Searches for exclusive Higgs and Z boson decays into a vector quarkonium state and a photon with the ATLAS experiment

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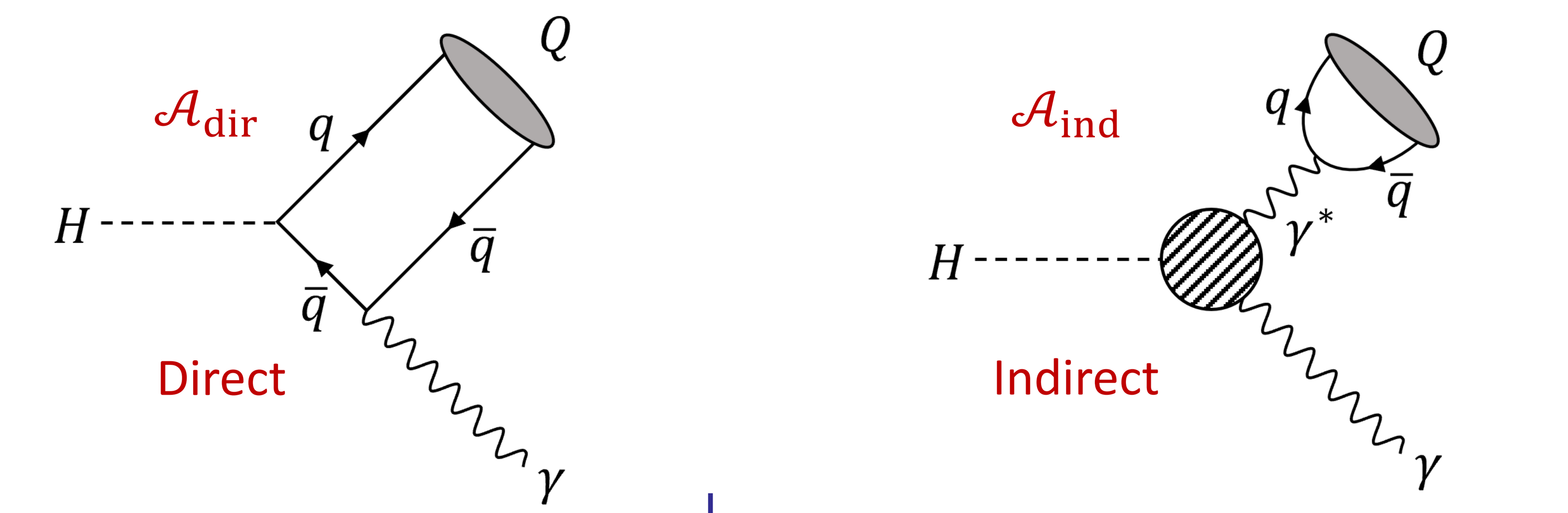
1. Motivation

- **$H \to Q\gamma$** sensitive to magnitude and sign of c- and b-quark Yukawa couplings
  - $\mathcal{A}_{\mathrm{dir}}$ and $\mathcal{A}_{\mathrm{ind}}$ contributions to decay amplitude destructively interfere



Charmonium: $Q = \mathrm{J}/\psi, \psi(2S)$

- $BR^{\mathrm{SM}}_{H\to\psi(nS)\gamma} \approx 10^{-6}$ †
- $|\mathcal{A}_{\mathrm{ind}}| \approx 20 \times |\mathcal{A}_{\mathrm{dir}}|$

Bottomonium: $Q = \Upsilon(1S, 2S, 3S)$

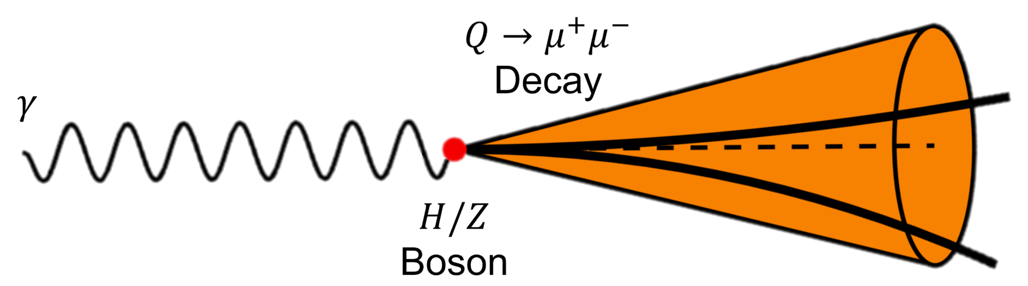
- $BR^{\mathrm{SM}}_{H\to\Upsilon(nS)\gamma} \approx 10^{-9} - 10^{-8}$ †
- $\mathcal{A}_{\mathrm{ind}}, \mathcal{A}_{\mathrm{dir}}$ almost cancel in SM

- **$Z \to Q\gamma$** offers a reference channel and a test of QCD factorisation
  - Receive analogous contributions from $\mathcal{A}_{dir}$ and $\mathcal{A}_{ind}$
  - $BR^{\mathrm{SM}}_{Z\to Q\gamma} \approx 10^{-8} - 10^{-7}$ ‡

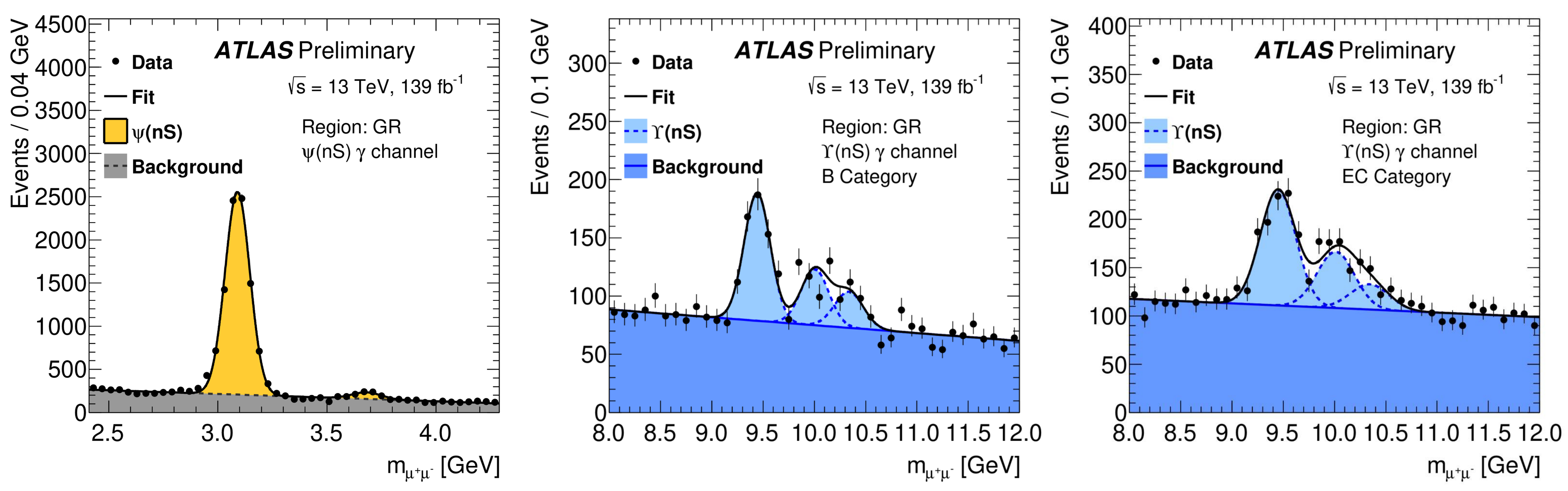
†Phys. Rev. D 100 (2019) 054038 ‡Phys. Rev. D 97 (2018) 016009

2. Event Selection

- Target $Q \to \mu^+\mu^-$: **Distinct signature**
  - Low QCD backgrounds compared to inclusive $H \to q\bar{q}$

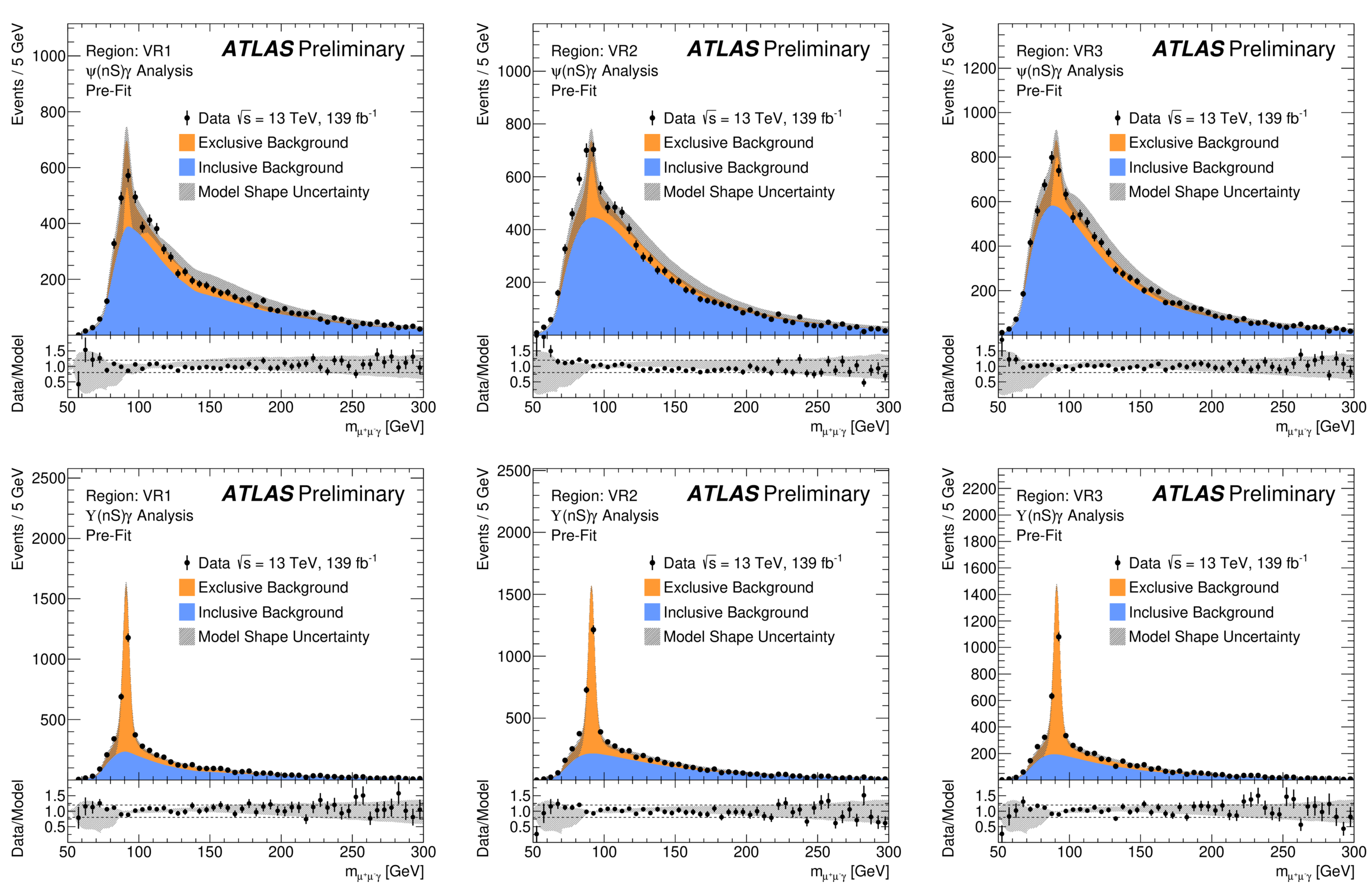


- **Dedicated** single photon + muon triggers with 139 fb^{-1} of $\sqrt{s}$ = 13 TeV data
  - Split $\Upsilon(nS)\gamma$ into barrel and endcap categories for better distinction between $\Upsilon(1S, 2S, 3S)$ states



3. Background Modelling

- **Exclusive background:** $q\bar{q} \to \mu^+\mu^-\gamma$
  - Analytical shape derived from a fit to simulated events
- **Inclusive background:** γ + jet and multi-jet events involving Q or $\mu^+\mu^-$
  - Non-parametric data-driven background model, based on ancestral sampling¶



- Assess performance in three validation regions
- Determine normalisation and constrain shape systematics using data

¶arXiv: 2112.00650 [hep-ex]; Phys. Lett. B 786 (2018) 134; JHEP 07 (2018) 127

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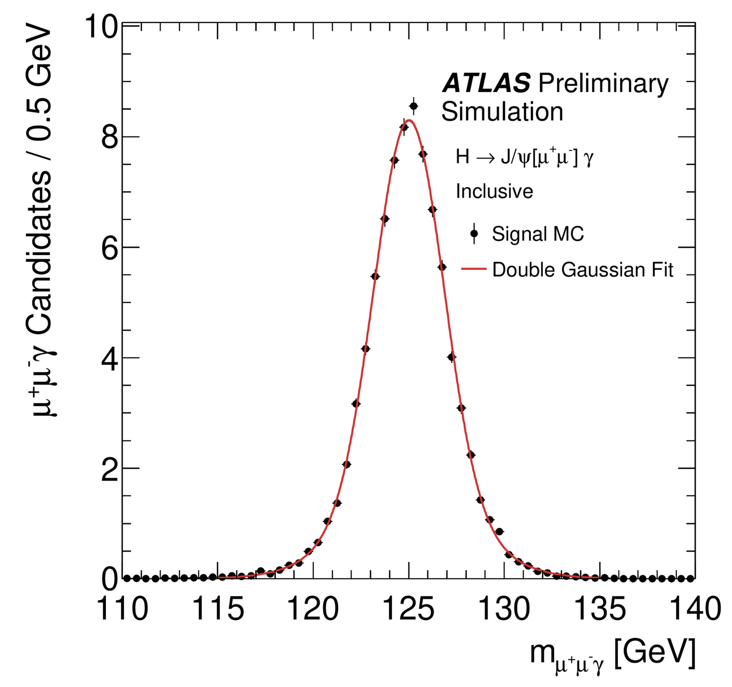
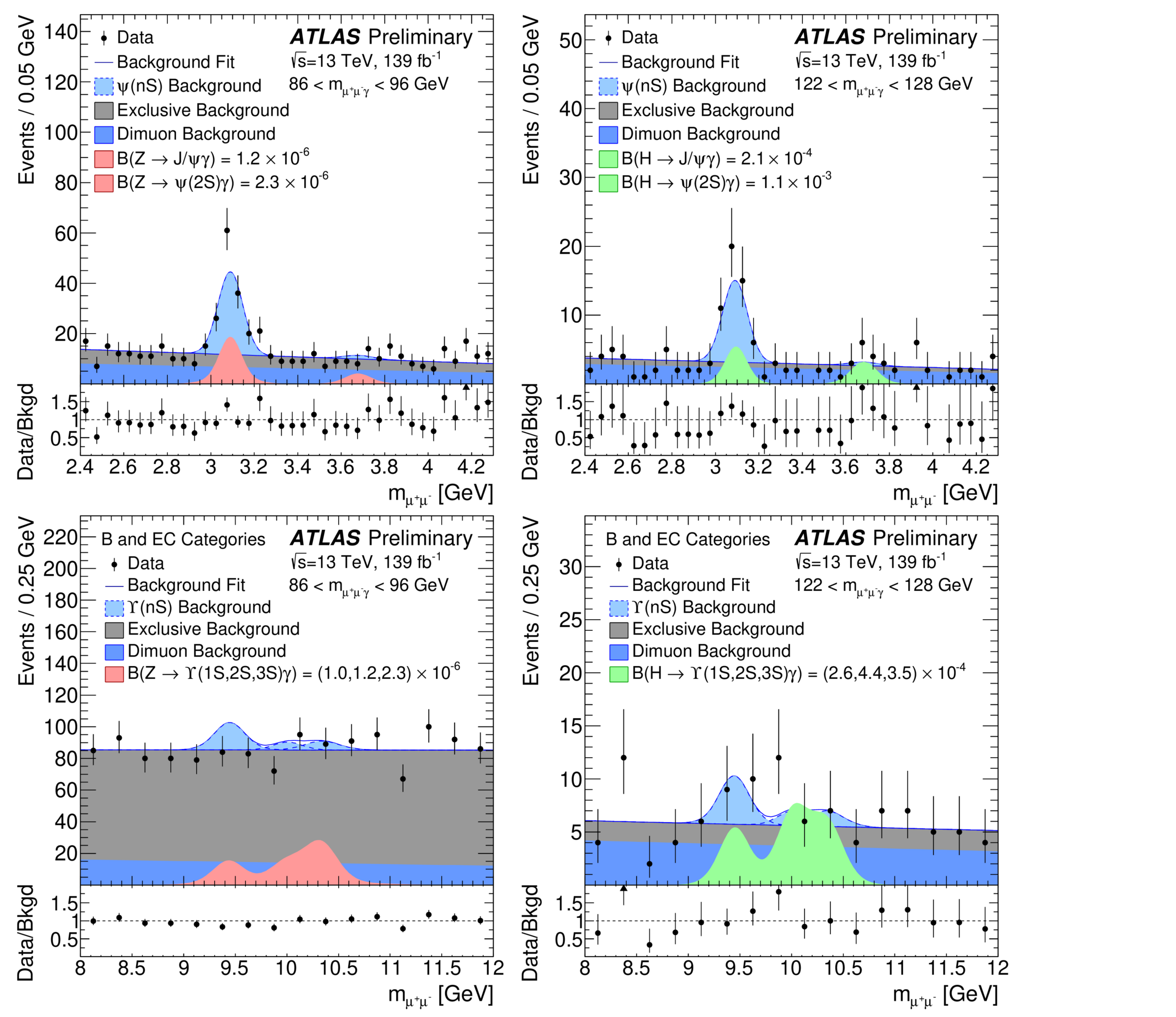
4. Signal Modelling

- Model H mass with double Gaussian distributions
  - Simulate ggH, VBF, VH, and $t\bar{t}H$ production modes separately
  - Acceptance ~ 19 – 21%
- Model Z mass with double Voigtian distributions × mass-dependent efficiency
  - Acceptance ~11 – 14%
- Resolution 1.6 – 1.8% for all signals

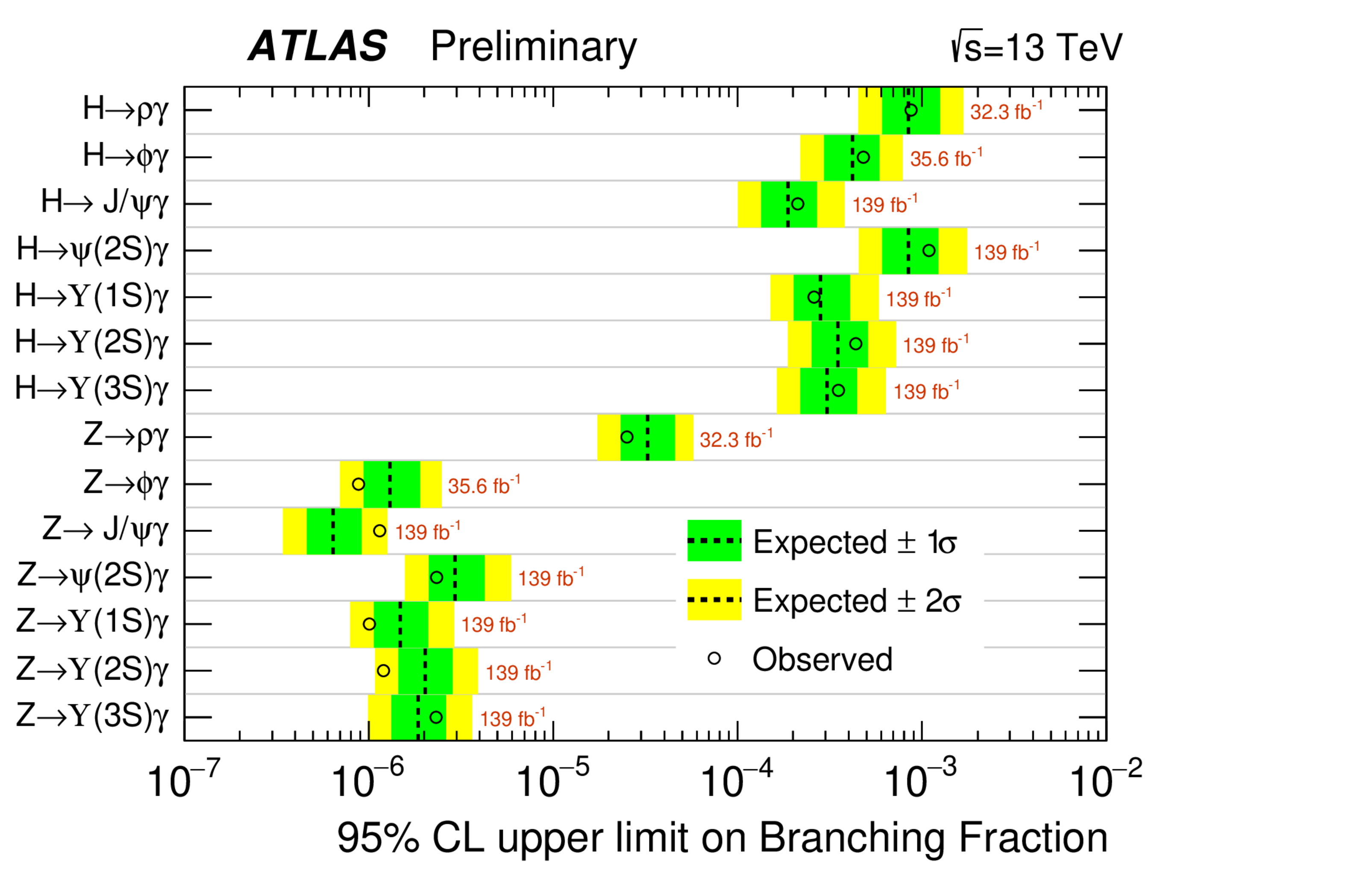


5. Results

- **2D unbinned maximum-likelihood fit** in $m_{\mu^+\mu^-\gamma}$ and $m_{\mu^+\mu^-}$
  - Distinguishes **all** signal and background sources from each other



- **Statistics limited:** Systematic uncertainties contribute at most 1% (5%) to the total uncertainty in the strength of the H (Z) signals
  - Main systematic uncertainty is the shape of the inclusive background



6. κ_c and κ_b Interpretation

- Define κ_q coupling modifier as the ratio of Yukawa coupling y_q over the SM-expectation: $\kappa_q = \frac{y_q}{y_q^{\mathrm{SM}}}$
- Combine with $H \to \gamma\gamma$ result§ to interpret in terms of $\kappa_{c,b}/\kappa_\gamma$, e.g.:

$$\frac{\mu_{H\to \mathrm{J}/\psi\,\gamma}}{\mu_{H\to\gamma\gamma}} \approx \frac{\left|\mathcal{A}_{\mathrm{ind}} + \frac{\kappa_c}{\kappa_\gamma}\mathcal{A}_{\mathrm{dir}}\right|^2}{\Gamma^{\mathrm{SM}}_{H\to \mathrm{J}/\psi\,\gamma}}$$

μ is the observed rate, normalised to the SM rate

- Observed (expected) bounds @ 95% CL:
  - κ_c/κ_γ: $[-136, 178]$ ($[-123, 164]$) from $H \to \mathrm{J}/\psi\,\gamma$
  - κ_b/κ_γ: $[-38, 40]$ ($[-37, 40]$) from combined $H \to \Upsilon(nS)\gamma$

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Exclusive Higgs