Higgs Boson in Lepton Decay Modes at CMS

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(for the CMS collaboration)

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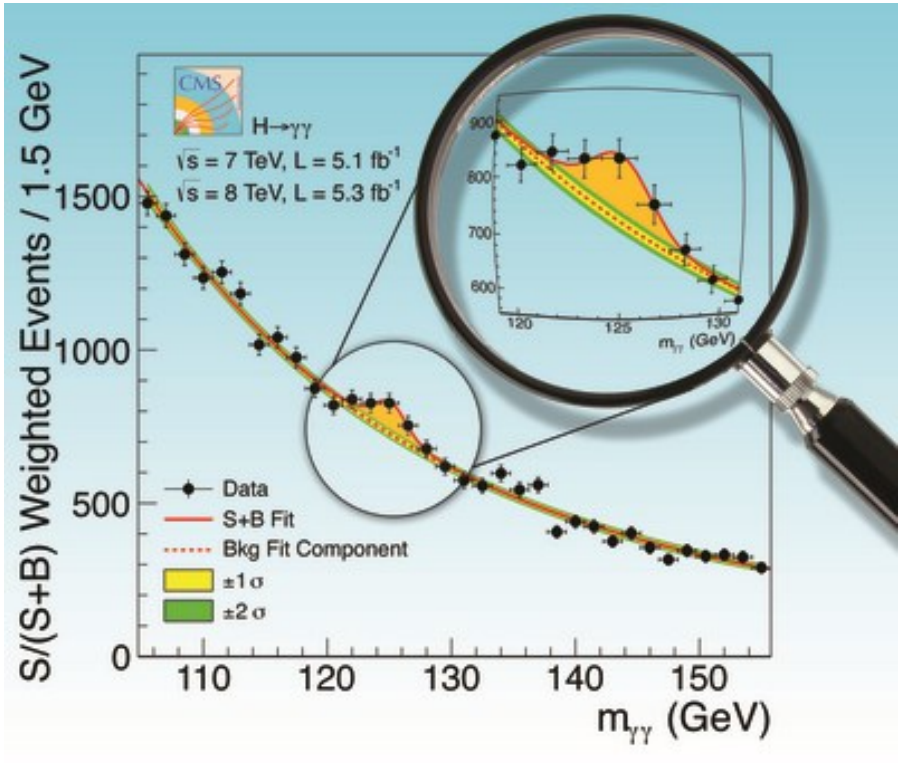
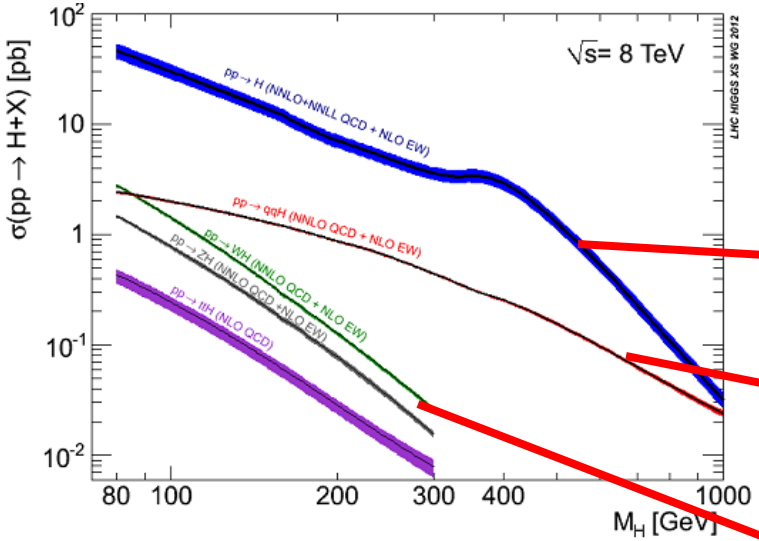


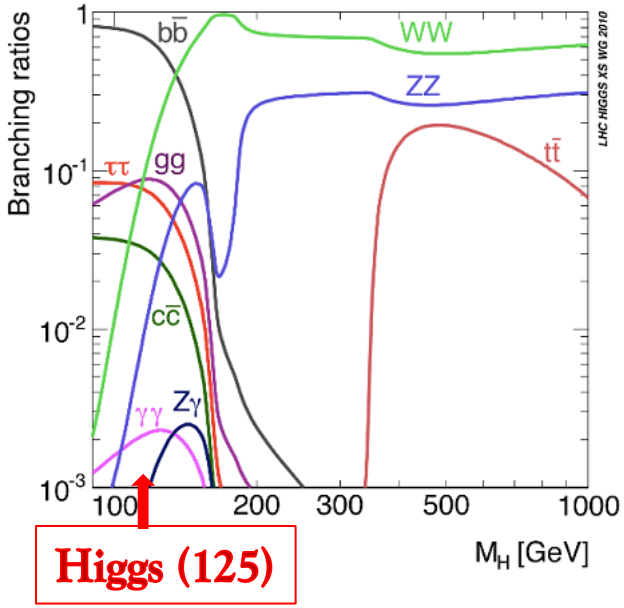
Outline

- Higgs Sector: SM & MSSM
- LHC and the CMS detector
- Higgs to Taus
- Higgs to Muons
- Summary and Outlook

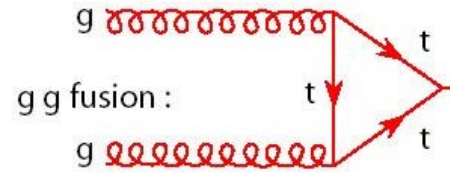
SM Higgs Sector

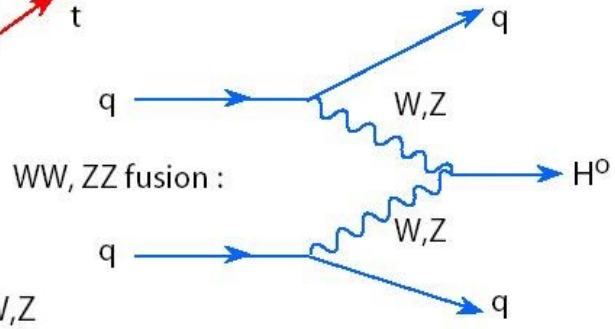
Great achievement to a four decade long quest
A Higgs-like state pinned down at 125 GeV mass

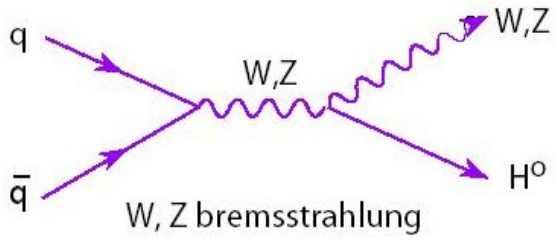




Higgs (125)







- Access to coupling of Higgs field with fermions
- Proportionality between mass and coupling in the fermion sector

Minimal Super- Symmetric Standard Model (MSSM)

Two isospin Higgs doublets

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} \text{ and } H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

2 Higgs doublets each with 4 degrees of freedom

- Coupling bbA ~ tanβ (ratio of the vev of the two doublets) at LO
- Production rate enhanced – high tanβ

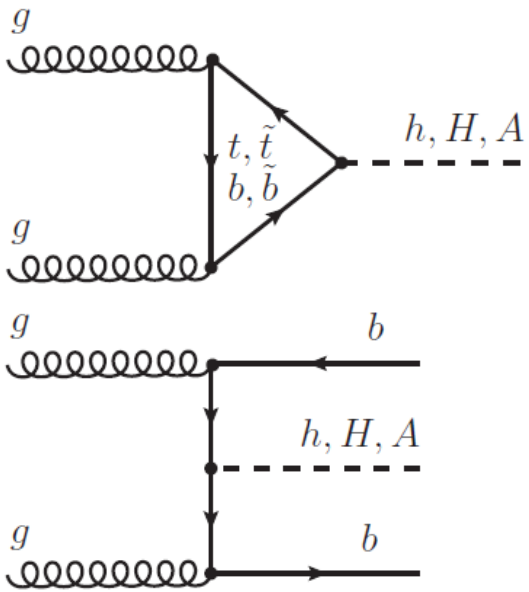
- Φ (h/H/A) decays to b-quark (~ 90%) and τ (~ 10%) pairs enhanced at all masses

- MSSM Higgs production and decays significantly affected by radiative corrections to Higgs mass

- Dominant corrections are due to top/stop at the one-loop level

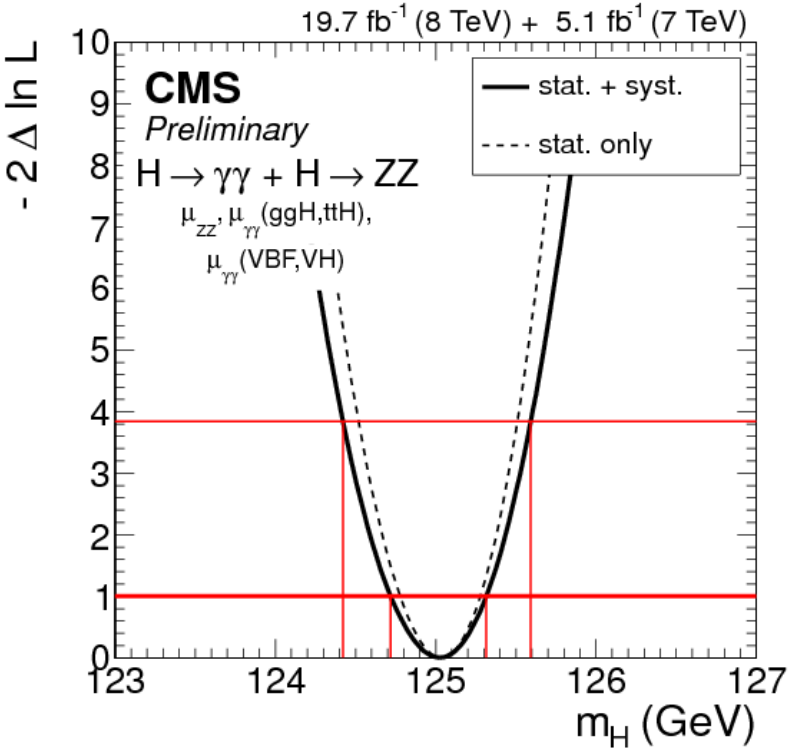
EW symmetry breaking: 5 physical Higgs bosons

Φ
- h, H (scalar, CP-even)
- A (pseudo-scalar, CP-odd)
- $H^{\pm}$ (charged)



2 free parameters (M_A , tan β) in MSSM space
MSSM predicts low mass Higgs $M_h \lesssim 135$ GeV in the m_h^{max} scenario

125 GeV Higgs : Interpretation on MSSM

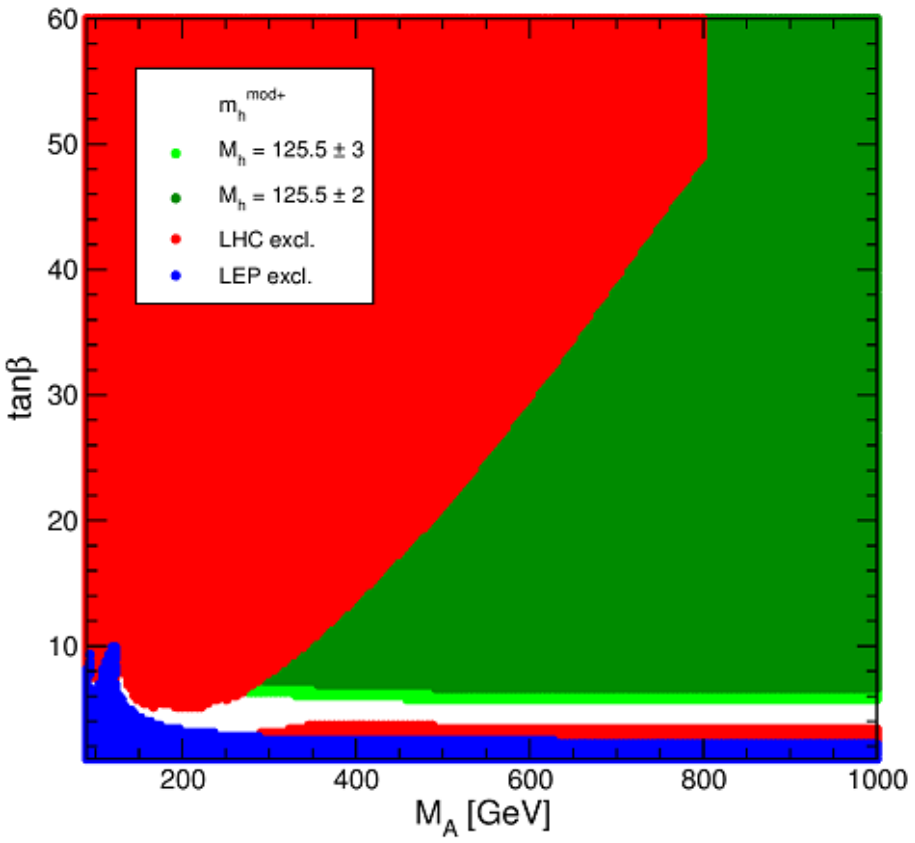


The mass value 125 GeV is rather large for the MSSM light h boson

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

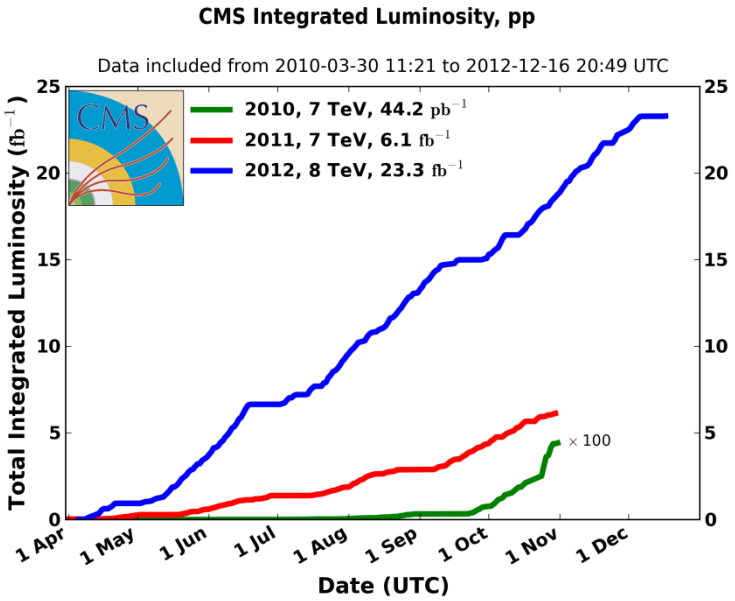
The stop mass scale M_{SUSY} ~ 1 TeV

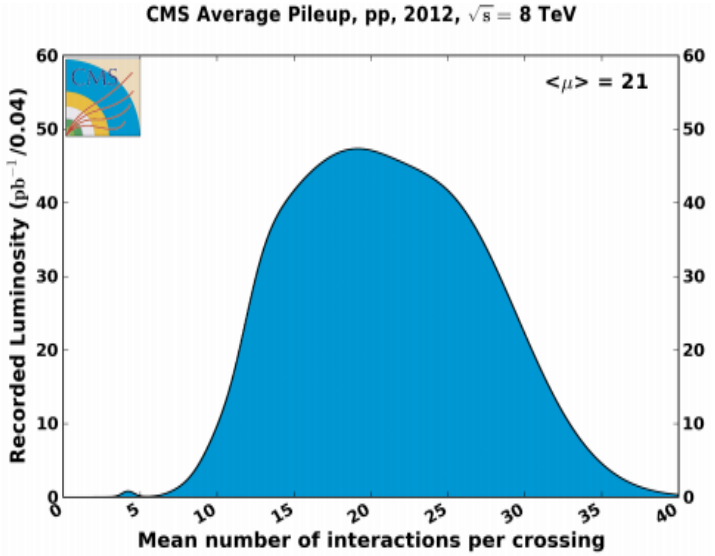
M. Carena et. al. , arXiv:1302.7033 [hep-ph]



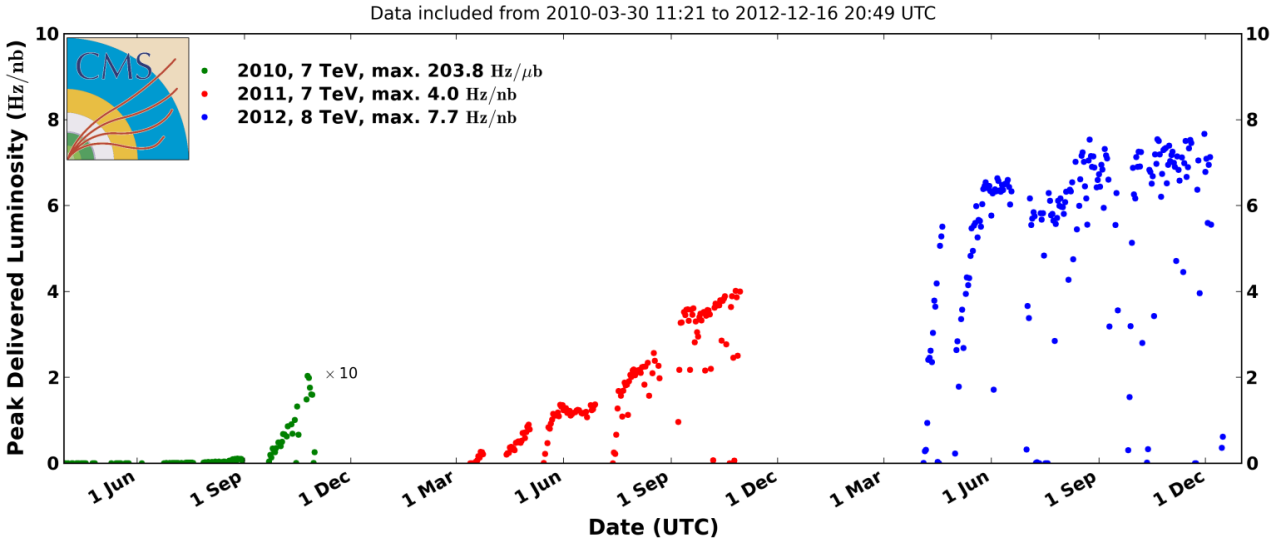
A new MSSM m_h benchmark scenario introduced – consistent with H(125)

The LHC





Overall data taking efficiency ~ 91%

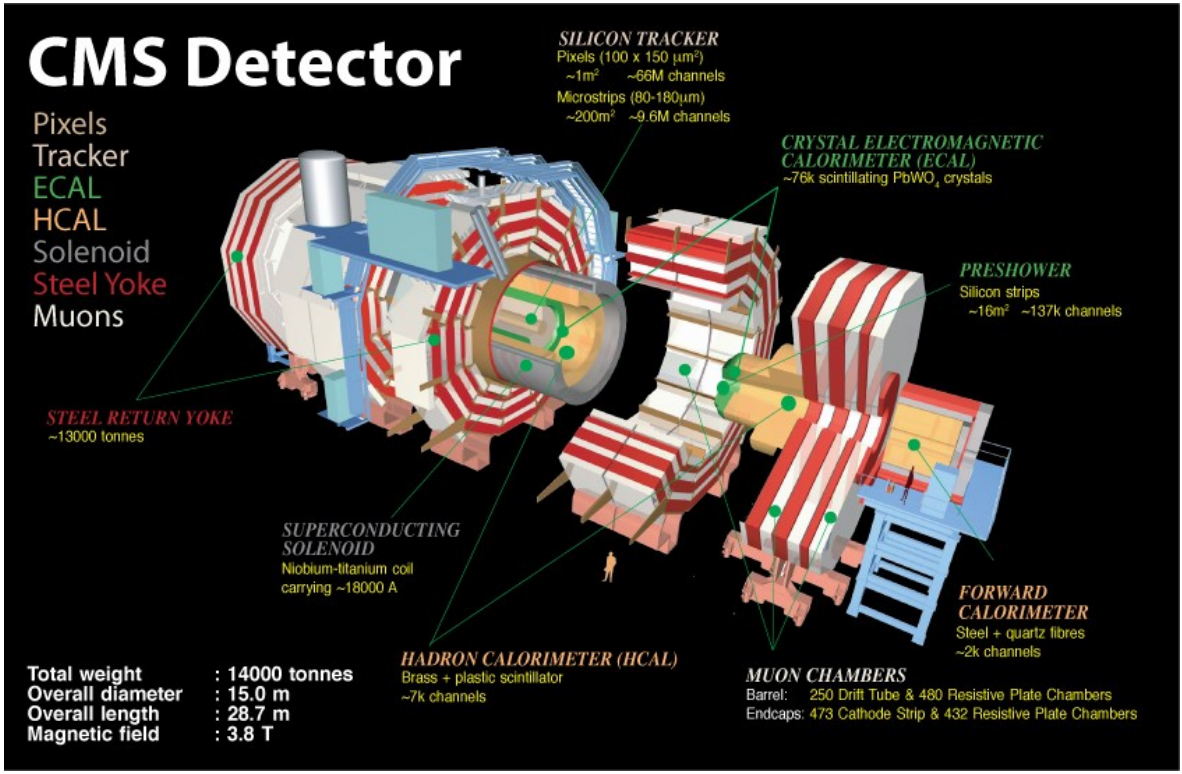


3.8 T superconducting solenoid envelop:

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

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

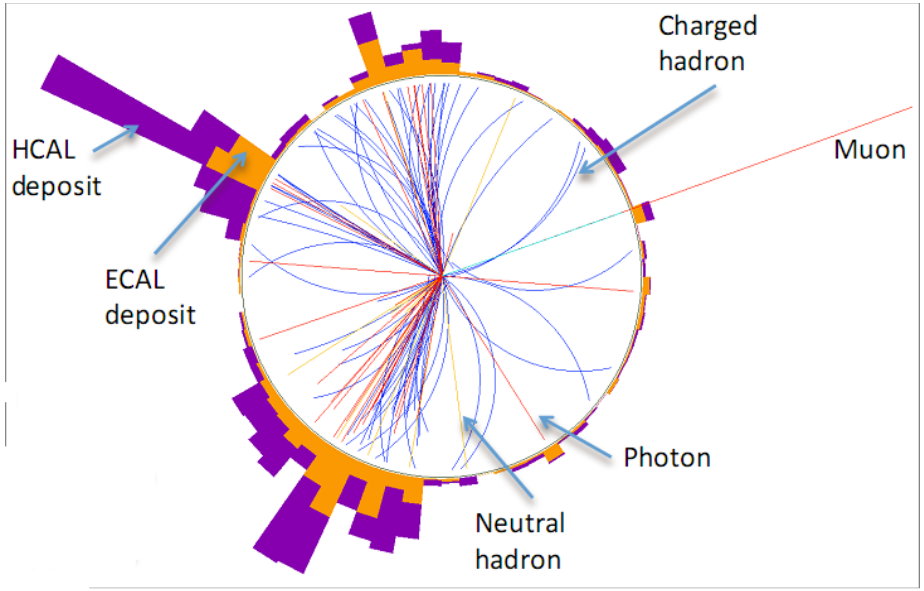
- Muon Chambers – gas ionization detectors embedded in steel return yoke outside the solenoid, $|\eta| < 2.4$
  Drift Tubes, Cathode Strips and Resistive Plate Chambers



⇒ Event description in form of mutually exclusive particles

⇒ identification of all stable particles
produced in the event

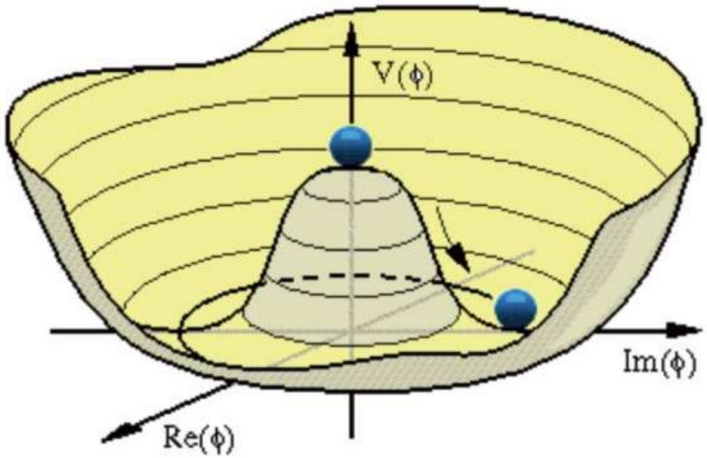
⇒ combining capabilities of each sub-detector
most precise measurement
of the energy and direction for each particle



⇒ 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

Tau and Muon reconstruction utilises this robust technique
excellent performing at high pileup

$H \rightarrow \tau\tau$



ττ Mass Reconstruction

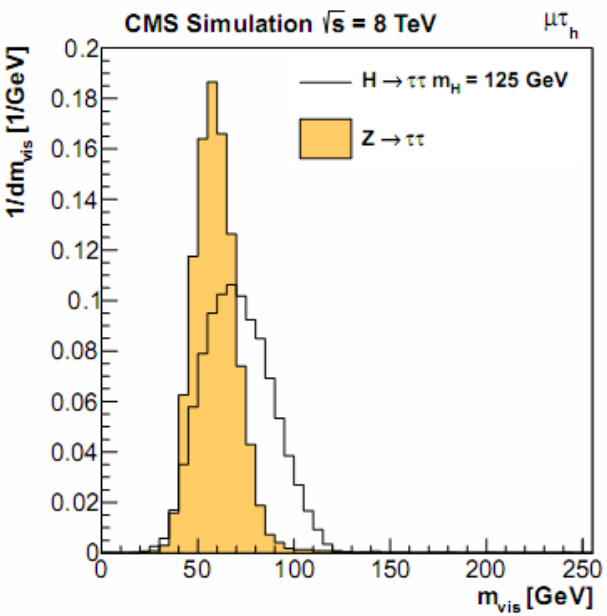
Mass of τ lepton pair reconstructed via a **Likelihood technique**, based on:

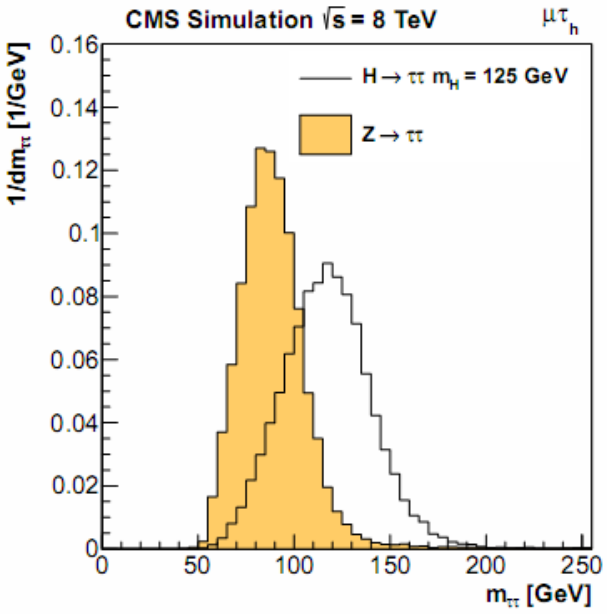
- **τ decay kinematics**
- **Compatibility of reconstructed E_T^{miss} with neutrino hypotheses**

$m_{\tau\tau}$ - Obvious observable to discriminate Z boson from the Higgs signal

Majority di-tau decay channels use $m_{\tau\tau}$ for signal extraction

$m_{\tau\tau}$ mass resolution ~ 10-20% depending on channel/category



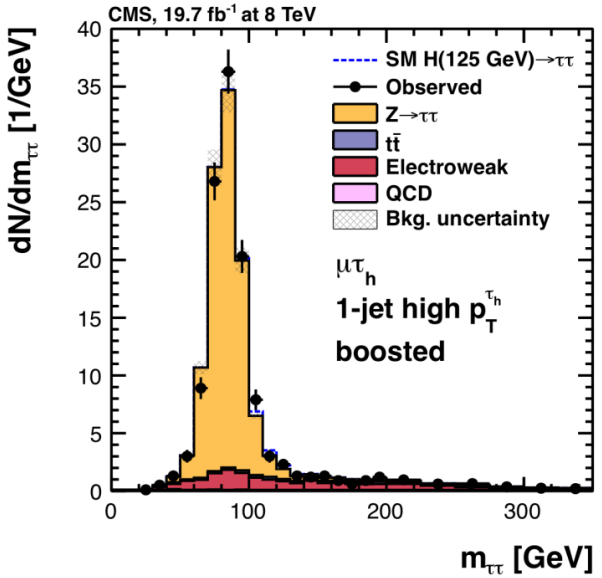


Decay final states : $\mu + \tau_h$, $e + \tau_h$, $\mu + e$, $\mu\mu$, ee , $\tau_h + \tau_h$

Improve sensitivity:

Different categories based on jet multiplicity and τ p_t

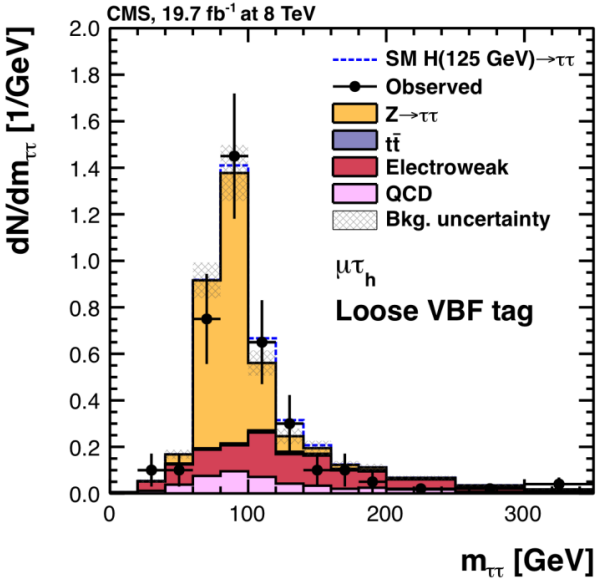
Optimized τ_{had}-isolation and e,μ→τ_{had} fake rejection

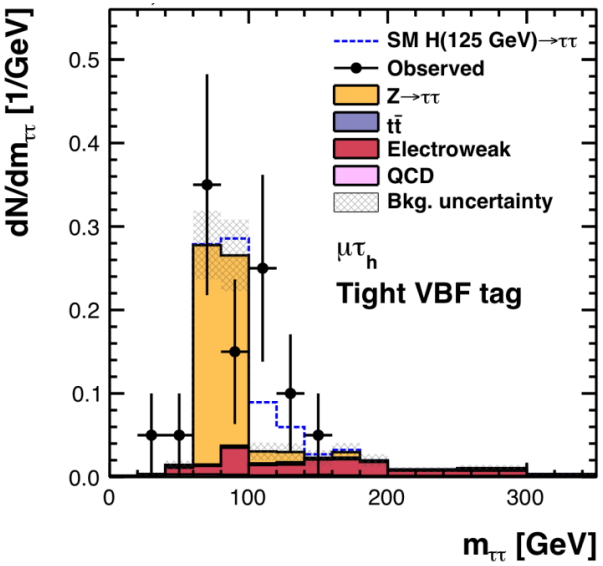


0 – jet category : constrains background, id efficiencies, energy scales

1 – jet category : improves the resolution of Higgs mass

2 – jet category : VBF process - high S/B ratio



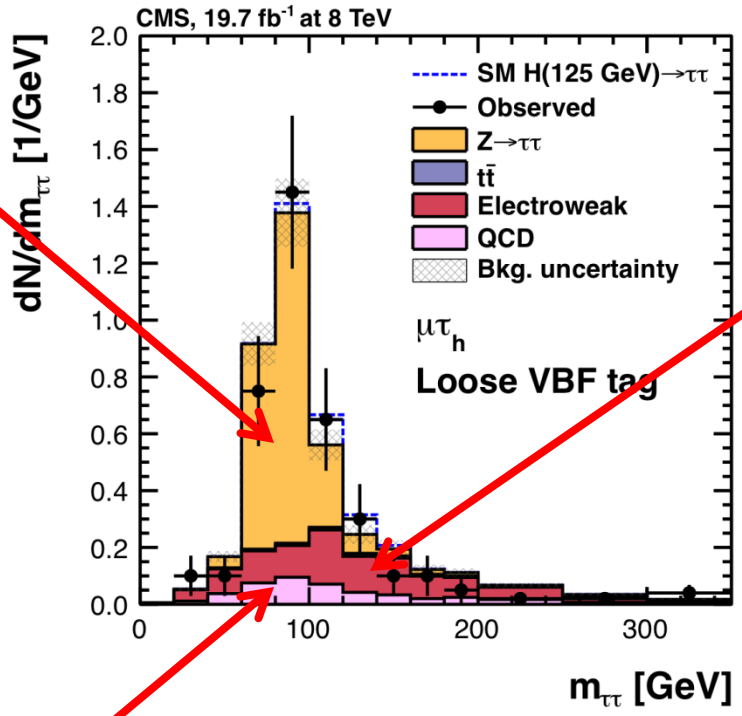


Background Estimation

Z→ττ : observed Z→μμ sample and replace μ by simulated τ (embedding)

W + jets : Shape from simulation, normalization from m_T/P_ζ sideband

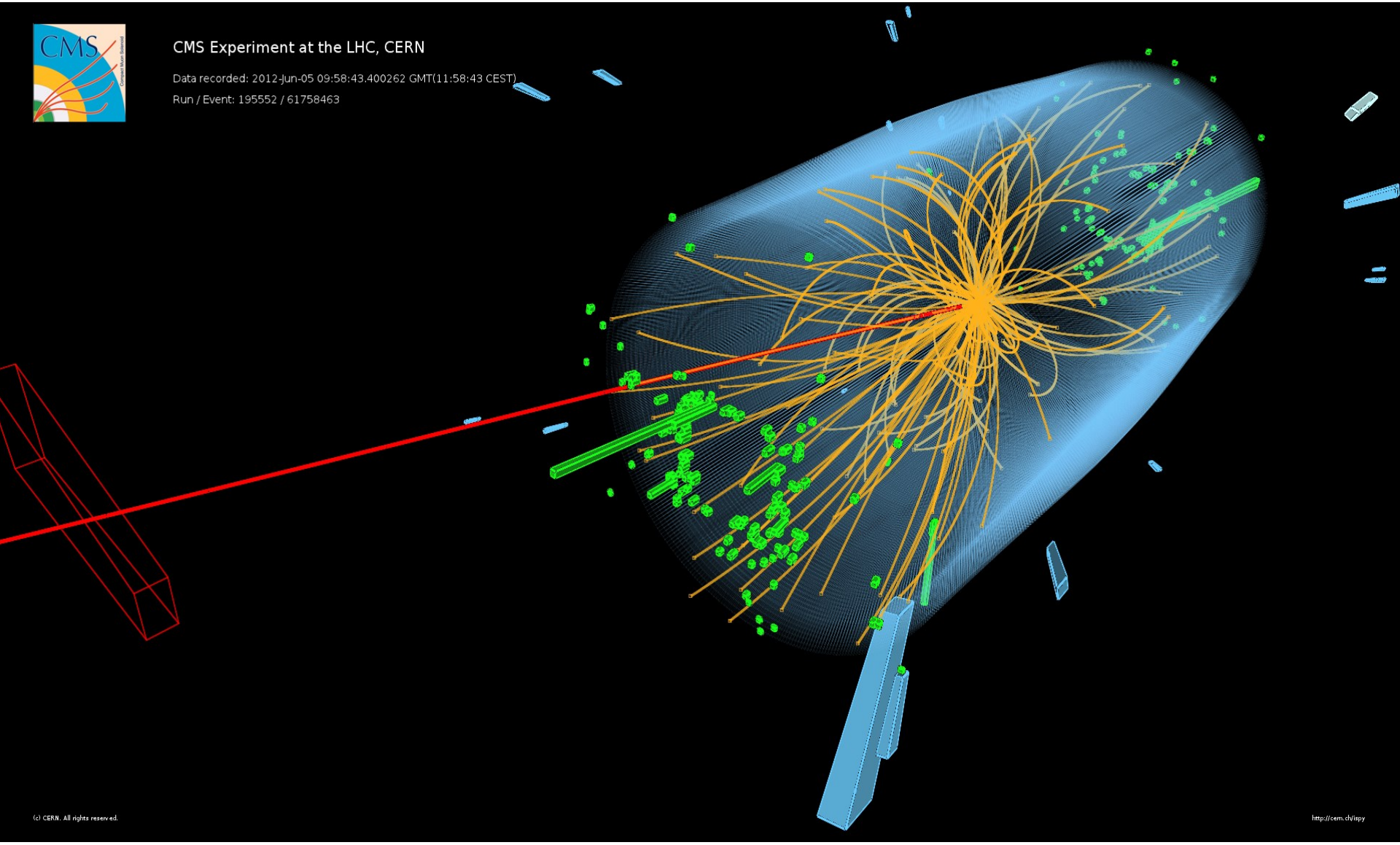
Z + jets : OS/SS ratio and lepton / jet faking hadronic τ with shape from simulation



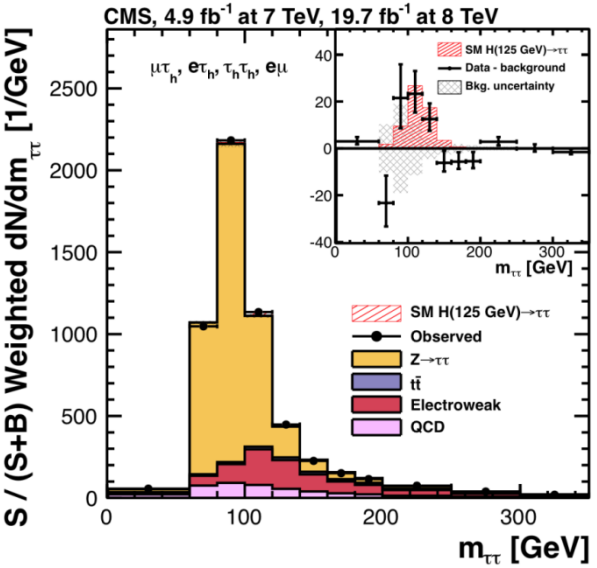
QCD : From OS/SS data and mass shape from SS data in relaxed lepton isolation

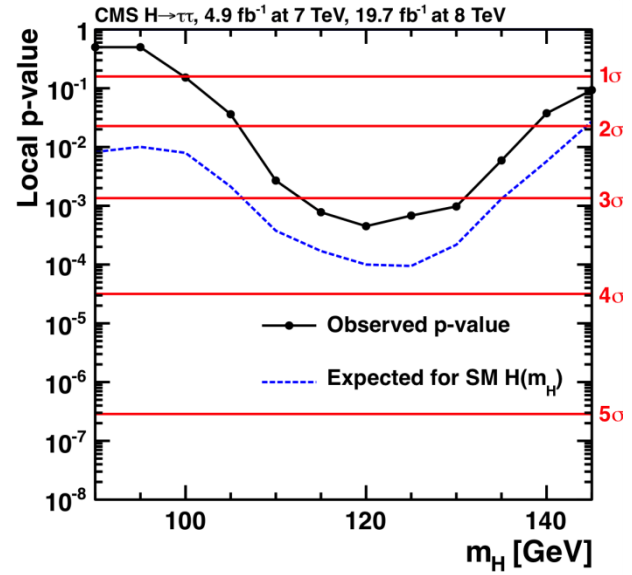
Top pair and Di-boson from simulation

VBF $H \rightarrow \tau\tau$ Event Display



SM H→ττ Results





Evidence for Higgs – Lepton Coupling

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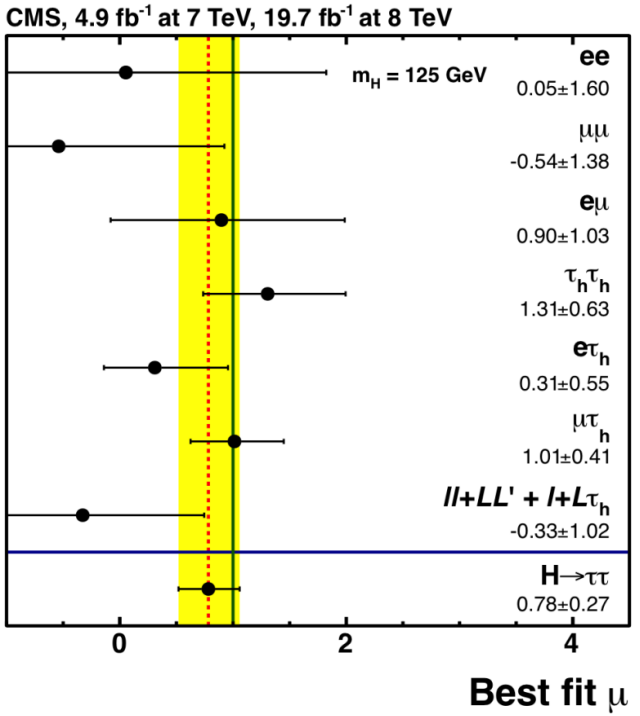
- Excess >3σ observed over m_H 110–130 GeV
- H→ττ best fit signal strength 0.78 ± 0.27 for m_H = 125 GeV
- Observed (expected) Significance 3.2σ (3.7σ) for m_H = 125 GeV
- Strong affirmation on Higgs-Fermion coupling, 1st Indication to Leptons

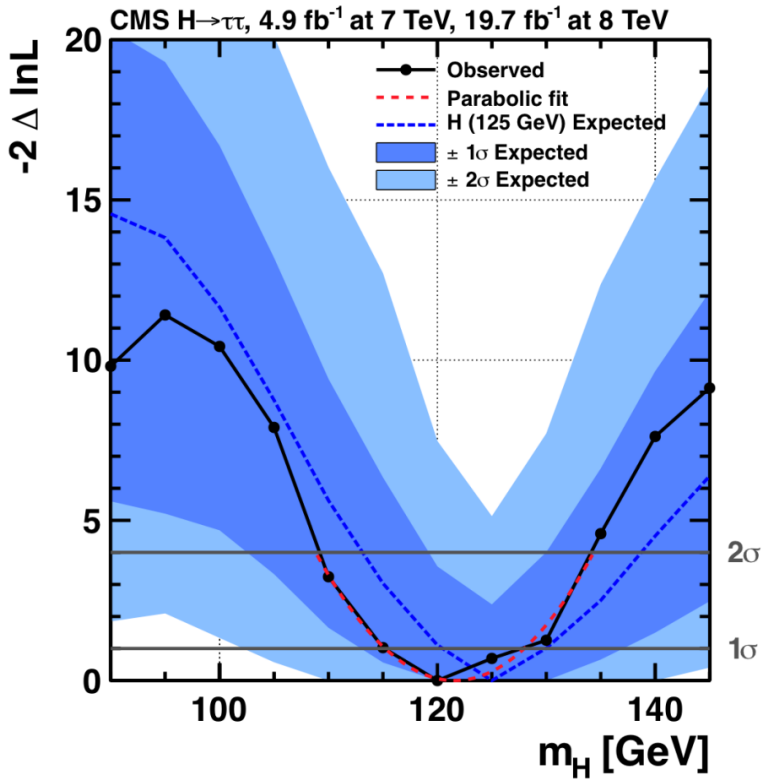


Signal strength μ compared to SM

μ = 0.78 ± 0.27

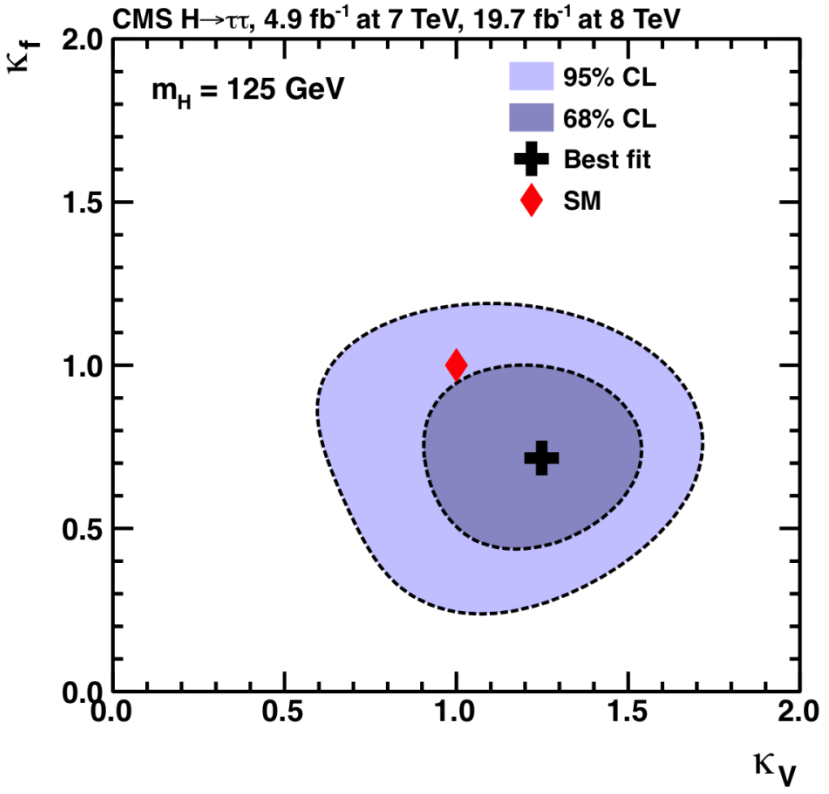
Mass & Couplings

background-only hypothesis includes the pp→ H(125 GeV)→WW process



Scan of $-2\Delta\ln L$, as function of m_H

M_H=122±7 GeV



Likelihood scan as a function of κ_V and κ_f
All nuisance parm. profiled for each point

pp→ H(125 GeV)→WW process added as a signal for vector boson coupling

MSSM Event Categories

arXiv:1408.3316 [hep-ex]

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

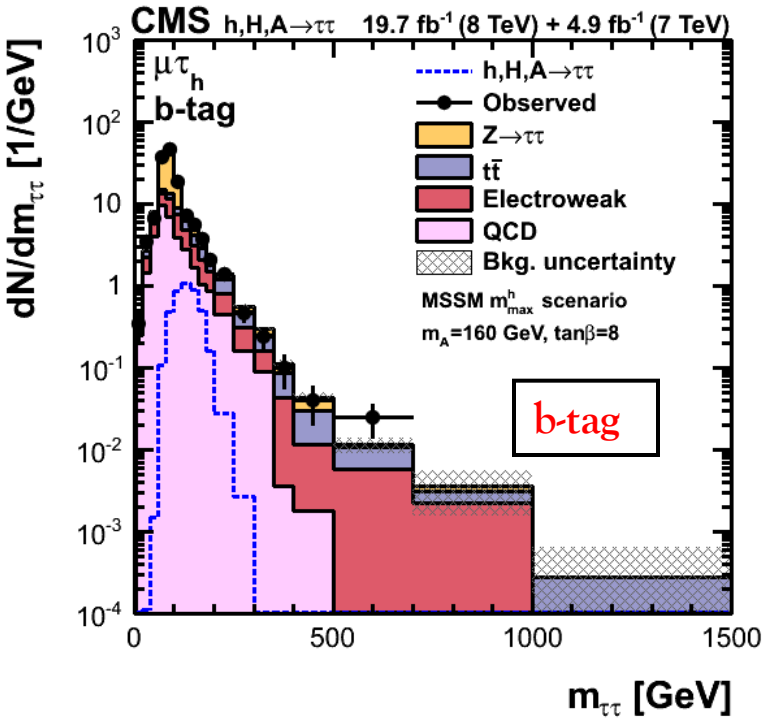
(to enhance sensitivity of $bb\Phi$ coupling)

B-tagging : based on secondary vertex + track-based life-time info

- b-tag :

≤ 1 jet with p_T > 30 GeV,

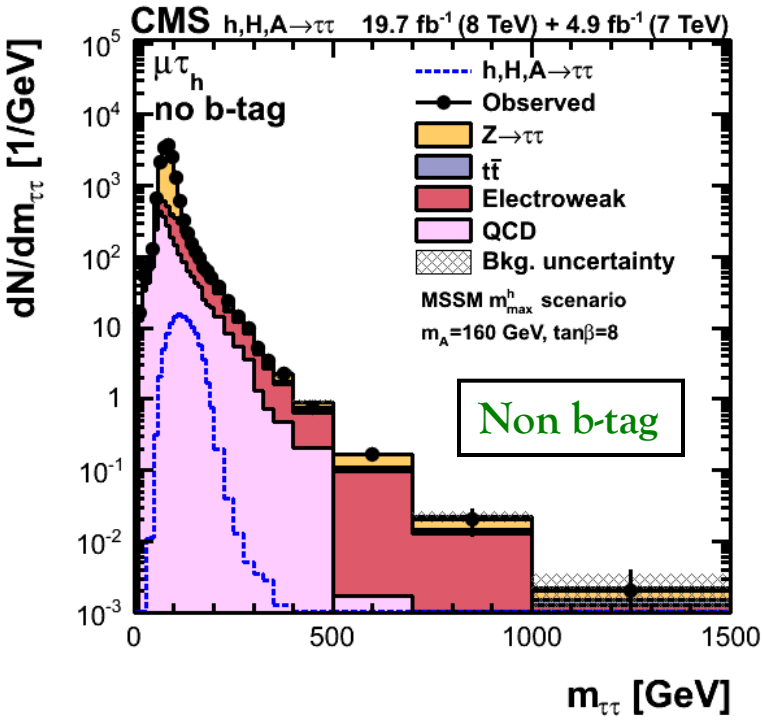
≥ 1 b-tagged jet with p_T > 20 GeV



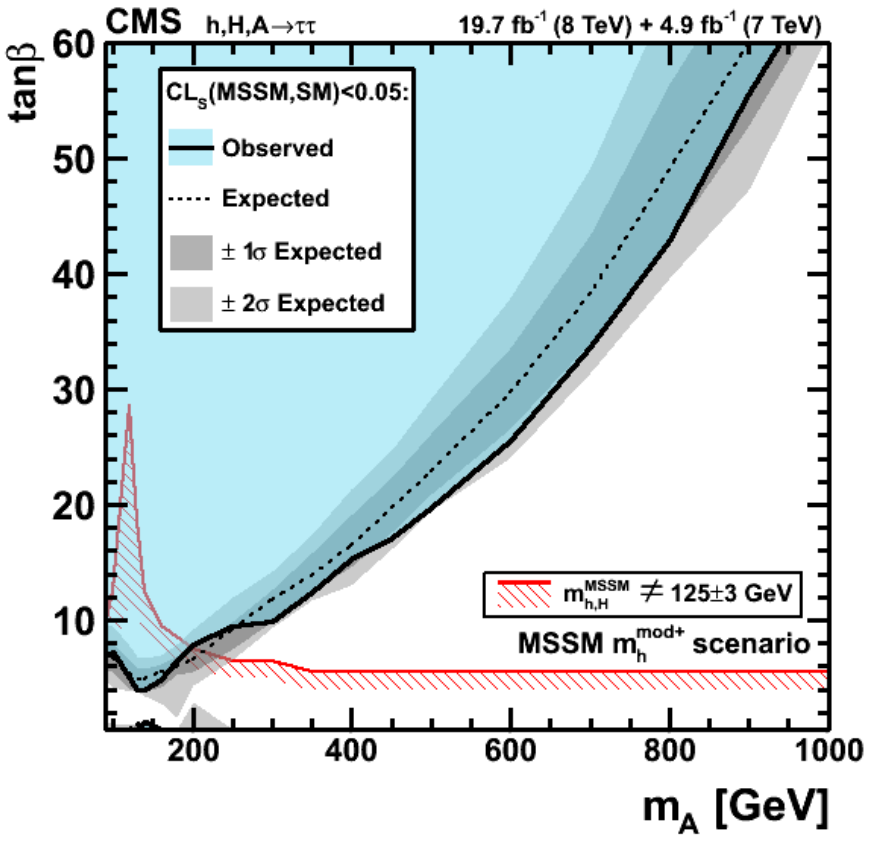
- Non b-tag :

≤ 1 jet with p_T > 30 GeV,

No b-tagged jet with p_T > 20 GeV



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

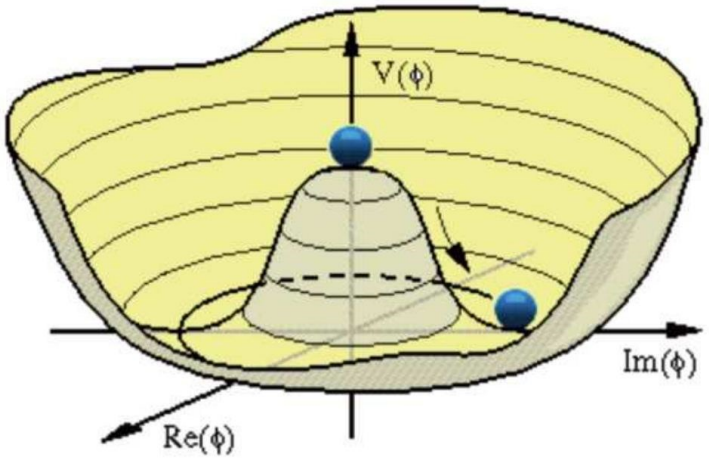


95% CL upper bound on cross-section x $\mathcal{Br}$ ($\Phi \to \tau\tau$) – based on the mass shape of $m_{\tau\tau}$ distribution mapped to m_A – tanβ plane (4FS + 5FS)

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

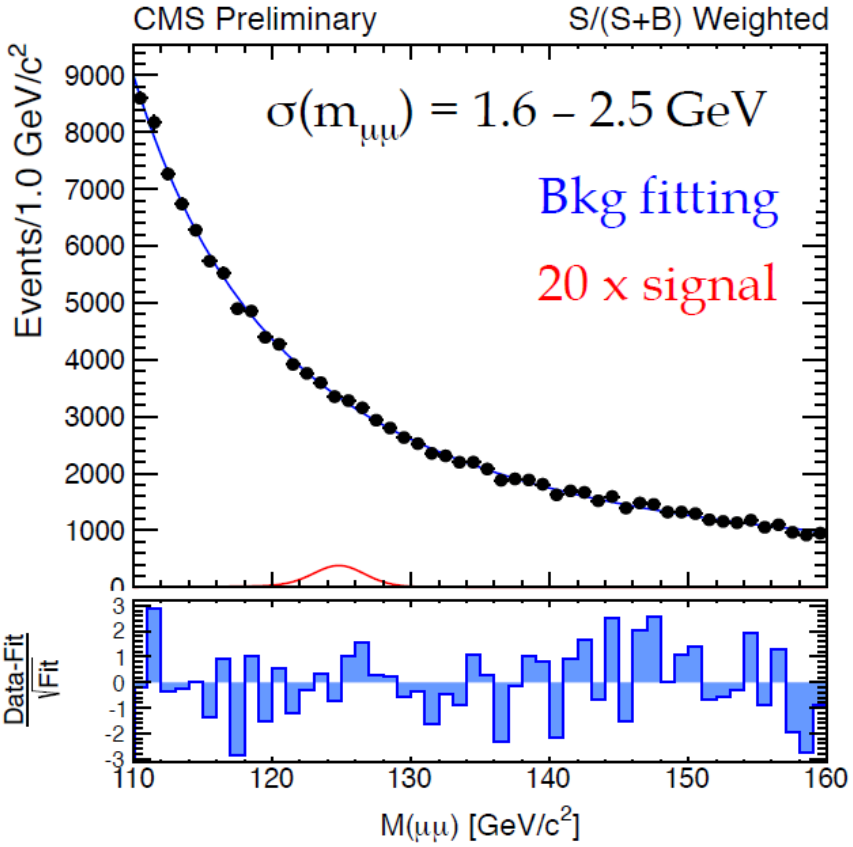
$H \rightarrow \mu\mu$



- Higgs decay BR is not same with ττ
  BR for H→μμ is ~2×10^{-4} for 125 GeV
  (10 times smaller than H→ γγ)

- Excellent μμ mass resolution
  Signal extraction by fitting $m_{\mu\mu}$ distribution (with signal and background shapes)

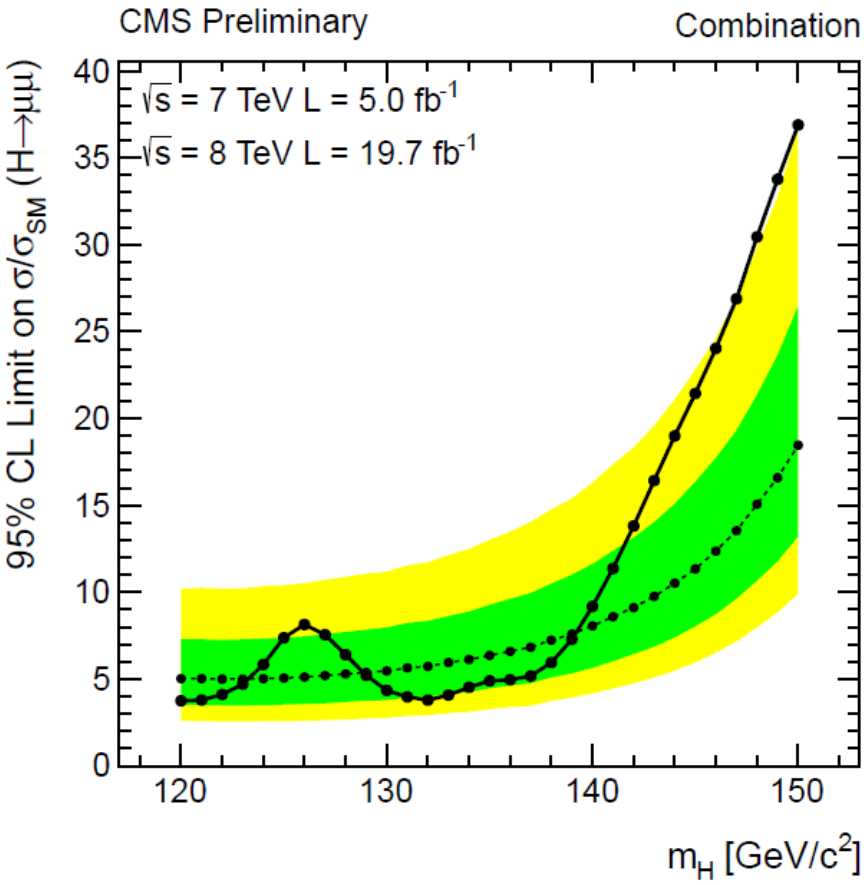
- Categorize events by jet multiplicity (gluon fusion and VBF categories), η^{μ} and $p_T^{\mu\mu}$ - 15 categories fitted



CMS PAS HIG-13-007

- No significant excess observed
- Limits at 125 GeV is 7.4 (5.1) observed (expected) x σ_{SM}
- Excess at 125 GeV is 1.1σ

Not expected to see signal in this channel with the statistics at this luminosity

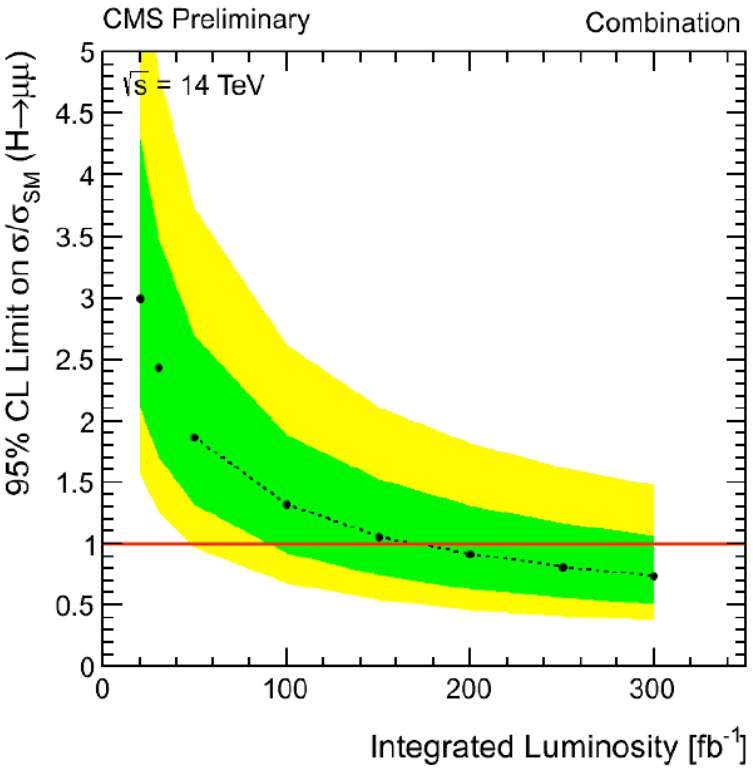


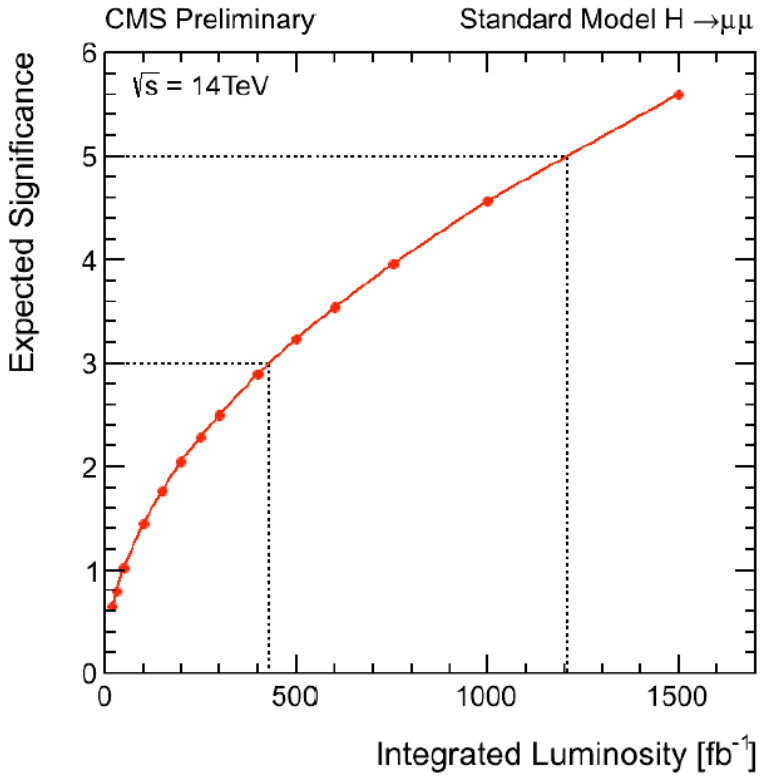
SM H→μμ @ 14 TeV

- Looking ahead ..... 5 σ discovery with ~1200 fb^{-1} @ 14 TeV

  Beyond LHC Run 2: in High Luminosity LHC

- Measure muon coupling with 8% precision ~3 ab^{-1} @14 TeV





https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13007TWiki

Summary & Outlook

- Higgs Boson @ 125 GeV - avenue of great interest in fermion decay modes
- Excess >3σ observed over m_H range 110–130 GeV in di-tau decay mode consistent with H(125)
- First Indication of Higgs coupling to Leptons from tau pair decay
- Results on Higgs decay to Muons and Taus show lepton non-universality
- Properties measurement of Higgs in Run 2 LHC

- Robust program of MSSM Higgs Boson searches with the CMS detector (H→ττ , bb and μμ modes)
- MSSM Higgs parameters significantly constrained with H→ττ (different MSSM benchmark scenarios)
- MSSM H→μμ search with full dataset underway