Search for anomalous couplings in boosted WW/WZ $\rightarrow l\nu qq$ production in proton-proton collisions at $\sqrt{s}$ = 8 TeV

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Outline

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- results

Introduction

motivation

- SM can be represented by an effective field theory, not the ultimate theory. Physics beyond SM add higher order operators to the SM Lagrangian,

$$\mathcal{L}^{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4} \mathcal{O}_j^{(8)} + \dots \,.$$

D6 operators have the largest impact, some of them contribute to Triple Gauge boson Couplings(TGC)

motivation

C and P conserving (red circle)

C and/or P violating (black circle)

- Anomalous couplings from Lagrangian approach

$$\frac{\mathcal{L}_{eff}^{VWW}}{g_{VWW}} = ig_1^V(W_{\mu\nu}^* W^\mu V^\nu - W_\mu^* V_\nu W^{\mu\nu}) + i\kappa_V W_\mu^* W_\nu V^{\mu\nu} + i\frac{\lambda_V}{M_W^2} W_{\lambda,\mu}^* W_\nu^\mu V^{\nu\lambda}$$
$$- g_4^V W_\mu^* W_\nu(\partial^\mu V^\nu + \partial^\nu V^\mu) + g_5^V \epsilon^{\mu\nu\lambda\rho}(W_\mu^* \partial_\lambda W_\nu - \partial_\lambda W_\mu^* W_\nu) V_\rho$$
$$+ i\tilde{\kappa}_V W_\mu^* W_\nu \tilde{V}^{\mu\nu} + i\frac{\tilde{\lambda}_V}{M_W^2} W_{\lambda\mu}^* W_\nu^\mu \tilde{V}^{\nu\lambda},$$

- Anomalous Couplings from Effective Field Theory approach

$$\mathcal{L}^{\rm eff} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \dots$$

C and P conserving →

$$\mathcal{O}_{WWW} = \mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W_\rho^\mu]$$
$$\mathcal{O}_W = (D_\mu\Phi)^\dagger W^{\mu\nu}(D_\nu\Phi)$$
$$\mathcal{O}_B = (D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi)$$

3 independent D6 operators affect electroweak vector boson self interactions

- Relationship between them

$$g_1^Z = 1 + c_W\frac{m_Z^2}{2\Lambda^2}$$
$$\kappa_\gamma = 1 + (c_W + c_B)\frac{m_W^2}{2\Lambda^2}$$
$$\kappa_Z = 1 + (c_W - c_B\tan^2\theta_W)\frac{m_W^2}{2\Lambda^2}$$
$$\lambda_\gamma = \lambda_Z = c_{WWW}\frac{3g^2m_W^2}{2\Lambda^2}$$

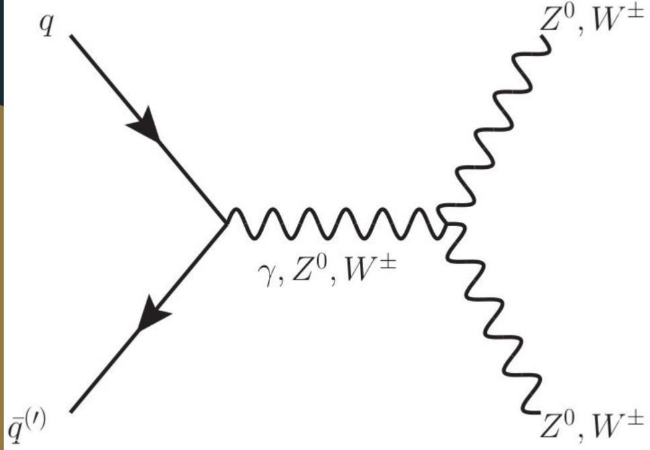
g_1^γ is fixed to 1 by EM gauge invariance

$$\Delta g_1^Z = \Delta\kappa_Z + \tan^2\theta_W\Delta\kappa_\gamma$$
$$\lambda_Z = \lambda_\gamma = \lambda$$

Three independent parameters

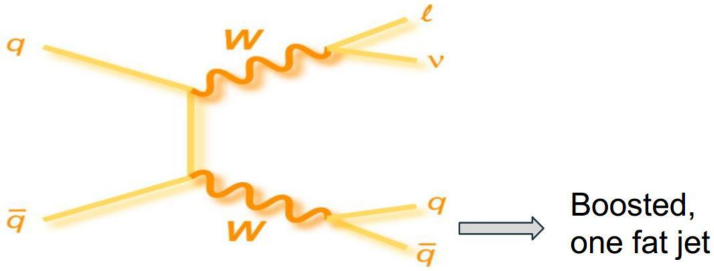
motivation

- WW production
  - WWγ and WWZ vertices
- WZ production
  - WWZ vertex only



Why boosted WV→lνqq

- Larger branch fraction of W/Z to quarks over pure leptonic final states
- Ability to reconstruct their pT in case of two W bosons
- Boosted final states are more sensitive to an aTGC signal



other results

Semileptonic channel(7 TeV)

- CMS Eur. Phys. J. C 73 (2013) 2283

$-0.038 < \lambda < 0.030$, $-0.11 < \Delta k_\gamma < 0.14$,

$-0.043 < \Delta k_Z < 0.033$, tight bound on $\Delta g_1^Z = 0$

- ATLAS JHEP01(2015)049

Parameter	Observed Limit	Expected Limit
$\lambda_Z = \lambda_\gamma$	[−0.039, 0.040]	[−0.048, 0.047]
$\Delta\kappa_\gamma$	[−0.21, 0.22]	[−0.23, 0.25]
Δg_1^Z	[−0.055, 0.071]	[−0.072, 0.085]

Semileptonic channel(8 TeV)

- ATLAS arXiv:1706.01702v3

Parameter	Observed [TeV^{-2}]	Expected [TeV^{-2}]	Observed [TeV^{-2}]	Expected [TeV^{-2}]
	$WV \to \ell\nu jj$		$WV \to \ell\nu J$	
c_{WWW}/Λ^2	[−5.3, 5.3]	[−6.4, 6.3]	[−3.1, 3.1]	[−3.6, 3.6]
c_B/Λ^2	[−36, 43]	[−45, 51]	[−19, 20]	[−22, 23]
c_W/Λ^2	[−6.4, 11]	[−8.7, 13]	[−5.1, 5.8]	[−6.0, 6.7]

Semileptonic channel(13 TeV)

- CMS PAS SMP-16-012

	aTGC	expected limit	observed limit
EFT param.	$\frac{c_{WWW}}{\Lambda^2}$ (TeV^{-2})	[-8.73 , 8.70]	[-9.46 , 9.42]
	$\frac{c_W}{\Lambda^2}$ (TeV^{-2})	[-11.7 , 11.1]	[-12.6 , 12.0]
	$\frac{c_B}{\Lambda^2}$ (TeV^{-2})	[-54.9 , 53.3]	[-56.1 , 55.4]
Vertex param.	λ	[-0.036 , 0.036]	[-0.039 , 0.039]
	Δg_1^Z	[-0.066 , 0.064]	[-0.067 , 0.066]
	$\Delta\kappa_Z$	[-0.038 , 0.040]	[-0.040 , 0.041]

Analysis strategy

Samples

- Data sample

Collected using single-lepton triggers with pT threshold of 24(27) GeV for muons(electrons). Total luminosity is 19.3(19.2) fb^{-1}

- WW/WZ sample

Generated at NLO using MG5_aMC@NLO

- W+jets sample

Generated at LO using MADGRAPH5

- top sample

Generated at NLO using POWHEG

Event reconstruction

All PF candidates

Lepton: muons(electrons)

- pt>25(30) GeV
- Consistent with Primary vertex
- Isolation with cone of ΔR=0.4(0.3)
- Additional lepton veto

jets:

For boosted

- CA8 jets for V_{had}
  - $pT_{leading}$>200 GeV
  - $pT_{subleading}$<80 GeV
- AK5 jets for others
  - "anti-btag"

MET

- MET > 50(70) GeV

Additional selection:

- W_{pT} > 200 GeV
- $\Delta R(\ell, J) > \pi/2$
- $\Delta\phi(MET, J) > 2.0$
- $\Delta\phi(W_{lep}, J) > 2.0$

W-tagging: Pruning + τ_{21}

Jet pruning aim to reduce the impact of underlying event (UE), pileup (PU), and soft QCD contributions to the jet.

$$z_{ij} = \frac{\min(p_{T,i}, p_{T,j})}{p_{T,(i+j)}} < z_{\text{cut}}$$

$$\Delta R_{ij} > D_{\text{cut}} = \alpha \times \frac{m}{p_T}$$

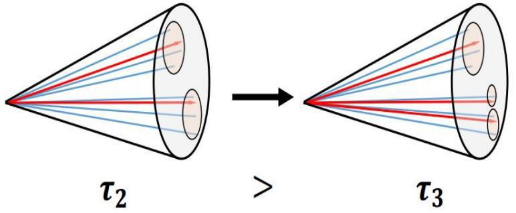
When recluster the jet, when two subjets commit these two conditions, remove the soft one.
$p_{T,i}$ and $p_{T,j}$are the transverse momenta of the i and j subjets and m and pT are with respect to the original jet. The default values for α and z_{cut} are 0.5 and 0.1, respectively.

"**N-subjettiness**"

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\}$$

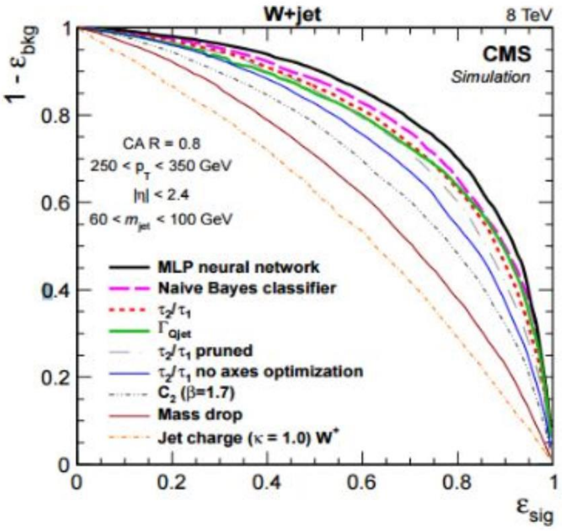
$$d_0 = \sum_k p_{T,k} R_0$$

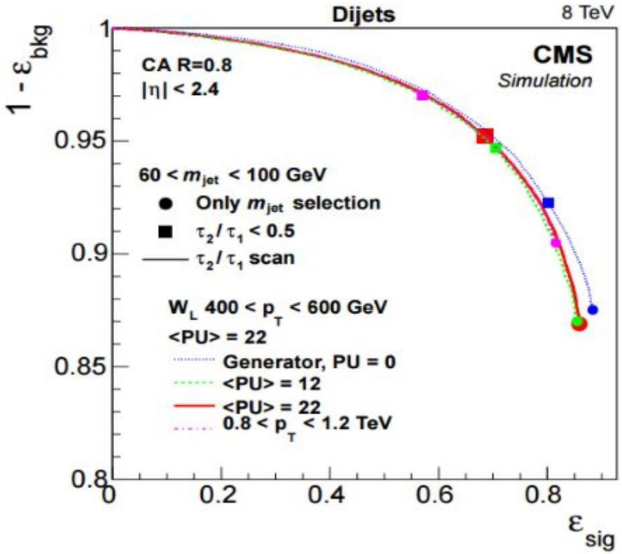
$\tau_N \sim 0$ means the fat jet has N subjets, $\tau_N >> 0$ means the fat jet most likely has more than N subjet.



For distinguishing QCD jets(typically 1 subjet) from a W-jet(typically 2 subjets),
$\tau_{21} = \tau_2/\tau_1 < 0.55$ is applied.

W-tagging: behavior and efficiency





Single $\tau 21$ has good performance on the separation between W-jets and QCD jets.

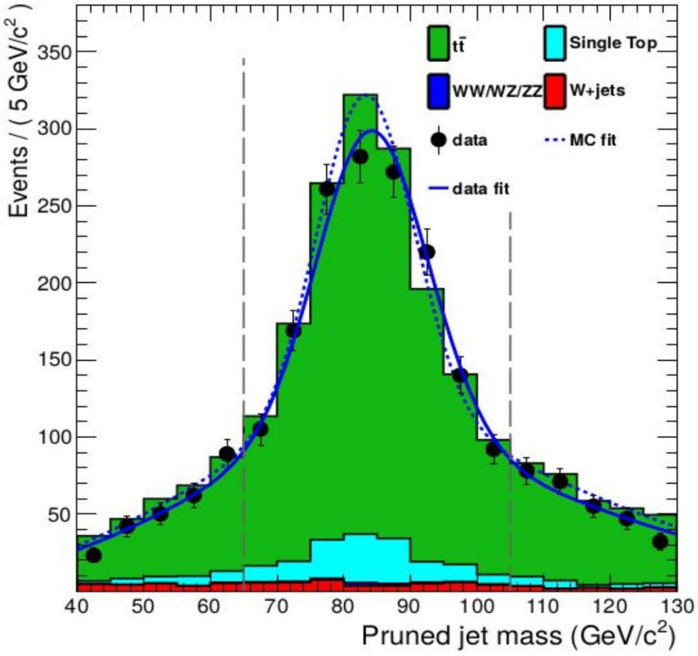
Some differences w/o PU, stable for PU=12 or 22

For $\tau 21 < 0.5$ and mjet~[60, 100]

eff(bkg) ~ 5% - 3%

eff(sig) ~ 70% - 55%

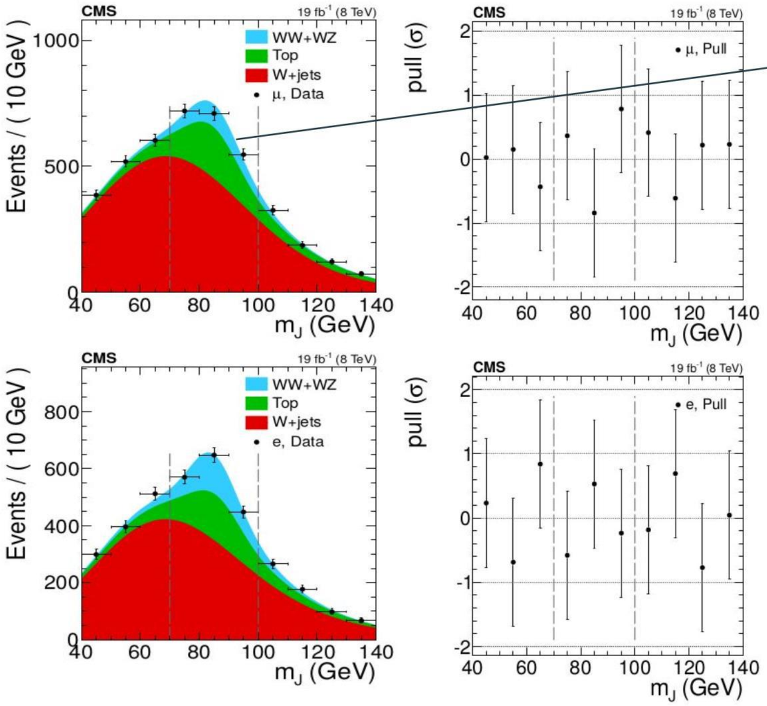
TTbar control sample



Constructed from requiring at least one AK5 b-tagged jet outside the CA8 jet.

Data shape is broader and is slightly shifted, then used to correct the SM diboson and top mJ shape.
mean: +1.1GeV,
σ: *1.16

Fit results to get the normalization



Shape come from MC fit, and corrected by ttbar control sample.

Quantity	μ channel	e channel
Data	1977	1666
W+jets	1318 (1.22 ± 0.06)	1023 (1.17 ± 0.07)
Top quark	450 (1.00 ± 0.08)	364 (1.00 ± 0.10)
WV	204 (1.35 ± 0.77)	285 (2.23 ± 0.84)
$\mathcal{A}\varepsilon$	9.7×10^{-5}	8.3×10^{-5}

background modeling: pT shape

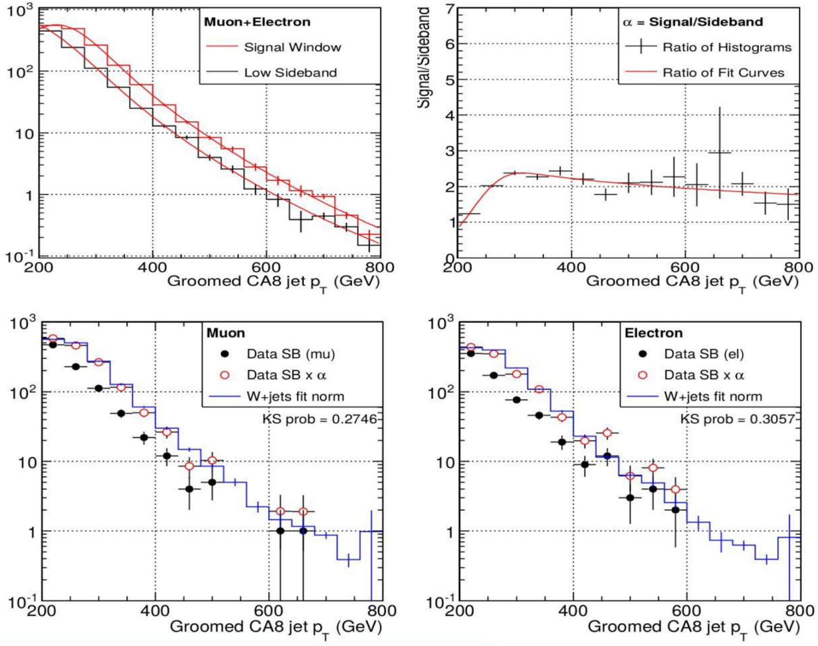
W+jets is only calculated in LO, and a new region of phase space was explored, we adjust the shape and normalization from MC by comparing it to a distribution derived using an alternative method.

m_J sideband, m_J~(40, 60) GeV, where top and SM diboson could be ignored.

Plot pT distribution of both signal and sideband, divide them after fitting to get the transfer function

Then multiply the data sideband pT by the transfer function got in previous step to get the W+jets pT distribution.

SM diboson and top pT shape from MC.

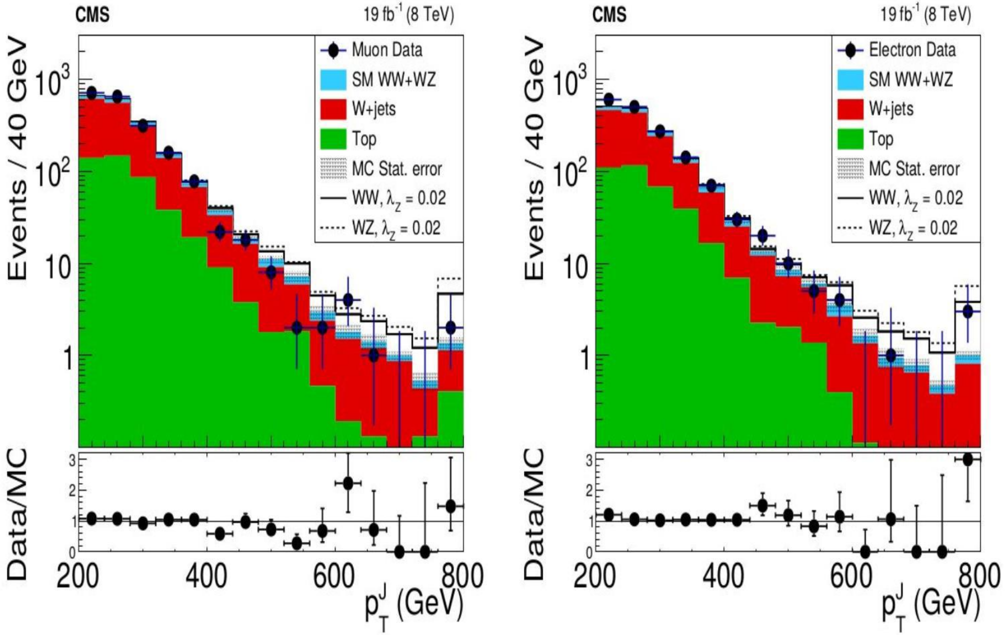


Results

Merged jet pT distribution:

uncertainty

W+jets normalization	20%
Scale and PDF	18-26%
luminosity	2.6%
others	negligible



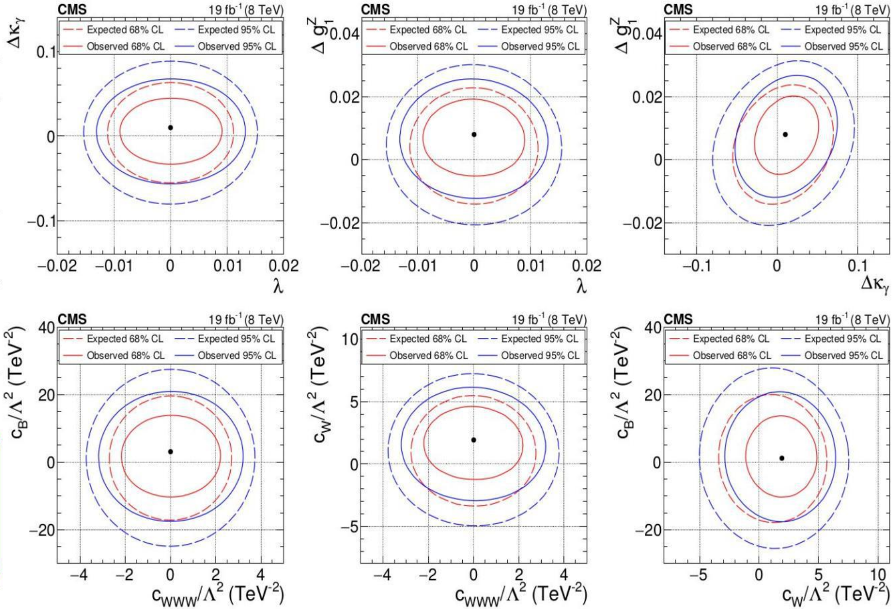
aTGC limit

No evidence for anomalous couplings is found, Set Higgs combination tool cards to get the limits

Parameter	Expected Limits	Observed Limits
λ_Z	$[-0.014, 0.013]$	$[-0.011, 0.011]$
$\Delta\kappa_\gamma$	$[-0.068, 0.082]$	$[-0.044, 0.063]$
Δg_1^Z	$[-0.018, 0.028]$	$[-0.0087, 0.024]$

c_{WWW}/Λ^2 (TeV^{-2})	c_B/Λ^2 (TeV^{-2})	c_W/Λ^2 (TeV^{-2})
$[-2.7, 2.7]$	$[-14, 17]$	$[-2.0, 5.7]$
$[-5.7, 5.9]$	$[-29.2, 23.9]$	$[-11.4, 5.4]$
$[-4.61, 4.60]$	$[-20.9, 26.3]$	$[-5.87, 10.54]$
$[-4.6, 4.2]$	$[-260, 210]$	$[-4.2, 8.0]$
$[-3.9, 4.0]$	$[-320, 210]$	$[-4.3, 6.8]$

Some other results



Thanks for Your Attention

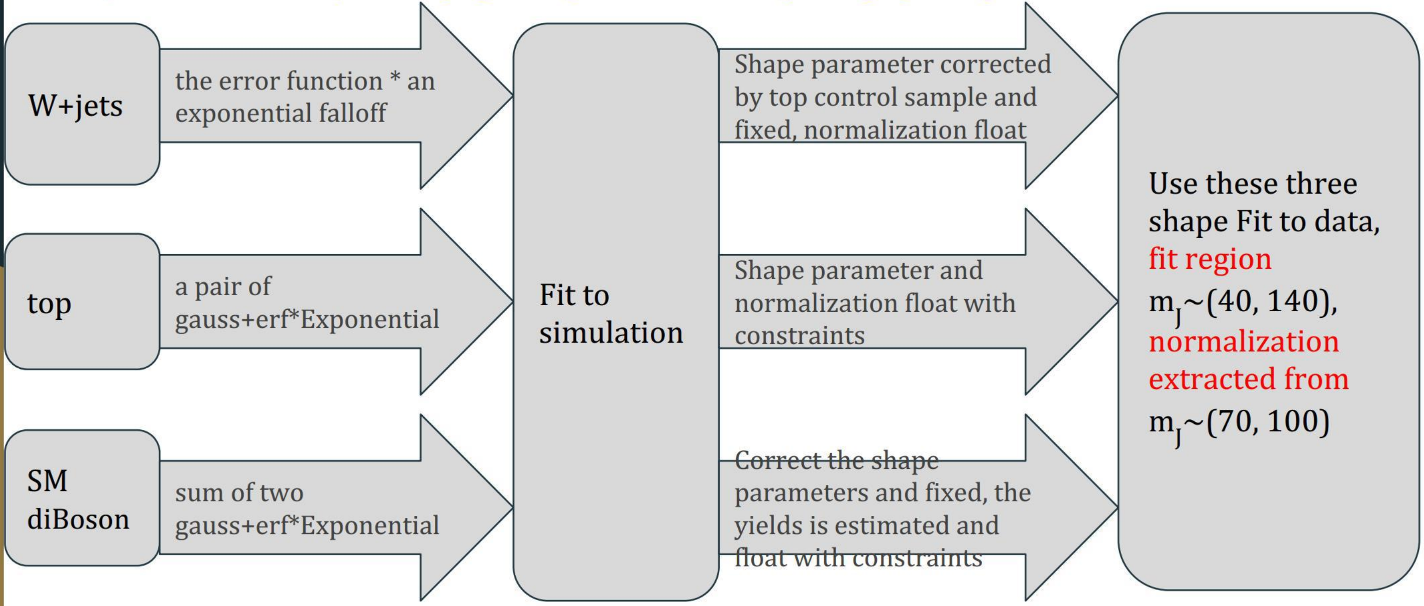
Back up

No form factor is used to make the unitarity safety.

there is no unique prescription to regulate this behavior or to apply a suppression factor, because such a regularization would depend on the scale of new physics which is unknown a priori. Hence, in the present analysis we do not apply any form factors or cut-off scale, Λ, for new physics.

background modeling: normalization extraction

After all the selections the background comprises three main components: W+jets, top quark(ttbar, and single top quark) and SM diboson.



Could distinguish between hadronic W and Z, though W and Z masses differ by about 10 GeV, the dijet mass resolution of the CMS near 80~100 GeV is about 12%, insufficient to distinguish between them. Therefore, signal sontains a mixture of WW and WZ.

Why not WZ only to study aTGC?

WZ decay to final state contains a lepton, neutrino, and a pair of b-quark jets, but dataset with two b-jets are too small

We compare the extrapolated distribution with the existing W+jets background that is constructed from MC and normalized to the m J fit yield using a Kolmogorov-Smirnov test. The test indicates that the two distributions are statistically consistent, thus completing the cross-check