Search for Higgs boson pair production in the $WW^{(*)}WW^{(*)}$ decay channel using ATLAS data recorded at $\sqrt{s} = 13$ TeV

Shuiting Xin, on behalf of The ATLAS Collaboration

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1)Motivation and introduction

- HH production rate could be larger than that predicted in the SM. Such extension includes
  - A modification to the SM Higgs self-coupling, λ_{HHH}.
  - The existence of a new heavy resonance which decays into a pair of Higgs bosons.
- Previous searches were performed for resonant and non-resonant HH production using various channels, such as bb$\gamma\gamma$, bbbb, bbWW, bb$\tau\tau$ and WW$\gamma\gamma$, with data from the ATLAS and CMS experiments.
- First di-higgs search with WW*WW* channel, also the first search for X → SS model.

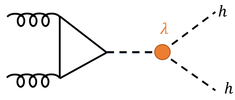


Fig.1SM non-resonant $pp \to HH$ process($\sigma = 33.41\ fb$)

- This work investigates HH production through three different processes.
  - SM HH production(non-resonant HH, Fig.1)
  - BSM processes(Fig.2)inspired by an extended Higgs sector, in which a neutral heavy Higgs boson, X , decays either directly into two SM Higgs bosons (resonant HH) or into a pair of new scalar bosons, S (X → SS).
- The analysis is divided into three independent channels depending on the number of light leptons(e and u) from leptonic decay of W bosons, and then statistically combined to give the final result.

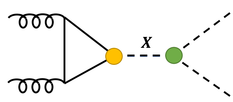


Fig.2 BSM resonant and X → SS process

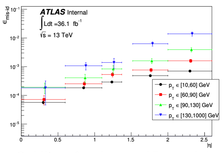
2)Common Analysis Strategy

- Relatively high decay branching ratio, use leptons final state to get cleaner signature.
- Data and MC samples, full 2015-2016 data(36.1fb^{-1}).
- Cut and count analysis
- Individual channels
  - Two(same sign)leptons
    - $ee, e\mu, \mu\mu$, missing energy, at least two jets
  - Three leptons
    - Total charge ± 1, missing energy, at least two jets
  - Four leptons
    - Total charrge 0, no jet requirement.
- Fake leptons estimate with a fake factor method for all channels
- Optimized selections based on $s/\sqrt{b}$ using TMVA CutsSA for each mass point (2l and 3l channel).
- b-jet veto to reject top quark backgrounds and stay orthogonal to most other decay channels.

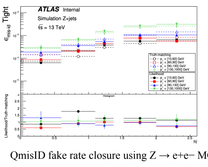
2 lepton(same sign) channel

- Background modeling
  - From simulation
    - Prompt leptons(VV,VVV,tV, ttV and ttH)
    - Vγ
  - From data-driven
    - Charge mis-ID(QmisID)(e.g Z+jets)
    - Fakes due to ttbar and W+jets
- QmisID background
  - Tight electrons Charge mis-ID rate ε is used measured with a likelihood technique around the Z-mass window

$$\ln L(\varepsilon|N_{SS}, N) = \sum_{i,j} \ln[N^{ij}(\varepsilon_i + \varepsilon_j - 2\varepsilon_i\varepsilon_j)]N^{ij}_{SS} - N^{ij}(\varepsilon_i + \varepsilon_j - 2\varepsilon_i\varepsilon_j)$$



QmisID rate from data around Z-mass window

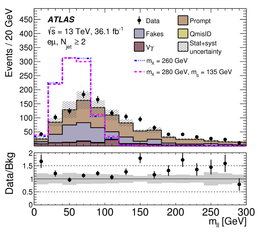


QmisID fake rate closure using Z → e+e− MC

- Fakes background
  - The fake factor is defined based on "tight" and "anti-tight" lepton.

$$\theta_\ell = \frac{N_{\ell\ell}}{N_{\ell f}}$$

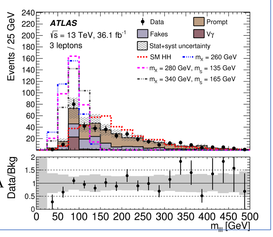
  - The amount of fake background is estimated with the control region and the fake factor.



- Signal Region optimization
  - Four variables using TMVA CutsSA: m_{ll} , $\Delta R_{l1j}, \Delta R_{l2j}, m_{l1jj}$

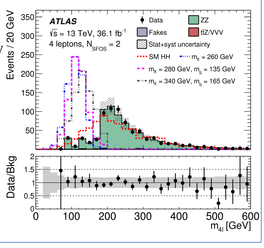
3 lepton channel

- Selection
  - Six flavour channels are split into two categories: OSFOS($\mu ee, e\mu\mu$), 1/2SFOS($eee, ee\mu, \mu\mu e, \mu\mu\mu$)
- Background modeling
  - From simulation
    - Prompt leptons(WZ,ZZ,tV,ttV/H and VVV)
    - Vγ
  - From data-driven
    - Fakes due to Zjets,ttbar
- Signal Region optimization
  - Four variables used in TMVA CutsSA



4 lepton channel

- Selection
  - Six flavour channels split into two categories: 0SFOS: $e\mu e\mu$, $e\mu\, ee$, $\mu\mu\, e\mu$, 1/2SFOS: $eeee$, $\mu\mu\mu\mu$ and $ee\mu\mu$.
  - Select dilepton mass to reject fakes
  - Two M4l regions to improve sensitivity
- Background modeling
  - From simulation
    - ZZ,ttZ,VVV(qq/gg->ZZ dominated)
  - From data-driven
    - Fakes due to WZ,Zjets,tV.

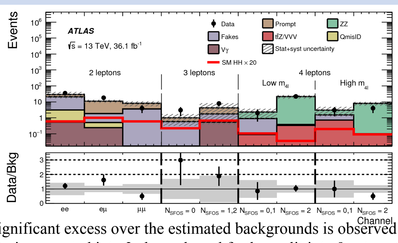


3) Systematics

- Dominating effects come from JER/JES(45%) and fake lepton background estimation(42%)for the non-resonant production search.
- Backgrounds uncertainties include prompt lepton, fake lepton, mischarge ID backgrounds estimation.
- Theoretical uncertainties include signal/backgrounds cross sections, PDF, QCD scale and parton shower modelling.
- Other small uncertainties include lepton measurements, pile-up modelling, b-tagging, ET miss modelling.
- Luminosity uncertainty.
- The relative impact of all systematic uncertainties are 71% (60%–79%) for the non-resonant (resonant) production searches. The statistical uncertainties are 71% (61%–80%) for the non-resonant (resonant) production searches.

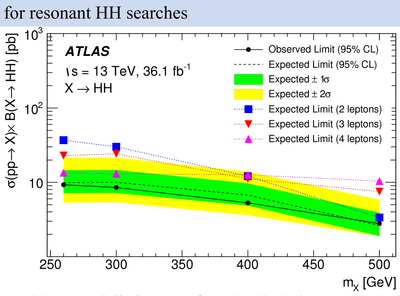
4)Results

Results for non-resonant HH searches



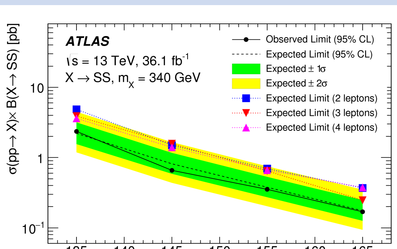
- No significant excess over the estimated backgrounds is observed in data.
- Analysis separated into 3 channels and further split into 9 categories.
- Combined observed (expected) limits on non-resonant HH cross section at 95% confidence level is 5.3 (3.8) pb, ~ 160 (120) X SM cross section.

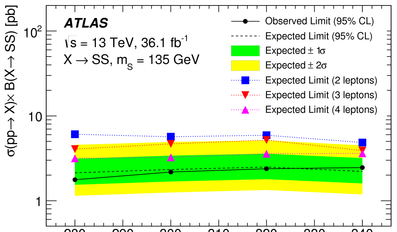
Results for resonant HH searches



Observed (expected) limits range from 8.5 (9.5) pb to 2.6 (2.5) pb.

Results for X→SS searches





Observed (expected) limits range from 2.4 (2.4) pb to 0.16 (0.17) pb.

Contect:xinshuiting@ihep.ac.cn