Direct ttH searches

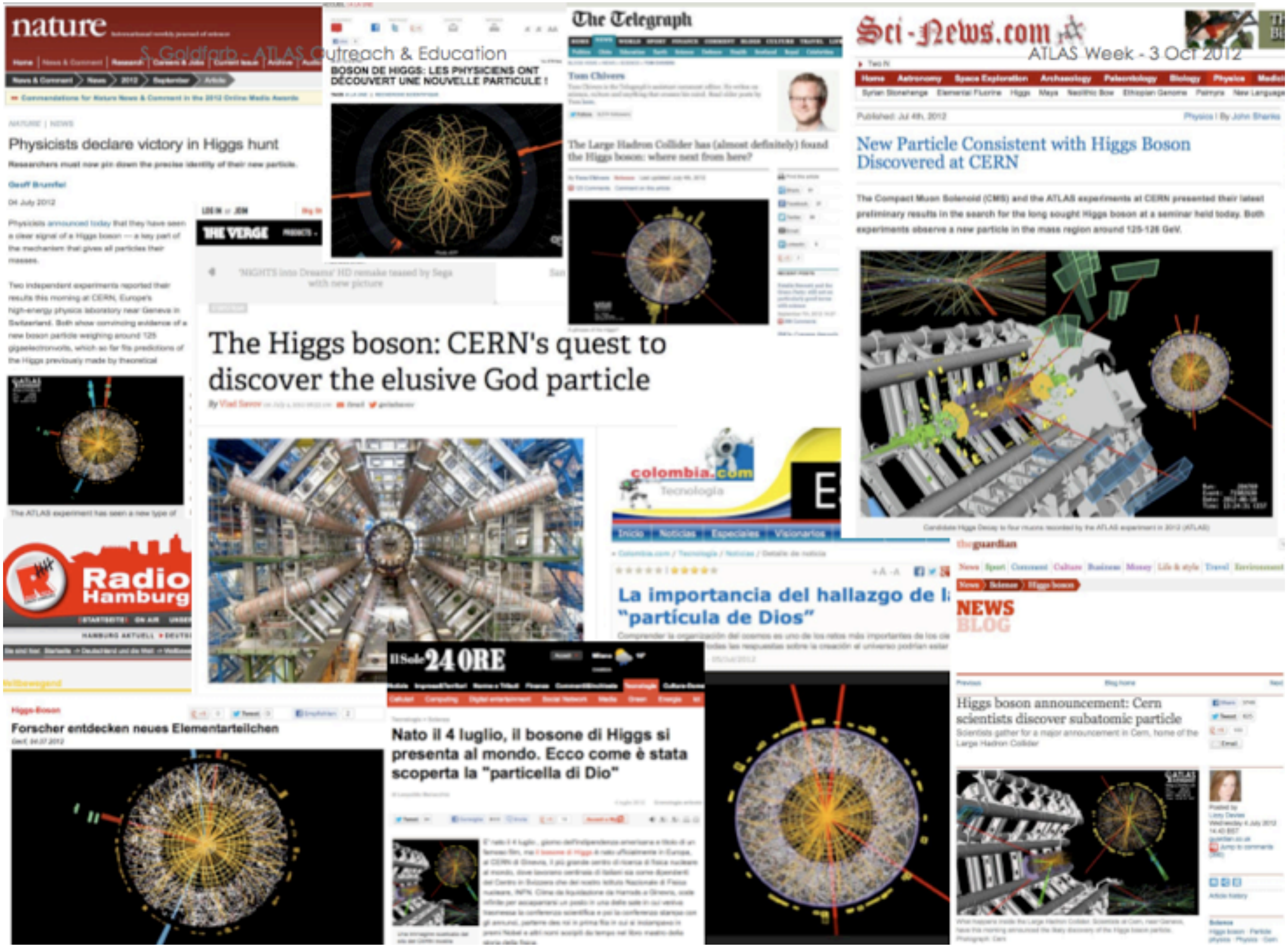
on behalf of ATLAS, CMS, CDF and DZero collaborations

+

Appropriate that Higgs discovery day took place on July 4 (aka Higgsdependence Day)?

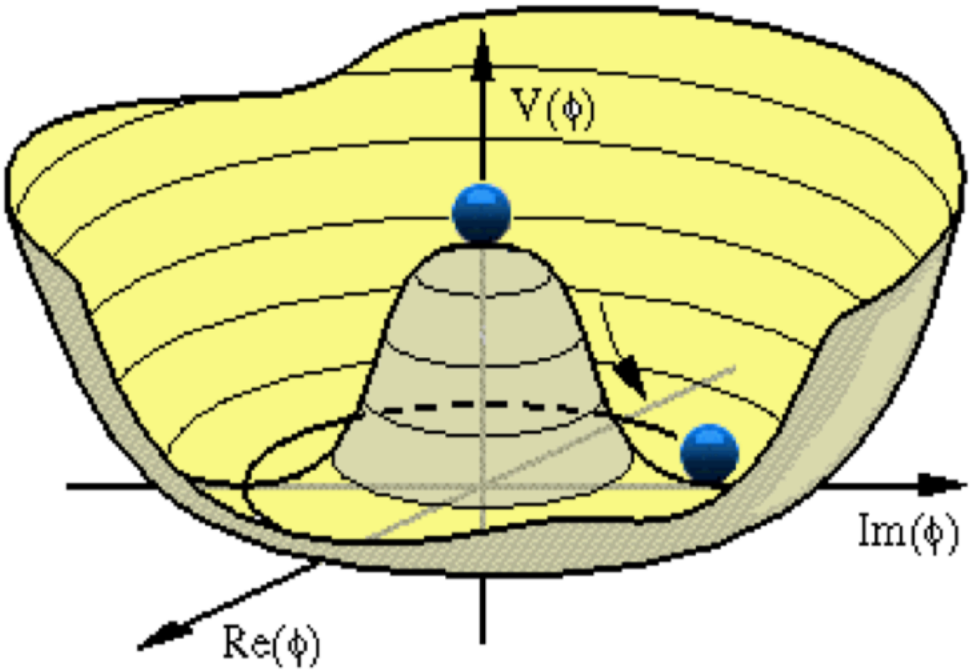
The new star of particle physics

The new star of particle physics



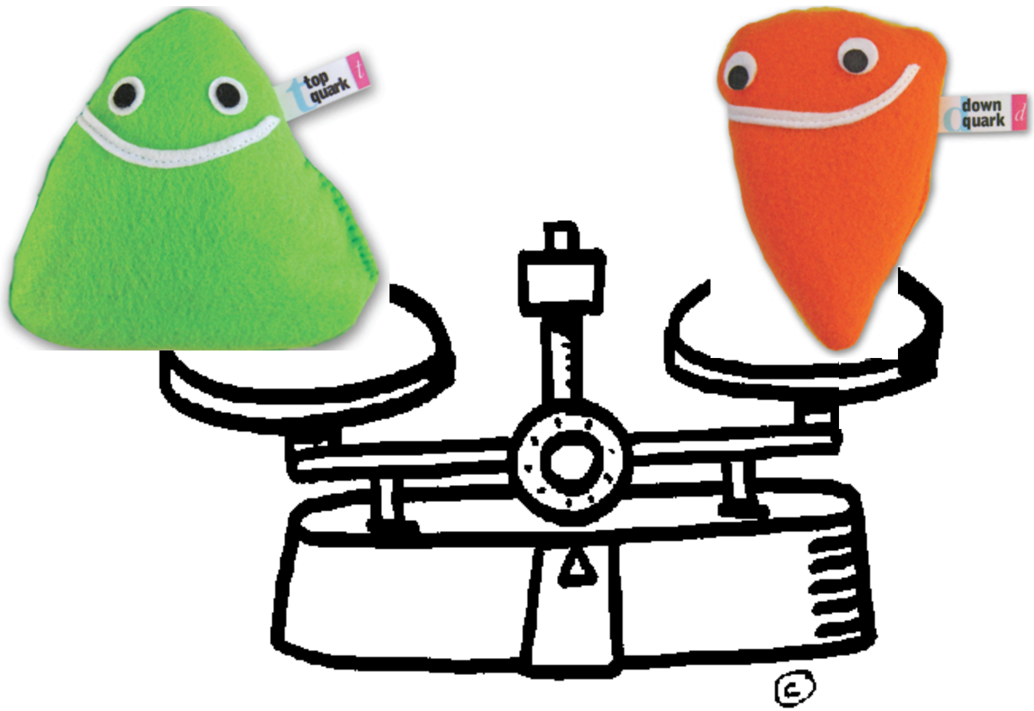
We knew something was responsible for electroweak symmetry breaking

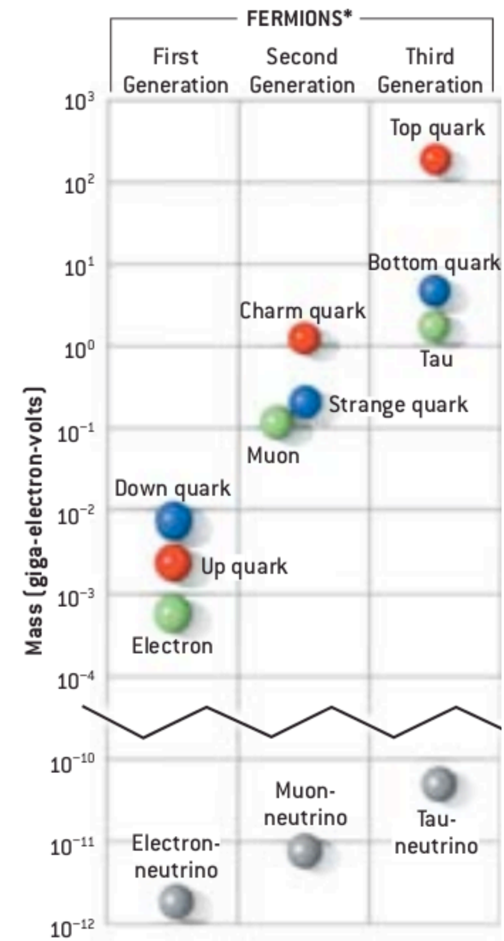
Higgs mechanism gives mass not just to W and Z bosons but also to all the fermions ...



Yukawa couplings

- Mass of fermions proportional to their coupling to the Higgs field
- Top quark Yukawa coupling > 0.9
  - Close to unity - why?
  - Does this point to a special role for the top quark in electroweak symmetry breaking?

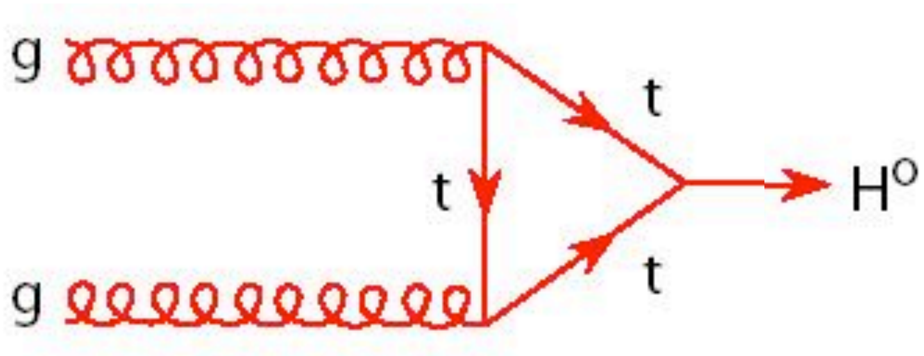


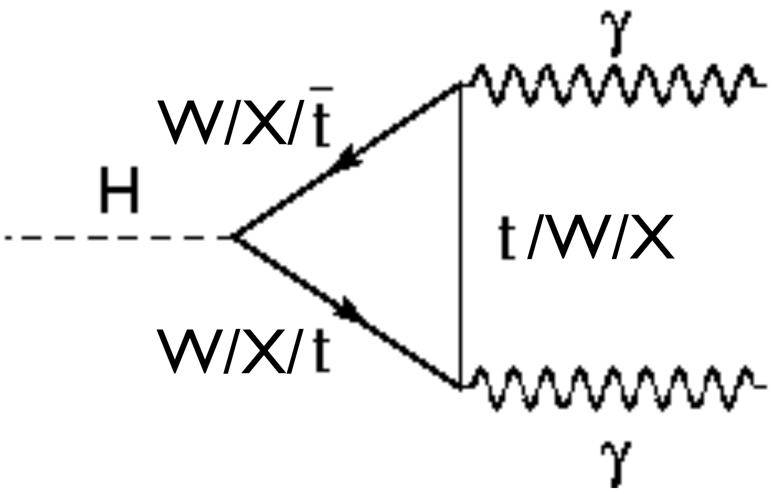


Already strong, indirect evidence of top quark-Higgs boson coupling

Gluon-gluon fusion (dominant Higgs production mechanism at LHC)

Induces decay to massless photons. Destructive interference with W boson

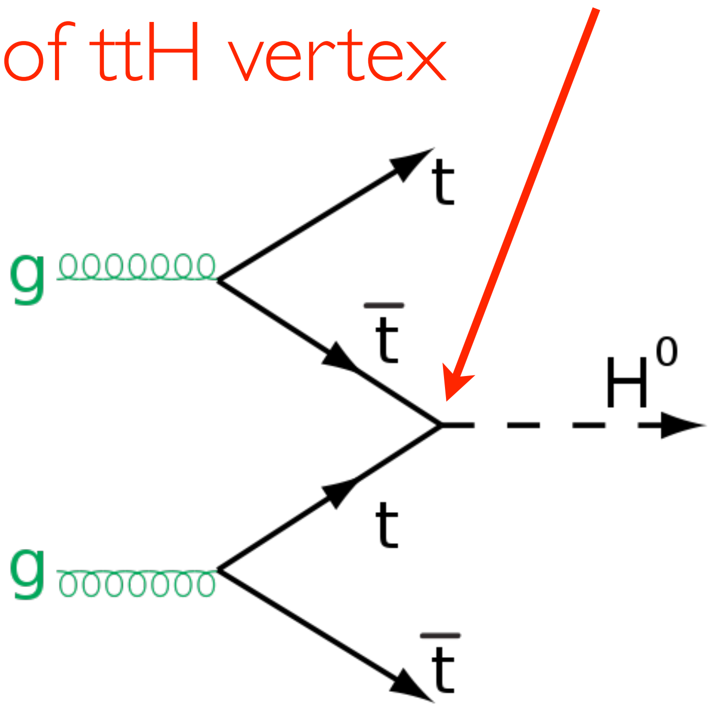




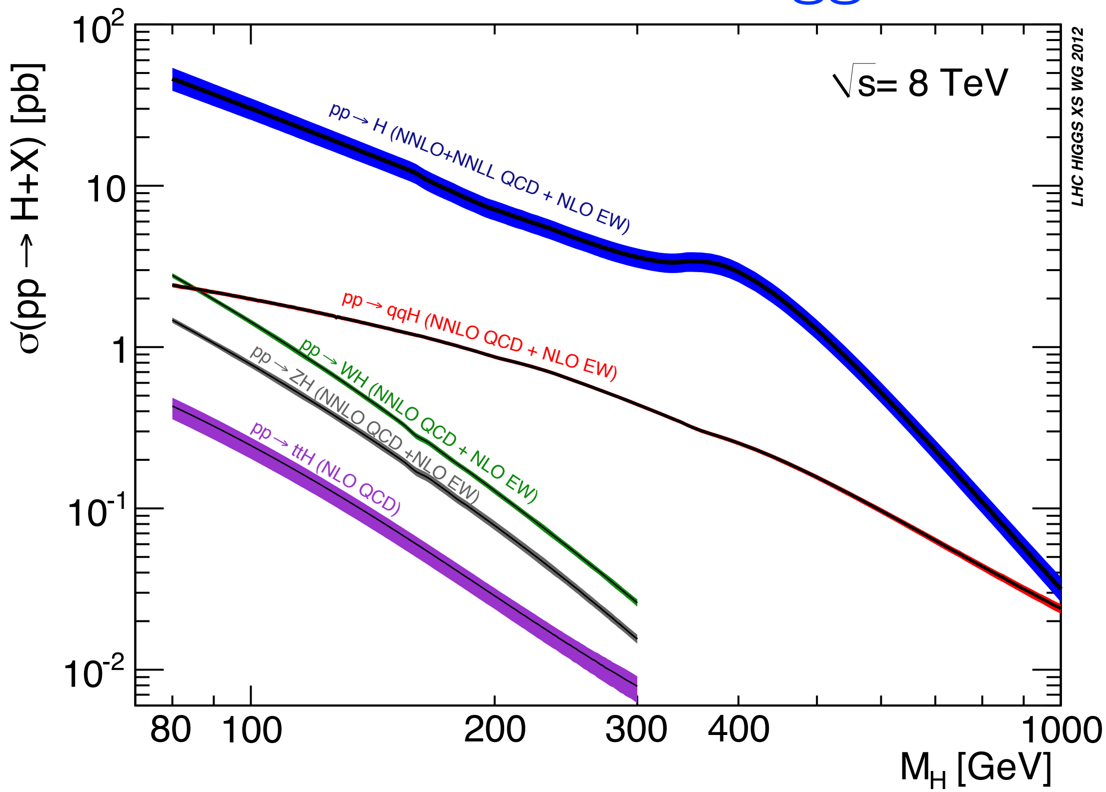
Cross sections for ttH production at 8 (14) TeV

- ggFusion: 19 pb (50 @ 14 TeV)
- VBFusion: 1.6 pb (4.2 @ 14 TeV)
- WH associated: 0.70 pb (1.5 @ 14 TeV)
- ZH associated: 0.42 pb (0.88 @ 14 TeV)
- ttH: 0.13 pb (0.61 @ 14TeV)

Direct observation of ttH vertex

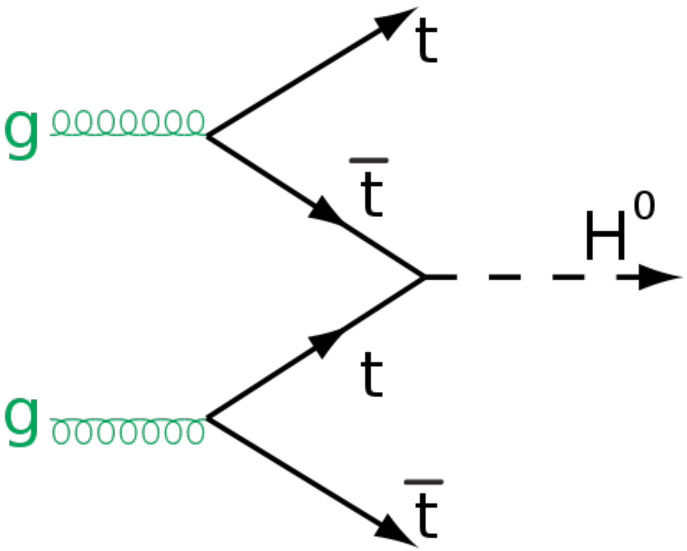


LHC Higgs WG

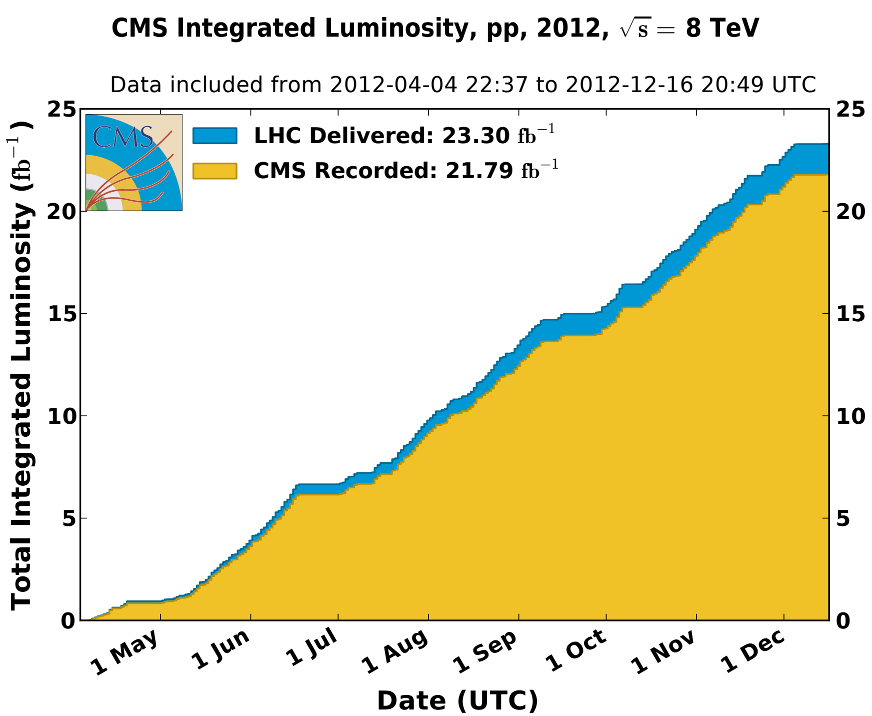


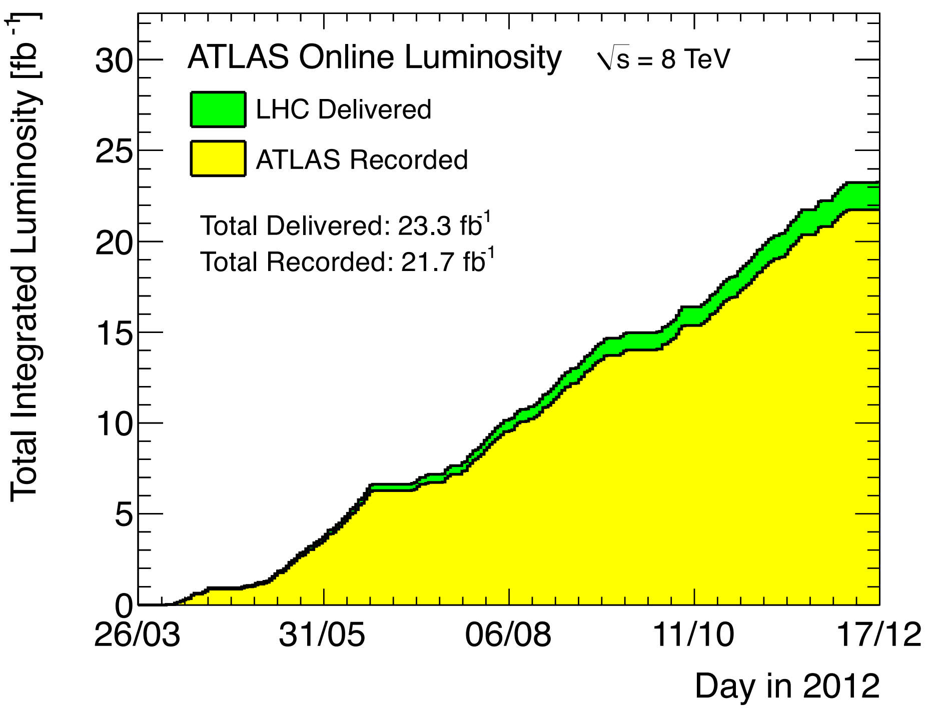
Direct searches for top-Higgs coupling are not easy ...

- We know that the production cross sections are small
  - Relative to other Higgs boson production processes, let alone ttbar production, EW processes and QCD
- Busy final state
  - Minimum of 8 final state objects in the event
- So what's the plan of attack?

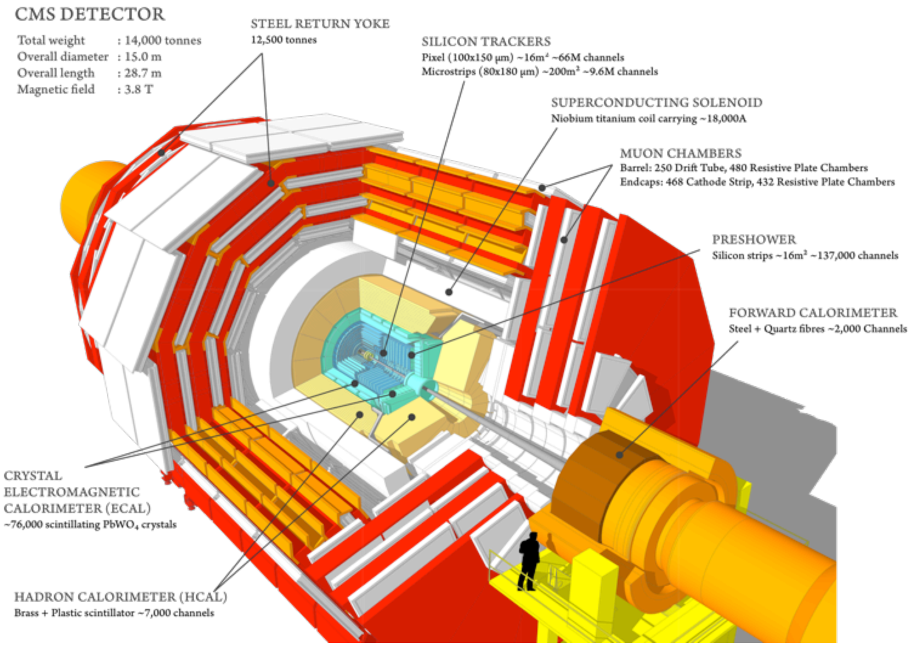


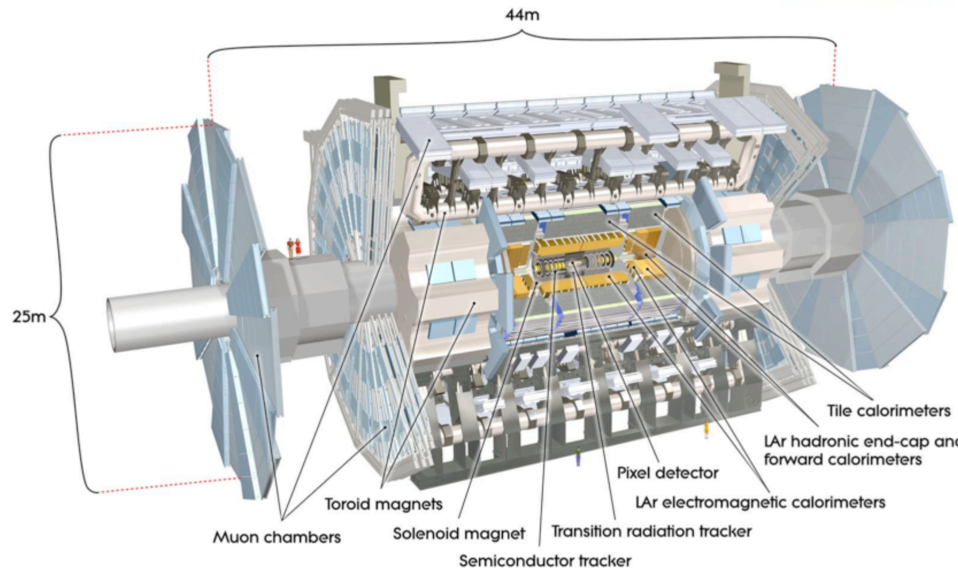
As much data as possible is needed and is used





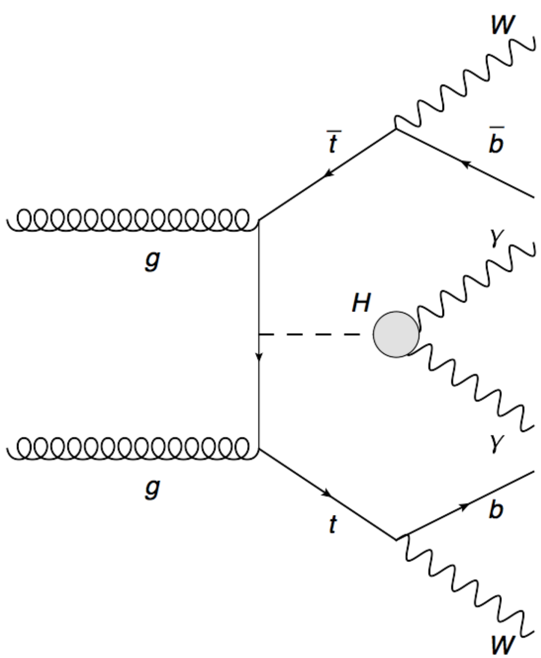
Need well-understood and performing detectors

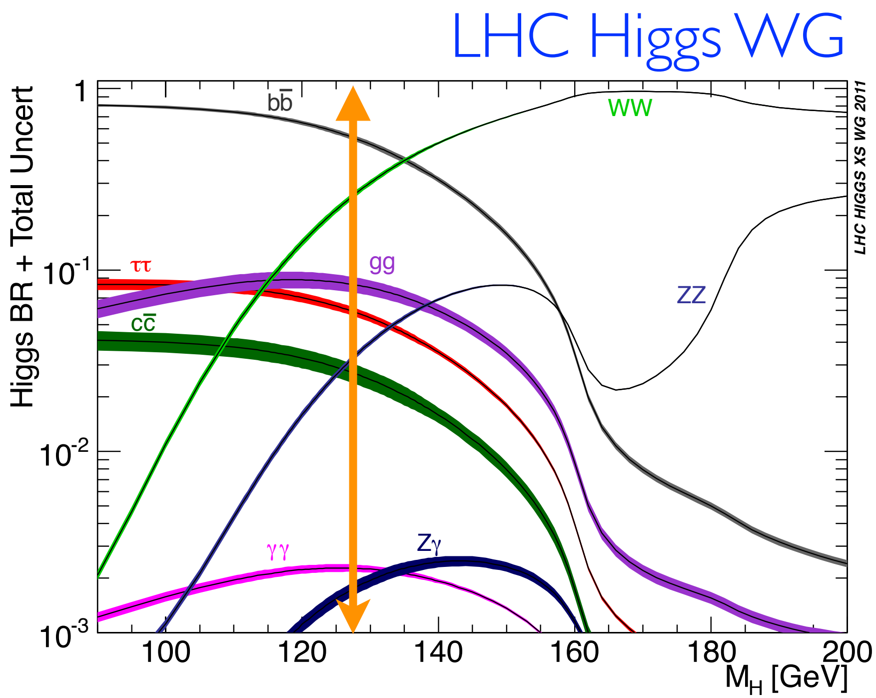




ttH, H→γγ

- Diphoton branching ratio @ 125 GeV = 2.28e-3
  - Low statistics for signal
- Narrow reconstructed Higgs boson mass resolution ~3 GeV
  - Fit the sidebands to estimate backgrounds





H→γγ object selection

	ATLAS (ATLAS-CONF-2013-080)	CMS (CMS PAS HIG-13-015)
	20.3 fb^{-1}	19.6 fb^{-1}
Photon E_T	35/25 GeV at trigger 40/30 GeV offline	26/18 and 36/22 GeV at trigger $0.5/m_{\gamma\gamma}$ / 25 GeV offline
Electron E_T	15 GeV	20 GeV
Muon p_T	10 GeV	20 GeV
Jet p_T	25 GeV	25 GeV
Jet b-tagging	80% efficiency (4% mistag)	70% efficiency (2% mistag)
Leptonic selection	One or more leptons, one or more b-tags, MET > 20 GeV. Reject events with e-photon mass near Z peak	One or more leptons, one or more b-tags, two or more jets
Hadronic selection (orthogonal)	0 leptons, two or more b-tags, six or more jets	0 leptons, one or more b-tags, four or more jets

ATLAS ttH, H→γγ

- Fit invariant mass distribution to exponentials
  - Background normalization from signal region sidebands (not in 120-130 GeV)
  - Slope of exponentials determined from control region sidebands (not in 120-130 GeV)

Sample composition

Channel	N_S	$ggF(\%)$	$VBF(\%)$	$WH(\%)$	$ZH(\%)$	$tH(\%)$	$t\bar{t}H(\%)$
Leptonic	0.55	0.6	0.3	7.7	2.4	6.1	82.8
Hadronic	0.36	5.3	1.1	1.1	1.3	—	91.2

ATLAS ttH, H→γγ systematic uncertainties

Uncertainties (in number of events) in background estimation

	Model choice	Shape difference between SR and CR	Quadratic sum
Leptonic	0.11	0.14	0.18
Hadronic	0.15	0.14	0.20

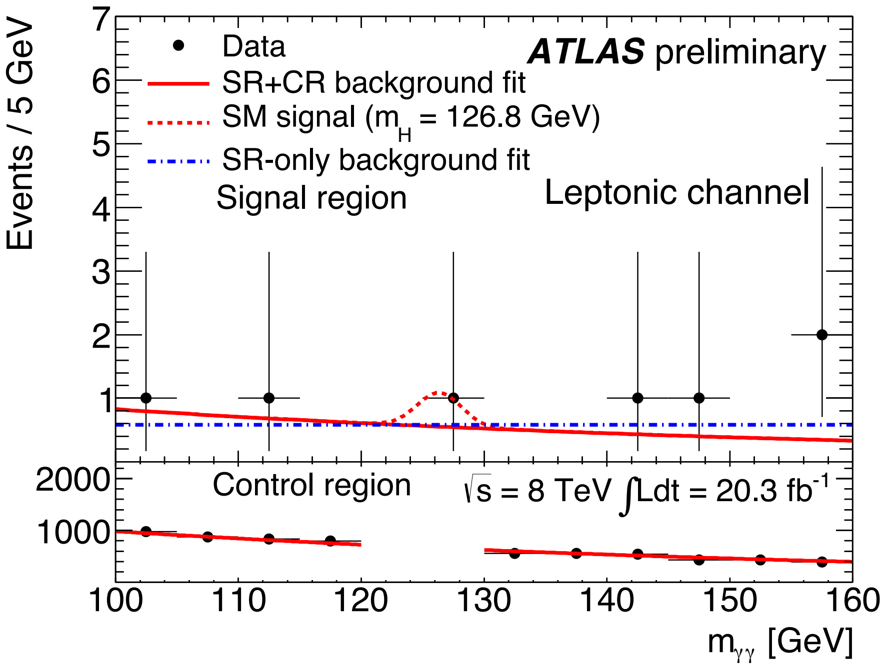
Systematic uncertainties small compared to statistical uncertainties

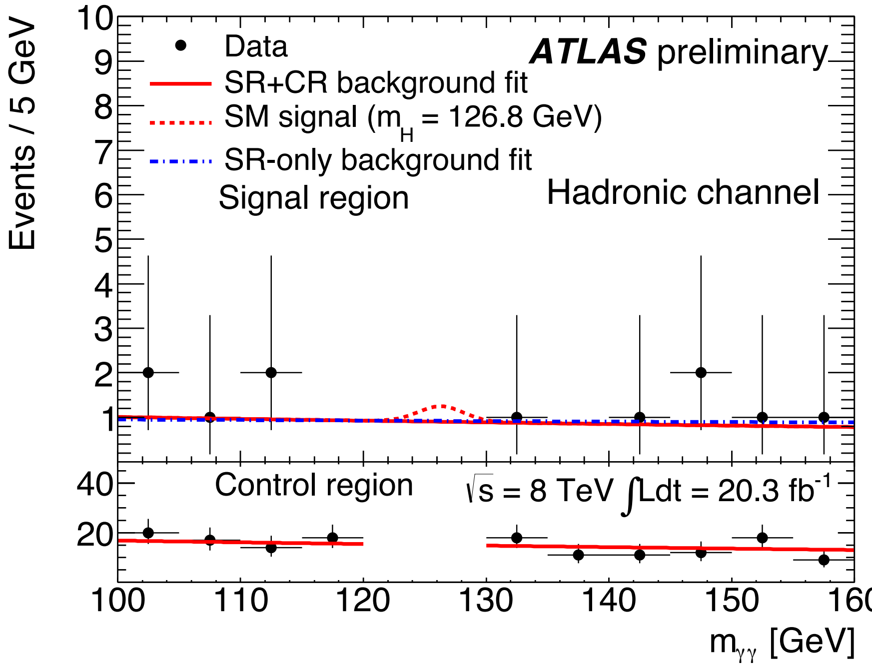
Systematic effect	Systematic uncertainty [%] Leptonic	Systematic uncertainty [%] Hadronic
Luminosity	±2.8	
Cross section	+8.7 / −12.1	
Branching ratio	+5.0 / −4.9	
QCD scale (acceptance only)	±3	±10
Trigger	±0.5	
Photon related	±13	
Electron related	±0.8	< ±0.1
Muon related	±0.2	< ±0.1
Jet energy scale	±0.4	±9.8
Jet energy resolution	±0.2	±3.4
Jet vertex fraction	±0.1	±1.0
b-jet energy scale	±0.2	±0.7
b-tagging	±2.1	±5.5

ATLAS ttH, H→γγ signal region

One event observed in signal region (in leptonic channel)

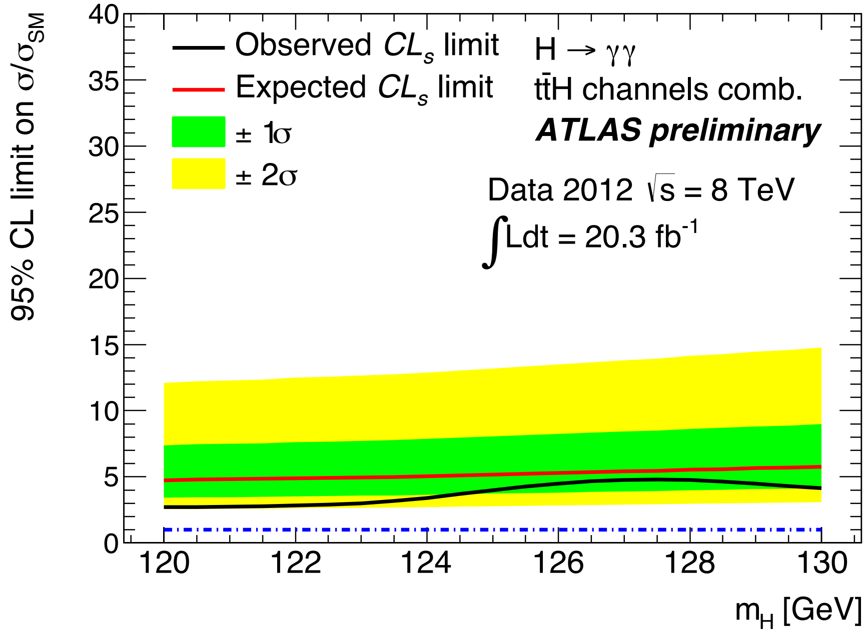
Channel	N_S	N_B	N_S/N_B
Leptonic	0.55	$1.2^{+0.6}_{-0.5}$	0.45
Hadronic	0.36	$1.9^{+0.7}_{-0.5}$	0.19

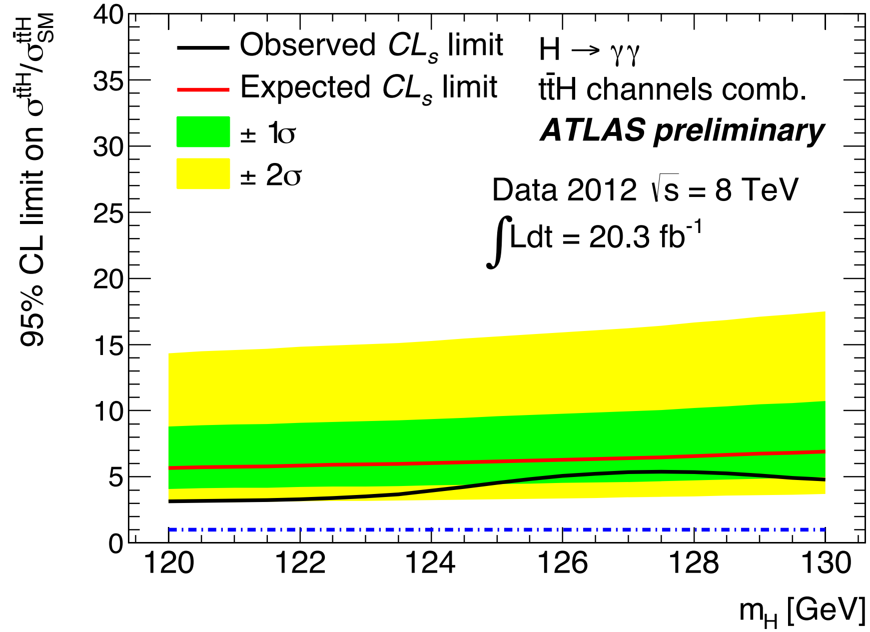




Combined expected (observed) upper limit of 6.4x (5.3x) SM ttH expectation

Combined expected (observed) upper limit of 5.4x (4.7x) the SM Higgs expectation





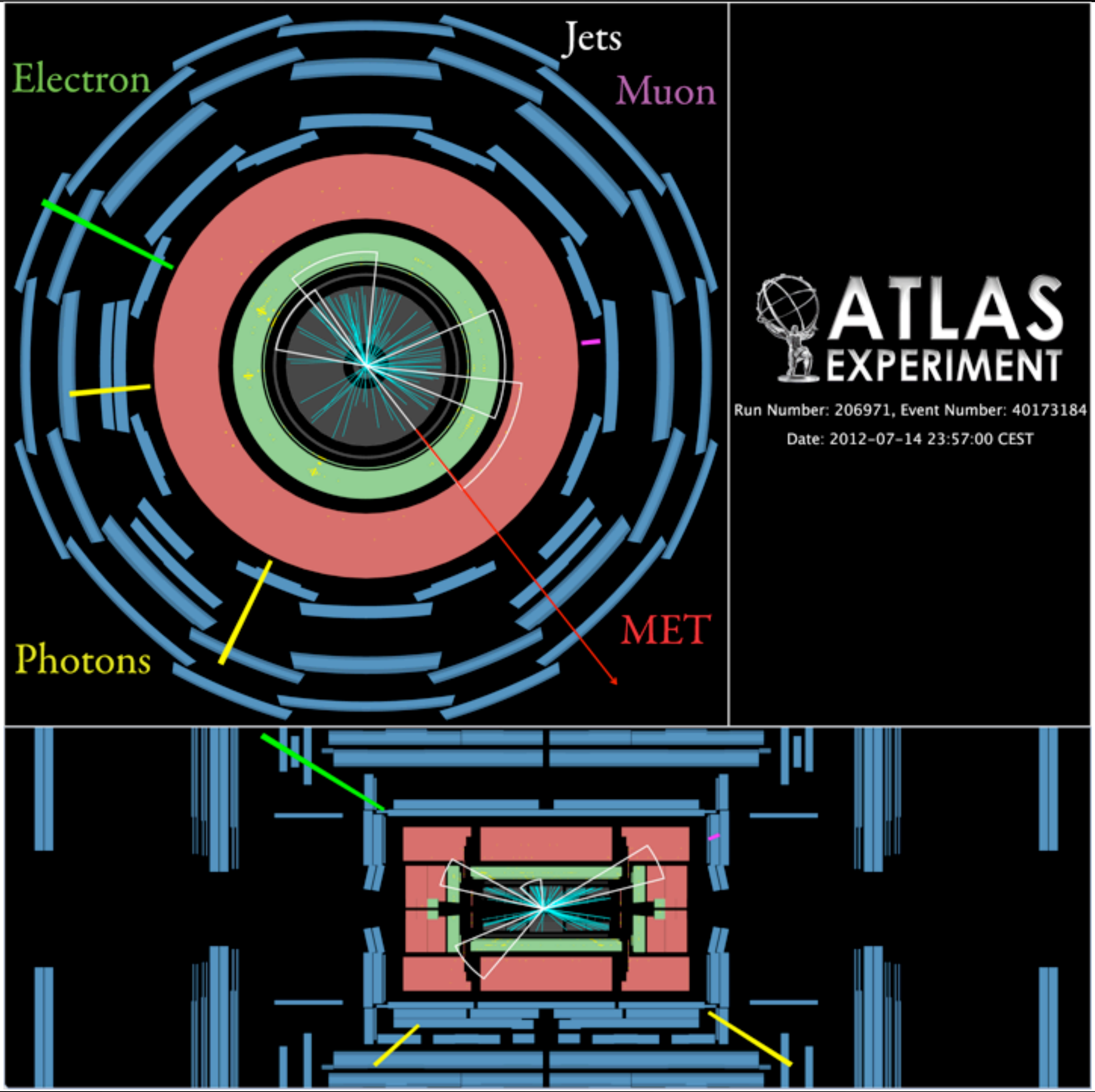
95% CL upper limits on ttH

	Observed limit	Expected limit
Combined (with systematics)	5.3	6.4
Combined (statistics only)	5.0	6.0
Leptonic (with systematics)	9.0	8.4
Leptonic (statistics only)	8.5	8.0
Hadronic (with systematics)	8.4	13.6
Hadronic (statistics only)	7.9	12.6

95% CL upper limits on Higgs production

	Observed limit	Expected limit
Combined (with systematics)	4.7	5.4
Combined (statistics only)	4.4	5.0
Leptonic (with systematics)	7.6	6.9
Leptonic (statistics only)	7.1	6.4
Hadronic (with systematics)	7.7	12.5
Hadronic (statistics only)	7.2	11.4

ATLAS ttH, H→γγ event



CMS ttH, H→γγ

- Select background model by fitting for spurious signal in control samples of events with one photon ID reversed
  - Choose exponential for leptonic channel and second-order polynominal for hadronic channel

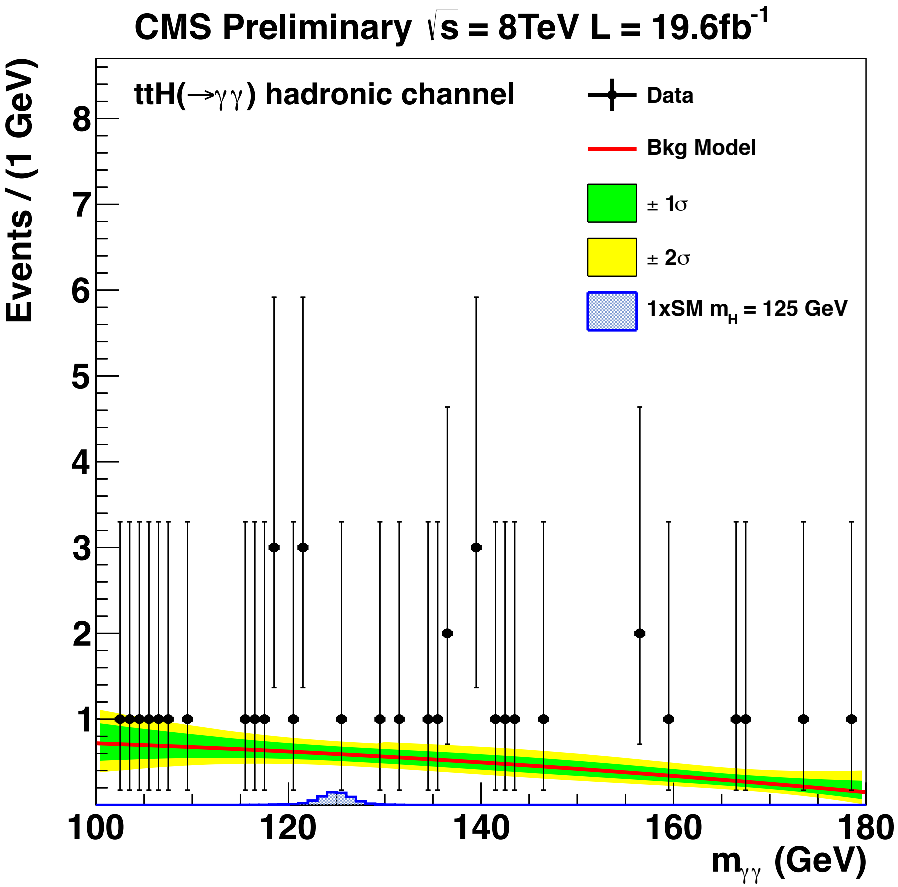
Process	Hadronic Channel	Leptonic Channel
$t\bar{t}H$	0.567 (87%)	0.429 (97%)
$gg \rightarrow H$	0.059 (9%)	0 (0%)
VBF H	0.006 (1%)	0 (0%)
WH/ZH	0.019 (3%)	0.013 (3%)
Total signal	0.65	0.44

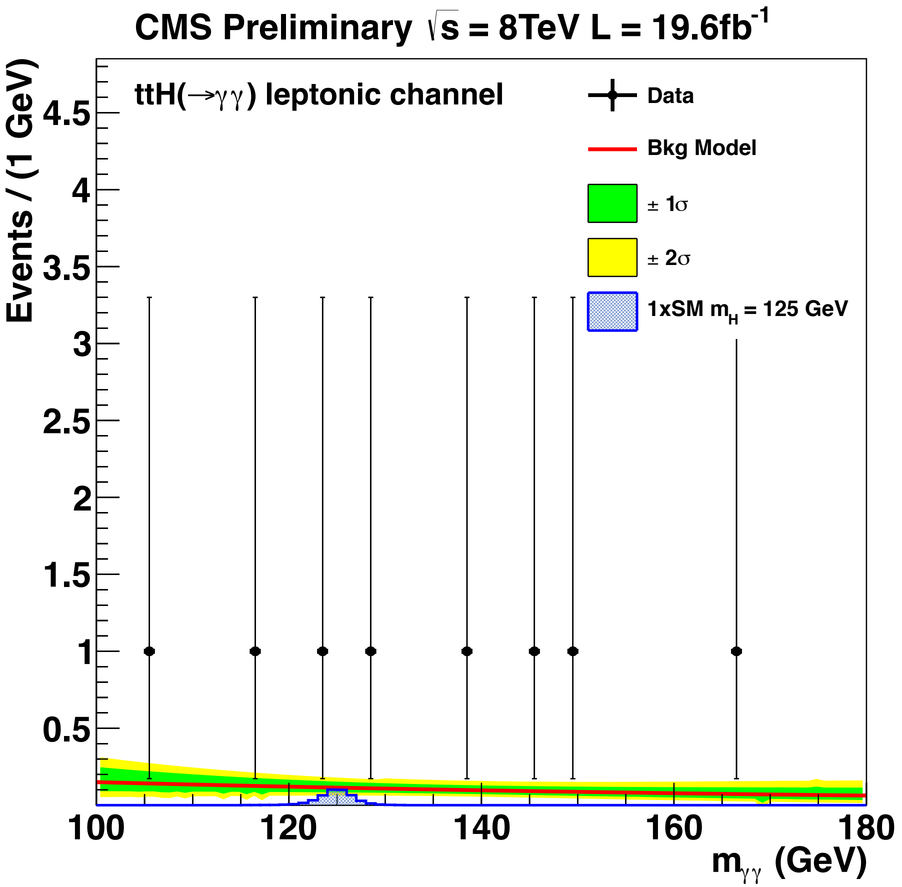
CMS ttH, H→γγ other systematic uncertainties

Overall 6% effect on limits (small)

Source	Hadronic Selection	Leptonic Selection
Luminosity	4.4%	4.4%
Photon reco	3-4%	3-4%
Jet Energy Scale	2% ttH, 5% other H	2% ttH, 5% other H
Jet Energy Resolution	<1% ttH, 1% other H	<1% ttH, 1% other H

CMS ttH, H→γγ results

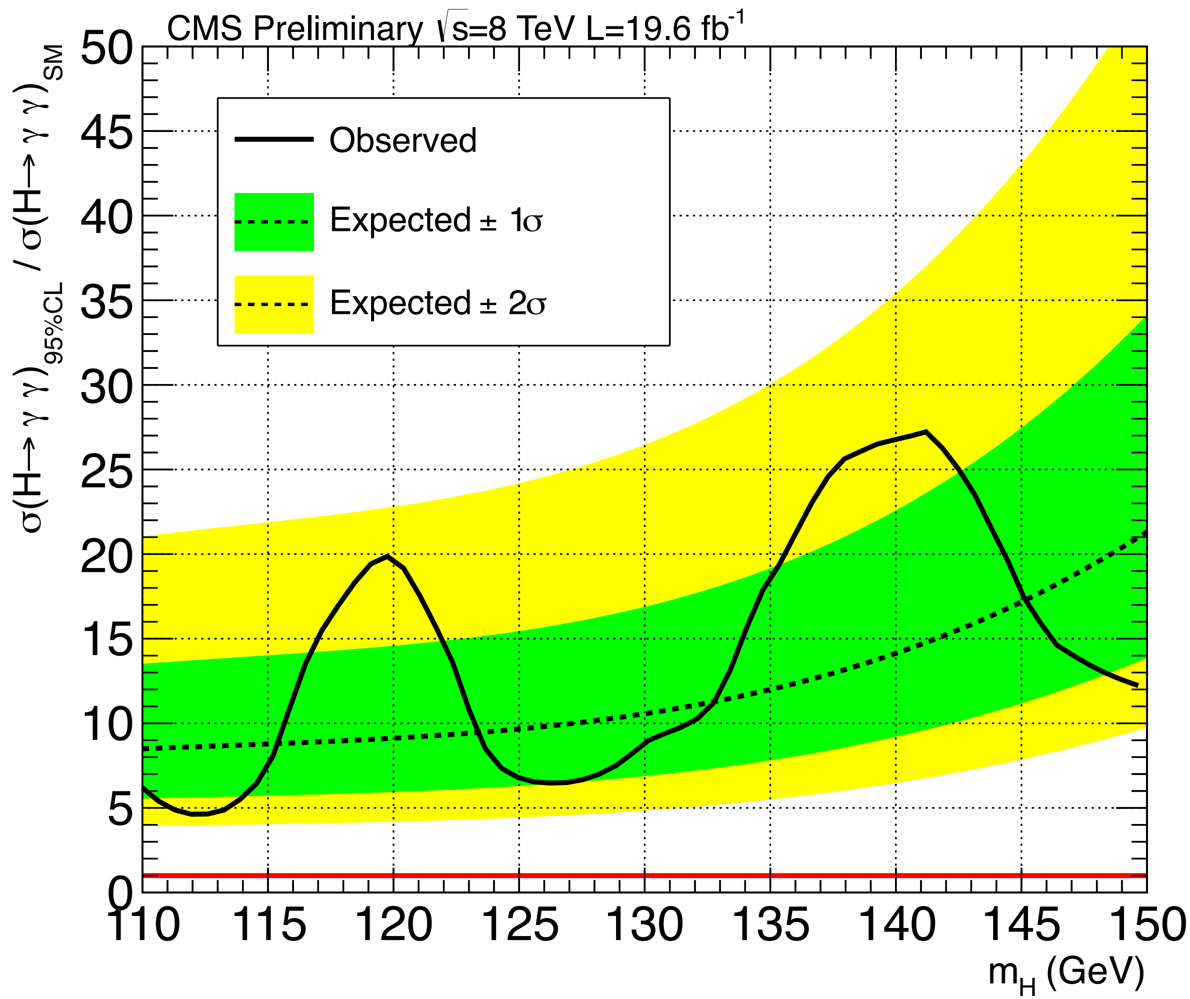




	Observed	Expected	Expected (No Syst.)
Hadronic Channel	6.8	9.2	8.8
Leptonic Channel	10.7	8.0	7.7
Combined	5.4	5.3	5.1

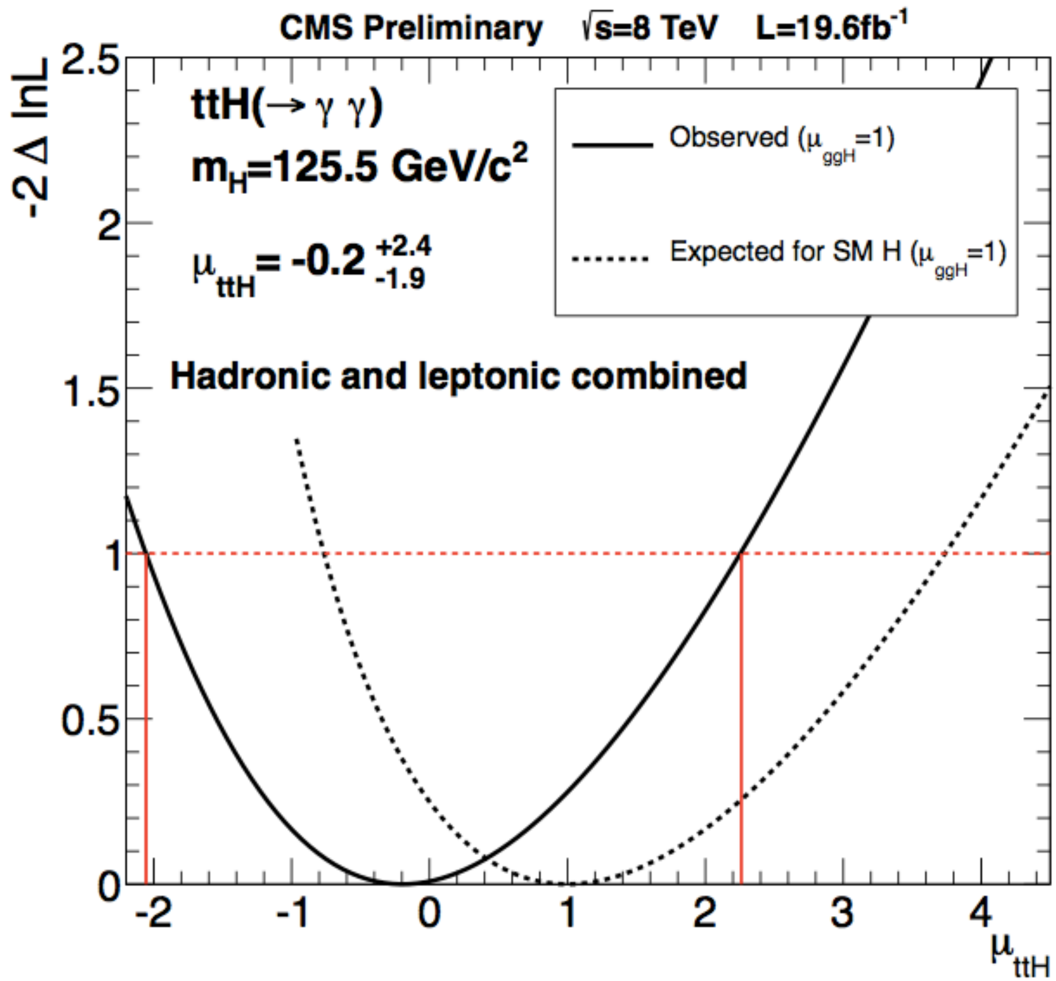
CMS ttH, H→γγ results

Combined expected (observed) upper limit of 5.3x (5.4x) the SM Higgs expectation



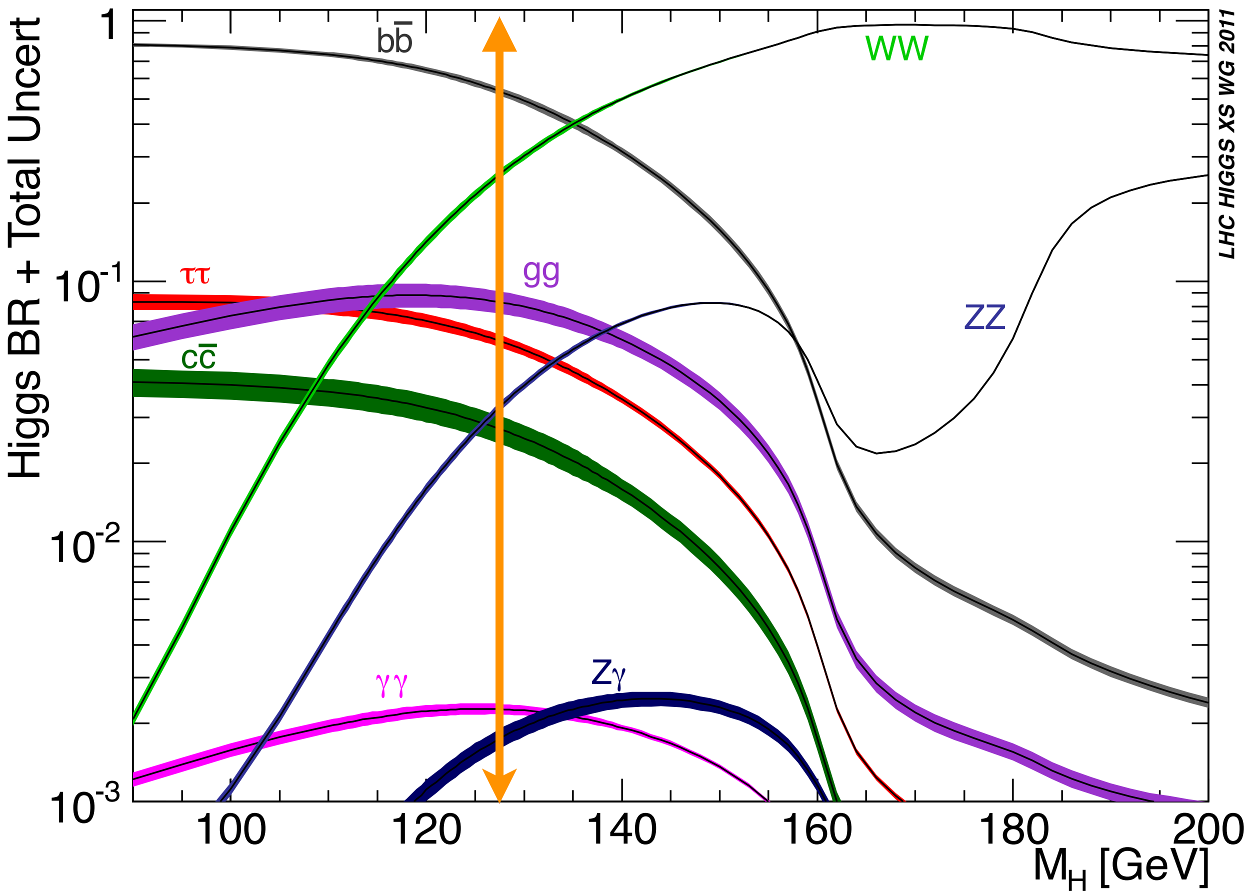
CMS ttH, H→γγ results

Signal strength (ttH) assuming all other production modes fixed to SM values = -0.2+2.4/-1.9



Alternative to narrow Higgs mass resolution

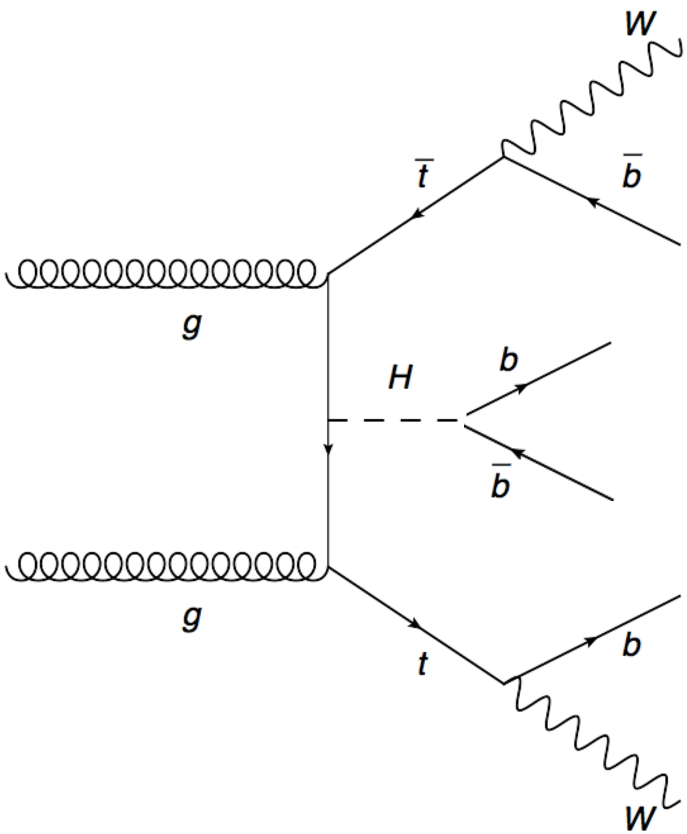
Aim for statistics: 57.7% of Higgs event decay to bb



ttH, H→bb

- Highest statistics, but challenging
  - We know that ttbar reconstruction is difficult to begin with and now we added two additional heavy flavor jets
  - Lots of jets, combinatorics, no narrow signal resonance

- Produced 1500 ttH, H→bb events at each LHC experiment in 2012
  - vs 100,000 ttbb events (with large uncertainty)
  - vs 5 million ttbar events
  - Multivariate techniques helpful

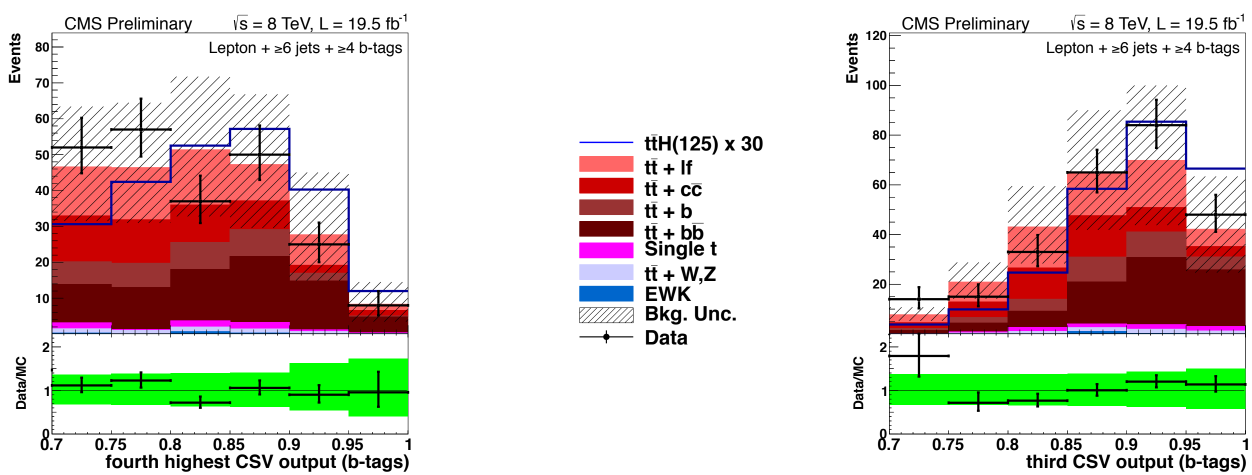


H→bb object selection

	4.7 fb^{-1}	19.5 fb^{-1}
	ATLAS (7 TeV), ATLAS-CONF-2012-135	CMS (8 TeV), CMS PAS HIG-13-019
Triggers	20-22 GeV single electron and 18 GeV single muon	Single lepton 27/24 GeV for e/mu, dilepton 17+8 GeV
Jets	25 GeV, 70% efficiency b-tagging (1% mistag rate)	30 GeV, at least two b-tags (70% efficiency, 2% mistag rate)
L+J selection	Four or more jets, single electron (muon) > 25 (20) GeV Ele: MET > 30 GeV, m_T > 30 GeV Mu: MET > 20 GeV, m_T+MET > 60 GeV	Four or more jets (3 with pt > 40 GeV), one 30 GeV lepton
DIL selection	-----	Two OS leptons, at least one lepton > 20 GeV, second lepton > 10 GeV

CMS ttH, H→bb analysis strategy

- Separate events into distinct categories
  - L+J: 4 jets + 3/4 b-tags, 5 jets + 3/4 b-tags, 6 jets + 2/3/4 b-tags
  - DIL: 3 jets + 2 b-tags, 4 jets + 2 b-tags, 3-jets + 3 b-tags
- Boosted decision tree trained separately for each category
  - 6j3b (jet closest to tag is promoted to b), 6j4b, 5j4b (loose 6th jet added) use an additional BDT (to separate ttbb from ttH) as input, including kinematic fit to ttbar hypothesis
- Use continuous b-tagging discriminant (not just cuts)
  - Scale factors for mistags from Z+2 jet events
  - Scale factors for heavy flavor from 2j2b DIL ttbar events



CMS ttH, H→bb

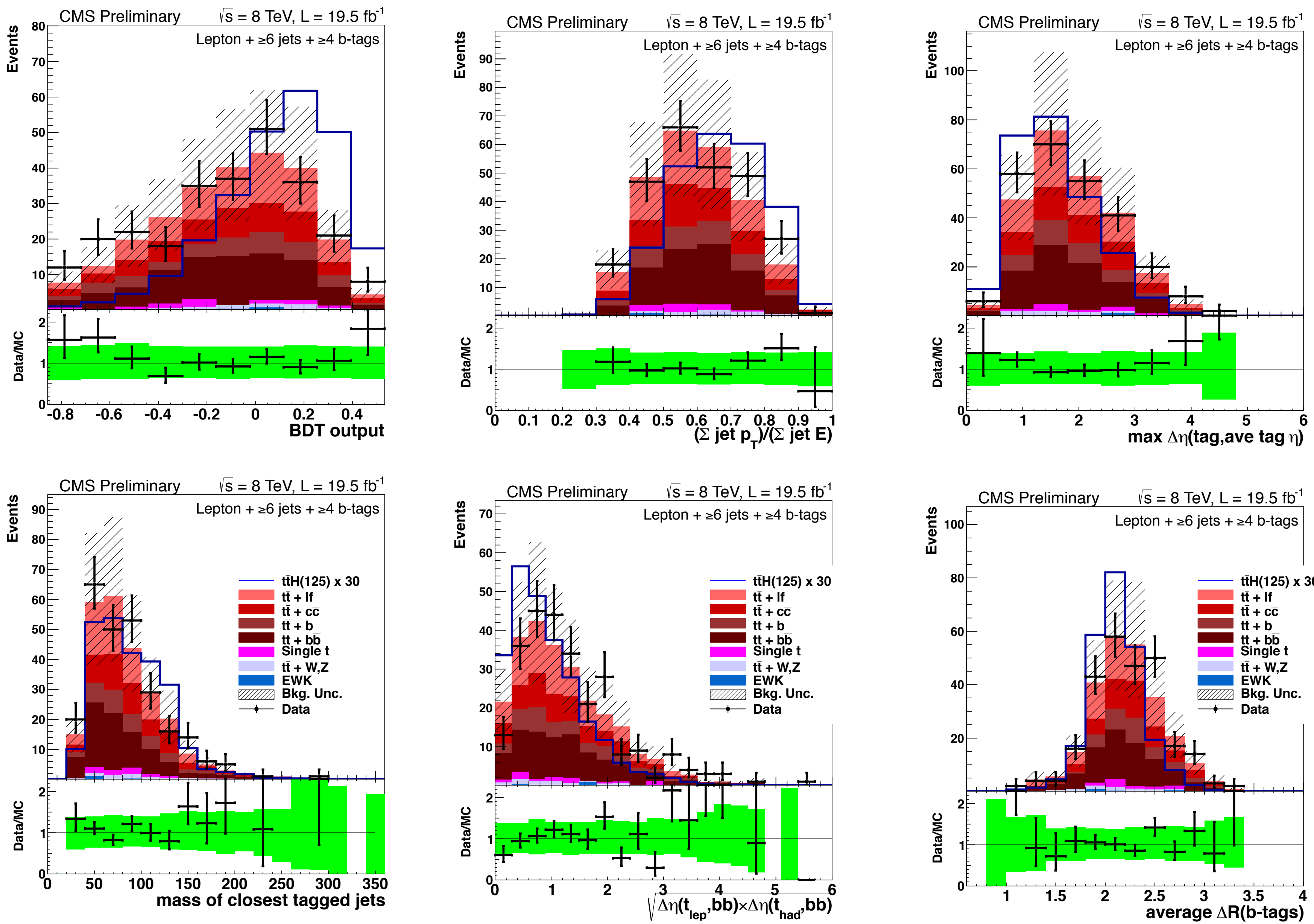
	3 jets + 2 b-tags	≥4 jets + 2 b-tags	≥3 b-tags
$t\bar{t}H(125)$	7.7 ± 1.4	16.1 ± 3.1	11.2 ± 2.5
$t\bar{t}$+lf	7460 ± 1060	3190 ± 680	289 ± 83
$t\bar{t}$+b	189 ± 97	172 ± 93	149 ± 82
$t\bar{t} + b\bar{b}$	38 ± 20	58 ± 31	80 ± 44
$t\bar{t} + c\bar{c}$	480 ± 260	510 ± 300	147 ± 79
$t\bar{t}V$	30.2 ± 6.3	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

Table 2: Expected event yields in 19.5 fb^{-1} for signal and backgrounds in the dilepton channel.

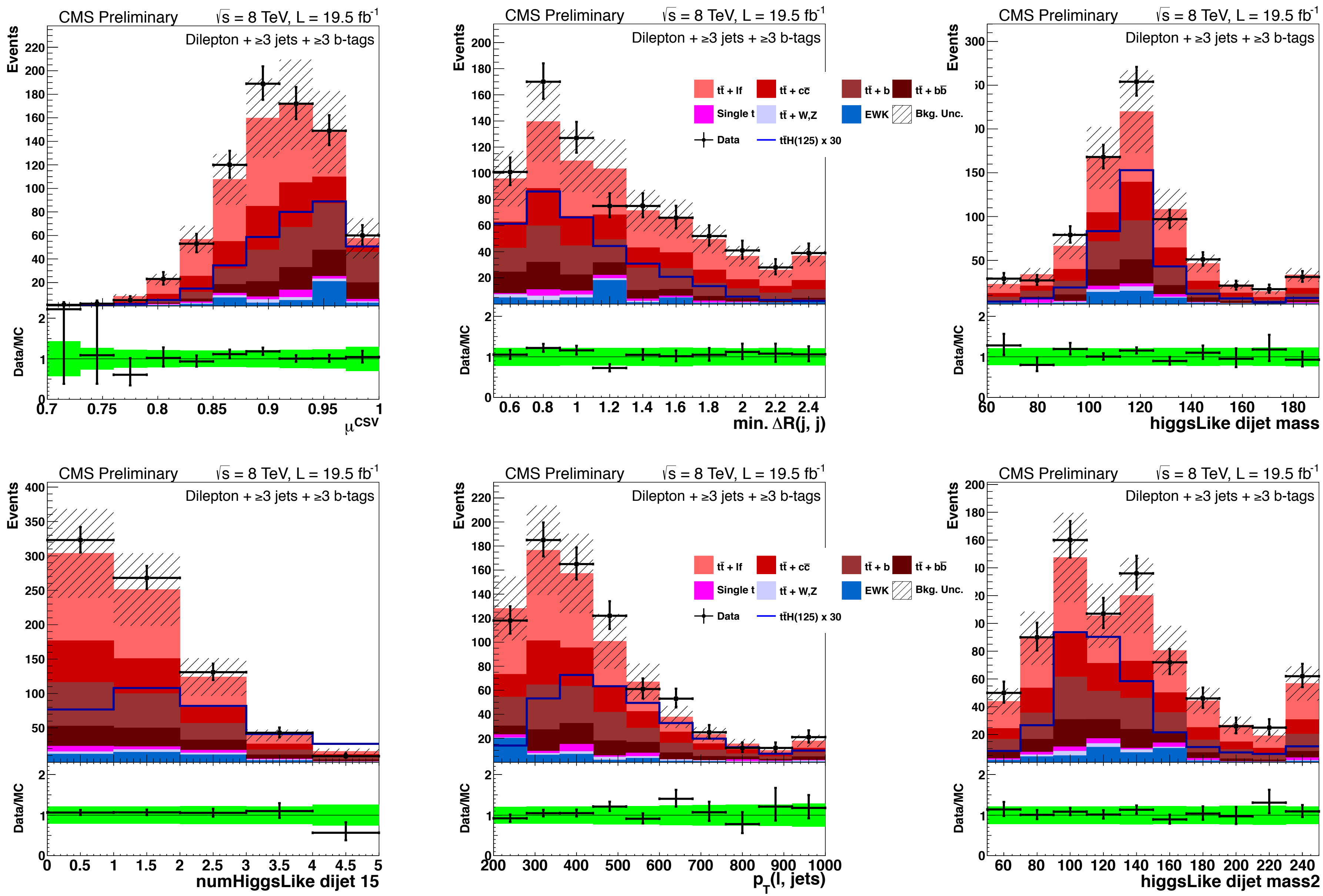
	≥6 jets 2 b-tags	4 jets 3 b-tags	5 jets 3 b-tags	≥6 jets 3 b-tags	4 jets 4 b-tags	5 jets ≥4 b-tags	≥6 jets ≥4 b-tags
$t\bar{t}H(125)$	33.4 ± 8.1	14.0 ± 3.0	21.1 ± 4.5	23.1 ± 5.5	1.8 ± 0.5	5.2 ± 1.4	8.3 ± 2.3
$t\bar{t}$+lf	7650 ± 2000	4710 ± 820	2610 ± 530	1260 ± 340	74 ± 30	79 ± 34	71 ± 36
$t\bar{t}$+b	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

Table 1: Expected event yields in 19.5 fb^{-1} for signal and backgrounds in the lepton + jets channel.

CMS ttH, H→bb BDT input (L+J)



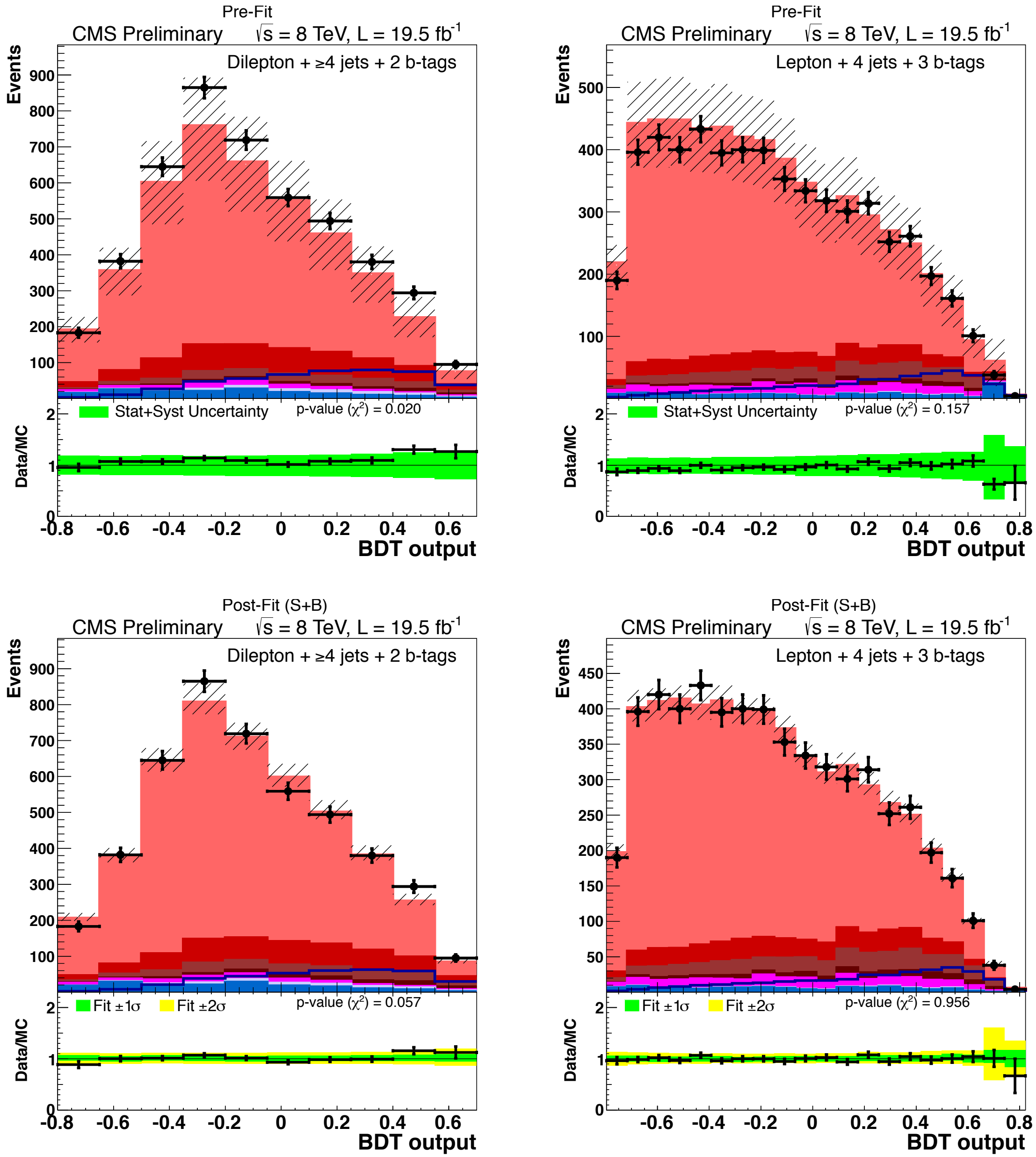
CMS ttH, H→bb BDT input (DIL)



Variation of tt+HF more than 6x the signal

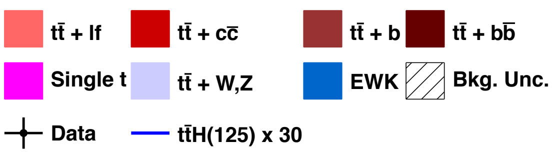
Uncertainties of the sum of $t\bar{t}$+lf, $t\bar{t}$+b, $t\bar{t}+b\bar{b}$, and $t\bar{t}+c\bar{c}$ events with ≥ 6 jets and ≥ 4 b-tags		
Source	Rate	Shape?
QCD Scale (all $t\bar{t}$+hf)	35%	No
QCD Scale ($t\bar{t}+b\bar{b}$)	17%	No
b-Tag bottom-flavor contamination	17%	Yes
QCD Scale ($t\bar{t}+c\bar{c}$)	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

CMS ttH, H→bb importance of profiling

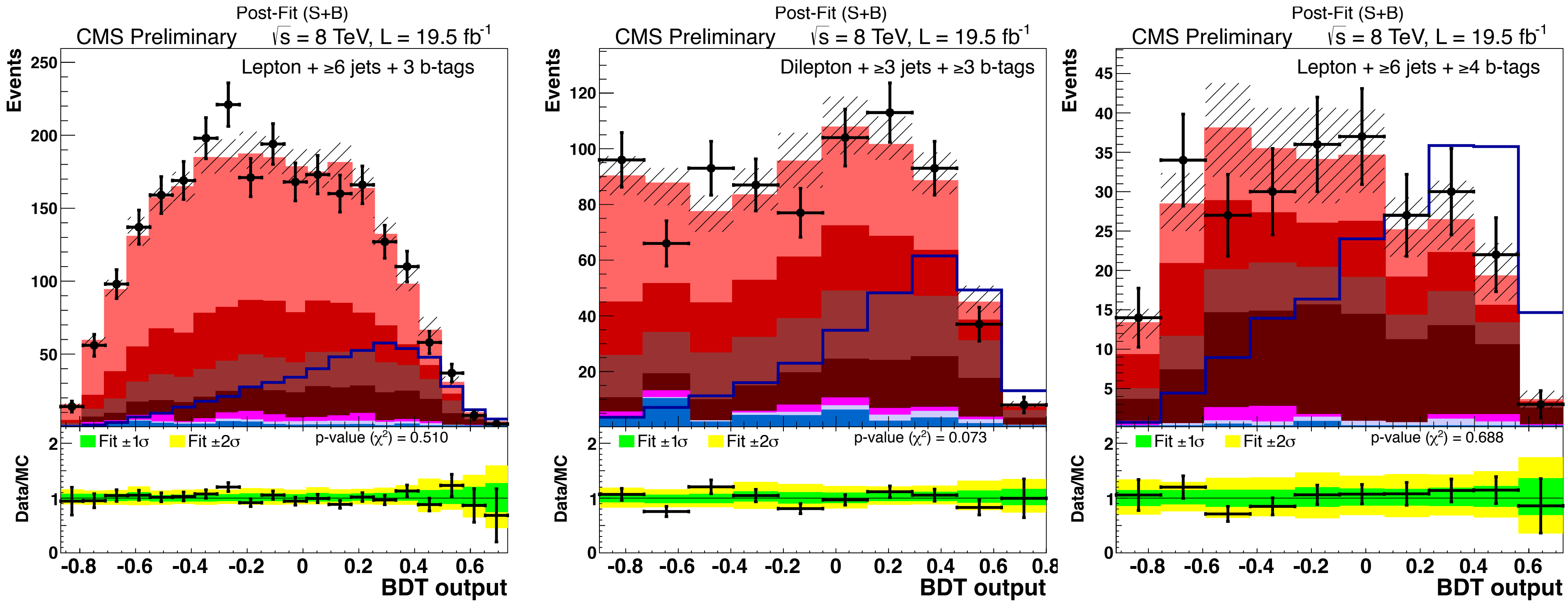


Pre-fit plots

Post-fit plots



Post-fit BDT plots after profiling of systematic uncertainties



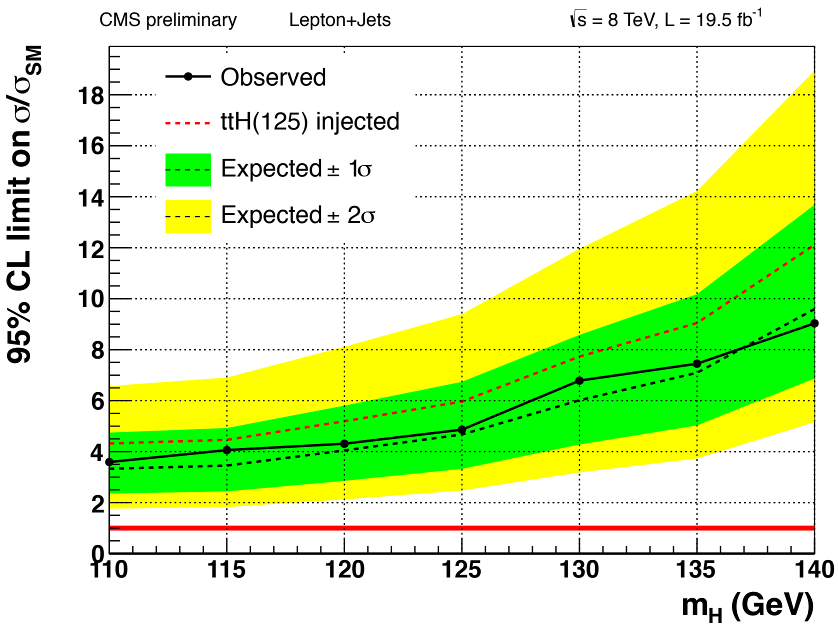
CMS ttH, H→bb results

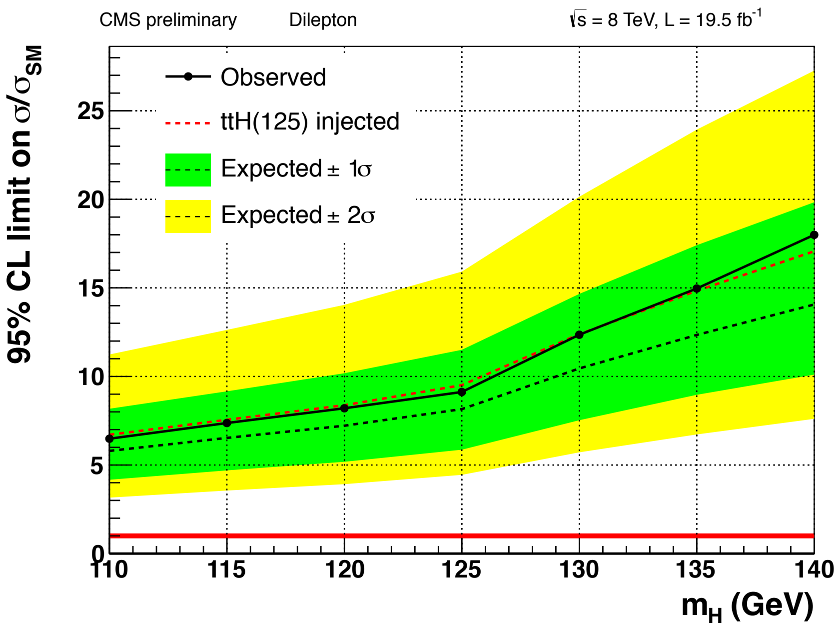
95% CL upper limits on Higgs production (lepton+jets)

Higgs Mass	Observed	Expected Median
110 GeV	3.6	3.3
115 GeV	4.1	3.5
120 GeV	4.3	4.0
125 GeV	4.9	4.7
130 GeV	6.8	6.0
135 GeV	7.4	7.1
140 GeV	9.0	9.6

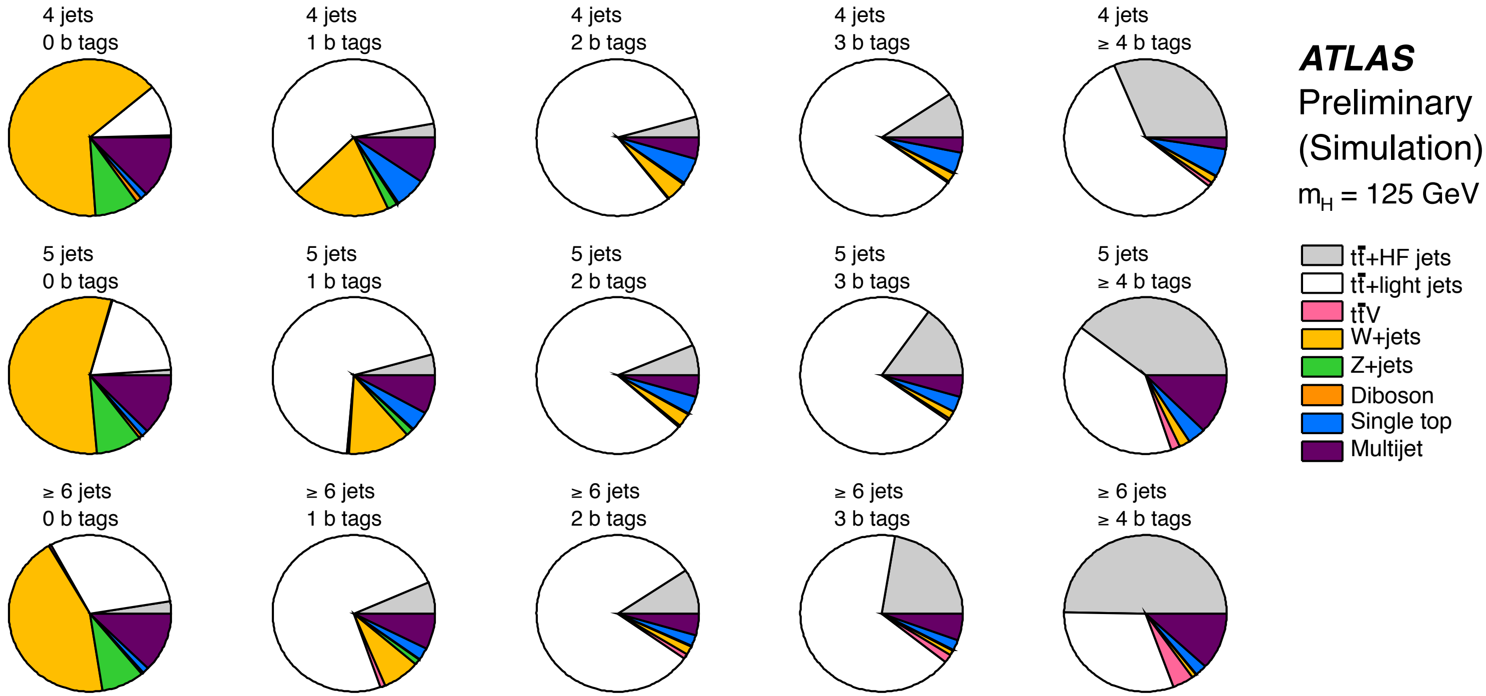
95% CL upper limits on Higgs production (dilepton)

Higgs Mass	Observed	Expected Median
110 GeV	6.5	5.8
115 GeV	7.4	6.5
120 GeV	8.2	7.2
125 GeV	9.1	8.2
130 GeV	12.4	10.5
135 GeV	15.0	12.3
140 GeV	18.0	14.1



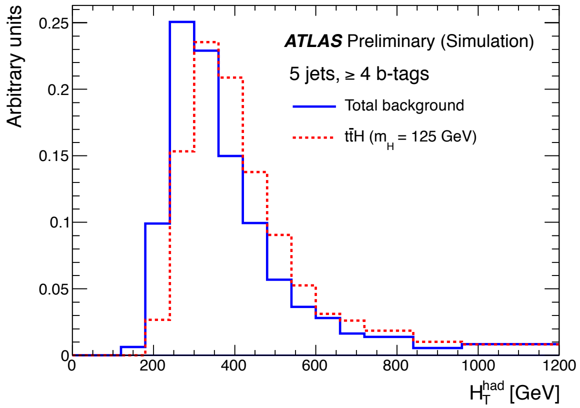


ATLAS ttH, H→bb

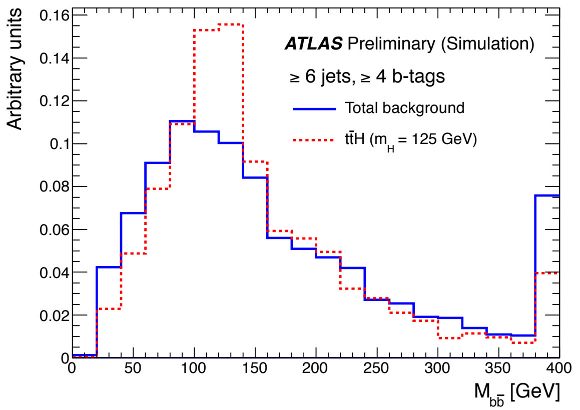


- Divide events based on njet and ntag
- Events with < 6 jets: Use H_T^{had} as single discriminating variable
- Events with ≥ 6 jets: Kinematic likelihood fit to ttH system with m_{bb} as variable of interest

ATLAS ttH, H→bb



	4 jets, 0 b tags	4 jets, 1 b tags	4 jets, ≥ 2 b tags	5 jets, 2 b tags	5 jets, 3 b tags
$t\bar{t}H(125)$	0.20 ± 0.03	1.1 ± 0.1	3.0 ± 0.2	2.7 ± 0.2	2.3 ± 0.1
$t\bar{t}$+ jets	3440 ± 230	12600 ± 400	13040 ± 160	5900 ± 100	837 ± 24
W+jets	28350 ± 1000	5100 ± 470	655 ± 100	210 ± 50	16 ± 4
Z+jets	3700 ± 600	480 ± 70	33 ± 6	16 ± 4	1.1 ± 0.3
Single top	500 ± 30	1380 ± 70	820 ± 40	266 ± 15	31 ± 2
Diboson	411 ± 50	85 ± 10	15 ± 2	3.1 ± 0.4	0.26 ± 0.05
$t\bar{t}V$	12 ± 3	35 ± 9	30 ± 8	32 ± 9	6 ± 2
Multijet	3800 ± 700	1560 ± 280	460 ± 90	210 ± 50	23 ± 10
Total bkg.	40200 ± 280	21240 ± 200	15040 ± 150	6640 ± 80	915 ± 24
Data	40209	21248	15066	6653	878



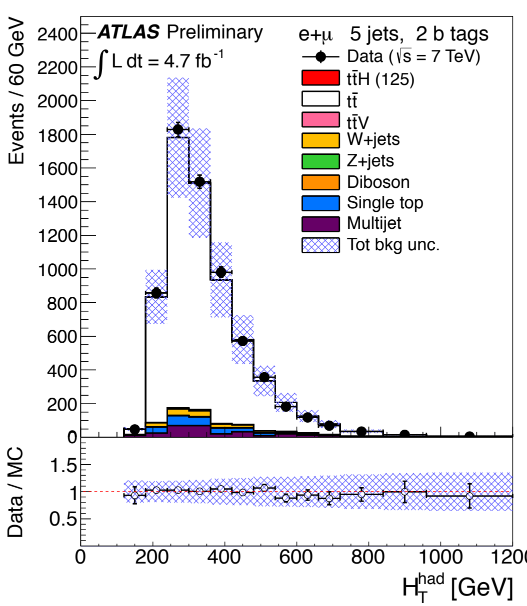
	5 jets, ≥ 4 b tags	≥ 6 jets, 2 b tags	≥ 6 jets, 3 b tags	≥ 6 jets, ≥ 4 b tags
$t\bar{t}H(125)$	0.74 ± 0.04	3.4 ± 0.2	4.0 ± 0.2	2.2 ± 0.1
$t\bar{t}$+ jets	38 ± 3	3030 ± 90	560 ± 20	54 ± 5
W+jets	1.1 ± 0.4	74 ± 20	8 ± 3	0.7 ± 0.3
Z+jets	0.03 ± 0.01	6 ± 2	0.4 ± 0.2	0.01 ± 0.01
Single top	1.6 ± 0.2	92 ± 7	15 ± 1	1.5 ± 0.2
Diboson	0.01 ± 0.01	0.7 ± 0.1	0.09 ± 0.03	0.01 ± 0.01
$t\bar{t}V$	0.8 ± 0.2	45 ± 10	13 ± 4	2.7 ± 0.7
Multijet	3 ± 2	114 ± 30	34 ± 10	4 ± 3
Total bkg.	45 ± 3	3360 ± 80	634 ± 19	62 ± 5
Data	41	3340	676	65

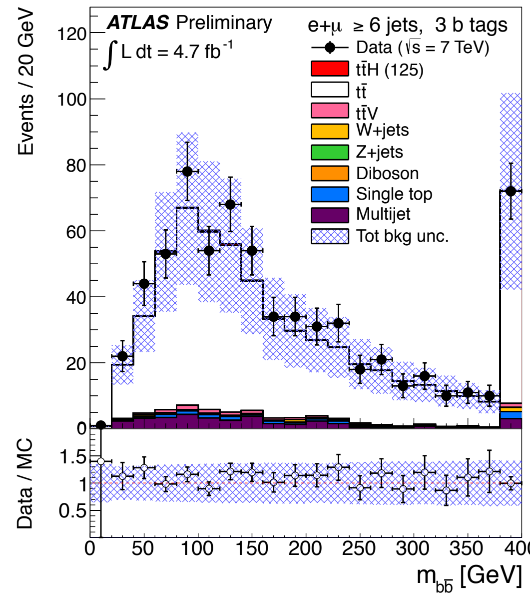
ATLAS ttH, H→bb systematic uncertainties

HF fraction, JES and tagging uncertainties dominate

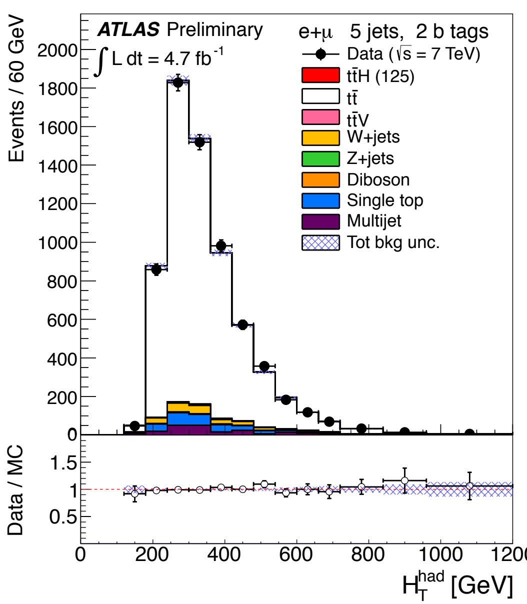
Systematic uncertainty	Status	Components
Luminosity	N	1
Lepton ID+reco+trigger	N	1
Jet vertex fraction efficiency	N	1
Jet energy scale	SN	16
Jet energy resolution	N	1
b-tagging efficiency	SN	9
c-tagging efficiency	SN	5
Light jet-tagging efficiency	SN	1
$t\bar{t}$ cross section	N	1
$t\bar{t}V$ cross section	N	1
Single top cross section	N	1
Dibosons cross section	N	1
V+jets normalisation	N	3
Multijet normalisation	N	7
W+heavy-flavour fractions	SN	4
$t\bar{t}$ modelling	SN	3
$t\bar{t}$+heavy-flavour fractions	SN	1
$t\bar{t}H$ modelling	N	1

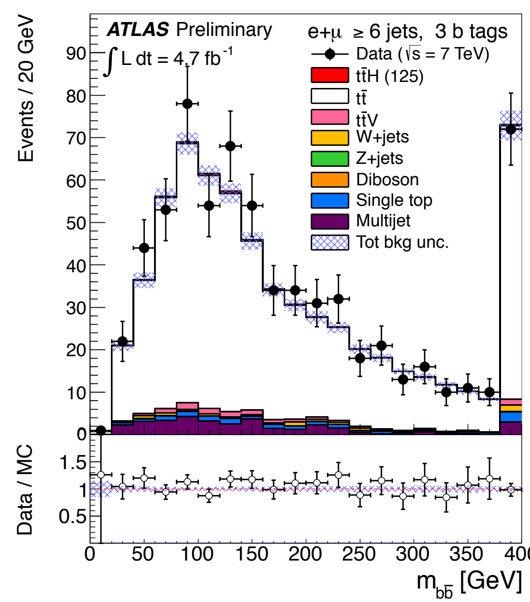
ATLAS ttH, H→bb profiling importance





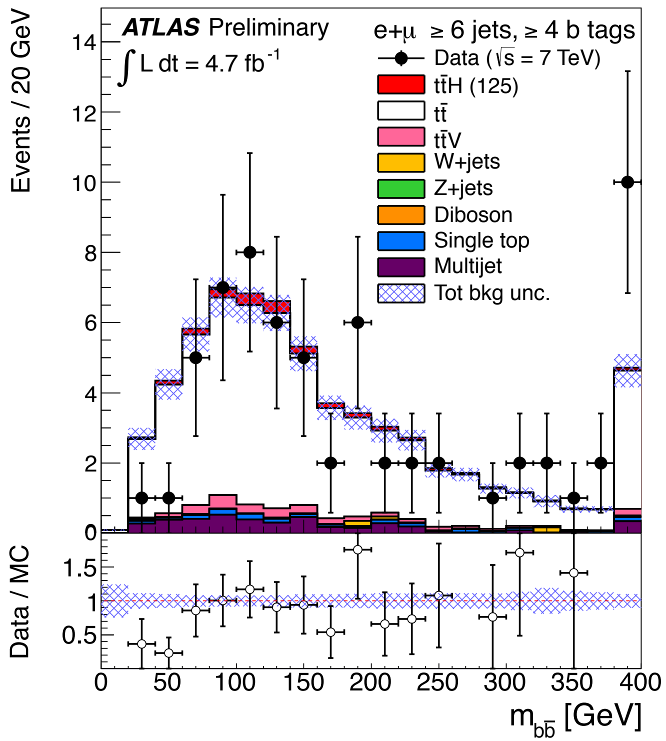
Pre-fit plots

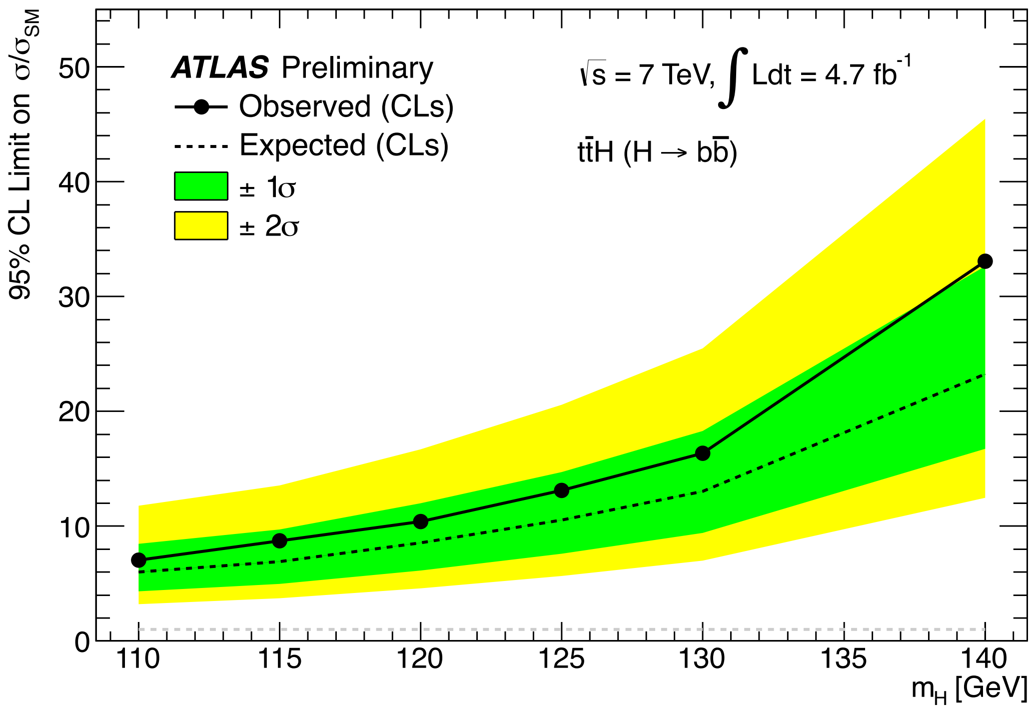




Post-fit plots

ATLAS ttH, H→bb results

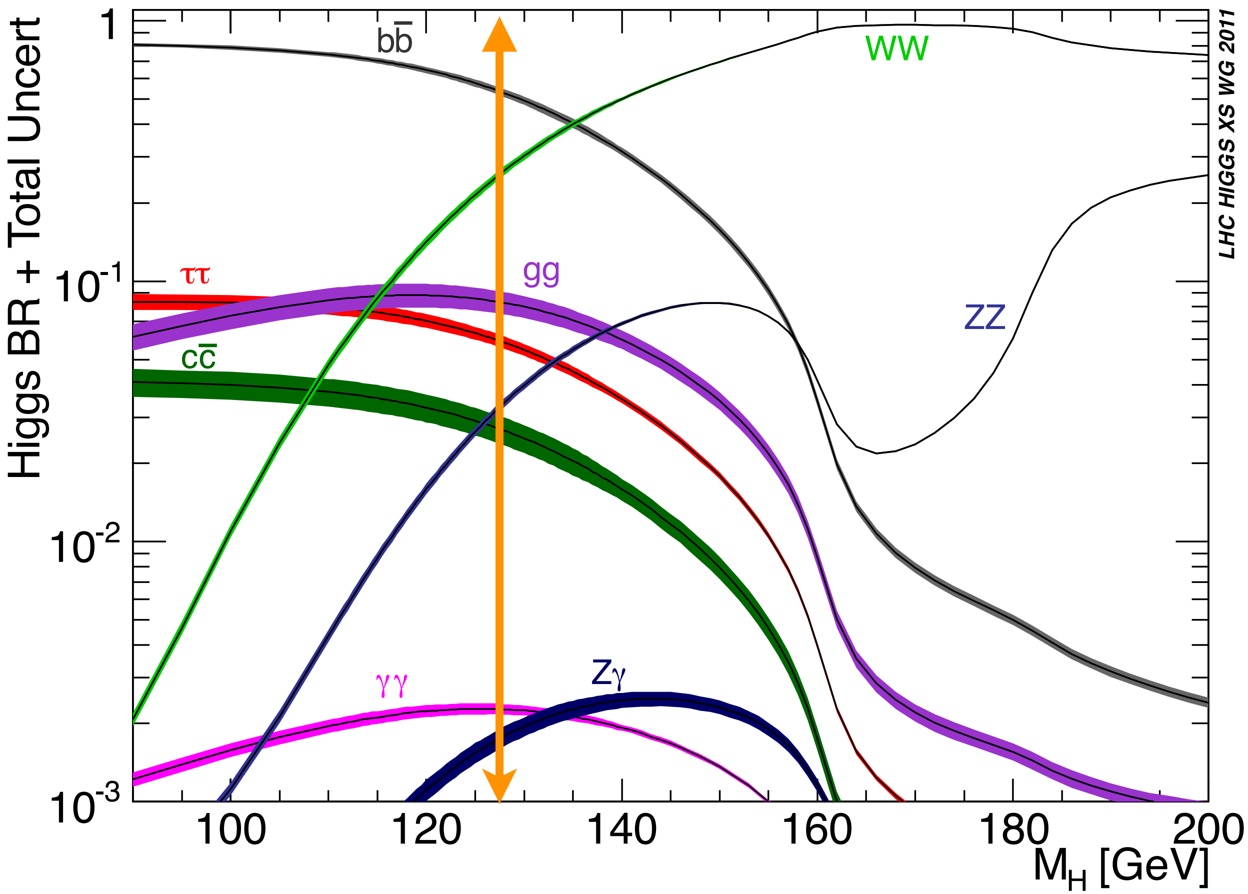




m_H (GeV)	observed	-2 s.d.	-1 s.d.	median	+1 s.d.	+2 s.d.	stat only
110	7.0	3.2	4.3	6.0	8.5	11.8	3.5
115	8.7	3.7	5.0	6.9	9.7	13.6	4.0
120	10.4	4.6	6.2	8.5	12.0	16.7	4.9
125	13.1	5.7	7.6	10.5	14.7	20.6	6.1
130	16.4	7.0	9.4	13.0	18.3	25.5	7.8
140	33.0	12.5	16.7	23.2	32.7	45.5	14.2

Other channels?

6.32% of decays to ditau

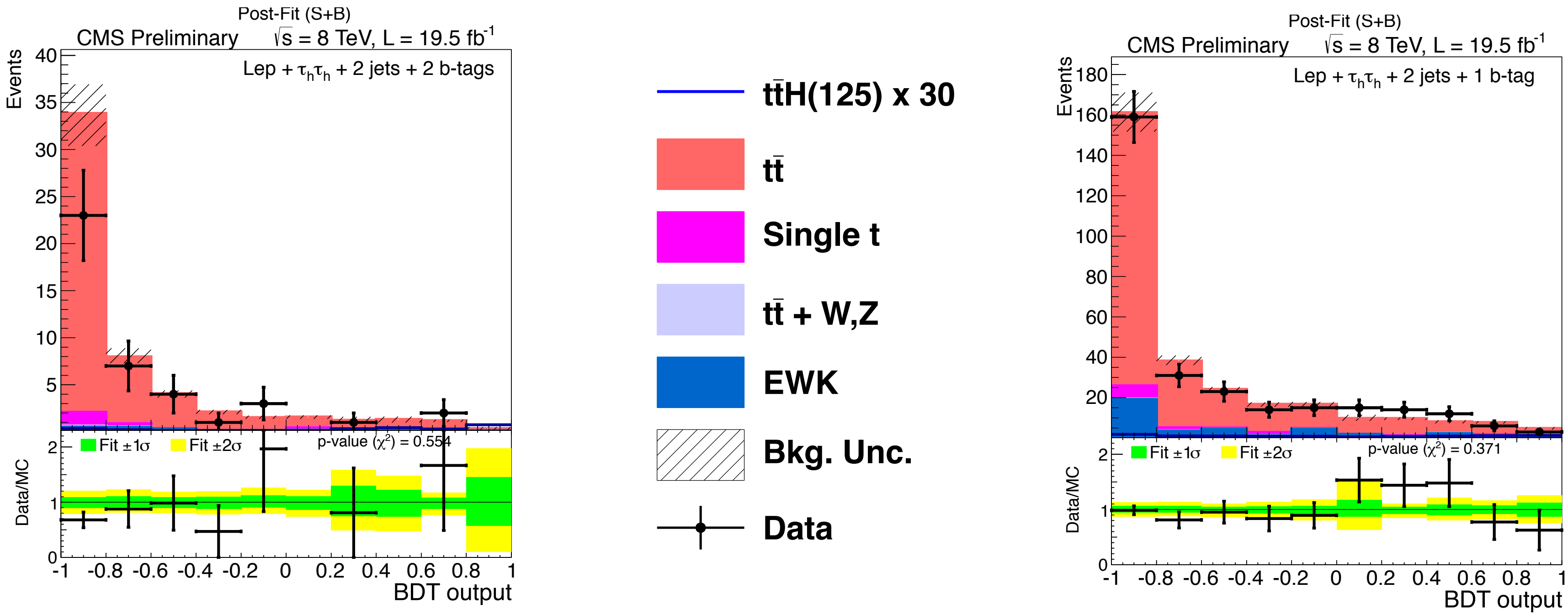


CMS ttH, H→$\tau\tau$

CMS PAS HIG-13-019, 19.5 fb^{-1}

- Start with same single lepton triggers and lepton selection as bb single lepton analysis
- Jet p_T > 30 GeV, $|\eta| < 2.4$, 2 or more jets
- Two OS hadronic one-prong tau jets > 20 GeV, $|\eta| < 2.1$ with p_T of pion > 5GeV
- Divide by 2, 3 or ≥ 4 jets and 1 vs 2 b-tags
- Uncertainty on tau fake rates from jets (electrons) of 20% (5%) per object
- BDT to separate signal and background

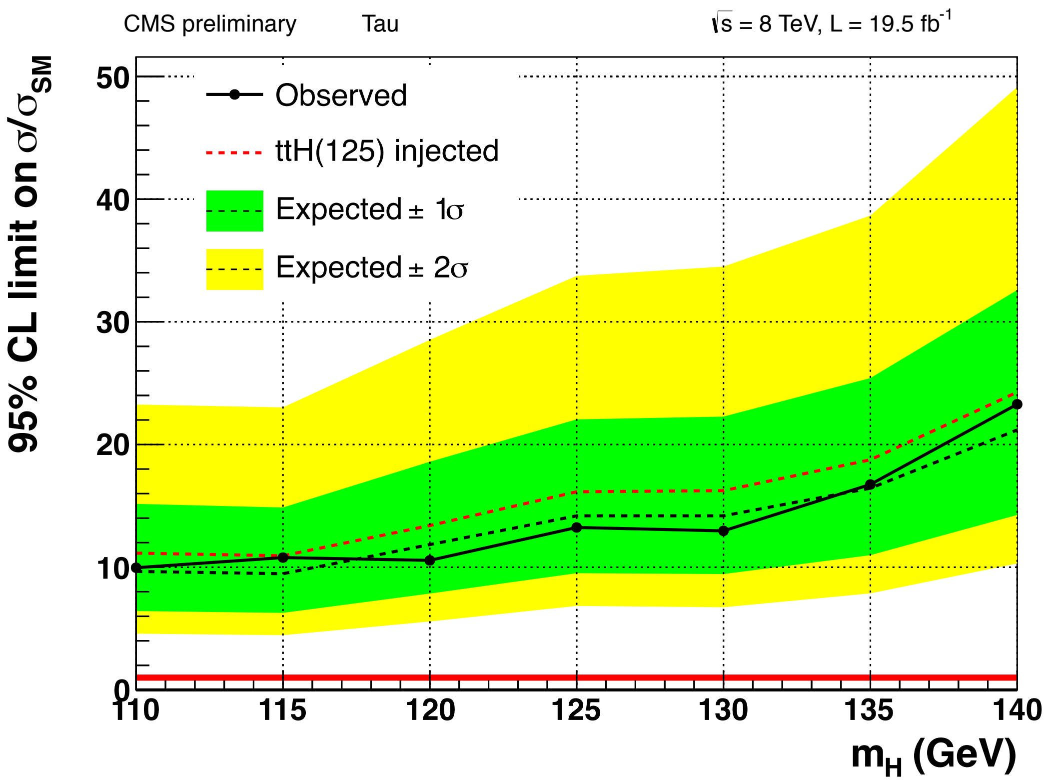
CMS ttH, H→$\tau\tau$



	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
tt̄H(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
tt̄	225 ± 69	119 ± 38	64 ± 22	48 ± 15	38 ± 12	27.0 ± 9.1
tt̄V	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

CMS ttH, $H \to \tau\tau$ results

Higgs Mass	Observed	Expected Median
110 GeV	10.0	9.7
115 GeV	10.8	9.5
120 GeV	10.6	11.8
125 GeV	13.2	14.2
130 GeV	13.0	14.2
135 GeV	16.7	16.4
140 GeV	23.3	21.2



With such complex analyses...

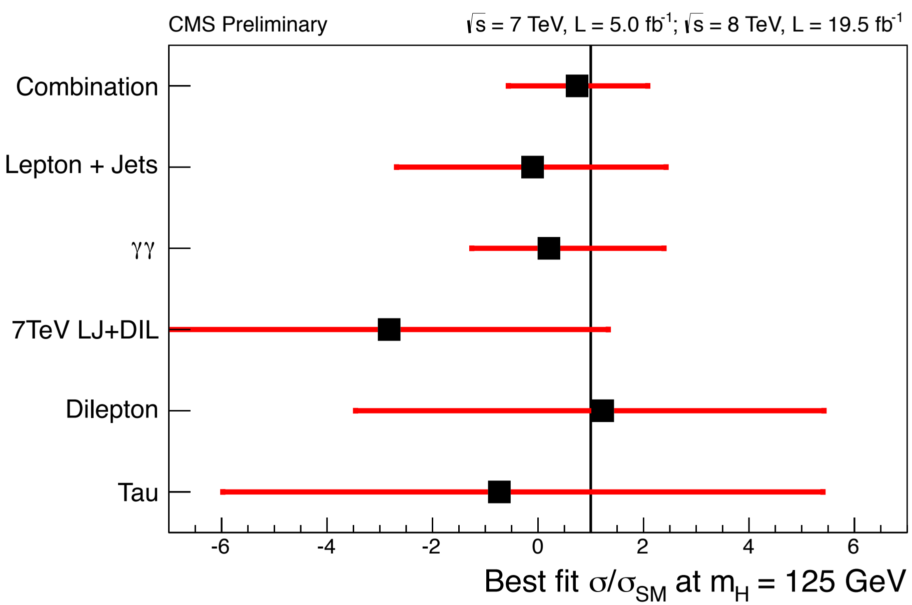
- Obvious need to attack from as many angles as possible
  - ttbar+jets and ttbar+HF will continue to be challenging at new energies and luminosities
- WW is on the way from both collaborations
  - CMS result nearly hot off the press - keep an eye out over the next week
- No matter what, will clearly need to combine in as many channels as possible

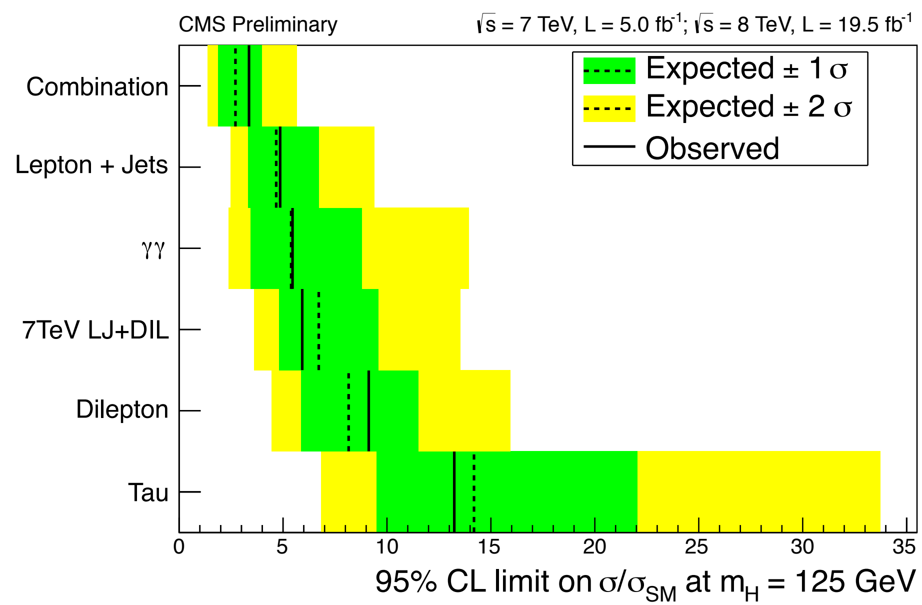
CMS ttH combination

CMS PAS HIG-13-019

Higgs Mass	Observed	Expected Median
110 GeV	2.2	2.0
115 GeV	2.9	2.1
120 GeV	3.9	2.4
125 GeV	3.4	2.7
130 GeV	3.9	3.3
135 GeV	5.5	3.8
140 GeV	8.0	4.7

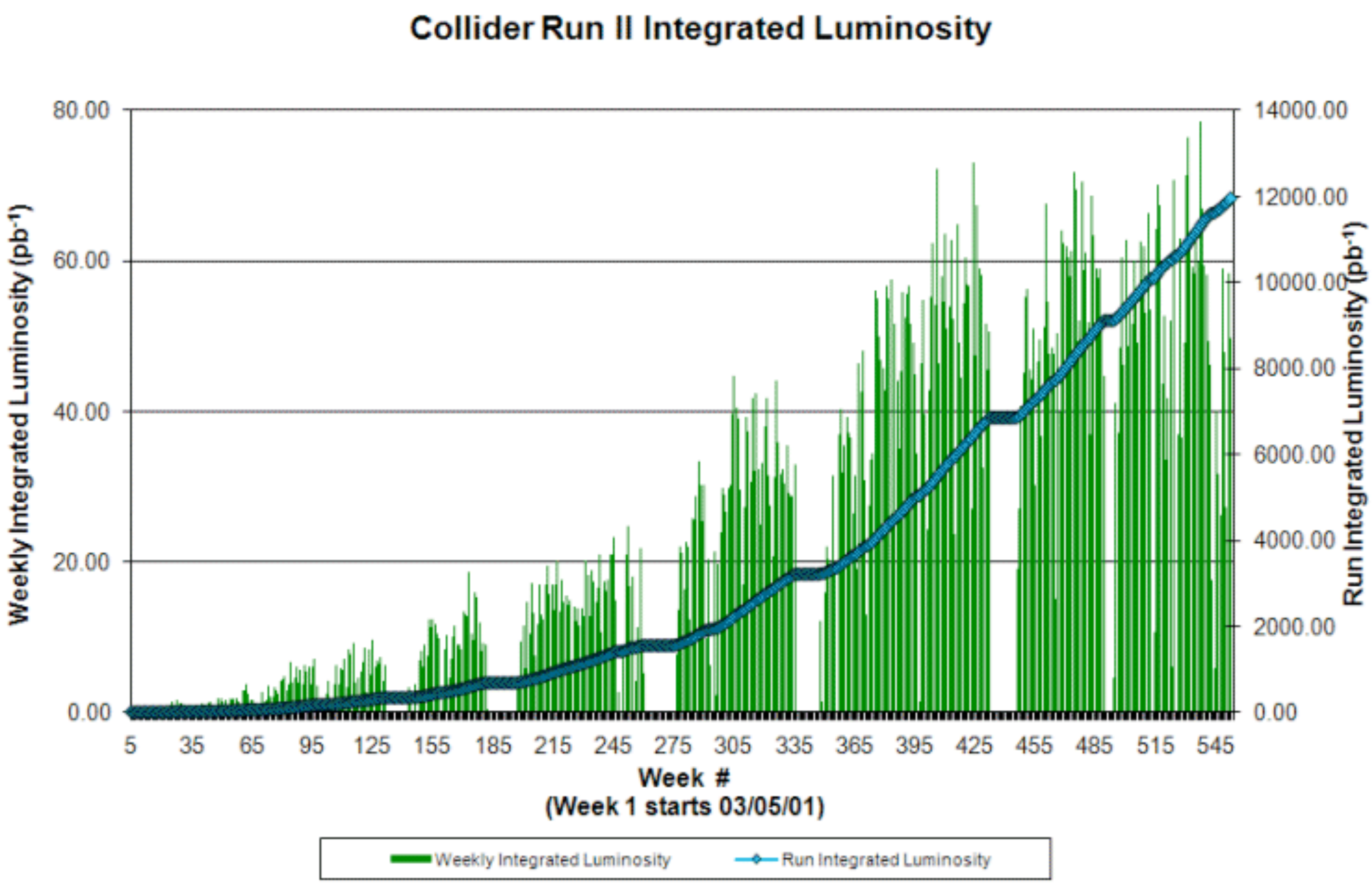
Best fit combined signal strength: 0.74 +1.34/-1.30





And what about the Tevatron experiments?

Substantial integrated luminosity and well understood detectors



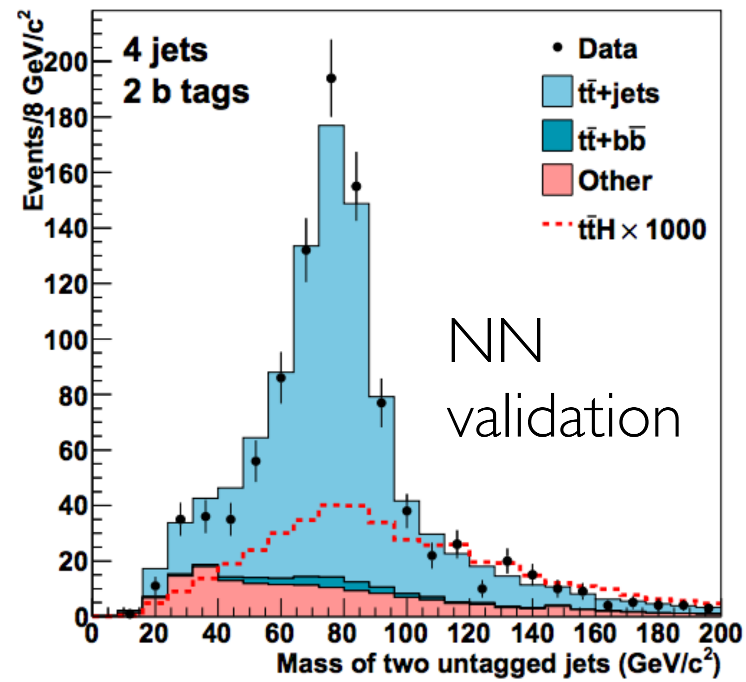
CDF semi-leptonic bb search

Phys Rev Lett 109.181802, 9.45 fb^{-1}

- Require single electron or muon > 18 GeV
- MET > 10 (muon), 20 (central ele), 25 (forward ele) GeV
- Jet p_T > 20 GeV, $|\eta|$ < 2.0, ≥ 2 b-tags

- Same strategy at the Tevatron and the LHC: Divide events by ntag, njet

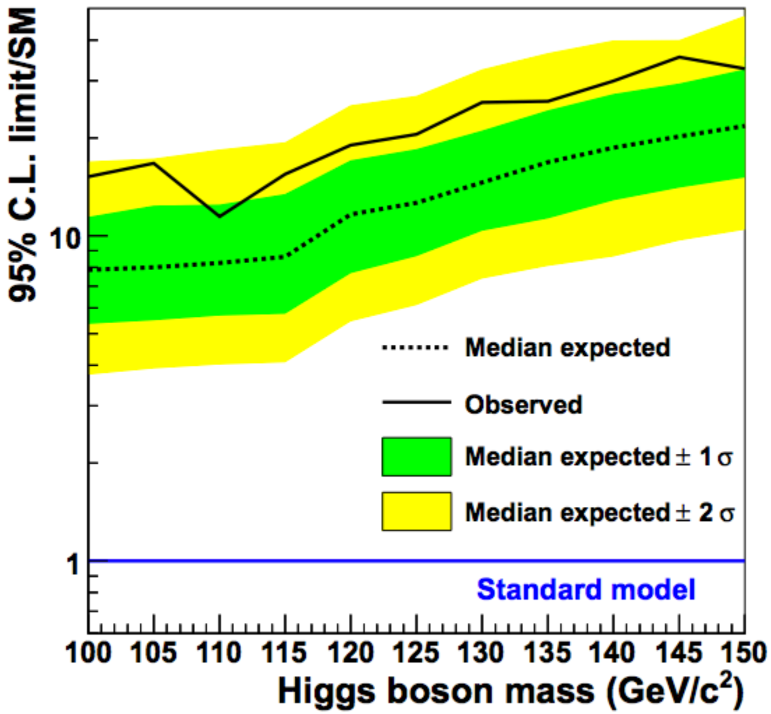
- Use neural networks to separate out signal and background
- Each NN uses 18 variables, including MET, jet E_T, scalar sums E_T of objects, dR between objects



CDF semi-leptonic bb

- Dominant detector uncertainties are the b-tag efficiency (5.4) and JES (7.8%)
    - Alter acceptance by 1-20% (also shape)
- 10% uncertainty on tt normalization (6.9% effect) and 100% uncertainty on tt+bb (9.0% effect)
- Smaller uncertainties on background normalization, ISR/FSR, PDFs, luminosity and mistag probability

Expected (observed) limit 12.6x (20.5x) the SM expectation



CDF 0-lepton bb

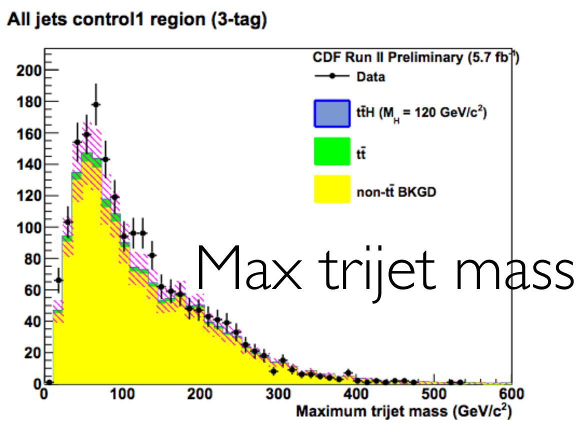
- Explicitly reject events with lepton
- Trigger requires four jets E_T > 15 GeV, ΣEt > 175 GeV
- Leading jet > 50 GeV, subleading jet > 40 GeV
- Require at least 2 b-tags, split by == 2 or > 2 tags
- Σ Jet + MET > 300 GeV
- Define METsignifiance = MET/(√(ΣEt)
- MET+jets channel (missing lepton):
    - METsignificance > 2 GeV$^{0.5}$
    - Njet: 5-8
- All-jets channel (no lepton):
    - METsignificance < 2 GeV$^{0.5}$
    - Njet: 7-11

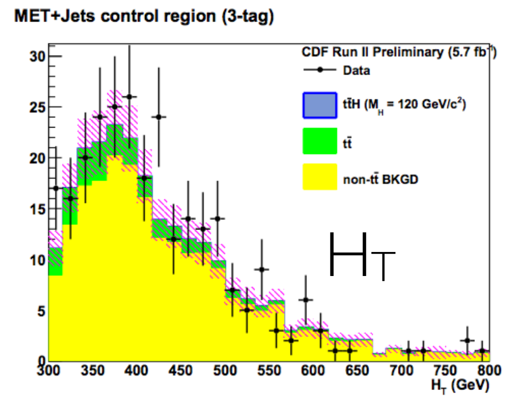
CDF II Preliminary 5.7 fb^{-1}

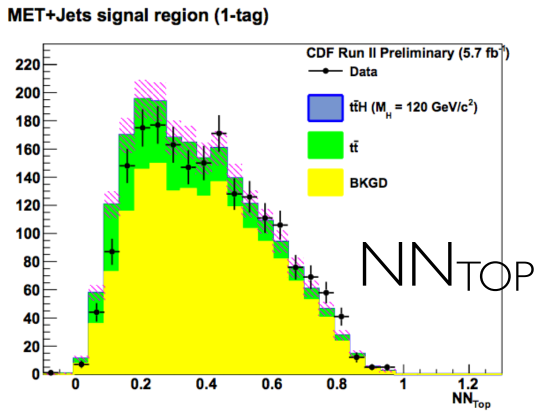
	2-tag ($\not{E}_T$ +jets)	3-tag ($\not{E}_T$ +jets)	2-tag (all jets)	3-tag (all jets)
Signal	1.0 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.1
$t\bar{t}$	316.1 ± 43.3	66.6 ± 9.8	120.7 ± 16.5	43.1 ± 6.4
non-$t\bar{t}$	488.9 ± 41.4	98.5 ± 12.6	328.9 ± 35.3	82.7 ± 11.8
Total Expected	806.0 ± 59.8	165.9 ± 16.0	450.3 ± 38.9	126.6 ± 13.4
Observed	756	151	424	133

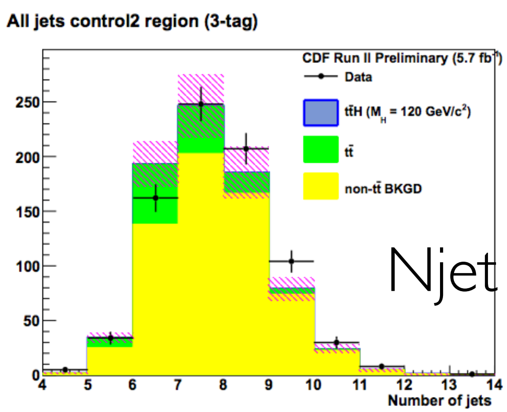
CDF 0-lepton signal vs background separation

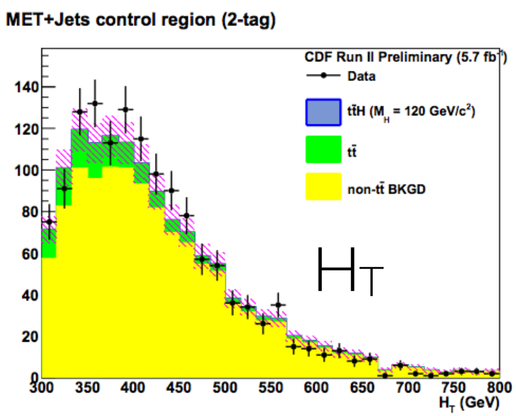
- Use NN_{top} to separate background from ttH signal
- Control regions of 1-btag or low NN_{QCD} scores
- Final discriminant is NN_{top} * NN_{QCD}

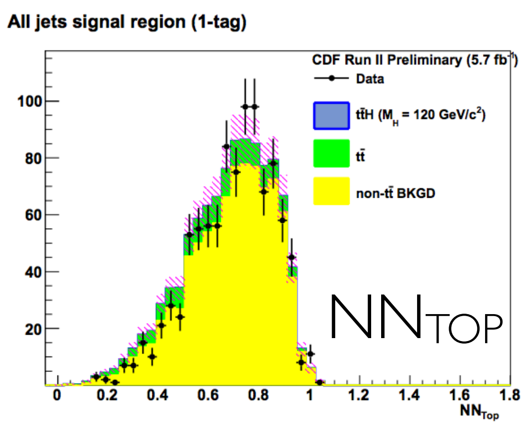












CDF 0-lepton systematic uncertainties

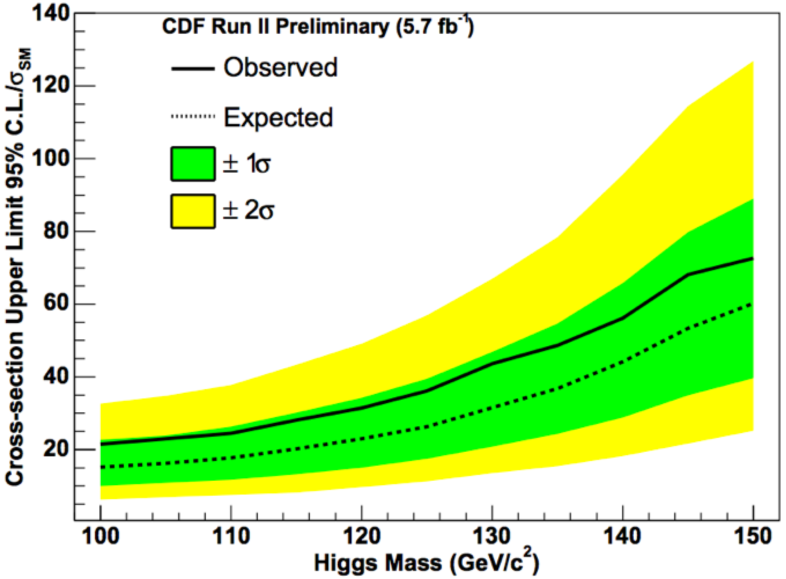
CDF II Preliminary 5.7 fb^{-1}

	$\not\!\!E_T$ +jets channel						All jets channel					
	$t\bar{t}H$		$t\bar{t}$		non-$t\bar{t}$		$t\bar{t}H$		$t\bar{t}$		non-$t\bar{t}$	
Systematic sources	2-tag	3-tag	2-tag	3-tag	2-tag	3-tag	2-tag	3-tag	2-tag	3-tag	2-tag	3-tag
Cross section	10%	10%	10%	10%	-	-	10%	10%	10%	10%	-	-
Trigger	7%	7%	7%	7%	-	-	7%	7%	7%	7%	-	-
Luminosity	6%	6%	6%	6%	-	-	6%	6%	6%	6%	-	-
B-Tag Scale Factor	7%	9%	7%	9%	-	-	7%	9%	7%	9%	-	-
JES	2%	3%	11%	13%	-	-	5%	7%	20%	22%	-	-
I/FSR	2%	2%	2%	2%	-	-	2%	2%	2%	2%	-	-
PDF	2%	2%	2%	2%	-	-	2%	2%	2%	2%	-	-
$t\bar{t}b\bar{b}$	-	-	3%	5%	-	-	-	-	3%	6%	-	-
BKGD Modeling	-	-	-	-	6%	6%	-	-	-	-	9%	9%
b-tag Categorization	-	-	-	-	5%	10%	-	-	-	-	5%	10%

- Biggest uncertainty is JES
- ttbb uncertainty of 100%
- Background uncertainties obtained by examining the low-NN region

CDF 0-lepton result

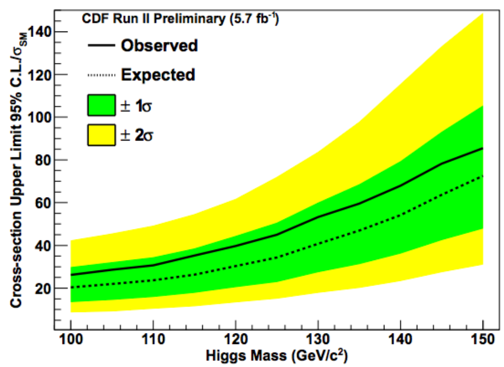
Limits for $t\bar{t}H$ in missing E_T+Jets and All Jets



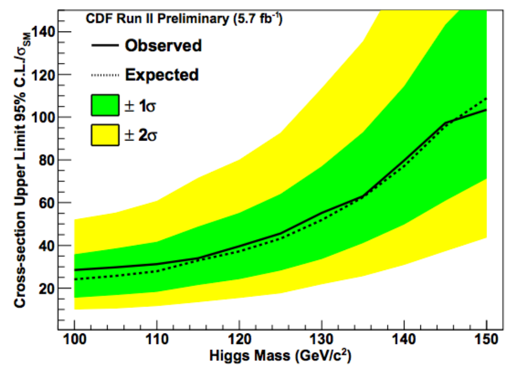
CDF II Preliminary 5.7 fb^{-1}

M_H	Expected Limits					Observed Limits
(GeV/c^2)	-2σ	-1σ	**Median**	1σ	2σ	
100	6.3	10.0	**15.2**	22.6	32.6	**21.5**
105	6.9	10.8	**16.3**	23.8	34.8	**23.0**
110	7.6	11.7	**17.8**	26.3	37.7	**24.5**
115	8.2	13.2	**20.2**	30.1	43.3	**28.1**
120	9.7	15.1	**22.9**	34.2	49.1	**31.4**
125	11.3	17.5	**26.2**	39.5	56.9	**36.2**
130	13.5	20.8	**31.5**	46.8	66.9	**43.6**
135	15.4	24.3	**36.8**	54.6	78.4	**48.6**
140	18.3	28.9	**44.2**	65.8	95.6	**56.2**
145	21.7	35.0	**53.4**	79.8	114.5	**68.1**
150	25.2	39.7	**60.3**	89.9	126.9	**72.6**

Limits for $t\bar{t}H$ in MET+Jets channel



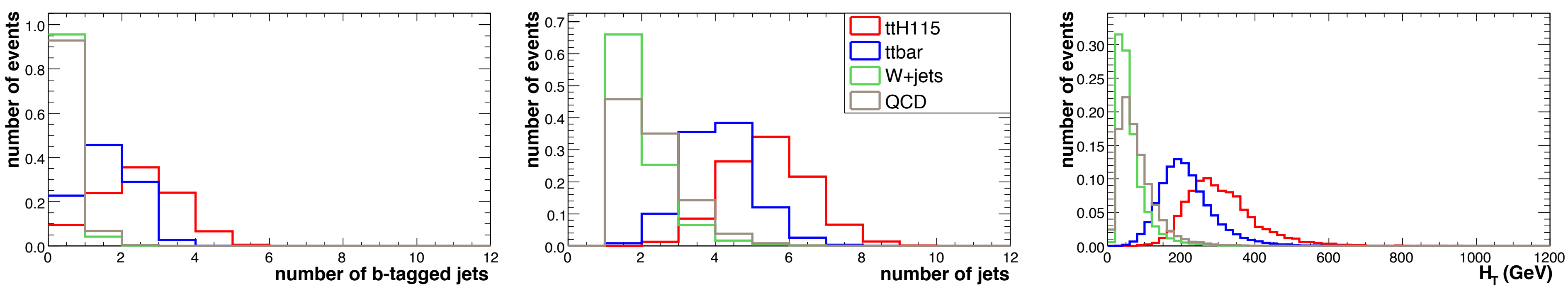
Limits for $t\bar{t}H$ in All Jets channel



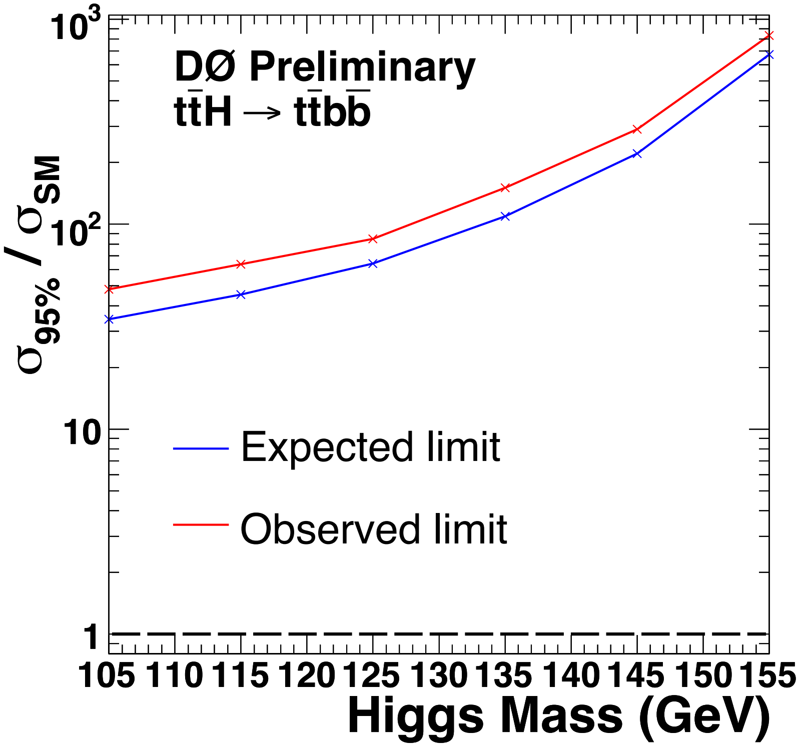
DZero ttH(bb) search

DZero Note 5739-CONF, 2.1 fb^{-1}

- Require single electron(muon) > 20 GeV with $|\eta|$ < 1.1 (2.0)
- For electron (muon), require MET > 20 (25) GeV
- Jet p_T > 20 GeV, $|\eta|$ < 2.5, ≥ 1 b-tag
- Leading jet > 40 GeV
- Split by njet and nbtag and then use H_T as discriminating variable



DZero ttH(bb) results

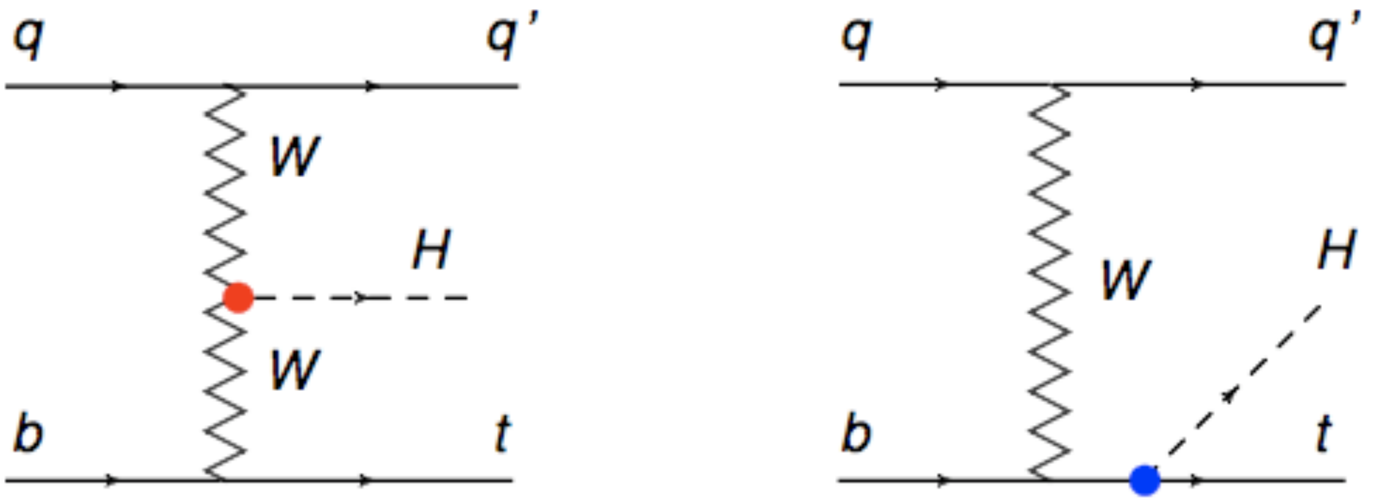


Higgs mass (GeV)	expected	observed
105	34.3	48.2
115	45.3	63.9
125	64.2	84.8
135	109	151
145	221	291
155	674	835

Uncertainties are profiled to reduce their effect. Dominated by ttbb uncertainty

Source	value
Event preselection	1.2%
Muon identification	2%
Electron identification	2.5%
Luminosity	6.1%
W background model	15%
Uncertainty on $\sigma_{t\bar{t}}$	10%
Uncertainty on $t\bar{t}b\bar{b}$	50%

Far into the future, exciting to look for single top + Higgs production (direct test of Yukawa sign), and maybe one day to probe the structure of the ttH vertex (is there any CP odd component)?



arXiv: 1211.0499

Conclusions and prospects

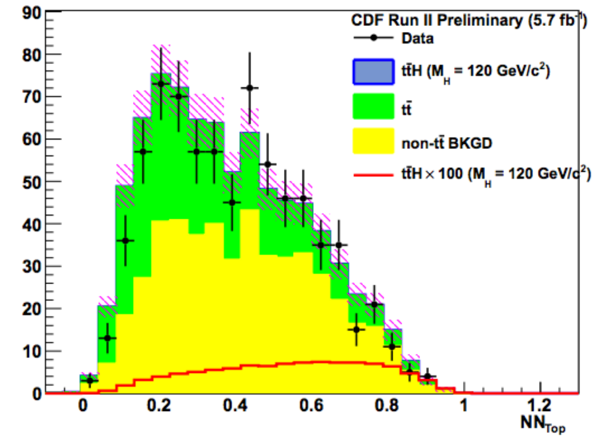
- Lots of hard work at the LHC and the Tevatron to search for ttH, with more to come
- Not too much more room for ttH to hide. Combination between experiments + a bit more data might be enough to see hints of a signal
- Hopefully getting closer to understanding if top quark has a special role in electroweak symmetry breaking

Backup

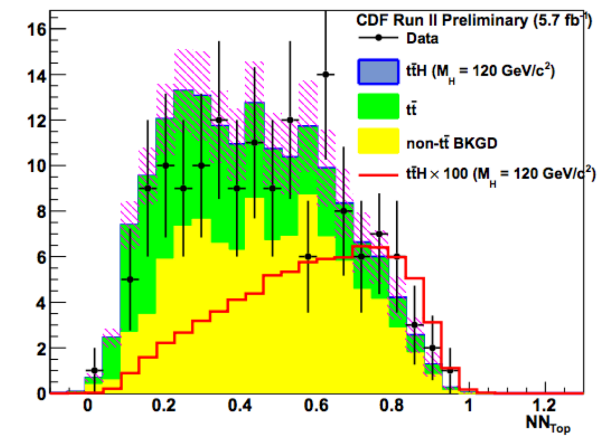
Backup

CDF 0-lepton final discriminant

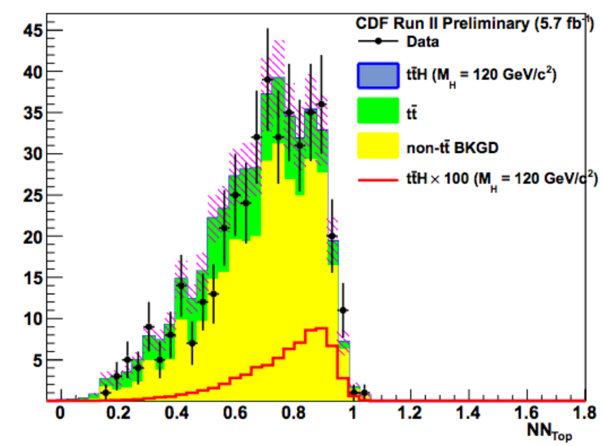
MET+Jets signal region (2-tag)



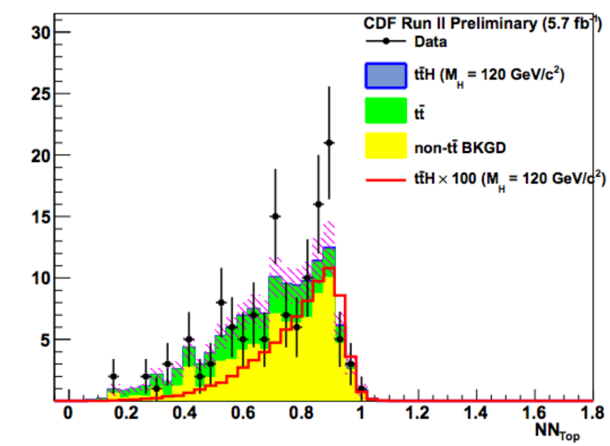
MET+Jets signal region (3-tag)



All jets signal region (2-tag)



All jets signal region (3-tag)



5 jets, $\geq$ 4 tags	$\geq$ 6 jets, 3 tags	$\geq$ 6 jets, $\geq$ 4 tags
ave ΔR(tag,tag)	tagged dijet mass closest to 125	H_3
max $\Delta\eta$ (tag, ave tag η)	$(\Sigma$ jet $p_T)/(\Sigma$ jet E)	ave ΔR(tag,tag)
$(\Sigma$ jet $p_T)/(\Sigma$ jet E)	$\sqrt{\Delta\eta(t^{lep},bb)\times\Delta\eta(t^{had},bb)}$	closest tagged dijet mass
tagged dijet mass closest to 125	H_1	sphericity
H_1	H_3	max $\Delta\eta$ (tag, ave jet η)
H_3	M3	max $\Delta\eta$ (tag, ave tag η)
$\sum p_T$(jets,lepton,MET)	max $\Delta\eta$ (tag, ave tag η)	mass(lepton,jet,MET)
fourth-highest CSV (tags)	max $\Delta\eta$ (tag, ave jet η)	$(\Sigma$ jet $p_T)/(\Sigma$ jet E)
aplanarity	max $\Delta\eta$ (jet, ave jet η)	abs $\Delta\eta$ (leptonic top, bb)
MET	abs $\Delta\eta$ (hadronic top, bb)	abs $\Delta\eta$ (hadronic top, bb)
	abs $\Delta\eta$ (leptonic top, bb)	$\sqrt{\Delta\eta(t^{lep},bb)\times\Delta\eta(t^{had},bb)}$
	sphericity	ave CSV (tags)
	aplanarity	best ΔR(b,b)
	min ΔR(tag,tag)	best Higgs boson mass
	jet 3 p_T	median inv. mass (tag pairs)

Table 15: List of variables used as inputs to the ttbb/ttH BDTs.

4 jets, 3 b-tags	4 jets, 4 b-tags
jet 1 p_T	jet 1 p_T
jet 2 p_T	jet 2 p_T
jet 3 p_T	jet 4 p_T
jet 4 p_T	HT
M3	$\sum p_T$(jets,lepton,MET)
$\sum p_T$(jets,lepton,MET)	M3
HT	ave CSV (tags)
lowest CSV (tags)	second-highest CSV (tags)
MHT	third-highest CSV (tags)
MET	lowest CSV (tags)

5 jets, 3 b-tags	5 jets, $\geq$ 4 b-tags
jet 1 p_T	max $\Delta\eta$ (tag, ave jet η)
jet 2 p_T	$\sum p_T$(jets,lepton,MET)
jet 3 p_T	$(\Sigma$ jet $p_T)/(\Sigma$ jet E)
jet 4 p_T	ave ΔR(tag,tag)
$\sum p_T$(jets,lepton,MET)	ave CSV (tags)
$(\Sigma$ jet $p_T)/(\Sigma$ jet E)	dev from ave CSV (tags)
HT	second-highest CSV (tags)
ave CSV (tags)	third-highest CSV (tags)
third-highest CSV (tags)	lowest CSV (tags)
fourth-highest CSV (jets)	ttbb/ttH BDT

$\geq$ 6 jets, 2 tags	$\geq$ 6 jets, 3 tags	$\geq$ 6 jets, $\geq$ 4 tags
$\sum p_T$(jets,lepton,MET)	H_0	$(\Sigma$ jet $p_T)/(\Sigma$ jet E)
HT	sphericity	ave ΔR(tag,tag)
mass(lepton,closest tag)	$(\Sigma$ jet $p_T)/(\Sigma$ jet E)	product($\Delta\eta$(leptonic top, bb), $\Delta\eta$(hadronic top, bb))
max $\Delta\eta$ (jet, ave jet η)	max $\Delta\eta$ (jet, ave jet η)	closest tag mass
min ΔR(lepton,jet)	$\sum p_T$(jets,lepton,MET)	max $\Delta\eta$ (tag, ave tag η)
H_2	ave CSV (tags)	ave CSV (tags)
sphericity	second-highest CSV (tags)	third-highest CSV (tags)
$(\Sigma$ jet $p_T)/(\Sigma$ jet E)	third-highest CSV (tags)	fourth-highest CSV (tags)
third-highest CSV (jets)	fourth-highest CSV (jets)	best Higgs boson mass
fourth-highest CSV (jets)	ttbb/ttH BDT	ttbb/ttH BDT

Table 14: BDT variables used in each analysis category of the lepton + jets channel.

Variable	Description
abs $\Delta\eta$ (leptonic top, bb)	Delta-R between the leptonic top reconstructed by the best Higgs mass algorithm and the b-jet pair chosen by the algorithm
abs $\Delta\eta$ (hadronic top, bb)	Delta-R between the hadronic top reconstructed by the best Higgs mass algorithm and the b-jet pair chosen by the algorithm
aplanarity	Event shape variable equal to $\frac{3}{2}(\lambda_3)$, where λ_3 is the third eigenvalue of the sphericity tensor as described in [31].
ave CSV (tags/non-tags)	Average b-tag discriminant value for b-tagged/non-b-tagged jets
ave ΔR(tag,tag)	Average ΔR between b-tagged jets
best Higgs boson mass	A minimum-chi-squared fit to event kinematics is used to select two b-tagged jets as top-decay products. Of the remaining b-tags, the invariant mass of the two with highest E_t is saved.
best ΔR(b,b)	The ΔR between the two b-jets chosen by the best Higgs boson mass algorithm
closest tagged dijet mass	The invariant mass of the two b-tagged jets that are closest in ΔR
dev from ave CSV (tags)	The square of the difference between the b-tag discriminant value of a given b-tagged jet and the average b-tag discriminant value among b-tagged jets, summed over all b-tagged jets
highest CSV (tags)	Highest b-tag discriminant value among b-tagged jets
H_0, H_1, H_2, H_3	The first few Fox-Wolfram moments [32] (event shape variables)
HT	Scalar sum of transverse momentum for all jets with $p_T > 30$ GeV/c
$\sum p_T$(jets,leptons,MET)	The sum of the p_T of all jets, leptons, and MET
$\sum p_T$(jets,leptons)	The sum of the p_T of all jets, leptons
jet 1, 2, 3, 4 p_T	The transverse momentum of a given jet, where the jet numbers correspond to rank by p_T
lowest CSV (tags)	Lowest b-tag discriminant value among b-tagged jets
mass(lepton,jet,MET)	The invariant mass of the 4-vector sum of all jets, leptons, and MET
mass(lepton,closest tag)	The invariant mass of the lepton and the closest b-tagged jet in ΔR (LJ channel)
max $\Delta\eta$ (jet, ave jet η)	max difference between jet eta and avg deta between jets
max $\Delta\eta$ (tag, ave jet η)	max difference between tag eta and avg deta between jets
max $\Delta\eta$ (tag, ave tag η)	max difference between tag eta and avg deta between tags
median inv. mass (tag pairs)	median invariant mass of all combinations of b-tag pairs
M3	The invariant mass of the 3-jet system with the largest transverse momentum.
MHT	Vector sum of transverse momentum for all jets with $p_T > 30$ GeV/c
MET	Missing transverse energy
min ΔR(lepton,jet)	The ΔR between the lepton and the closest jet (LJ channel)
HiggsLike dijet mass(2)	the invariant mass of a jet pair(at least one is b-tagged) ordered in closeness to a Higgs boson mass (DIL channel)
number of HiggsLike dijet 15	number of jet pairs(at least one is b-tagged) whose invariant mass is within 15 GeV window of a Higgs boson mass (DIL channel)
min ΔR(tag,tag)	The ΔR between the two closest b-tagged jets
min ΔR(jet,jet)	The ΔR between the two closest jets
$\sqrt{\Delta\eta(t^{lep},bb)\times\Delta\eta(t^{had},bb)}$	square root of the product of abs $\Delta\eta$ (leptonic top, bb) and abs $\Delta\eta$ (hadronic top, bb)
second-highest CSV (tags)	Second-highest b-tag discriminant value among b-tagged jets
sphericity	Event shape variable equal to $\frac{3}{2}(\lambda_2+\lambda_3)$, where λ_2 and λ_3 are the second and third eigenvalues of the sphericity tensor as described in [31]
$(\Sigma$ jet $p_T)/(\Sigma$ jet E)	The ratio of the sum of the transverse momentum of all jets and the sum of the energy of all jets
tagged dijet mass closest to 125	The invariant mass of the b-tagged pair closest to 125 GeV/c^2
$t\bar{t}b\bar{b}/t\bar{t}H$ BDT	BDT used to discriminate between $t\bar{t}b\bar{b}$ and $t\bar{t}H$ in the LJ $\geq$ 6 jets, $\geq$ 4 tags, $\geq$6 jets + 3 tags, and 5 jets + $\geq$4 tags categories. See text for description and table 15 for list of variables.

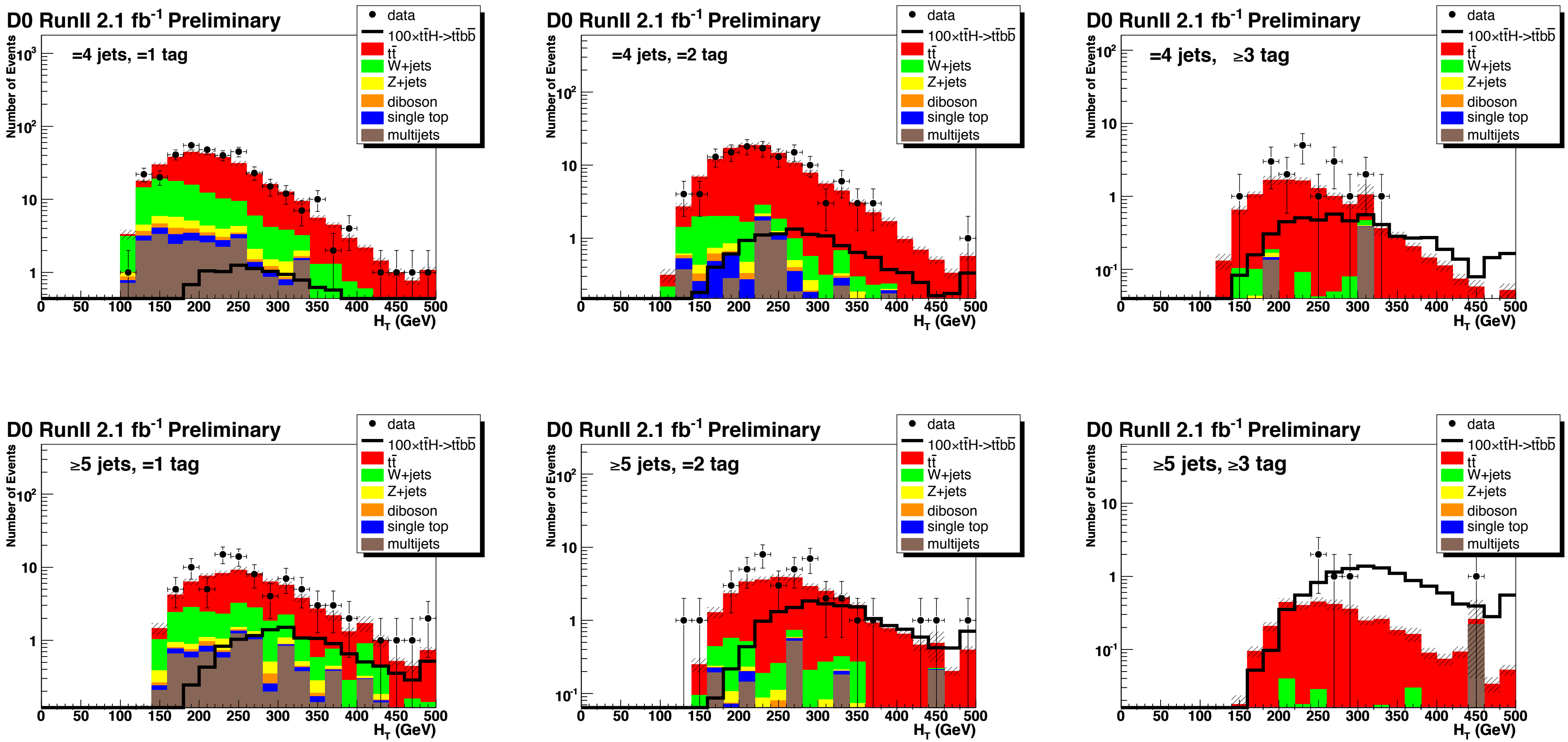
Table 13: Event variables used in BDT training and their descriptions.

CMS ttH, H → $\tau\tau$

Variable	Description
Tau1Pt	The p_{T} of the more energetic τ
Tau2Pt	The p_{T} of the less energetic τ
Tau1Eta	The $\lvert\eta\rvert$ of the more energetic τ
Tau1IsolationMVA2Raw	The HPS MVA2 score of the more energetic τ
Tau2IsolationMVA2Raw	The HPS MVA2 score of the less energetic τ
DitauVisibleMass	The reconstructed visible mass from the τ-pair
DeltaRTau1Lepton	The distance between the more energetic τ and the lepton
Tau1DecayMode	The decay mode of the more energetic τ
Tau2DecayMode	The decay mode of the less energetic τ
LeadingJetPt	The leading jet p_{T}, excluding jets from the selected τ

Table 17: Event variables used for the MVA training of the tau channel and their descriptions.

DZero ttH(bb) signal region



CMS ttH, H→bb systematic uncertainties

Source	Shape	Remarks
Luminosity	No	Signal and all backgrounds
Lepton ID/Trigger efficiency	No	Signal and all backgrounds
Pileup	No	Signal and all backgrounds
Top p_T reweighting	Yes	Only $t\bar{t}$ background
Jet Energy Resolution	No	Signal and all backgrounds
Jet Energy Scale	Yes	Signal and all backgrounds
b-Tag bottom-flavor contamination	Yes	Signal and all backgrounds
b-Tag bottom-flavor statistics (linear)	Yes	Signal and all backgrounds
b-Tag bottom-flavor statistics (quadratic)	Yes	Signal and all backgrounds
b-Tag light-flavor contamination	Yes	Signal and all backgrounds
b-Tag light-flavor statistics (linear)	Yes	Signal and all backgrounds
b-Tag light-flavor statistics (quadratic)	Yes	Signal and all backgrounds
b-Tag Charm uncertainty (linear)	Yes	Signal and all backgrounds
b-Tag Charm uncertainty (quadratic)	Yes	Signal and all backgrounds
QCD Scale ($t\bar{t}H$)	No	Scale uncertainty for NLO $t\bar{t}H$ prediction
QCD Scale ($t\bar{t}$)	No	Scale uncertainty for NLO $t\bar{t}$ and single top predictions
QCD Scale (V)	No	Scale uncertainty for NNLO W and Z prediction
QCD Scale (VV)	No	Scale uncertainty for NLO diboson prediction
PDF (gg)	No	Parton distribution function (PDF) uncertainty for gg initiated processes ($t\bar{t}$, $t\bar{t}Z$, $t\bar{t}H$)
PDF ($q\bar{q}$)	No	PDF uncertainty for $q\bar{q}$ initiated processes ($t\bar{t}W$, W, Z).
PDF (qg)	No	PDF uncertainty for qg initiated processes (single top)
Madgraph Q^2 Scale ($t\bar{t}$+0p,1p,2p)	Yes	Madgraph Q^2 scale uncertainty for $t\bar{t}$+jets split by parton number. There is one nuisance parameter per parton multiplicity and they are uncorrelated.
Madgraph Q^2 Scale ($t\bar{t}$+b/$b\bar{b}$/$c\bar{c}$)	Yes	Madgraph Q^2 scale uncertainty for $t\bar{t}$+b/$b\bar{b}$/$c\bar{c}$.
Madgraph Q^2 Scale (V)	No	Varies by jet bin.
Extra $t\bar{t}$+hf rate uncertainty	No	A 50% uncertainty in the rate of $t\bar{t}$+b, $t\bar{t}+b\bar{b}$, $t\bar{t}+c\bar{c}$.
τ Energy Scale	Yes	Tau signal and background
τ ID efficiency	Yes	Tau signal and background
τ Jet Fake Rate	Yes	Tau signal and background
τ Electron Fake Rate	Yes	Tau signal and background

Table 4: Summary of the systematic uncertainties considered in the inputs to the limit calculation. Except where noted, each row in this table is treated as a single, independent nuisance parameter.

DZero ttH(bb) yields and uncertainties

Uncertainties are profiled to reduce their effect. Dominated by ttbb uncertainty

Source	value
Event preselection	1.2%
Muon identification	2%
Electron identification	2.5%
Luminosity	6.1%
W background model	15%
Uncertainty on $\sigma_{t\bar{t}}$	10%
Uncertainty on $t\bar{t}b\bar{b}$	50%

	e+jets					
	4j1t	4j2t	4j3t	5j1t	5j2t	5j3t
Signal	0.0675	0.0684	0.0318	0.0765	0.0882	0.0669
$t\bar{t}$	110 ± 1	60.5 ± 0.4	5.98 ± 0.12	25.5 ± 0.3	15.0 ± 0.2	1.97 ± 0.07
non-$t\bar{t}$ Bkg	67.2 ± 2.9	8.96 ± 0.97	0.35 ± 0.14	12.9 ± 1.3	2.52 ± 0.62	0.31 ± 0.22
sum Bkg	177 ± 3.0	69.5 ± 1.1	6.32 ± 0.18	38.4 ± 1.4	17.6 ± 0.7	2.28 ± 0.23
Observed	179	57	10	42	22	3

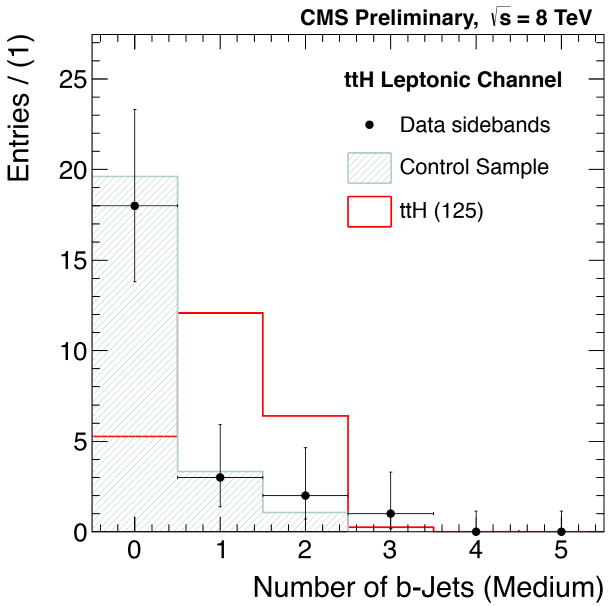
	μ+jets					
	4j1t	4j2t	4j3t	5j1t	5j2t	5j3t
Signal	0.0433	0.0462	0.0237	0.0555	0.0684	0.0504
$t\bar{t}$	91.0 ± 0.5	51.5 ± 0.4	5.04 ± 0.11	20.4 ± 0.2	12.1 ± 0.2	1.47 ± 0.05
non-$t\bar{t}$ Bkg	56.6 ± 2.5	8.5 ± 1.2	0.82 ± 0.44	12.7 ± 1.3	1.84 ± 0.36	0.11 ± 0.10
sum Bkg	148 ± 2.5	60.0 ± 1.2	5.86 ± 0.45	33.2 ± 1.4	14.0 ± 0.4	1.57 ± 0.11
Observed	170	68	9	44	20	2

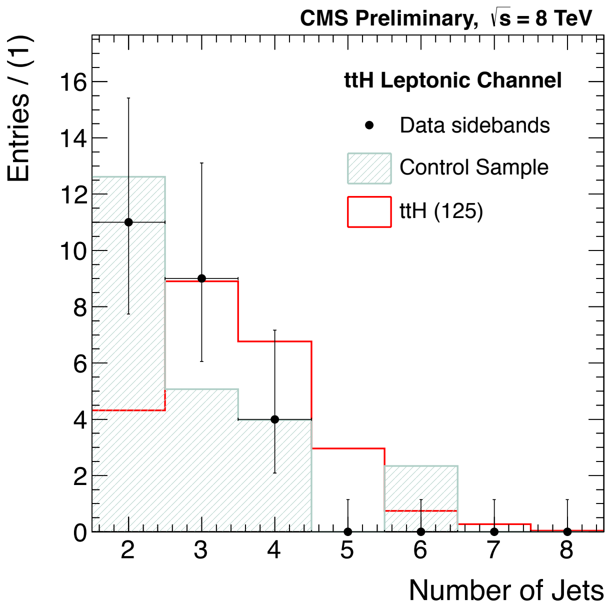
CDF semi-leptonic bb search

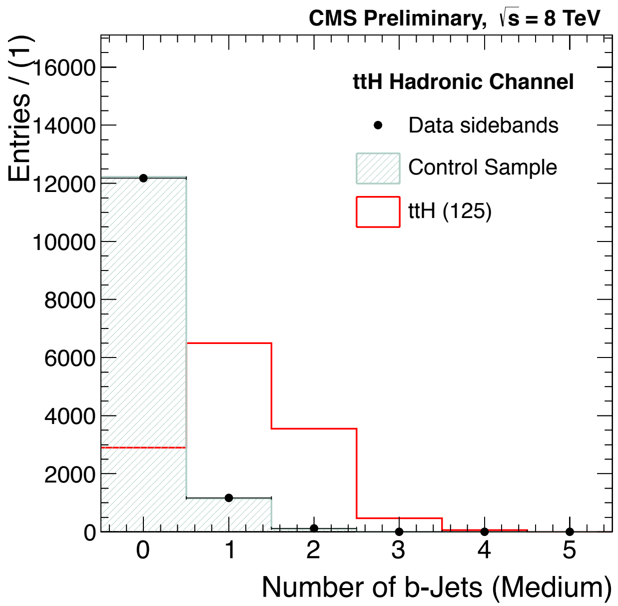
Process	4 jets	5 jets	≥ 6 jets
$t\bar{t}$ + jets	962 ± 89	294 ± 27	77 ± 7.1
$t\bar{t} + b\bar{b}$	32 ± 27	17 ± 14	8.2 ± 6.9
W/Z + jets	105 ± 32	26 ± 8.0	7.1 ± 2.2
Multijet	31 ± 16	0.0 ± 1.0	0.0 ± 1.0
Single top	19 ± 2.2	3.7 ± 0.43	0.61 ± 0.070
Diboson	5.2 ± 0.44	1.2 ± 0.11	0.25 ± 0.025
Total background	1150 ± 106	340 ± 33	93 ± 11
Observed	1133	368	114
$t\bar{t}H$	0.65 ± 0.075	1.1 ± 0.13	1.2 ± 0.14
WH	0.52 ± 0.061	0.07 ± 0.008	negligible
ZH	0.09 ± 0.011	0.02 ± 0.002	negligible

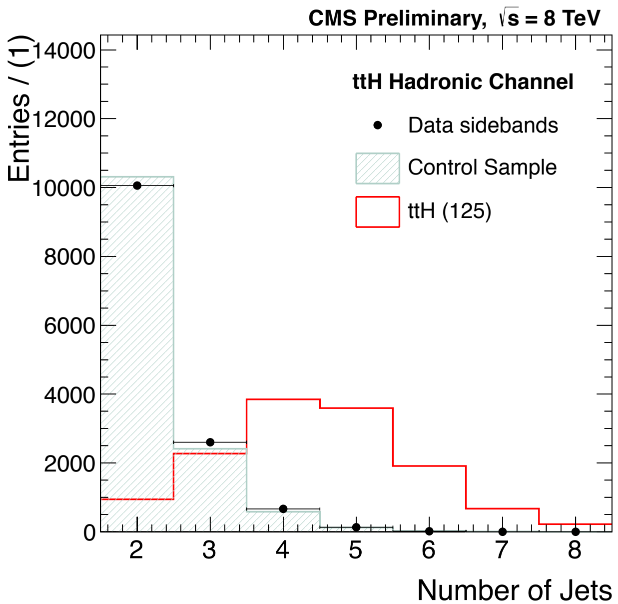
CMS ttH, H→γγ CR

- Reweight data in control region to match pt and **η** distributions in SR
- Plots: >= 1 lepton (leptonic channel) or >= 2 jets (hadronic channel)

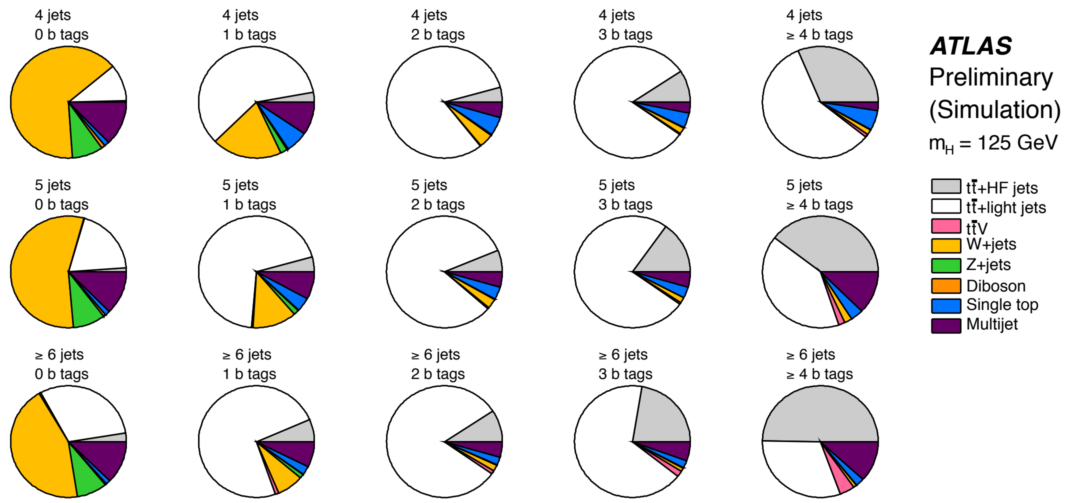




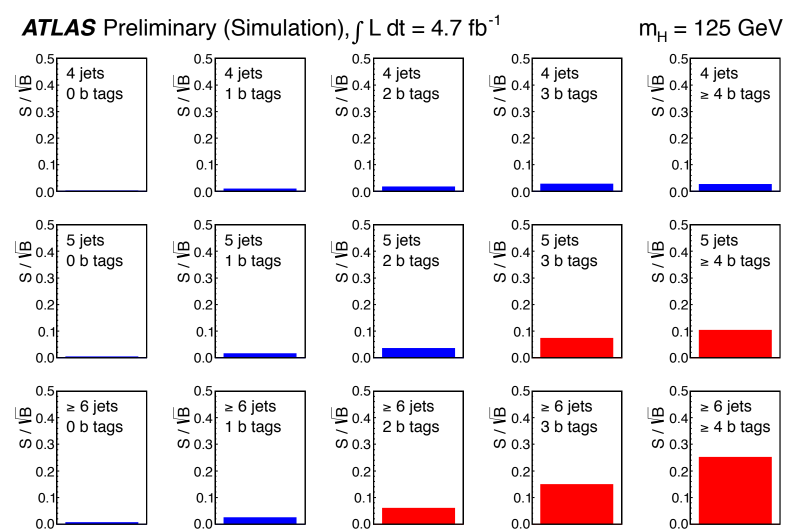




ATLAS ttH, H→bb

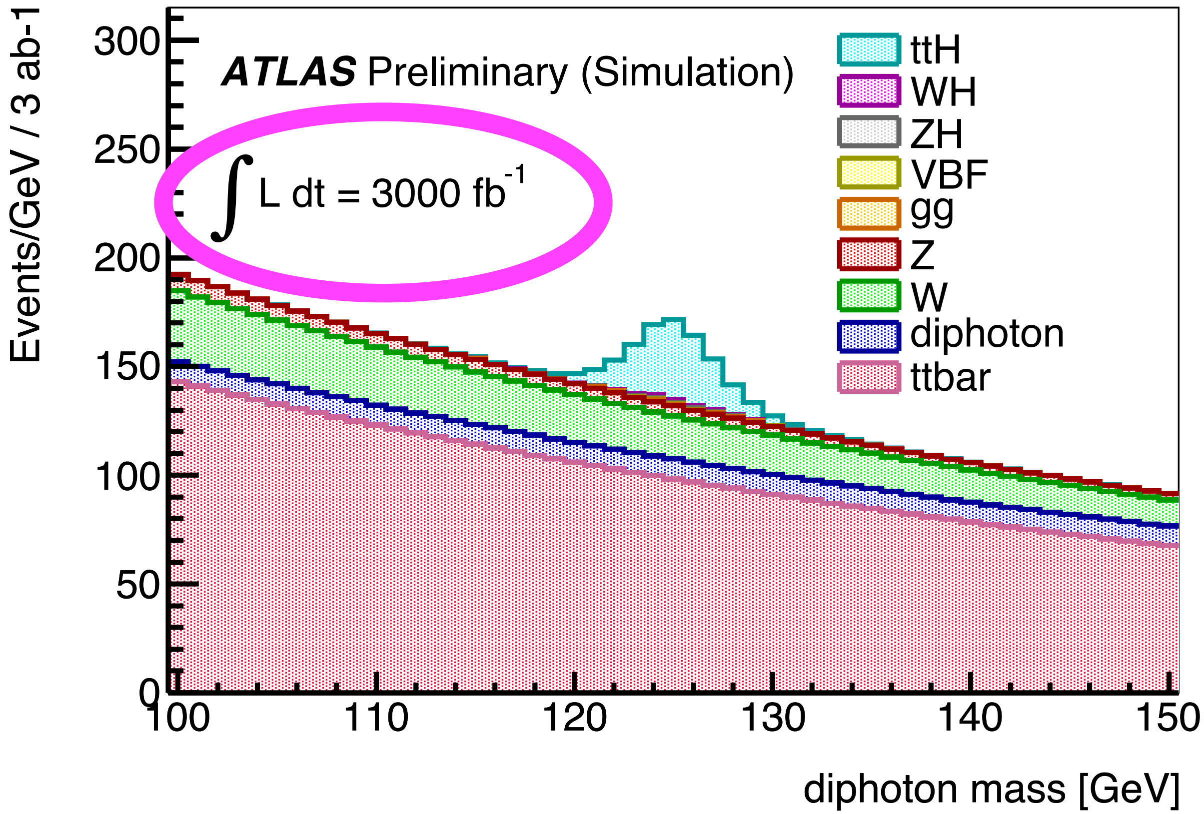


- Divide events based on njet and ntag
- Events with < 6 jets: Use H_T^{had} as single discriminating variable
- Events with ≥ 6 jets: Kinematic likelihood fit to ttH system with m_{bb} as variable of interest



What about longer term?

Clear that discovery of ttH will take quite some time.
Precision measurements even longer



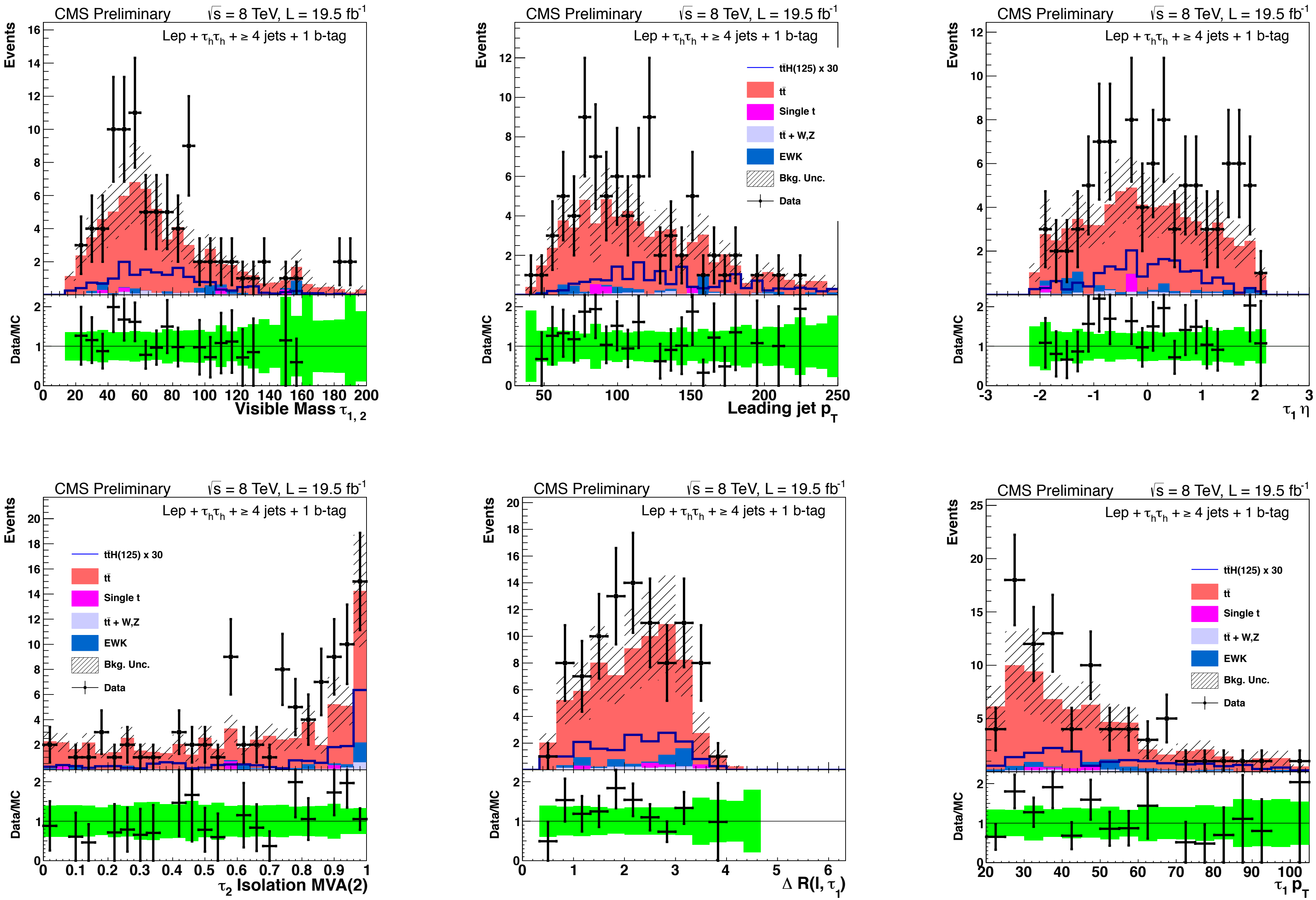
Channel	Exp (σ/σ_{SM})	Obs (σ/σ_{SM})
LJ	4.7	4.9
DIL	8.2	9.1
TAU	14.2	13.2
7 TeV LJ + DIL	6.7	5.9
$\gamma\gamma$	5.4	5.5
COMB	2.7	3.4

95% CL upper limits

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	$+0.74^{+1.34}_{-1.30}$

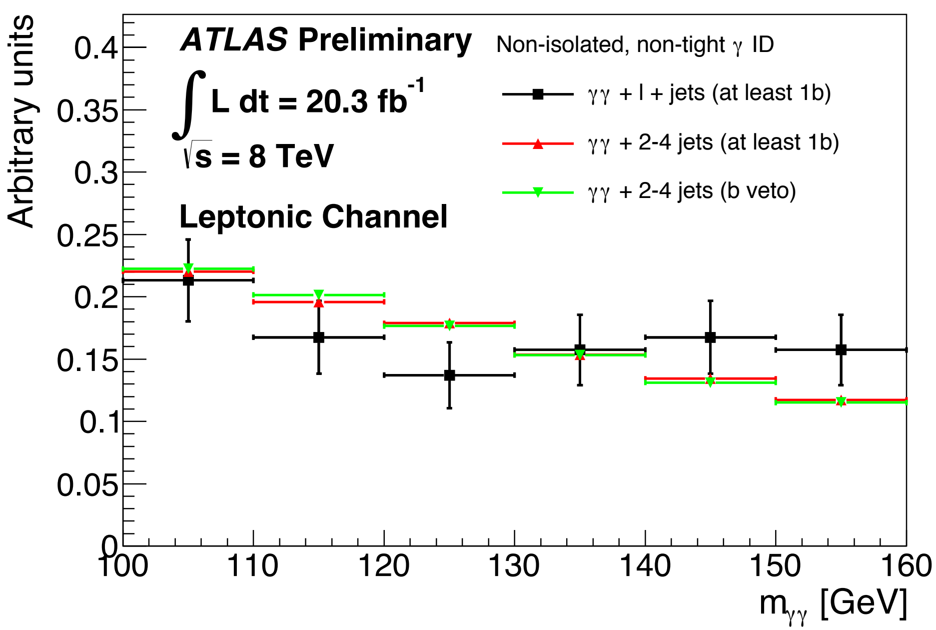
Best fit signal strength

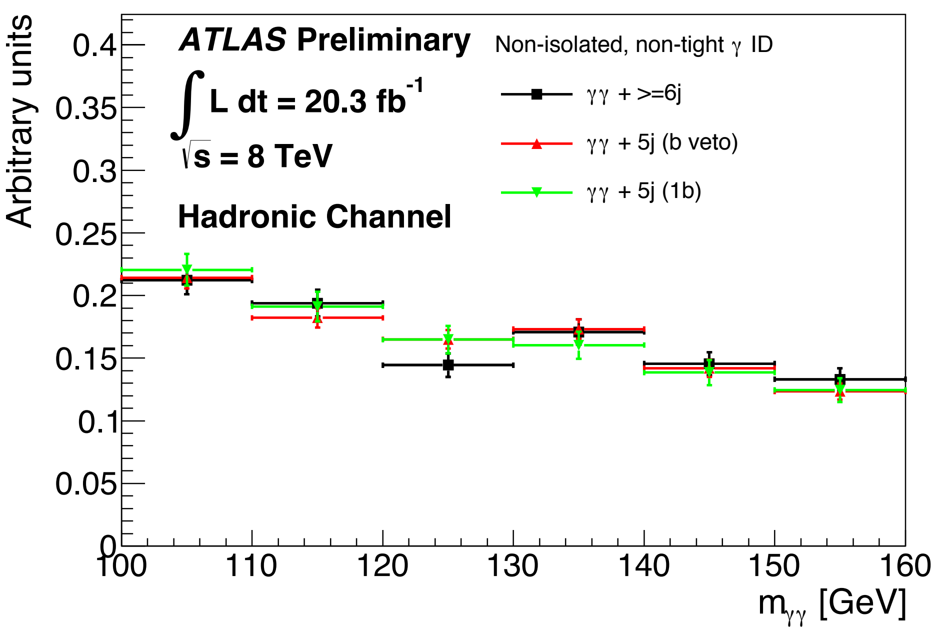
CMS ttH, H→$\tau\tau$ BDT



ATLAS ttH, H→γγ control regions

- Leptonic control region: replace lepton with jet, no b-tag requirement, $2 \leq$ njet ≤ 4
- Hadronic control region: == 5 jets, no b-tag requirement
- Reverse photon ID and remove isolation criteria and then check control region assumptions



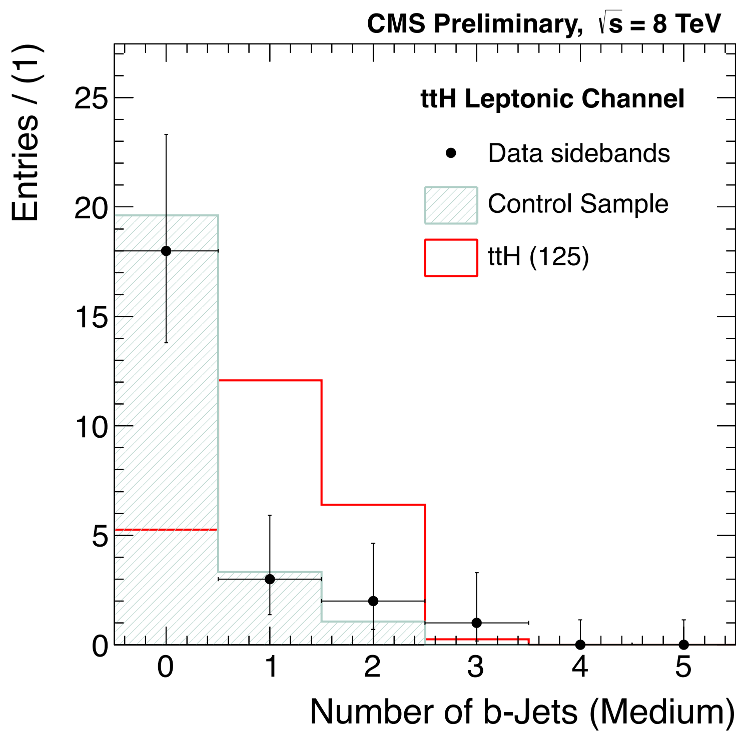


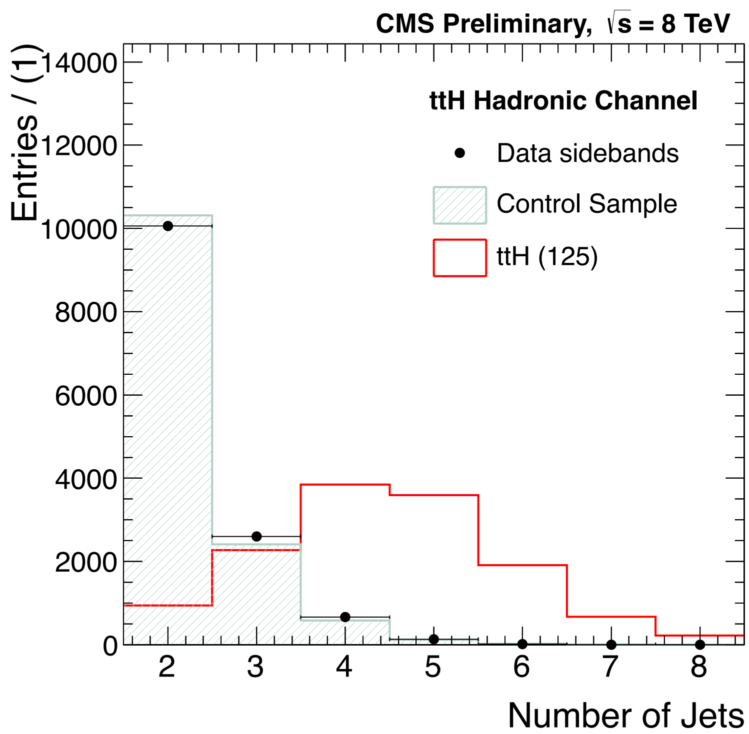
H→γγ simulation and non-ttH Higgs uncertainties

	ATLAS	CMS
(tt/W/Z) + H	Pythia	Pythia
ggF, VBF	Powheg + Pythia	Powheg + Pythia
tH	Madgraph + Pythia	--
non-ttH + jets uncertainties	50% in hadronic channel	30%
ggF + HF	200% uncertainty from tt+HF measurement	100% uncertainty from tt+HF measurement
WH/VBF + HF	150% uncertainty (from W+b measurement)	--

CMS ttH, H→γγ CR

- Reweight data in control region to match pt and η distributions in SR
- Plots: >= 1 lepton (leptonic channel) or >= 2 jets (hadronic channel)





H→bb simulation samples

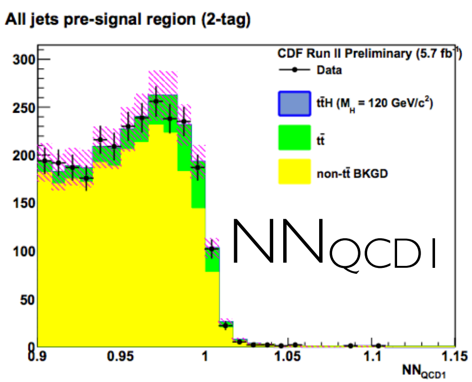
	ATLAS (7 TeV)	CMS (8 TeV)
ttH	Pythia	Pythia
W/Z + jets	Alpgen + Herwig	Madgraph + Pythia
ttW, ttZ	Madgraph + Pythia	Madgraph + Pythia
Single top	MC@NLO + Herwig (s-channel and WT), ACER+Pythia (t-channel)	Powheg + Pythia
Dibosons	Herwig	Pythia
tt+jets	Alpgen+Herwig up to 5 additional partons separated into tt+LF/tt+HF	Madgraph + Pythia, split into ttbb/ttb/ttc(c) based on reco-to-truth matching

H→bb simulation samples

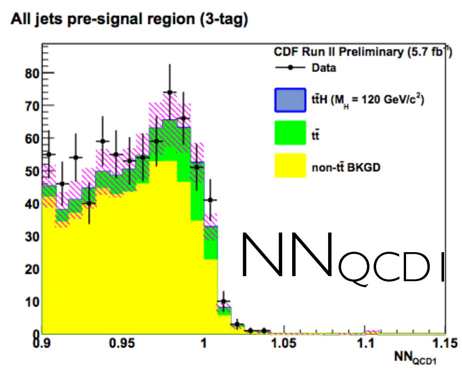
	ATLAS (7 TeV)	CMS (8 TeV)
tt+jets reweighting	-----	Top p_T reweighting to NNLO predictions (uncertainty by halving/ doubling the correction)
tt+jets uncertainty	Factorization $Q^2 = \sum(m^2+p_T{}^2)$ varied up and down by x2. Also compare to x_1x_2s (larger). tt+HF fraction assigned 50% uncertainty. Renormalization scale independently up and down by x2 at each vertex (LF only)	Scale variations (factorization and renormalization) varied up and down by x2 (separately for ttbb/ttcc/tt light) + extra 50% for tt+HF

CDF 0-lepton background estimation

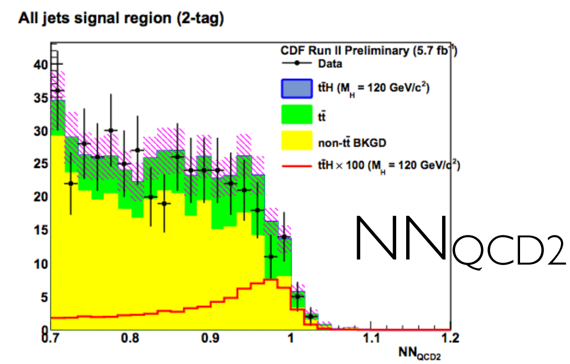
- Use neural networks trained with no b-tag requirement to separate QCD from signal (separately for each channel)
  - Variables include METsignificance, angles, jet E_T, invariant masses
- Missing lepton: Require $NN_{QCD} > 0.8$
- All-jets: Require $NN_{QCD1} > 0.9$, $NN_{QCD2} > 0.7$



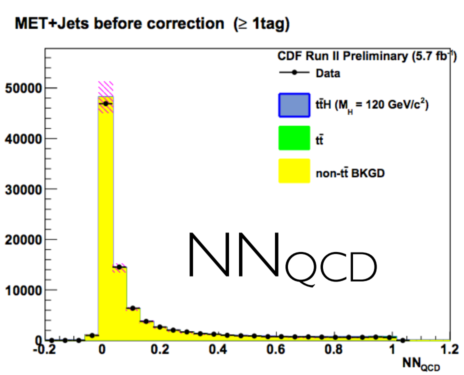
(b) 2-tag (Pre-signal)



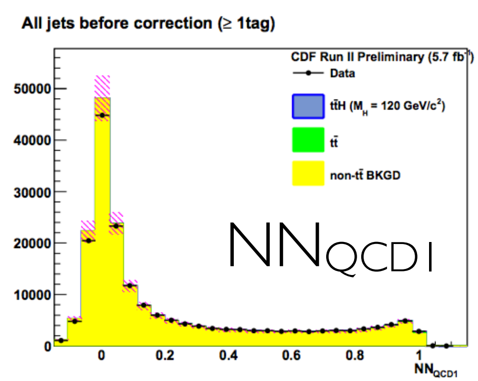
(c) 3-tag (Pre-signal)



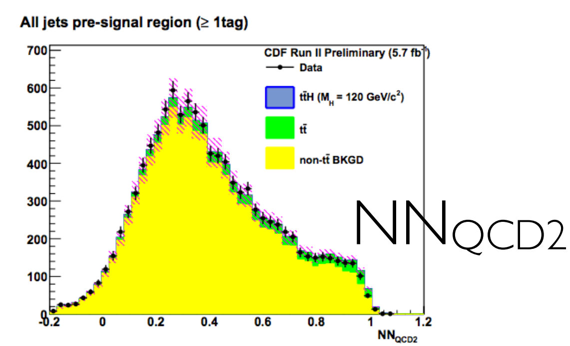
(b) 2-tag (Signal)



(a) Inclusive tagged sample



(a) Inclusive tagged sample



(a) Inclusive tagged sample (Pre-signal)