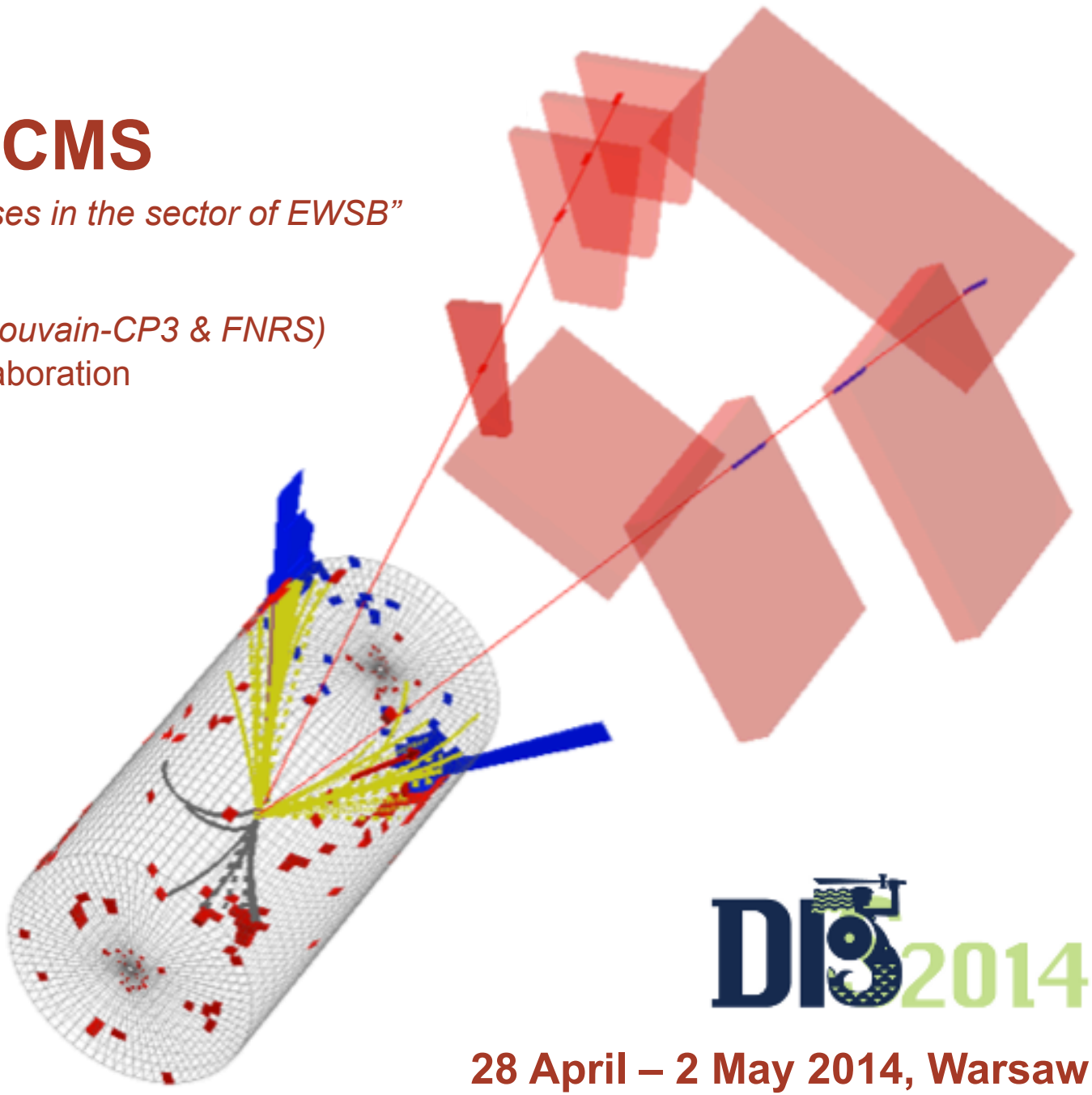
BSM Scalar Searches at CMS

"Searches for new processes in the sector of EWSB"

Tristan du Pree *(UCLouvain-CP3 & FNRS)*
on behalf of the CMS Collaboration



DIS 2014

28 April – 2 May 2014, Warsaw

Motivation

After the discovery of the 125 GeV boson…
search for BSM processes in the scalar sector

- **Precision studies of properties**
  - **Couplings**: production & decays
    - CMS-HIG-13-005, see presentation by Linda Finco
  - **Rare decays**: Zγ, γ*γ, μμ
  - **Invisible decays**: Dark Matter
- **Direct searches for extended scalar sector**
  - **Extra singlets/doublets**
    - **2HDMs**
    - **MSSM**
    - **NMSSM**

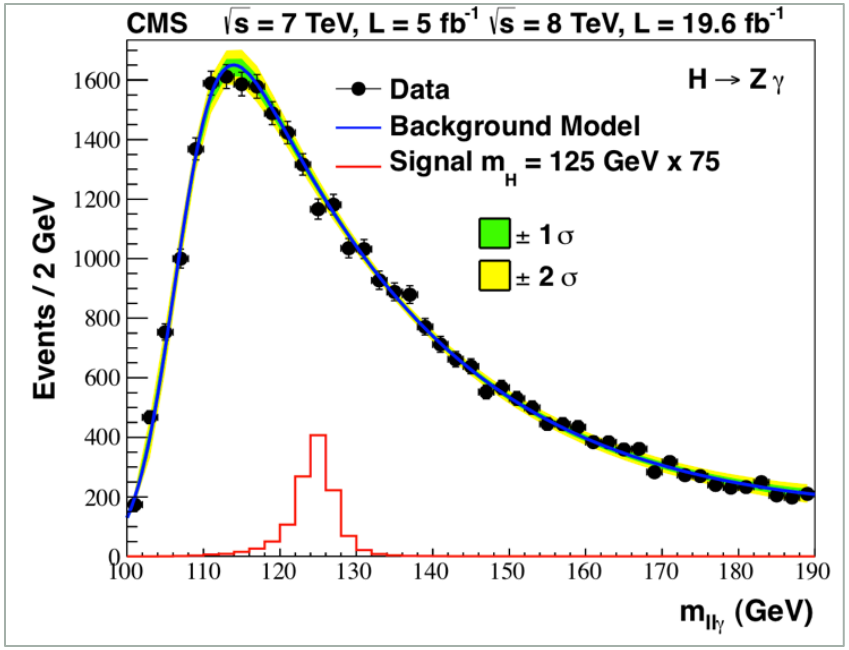
- **Interplay between direct & indirect searches**
- **Today's focus: recent results on direct searches**

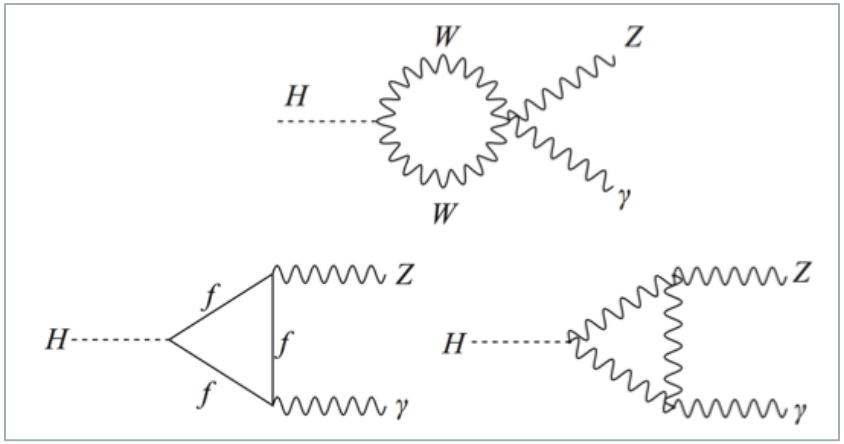
Phys.Lett.B726(2013)587

H→Zγ

Rare decay

- Small BR in SM: 0.1%
- Loops: sensitive to undiscovered processes
  - E.g. composite Higgs





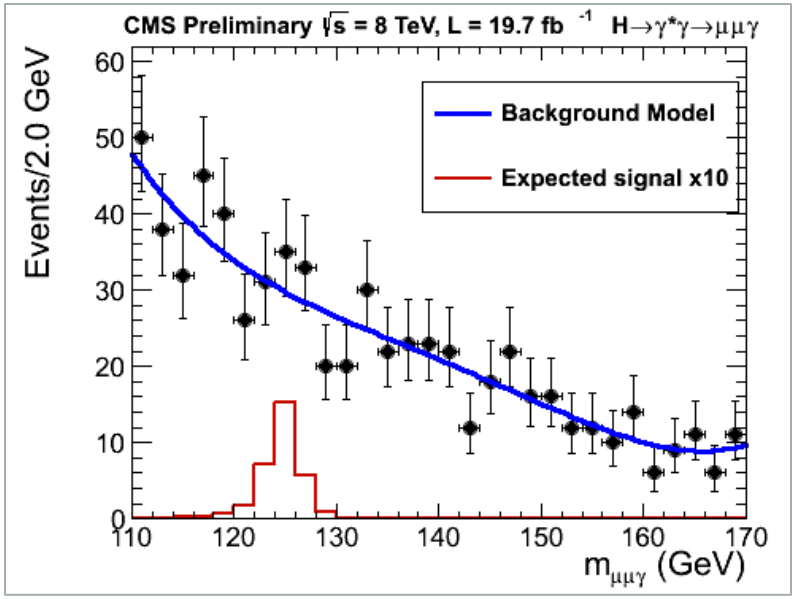
7+8 TeV (24.6 fb^{-1})

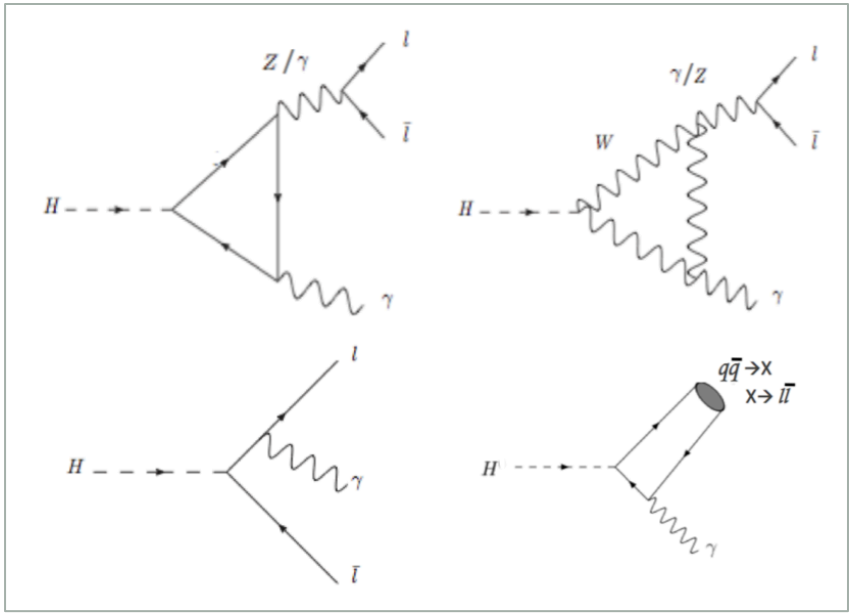
- Search in Z(ee)+γ and Z(μμ)+γ final states
  - 5 event cat's (jets, leptons, photon)
  - Use invariant mass $\mathbf{m_{llγ}}$
- Exclusion limit at 125 GeV
  - Observed: **>9.5 x BR$_{SM}$** @95%CL
  - Expected: >10 x BR$_{SM}$

CMS-HIG-14-003

H→γ*γ→μμγ

- **Rare Dalitz decay**
  - Various contributions to same final state
  - Sensitive to e.g. new resonances
  - Selection w.r.t. Zγ: $\mathbf{m_{\mu\mu}<20\ GeV}$





8 TeV (19.7 fb-1)

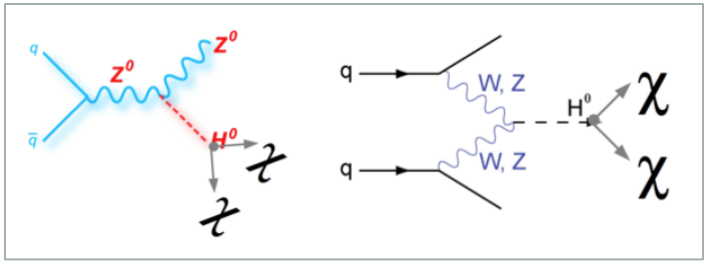
- Use invariant mass $\mathbf{m_{\mu\mu\gamma}}$
- Limit at 125 GeV
  - Exclude **>11** (7) **x** $\mathbf{BR_{SM}}$ @95%CL

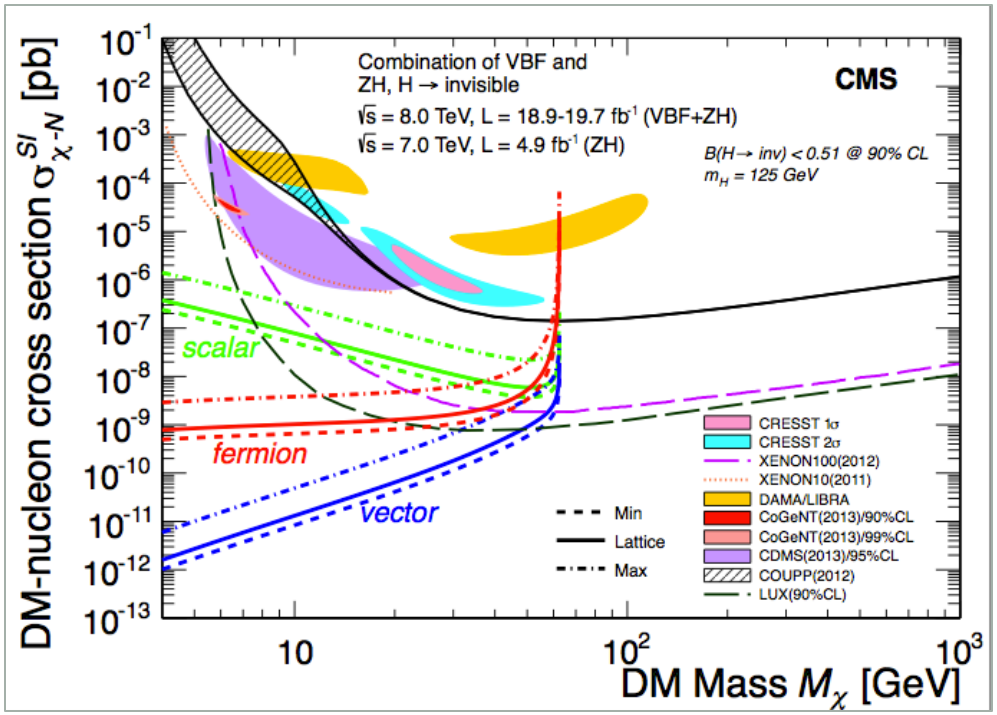
CMS-HIG-13-030

H→χχ

Direct search for invisible decays

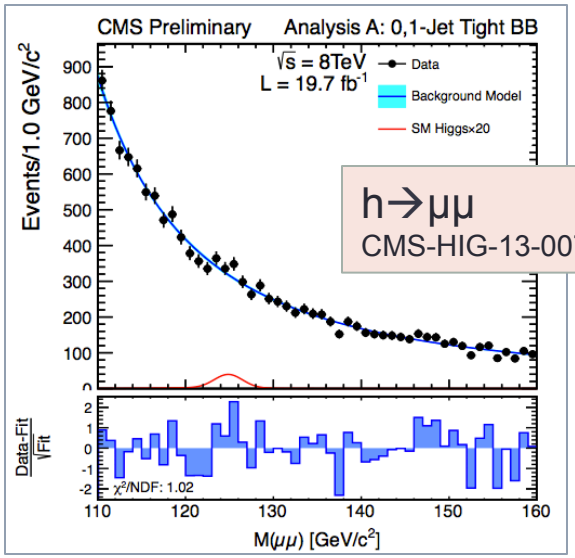
- Exploit associated production in VBF and VH final states





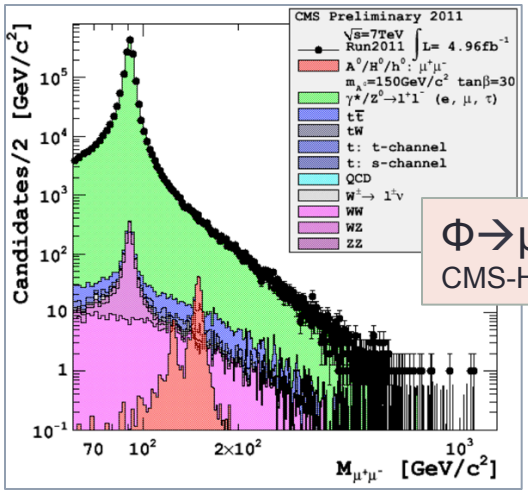
Limits on BR_{inv}

- Combine searches
  - VBF, Z(ll)H, Z(bb)H
- **Direct exclusion limit: BR_{inv} > 58%** (46%)
  - Indirect (width): > 52% (56%)
    - CMS-HIG-13-005
- **Interpret as DM limits** Higgs-portal models
  - Scalar, vector, fermion DM



h→μμ
CMS-HIG-13-007

PROPERTIES→SEARCHES



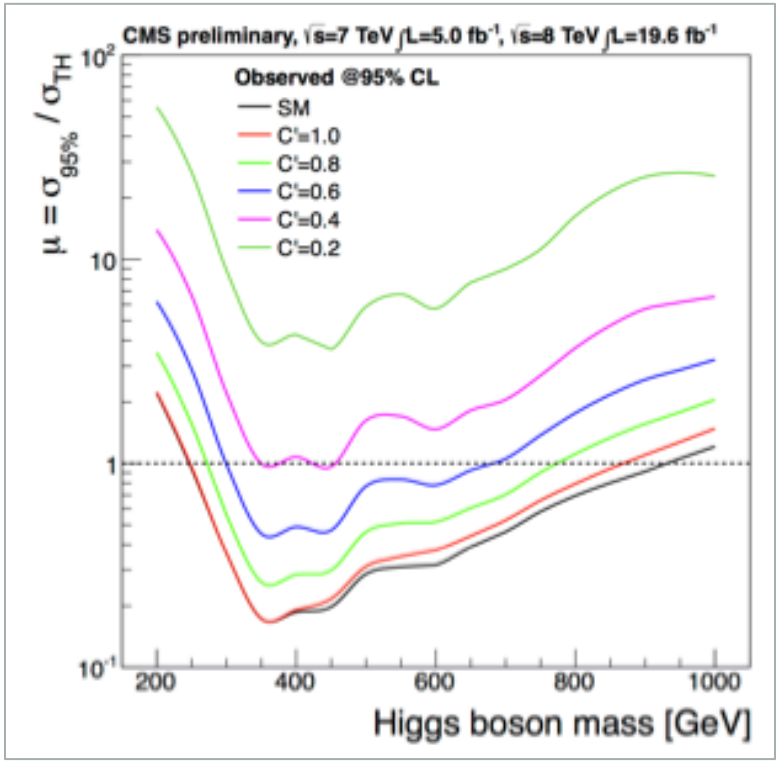
Φ→μμ
CMS-HIG-12-033

CMS-HIG-13-014

Singlet

SM+EW singlet field

- Mixing ➔ heavy Higgs with SM Higgs-like couplings



Rescale light h couplings:

$$\mu_h = \frac{\sigma_h \times \mathrm{BR}_h}{(\sigma_h \times \mathrm{BR}_h)_{\mathrm{SM}}} = C^2$$

Heavy H:

$\mu_H = C'^2(1 - \mathrm{BR}_{H,new})$

- $C'^2 = 1 - \mu_h$
  - unitarity

Results

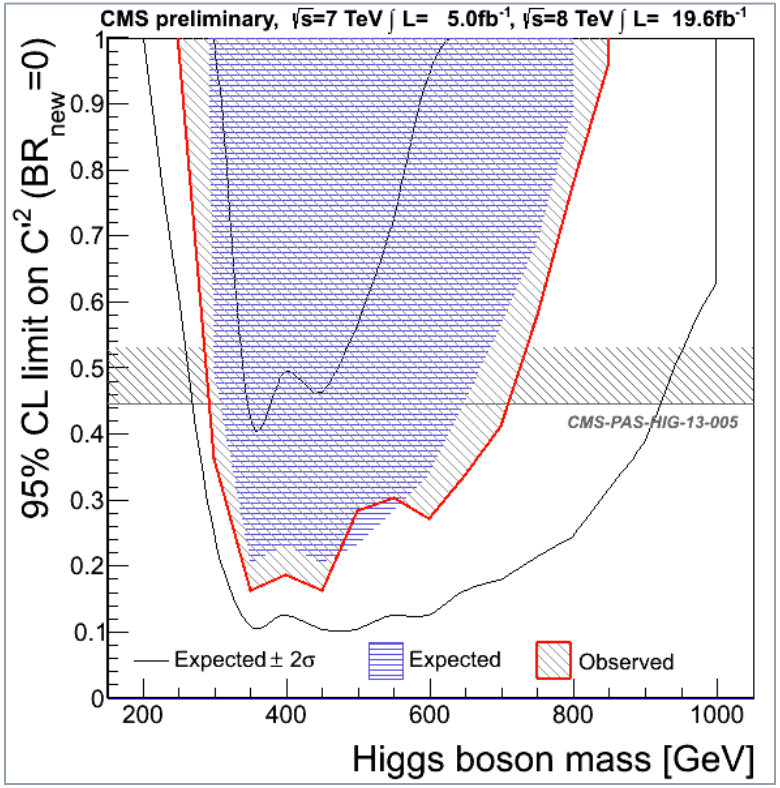
- Exclude SM-like heavy Higgs up to 1 TeV
  - With H→ZZ→llvv alone
- Exclude large C'
  - Assuming $\mathrm{BR}_{new}=0$
- Room left for smaller C'

CMS-HIG-13-014

Singlet

SM+EW singlet field

- Mixing ➔ heavy Higgs with SM Higgs-like couplings



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2HDMs

- **Effective theory with two complex scalar doublets**
  - 5 physical scalar fields after EWSB
    - 3 neutral: **h**, **H** (CP-even), **A** (CP-odd)
    - 2 charged: **$H^{\pm}$**
- **Couplings described by 2 mixing angles**
  - **tanβ** = v_1/v_2
  - **α** mixing angle h/H

Coupling strength	Type I	Type II
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$

- Type 1
  Φ_1 coupled to V, **Φ_2** to f
- Type 2
  Φ_1 coupled to u-type,
  Φ_2 to d-type quarks

- Using measurements of h(125), indirect limits can already be set
  - See e.g. ATLAS-CONF-2014-010

CMS-HIG-13-025

H→hh & A→Zh

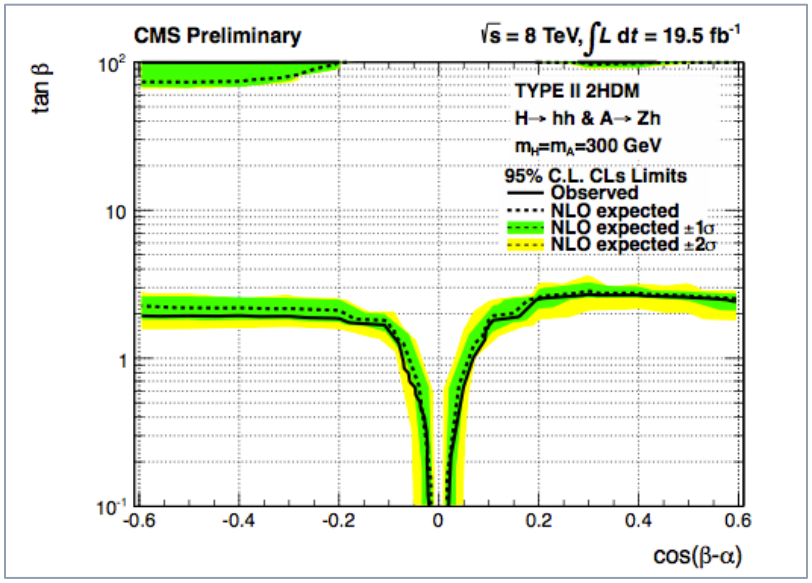
- **Direct 2HDM searches**
  - H→hh ($2m_h<m_H<2m_t$)
  - A→Zh ($m_h+m_Z<m_A<2m_t$)
- **Various final states**
  - Leptons/photons/etc

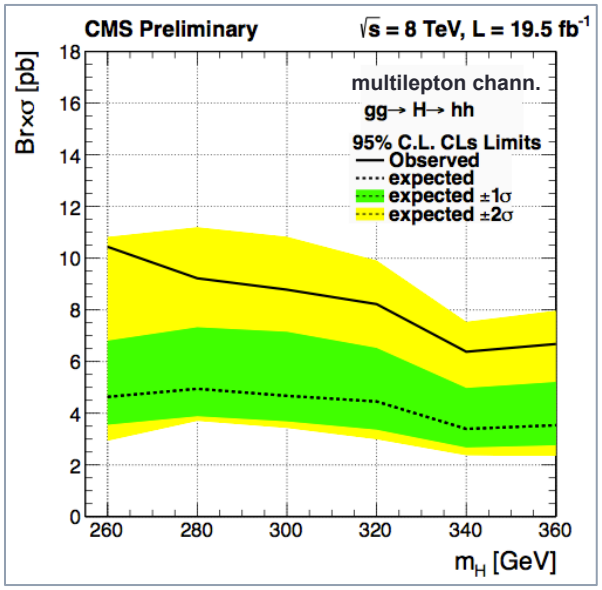
H→hh final states

	$h \to WW^*$	$h \to ZZ^*$	$h \to \tau\tau$	$h \to bb$	$h \to \gamma\gamma$
$h \to WW^*$	✓	✓	✓	X	✓
$h \to ZZ^*$	-	✓	✓	✓	✓
$h \to \tau\tau$	-	-	✓	X	✓
$h \to bb$	-	-	-	X	X
$h \to \gamma\gamma$	-	-	-	-	X

A→Zh final states

	$h \to WW^*$	$h \to ZZ^*$	$h \to \tau\tau$	$h \to \gamma\gamma$
$Z \to ll$	✓	✓	✓	✓
$Z \to qq$	X	✓	X	X
$Z \to \nu\nu$	X	✓	X	X





➢ **Direct constraints** on 2HDMS of Type I and Type II

CMS-HIG-13-025

H→hh & A→Zh

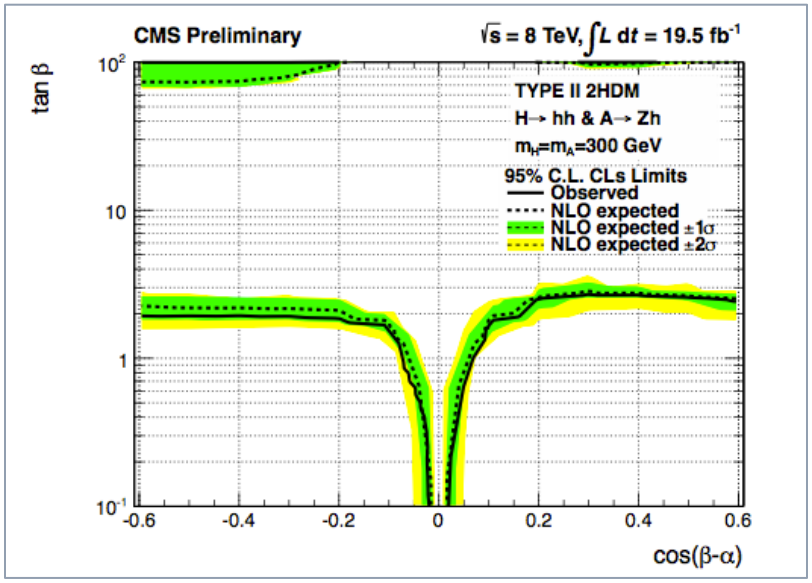
- **Direct 2HDM searches**
  - H→hh ($2m_h<m_H<2m_t$)
  - A→Zh ($m_h+m_Z<m_A<2m_t$)
- **Various final states**
  - Leptons/photons/etc

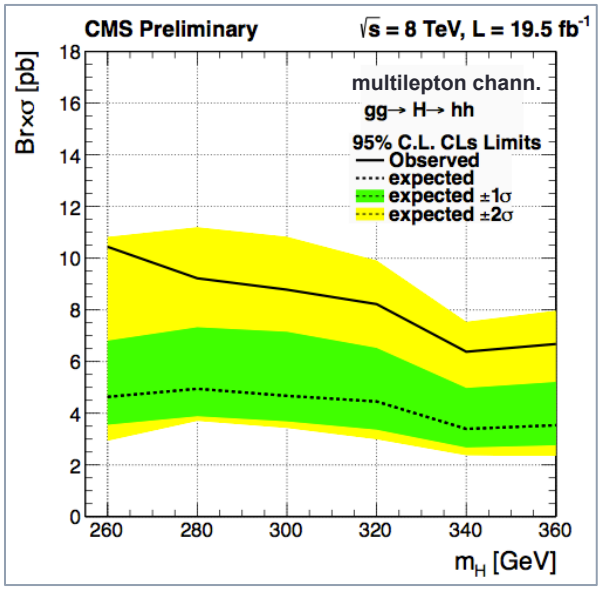
H→hh final states

	$h \to WW^*$	$h \to ZZ^*$	$h \to \tau\tau$	$h \to bb$	$h \to \gamma\gamma$
$h \to WW^*$	✓	✓	✓	X	✓
$h \to ZZ^*$	-	✓	✓	✓	✓
$h \to \tau\tau$	-	-	✓	X	✓
$h \to bb$	-	-	-	X	X
$h \to \gamma\gamma$	-	-	-	-	X

A→Zh final states

	$h \to WW^*$	$h \to ZZ^*$	$h \to \tau\tau$	$h \to \gamma\gamma$
$Z \to ll$	✓	✓	✓	✓
$Z \to qq$	X	✓	X	X
$Z \to \nu\nu$	X	✓	X	X





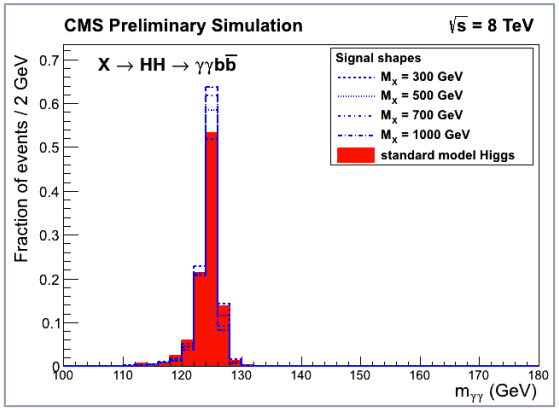
➢ **Direct constraints** on 2HDMS of Type I and Type II

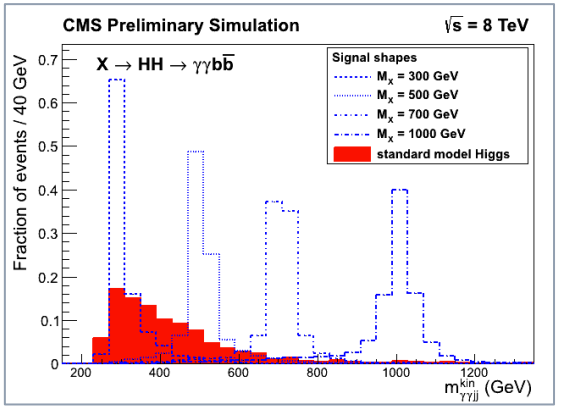
X→h(γγ)h(bb)

NEW CMS-HIG-13-032

Search hh resonance

- m_X = [260,1100] GeV
  - **2 γ**
  - **1/2 b**-tagged jets
- Public since Monday!





- See presentation by M.Gouzevitch for details on photon reconstruction

X→h(γγ)h(bb)

NEW CMS-HIG-13-032

Search hh resonance

- m_X = [260,1100] GeV
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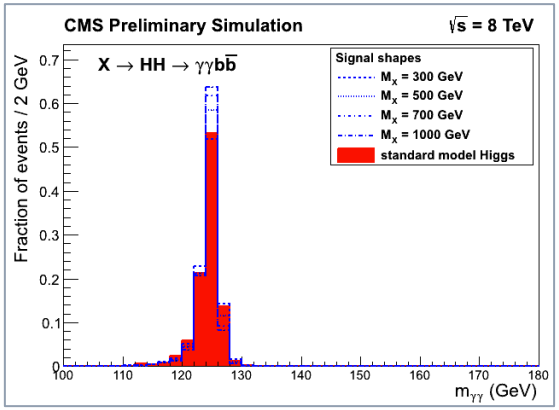
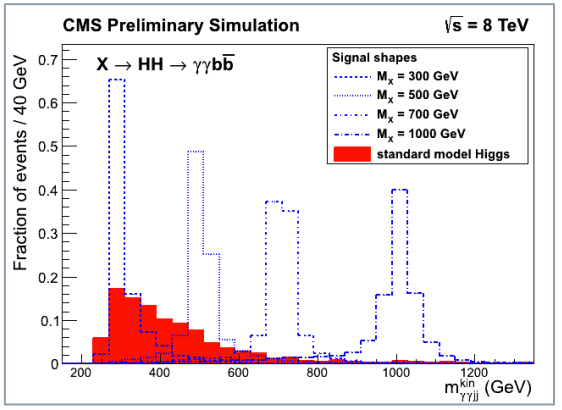
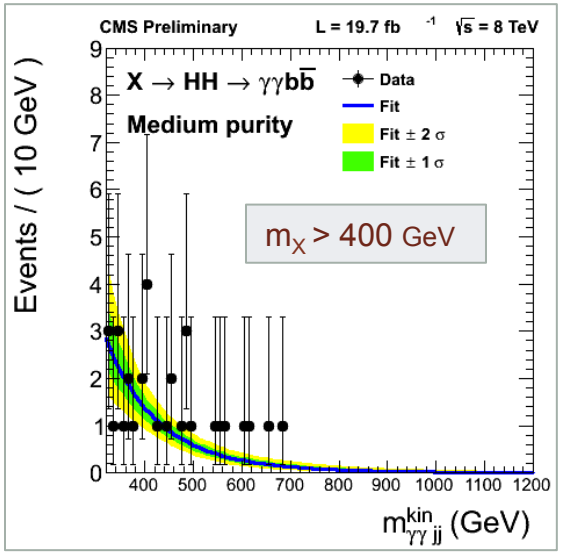
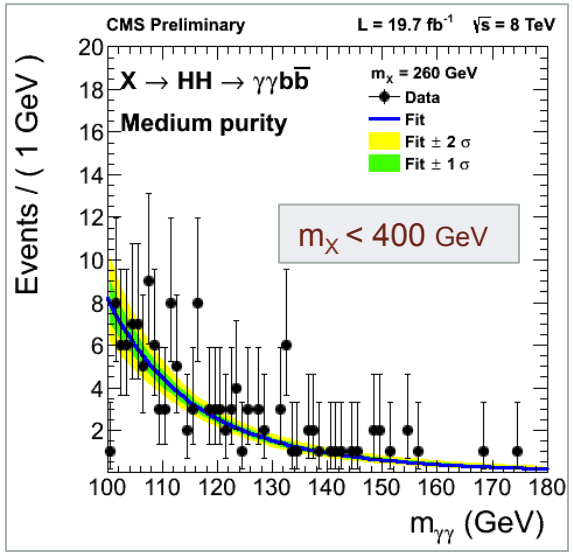








Fits

- Polynom. background

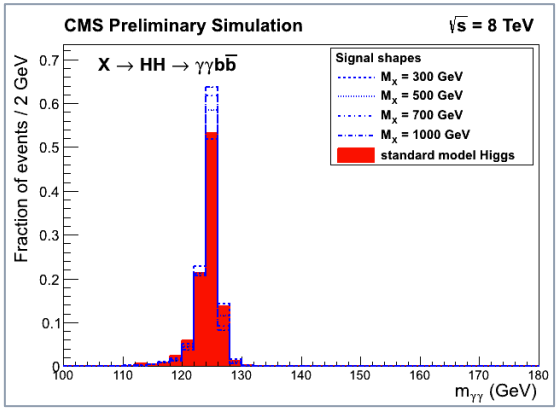
1. **m(γγjj)**
   - m_X>400 GeV
   - Kinematic fit
2. **m(γγ)**
   - m_X<400 GeV

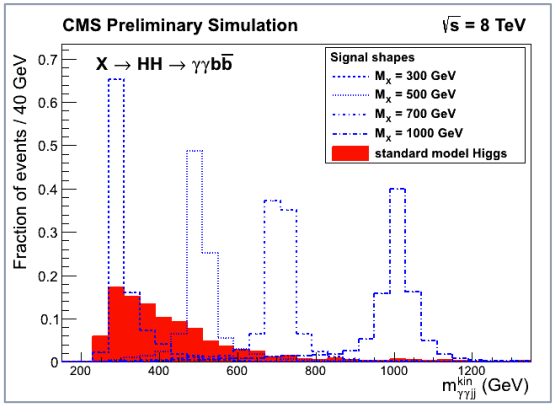
X→h(γγ)h(bb)

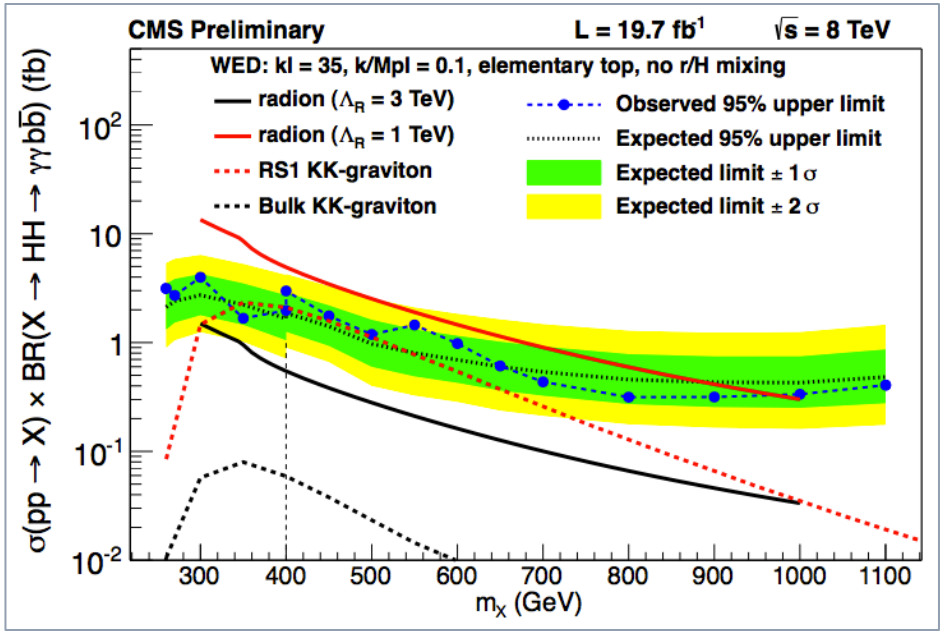
NEW CMS-HIG-13-032

Search hh resonance

- m_X = [260,1100] GeV
  - **2 γ & 1/2 b**-tagged jets
  - >400GeV: **kinematic fit**
- Public since Monday!







Spin hypothesis

- Test spin-0 and spin-2 models
- Selection minimally sensitive

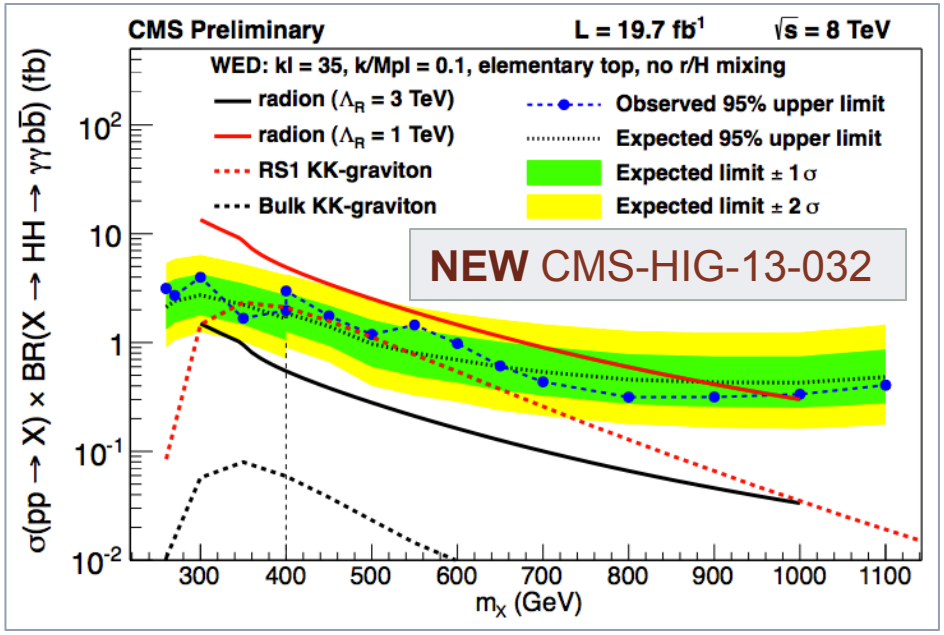
Limits

- Warped extra dimensions
  - Radion scale Λ_R = 1 TeV
  - **Radion mass exclusion: M_X < 970 GeV**

X→h(γγ)h(bb)

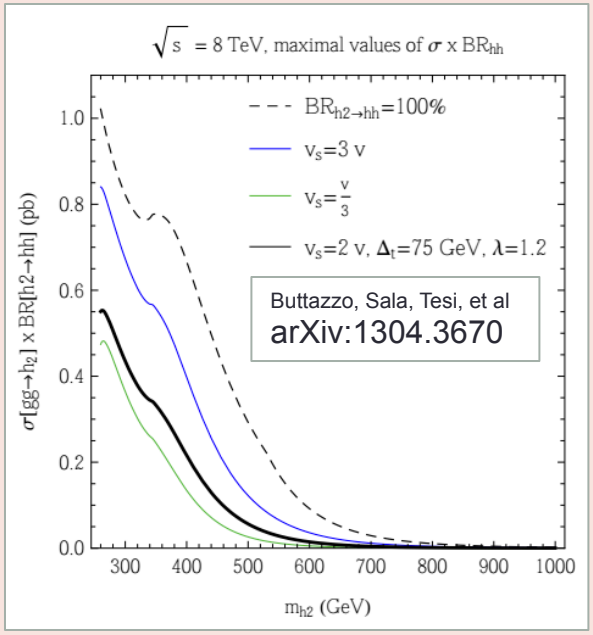
Search hh resonance

- m_X = [260,1100] GeV
  - **2 γ & 2 b**-tagged jets
  - >400GeV: **kinematic fit**
- Public since a week!



Plan:

- 2HDM interpretation
  - **H→h(γγ)h(bb)**
- Example: (N)MSSM



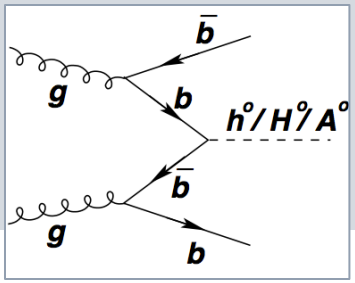
MSSM

- **MSSM scalar sector**
  - A particular 2HDM Type II model
  - Phenomenology described in **tanβ vs m_A**
- **Indirect exclusion** from h(125) on m_A
  - Simplified MSSM (arXiv:1305.2172)
- **Direct searches**
  - **Neutral scalars**
  - **Charged Higgses**

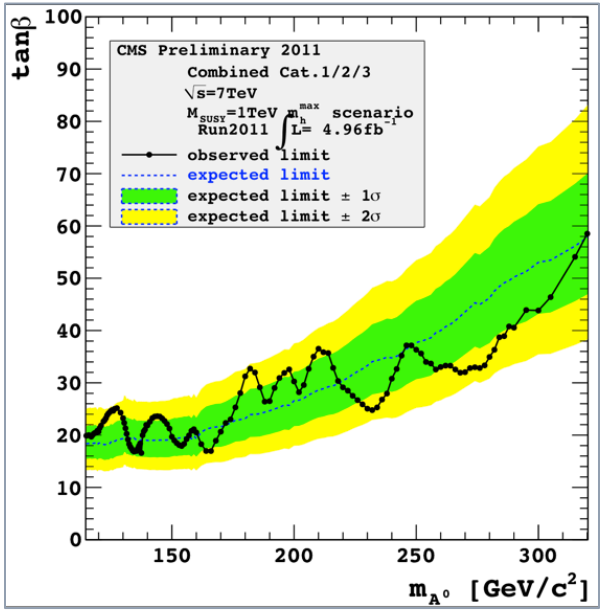
Φ→bb and Φ→μμ

Various direct MSSM searches

- Φ→bb and Φ→μμ
  - Possibly with b's in final state



CMS-HIG-12-033



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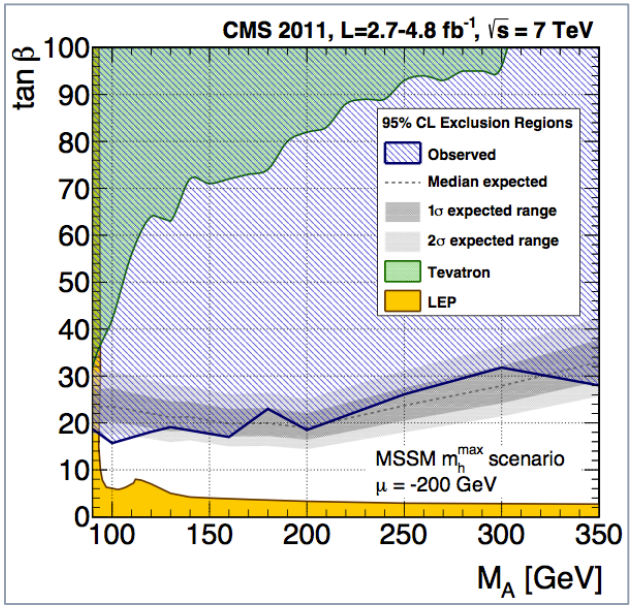
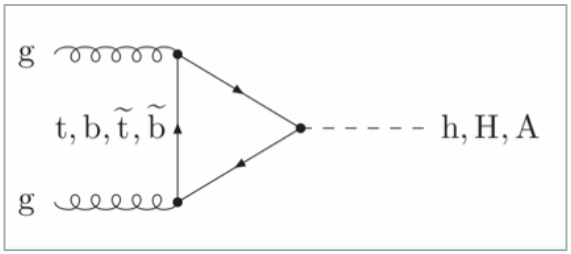
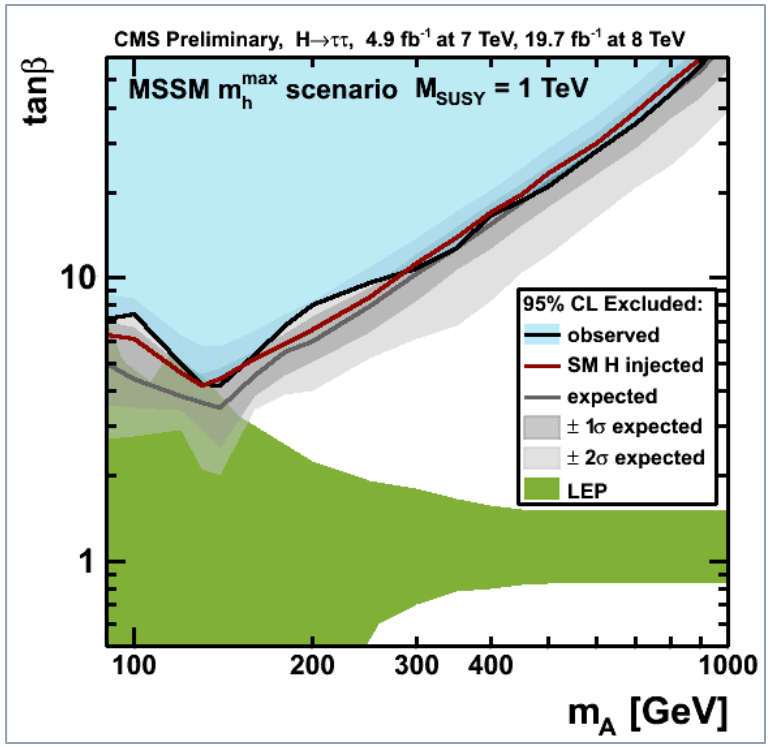


Φ→ττ

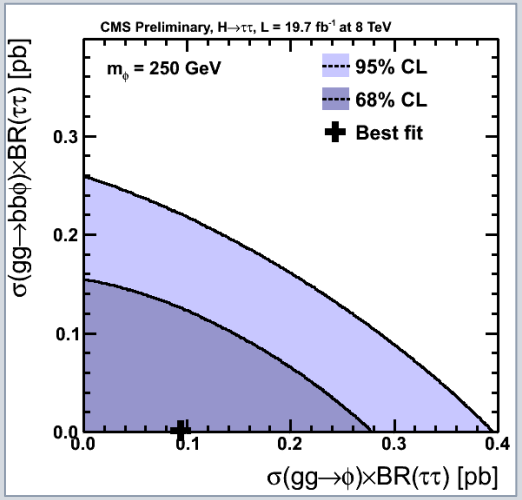
CMS-HIG-13-021

- Direct search for MSSM neutral Higgs with Φ→ττ
- **m_A<140 GeV** almost excluded
  - Φ→ττ + LEP





- Split b-tag multiplicity
  - Model-independent limits:

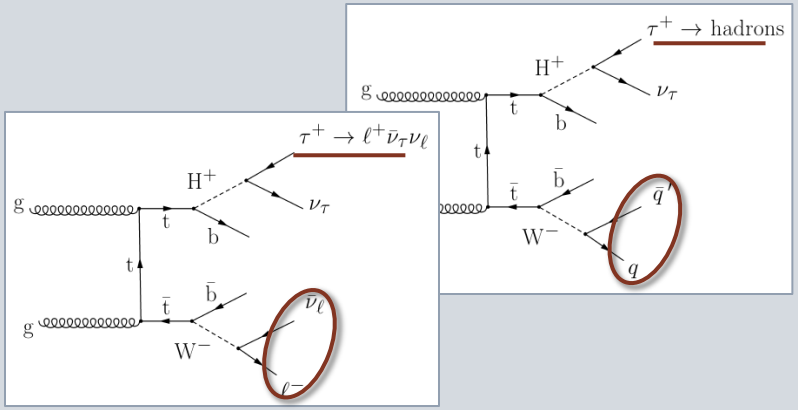


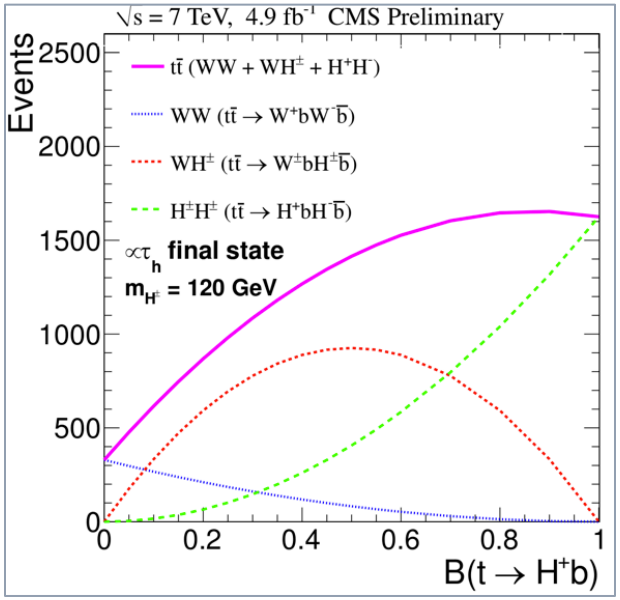
CMS-HIG-11-019

$H^{\pm}\rightarrow\tau\nu$

MSSM $H^{\pm}\rightarrow\tau\nu$

- $m_{H\pm} < m_t$: ttbar decay
  - $tt\rightarrow HbWb$
- $H^{\pm}\rightarrow\tau^{\pm}\nu$ significant
  - Also for small tanβ
- Combining various channels
  - Fully hadronic, e-tau, e-mu





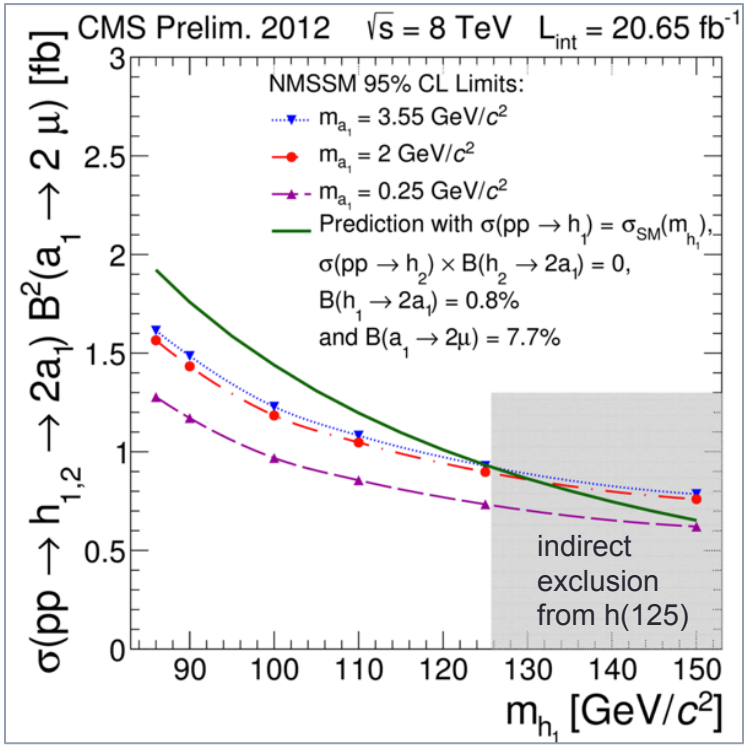
Limits (4.9fb^{-1} @ 7TeV)

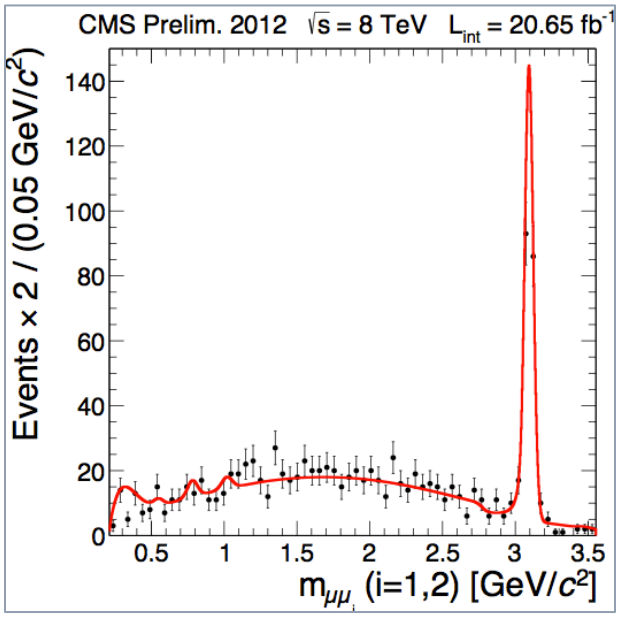
- **BR($t\rightarrow H^+b$) > 2-4 %**
  - $80 < m_H < 160$ GeV
  - Assuming BR($H^+\rightarrow\tau\nu$=1)

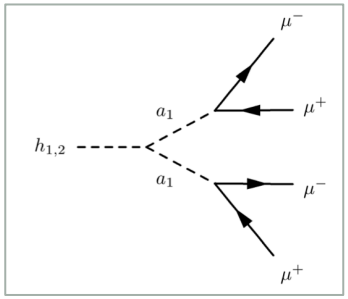
NMSSM

CMS-HIG-13-010

- Beyond MSSM: NMSSM
  - Additional gauge singlet
- Further extend Higgs sector
  - Additional **CP-even & CP-odd**
- Larger phenomenology
  - Neutral scalars with **m<125** not excluded in NMSSM





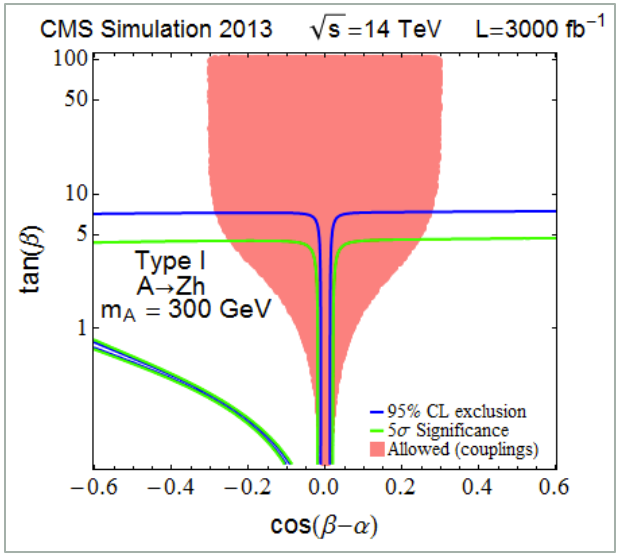


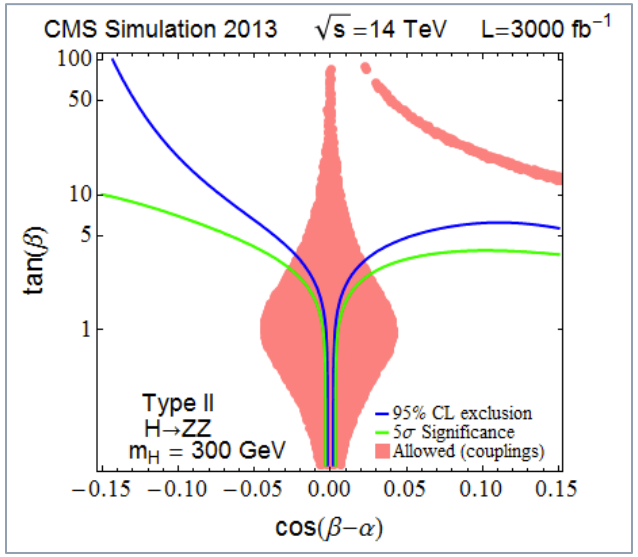
- Most recent search: **$h_{1,2} \to a_1 a_1 \to 4\mu$**
  - $2m_\mu < m_a < 2m_\tau$
- Limits on various BSM models

Prospects

CMS-FTR-13-024

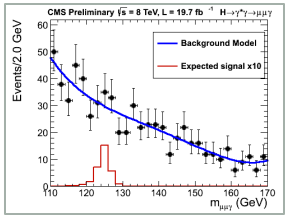
- **Outlook** beyond RunII
  - 3000 fb^{-1} at 14TeV
- **Direct searches**
  - H→ZZ, A→Zh, …
- Cover regions of phasespace not excluded by indirect constraints

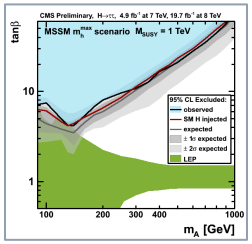


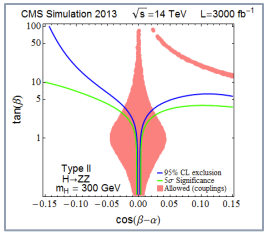


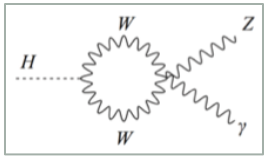
Conclusions

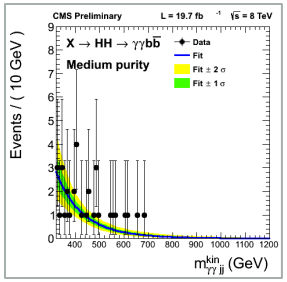
- **After h(125) discovery**
  - Now entering domain of precision physics
  - No deviation from SM expectations
    - Indirect constraints of BSM phase space
- **Variety of direct searches** being conducted
  - Rare decays, invisible decays, 2HDM, (N)MSSM, etc..
- **Plan: further extend scope** of direct BSM searches in scalar sector
  - Probe uncovered phasespace





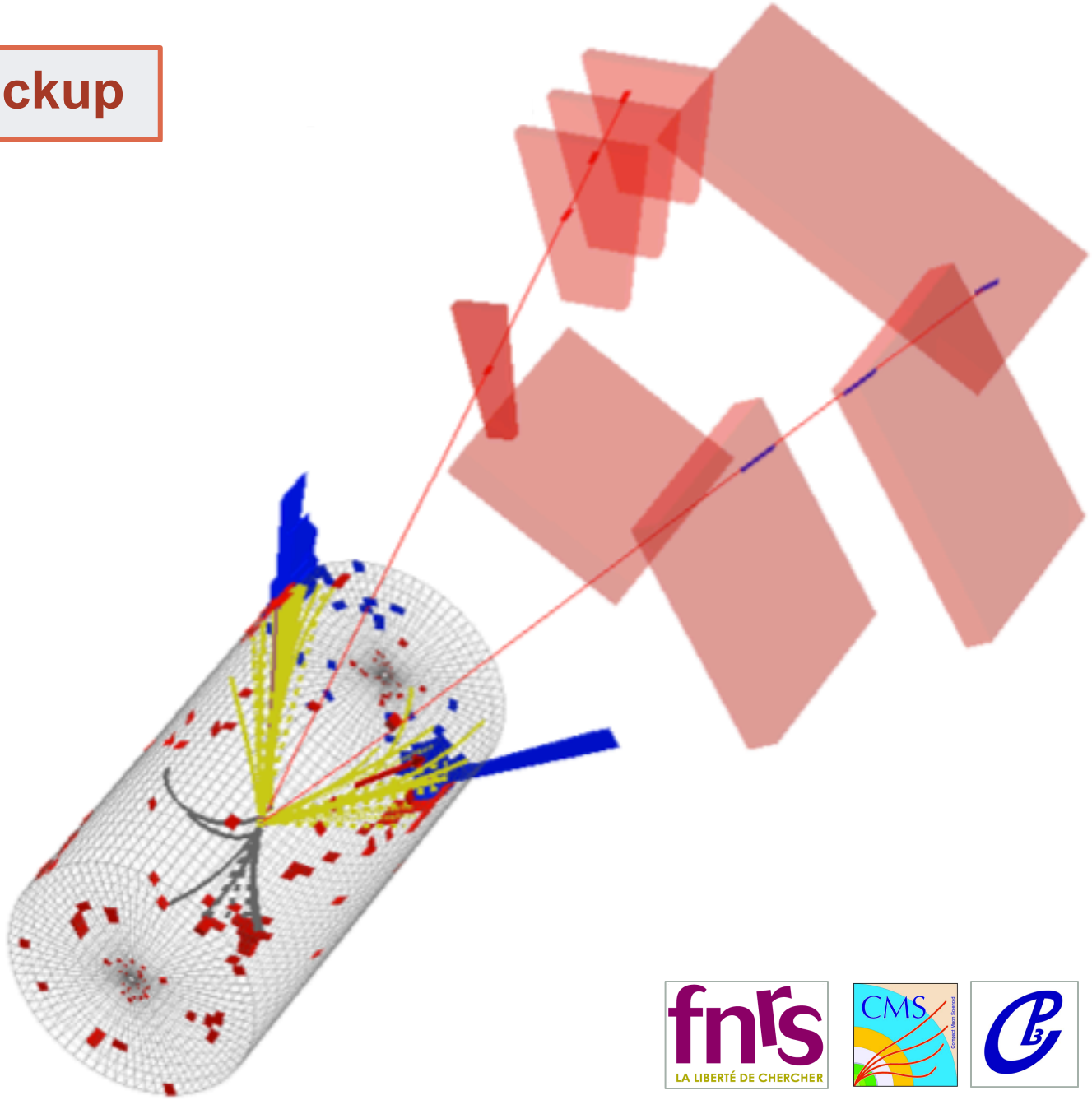






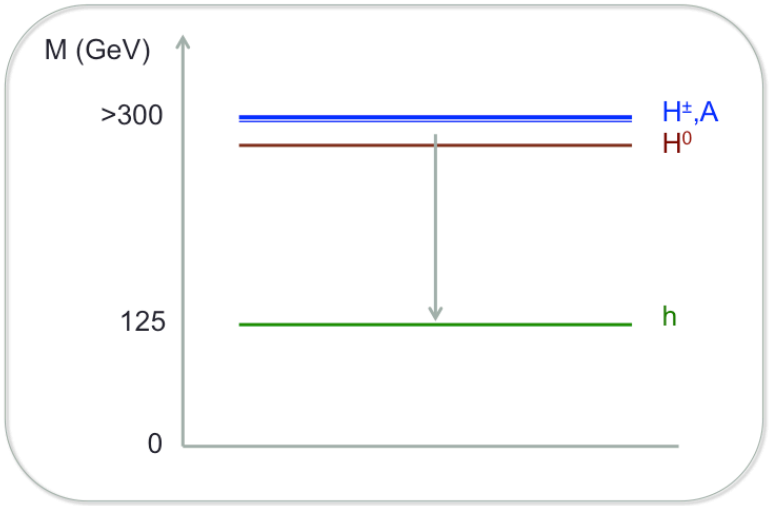

Thank you for your attention
& *smacznego!*

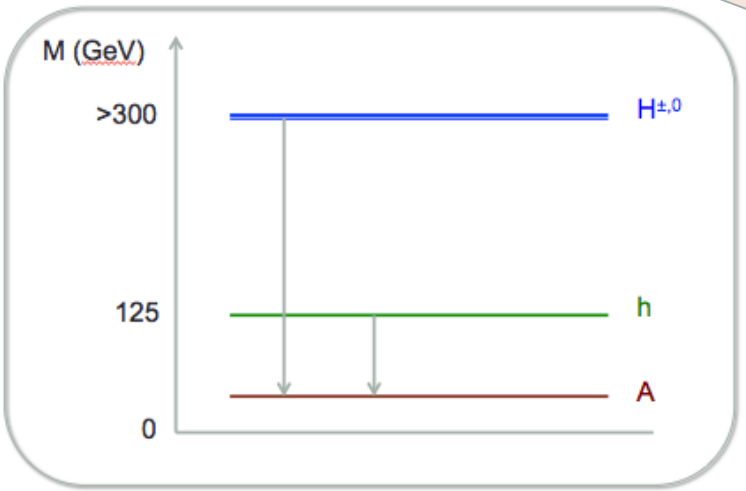
Backup



Hierarchy sketches

Illustrations similar to http://arxiv.org/abs/hep-ph/0703051



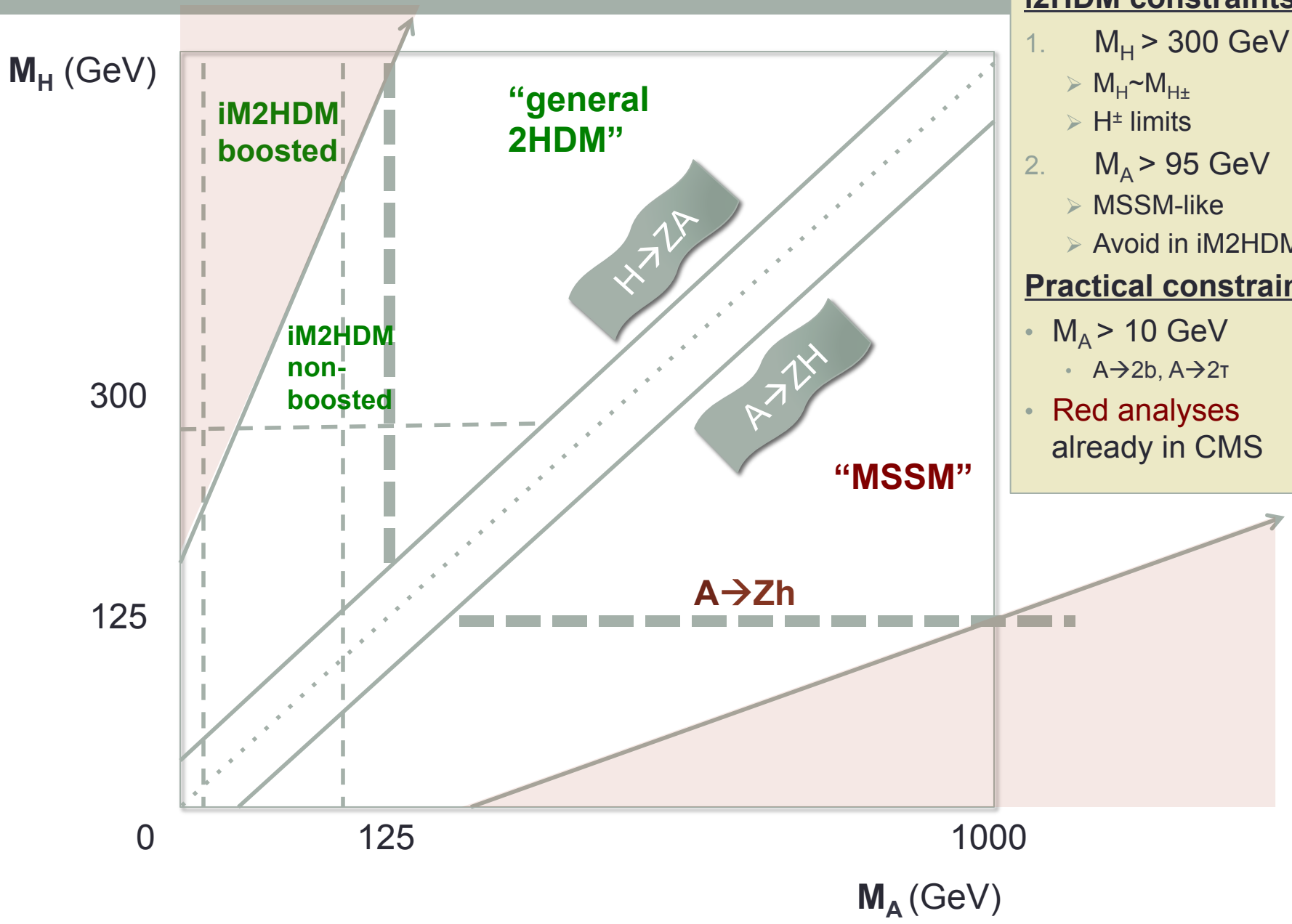


1. Usual hierarchy

- Example: MSSM
  - SM-like Higgs boson lightest
    - Heavy susy Higgses
  - Ongoing CMS search for **A→Zh**
    - Final state: A→Z(ll)h(bb) with 125 GeV h→bb

2. Alternative: inverted hierarchy

- From "A Twisted Custodial Symmetry in the Two-Higgs-Doublet Model"
  - http://arxiv.org/abs/hep-ph/0703051
- **Light pseudoscalar A**
  - M_A: few GeV (NMSSM) or more
  - Possibility: **H→ZA**



i2HDM constraints:

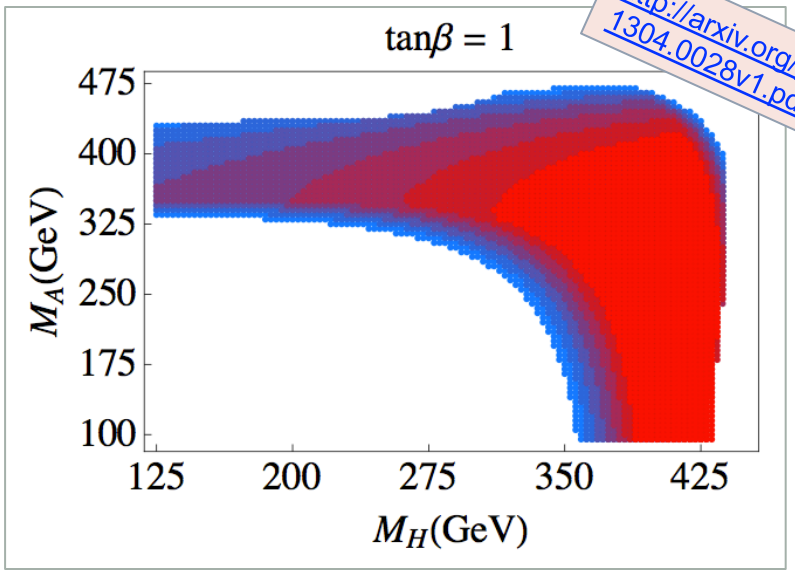
1. $M_H > 300$ GeV
   - $M_H \sim M_{H^\pm}$
   - $H^\pm$ limits
2. $M_A > 95$ GeV
   - MSSM-like
   - Avoid in iM2HDM

Practical constraints:

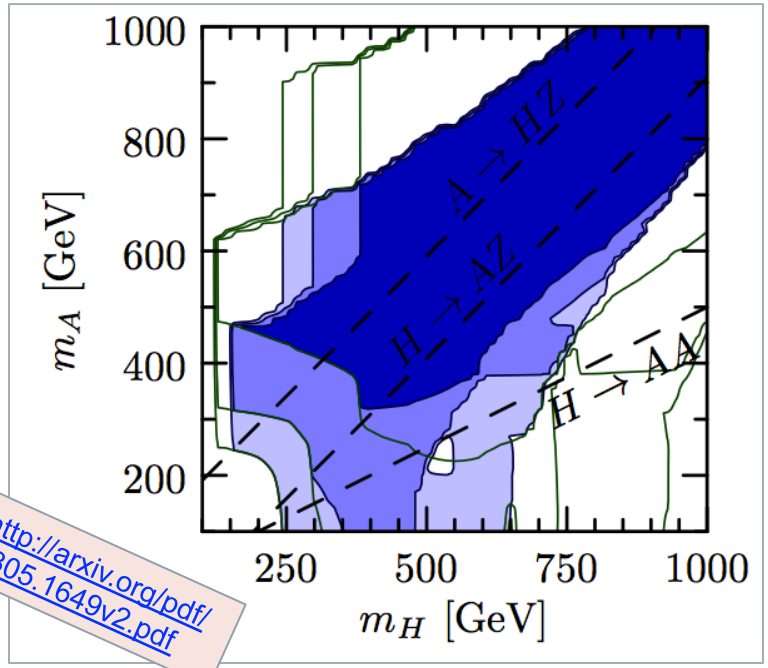
- $M_A > 10$ GeV
  - $A \to 2b$, $A \to 2\tau$
- Red analyses already in CMS

Recent constraints

- **Examples.** NB: these papers use the MSSM-like constraint from LEP
  - M_A > 95 GeV
- Even then still **much room remaining**
  - Also with inverted hierarchy



http://arxiv.org/pdf/1304.0028v1.pdf



http://arxiv.org/pdf/1305.1649v2.pdf

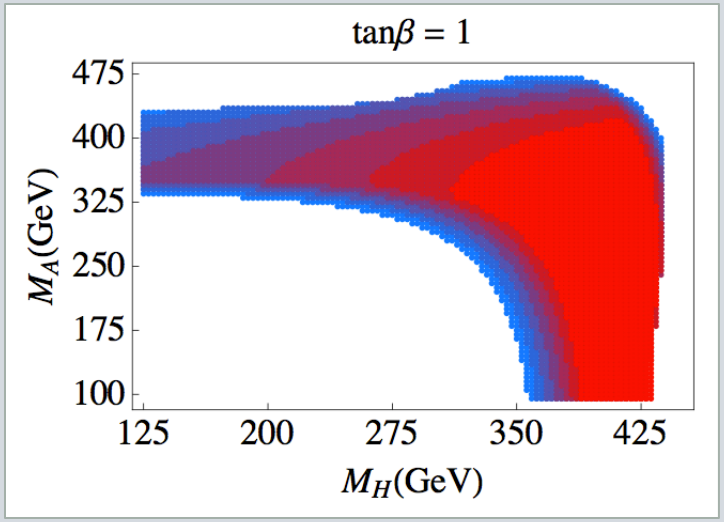
Top plot (tanβ=1) favors

- **Heavy M_H** (~400 GeV)
- **Lighter M_A** (95-400 GeV)

Limits & couplings

http://arxiv.org/pdf/1304.0028v1.pdf

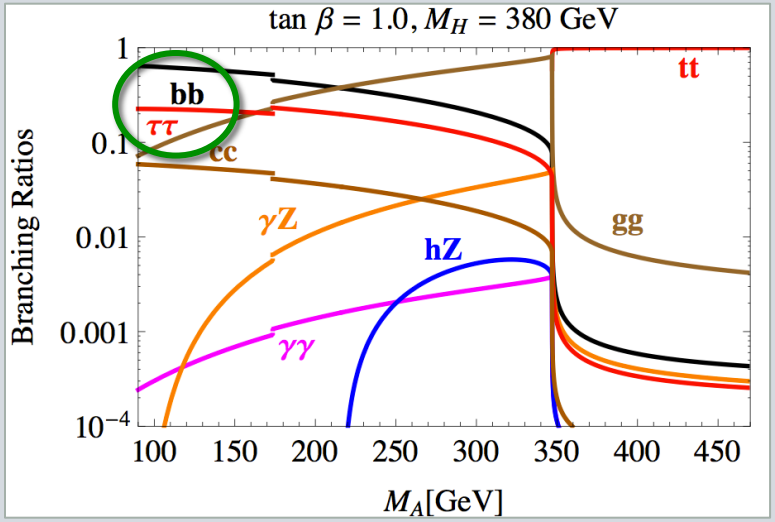
- **Recent limits**



This plot (tanβ=1) favors

- **Heavy M_H** (~400 GeV)
- **Lighter M_A** (95-400 GeV)

- **BRs**



If M_A small → dominant decays:

- **A→bb**
- **A→ττ**
  - H→Z(ll)A(bb) and H→Z(ll)A(ττ)