Refining the picture of the Higgs boson

November 20 2020

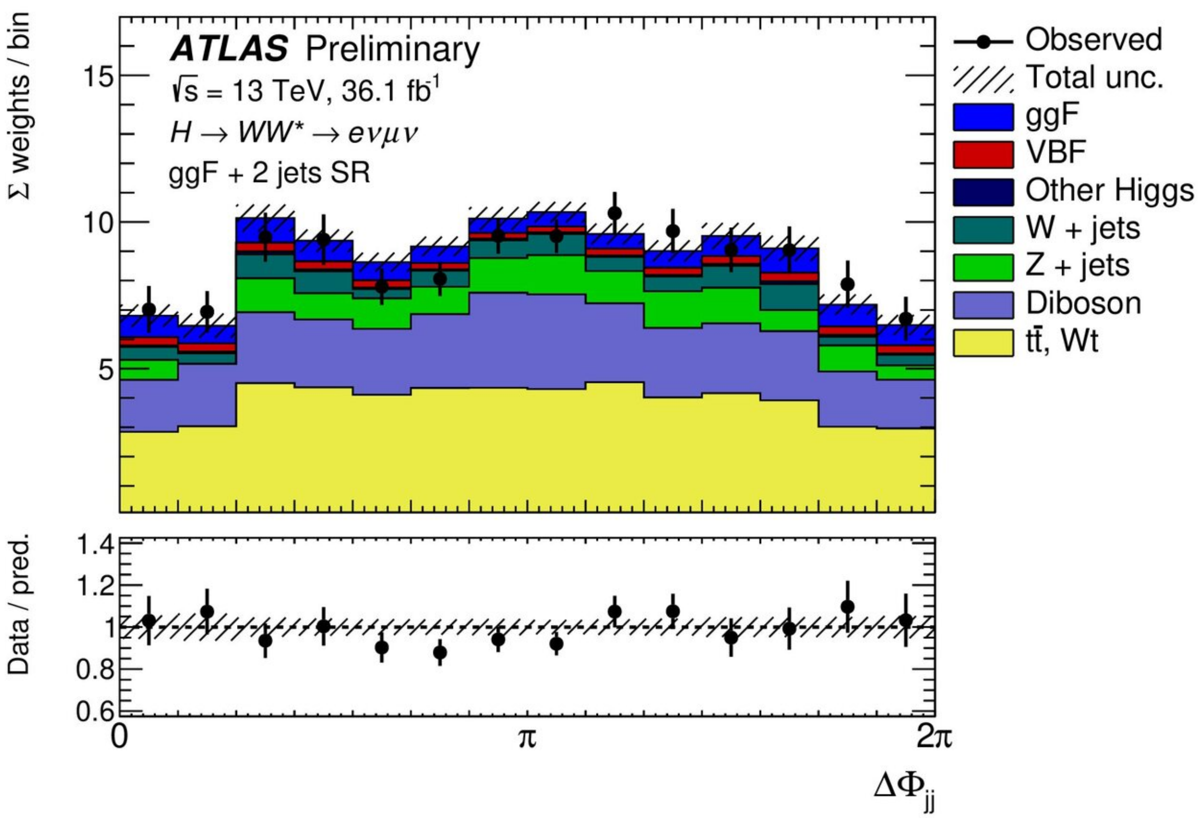

Figure 1: The weighted distribution of the azimuthal angle between two jets in the signal region used in the CP measurement. The signal and background yields are determined from the fit. Data-to-simulation ratios are shown at the bottom of the plot. The blue histogram represents measured signal; the shaded areas depict the total uncertainty. Credit: ATLAS Collaboration/CERN

To explain the masses of electroweak bosons—the W and Z bosons—theorists in the 1960s postulated a mechanism of spontaneous symmetry breaking. While this mathematical formalism is relatively simple, its cornerstone—the Higgs boson – remained undetected for almost 50 years.

Since its discovery in 2012, researchers of the ATLAS and CMS experiments at CERN's Large Hadron Collider (LHC) have tirelessly investigated the properties of the Higgs boson. They've measured its mass to be around 125 GeV—that's about 130 times the mass of the proton at rest—and found it has zero electric charge and spin.

The mirror image

Researchers set out to determine the Higgs boson's parity properties by measuring its decays to pairs of W bosons (H → WW*), Z bosons (H → ZZ*) and to photons (H → γγ). Through these measurements, they confirmed that the Higgs boson has even charge-parity (CP). This means that—as predicted by the Standard Model—the Higgs boson's interactions with other particles do not change when "looking" in the CP mirror.

As any distortions in this CP mirror (or "CP violation in Higgs interactions"), such as CP-odd admixture, would indicate the presence of as-yet undiscovered phenomena, physicists at the LHC are scrutinizing the strengths of Higgs-boson couplings very carefully. A new result from the ATLAS Collaboration, released for the Higgs 2020 conference, aims at enriching the Higgs picture by studying its WW* decays.

One new ATLAS study examines the CP nature of the effective coupling between the Higgs boson and gluons (the mediator particles of the strong force). Until now, the gluon-fusion-induced production of a Higgs boson, in association with two particle jets, had not been studied in a dedicated analysis. The study of this production mechanism is an excellent way to search for signs of CP violation, as it affects the Higgs-boson kinematics, leaving a trace in the azimuthal angle between the jets measured by ATLAS.

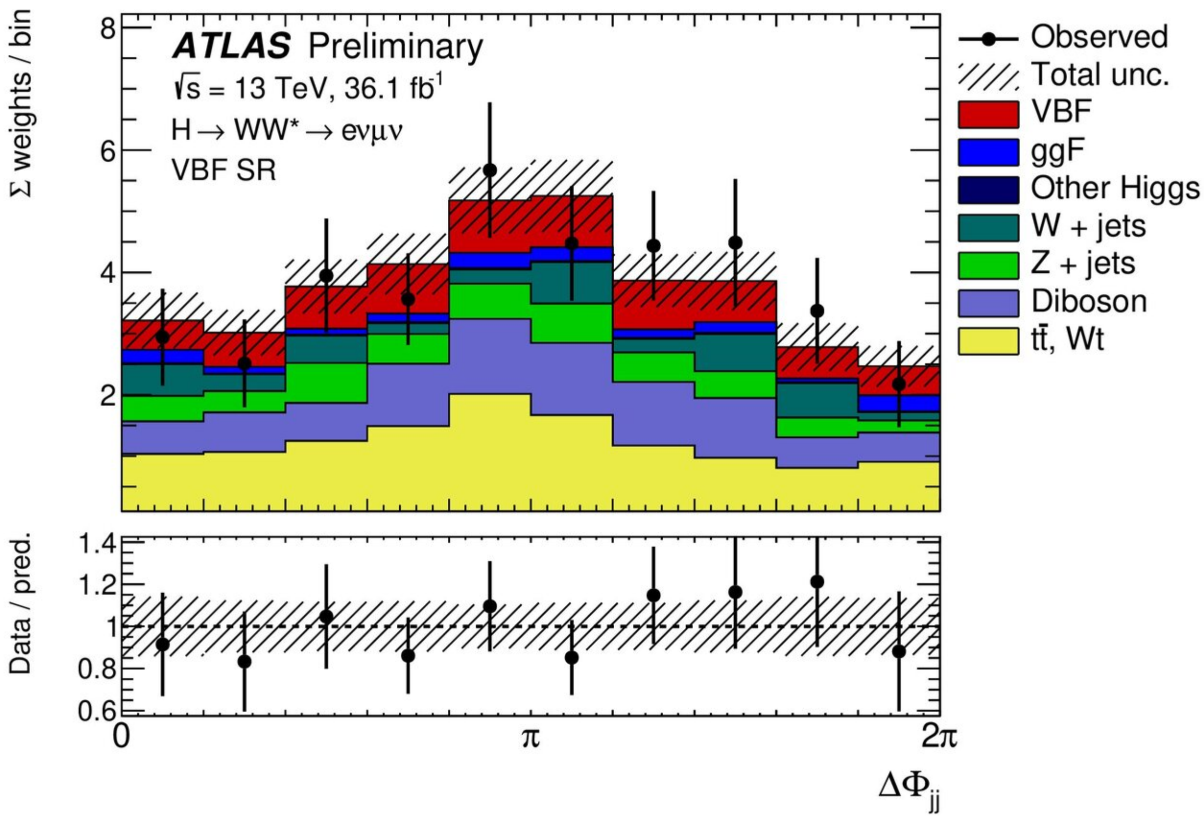

Figure 2: The weighted distribution of the azimuthal angle between two jets in the signal region used in the polarisation measurement. The signal and background yields are determined from the fit. Data-to-simulation ratios are shown at the bottom of the plot. The red histogram represents measured signal; the shaded areas depict the total uncertainty Credit: ATLAS Collaboration/CERN

Polarization filter

At high energies, the weak and electromagnetic forces merge into a single electroweak force. Yet at low energies, electromagnetic waves (such as light) can travel an infinite distance, while weak interactions have a finite range. This is because unlike photons (the carriers of the electromagnetic force), W and Z bosons are massive. Their masses originate from interactions with the Higgs field.

Another difference is that electromagnetic waves are transverse; oscillations in the electromagnetic field only occur in the plane perpendicular to its propagation. W and Z bosons, on the other hand, have both longitudinal and transverse polarisations due to their interactions with the Higgs field. There is a subtle interplay between these longitudinal polarisations and the boson masses that ensures that Standard Model predictions remain finite.

Should the Higgs boson not be a fundamental scalar particle, and instead an entity arising from new dynamics, a different (more complicated) mechanism would have to give mass to the W and Z bosons. In such a case, the measured Higgs-boson couplings with electroweak bosons may deviate from the predicted Standard Model values.

The ATLAS Collaboration has released its first study of individual polarization-dependent Higgs-boson couplings to massive electroweak bosons. Specifically, physicists examined the production of Higgs bosons through vector-boson fusion in association with two jets. Just as a polarizing filter helps you to take a sharper picture at a seaside by selectively absorbing polarized light, this new ATLAS study investigated individual Higgs-boson couplings to longitudinally and transversely polarized electroweak bosons. Further, similar to the study of the Higgs-boson coupling to gluons, the presence of a new mechanism would impact the kinematics of the jets measured by ATLAS.

Follow those jets!

The main challenge of these analyses is the rarity of the Higgs-boson events being studied. For the signal selections studied in the new ATLAS result, only about 60 Higgs bosons are observed via gluon fusion and only 30 Higgs bosons via vector-boson fusion. Meanwhile, background events are almost a hundred times more abundant. To tackle this challenge, both analyses not only counted events but also looked into the shapes of the azimuthal angle (the angle transverse to the direction of the proton beams) between the two jets. The correlation between these jets has helped resolve properties of Higgs-boson production.

Researchers used the technique of parameter morphing to interpolate and extrapolate the distribution of this angle from a small set of coupling benchmarks to a large variety of coupling scenarios.The fitted distributions of the azimuthal angle between the jets are shown in Figures 1 and 2.

So far, both distributions show no sign of new physics. Once more LHC data is analyzed (these studies only include data collected in 2015 and 2016), the shaded areas in the plots that represent the measurement's uncertainty should decrease. This will provide an even sharper picture of the Higgs boson.

More information: Constraints on Higgs boson properties using $WW^*(\rightarrow e\nu\mu\nu)jj$ production in 36.1fb−1 of 13TeV proton-proton collisions with the ATLAS detector (ATLAS-CONF-2020-055): atlas.web.cern.ch/Atlas/GROUPS … ATLAS-CONF-2020-055/

Provided by ATLAS Experiment