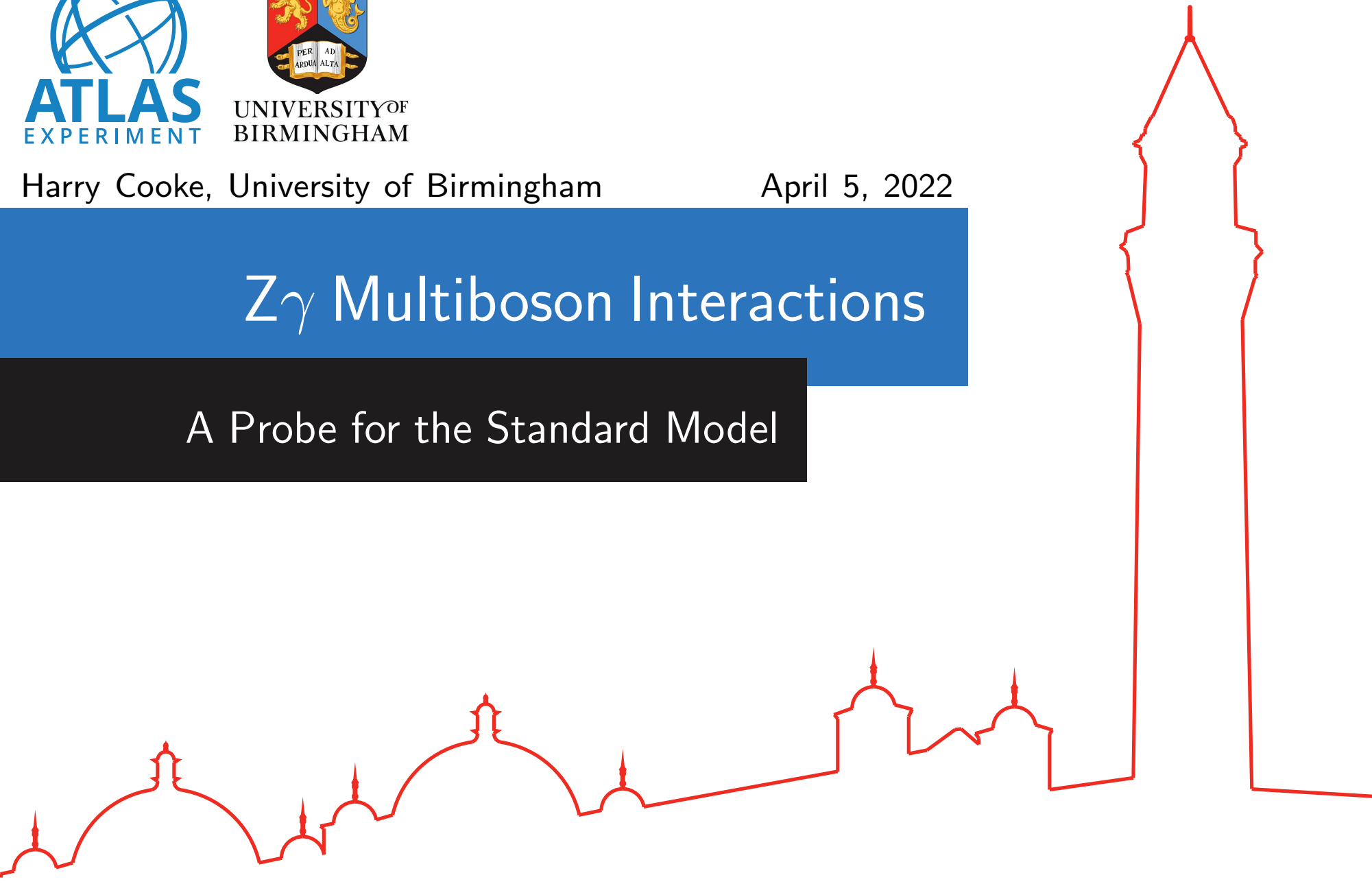


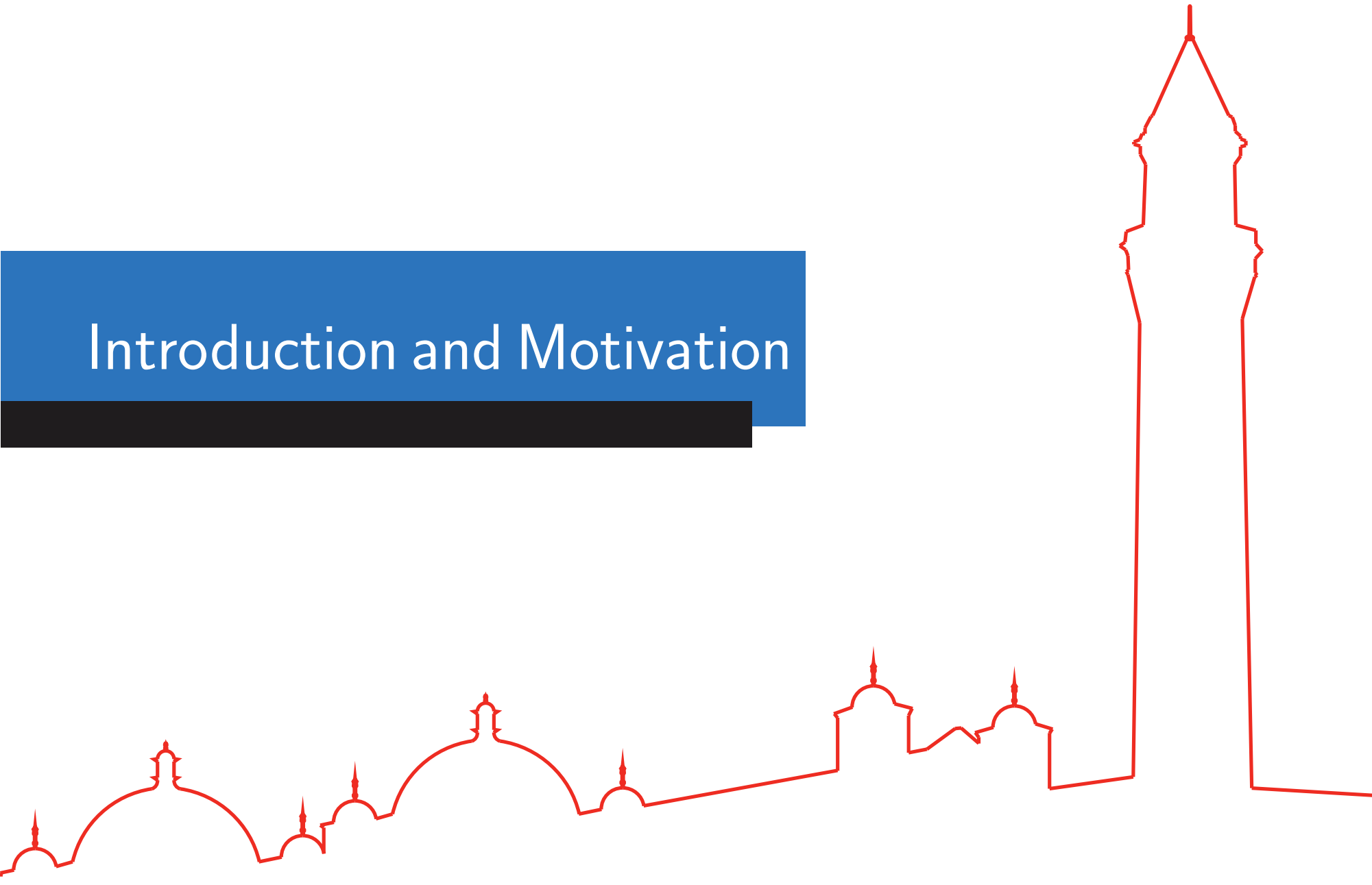
Harry Cooke, University of Birmingham

April 5, 2022

$Z\gamma$ Multiboson Interactions

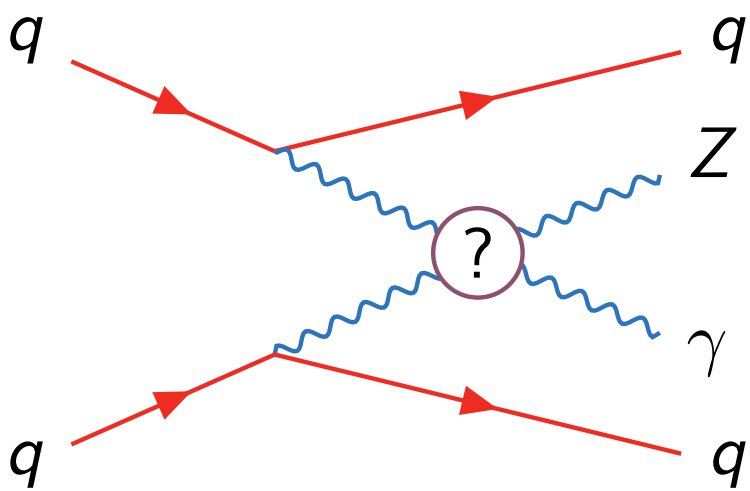
A Probe for the Standard Model

Introduction and Motivation

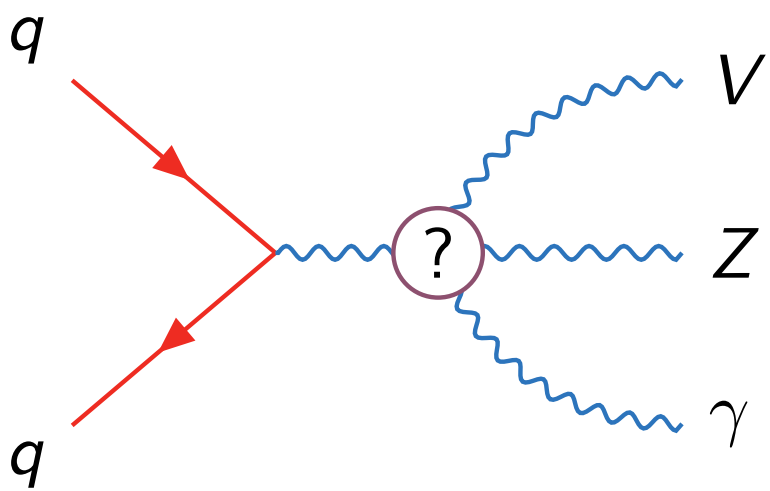


Introduction

- What are multiboson interactions and why are they interesting?
- Many processes being studied by ATLAS, will focus on two I have been involved with
  - Both featuring a Z boson and a photon in the final state
  - Both feature 4 bosons interacting at a single vertex (quartic couplings)



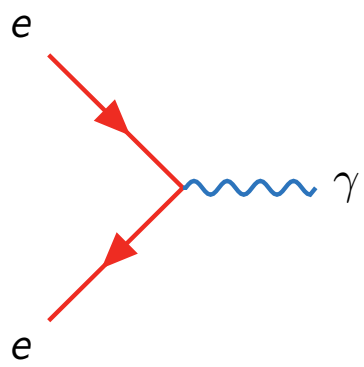
VBS Zγ

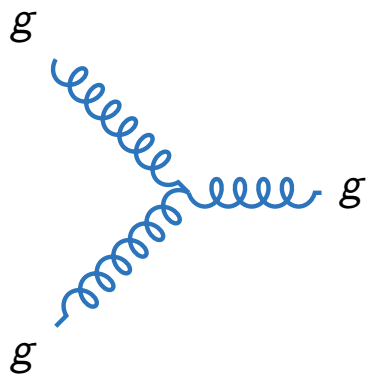


Semileptonic VZγ

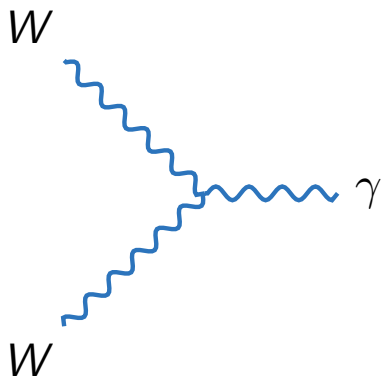
Multiboson Interactions

- Processes with multiple gauge bosons interacting at the same vertex
  - Contrary to 'typical' vertices with two fermions and a boson

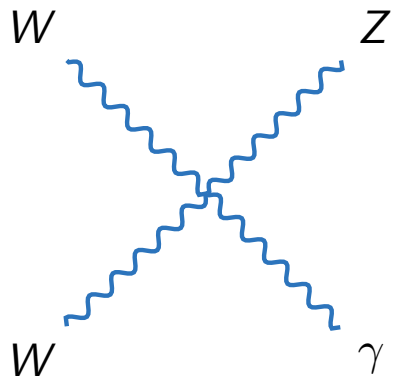




- For gluons, this is very common, but less so for electroweak bosons
- Even rarer interactions exist in the Standard Model with 4 bosons at a vertex



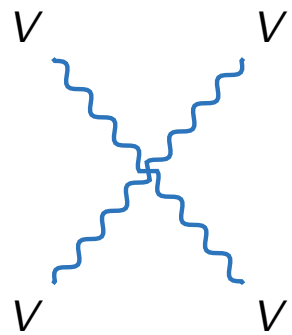
Triple Gauge Coupling (TGC)



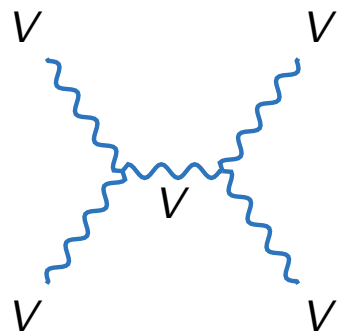
Quartic Gauge Coupling (QGC)

In the Standard Model

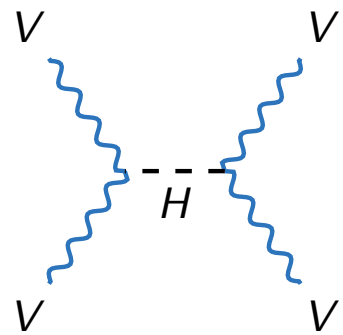
- The Standard Model provides several mechanisms for four bosons to interact at tree level



Quartic coupling

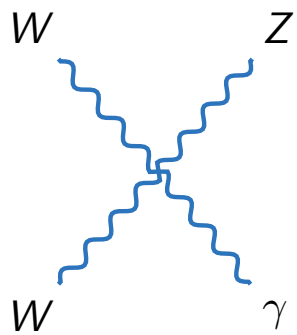


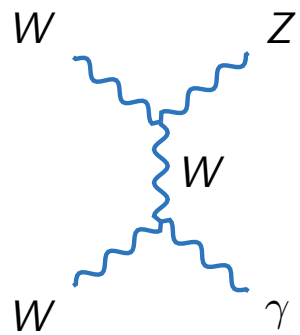
Triple couplings



Higgs exchange

- Due to the lack of neutral couplings and Higgs-photon couplings in the Standard Model, only two vertices are possible with a Z boson and a photon

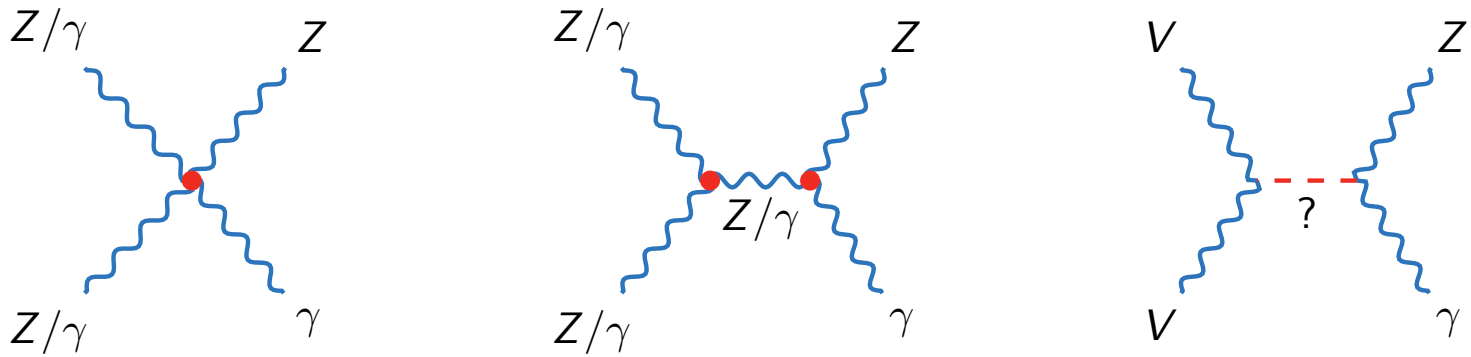




Beyond the Standard Model

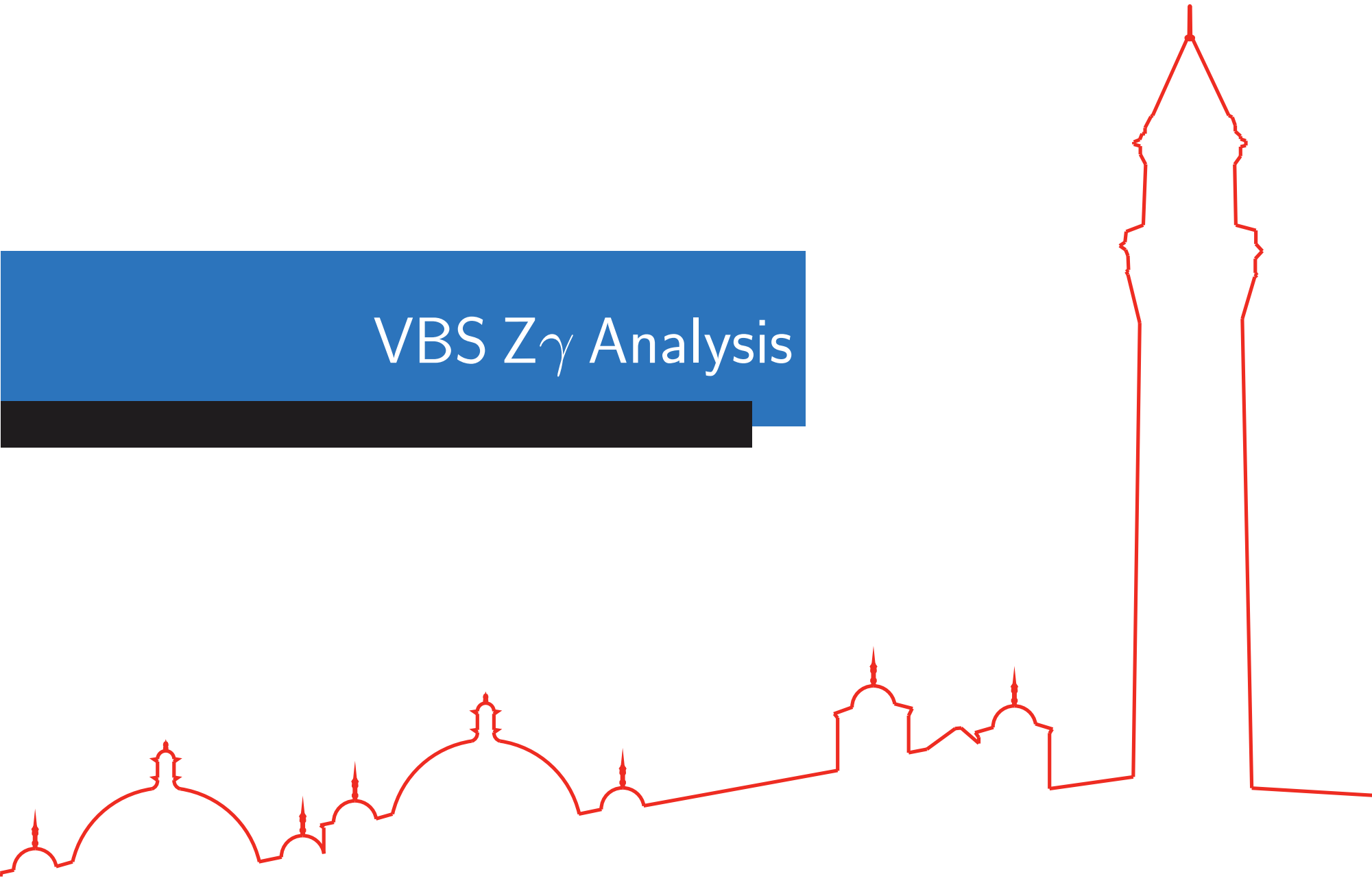
Theories beyond the Standard Model could introduce further mechanisms for interactions involving a Z boson and a photon

- Neutral couplings could be introduced by a BSM theory
- A new resonance may exist that decays to Zγ



The presence of any such diagrams could change the observed rate of the VBS Zγ or VZγ processes from the Standard Model prediction

VBS Zγ Analysis

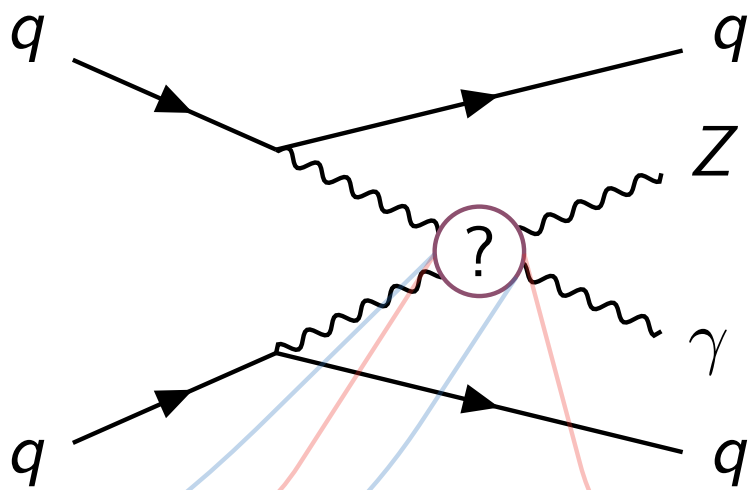


VBS Zγ

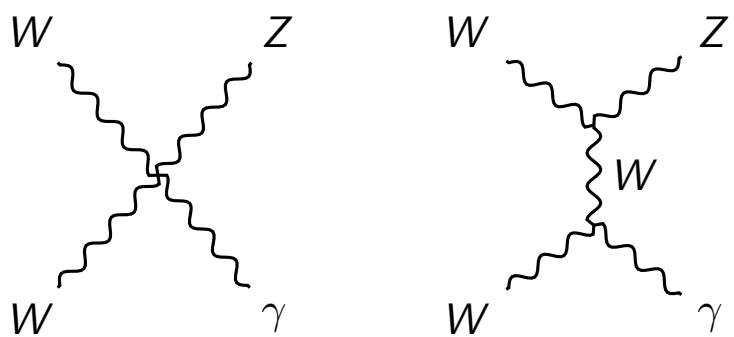
Measurement of electroweak production of Zγ with two jets

- Z decaying to two electrons or muons
  - ⇒ Gives a *jjllγ* final state
- Focus on vector-boson scattering (VBS) topologies which contain multiboson interactions

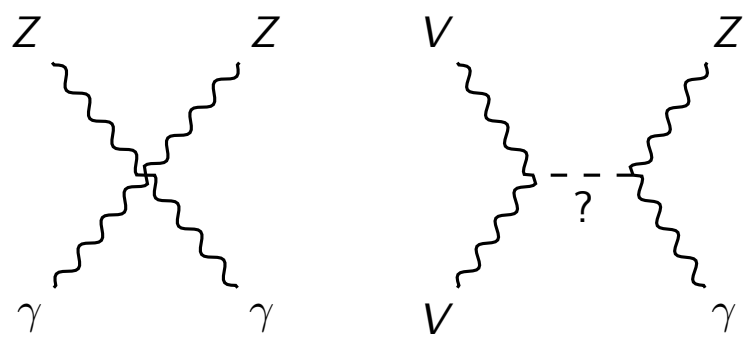
Complete info on the analysis here



SM Vertices



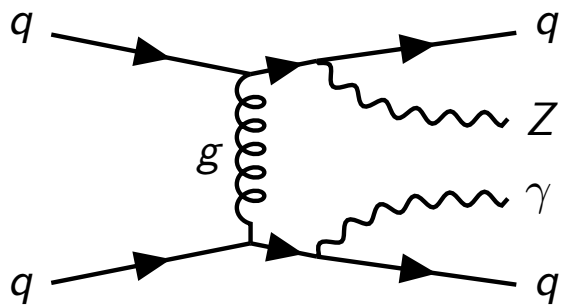
BSM Vertices



Backgrounds

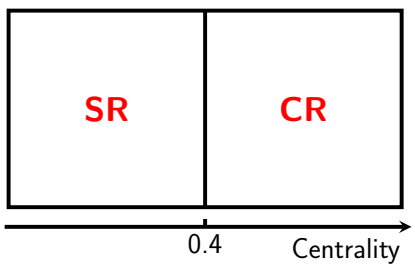
QCD $Z\gamma$

- Dominant background is QCD $Z\gamma$ production



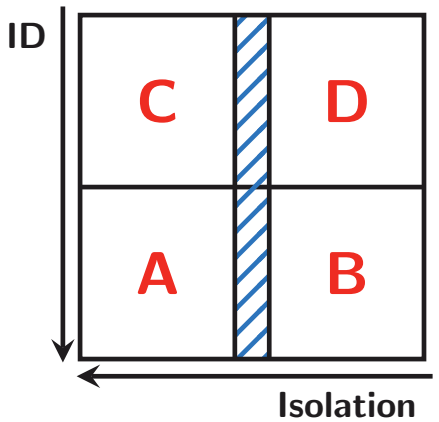
- Key difference is colour-connected jets
  - Smaller separation between jets
  - QCD activity in the gap

Known mismodelling for high dijet masses, corrected from data in a control region



Z+jets

- Second largest background, Z+jets with a jet faking a photon
- Fake photon yield estimated from data with ABCD method



Other backgrounds

- Other, smaller backgrounds include
  - $t\bar{t}\gamma$
  - WZjj
  - Pile-up background

Selection

- Enhance VBS component by cutting on jet rapidity difference and dijet mass
- Discriminate against QCD background by requiring the $Z\gamma$ system to be central and placing a veto on 'gap jets'
- Remove FSR processes, where the photon is a decay product of the Z, by cutting on $m_{\ell\ell\gamma}$ and $m_{\ell\ell}$

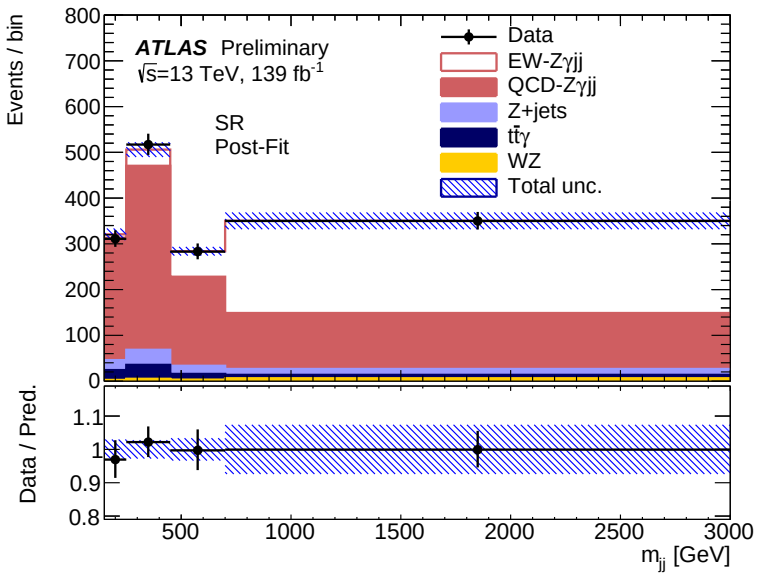
	$\ell^+\ell^-\gamma jj$ preselection
Lepton	$p_T^\ell > 30, 20$ GeV $\lvert\eta_e\rvert < 2.47$ (excl. $1.37 < \lvert\eta_e\rvert < 1.52$) $\lvert\eta_\mu\rvert < 2.5$ Exactly 2 leptons
Photon	$E_T^\gamma > 25$ GeV $\lvert\eta_\gamma\rvert < 2.37$ (excl. $1.37 < \lvert\eta_\gamma\rvert < 1.52$) At least 1 photon
Jet	$p_T^j > 50$ GeV $\lvert y_j\rvert < 4.5$ At least 2 jets $\lvert\Delta y_{jj}\rvert > 1.0$ $m_{jj} > 150$ GeV No b-jets $N_j^{\text{gap}} = 0$
Boson	$m_{\ell\ell} > 40$ GeV $m_{\ell\ell} + m_{\ell\ell\gamma} > 182$ GeV $\zeta(\ell\ell\gamma) < 5$

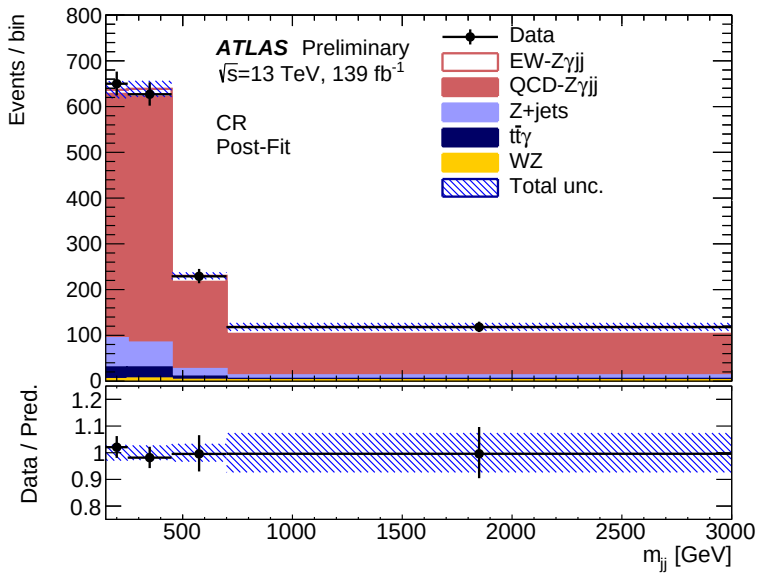
Results

For full result see
ATLAS-CONF-2021-038

- Significance extracted from a template fit in m_{jj}
  - Observed 10σ excess (expected 11σ)

$\Rightarrow$ First observation by ATLAS of this process



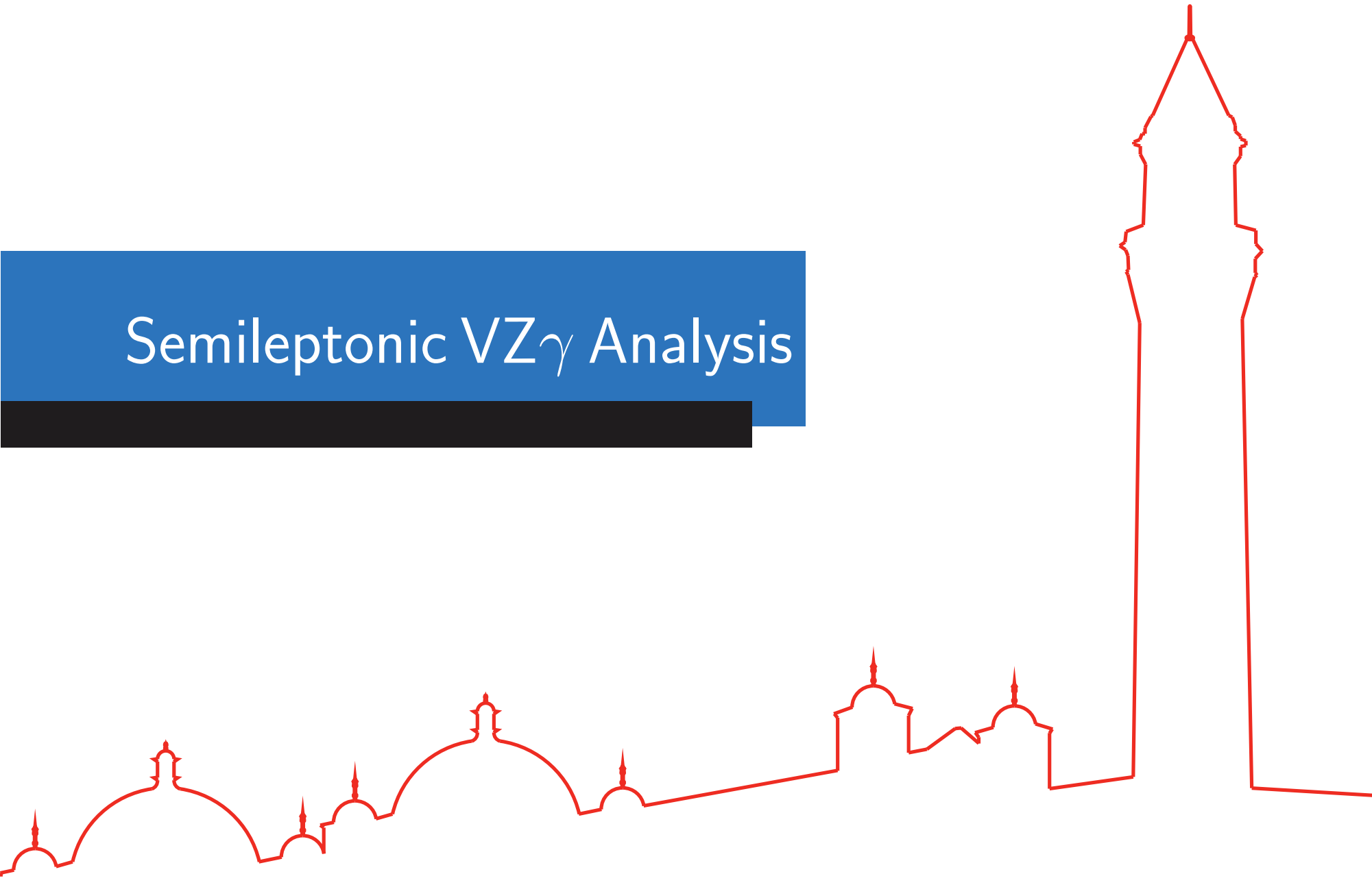


Measured fiducial cross-sections for EW and EW+QCD production:

$$\sigma_{EW} = 4.49 \pm 0.40\ (\text{stat.}) \pm 0.42\ (\text{syst.})\ \text{fb}$$

$$\sigma_{EW+QCD} = 20.6 \pm 0.6\ (\text{stat.})^{+1.2}_{-1.0}\ (\text{syst.})\ \text{fb}$$

Semileptonic VZγ Analysis



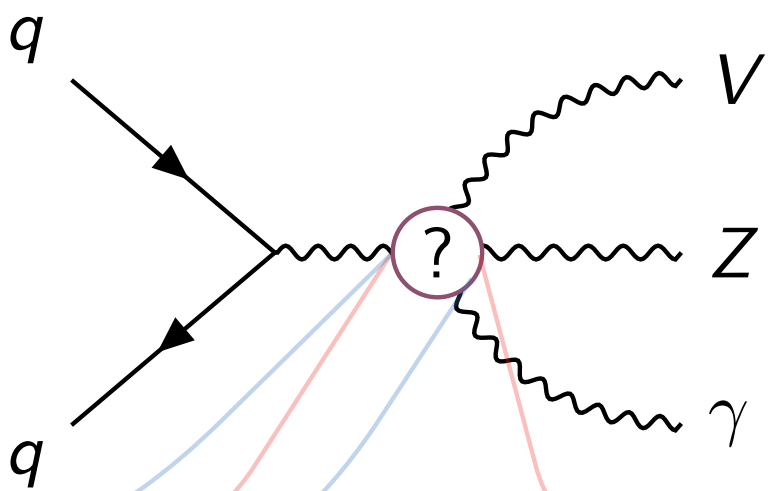
Semileptonic VZγ

Search for production of triboson VZγ processes

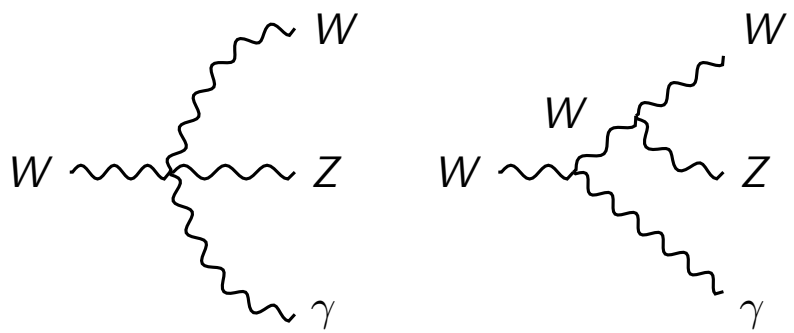
- V is a W or Z boson decaying to quarks (jets)
- Z boson decaying to two electrons or muons

  ⇒ Gives a *jjllγ* final state

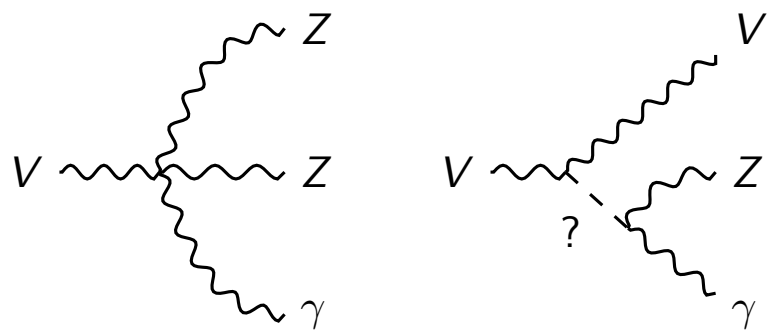
First attempt to measure this process



SM Vertices



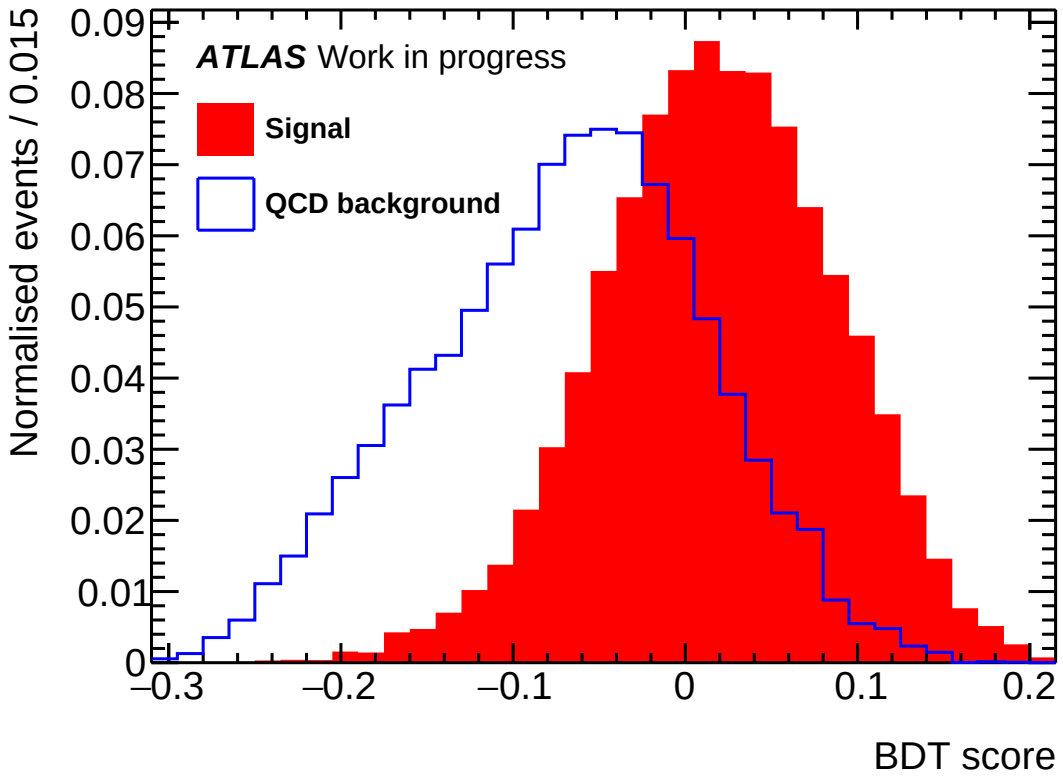
BSM Vertices



BDT Selection

Rank	Variable	Importance
1	$\lvert\Delta y_{jj}\rvert$	8.266e-02
2	$\cos\theta^*$	8.025e-02
3	$\cos\theta_{\mathrm{CS}}$	7.614e-02
4	$y_{j,2}$	7.028e-02
5	$y_{j,1}$	6.636e-02
6	$\Delta R_{\mathrm{min}}(y,j)$	6.628e-02
7	$\Delta R(Z\gamma,jj)$	6.265e-02
8	y_{jj}	6.258e-02
9	p^T balance	6.040e-02
10	$\Delta\phi(ll\gamma,jj)$	5.392e-02
11	p^T_{jj}	5.266e-02
12	$\log(\zeta(Z\gamma))$	5.190e-02
13	$m_{j,2}$	4.446e-02
14	N_j^{btag}	3.861e-02
15	$p^T_{j,1}$	3.629e-02
16	N_j	3.112e-02
17	$m_{j,1}$	3.017e-02
18	N_j^{gap}	2.929e-02
19	$p^T_{j,2}$	3.988e-03

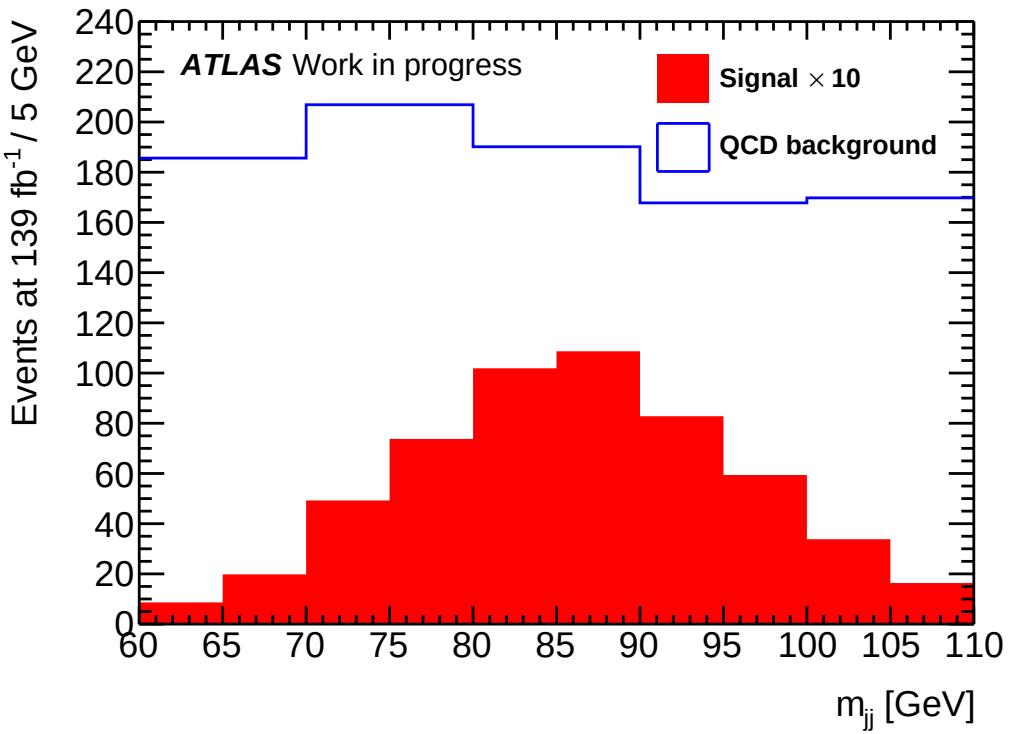
BDT selection focuses on jet variables, to identify cases where jets are from a boson decay.



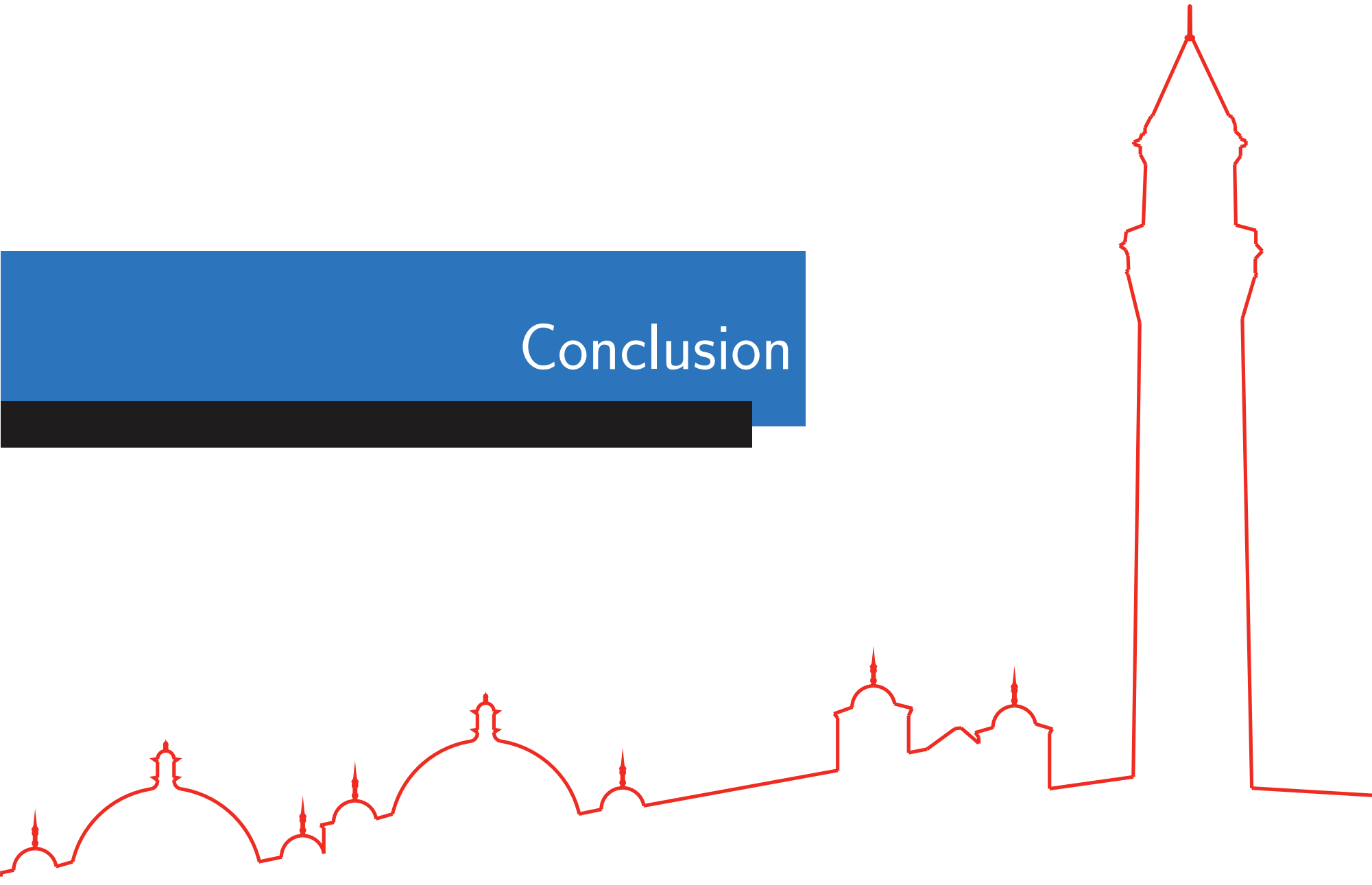
Currently in development, working to optimise discrimination against the dominant background: QCD production of Zγ +jets

Outlook

- Sensitivity estimate for SM cross-section currently at 1-2σ level
  - Analysis optimisation continuing
- Constraining this channel should be of interest for BSM constraints
  - e.g. effective field theories (EFTs) or new physics models

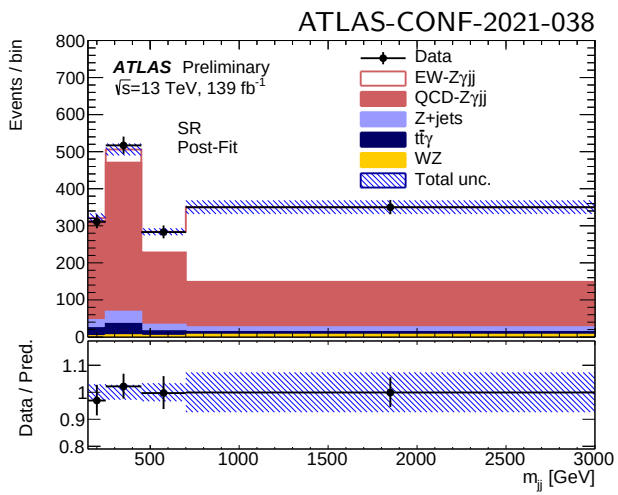


Conclusion

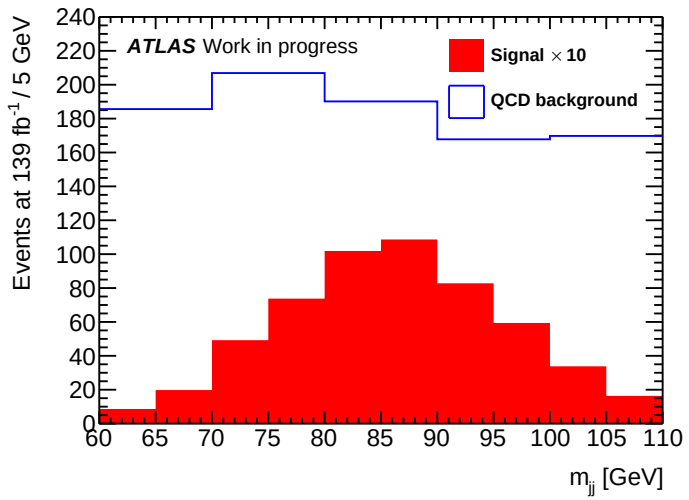


Conclusion

- Multiboson interactions are rare standard model processes, but also act as a probe for new physics
- Measuring processes with a $Z\gamma$ pair gives sensitivity to possible neutral couplings in beyond Standard Model theories
- Two analyses discussed that look to measure $Z\gamma$ processes with contributions from quartic vertices:



10σ VBS $Z\gamma$ observation



Developing $VZ\gamma$ significance