

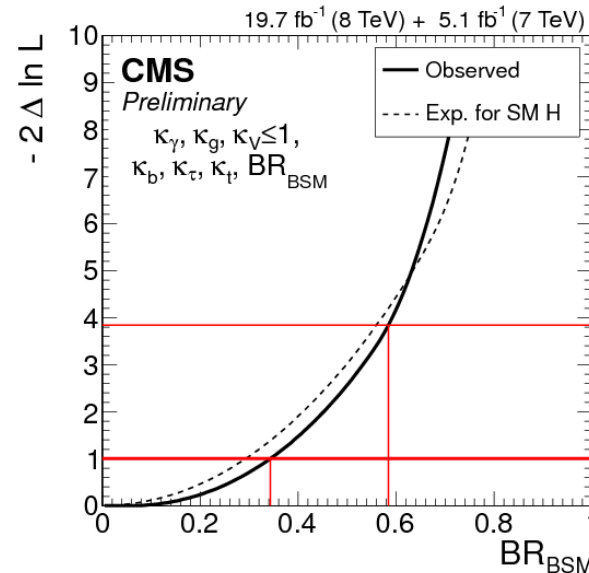
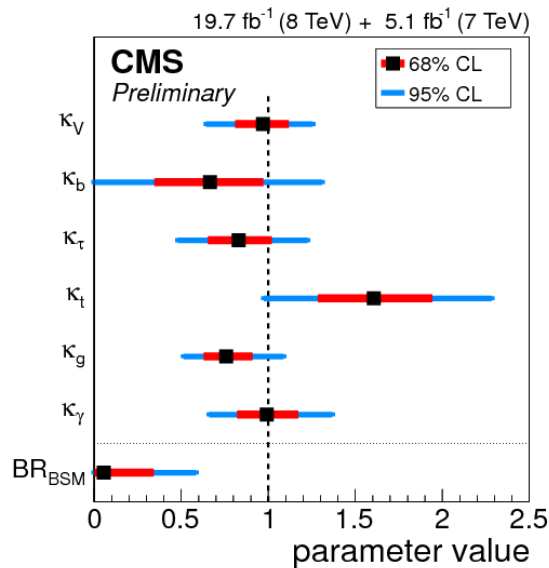
# **MSSM and 2HDM**

**A. Nikitenko, IC**

**15<sup>th</sup> April, Higgs Tools meeting,  
Freiburg**

# BSM Physics with Higgs bosons

- additional Higgs bosons
- non SM decays of h(125)



**$BR_{BSM} < 0.58$  at 95% CL (CMS)**

- precise measurements for h(125)

# Layout

- Run I direct searches for additional Higgs bosons and interpretation of  $\sigma \times \text{BR}$  limits in MSSM and 2HDM

- $\phi \rightarrow \tau\tau$   $\phi = h, H, A$

- $H^+ \rightarrow \tau\nu$

- $A \rightarrow Zh$

- $H \rightarrow hh$

MSSM and 2HDM Higgs sector:

CP even  $h$  and  $H$ , CP-odd  $A$ ,  $H^+$

Higgs sector is defined by:

two free parameters at tree level in MSSM:  $m_A$ ,  $\tan\beta$

seven free parameters in 2HDM:

$m_h, m_H, m_A, m_{H^+}, \alpha, \tan\beta, m_{12}$

- Preparation for Run II searches

# Benchmarks and tools used so far by ATLAS and CMS for the interpretation in MSSM and 2HDM

- MSSM benchmark scenarios, arXiv:1302.7033:

MSSM Higgs Boson Searches at the LHC:

Benchmark Scenarios after the Discovery of a Higgs-like Particle

M. CARENA<sup>1,2</sup>, S. HEINEMEYER<sup>3</sup>, O. STÅL<sup>4</sup>, C.E.M. WAGNER<sup>2,5</sup> AND G. WEIGLEIN<sup>6\*</sup>

– *tools: XS - HIGLU, SusHi, FeynHiggs; BRs: FeynHiggs+HDECAY*

- 2HDM tools (no benchmark scenarios yet), arXiv:1312.5571:

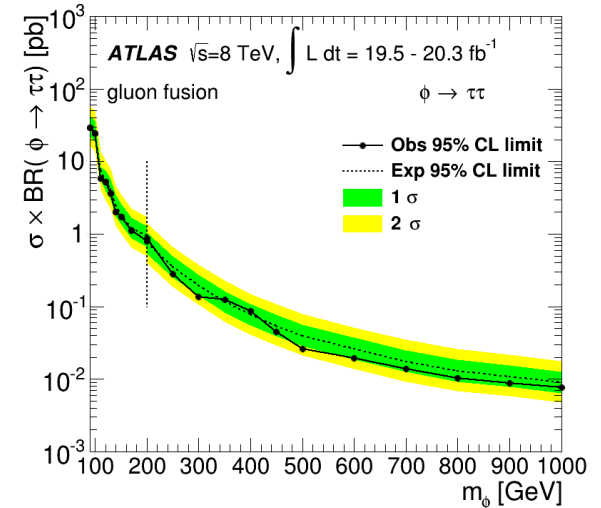
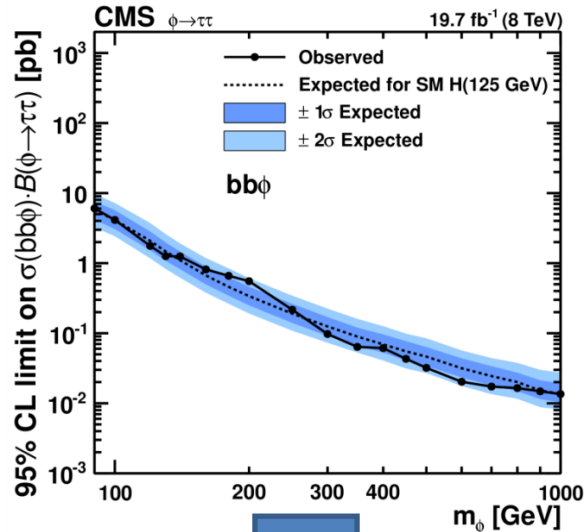
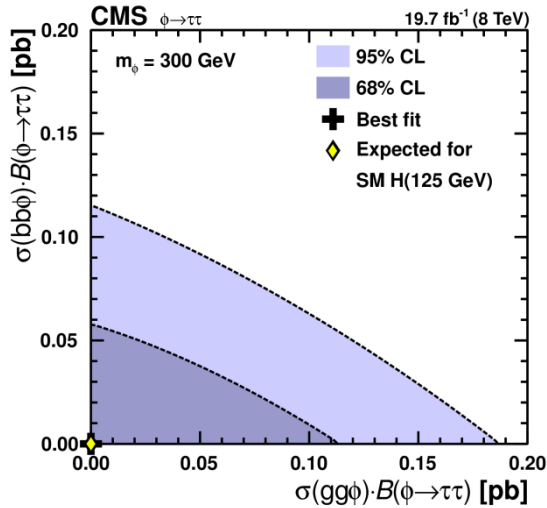
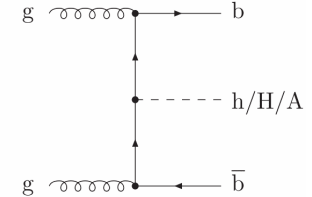
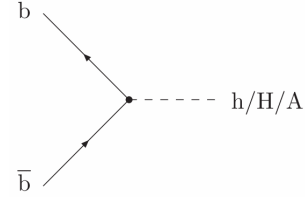
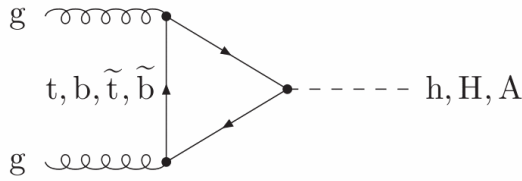
LHC Higgs Cross Section Working Group

Interim recommendations for the evaluation of Higgs production cross sections and branching ratios at the LHC in the Two-Higgs-Doublet Model

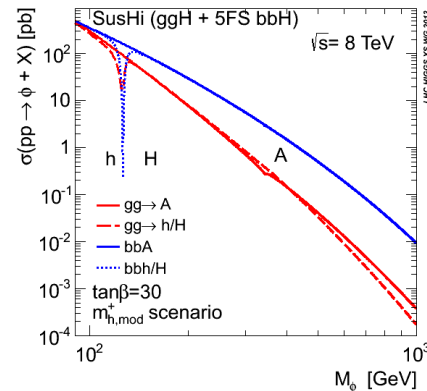
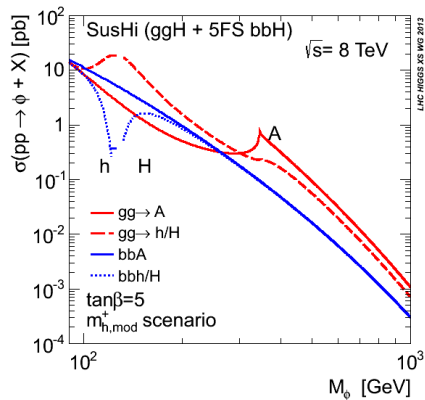
R. Harlander<sup>1</sup>, M. Mühlleitner<sup>2</sup>, J. Rathsman<sup>3</sup>, M. Spira<sup>4</sup>, O. Stål<sup>5</sup>

– *SusHi+FeynHiggs or HIGLU+HDECAY*

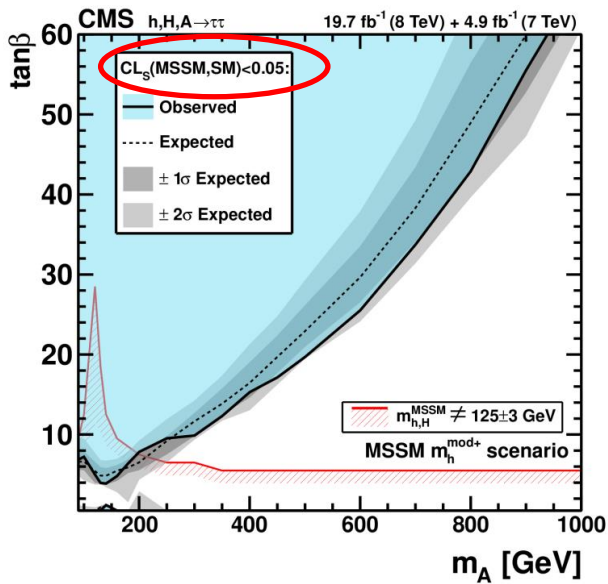
# $\phi \rightarrow \tau\tau$ : "model independent" limits



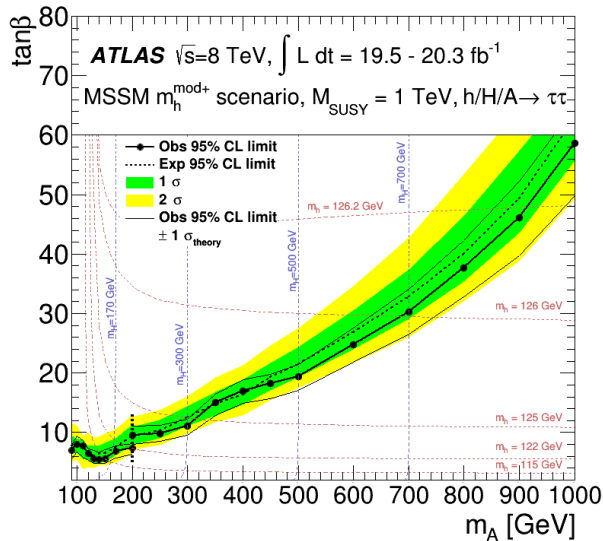
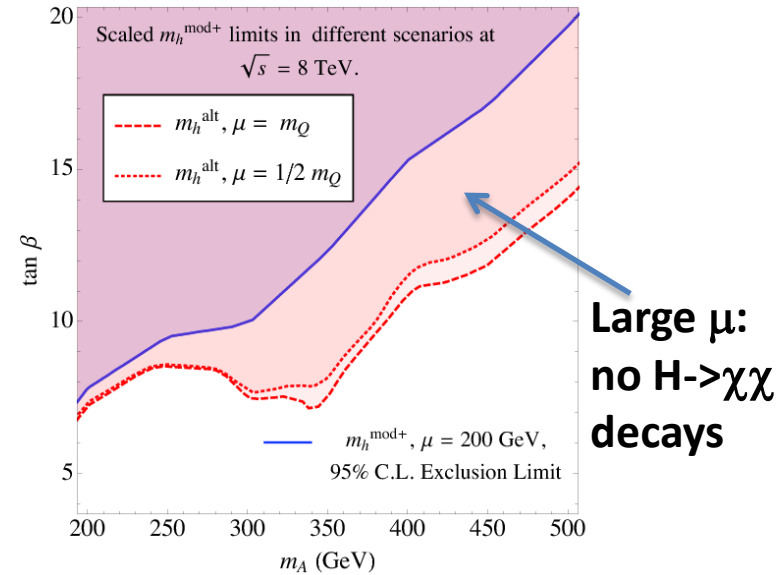
• Go to MSSM interpretation using inclusive cross section from LHCHSWG



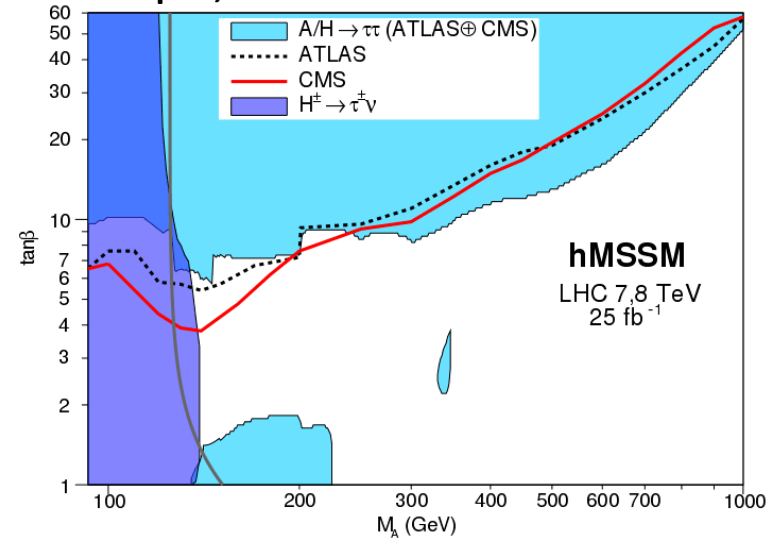
# $\phi \rightarrow \tau\tau$ : interpretation in MSSM benchmark scenarios



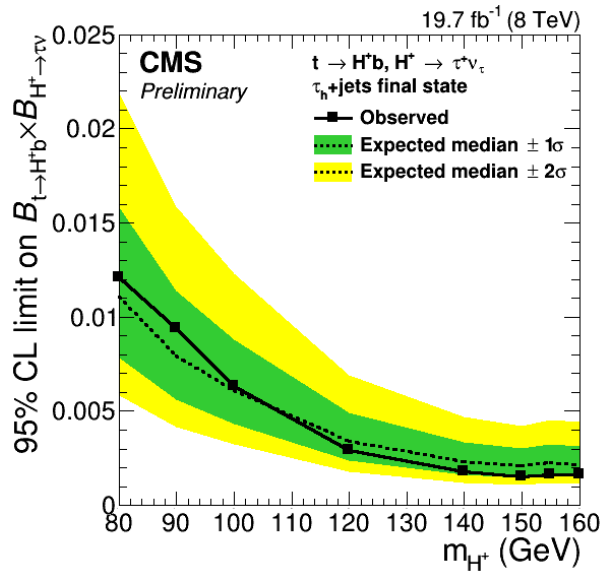
Carena, Haber, Low, Shah,  
Wagner, arXiv:1410.4969



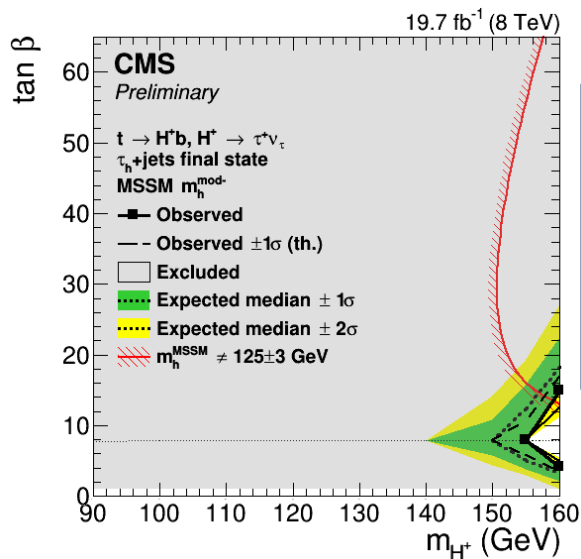
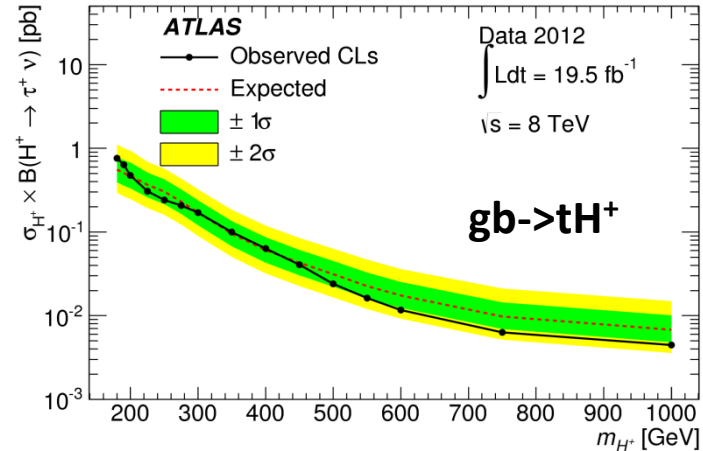
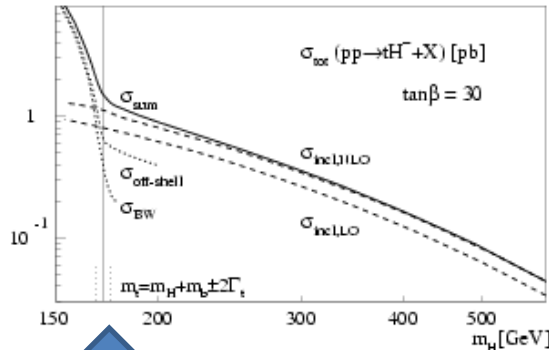
Djouadi, Maiani, Polosa, Quevillon,  
Riquer, arXiv:1502.05653



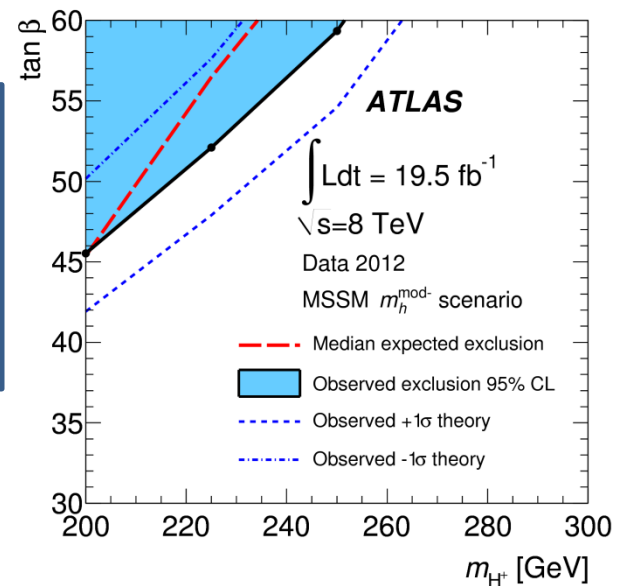
# H<sup>+</sup>->τν: “model independent” limits and MSSM interpretation



T. Plehn et al., hep-ph/0312286



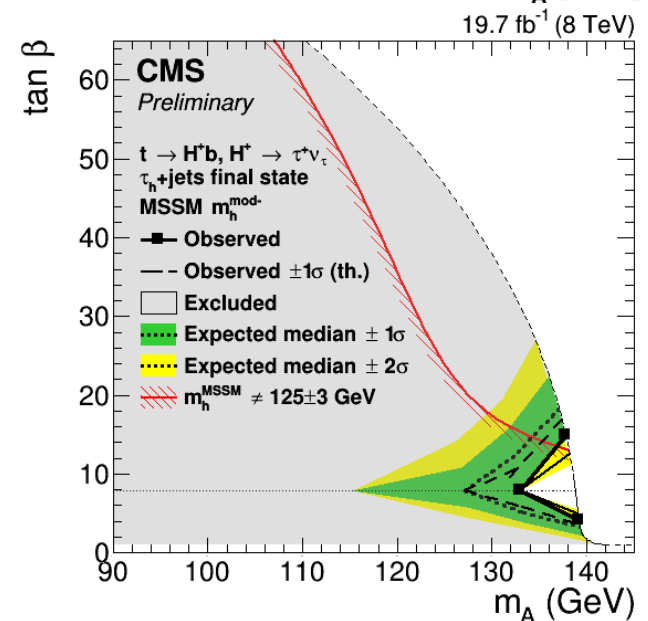
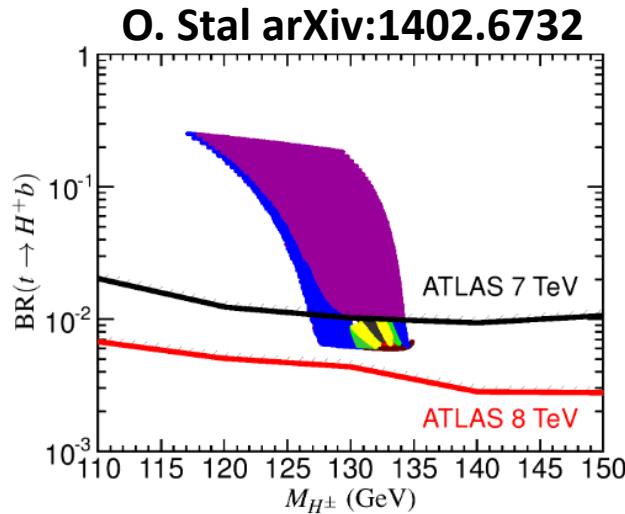
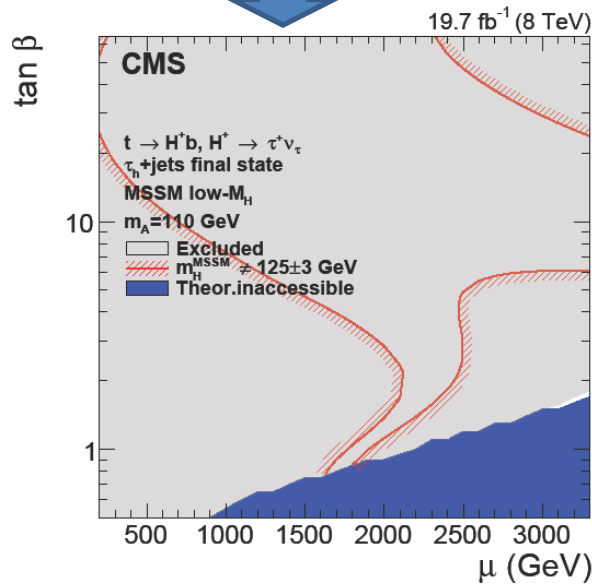
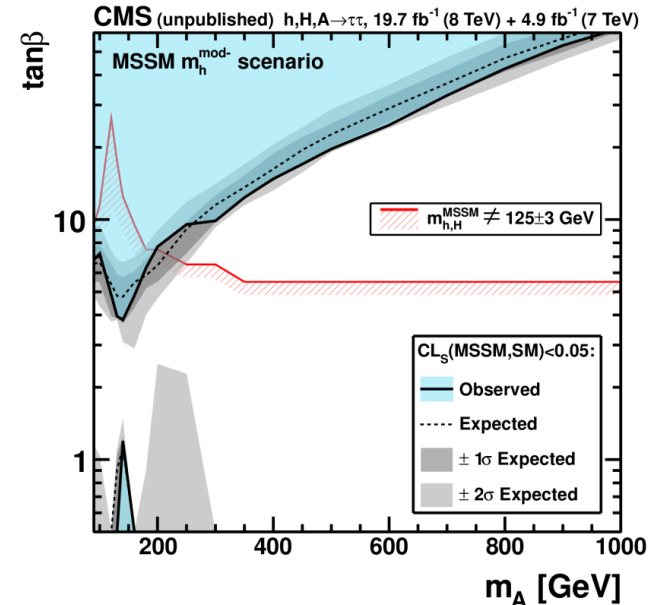
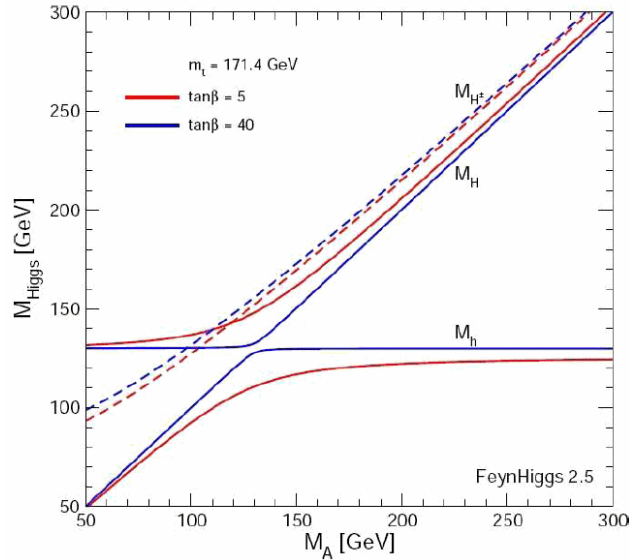
no cross-sections yet  
available from  
LHCHSWG to close  
the gap m<sub>H<sup>+</sup></sub> [160-200] GeV



# What MSSM Higgs boson is discovered h or H ?

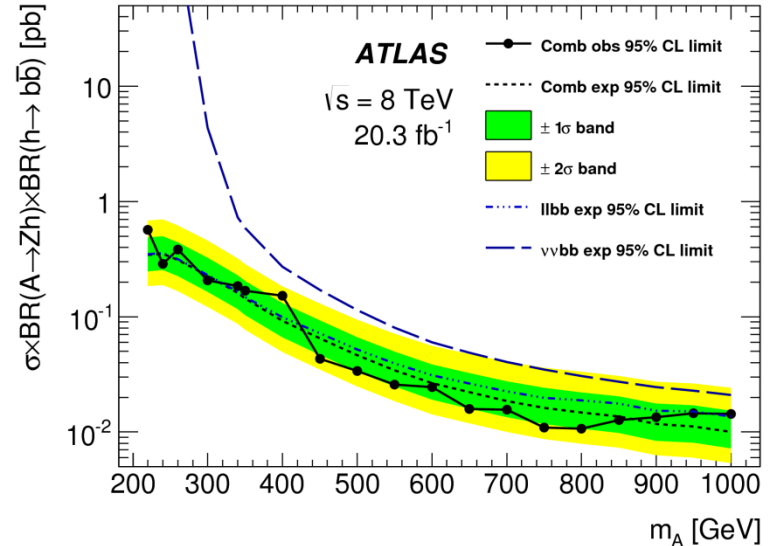
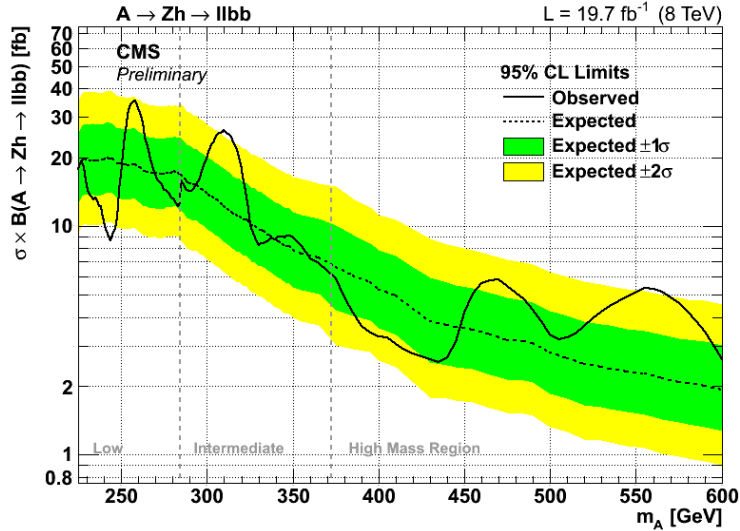
## low $m_H$ scenario

$$\begin{aligned}
 m_t &= 173.2 \text{ GeV}, \\
 M_A &= 110 \text{ GeV}, \\
 M_{\text{SUSY}} &= 1500 \text{ GeV}, \\
 M_2 &= 200 \text{ GeV}, \\
 X_t^{\text{OS}} &= 2.45 M_{\text{SUSY}} \text{ (FD)} \\
 X_t^{\overline{\text{MS}}} &= 2.9 M_{\text{SUSY}} \text{ (RG c)} \\
 A_b &= A_\tau = A_t, \\
 m_{\tilde{g}} &= 1500 \text{ GeV}, \\
 M_{\tilde{l}_3} &= 1000 \text{ GeV}.
 \end{aligned}$$



**It is the little Higgs boson, h !**

# A → Zh: the $\sigma \times \text{BR}$ limits



- so far 2HDM interpretation is done in the “physics basis,” CP-conserving with input:  $m_h, m_H, m_A, m_{H^\pm}, \alpha, \tan\beta, m_{12}$ 
  - additional parameters  $\lambda_6, \lambda_7 = 0$  as result of  $Z_2$  symmetry ( $H_1 \rightarrow H_1, H_2 \rightarrow -H_2$ ) and  $m_{12}$  is taken as in MSSM:  $m_A^2 = m_{12}^2 / (\sin\beta \cos\beta) - \lambda_5 v^2$  with  $\lambda_5 = 0$  as in MSSM

$$\begin{aligned}
 V_{2\text{HDM}} = & m_{11}^2 |\Phi_1|^2 + m_{22}^2 |\Phi_2|^2 - \left[ m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.} \right] \\
 & + \frac{1}{2} \lambda_1 |\Phi_1|^4 + \frac{1}{2} \lambda_2 |\Phi_2|^4 + \lambda_3 |\Phi_1|^2 |\Phi_2|^2 + \lambda_4 (\Phi_1^\dagger \Phi_2) (\Phi_2^\dagger \Phi_1) \\
 & + \left\{ \frac{1}{2} \lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[ \lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2) \right] (\Phi_1^\dagger \Phi_2) + \text{h.c.} \right\}
 \end{aligned}$$

# A→Zh→ℓℓbb: interpretation in 2HDM

	$h\bar{U}U$	$h\bar{D}D$	$h\bar{E}E$	$H\bar{U}U$	$H\bar{D}D$	$H\bar{E}E$	$iA\bar{U}\gamma_5 U$	$iA\bar{D}\gamma_5 D$	$iA\bar{E}\gamma_5 E$
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	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$-\cot\beta$	$-\tan\beta$	$\cot\beta$

$$c_{\beta-\alpha}$$

$$HW^+W^-$$

$$HZZ$$

$$ZA h$$

$$W^\pm H^\mp h$$

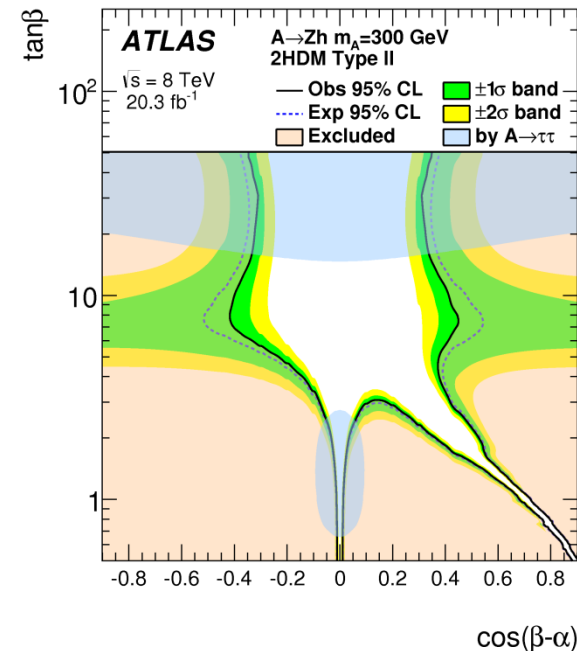
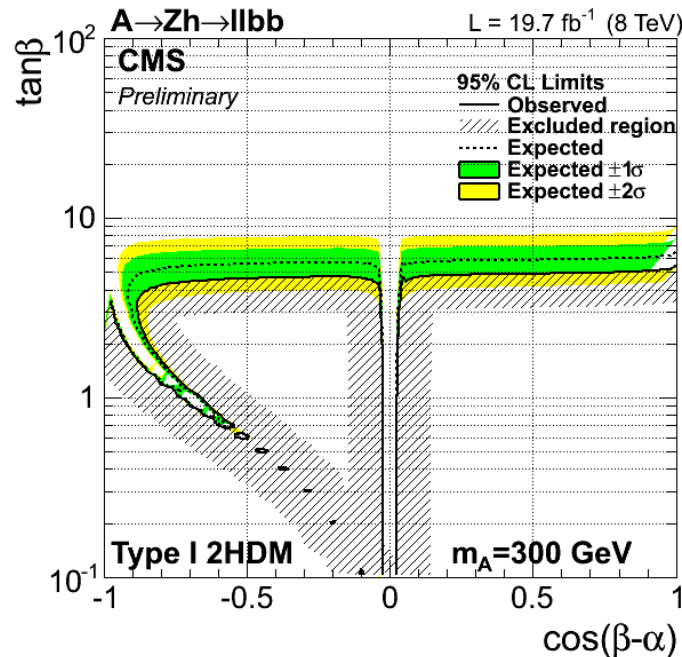
$$s_{\beta-\alpha}$$

$$hW^+W^-$$

$$hZZ$$

$$ZA H$$

$$W^\pm H^\mp H$$



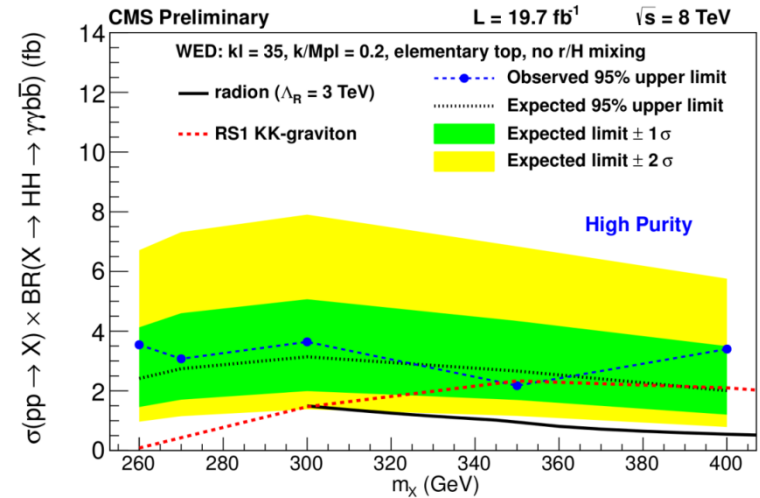
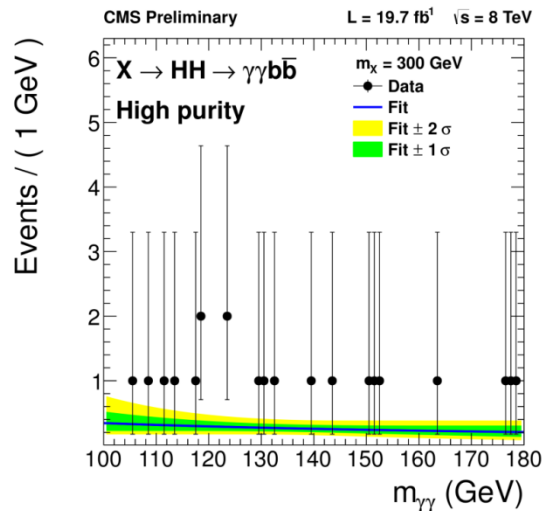
Work on proposal for 2HDM benchmark scenarios:

- O. Stal, H.E. Haber: work in progress on benchmarks in 2HDM Hybrid basis
- Call from LHCHSWG/WG3 for defining 2HDM benchmarks for LHC

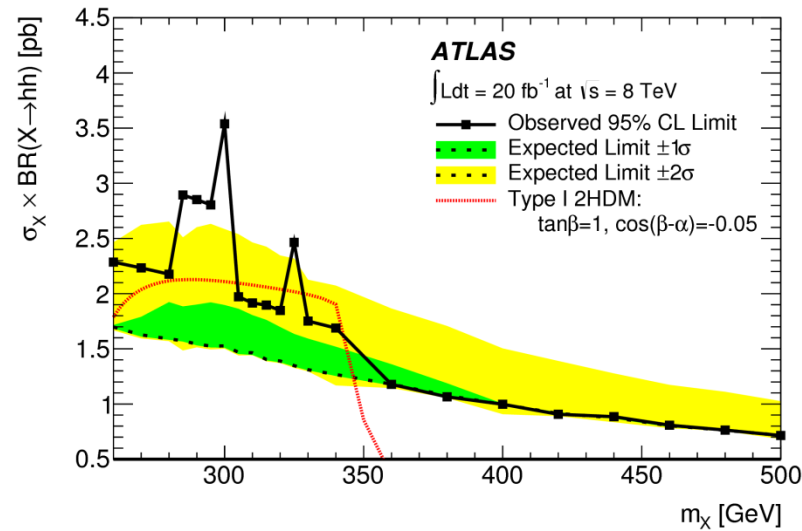
# MSSM “low $\tan\beta$ ” mode: $H \rightarrow hh \rightarrow \gamma\gamma bb$

- Search strategy:

- looking for signal in  $m_{\gamma\gamma}$  distribution for  $\gamma\gamma bb$  events selected within  $m_{bb}$  and  $m_{\gamma\gamma bb}$  mass windows

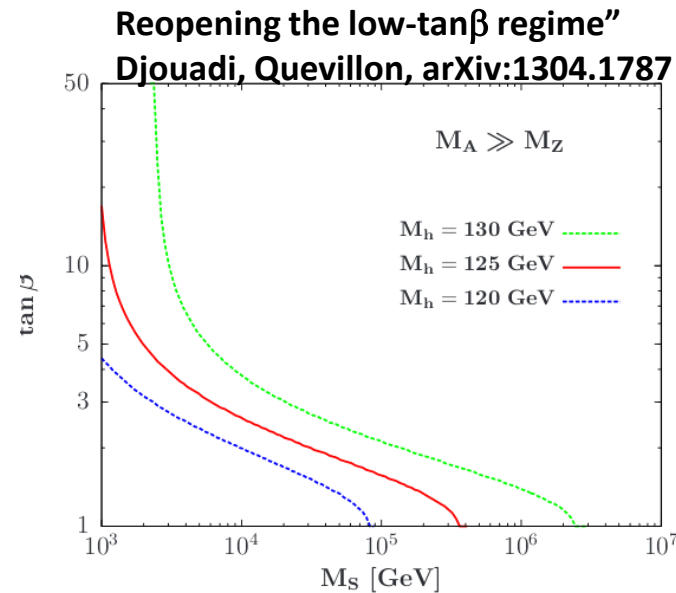
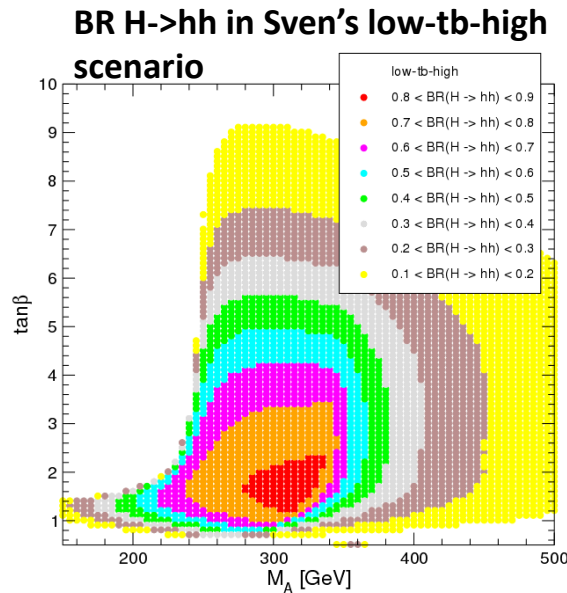


Interpretation of  $A \rightarrow Zh$  and  $H \rightarrow hh$  analyses in MSSM requires MSSM with very large  $M_{SUSY}$  in order to have  $m_h = 125 \text{ GeV}$  at low  $\tan\beta$ , where BRs  $A \rightarrow Zh$  and  $H \rightarrow hh$  are large



# MSSM: “low $\tan\beta$ ” scenarios (I)

- Interpretation of  $H \rightarrow hh$  and  $A \rightarrow Zh$  ATLAS/CMS analyses in MSSM requires MSSM with very heavy  $M_{\text{SUSY}}$  to have  $m_h = 125$  GeV at low  $\tan\beta$  where BRs  $H \rightarrow hh$ ,  $A \rightarrow Zh$  are large



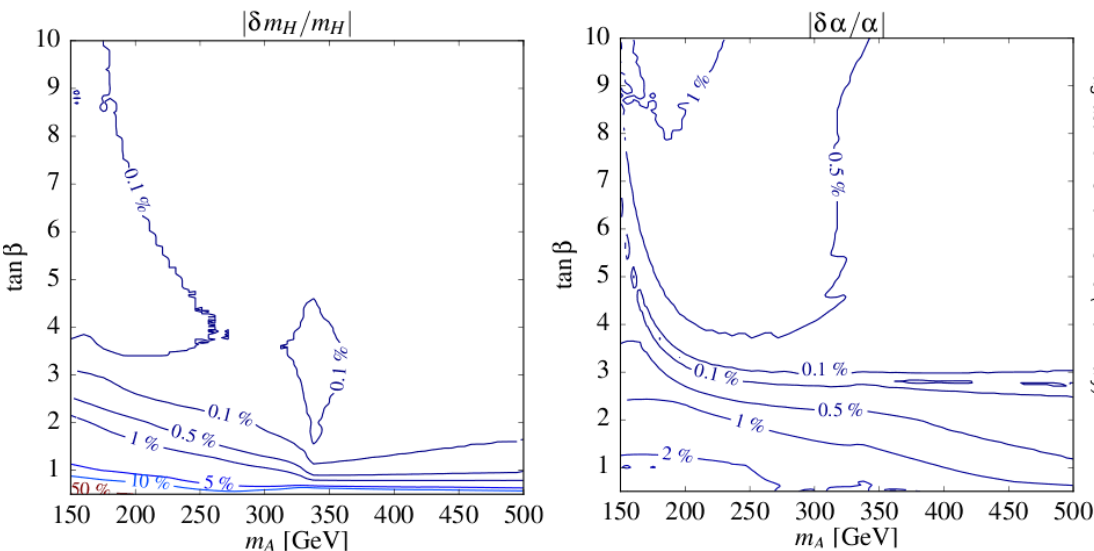
- Scenarios proposed (to ATLAS and CMS) so far:
  - Sven Heinemeyer’s “low-tb-high” scenario (FeynHiggs)
  - hMSSM (A. Djouadi et al. arXiv:1307.5205)
    - with 3 nput parameters:  $m_h$ ,  $M_A$ ,  $\tan\beta$
    - implemented in HDECAY;  $\text{BR}(H \rightarrow hh)$  w/o EWK radiative corrections yet

# MSSM: “low $\tan\beta$ ” scenarios (II)

- Comparison of FH and hMSSM with 2HDM EFT (Carlos Wagner, Gabriel Lee) is on the way within LHCHSWG (Pietro Slavich) to provide recommendations and limitations for these scenarios for ATLAS and CMS
  - so far  $m_H$ ,  $m_{H^\pm}$  and mixing angle  $\alpha$  agrees within 5 % for small  $\mu$  and large  $\mu$  (in no mixing,  $X_t=0$  and max mixing cases) between hMSSM and 2HDM
  - still need to compare BRs; no yet EWK corrections to BR( $H \rightarrow hh$ ) in hMSSM

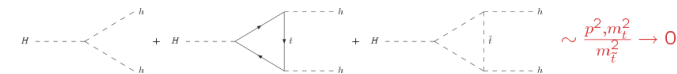
Comparing FeynHiggs and hMSSM in Sven’s low- $\tan\beta$  scenario

$H \rightarrow hh$ ; from M. Spira talk 12<sup>th</sup> Febr, WG3

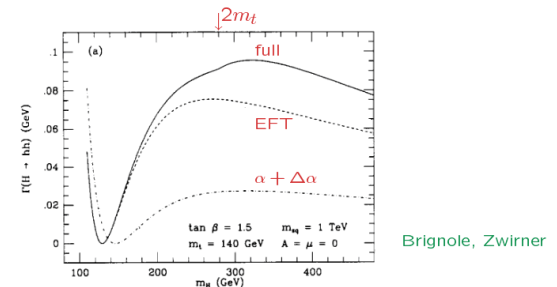


E. Bagnaschi & P.S. for HXSWG (Preliminary)

$H \rightarrow hh$ : process-dependent corrections



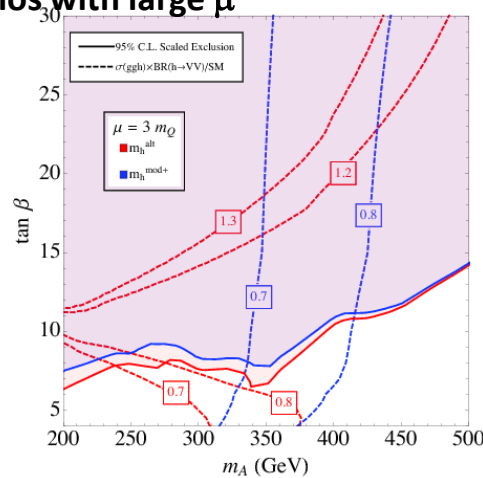
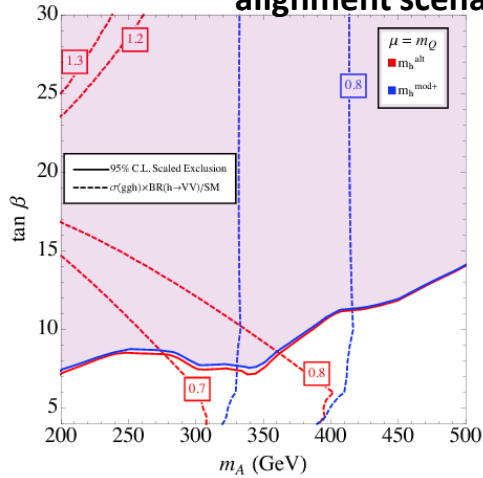
- $\lambda_{Hhh} \rightarrow \lambda_{Hhh} + \Delta\lambda_{Hhh}|_{p^2 \rightarrow 0} \rightarrow$  effective coupling (EFT)  
heavy particles decouple [keep  $m_t$ ] Appelquist, Carazzone
- $\Rightarrow$  process-dependent corrections coincide for hMSSM and 2HDM!



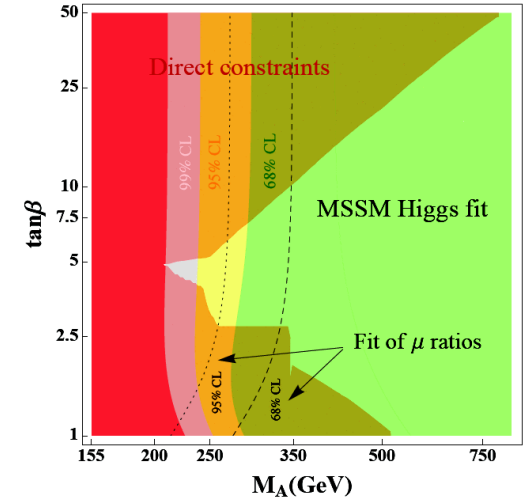
# Complementarity between precision measurements of h(125) and direct searches (I)

Carena, Haber, Low, Shah, Wagner, arXiv:1410.4969

alignment scenarios with large  $\mu$



Djouadi et.al. arXiv:1307.5205

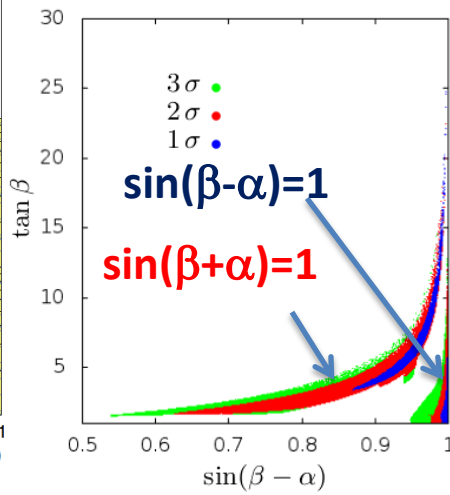
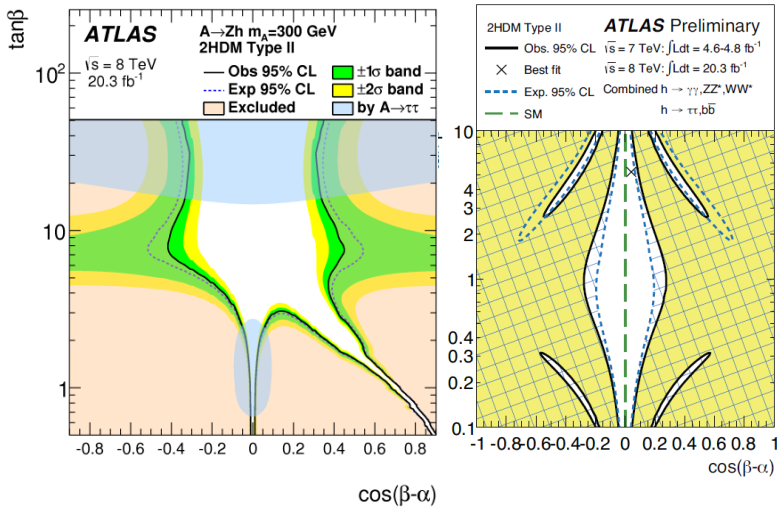


MSSM

2HDM

Ferreira, Guedes, Gunion, Haber, Sampaio, Santos arXiv:1410.1926

Type II



$\sin(\beta-\alpha)=1 \Rightarrow$  SM like limit (alignment)  
 $k_F=k_V=1$   
 $\sin(\beta+\alpha)=1 \Rightarrow k_D=-1$  ( $k_U=k_V=1$ )  
 “wrong sign” limit; can be excluded with  $\sim 5\%$  accuracy on  $h \rightarrow \gamma\gamma$  measurement

# Conclusion from Run I analyses about MSSM and 2HDM Higgs bosons

- **MSSM**
  - light  $A$ ,  $m_A < \sim 250$  GeV (low  $m_H$  scenario) is excluded
- **2HDM**
  - light  $A$  ( $< m_Z$ ) is allowed
  - scenarios are possible
    - $m_h=125$  GeV or  $m_H=125$  GeV;
    - alignment or decoupling (for  $m_h=125$  GeV)
    - wrong sign Yukawa
    - Inert 2HDM (do not mention in my talk)

# Preparation for Run II

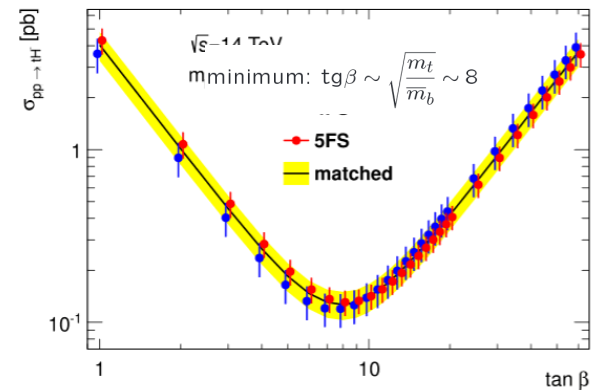
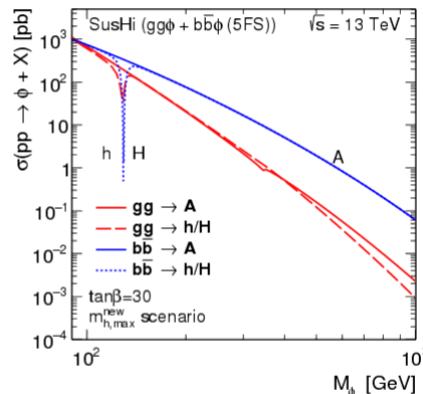
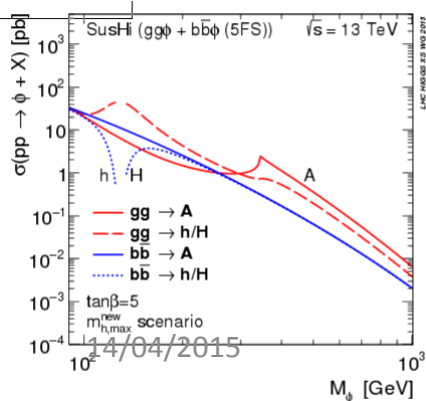
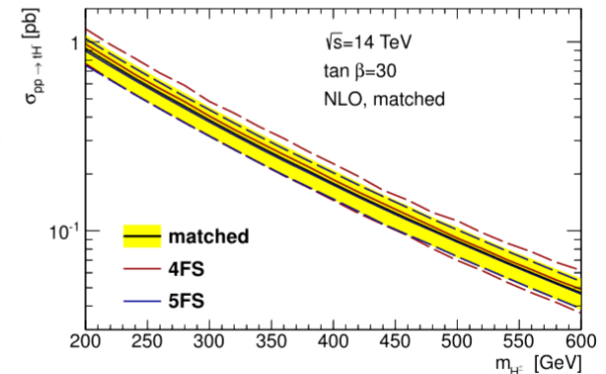
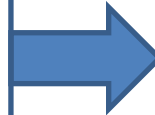
# MSSM: inclusive cross-sections

- **New for 13 TeV analyses (S. Liebler, talk on 9<sup>th</sup> LHCHSWG workshop Jan 2015 ):**
  - **bb $\phi$ :** add  $y_t y_b$  interference term
  - **gg $\rightarrow\phi$ :** change scale ( $\mu_F/\mu_R$  from  $m_\phi$  to  $0.5m_\phi$ ) and uncertainty
  - **PDF+ $\alpha_s$  uncertainty** as function of  $m_\phi$  (not for every SUSY point)
  - **13/14 TeV root files** for Run I benchmark scenarios (Carena et al. 13)
  - **Santander matched xs** for pp $\rightarrow H^+tb$ ; new scale setting for 5FS

arXiv:1409.5615

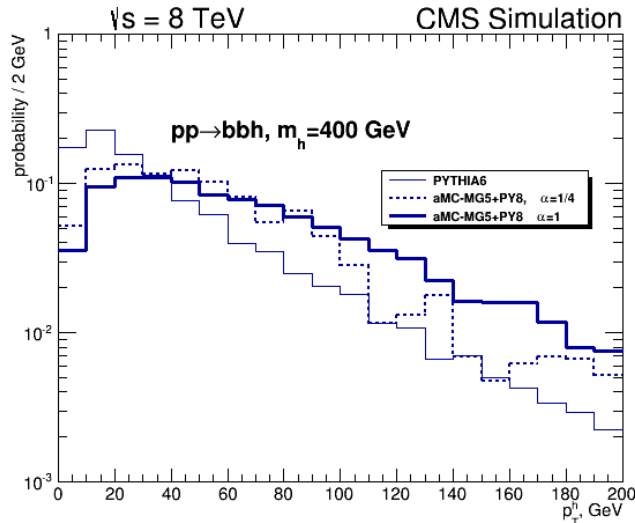
Improved cross-section predictions for heavy charged Higgs boson production at the LHC

Martin Flechl<sup>1,2</sup>, Richard Klees<sup>3</sup>, Michael Krämer<sup>3,4</sup>, Michael Spira<sup>5</sup>,  
and Maria Ubiali<sup>6,7</sup>



# MSSM/2HDM: signal generation (I)

- **bb $\phi$**  : from LO (PY6, Sherpa) to NLO
  - current recommendation of LHCHSWG: use pp->bbH 4SF MG5\_aMC@NLO (*M. Weisemann et al arXiv:1409.5301*)
    - will be updated once ongoing studies with Sherpa are finalized
    - have (at least) two NLO MCs and 4FS vs 5FS comparison
    - $p_T^H$  is harder at NLO
    - Difference in jet veto used for MSSM H-> $\tau\tau$  analyses is  $\sim 30\%$



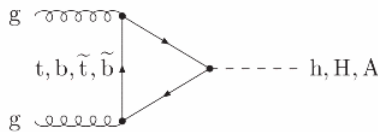
selections	pp->bbA, A-> $\tau\tau$ , $m_A=400$ GeV	
	MG5_aMC@NLO+PY8	PY6
$p_T^\tau > 45$ GeV, $ \eta^\tau  < 2.4$	0.895	0.860
$\geq 1$ b-jet, $p_T > 30$ GeV, $ \eta  < 2.4$	0.383	0.346
1 b-jet no other jets $p_T > 30$ GeV, $ \eta  < 4.7$	0.379	0.579

# MSSM/2HDM: signal generation (II)

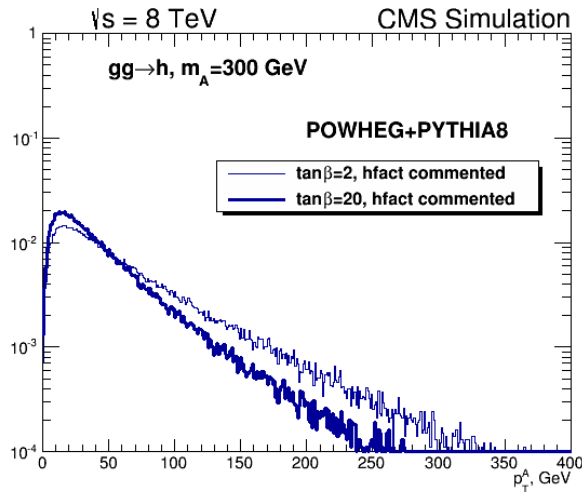
- $gg \rightarrow \phi$  : proper generation of Higgs  $p_T$**

$p_T$  Higgs spectrum depends on  $\tan\beta$  and on resummation scale for t, b and tb

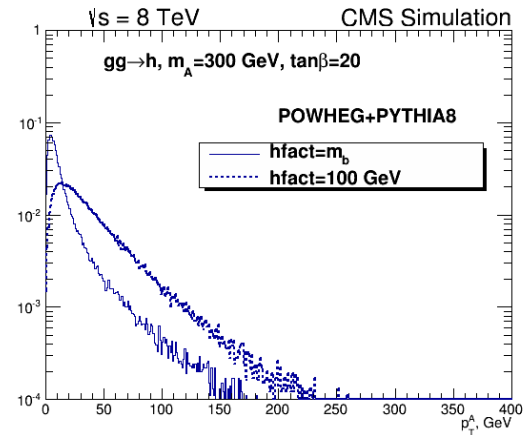
dependence on  $\tan\beta$



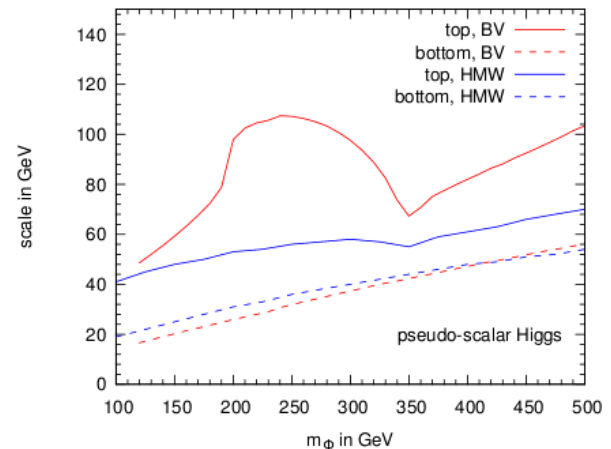
1. Spira et al. hep-ph/0604156
2. J. Alwall, Q Li, F. Maltoni arXiv:1110.1728
3. E. Bagnaschi, G. Degrossi, P. Slavich, A. Vicini arXiv:1111.2854



dependence on resummation scale



H. Mantel talk LHCHXSWG Jan 15



BV-  
Bagnaschi,  
Vicini

HMW-  
Harlander,  
Mantel,  
Wiesemann

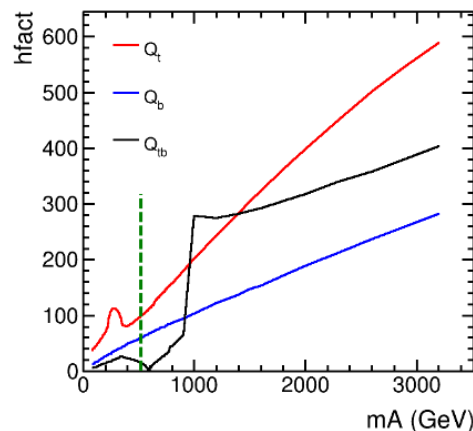
# MSSM $gg \rightarrow \phi$ : proper generation of Higgs $p_T$

- In CMS we (Yuta Takahashi++) try a new procedure for MSSM  $gg \rightarrow H$  generation based on LHCHSWG recommendation for SM  $gg \rightarrow H$  generation (E. Bagnaschi, M. Wiesemann, R. Harlander):

- generate 5 SM  $gg \rightarrow H$  datasets with only t, only b and t+b in the loop:
  - $gg \rightarrow H(t, Q_t)$ ,  $gg \rightarrow H(t, Q_{tb})$ ,  $gg \rightarrow H(b, Q_b)$ ,  $gg \rightarrow H(b, Q_{tb})$ ,  $gg \rightarrow H(t+b, Q_{tb})$
- add them together weighed with the SM cross-sections and MSSM Yukawas at a given  $m_A$ ,  $\tan\beta$ :
  - $\sigma(Q_t, Q_b, Q_{tb}) = y_t^2 \chi \sigma_{SM}^t(Q_t) + y_b^2 \sigma_{SM}^b(Q_b) + y_t y_b \sigma_{SM}^{tb}(Q_{tb})$ 
    - where  $\sigma_{SM}^{tb}(Q_{tb}) = \sigma_{SM}^{t+b}(Q_{tb}) - \sigma_{SM}^t(Q_{tb}) - \sigma_{SM}^b(Q_{tb})$

most recent  $Q_b, Q_t, Q_{tb}$  scales  
from Emanuele Bagnaschi

# mh	htop	hbot	htb(interference)
80	38	12	6
90	40	13	6
100	42	14	7
110	44	16	8
120	47	17	8
125	48	18	9
130	50	18	9
140	52	19	10
150	55	21	11
160	58	22	11
170	61	23	12
180	64	24	13
190	67	26	14
200	71	27	14



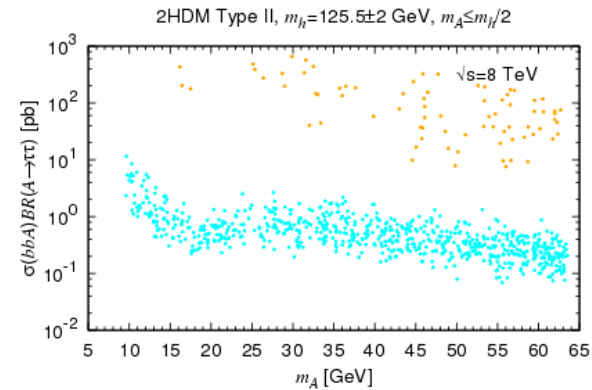
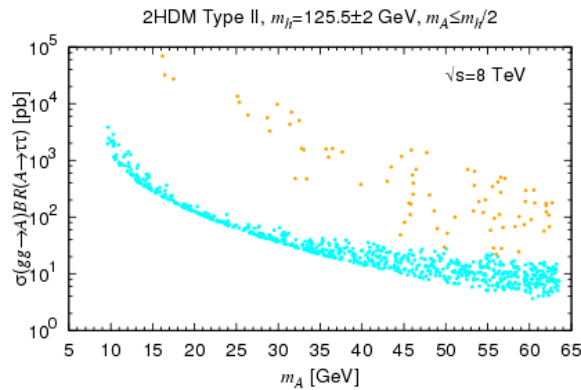
$\sigma_{SM}^{H,A}$ ,  $m_{h/H/A}$  and  $Y_t, Y_b$  vs  $\tan\beta$  from  
Stefan Leibler

<http://www.desy.de/~sleibler/LHCHSWG>

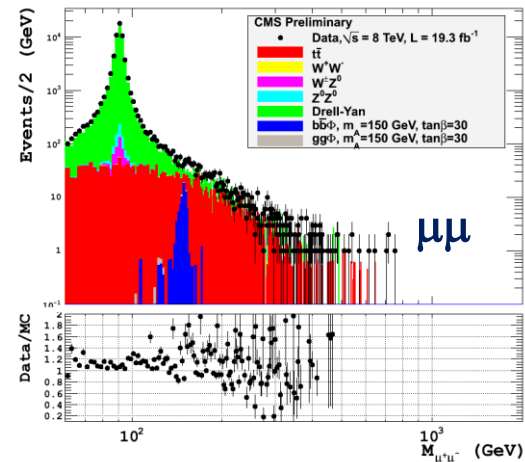
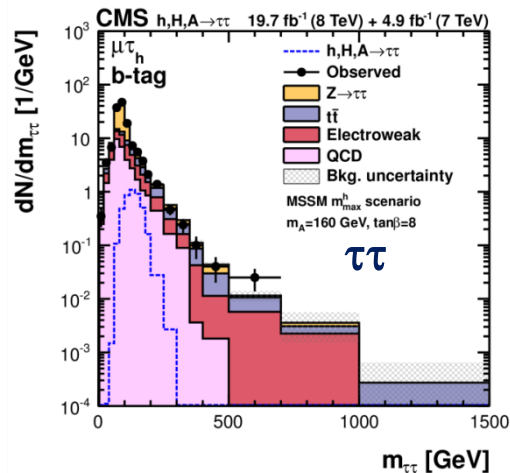
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<a href="#">mhmodp_13000_higgs_H..&gt;</a>	27-Mar-2015	12:06	2.2M
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<a href="#">mhmodp_13000_higgs_h..&gt;</a>	27-Mar-2015	12:06	2.2M

# Open a new mass search region for $pp \rightarrow bb\phi$ and $gg \rightarrow \phi$ , $\phi \rightarrow \mu\mu$ , $\tau\tau$ analyses

- $\sim 20 \text{ GeV} < m_A < 60 \text{ GeV}$  in 2HDM Type II
  - Motivated by Gunion et al. arXiv:1412.3385, arXiv:1405.3584

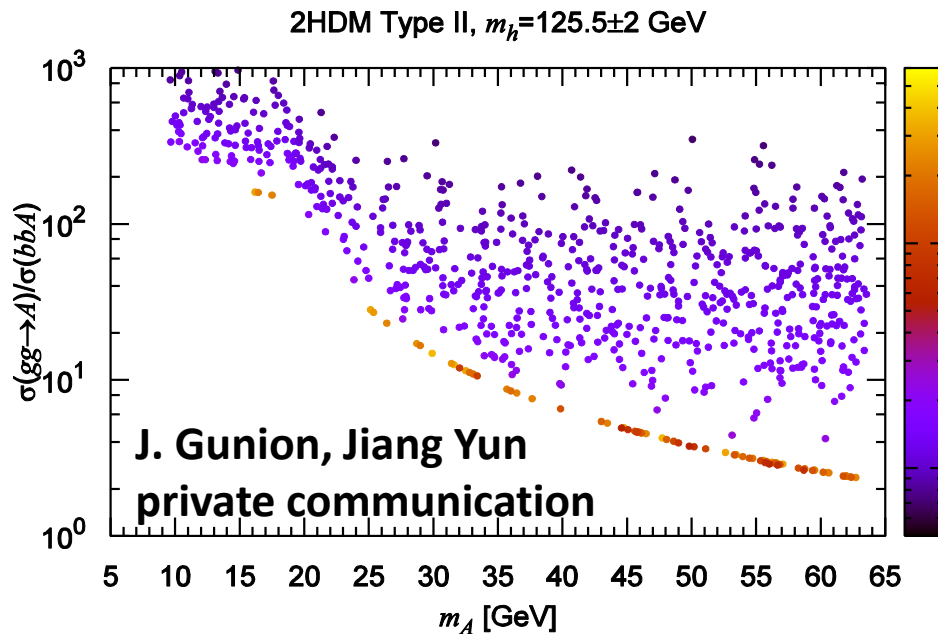
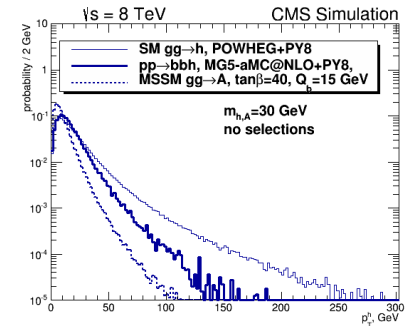
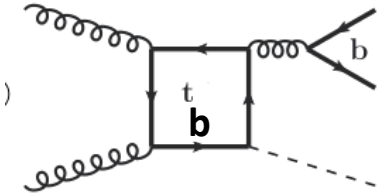


- Re-consider public 8 TeV analyses; will continue with 13 TeV data



- $\sigma(\text{gg} \rightarrow A)$  at low  $m_A$  can be much bigger than  $\sigma(\text{bb}A)$ 
  - $\text{gg} \rightarrow A$  contamination in b-tag category can be significant from two sources:

- $\text{gg} \rightarrow A + \text{gluon}$ 
  - gluon  $\rightarrow \text{bb}$
  - gluon is mistagged as b-jet



10  
tan $\beta$   
1

**Brown = wrong sign Yukawa cases:**  
 $\text{gg} \rightarrow A / \text{bb}A$  ratio  $\sim 10$   
 at  $m_A = 30$  GeV

**Blue = normal sign Yukawa cases:**  
 $\text{gg} \rightarrow A / \text{bb}A$  ratio can be 100  
 at  $m_A = 30$  GeV

# How to generate $gg \rightarrow A + g$ , $g \rightarrow bb$ ?

- Discussed with T. Sjöstrand, M. Wiesemann, M. Spira, S. Frixione, F. Maltoni
  - for now use NLO  $gg \rightarrow A$  (POWHEG, aMC@NLO) and see how often you get events with bb from gluon splitting in shower.

MC generator	bbh, aMC@NLO_MG5 +PY8 with $Q_{sh}$ variation 0.5, 2.0 of the nominal $\alpha=0.25$	gg->A NLO in MSSM generation $Q_b$ is varied as 0.5, 2.0 of nominal scale $Q_b=15$ GeV	
Parton level selections		SM gg->A POWHEG+PY8	b-quark only in loop MSSM $\tan\beta=40$ POWHEG+PY8
$p_T^{\mu^{1,2}} > 25, 25$ GeV $ \eta^{\mu^{1,2}}  < 2.1, 2.4$	<b>0.005</b> 0.004/0.006	<b>0.018</b>	<b><math>7.44 \times 10^{-4}</math></b> $5.8/8.4 \times 10^{-4}$
$\geq 1$ jet, $p_T > 30$ GeV, $ \eta  < 2.4$	<b>0.867</b> 0.851/0.898	<b>0.835</b>	<b>0.695</b> 0.682/0.670
$\geq 1$ b-jet, $p_T^b > 30$ GeV, $ \eta^b  < 2.4$	<b>0.819</b> 0.856/0.796	<b>0.042</b>	<b>0.030</b> (30%*) 0.037/0.047
total eff, $\varepsilon$	<b><math>3.7 \times 10^{-3}</math></b>	<b><math>6.4 \times 10^{-4}</math></b>	<b><math>1.5 \times 10^{-5}</math></b>
Ratio $\varepsilon(gg \rightarrow A)/\varepsilon(bbA)$		<b>0.17</b>	<b>0.0041</b>

- In wrong sign Yukawa cases (high  $\tan\beta$ )  $gg \rightarrow A$  contamination to b-tag category is negligible
- In normal sign Yukawa cases (low  $\tan\beta$ )  $gg \rightarrow A$  contamination in b-tag category is dominant !
  - *how certain are predictions for  $gg \rightarrow A + \text{gluon}$ ,  $\text{gluon} \rightarrow bb$  ?*

Date: Thu, 19 Mar 2015 15:30:00 +0100  
 From: Marius Wiesemann <dr.wiesemann@gmail.com>  
 To: Alexandre Nikitenko <anikiten@mail.cern.ch>  
 Cc: Michael Spira <Michael.Spira@psi.ch>  
 Subject: Re: question on  $gg \rightarrow h+g$ ,  $g \rightarrow bb$  (II)

Hi Sasha,

I discussed the issue with my MG5\_aMC colleagues and they basically said the same. Either to do  $gg \rightarrow H$  at NLO to get b's from the shower or/and produce b-loop induced  $gg \rightarrow H+bb$  in 4FS (I am currently figuring out if that is already feasible with MG5\_aMC). Fabio agreed with Michael that the latter will suffer from large logarithms, but also pointed out that it should be sufficient to obtain a first estimate when appointing an conservative error to it. This maybe more reliable than relying purely on the shower.

Unfortunately noone had an idea how to match the two, but I think if they are reasonable close, the right answer is somewhere in-between.

Cheers, Marius

Date: Mon, 16 Mar 2015 15:45:17 +0100  
 From: Torbjorn Sjostrand <torbjorn@thep.lu.se>  
 To: Alexandre Nikitenko <anikiten@mail.cern.ch>  
 Subject: Re: question on  $gg \rightarrow h+g$ ,  $g \rightarrow bb$

Dear Sasha,

It is a tricky question. The shower falls within the error bars of LEP measurements on  $g \rightarrow b + b\bar{b}$ , and consistently includes the b mass. It qualitatively describe Tevatron/LHC data, but quantitatively not. So I am afraid the picture is not fully clear yet. Specifically, the status in the  $m(b + b\bar{b}) = m_Z$  region may be of special interest for you, and here I am not up to date on what has been done to pin down rates by comparing with control processes like  $Zbb$ .

You can of course also compare with the LO process  $hbb$ , e.g. with Madgraph + Pythia, but then with unknown NLO corrections to the rate. At least it can be useful to compare with the shower ansatz. As usual, the shower should do better for small  $bb$  masses and the matrix elements better for large.

Best, Torbjörn

**Message from T. Sjostrand:**

**$g \rightarrow bb$  from shower gives qualitative rather than quantitative description**

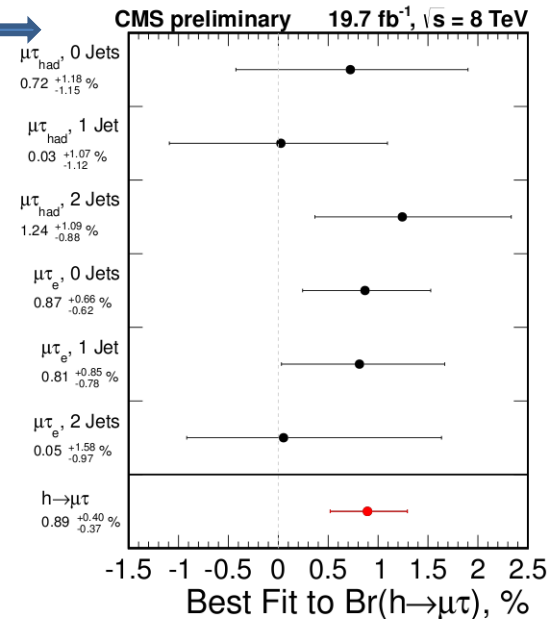
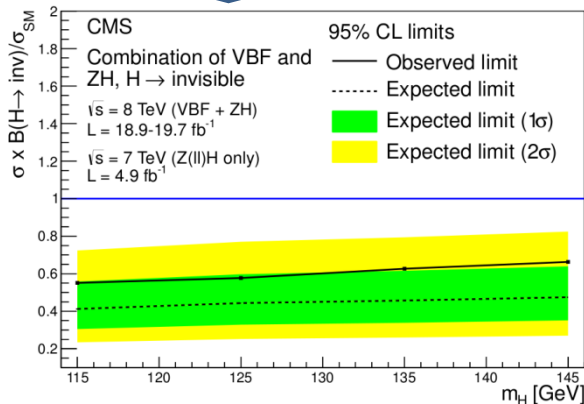
# “Exotics”

- **h(125)->XX analyses (CMS) with 8 TeV and continue with 13 TeV**
  - inspired, in particular by
    - Stefano Moretti et. al, arXiv:0805.3505
    - King, Muhlleitner, Nevzorov, Walz arXiv:1211.5074
    - M. Strassier et. al, arXiv:1312.4992
  - h(125)->AA->4 $\tau$ ,  $2m_\tau < m_A < 2m_b$ , approved with 8 TeV
  - h(125)->AA-> $\mu\mu bb$ ,  $2m_b < m_A < m_h/2$  still to be approved
- **LFV h(125)-> $\mu\tau$**
- **h(125)->invisible (VBF, Zh)**

**Latest ATLAS analysis on VBF h(125)->invis:**

$$BR_{obs} < 0.29$$

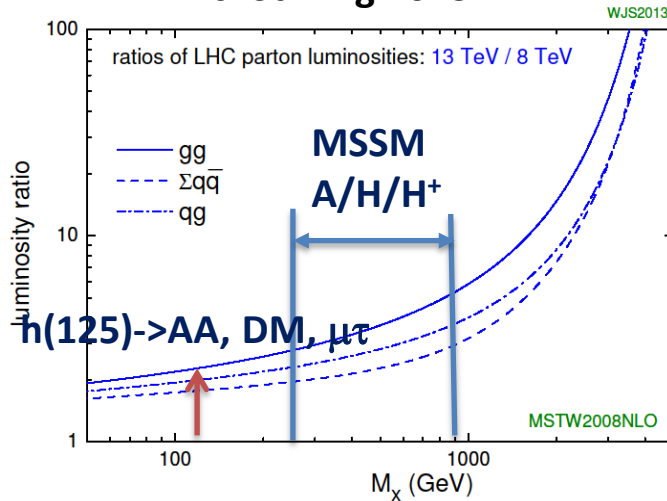
$$BR_{exp} < 0.35$$



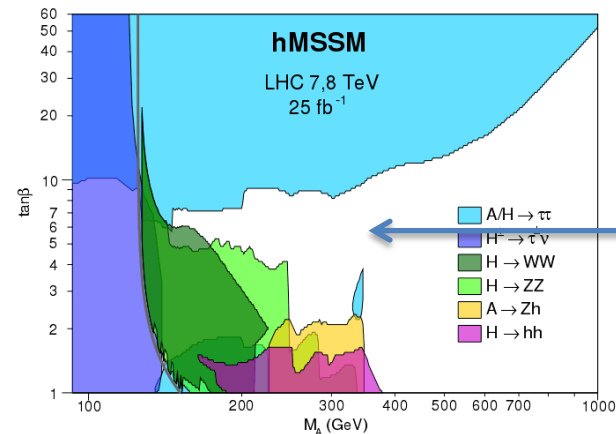
# Prospects for 2015-2016

- No immediate discovery for Higgs-Exotics channels with first 5-10 fb<sup>-1</sup> is expected so far: rare processes, need luminosity
  - with ~ 5-10 fb<sup>-1</sup> at 13 TeV expect to reach 8 TeV/20 fb<sup>-1</sup> sensitivity of current 8 TeV analyses and start to explore a new territory

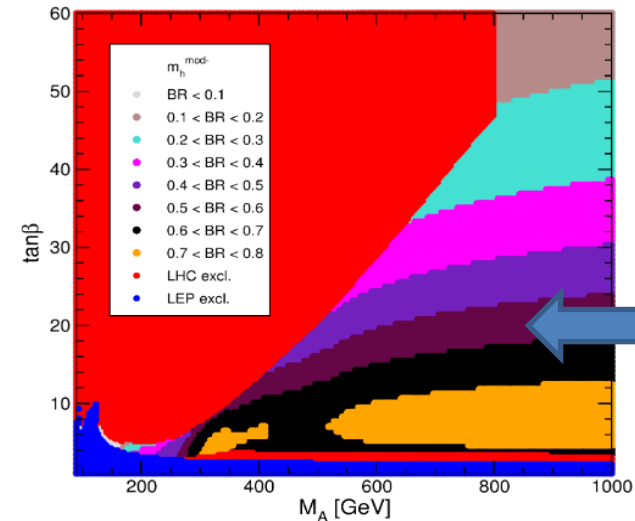
J. Stirling 2013



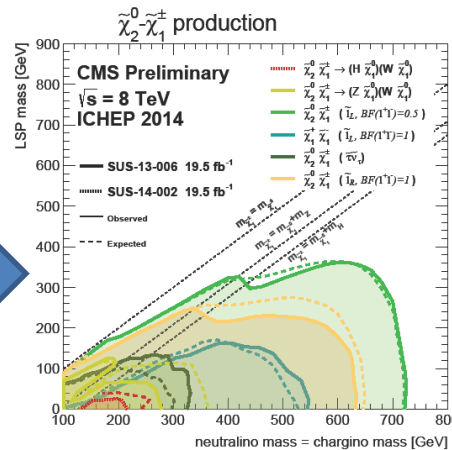
A. Djouadi et al arXiv:1502.05653



M. Carena et al arXiv:1302.7033



Light  $\chi$ 's seems are not excluded yet

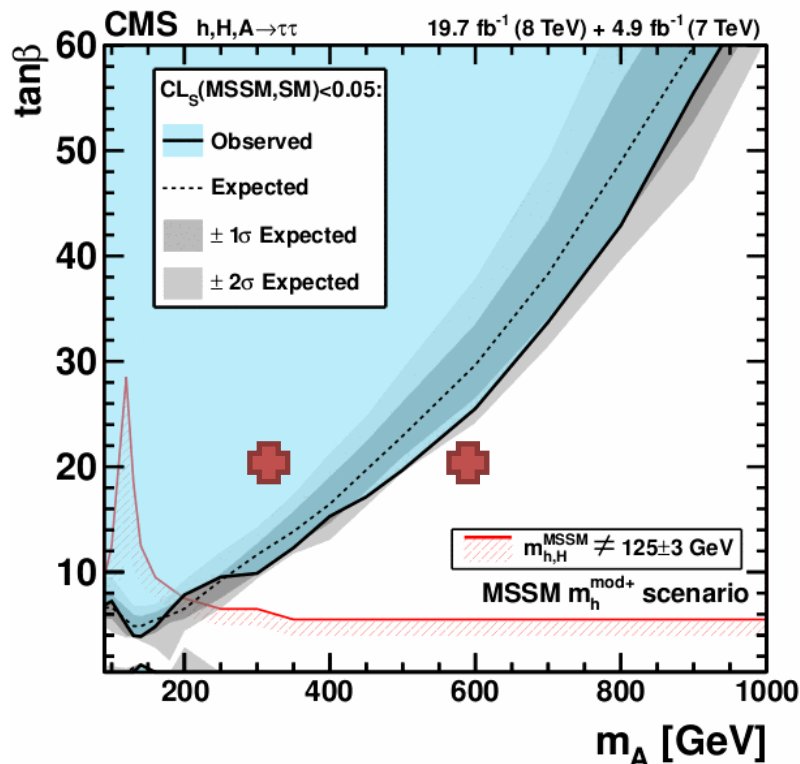


H/A → χχ



**THE END**

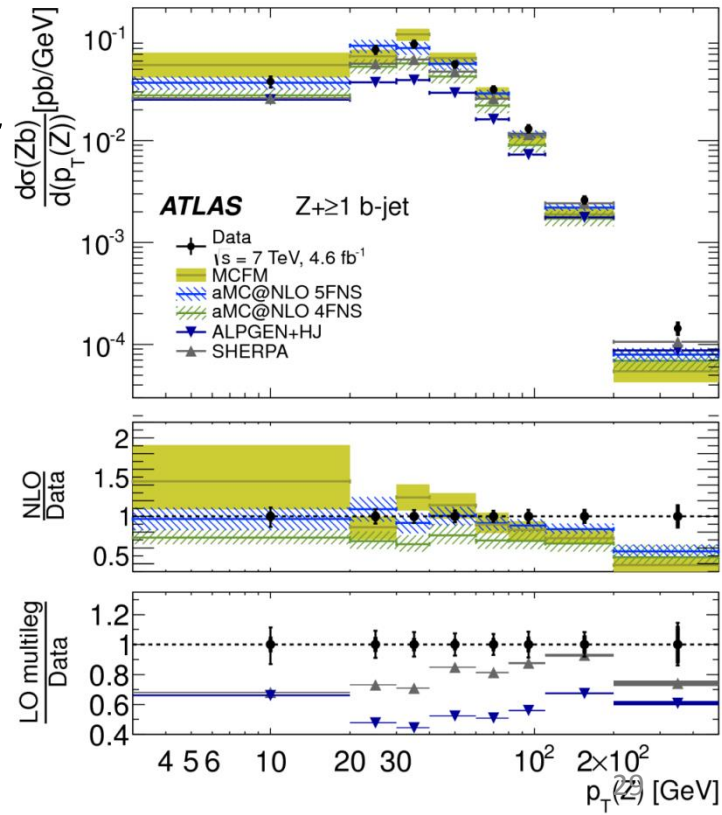
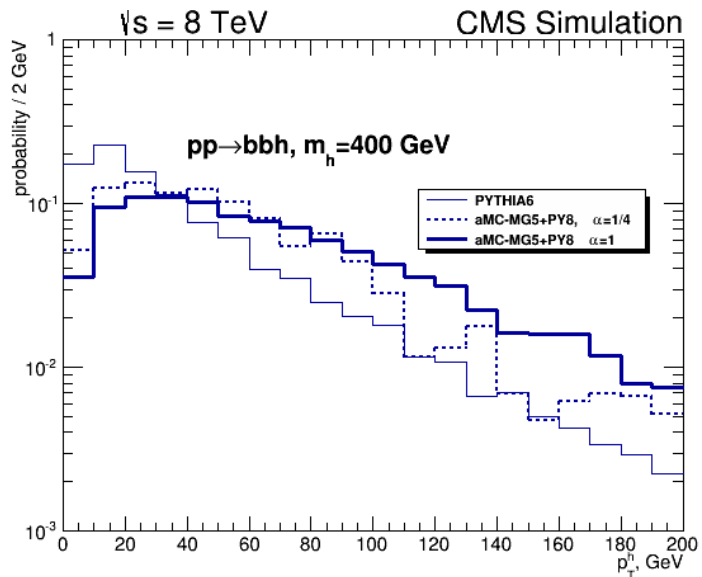
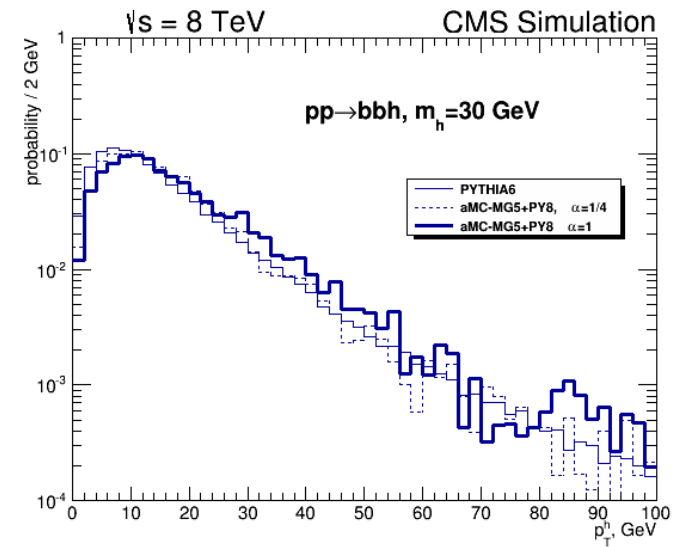
- Non b-tag category is also dominated by bbH at large  $m_A$



	$m_A=300 \text{ GeV}$ $\tan\beta = 20$	$m_A=600 \text{ GeV}$ $\tan\beta=20$
$\sigma(\text{gg} \rightarrow \text{A} + \text{H}) / \sigma(\text{bb} \rightarrow \text{A} + \text{H})$	0.16	0.08
$\sigma(\text{gg} \rightarrow \text{A} + \text{H}) / \sigma(\text{bb} \rightarrow \text{A} + \text{H}) \times (\epsilon_{\text{gg} \rightarrow \text{H}} / \epsilon_{\text{bb} \rightarrow \text{H}})^{\text{exp}}$	0.20	0.27

# bbH MC

- $pp \rightarrow bbH$  aMC@NLO vs PY6/8
  - harder Higgs  $p_T$ 
    - $p_T$  is sensitive to shower scale,  $Q_{sh}$  in MG5\_aMC@NLO
    - use Z+b data to tune  $Q_{sh}$  and apply it to H+b
  - (very) different efficiency of the jet veto
    - change of selection strategy for light pseudoscalar A analysis  $pp \rightarrow bbA, A \rightarrow \tau\tau/\mu\mu$



# Signal selection efficiencies MG5\_aMC@NLO+PY8 vs PY6 for $pp \rightarrow bbA$ , $A \rightarrow \mu\mu$ , $m_a = 30$ GeV

	Selection on muon $p_T$ , GeV $ \eta  < 2.1$ for both muons					
	10		15		20	
	NLO+PY8	PY6	NLO+PY8	PY6	NLO+PY8	PY6
<b>Muon selections</b>	<b>0.368</b>	<b>0.379</b>	<b>0.059</b>	<b>0.057</b>	<b>0.013</b>	<b>0.014</b>
<b><math>\geq 1</math> b-jet after <math>\mu</math>'s sel. <math>p_T &gt; 30</math> GeV, <math> \eta  &lt; 2.4</math></b>	<b>0.104</b>	<b>0.106</b>	<b>0.280</b>	<b>0.379</b>	<b>0.558</b>	<b>0.731</b>
<b>1 b-jet no other jets <math> \eta  &lt; 4.7</math></b>	<b>0.628</b>	<b>0.751</b>	<b>0.643</b>	<b>0.722</b>	<b>0.553</b>	<b>0.640</b>

- **Huge difference in additional jet veto**
  - decided to change a search strategy dropping the jet veto from the selections