
Run II Higgs Results & $t\bar{t}H$ Searches

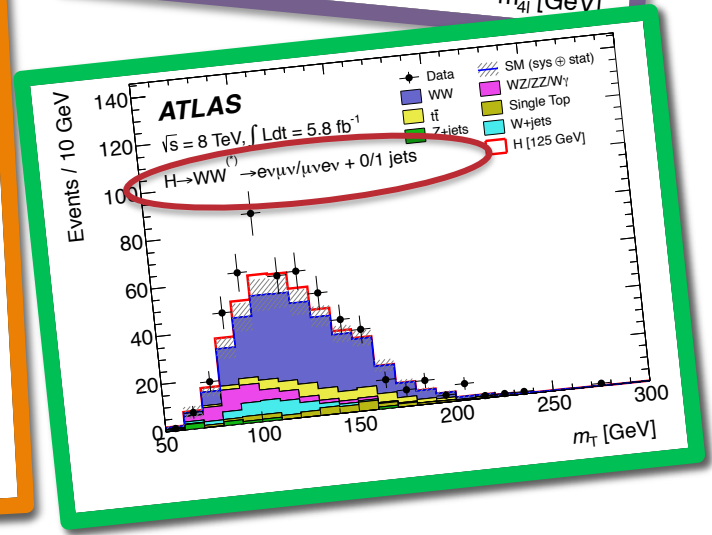
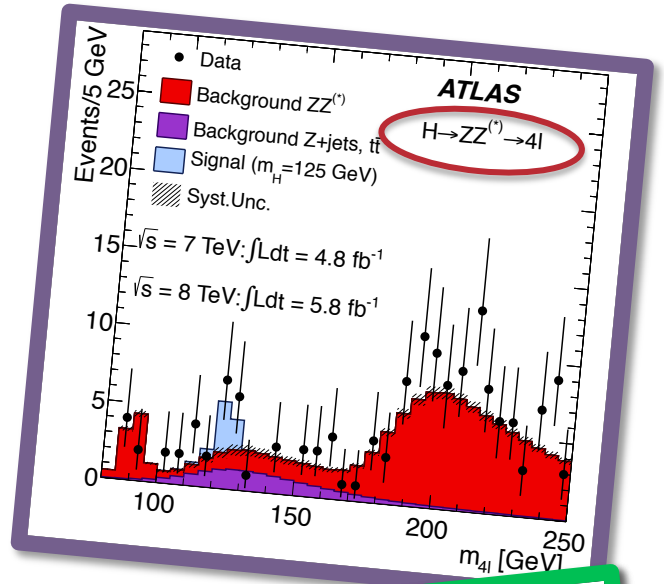
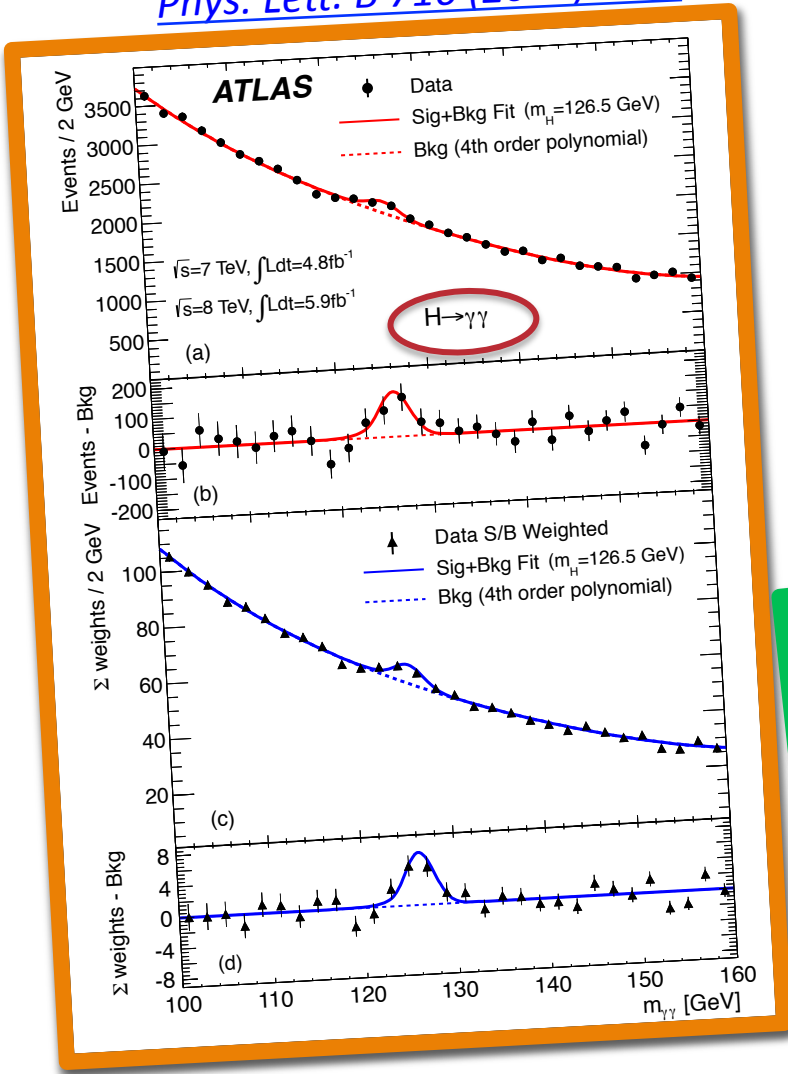
Snežana Nektarijević

Nikhef Jamboree
15/12/15, Amsterdam

Higgs Discovery

- $H \rightarrow \gamma\gamma$
- $H \rightarrow ZZ^{(*)} \rightarrow 4l$
- $H \rightarrow WW^{(*)} \rightarrow e\nu\mu\nu$
/ $\mu\nu e\nu$

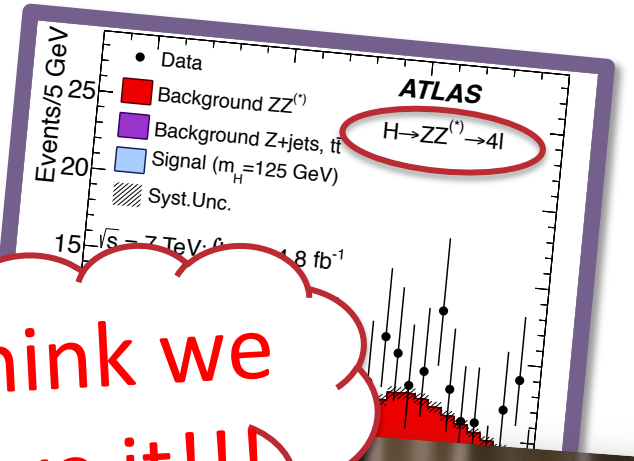
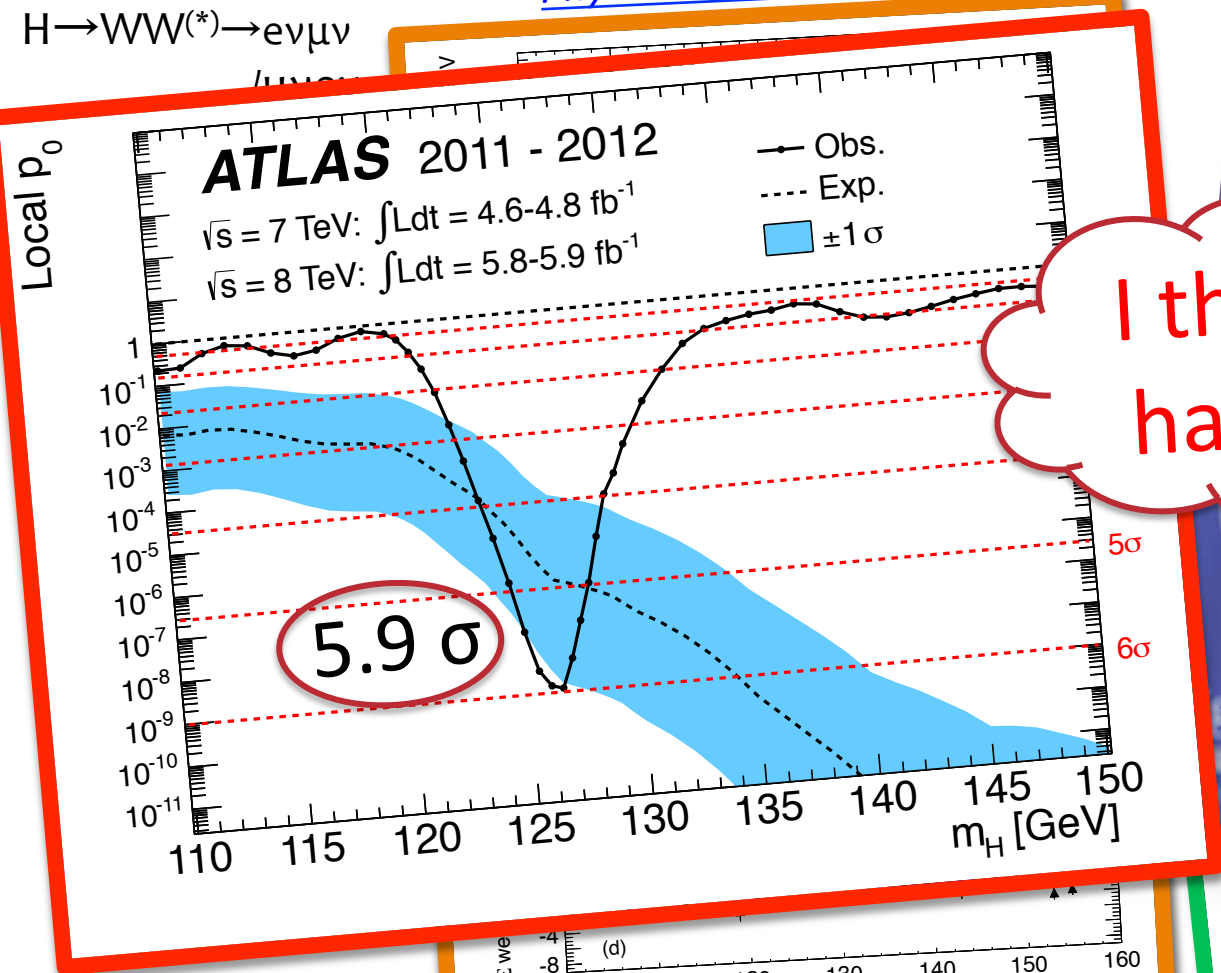
Phys. Lett. B 716 (2012) 1-29



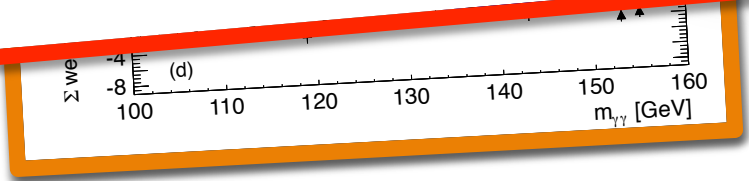
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[Phys. Lett. B 716 \(2012\) 1-29](#)



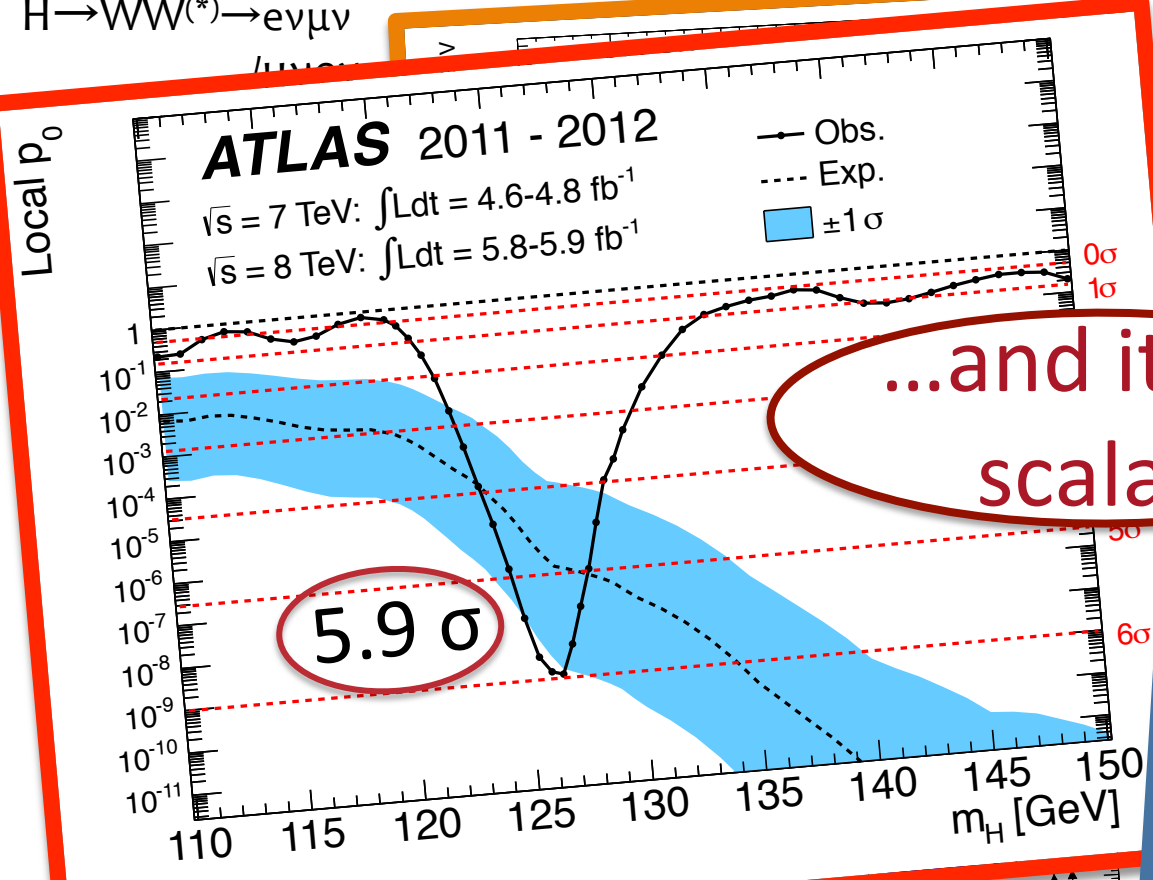
I think we have it!!!



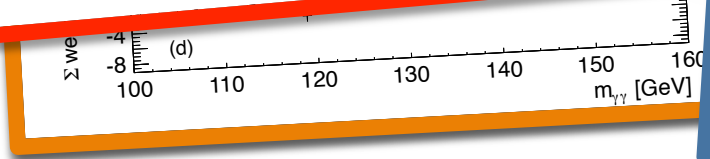
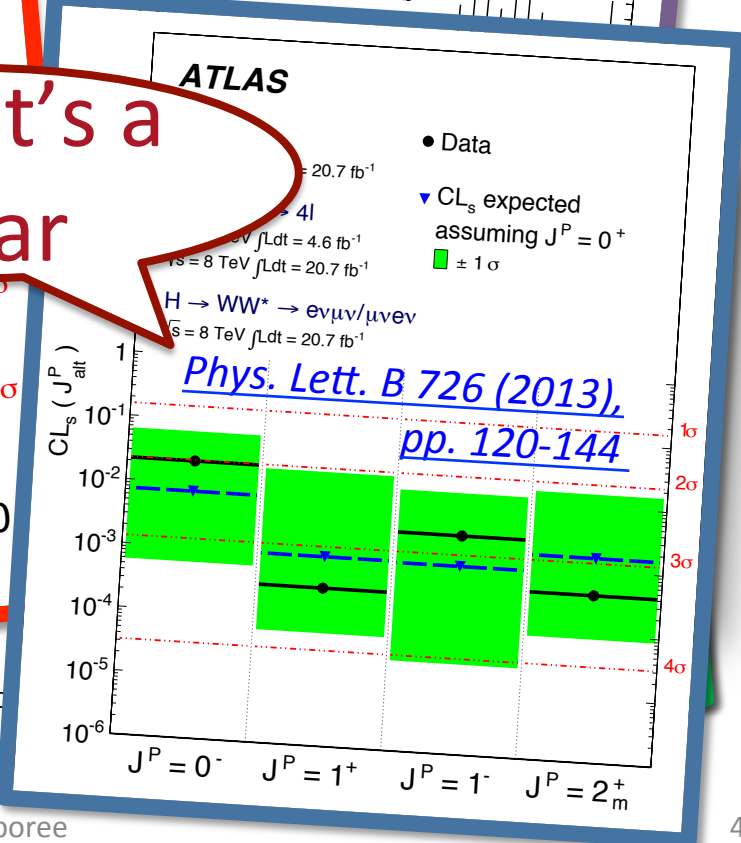
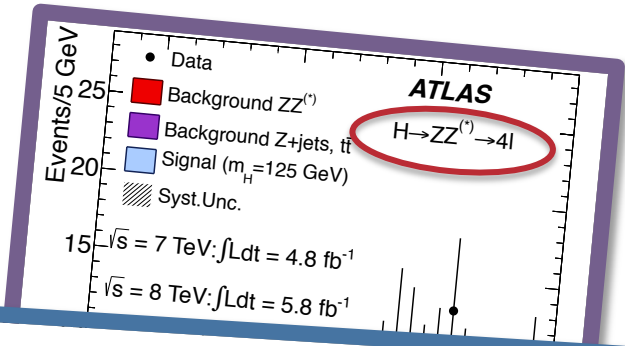
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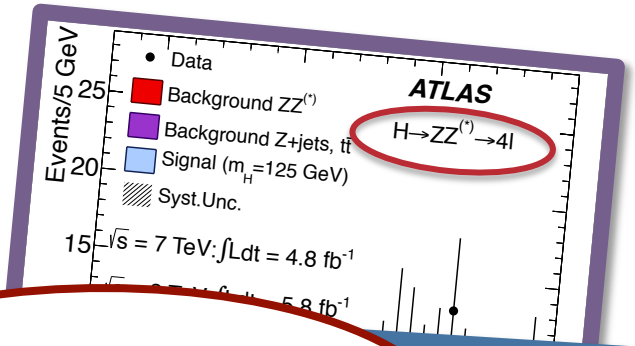
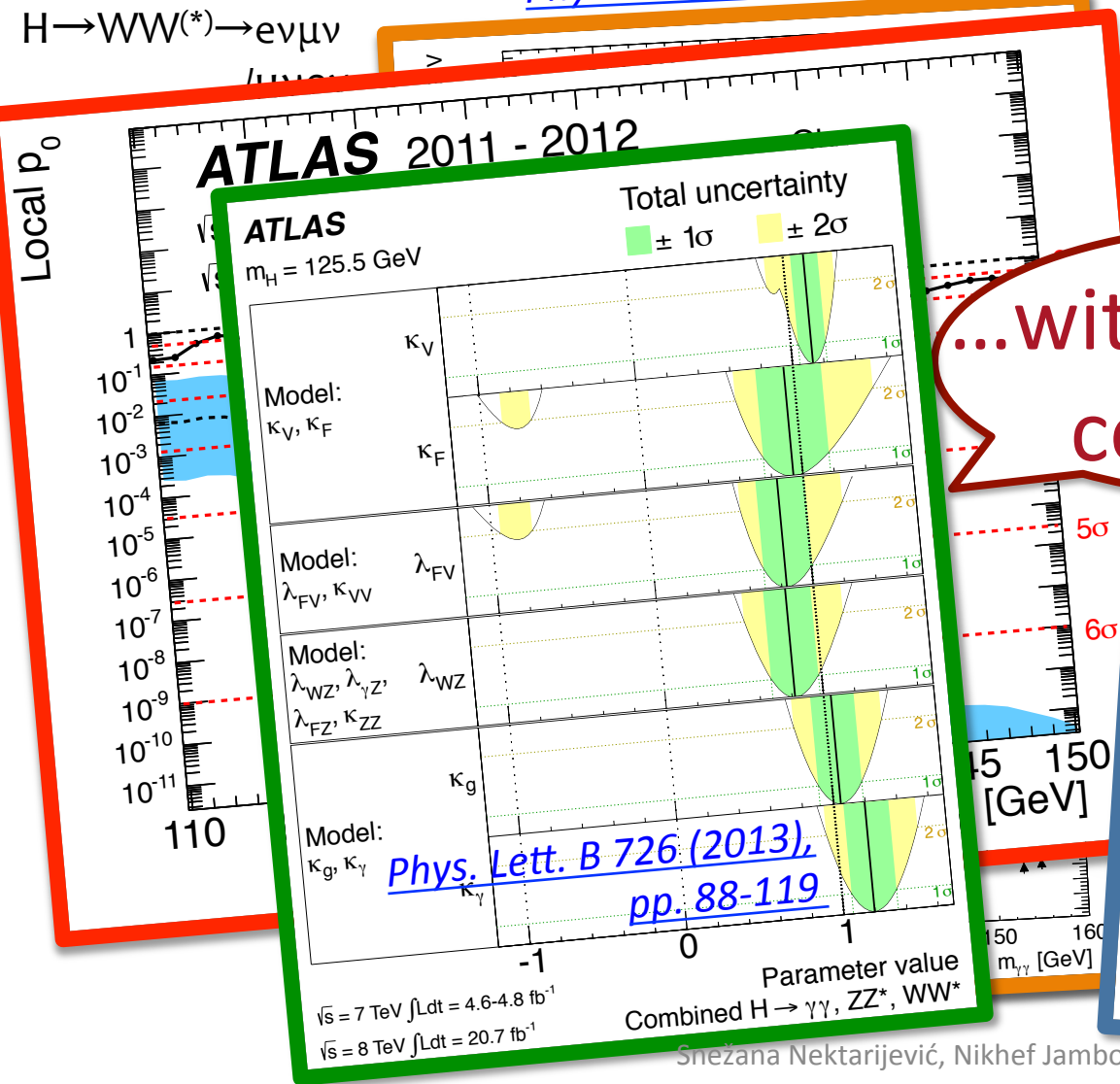
...and it's a scalar



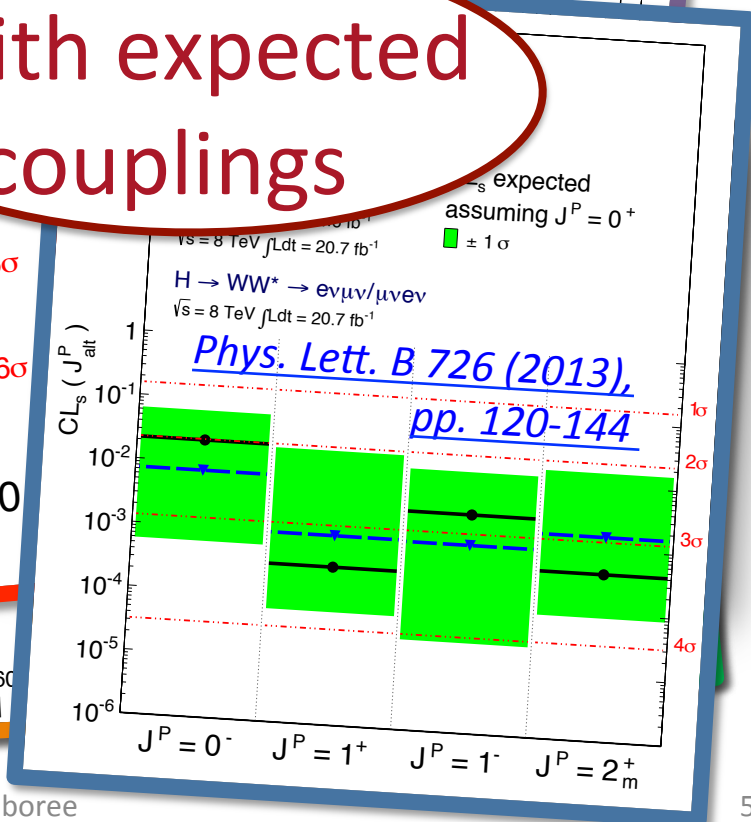
Higgs Discovery

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[Phys. Lett. B 716 \(2012\) 1-29](#)



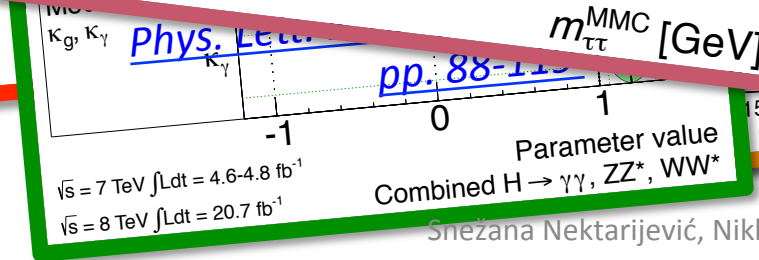
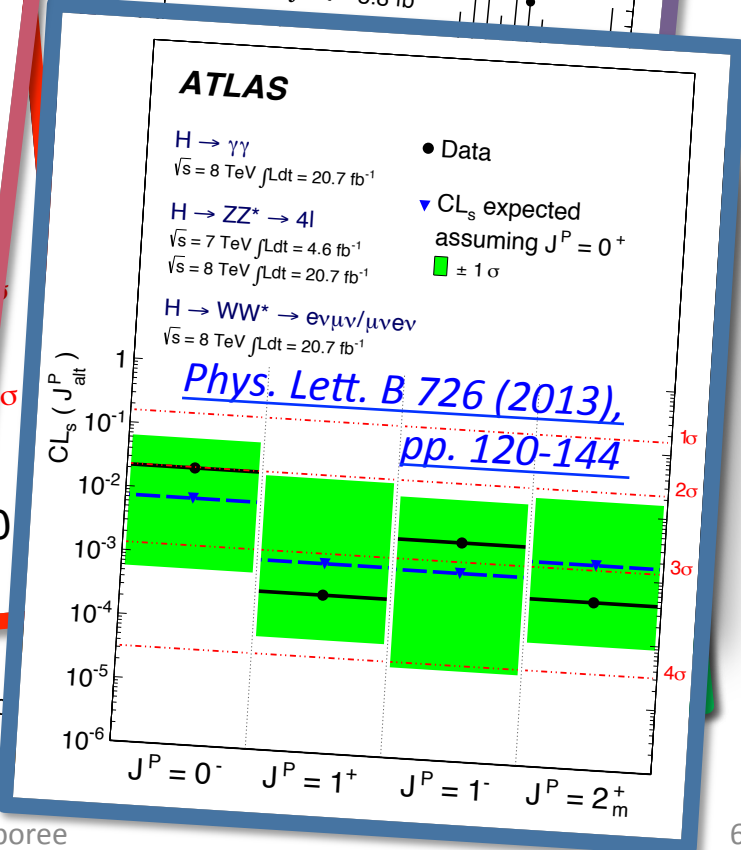
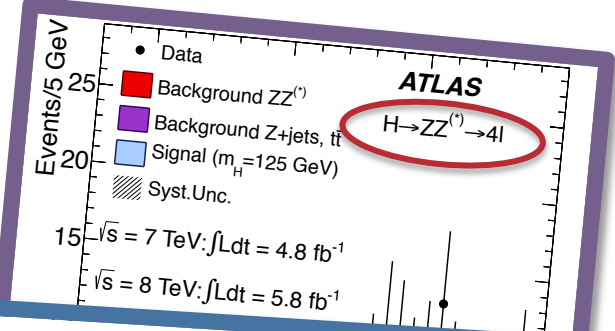
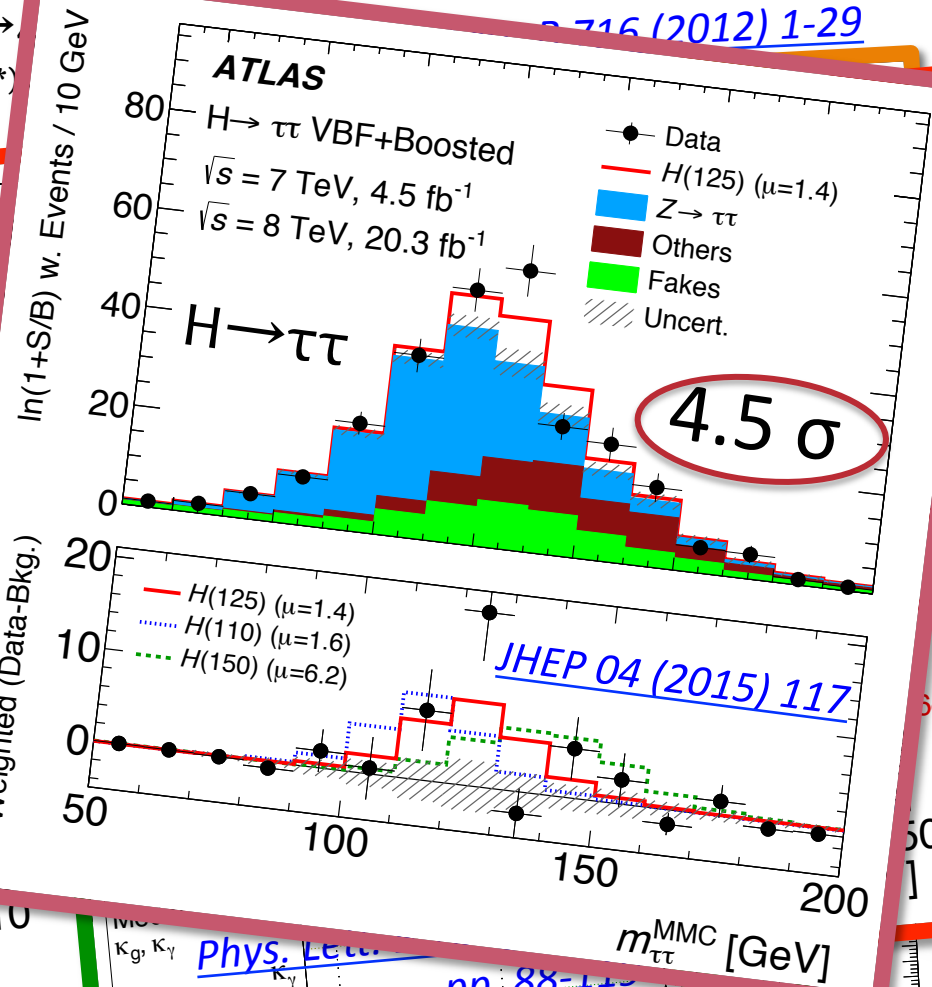
...with expected couplings



Higgs Discovery

$H \rightarrow \gamma\gamma$
 $H \rightarrow ZZ^{(*)} \rightarrow 4l$
 $H \rightarrow WW^{(*)}$

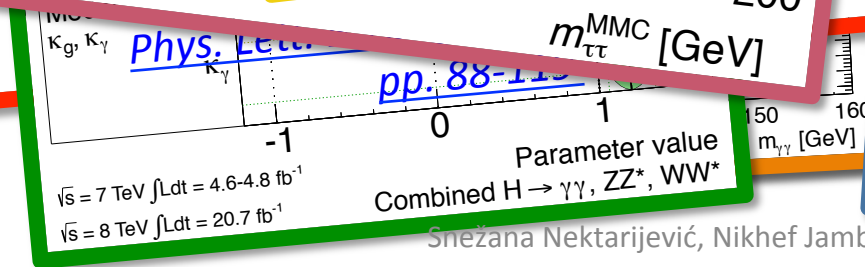
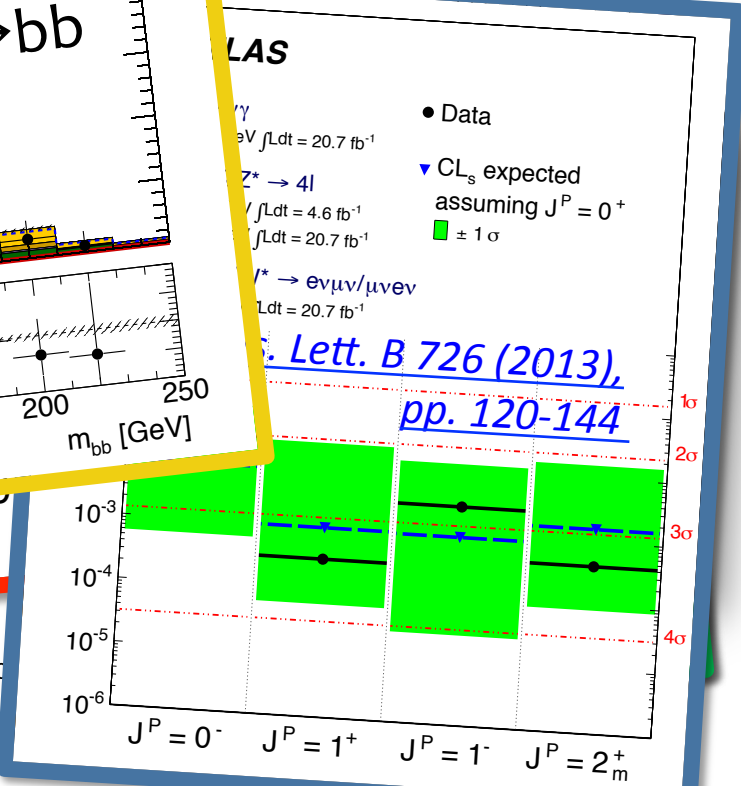
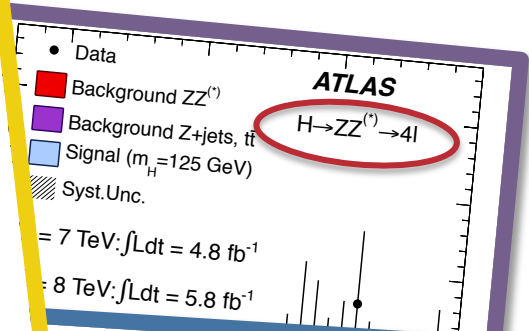
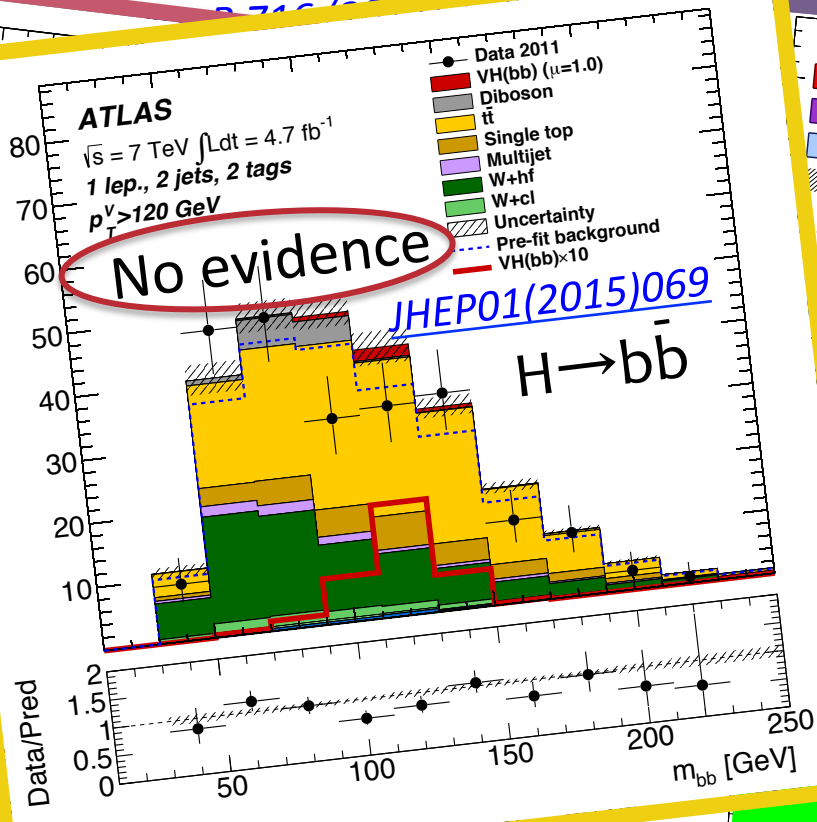
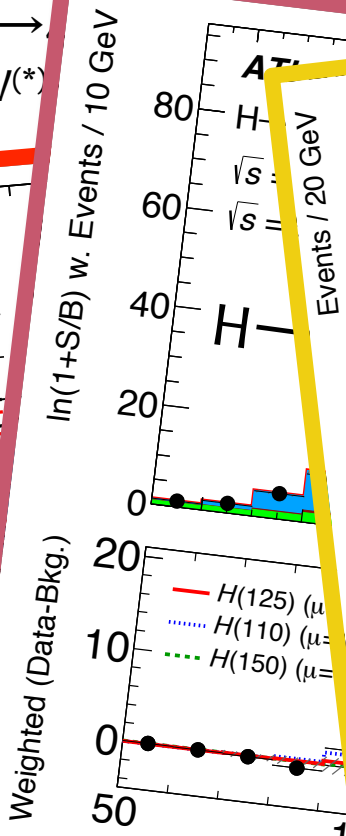
Local p_0



Higgs Discovery

$H \rightarrow \gamma\gamma$
 $H \rightarrow ZZ^{(*)} \rightarrow 4l$
 $H \rightarrow WW^{(*)}$

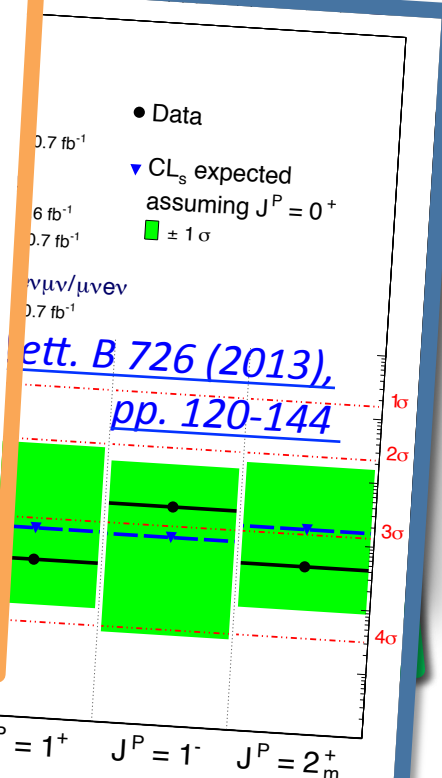
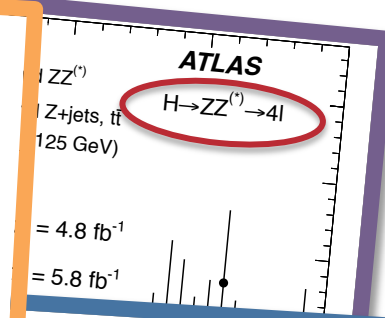
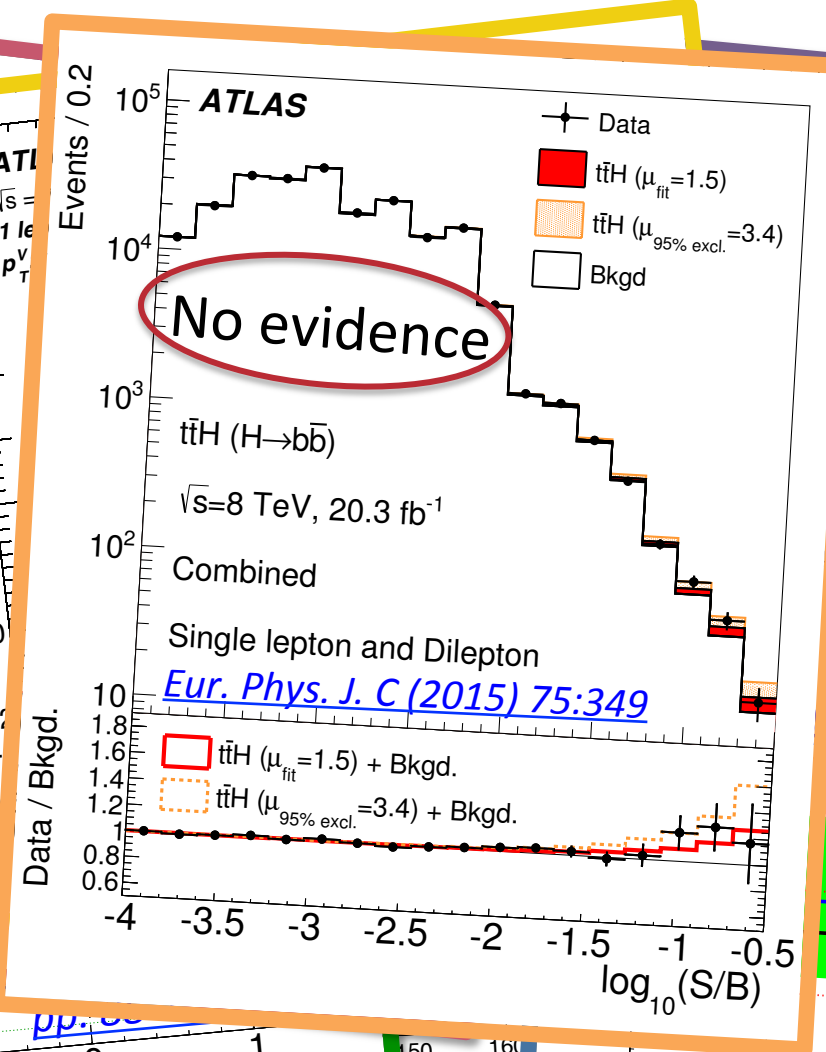
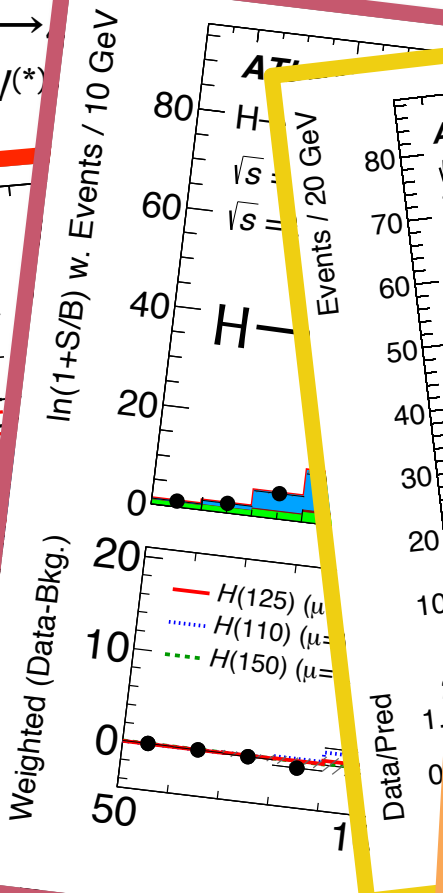
Local p_0



Higgs Discovery

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 $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

Local p_0

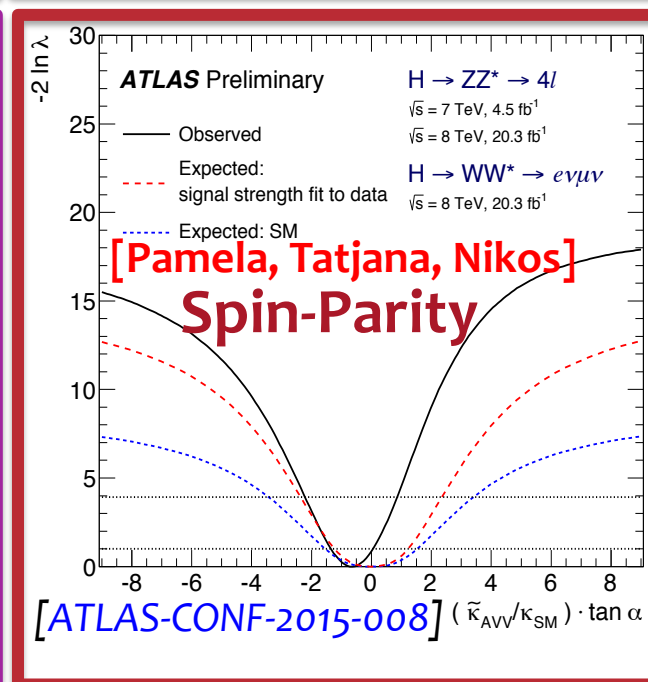
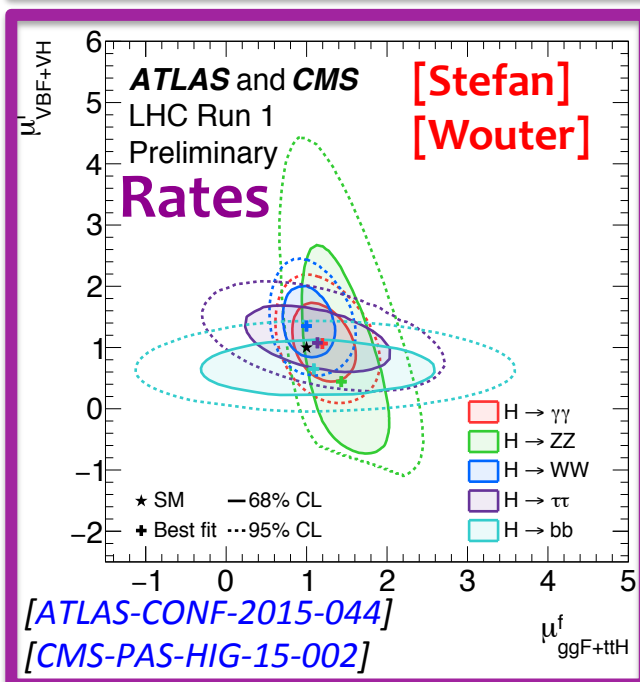
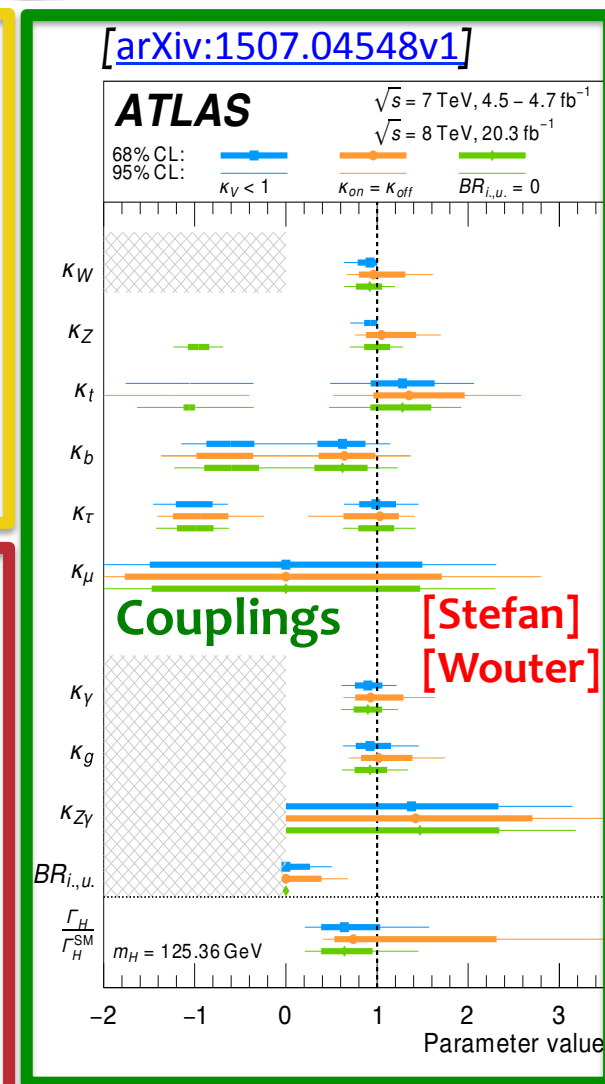
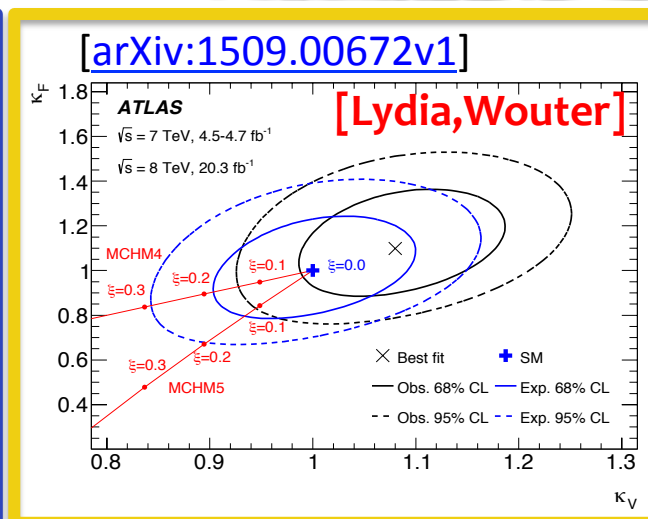
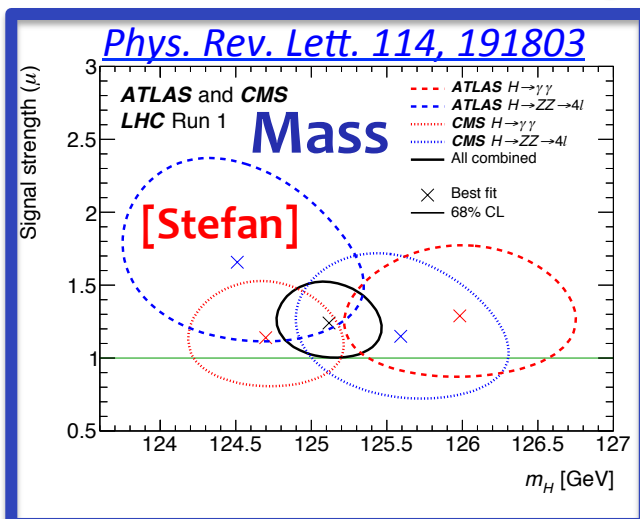


$\sqrt{s} = 7 \text{ TeV} \int L dt = 4.6-4.8 \text{ fb}^{-1}$
 $\sqrt{s} = 8 \text{ TeV} \int L dt = 20.7 \text{ fb}^{-1}$

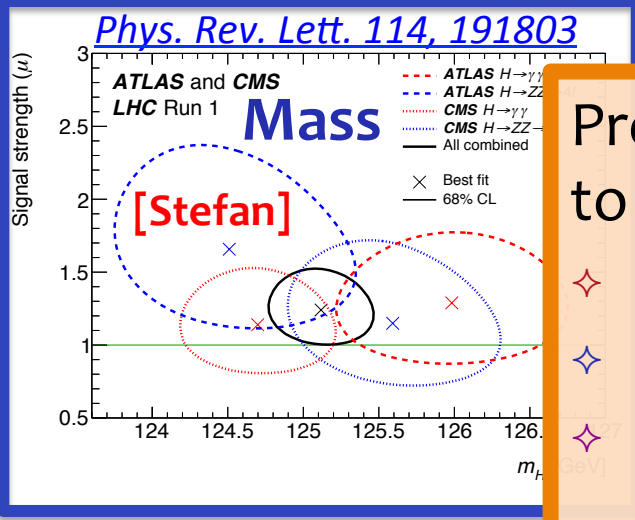
Parameter value
 Combined $H \rightarrow \gamma\gamma, ZZ^*, WW^*$

Run I Legacy

ATLAS (+ CMS) Combinations



Higgs physics towards Run II

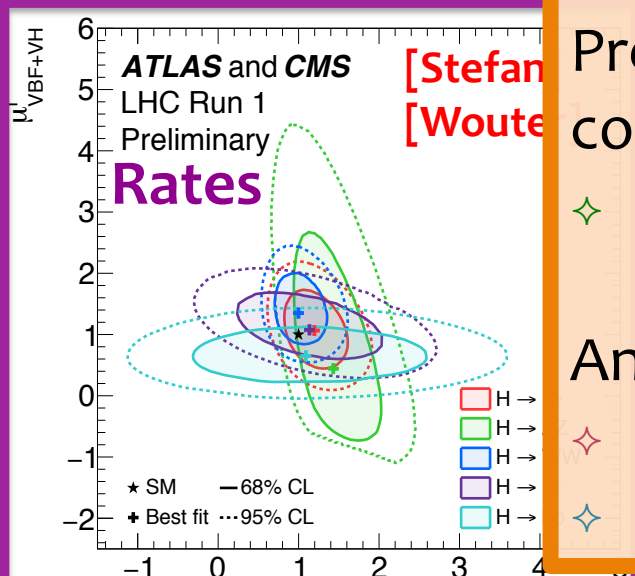


[arXiv:1509.00672v1]

[arXiv:1507.04548v1]

Production/decay channels need to be confirmed for H(125):

- ✦ $t\bar{t}H$ production
- ✦ $H \rightarrow b\bar{b}$ decay
- ✦ Rare decays ($H \rightarrow Z\gamma/\mu\mu\dots$)

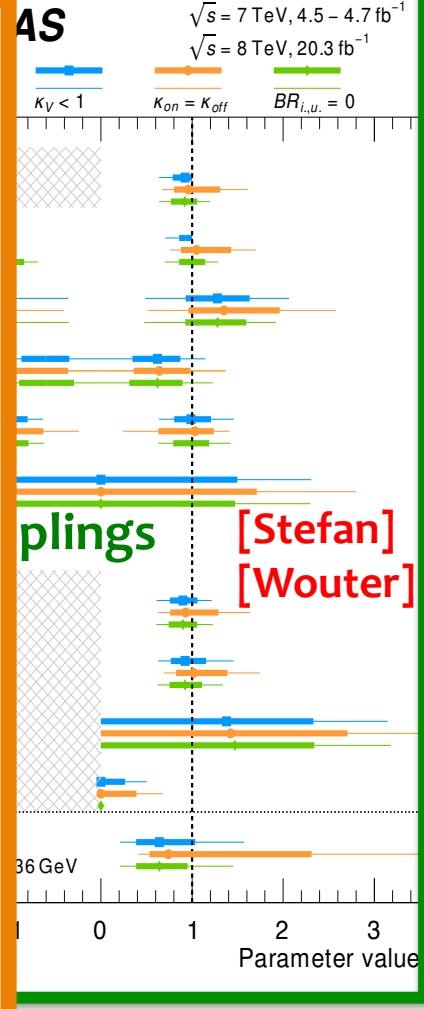


Precision measurements to be continued/refined:

- ✦ Couplings

Anything else than H(125)?

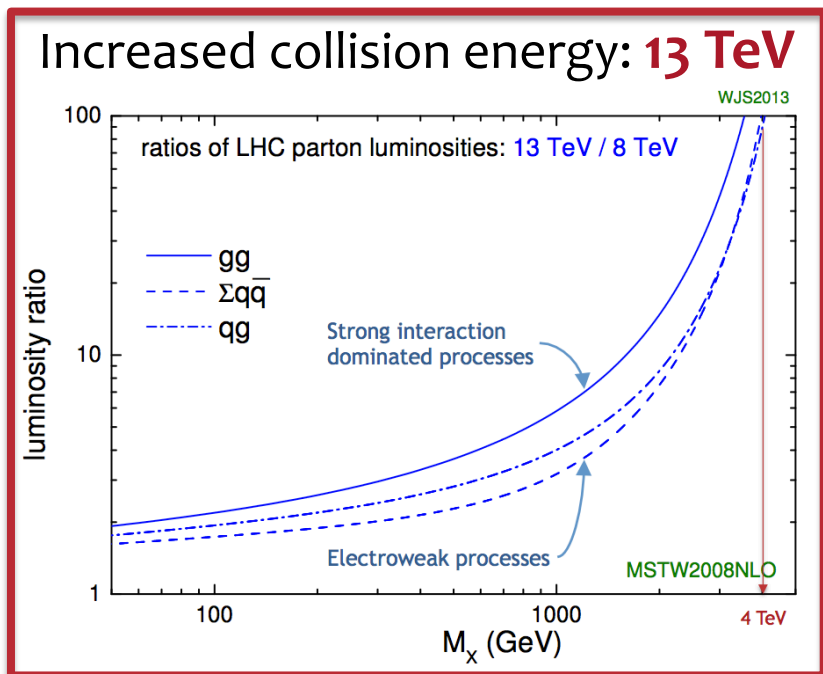
- ✦ Extended Higgs sector?
- ✦ Exotic Higgs-like states?



[ATLAS-CONF-2015-044]
[CMS-PAS-HIG-15-002]

[ATLAS-CONF-2015-008] ($\tilde{\kappa}_{AVV}/\kappa_{SM}$) · tan α

Run II expectations & early Higgs results



Cross section gain higher for higher mass final states

- ✧ Early analyses (**2015, 3.2 fb⁻¹**):
 - ✦ Searches for heavy states
- ✧ Coming next (**summer 2016**):
 - ✦ Searches for $t\bar{t}H$

Covered in this talk

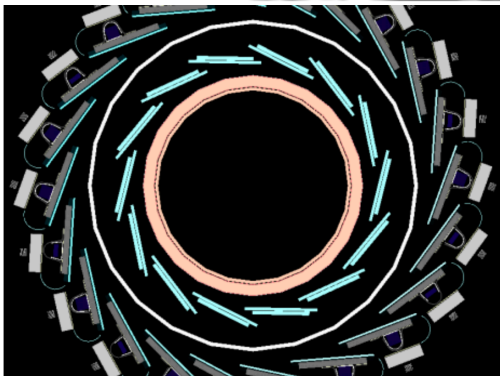
SM/Extended Higgs sector:

- ✧ $H \rightarrow \gamma\gamma$
- ✧ Low/High mass $H \rightarrow 4l$
- ✧ H cross section combination
- ✧ $A \rightarrow \tau\tau$

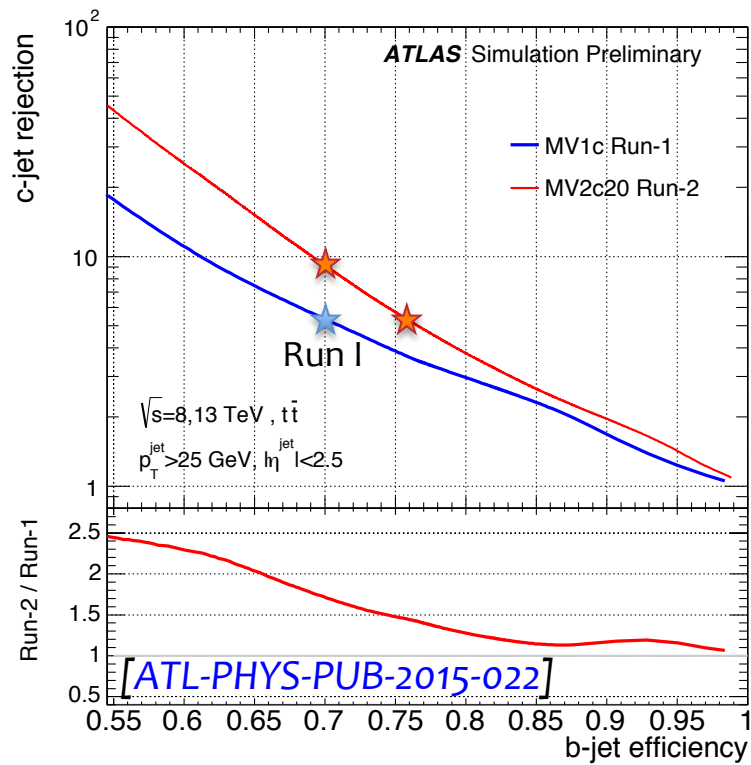
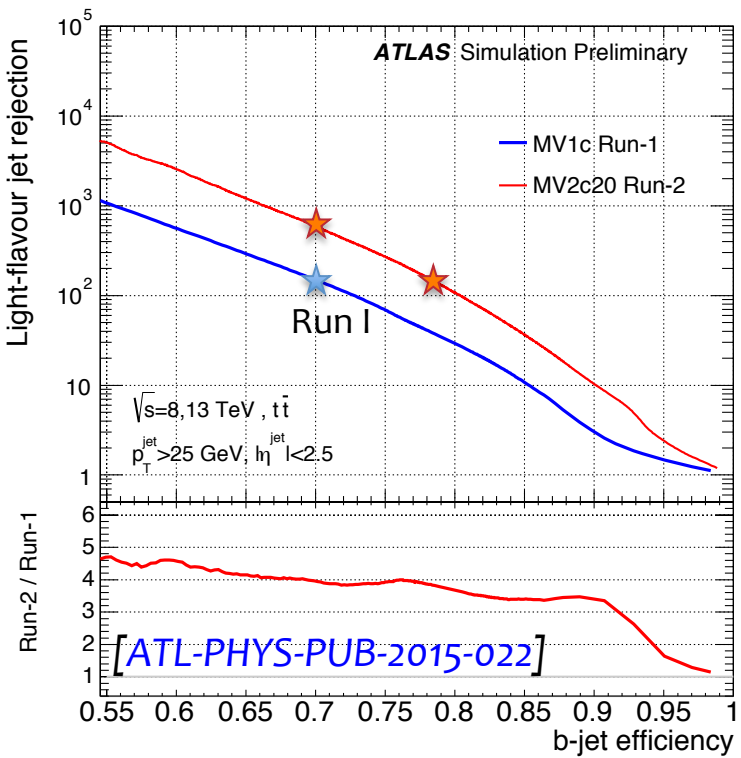
Exotics:

- ✧ High mass $H \rightarrow ZZ \rightarrow llj$
- ✧ High mass $H \rightarrow ZZ \rightarrow \nu\nu j$
- ✧ High mass $H \rightarrow WW \rightarrow l\nu j$
- ✧ High mass $H(\rightarrow VV) \rightarrow jj$
- ✧ High mass $H \rightarrow \gamma\gamma$
- ✧ High mass VH

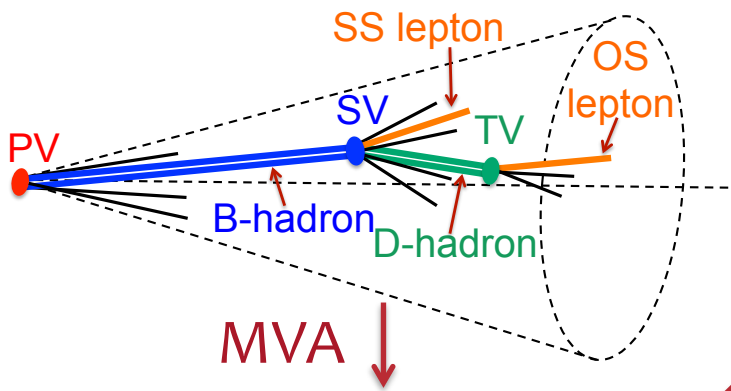
B-tagging



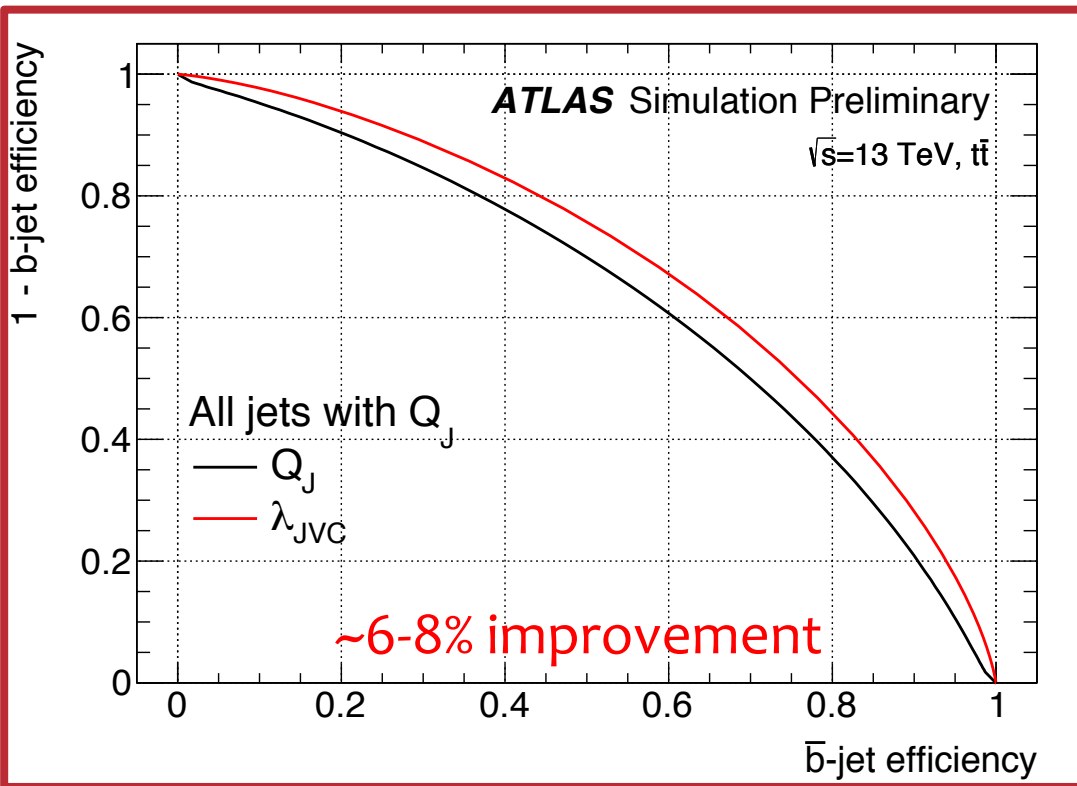
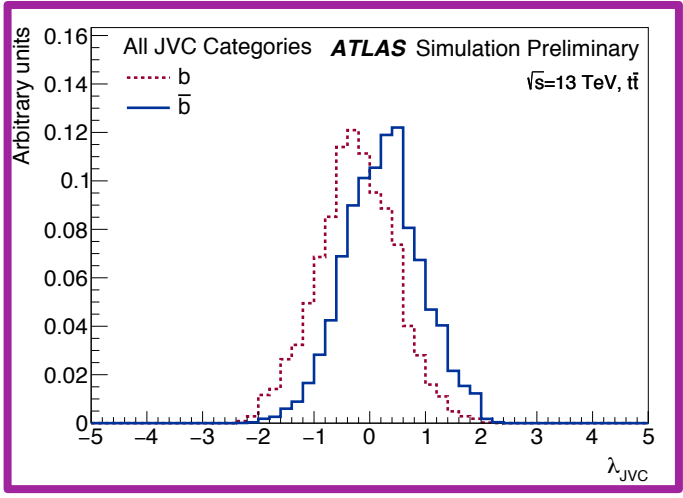
- ✧ New tracker layer **IBL** → improved tracking
- ✧ Significantly improved identification of jets originating from b-quarks (**b-tagging**)
 - ✧ Reoptimised underlying **basic algorithms** and the **final MVA** (especially for hard jets)



$$Q_{jet} = \frac{\sum_{i \in Tr} q_i \cdot (p_T^i)^\kappa}{\sum_{i \in Tr} (p_T^i)^\kappa}$$



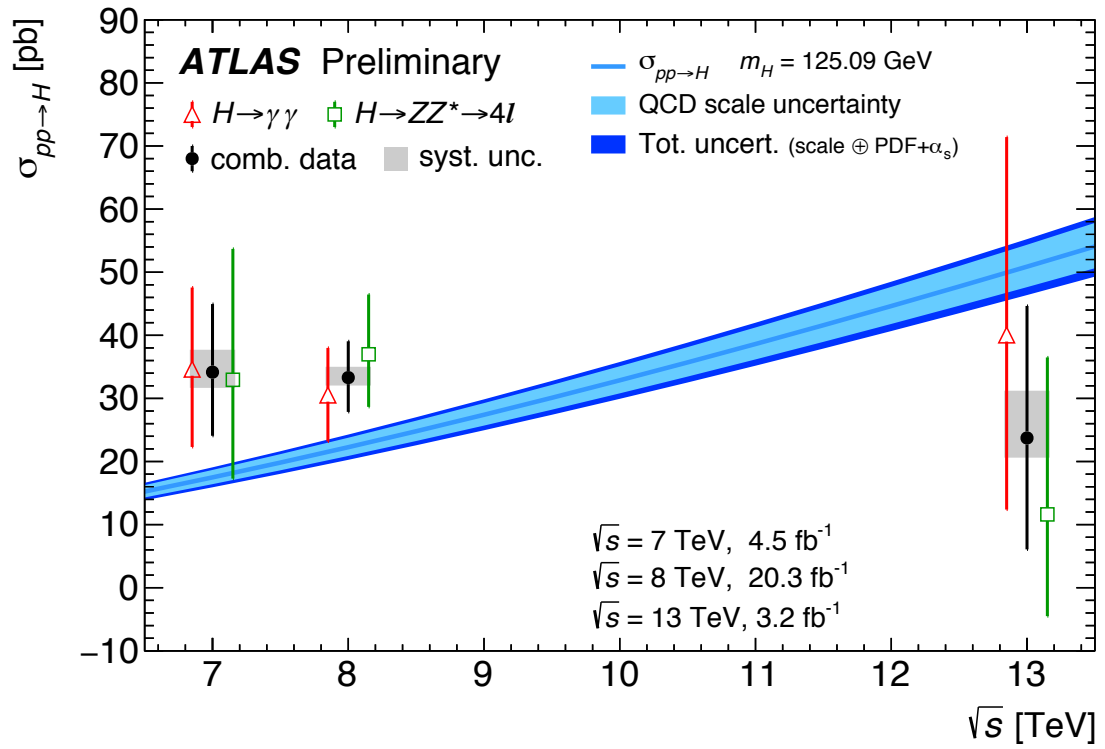
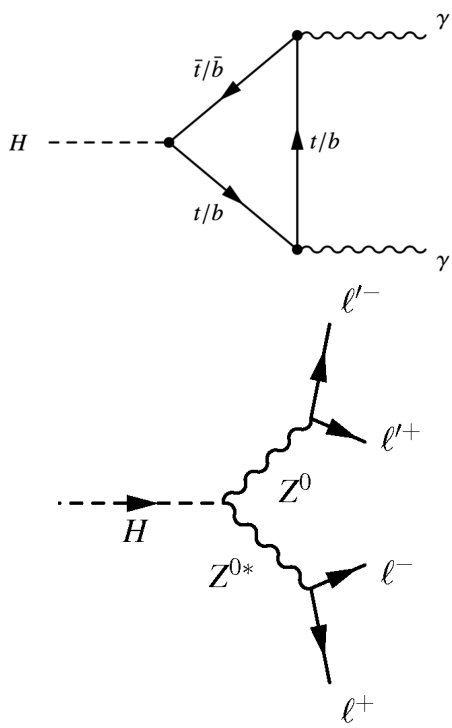
MVA ↓



Higgs Results with 2015 Data

Total production cross section $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^* \rightarrow 4\ell$

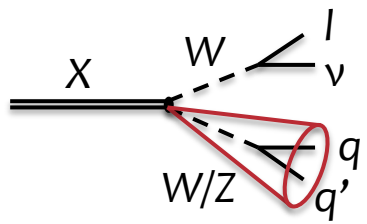
[ATLAS-CONF-2015-069]



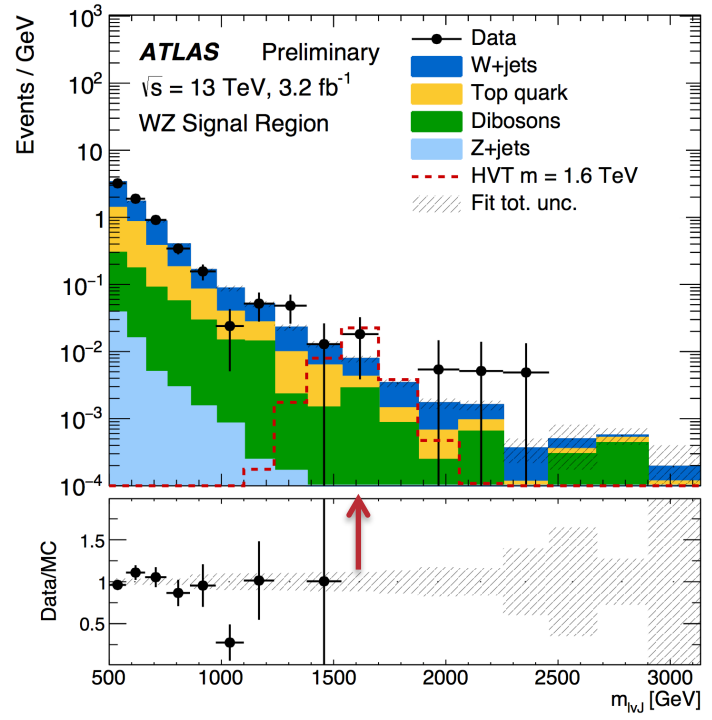
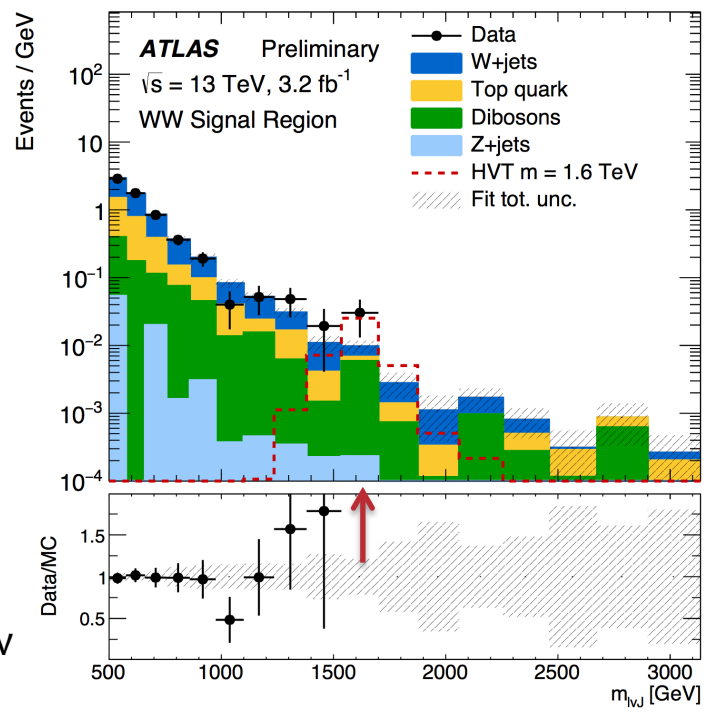
	7 TeV	8 TeV	13 TeV
Fiducial cross section [fb]			
$H \rightarrow \gamma\gamma$	49 ± 18	43 ± 10	52^{+40}_{-37}
$H \rightarrow ZZ^* \rightarrow 4\ell$	$1.9^{+1.2}_{-0.9}$	2.1 ± 0.5	$0.6^{+1.3}_{-0.9}$
Total cross section [pb]			
$H \rightarrow \gamma\gamma$	35^{+13}_{-12}	$30.5^{+7.5}_{-7.4}$	40^{+31}_{-28}
$H \rightarrow ZZ^* \rightarrow 4\ell$	33^{+21}_{-16}	37^{+9}_{-8}	12^{+25}_{-16}
Combination	34 ± 10 (stat.) $^{+4}_{-2}$ (syst.)	$33.3^{+5.5}_{-5.3}$ (stat.) $^{+1.7}_{-1.3}$ (syst.)	24^{+20}_{-17} (stat.) $^{+7}_{-3}$ (syst.)
LHC-XS	17.5 ± 1.6	22.3 ± 2.0	$50.9^{+4.5}_{-4.4}$

Heavy $H \rightarrow WW/WZ \rightarrow l\nu qq$

[ATLAS-CONF-2015-075]

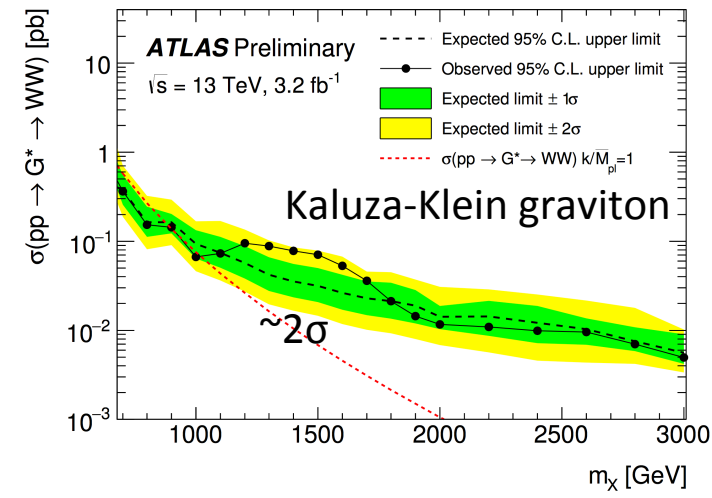
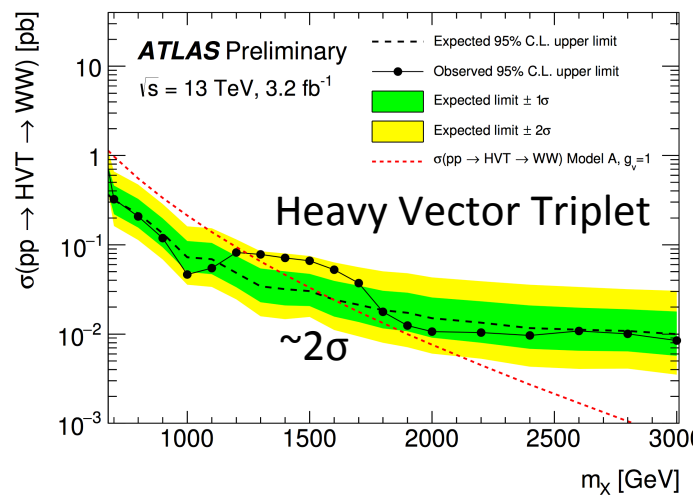
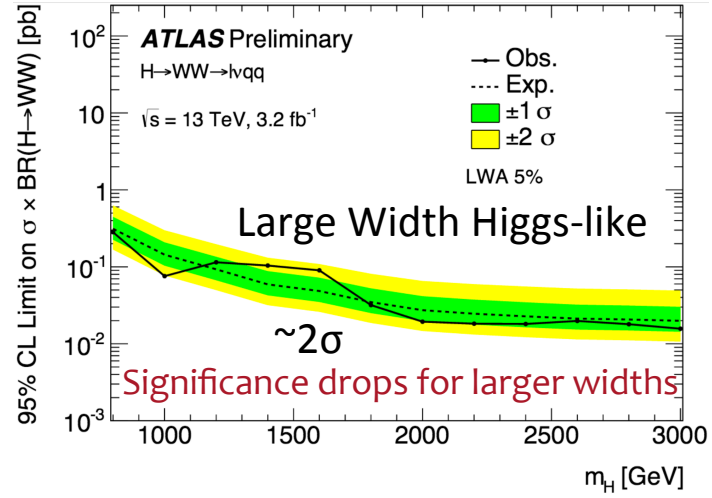
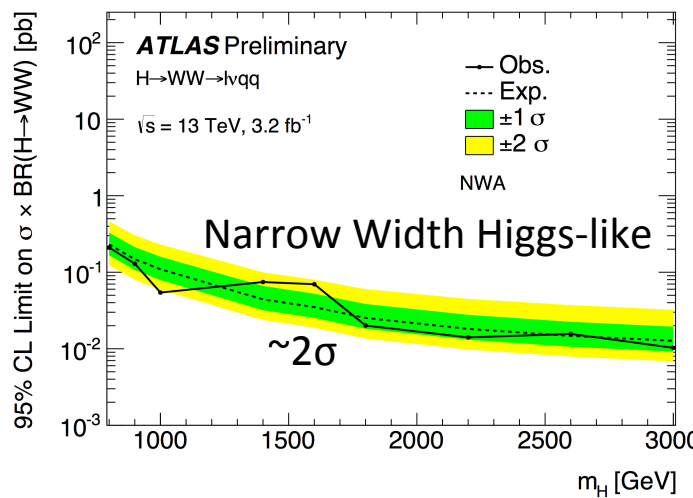
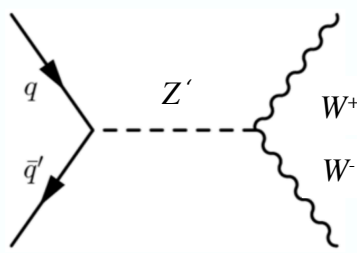
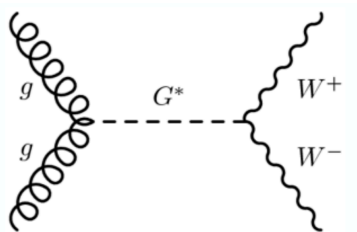
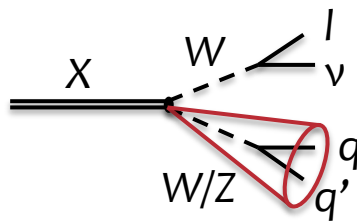


- Event selection:
- ◇ 1 lepton
 - ◇ $E_T^{\text{miss}} > 100 \text{ GeV}$
 - ◇ ≥ 1 boson tagged
 - ◇ **large-R jet**
 - ◇ + W/Z mass window



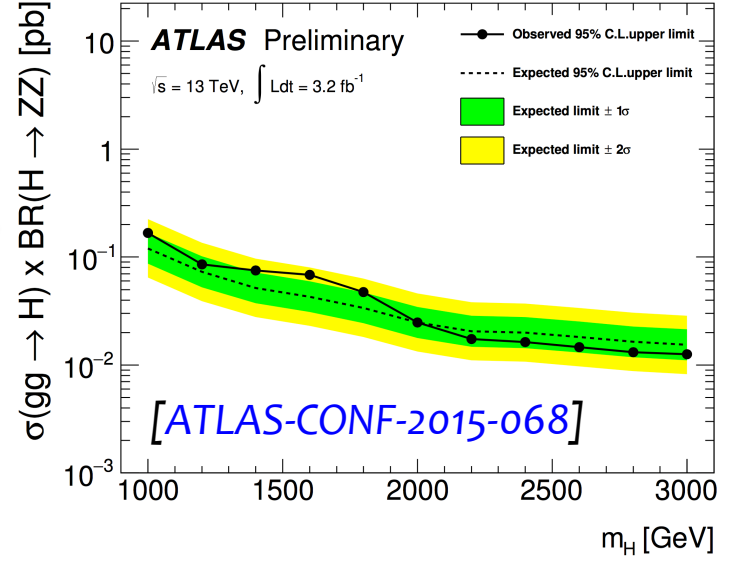
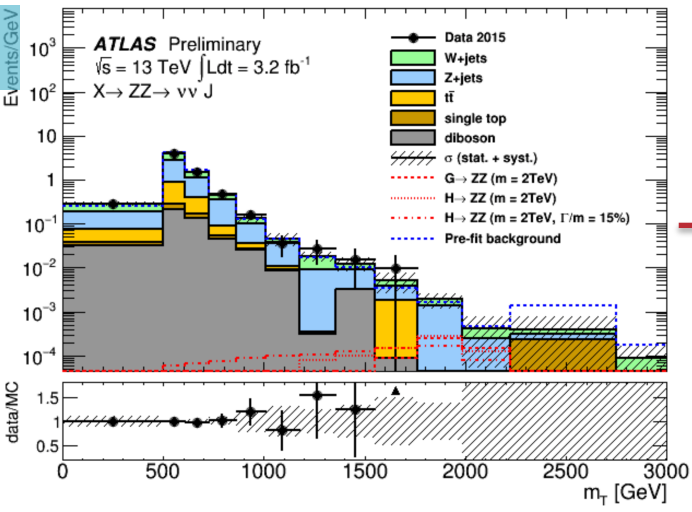
Heavy $H \rightarrow WW/WZ \rightarrow l\nu qq$

[ATLAS-CONF-2015-075]

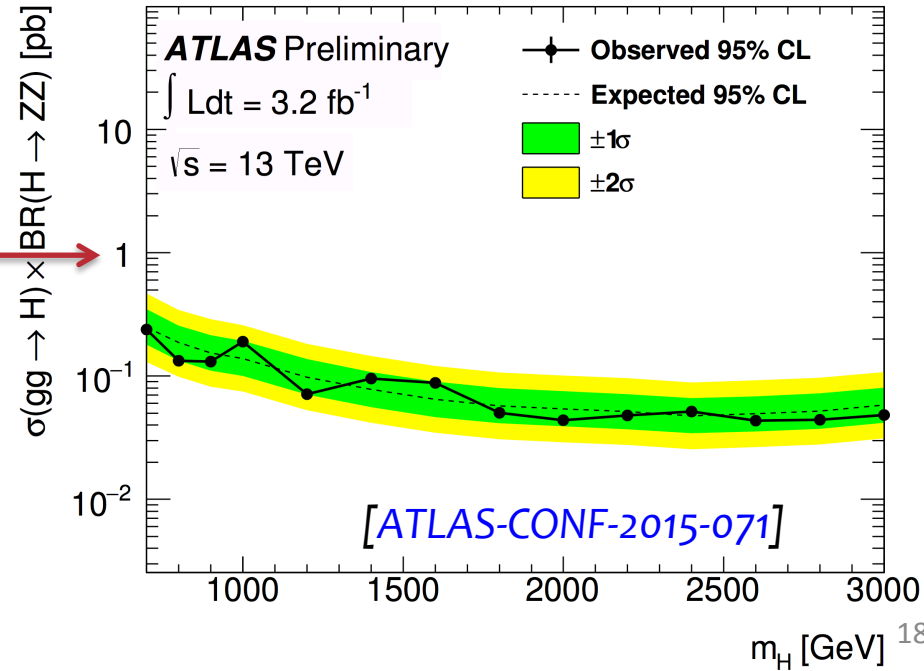
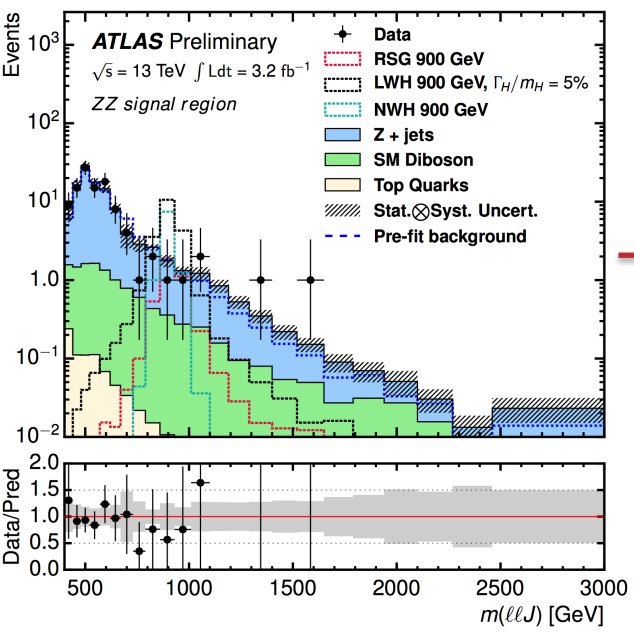


Similar results

$H \rightarrow ZZ \rightarrow \nu\nu qq$

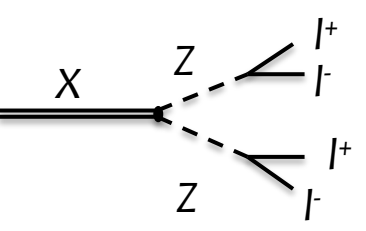


$H \rightarrow ZZ \rightarrow \ell\ell qq$



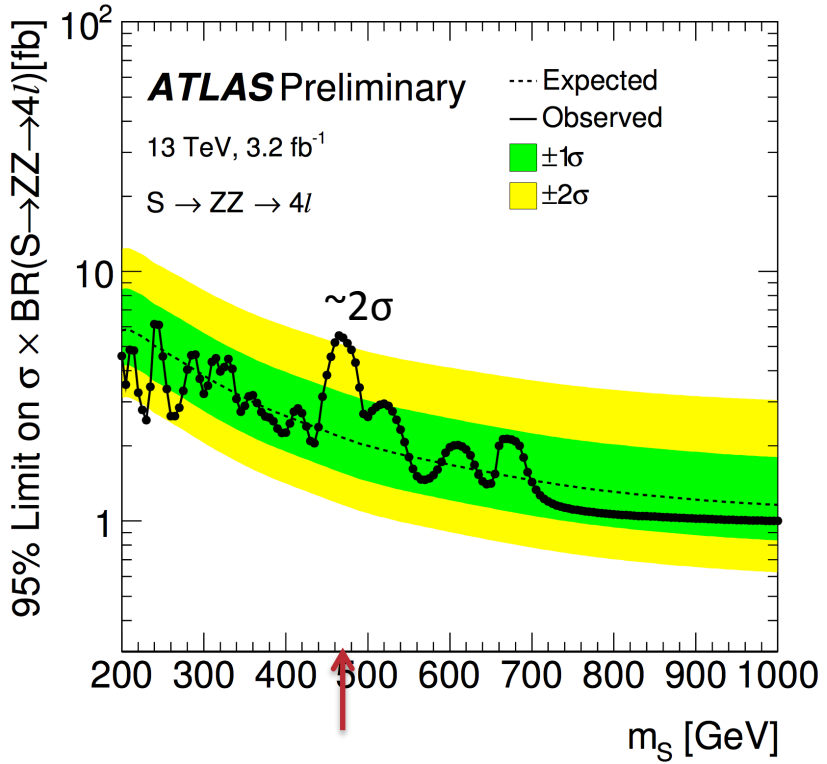
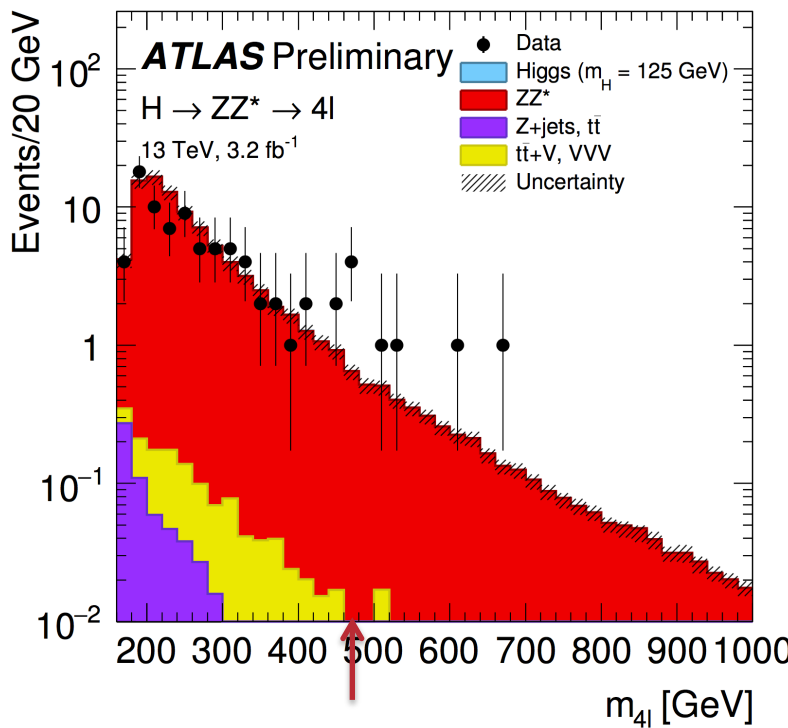
Heavy $H \rightarrow ZZ^* \rightarrow 4l$ – Heavy H

[ATLAS-CONF-2015-059]



- ◇ Mass range tested:
 - + $200 < m_{4l} < 1000$ GeV
- ◇ Sensitive to:
 - + 2HDM
 - + additional (EWS)

- ◇ Event selection:
 - + 4 leptons
 - + Signal regions defined with the W/Z mass window for the fat jet mass

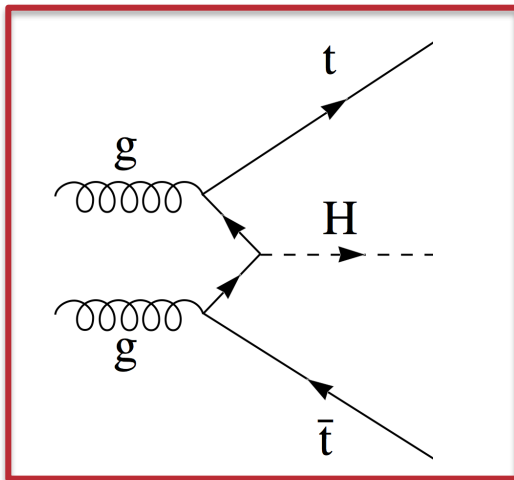


Run I/II Searches for $t\bar{t}H$

Why $t\bar{t}H$?

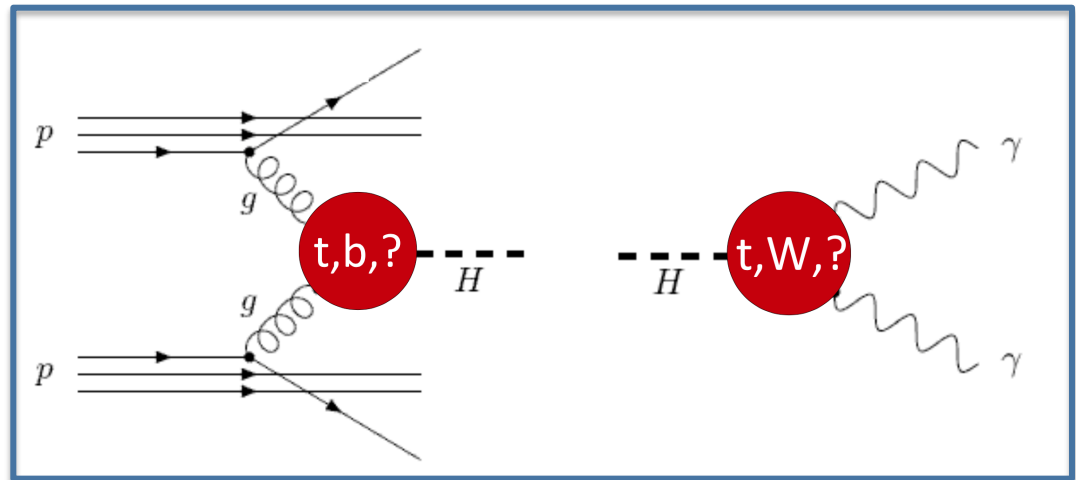
- ✧ Observe Higgs associated production with fermions
- ✧ Measure Higgs-top Yukawa coupling Y_t
 - ✧ Indirect constraints on Y_t from processes involving heavy quark loops
 - ✧ assuming no new heavy particles
 - ✧ $t\bar{t}H$ offers a direct access to measuring Y_t at tree-level

Direct access to Y_t



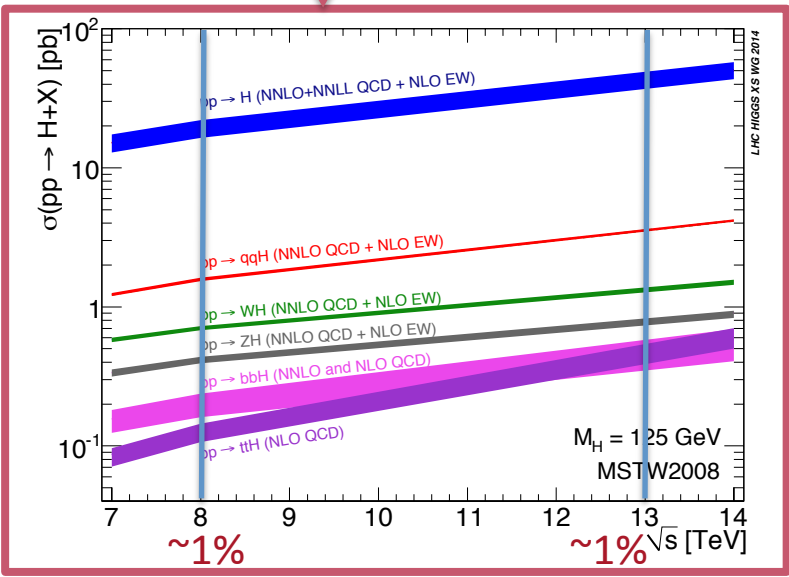
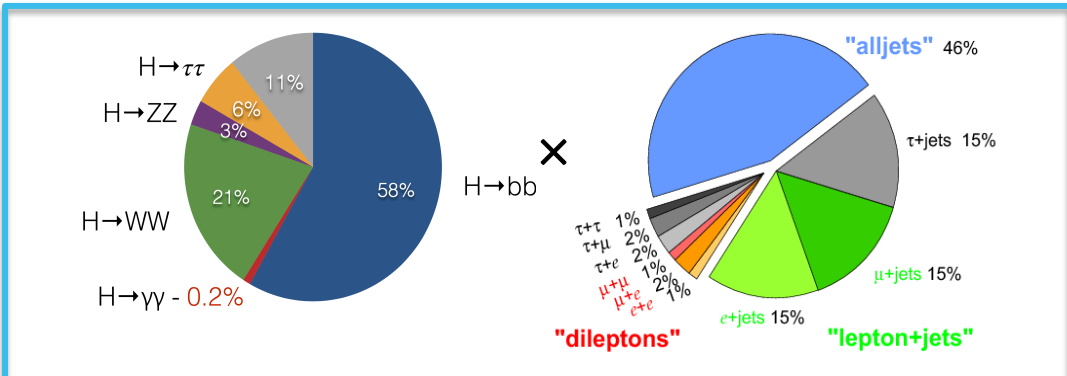
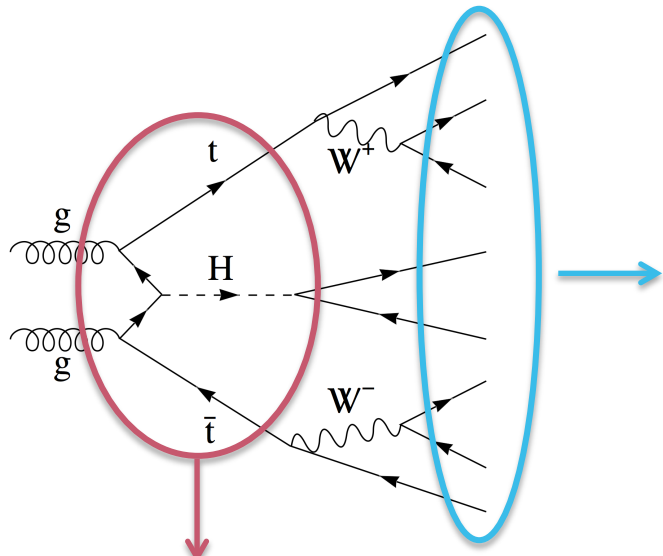
$$\sigma(t\bar{t}H) \propto g_{t\bar{t}H}^2$$

Indirect access to Y_t



$t\bar{t}H$ Production and decays

[Nicolo, Frank, Valerio, Luca, Tim, Snežana]

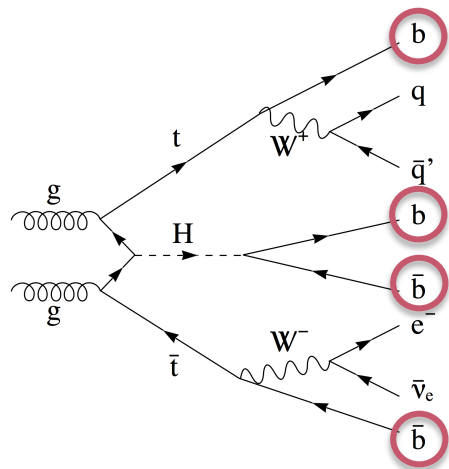


	tt all-had	tt l+jets	tt di-lepton
$H \rightarrow b\bar{b}$		✓	✓
$H \rightarrow \tau\tau$		✓	✓
$H \rightarrow WW^*$		✓	
$H \rightarrow ZZ^*$		✓	✓
$H \rightarrow \gamma\gamma$	✓	✓	✓

- Search for $t\bar{t}H$ ($H \rightarrow b\bar{b}$) 8 TeV [Eur. Phys. J. C (2015) 75:349]
- Search for $t\bar{t}H$ ($H \rightarrow \gamma\gamma$) 7+8 TeV [Physics Letters B 740 (2015) 222]
- Search for $t\bar{t}H$ (multilepton) 8 TeV [Physics Letters B 749 (2015) 519-541]

$t\bar{t}H$ ($H \rightarrow b\bar{b}$) in $l+jets$

Regions & Background Composition [Nicolo, Frank, Valerio, Luca, Tim, Snežana]



Complex final state:

1 lep, 4 b-jets, 2 light jets, E_t^{miss}

Events categorised acc. to the number of jets and b-tagged jets

B-tagging plays a key role \rightarrow optimisation studies for Run II by SN

Background dominated by $t\bar{t}$ +jets

Especially $t\bar{t}$ +HF in regions with a high b-tag multiplicity

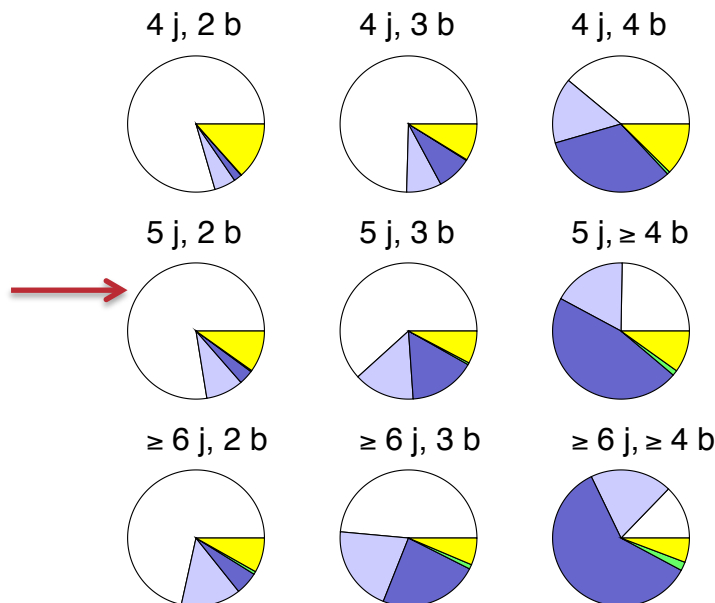
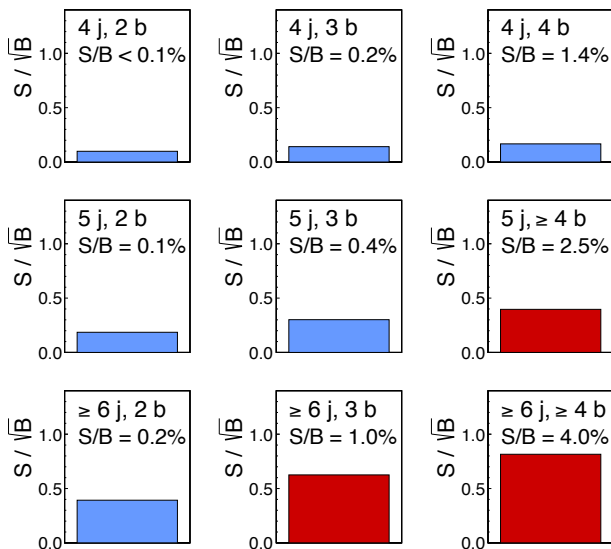
Tim: $t\bar{t}$ +HF uncertainty studies for Run II

Signal depleted

Signal rich

ATLAS Simulation
 $\sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1}$

Single lepton
 $m_H = 125 \text{ GeV}$



ATLAS Simulation

$m_H = 125 \text{ GeV}$
 $\sqrt{s} = 8 \text{ TeV}$

$t\bar{t}$ +light
 $t\bar{t}$ + $c\bar{c}$
 $t\bar{t}$ + $b\bar{b}$
 $t\bar{t}$ +V
 non- $t\bar{t}$

Single lepton

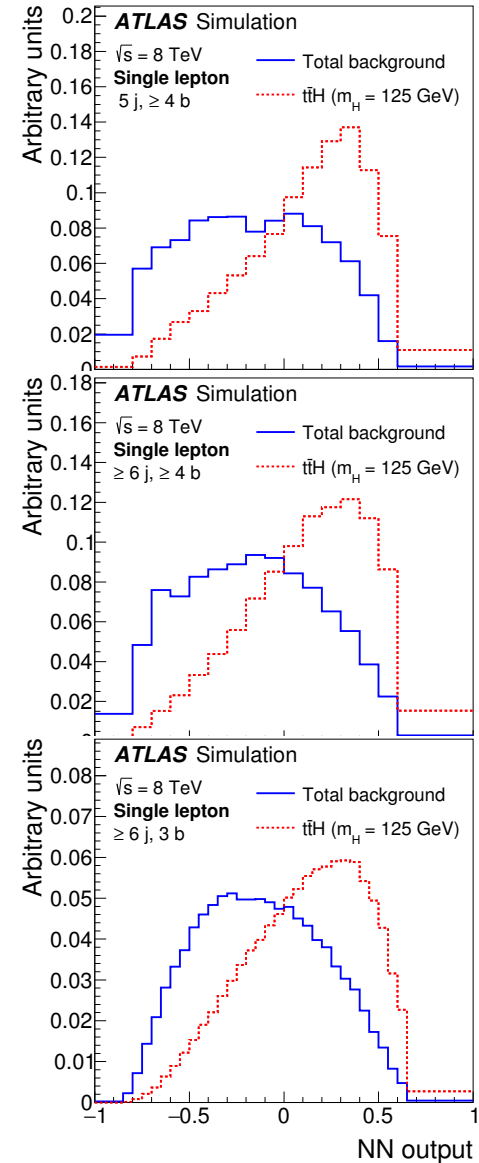
$t\bar{t}H$ ($H \rightarrow b\bar{b}$) in $l+jets$

Event reconstruction Run I/II

[Nicolo, Frank, Valerio, Luca, Tim, Snežana]

	2 b-tags	3 b-tags	4 b-tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NN*	NN
6 jets	H_T^{had}	NN	NN

- ❖ MVA discriminators in signal-rich regions
- ❖ Dedicated NN to separate $t\bar{t}+bb/cc$
 - ✦ in the region with 5 jets and 3 b-tags
- ❖ Employing advanced analysis techniques:
 - ✦ **Matrix Element Method** weights as input for the final MVA
- ❖ Exploring **new possibilities in Run II**:
 - ✦ MVA based object assignment of initial partons \rightarrow **Luca Colasurdo**
- ❖ Simultaneous shape fit in all regions

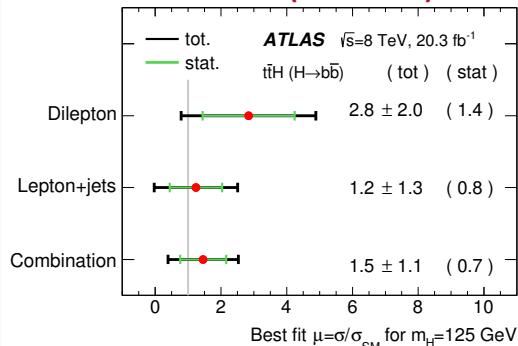


ttH Searches in Run I

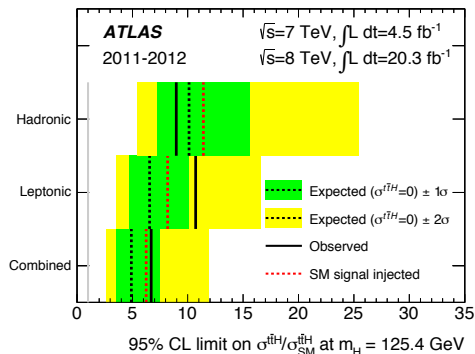
Combined Run I results

[Nicolo, Frank, Valerio, Stefan, Wouter]

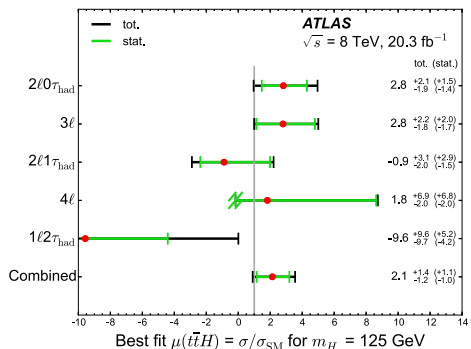
ttH (H → bb)



ttH (H → γγ)

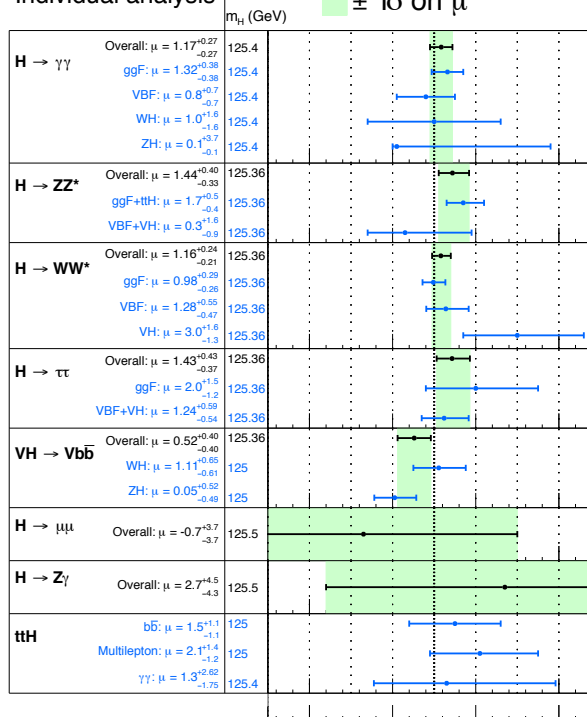


ttH (multilepton)



ATLAS

Individual analysis



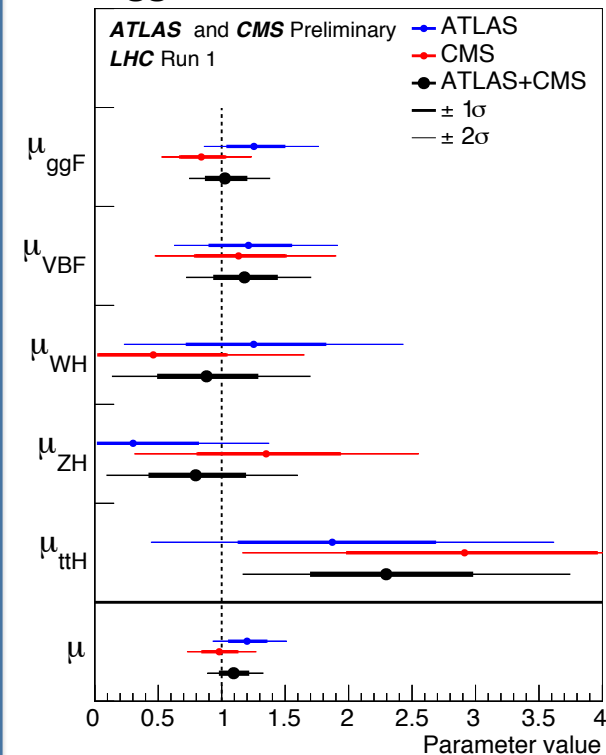
$\sqrt{s} = 7$ TeV, 4.5-4.7 fb⁻¹

$\sqrt{s} = 8$ TeV, 20.3 fb⁻¹

$$\mu_{ttH}^{ATLAS} = 1.81 \pm 0.80$$

ATLAS+CMS

Higgs Combination

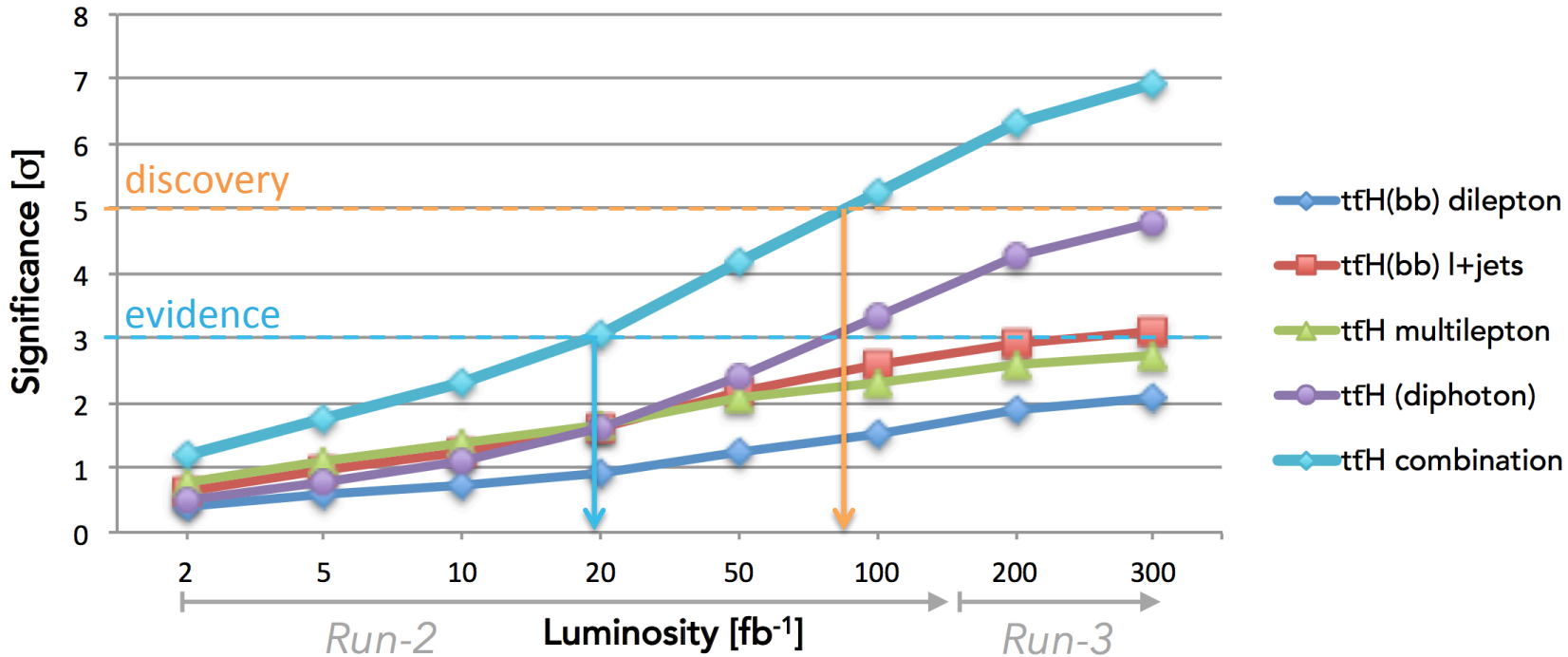


$$\mu_{ttH}^{ATLAS+CMS} = 2.3^{+0.7}_{-0.6}$$

* all-hadronic ttH (H → bb) not yet included in the combinations

Projections for Run II/III

* Rough estimates scaling cross sections and Luminosity



- ✧ Evidence expected with 20 fb⁻¹ with a combination
- ✧ Discovery expected at the end of Run II

Conclusions

- ✧ Great Run I legacy for Higgs physics
 - ✦ Higgs discovery in $H \rightarrow WW/ZZ/\gamma\gamma$, evidence in $H \rightarrow \tau\tau$
 - ✦ Plenty of precision measurement on Higgs properties
 - ✧ Mass, spin-parity properties, couplings
- ✧ High hopes for Run II
 - ✦ Increase of CME and integrated luminosity
 - ✦ Improved instrumentation and reconstruction tools
 - ✦ Expansion of advanced analysis techniques
- ✧ Strong **Nikhef** involvement in the discovery, and other Run I/II activities
- ✧ **Stay tuned for new exciting results!**

Backup
