Dim-8 EFT Signal Sample Modeling in $W^{\pm}W^{\pm}jj$ and $W^{\pm}Zjj$

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VBSCan combination meeting
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Introduction

Goal is to extract limits on dim-8 EFT parameters using results from VBS analyses @13 TeV

- Follow the lines of the recommendations provided by the LHCEW-WG aGC taskforce (ATL-COM-PHYS-2017-433)
- Use EFT parametrisation from: O. Eboli, M. Gonzalez-Garcia (2016) (arxiv: 1604.03555)
- Use MG5 + Pythia8 for EFT modeling and the approach of splitting the different EFT expansion terms
- Use the clipping method as unitarisation procedure at large $\sqrt{s}$

This talk presents the current status of the sample generation and its validation for the $W^{\pm}Zjj$ and $W^{\pm}W^{\pm}jj$ process.

Set of 18 dim-8 operators affecting quartic boson vertices:

Dim-8 operator / Quartic vertex	$\mathcal{O}_{S0}$ $\mathcal{O}_{S1}$ $\mathcal{O}_{S2}$	$\mathcal{O}_{M0}$ $\mathcal{O}_{M1}$ $\mathcal{O}_{M7}$	$\mathcal{O}_{M2}$ $\mathcal{O}_{M3}$ $\mathcal{O}_{M4}$ $\mathcal{O}_{M5}$	$\mathcal{O}_{T0}$ $\mathcal{O}_{T1}$ $\mathcal{O}_{T2}$	$\mathcal{O}_{T5}$ $\mathcal{O}_{T6}$ $\mathcal{O}_{T7}$	$\mathcal{O}_{T8}$ $\mathcal{O}_{T9}$
WWWW	✓	✓		✓		
W^+W^-ZZ	✓	✓	✓	✓	✓	
$W^+W^-Z\gamma$		✓	✓	✓	✓	
$W^+W^-\gamma\gamma$		✓	✓	✓	✓	
ZZZZ	✓	✓	✓	✓	✓	✓
ZZZγ		✓	✓	✓	✓	✓
ZZ$\gamma\gamma$		✓	✓	✓	✓	✓
Z$\gamma\gamma\gamma$				✓	✓	✓
$\gamma\gamma\gamma\gamma$				✓	✓	✓

Signal modelling
Generation with Madgraph

Madgraph is able to generate the individual contributions of the SM+EFT amplitude:

$$\left|\mathcal{A}_{\mathrm{SM}} + \sum_i \frac{f_i}{\Lambda^4}\mathcal{A}_i\right|^2 = |\mathcal{A}_{\mathrm{SM}}|^2 + \sum_i 2\frac{f_i}{\Lambda^4}\mathcal{R}e(\mathcal{A}_i^*\mathcal{A}_{\mathrm{SM}}) + \sum_i \frac{f_i^2}{\Lambda^8}|\mathcal{A}_i|^2 + \sum_{i,j,i\neq j} 2\frac{f_i f_j}{\Lambda^8}\mathcal{R}e(\mathcal{A}_i^*\mathcal{A}_j)$$

Interference SM-EFT | Pure EFT (quadratic term) | EFT cross term

⇒ This splitting can be used to scan the whole parameter space with only a few generated samples (by scaling of the different terms)

⇒ Validation of this approach should be done for each channel (and model)

- NEW! UFO models for the full set of operators: SM_LSMT_Ind5
- VBSCan proposal on metadata parameters for MG generation (SM parameters, theoretical uncertainties, PS cuts)
- Constraints of parameter space exist (positivity bounds) but have not been taken into account so far

The sample generation is an ongoing effort for $W^{\pm}Zjj$ and $W^{\pm}W^{\pm}jj$ VBS channels:

- $W^{\pm}Zjj$ and $W^{\pm}W^{\pm}jj$ final state sensitive to: $f_{S0} = f_{S2}$, f_{S1}, f_{M0}, f_{M1}, f_{T0}, f_{T1}, f_{T2}
- Use current 13 TeV 1-dim limits from CMS as baseline for $W^{\pm}W^{\pm}jj$

Validation steps

1. Check if generator cross section fulfills:

$$\mathrm{FULL}(x_n) = \mathrm{SM} + \mathrm{INT}(x_n) + \mathrm{QUAD}(x_n)$$

2. Check differential distribution if this equation holds in all PS regions
3. Check scaling between different parameter values (1-dim case: $(f_{s,0}) = (x)$):

$$\mathrm{FULL}(x) = \mathrm{SM} + \frac{x}{x_n}\mathrm{INT}(x_n) + \frac{x^2}{x_n^2}\mathrm{QUAD}(x_n)$$

4. Check scaling between different parameter values (2-dim case: $(f_{s,0},f_{s,1}) = (x,y)$):

$$\mathrm{FULL}(x,y) = \mathrm{SM} + \frac{x}{x_n}\mathrm{INT}(x_n) + \frac{x^2}{x_n^2}\mathrm{QUAD}(x_n) + \frac{y}{y_n}\mathrm{INT}(y_n) + \frac{y^2}{y_n^2}\mathrm{QUAD}(y_n) + \frac{xy}{x_n y_n}\mathrm{CROSS}(x_n, y_n)$$

$$\mathrm{CROSS}(x_n, y_n) = \mathrm{QUAD}(x_n, y_n) - \mathrm{QUAD}(x_n) - \mathrm{QUAD}(y_n)$$

Technical details

$W^{\pm}Zjj$

Setup

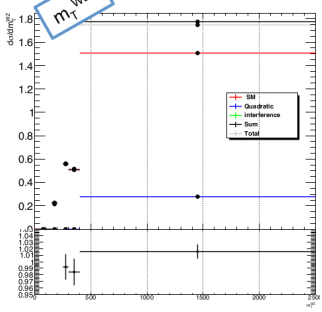
Generator:	• Madgraph 2.6.5
Model:	• Eboli, Gonzales-Garcia model, SM_LST
Process:	$dd \to e + e - \mu - \bar{\nu_\mu} ud$
Number of events	• 50k
Level:	• generator level only
Method:	• "Decomposition" of the total sample
EFT parameter values:	• Tested at the latest limit values for the WZjj provided by CMS
Choice of operators	• fS0, fS1 • fT0, fT1, fT2 • fM0, fM1

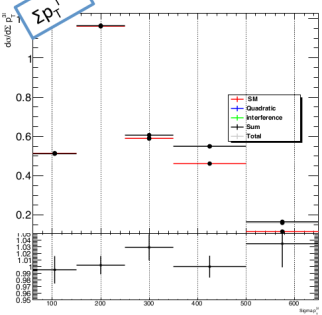
EFT Parameter: f_{S1}

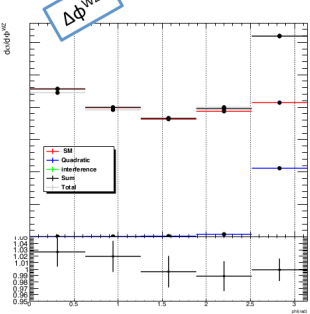
- **f_{s1}=42 TeV^{-4}**
- Decomposition Validation in the total phase space (Loose PS on WZjj final state)

SM xsec(fb)	INT xsec(fb)	QUAD xsec(fb)	TOTAL xsec(fb)	SUM xsec(fb)	Difference %
0.1065	-0.0003	0.0091	0.1151	0.1153	0.17

- Fiducial Phase space: (truth selection for WZ VBS final state)





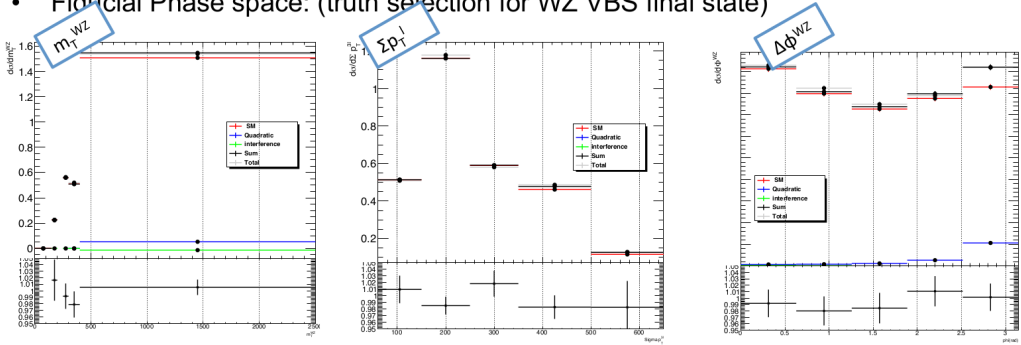


EFT Parameter: f_{T0}

- **f_{T0}=0.8 TeV^{-4}**
- Decomposition Validation in the total phase space (Loose PS on WZjj final state)

SM xsec(fb)	INT xsec(fb)	QUAD xsec(fb)	TOTAL xsec(fb)	SUM xsec(fb)	Difference %
0.1065	-0.0004	0.0051	0.1103	0.1113	0.87

- Fiducial Phase space: (truth selection for WZ VBS final state)

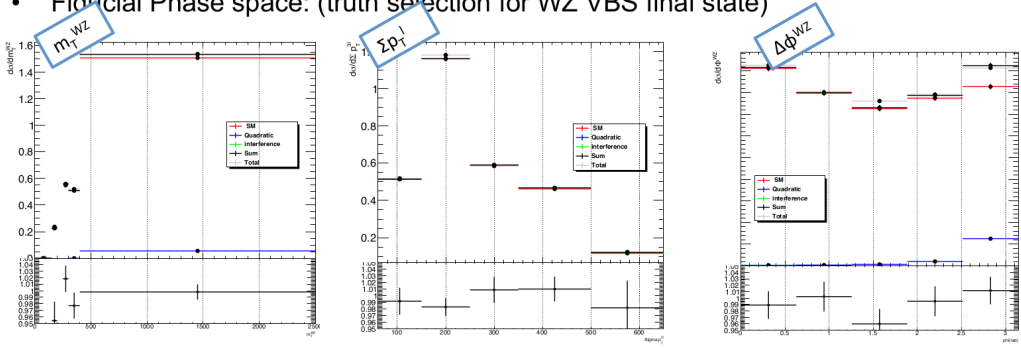


EFT Parameter: f_{T1}

- **f_{T1}=0.55 TeV^{-4}**
- Decomposition Validation in the total phase space (Loose PS on WZjj final state)

SM xsec(fb)	INT xsec(fb)	QUAD xsec(fb)	TOTAL xsec(fb)	SUM xsec(fb)	Difference %
0.1065	-0.001	0.0057	0.1103	0.1112	0.83

- Fiducial Phase space: (truth selection for WZ VBS final state)

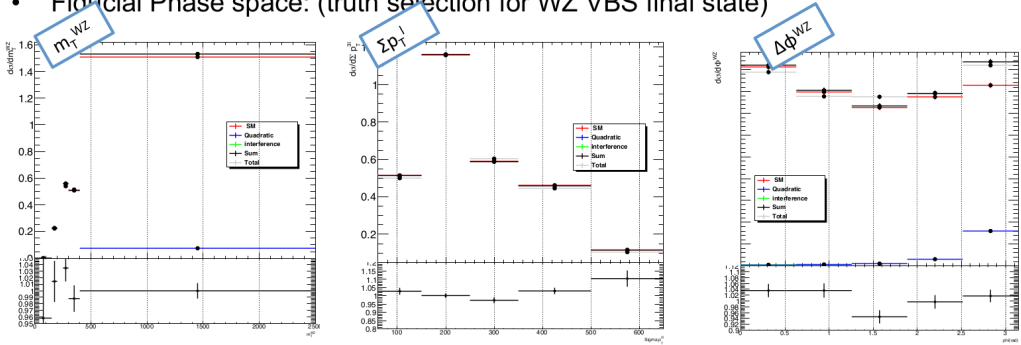


EFT Parameter: f_{T2}

- **f_{T2}=1.85 TeV^{-4}**
- Decomposition Validation in the total phase space (Loose PS on WZjj final state)

SM xsec(fb)	INT xsec(fb)	QUAD xsec(fb)	TOTAL xsec(fb)	SUM xsec(fb)	Difference %
0.1065	-0.002	0.007	0.111	0.112	0.8

- Fiducial Phase space: (truth selection for WZ VBS final state)

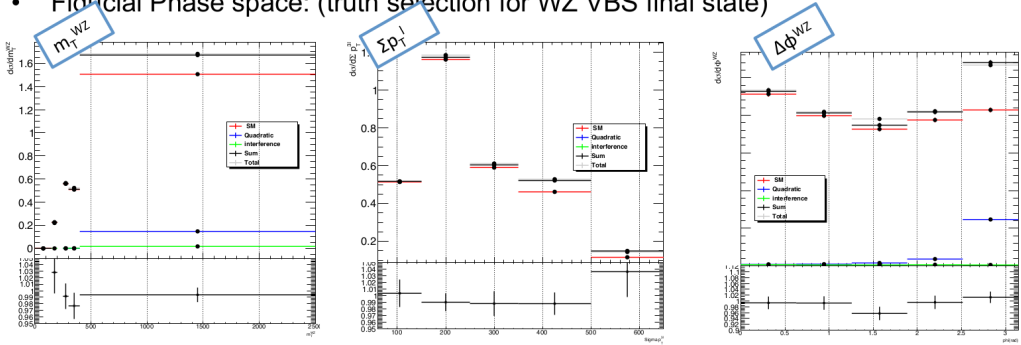


EFT Parameter: f_{M0}

- **f_{M0}=9.15 TeV^{-4}**
- Decomposition Validation in the total phase space (Loose PS on WZjj final state)

SM xsec(fb)	INT xsec(fb)	QUAD xsec(fb)	TOTAL xsec(fb)	SUM xsec(fb)	Difference %
0.1065	0.001	0.008	0.114	0.115	0.332

- Fiducial Phase space: (truth selection for WZ VBS final state)

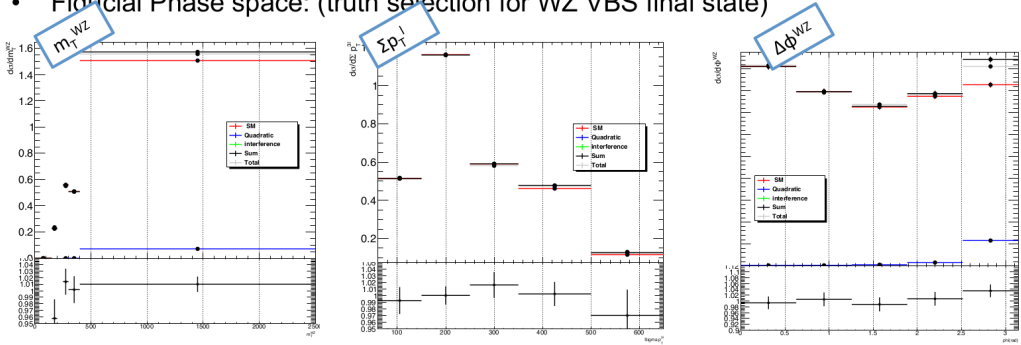


EFT Parameter: f_{M1}

- **f_{M1}=9.45 TeV^{-4}**
- Decomposition Validation in the total phase space (Loose PS on WZjj final state)

SM xsec(fb)	INT xsec(fb)	QUAD xsec(fb)	TOTAL xsec(fb)	SUM xsec(fb)	Difference %
0.1065	-0.00017	0.00348	0.10920	0.10981	0.558

- Fiducial Phase space: (truth selection for WZ VBS final state)



Technical details

$W^{\pm}W^{\pm}jj$

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Sample generation details for validation studies:

- Generator: MG5_aMC@NLO (v2.6.5) + Pythia8 (v8.235) (+VBS fix)
- Process: $uu > dde^{+}\mu^{+}\nu\nu$
- Model: O. Eboli, M. Gonzalez-Garcia (2016)
  SM_LSMT_Ind5
- Parameter values: Based on 13 TeV 1-dim limits from CMS
- Method: Split amplitude in SM, linear and quadratic term in EFT parameters

	Observed limits (TeV $^{-4}$)	Expected limits (TeV $^{-4}$)	Previously observed limits (TeV $^{-4}$)
f_{S0}/Λ^4	$[-7.7, 7.7]$	$[-7.0, 7.2]$	$[-38, 40]$, [11]
f_{S1}/Λ^4	$[-21.6, 21.8]$	$[-19.9, 20.2]$	$[-118, 120]$, [11]
f_{M0}/Λ^4	$[-6.0, 5.9]$	$[-5.6, 5.5]$	$[-4.6, 4.6]$, [36]
f_{M1}/Λ^4	$[-8.7, 9.1]$	$[-7.9, 8.5]$	$[-17, 17]$, [36]
f_{M6}/Λ^4	$[-11.9, 11.8]$	$[-11.1, 11.0]$	$[-65, 63]$, [11]
f_{M7}/Λ^4	$[-13.3, 12.9]$	$[-12.4, 11.8]$	$[-70, 66]$, [11]
f_{T0}/Λ^4	$[-0.62, 0.65]$	$[-0.58, 0.61]$	$[-0.46, 0.44]$, [37]
f_{T1}/Λ^4	$[-0.28, 0.31]$	$[-0.26, 0.29]$	$[-0.61, 0.61]$, [37]
f_{T2}/Λ^4	$[-0.89, 1.02]$	$[-0.80, 0.95]$	$[-1.2, 1.2]$, [37]

CMS-SMP-17-004

Summary of generator cross sections

Validation step 1

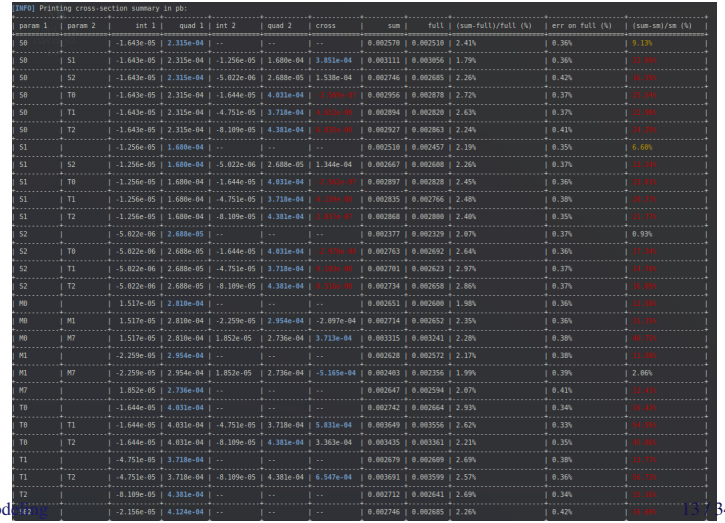
Parameter	$f_{S0} = f_{S2}$	f_{S1}	f_{T0}	f_{T1}	f_{T2}	f_{M0}	f_{M1}	f_{M7}
Value (TeV^{-4})	8.0	20.0	0.6	0.3	1.0	6.0	10.0	13.0

Specifics:

- Process: $uu > dde^+\mu^+\nu\nu$
- $\sigma_{SM}^{gen} = 0.002355\,\text{pb}$
- Parameter values at current 1D limits

Results:

- Split contributions sum up to the full cross section (independent generation) with $1-3\%$ discrepancy (column 10)
- Quadratic or cross term is dominant over interference term for all tested points (blue numbers)
- Deviation from SM sizable for most parameters (last column)



[INFO] Printing cross-section summary in pb:

param 1	param 2	int 1	quad 1	int 2	quad 2	cross	sum	full	(sum-full)/full (%)	err on full (%)	(sum-sm)/sm (%)
SM		-1.643e-05	2.315e-04	--	--	--	0.002570	0.002510	2.41%	0.36%	9.13%
SM	S1	-1.643e-05	2.315e-04	-1.256e-05	1.680e-04	3.851e-04	0.003111	0.003056	1.79%	0.36%	32.09%
SM	S2	-1.643e-05	2.315e-04	-5.022e-06	2.688e-05	1.538e-04	0.002746	0.002685	2.26%	0.42%	16.61%
SM	T0	-1.643e-05	2.315e-04	-1.644e-05	4.031e-04	-2.906e-04	0.002956	0.002878	2.72%	0.37%	25.56%
SM	T1	-1.643e-05	2.315e-04	-4.751e-05	3.718e-04	8.952e-04	0.002894	0.002820	2.63%	0.37%	22.90%
SM	T2	-1.643e-05	2.315e-04	-8.109e-05	4.381e-04	6.955e-04	0.002927	0.002863	2.24%	0.41%	24.35%
S1		-1.256e-05	1.680e-04	--	--	--	0.002510	0.002457	2.19%	0.35%	6.60%
S1	S2	-1.256e-05	1.680e-04	-5.022e-06	2.688e-05	1.344e-04	0.002667	0.002608	2.26%	0.37%	13.24%
S1	T0	-1.256e-05	1.680e-04	-1.644e-05	4.031e-04	-2.955e-04	0.002897	0.002828	2.45%	0.36%	23.01%
S1	T1	-1.256e-05	1.680e-04	-4.751e-05	3.718e-04	4.159e-04	0.002835	0.002766	2.48%	0.38%	20.37%
S1	T2	-1.256e-05	1.680e-04	-8.109e-05	4.381e-04	3.887e-04	0.002868	0.002800	2.44%	0.35%	21.74%
S2		-5.022e-06	2.688e-05	--	--	--	0.002377	0.002329	2.07%	0.37%	0.95%
S2	T0	-5.022e-06	2.688e-05	-1.644e-05	4.031e-04	-2.970e-04	0.002763	0.002692	2.64%	0.36%	17.34%
S2	T1	-5.022e-06	2.688e-05	-4.751e-05	3.718e-04	9.103e-04	0.002701	0.002623	2.97%	0.37%	14.70%
S2	T2	-5.022e-06	2.688e-05	-8.109e-05	4.381e-04	6.724e-04	0.002734	0.002658	2.86%	0.37%	16.15%
M0		1.517e-05	2.810e-04	--	--	--	0.002651	0.002600	1.98%	0.36%	12.60%
M0	M1	1.517e-05	2.810e-04	-2.259e-05	2.954e-04	-2.097e-04	0.002714	0.002652	2.35%	0.36%	15.26%
M0	M7	1.517e-05	2.810e-04	1.852e-05	2.736e-04	3.713e-04	0.003315	0.003241	2.28%	0.38%	40.75%
M1		-2.259e-05	2.954e-04	--	--	--	0.002628	0.002572	2.17%	0.38%	11.58%
M1	M7	-2.259e-05	2.954e-04	1.852e-05	2.736e-04	-5.165e-04	0.002483	0.002356	1.99%	0.39%	2.86%
M7		1.852e-05	2.736e-04	--	--	--	0.002647	0.002594	2.07%	0.41%	12.41%
T0		-1.644e-05	4.031e-04	--	--	--	0.002742	0.002664	2.93%	0.34%	16.41%
T0	T1	-1.644e-05	4.031e-04	-4.751e-05	3.718e-04	5.831e-04	0.003649	0.003556	2.62%	0.33%	54.99%
T0	T2	-1.644e-05	4.031e-04	-8.109e-05	4.381e-04	3.363e-04	0.003435	0.003361	2.21%	0.35%	46.49%
T1		-4.751e-05	3.718e-04	--	--	--	0.002679	0.002609	2.69%	0.38%	13.77%
T1	T2	-4.751e-05	3.718e-04	-8.109e-05	4.381e-04	6.547e-04	0.003691	0.003599	2.57%	0.36%	56.73%
T2		-8.109e-05	4.381e-04	--	--	--	0.002712	0.002641	2.69%	0.34%	15.18%
SM		-2.156e-05	4.124e-04	--	--	--	0.002746	0.002685	2.26%	0.42%	16.61%

Differential distributions

Validation of 1D sums

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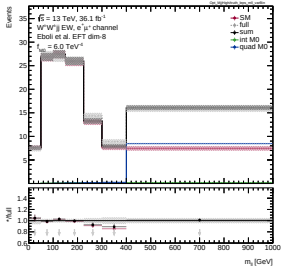
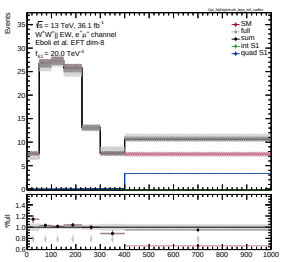
1D points:

- Full $W^{\pm}W^{\pm}jj$ process: $pp > jjl^{\pm}l^{\pm}\nu\nu$
- Phase space: Fiducial region with m_{jj} and Δy_{jj} cuts
- Split contributions sum up to the full cross section (independent generation) within $\sim 5\%$
- Quadratic term is dominant over interference term

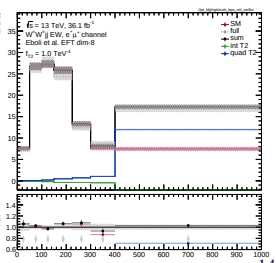
$f_{M0} = 6.0\,\mathrm{TeV}^{-4}$



$f_{S1} = 20.0\,\mathrm{TeV}^{-4}$



$f_{T2} = 1.0\,\mathrm{TeV}^{-4}$



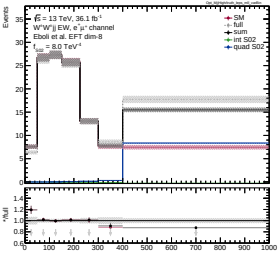
Differential distributions

Validation of 1D sums

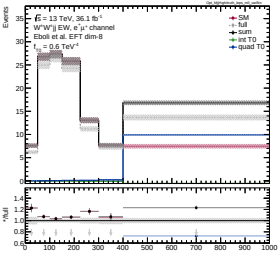
1D points:

- Full $W^{\pm}W^{\pm}jj$ process: $pp > jjl^{\pm}l^{\pm}\nu\nu$
- Phase space: Fiducial region with m_{jj} and Δy_{jj} cuts
- Larger discrepancies between the split contributions sum and the full cross section (independent generation)
- Quadratic term is dominant over interference term

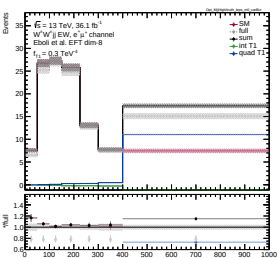
$f_{S0} = f_{S2} = 8.0\,\mathrm{TeV}^{-4}$



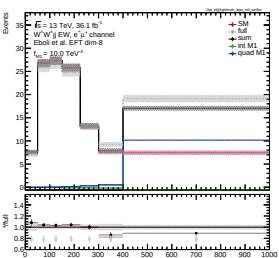
$f_{T0} = 0.6\,\mathrm{TeV}^{-4}$



$f_{T1} = 0.3\,\mathrm{TeV}^{-4}$



$f_{M1} = 10.0\,\mathrm{TeV}^{-4}$



Differential distributions

Validation of 2D sums

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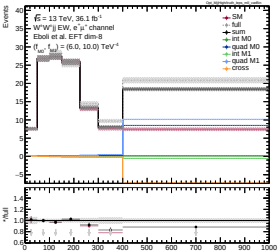
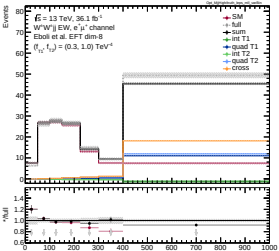
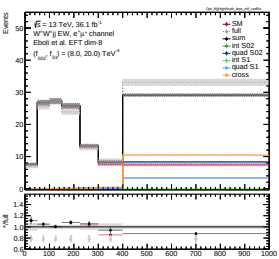
$f_{M0}, f_{M1} = (6.0, 10.0)\,\mathrm{TeV}^{-4}$



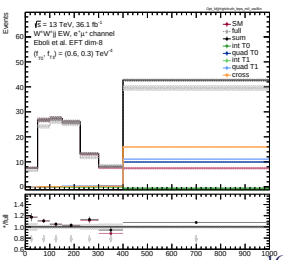
$f_{T1}, f_{T2} = (0.3, 1.0)\,\mathrm{TeV}^{-4}$



$f_{S0} = f_{S2}, f_{S1} = (8.0, 20.0)\,\mathrm{TeV}^{-4}$



$f_{T0}, f_{T1} = (0.6, 0.3)\,\mathrm{TeV}^{-4}$



2D points:

- Full $W^{\pm}W^{\pm}jj$ process: $pp > jjl^{\pm}1^{\pm}\nu\nu$
- Phase space: Fiducial region with m_{jj} and Δy_{jj} cuts
- Split contributions deviates from the full cross section (independent generation) up to 15% in some bins
- Quadratic or cross term is dominant over interference term

Hunting for the reason of the non-closure in $W^{\pm}W^{\pm}jj$

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Contacted the Madgraph authors:

⇒ Launchpad ticket: https://answers.launchpad.net/mg5amcnlo/+question/683400

Tests I made:

- Smaller parameter values (influence of quadratic term)
- Statistical limitations in the tails
- Negative parameter values (influence of interference term)
- New definition of QUAD term
- Look into wider phase space (not VBS)
- Quadratic dependence of FULL cross section
- Integration of QUAD+INT contribution together (check if integration of INT term works properly)
- Restricting the model in the proc_card.dat or in a restrict_XXX.dat (more stable integration results)
- Testing various dynamical scales in Madgraph

One promising test result:

- Retrieving the QUAD and INT contribution purely from FULL and SM samples

Dependence of the scale choice

- Default dynamical scale in Madgraph is a cluster scale
- Madgraph support clarifies that this is not an optimal scale choice for the decomposition as this scale choice depends on the Feynman diagrams of the underlying process and is even not defined for the interference term

  (https://answers.launchpad.net/mg5amcnlo/+question/683400)

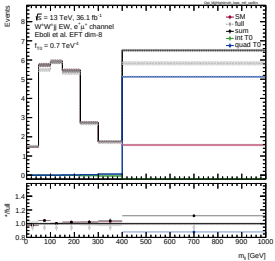
  $\Rightarrow$ For the interference the scale is internally set to something else (unknown what it is)

  $\Rightarrow$ Setting the scale to $H_T/2$ for all samples in this test
- Reduced process: $uu > dde^+\mu^+\nu\nu$, $f_{T0} = 0.7\,\text{TeV}^{-4}$

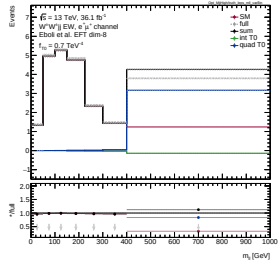
$\Rightarrow$ Discrepancies seem to be reduced especially in the lower m_{ll} regions, but remain in the tails

$\Rightarrow$ Be aware that scales do not match between the decomposition samples if you use the default scale.

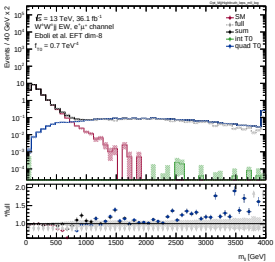
m_{ll} for Cluster scale (default)



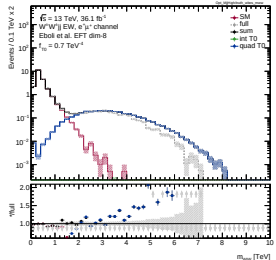
m_{ll} for $H_T/2$ scale



m_{ll} with $H_T/2$ scale



m_{WW} with $H_T/2$ scale



Testing various dynamical scales

- MG authors suggested that the non-closure might be due to the interference term and the scale settings

  (see this launchpad https://answers.launchpad.net/mg5amcnlo/+question/683400)

- First test: various dynamical scales in MG:

```
dynamical_scale_choice (new in 2.3)

                        -1 : MadGraph5_aMC@NLO default (different for LO/NLO/ ickkw mode) same as previous version.
                         0 : Tag reserved for user define dynamical scale (need to be added in setscales.f).
                         1 : Total transverse energy of the event.
                         2 : sum of the transverse mass
                         3 : sum of the transverse mass divide by 2
                         4 : \sqrt(s), partonic energy (only for LO run)
```

Sample generation details:

- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$

- QUAD term drastically different in default (-1) scale
- INT term small and differences sizable
- SM, SUM and FULL $\sim 10 - 15\%$ differences which is reasonable
- default (-1) scale shows largest deviation from FULL

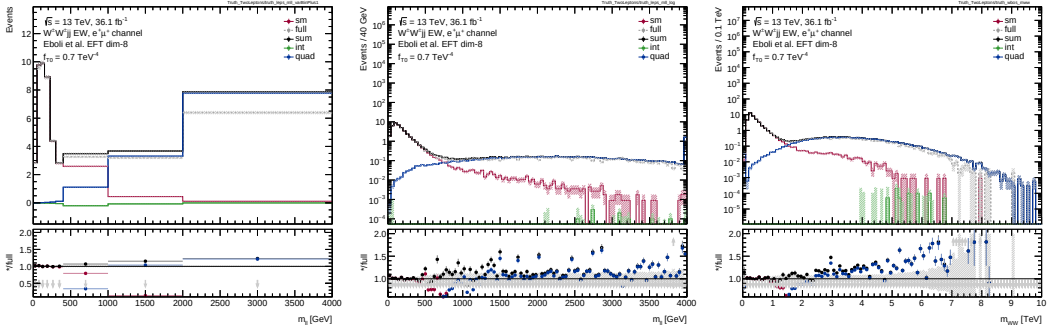
Cross sections in pb at LHE level:

	DynScale = -1	DynScale = 1	DynScale = 2	DynScale = 3	DynScale = 4
SM	0.00233	0.00197	0.00197	0.00209	0.00175
INT	-1.67E-06	-1.22E-05	-1.22E-05	-1.32E-05	-1.02E-05
QUAD	0.00041	0.00021	0.00021	0.00024	0.00019
SUM	0.00273	0.00217	0.00217	0.00232	0.00193
FULL	0.00262	0.00213	0.00213	0.00228	0.00190
(SUM-FULL)/FULL	4.34%	1.80%	1.75%	1.68%	1.38%

Differential distributions

scale $= -1$ (default)

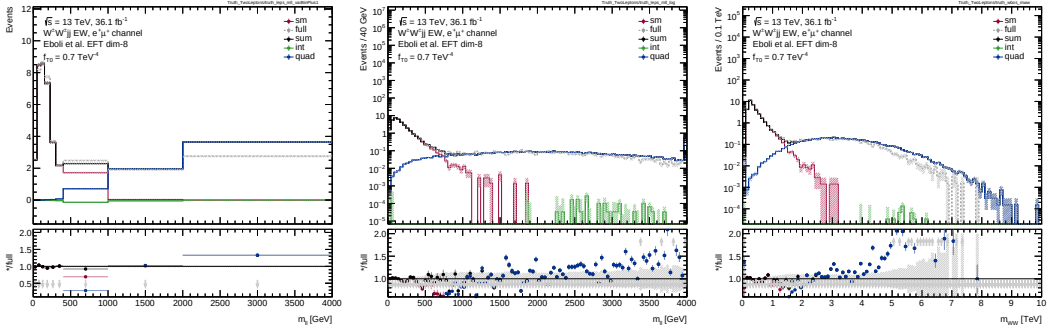
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\mathrm{TeV}^{-4}$
- Largest quadratic contribution



Differential distributions

scale = 2 ($\sum H_T$)

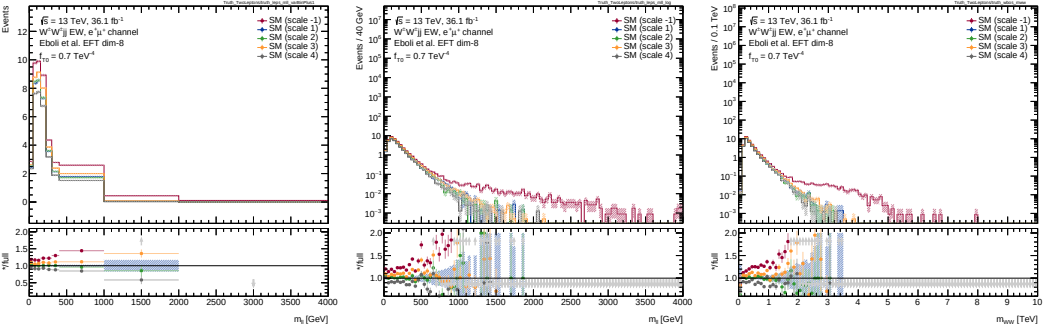
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Much reduced quadratic contribution compared to default scale



Differential distributions

Comparison of SM term for all scales

- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Default scale shows largest SM contribution, especially in tails of invariant masses
- Differences between scales up to 50% in some bins

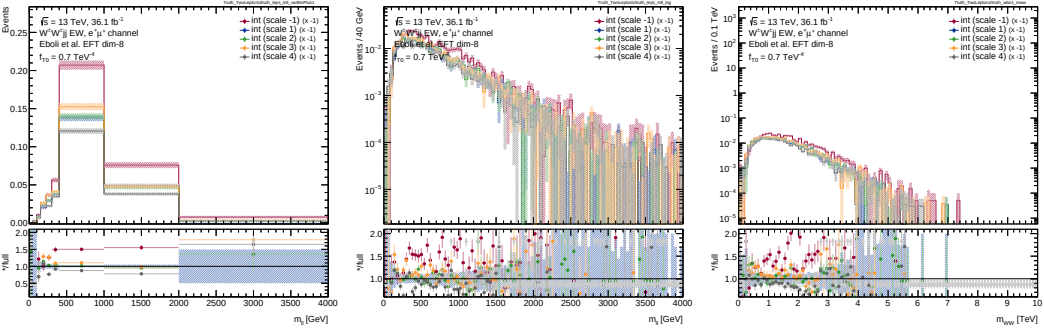


⇒ Launchpad ticket for SM shape with default scale: https://answers.launchpad.net/mg5amcnlo/+question/684056

Differential distributions

Comparison of INT term for all scales

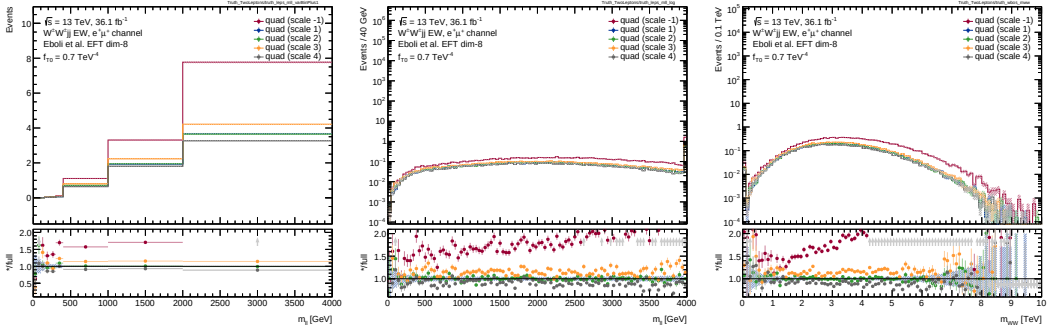
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Default scale shows largest INT contribution
- INT negative throughout mass spectra, small in tails



Differential distributions

Comparison of QUAD term for all scales

- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Default scale shows largest QUAD contribution, more uniformly over mass spectra
- Differences between scales huge in tails



QUAD and INT contribution purely from FULL and SM

The idea

The INT and QUAD contributions can be obtained purely with FULL and SM samples. This makes it possible to validate the different parts of the decomposition independent of it. Generating a FULL sample with a positive value FULL(x) and the same negative value FULL(−x) can give the INT term, as:

$$|\mathrm{INT}| = \frac{1}{2}\,|\mathrm{FULL}(x) - \mathrm{FULL}(-x)|$$

The QUAD term can similarly be obtained with:

$$\mathrm{QUAD} = \frac{1}{2}\,(\mathrm{FULL}(x) + \mathrm{FULL}(-x)) - \mathrm{SM}$$

QUAD and INT contribution purely from FULL and SM

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Differential distributions

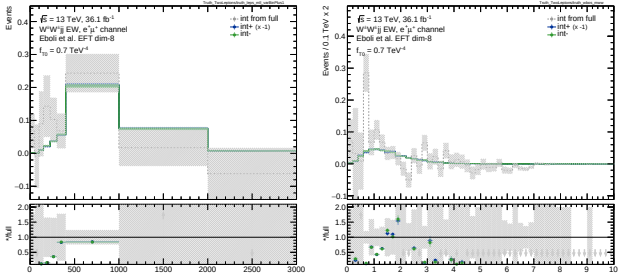
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\mathrm{TeV}^{-4}$
- Statistics is poor for the INT from the FULL samples, but INT is small and deviations are inside the statistical uncertainties
- QUAD term shows significant discrepancy when retrieved from FULL and SM samples

⇒ This makes it obvious that the discrepancies between the SUM and the FULL in the validation comes from the QUAD contribution.

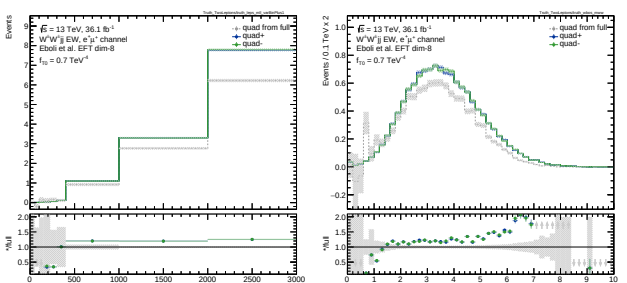
⇒ The MG authors believe that the FULL case has problems with the integration in these high tails which makes the FULL (!) sample not truthworthy.

⇒ This can be tested with placing a cut on m_{ll} or m_{WW} at generation level to populate the FULL sample in the tails and re-integrate. Closure should then be obtained between the SUM and the FULL sample.

INT term

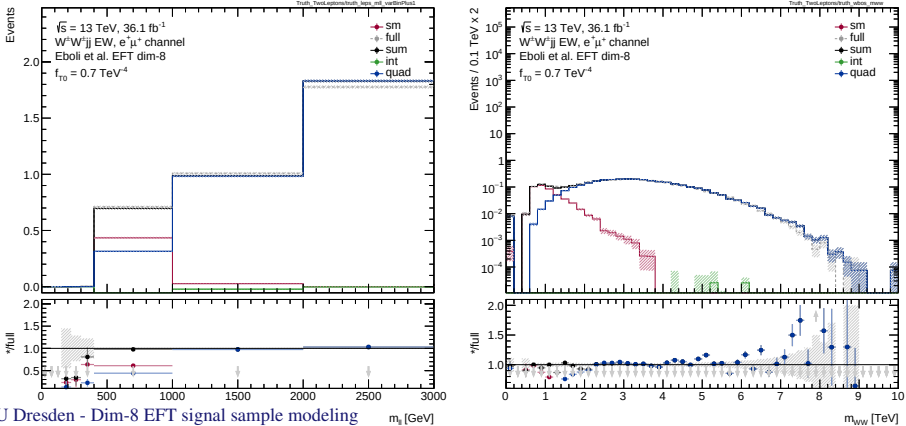


QUAD term



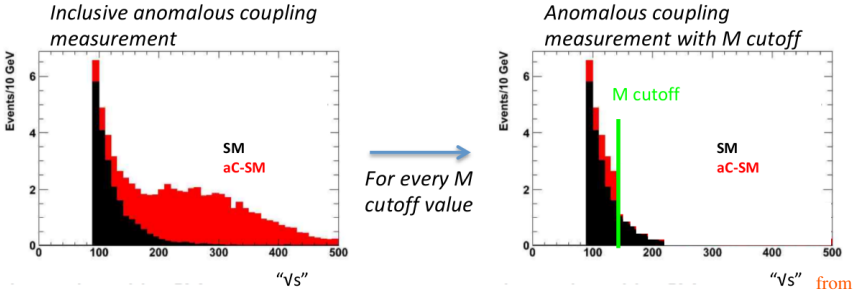
Testing the integration in the high mass tails

- $m_{ll} > 500\,\text{GeV}$ at MG generation level
  $\Rightarrow$ Improve the integration of the FULL sample in the high mass tails
- Process: $uu > dd\mu^+\mu^+\nu\nu$ (same flavour only technically possible in MG), parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- The agreement is good also in the very high tails!
  $\Rightarrow$ The FULL sample is problematic in the tails when no mass cut is placed. The decomposition works fine also without the cut. Hence, the decomposition is preferred over the FULL generation now also from a physics point of view!



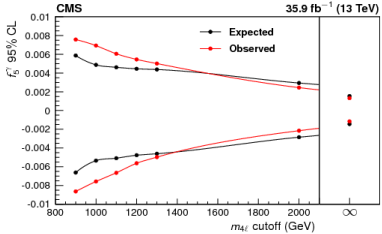
Restoring unitarity at large $\sqrt{s}$

The clipping method



from Senka Duric

- Use the EFT prediction only up to a clipping energy $\sqrt{\hat{s}} = E_{clip}$ and set any contribution from this theory to 0 beyond this energy
- The clipping is done at parton level
- The SM predictions as well as the data remain untouched
- Derive aQGC limits for various E_{clip}



This approach follows the LHCEW_WG recommendations.

CMS-SMP-16-017-003

Clipping studies

The clipping variable: m_{WW}

Definition of m_{WW}:

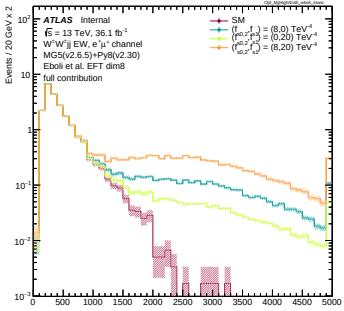
- At matrix level (i.e. before showering) in order to mimic $\sqrt{\hat{s}}$
- Take $W^{\pm}$ bosons (PDG-ID $= 24$) with status $= 22$ or 23 and barcode < 200.000
- Build invariant mass of $W^{\pm}W^{\pm}$-system
- Tested $E_{clip} = 500, 1000, 1500, 2000\,\text{GeV}$

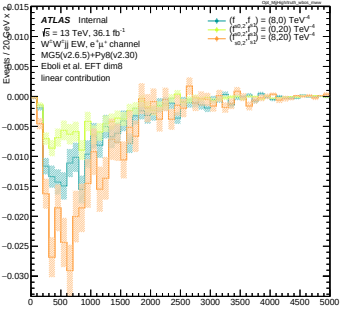
f_{Si} with nominal values

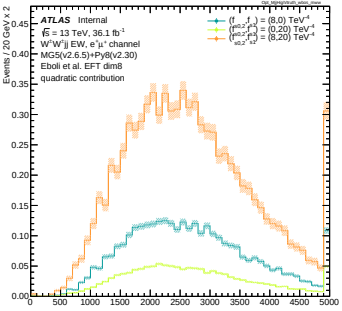
full contribution = SM + QUAD + INT + CROSS

INT only

QUAD only







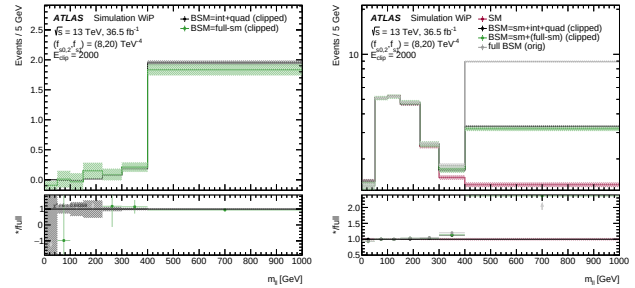
Clipping studies

Validation of clipping

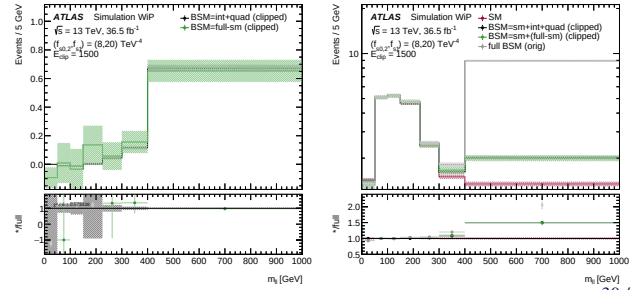
Can we clip the individual terms, i.e. INT and QUAD and then add them together?

⇒ Compare clipping FULL-SM and QUAD+INT

$E_{clip} = 2000\,GeV$



$E_{clip} = 1500\,GeV$



Clipping studies

Impact on m_{ll} distribution

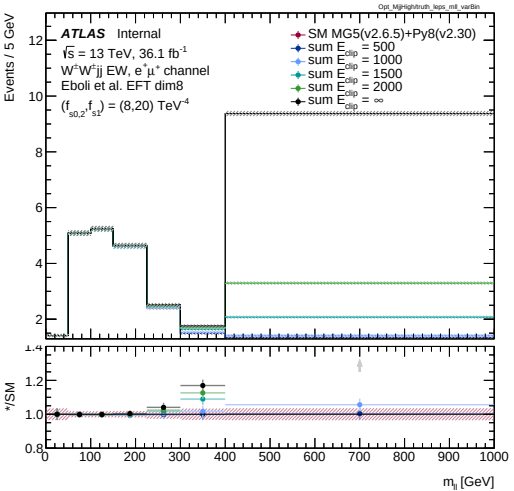
- Different clipping energies:
  $E_{clip} = 500, 1000, 1500, 2000\,\text{GeV}$
- For these parameter choice and values, clipping below 1500 GeV removes almost all BSM effects
- Decision on which clipping energies to use

  $\Rightarrow$ Below $E_{clip} = 1000\,\text{GeV}$ probably not possible
- Choice of parameter values depends on the clipping impact as well

  $\Rightarrow$ Small E_{clip} leads to weak limits

  $\Rightarrow$ Reach for parameter values must be reasonably large in this case

$f_{S02}, f_{S1} = (8.0, 20.0)\,\text{TeV}^{-4}$

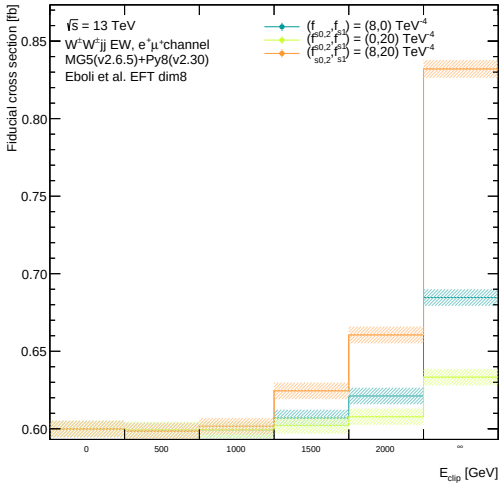


Clipping studies

Impact on cross section

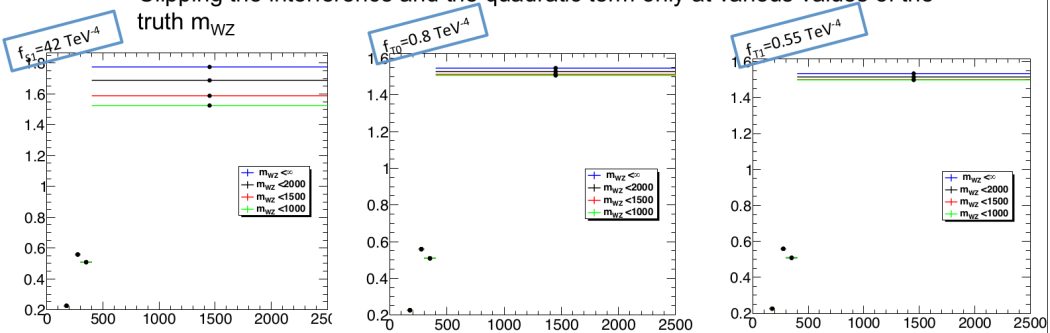
- Impact of the clipping on the full cross-section of the sample (i.e. including the SM contribution)
- Clipping very low ($E_{clip} = 500\,GeV$) results in a smaller cross-section compared to the SM for the tested parameters and values:

  f_{S02}, f_{S1} with current $W^{\pm}W^{\pm}jj$ CMS 1D limits
- Reason: quadratic contibution gets clipped away completely and the interference contribution with SM is negative in this case



Example of clipping in m_T^{WZ}

- Comparison of the distributions of the total generated sample and the clipped distributions
  - Clipping the interference and the quadratic term only at various values of the truth m_{WZ}



Summary

- The Madgraph generation with split contributions in the $W^{\pm}W^{\pm}jj$ final state works well for many of the parameters
- The total cross section closure works within $\sim 2\%$ for all tested parameters
- However, some parameters show discrepancies up to $\sim 15\%$ in the high tails of some differential distributions in the $W^{\pm}W^{\pm}jj$ final state; the $W^{\pm}Zjj$ final states looks fine!

  $\Rightarrow$ m_{ll} and m_{WW} (the clipping energy) affected
  $\Rightarrow$ Performed many tests to get to the source of the discrepancies.
  - Retrieving the decomposed contributions from the FULL samples show discrepancies between the QUAD and the FULL contribution
    $\Rightarrow$ This has also been seen in the ZZjj case
    $\Rightarrow$ MG authors suggest that the FULL has integration problems in the high mass tails
    $\Rightarrow$ This was veryfied with an m_{ll} cut at generation level
  - We can only use the decomposed samples in these cases
- The clipping seems to work as expected

Take-aways:

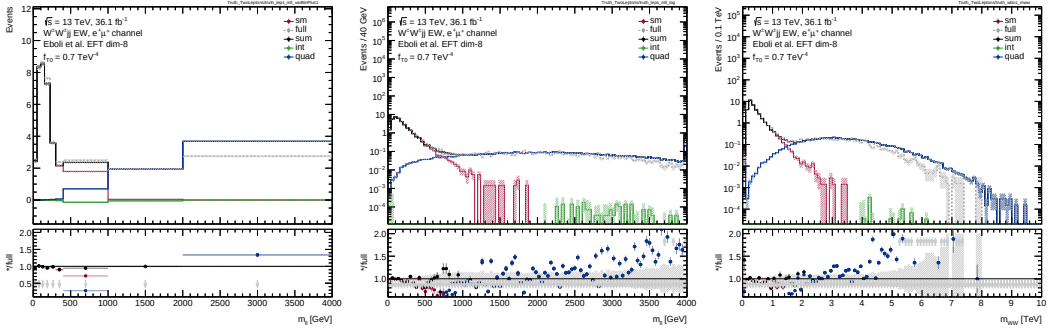
- The scales will not be consistent between the decomposed samples if you are using the default dynamical scale in MG
- The default scale in Madgraph shows consistently larger cross sections for the $W^{\pm}W^{\pm}jj$ and the $W^{\pm}Zjj$ final states
- Restricting the model with all parameters that are initially zero, makes the integration more stable
- The FULL sample suffers from integration problems and cannot be trusted in the high mass tails in the $W^{\pm}W^{\pm}jj$ case!

MORE MATERIAL

Differential distributions

scale = 1 (E_T^{tot})

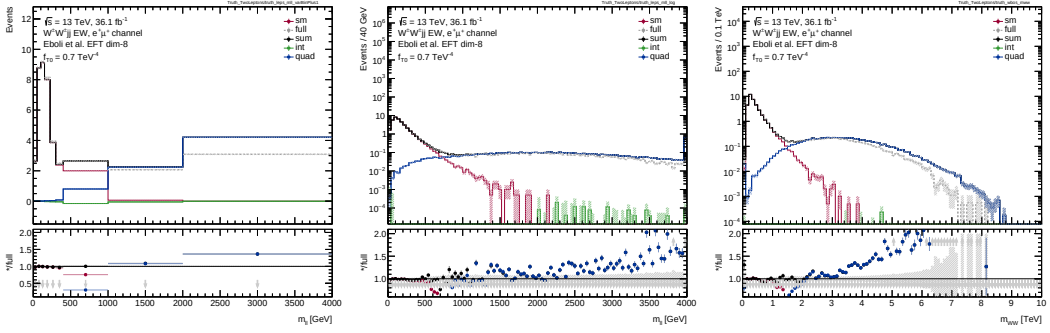
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Much reduced quadratic contribution compared to default scale



Differential distributions

scale = 3 ($\sum H_T/2$)

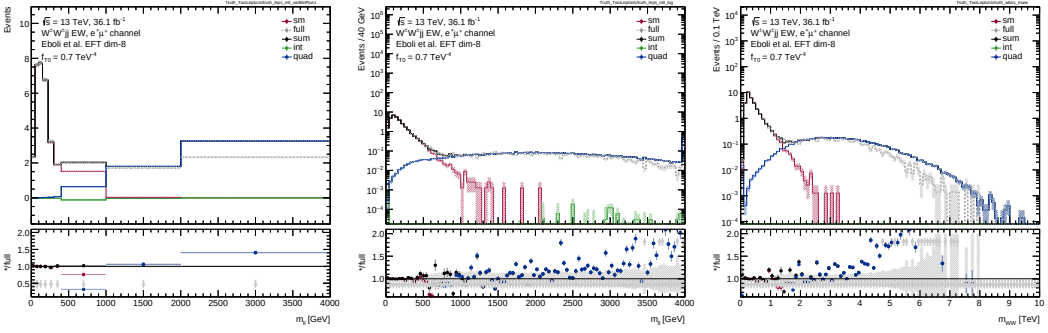
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\mathrm{TeV}^{-4}$
- Much reduced quadratic contribution compared to default scale



Differential distributions

scale = 4 ($\sqrt{s}$)

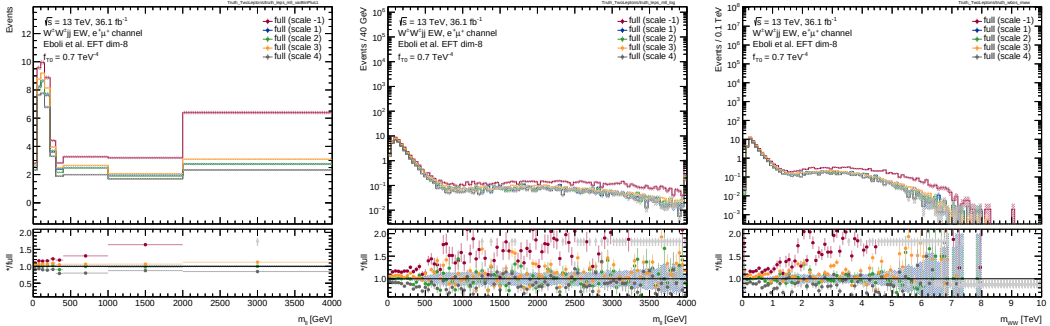
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\mathrm{TeV}^{-4}$
- Much reduced quadratic contribution compared to default scale



Differential distributions

Comparison of FULL sample for all scales

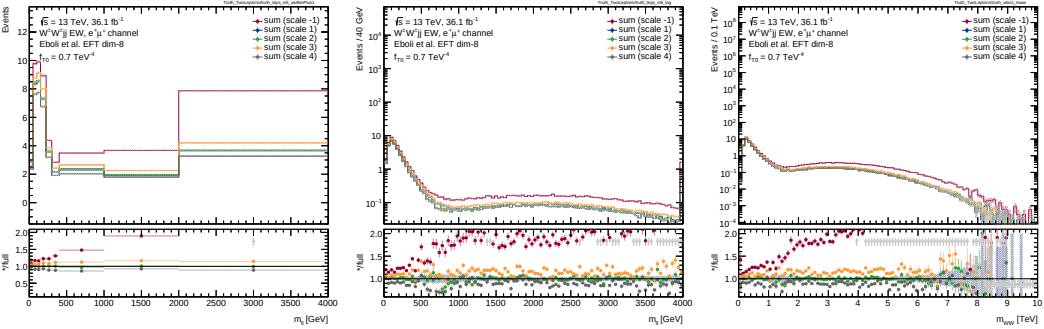
- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Default scale shows largest FULL contribution, especially in tails of invariant masses
- Differences between scales up to $> 50\%$ in some bins



Differential distributions

Comparison of SUM for all scales

- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Default scale shows largest SUM contribution, especially in tails of invariant masses
- Differences between scales up to $> 50\%$ in some bins



Restricting the model

Details and total cross section

- MG authors suggested that restricting the model could help

  (Initially suggested to the ZZ case, see these launchpads: https://answers.launchpad.net/mg5amcnlo/+question/678974, https://answers.launchpad.net/mg5amcnlo/+faq/2312)

- This means: One can remove all couplings that are 0 directly before the generation, which should make it faster and more stable
- Placing a restrict_XXX.dat card in the model folder and insert all couplings that should be 0
- As shown in the total cx explicitely adding NP=0 for each parameter that should stay 0 the proc_card.dat makes no difference

Sample generation details:

- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\mathrm{TeV}^{-4}$
- Shows differences in SM, INT, FULL; QUAD exact identical
- Shows better agreement with FULL due to increased FULL cx

Cross sections in pb at gridpack level:

	in proc_card.dat	restriction_card	(proc - restrict)/proc
SM	0.00209	0.00211	0.81%
INT	-1.32E-05	-1.30E-05	-1.44%
QUAD	0.00024	0.00024	0.00%
SUM	0.00232	0.00234	0.74%
FULL	0.00228	0.00232	1.67%
(SUM-FULL)/FULL	1.63%	0.71%	

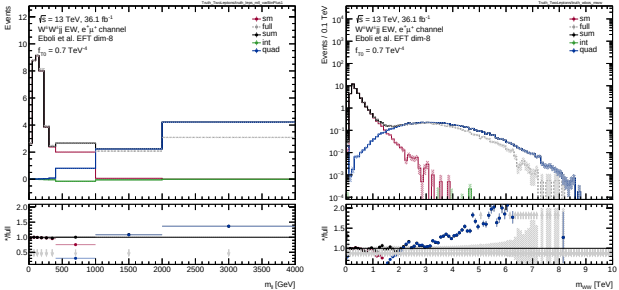
Restricting the model

Differential distributions

- Process: $uu > dde^+\mu^+\nu\nu$
- Parameter: $f_{T0} = 0.7\,\text{TeV}^{-4}$
- Distributions with restriction show slightly better agreement

$\Rightarrow$ Make sure you are using this to generate your samples if you have a lot of parameters that are zero

without restriction



with restriction