

# Collider Constraints on Massive Gravitons



Malak Ait Tamlihat, David d'Enterria, Laurent Schoeffel, Hua-Sheng Shao, and Yahya Tayalati 

## 1 Introduction

General Relativity (GR) serves as a classical field theory describing gravity through an interacting massless tensor (spin-2) field. This theory, when quantized, introduces gravitons, which are considered massless due to the diffeomorphism invariance of GR. However, gauge invariance doesn't universally guarantee zero masses for gauge states, and quantum effects from other fields can confer mass to gravitons without compromising the fundamental properties of GR [1]. Although the existence of a self-consistent quantum field theory of GR applicable across all energy scales remains an open question, employing an Effective Field Theory (EFT) approach enables the exploration of practical consequences. This approach has revealed the emergence of massive spin-2 degrees of freedom in various gravity modifications.

---

M. Ait Tamlihat (✉)

Faculty of Sciences, Mohammed V University in Rabat, Rabat, Morocco  
e-mail: [malak.ait.tamlihat@cern.ch](mailto:malak.ait.tamlihat@cern.ch)

D. d'Enterria  
CERN, EP Department, Geneva, Switzerland

L. Schoeffel  
Ifu, CEA, Université Paris-Saclay, Gif-sur-Yvette, France

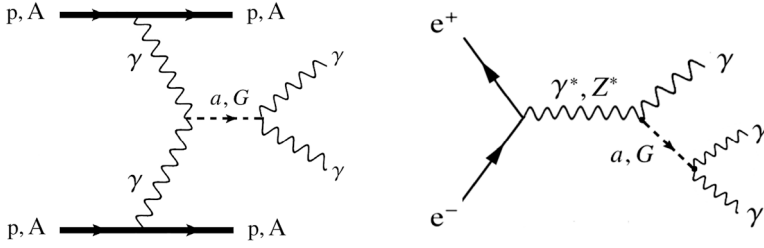
H.-S. Shao  
Laboratoire de Physique Théorique et Hautes Energies (LPTHE), UMR 7589, Sorbonne Université et CNRS, Paris Cedex 05, France

Y. Tayalati  
Faculty of Sciences, Mohammed V University in Rabat, Rabat, Morocco

Institute of Applied Physics, Mohammed VI Polytechnic University, Hay Moulay Rachid, Ben Guerir, Morocco

© The Author(s) 2026

Y. Tayalati, M. Gouighri (eds.), *The First African Conference on High Energy Physics*, Springer Proceedings in Physics 425,  
[https://doi.org/10.1007/978-3-031-88933-2\\_24](https://doi.org/10.1007/978-3-031-88933-2_24)



**Fig. 1** Diagrams showing the decay of an ALP or graviton into two photons (left), and the production of an ALP or graviton in  $e^+e^-$  collisions, leading to a triphoton final state (right)

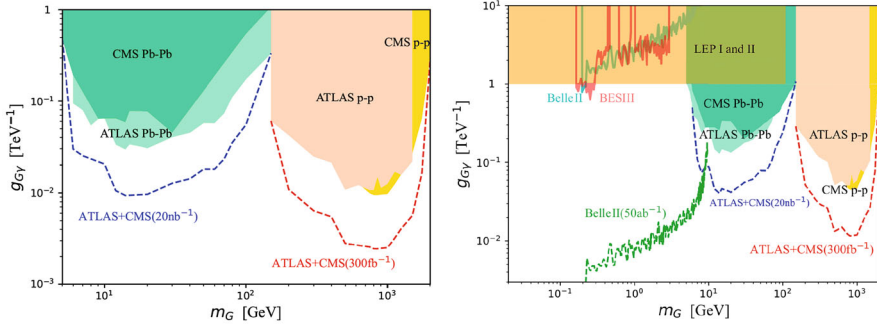
The interaction between the graviton and photons [2] is described within this context, by the following formula:

$$L_\gamma^G = g_{G\gamma} \left( -F_{\mu\rho} F_\nu^\rho + \frac{1}{4} \eta_{\mu\nu} (F_{\rho\sigma})^2 \right) G^{\mu\nu}, \quad (1)$$

where  $F_{\mu\rho}$  is the electromagnetic field,  $\eta_{\mu\nu}$  the flat spacetime metric, and  $g_{G\gamma}$  is the G- $\gamma$  coupling. Photon-photon collisions offer exceptional environment for probing particles beyond the standard model (BSM) that interact with photons, such as spin-0 Axion-Like Particles (ALPs) and spin-2 tensor particles like gravitons. In this study, we establish upper bounds on  $g_{G\gamma}$  across a range of graviton masses  $m_G$  spanning from 100 MeV to 2 TeV. Through simulating various productions of both ALPs and gravitons, based on the diagrams depicted in Fig. 1 and considering the distinctive cross sections,  $\gamma\gamma$  partial widths, and decay characteristics between both particles, we reinterpret the existing experimental limits on the ALP- $\gamma$  coupling to deduce constraints for the G- $\gamma$  coupling. We derive these constraints in two distinct contexts. Initially, we adopt a simplified approach assuming a 100% decay branching fraction of the graviton into two photons ( $\mathcal{B}_{G \rightarrow \gamma\gamma} = 1$ ). This scenario, commonly employed in ALPs searches [3–10], maximizes the sensitivity of the graviton-photon coupling. Subsequently, we examine a more practical situation in which the graviton has universal couplings to all Standard Model particles. In this case, the graviton predominantly decays into diphotons only for lower  $m_G$  values. However, as we go beyond a few GeV, the emergence of kinematic phase space for decays to massive Standard Model fermions or bosons becomes significant. Consequently, the branching fraction decreases to  $\mathcal{B}_{G \rightarrow \gamma\gamma} \approx 0.05$ . The universal coupling scenario enables a proper computation of the  $e^+e^- \rightarrow G\gamma$  cross sections without encountering issues related to the violation of perturbative unitarity.

## 2 Results

When considering graviton limits from PbPb or pp Ultra-Peripheral Collisions (UPCs), it is possible to maintain the simplifying assumption of unity diphoton-decay branching fractions ( $\mathcal{B}_{G \rightarrow \gamma\gamma} = 1$ ). The corresponding upper exclusion limits



**Fig. 2** Exclusion Limits at 95% CL on graviton-photon coupling, with  $\text{Br}(G \rightarrow \gamma\gamma) = 1$  (Left) and an universal graviton coupling to SM particles (Right). Projected limits (indicated by dashed lines) are also showcased for the ultimate integrated luminosities anticipated at LHC and Belle II

at a 95% confidence level (CL) for the graviton-photon coupling ( $g_{G\gamma}$ ) are illustrated in the left of Fig. 2. Additionally, we present extrapolated limits (depicted by dashed curves) by projecting the current findings to the future integrated luminosities in future PbPb and pp collisions at the HL-LHC. Specifically, we consider  $\mathcal{L} = 20 \text{ nb}^{-1}$  for PbPb and a conservative estimate of  $\mathcal{L} = 300 \text{ fb}^{-1}$  for the pp scenario. To derive  $\mathcal{B}_{G \rightarrow \gamma\gamma}$  limits at  $e^+e^-$  colliders, we take into account the universal coupling scenario. Within this framework, the diphoton branching ratio of the graviton is set for each  $m_G$ . The results are depicted in Fig. 2 (Right), showcasing upper limits on the graviton-photon coupling across the range of  $g_{G\gamma} \approx 1 - 0.05 \text{ TeV}^{-1}$  for masses  $m_G \approx 100 \text{ MeV} - 2 \text{ TeV}$ . Additionally, the figure illustrates extrapolated limits (dashed curves) corresponding to the anticipated total integrated luminosities throughout the entire operational lifetime of the HL-LHC and Belle II experiments. These extrapolations suggest the potential for improving current constraints by approximately 100-fold in the low-mass region and by a factor of 4 at higher masses.

The findings showcased in this study rival existing inclusive graviton searches. The exclusive production and decay of gravitons into photon pairs ( $\gamma\gamma$ ) are subject to negligible standard model backgrounds. Through meticulous control of instrumental effects and consistent integrated luminosities, the coupling limits for  $G\text{-}\gamma$  derived from exclusive analyses have the potential to surpass those obtained from standard inclusive graviton searches at the LHC.

### 3 Conclusion

In this work, we explored the prospect of detecting massive spin-2 gravitons coupling to photons. We established 95% upper limits for  $g_{G\gamma}$  in the range of approximately  $1 - 0.1 \text{ TeV}^{-1}$  for graviton masses  $m_G = 5 - 100 \text{ GeV}$  in PbPb and pp collisions, and over  $g_{G\gamma} \approx 0.5 - 0.05 \text{ TeV}^{-1}$  for  $m_G = 150 \text{ GeV} - 2 \text{ TeV}$ .

**Acknowledgments** This work is supported by the Moroccan Ministry of Higher Education, Scientific Research and Innovation, the European Union’s Horizon 2020 research and innovation program (grant agreement No. 824093, STRONG-2020, EU Virtual Access “NLOAccess”), the ERC grant (grant agreement ID 101041109, “BOSON”) and the French ANR (grant ANR-20-CE31-0015, “PrecisOnium”).

## References

1. K. Hinterbichler, Theoretical aspects of massive gravity. *Rev. Mod. Phys.* **84**(3), 671–710 (2012). <https://doi.org/10.1103/RevModPhys.84.671>
2. M. Fierz, W. Pauli, On relativistic wave equations for particles of arbitrary spin in an electromagnetic field. *Proc. R. Soc. Lond. A* **173**, 211–232 (1939). <https://doi.org/10.1098/rspa.1939.0140>
3. ATLAS Collaboration, G. Aad et al., Measurement of light-by-light scattering and search for axion-like particles with 2.2 nb<sup>-1</sup> of Pb+Pb data with the ATLAS detector. *J. High Energy Phys.* **2021**(03), 243 (2021). [https://doi.org/10.1007/JHEP11\(2021\)050](https://doi.org/10.1007/JHEP11(2021)050)
4. CMS Collaboration, A.M. Sirunyan et al., Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV. *Phys. Lett. B* **797**, 134826 (2019). <https://doi.org/10.1016/j.physletb.2019.134826>
5. ATLAS Collaboration, G. Aad et al., Search for an axion-like particle with forward proton scattering in association with photon pairs at ATLAS. *J. High Energy Phys.* **2023**(07), 234 (2023). [https://doi.org/10.1007/JHEP07\(2023\)234](https://doi.org/10.1007/JHEP07(2023)234)
6. TOTEM and CMS Collaboration, A. Tumasyan et al., First search for exclusive diphoton production at high mass with tagged protons in proton-proton collisions at  $\sqrt{s} = 13$  TeV. *Phys. Rev. Lett.* **129**, 011801 (2022). <https://doi.org/10.1103/PhysRevLett.129.011801>
7. Belle-II Collaboration, F. Abudinén et al., Search for axion-like particles produced in  $e^+e^-$  collisions at Belle II. *Phys. Rev. Lett.* **125**, 161806 (2020). <https://doi.org/10.1103/PhysRevLett.125.161806>
8. BESIII Collaboration, M. Ablikim et al., Search for an axion-like particle in radiative  $J/\psi$  decays. *Phys. Lett. B* **838**, 137698 (2023). <https://doi.org/10.1016/j.physletb.2023.137698>
9. M. Baillargeon, F. Boudjema, E. Chopin, V. Lafage, New physics with three photon events at LEP. *Z. Phys. C* **71**, 431–442 (1996). <https://doi.org/10.1007/s002880050188>
10. D. d’Enterria, M. Ait Tamlihat, L. Schoeffel, H. Shao, Y. Tayalati, Collider constraints on massive gravitons coupling to photons. *Phys. Lett. B* **846**, 138237 (2023). <https://doi.org/10.1016/j.physletb.2023.138237>

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

