PROCEEDINGS OF SCIENCE

# Resummation effects in HECO pair production at the LHC: UFO implementation

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Several theories that lie beyond the Standard Model include the existence of High Electric Charge Objects (HECOs). Due to the large coupling, the perturbation theory breaks down. Nevertheless, one can resum the QED corrections at a UV fixed point for high electric charge and mass values. In this study, a HECO is assumed to be a spin-½ Dirac fermion which couples to photons and $Z^0$ bosons. At colliders, HECOs can be pair-produced via Drell–Yan and Photon-Fusion processes. The Universal FeynRules Output (UFO) implementation — including resummation effects — was performed for both production mechanisms, thus being available for Monte Carlo generators such as MadGraph5. The UFO models were successfully validated by comparing cross-section values obtained by analytical calculations through Wolfram Mathematica and those computed by MadGraph5. In this work, we perform a Dyson–Schwinger resummation scheme, which makes the computation of the pertinent HECO-production cross sections reliable, thus allowing us to extract improved mass bounds for such objects from ATLAS and MoEDAL searches.

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## 1. Introduction

Various theoretical particle physics models of new physics predict sectors with High Electric Charge Objects (HECOs), examples of which are Q-balls [1, 2], aggregates of ud-quarks [3], strange-quark matter [4], as well as black-hole remnants in models with extra spacetime dimensions [5, 6]. Such object are actively sought by ATLAS [7] and MoEDAL [8, 9] collaborations at the Large Hadron Collider (LHC) with good prospects for the future [10]. These searches have been performed at tree-level so far, but due to the large coupling $g = ne$ the perturbation theory breaks down and resummation is needed. In this study, we assume HECO to be a spin-½ Dirac fermion and $n \geq 11$. By employing specific Dyson–Schwinger (DS) techniques, as detailed in [11] and previously applied to the magnetic monopoles case [12], we derived an effective Lagrangian which describes the dynamics of HECOs through appropriately dressed Drell—Yan (DY) and photon-fusion (PF) processes [13, 14].

## 2. Feynman rules

Being $\Lambda$ the ultraviolet (UV) cutoff that plays the role of the energy scale at which new physics appears, the interaction of HECO with photon only is described by the following Feynamn rules:

- *Running mass:* $\mathcal{M}(\Lambda) = \Lambda \exp\left(-\frac{2\pi}{\alpha^\star}(Z^\star - 1)\right)$,
- *HECO propagator:* $G^{\text{eff}} = i\frac{\not{p}+\mathcal{M}(\Lambda)}{p^2-\mathcal{M}(\Lambda)^2}$ ,
- *$\gamma$ propagator:* $\Delta^{\text{eff}}_{\mu\nu} = \frac{-i}{q^2}\left(\eta_{\mu\nu} + \frac{\omega^\star}{1+\omega^\star}\frac{q_\mu q_\nu}{q^2}\right)$,
- *Photon–HECO vertex:* $\Gamma^{\text{eff}}_\mu = g\,Z^\star \gamma_\mu$,

where $\hat{\alpha}^\star$ represents the rescaled electric coupling, defined as $\hat{\alpha}^\star = \frac{g^2/4\pi}{1+\hat{\omega}^\star}$, $Z^\star$ denotes the wave-function renormalisation and $\omega^\star = \frac{4}{3}\left(1 - \frac{1}{Z^\star}\right)$. By following the same procedure applied to the photon, we can introduce the additional interaction with the $Z^0$ boson by replacing:

- $g^2 \longrightarrow \hat{g}^2 \equiv g^2 + 3g'^2/4$ , where $g'$ is the $Z^0$–HECO coupling,
- $\hat{Z}^\star = \frac{2}{9}(3+\eta)\left(1 + \sqrt{1 - \frac{9\eta}{(3+\eta)^2}}\right)$ with $\eta \equiv g^2/\hat{g}^2 < 1$,
- $\hat{\omega}^\star = \frac{4}{3}\eta\left(1 - \frac{1}{\hat{Z}^\star}\right)$ .

## 3. Universal Feynrules Output models

The implementation of resummation effects for Universal Feynrules Output (UFO) [15] models was conducted to simulate the production mechanisms of DY and PF involving spin-½ HECOs at the LHC. Two UFO models — suitable for Monte Carlo event generators such as MadGraph5 [16] — were developed for both $\gamma$-only and $\gamma/Z^0$ exchanges. The former considers the sole contribution from $\gamma$ exchange, in order to simulate DY and PF processes. The latter includes the additional exchange of the $Z^0$ boson in DY production. One incorporates resummation effects into these models by using the above-mentioned Feynman rules, ensuring reliable predictions for the cross-section related to the production mechanisms.



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New parameters, namely the charge multiplicity $n$ and the cutoff energy scale $\Lambda$, are introduced into the UFO models, supplementing the standard ones like the centre-of-mass energy or Parton Distribution Functions (PDFs). These additional parameters directly influence the HECO mass, consequently affecting the cross-section values. The UFO models were effectively validated by comparing cross-section values obtained through analytical calculations using Wolfram Mathematica — specifically the FeynCalc package [17] — with those computed through MadGraph5.

## 4. Impact on the cross section and the mass limits

The results show a significant impact of the resummation on the production cross sections. The calculations are performed considering $pp$ collisions at $\sqrt{s} = 13$ TeV. For the DY process, the `NNPDF23` [18] PDF is utilised, while for the PF process, the `LUXqed17` [19] PDF is employed. Figure 1 illustrates the effect of resummation on cross-section values as a function of the HECO mass. Upon examining the values before and after incorporating resummation effects, an enhancement in the cross-sections becomes apparent. It is observed that the production becomes larger with resummation by a factor of $\sim 2.1$ and $\sim 4.75$ for DY and PF, respectively. The cross-section values associated with the PF process surpass those of the DY process at the LHC energies. This distinction in behavior stems from the cross-section dependence, which scales proportionally to $n^2$ for DY and $n^4$ for PF.

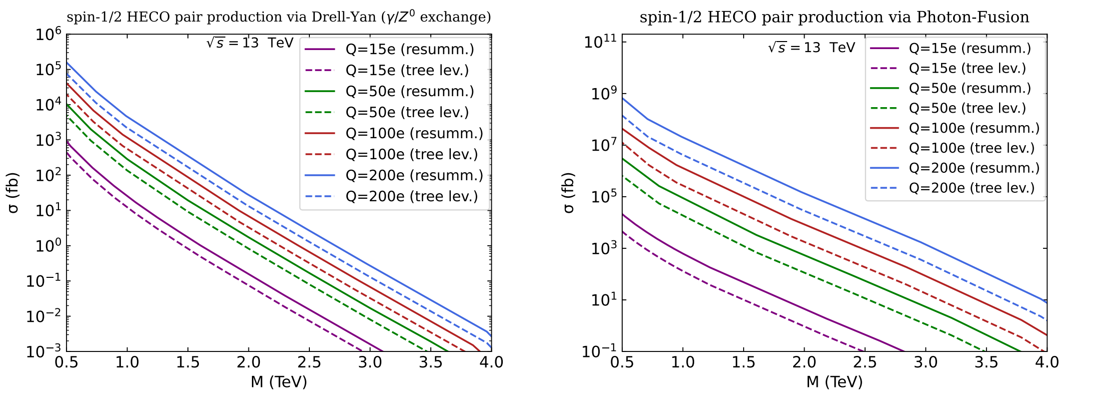


**Figure 1:** Comparison of cross sections obtained before (dashed-line) and after (solid line) resummation as a function of the HECO mass $M$ for electric charges $Q = 15e$, $50e$, $100e$ and $200e$, demonstrating the significant effect of the resummation by increasing the corresponding values.

In Figure 2, the left column illustrates the cross-section values for DY processes, while the right column depicts those for PF processes, each plotted against HECO mass $M$ and $n$ parameters.

The study extends to the re-interpretation of experimental data from ATLAS [20, 21] and MoEDAL [22, 23] collaborations. The implementation of DS resummation techniques leads to more stringent mass limits for spin-½ HECOs compared to limits derived from tree-level calculations. In [11] the 95% CL experimental mass limits for various spin-½ HECOs based on DS resummation are provided, showing consistently more stringent constraints. The increase in the mass limits covers a broad spectrum of values, reaching up to 30%.

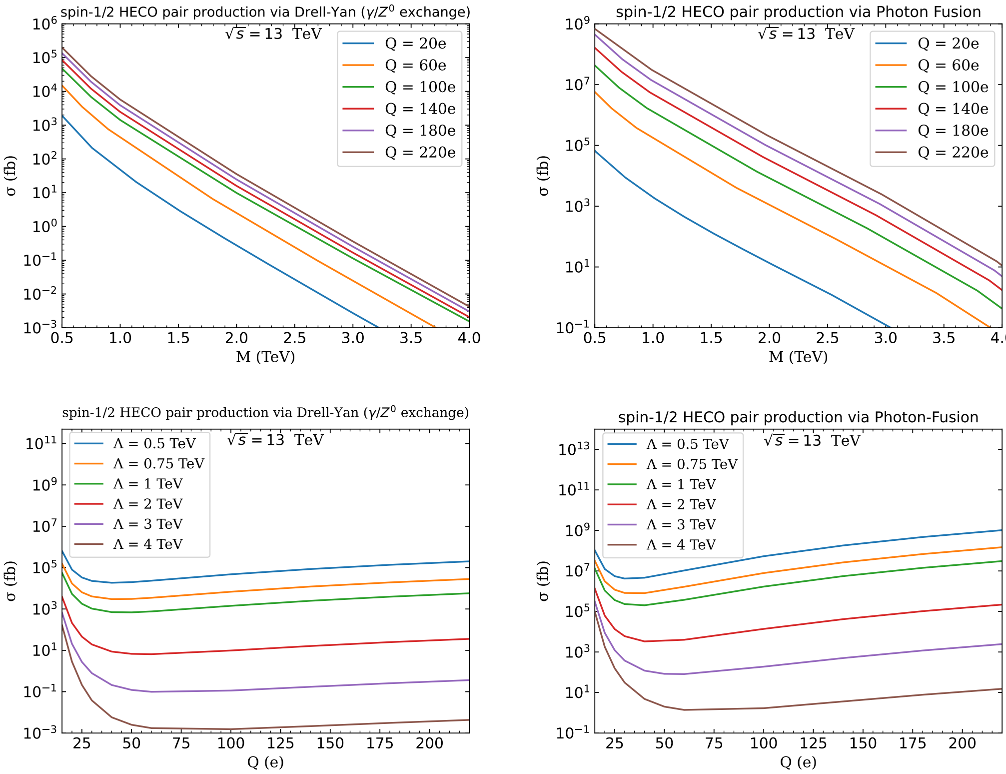


**Figure 2:** Cross-section values for both DY with $\gamma/Z^0$ exchange (left) and PF (right) after resummation. The HECO pair cross section production at $\sqrt{s} = 13$ TeV is drawn as a function of: (top) the HECO mass $M$ for various charge values; (bottom) the charge $Q$ for different cutoff $\Lambda$ values.

## 5. Conclusions

This work explores resummation methods for analyzing High Electric Charge Objects, potential indicators of physics beyond the Standard Model, actively sought in collider experiments. Using specific Dyson–Schwinger techniques, we derive an effective Lagrangian to describe HECO dynamics through Drell–Yan and Photon-Fusion processes. This leads to theoretically reliable mass bounds and improved data interpretation compared to tree-level approaches. The study applies resummation effects to UFO models compatible with Monte Carlo event generators, specifically focusing on DY and PF production mechanisms involving spin-½ HECOs at the LHC. New input parameters, HECO charge multiplicity $n$ and UV cutoff $\Lambda$, were introduced and they affect the cross section values. The incorporation of resummation effects enhances production rates via DY ($\sim 2.1$ times) and PF ($\sim 4.75$ times). The results are used to reinterpret results from experiments such as ATLAS and MoEDAL, providing more reliable HECO mass bounds.

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