Electroweak production of two jets in association with a Z boson and a high-energy photon with the ATLAS detector

Zhijun Liang (IHEP, CAS)
梁志均
中国科学院高能物理研究所
On behalf of ATLAS collaboration

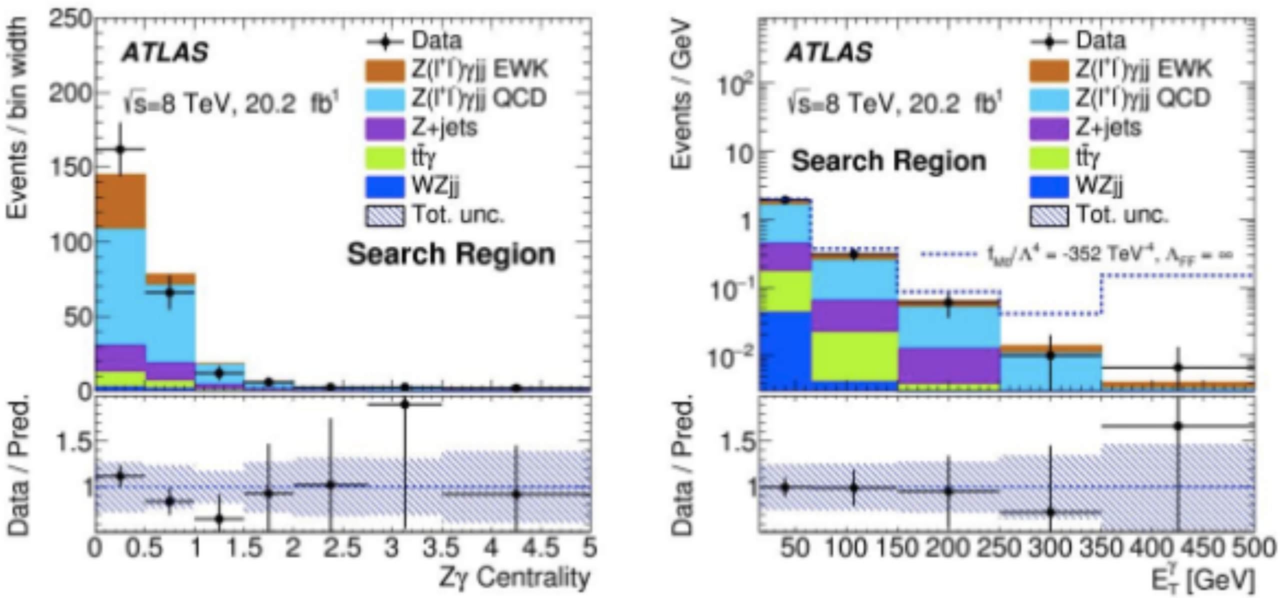
Latest ATLAS news

https://arxiv.org/abs/1705.01966

New insight into the Standard Model

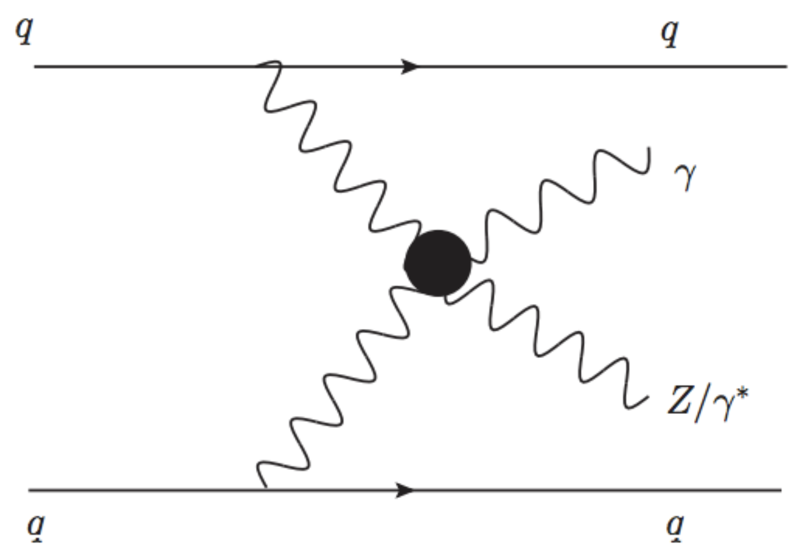
ATLAS releases the first study of a pair of neutral bosons produced in association with a high-mass dijet system

By ATLAS Collaboration, 9th May 2017

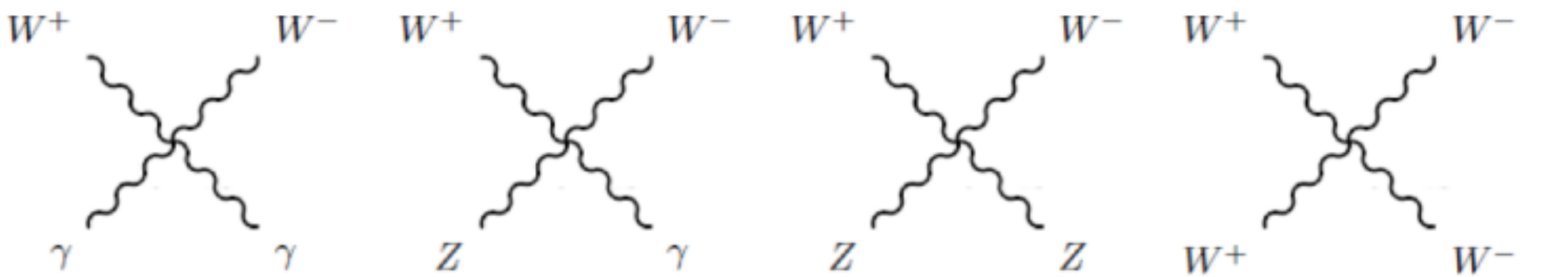


Introduction

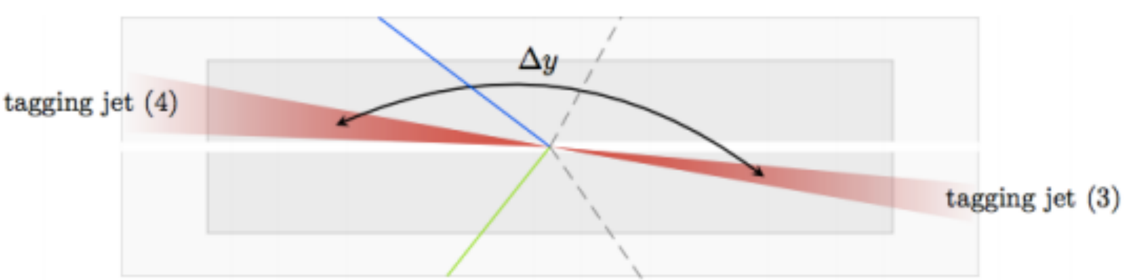
- Study of the VBS Zγ production at 8 TeV
  - Measure the EW Zγ fiducial production cross section that is sensitive to VBS process
  - Limits on anomalous Quartic Gauge Couplings (aQGC)
- Motivation:
  - higher production rate than WW/ZZ/WZ VBS processes
  - Important test of SM EWK sector and EFT parameterization of anomalous couplings
- Channels :
  - Leptonic channel (Z->ee, Z->μμ)
  - Neutrino channel (Z->νν)

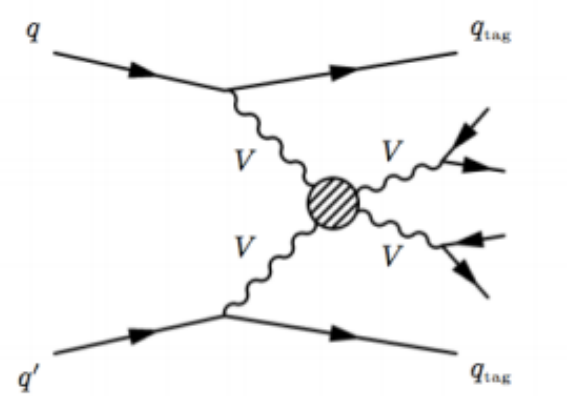


- Reminder of **Quartic Gauge Boson Couplings (QGCs)**
  - SM model predicts gauge boson self coupling
    - Four gauge boson vertex:
      - WWγγ , WWZγ , WWWW, WWZZ, ZZZZ ...



- Vector boson scattering (VBS) is one of the process to stduy QGCs.
  - Diboson + two forward jets in event topology





Fiducial region for Lepontic channel

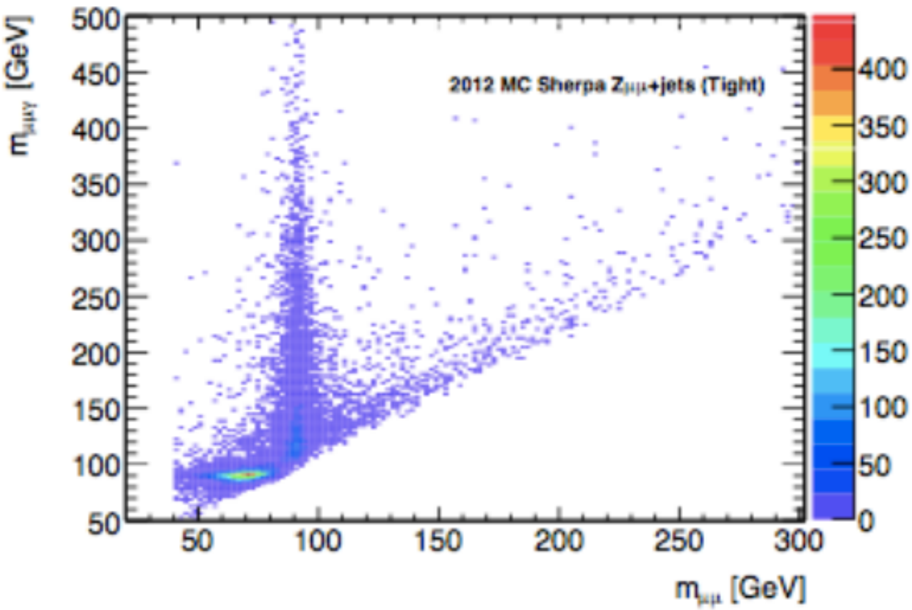
Dataset: 8TeV full dataset collected by ATLAS

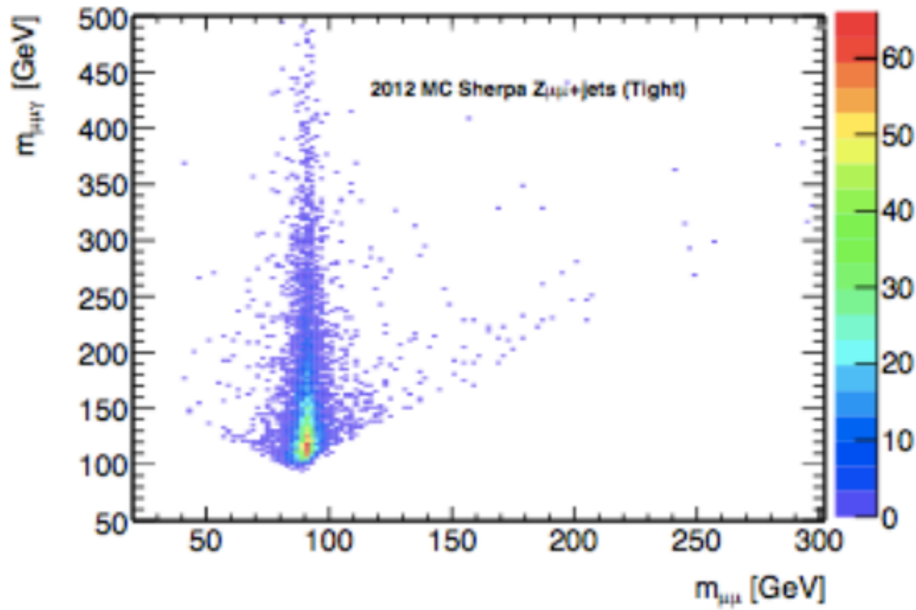
Trigger : Use both Single lepton and di-lepton trigger

Objects	Particle- (Parton-) level selection
Leptons	$p_T^\ell > 25$ GeV and $\lvert\eta^\ell\rvert < 2.5$ Dressed leptons, OS charge
Photon (kinematics)	$E_T^\gamma > 15$ GeV, $\lvert\eta^\gamma\rvert < 2.37$ $\Delta R(\ell, \gamma) > 0.4$
Photon (isolation)	$E_T^{\text{iso}} < 0.5 \cdot E_T^\gamma$ (no isolation)
FSR cut	$m_{\ell\ell} + m_{\ell\ell\gamma} > 182$ GeV $m_{\ell\ell} > 40$ GeV
Particle jets (Outgoing partons) (j = jets) (p = outgoing quarks or gluons)	At least two jets (outgoing partons) $E_T^{j(p)} > 30$ GeV, $\lvert\eta^{j(p)}\rvert < 4.5$ $\Delta R(\ell, j(p)) > 0.3$ $\Delta R(\gamma, j(p)) > 0.4$
Control region (CR)	$150 < m_{jj(pp)} < 500$ GeV
Search region (SR)	$m_{jj(pp)} > 500$ GeV
aQGC region	$m_{jj(pp)} > 500$ GeV $E_T^\gamma > 250$ GeV

Effect of FSR cut

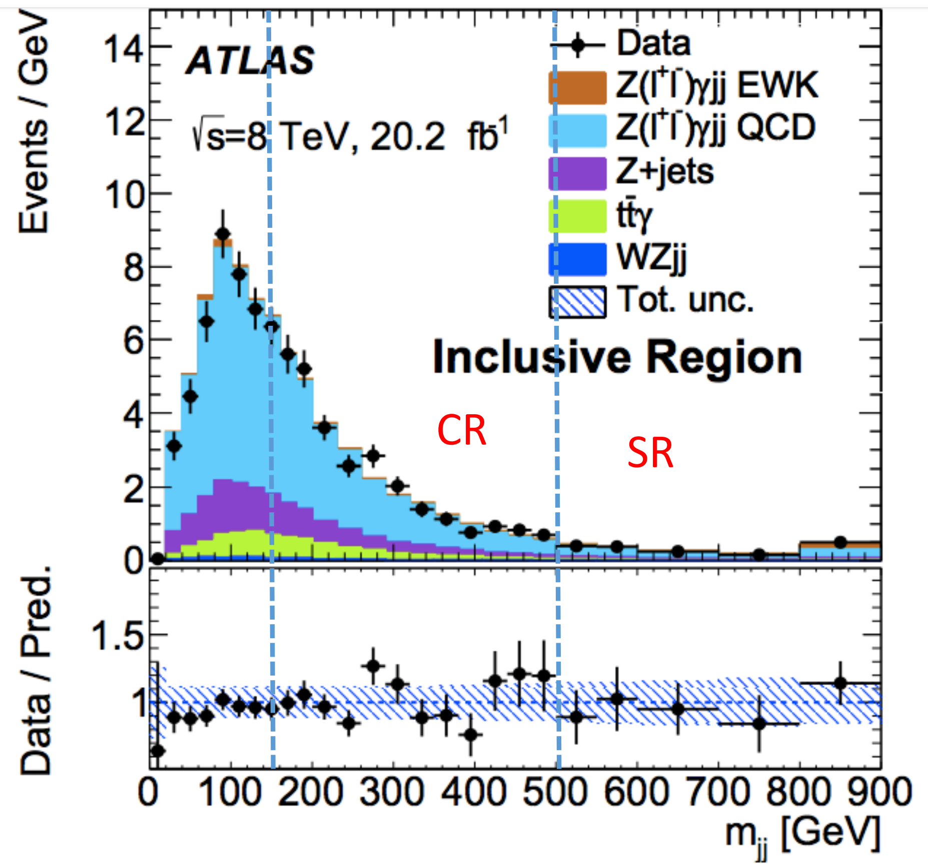
FSR cut	$m_{\ell\ell} + m_{\ell\ell\gamma} > 182$ GeV $m_{\ell\ell} > 40$ GeV





Kinematics distribution

- Inclusive region: $l^+l^- \gamma$ +2 jets
- Signal regions(SR) :$l^+l^- \gamma$ +2 jets + Mjj>500GeV
- Control regions(CR): $l^+l^- \gamma$ +2 jets + 150GeV<Mjj<500GeV

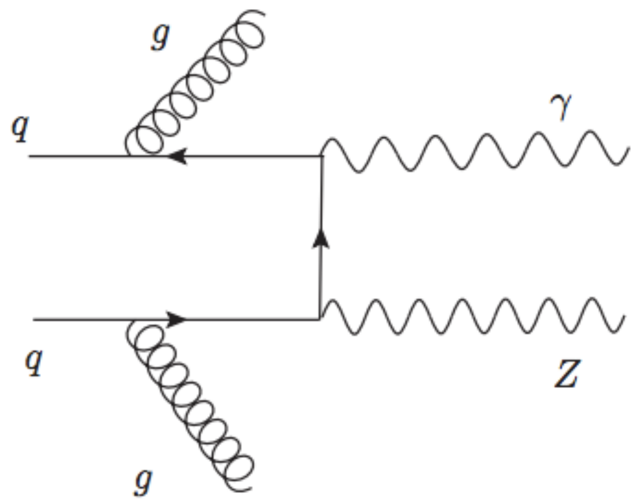


Analysis Overview

- Cross section measurement:
  - Separate the QCD and EW components assuming interference negligible
  - The fiducial region for EW cross section (signal-enhanced) : mjj>500 GeV
  - Control region is build (background enhanced): 150<mjj<500 GeV
    - control normalisation of QCD Zγ background
    - constraint systematic uncertainties
  - Limits on anomalous Quartic Gauge Couplings (aQGC) in high γ pT region

Background in charged-lepton channel

- Dominant Background (QCD Zγ + 2jets)
  - data-driven estimation
- "EWK" backgrounds
  - ttbar + gamma : Madgraph
  - Diboson (mainly WZ)



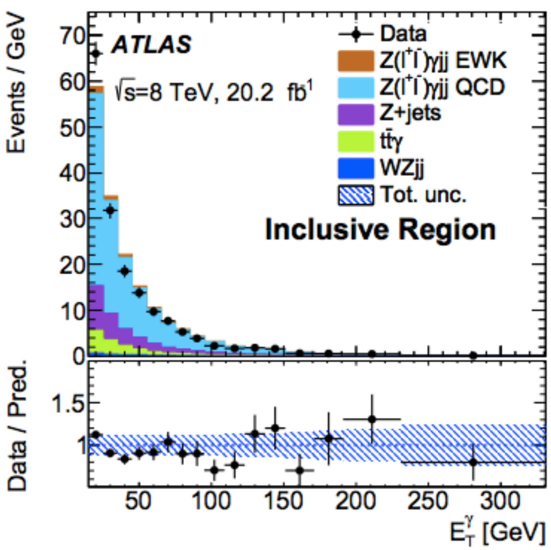
Background summary in charged-lepton channel

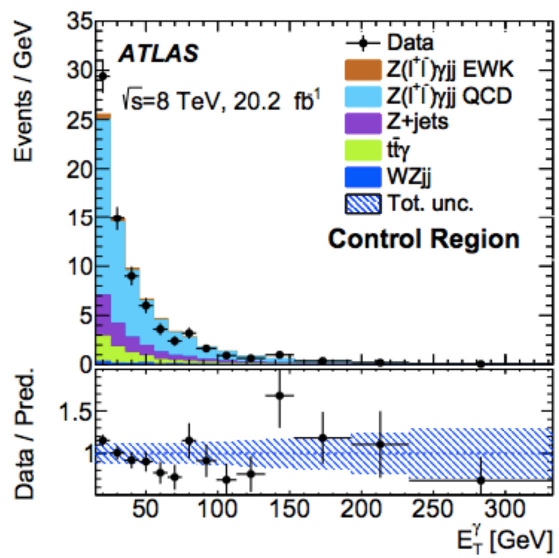
- ~15% Zjets contribution
- ~70% $Z\gamma$ QCD

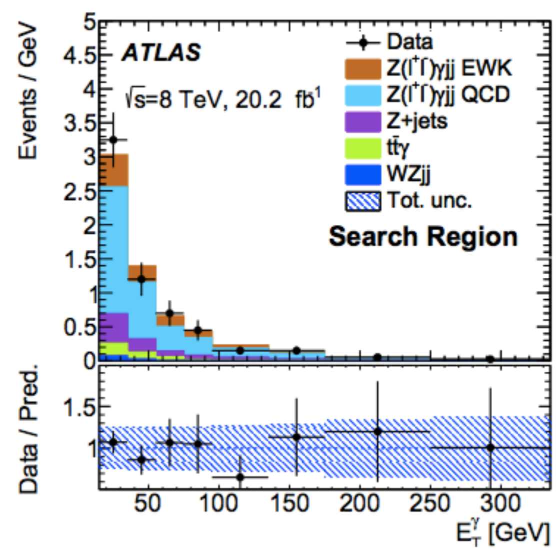
	Inclusive region $Z(\ell^+\ell^-)\gamma + \geq 2$ jets		Control region $150 < m_{jj} < 500$ GeV		Search region $m_{jj} > 500$ GeV	
	$e^+e^-\gamma jj$	$\mu^+\mu^-\gamma jj$	$e^+e^-\gamma jj$	$\mu^+\mu^-\gamma jj$	$e^+e^-\gamma jj$	$\mu^+\mu^-\gamma jj$
Data	781	949	362	421	58	72
Z+jets bkg.	134 ± 36	154 ± 42	57 ± 16	67 ± 18	8.5 ± 2.5	9.4 ± 2.7
Other bkg. ($t\bar{t}\gamma$, WZ)	88 ± 17	91 ± 18	47 ± 9	46 ± 9	5.8 ± 1.1	5.0 ± 1.0
$N_{\text{data}} - N_{\text{bkg}}$	559 ± 46	704 ± 53	258 ± 24	308 ± 27	44 ± 7	58 ± 8
$N_{Z\gamma\ \text{QCD}}$ (SHERPA MC)	583 ± 41	671 ± 47	249 ± 24	290 ± 26	37 ± 5	41 ± 5
$N_{Z\gamma\ \text{EWK}}$ (SHERPA MC)	25.4 ± 1.5	27.3 ± 1.7	8.6 ± 0.6	9.3 ± 0.6	11.2 ± 0.8	11.6 ± 0.7
$N_{Z\gamma}$ (SHERPA MC)	608 ± 42	698 ± 49	258 ± 25	299 ± 27	48 ± 6	53 ± 6

Kinematics distribution: photon pT (pre-fit)

Signal and background shape in photon pT is similar

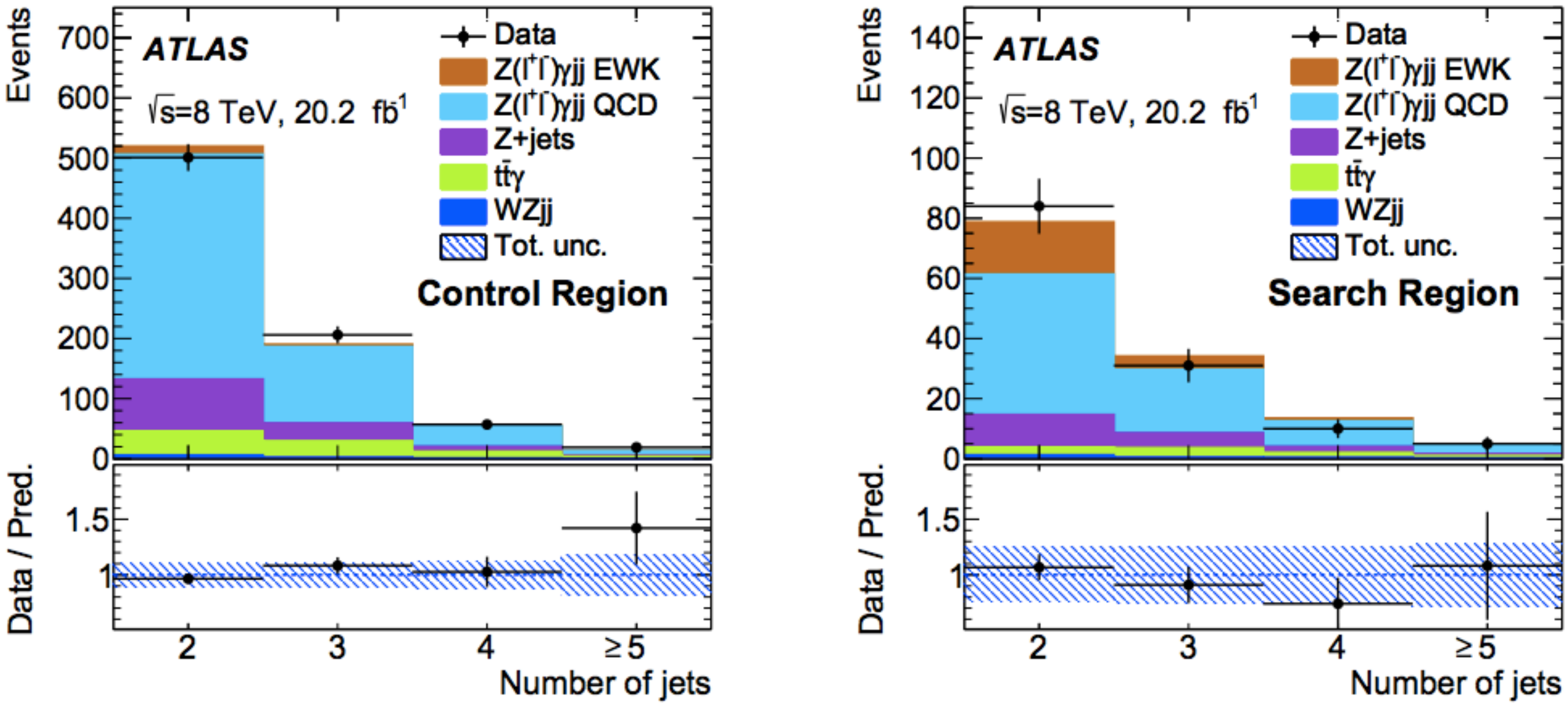




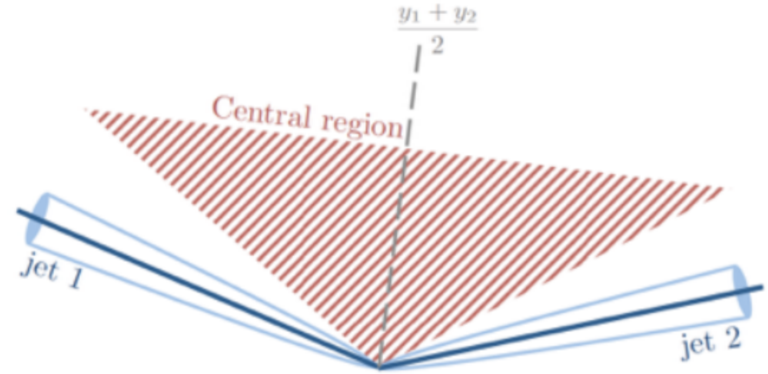


Kinematics distribution: Number of jets (pre-fit)

- Signal and background shape is similar

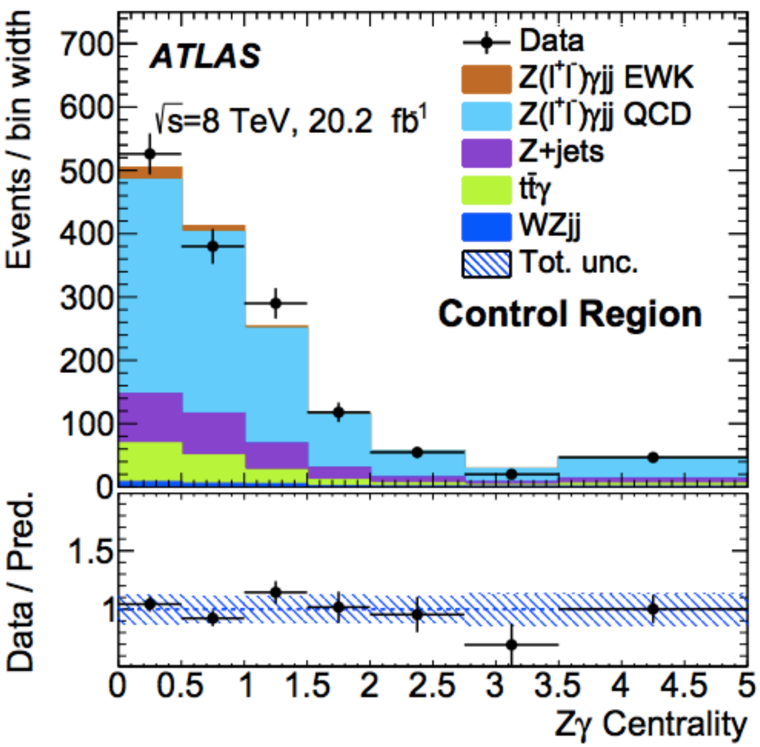


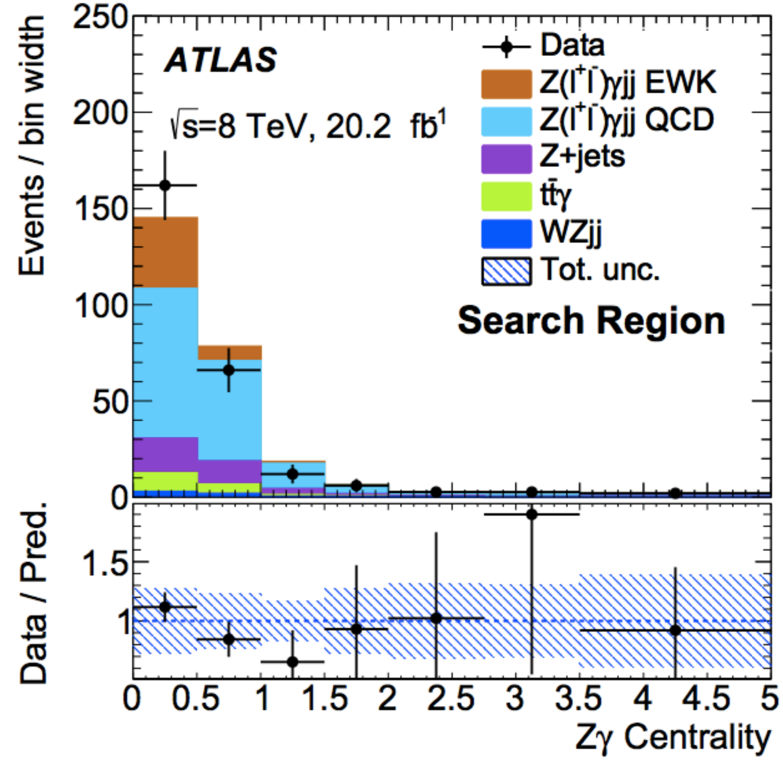
Kinematics distribution: $Z\gamma$ centrality (pre-fit)



- Signal is more likely to has low $Z\gamma$ centrality

$$\zeta_{Z\gamma} = \left| \frac{y_{Z\gamma} - (y_{j1} + y_{j2})/2}{(y_{j1} - y_{j2})} \right|$$

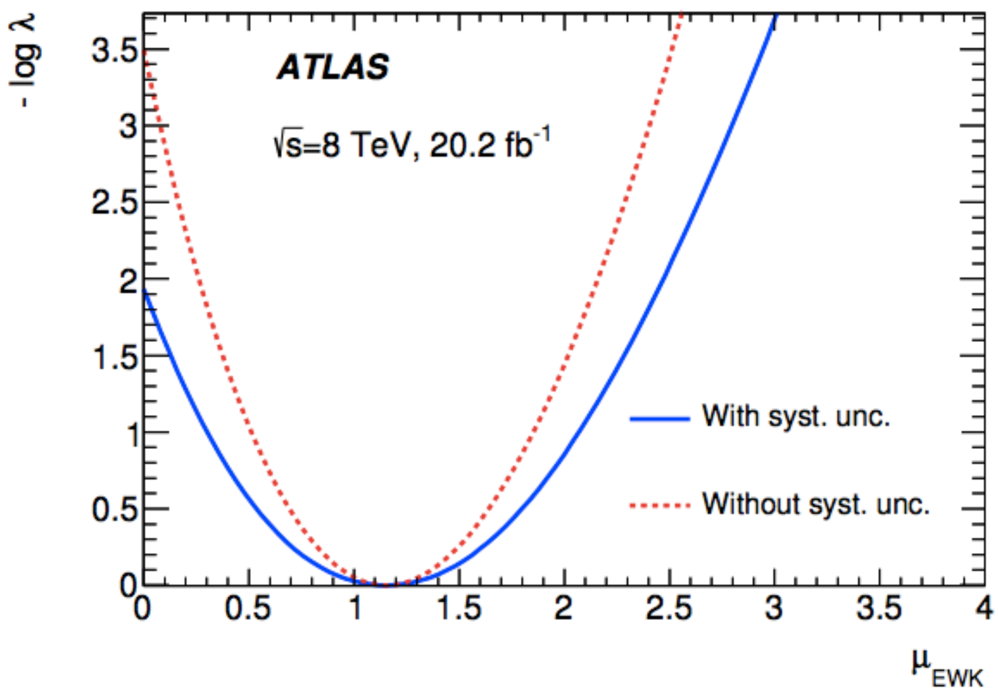




Cross section measurement

- Binned fit Zgamma based on $Z\gamma$ centrality
  - Simultaneous fit on both CR and SR regions.
  - Signal template from signal MC

$$L_{SR+CR} = \prod_{i=1}^{N} Pois(n^i_{SR} | \lambda^i_{SR}(\mu_{sig} \times N^{sig,i}_{SR}, \mu_b \times N^{b,i}_{SR}, \vec{\theta})) \times C_{sys}(\vec{\delta}, \vec{\theta})$$

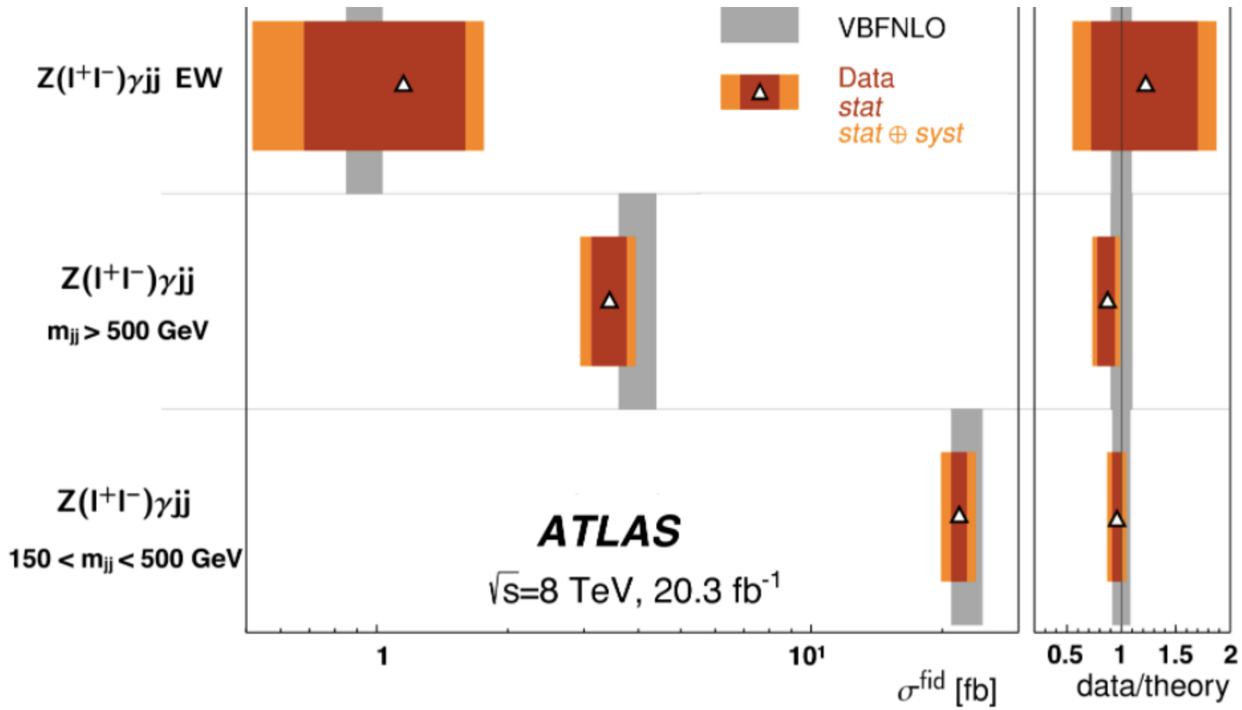


$$\mu = \frac{N^{\mathrm{signal}}_{\mathrm{data}}}{N^{\mathrm{signal}}_{\mathrm{MC}}}$$

Cross section results

Theory prediction from VBFNLO

Channel	Phase-space region	Process type	Measured cross-section [fb]	Predicted cross-section [fb]
$Z(\ell^+\ell^-)\gamma jj$	Search region	EWK	1.1 ± 0.5 (stat) ± 0.4 (syst)	0.94 ± 0.09
$Z(\ell^+\ell^-)\gamma jj$	Search region	EWK+QCD	3.4 ± 0.3 (stat) ± 0.4 (syst)	4.0 ± 0.4
$Z(\ell^+\ell^-)\gamma jj$	Control region	EWK+QCD	21.9 ± 0.9 (stat) ± 1.8 (syst)	22.9 ± 1.9



Systematics

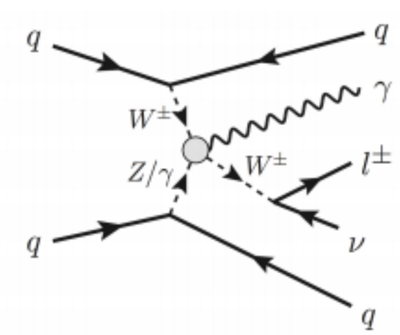
- Jet energy scale is one of the major systematics
  - Especially for the forward jet calibration
- Theory systematics
  - Uncertainty due to the choice of QCD scale

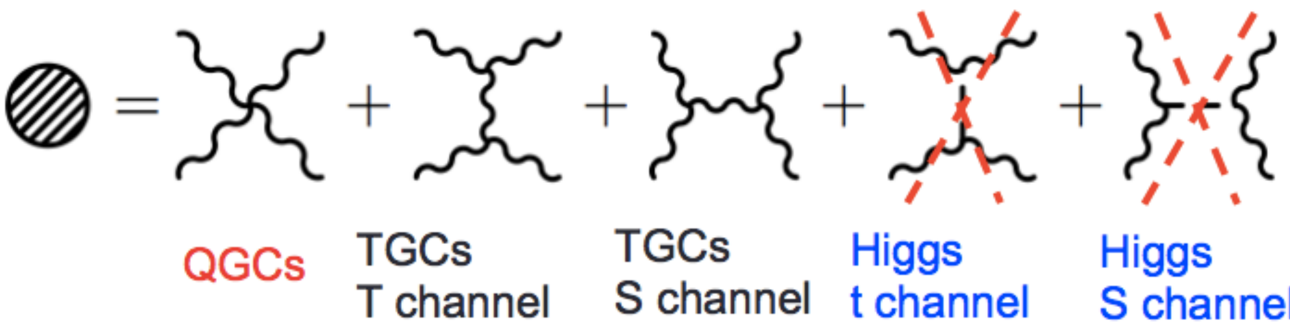
Source of uncertainty	EWK [%]	Total (EWK+QCD) [%] SR	CR
Statistical	40	9	4
Jet energy scale	36	9	4
Theory	10	5	4
All other	8	5	6
Total systematic	38	11	8

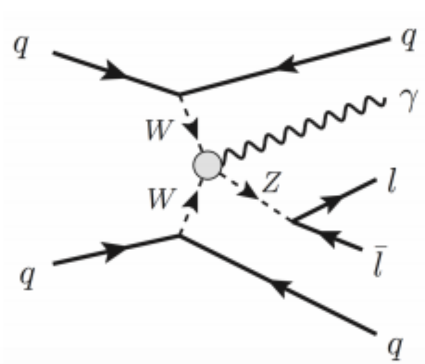
Anomalous quartic gauge-boson couplings

- Zγ+dijet VBS : photon+ two opposite charge leptons + dijet
  - Sensitive to QGCs in WWZγ vertex
  - No contamination from aTGCs

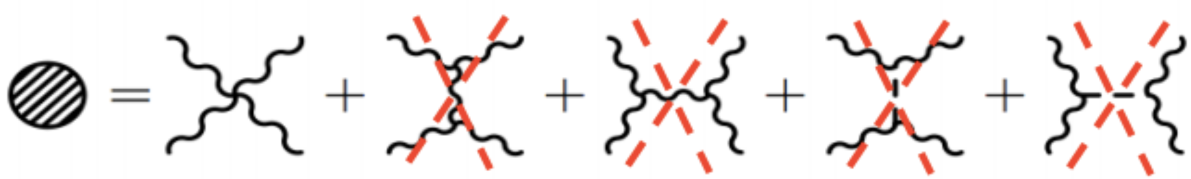
Wγ+dijet VBS







Zγ+dijet VBS



Anomalous quartic gauge-boson couplings

$$\mathcal{L} = \mathcal{L}^{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i + \sum_j \frac{f_j}{\Lambda^4} O_j.$$

- Zγjj VBS
  - Sensitive to WWAZ ,ZZZA, ZAAA aQGCs coupling
- Effective field theory

Higgs field

$$\mathcal{L}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$
$$\mathcal{L}_{S,1} = \left[(D_\mu\Phi)^\dagger D^\mu\Phi\right] \times \left[(D_\nu\Phi)^\dagger D^\nu\Phi\right]$$

Higgs - Gauge boson field(L_M)

$$\mathcal{L}_{M,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,1} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,2} = \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,4} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\mu\Phi\right] \times B^{\beta\nu}$$
$$\mathcal{L}_{M,5} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\nu\Phi\right] \times B^{\beta\mu}$$
$$\mathcal{L}_{M,6} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\nu} D^\mu\Phi\right]$$
$$\mathcal{L}_{M,7} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\mu} D^\nu\Phi\right]$$

Gauge boson field (L_T)

$$\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$$
$$\mathcal{L}_{T,1} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}\right]$$
$$\mathcal{L}_{T,2} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}\right]$$
$$\mathcal{L}_{T,5} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,6} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times B_{\mu\beta}B^{\alpha\nu}$$
$$\mathcal{L}_{T,7} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times B_{\beta\nu}B^{\nu\alpha}$$
$$\mathcal{L}_{T,8} = B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,9} = B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}$$

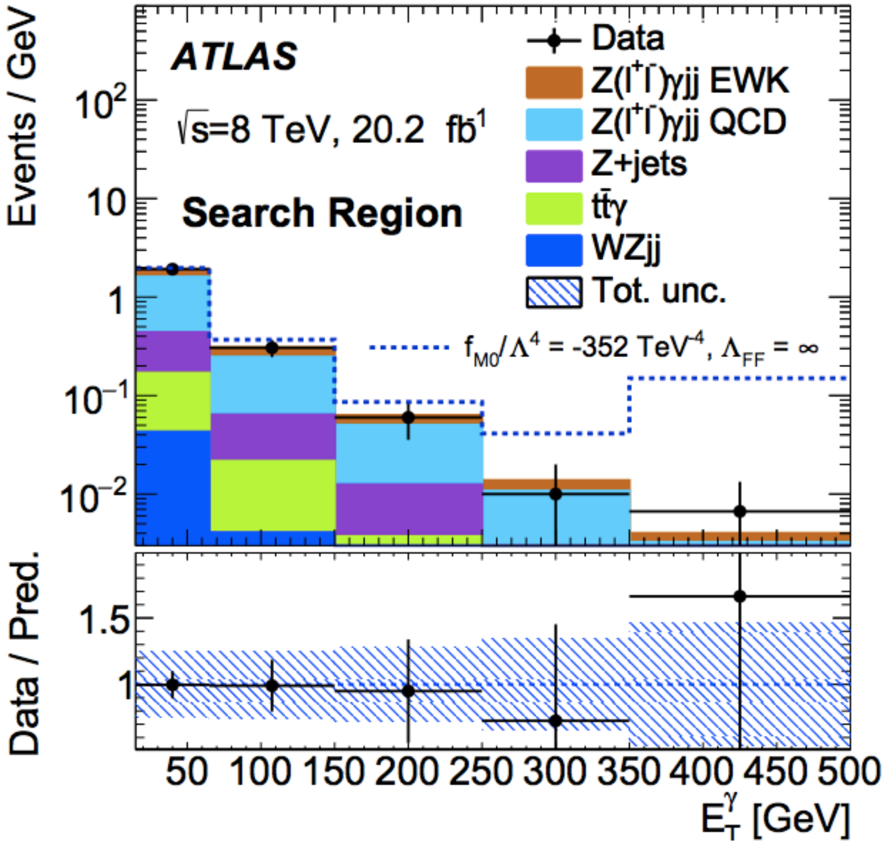
	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}$, $\mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}$, $\mathcal{L}_{M,1}$,$\mathcal{L}_{M,6}$,$\mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}$,$\mathcal{L}_{M,3}$, $\mathcal{L}_{M,4}$,$\mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}$,$\mathcal{L}_{T,1}$,$\mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}$,$\mathcal{L}_{T,6}$,$\mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}$,$\mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

O.J.P.Eboli, et.al. Phys.Rev.D74:073005,2006

Anomalous quartic gauge-boson couplings Lepontic channel

- aQGCs region= SR region + ET(γ)>250 GeV

	$m_{jj} > 500$ GeV, $E_T^{\gamma} > 250$ GeV, $\ell^+\ell^-\gamma jj$
Data	2
Z+jets background	0.28 ± 0.08
$W(\ell\nu)\gamma$+jets background	-
γ+jets background	-
$W(e\nu)$+jets background	-
$t\bar{t}\gamma$, WZ background	0.02 ± 0.01
$N_{data} - N_{bkg}$	1.7 ± 1.4
$N_{Z\gamma\ QCD}$ (SHERPA MC)	1.2 ± 0.4
$N_{Z\gamma\ EWK}$ (SHERPA MC)	0.41 ± 0.04
$N_{Z\gamma}$ (SHERPA MC)	1.6 ± 0.4



Fiducial region for neutrino channel

Objects	Particle- (Parton-) level selection
Neutrinos	$E_{\mathrm{T}}^{\nu\bar{\nu}} > 100$ GeV
Photon (kinematics)	$E_{\mathrm{T}}^{\gamma} > 150$ GeV, $\lvert\eta^{\gamma}\rvert < 2.37$ $\Delta R(\ell,\gamma) > 0.4$
Photon (isolation)	$E_{\mathrm{T}}^{\mathrm{iso}} < 0.5 \cdot E_{\mathrm{T}}^{\gamma}$
Generator-level jets (Outgoing quarks) $(pp \to Z\gamma qq)$	At least two jets (quarks) $E_{\mathrm{T}}^{j(q)} > 30$ GeV, $\lvert\eta^{j(q)}\rvert < 4.5$ $\Delta R(\gamma, j(q)) > 0.4$
Event kinematic selection	$\lvert\Delta\phi(E_{\mathrm{T}}^{\nu\bar{\nu}}, \gamma jj(qq))\rvert > \frac{3\pi}{4}$ $\lvert\Delta\phi(E_{\mathrm{T}}^{\nu\bar{\nu}}, \gamma)\rvert > \frac{\pi}{2}$ $\lvert\Delta\phi(E_{\mathrm{T}}^{\nu\bar{\nu}}, j(q))\rvert > 1$ $E_{\mathrm{T}}^{\gamma} > 150$ GeV $\lvert\Delta y_{jj(qq)}\rvert > 2.5$ $\zeta_{\gamma} < 0.3$ $p_{\mathrm{T}}^{\mathrm{balance}} < 0.1$ $m_{jj(qq)} > 600$ GeV

Background composition in neutrino channel

Major backgrounds

$(Z \rightarrow \nu\nu)\gamma$ QCD – **from MC** (for aQGC limits).

A combined cross section is measured together with VBS Znng in a aQGC sensitive region

$W+\gamma$ – shape **from MC** with normalization from data in CR region with inversed charged lepton veto. *Same technique as in Zγ(γ) analysis.*

Extrapolation to aQGC phase space done using MC. Stability for MC vs data Transfer Factor (TF) checked for VBS cuts.

$W \rightarrow e\nu$ – data-driven method: fake-rate from Z peak, e+E_T(miss) control region. *Same technique as in Zγ(γ) analysis.*

No extrapolation, since background can be estimated for VBS region directly.

Z+jets - data-driven method: ABCD based on photon ID and Isolation. *Same technique as in Zγ channel.*

Same extrapolation as for Z(ll)γ.

γ+jet – data-driven method: ABCD based on E_T(miss) and $\Delta\phi(E_T(\text{miss}),\text{jets})$.

Extrapolation was done using data control region. R_MC stability was checked vs VBS topology cuts.

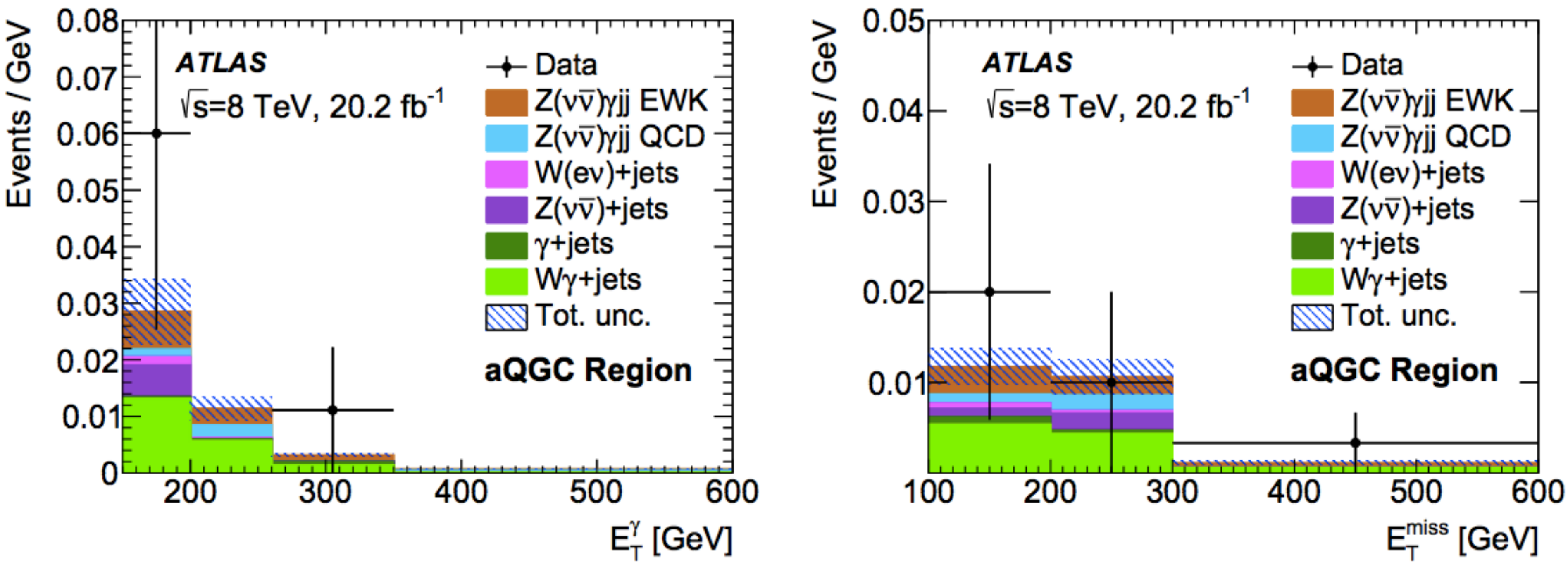
Microsoft PowerPoint

Background composition in neutrino channel

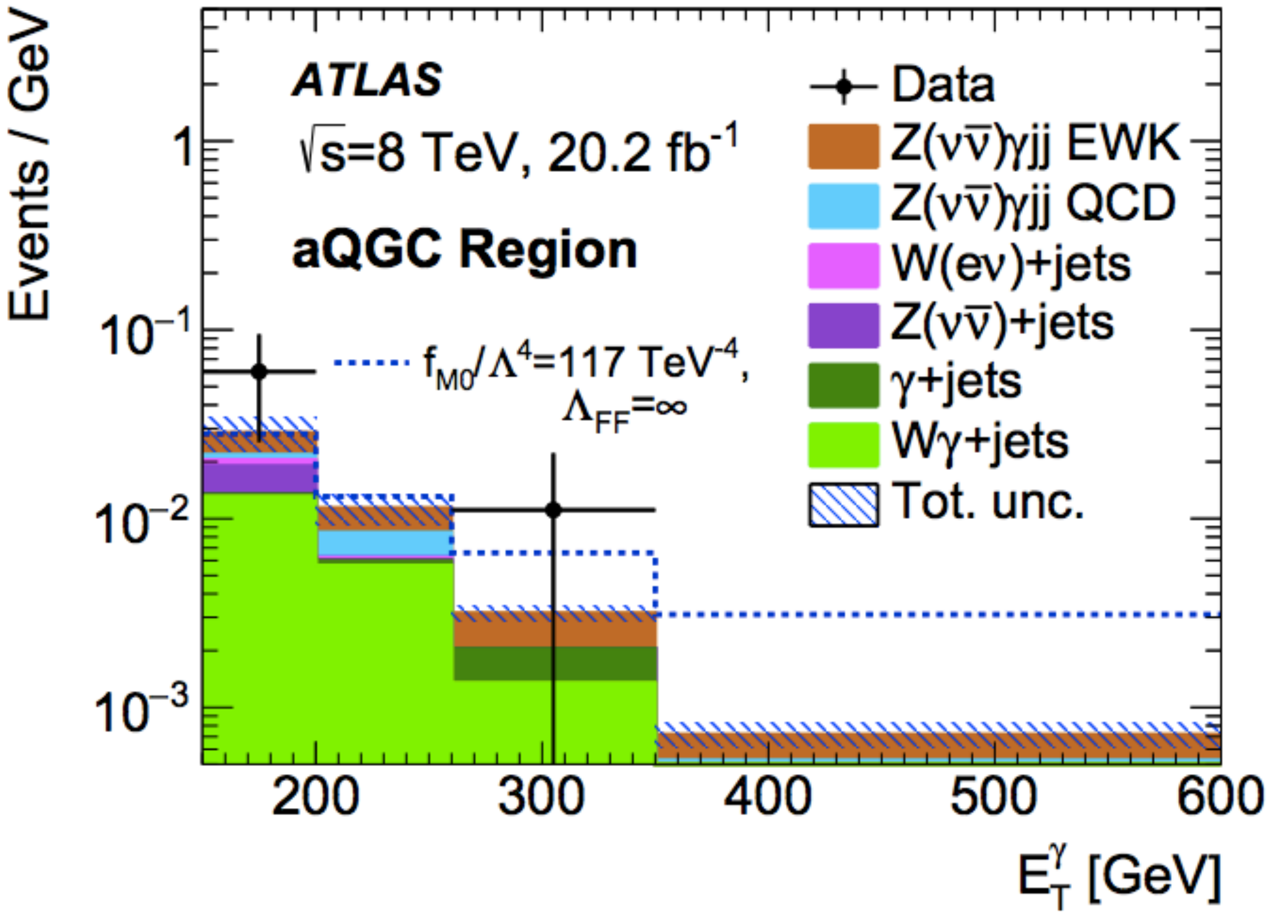
Wgamma is major background

	$m_{jj} > 600$ GeV $E_T^{\gamma} > 150$ GeV $\nu\bar{\nu}\gamma jj$
Data	4
Z+jets background	0.3 ± 0.2
$W(\ell\nu)\gamma$+jets background	1.1 ± 0.5
γ+jets background	0.13 ± 0.08
$W(e\nu)$+jets background	0.09 ± 0.04
$t\bar{t}\gamma$, WZ background	-
$N_{\text{data}} - N_{\text{bkg}}$	2.4 ± 2.0
$N_{Z\gamma\ \text{QCD}}$ (SHERPA MC)	0.29 ± 0.07
$N_{Z\gamma\ \text{EWK}}$ (SHERPA MC)	0.65 ± 0.05
$N_{Z\gamma}$ (SHERPA MC)	0.9 ± 0.1

Kinematics distribution:



Anomalous quartic gauge-boson couplings
Neutrino channel



aQGCs limits

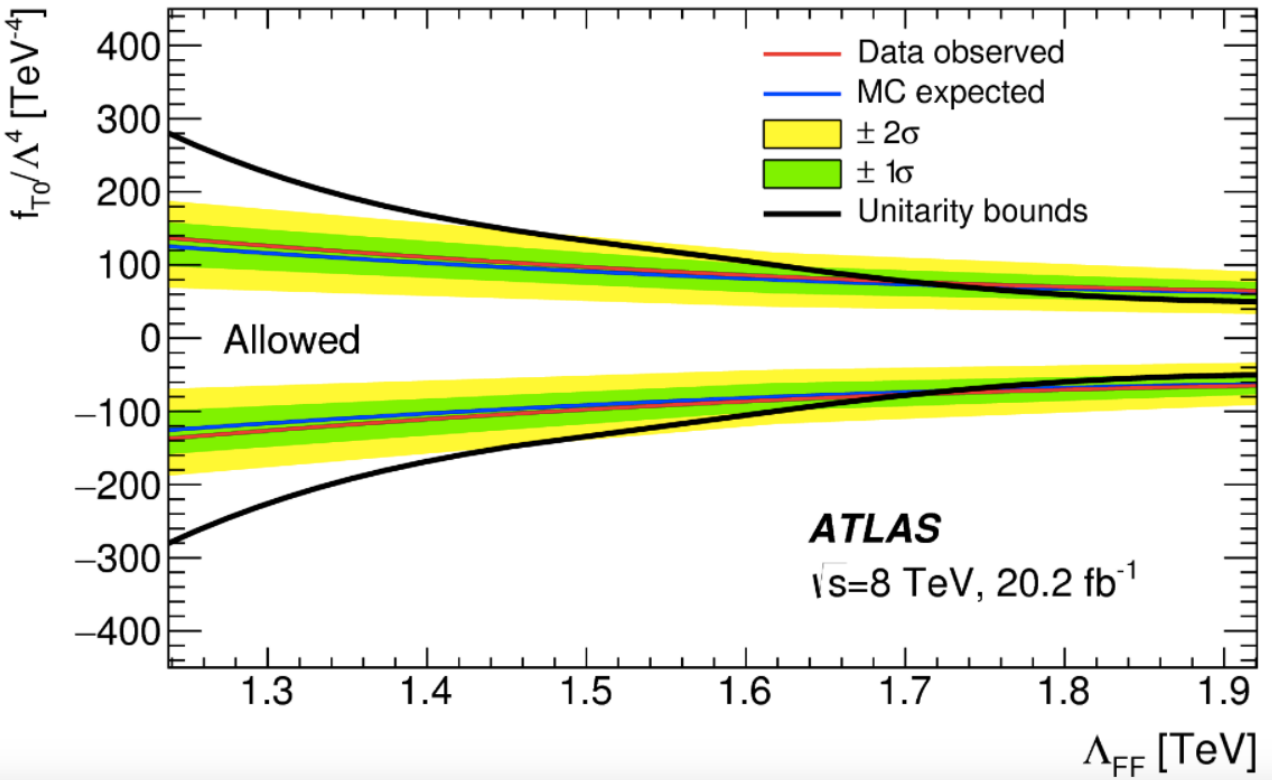
aQGCs limit from this ATLAS analysis is similar to corresponding CMS analysis

	Limits 95% CL	Measured [TeV^{-4}]	Expected [TeV^{-4}]
ATLAS $Z(\to \ell\bar{\ell}/\nu\bar{\nu})\gamma$-EWK	f_{T9}/Λ^4	$[-3.9, 3.9]$	$[-2.7, 2.8]$
	f_{T8}/Λ^4	$[-1.8, 1.8]$	$[-1.3, 1.3]$
	f_{T0}/Λ^4	$[-3.4, 2.9]$	$[-3.0, 2.3]$
	f_{M0}/Λ^4	$[-76, 69]$	$[-66, 58]$
	f_{M1}/Λ^4	$[-147, 150]$	$[-123, 126]$
	f_{M2}/Λ^4	$[-27, 27]$	$[-23, 23]$
	f_{M3}/Λ^4	$[-52, 52]$	$[-43, 43]$
CMS $Z(\to \ell\bar{\ell})\gamma$-EWK	f_{T9}/Λ^4	$[-4.0, 4.0]$	$[-6.0, 6.0]$
	f_{T8}/Λ^4	$[-1.8, 1.8]$	$[-2.7, 2.7]$
	f_{T0}/Λ^4	$[-3.8, 3.4]$	$[-5.1, 5.1]$
	f_{M0}/Λ^4	$[-71, 75]$	$[-109, 111]$
	f_{M1}/Λ^4	$[-190, 182]$	$[-281, 280]$
	f_{M2}/Λ^4	$[-32, 31]$	$[-47, 47]$
	f_{M3}/Λ^4	$[-58, 59]$	$[-87, 87]$
CMS $W(\to \ell\nu)\gamma$-EWK	f_{T0}/Λ^4	$[-5.4, 5.6]$	$[-3.2, 3.4]$
	f_{M0}/Λ^4	$[-77, 74]$	$[-47, 44]$
	f_{M1}/Λ^4	$[-125, 129]$	$[-72, 79]$
	f_{M2}/Λ^4	$[-26, 26]$	$[-16, 15]$
	f_{M3}/Λ^4	$[-43, 44]$	$[-25, 27]$

aQGCs limits with form factor

$$f \to \left(1+\frac{s}{\Lambda_{FF}^2}\right)^{-n} \times f.$$

- In order to avoid the aQGCs model violating unitarity.
- We also provide limits with form factors



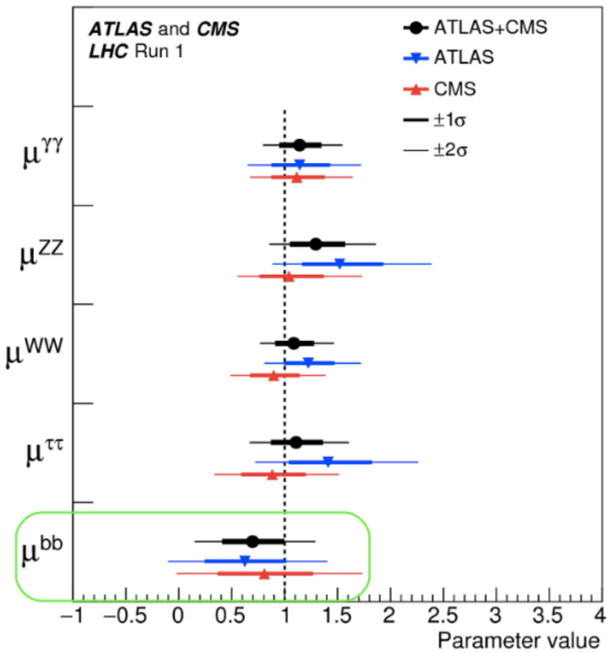
Summary

- Observed significance for Zγ j j EWK production: 2σ
- The total Zγ j j production (EWK+QCD) cross-section is also measured in signal region and control regions.
- aQGCs Limits are set using high γ pT regions.

Backup

Higgs-bottom Yukawa coupling

- H→bb̄ has the largest predicted branching ratio (~58%)
  - Test of Yukawa coupling between b-quarks and Higgs boson
- Evidence of fermionic decays in Run 1:
  - H → bb: 2.6σ (expected 3.7σ)



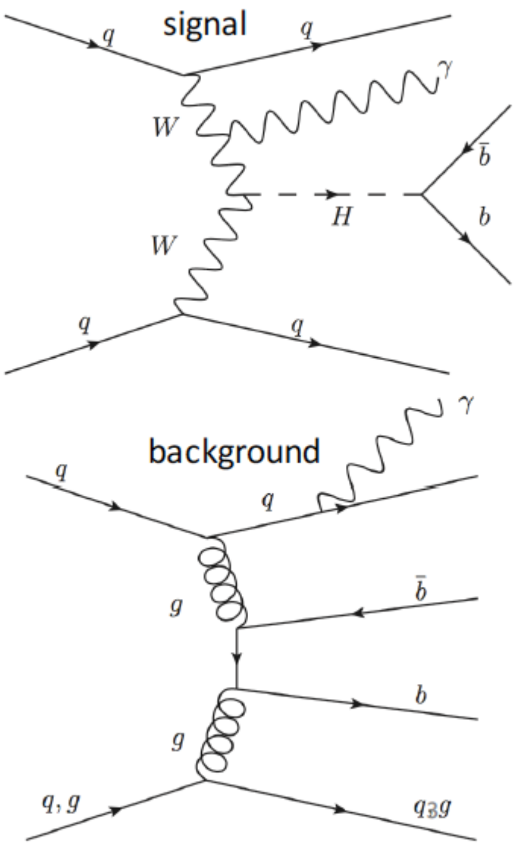
$$\mu_{bb}^{CMS+ATLAS} = 0.70^{+0.29}_{-0.27}$$

channel	Reference	Integrated Lumiosity
VH(bb̄)	ATLAS-CONF-2016-091	13.2 fb^{-1} (13TeV)
VBF H(bb)γ	ATLAS-CONF-2016-063	12.5 fb^{-1} (13TeV)

VBF H(bb)γ

ATLAS-CONF-2016-063

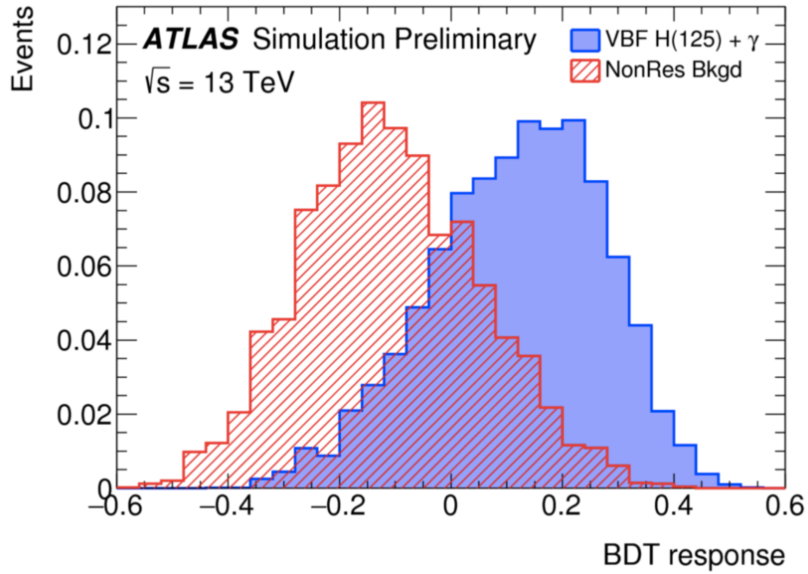
- Search for H->bb in VBF events containing a central photon
- Advantages of requiring a photon
  - extra handle for trigger
  - suppresses QCD background containing initial state gluons
  - Special VBF production
  - Sensitive to WWH VBF production
  - not sensitive to ZZH VBF
- Existing results for inclusive VBF (H->bb)
  - ATLAS in Run 1
    - observed (expected) upper limit : 4.4 (5.4) x SM
  - CMS in Run 1
    - observed (expected) significance : 2.2 (0.8) x SM
    - observed (expected) upper limit : 5.5 (2.5) x SM
  - CMS in Run 2 (2015 data)
    - observed (expected) upper limit: 3.0 (5.0) x SM



VBF H(bb)γ : event selection

ATLAS-CONF-2016-063

- Trigger:
  - L1 trigger: single photon (pT > 25 GeV)
  - High level trigger: 4 jets pT > 35 GeV, mjj> 700 GeV
- Offline Selection:
  - Tight ID photon, pT > 30 GeV
  - 4 jets with pT> 40 GeV
  - 2central(|η|<2.5) b-tagge djets
  - pT(bb)>80GeV
  - mjj> 800 GeV



- BDT discriminant

$$\Delta R(jet, \gamma), m_{jj}, \Delta\eta_{jj}, H_T^{soft}, jet\ width, \gamma\ centrality, p_T^{balance}$$

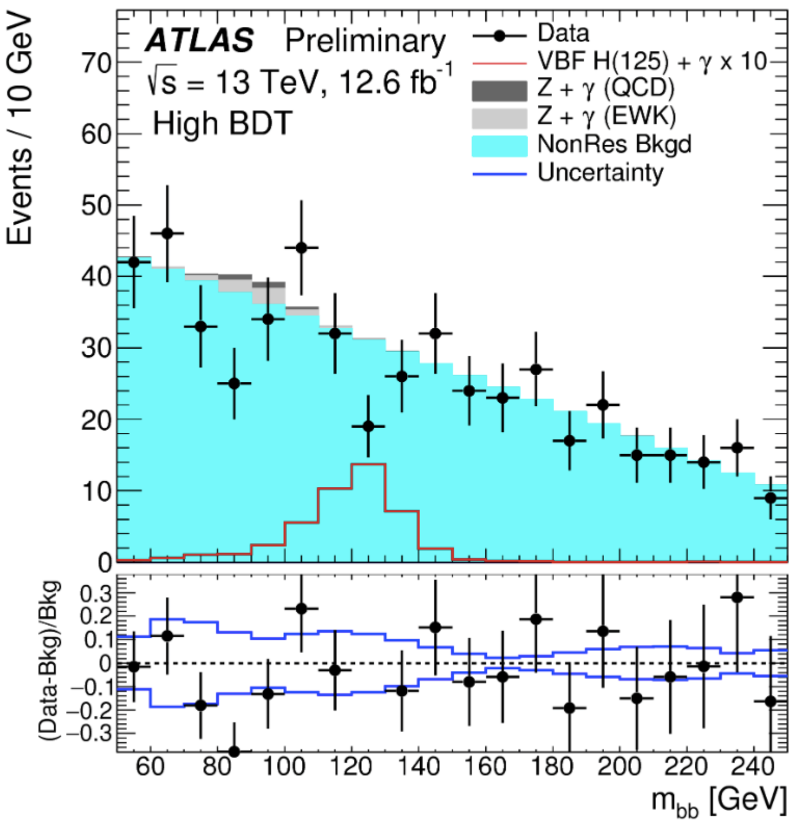
- Define 3 regions with different S/B
- Fit m_{bb} in 3 regions

VBF H(bb)γ signal extraction

ATLAS-CONF-2016-063

- Non-resonant background (γ+jets) estimated with 2nd order polynomial fit.

High BDT score region



Result	$H(\to b\bar{b}) + \gamma jj$	$Z(\to b\bar{b}) + \gamma jj$
Expected significance	0.4	1.3
Expected p-value	0.4	0.1
Observed p-value	0.9	0.4
Expected limit	$6.0\ ^{+2.3}_{-1.7}$	$1.8\ ^{+0.7}_{-0.5}$
Observed limit	4.0	2.0
Observed signal strength μ	$-3.9\ ^{+2.8}_{-2.7}$	$0.3\ \pm0.8$

VBF H（bb）γ production cross section limit

- Expected 95% CL limit:

  $6.0^{+2.3}_{-1.7}$

- Observed 95% CL limit:

  $4\times(\sigma\times BR)^{SM}$

Table 4: Summary of the main relative uncertainties in the MC-based EWK and QCD yields for the electron (muon when different) and neutrino channels in the aQGC region. The uncertainties in the Z+jets, $W(\ell\nu)\gamma$+jets, γ+jets, and $W(e\nu)$+jets yields, estimated with data, are detailed in the text.

Source of uncertainty	EWK yield [%] $\ell^+\ell^-$ channel	EWK yield [%] $\nu\bar{\nu}$ channel	QCD yield [%] $\ell^+\ell^-$ channel	QCD yield [%] $\nu\bar{\nu}$ channel
Trigger	0.2 (0.4)	2	0.2 (0.4)	2
Pile-up		0.6		
Lepton selection	3.8 (2.3)	-	3.8 (2.3)	-
E_T^{miss} reconstruction	-	0.4	-	0.4
Photon selection	6.5	3.3	6.5	3.3
Jet reconstruction	2.5	3.2	12	3.2
Total experimental	8.0 (7.4)	5.1	13	5.1
Theory	8.7	4.1	3.8	4.1

Table 2: Summary of the dominant experimental systematic uncertainties in the event yield in the CR and S
for the electron (muon when different) channel and for the signal and main background components.

Source of uncertainty	EWK yield [%] CR	EWK yield [%] SR	QCD yield [%] CR	QCD yield [%] SR	Bkg. yield [%] CR	Bkg. yield [%] SR
Trigger	0.2 (0.4)					
Pile-up	0.6					
Lepton selection	3.8 (2.3)					
Photon selection	1.6					
Jet reconstruction	1.1	2.5	5.0	12	4.9	12
Bkg. 2D sideband	-	-	-	-	26	26
Total experimental	4.3 (3.1)	4.9 (3.8)	6.5 (5.8)	13 (12)	27 (27)	29 (29)
Theory	5.2	8.7	5.6	3.8	5.6	3.8