XLIV International Meeting on Fundamental Physics - Madrid, 4-8 April 2016

Search for dihiggs production in the γγbb channel at 13 TeV with the ATLAS detector

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Introduction

Why search for **Higgs pairs**?

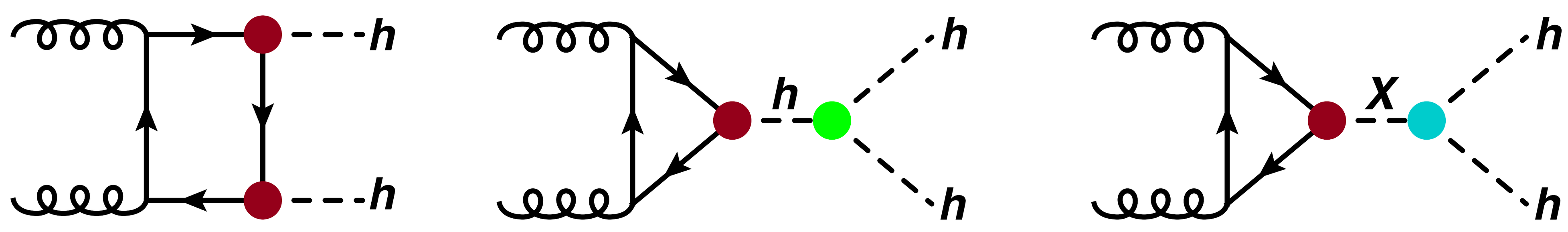
- Extremely small SM expectation (destructive interference)
- BSM effects (e.g. ttH or hhh couplings) could enhance rate.
- Many BSM production modes:
  - ✓ Two Higgs doublet model, gravitons…

Why **hh->γγbb**?

- h->bb has the highest Branching Ratio (~ 0.57)
- Clean **diphoton trigger and low backgrounds.**
- ATLAS has a small 2.4σ excess in the Run 1 result in this channel.

Conference Note (13 TeV): ATLAS-CONF-2016-004

Leading-order production modes for Higgs boson pairs in the Standard Model through



(a) a heavy-quark loop (b) the Higgs self-coupling

The total SM contribution is the sum of the two modes, which includes significant destructive interference

BSM Higgs boson pair production could proceed through changes in the SM Higgs couplings in (a), (b) or an intermediate resonance, X

Data and Monte Carlo Samples

- This study analyses the **13 TeV pp collision data** collected by the ATLAS detector at the LHC corresponding to an integrated luminosity of 3.2 fb^{-1}.
- To simulate the processes, Monte Carlo events are generated by various **generators**: MadGraph (resonant and non-resonant di-Higgs signal, continuum backgrounds), Pythia8 (inclusive di-jet), SHERPA (Z->ee, gamma+jet), and POWHEG (Standard Model single Higgs simulation).

Object Definitions and Event Selection

- Initial goal: **cross-check the Run 1 excess**
- Stay close to Run 1 object definitions and event selection
- Trigger, vertex and di-photon selection from H->γγ group
- A common selection is used between the resonant and non-resonant production; the treatment diverges only in a final cut on $m_{\gamma\gamma bb}$ for the resonant production and in the statistical model used to interpret the results
  - ✓ **Photons**: Isolated ; Tight ID ; p_T: 0.35 (0.25) · $m_{\gamma\gamma}$; 105 < $m_{\gamma\gamma}$ [GeV] < 160
  - ✓ **Jets**: p_T > 25 GeV ; |η| < 2.5 ; |JVT| > 0.64
  - ✓ **Muons**: Medium ID ; p_T > 4 GeV ; |η| < 2.5
  - ✓ **b-jets**: p_T: 55 (35) GeV ; 95 < m_{jj} [GeV] < 135
  - ✓ Remove objects **overlapping with selected photons**
- Different **categories** depending on the number of b-jets in an event.
  - 0 b-jets in an event: 0 b-tag category, **control** region
  - 2 b-jets in an event: 2 b-tag category, **signal** region
  - 3 or more b-jets: vetoed in order to remain orthogonal to 4b channel

Analysis Strategy

The **enhancements** to the SM rate take two basic forms – non-resonant and resonant:

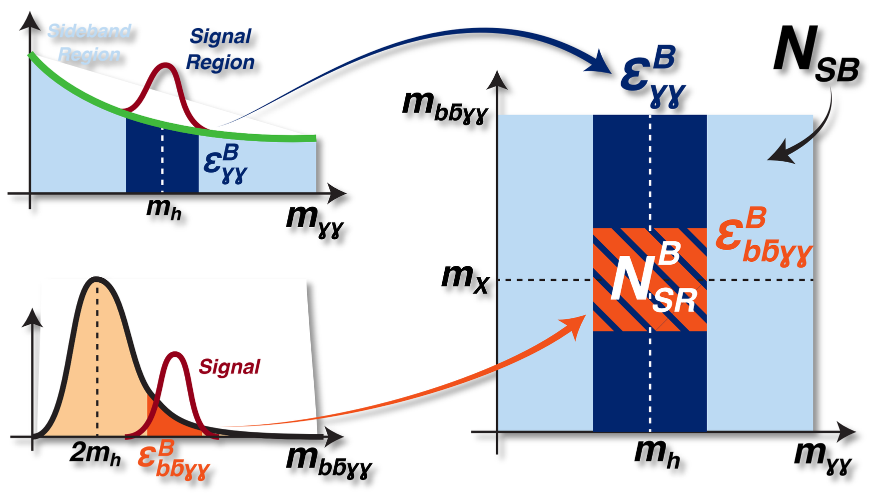
- **Non-resonant:** Simultaneous Signal + Background fit in $m_{\gamma\gamma}$ window

Signal Region	Control Region
We fit the Standard Model single-Higgs and di-Higgs Monte Carlo with a Double-Sided Crystal Ball function	We fit the 0-tag continuum MC with an exponential and use the same shape in the SR, normalising to the sidebands

- **Resonant:** Cut-and-count approach

✓ Require $|m_H - m_{\gamma\gamma}| < 2\sigma_{\gamma\gamma}$
✓ Constrain bb mass to m_H
✓ Inside the 95% efficient $m_{bb\gamma\gamma}$ window

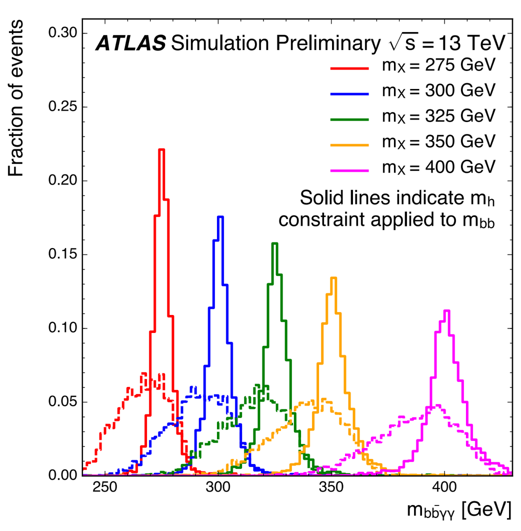
$$N^{SR}_{continuum} = N^{sideband}_{continuum} \times \frac{\varepsilon^{SR}_{\gamma\gamma}}{1-\varepsilon^{SR}_{\gamma\gamma}} \varepsilon^{SR}_{\gamma\gamma bb}$$



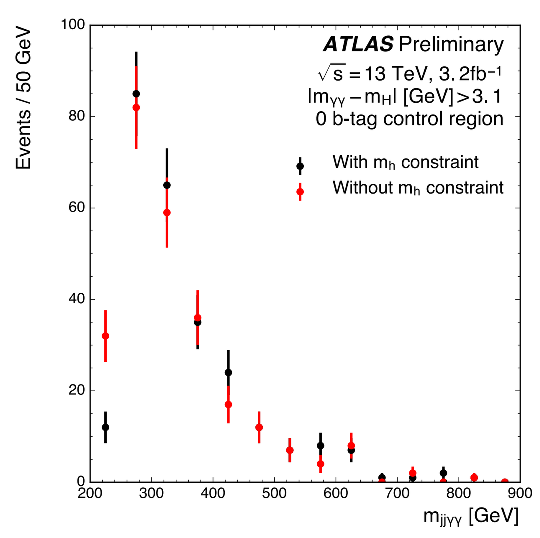
Background contribution from Control Regions

Optimisation studies

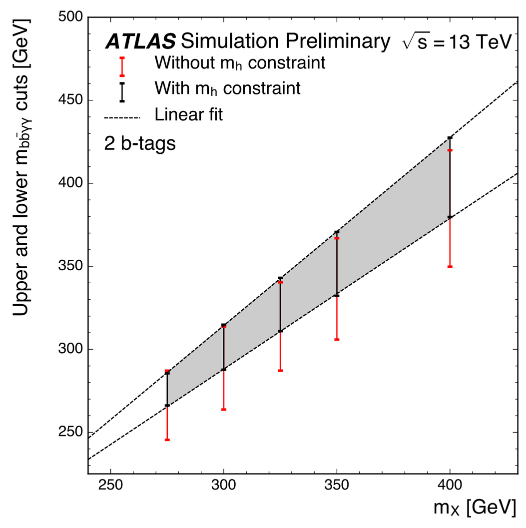
- New di-photon primary vertex selection
- New re-optimised photon isolation
- New b-tagging selection:
  Studies carried out with Monte Carlo simulation show that the maximum **significance** for the 2 b-tag category is achieved with the loosest option, the 85% w.p.
- bb mass constrained: The effect of the m_H/m_{bb} scaling on the $m_{bb\gamma\gamma}$ mass resolution



(a) for di-Higgs signal samples



(b) for data in the 0-tag Control Region



95% efficient mass windows as a function of the mass of the resonance

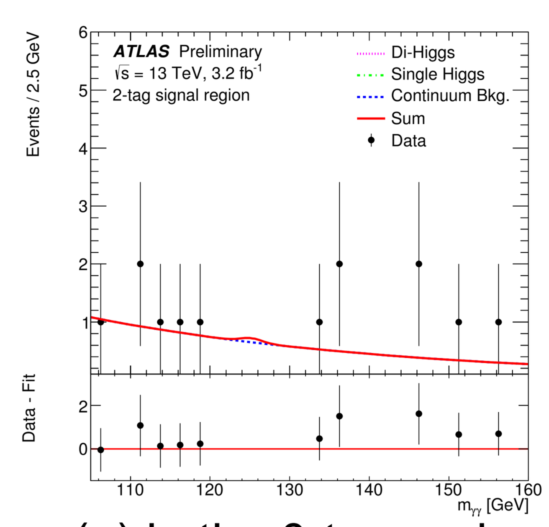
Uncertainties

Main sources:

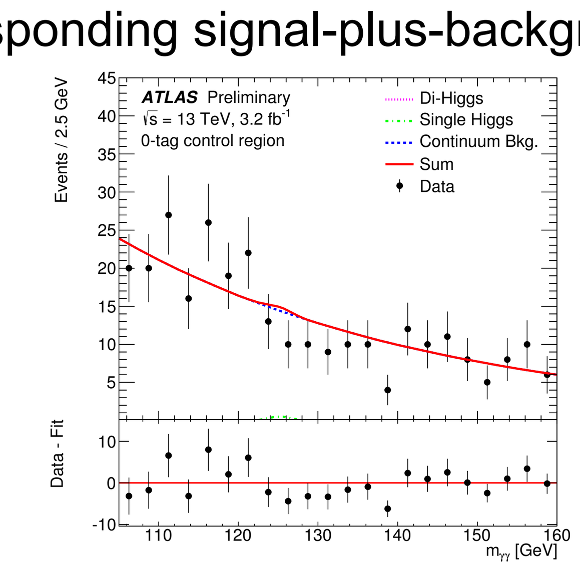
- Statistical uncertainties dominant
- Reconstruction-level systematics reduced from 86 nuisance parameters (e.g. Photon Energy Resolution, Jet Energy Scale, b-tagging, etc.)
- **Non-resonant** fit systematics: using 3 alternative $m_{\gamma\gamma}$ fit functions and 3 loose photons sidebands to take the maximal deviation from nominal. Overall 11% uncertainty.
- **Resonant** fit systematics:
  - Using a Landau function to fit the $m_{bb\gamma\gamma}$ distribution, obtain its efficiency and compare to event counting (20%)
  - Heavy flavour uncertainty (11%)
  - Fit procedure uncertainty, m_H dependent
  - The continuum uncertainty is their combination in quadrature

Results: Non-resonant analysis

Di-photon invariant mass spectrum for data in the non-resonant mode, together with the corresponding signal-plus-background fit:

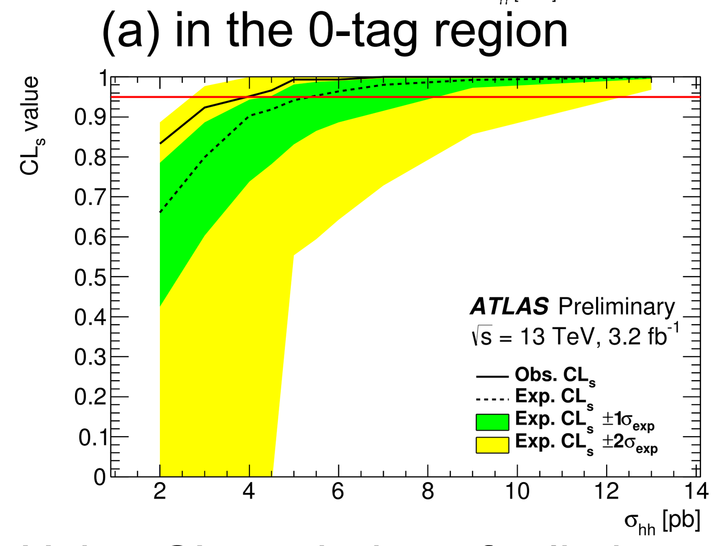


(a) in the 0-tag region



(b) in the 2-tag region

- μ is allowed to float in the fit
- It looks like background-only
- Inclusive selection: 13 (287) events for Signal Region (Control Region)



Using CL_s technique for limit setting
Observed (expected) limits: 3.9 (5.4) pb

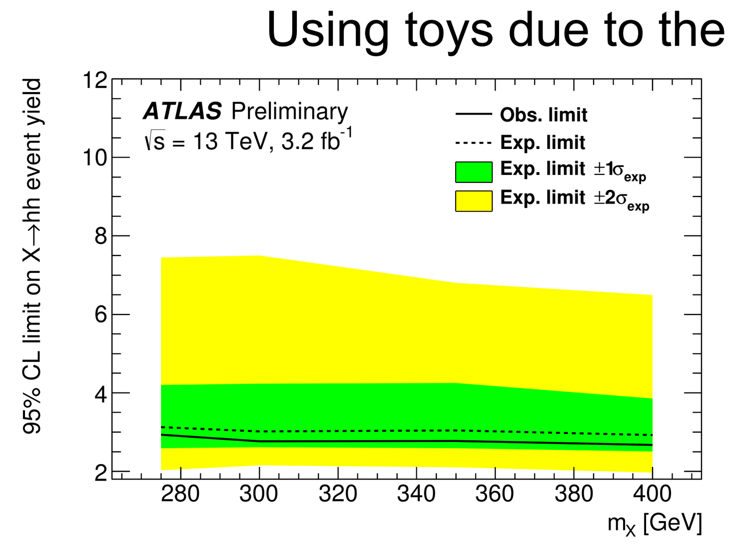
In $m_{\gamma\gamma}$ window:

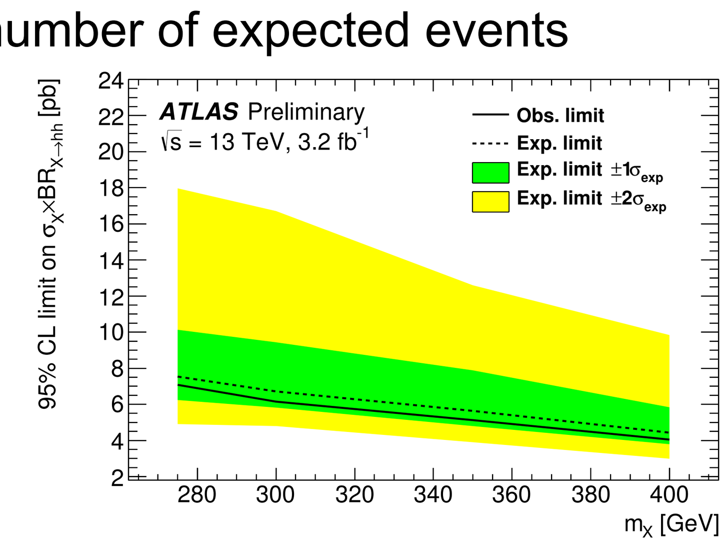
Process	0-tag	2-tag
Continuum background	35.8 ± 2.1	1.63 ± 0.30
SM single-Higgs	1.8 ± 1.5	0.14 ± 0.05
SM di-Higgs	<0.001	0.027 ± 0.006
Observed	27	0

There are 0 (27) observed events for SR (CR) and the background expectations are 2 (38) events

Results: Resonant analysis

Resonant search sets limits in range 275 to 400 GeV
Using toys due to the low number of expected events





Observed (expected) range: [7.0,4.3] ([7.5,4.8]) pb