ttH(H->bb) searches in ATLAS and CMS

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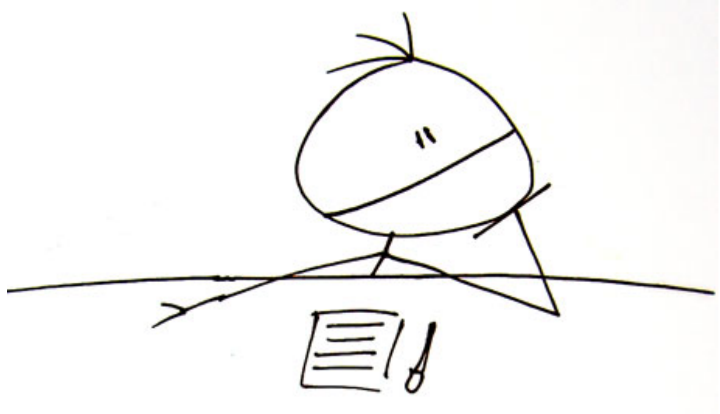
Collider Cross Talk, 18 October 2012

Why?



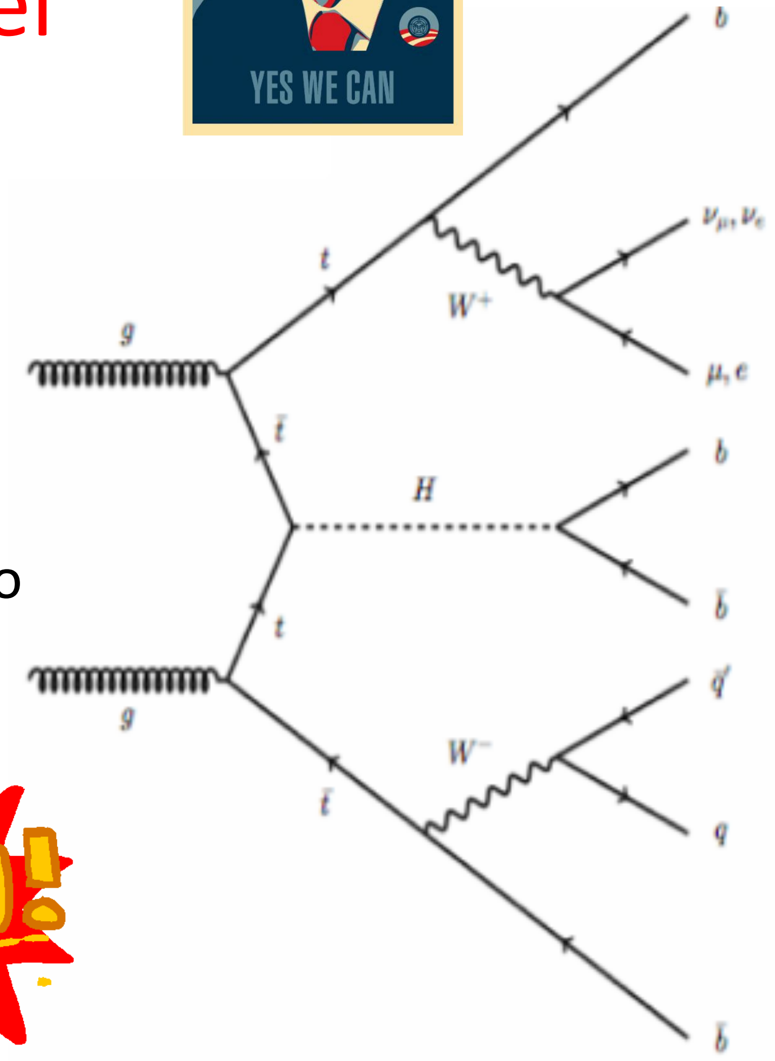
- If ***particle X*** is the Standard Model Higgs, then we need to see fermionic couplings
- ttH, H->bb depends on couplings to two heaviest fermions in SM – large mass => large coupling
- Clear interest in measuring top Yukawa couplings at tree level, with no additional assumptions
- Can only be done in ttH
- Can access ttH, H→anything given enough lumi - Foremost is ttH, H→bb

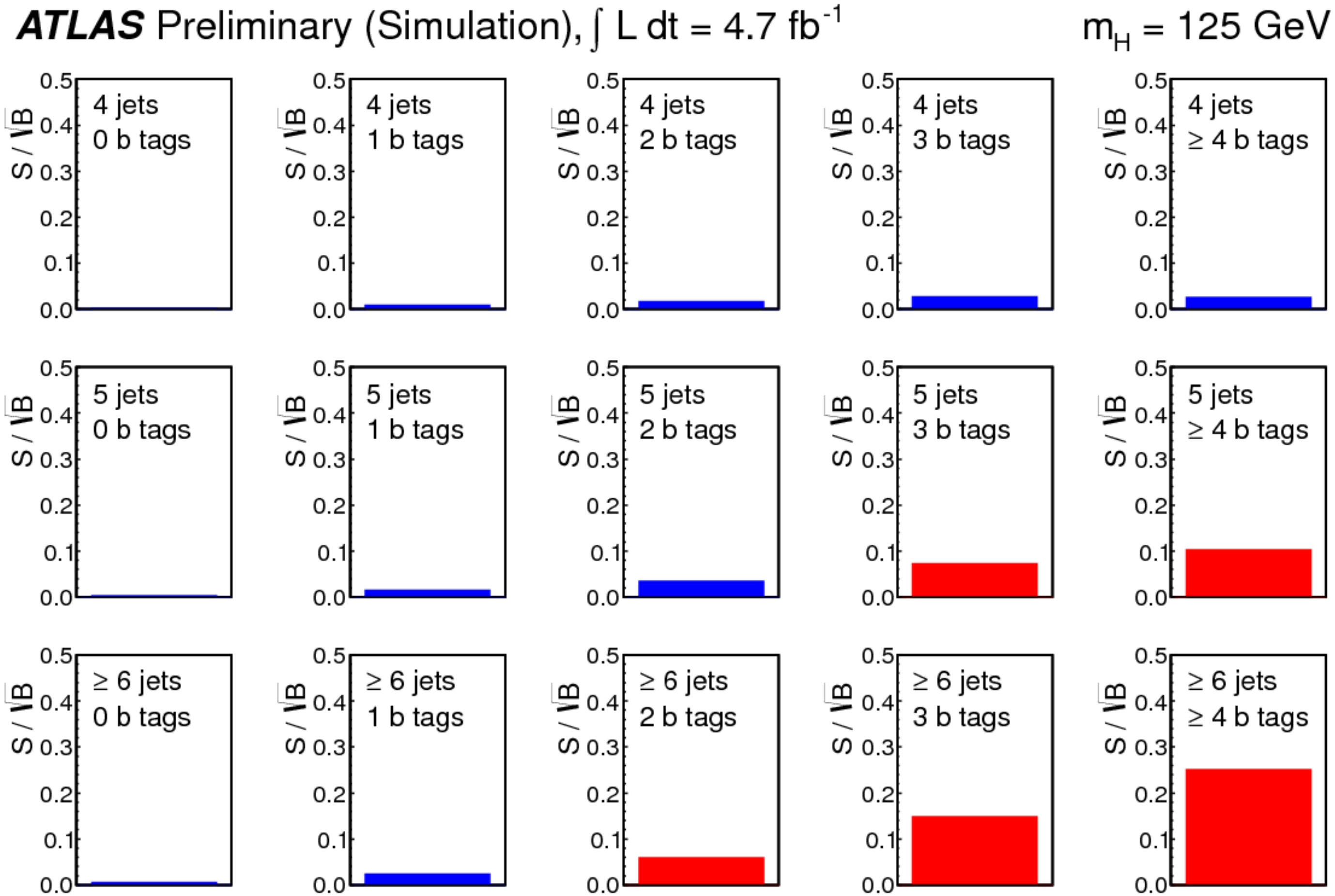
Early LHC ttH analyses:

A **yes we can!** channel

- First LHC results shown by **CMS** at ICHEP
  - CMS-PAS-HIG-12-025: https://cdsweb.cern.ch/record/1460423/
  - **Single-lepton** and **di-lepton** modes
  - 2011 data (5fb^{-1})

- **ATLAS** released ttH analysis a few weeks ago
  - ATLAS-CONF-2012-135: https://cdsweb.cern.ch/record/1478423
  - **Single-lepton** mode
  - 4.7fb^{-1} of 2011 data

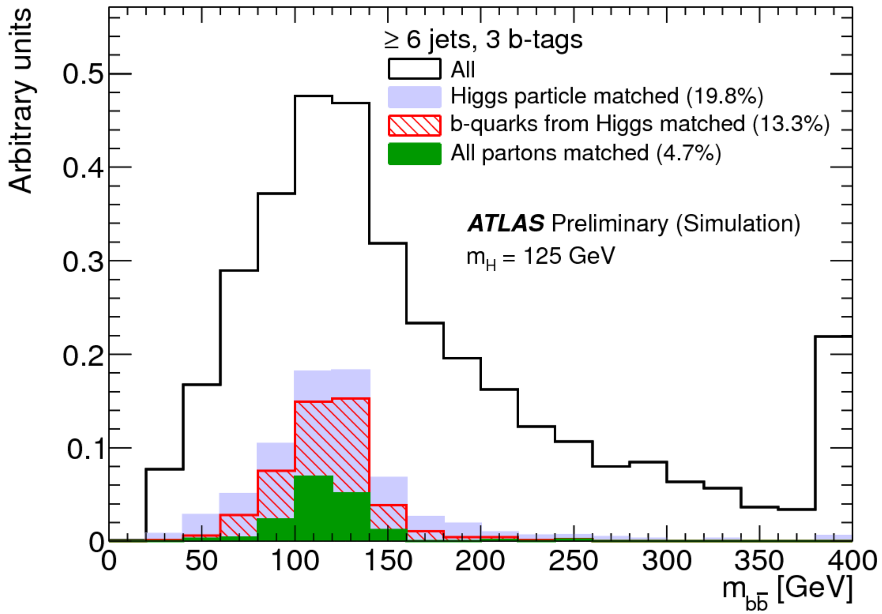



ATLAS Preliminary (Simulation), ∫ L dt = 4.7 fb-1
mH = 125 GeV
S / √B
0.5
0.4
0.3
0.2
0.1
0.0
4 jets
0 b tags
1 b tags
2 b tags
3 b tags
≥ 4 b tags
5 jets
≥ 6 jets

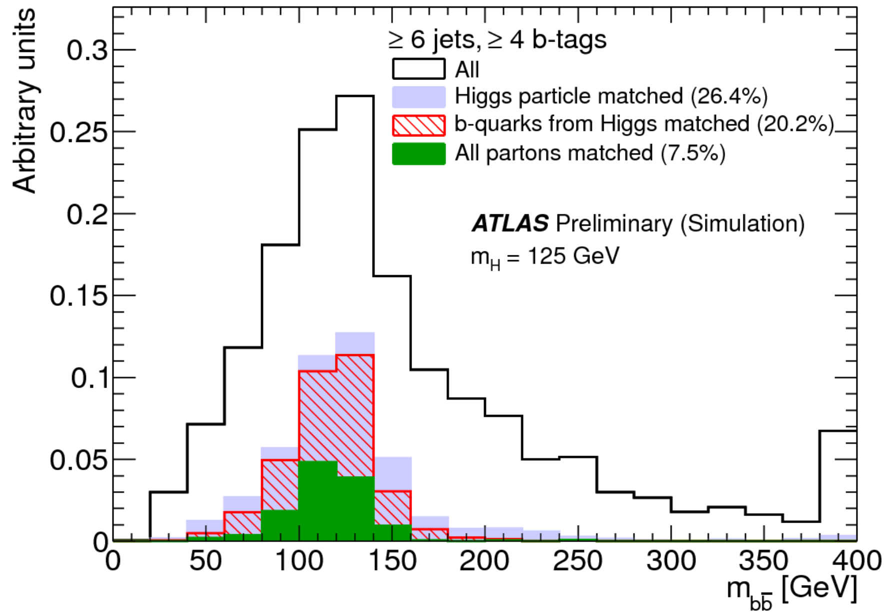
Category	signal (M=125) $H \to bb$	background	$S/\sqrt{B}$
4 jets, 0 tags	0.20	40200	0.001
4 jets, 1 tag	1.1	21240	0.008
4 jets, ≥ 2 tags	3.0	15040	0.02
5 jets, 2 tags	2.7	6640	0.03
≥ 6 jets, 2 tags	3.4	3360	0.06
5 jets, 3 tags	2.3	915	0.08
5 jets, ≥ 4 tags	0.74	45	0.11
≥ 6 jets, 3 tags	4.0	634	0.16
≥ 6 jets, ≥ 4 tags	2.2	62	0.28

Yields after the fit

Thanks Sarah Boutle for this table

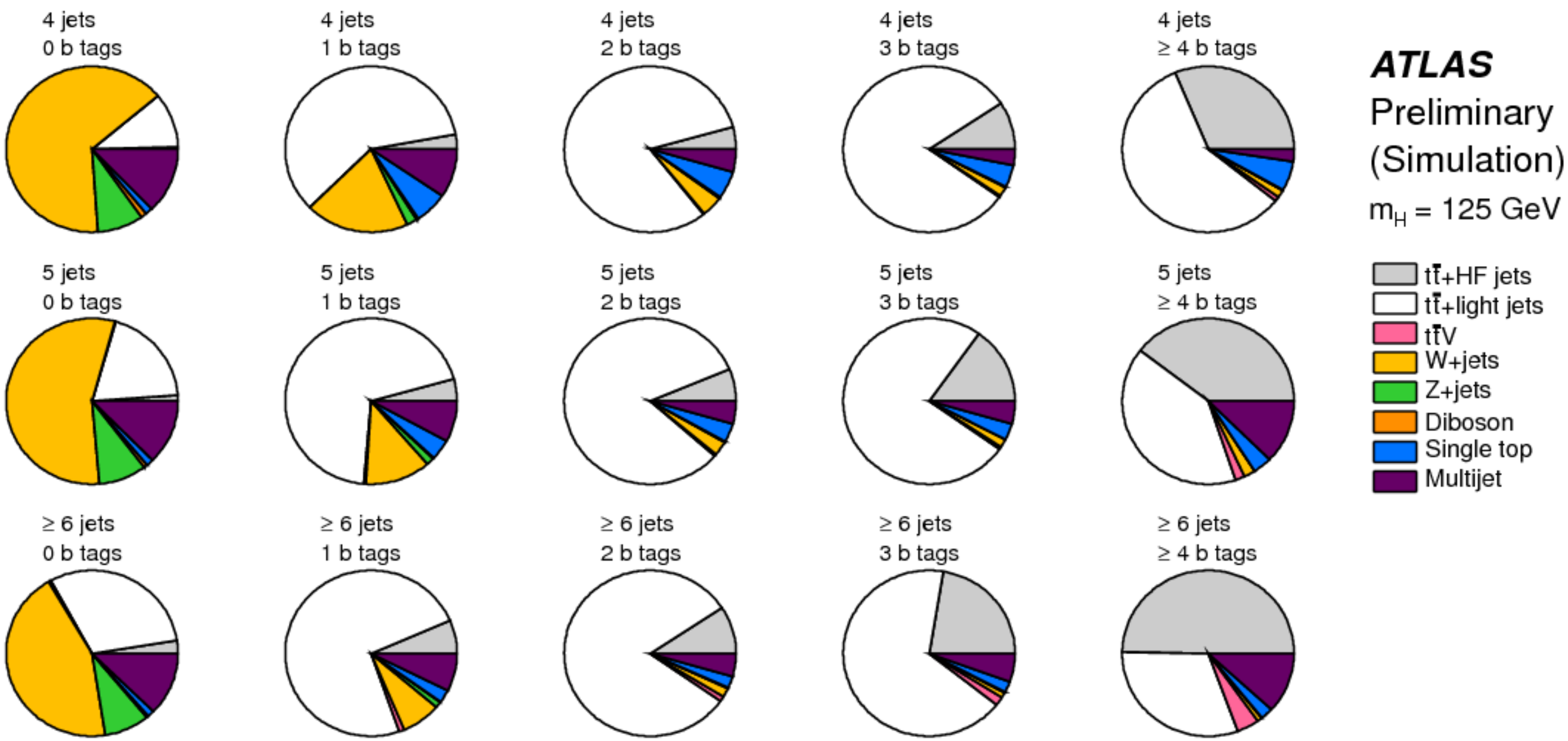


Arbitrary units
≥ 6 jets, 3 b-tags
All
Higgs particle matched (19.8%)
b-quarks from Higgs matched (13.3%)
All partons matched (4.7%)
ATLAS Preliminary (Simulation)
m_H = 125 GeV
$m_{b\bar{b}}$ [GeV]

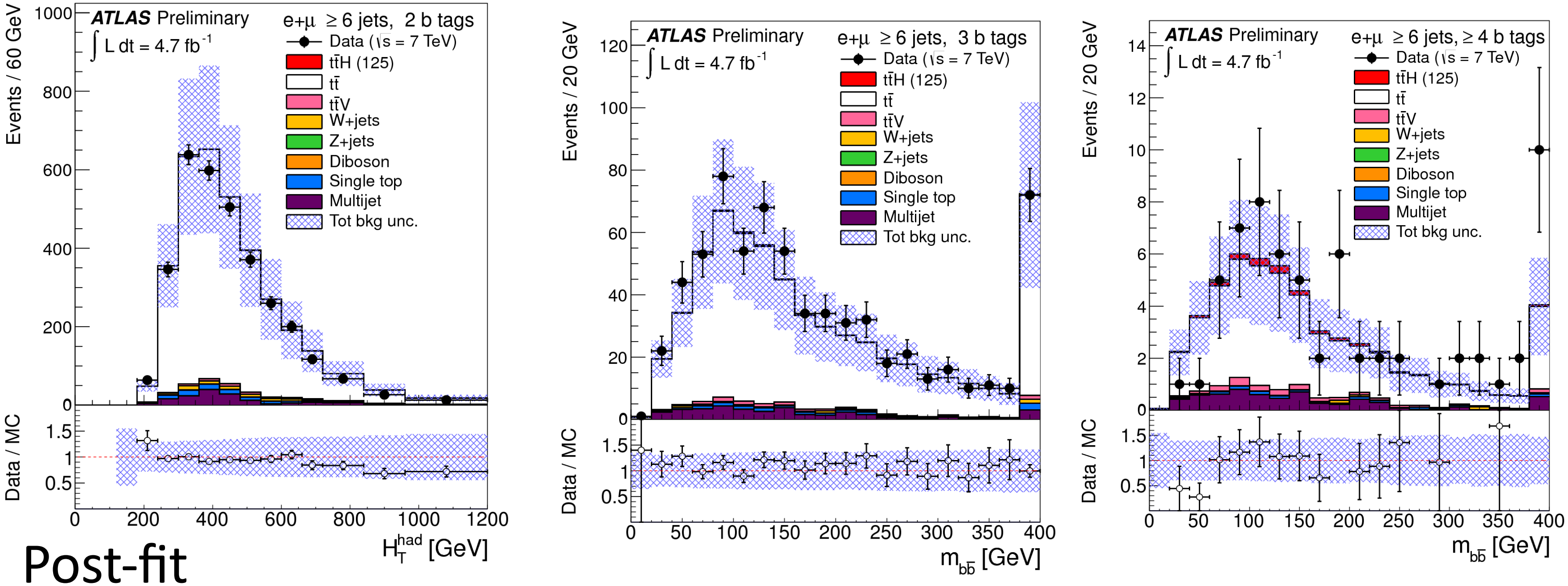


Arbitrary units
≥ 6 jets, ≥ 4 b-tags
All
Higgs particle matched (26.4%)
b-quarks from Higgs matched (20.2%)
All partons matched (7.5%)
ATLAS Preliminary (Simulation)
m_H = 125 GeV
$m_{b\bar{b}}$ [GeV]

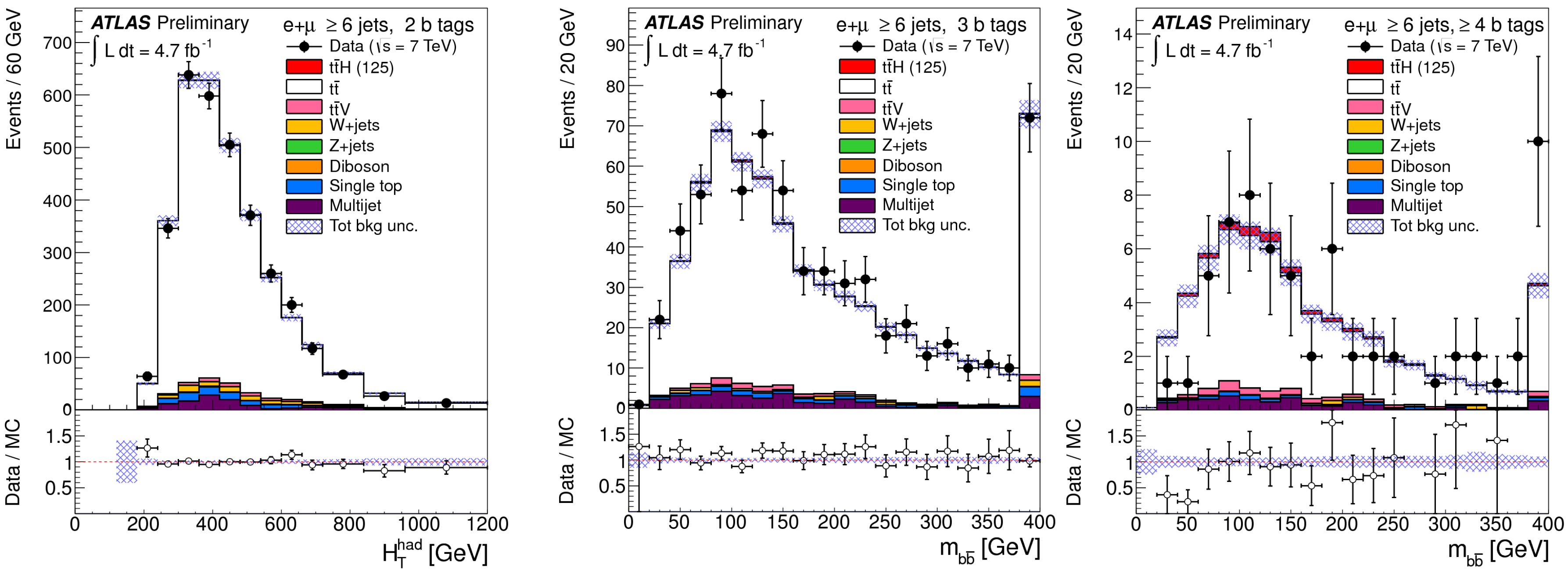
ATLAS Analysis

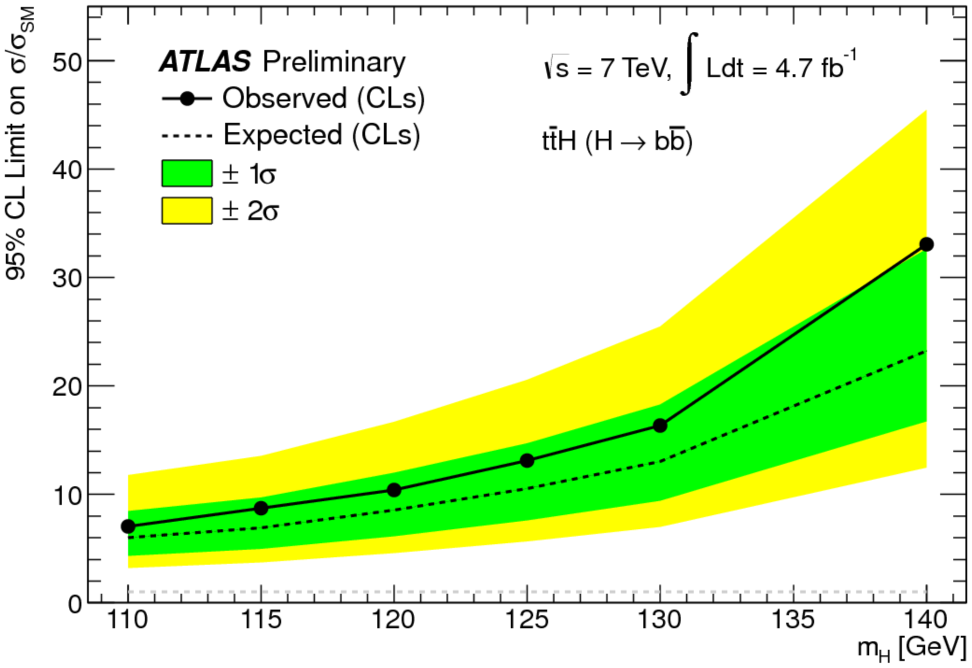


Pre-fit

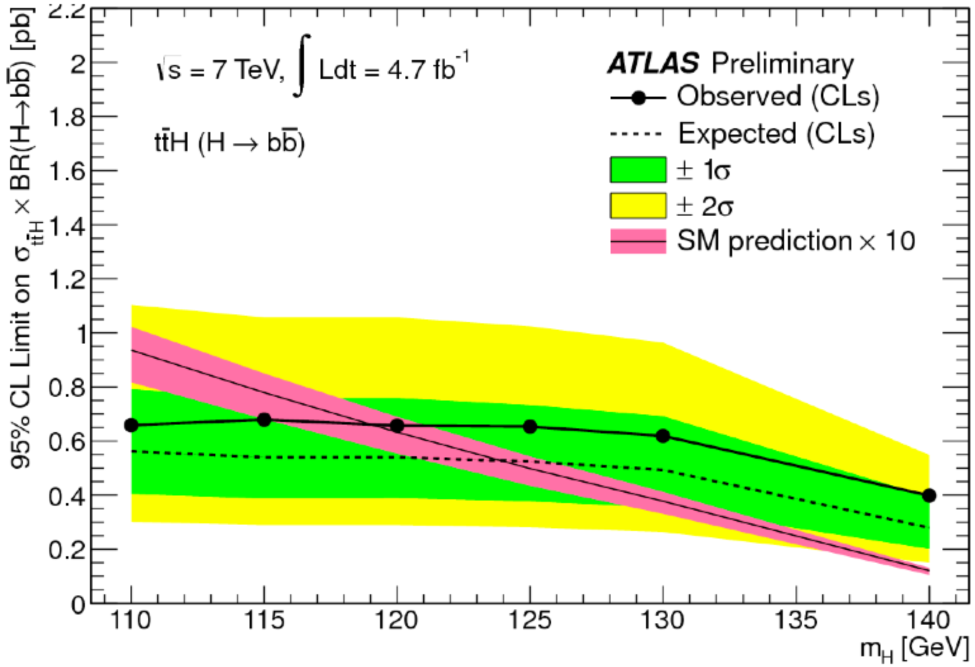


Post-fit





m_H (GeV)	observed	median	stat only
110	7.0	6.0	3.5
115	8.7	6.9	4.0
120	10.4	8.5	4.9
125	13.1	10.5	6.1
130	16.4	13.0	7.8
140	33.0	23.2	14.2



Expected event yields in each Lepton plus jets category in 5 fb^{-1}

Category	signal (M=120) H→anything	background	S/√B
≥ 6 jets, 2 tags	6.3	2255.8	0.13
4 jets, 3 tags	3.5	1041.6	0.11
5 jets, 3 tags	4.7	666.7	0.18
≥ 6 jets, 3 tags	4.4	404.9	0.22
4 jets, ≥ 4 tags	0.5	20.0	0.11
5 jets, ≥ 4 tags	1.2	31.8	0.21
≥ 6 jets, ≥ 4 tags	1.7	39.3	0.27

- **Included also, the dilepton channel**
  - μμ, ee, eμ channels
  - Require 1 tight muon/electron (20 GeV) and 1 loose muon/electron (10,15 GeV), at least 2 jets (30GeV) and 2 b-tags

Expected event yields in each Dilepton category in 5 fb^{-1}

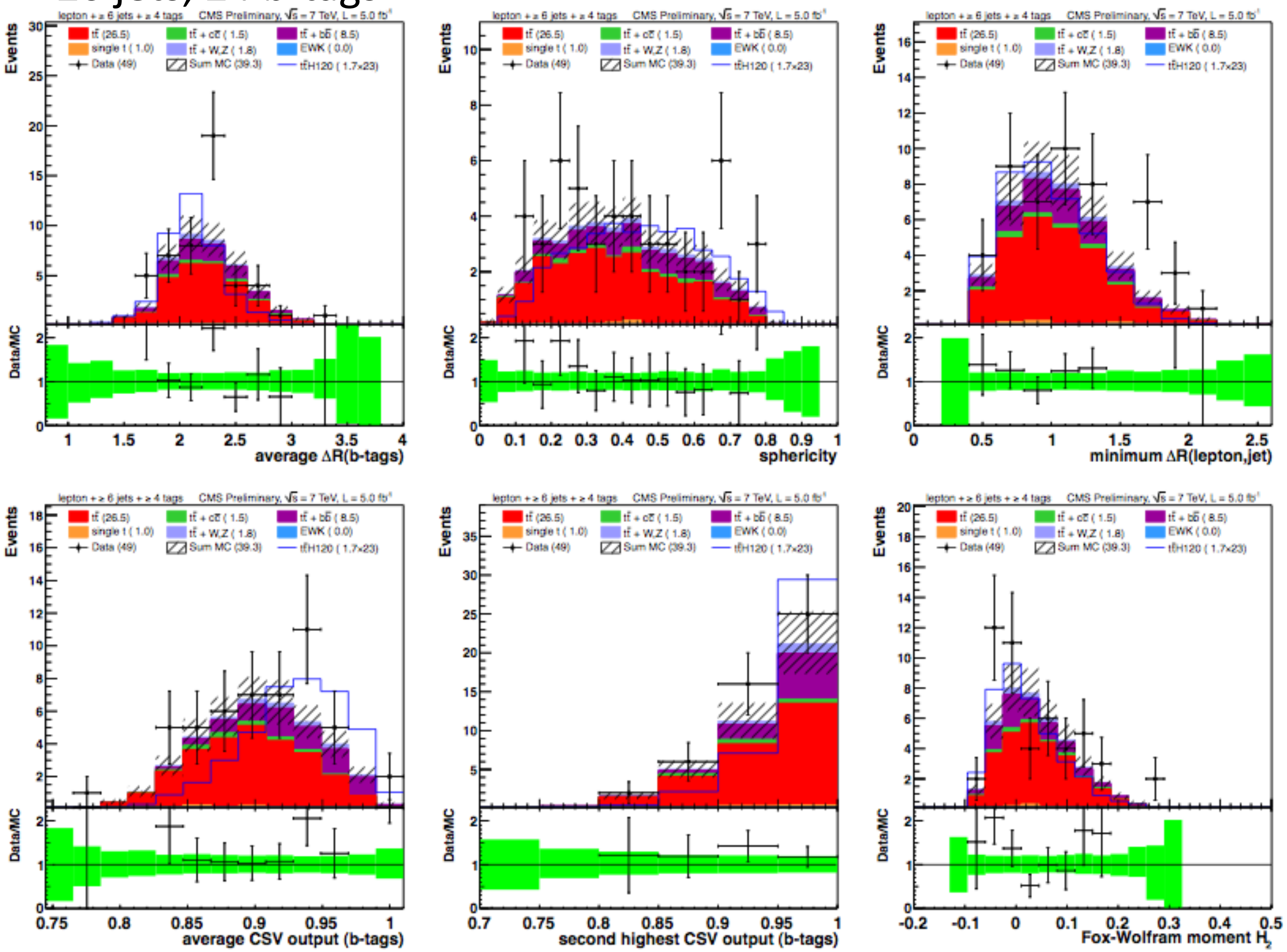
Category	signal (M=120) H→anything	background	S/√B
2 jets, 2 tags	0.7	4306.0	0.01
≥ 3 jets, ≥ 3 tags	2.9	167.6	0.22

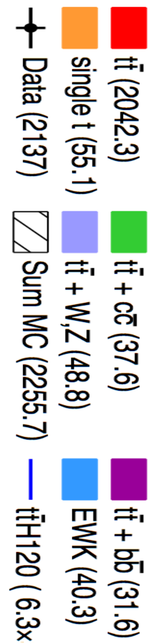
Thanks Sarah Boutle

CMS Analysis

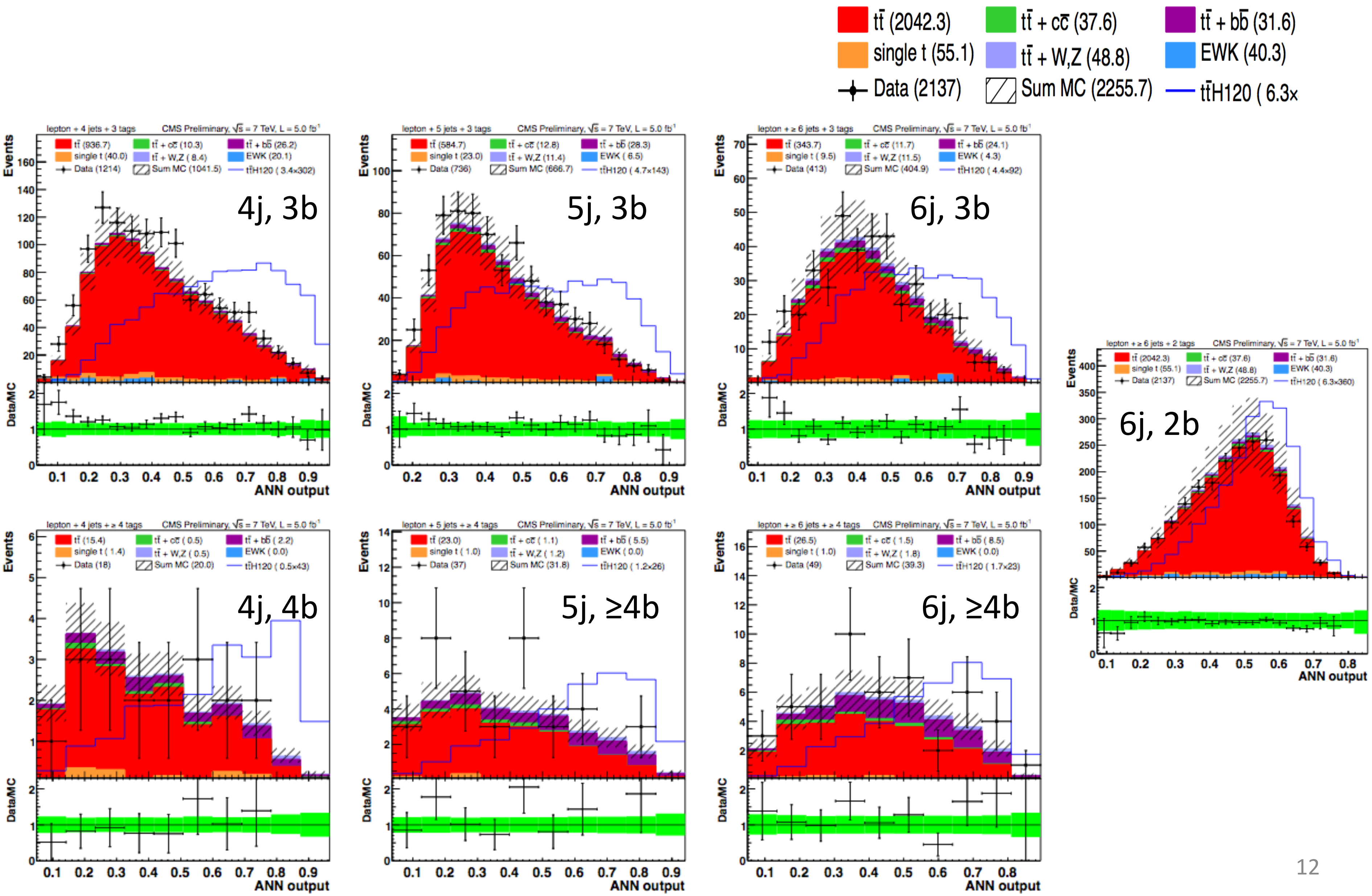
- Neural-net based analysis of 2011 data
- Separate events into categories of #jets and #b-tagged jets
- 10 best kinematic/event shape/b-tagging variables chosen from "pool of candidates"
- Optimized for each #jets/#b-tags category
- Simultaneous fit for S and B on NN output distributions

≥6 jets, ≥4 b-tags



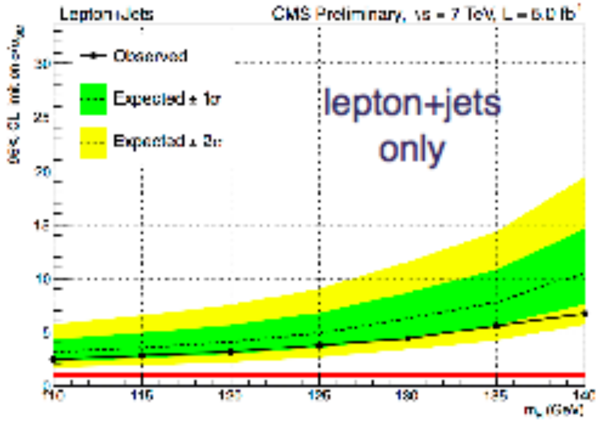


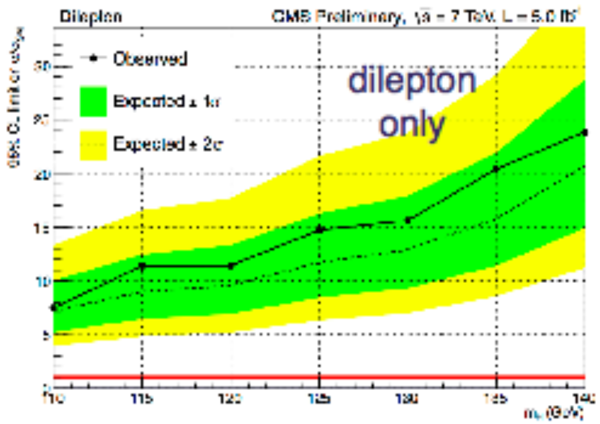
CMS Analysis: Neural Net Output

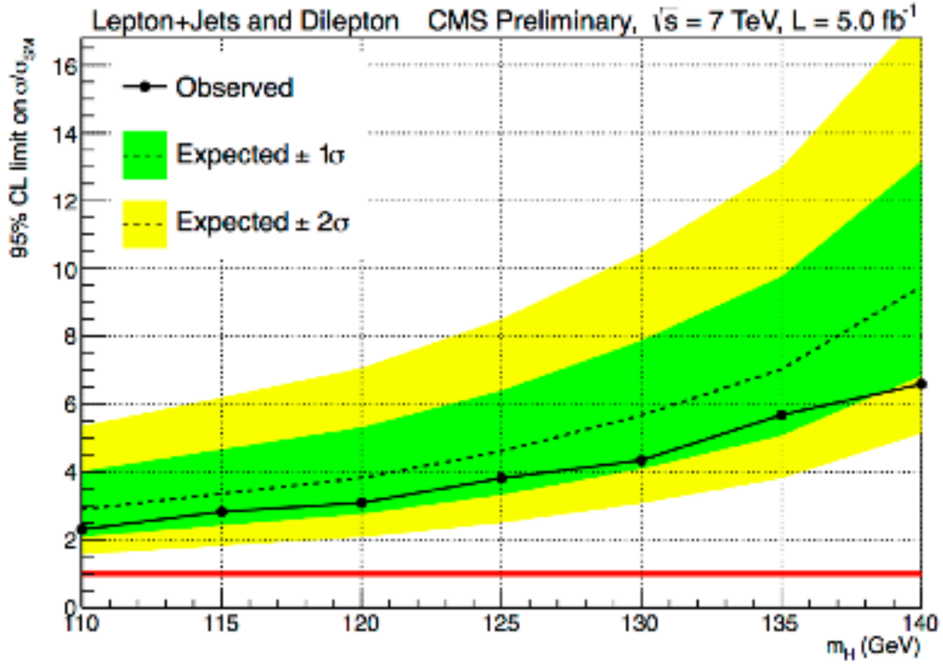


At Higg's mass 125 GeV

- expect to set a limit of 4.6 x σ_{SM}
- observed upper limit: 3.8 x σ_{SM}

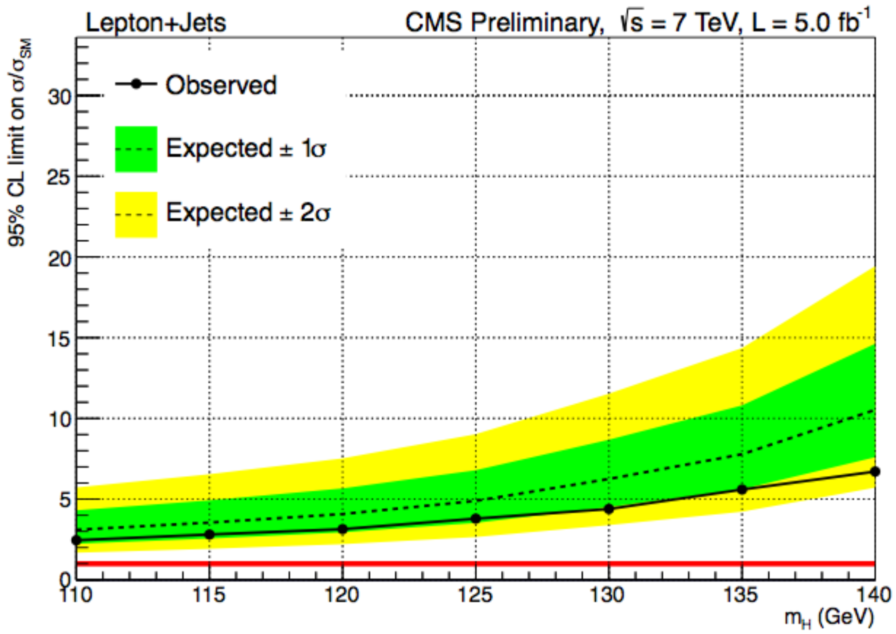






Source	Rate	Shape?	Notes
Luminosity	2.2%	No	All signal and backgrounds
Lepton ID/Trig	1.8%	No	All signal and backgrounds
Pileup	1%	No	All signal and backgrounds
Jet Energy Resolution	1.5%	No	All signal and backgrounds
Jet Energy Scale	0-66%	Yes	All signal and backgrounds
QCD Scale ($t\bar{t}H$)	12.5%	No	Scale uncertainty for NLO $t\bar{t}H$ prediction
QCD Scale ($t\bar{t}$)	2-12%	No	Scale uncertainty for NLO $t\bar{t}$, $t\bar{t}V$, and single top predictions
QCD Scale (V)	1.2-1.3%	No	Scale uncertainty for NNLO W and Z prediction
QCD Scale (VV)	3.5%	No	Scale uncertainty for NLO diboson prediction
pdf (gg)	9%	No	Pdf uncertainty for gg initiated processes ($t\bar{t}$, $t\bar{t}Z$, $t\bar{t}H$)
pdf ($q\bar{q}$)	4.2-7%	No	Pdf uncertainty for $q\bar{q}$ initiated processes ($t\bar{t}V$, W, Z)
pdf (qg)	4.6%	No	Pdf uncertainty for qg initiated processes (single top)
Factorization scale ($t\bar{t}$)	0-20%	Yes	Uncorrelated between $t\bar{t}$+jets/$b\bar{b}$/$c\bar{c}$; varies by jet bin
Factorization scale (V)	20-60%	No	Varies by jet bin
b-Tag SF (b/c)	0-15.2%	Yes	All signal and backgrounds
b-Tag SF (mistag)	0-10.6%	Yes	All signal and backgrounds

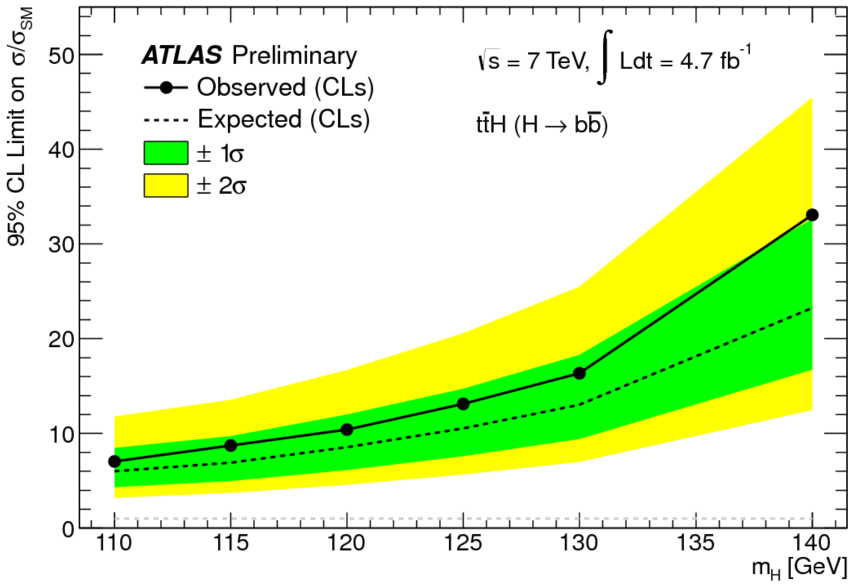
CMS



m_H (GeV/c^2)	Obs limit	Median Exp limit
110	2.5	3.1
115	2.8	3.6
120	3.1	4.1
125	3.8	4.9
130	4.4	6.3
135	5.6	7.8
140	6.7	10.5

Lepton+jets mode

ATLAS



m_H (GeV)	observed	median	stat only
110	7.0	6.0	3.5
115	8.7	6.9	4.0
120	10.4	8.5	4.9
125	13.1	10.5	6.1
130	16.4	13.0	7.8
140	33.0	23.2	14.2

Very big difference!...

Bonus slides

ATLAS & CMS Selection (l+jets)

ATLAS	CMS
e: p_T>25GeV |η|<2.5	e: p_T>30GeV |η|<2.5
μ: p_T>20GeV |η|<2.5	μ: p_T>30GeV |η|<2.1
jets: (0.4): p_T>30GeV / 40GeV	Jets (0.5): p_T>30/40GeV |η|<2.4
B-tag: 70% (b) 20% (c) 0.8% (lite)	B-tag: 70% (b) 20% (c) 2% (lite)
e ch.: E_T^{miss} > 30 GeV M_T^W > 30GeV	
μ ch.: E_T^{miss}> 20GeV E_T^{miss}+M_T^W > 60GeV	

Data-driven background detemination

- **Multijets (5.6 e and 0.6 μ)**
  - Matrix Method (MM): "tight" and "loose" where tight is subset of loose

$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$$
$$N^{tight} = \varepsilon_{real} N^{loose}_{real} + \varepsilon_{fake} N^{loose}_{fake}$$

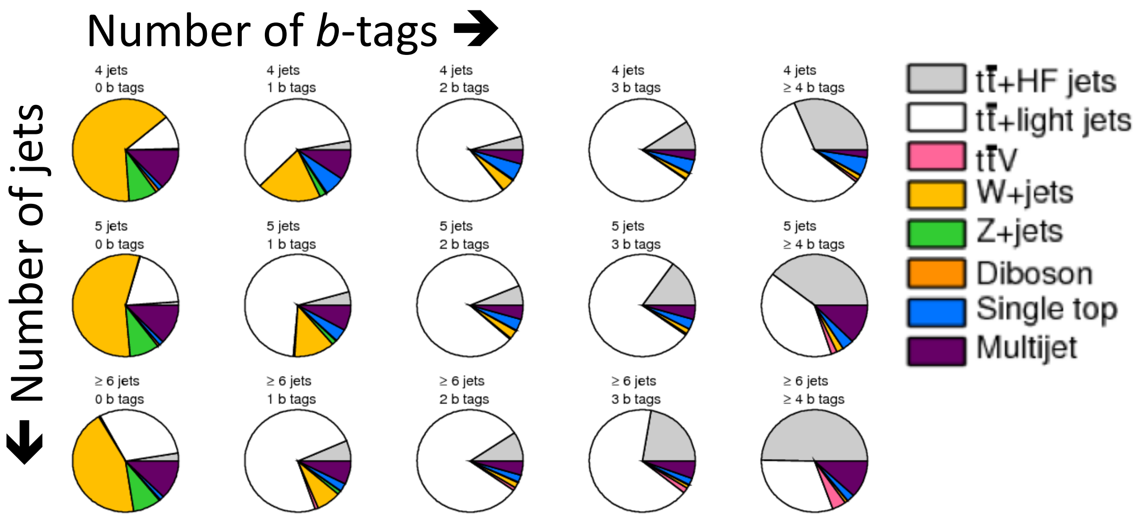
  - Problem: correlated with data and statistics low with more than 2 b tags.
  - Solution: Use $N_b \geq 2$ to get shape and matrix method in each region to get rate.

- **W+ jets (0.55)**
  - Exploit asymmetry in W^+ & W^- (ATL-COM-PHYS-2012-1197):
  - Measure $(N_{W+} - N_{W-})_{meas}$, use $r_{MC} = W^+/W^-$ to get $N_W = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(N_{W+} - N_{W-})_{meas}$.
  - Flavour fractions from:
  - $N^{W^\pm,tag} = N^{W^\pm,pre-tag}(P_{bb}F_{W^\pm bb} + P_{bb}F_{W^\pm cc} + P_{bb}F_{W^\pm c} + P_{bb}F_{W^\pm light})$
  - $F_{W^\pm bb} + F_{W^\pm cc} + F_{W^\pm c} + F_{W^\pm light} = 1$
  - 20% correction to pre-tag sample
  - $W_{b\bar{b}}$,$W_{c\bar{c}}$, W_c, W+light jets also in similar way from data.
  - Scale $W_{b\bar{b}}$,$W_{c\bar{c}}$, by 1.13(1.22) for e (μ).
  - Scale W_c by K=1.52 and then 0.88(0.95) for e (μ).
  - Preserve normalisation: Scale W+light by 1.01(0.98) for e (μ).

Profiling

Parameters strongly constrained:

- W+jets and QCD normalization, tt , b-tag:
  - 4 jet channels
- W+jet and tt:
  - 4 jet 0b (W+jet), 4 jet 1b and 2b
- b tagging:
  - 4 jet evolution across the number of b-tags
- tt modelling and rate uncertainties:
  - 4, 5 and 6 jets with 2 b-tags
- tt+HF fraction:
  - 5 channels with 3 and 4 b-tags



Ordered nuisance parameters:

Level	Most Important	σ/σ_{SM}
N	Start	12.19
N-1	ttbar HF	9.77
N-2	Ltag	9.40
N-3	Ctag	8.08
N-4	QCD Norm	7.09
N-5	JES	6.94
All	Stat	6.10

- Effect of each systematic uncertainty evaluated with "N-1" test (and "N-m"):
  - Remove one, put back, remove next…
  - Largest impact: freeze (parameter set to the best fitted value) and repeat

Systematic Uncertainties

- **tt+heavy-flavour** fractions: Vary by 50% - theory studies suggest cross section uncertainty is 75% ; should be weighted down by the fraction of this background. Fit puts it at 30%.

- **tt modeling** (Alpgen):
  - **Qfac**: (±2.3%) The factorization scale for the hard scatter is varied by a factor of two up and down relative to the original scale, $Q^2 = \Sigma_{partons} m^2 + p^2_T$
  - **kTfac**: (±9.2%) The renormalisation scale associated with the evaluation of α_s at each local vertex in the matrix element calculation is varied by a factor of two up and down relative to the original scale, k_T , between two partons.
  - Functional form of the factorization scale (**iqopt2**): (± 13%) Default choice (=1) for dynamic factorization scale, $Q^2 = \Sigma_{partons} m^2 + p^2_T$, changed to $Q^2 = x_1 x_2 s$. This has an order of magnitude larger effect than Qfac.

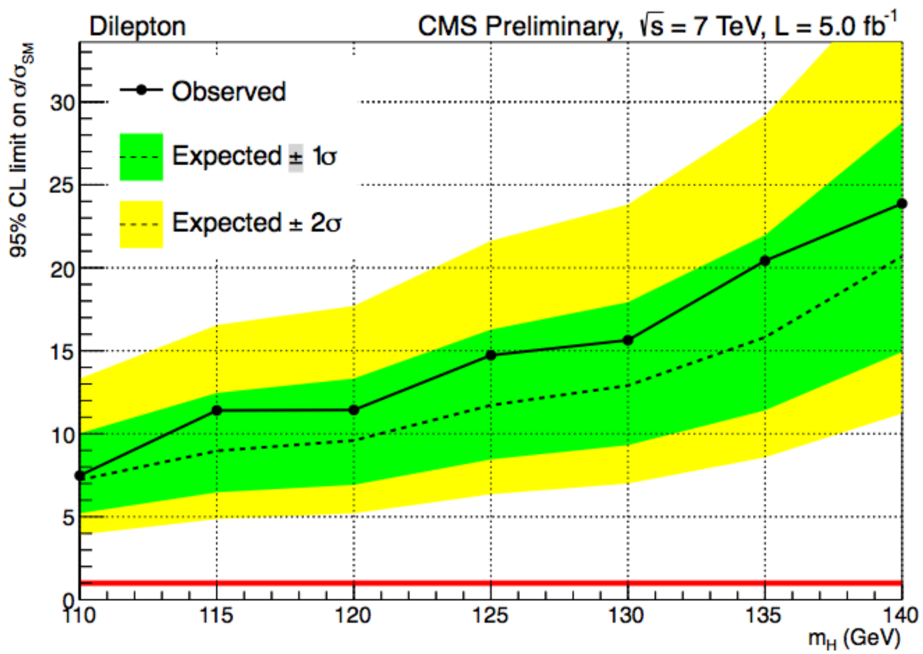
- **tt cross section**: +9.9 -10.7% using NNLO Hathor.

- **Jet Energy scale**: 16 eigenvectors recommended by the jet/ ETmiss group are varied.

- **b, c and light tagging**: 9 (btag),5(ctag) eigenvectors recommended by b-tagging group are varied for heavy flavours and the one value for light flavours.

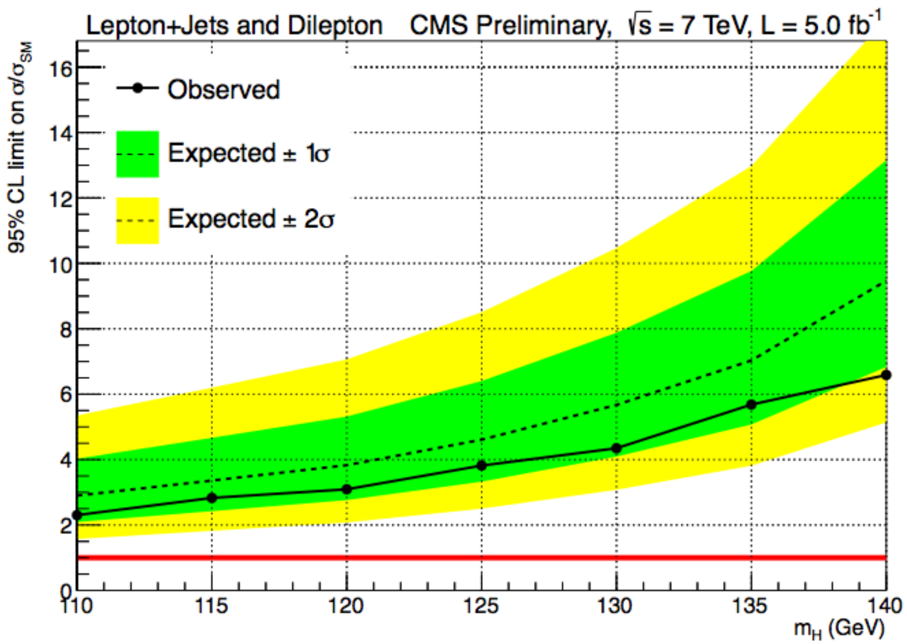
- **QCD Multijets**: Mostly in the electron channel. Correlated 50% uncertainty plus uncorrelated statistical estimate in each channel (66% in 6 jet 4 b-tag)

- **ttH parton shower modelling**: 1-5% effect at mH = 120 GeV



Di-lepton channel

m_H (GeV/c^2)	Obs limit	Median Exp limit
110	7.5	7.2
115	11.4	8.9
120	11.4	9.6
125	14.7	11.7
130	15.6	12.8
135	20.4	15.8
140	23.8	20.6



Single-lepton + Di-lepton channels combined
(di-lepton improves expected limit by 6.5%)

m_H (GeV/c^2)	Obs limit	Median Exp limit
110	2.3	2.9
115	2.8	3.5
120	3.1	3.8
125	3.8	4.6
130	4.4	5.7
135	5.7	7.0
140	6.6	9.5

ATLAS/CMS differences

Systematics:

- No QCD systematics (no QCD background?!)
- No ttH modeling
- No W+jets/HF systematic
- No JVF systematic (pileup suppression)
- Different treatment of Jet Energy Scale (ATLAS 16 NP), b-tag sys. (ATLAS 9 NP) and c-tag sys (ATLAS 5 NP): CMS one Nuis. Par.
- b and c tagging correlated
- One tt systematic uncertainty (ATLAS 3 NP)
- ttbar+HF 20% instead of 50% uncertainty

Summary:

- ATLAS using CMS systematics: 35% better
- 20% improvement from more signal
- Remaining improvement from use of Multivariate analysis (22%)

In numbers:

- σ/σ_{SM} = 10.5 -> 7.8 from systematics
- Take 22% improvement from MVA: -> 6.1
- Take 20% additional signal: σ/σ_{SM} -> 5.1 (expect)
- CMS: 4.9 (expected)

Cuts:

- Electrons and muon:
  - ATLAS p_T>20/25GeV
  - CMS p_T > 30 GeV
- Jets:
  - ATLAS pT>25GeV
  - CMS 3 leading jets pt > 40 GeV (otherwise 30 GeV)
- More signal and higher cuts. Not clear what signal sources are used

Channel	Signal		Background		$S/\sqrt{(B)}$		Ratio: $S/\sqrt{(B)}$
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	CMS/ATLAS
6jet, 2tag	4.45	6.3	3567.38	2255.8	0.0745	0.133	1.78
4jet, 3tag	1.23	3.5	1294.14	1041.6	0.0341	0.108	3.17
5jet, 3tag	2.8	4.7	887.25	666.7	0.0940	0.182	1.94
6jet, 3tag	4.61	4.4	622.88	404.9	0.1847	0.219	1.18
4jet, 4tag	0.16	0.5	19.94	20	0.0358	0.112	3.12
5jet, 4tag	0.83	1.2	38.33	31.8	0.1341	0.213	1.59
6jet, 4tag	2.28	1.7	53.12	39.3	0.3128	0.271	0.86
Total	16.4	22.3			0.4084	0.492	1.20