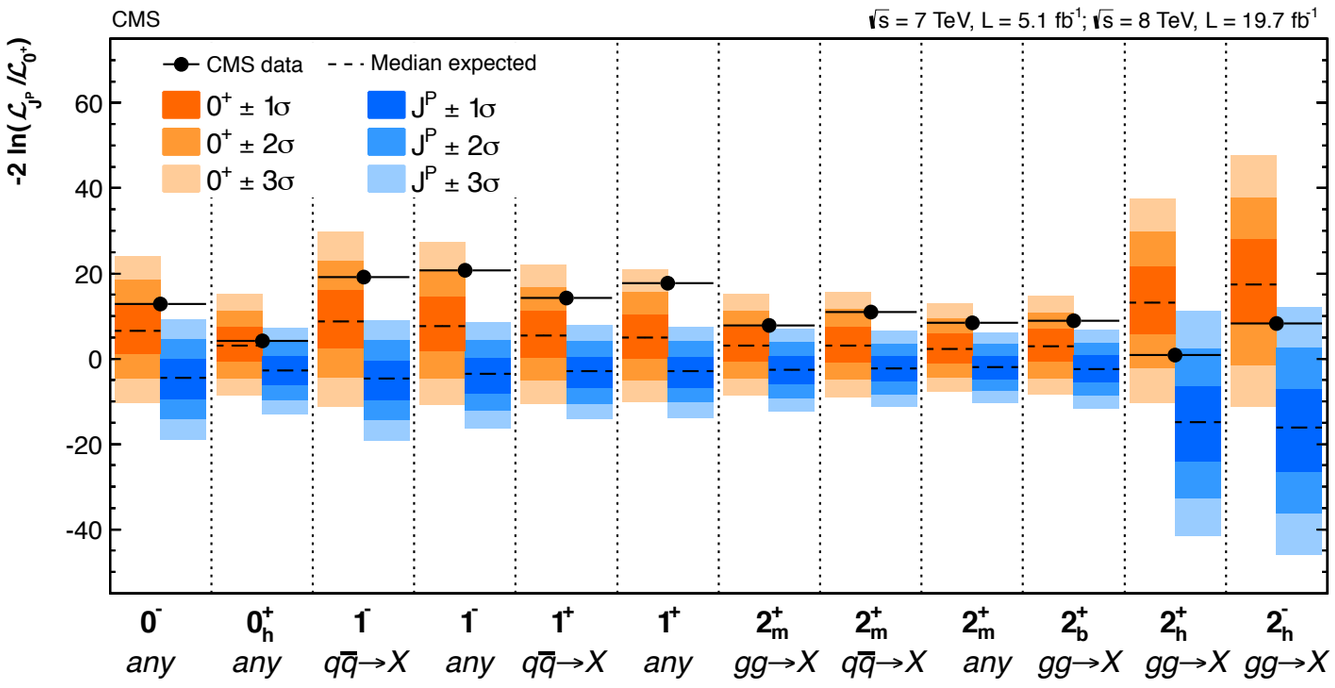
Prospects and Summary

Not in this talk:

Higgs trilinear coupling
- See talk by O. Bondu

ttH production
- See talk by T. Strebler

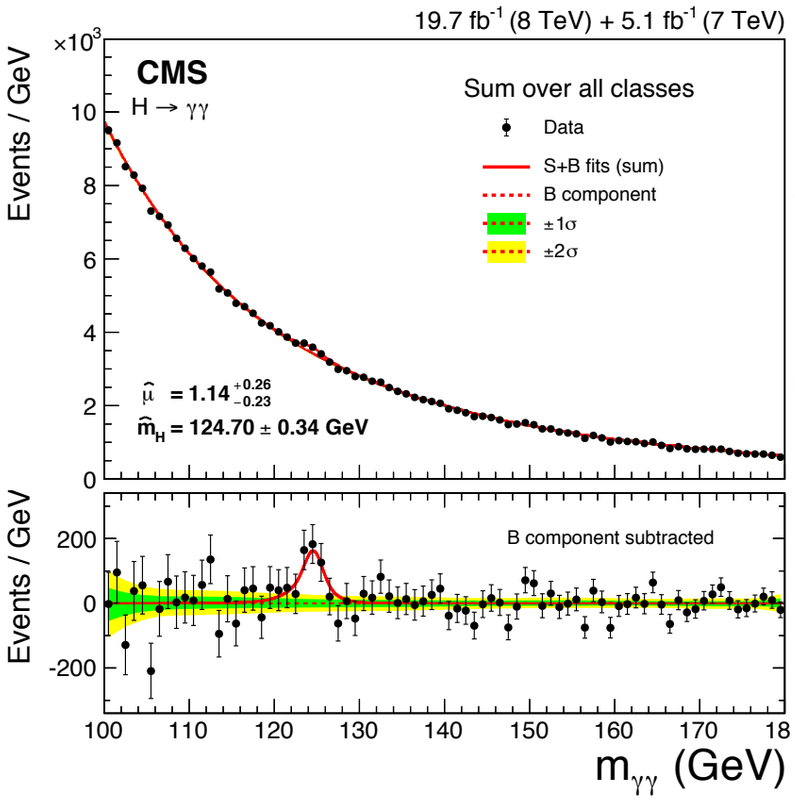
Motivation

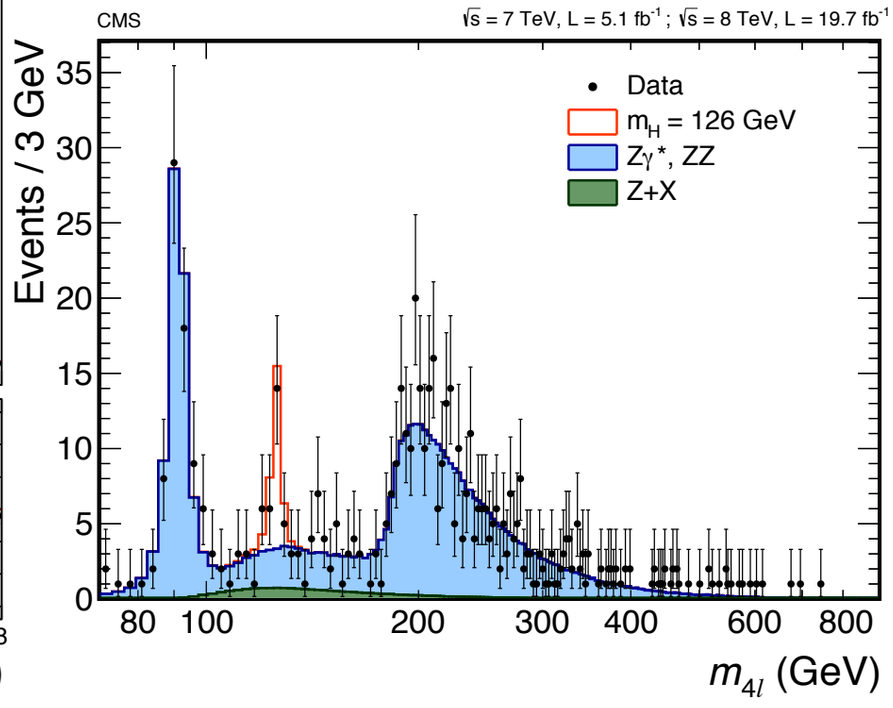


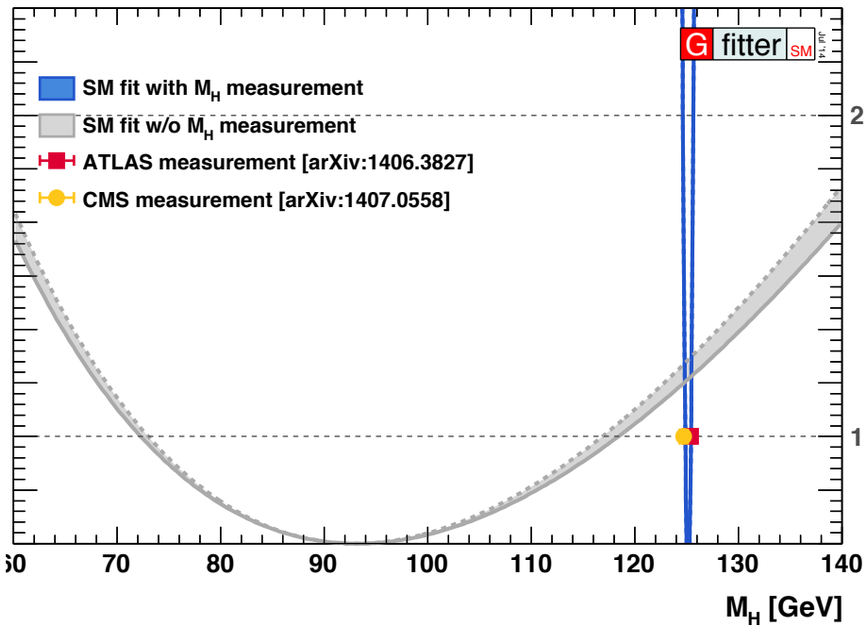
The evidence for the existence of H(125) is well beyond any doubt

- Mass a bit on the high side, but well compatible
- Spin and parity: 0^+
- Branching ratio, couplings are (so far) compatible with H.

If NP is coupled with the Higgs sector→modification of the couplings to SM particles.







K-framework and PO

Couplings, κ

Parameters scale cross sections and partial widths relative to SM

$$\kappa_j^2 = \sigma_j/\sigma_j^{\mathrm{SM}} \qquad \kappa_j^2 = \Gamma_j/\Gamma_j^{\mathrm{SM}}$$

$$\sigma_i \cdot \mathrm{BR}^f = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_{\mathrm{H}}},$$

Total width determined as

$$\Gamma_{\mathrm{H}} = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{BR}_{\mathrm{BSM}}}$$

Where

$$\kappa_H^2 = \sum_j \mathrm{BR}_{\mathrm{SM}}^j \kappa_j^2$$

At first, signal strengths μ (ratio of observed cross-section to SM predictions)

- Good to verify H(125) properties and to check compatibility with SM
- Not ideal parametrization when introducing NP

Second step, K-framework:

- Disentangles production and decay mechanisms. Notation $k_f = \{k_t, k_b, k_\tau\}$; $k_V = \{k_W, k_Z\}$
- Effective coupling modifiers for processes with loops (k_g, k_γ, k_H…)
- Also possible to describe as coupling modifier ratios $\lambda_{ij}=\kappa_i/\kappa_j$
- Production processes: ggF, VBF, WH, ZH, ttH
- Decay channels: HZZ,WW,γγ,ττ,bb,μμ

Next step: PseudoObservables (not for this talk)

H coupling to bosons: WW

More details in Lorenzo's talk

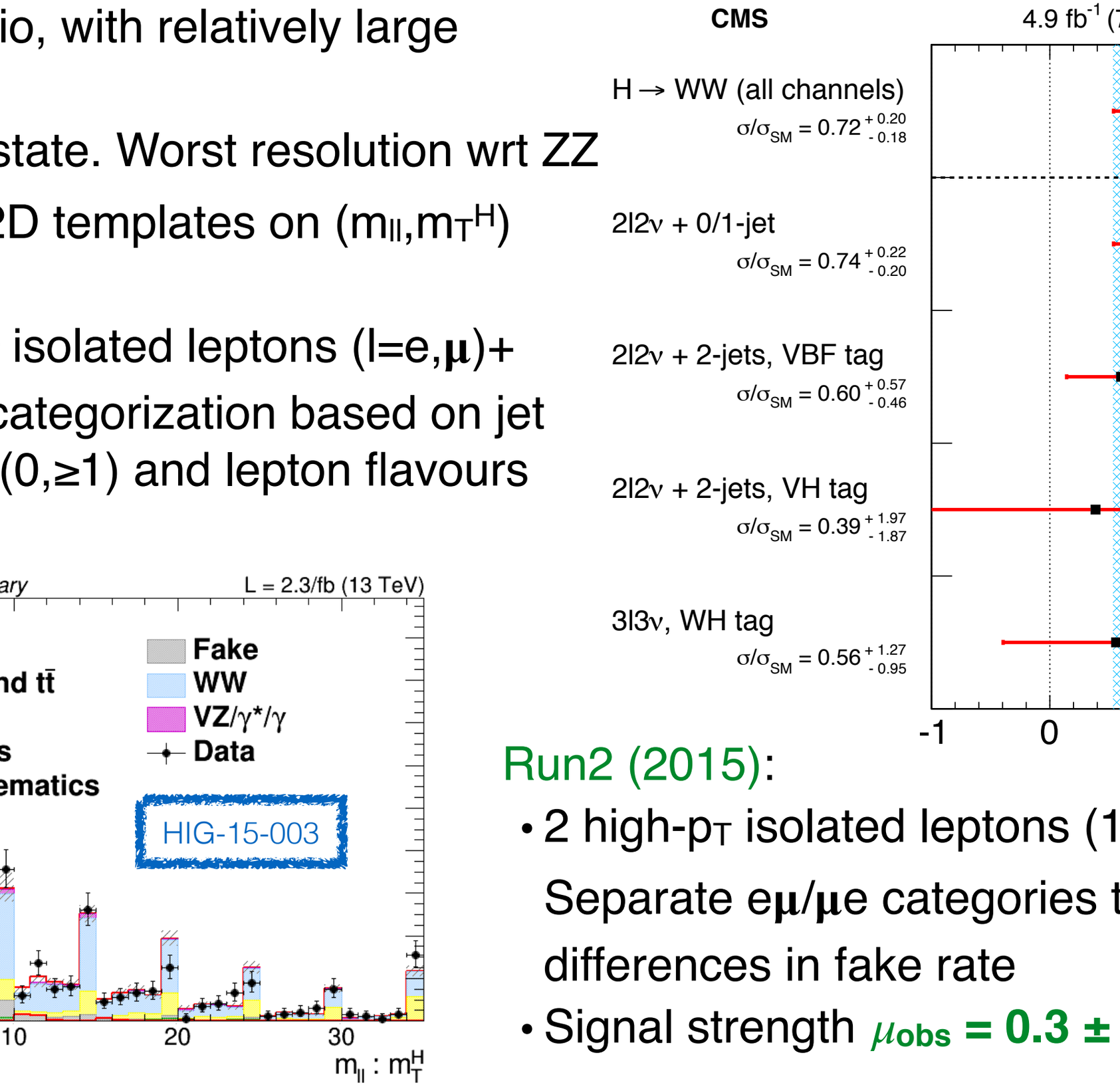
Good S/B ratio, with relatively large background

ν in the final state. Worst resolution wrt ZZ

Analysis on 2D templates on (m_{ll},m_T^H)

Run1:

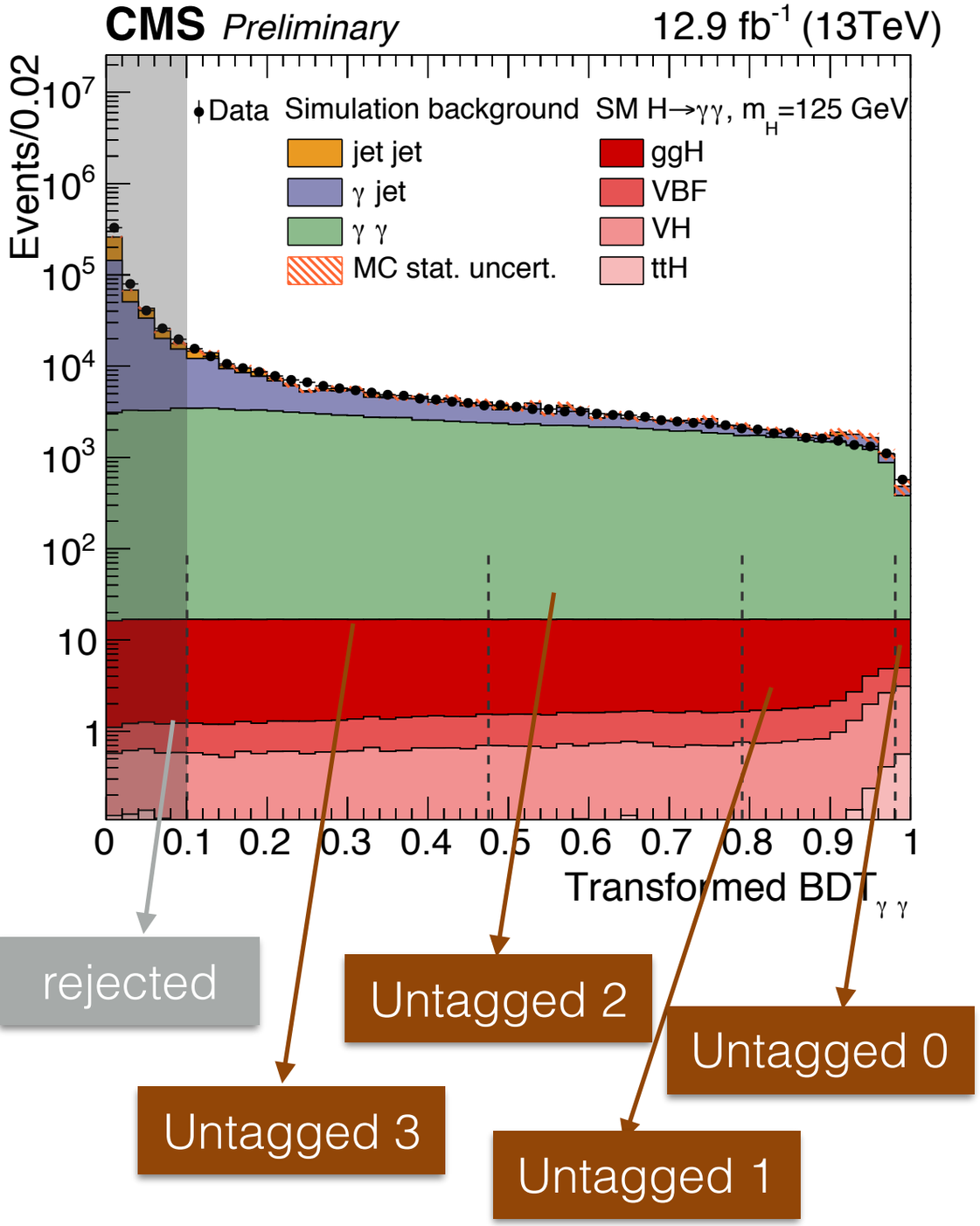
- 2-3 high-p_T isolated leptons (l=e,μ)+ MET, with categorization based on jet multiplicity (0,≥1) and lepton flavours (ee,eμ,$\mu\mu$)

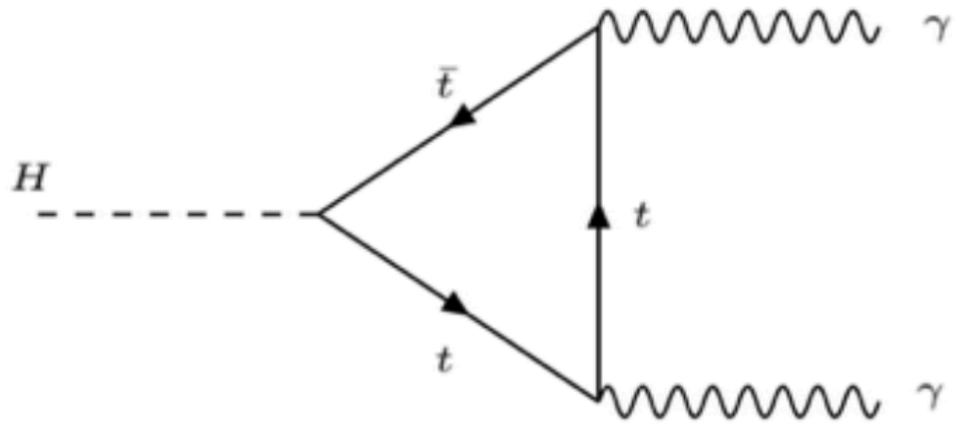


Run2 (2015):

- 2 high-p_T isolated leptons (1e,1μ) Separate eμ/μe categories to exploit differences in fake rate
- Signal strength μ_{obs} **= 0.3 ± 0.7**

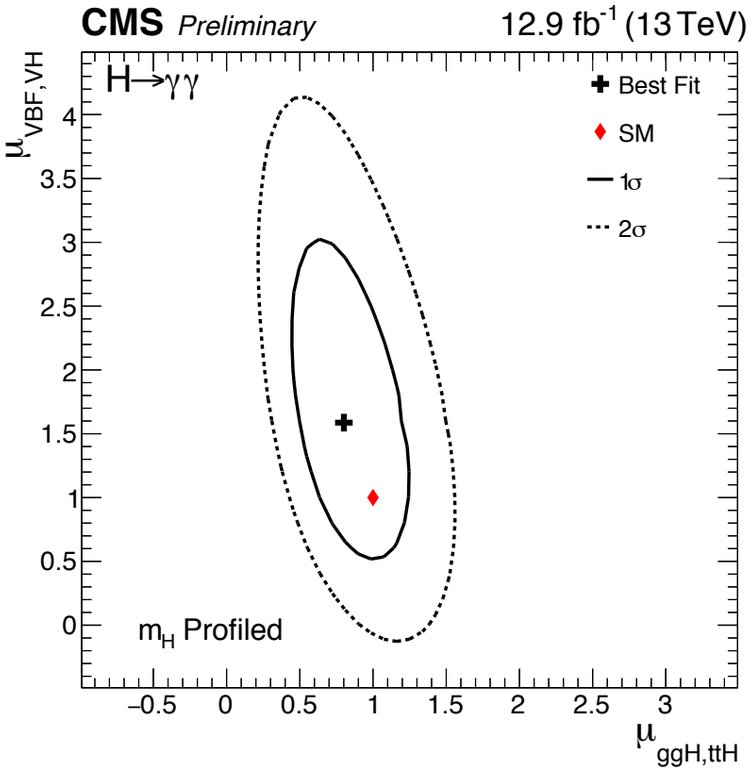
H→γγ

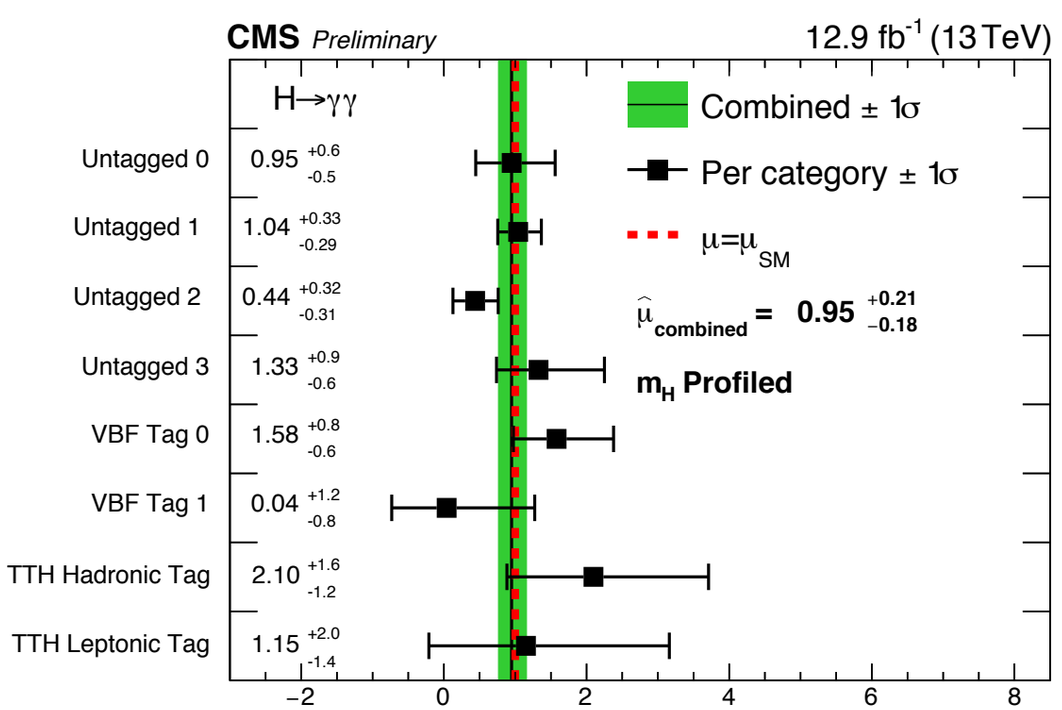




- Very clean channel for discovery and signal strength measurements
- Search strategy: peak over (abundant) and regular background
- Vertex+photonID+kinematic BDT to select and classify the events
- Indirect probe of coupling through production loops
- Categorisation:
- 4 untagged categories with different relative contributions of VH/ggH
- 2 ttH-tagged categories (leptonic/hadronic top decay)
- 2 VBF-tagged categories

H coupling to bosons: γγ

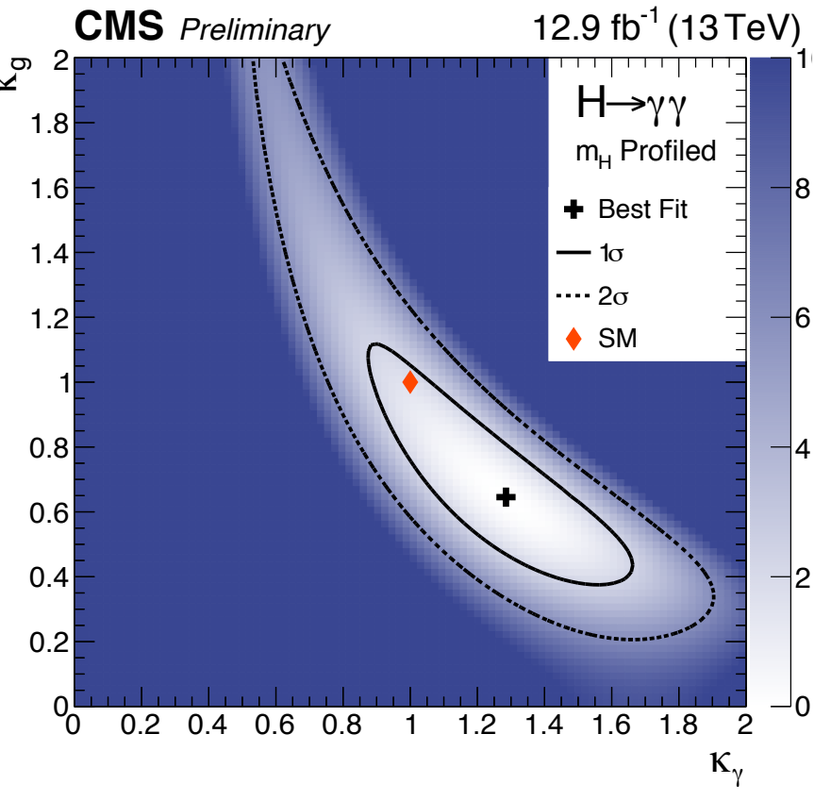


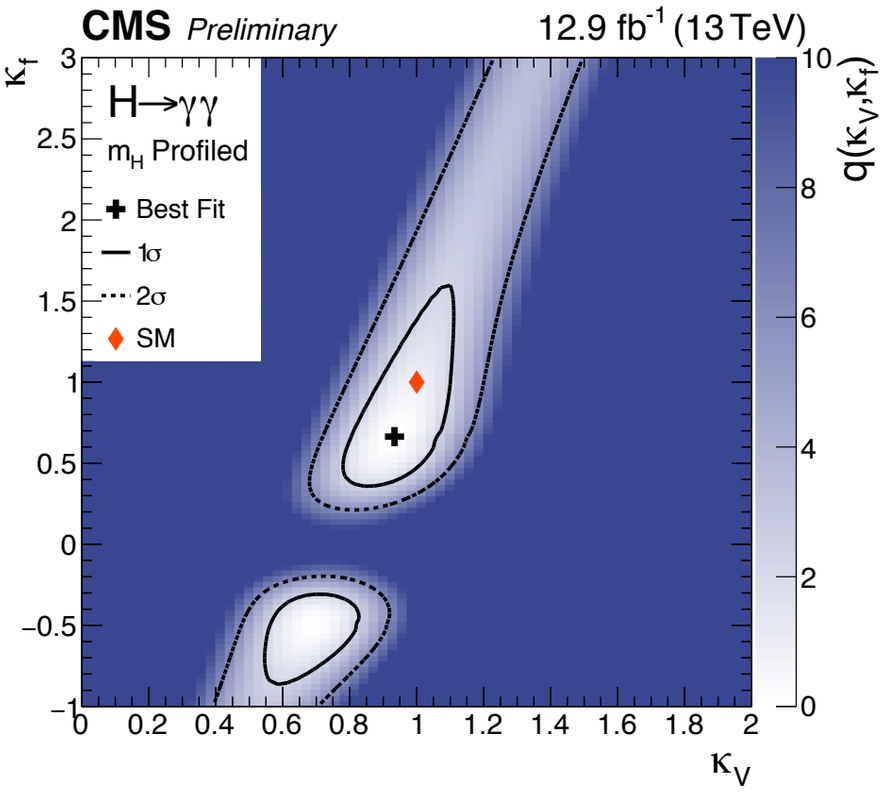


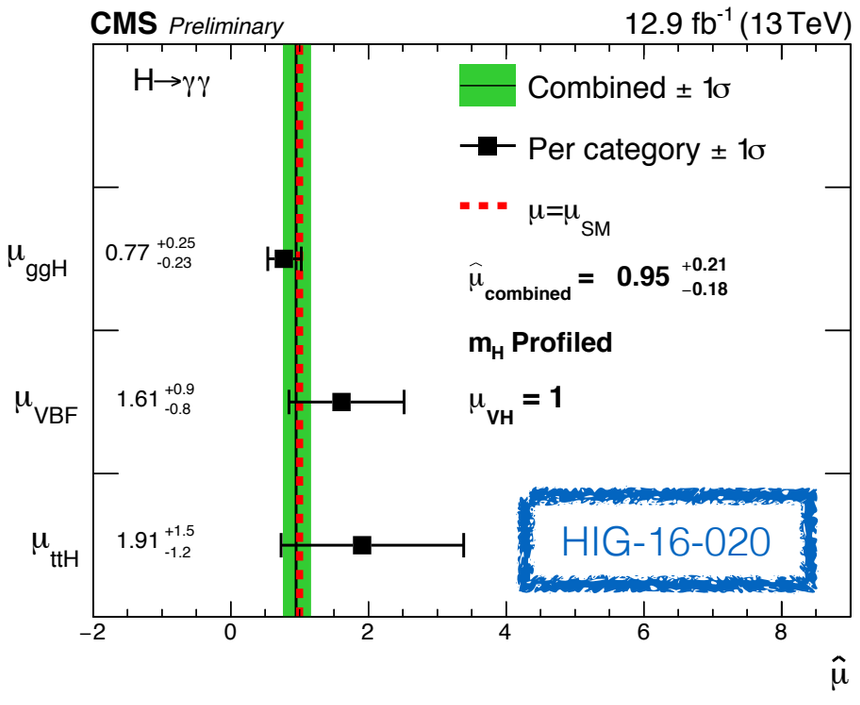
Signal strengths are compatible with SM expectations.

In run1, small upward fluctuation in ttH (1σ in γγ, 2σ globally).

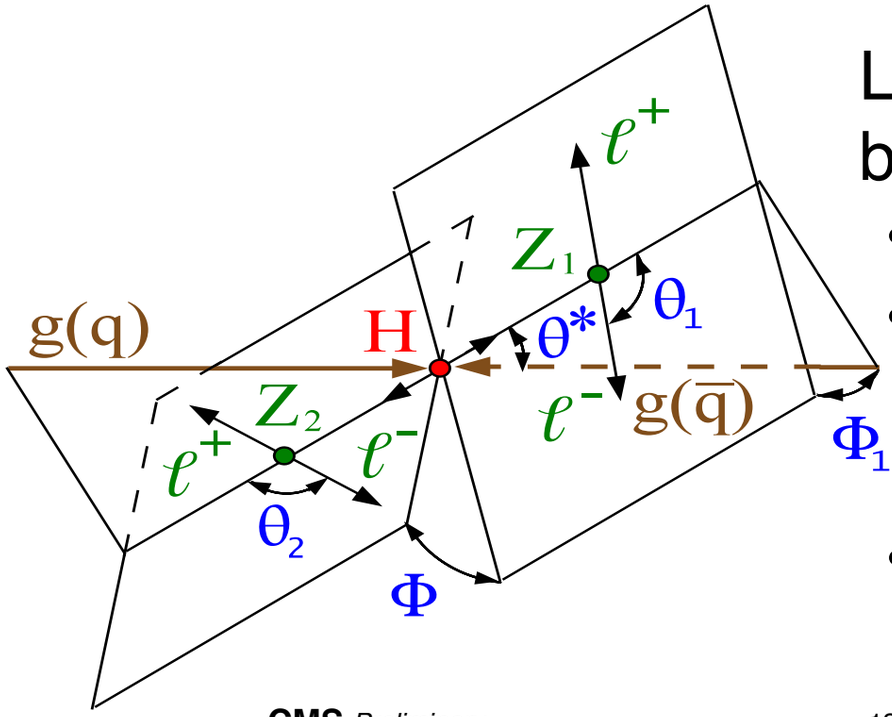
Not able yet to confirm it, but higher luminosity results are on the way





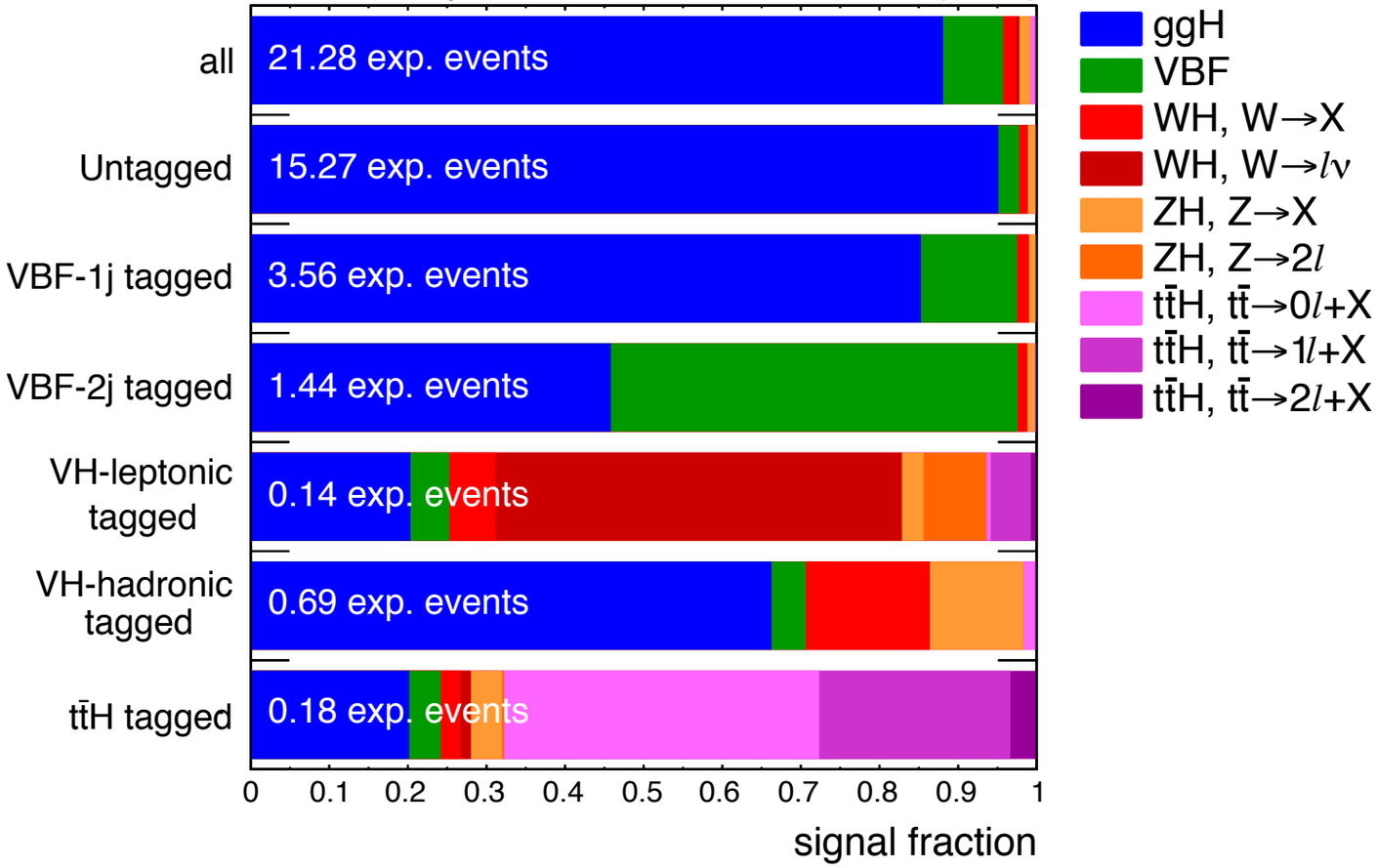


H→ZZ→4l



Low signal rate, but very clear topology wrt a small background (mainly qqZZ, Z+jets)

- 4 isolated leptons in final state combined in 2 Z pairs
- Can exploit kinematical information (matrix element KD discriminants) to separate signal and background and categorise events in different production modes.
- Can probe 4 different production modes (ggH, VBF, ttH, VH)



Untagged events

4leptons+1jet+high KD

4leptons+{2,3,4}non b-jets+high KD

5-6leptons+≤3 non-b jets

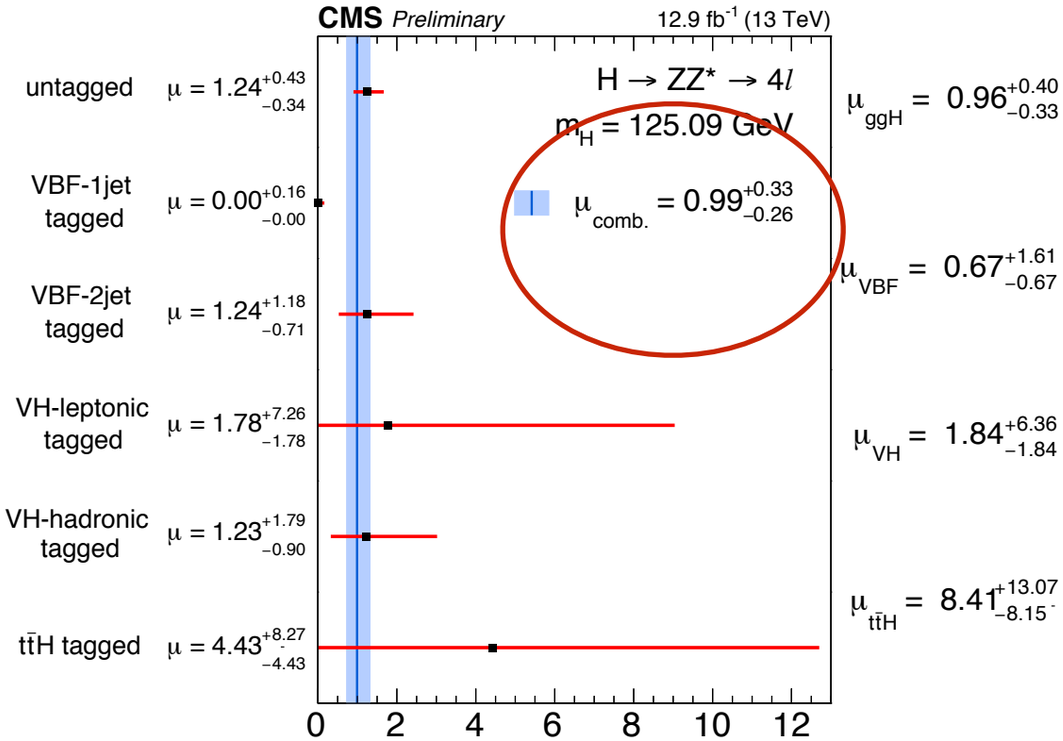
4leptons +{2,3,4}non b-jets+high KD

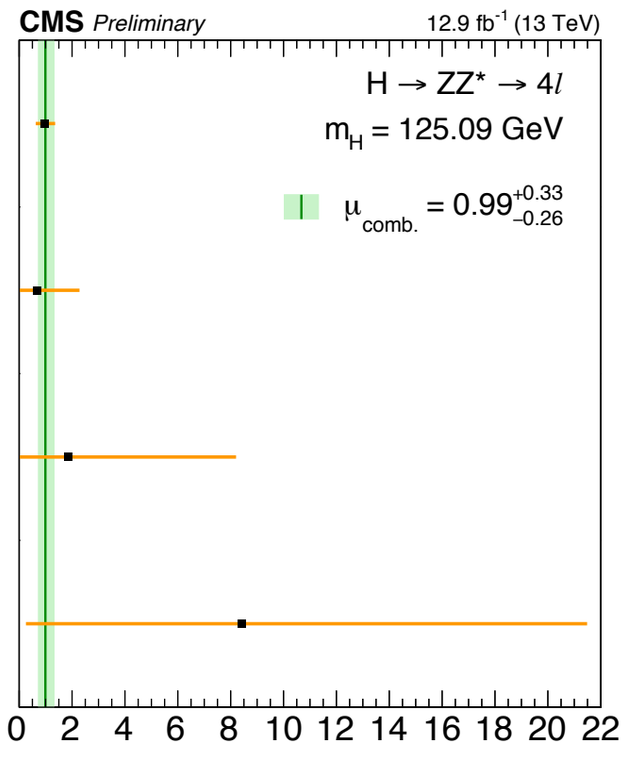
4leptons+4 jets (≥1b-tag) or 1 lepton

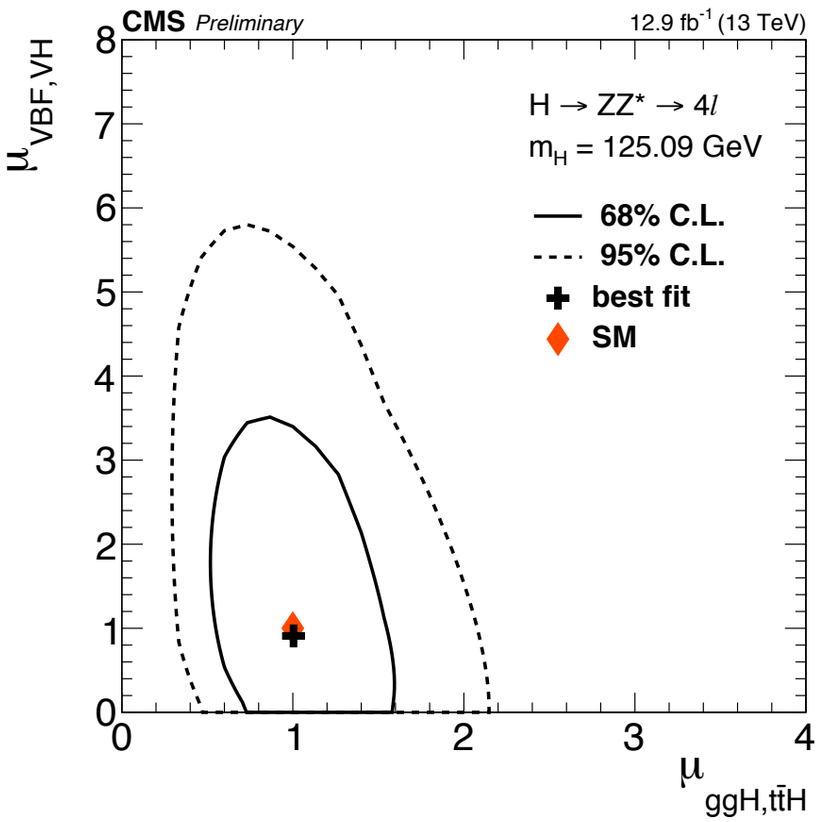
H coupling to bosons: ZZ

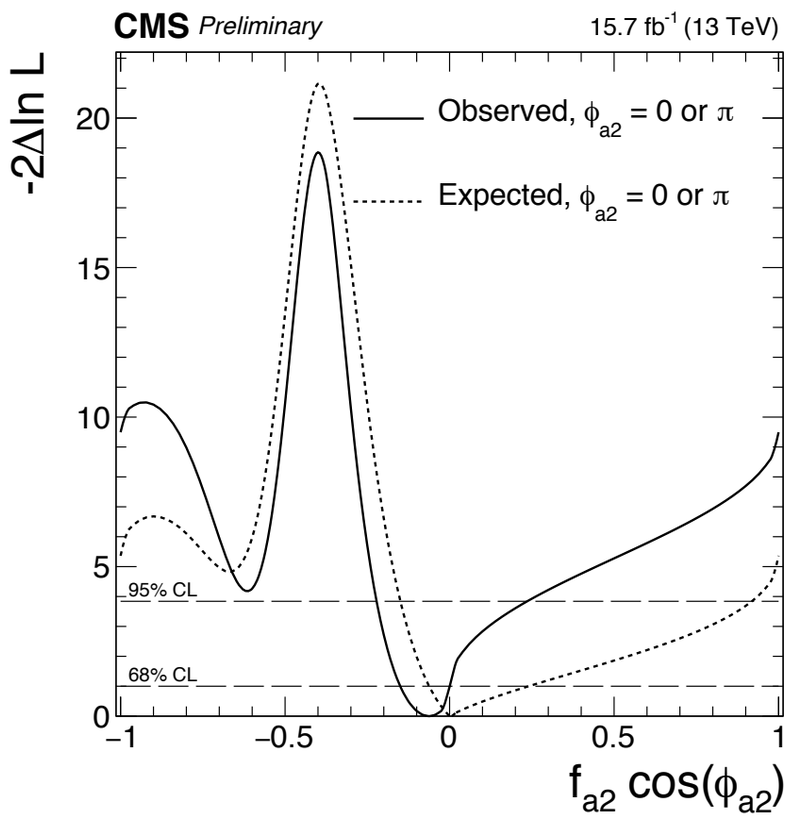
Signal strengths in run2 are consistent with SM expectations

ttH production is being reported for the first time by CMS in the ZZ channel









No evidence for anomalous HZZ couplings so far

HIG-16-033

H coupling to fermions: bb

Run2

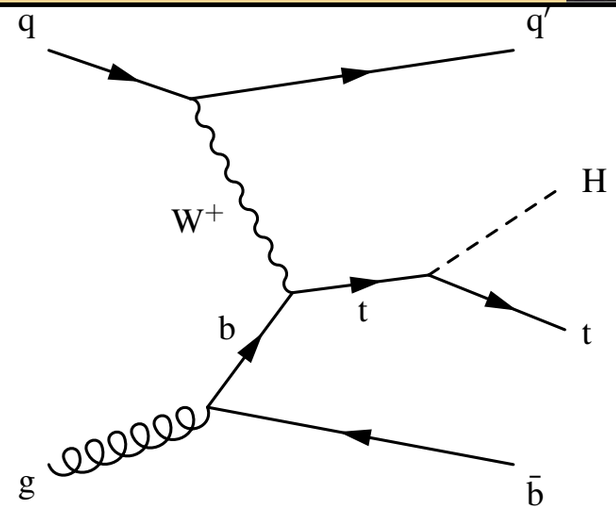
Large amount of SM processes with 2 b-jets in the final state

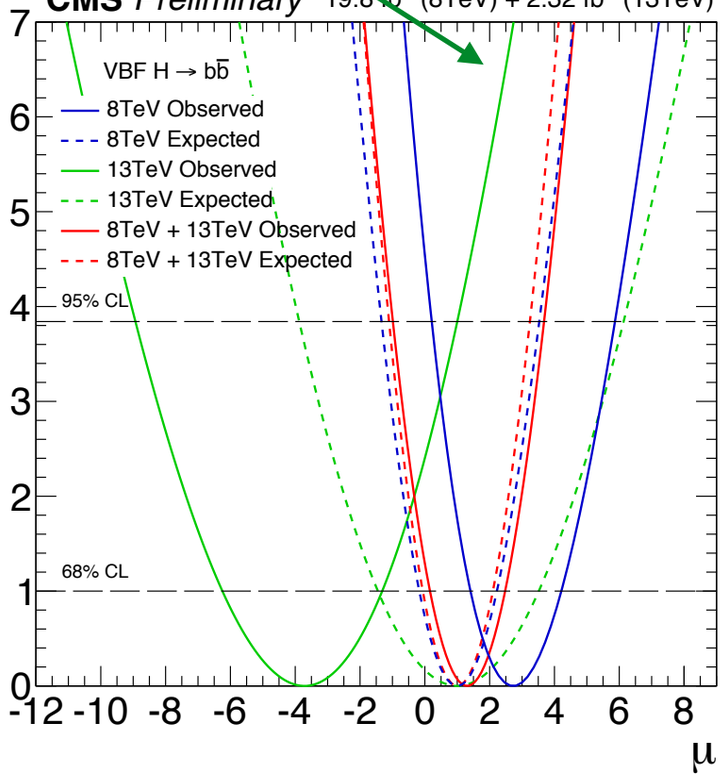
- Necessity of kinematic handles to separate signal from background

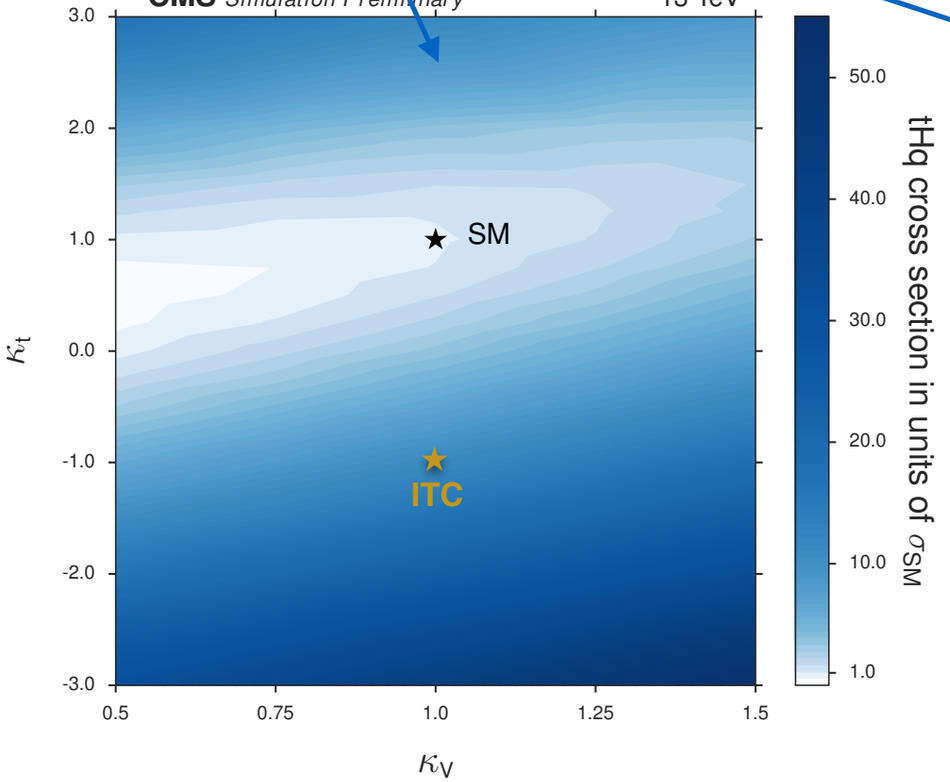
Instead of probing gluon-fusion:

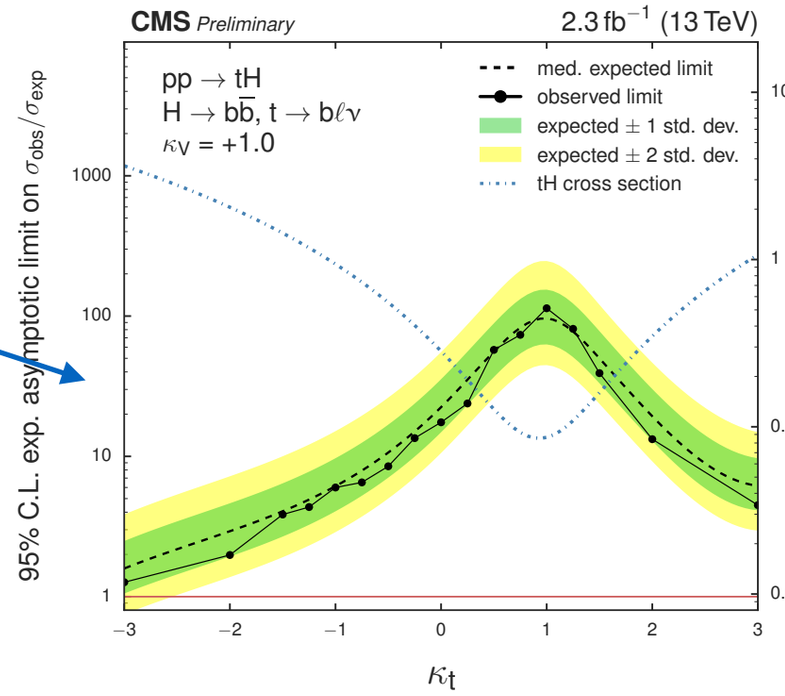
- ttH (see Thomas')
- single-top + H HIG-16-019

  Top+Higgs interference in tHq diagrams is destructive in SM, while it is constructive for inverted top coupling. Can probe kt sign
- VBF HIG-16-003
- VH









tHq exclusion ($2.3fb^{-1}$):

$\sigma_{obs} = 113x\sigma_{SM}$

$\sigma_{obs} = 6x\sigma_{ITC}$

Still some way to go

H coupling to fermions: ττ

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Most sensitive fermionic decay channel

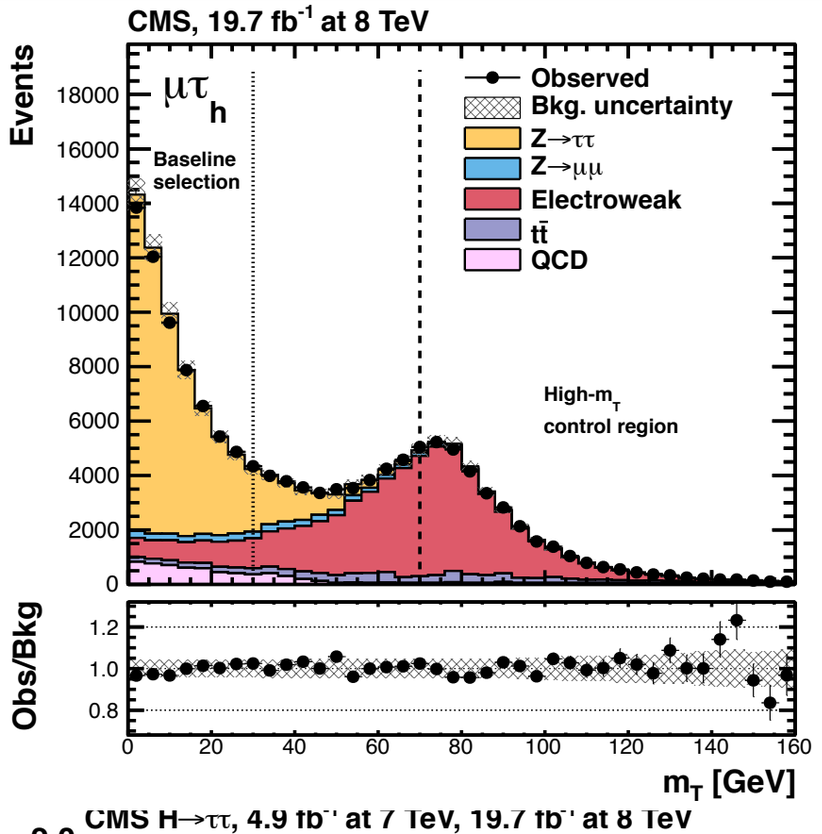
Final state events organised in channels according to τ decay

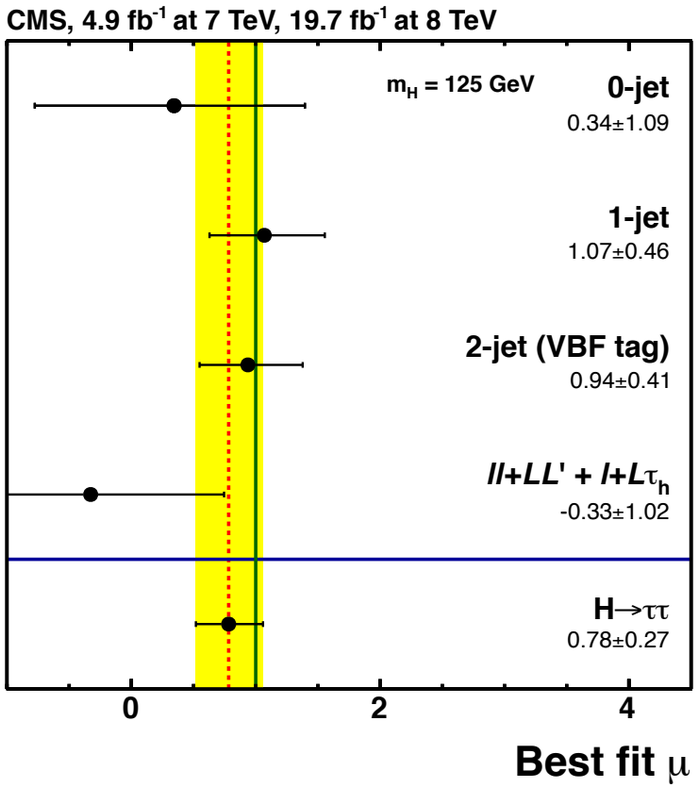
Jet-tagged and VH-tagged categories to separate different final states

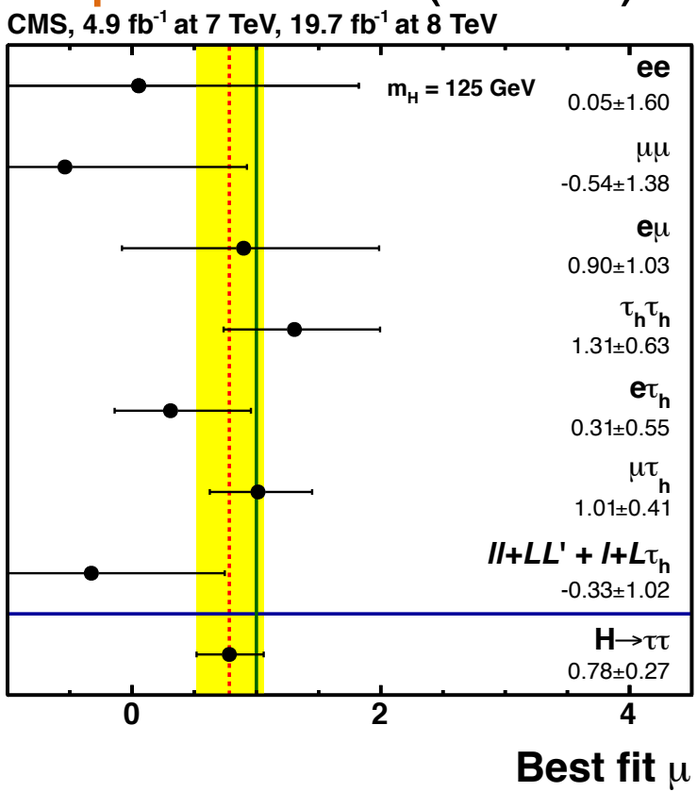
Likelihood based algorithm to reconstruct τ mass

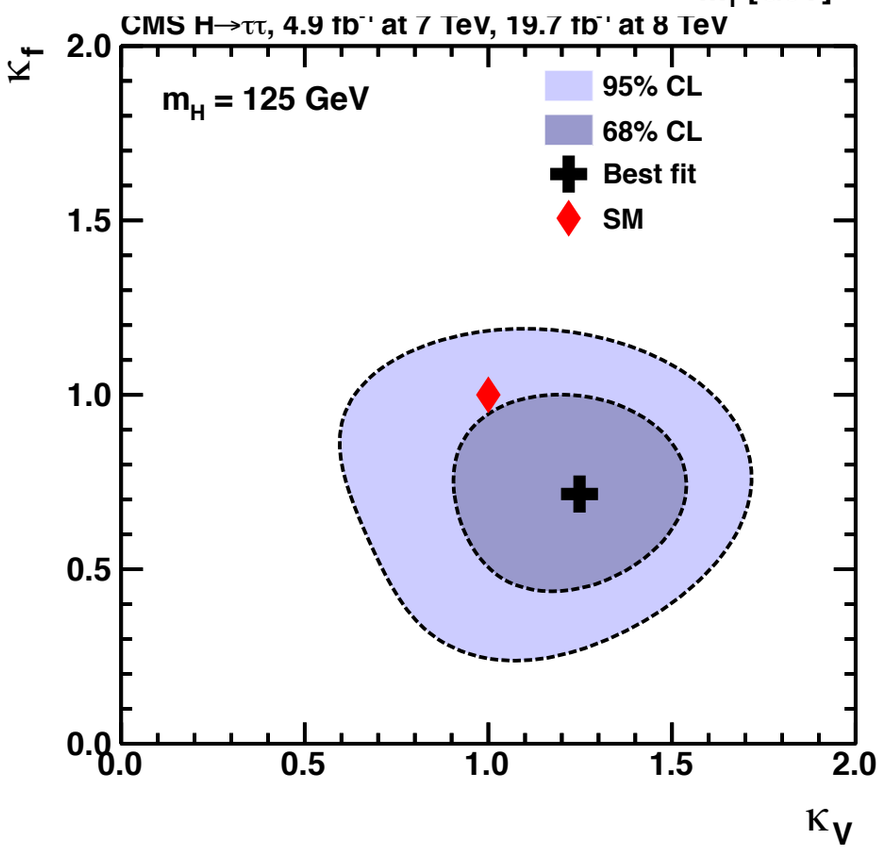
Cut on transverse mass m_T to improve S/B

Main focus@13TeV on BSM interpretations (so far)







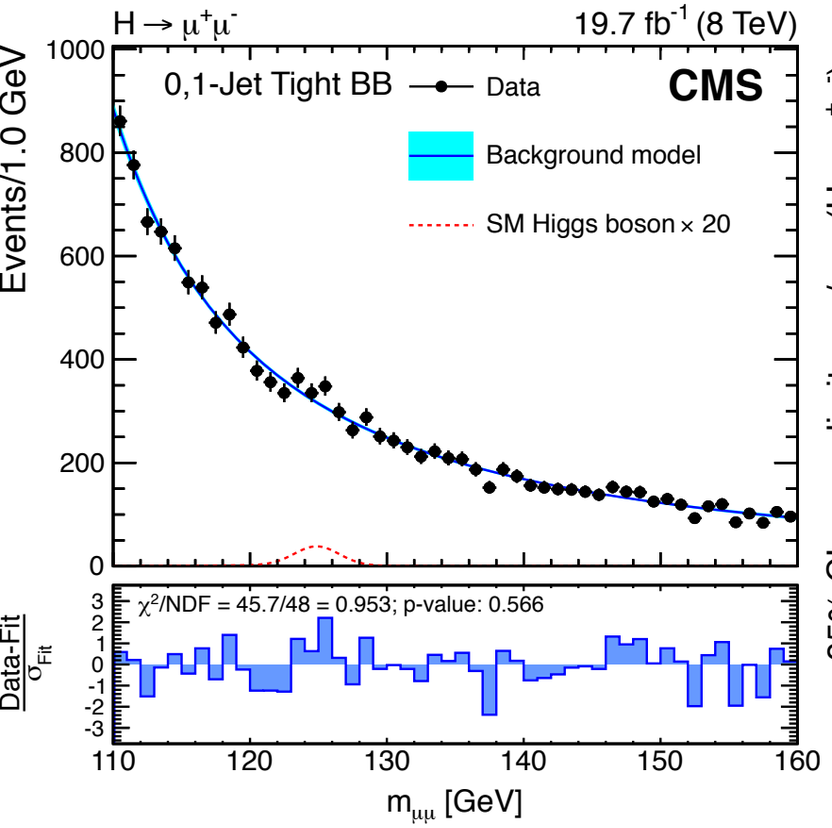


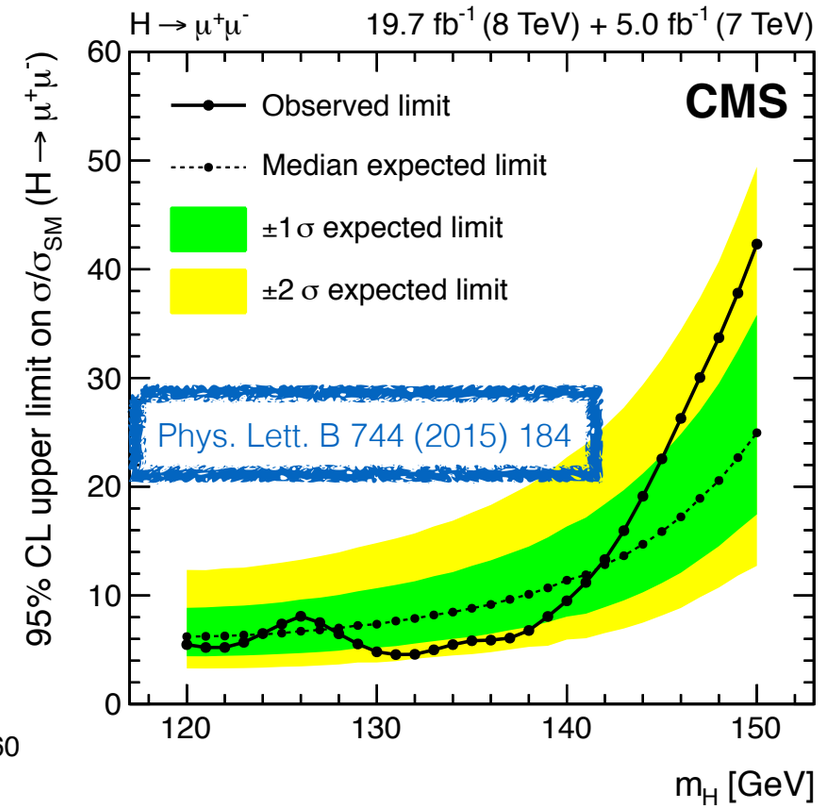
H coupling to fermions: muons

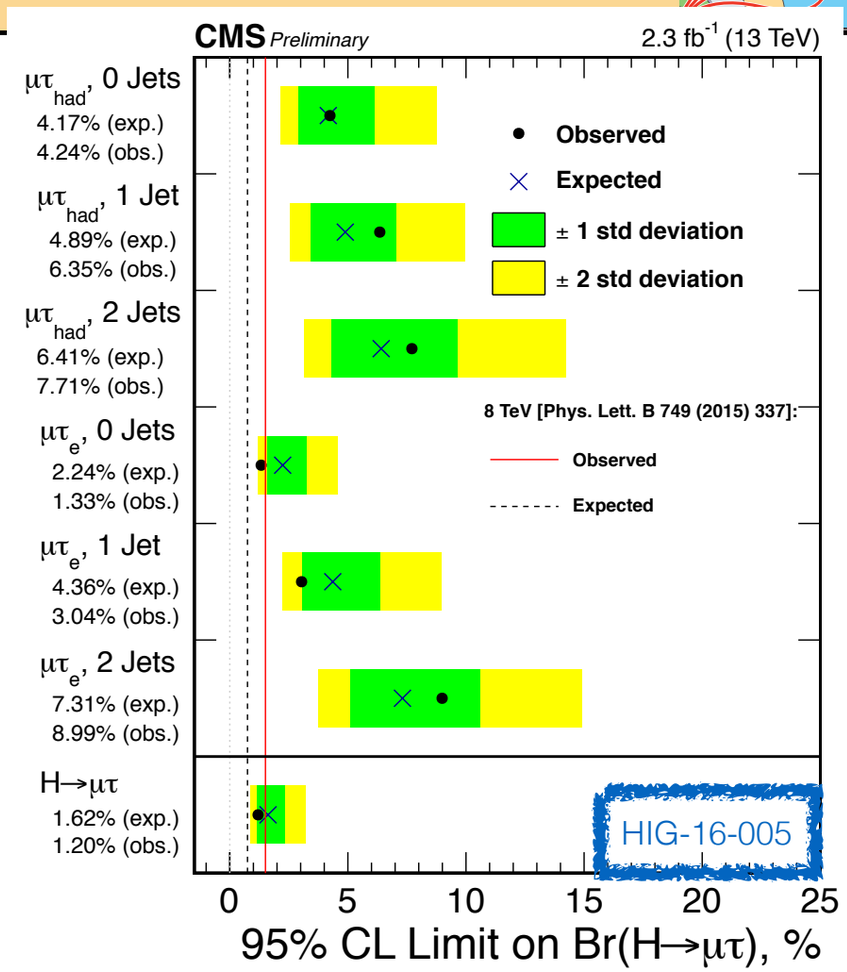
Difficult measurement, very small branching fraction $B(H\to\mu\mu)=2.2\cdot10^{-4}$ (and even smaller to electrons).

- Search for bumps in the invariant mass spectra of isolated OS lepton pairs
- Events categorised according to the number of jets (<2,≥2)
- Not sensitive to the SM yet. Run1 excludes ~7xσ_{SM}

Useful channel to test for H couplings scaling and BSM physics.







Also possible to probe LFV coupling, in H→ll decays

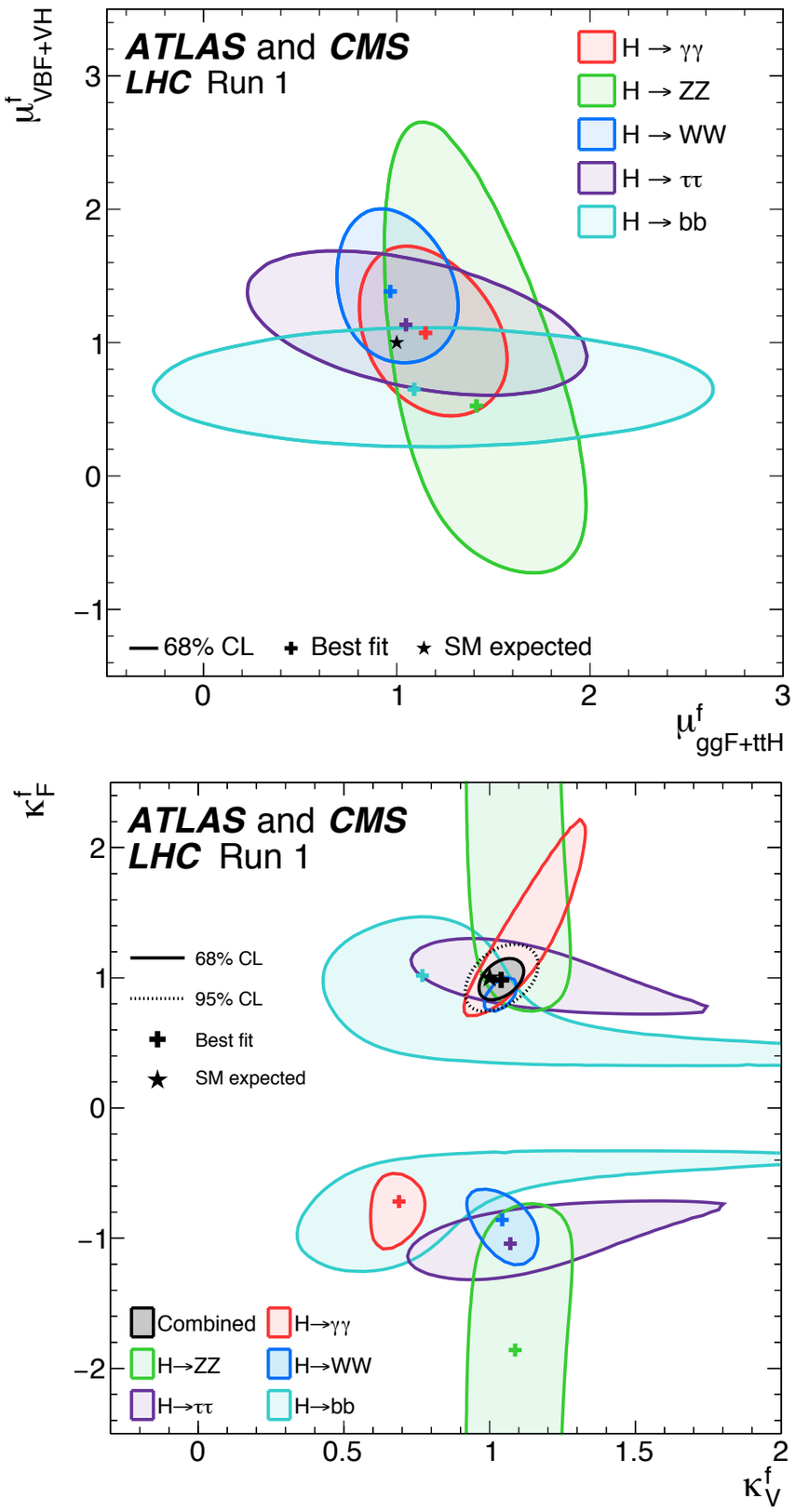
In Run1:

- BR(H→$\mu\tau$)<1.51%
- BR(H→eτ)<0.69%

  BR(H→eμ)<0.035%

2015 sensitivity already close to run1 BR(H→$\mu\tau$)<1.2%

Combination of couplings (Run1)



- ATLAS and CMS combination are largely in agreement and compatible with the SM
- Huge effort to process the results (and systematic uncertainties) coherently among the experiments
- No evidence of deviations observed in run1 (given the uncertainties) neither in signal strengths nor couplings
- Run2 results coming in now

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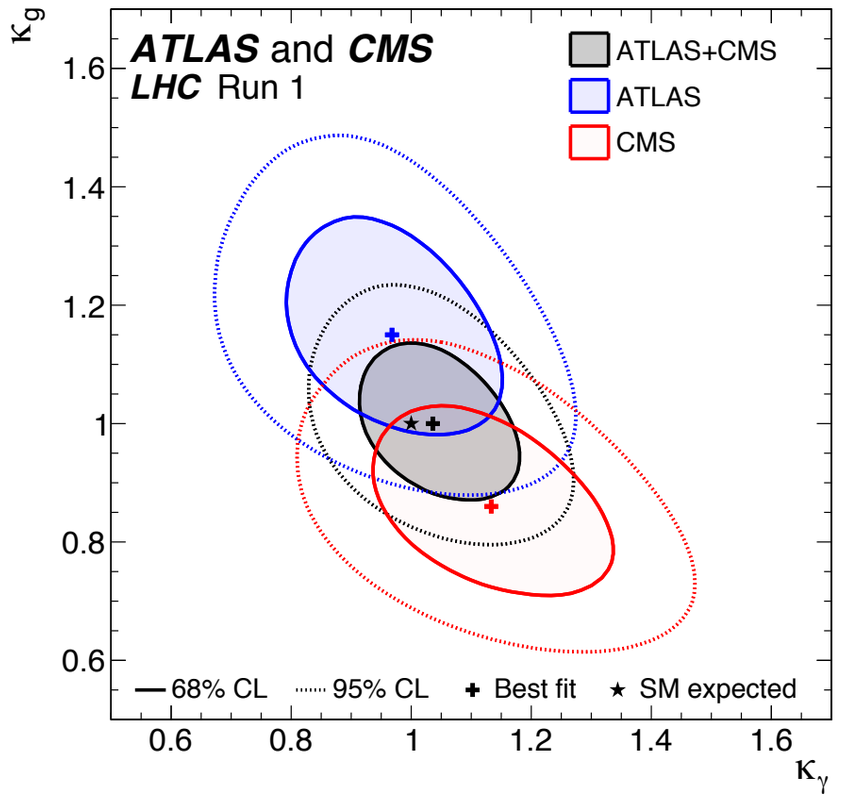
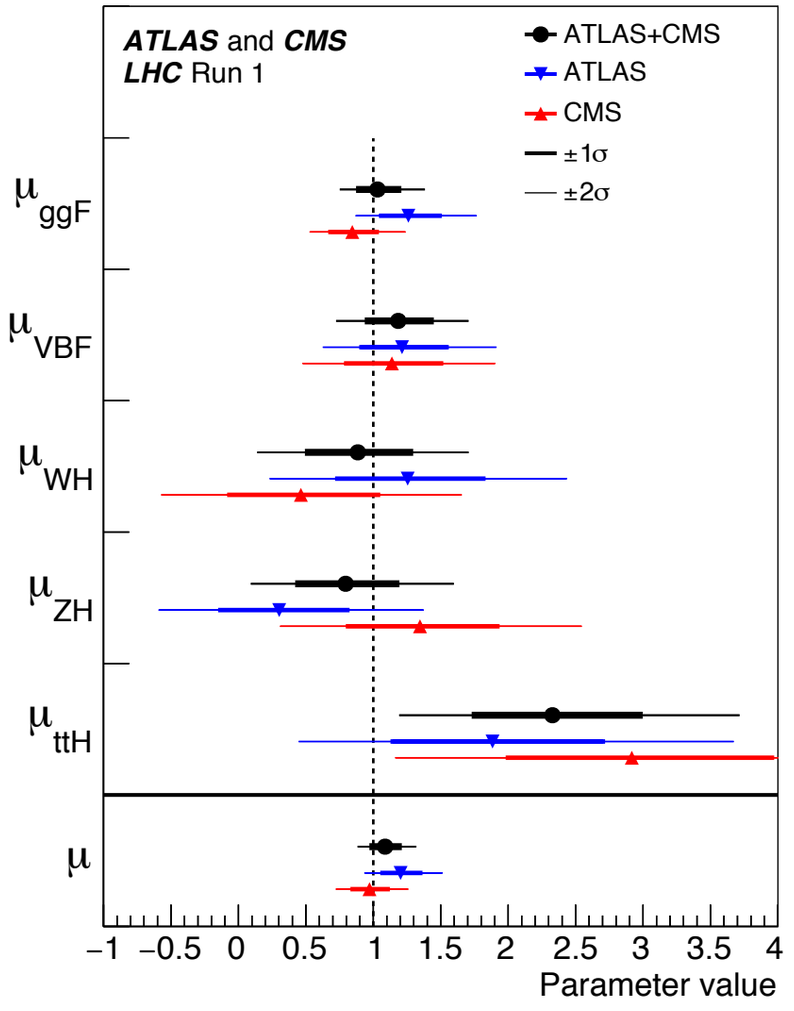
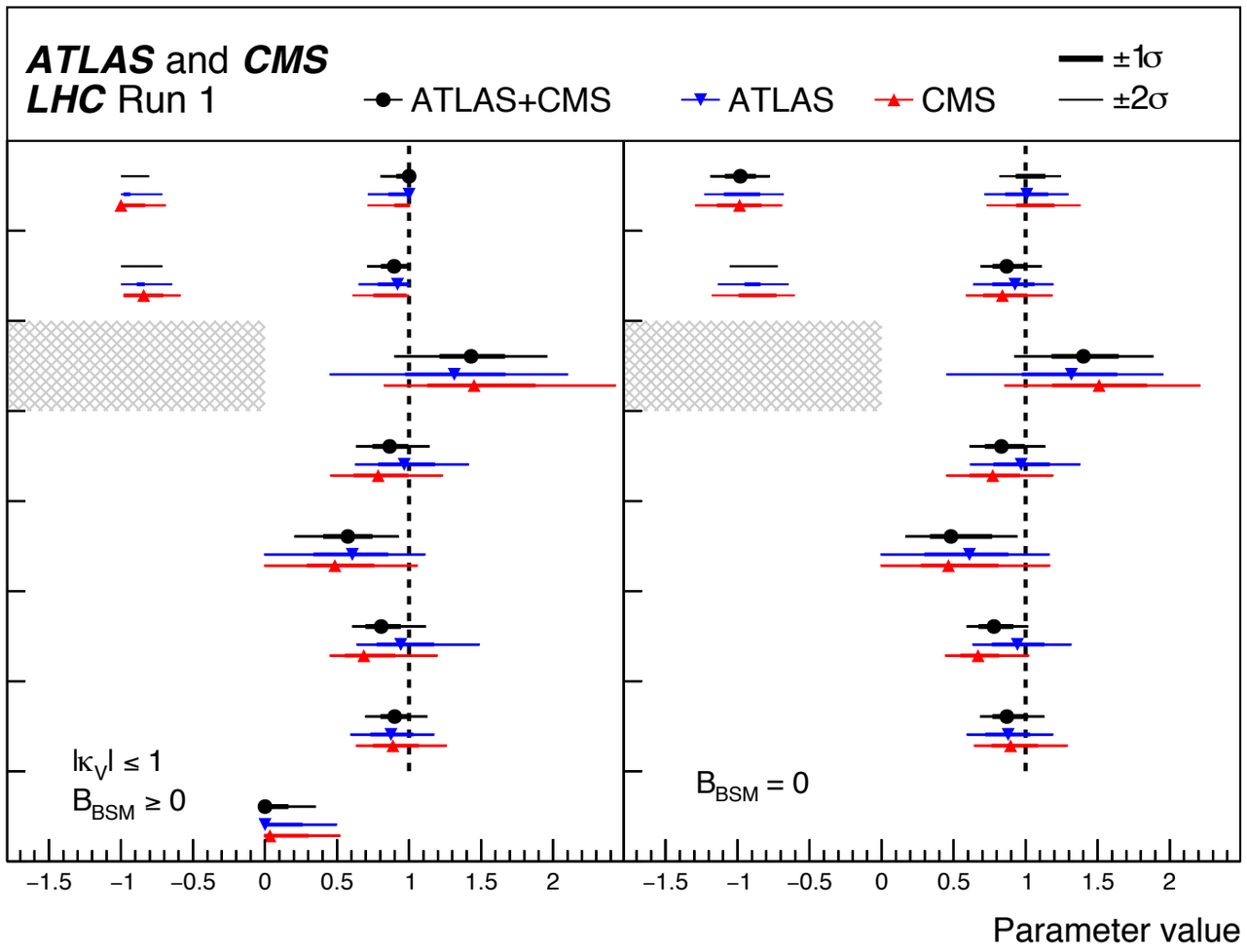
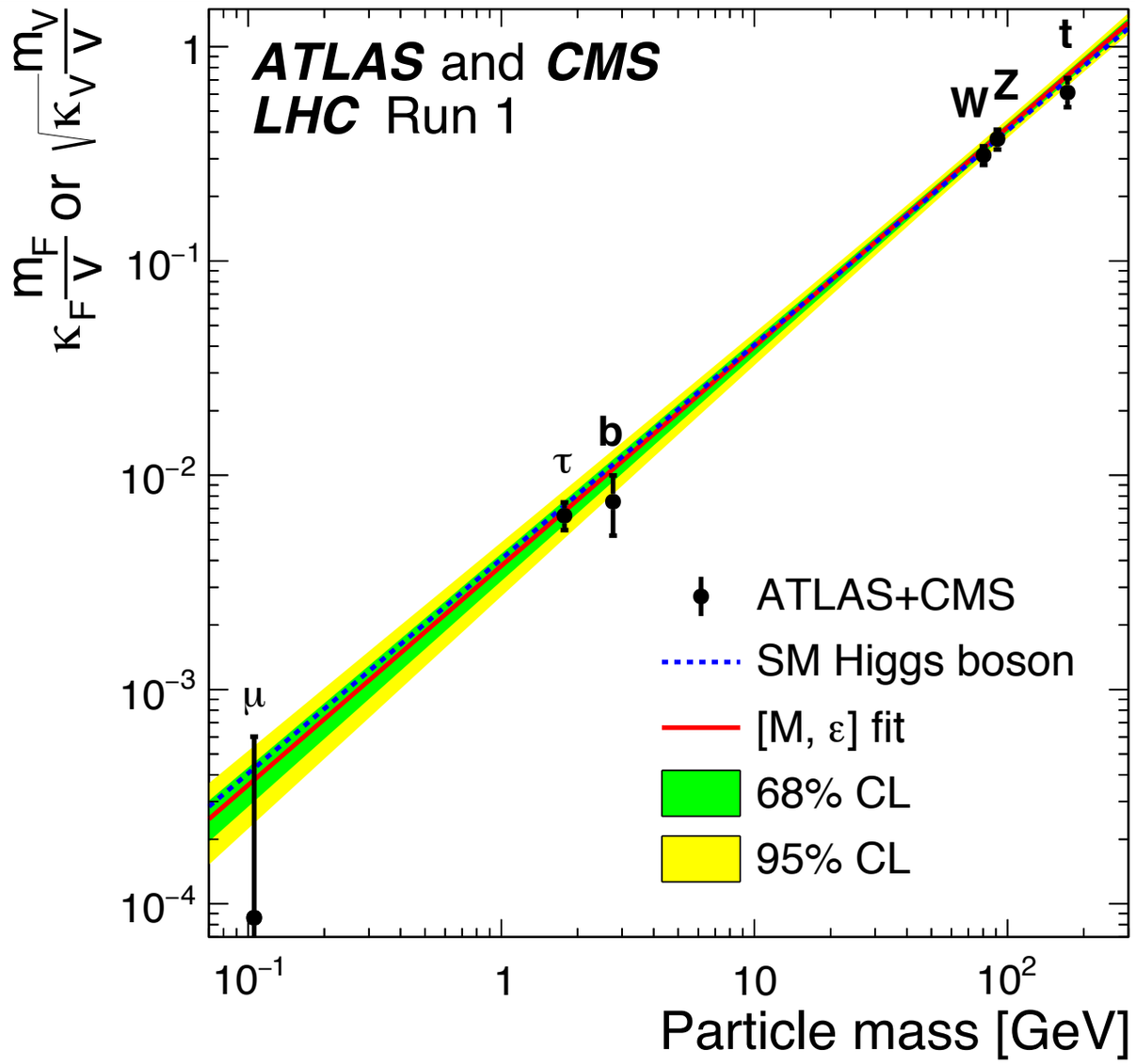




The big picture

- k-framework scaling model is very effective in predicting the value of the couplings
- Still room for deviations, especially in the unprobed low mass region
- But room for BSM is closing down (B_{BSM}<0.34)





Very difficult to probe this scaling beyond current range at LHC, but precise measurements are arriving from Run2 to reduce uncertainties

Prospects

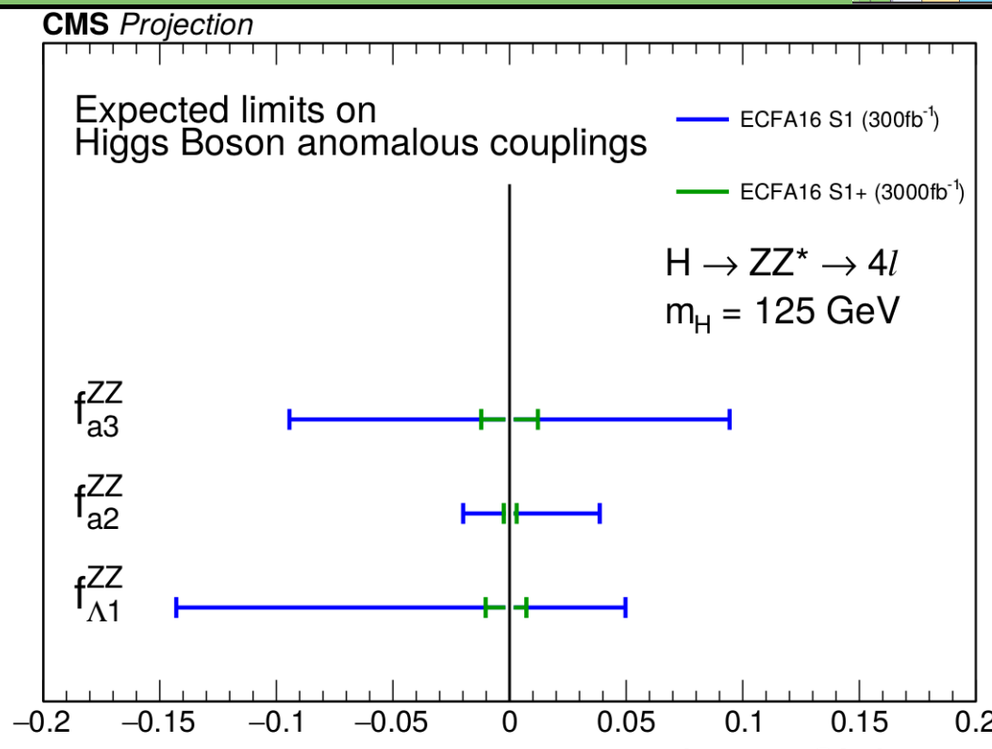
DP-2016-042

Projections for CMS performance including detector upgrades for HL-LHC

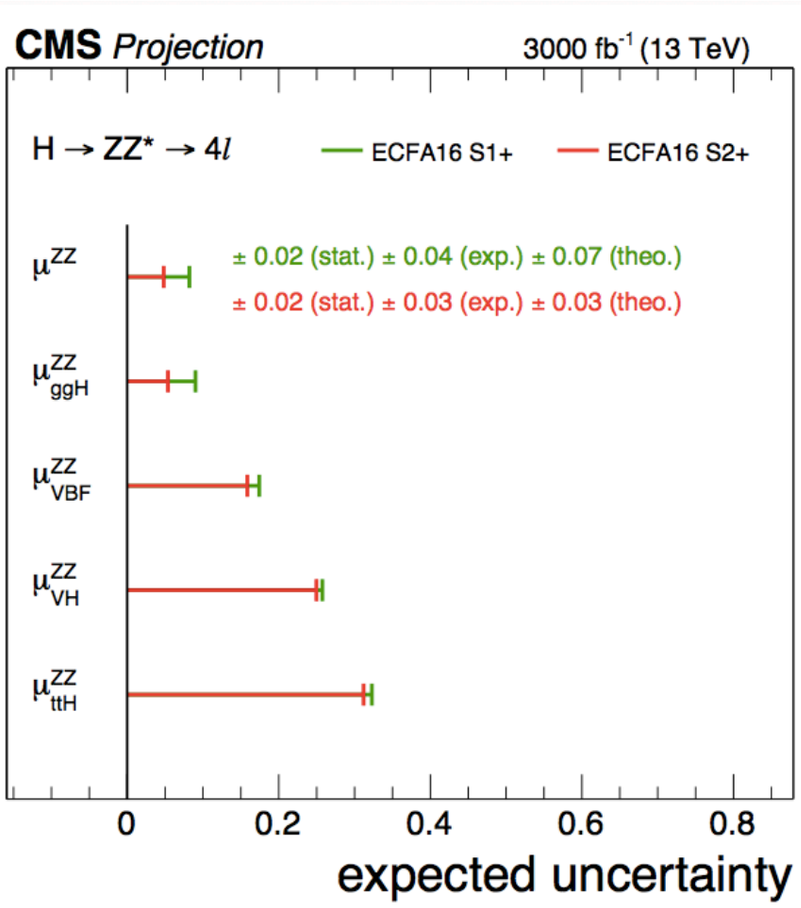
Systematics kept constant (S1) or scaled (S2)

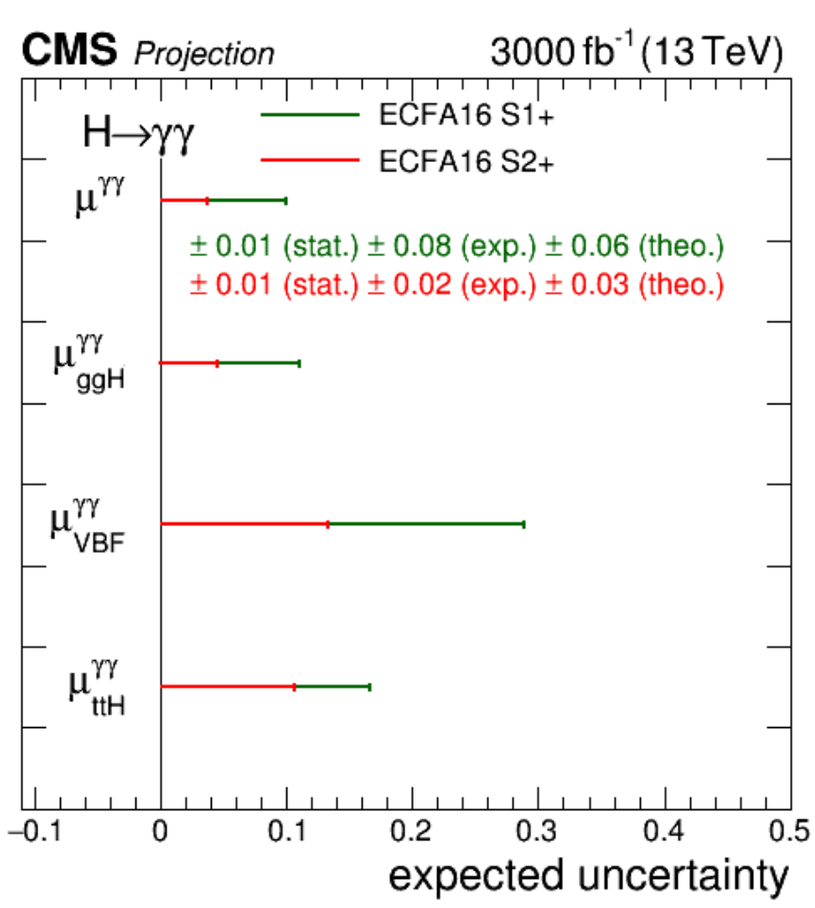
Important reductions of the uncertainties in the H→γγ and H→ZZ channels

Will gain access even to rare production modes



expected 95% CL limits





Extrapolations based on 2015 data

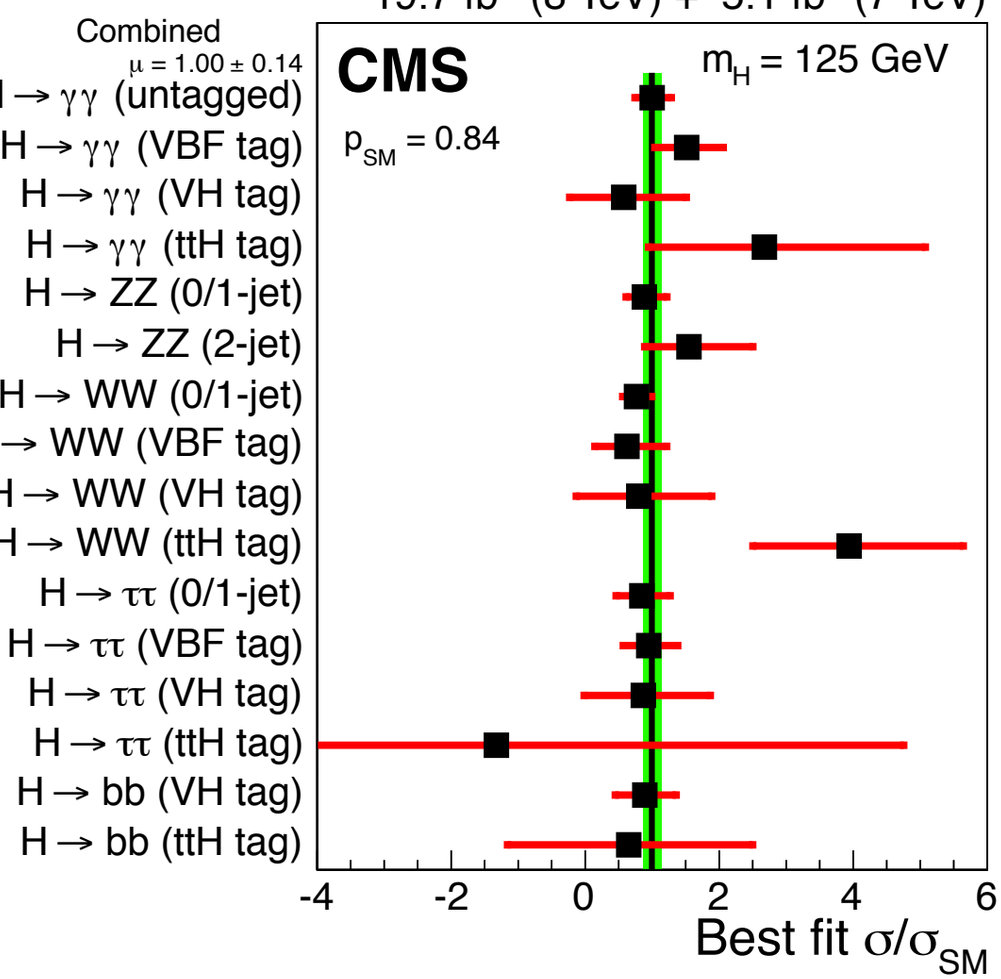
Analyses already doing their best to overperform these predictions

Conclusions

The measurement of the couplings of the Higgs boson to SM particles is one of our best handles to explore BSM physics

CMS is providing an extensive measurement of the couplings covering a wide range of production (ggH, VBF, VH, ttH) and decay (ZZ, $\gamma\gamma$, WW, $\tau\tau$, ll, bb) modes

The combination of (Run1) results with ATLAS showed very good agreement between the experiments and with the SM predictions, with fermionic/bosonic scaling holding up nicely



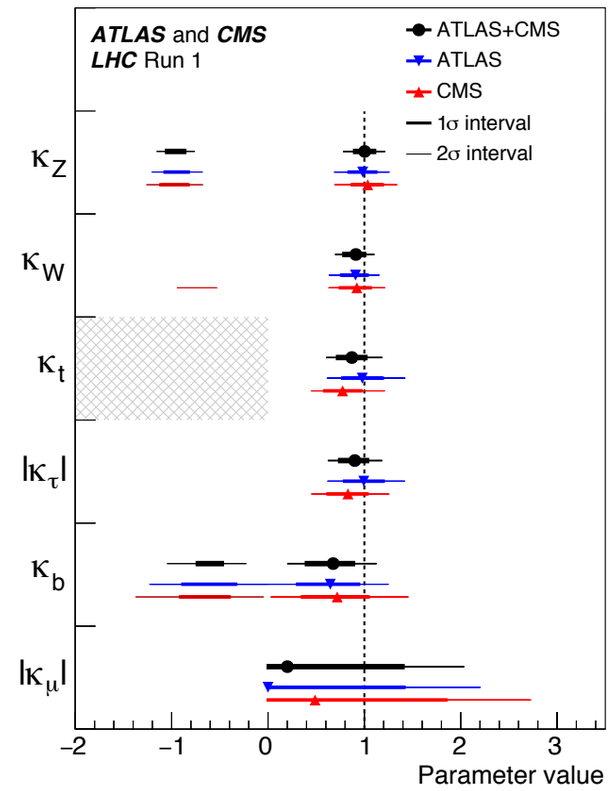
The BR for BSM physics is getting narrower (<0.34 with Run1 results)

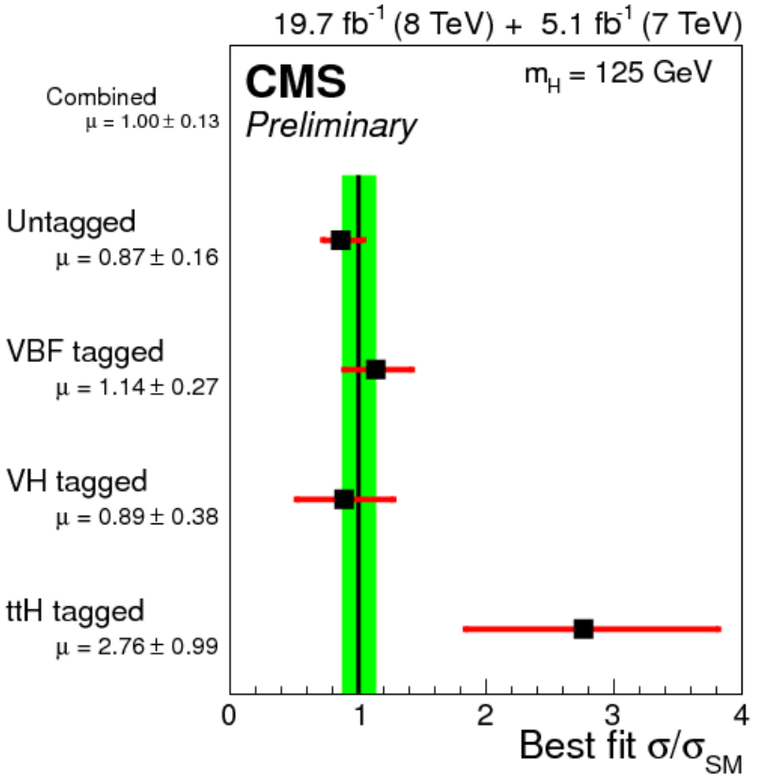
New results are coming soon for Run2 results at 13TeV, and prospects for our capabilities to precisely measure the H couplings at HL-LHC are looking good

BACKUP

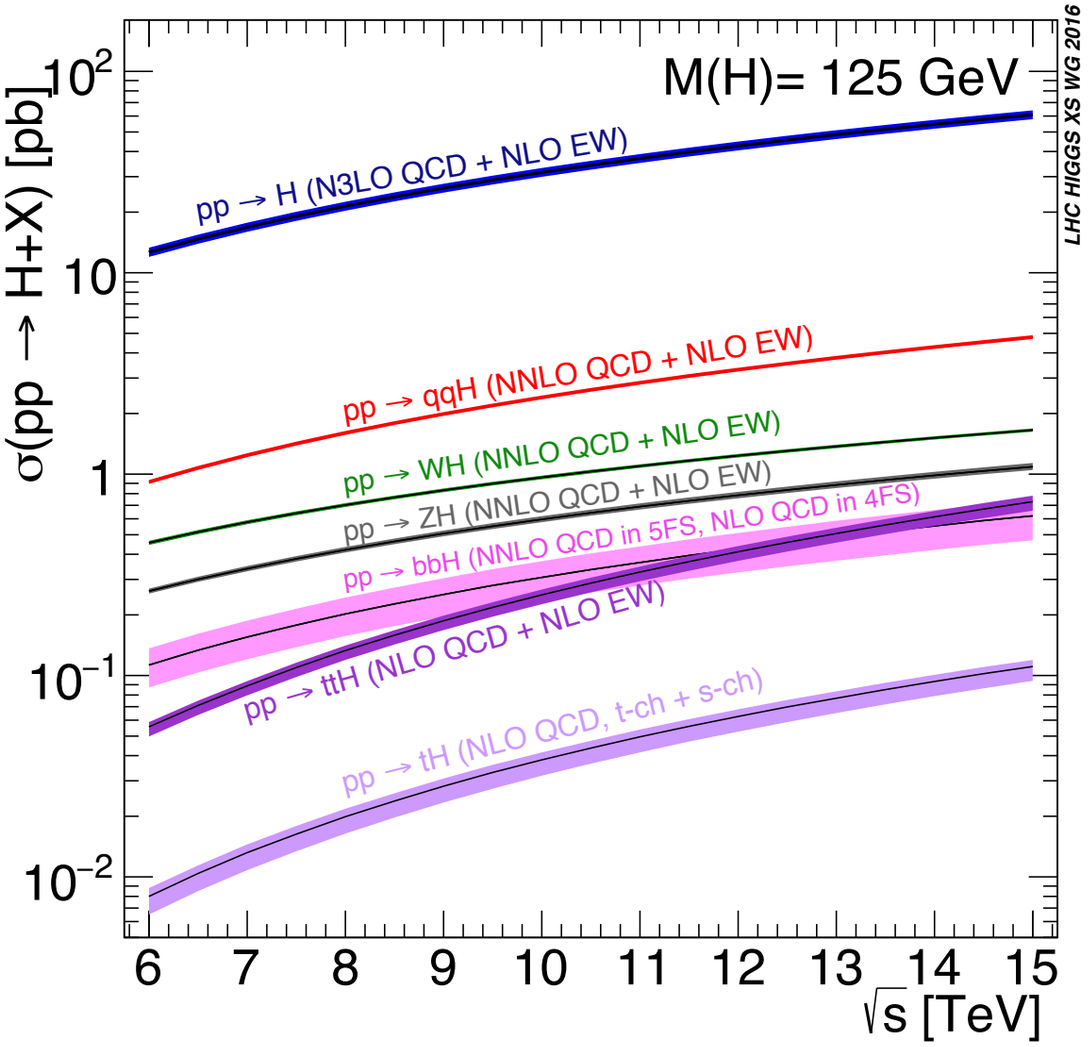
Run1 signal strength results

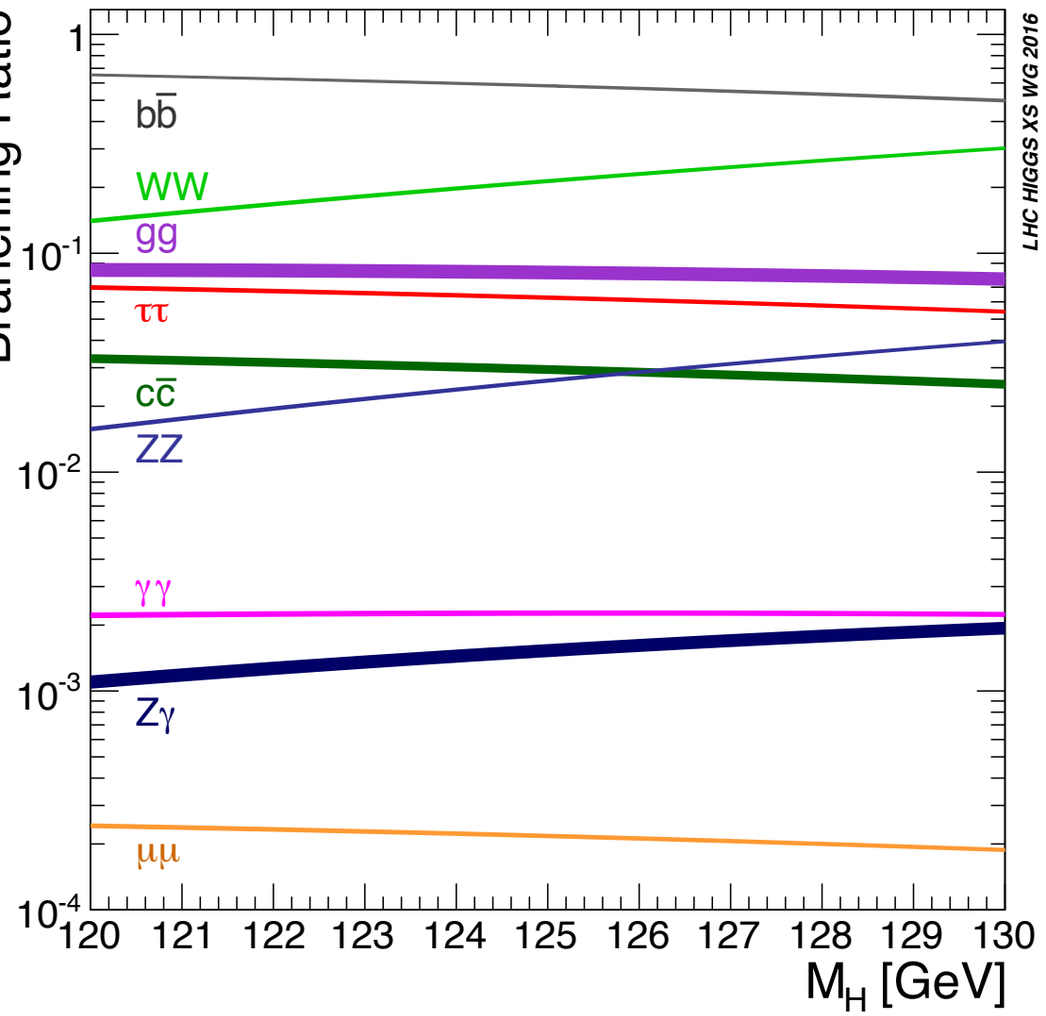
- Small (~2σ) overfluctuation in ttH
- Not large per se, but we are starting to see it in many channels across CMS and ATLAS
- top-Yukawa coupling is the strongest H coupling, if confirmed it would be an important hint of modifications in the SM loops
- Let's wait and see for confirmations from Run2





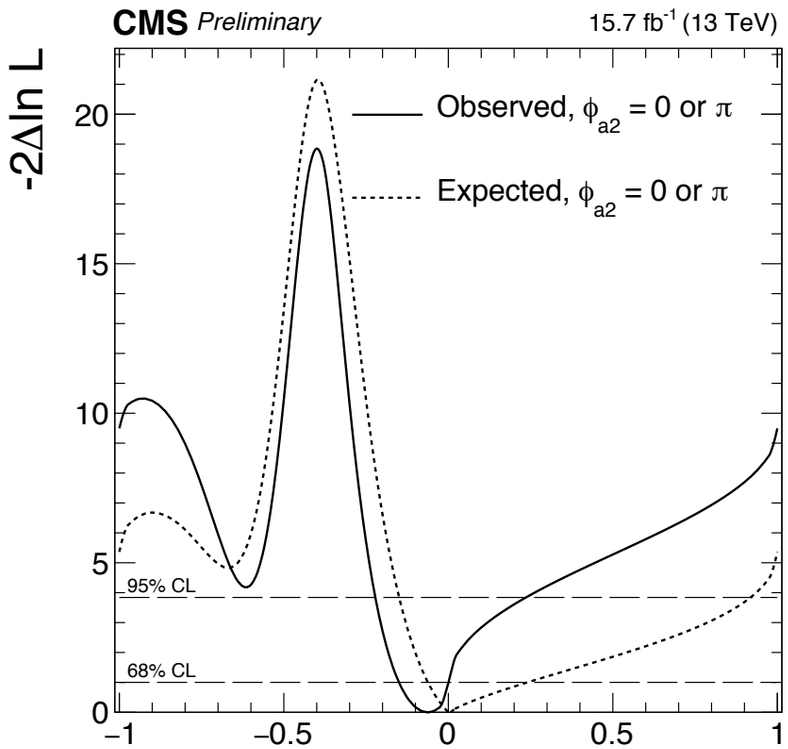
Higgs production at the LHC



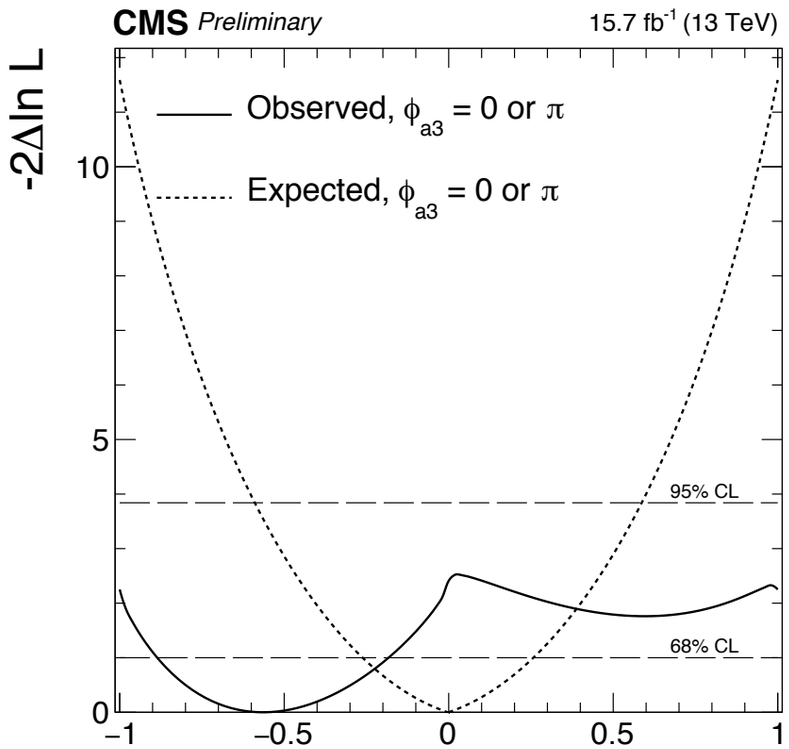


- Higgs production at the LHC dominated by gluon fusion
- At 13TeV, VBF and ttH accessible, providing informations on VH, H-t coupling

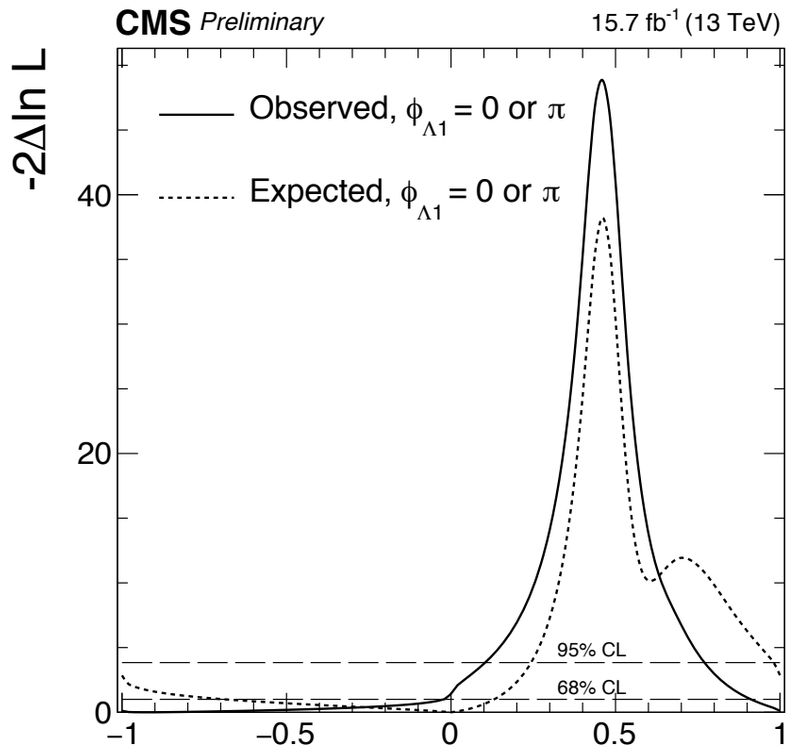
HVV anomalous couplings



$f_{a2}\cos(\phi_{a2})$



$f_{a3}\cos(\phi_{a3})$



$f_{\Lambda 1}\cos(\phi_{\Lambda 1})$

Phys. Rev. D 92, 012004 (2015)

$$f_{a3} = \frac{|a_3|^2\sigma_3}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4 + \ldots}, \quad \phi_{a3} = \arg\left(\frac{a_3}{a_1}\right),$$

$$f_{a2} = \frac{|a_2|^2\sigma_2}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4 + \ldots}, \quad \phi_{a2} = \arg\left(\frac{a_2}{a_1}\right),$$

$$f_{\Lambda 1} = \frac{\tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4 + \ldots}, \quad \phi_{\Lambda 1},$$

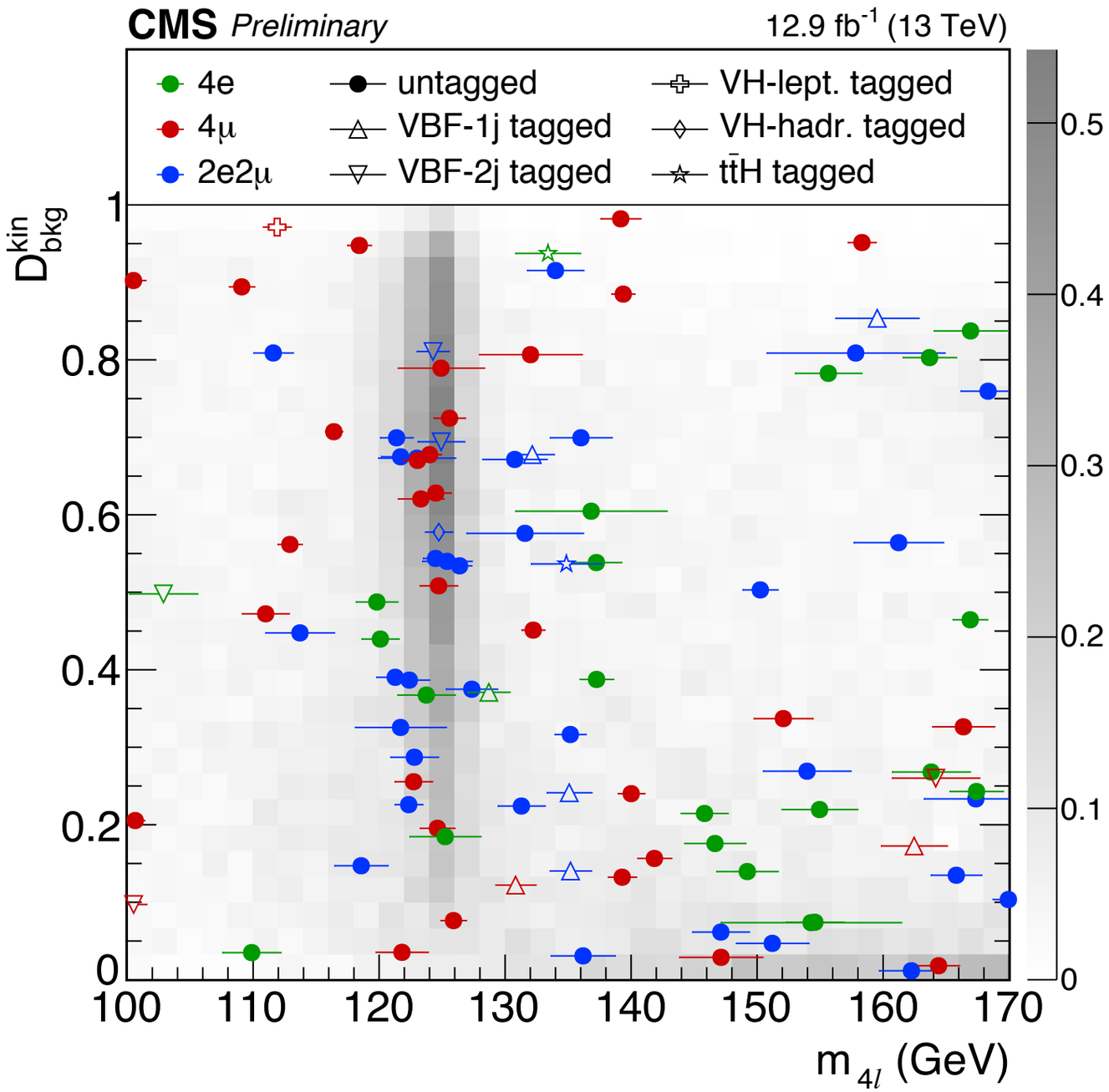
Expanded HVV amplitude to include anomalous coupling in the tensor structure. a2,a3 can be interpreted as anomalous couplings, Λ1 is the NP scale

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{(\Lambda_1^{\mathrm{VV}})^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f^{*(1)}_{\mu\nu} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f^{*(1)}_{\mu\nu} \tilde{f}^{*(2),\mu\nu},$$

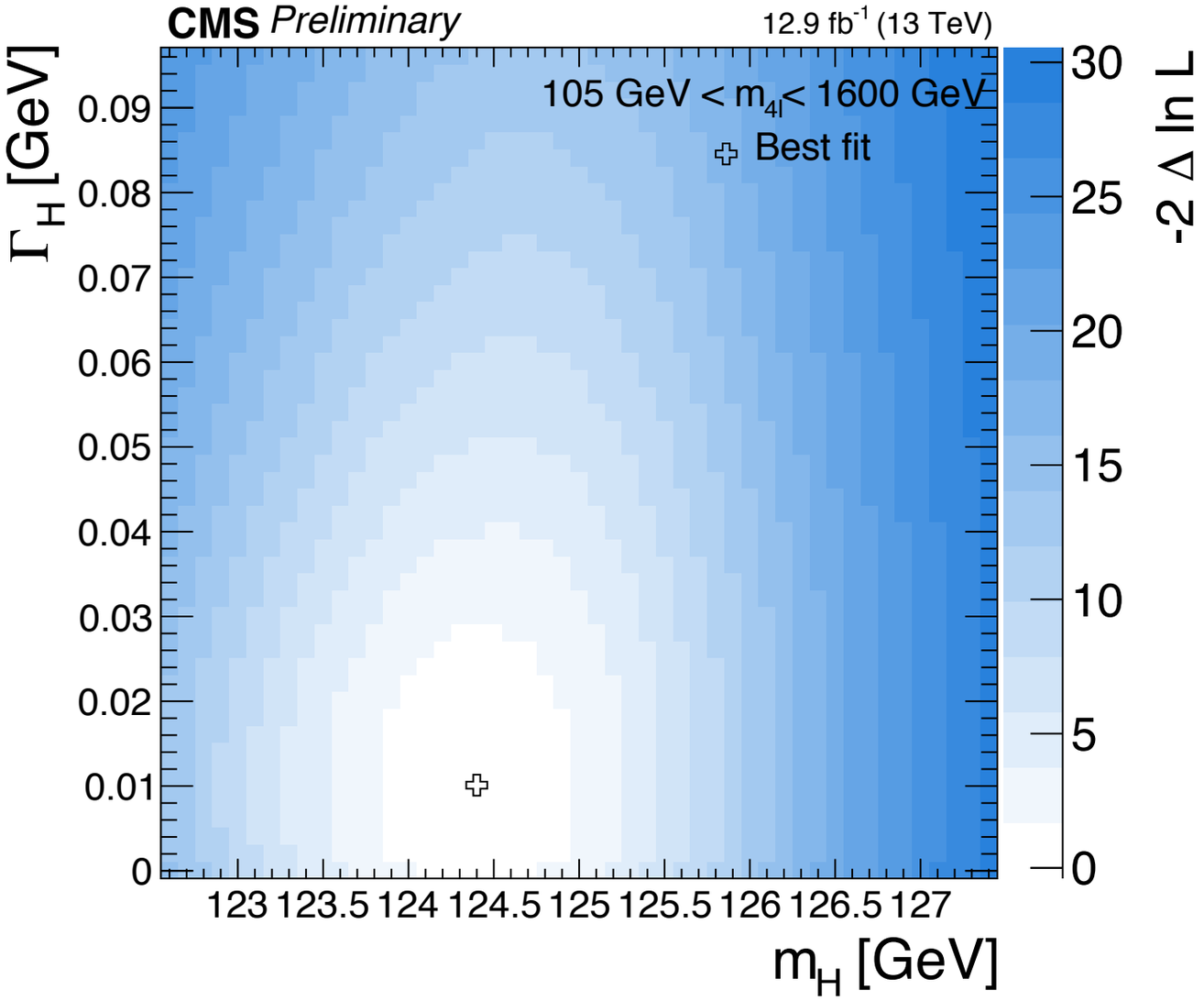
ZZ: event distribution by category

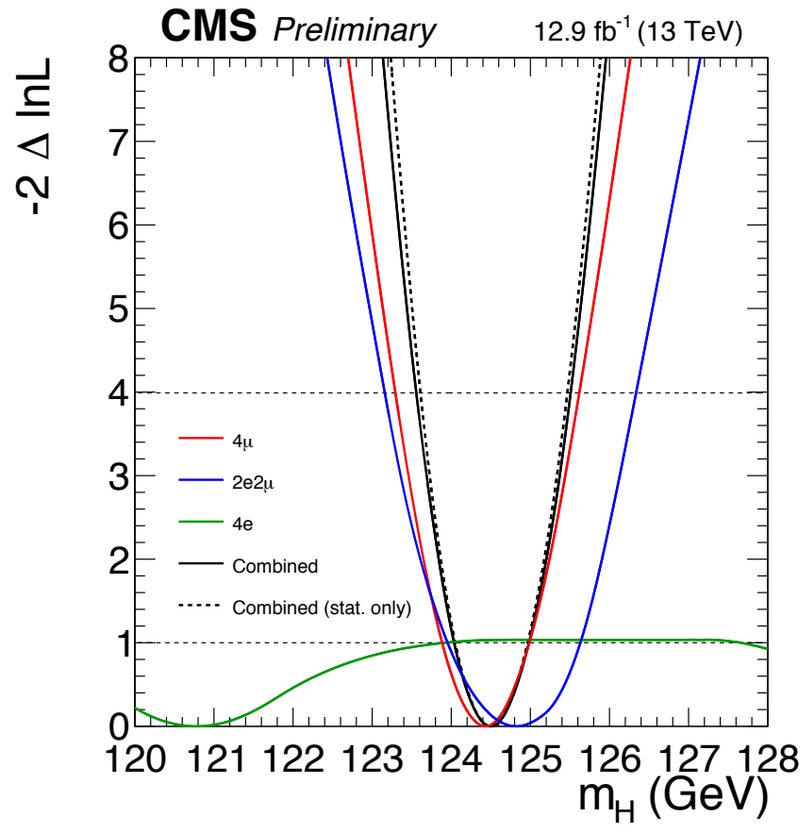
Only 1 event observed (4.9 expected) in the peak region $118<m_{4l}<130$GeV for VBF-1j category

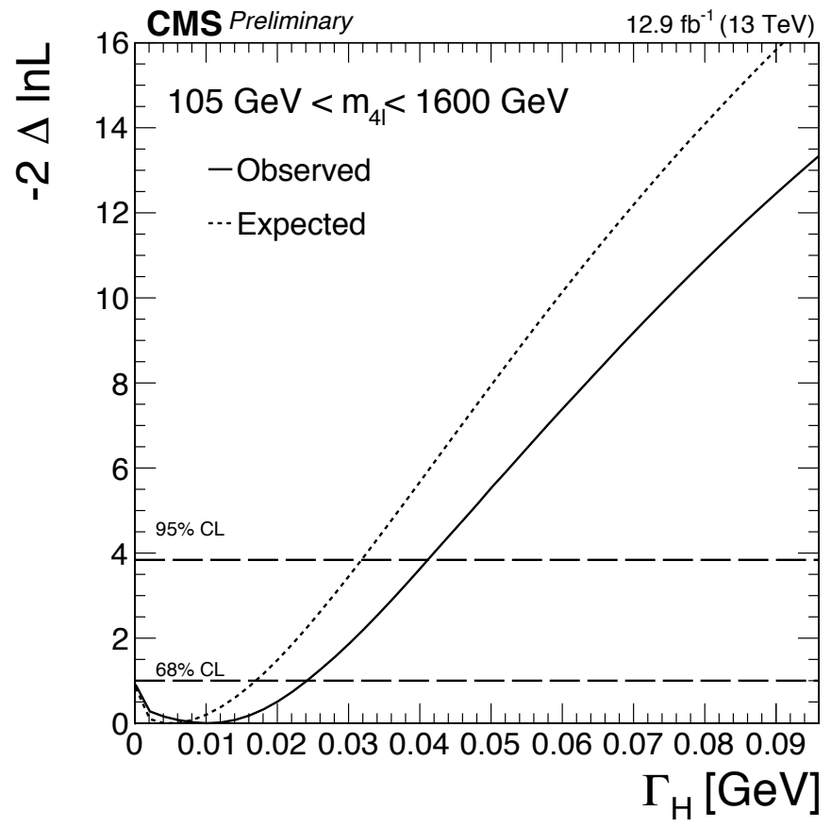
- It is a low-KD 4e event



Mass and width







Run1 results are essentially confirmed

H coupling to fermions: $\tau\tau$ Run2