

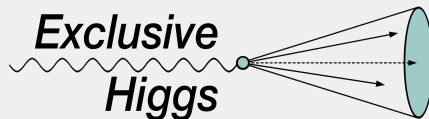
# Search for Exclusive Hadronic W Decays

Júlia Silva

IoP HEPP & APP Conference 2022



UNIVERSITY OF  
BIRMINGHAM



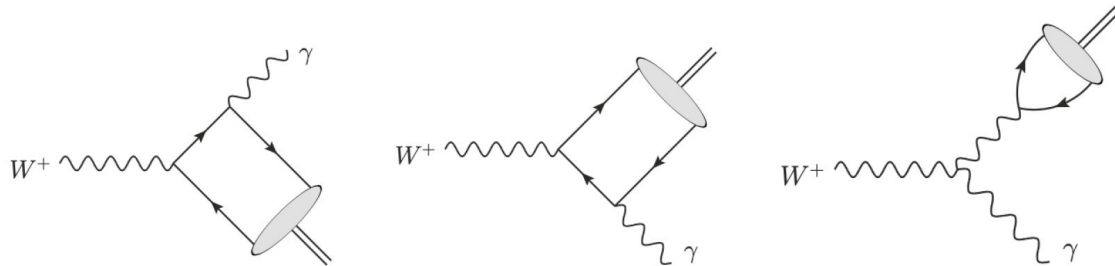
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# Motivation

- **None of the exclusive hadronic W decays predicted by the Standard Model have been observed!**
  - ◆ These can offer novel precision studies of QCD factorisation ([arXiv:1501.06569](https://arxiv.org/abs/1501.06569))
  
- **Searches currently underway for  $W^\pm \rightarrow \pi^\pm \gamma$ ,  $W^\pm \rightarrow \rho^\pm \gamma$  and  $W^\pm \rightarrow K^\pm \gamma$  at ATLAS, using LHC Run-2 data**

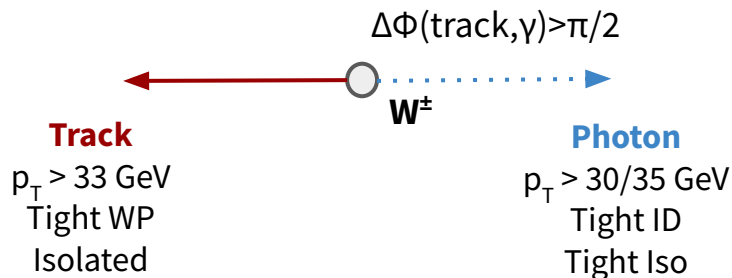
Channel	SM predictions	95% CL Limits	
		<a href="#">CDF</a>	$<7 \times 10^{-6}$
$W^\pm \rightarrow \pi^\pm \gamma$	$(4.0 \pm 0.8) \times 10^{-9}$	<a href="#">CMS</a>	$<1.5 \times 10^{-5}$
$W^\pm \rightarrow K^\pm \gamma$	$(3.3 \pm 0.7) \times 10^{-10}$	No limits available	
$W^\pm \rightarrow \rho^\pm \gamma$	$(8.7 \pm 1.9) \times 10^{-9}$		



- $W^\pm \rightarrow \pi^\pm/K^\pm + \gamma$ : **Isolated high  $p_T$  track** recoiling against **isolated high  $p_T$  photon**
- $W^\pm \rightarrow \rho^\pm (\rightarrow \pi^\pm + \pi^0) + \gamma$ : extra **electromagnetic deposition** coming from  $\pi^0$

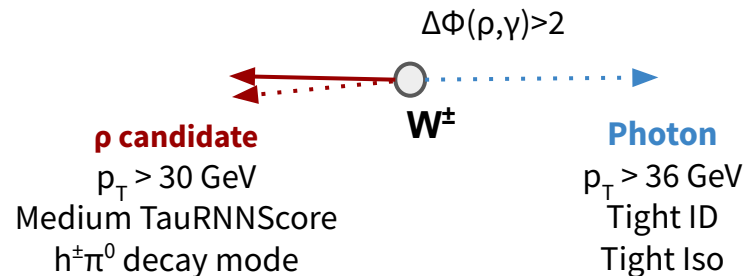
## track + photon

- Sensitive to  $W^\pm \rightarrow \pi^\pm/K^\pm/\rho^\pm + \gamma$  decays
- **Dedicated triggers**: track ( $p_T > 30$  GeV) + photon ( $p_T > 25/35$  GeV)



## $\rho$ + photon

- Sensitive to  $W^\pm \rightarrow \rho^\pm (\rightarrow \pi^\pm \pi^0) \gamma$  decay
- **$\rho$ -candidate** reconstructed as **1-prong  $\tau$ -lepton**
- No dedicated triggers, using **di-photon** triggers

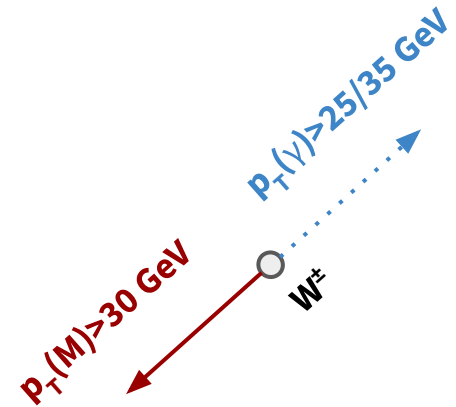


# Dedicated Trigger

- **Dedicated triggers allow us to identify specific event topology**
  - ◆ Developed for exclusive Higgs/Z/W analyses
  - ◆ Using modified tau-lepton trigger algorithms (meson decay similar to hadronic tau decays)
- **Collected  $136 \text{ fb}^{-1}$  from 2016 to 2018**
  - ◆ With around **56% efficiency** wrt offline selection

## Requirements:

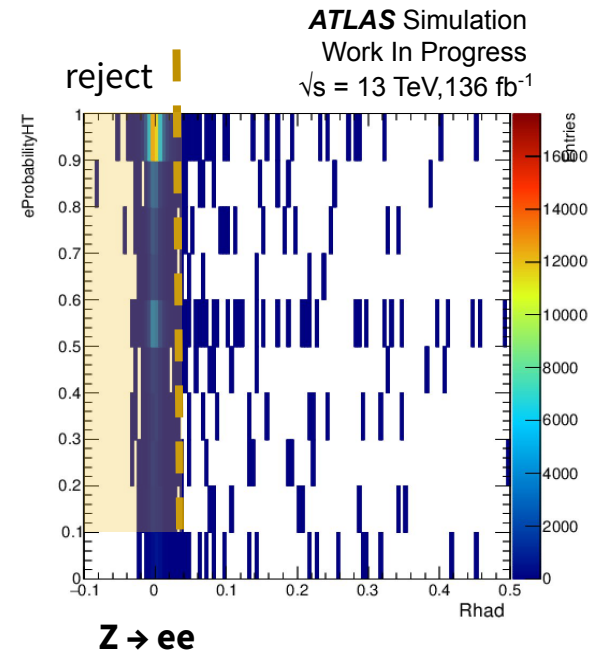
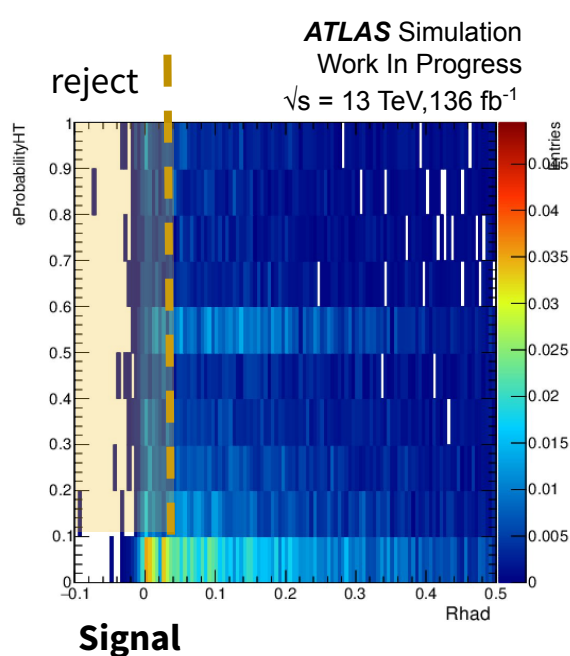
- **single track** ( $p_T > 30 \text{ GeV}$ )
- **single photon:**
  - ◆  $p_T > 35 \text{ GeV}$  for most of 2016
  - ◆ Threshold lowered to  $p_T > 25 \text{ GeV}$  at the end of 2016
- $m(M+\gamma) > 50 \text{ GeV}$
- $0.4 < E_T(\tau)/p_T(\text{lead track}) < 0.85$
- $\Delta R(\tau, \text{lead track}) < 0.06$
- No wide tracks ( $0.2 < \Delta R < 0.4$  wrt  $\tau$ )



[used in track + photon analysis]

# Z → ee rejection

- Resonant background arising from **Z → ee events**, with electron faking a photon
- Peaking background, close to signal, not modelled by background modelling method
- Devised background rejection selection (here exemplifying with track+photon final state)

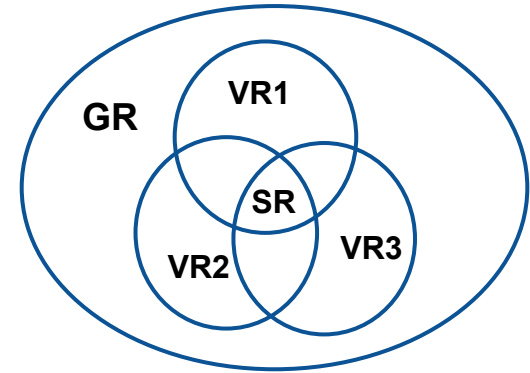


- Look for closest reconstructed electron to track in  $\Delta R$
- Reject if  $e\text{ProbabilityHT} > 0.1$  and  $R_{had} < 0.03$

### Efficiencies:

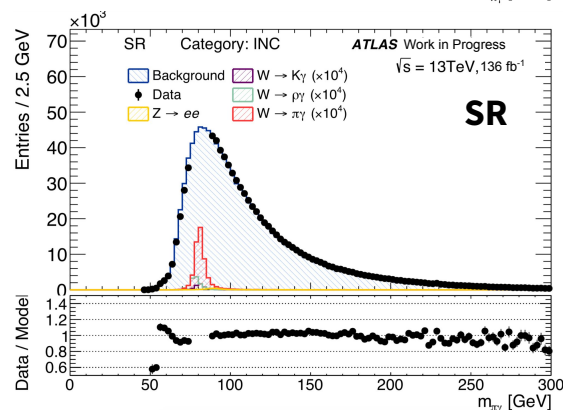
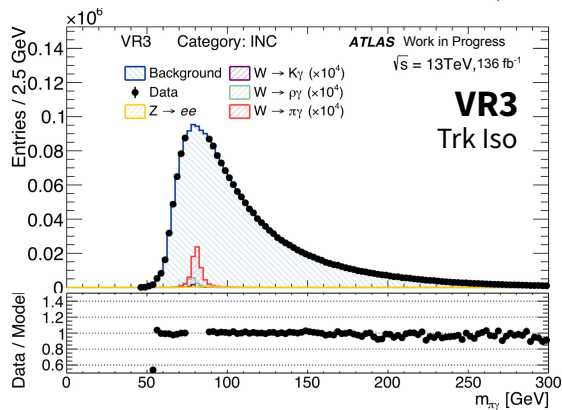
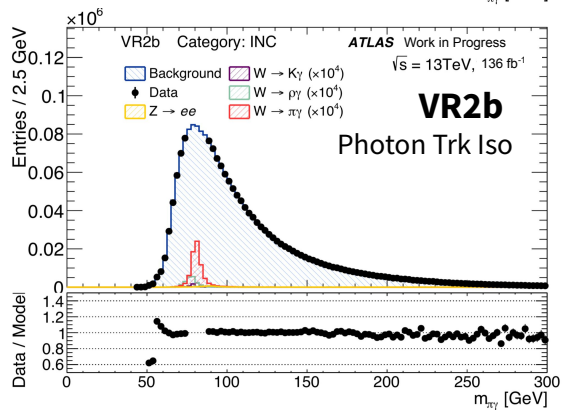
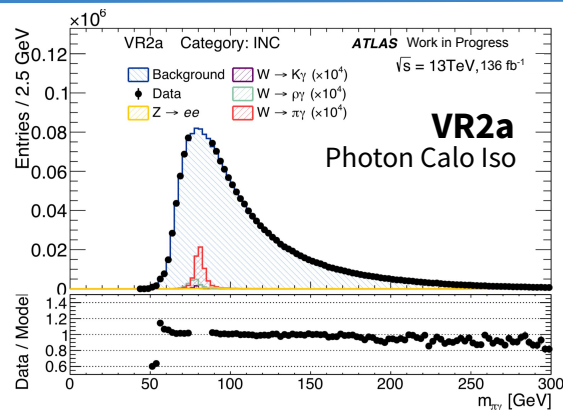
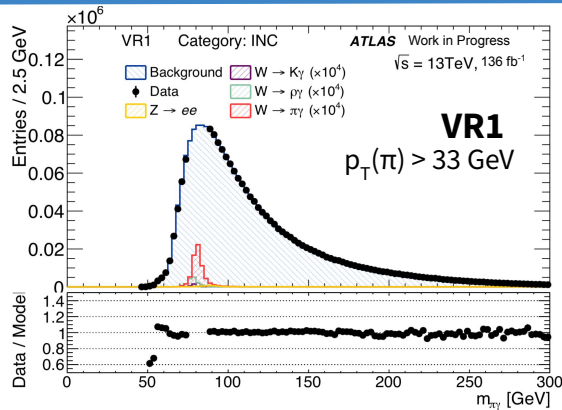
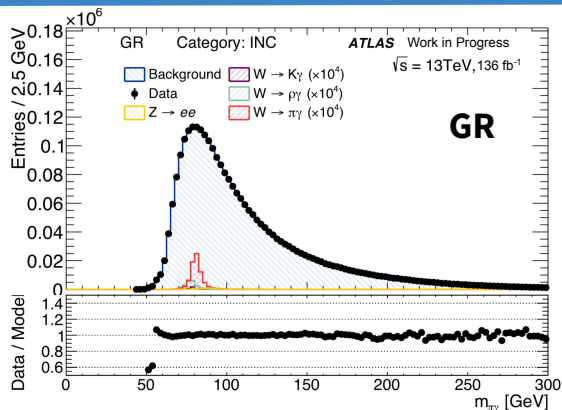
- Signal = 95%
- Z → ee Background = 9%

- **Main background arising from dijet and jet + photon processes for both final states**
  - ◆ Neither shape or normalisation reliably modelled by MC
- **A data-driven non-parametric method is applied** ([arXiv:2112.00650](https://arxiv.org/abs/2112.00650)):
  - ◆ **Generation Region** (GR): Large sample of W candidates, with relaxed requirements
  - ◆ Model relevant kinematic/isolation distributions from data in GR → create 2D/3D templates that should model highest correlations in data
  - ◆ Generate pseudo-candidates after sampling from templates
  - ◆ Apply **Signal Region** requirements
  - ◆ **Validation Regions** (VR): check the model



	track + photon selection
VR1	GR + $p_T(\pi) > 33$ GeV
VR2	GR + Photon Iso
VR3	GR + Track Iso
SR	GR + all of the above

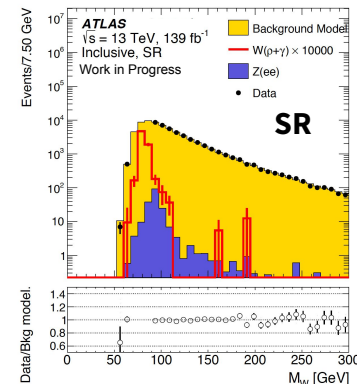
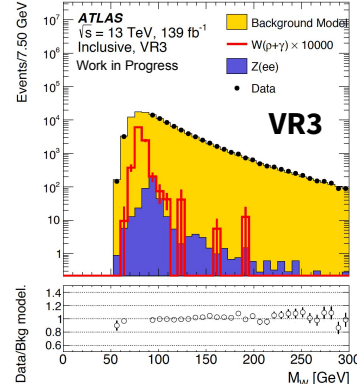
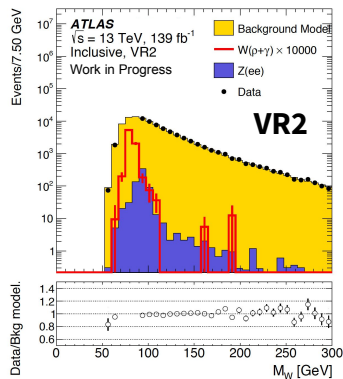
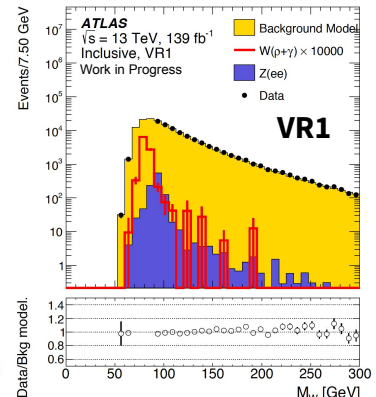
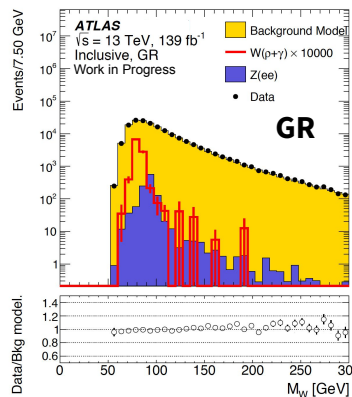
# m(track+ $\gamma$ )



→ The same non-parametric data-driven background modelling method used

- ◆  $\gamma$  and  $\tau$  variables used in the modelling

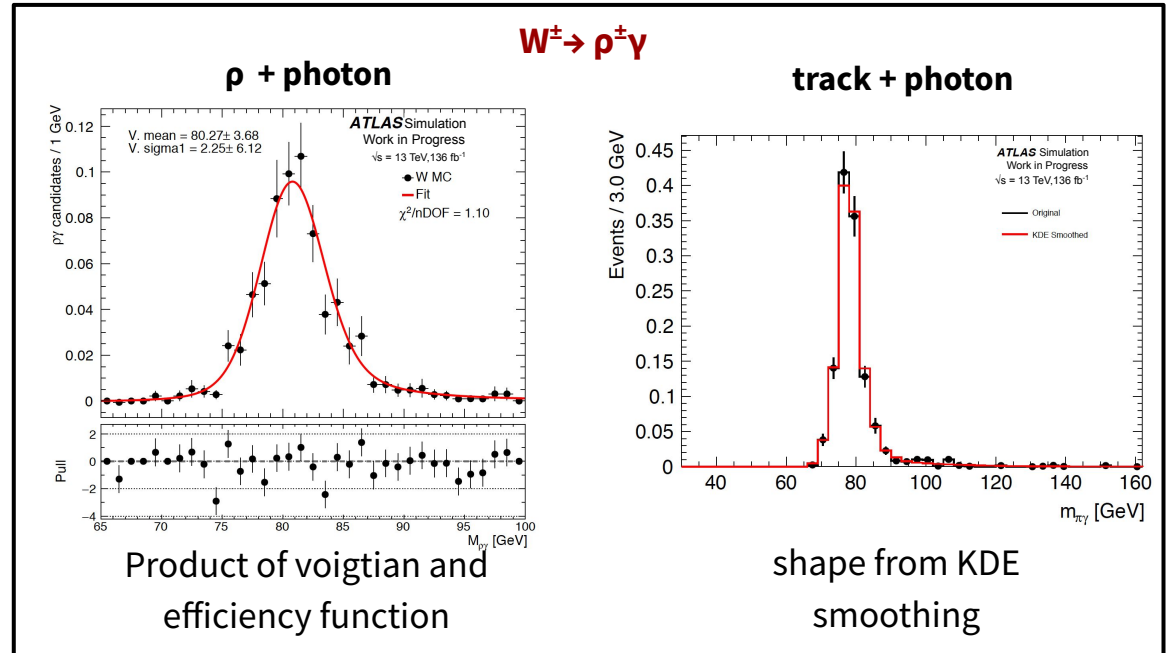
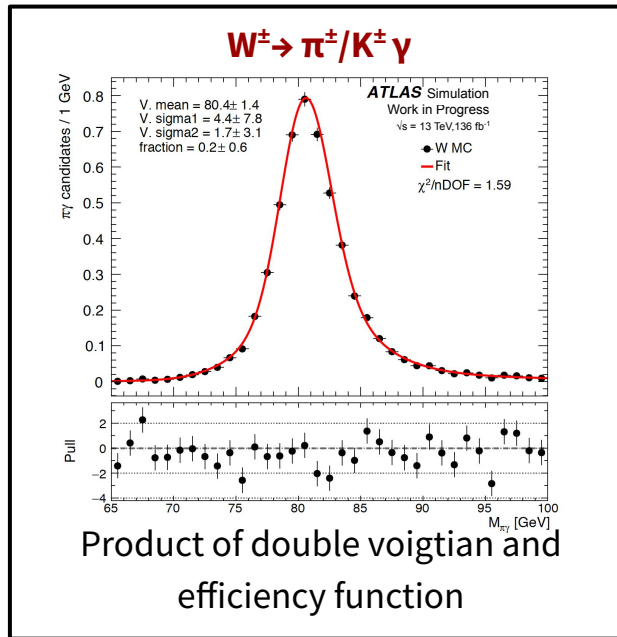
	$\rho$ + photon Selection
<b>VR1</b>	$GR + p_T(\tau) > 30 \text{ GeV}$
<b>VR2</b>	$GR + \Delta R(\tau, \text{track}) < 0.065$
<b>VR3</b>	$GR + \log( d_0(\tau) ) < -1.2$
<b>SR</b>	GR + all of the above





# Signal Modelling

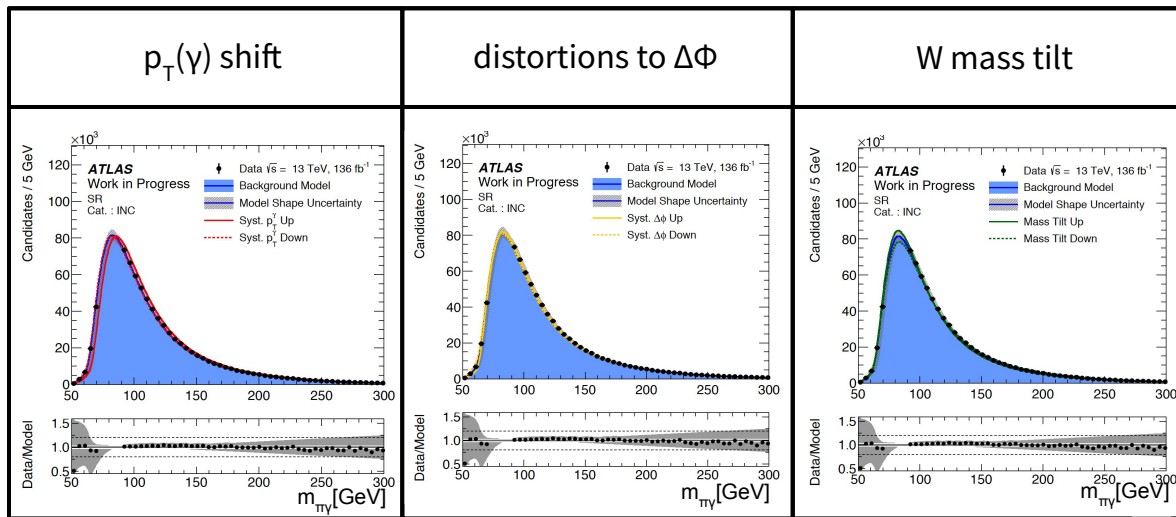
- Decays modelled with Powheg + Pythia generators
- Reconstructed W invariant mass shape modelled through:



# Systematic Uncertainties

## Background Systematics:

- Estimated through modifications to modelling procedure:
  - $p_T(\gamma)$  shifted by  $\pm 3$  GeV
  - distortions to  $\Delta\Phi$
  - W mass tilt through linear re-weighting



[plots from track + photon final state]

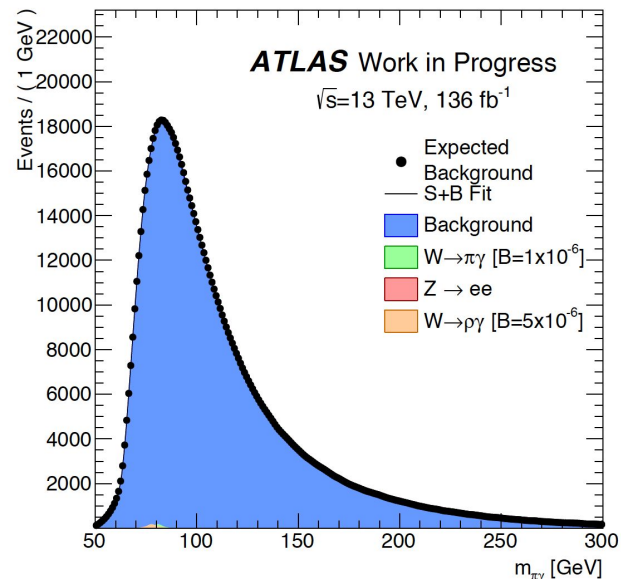
## Signal Systematics:

Source	track + photon	$\rho$ + photon
Cross Section	<b>3.4 %</b>	
Luminosity	1.7 %	
Photon Efficiency	2.1 %	1.9 %
Track Efficiency	1.2 %	-
EG Scale	0.2 %	<b>3.0 %</b>
EG Resolution	0.1 %	<b>4.9 %</b>
Trigger	0.4 %	<b>10 %</b>

# Expected Results: $W^\pm \rightarrow \pi^\pm/K^\pm + \gamma$

## Unbinned Maximum Likelihood Fit in track + photon mass

- ◆ Floating background normalisations
- ◆ Nuisance parameters for systematic uncertainties
  - Background shape systematics as “morphing” NPs
- ◆ Asymptotic  $CL_s$  with profile likelihood as test statistic



	Expected ( $\times 10^{-6}$ )	$\pm 1 \sigma$	$\pm 2 \sigma$
$W \rightarrow \pi\gamma$	1.30	1.81/0.93	2.42/0.70
$W \rightarrow K\gamma$	1.17	1.62/0.84	2.18/0.63

$W \rightarrow K\gamma$  set to 0,  $W \rightarrow \rho\gamma$  profiled

$W \rightarrow \pi\gamma$  set to 0,  $W \rightarrow \rho\gamma$  profiled

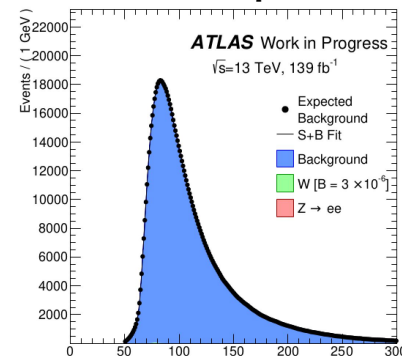
# Expected Results: $W^\pm \rightarrow \rho^\pm + \gamma$

- **Practically no overlap between events in the two final states ( $< 0.3\%$ )**
  - ◆ Dedicated triggers and diphoton triggers used found to be  $\sim$ orthogonal
- **Unbinned Maximum Likelihood Fit in track + photon and  $\rho$  + photon mass**
  - ◆ performed single fit in two categories, with correlated  $\mu(W \rightarrow \rho\gamma)$
  - ◆ combination improves limit on  $\text{Br}(W \rightarrow \rho\gamma)$  by  $\sim 20\%$

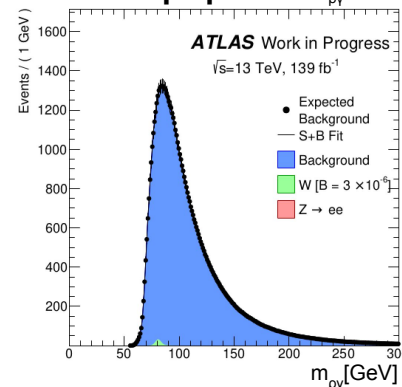
	Expected ( $\times 10^{-6}$ )	$\pm 1\sigma$	$\pm 2\sigma$
<b>track + photon*</b>	7.12	9.91/5.13	13.29/3.82
<b><math>\rho</math> + photon</b>	4.06	5.79/2.93	8.17/2.18
<b>combined</b>	3.28	5.29/2.36	7.04/1.76

[\* $W \rightarrow \pi\gamma$  fixed to 0 in this result]

**track+  $\gamma$  SR**



**$\rho$ + $\gamma$  SR**



- **None of the exclusive hadronic decays of the W boson have been observed**
  - ◆ Weak or no experimental constraints available
- **Searches for these decays enabled by:**
  - ◆ Dedicated meson + photon triggers
  - ◆ Data-driven non-parametric background modelling method
- **Expected upper limits:**
  - ◆ Expected to set best upper limit on  $B(W^\pm \rightarrow \pi^\pm \gamma)$  at 95% CL
  - ◆ Setting first limits on  $B(W^\pm \rightarrow \rho^\pm \gamma)$  and  $B(W^\pm \rightarrow K^\pm \gamma)$ !



**THANK YOU AND STAY TUNED!!!**

# BACK-UP

# Background Model - trk + photon

