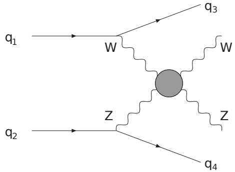
Collider phenomenology of vector resonances in WZ scattering processes

Presented by **Rafael L. Delgado**
A.Dobado, D.Espriu, C.Garcia-Garcia, M.J.Herrero, X.Marcano and J.J.Sanz-Cillero



Based on JHEP**1711**, 098
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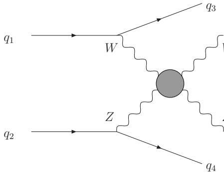
2nd August 2018, Maynooth University, Ireland

Our case of study

$pp \to WZj_1j_2$

by $WZ \to WZ$ scattering



- We are interested in $WZ \to WZ$. Isovector channel ($IJ = 11$).
- The Inverse Amplitude Method (IAM) is used. We do not use the ET in this study, i.e., we consider gauge bosons W and Z in the external legs.
- We couple with initial pp collider states via MadGraph v5 [JHEP**1711**, 098]. Final states: $WZjj$ or $l_1^+ l_1^- l_2^+ \nu jj$.
- We use a Proca 4-vector formalism to obtain an effective theory that MadGraph can process. Proca paramenters are computed from the original EFT ones. No additional parameters needed.

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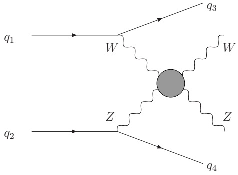

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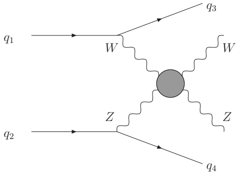

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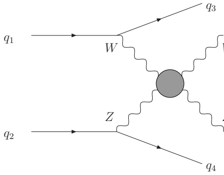

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EFTs + Unitarization Procedures

- We are interested in the collider phenomenology of Vector Bosons Scattering ($WZ \to WZ$), since it is very sensitive to new physics in the EW sector in the LHC.
- Bottom to Top approach: we construct an EFT for the EW sector. $SU(2)_L \times SU(2)_R$, EChL copy of ChPT in QCD.
- Degrees of freedom: Gauge Bosons $W^{\pm}$, Z + Higgs-like particle (h).
- 4 considered parameters: a, $b = a^2$, a_4, a_5.
- The NLO-computed EFT grows with the CM energy like $A \sim s^2$. Hence, it will eventually reach the unitarity bound, becoming non-perturbative. Options:
  - Limit the validity range of the EFT to the perturbative region. Consider it as a useful parameterization of slight deviations from the SM in the range under the TeV scale.
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Effective Lagrangian: considered parameters

$$\mathcal{L}_2 = \frac{v^2}{4}\left[1 + 2a\frac{h}{v} + b\left(\frac{h}{v}\right)^2 + \dots\right]\mathrm{Tr}(D_\mu U^\dagger D_\mu U) + \frac{1}{2}\partial_\mu h \partial^\mu h + \dots$$

$$\mathcal{L}_4 = a_4[\mathrm{Tr}(V_\mu V_\nu)][\mathrm{Tr}(V^\mu V^\nu)] + a_5[\mathrm{Tr}(V_\mu V^\mu)][\mathrm{Tr}(V_\nu V^\nu)] + \dots$$

$$V_\mu = (D_\mu U)U^\dagger, \qquad U = \exp\left(\frac{i\omega^a\tau^a}{v}\right)$$

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Unitarity problem

- VBS amplitude rises with energy, eventually leading to violation of unitarity at some new physics state.
- This leads to an *OVERESTIMATED* number of events in VBS due to an unphysical prediction of EFT. That is, amplitudes *cannot* grow uncontrolled.
- Exception, MSM: Higgs exchange exactly cancels this energy rise in VBS, restoring unitarity event at LO.
- Two options:
  - Set up a low-energy cut-off on the theory, due to the validity limits of the EFT itself. This limit, indeed, comes from the UV completion, whose specification would require to pick up a full (renormali. and unitar.) model from the *theory zoo*.
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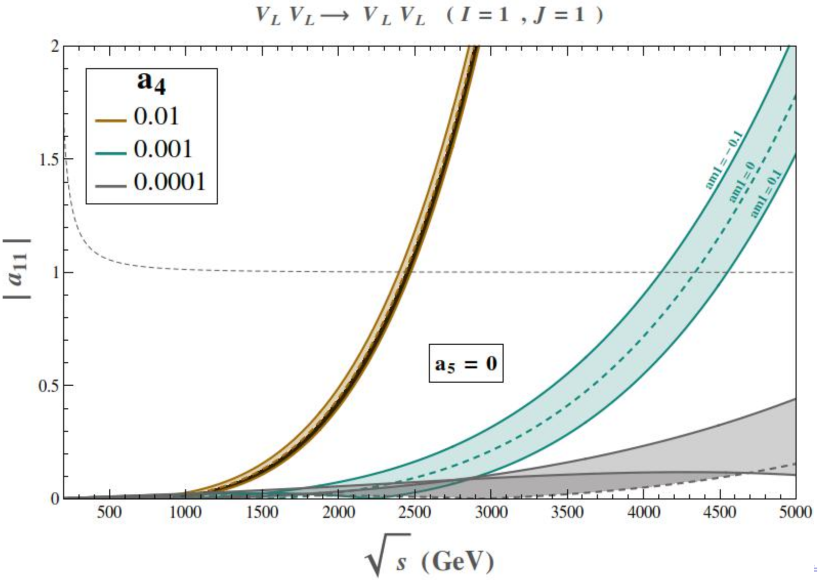

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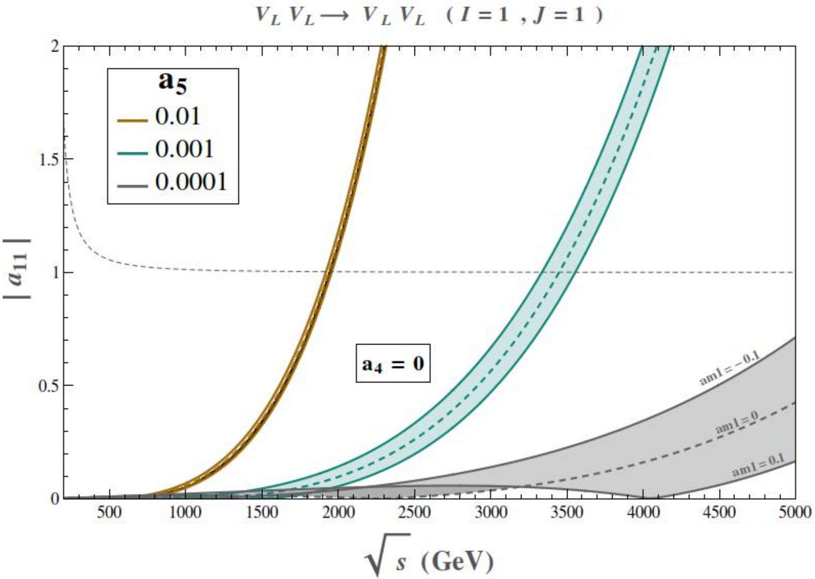

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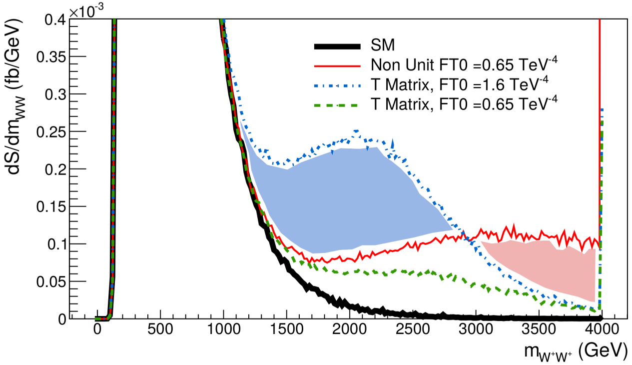

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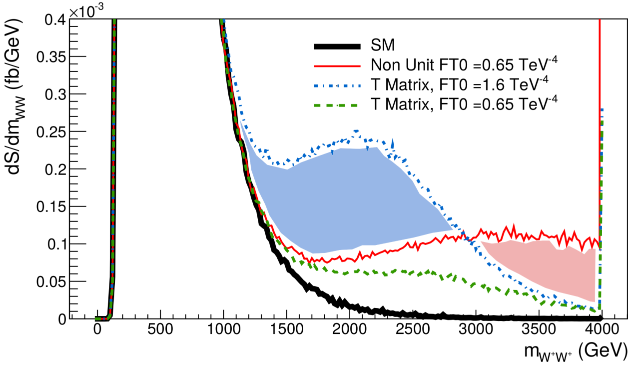

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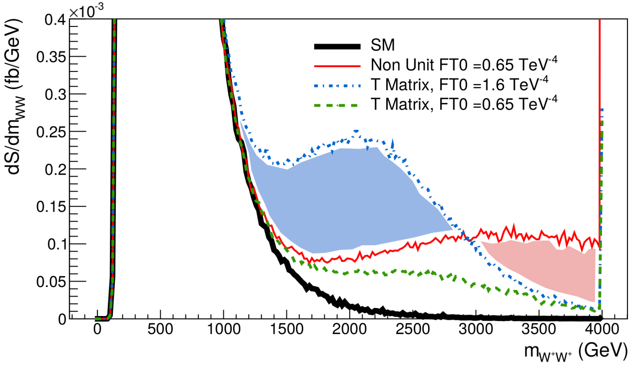

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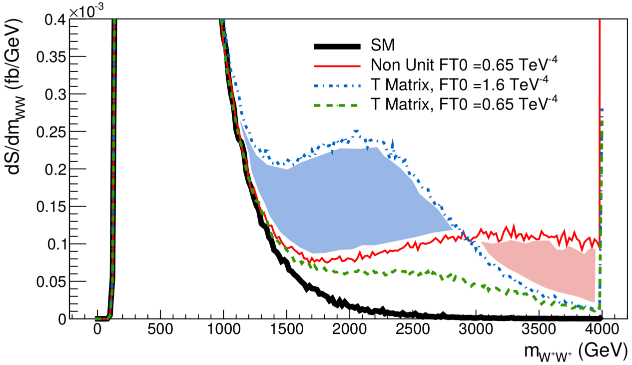

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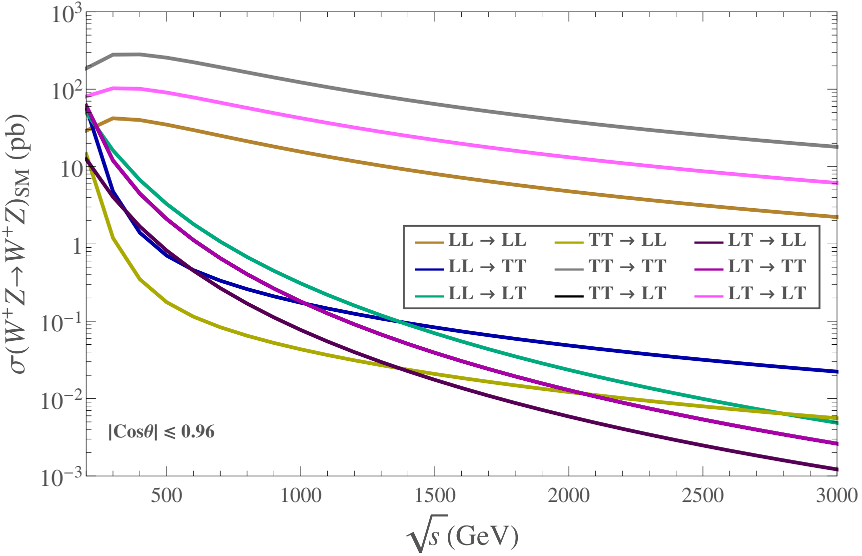
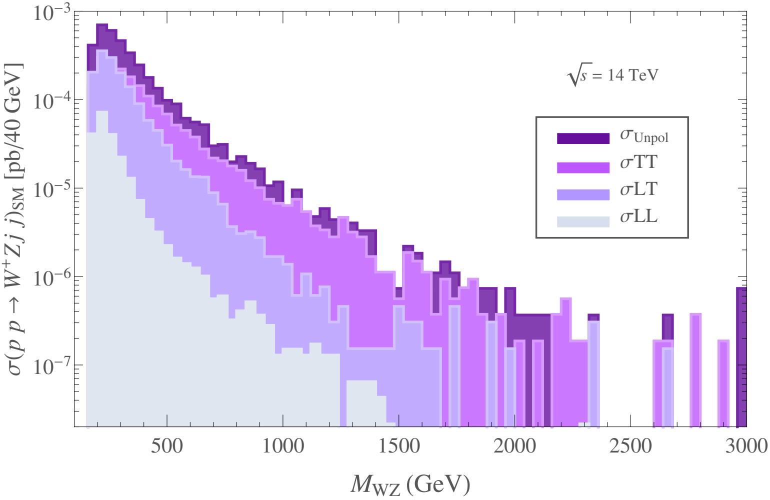
Polarization: SM, integrated $|\cos\theta| \leq 0.90$



Polarization: SM background, $pp \to W^+Zjj$



$|\eta_{j_1,j_2}| < 5;$ $\eta_{j_1} \cdot \eta_{j_2} < 0;$ $|\eta_{W,Z}| < 2$

Isovector Resonance

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BP	$M_V(\text{GeV})$	$\Gamma_V(\text{GeV})$	$g_V(M_V^2)$	a	$a_4 \cdot 10^4$	$a_5 \cdot 10^4$
BP1	1476	14	0.033	1	3.5	-3
BP2	2039	21	0.018	1	1	-1
BP3	2472	27	0.013	1	0.5	-0.5
BP1'	1479	42	0.058	0.9	9.5	-6.5
BP2'	1980	97	0.042	0.9	5.5	-2.5
BP3'	2480	183	0.033	0.9	4	-1

These BPs have been selected for vector resonances emerging at mass and width values that are of phenomenological interest for the LHC.

Considered backgrounds: The pure SM-EW background, of order $\mathcal{O}(\alpha_{\rm em}^2)$. The mixed SM-QCDEW background, of order $\mathcal{O}(\alpha_{\rm em}\alpha_s)$.

Isovector Resonance: *WZ* in final state

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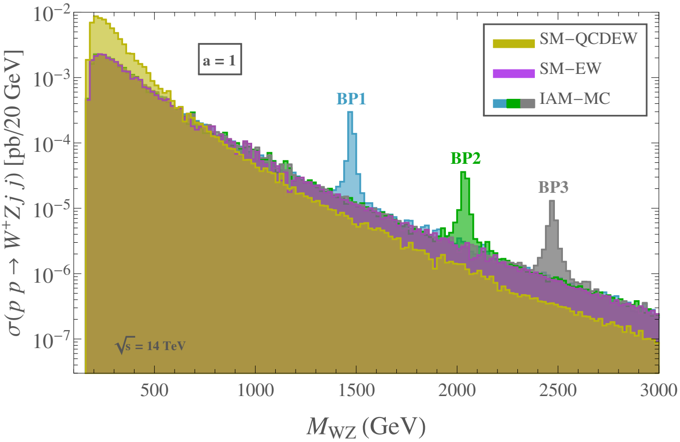
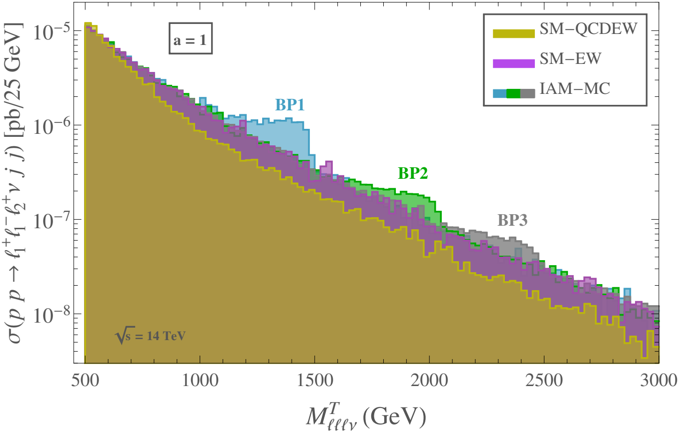


$a = 1$; $a_4 \cdot 10^4 = 3.5$ (BP1), 1 (BP2), 0.5 (BP3);

$-a_5 \cdot 10^4 = 3$ (BP1), 1 (BP2), 0.5 (BP3).

Isovector Resonance: leptonic final state

JHEP1711, 098



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Conclusions

- Studied $2 \to 2$ scattering processes within the EWSBS: $WZ \to WZ$.
- We provide a MadGraph v5 model for the unitarized EChL using the Inverse Amplitude Method (IAM). We do not rely on the naive K-matrix.
- We are able to reproduce collider signals, as required by experimentalists.
- We present realistic predictions of $(lll\nu jj)$ events at LHC from V resonance production via WZ scat. and compare with backgs.
- Prospects for the Benchmark Points at the LHC ($14\,\mathrm{TeV}$):

	$\mathcal{L} = 300\,\mathrm{fb}^{-1}$			$\mathcal{L} = 1000\,\mathrm{fb}^{-1}$			$\mathcal{L} = 3000\,\mathrm{fb}^{-1}$		
	N_l^{IAM}	N_l^{SM}	σ_l^{stat}	N_l^{IAM}	N_l^{SM}	σ_l^{stat}	N_l^{IAM}	N_l^{SM}	σ_l^{stat}
BP1	2	1	0.6	6	4	1.1	19	13	1.8
BP2	0.6	0.4	-	1	1	0	4	3	0.1
BP3	0.1	0.1	-	0.4	0.3	-	1	1	0
BP1'	6	2	2.3	19	8	4.2	57	23	7.2
BP2'	2	0.9	1	6	3	1.8	19	9	3.7
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	N_l^{IAM}	N_l^{SM}	σ_l^{stat}	N_l^{IAM}	N_l^{SM}	σ_l^{stat}	N_l^{IAM}	N_l^{SM}	σ_l^{stat}
BP1	2	1	0.6	6	4	1.1	19	13	1.8
BP2	0.6	0.4	-	1	1	0	4	3	0.1
BP3	0.1	0.1	-	0.4	0.3	-	1	1	0
BP1'	6	2	2.3	19	8	4.2	57	23	7.2
BP2'	2	0.9	1	6	3	1.8	19	9	3.7
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Conclusions

- Studied $2 \to 2$ scattering processes within the EWSBS: $WZ \to WZ$.
- We provide a MadGraph v5 model for the unitarized EChL using the Inverse Amplitude Method (IAM). We do not rely on the naive K-matrix.
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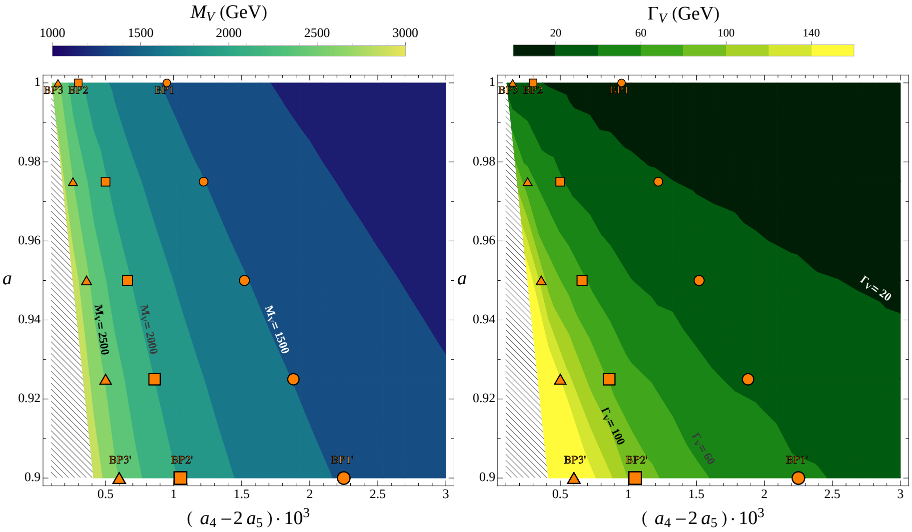
Backup Slides

Election of the benchmark points



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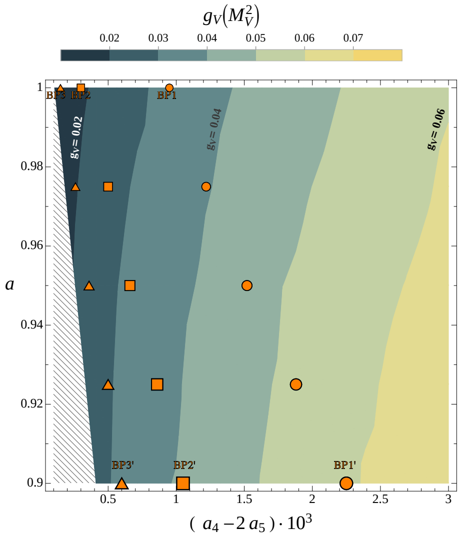
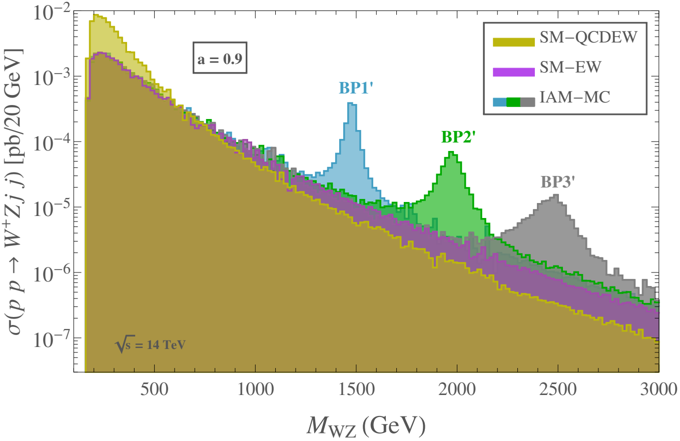


Isovector Resonance: *WZ* in final state

JHEP1711, 098



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Isovector Resonance: leptonic final state

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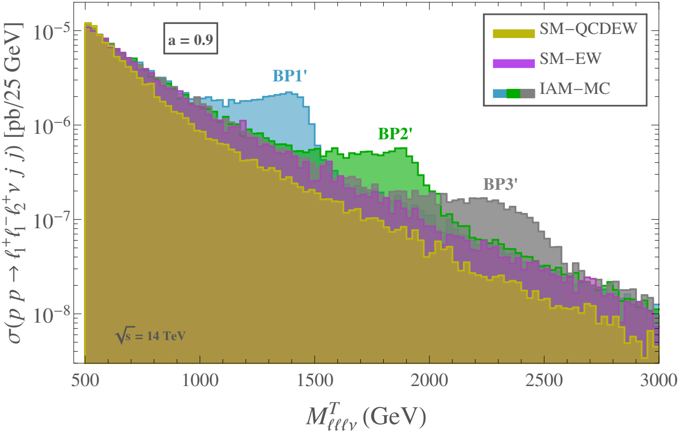

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- Options for searching BSM physics:
- From Top to Bottom: construct a full theory (renormalizable and UV complete). Describe the TeV scale in terms of the parameters of the BSM Lagrangian. I.e.: MSSM has $\sim$ 100 free parameters.
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Linear vs. non–linear: linear representation

- The ω^a and h fit in a left $SU(2)$ doublet.
- The Higgs always appears in the combination $h + v$.
- Typical situation when h is a fundamental field.
- Based in a **cutoff Λ expansion**: $\mathcal{O}(d)/\Lambda^{d-4}$, d and operator of dimension $d = 4, 6, 8, \ldots$.
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