BSM Higgs searches and Higgs portal to dark matter @ATLAS

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Outline

- Introduction
- Overview BSM Higgs
- BSM Higgs searches
  - Constraints via Higgs coupling measurement
  - Neutral Higgs boson searches
  - Charged Higgs searches
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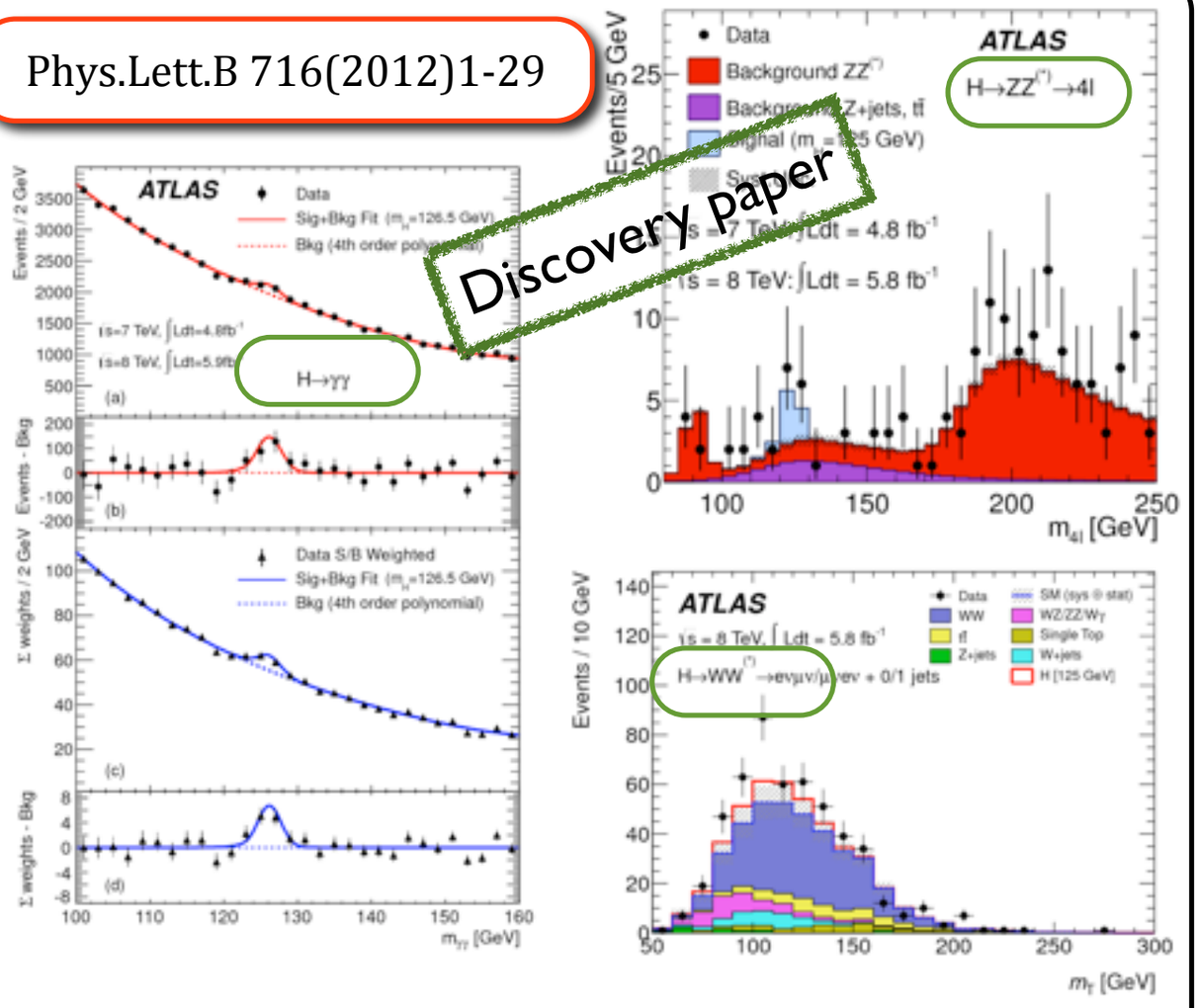
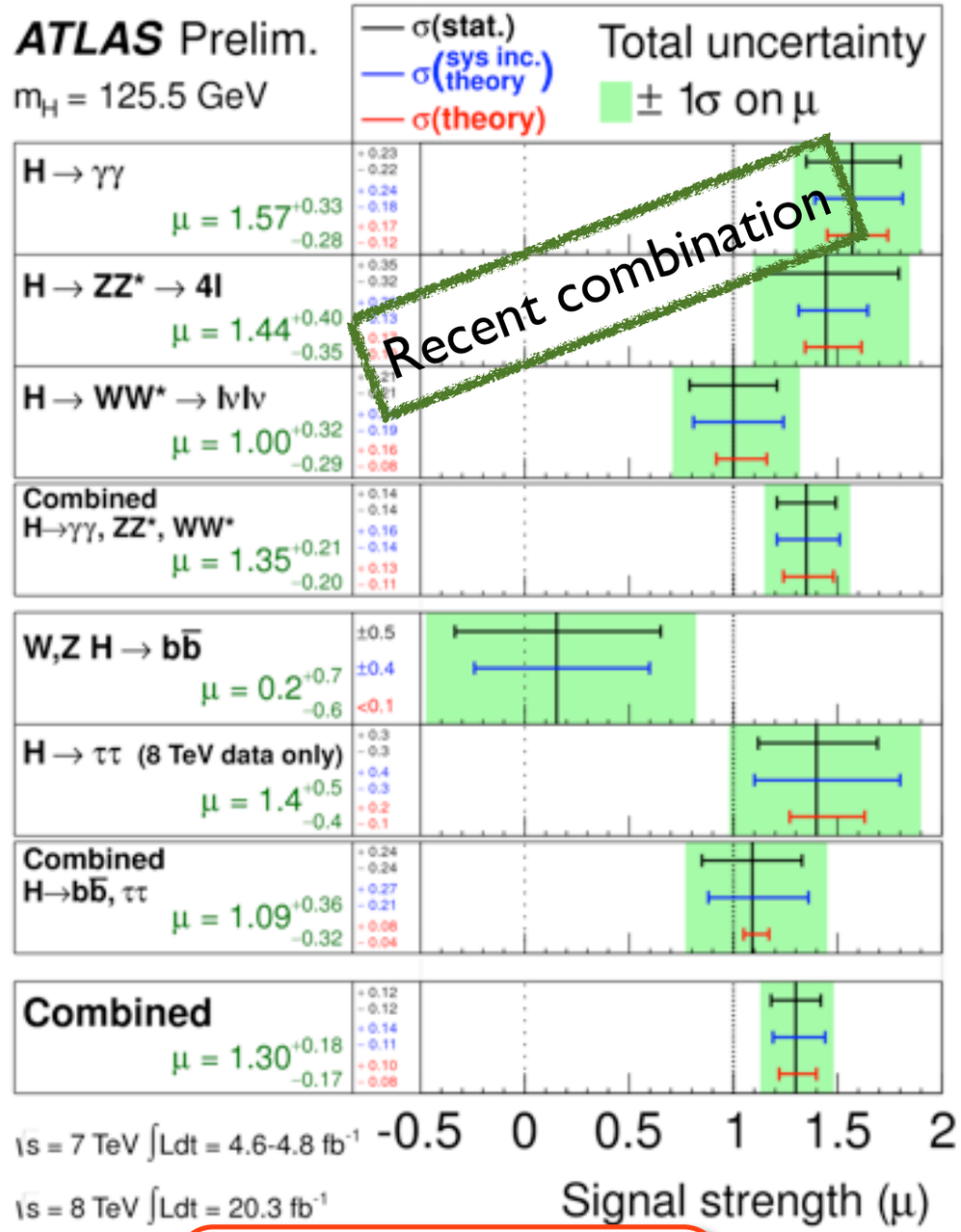
  - Flavor Changing Neutral Current (FCNC) t→qH search
- Invisible Higgs Decays
- Conclusion

The "new" scalar boson

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



Discovery paper



Recent combination

- **This scalar boson consistent with SM Higgs**

- $m_H \sim 125.5$ GeV

$$\mu = 1.30 \pm 0.12(stat)^{+0.14}_{-0.11}(syst)$$

- Evidence of Higgs decay to fermions: 3.7σ

$$\mu^{bb,\tau\tau} = 1.09 \pm 0.24(stat)^{+0.27}_{-0.21}(syst)$$

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$$\kappa_V = 1.15 \pm 0.08$$

$$\kappa_F = 0.99^{+0.17}_{-0.15}$$

Introduction

- **Discovery of a scalar boson consistent with SM Higgs**
  - Is it SM Higgs or something else ?
  - new window for physics beyond SM

- **Non-SM interpretation**
  - the observed boson: part of an extended scalar sector
  - large variety of models: 2HDM, MSSM...

- **Search strategies:**
  - direct searches: additional charged or neutral Higgs bosons
  - indirect searches: measurement of properties of Higgs boson, constraints to be in-compatible with the SM

Overview BSM Higgs

- **Two Higgs Doublet Model (2HDM)**
  - an additional doublet
  - four types based on coupling structure

- **Minimal Supersymmetric Standard Model (MSSM)**
  - search for neutral and charged Higgs bosons

- **Minimal Composite Higgs Model (MCHM)**
- **Next-to-Minimal SUSY (NMSSM)**

- **2HDM and MSSM have a rich phenomenology, compatible with SM-like Higgs boson. Focus in this talk**

Two Higgs Doublet Models

- **2HDM: one of the simplest extensions of the SM**
  - adding a second EW doublet to the Higgs sector
  - predicted 5 Higgs bosons:
    - 3 neutral: h^0(CP even), H^0(CP even), A^0 (CP odd)
    - 2 charged: $H^{\pm}$
- **Described by:**
  - 4 Higgs boson masses
  - tan β (ratio of vacuum expectation values of the doublets)
  - mixing parameter α (between two neutral CP even Higgs: h^0 H^0)
- **Four types: based on coupling structure**

Coupling scale factor	Type I	Type II	Type III	Type IV
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

- **MSSM: 2HDM type II + SUSY sector**

Constraints on 2HDM via Higgs Couplings

- light Higgs couplings measured by combination of various channels (7+8 TeV)
- Using SM Higgs boson masses mH ~ 125.5 GeV

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- Express SM couplings in context of the four types of 2HDM
- Set 95% CL exclusion limits in cos(β-α), tan β plane.

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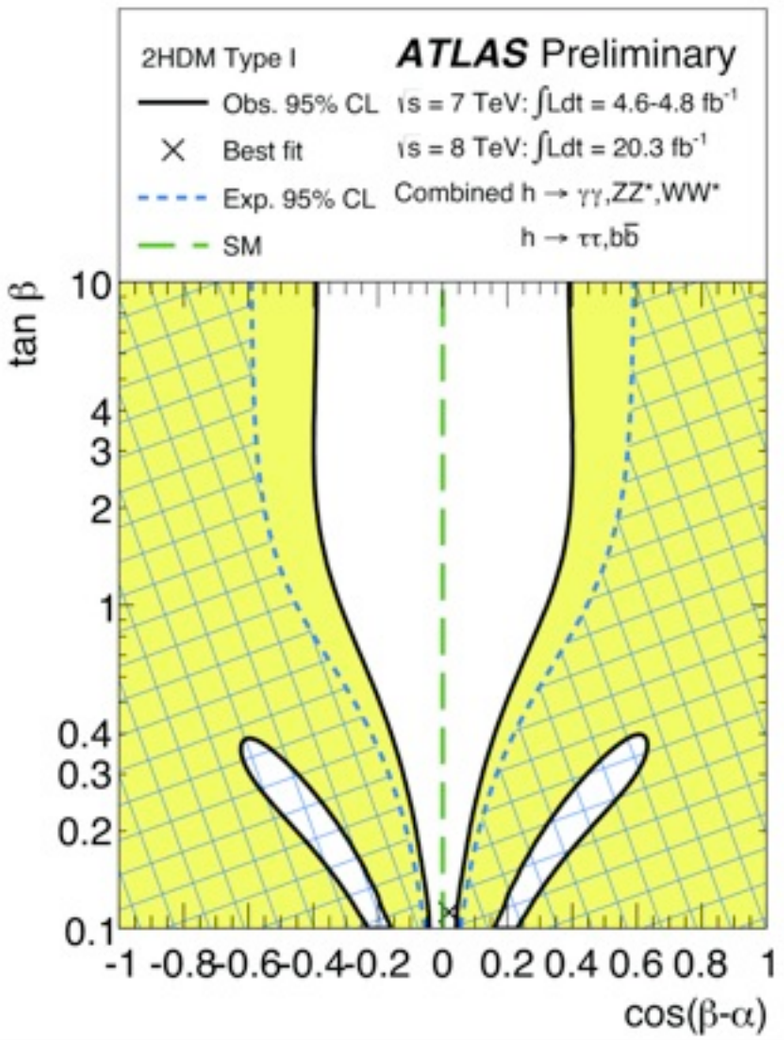
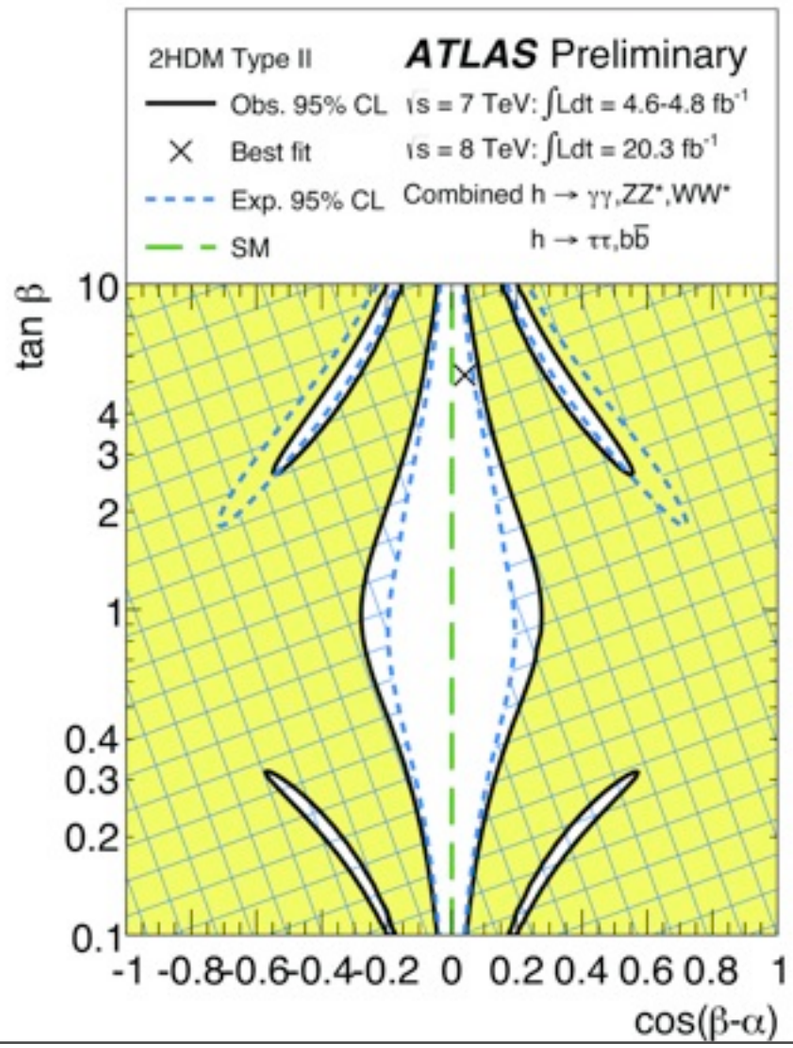
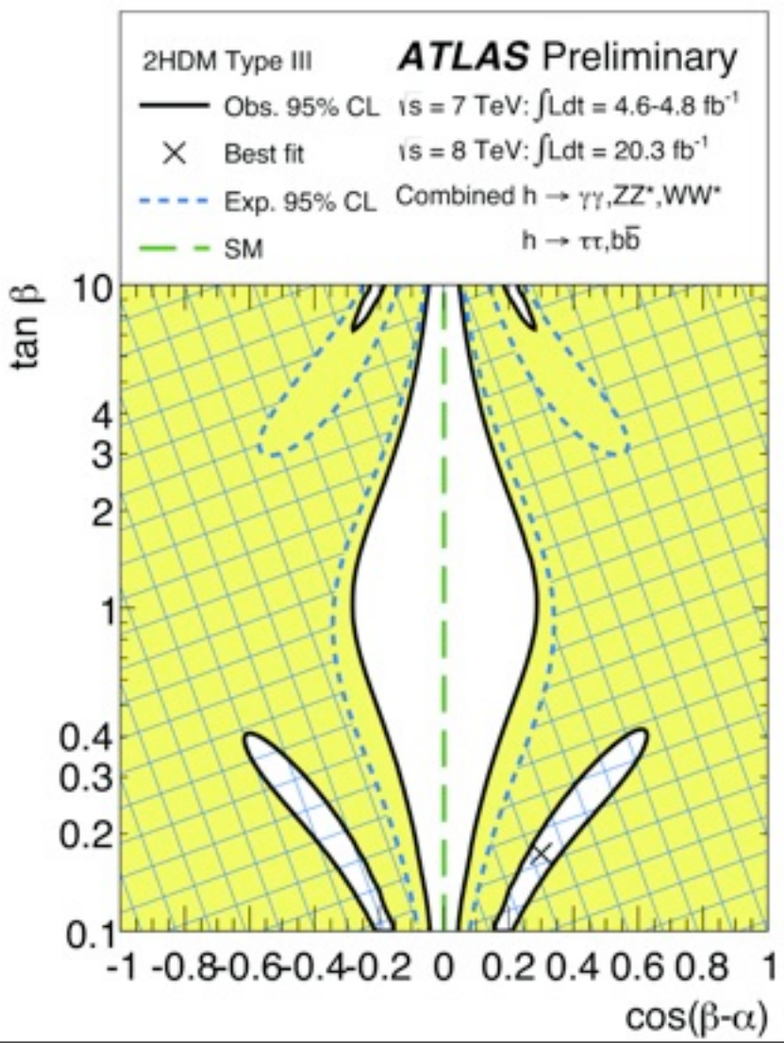
- data consistent with SM-like argument at cos(β-α)=0 within 1-2σ for all models

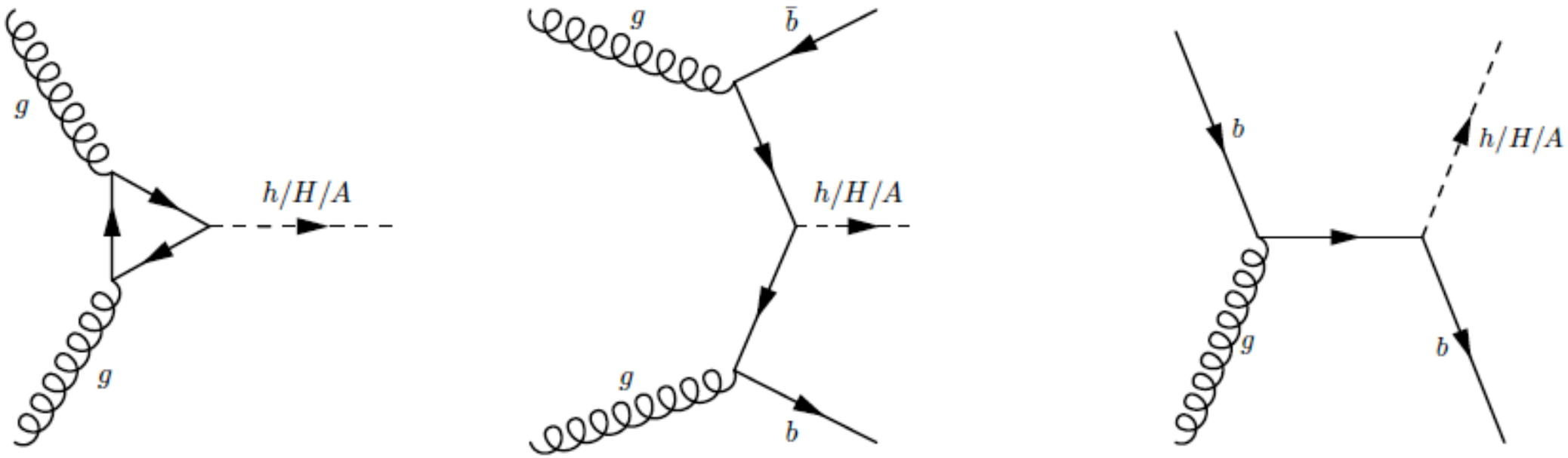






Neutral Higgs bosons searches

- **The couplings of MSSM Higgs bosons to down-type fermions enhanced**
  - especially for large **tan β value**
  - enhanced production mode with associated b-quarks
  - increased branching fraction to τ leptons and b-quarks
    - 3 neutral: h^0(CP even), H^0(CP even), A^0 (CP odd)
    - the ττ decay mode sensitive to neutral higgs boson searches

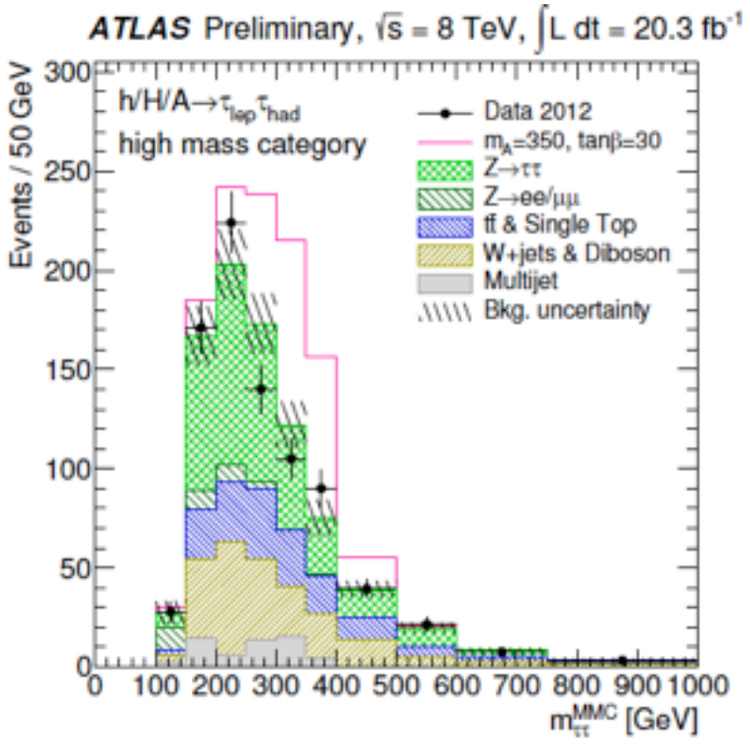


Neutral Higgs boson searches

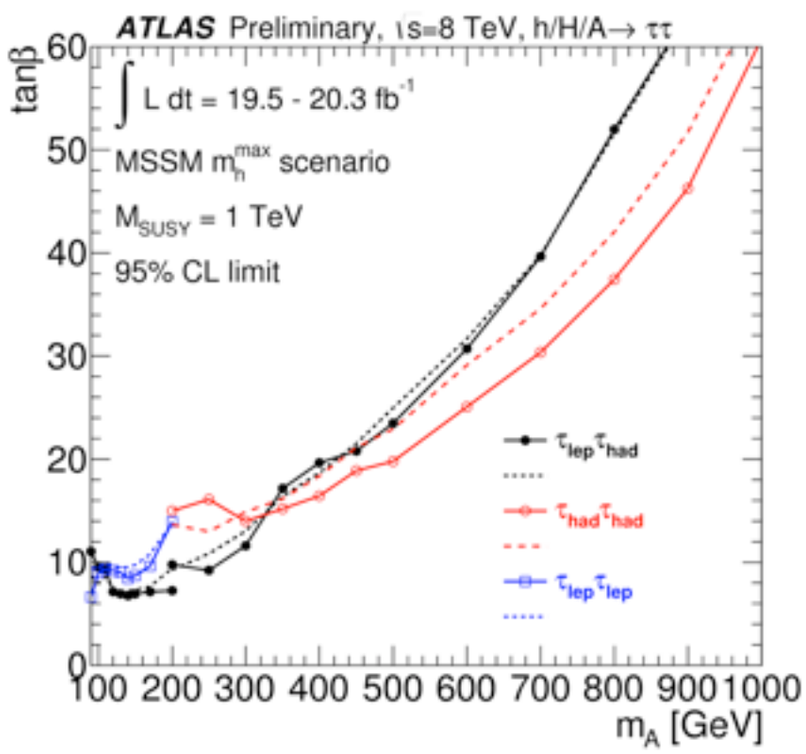
- **Search through ττ decay mode, using the following channels** ATLAS-CONF-2014-049
  - $\tau_e\,\tau_\mu$ (6%), $\tau_e\tau_{had}$ (23%), $\tau_\mu\,\tau_{had}$ (23%), $\tau_{had}\tau_{had}$ (42%)
  - discriminating variable: $m_{\tau\tau}$ (using Missing Mass Calculator) or m_T^{total}

$$m_{\mathrm{T}}^{\mathrm{total}} = \sqrt{m_{\mathrm{T}}^2(\tau_1,\tau_2) + m_{\mathrm{T}}^2(\tau_1, E_{\mathrm{T}}^{\mathrm{miss}}) + m_{\mathrm{T}}^2(\tau_2, E_{\mathrm{T}}^{\mathrm{miss}})}$$

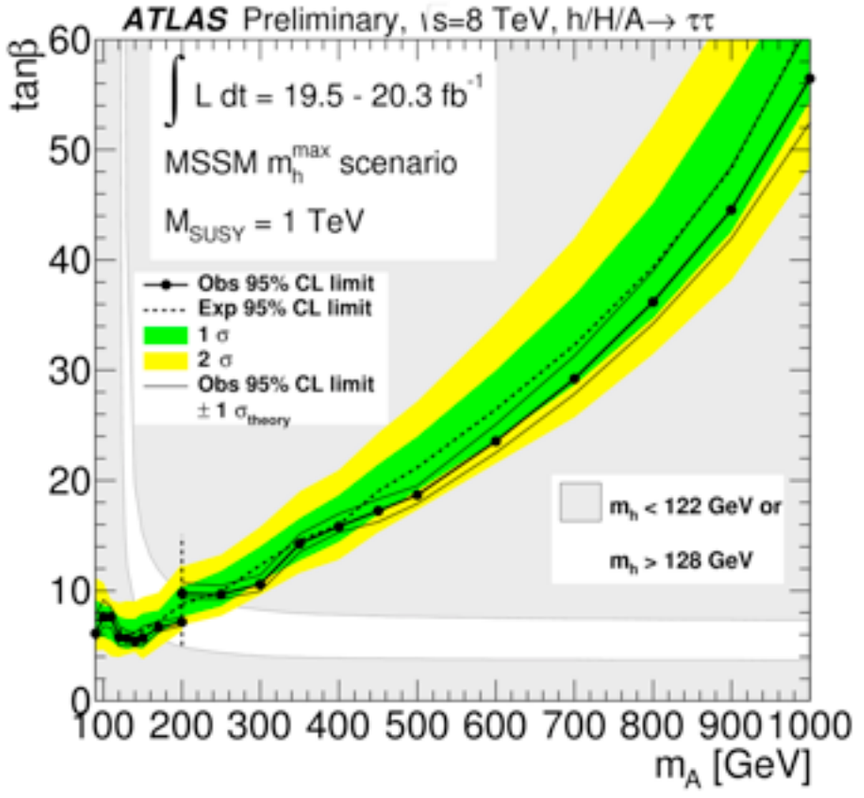
$m_{\tau\tau}$ in $\tau_{lep}\,\tau_{had}$ (high mass category)



exclusion limits from each channel



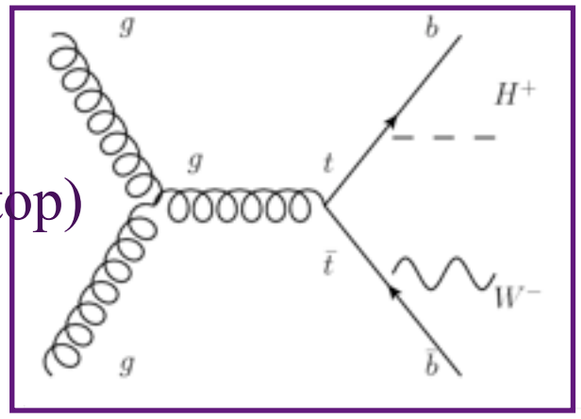
exclusion limits combining all channels

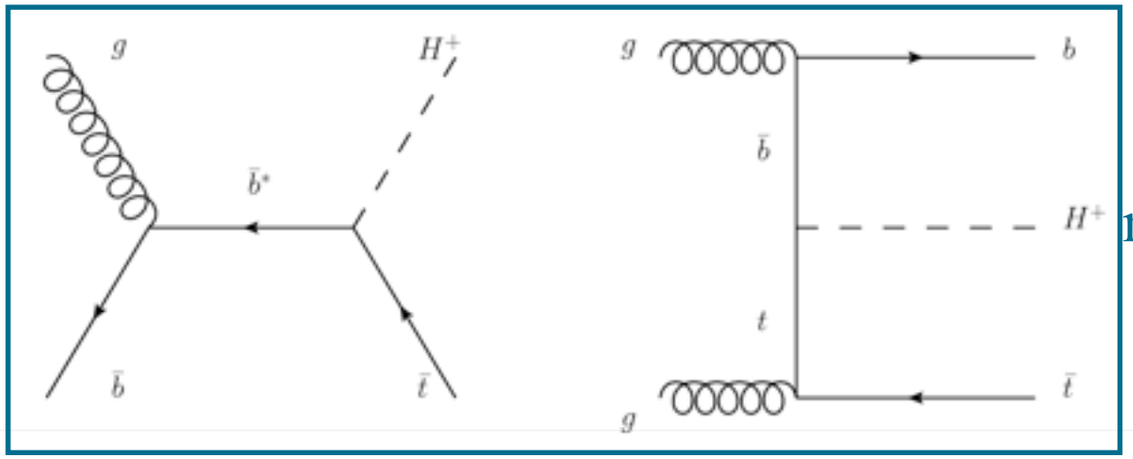


Charged Higgs searches (1)

- **Charged Higgs production involves top-quarks**
  - Production mode depending on m(H+) relative to m(top)

m(H+) < m(top)





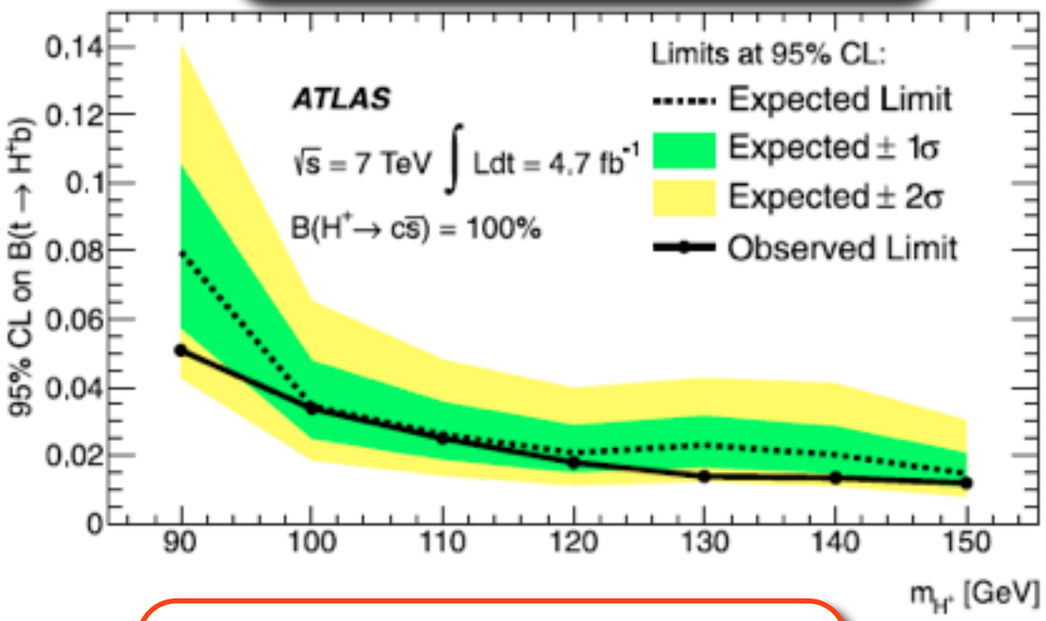
m(H+) > m(top)

- **Decay via H+→τυ/cs/tb, branching ratio depending on m(H+) and tan β**
  - light charged Higgs: tan β < 1, H+→cs dominant; tan β > 1, H+→τυ dominant
  - heavy charged Higgs: H+→τυ still sizeable, H+→tb become large

Charged Higgs searches (2)

EPJC736(2013)2465

- **Light charged Higgs search through channel ttbar→bW(→lυ)bH⁺(→cs)**
  - very similar final states as SM **ttbar**→bW(→lυ)bW(→jj), discriminate on m_{jj}
  - limit set on BR(t→ bH+) assuming BR(H^+→cs)=100%



- **Light/heavy charged Higgs search through channel H+→τυ**

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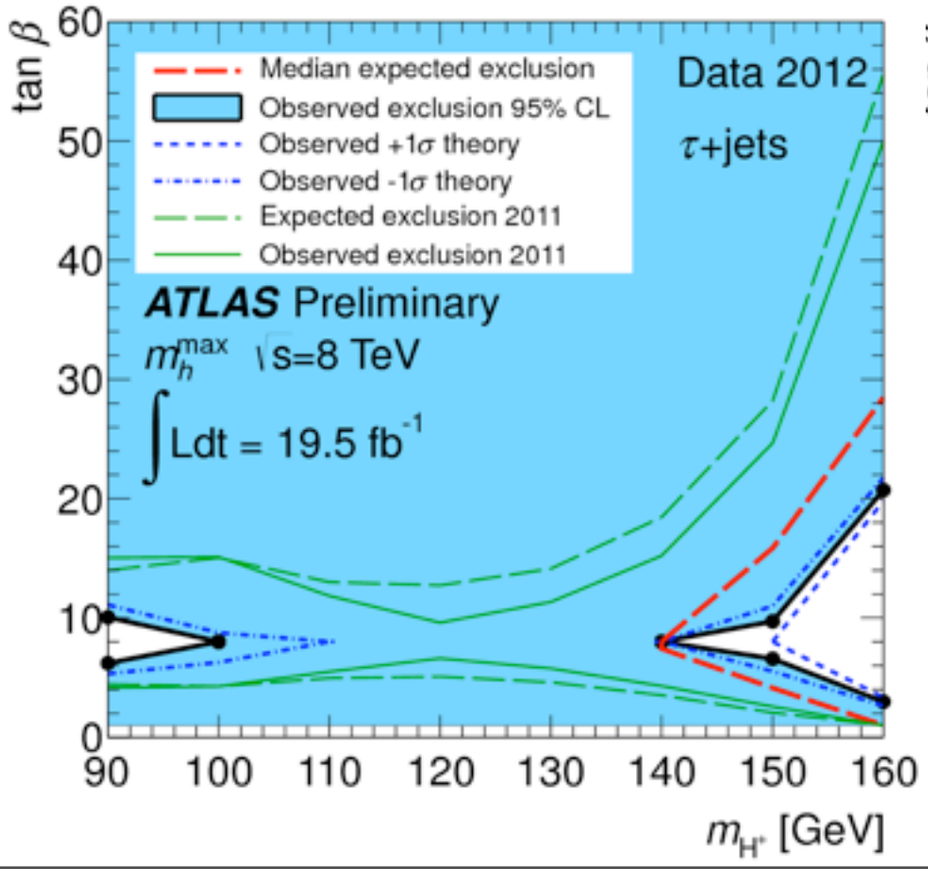
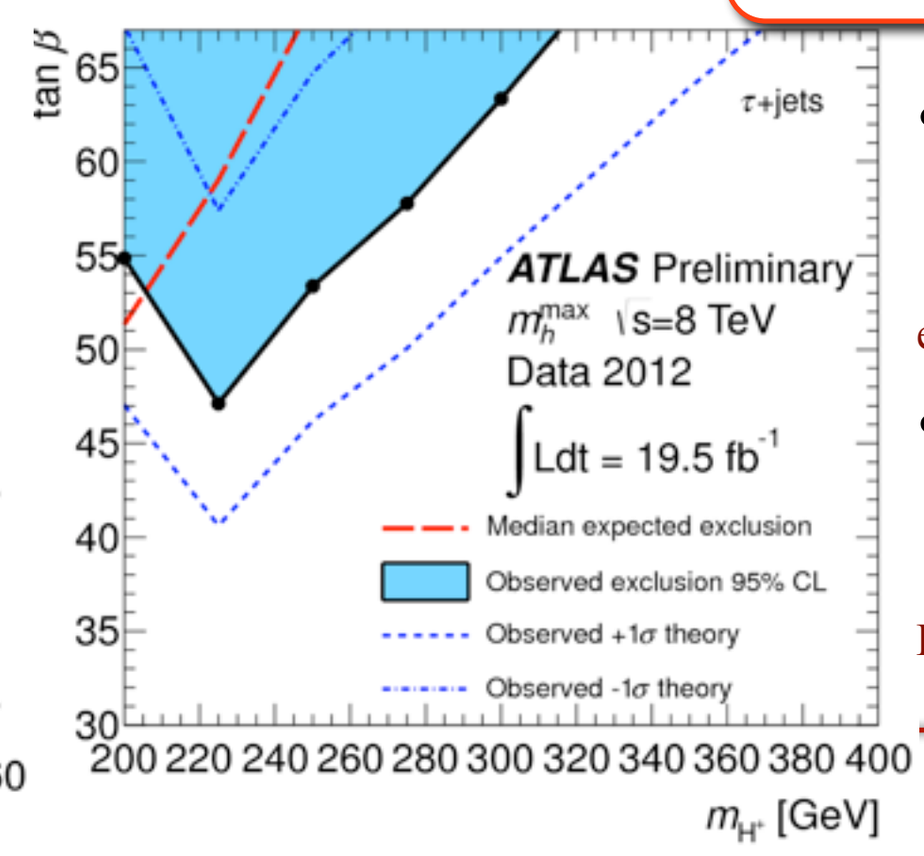




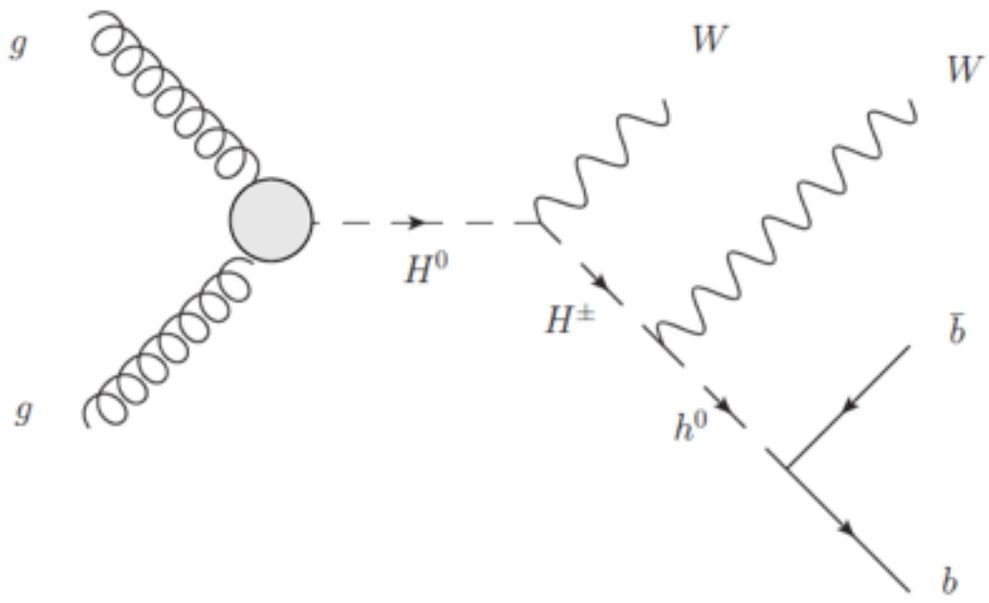
- Light charged Higgs: 95% CL limit on BR(t→H^+b) 0.24-2.1% in mass range [90, 160] GeV

exclusion of most parameter space

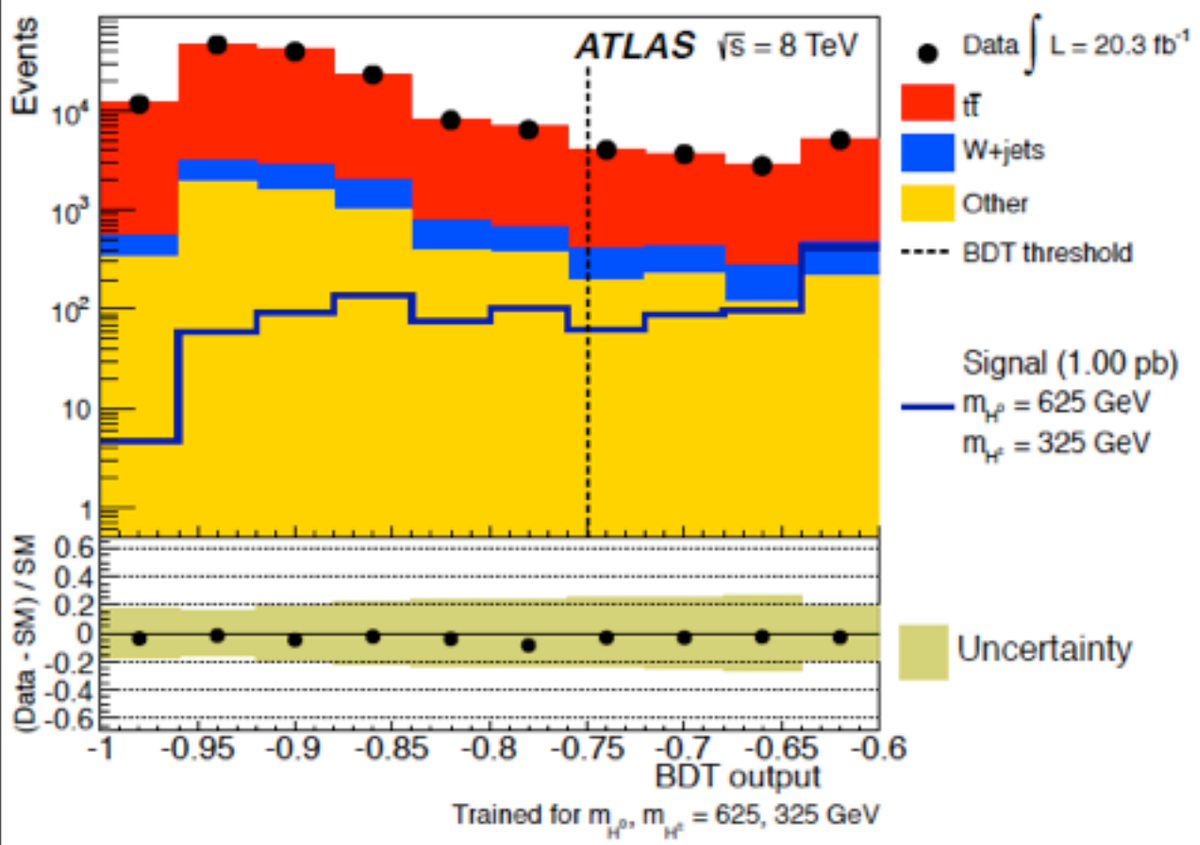
- Heavy charged Higgs: 95%CL limit on production x-section 0.017-0.9 pb, assuming BR(H+→τυ)=100%

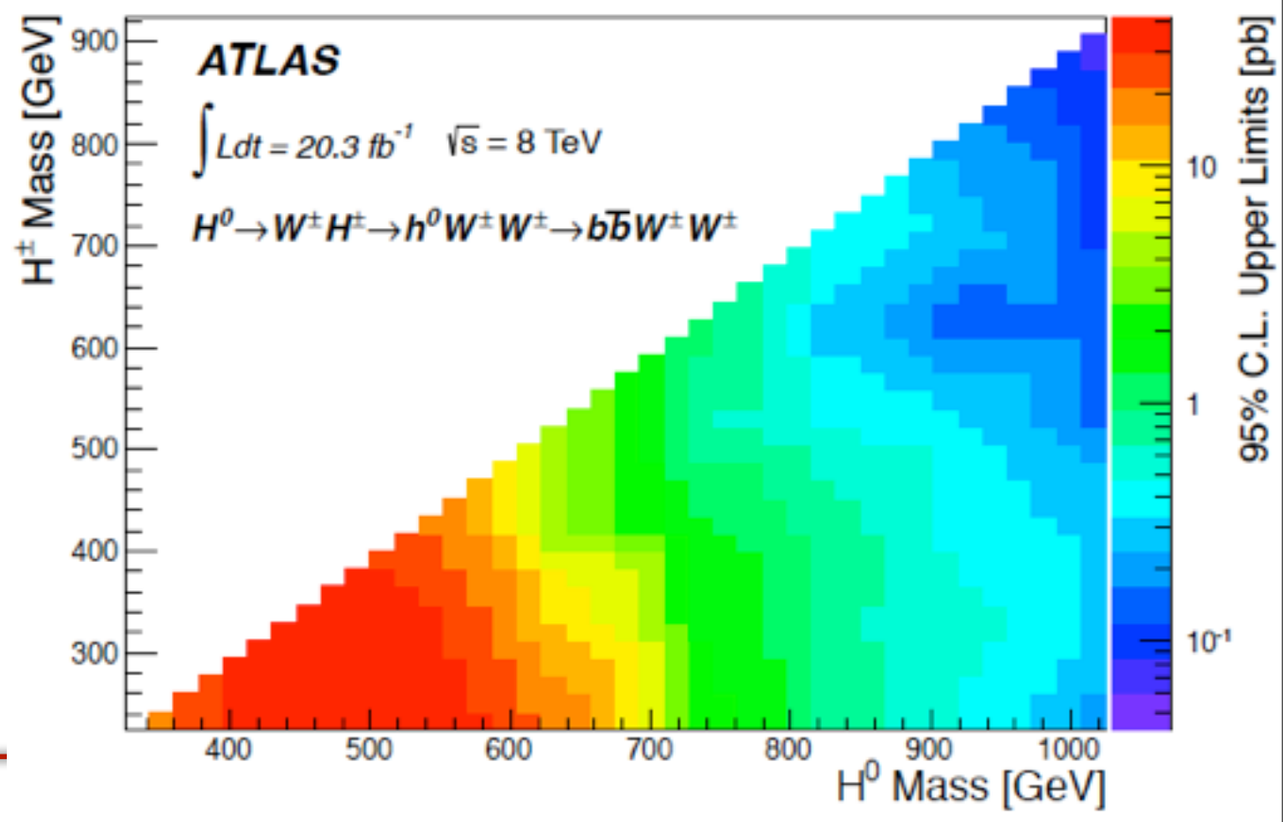
First limit in high mass range

2HDM multi-Higgs Cascade



- **search for cascade decay $H^0 \rightarrow WH^+ \rightarrow WWh^0 \rightarrow WWbb$**
- **Same topology as top pair events**
- **Search ranges:** Phys.Rev.D89(2014)032002
  - 225 GeV < m(H^+) < 925 GeV
  - 325 GeV < m(H^0) < 1025 GeV
- **Use Boosted Decision Trees to largely account for the kinematic difference between signal and top pair events**





2HDM Higgs and FCNC top decays (1)

- **Flavor-Changing Neutral Current (FCNC) search**
  - previous search conducted in t→c(u)Z decay by LEP and HERA experiments
  - t→c(u)H is opened up since discovery of Higgs

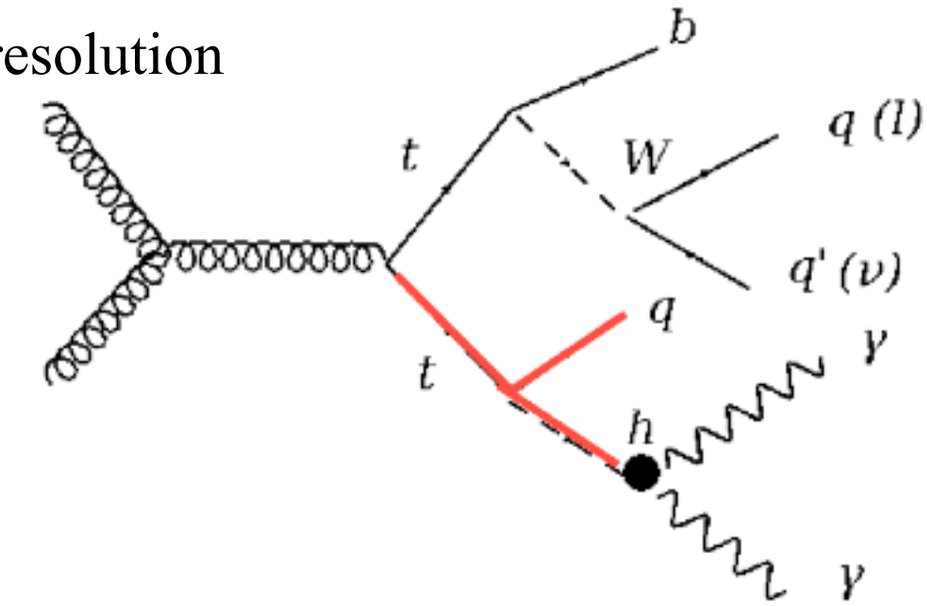
- **FCNC forbidden at tree level, strongly suppressed by GIM mechanism**
  - expectation for BR(t→cH)~$3 \cdot 10^{-15}$

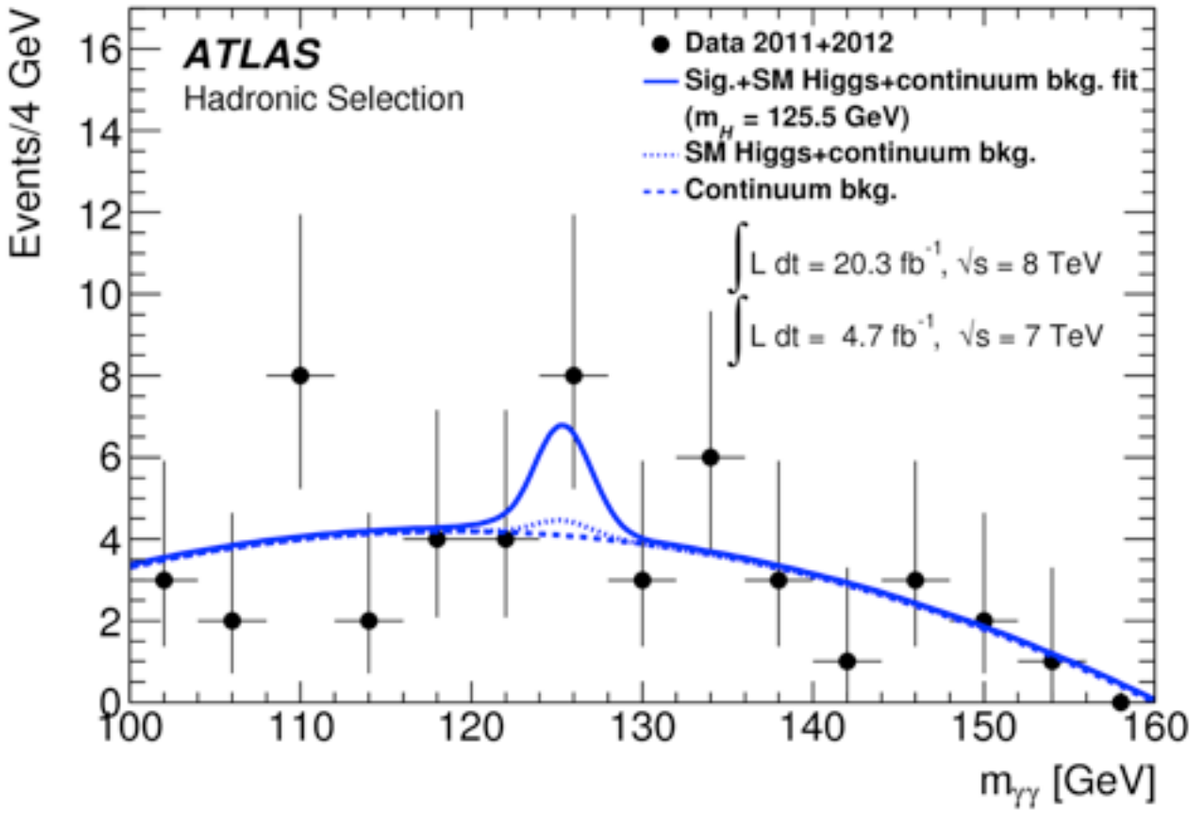
- **Coupling increase in 2HDM: ~0.15%**
  - if observation of FCNC: clear signal of new physics

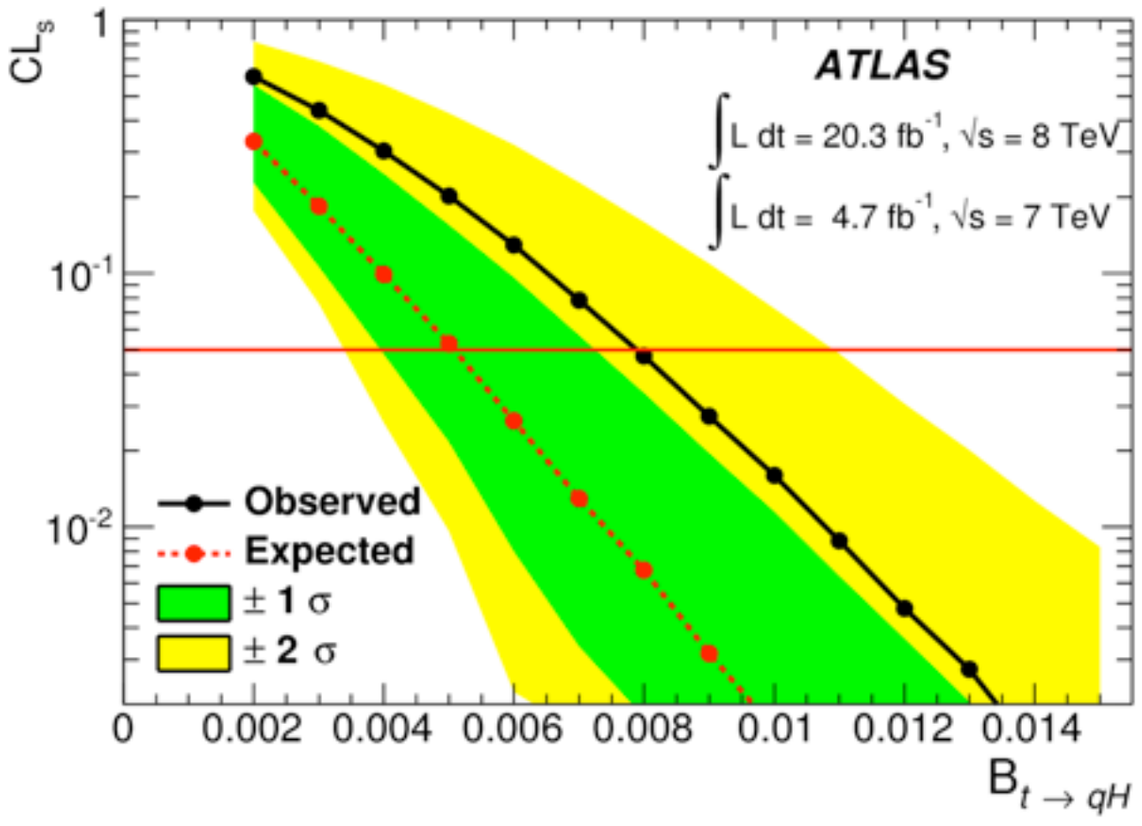
2HDM Higgs and FCNC top decays (2)

JHEP06(2014)008

- **Search is done through ttbar→bW(→jj or lυ)qH(→γγ)**
  - Higgs decay to diphoton provide mass peak with good resolution
- **Limits:**
  - BR(t→cH)<0.79%(0.51%) observed(expected)
  - coupling sqrt($\lambda_{tcH}^2+\lambda_{tuH}^2$) < 0.17 (0.14)



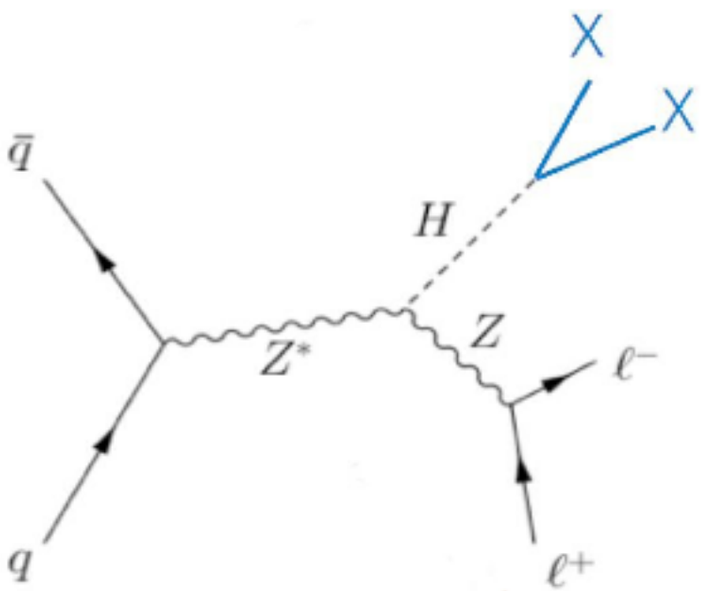




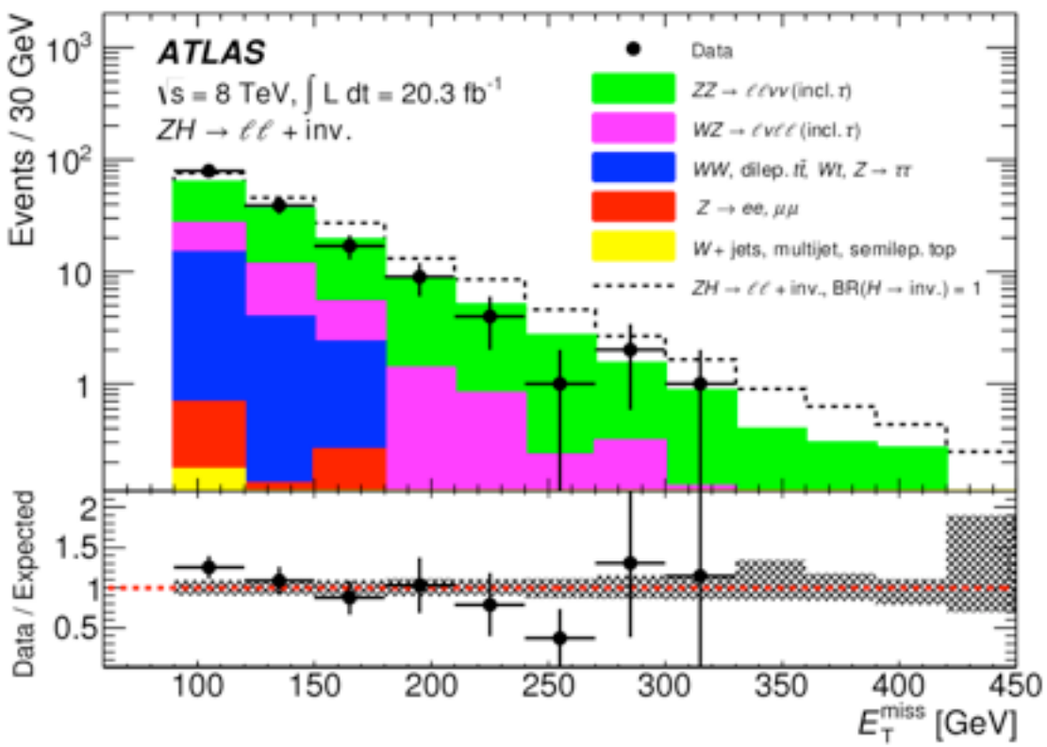
Invisible Higgs decay

- **Search for evidence of invisible Higgs decay mode**
  - use LHC data to constrain the branching ratio of invisible Higgs decays
  - extensions of the SM allow Higgs decay into stable or long-lived particles
    - e.g dark matter candidate as Weak Interacting Massive Particle(WIMP)

- **Using the Higgs production in association with a Z-boson: Z+H→*ll* + inv**
  - Z boson decay to lepton pairs
  - Assuming SM rate for Z+H production

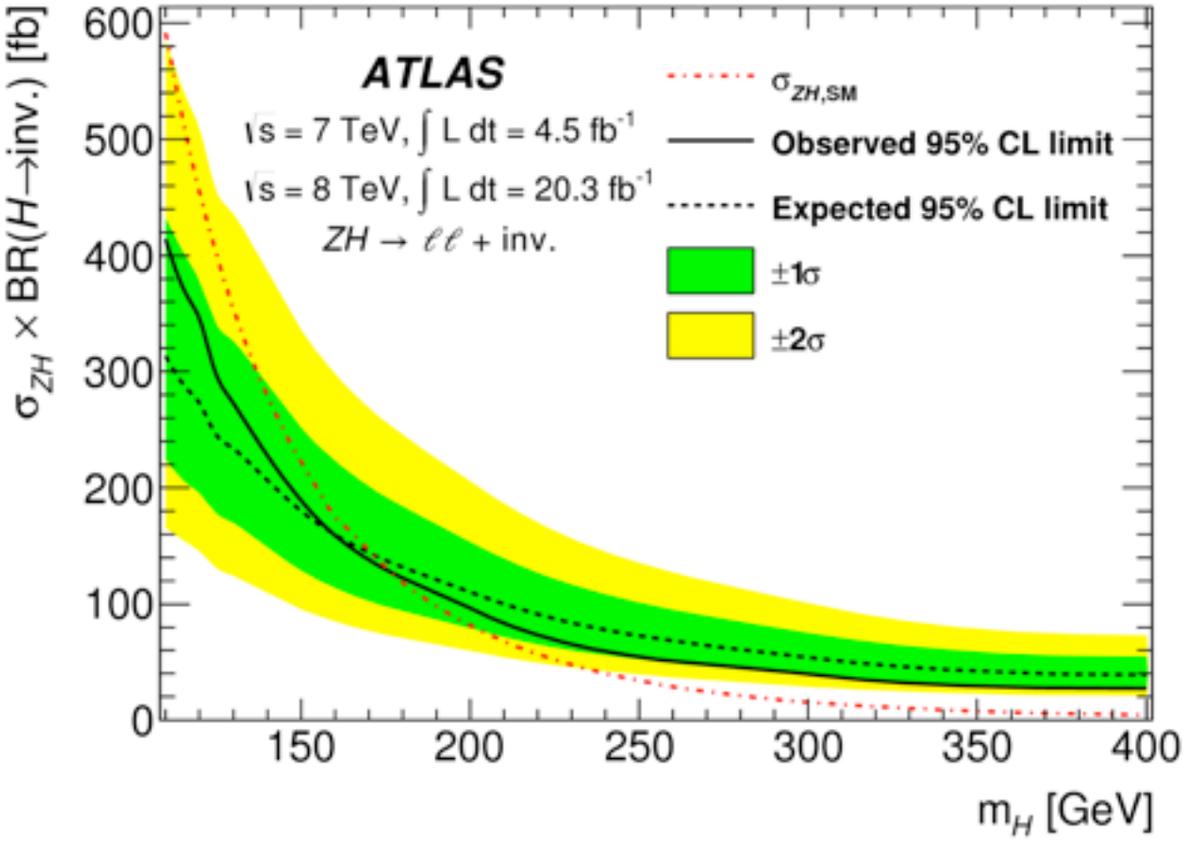


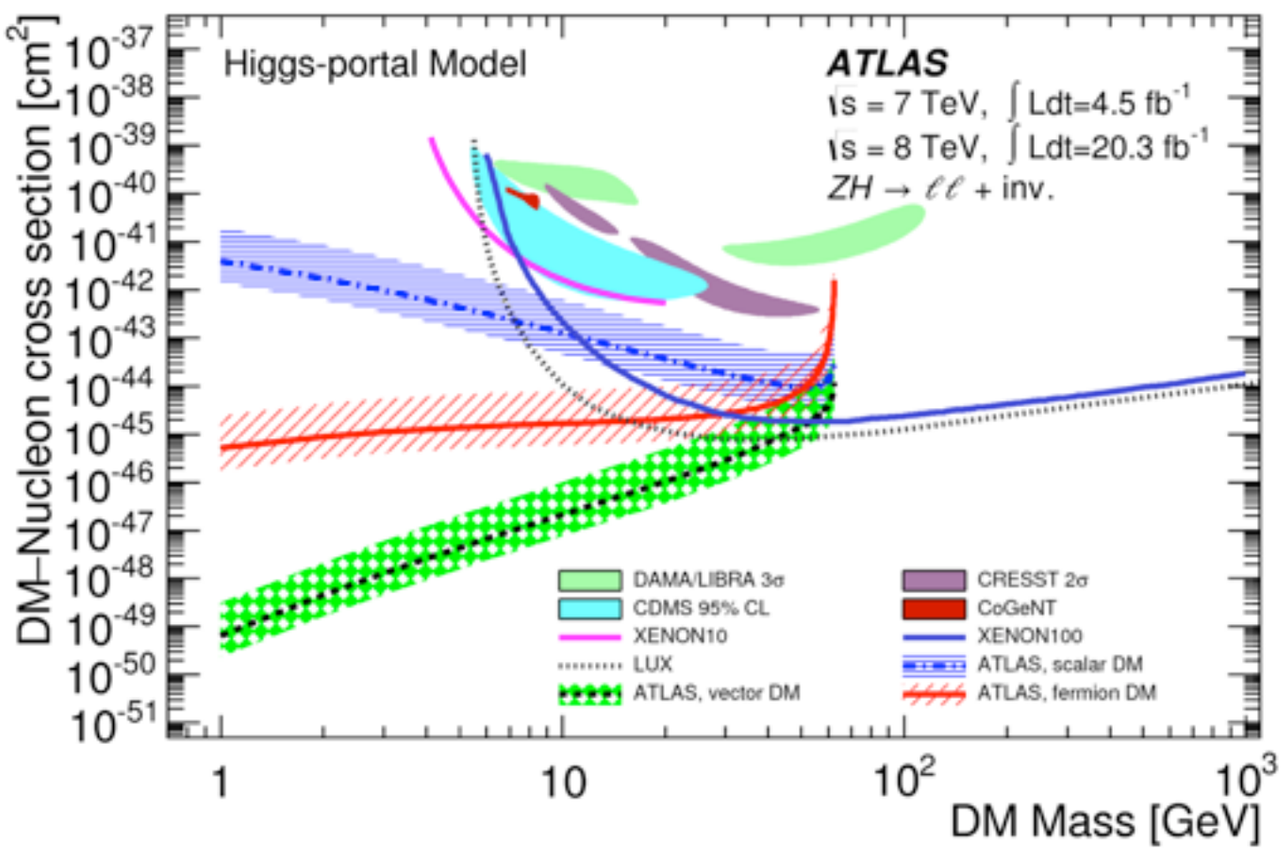
Phys.Rev.Lett 112(2014)201802



Invisible Higgs decay -- result

- **Upper limit for branching ratio of invisible Higgs decay**
  - mass range: $100 < mH < 400$ GeV
  - BR(H→inv.) < 75%(62%) observed(expected) at 95% CL
- **Strongest limit on low mass DM-nucleon scattering cross section**
  - three models: DM is scalar, a vector or a Majorana fermion





Conclusion

- **BSM Higgs search very active field**
  - large variety of analyses
  - large potential to make a discovery
- **Rich results are produced**
  - tight constraints to neutral and charged Higgs
  - explore FCNC searches
  - limits on invisible Higgs decays
- **No sign for new physics found yet!**
- **Still lots of analyses ongoing based on 8 TeV data. Large physics potential expected at Run 2 (13 TeV).**

- backup

Standard Model Couplings

$$\kappa_\gamma^2 \sim 1.59 \cdot \kappa_W^2 - 0.66 \cdot \kappa_W \kappa_t + 0.07 \cdot \kappa_t^2 \quad (2)$$

$$\kappa_g^2 \sim 1.06 \cdot \kappa_t^2 - 0.07 \cdot \kappa_t \kappa_b + 0.01 \cdot \kappa_b^2 \quad (3)$$

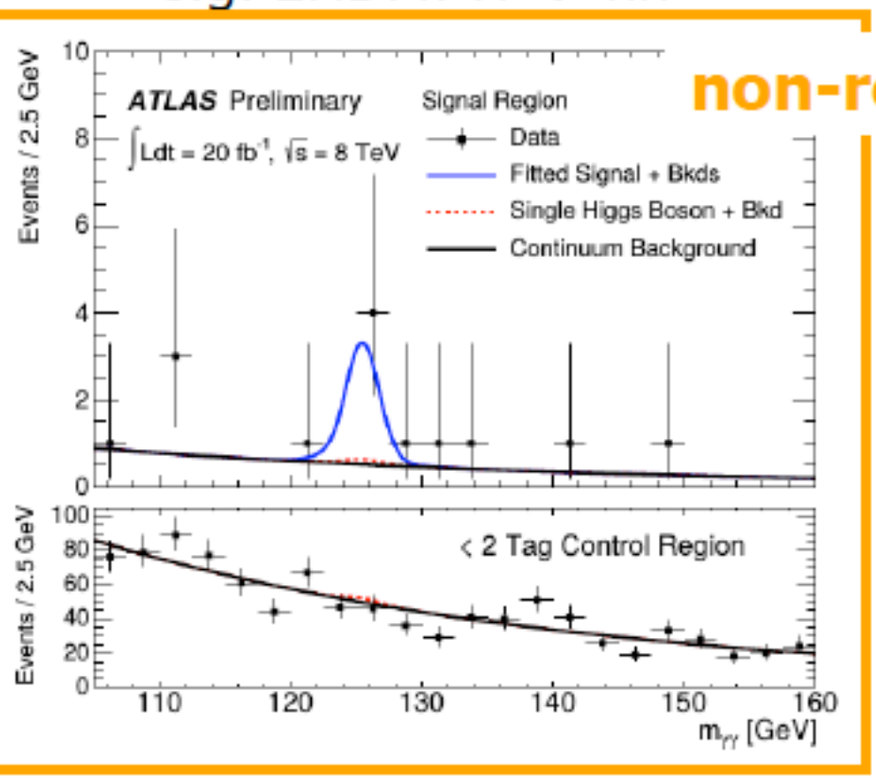
$$\kappa_{VBF}^2 \sim 0.74 \cdot \kappa_W^2 + 0.26 \cdot \kappa_Z^2 \quad (4)$$

$$\kappa_H^2 \sim 0.57 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.09 \cdot \kappa_g^2 + 0.06 \cdot \kappa_\tau^2 + 0.03 \cdot \kappa_Z^2 + 0.03 \cdot \kappa_c^2. \quad (5)$$

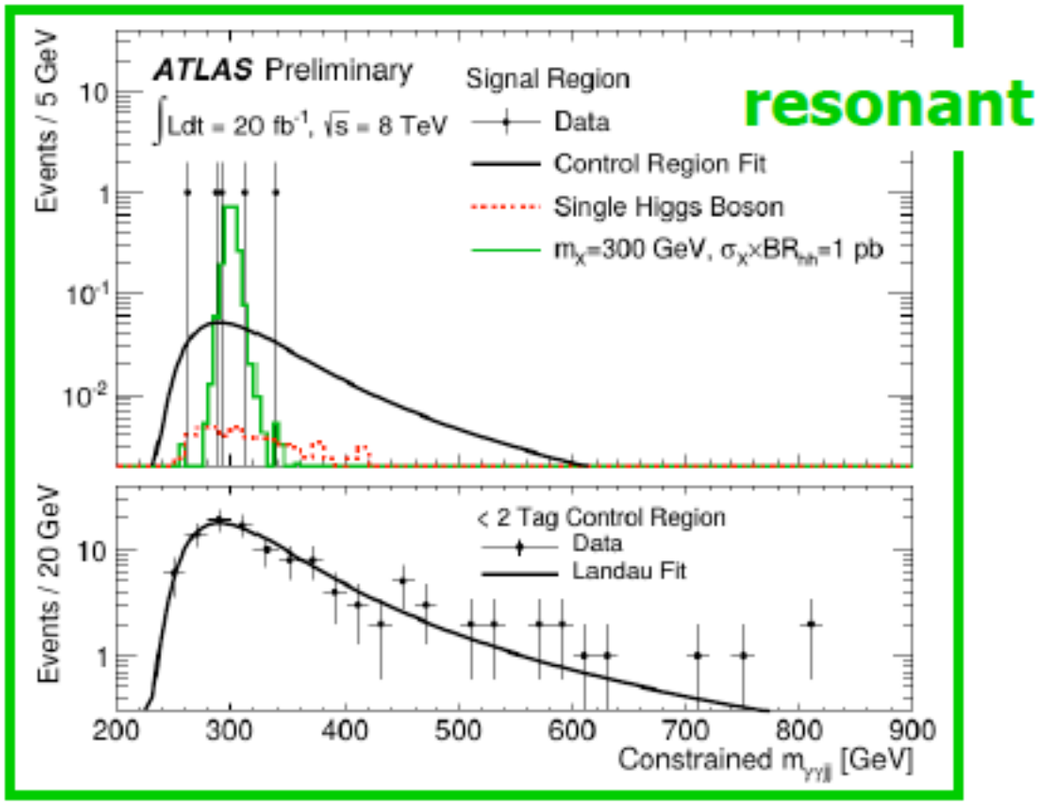
Higgs Pair production

- Search for non SM with either **resonant** (X → hh) or **non-resonant** pair production of Higgs bosons
  - hh → γγ bb channel
  - **arXiv: 1406.5053[hep-ex]**
- Predicted rates in SM for hh several orders of magnitude smaller than for the single h production
  - variety of extensions of SM could enhance hh production
  - e.g. 2HDM: H → hh

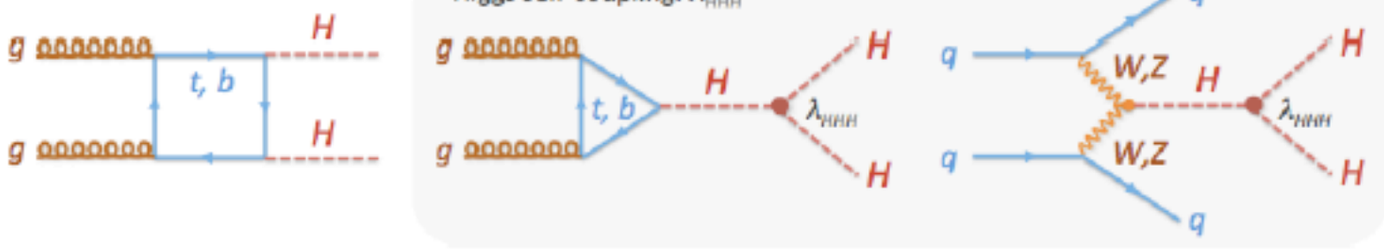
non-resonant



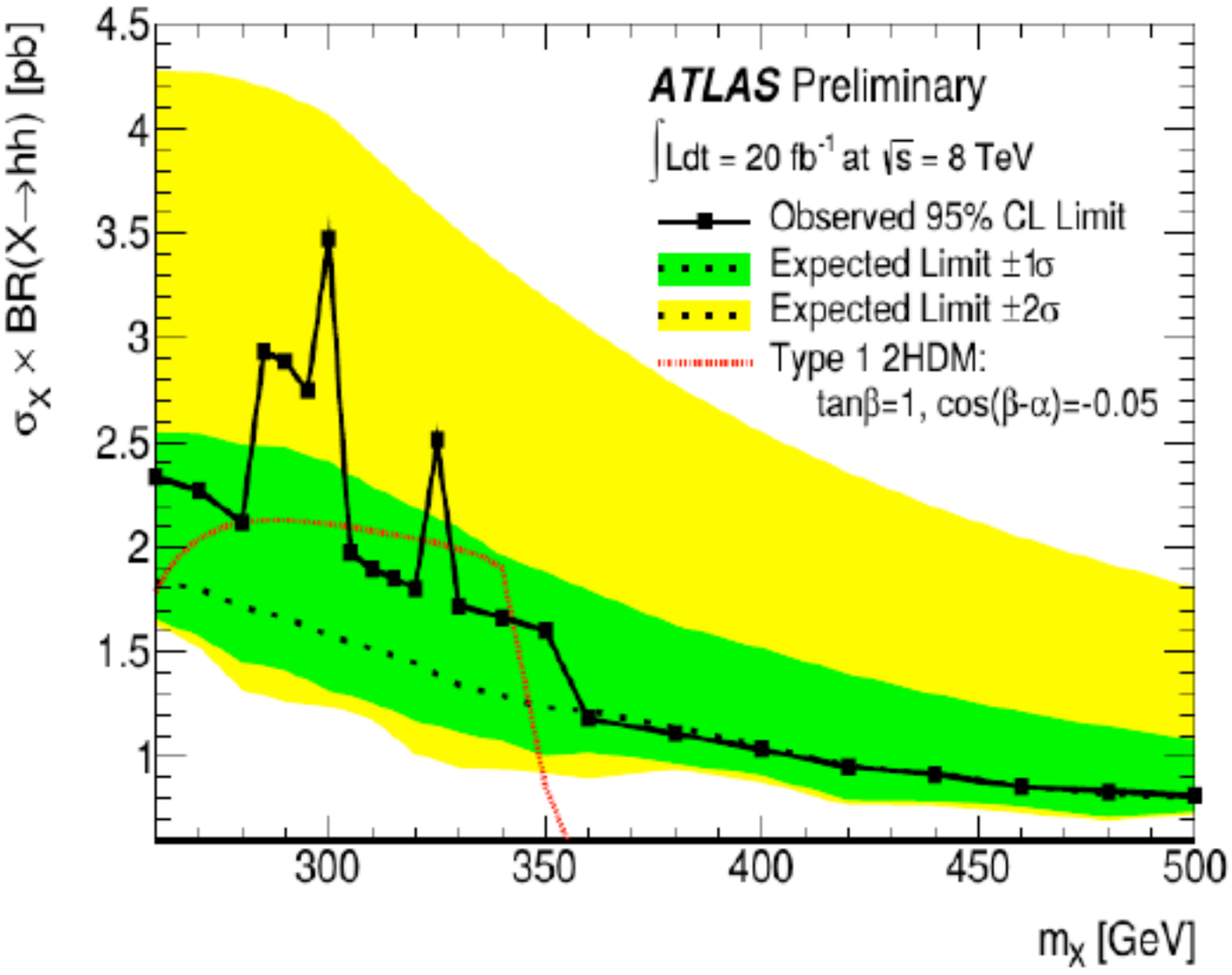
resonant



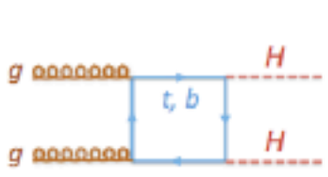
Higgs Pair production

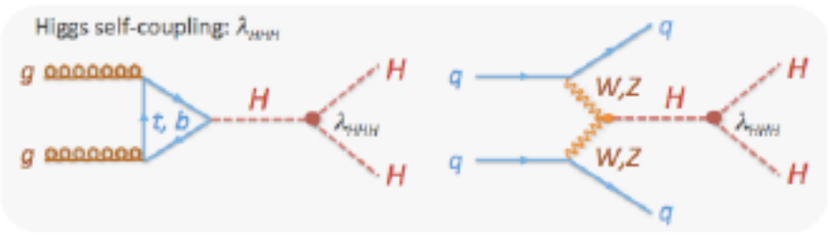


- **Decay channel hh → γγbb**
- upper limit for anomalous non resonant hh production
  - **obersved 2.2 pb,**
  - **expected 1.0 pb**
  - (SM hh production ~ 10 fb)
- 95%CL upper limit on cross section times BR as a function of m_X for a narrow scalar resonance



Higgs Pair production





- **Decay channel**
  X → HH → bbbb
- **ATLAS-CONF-2014-005**
- Search for TeV resonance decaying into SM Higgs bosons
- Result interpreted with first KK excitation of Graviton G* as signal (in a Randall-Sundrum model)
- Upper limit at 95% CL derived as a function of m(G*)
- KK Graviton **excluded** between **590 and 710 GeV**