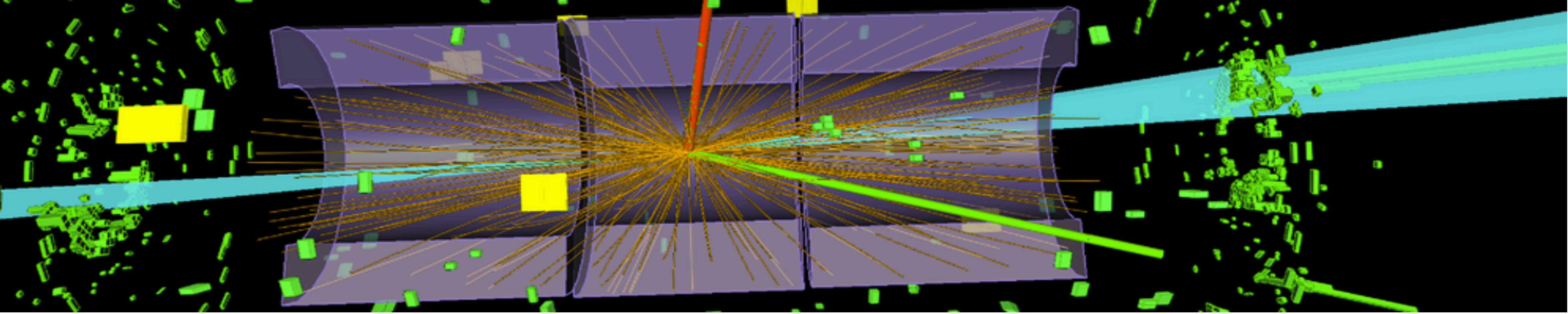

Searches for non-Standard Model decays to two light bosons of the Higgs boson

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On behalf of the ATLAS Collaboration

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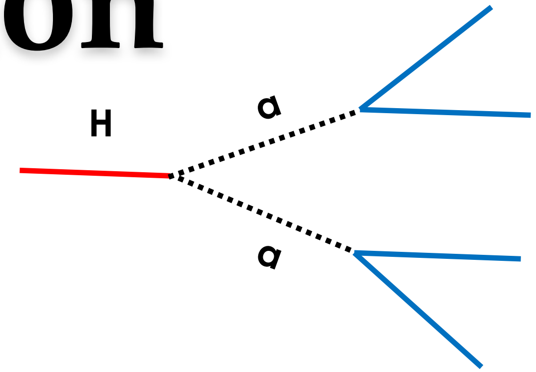
Introduction



- **Exotic Higgs boson decays are a powerful probe for BSM physics**
- **Very narrow Higgs decay width → sensitivity to small couplings to non-SM particles**
- **Current measurements at the LHC constrain non-SM BR of the Higgs boson to less than 30% at 95% CL**
  - Ample room for exotic Higgs boson decays compatible with observations to date
  - Motivation for direct searches for non-SM Higgs decays

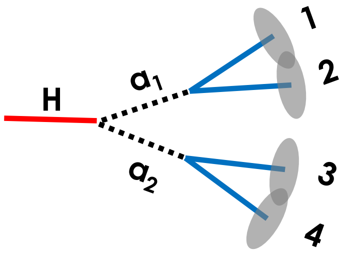
Four different topologies for the decay of the Higgs boson to a pair of spin-zero particles ***a*** or spin-1 $\boldsymbol{Z_d}$ decaying into a pair of SM particles:

$(bb)(bb)$ arXiv:1806.07355
$(bb)(\mu\mu)$ arXiv:1807.00539
$(ll)(ll)$: $4e, 4\mu, 2e2\mu$ arXiv:1802.03388
$(\gamma\gamma)(gg)$ arXiv:1803.11145

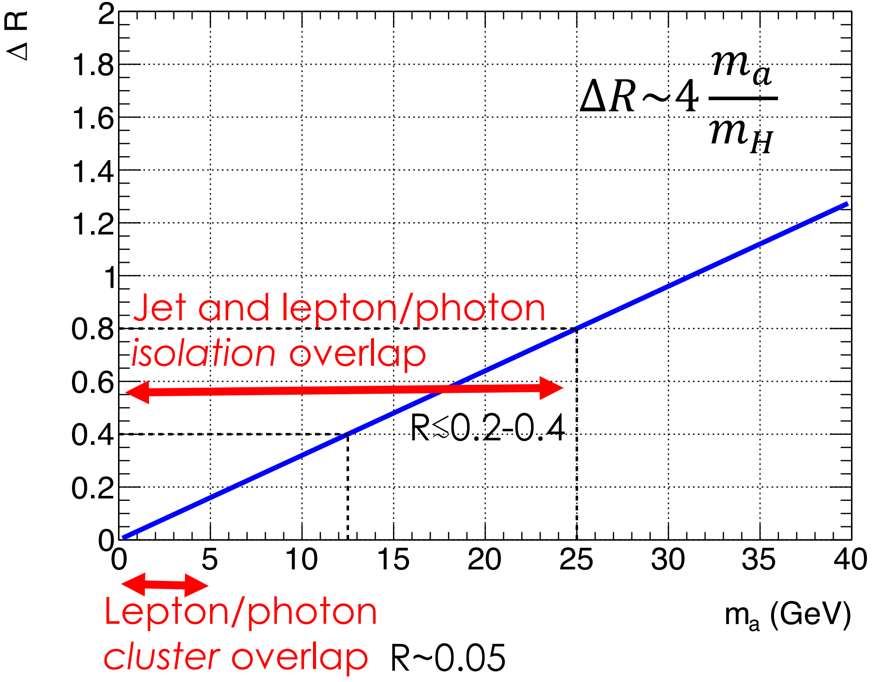
2015-2016 dataset at $\sqrt{s} = 13\ TeV$,
integrated luminosity = 36.1 fb^{-1}

Experimental handles and challenges

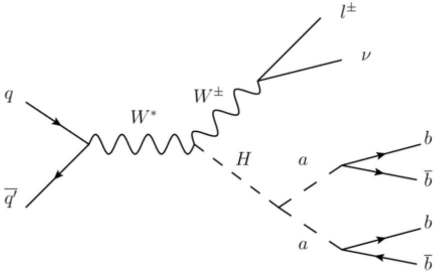
- **Mass constraints:**
  - $m_{12} = m_{34}$
  - $m_{1234} = m_H$

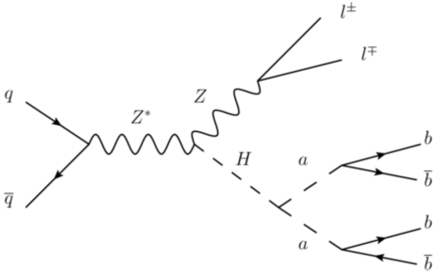


- a-boson decay products are soft
  - Often below reconstruction threshold
- For light a-bosons decays, the Lorentz boost can be large enough to lead to **opening angles smaller than the angular size of physics objects**
  - Limit discovery reach at low a-boson mass in current analyses
  - Need new reconstruction techniques using lepton/jet substructure to enhance sensitivity to low a-boson mass particles

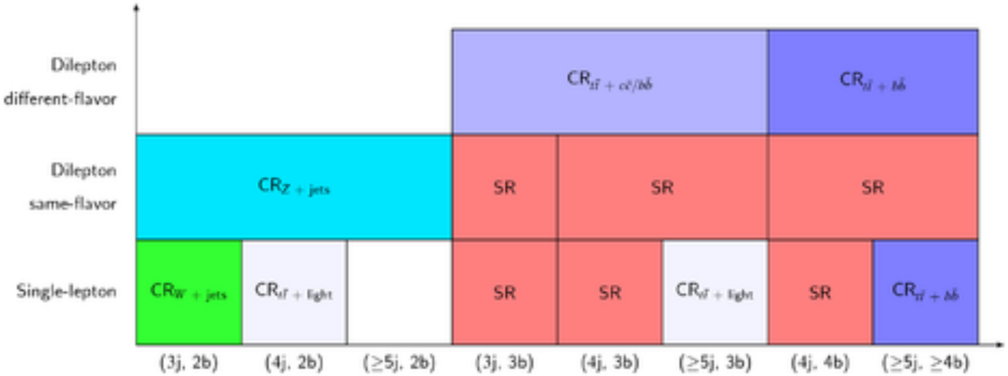


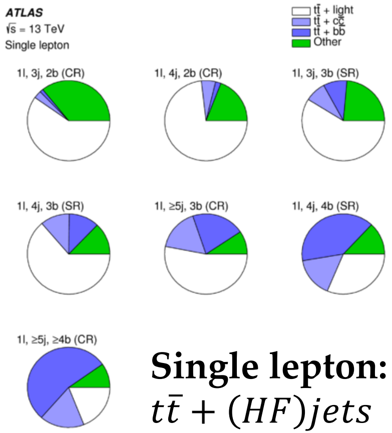
$H \to aa \to 4b$



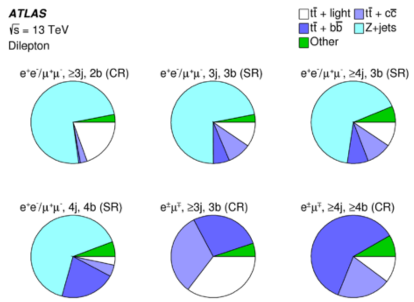


- Higgs boson produced in association with a *W* or a *Z* boson
- a-boson decays into b-quarks promptly or with $c\tau_a$ up to 6mm





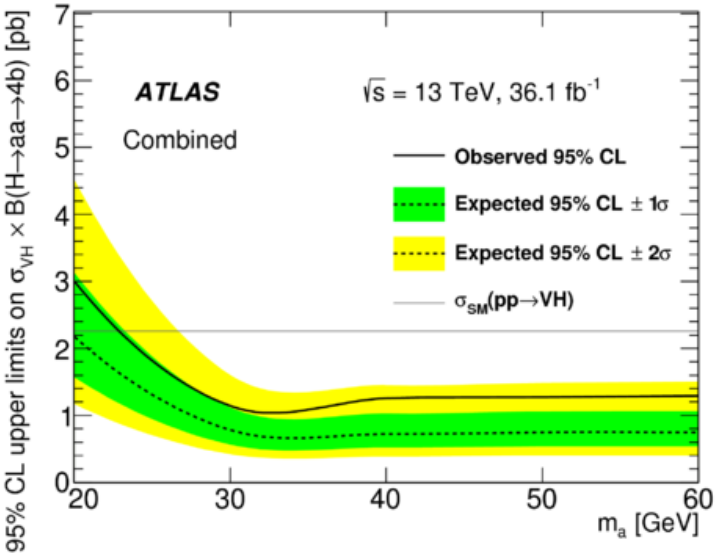
Single lepton:
$t\bar{t} + (HF)jets$

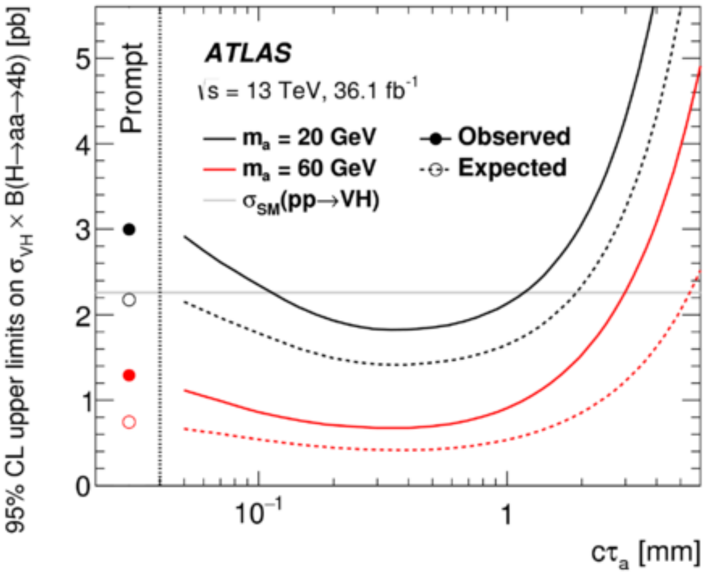


Dilepton:
$Z + (HF)jets$

- Events categorized according to n_l, n_j, n_b
- Signal regions: $\geq 3j, \geq 3b$
- Control regions populated by two main background processes

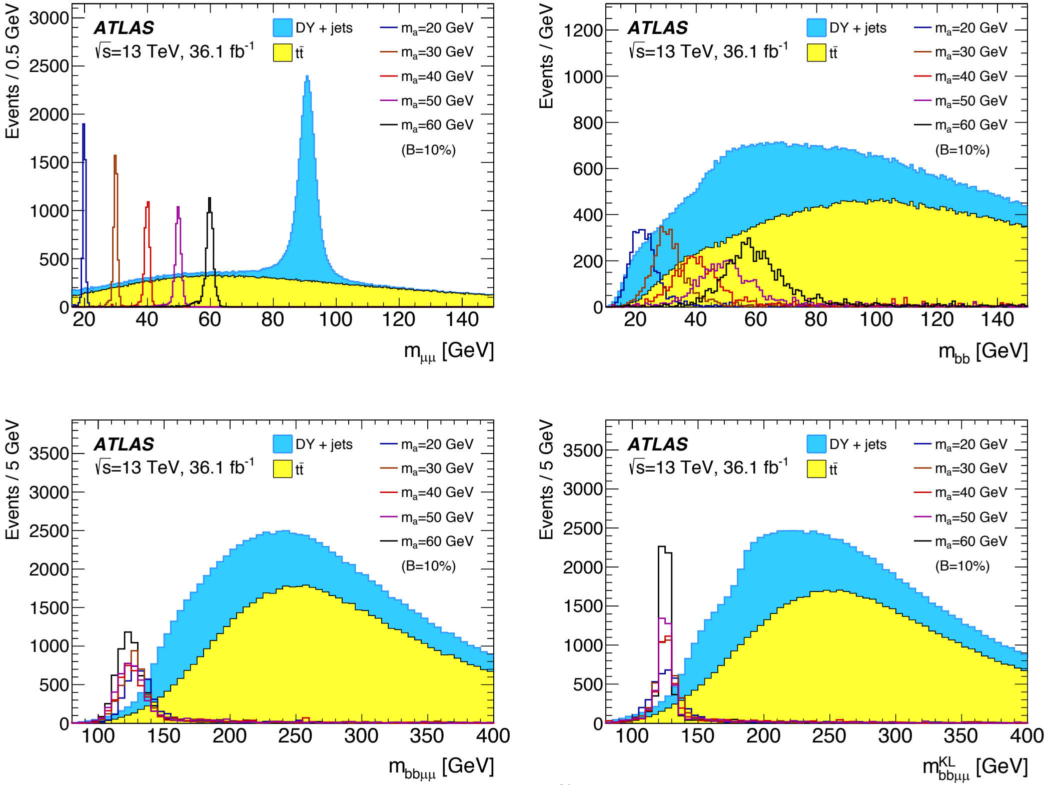
$H \rightarrow aa \rightarrow 4b$





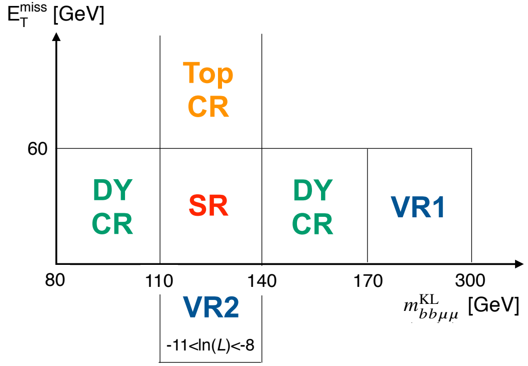
- BTDs trained in each SR and for three a-boson masses (20-30-50 GeV)
- b-jet pairs chosen to minimize $m_{bb1} - m_{bb2}$
- Profile likelihood fit across all SR and CR. Normalization of backgrounds are allowed to float
- Dominant uncertainties: heavy flavour tagging, background and signal modeling
- Combined observed upper limits for prompt decays: 3.0pb - 1.3pb
- Best limits for a-bosons with $c\tau_a$~0.4mm: 1.8pb - 0.68pb

$H \to aa \to bb\mu\mu$

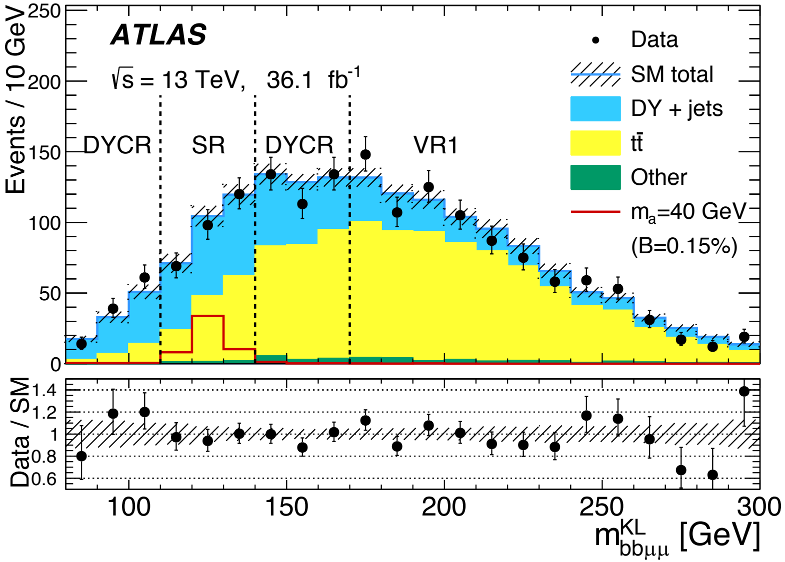


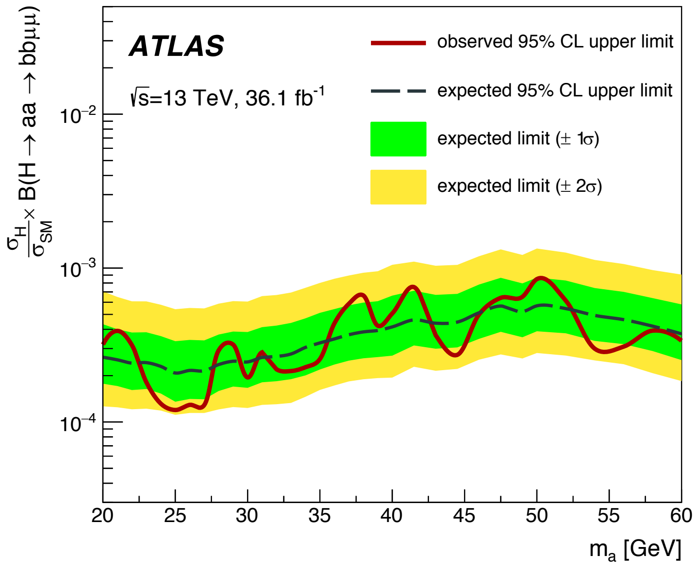
KL fit

- Dimuon signature
  - triggering and mass reconstruction
  - models with enhanced lepton couplings
- $m_{\mu\mu}$ invariant mass resolution is 10x better than m_{bb} → use a kinematic fit exploiting the symmetry of $H \to aa$ decays:
  - 2x improvement in $m_{bb\mu\mu}$ resolution
  - Require $|m_{bb\mu\mu} - m_H| < 15\ GeV$



$H \to aa \to bb\mu\mu$





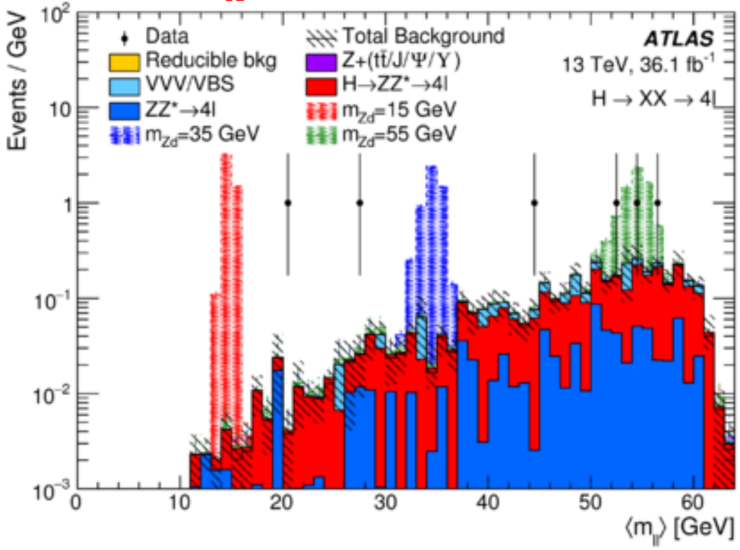
- Top background, modeled using simulation, and Drell-Yan, estimated from 0-tag data templates are normalized in a profile likelihood fit to the data over the control and signal regions
- Dominant uncertainties: jet energy scale and resolution, signal and background modeling, and DY template
- Upper limits on $\left(\frac{\sigma_H}{\sigma_{SM}}\right) xB(H \to aa \to bb\mu\mu)$ range between 10^{-4} and 10^{-3}

4 lepton final states

- Benchmark models:
  - Dark sector $U(1)_d$ → BSM vector boson Z_d: $\boldsymbol{H \to Z_d Z_d \to 4l}$
  - Two Higgs doublet model extended by one complex scalar singlet field (2HDM+S) → BSM pseudoscalar boson a: $\boldsymbol{H \to aa \to 4\mu}$

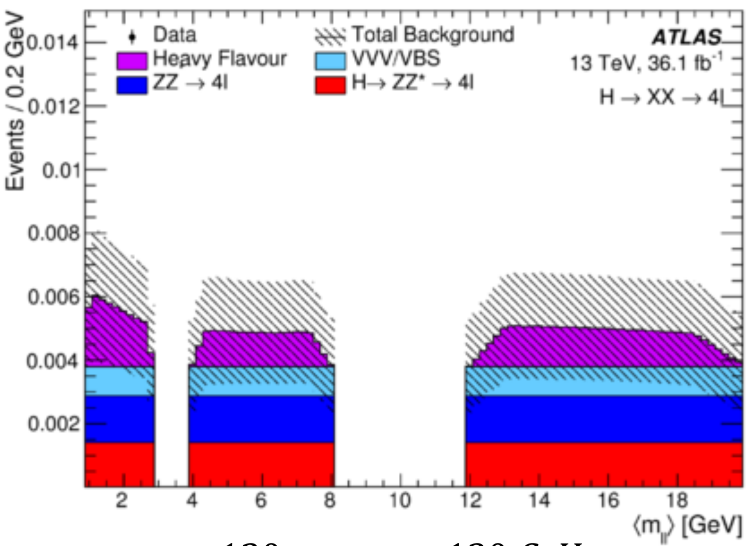
$$\delta m = |m_{12} - m_{34}|$$
$$\left(m_{34}/m_{12}\right) > 0.85$$

$15 < m_X < 60\ GeV$



$115 < m_{4l} < 130\ GeV$

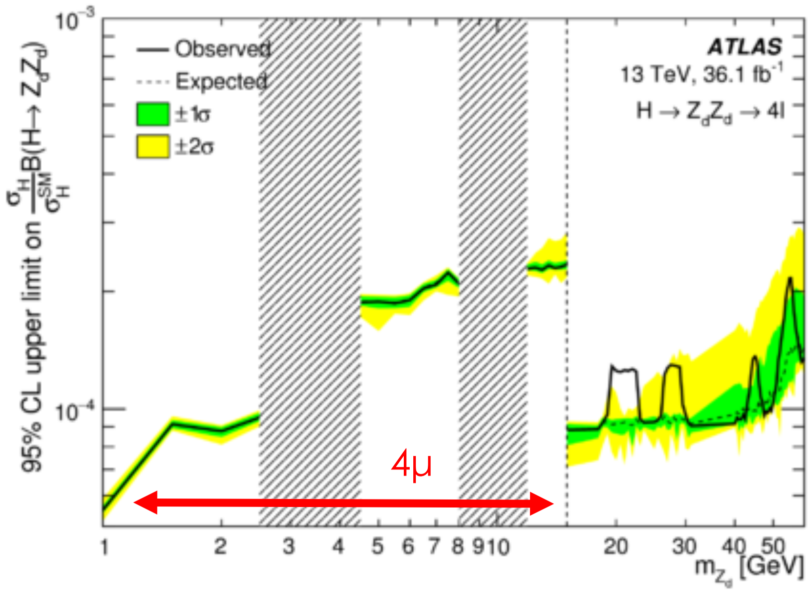
$1 < m_X < 15\ GeV \quad (X \to \mu\mu)$



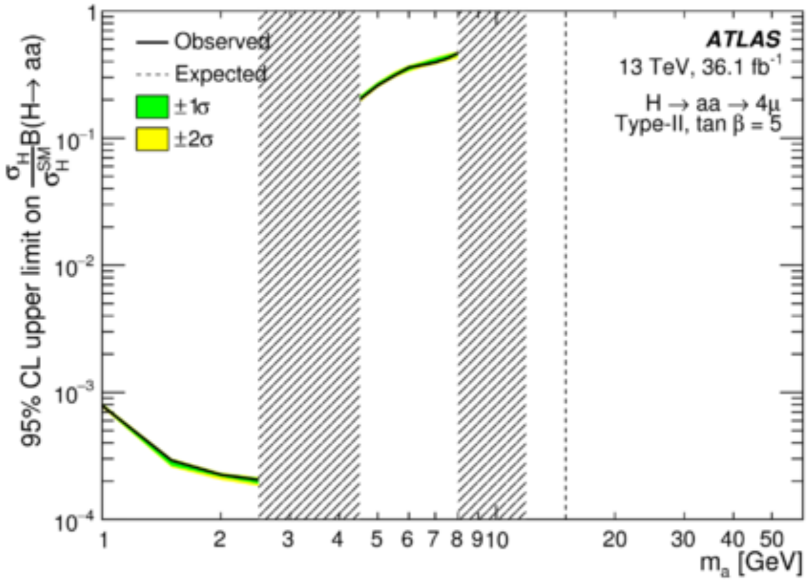
$120 < m_{4\mu} < 130\ GeV$

4 lepton final states

$H \rightarrow Z_d Z_d \rightarrow 4l$



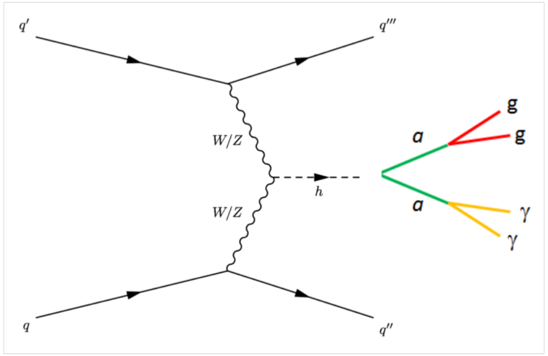
$H \rightarrow aa \rightarrow 4\mu$



- Dominant systematic uncertainties arise from lepton reconstruction and identification, MC background and signal modeling
- Low mass region suffer from heavy flavour backgrounds (double semileptonic decays)

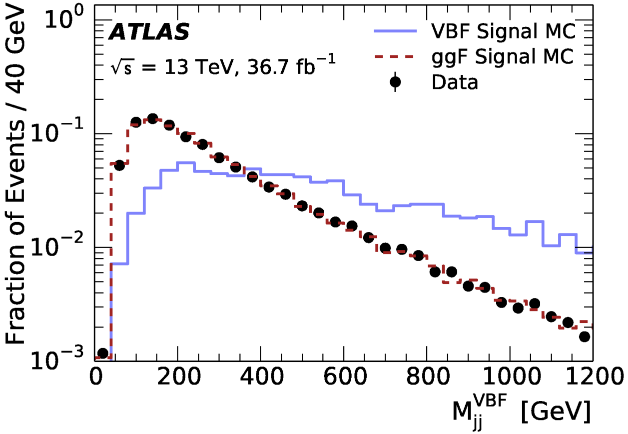
$VBF\ H \to aa \to \gamma\gamma gg$

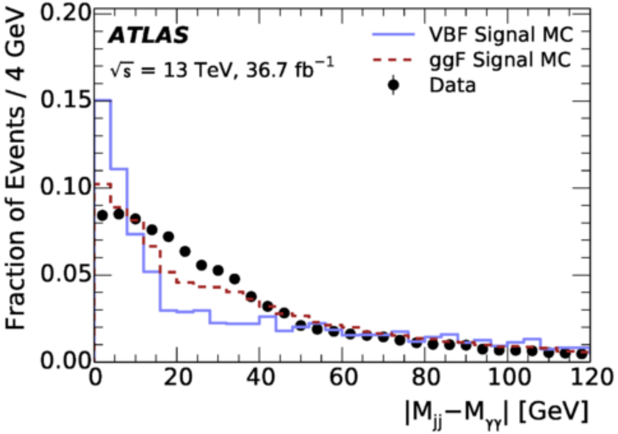
- Final state relevant in models where the **fermionic decays are suppressed** → the a-boson only decays to photons or gluons
- **VBF production mode** has higher cross section than VH and provides experimental handles to suppress backgrounds

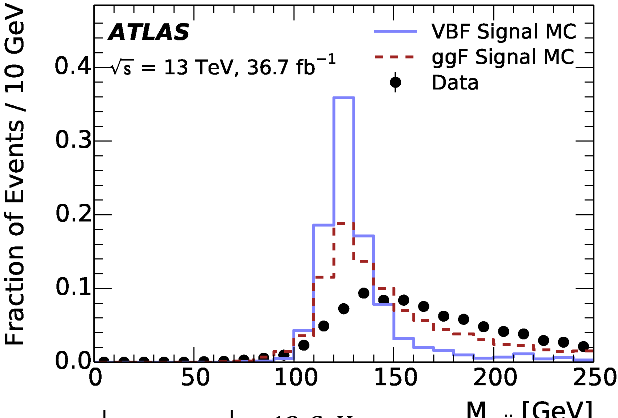


Di-photon trigger
4 or more jets
VBF jet selection:
- m_{jj}^{VBF}>500 GeV
- Leading p_T > 60 GeV

$$100 < m_{\gamma\gamma jj} < 150\ GeV$$
$$|m_{jj} - m_{\gamma\gamma}| < 12 - 24GeV$$



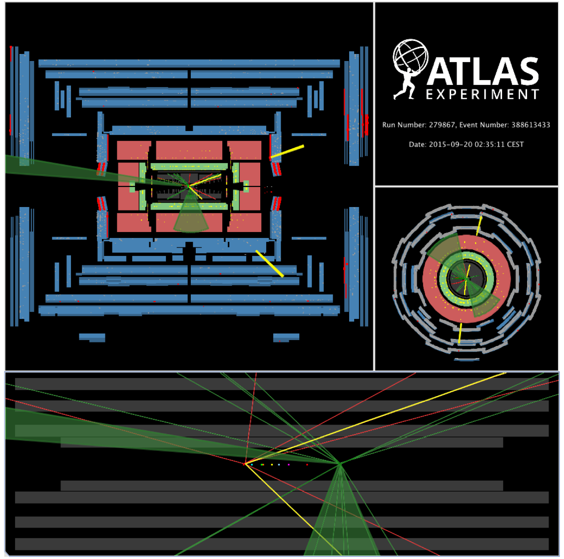


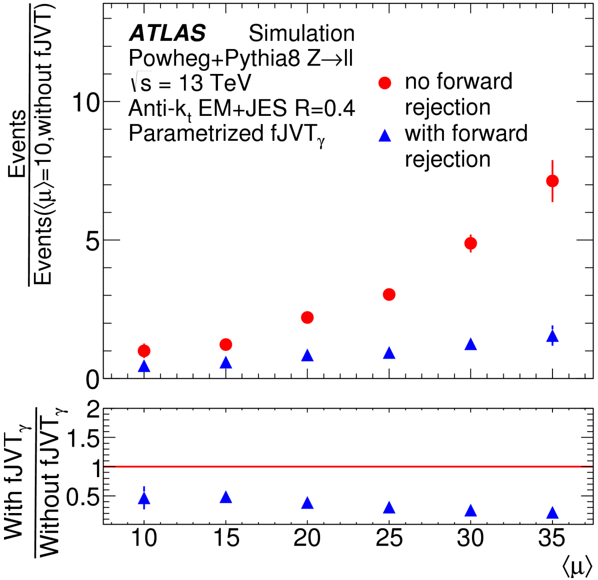


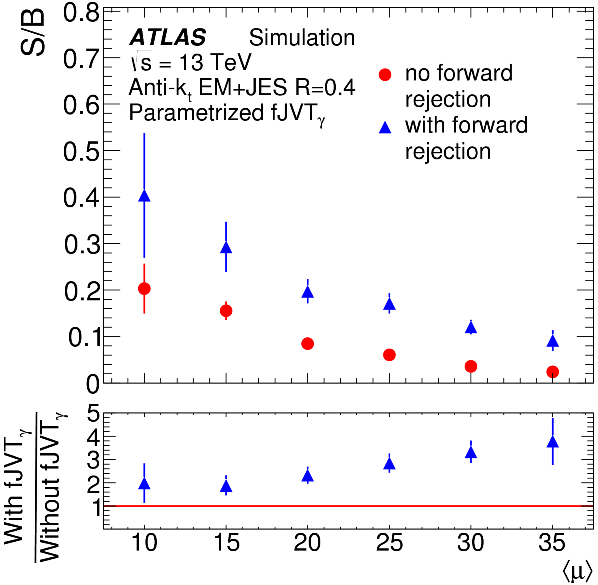
$|m_{jj} - m_{\gamma\gamma}| < 12\ GeV$

Forward pileup jet tagging

Use tracks in the central region to indirectly tag forward pileup jets ($|\eta| > 2.5$) exploiting angular correlations of QCD jets produced in pileup interactions

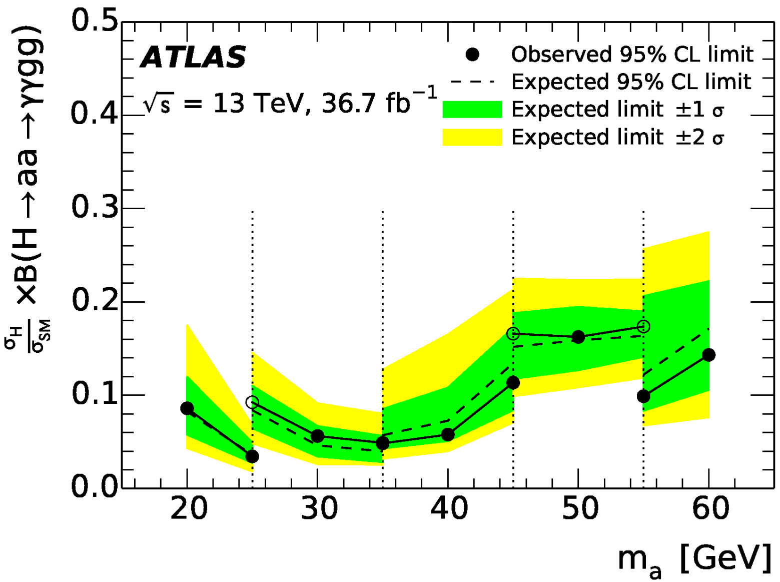


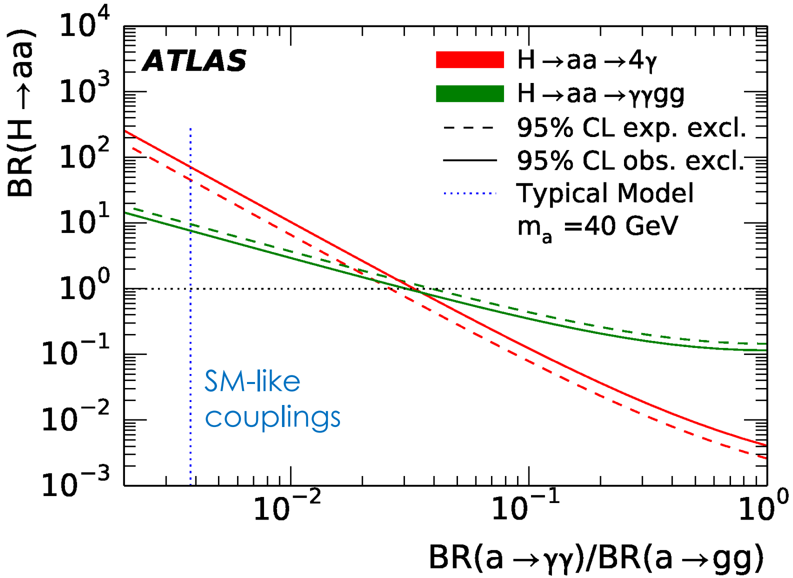




Broad impact on VBF physics analyses at ATLAS: factor of 4 improvement in signal purity for $VBF\ Z \rightarrow \tau\tau$ in the leptonic channel

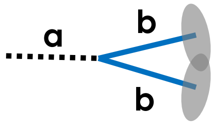
$VBF\ H \rightarrow aa \rightarrow \gamma\gamma gg$

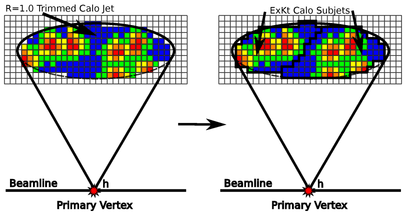




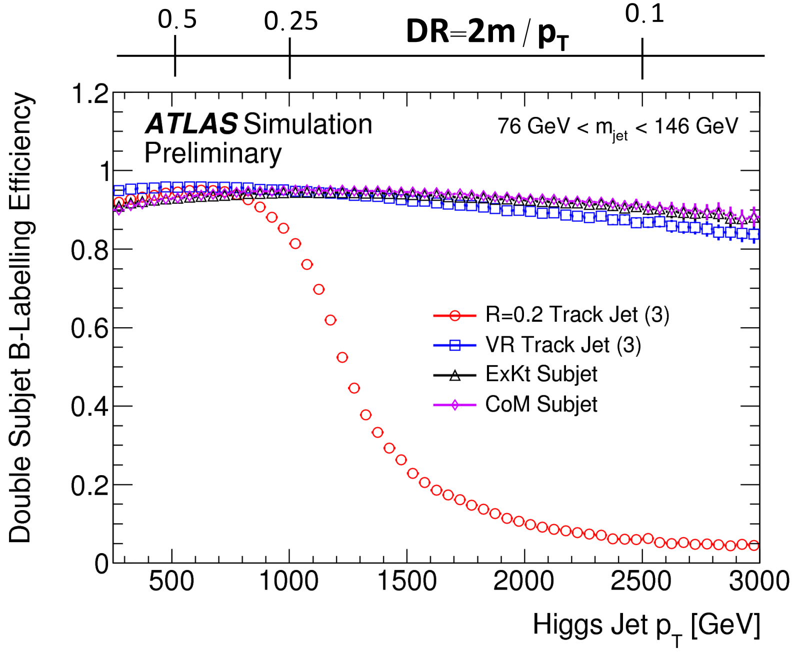
- Data driven ABCD background estimation (isolation, $|m_{jj} - m_{\gamma\gamma}|$)
- Dominant uncertainties: low number of observed events, jet energy scale and resolution
- Upper limits on $\left(\frac{\sigma_H}{\sigma_{SM}}\right) xB(H \rightarrow aa \rightarrow \gamma\gamma gg)$ range between 0.06 and 0.16
- Search commentary to $H \rightarrow aa \rightarrow \gamma\gamma\gamma\gamma$ and more sensitive to scenarios with enhanced gluon couplings

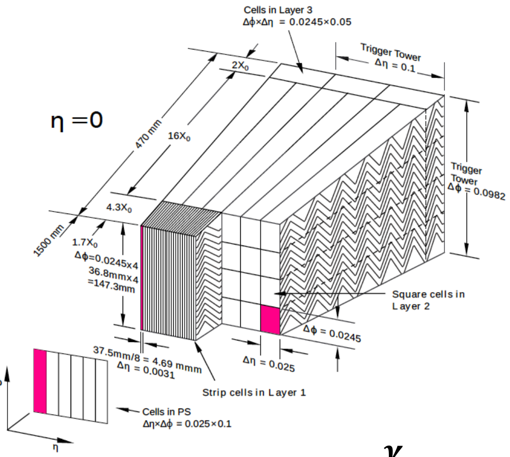
Enhancing the discovery potential to low m_a

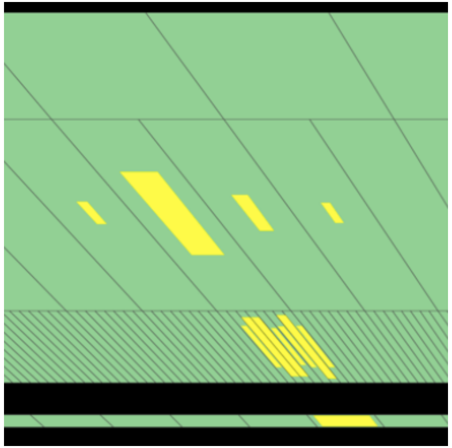


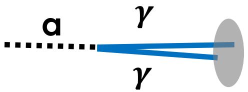


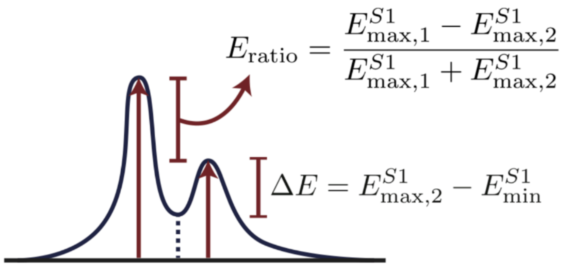
Jet substructure











Exploit highly segmented EM calorimeter: isolated single photon clusters with substructure

ATLAS EXOT-2017-08

Summary

- Exotic Higgs boson decays are a powerful probe to search for physics beyond the Standard Model
- Several new searches for exotic decays of the Higgs boson to two light bosons have been pursued using 36.1 fb^{-1} of data in multiple final states ($4b, bb\mu\mu, 4l, \gamma\gamma jj$)
- Data found consistent with SM background predictions, leading to upper limits on the branching ratio for non-SM decays of the Higgs boson to two light bosons
- Several new experimental techniques will enhance the discovery potential to lower a-boson masses, exploiting the high granularity of the ATLAS EM Calorimeter and jet and photon substructure techniques