



Beyond-the-Standard Model Higgs Physics using the ATLAS Experiment

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Introduction

- We discovered a Standard Model (SM) like Higgs boson at $m_H=125$ GeV.
 - This is not the end of the story.
 - **There are indications that SM is incomplete.**
- There is a lot of room for non-SM interpretation.
 - Two Higgs Doublet Models (2HDM)
 - there are two electroweak doublets (only one doublet in SM).
 - Minimal Supersymmetric Standard Model (MSSM)
 - solution to “hierarchy problem” and dark matter candidates.
 - Next-to-Minimal Supersymmetric Model (NMSSM)
 - solves the problem with an additional electroweak singlet S , and the resulting Higgs sector contains the MSSM Higgs content.

Searches

➤ Next to Minimal:

- NMSSM $a_1 \rightarrow \mu\mu$
- NMSSM $h \rightarrow a_1 a_1 \rightarrow 4\gamma$

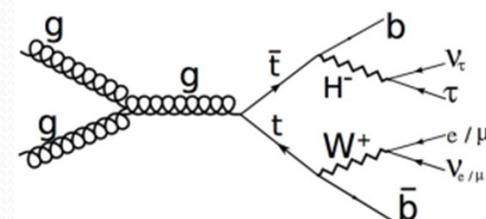
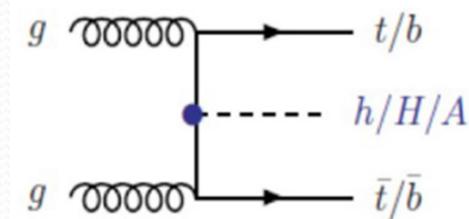
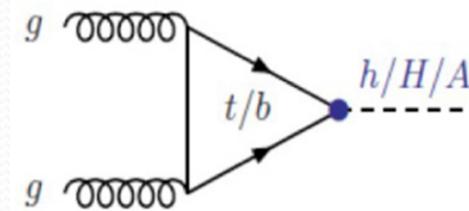
➤ Neutral Higgs searches:

- $H^0 \rightarrow \tau^+\tau^-$ and $\mu^+\mu^-$
- 2HDM $H^0 \rightarrow W^+W^-$
- Invisible Higgs
- Fermiophobic $H^0 \rightarrow \gamma\gamma$

➤ Charged Higgs searches:

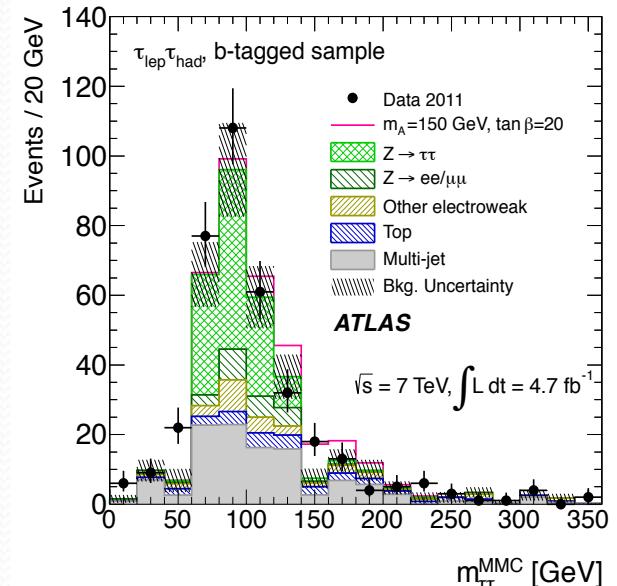
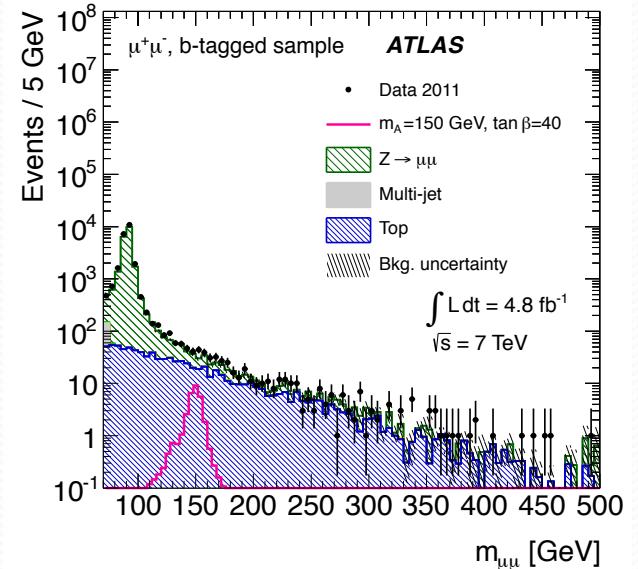
- $H^\pm \rightarrow \tau^\pm\nu + \text{jets}$
- $H^\pm \rightarrow cs$
- Doubly charged Higgs

- Measurements of Higgs boson coupling scale factors in different coupling parametrizations.



MSSM Higgs

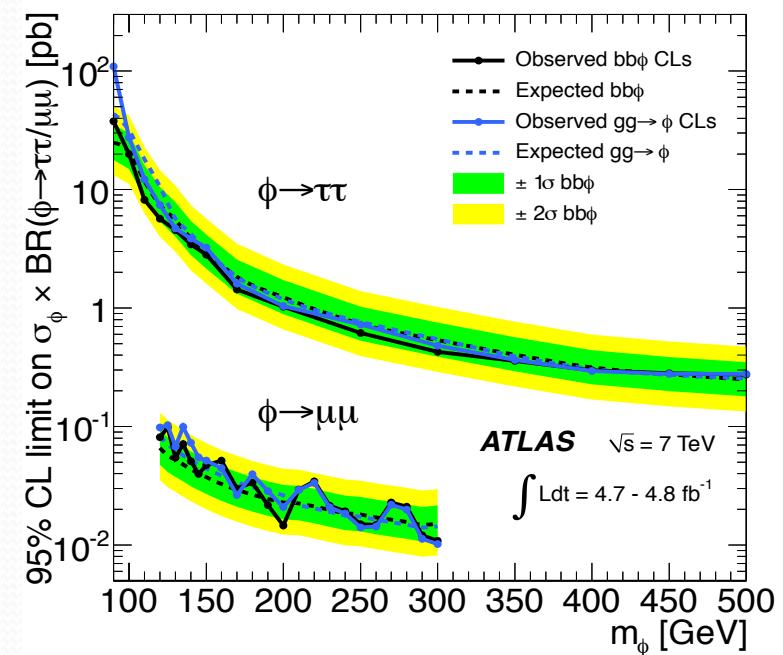
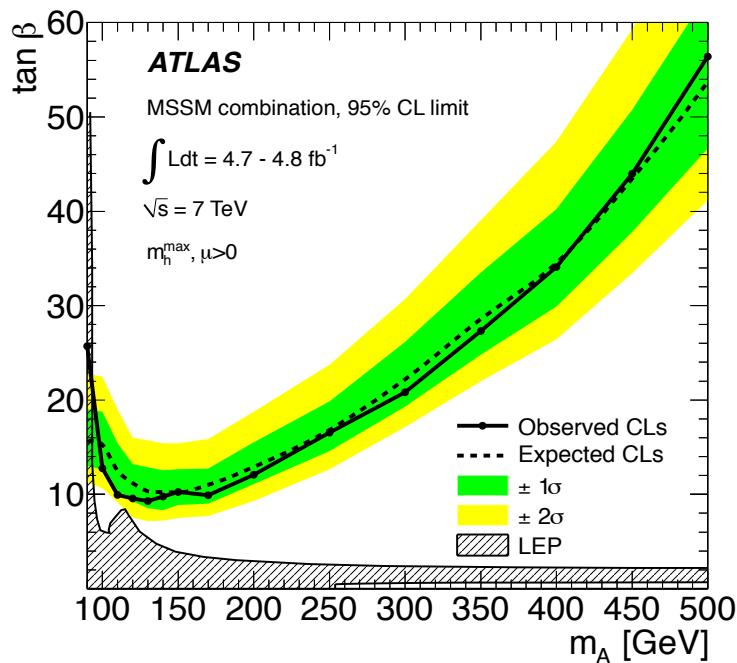
- Search for Neutral Higgs heavy (H) CP-even/light (h)/ CP-odd (A)
 - decaying $\tau\tau/\mu\mu$
- Production: gluon fusion, b-associated production.
 - separated into b-tagged and b-vetoed
- $\tau\tau$ -channel: three groups
 - ($e\mu$, l+had,had+had)
- $\mu\mu$ -channel:
 - $pT > 20 \text{ GeV}$, $|\eta| < 2.5$, MET $< 40 \text{ GeV}$



MSSM Higgs results

- Obtain combined limits for both channels
 - $\tan\beta$ vs m_A in m_h^{\max} , $\mu > 0$ MSSM scenario
 - limit on production for a generic single scalar boson decaying into $\mu\mu/\tau\tau$

JHEP02(2013)095



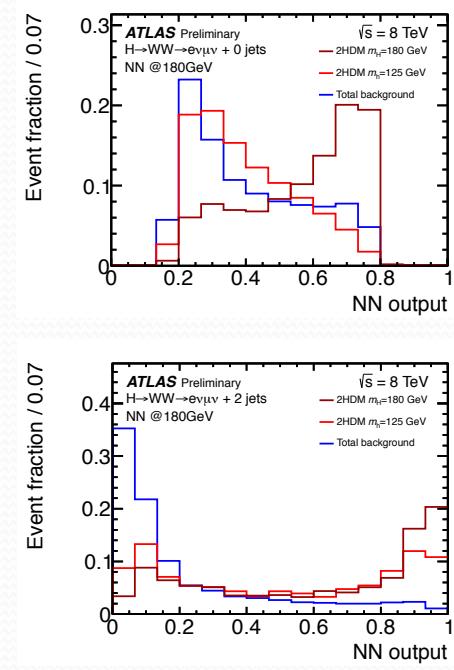
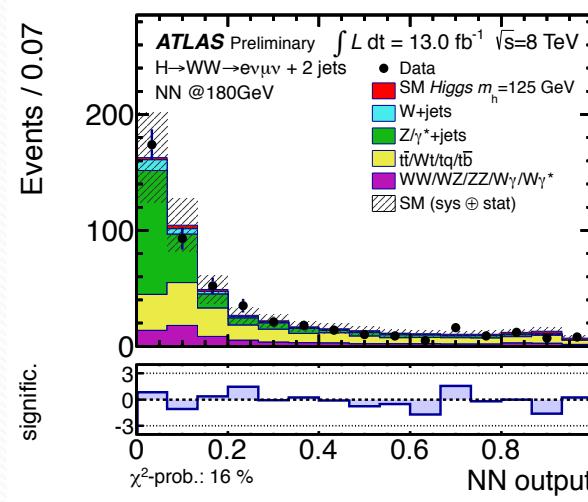
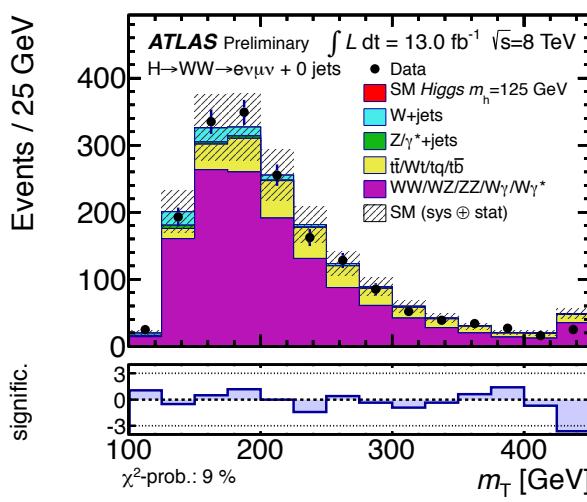
2HDM

Simple extension of SM scalar sector, yet with rich phenomenology:

- Baryon asymmetry – contrary to the SM, allow for both explicit and spontaneous CP violation
- Dark matter candidates
- Flavour Changing Neutral Current
- ...
- Higgs sector of 2HDM models described by parameters: 4 Higgs masses, $\tan \beta$ (ratio of vacuum expectation values vev) and α mixing between the two neutral CP even states h, H
 - Type I: One Higgs doublet couples to vector bosons (“fermiophobic”), while the other couples to fermions.
 - Type II: “MSSM like” model, one doublet couples to up-type quarks, the other to down-type quarks
 - Type III: “Lepton-specific” model, Higgs bosons have same couplings to quarks as type I and to leptons as in type II
 - Type IV: “Flipped” model, Higgs bosons have same couplings to quarks as in type II and to leptons as in type I

2HDM Higgs

- Search for a heavier neutral (H) CP-even partner of 125 GeV “light” Higgs
 - Probe the hypothesis of simultaneous presence of signals from both light (125GeV) Higgs and its heavier partner – the first analysis of this kind!
- Production: gluon fusion, vector boson fusion (VBF)
- Decay: $H \rightarrow WW^* \rightarrow e\nu\mu\nu$
- Selection: split into 0-jet and 2-jet channels
- Use neural network to separate signal from background
 - 0 jets has better S/B but worse NN separation

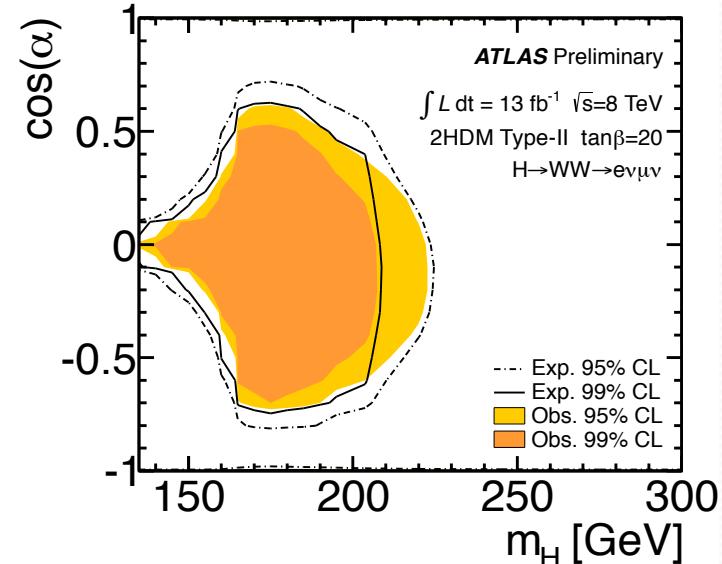
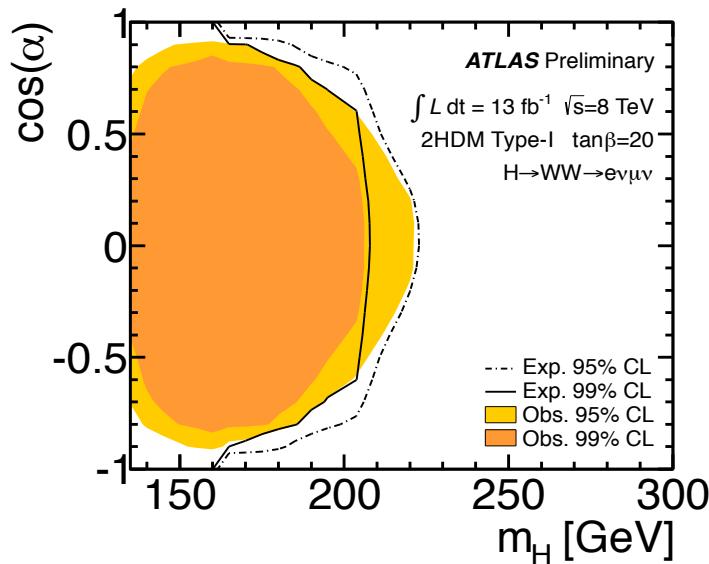




2HDM Higgs results

- No evidence found in the 135—300 GeV mass region
- Limits set in terms of $\cos(\alpha)$ and m_H
 - Type-I: all quarks couple to only one Higgs doublet
 - Type-II: $+2/3$ RH quarks couple to one HD, $1/3$ RH quarks couple to the other HD

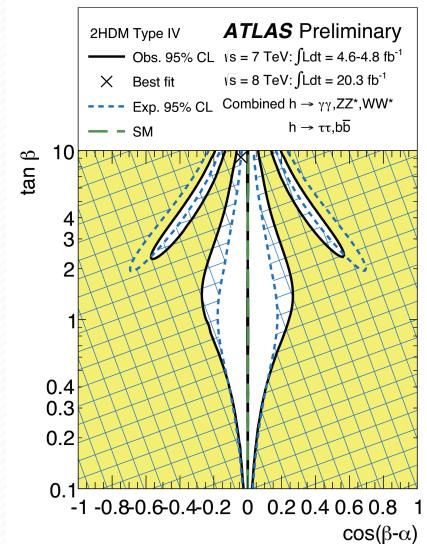
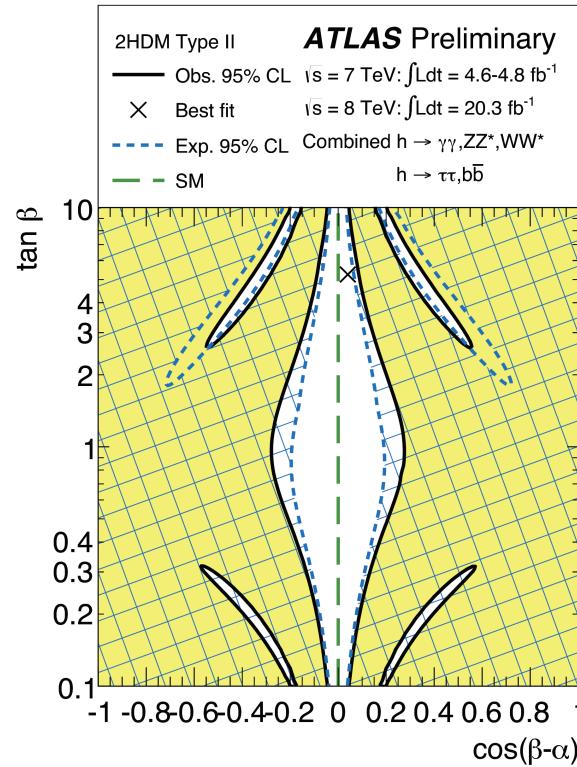
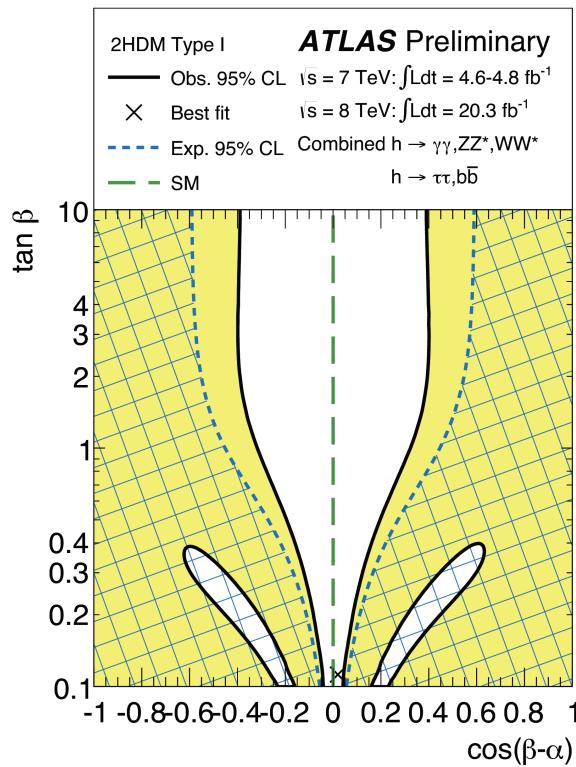
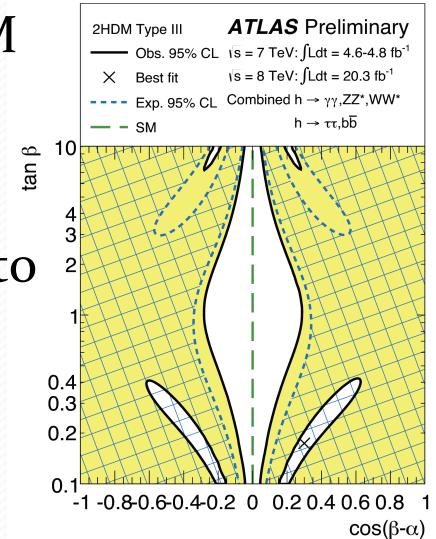
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2HDM results

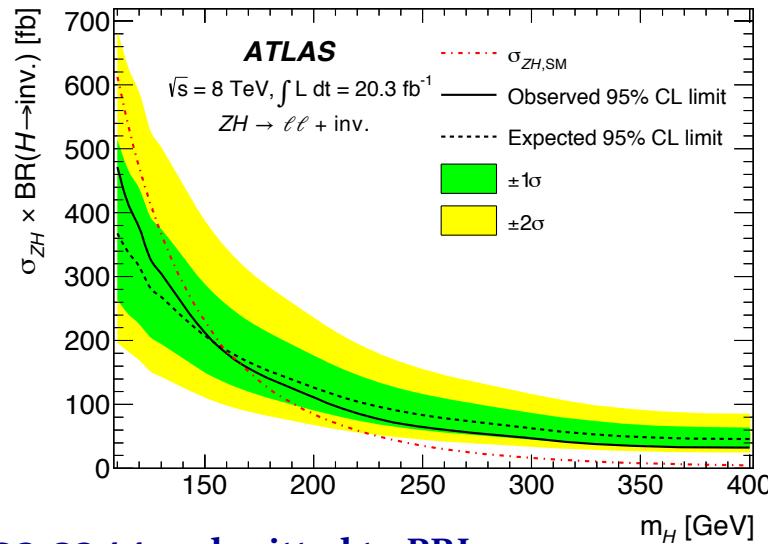
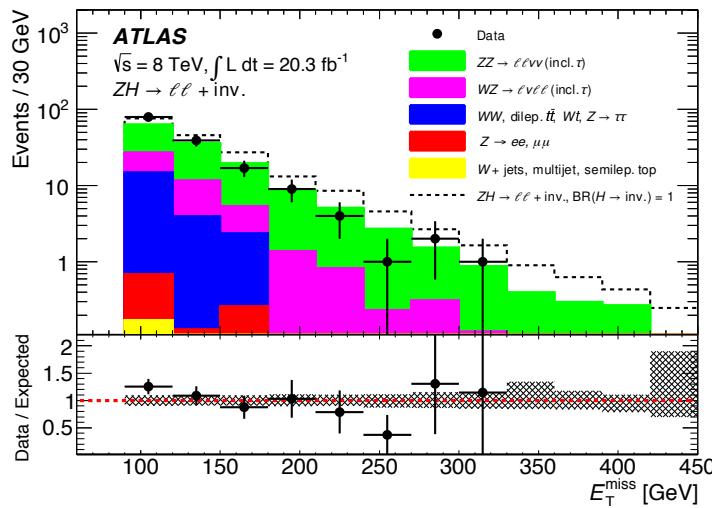
- Observed exclusion limit (95% CL) for four types of 2HDM mode in terms of $\cos(\beta-\alpha)$, $\tan \beta$ parameter space
- Compared with expected exclusion limits for SM Higgs Boson
- Data are consistent with SM alignment limit $\cos(\beta-\alpha) = 0$ to within $1-2\sigma$ for all models

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Invisible Higgs

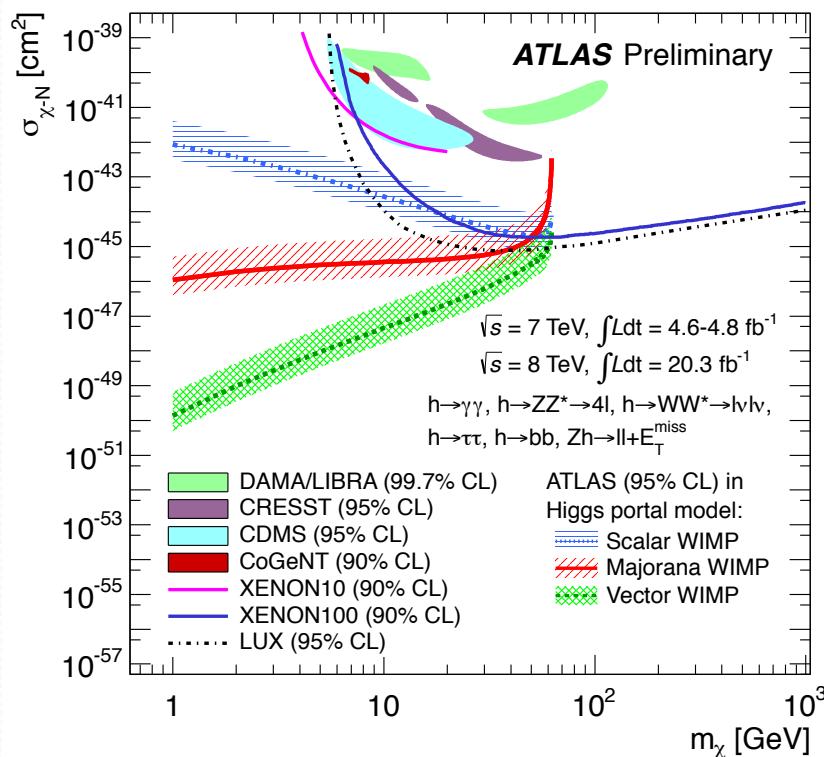
- Production: associated ZH, $Z \rightarrow ll$ ($l=e,\mu$)
- H decay: stable/long lived weakly interacting particles
- Selection: $pT l > 20$ GeV, $|m_{ll} - m_Z| < 15$ GeV, MET > 90 GeV
- Limits are set in two scenarios:
 - on invisible BR of a SM Higgs at $m_H = 125$ GeV: at 95% C.L. observed/expected limits are 65%/84%
 - on production \times BR of a Higgs-like particle vs m_H



arXiv:1402.3244, submitted to PRL

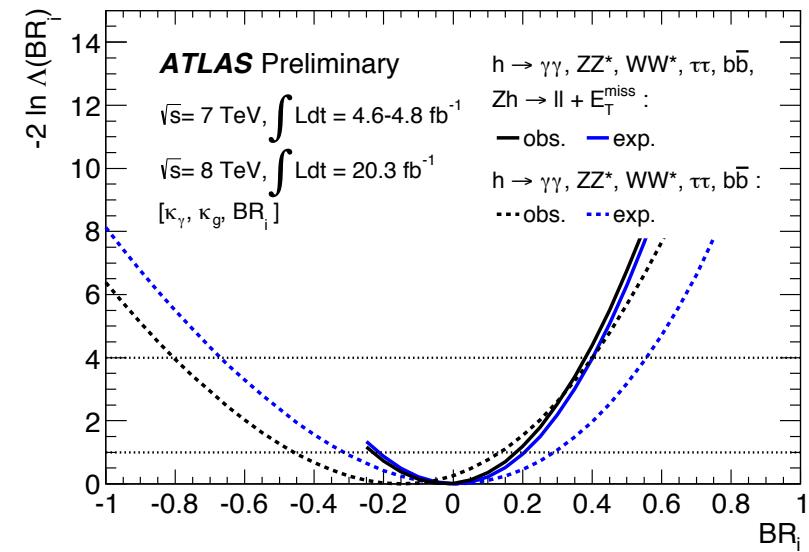
Higgs and Dark matter

- Model extends SM to include weakly interacting massive particles (WIMPs) coupling to Higgs boson
- Dark matter-nucleon scattering as well as decay rate inferred from Higgs invisible decays



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- Likelihood scan of the invisible branching ratio of the Higgs boson.

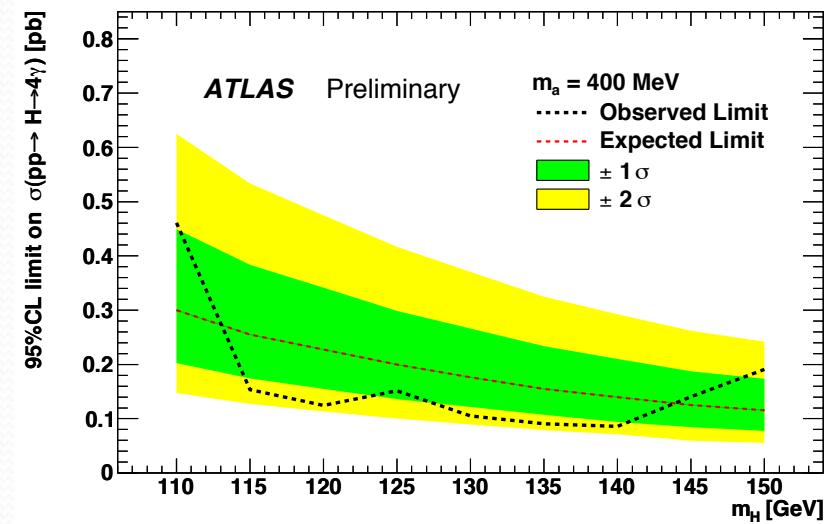
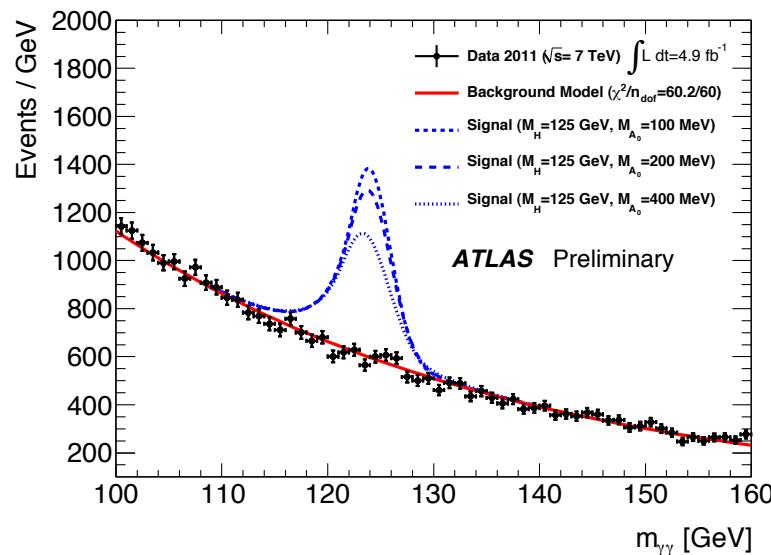


- Upper limit at 95% CL on the WIMP-nucleon scattering cross section in a Higgs portal model as a function of the mass of the dark matter particle.

$h \rightarrow aa \rightarrow 4\gamma$ (NMSSM)

- Diphotos from a decays are highly collimated and result in a single EM cluster
- Selection: similar to $h \rightarrow \gamma\gamma$ but modified photon identification to detect photon pairs from Higgs decays
- Limits on $\text{prod} \times \text{BR}$ for $m_a = 100, 200, 400 \text{ MeV}$

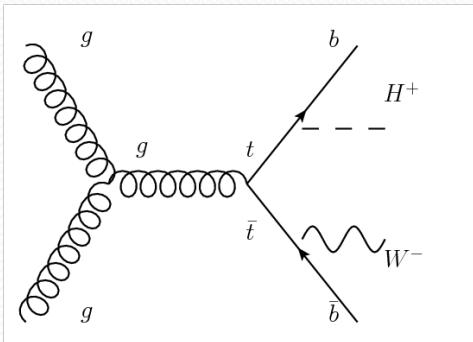
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Charged Higgs

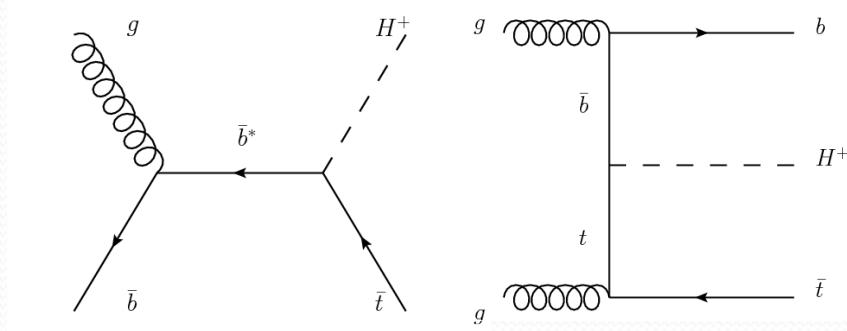
- Charged Higgs H^\pm are predicted in several scenarios, with Higgs triplets, MSSM and 2HDM.
- SM doesn't have H^\pm , so its observation would indicate BSM
- H^\pm production and decay depends on mH^\pm compared to m_t

$mH^\pm < m_t$



Top decay
Light Charged Higgs

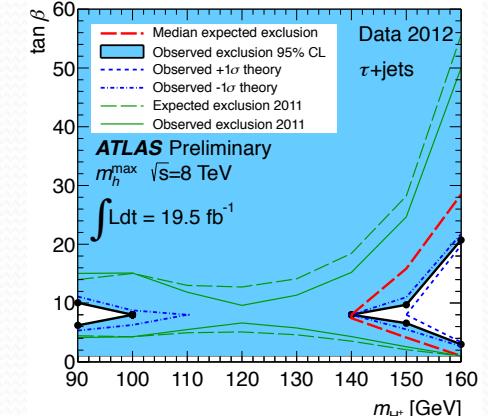
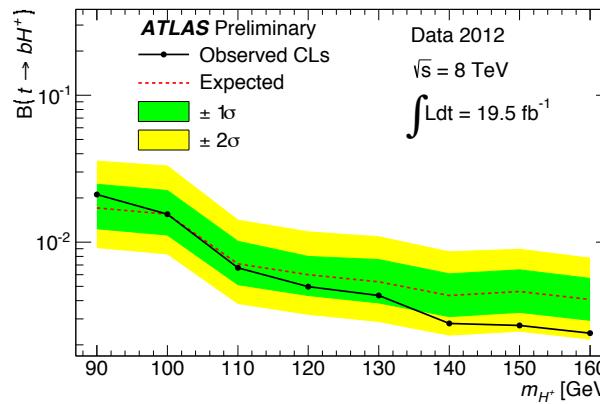
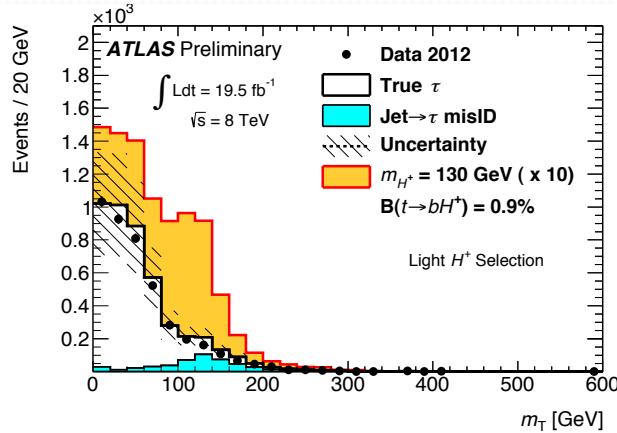
$mH^\pm > m_t$



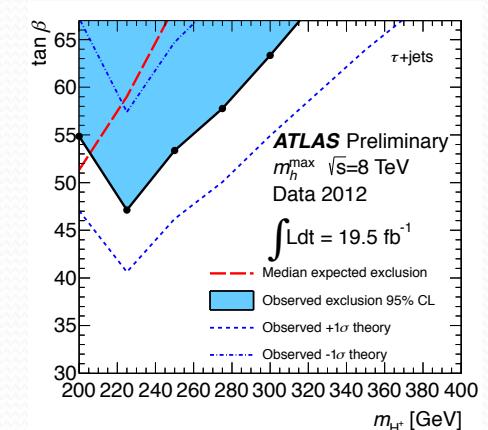
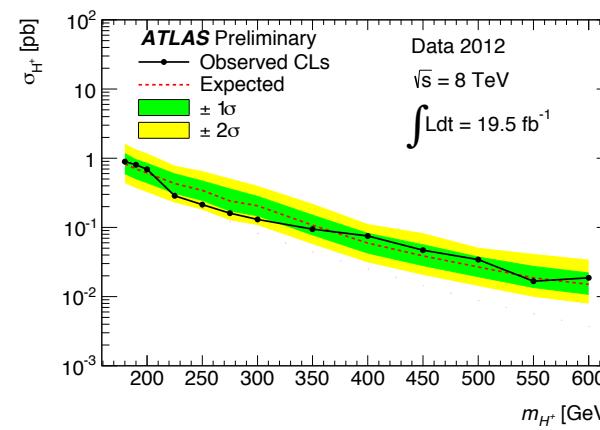
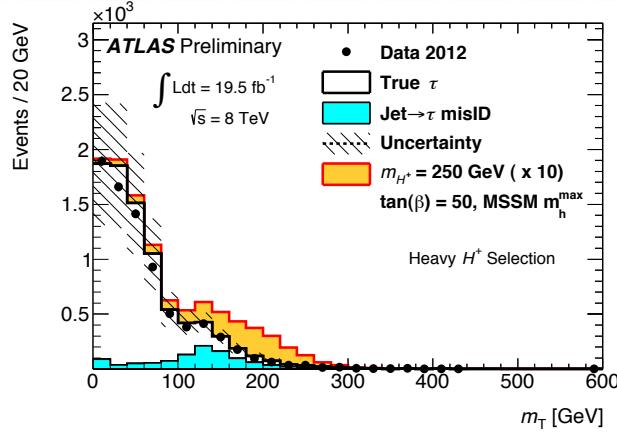
Top Associated Production
Heavy Charged Higgs

Charged Higgs results

Light Higgs ($mH^\pm < mt$), $t\bar{t} \rightarrow H b W b$



Heavy Higgs ($mH^\pm > mt$)

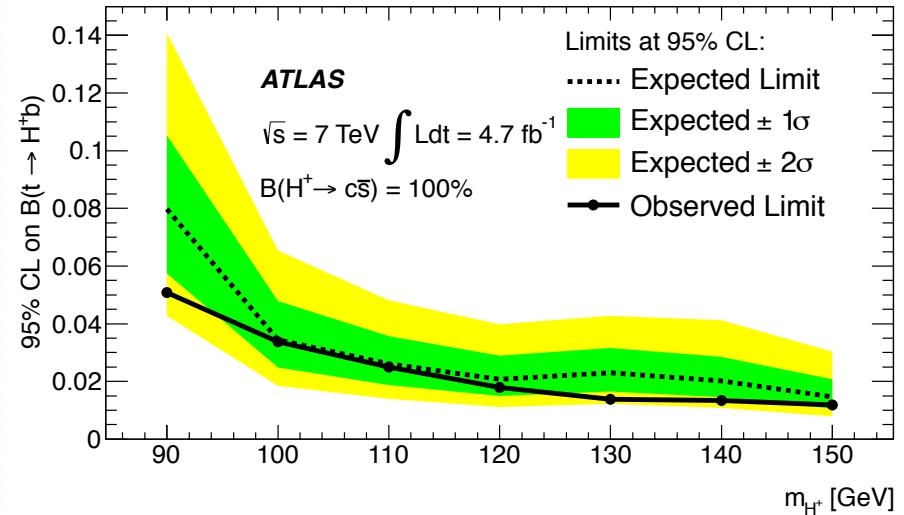
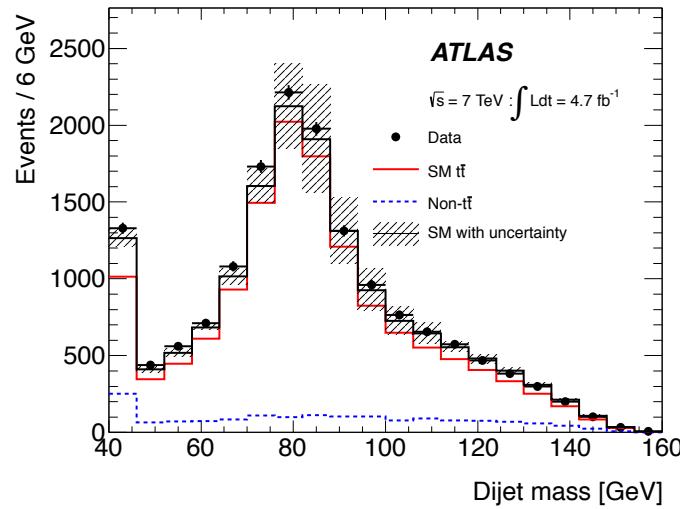
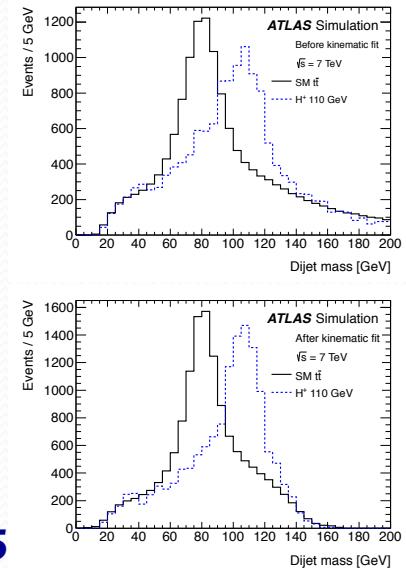




Light charged Higgs $H^\pm \rightarrow c\bar{s}$

- Search for the light charged Higgs in top decays
- $H^\pm \rightarrow 2\text{jets}$, and leptons from second top
- Selection: e/μ and ≥ 4 Jets (of which 2 b-tagged)
High Missing Energy
- Look for a second peak in dijet mass, set limits
on $\text{Br}(t \rightarrow bH^+)$

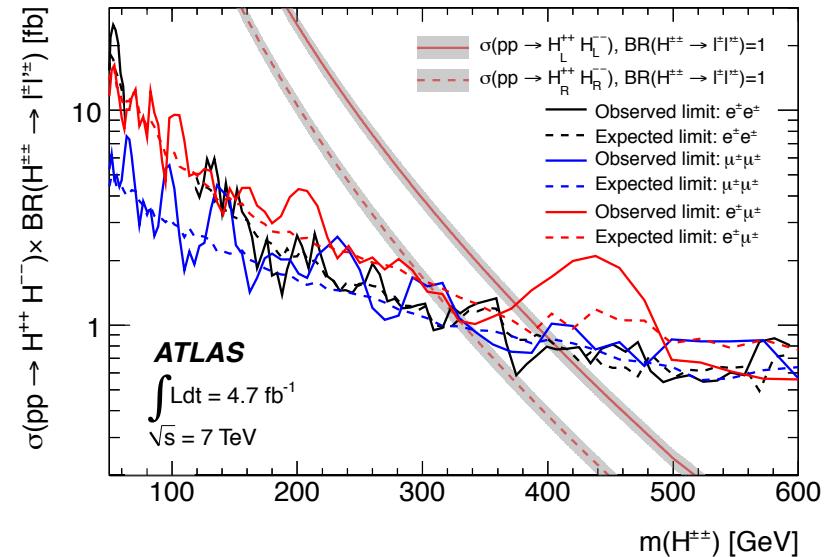
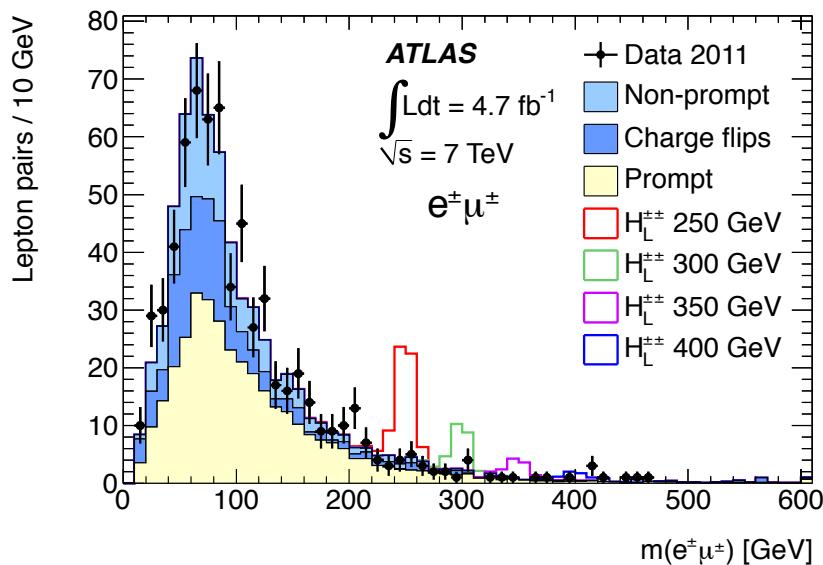
Eur. Phys. J. C73 (2013) 2465



Doubly charged Higgs

- Appears in LR symmetric models, Seesaw Type II, Little Higgs
- Possible way to probe origin of neutrino masses at the LHC!
- Production: mostly pairs: $H^{++} H^{--}$
- Method: generic same-sign dilepton spectrum search
 - $pT e > 25 \text{ GeV}, pT \mu > 20 \text{ GeV}, Z\text{-window}$

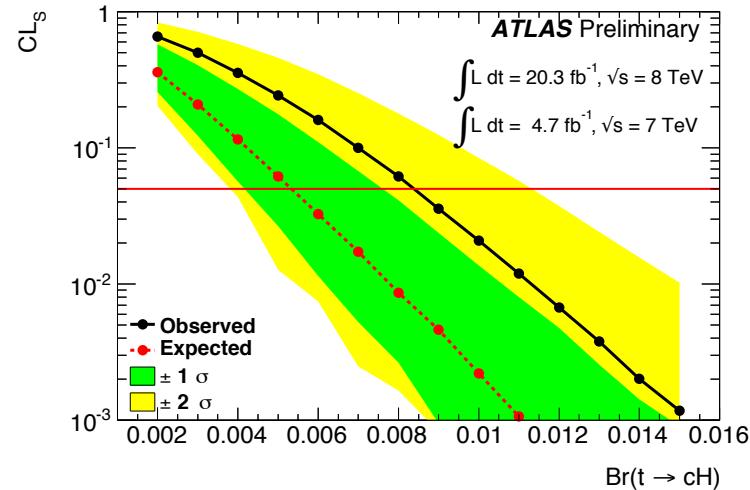
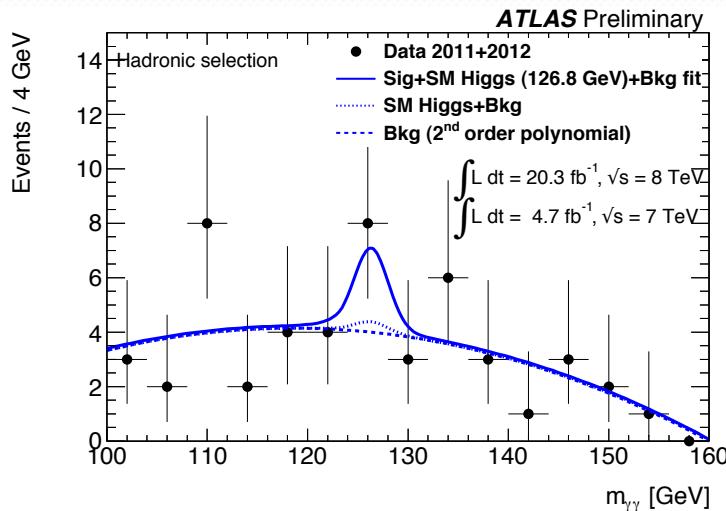
Eur. Phys. J. C72 (2012) 2244



➤ Search for FCNC in $t \rightarrow cH$, $H \rightarrow \gamma\gamma$

- In SM, FCNC are forbidden at tree level, suppressed by GIM mechanism at higher orders
 - Observation \rightarrow direct indication of new physics
- Selection: two photons ($pT > 40/30$ GeV)
 - $t\bar{t} \rightarrow bW cH \rightarrow bjj \gamma\gamma$: ≥ 4 jets, ≥ 1 b-jet, top mass cuts
 - $t\bar{t} \rightarrow bW cH \rightarrow blv \gamma\gamma$: 1 e/ μ , $mT > 30$ GeV, ≥ 2 jets, ≥ 1 b-jet, top mass cuts
- Observed/expected limits at 95% CL:
 - $\text{Br}(t \rightarrow cH)$: 0.83/0.53%, tcH coupling 0.17/0.14

ATLAS-CONF-2013-081



Conclusions

- Performed many different searches for extended BSM Higgs sector with ATLAS, however no evidence found. Limits have been set.
- Many analyses on full Run I data set are still to be completed.
- We now know where in the phase space to focus our efforts as we prepare for Run II.
- Further analysis still in progress.
- Looking forward to new exciting discoveries!

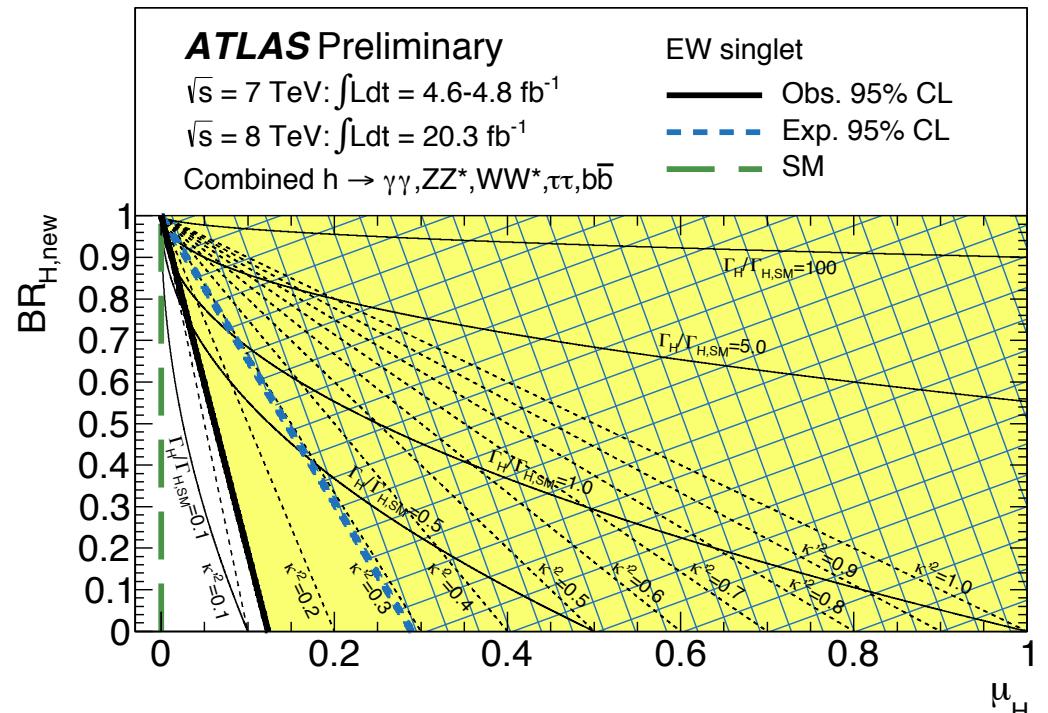


BACKUP SLIDES



Additional electroweak singlet

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- Observed and expected upper limits at 95% CL on the squared coupling, κ'^2_2 , of a heavy Higgs boson arising through an additional EW singlet, shown in the $(\mu_H, BR_{H,\text{new}})$ plane.

MSSM simplified model

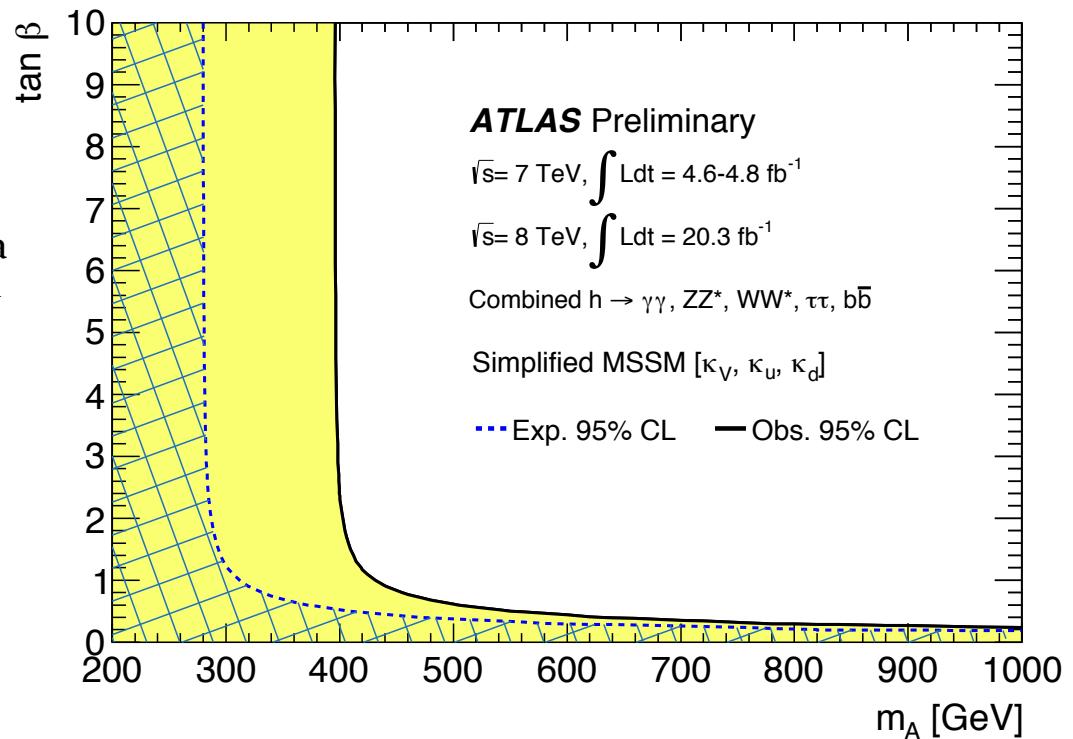
Coupling scale factor	Type I	Type II	Type III	Type IV
k_v	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
k_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
k_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
k_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

- Regions of the $(m_A, \tan \beta)$ plane excluded in a simplified MSSM model via fits to the measured rates of Higgs boson production and decays. The likelihood contours where $-2 \ln \Lambda = 6.0$, corresponding approximately to 95% CL (2σ), are indicated for the data and expectation assuming the SM Higgs sector.

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04/30/2014

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Cascade Higgs search

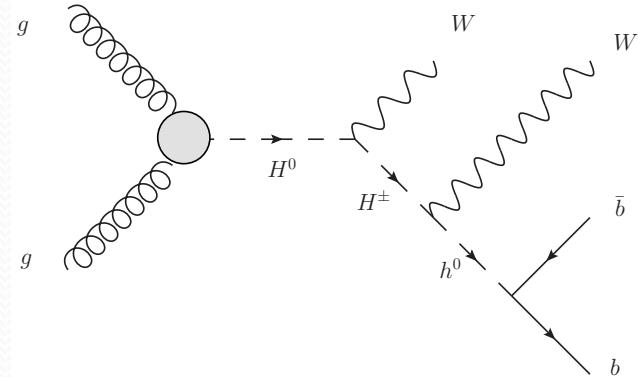


Diagram showing the Higgs-boson cascade
 $gg \rightarrow H^0 \rightarrow W^\pm H' \rightarrow W^\pm W' h^0 \rightarrow W^\pm W' b\bar{b}$.

Phys. Rev. D 89, 032002 (2014)

