Observation of electroweak production of Wγ with two jets in proton-proton collisions at $\sqrt{s}$=13 TeV

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Outline

Introduction

Previous study by CMS :

- VBS has quite distinguished characteristics, including two widely separated jets with large invariant mass.
- There have been many more studies coming out from both ATLAS and CMS.
- Based on data collected at $\sqrt{s}$ = 8 TeV, corresponding to an integrated luminosity of approximately 20.0 fb^{-1}, the observed (expected) significance for Wγ scattering were 2.7 (1.5) standard devidation.

Measurement of electroweak-induced production of $W\gamma$ with two jets in pp collisions at $\sqrt{s} = 8$ TeV and constraints on anomalous quartic gauge couplings

The CMS Collaboration*

Abstract

A measurement of electroweak-induced production of $W\gamma$ and two jets is performed, where the W boson decays leptonically. The data used in the analysis correspond to an integrated luminosity of 19.7 fb^{-1} collected by the CMS experiment in $\sqrt{s} = 8$ TeV proton-proton collisions produced at the LHC. Candidate events are selected with exactly one muon or electron, missing transverse momentum, one photon, and two jets with large rapidity separation. An excess over the hypothesis of the standard model without electroweak production of $W\gamma$ with two jets is observed with a significance of 2.7 standard deviations. The cross section measured in the fiducial region is $10.8 \pm 4.1\,(\text{stat}) \pm 3.4\,(\text{syst}) \pm 0.3\,(\text{lumi})$ fb, which is consistent with the standard model electroweak prediction. The total cross section for $W\gamma$ in association with two jets in the same fiducial region is measured to be $23.2 \pm 4.3\,(\text{stat}) \pm 1.7\,(\text{syst}) \pm 0.6\,(\text{lumi})$ fb, which is consistent with the standard model prediction from the combination of

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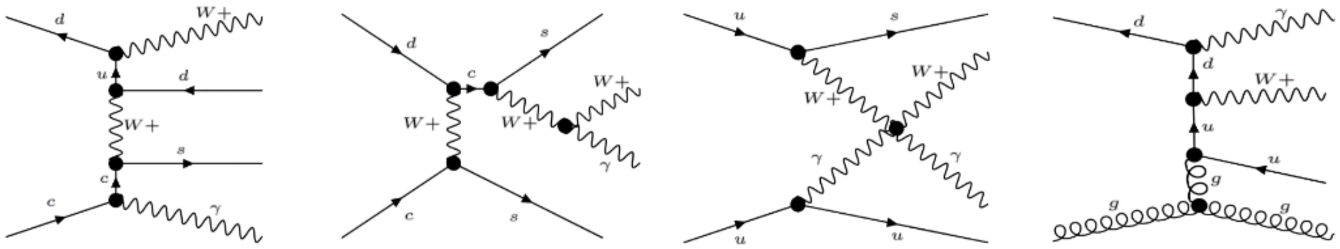
Introduction

arXiv : 2008.10521

Analysis content :

- Search for EWK production of W$\boldsymbol{\gamma}$
- Measurement of fiducial cross section
- Search for anomalous coupling



Vector Boson Scattering:

- Candidate events have exactly one identified lepton, one E_T^{miss}, one identified photon, two jets with large rapidity separation and dijet mass.
- In the analysis we consider: $\mu\nu_\mu\gamma$jj, $e\nu_e\gamma$jjfor the photon we consider it separately in barrel and endcap region, so we have 4 channels

Object reconstruction

Lepton candidates :

- If electron, |η|<2.5 ,P_T>25 GeV; if muon, |η|<2.4 and P_T >20 GeV .

Photon candidates :

- |η|<2.5 and P_T >20 GeV, excluding the ECAL transition region of 1.444<|η|<1.566.

Jets candidates :

- PF objects using the anti-kTjet clustering algorithm with adistance parameter of 0.4.

$\mathbf{E_T^{miss}}$ **:**

- computed as the negative of the vector sum of the P_T of all the PF candidatesin an event, and its magnitude is denoted as E_T^{miss}.

Sample selection

- one tight lepton, second lepton veto
- E_T^{miss}>30 GeV, m_T(W)>30 GeV
- P_T^{γ}>25 GeV, $|\eta_\gamma|$<1.4442 or 1.566< $|\eta_\gamma|$<2.5
- $|m_{l,\gamma} - m_Z|$>10 GeV in electron channel
- P_T^{j1}>40 GeV, P_T^{j2}>30 GeV
- $|\eta_j|$<4.7, $\Delta R_{l,\gamma}$>0.5 , $\Delta R_{j,\gamma}$>0.5 , $\Delta R_{j,l}$>0.5 , $\Delta\phi_{j,met}$>0.5

Basic selection

- 200 GeV<m_{jj}<400 GeV

Low m_{jj} control region

- m_{jj}>500 GeV
- $|\Delta\eta_{jj}|$>2.5
- $m_{W\gamma}$>100 GeV, $m_{l\gamma}$>30 GeV
- Zepp=$|\eta_{W\gamma} - (\eta_{j1} + \eta_{j2})/2| < 0.9$
- Dphi=$|\ \phi_{W\gamma} - \phi_{j1,j2}\ | > 2$

VBS signal region

Background estimation

- We consider following background categories; estimation method are listed for each category

Category	Estimation mehods
QCD Wγ	from simulation
Fake photon	template fit method, data-driven
Fake lepton	from fake rates and “Tight+Loose” “Loose+Loose” data events
Double fake	fake photon + fake lepton
TTγ	from simulation
Zγ	from simulation
STop	from simulation
VV	from simulation
e $\rightarrow \gamma$	from simulation

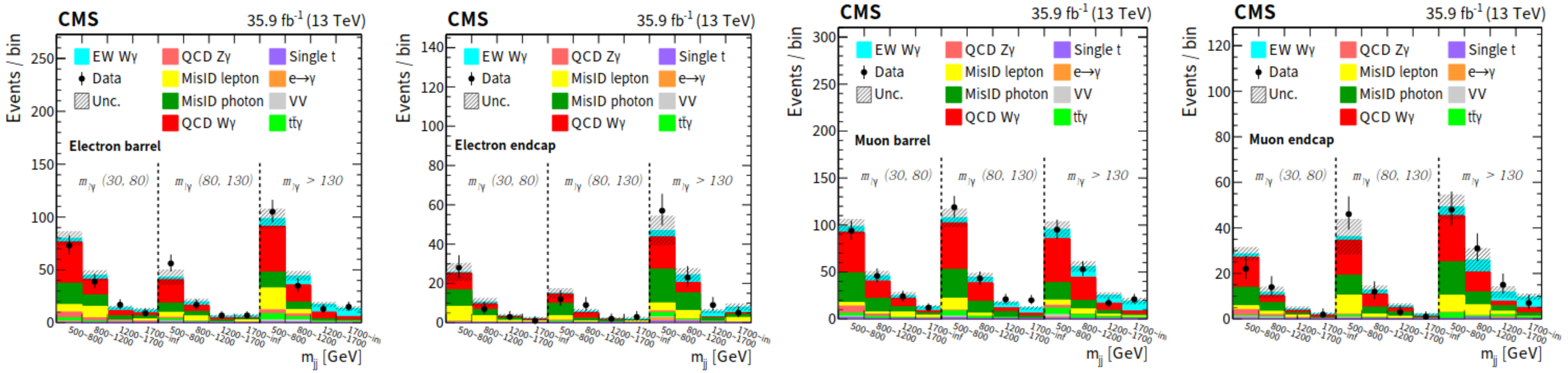
- In all cases where simulation is used, pile-up reweighting, lepton and trigger, tracking, ID and Isolation efficiency scale factors are applied.

Background estimation

- Fake photon
  - make 3 templates, data template, MC true template, and fake template (plj-sample)
  - Get fake fraction by fit data template with MC true template and fake template
  - $weight = \frac{data \times fraction}{plj}$
- Fake lepton
  - 2 kind of leptons, tight lepton and loose lepton
  - $fake\_rate = \text{tight} / \text{loose}$
  - $weight = \frac{fake\_rate}{1 - ake\_rate}$
- Double fake

  consider both fake photon and fake lepton

Significance



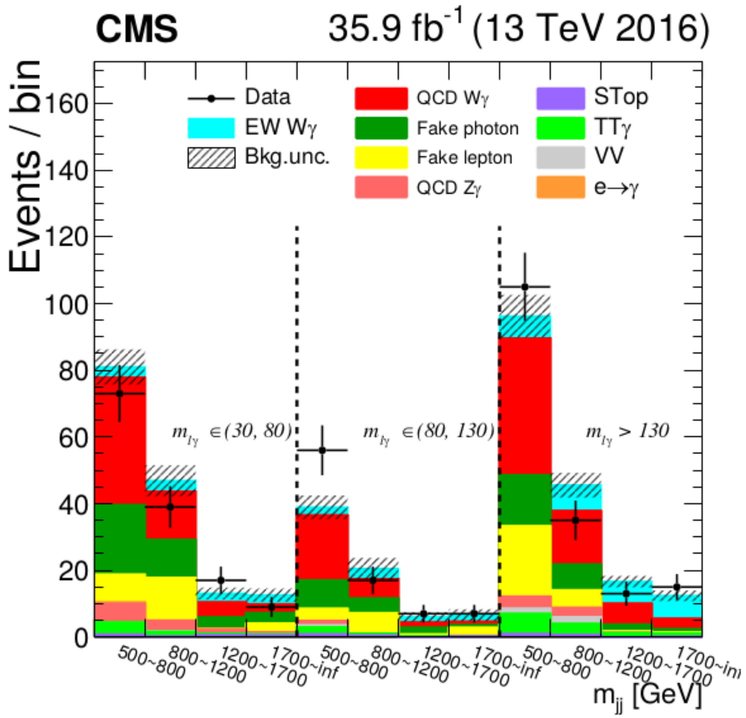
- Extract signal via the feature of VBS process, large invariant mass and Δη jj of two jets
- The significance is calculated using a simultaneous fit in the signal region with 2D mjj-Δηjj binning and the control region in 4 categories for muon/electron choice and barrel photon/endcap photon choice.

- The observed (expected) statistical significance for 2016's 13TeV data is 4.9 σ (4.6 σ).
- After the combination with 8 TeV data, the observed (expected) significance is 5.3 σ (4.8 σ).

Fiducial XS

Fiducial region

- P_T^l>30 GeV, η_l<2.4, p_T^{miss}>30 GeV
- m_T(W)>30 GeV, P_T^γ>25 GeV
- $|\eta_\gamma|$<1.4442 (barrel), 1.566<$|\eta_\gamma|$<2.5 (endcap)
- P_T^{j1}>40 GeV, P_T^{j2}>30 GeV, η_j<4.7
- m_{jj}>500 GeV, $|\Delta\eta_{jj}|$>2.5
- $\Delta R_{l,\gamma}$>0.5, $\Delta R_{j,\gamma}$>0.5, $\Delta R_{l,j}$>0.5



The fiducial cross section is defined as:

$$\sigma_{fiducial\_XS} = \sigma_{generator} \cdot \mu_{signal\_strength} \cdot \epsilon_{generated\_to\ fiducial}$$

- $\sigma_{generator}$ is the cross section of the Monte Carlo signal sample.
- $\mu_{signal\_strength}$ is the signal strength from fitting.
- $\epsilon_{generated\_to\ fiducial}$ is the fracation of the generated signal events passing the ficucial region selection.

$$\sigma_{EW}^{fid} = 20.39 \pm 4.49 \text{ fb}$$

$$\sigma_{EW+QCD}^{fid} = 109.43 \pm 15.7 \text{ fb}$$

aQGC limits

SM lagrangiancan be extended with higher dimensional operators remaining SU(2)×U(1) gauge symmetry

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{F_i}{\Lambda^4} o_i$$

$$\begin{aligned}
\mathcal{L}_{T,0} &= \frac{f_{T0}}{\Lambda^4} Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times Tr[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}], \\
\mathcal{L}_{T,1} &= \frac{f_{T1}}{\Lambda^4} Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times Tr[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}], \\
\mathcal{L}_{T,2} &= \frac{f_{T2}}{\Lambda^4} Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}] \times Tr[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}], \\
\mathcal{L}_{T,5} &= \frac{f_{T5}}{\Lambda^4} Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times B_{\alpha\beta}B^{\alpha\beta}, \\
\mathcal{L}_{T,6} &= \frac{f_{T6}}{\Lambda^4} Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times B_{\mu\beta}B^{\alpha\nu}, \\
\mathcal{L}_{T,7} &= \frac{f_{T7}}{\Lambda^4} Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}] \times B_{\beta\nu}B^{\nu\alpha},
\end{aligned}$$

Contain an SU(2) field strength, the U(1) field strength, and the covariant derivative of the Higgsdoublet field.

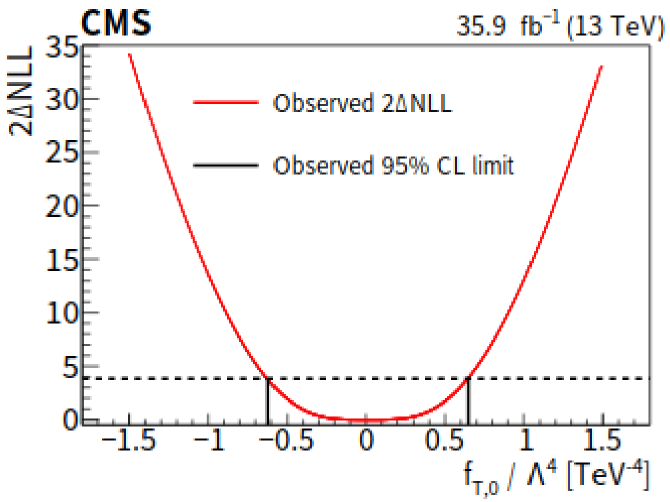
Contain only the two field strengths.

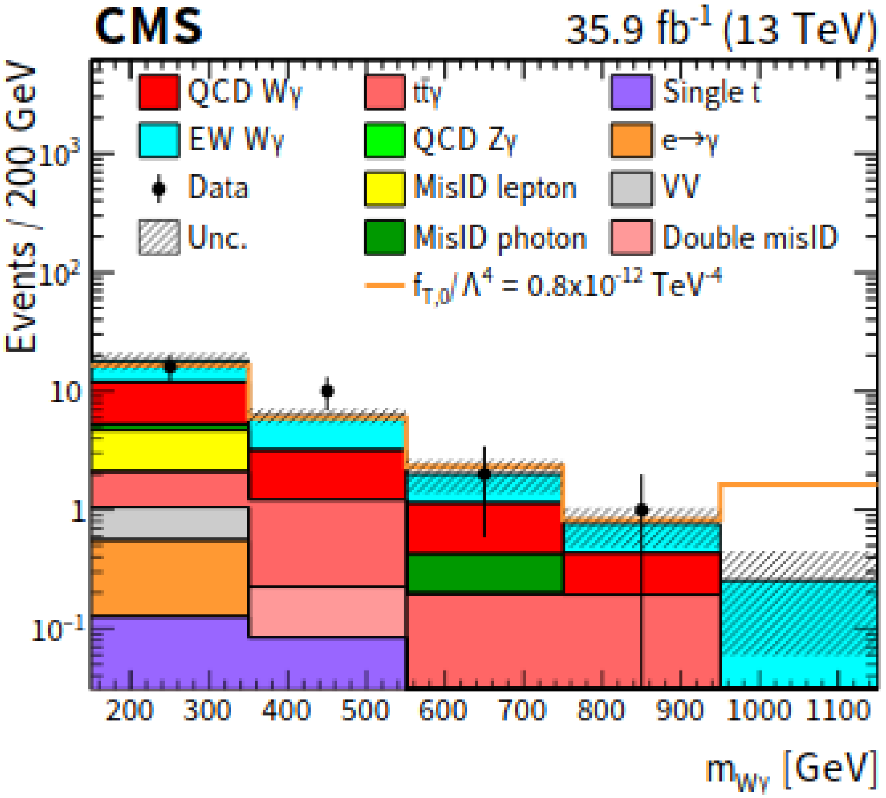
$$\begin{aligned}
\mathcal{L}_{M,0} &= \frac{f_{M0}}{\Lambda^4} \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right], \\
\mathcal{L}_{M,1} &= \frac{f_{M1}}{\Lambda^4} \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right], \\
\mathcal{L}_{M,2} &= \frac{f_{M2}}{\Lambda^4} \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right], \\
\mathcal{L}_{M,3} &= \frac{f_{M3}}{\Lambda^4} \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right], \\
\mathcal{L}_{M,4} &= \frac{f_{M4}}{\Lambda^4} \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\mu\Phi\right] \times B^{\beta\nu}, \\
\mathcal{L}_{M,5} &= \frac{f_{M5}}{\Lambda^4} \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\nu\Phi\right] \times B^{\beta\mu}, \\
\mathcal{L}_{M,6} &= \frac{f_{M6}}{\Lambda^4} \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\nu} D^\mu\Phi\right], \\
\mathcal{L}_{M,7} &= \frac{f_{M7}}{\Lambda^4} \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\mu} D^\nu\Phi\right].
\end{aligned}$$

aQGC limits

Selection

- one tight lepton, second lepton veto
- E_T^{miss}>30 GeV, $m_T(W)$>30 GeV
- $|\eta_\gamma|$<1.4442 or 1.566< $|\eta_\gamma|$<2.5
- $|m_{l,\gamma} - m_Z|$>10 GeV in electron channel
- P_T^{j1}>40 GeV, P_T^{j2}>30 GeV, $|\eta_j|$<4.7
- $\Delta R_{l,\gamma}$>0.5 , $\Delta R_{j,\gamma}$>0.5 , $\Delta R_{j,l}$>0.5 , $\Delta\phi_{j,met}$>0.5
- P_T^{γ}>100 GeV
- m_{jj}>800 GeV, $|\Delta\eta_{jj}|$>2.5





$m_{W\gamma}$ binning :

[500, 800, 1200, 1700, inf) GeV

aQGC limits

Observed limits [TeV^{-4}]	Expected limits [TeV^{-4}]	Unitarity bound [TeV]
$-8.07 < f_{M0}/\Lambda^4 < 7.99$	$-7.67 < f_{M0}/\Lambda^4 < 7.55$	1.0
$-11.79 < f_{M1}/\Lambda^4 < 12.09$	$-10.79 < f_{M1}/\Lambda^4 < 11.27$	1.2
$-2.81 < f_{M2}/\Lambda^4 < 2.81$	$-2.68 < f_{M2}/\Lambda^4 < 2.68$	1.3
$-4.41 < f_{M3}/\Lambda^4 < 4.49$	$-4.04 < f_{M3}/\Lambda^4 < 4.10$	1.5
$-4.99 < f_{M4}/\Lambda^4 < 4.95$	$-4.70 < f_{M4}/\Lambda^4 < 4.67$	1.5
$-8.27 < f_{M5}/\Lambda^4 < 8.31$	$-7.85 < f_{M5}/\Lambda^4 < 7.73$	1.8
$-16.15 < f_{M6}/\Lambda^4 < 15.99$	$-15.35 < f_{M6}/\Lambda^4 < 15.11$	1.0
$-20.78 < f_{M7}/\Lambda^4 < 20.22$	$-19.42 < f_{M7}/\Lambda^4 < 18.70$	1.3
$-0.62 < f_{T0}/\Lambda^4 < 0.64$	$-0.60 < f_{T0}/\Lambda^4 < 0.62$	1.4
$-0.35 < f_{T1}/\Lambda^4 < 0.39$	$-0.34 < f_{T1}/\Lambda^4 < 0.38$	1.5
$-0.99 < f_{T2}/\Lambda^4 < 1.18$	$-0.98 < f_{T2}/\Lambda^4 < 1.16$	1.5
$-0.45 < f_{T5}/\Lambda^4 < 0.46$	$-0.43 < f_{T5}/\Lambda^4 < 0.44$	1.8
$-0.36 < f_{T6}/\Lambda^4 < 0.38$	$-0.34 < f_{T6}/\Lambda^4 < 0.36$	1.7
$-0.87 < f_{T7}/\Lambda^4 < 0.93$	$-0.83 < f_{T7}/\Lambda^4 < 0.89$	1.8

aQGC limits

- The unitarity bound (Ubound) is defined as the scattering energy at which the aQGC coupling strength, when set equal to the observed limit.

- All coupling parameter limits are in $T\mathrm{eV}^{-4}$, while the Ubound values are in TeV

- For the parameters $f_{M,2-5}/\Lambda_4$ and $f_{T,6-7}/\Lambda_4$, the constraints are the most stringent to date.

Summary and future plan

Summary :

- Observed (expected) significance for only 2016’s 13TeV data : 4.9 σ (4.6 σ).
- Observed (expected) significance after the combination with 8TeV data : 5.3 σ (4.8 σ)
- The fiducial XS are :

$$\sigma_{EW}^{fid} = 20.39 \pm 4.49 \text{ fb} \ ; \sigma_{EW+QCD}^{fid} = 109.43 \pm 15.7 \text{ fb}$$

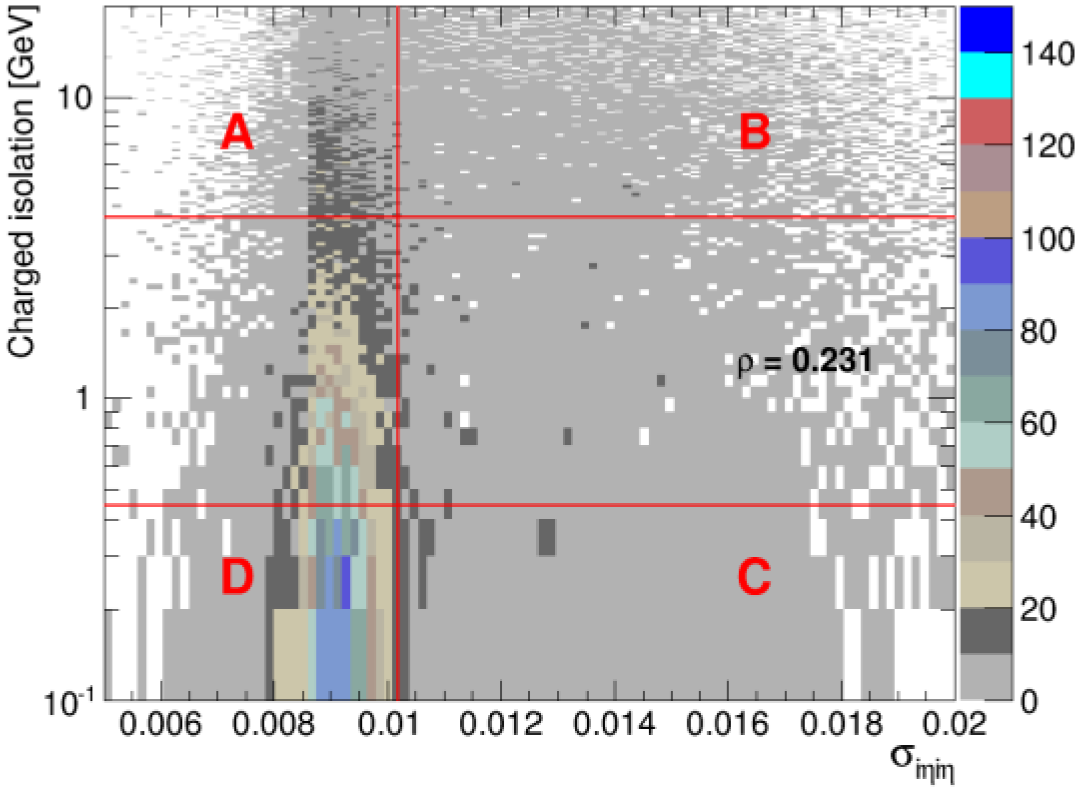
- aQGC results

Future plan :

The full RunII VBS WGamma analysis is ongoing now and will have all results soon.

THANK YOU

Back up



Charged isolation [GeV]
10
1
10^{-1}
A
B
C
D
ρ = 0.231
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
$\sigma_{i\eta i\eta}$
140
120
100
80
60
40
20
0

Back up