BSM searches in the BEH sector in CMS

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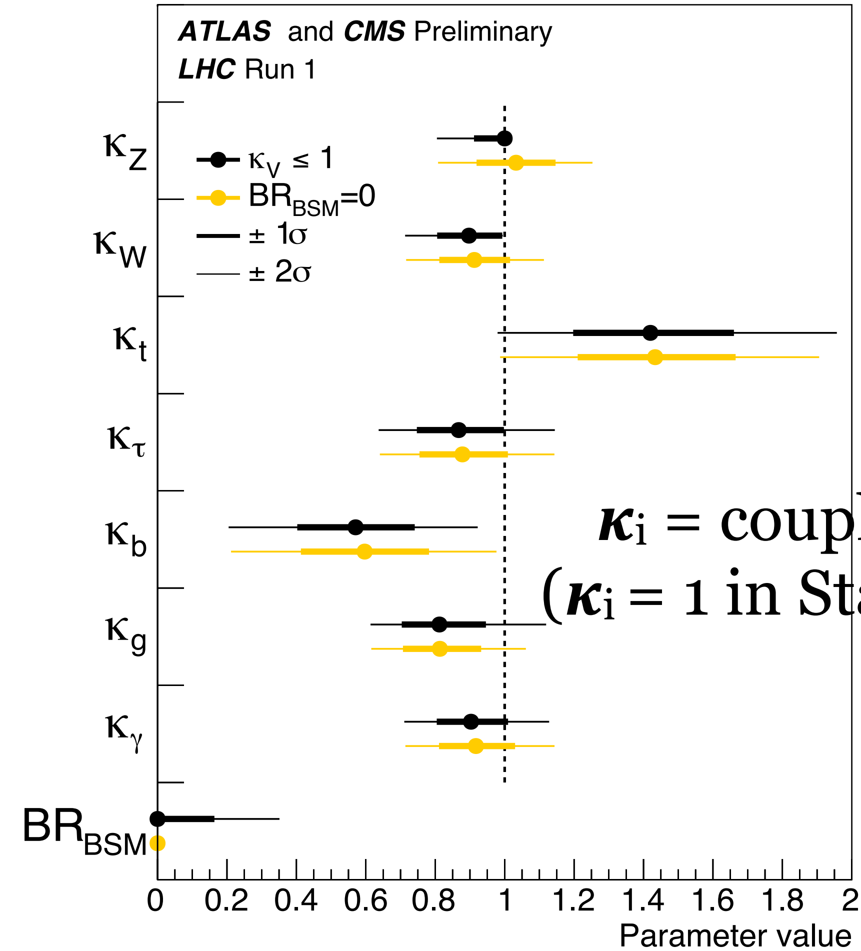
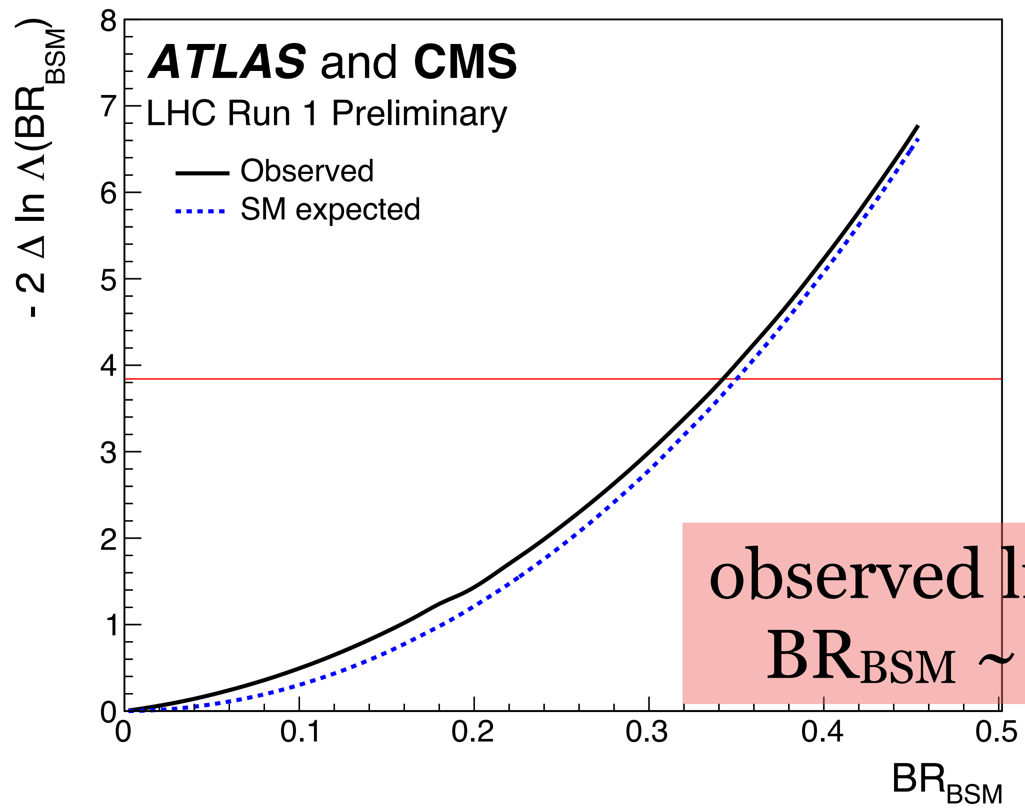
BSM physics in the scalar sector:

HIG-15-002

- **Test the discovered scalar boson at 125 GeV:**
  - Is Higgs deviating from SM ?
    ⇒ measure H(125) properties
  - Exotic decays of the H(125)



κ_i = coupling modifier
(κ_i = 1 in Standard Model)



observed limit on BR_{BSM} ~ 35 %

- **Search for more scalar bosons**
  ⇒ Various BSM models are predicting more than 1 scalar boson

Outline:

- **High mass searches:**
  - combination of run I high mass searches
  - high mass searches @ 13 TeV

- **Searches for exotic decay of the Higgs @ 13 TeV:**
  - Higgs to Invisible
  - Lepton Flavour Violating decay
  - H(125) to light pseudo-scalars

Heavy Scalar: 2HDM benchmark model

HIG-16-007

Combination performed in benchmark model

- 2HDM:
  - addition of a Higgs doublet with the same quantum numbers than the SM one
  - 5 degrees of freedom in the scalar sector: 2 scalars (h, H) + 1 pseudo-scalar (A) + 2 charged (H^+, H^-)
  - 2 main type of models:
    - **type-I**, the $SU(2)_L$ doublets couple to both up- and down-type fermions equally
    - **type-II**, one doublet couples exclusively to up-type and the other exclusively to down-type fermions
  - benchmark constrain on the parameters :

Parameter	Value (type I or type II)
m_h	125.09 GeV
m_A	$m_H + 100$ GeV
m_{H^+}	$m_H + 100$ GeV
$\cos(\beta-\alpha)$	0.1
m_{12}^2	$\max(1-\tan\beta^{-2}, 0)\cdot\frac{1}{2}\sin(2\beta)(m_A^2+\lambda_5 v^2)$

Parameter space chosen where different searches are complementary and theory is consistent

- MSSM:
  - type-II: fermion-boson symmetry fixes all mass relations between the Higgs bosons and the angle α, at tree-level
  - when m_h fixed → 2 parameters left free: m_A and tan β

Constrains from H(125)

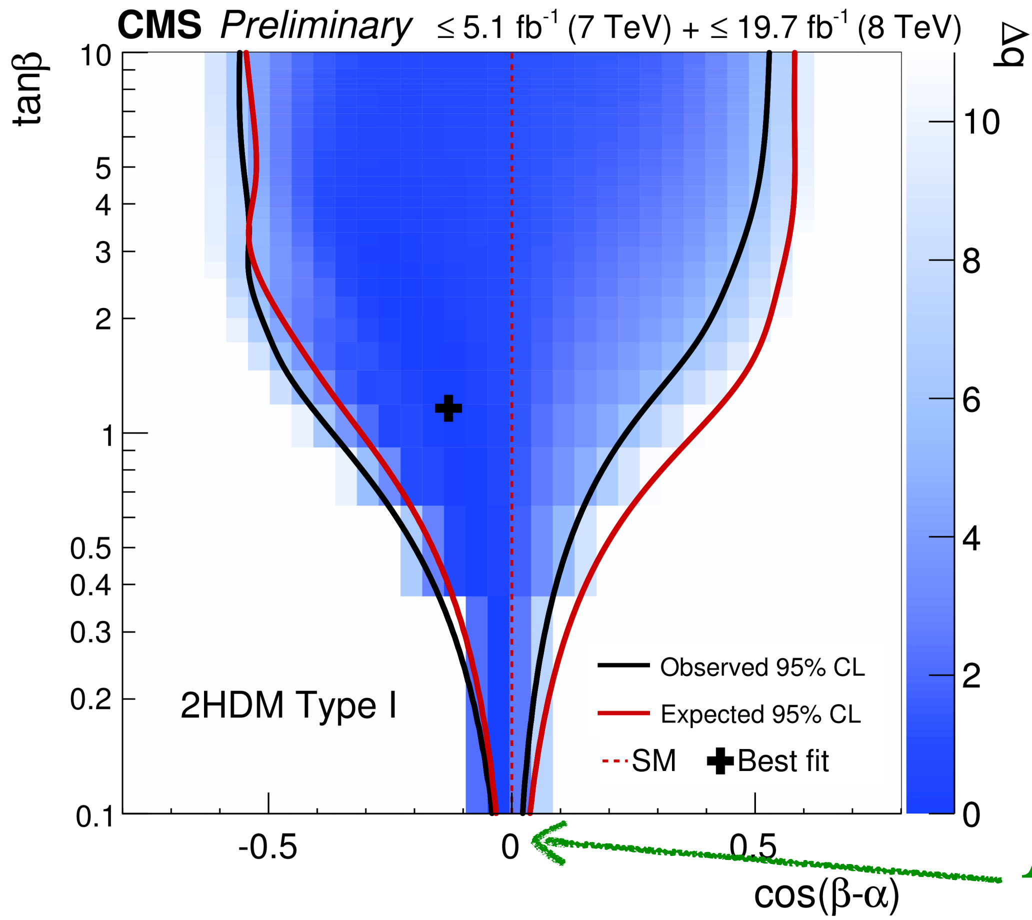
HIG-16-007

CMS measurements of H(125) couplings strongly constrain heavy scalar sector

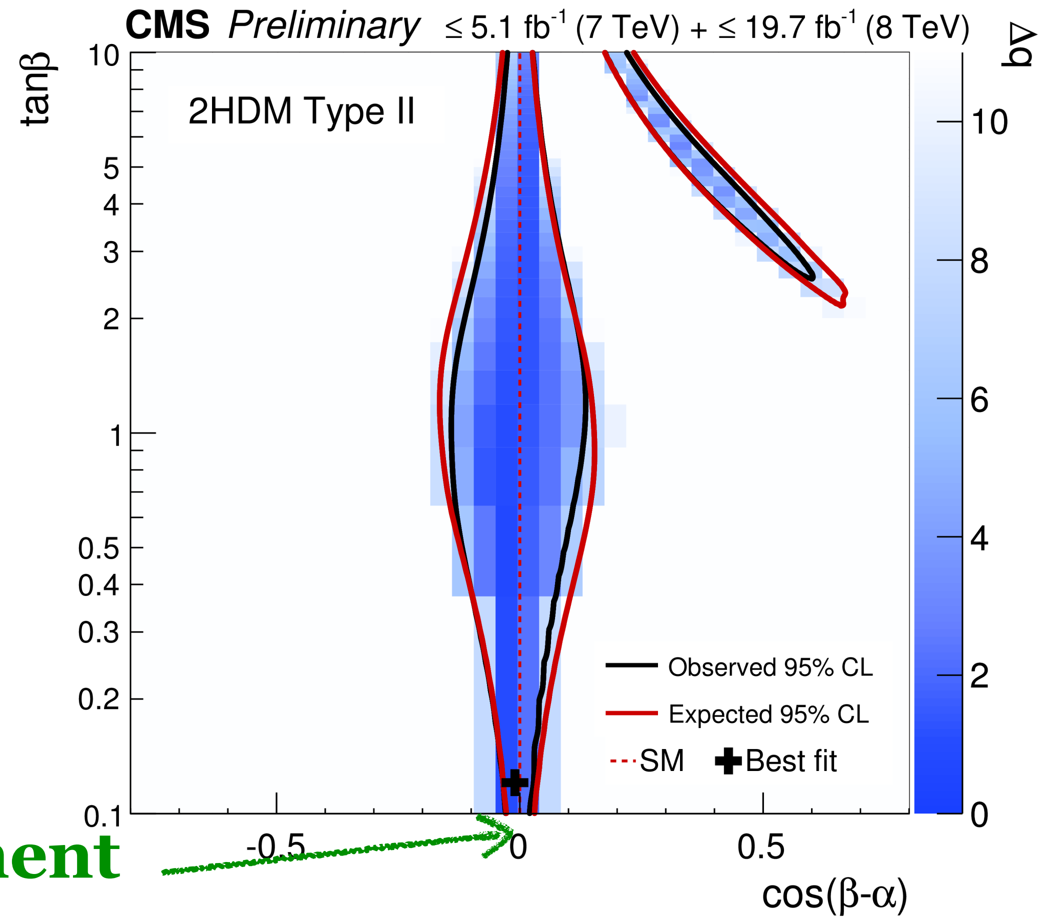
κ_i = coupling modifier
($\kappa_i = 1$ in Standard Model)

	2HDM type I	2HDM type II/MSSM	hMSSM
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\frac{s_d+s_u\tan\beta}{\sqrt{1+\tan^2\beta}}$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$s_u\frac{\sqrt{1+\tan^2\beta}}{\tan\beta}$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$s_d\sqrt{1+\tan^2\beta}$

2HDM Type I



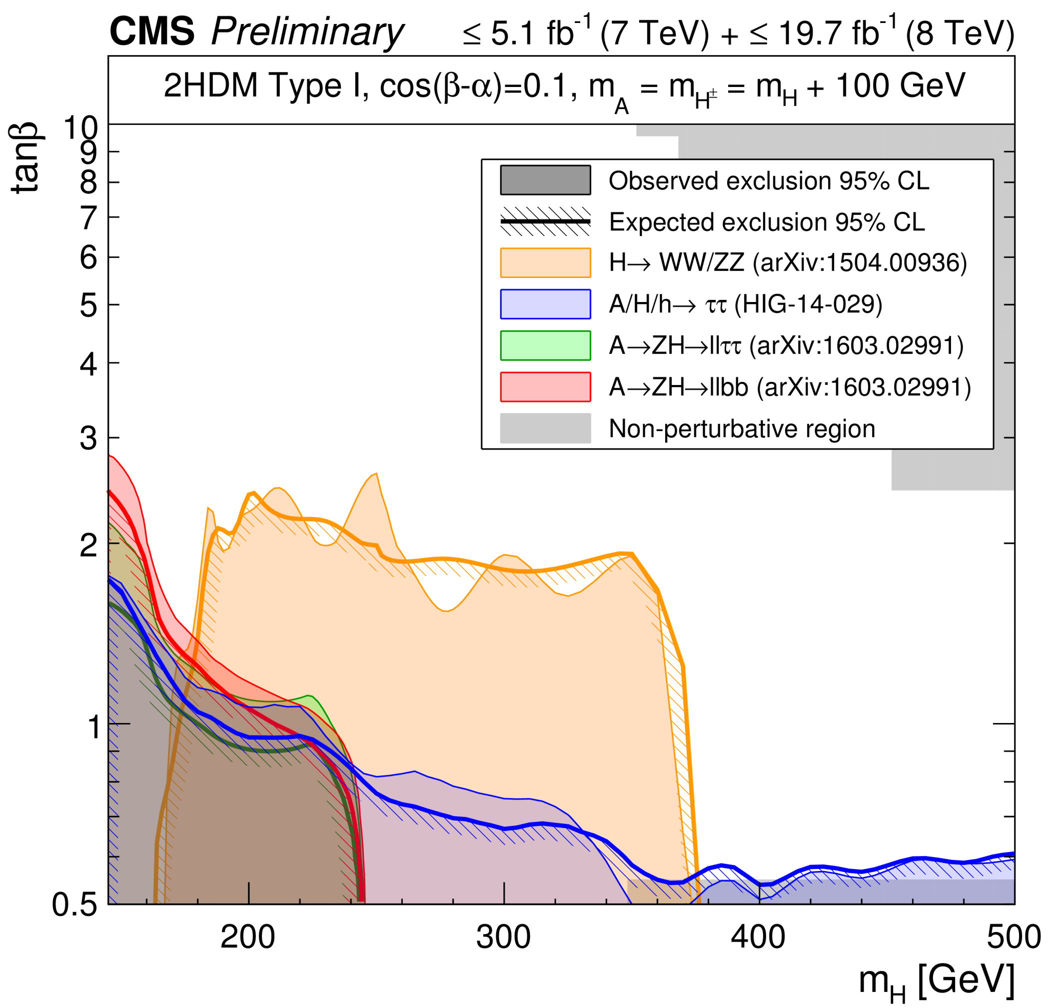
2HDM Type II

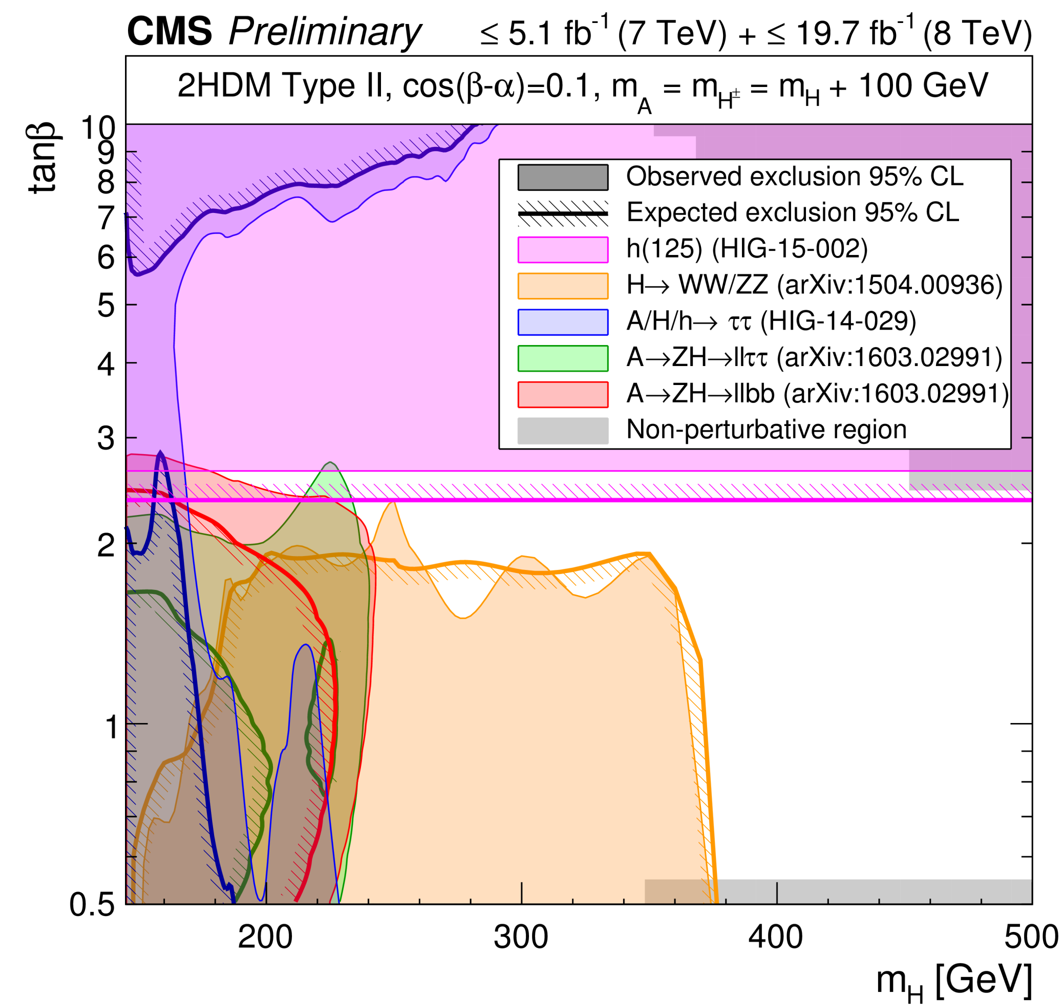


Alignement limit

Heavy Scalars: Run 1 Summary

Direct searches in benchmark 2HDM:





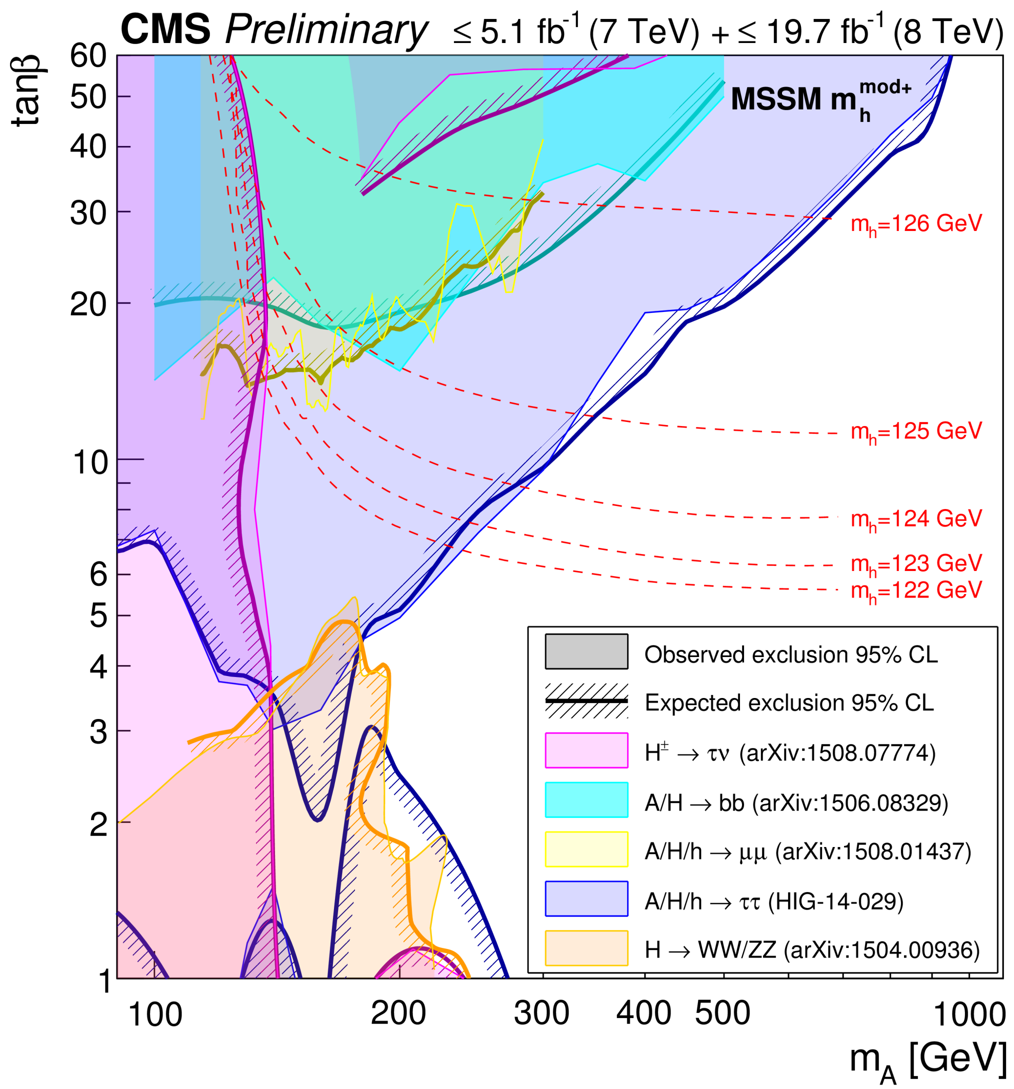
Type-II models more constrained

Heavy Scalars: Run 1 Summary

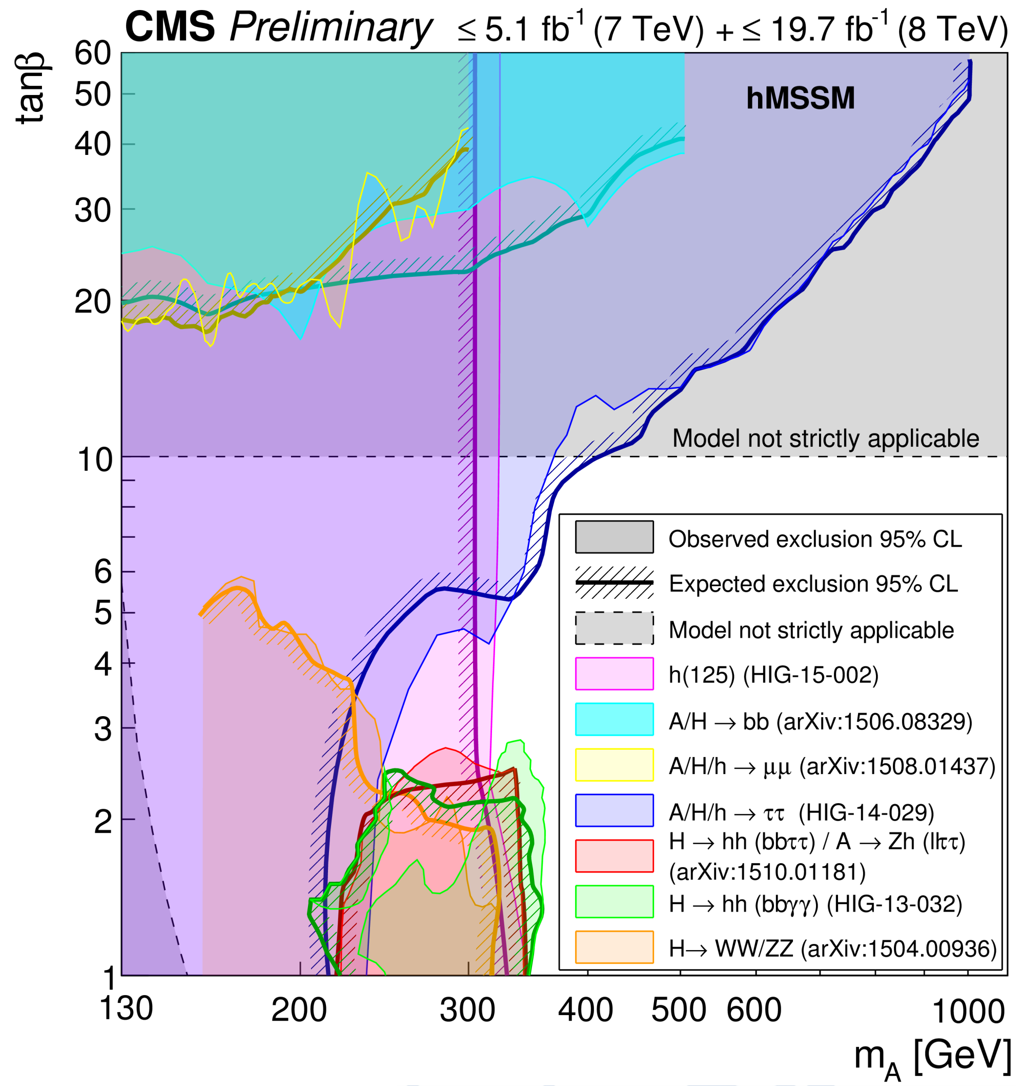
HIG-16-007

MSSM constraints from direct searches :

m_h^{mod+} (m_h = 125 ± 3 GeV)



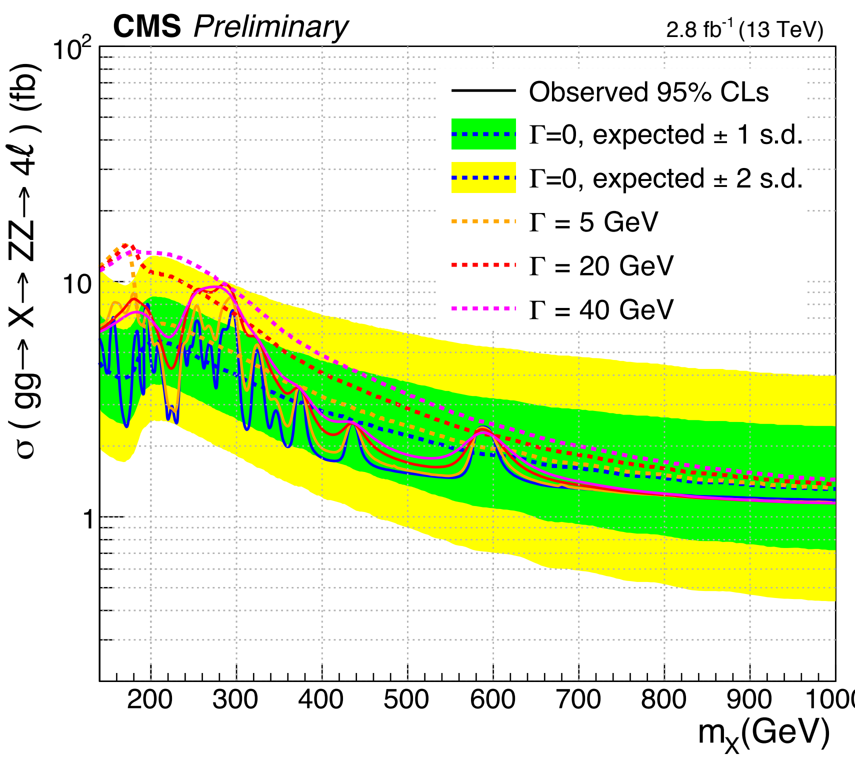
hMSSM (m_h = 125 GeV)

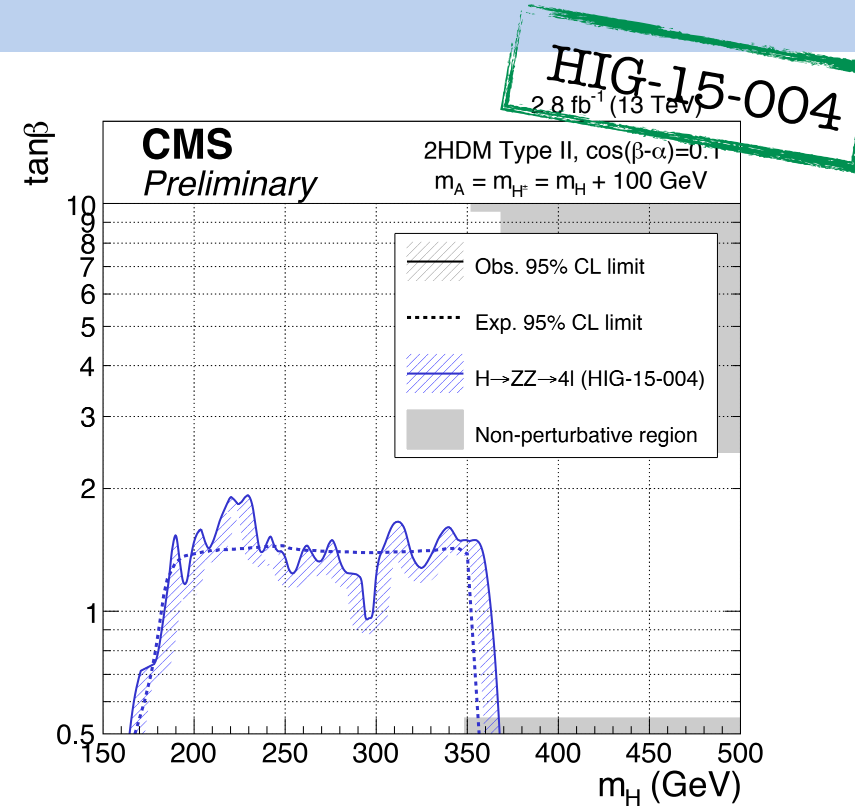


Heavy Scalar 13 TeV

H->ZZ->4l

- search using m4l
- generic cross section limits for several widths





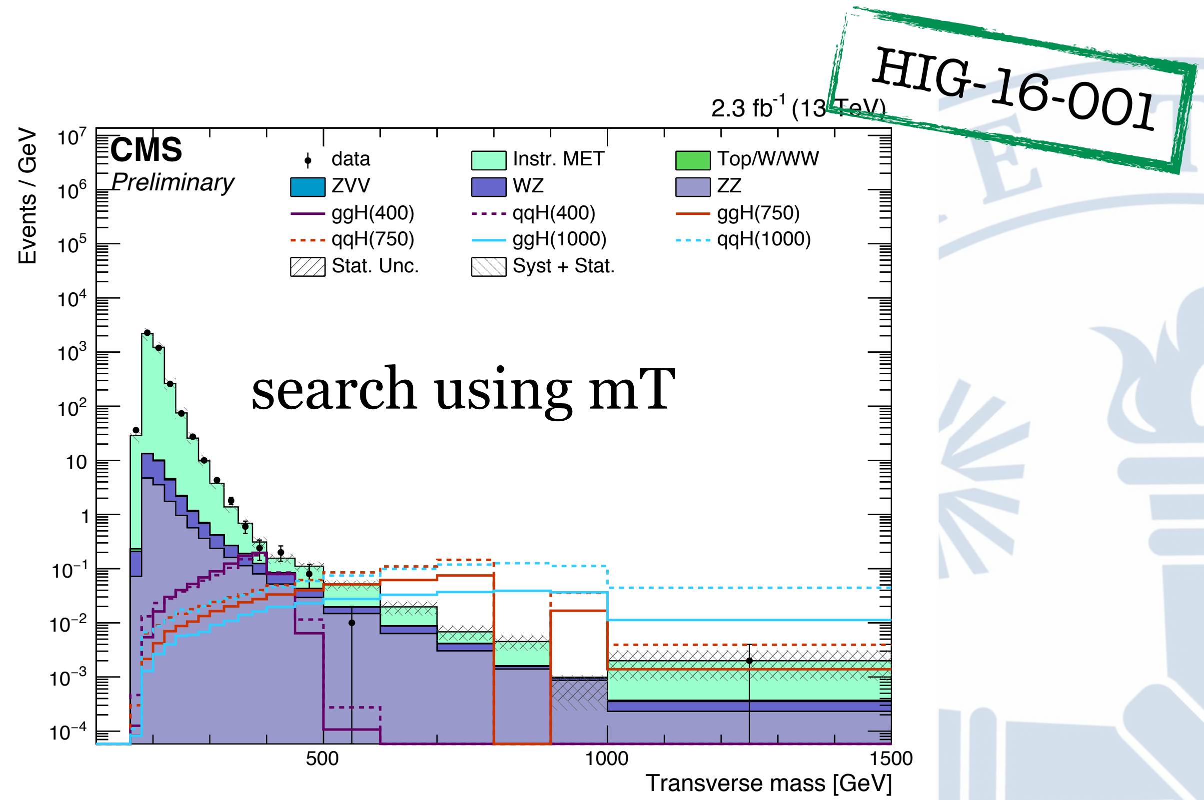
H->ZZ->2l2ν

- EWK singlet model

$$\mu' = C'^2 \left(1 - \mathcal{B}_{\text{new}}\right)$$

$$\Gamma' = \Gamma_{\text{SM}} \frac{C'^2}{1 - \mathcal{B}_{\text{new}}}$$

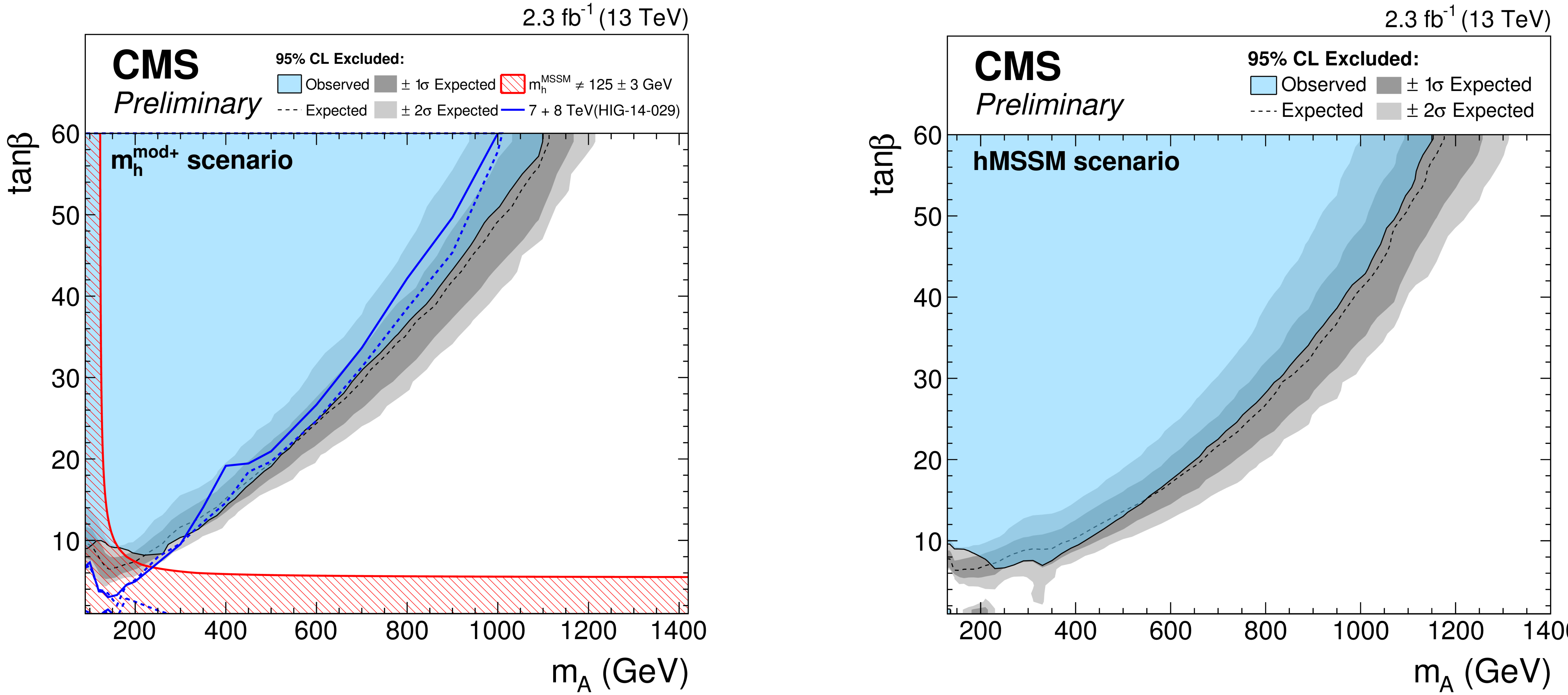
- generic gluon-fusion and VBF cross section limits independent of width



MSSM $\Phi \to \tau\tau$ at 13 TeV

HIG-16-006

- Production = ggΦ and bbarΦ
- Combine $\tau_e\tau_\mu$, $\tau_l\tau_h$, $\tau_h\tau_h$ and $\tau_\mu\tau_\mu$ channels
  - branching fraction of the neutral scalars (Φ) in $\tau\tau$ varies from 5 to 10% in the (m_A,tanβ) phase space probed by this analysis
- Event categories using multiplicity of b jets and p_T of τ_h enhance sensitivity
- Interpretation in MSSM (m_A,tanβ) parameter space with M_{SUSY} = 1 TeV in



- Also Model-independent limits: exclude $\sigma \times BR(\tau\tau) > 30(20)$ pb @ $m\varphi$ = 90 GeV down to 40(30) fb @ 1 TeV for ggH (bbH).

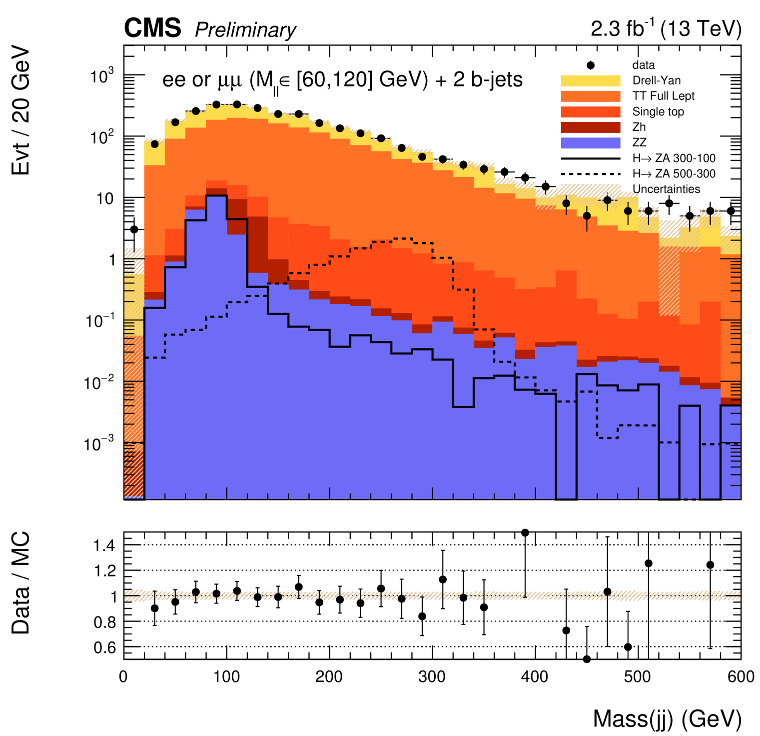
Heavy Scalar 13 TeV

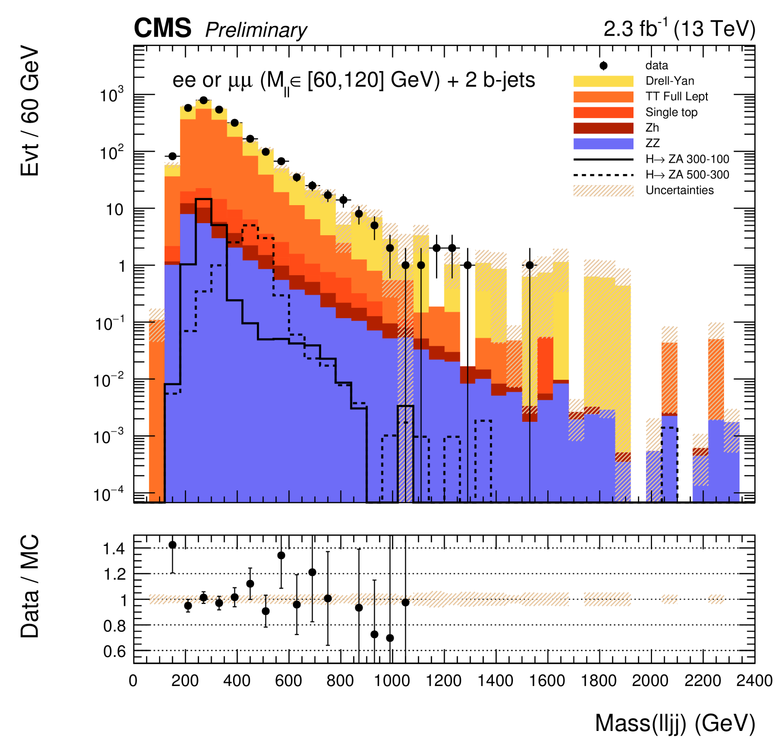
HIG-16-010

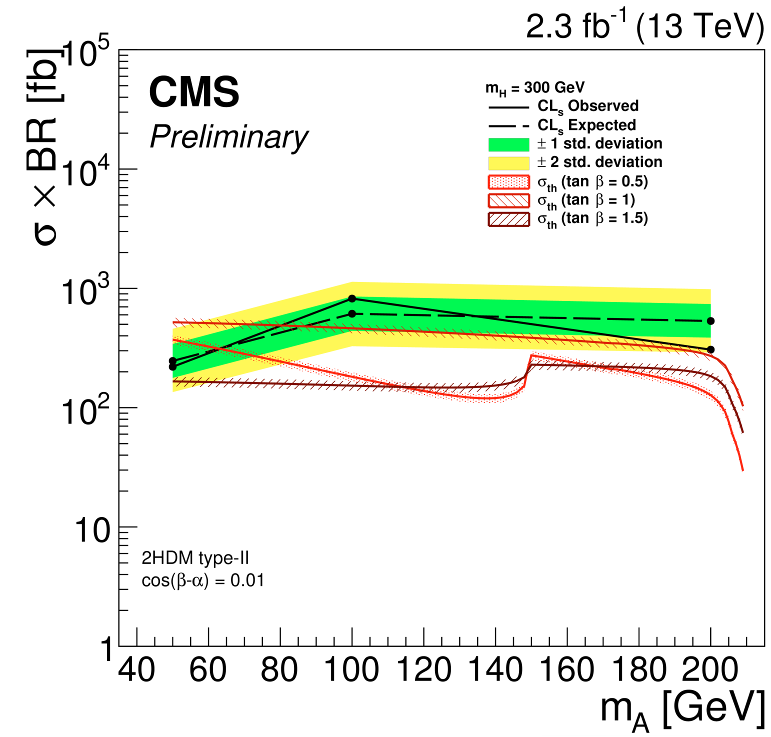
H->Z(ll)A(bb)

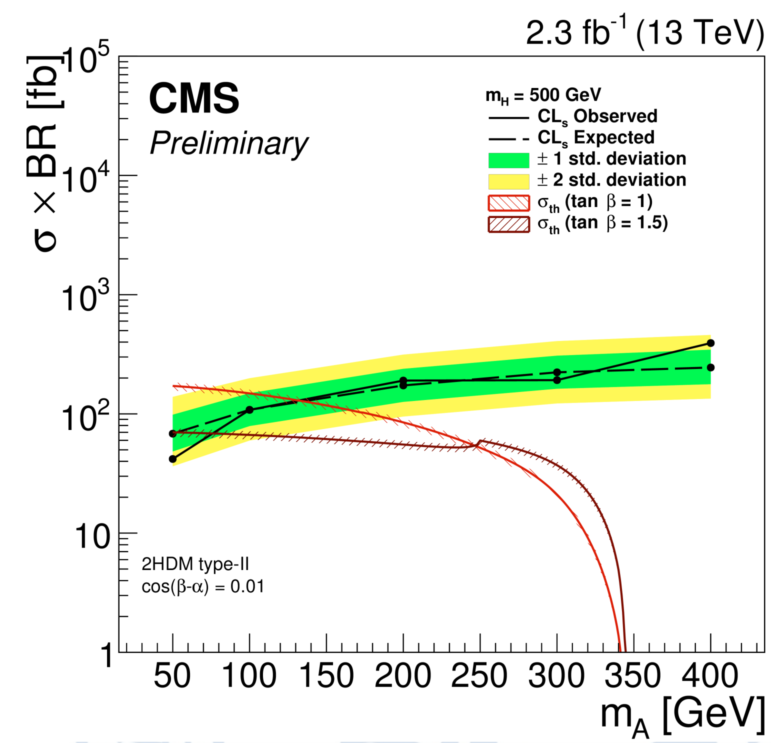
- 2HDM with inverted mass hierarchy (light A)
- 2D search in (m_{bb}, m_{llbb}) plane

- Signal region centered on (m_A, m_H) + m_{ll} around Z peak
- Background filed in mll sidebands
- Type-II 2HDM interpretation





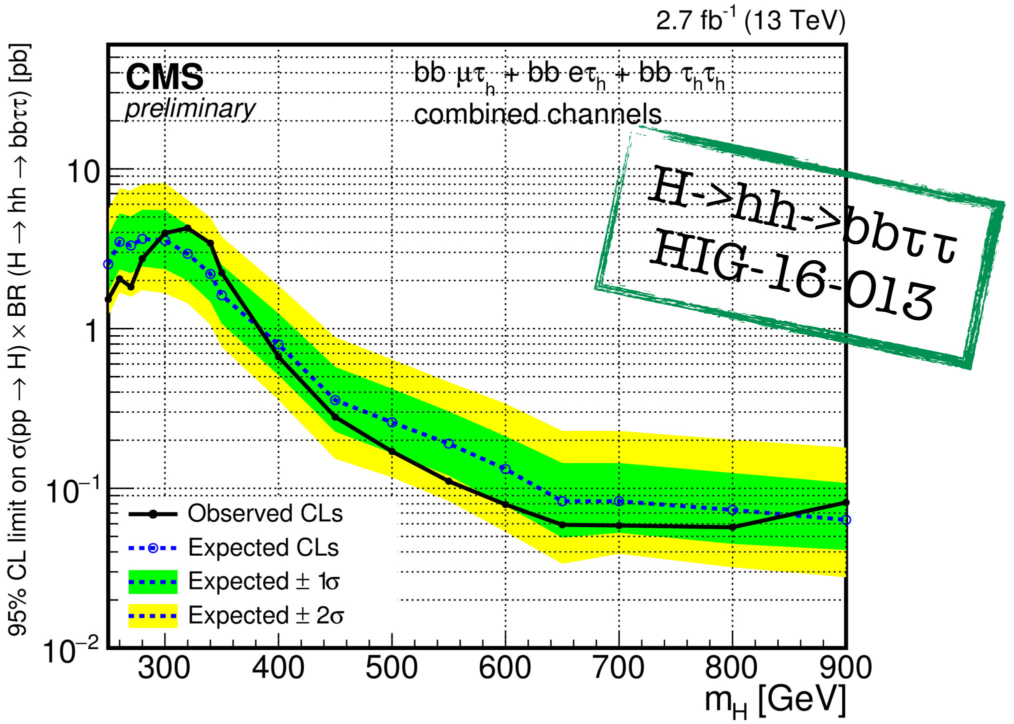




X→hh: 13 TeV

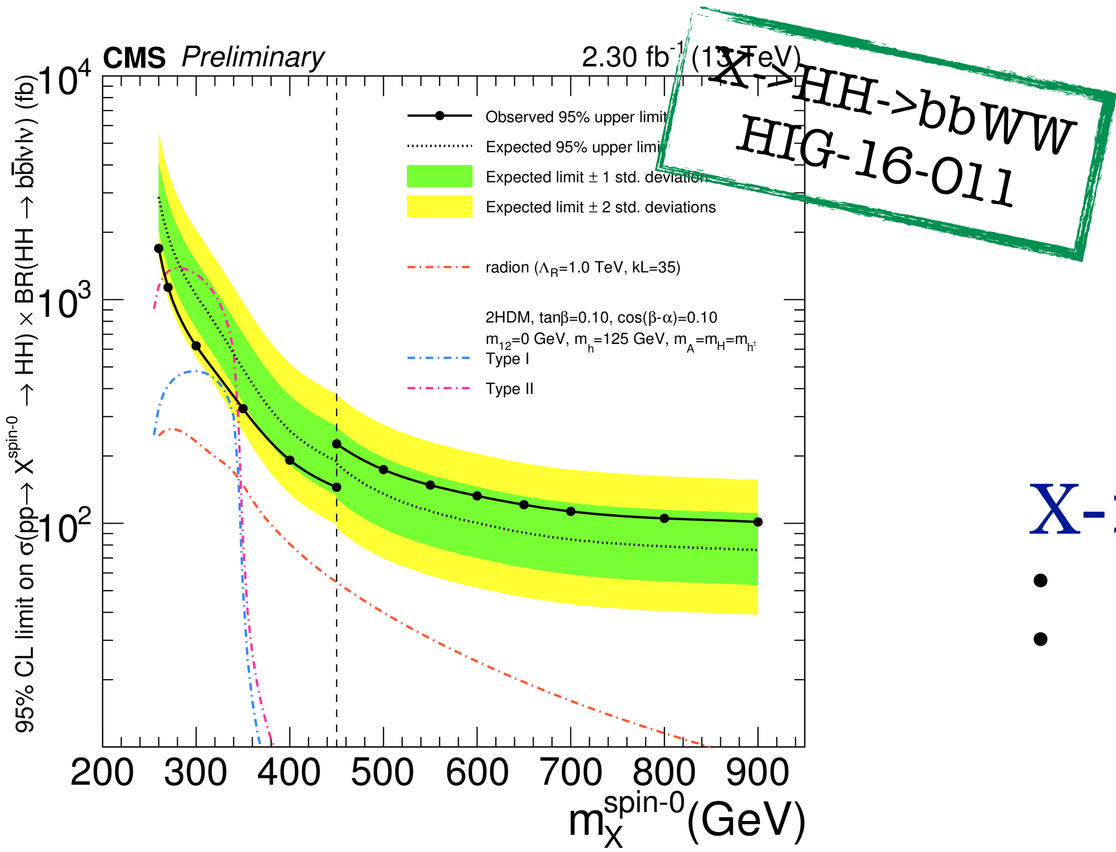
H->hh->bbττ

- Search using m_H
- 3 categories: $bbe\tau_h$, $bb\mu\tau_h$, $bb\tau_h\tau_h$
- kinematic fix fixing $m_{bb}=m_{\tau\tau}$=125 GeV



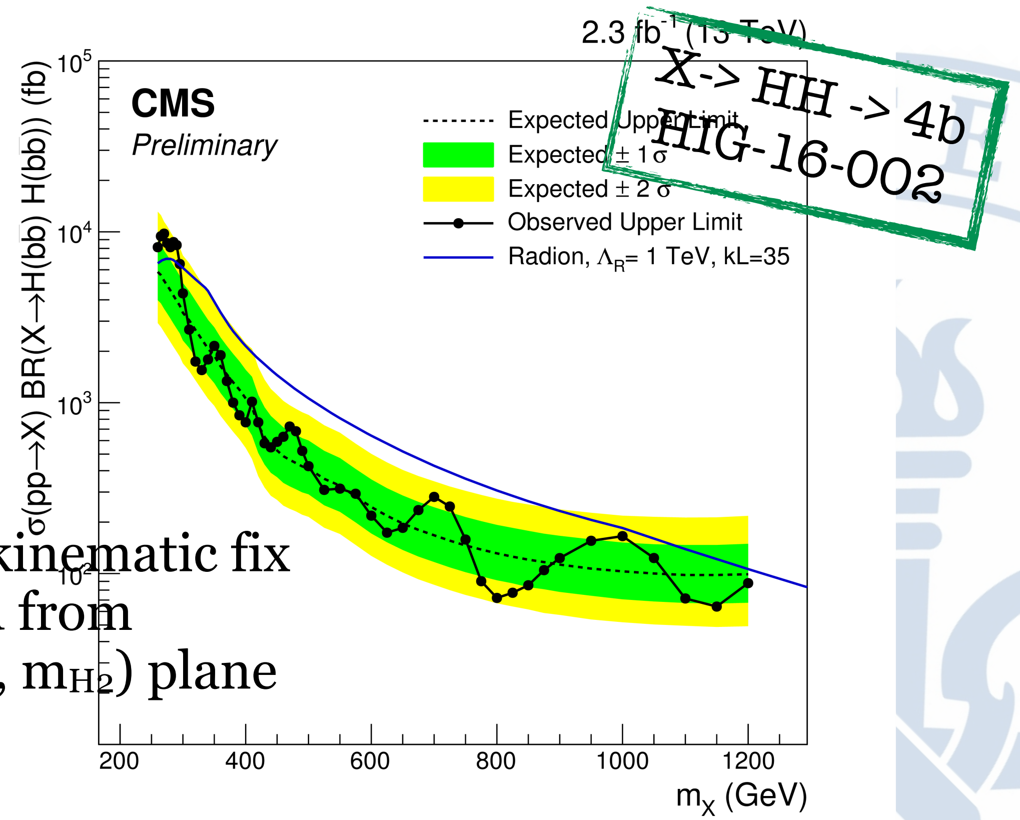
X(spin-0 or 2)->HH->bbW(lν)W(lν)

- Search using yields in 4 event categories
  On/offpeak m_{bb} x low/high BDT score
- BDT trained at mX = 400 and 650 GeV



X-> HH -> 4b

- Search using mX kinematic fix
- Bg shape obtained from sidebands in (m_{H1}, m_{H2}) plane

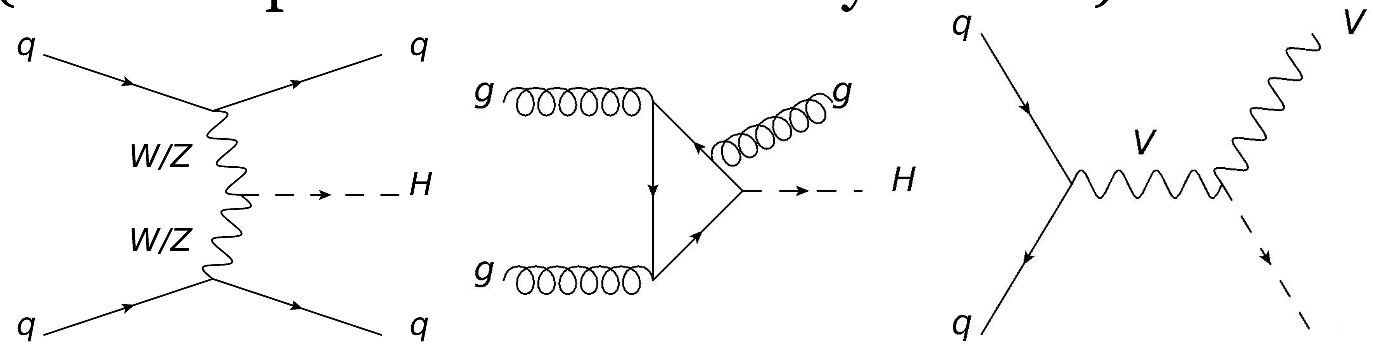


Searches for exotic decay of the Scalar Boson:

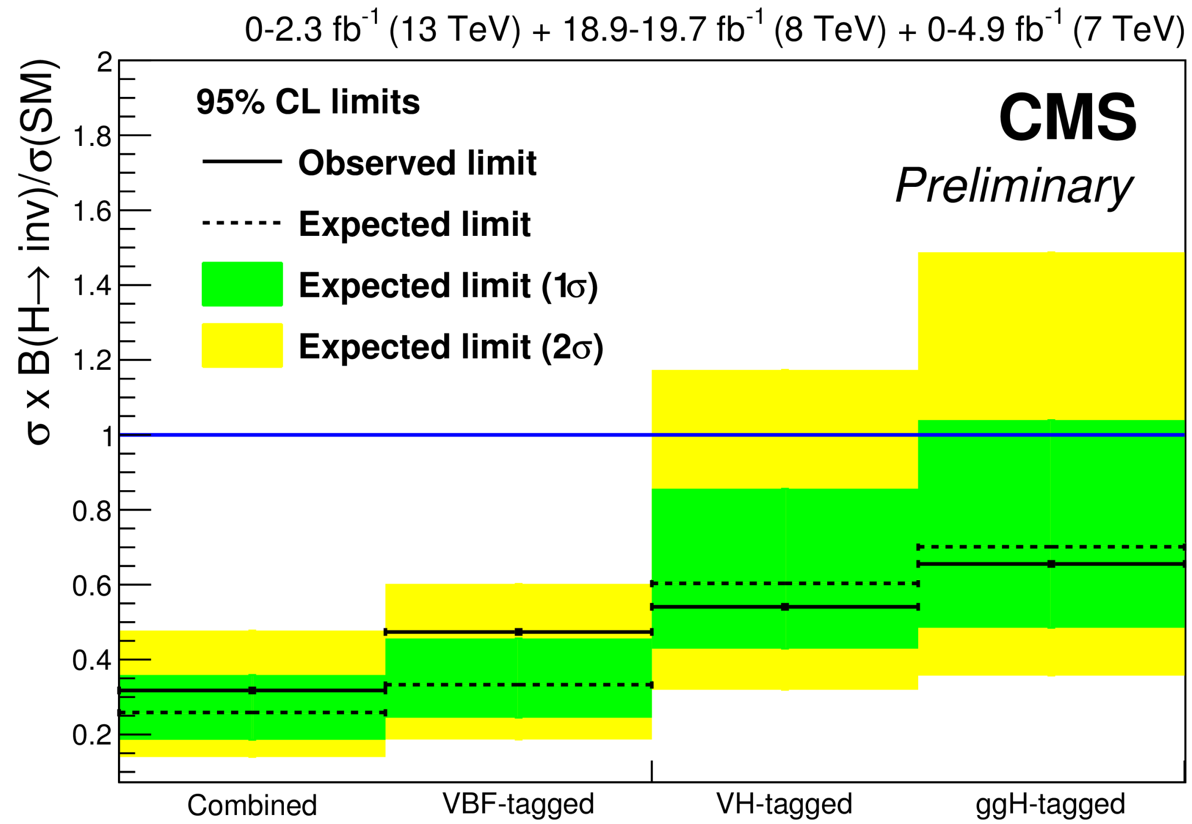
Higgs to Invisible

PAS-HIG-16-009

- Possible in a wide range of models
  (for example neutralino in susy models)



- Combination of several channels tagging the H production:
  - VBF H(inv.)
  - Z→ll H(inv.)
  - Z→bb H(inv.)
  - Monojet + V(had.)Htagged
- **Final state**= production tagging + MET
  - main background = Z+jets (+ ttbar for Z→bb)



Result for m_h=125GeV/c²:
32% (exp. 26%)
VBF only : 48% (exp. 32%)

Lepton flavour violating decay:

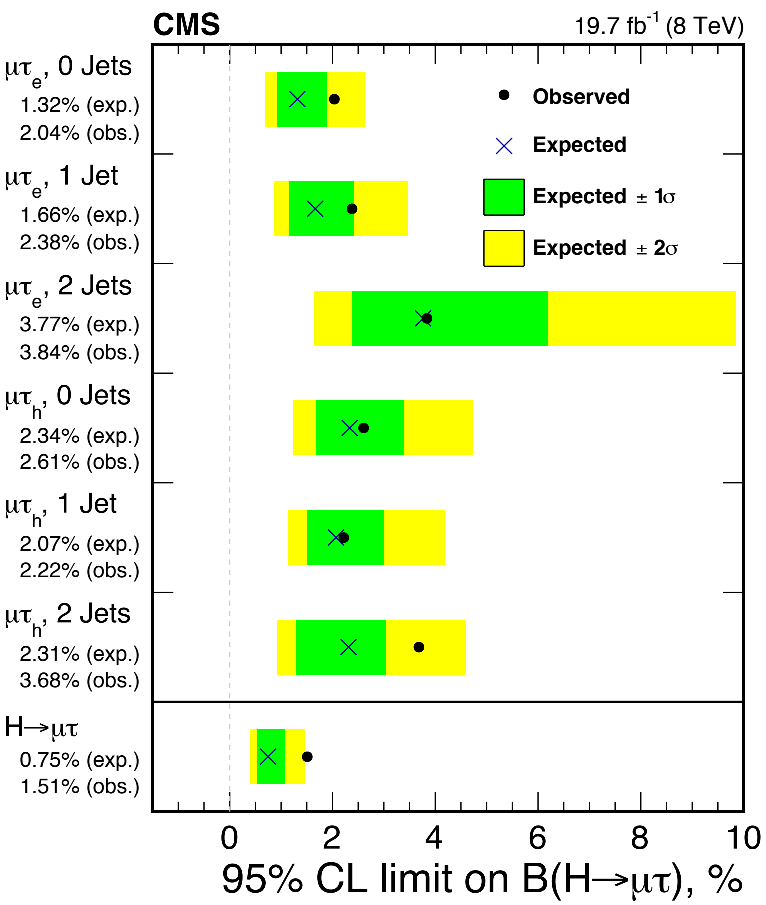
- forbidden in SM but allowed by many BSM models
  - Higgs doublet, composite Higgs, Randall-Sundrum models

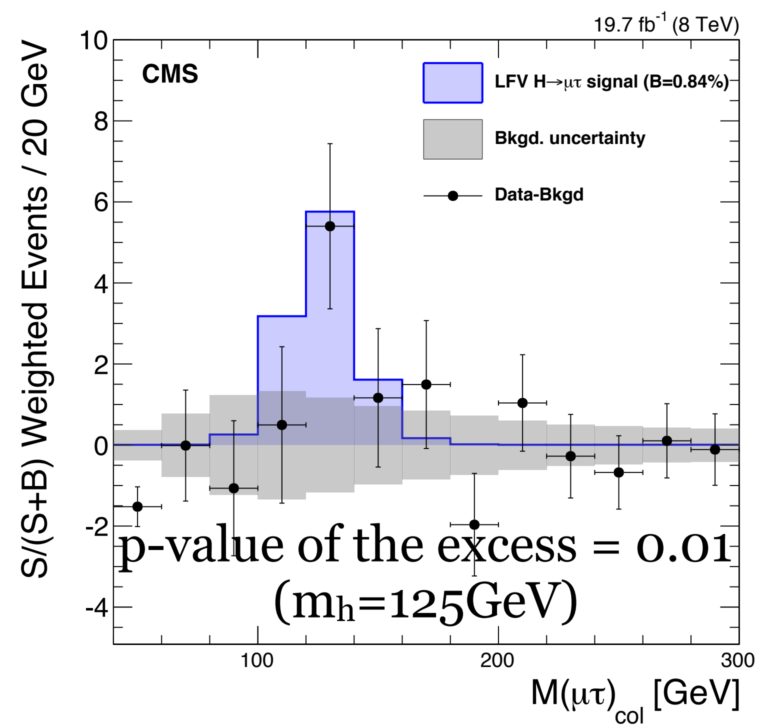
- $H \to \mu\tau_h$, $H \to \mu\tau_e$

analyses similar to SM $H \to \tau\tau$ but different kinematic

- $H \to e\tau_h$, $H \to e\tau_\mu$

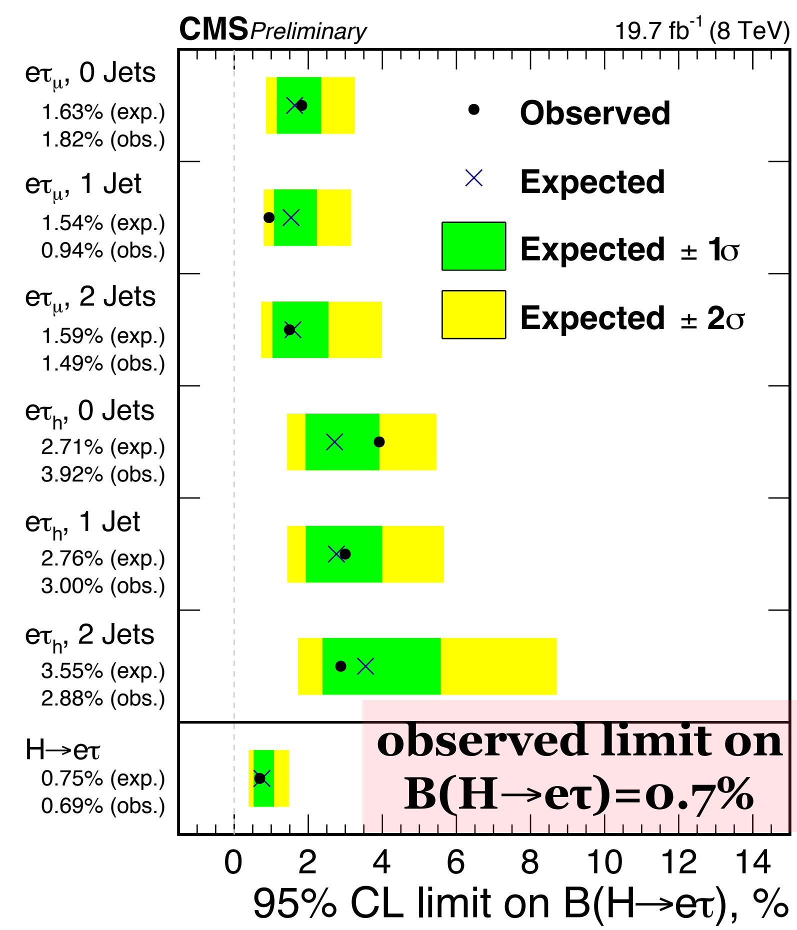
PLB 749 (2015) 337





p-value of the excess = 0.01 (m_h=125GeV)

PAS-HIG-14-040



observed limit on $B(H \to e\tau)$=0.7%

observed limit on $B(H \to \mu\tau)$=1.51% (exp. 0.75)
best fit fraction $B(H \to \mu\tau)$=0.84+0.39-0.37 %

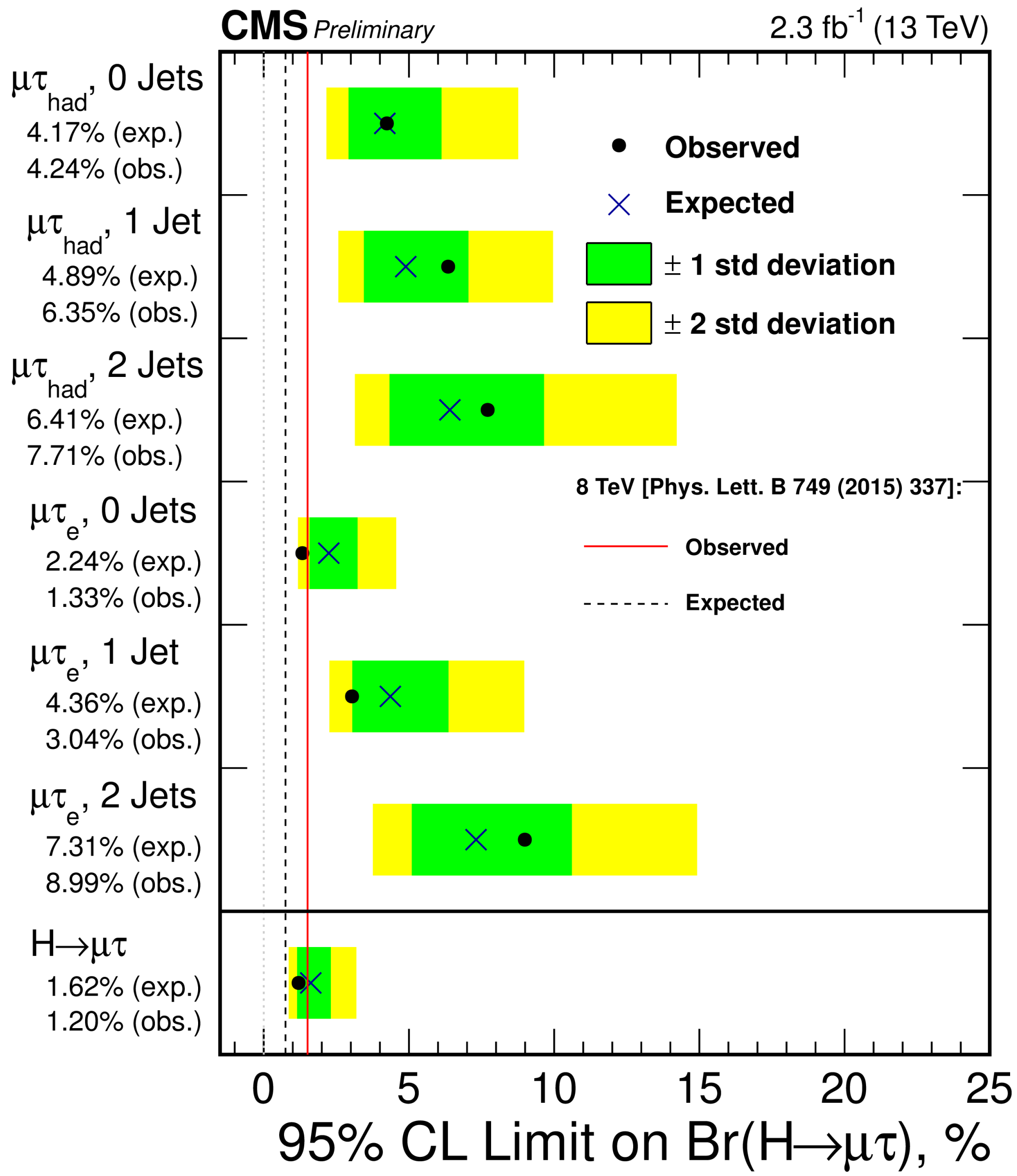
- $H \to e\mu$

observed limit on $B(H \to e\mu)$=0.036%

Lepton flavour violating decay:

CMS-PAS-HIG-16-005

- $H \to \mu\tau_h$, $H \to \mu\tau_e$ 13 TeV



2015: observed limit = 1.20% (exp. 1.63)

2015 data not enough to conclude: More data needed !

Lepton flavour violating decay:

- constraints on Yukawa couplings:

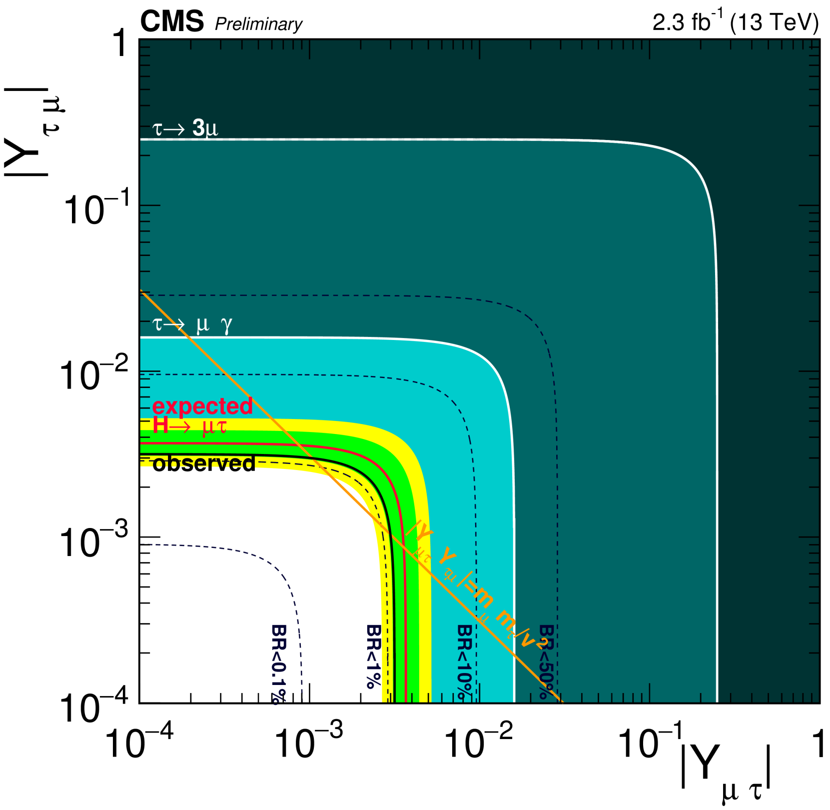
$$B(H \to \ell^\alpha \ell^\beta) = \frac{\Gamma(H \to \ell^\alpha \ell^\beta)}{\Gamma(H \to \ell^\alpha \ell^\beta) + \Gamma_{SM}}$$

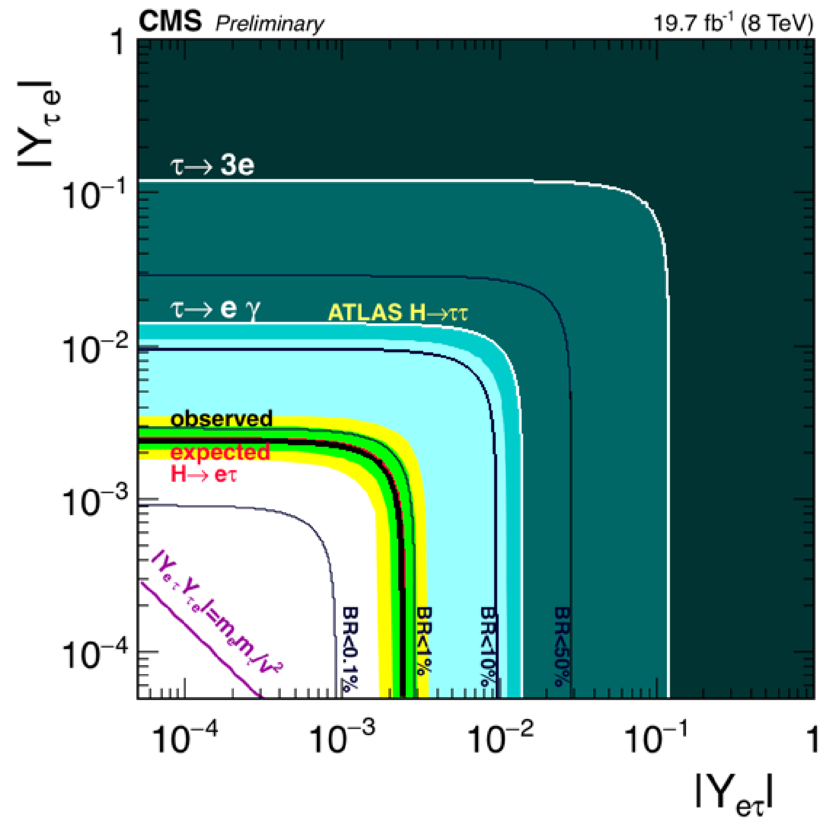
M_H=125 GeV
Γ_{SM} = 4.1 MeV

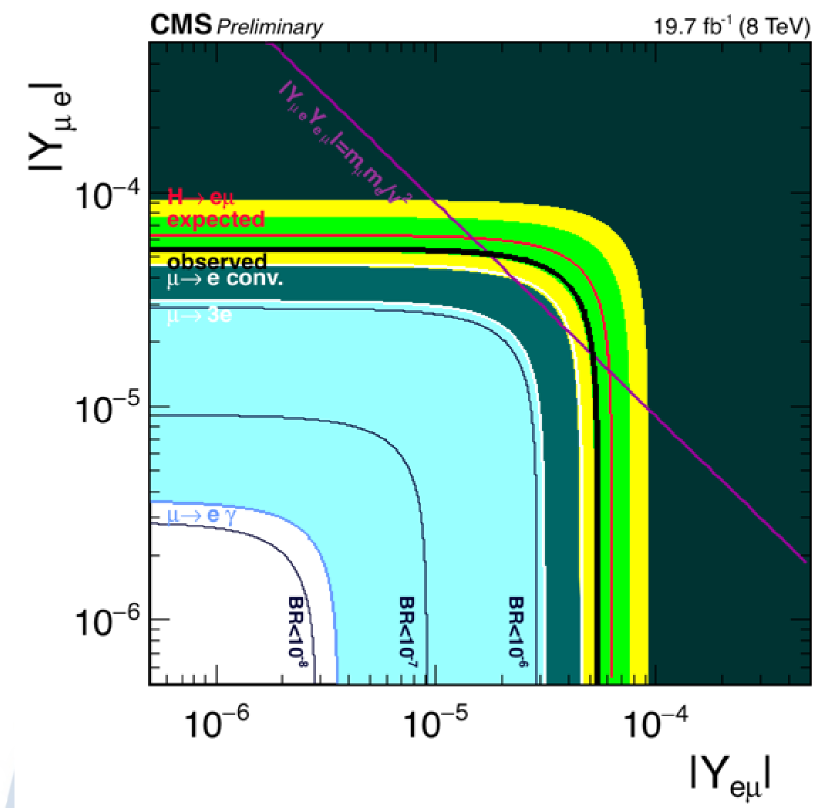
$$\Gamma(H \to \ell^\alpha \ell^\beta) = \frac{m_H}{8\pi}\left(|Y_{\ell^\beta \ell^\alpha}|^2 + |Y_{\ell^\alpha \ell^\beta}|^2\right)$$

CMS-PAS-HIG-16-005

PAS-HIG-14-040





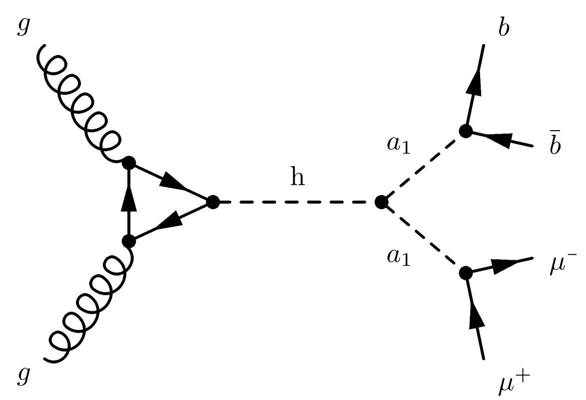


observed constraint:

$$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 3.16 \times 10^{-3}$$

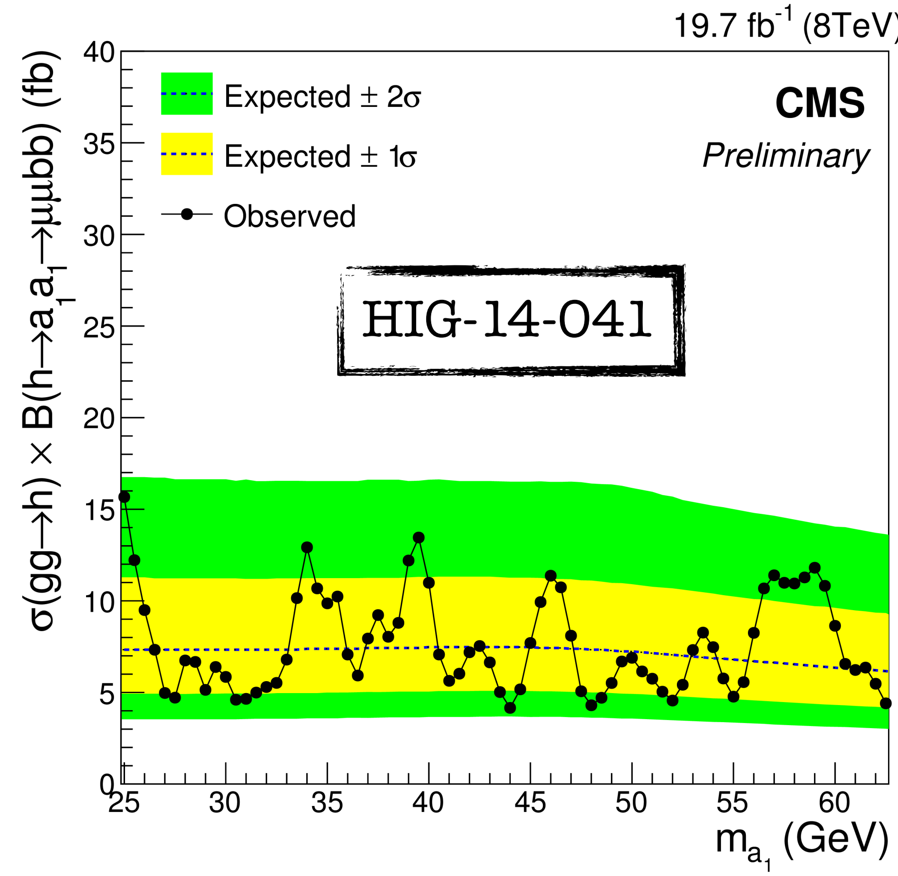
<u>Naturalness limit:</u> $Y_{ij}Y_{ji} \leq m_i m_j / v^2$

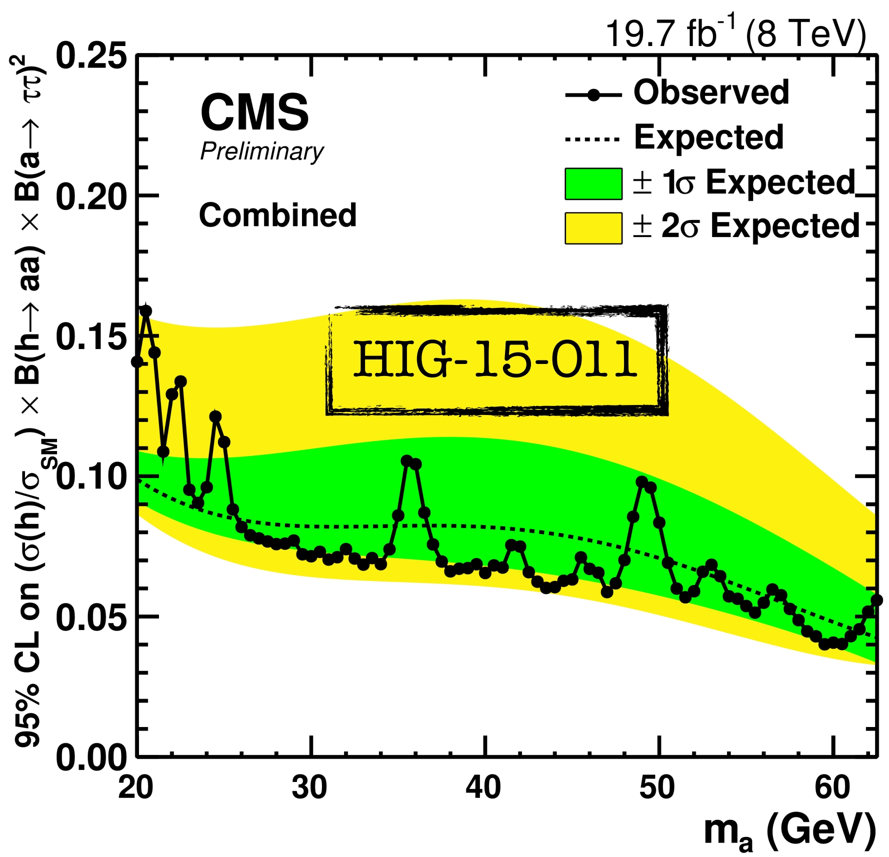
H(125) → a1 a1 : 8 TeV



H → a1 a1 → μμbb

- $20 < m_{a1} < 70$ GeV
- $|m_{\mu\mu bb} - 125| < 25$ GeV
- Search for peak in $m_{\mu\mu}$





H → a1 a1 → μμττ

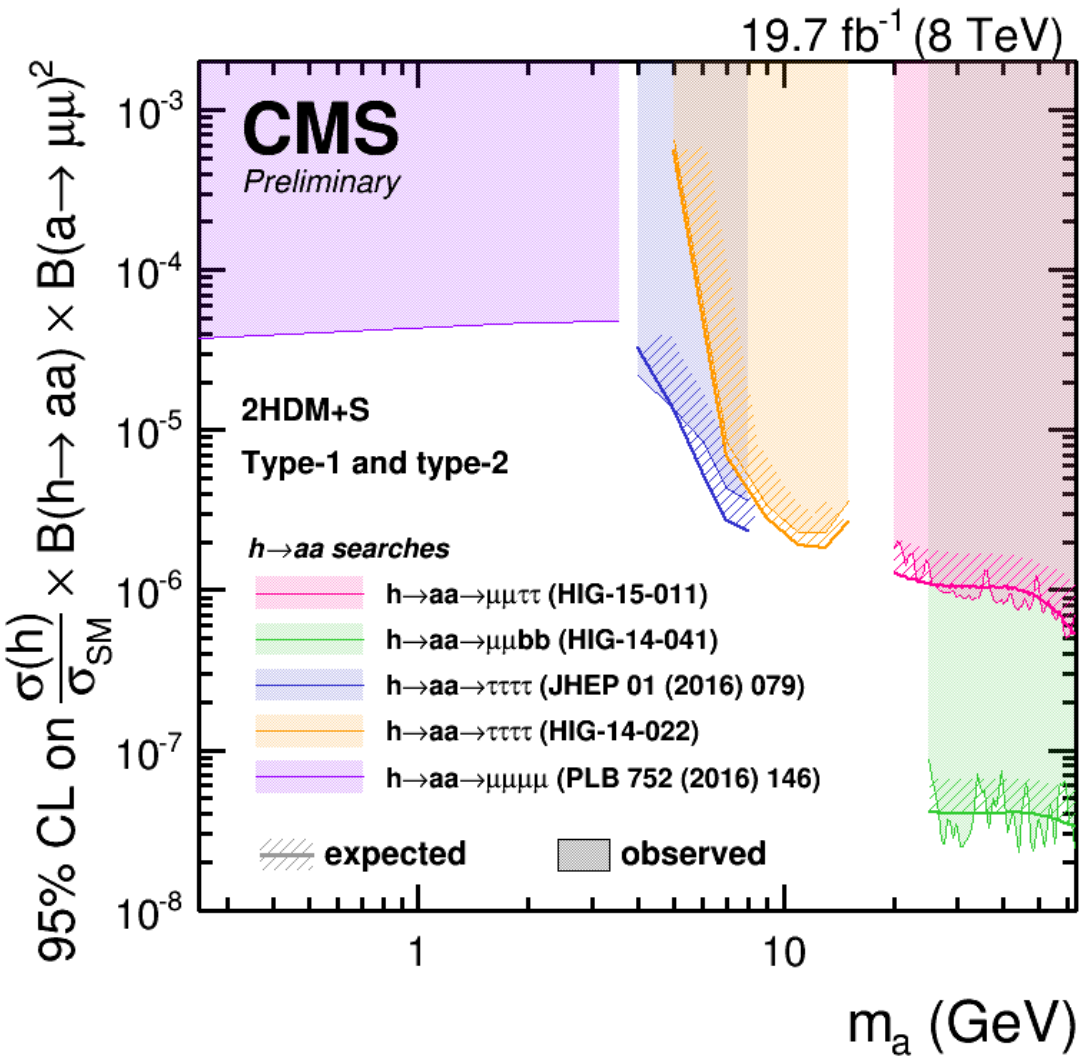
- 5 different ττ decay modes
- $20 < m_{a1} < 62.5$ GeV
- $|m_{\mu\mu\tau\tau} - 125| < 25$ GeV
- $|m_{\mu\mu} - m_{\tau\tau}|/m_{\mu\mu} < 0.8$

$H(125) \rightarrow a_1 a_1$: 2HDM+S summary

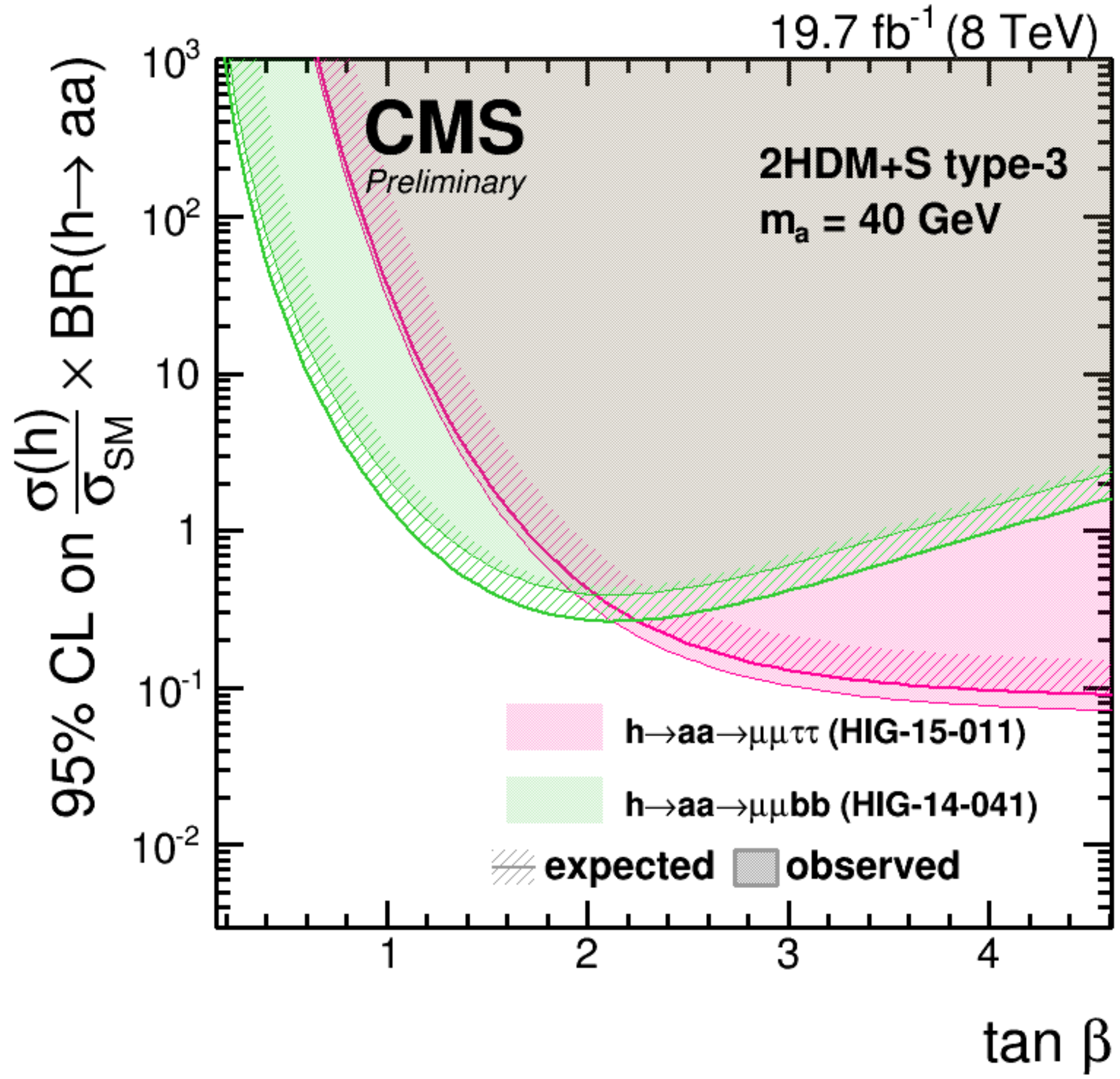
hlps://twiki.cern.ch/twiki/bin/viewauth/CMSPublic/SummaryResultsHIG

a1 couplings to fermions depend on model type and tanβ

Type-1 and -2 limits are ~indep. of tanβ

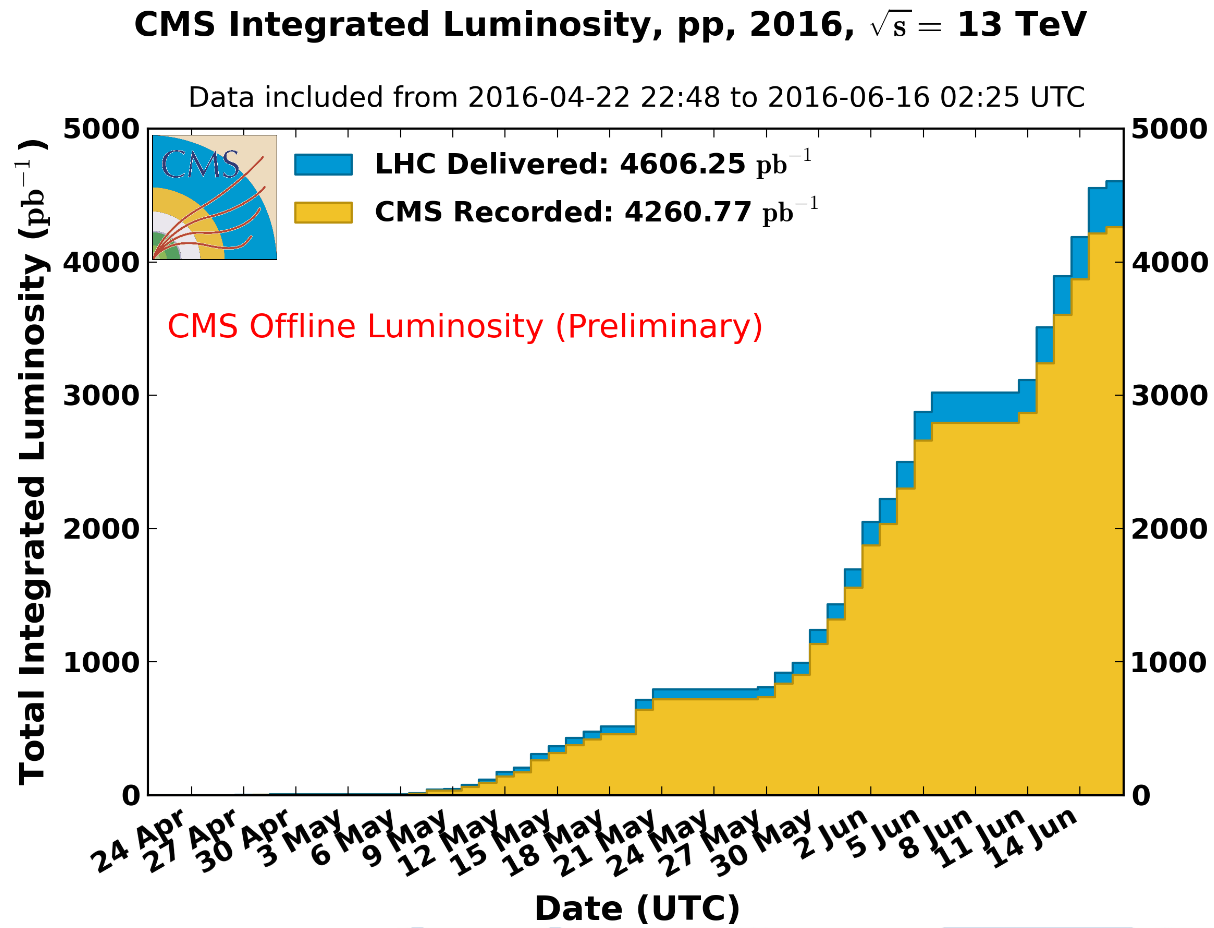


Sensitivity to B(h→aa) in Type-3 and -4



Conclusion:

- CMS searches for BSM scalar sector at 13 TeV in LHC Run 2 are well under way
  - Sensitivity with 2015 data (2.1fb-1) already comparable with sensitivity from Run 1 dataset
- In 2016, CMS and the LHC are performing very well !
  - More results with come soon !



Back-Up

2HDM

arxiv:1507.04281

	$h\overline{U}U$	$h\overline{D}D$	$h\overline{E}E$	$H\overline{U}U$	$H\overline{D}D$	$H\overline{E}E$	$iA\overline{U}\gamma_5 U$	$iA\overline{D}\gamma_5 D$	$iA\overline{E}\gamma_5 E$
Type I	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$-\cot\beta$	$\cot\beta$	$\cot\beta$
Type II	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$-\cot\beta$	$-\tan\beta$	$-\tan\beta$
Type X	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$-\cot\beta$	$\cot\beta$	$-\tan\beta$
Type Y	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$-\cot\beta$	$-\tan\beta$	$\cot\beta$