Search for the rare decay $H \to \phi\,\gamma$ with ATLAS data at $\sqrt{s} = 13$ TeV

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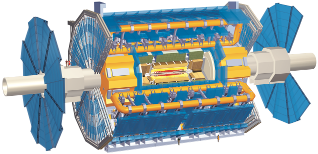
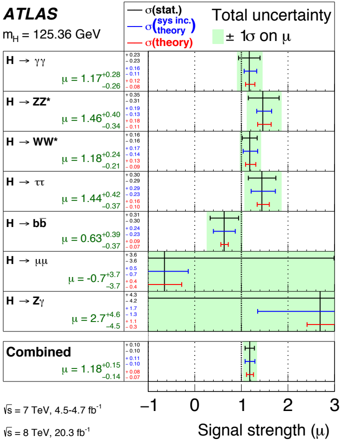
22nd March 2016



Motivation:

- Since the discovery of the Higgs boson, attention has now shifted to understanding the couplings of the particle to determine whether it is the SM Higgs boson
- Some searches aim to probe the Higgs Yukawa couplings to lighter quarks and explore the feasibility of decay channels for future higher luminosity investigations
- A search was performed by ATLAS last year for the rare decays of the Higgs and Z bosons to $\{J/\psi, \Upsilon(nS)\}, \gamma$

  (PRL 114, 121801 (2015) arXiv:1501.03276)



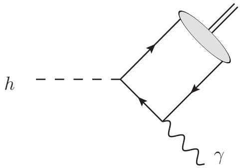
Eur. Phys. J. C (2016) 76:6 $\mu = \sigma/\sigma_{SM}$

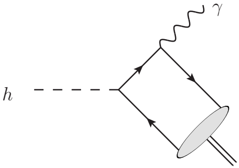
- Now searching for $H(Z) \to \phi\gamma$ to provide a probe of the $H \to s\bar{s}$ Yukawa coupling - **entirely unconstrained by existing measurements**

$H \rightarrow V\gamma$ Production Mechanisms

Direct Contribution:

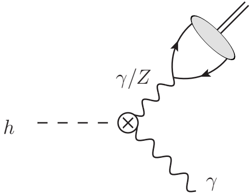
- Higgs boson decays to quark-antiquark pair
- One quark radiates a photon before forming a quarkonium





Indirect Contribution:

- Higgs boson decays through a top-quark or vector-boson loop to γ and a $\gamma*$ (virtual photon)
- Virtual photon then decays in to quarkonium
- Decay amplitudes can be inferred from $H \rightarrow \gamma\gamma$ and the coupling of the quarkonium to a virtual photon



SM Branching Fractions

Predictions for SM branching fractions:

- Expected H and Z SM branching fraction of $\mathcal{O}(10^{-6})$ and $\mathcal{O}(10^{-8})$:
  - $\boldsymbol{\mathcal{B}(H \to \phi\,\gamma) = (2.3 \pm 0.1) \times 10^{-6}}$

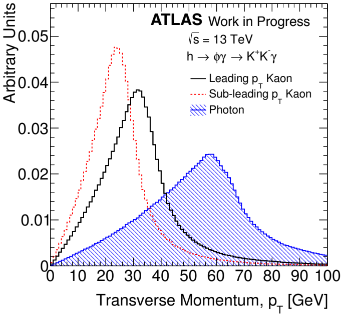
    - JHEP 1508 (2015) 012 (arXiv:1505.03870)
  - $\boldsymbol{\mathcal{B}(Z \to \phi\,\gamma) = (1.2 \pm 0.1) \times 10^{-8}}$

    - PRD 92, 014007 (2015) (arXiv:1411.5924)
- At this small branching fraction we expect only a small number of events ($\sim$350) over the lifetime of ATLAS (3000 fb^{-1})
- **The observation of a deviation from the SM branching fraction could indicate potential BSM physics**

Analysis Strategy

Aim

- Perform first search for $H \to \phi\gamma$ decays with the ATLAS 2015 pp data at $\sqrt{s} = 13$ TeV
- Develop a simple cut-based blind analysis
- **Provide the first direct sensitivity to strange quark Yukawa coupling**
- Also performing a similar search for $Z \to \phi\gamma$ decays



Plan

- Reconstruct only $\phi \to K^+K^-$ decays, $\mathcal{B}(\phi \to K^+K^-) = 49\%$ (the rest of ϕ width is into $K_s^0 K_L^0$ and inclusive hadronic decays)
- Exploit the distinctive topology of a pair of high p_T isolated tracks, with a very small opening angle ($\Delta R < 0.05$), recoiling against a hard isolated photon
- **Implement and commission dedicated trigger to collect these events - No appropriate ATLAS triggers in Run 1**

Trigger and Samples

HLT $\phi \to K^+K^-$ Selection:

- The topology of a boosted $\phi \to K^+K^-$ is somewhat similar to a low multiplicity hadronic τ decay
- Require exactly two tracks with invariant mass (under pion hypothesis) of $200 < m_{\pi\pi} < 450$ MeV
- The leading track (in p_T) must have $p_T > 15$ GeV

Data Sample

- Data sample corresponding to **2.73 fb^{-1}** was collected during the latter half of the 2015 $\sqrt{s} = 13$ TeV run

MC Samples

- Generated ggH, VBF, WH, ZH MC samples (∼100k events each)
- Also a Z MC simulation sample (∼60k events)

Analysis Kinematic Selection:

- Photons must satisfy $p_T^\gamma > 35$ GeV
- Leading track $p_T > 20$ GeV and sub-leading track $p_T > 15$ GeV
- Linearly increasing di-track transverse momentum requirement, from 40 GeV at $m_{KK\gamma} \leq 91$ GeV to 45 GeV at $m_{KK\gamma} \geq 125$ GeV
- Require $\Delta\phi(K^+K^-, \gamma) > 0.5$ (removes $\sim$ collinear $\phi\gamma$ pairs)
- Require detector η limitations

Estimation of the acceptances from Higgs MC simulation samples using the analysis kinematic selection:

Higgs Production	Acceptance
ggH	45%
VBF	41%
WH	36%
ZH	37%

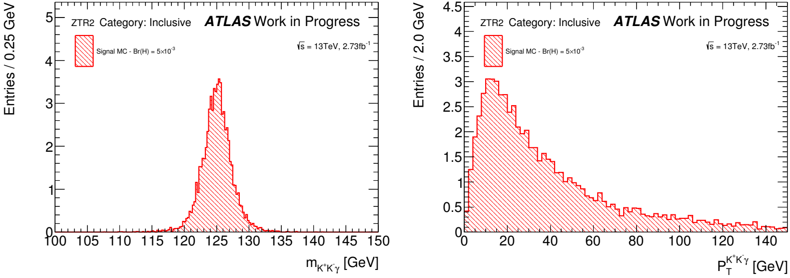
Z Production	20%

Signal Region (ZTR2)

In addition to kinematic selection requirements:

- Require standard ATLAS isolation requirements on photon and tracks
- Require consistency with ϕ mass: $|m_{KK} - m_\phi| < 20$ MeV

Three-body distributions in H Signal MC:

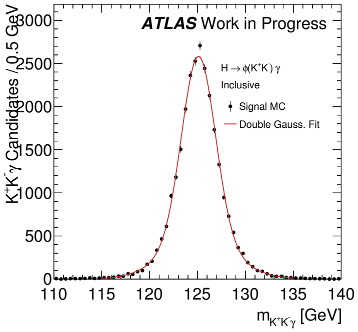


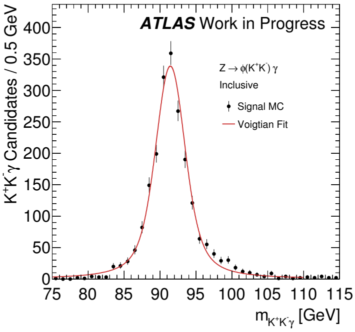
Selection essentially defined by trigger and detector acceptance, total $A \times \epsilon$ around 18% for Higgs signal and 8% for the Z signal

Three-body Mass Resolution:

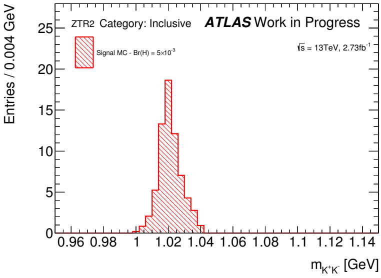
- Estimated by fitting a double Gaussian to the simulated signal three body mass distributions

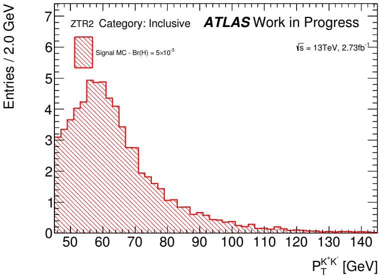
- Events are split into four individual categories based on track η and photon conversion status (i.e. converted or unconverted) - **mass resolution ranges between 1.5 GeV (Barrel Unconverted) and 2.4 GeV (Endcap Converted) for Higgs signal**

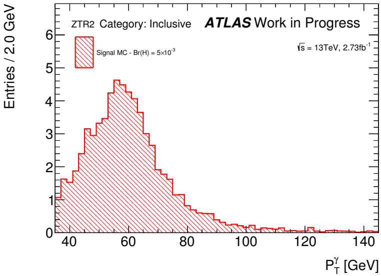


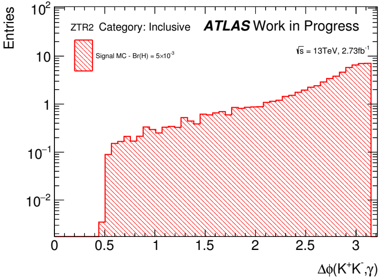


Kinematic Distributions in H Signal MC



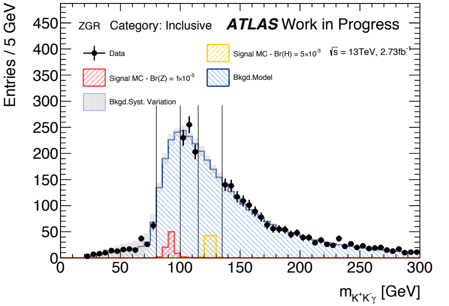






Background Model:

- Expected to be dominated by multi-jet and γ+jet processes, where the ϕ meson is within the jet
- Events from a loose selection in data are used to build templates for the kinematic distributions of the ϕ candidate and photon
- Correlations between distributions are modelled and retained
- Distributions are sampled to build "pseudo-candidates" for the three-body 4-vector

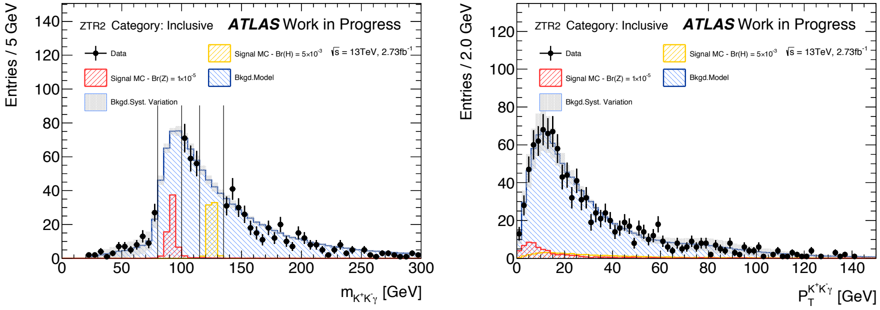


- Large samples of "pseudo-candidates" are used to build background model templates in the important kinematic distributions (e.g. $m_{KK\gamma}$)

Background model normalised to data in a loose region where all requirements apart from isolation and ϕ p_T are applied

Distributions - Inclusive Three-body Mass and p_T

Region of $80 < m_{KK\gamma} < 100$ GeV and $115 < m_{KK\gamma} < 135$ GeV currently blinded



Signal normalisation: $\mathcal{B}(Z \to \phi\gamma) = 1 \times 10^{-5}$ and $\mathcal{B}(H \to \phi\gamma) = 5 \times 10^{-3}$

Expected Sensitivity

Based on predicted background normalisation, the following expected branching fraction limits at 95% CL are estimated:

- $\mathcal{B}(H \to \phi\,\gamma) = \mathcal{O}(10^{-3})$
- $\mathcal{B}(Z \to \phi\,\gamma) = \mathcal{O}(10^{-6})$

To be compared to expected SM values of:

- $\boldsymbol{\mathcal{B}(H \to \phi\,\gamma) = (2.3 \pm 0.1) \times 10^{-6}}$ - JHEP 1508 (2015) 012 (arXiv:1505.03870)
- $\boldsymbol{\mathcal{B}(Z \to \phi\,\gamma) = (1.2 \pm 0.1) \times 10^{-8}}$ - PRD 92, 014007 (2015) (arXiv:1411.5924)

Summary

Conclusion

- A search for the rare decays $H \to \phi\gamma$ has been developed using the 2015 ATLAS pp dataset at $\sqrt{s} = 13$ TeV ($2.73 fb^{-1}$)
- Background shape calculated using a data driven method and verified using signal side-bands
- Analysis currently blinded in regions of $80 < m_{KK\gamma} < 100$ GeV and $115 < m_{KK\gamma} < 135$ GeV
- Expected branching fraction limits of around $\mathcal{O}(10^{-3})$ (Higgs) and $\mathcal{O}(10^{-6})$ (Z)

Backup

ATLAS Detector