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$ZZ\gamma$ - The Next Step Tackling Anomalous Gauge Couplings

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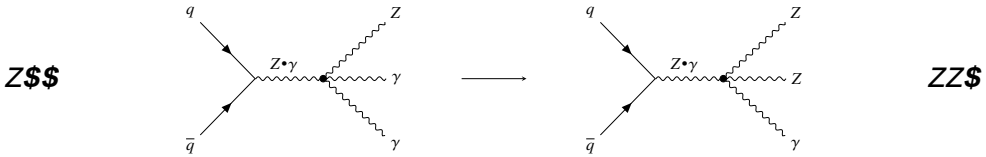
ATLAS-Heidelberg Meeting @ Trifels 2022

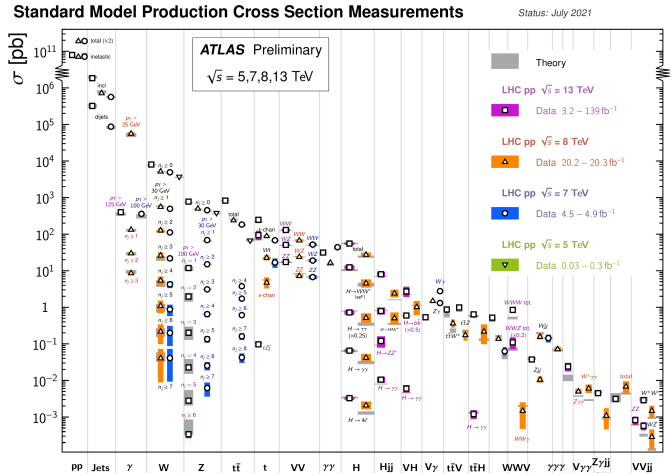
Motivation



	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

Relation between the dimension-8 operators and the quartic gauge vertices. All vertices a□ected by dimension-8 operators are marked with an X

Motivation



ATL-PHYS-PUB-2021-032

measurement of $ZZ\gamma$ production for the first time

low number of expected events for Run 2

better results with Run 3 expected

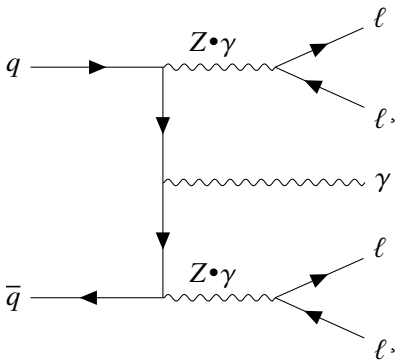
good event selection crucial

Triple Gauge Boson Production

Run 2 data (2015-2018)

fully leptonic decay
$ZZ^{1} \; ! \;\; ee, \mu\mu^{0}\gamma$

signal: $\ell\ell\ell\ell\gamma$



Event Selection

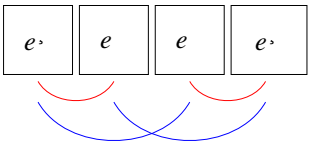
2 pairs of 2 opposite-sign same-flavour leptons ($4e$, 4μ, $2e2\mu$)

1 photons, $p_T > 15$ GeV

invariant mass m > 40 GeV

min(j m -1 m_Z j , j m -2 m_Z j)

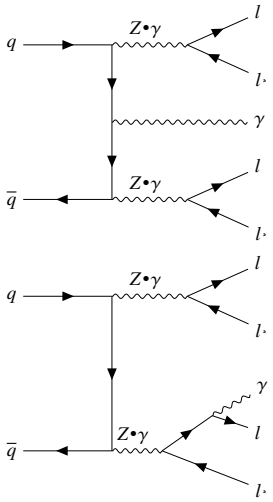
FSR rejection cut

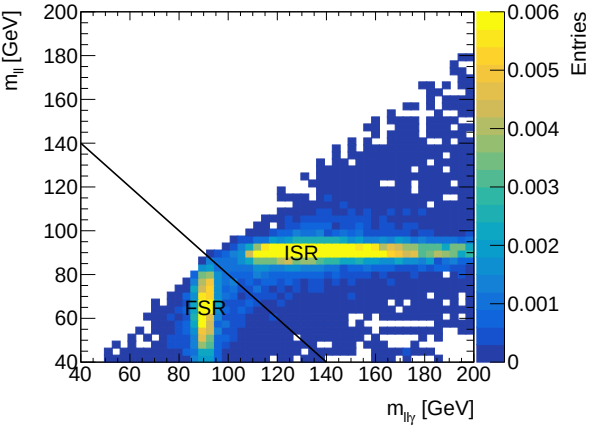


Inital State Radiation (ISR) and Final State Radiation (FSR)

ISR

FSR





Correlation plot between the invariant masses

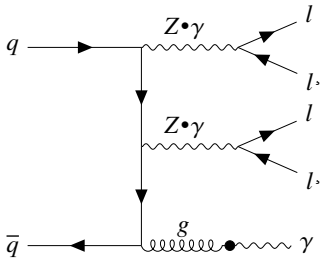
FSR cut: $^{1}m_{W}$, $m^{o} > 2\ m_{Z}$

Background

Background contamination in the signal region: any process with (prompt or fake) photons and right amount/kind of leptons

Dominant background: fake photon background

Other background: prompt photon background, pileup



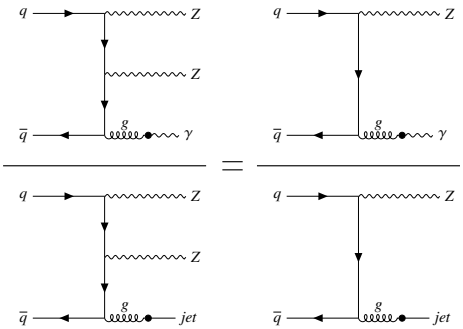
Fake Photon Estimation

Ansatz

jet ratio method $\frac{N_{ZZW}^{W\text{fake}}}{N_{ZZ}^{\text{jets}}} = \frac{N_{ZW}^{W\text{fake}}}{N_{Z}^{\text{jets}}}$

jet cuts match photon cuts

$N_{ZZW}^{W\text{fake}} = N_{ZW}^{W\text{fake}} \frac{N_{ZZ}^{\text{jets}}}{N_{Z}^{\text{jets}}}$



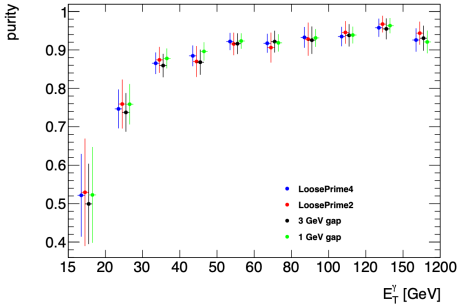
Fake Photon Estimation - Expected Fakes $Z\gamma$

$N_{ZW}^{W_{\text{fake}}}$ from $Z\gamma$ analysis
(see JHEP 03 (2020) 054)

$Z\gamma$ event selection, $\gamma_{p_T} > 15$GeV

$N_{ZW}^{W_{\text{fake}}} = N_{\text{sig}} \frac{1 - P^{\text{o}}}{P}$

bin-wise with right purity



	$\gamma_{p_T} > 15$ GeV			$\gamma_{p_T} > 30$ GeV			comparison $Z\gamma$	
N_{sig}		166 624	270		79 427	170	79 485	167
N_{fake}	60 743	154	15 698	9 283	22	1 285	9 592	256 (tot.)

The expected number of ZZ and Z events with at least one jet.

	N_{ZZ}^{jets}	N_{Z}^{jets}	$\frac{N_{ZZ}^{jets}}{N_{Z}^{jets}}$
PowhegPythia8	1169 6	(74.640 0.016)10^{6}	(1.566 0.008)10^{5}

$N_{ZZW}^{Wake} = 0•797 \quad 0•005\ (stat.) \quad 0•17\ (syst.)$

Sherpa 2.2.5 ZZW sample (only on-shell)

Sherpa 2.2.11 W sample (on- and o -shell)

Number of expected events on particle and on reco level.

	reco level HWW framework				particle level rivet			
	all cuts		m _ Z 5 GeV		all cuts	m _ Z 5 GeV		
Sherpa 2.2.5	4.97	0.05	2.93	0.04	14.8	10.3		
Sherpa 2.2.11	22.5	0.3	9.02	0.20	23.0	10.1		

Overview of the expected events from signal and background processes as well as the combined contributions.

		Events
Sherpa 2.2.5 ZZW	4.97	0.05 (stat.)
Sherpa 2.2.11 W	22.5	0.3 (stat.)
Signal		13•7 8•8
ZZW fakes		0.80 0.17
Pileup		0.6 0.5
Total Background		1.4 0.5
N_{tot}		15 9

ZZ$:

- signal: 4 ¸ W(ISR only)
- main background: fake photons
- Run 2 - expected events: 159

EFT and Run 3:

- too little events for limits
- hope for Run 3

Thank you for your attention!

Backup

Z bosons:

2 opposite-sign same-flavor pairs

$m_{ll} > 40$ GeV

min(j $m_{ll\text{-}1}$ m_Z j , j $m_{ll\text{-}2}$ m_Z j)

leptons:

p_T: 30 GeV, 25 GeV, 10 GeV, 10 GeV

single lepton trigger preferred

$R^1 l, \gamma^o$ 0.4

electron channel: tight ID for leading electron

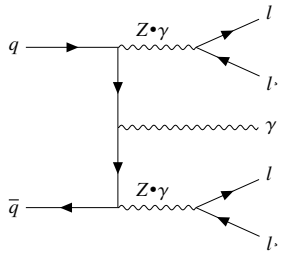
muon channel: tight Iso for leading muon

photon:

p_T 15 GeV

tight ID

loose Iso



Prompt Photon Background

$WZ\gamma$ (on shell; on+o□ shell)

$t\bar{t}\gamma$

all cuts: only 3 events in $WZ\gamma$ on+o□ shell

$WZ\gamma$ on shell and $t\bar{t}\gamma$ event selection without FSR cut: 1 event left per sample

Expected events with their statistical uncertainty for the prompt photon background.

Sample	Expected Events		Expected Events (no FSR rejection)	
$WZ\gamma$ on+o□ shell	0.034	0.024		
$WZ\gamma$ on shell		0	0.005	0.005
$t\bar{t}\gamma$		0	0.046	0.046

Pile up

so far only theoretical calculation

$$N_{ZZ,W} = \langle\mu\rangle L \frac{f_{ZZ} f_W}{f_{\text{inel}}}$$

$$N_{ZZ,W} = 0.6 \quad 0.5$$

$$C = \frac{\text{Expected events on reconstruction level}}{\text{Expected events on particle level}}$$

$$N_{ZZ,W} = \langle\mu\rangle L \frac{C_{ZZ} f_{ZZ} C_W f_W}{C_{\text{inel}} f_{\text{inel}}}$$

EFT Lagrangian

add to SM Lagrangian Operators of dimension > 4

SM NP

$\mathcal{L}_{EFT} = \mathcal{L}_{D=4} + \frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \dots$: scale of NP

$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{d>4} \sum_i \frac{f_i^d}{\Lambda^{d-4}} O_i^d$ O_i^d : Operator of dimension d, f_i^d : coe□cient

lowest dimension fulfilling lepton/baryon conservation + only anomalous QGC: **dim-8**