Search for exclusive Higgs and Z boson decays to $\phi\gamma$ and $\rho^0\gamma$ with the ATLAS detector

Rhys Owen[1]

University of Birmingham[1]

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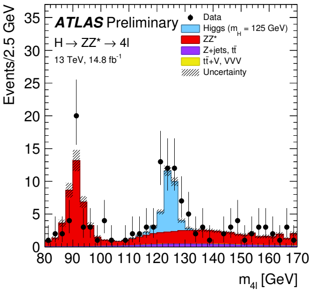
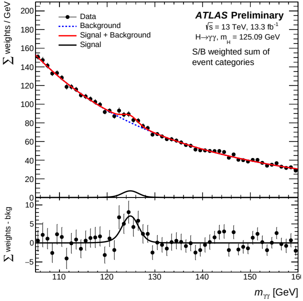
Introduction

- Higgs Boson discovered at LHC
- Leading discovery channels all involve bosons

However in the Standard Model fermions couple to the Higgs boson via a different mechanism



ATLAS-CONF-2016-079



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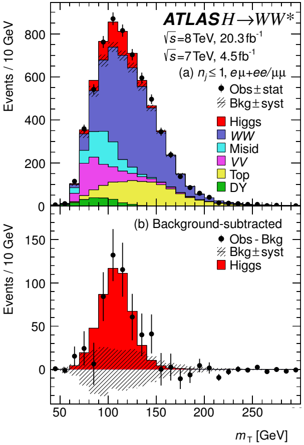
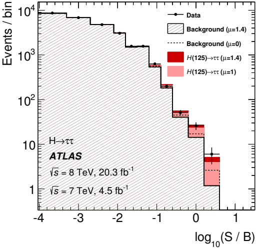


Phys.Rev. D92 (2015) no.1, 012006

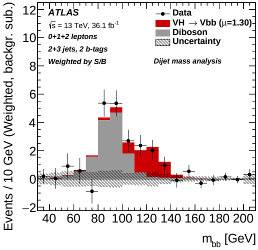
Current Status of Search for Yukawa Couplings

$H \to \tau\tau$



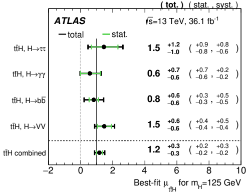
JHEP 04 (2015) 117

$H \to b\bar{b}$



JHEP 12 (2017) 024

top associated production



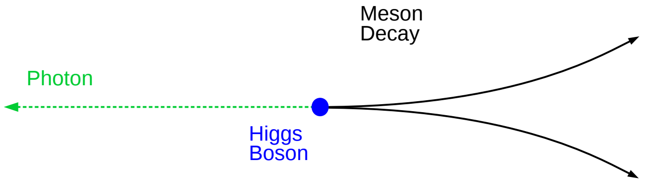
arXiv:1712.08891

There are several ATLAS searches on-going with sensitivity to the Yukawa couplings

- The first direct evidence came from the observation of $H \to \tau\tau$ $(4.5(3.2)\sigma)$
- Now complimented by observations of VH $H \to b\bar{b}$ $(3.5(3.0)\sigma)$ and ttH $(4.1(2.8)\sigma)$ production.
- Also ongoing searches for direct $c\bar{c}$ production **(arXiv:1802.04329 submitted to PRL)**
- Most "Obvious" channels suffer from large backgrounds and other experimental challenges

Light fermions of the first and second generation fermions pose the additional problem of very small predicted couplings

Higgs Boson $\rightarrow \mathcal{M}\gamma$

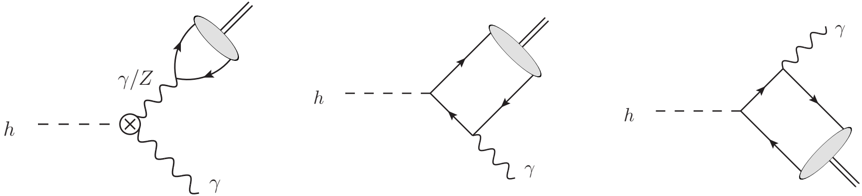


One promising channel is Higgs boson decays to a photon and a meson

- Gives direct access the Yukawa couplings
- A distinctive decay topology to select the events over SM background
- At the cost of a small SM branching ratio
- The first search in this channel was $H \rightarrow J/\psi\gamma$ **(Phys.Rev.Lett. 114 (2015) 121801)**
- One of the only ways to proble the light quark couplings at the LHC

Channel	SM Branching Ratio
$BR(H \rightarrow s\bar{s})$	$(2.5 \pm 4.9) \times 10^{-4}$ **(arXiv:1307.1347)**
$BR(H \rightarrow \phi\gamma)$	$(2.3 \pm 0.1) \times 10^{-6}$ **(JHEP08(2015)012)**

ATLAS Searches for Higgs Boson $\to \phi$ or $\rho^0\gamma$

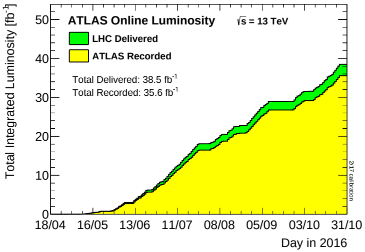


The Latest $M\gamma$ search from ATLAS is for $H \to \phi\gamma$ and $H \to \rho^0\gamma$
arXiv:1712.02758 submitted to JHEP

- SM prediction $\mathcal{B}(H \to \phi\gamma) = (2.3 \pm 0.1) \times 10^{-6}$(JHEP08(2015)012)
- SM prediction $\mathcal{B}(H \to \rho^0\gamma) = (1.7 \pm 0.1) \times 10^{-5}$(JHEP08(2015)012)
- The direct diagrams (centre and left) give access to the strange (up / down) Yukawa couplings.

Analysis Strategy

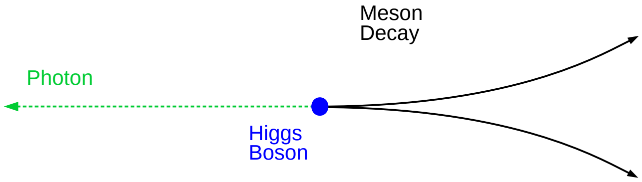
- Analysis performed using 2015 + 2016 pp dataset
- Data is selected with a dedicated trigger
- Backgrounds are modelled from data and SM signals are generated using the ATLAS simulation infrastructure.
- These are combined in a Maximum Likelihood fit to obtain CL_s limits on the Branching Ratio



ATLAS pp 25ns run: April-October 2016												
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets		Trigger
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid	L1
98.9	99.9	99.7	99.3	98.9	99.8	99.8	99.9	99.9	99.1	97.2	98.3
Good for physics: 93-95% (33.3-33.9 fb^{-1})											

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between April-October 2016, corresponding to an integrated luminosity of 35.9 fb^{-1}. The toroid magnet was off for some runs, leading to a loss of 0.7 fb^{-1}. Analyses that don't require the toroid magnet can use that data.

Dedicated Trigger



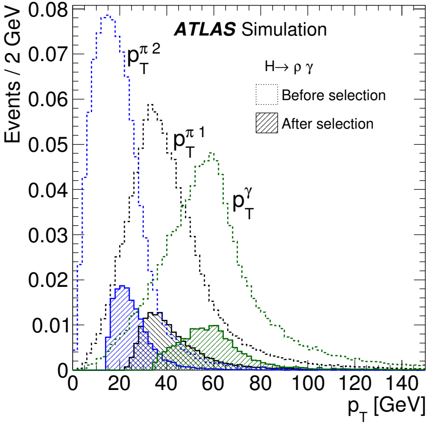
Trigger developed specifically for this topology

- Require both a photon and di-track in the Higher Level Trigger (HLT)
- ATLAS HLT uses sequential chains of software algorithms
- Meson Gamma triggers combination of standard photon algorithms and customised Tau algorithm
- photon of p_T greater than 35 GeV
- Invariant mass of the two tracks consistent with the meson mass
- Leading track $p_T > 15$ GeV

Trigger efficiency is (w.r.t. offline selection) $\approx$ 80%

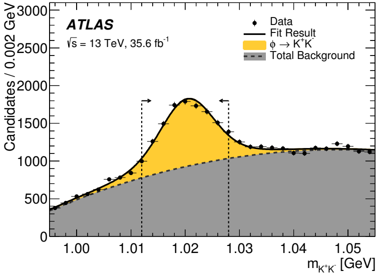
Event Selection

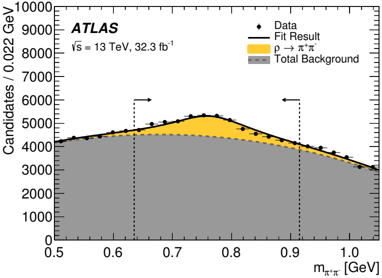
- Events from LHC stable beams with all ATLAS sub-detectors operating normally
- Dedicated trigger
- Select Photons ($p_T > 35 GeV$)
  - Passing "Tight" photon identification requirements
  - Both track and calorimeter isolation
- Select track pairs ($p_T > 20, 15 GeV$)
  - ATLAS has no way to distinguish pions and kaons in the relevant p_T range
  - All tracks assumed to to be $K^{\pm}$ for $\phi\gamma$ or $\pi^{\pm}$ for $\rho\gamma$
- Build three-body (Higgs) mass for candidate events



Meson Selection

- Di-track invariant mass is required to be within ± 8 MeV of the ϕ meson mass or ± 140 MeV of the ρ meson mass
- Di-track pair closest to the meson mass is selected
- The sum of p_T of the tracks within $\Delta R = 0.2$ of the meson is required to be less than 10% of the di-track p_T (excluding the selected tracks)
- A further requirement is placed on the candidates that the azimuthal angle between the meson and the photon must be $\Delta\phi(M, \gamma) > 0.5$
- A final p_T requirement is placed on the ϕ candidate dependant on the three body mass. 40 GeV at the Zmass rising linearly to 45 GeV at the Higgs boson mass





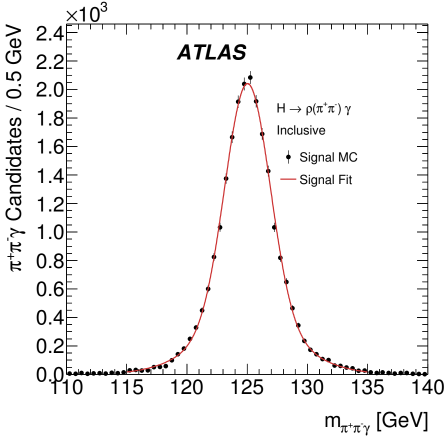
Signal Modelling

Several Higgs boson production modes considered

- Gluon fusion
- Vector Boson Fusion
- WH,ZH associated production
- Gluon fusion cross section scaled to include other sub-leading Higgs production processes (ttH, bbH)

Higgs boson decay simulation

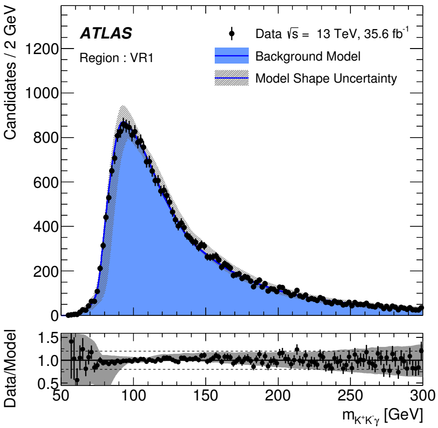
- Modelled in Pythia
- Meson helicity not simulated but corrected for by re-wighting sample



Background Modelling

Background dominated by multijet and γ-jet events

- Data here from a loosened selection
- Background shows a kinematic peak at ≈ 100 GeV.
- Difficult to generate a Monte Carlo sample with a large acceptance to the signal region
- Also difficult to model with a reasonable polynomial
- Instead a non-parametric data driven method is used to model this shape



Background Procedure

Use loose selection of events

- The isolation cuts are removed
- The di-track $p_T$cut is loosened
- Selecting $\approx 54,000$ $\phi\gamma$ events ($\approx 220,000$ $\rho\gamma$ events)

Produce Kinematic and Isolation PDF's

- The p_T,η,ϕ values for the candidate tracks and photons are transformed to PDFs
- PDFs are also generated for the associated isolation values
- Multidimensional PDFs are used to retain the correlations

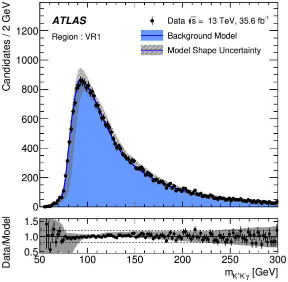
Create pseudo-candidates

- Kinematic variables are sampled from the PDFs (retaining their correlations)
- This enables the generation of a large ensemble of pseudo-candidates

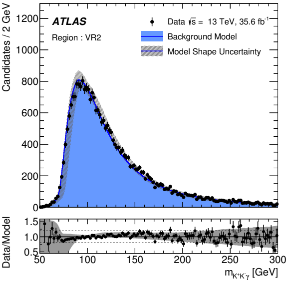
Background Validation

Generated pseudo-candidates then exhibit the same kinematic and isolation properties that they were modelled from

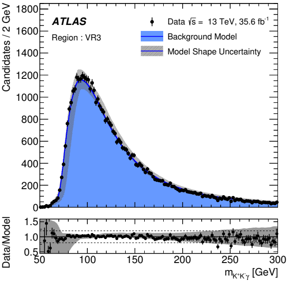
- Independently applying the loosened selection criteria shifts both the shape and normalisation of the data
- This is matched accurately with the behaviour of the pseudo-candidates



p_T CR



Photon Isolation CR

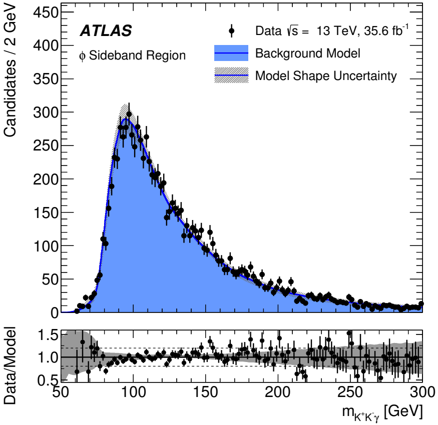


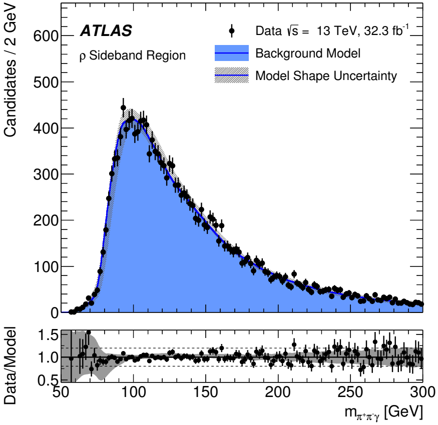
Meson Isolation

Background Closure

A further closure is performed using a sideband defined in the meson mass

- Not sensitive to signal therefore possible to see the full distribution before unblinding.

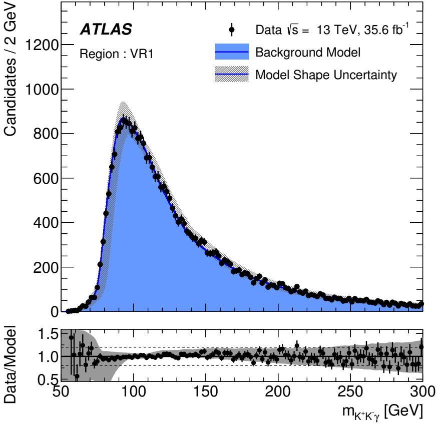




Background Systematics

The normalisation of the background is unconstrained in the final fit so the largest systematic effect would be from deviation in the shape

- These variations are introduced by altering the PDFs describing the di-track p_T and $\Delta\phi(M, \gamma)$
- A further global shift of the three body mass shape is included motivated by the changes seen when removing the smallest correlation.
- These three shape variations describe the uncertainty shown in the plot.



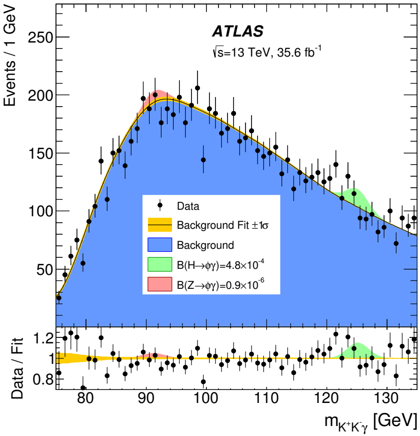
Signal Systematics

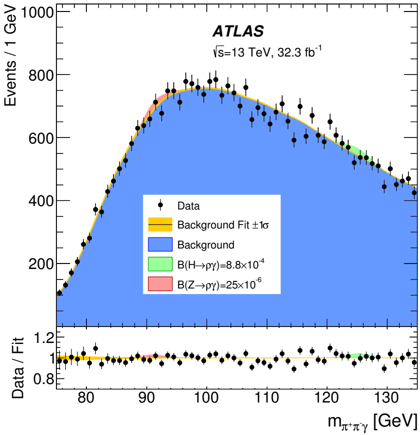
The following systematics are calculated for the signal yield

Systematic	Signal Uncertainty
Total H Cross section	3.6%
Luminosity	3.4%
Photon ID and Reco	2.5%
Trigger Efficiency	2%
Track Reconstruction	6%

- The track uncertainty covers material effects and the behaviour of the tracking algorithms with two close by tracks

Final $m_{M\gamma}$ Fit





	Observed yields (Mean expected background)					Expected signal yields	
	Mass range [GeV]					H	Z
	All	81–101		120–130		$[\mathcal{B} = 10^{-4}]$	$[\mathcal{B} = 10^{-6}]$
$\phi\gamma$	12051	3364	(3500 ± 30)	1076	(1038 ± 9)	15.6 ± 1.5	83 ± 7
$\rho\gamma$	58702	12583	(12660 ± 60)	5473	(5450 ± 30)	17.0 ± 1.7	7.5 ± 0.6

Results

No significant excess was observed so limits are set on the branching ratio

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

- Naive scaling of these results to $3000\,\text{fb}^{-1}$ will give an order of magnitude improvement bringing the $\rho\gamma$ analysis close to the SM value.

Conclusions

Discovering the Higgs boson was just the beginning

- Probing its couplings especially to fermions can provide a telling window to the standard model
- Exclusive decays to mesons and photons can provide an opportunity to directly observe these couplings
- Work is on-going to explore these channels at the LHC with ATLAS