Search for rare and exotic Higgs Boson decay modes and Higgs Boson pair production with the ATLAS detector

6th International Conference on New Frontiers in Physics (ICNFP2017)

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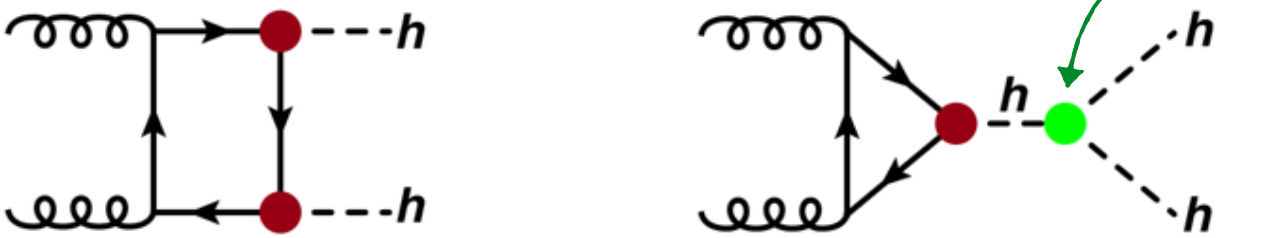
On behalf of the ATLAS Collaboration

PAIR PRODUCTION

Many thanks to Will Davey for the sketches

Higgs pair production

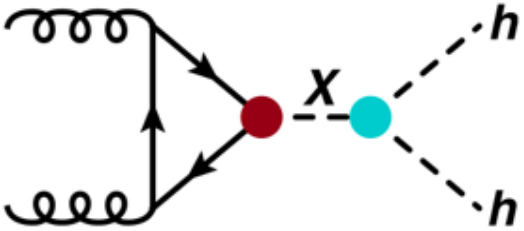
Standard Model



33.4 fb @ 13 TeV (significant destructive interference)

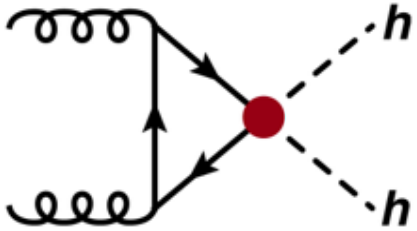
Beyond Standard Model

Resonant



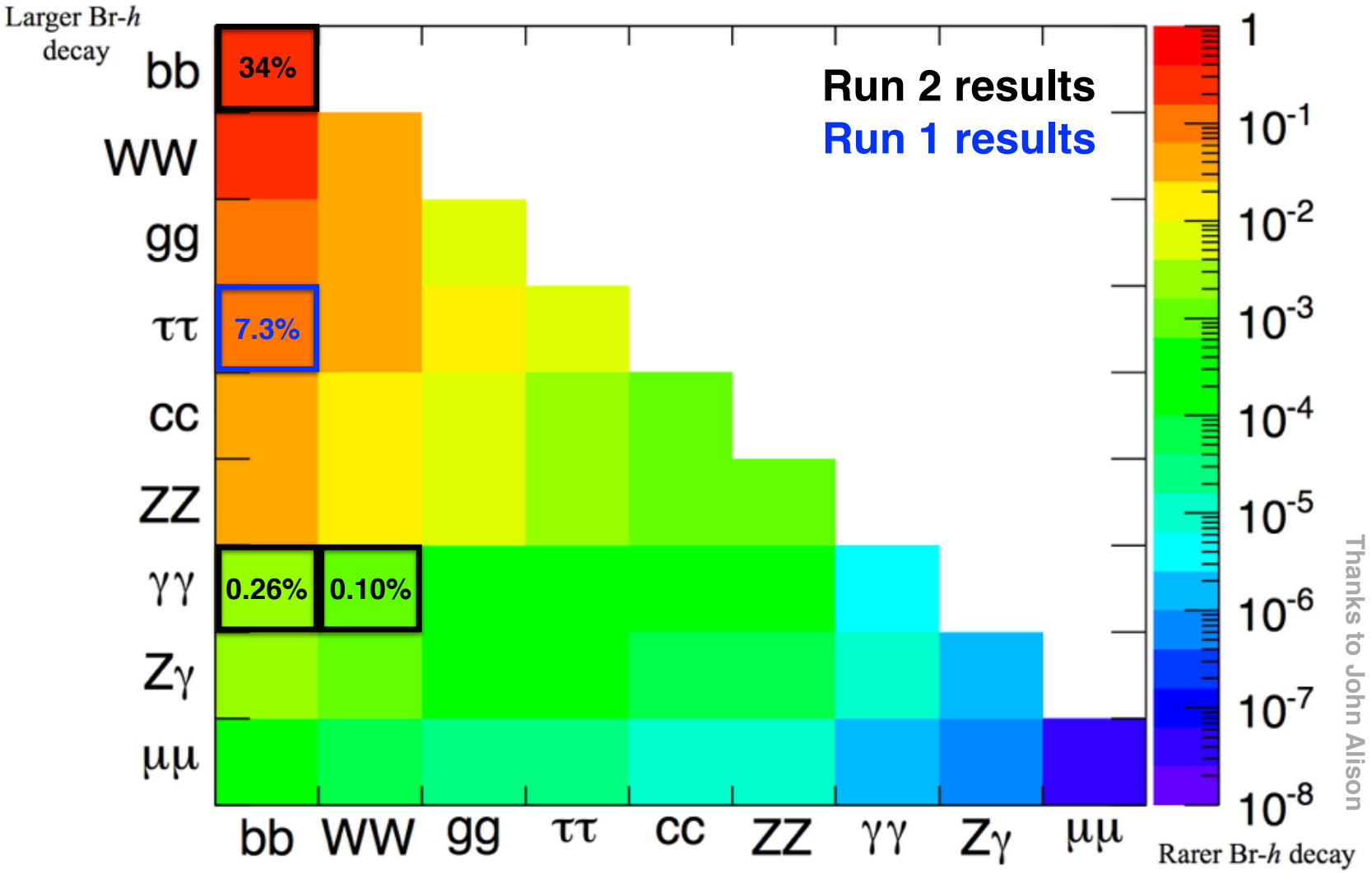
KK gravitons, heavy higgs, …

Non-resonant



tthh vertex, coloured scalars, …

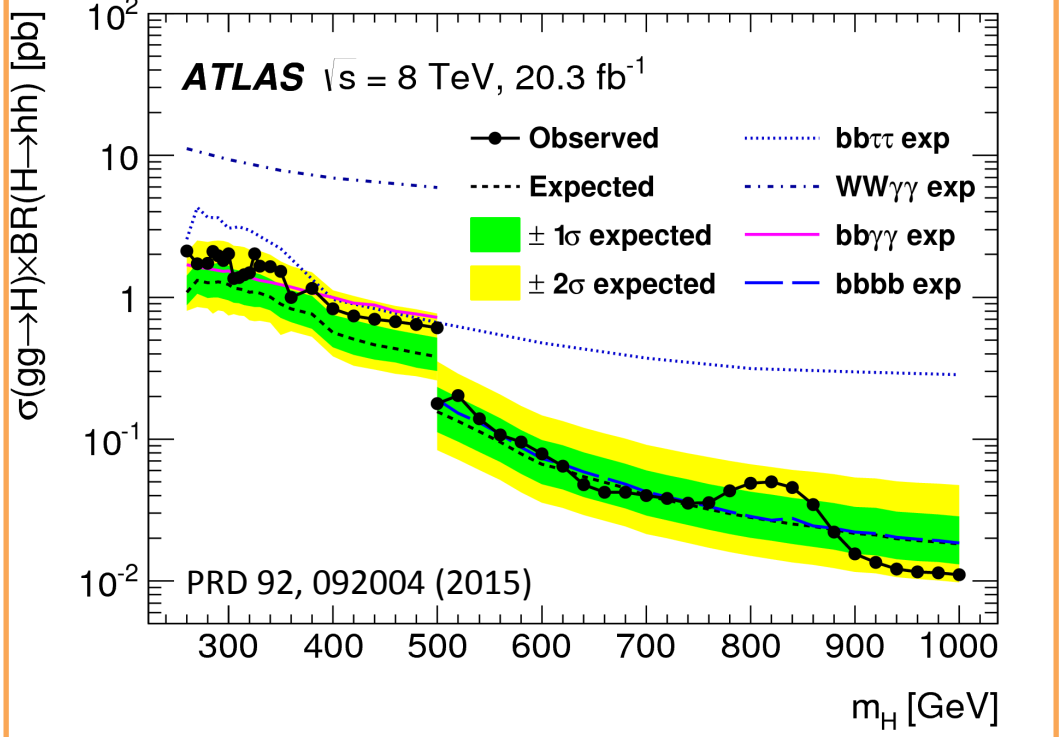
Higgs pair decay



NB: Color scheme shows the BR with Red at the highest

ATLAS results so far

Run1 Combined Result



Run2 Results So Far

hh→bb bb (13.3 fb^{-1})
ATLAS-CONF-2016-049

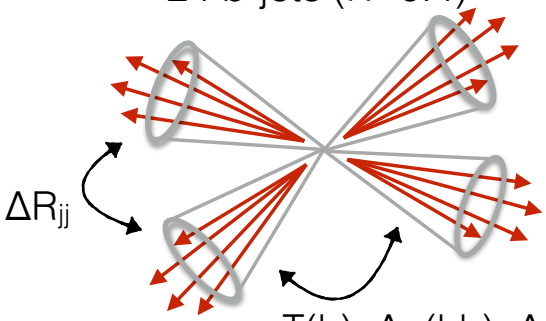
hh→γγWW* (13.3 fb^{-1})
ATLAS-CONF-2016-071

hh→bb γγ(3.2 fb^{-1})
ATLAS-CONF-2016-004

hh→bbbb: Strategy

Resolved

≥4 b-jets (R=0.4)

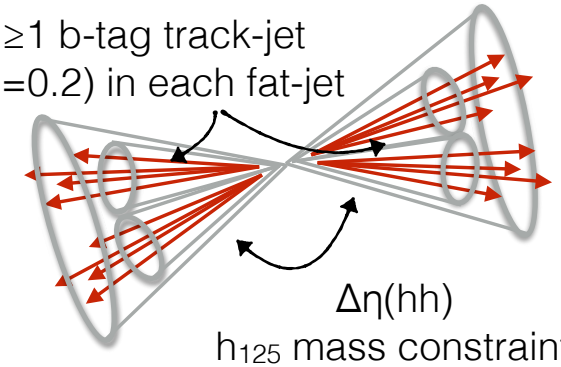


pT(h), Δη(hh), ΔR(hh)
h_{125} mass constraint

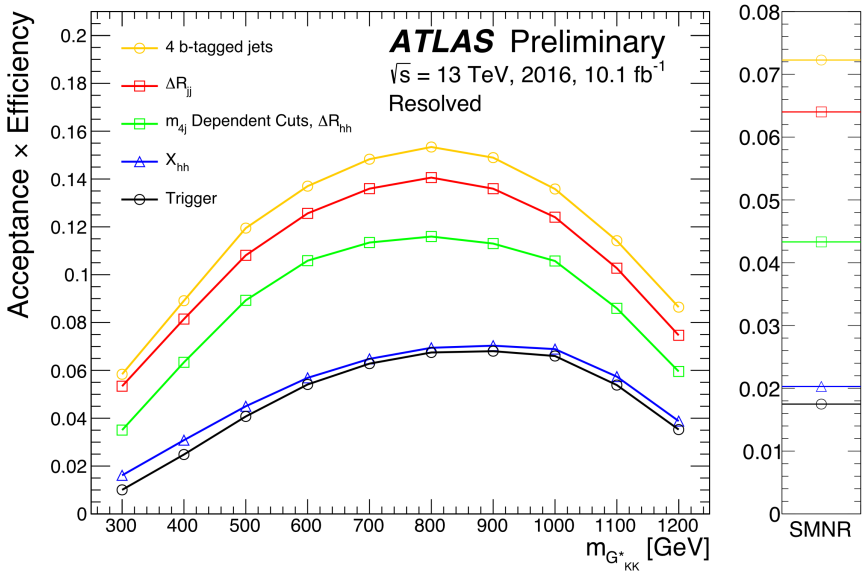
Boosted

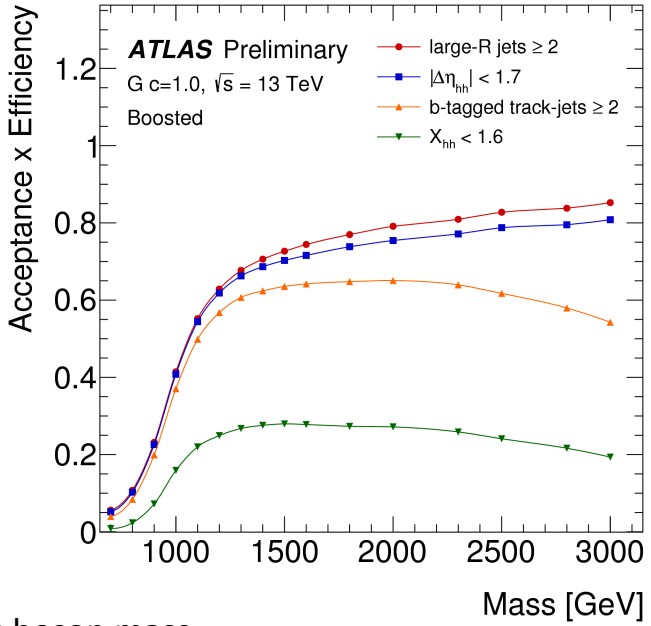
≥2 trimmed fat-jets (R=1.0, 450/250 GeV)

≥1 b-tag track-jet
(R=0.2) in each fat-jet



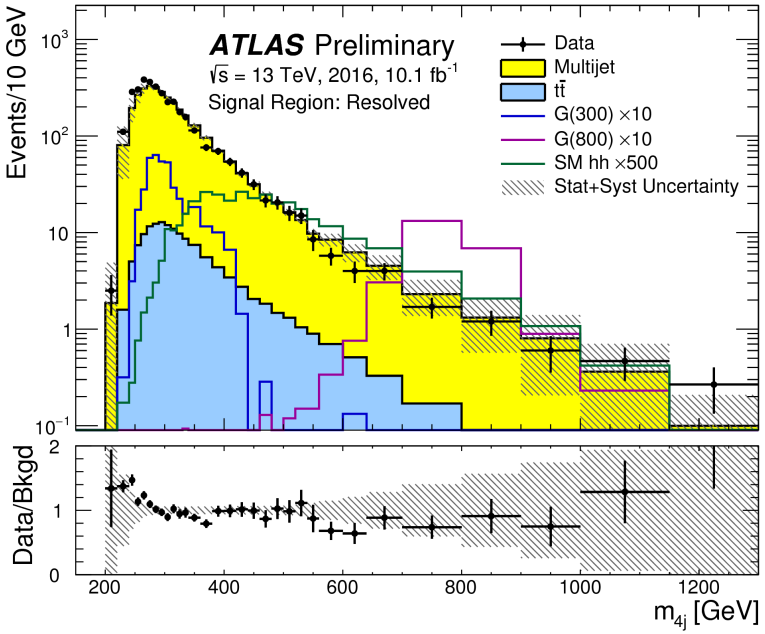
h_{125} mass constraint

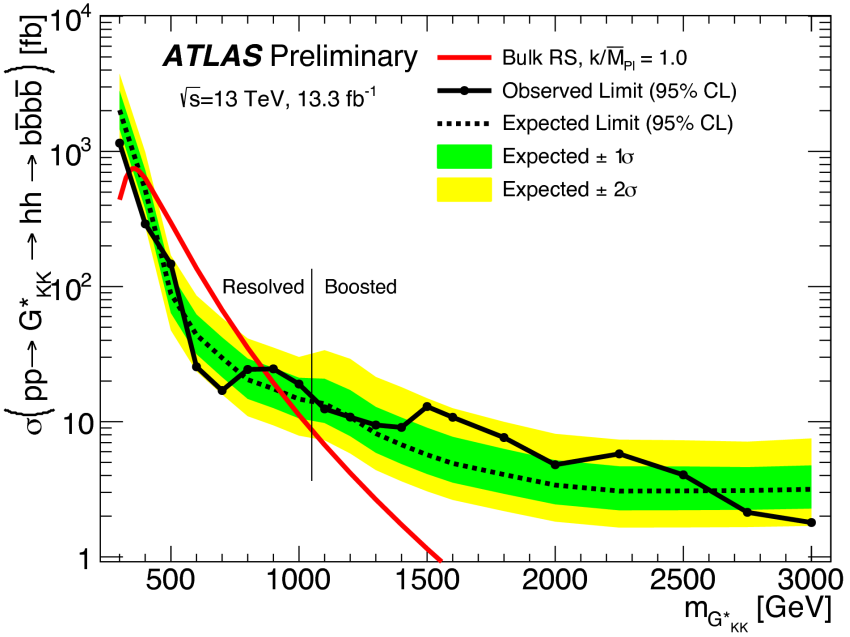


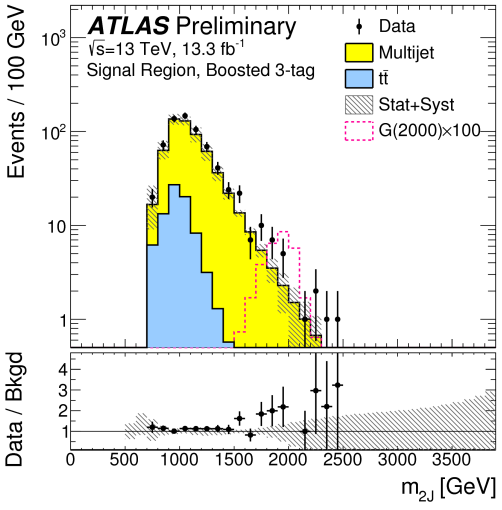


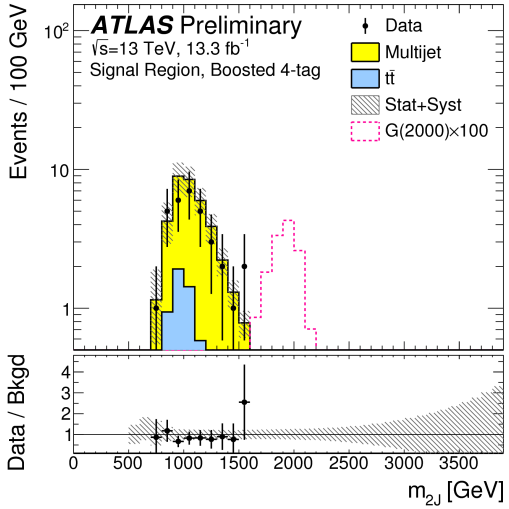
NB: X_{hh} checks the mass consistency with a Higgs boson mass

hh→bbbb: Results









Non-Resonant Limit

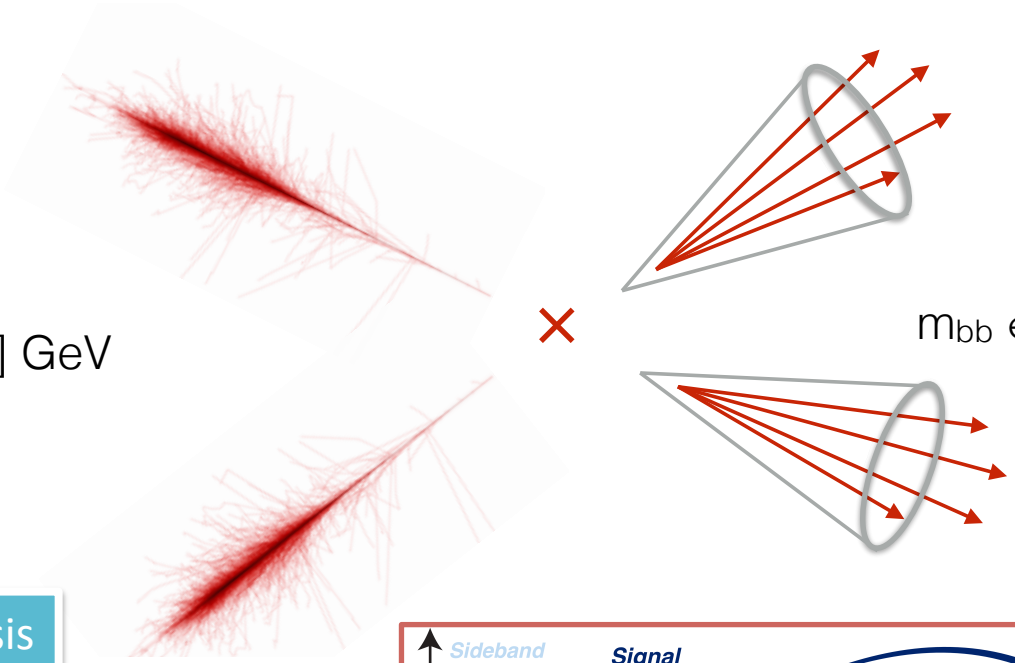
σ(pp →hh→bb bb) < 330 fb

σ(SM) < 11.3 fb

σ/σ(SM) < 29

hh→bb γγ: Strategy

2 photons
$m_{\gamma\gamma} \in [105, 160]$ GeV



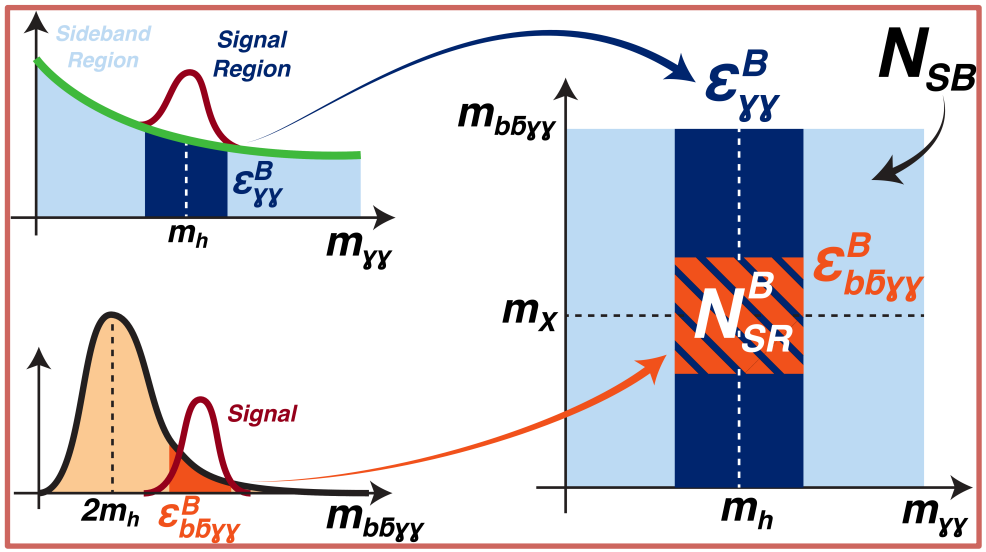
2 b-jets
$m_{bb} \in [95, 135]$ GeV

Non-Resonant Analysis

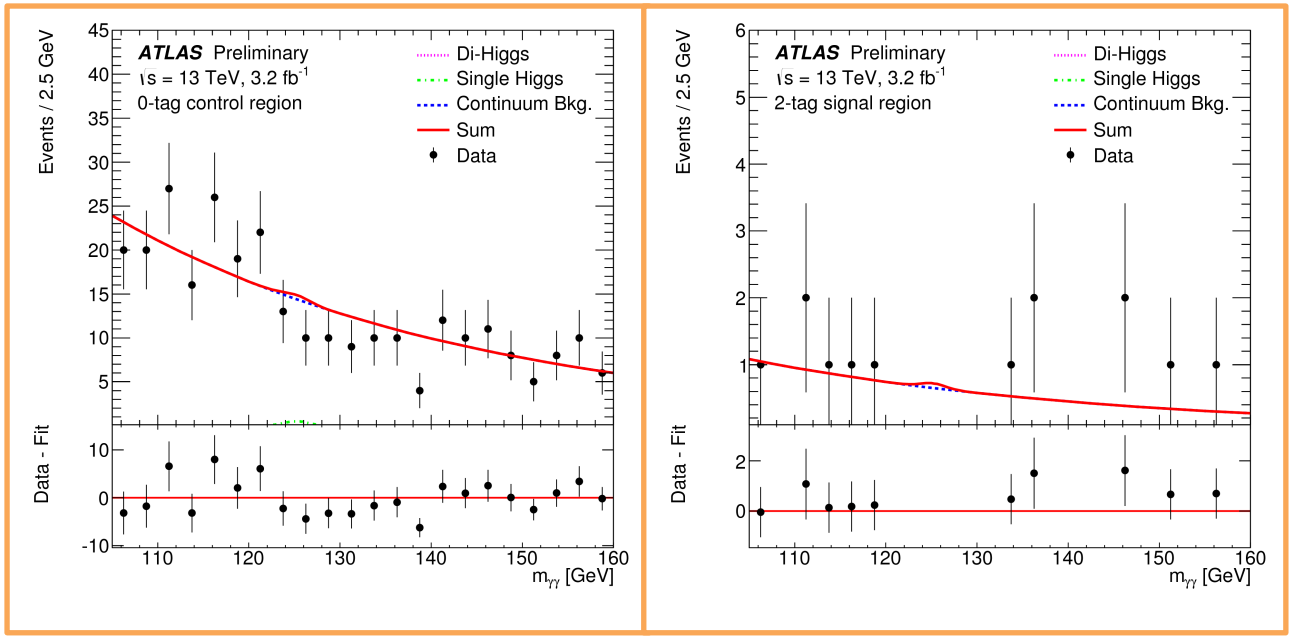
Unbinned fit to $m_{\gamma\gamma}$

Resonant Analysis

Counting Experiment in $m_{\gamma\gamma}$ and $m_{bb\gamma\gamma}$ window

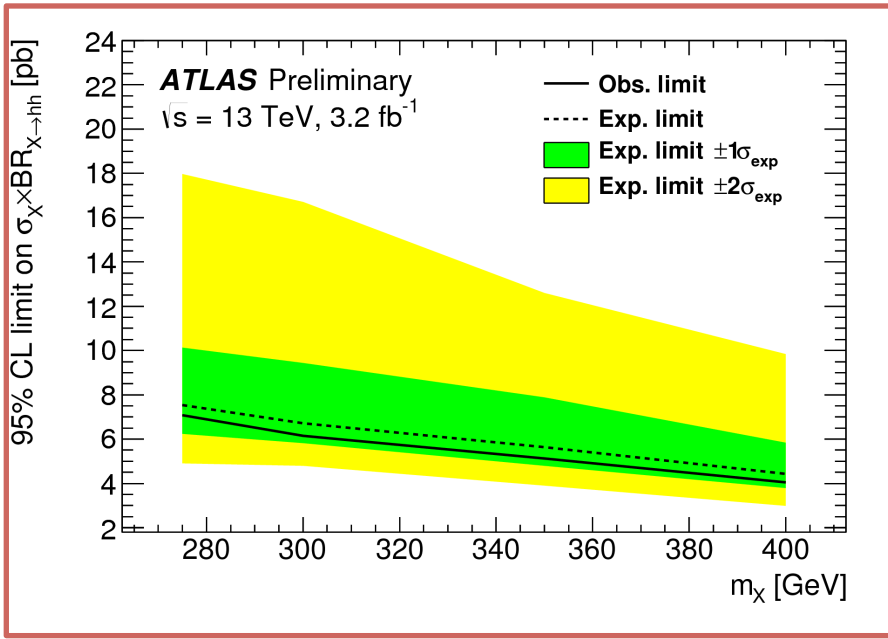


hh→bb γγ: Results



Non-Resonant Limit

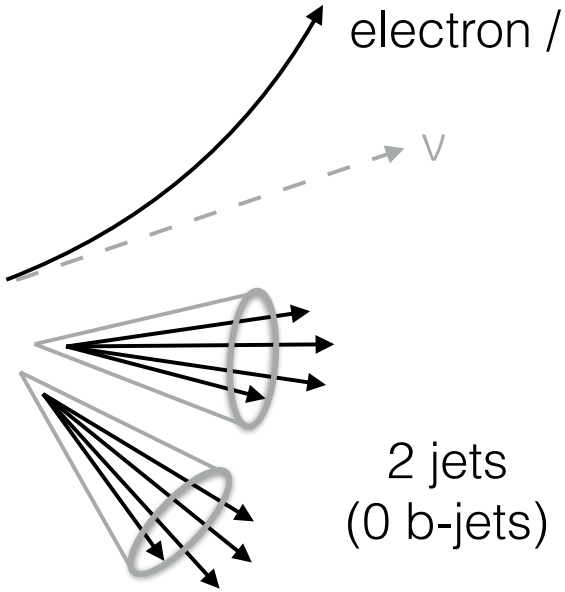
σ(pp →hh→bbγγ) < 10 fb
σ(SM) < 0.088 fb
σ/σ(SM) < 120



hh→γγWW*: Strategy

2 photons
$m_{\gamma\gamma} \in [105, 160]$ GeV
tighten to 6.8 GeV

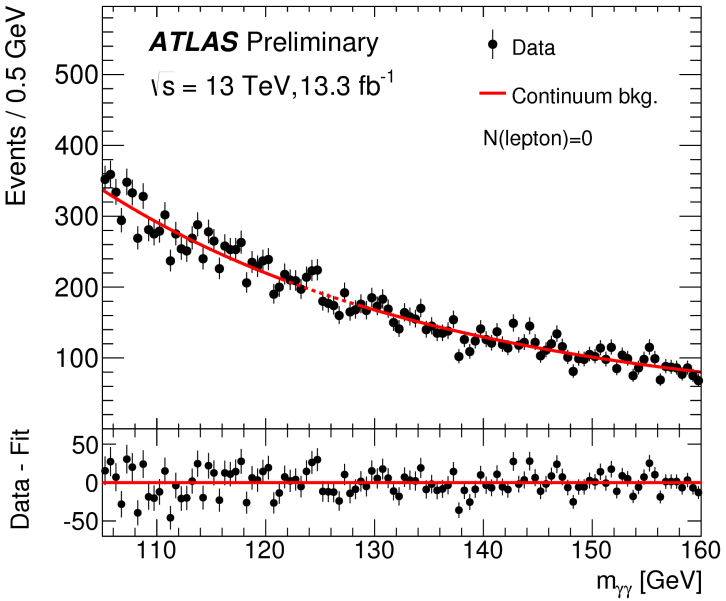
×

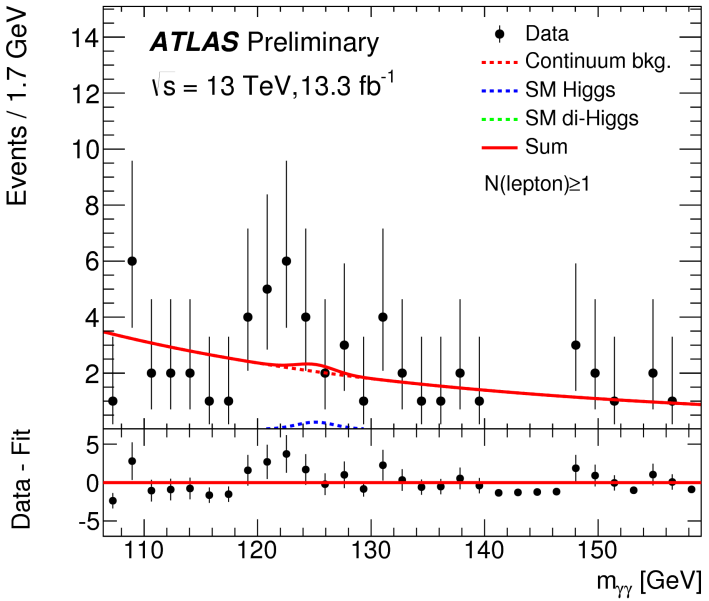


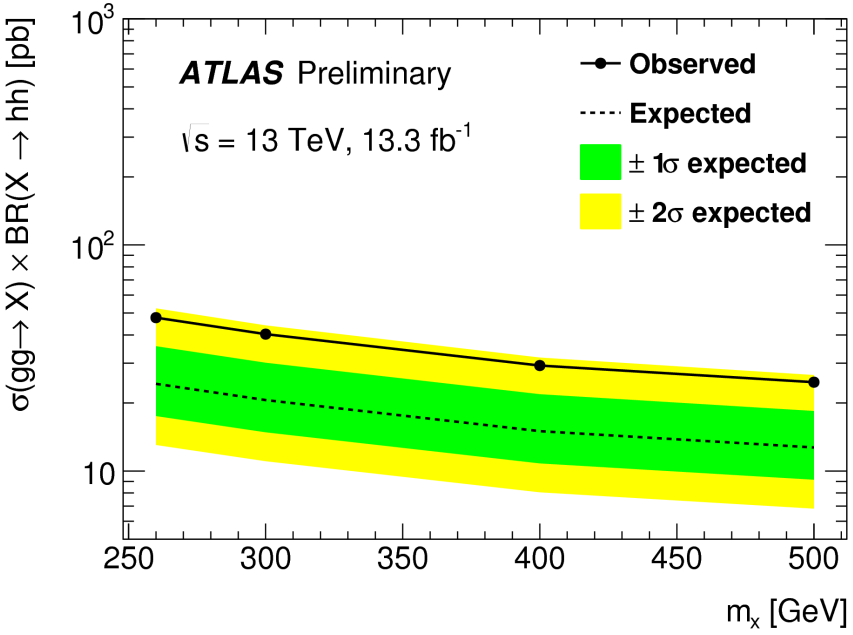
Counting experiment in the final Signal Region:
1 or more lepton
$|m_{\gamma\gamma}-m_h| < 2\sigma_{\gamma\gamma}$

Sidebands are defined, in 0-lepton and ≥1-lepton region , by inverting:
$|m_{\gamma\gamma}-m_h| < 2\sigma_{\gamma\gamma}$

hh→γγWW*: Results







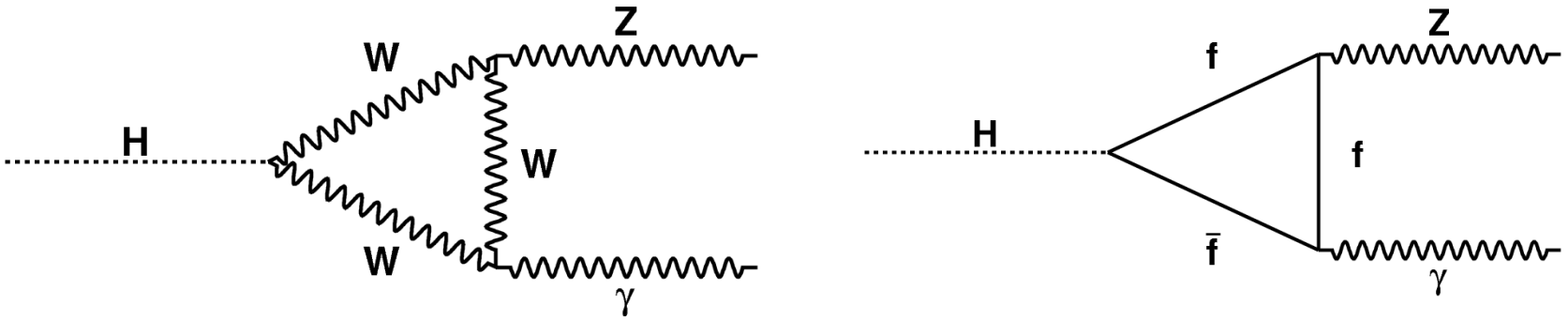
Non-Resonant Limit

σ(pp →hh→γγWW*) < 24 fb
σ(SM) < 0.033 fb
σ/σ(SM) < 750

RARE DECAYS

h→Zγ

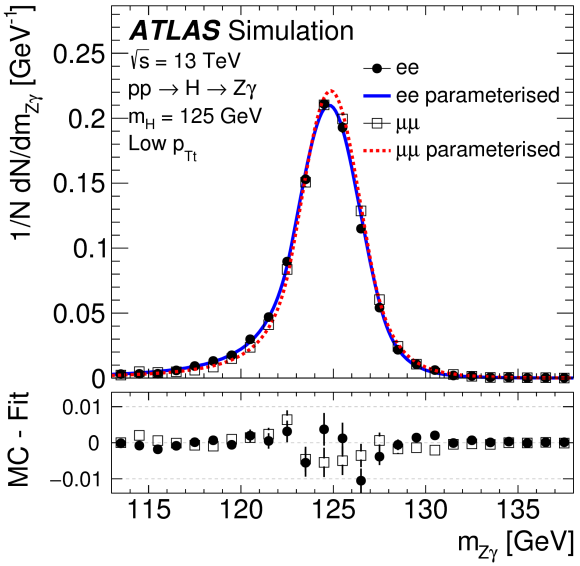
- h→Zγ proceeds via loop diagrams and has small BR
  - SM BR ~1.5 X 10^{-3} (m_h = 125 GeV)

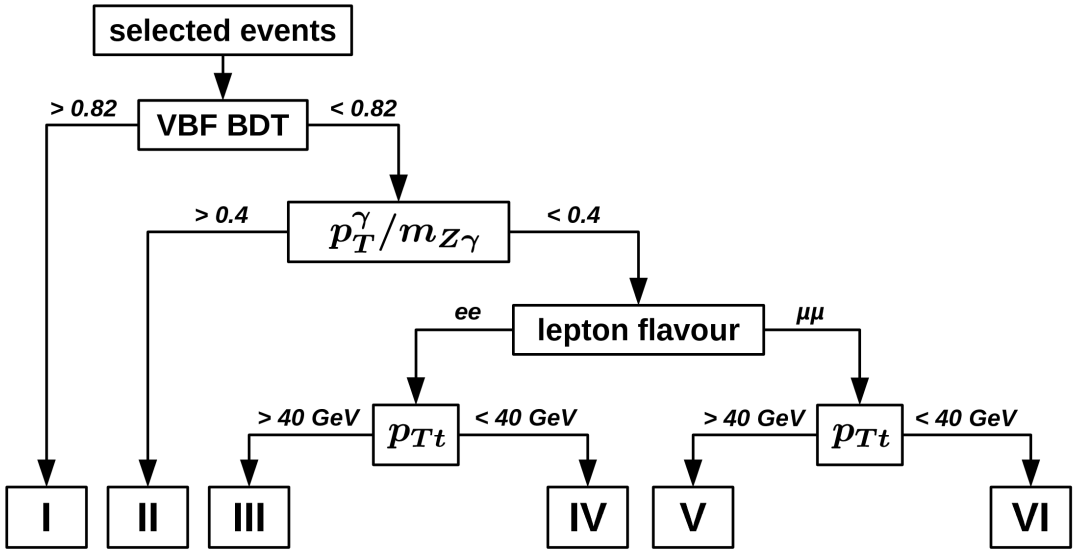


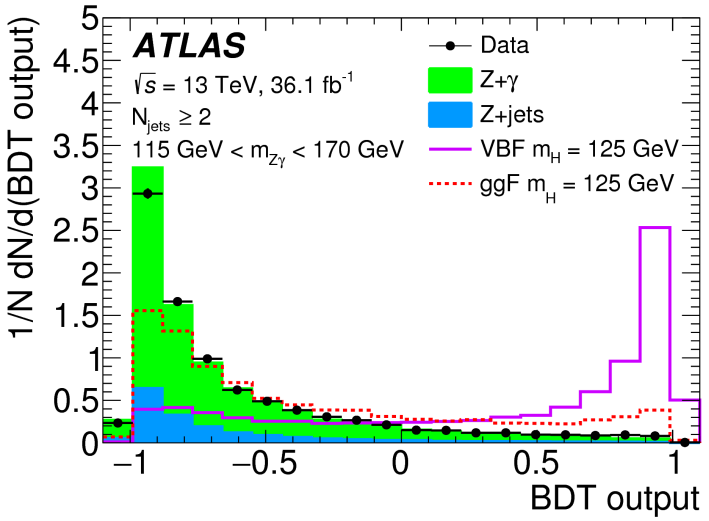
- Deviation from SM prediction of h→Zγ BR is expected if:
  - h is a neutral scalar of different origin
  - h is a composite state
- Run1 ATLAS Result Phys. Lett. B 732 C(2014) 8-27
  - Observed UL at 95% CL 11 times the SM
- Run2 ATLAS Result submitted to JHEP and presented today
  - **arXiv:1708.00212**

h→Zγ: Strategy

- Signal extracted via s+b fit to $m_{Z\gamma}$
  - Mass resolution critical, improved via kinematic fit
- 6 categories enhance sensitivity

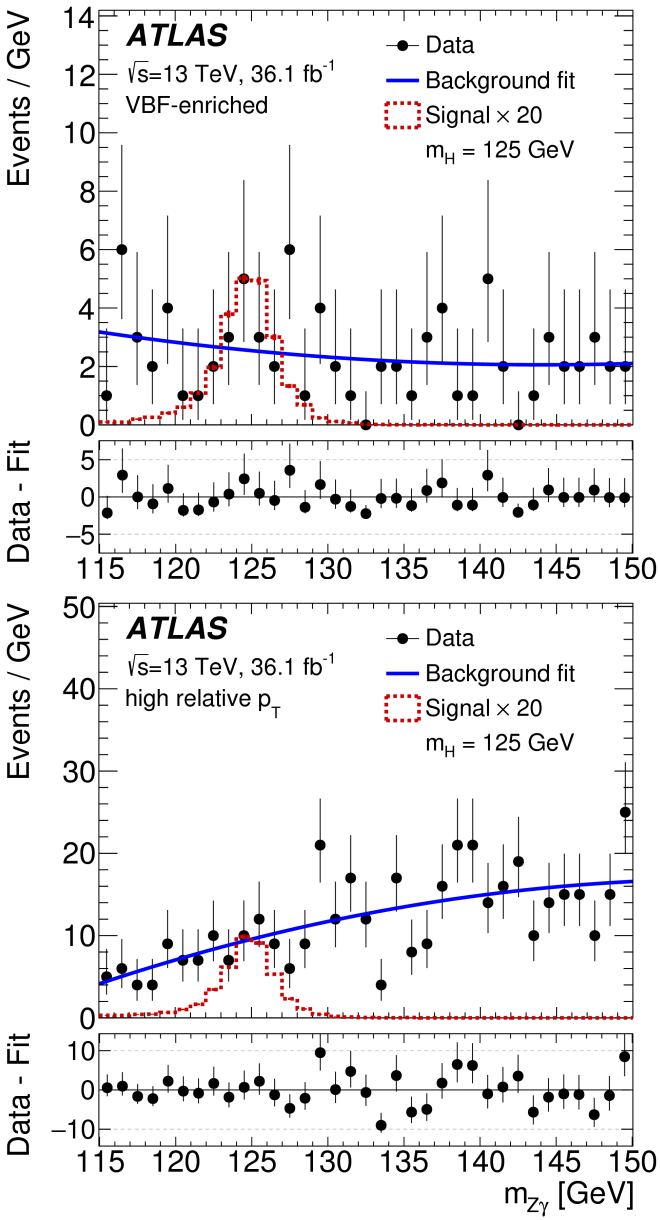






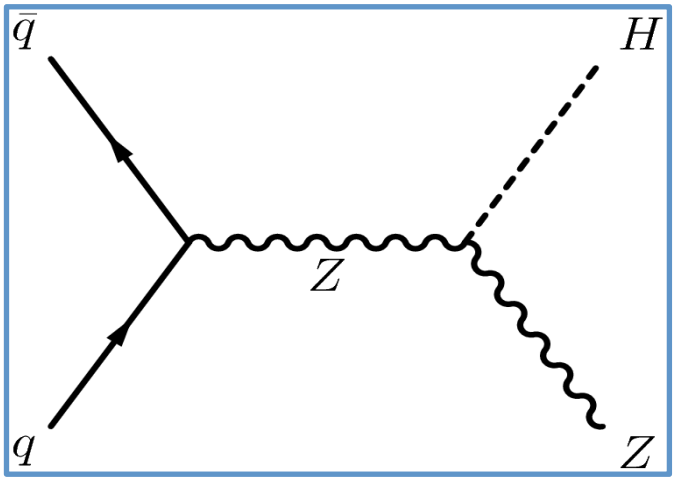
h→Zγ: Results

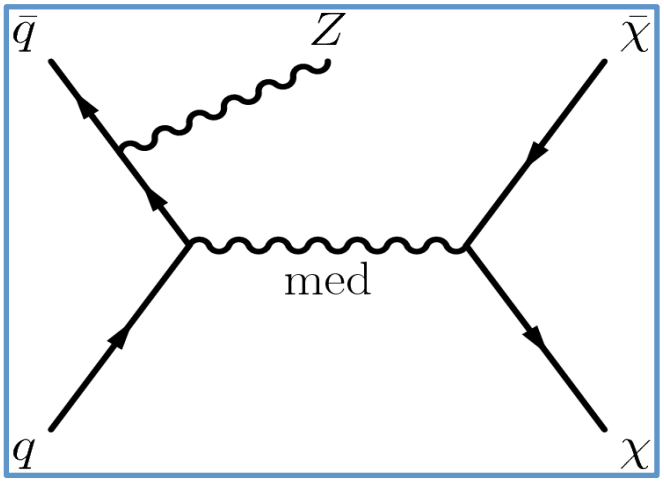
- Fit over 115-150 GeV mass range
- Signal: double sided Crystal Ball
- Background modeled by Bernstein polynomials
  - Shape from Z+γ (fast) simulation
  - Parameters from fit to data
- Background composition (Z+jets, Z+γ) is estimated by data-driven method using looser isolation
- 95% CL upper limit 6.6 (4.4) SM observed (expected)



h→Invisibles

- Search for pp→Zh→$\ell\ell$+E_T^{miss}
- Clean dilepton signature from Z decay, missing transverse momentum from invisibly decaying Higgs decay

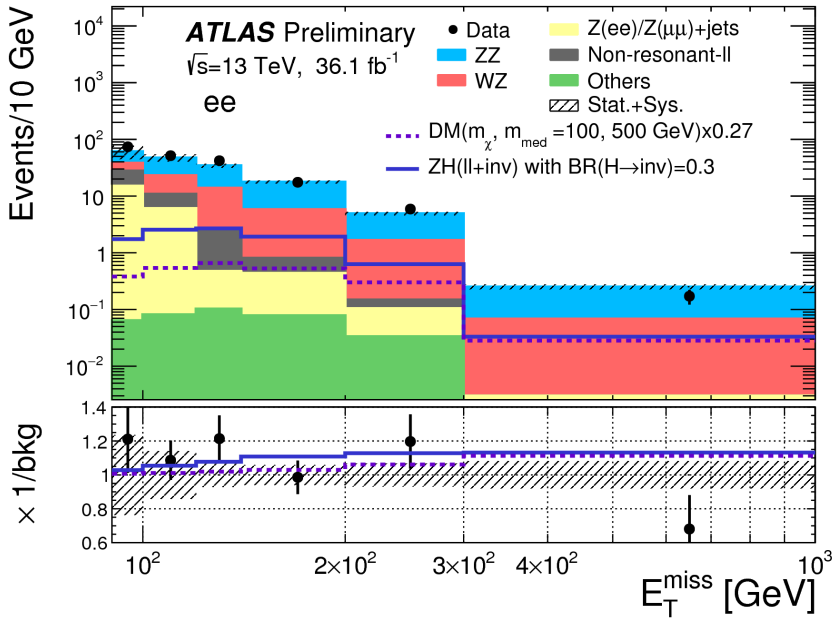


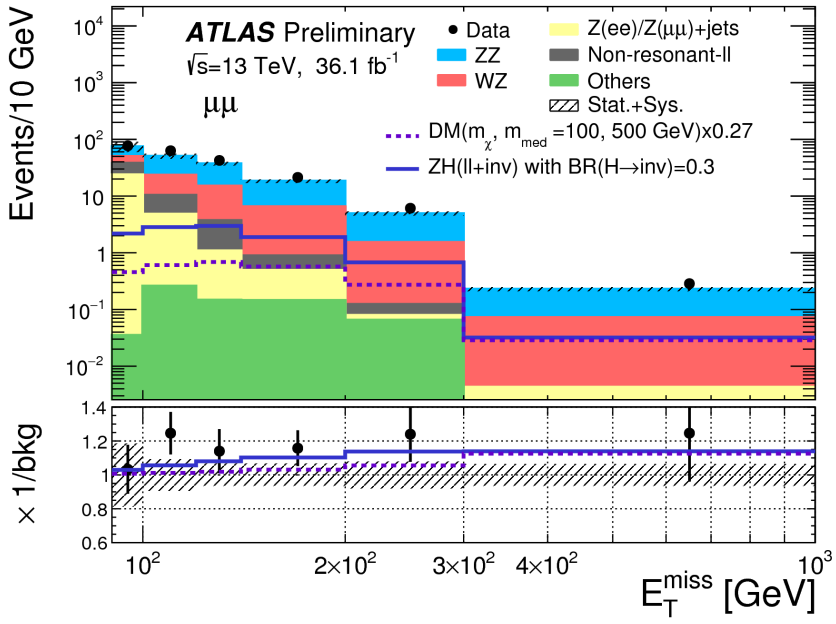


- In the SM, invisible decay of the Higgs boson via h→ZZ→νννν has BR of $1.06X10^{-3}$
- A deviation from the above BR can indicate new physics
- In fact, several BSM theories predict such a deviation
  - Light neutralinos, graviscalars, Majorons, dark matter through Higgs portals
- Result presented today from ATLAS-CONF-2017-040

h→Invisibles: Strategy

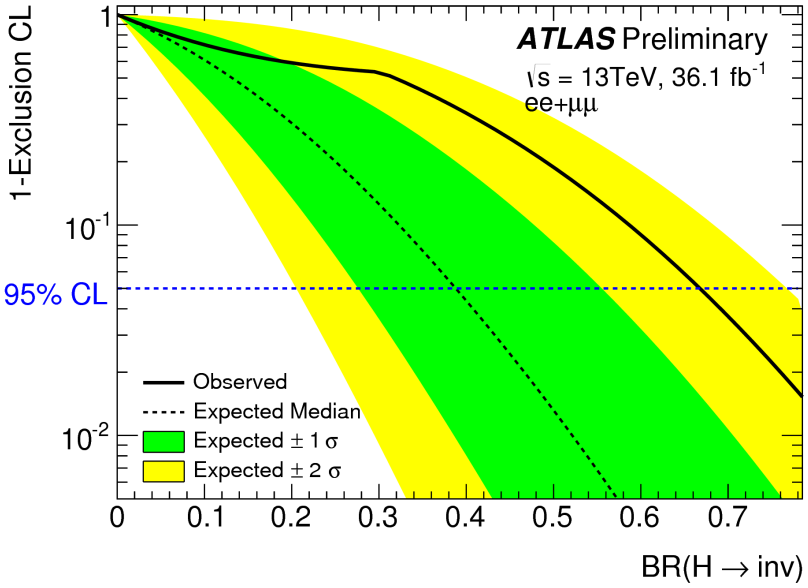
- Bin by bin fit in the MET distribution in *ee* only, $\mu\mu$ only, and combined *ee* +$\mu\mu$ channel

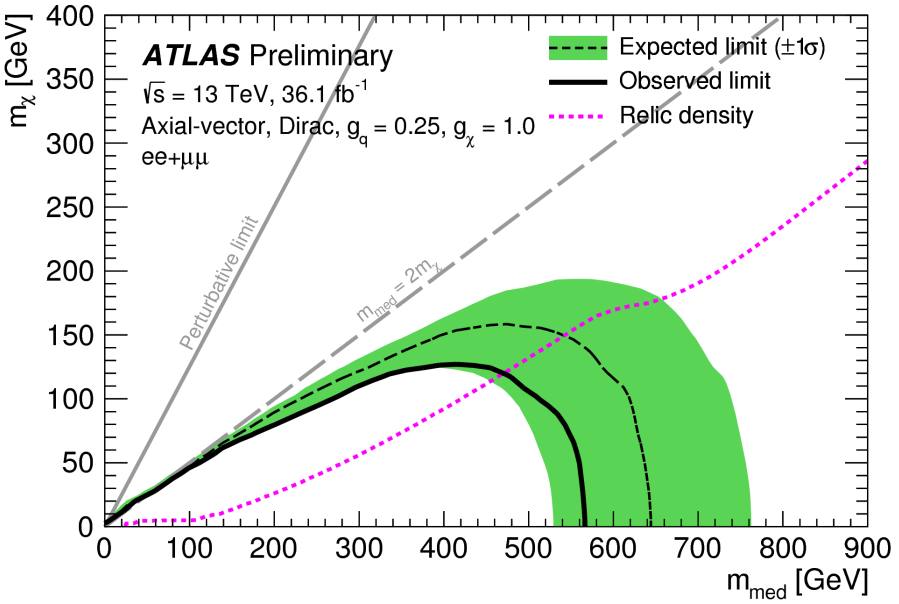




- Similar sensitivity in *ee* and $\mu\mu$ channels
- No significant deviation from the SM
- Largest deviation(2.2σ) in mumu channel, and 1.5σ for combined channel

h→Invisibles: Results

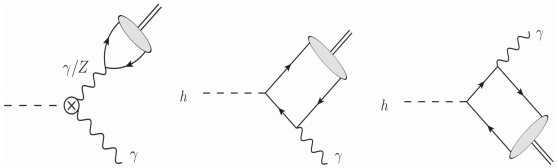


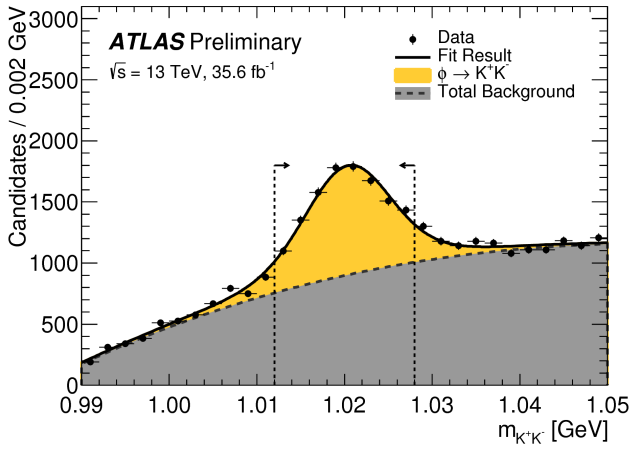


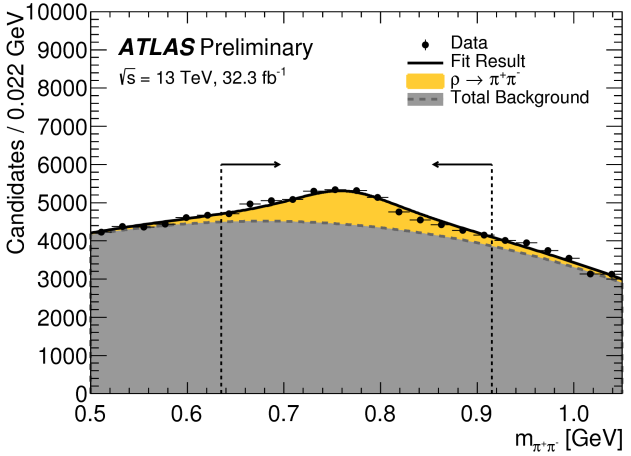
- Exclusion limit on *B*(H→inv.) assuming SM ZH cross section
  - Observed (Expected) limit of 67% (39%).
    - Run 1 results were 75% (62%)
- 95% CL exclusion limit in 2D m_χ and m_{med}
- Mediator mass m_{med} is excluded up to 560 GeV for a light WIMP
- WIMP mass m_χ is excluded up to 130 GeV for m_{med} = 400 GeV.

h→ϕγ, ργ

- h→ϕγ, h→ργ sensitive to coupling with light quarks
- Expected SM:
  - BR (h→ϕγ) 2.31X10^{-6}
  - BR (h→ργ) 1.68X10^{-5}



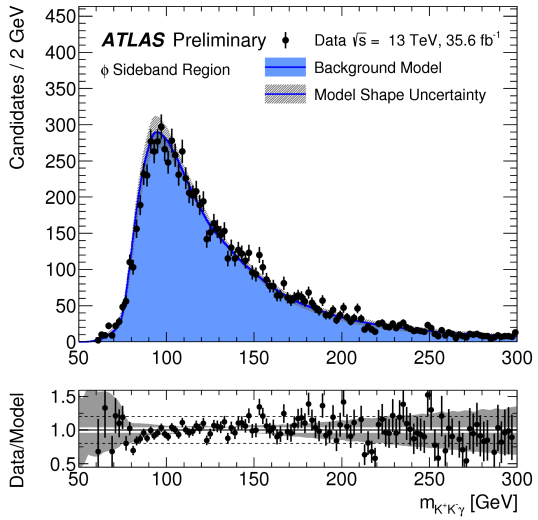


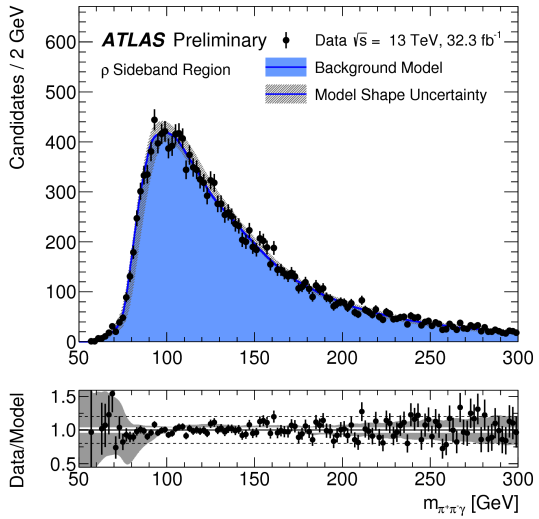


- Reconstruct ϕγ→K+K-γ (~50%), and ργ→π+π-γ (~100%)
- Two high-pT (20, 15 GeV) isolated tracks consistent with ϕ, ρ mass hypothesis recoiling against γ (pT > 35 GeV)
- Result presented today from ATLAS-CONF-2017-057

h→ϕγ, ργ: Strategy

- Main background from random tracks and γ combinations in multijet and γ+jet
  - Data-driven template modeling of background
- Model validated in validation regions by adding: the *p*T requirement (VR1), the photon isolation (VR2), and the meson isolation requirement (VR3)





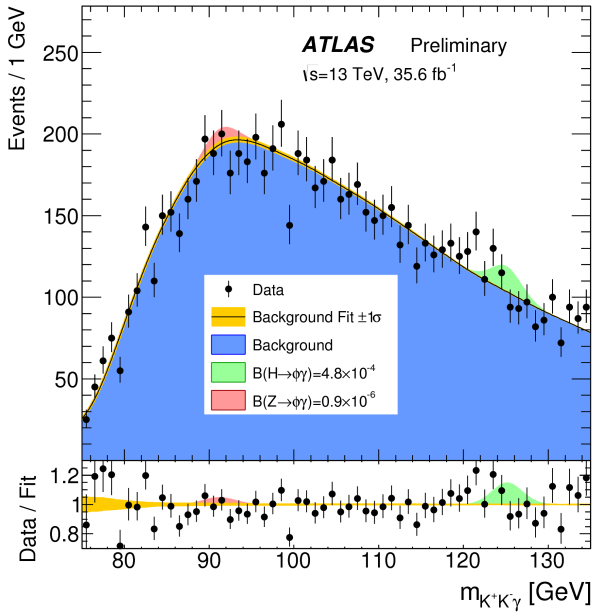
- Model shape uncertainty estimated from modifications to modeling procedure
- Further validation in mass sidebands. Background model describes data within uncertainties.

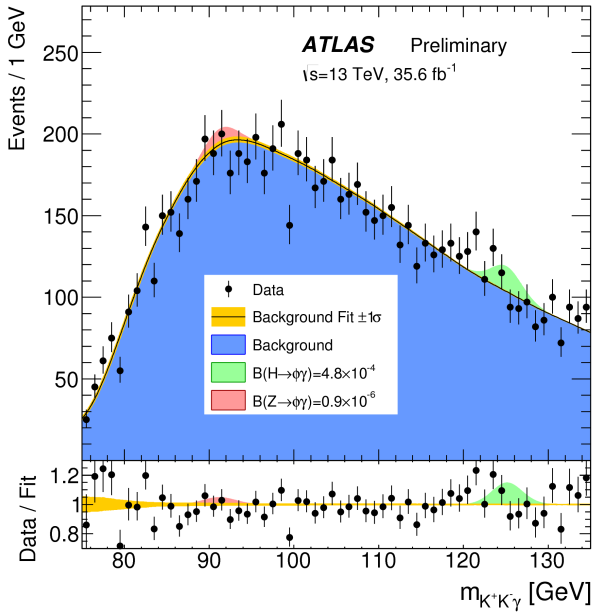
h→ϕγ, ργ: Results

- No significant excess above the SM
- Unbinned maximum likelihood fit to extract upper limits

Branching Fraction Limit (95% CL)	Expected	Observed
$\mathcal{B}(H \to \phi\gamma)\,[\,10^{-4}\,]$	$4.2^{+1.8}_{-1.2}$	4.8
$\mathcal{B}(Z \to \phi\gamma)\,[\,10^{-6}\,]$	$1.3^{+0.6}_{-0.4}$	0.9
$\mathcal{B}(H \to \rho\gamma)\,[\,10^{-4}\,]$	$8.4^{+4.1}_{-2.4}$	8.8
$\mathcal{B}(Z \to \rho\gamma)\,[\,10^{-6}\,]$	33^{+13}_{-9}	25

- The observed 95% confidence level upper limits on BR $H \to \phi\gamma$ and $Z \to \phi\gamma$ decays are approx. 208 and 87 times SM
- For the ργ decays: 52 and 597 times SM





Conclusion & Outlook

- The SM-like Higgs boson can be used as a tool to search for new physics and for precision measurements
- Several searches have been performed using the ATLAS detector but neither pair production nor rare/exotic decay of the Higgs boson has been observed yet
- Some of these production and decay modes may become observable in near future, so we look forward to the data to be collected in 2017 and 2018 (and of course HL-LHC!)
- Many more results available at:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic