Non-MSSM Higgs boson searches with CMS

Martin Flechl (HEPHY Vienna)

for the CMS collaboration

SUSY16, 2016/07/05

HEPHY Institut für Hochenergiephysik

CERN

CMS

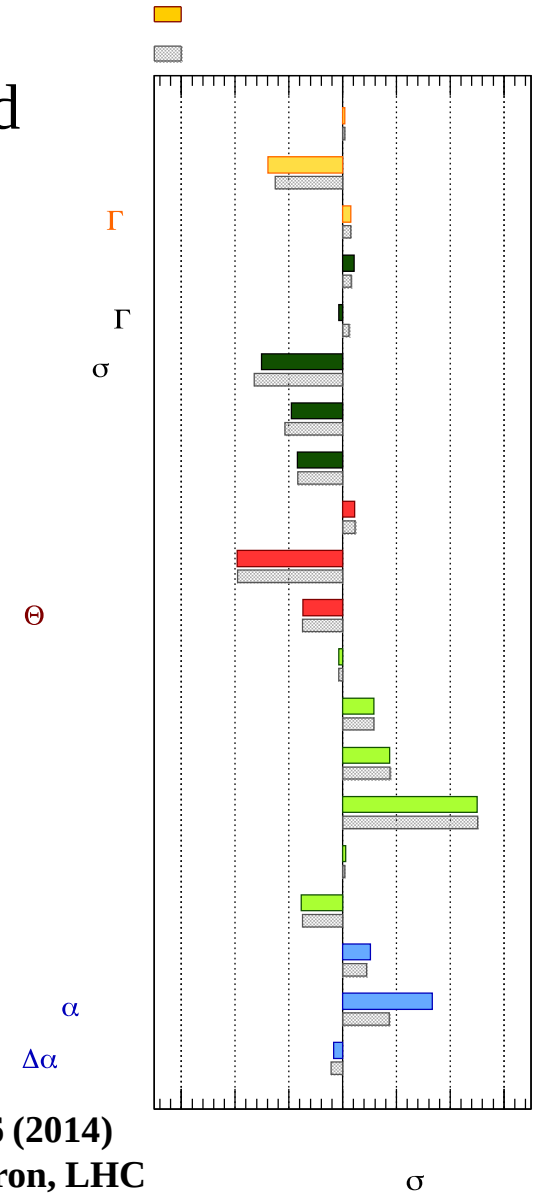
FWF Der Wissenschaftsfonds.

Higgs & EW theory status: run 1

- Global EW fit (Gfitter collaboration) after Higgs boson discovery & m_H measured
  - χ^2 / dof = 17.8 / 14 (p value: 0.21)
    [for m_H=300 GeV, would be p=3x10^{-5}]

- For the first time: self-consistent EW sector
  - **No direct observation of BSM physics**
  - **No (indirect) indication of BSM physics in h(125) measurements**
    - **Higgs boson coupling strength SM-like**
    - **consistent with a 0+ state**
    - **Higgs boson mass and width**

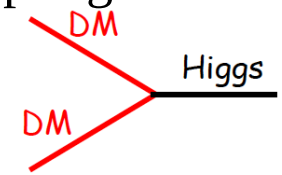
- Time to forget about the Higgs boson and move on to something more interesting?



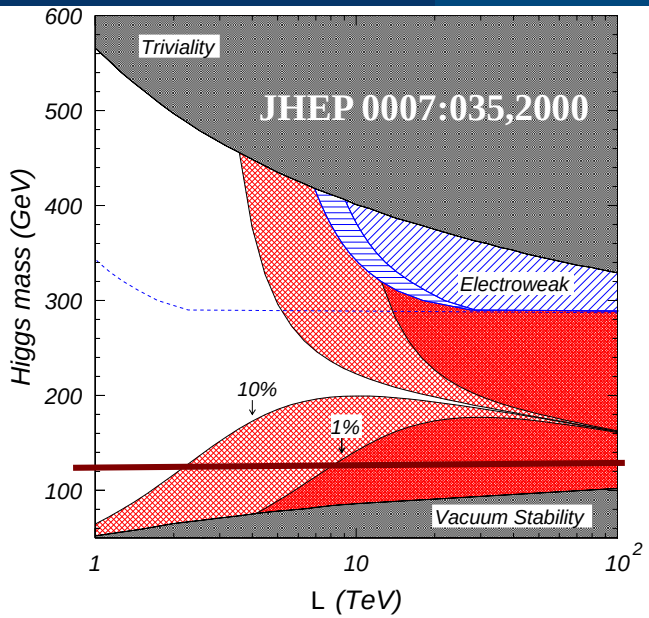
Eur. Phys. J. C 74, 3046 (2014)
Data: LEP, SLC, Tevatron, LHC

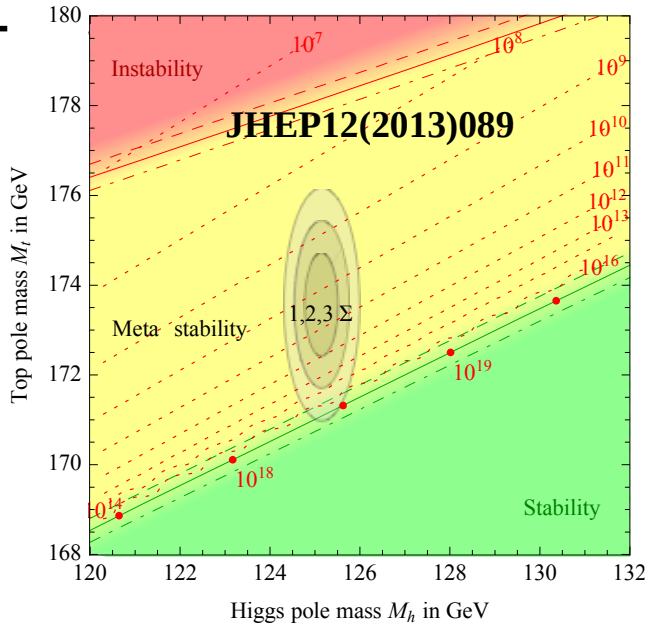
Open questions in the Higgs sector

- **Naturalness**: $m_H^2 \sim \mu^2 + c\Lambda^2$.
  - If it is real: low fine-tuning requires TeV-scale BSM physics (for 1%: Λ<10 TeV)
- **Vacuum stability**
  - Nature of EW vacuum tied to m_{top} and m_H
- **Dark matter, dark sector**
  - H could be the only SM particle coupling to DM



- **Direct probe for BSM physics**
  - Search for additional Higgs bosons (on-shell)
- **Indirect probe for BSM physics**
  - BSM models: typical effect on couplings O(5%)
    - MSSM, composite Higgs, twin-Higgs, add. singlet
    - Just about to enter this region of precision!





Outline

Searches in this talk

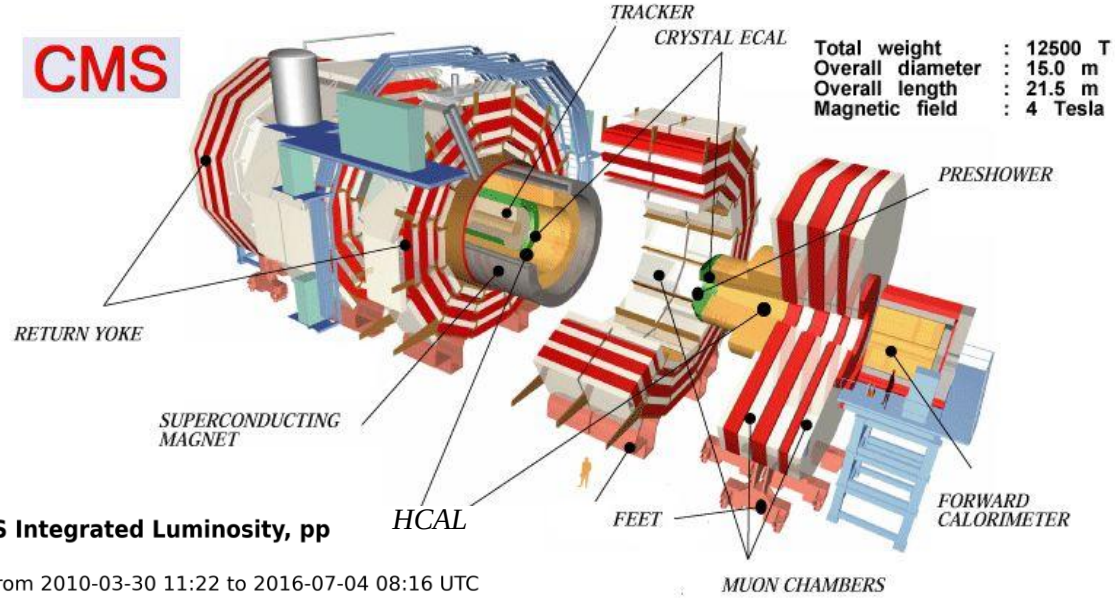
- High-mass Higgs boson
- 2HDM summary
- h→aa
- Di-Higgs
- H→invisible
- LFV Higgs boson decays

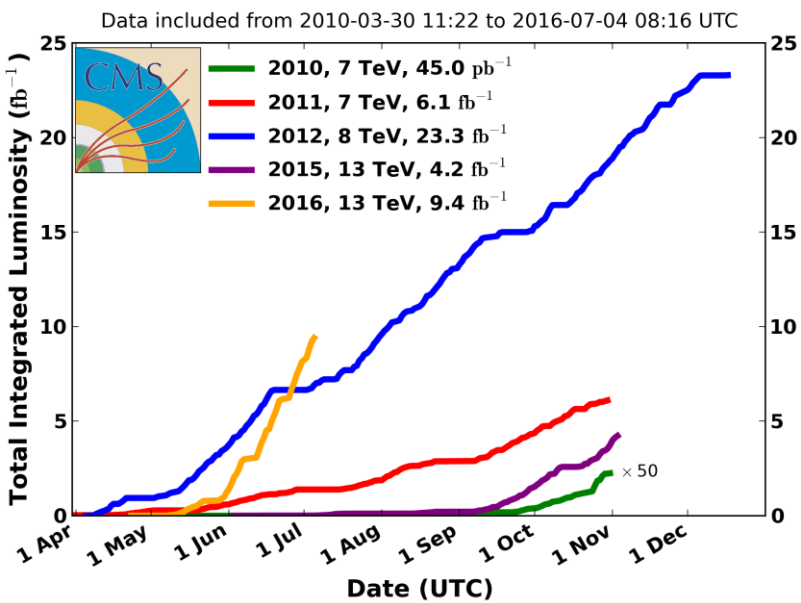
MSSM Higgs boson searches with CMS: see previous talk by Ye Chen

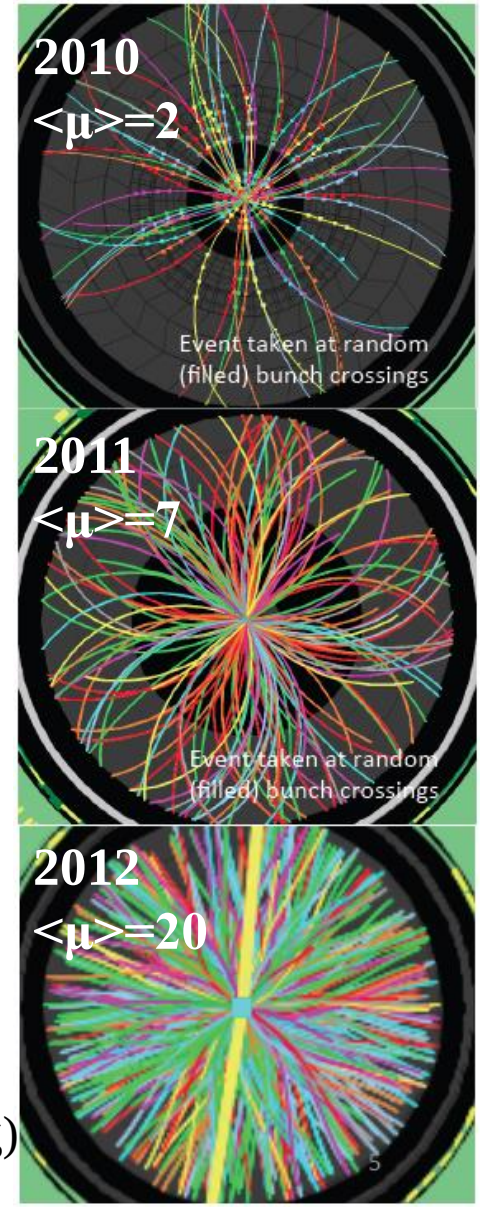
I will focus on **13 TeV results**, with very few exceptions.
All CMS Higgs results can be found here:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

CMS experiment





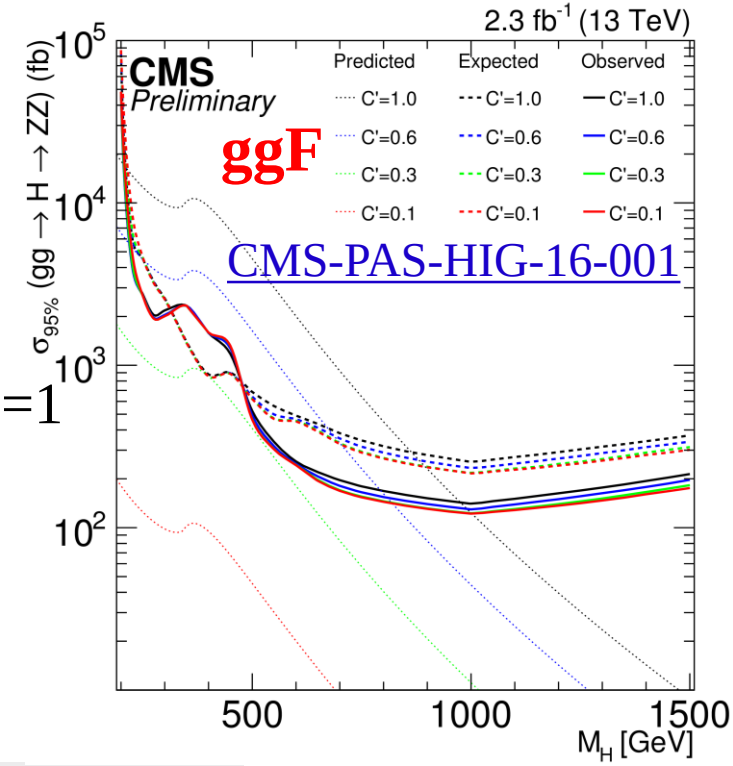


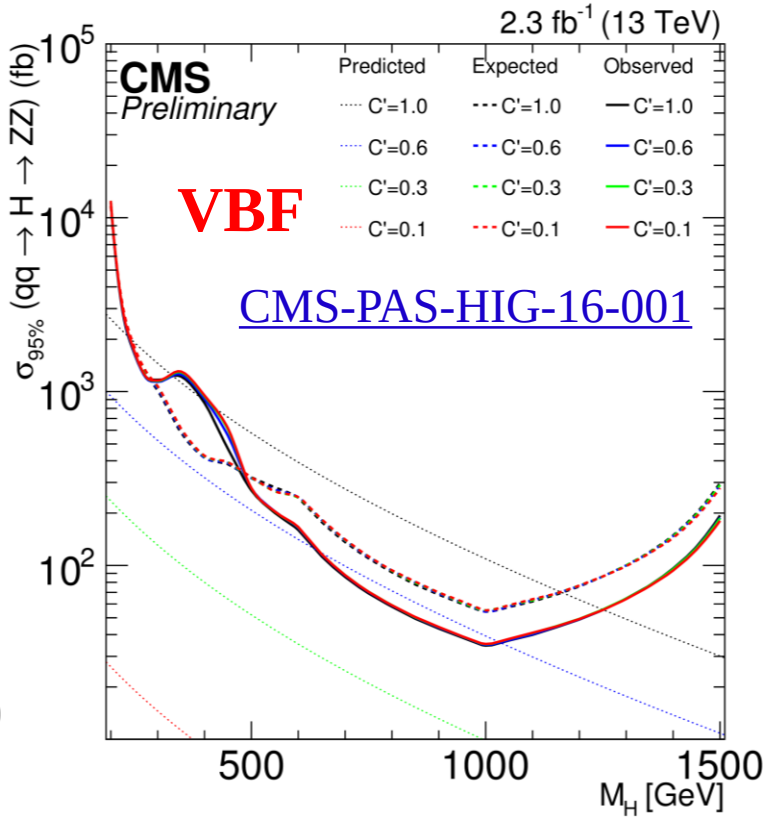
2015: <μ>=14 (25 ns)
<μ>=20 (50 ns)
2016: <μ>≈21 (& rising)
2030s: <μ>=200

High-mass Higgs boson searches

- Workhorses for high-mass SM-like Higgs boson searches
  - **ZZ→4l** CMS-PAS-HIG-15-004 **ZZ→llνν** CMS-PAS-HIG-16-001
    ZZ→llqq **WW→lνlν** **WW→lνqq**
- No significant excess observed
  - **llνν**: Limit for singlet mixing with h(125), separately for ggF and VBF
  - C'... coupling scaling factor

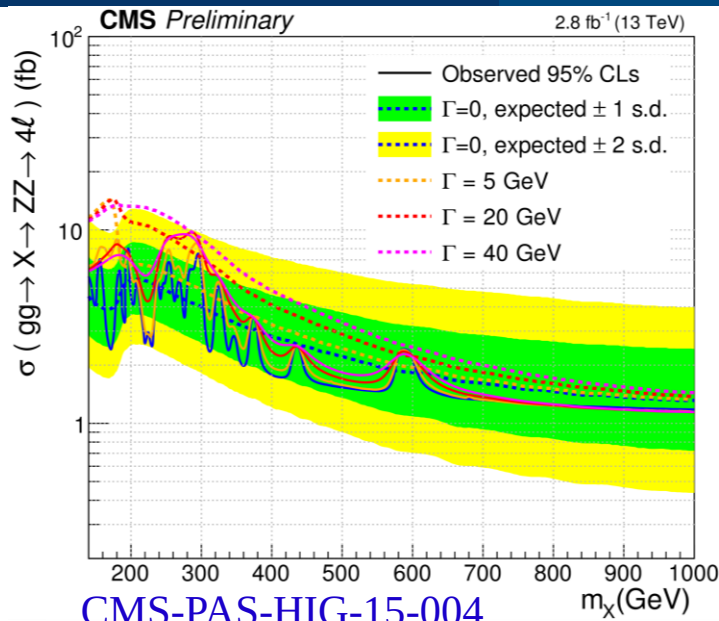
$C_{125}^2+C'^2=1$



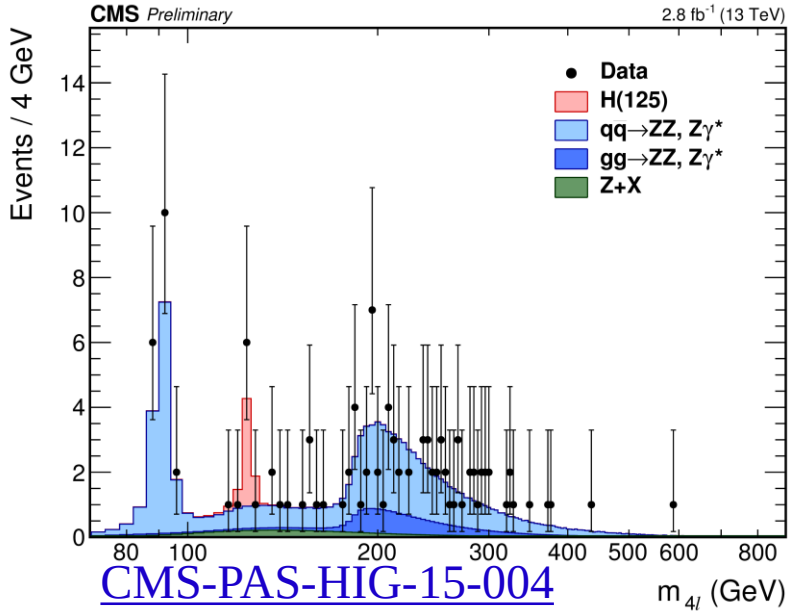


High-mass Higgs boson searches

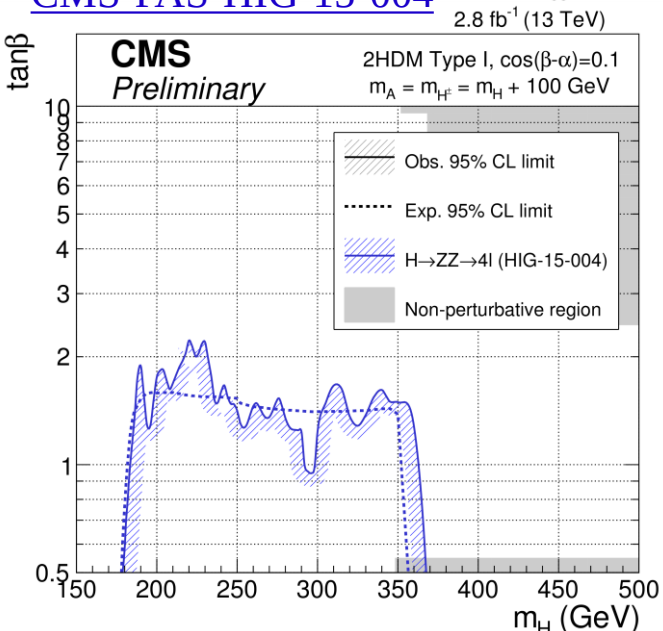
- **H→4l**
  - No event observed for m_{4l}>600 GeV
  - No significant excess
    - **Limit on σ(gg→X→ZZ→4l)**
      a few fb for m_X < 1 TeV
  - Low tan β exclusion in **type-I/II 2HDM** for mH from about $2m_Z$ to $2m_t$



CMS-PAS-HIG-15-004

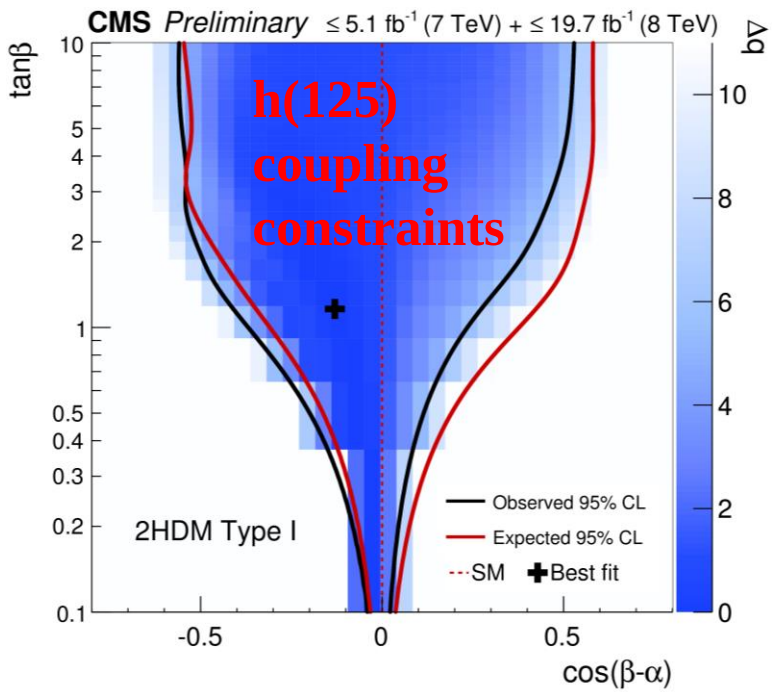


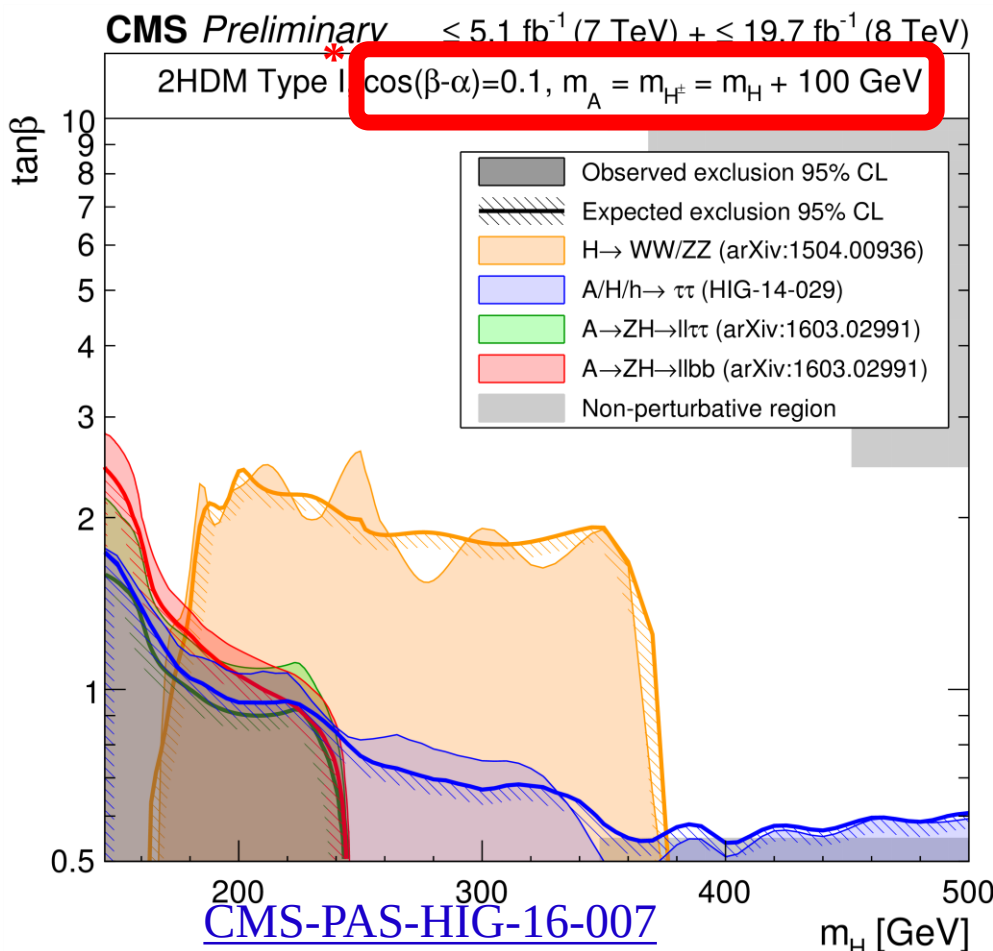
CMS-PAS-HIG-15-004



2HDM interpretation

- **Summary of run-1 results** (not a combination!)
- **2HDM type-I** (all fermions couple to the same Higgs doublet)
  - Constrained for $|\cos(\beta-\alpha)|>0.5$ or $\tan\beta<3$*, via VV ($m_H<2m_t$) and $\tau\tau$
  - Best-fit close to the alignment limit $\cos(\beta-\alpha)=0$

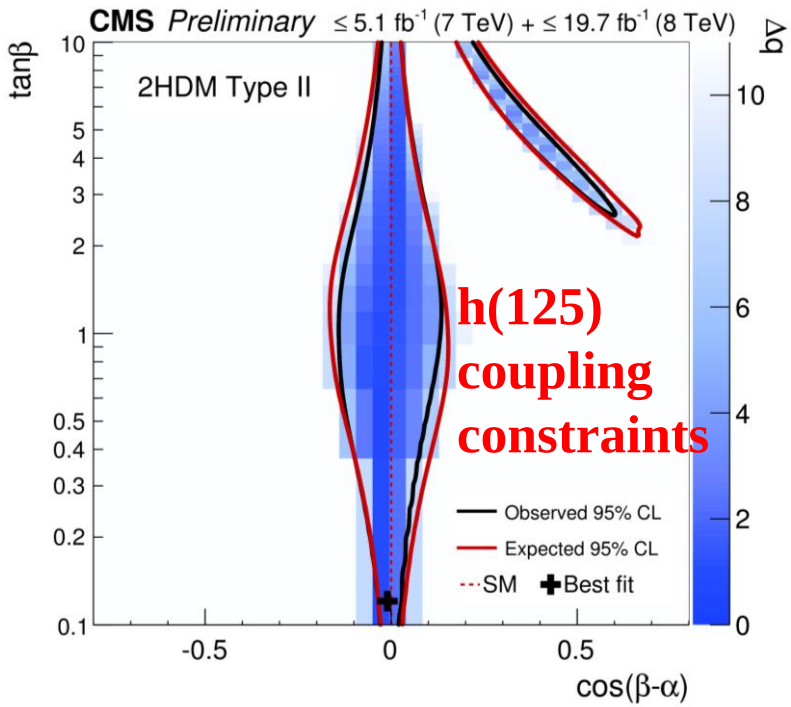


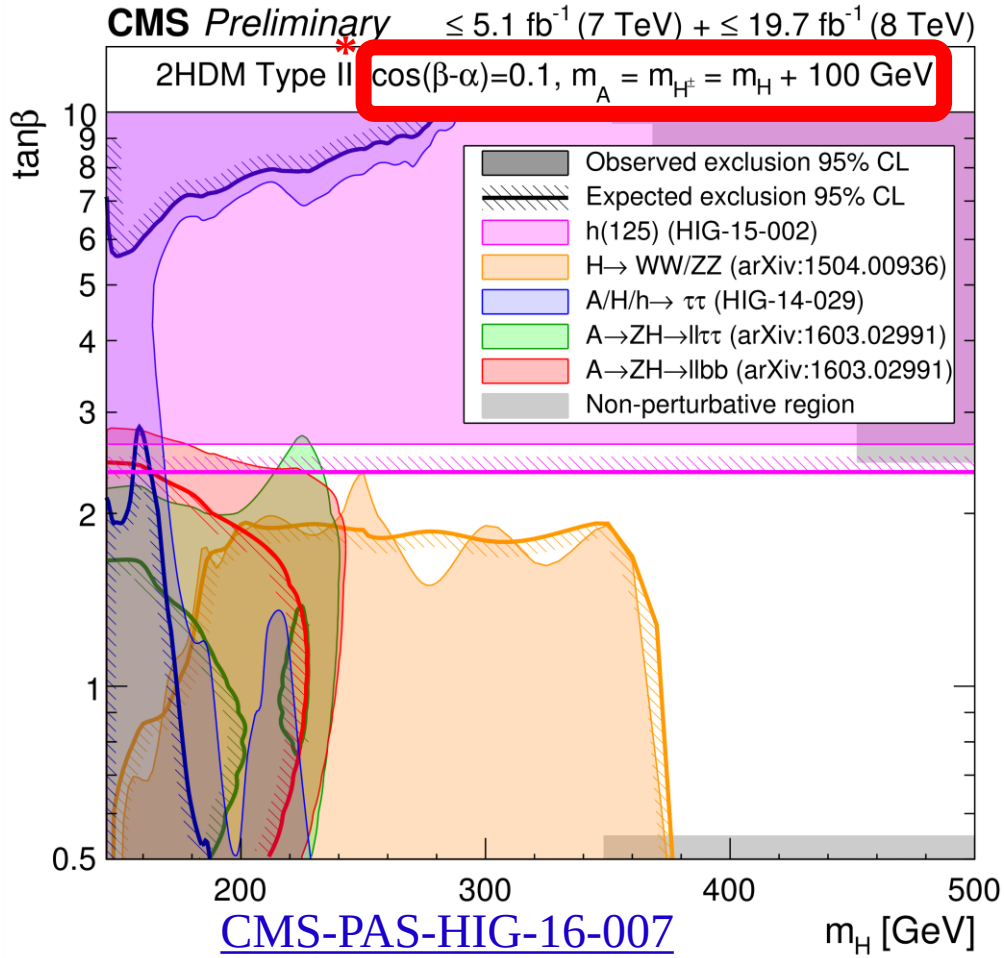


CMS-PAS-HIG-16-007

2HDM interpretation

- **Summary of run-1 results** (not a combination!)
- **2HDM type-II** (up/down-type fermions couple to different doublet)
  - Constrained for |cos(β-α)|>0.2 (VV, ττ, coupling fits)
  - Best-fit at the alignment limit cos(β-α)=0



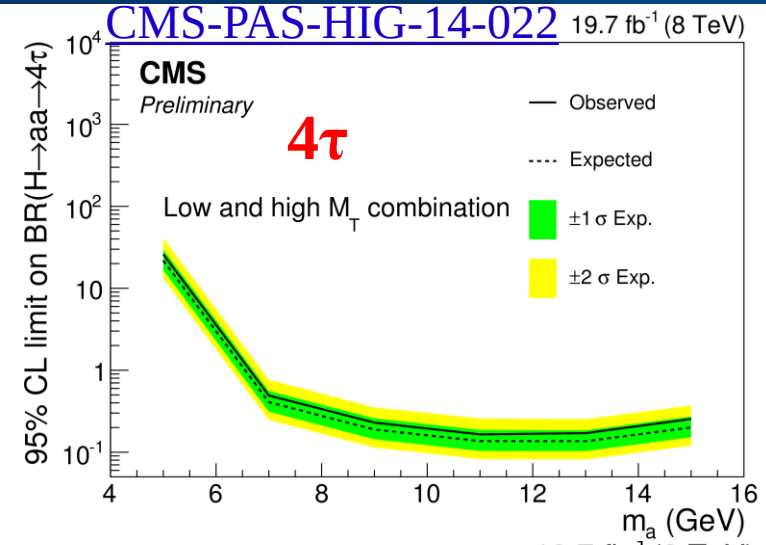


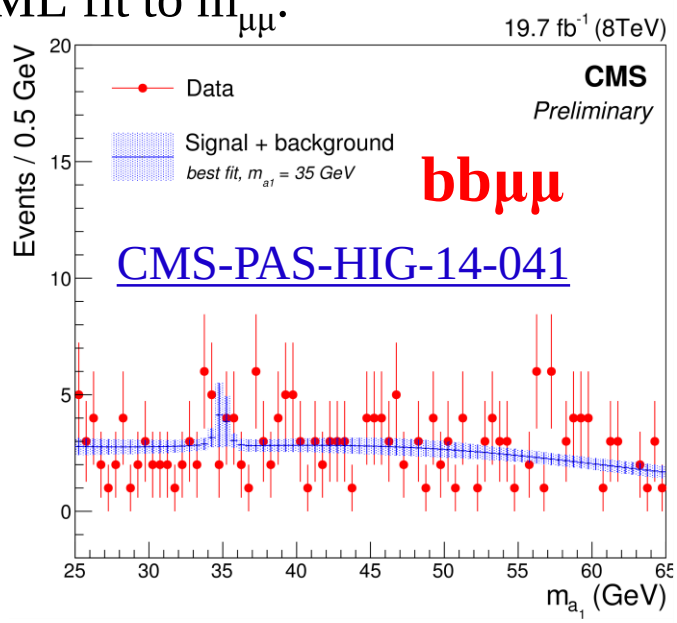
CMS-PAS-HIG-16-007

h(125)→aa

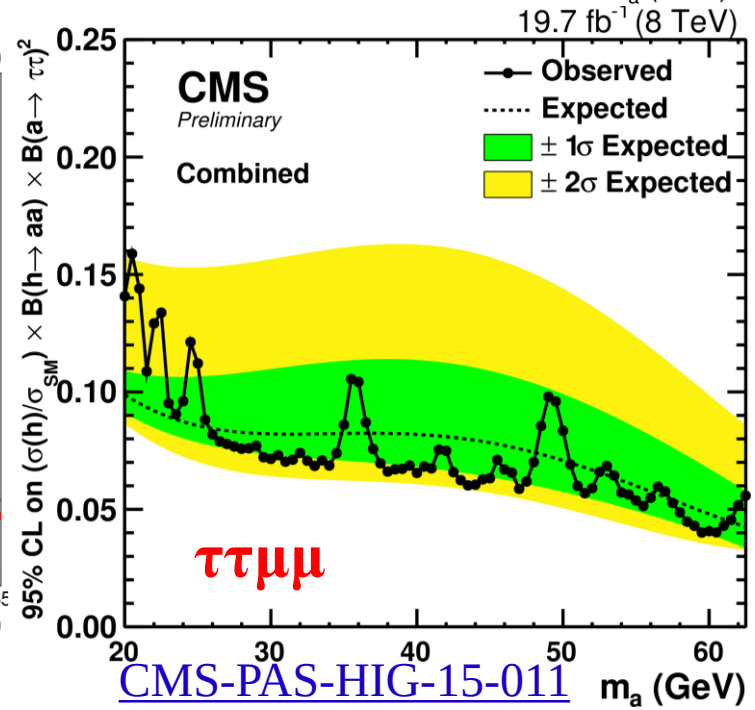
- Mainly motivated by **2HDM+singlet** models (e.g. NMSSM); 7 Higgs bosons
- Decays investigated: γγ, μμ, ττ, bb
  - **aa→4τ**: 5-15 GeV - subjet techniques
  - **aa→bbμμ, ττμμ**: 20 GeV - $m_h/2$
    - require $m_{bb\mu\mu / \tau\tau\mu\mu}$ to be (125±25) GeV
    - Unbinned ML fit to $m_{\mu\mu}$.
- No excess observed

CMS-PAS-HIG-14-022





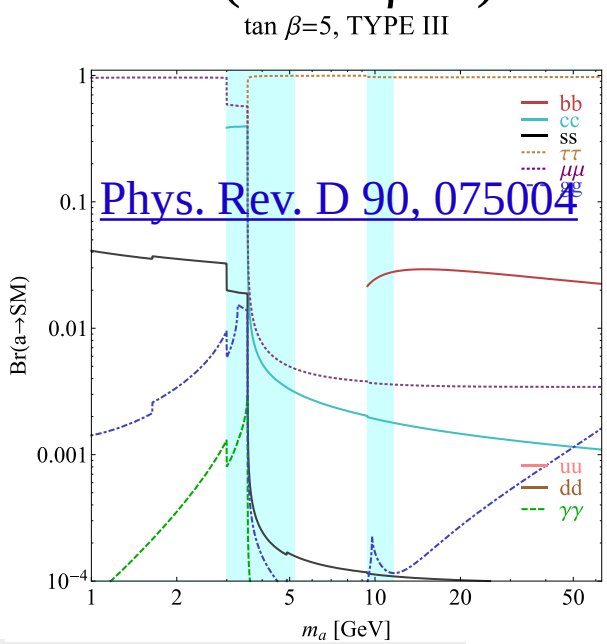
CMS-PAS-HIG-14-041



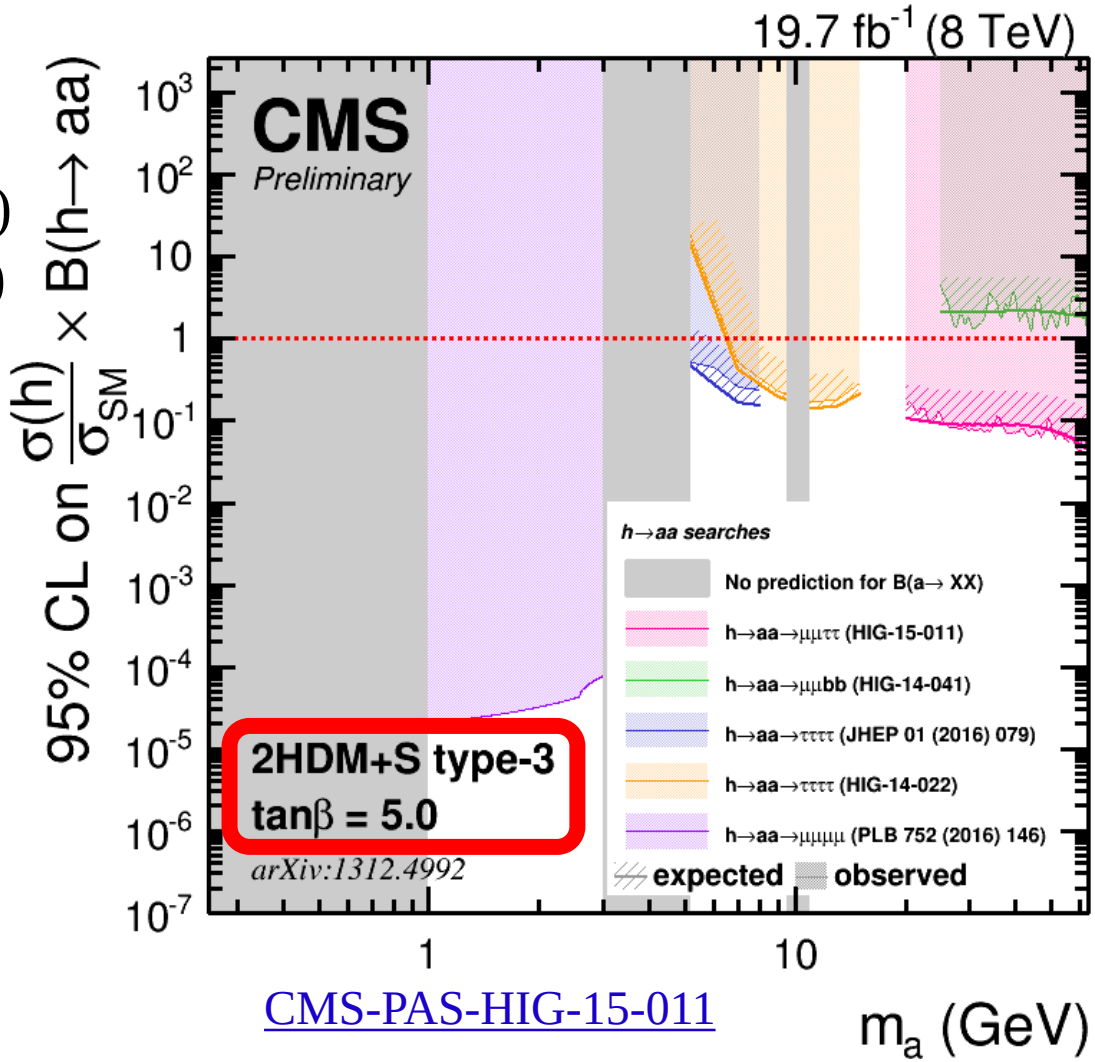
CMS-PAS-HIG-15-011

h→aa: summary

- For specific models, BRs are fixed; results can be compared
- Analyses are sensitive in different m_a regions
- Example: **2HDM type-3+S**
  - For SM production xsec, BR(h→aa)<10^{-4} (1-3 GeV) or <5%-50% (5-62.5 GeV) excluded (at tan β=5)



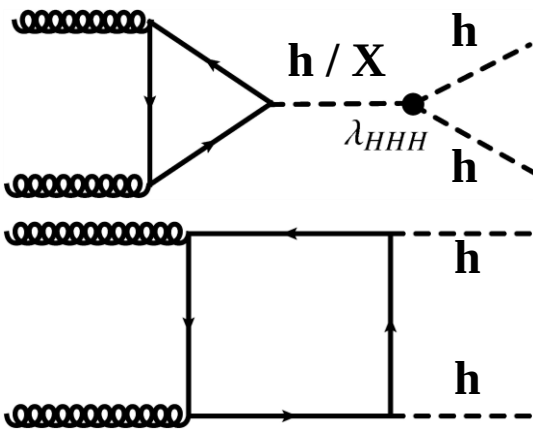
Phys. Rev. D 90, 075004

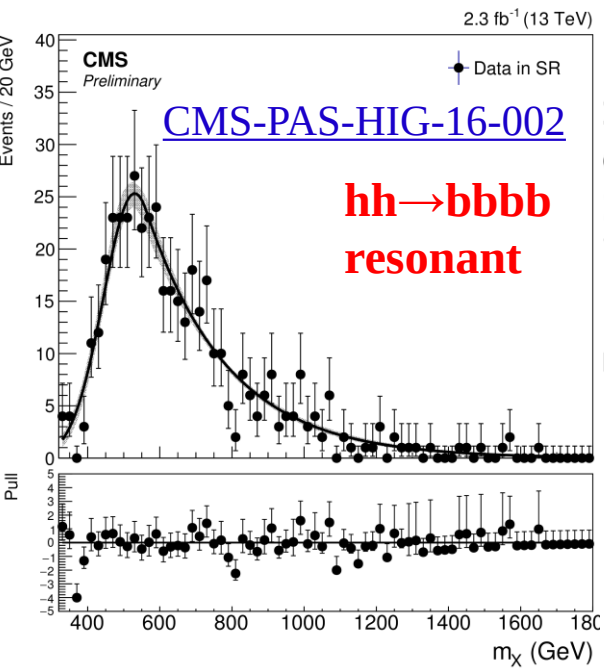


CMS-PAS-HIG-15-011

Di-Higgs searches: bbbb bbγγ bbWW

- Strong suppression in SM (negative interference)
  - Enhanced by **resonance**, or particle in the **loop**?
- Channels: **$h_1 \to bb$** (high rate), **$h_2 \to bb/WW/\tau\tau/\gamma\gamma$**
- require two decays compatible with h(125)
- **Resonance search**: spin-0 (radion) and spin-2 (G)
- No excess observed

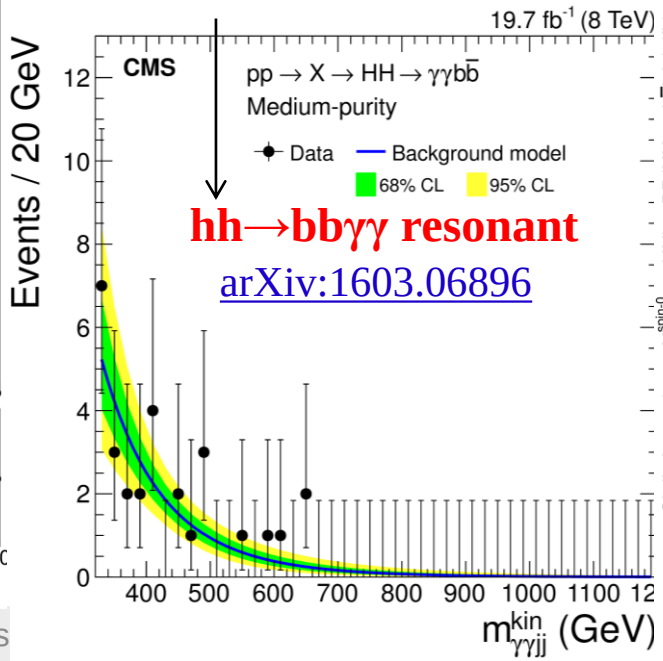




CMS-PAS-HIG-16-002

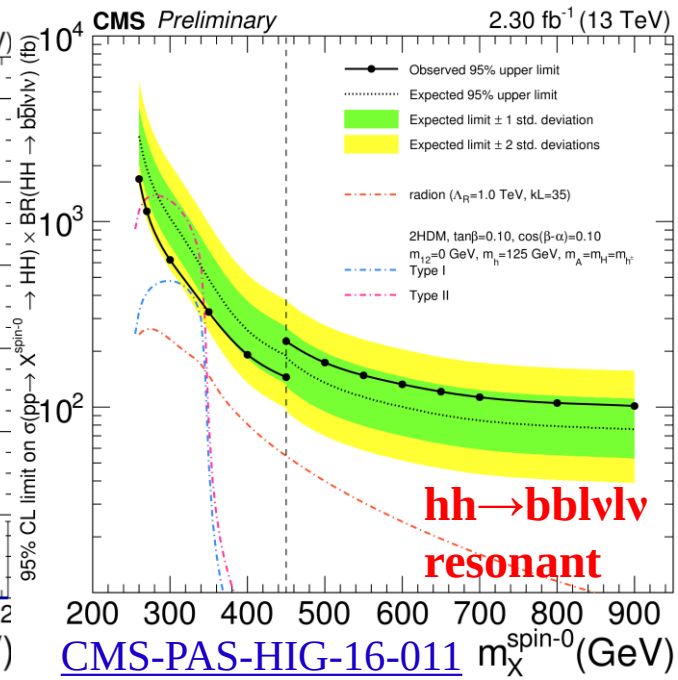
hh→bbbb resonant

3σ (local) excess at 300 GeV, ATLAS, run 1, PRL 114, 081802 (2015)



hh→bbγγ resonant

arXiv:1603.06896

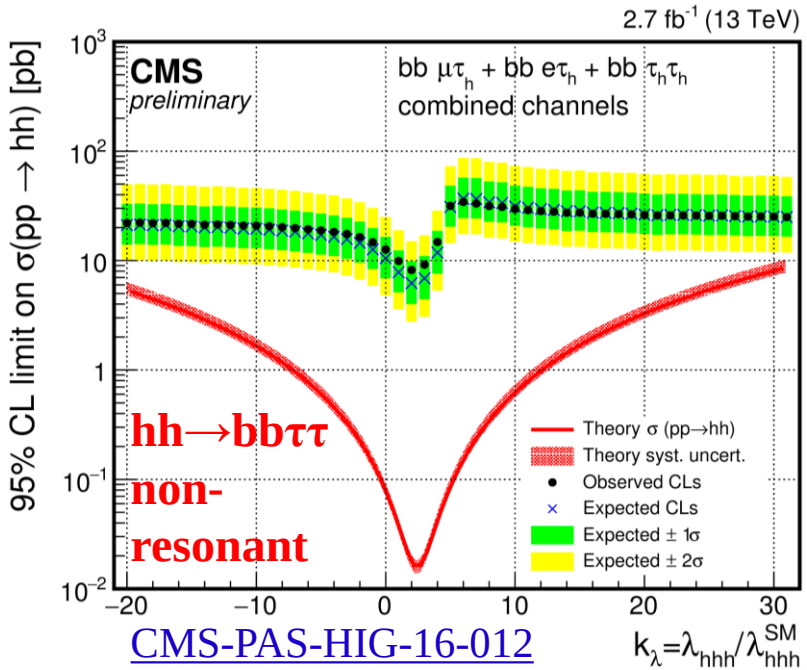


hh→bblνlν resonant

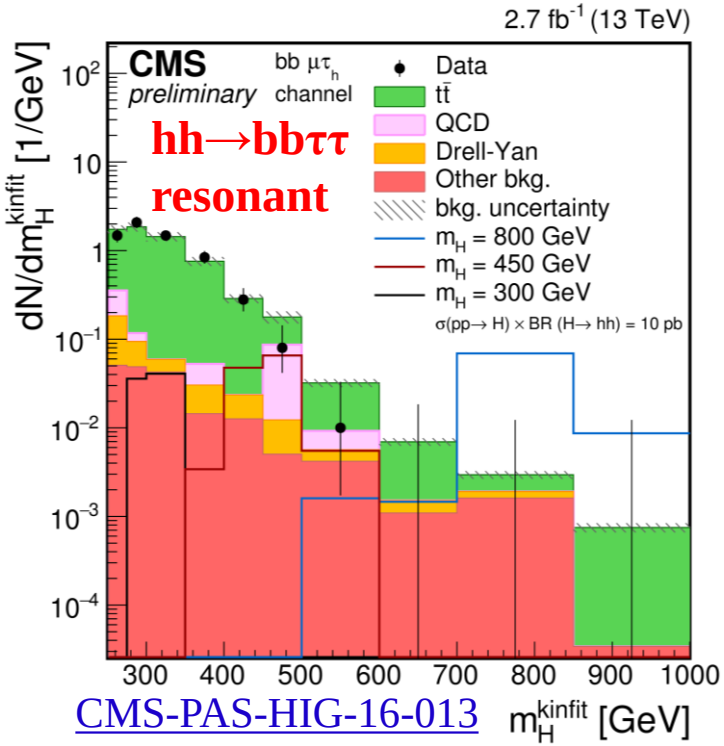
CMS-PAS-HIG-16-011

Di-Higgs searches: bbττ

- **hh→bbττ** studies for **resonant** and **non-resonant** case
  - bb + $e\tau_h$ / $\mu\tau_h$ / $\tau_h\tau_h$
  - $80 < m_{bb}$, $m_{\tau\tau}$ [GeV] < 160
  - No excess observed
  - For $\lambda=\lambda_{SM}$: **limit σ(hh)<8.8 pb** (<7.2 pb exp.), 95% CL
    - **200 times the SM cross section**



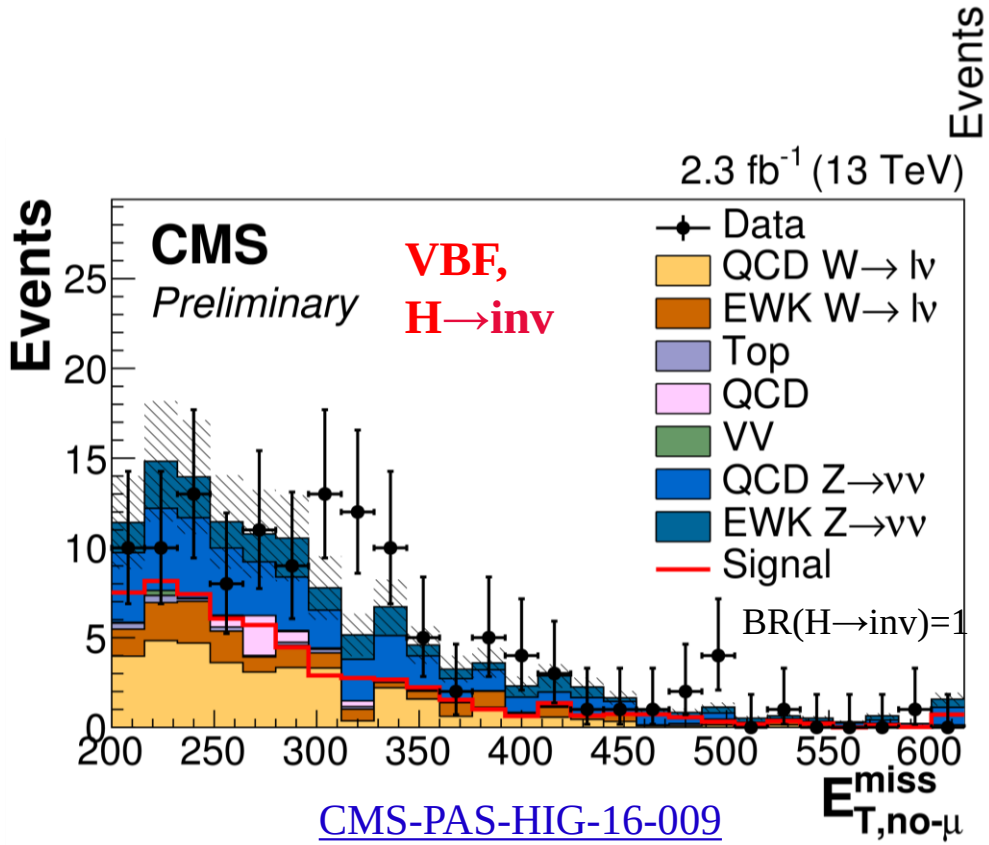
CMS-PAS-HIG-16-012



CMS-PAS-HIG-16-013

H→invisible

- **Models**: e.g. SUSY with R-parity; large extra dimensions (graviscalar)
- **VBF** qqH→qq+inv: Main bkg Z→νν, W→lν. **BR(H→inv)<69%** (2015)
- **ZH**→ll+inv: Main bkg ZZ→llνν, WW→lνlν. **BR(H→inv)<81%** (run 1)



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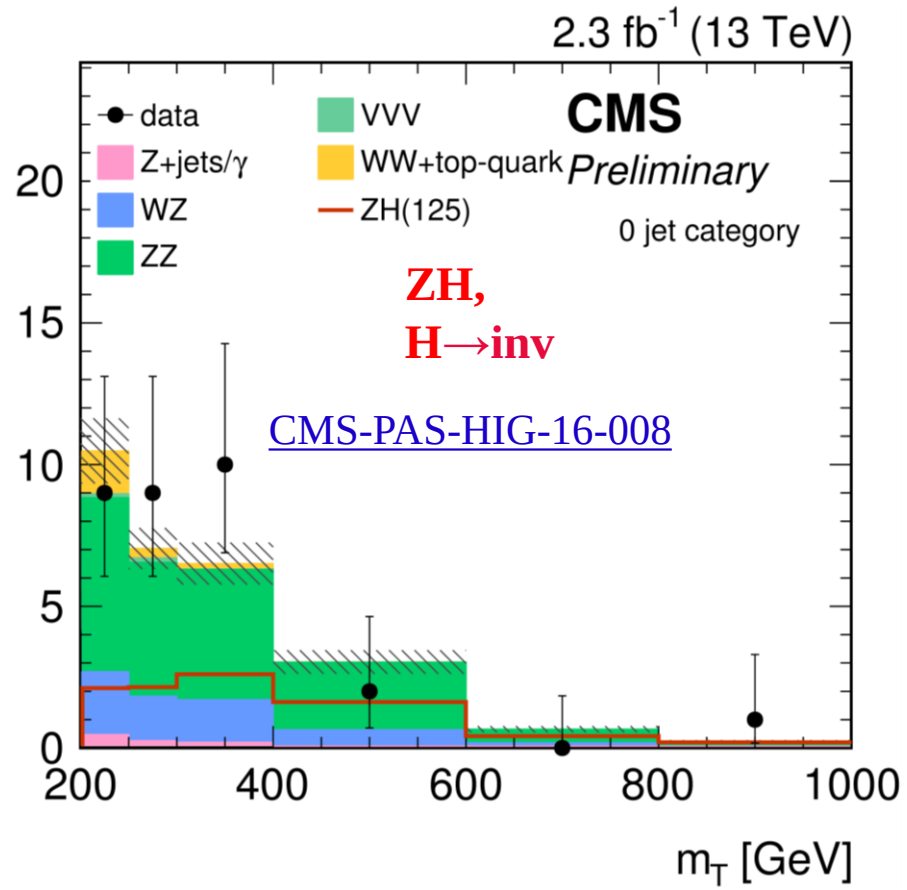
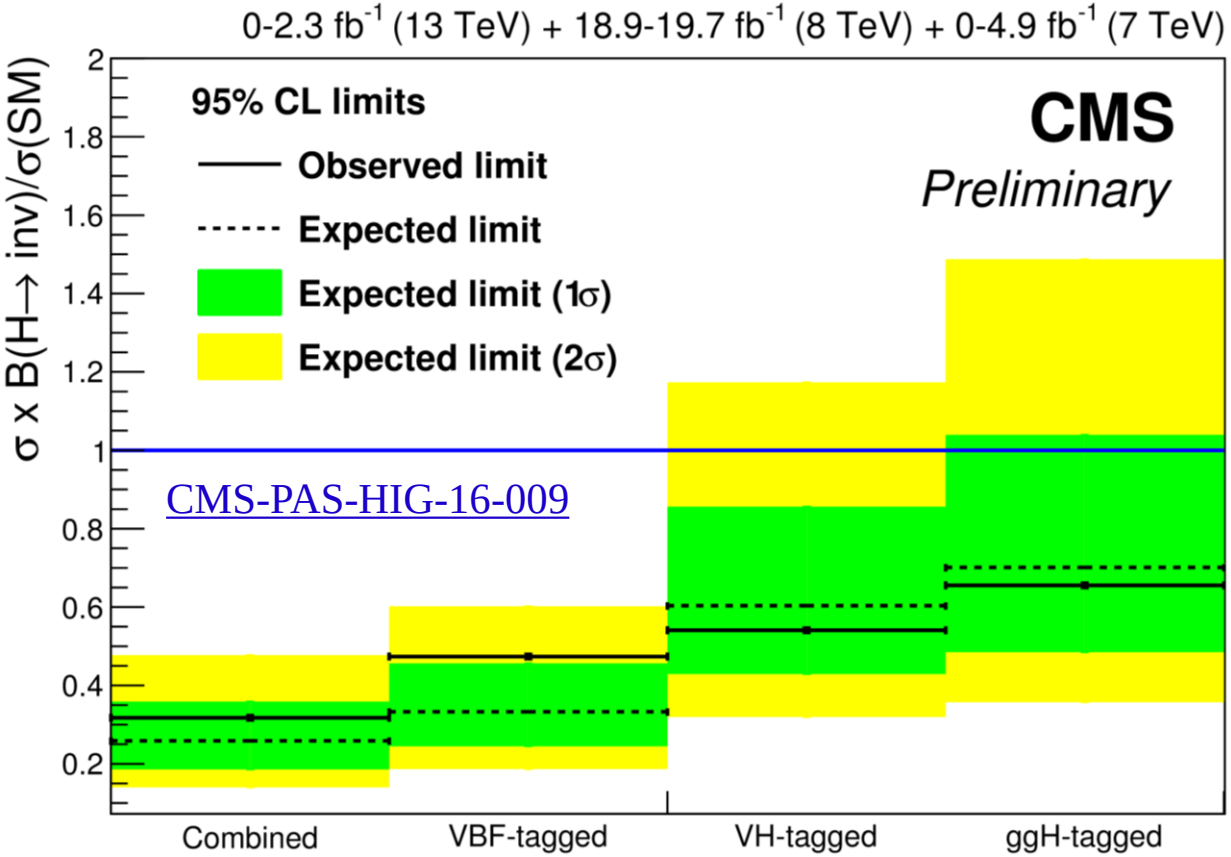


CMS-PAS-HIG-16-008

H→invisible combination

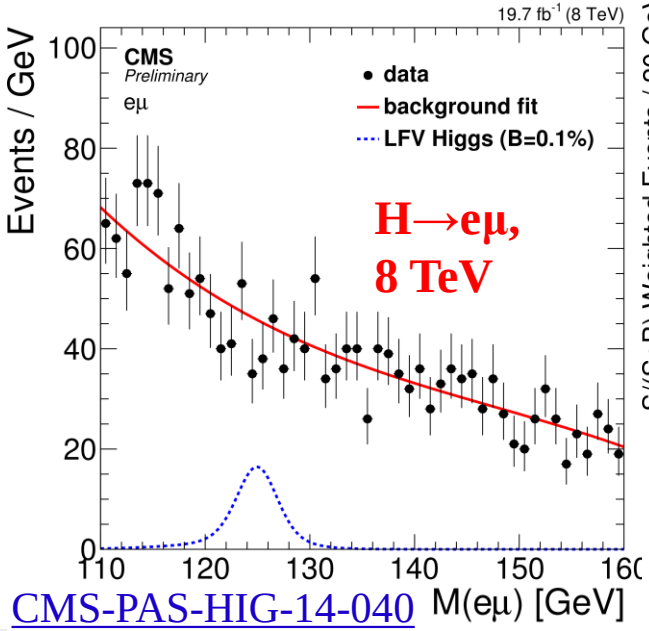
- Channels: VBF, VH, ggF
- **Run 1 + Run 2 results**
- **BR(H→inv)<32%** (exp. 26%)



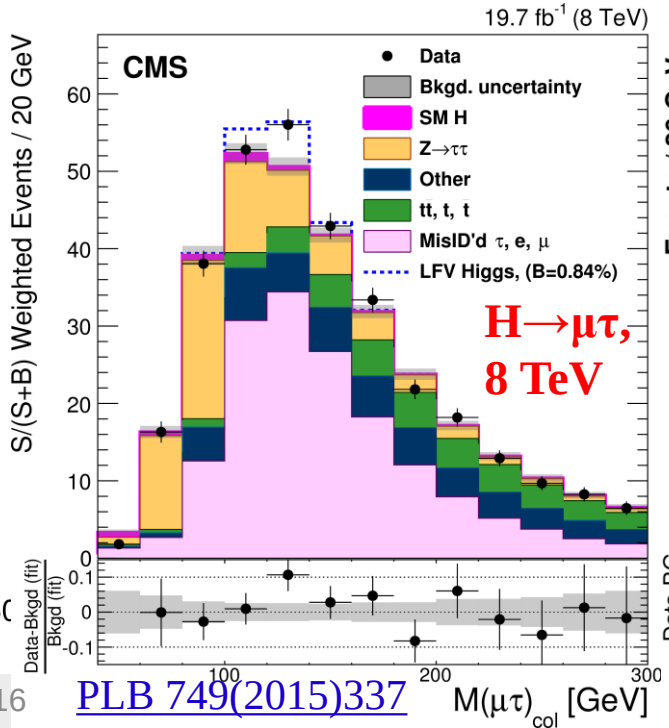
LFV Higgs boson decays

- Unobservable in the SM (tiny effect from neutrino sector)
  - Possible in BSM via particles with LFV couplings in loops
- CMS studies:
  - **H→eμ**: severely constrained by μ→eγ. Fit to m(eμ).
  - **H→eτ**
  - **H→μτ**

  } Weak constraints from τ→μγ/eγ, e/μ dipole moments. Discriminant: collinear mass m(eτ), m(μτ)



CMS-PAS-HIG-14-040



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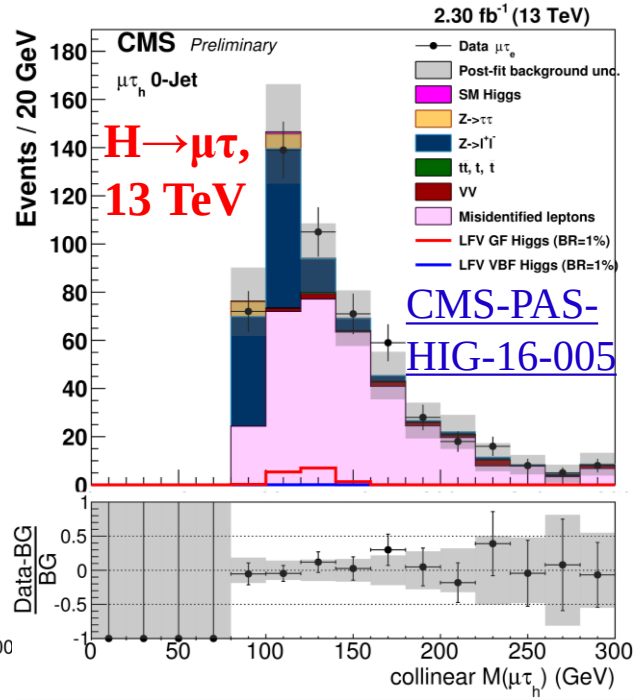


CMS-PAS-HIG-16-005

LFV Higgs boson decays: results

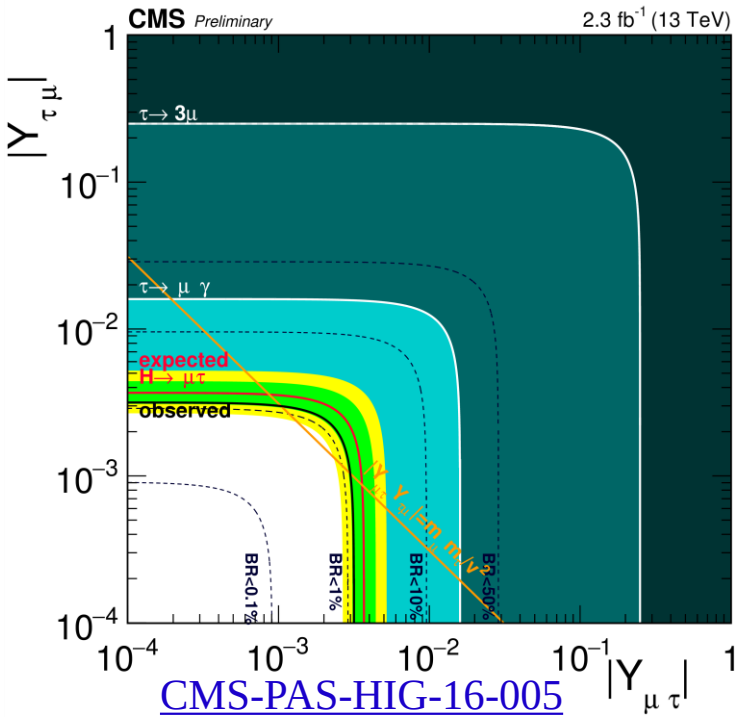
all limits on this slide: 95% C.L.

	Limit (obs)	Limit (exp)	Best-fit
H→eμ	<0.04%	<0.05	--
H→eτ	<0.7%	<0.8%	-0.1%±0.4%
H→μτ (8 TeV)	<1.5%	<0.8%	+0.8%±0.4%
H→μτ (13 TeV)	<1.2%	<1.6%	-0.8%±0.8%

← ATLAS: 0.5%±0.5%

- Small excess (2σ) in run 1 (μτ)
  - Deficit in run 2, results compatible
- No indication of H→eμ/eτ decays
- **Pre-LHC limits on H→μτ/eτ improved by factor 5**

	Coupling	Pre-LHC limit	CMS limit
H→eμ	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$3.6 \cdot 10^{-6}$	$5.4 \cdot 10^{-4}$
H→eτ	$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	0.014	0.0024
H→μτ	$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	0.016	0.0032



CMS-PAS-HIG-16-005

Conclusions

- Strong program of BSM Higgs physics at CMS

  ...but results agree with SM expectation

- Searches for additional heavy Higgs bosons enter **uncharted territory at √s=13-14 TeV**
  - Discovery or much improved constraints expected this year
- Several measurements require **more data** to ultimately probe the SM
  - Di-Higgs production (self-coupling measurement)
  - h(125) couplings

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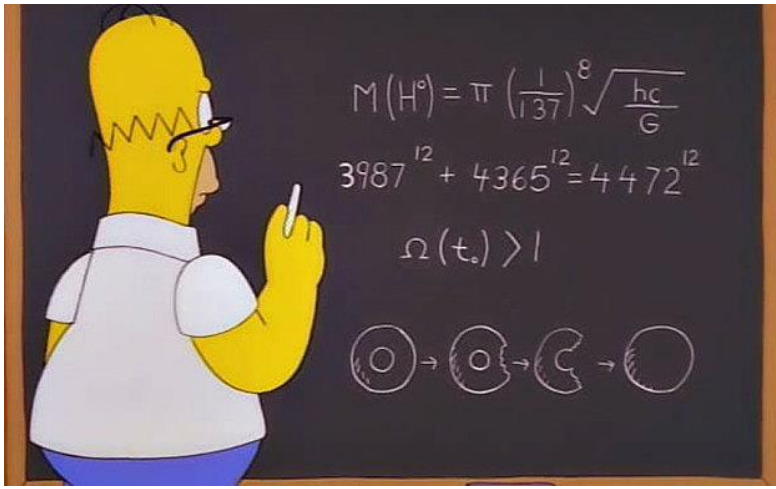
  - h(125) couplings

Stay tuned for Run 2 results!

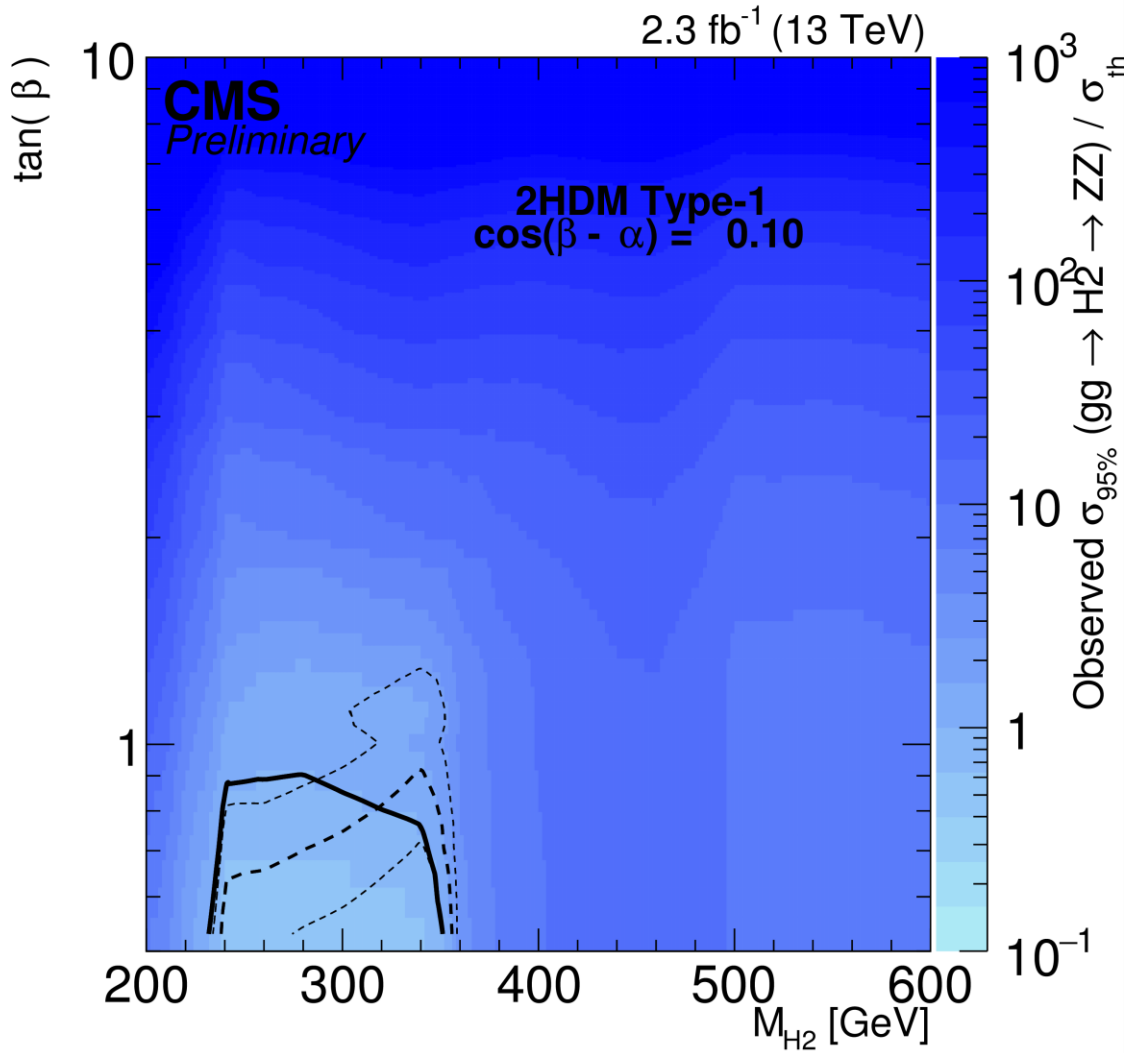
The mass of which Higgs boson did Prof. Homer predict?

m_H=775 GeV, FOX Rev. Lett. (1998)

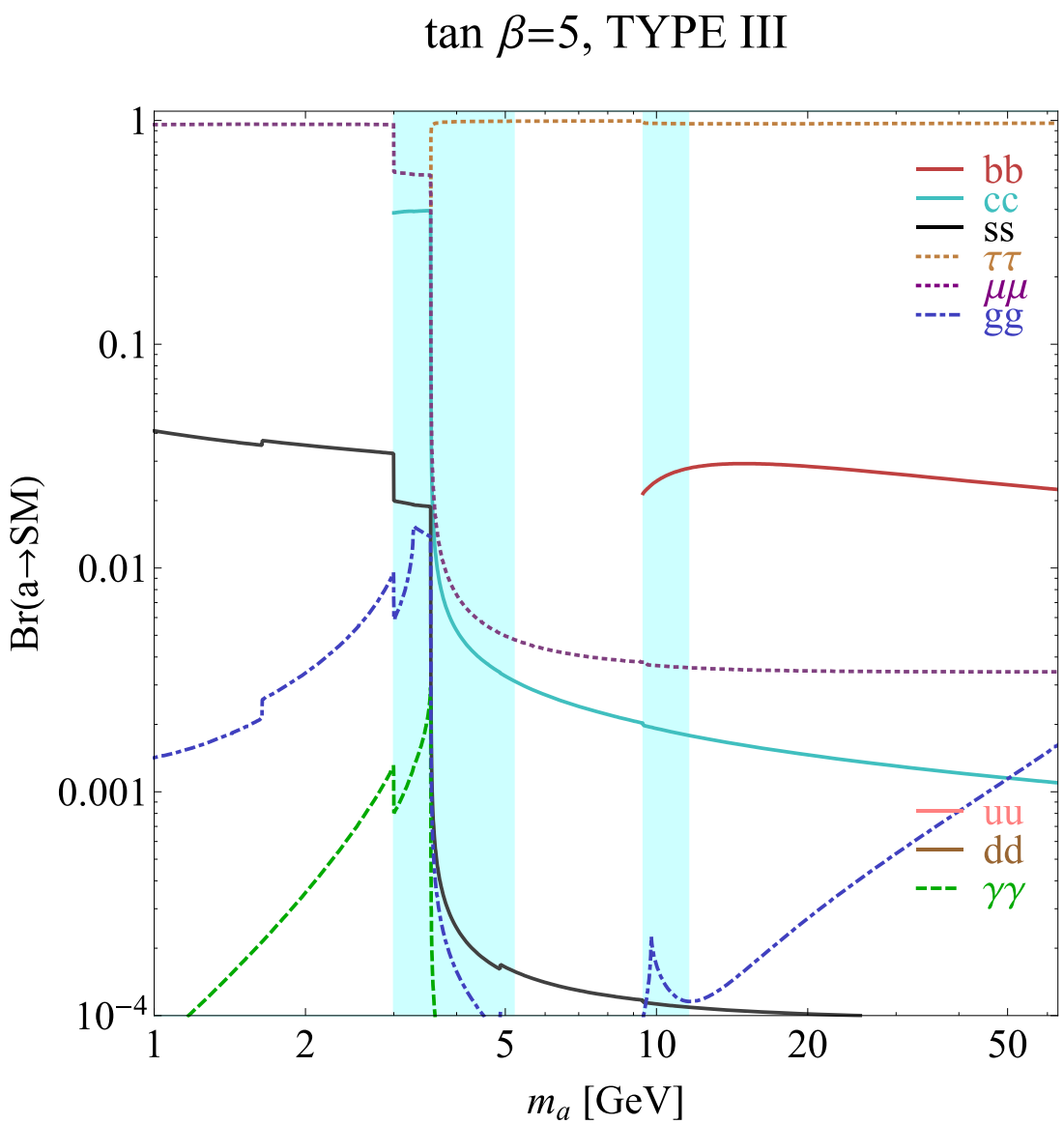


Backup slides

llvv 2HDM interpretation



a decays


tan β=5, TYPE III
Br(a→SM)
1
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0.01
0.001
10−4
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ma [GeV]
bb
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ττ
μμ
gg
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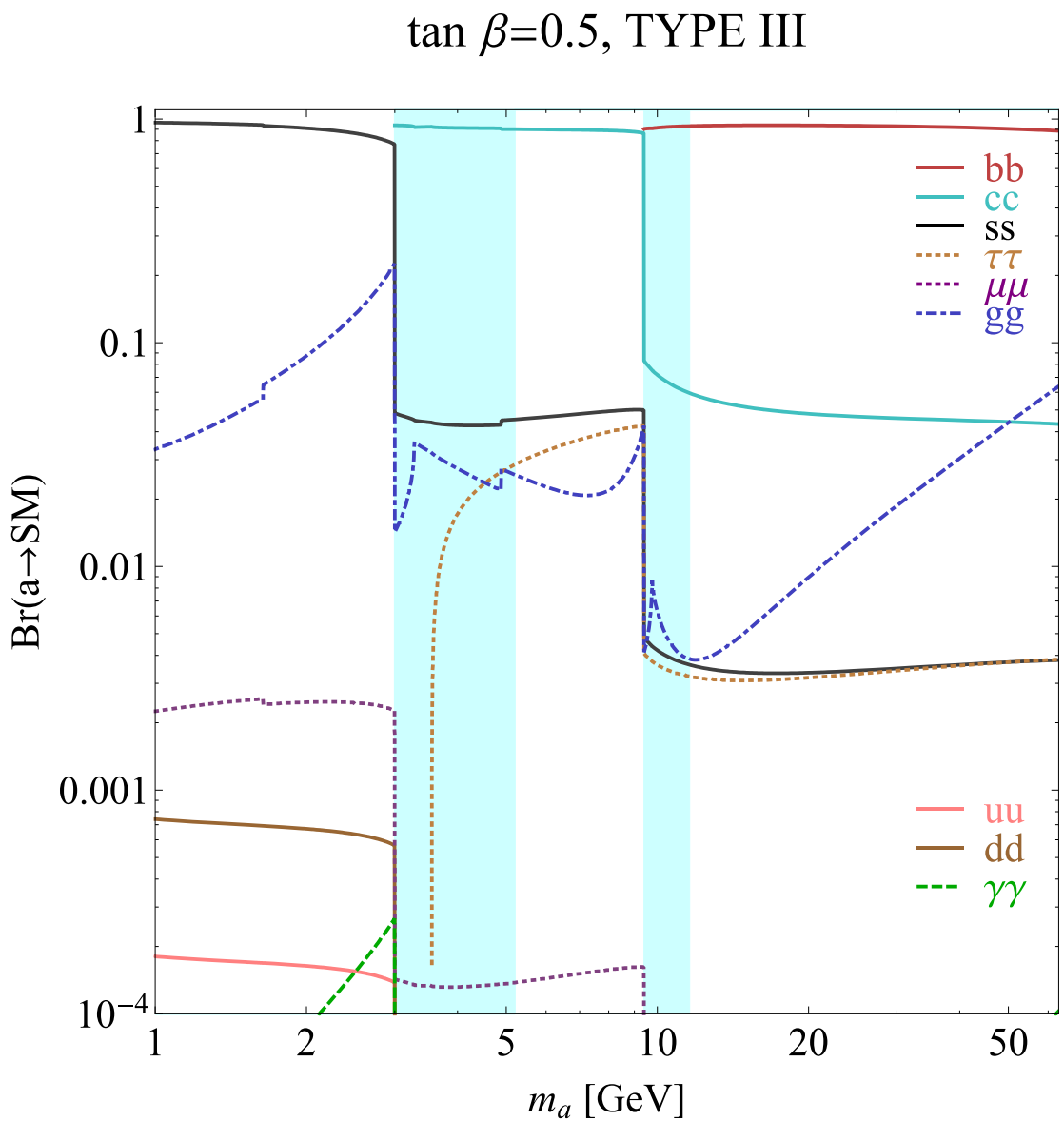
dd
γγ

a decays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Br(a→SM)
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m_a [GeV]
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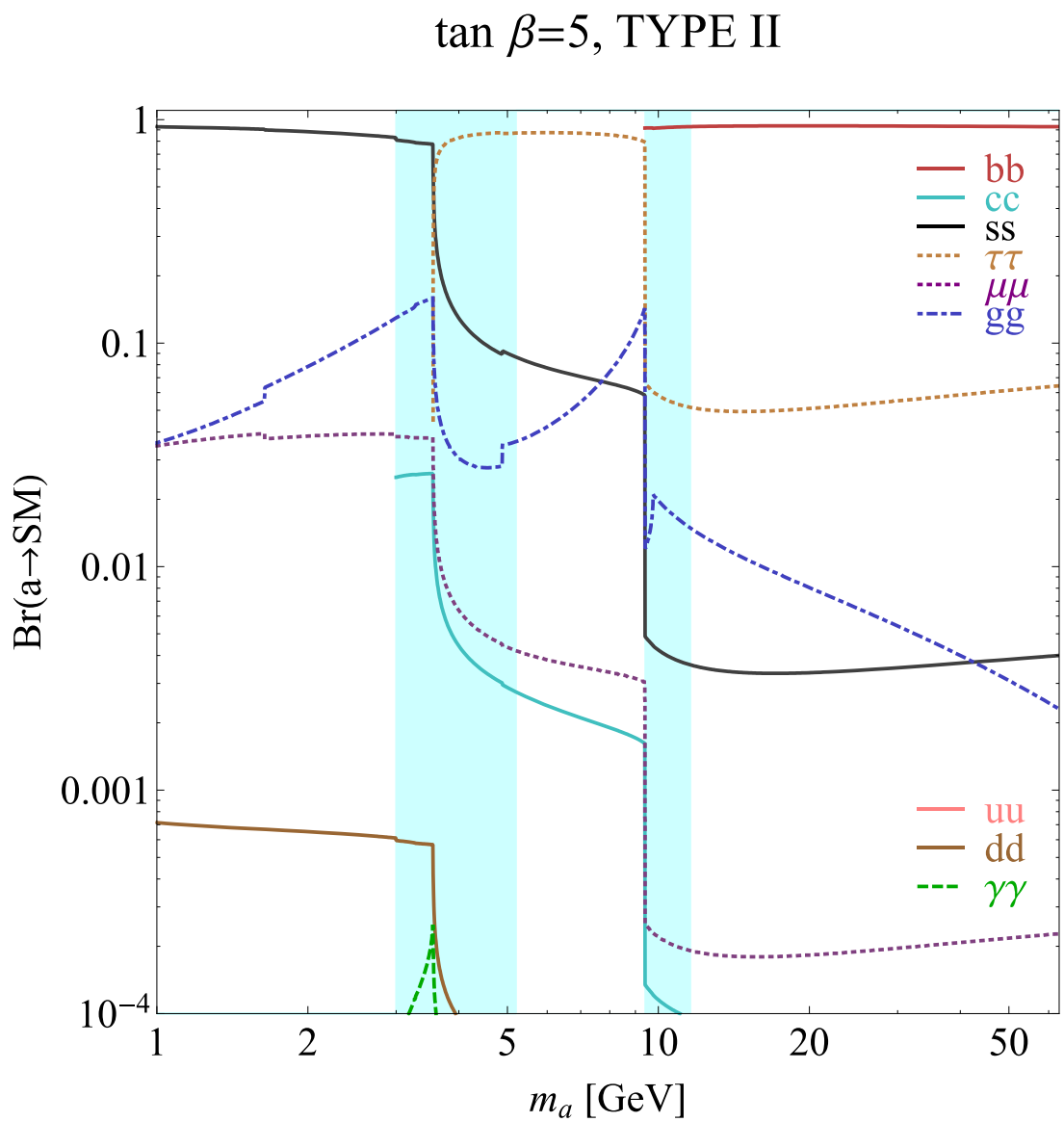
a decays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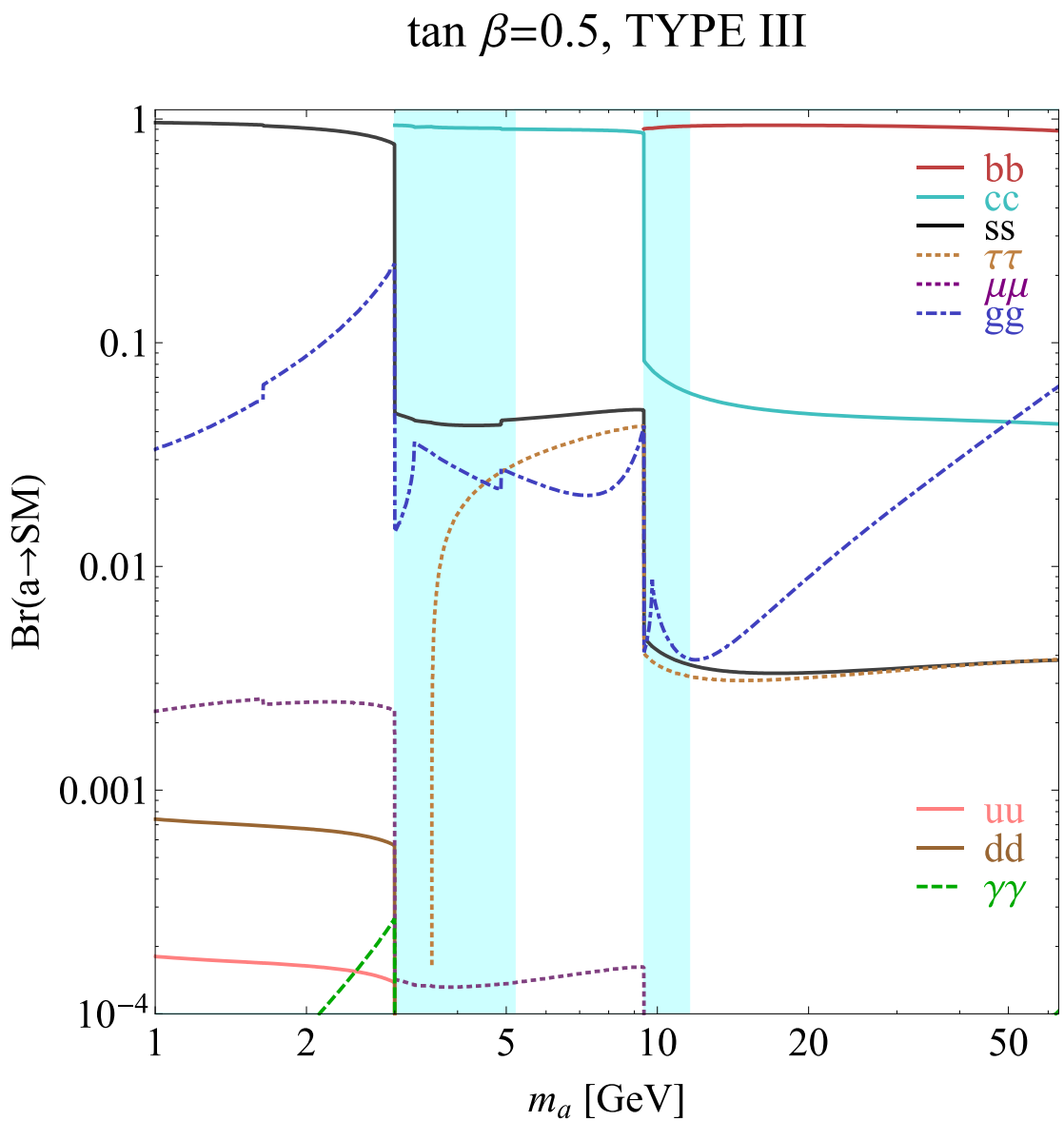
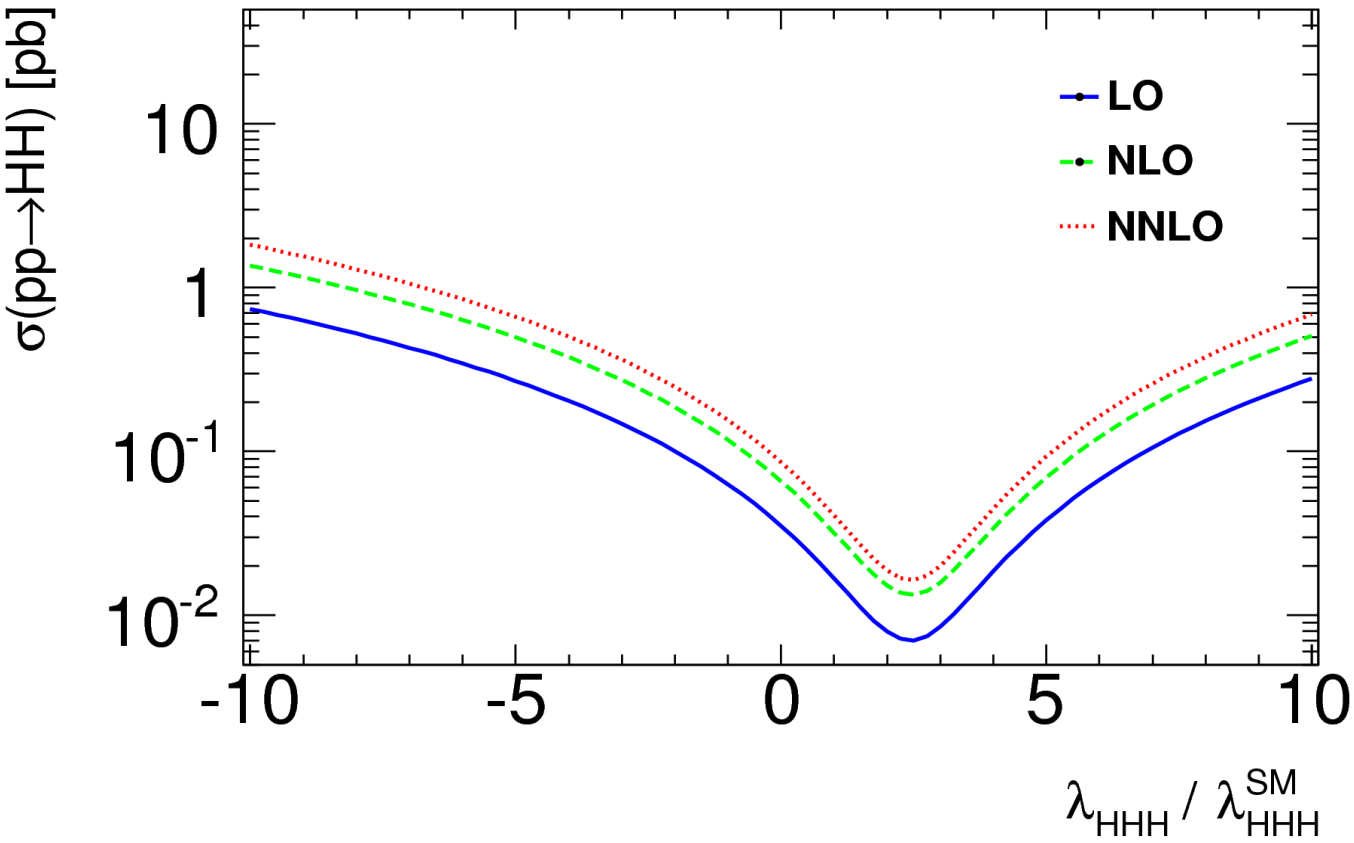
γγ

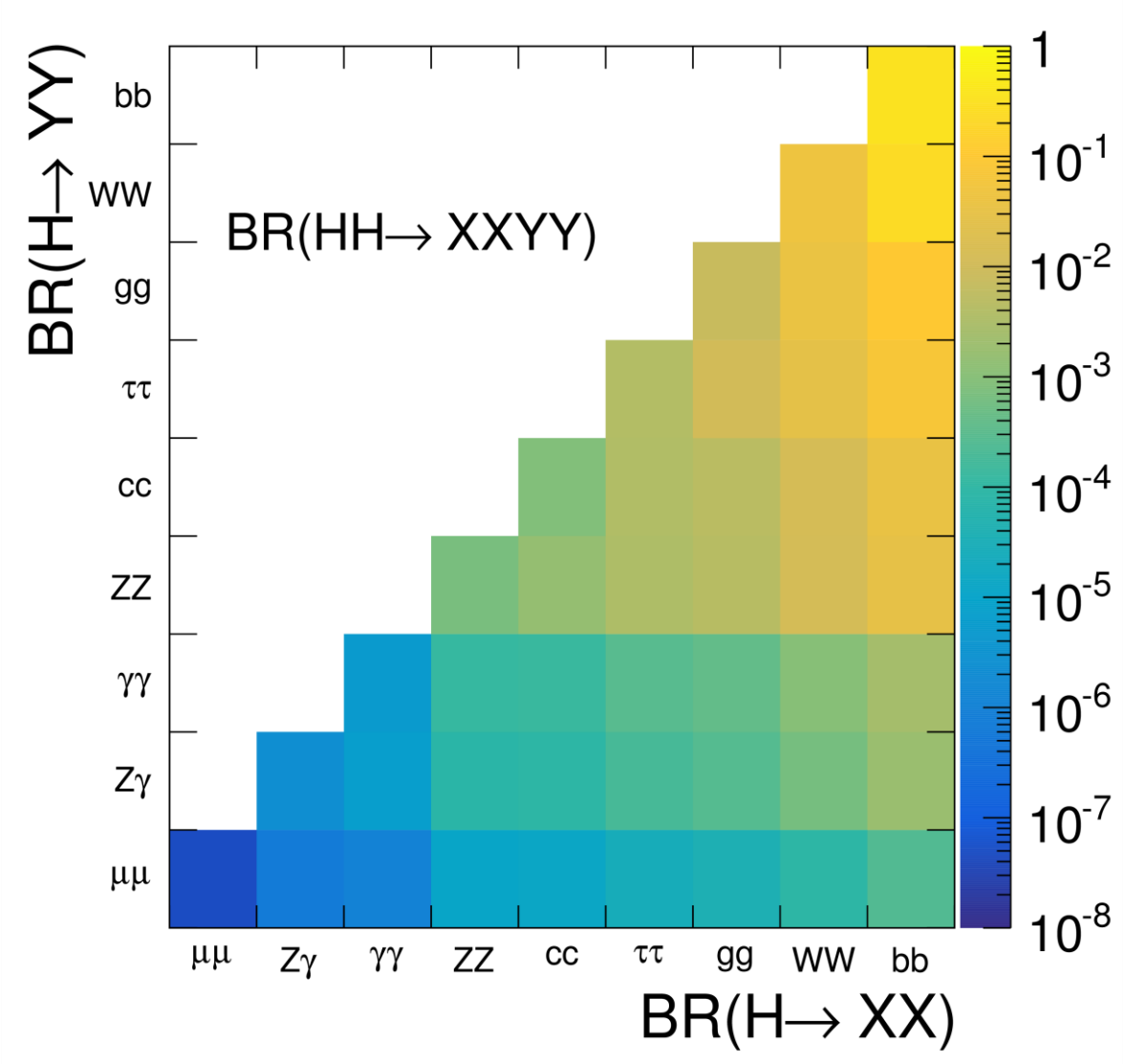
a decays


tan β=0.5, TYPE III
Br(a→SM)
1
0.1
0.01
0.001
10^{-4}
1
2
5
10
20
50
m_a [GeV]
bb
cc
ss
$\tau\tau$
$\mu\mu$
gg
uu
dd
$\gamma\gamma$

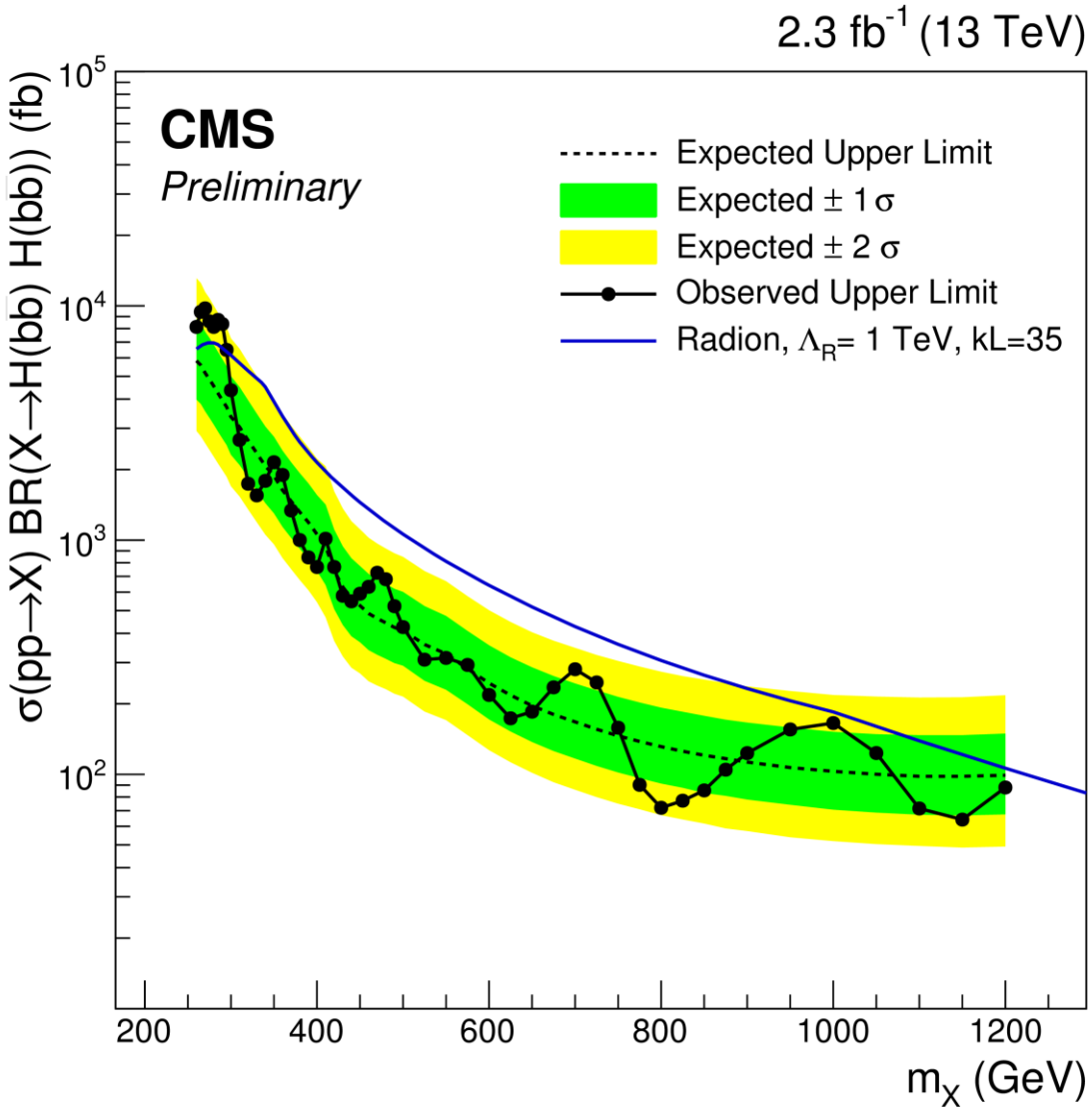
Double Higgs production



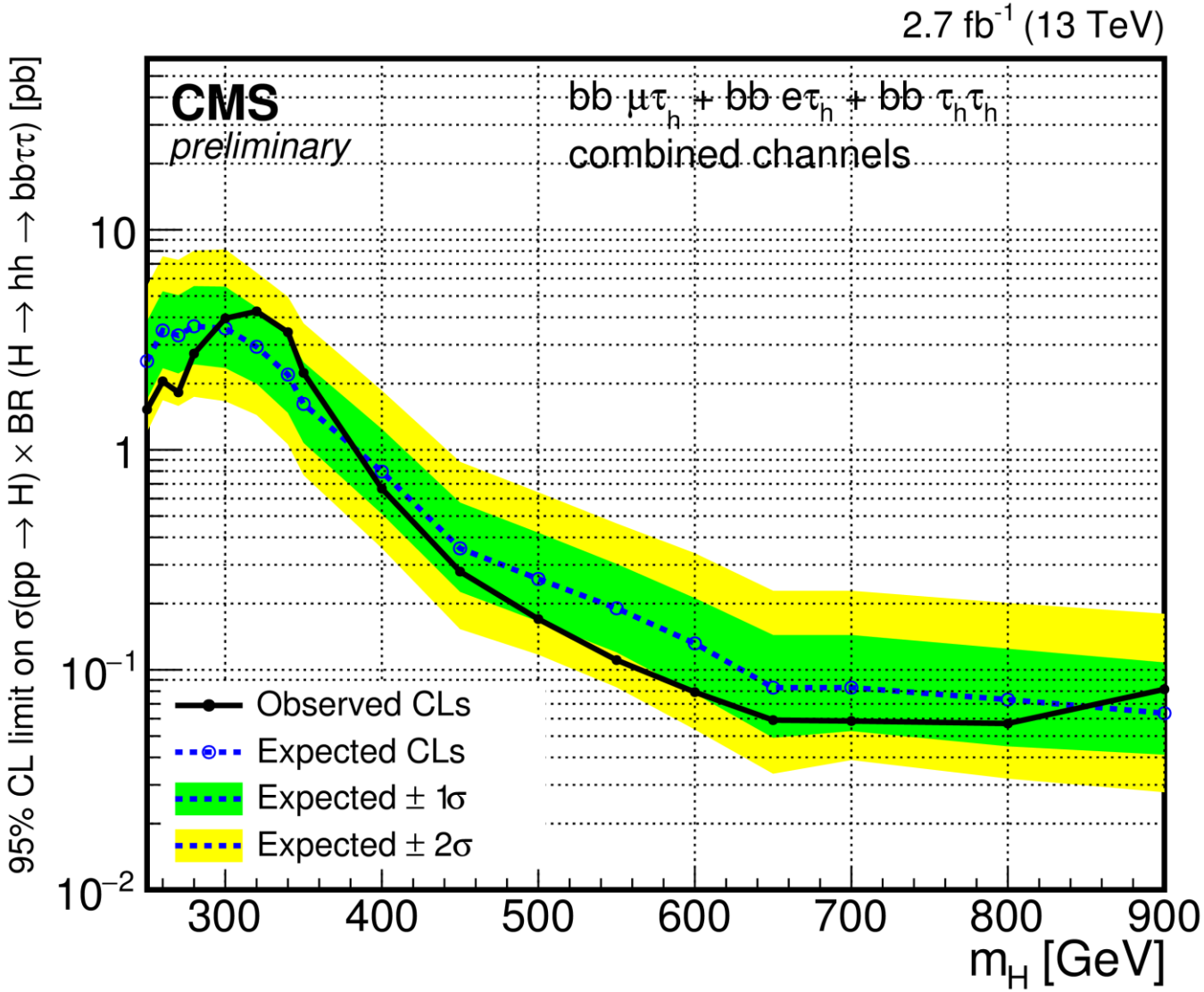
Di-Higgs BR


BR(HH→ XXYY)
BR(H→ YY)
bb
WW
gg
ττ
cc
ZZ
γγ
Zγ
μμ
μμ
Zγ
γγ
ZZ
cc
ττ
gg
WW
bb
BR(H→ XX)
1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
10-8

HH->bb bb exclusion



HH->bb ττ exclusion



HH->bb μμ exclusion