BSM Higgs searches at LHC

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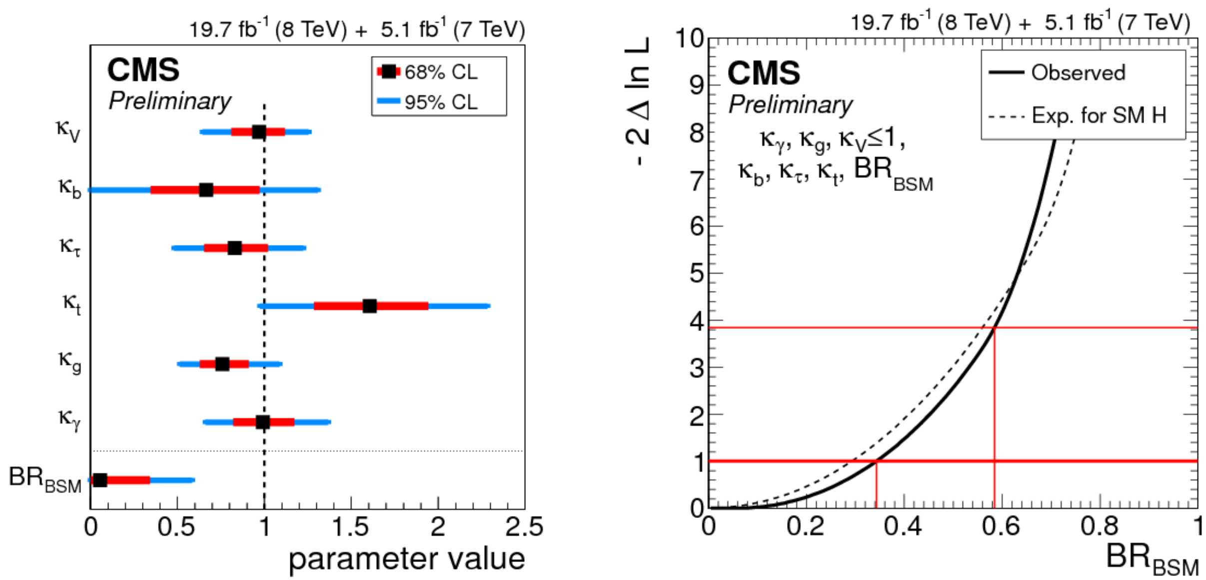
Seminar at RAL, 10th December

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)

will be discussed

- last year new results on direct searches for
  - H->$\tau\tau$
  - H->h(125)h(125)->$\gamma\gamma$bb
  - A->Zh->$\ell\ell$bb
  - H^+->$\tau\nu$
  - h->$\gamma\gamma$, m_h=[60-1000] GeV
  - h(125)->DM (invisible)
  - h(125)->$\mu\tau$ (LFV)
  - h(125)->XX->4τ, X – a light Higgs boson
- "model independent" σxBR limits and interpretations in MSSM and 2HDM
- prospects for 2015/2016

Higgs bosons in MSSM

- Unconstrained MSSM is the most "economic" version of SUSY (104 free parameters); 22 parameters in pMSSM
- It requires two Higgs superfields
  - P. Fayet (1975, 1976)
- Their scalar components, H1 and H2 give separately masses for up and down type of fermions
- 5 Higgs particles: CP even h and H, CP odd A, and $H^{+/-}$

Superfield	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	Particle content
$\hat{Q}$	3	2	$\frac{1}{3}$	(u_L, d_L), $(\tilde{u}_L, \tilde{d}_L)$
$\hat{U}^c$	$\overline{3}$	1	$-\frac{4}{3}$	$\overline{u}_R$, $\tilde{u}_R^*$
$\hat{D}^c$	$\overline{3}$	1	$\frac{2}{3}$	$\overline{d}_R$, $\tilde{d}_R^*$
$\hat{L}$	1	2	-1	(ν_L, e_L), $(\tilde{\nu}_L, \tilde{e}_L)$
$\hat{E}^c$	1	1	2	$\overline{e}_R$, $\tilde{e}_R^*$
$\hat{H}_1$	1	2	-1	H_1, $\tilde{H}_1$
$\hat{H}_2$	1	2	1	H_2, $\tilde{H}_2$

The superfields of the fermions and Higgs bosons in the MSSM

At tree level Higgs sector of MSSM is determined by only two parameters:

M_A and $\tan(\beta)$

$1 < \tan(\beta) = v_2/v_1 = (v \sin(\beta)) / (v \cos(\beta)) < 60$

where v_1 and v_2 are vacuum expectation values (vev) of the neutral components of two Higgs doublets.

$v_1^2+v_2^2 = v^2 = 2M_Z^2 /(g_2^2+g_1^2) = (246\ \mathrm{GeV})^2$

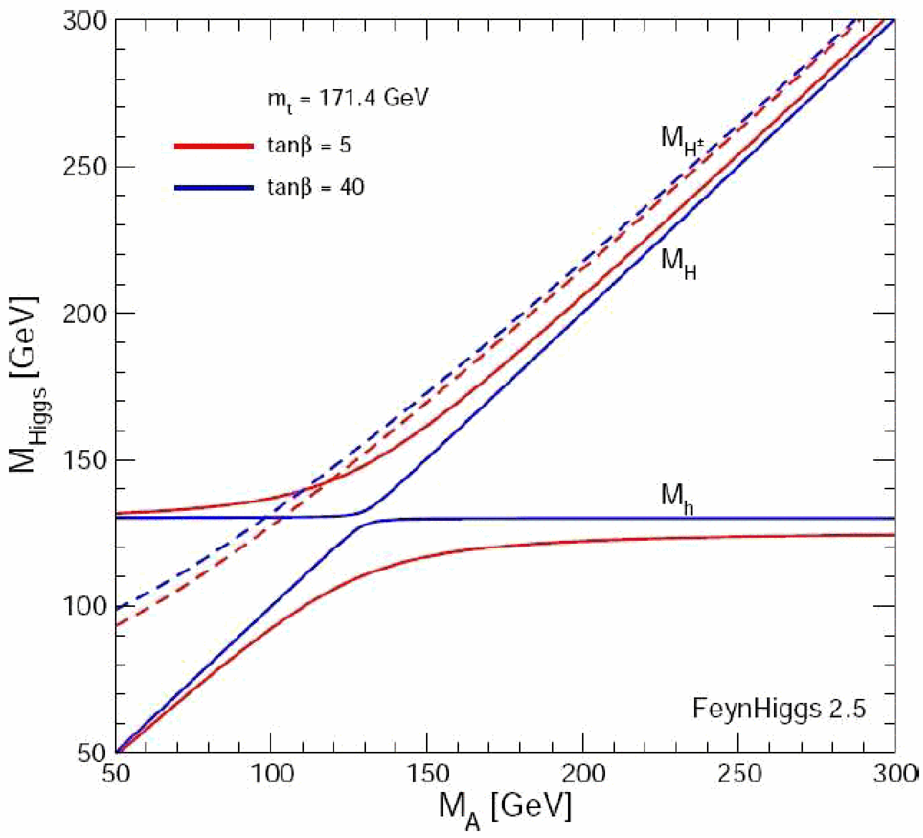
Higgs masses at tree level

$m_{H,h}^2 = ½[(m_A^2 +m_Z^2) \pm ((m_A^2 +m_Z^2)^2 – 4m_Z^2m_A^2 (\cos^2 2\beta))^{1/2}]$

$m_{H+}^2 = m_A^2 + m_W^2$

$m_h < m_Z$

Masses of MSSM Higgs bosons

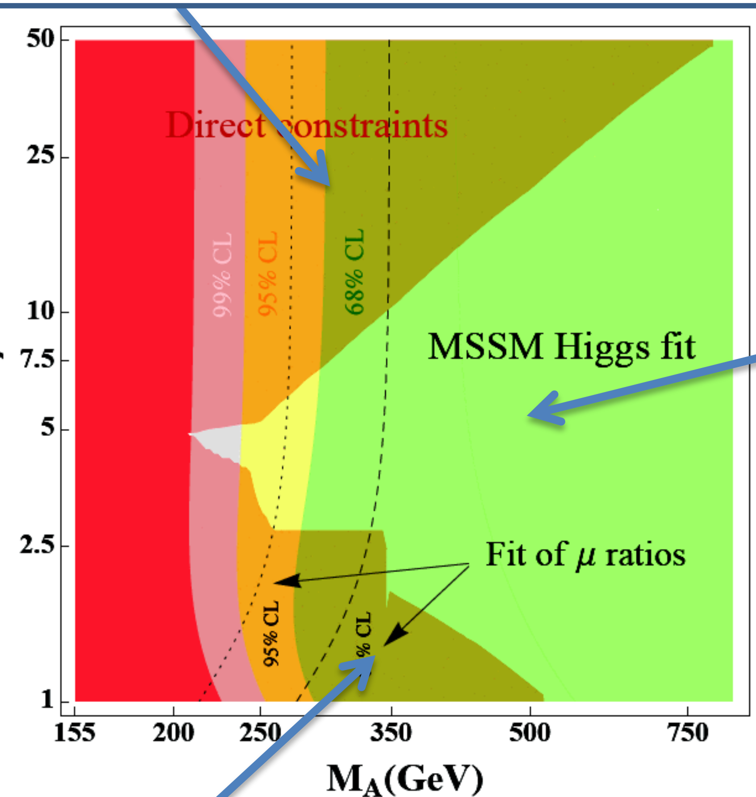


- **Five Higgs bosons in MSSM:**
  - **two CP-even h, H; one CP-odd A, two charged $H^{+/-}$**
  - ***what is discovered as state of 125 GeV, h or H ?***

Landscape of
BSM Higgs channels in MSSM

- ***High tanβ*: $\phi\to\tau\tau$, $\phi\to\mu\mu$,bb; $H^+\to\tau\nu$, tb**

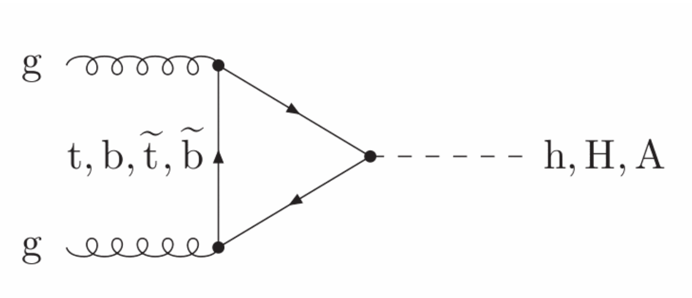
A. Djouadi et.al. arXiv:1307.5205

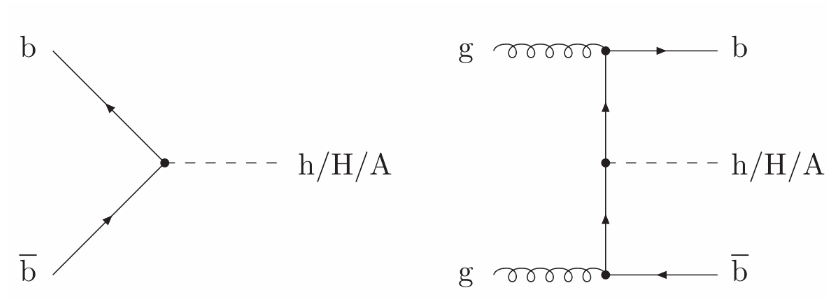


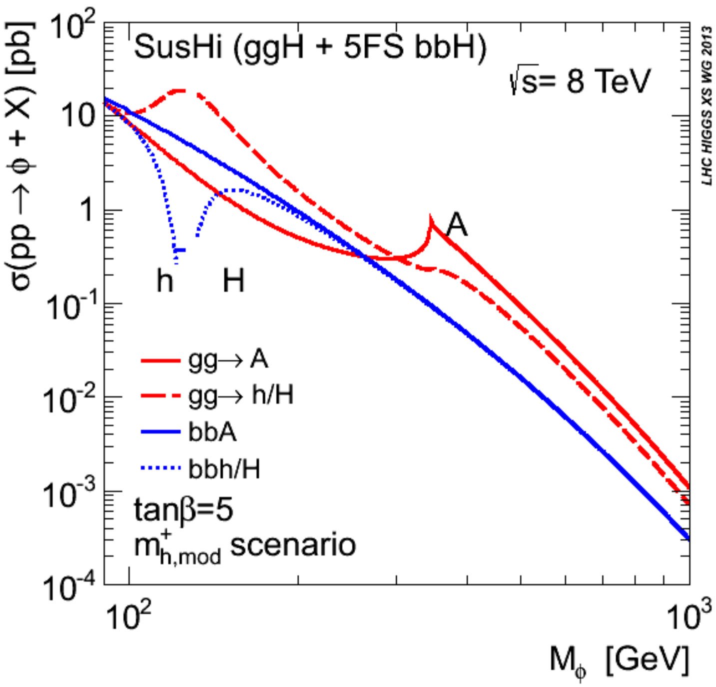
- ***Intermediate tanβ*:**
  - ***$H/A\to\chi_i^0\chi_j^0$, $\chi_i^+\chi_j^-$***
  - ***$H^+\to\chi_i^+\chi_j^0$***

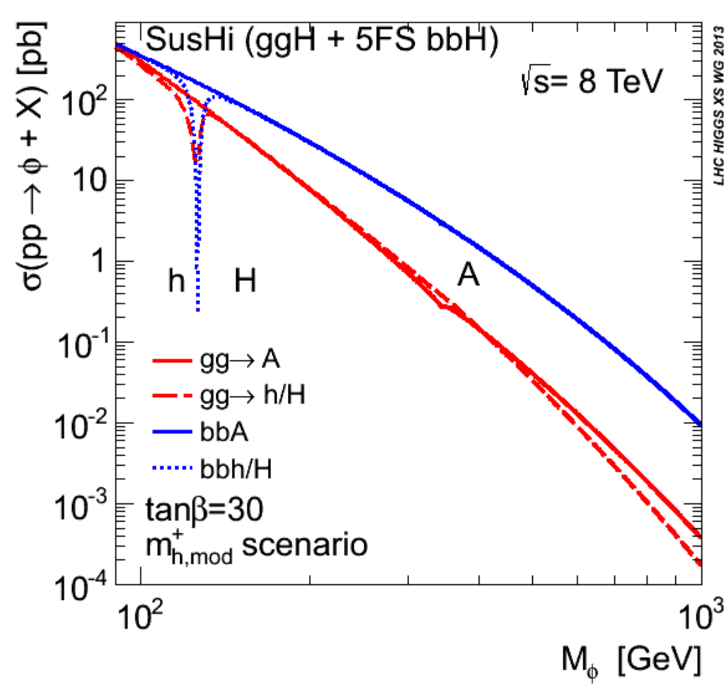
- ***Low tanβ*: A$\to$Zh; H$\to$hh, tt; $H^+\to$cs, cb, $\tau\nu$, tb, Wh**

MSSM neutral $\phi \to \tau\tau$



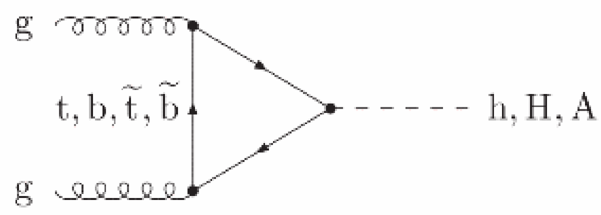


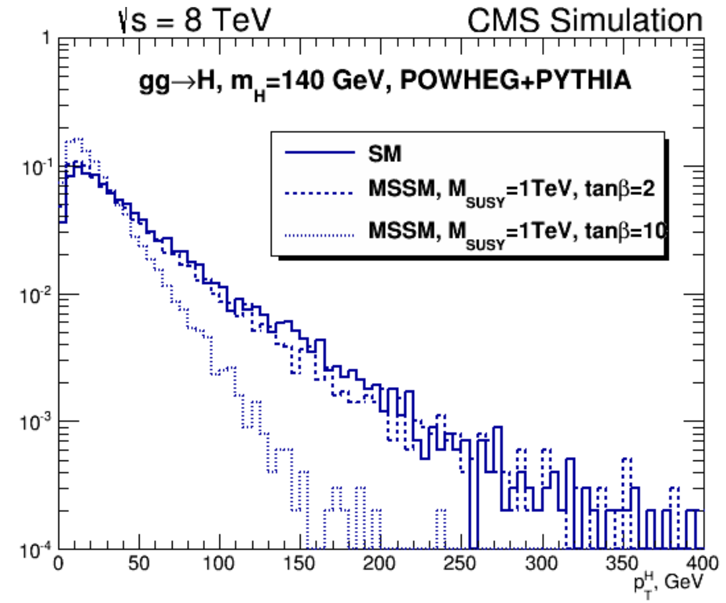




- **split events into b-tag and no-b-tag categories**
- **consider $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_h\tau_h$, $\tau_e\tau_\mu$, $\tau_\mu\tau_\mu$ final states**

gg->H in SM and MSSM





At high tanβ b-loop dominates and Higgs p_T is changing
This effect is discussed in:

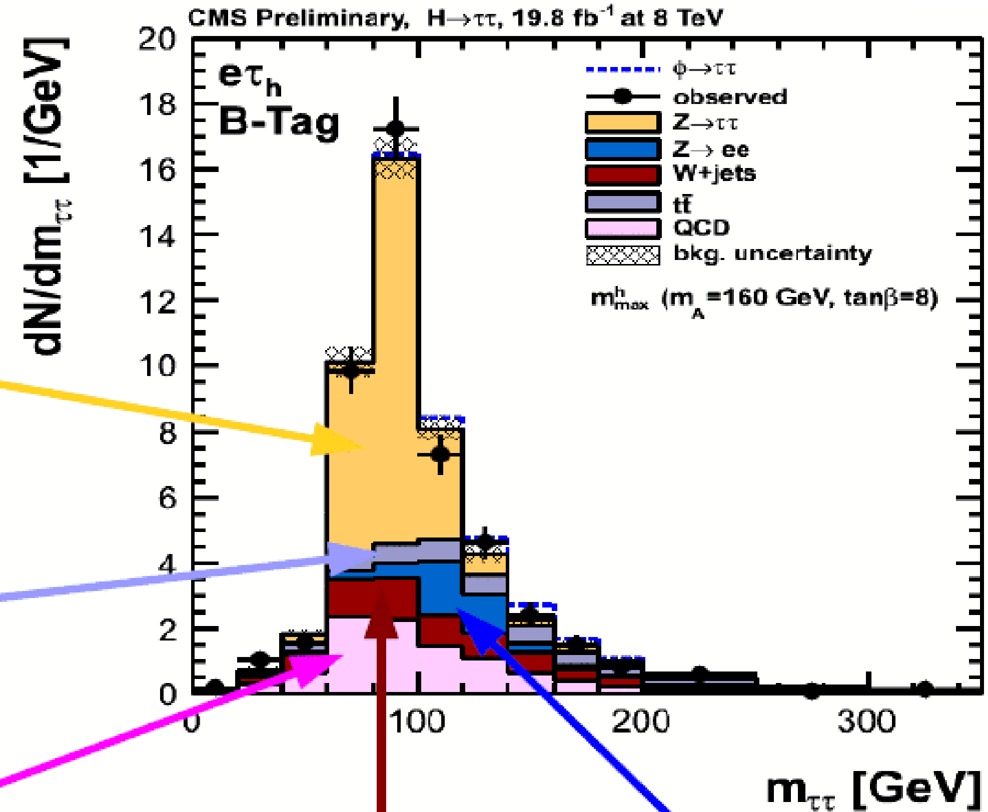
1. *Spira et al. hep-ph/0604156*
2. *J. Alwall, Q Li, F. Maltoni arXiv:1110.1728*
3. *E.Bagnaschi, G. Degrassi, P. Slavich, A.Vicini. arXiv:1111.2854*

CMS analysis is designed in a such way that signal acceptance is model independent:

does not depends on assumption of what is in the loop

Background estimation in $\Phi \rightarrow \tau\tau$

$Z/\gamma^* \rightarrow \tau\tau$:
- Embedding: in $Z \rightarrow \mu\mu$, replace μ by sim. τ decay
- Normalized from $Z \rightarrow \mu\mu$ events



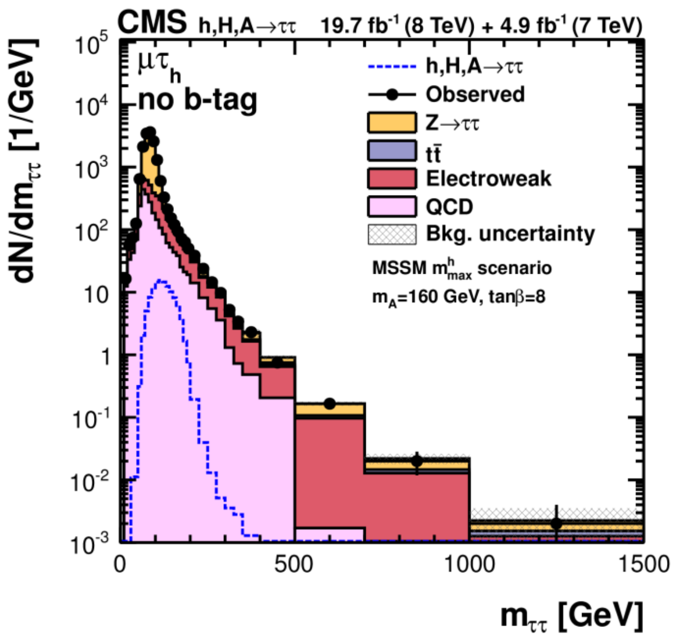
ttbar:
- From simulation
- Normalization from sideband

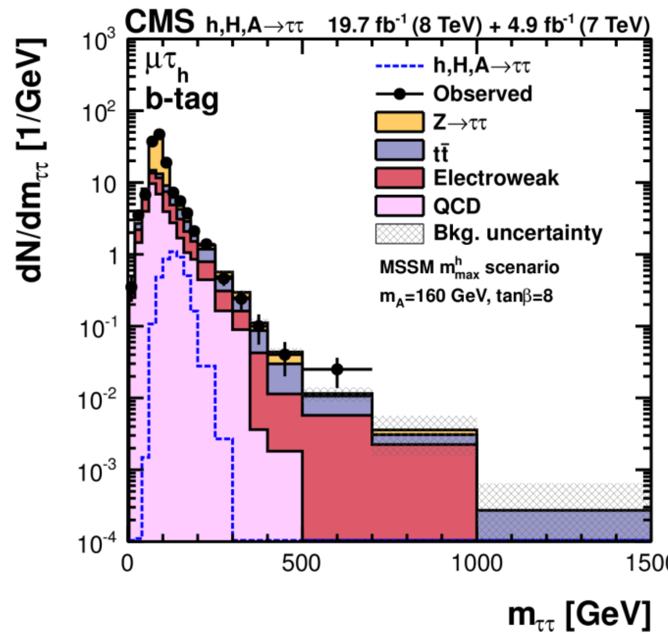
QCD:
- Normalization & shape taken from SS/OS or fakerate

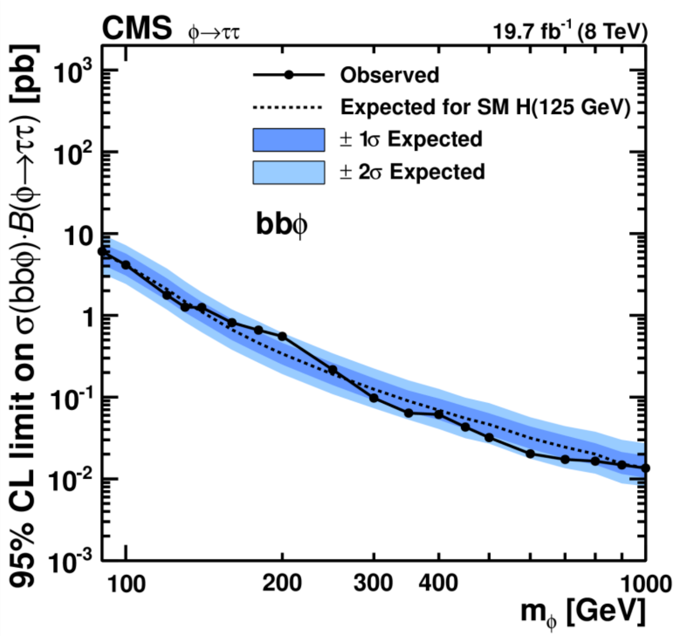
Di-boson/W+jets:
- From simulation or data
- Normalization from sideband

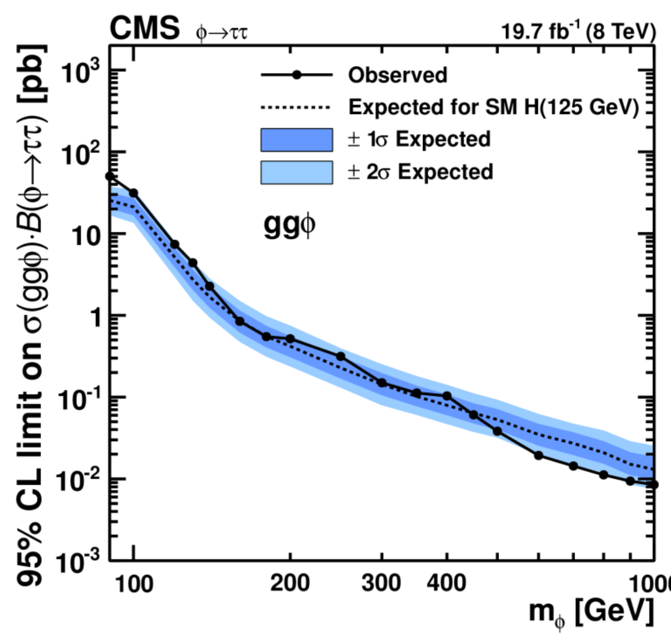
$Z/\gamma^* \rightarrow ee$ ($\mu\mu$):
- From simulation or data
- Corrected for jet $\rightarrow \tau$, $e/\mu \rightarrow \tau$ fakerate

ϕ->ττ : “model independent” limits



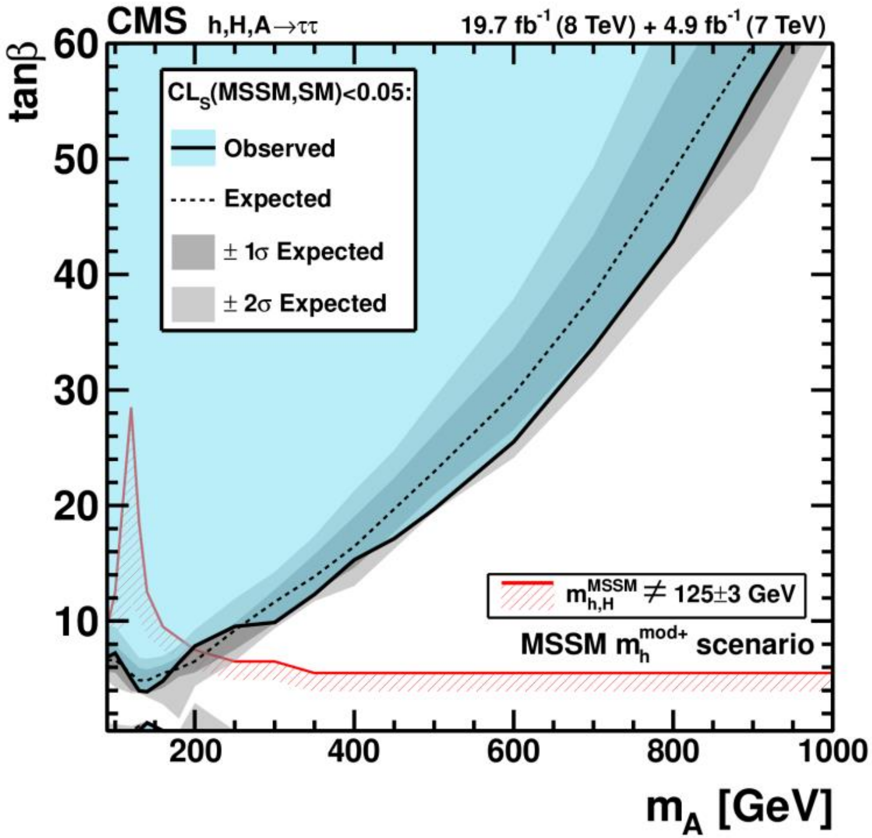


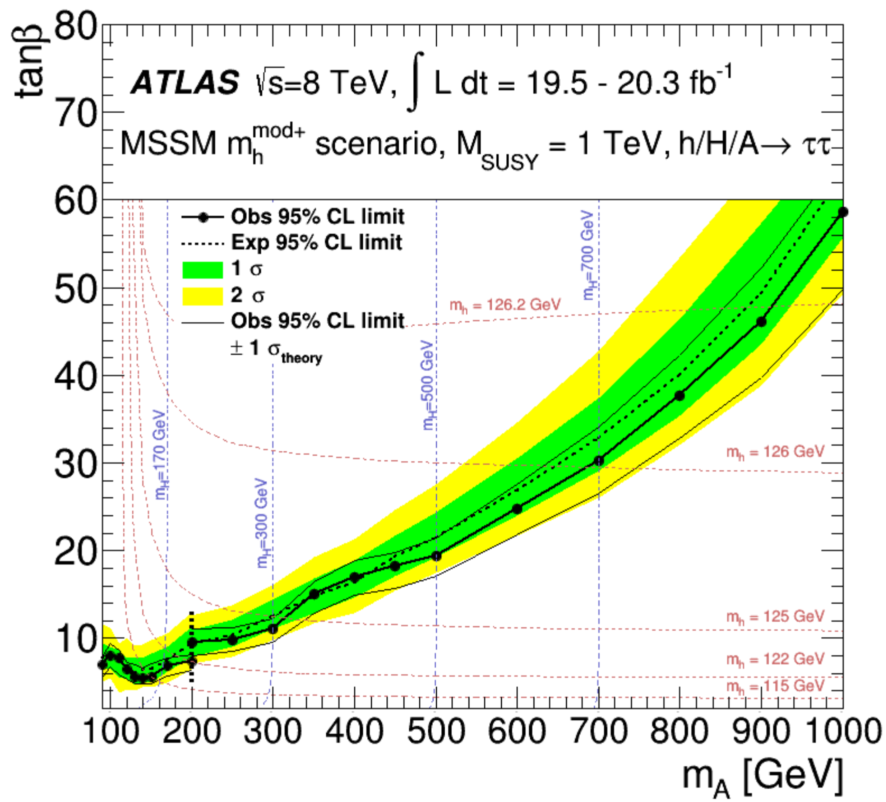




φ->ττ : limits in MSSM benchmark scenarios

- m_h^{mod+} scenario from M.Carena at al. arXiv:1302.7033





Signal selection efficiencies MG5_aMC@NLO+PY8 vs PY6 pp->bbA, A->$\tau\tau$, m_A=400 GeV

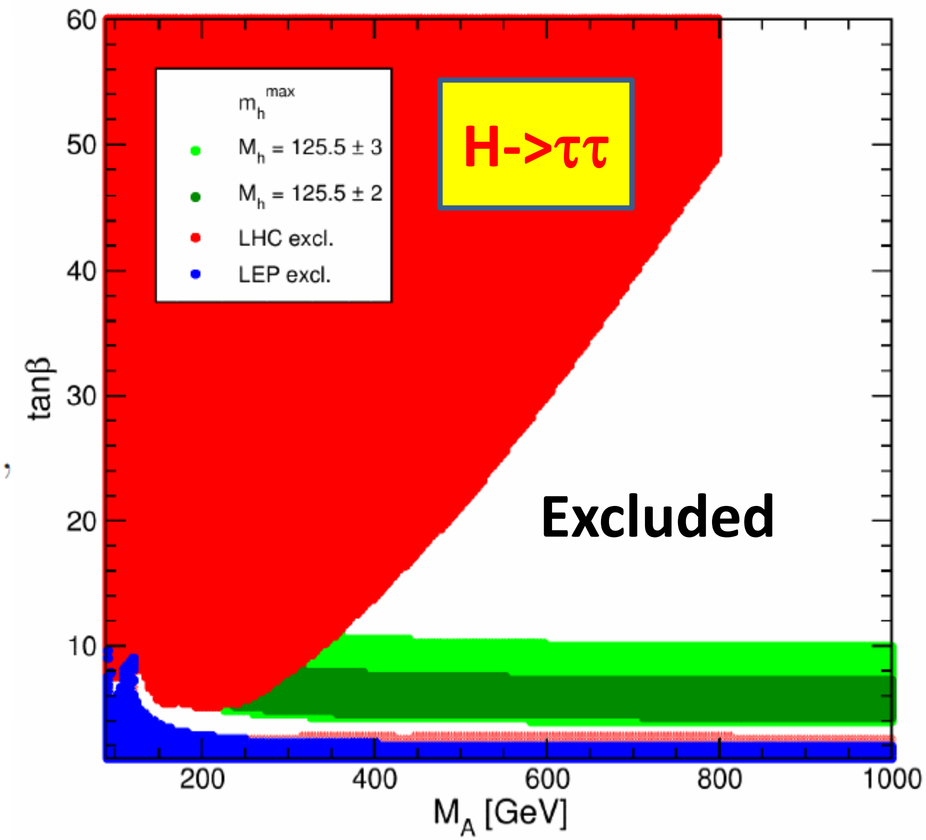
	Selection on τ_h p_T and η for both τ_h used in CMS MSSM H->$\tau_h\tau_h$ analysis (still need to apply on τ_h but not to τ)	
	p_T^{τ} >45 GeV, $\lvert\eta^{\tau}\rvert$ < 2.4, DR(τ-j) > 0.5	
	NLO+PY8	PY6
Tau kinematics	0.895	0.860
>= 1 b-jet after μ's sel. p_T >30 GeV, $\lvert\eta\rvert$<2.4	0.383	0.346
Following efficiencies are relative to muon and >= 1 b-jet selection; jets p_T^j > 30 GeV		
1 b-jet no other jets $\lvert\eta\rvert$<2.4	0.466	0.660
1 b-jet >=1 light jet $\lvert\eta\rvert$<2.4	0.378	0.194
2 b-jets + X	0.155	0.147
1 b-jet no other jets $\lvert\eta\rvert$< 4.7	0.379	0.579

A few words on interpretation in the “benchmark” scenarios

MSSM benchmark scenarios (I)
(from M. Carena et al arXiv:13027033)

- m_h^{max} updated scenario:
  - green strip is allowed region of M_A-tanβ

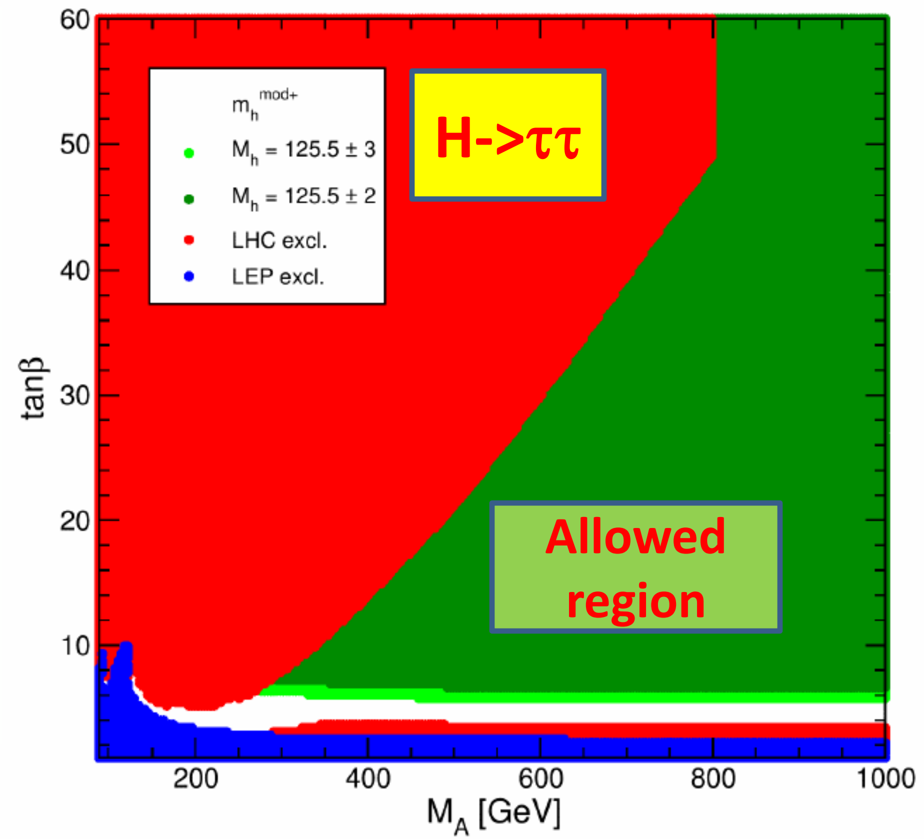
$$\begin{aligned} m_t &= 173.2\ \text{GeV}, \\ M_{\text{SUSY}} &= 1000\ \text{GeV}, \\ \mu &= 200\ \text{GeV}, \\ M_2 &= 200\ \text{GeV}, \\ X_t^{\text{OS}} &= 2\, M_{\text{SUSY}}\ \text{(FD calculation)}, \\ X_t^{\overline{\text{MS}}} &= \sqrt{6}\, M_{\text{SUSY}}\ \text{(RG calculation)}, \\ A_b &= A_\tau = A_t, \\ m_{\tilde{g}} &= 1500\ \text{GeV}, \\ M_{\tilde{l}_3} &= 1000\ \text{GeV}\ . \end{aligned}$$



MSSM benchmark scenarios (II)
(from M. Carena et al arXiv:13027033)

- m_h^{mod} scenario:
  - green area is allowed region of M_A-tanβ

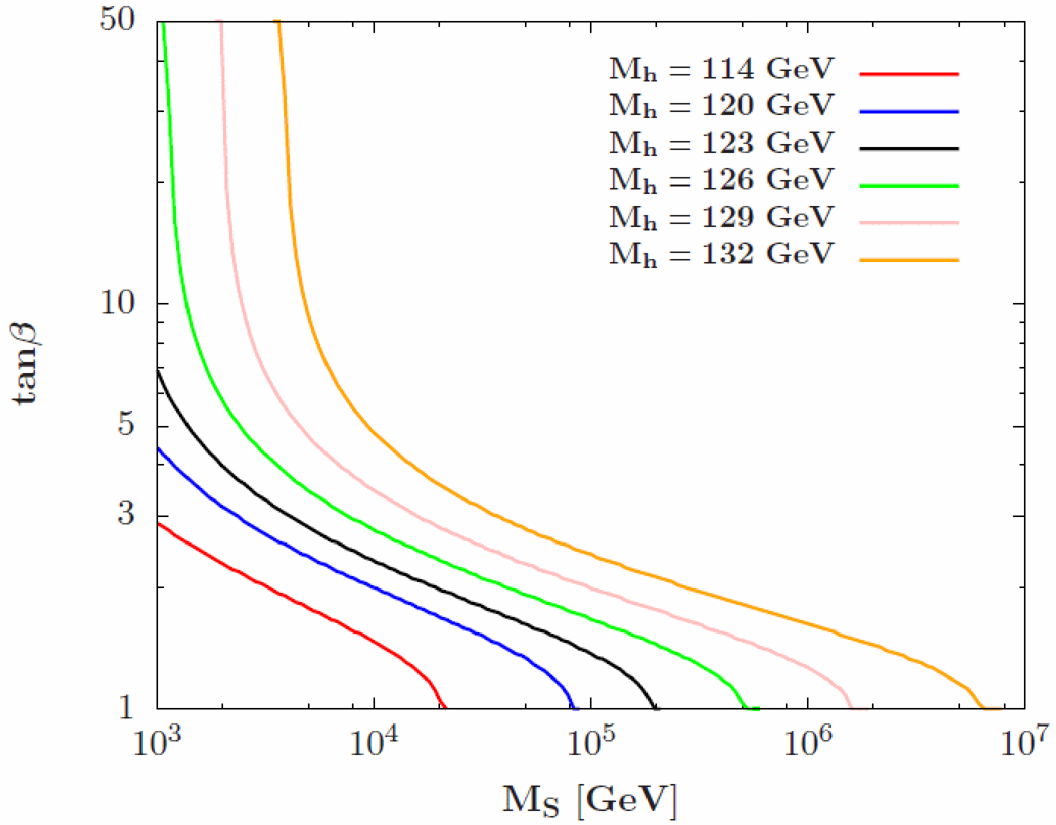
$$
\begin{aligned}
m_t &= 173.2 \text{ GeV}, \\
M_{\rm SUSY} &= 1000 \text{ GeV}, \\
\mu &= 200 \text{ GeV}, \\
M_2 &= 200 \text{ GeV}, \\
X_t^{\rm OS} &= 1.5\, M_{\rm SUSY} \text{ (FD calculation)}, \\
X_t^{\overline{\rm MS}} &= 1.6\, M_{\rm SUSY} \text{ (RG calculation)}, \\
A_b &= A_\tau = A_t, \\
m_{\tilde g} &= 1500 \text{ GeV}, \\
M_{\tilde l_3} &= 1000 \text{ GeV} .
\end{aligned}
$$



Is low tanβ region excluded ?

(A. Djouadi at el., arXiv:1304.1787)

- **Low tanβ region is not excluded for large M_S**

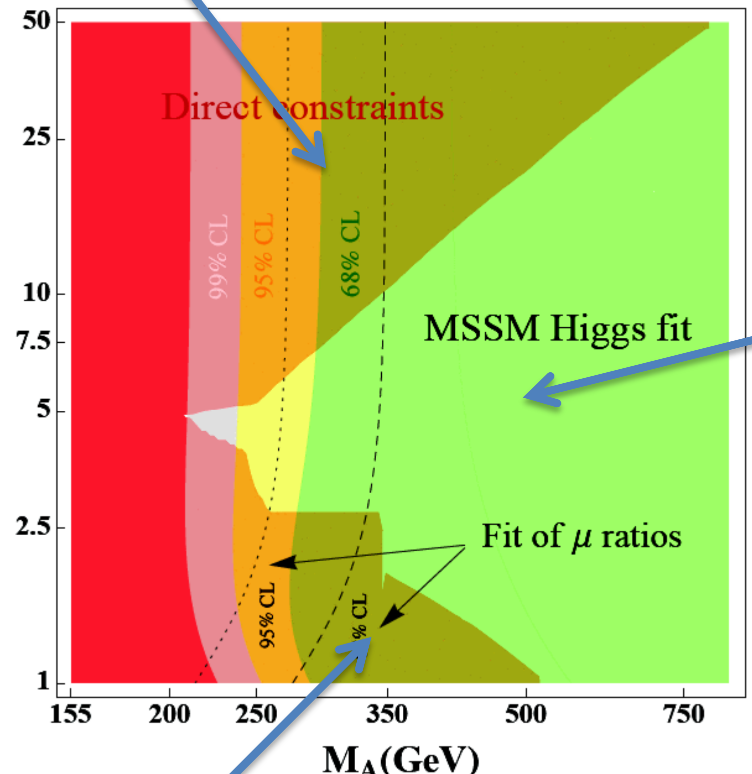


with m_t uncertainty 3 GeV (from tt~ cross-section) $\Delta^{th}m_h$ is ~ 6 GeV

Landscape of BSM Higgs channels in MSSM

- ***High tanβ*** : $\phi \to \tau\tau$, $\phi \to \mu\mu$, bb; $H^+ \to \tau\nu$, tb

A. Djouadi et.al. arXiv:1307.5205

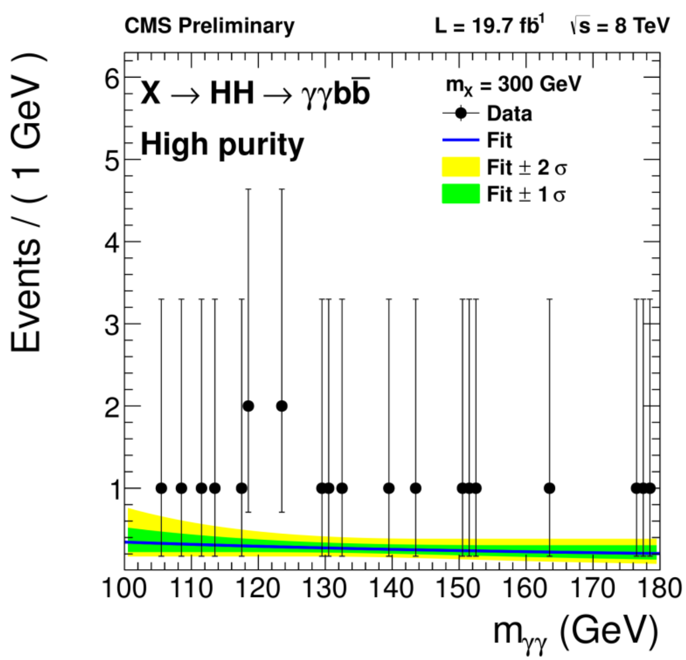


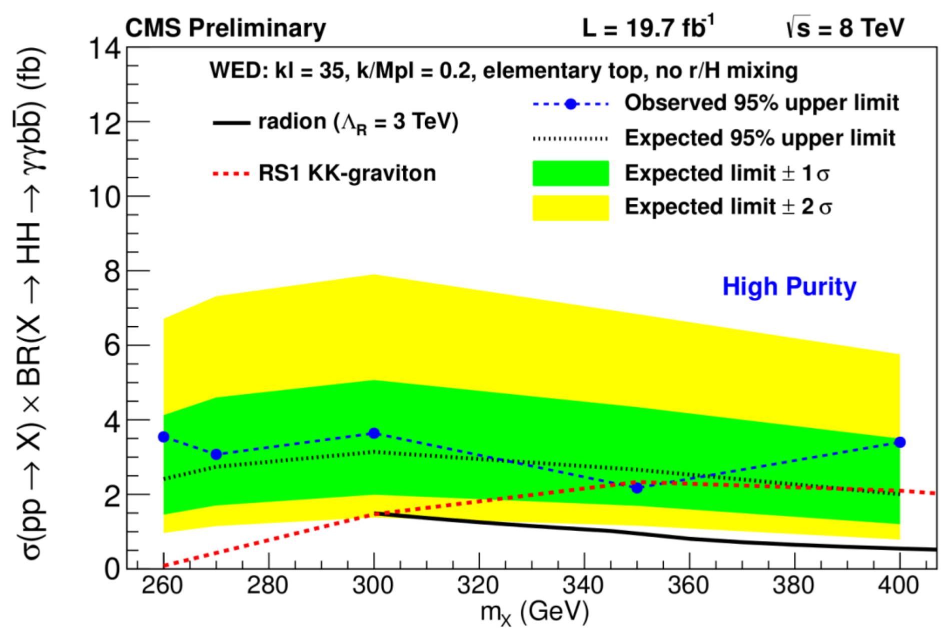
- ***Intermediate tanβ***:
  - $H/A \to \chi_i^0 \chi_j^0$, $\chi_i^+ \chi_j^-$
  - $H^+ \to \chi_i^+ \chi_j^0$

- ***Low tanβ***: $A \to Zh$; $H \to hh$, tt; $H^+ \to$ cs, cb, $\tau\nu$, tb, Wh

low tanβ mode :H → hh → γγbb

- **Search strategy:**
  - looking for signal in $m_{\gamma\gamma}$ distribution for γγbb events selected within m_{bb} and $m_{\gamma\gamma bb}$ mass windows
- **In hMSSM (A. Djouadi et.al. arXiv:1307.5205):**
  - σ(gg→H)xBR(H→hh→γγbb)=2.9 fb for m_A=300 GeV, tanβ=2
    - close to observed limit ! hMSSM numbers provided by J. Quevillon



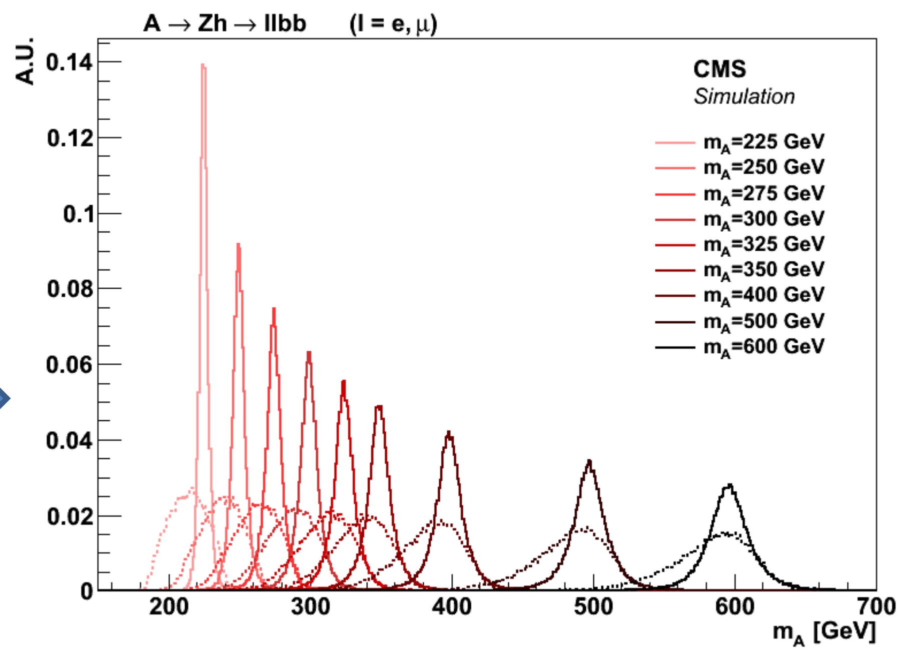


Theorists are invited to make the model interpretation

low tanβ modes: A->Zh->ℓℓbb

- Select events with two leptons (μμ, ee):
  - p_T > 20 GeV, 10 GeV
  - $m_{\ell\ell}$ =[75-105] GeV
- two b-tagged jets p_T > 20 GeV, |η|<2.4
  - Jet energy is corrected with kinematic fit using h(125) mass constraint
  - m_{bb} = [90-140] GeV

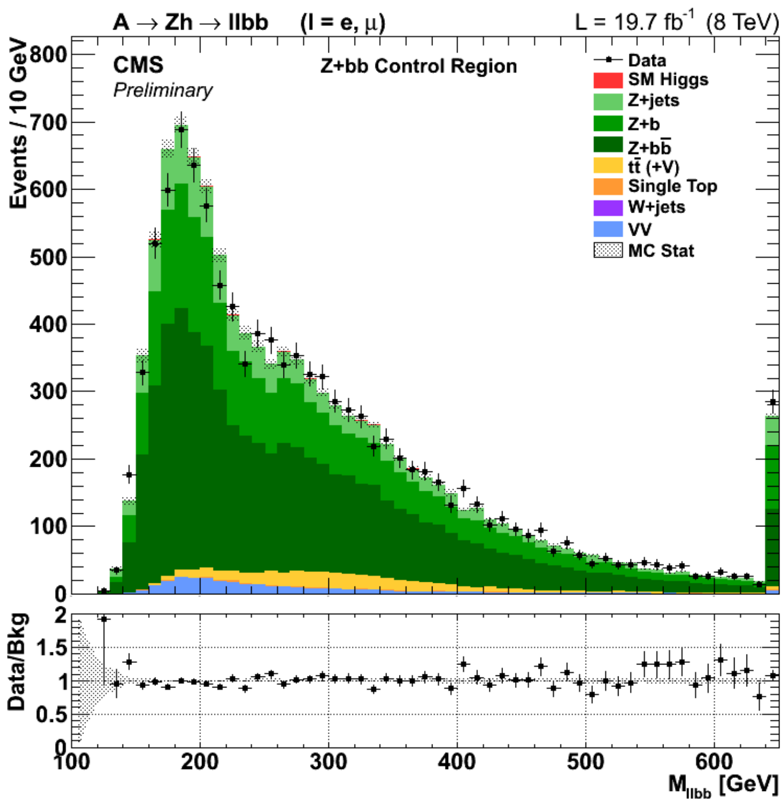
Improvement in the A boson reconstructed mass, ℓℓbb with kinematic fit using h mass constraint

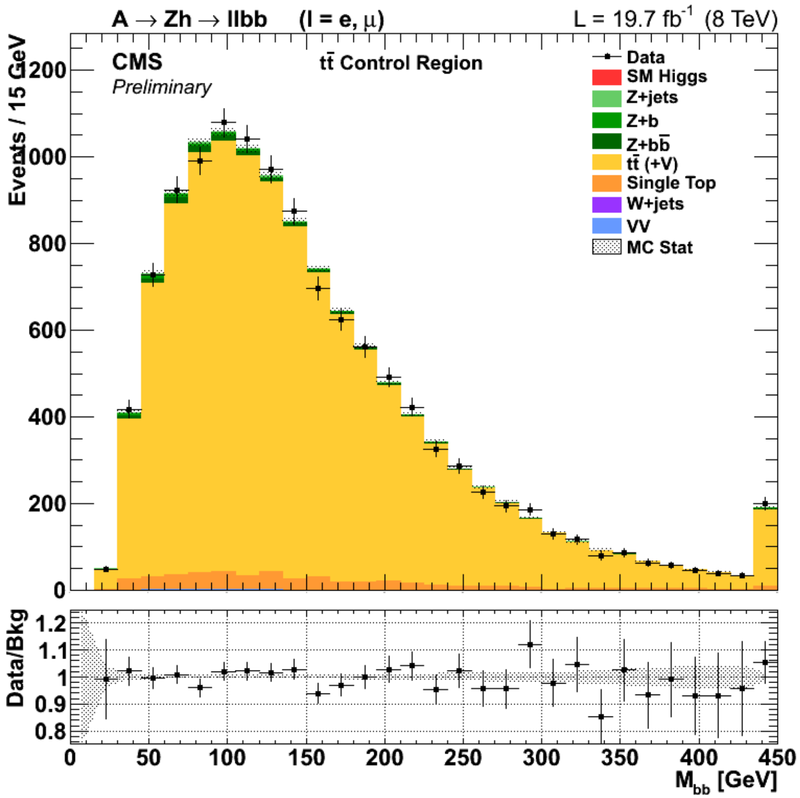


Control regions for dominant backgrounds

Control Region	Z mass [GeV]	h mass [GeV]	CSV_1	CSV_2	E_T^{miss} [GeV]
Z+0 b-jets	$80 < m_{\ell\ell} < 100$	$m_{bb} < 90, m_{bb} > 140$	-	-	-
Z+1 b-jets	$80 < m_{\ell\ell} < 100$	$m_{bb} < 90, m_{bb} > 140$	Tight	not Loose	< 40
Z+2 b-jets	$80 < m_{\ell\ell} < 100$	$m_{bb} < 90, m_{bb} > 140$	Tight	Loose	< 40
Top	$m_{\ell\ell} < 80, m_{\ell\ell} > 100$	-	Tight	Loose	> 40

	Z+jets	Z+b	$Z + b\bar{b}$	$t\bar{t}$
Scale Factors	1.069 ± 0.002	0.945 ± 0.012	1.008 ± 0.020	0.984 ± 0.010

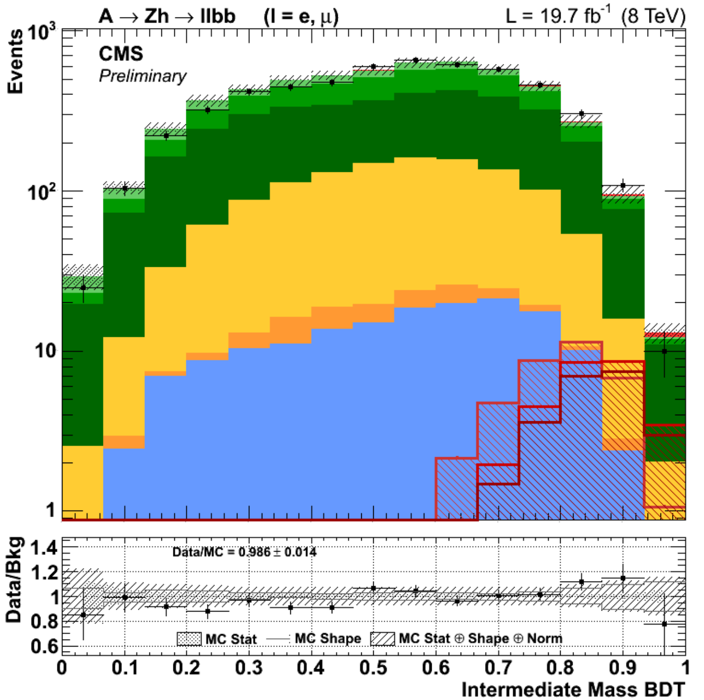


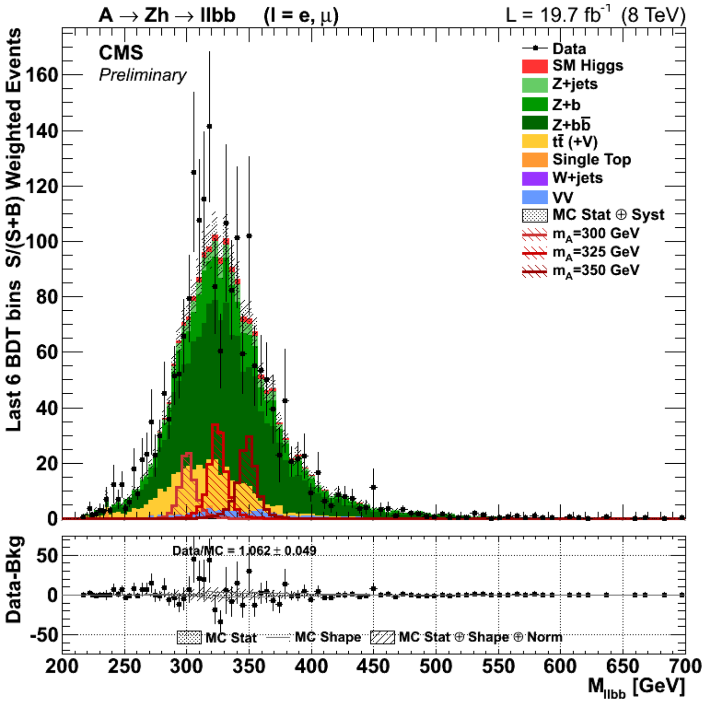


Signal extraction

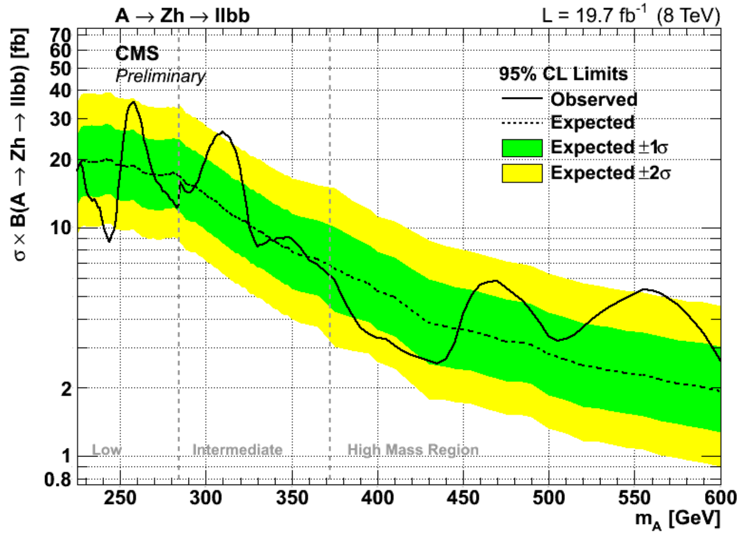
- **2D fit of $m_{\ell\ell bb}$ and BDT output**

Variable	Description
CSV_1	highest CSV value between the two jets
CSV_2	second-highest CSV value
$m_{\ell\ell}$	invariant mass of the lepton pair
p_T^Z	p_T of the Z candidate
p_T^h	p_T of the dijet pair (h candidate)
ΔR_{bb}	angular separation of the two jets in the $\eta - \varphi$ space
τ_{bb}	twist angle between the two jets $\tau \equiv \tan^{-1} \Delta\varphi / \Delta\eta$ [30]
E_T^{miss} sign	Missing Energy Significance [31]
χ^2	χ^2 of the kinematic fit
S_T	scalar sum of the p_T of jets, leptons and E_T^{miss} in the event
nJets	number of jets with $p_T > 20\,\text{GeV}$ in the event
Centrality	Centrality of the four decay products in the A rest frame [30]
Aplanarity	event Aplanarity calculated with the four decay products [30]
$\cos\theta^*$	production polar angle of the A candidate in its rest frame
$\cos\theta_1$	Z decay angle w.r.t. its flight direction in the Z rest frame
Pull Angle	angle of the pull vector of the highest-p_T jet [32]

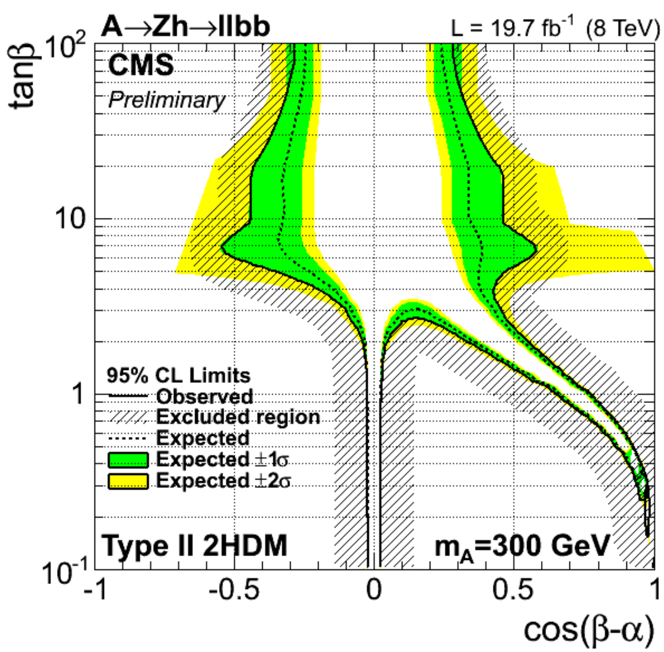




A-Zh->ℓℓbb: interpretation of limits



- in 2HDM



- in hMSSM
  - for m_A=300 GeV, tanβ=3.0

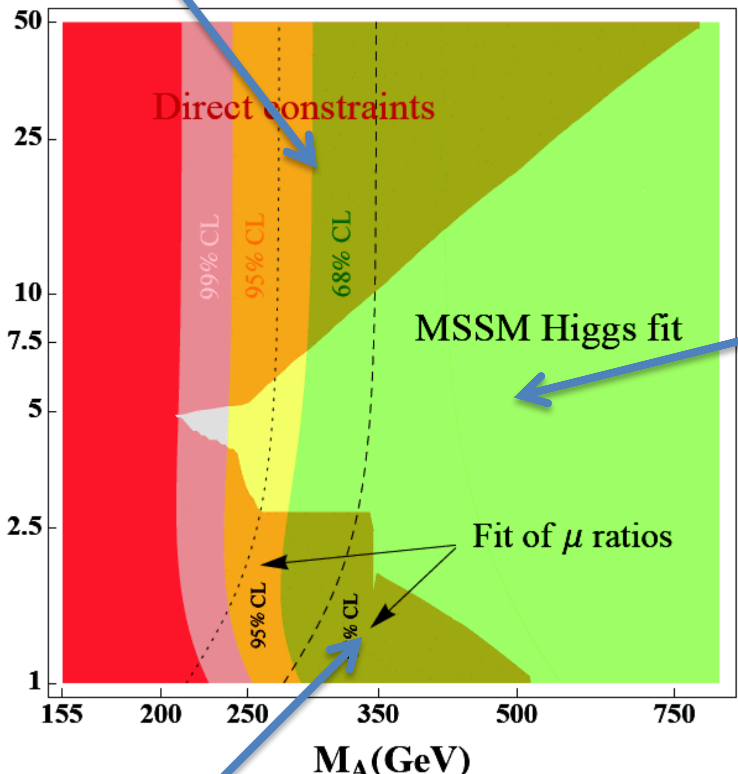
σ(gg->A)xBR(A->Zh)xBR(Z->ee+μμ)=18.2 fb

- close to observed limit !
- hMSSM numbers provided by J.Quevillon

Landscape of BSM Higgs channels in MSSM

- *High* $\tan\beta$: $\phi\to\tau\tau$, $\phi\to\mu\mu, bb$; $H^+\to\tau\nu$, tb

A. Djouadi et.al. arXiv:1307.5205

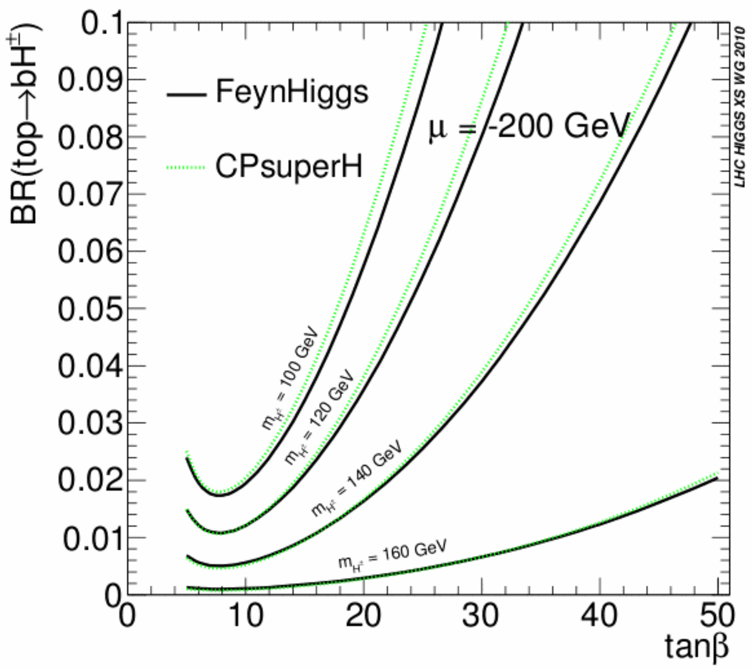


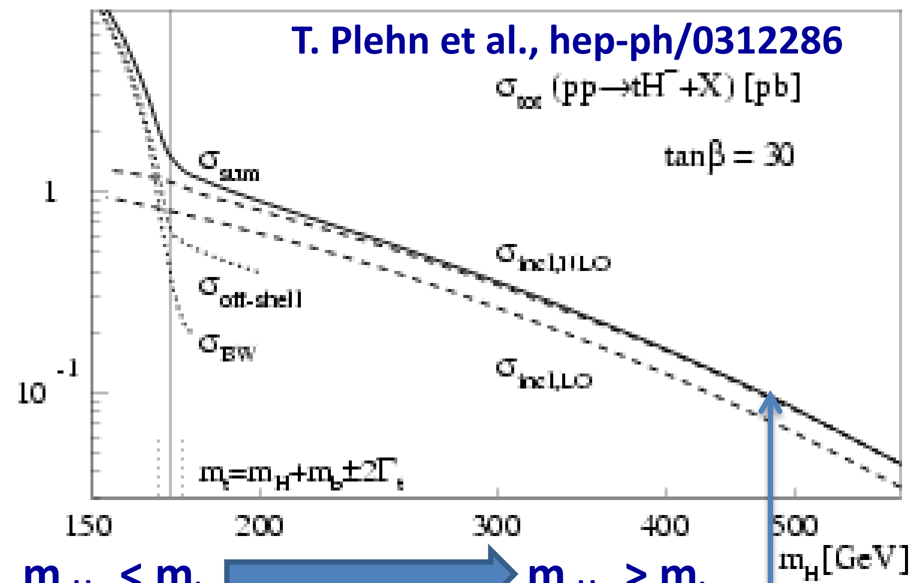
- *Intermediate* $\tan\beta$:
  - $H/A\to\chi_i^0\chi_j^0$, $\chi_i^+\chi_j^-$
  - $H^+\to\chi_i^+\chi_j^0$

- *Low* $\tan\beta$: $A\to Zh$; $H\to hh$, tt; $H^+\to cs$, cb, $\tau\nu$, tb, Wh

Searches for $H^+ \to \tau\nu$ ($t \to bH^+$, $gb \to tH^+$)

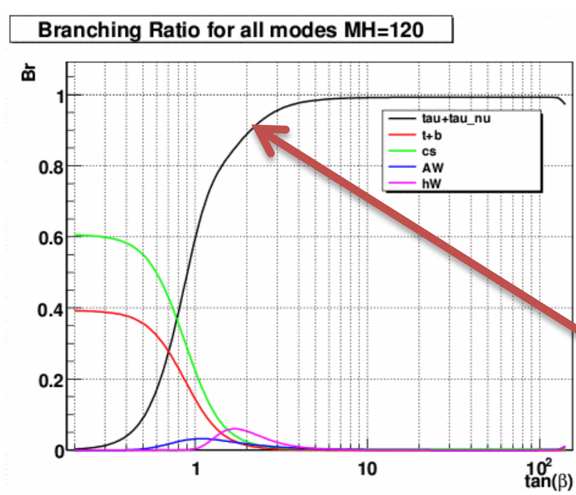
$$g_{H^+\bar{t}b} \quad \propto \quad m_b \tan\beta(1+\gamma_5) + m_t \cot\beta(1-\gamma_5)$$





$m_{H+} < m_t$ → $m_{H+} > m_t$

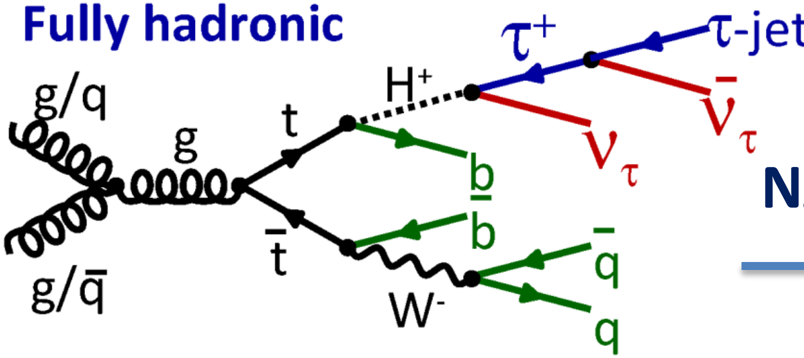
pp->tbH⁺ is in MC@NLO (T.Plehn et al)
recipie for $m_{H+} \sim m_t$: add tt and tbH⁺
4FS and 5FS NLO calculations exist



- ***Study decay mode $H^+ \to \tau\nu$***

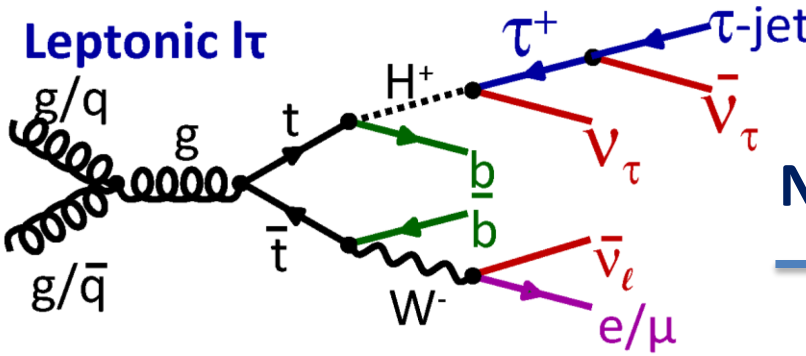
$H^+ \to \tau\nu$. Topologies considered:

Fully hadronic



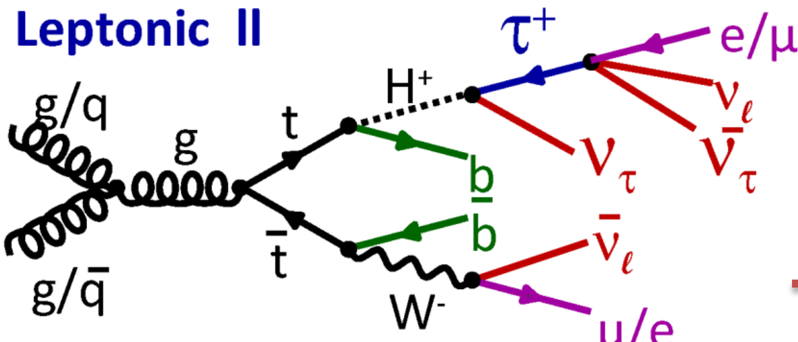
$N_{tt}^{SUSY} > N_{tt}^{SM}$

Leptonic lτ



$N_{tt}^{SUSY} > N_{tt}^{SM}$

Leptonic ll



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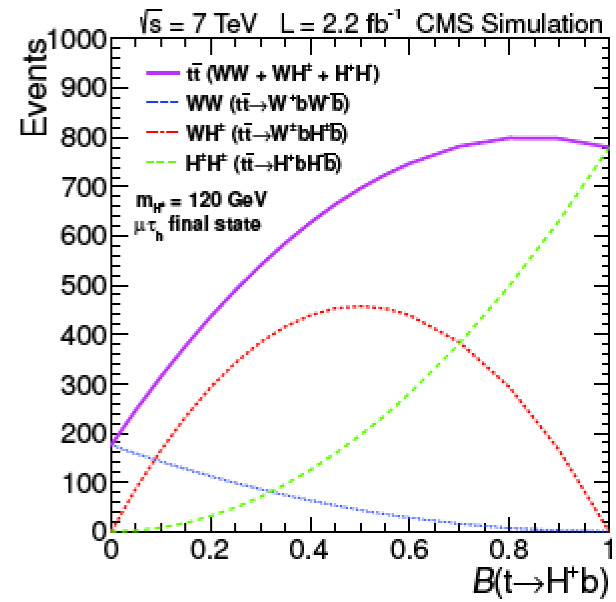
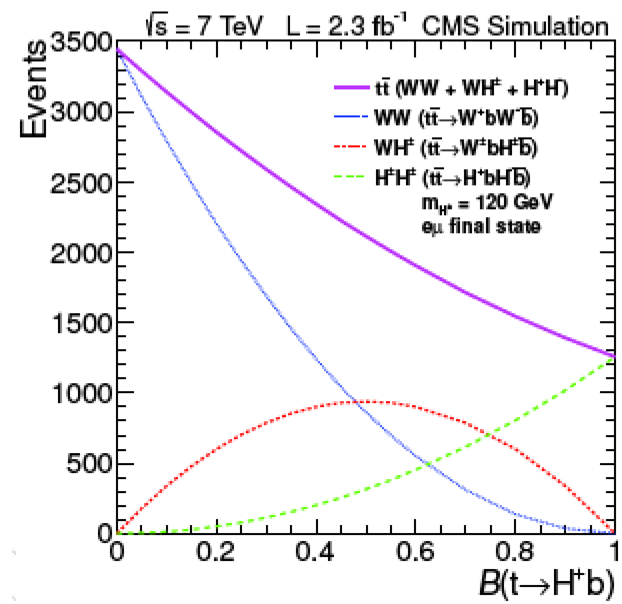
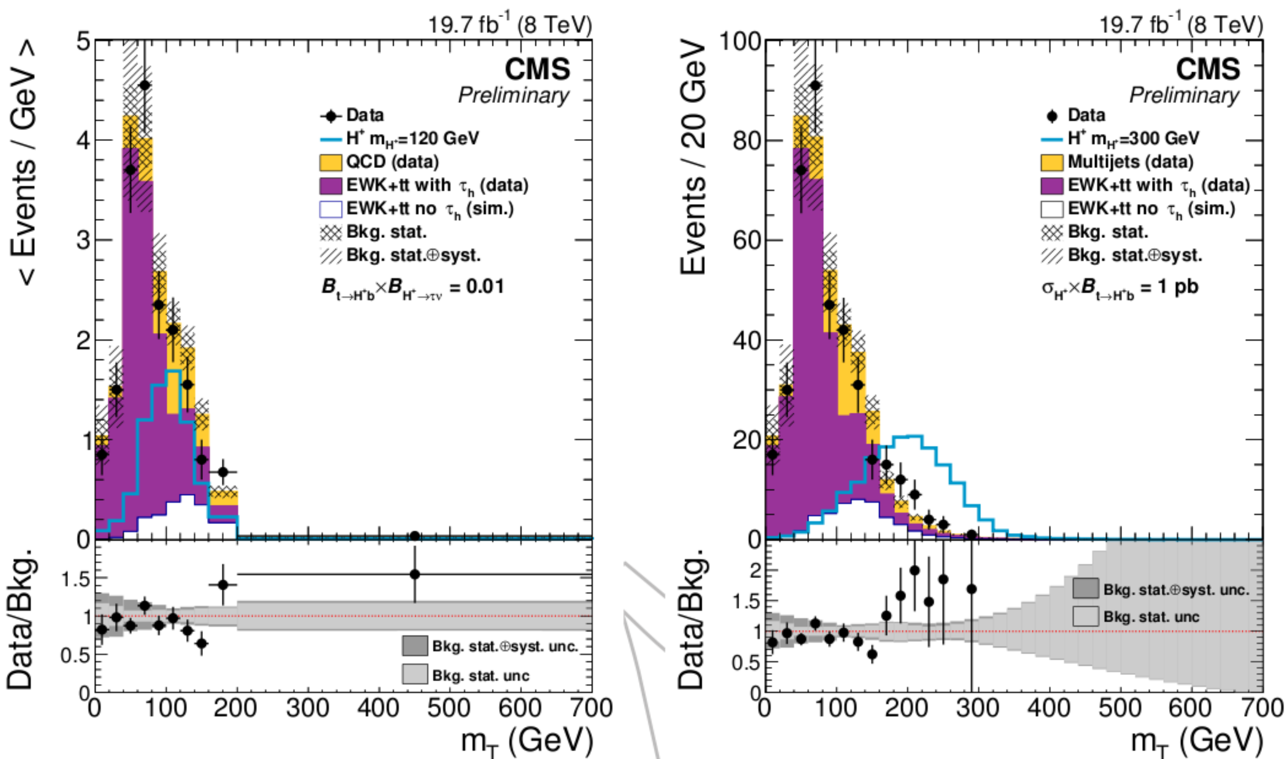


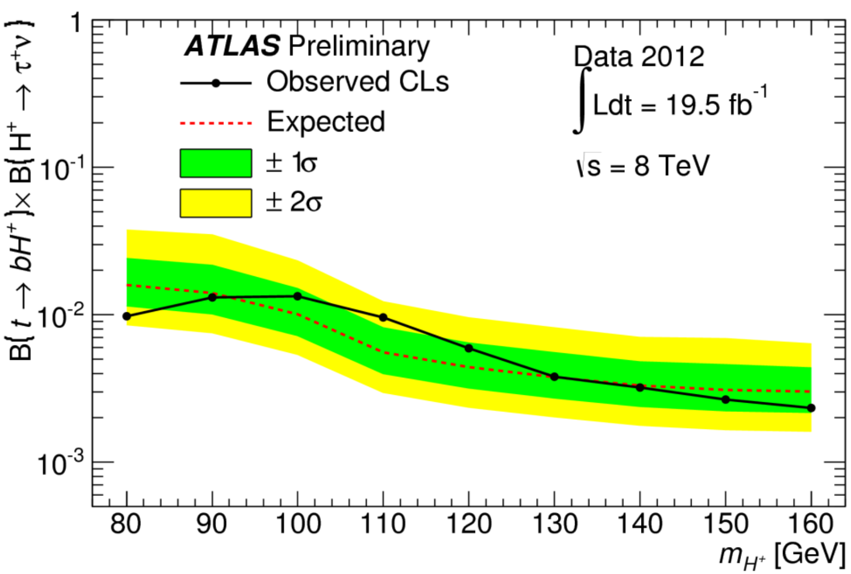


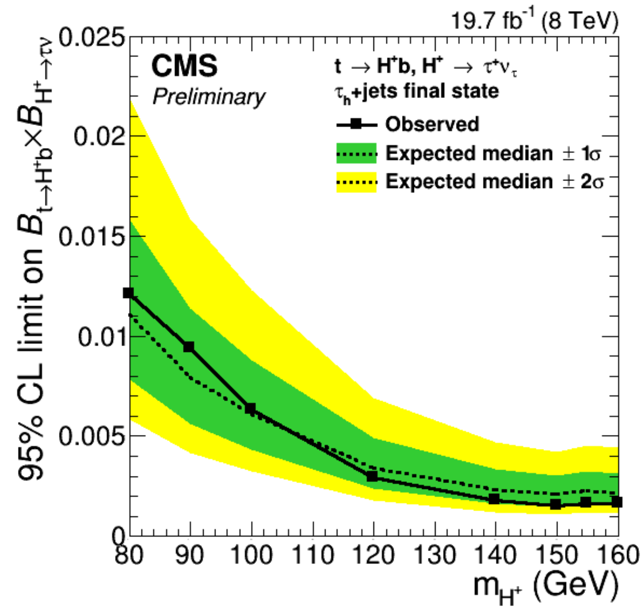
τ_h+jets is the most sensitive topology

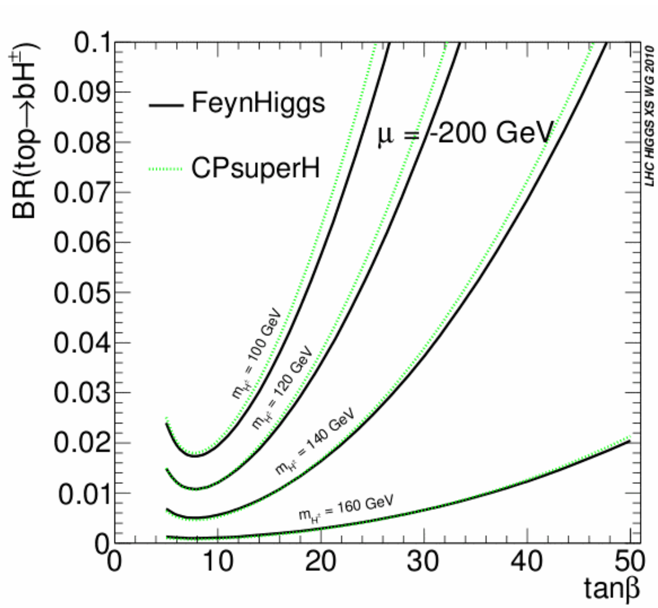
- $\tau_h+E_T^{miss}$ (35,70) trigger at HLT; seeded by L1 E_T^{miss} > 40 GeV
- at least 3 jets p_T > 30 GeV, $|\eta|<2.4$, at least one b-tagged jet
- one τ_h with p_T > 41 GeV, $|\eta|<2.1$, $R_\tau=p_T^{\pi}/p_T^{\tau h} > 0.7$
- Lepton veto
- E_T^{miss} > 60 GeV, cuts on $\Delta\phi(\tau_h,E_T^{miss})$, $\Delta\phi(\text{jet},E_T^{miss})$
- W+tt~ with real τ's from embedding, multijet bkg from data

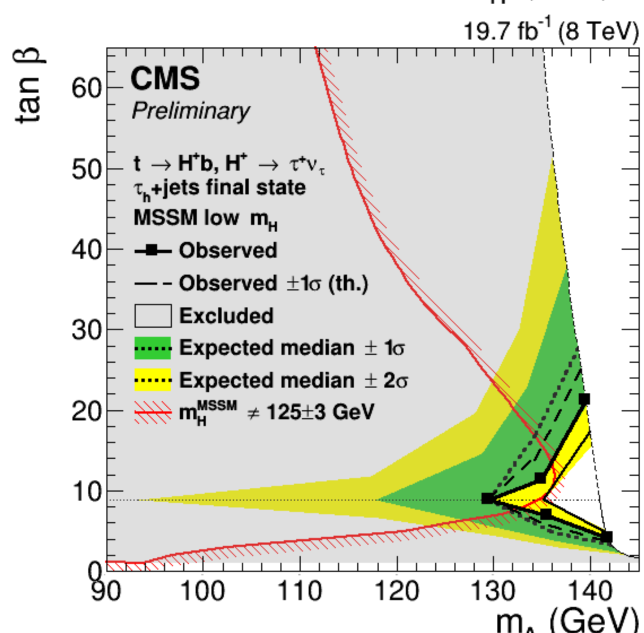


H+->τν: "model independent" limits

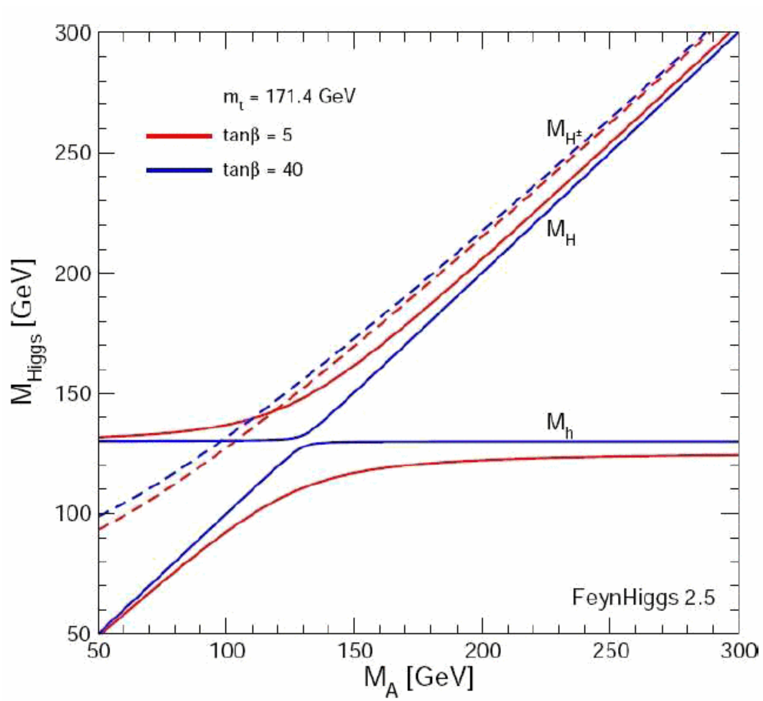


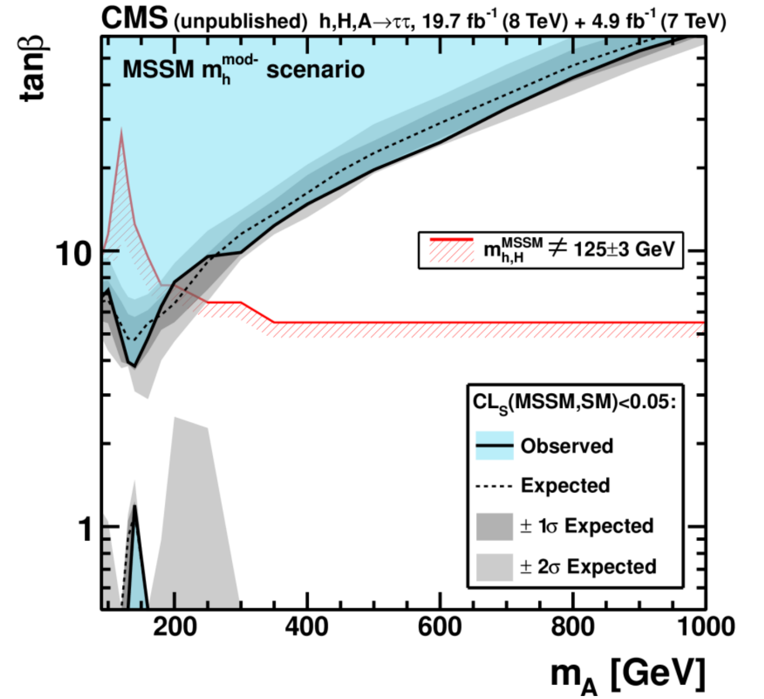


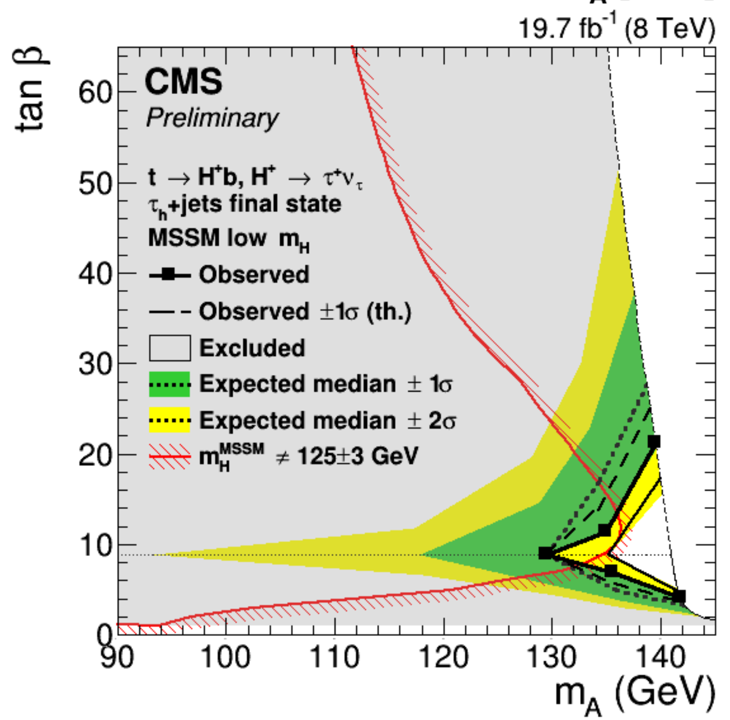




What Higgs boson is discovered in MSSM, h or H ?





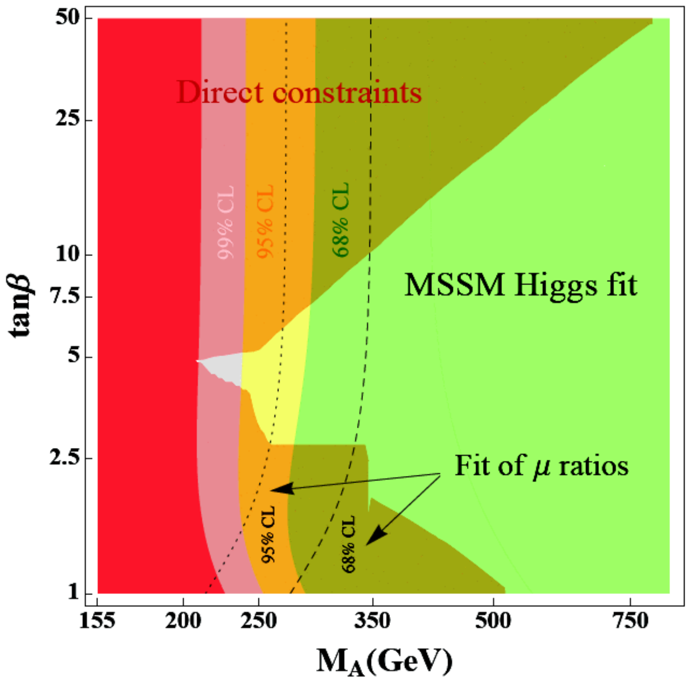


It is the little Higgs boson, h !

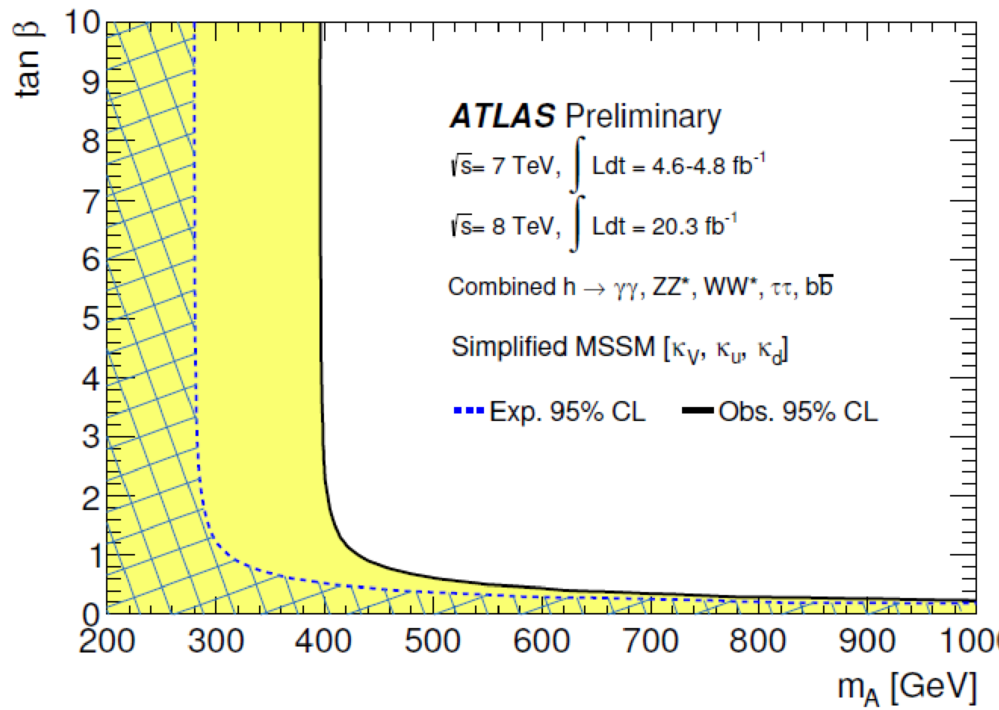
Interpretation of h measurements in hMSSM (A. Djouadi et.al. arXiv:1307.5205)

- Plots below are valid under conditions
  - small Δ_b (SUSY QCD) corrections – decoupling regime
  - heavy stops – no stop (and sbottom) in the gg->h loop
  - no charginos, staus in h->$\gamma\gamma$
  - no invisible decays

A. Djouadi et.al. arXiv:1307.5205



ATLAS-CONF-2014-010



$$\mathcal{L}_h = c_V\, g_{hWW}\, h\, W^+_\mu W^{-\mu} + c_V\, g_{hZZ}\, h\, Z^0_\mu Z^{0\mu} - c_t\, y_t\, h\bar{t}_L t_R - c_t\, y_c\, h\bar{c}_L c_R - c_b\, y_b\, h\bar{b}_L b_R - c_b\, y_\tau\, h\bar{\tau}_L \tau_R + \text{h.c.}$$

$$c_V^0 = \sin(\beta-\alpha)\,, \quad c_t^0 = \frac{\cos\alpha}{\sin\beta}\,, \quad c_b^0 = -\frac{\sin\alpha}{\cos\beta}$$

Searches for non SM h(125) decays

- h->XX, X = Higgs boson in NMSSM or 2HDM+S
- h->DM (invisible) MSSM, NMSSM, Higgs-portal DM
- LFV h->$\mu\tau$

NMSSM and
Higgs bosons in NMSSM

- **Enlarged (pseudo-)scalar and neutralino sector:** 2 complex doublets $\hat{H}_u, \hat{H}_d$, 1 complex singlet $\hat{S}$

7 bosons:	$H_1, H_2, H_3, A_1, A_2, H^+, H^-$
5 neutralinos:	$\tilde{\chi}_i^0$ $(i = 1, ..., 5)$

- **Significant changes of the phenomenology**

Resent NMSSM scans of LHC h(125):

S.F. King, M. Muehlleitner, R. Nevzorov, K. Walz
arXiv:1211.5074, accepted by Nucl. Phys. B,
"Natural NMSSM Higgs Bosons"

S.F. King, M. Muehlleitner, R. Nevzorov
Nucl. Phs. B860 (2012) [arXiv:1201.2671[hep-ph]]
"NMSSM Higgs Benchmarks Near 125 GeV"

Next-to Minimal Supersymmetric Standard Model

Field content:

NMSSM superfields = MSSM superfields + Higgs superfield singlet $\hat{S}$

Superpotential:

$$W_{\mathrm{NMSSM}} = W_{\mathrm{MSSM}}|_{\mu=0} - \lambda\, \hat{S}\, \hat{H}_d^1\, \hat{H}_u^2 + \lambda\, \hat{S}\, \hat{H}_d^2\, \hat{H}_u^1 + \frac{1}{3}\, \kappa\, \hat{S}^3$$

2 new coupling parameters: λ, κ ($\hat{H}_d$, $\hat{H}_u$: Higgs doublet superfields)

μ **term of the MSSM:** $W_{MSSM} = \ldots \mu \hat{H}_d^1\, \hat{H}_u^2 + \ldots$

$\rightarrow$ dynamically generated in the NMSSM **$\mu=\lambda\langle S\rangle$**

(scalar Higgs singlet field has a vacuum expectation value v_S)

Soft-breaking part extended: New parameters: m_S^2, A_λ, A_κ

- **solve "μ-problem" of MSSM (Kim, Nilles 1984)**
  - **μ term gives mass to the MSSM Higgs doublets of order μ**
    - **Naturally it should be order of SUSY breaking scale ~ Plank scale**
    - **But it needs to be on the weak scale**

$\mathcal{NMSSM}$ $\mathcal{S}$calar $\mathcal{B}$oson $\mathcal{M}$ass in $\mathcal{V}$iew of the $\mathcal{LHC}$ $\mathcal{R}$esults

- **Vast literature on NMSSM scalar boson of ~ 125-126 GeV**

  Hall eal; Ellwanger; Gunion eal; King,MMM,Nevzorov; Albornoz Vasquez eal; Cao eal; Gabrielli eal; Ellwanger, Hugonie; Kang eal; Cheung eal; Jeong eal; Hardy eal; Kim eal; Arvanitaki eal; ...

- **Compatibility of NMSSM scalar boson mass with LHC Searches:**

  $\star$ Upper mass bounds + corrections to the MSSM, NMSSM scalar boson mass:

  MSSM: $m_h^2 \approx M_Z^2 \cos^2 2\beta + \Delta m_h^2$

  NMSSM: $m_h^2 \approx M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \Delta m_h^2$

  $\Rightarrow M_H \approx 126$ requires:

  MSSM: $\Delta m_h \approx 85$ GeV ($\tan\beta$ large) $\Rightarrow$ large corrections are needed $\rightsquigarrow$ conflict with fine-tuning

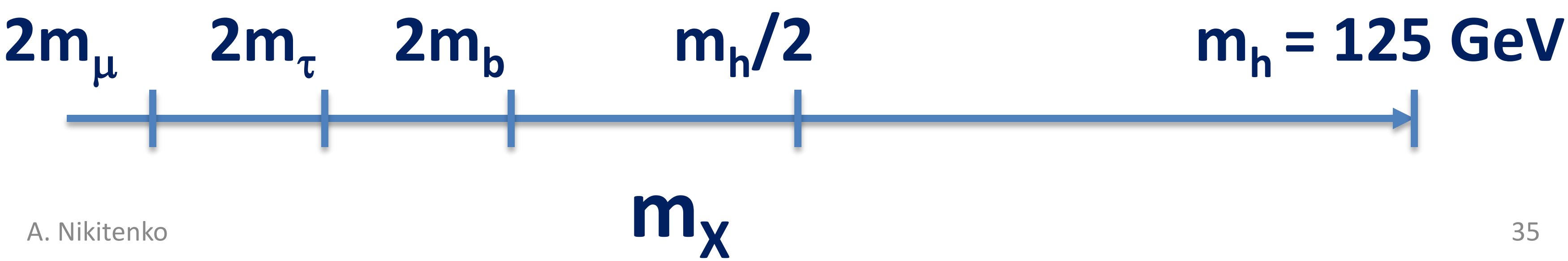
  NMSSM: $\Delta m_h \approx 55\,\text{GeV}$ $(\lambda = 0.7, \tan\beta = 2)$

  $\Rightarrow$ NMSSM requires less fine-tuning

  Hall,Pinner,Ruderman; Ellwanger; Arvanitaki,Villadoro; King,MMM,Nevzorov; Kang,Li,Li; Cao,Heng,Yang,Zhang,Zhu

Grand picture of the present CMS h(125)->XX analyses (NMSSM or 2HDM+S)

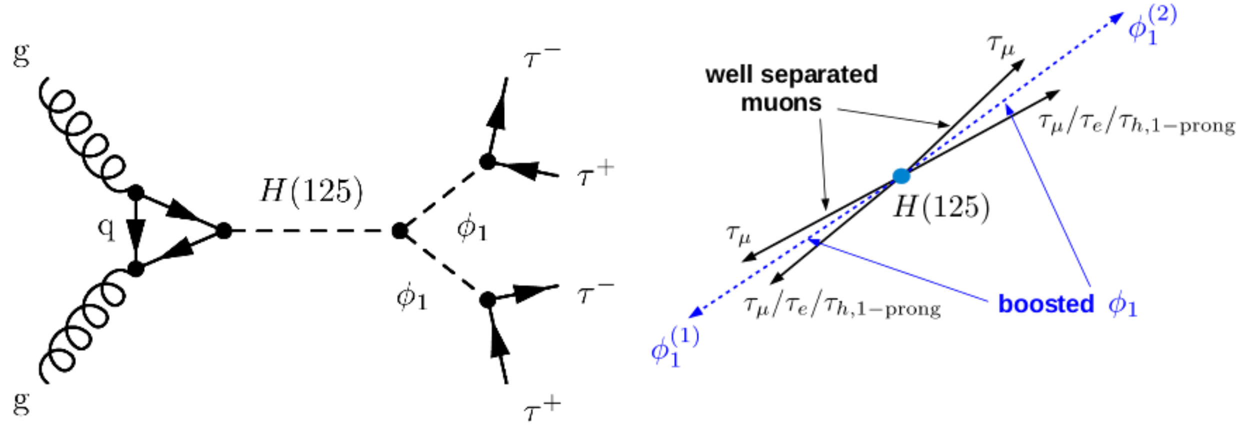
- $2m_\mu < m_X < 2m_\tau$
  - h->XX->4μ done in 2012
- $2m_\tau < m_X < 2m_b$
  - h->XX->$\tau_\mu\tau_h\tau_\mu\tau_h$ approved in Dec.2014 !
- $2m_b < m_X <$ 125/2 GeV
  - h->XX->$\mu\mu bb$ in progress



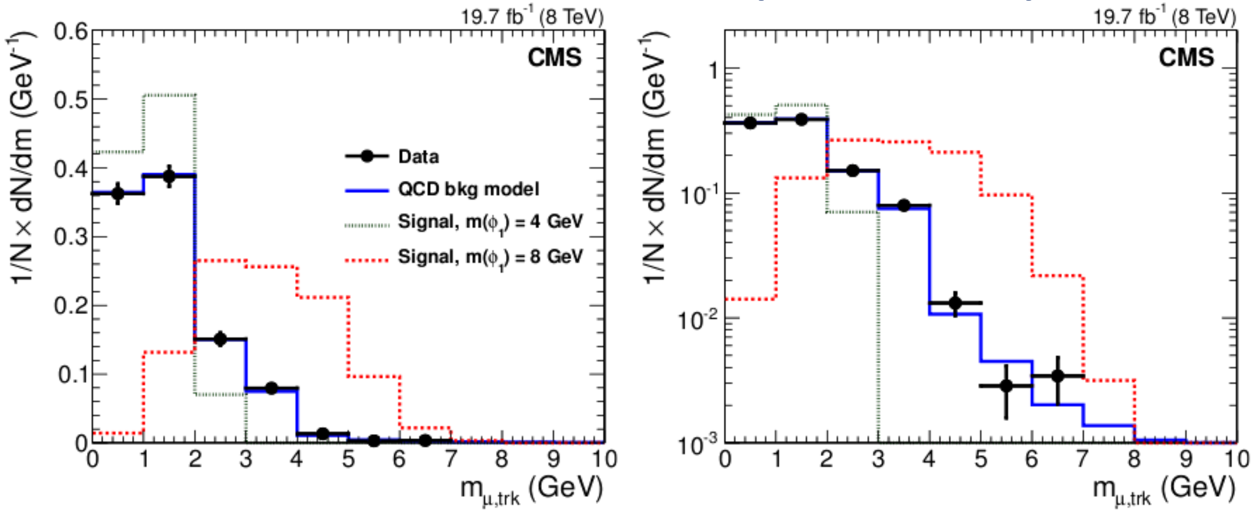
h(125)->XX->ττττ analysis; $2m_\tau < m_X < 2m_b$

- **Collaboration of DESY, RAL+NExT (Soton), UCR and IC**

Topology:

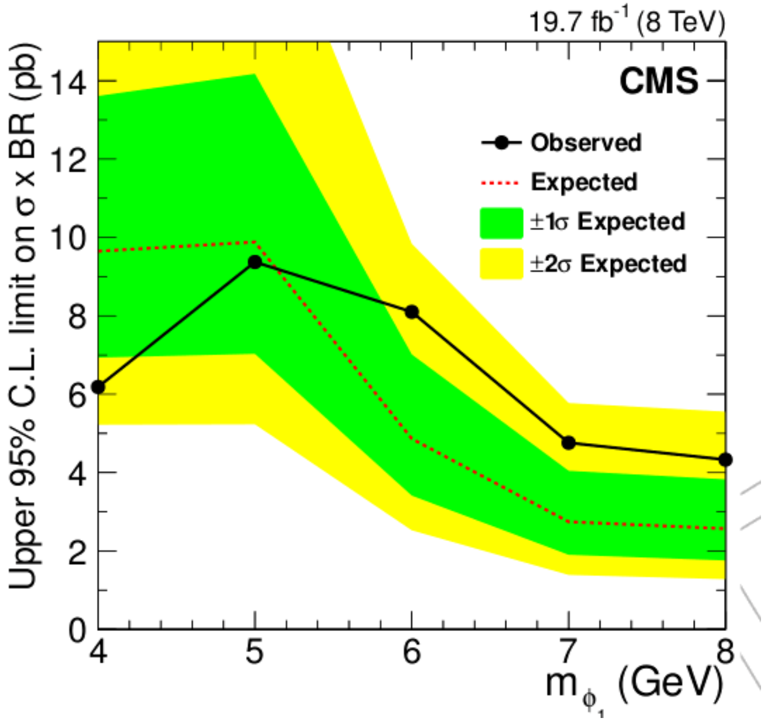


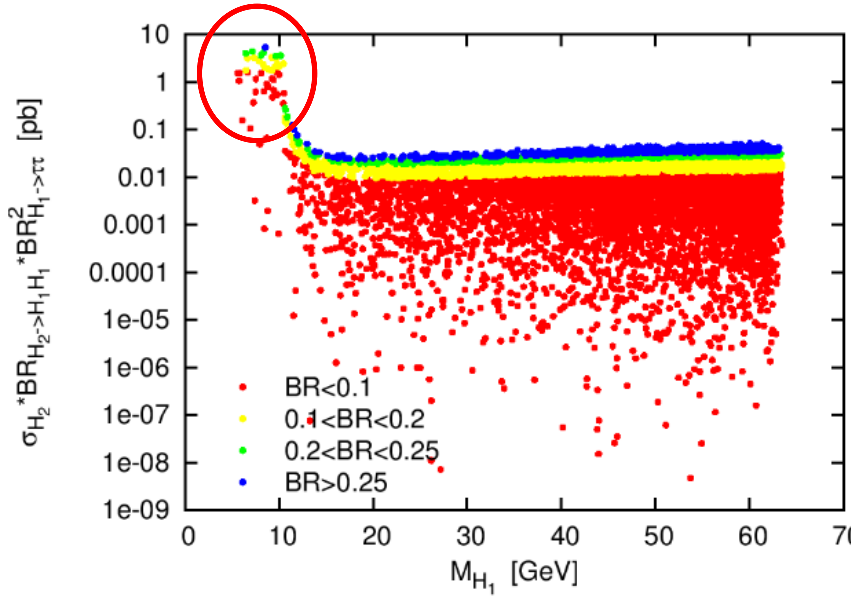
Signal is extracted from 2D of di-mass(muon-track) distributions



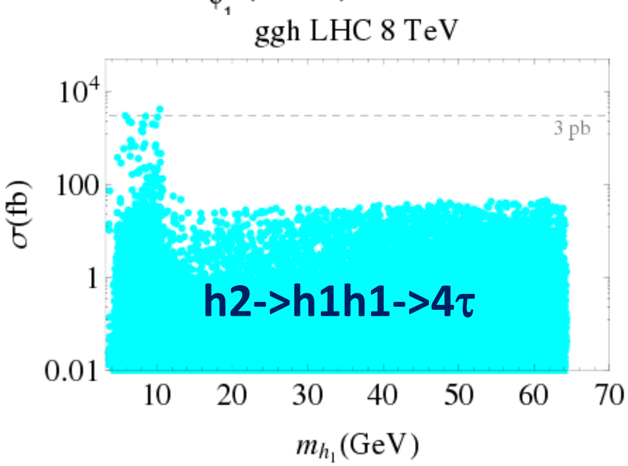
Result: *limits are already sensitive to NMSSM !*

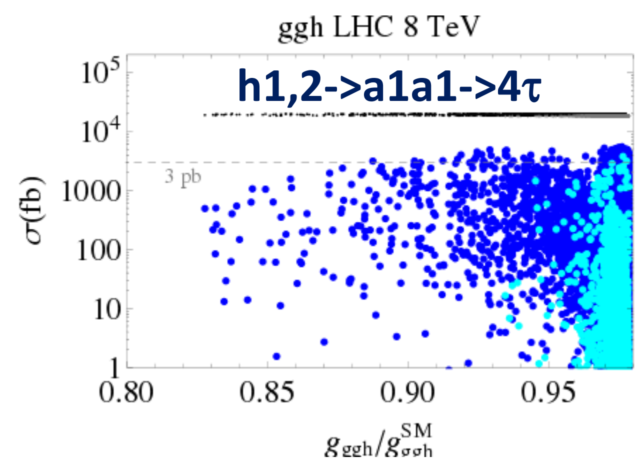
King at al. arXiv:1211.5074[hep-ph]
h2->h1h1->4t





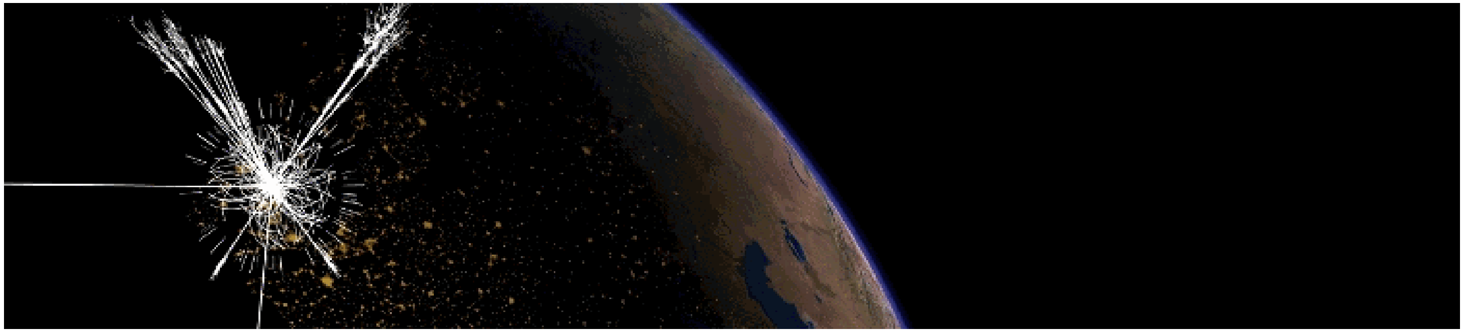
NMSSM scans by Daniele Barducci





Non-SM h decays:

searches for $h \rightarrow$invisible with VBF h, Zh (Z->ℓℓ,bb)



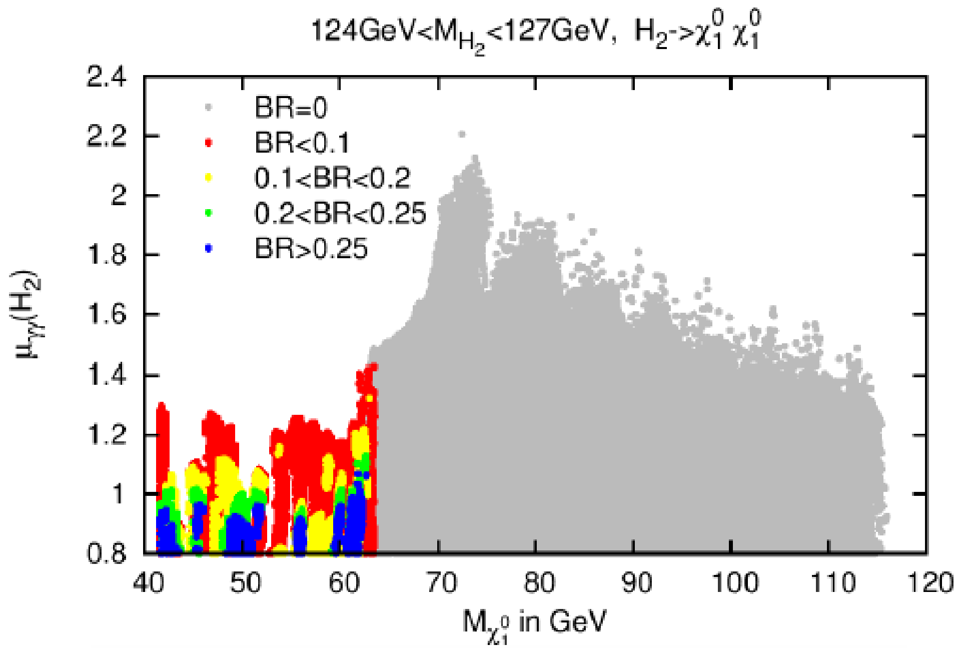
Detection of Dark Matter

H->invisible BR in (N)MSSM

- **NMSSM H_2 (125)>$\chi^0\chi^0$**

  S. King et al., arXiv:1211.5074

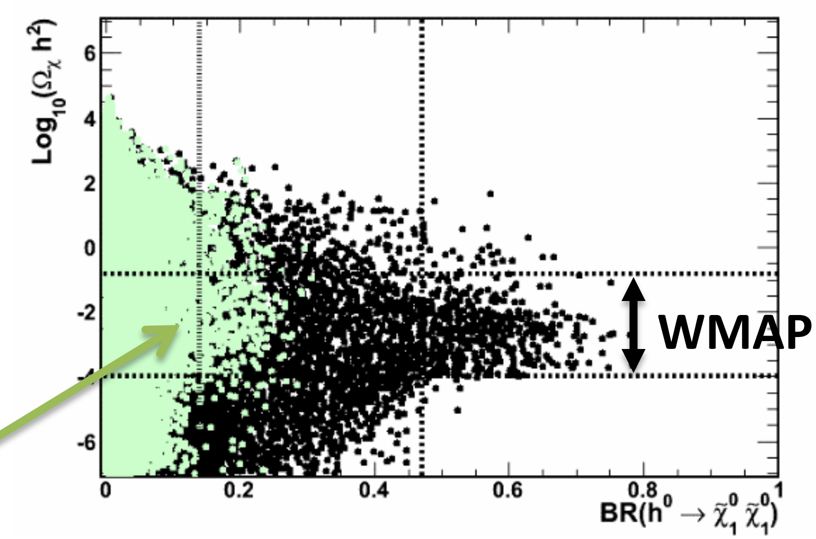
  BR ~ 10-20 %



- **pMSSM h->$\chi^0\chi^0$**

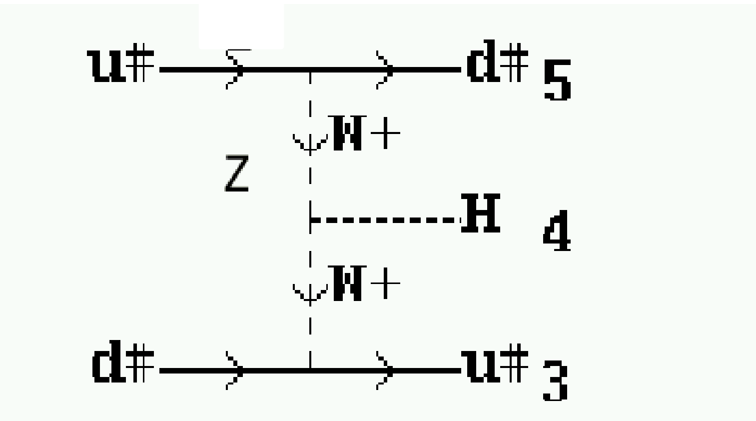
  A. Arbey et al., arXiv:1211.4004

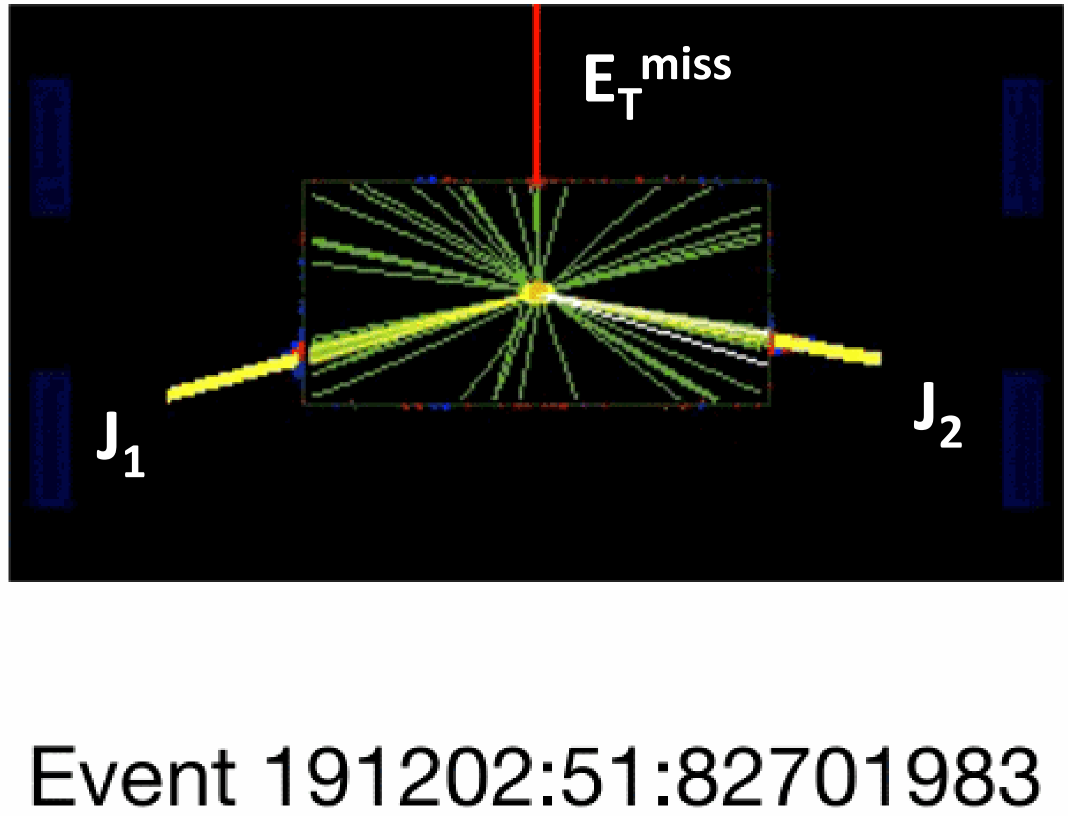
  BR < 25 %



Compatible with LHC Higgs data
(green color)

most sensitive mode qq’→qq’h (VBF h)

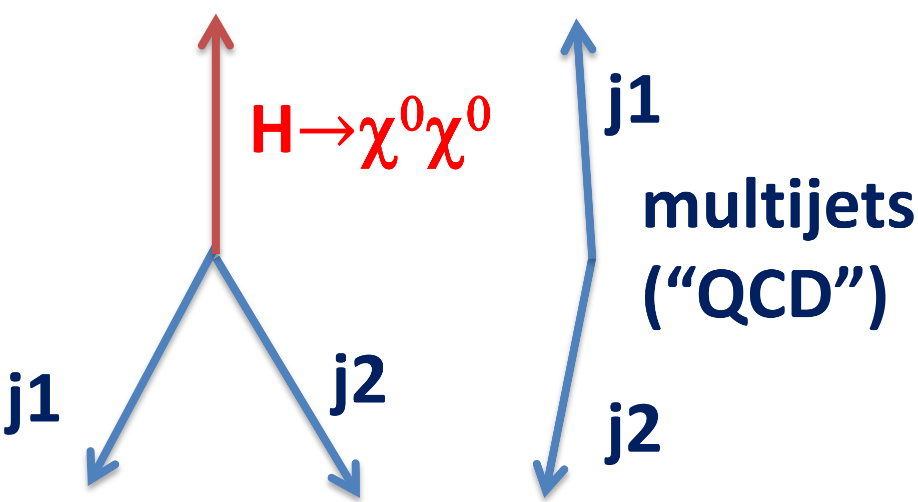


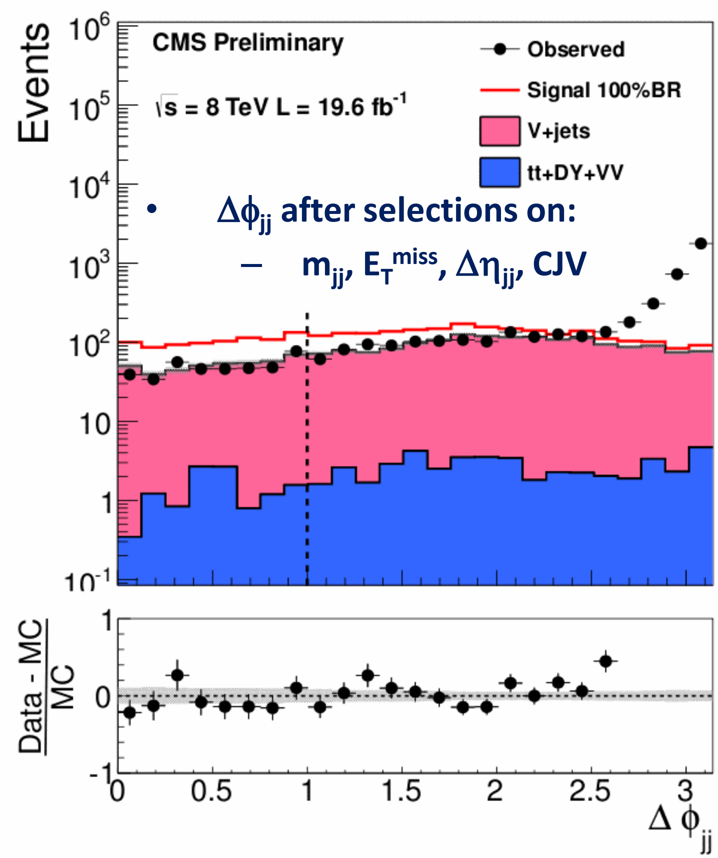


VBF $h \to$ invisible: offline signal selections and topology

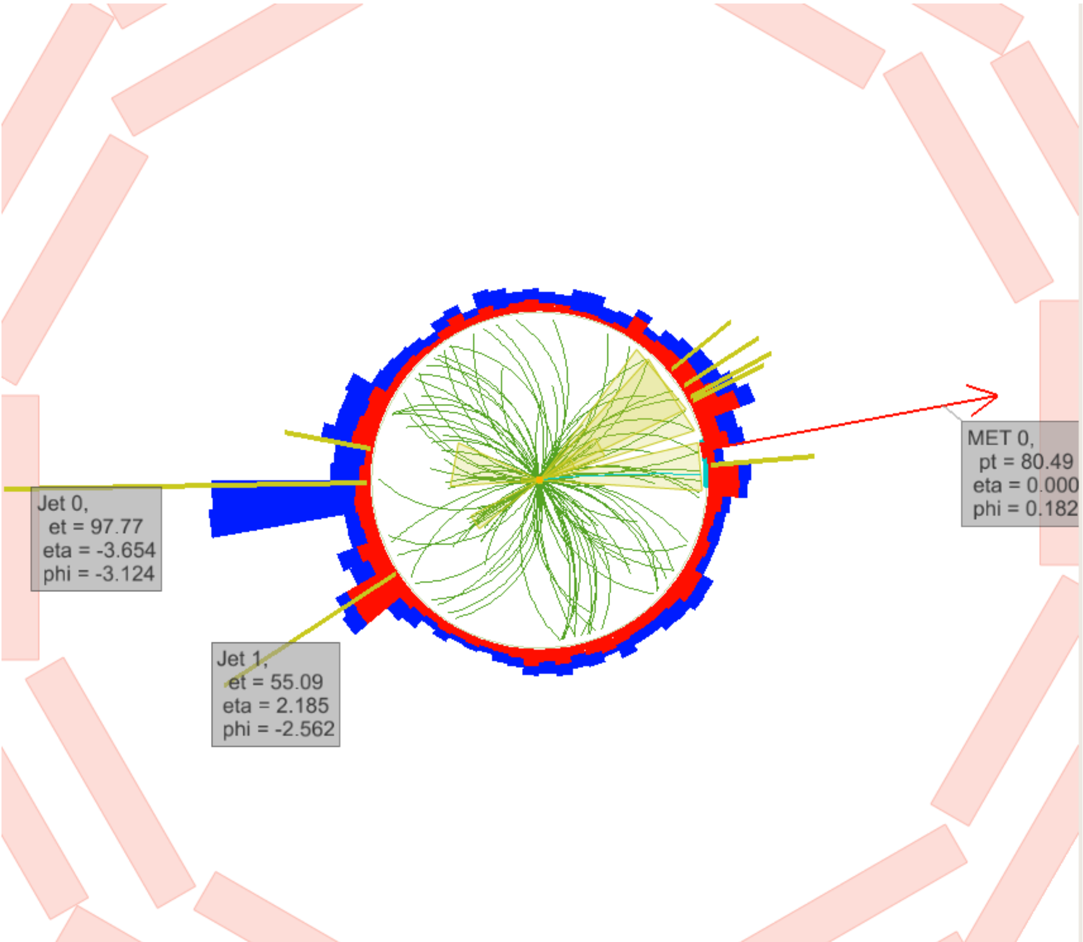
- two jets $p_T > 50$ GeV, $|\eta| < 4.7$
- $m_{jj} > 1100$ GeV
- $\Delta\eta_{jj} > 4.2$
- $E_T^{miss} > 130$ GeV
- $\Delta\phi_{jj} < 1.0$
- Central Jet Veto (CJV)

Signal: small $\Delta\phi_{jj}$
QCD: large $\Delta\phi_{jj}$





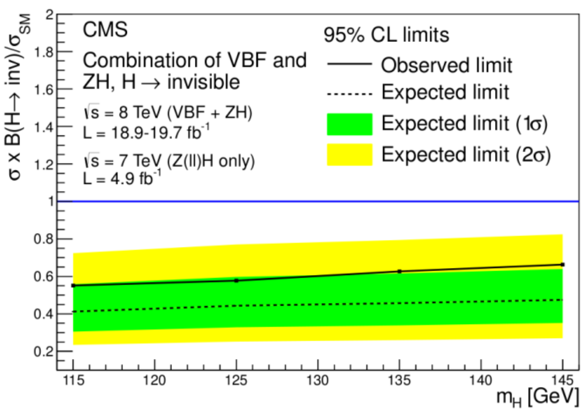
Signal region, with CJV (x,y view)



	▽pT	eta	phi
0	97.8	-3.654	-3.124
1	55.1	2.185	-2.562
2	27.0	-0.200	0.084
3	24.8	2.286	0.502
4	23.4	-2.044	2.958
5	23.0	0.359	0.575
6	21.6	-2.901	0.472
7	20.4	1.349	0.691

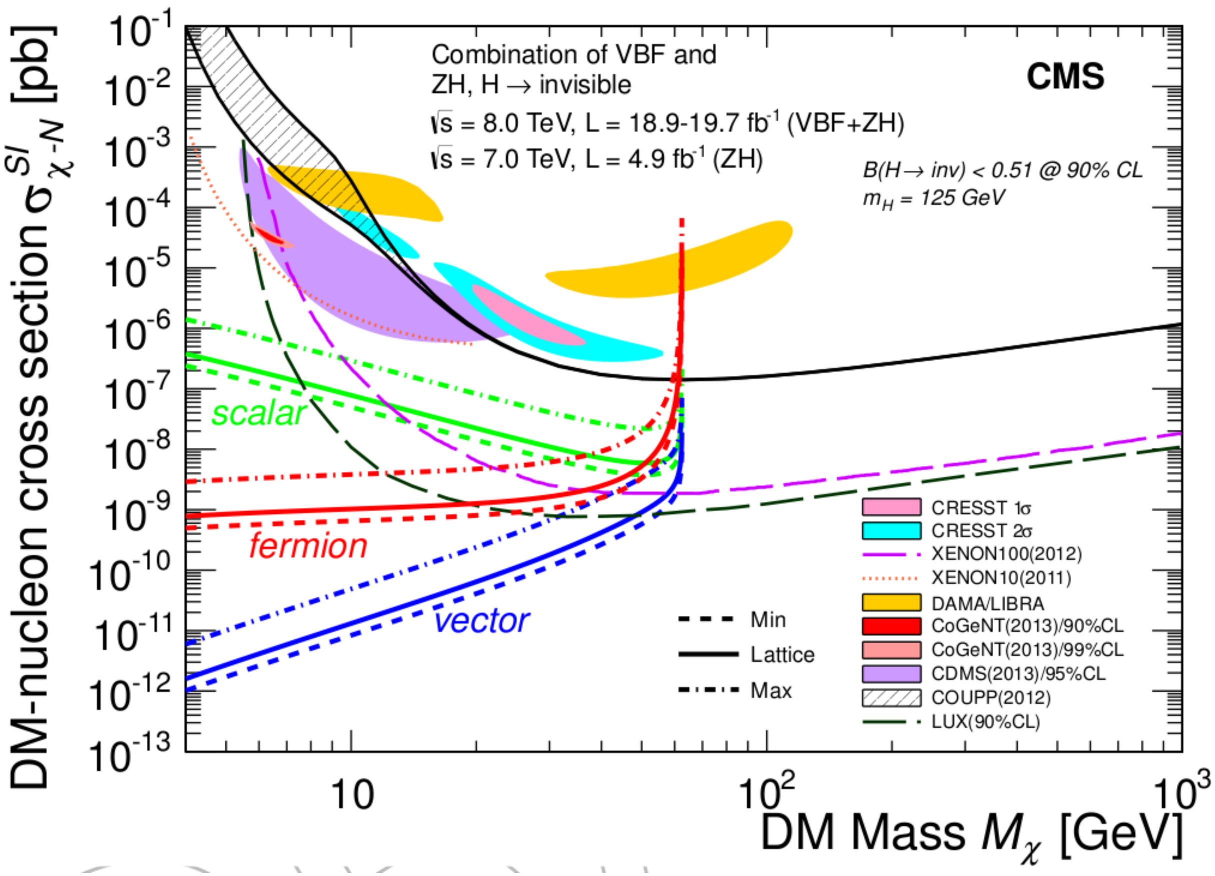
Interpretation of H->invisible direct search in Higgs-portal Dark Matter model

(as in A. Djouadi et.al arXiv:1112.3299, arXiv:1205.3169)



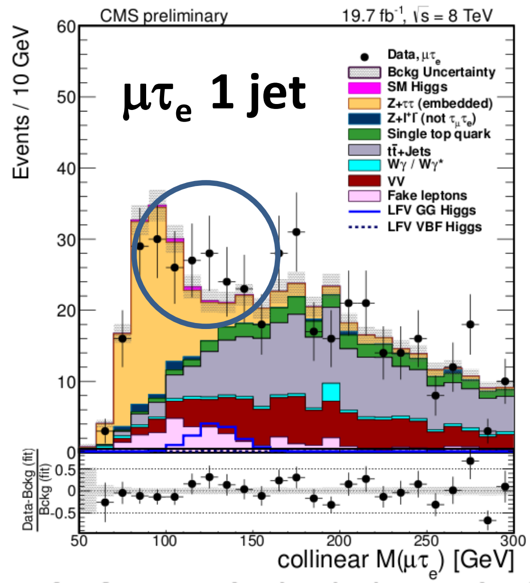
BR($h_{125\ GeV}$→inv) < 0.58 at 95 % CL (expected < 0.44)

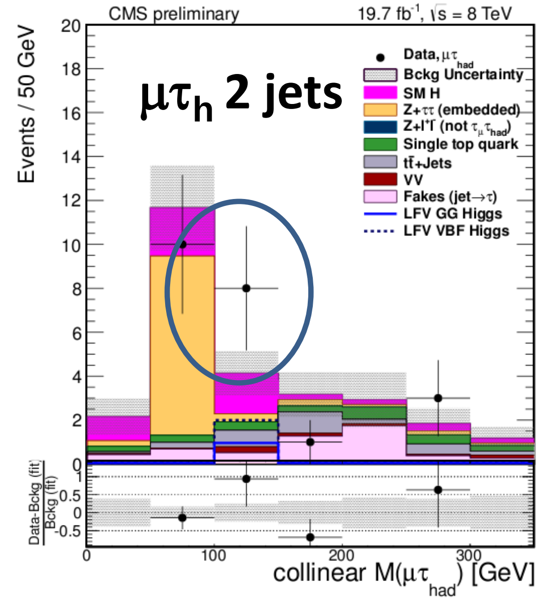
with VBF+ZH



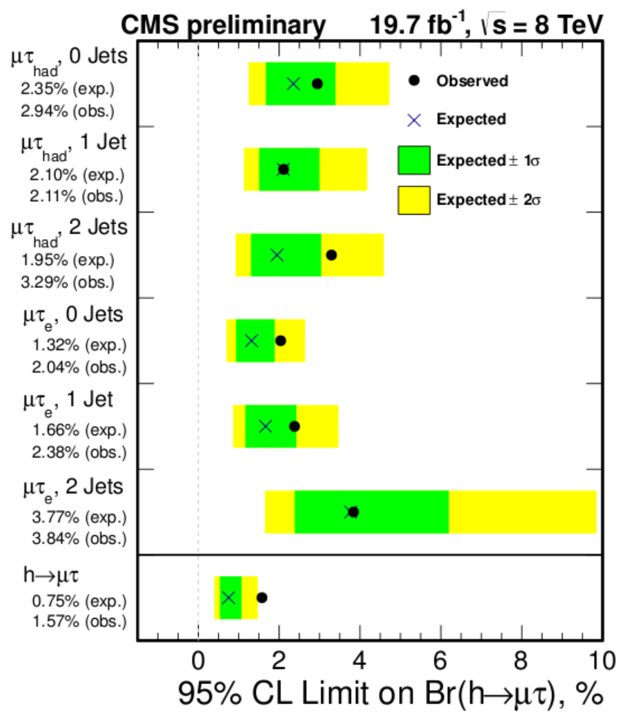
Non-SM h decays:
LFV with $h \to \mu\tau$

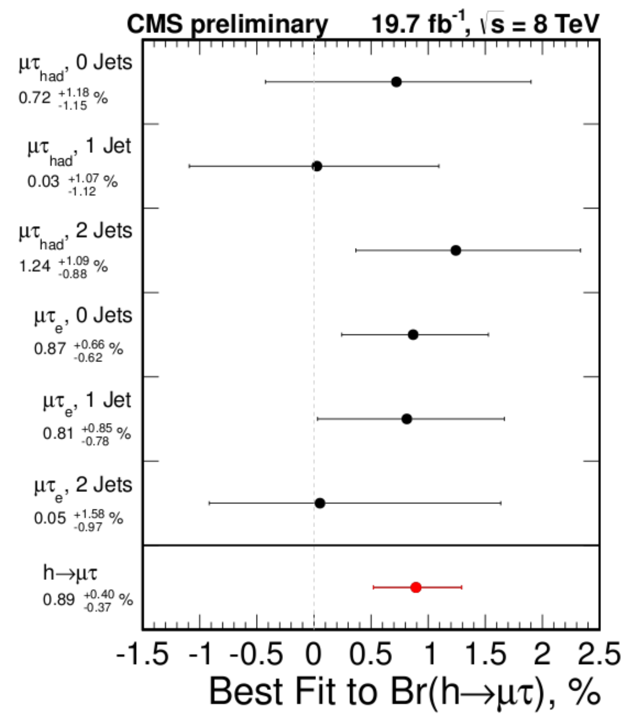
- Events are subdivided on 0, 1, 2 jet categories
- $\mu\tau_e$, $\mu\tau_h$ topologies
- m_h is reconstructed in collinear approximation





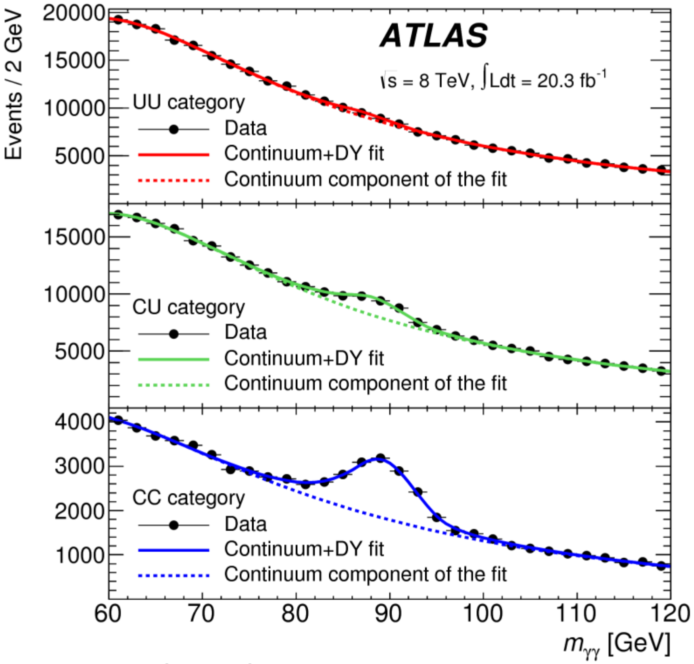
- **Upper limit:**
  - BR < 1.57 %
- **~ 2.5 σ access**



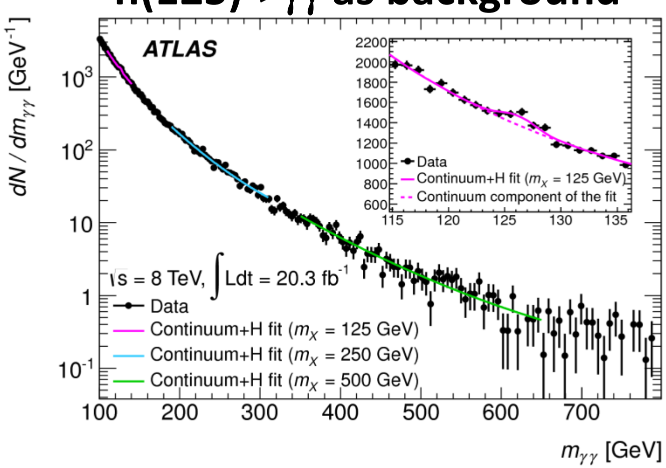


Search for scalar di-photon resonances, m_X=[65-600] GeV

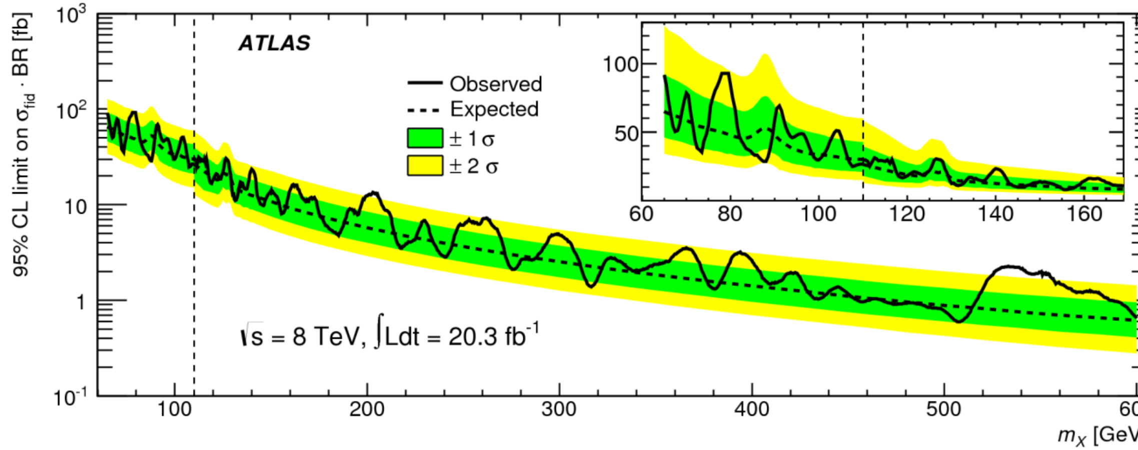
Z->ee as background



h(125)->γγ as background



Result: limit on σ x BR in fiducial volume



Is it sensitive to Higgs Singlet Extension of the SM ?

From talk of Tania Robens at SUSY 2014

What about the "inverse" scenario, ie. $m_H = 125.7\,\mathrm{GeV}$

mainly ruled out by LEP and/ or χ^2 fit from HiggsSignals
however, *still* large number produced due to large $\sigma_{gg\to h}$

m_h[GeV]	$\lvert\sin\alpha\rvert_{\text{min, exp}}$	$\lvert\sin\alpha\rvert_{\text{min, }2\sigma}$	$(\tan\beta)_{\max}$	$\#gg\ \sim$
110	0.82	0.89	9.2	10^5
100	0.86	−−	10.1	10^5
90	0.91	−−	11.2	10^5
80	0.98	−−	12.6	10^4
70	0.99	−−	14.4	10^4
60	0.98	$\gtrsim$ 0.99	16.8	10^4

$$\sigma \times BR = (1-\sin^2\alpha)\sigma_{SM} \times BR_{SM} < 12.2\ \text{fb at 100 GeV}$$

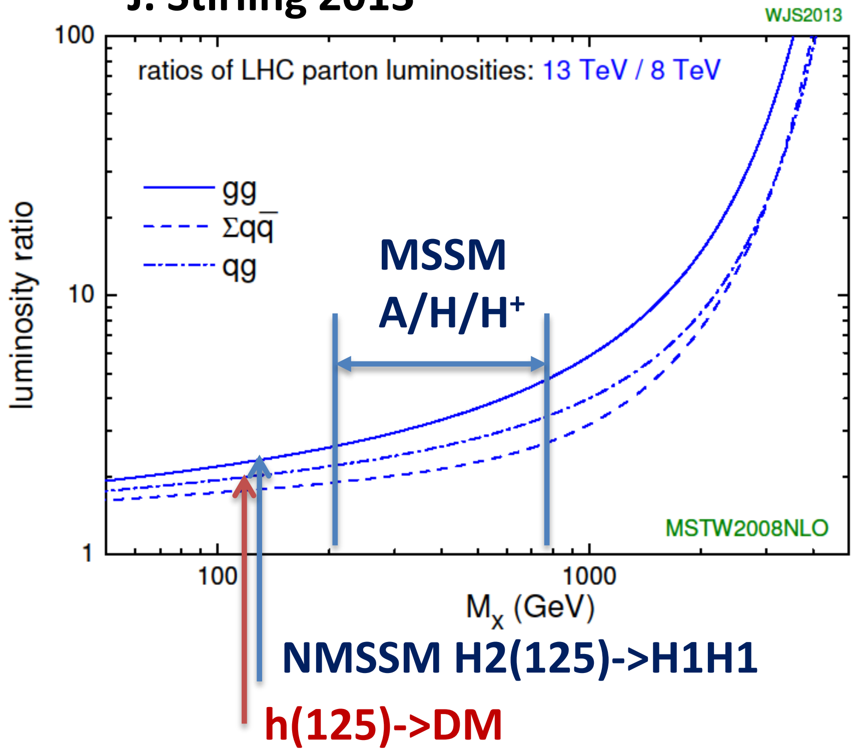
Prospects for 2015-2016

- **No immediate discovery for Higgs-Exotics channels with first 5-10 fb^{-1} in 2015 is expected so far:**

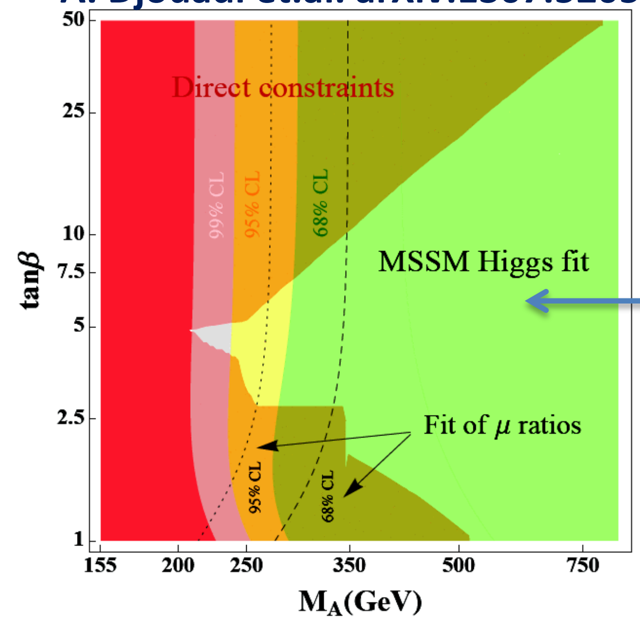
  rare processes, need luminosity

  - with ~ 5-10 fb^{-1} at 13 TeV expect to reach 8 TeV/20 fb^{-1} sensitivity of current 8 TeV analyses and start to explore a new territory

J. Stirling 2013



A. Djouadi et.al. arXiv:1307.5205

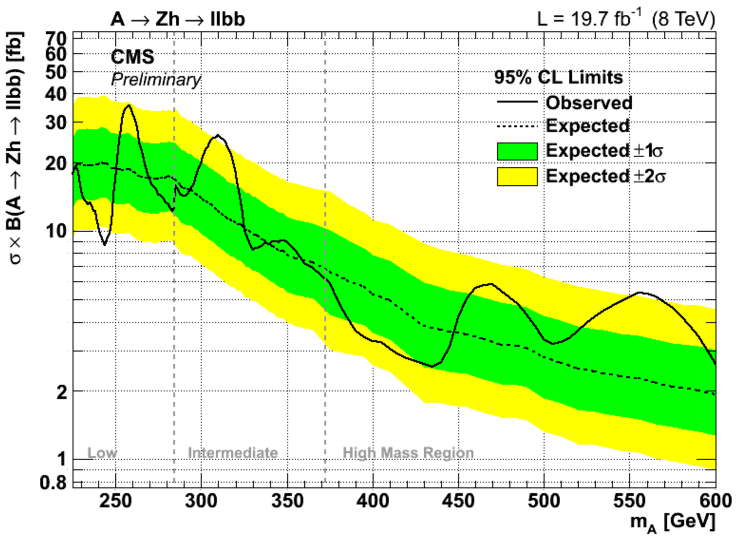


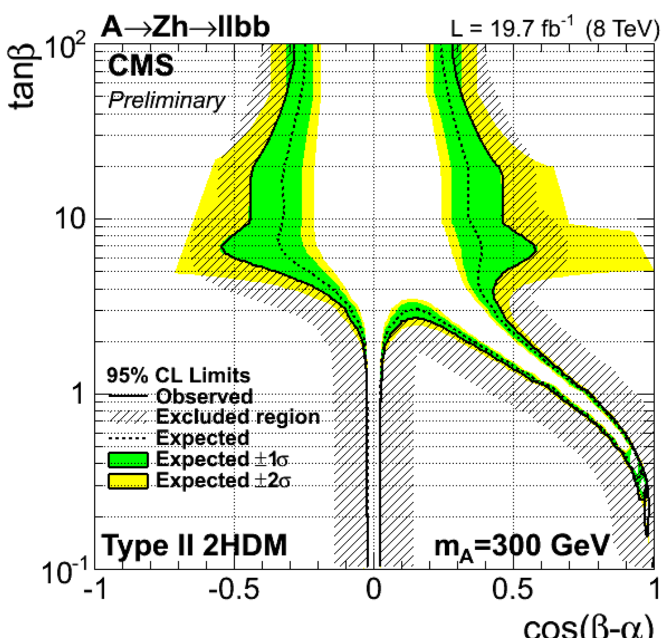
Conclusions

- Very reach physics program for BSM Higgs boson searches at LHC
- We expect to have a second discovery in the Higgs sector during LHC or HL-LHC operation

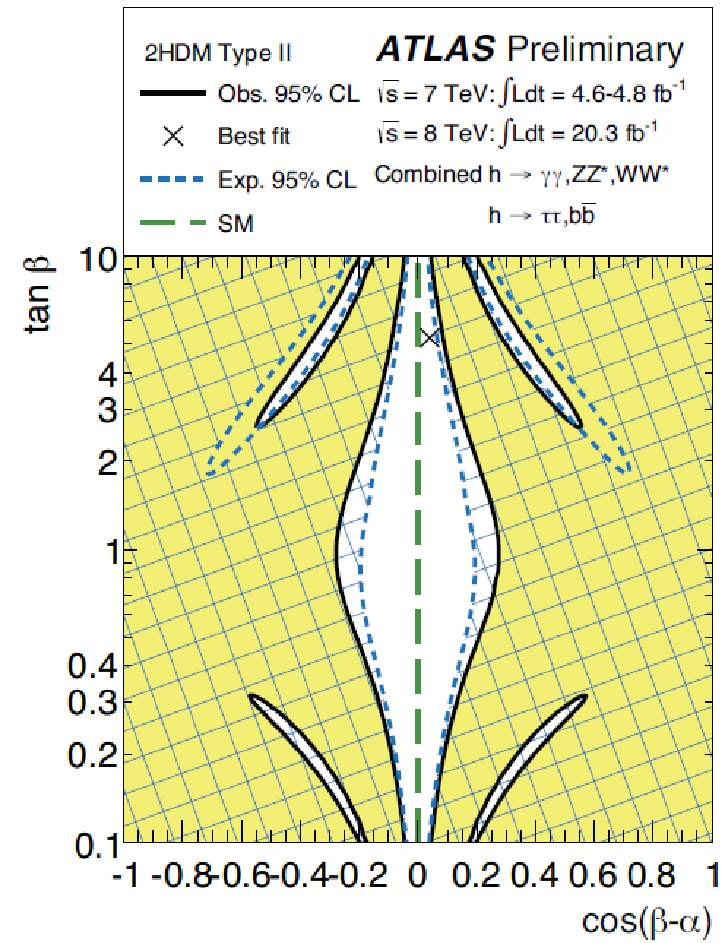
THE END

A-Zh->ℓℓbb: limits and interpretation in 2HDM



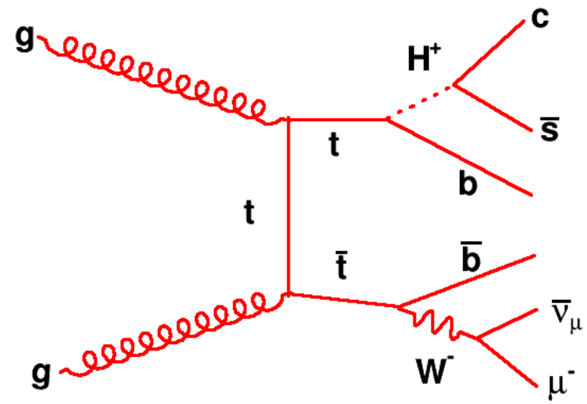


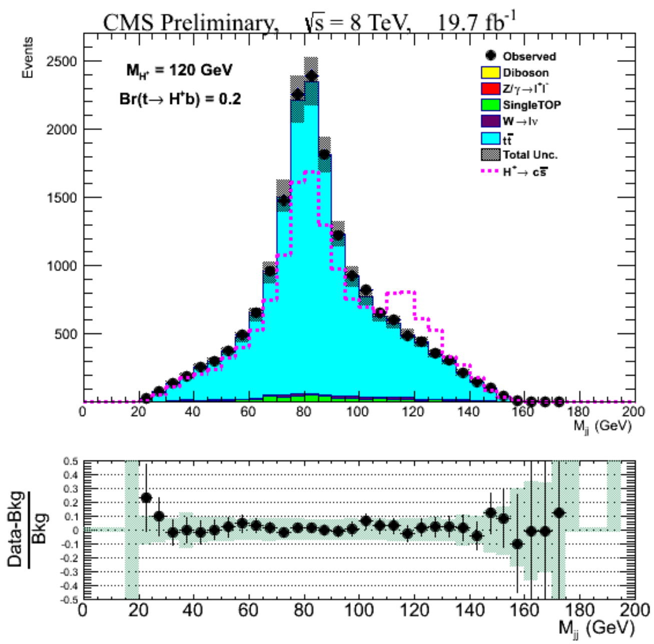
- **and from ATLAS measurement of h(125) ATLAS-CONF-2014-010**

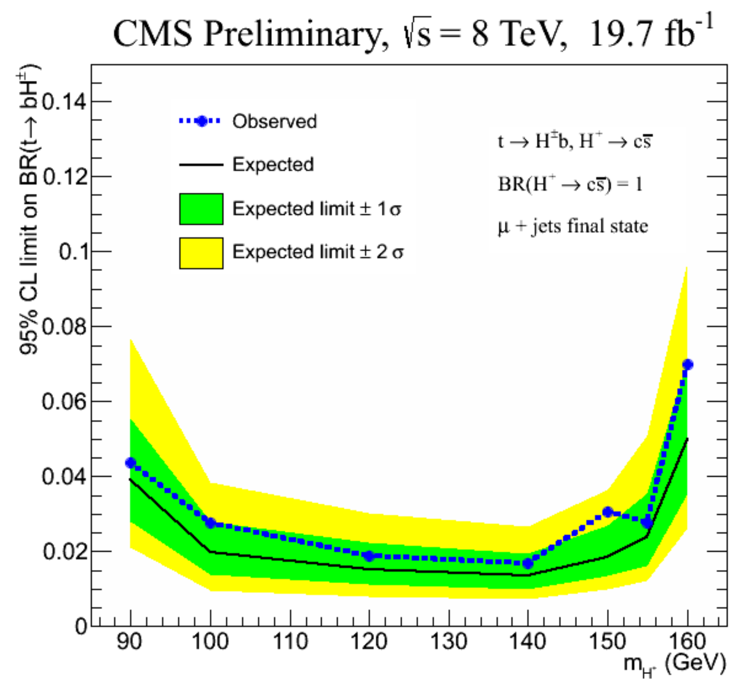


$t\bar{t} \rightarrow bWbH^+$, $H^+ \rightarrow cs$, $m_{H+} < m_t$

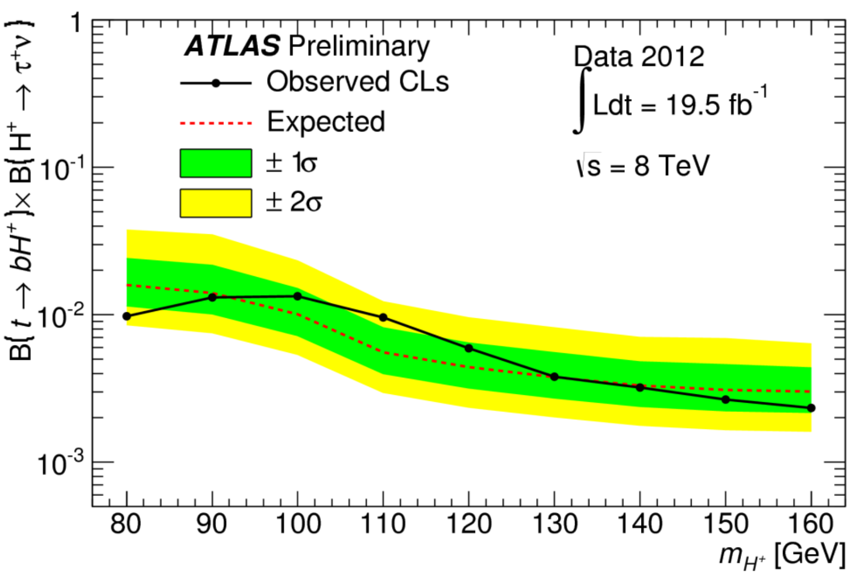
- **Search strategy:**
  - trigger with muon from t->Wb->μνb decay
  - search for bump in di-jet mass distribution for jets from 2nd top decay
  - kinematic fit with top mass constraint

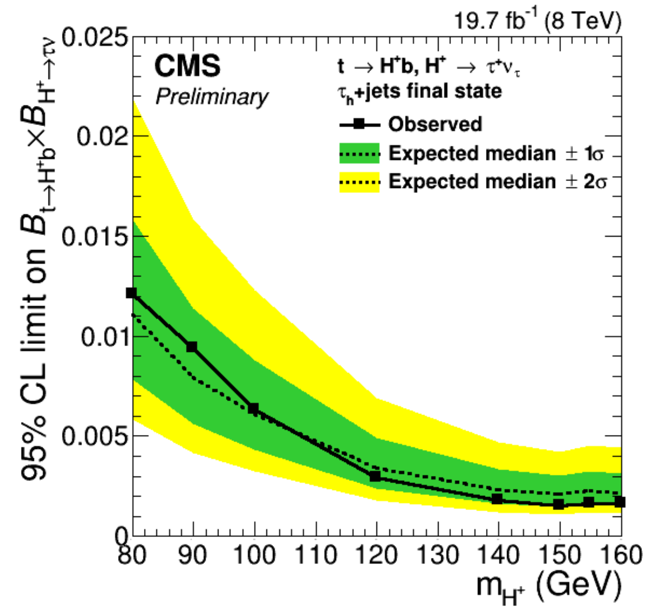


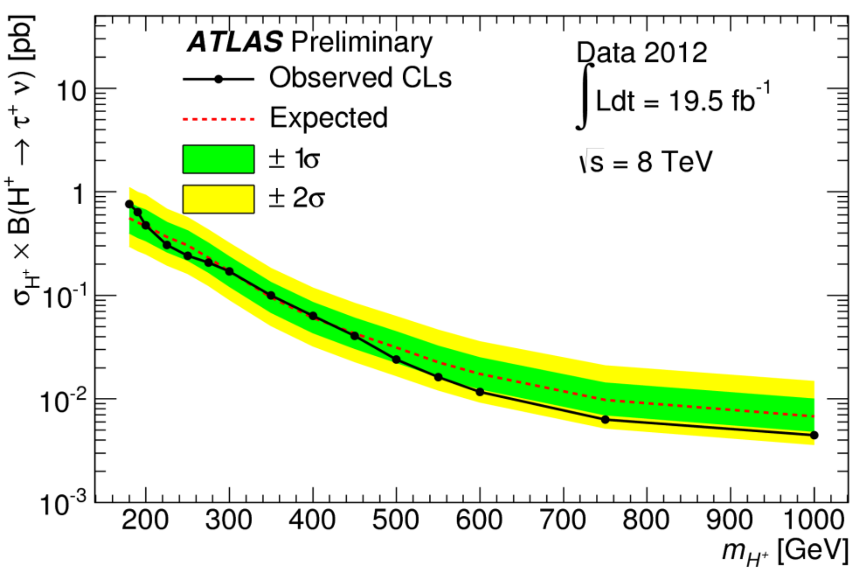


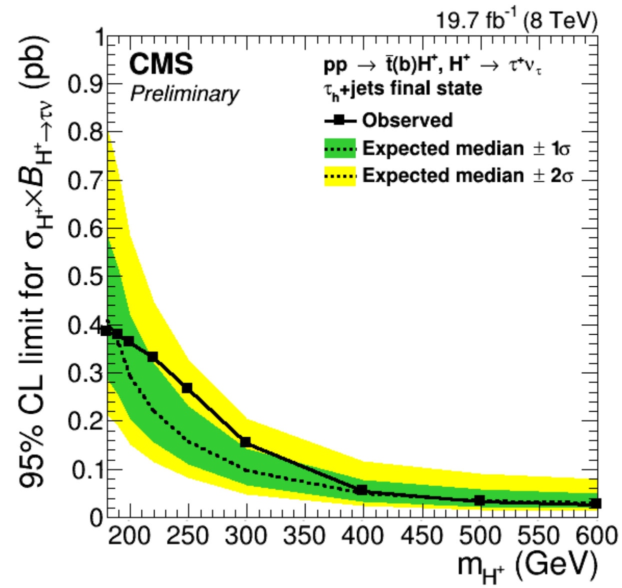


$H^+ \to \tau\nu$: "model independent" limits









$H^{+}\text{->}\tau\nu$: limits in MSSM benchmark scenarios

- m_h^{mod+} scenario from M.Carena at al. arXiv:1302.7033