ATLAS experiment observes light scattering off light

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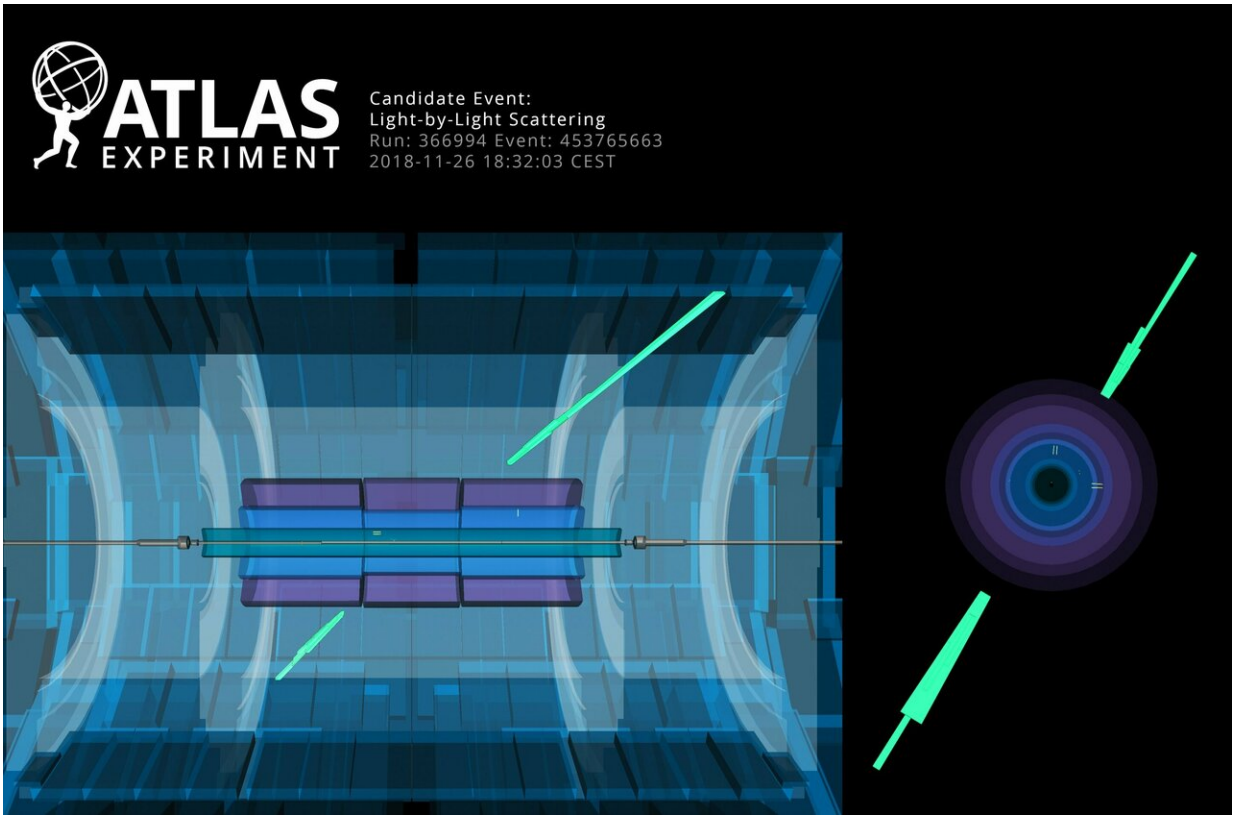

ATLAS event display showing the energy deposits of two photons in the electromagnetic calorimeter (green) on opposite sides and no other activity in the detector, which is the clean signature of light-by-light scattering. Credit: ATLAS Collaboration/CERN

Light-by-light scattering is a very rare phenomenon in which two

photons interact, producing another pair of photons. This process was among the earliest predictions of quantum electrodynamics (QED), the quantum theory of electromagnetism, and is forbidden by classical physics theories (such as Maxwell's theory of electrodynamics).

Direct evidence for light-by-light scattering at high energy had proven elusive for decades, until the Large Hadron Collider (LHC) began its second data-taking period (Run 2). Collisions of lead ions in the LHC provide a uniquely clean environment to study light-by-light scattering. Bunches of lead ions that are accelerated to very high energy are surrounded by an enormous flux of photons. Indeed, the coherent action from the large number of 82 protons in a lead atom with all the electrons stripped off (as is the case for the lead ions in the LHC) give rise to an electromagnetic field of up to 10^{25} Volt per metre. When two lead ions pass close by each other at the centre of the ATLAS detector, but at a distance greater than twice the lead ion radius, those photons can still interact and scatter off one another without any further interaction between the lead ions, as the reach of the (much stronger) strong force is bound to the radius of a single proton. These interactions are known as ultra-peripheral collisions.

In a result published in *Nature Physics* in 2017, the ATLAS Experiment at CERN found thirteen candidate events for light-by-light scattering in lead-lead collision data recorded in 2015, for 2.6 events expected from background processes. The corresponding significance of this result was 4.4 standard deviations – making it the first direct evidence of high-energy light-by-light scattering.

On 17 March 2019, at the *Rencontres de Moriond* conference (La Thuile, Italy), the ATLAS Experiment reported the observation of light-by-light scattering with a significance of 8.2 standard deviations. The result utilises data from the most recent heavy-ion run of the LHC, which took place in November 2018. About 3.6 times more events (1.73 nb^{-1}) were

collected compared to 2015. The increased dataset, in combination with improved analysis techniques, allowed the measurement of the scattering of light-by-light with greatly improved precision. A total of 59 candidate events were observed, for 12 events expected from background processes. From these numbers, the cross section of this process, restricted to the kinematic region considered in the analysis, was calculated as 78 ± 15 nb.

Curiously, the signature of this process – two photons in an otherwise empty detector – is almost the opposite of the tremendously rich and complex events typically observed in high-energy collisions of two lead nuclei. Observing it required the development of improved trigger algorithms for fast online event selection, as well as a specifically-adjusted photon-identification algorithm using a neural network, as the studied photons have about ten times less energy than the lowest energetic photons usually measured with the ATLAS detector. Being able to record these events demonstrates the power and flexibility of the ATLAS detector and its event reconstruction, which was designed for very different event topologies.

This new measurement opens the door to further study of the light-by-light scattering process, which is not only interesting in itself as a manifestation of an extremely rare QED phenomenon, but may be sensitive to contributions from particles beyond the Standard Model. It allows for a new generation of searches for hypothetical light and neutral particles.

More information: Observation of light-by-light scattering in ultraperipheral Pb+Pb collisions with the ATLAS detector (ATLAS-CONF-2019-002): cdsweb.cern.ch/record/2667214

Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC, *Nature Physics* (2017). DOI:

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