# BSM CONTRIBUTIONS TO THE $Z\gamma\gamma$ AND $ZZ\gamma$ SELF COUPLINGS AT HIGH ENERGIES

N L Belyaev, A H Kamaletdinov and E Y Soldatov
NRNU MEPhI
Kamaletdinov.A.H@yandex.ru

## Introduction

The CP conserving $Z\gamma\gamma$ and $ZZ\gamma$ couplings in the SM and MSSM models at loop level were investigated. For the both models the coupling parameters $h_3^Z$, $h_3^\gamma$, $f_5^\gamma$ were estimated for the energy ranges, accessible at the LHC. Extension of the considered energy range up to 14 TeV leads to a possibility to constrain theories using experimental limits on anomalous couplings from the LHC experiments. It was found that in order to constrain the MSSM model parameters, a measurement accuracy of the order $10^{-7}$ is required.

## Loop contribution of the $Z\gamma\gamma$ and $ZZ\gamma$ couplings

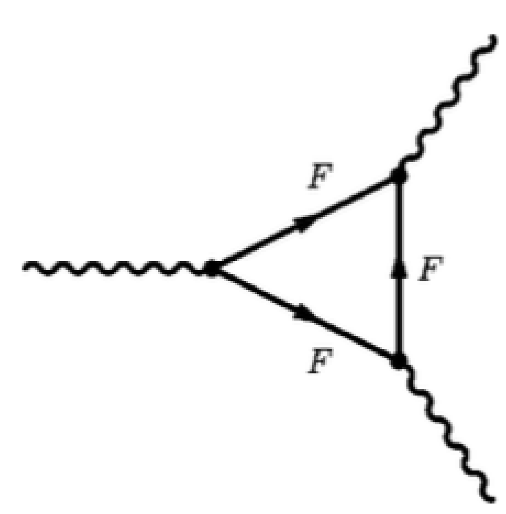
We investigate the $h_3^\gamma, h_3^Z, f_5^\gamma$ couplings in the $\gamma \to Z\gamma$, $Z \to Z\gamma$ and $\gamma \to ZZ$ decays, respectively up to 14 TeV for SM and MSSM models because they can make a significant contribution to the decay width in order to be noticeable in the experiment.

The corresponding decay amplitudes can be written as follows [3]:

$$\Gamma^{\alpha\beta\mu}_{Z\gamma V} = \frac{i(s-m_V^2)}{m_Z^2}\Big(h_1^V(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + \frac{h_2^V}{m_Z^2}P^\alpha((Pq_2)g^{\mu\beta} - q_2^\mu P^\beta) - $$
$$ - h_3^V \epsilon^{\mu\alpha\beta\rho} q_{2\rho} - \frac{h_4^V}{m_Z^2} P^\alpha \epsilon^{\mu\beta\rho\sigma} P_\rho q_{2\sigma}\Big)$$
$$\Gamma^{\alpha\beta\mu}_{ZZV} = \frac{i(s-m_V^2)}{m_Z^2}\Big(f_4^V(P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}) - f_5^V \epsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho\Big)$$

The results obtained in the work [3] were extended and the possibility to constrain the MSSM parameters by using observational data, obtained at the LHC experiments, was investigated [1,2]. The effective couplings $h_3^V, h_3^Z, f_5^V$ here defined as the coefficients of the terms $\epsilon^{\mu\alpha\beta\rho}q_{2\rho}$ and $\epsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho$, respectively.

$$h_3^\gamma(j) = -N_f \frac{e^2 Q_j^2 g_{aj}}{2\pi^2 \sin\Theta_w \cos\Theta_w} I_3^\gamma$$
$$h_3^Z(j) = -N_f \frac{e^2 Q_j^2 g_{vj} g_{aj}}{4\pi^2 \sin^2\Theta_w \cos^2\Theta_w} I_3^Z$$
$$f_5^\gamma(j) = N_f \frac{e^2 Q_j^2 g_{vj} g_{aj}}{4\pi^2 \sin^2\Theta_w \cos^2\Theta_w} I_5^\gamma$$




where the expressions for $I_3^\gamma$, $I_3^Z$, $I_5^\gamma$ can be taken from [3].

## Methodology

The allowed values of the effective couplings $h_3^\gamma, h_3^Z, f_5^\gamma$, extracted from the experiments, lie in the intervals, that shown in table 3.

**Table 1:** Experimental constrains on the effective couplings $h_3^\gamma$, $h_3^Z$ and $f_5^\gamma$.

| $\sqrt{s}$, TeV | $h_3^\gamma$ | $h_3^Z$ | $f_5^\gamma$ |
|---|---|---|---|
| 7 | $[-2.9 \div 2.9]\cdot 10^{-3}$ | $[-2.7 \div 2.7]\cdot 10^{-3}$ | $[-1.6 \div 1.5]\cdot 10^{-2}$ |
| 8 | $[-9.5 \div 9.9]\cdot 10^{-4}$ | $[-7.8 \div 8.6]\cdot 10^{-4}$ | $[-3.8 \div 3.8]\cdot 10^{-3}$ |
| 13 | $[-3.7 \div 3.7]\cdot 10^{-4}$ | $[-3.2 \div 3.3]\cdot 10^{-4}$ | $[-6.8 \div 7.5]\cdot 10^{-4}$ |

In order to calculate the loop amplitudes of the $\gamma \to Z\gamma$, $Z \to Z\gamma$ and $\gamma \to ZZ$ processes, the following Lagrangian was used:

$$L = -eQ_j A^\mu \overline{f}_j \gamma_\mu f_j - \frac{e}{2c_w s_w} Z^\mu \overline{f}_j(\gamma_\mu g_{vj} - \gamma_\mu\gamma_5 g_{aj}) f_j -$$
$$ - \frac{e}{2c_w s_w} Z^\mu \overline{f}_1(\gamma_\mu g_{v12} - \gamma_\mu\gamma_5 g_{a12}) f_2$$

The effective couplings $h_3^V, h_3^Z, f_5^V$ were calculated as the coefficients of the terms $\epsilon^{\mu\alpha\beta\rho}q_{2\rho}$ and $\epsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho$, respectively. In this context, the parameter $\Lambda$ is a free parameter of the MSSM model and the masses of Chargino can be expressed as follows [4]:

$$M^2_{\chi 1,2} = \frac{1}{2}\Big(\Lambda^2 + \mu^2 + 2m_W^2 \mp \sqrt{(\Lambda^2 + \mu^2 + 2m_W^2)^2 - 4(\Lambda\mu - m_W^2 \sin(2\beta))^2}\Big)$$

The variation of $M_{\chi 1}$ and $M_{\chi 2}$ affects the Charginos' contribution to the $h_3^\gamma$, $h_3^Z$ and $f_5^\gamma$ couplings. The goal is to study the possibility to constrain the characteristic energy scale parameter $\Lambda$ from the experimental limits on the couplings.

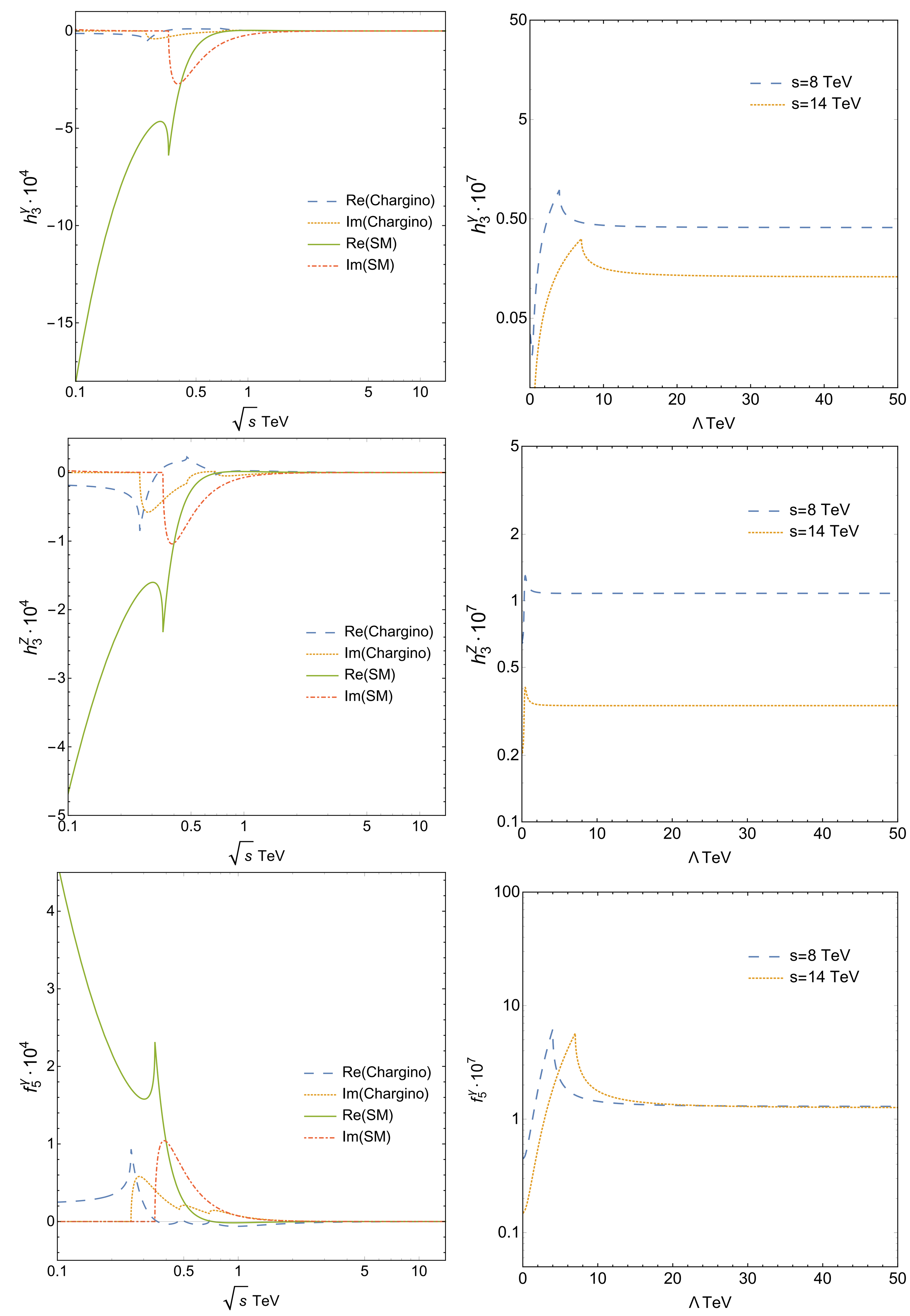



**Figure 1:** The SM and MSSM contributions to the $h_3^\gamma$, $h_3^Z$ and $f_5^\gamma$ couplings as functions of $\sqrt{s}$ (left) and $\Lambda$ (right).

| $\sqrt{s}$, TeV | $h_3^\gamma \cdot 10^7$ | $h_3^Z \cdot 10^7$ | $f_5^\gamma \cdot 10^7$ |
|---|---|---|---|
| 7 (SM) | 6.55 | 2.34 | 2.4 |
| 7 (MSSM) | 0.12 | 2.97 | 1.5 |

| $\sqrt{s}$, TeV | $h_3^\gamma \cdot 10^7$ | $h_3^Z \cdot 10^8$ | $f_5^\gamma \cdot 10^8$ |
|---|---|---|---|
| 13 (SM) | 2.12 | 7.58 | 7.58 |
| 13 (MSSM) | 0.13 | 2.62 | 1.69 |

## Conclusion / Discussion

The results and predictions obtained during this study are directly applicable to the search for anomalous couplings, which are being carried out by LHC experiments right now.

In case of SM and MSSM, the expected values of the coupling parameters $h_3^\gamma, h_3^Z$ and $f_5^\gamma$ are of the order of $10^{-7}$ and they will be likely accessible on the HL-LHC. Thus the suggested approach demonstrates great potential and can be used to constrains other BSM theories.

## References

[1] ATLAS Collaboration. Measurement of the $Z\gamma \to \nu\overline{\nu}\gamma$ production cross section in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector and limits on anomalous triple gauge-boson couplings. *JHEP*, 12:010, 2018.

[2] CMS Collaboration. Measurements of pp $\to$ ZZ production cross sections and constraints on anomalous triple gauge couplings at $\sqrt{s} = 13$ TeV, arXiv:2009.01186. *Subm to EPJC*, 2020.

[3] G. Gounaris, J. Layssac, and F. Renard. New and standard physics contributions to anomalous Z and gamma selfcouplings. *Phys. Rev. D*, 62:073013, 2000.

[4] H. E. Haber and G. L. Kane. The Search for Supersymmetry: Probing Physics Beyond the Standard Model. *Phys. Rept.*, 117:75–263, 1985.