# Search for H/A $\rightarrow$ Z A/H and A/H decaying to a fermion pair

A. Mertens
On behalf of the CMS collaboration



CP3 - Center for Cosmology, Particle Physics and Phenomenology
UCL, Louvain-la-Neuve
Belgium

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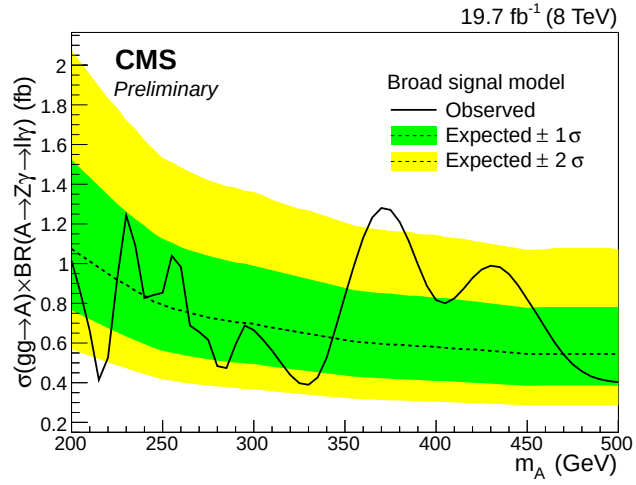
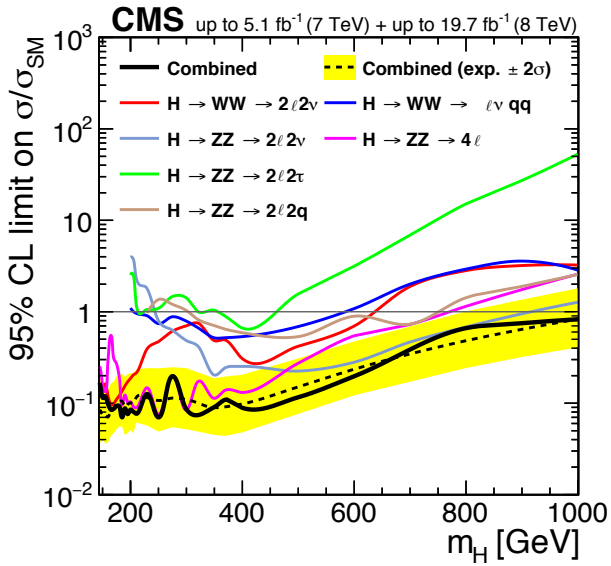
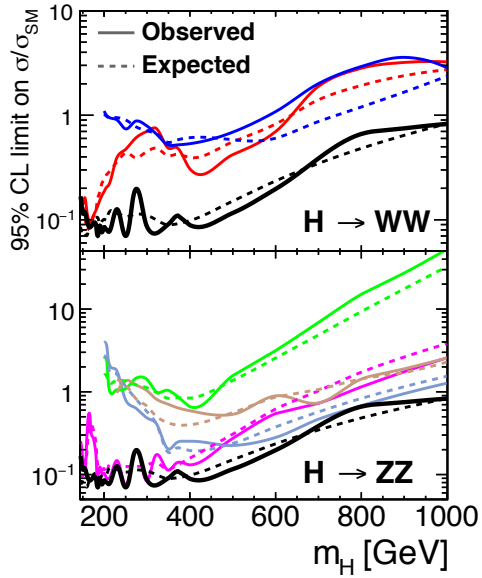
# Scalar sector and heavy (pseudo-)scalars

- Simple extended scalar sector:
  - neutral pseudo-scalar $A$
  - neutral scalar $H$
  - ...
- $A \to Z\gamma$ (CMS-PAS-HIG-14-031)
- $H \to WW/ZZ$ (CMS-HIG-13-031-001)

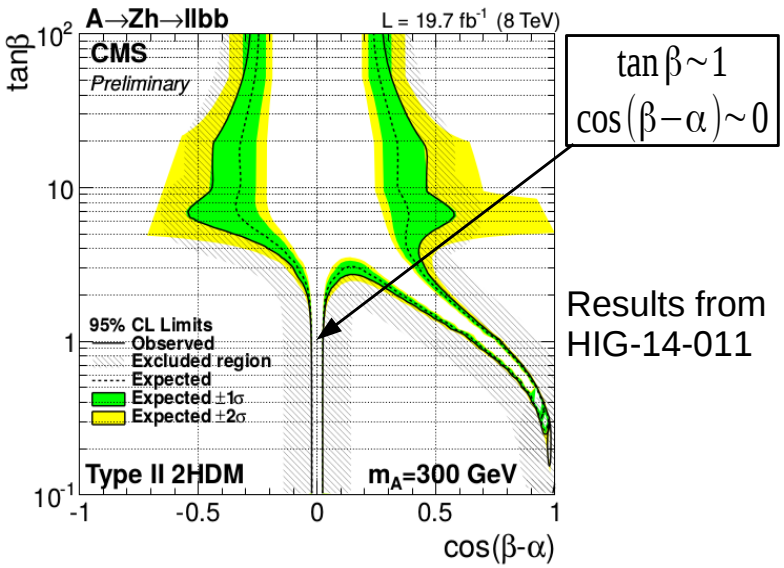


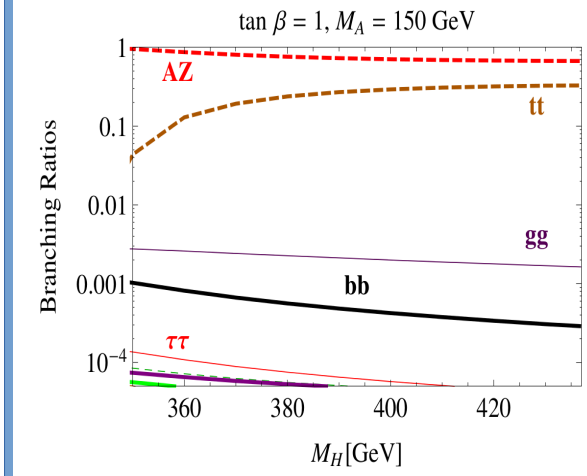
# Two-Higgs-Doublet-Model

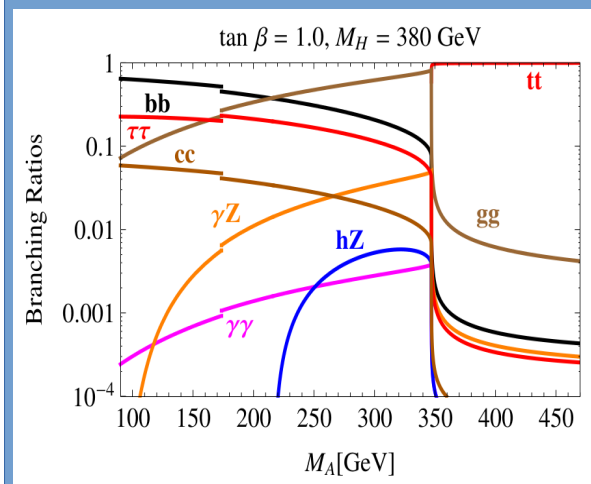
- 5 physical scalar fields
  - 3 neutral: *h*, *H*, *A*
  - 2 charged: $H^{\pm}$
- 2 parameters:
  - $\tan\beta = v_1 / v_2$
  - $\alpha$ is the mixing angle h/H
- particular value:
  $\cos(\beta - \alpha) = 0 \rightarrow h^{2HDM} = h^{SM}$




Results from HIG-14-011

$$M_H > M_A + M_Z$$




From arXiv:1304.0028

# Two NEW analyses: HIG-15-001

2HDM type-II

$\cos(\beta - \alpha) = 0.01$, $\tan\beta = 1.5$

$pp \to H/A \to Z\ A/H$

*llbb* final state

- Large $A/H \to bb$ Branching ratio.
- Large background from $t\bar{t}$ and DY+bb

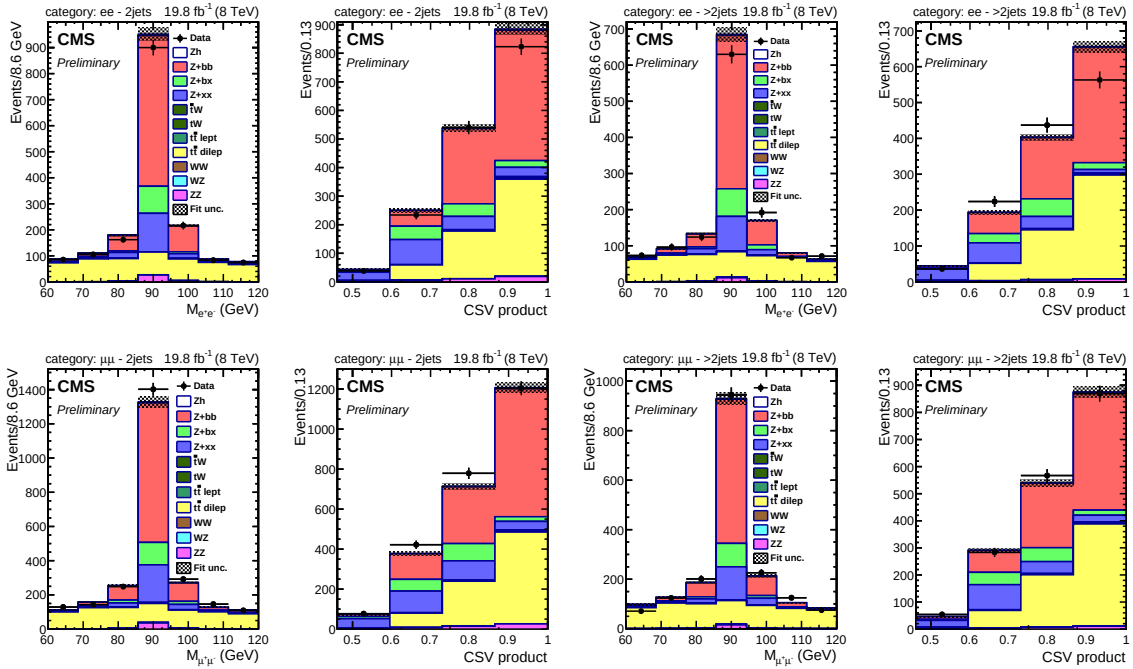
*ll*$\tau\tau$ final state

- Smaller $A/H \to \tau\tau$ Branching ratio.
- Smaller background (ZZ, fakes)

# *llbb*: Selection and Background

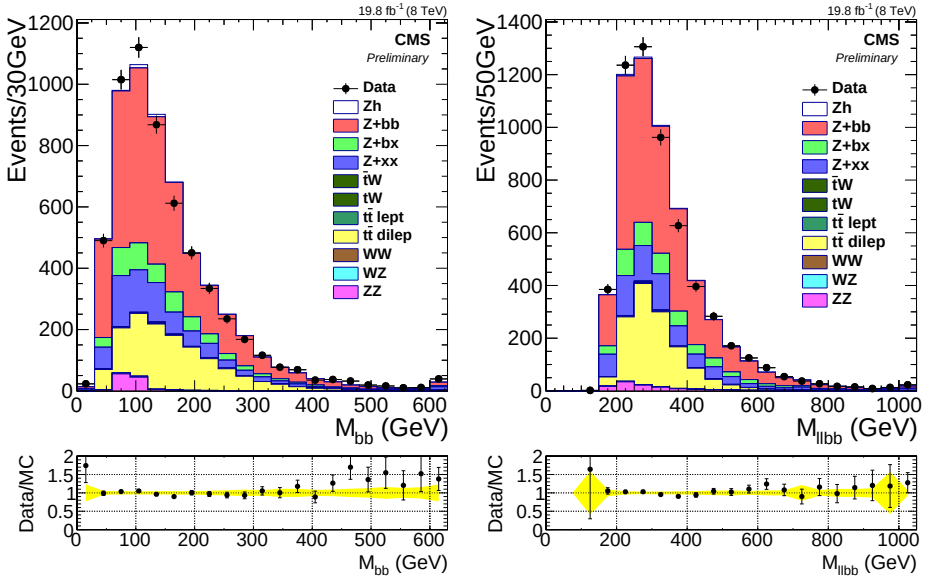
| Selection | |
|---|---|
| 2 OS SF leptons | $p_T > 20$ GeV, $\|\eta\| < 2.5(2.4)$ |
| $76 < M_{ll} < 106$ GeV | |
| 2 b-tagged jets | $p_T > 30$ GeV, $\|\eta\| < 2.4$ |
| $E_T^{miss}$-significance $< 10$ | |

- DY and ttbar : Data driven normalisation.

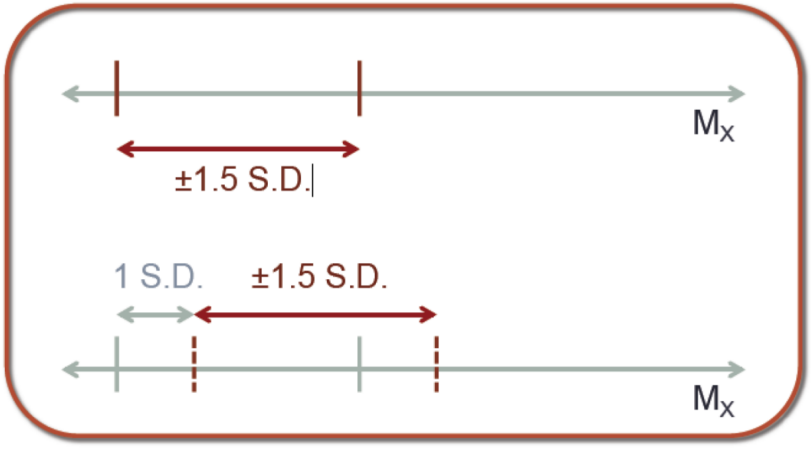


# *llbb*: Variables of interest and analysis strategy

- Two main observables in this analysis (ee & $\mu\mu$ combined):
- DY is rescaled to NLO shape in $M_{llbb}$
- Good agreement inclusively: The Yellow band represent the statistical error on the MC.
- We want to search for excesses in the 2D plane ($M_{bb}$,$M_{llbb}$).



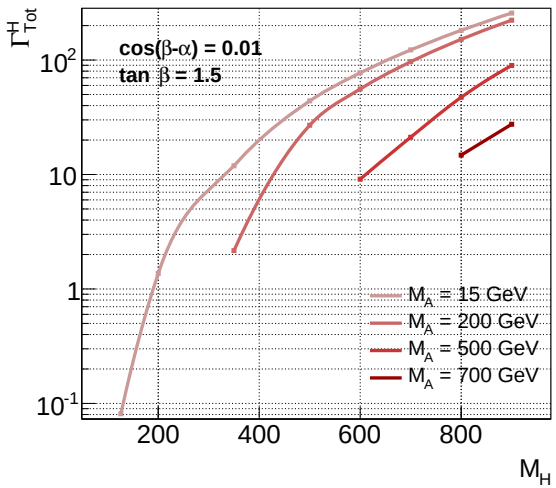

cut and count analysis




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

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

# *llbb*: Signal efficiency and re-interpretation



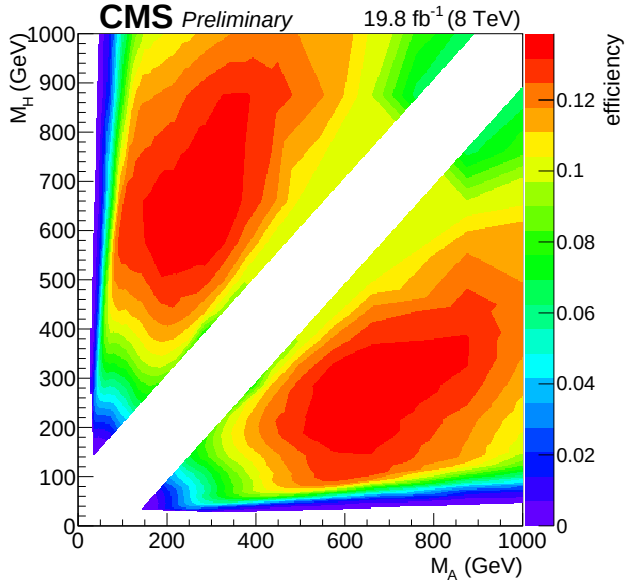

Results are valid for any model with relatively narrow H, at least compared to the exp resolution:

- $\Gamma_{H/A} \ll 0.15 \times M_{H/A}$

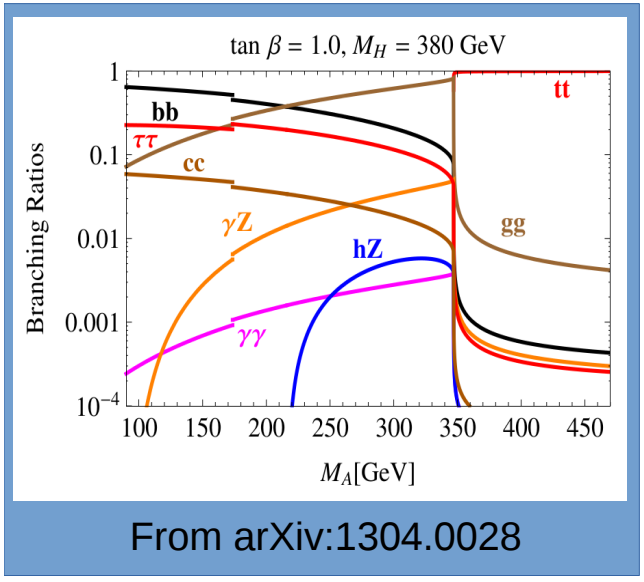
Or when $\Gamma_H \leq \Gamma_{Benchmark}$

If not:

- Signal efficiency map for the benchmark model.
- To be recasted: only the efficiency has to be substituted.



# $ll\tau\tau$: Motivation and event selection




From arXiv:1304.0028

| A selection |
|---|
| $A \to e\mu,\ e\tau,\ \mu\tau,\ \tau\tau$ |

| |
|---|
| $e : p_T > 10GeV,\ \lvert\eta\rvert < 2.5$ |
| $\mu : p_T > 10GeV,\ \lvert\eta\rvert < 2.4$ |
| $\tau : p_T > 10GeV,\ \lvert\eta\rvert < 2.3$ |

| Z selection |
|---|
| 2 OS SF leptons |

| Electrons |
|---|
| $p_T > 20(10)$ GeV, $\lvert\eta\rvert < 2.5$ |
| Muons |
| $p_T > 20(10)$ GeV, $\lvert\eta\rvert < 2.4$ |

Extra cuts:

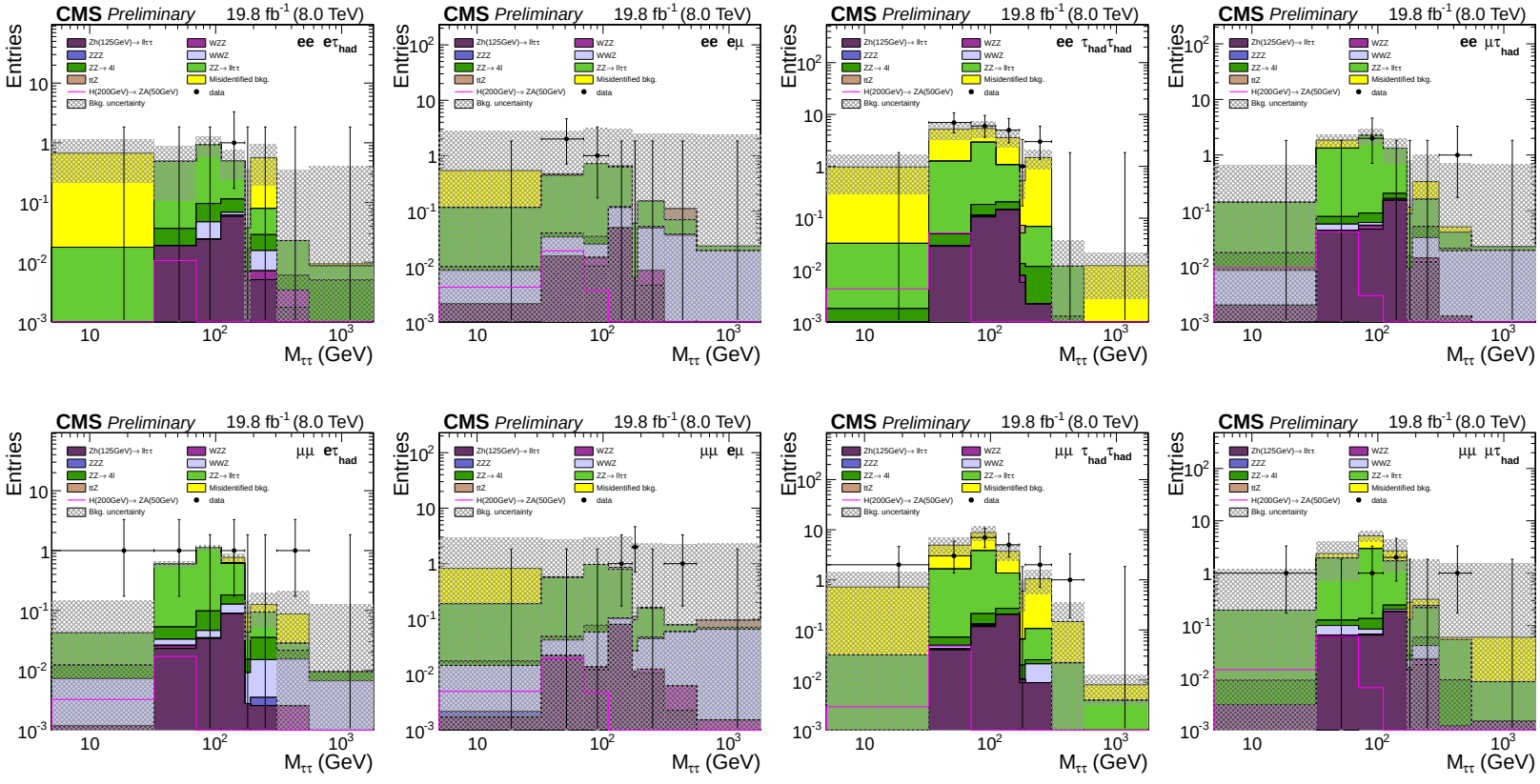
- $\Delta\phi(Z, \not{E}_T) > 1.5$
- B-jet veto
- extra lepton veto

Two analyses:

- Cut and Count ($L_T$)
- Shape based (cut on $L_T$, $M_{\tau\tau}$)

# $ll\tau\tau$: Background and $M_{\tau\tau}$ distributions

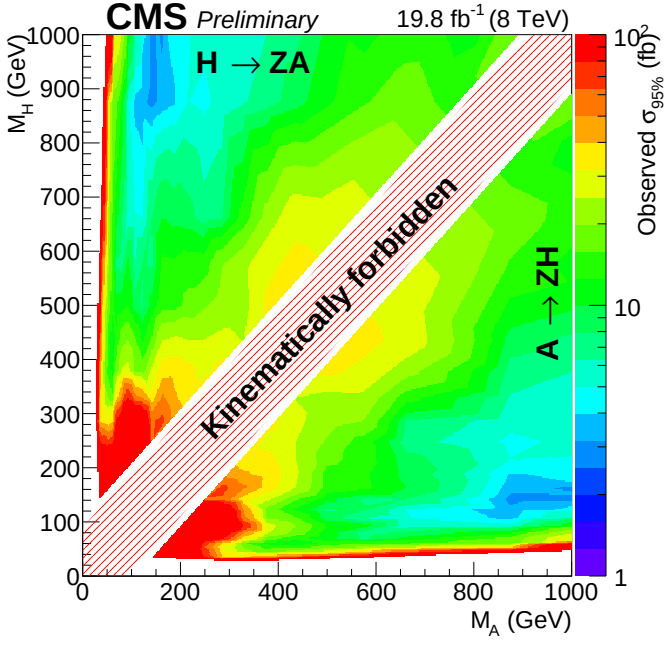
- $M_{\tau\tau}$ reconstructed with SVFit method using the two taus and the missing-$E_T$.
- Distribtion after cut on $L_T$
  - $L_T > 20$ GeV for $e\mu$, $\mu\tau_h$, $\tau_h\tau_h$
  - $L_T > 40$ GeV for $e\tau_h$



# Results : Limit on the Cross-section

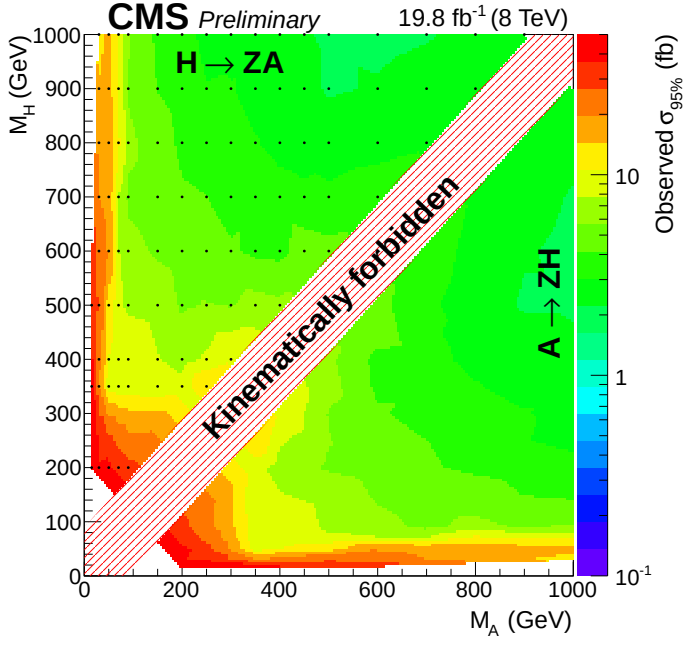
## Observed limit on σ(fb)

*llbb* final state:




$\sigma(\text{fb}) \gtrsim 10$ fb

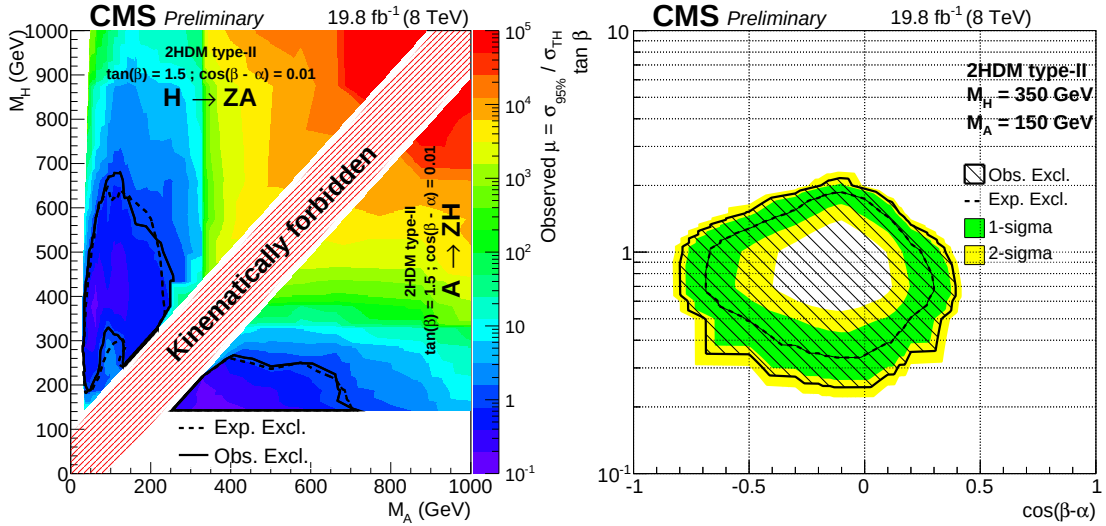
*llττ* final state (C&C):



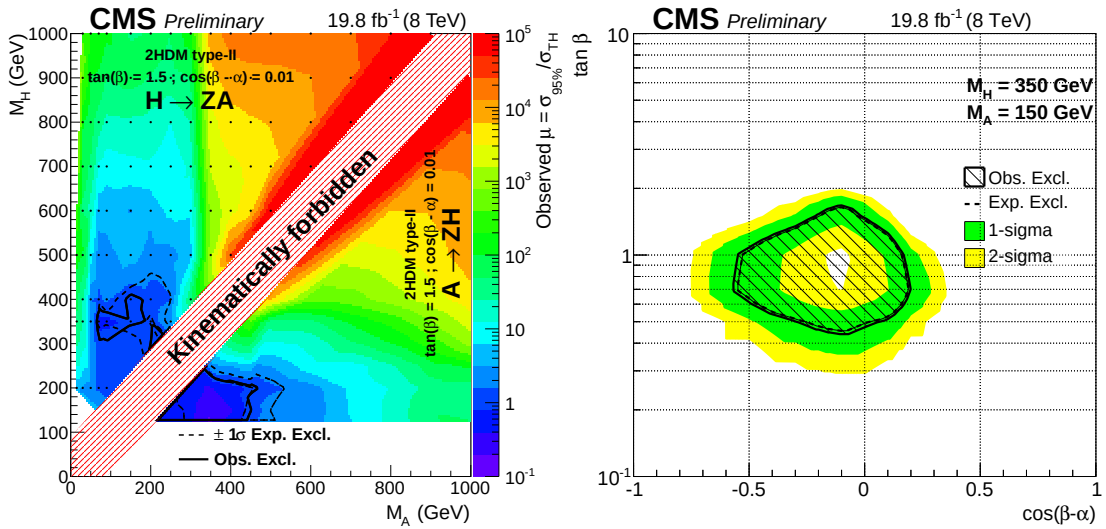

$\sigma(\text{fb}) \gtrsim 2$ fb

# Results: 2HDM interpretation

*llbb* Exclusion on $\mu = \sigma_{95\%}/\sigma_{TH}$ and 2HDM parameters exclusion:




*llττ* Exclusion on $\mu = \sigma_{95\%}/\sigma_{TH}$ and 2HDM parameters exclusion:



# Conclusion

A 2HDM motivated search in the *llbb* and *ll*$\tau\tau$ final state has been presented.

- this analysis is sensitive to new/uncovered territory

Results interpreted in terms of 2HDM $H/A \rightarrow ZA/H \rightarrow llbb(\tau\tau)$ decay channel.

- Limit on cross-section x BR
- Limit on $\mu$ for one given class of models (Model dependent)
- Limit on $\tan\beta - \cos(\beta - \alpha)$

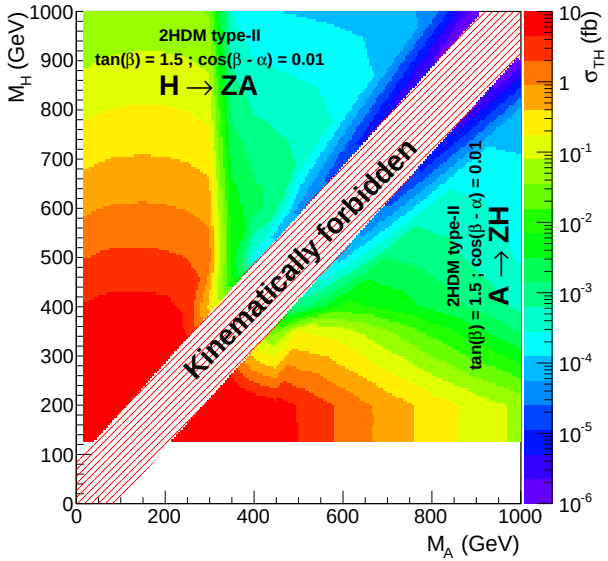
Good perspective for Run II

- Higher Energy,higher luminosity $\rightarrow$ better sensitivity
- Include boosted topology
  - Low $M_A$ and/or high $M_H$
  - A new phase space with discovery potential

# Back-up

# Signal generation

Cross section times branching ratio values for the processes $H/A \rightarrow ZA/H \rightarrow ll\tau\tau$ (in fb) normalized to NNLO SusHi predictions.



# Simulation samples generation

MadGraph5 + Pythia 6

- W/Z+jets
- $t\bar{t}$+jets
- di-boson

POWHEG

- $q\bar{q} \rightarrow ZZ$
- single top

The signal $gg \rightarrow H \rightarrow ZA$ was generated using MadGraph5 + Pythia6 renormalised to the NNLO cross-section (using SusHi)

# $ll\tau\tau$ analysis: Event selection

| Z selection |
|---|
| 2 OS SS leptons |
| PF electrons |
| $p_T > 20(10)$ GeV, $\|\eta\| < 2.5$ |
| $\Delta\beta$ iso $< 0.3$ |
| PF muons |
| $p_T > 20(10)$ GeV, $\|\eta\| < 2.4$ |
| $\Delta\beta$ iso $< 0.3$ |

| A selection | |
|---|---|
| $e : p_T > 10GeV$, $\|\eta\| < 2.5$ and $\Delta Biso < 0.1$ | |
| $\mu : p_T > 10GeV$, $\|\eta\| < 2.4$ and $\Delta Biso < 0.1$ | |
| $\tau : p_T > 10GeV$, $\|\eta\| < 2.3$ and $\Delta Biso < 0.1$ | |
| $A \to e\mu$ | Loose MVA ID, Loose ID |
| $A \to e\tau$ | Tight MVA ID, Anti-muon2 Loose and Anti-electron Tight MVA |
| $A \to \mu\tau$ | Loose ID, Anti-muon2 Tight and Anti-electron Loose |
| $A \to \tau\tau$ | Anti-muon2 Loose and Anti-electron Loose |

# *llbb*: Systematics

| source | Unc.[%] |
|---|---|
| Luminosity | 2.6 |
| Pile-up effects | 1-3 |
| Lepton ID/Isolation/ES | 2 |
| Lepton trigger efficiency | 1 |
| Jet ES/ resolution | 3 |
| B-tagging and mis-tag eff. | 5(4-6) |
| Bkg. normalisation | |
| ZZ | 11 |
| DY+jets and $t\bar{t}$ | < 8 |
| tW, WW, WZ and Zh | 6-23 |
| Drell-Yann bkg. modelling | 5-30 |
| Signal eff. extrapolation | 3-50 |
| Signal (PDF,scale) | 5-6 |

| Object definitions |
| --- |
| Leptons<br>$p_T > 20 GeV$, $\|\eta\| < 2.5(2.4)$ |
| Jets anti-$k_T$<br>$p_T > 30 GeV$, $\|\eta\| < 2.4$ |
| B-tagging<br>CSV medium WP |

| Selection cuts |
| --- |
| 2 OS SF leptons |
| $76 < M_{ll} < 106 GeV$ |
| 2 b-tagged jets |
| $E_T^{miss}$-significance $< 10$ |