BSM Higgs Physics at the CMS Experiment

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(for the CMS collaboration)

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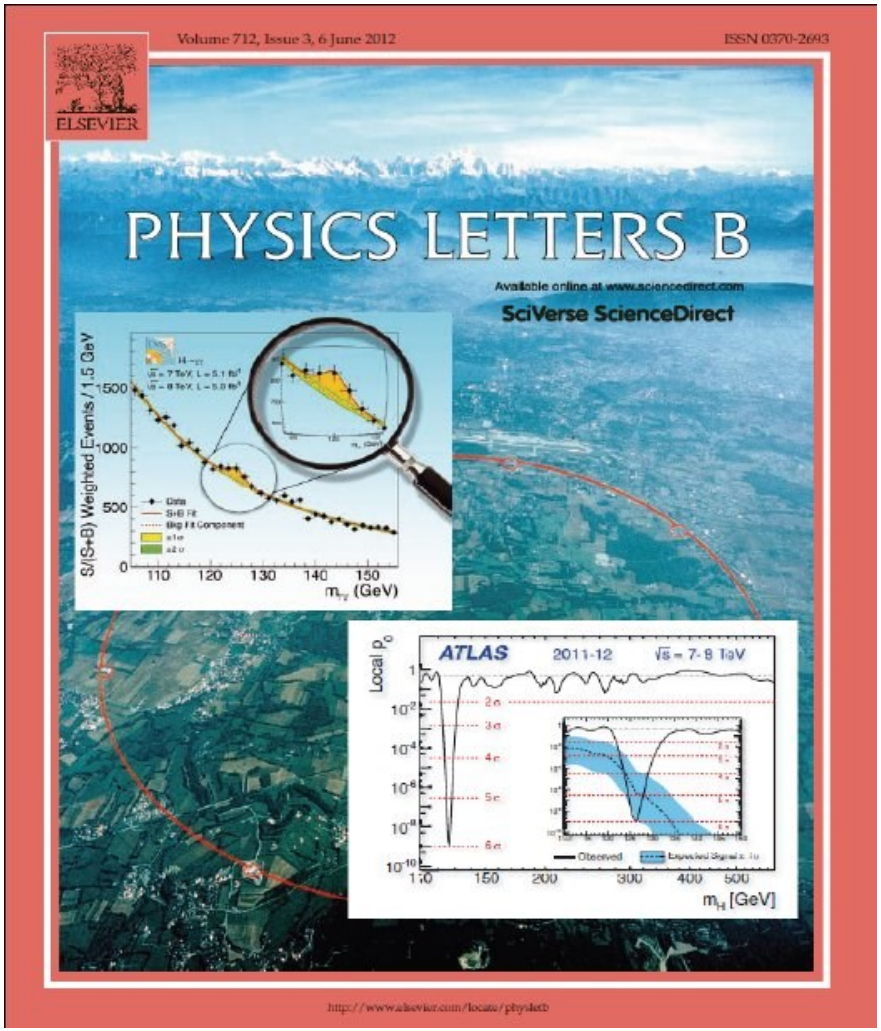
Outline

- The BSM Higgs Sector
- LHC and CMS detector
- MSSM Higgs searches
- LFV Higgs Decays
- Invisible Higgs Decays
- Summary and Outlook

**Higgs is a journey,
not a destination**

Higgs Boson Discovery

Great achievement to a four decade long quest
A Higgs-like state pinned down at 125 GeV mass



Higgs Story So Far

- We know it exists! Phys. Lett. B 716 (2012) 30
- We know its a boson.

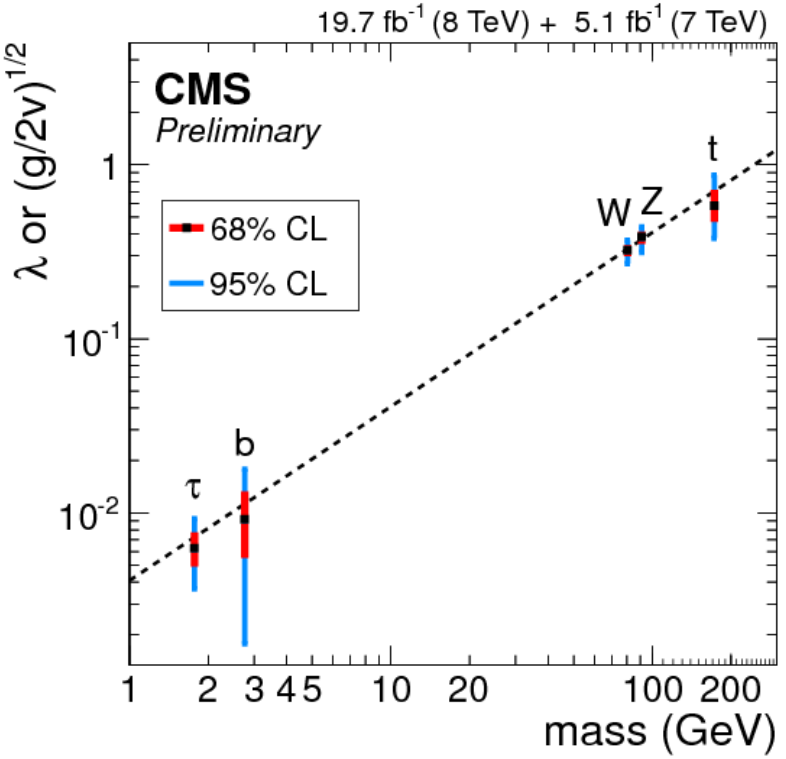
- We know its mass : CMS PAS HIG-14-009

$$m_H(\text{CMS}) = 125.03\ ^{+0.26}_{-0.27}\ (\text{stat})\ ^{+0.13}_{-0.15}(\text{syst})$$

- We have strong evidence that it couples to fermions Nat. Phys. 10 (2014) 557
  Couplings are determined within 15 to 20% accuracy, leaving room for BSM physics

- We have reasons to believe that it is a spin 0 CP even object
  Phys. Rev. D 89 (2014) 092007

- We know it's a Higgs boson!



Is this **THE Higgs** boson (of the SM) or is it just **A Higgs** boson?

BSM Higgs

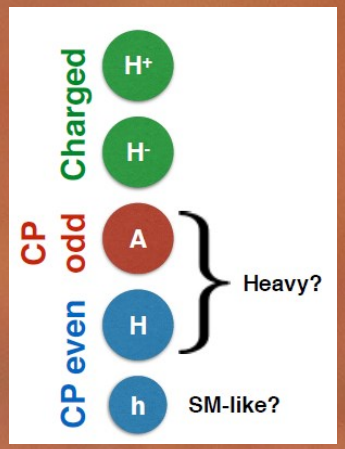
- Run I searches covered a large range of BSM Higgs boson signatures

- LHC is the discovery machine
  → the adventure in the TeV energy regime has just begun

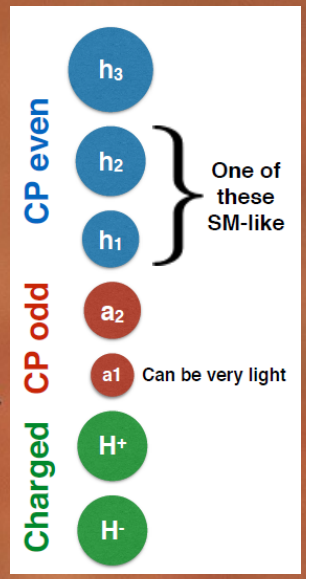
Lepton Flavour Violating Higgs Decays

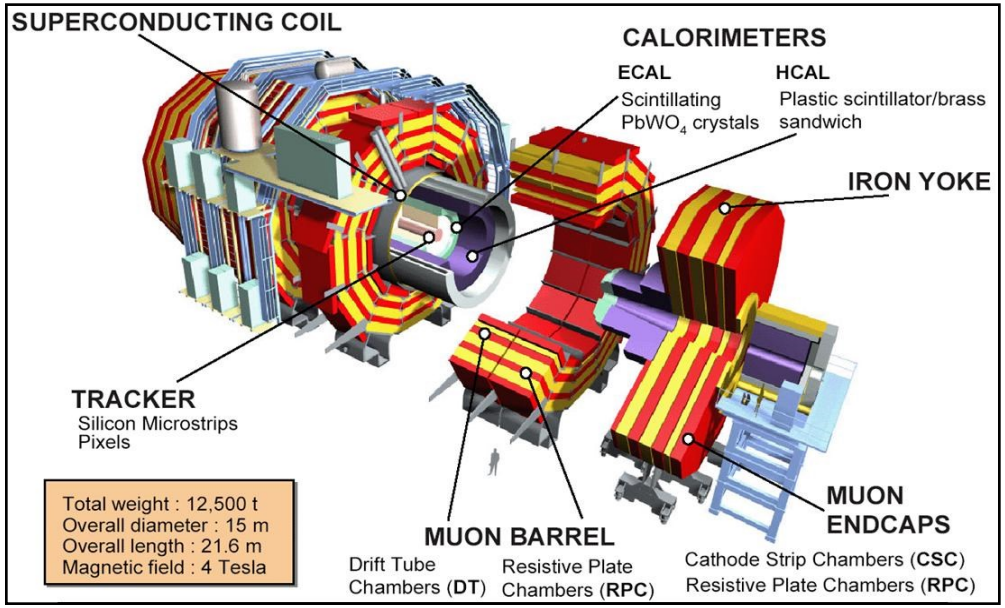
Invisible Higgs Decays

MSSM / 2 HDM

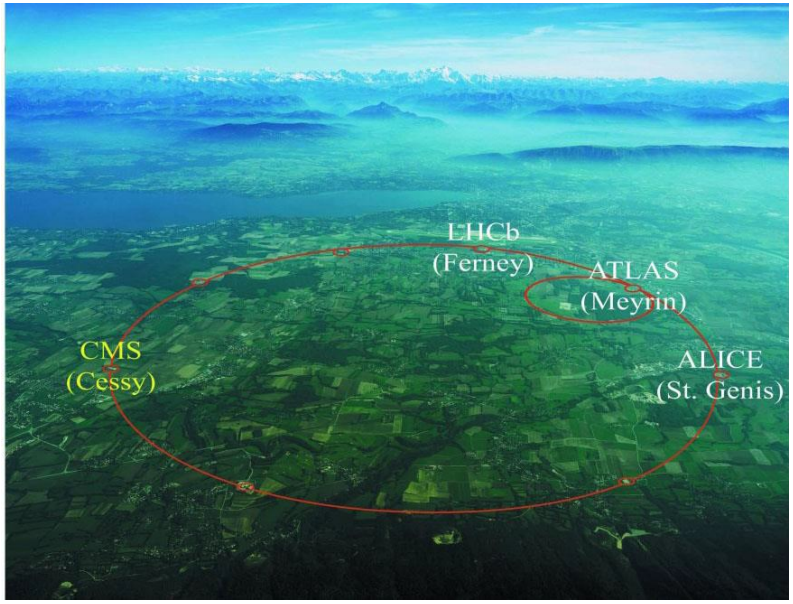


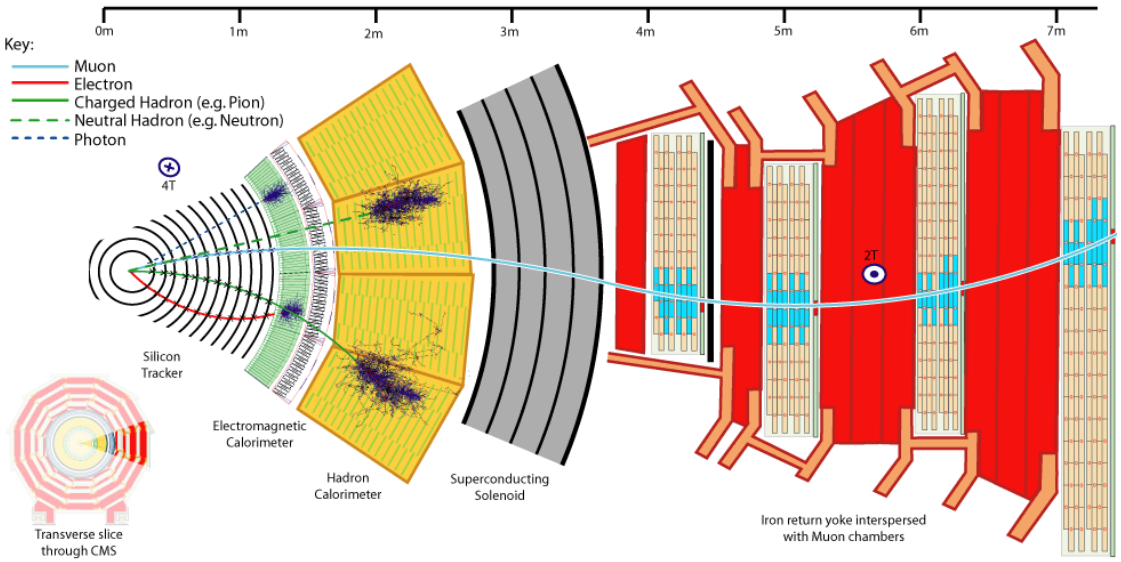
Next-to-MSSM (NMSSM)



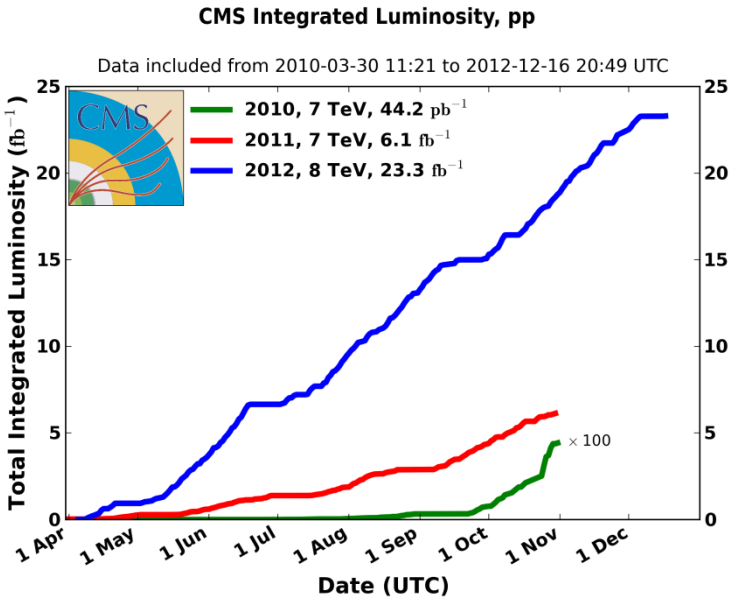


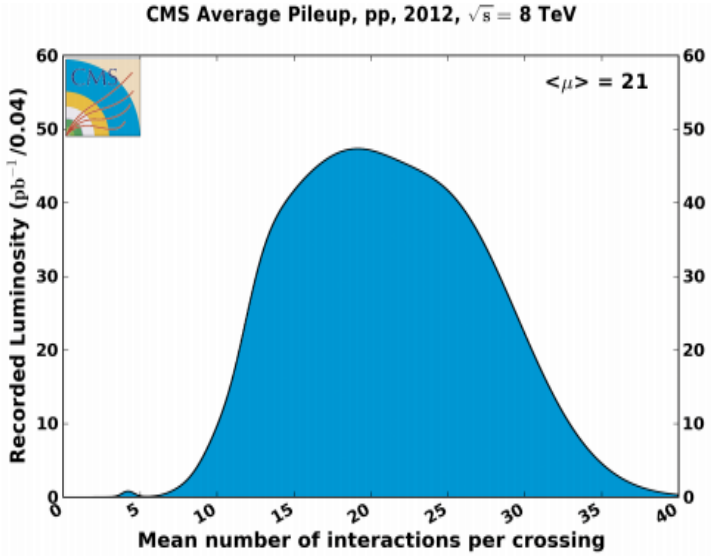
Accelerator, Detector and Physics Objects

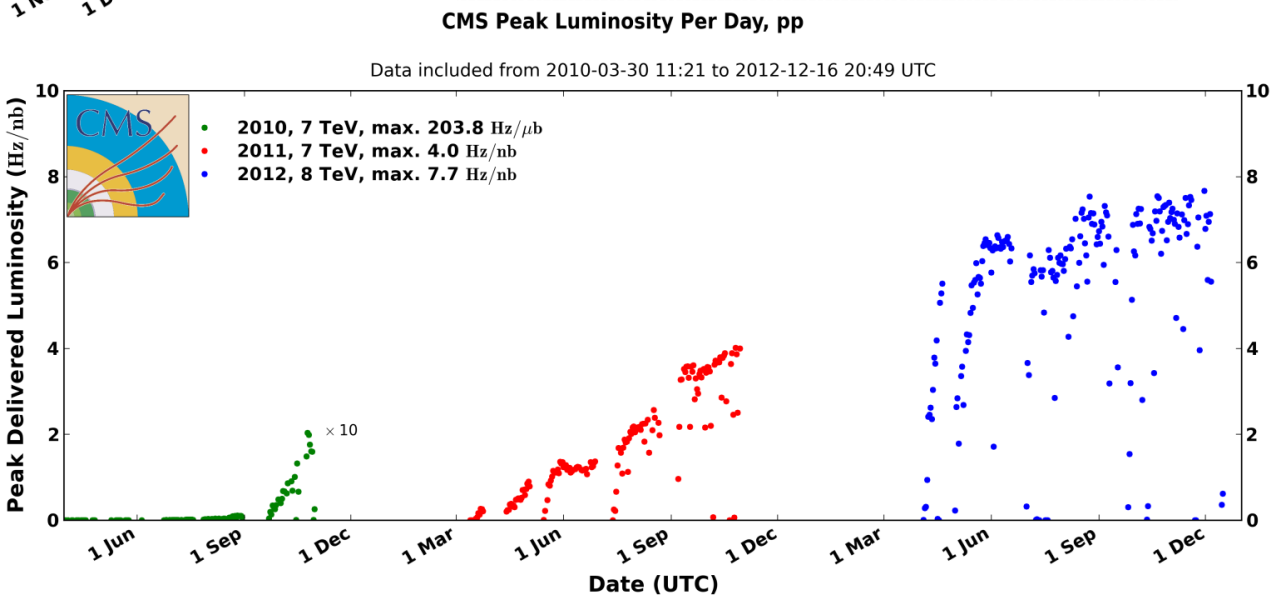




The LHC







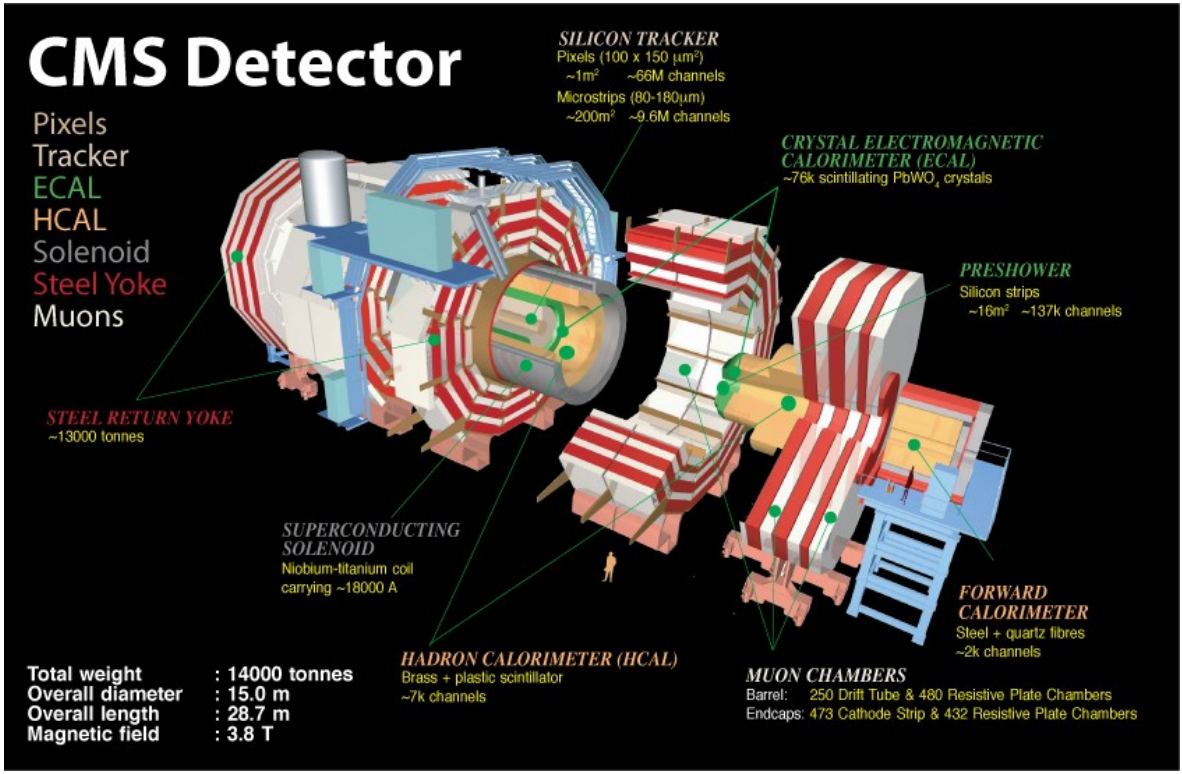
Overall data taking efficiency ~ 91%

3.8 T superconducting solenoid envelop:

- Tracker (silicon pixel and strip detectors) $|\eta| < 2.5$
- ECAL ($PbWO_4$ crystals)
- HCAL (brass/scintillator samplers)

  Barrel $|\eta| < 1.48$
  Endcap $1.48 < |\eta| < 3.0$

- Muon Chambers – gas ionization detectors embedded in steel return yoke outside the solenoid, $|\eta| < 2.4$
  Drift Tubes, Cathode Strips and Resistive Plate Chambers

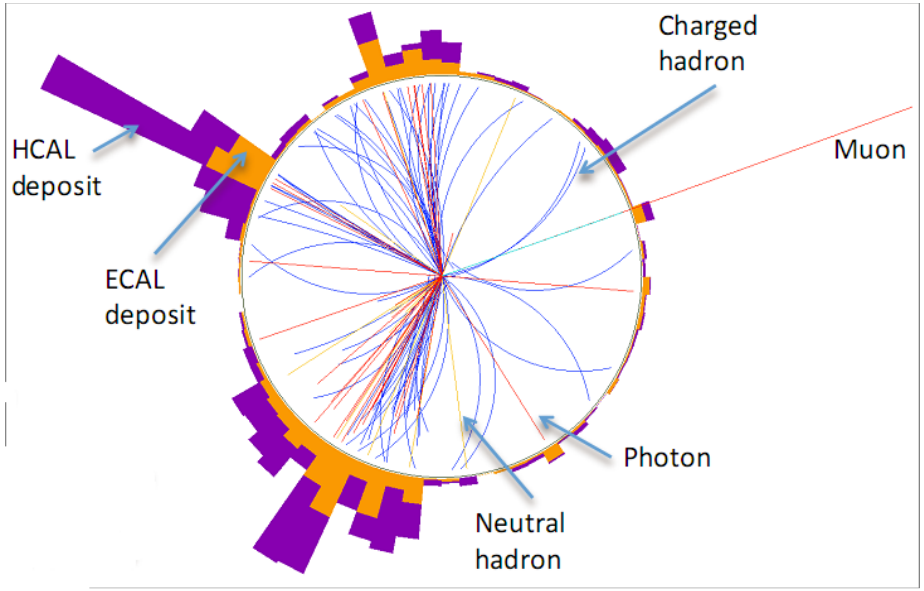


Particle Flow Technique

⇒ Event description in form of mutually exclusive particles

⇒ identification of all stable particles
produced in the event

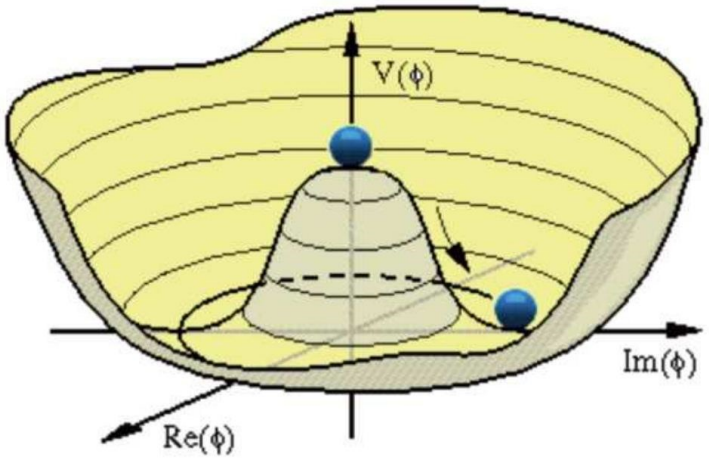
⇒ combining capabilities of each sub-detector
most precise measurement
of the energy and direction for each particle



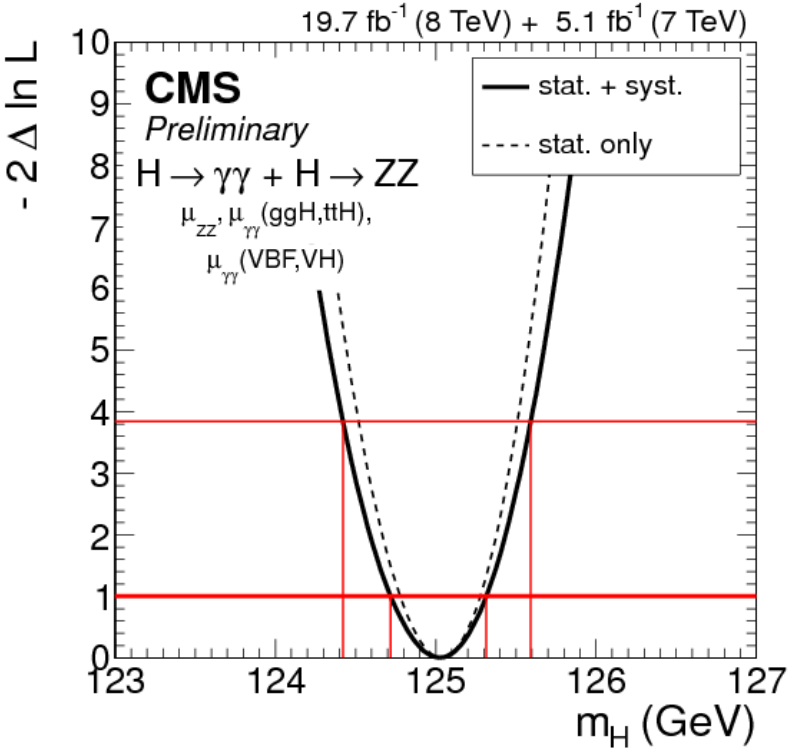
⇒ individual measurements combined
by a geometrical linking algorithm,
e.g. extrapolating a charged-particle track into ECAL and HCAL
particle ID on blocks of linked elements

Physics object reconstruction utilises this technique, excellent performing even at high pileup

Higgs in MSSM / 2HDM



125 GeV Higgs : Interpretation on MSSM

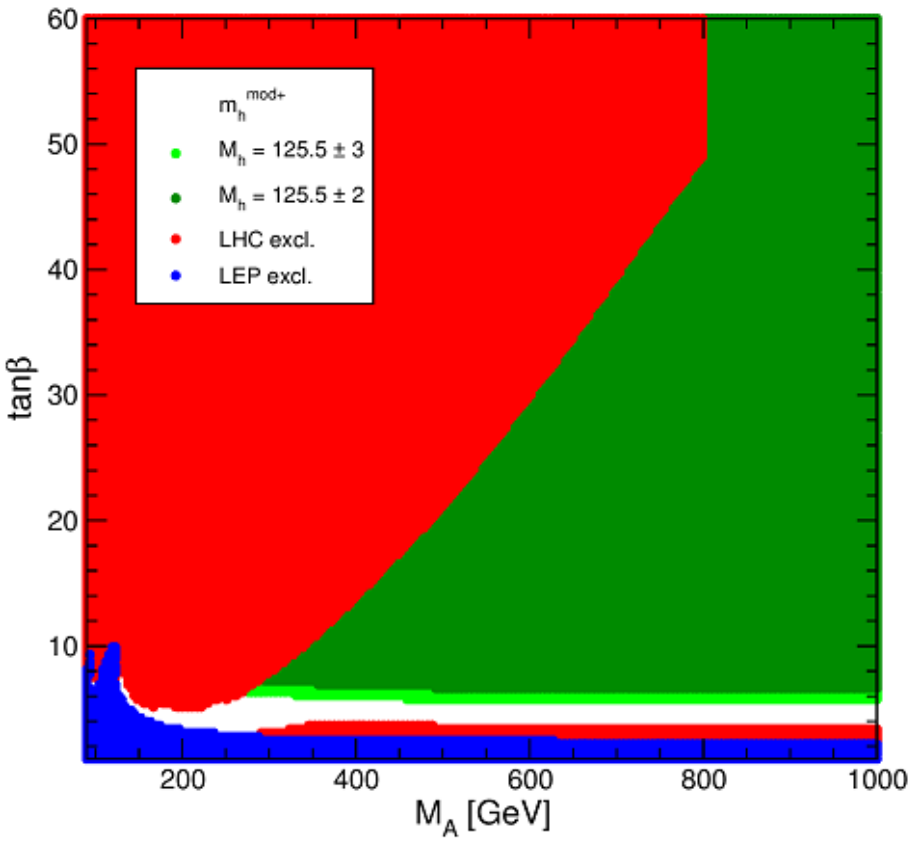


The mass value 125 GeV is rather large for the MSSM light h boson

Maximizing M_h is maximizing the radiative corrections at 1-loop level

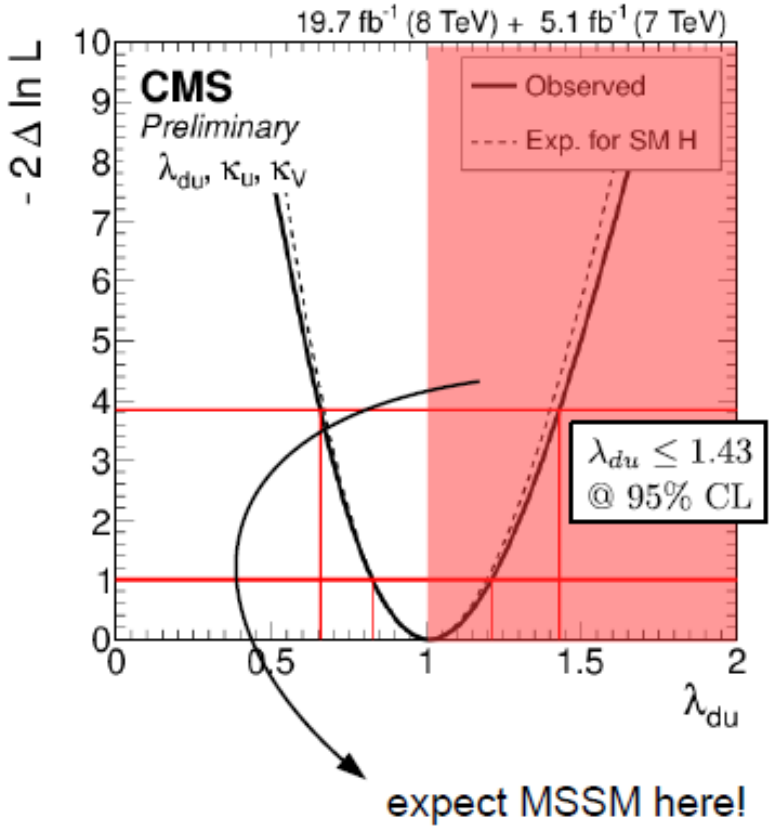
The stop mass scale M_{SUSY} ~ 1 TeV

M. Carena et. al. , arXiv:1302.7033 [hep-ph]



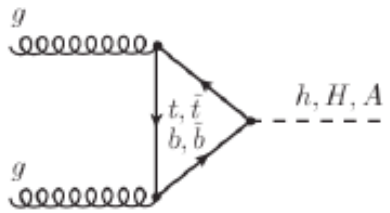
A new MSSM m_h benchmark scenario introduced – consistent with H(125)

- In MSSM coupling to down-type fermions enhanced for $\tan\beta \gg 1$.

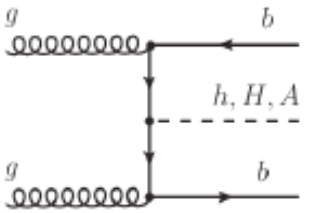


- Interesting decay channels:
  - $H \to \tau\tau$ ($\hat{\kappa}_\tau = 0.84^{0.19}_{0.18}$)
  - $H \to bb$ ($\hat{\kappa}_b = 0.74^{0.33}_{0.29}$)

- Interesting production modes:



$gg \to H$ ("$gg\phi$")



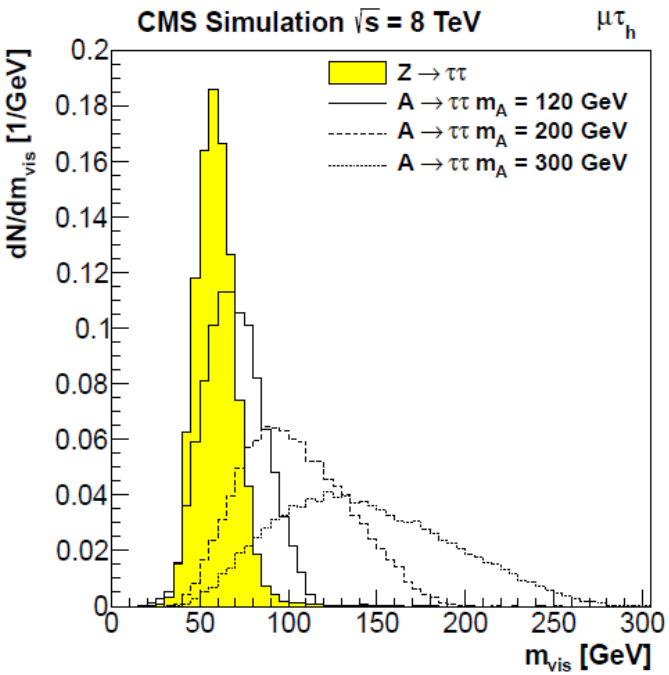
$gg \to Hb\bar{b}$ ("$bb\phi$")

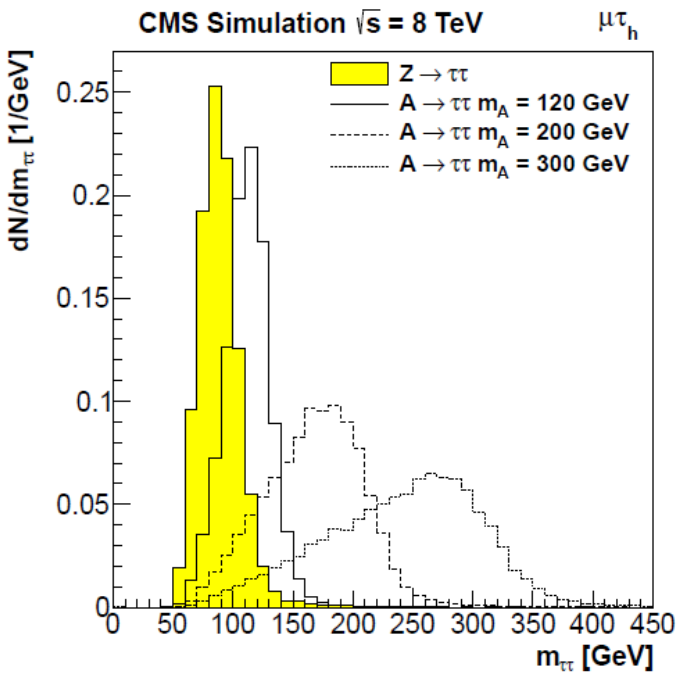
CMS-PAS-HIG-14-009

Mass of τ lepton pair reconstructed via a **Likelihood technique**, based on:

- τ decay kinematics
- Compatibility of reconstructed E_T^{miss} with neutrino hypotheses

Tau pair mass is the obvious observable to discriminate Z boson from the Higgs signal





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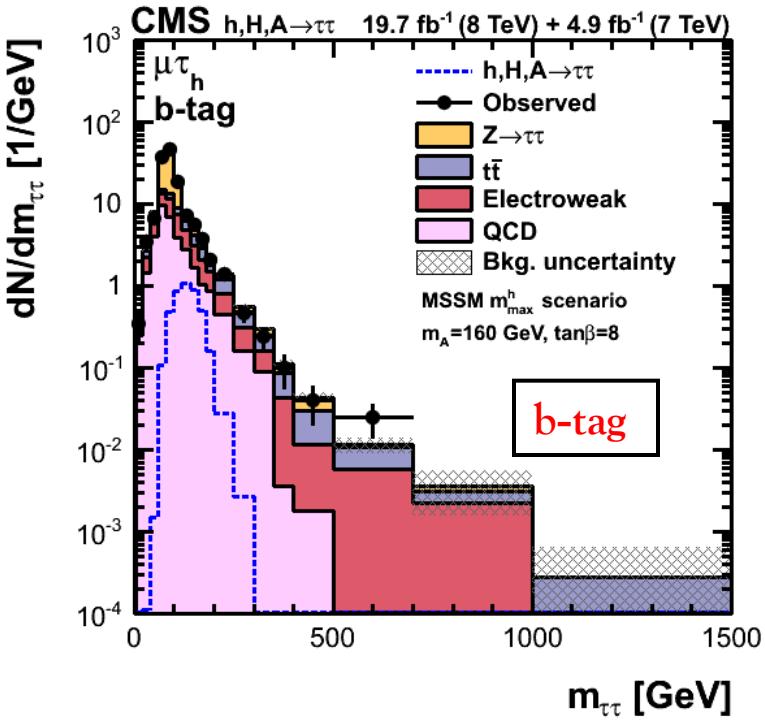
Decay final states : $\mu + \tau_h$, $e + \tau_h$, $\mu + e$, $\mu\mu$, $\tau_h + \tau_h$
Selected Events analyzed in 2 Categories: b-Tag and non-b-Tag
(to enhance sensitivity of $bb\Phi$ coupling)
B-tagging : based on secondary vertex + track-based life-time info

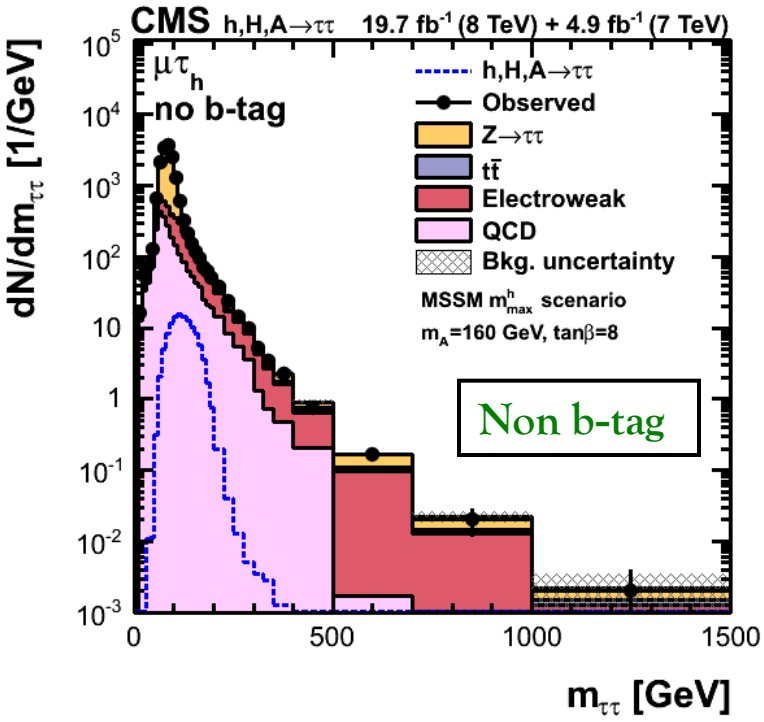
- b-tag :

≤ 1 jet with p_T > 30 GeV,
≥ 1 b-tagged jet with p_T > 20 GeV

- Non b-tag :

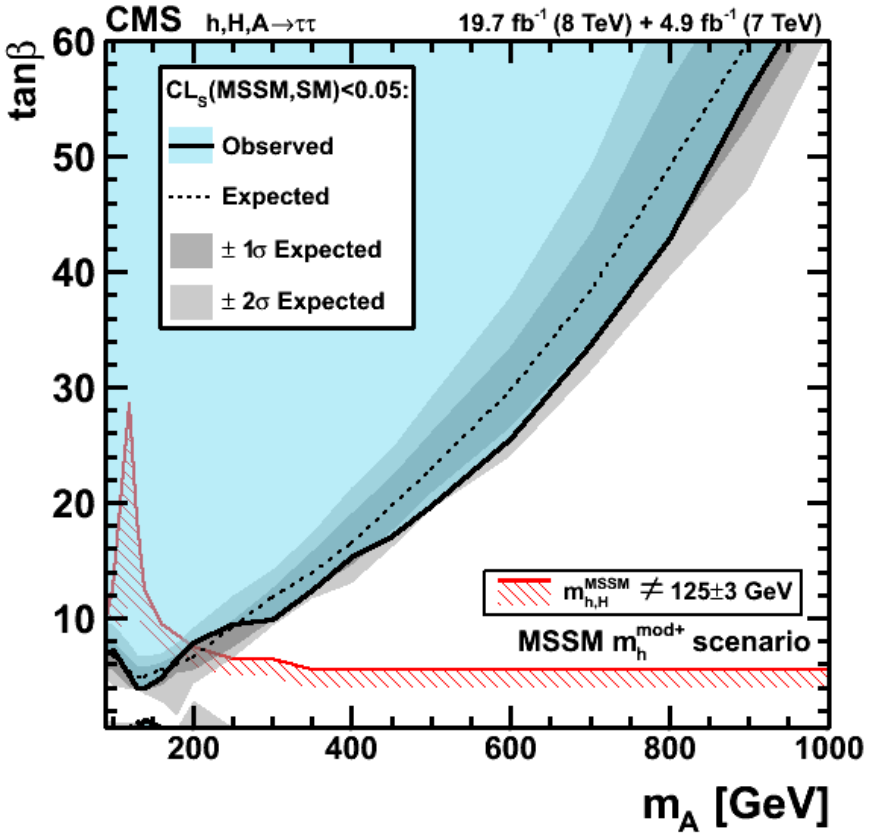
≤ 1 jet with p_T > 30 GeV,
No b-tagged jet with p_T > 20 GeV





Neutral MSSM Higgs

https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13021PaperTwiki

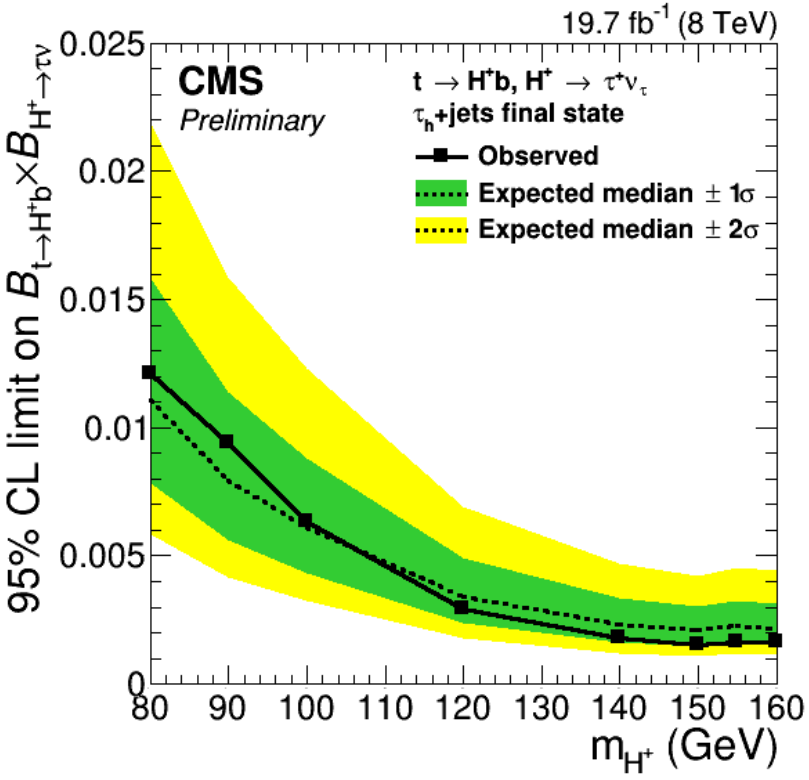


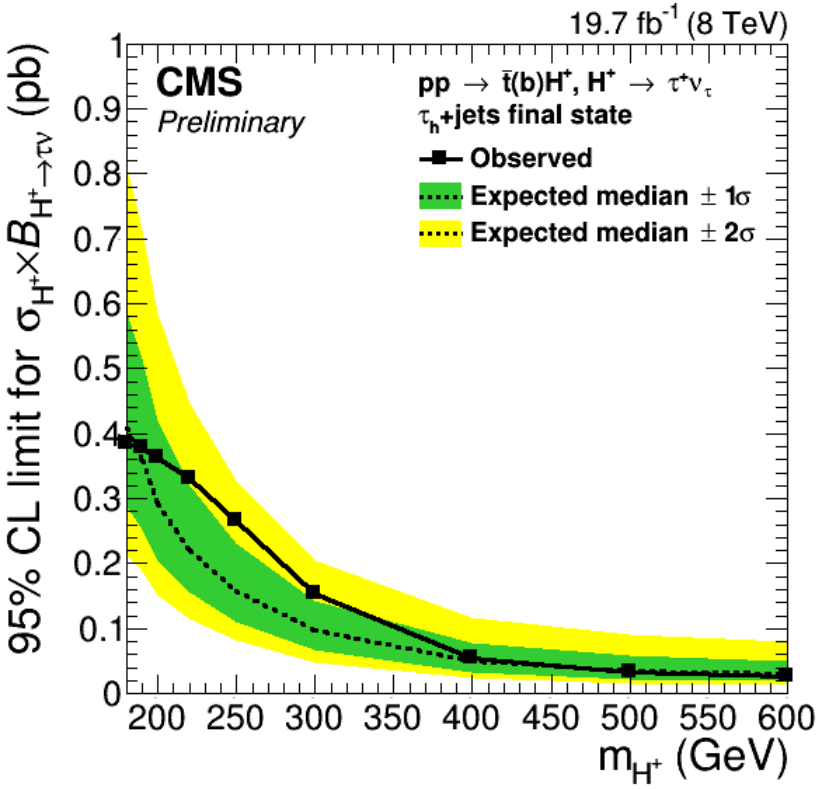
95% CL upper bound on cross-section x $\mathcal{Br}$ ($\Phi \to \tau\tau$) – based on the mass shape of $m_{\tau\tau}$ distribution mapped to m_A – tanβ plane (4FS + 5FS)

Uncertainties –

- Theory
- Normalization (Lumi, Efficiencies)
- Shape (Energy scale)

This excludes previously unexplored region:
now reaching as low as tan β ~ 3.9 at m_A = 140 GeV



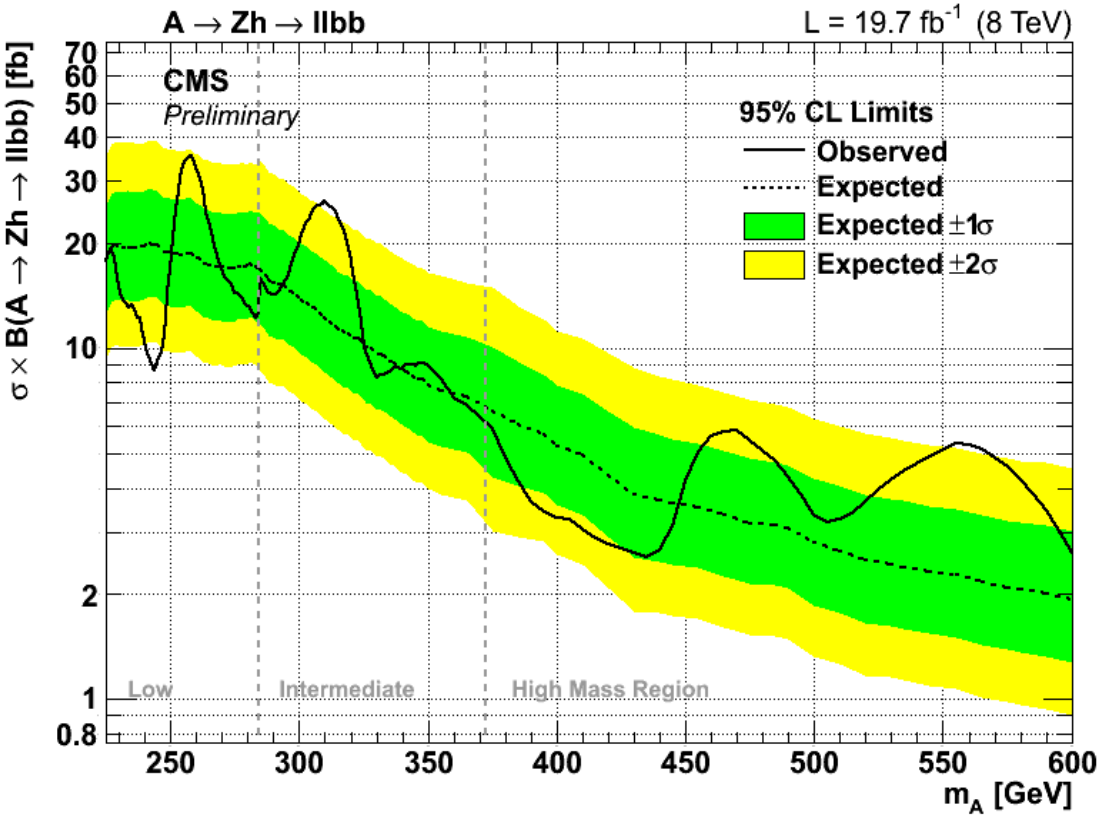


charged Higgs boson search in: **CMS PAS HIG-14-020**

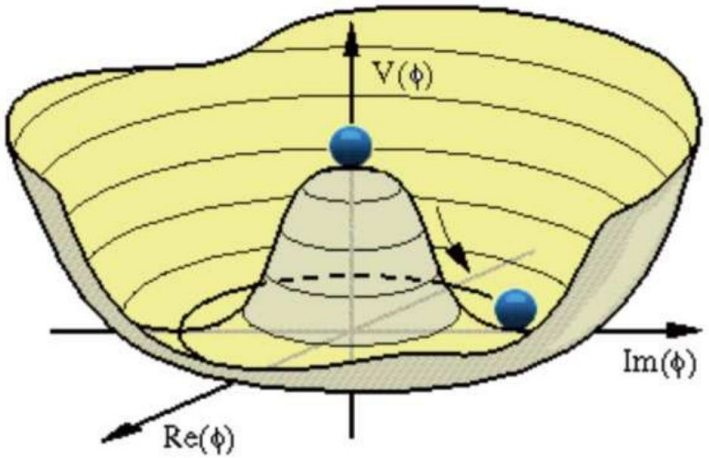
tt-bar → $H^{\pm}$Wbb process for charged Higgs boson mass lighter than Δm(top-bottom)
pp→$H^{\pm}$tb process for charged Higgs boson mass heavier than Δm(top-bottom)

CMS PAS HIG-14-011

- Pseudoscalar heavy Higgs boson A decaying into a Z boson and a light Higgs boson h
- Z decaying into lepton pair (electrons or muons) and h into a pair of b-quarks
- h assumed SM-like Higgs boson with 125 GeV mass
- Global significance 1.5σ at 560 GeV in narrow width approx assuming width Γ_A= 30 GeV
- Results further interpreted in 2 Higgs Doublet Model scenario

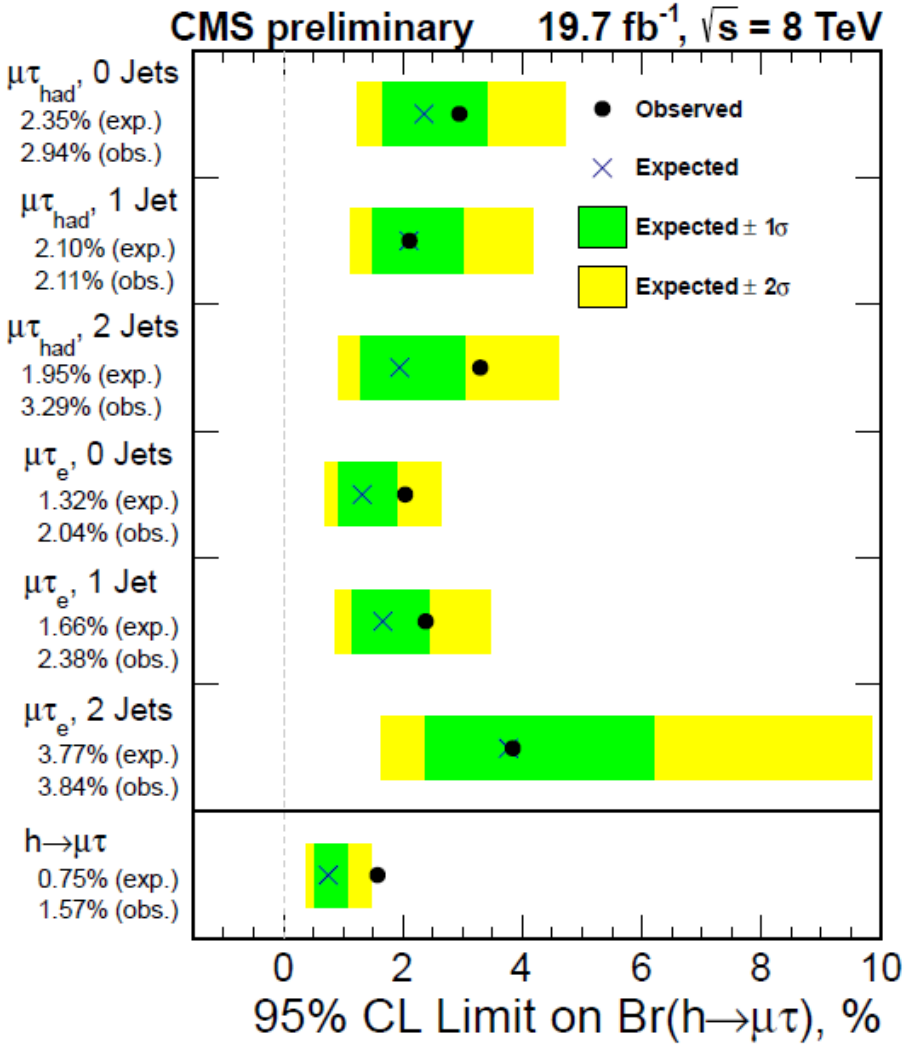


Lepton Flavour Violating Higgs Decays



- Decay modes in $H \rightarrow \mu\tau_e$ and $H \rightarrow \mu\tau_{had}$ channel
- Dominant background in the $H \rightarrow \mu\tau_e$ channel is $Z \rightarrow \tau_\mu\tau_e$
- Dominant background in the $H \rightarrow \mu\tau_{had}$ channel from jets faking taus in W+jets, QCD multi-jet and tt+jets events

- Sensitivity is an order of magnitude better than existing indirect limits
- Slight excess of signal events observed with a significance of 2.5σ
- p-value of excess at m_H=126 GeV is 0.007

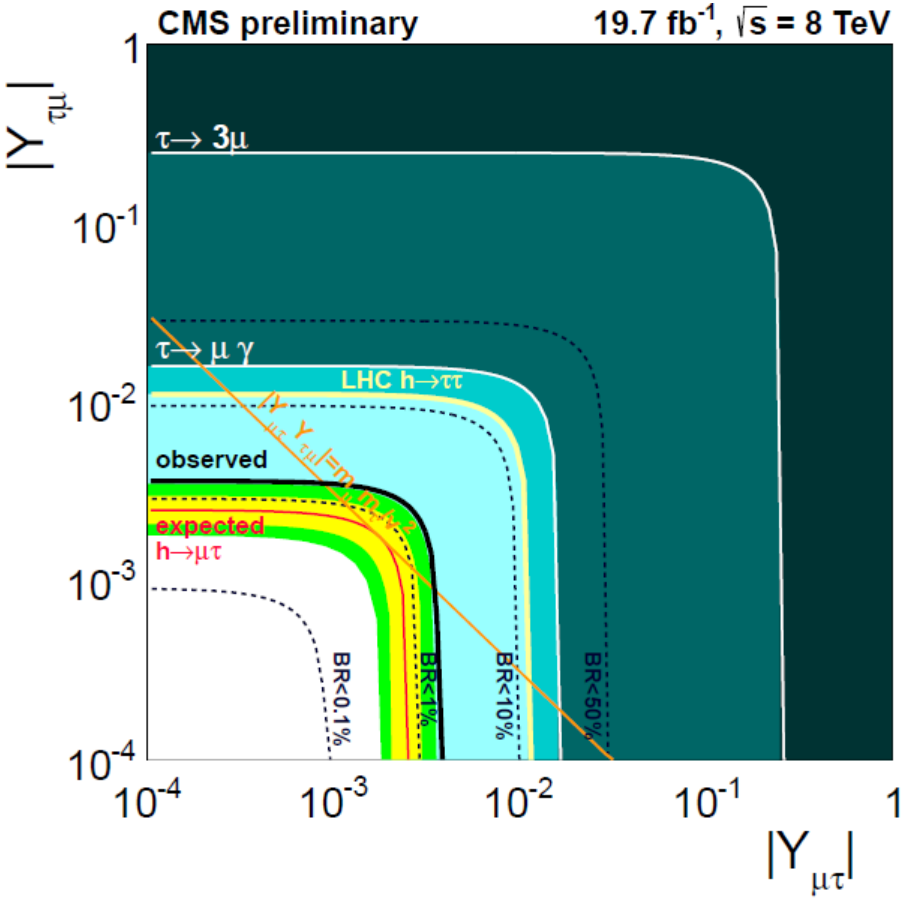


CMS PAS HIG-14-005

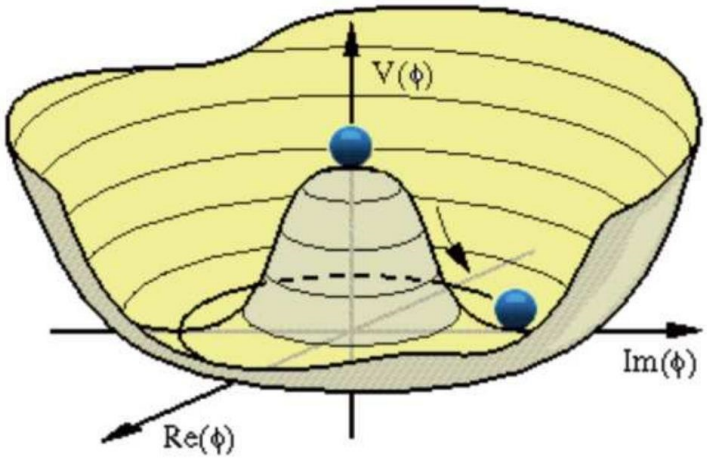
$$B(H \to l^{\alpha} l^{\beta}) = \frac{\Gamma(H \to l^{\alpha} l^{\beta})}{\Gamma(H \to l^{\alpha} l^{\beta}) + \Gamma_{SM}}$$

$$\Gamma(H \to l^{\alpha} l^{\beta}) = \frac{m_h}{8\pi}(|Y_{l^{\beta} l^{\alpha}}|^2 + |Y_{l^{\alpha} l^{\beta}}|^2)$$

- Constraint placed on B(H →μτ) < 1.57% at 95% CL
- The best fit branching fraction is B(H →μτ) = $(0.89^{+0.40}_{-0.37})$%
- The limit is subsequently used to constrain the $Y_{\mu\tau}$ Yukawa coupling



Invisible Higgs Decays



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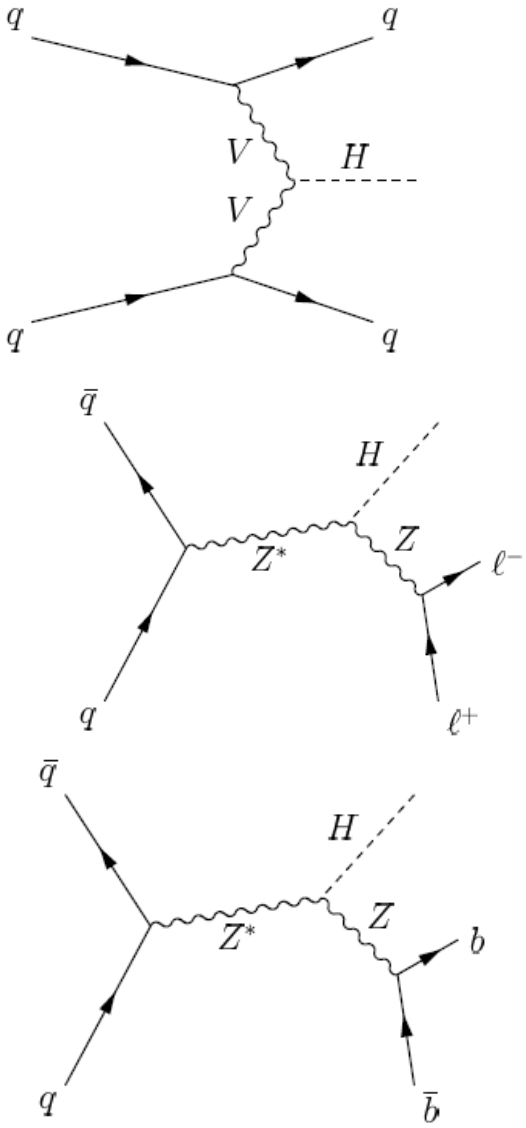

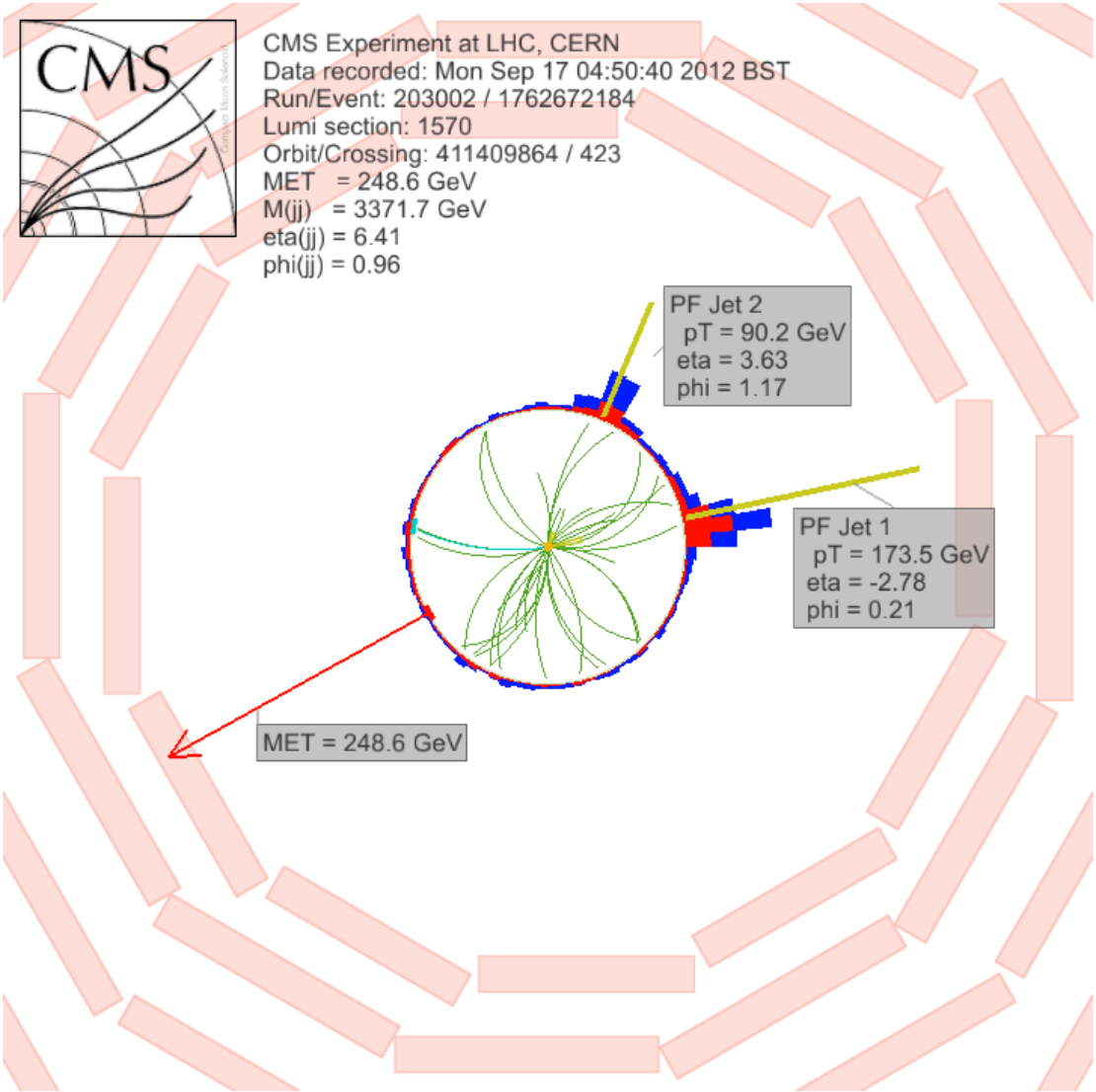

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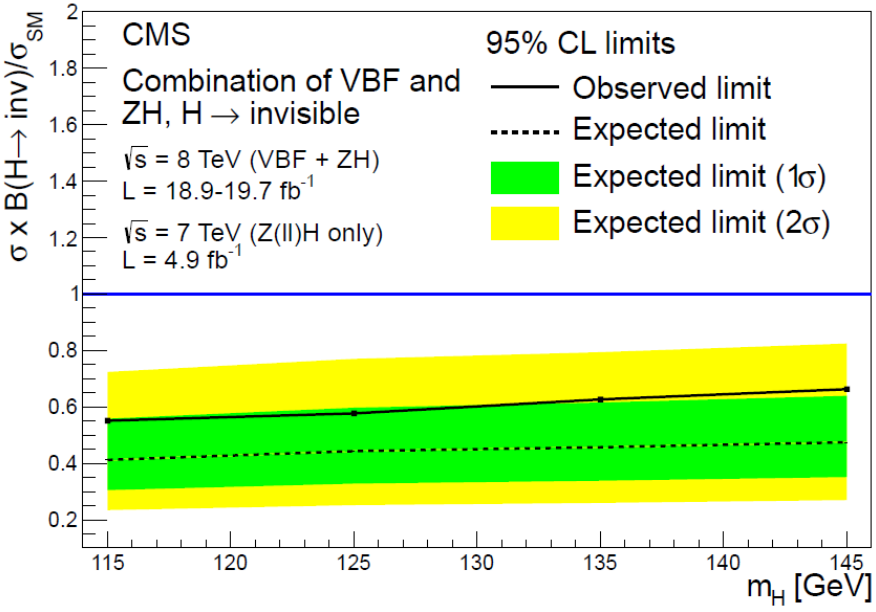
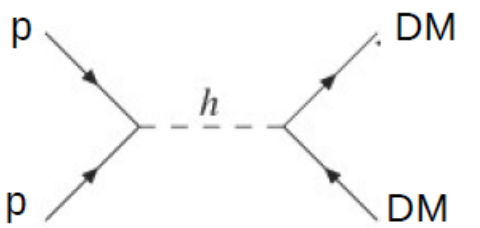


Excluded on 95% CL:

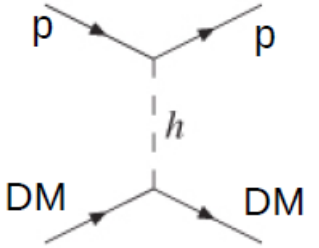
BR(H→inv.) < 0.58 at 125 GeV

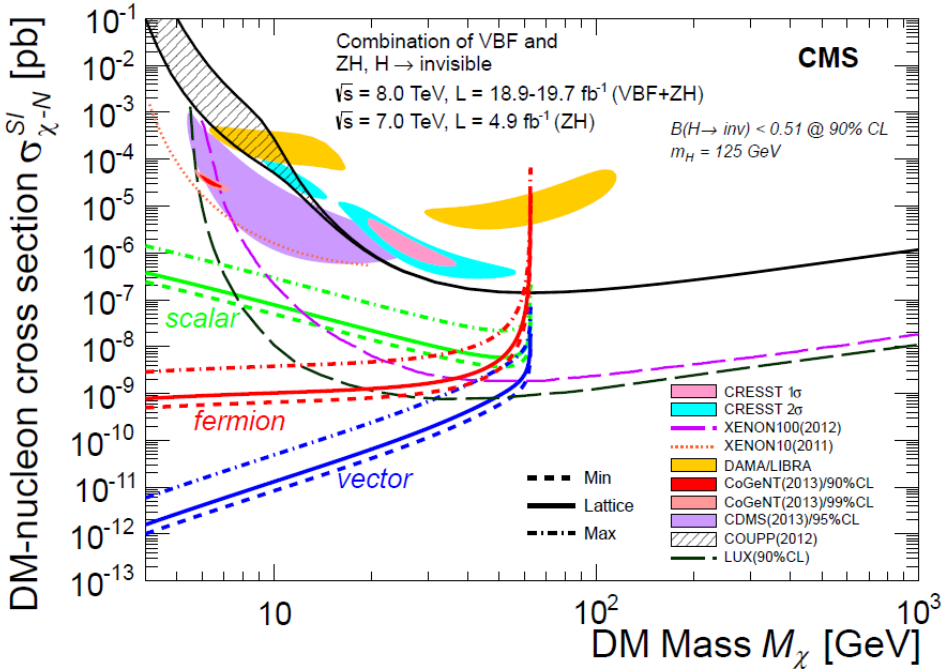
(expected < 0.44)

Measured:



Translate into:





Summary & Outlook

- Higgs Boson @ 125 GeV - avenue of great interest in BSM
- MSSM Higgs parameters significantly constrained with $H \rightarrow \tau\tau$ (different MSSM benchmark scenarios)
- LFV Higgs decays show slight excess at 125 GeV
- Invisible Higgs decays connecting Dark Matter
- NMSSM Higgs searches underway with full run-1 data
- No signal of BSM Higgs spotted so far at LHC
- A robust program for BSM Higgs physics with run-2 data