Searches for Exclusive Flavour-Violating Decays of the Higgs and Z Bosons to a Meson and a Photon with the ATLAS Experiment

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Flavour-Violating Decays with Displaced Vertices

- $H \to D^*\gamma$, $Z \to D^0\gamma$ and $Z \to K_s\gamma$ are heavily suppressed in the Standard Model: observation would imply the existence of flavour-violating couplings of the Higgs and Z bosons
- Decays have a distinct signature and are not yet constrained in experiment
- Able to use analysis techniques from simlar previous ATLAS exclusive searches such as $H(Z) \to (\phi/\rho)\gamma$ [1]
- Capture both D^* decays to $D^0\pi^0$ and $D^0\gamma$, where the π^0 and γ are soft
- Search for $D^0 \to K^-\pi^+$ and $K_s \to \pi^-\pi^+$ decay channels, where the D^0 $(c\tau_0 = 0.1 \text{ mm})$ and K_s $(c\tau_0 = 2.7 \text{ cm})$ decay vertices are displaced

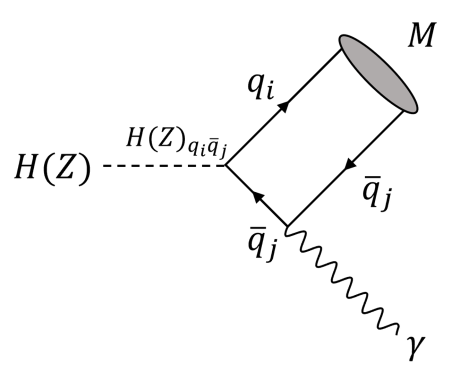

Figure 1: Feynman Diagram

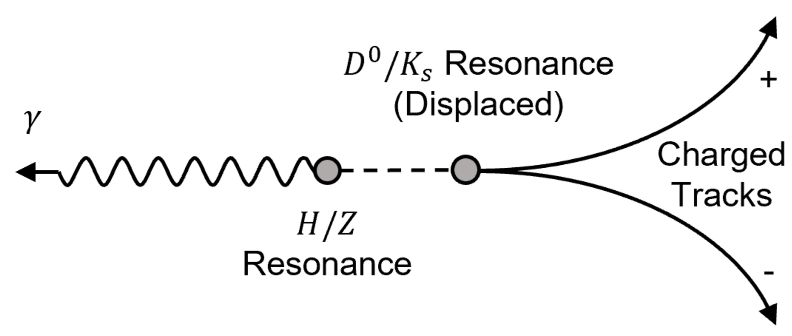

Figure 2: Experimental Signature

Event Selection

- ATLAS operated triggers dedicated to detection of these decays from 2016–2018, using modified τ-trigger algorithms
- $H \to D^*\gamma$ and $Z \to D^0\gamma$ searches share a selection, where the D^0 candidate in the decay of the D^* is targeted, and not the additional π^0 or γ

D^0 (K_s) Selection
$p_T^{sublead-track} > 5$ GeV
$p_T^{lead-track} > 20$ GeV
$\lvert\eta^{tracks}\rvert < 2.5$
Oppositely charged tracks
Loose quality tracks
$1800(460) < m^{D^0(K_s)} > 1930(538)$ MeV
$p_T^{D^0(K_s)} > 39(38)$ GeV
Isolated in Inner Detector
$D^0(K_s)$ vertex L_{xy} significance $> 3(5)$

γ Selection
$p_T^{\gamma} > 35$ GeV
$\lvert\eta^{\gamma}\rvert < 2.37$
$1.37 < \lvert\eta^{\gamma}\rvert < 1.52$
Tight quality
Isolated in Calorimeter
Isolated in Inner Detector
$\Delta\phi(D^0(K_s), \gamma) > \frac{\pi}{2}$

- Use highest-p_T photon and track-pair nearest meson mass if multiple exist

Non-Parametric Data-Driven Background Model

- Background is a complex mix of multi-jet and γ+jet events where a meson candidate is reconstructed within a jet
- Difficult to model with simulation so use a data-driven approach [2]
- $H \to D^*\gamma$ and $Z \to D^0\gamma$ searches share a background model

Procedure

1. Define a loose, background-dominated event selection region and model important variables and their correlations in data
2. Sample kinematic and isolation variables from model to generate pseudocandidate events
3. Apply validation region selections to pseudocandidates to evaluate model performance
4. Apply full signal region selection to get required background distribution

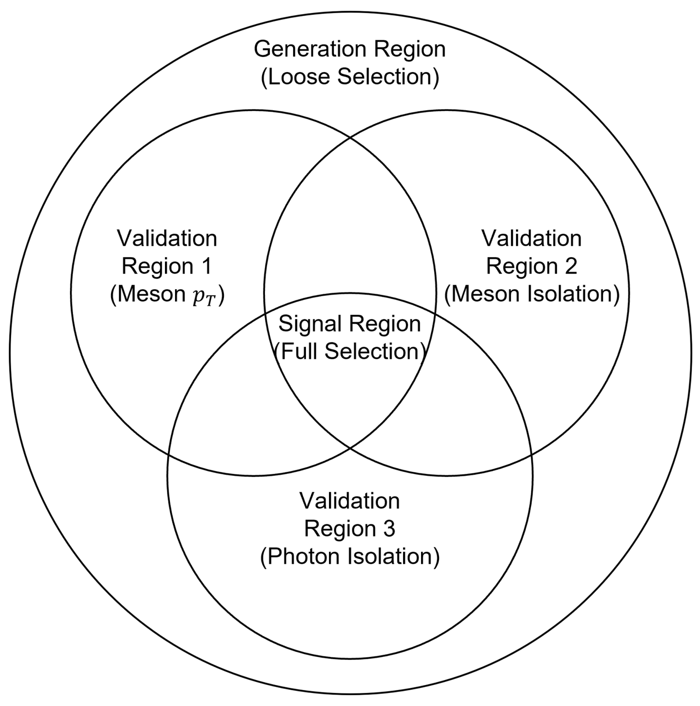

Figure 3: Overlapping Selection Regions

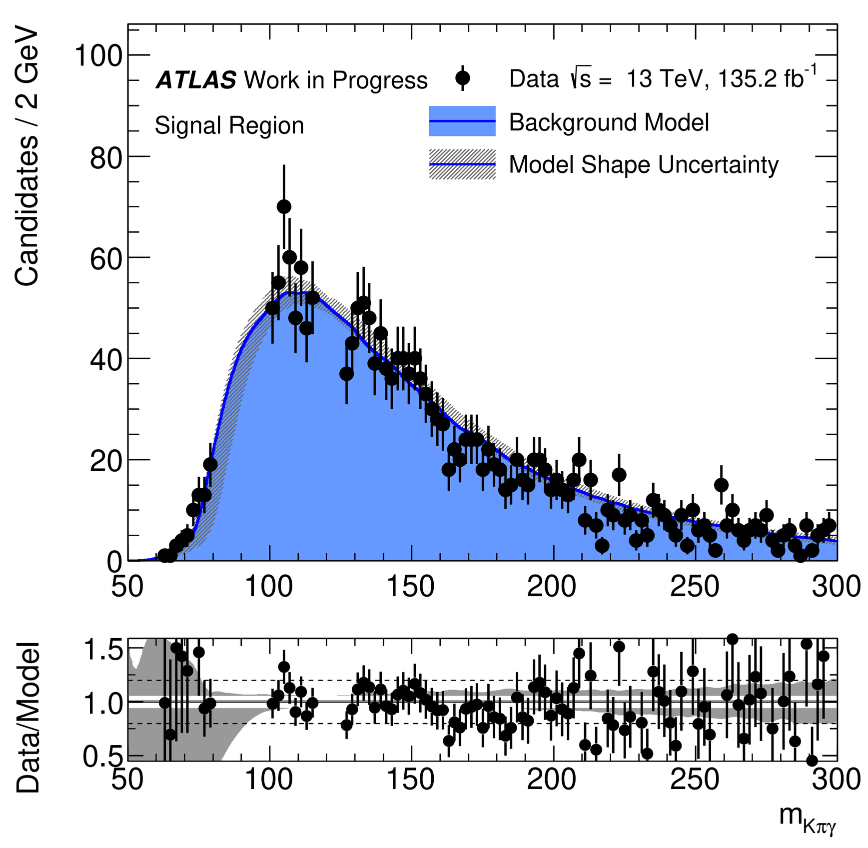

Figure 4: $H(Z) \to D^*(D^0)\gamma$ Background Model

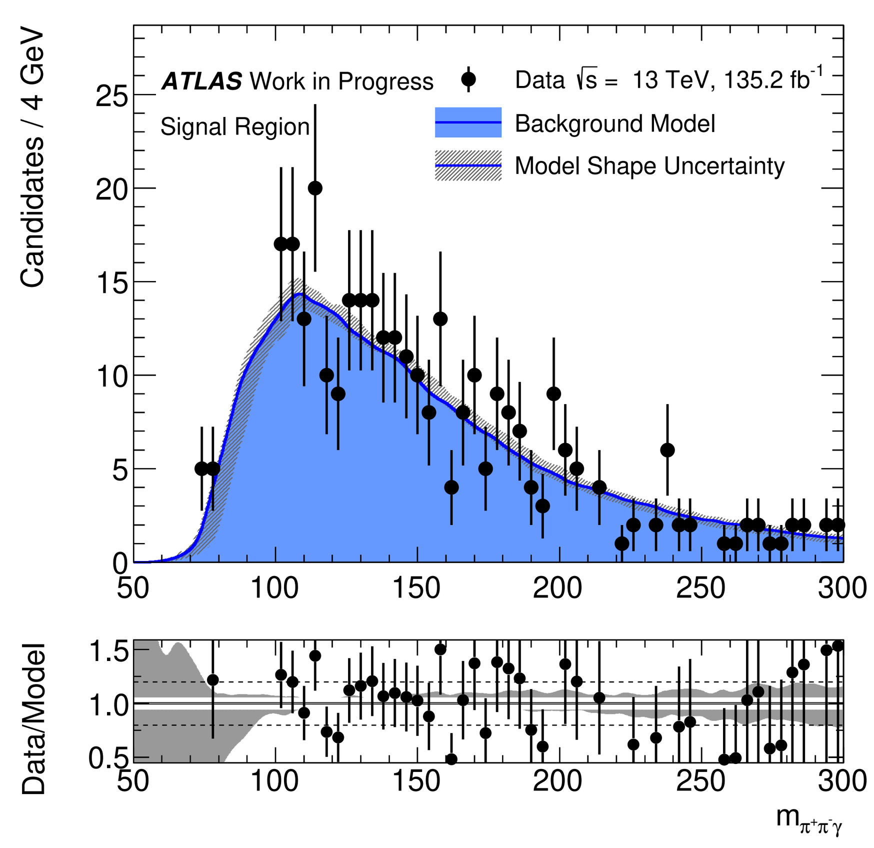

Figure 5: $Z \to K_s\gamma$ Background Model

Signal Model

$H \to D^*\gamma$

- Simulate Higgs boson production modes separately: gluon-gluon fusion, vector boson fusion, and associated production with a Z, $W^\pm$ or $t\bar{t}$ pair
- Model is a sum of two Gaussian functions
- Good resolution on H mass despite missing soft π^0/γ

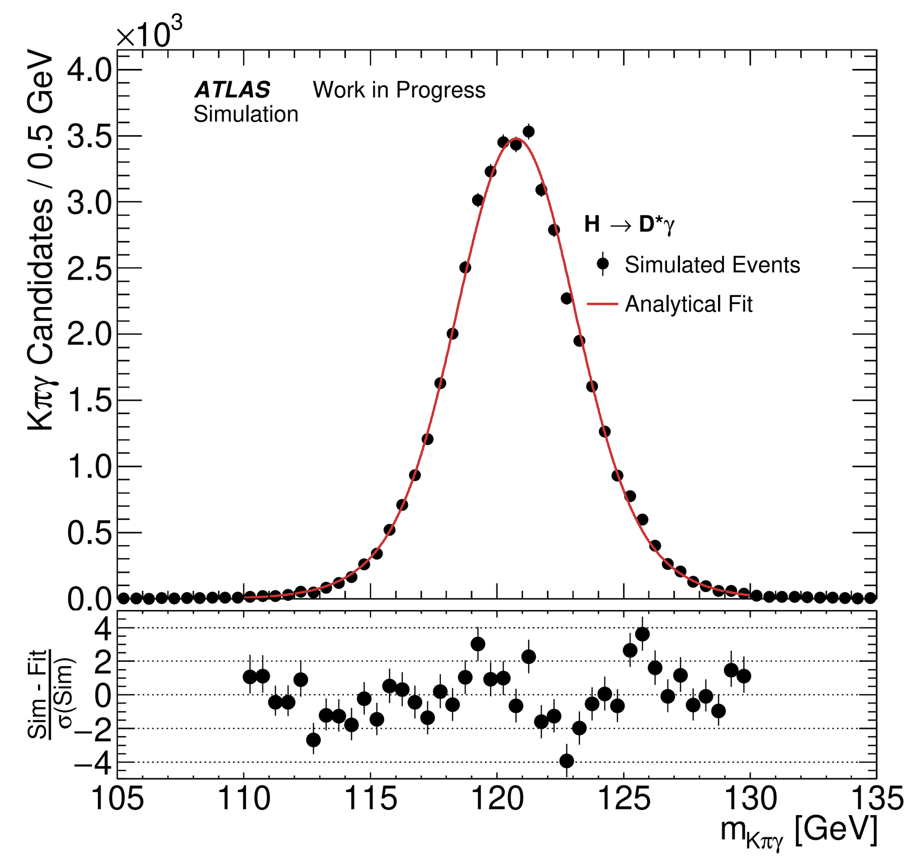

Figure 6: $H \to D^*\gamma$ Model

$Z \to D^0\gamma$ and $Z \to K_s\gamma$

- Simulate Z boson production inclusively
- Models are a sum of two Voigtian functions multiplied by mass-dependent efficiency

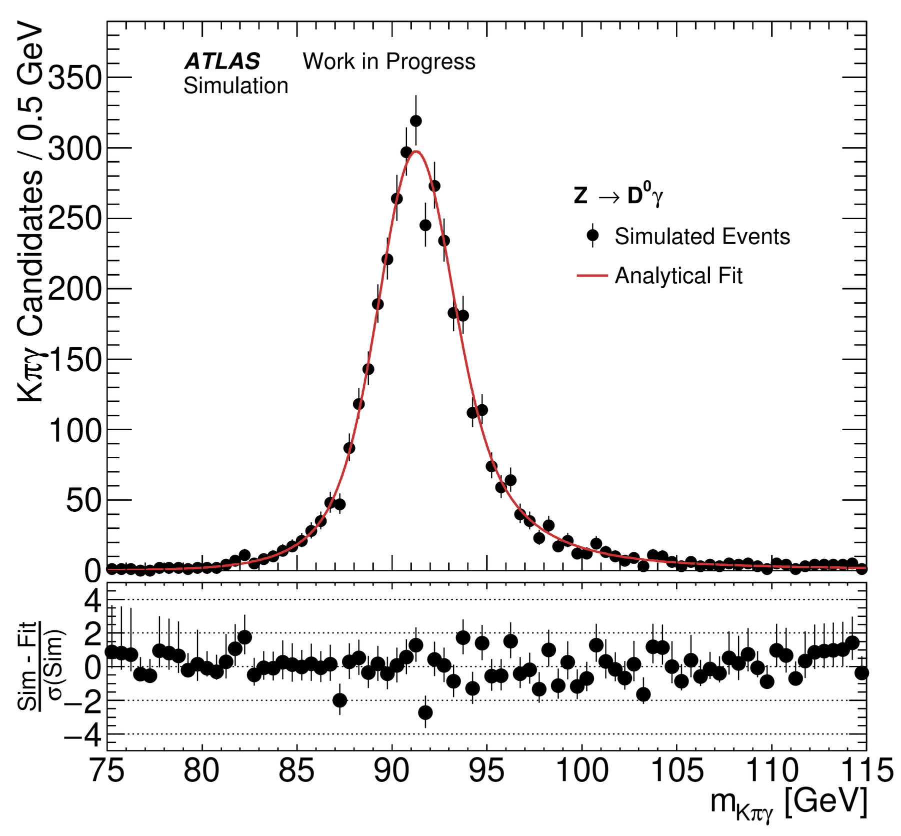

Figure 7: $Z \to D^0\gamma$ Model

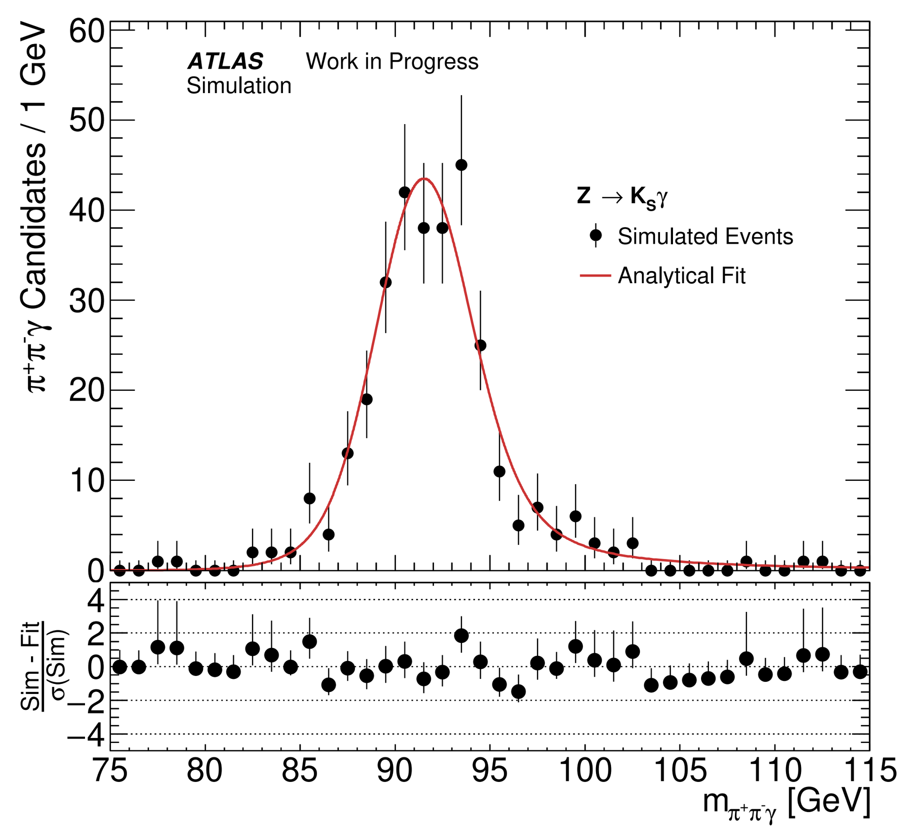

Figure 8: $Z \to K_s\gamma$ Model

Expected Results

Decay Channel	Expected Limit
$\mathcal{B}(H \to D^*\gamma)[\,10^{-3}\,]$	$1.3^{+0.5}_{-0.4}$
$\mathcal{B}(Z \to D^0\gamma)[\,10^{-6}\,]$	$2.6^{+1.1}_{-0.7}$
$\mathcal{B}(Z \to K_s\gamma)[\,10^{-6}\,]$	$2.5^{+1.1}_{-0.7}$

- Create Asimov dataset of expected backgrounds obtained from a fit to blinded data
- Extract expected limits on the decay branching fractions, including statistical uncertainties

Summary

- Use techniques from previous exclusive searches to look for new physics with flavour-violating decays of the Higgs and Z Bosons that involve displaced vertices
- Estimated expected limits using current signal and background models
- Next steps are to implement systematic shape and normalisation uncertainties

References

[1] ATLAS Collaboration, *Search for exclusive Higgs and Z boson decays to $\phi\gamma$ and $\rho\gamma$ with the ATLAS detector*, *JHEP* **07** (2018) 127, [1712.02758].

[2] A. Chisholm et al., *Non-Parametric Data-Driven Background Modelling using Conditional Probabilities*, 2112.00650.

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