38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

AUGUST 3 - 10, 2016
CHICAGO

Search for A→ Zh and H → ZA

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On behalf of the CMS collaboration

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Introduction to Two-Higgs-Doublet-Models

- An extension of the SM: adding one doublet of complex fields: 8 degrees of freedom.
  - 3 are eaten by the W and Z bosons to acquire a mass.
  - 5 remaining are new (pseudo-)scalar particles: h, H, A and $H^{\pm}$

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  - $\tan\beta = \frac{v_2}{v_1}$

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- the mixing angle of the two neutral even states : α
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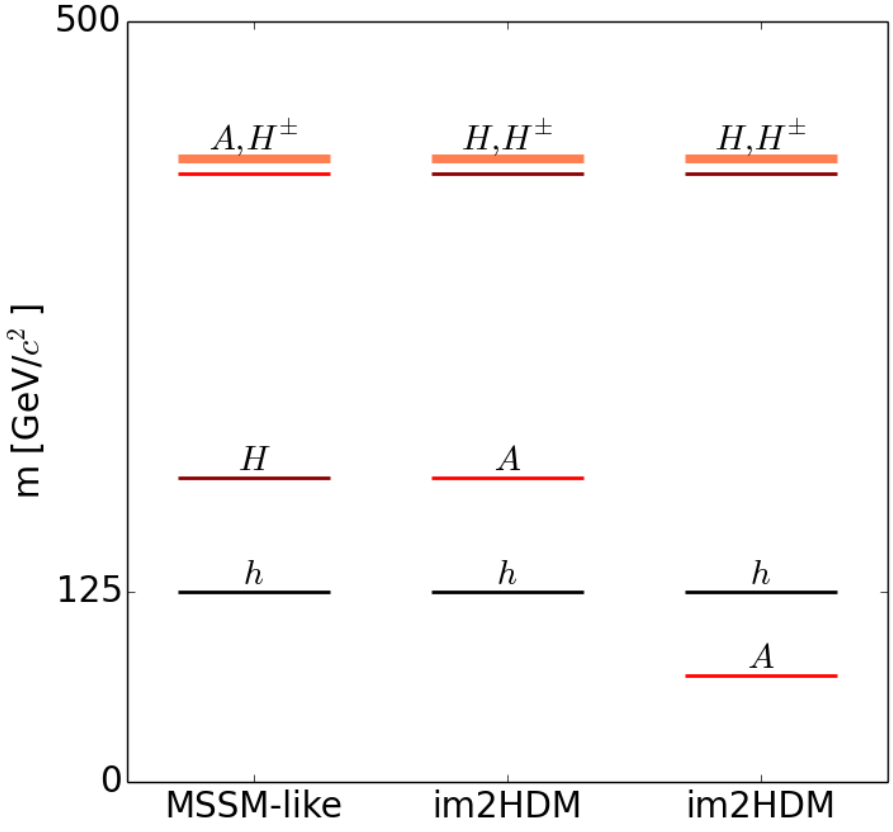
- Coupling to fermions in type-II:
  - One doublet couple to up-type quarks
  - The other couple to down-type quarks and charged leptons

The parameters of the 2HDM

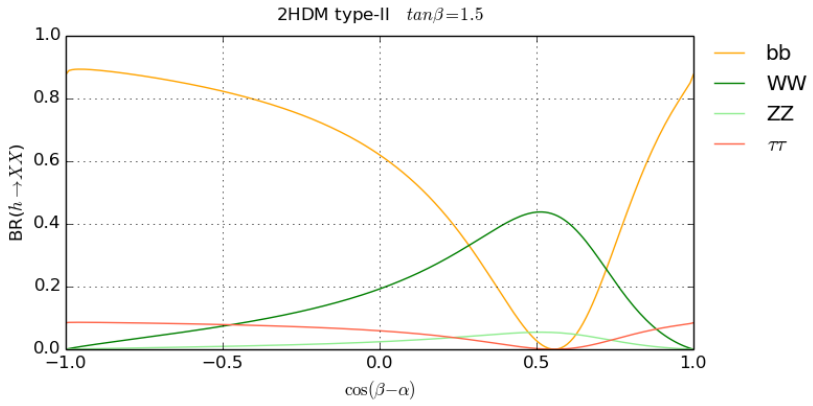
- 5 physical scalar fields
  - 3 neutral: h, H, A
  - charged: $H^{\pm}$
- 3 extra parameters
  - $\tan\beta$
  - $\cos(\beta - \alpha)$
  - m_{12}^2
- Custodial symmetry
- Several mass hierarchies
  im2HDM[0904.0705]



Two Higgs Doublet Models: limit from higgs couplings

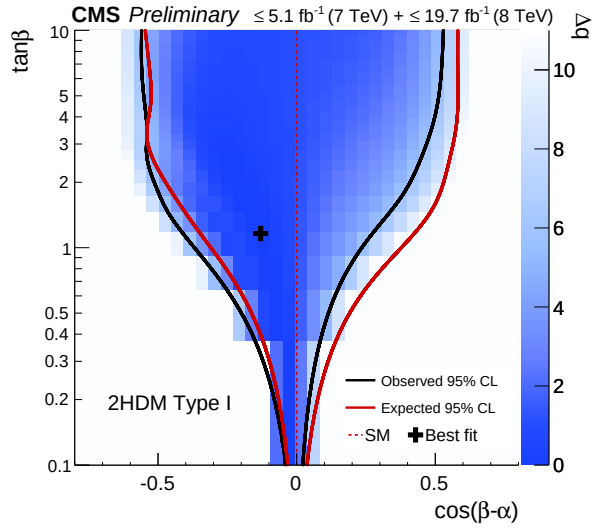
h^{125} couplings to SM particles measured:

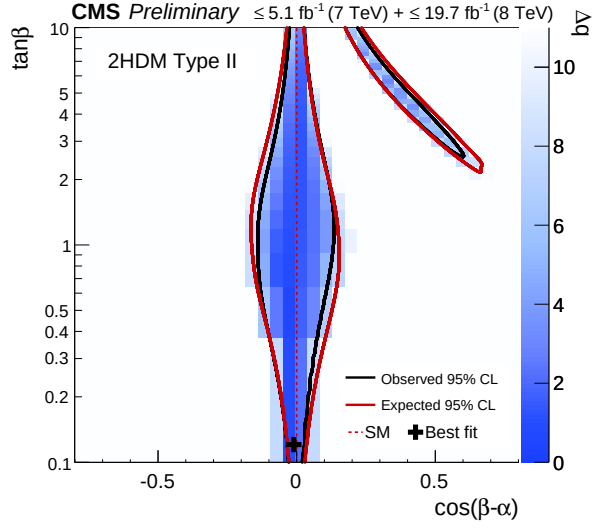
- Limit on the couplings of lightest scalar of the 2HDM
- Limit on $\tan\beta$ and $\cos(\beta-\alpha)$



Alignment limit favored:

- $\cos(\beta-\alpha)=0$
- $h^{2HDM}=h^{SM}$

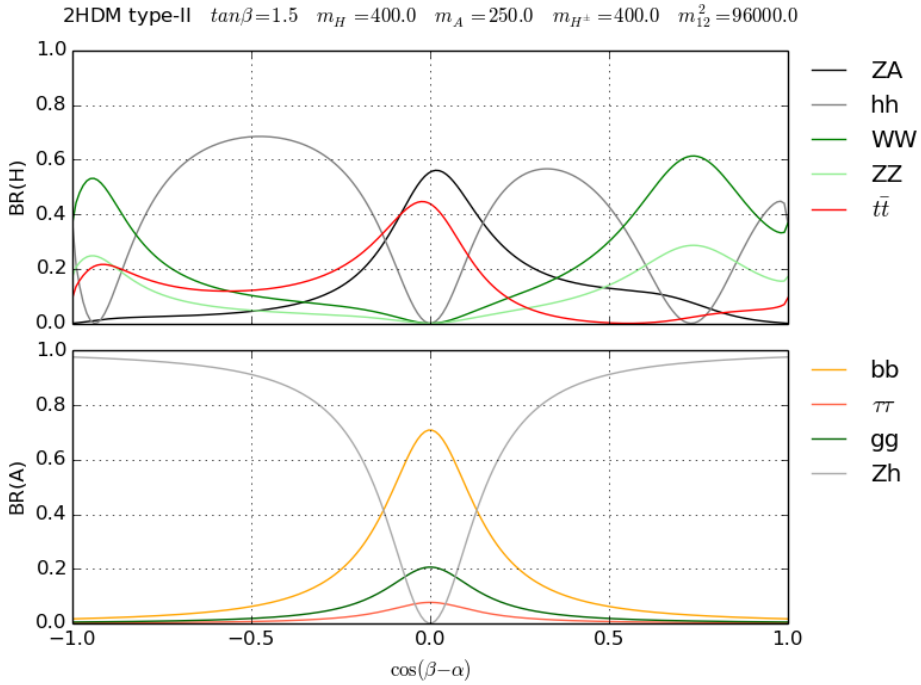




[CMS-PAS-HIG-16-007]

New (pseudo-)scalar decays: $\tan\beta = 1.5$

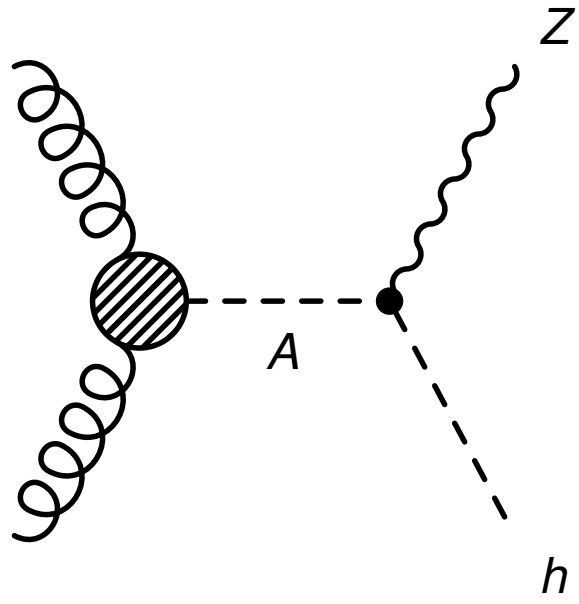
- im2HDM type II
- $m_{12}^2 = m_{H^\pm}^2[\tan\beta/(1+\tan\beta^2)]$
- $cos(\beta-\alpha) \approx 0$
  - $H \to ZA$, $H \to t\bar{t}$, $A \to b\bar{b}$
- $A \to Zh$, $H \to VV, hh$
- Nice complementarity
  $H \to ZA, hh, t\bar{t}, VV$
- $A \to Zh, bb$



Focus on $A \to Zh$ and $H \to ZA \to llbb/ll\tau\tau$

$A \to Zh$ in CMS

Search for $A \to Zh$

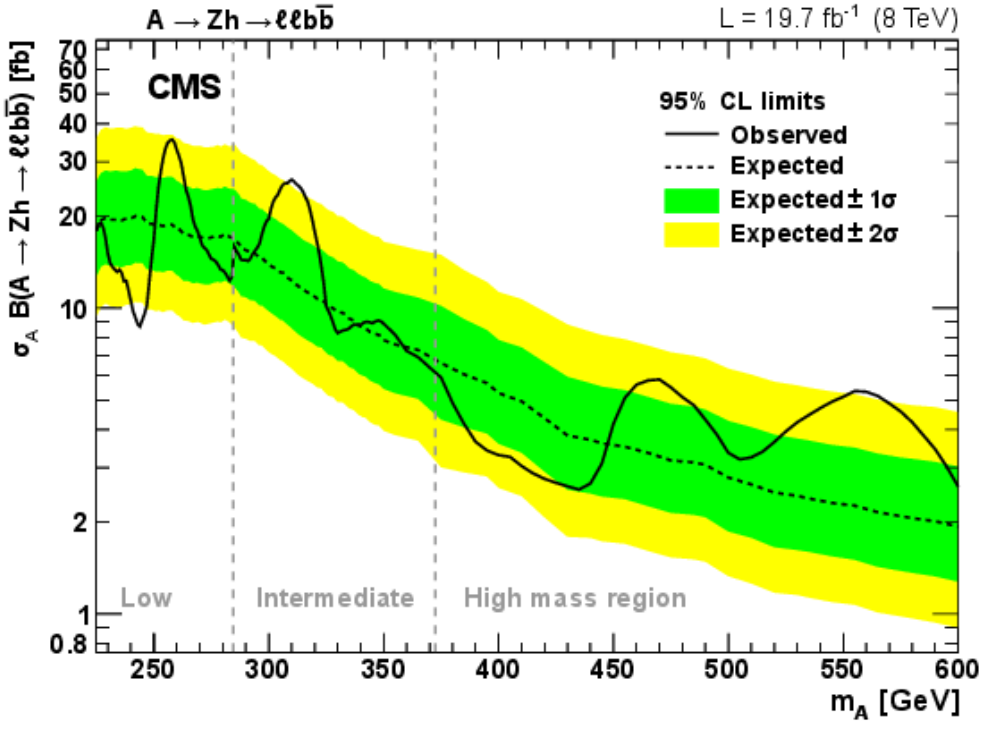


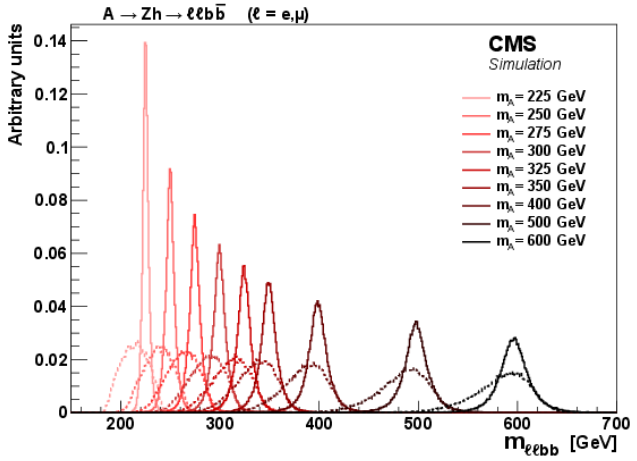
- arXiv:1410.2751 CMS-HIG-13-025 $h \to WW^*, ZZ^*, \tau\tau$, $h \to \gamma\gamma$
- arXiv:1504.04710 CMS-HIG-14-011 $h \to b\bar{b}$
- arXiv:1510.01181 CMS-HIG-14-034 $h \to \tau\tau$

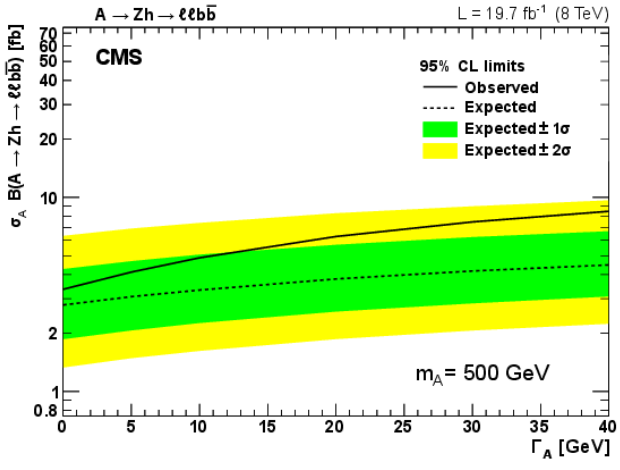
$A \to Zh$: Cross section limits

$A \to Z(ll)h(bb)$

- Kinematic fit using resolution on $m_h = 125$.
- BDT trained in 3 mass regions
- NWA and width dependance



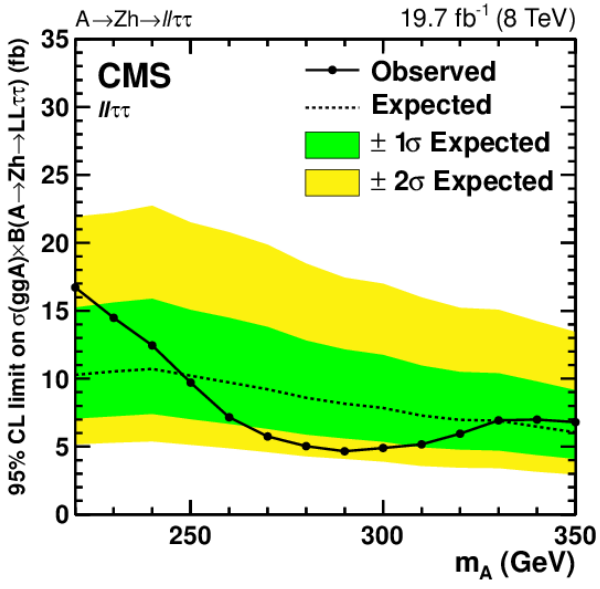


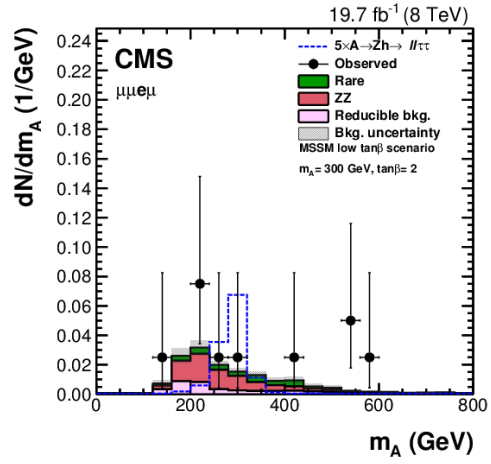


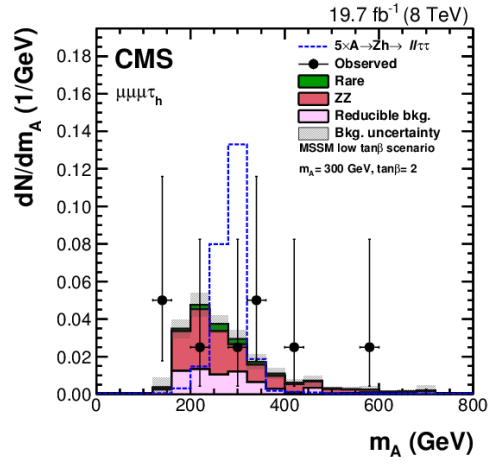
$A \to Zh$: Cross section limits

$A \to Z(ll)h(\tau\tau)$

- A boson mass reconstructed from the Z and the h using `SVFit` to improve the resolution.
- 8 categories: ll+$e\mu/e\tau/\mu\tau/\tau\tau$



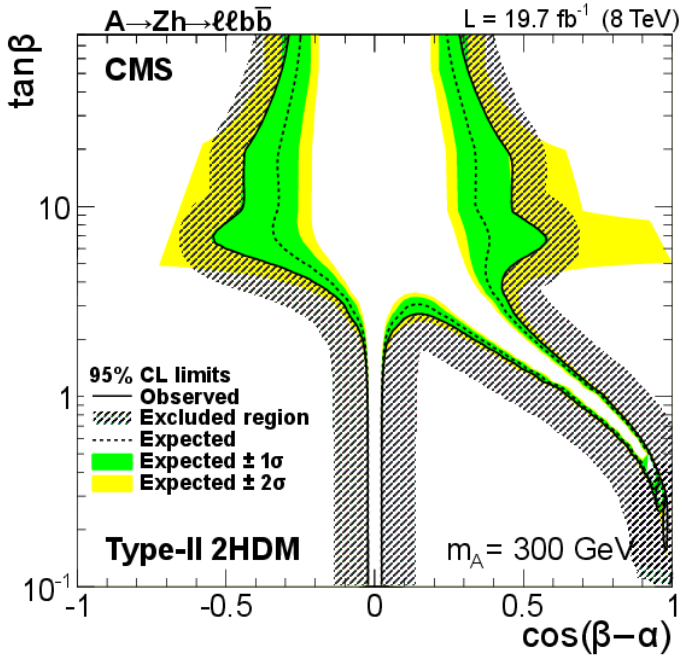




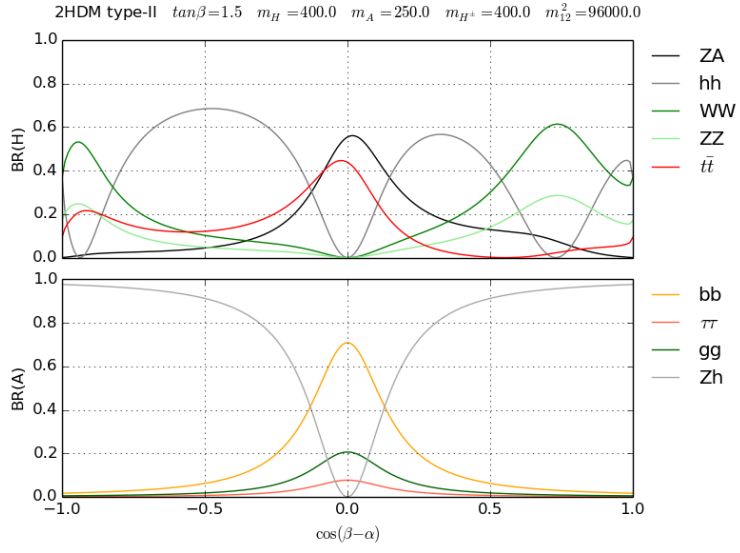
$A \to Zh$ Results and interpretation

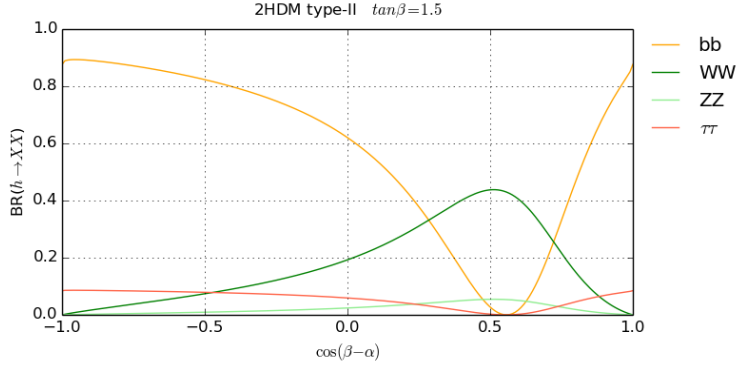
$A \to Z(ll)h(bb)$

- *type II*
- $m_{12}^2 = m_A^2[\tan\beta/(1+\tan\beta^2)]$
- $m_A = m_H = 300$ GeV
- $A \to ll\tau\tau$ similar results

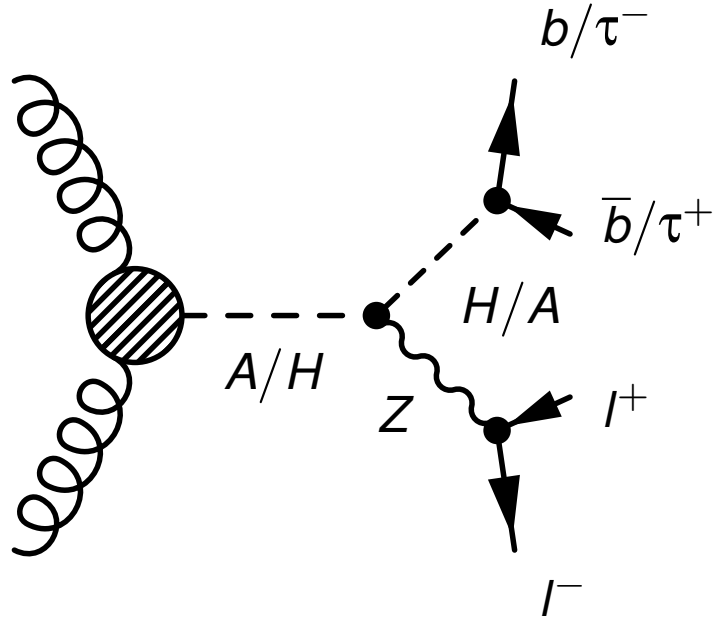


BR at $\tan\beta = 1.5$





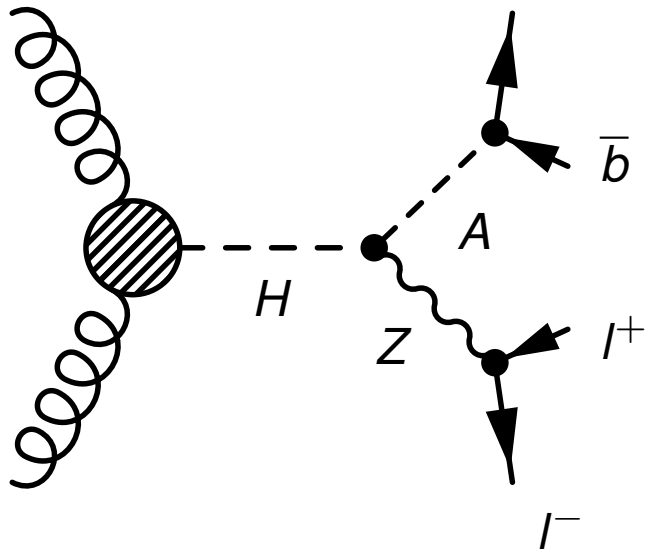
Search for $H \to ZA$ or $A \to ZH$

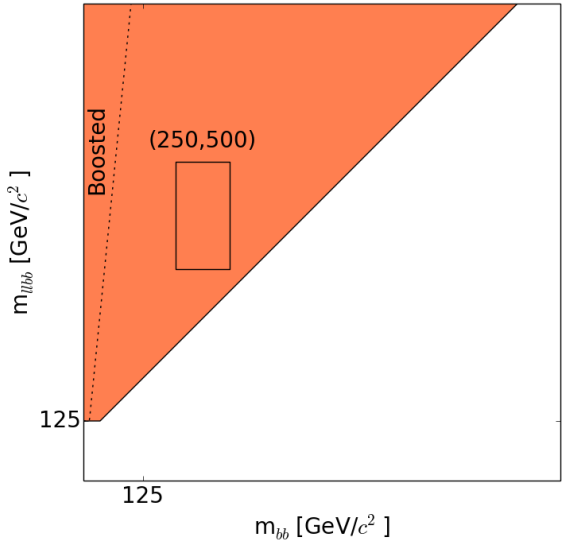


- arXiv:1603.02991 (PLB 759 (2016) 369)
  $H \to ZA \to llbb/ll\tau\tau$
- CMS-PAS-HIG-16-010 $H \to ZA \to llbb$

$H \to ZA \to llbb$ Strategy

- Designed for easy recasting
- Select events with a Z candidate and two b-jets
- Search for excess in the plane (m_{bb}, m_{llbb})





Selection cuts	Rejected Bkg
2 OS SF leptons	QCD & W+jets
$76 < M_{ll} < 106 GeV$	non-res. DY & $t\bar{t}$
2 b-tagged jets	DY + light jets
E_T^{miss}-sig. < 10	$t\bar{t}$

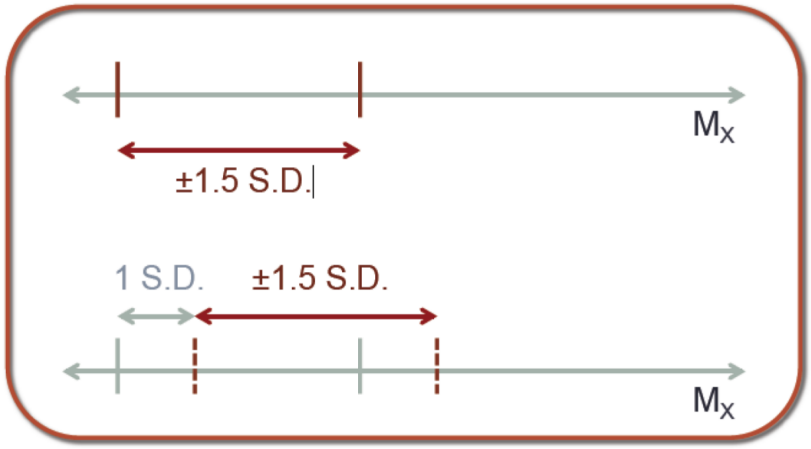
Table : baseline selection

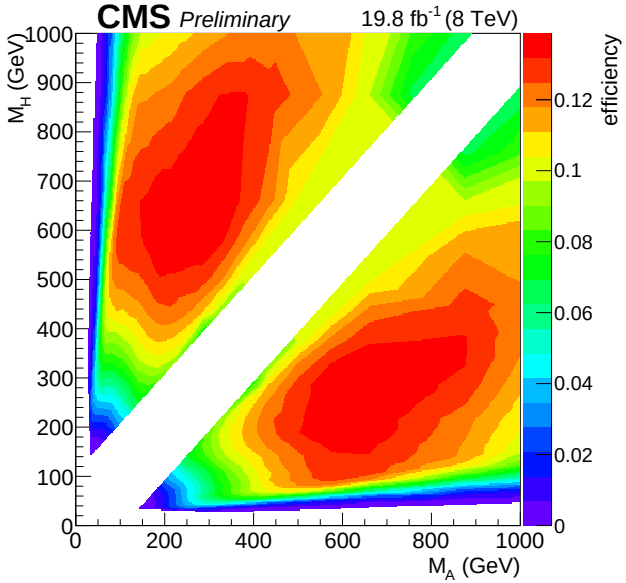
$H \to ZA \to llbb$ at 8 TeV: The analysis

Definition of [M_{bb}, M_{llbb}] bins:

- Resolution is about 15% of the reconstructed mass.
- Width is driven by the resolution

  $\to$ Width = 3 S.D.
- Bins are overlapping to cover the whole phase space properly.





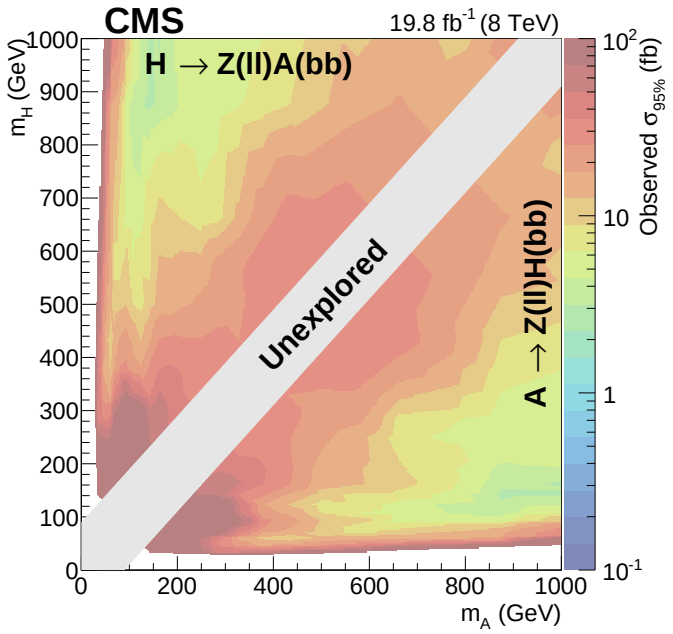
Signal efficiency map obtained with

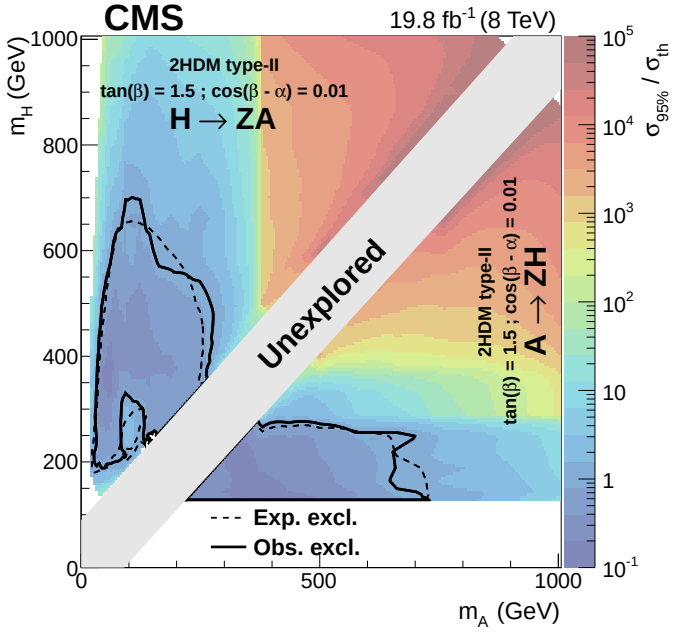
- 13 FullSim samples
- 300 Delphes samples
- Mirroring $M_A - M_H$.

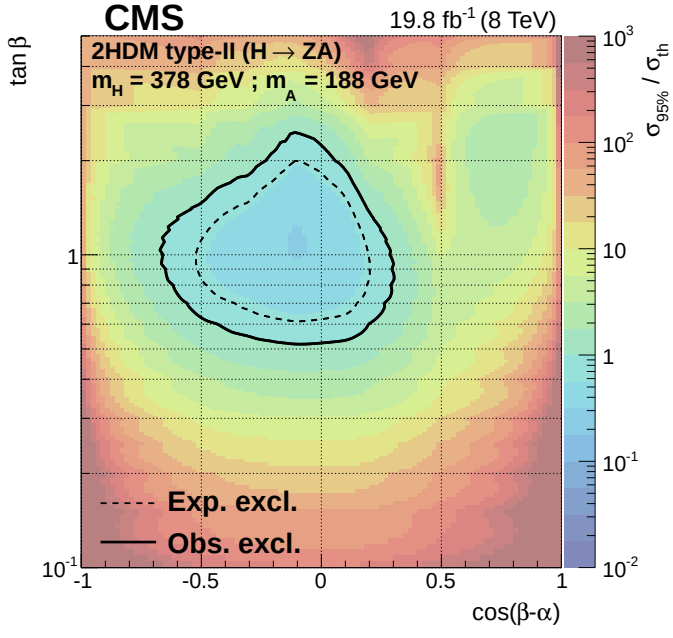
Delphes samples used for the shape of the signal efficiencies between the FullSim samples

$H \to ZA$ at 8 TeV: Limits arXiv:1603.02991

- Model independant results
- Limit on the signal strenght for 2HDM type-II
  - $\cos(\beta - \alpha) = 0.01$, $\tan\beta = 1.5$
  - $m_A = 150$ GeV, $m_H = 350$ GeV

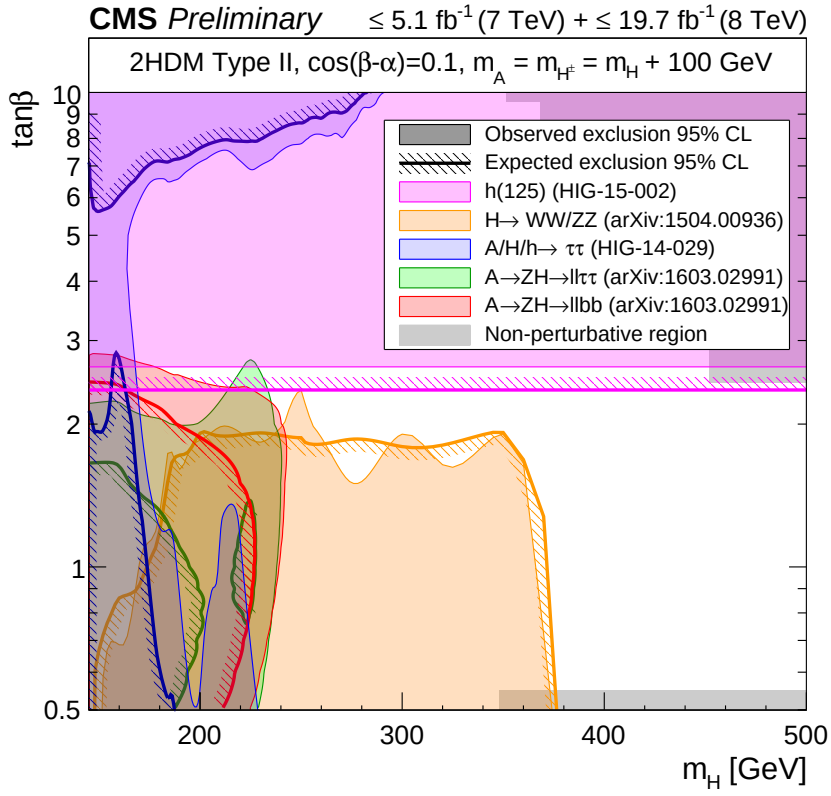






Summary of 8 TeV analyses

- 2HDM predicts the existence of 5 scalars
- Lots of interesting final states are concerned
  - $A \rightarrow Zh$
  - $H \rightarrow ZA$ or $A \rightarrow ZH$
- Best results are at 8 TeV so far

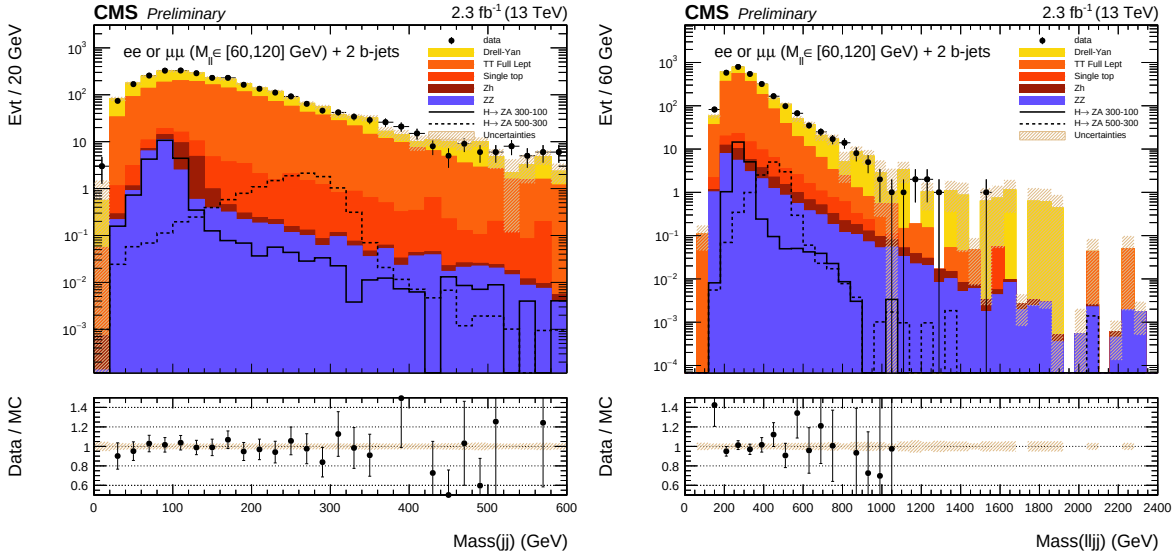


[CMS-PAS-HIG-16-007]

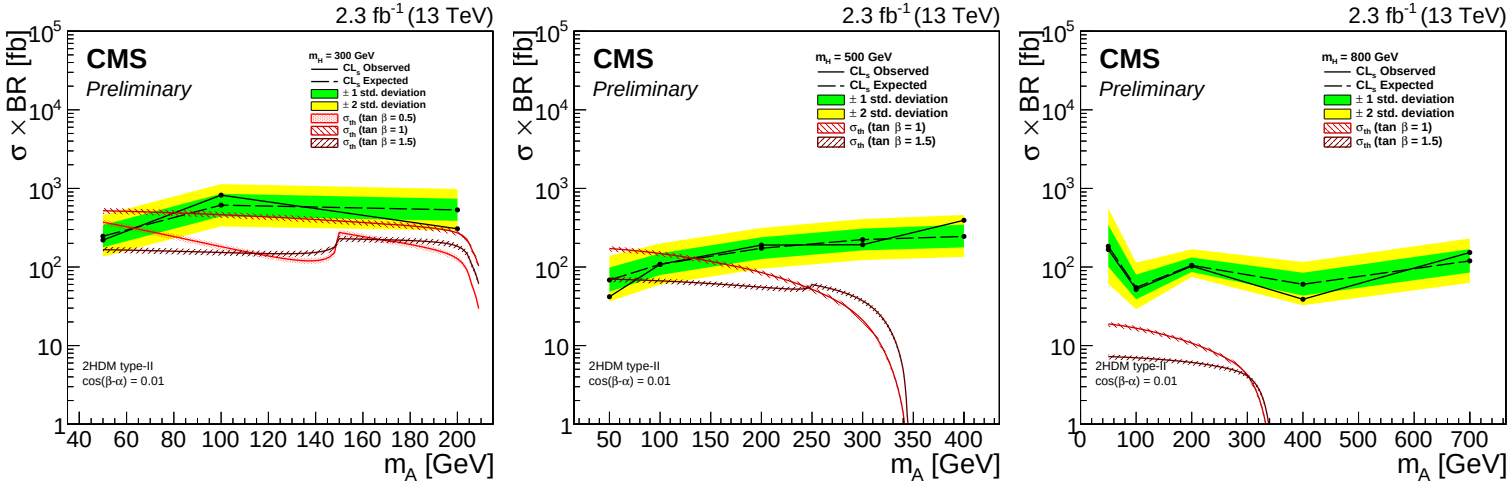
And 13 TeV data are currently collected....

$H \rightarrow ZA$ at 13 TeV CMS-PAS-HIG-16-010

Analysis similar to 8 TeV

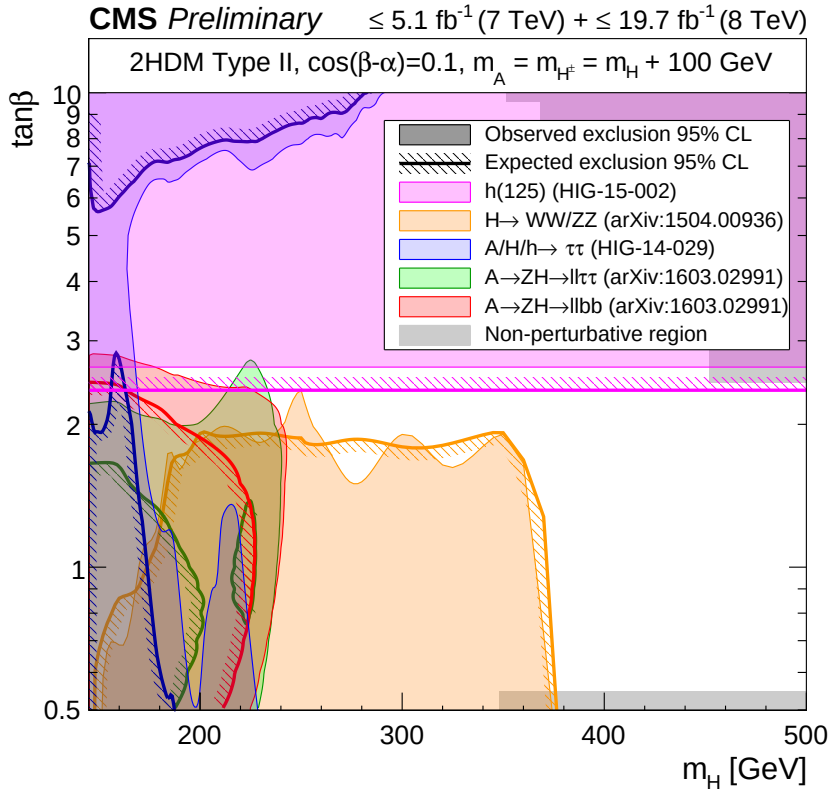


No excesses observed. Set of limits in the signal cross-section



Conclusion

- 2HDM predicts the existence of 5 scalars
- Lots of interesting final states are concerned
  - $A \rightarrow Zh$
  - $H \rightarrow ZA$ or $A \rightarrow ZH$
- Best results are at 8 TeV so far
- 13 TeV analysis ongoing



[CMS-PAS-HIG-16-007]

Thanks for your attention!

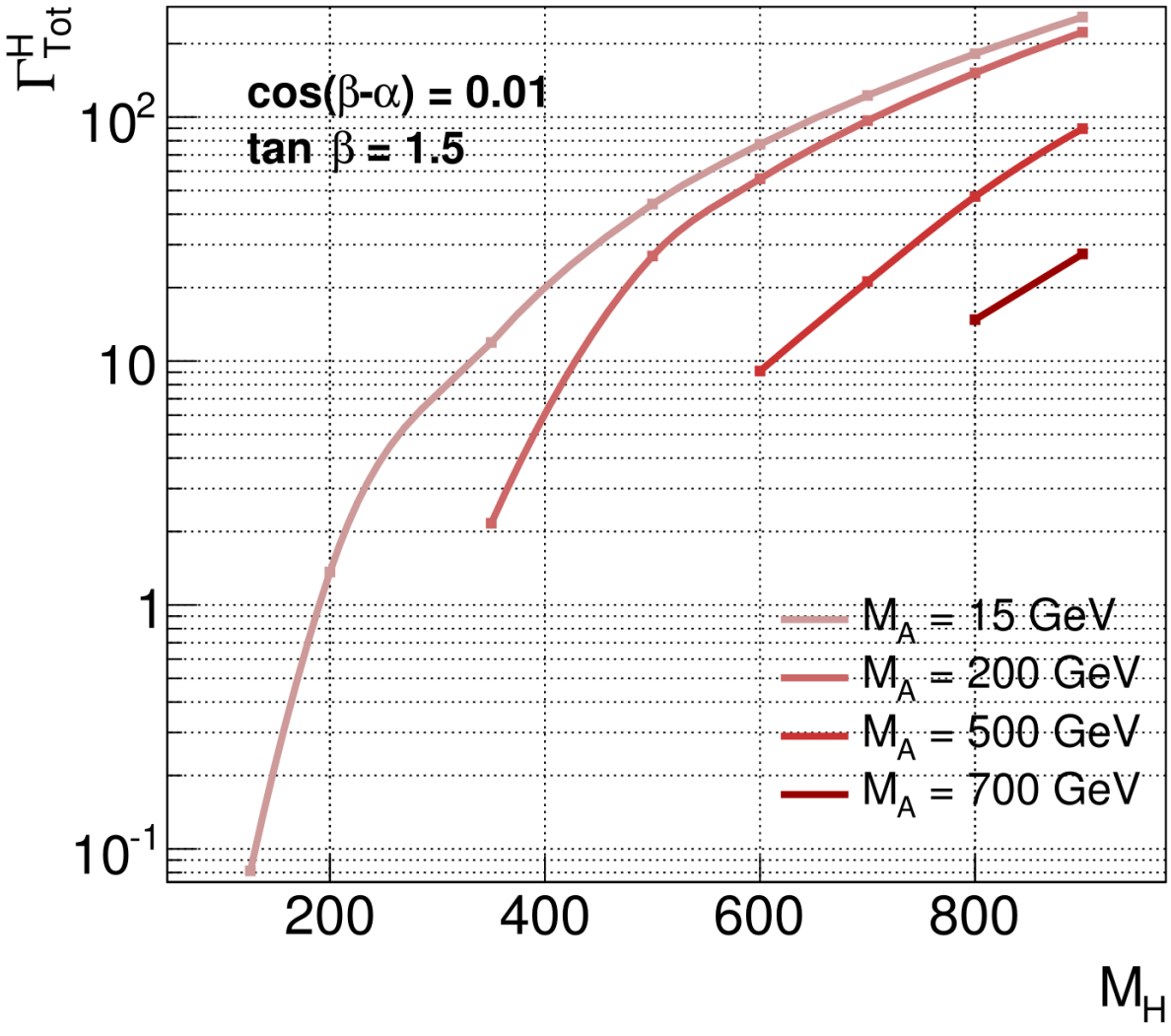
Where to look for new scalars?

- the story changes for other masses, values of m_{12}^2, or type of 2.
- 5 parameters is a lot to have a clear view in only a few plots

Several interesting and complementary final states:

- SM-higgs-like searches: $b\bar{b}$, $\tau\tau$, $t\bar{t}$, ZZ, WW,...
- SM-higgs decays: Zh and hh
- Exotic decays: ZA

$H \rightarrow ZA$: width



mass-splitting : 1405.5537

Echoes of the Electroweak Phase Transition:
Discovering a second Higgs doublet through $A_0 \to H_0 Z$.