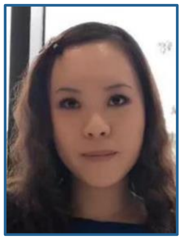
# MODEL OF MAGNETIC MONOPOLE PRODUCTION IN HEAVY-ION ULTRAPERIPHERAL COLLISIONS AT THE LHC

**SUMMARY**: A Monte Carlo model has been implemented and used to compute the kinematics and production rates of magnetic monopoles in heavy-ion ultraperipheral collisions at the LHC.



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## INTRODUCTION

A magnetic monopole, an object that emits a radial magnetic field, does not exist in classical electrodynamics. Yet, in 1931, Dirac postulated the existence of particles with magnetic charges [1] and proved their consistency with quantum mechanics given their charges are integer multiples of the fundamental magnetic charge ($g_D$). This result implies that the existence of such a magnetic monopole would explain the quantization of electric charge.

High-energy particle colliders have been on a quest to discover stable Dirac monopoles, which have no substructure and would be created in pairs to conserve magnetic charge. Recently these searches have been conducted with proton-proton collisions at CERN's Large Hadron Collider (LHC). The monopole production rates are predicted by benchmark models, such as the fusion of photons radiated by the colliding protons. However, the LHC not only collides protons but also heavy ions, which produce large electromagnetic fields as they move at ultrarelativistic velocities. Ultraperipheral collisions, where the ions pass each other with no direct interaction, could produce magnetic monopoles from the radiated photons via the photon fusion mechanism.

## HEAVY-ION ULTRAPERIPHERAL COLLISIONS

Heavy-ion collisions are characterized by the distance between the colliding ions transverse to their directions of motion. In ultraperipheral collisions (UPC), where the distance $b$ is larger than twice their radii $R_A$, the photons radiated from the ions undergo the photon-fusion process while the ions are left intact (see Figure 1). The strong electromagnetic fields propagate as low-momentum photons, as described in the equivalent photon method by Weizsäcker and Williams [2, 3].

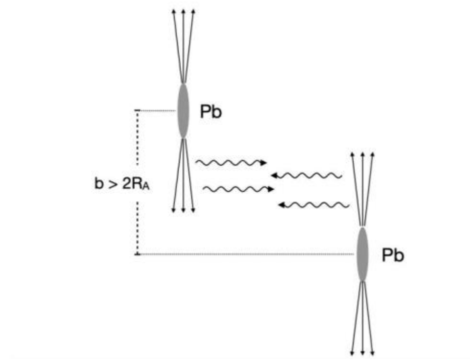


Figure 1. Depiction of propagation of photons radiated by colliding heavy ions, such as lead, in ultraperipheral collisions.

Listed in Table 1 are several collision systems considered at the LHC design beam energy of 7 TeV, where the ions are fully stripped with no remaining electrons. Only the protons in the ions are accelerated, hence, the effective collision energy, denoted as the nucleon-nucleon center-of mass energy $\sqrt{s_{NN}}$ is proportional to the charge-to-mass ratio $Z/A$. Consequently, $\sqrt{s_{NN}}$ is higher for collisions of light ions such as oxygen and maximized in proton-proton collisions. As far as ultraperipheral collisions are concerned, the maximum photon-photon center-of-mass energy $\sqrt{s_{\gamma\gamma}^{max}}$ sets the monopole energy scale. As the photon interaction takes place at a distance on the order of the nuclear radius $R_A$, the photon wavelength cannot be smaller than $R_A$. The uncertainty principle then implies that the maximal photon momentum scales as $\hbar/R_A$. The $1/R_A$ dependence of the photon momentum suppresses $\sqrt{s_{\gamma\gamma}^{max}}$ to be on the order of 200 GeV in xenon-xenon and lead-lead collisions. The LHC program foresees the addition of oxygen-oxygen collisions, which result in higher $\sqrt{s_{\gamma\gamma}^{max}}$.

| | $\sqrt{s_{\rm NN}}$ [TeV] | $R_A$ [fm] | $Z/A$ | $\sqrt{s_{\gamma\gamma}^{\rm max}}$ [GeV] |
|---|---|---|---|---|
| p | 14 | 0.8 [4] | 1.0 | $3.6 \times 10^3$ |
| $^{16}_{8}$O | 7.0 | 3.0 | 0.50 | 490 |
| $^{129}_{54}$Xe | 5.9 | 6.1 | 0.42 | 204 |
| $^{208}_{82}$Pb | 5.5 | 7.1 | 0.39 | 164 |

Table 1. Parameters in different ultraperipheral collision systems: nucleon-nucleon center-of-mass energy $\sqrt{s_{NN}}$, nuclear radius $R_A$, charge-to-mass ratio $Z/A$, and maximum photon-photon center-of-mass energy $\sqrt{s_{\gamma\gamma}^{max}}$.

## IMPLEMENTATION AND RESULTS

The monopole production model is built within a Monte Carlo event generator called MadGraph5_aMC@NLO [5]. The photon-fusion model was validated by comparing the monopole production rate predicted by the Monte Carlo generator to a theoretical calculation for a fixed photon momentum. However, the photons in heavy-ion collisions have a nontrivial momentum distribution. We follow the Weizsäcker-Williams approach to implement this distribution, so we can compute the true production rate as a weighted sum of probabilities at different photon momenta.

At the LHC design collision energy, the photons are kinematically bounded by a maximum of 82 GeV in $\sqrt{s_{NN}}$ = 5.5 TeV lead-lead ultraperipheral collisions. Therefore, we examine the production of spin-1/2 $1g_D$ monopoles with masses up to 80 GeV with our model. Although proton-proton collisions are capable of producing monopoles with masses up to 4000 GeV, the lead-lead ultraperipheral production dominates the proton-proton production for the mass range considered in Figure 2. The monopole transverse momentum distribution is shown in Figure 3, indicating a dedicated search is not practical in ATLAS or other general-purpose LHC detectors that are designed to measure particles with high transverse momenta. For example, a few hundred GeV of transverse momentum is required to measure magnetic monopoles in the ATLAS detector.

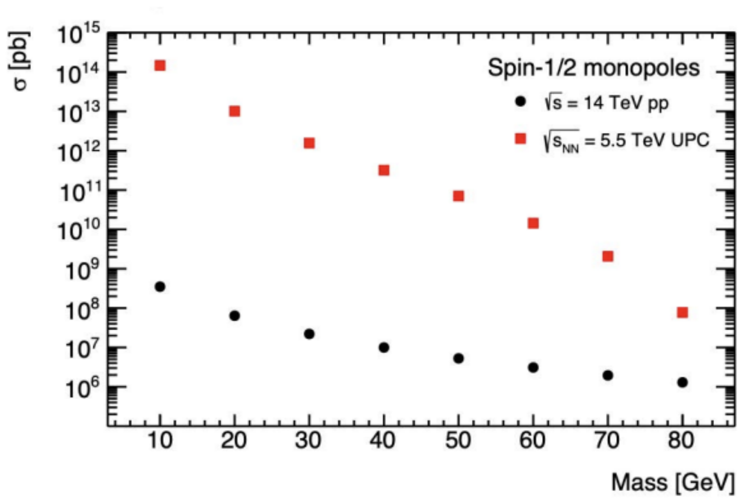


Figure 2. Cross sections for spin-1/2 $1g_D$ monopoles via proton-proton (pp) collisions and via lead-lead ultraperipheral collisions (UPC).

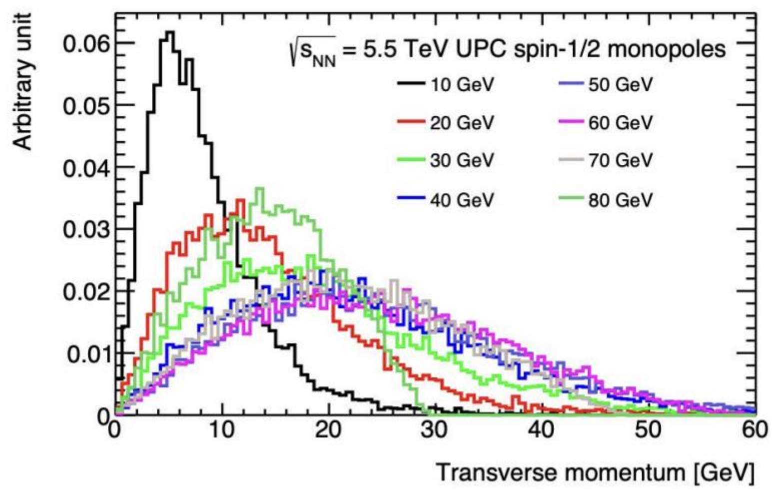


Figure 3. Transverse momentum of spin-1/2 $1g_D$ monopoles in lead-lead ultraperipheral collisions (UPC).

## CONCLUSION

In conclusion, we have studied monopole production in $\sqrt{s_{NN}}$ = 5.5 TeV heavy-ion ultraperipheral collisions and compared it to the proton-proton production system at the equivalent collision energy. The monopole kinematics are significantly constrained in the ultraperipheral collisions, hence, their production in both collision types is examined in a mass range that is accessible in ultraperipheral collisions, where their production is greatly enhanced due to the large nuclear charge. However, the low transverse momenta of these monopoles make it very challenging to measure them in general-purpose LHC detectors.

## REFERENCES

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