Higgs boson to fermions in CMS

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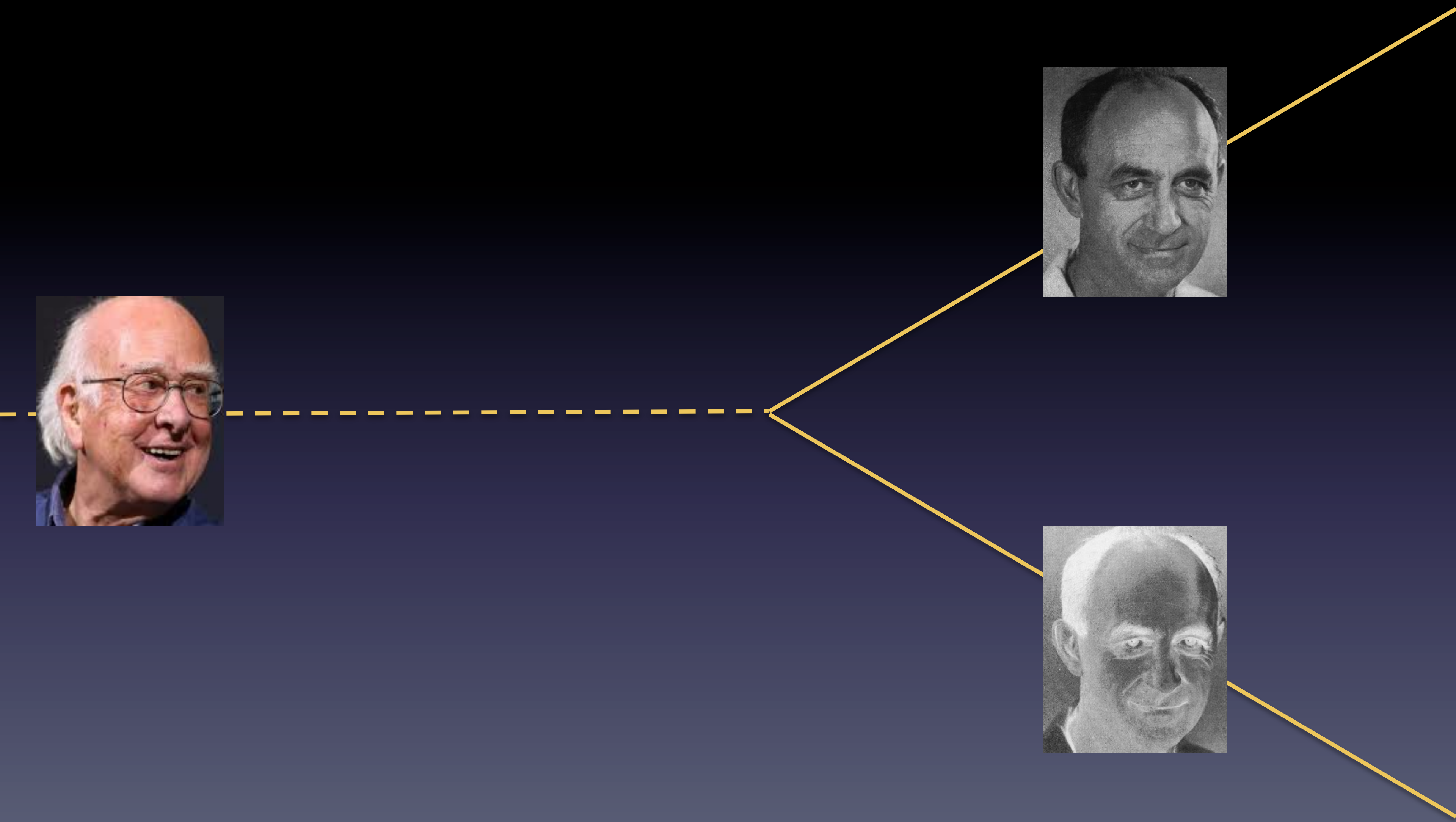
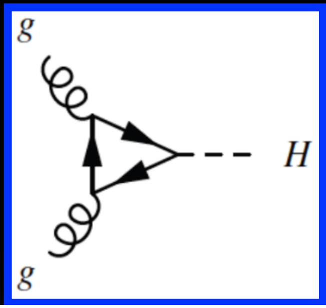
PASCOS 2013

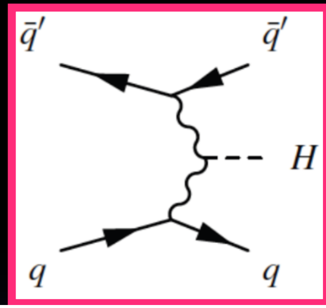
does it decay to fermions ?



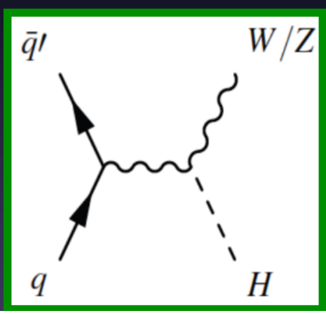
H production at LHC



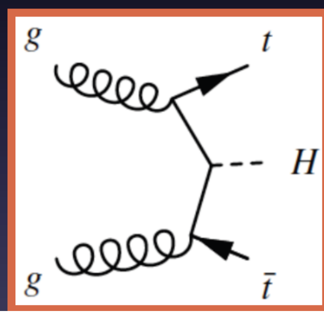
gluon fusion (GF)



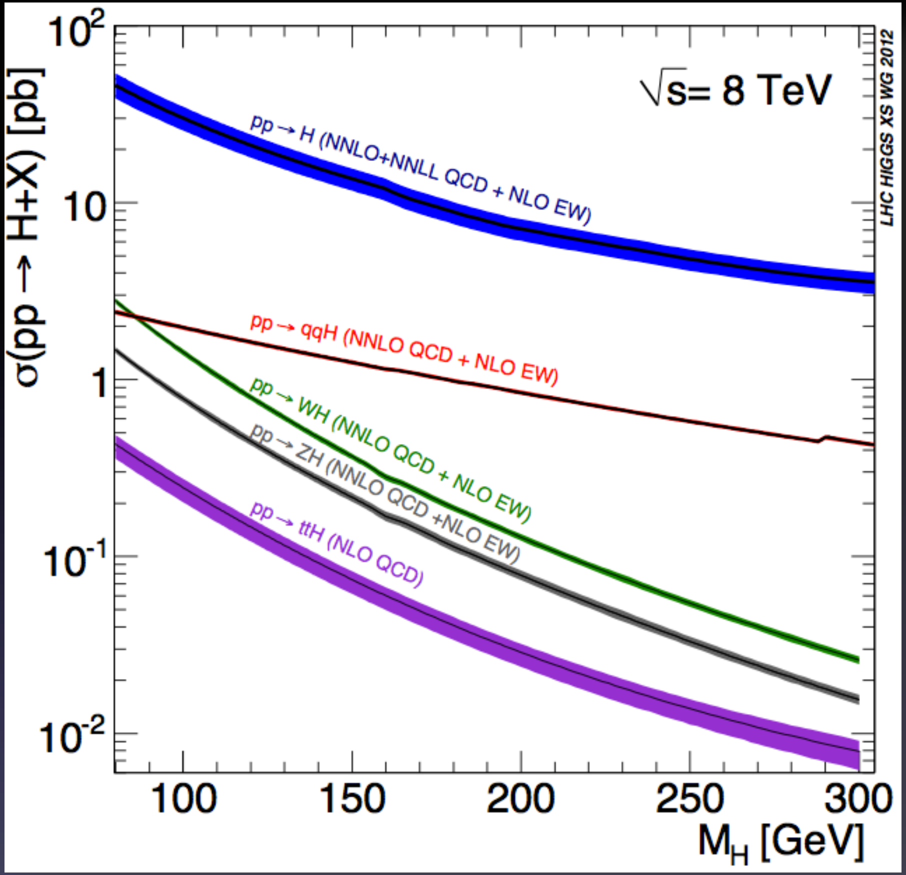
weak fusion (VBF)



H-strahlung (VH)



top fusion (ttH)

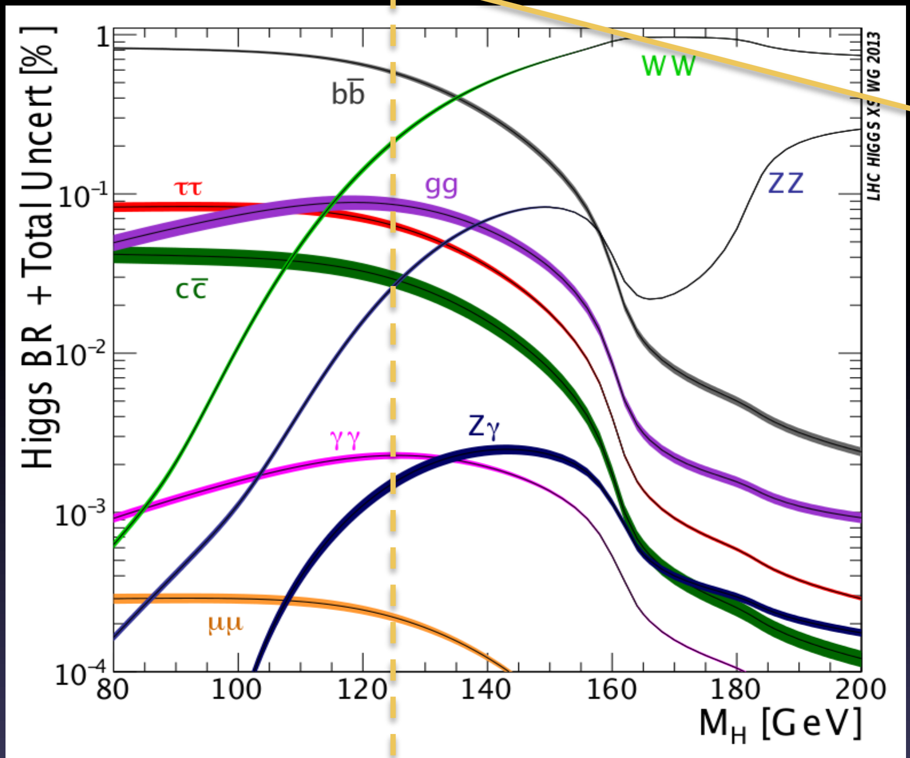


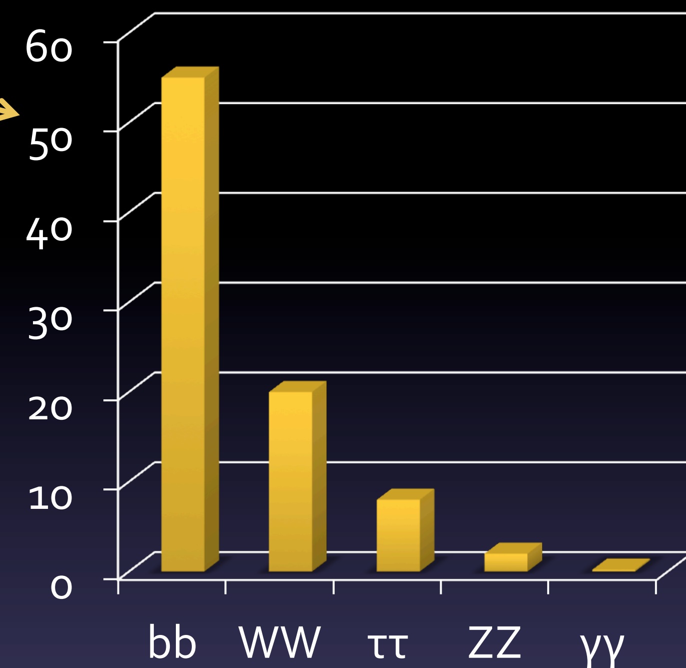
In pp with E_{CM}=8TeV at 2012 LHC peak luminosity (7 10^{33} cm^{-2} s^{-1})

500 Higgs bosons/hour

(out of 60 billion collisions / hour)

H decay



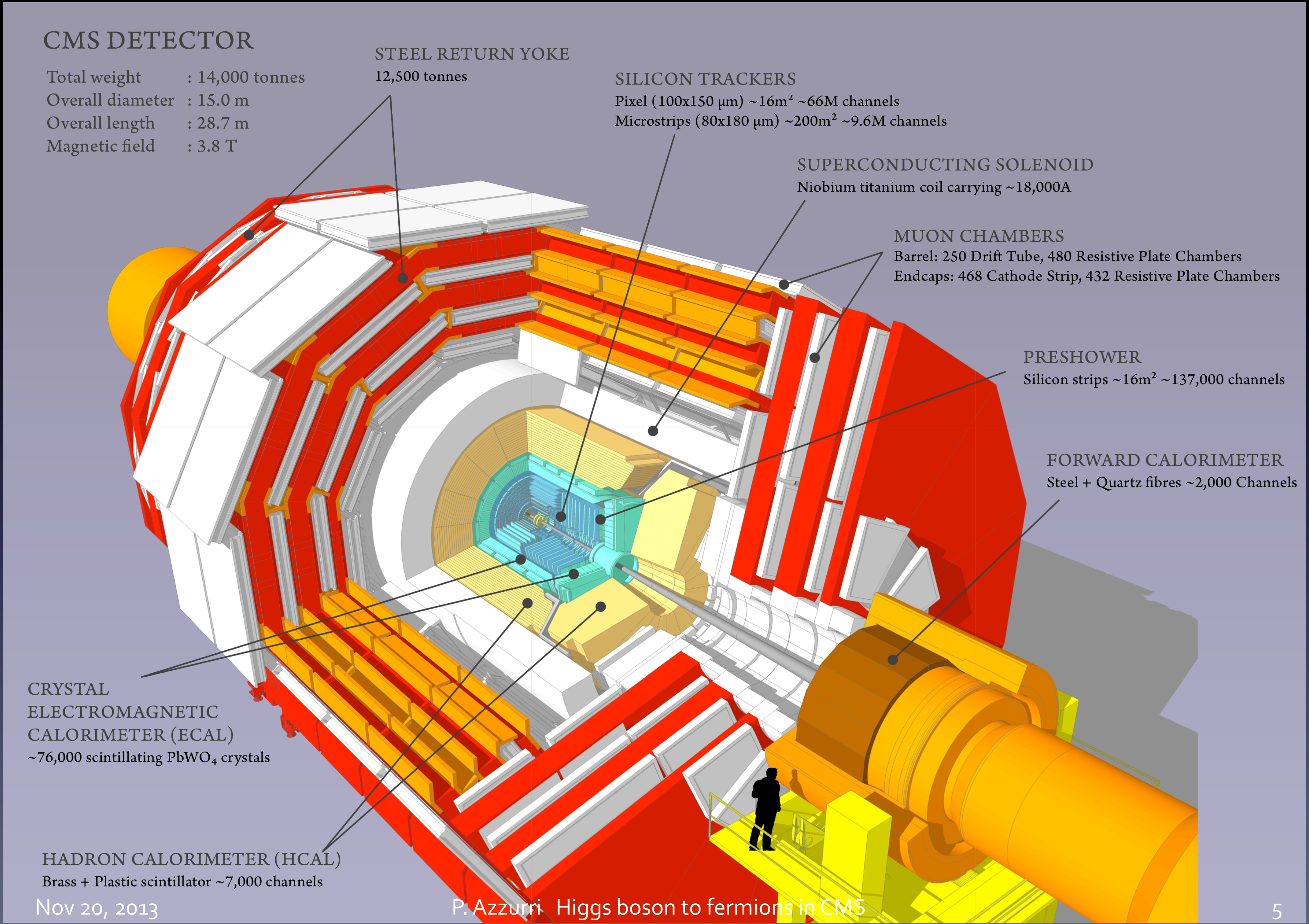


at m_H= 125 GeV

- larger cross sections (also for background)
- small natural width (few MeV)

  m_H is reconstructed with experimental width
- **accessible fermionic decays (bb+ττ)**

CMS


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

CMS analyses

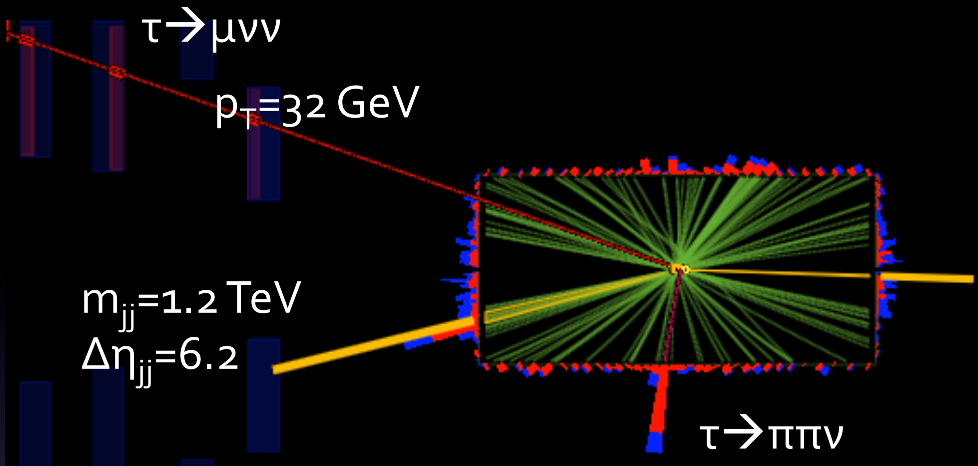
analyzed data samples luminosities (@7TeV + @8TeV)

	GF	VBF	VH	ttH
H→ZZ	5.1+19.6 fb^{-1}	5.1+19.6 fb^{-1}	5.1+19.6 fb^{-1}	0.0+19.6 fb^{-1}
H→γγ	5.1+19.6 fb^{-1}	5.1+19.6 fb^{-1}	5.1+19.6 fb^{-1}	0.0+19.6 fb^{-1}
H→WW	4.9+19.5 fb^{-1}	4.9+19.5 fb^{-1}	4.9+19.5 fb^{-1}	0.0+19.6 fb^{-1}
H→ττ	**4.9+19.4 fb^{-1}**	**4.9+19.4 fb^{-1}**	**5.0+19.5 fb^{-1}**	**0.0+19.5 fb^{-1}**
H→bb		**0.0+19.0 fb^{-1}**	**5.0+19.0 fb^{-1}**	**5.0+19.5 fb^{-1}**

HIG-13-004	HIG-13-004	HIG-12-053	HIG-13-019
	HIG-13-011	HIG-13-012	HIG-13-019

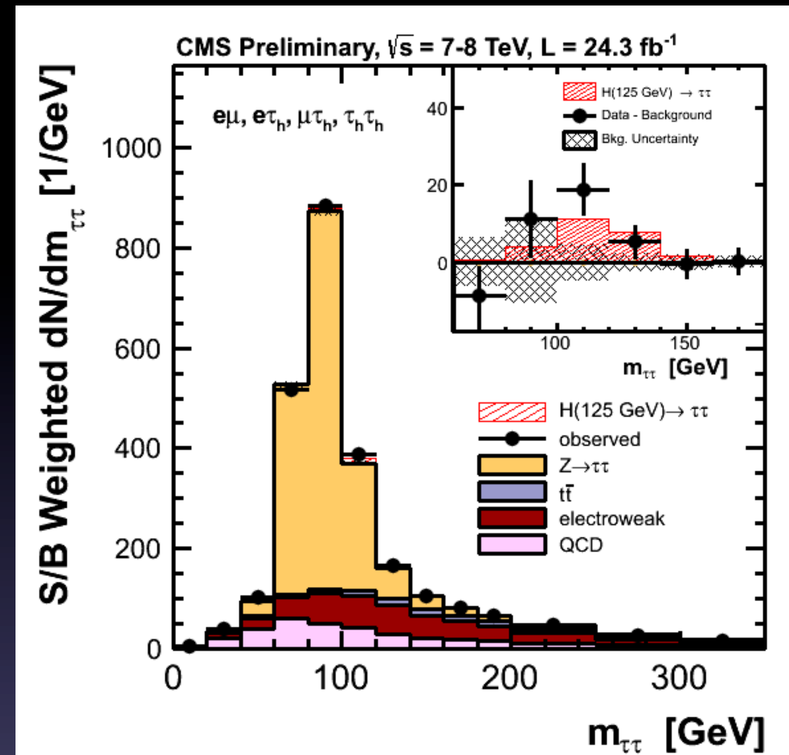
most recent results

GF,VBF H→ ττ



p_T=44 GeV

http://cds.cern.ch/record/1528271/files/HIG-13-004-pas.pdf
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13004TWiki

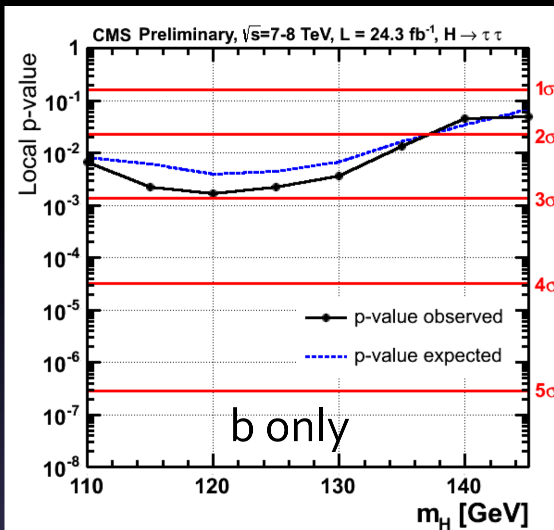


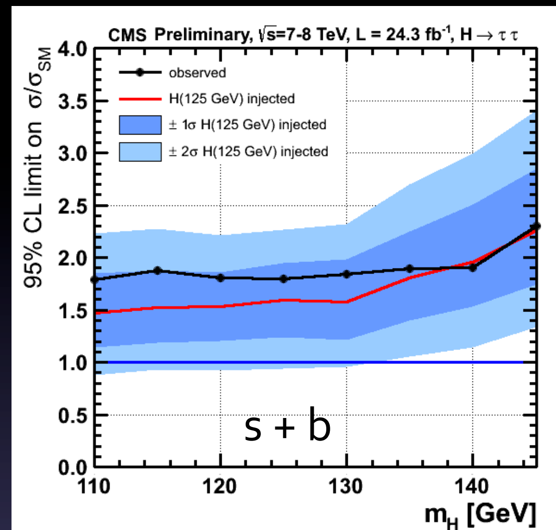
- Visible mass is used as discriminating observable with a limited resolution due to several neutrinos in the final state (but nearly collinear with the visible products)
- SVFit algorithm recovers MET information from kinematic likelihood improving the invariant mass and the S/B discrimination

A particle-flow (PF) algorithm combines the information from all CMS subdetectors to identify and reconstruct individual particles (charged hadrons, neutral hadrons, photons, muons, and electrons.)

(GF) VBF H→ ττ

results



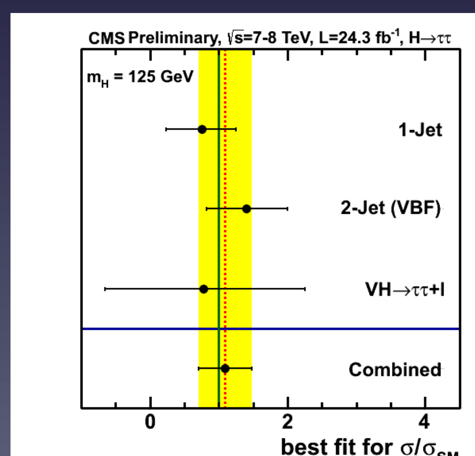


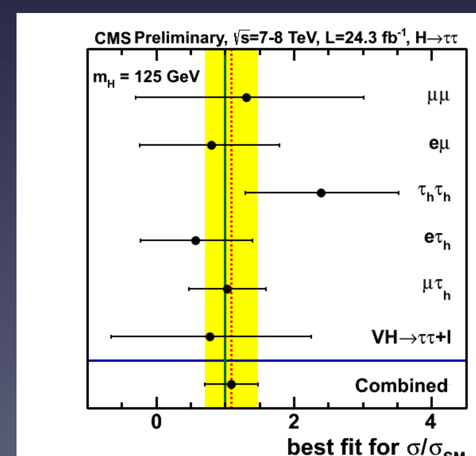
modified frequentist profile-likelihood ratio test statistic

SM signal strength
$\mu = 1.1 \pm 0.4$
@m_H=125 GeV

almost 3σ evidence

no signal measurement in the 0-jet category
(constrains syst uncertainties)

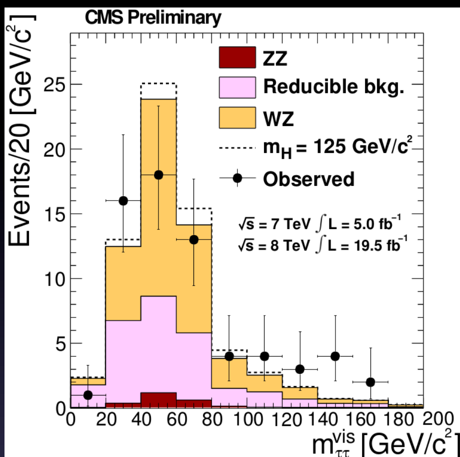




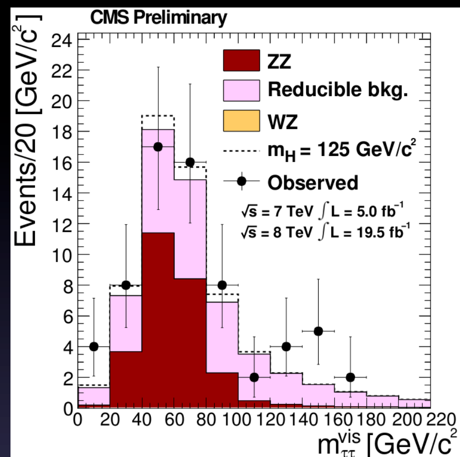
VH H→ ττ

V=W(→lν),Z(→ll)

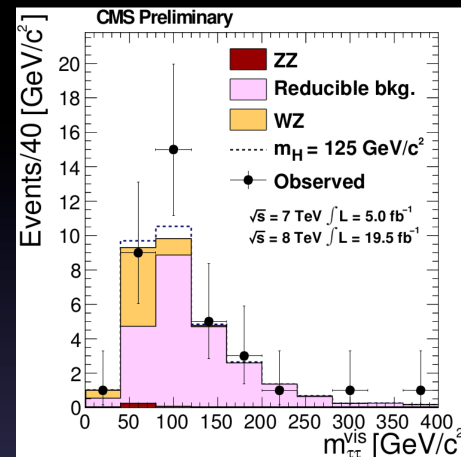
https://cds.cern.ch/record/1528147?ln=en
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12053TWiki



$ll\tau_h$



$ll\tau\tau$



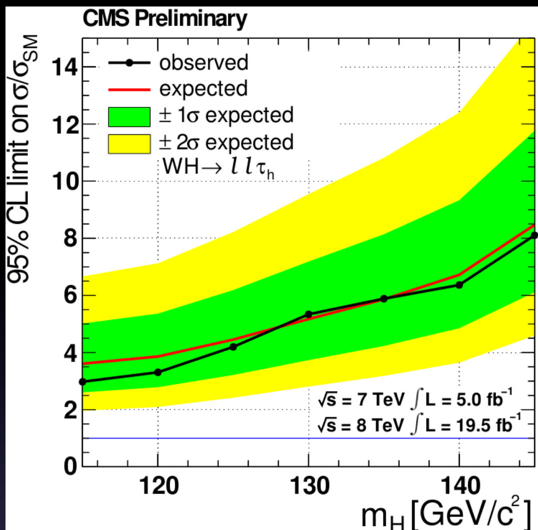
$l\tau_h\tau_h$

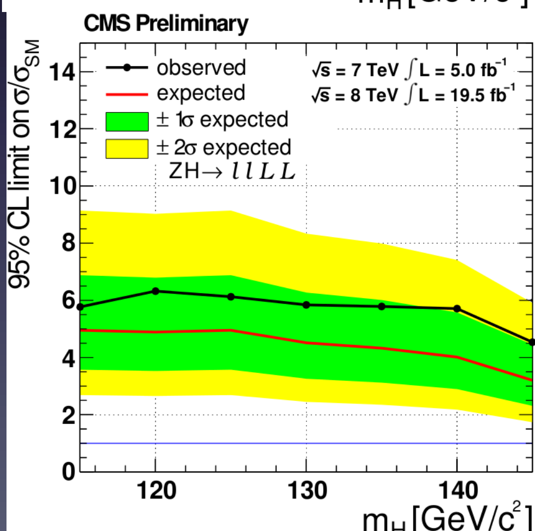
searched final states

Process	$\ell\ell\tau_h$	$\ell\tau_h\tau_h$	$\ell\ell LL$
Reducible backgrounds	26.3 ± 4.7	20.8 ± 4.2	25.2 ± 10.0
WZ	35.3 ± 3.9	6.3 ± 0.9	
ZZ	2.5 ± 0.3	0.39 ± 0.08	27.2 ± 3.8
Total bkg.	64.1 ± 6.2	27.5 ± 4.3	52 ± 11
VH→V$\tau\tau$(m_H = 125 GeV/c^2)	3.6 ± 0.4	1.2 ± 0.2	2.1 ± 0.2
VH→VWW (m_H = 125 GeV/c^2)	0.50 ± 0.05	0	1.13 ± 0.09
Observed	65	36	66

VH H→ ττ

results

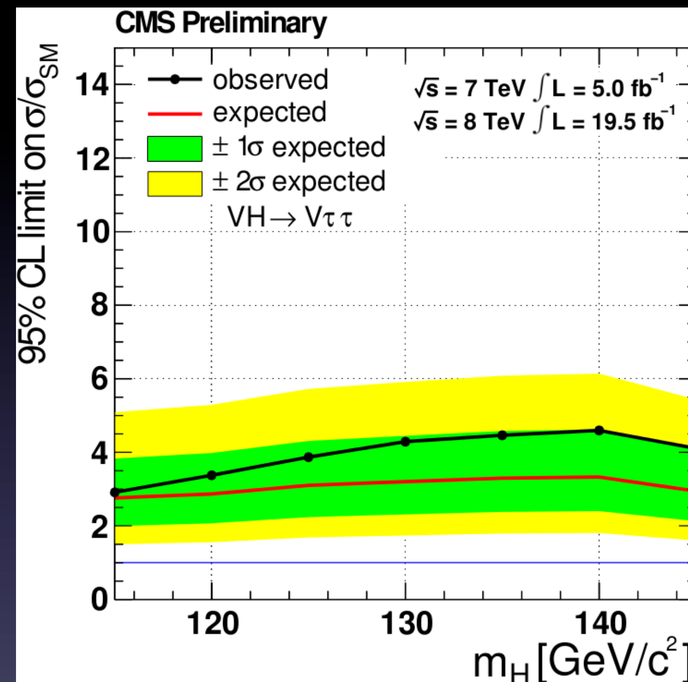




lower

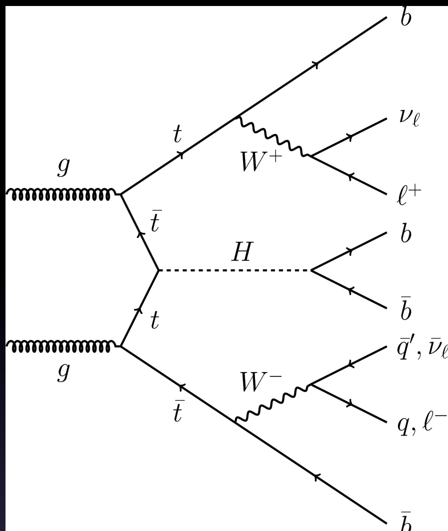
m_H

higher



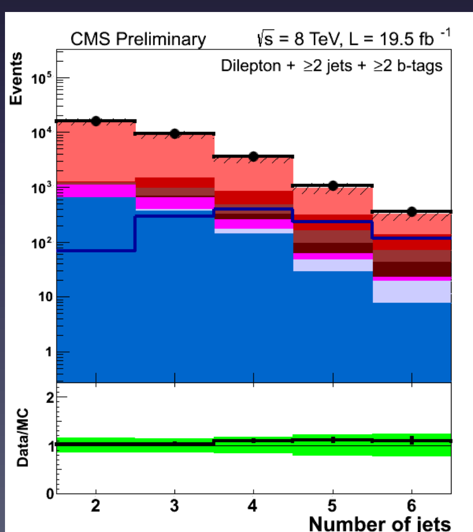
data compatible with both the background-only prediction and the presence of a SM Higgs boson

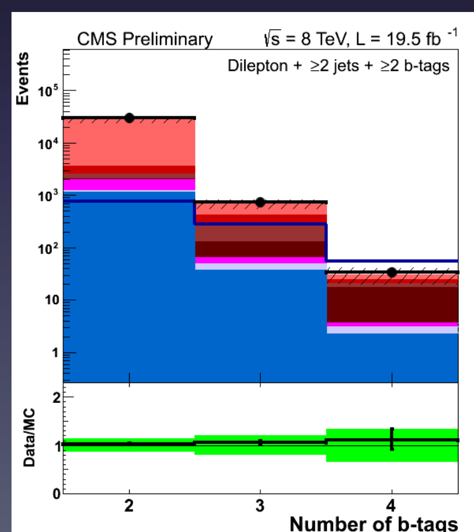
ttH H→ ττ,bb

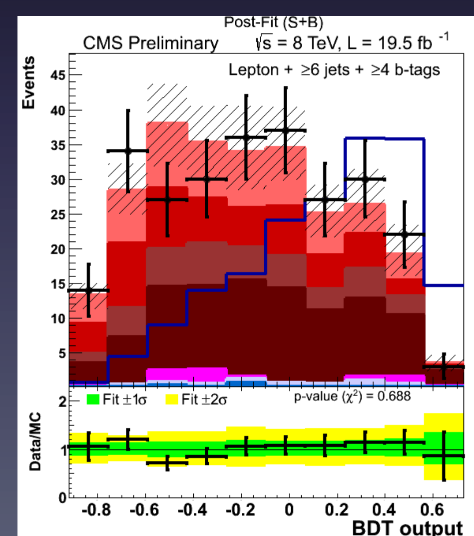


- search for semileptonic or dileptonic top pairs
- dealing with 6 or 4 final state signal jets (2 τ-jets)
- 4 signal b-jets (or 2b & 2τ)
- irreducible ditop + jets background

Jet b-tagging with the Combined Secondary Vertex (CSV) algorithm: combines tracks impact parameters and reconstructed secondary vertices within the jets in a multivariate analysis.



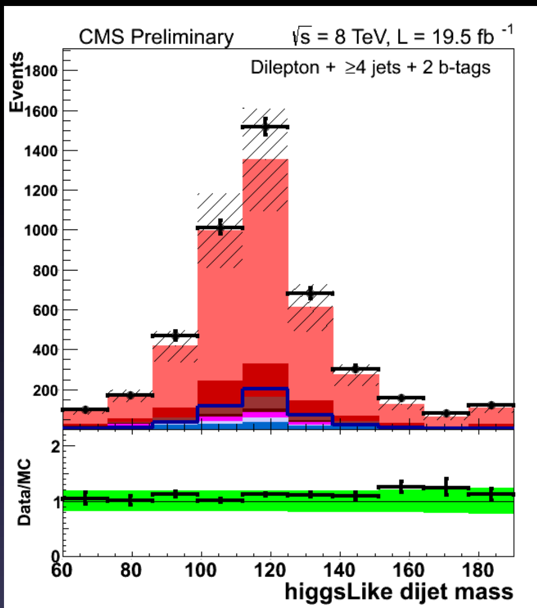


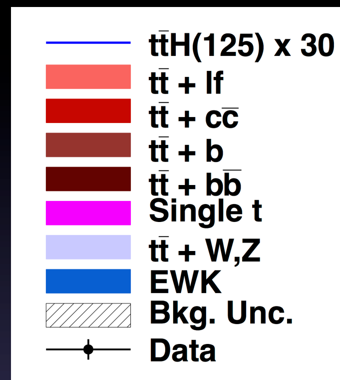


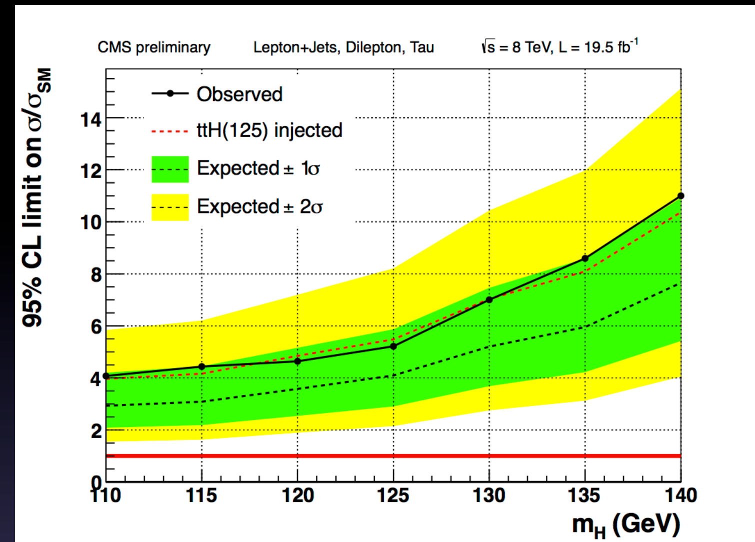
ttH H→ ττ,bb

results

"Higgs mass" defined in semileptonic with many jets

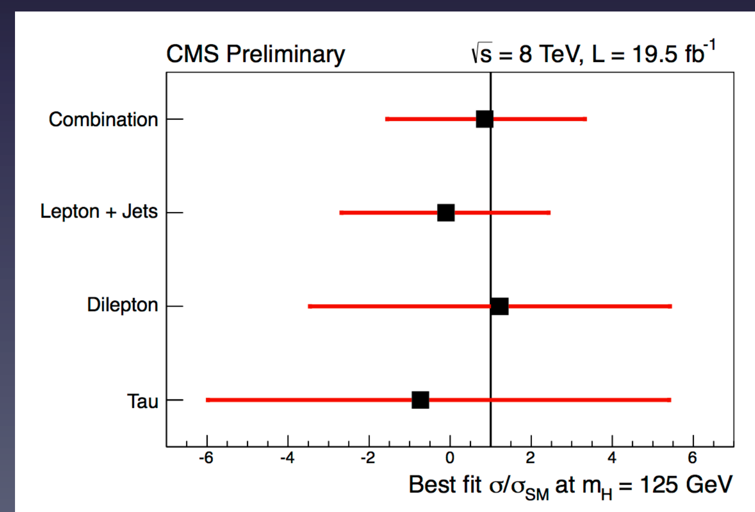






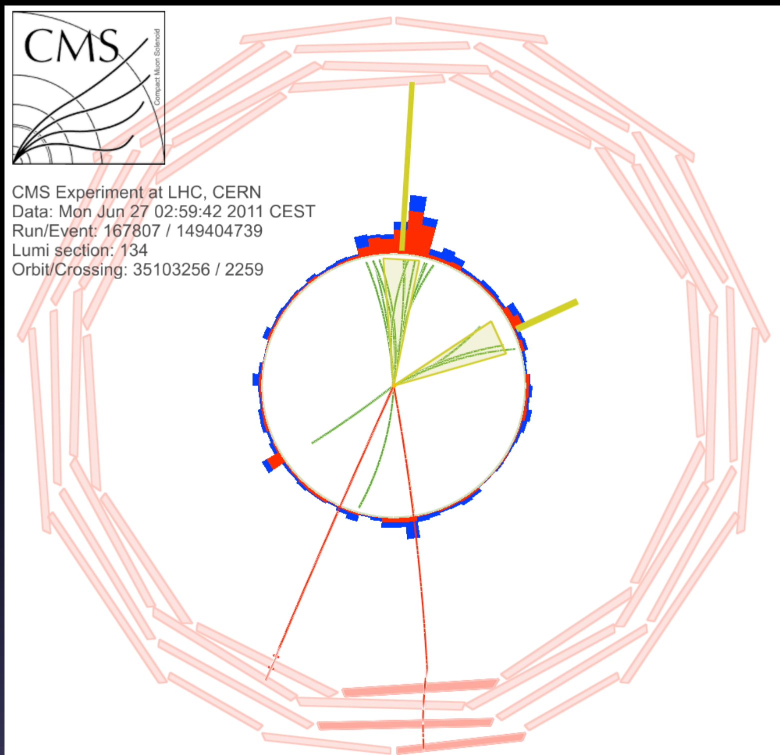
$\mu = 0.85 \pm 2.47$
$@m_H$=125 GeV

Slight excess observed, compatible with SM Higgs at 125GeV



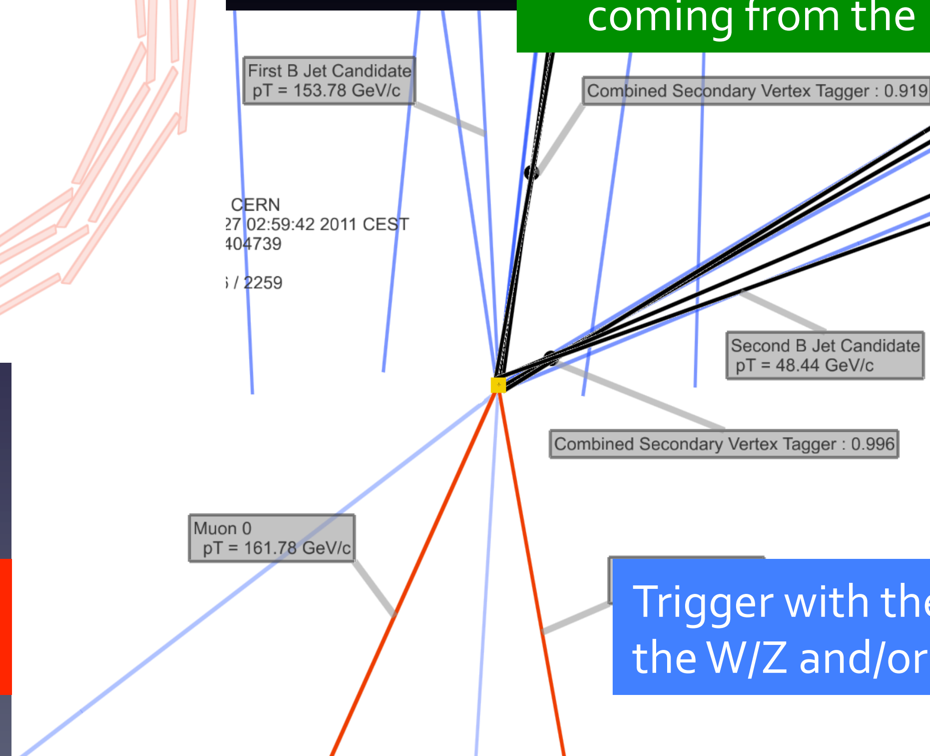
https://cds.cern.ch/record/1564682?ln=en
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13019TWiki

VH H→ bb



searched channels with
- Z->ll (ee, μμ)
- W→lν (e, μ, τ)
- Z-> νν

CSV b-tagging to identify the jets coming from the Higgs decay



V+(b)jets, ttbar, single top, WW/WZ/ZZ backgrounds

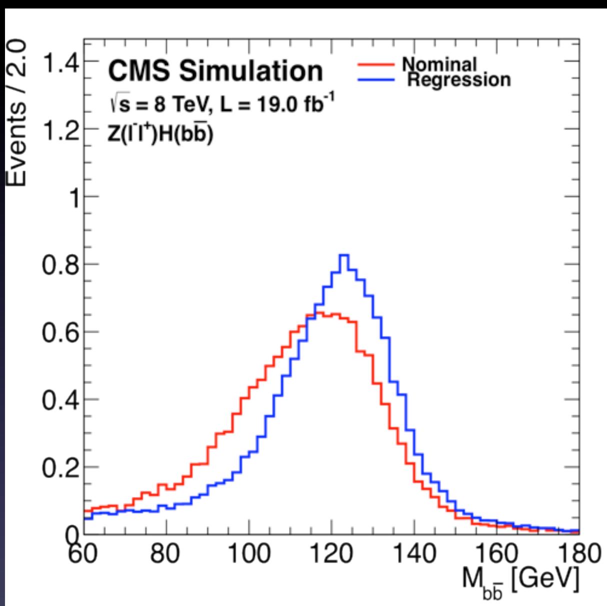
Trigger with the lepton(s) from the W/Z and/or MET+jets

VH H→ bb

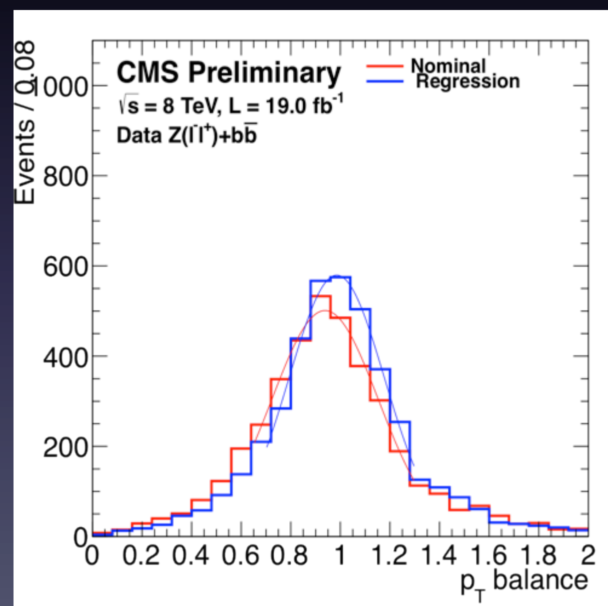
jet energy regression

<u>the dijet (bb) mass is the most discriminating variable</u>

Use a BDT regression in order to correct the jet energy exploiting jet and b-tag variables
=> ~ 15% improvement in mass resolution



Distributions of dijet invariant mass in signal Z(ll)H(bb) events before and after the regression is applied.



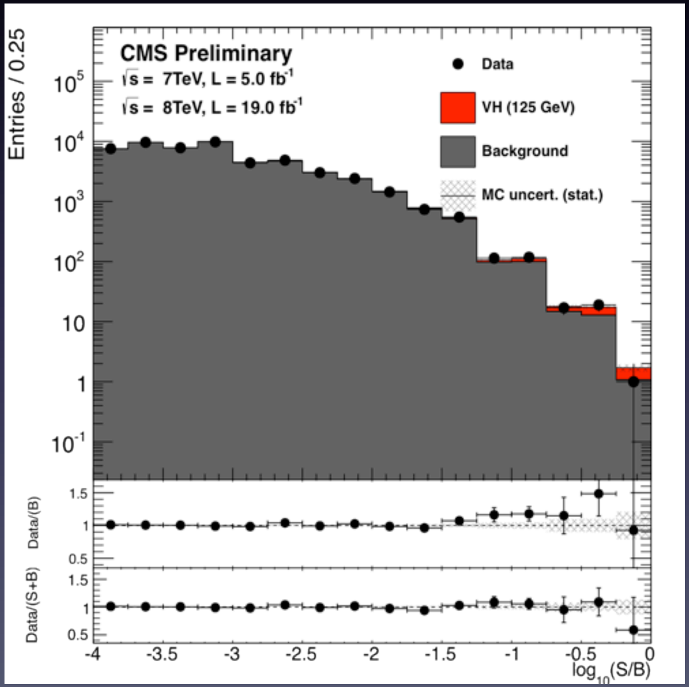
validated on Z+bb events

http://arxiv.org/pdf/1310.3687v1.pdf
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13012TWiki

VH H→ bb

MVA analysis

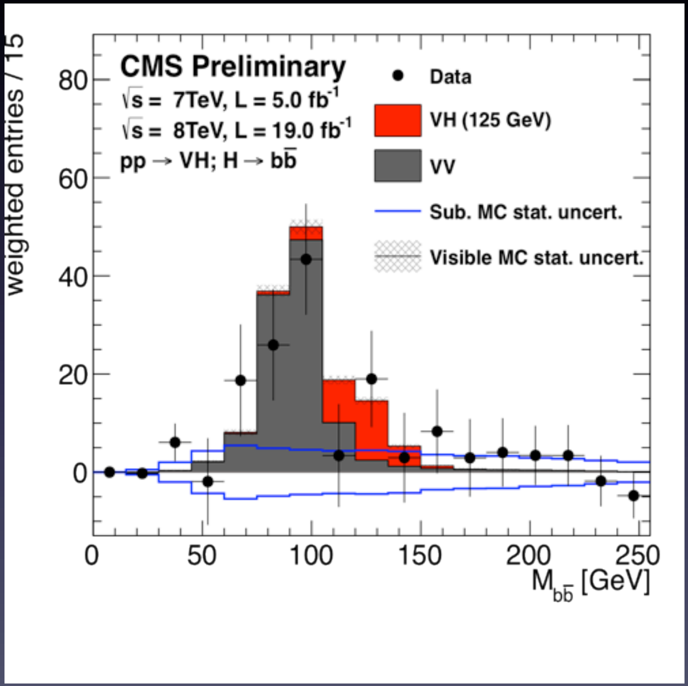
- 2-3 pT categories per channel
- intermediate BDTs to discriminate different backgrounds
- Final BDT for shape fitting



Combination of all BDT discriminants using expected S/B

cross-check analysis

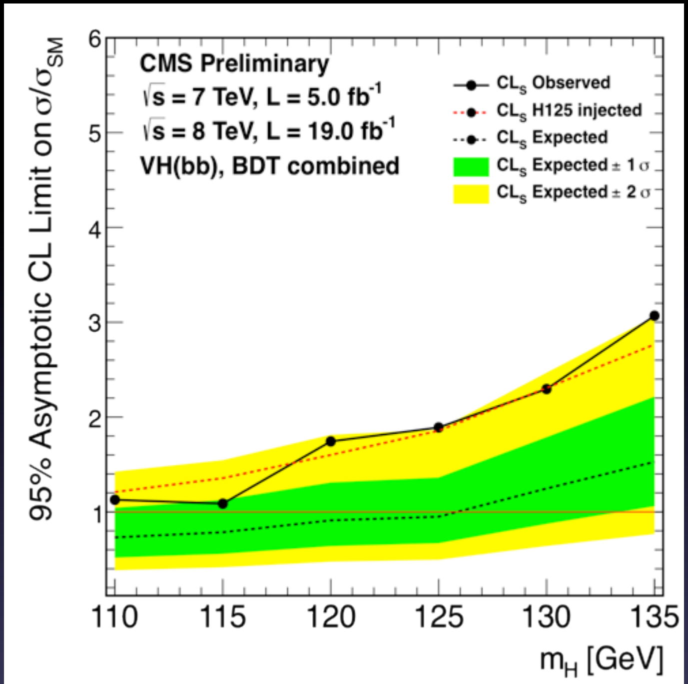
- 2-3 pT categories per channel
- Tighter selection
- Invariant mass shape fit



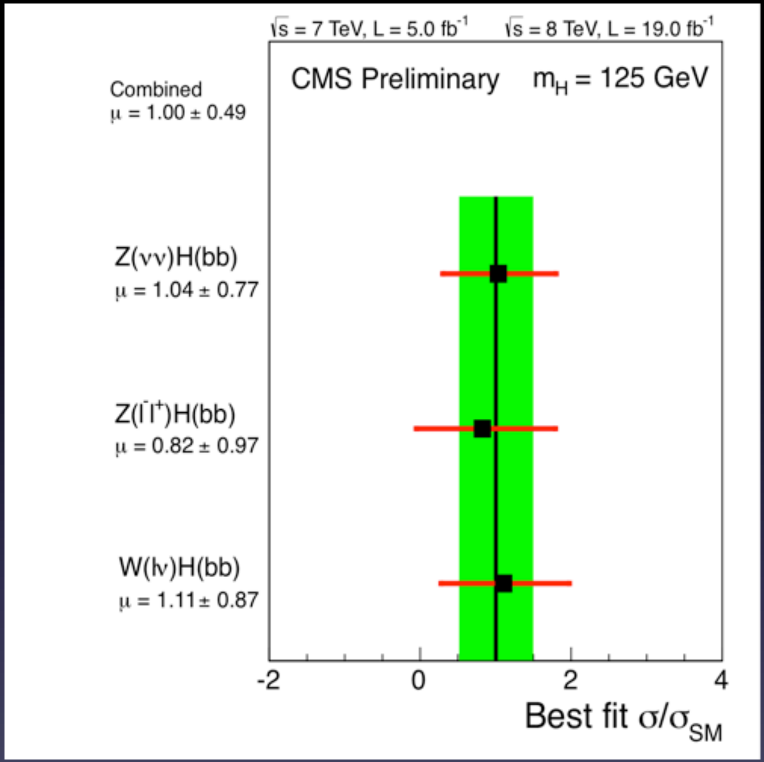
m_{bb} for all channels, backgrounds subtracted (except VV)

VH H→ bb

results

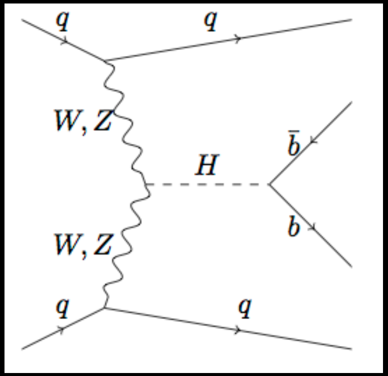


expected and observed 95% CL cross section upper limits



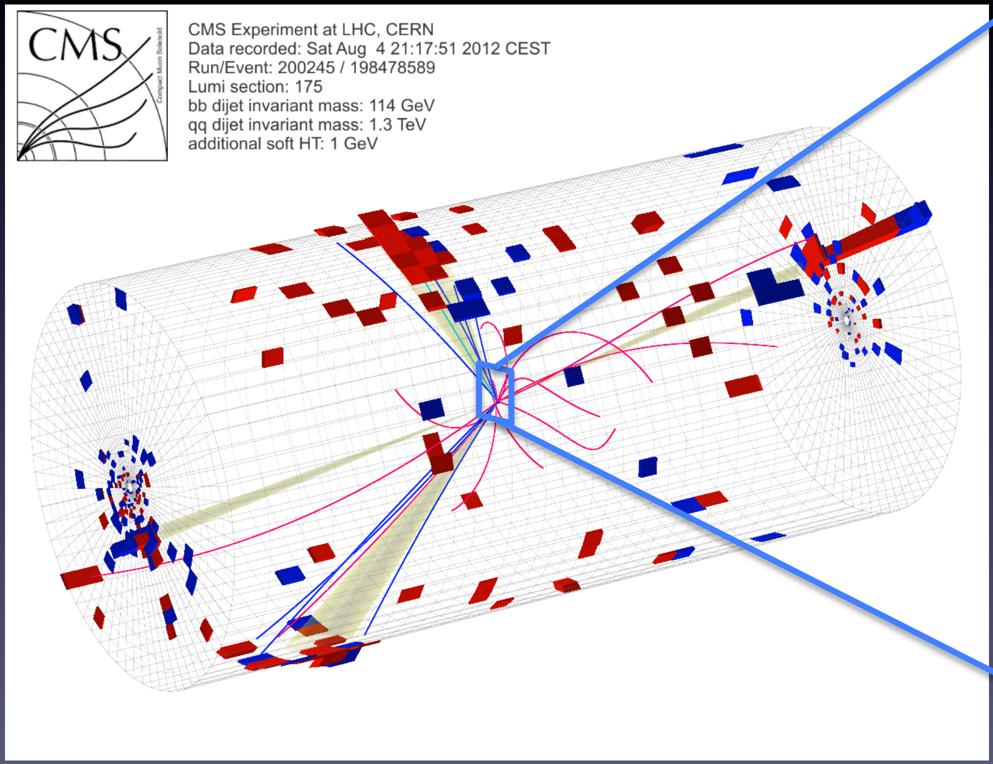
2σ expected, 2σ observed !
μ=1.0±0.5

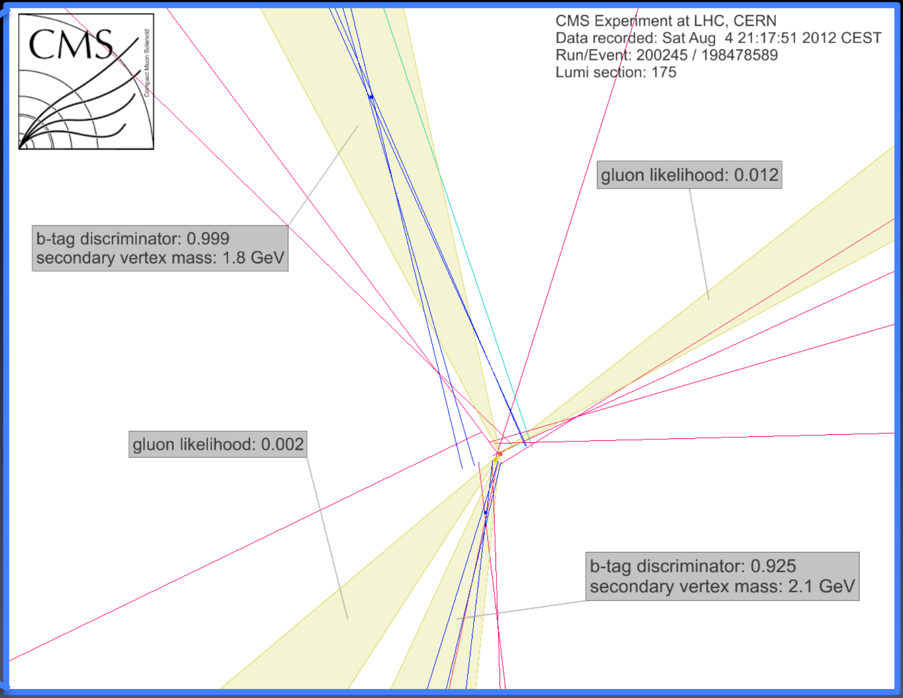
VBF H→ bb



fully hadronic four-jet (qqbb) final state

https://cds.cern.ch/record/1547579?ln=en
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13011TWiki

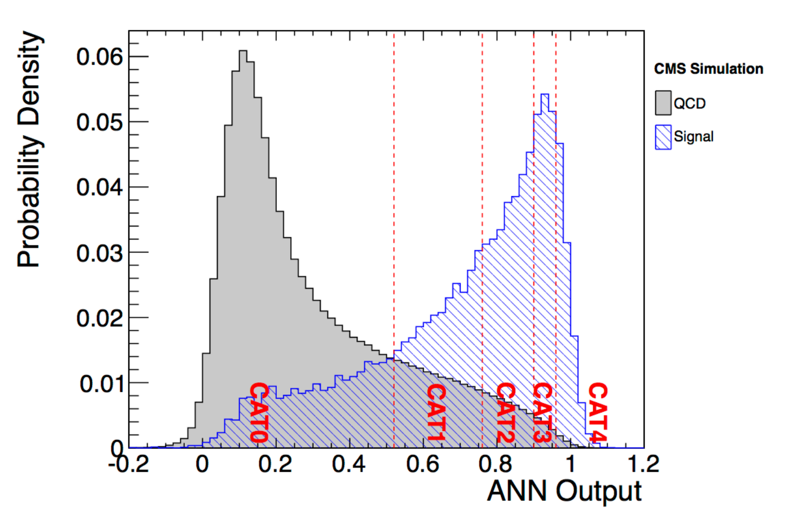


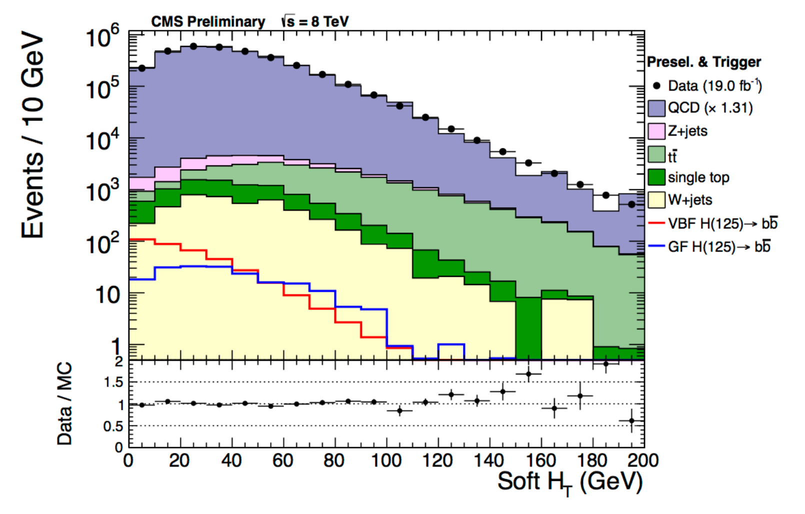


VBF H→ bb

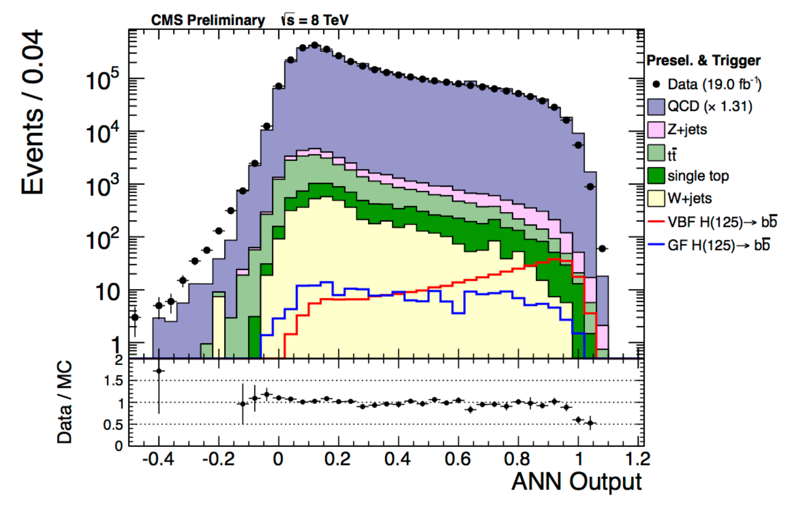
ingredients & steps

- **dedicated L1 and HLT trigger paths**
- **offline ANN event discrimination using**
  - VBF tagging (qq) jet pair kinematics
  - b-tag and q/g jet discriminators
  - additional hadronic activity





H_T of "soft" track-jets in the rapidity gap

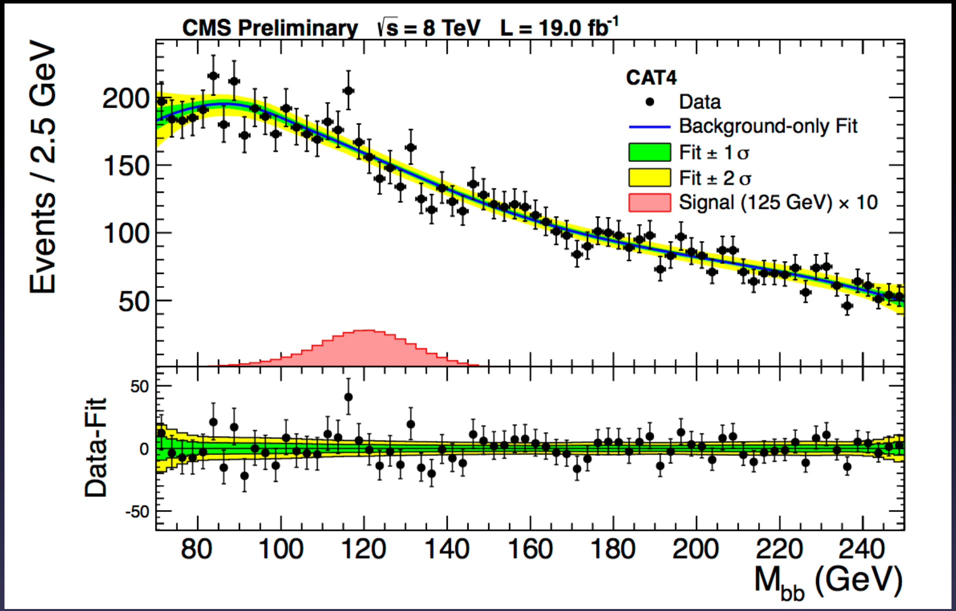


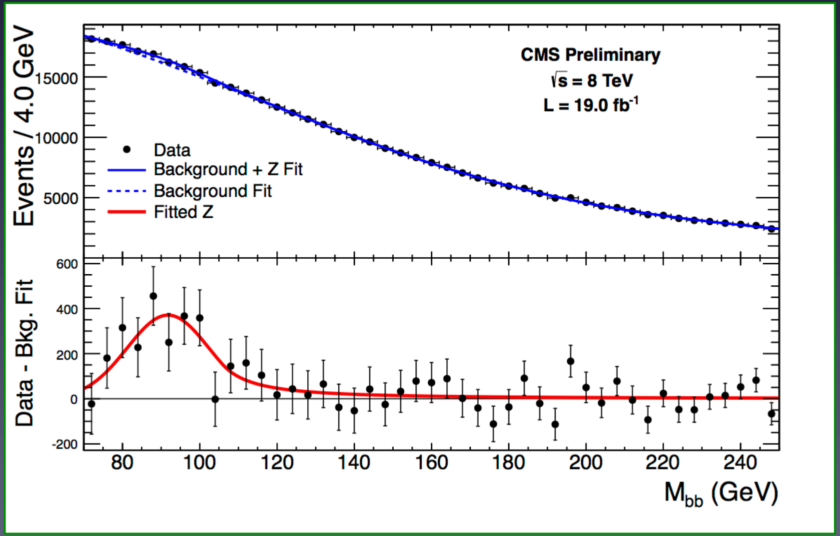
VBF H→ bb

m_{bb} analysis

- **b-jet energy regression**
- **fit of the m(bb) distributions**

QCD background: floating 5^{th} order Bernstein polynomial
Other (Z,top) backgrounds fixed from MC
Signal shape fixed

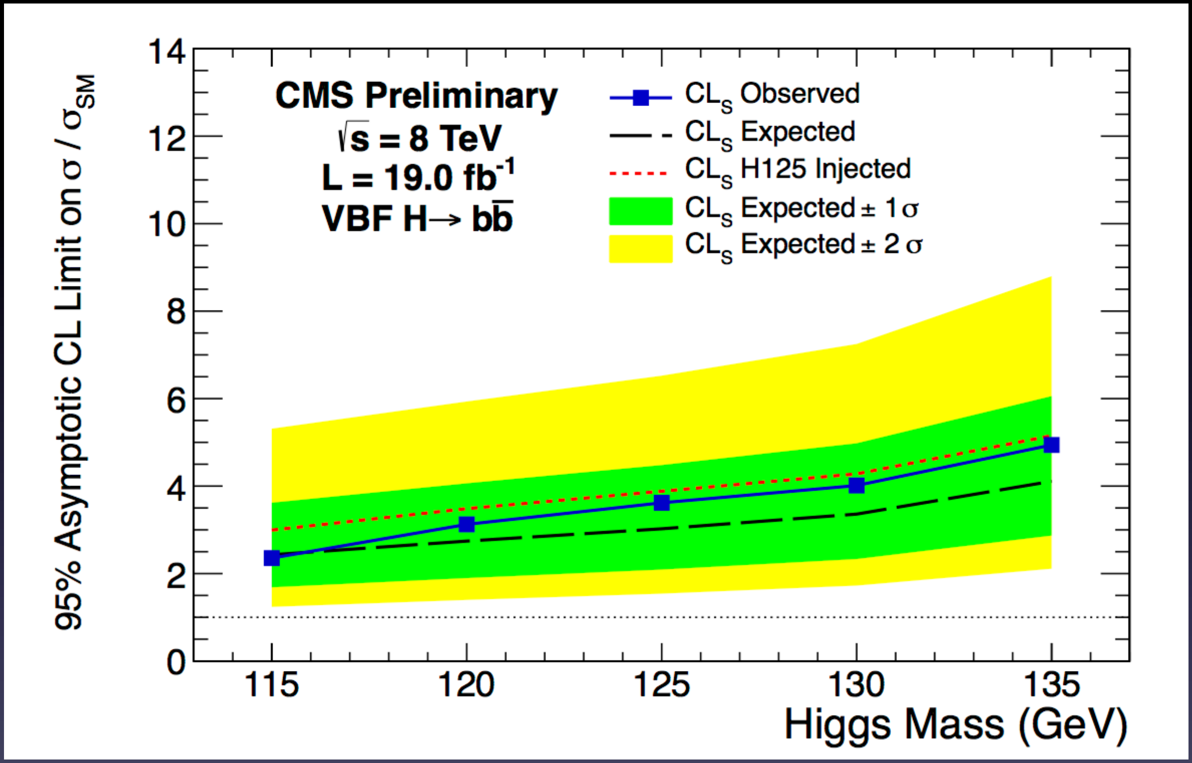




Z peak fit in signal depleted (CAT0) sample
2844±1127 events in the Z peak
with 2562 expected.
Using a looser selection :
13188±1638 fitted with 13305 expected

VBF H→ bb

results



@m_H=125 GeV

μ=0.71±1.42

https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13011TWiki
https://cds.cern.ch/record/1547579?ln=en

Conclusions

- is it fermiophobic ? no way
- does it decay to taus? very probably yes
- does it decay to b-quarks ? probably yes
- with minimal-SM rates ? possibly but not stringent
- to other fermions ? dunno

the exploration of the Higgs sector has just begun

backUp

GF,VBF H→ ττ

event yields

Process	0-Jet	1-Jet high p_T	VBF
$Z\to\tau\tau$	84833 ± 1927	4686 ± 232	109 ± 11
QCD	18313 ± 478	481 ± 38	48 ± 7
EWK	8841 ± 653	1585 ± 153	63 ± 9
$t\bar{t}$	11 ± 1	155 ± 11	5 ± 1
Total Background	111998 ± 2090	6908 ± 281	225 ± 16
$H\to\tau\tau$	- ± -	73 ± 13	11 ± 2
Observed	112279	7011	240
Signal Eff.			
$gg\to H$	-	$1.99\cdot10^{-3}$	$8.51\cdot10^{-5}$
$qq\to H$	-	$4.09\cdot10^{-3}$	$3.46\cdot10^{-3}$
$qq\to Ht\bar{t}$ or VH	-	$3.00\cdot10^{-3}$	$1.60\cdot10^{-5}$

$\mu\tau_h$

Process	0-Jet	1-Jet high p_T	VBF
$Z\to\tau\tau$	25161 ± 708	792 ± 62	47 ± 6
QCD	7706 ± 307	3 ± 0.3	17 ± 4
EWK	9571 ± 510	365 ± 53	44 ± 6
$t\bar{t}$	4 ± 0.5	47 ± 4	4 ± 1
Total Background	42443 ± 924	1207 ± 82	113 ± 9
$H\to\tau\tau$	- ± -	15 ± 3	5 ± 1
Observed	42481	1217	117
Signal Eff.			
$gg\to H$	-	$3.94\cdot10^{-4}$	$3.33\cdot10^{-5}$
$qq\to H$	-	$1.10\cdot10^{-3}$	$1.78\cdot10^{-3}$
$qq\to Ht\bar{t}$ or VH	-	$8.30\cdot10^{-4}$	$1.46\cdot10^{-6}$

$e\tau_h$

Process	1-Jet	VBF
$Z\to\tau\tau$	428 ± 90	47 ± 28
QCD	210 ± 31	61 ± 10
EWK	41 ± 9	4 ± 1
$t\bar{t}$	29 ± 6	2 ± 2
Total Background	709 ± 95	114 ± 30
$H\to\tau\tau$	9 ± 4	4 ± 2
Observed	718	120
Signal Eff.		
$gg\to H$	$2.52\cdot10^{-4}$	$4.99\cdot10^{-5}$
$qq\to H$	$5.93\cdot10^{-4}$	$1.20\cdot10^{-3}$
$qq\to Ht\bar{t}$ or VH	$9.13\cdot10^{-4}$	$3.59\cdot10^{-5}$

$\tau_h\tau_h$

Process	0-Jet	1-Jet high p_T	VBF
$Z\to\tau\tau$	48882 ± 1282	1830 ± 105	61 ± 6
QCD	4374 ± 249	395 ± 36	19 ± 2
EWK	1185 ± 89	461 ± 44	7 ± 1
$t\bar{t}$	74 ± 5	1100 ± 66	19 ± 2
Total Background	54514 ± 1309	3785 ± 137	105 ± 7
$H\to\tau\tau$	- ± -	23 ± 4	5 ± 0.6
Observed	54694	3774	118
Signal Eff.			
$gg\to H$	-	$6.04\cdot10^{-4}$	$3.27\cdot10^{-5}$
$qq\to H$	-	$1.37\cdot10^{-3}$	$1.80\cdot10^{-3}$
$qq\to Ht\bar{t}$ or VH	-	$1.38\cdot10^{-3}$	$1.32\cdot10^{-5}$

$e\mu$

Process	0-Jet	1-Jet high p_T	VBF
$Z\to\mu\mu$	1925174 ± 52051	685272 ± 27303	380 ± 38
$Z\to\tau\tau$	20669 ± 470	3888 ± 157	116 ± 9
QCD	1299 ± 226	561 ± 161	6 ± 11
EWK	4732 ± 1594	7827 ± 1297	22 ± 9
$t\bar{t}$	4708 ± 2110	2168 ± 522	15 ± 5
Total Background	1956582 ± 52120	699717 ± 27418	539 ± 42
$H\to\tau\tau$	- ± -	37 ± 5	5 ± 1
Observed	1956931	700020	548
Signal Eff.			
$gg\to H$	-	$9.50\cdot10^{-4}$	$7.23\cdot10^{-5}$
$qq\to H$	-	$1.85\cdot10^{-3}$	$1.03\cdot10^{-3}$
$qq\to Ht\bar{t}$ or VH	-	$2.95\cdot10^{-3}$	$1.39\cdot10^{-4}$

$\mu\mu$

GF,VBF H→ ττ

Experimental Uncertainties		Propagation into Event Categories		
Uncertainty	Uncert.	*0-Jet*	*1-Jet*	*VBF*
Electron ID & Trigger (†*)	±2%	±2%	±2%	±2%
Muon ID & Trigger (†*)	±2%	±2%	±2%	±2%
Tau ID & Trigger (†)	±8%	±8%	±8%	±8%
Tau Energy Scale (†)	±3%	±3%	±3%	±3%
Electron Energy Scale (†)	±1%	±1%	±1%	±1%
JES (Norm.) (†*)	±2.5 – 5%	∓3 – 15%	±1 – 6%	±5 – 20%
MET (Norm.) (†*)	±5%	±5 – 7%	±2 – 7%	±5 – 8%
b-Tag Efficiency (†*)	±10%	∓2%	∓2 – 3%	∓3%
Mis-Tagging (†*)	±30%	∓2%	∓2%	∓2 – 3%
Norm. Z production (†*)	±3%	±3%	±3%	±3%
$Z \to \tau\tau$ Category	±3%	±0 – 5%	±3 – 5%	±10 – 13%
Norm. $t\bar{t}$ (†* ex.vbf)	±10%	±10%	±10%	±12 – 33%
Norm. Diboson (†* ex. vbf)	±15 – 30%	±15 – 30%	±15 – 30%	±15 – 100%
Norm. QCD Multijet	±6 – 32%	±6 – 32%	±9 – 30%	±19 – 35%
Lumi 7 TeV (8 TeV)	±2.2(4.2)%	±2.2(4.2)%	±2.2(4.2)%	±2.2(4.2)%
Norm. W+jets	±10 – 30%	±20 – 27%	±10 – 33%	±12.4% – 30%
Norm. $Z \to \ell\ell$: e fakes τ_h (†)	±20%	±20%	±36%	±22%
Norm. $Z \to \ell\ell$: μ fakes τ_h (†)	±30%	±30%	±30%	±30%
Norm. $Z \to \ell\ell$: jet fakes τ_h	±20%	±20%	±20%	±40%

Theory Uncertainties (SM)		Propagation into Limit Calculation		
Uncertainty	Uncert.	*0-Jet*	*1-Jet*	*VBF*
PDF (†*)	-	-	±2 – 8%	±2 – 8%
$\mu_r/\mu_f(gg \to H)$ (†*)	-	-	±10%	±30%
$\mu_r/\mu_f(qq \to H)$ (†*)	-	-	±4%	±4%
$\mu_r/\mu_f(qq \to VH)$ (†*)	-	-	±4%	±4%
UE & PS (†*)	-	-	±4%	±4%

systematic uncertainties

(*) : correlation between separate channels.

(†) correlation between separate categories.

GF,VBF H→ ττ

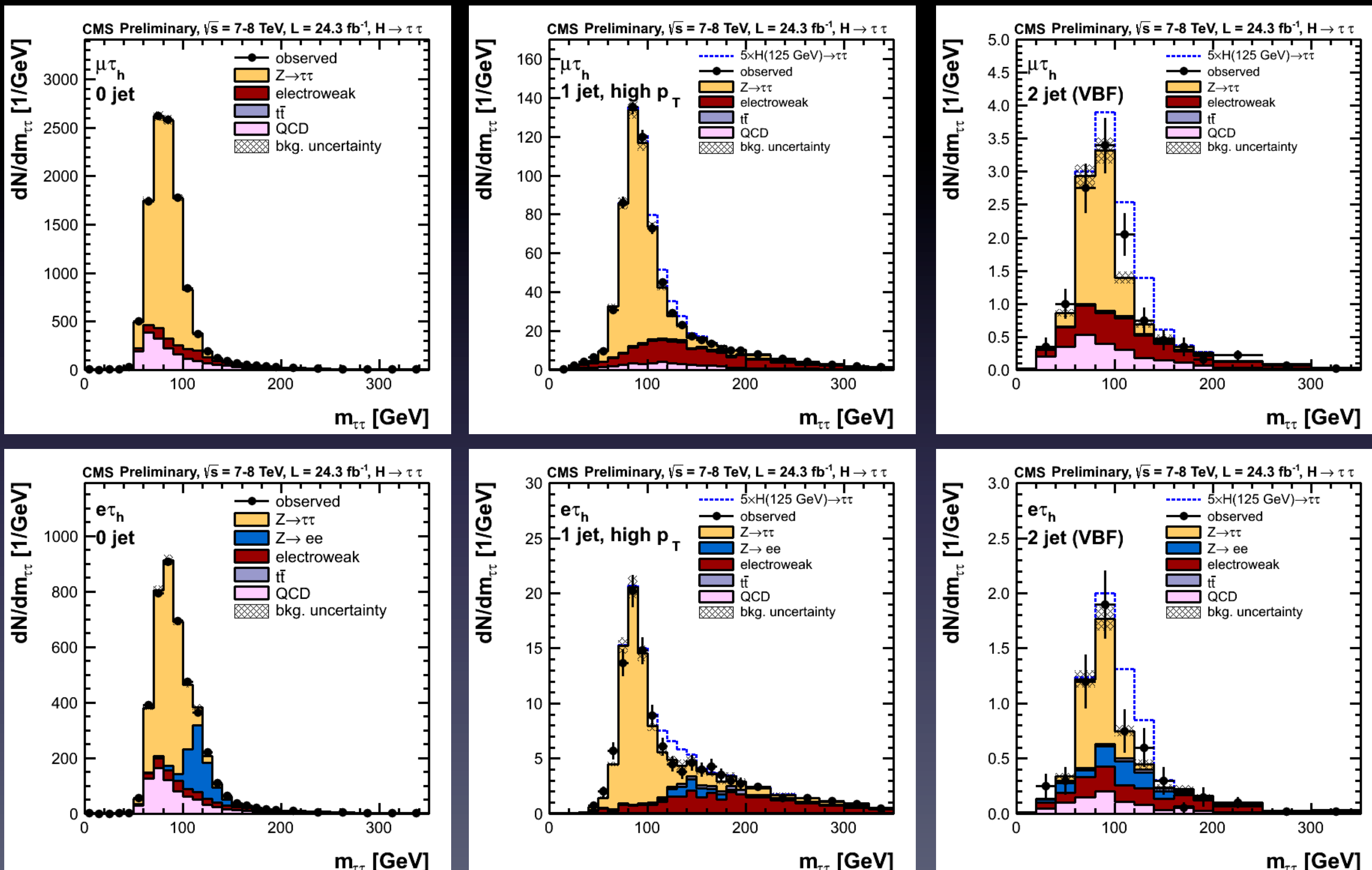
signal limits and significances

SM Higgs	Expected limit								
m_H	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	Obs. Limit	Obs. 1-CL_b	Exp. Sig.	Obs Sig.
110 GeV	0.45	0.60	0.84	1.16	1.54	1.79	0.0067	2.4	2.47
115 GeV	0.43	0.58	0.80	1.11	1.48	1.88	0.0023	2.5	2.84
120 GeV	0.41	0.55	0.76	1.05	1.39	1.81	0.0017	2.65	2.93
125 GeV	0.42	0.55	0.77	1.07	1.42	1.80	0.0022	2.62	2.85
130 GeV	0.44	0.59	0.82	1.13	1.51	1.84	0.0037	2.47	2.68
135 GeV	0.51	0.68	0.94	1.31	1.74	1.90	0.0135	2.12	2.21
140 GeV	0.60	0.79	1.10	1.52	2.03	1.90	0.0457	1.83	1.69
145 GeV	0.74	0.98	1.36	1.88	2.50	2.30	0.0487	1.49	1.66

includes associated VH(→ττ) searches

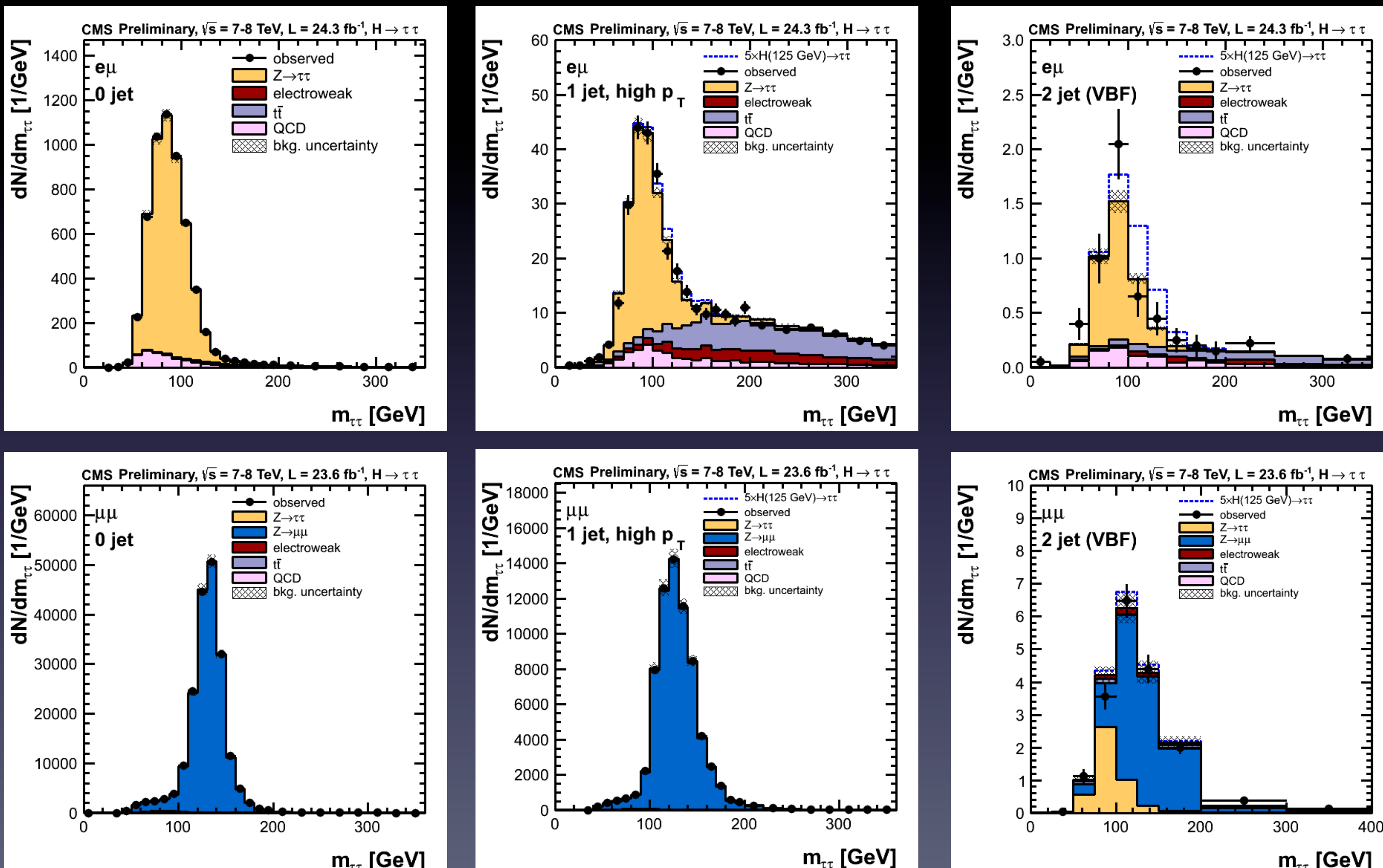
GF,VBF H→ ττ

$m_{\tau\tau}$ distributions (+0,1,2 jets)



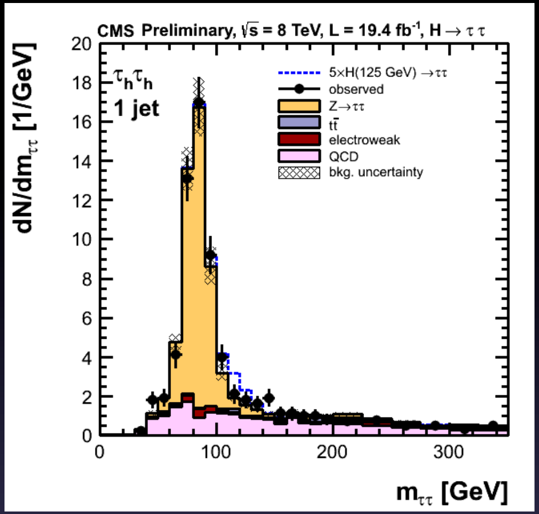
GF,VBF $H \rightarrow \tau\tau$

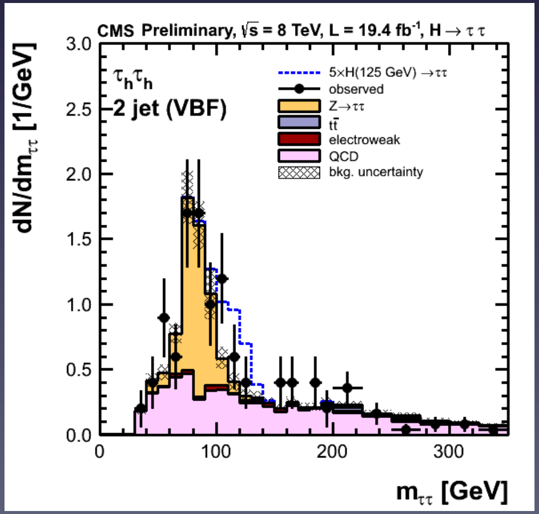
$m_{\tau\tau}$ distributions (+0,1,2 jets)



GF,VBF H→ ττ

$m_{\tau\tau}$ distributions (+1,2 jets)





VH H→ ττ

systematic uncertainties

μ and e reconstruction efficiencies	from 1 to 3%
τ_h identification	from 6 to 12%
τ_h energy scale ($\ell\tau_h\tau_h$)	3%
trigger efficiency	from 1 to 3.5%
b-tagged jet veto	1%
jet energy scale	1%
unclustered energy scale ($\ell\tau_h\tau_h$)	3.7%
e veto ($\ell\tau_h\tau_h$)	3.8%
μ veto ($\ell\tau_h\tau_h$)	0.7%
integrated luminosity 2011(2012)	2.2% (4.4%)
PDF (PDF4LHC prescription)	from 4 to 15%
non-prompt background estimation	from 15 to 35%
WZ cross-section	12%
ZZ cross-section	10%

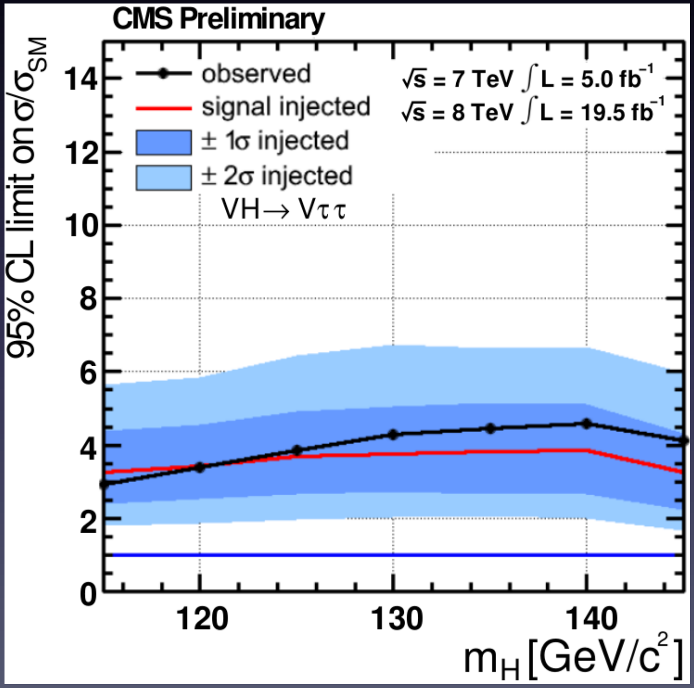
VH H→ ττ

limits

m_H [GeV/c^2]	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	Obs. Limit
115	1.50	1.99	2.76	3.83	5.09	2.91
120	1.56	2.07	2.87	3.98	5.29	3.38
125	1.68	2.24	3.10	4.31	5.72	3.87
130	1.74	2.31	3.20	4.45	5.91	4.29
135	1.79	2.38	3.30	4.58	6.08	4.46
140	1.81	2.40	3.33	4.62	6.14	4.60
145	1.60	2.13	2.95	4.09	5.44	4.11

Expected and observed 95% CL upper limits on SM Higgs boson production expressed as σ/σ_{SM}: the ratio of the excluded production x BR to the SM prediction

Observed combined 95% CL upper limits on SM Higgs productions compared top the expectations with SM signal



ttH H→ bb

yields

	≥6 jets 2 b-tags	4 jets 3 b-tags	5 jets 3 b-tags	≥6 jets 3 b-tags	4 jets 4 b-tags	5 jets ≥4 b-tags	≥6 jets ≥4 b-tags
$t\bar{t}H(125)$	33.4 ± 8.1	14.0 ± 3.0	21.1 ± 4.5	23.1 ± 5.5	1.8 ± 0.5	5.2 ± 1.4	8.3 ± 2.3
$t\bar{t}$+lf	7650 ± 2000	4710 ± 820	2610 ± 530	1260 ± 340	74 ± 30	79 ± 34	71 ± 36
$t\bar{t}$+b	530 ± 300	350 ± 190	360 ± 200	280 ± 160	21 ± 12	29 ± 17	33 ± 20
$t\bar{t}+b\bar{b}$	220 ± 120	99 ± 52	158 ± 85	200 ± 110	13.1 ± 7.3	38 ± 21	78 ± 47
$t\bar{t}+c\bar{c}$	1710 ± 1110	440 ± 230	520 ± 290	470 ± 280	19 ± 11	32 ± 18	52 ± 31
$t\bar{t}V$	99 ± 27	16.2 ± 3.8	23.9 ± 5.7	28.8 ± 7.4	1.1 ± 0.4	2.5 ± 0.7	5.8 ± 1.8
Single t	264 ± 54	235 ± 41	116 ± 22	55 ± 14	3.4 ± 1.6	10.3 ± 5.3	7.3 ± 3.1
V+jets	160 ± 110	122 ± 95	44 ± 38	29 ± 27	2.1 ± 2.4	1.9 ± 1.7	1.2 ± 1.3
Diboson	5.9 ± 1.6	6.3 ± 1.4	2.4 ± 0.7	1.0 ± 0.4	0.3 ± 0.2	0.1 ± 0.1	0.2 ± 0.1
Total bkg	10630 ± 2790	5970 ± 1060	3830 ± 790	2310 ± 620	133 ± 44	193 ± 62	249 ± 90
Data	10724	5667	3983	2426	122	219	260

lepton+jets

	3 jets + 2 b-tags	≥4 jets + 2 b-tags	≥3 b-tags
$t\bar{t}H(125)$	7.7 ± 1.4	16.1 ± 3.1	11.2 ± 2.5
$t\bar{t}$+lf	7460 ± 1060	3190 ± 680	289 ± 83
$t\bar{t}$+b	189 ± 97	172 ± 93	149 ± 82
$t\bar{t}+b\bar{b}$	38 ± 20	58 ± 31	80 ± 44
$t\bar{t}+c\bar{c}$	480 ± 260	510 ± 300	147 ± 79
$t\bar{t}V$	30.2 ± 6.3	54 ± 12	11.9 ± 2.9
Single t	229 ± 35	97 ± 16	17.3 ± 5.1
V+jets	350 ± 130	151 ± 66	40 ± 23
Diboson	10.4 ± 1.7	3.1 ± 0.6	0.7 ± 0.4
Total bkg	8770 ± 1250	4230 ± 850	740 ± 190
Data	9060	4616	774

dileptons

$t\bar{t}H$ H→ ττ

yields

	2 jets 1 b-tag	3 jets 1 b-tag	≥4 jets 1 b-tag	2 jets 2 b-tags	3 jets 2 b-tags	≥4 jets 2 b-tags
$t\bar{t}H(125)$	0.4 ± 0.1	0.6 ± 0.1	0.6 ± 0.2	0.1 ± 0.0	0.2 ± 0.1	0.4 ± 0.1
$t\bar{t}$	225 ± 69	119 ± 38	64 ± 22	48 ± 15	38 ± 12	27.0 ± 9.1
$t\bar{t}V$	1.1 ± 0.3	1.3 ± 0.3	1.4 ± 0.4	0.4 ± 0.1	0.6 ± 0.2	1.1 ± 0.3
Single t	11.2 ± 4.0	3.0 ± 1.4	1.1 ± 1.0	1.9 ± 1.1	0.9 ± 0.6	0.6 ± 0.7
V+jets	33 ± 17	11.7 ± 6.8	3.8 ± 2.8	1.4 ± 0.9	0.4 ± 0.3	0.5 ± 0.6
Diboson	0.9 ± 0.2	0.7 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1
Total bkg	271 ± 82	135 ± 41	71 ± 24	52 ± 16	40 ± 12	29.2 ± 9.4
Data	292	171	92	41	48	35

tau channels (all events have two τ tagged jets.)

ttH H→ ττ,bb

systematic uncertainties

Uncertainties of the sum of $t\bar{t}$+lf, $t\bar{t}$+b, $t\bar{t}+b\bar{b}$, and $t\bar{t}+c\bar{c}$ events with ≥ 6 jets and ≥ 4 b-tags		
Source	Rate	Shape?
QCD Scale (all $t\bar{t}$+hf)	35%	No
QCD Scale ($t\bar{t}+b\bar{b}$)	17%	No
b-Tag bottom-flavor contamination	17%	Yes
QCD Scale ($t\bar{t}+c\bar{c}$)	11%	No
Jet Energy Scale	11%	Yes
b-Tag light-flavor contamination	9.6%	Yes
b-Tag bottom-flavor statistics (linear)	9.1%	Yes
QCD Scale ($t\bar{t}$+b)	7.1%	No
Madgraph Q^2 Scale ($t\bar{t}+b\bar{b}$)	6.8%	Yes
b-Tag Charm uncertainty (quadratic)	6.7%	Yes
Top p_T Correction	6.7%	Yes
b-Tag bottom-flavor statistics (quadratic)	6.4%	Yes
b-Tag light-flavor statistics (linear)	6.4%	Yes
Madgraph Q^2 Scale ($t\bar{t}$ + 2 partons)	4.8%	Yes
b-Tag light-flavor statistics (quadratic)	4.8%	Yes
Luminosity	4.4%	No
Madgraph Q^2 Scale ($t\bar{t}+c\bar{c}$)	4.3%	Yes
Madgraph Q^2 Scale ($t\bar{t}$+b)	2.6%	Yes
QCD Scale ($t\bar{t}$)	3%	No
pdf (gg)	2.6%	No
Jet Energy Resolution	1.5%	No
Lepton ID/Trigger efficiency	1.4%	No
Pileup	1%	No
b-Tag Charm uncertainty (linear)	0.6%	Yes

ttH H→ ττ,bb

limits and fit values

Higgs Mass	Observed	Expected Median	Expected 68% C.L. Range	Expected 95% C.L. Range
110 GeV	4.1	2.9	[2.1,4.2]	[1.6,5.8]
115 GeV	4.4	3.1	[2.2,4.5]	[1.6,6.2]
120 GeV	4.6	3.6	[2.5,5.2]	[1.9,7.2]
125 GeV	5.2	4.1	[2.9,5.9]	[2.2,8.2]
130 GeV	7.0	5.2	[3.7,7.5]	[2.8,10.4]
135 GeV	8.6	6.0	[4.2,8.6]	[3.1,12.0]
140 GeV	11.0	7.7	[5.4,10.9]	[4.1,15.1]

Channel	$\mu_{t\bar{t}H}$
LJ	$-0.10^{+2.53}_{-2.58}$
DIL	$+1.23^{+4.20}_{-4.69}$
TAU	$-0.73^{+6.14}_{-5.24}$
7 TeV LJ + DIL	$-2.82^{+4.16}_{-4.92}$
$\gamma\gamma$	$+0.21^{+2.18}_{-1.46}$
COMB	$+0.74^{+1.34}_{-1.30}$

VH $H \rightarrow bb$

VH H→ bb

Selection criteria for the signal region

Variable	W($\ell\nu$)H	W($\tau\nu$)H	Z($\ell\ell$)H	Z($\nu\nu$)H
p_T(V)	[100–130] [130–180] [>180]	[>120]	[50–100] [>100]	[100–130] [130–170] [>170]
$m_{\ell\ell}$	–	–	[75–105]	–
$p_T(j_1)$	>30	>30	>20	>60
$p_T(j_2)$	>30	>30	>20	>30
p_T(jj)	>100	>120	–	[>100] [>130] [>130]
m(jj)	<250	<250	[40–250] [< 250]	<250
E_T^{miss}	>45	>80	–	[100–130] [130–170] [> 170]
$p_T(\tau)$	–	>40	–	–
p_T(track)	–	>20	–	–
CSV_{max}	>0.40	>0.40	[>0.50] [>0.244]	>0.679
CSV_{min}	>0.40	>0.40	>0.244	>0.244
N_{aj}	–	–	–	[< 2] [–] [–]
$N_{a\ell}$	=0	=0	–	=0
$\Delta\phi$(V, H)	–	–	–	>2.0
$\Delta\phi(E_T^{miss}, \text{jet})$	–	–	–	[>0.7] [>0.7] [>0.5]
$\Delta\phi(E_T^{miss}, E_T^{miss}(\text{tracks}))$	–	–	–	<0.5
E_T^{miss} significance	–	–	–	[>3] [–] [–]
$\Delta\phi(E_T^{miss}, \ell)$	$< \pi/2$	–	–	–

VH H→ bb

Selection criteria for the m(jj) analysis

Variable	W(ℓν)H	W(τν)H	Z(ℓℓ)H	Z(νν)H
$p_T(V)$	[100–150] [>150] (e) [100–130] [130–180] [>180] (μ)	[<250]	[50–100] [100–150] [>150]	[100–130] [130–170] [>170]
$m_{\ell\ell}$	–	–	$75 < m_{\ell\ell} < 105$	–
$p_T(j_1)$	>30	>30	>20	[> 60][> 60][> 80]
$p_T(j_2)$	>30	>30	>20	>30
$p_T(jj)$	>100	>120	–	[> 110][> 140][> 190]
N_{aj}	=0	=0	–	=0
$N_{a\ell}$	=0	=0	–	=0
E_T^{miss}	>45	>80	< 60	–
$p_T(\tau)$	–	>40	–	–
$p_T(track)$	–	>20	–	–
CSV_{max}	0.898	0.898	0.679	0.898
CSV_{min}	>0.5	>0.4	>0.5	>0.5
$\Delta\phi(V,H)$	>2.95	>2.95	–	>2.95
$\Delta R(jj)$	–	–	[–][–][< 1.6]	–
$\Delta\phi(E_T^{miss}, jet)$	–	–	–	[> 0.7][> 0.7][> 0.5]
$\Delta\phi(E_T^{miss}, E_T^{miss}(tracks))$	–	–	–	<0.5
$\Delta\phi(E_T^{miss}, \ell)$	$< \pi/2$	–	–	–

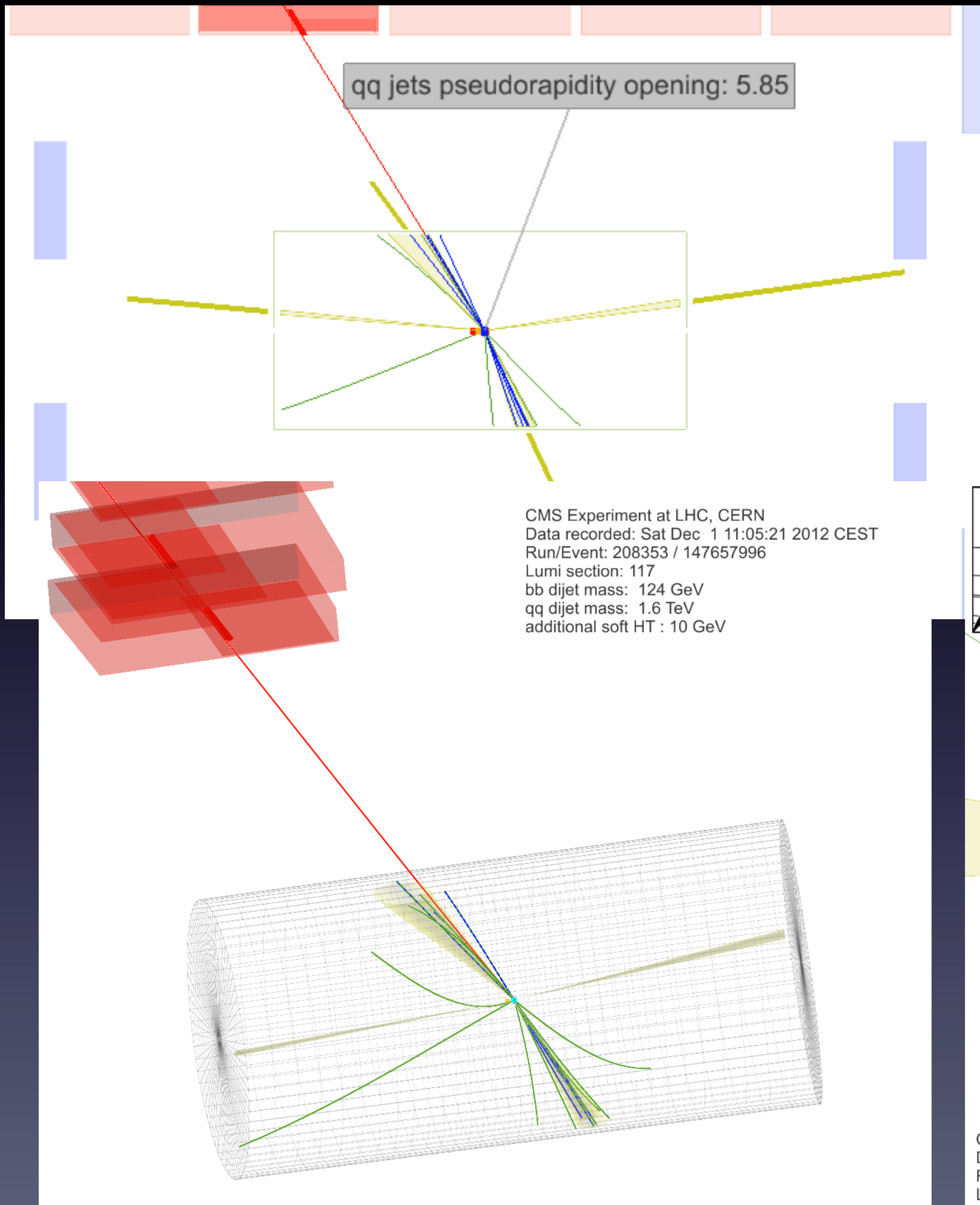
VH $H \rightarrow bb$

sources of systematic uncertainty

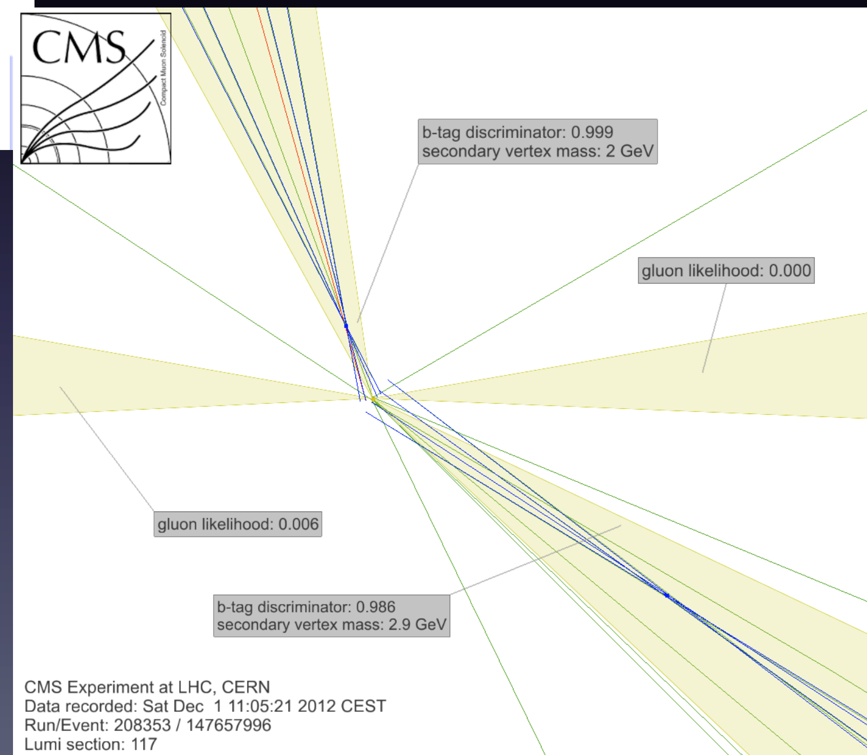
Source	Type	Event yield uncertainty range (%)	Individual contribution to μ uncertainty (%)	Effect of removal on μ uncertainty (%)
Luminosity	norm.	2.2–2.6	<2	<0.1
Lepton efficiency and trigger (per lepton)	norm.	3	<2	<0.1
$Z(\nu\nu)H$ triggers	shape	3	<2	<0.1
Jet energy scale	shape	2–3	5.0	0.5
Jet energy resolution	shape	3–6	5.9	0.7
Missing transverse energy	shape	3	3.2	0.2
b-tagging	shape	3–15	10.2	2.1
Signal cross section (scale and PDF)	norm.	4	3.9	0.3
Signal cross section (p_T boost, EW/QCD)	norm.	2/5	3.9	0.3
Monte Carlo statistics	shape	1–5	13.3	3.6
Backgrounds (data estimate)	norm.	10	15.9	5.2
Single top quark (simulation estimate)	norm.	15	5.0	0.5
Dibosons (simulation estimate)	norm.	15	5.0	0.5
MC modeling (V+jets and $t\bar{t}$)	shape	10	7.4	1.1

Due to correlations, the total systematic uncertainty is less than the sum in quadrature of the individual uncertainties

VBF H→ bb



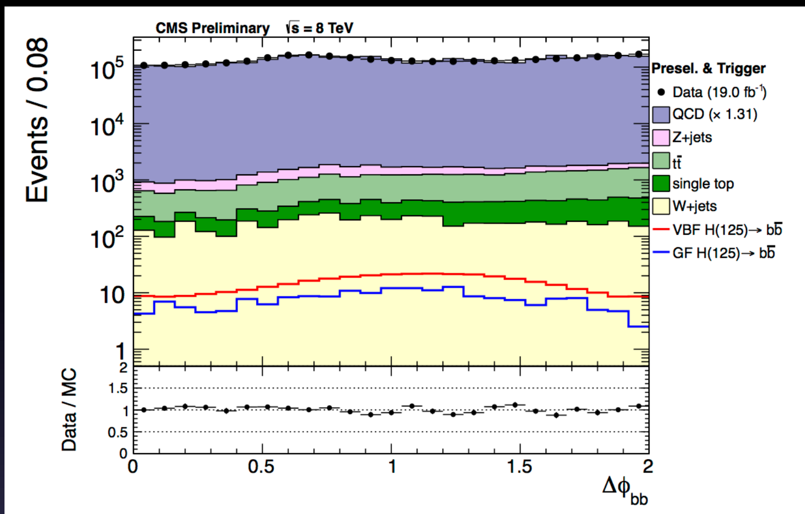
qq jets pseudorapidity opening: 5.85
CMS Experiment at LHC, CERN
Data recorded: Sat Dec 1 11:05:21 2012 CEST
Run/Event: 208353 / 147657996
Lumi section: 117
bb dijet mass: 124 GeV
qq dijet mass: 1.6 TeV
additional soft HT : 10 GeV

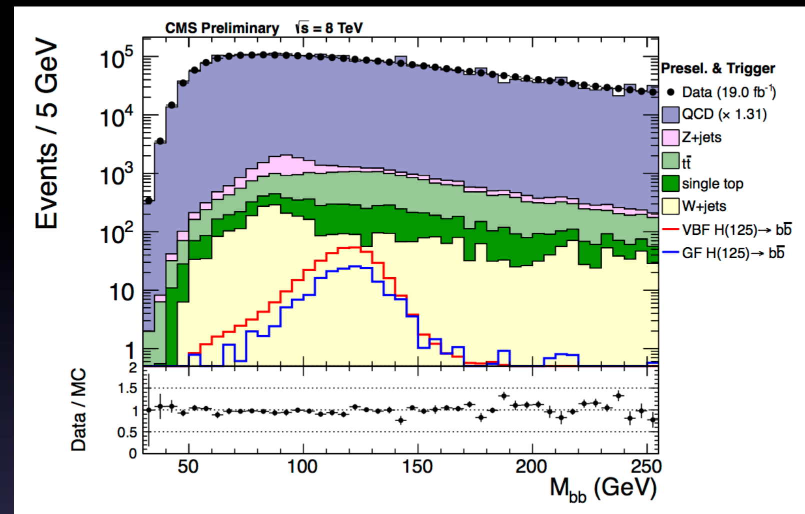


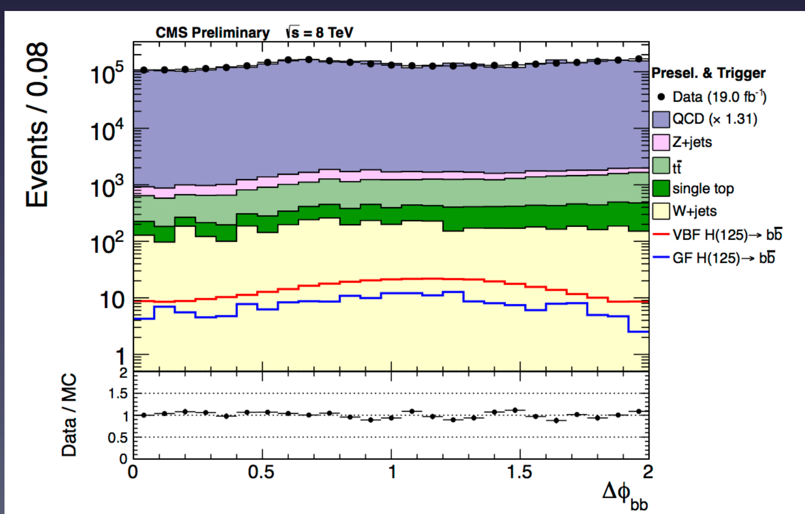
CMS
b-tag discriminator: 0.999
secondary vertex mass: 2 GeV
gluon likelihood: 0.000
gluon likelihood: 0.006
b-tag discriminator: 0.986
secondary vertex mass: 2.9 GeV
CMS Experiment at LHC, CERN
Data recorded: Sat Dec 1 11:05:21 2012 CEST
Run/Event: 208353 / 147657996
Lumi section: 117

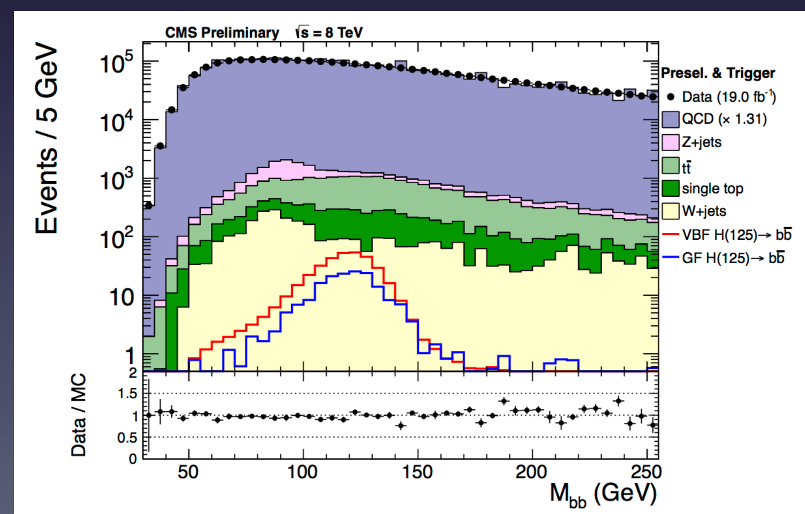
VBF H→ bb

event preselection



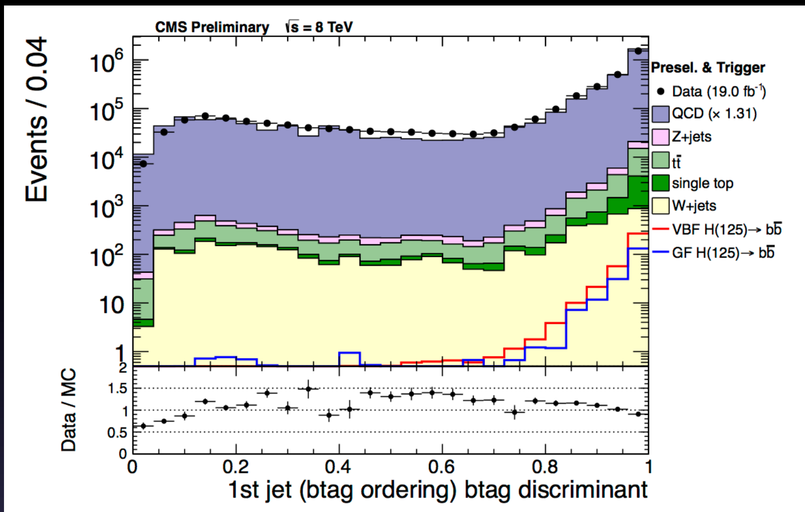


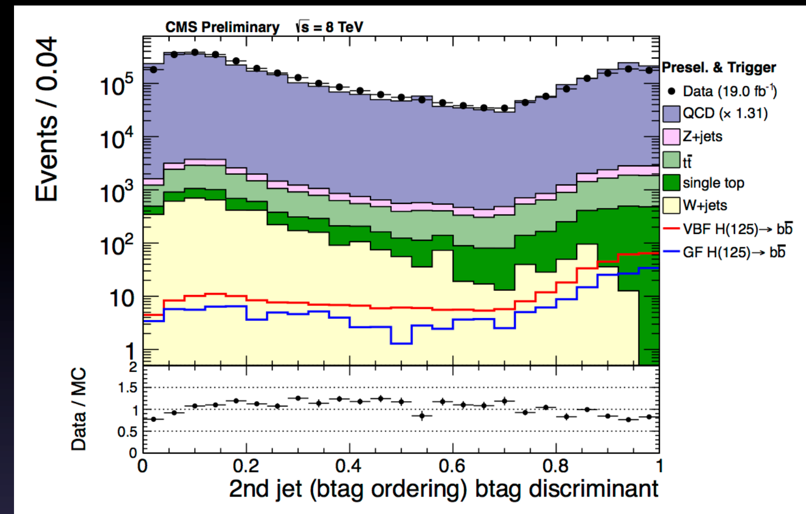


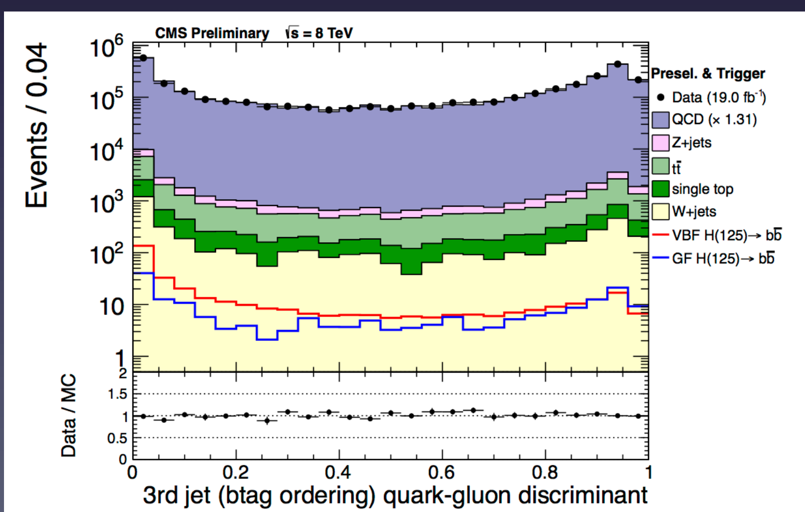


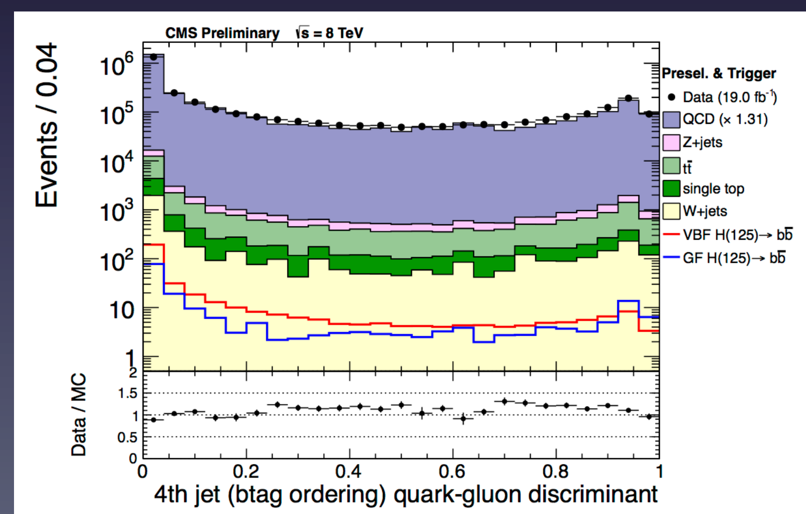
VBF H→ bb

4-jet flavor id



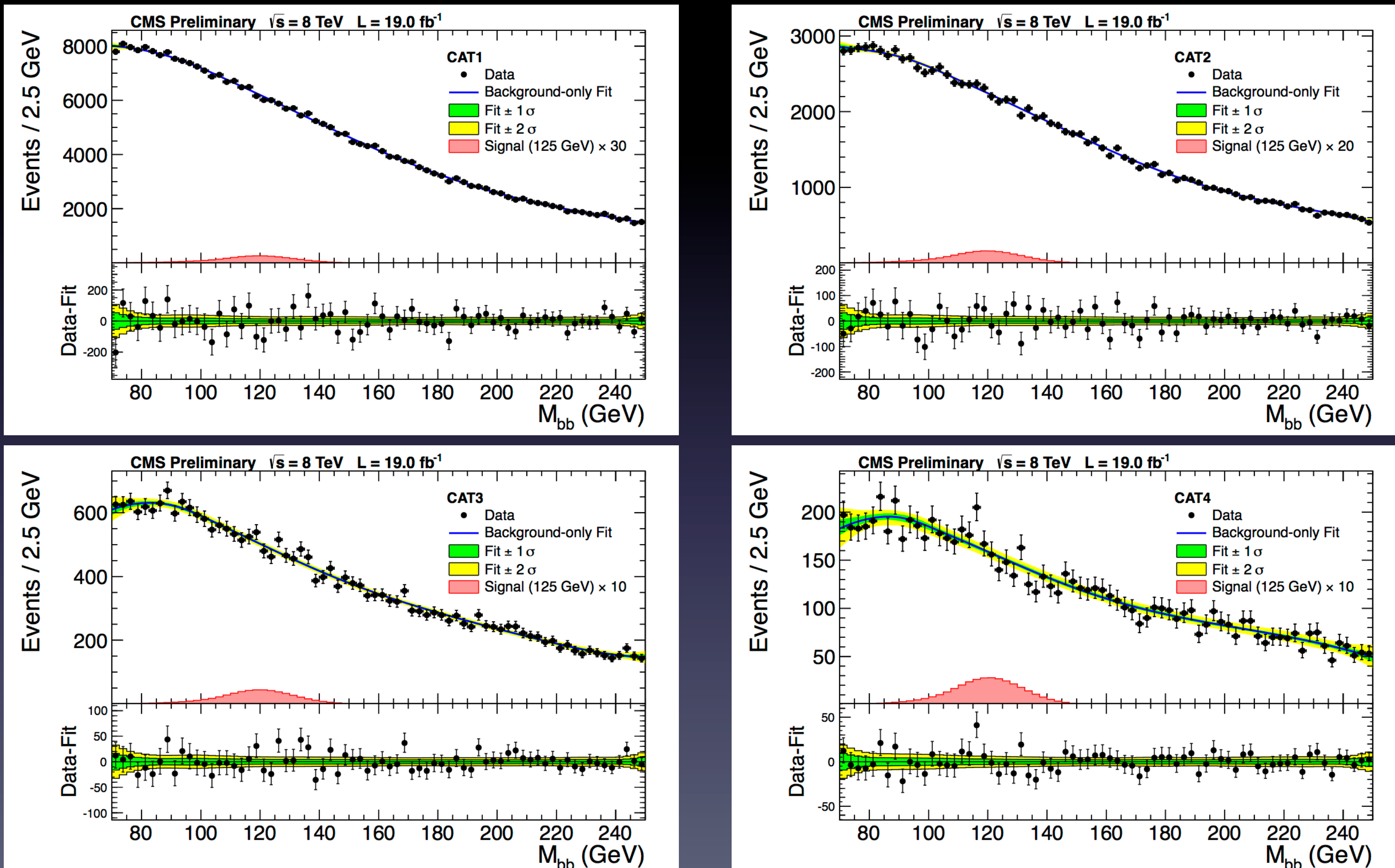






VBF H→ bb

m_{bb} distribution fits



VBF H→ bb

preselection and classification

p_T(jets) > 85, 70, 60, 40 GeV
m_{qq}>300 GeV, $\Delta\eta_{qq}$>2.5, $\Delta\phi_{bb}$<2

Sample/ANN range	< 0.52 Cat. 0	0.52 – 0.76 Cat. 1	0.76 – 0.90 Cat. 2	0.90 – 0.96 Cat. 3	> 0.96 Cat. 4
QCD	1.8e+6	3.1e+5	1.1e+5	2.6e+4	8.3e+3
Z +jets	5487	1211	531	123	56
$t\bar{t}$	12340	993	181	30	15
single top	2689	600	198	40	17
W+jets	1987	230	50	4	<1
VBF $M_H(125)$	65	79	84	59	23
GF $M_H(125)$	94	37	18	6	2
Data	1826994	312058	113290	26045	8420

ANN output boundaries for the definition of preselected event categories and expected number of events in the *m*bb interval [75, 255 GeV]

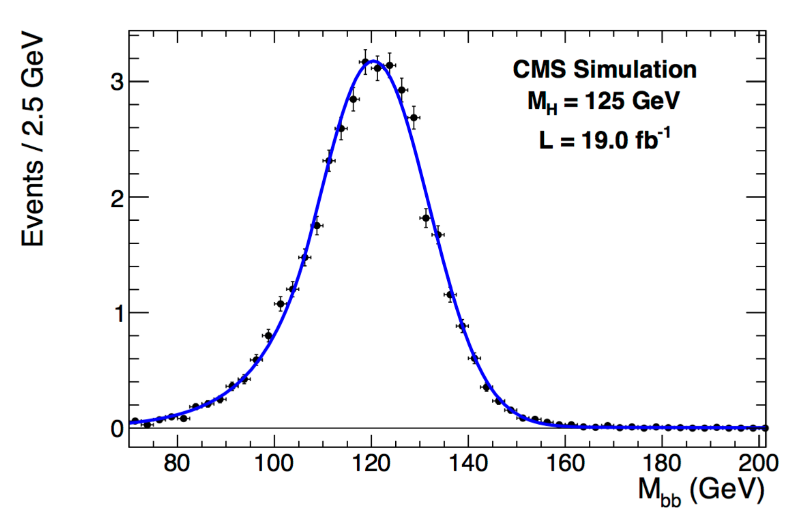
VBF H→ bb

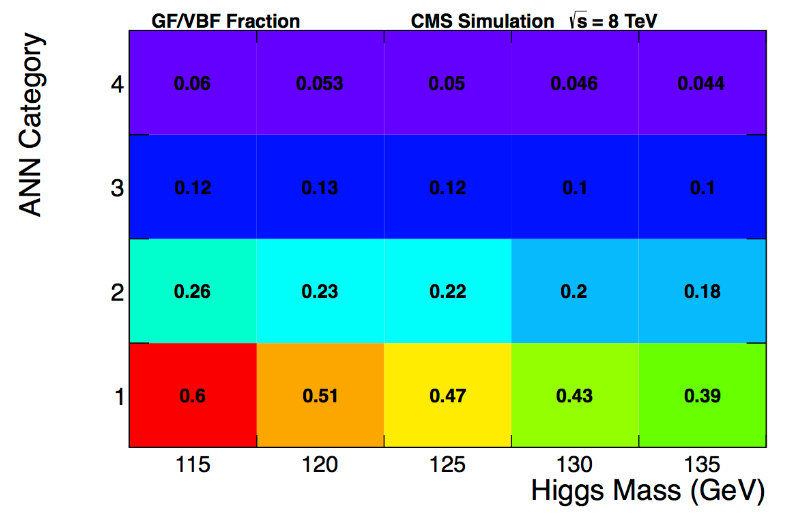
systematic uncertainties

Source	Uncertainty
Background fit	depending on the statistics of each category
Z+jets cross section	±20%
top cross section	±20%
Signal and Z peak position (JES)	±1.5%
Signal and Z resolution	±10%
Luminosity	±2.6%
Trigger efficiency	$\pm 5-8\%$
Signal acceptance due to JES	±10%
Signal acceptance due to JER	±2%
VBF cross section	±3%
VBF Monte Carlo acceptance	±10%
PDF	±5%
VBF ANN shape due to b-tag	±2%
VBF ANN shape due to quark-gluon discriminator	±2%
VBF ANN shape due to UE modeling	$-8 - +2\%$
GF cross section	±15%
GF Monte Carlo acceptance	±50%
GF ANN shape	±50%

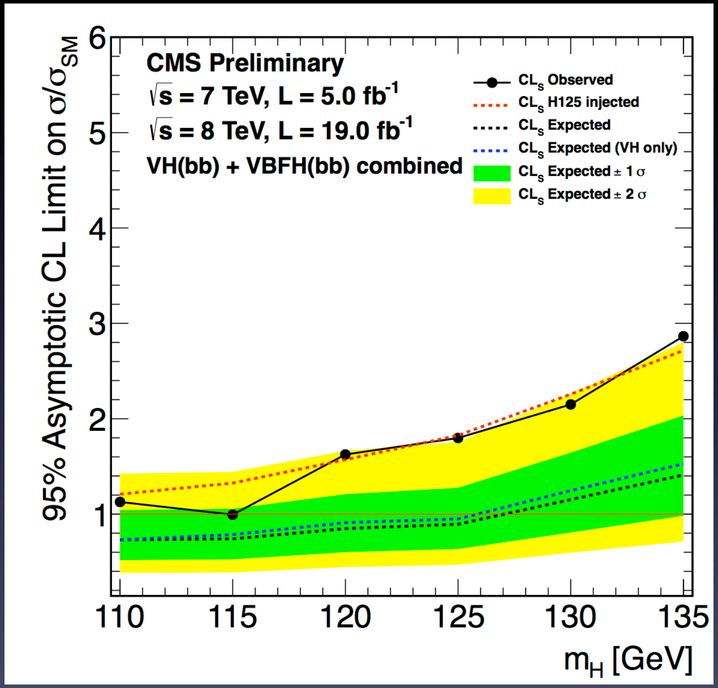
VBF H→ bb

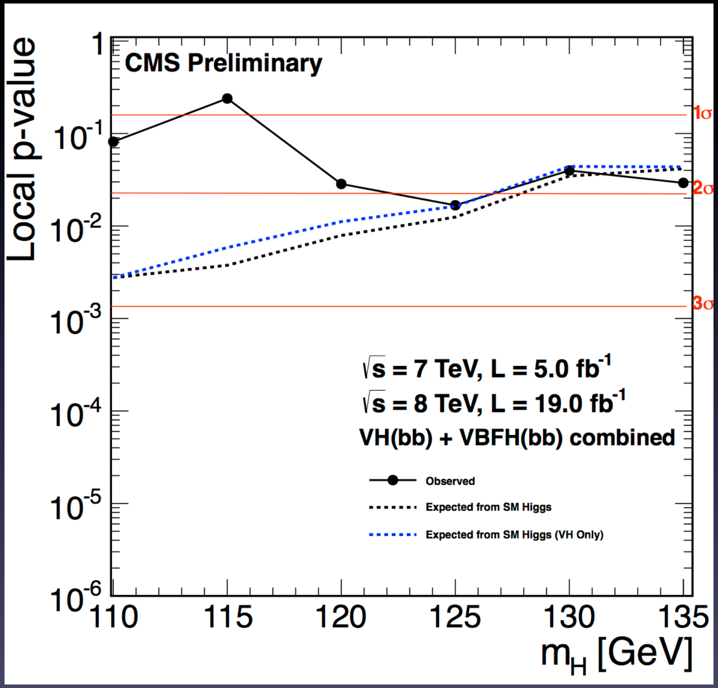
signal m_{bb} shape & GF contributions



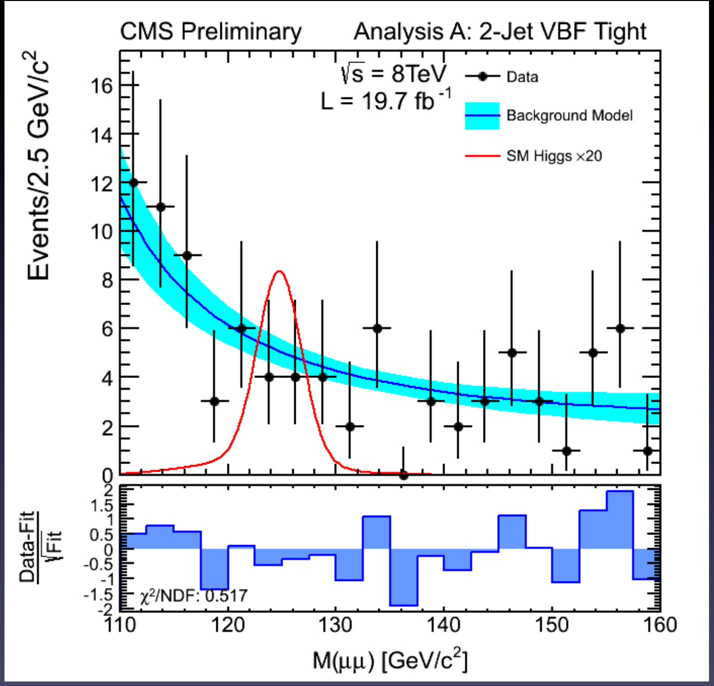


(VBF & VH) H→ bb combined

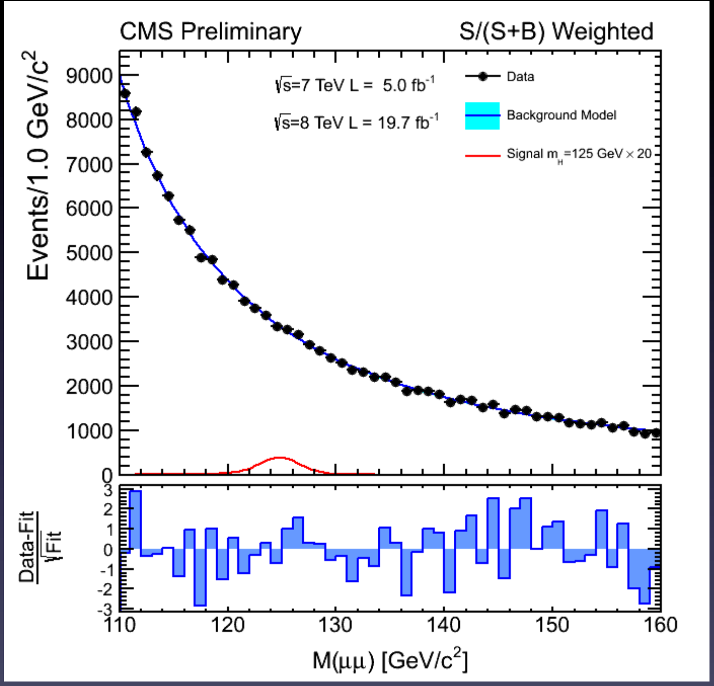




GF,VBF H→ μμ

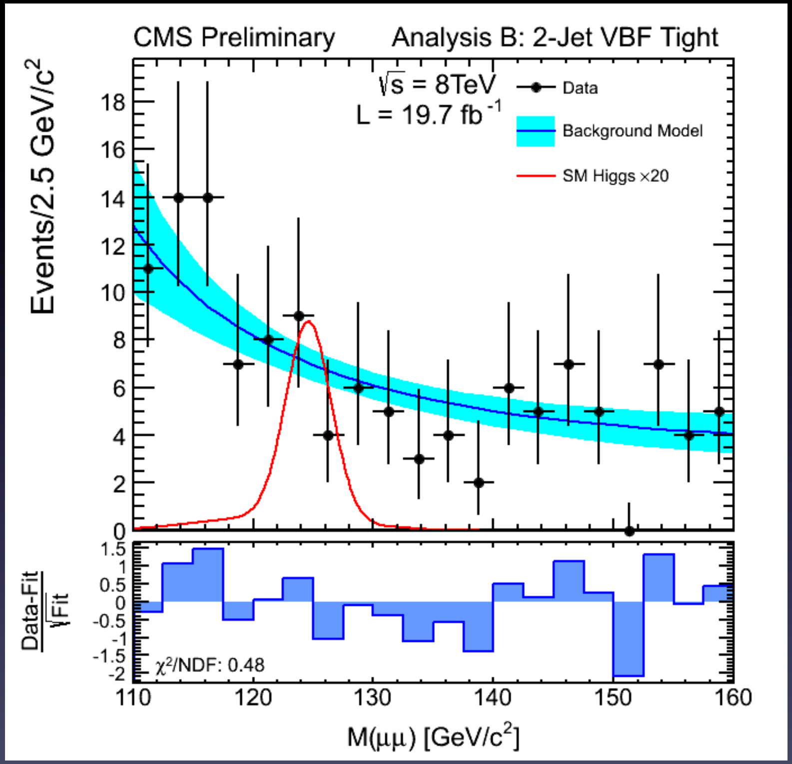


(A) 2 jets VBF Tight category at 8 TeV

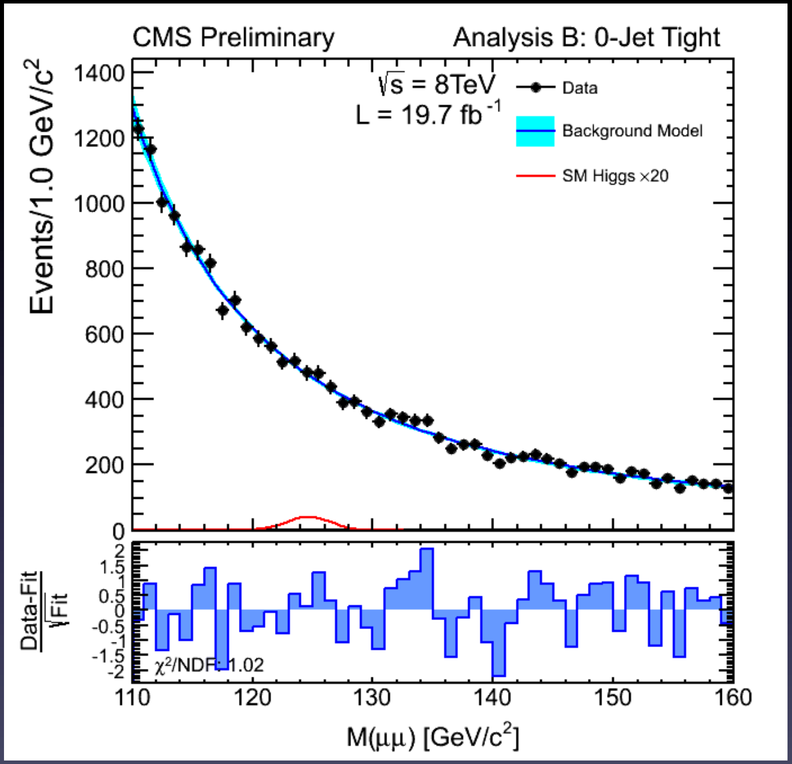


(A) full weighted spectrum

GF,VBF H→ μμ



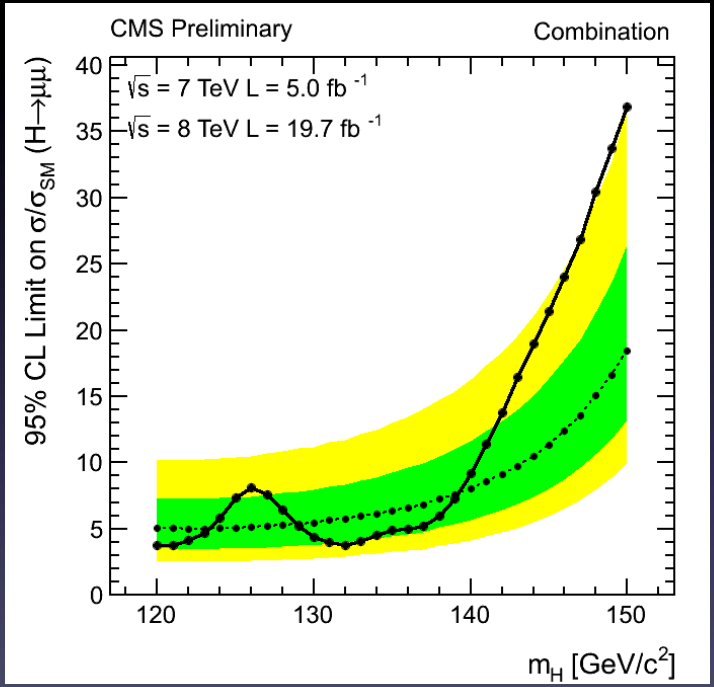
(B) 2 jets VBF Tight category at 8 TeV

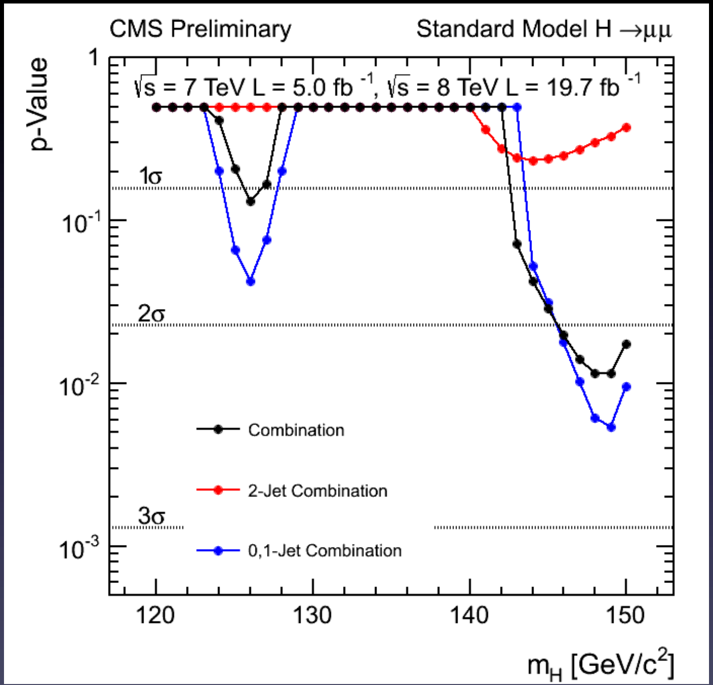


(B) 0 jets with $p_T(\mu\mu)>15$ GeV

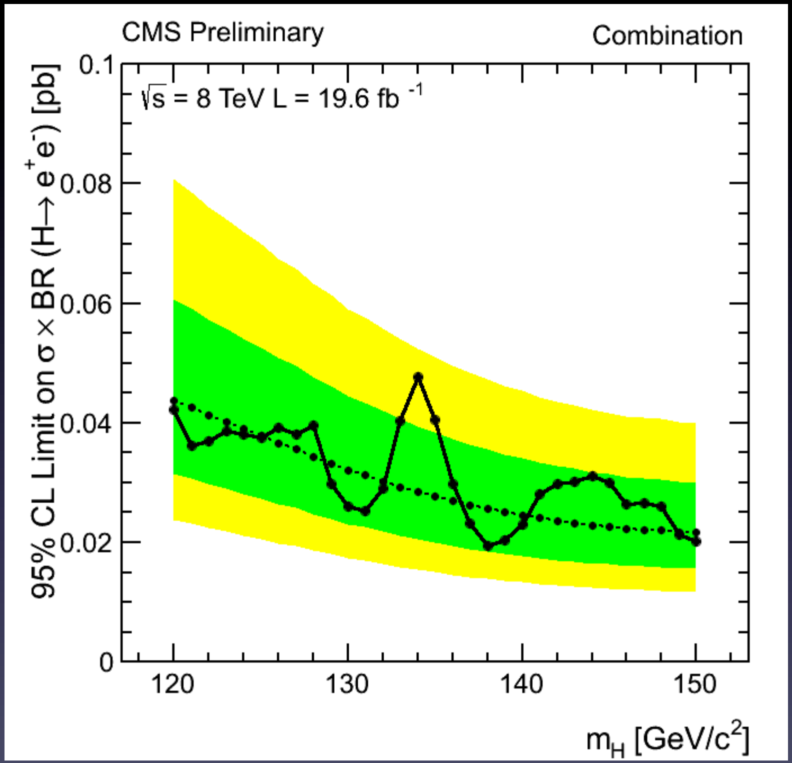
GF,VBF H→ μμ

https://cds.cern.ch/record/1606831?ln=en
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13007TWiki



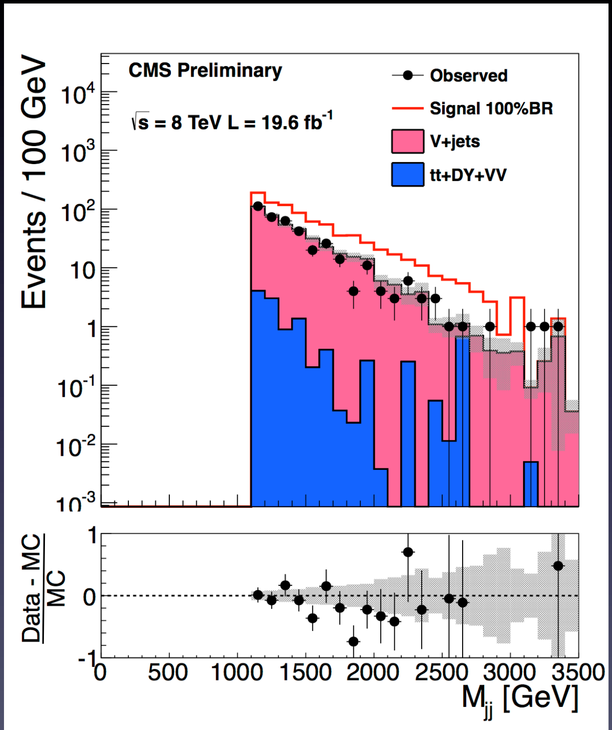


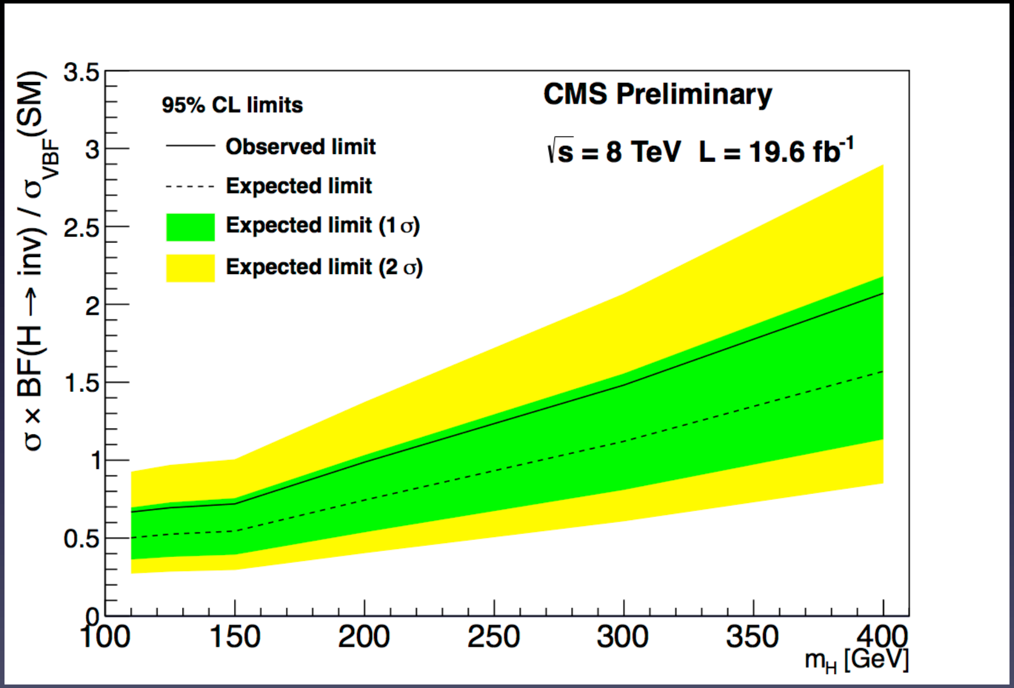
VBF H→ ee


CMS Preliminary
Combination
√s = 8 TeV L = 19.6 fb -1
95% CL Limit on σ × BR (H→ e+e-) [pb]
0.1
0.08
0.06
0.04
0.02
0
120
130
140
150
mH [GeV/c2]

VBF H→ invisible

https://cds.cern.ch/record/1596283?ln=en
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13013TWiki





VBF H→ invisible