Rare Higgs and Z Boson Decays to a Meson and a Photon at the ATLAS experiment

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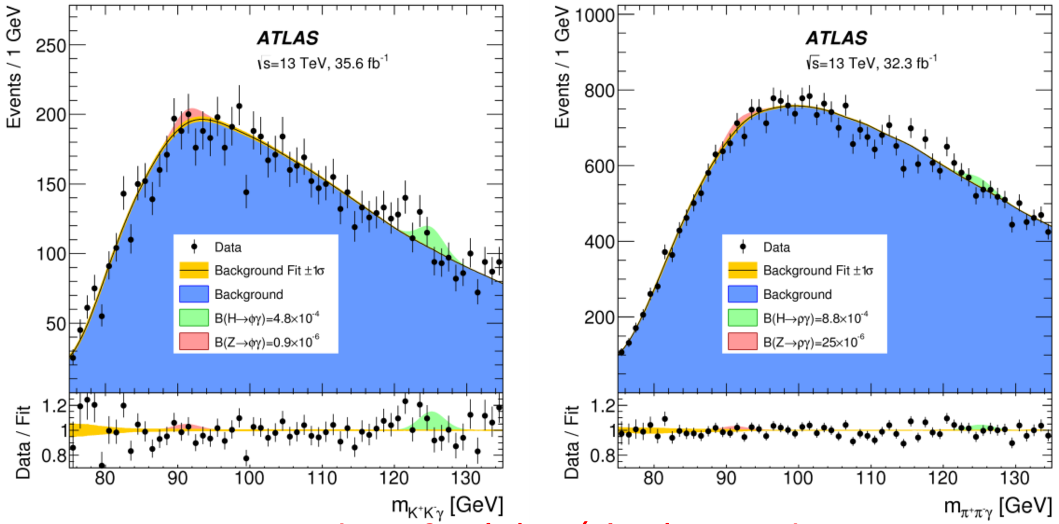
Decays of the Higgs and Z Bosons to a Meson and a Photon

- **ATLAS has conducted a sweep of $H(Z) \rightarrow \mathcal{M}\gamma$ searches**
  - Published 14 limits with 36.1 fb^{-1} of $\sqrt{s} = 13$ TeV data
    - Heavy mesons: $H(Z) \rightarrow Q\gamma;\ Q = J/\psi, \psi(2S), \Upsilon(1S, 2S, 3S)$
    - Light mesons: $H(Z) \rightarrow \phi\gamma$ and $H(Z) \rightarrow \rho\gamma$

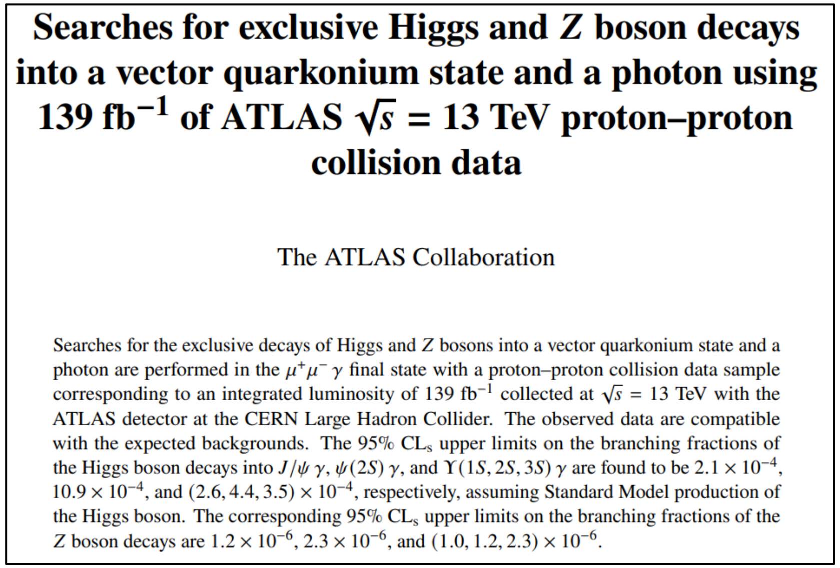
Published results:
$H(Z) \rightarrow (J/\psi, \psi(2S), \Upsilon)\gamma$ Partial Run 2: Phys.Lett.B 786 (2018) 134-155
$H(Z) \rightarrow (\phi, \rho)\gamma$ Partial Run 2: JHEP 07 (2018) 127
$H(Z) \rightarrow \phi\gamma$ Run 1: Phys.Rev.Lett. 117 (2016) 11, 111802
$H(Z) \rightarrow (J/\psi, \Upsilon)\gamma$ Run 1: Phys.Rev.Lett. 114 (2015) 12, 121801

  - Operate **dedicated** triggers and developed novel methods to model the backgrounds

- **Today I will showcase the latest $H(Z) \rightarrow Q\gamma$ search**
  - Use full 139 fb^{-1} of 13 TeV dataset
    - Results were public for ICHEP2022
    - Recently accepted by EPJC



Results of $H(Z) \rightarrow (\phi, \rho)\gamma$ Analyses



Searches for exclusive Higgs and Z boson decays into a vector quarkonium state and a photon using 139 fb^{-1} of ATLAS $\sqrt{s} = 13$ TeV proton–proton collision data

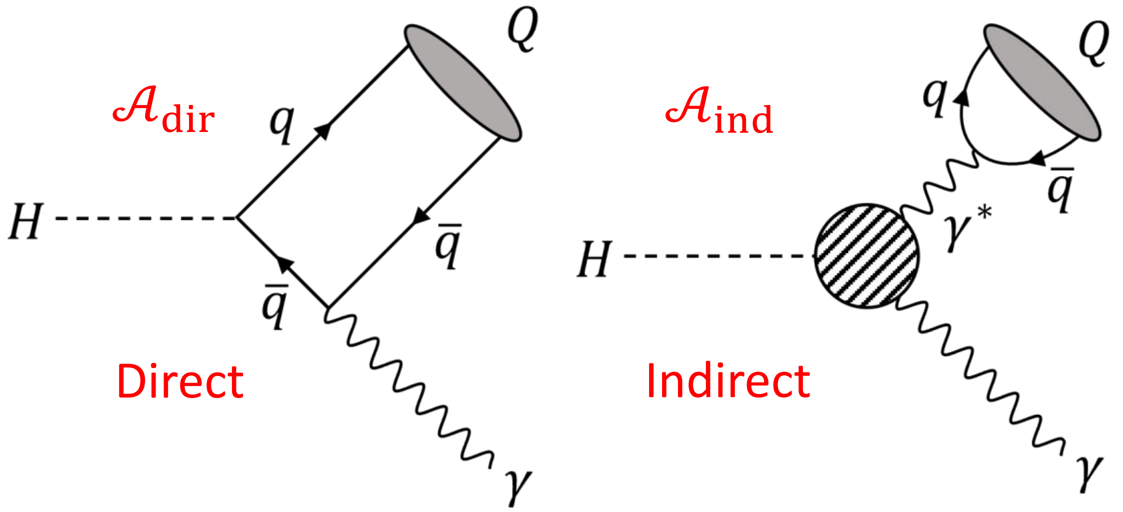
The ATLAS Collaboration

Searches for the exclusive decays of Higgs and Z bosons into a vector quarkonium state and a photon are performed in the $\mu^+\mu^-\gamma$ final state with a proton–proton collision data sample corresponding to an integrated luminosity of 139 fb^{-1} collected at $\sqrt{s} = 13$ TeV with the ATLAS detector at the CERN Large Hadron Collider. The observed data are compatible with the expected backgrounds. The 95% CL_s upper limits on the branching fractions of the Higgs boson decays into $J/\psi\,\gamma$, $\psi(2S)\,\gamma$, and $\Upsilon(1S, 2S, 3S)\,\gamma$ are found to be 2.1×10^{-4}, 10.9×10^{-4}, and $(2.6, 4.4, 3.5) \times 10^{-4}$, respectively, assuming Standard Model production of the Higgs boson. The corresponding 95% CL_s upper limits on the branching fractions of the Z boson decays are 1.2×10^{-6}, 2.3×10^{-6}, and $(1.0, 1.2, 2.3) \times 10^{-6}$.

New 139 fb^{-1} $H(Z) \rightarrow Q\gamma$ results: arXiv:2208.03122

$H(Z) \rightarrow Q\gamma$: Motivation

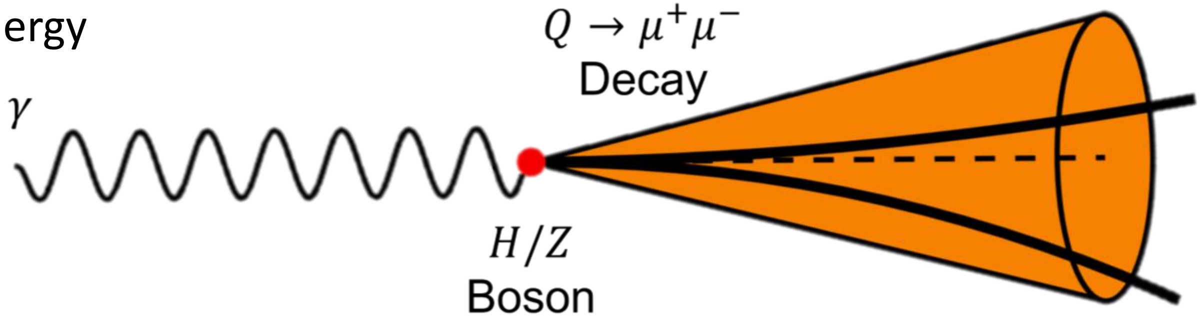
- **Search for $H(Z) \rightarrow Q\gamma \rightarrow \mu^+\mu^-\gamma$**
  - $Q = J/\psi, \psi(2S)$ (charmonium) or $\Upsilon(1S, 2S, 3S)$ (bottomonium)
  - Two contributions to decay amplitude, $\mathcal{A}_{\text{dir}}$ and $\mathcal{A}_{\text{ind}}$, which destructively interfere
  - Distinct signature avoids large QCD backgrounds seen in inclusive searches



Decay Amplitudes

- Higgs boson decays probe b- and c-quark Yukawa couplings
  - Sensitive to both the magnitude and the sign

- Z boson decays provide a test of QCD factorisation
  - Small power corrections in terms of the ratio of the QCD energy scale over Z mass
  - Clean probe of meson light cone distribution amplitudes from a theory perspective



Event Signature

$H(Z) \to Q\gamma$: Branching Ratio Predictions and Previous Results

Vector quarkonium state	SM branching fraction, $\mathcal{B}(H \to Q\gamma)$ Ref. [31] (2015)	Refs. [33, 34] (2017)	Ref. [36] (2019)
J/ψ	$2.95^{+0.17}_{-0.17} \times 10^{-6}$	$2.99^{+0.16}_{-0.15} \times 10^{-6}$	$3.01^{+0.15}_{-0.15} \times 10^{-6}$
$\Upsilon(1S)$	$4.61^{+1.76}_{-1.23} \times 10^{-9}$	$5.22^{+2.02}_{-1.70} \times 10^{-9}$	$9.97^{+4.04}_{-3.03} \times 10^{-9}$
$\Upsilon(2S)$	$2.34^{+0.76}_{-1.00} \times 10^{-9}$	$1.42^{+0.72}_{-0.57} \times 10^{-9}$	$2.62^{+1.39}_{-0.91} \times 10^{-9}$
$\Upsilon(3S)$	$2.13^{+0.76}_{-1.13} \times 10^{-9}$	$0.91^{+0.48}_{-0.38} \times 10^{-9}$	$1.87^{+1.05}_{-0.69} \times 10^{-9}$

Higgs boson decays

(Refs: 31, 33, 34, 36)

Vector quarkonium state	SM branching fraction, $\mathcal{B}(Z \to Q\gamma)$ Ref. [46] (2015)	Ref. [47] (2015)	Ref. [48] (2018)
J/ψ	$8.02^{+0.46}_{-0.44} \times 10^{-8}$	$9.96^{+1.86}_{-1.86} \times 10^{-8}$	$8.96^{+1.51}_{-1.38} \times 10^{-8}$
$\Upsilon(1S)$	$5.39^{+0.17}_{-0.15} \times 10^{-8}$	$4.93^{+0.51}_{-0.51} \times 10^{-8}$	$4.80^{+0.26}_{-0.25} \times 10^{-8}$
$\Upsilon(2S)$	-	-	$2.44^{+0.14}_{-0.13} \times 10^{-8}$
$\Upsilon(3S)$	-	-	$1.88^{+0.11}_{-0.10} \times 10^{-8}$

Z boson decays

(Refs: 46, 47, 48)

$J/\psi, \psi(2S)$:

- $|\mathcal{A}_{\text{ind}}| \approx 20 \times |\mathcal{A}_{\text{dir}}|$

$\Upsilon(1S, 2S, 3S)$:

- $\mathcal{A}_{\text{ind}}, \mathcal{A}_{\text{dir}}$ almost cancel in SM

- Previous ATLAS $Q\gamma$ result used 36.1 fb^{-1} of 13 TeV dataset
  - Updated results use full available 139 fb^{-1}
- CMS searched for $H(Z) \to J/\psi\,\gamma$ with 35.9 fb^{-1} at 13 TeV
  - $\mathcal{B}(H \to J/\psi\,\gamma) < 7.6 \times 10^{-4}$; $\mathcal{B}(Z \to J/\psi\,\gamma) < 1.4 \times 10^{-6}$
  - Eur. Phys. J. C 79 (2019) 94
- CMS also searched for $H(Z) \to QQ$ with 37.5 fb^{-1} at 13 TeV
  - Phys. Lett. B 797 (2019) 134811

Branching fraction limit (95% CL)	Expected	Observed
$\mathcal{B}(H \to J/\psi\,\gamma)$ [10^{-4}]	$3.0^{+1.4}_{-0.8}$	3.5
$\mathcal{B}(H \to \psi(2S)\,\gamma)$ [10^{-4}]	$15.6^{+7.7}_{-4.4}$	19.8
$\mathcal{B}(Z \to J/\psi\,\gamma)$ [10^{-6}]	$1.1^{+0.5}_{-0.3}$	2.3
$\mathcal{B}(Z \to \psi(2S)\,\gamma)$ [10^{-6}]	$6.0^{+2.7}_{-1.7}$	4.5
$\mathcal{B}(H \to \Upsilon(1S)\,\gamma)$ [10^{-4}]	$5.0^{+2.4}_{-1.4}$	4.9
$\mathcal{B}(H \to \Upsilon(2S)\,\gamma)$ [10^{-4}]	$6.2^{+3.0}_{-1.7}$	5.9
$\mathcal{B}(H \to \Upsilon(3S)\,\gamma)$ [10^{-4}]	$5.0^{+2.5}_{-1.4}$	5.7
$\mathcal{B}(Z \to \Upsilon(1S)\,\gamma)$ [10^{-6}]	$2.8^{+1.2}_{-0.8}$	2.8
$\mathcal{B}(Z \to \Upsilon(2S)\,\gamma)$ [10^{-6}]	$3.8^{+1.6}_{-1.1}$	1.7
$\mathcal{B}(Z \to \Upsilon(3S)\,\gamma)$ [10^{-6}]	$3.0^{+1.3}_{-0.8}$	4.8

Results of 36.1 fb^{-1} $H(Z) \to Q\gamma$: Phys. Lett. B 786 (2018) 134-155

$H(Z) \rightarrow Q\gamma$: Event Selection

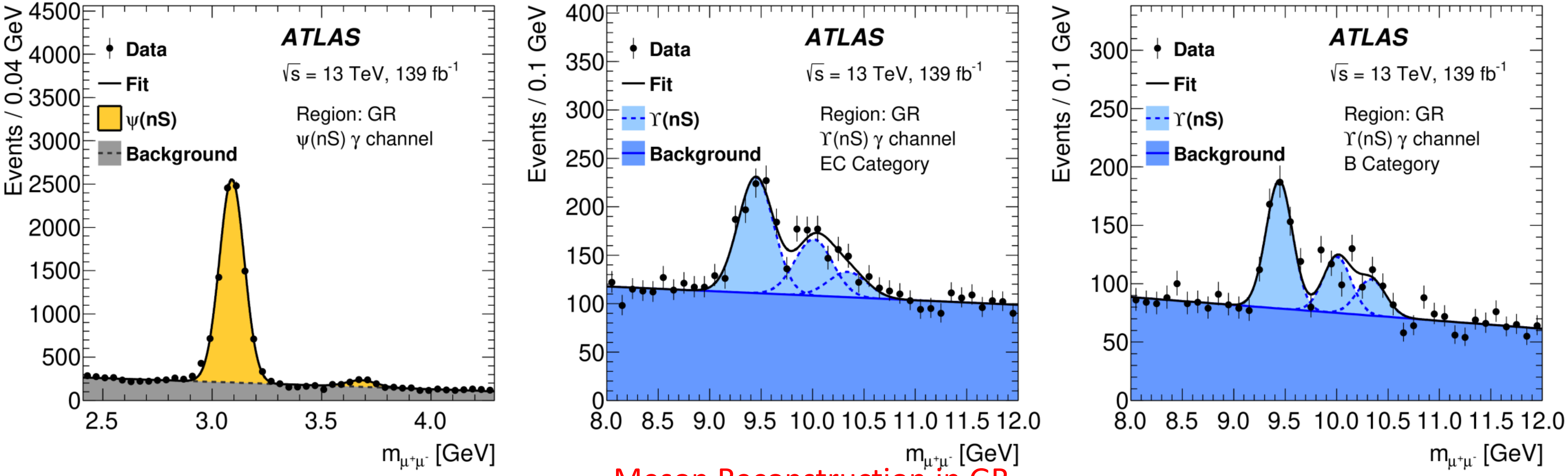
- Unique signature provides handle for triggering
  - Operated **dedicated** photon + muon triggers during Run 2, seeded from L1Calo
  - High trigger efficiency, $> 97\%$, with respect to offline selection

Photon Selection:
- $p_T^\gamma > 35$ GeV
- $|\eta^\gamma| < 2.37$ and outside transition region $1.37 < |\eta^\gamma| < 1.52$
- Tight quality
- $\Delta\phi(Q,\gamma) > \pi/2$
- Photon isolation

Meson Selection:
- $p_T^{\text{lead}} > 18$ GeV; $p_T^{\text{sublead}} > 3$ GeV
- $|\eta^\mu| < 2.5$
- Oppositely charged muons
- Medium quality
- $m(\mu^+\mu^-)$ near meson mass
- Transverse decay length significance $|L_{xy}/\sigma_{L_{xy}}| < 3$
- $p_T(\mu^+\mu^-)$ cut varies with $m(\mu^+\mu^-\gamma)$
- Muon isolation

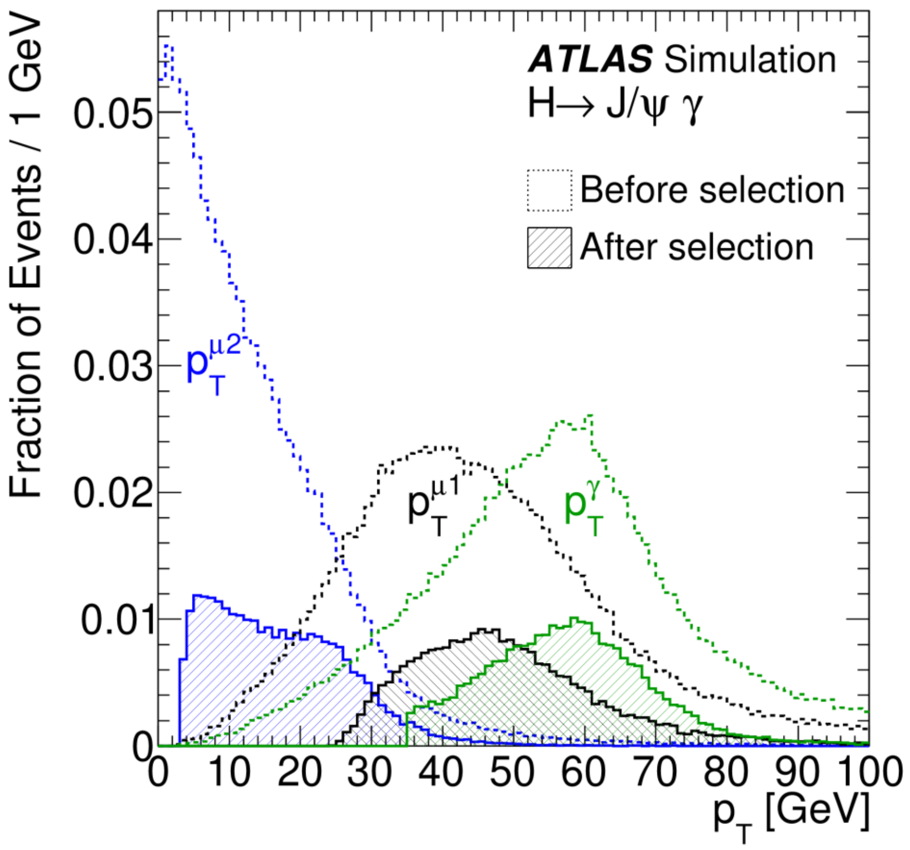
- Split $\Upsilon(nS)$ into Barrel (B) and Endcap (EC) categories
  - Improved resolution in barrel helps resolve each state

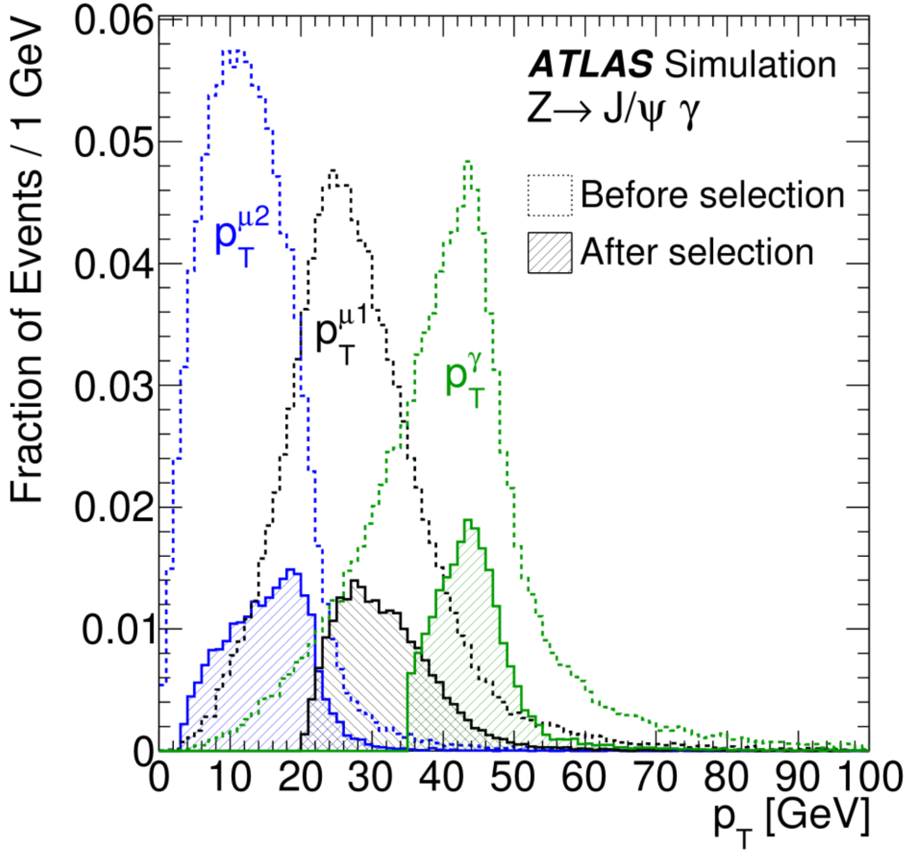
Red: Not applied in "Generation Region" (GR)



Meson Reconstruction in GR

$H(Z) \rightarrow Q\gamma$: Signal Efficiency





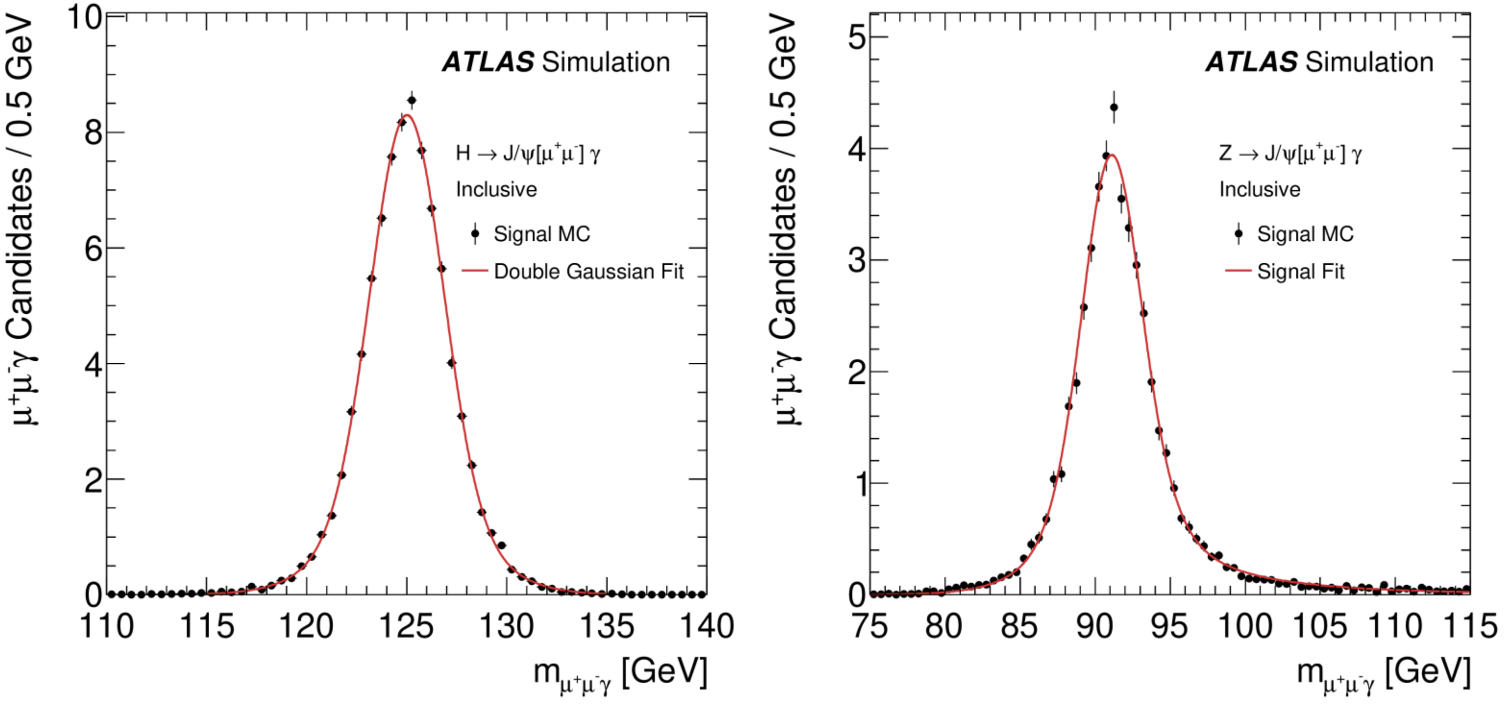
Generator-level p_{T} of Decay Products for J/ψ channels

- Total signal efficiencies:
  - $H \rightarrow \psi(nS)\gamma \approx 19\%$
  - $H \rightarrow \Upsilon(nS)\gamma \approx 21\%$
  - $Z \rightarrow \psi(nS)\gamma \approx 11\%$
  - $Z \rightarrow \Upsilon(nS)\gamma \approx 14\%$

- Softer photon and muon p_{T} in Z boson decays leads to smaller signal efficiencies compared to Higgs boson decays

$H(Z) \rightarrow Q\gamma$: Signal Modelling and Resolution

- Simulate signal event for all $Q\gamma$ decay channels with Monte Carlo
  - Consider all relevant Higgs boson production modes: gluon fusion, vector boson fusion, and WH, ZH and $t\bar{t}H$ associated production
  - Z boson samples are produced inclusively
- Achieve a signal resolution of $1.6\% - 1.8\%$ across all channels
  - Higgs boson shape: double Gaussian
  - Z boson shape: double Voigtian multiplied by mass-dependent efficiency



Signal Resolution for J/ψ channels

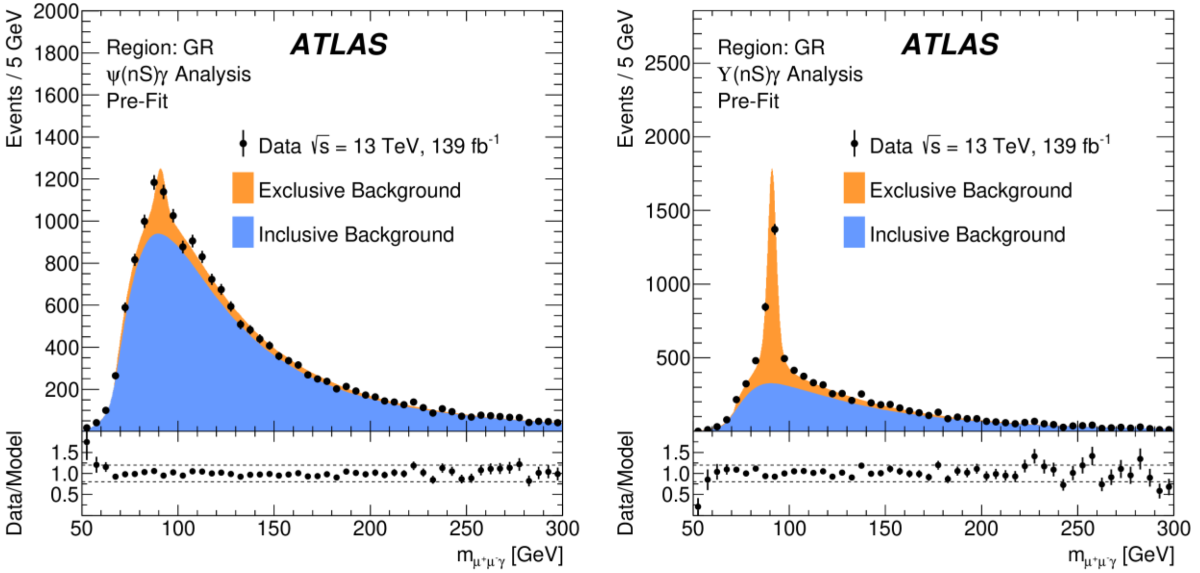
$H(Z) \rightarrow Q\gamma$: Signal Systematic Uncertainties

Source of systematic uncertainty	Signal yield uncertainty			
	$H \rightarrow \psi(nS)$	$H \rightarrow \Upsilon(nS)$	$Z \rightarrow \psi(nS)$	$Z \rightarrow \Upsilon(nS)$
Total cross section	5.8%		2.9%	
Integrated luminosity	1.7%		1.7%	
Signal acceptance	1.8%		1.0%	
Muon reconstruction	2.3%	2.2%	2.4%	2.4%
Photon identification	1.7%	1.7%	1.9%	1.9%
Pile-up uncertainty	0.8%	0.7%	1.1%	1.1%
Trigger efficiency	0.7%	0.7%	0.8%	0.8%
Photon energy scale	0.1%	0.1%	0.2%	0.2%
Muon momentum scale	0.1%	0.1%	0.5%	0.2%
Muon momentum resolution (ID)	<0.01%	0.01%	0.06%	0.02%
Muon momentum resolution (MS)	0.02%	0.01%	0.04%	0.01%

- Take into account relevant uncertainties on the total signal yield
    - Nuisance parameters with standard Gaussian constraints in maximum likelihood fit
    - Shape uncertainties found to be negligible

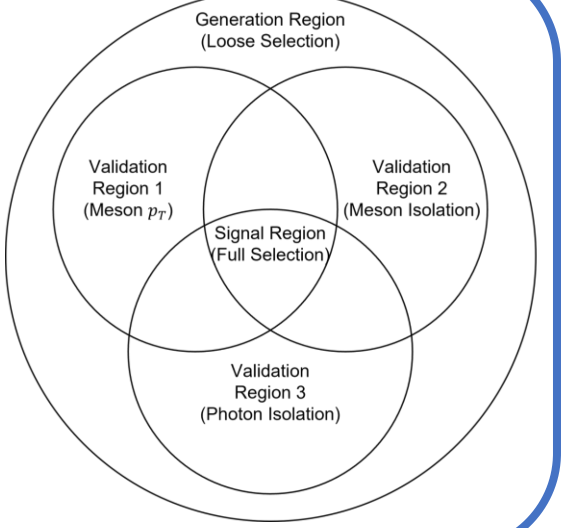
$H(Z) \to Q\gamma$: Background Modelling

- **Exclusive background**
  - $\mu^+\mu^-\gamma$ production via Drell-Yan
  - Modelled with an analytical fit to simulated events
    - Threshold function + Voigtian function
- **Inclusive background**
  - Multi-jet and γ+jet sources with Q or dimuon production
  - Non-parametric data-driven background model
    - JHEP 10 (2022) 001



Background in Generation Region

1. Model correlations in data in loose Generation Region, then sample pseudocandidate events
2. Apply Validation Region selection to evaluate performance
3. Apply Signal Region selection for final model



Region		$p_T^{\mu\mu}$	Photon Isolation	Q Isolation
Generation Region	(GR)	> 30 GeV	Relaxed	Relaxed
Validation Region 1	(VR1)	Full	Relaxed	Relaxed
Validation Region 2	(VR2)	> 30 GeV	Relaxed	Full
Validation Region 3	(VR3)	> 30 GeV	Full	Relaxed
Signal Region	(SR)	Full	Full	Full

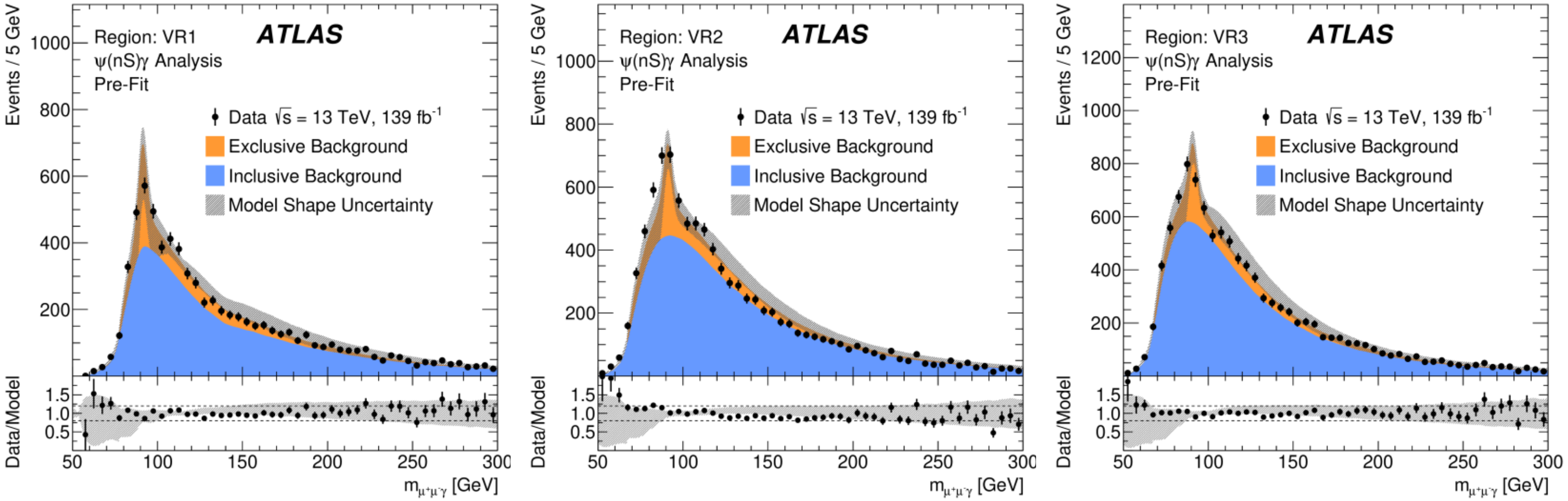
Region Definitions

$H(Z) \rightarrow Q\gamma$: Background Validation and Systematic Uncertainties

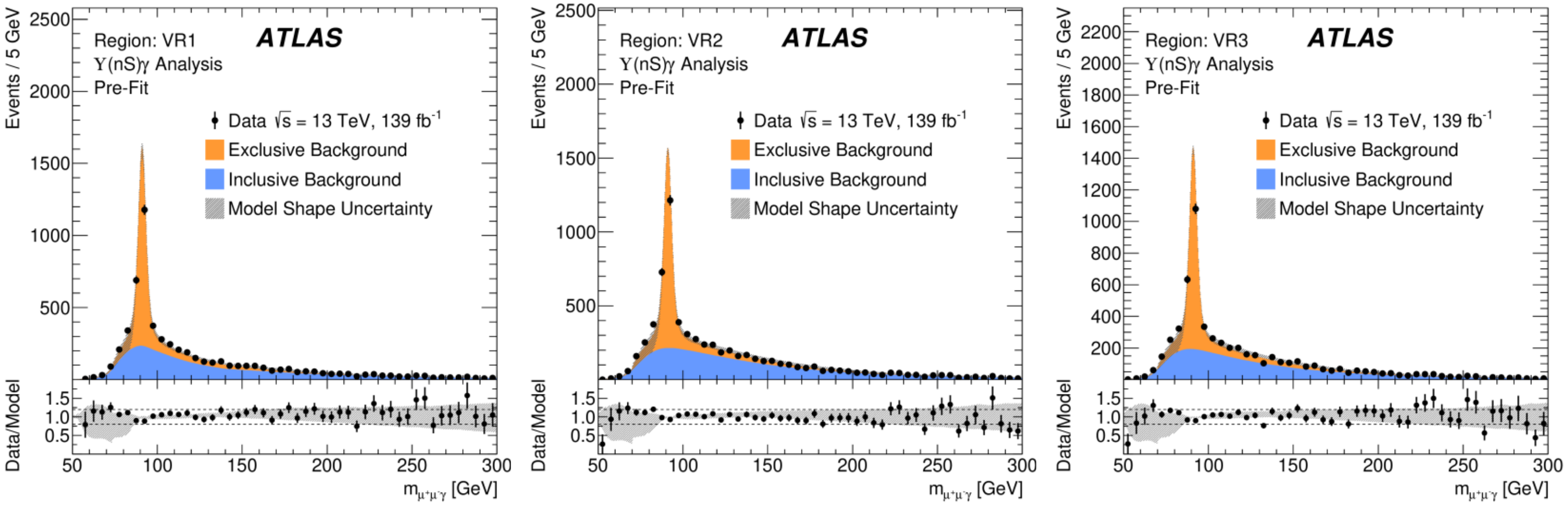
- Validation plots are pre-fit
  - Normalisation set to events in mass range
  - Ratio of inclusive/exclusive background extracted from GR
  - Each of these are free in final fit

- Systematic uncertainties accounted for with shape variations
  - Mass tilt: reweight mass distribution with a tilt function
    - Distribution can adapt to tilts in ratio
  - Photon p_T shift: shift generated photon p_T in GR
    - Distribution can shift higher/lower
  - $\Delta\phi$ distortion: reweight generated $\Delta\phi$ in GR
    - Width of distribution can increase/decrease

Background Validation



$\psi(nS)$ Background

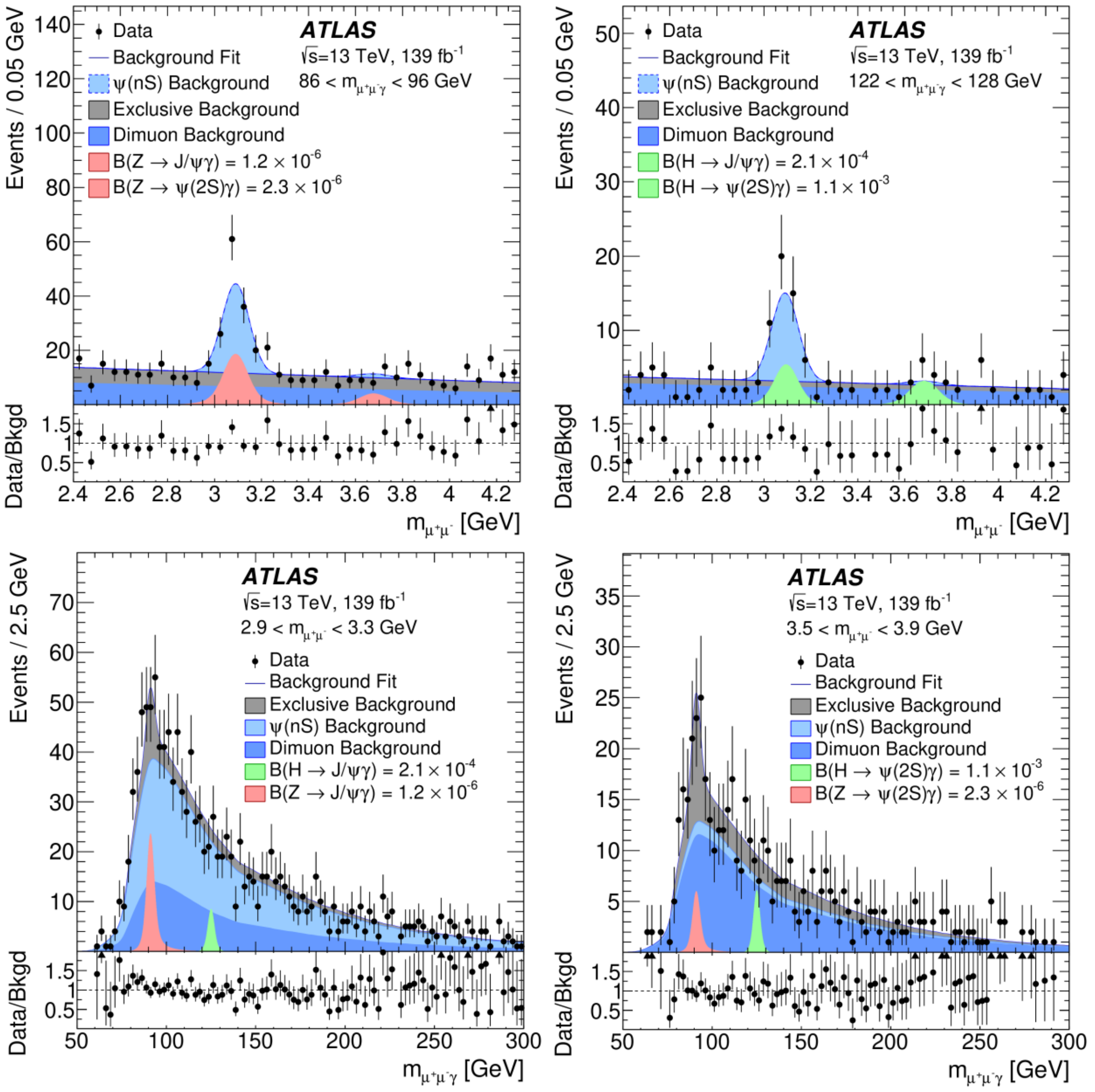


$\Upsilon(nS)$ Background

$H(Z) \rightarrow \psi(nS)\gamma$: Projection of Fit in Regions

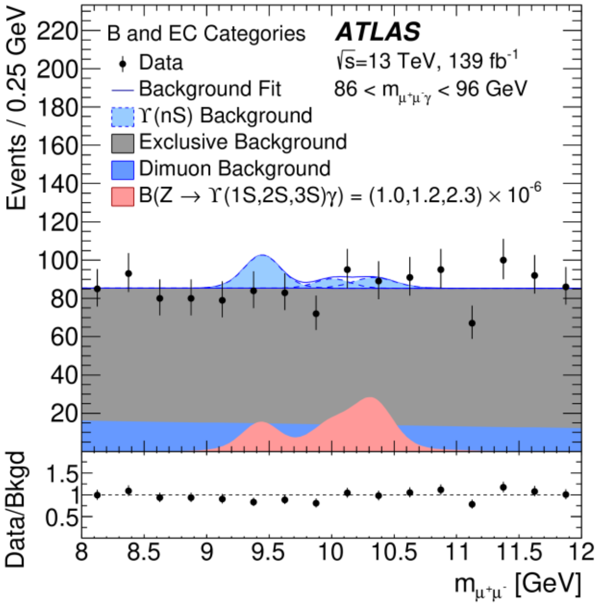
- Use **2D** unbinned likelihood fit in $m(\mu^+\mu^-), m(\mu^+\mu^-\gamma)$
  - Discriminates between **all** signal and background contributions

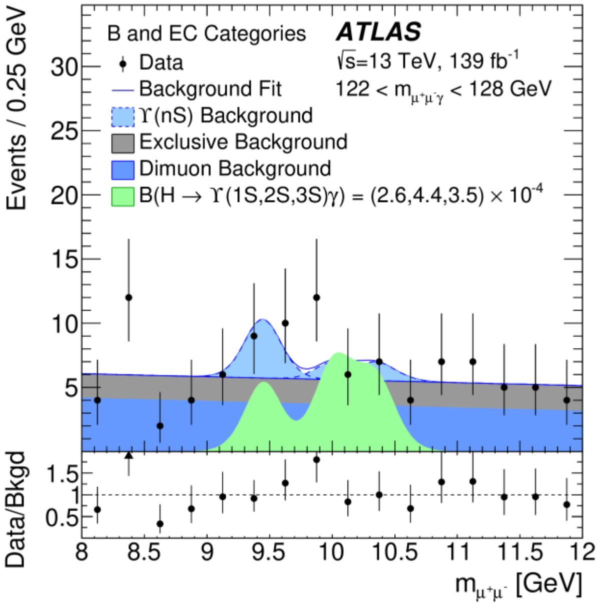
- $\psi(nS)\gamma$ analysis fit is performed inclusively in a single category
  - Fit to data with three-body mass < 300 GeV in the signal region
  - Project fit near each signal resonance

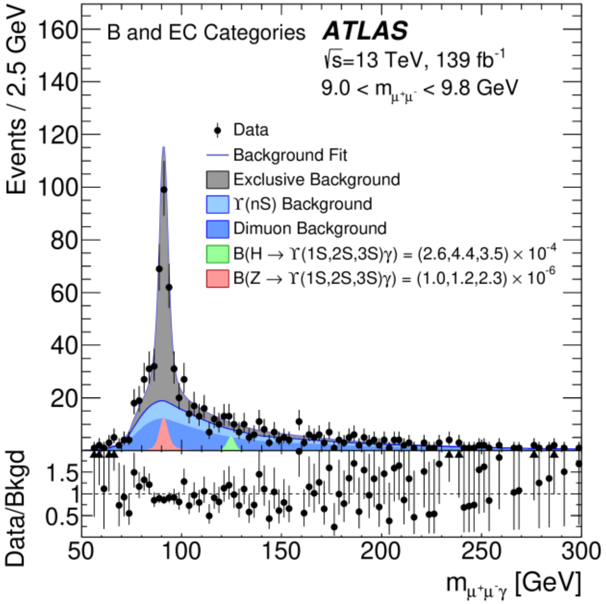


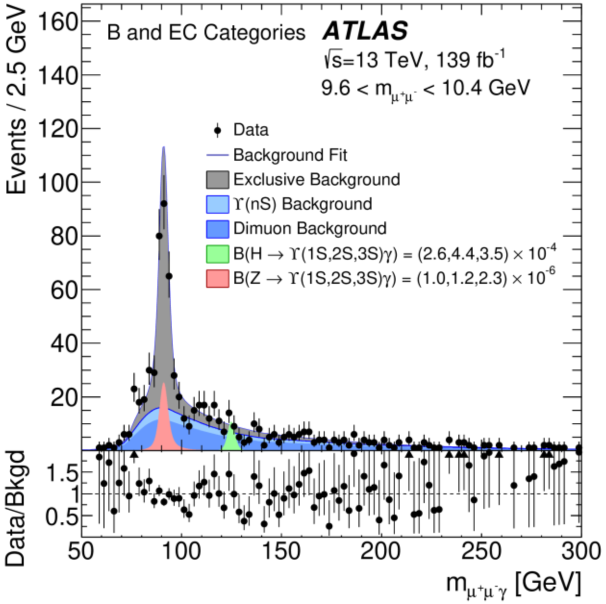
$H(Z) \rightarrow \Upsilon(nS)\gamma$: Projection of Fit in Regions

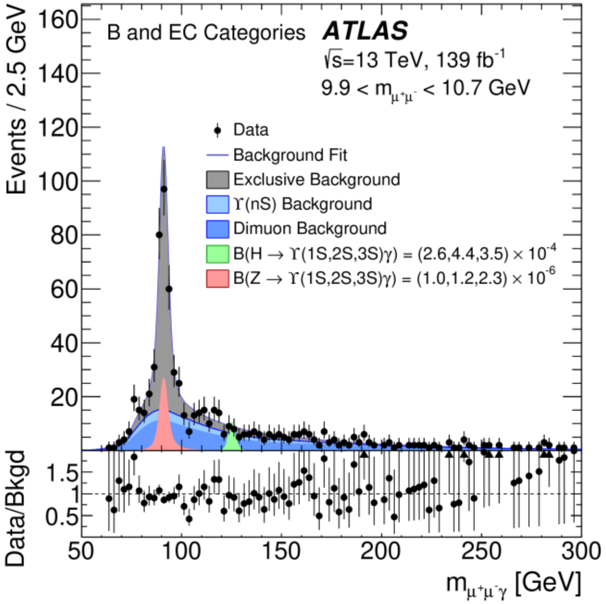
- Use **2D** unbinned likelihood fit in $m(\mu^+\mu^-), m(\mu^+\mu^-\gamma)$
  - Discriminates between **all** signal and background contributions
- $\Upsilon(nS)\gamma$ analysis fit is performed simultaneously in the barrel and endcap categories
  - Fit to data with three-body mass < 300 GeV in the signal region
  - Project fit near each signal resonance











$H(Z) \rightarrow Q\gamma$: 139 fb^{-1} Analysis Limits and κ Interpretation

- Extract 95% CL upper limits on decay channels
  - Approximately a factor two improvement over the 36.1 fb^{-1} result
- Statistical uncertainty dominates
  - Systematics reduce sensitivity to the H (Z) signals by at most 1% (5%)
  - Main systematics are in the inclusive background shape

Decay channel	95% CL upper limits: Branching fraction, Higgs boson [10^{-4}], Expected	Branching fraction, Higgs boson [10^{-4}], Observed	Branching fraction, Z boson [10^{-6}], Expected	Branching fraction, Z boson [10^{-6}], Observed	$\sigma \times \mathcal{B}$, Higgs boson [fb], Observed	$\sigma \times \mathcal{B}$, Z boson [fb], Observed
$J/\psi\,\gamma$	$1.9^{+0.8}_{-0.5}$	2.1	$0.6^{+0.3}_{-0.2}$	1.2	12	71
$\psi(2S)\,\gamma$	$8.5^{+3.8}_{-2.4}$	10.9	$2.9^{+1.3}_{-0.8}$	2.3	61	135
$\Upsilon(1S)\,\gamma$	$2.8^{+1.3}_{-0.8}$	2.6	$1.5^{+0.6}_{-0.4}$	1.0	14	59
$\Upsilon(2S)\,\gamma$	$3.5^{+1.6}_{-1.0}$	4.4	$2.0^{+0.8}_{-0.6}$	1.2	24	71
$\Upsilon(3S)\,\gamma$	$3.1^{+1.4}_{-0.9}$	3.5	$1.9^{+0.8}_{-0.5}$	2.3	19	135

- Combine with $H \rightarrow \gamma\gamma$ [§] to interpret in terms of $\kappa_{c,b}/\kappa_\gamma$:

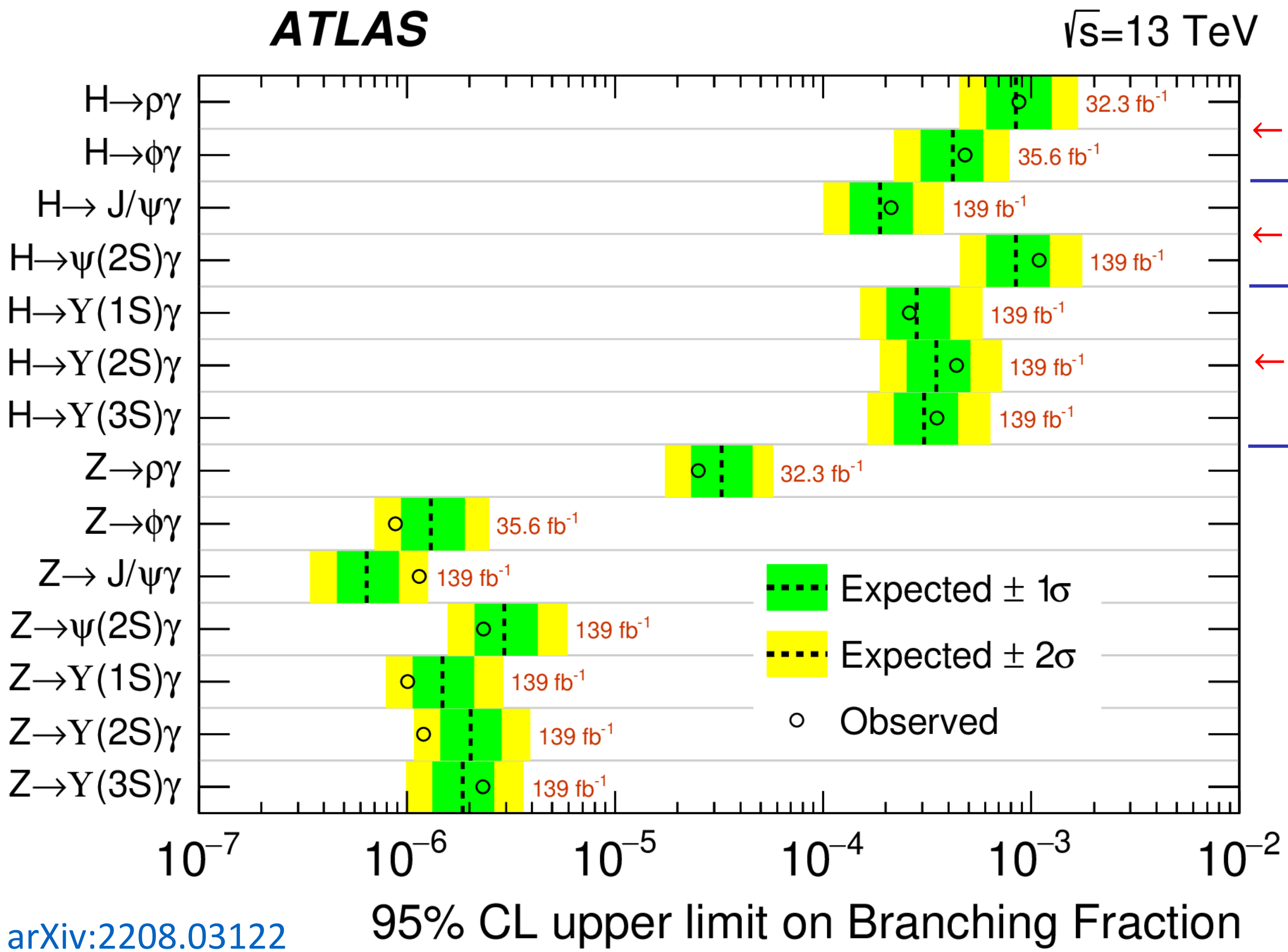
$$\frac{\mu_{H\rightarrow J/\psi\,\gamma}}{\mu_{H\rightarrow\gamma\gamma}} \approx \frac{\left|\mathcal{A}_{\rm ind} + \frac{\kappa_c}{\kappa_\gamma}\mathcal{A}_{\rm dir}\right|^2}{\Gamma^{\rm SM}_{H\rightarrow J/\psi\,\gamma}}$$

μ is the observed rate, normalised to the SM rate

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

[§] ATLAS-CONF-2020-026

Summary of Exclusive $H(Z) \rightarrow M\gamma$ Search Results



← Light mesons: JHEP 07 (2018) 127

← Charmonium

← Bottomonium

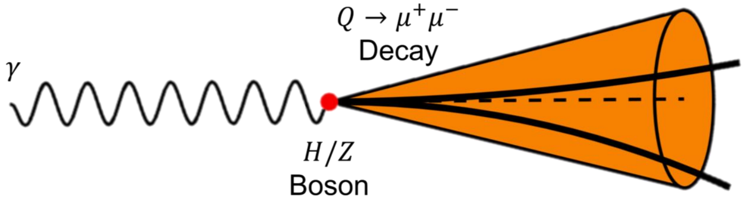
- ATLAS has the most stringent limits on each of these decay channels

arXiv:2208.03122

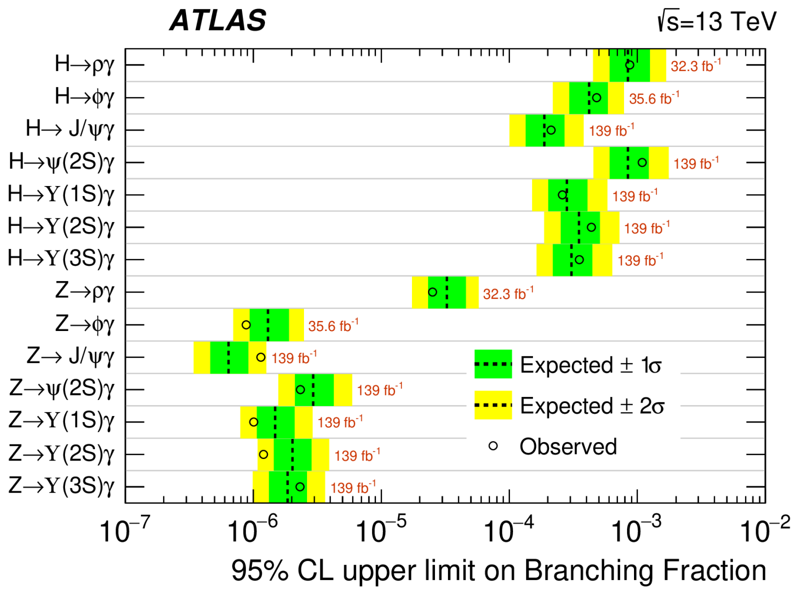
Conclusions

Searches for the rare decays $H(Z) \rightarrow J/\psi\gamma, \psi(2S)\gamma$, and $\Upsilon(1S, 2S, 3S)\gamma$

- Results using $139\ \text{fb}^{-1}$ $\sqrt{s} = 13$ TeV dataset are now public: [arXiv:2208.03122](https://arxiv.org/abs/2208.03122)
  - H decays probe magnitude and sign of b- and c-quark Yukawa couplings
  - Z decays provide a test of QCD factorisation
  - Search for $Q \rightarrow \mu^+\mu^-$ decay channels with dedicated photon+muon triggers
- Signal model
  - Analytical fit to simulated events
  - Resolution of $1.6\% - 1.8\%$ on H/Z mass
- Background Model
  - Exclusive contribution from $\mu^+\mu^-\gamma$ production via Drell-Yan
    - Analytical fit to simulated events
  - Inclusive contribution from multi-jet and γ+jet sources with Q or dimuon production
    - Non-parametric data-driven background model
- 2D fits in $m(\mu^+\mu^-\gamma), m(\mu^+\mu^-)$ discriminate signal resonances and sources of background
  - Set improved limits on all 10 decay channels, and interpret results in the κ framework



Event Signature

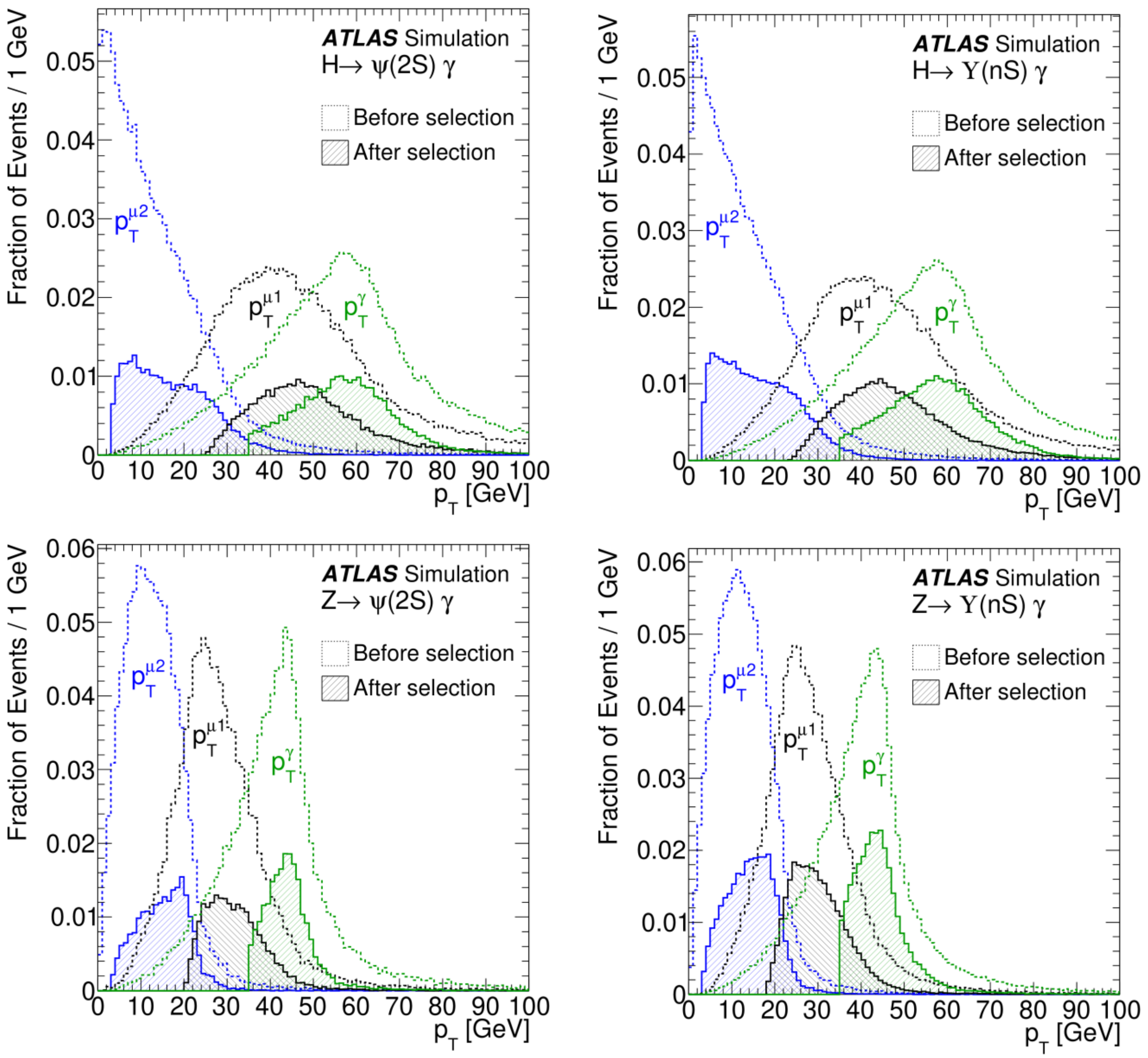


$H(Z) \rightarrow M\gamma$ Limits

ADDITIONAL SLIDES

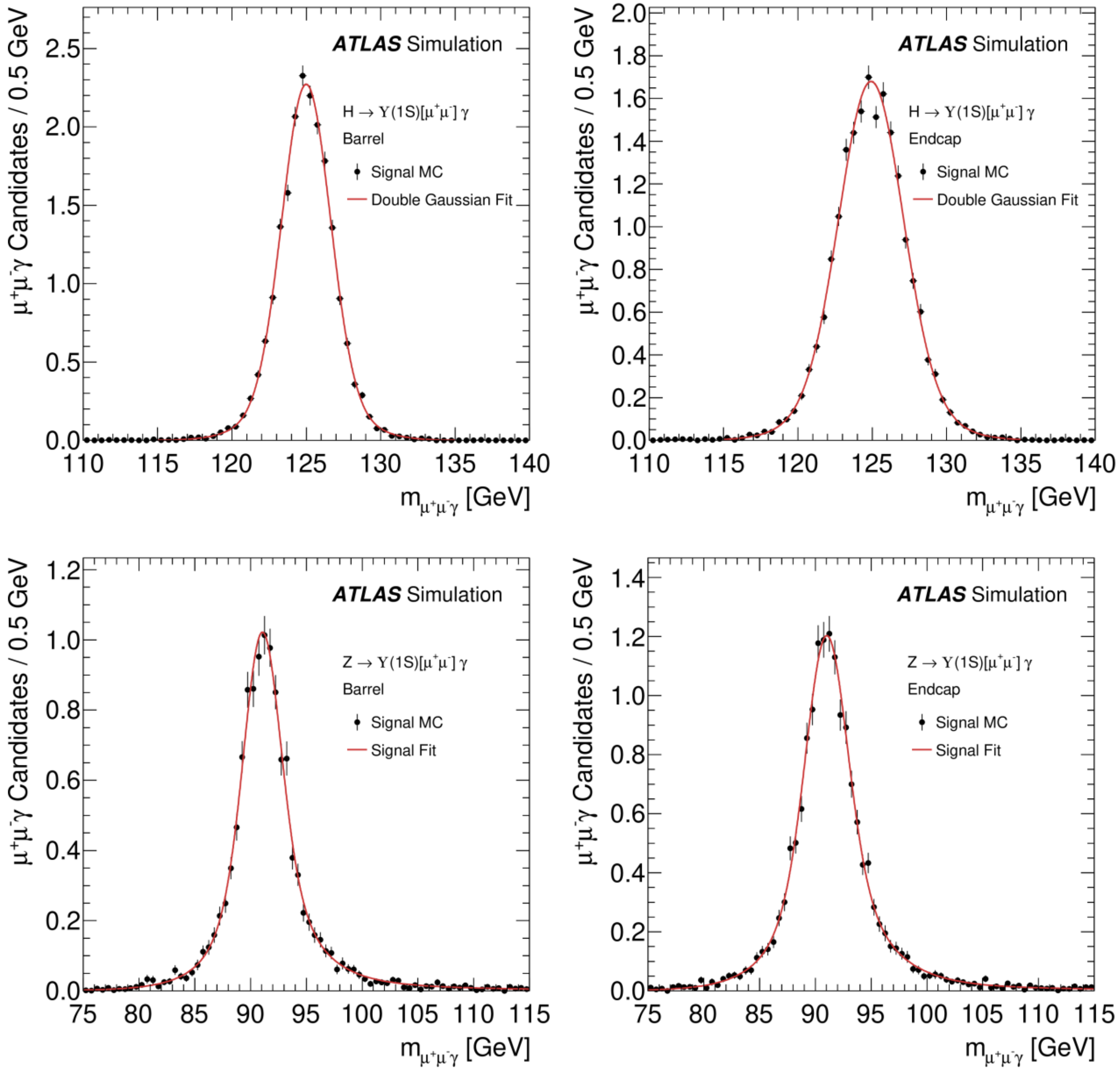
$H(Z) \rightarrow Q\gamma$: Trigger Strategy and Acceptance

- Generator p_{T} plots for $\psi(2S)\gamma$ and $\Upsilon(nS)\gamma$ channels

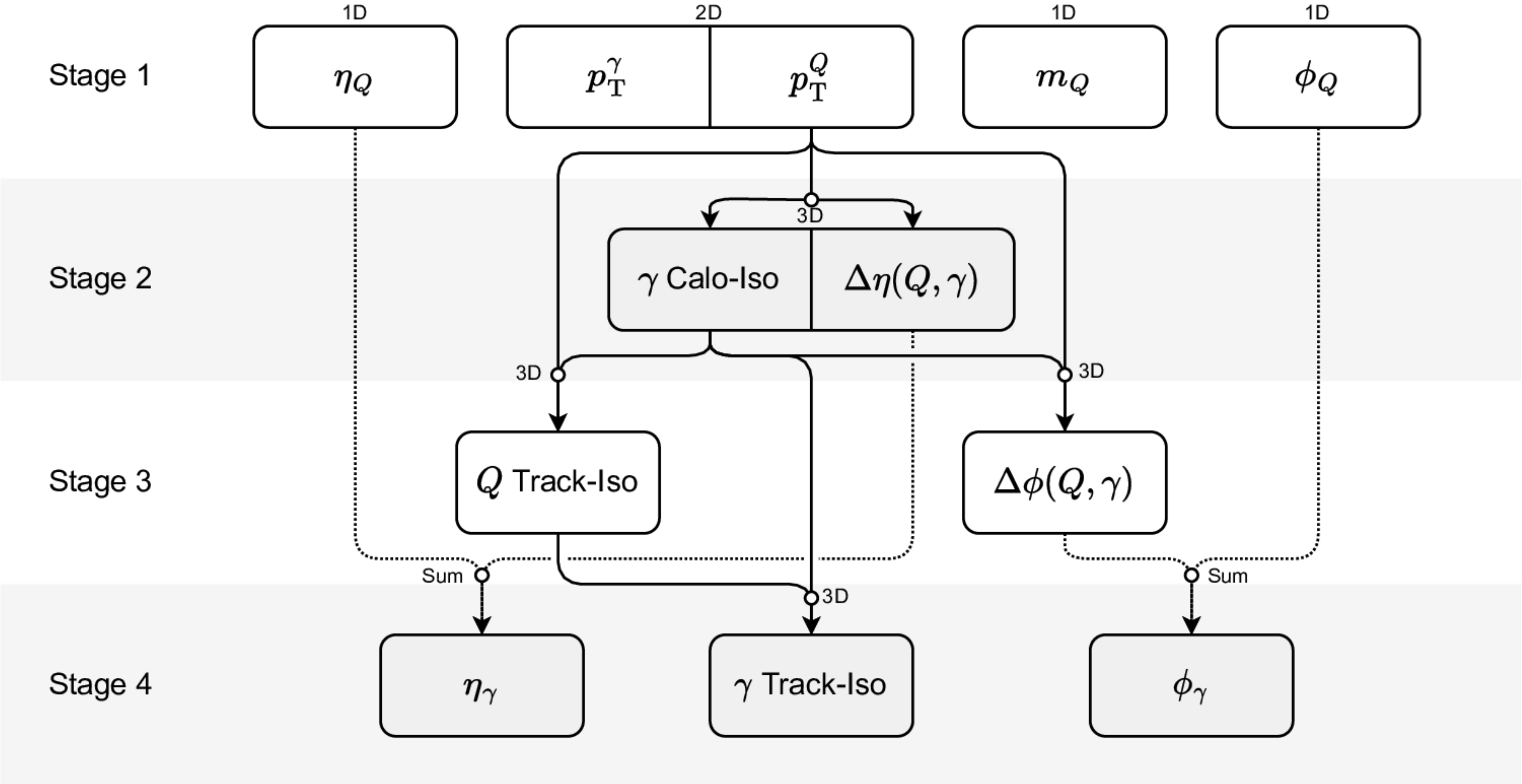


$H(Z) \rightarrow Q\gamma$: Signal Modelling and Resolution

- Signal resolution plots for $\Upsilon(1S)\gamma$ channels in B and EC categories

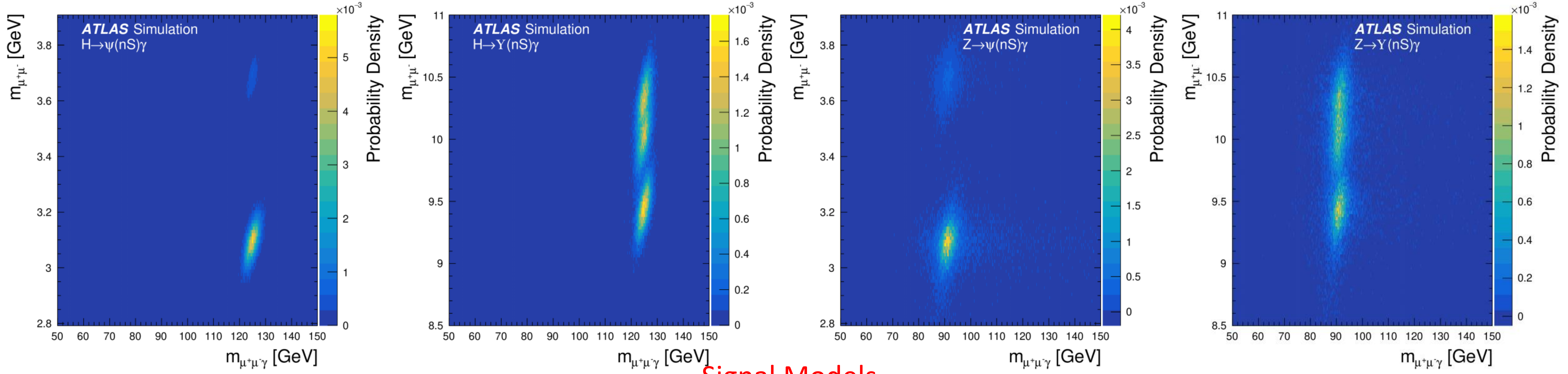


$H(Z) \to Q\gamma$: Sequential Sampling Scheme

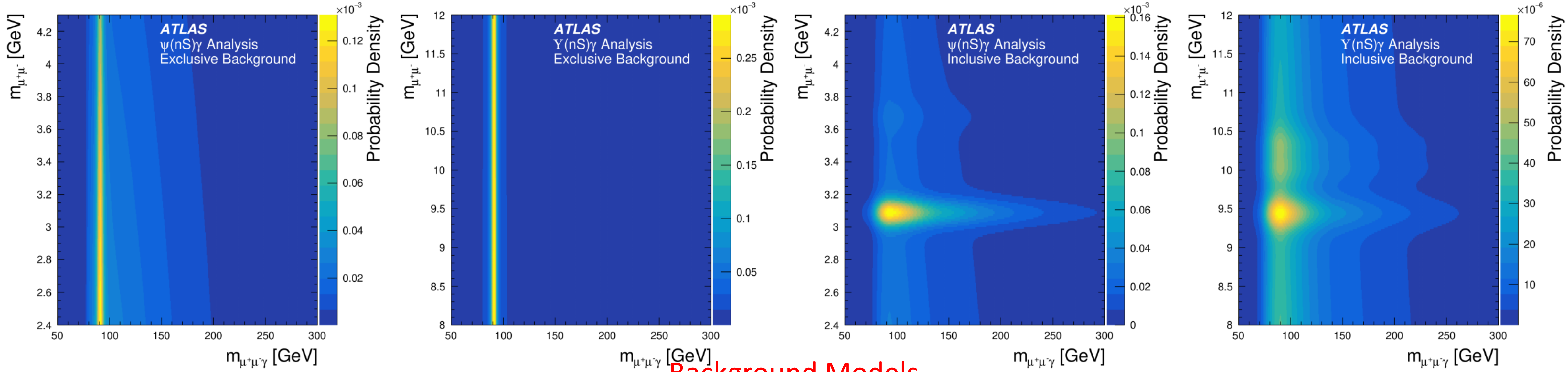


- Create probability density functions for kinematic and isolation variables using data in generation region
  - Sample from these following the above scheme to generate pseudocandiate events

$H(Z) \rightarrow Q\gamma$: Three-body Versus Dimuon Mass



Signal Models



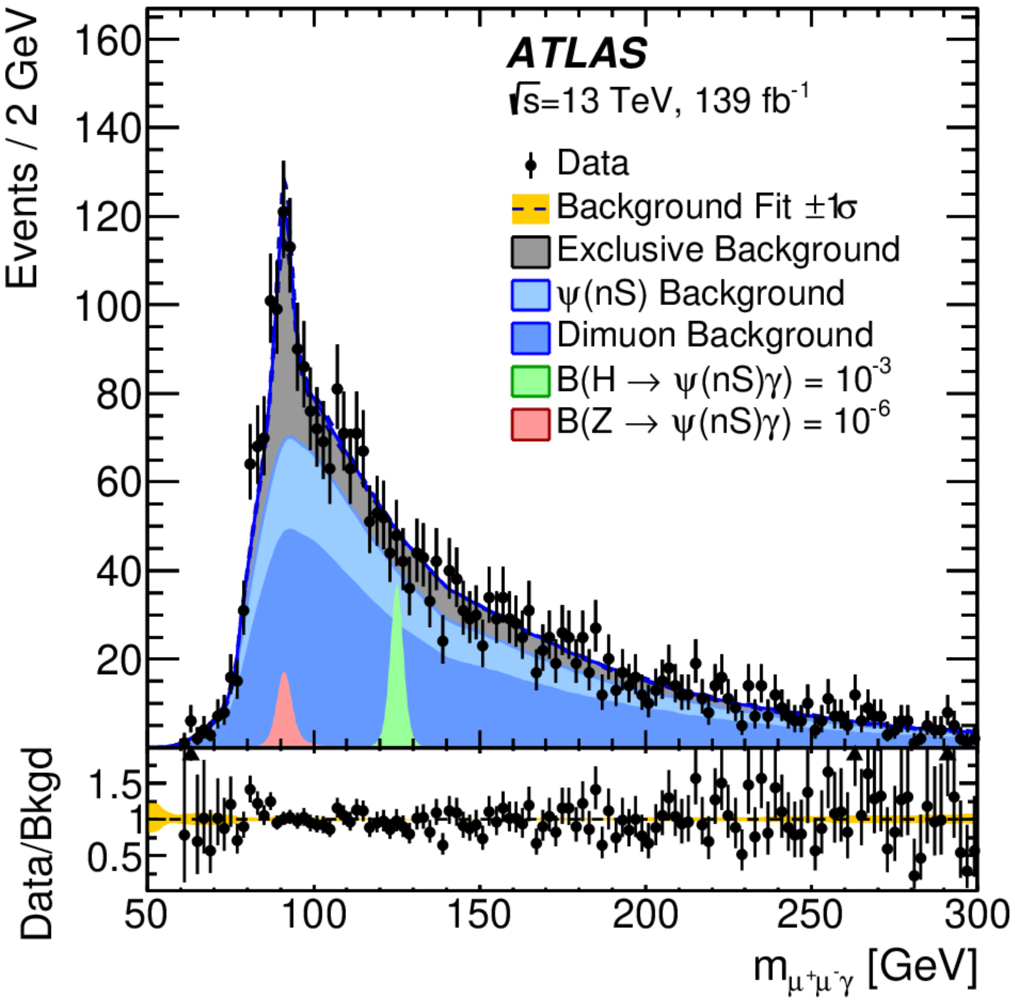
Background Models

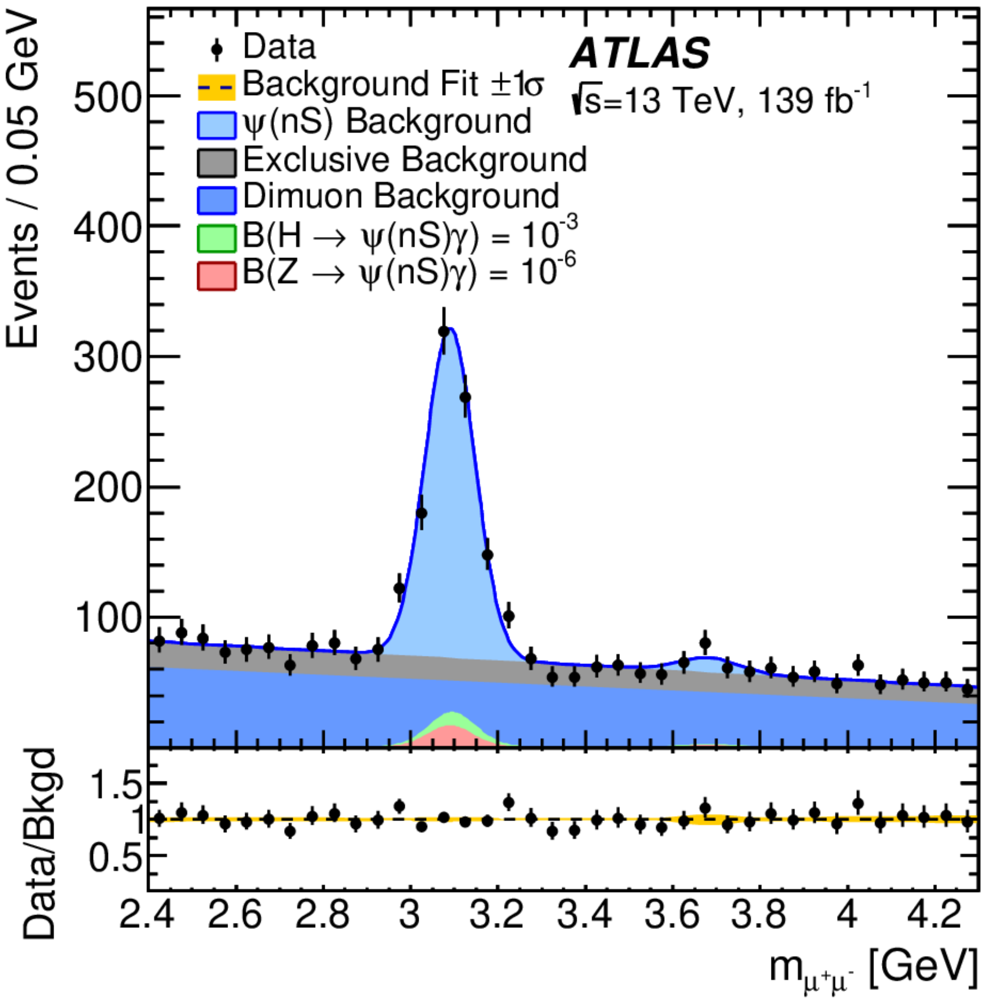
$H(Z) \to Q\gamma$: Observed and Expected Events

Category	$m_{\mu^+\mu^-}$ range [GeV]	Observed (expected) background, $m_{\mu^+\mu^-\gamma}$ range [GeV]: 86–96		Observed (expected) background, $m_{\mu^+\mu^-\gamma}$ range [GeV]: 122–128		Z signal for $\mathcal{B} = 10^{-6}$	H signal for $\mathcal{B} = 10^{-3}$
Inclusive	2.9–3.3	198	(185.6 ± 5.9)	61	(59.1 ± 1.6)	51.1 ± 2.5	84.3 ± 5.9
Inclusive	3.5–3.9	83	(82.5 ± 4.0)	21	(22.9 ± 0.9)	6.7 ± 0.3	11.4 ± 0.8
Barrel	9.0–9.8	125	(125.3 ± 4.7)	12	(11.6 ± 0.6)	12.3 ± 0.6	19.9 ± 1.4
Barrel	9.6–10.4	118	(121.9 ± 4.6)	14	(10.7 ± 0.6)	9.3 ± 0.5	15.1 ± 1.1
Barrel	9.9–10.7	102	(119.9 ± 4.5)	11	(10.2 ± 0.6)	10.8 ± 0.5	17.2 ± 1.2
Endcap	9.0–9.8	133	(162.9 ± 5.7)	16	(13.6 ± 0.7)	16.1 ± 0.8	19.4 ± 1.4
Endcap	9.6–10.4	150	(157.1 ± 5.6)	11	(11.7 ± 0.5)	12.2 ± 0.6	15.0 ± 1.1
Endcap	9.9–10.7	171	(156.7 ± 5.8)	7	(11.4 ± 0.6)	13.9 ± 0.7	16.8 ± 1.2

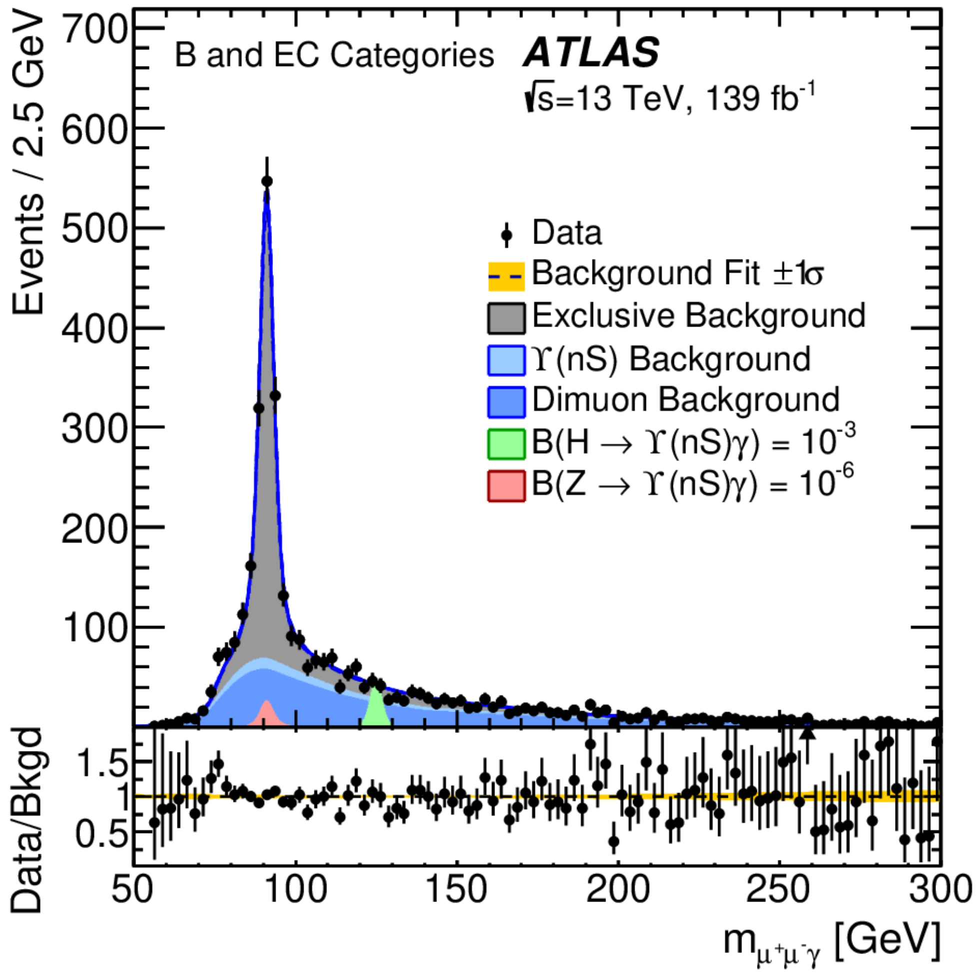
- Table of observed and expected background events in ranges of interest
  - Expected signal events are shown using reference branching ratios for each decay channel

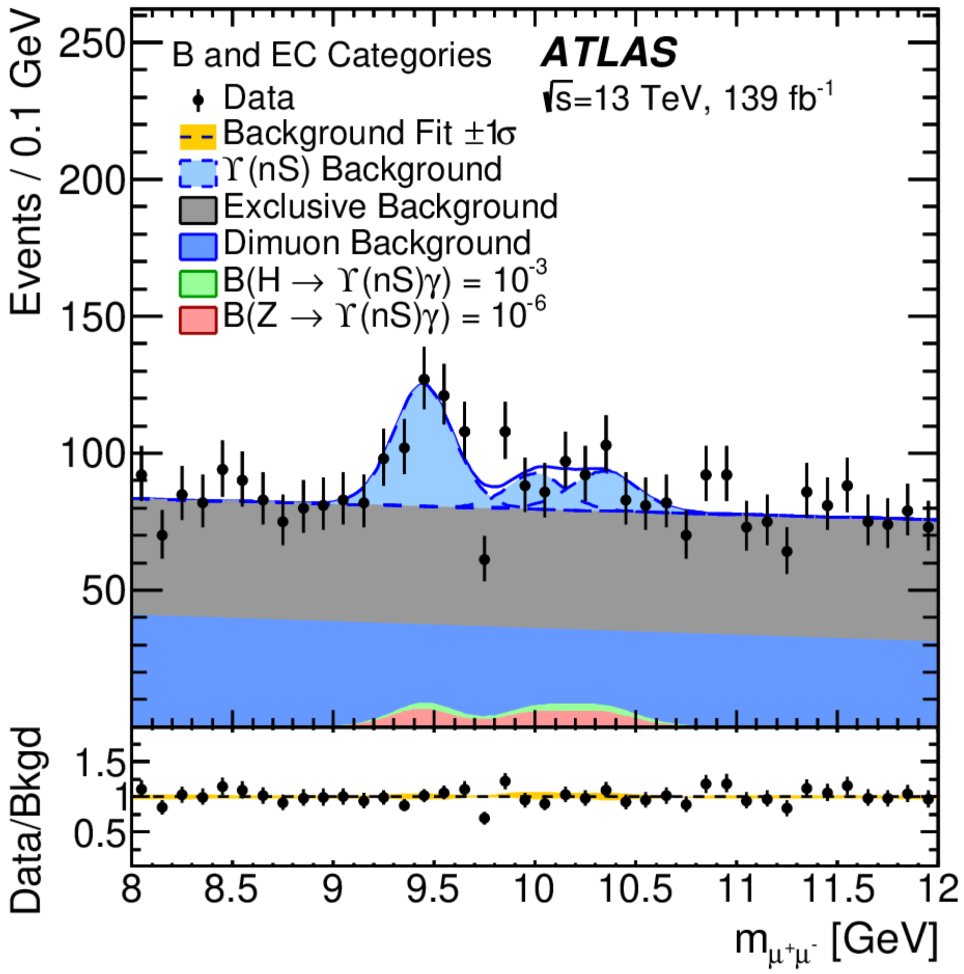
$H(Z) \to \psi(nS)\gamma$: Inclusive Fit



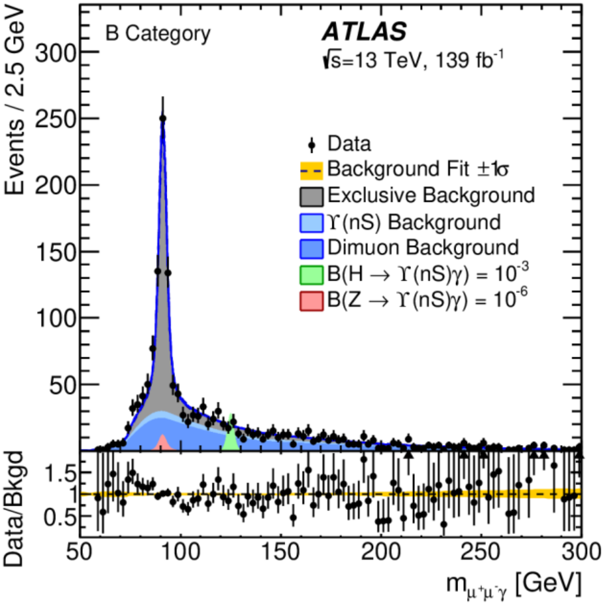


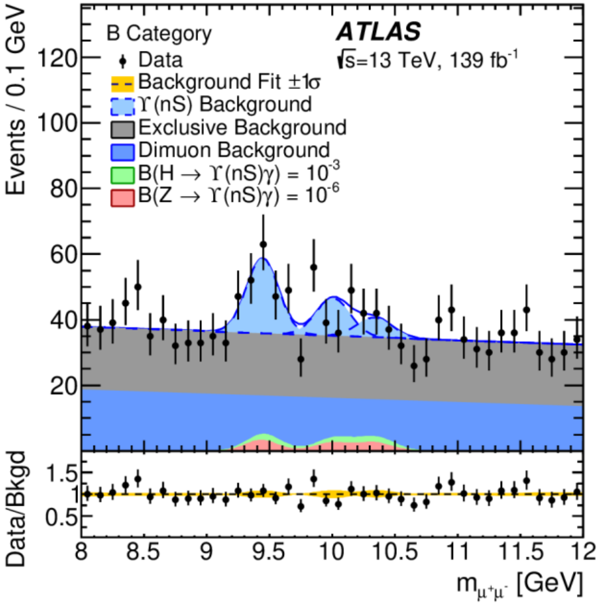
$H(Z) \to \Upsilon(nS)\gamma$: Inclusive Fit

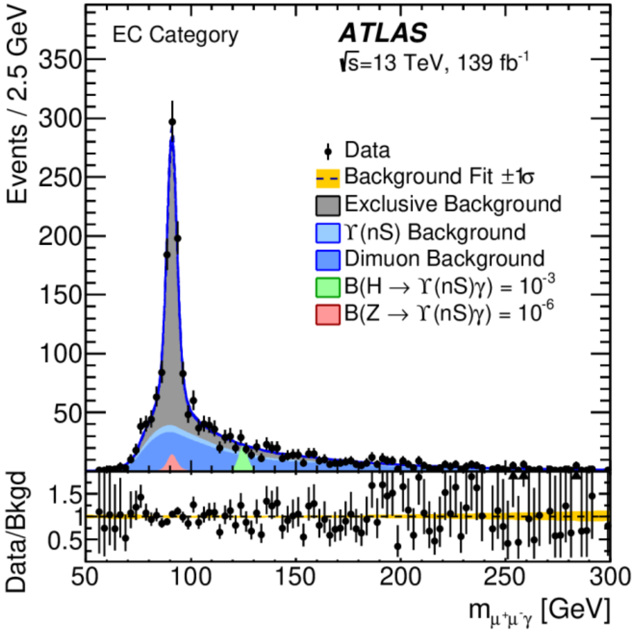


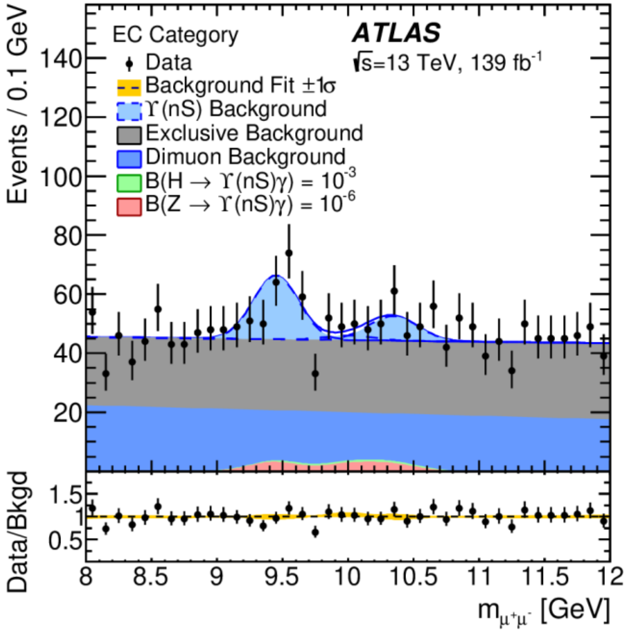


$H(Z) \to \Upsilon(nS)\gamma$: Fit in Separate B and EC Categories

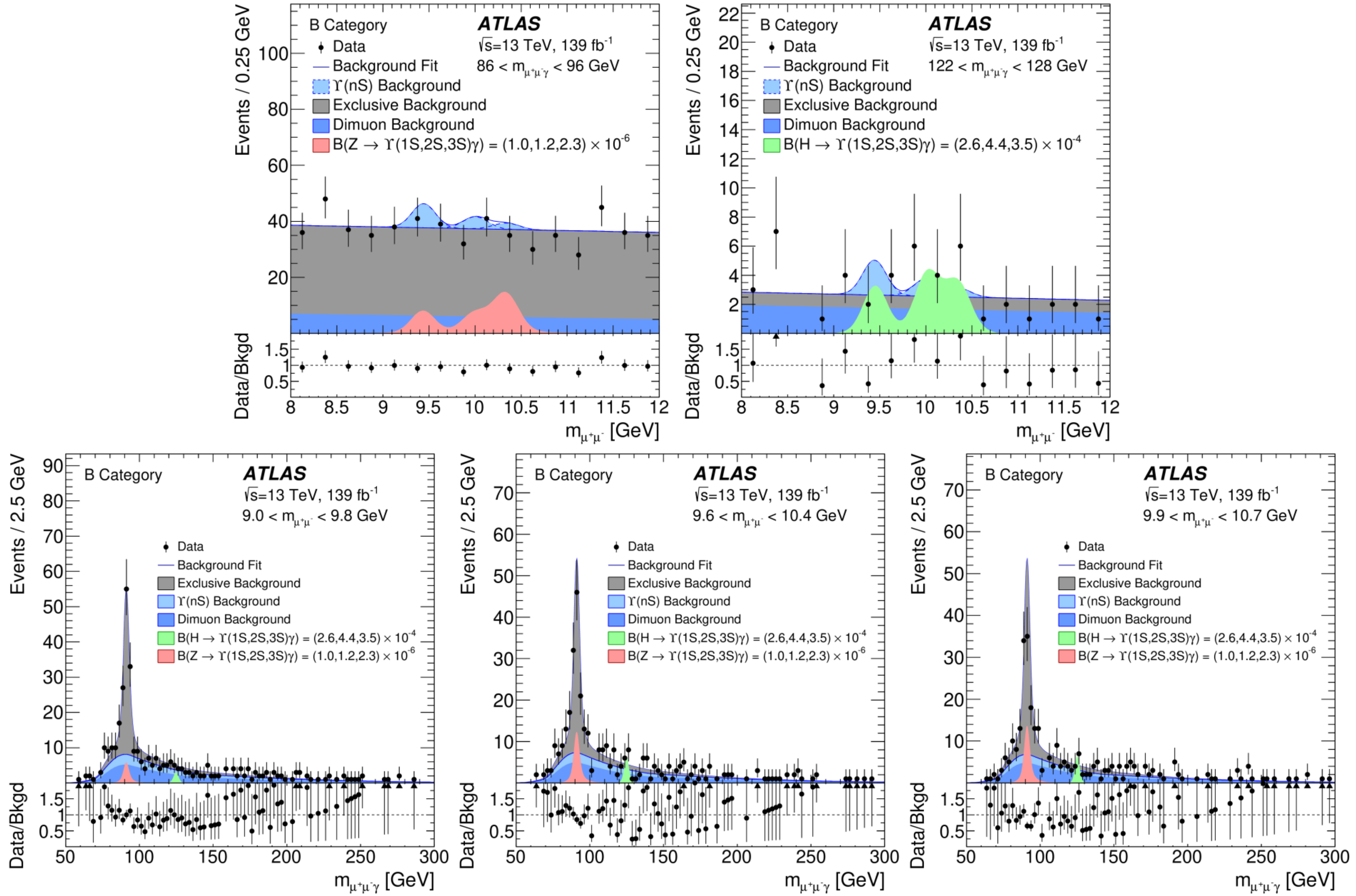




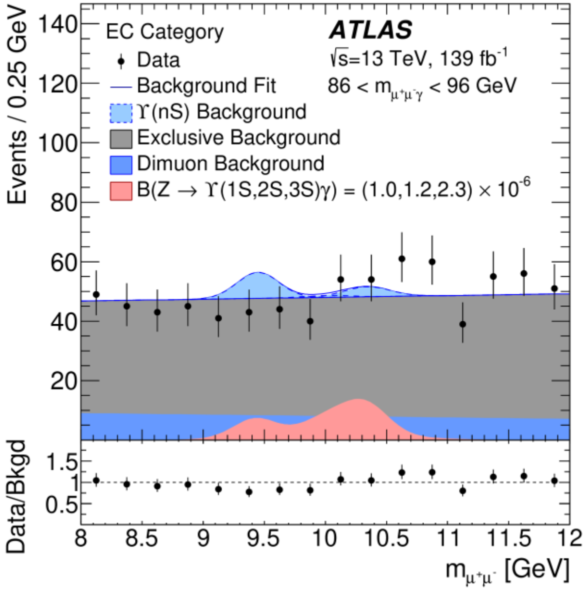


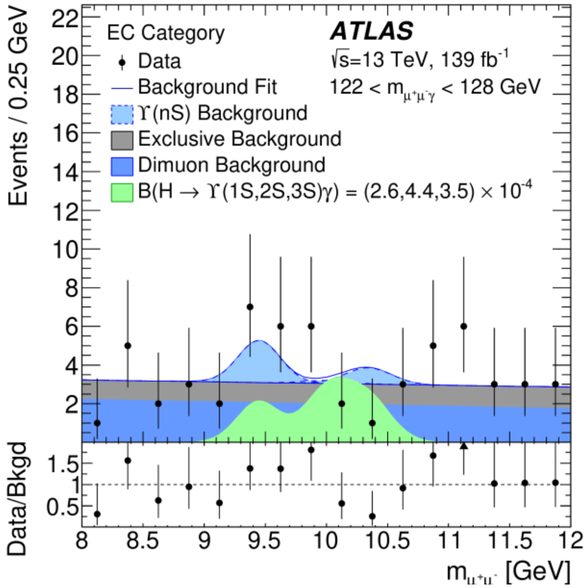


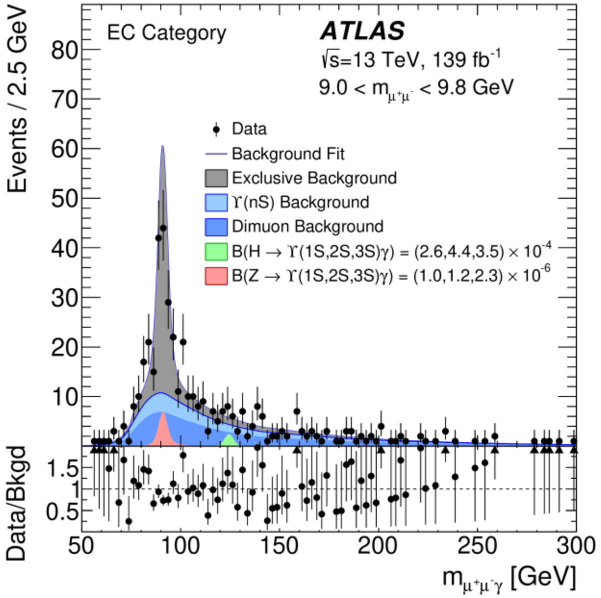
$H(Z) \rightarrow \Upsilon(nS)\gamma$: Barrel Category Projections

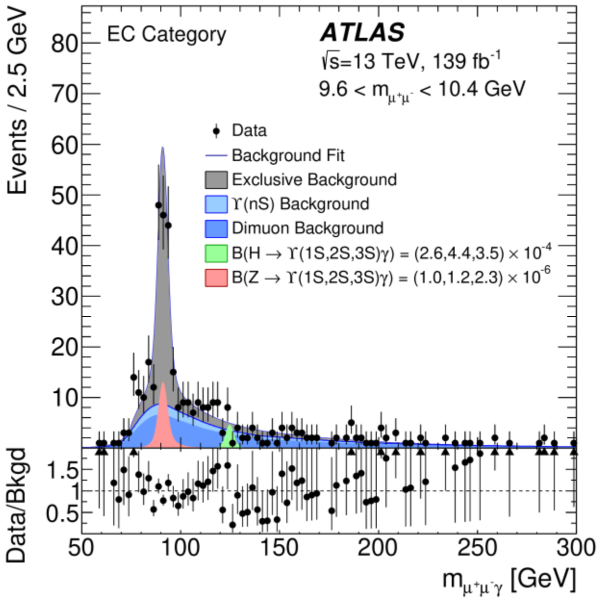


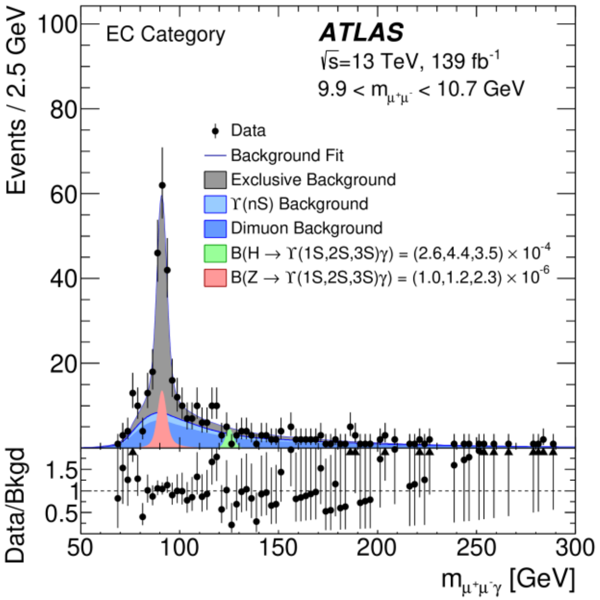
$H(Z) \rightarrow \Upsilon(nS)\gamma$: Endcap Category Projections





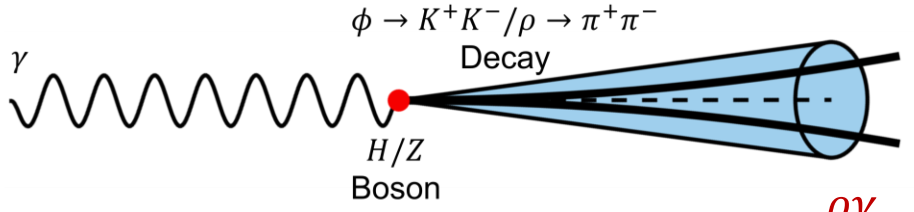




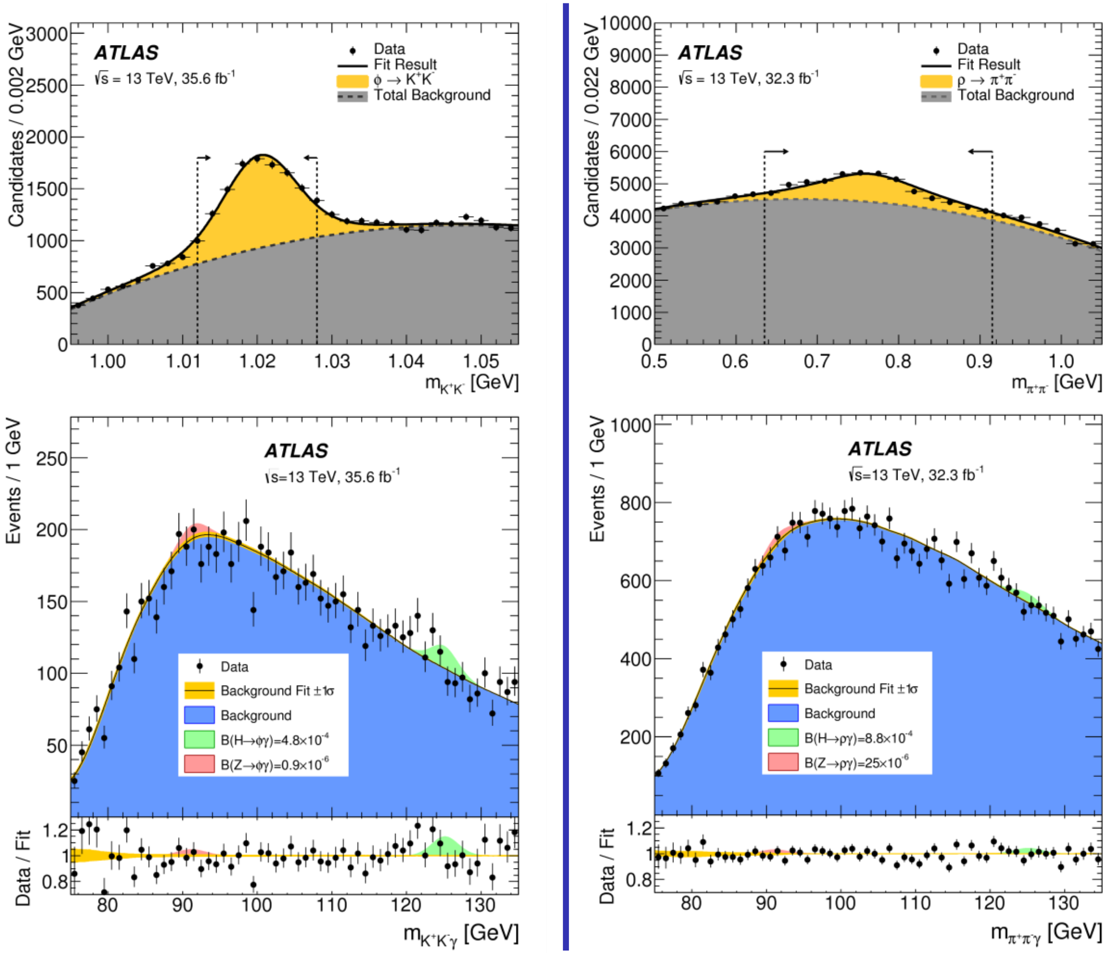


Search for $H \to (\phi/\rho)\gamma$: Early Run 2 Analysis Results

- $H \to \phi(K^+K^-)\gamma$ sensitive to magnitude and sign of y_s
  - $H \to \rho(\pi^+\pi^-)\gamma$ sensitive to magnitude and sign of $y_{u,d}$
- Direct and indirect decay amplitudes analogous to $H \to Q\gamma$
  - $BR^{SM}_{H\to\phi\gamma(\rho\gamma)} \approx 10^{-6}(10^{-5})$
- Include analogous searches for $Z \to (\phi/\rho)\gamma$
  - $BR^{SM}_{Z\to\phi\gamma(\rho\gamma)} \approx 10^{-8}$
- **Dedicated** triggers based on single photon + modified τ-lepton algorithms
  - Signal resolution ≈ 1.8%
- Similar signal and background modelling strategy to $H \to Q\gamma$
  - Background model is fully data driven
    - No backgrounds resonant in $m(K^+K^-\gamma)$ or $m(\pi^+\pi^-\gamma)$
    - Validate model in $m(K^+K^-)$ and $m(\pi^+\pi^-)$ sidebands
- Use unbinned likelihood fit to $m(K^+K^-\gamma)$ and $m(\pi^+\pi^-\gamma)$



$\phi\gamma$ $\rho\gamma$



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Limits for $H \rightarrow (\phi/\rho)\gamma$

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

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