Heavy Higgs Searches in Diboson Final States*

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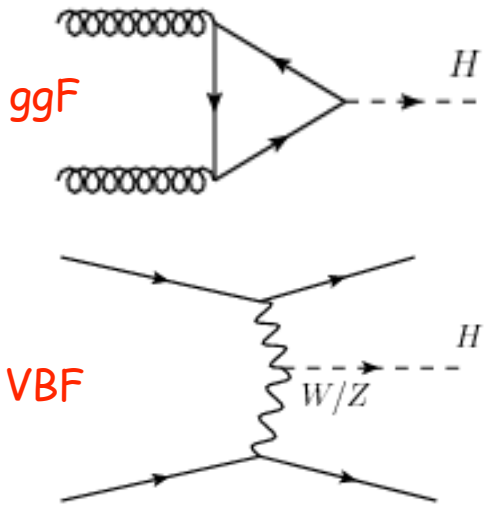
on behalf of the ATLAS Collaboration

- Introduction
- Results
- Summary & perspectives

* Higgs BSM searches in other final states covered in Anna Kaczmarska's talk

Introduction

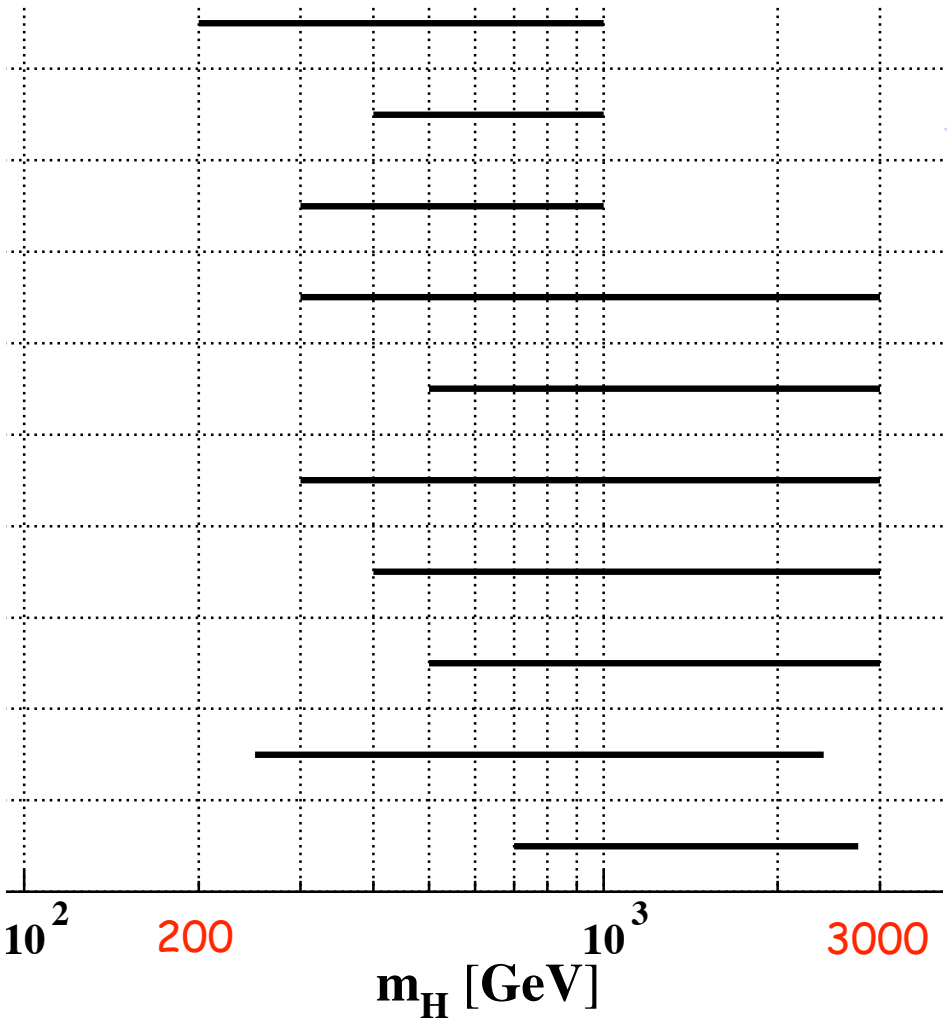
- Heavy Higgs bosons predicted in many BSM models
- Two examples are:
  1. Two Higgs Doublet Model (2HDM): h, H, A, H^+, H^-
  2. EW singlet model: h, H
- Searches performed in all diboson decay channels in fairly model independent ways:
  - ➢ Narrow Width Approximation (NWA)
    4 MeV, width << detector resolution
  - ➢ Large Width Assumption (LWA)
    with width up to 15% of the mass
  - ➢ Production modes:
    gluon-gluon fusion (ggF) and
    Vector boson fusion (VBF)



- Using latest 13TeV data sets of 2015 + 2016
  with sensitivity often exceeding those published with 7/8TeV data and also extending to higher mass range

Overview of Diboson Modes & Mass Range

Channel	Lumi (fb^{-1})	Ref
ZZ→4l NWA	14.8	ATLAS-CONF-2016-079
LWA	14.8	ATLAS-CONF-2016-079
ZZ→llνν NWA	13.3	ATLAS-CONF-2016-056
ZZ→llqq NWA	13.2	ATLAS-CONF-2016-082
ZZ→ννqq NWA	13.2	ATLAS-CONF-2016-082
WW→lνlν NWA	13.2	ATLAS-CONF-2016-074
LWA	13.2	ATLAS-CONF-2016-074
WW→lνqq NWA	13.2	ATLAS-CONF-2016-062
Zγ→llγ NWA	13.3	ATLAS-CONF-2016-044
Zγ→qqγ NWA	3.2	arXiv:1607.06363

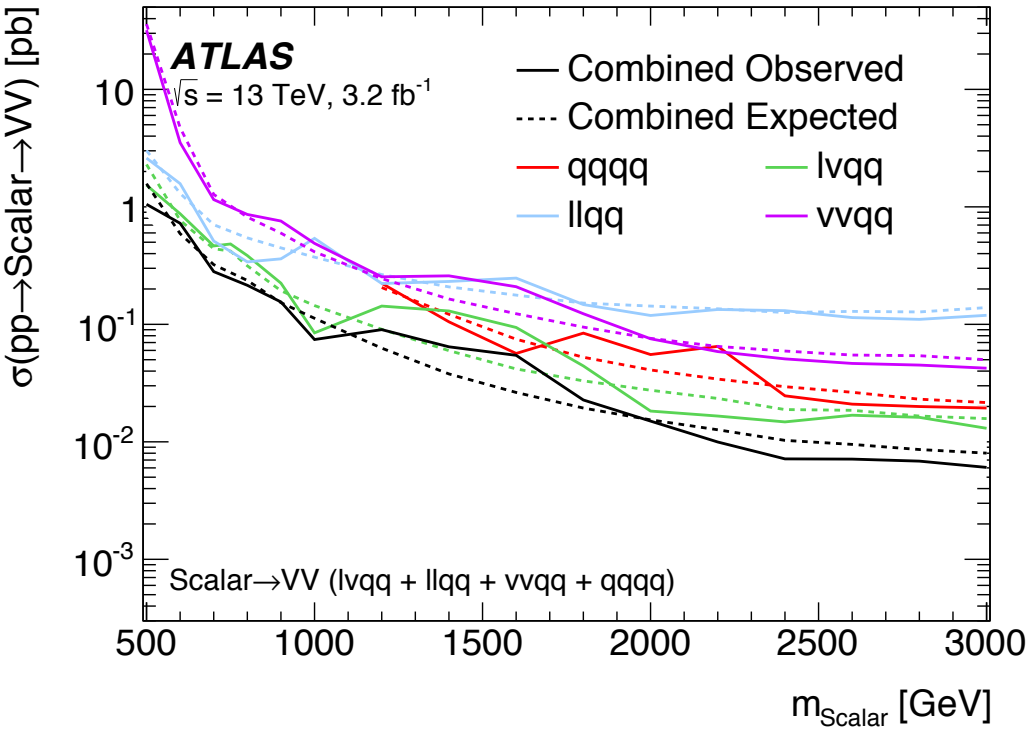


γγ mode covered in Yee Chinn Yap's talk

Sensitivity Comparison in Different Modes

Searches for heavy diboson resonances in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector (arXiv:1606.04833)

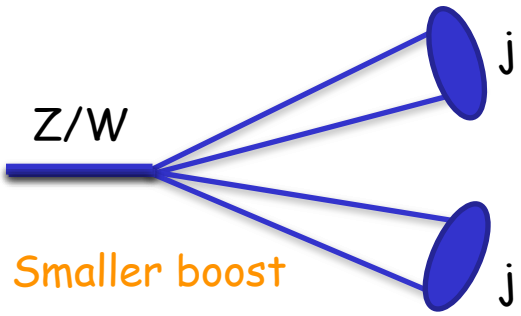
- Comparison shown only for hadronic and semi-hadronic final states (see also slide 16)
- Decay modes have no event overlap
- All decay modes except for qqqq updated here with more data from 2016



General Search Strategy

- Optimised event selection for a given heavy Higgs boson signal
- Data-driven background estimation/control for dominant backgrounds whenever possible
- Statistic analysis based on either full reconstructed mass m_H or transverse mass m_T distributions from signal (and control) regions
- Hadronic Z/W decays reconstructed with

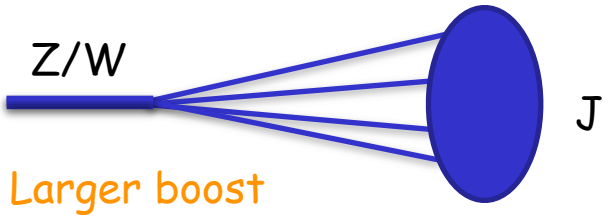
resolved small-R ($\Delta R=0.4$) jet at low mass



merged large-R ($\Delta R=1$) jet at high mass

Use energy correlation ratio $D_2^{(\beta=1)}$ to infer two-prong substructure

(ATL-PHYS-PUB-2015-033)



Decay Modes with Fully Reconstructed Leptons

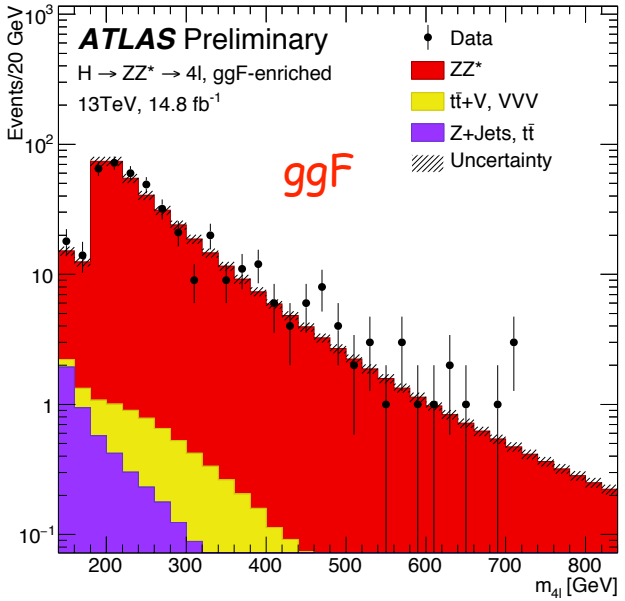
- $ZZ \to 4l$ (4e, 2e2μ, 2μ2e, 4μ),
  m_{4l} (apply Z mass constraints)
  ⇨ Excellent mass resolution

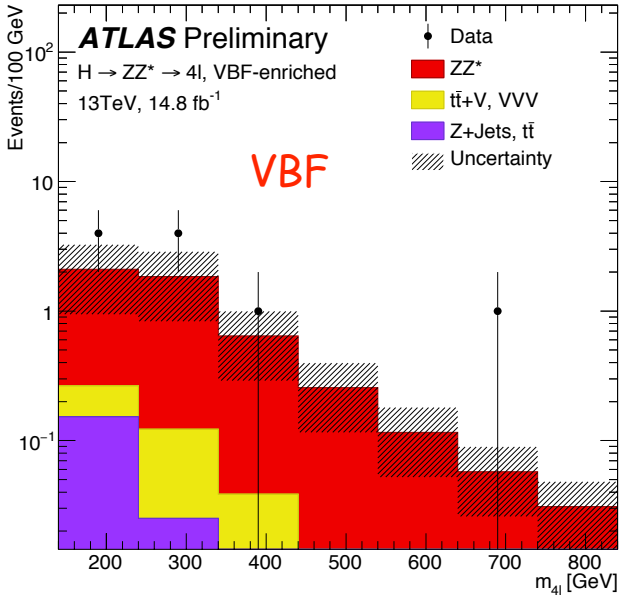
- ggF & VBF NWA signal

- LWA signal (1%, 5% and 10% m_H)

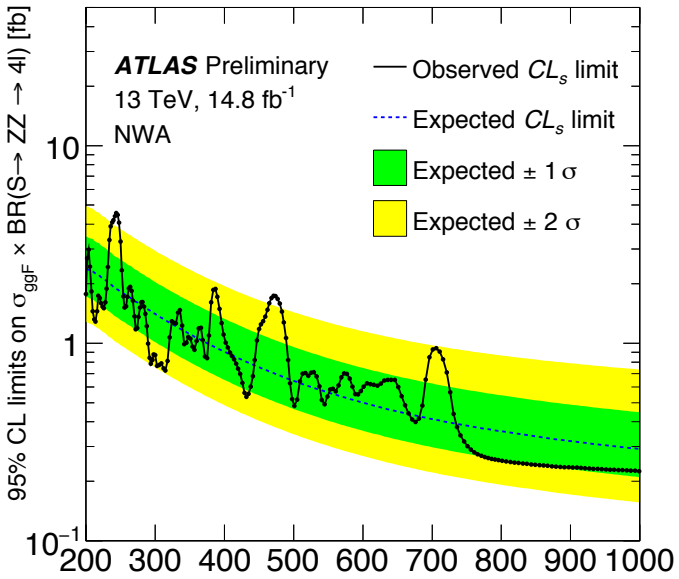
- 4 signal categories:
  - VBF: m_{jj}>400GeV, $|\Delta\eta_{jj}|$>3.3
  - otherwise ggF (4e, 2e2μ,4μ)

- Dominant background:
  non-resonant ZZ*





Decay Modes with Fully Reconstructed Leptons



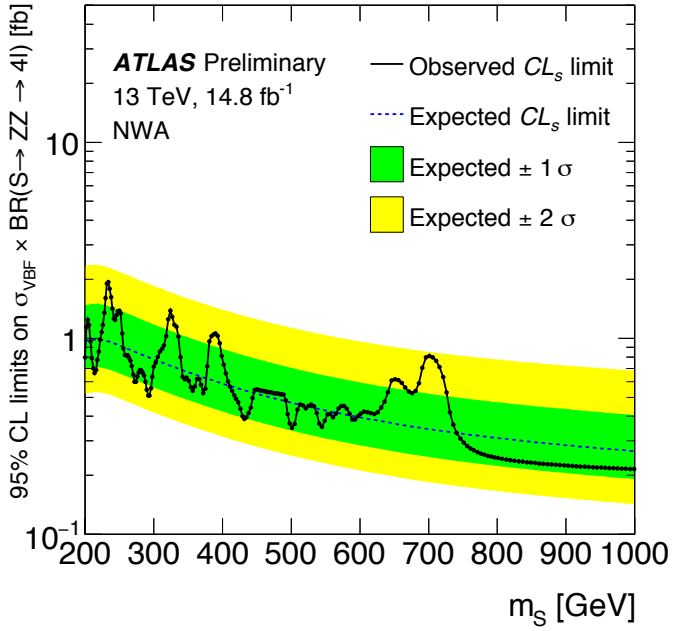
ggF NWA

95% CL upper limits on σ×B(H→ZZ)

VBF NWA

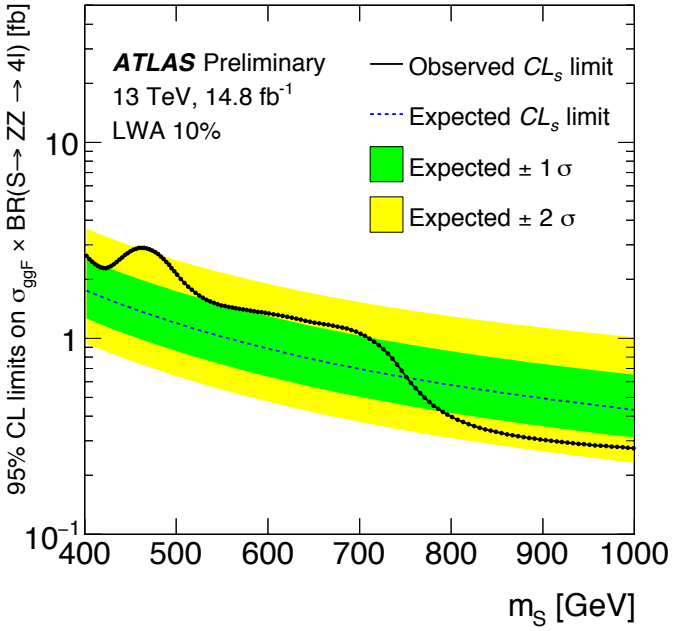
LWA 10% m_H

Unshown 1%, 5% m_H also available



NWA limits valid for models with width <0.5% of the mass

When fitting ggF VBF left free vice versa for VBF

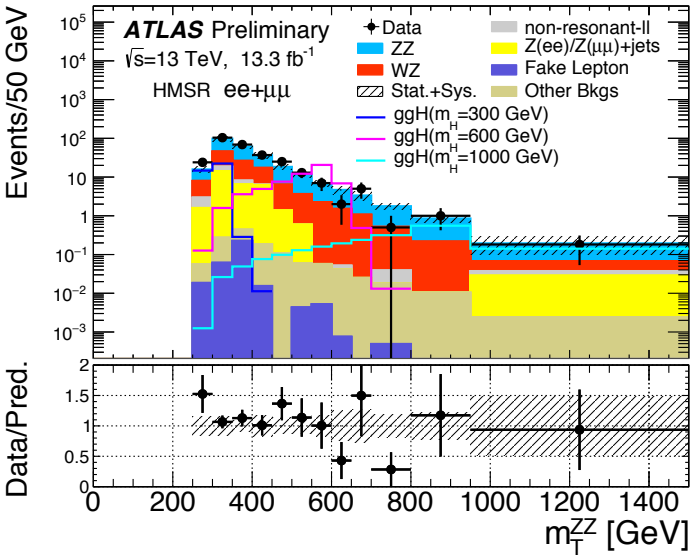


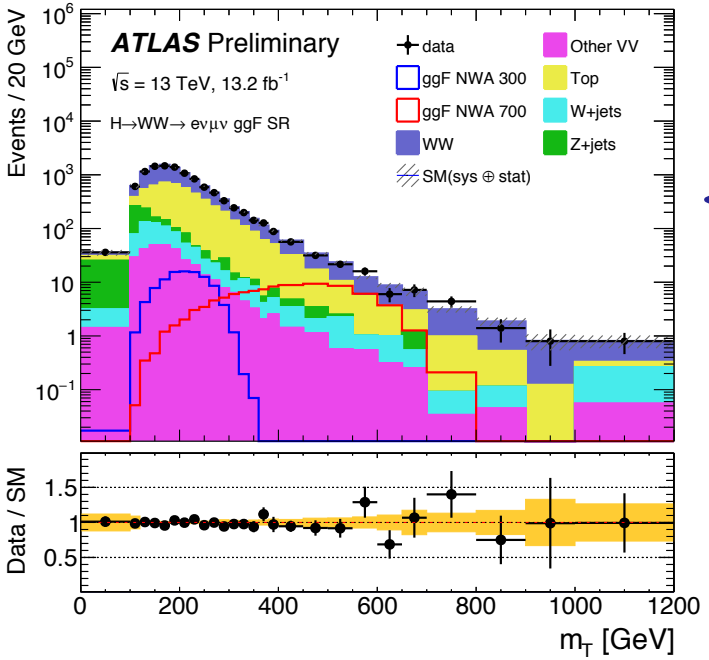
Leptonic Decay Modes with Neutrinos

- ZZ→llνν, WW→lνlν
  - ⇨ m_H cannot be fully reconstructed
    Use m_T instead

$$m_T^{ZZ} = \sqrt{\left(\sqrt{m_Z^2 + |p_T^{\ell\ell}|^2} + \sqrt{m_Z^2 + |E_T^{\rm miss}|^2}\right)^2 - |\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{\rm miss}|^2}$$

$$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{\rm miss} \left[1 - \cos\Delta\phi\left(p_T^{\ell\ell}, E_T^{\rm miss}\right)\right]}$$

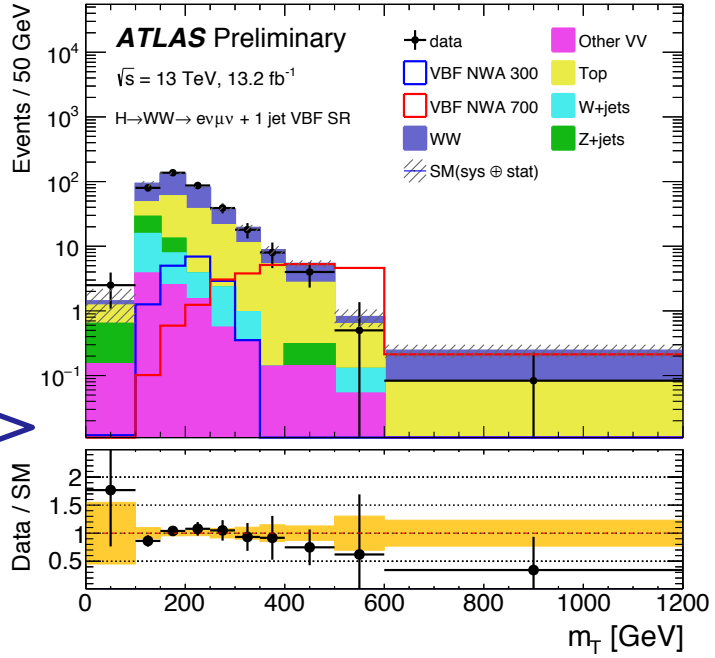




ZZ signal region (SR)

WW SR for quasi. incl. ggF: new for ICHEP

WW SR for 1 jet VBF: new for ICHEP



Leptonic Decay Modes with Neutrinos

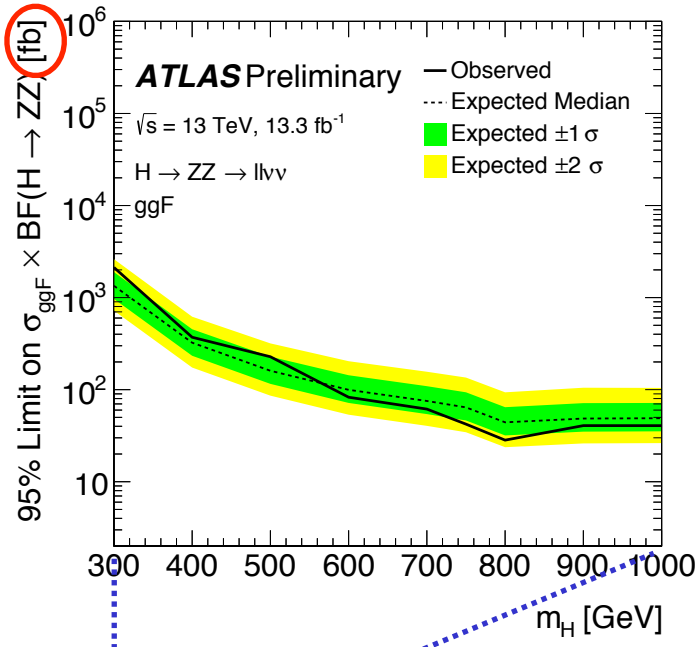
95% CL upper limits on σ×B(H→ZZ/WW)

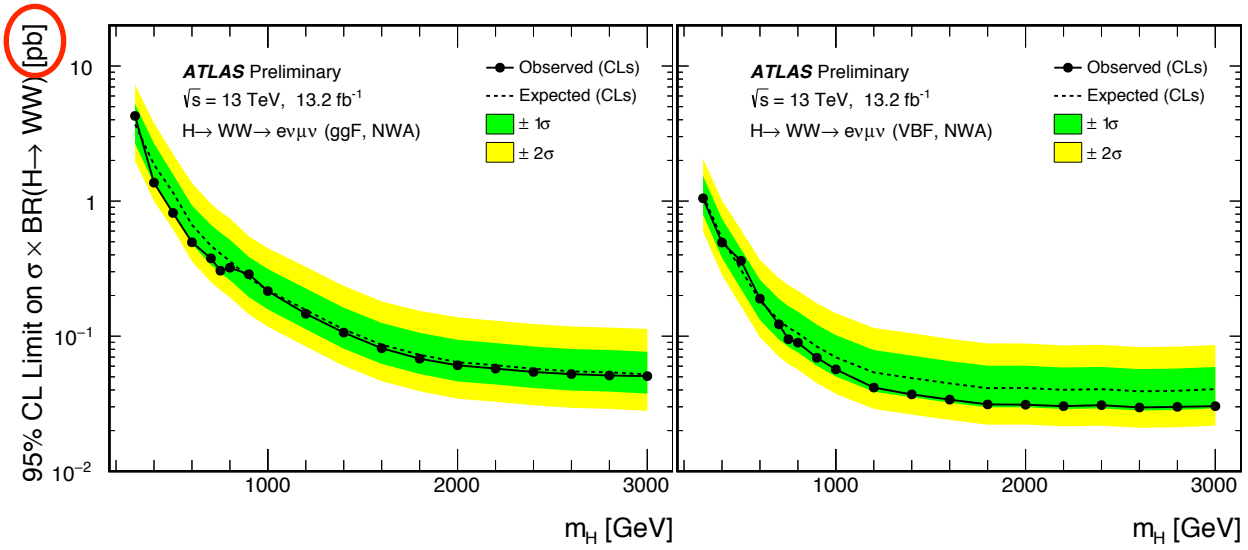
ZZ:
ggF NWA

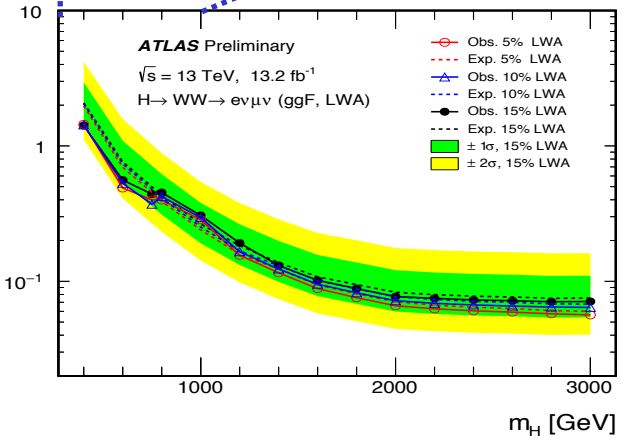
WW:
ggF NWA

WW:
VBF NWA

WW:
ggF LWA
5%, 10%, 15% m_H

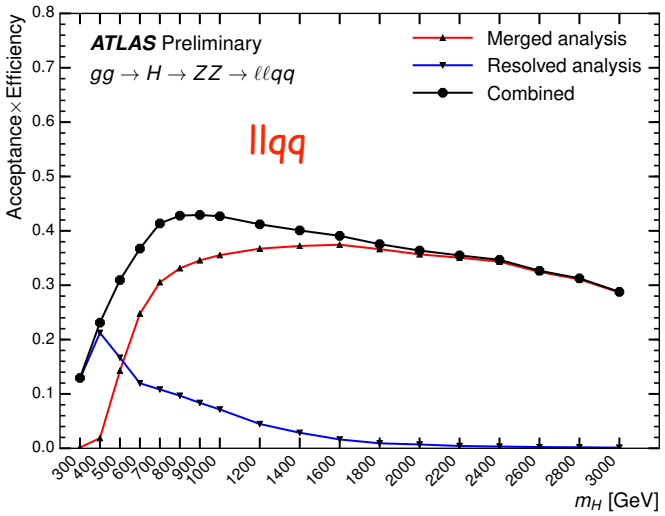


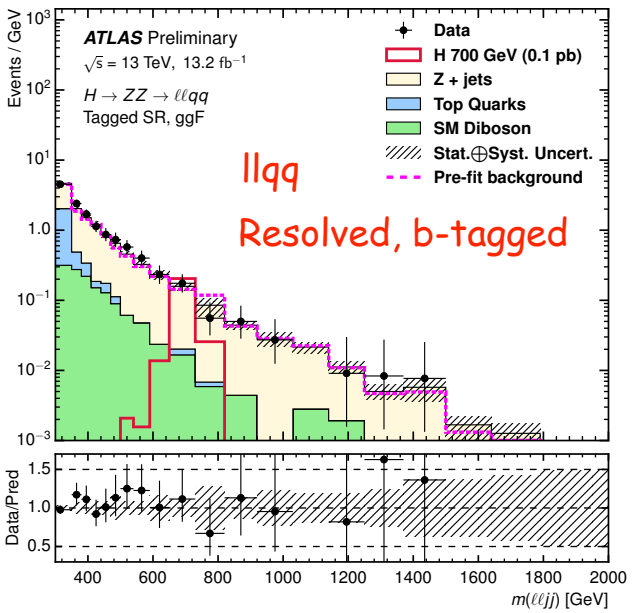


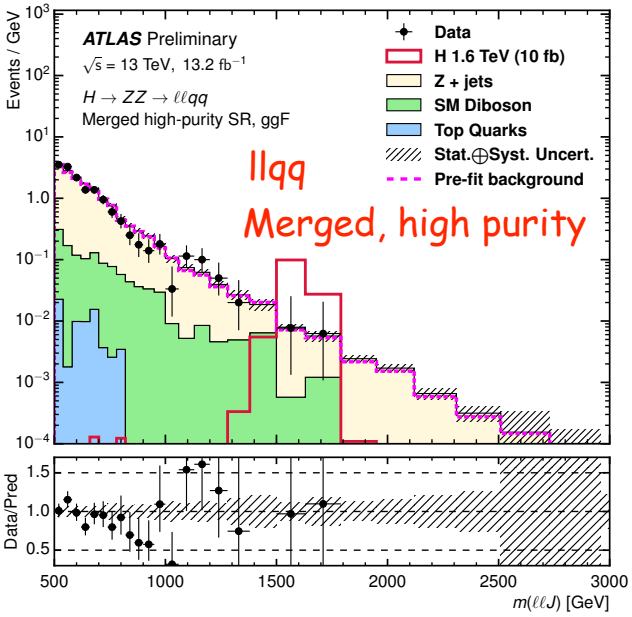


Semi-Hadronic Decay Modes

- ZZ→llqq, vvqq, WW→lvqq
  - llqq: resolved and merged jets
  - vvqq, lvqq: merged jet only
  - resolved jet analysis subdivided into b-tagged and untagged categories
  - merged jet analysis has two categories:
    1) High-purity: two-prong substructure
    2) Low-purity: otherwise
  - llqq VBF: m_{jj}>600GeV, $|\Delta\eta_{jj}|$>3.1



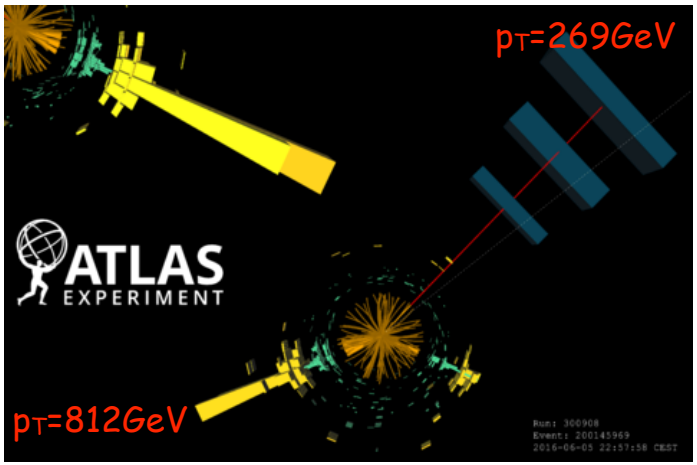


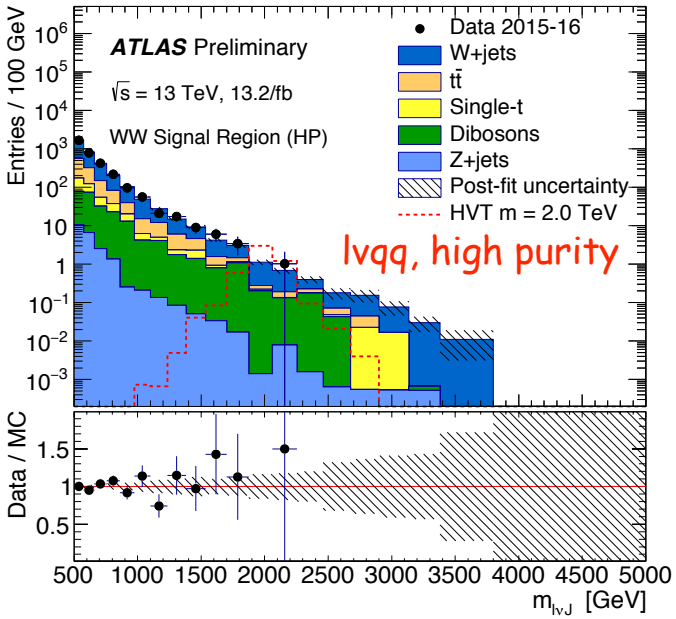


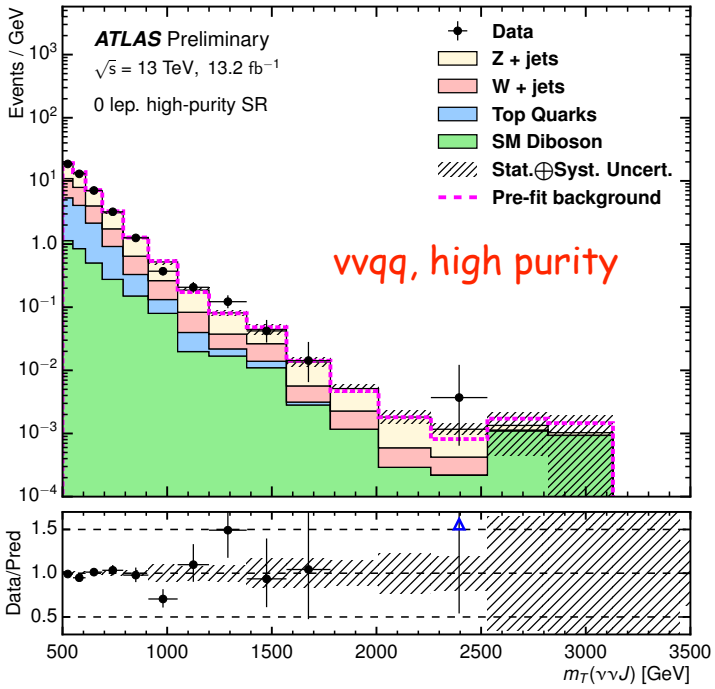
Semi-Hadronic Decay Modes

- ZZ→llqq, vvqq, WW→lvqq
  - llqq: resolved and merged jets
  - vvqq, lvqq: merged jet only
  - resolved jet analysis subdivided into b-tagged and untagged categories
  - merged jet analysis has two categories:
    1) High-purity (HP): two-prong substructure
    2) Low-purity: otherwise
  - llqq VBF: m_{jj}>600GeV, $|\Delta\eta_{jj}|$>3.1

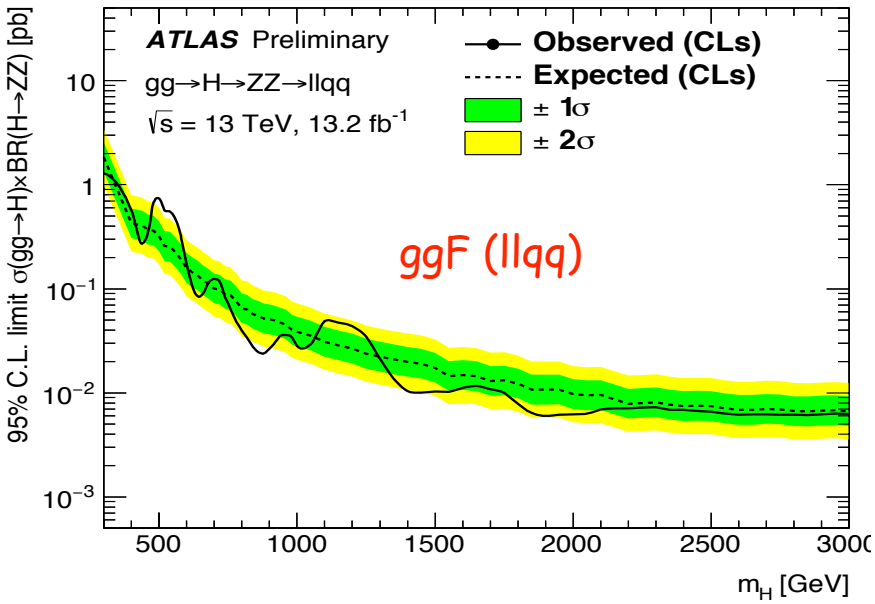
E_T^{miss}=458GeV, m_{lvJ}=1.56TeV

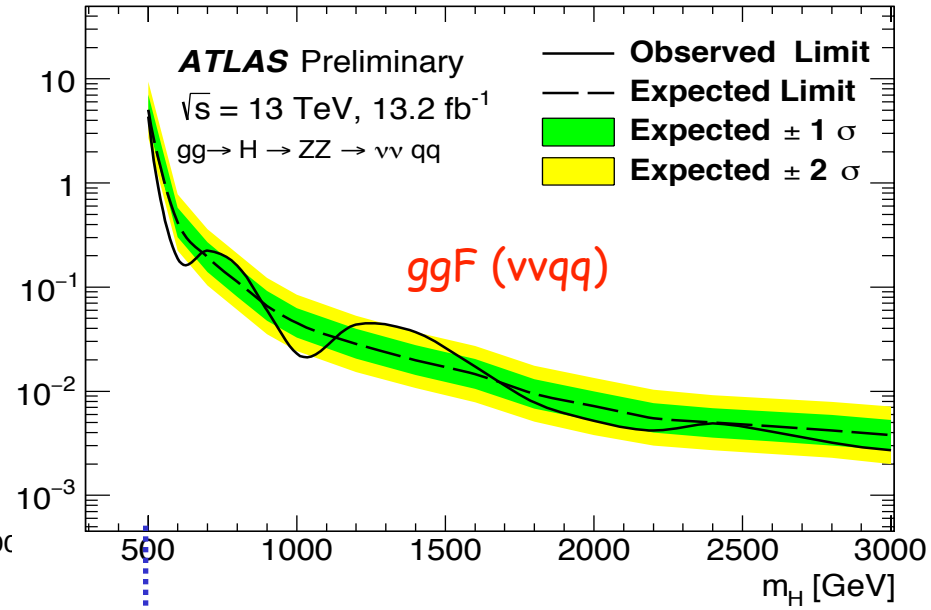


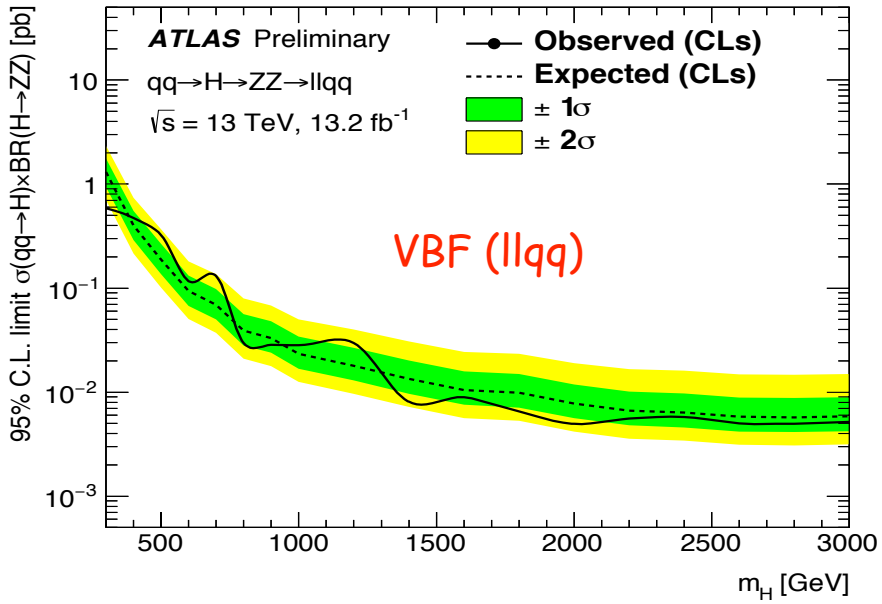


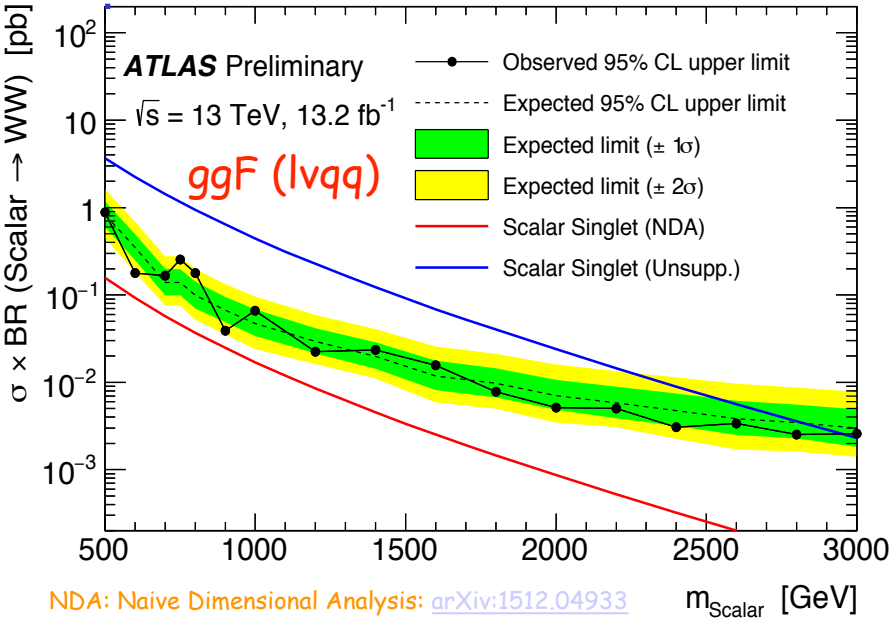


Semi-Hadronic Decay Modes (95% CL Upper Limits)









NDA: Naive Dimensional Analysis: arXiv:1512.04933

Decay Modes with Photon (γ)

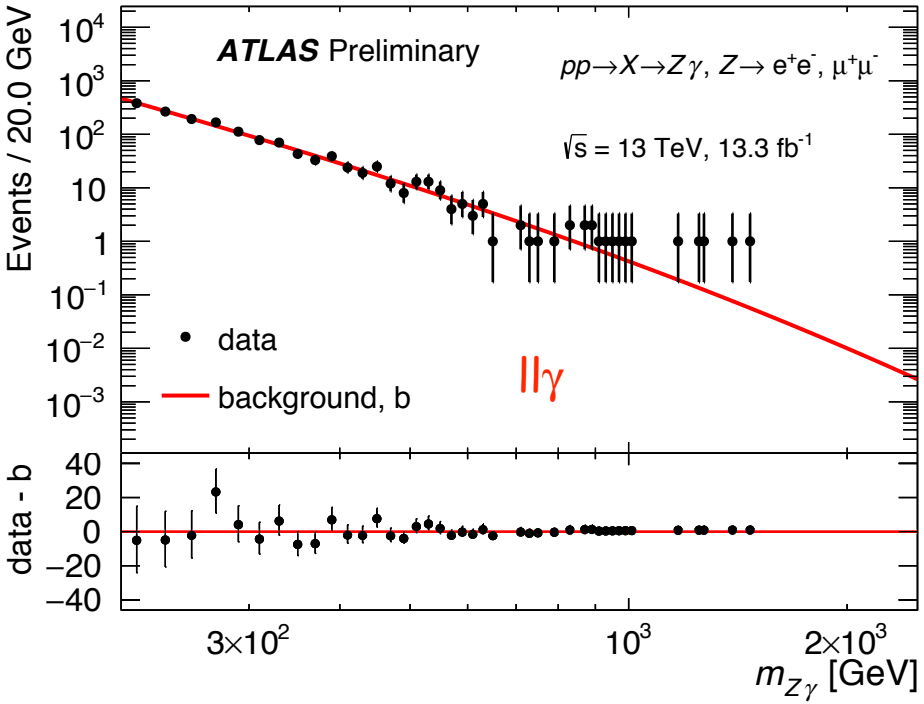
- $Z\gamma \to ll\gamma$ (13.3fb^{-1}), $qq\gamma$ (published 3.2fb^{-1})
- qq being a large-R (boosted) jet
- Dominant backgrounds:

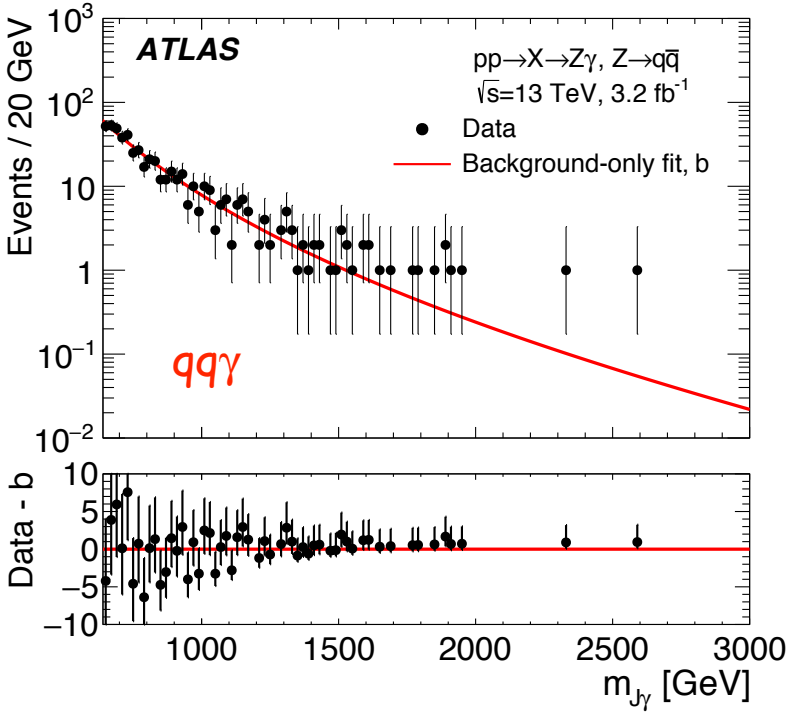
  $ll\gamma$: non-resonant Z+γ (90%) + Z+jets (10%)

  $qq\gamma$: γ+jets

  Modeled with $f_{\rm bkg}(m_{Z\gamma}) = \mathcal{N}(1-x^k)^{p_1+\xi p_2} x^{p_2}$

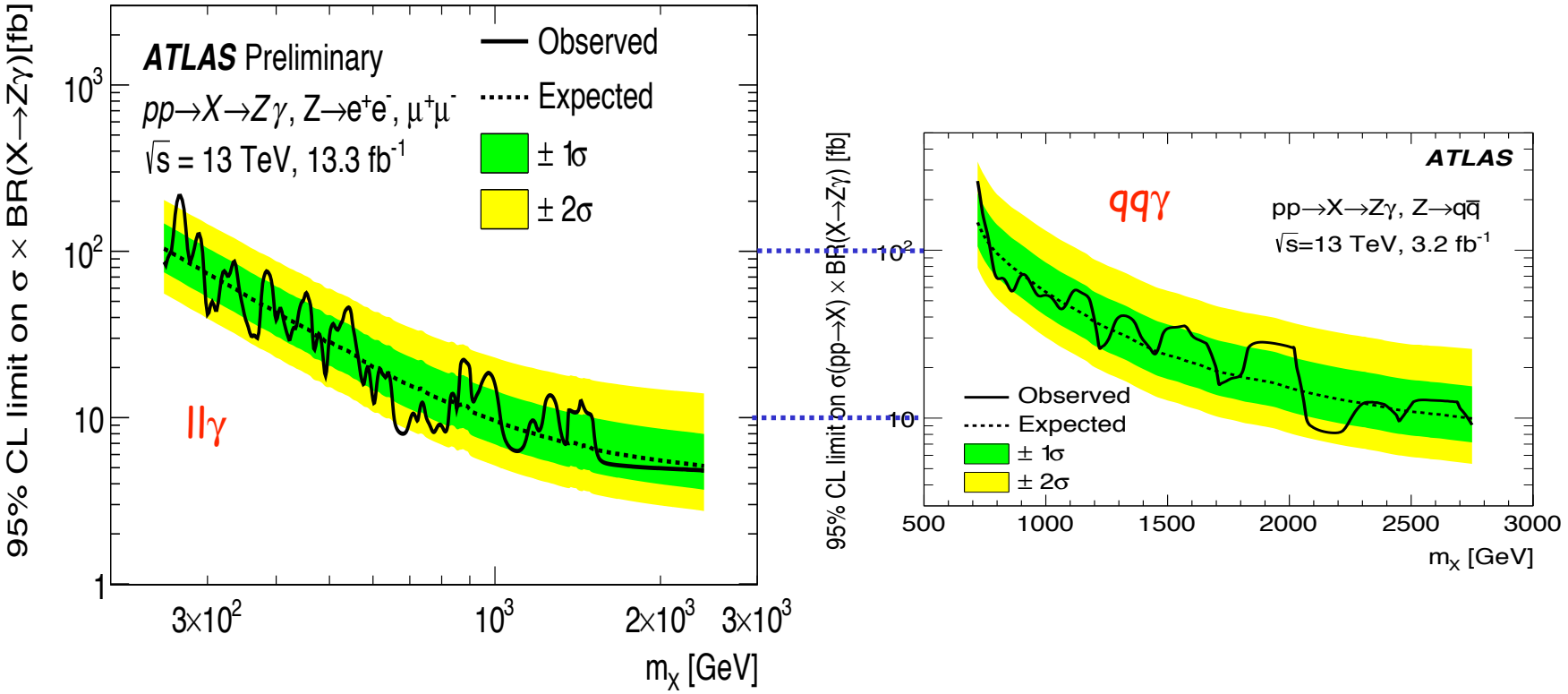
$$x = m_{Z\gamma}/\sqrt{s}$$
$$k = 1/3, \quad \xi = 0 \quad \text{for } ll\gamma$$
$$k = 1, \quad \xi \sim 10 \quad \text{for } qq\gamma$$





Decay Modes with Photon (γ)

- 95% CL upper limits on σ×B(H→Zγ)



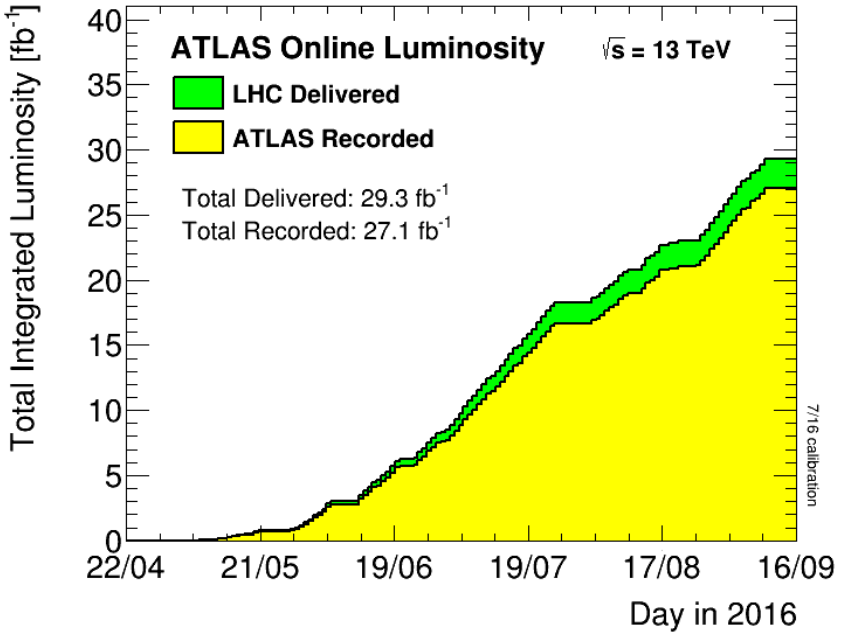
⇨ leptonic (hadronic) Z decay channel has better sensitivity at low (high) mass

Summary & Perspectives

- Heavy Higgs boson has been searched for using up to 14.8fb^{-1} @ 13TeV
  - ➢ in many diboson decay modes
    fully leptonic (ZZ→4l) including neutrinos (ZZ→llvv, WW→lvlv)
    semi-hadronic (ZZ→llqq, vvqq, WW→lvqq)
    with γ (ZZ→llγ, qqγ)
    fully hadronic (ZZ→qqqq)

- No significant deviation found
  - ⇨ Stringent upper limits set on its production in ggF & VBF production modes with NWA & LWA lineshapes over wide range

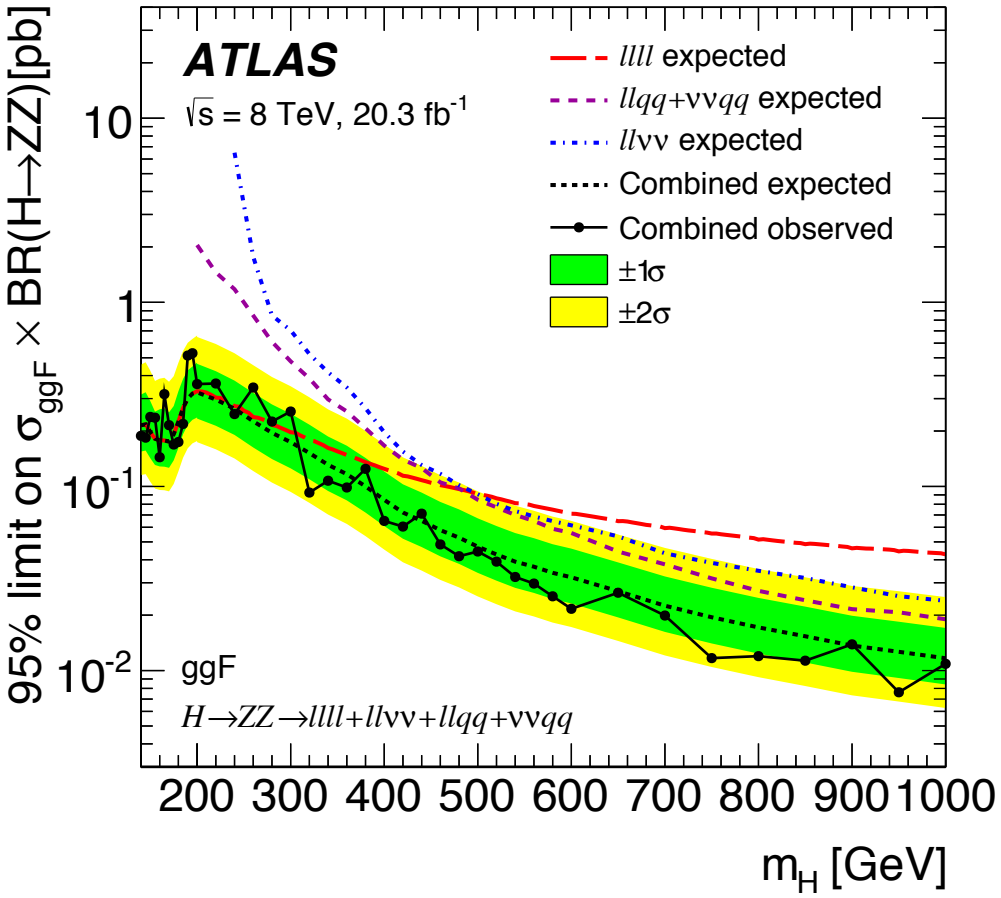
- More data have been and are being taken
  - ⇨ good perspective for discovery or more stringent constraints.



Backup

Search for an additional, heavy Higgs boson in the H → ZZ decay channel at √s = 8 TeV in pp collision data with the ATLAS detector (published in EPJC)

Complementary sensitivity with llll being the best at low mass



Backup

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ZZ→4l NWA	14.8	ggF: lumi, VBF: jet syst	ATLAS-CONF-2016-079
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ZZ→llνν NWA	13.3	Z+jets	ATLAS-CONF-2016-056
ZZ→llqq NWA	13.2	Large-R jet E scale/resolution	ATLAS-CONF-2016-082
ZZ→ννqq NWA	13.2	W/Z + jets modelling	ATLAS-CONF-2016-082
WW→lνlν NWA	13.2	top modelling	ATLAS-CONF-2016-074
LWA	13.2	top modelling	ATLAS-CONF-2016-074
WW→lνqq NWA	13.2	Large-R jet, shape of W+jets,ttbar	ATLAS-CONF-2016-062
Zγ→llγ NWA	13.3	Stat unc.	ATLAS-CONF-2016-044
Zγ→qqγ NWA	3.2	Jet mass/energy resolution	arXiv:1607.06363