Letter of intent: gammaUPC4LHC

Title: Improving Monte Carlo modeling of photon-induced processes in ultraperipheral collisions at the LHC

Project leader: Hua-Sheng Shao (LPTHE Paris, CNRS)

1. **Research objectives**

The physics program in ultraperipheral collisions (UPCs) at colliders such as the CERN LHC has gained a significant and increasing attention within the particle and nuclear physics communities. This growing interest is driven by significant experimental advances and the potential for novel physics insights. Photon-hadron processes in UPCs offer unique opportunities to probe proton and nuclear structure—such as coherent and incoherent photon fluxes, nuclear profiles, (nuclear) parton distribution functions (PDFs), generalized parton distribution functions (GPDs), and Wigner distributions—as well as to explore long-sought phenomena like parton saturation. Photon-photon processes in UPCs enable novel precision tests of the Standard Model (SM) and open new avenues for searches beyond the SM (BSM), including investigations of the tau anomalous magnetic moment (g-2), anomalous quartic gauge couplings, and searches for potential new particles. As a result, the field is rapidly expanding, as reflected in community events such as the UPC-2025 conference (https://indico.global/event/9992/).

To unambiguously interpret current and future experimental measurements, it is essential to improve theoretical predictions and Monte Carlo modeling of UPC processes. To address this need, the open-access gamma-UPC (https://www.lpthe.jussieu.fr/~hshao/gammaupc.html) program was developed. It is the first—and currently the only—publicly available code capable of automatically simulating arbitrary coherent (elastic) photon-photon UPC processes within both the SM and BSM, including final states involving elementary particles and quarkonia. Recently, next-to-leading order (NLO) QCD and electroweak (EW) corrections for general two-photon SM processes in UPCs have also been automated within the same framework (gamma-UPC+MadGraph5_aMC@NLO). The gamma-UPC code is now seeing increasing adoption by the LHC collaborations.

In this proposal, we aim to significantly advance this framework in the following directions:

1) Incoherent photon-induced UPC processes in proton and nuclear collisions: Incoherent photon-induced processes are important—and in some cases dominant—backgrounds to coherent two-photon processes. For example, they play a critical role in the tau g-2 measurement in proton-proton collisions at the LHC.
2) Inclusive UPC photoproduction processes: These involve one beam particle remaining intact while the other breaks up due to parton emission in a hard interaction. Such processes offer an alternative method to probe nuclear PDFs, accessing complementary (x,Q^2) regions compared to standard inclusive measurements.

3) Automated Monte Carlo simulations of coherent photoproduction processes involving GPDs: Photon-hadron processes directly probe GPDs and are essential for understanding the spatial and momentum distributions of partons inside nucleons and nuclei.
4) Spin-correlated tau hadronic decays at NLO electroweak accuracy in $\gamma\gamma \to \tau^+\tau^-$: Currently, such decays cannot be simulated with NLO EW precision. Implementing this feature is crucial for comparing with high-precision experimental measurements and for a reliable determination of the tau g-2.
5) Extension beyond collinear factorization: The current gamma-UPC framework is based on collinear factorization, which limits access to observables such as azimuthal angular modulations. Since the coherently emitted photons are largely linearly polarized, azimuthal correlations in the final states in $\gamma\gamma$ processes could provide direct sensitivity to the generalized transverse-momentum-dependent photon distribution function (γ-GTMD), or the five-dimensional Wigner distribution. This distribution is also relevant for ongoing and future programs at RHIC and the EIC in the US.

In summary, the gammaUPC4LHC project can be systematically improved to deliver beyond-state-of-the-art theoretical tools to support current and future experiment measurements at CERN's flagship facility, the LHC. This LoI aims mostly at funding a postdoctoral position to develop a fraction of the 5 research axes mentioned above, and deliver an updated public code to use by the experimental and phenomenological collider communities.

2. Connection to Transnational Access infrastructures (TAs) and/or Virtual Access projects (VAs)

The gammaUPC4LHC project aims to develop indispensable Monte Carlo simulation tools for photon-induced processes in ultraperipheral proton and ion collisions at the LHC, part of CERN's TA (Transnational Access) infrastructure. While the tools will be openly accessible, they may also be integrated into the VA NLOAccess web portal to further enhance user accessibility and dissemination.

3. **Estimated budget request**

Personnel costs: A postdoc with a 2-year CNRS contract based at LPTHE in Paris :

165k Euros (including 25% administrative overhead)

Travel budget, including visits to CERN of the participants : 30k Euros

Total: 195k Euros

4. **Participating and partner institutions**

LPTHE Paris (CNRS): Hua-Sheng Shao

CERN: David d'Enterria