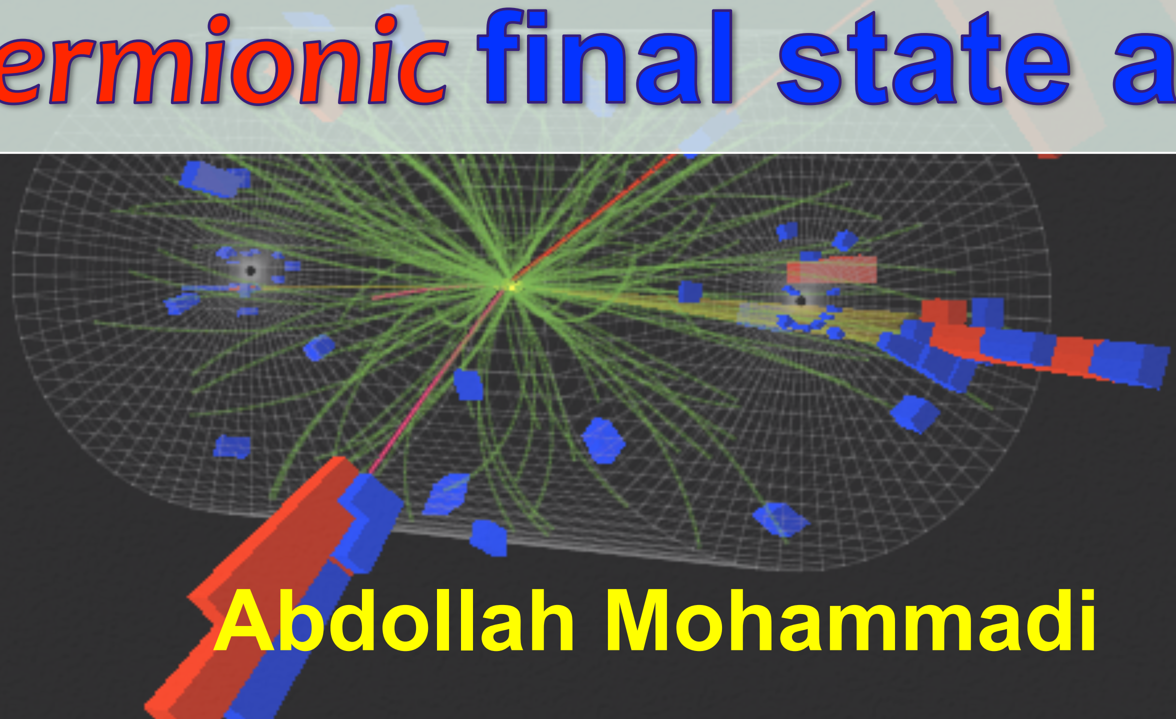
CMS Experiment at LHC, CERN
Data recorded: Sun Nov 25 00:15:46 2012 CEST
Run/Event: 207898 / 97057018

UNIVERSITÉ LIBRE DE BRUXELLES

Search for SM Higgs boson in *fermionic* final state at CMS



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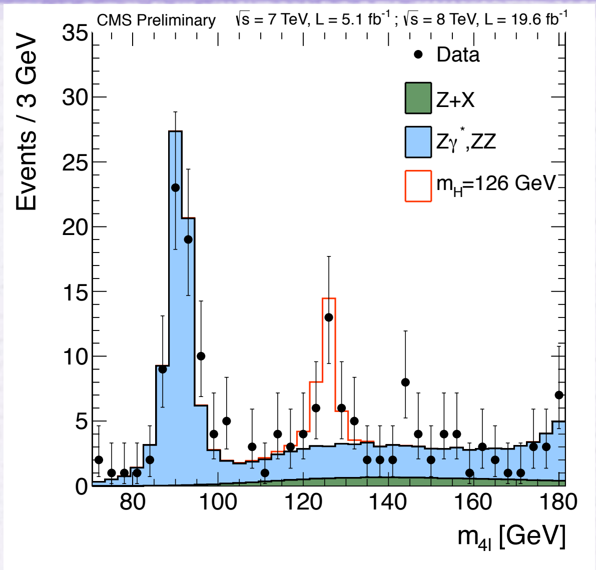
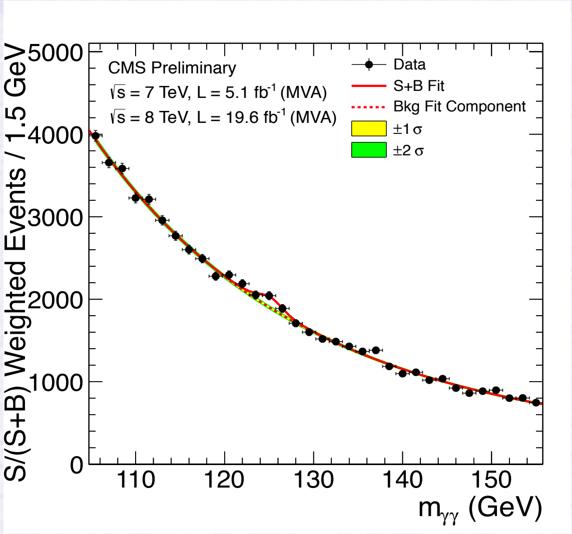
2nd LHC-IPM Meeting, Tehran, Iran

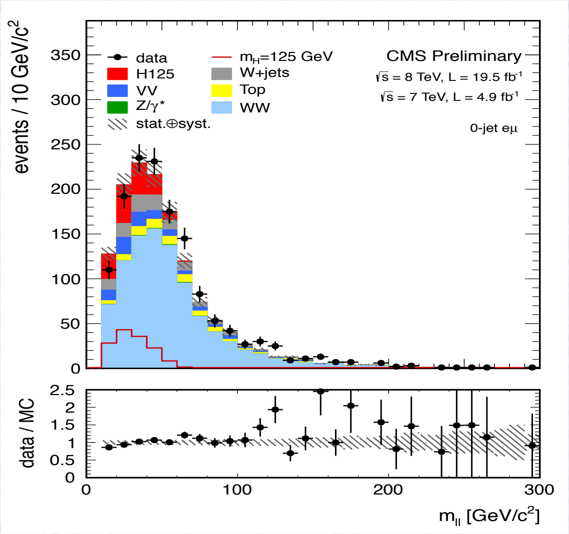
Oct. 2013

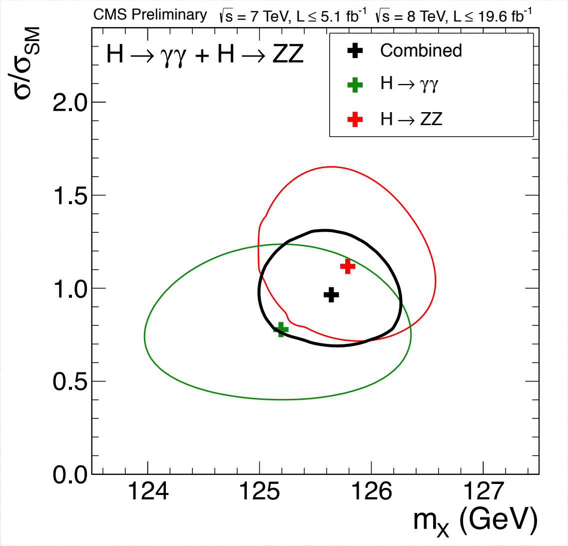
CMS

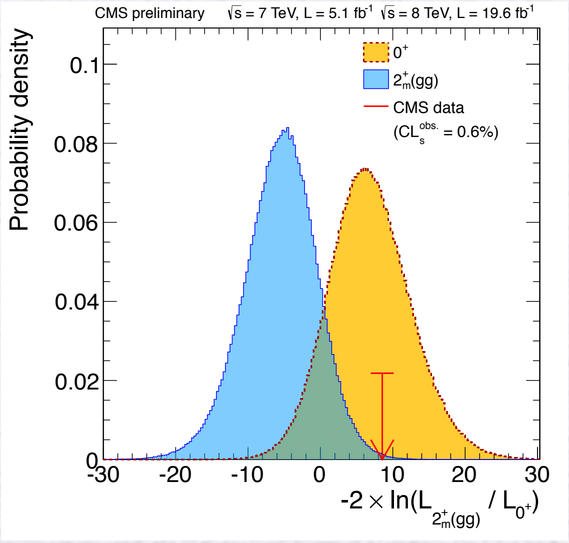
Enough indications for a **new** particle (scalar boson) @ ~125 GeV







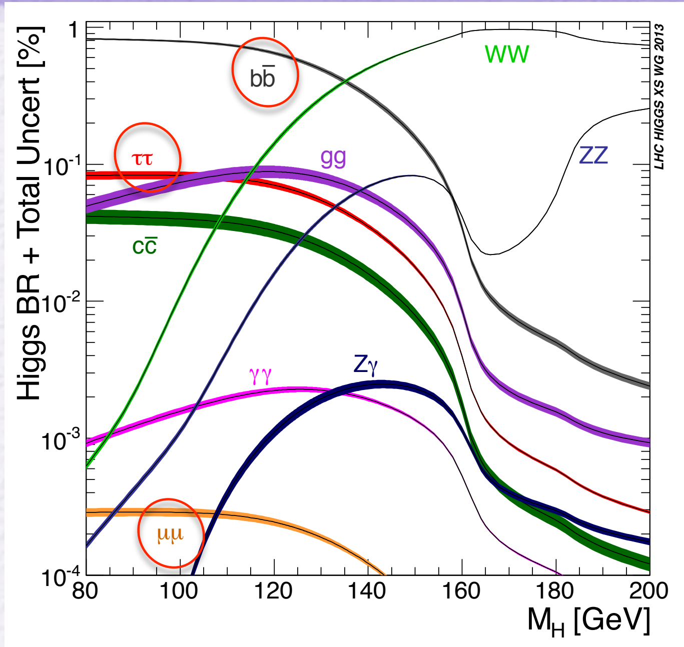


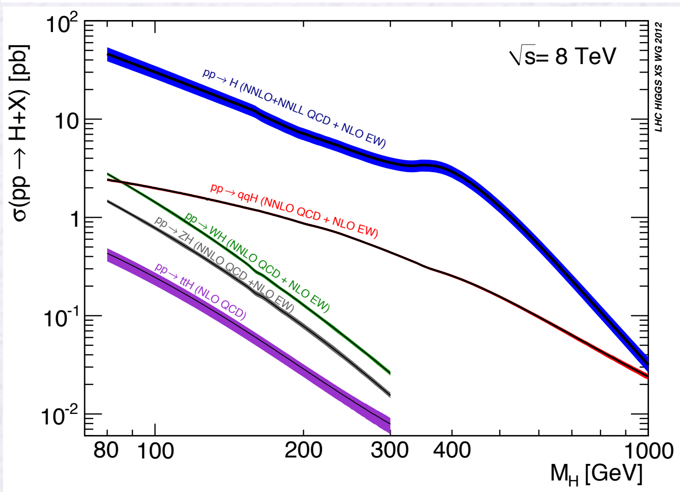


Our friend couples to bosons, what about coupling to fermions??

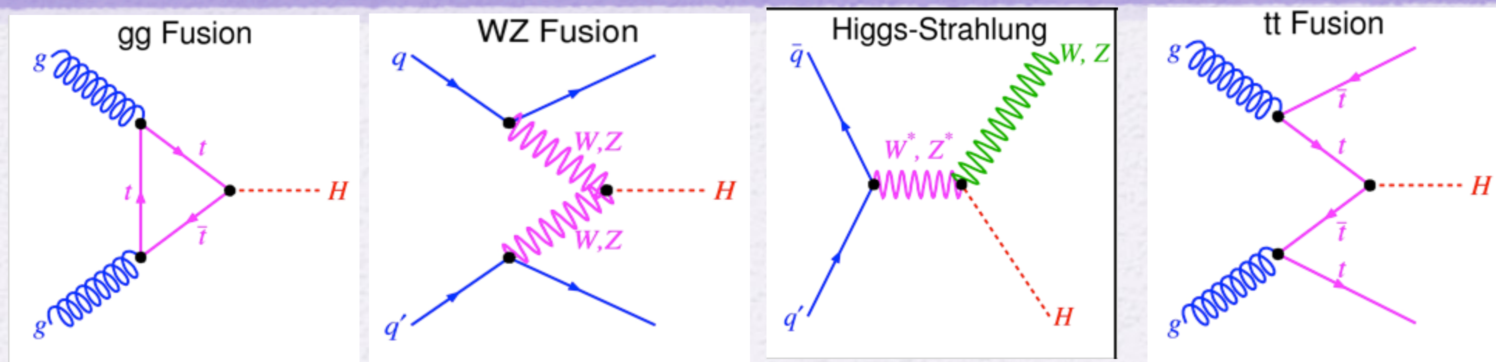
Introduction

- Observation of the scalar boson in fermionic final states is a check to confirm the resonant at 125 GeV is the Higgs boson predicted by standard model.
- **H→*bb*, H→*ττ*** and **H→μμ are the possible fermionic decay channels(to** check the Yukawa couplings between fermions and Higgs boson)
- The current results are based on full 2011 and 2012 CMS data and includes all main Higgs production modes.





5 Production & 3 Decay modes



	GGF Glu-Glu Fusion	VBF vector boson fusion	(W/Z)H WZ associated	ttH tt associated
H→*bb*	✗	✔	✔	✔
H→ττ	✔	✔	✔	✔
H→μμ	✔	✔	✗	✗

HIG-13-011

HIG-13-012

HIG-13-019

HIG-13-004

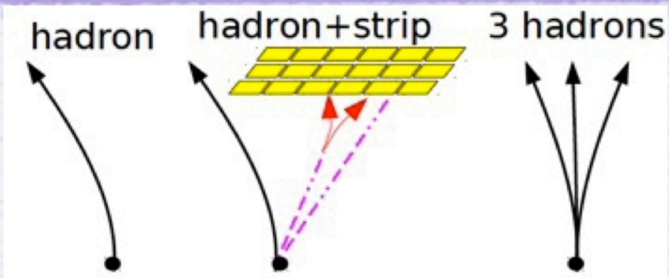
HIG-12-053

HIG-13-007

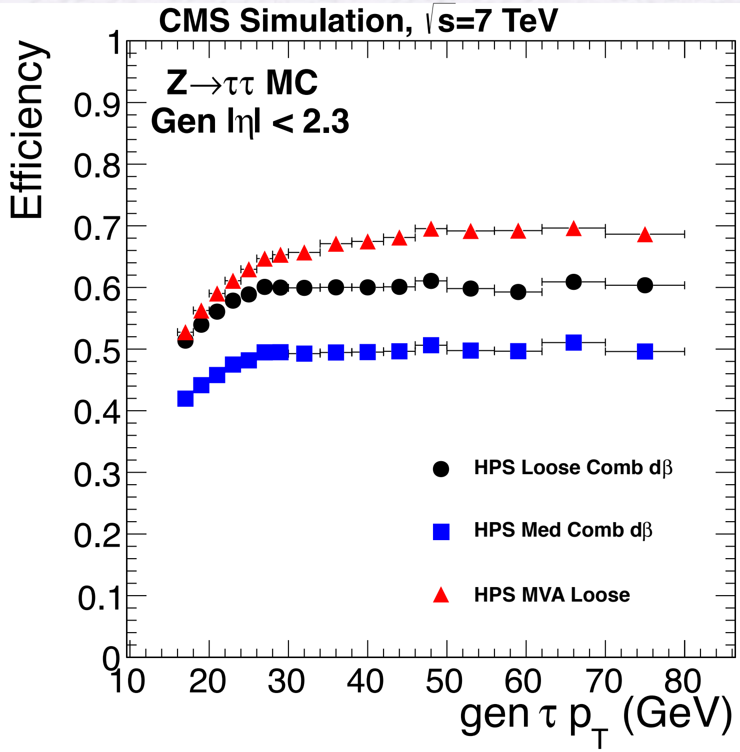
$H \to \tau\tau$

Tau Reco & Id

Decay mode	Resonance	Mass (MeV/c^2)	Branching fraction (%)
$\tau^- \rightarrow h^- \nu_\tau$			11.6%
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	ρ^-	770	26.0%
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	a_1^-	1200	9.5%
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	a_1^-	1200	9.8%
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$			4.8%

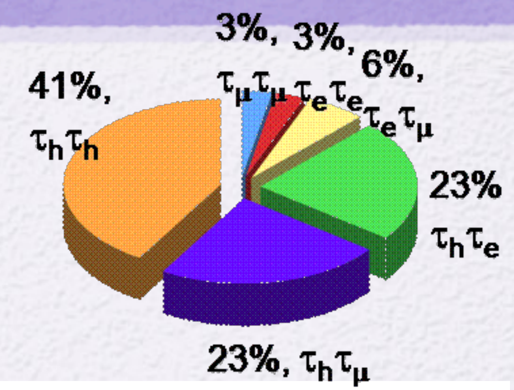


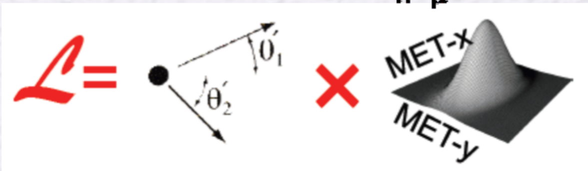
- Reconstruct the hadronic decays of tau based on the PFlow algorithm in 1-prong, 1-prong+π_0's and 3-prongs.
- For isolation, use multivariate discriminant based on Σp_T of particles in rings around τ_h
- ε_{rec}>60% (flat for $p_T(\tau)$>30GeV),Fakerate 1–3%.
- Efficiency and momentum resolution (nearly) independent from pileup

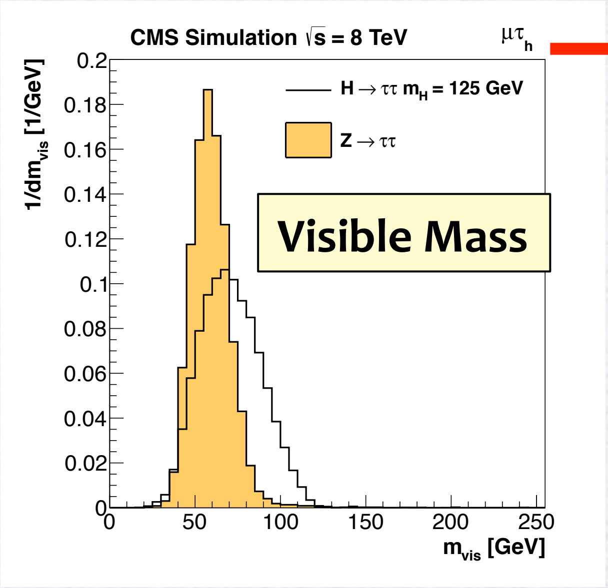


di-τ Mass Reconstruction

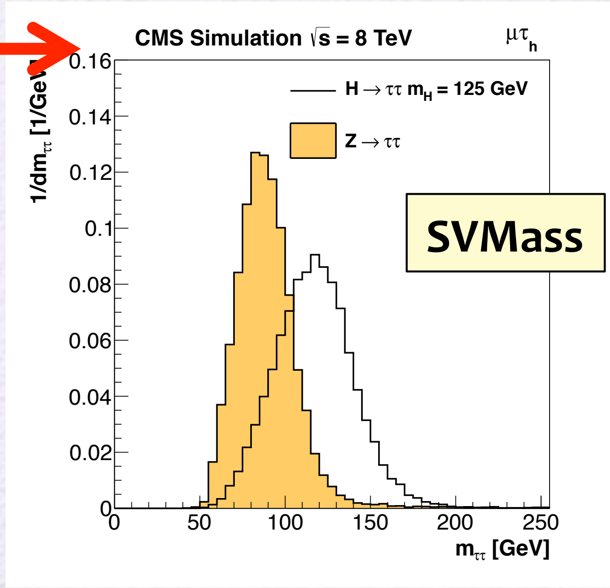
- Determine invariant mass of di-τ system with maximum likelihood method.
- marginalize the unobserved neutrinos d.o.f.
- Inputs: four-vector information of visible leptons, x- and y- component of MET and MET resolution







- Improve the Mass resolution (15-20%)
- Increase Z/H separation
- Impact on Limit/Sign. ~ 30%



Event Categories

$e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$

Number of Jets

Pt (τ/μ)

0-jet, low-p_T	1-jet, low-p_T	2-jet, VBF
Large background & **No fit for signal,** constrain uncertainties	Enhancement due to jet requirement & Better mass resolution	≥ 2 jets M_{jj} > 500 GeV & $\Delta\eta$ > 3.5 Central jet veto VBF H signal enhanced
0-jet, high-p_T	**1-jet, high-pT**	
Large background & **No fit for signal,** constrain uncertainties	$Z \to \tau\tau$ suppressed by high-$p_T(\tau)$	

$\tau_h\tau_h$

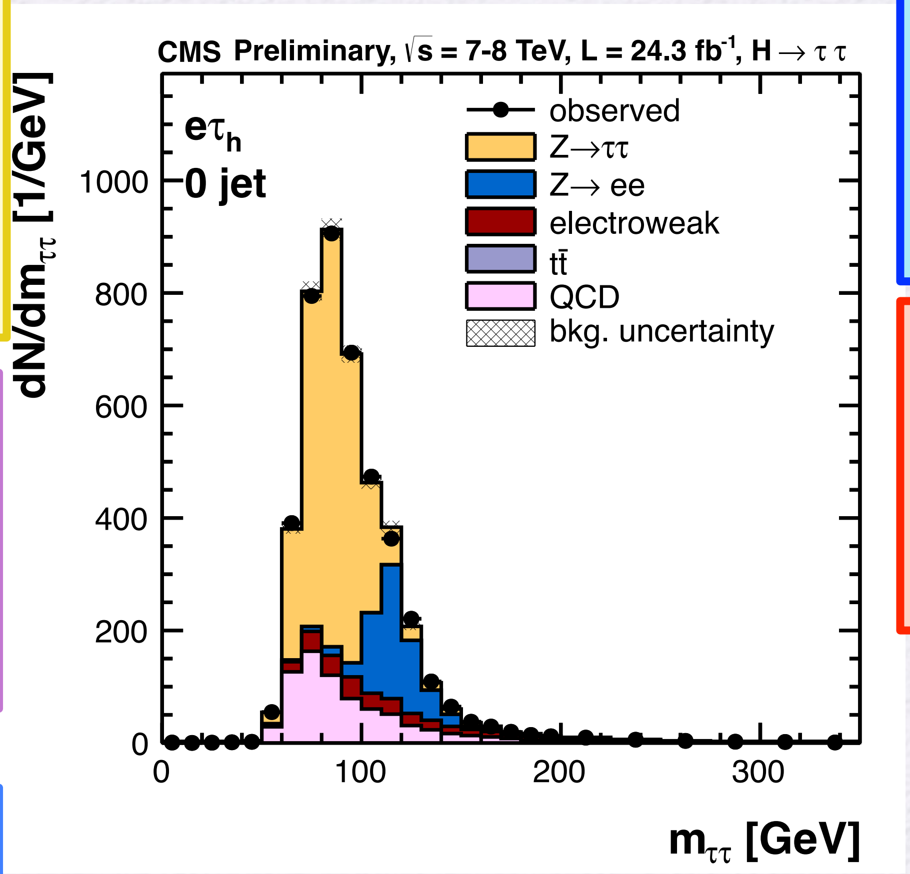
1-jet	2-jet, VBF
$p_T(\tau\tau)$ > 140 GeV	$p_T(\tau\tau)$ > 110 & M_{jj} > 250 GeV
Better mass resolution	$\Delta\eta$> 2.5 & Central jet veto

Background Anatomy

Z→ττ:
- Irreducible BG
- Shape and norm from Embedded samples: Take the Z→μμ, replace μ by sim. τ decay.
- Norm is rescaled to observed Z→μμ

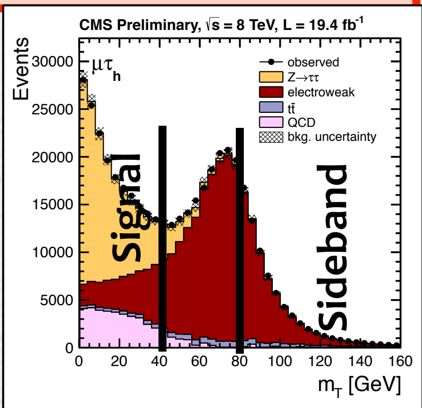
QCD:
- Suppressed by isolation
- Normalization & shape taken from SS from Data

TTbar:
- Normalization & shape from MC from Sideband



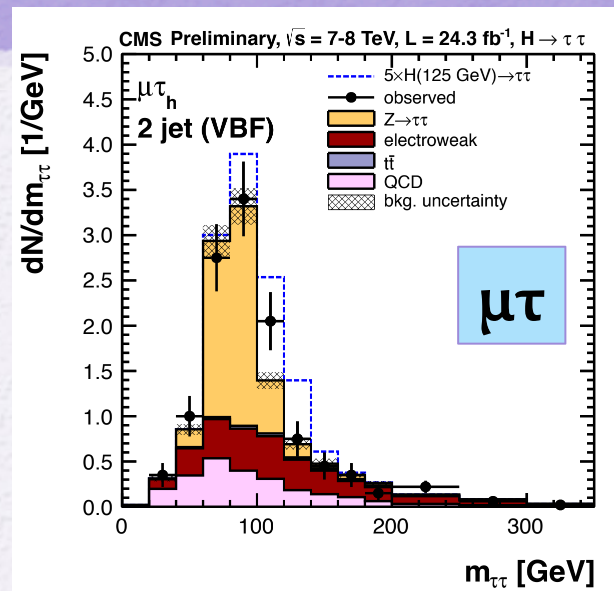
Z→ee(/μμ):
- Suppressed by extra lep. veto and tau dis. against leptons
- Normalization and shape from MC
- Corrected for Z→μμ data over MC

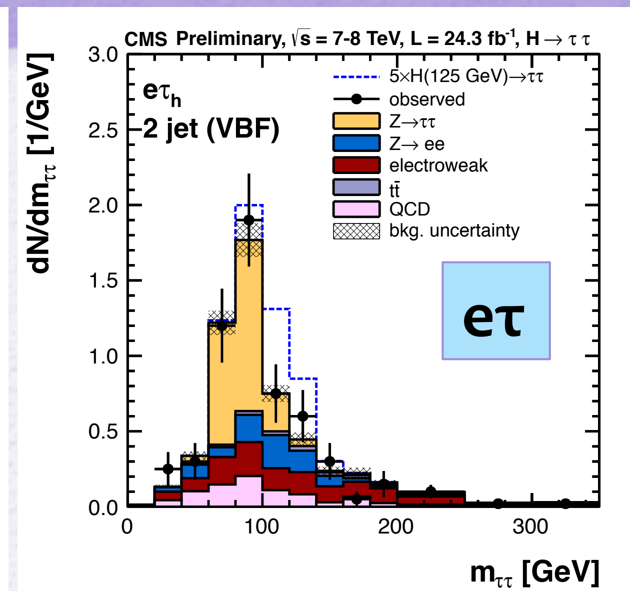
Diboson/W+jets:
- Suppressed by topological cuts
- Normalization from sideband. (data/mc scale)
- Shape from MC

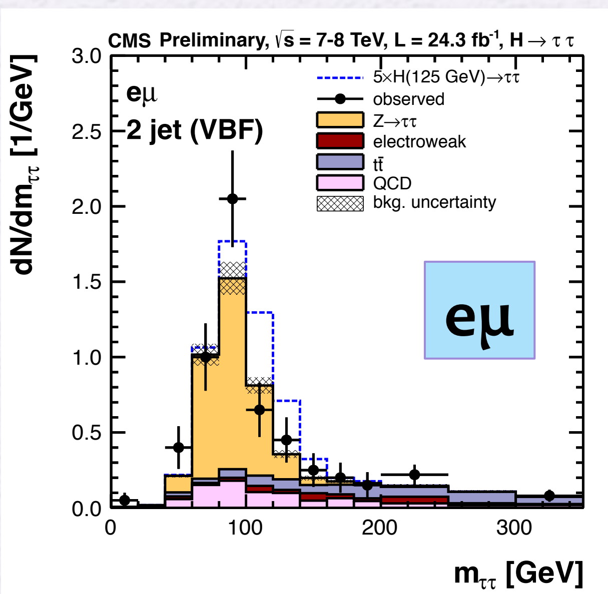


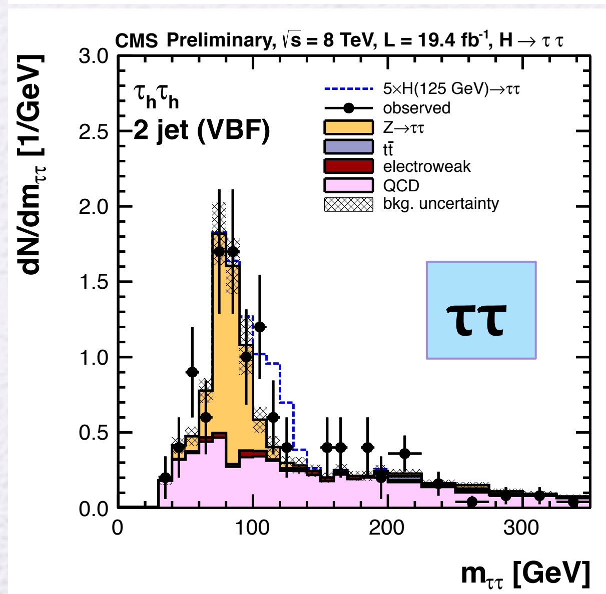
2-Jet VBF Category

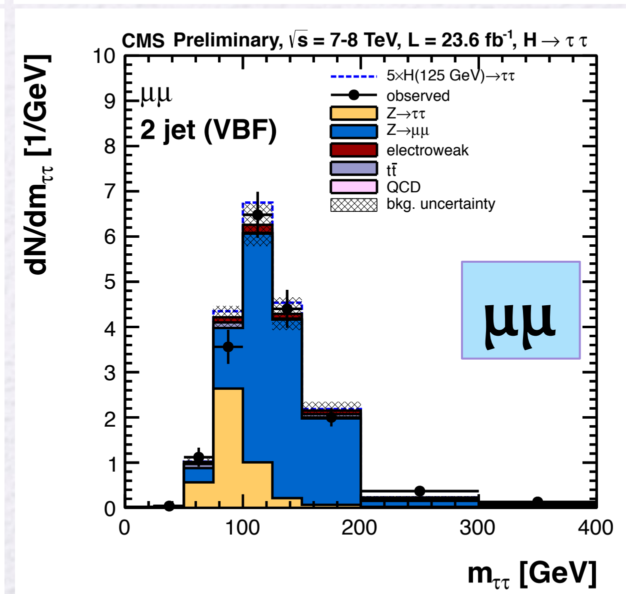
- After template fit has been applied (S+B hypothesis)
- Shaded bands correspond to uncertainties after fit.









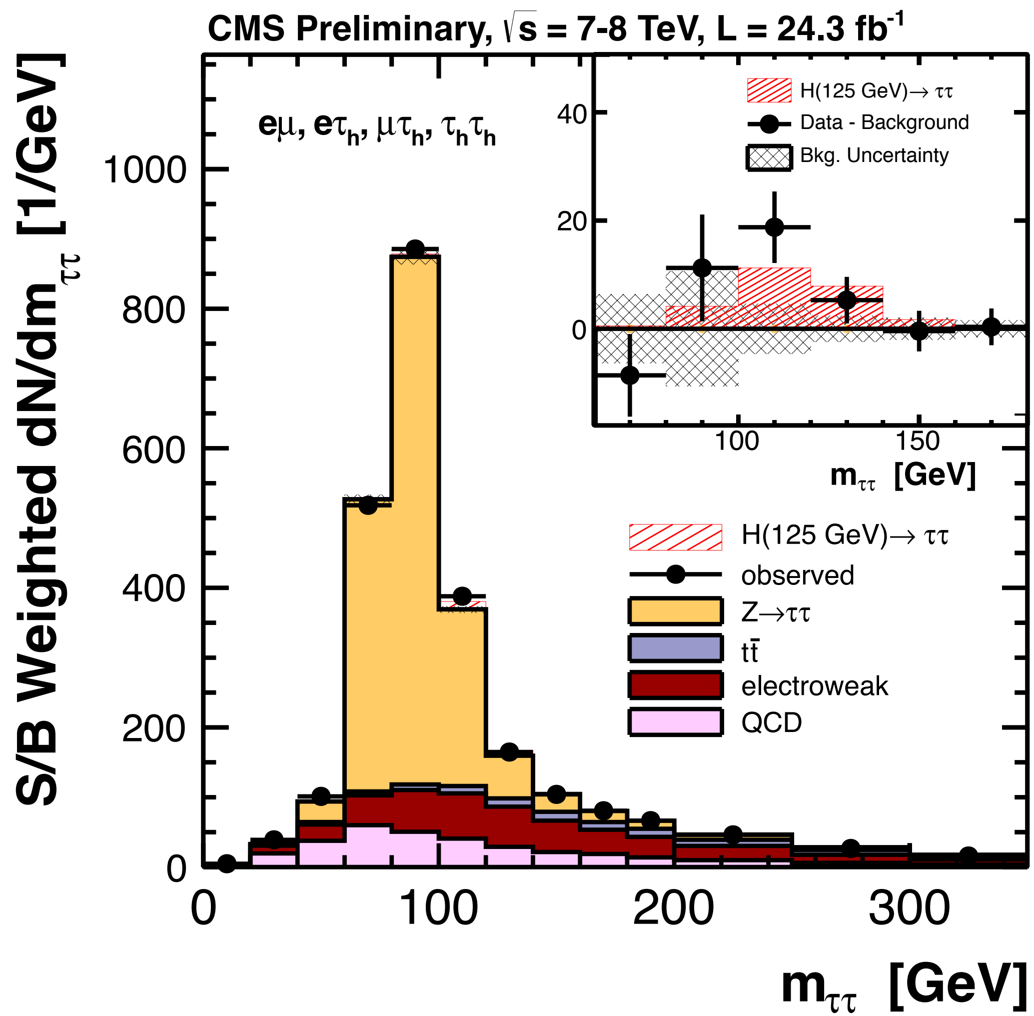


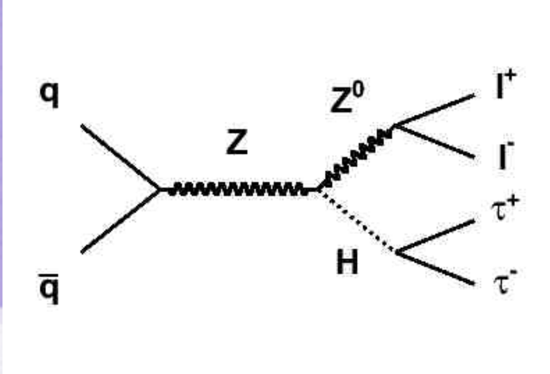
Combined Weighted Mass

Combine channels and categories weighting each by **S/B** :

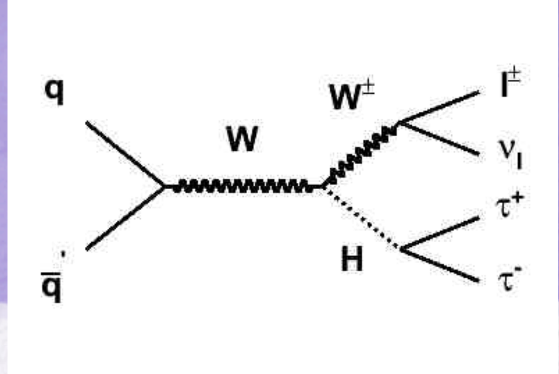
*(**S** is expected signal and **B** is fitted background in $m_{\tau\tau}$ interval containing 68% of signal around 125 GeV)*

Excess of events between 100-140 GeV compatible with H→ττ *from SM*



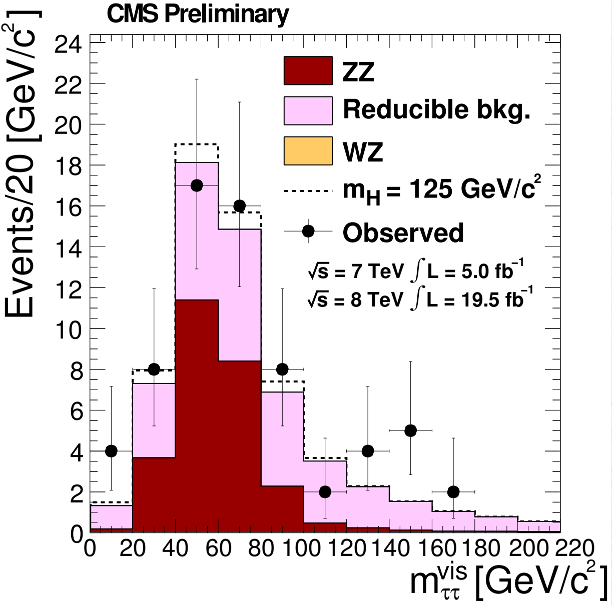


$VH \to V\tau\tau$

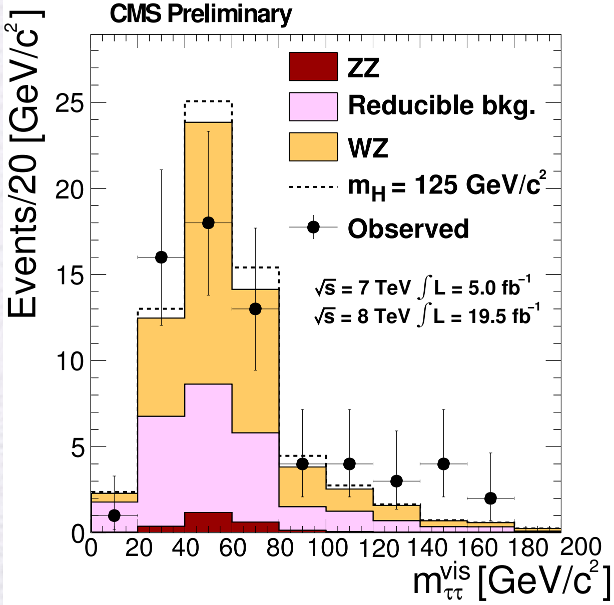


- Reducible BG: QCD,W/Z+jets, ttbar, … : Estimated from data using fake rate method
- Irreducible BG: WZ for WH and ZZ for ZH: Estimated from MC
- Further topological cuts to suppress large backgrounds

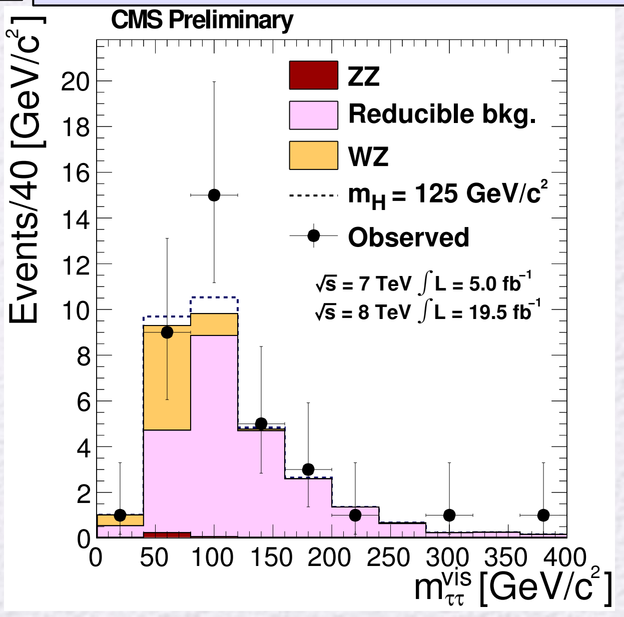
$Z \to (\mu\mu, ee)H \to (\tau_h\tau_h, \tau_h\mu, \tau_h e, e\mu)$



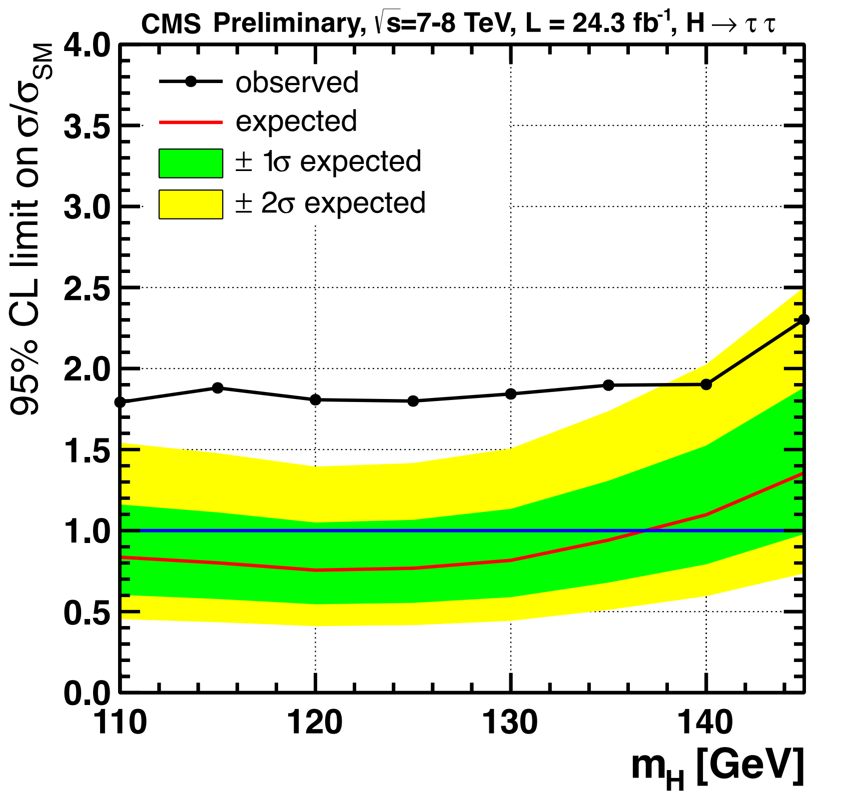
$W \to (\mu\nu)H \to (\tau_h\mu, \tau_h e)$

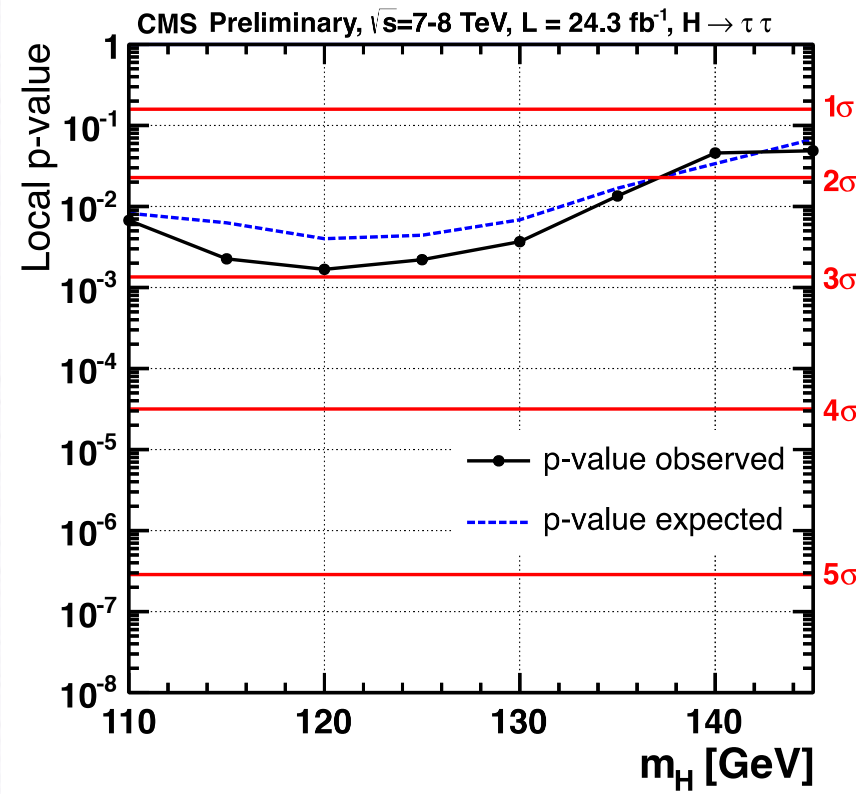


$W \to (\mu\nu, e\nu)H \to (\tau_h\tau_h)$



Limit, p-value and Significance



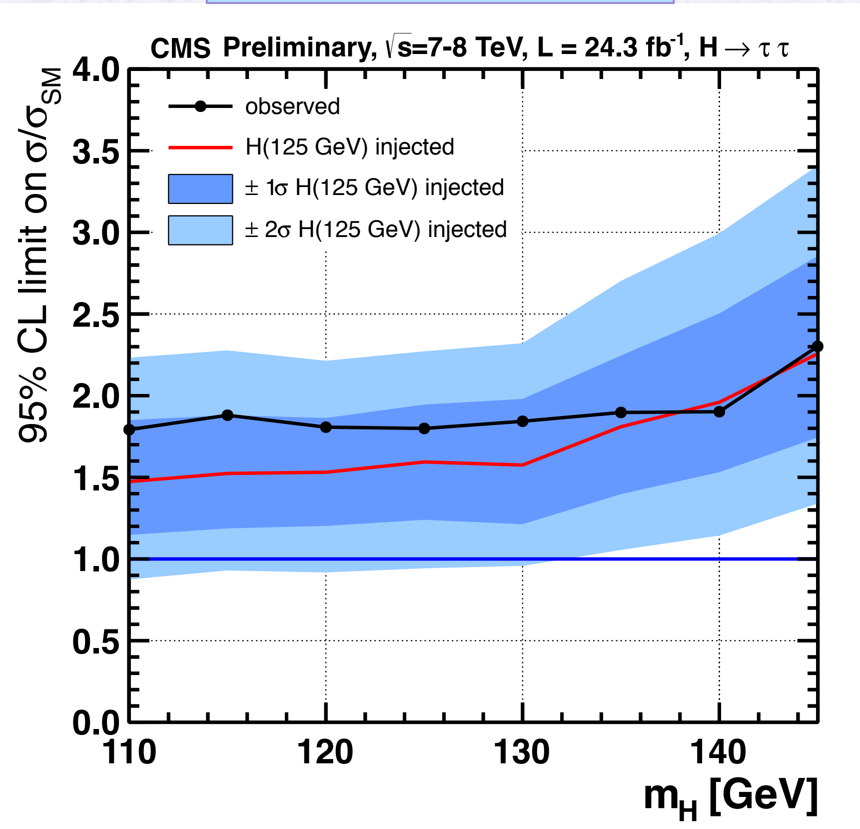


- Broad excess compatible with a presence of a SM Higgs boson at 125 GeV

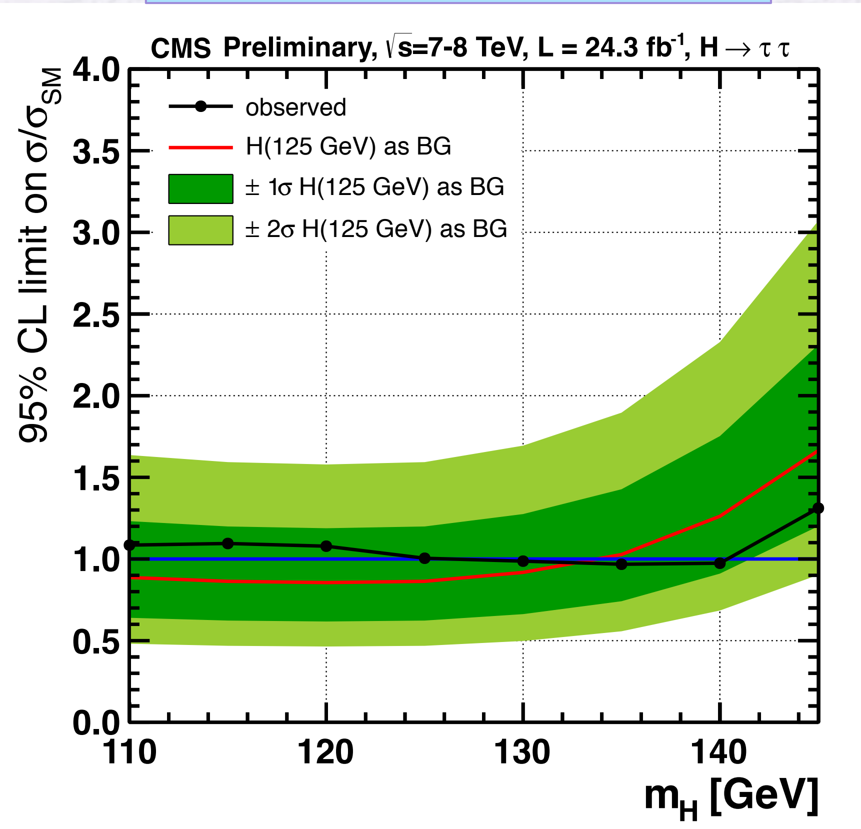
- Minimum p-value at 120 GeV corresponds to 2.93σ → **Indicate that our friend couples to τ lepton**

Compatibility of Excess with SM Higgs boson

Signal Injection

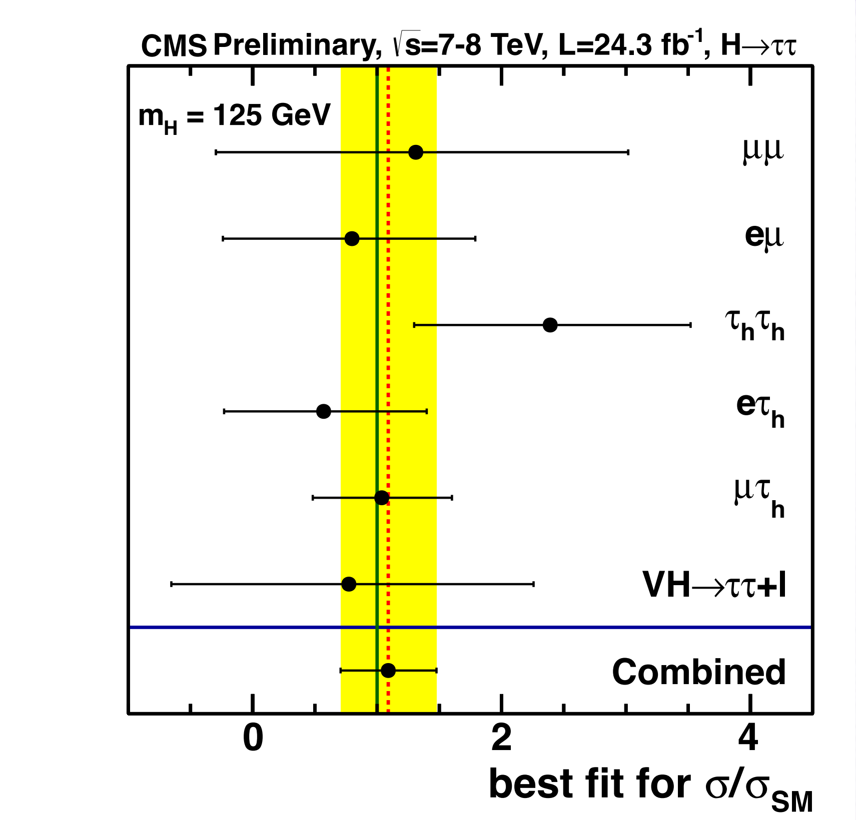


H125 as background

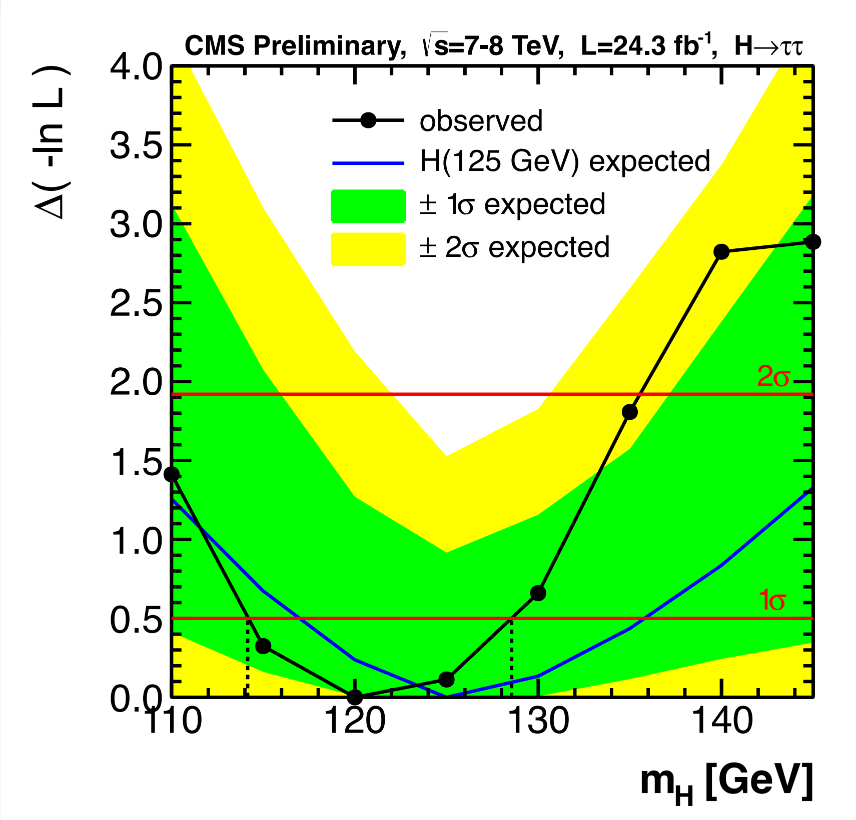


Both limit plots shows consistency of the excess with one and only one SM Higgs boson at 125 GeV.

Best Fit Signal Strength & Mass



Best-fit signal strength values, σ/σ_{SM} for independent Channel



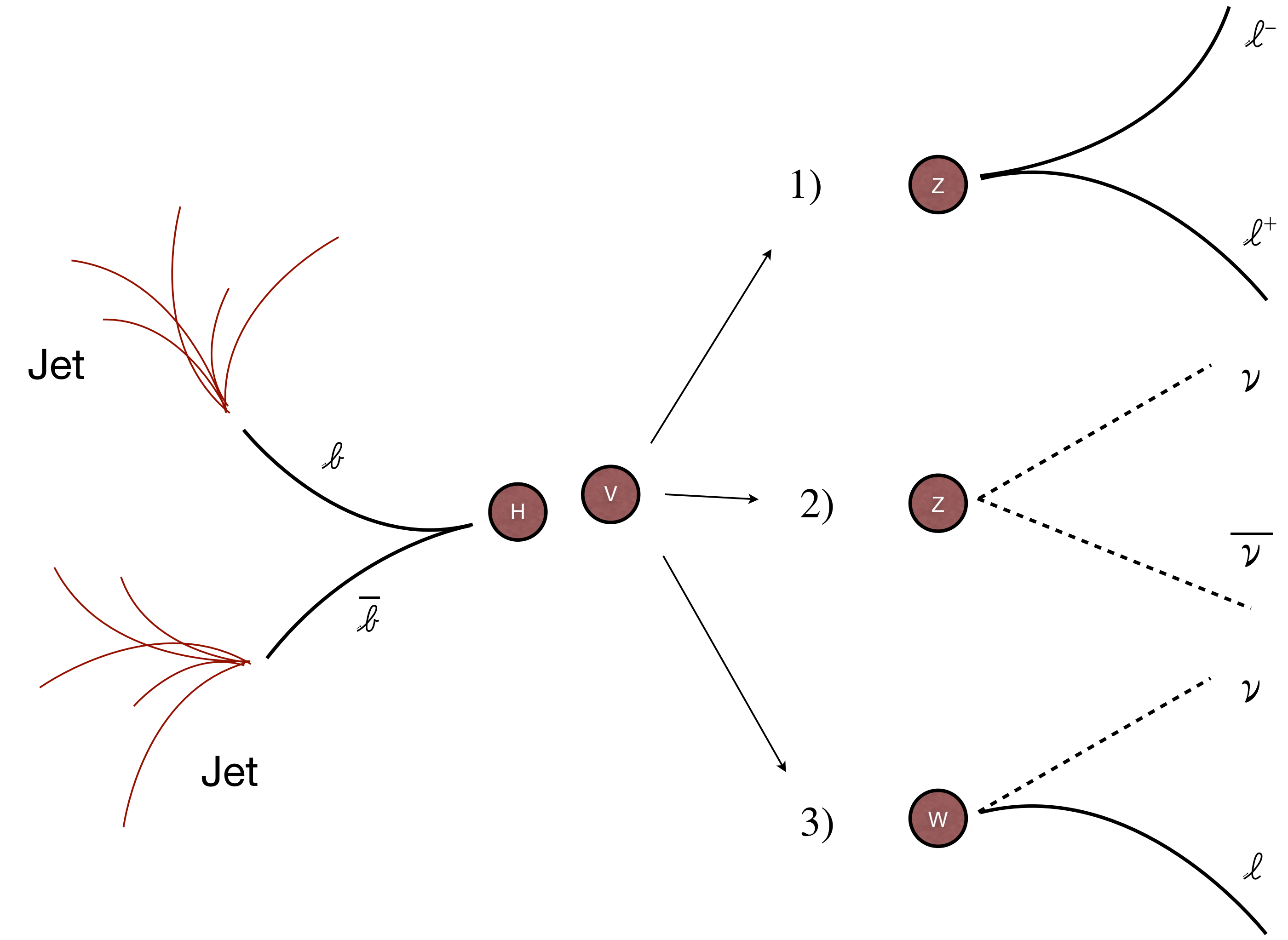
Log likelihood versus SM Higgs boson fit mass

signal strength μ=1.1±0.4

$m_H = 120^{+9}_{-7}$(stat+syst) GeV

H→*bb*

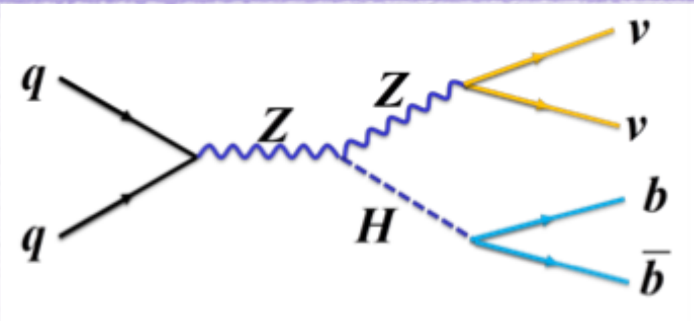
(V)H→(W/Z)*bb*

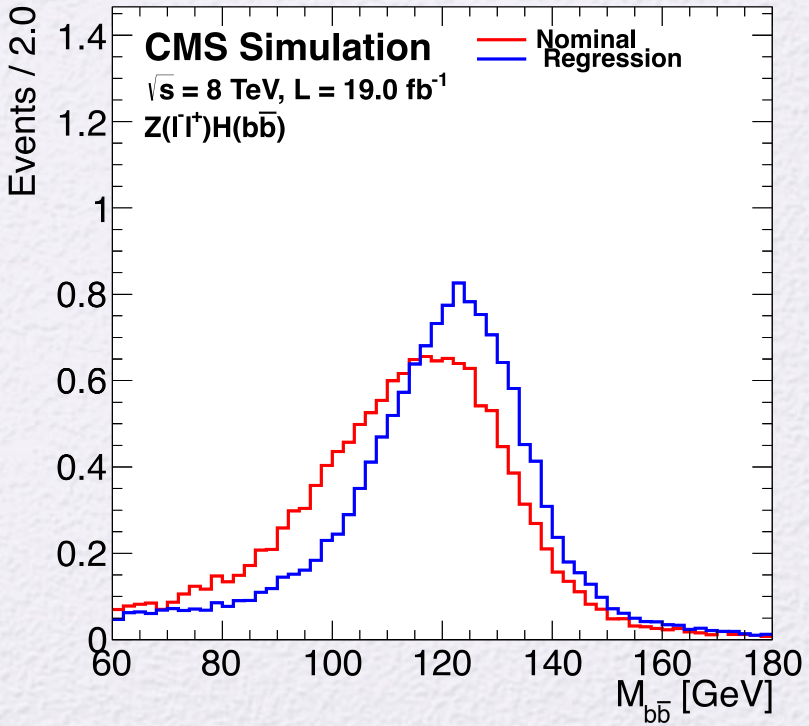


VHbb Strategy

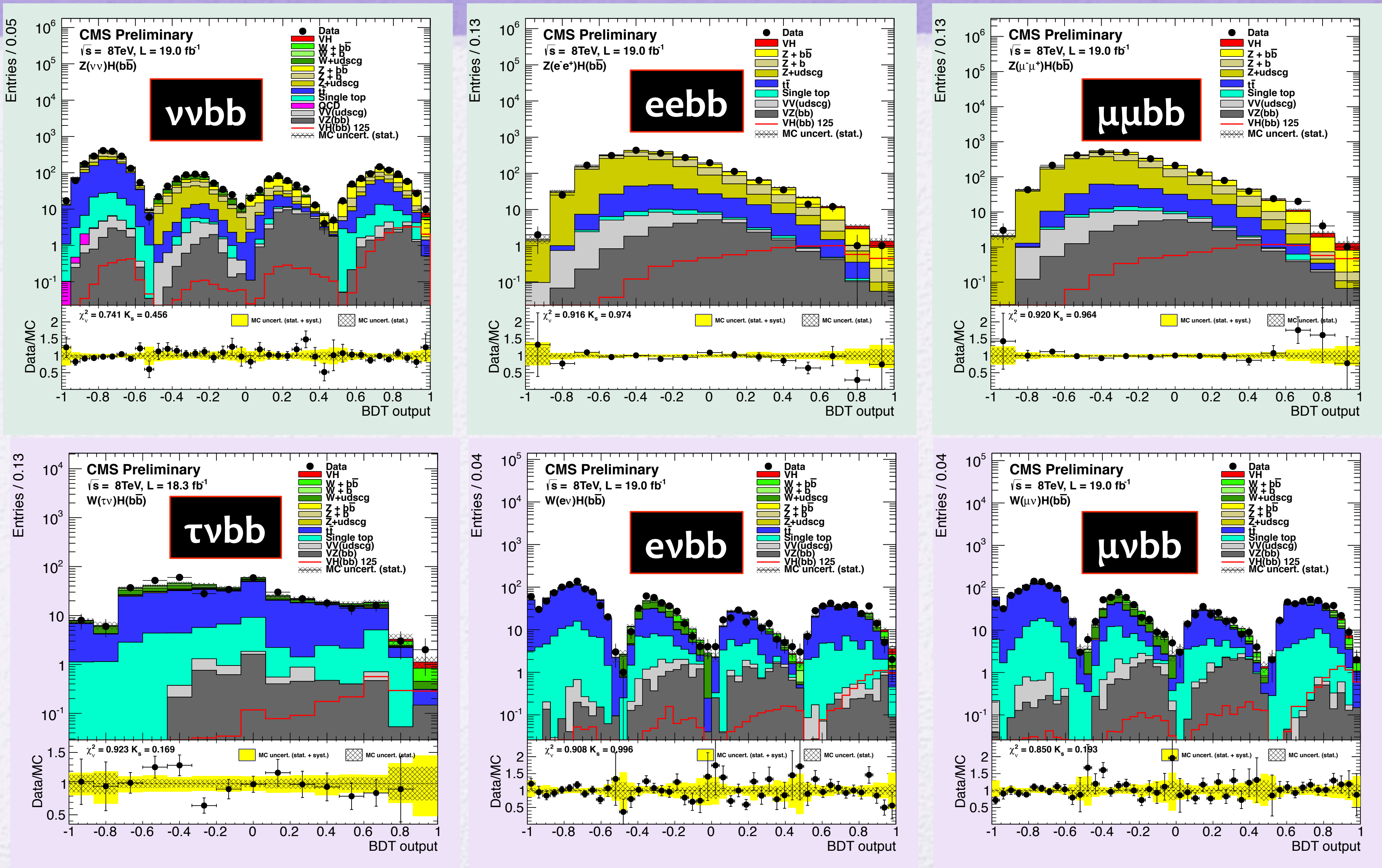
Di-jet selection in boosted regime:

- 6 final states (Wμν, Weν, Wτν, Zνν, Zμμ, Zee)
- Final state with leptons (MET), b-tag
- binning in vector boson PT
- Normalization of dominant backgrounds V+jets and tt extracted from data
- Improve mass resolution using a BDT regression
- BDT (discriminate signal from background) used for fitting mc to data

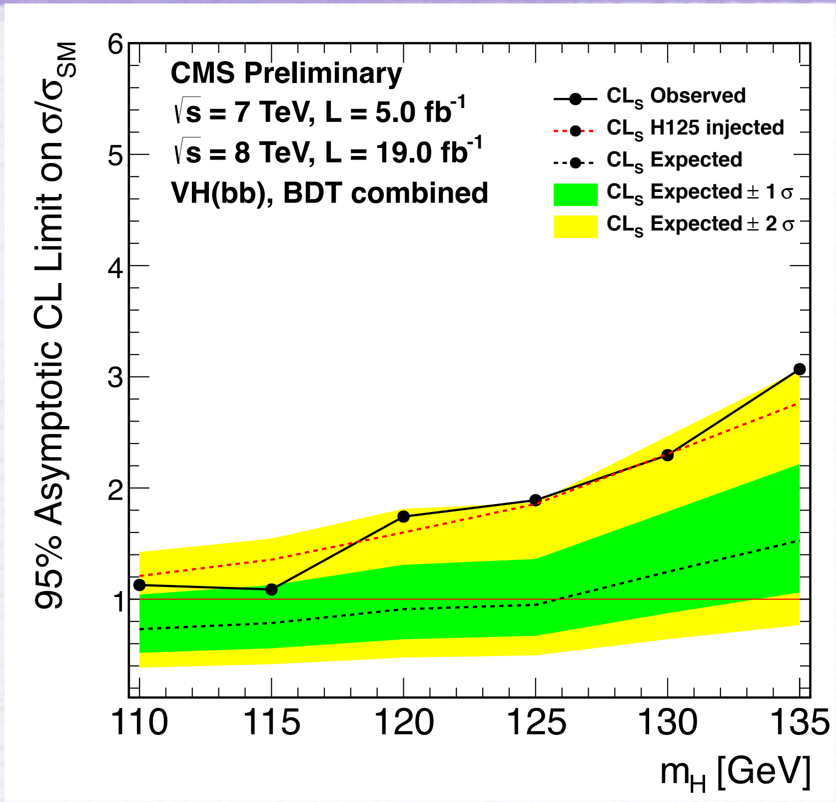


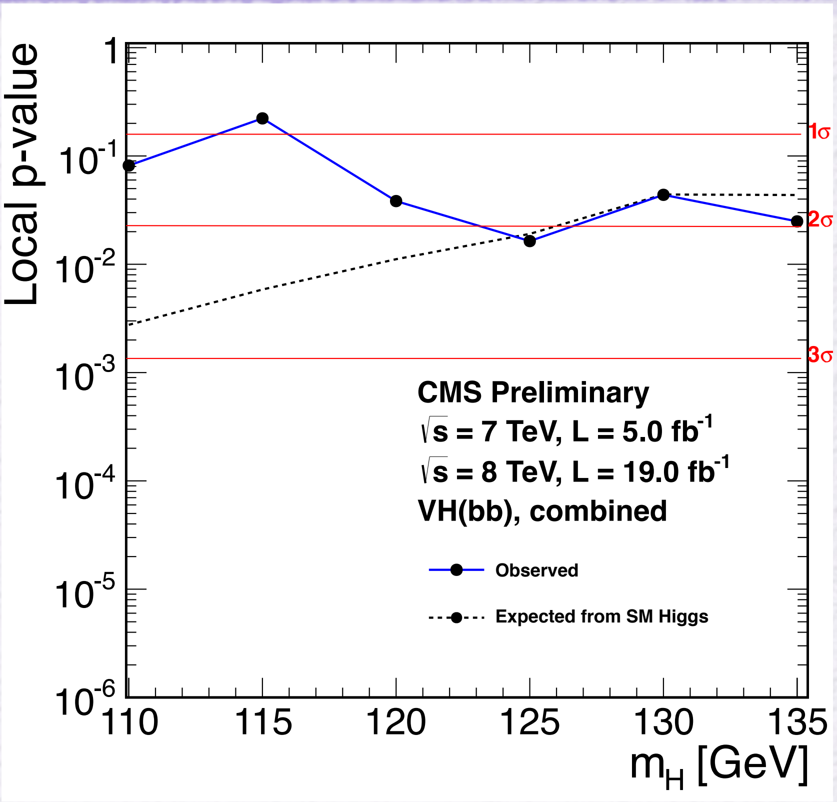


BDT Output for different final states



Limit and Significance





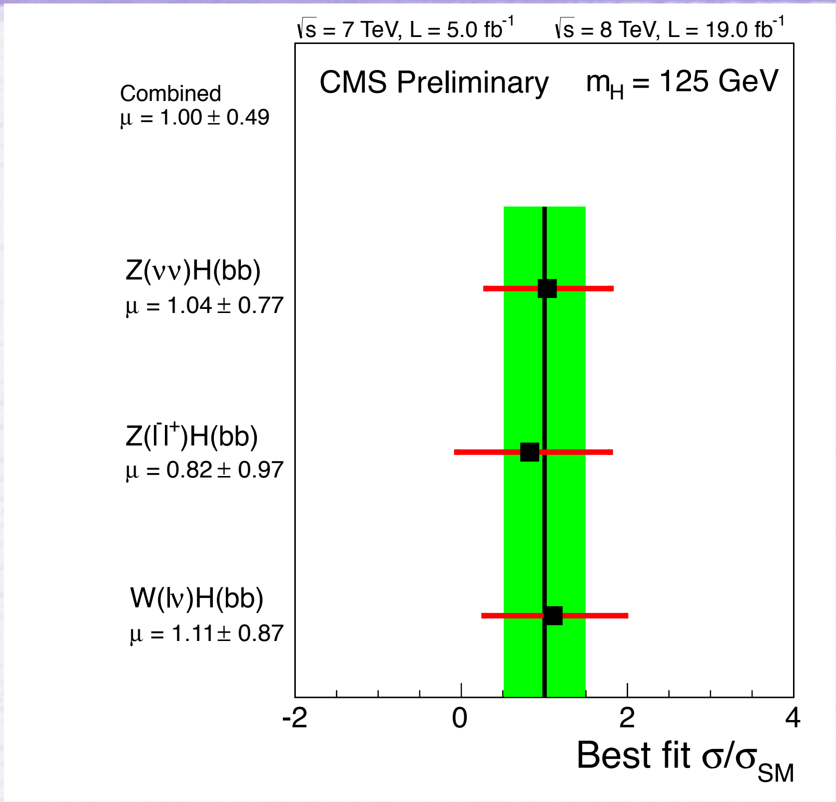
For mH = 125 GeV

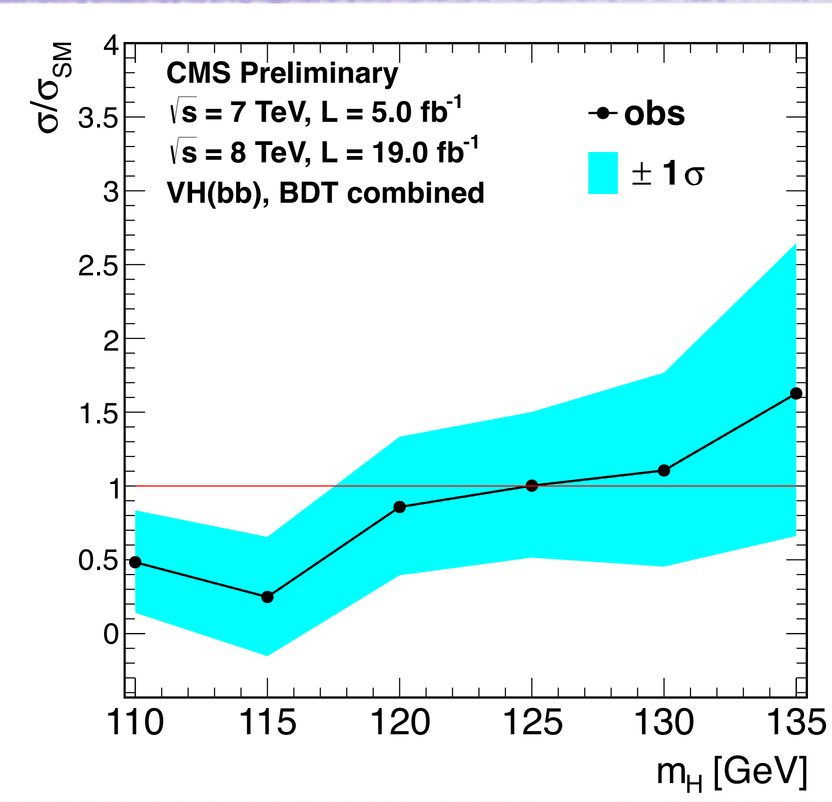
- Observed 1.89 x SM
- Expected 0.95 x SM

Observed agrees well with expectation from SM Higgs boson at 125 GeV

Significance 2.1 σ (2.1σ)

Best Fit

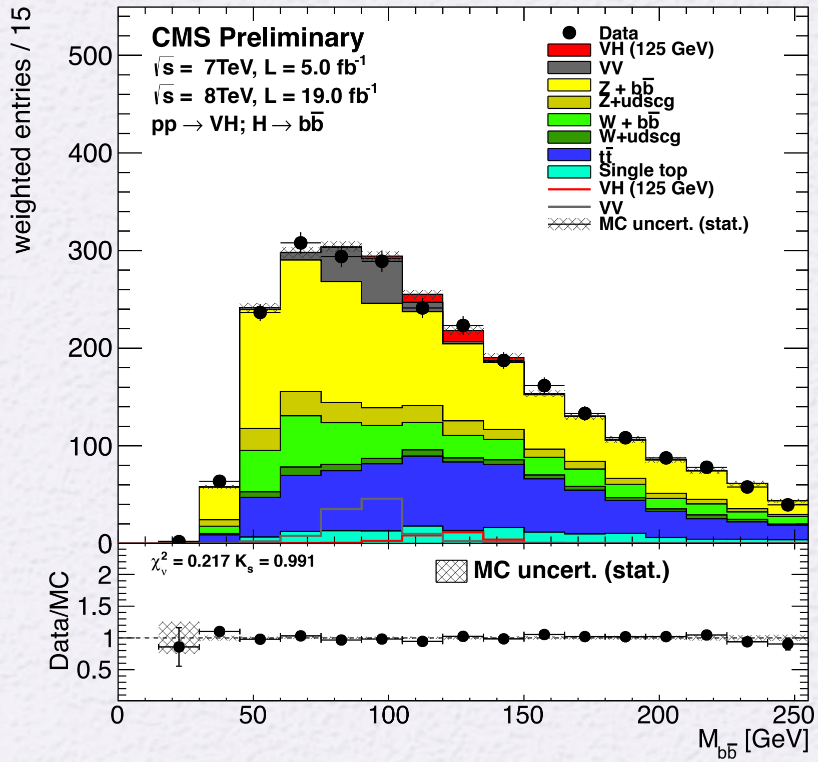


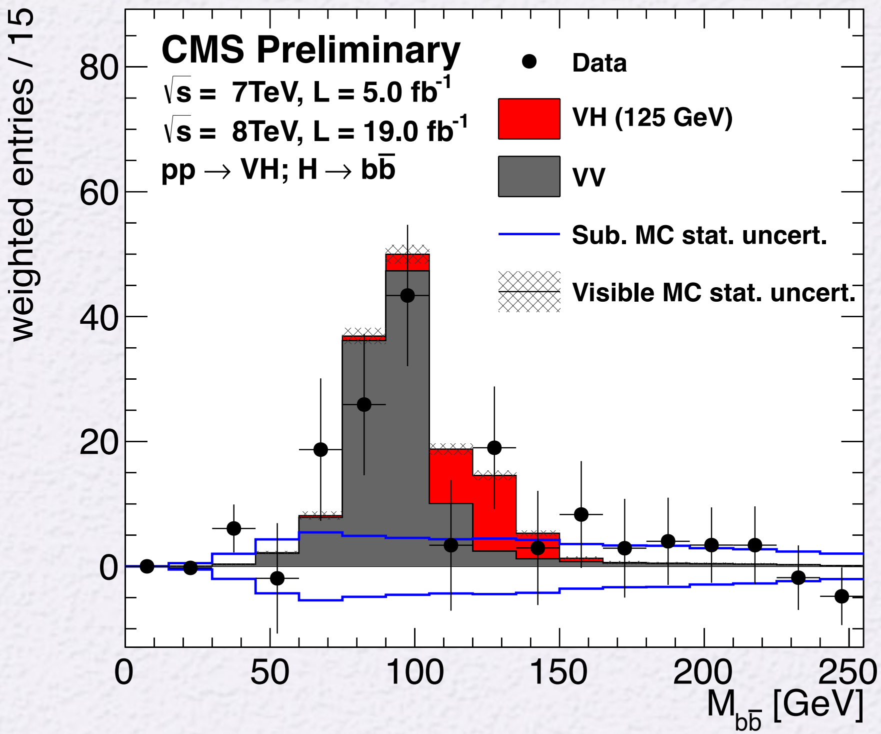


$\mu = 1.0 \pm 0.5$

All modes are compatible

Combined Mass

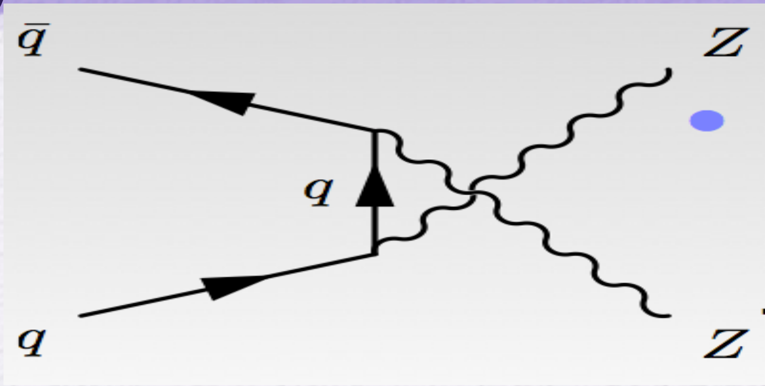




Weight each category by s/(s+b) in window 105-150 GeV

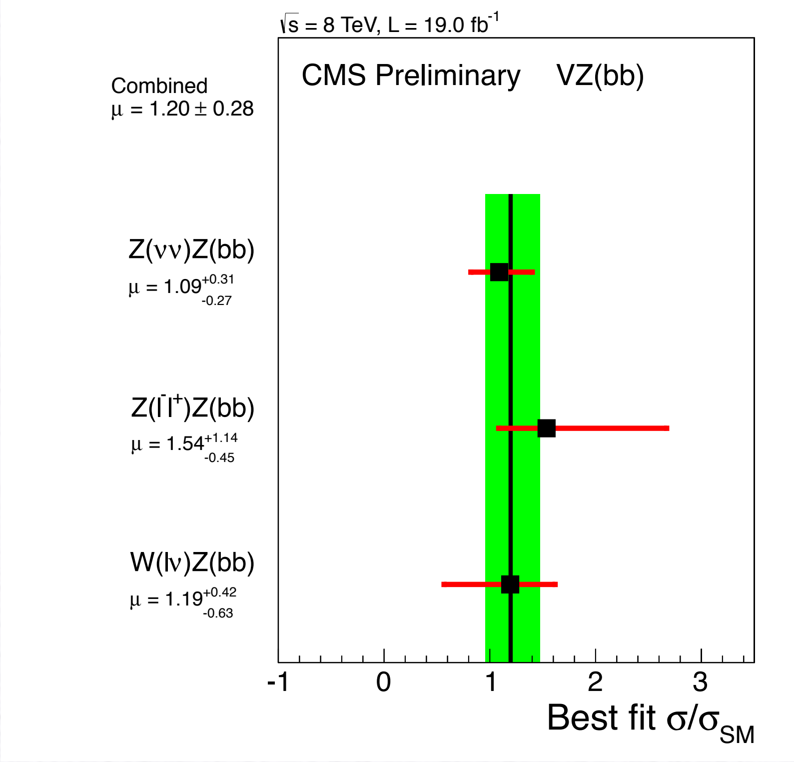
Subtract all BG, except VV, from Data

Validation of BDT using VZ(bb)



As Validation of MVA, BDT is trained using di-boson as signal and other processes (including VH) as BG.

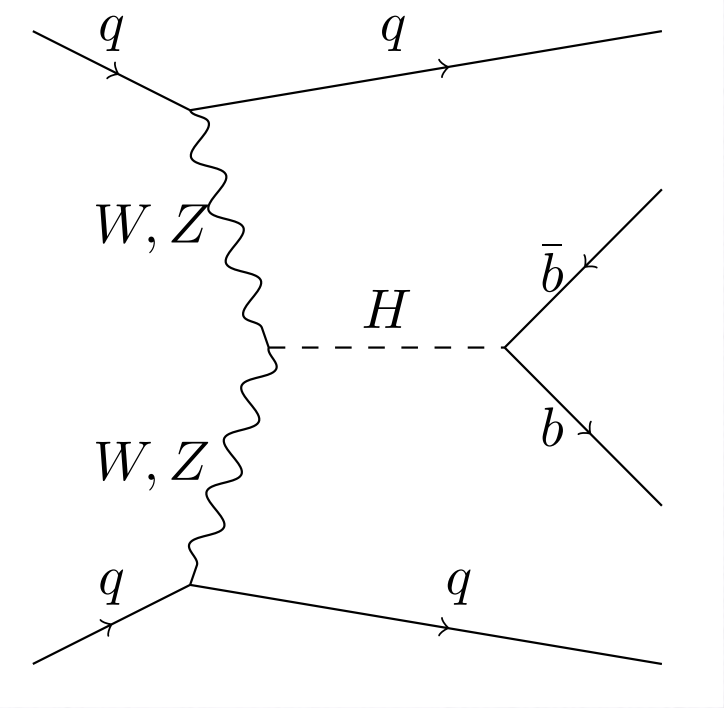
	BDT VZ(bb)
Exp. Sig	**6.3 σ**
Obs. Sig	**7.5 σ**
μ	**$1.19^{+0.27}_{-0.23}$**



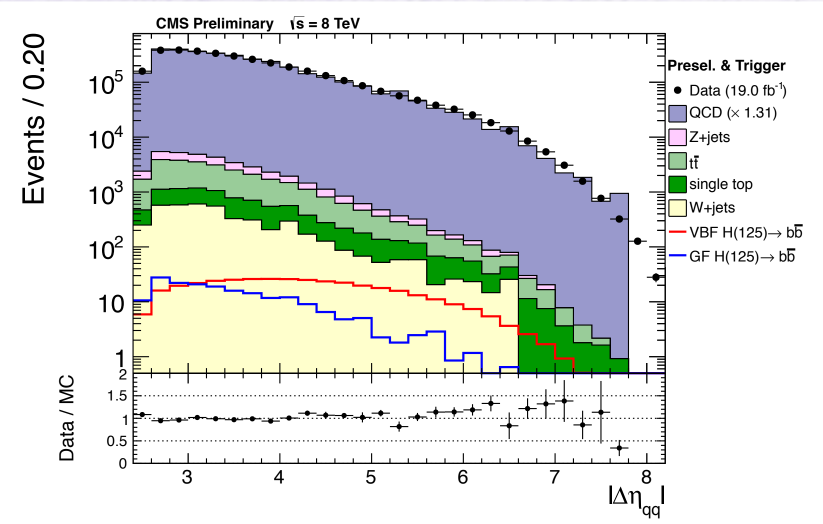
VBF_H→bb

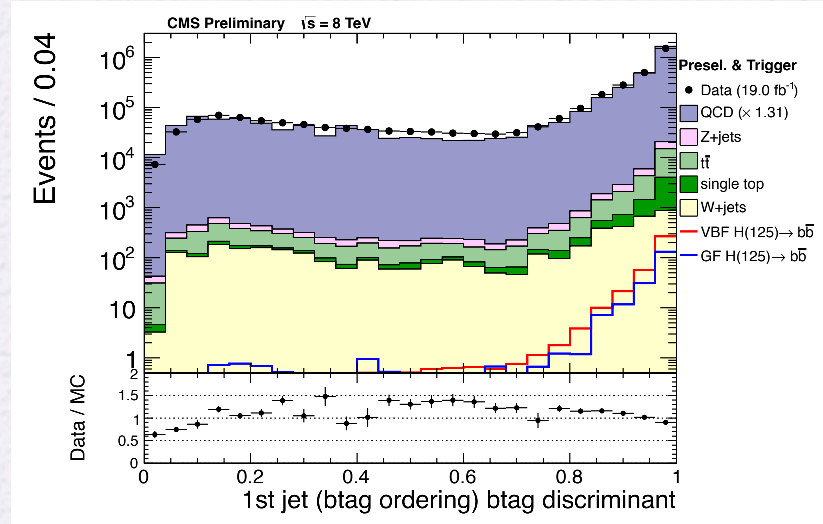
- Using 4-jet Trigger (one is required to be btag)

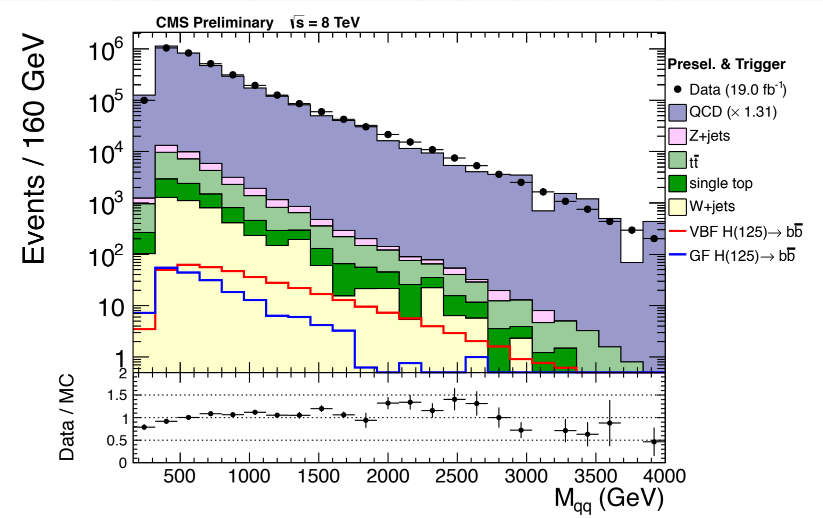
- Key information to suppress large QCD and ttbar:
  - two b-jets (Non back to back)
  - two forward jets(light quarks)
  - Quark gluon tagger to separate quark jet (in signal) from gluon (in QCD)
  - Other topological variable to set up the neural network technique.

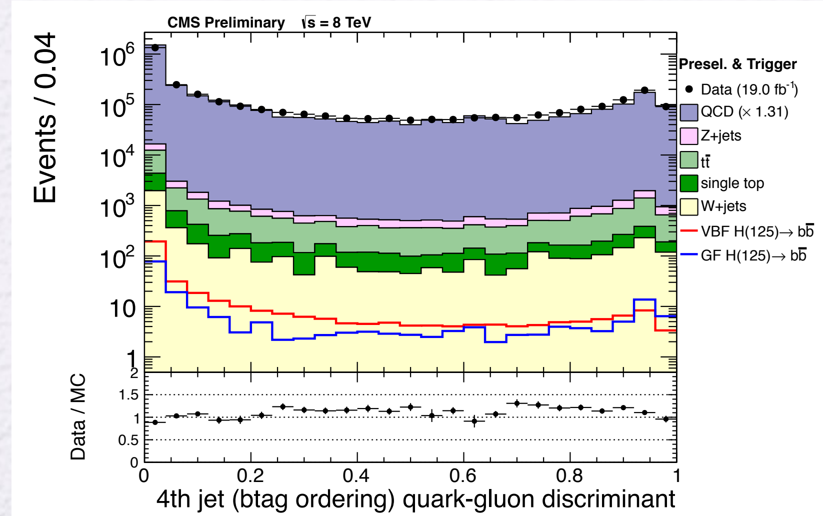


Different variables as input of MVA



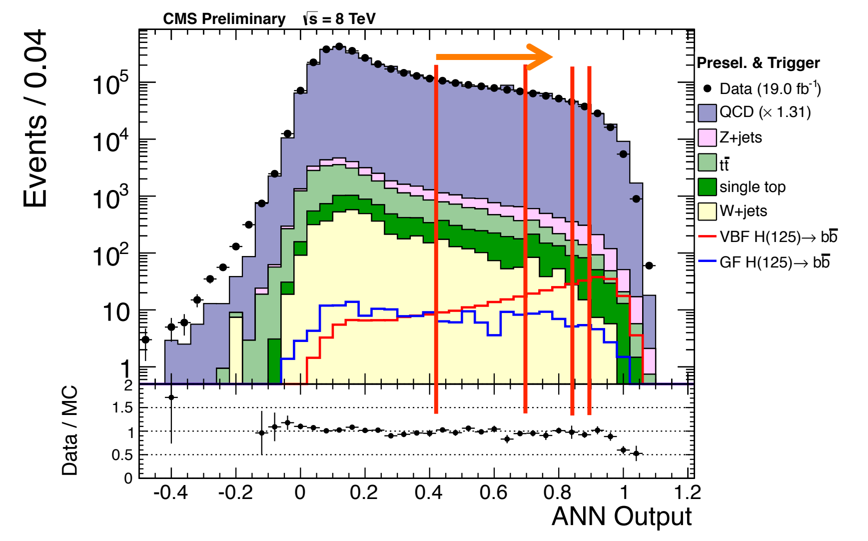






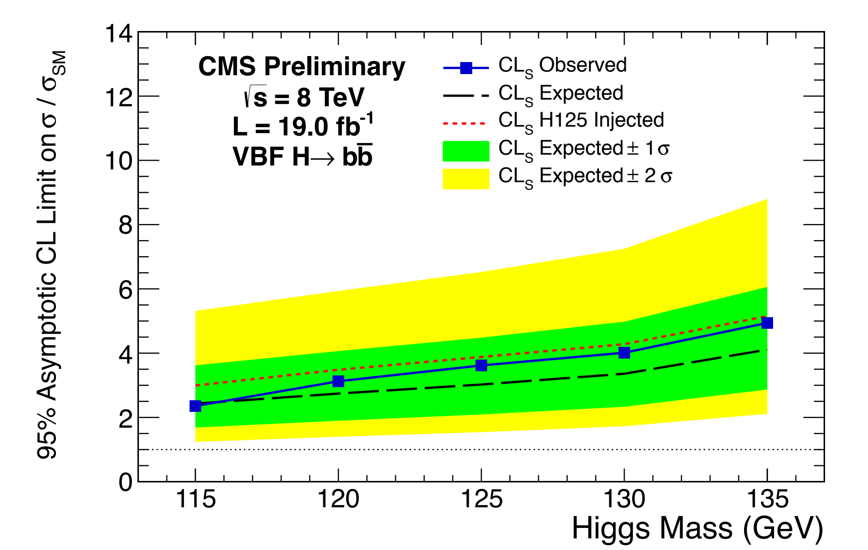
ANN output and Limit

The ANN output splited into 4 categories to increase sensitivity

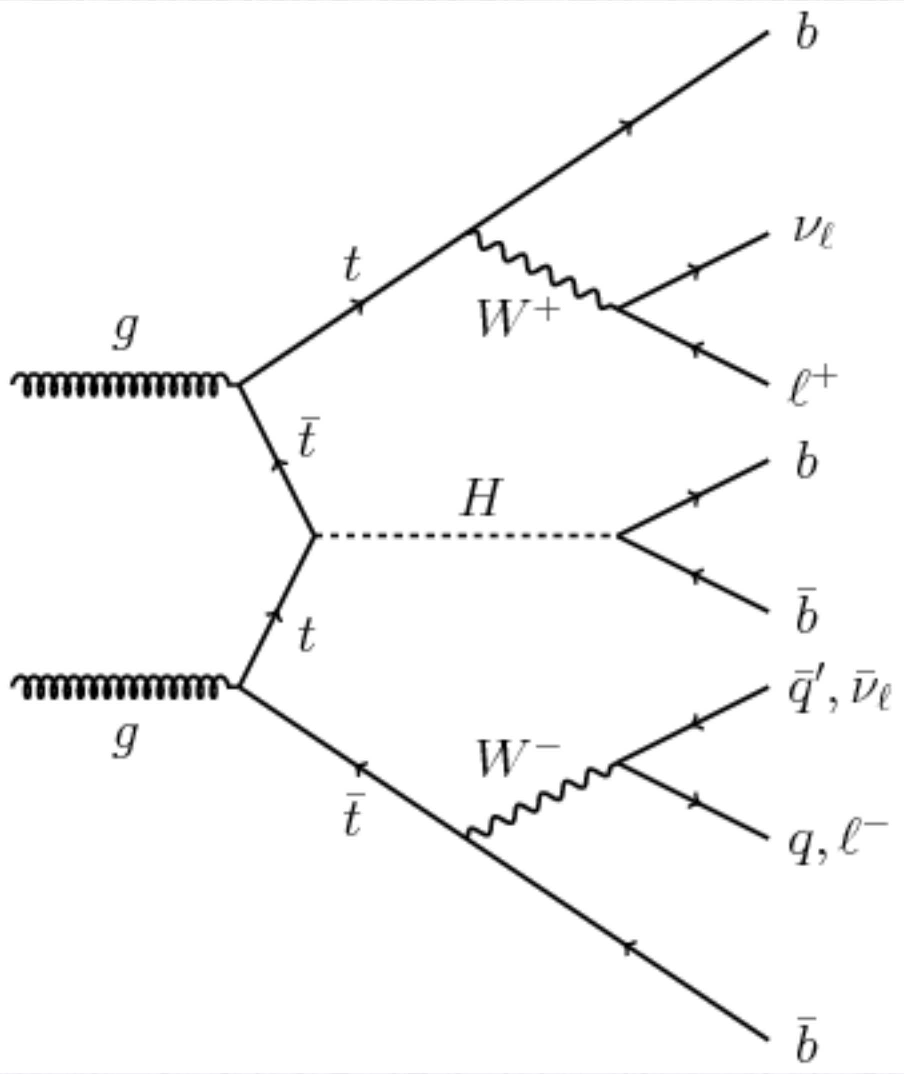


@ 125 GeV

- obs. limit = 3.6 x SM
- exp limit = 3.0 x SM
- $\mu = \sigma/\sigma_{SM} = 0.7 \pm 1.4$



ttH→tt(*bb*,ττ)



Channels and Categoriez

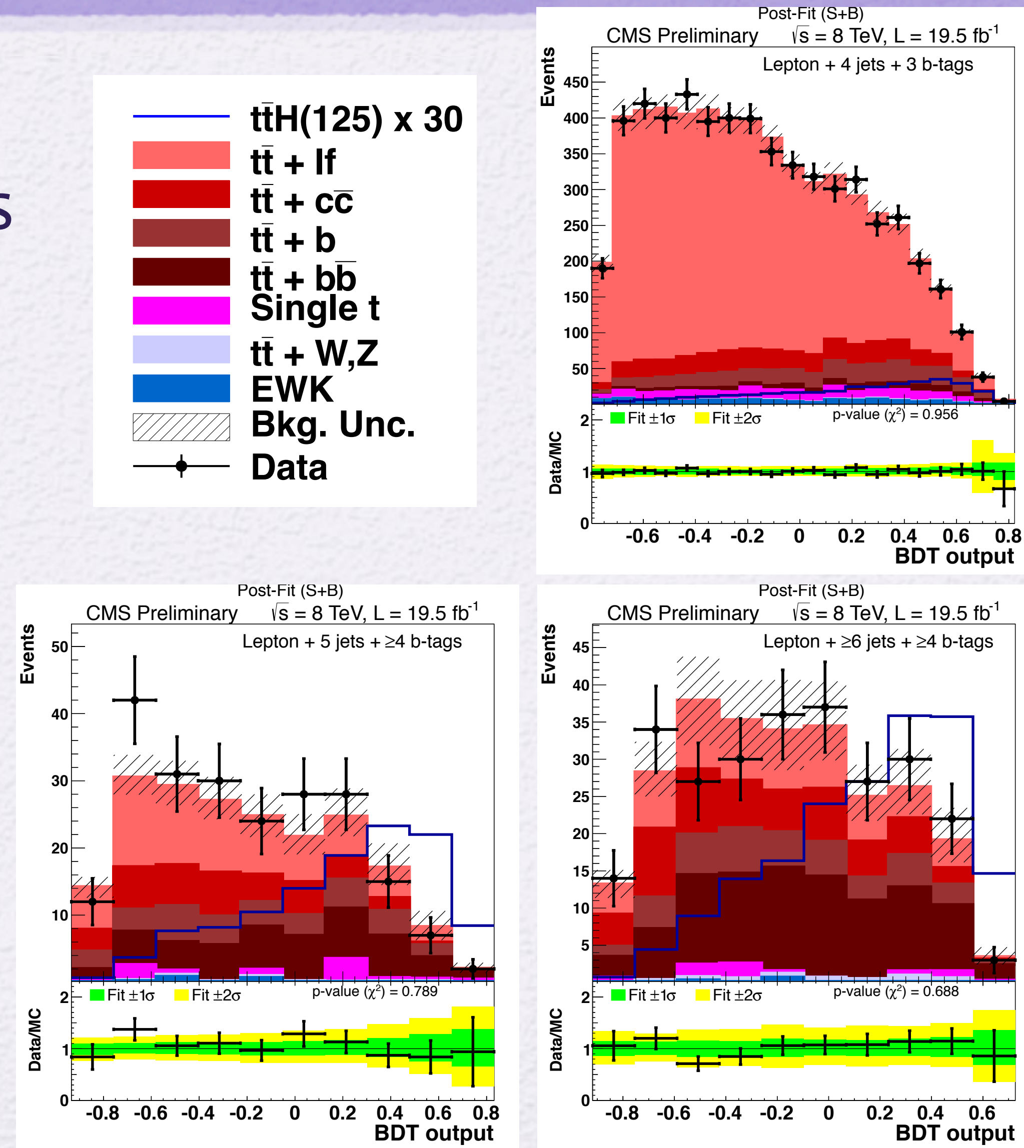
3 different channels:

- lepton+jets (tt → lνqq' bb, H → bb)
  - 1 iso-lepton + ≥ 4 jets (≥ 2 b-tagged)
- di-lepton+jets (tt → $l^+\nu l^-\nu$ bb, H → bb)
  - 2 OS isolated lepton + ≥ 3 jets (≥ 2 b-tagged)
- tau+jets (tt → lνqq' bb, H → $\tau^+\tau^-$)
  - 1 iso-lepton + ≥ 4 jets ($2\tau_h$ + ≥ 1 b-tagged)

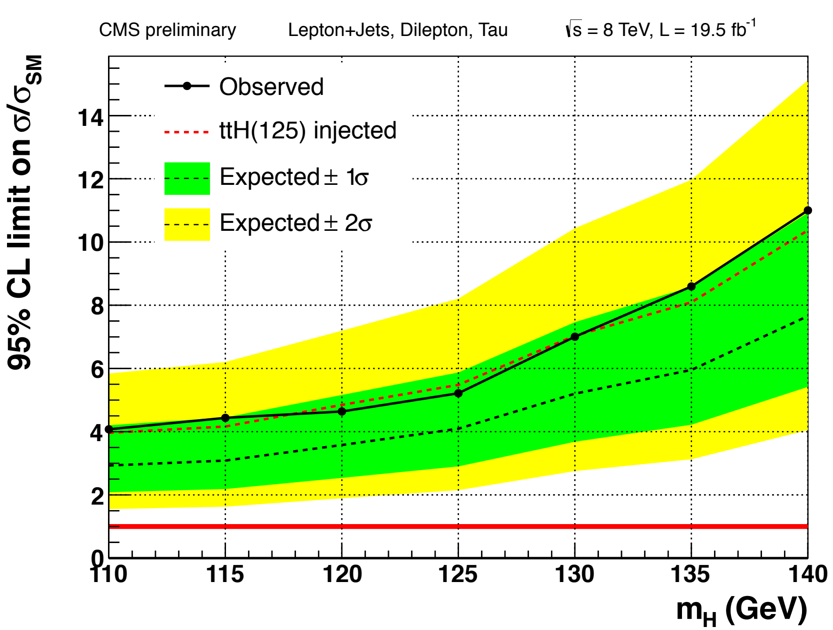
- Each channel divides to several sub channels based on the number of jets or bjet
- BDT is trained for each sub-channels separately.

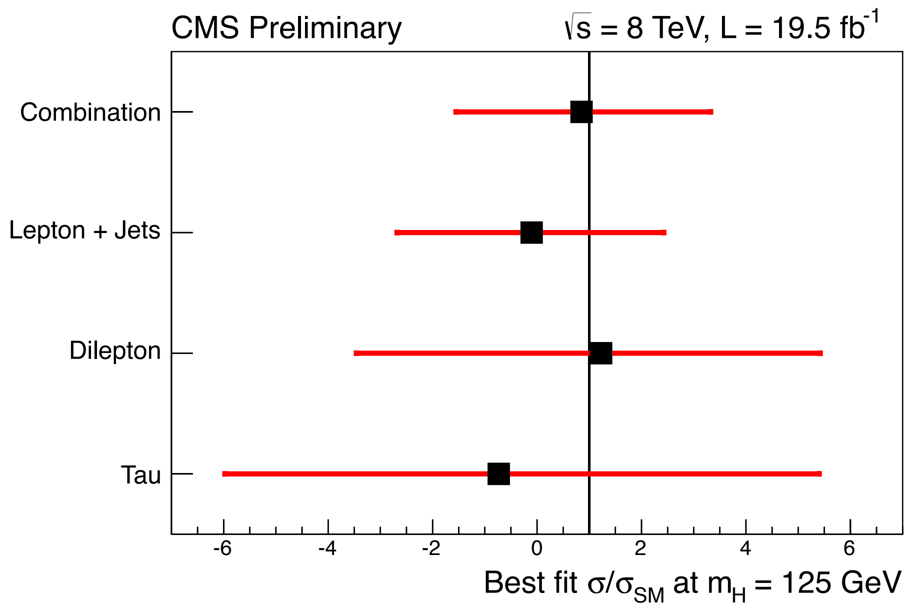
Lepton + Jets

- combination of different number of jets and b-jets (7 sub channels)
- reconstruct two top quarks based on the χ^2 calculation
- The "best Higgs boson mass" is mass of two highest pT jets not assigned to top-quark



Limit and Best Fit





@ 125 GeV: obs. limit = 5.2 x SM - exp limit = 4.1x SM

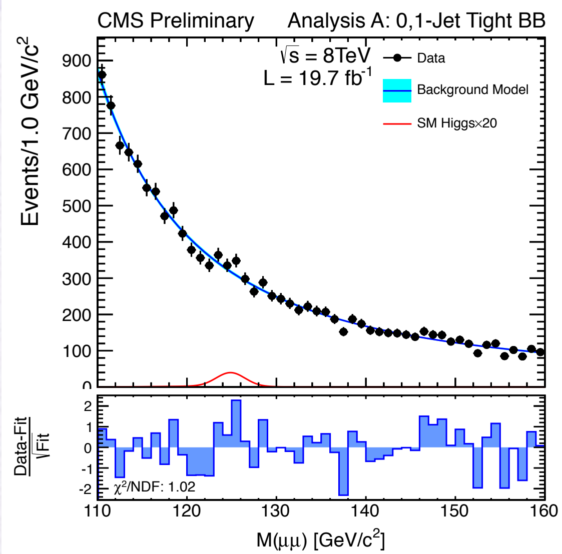
Observed agrees well with expectation from SM Higgs boson at 125 GeV

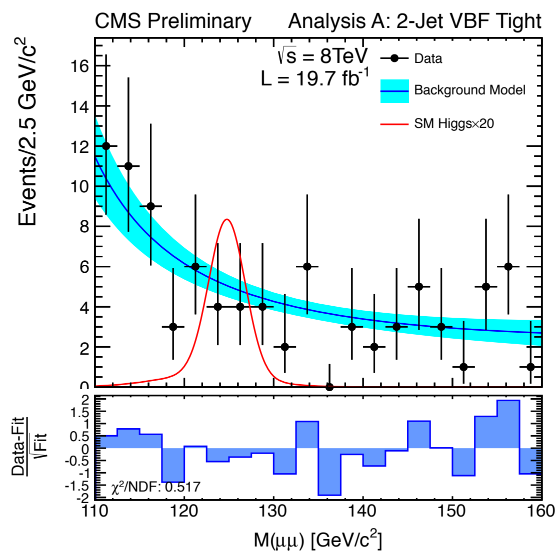
signal strength $\mu = 0.85^{+2.47}_{-2.41}$

$H \to \mu\mu$

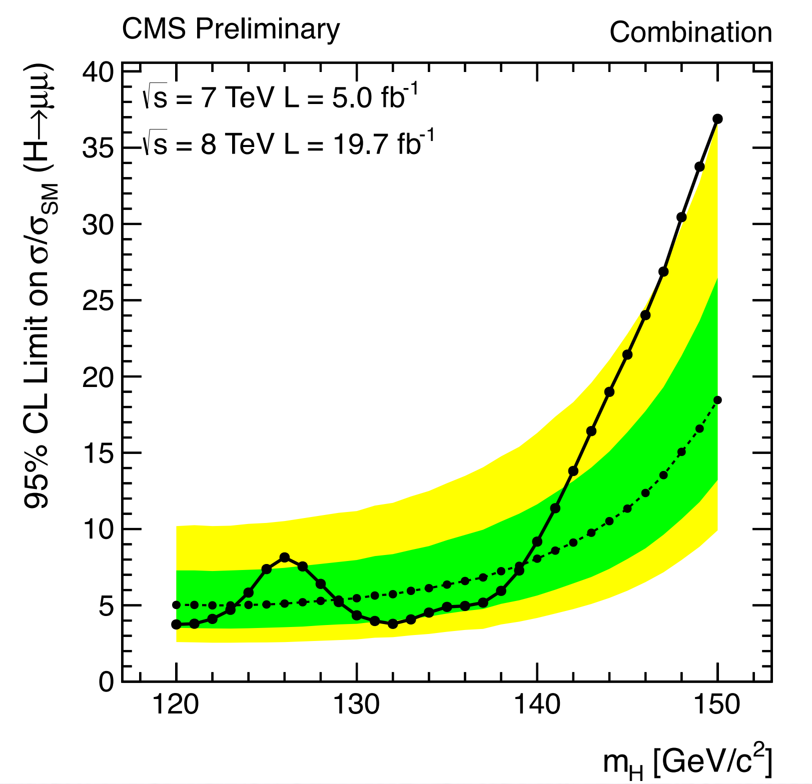
Analysis Strategy

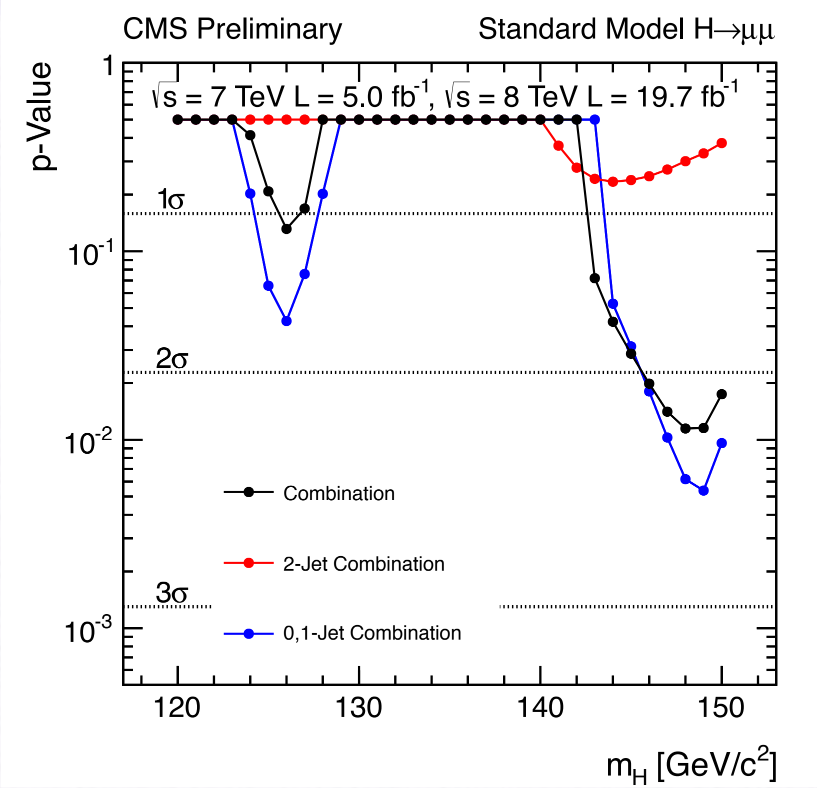
- Two isolated muon + further jets
- Categorization based on the jet multiplicity:
  - 2jets (VBF, GGF tight and GGF loose based on M_{jj} *and* $\Delta\eta_{jj}$)
  - 0-1Jet (loose and Tight based on $p_T(\mu\mu)$)
- More categorization based on η of each muon to optimize the $M_{\mu\mu}$ resolution: $|\eta|$ in [0,0.8]-[0.8,1.6]-[1.6,2.1]
- $M_{\mu\mu}$ used to fit:
  - double Gaussian function for shape of the signal
  - polynomial and an exponential term for BG shape [dominated by the Drell-Yan]





Limit and Significance





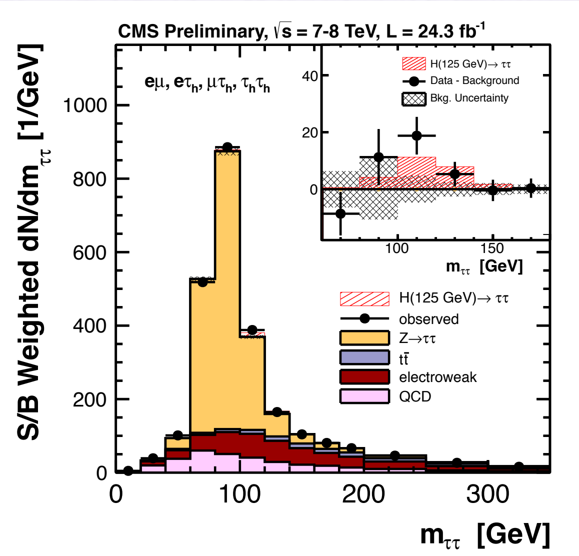
@ 125 GeV

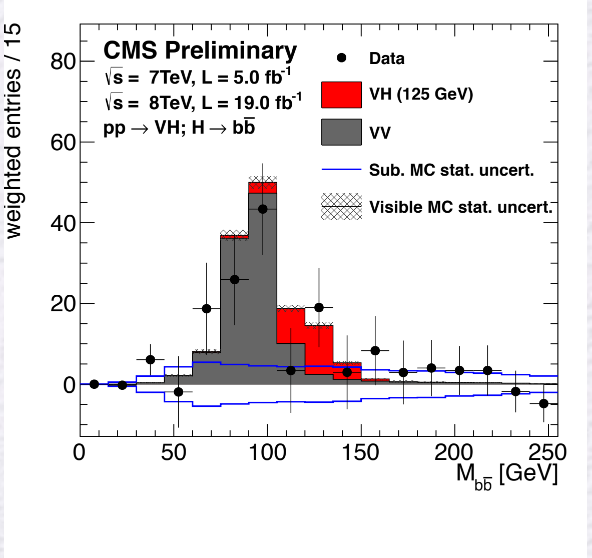
- obs. limit = 6.6 x SM
- exp limit = 4.9 x SM

A broad excess @ 149 GeV
~ local significance of 2.8 σ
reduced to ~ 0.8 σ after LEE

Conclusions

- Full search is done for fermionic decays of Higgs boson in 5 production and 3 decay modes with the full 2011+2012 dataset collected by CMS
- A wide excess compatible with SM Higgs is observed both in **H→*ττ*** and **H→*bb***
  - Observed significance of ~ 2.1σ for **H→*bb*** and ~ 2.9 for **H→*ττ***
- All results are compatible with the presence of SM Higgs boson at the mass predicted by bosonic decays
- New updated and improved **H→*ττ*** results will appear soon, stay tuned …

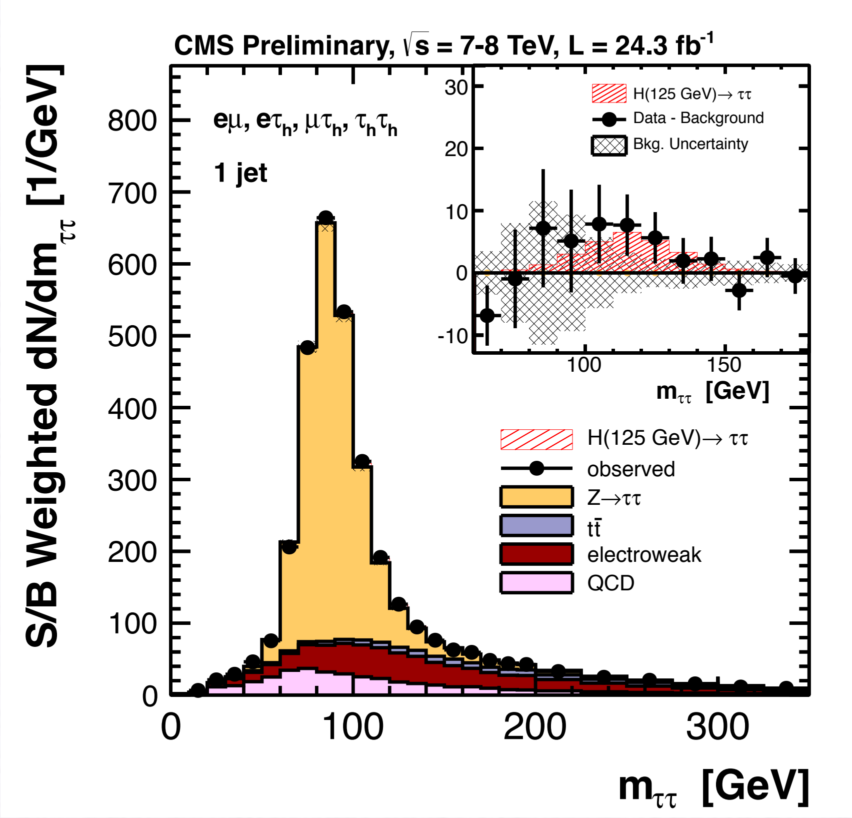




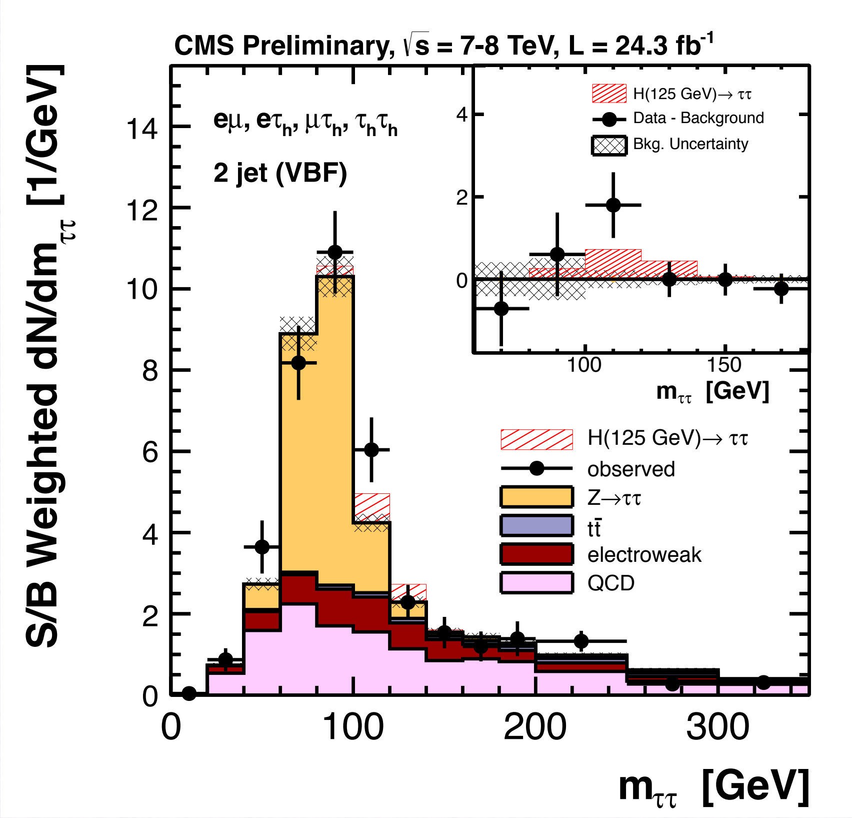
Back Up

Weighted Mass

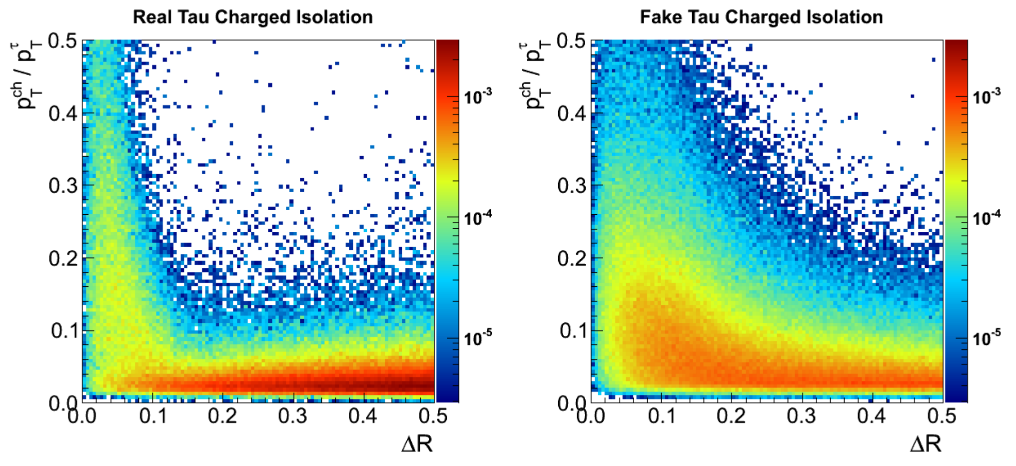
1 Jet Category

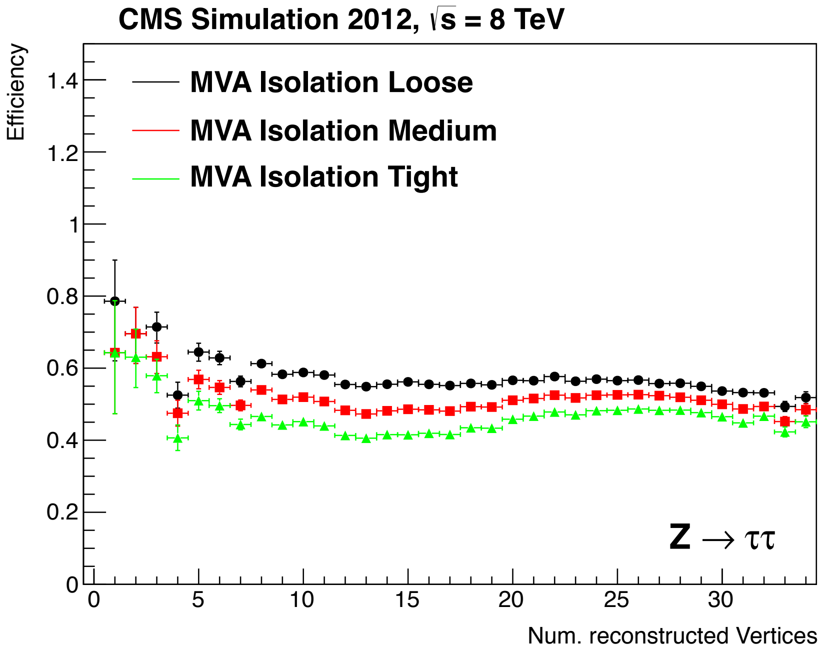


VBF Category



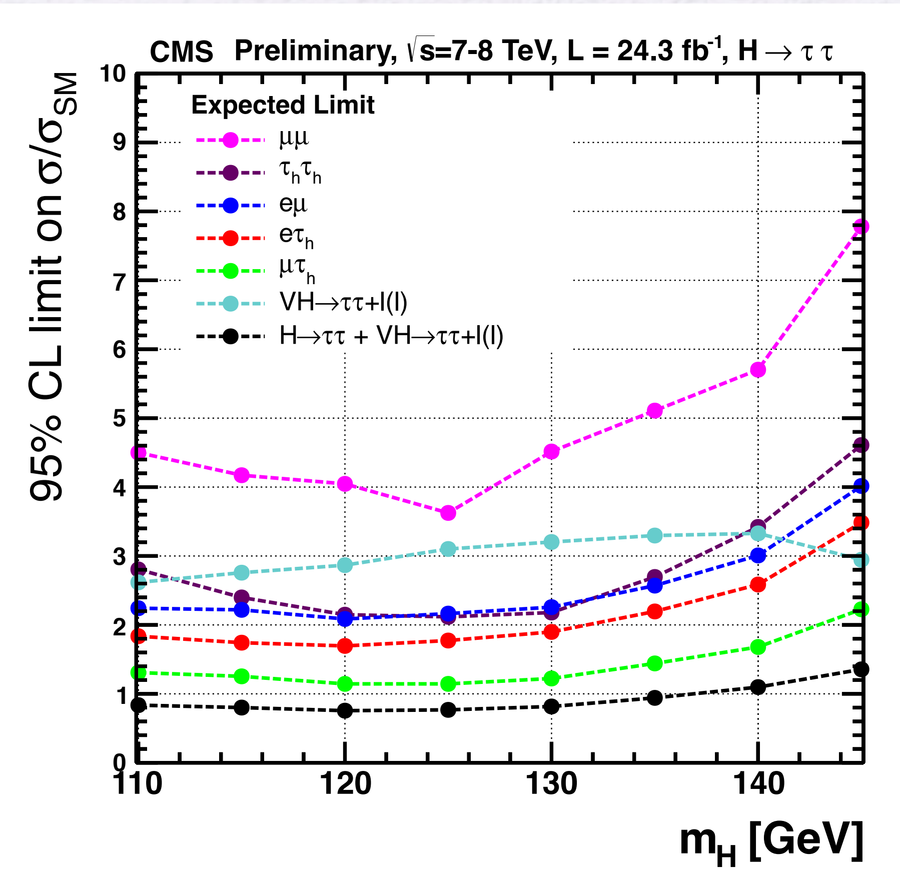
More about Tau ID



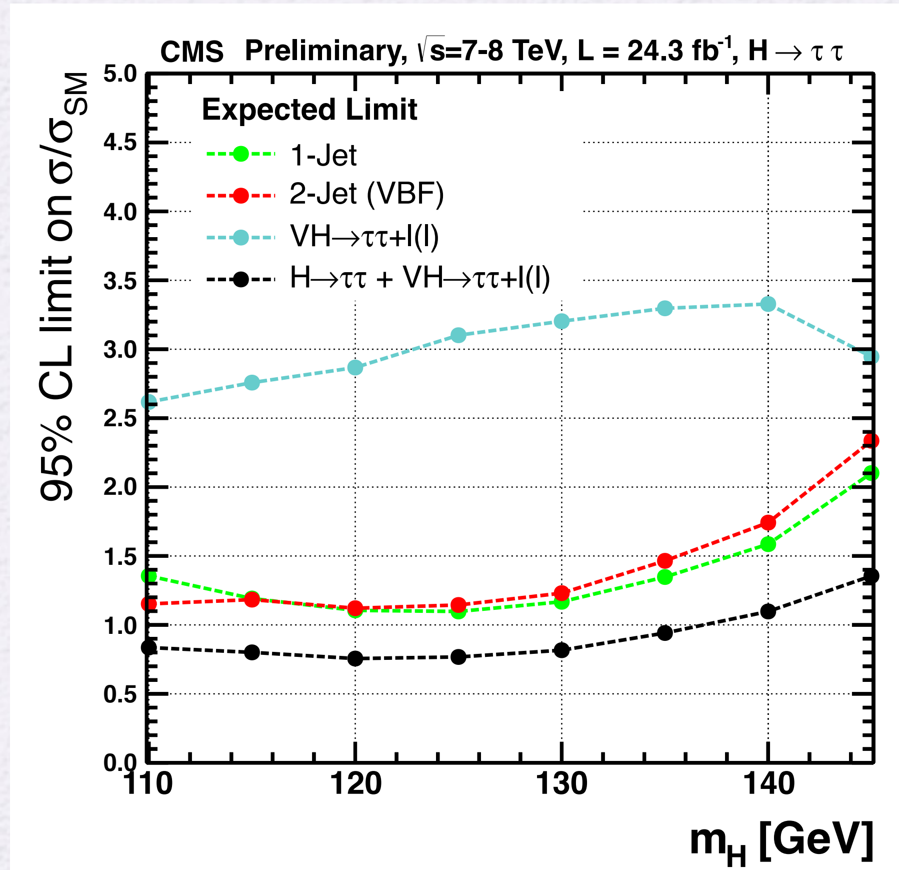


Expected Limit

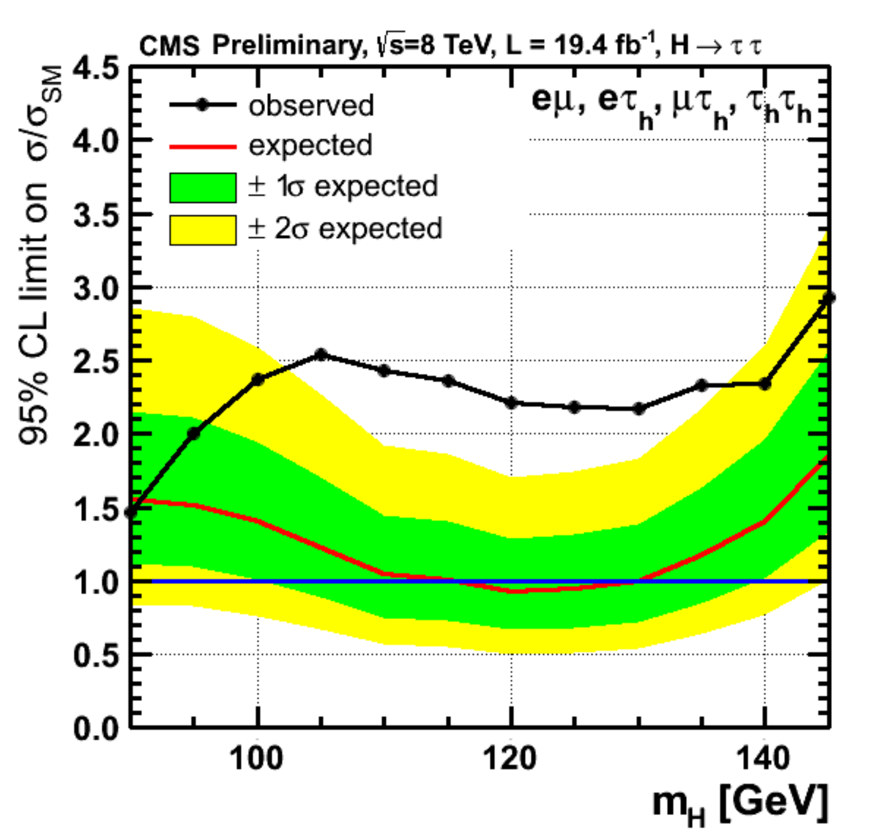
Per Channel

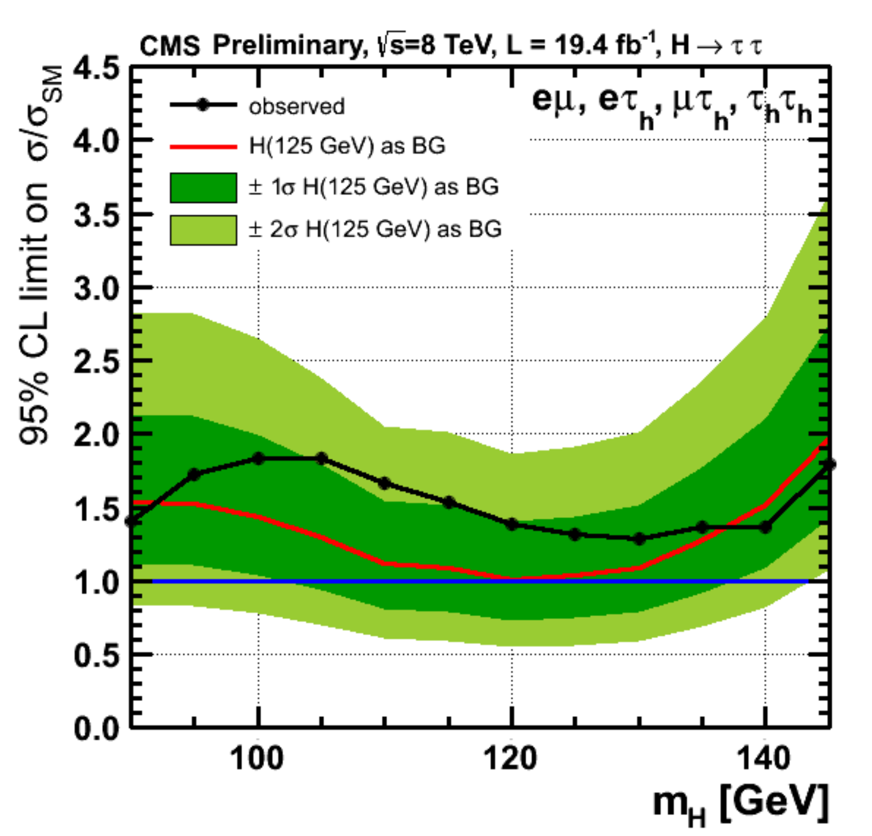


Per Category



Extended Limit (Down to 90 GeV)

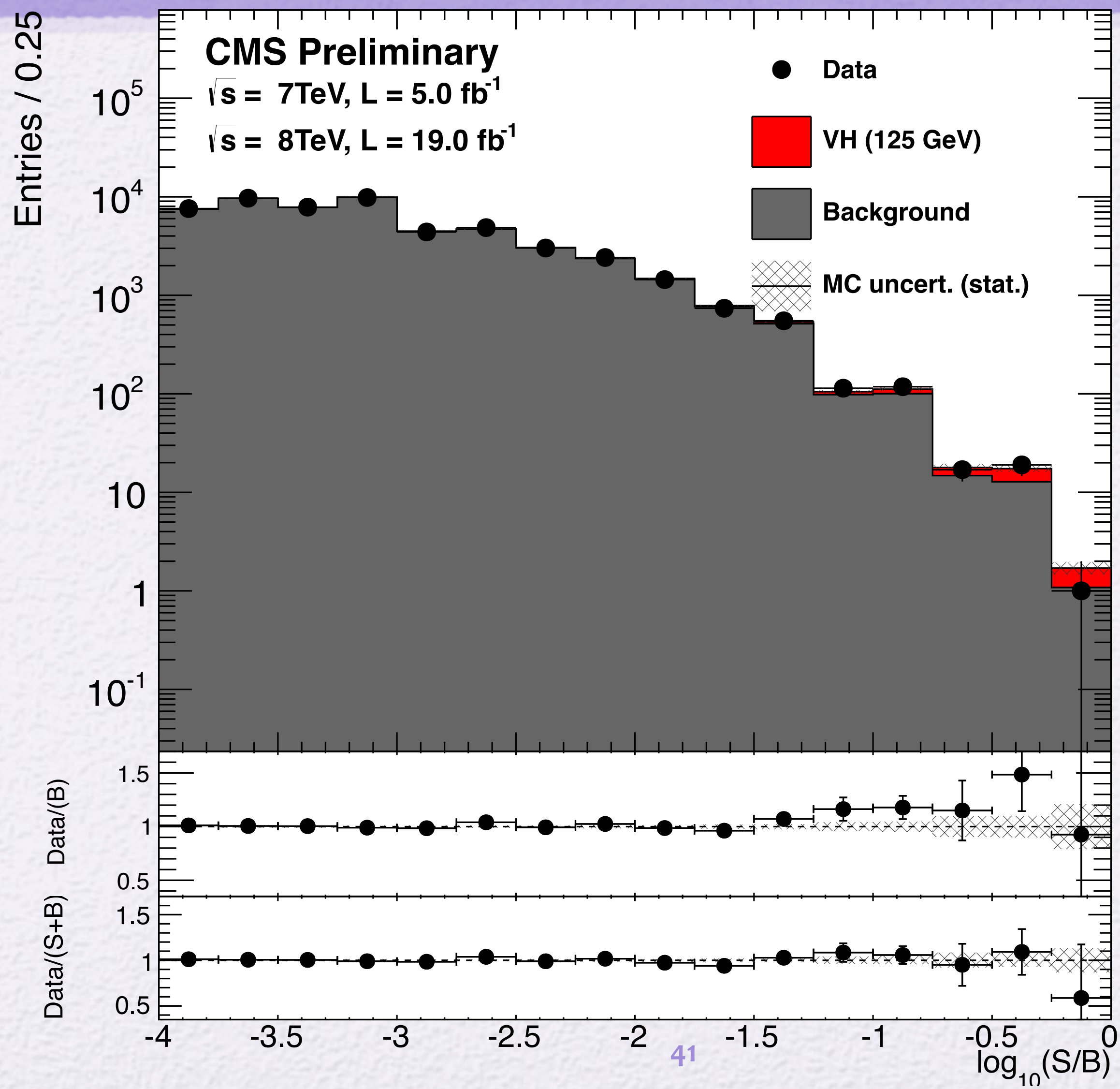




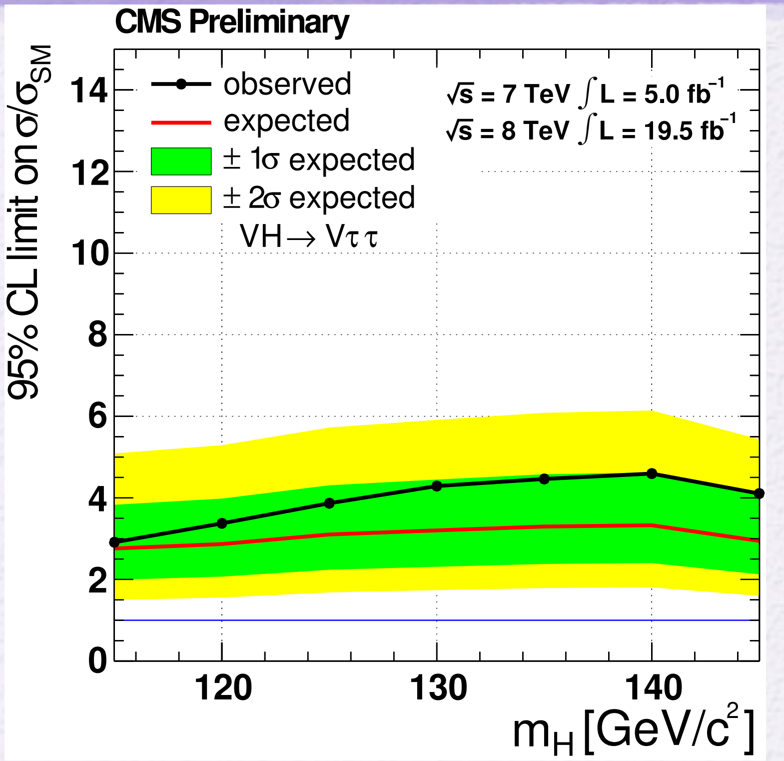
Systematics

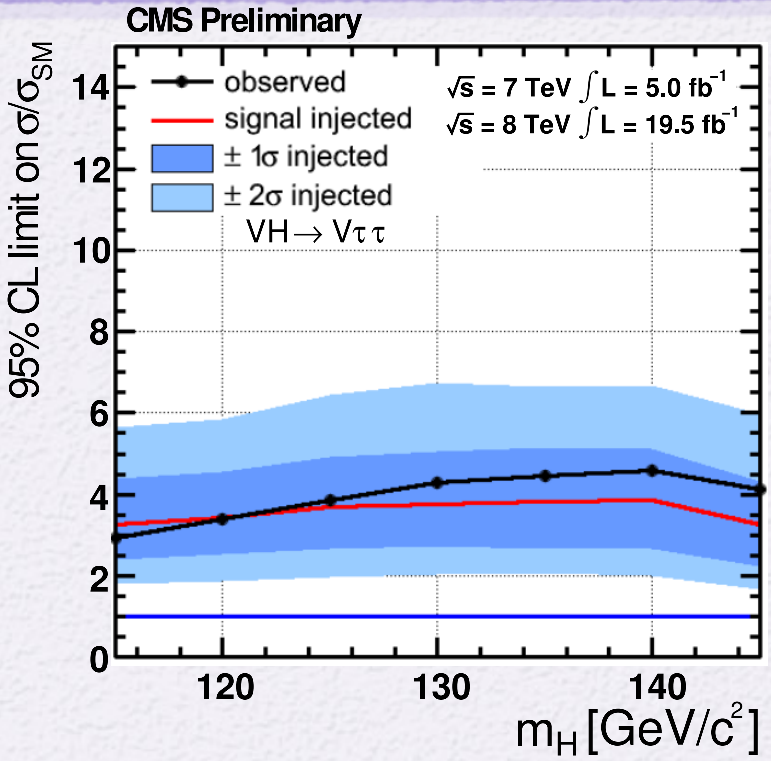
Uncertainty	**Uncert.**	**Applied on …**
Electron Id & Trigger	2%	Normalization
Muon Id & Trigger	2%	Normalization
Tau Id & Trigger	8%	Normalization
Tau Energy Scale	3%	Shape
Electron Energy Scale	1%	Shape (emu channel)
JES	2.5-5%	Normalization
MET	5%	Normalization
b-tag efficiency	10%	Normalization
Luminosity 7 TeV (8TeV)	2.2% (4.2%)	Normalization
ttbar and Diboson	10-30%	Normalization
QCD multijet	6-32%	Normalization
Z→ll (e,mu,jet fake)	(20%,30%,20%)	Normalization
PDF	2-8 %	Normalization

Combined BDT for VHbb



Combined VHττ Results



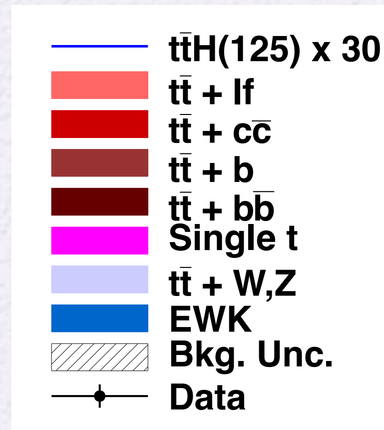


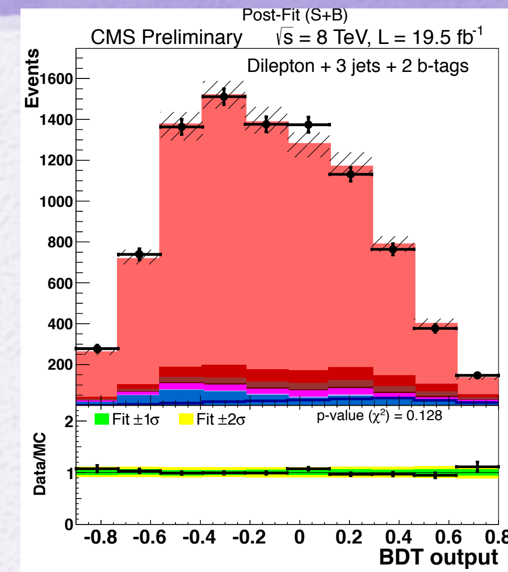
- Sensitivity of ~3xSM
- Small excess

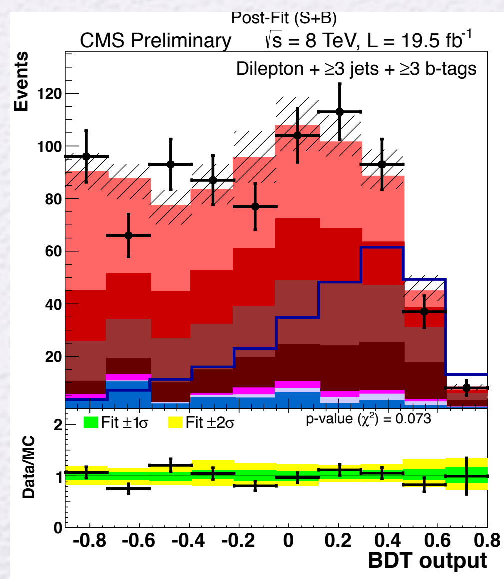
- consistent with both SM Higgs at 125 GeV and background

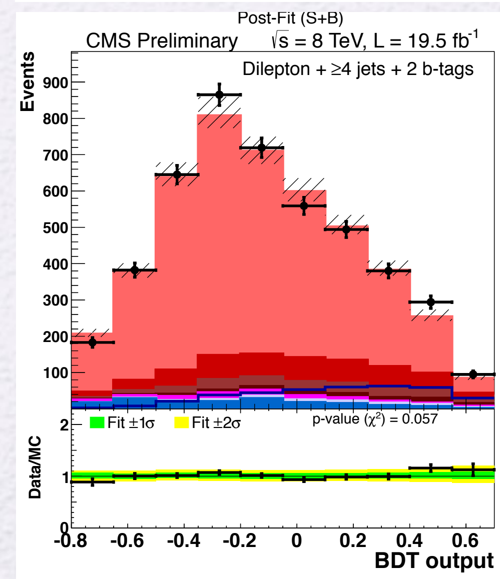
Di-Lepton + Jets

- combination of different number of jets and b-jets (3 sub channels)

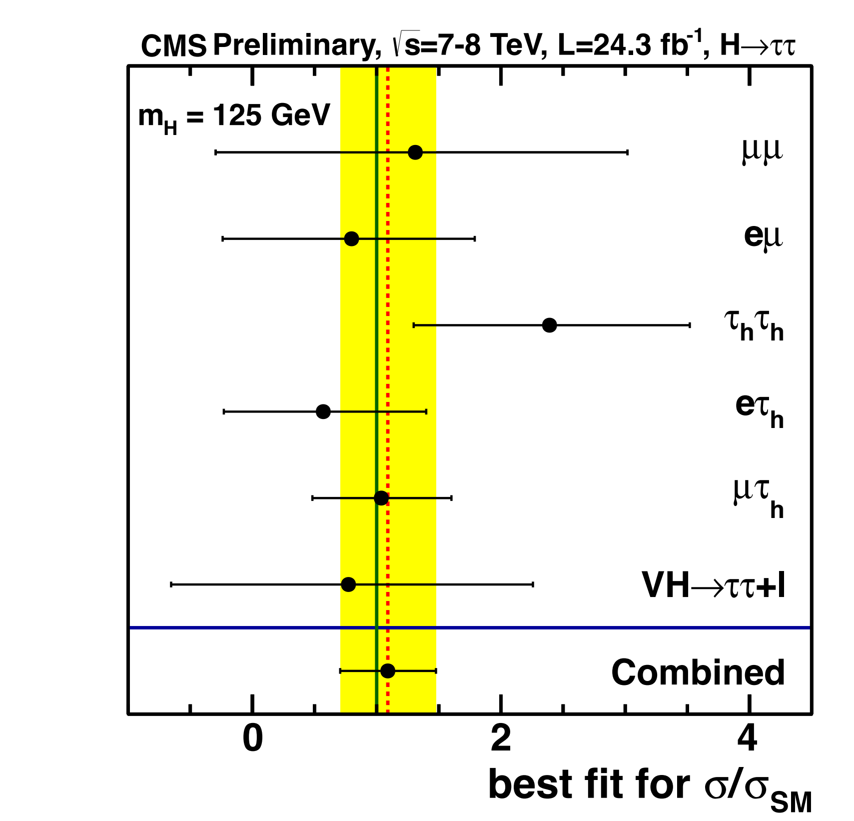


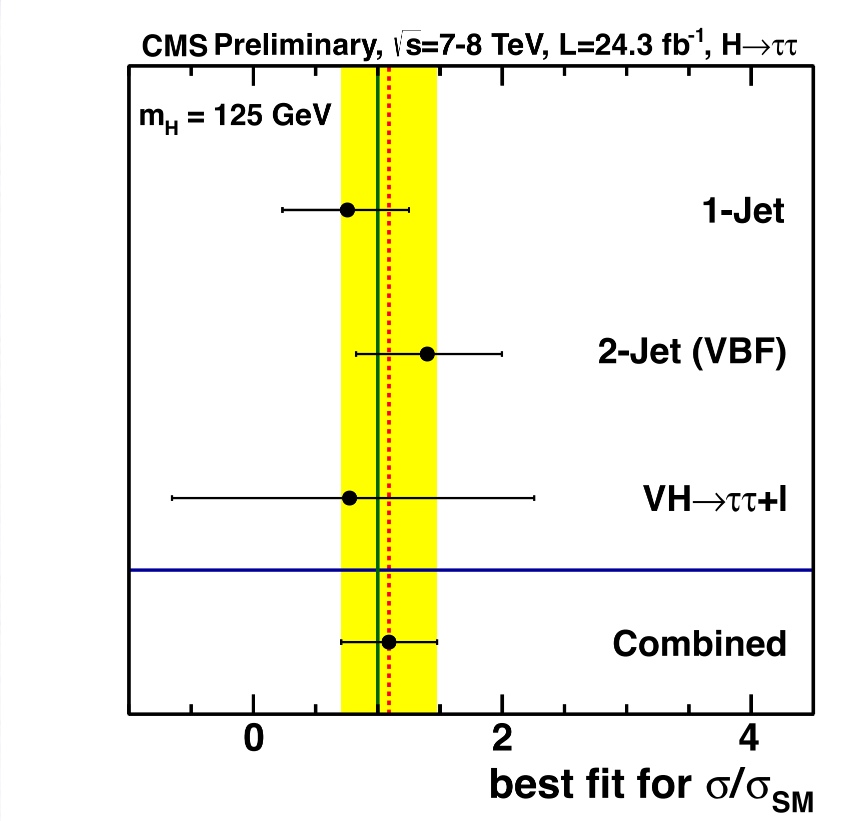






Best Fit Signal Strength

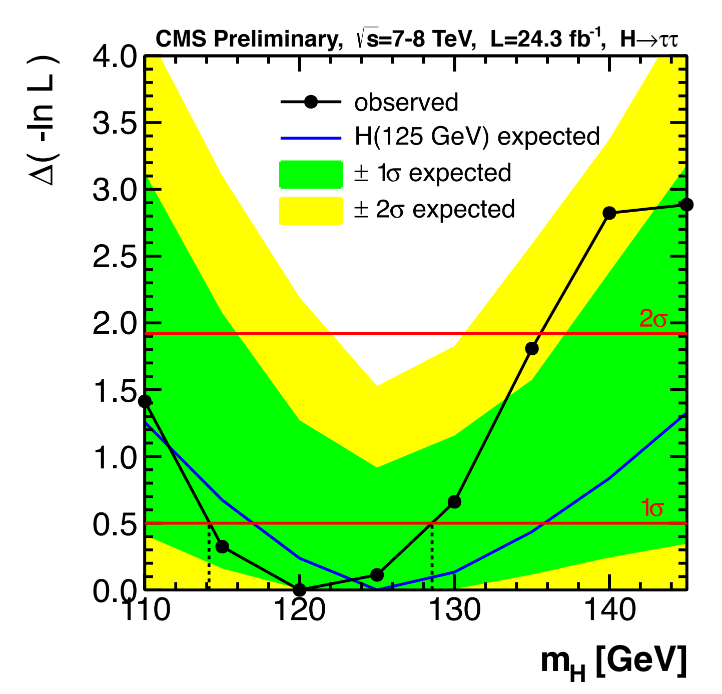


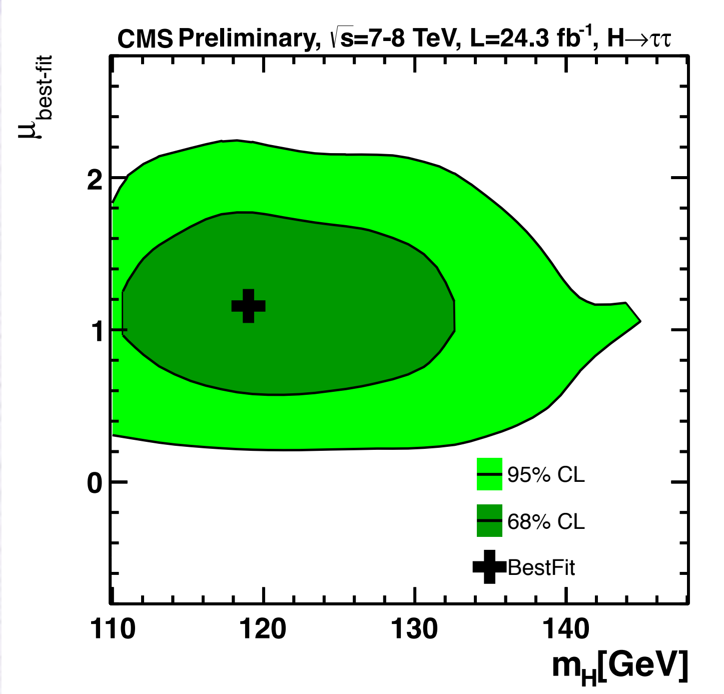


Best-fit signal strength values, σ/σ_{SM} for independent Channel(categories) on left(right)

signal strength μ=1.1±0.4

Mass and Best Fit v.s. Mass





Log likelihood versus SM Higgs boson fit mass

$m_H = 120^{+9}_{-7}$(stat+syst) GeV

Best fit of signal strength compared to the SM expectation (mu) as a function of the Higgs mass

Tau+ Jets

- combination of different number of jets and b-jets (6 sub channels)
- use ttH (H→ττ) as signal and tt+jets as BG in training the BDT