BSM Higgs II

ATLAS Results and Experimental Considerations

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on behalf of the ATLAS experiment

October 1, 2014

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Topics

1. Searches for Resonant (Di-)Higgs Production
   - $H \to hh \to \gamma\gamma bb$
   - $G^* \to hh \to bbbb$
   - High Mass $h \to \gamma\gamma$
2. Extended Higgs Sector
   - Cascading Higgs Decay:
     $H^0 \to W^{\pm}H^{\mp} \to W^{\pm}W^{\mp}h \to \ell\nu qqbb$
3. Re-interpretation of SM Results
   - Using SM coupling measurements
4. Common Experimental Issues

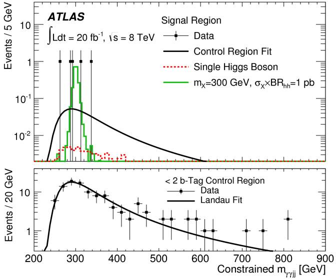
Dataset

- All analyses use 20 fb^{-1} of pp data collected in 2012, with $\sqrt{s} = 8\,TeV$
- The SM interpretation result includes 5 fb^{-1} of pp data collected in 2011, with $\sqrt{s} = 7\,TeV$

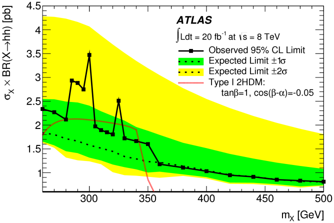
$H \to hh \to \gamma\gamma bb$

http://arxiv.org/abs/1406.5053

- Overview
  - Signal region with 2 photons and 2 b-tagged jets, using $m_{\gamma\gamma}$ and m_{bb} to reduce background
  - Control region with 2 photons and $<$ 2 b-tagged jets
  - Uses unprescaled di-photon trigger
  - Search for resonant and non-resonant *hh* production
  - Results presented as model independent limits
  - Type I 2HDM benchmark point used for illustration



- Statistical Method
  - Unbinned data is fit to bkg. and sig. models
  - Very few selected events in signal region
  - Control region used to derive background model



- Uncertainties: **O(50%) statistical uncertainty**

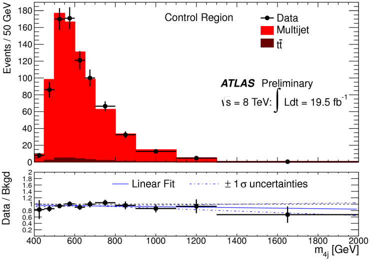
Non-Higgs Background: O(30%) from modeling
SM Higgs Background: O(20%) from Jet ES/ER
SM Higgs Background: O(15%) SM Higgs theory

- **Non-resonant** ***hh*****:** Assuming SM BRs, exp. (obs.) limit of $1.0^{+0.6}_{-0.3}$ pb (2.2 pb)
- **Resonant** $H \to hh$**:** The observed exclusion ranges from 0.8 pb to 3.5 pb, @ 95% CL, and is weaker than expected below 350 GeV

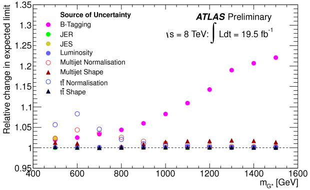
$G^* \to hh \to bbbb$

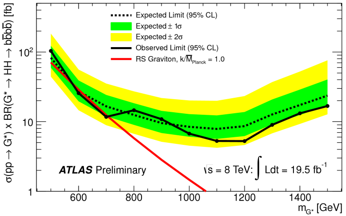
ATLAS-CONF-2014-005

- Overview
  - Signal region with 4 b-tagged jets and requiring two di-jet masses are compatible with the *hh* hypothesis
  - Uses 3 b-jet triggers (+ 2 high-thresh. jet triggers for large m_{G^*})
  - Dominated by multi-jet backgrounds
  - Results interpreted as limit on the production of a KK excitation of the Graviton (G^*)



- Statistical Method
  - Cut and count analysis, with backgrounds constrained by control regions





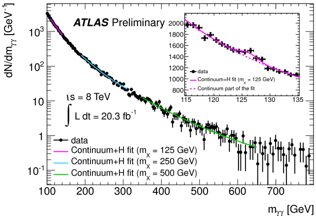
(SM BRs for Higgs decays are Assumed)

- The benchmark model is excluded for G^* masses between 590 and 710 GeV, @ 95% CL

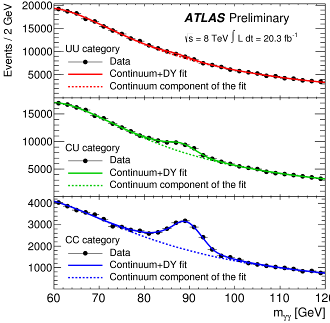
High Mass $h \to \gamma\gamma$

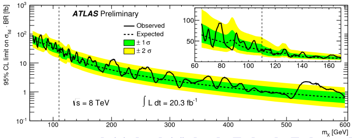
ATLAS-CONF-2014-031

- Overview
  - Separate low and high mass analysis
  - Signal regions with 2 tight photons
  - Uses unprescaled di-photon trigger
  - Results presented as model independent limits
- Statistical Method
  - Fit to background and signal models
  - **Double-sided** Crystal Ball used for H (and Z)
- Uncertainties
  - Signal bias from modeling $<$ 20% of stat. uncert.
  - O(10-40%) of signal yield from γ ER
  - O(10%) Higgs theory
- High Mass Analysis
  - Fit in several $\Delta m_{\gamma\gamma}$ pieces



- Low Mass Analysis
  - Z and SM Higgs (125 GeV) taken as background
  - Split by converted (C) or unconverted (U) γ
  - Best S/B in UU, while most Z background in CC



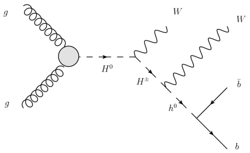


- No observed excess from 65-600 GeV

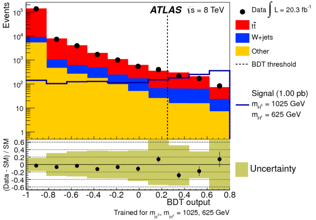
$H^0 \to W^\pm H^\mp \to W^\pm W^\mp h \to \ell\nu qqbb$

Phys. Rev. D 89, 032002 (2014)

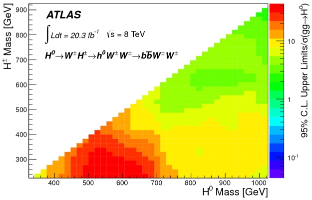
- Overview
  - Signal region with ≥ 4 jets (2-btagged), $\not{E}_T$ and 1 lepton
  - Uses unprescaled single-lepton trigger
  - MVA used to distinguish signal from $t\bar{t}$
  - Results interpreted as limit on gg production cross section relative to SM production



- Statistical Method
  - Cut and count based on BDT discriminant
- Uncertainties
  - O(15%) b-tagging
  - O(10%) Jet ES and ER



BDT Output



Observed Limits

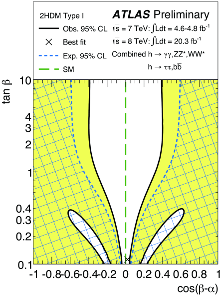
- No excess above SM expectation observed
- Limits range from 0.065 to 43 pb, @ 95% CL, based on H^0 and $H^\pm$ masses

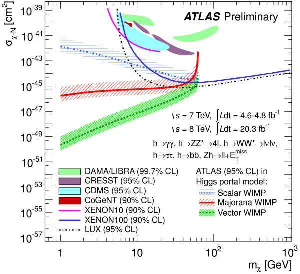
Reinterpretation of SM Results

ATLAS-CONF-2014-010

- Overview
  - Used SM results from: $h \to \gamma\gamma$, $h \to ZZ$, $h \to WW$, $h \to \tau\tau$, $h \to bb$ and $Zh \to ll + \not{E}_T$
  - Triggers vary between input analyses
  - Results interpreted 2HDM, MSSM (not covered in this talk) and Higgs, as a portal to dark matter
  - WIMP production from $h \to$inv, with BR($h \to$inv.) from SM results and un-measured couplings taken from SM predictions

- Statistical Method
  - A likelihood is constructed from the results of the SM analyses
- Uncertainties
  - Systematics and their correlations modeled by introducing nuisance parameters





- A large portion of the Type I 2HDM is excluded @ 95% CL (left)
- Strong limits are set on the WIMP production x-sec for each of 3 propagators (right)

Common Experimental Issues

Triggers

- Extensive use of multi-object triggers in Run I Analyses
- Planned Run II upgrades (e.g. topological triggers at L1) vital for BSM Higgs physics

Systematic Uncertainties

- Largest experimental uncerts. tend to be related to jets in the MC backgrounds: b-tagging, ES and ER
- Following those, SM Higgs theory uncerts.

Statistical Methods

- Analyses with resonances benefit from using background and signal models
  - Even in the case of low statistics, where binned and un-binned are comparable
  - Modeling removes many dominant MC based systematic uncerts.
- For analyses with low statistics, can be conservative in modeling uncerts., without impacting performance
- With larger statistics (e.g. in Run II) the understanding of background models will have to be much more precise

Concluding Thoughts

- We have had a very successful BSM physics program in Run I
  - And we have several more analyses begin finalized at ATLAS
- It is time to look ahead to
  - The potential for more statistical combinations with CMS
  - Preparations for Run II data taking and analysis
- It is vital to work to better understand our experimental uncertainties and to see what ATLAS and CMS can learn from each other as we prepare for Run II of the LHC

Backup Slides

bbbb Triggers

- EF_b45_medium_4j45_a4tchad_L2FS: A trigger requiring at least four jets with p_T greater than 45 GeV, at least one of which is b-tagged online. The online b-tagging used has an efficiency to tag b-jets of 50%, evaluated in an MC sample of $t\bar{t}$ events.
- EF_2b35_loose_j145_j35_a4tchad: A trigger requiring at least two online b-tagged jets with p_T greater than 35 GeV, and at least one jet with p_T greater than 145 GeV that may or may not be one of the two b-tagged jets. The online b-tagging used has an efficiency to tag b-jets of 60%, evaluated in an MC sample of $t\bar{t}$ events.
- EF_b45_medium_j145_j45_a4tchad_ht500: A trigger requiring at least one jet with p_T greater than 145 GeV, at least one jet with p_T greater than 45 GeV, one of which is b-tagged online. In addition to this, the trigger also requires the scalar sum of the p_T of all jets in the event with $p_T > 30$ GeV and $|\eta| < 2.5$ to be greater than 500 GeV. The online b-tagging used has an efficiency to tag b-jets of 50%, evaluated in an MC sample of $t\bar{t}$ events.
- EF_j360_a4tchad: A trigger requiring at least one jet with p_T greater than 360 GeV.
- EF_4j80_a4tchad_L2FS: A trigger requiring at least 4 jets with p_T greater than 80 GeV.

The Double Sided Crystal Ball

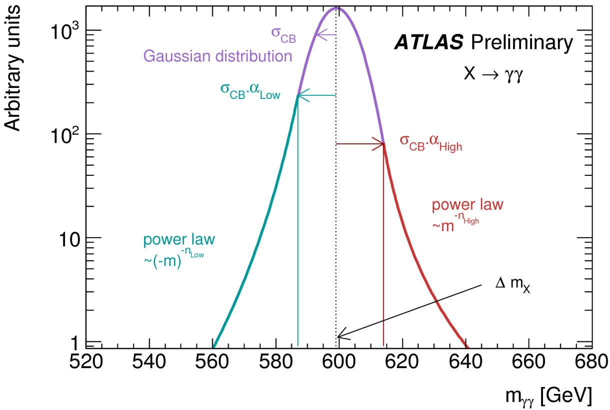


Figure: Description of the double-sided Crystal Ball function parameters: $\Delta m_X = m_X - \mu_{CB}$, where μ_{CB} is the peak of the Gaussian distribution, σ_{CB} represents the width of the Gaussian part of the function, α_{Low} (α_{High}) is the point where the Gaussian becomes a power law on the low (high) mass side, n_{Low} (n_{High}) is the exponent of this power law. (ATLAS-CONF-2014-031)