Search for non-SM Higgs bosons with CMS

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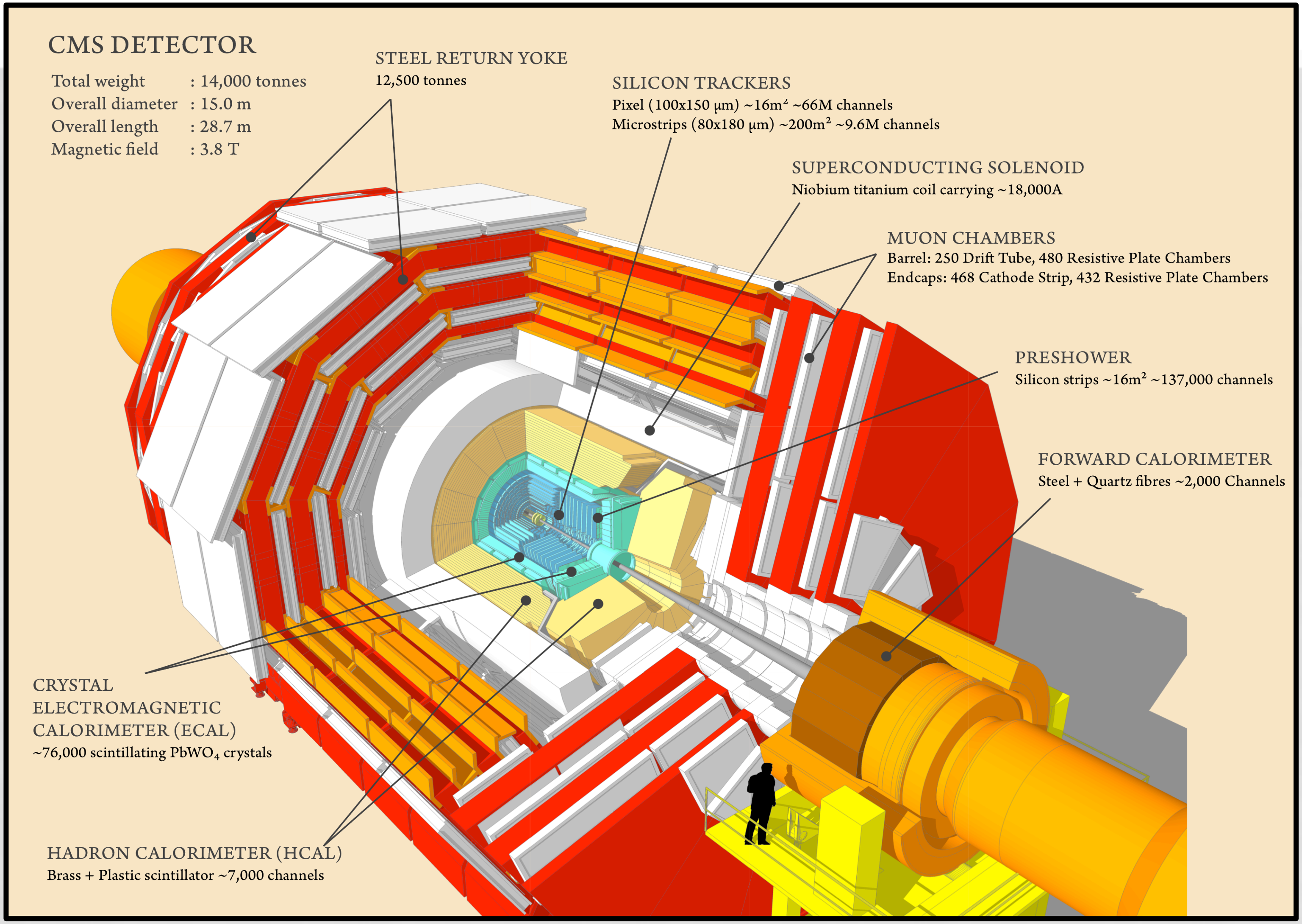
on behalf of the CMS collaboration

PASCOS2013 • 20-26 Nov 2013
Taipei (Taiwan)

Compact Muon Solenoid (CMS)



What're in this talk?

non-SM Higgs

"Invisible Higgs"

VBF H → invisible	CMS PAS HIG 13-013
Z(ll)H, H → invisible	CMS PAS HIG 13-018
Z(bb)H, H → invisible	CMS PAS HIG 13-028

"MSSM Higgs sector"

$\Phi \rightarrow \tau\tau$	CMS PAS HIG 13-021
$\Phi \rightarrow \mu\mu$	CMS PAS HIG 12-011
$\Phi \rightarrow bb$	CMS PAS HIG 12-033
$H^{\pm} \rightarrow \tau^{\pm}\nu$	CMS PAS HIG 11-019, HIG 12-052

"NMSSM Higgs"

$h \rightarrow 2a + X \rightarrow 4\mu + X$	CMS PAS HIG 13-010

Introduction

The discovery of a new Boson (The Nobel Prize 2013!)

- $m_X = 125.7 \pm 0.3$ (stat.) $\pm\ 0.3$ (syst.) GeV
- Properties are consistent with SM Higgs

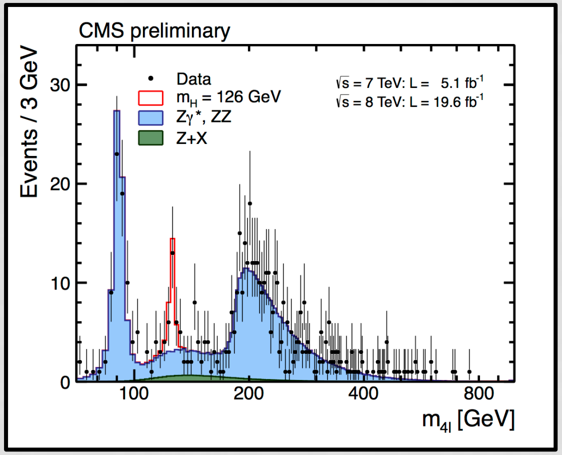
What's the problem of SM? Why we need BSM?

- Hierarchy problem
- Dark matter particle(s)
- Naturalness
- Asymmetry of matter-antimatter
- etc.

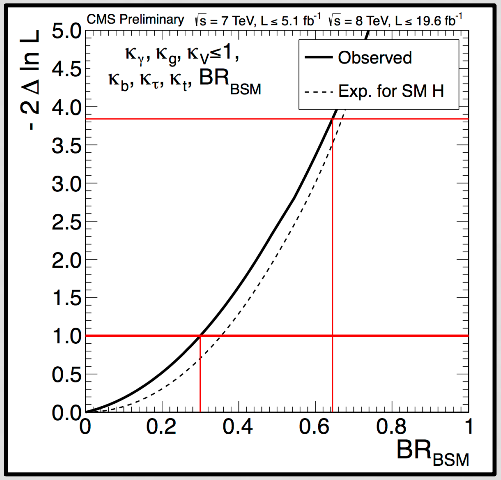
The current accuracy of Higgs boson measurement constrains Br(H→BSM decays) < 0.64 (95% CL.)

- still have plenty of room for non-SM Higgs

CMS PAS HIG 13-002



CMS PAS HIG 13-005



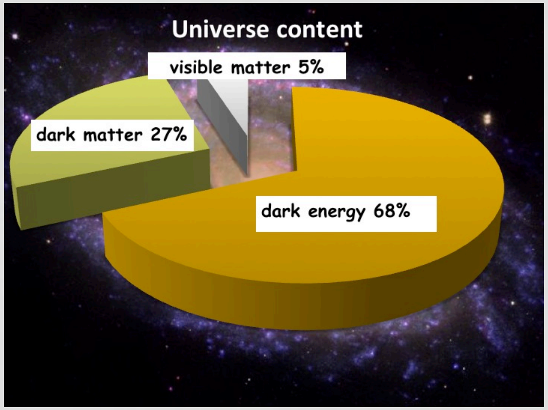
“Invisible Higgs”

Searches of H → Invisible

BR(H → invisible) in SM, Higgs can only decays via H→ZZ*→νννν (~0.1%)

Significant BR(H → invisible) would be a strong sign of physics beyond the SM

- H → 2LSPs in SUSY
- H → graviscalars in the ADD model



Evidence of Dark matter (DM)

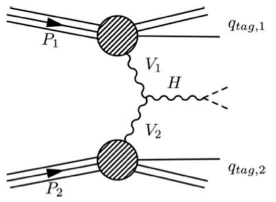
- LHC is currently most sensitive DM detection apparatus, at least in the context of simple Higgs-portal models

H → invisible topologies proposed for LHC searches

- VBF H → inv : D. Zeppenfeld, O.J.Eboli 2000
- Z(ll,bb)H, H → inv : D.P. Roy, D. Choudhuri 1994
- gg → H+jet, H → inv : A. Djouadi et. al. arXiv:1205.3169

} combined soon!!

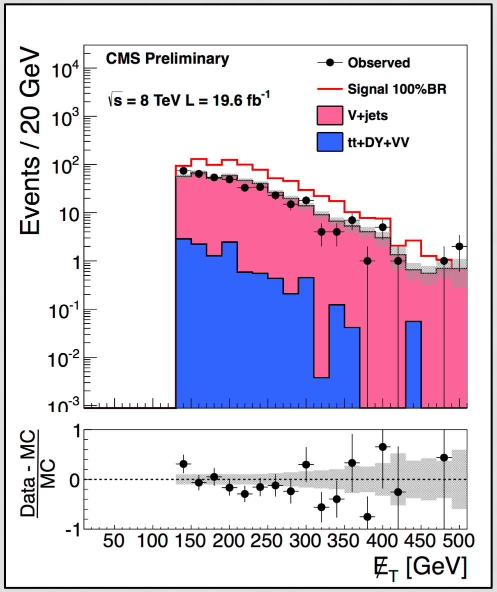
VBF H → Invisible

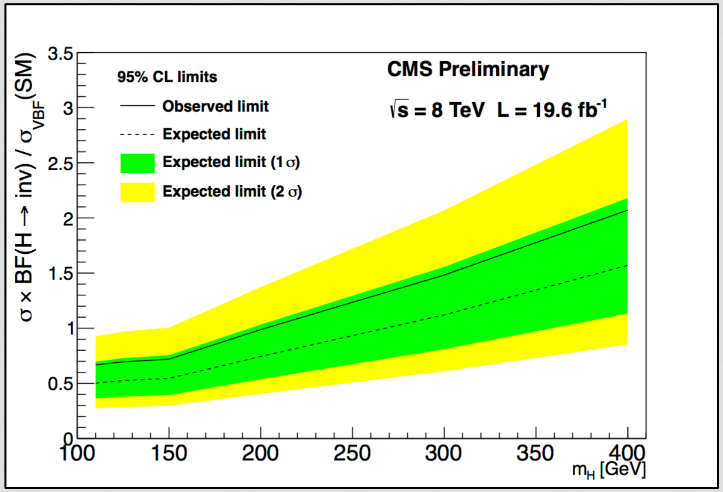


Special VBF+MET triggers for VBF H → invisible

Events are tagged with 2 jets and large missing transverse energy

- jet pT > 50 GeV, |η| < 4.7
- M_{jj} > 1100 GeV, $\Delta\eta_{jj}$ > 4.2
- missing transverse energy > 130 GeV
- $\Delta\Phi_{jj}$<1.0 and Central jet veto – largely reduce QCD multijets



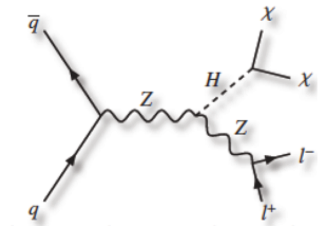


CMS PAS HIG 13-013

- Main backgrounds from Z(→νν)+jets and W+jets estimated using data-driven methods.
- **@ mH = 125 GeV**

  Br(H → inv) < 0.69 (0.53 expected) at 95% CL.

Z(ll)H → Invisible



CMS PAS HIG 13-018

Higgs production in associated with a Z boson

- lower cross-section than VBF but cleaner events
- events with two opposite charged leptons (only e,μ) and large missing transverse energy (MET)

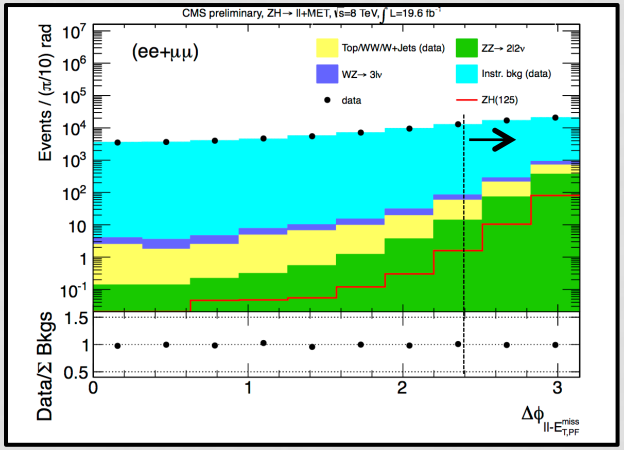
Main backgrounds from irreducible ZZ(→llνν) and WZ(→lνll) when lepton from W is unidentified

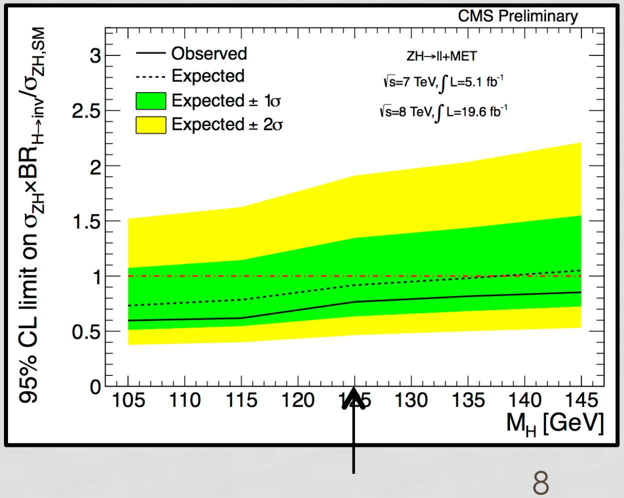
- introduce offline cuts $|MET-p^{ll}_T|/p^{ll}_T$ and $\Delta\Phi_{ll\text{-}MET}$, reject most of reducible backgrounds

Good agreement between data/MC prediction is shown

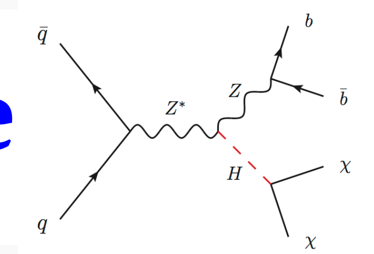
@ mH = 125 GeV

- **Br(H → inv) < 0.75 (0.91 expected) at 95% CL.**





Z(bb)H → Invisible



CMS PAS HIG 13-028

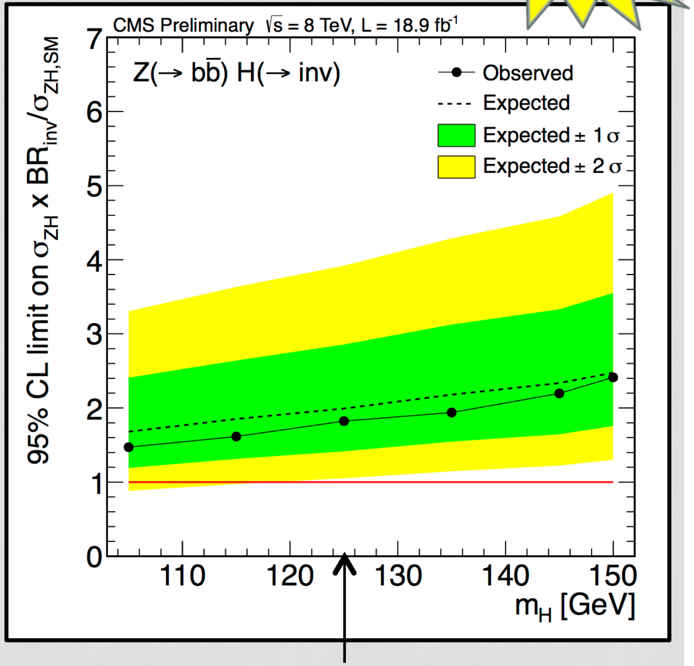
NEW

Higgs production in associated with a Z boson

- Z(→bb)H(→inv) require events with a pair of central jets and missing transverse energy
- same final state with VH(→bb) [CMS PAS HIG 13-012] but different mass of the resonance

Multivariate (BDT) regression technique applied to calibrate b jet energy on top of standard CMS corrections

- first used in CDF (arXiv:1107.3026)
- BDT shape analysis



Sensitive within mass range of Higgs 105-150 GeV

@ mH = 125 GeV at 95% CL.

Br(H → inv) < 1.82 (1.99 exp.)

“MSSM Higgs sector”

Higgs sector of MSSM (1)

Higgs sector in SUSY contains two scalar doublets

- five physical Higgs bosons

3 neutral Higgs : Φ = CP-even *h* and *H*, CP-odd *A*

2 charged Higgs : $H^{\pm}$

- Standard Model-like Higgs : *h*

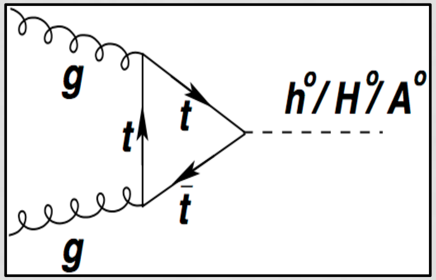
At tree level, Higgs sector is determined by only two parameters

- m_A and $\tan\beta = v_u/v_d$

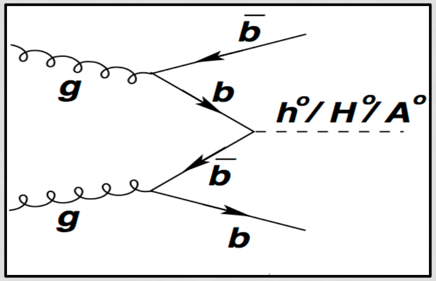
Neutral Higgs "Φ" decay channels

- Br(Φ → bb) ~90%
- Br(Φ → ττ) ~10%
- Br(Φ → μμ) very low but allows good mass reconstruction

" MSSM Higgs Production "



gluon-fusion : small and moderate value of tanβ

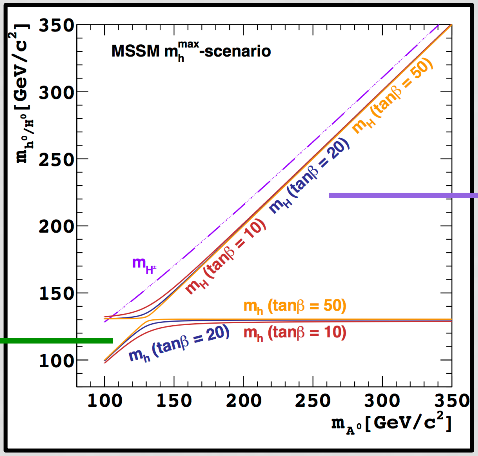


b-associated : large value of tanβ

Higgs sector of MSSM (2)

At large tanβ, mass of CP-odd boson A is usually degenerate with one of CP-even bosons, h and H

For $m_A << m_h^{max}$ the masses of A and h are nearly degenerate, H becomes SM-like Higgs boson



For $m_A >> m_h^{max}$ the masses of A and H are nearly degenerate, h becomes SM-like Higgs boson

The observation of H(125) does not exclude a heavy MSSM Higgs in wide range of tanβ, so still fits both SM and MSSM

Charged Higgs "$H^\pm$" decay modes depend on mass of $H^\pm$

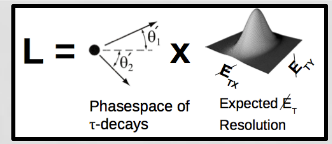
- Light $H^\pm$ ($m_H^\pm < m_{top}$) : dominated by $H^\pm \rightarrow \tau^\pm \nu$
- Heavy $H^\pm$ ($m_H^\pm > m_{top}$) : $H^\pm \rightarrow tb$ and $H^\pm \rightarrow \tau^\pm \nu$

MSSM $\Phi \rightarrow \tau\tau$

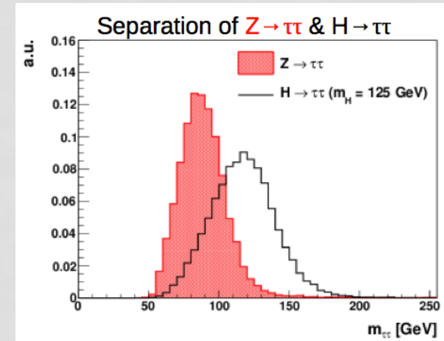
CMS PAS HIG 13-021

Reconstructed via 5 (out of 6) $\tau\tau$ final states

- $e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$, $\tau_h\tau_h$ (new!)

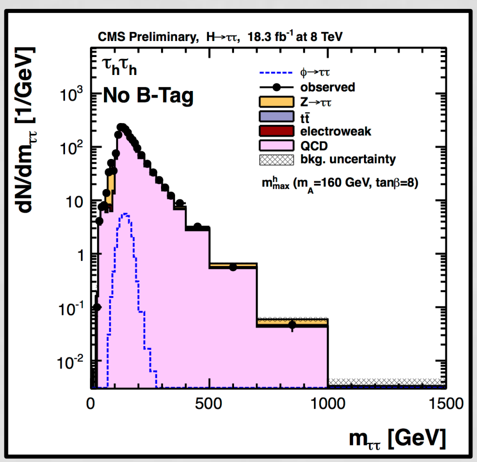


Signal extraction : determine invariant mass of di-τ system using maximum likelihood method (15-20% resolution of $M_{\tau\tau}$)

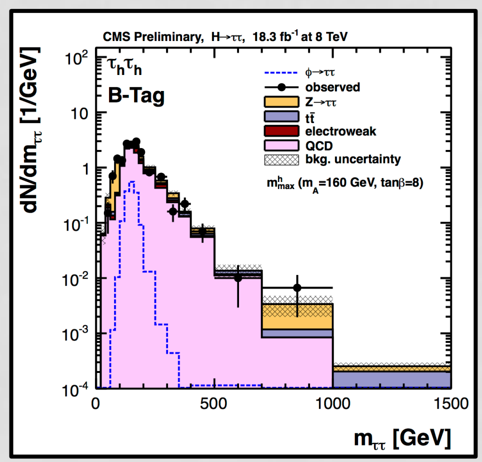


Main backgrounds from $Z\rightarrow\tau\tau$ (embedding $Z\rightarrow\mu\mu$), QCD, $Z\rightarrow ee/\mu\mu$, ttbar and Diboson

Categorization of selected events



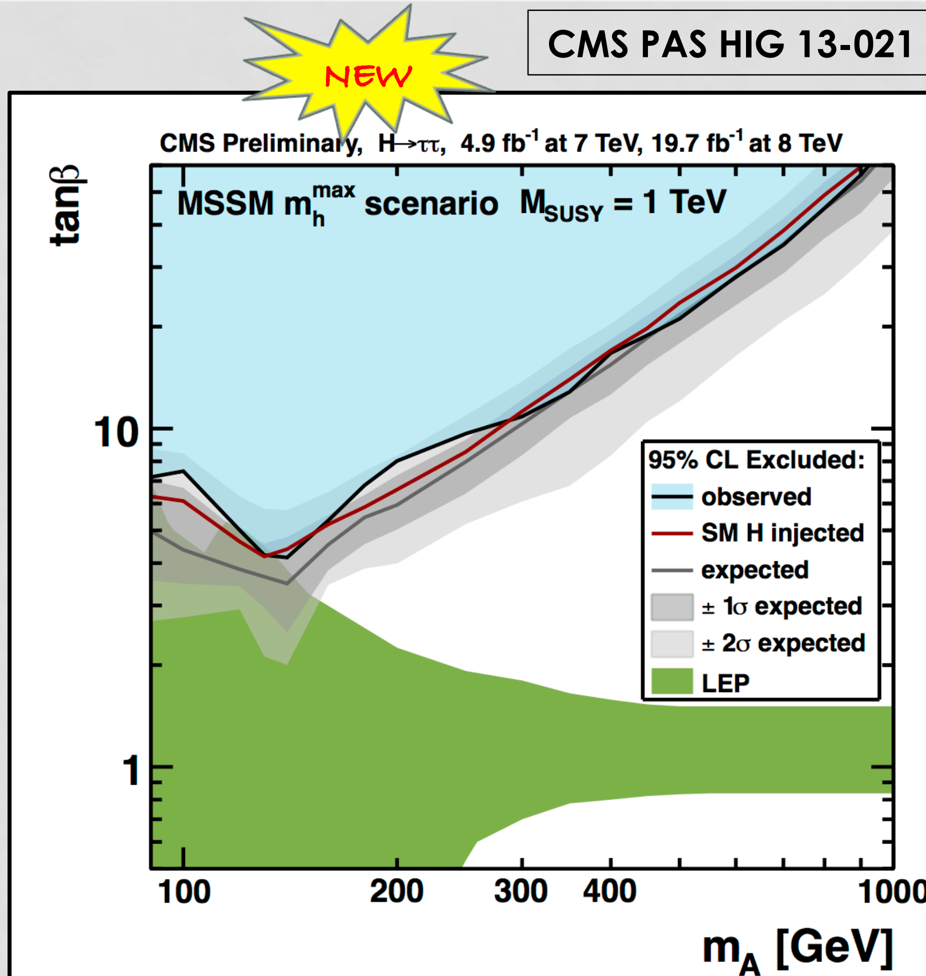
No B-Tag
sensitive to gluon fusion production, no b-tagged jets with $p_T > 20$ GeV



B-Tag
to enhance Higgs boson production associated with b-quarks, at least one b-tagged jet with $p_T > 20$ GeV

MSSM $\Phi \rightarrow \tau\tau$

CMS PAS HIG 13-021



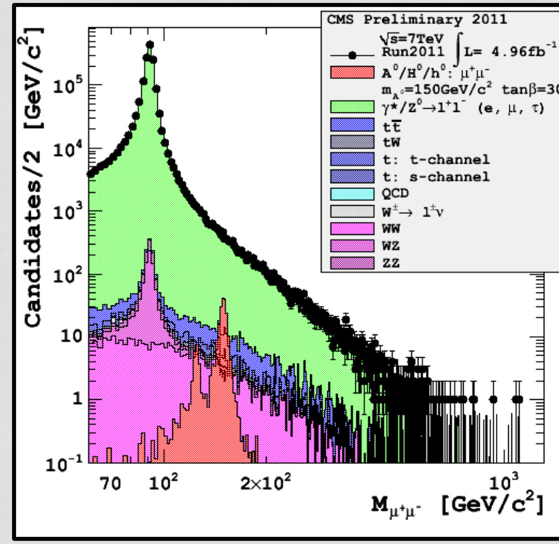
No excess events over the predicted SM background in any categories

Exclude values of tanβ as low as 4.2 at m_A=140 GeV for the MSSM m_h^{max} scenario (at 95% CL.)

- assuming no MSSM but a SM Higgs 125-126 GeV (red line)
- assuming no (neither MSSM nor SM) Higgs → ττ signal (grey line)
- LEP result (green band)

MSSM $\Phi \rightarrow \mu\mu$

CMS PAS HIG 12-011



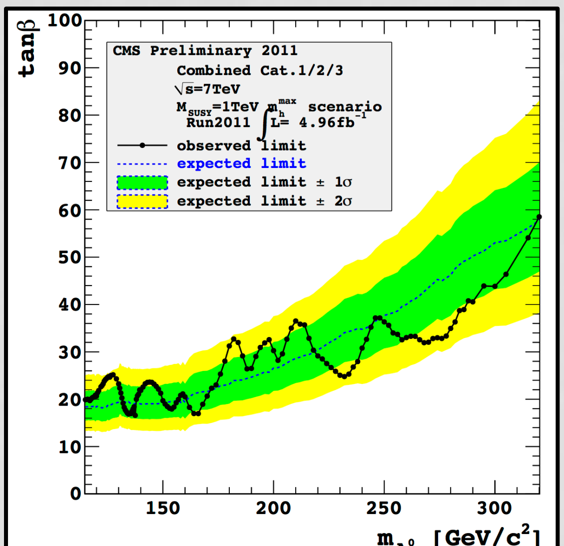
Good mass resolution due to full reconstructed final state

- events with two opposite charged high p_T muons
- three non-overlapping categories :

cat1 $\geq$ 1 b-tagged jet for $gg \rightarrow bb\Phi$

cat2 failed cat 1 but 3rd muon with p_T>3 GeV

cat3 failed cat1 and cat2 (purely di-muon events) $gg \rightarrow \Phi$



Main backgrounds : Drell-Yan (Z^0bb), ttbar (cat1), WW (cat3)

No excess events is observed over SM background

Exclude range of tanβ 16-26 for m_A 115 to 175 GeV in the MSSM m_h^{max} scenario at 95% CL.

MSSM $\Phi \to bb$

CMS PAS HIG 12-033

Highest branching fraction (~90%) but also large QCD multijet background

- dedicated trigger to identify b-tagged jets
- challenging background estimates (data-driven method)

Two categories of selected events for $gg \to bb\Phi$ production

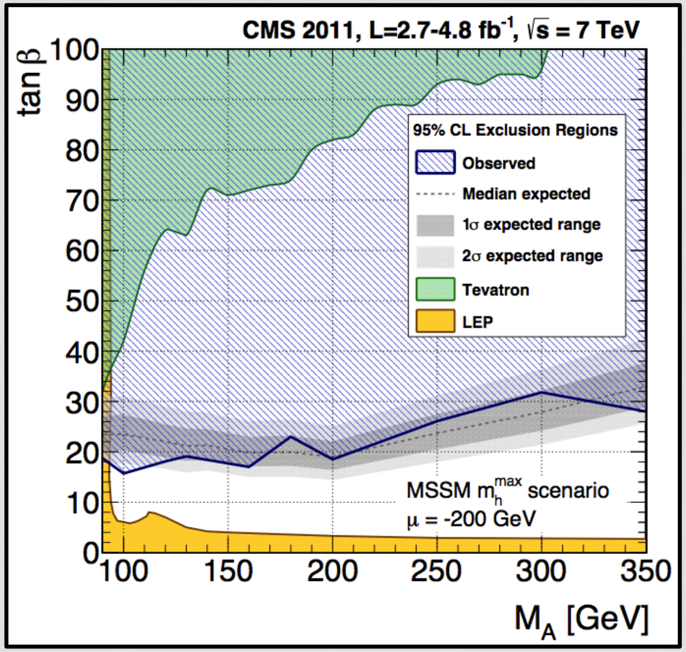
- All hadronic : three b-tagged leading jets (sorted by p_T)
- Semileptonic : two b-tagged leading jets + a muon

$p_T > 15$ GeV in a jet

Signal extraction from a peak in the di-jet mass M_{12}

No signal over the expected SM background

Upper limits reach as low as $\tan\beta \sim 18$ for $m_A \sim 100$ GeV in the MSSM m_h^{max} scenario (at 95% CL.)

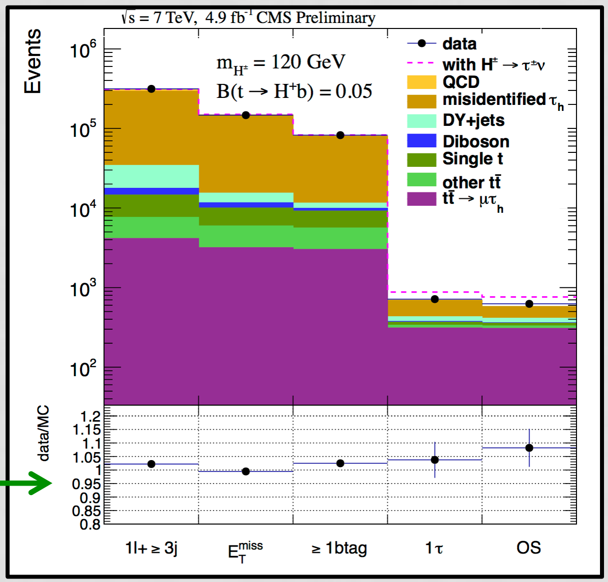


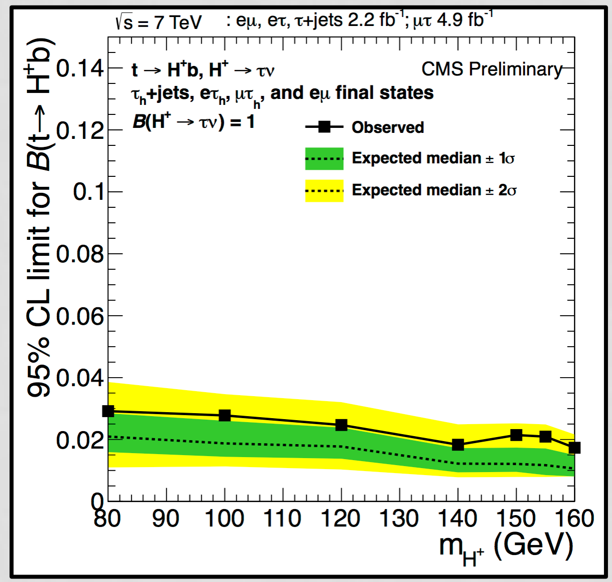
MSSM $H^+ \rightarrow \tau^+\nu$

CMS PAS HIG 11-019
&
CMS PAS HIG 12-052

Dominant decay mode for light $H^\pm$ ($m_{H^\pm} < m_{top}$) and $\tan\beta > 5$

Combined result of 4 final states : τ_h+jets, $e\tau_h$, $e\mu$ and $\mu\tau_h$





data/MC agree well
no excess over SM prediction

Upper limits on $Br(H^\pm \rightarrow \tau^\pm\nu)$ between 2-3% for Higgs mass 80-160 GeV assuming $Br(H^\pm \rightarrow \tau^\pm\nu) = 1$

“NMSSM Higgs”

Higgs sector of NMSSM

Next to Minimal Supersymmetric Standard Model

- NMSSM superfields = MSSM superfields + Higgs superfield singlet $\hat{S}$
- solve "μ-problem" of MSSM
- requires less fine-tuning

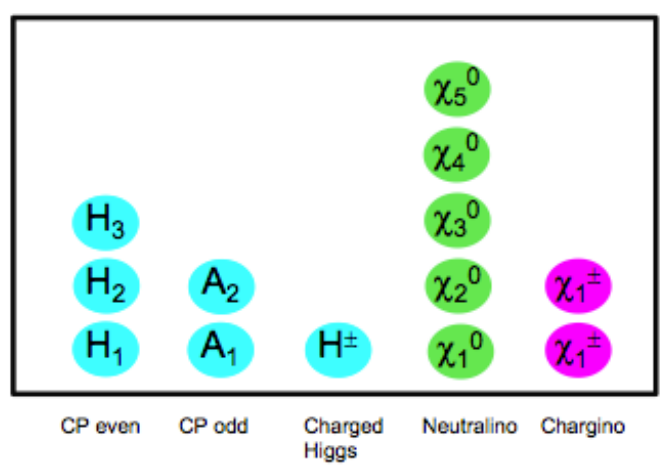
Additional two Higgs boson from singlet $\hat{S}$

- seven physical Higgs bosons

5 neutral Higgs : 3 CP-even $h_{1,2,3}$, CP-odd a_1 a_2

($m_{h1} < m_{h2} < m_{h3}$) and ($m_{a1} < m_{a2}$)

2 charged Higgs : $H^{\pm}$



A fifth neutralino. compared to four in MSSM

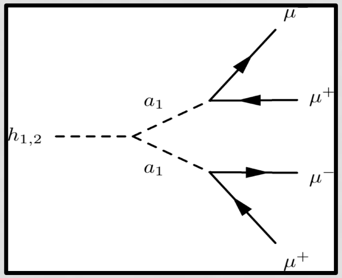
$\mathbf{H \rightarrow 2a + X \rightarrow 4\mu + X}$

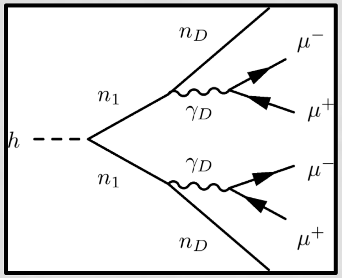
CMS PAS HIG 13-010

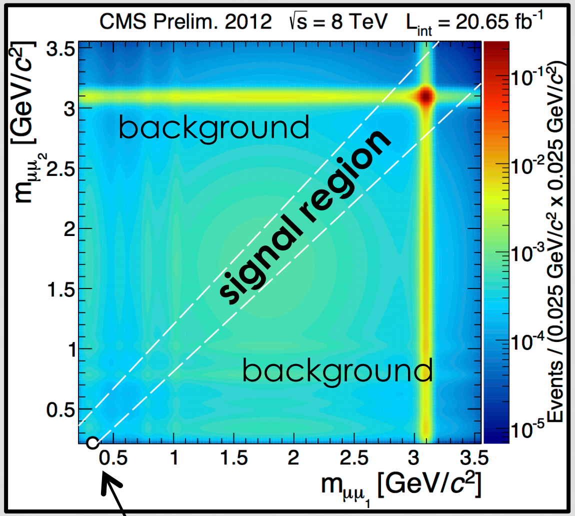
Search of a non-SM Higgs decays to two new light bosons, each decays to dimuon pair.

Two models interpretation

- NMSSM benchmark $h_{1,2} \rightarrow 2a_1 \rightarrow 4\mu$
- Dark SUSY benchmark $h \rightarrow 2n_1 \rightarrow 2n_D + 2\gamma_D \rightarrow 2$







observed 1 event w.r.t

3.8 ± 2.1 expected SM background

Analysis strategy

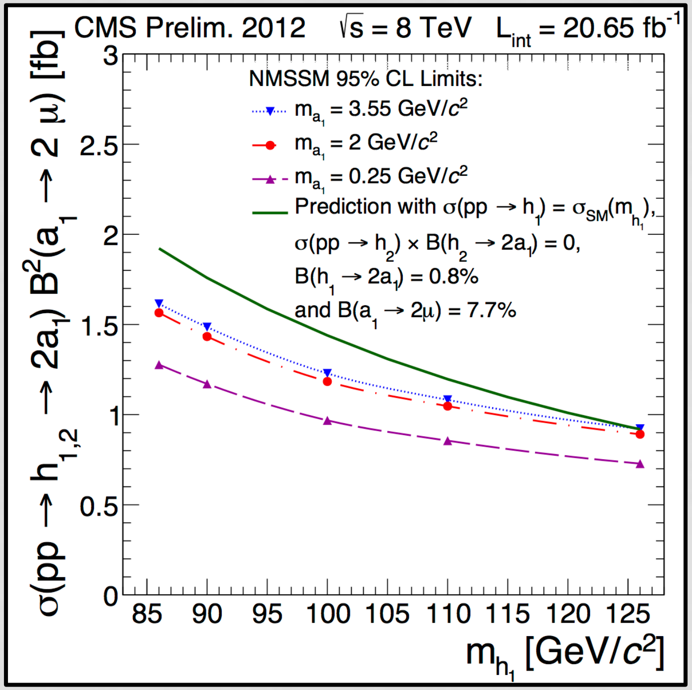
- $\geq$ 1 muon $p_T > 17$ GeV $|\eta| < 0.9$ (central region) +
  $\geq$ 3 muons $p_T > 8$ GeV $|\eta| < 2.4$
- grouped 2 opposite charged muons with $m_{\mu\mu} < 5$ GeV
- two dimuons from same pp collision $|z_{\mu\mu 1} - z_{\mu\mu 2}| < 0.1$ cm
- diagonal signal region : $|m_{\mu\mu 1} - m_{\mu\mu 2}| < 5\sigma$ ($m_{\mu\mu 1} \approx m_{\mu\mu 2}$)

Main backgrounds from bb, J/ψ and pp → 4μ

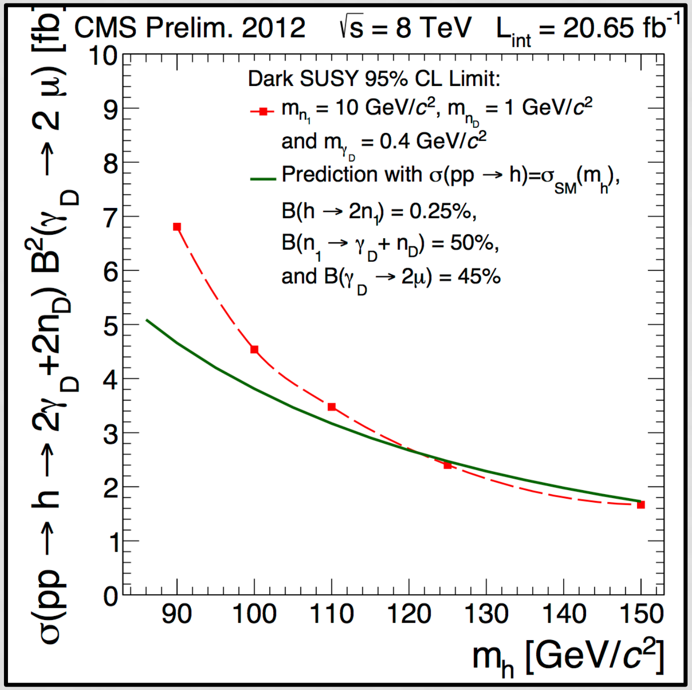
$H \to 2a + X \to 4\mu + X$

CMS PAS HIG 13-010

"NMSSM"



"Dark SUSY"



95% CL. Upper limit on the Higgs boson production in NMSSM and Dark SUSY as functions of h_1 or h Higgs boson mass

Summary

- A large amount of non-SM Higgs searches has been presented using data collected with the CMS detector during LHC Run I

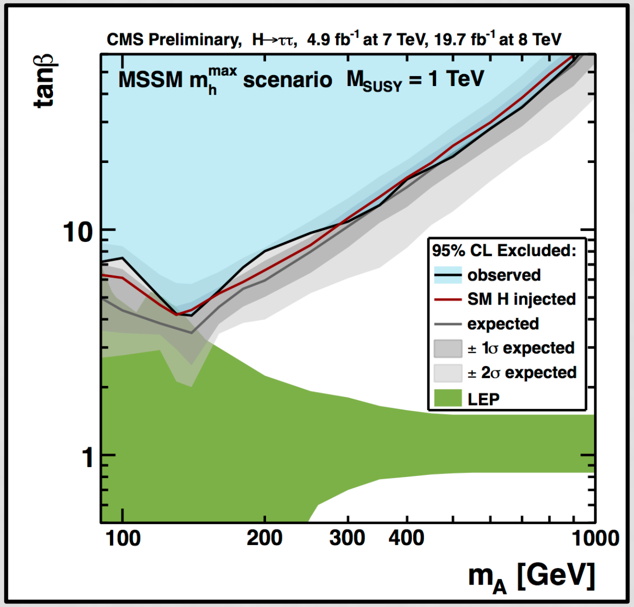
- No sign of new physics so far

- Stay tuned for LHC Run II!

BACKUP

MSSM $\Phi \rightarrow \tau\tau$

CMS PAS HIG 13-021



Zoom