Consistent Searches for SMEFT Effects in Non-Resonant Dijet Events

Stefan Alte, Johannes Gutenberg-Universität Mainz Matthias König and William Shepherd



The operation of the LHC is a success story.

The operation of the **LHC** is a **success story**.

However, NP has not yet been discovered.

Status: July 2017						(C dt = 1	3 2 - 37 0) fb ⁻¹	Jr - 8 13 TeV
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Dult FIS Gyr → WW → gg	v tex	1.1	784	20.1	5.75 TeV		$k(\mathbf{R}_{0} = 1.0)$	ATLAS-CONF-0017-00
2UED / RPP	1.6,8	$\geq 2 \ h_i \geq 3$) Yes	10.2	Const Seller		Then $(0, t)$, $\mathcal{B}(\mathcal{A}^{(\lambda 1)} \rightarrow \mathcal{B}) = 1$	ATLX5-CONF-2116-11
88M 2* → <i>l</i> l	2 4.,4			36.1	L'exasta	4.5 197		WL88-CONF-2017-02
$SSM 2^* \rightarrow rr$	21			26.1	Crass 2.4 TeV			ATLAS-CONF-2017-05
Leptophotoc 2" bb		2.5		0.2	Crass 1.5 TeV			9580.86794
Febrobusic 5. → II		510/511	12) Yes	3.2	2.0 TeX		15m - 3%	MU85 CONF-2016-01
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Scalar LQ 1 [#] gen	2.4	221	-	3.2	Q mass 1.1 TeV		$\beta = 1$	1685.86335
Scalar Ltg 2 ^m gen	2.2	3.23		362	12 mass 1.06 TeV		3-1	105.0035
SCREETLD 3** Bea	14.3	216,20	1 166	20.3	10 Maria 643 DAV			1580.84735
$VLQ TT \rightarrow He + X$	0 or 1 e, a	$> 2 $ $b_1 > 3$	11 765	13.2	Loses 1.2 TeV		$B(T \rightarrow H2) = 1$	WUKS CONF 2016 11
$VLD TT \rightarrow Zt + X$	14.8	519553	1 1965	36.1	Fichais 1.16 TeX		$P(T \rightarrow 2t) = 1$	1785.10754
$VLD TT \rightarrow Wh + X$	14.8	≥ 16, ≥ 14	(2) Yes	26.1	Fran 1.35 TeV		$P(T \rightarrow Mb) = 1$	CEFN-EP-2017-894
$VLQ.88 \rightarrow Hb + X$	10.0	22623	0.968	20.3	5 mm 200 GeV		$P(S \rightarrow He) = 1$	1585.84306
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ND 00 - Weller	1.4.4	> 41	Yes .	20.2	Contra (646 Gav)			1510 MANA
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Excited lepton ("	24.4			20.3	10101	990 B	A = 3.8 DeV	1611 2121
Excited lepton v*	3 e, y, r			20.3	Trace Sa Ter		A = 1.8 TeV	1411,2921
LRSW Majorana y	21.1	21		20.3	Cana 2010		er(Mu) = 2.4 TeV, so mixing	1586,86820
Higgs triplet H ^{*+} → (/	2.3.4 e.p (St	5) -		36.1	f ¹¹ mans ITO GeV		Df production	ALAS CONF 2017-OR
Higgs triplet H ^{*+} → Cr	3 e, µ, τ			20.2	411 mass 600 GeV		DF productors, $\mathcal{B}(M_1^{++} \rightarrow \ell \tau) = 1$	1411,2921
Monotop (nan res prod)	14.4	1.0	Yes	20.3	piny 1 invitable particle mass. 657 GeV		Aut.cm = 0.2	1410,5484
Multi-charged particles				20.3	nuti sharged particle mass 765 GeV		DF productions (q) - Se	1584,84188
Magnetic monopoles	-	-	-	7.0	tosopie mas 1.34 W/.		Df production, (g) = 1,g_{\rm T}, apix 1/2	1109.01009
-	VS-8 TeV	5-1	3 TeV		and a construction of			1
					10"* 1	1	^U Mass scale [TeV]	

*Only a selection of the available mass limits on new states or phenomena is shown 1 Smail-radius (large-radius) lets are denoted by the letter (13).

ATLAS (2017)

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In the case of the SMEFT, the Lagrangian is expanded in inverse powers of the NP mass scale $\Lambda.$

The search for NP in tails of distributions is complicated by the fact that the momentum transfer is not constant: EFT effects grow $\sim \frac{E}{\Lambda}$.

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We propose an alternative approach and constrain SMEFT effects in dijet production at the LHC.

"Consistent Searches for SMEFT Effects in Non-Resonant Dijet Events", Alte, König and Shepherd, JHEP 1801 (2018) 094, arXiv:1711.07484.

In the SMEFT, the SM Lagrangian is supplemented by local, higher-dimensional operators built out of SM fields and respecting the SM gauge group.

$$\mathcal{L}_{\mathsf{SMEFT}} = \mathcal{L}_{\mathsf{SM}} + \mathcal{L}^{(5)} + \mathcal{L}^{(6)} + \mathcal{L}^{(7)} + \mathcal{L}^{(8)} + \dots,$$

where

$$\mathcal{L}^{(i)} = \sum_{k=1}^{N_i} \frac{c_k^{(i)}}{\Lambda^{i-4}} Q_k^{(i)}.$$

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The **leading (non-trivial) contribution** to dijet production arises from **dimension-six operators**.

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We work in the **"Warsaw" basis**, assume **baryon-number**, **lepton-number and CP-conservation**. The contributing operators are:

$$\begin{array}{c} Q_{qq}^{(1)} & (\bar{q}) \\ Q_{uu} & (\bar{u}) \\ * & Q_{ud}^{(1)} & (\bar{u}) \\ * & Q_{qu}^{(1)} & (\bar{q}) \\ * & Q_{qd}^{(1)} & (\bar{q}) \\ * & Q_{qd}^{(1)} & (\bar{q}) \\ * & Q_{G} & f' \end{array}$$

$$\begin{aligned} & \left(\bar{q}_{p}\gamma_{\mu}q_{r}\right)\left(\bar{q}_{s}\gamma^{\mu}q_{t}\right) \\ & \left(\bar{u}_{p}\gamma_{\mu}u_{r}\right)\left(\bar{u}_{s}\gamma^{\mu}u_{t}\right) \\ & \left(\bar{u}_{p}\gamma_{\mu}u_{r}\right)\left(\bar{d}_{s}\gamma^{\mu}d_{t}\right) \\ & \left(\bar{q}_{p}\gamma_{\mu}q_{r}\right)\left(\bar{u}_{s}\gamma^{\mu}u_{t}\right) \\ & \left(\bar{q}_{p}\gamma_{\mu}q_{r}\right)\left(\bar{d}_{s}\gamma^{\mu}d_{t}\right) \\ & f^{ABC}G_{\mu}^{A\nu}G_{\nu}^{B\rho}G_{\rho}^{C\mu} \end{aligned}$$

$$\begin{array}{c|c} Q_{qq}^{(3)} & \left(\bar{q}_{p} \gamma_{\mu} \tau^{I} q_{r} \right) \left(\bar{q}_{s} \gamma^{\mu} \tau^{I} q_{t} \right) \\ Q_{dd} & \left(\bar{d}_{p} \gamma_{\mu} d_{r} \right) \left(\bar{d}_{s} \gamma^{\mu} d_{t} \right) \\ Q_{ud}^{(8)} & \left(\bar{u}_{p} \gamma_{\mu} T^{A} u_{r} \right) \left(\bar{d}_{s} \gamma^{\mu} T^{A} d_{t} \right) \\ Q_{qu}^{(8)} & \left(\bar{q}_{p} \gamma_{\mu} T^{A} q_{r} \right) \left(\bar{u}_{s} \gamma^{\mu} T^{A} u_{t} \right) \\ Q_{qd}^{(8)} & \left(\bar{q}_{p} \gamma_{\mu} T^{A} q_{r} \right) \left(\bar{d}_{s} \gamma^{\mu} T^{A} d_{t} \right) \end{array}$$

no interference

The dijet cross section in the SMEFT can be written as

$$\sigma_{\text{dijet}} = \sigma_{\text{SM}} + \frac{1}{\Lambda^2} \sigma_{\text{dim}6-\text{SM}} + \frac{1}{\Lambda^4} \sigma_{\text{dim}6} + \dots$$

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Many EFT analyses pursue neither of the two options.

We recast a recent CMS analysis $_{\mbox{\tiny CMS}\ (2017)},$ where

- the dimension-six squared piece is taken into account.
- the single-operator case is considered.
- bounds on the NP scale Λ are derived.

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We derive bounds for both the fixed-Wilson and the fixed-scale case.

The Multioperator Case

The search analyses the cross section differential in the dijet invariant mass m_{ii} and the angular variable

$$\chi = e^{|y_1 - y_2|} \, .$$

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Searches in Normalized Angular Distributions

Reproduction of the CMS Analysis

$$\frac{d\sigma}{d\chi}\Big|_{\text{signal}} = \left. \frac{d\sigma}{d\chi} \right|_{\text{SM}} + \frac{1}{\Lambda^2} \left. \frac{d\sigma}{d\chi} \right|_{\text{interference}} + \frac{1}{\Lambda^4} \left. \frac{d\sigma}{d\chi} \right|_{\text{BSM}} + \dots$$
 for validation only!

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for validation only!
$$\frac{0.20}{0.16} \int_{0.16}^{0.20} \int_{0.16}^{0.20} \int_{\text{Signal K + 10}}^{0.20} \int_$$

Using LO QCD Monte-Carlo samples, a Chi-Squared Fit to the CMS data results in bounds on Λ which agree within $\sim 1~\text{TeV}$ with the CMS bounds.

Truncation at Dimension-Six Interference

$$\begin{aligned} \left. \frac{d\sigma}{d\chi} \right|_{\text{signal}} &= \left. \frac{d\sigma}{d\chi} \right|_{\text{SM}} + \frac{1}{\Lambda^2} \left. \frac{d\sigma}{d\chi} \right|_{\text{interference}} + \mathcal{O}\left(\frac{1}{\Lambda^4}\right) \\ \Delta\left(\frac{d\sigma}{d\chi}\right) \right|_{\text{theo}} &= \frac{1}{\Lambda^4} \left. \frac{d\sigma}{d\chi} \right|_{\text{BSM}} \end{aligned}$$

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 $m_{ii} > 4.8 \text{ TeV}$



Including the new theory error, we find no bounds on Λ .

Searches in Unnormalized Distributions

Signal and Theory Error

We use the signal

$$\sigma_{\rm signal} = \sigma_{\rm SM} + \frac{1}{\Lambda^2} \, \sigma_{\rm interference} \, , \label{eq:signal}$$

where we switch on the operators $Q_{aq}^{(1)}$ and $Q_{au}^{(8)}$.

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where we switch on the **operators** $Q_{qq}^{(1)}$ and $Q_{qu}^{(8)}$.

Our theory error models both the dimension-six squared piece and the dimension-eight-interference piece:

$$\Delta \sigma_{
m theo} = rac{1}{\Lambda^4} \, \sigma_{
m dim6} \; ,$$

where we replace the squared Wilson coefficients by

$$\begin{split} \Delta_{\mathrm{theo},1} &= \max\left\{c_k^2; \ g_s \, c_8 \sqrt{N_8}\right\}\\ \text{or} \qquad \Delta_{\mathrm{theo},2} &= \sqrt{c_k^4 + \left(g_s \, c_8 \sqrt{N_8}\right)^2} \end{split}$$





Including the theory uncertainty, the bounds weaken. Some amount of integrated luminosity is needed to obtain bounds.



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Above this integrated luminosity, we do not only find a lower bound for $\Lambda,$ but rather an excluded region.



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Can we do better?

Searches in the Dijet Invariant Mass Spectrum



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The searches in the dijet invariant mass spectrum yield bounds at lower integrated luminosity compared to the searches in the angular spectrum.

We introduce a **new theory error** to account for **higher-order contributions**.

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Two distinct linear combinations of Wilson coefficients **contribute to the angular spectra**.

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Two distinct linear combinations of Wilson coefficients **contribute to the angular spectra**.

The searches in **unnormalized** m_{jj} **distributions** reach **higher** scales at lower integrated luminosity compared to searches in angular spectra.

Besides fixing the Wilson coefficients and fitting for the NP scale, we can also fix the NP scale and fit for the Wilson coefficient.

