Projected Sensitivities on Triple Gauge Couplings at the FCC-μp

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Outline

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- $\mu^-\gamma \rightarrow \mu^-\gamma Z \rightarrow \mu^-\gamma\nu_l\bar{\nu}_l$ process at FCC-μp Collider
- A Cut-based Analysis
- Sensitivities on aNTGC
- Conclusions
- References

Theoretical Background

- Non-Abelian structure of Standard Model $\Rightarrow$ couplings between gauge bosons.
- Triple couplings
  $\Rightarrow \gamma WW$, ZWW in EW
  $\Rightarrow$ ZZZ, ZZγ Z$\gamma\gamma$ don't exist at the tree level (No Dim-6 but Dim-8)
- Standard Model - Nothing to expect
- New physics parametrized with effective Lagrangian.
  ☐ enhancing existing couplings
  ☐ introduce non-SM couplings

Theoretical Background

Main goals

- test the non-Abelian structure of the Standard Model.
- exploring new physics beyond the Standard Model.

EFT approach

- adding high-dimensional operators that are invariant under $SU(2)_L \times U(1)_Y$ to the SM Lagrangian.

Theoretical Background

$$\mathcal{L}^{\mathrm{NTGC}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^4}(\mathcal{O}_i + \mathcal{O}_i^\dagger)$$

$$\mathcal{O}_{\widetilde{B}W} = iH^\dagger \widetilde{B}_{\sigma\rho} W^{\sigma\nu}\{D_\nu, D^\rho\}H,$$

$$\mathcal{O}_{BW} = iH^\dagger B_{\sigma\rho} W^{\sigma\nu}\{D_\nu, D^\rho\}H,$$

$$\mathcal{O}_{WW} = iH^\dagger W_{\sigma\rho} W^{\sigma\nu}\{D_\nu, D^\rho\}H,$$

$$\mathcal{O}_{BB} = iH^\dagger B_{\sigma\rho} B^{\sigma\nu}\{D_\nu, D^\rho\}H$$

Theoretical Background

where,

$$B_{\sigma\rho} = \left(\partial_\sigma B_\rho - \partial_\rho B_\sigma\right),$$

$$W_{\sigma\rho} = \sigma^i \left(\partial_\sigma W^i_\rho - \partial_\rho W^i_\sigma + g\epsilon_{ijk} W^j_\sigma W^k_\rho\right),$$

$$D_\mu \equiv \partial_\mu - i\frac{g'}{2} B_\mu Y - i g_W W^i_\mu \sigma^i .$$

Photon Spectrum

$$f_{\gamma(x)} = \frac{\alpha}{\pi E_p}\{[1-x][\varphi(\frac{Q^2_{max}}{Q^2_0}) - \varphi(\frac{Q^2_{min}}{Q^2_0})],$$

where the function φ is given as:

$$\varphi(\theta) = (1+ky)\left[-ln(1+\frac{1}{\theta}) + \sum_{s=1}^{3}\frac{1}{s(1+\theta)^s}\right] + \frac{y(1-l)}{4\theta(1+\theta)^3} + m(1+\frac{y}{4})\left[ln\left(\frac{1-l+\theta}{1+\theta}\right) + \sum_{s=1}^{3}\frac{l^s}{s(1+\theta)^s}\right].$$

Photon Spectrum

$$y = \frac{x^2}{(1-x)},$$

$$k = \frac{1+\mu_p^2}{4} + \frac{4m_p^2}{Q_0^2} \approx 7.16,$$

$$l = 1 - \frac{4m_p^2}{Q_0^2} \approx -3.96,$$

Photon Spectrum

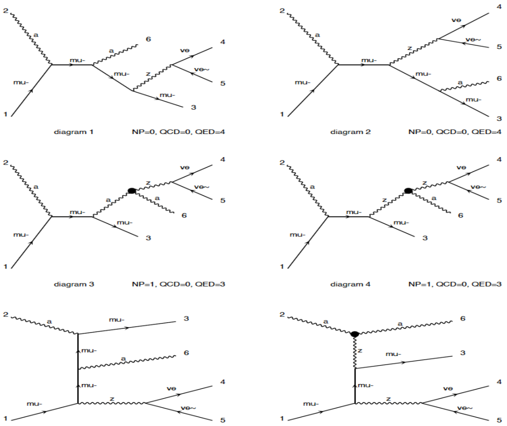
$$m = \frac{\mu_p^2 - 1}{b^4} \approx 0.028.$$

$$\sigma = \int f_\gamma(x) d\hat{\sigma} dE_1.$$

$$\sigma_{Tot} = \sigma_{SM}(\sqrt{s}) + \sigma_{(INT)} + \sigma_{(NP)}$$

$\mu^- \gamma \rightarrow \mu^- \gamma Z \rightarrow \mu^- \gamma \nu_l \bar{\nu}_l$ process at FCC-μp Collider ($\sqrt{s} = 24.5$ TeV)

Feynman Diagrams



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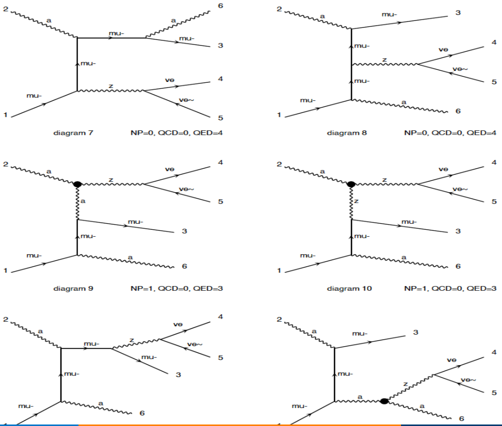

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Feynman Diagrams

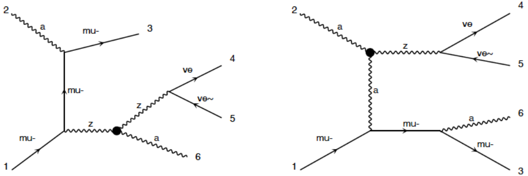
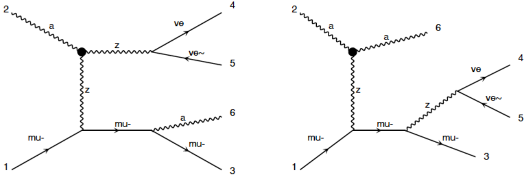


diagram 13 NP=1, QCD=0, QED=3

diagram 14 NP=1, QCD=0, QED=3



Object-I

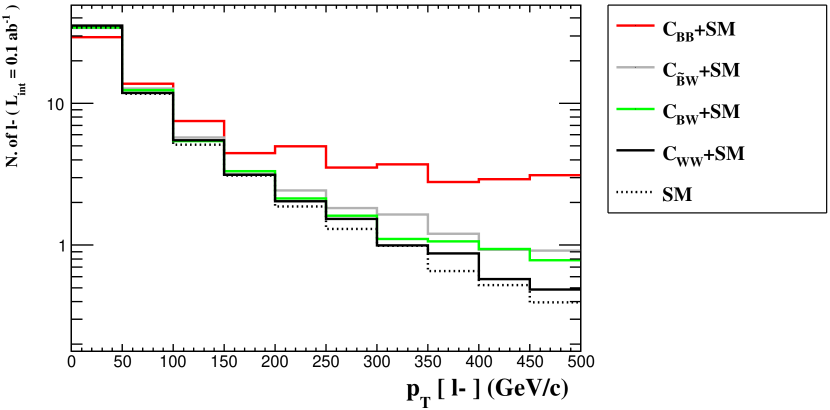


Figure: The number of expected events as a function of $p_T^{l^-}$.

Object-II

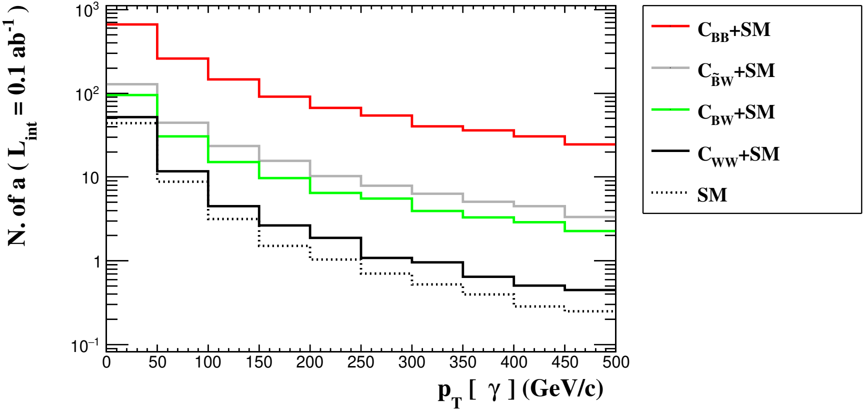


Figure: The number of expected events as a function of p_T^γ.

A Cut-based Analysis

Object-III

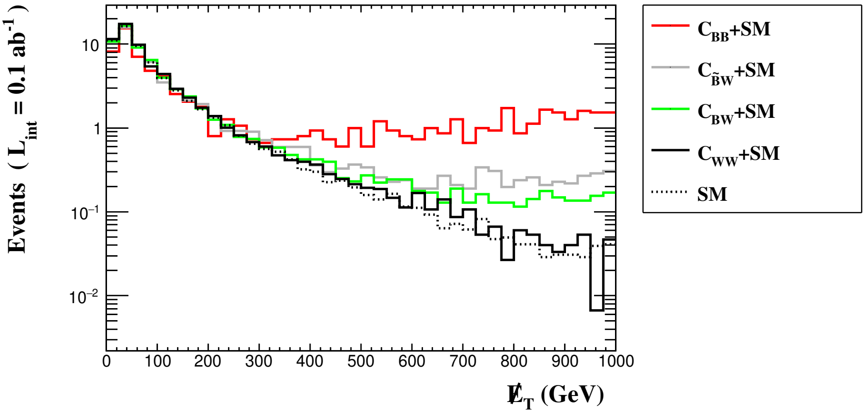


Figure: The number of expected events as a function of missing energy transverse $\not{E}_T$.

A Cut-based Analysis

Table: Particle-level selections cuts for the signals at the Muon Collider.

Kinematic cuts	C_{BB}/Λ^4, C_{BW}/Λ^4, $C_{\widetilde{B}W}/\Lambda^4$, C_{WW}/Λ^4
Cut-I	$p_T^{\mu} > 70$ GeV
Cut-II	$p_T^{\gamma} > 100$ GeV
Cut-III	$\not{E}_T > 350$

Table: Number of events for $\mu^- \gamma \to \mu^- \gamma Z \to \mu^- \gamma \nu_l \bar{\nu}_l$ and SM background after cuts.

Kinematic cuts	C_{BB}/Λ^4	$C_{\widetilde{B}W}/\Lambda^4$	C_{BW}/Λ^4	C_{WW}/Λ^4	SM
Cut-0	1718	298	203	79	61
Cut-I	1681	257	163	38	21
Cut-II	795	122	74	14	6
Cut-III	790	117	69	9	1

Sensitivities on aNTGC

$$\chi^2 = \left(\frac{\sigma_{SM} - \sigma_{Tot}}{\sigma_{SM}\sqrt{(\delta_{st})^2 + (\delta_{sys})^2}} \right)^2$$

$$\delta_{st} = \frac{1}{\sqrt{N_{SM}}}$$

$$N_{SM} = \mathcal{L}_{\text{int}} \times \sigma_{SM}$$

- Sensitivities are obtained at the 95% C.L.

Sensitivities on aNTGC

Couplings	0%	5%	10%
$\mathcal{L} = 5$ ab^{-1}			
C_{BB}/Λ^4	$[-0.019; 0.023]$	$[-0.020; 0.024]$	$[-0.022; 0.026]$
C_{BW}/Λ^4	$[-0.066; 0.078]$	$[-0.069; 0.081]$	$[-0.077; 0.089]$
$C_{\widetilde{B}W}/\Lambda^4$	$[-0.058; 0.053]$	$[-0.060; 0.056]$	$[-0.066; 0.062]$
C_{WW}/Λ^4	$[-0.18; 0.20]$	$[-0.18; 0.21]$	$[-0.20; 0.23]$

Sensitivities on aNTGC

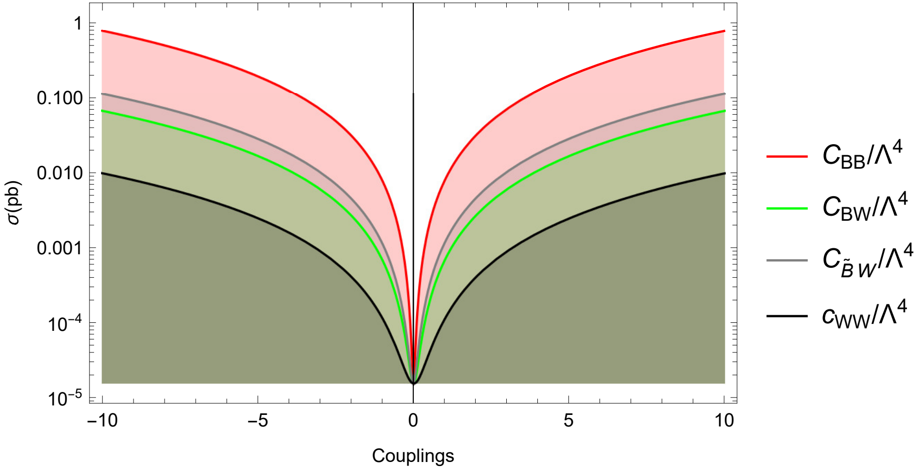


Figure: Cross-section for the process $\mu^-\gamma \to \mu^-\gamma Z \to \mu^-\gamma\nu_l\bar{\nu}_l$ in terms of the anomalous C_{BB}/Λ^4, C_{BW}/Λ^4, $C_{\widetilde{B}W}/\Lambda^4$, C_{WW}/Λ^4 couplings

Sensitivities on aNTGC

Experimental Results on aNTGC

$$-1.1\,\mathrm{TeV}^{-4} < \frac{C_{\widetilde{B}W}}{\Lambda^4} < 1.1\,\mathrm{TeV}^{-4},$$

$$-2.3\,\mathrm{TeV}^{-4} < \frac{C_{WW}}{\Lambda^4} < 2.3\,\mathrm{TeV}^{-4},$$

$$-0.65\,\mathrm{TeV}^{-4} < \frac{C_{BW}}{\Lambda^4} < 0.64\,\mathrm{TeV}^{-4},$$

$$-0.24\,\mathrm{TeV}^{-4} < \frac{C_{BB}}{\Lambda^4} < 0.24\,\mathrm{TeV}^{-4}.$$

Sensitivities on aNTGC

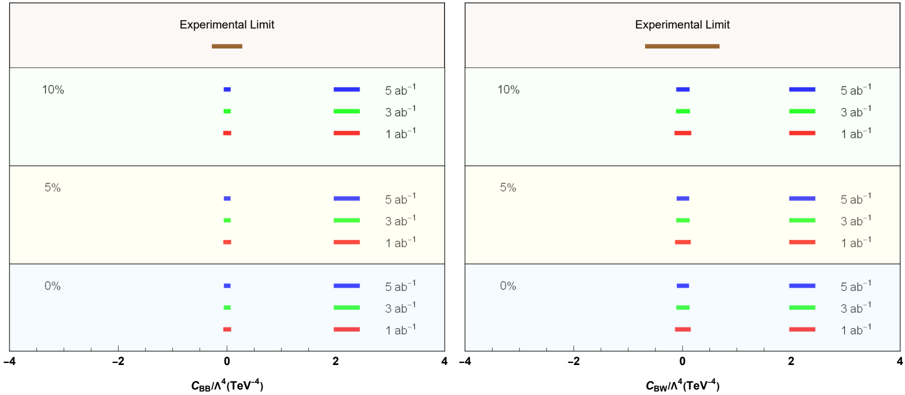


Figure: Comparison of the current experimental limits and projected sensitivity on the anomalous C_{BB}/Λ^4 and C_{BW}/Λ^4.

Sensitivities on aNTGC

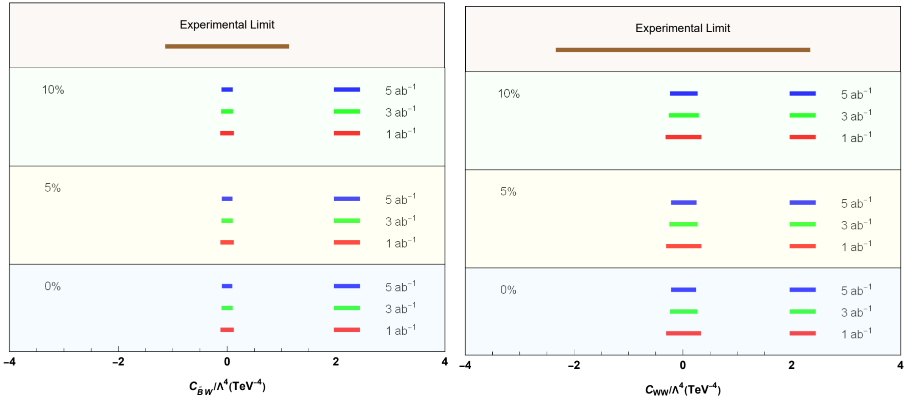


Figure: Comparison of the current experimental limits and projected sensitivity on the anomalous $C_{\widetilde{B}W}/\Lambda^4$ and C_{WW}/Λ^4.

Conclusions

- A study for the sensitivity on dim-8 aNTGC in a model independent way via the process $\mu^- \gamma \to \mu^- \gamma Z \to \mu^- \gamma \nu_l \bar{\nu}_l$ at FCC-μp collider has been performed.
- Effective Field Theory(EFT) approach are used to parametrize the new physics effects with high dimensional operator.
- A cut-based method has been applied during the analysis.
- Sensitivities are composed under various systematic uncertainties.
- Obtained results are improved the latest experimental limits by a factor of 8 to 20 times.

References

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