Production of Charged BSM Particles at Future Heavy-Ion Colliders Via Photon-Photon Fusion

Laura Jeanty and Jenna Kishinevsky
*University of Oregon**

Lawrence Lee
Harvard University†
(Dated: August 25, 2020)

I. INTRODUCTION

Ultra-peripheral heavy ion collisions (UPCs) provide a unique source of long-range coherent photon-photon interactions from a hadron collider. Such collisions represent purely electromagnetic interactions in a usually QCD-dominated collider environment.

Because of the large electric charge Z of the nuclei used in such colliders, the leading-order cross-sections for such processes that grow as Z^4 are greatly enhanced. For heavy ions such as lead nuclei, the Z^4 scaling provides an increase in production of order 10^7 which may allow for a compensation in the relatively low integrated luminosities of such datasets.

Ultra-peripheral heavy ion collisions provide a unique opportunity to search for electrically charged Beyond the Standard Model (BSM) particles produced via photon-photon interactions. While an energy cutoff ω_{max} limits the mass reach of this production mode, the photon-photon initial state provides the clean final states and minimal detector activity more commonly associated with lepton colliders. Existing studies of BSM production in UPCs have focused on the modification of photon-photon scattering due to the contributions from axion-like particles (ALPs) [1].

In this work, we plan to study the potential sensitivity of UPCs to the benchmark scenario of higgsino production. Light higgsinos are well motivated by naturalness arguments, but a pure or nearly-pure higgsino LSP results in three chargino and neutralino states that are nearly degenerate in mass [2]. Searches for multi-lepton final states at hadron colliders are sensitive to mass differences between the lightest chargino and the lightest neutralino (Δm) down to a few GeV [3]. Mass differences up to about 0.3 GeV produce long-lived charginos that produce a characteristic disappearing track signature [4]. For intermediate Δm, limits from LEP still provide the best sensitivity. UPCs offer the clean environment of a lepton-collider, which may allow access to the experimentally difficult regime of $0.3 < \Delta m < 10$ GeV. We aim to quantify the sensitivity to chargino pair production from photon-photon interactions in UPCs for future proposed heavy ion colliders, as a function of ion species, integrated luminosity, beam energy, and Δm. Additional signal scenario benchmarks, such as R-Parity-violating (RPV) SUSY models, will also be explored.

II. CROSS-SECTION AND LUMINOSITY CONSIDERATIONS

The overall number of BSM events produced will increase with integrated luminosity as well as the charge of the colliding ions. Due largely to beam losses, achievable integrated luminosities are much lower for heavier ion species. Using lighter ions such as Xe or O can provide increased luminosities at the cost of a larger probability of pileup. However, these ions will also suffer from lower electric charge.

In addition, the energy cutoff for coherent photon-photon interactions ω_{max} scales linearly with the relativistic γ factor of the colliding ions, and therefore the fraction of the nuclei formed by protons. For the largest sample of heavy BSM charged particles, it is desirable to have ions with large Z and small A. Therefore, an optimal collider configuration will be investigated for various accelerator abilities.

Asymmetric collisions may also be explored, especially for the proton-ion case where the large boost of the proton can be leveraged for high-mass reach.

III. BACKGROUND PROCESS CONSIDERATION

In addition to investigating the optimal collider configuration for signal production, we aim to perform simple explorations of background processes, and potential handles for background rejection, in order to estimate the sensitivity reach.

Due to the absence of any collision activity except the hard-scatter process in an event with a single UPC, backgrounds to BSM searches in UPCs are dominated by photon-induced Standard Model processes with similar final states. For standard chargino production, we expect the largest backgrounds to be WW, $\tau\tau$, and $q\bar{q}$ production, depending on the specifics of the SUSY mass spectrum.

* Laura.Jeanty@cern.ch
† Lawrence.Lee.Jr@cern.ch; This project is performed with guidance and support from David d'Enterria (CERN).

Considering RPV SUSY models opens up a separate set of background considerations. Decays via the baryon-number-violating RPV coupling of the form UDD can give rise to six-jet events from chargino-production. Background processes for such a search in UPC events are likely to be from $t\bar{t}$ production.

IV. EXPLORATION OF FUTURE COLLIDER REACH

With a number of proposed future heavy-ion colliders, we plan to explore the UPC BSM sensitivity reach for these proposed accelerator facilities. We will also benchmark these sensitivities against simplified expectations of the reach at proposed lepton colliders.

This work will include studies of signal production rate as a function of collider configuration. Additional studies will include explorations into potential triggers, and rudimentary studies of background processes and their rejection. For a simple modeling of detector effects, DELPHES models will be employed.

[1] S. Knapen, T. Lin, H. K. Lou, and T. Melia, Searching for axionlike particles with ultraperipheral heavy-ion collisions, Phys. Rev. Lett. **118**, 171801 (2017).

[2] S. D. Thomas and J. D. Wells, Phenomenology of massive vectorlike doublet leptons, Phys. Rev. Lett. **81**, 34 (1998), arXiv:hep-ph/9804359.

[3] The ATLAS Collaboration, Searches for electroweak production of supersymmetric particles with compressed mass spectra in $\sqrt{s} = 13$ TeV pp collisions with the atlas detector, Phys. Rev. D **101**, 052005 (2020).

[4] The ATLAS Collaboration, *Search for direct pair production of higgsinos by the reinterpretation of the disappearing track analysis with 36.1 fb^{-1} of $\sqrt{s} = 13$ TeV data collected with the ATLAS experiment*, Tech. Rep. ATL-PHYS-PUB-2017-019 (CERN, Geneva, 2017).