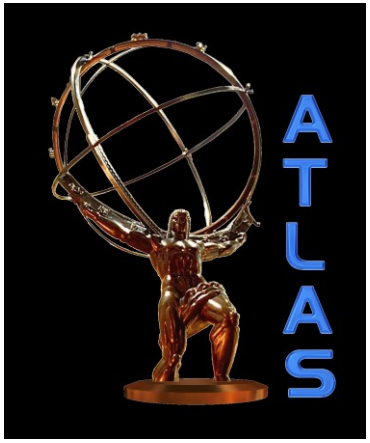
HH→WW*WW* Analysis with the ATLAS Detector



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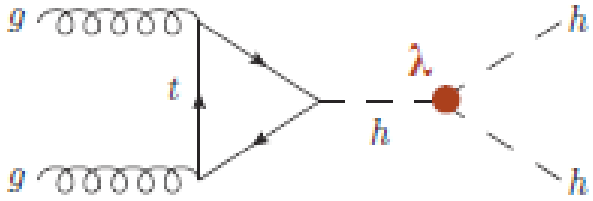
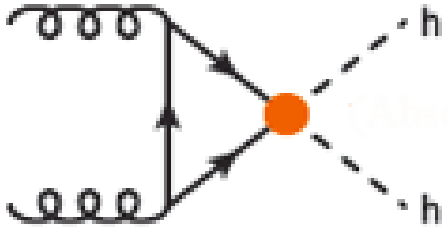
Outline

- Motivation
- Common Strategy
- Individual Analyses
- Systematics
- Results
- Summary & Outlook

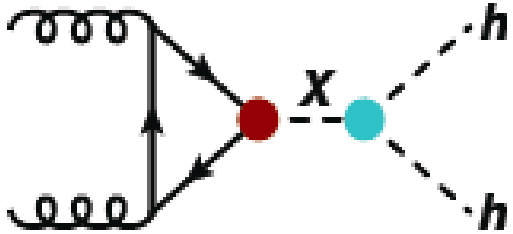
Standard Model



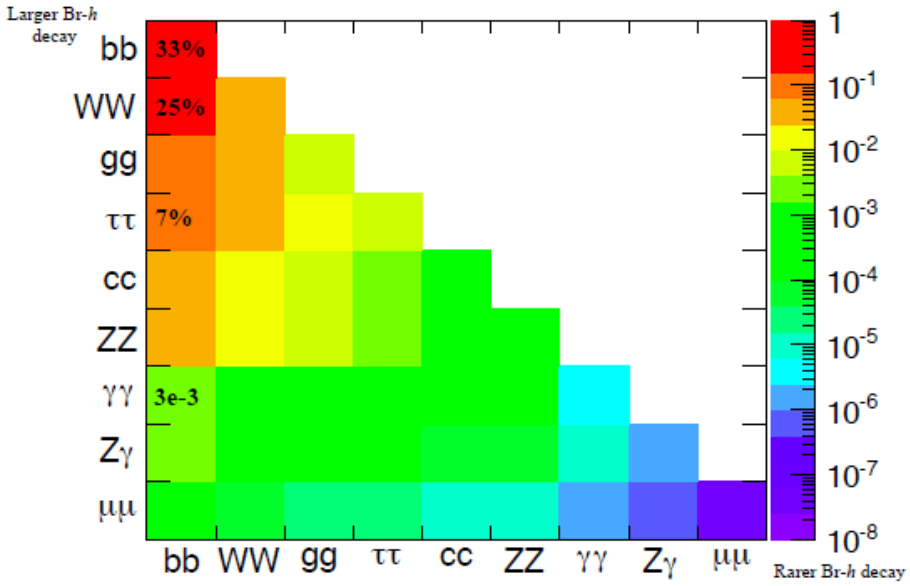
New Interaction

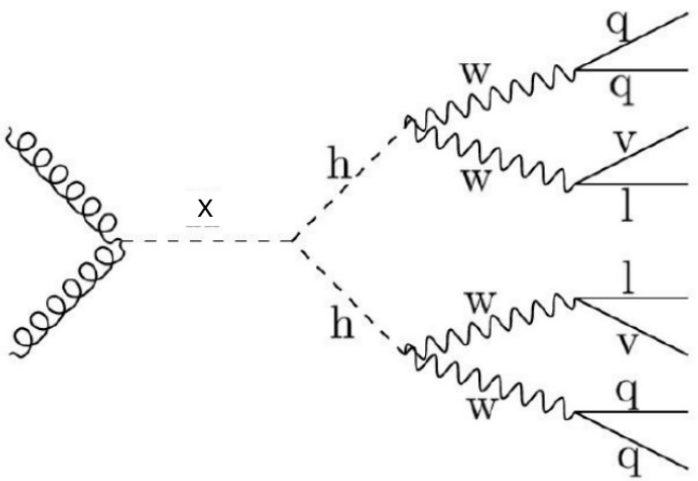


New Resonance



Motivation





SM $\sigma_{\text{Non-resonant HH}}$ = 33.41 fb @13 TeV

Pioneer additional decay channels in search of HH

Explore BSM Higgs-like model searches

- First di-higgs search with WW*WW* channel
  - Non-resonant and resonant di-higgs production search
  - m_X scan: 260-500 GeV
- First search for X→SS model, S decays only to SM particles
  - m_X scan: 280-340 GeV (270 GeV < m_X < $2m_t$, 4W dominates)
  - m_S scan: 135-165 GeV (135 GeV < m_S < $m_X/2$, on-shell decay)

Common Analysis Strategy

Relatively high decay branching ratio, however dominated by QCD backgrounds, use leptons to get cleaner signature

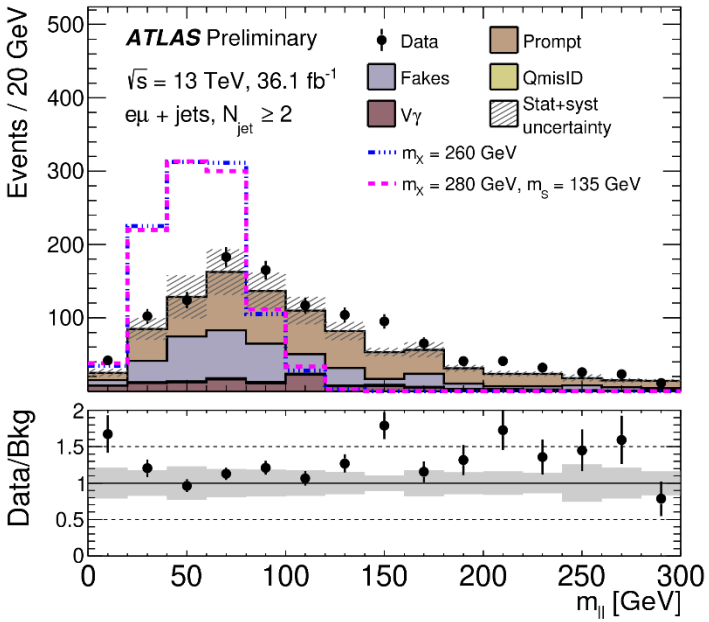
- 2015+2016 full data: 36 fb^{-1}
- Cut and count analysis
- Separated by three analysis channels defined by number of leptons
  - Two (same sign) leptons
    - ee, eμ, μμ, missing energy, at least two jets, b-jet veto
  - Three leptons
    - Total charge ±1, missing energy, at least two jets, b-jet veto
  - Four leptons
    - Total charge 0, b-jet veto
- Optimized selections based on $S/\sqrt{B}$ for each mass point
- b-jet veto to reject top quark backgrounds and stay orthogonal to most other decay channels
- Combined analysis with three individual channels

Two (Same Sign) Lepton Channel

Selection

- Two same sign leptons
  - Tight criteria, $p_{T1} > 30$GeV, $p_{T2} > 20$GeV
  - $E_T^{miss} > 10$ GeV
- Z mass veto, b-jet veto
- Three flavour channels
  - ee, eμ, μμ
- Two N_{jet} regions to improve sensitivity
  - $N_{jet} >= 2$ for $m_X < 300$ GeV
  - $N_{jet} >= 3$ for $m_X > 300$ GeV and non-resonant HH search
- Rank and select four variables for further optimization
  - Invariant masses of leptons, leptons and two nearest jets, all objects
  - Angular distance between lepton and nearest jet
  - Optimize $S/\sqrt{B}$ for each mass point and category by scanning selected variables with various cuts (TMVA CutsSA option): ~ 1:60 (non resonant search)

Two (Same Sign) Lepton Channel



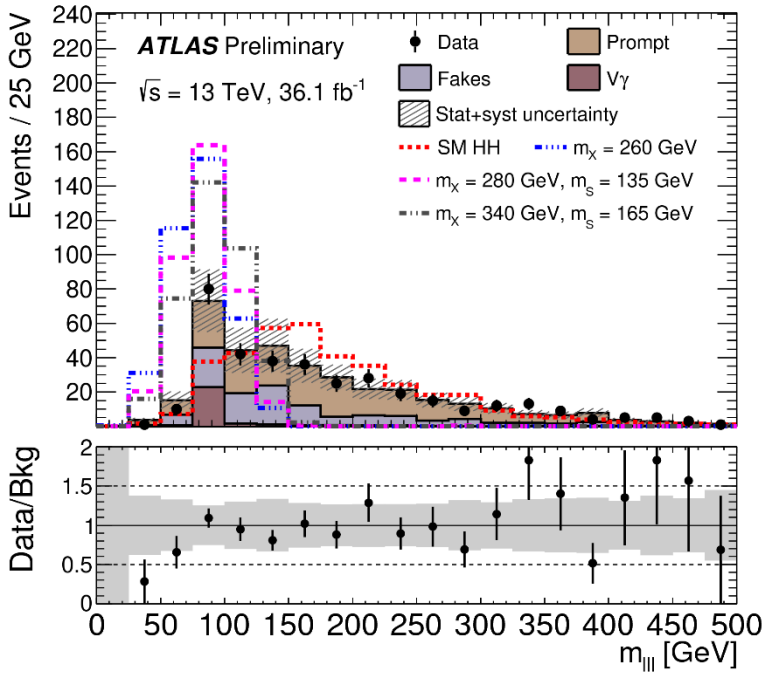
- **Backgrounds dominated by prompt lepton backgrounds and fake lepton backgrounds**
  - **Prompt lepton backgrounds: WZ, ZZ, tV, ttV/H and VVV**
  - **Fake lepton backgrounds: W+jets, tt, Vγ**
- **Background modeling**
  - **Prompt lepton and Vγ backgrounds modelled by MC**
  - **Fake lepton and charge mis-charge ID backgrounds modelled by data driven fake factor method**

Three Lepton Channel

Selection

- Three leptons
  - Tight criteria, total charge ±1, p_{T1} > 10GeV, $p_{T2,3}$ > 20GeV
  - Lepton 1 has opposite sign (OS), lepton 2 and 3 have same sign
  - E_T^{miss} > 30 GeV
- Z mass veto, b-jet veto
- Six flavour channels split into two categories
  - 0SFOS (same flavor opposite sign pair): e eμ, μ eμ
  - 1/2SFOS: eee, μμμ, e μμ, μ ee
- Rank and select four variables for further optimization
  - Invariant masses of three leptons, lepton and two nearest jets, all leptons and two leading jets
  - Angular distance between two leptons
  - Optimize S/√B for each mass point and category by scanning selected variables with various cuts (TMVA CutsSA option): ~1:50 (non resonant search)

Three Lepton Channel



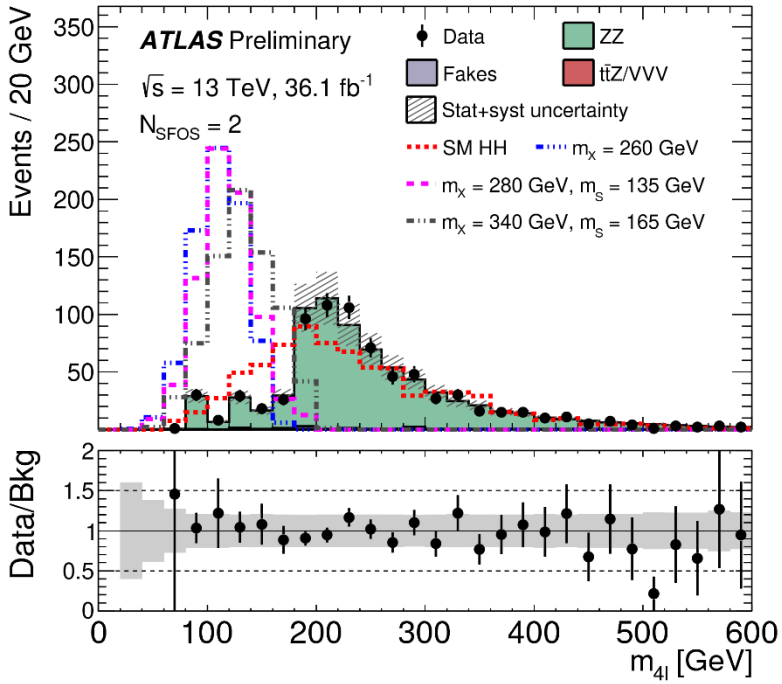
- **Backgrounds dominated by prompt lepton backgrounds and fake lepton backgrounds**
  - **Prompt lepton backgrounds: WZ, ZZ, tV, ttV/H and VVV**
  - **Fake lepton backgrounds: Z+jets, tt, Vγ**
- **Background modeling**
  - **Prompt lepton and Vγ backgrounds modelled by MC**
  - **Fake lepton backgrounds modelled by data driven fake factor method**

Four Lepton Channel

Selection

- Four leptons
  - Medium criteria, total charge 0, p_T > 10GeV
- b-jet veto
- Minimum dilepton mass to reject fakes
- Six flavour channels split into two categories
  - 0/1SFOS: eμ eμ, ee eμ, μμ eμ
  - 2SFOS: ee ee, μμ μμ, ee μμ
  - Best S/√B for 0/1SFOS channel: 1:150 (non resonant search)
  - 2SFOS dominated by ZZ backgrounds
- Two M_{4l} regions to improve sensitivity
  - M_{4l} < 180 GeV
  - M_{4l} > 180 GeV
  - Z mass veto, lepton pair angular separation veto

Four Lepton Channel



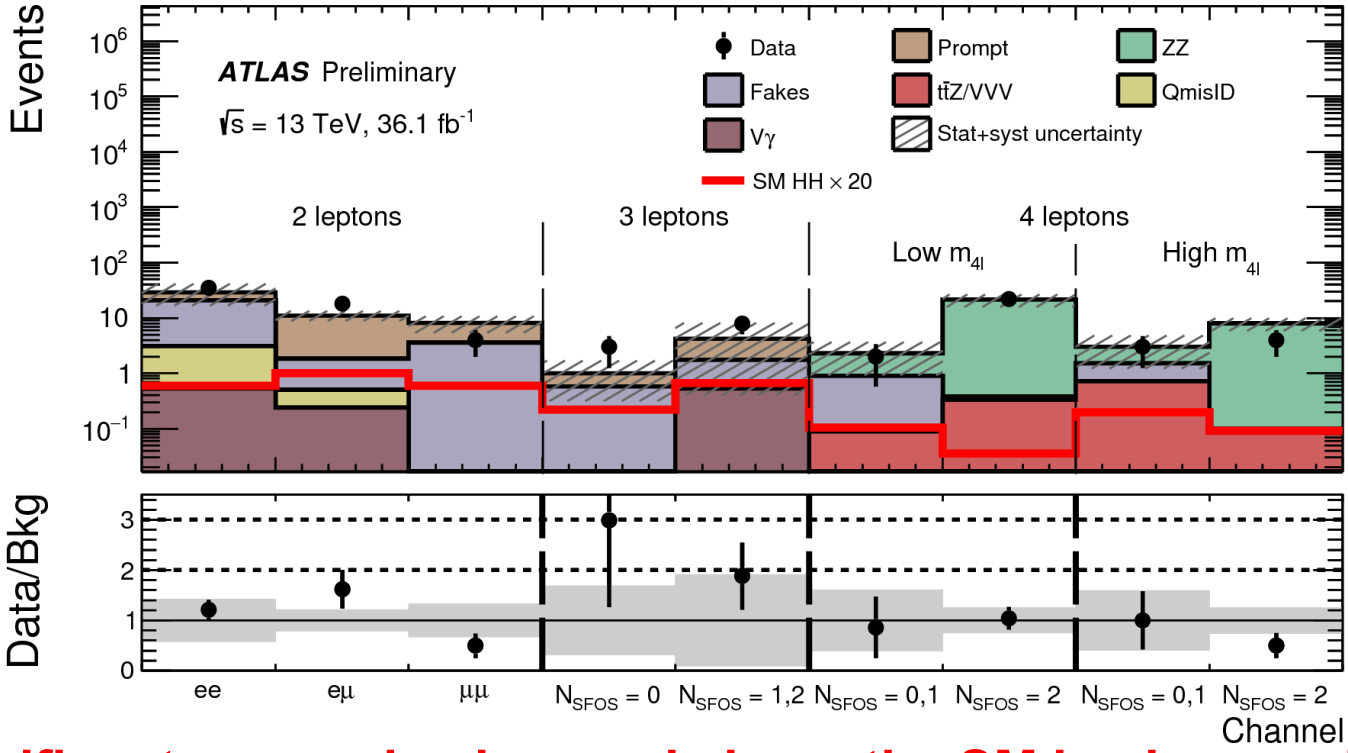
- **Backgrounds dominated by qq/gg→ZZ backgrounds and fake lepton backgrounds**
  - **Fake lepton backgrounds: WZ, Z+jets, tV, tt, ttW**
  - **More sensitive in low mass searches**
- **Background modeling**
  - **ZZ, ttZ, VVV backgrounds modelled by MC**
  - **All other backgrounds modelled by data driven fake factor method**

Systematics

Systematical uncertainties

- Dominating effects come from JER/JES and fake lepton background estimation
  - Background uncertainty includes prompt lepton, fake lepton, mischarge ID backgrounds estimation
- Theoretical uncertainty includes signal/backgrounds cross sections, PDF, QCD scale and parton shower modelling
- Other small uncertainties include lepton measurements, pile-up modelling, b-tagging, E_T^{miss} modelling
- Luminosity uncertainty
- Statistical uncertainty and systematical uncertainty have similar overall impacts
- Room for improvement, e.g. fake estimation

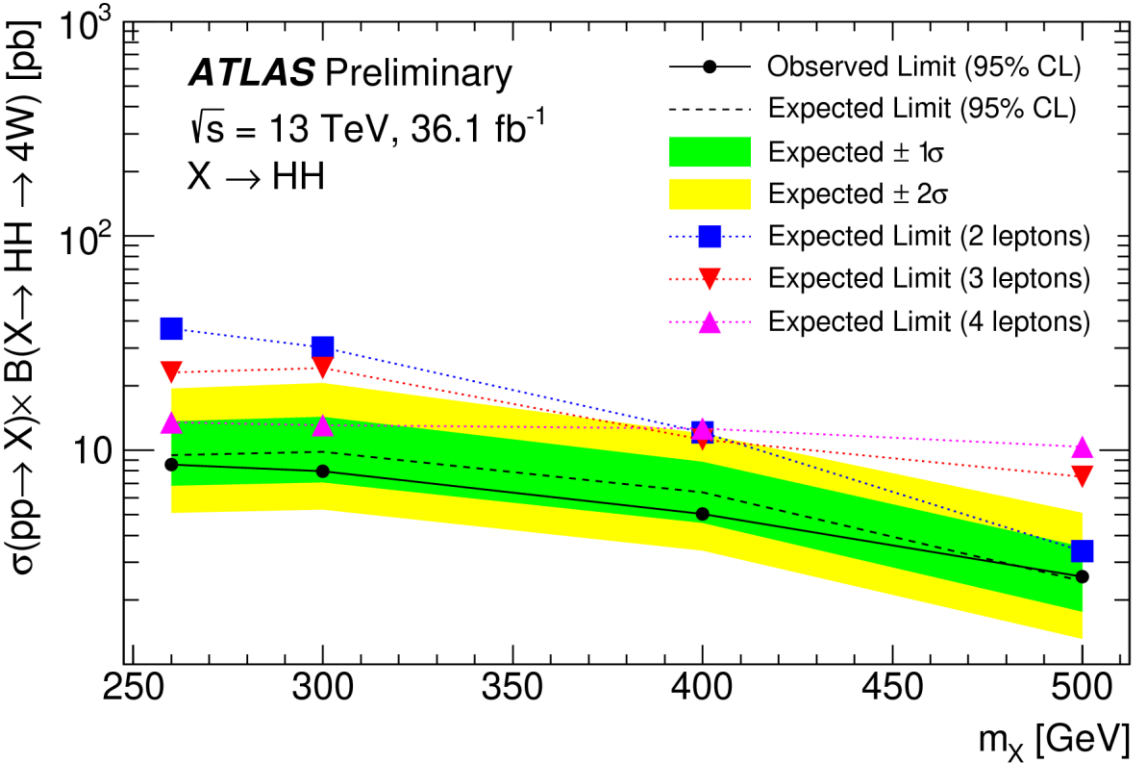
Results for non-resonant HH searches



No significant excess is observed above the SM background expectation

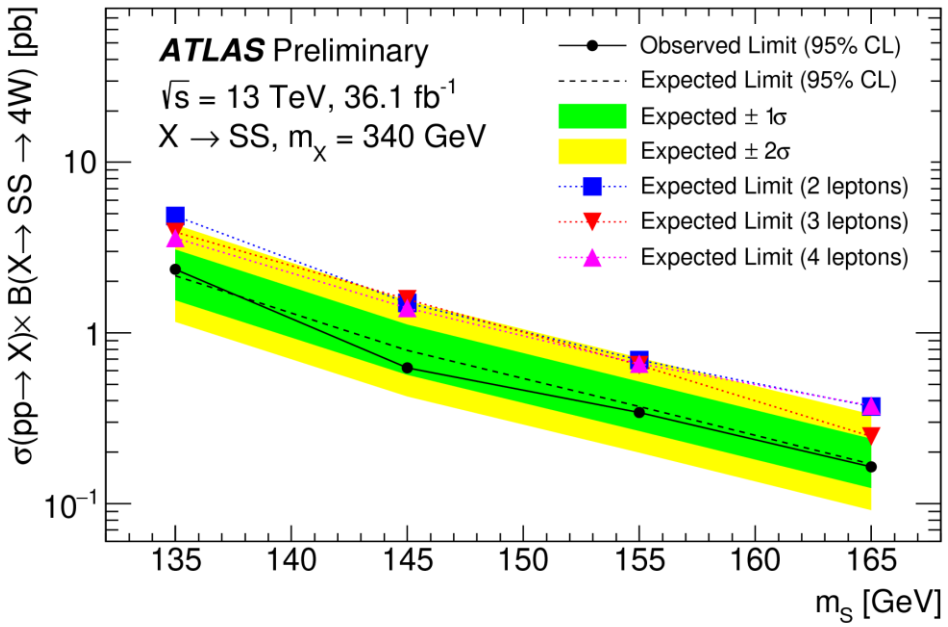
- **Analysis separated into 3 channels and further split into 9 categories**
- **Cut and count analysis for each category and calculate upper limit at 95% confidence level**
- **Combined observed (expected) limits on non-resonant HH cross section is 5.3 ($3.7\ ^{+1.6}_{-1.0}$) pb, ~ 160 ($110\ ^{+50}_{-31}$) X SM cross section.**

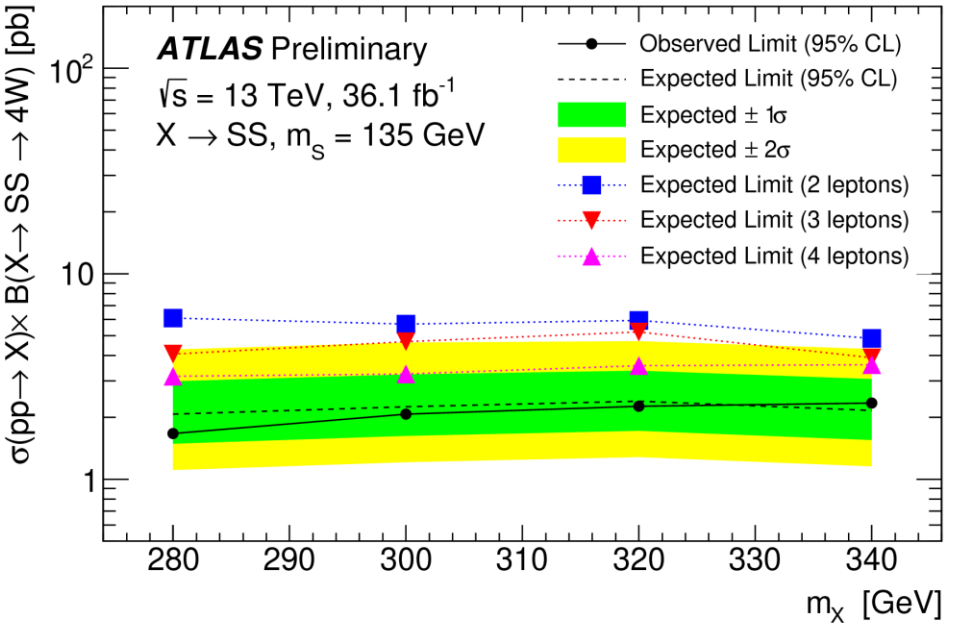
Results for Resonant HH searches



- **Set upper limits on resonant HH production cross section times branching ratio of 4W final state**
  - **Observed (expected) limits range from 8.5 (9.5) pb to 2.6 (2.5) pb**
  - **Best limit set for m_X = 500 GeV**

Results for X→ SS searches





- **Set upper limits on X→ SS production cross section times branching ratio of 4W final state**
  - **Observed (expected) limits range from 2.4 (2.4) pb to 0.16 (0.17) pb**
  - **Best limit set for m_X = 340 GeV and m_S = 165 GeV**

Summary and Outlook

First di-higgs production search done in WW*WW* channel

- No significant excess is observed above the backgrounds
- SM non-resonant HH and BSM resonant HH searches performed
  - Non-resonant HH: ~160 ($110\ ^{+50}_{-31}$) X SM cross section
  - Resonant HH: 8.5 (9.5) pb to 2.6 (2.5) pb
- Also first X→SS model search: 2.4 (2.4) pb to 0.16 (0.17) pb
- Set upper limits on non-resonant HH cross section, and also production cross section times branching ratio of 4W final state for resonant HH and X→SS searches

2015+2016 full data with 36 fb^{-1} analyzed

- Expect to include full Run2 data in the future

Possible improvements

- (Boosted) one lepton channel interesting: manpower needed
- Re-optimize analysis using MVA method, add more variables/selections to suppress/discriminate backgrounds
- Consider low mass region $m_X < 280$ and $m_s > m_X/2$ (off shell decays)