Strategic vision for energy frontier photon collider science

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Recent landmark results are renewing interest in using the LHC as a photon–photon $\gamma\gamma$ collider. We initiate our strategic vision to transform QED production at the LHC and beyond into a flagship programme with a thriving community this decade. This defines the science drivers for precision measurements and new physics searches such as electromagnetic dipole moments and dark sectors. We identify opportunities to invest in technology and theory, interdisciplinary synergies with laser science and astrophysics, and community outreach to expand this exciting programme.

I. INTRODUCTION

Electromagnetic fields surrounding protons and heavy ions at the LHC source high energy photons that collide to produce new particles [1–8]. Recent breakthroughs at colliders are renewing interest for probing QED production in uncharted strong-field regimes. Highlights include observing Schwinger production $\gamma\gamma \to \ell\ell$ [9–12], light-by-light scattering $\gamma\gamma \to \gamma\gamma$ [13–16], and evidence for electroweak boson pairs $\gamma\gamma \to WW$ [17, 18]. We recently proposed dark matter via sleptons $\gamma\gamma \to \tilde{\ell}\tilde{\ell} \to \ell\tilde{\chi}_1^0\ell\tilde{\chi}_1^0$ [19] and tau $g-2$ modifications with $\gamma\gamma \to \tau\tau$ [20] as key targets among new physics searches [21–28]. This remarkable progress is emerging from heavy ion, forward physics, soft QCD, electroweak, and BSM groups, with interest from the accelerators, lasers, and astrophysics communities. This motivates an ambitious vision for the next decade of photon collider science.

II. GOALS

This *Letter of Interest* proposes a framework to develop our strategic vision for photon collider science at the LHC and beyond. We plan to explore the following:

- **Science drivers and big questions**. What are our transformative science goals? QED is famously tested to parts per billion, but only for the electron $g-2$. How do we achieve precision for other particles? Which photon collision data can probe the pressing questions of matter–antimatter asymmetry, strong CP, electroweak symmetry breaking, mass hierarchies, the flavour sector, dark matter, cosmic acceleration? What discoveries can we make before the next Snowmass? The LHC is a unique laboratory for testing QED at the highest energy strong-field regimes. How do we connect this to science drivers of the high-intensity lasers community? What can we learn from photon collisions in extreme astrophysical phenomena?
- **Physics targets, probes, benchmarks**. Photon fusion production can occur for any particles with a photon coupling. How do we see unobserved rare SM processes and measure their rates precisely? How can photon collisions in nature complement laboratory probes: early universe, black holes, neutron stars, supernovae, gamma ray bursts, cosmic rays, thunderstorms. BSM targets: dark sectors, supersymmetry, extra Higgs bosons, axion-like particles, effective field theories, anomalous couplings.
- **Facilities, instrumentation, software**. How do we capitalise on different beams, upgraded ATLAS and CMS to complement existing and proposed facilities in the US and worldwide? How do we underscore the importance of upgraded forward proton spectrometers with picosecond timing for AFP/CT-PPS [29, 30], and Zero Degree Calorimeters [31] crucial for this programme? What trigger innovations are required? What capabilities of LHCb and ALICE could be uniquely beneficial? What investments in Monte Carlo simulation and reconstruction software are required?
- **Interdisciplinary synergies**. How do we develop a common framework to exchange and explore the complementarity of strong-field QED with disciplines outside HEP: laser physics, plasma physics, quantum science, astrophysics, cosmology, nuclear physics, atmospheric physics? How do we engage given sociological and funding differences?
- **Outreach, education, applications**. "Turning light into (dark) matter" captures the public imagination. How do we publicise the importance of this science to the wider community and funding agencies? How do we attract and train diverse newcomers to sustain vibrant careers in this programme? What novel technological, medical, industrial applications of photon collider research could arise?
- **Snowmass intersections**. We select *Energy Frontier* EF09 as our initial home in the EF06–10 neighbourhood. Cross-frontier science synergies include *Rare Processes and Precision* RF03 tau $g-2$, RF06 new probes; *Instrumentation* IF03 AFP/CT-PPS trackers and time-of-flight; *Cosmic* CF07 astrophysical photon collisions; *Theory* TF07 collider phenomenology; *Accelerator* AF4 $\gamma\gamma$ collider.

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