Anomalous coupling studies

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Background anomalous contributions: general

- Conventional EFT signal: anomalous terms from signal process.
- Non-zero EFT coefficients also affect background processes.
- Some new analyses are implementing EFT effect on background into the limit-setting procedure, e.g. ssWW analysis.
- Issue mentioned at the previous meeting: significant backgrounds are estimated from data, therefore anomalous contributions can be included to the estimation.

Background anomalous contributions: $Z(\nu\bar{\nu})\gamma$ analysis

- Our case ($Z(\nu\bar{\nu})\gamma$ inclusive): $W(\ell\nu)\gamma$ is also affected by the EFT nTGC operators.

Operator	ZZZ, $ZZ\gamma$, $Z\gamma\gamma$	$\gamma\gamma\gamma$	WWZ	$WW\gamma$
$\mathcal{O}_{G\pm}$	○	○	○	○
$\mathcal{O}_{\tilde{B}W}$	○		○	○
$\mathcal{O}_{BW}$	○		○	○
$\mathcal{O}_{WW}$	○		○	
$\mathcal{O}_{BB}$	○			

- Only three operators have significant effect on $W(\ell\nu)\gamma$ production.

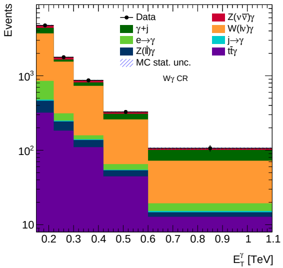
Coefficient	ATGC from $Z(\nu\bar{\nu})\gamma$	ATGC from $Z(\nu\bar{\nu})\gamma + W(\ell\nu)\gamma$	Improvement
$C_{\tilde{B}W}/\Lambda^4$	[-0.35; 0.34]	[-0.33; 0.32]	6.4%
C_{BW}/Λ^4	[-0.63; 0.63]	[-0.60; 0.60]	5.1%
C_{G+}/Λ^4	$[-6.5; 4.7] \cdot 10^{-3}$	$[-6.1; 4.5] \cdot 10^{-3}$	4.9%

- $W(\ell\nu)\gamma$ production signal strength $\mu_{W\gamma}$ is estimated from the fit in the control region.

Background anomalous contributions: investigation

- Fit in the $W\gamma$ CR was made on Asimov data (simplified stat. model).

1. Asimov data without EFT.



Result: $\mu_{W\gamma} = 1.00^{+0.02}_{-0.02}$.

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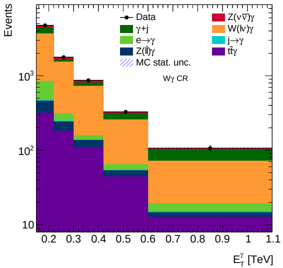
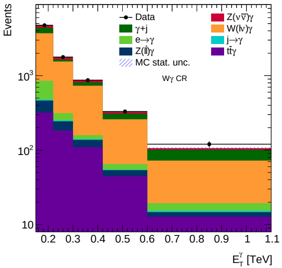


Result: $\mu_{W\gamma} = 1.00^{+0.02}_{-0.02}$.

2. Asimov data with $C_{BW}/\Lambda^4 = 0.63$ TeV^{-4}.



Result: $\mu_{W\gamma} = 1.01^{+0.02}_{-0.02}$.

Background anomalous contributions: investigation

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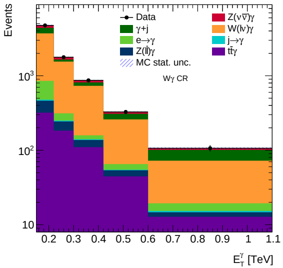
1. Asimov data without EFT.



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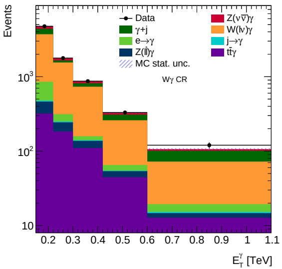
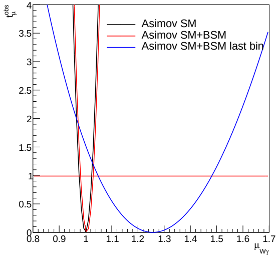


Result: $\mu_{W\gamma} = 1.01^{+0.02}_{-0.02}$.

3. Fit of the case 2, but only in the last bin (enhancing EFT contributions).
Result: $\mu_{W\gamma} = 1.26^{+0.22}_{-0.21}$.



Background anomalous contributions: results

- Fit in the CR measures parameter $\mu_{W\gamma}$, which changes the yields flat.
- The largest contribution to the fit in the CR comes from the first bin, enriched by the SM events.
- The largest contribution to the EFT fit comes from the last bin, enriched by the BSM events. This fit measures EFT coefficients, which significantly changes the shape of the distribution.
- Is the problem avoided in this case?

Reinterpretation of the limits

• The most general way to translate EFT coefficients into the parameters of new physics models is to match model-independent and model-dependent effective Lagrangians.

• Model-independent Lagrangian can be constructed using EFT:

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}^{(5)} + \mathcal{L}^{(6)} + \mathcal{L}^{(7)} + \mathcal{L}^{(8)} + \ldots, \quad \mathcal{L}^{(d)} = \sum_i \frac{C_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}.$$

• Operators are constructed from the SM fields, so they represent loop contributions from new heavy particles at currently accessible energies. Example: $\mathcal{O}_{\mathrm{T8}} = B_{\mu\nu} B^{\mu\nu} B_{\alpha\beta} B^{\alpha\beta}$.

• Computations of the effective model-dependent Lagrangian is a more complicated issue. Tool of the effective action in the quantum field theory can help with this.

Effective model-dependent action: QED example

$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{\psi}(i\not{D} - m)\psi$ — full Lagrangian of QED.

Let's assume that we work at energies much smaller than the fermion mass, so we can integrate the fermion field out. Generating functional:

$$Z(J^\mu, \eta, \bar{\eta}) = \int DA^\mu D\psi D\bar{\psi} e^{iS} = \int DA^\mu D\psi D\bar{\psi} \exp i \int d^4x(\mathcal{L} + \bar{\eta}\psi + \bar{\psi}\eta + J^\mu A_\mu).$$

It depends on the so-called "field sources". Fermionic sources are zero due to the low energies:

$$Z(J^\mu, 0, 0) = \int DA^\mu D\psi D\bar{\psi} \exp i \int d^4x(\mathcal{L}_{\text{eff}} + J^\mu A_\mu).$$

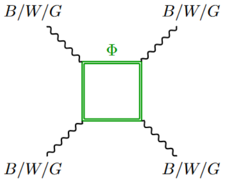
$\mathcal{L}_{\text{eff}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - i\text{Tr} \log(i\not{D} - m)$ — effective QED Lagrangian.

The simplest way to understand the second term:

$\text{Tr} \log(i\not{D} - m) = \sum_{n=1}^{\infty} \frac{e^n}{n} \text{Tr} \left(\frac{1}{i\not{\partial} - m} \not{A} \right)^n$ — expansion at low energies, representing multiphoton interactions.

Matching the Lagrangians

Consider 4-photon interactions.



1. EFT: $\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + C_1(F_{\mu\nu}F^{\mu\nu})^2 + C_2(\tilde{F}_{\mu\nu}F^{\mu\nu})^2$ — two operators with Wilson coefficients C_1 and C_2.

2. Effective QED action: $\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \dfrac{\alpha^2}{90m^4}(F_{\mu\nu}F^{\mu\nu})^2 + \dfrac{7\alpha^2}{360m^4}(\tilde{F}_{\mu\nu}F^{\mu\nu})^2$.

3. Matching:

$$C_1 = \frac{\alpha^2}{90m^4},\ C_2 = \frac{7\alpha^2}{360m^4}.$$

Reinterpretation of the aQGC Wilson coefficients

- Model: minimal SM extension — SM plus one heavy field.
- Matching of EFT and effective model-dependent Lagrangian is given in the table (paper).

	scalar	fermion	vector
$c_1^{B^4}$	$\frac{7}{32}g_1^4Q^4$	$\frac{1}{2}g_1^4Q^4$	$\frac{261}{32}g_1^4Q^4$
$c_2^{B^4}$	$\frac{1}{32}g_1^4Q^4$	$\frac{7}{8}g_1^4Q^4$	$\frac{243}{32}g_1^4Q^4$
$c_1^{W^4}$	$g_2^4\left[\frac{7}{32}\Lambda(\mathbf{R}_2)+\frac{1}{48}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{1}{2}\Lambda(\mathbf{R}_2)+\frac{1}{48}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{261}{32}\Lambda(\mathbf{R}_2)-\frac{3}{16}I_2(\mathbf{R}_2)\right]$
$c_2^{W^4}$	$g_2^4\left[\frac{1}{32}\Lambda(\mathbf{R}_2)+\frac{1}{336}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{7}{8}\Lambda(\mathbf{R}_2)+\frac{19}{336}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{243}{32}\Lambda(\mathbf{R}_2)-\frac{27}{112}I_2(\mathbf{R}_2)\right]$
$c_3^{W^4}$	$g_2^4\left[\frac{7}{16}\Lambda(\mathbf{R}_2)-\frac{1}{48}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\Lambda(\mathbf{R}_2)-\frac{1}{48}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{261}{16}\Lambda(\mathbf{R}_2)+\frac{3}{16}I_2(\mathbf{R}_2)\right]$
$c_4^{W^4}$	$g_2^4\left[\frac{1}{16}\Lambda(\mathbf{R}_2)-\frac{1}{336}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{7}{4}\Lambda(\mathbf{R}_2)-\frac{19}{336}I_2(\mathbf{R}_2)\right]$	$g_2^4\left[\frac{243}{16}\Lambda(\mathbf{R}_2)+\frac{27}{112}I_2(\mathbf{R}_2)\right]$
$c_1^{G^4}$	$g_3^4\left[\frac{7}{32}\Lambda(\mathbf{R}_3)+\frac{1}{96}I_2(\mathbf{R}_3)\right]$	$g_3^4\left[\frac{1}{2}\Lambda(\mathbf{R}_3)+\frac{1}{96}I_2(\mathbf{R}_3)\right]$	$g_3^4\left[\frac{261}{32}\Lambda(\mathbf{R}_3)-\frac{3}{32}I_2(\mathbf{R}_3)\right]$
$c_2^{G^4}$	$g_3^4\left[\frac{1}{32}\Lambda(\mathbf{R}_3)+\frac{1}{672}I_2(\mathbf{R}_3)\right]$	$g_3^4\left[\frac{7}{8}\Lambda(\mathbf{R}_3)+\frac{19}{672}I_2(\mathbf{R}_3)\right]$	$g_3^4\left[\frac{243}{32}\Lambda(\mathbf{R}_3)-\frac{27}{224}I_2(\mathbf{R}_3)\right]$
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$c_5^{G^4}$	$\frac{1}{32}g_3^4I_2(\mathbf{R}_3)$	$\frac{1}{32}g_3^4I_2(\mathbf{R}_3)$	$-\frac{9}{32}g_3^4I_2(\mathbf{R}_3)$
$c_6^{G^4}$	$\frac{1}{224}g_3^4I_2(\mathbf{R}_3)$	$\frac{19}{224}g_3^4I_2(\mathbf{R}_3)$	$-\frac{81}{224}g_3^4I_2(\mathbf{R}_3)$
$c_1^{B^2W^2}$	$\frac{7}{16}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$\frac{261}{16}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$
$c_2^{B^2W^2}$	$\frac{1}{16}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$\frac{7}{4}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$\frac{243}{16}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$
$c_3^{B^2W^2}$	$\frac{7}{8}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$2g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$\frac{261}{8}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$
$c_4^{B^2W^2}$	$\frac{1}{8}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$\frac{7}{2}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$	$\frac{243}{8}g_1^2g_2^2Q^2I_2(\mathbf{R}_2)$
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Example: reinterpretation of the limit $|f_{T8}/\Lambda^4| < 0.06$ TeV^{-4}.

Scalar: $M > 0.3|Q|$ TeV
Fermion: $M > 0.37|Q|$ TeV
Vector: $M > 0.74|Q|$ TeV

Restrictions and problems

- We have unitarized and non-unitarized limits. Which ones should be used? Unitarized limits are necessarily accompanied by the clipping energy. Therefore, clipping energy also should be reinterpreted!

- This matching works only for models with one new particle, or with several particles, **each not interacting with others**. If we have complicated model like MSSM, where new particles interact with the SM particles as well as with other MSSM particles, the matching will be another.

- New particle should be able to make significant contribution to the experimental signature only in the loop!

- Theorists work on this topic hardly, new matchings come and should be studied.