Search For Rare & Exotic Higgs Decay And Production: Status and Perspectives

P. Meridiani

on behalf of the ATLAS and CMS collaborations

Moriond EWK - La Thuile - 17/03/2015

INFN Istituto Nazionale di Fisica Nucleare

ATLAS

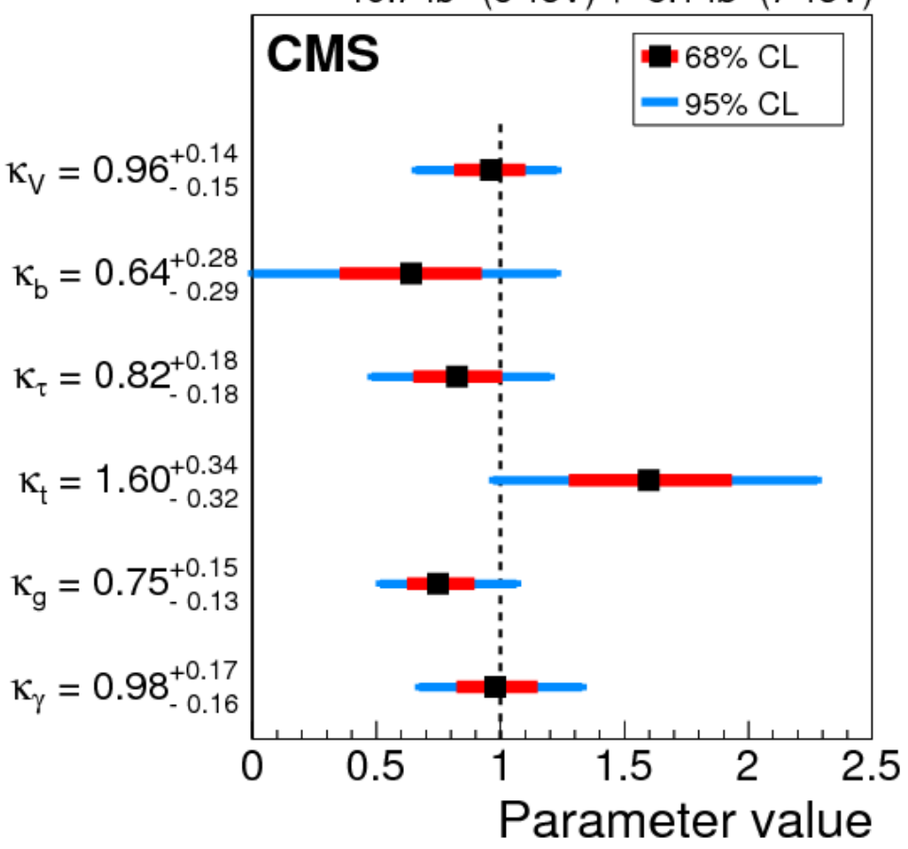
CMS Compact Muon Solenoid

BSM Higgs Physics

Unveil new physics in the Higgs sector

Measurement of Higgs couplings

probing direct couplings to third generation fermions,W/Z, BSM contribution to ggH and Hγγ



Direct searches

- **Rare SM Higgs decays** (e.g 2nd generation fermions, Z/γ*+γ)
- **Decays not allowed in the SM** (e.g. LFV H→μτ)
- **Rare SM production modes** (e.g t+H, HH)
- **Invisible or quasi-invisible Higgs** decays
- **Search for extended Higgs sector**: additional neutral or charged scalars

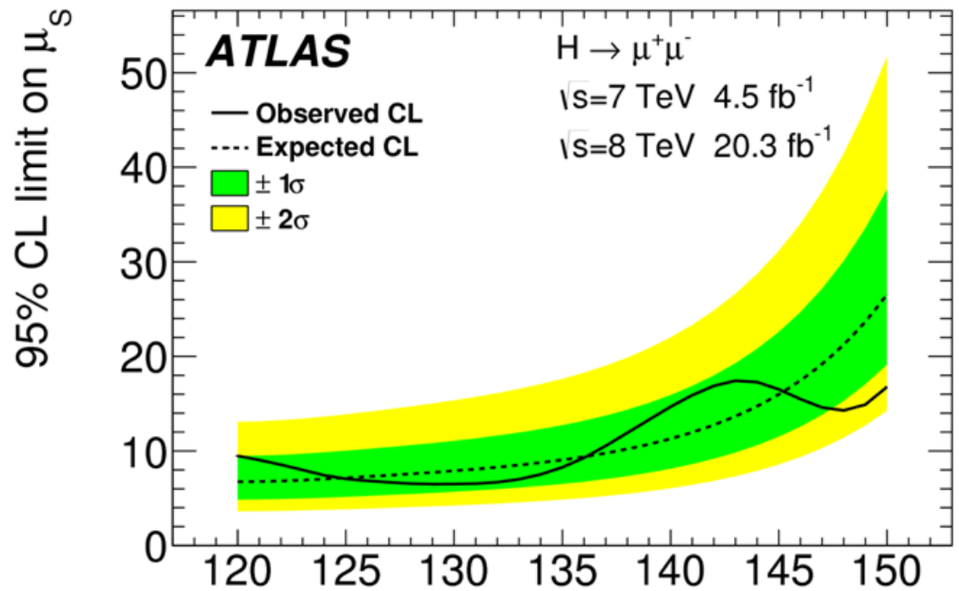
DISCLAIMER: Impossible to cover all direct search analyses. Focussing on most recent RunI results/updates

H→μμ & H→ee

BR(H→μμ)=2.2x10^{-4} ~ 1/10 x BR(H→γγ)

H(125)→μμ 95% CL exclusion limits

ATLAS: PLB 738 (2015)	**>7.0(7.2) x SM**
CMS: arXiv:1410.6679	**>7.4(6.5) x SM**

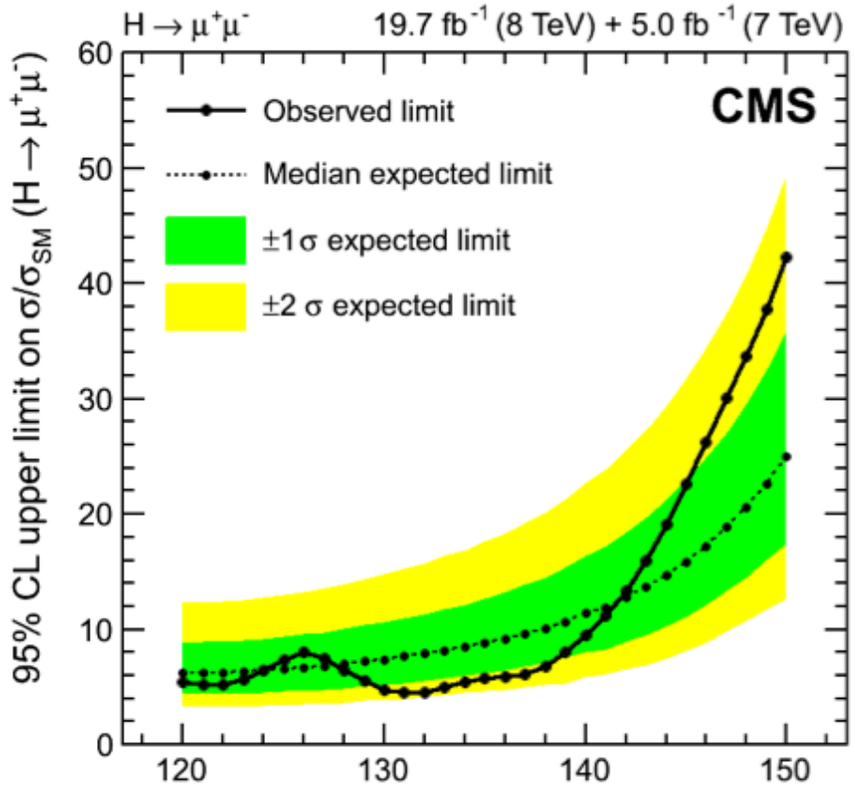


ATLAS: PLB 738 (2015) 68

Together with evidence of H→$\tau\tau$, confirm evidence of lepton non-universality

Potential sensitivity in Run 2 to exclude H→μμ

H→ee: CMS put 95% CL exclusion limit on σ x BR(H(125)→ee)=41fb

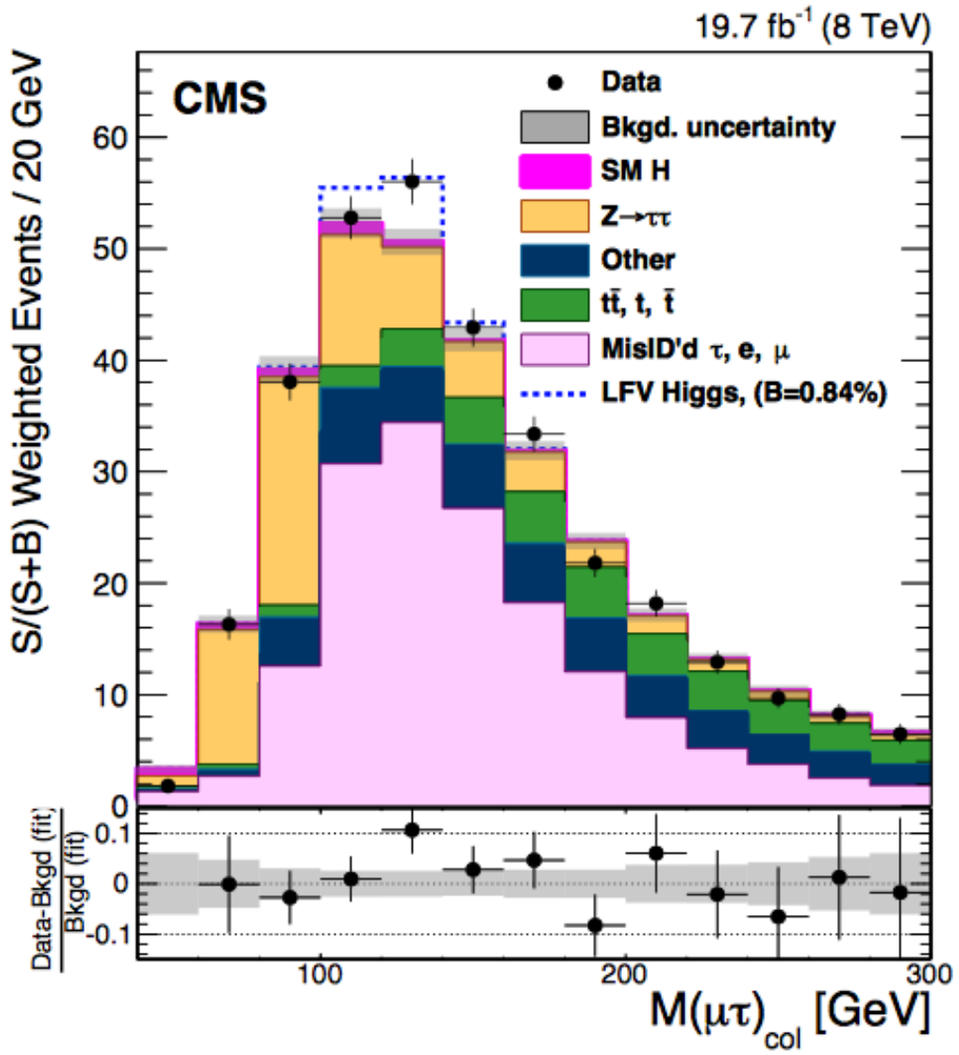


CMS: arXiv:1410.6679

Lepton Flavour Violating Decays

Lepton flavor violating decays can arise in several BSM theories with >1 Higgs doublet

Indirect limits on BR(H→μτ)<~10% from τ rare decays search (τ→3μ,τ→μγ)

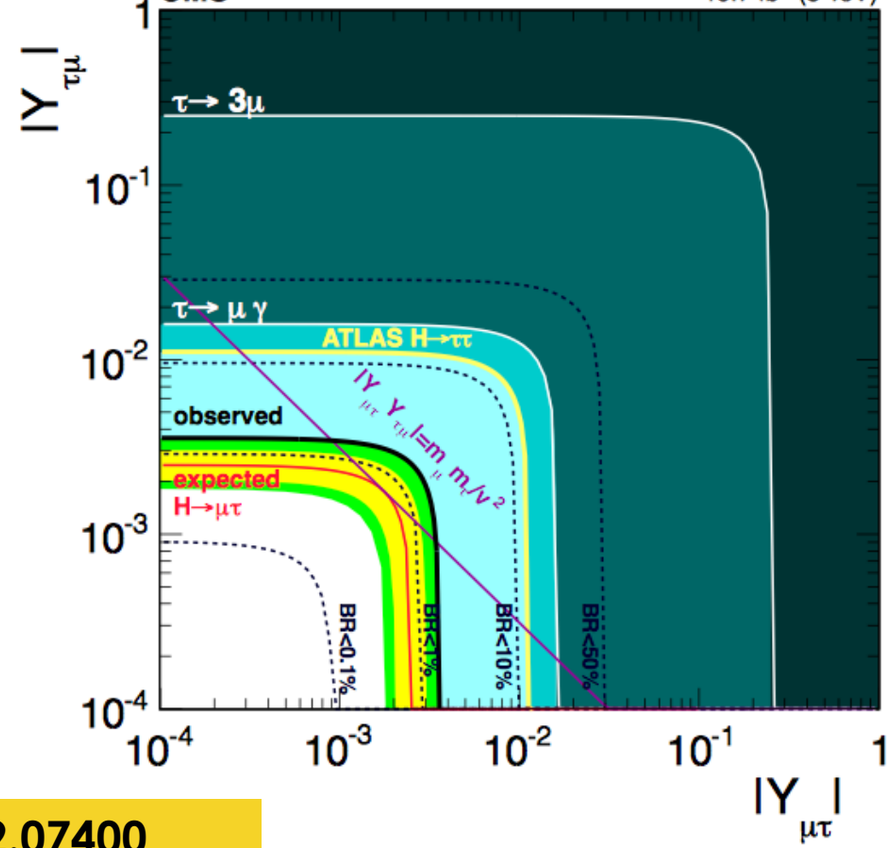


$$\Gamma(H \to \ell^\alpha \ell^\beta) = \frac{m_H}{8\pi}\left(|Y_{\ell^\beta \ell^\alpha}|^2 + |Y_{\ell^\alpha \ell^\beta}|^2\right)$$

Indirect limit can be obtained re-interpreting H→ττ search

First direct limit on BR(H→μτ) < 0.75% (2.4σ excess)

$$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 3.6 \times 10^{-3}$$



CMS: arXiv:1502.07400

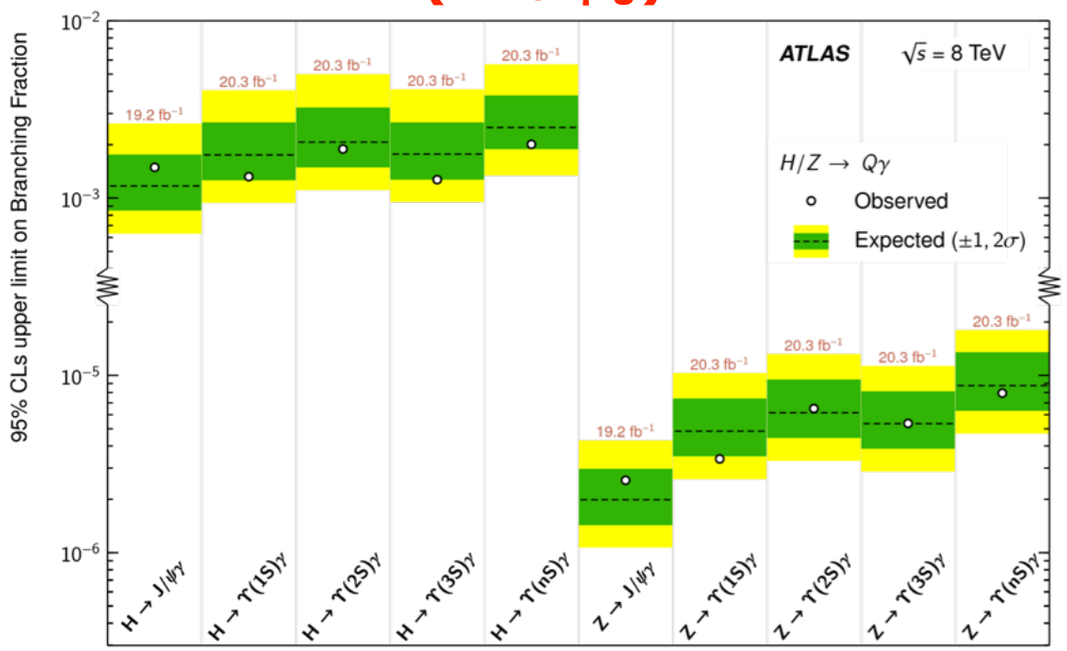
H→J/ψγ,ϒγ

Very small BR

BR(H→J/ψγ) ~ 3x10^{-6}

Proposed to probe Hcc coupling @ HL-LHC

Limit on H(→J/ψγ) ~ x 540 SM



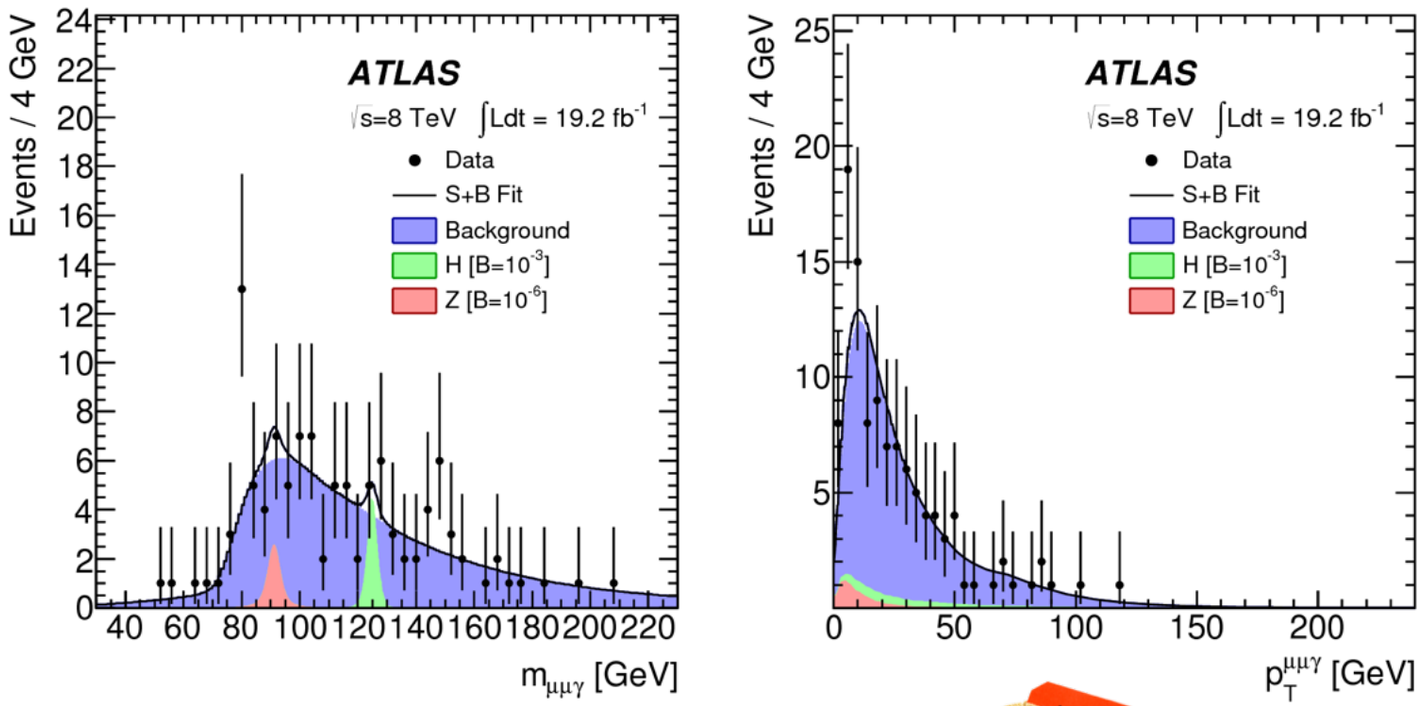
Main background

quarkonium production + fake photon

Multidimensional likelihood fit

H→Qγ & Z→Qγ signal hypotheses are considered

J/ψ+γ candidates



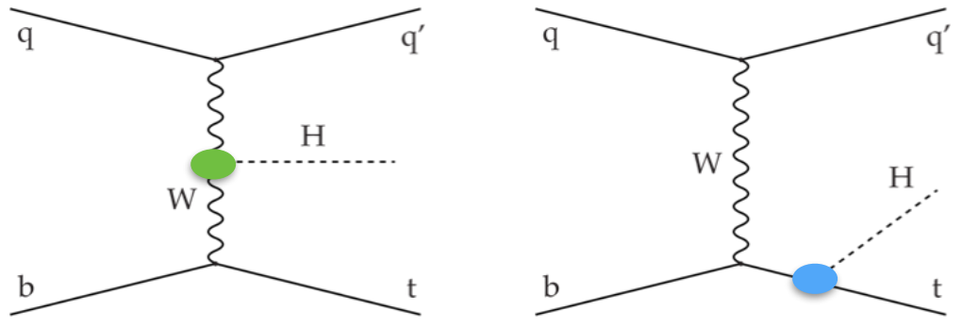
ATLAS: arXiv:1501.03276

NEW

Top+Higgs Production

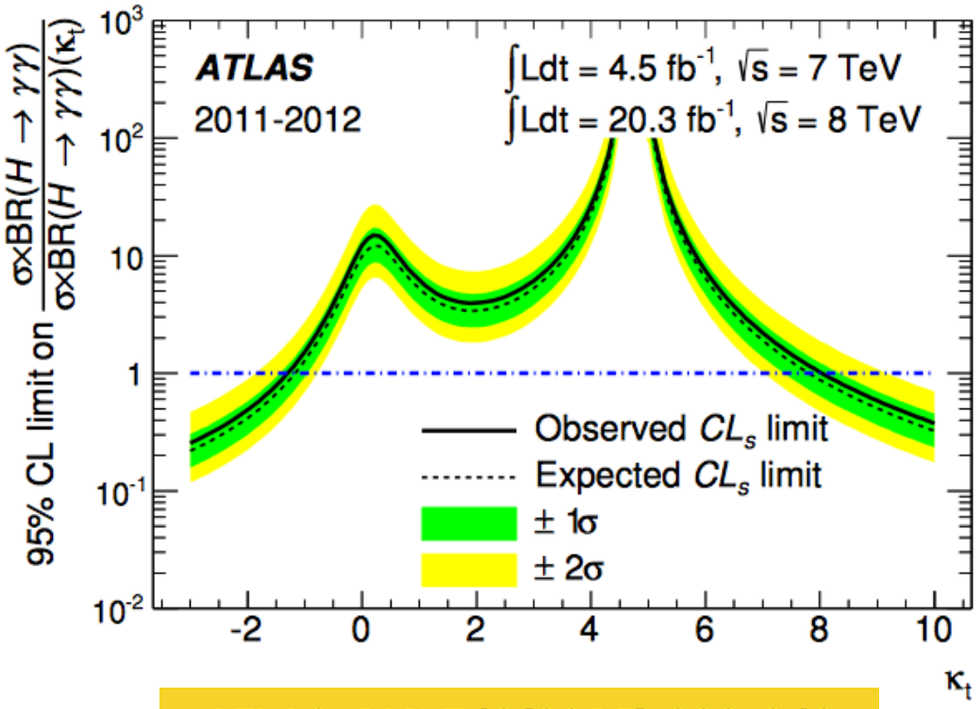
Y_t indirectly probed by gluon-fusion production
directly measured using ttH

t+H production
in SM destructive interference between t-channel diagrams
sensitive to relative sign between Y_t and g_{HWW}
x13 σ if reversed wrt SM



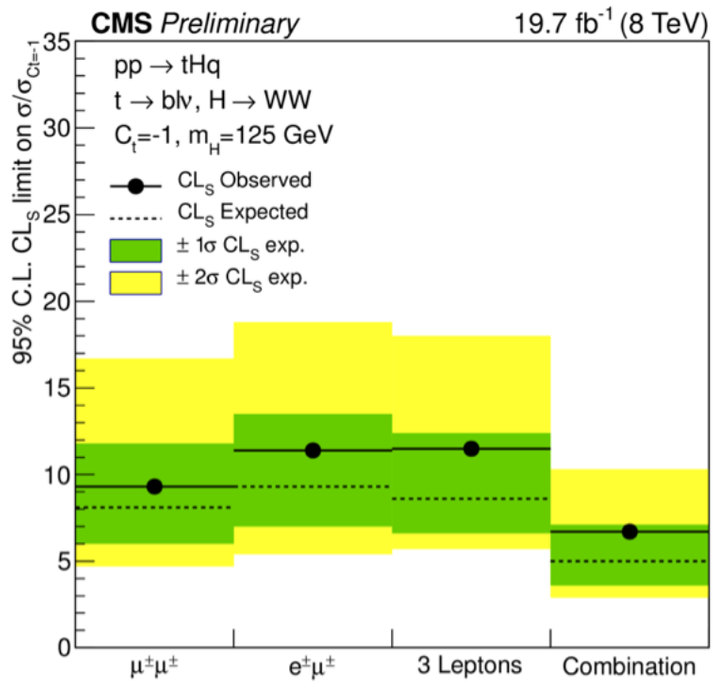
Re-interpretation of the ttH(→γγ) search

H→γγ ~ x 2 if relative sign reversed



ATLAS: PLB 740(2015) 222-242

Direct search for t+H: multi-lepton analysis from CMS (H→WW,H→ττ)
2 same-sign leptons, 3 leptons final state



CMS: HIG-14-026 NEW

95% CL exclusion limits

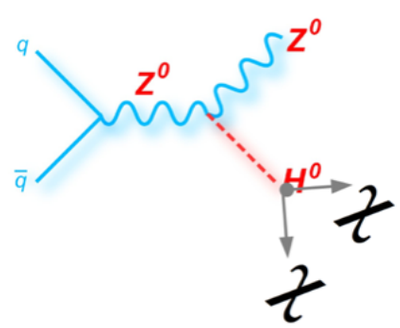
CMS HIG-14-001 t+H(→γγ)	**4.1(4.1) x σ(k_t=-1)**
CMS HIG-14-015 t+H(→bb)	**7.6(5.2) x σ(k_t=-1)**

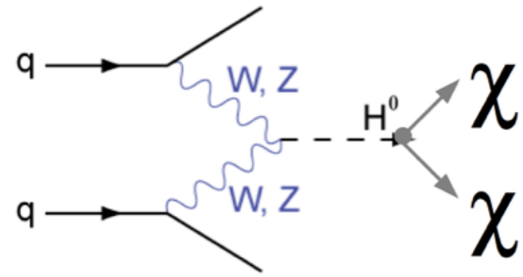
Combination to be published soon

Invisible Higgs Decays

Direct search: exploit associated ZH and VBF production

- boosted Z + MET
- 2 jets with high Mjj + MET





New channels entering into the game with high potential for Run II

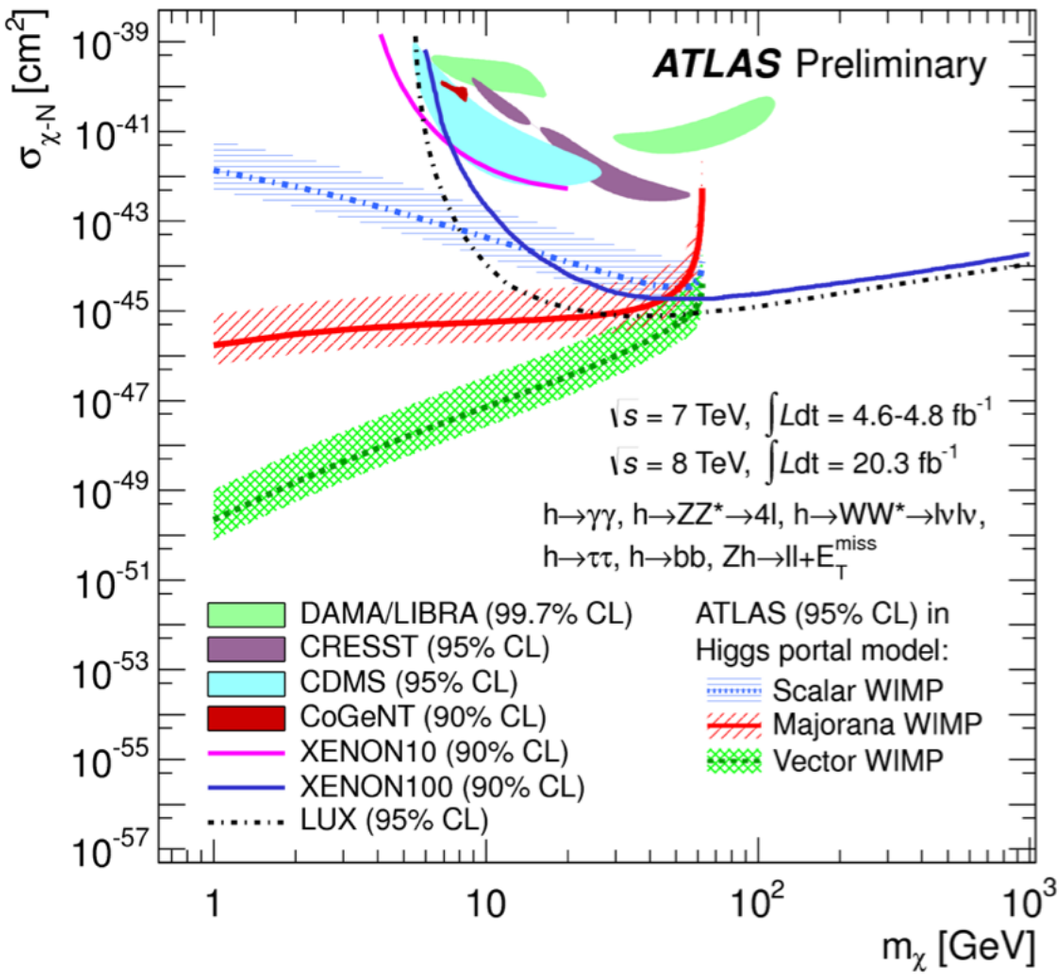
- mono-jet & tt+MET searches can be re-interpreted as invisible Higgs decay
- see C. Doglioni's & D. Pinna's talks

CMS: Eur. Phys. J.C. 74 (2014) VBF+Z(→ll)H	>58(44)%
CMS: arxiV:1412.8662 combined (direct+indirect)	>32(29)%

ATLAS: PRL 112, 201802 (2014) Z(→ll)H	>75(62)%
ATLAS-CONF-2014-010: combined (direct+indirect)	>37(39)%

BR limit can be Interpreted as DM limit in "Higgs-portal" models

- Better interpretation in the future using recipes from LHC-DMF



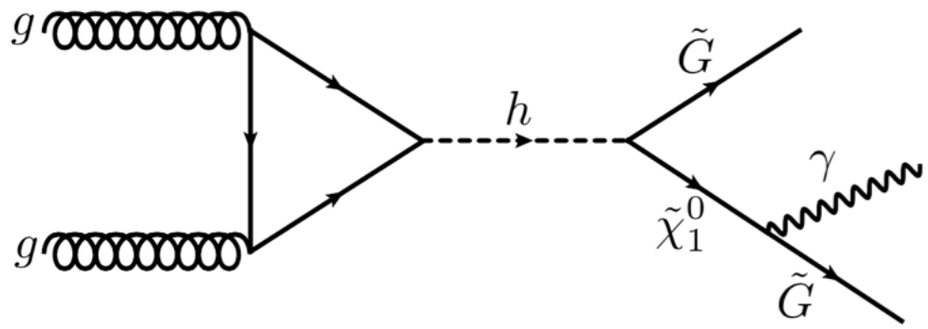
ATLAS-CONF-2014-010

QUASI INVISIBLE HIGGS DECAY

Higgs decays to neutralinos/ gravitinos studied in γ+MET

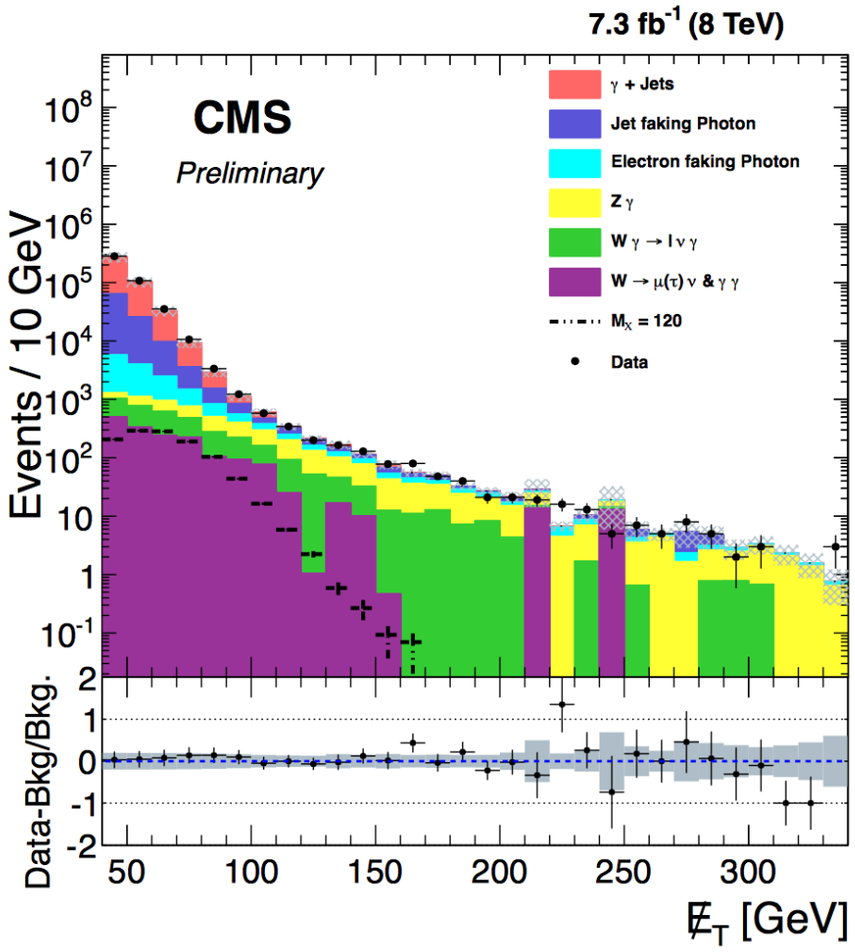
GMSB $h \to \tilde{G}\,\tilde{\chi}^0 \to \tilde{G}\,\tilde{G}\,\gamma$

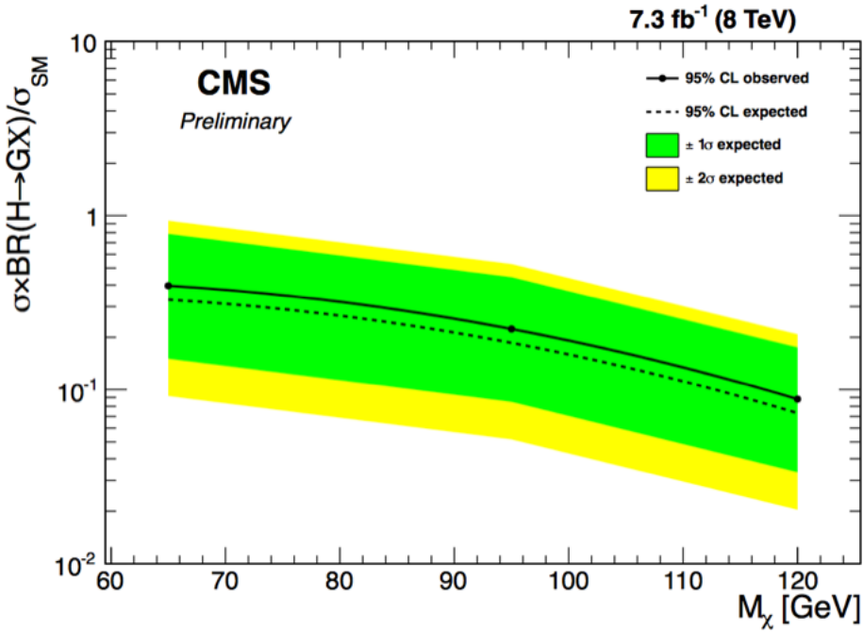
NMSSM $h \to \tilde{\chi}_2^0\,\tilde{\chi}_1^0 \to \tilde{\chi}_1^0\,\tilde{\chi}_1^0\,\gamma$



Inclusive analysis performed on a special parked dataset

γ p_T>30 GeV





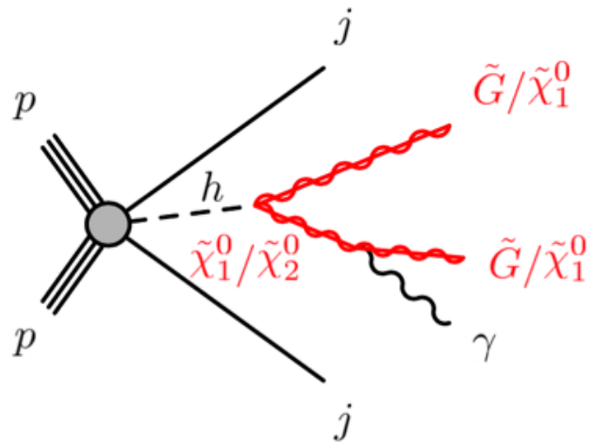
Optimized for $m_h/2 < m_{\tilde{\chi}_1^0} < m_h$ below γγ+MET will dominate

CMS: HIG-14-024 NEW

QUASI INVISIBLE (VBF)

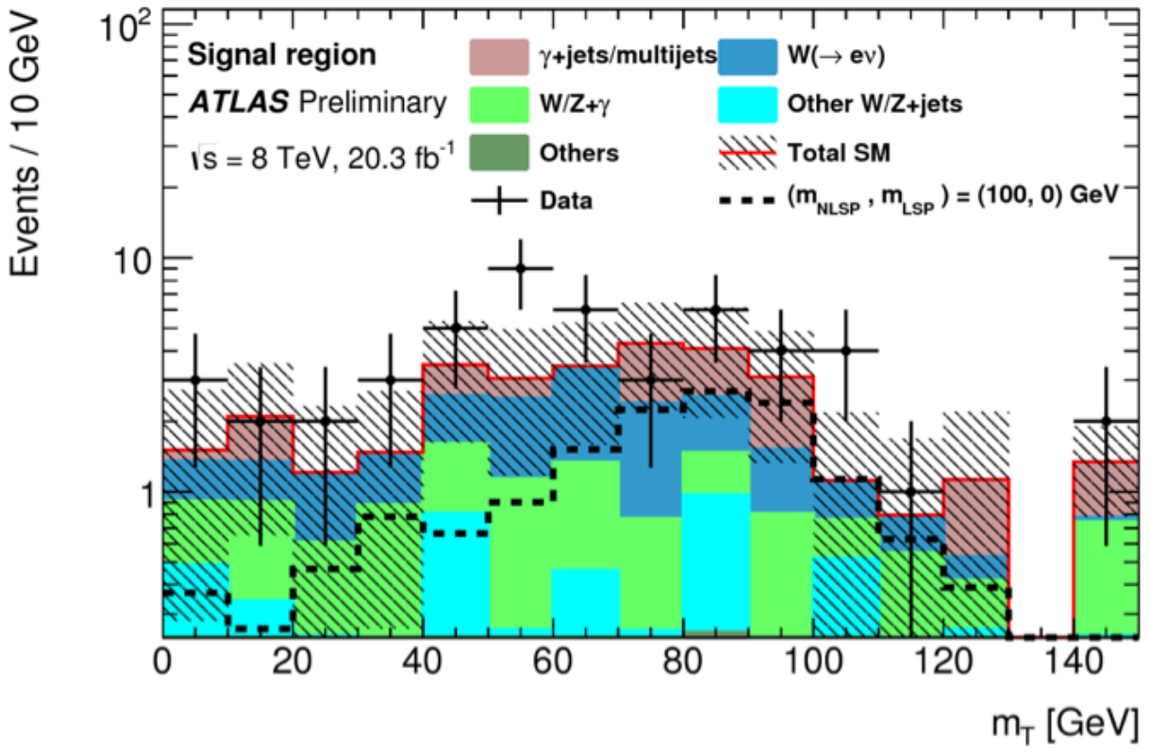
Similarly to invisible Higgs analysis, associated Higgs production can be exploited too

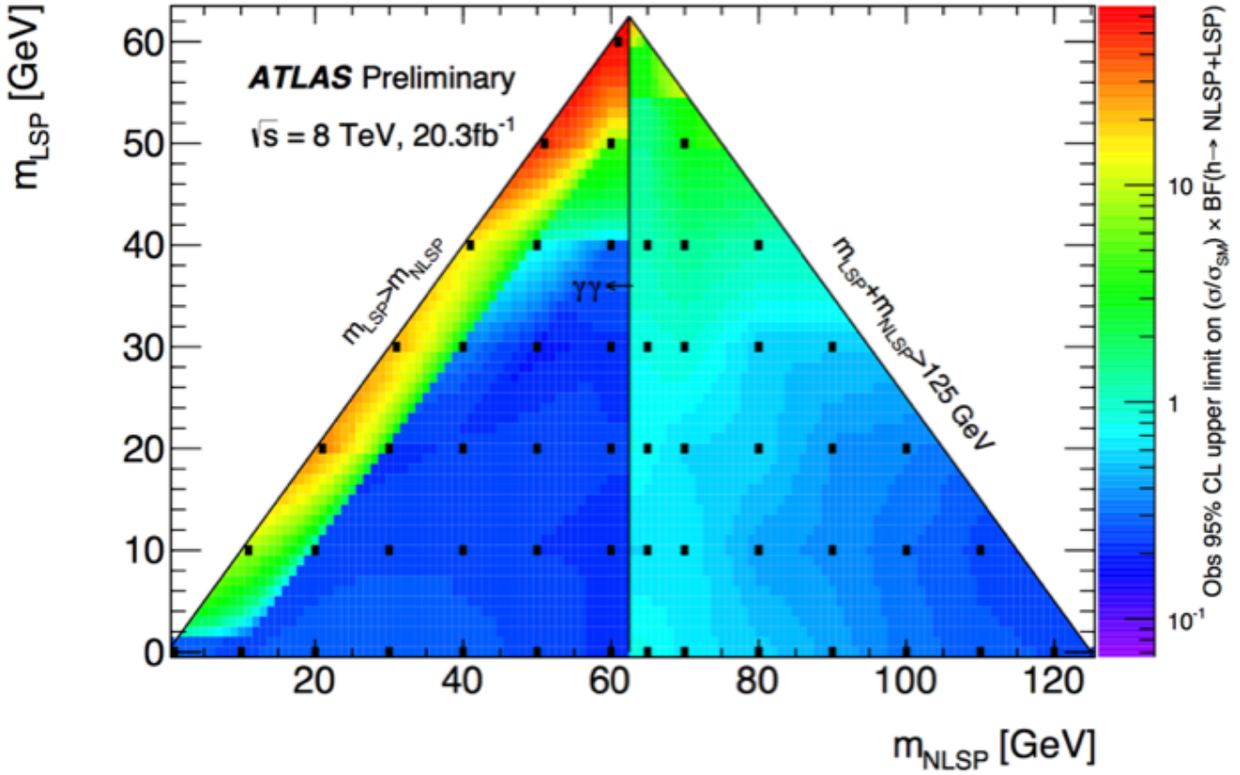
VBF



1 γ (p_T>40 GeV), 2 jets (VBF topology), E_T^{MISS}

Main background
γ+jets, W(→eν)+jets





ATLAS-CONF-2015-001 NEW

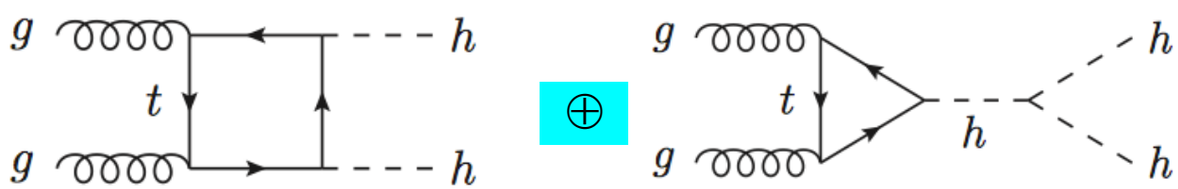
DOUBLE HIGGS PRODUCTION

SM non-resonant HH production too small to be probed in Run I

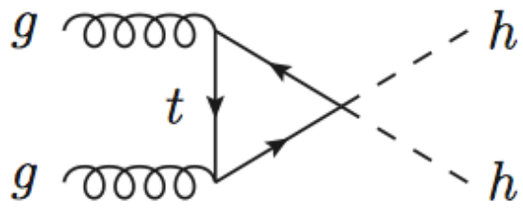
negative interference between 2 diagrams

σ_{NNLO}(pp→HH) @ 8 TeV=9.96 fb

SM hh production



Anomalus BSM hh production

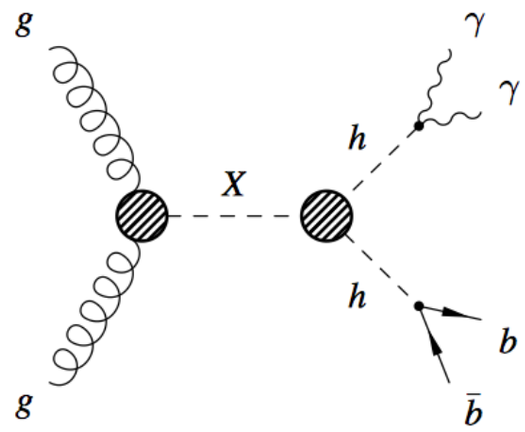


Non-resonant production can be significantly enhanced if new BSM couplings

HH kinematics can be affected

Subject for Run II & beyond

Resonant BSM hh production



In Run I: resonant HH production from new BSM spin 0 or spin 2 particle

Double Higgs Searches in Run I

Best channel at low m_{HH} mass is $\gamma\gamma bb$

allows exclusion of same region of 2HDM space parameter ($m_X<2m_t$)

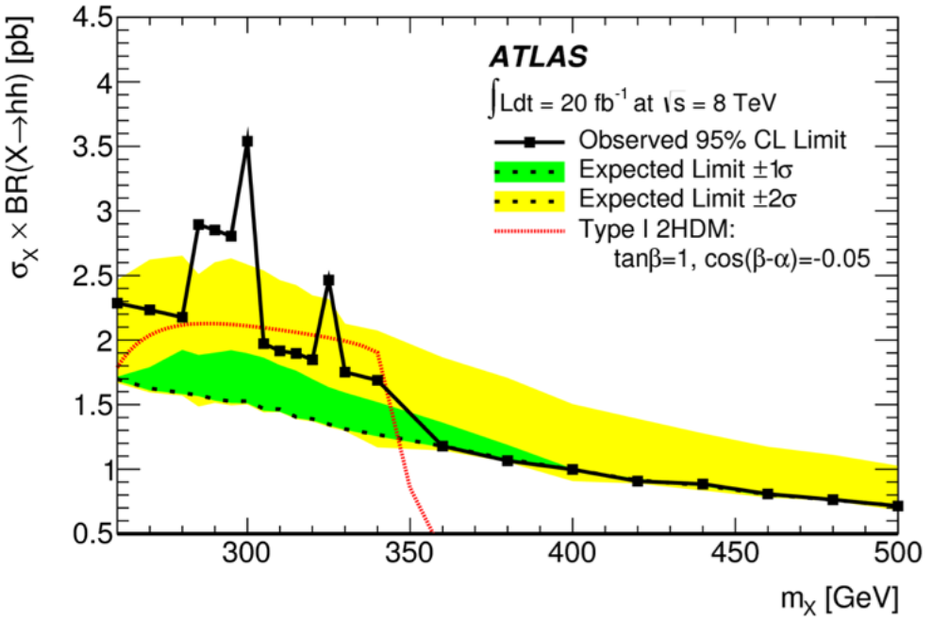
4b analysis most sensitive at high mass

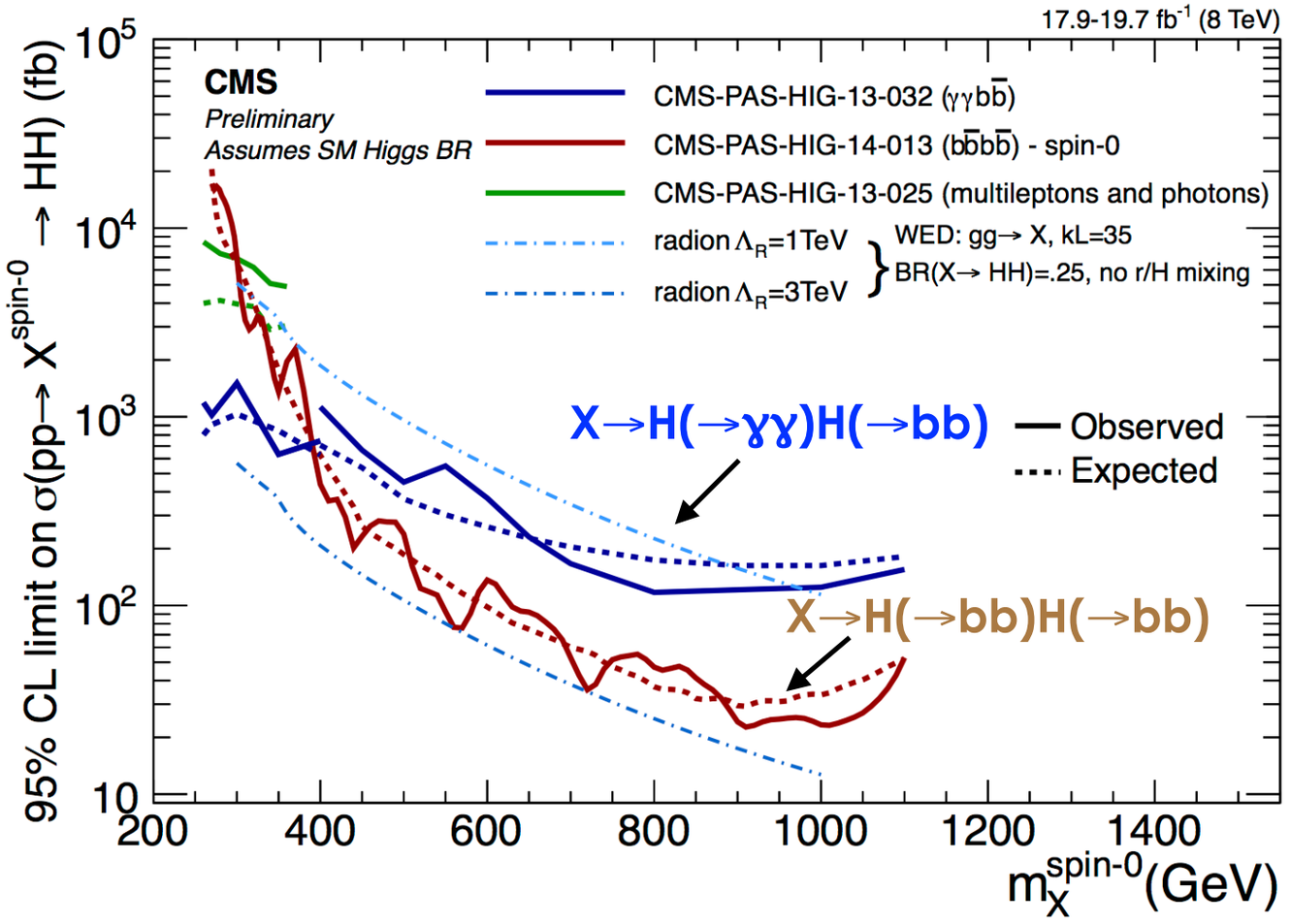
non-resonant production ~ m_{HH}=400 GeV

CMS: HIG-13-025
HIG-13-032
HIG-14-013

ATLAS: Phys. Rev. Lett. 114, 081802 (2015)

$X \to H(\to\gamma\gamma)H(\to bb)$





A→ZH

Neutral CP-odd scalar

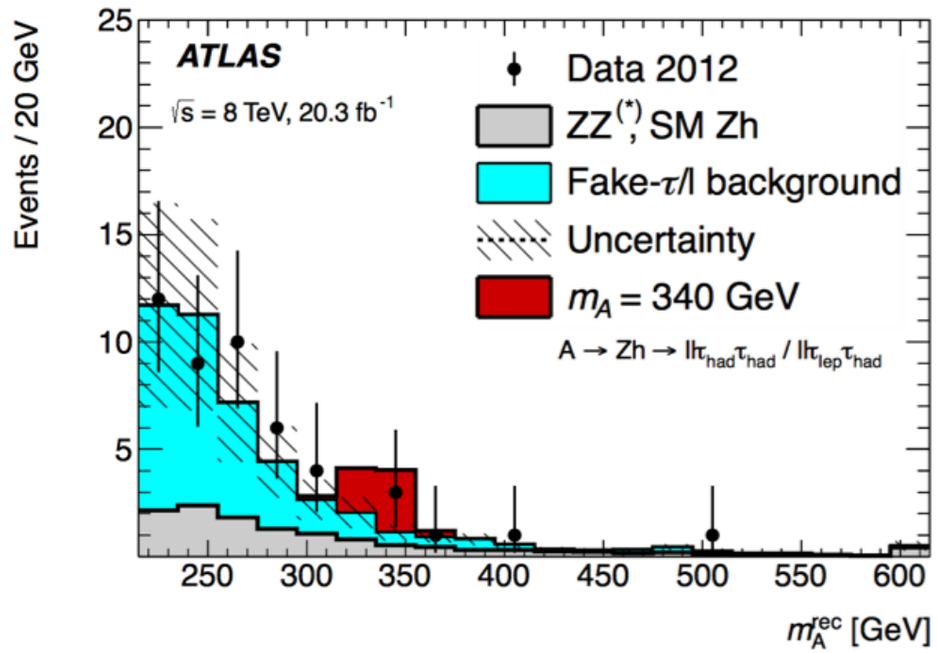
2HDM, MSSM…

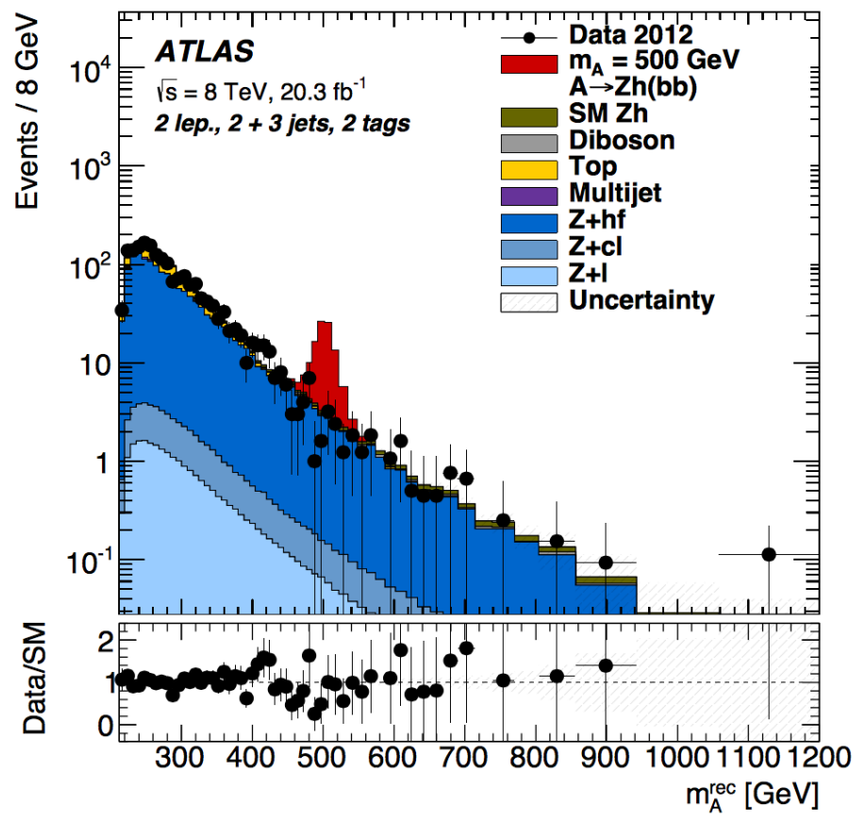
New result for A→ZH:

Z(→ll)+H(→$\tau\tau$,→bb)

Z(→$\nu\nu$)+H(→bb)

Extend sensitivity in regions not covered by the A→$\tau\tau$ search (for $m_A < 2m_t$)





ATLAS: arXiv:1502.04478

NEW

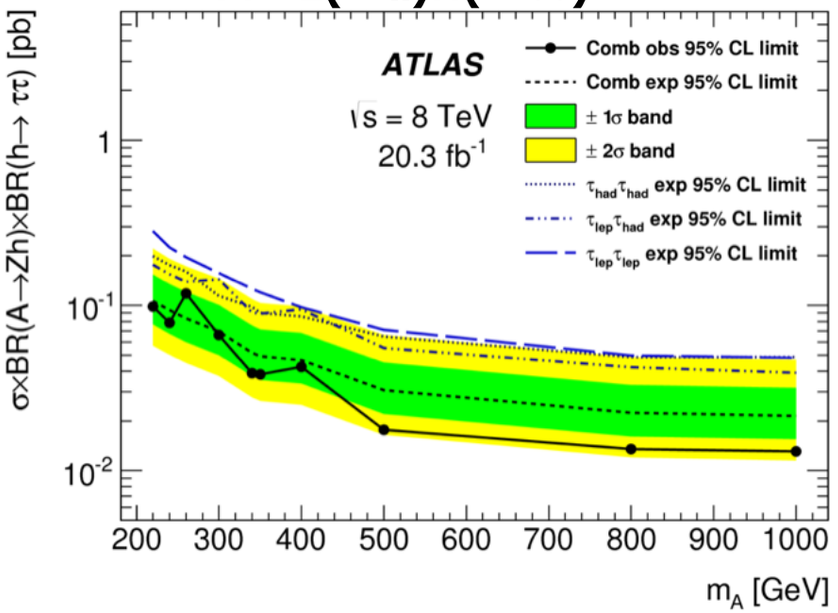
A→ZH

Neutral CP-odd scalar
2HDM, MSSM…

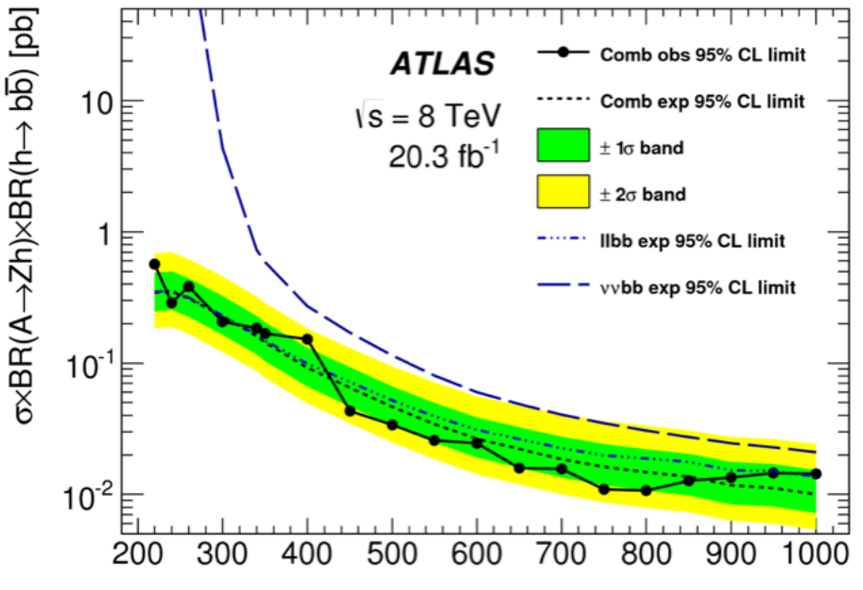
New result for A→ZH:
Z(→ll)+H(→$\tau\tau$,→bb)
Z(→$\nu\nu$)+H(→bb)

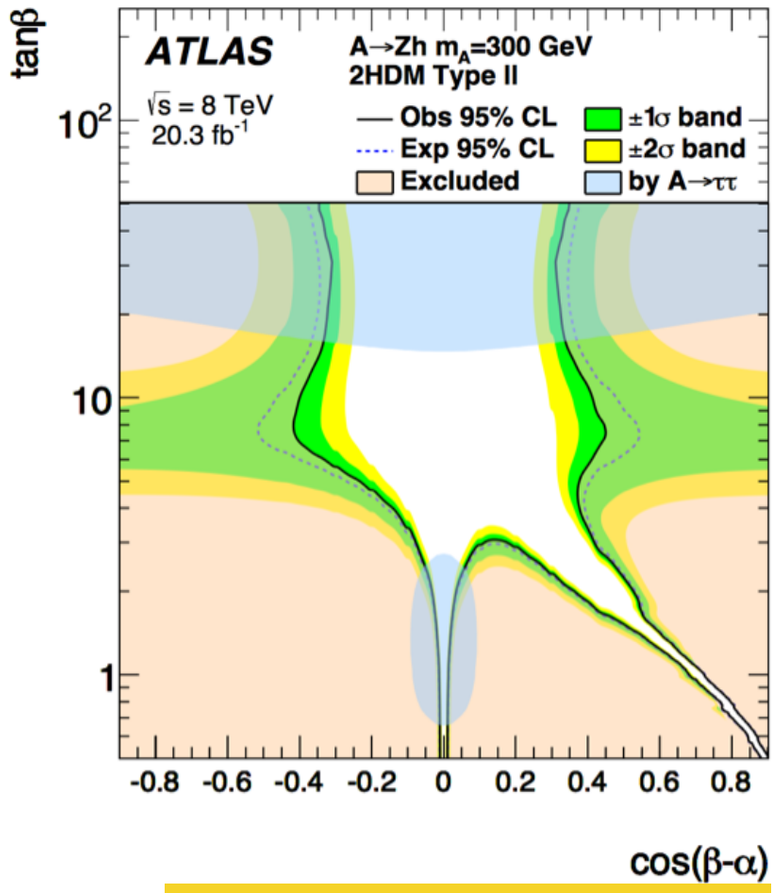
Extend sensitivity in regions not covered by the A→$\tau\tau$ search (for $m_A < 2m_t$)

A→Z(→ll)H(→$\tau\tau$)



A→Z(→ll,→$\nu\nu$)H(→bb)





ATLAS: arXiv:1502.04478

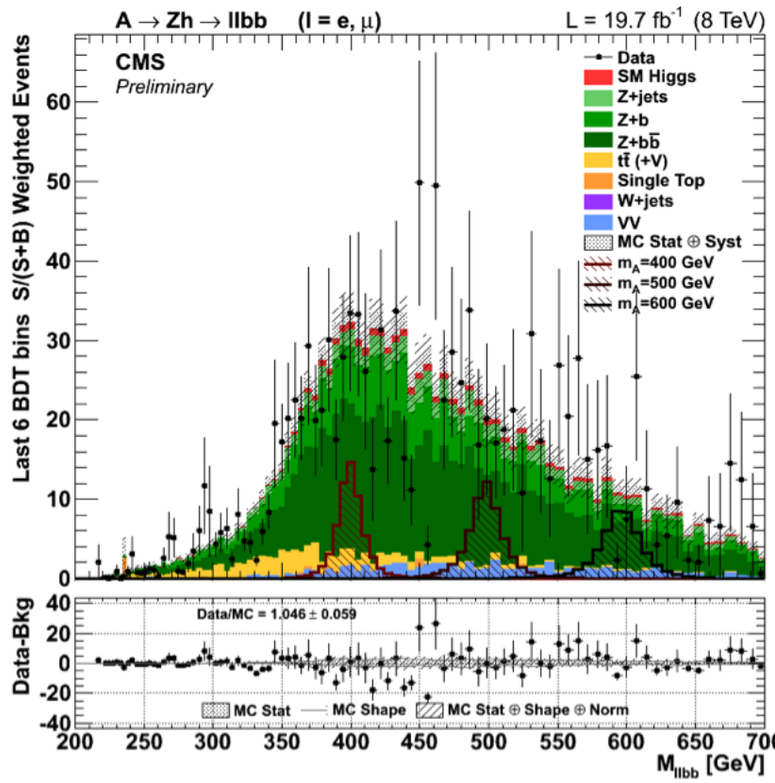
NEW

A→ZH

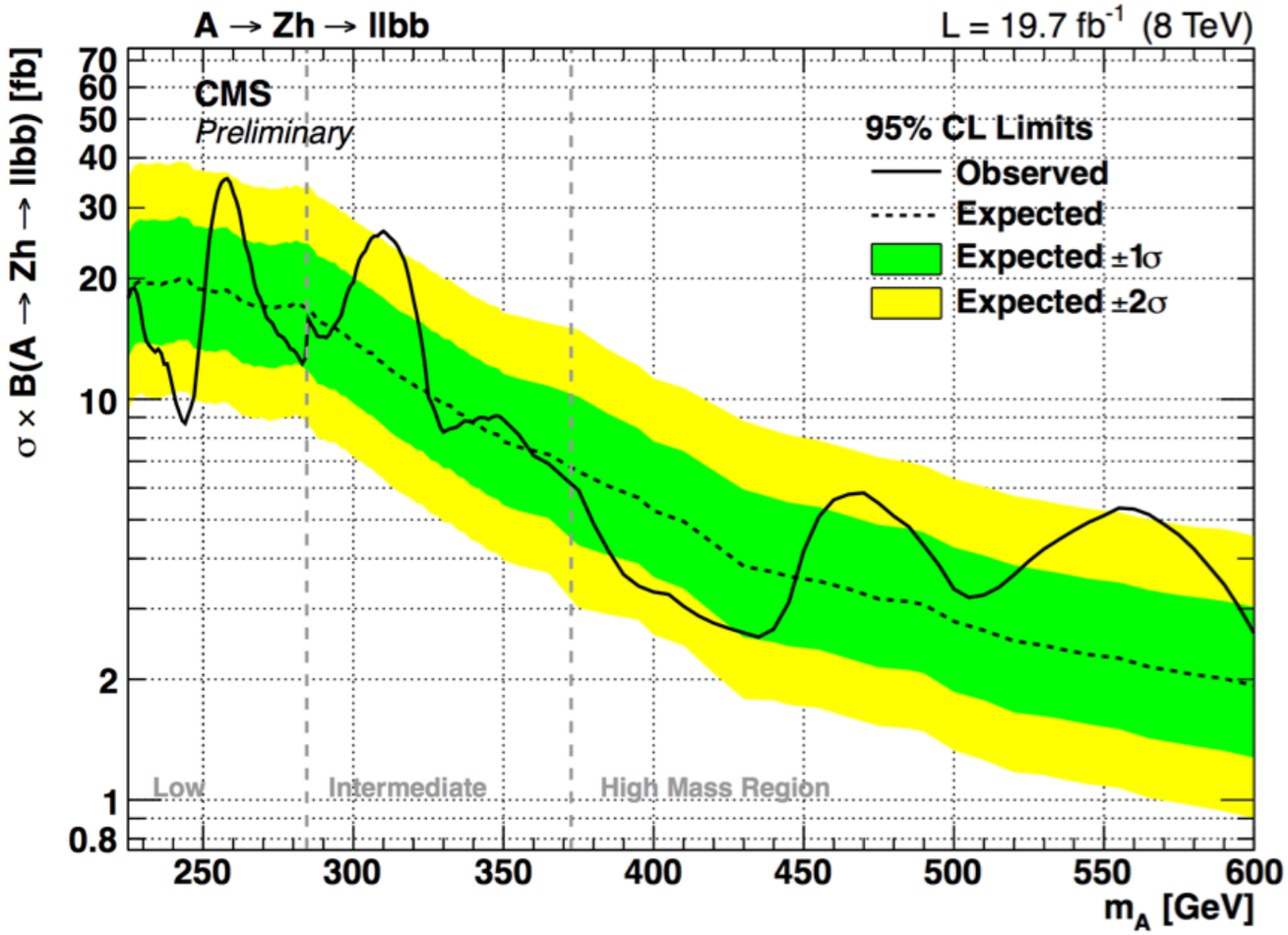
CMS: A→Z(→ll)H(→bb)

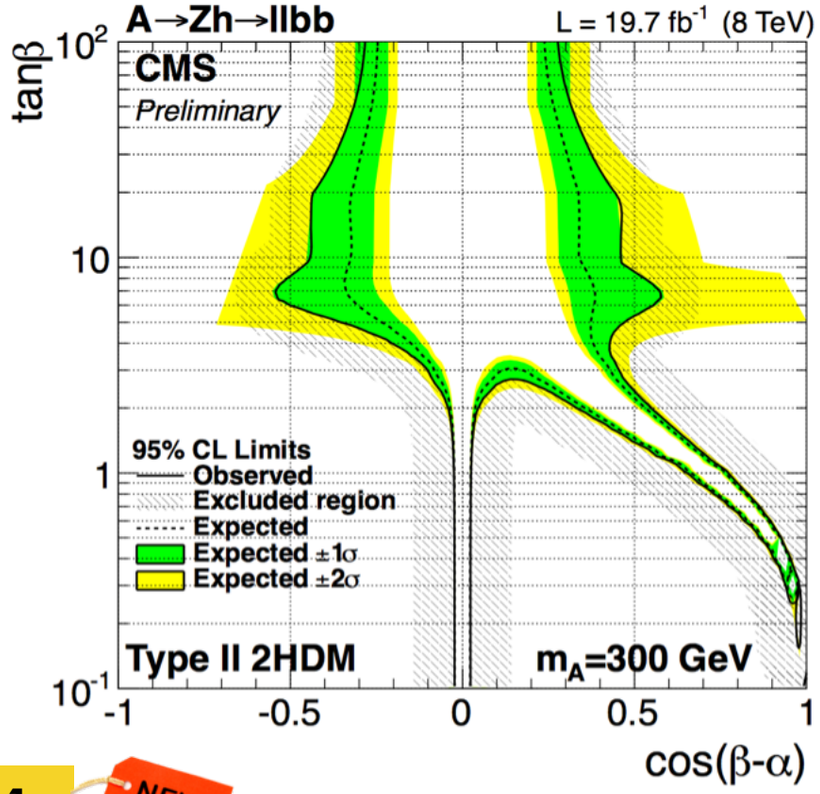
Multivariate technique (BDT optimized for 3 different mass regions)

Model independent + 2HDM interpretation



Model independent limit





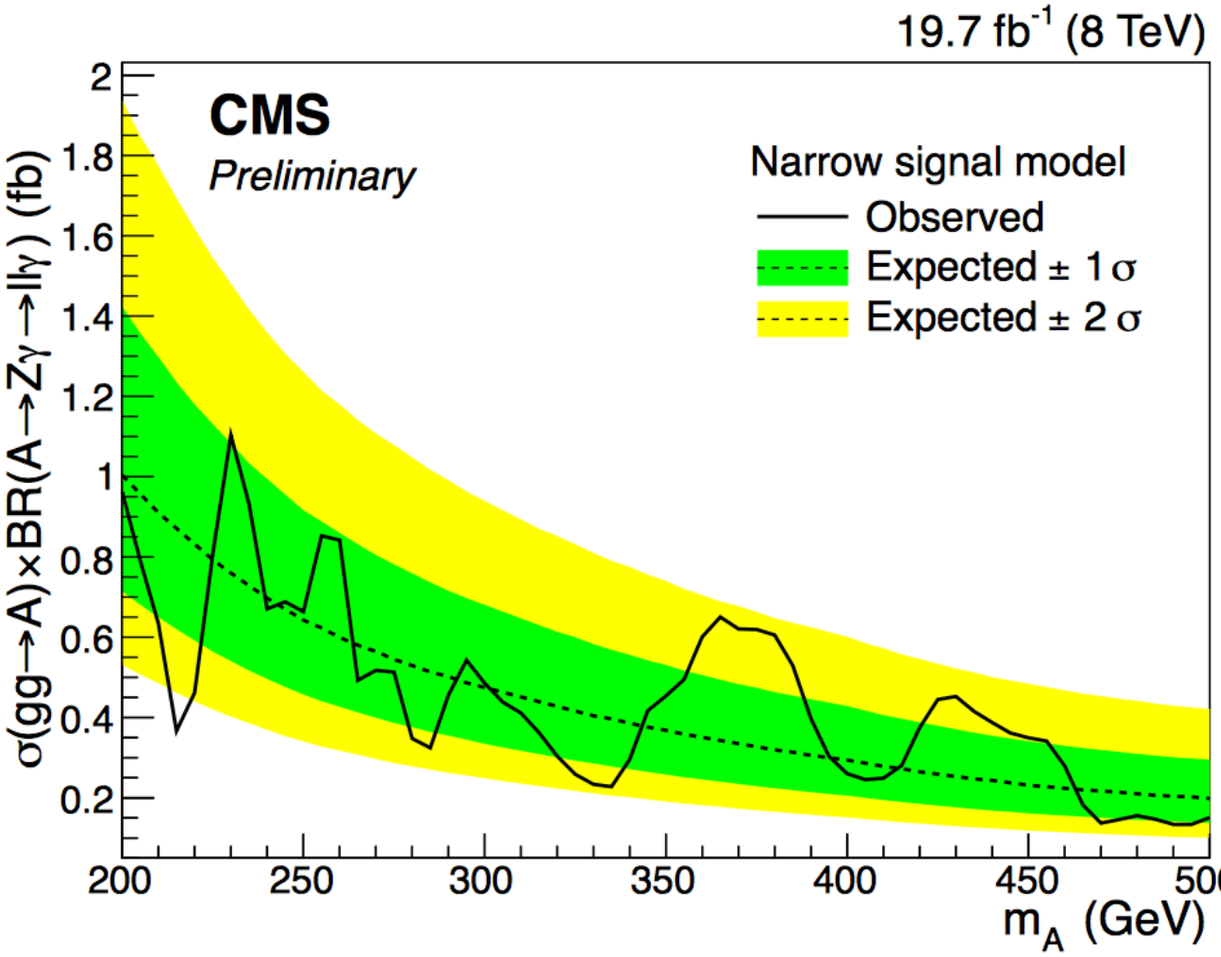
CMS-HIG-14-011

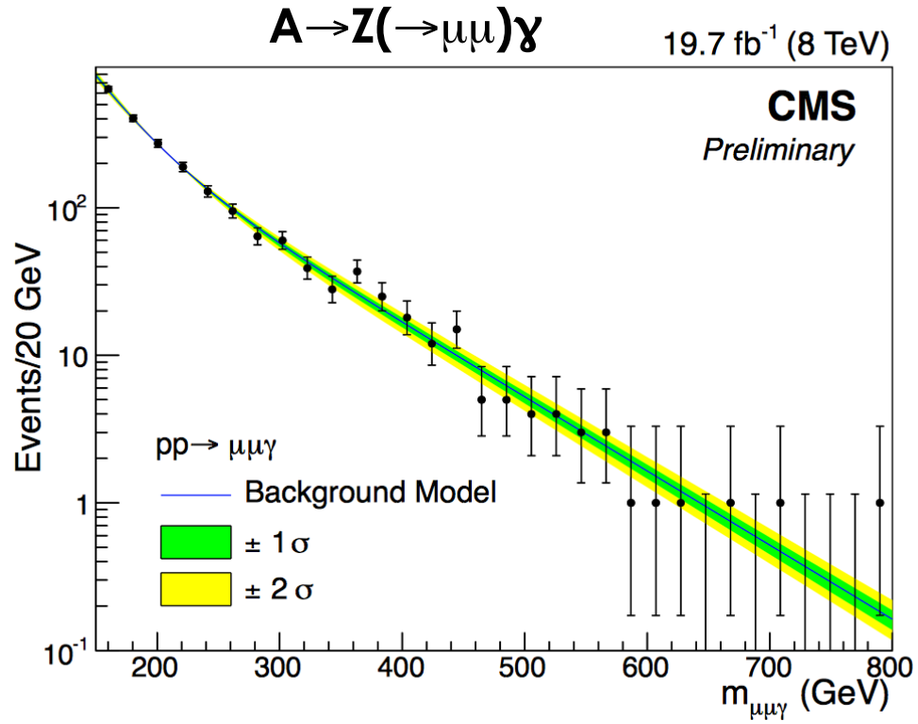
NEW

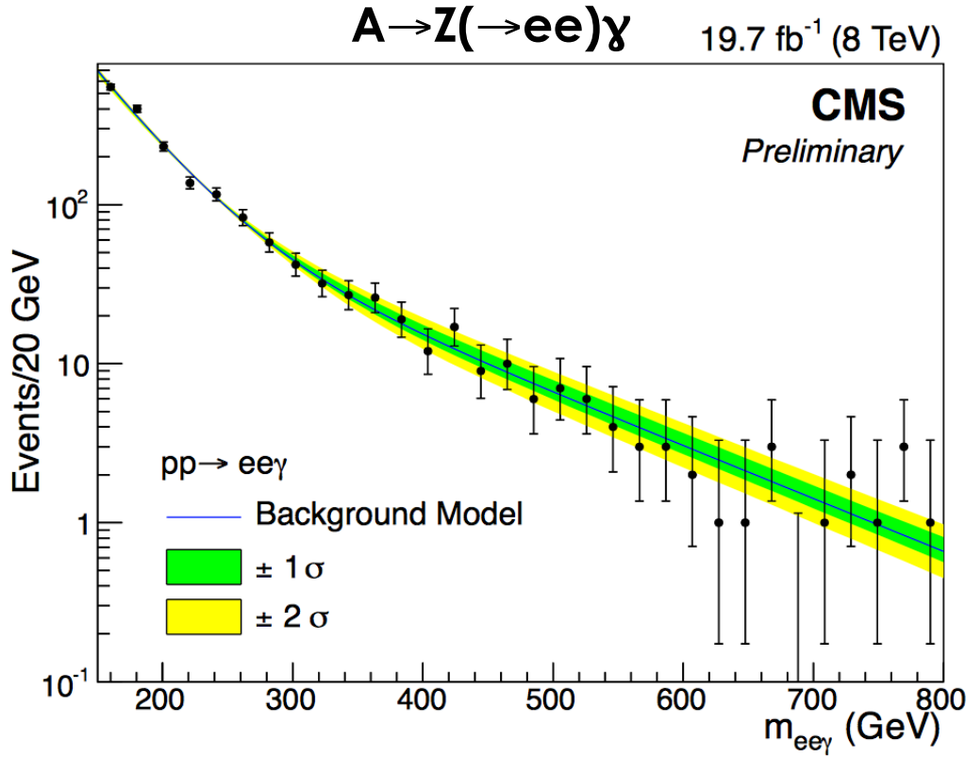
A→Z(→ll)γ

CMS: A→Z(→ll)γ

A→Zγ can be significantly enhanced for $m_A<2m_t$ in some composite Higgs models







CMS-HIG-14-031 NEW

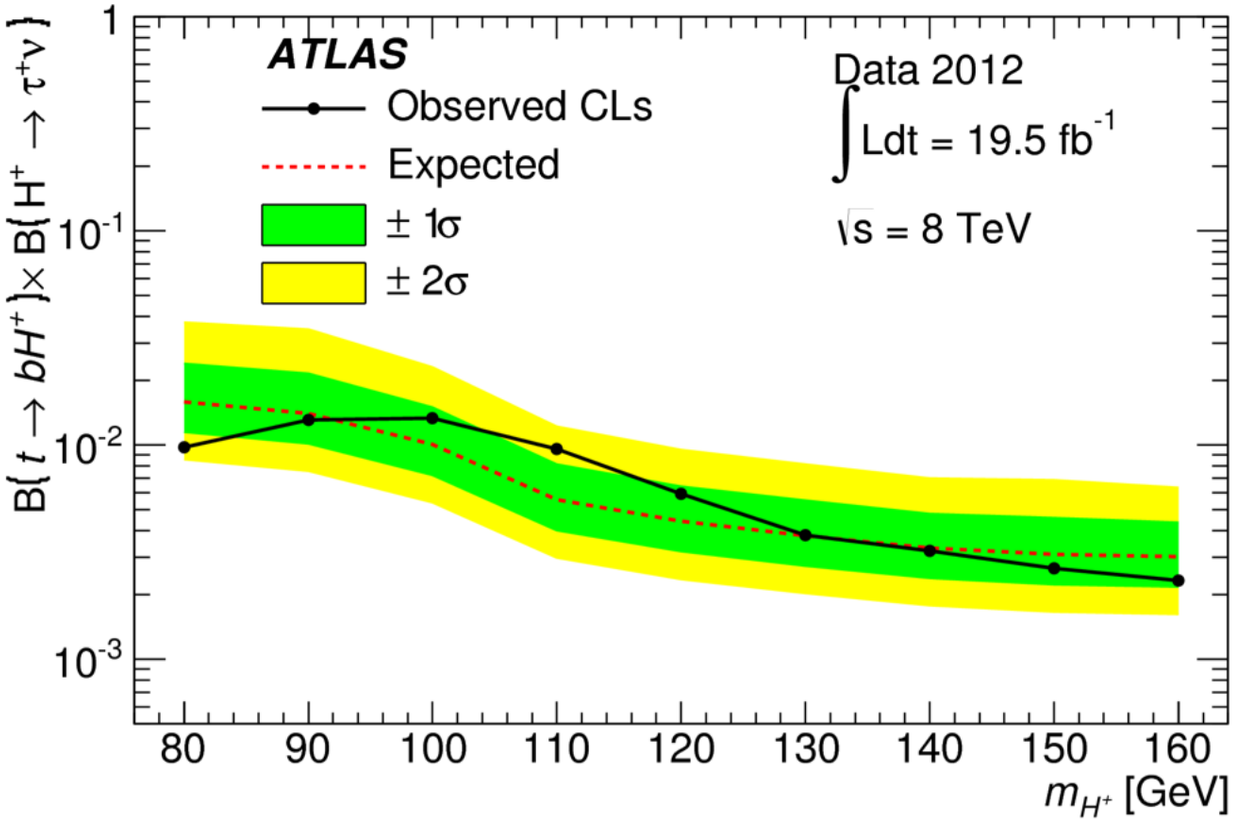
CHARGED HIGGS: $H^{\pm}\to\tau^{\pm}\nu$

$M_{H^{\pm}}<m_{top}$: production in tt decay [$tt\to HbWb$]

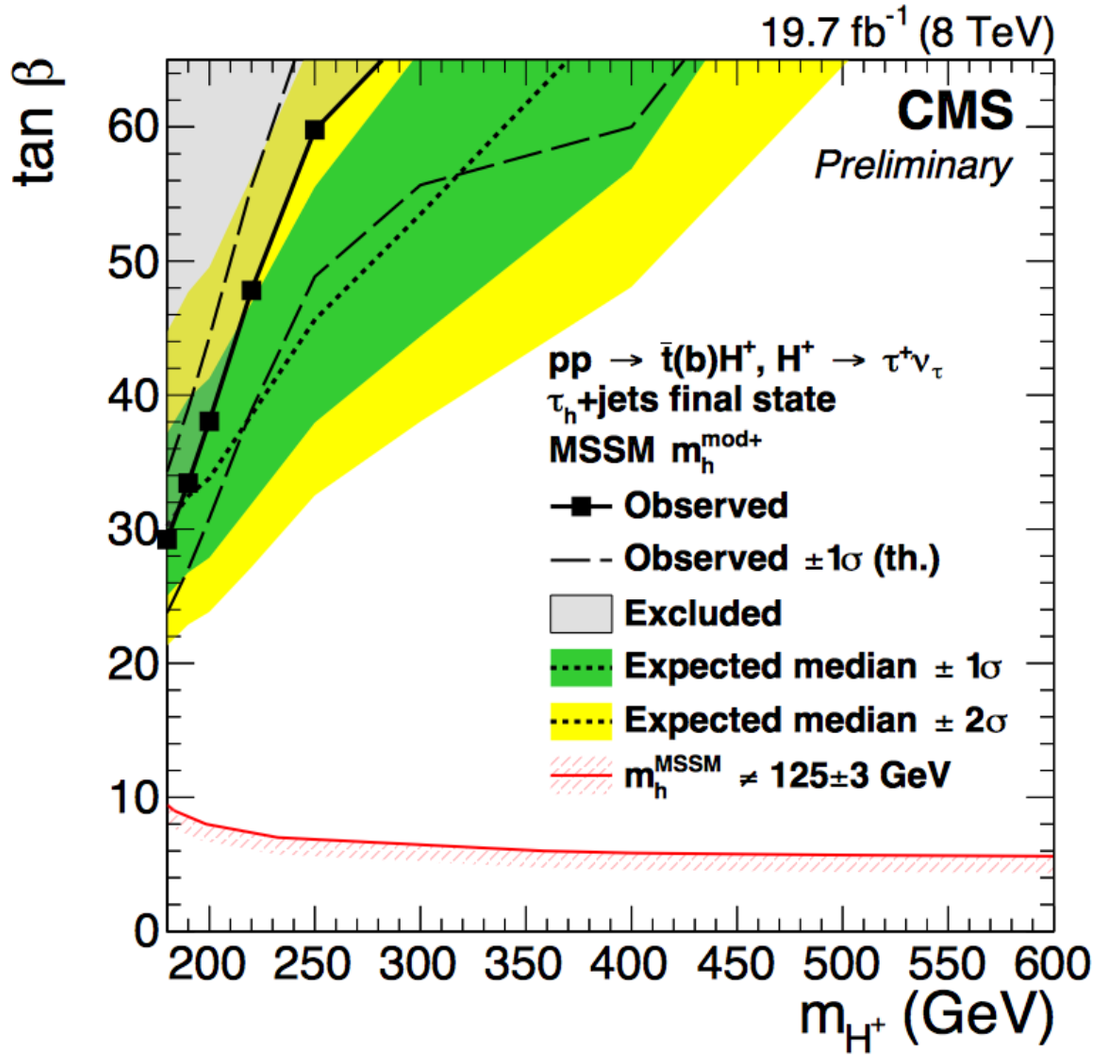
$H^{\pm}\to\tau^{\pm}\nu$ decay is significant also for small tanβ (100% for tanβ>X)

τ+jets final state: hadronic τ decay

almost able to exclude full MSSM phase space for $90<m_{H^{\pm}}<160$ GeV



$M_{H^{\pm}}>m_{top}$: associated production with top [tH(b)]



CMS-HIG-14-020

ATLAS: arXiv: 1412.6663 NEW

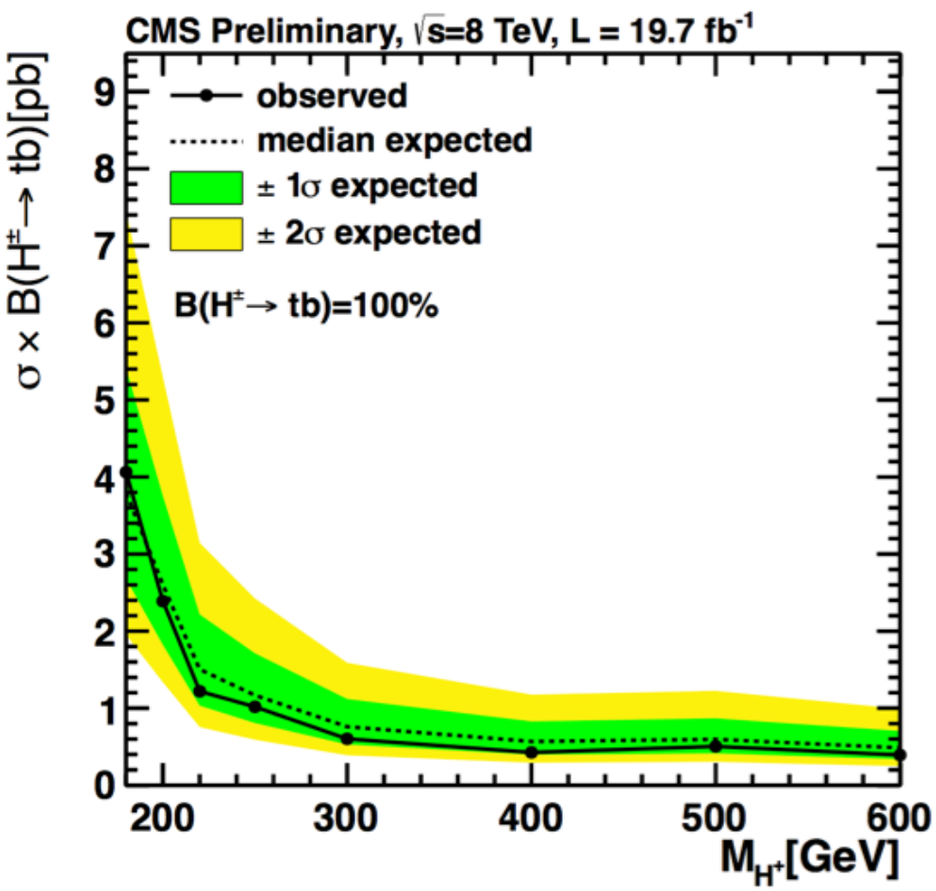
CHARGED HIGGS

Search for $H^+ \to tb$ performed for $m_{H+} > m_t$ in di-lepton + b-jets final state

sensitive to both $H^+ \to tb$ & $H^+ \to \tau\nu$

partial model independent interpretation provided for $BR(H^+ \to tb)=1$ or $BR(H^+ \to \tau\nu)=1$

Less sensitive than $H^+ \to \tau_{had}\nu$ for MSSM interpretation



CMS-HIG-13-026

Higgs triplet model

$H^{\pm} \to W^{\pm}Z$ allowed at tree level

Search performed with VBF production of charged Higgs

2 jets (VBF topology), 2 central jets (W decay), 2 leptons (Z)

ATLAS: $H^+ \to WZ$ PLOTS NOT YET PUBLIC

ATLAS HIGG-2014-13 NEW

$H \to a_1 a_1 \to 2\mu 2\tau$

Non minimal SUSY models not extensively tested in Run I at LHC

- **NMSSM=MSSM + 1 singlet**
- **3 CP-even, 2 CP-odd, 2 charged scalars**
- **CP-odd a_1 assumed to be light**

$H \to a_1 a_1 \to 2\mu 2\tau$ offers advantages wrt 4τ despite the smaller BR
possibility to use $m_{\mu\mu}$ as final observable

Boosted a_1 decays
A third lepton (μ,e) from τ decay

similar issues with boosted a_1 decays

search performed in range
$3.7 < m_{a1} < 50$ GeV

ATLAS: $2\mu 2\tau$
PLOTS NOT YET PUBLIC

ATLAS HIGG-2014-02 NEW

PERSPECTIVES FOR RUN 2

Simple rescaling of Higgs & bkg σ 13/8 TeV

Run I sensitivity should be reached for the H~ 10 fb^{-1} @ 13 TeV
10fb^{-1} are excepted to be collected in 2015!

ATLAS+CMS are preparing to keep as much as possible similar thresholds for trigger (higher lumi, higher pile-up) & physics object performance

CONCLUSIONS

Extensive searches performed with Run I data for many rare & BSM Higgs decays and production modes

BR for Higgs invisible decays constrained <30%, several other BSM decay modes are significantly constrained

Also extended Higgs sector probed for additional neutral and charged scalar

no luck so far…

Run II offer a great potential to further probe BSM scenarios

about 10 fb^{-1} @ 13 TeV needed to achieve similar sensitivity to Run I

Eagerly awaiting LHC restart!