TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Properties of the Higgs Boson: Spin & CP

presented by Doug Schouten, TRIUMF

ATLAS EXPERIMENT

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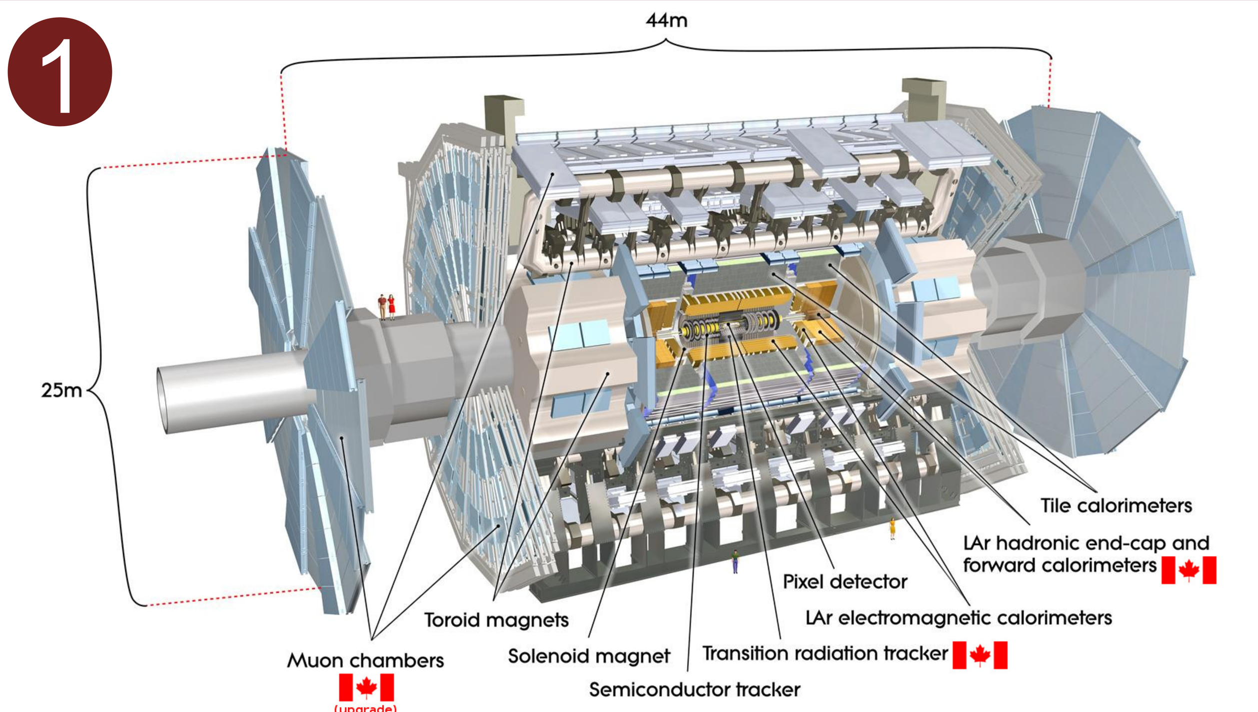


Figure: *TRIUMF contributed (and is contributing) to the design and construction of ATLAS*

ATLAS 2012 p-p run										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.4	100	95.0	98.7	100	99.2	100	99.9	100	100

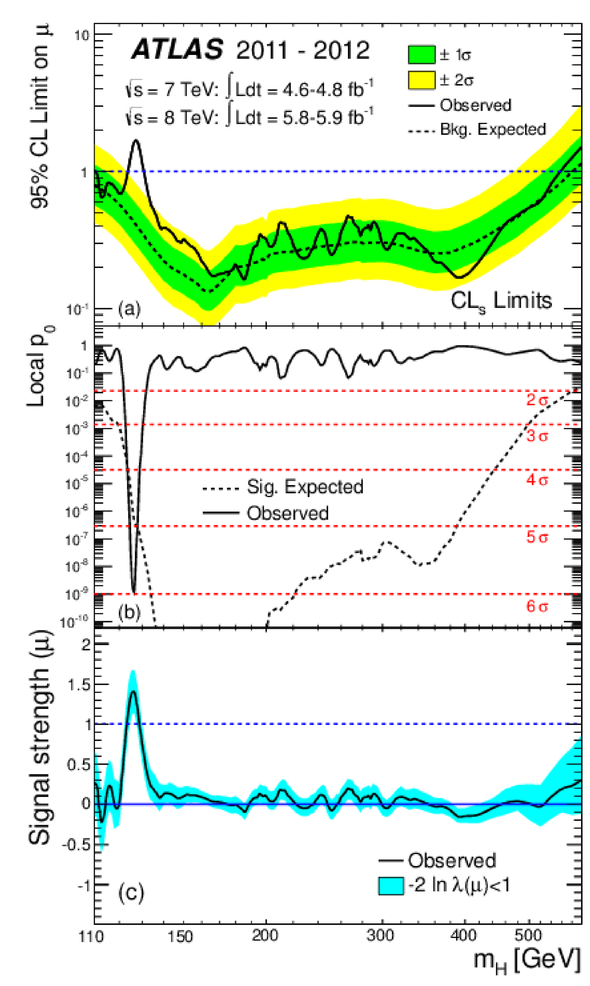
Table: *ATLAS operation efficiency is > 95%*

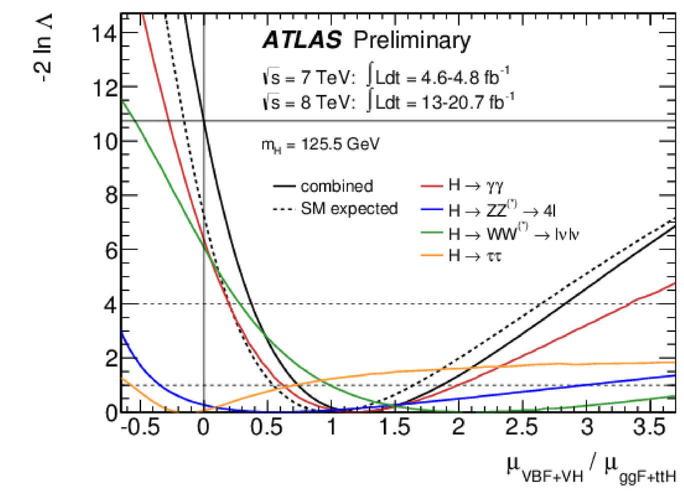
The ATLAS detector recorded proton-proton collisions at 8 TeV during 2012. The successful operation of this impressive detector allowed the collaboration to perform extensive studies of the Standard Model, and beyond.

Discovery!

In July, 2012, ATLAS reported on the observation of a new "Higgs-like" boson with a mass of ~ 125 GeV. The signal strength and p_0 as a function of particle mass (left plots) indicate that this is what would be expected if there truly was a Higgs boson in nature.

Evidence for the new particle was seen in various decay modes, namely γγ, ZZ and WW. By analyzing the number of events observed in these channels, ATLAS collaborators were able to measure the coupling strengths (top right plot) of the Higgs-like boson to the gauge bosons of the Standard Model. They are consistent with the expected values for the SM Higgs boson.





References:

ATLAS Collaboration, *Evidence for the spin-0 nature of the Higgs boson using ATLAS data*, Physics Letters B, Volume **726**, Issues 1–3, Pages 120-144

What Next?

The directions in the roadmap of discovery are clear: in order to determine whether this is a ***Higgs*** boson, it is necessary to experimentally determine its properties such as spin and charge-parity, and also to measure the couplings more precisely.

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Devise Test of Spin-0 versus Spin-X

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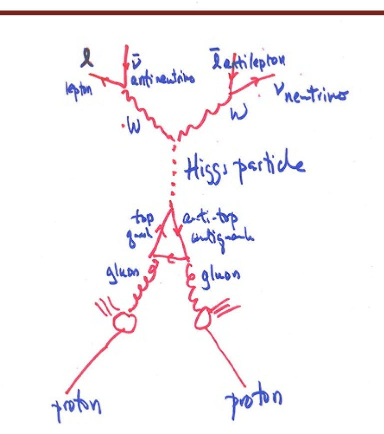
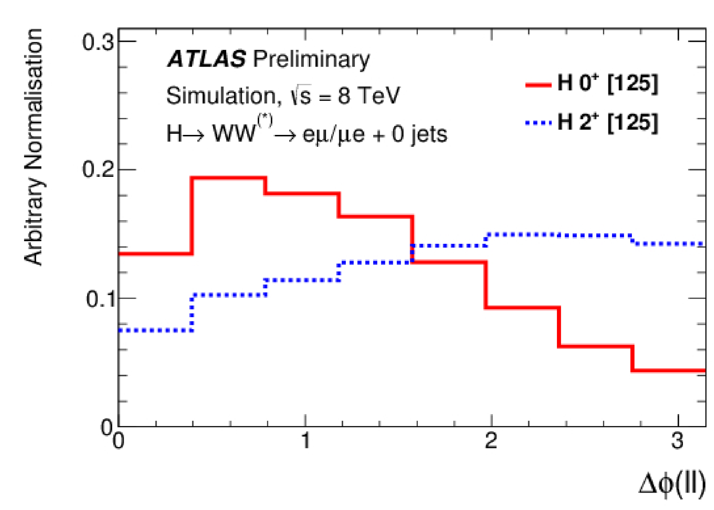
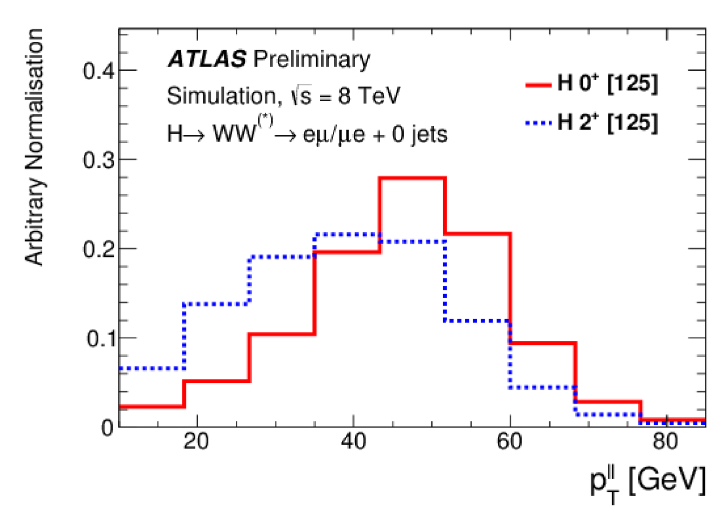


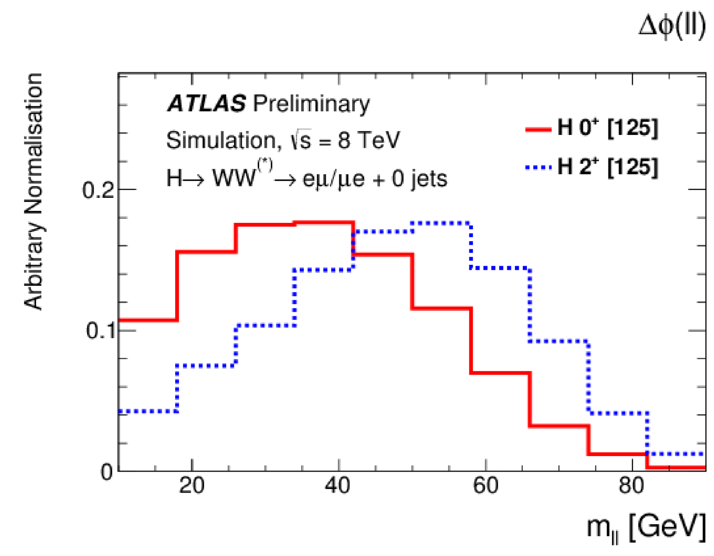
In the H→ WW(*) → lvlv decay mode, the spin and charge-parity (CP) are apparent in the angles and momenta of the charged leptons.

The SM spin-0 Higgs is produced through gluon pair fusion via a top quark loop. For a spin-2 particle, one must also consider p-wave quark-quark annihilation processes.

Therefore, we measure the angles and momenta of the leptons and neutrinos (missing E_T), and with various assumed fractions of qq production, we test the hypothesis that the new particle is a spin-2 resonance, in favor of the Standard Model spin-0.







The spin & CP information affects many observables. These quantities are combined into a multi-variate discriminant, using boosted decision trees (BDT).

The BDT identifies regions of the parameter space that have high signal purity. This is done by placing simple cuts on a set of input variables, which for this measurement are the dilepton mass (m_{ll}) and transverse momentum (p_T^{ll}), the angle between the leptons (Δφ), and the transverse mass (m_T).

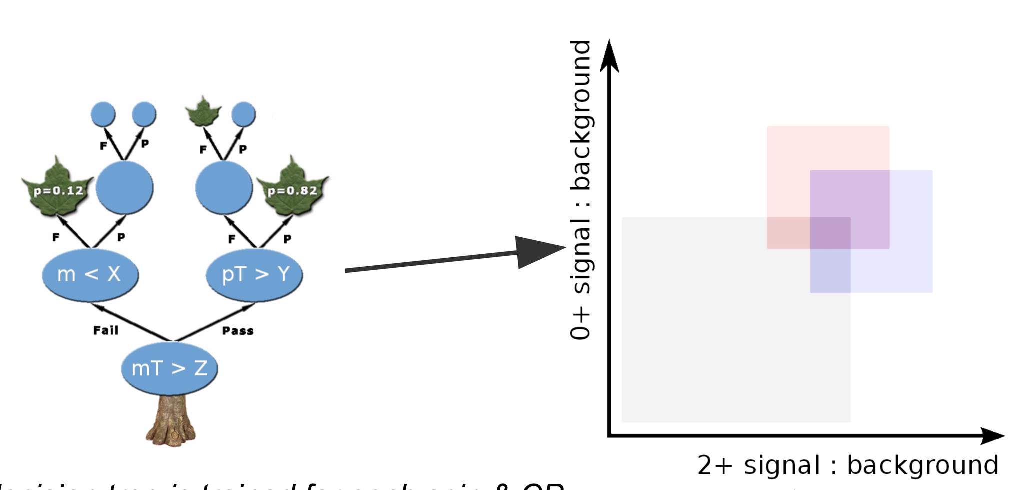
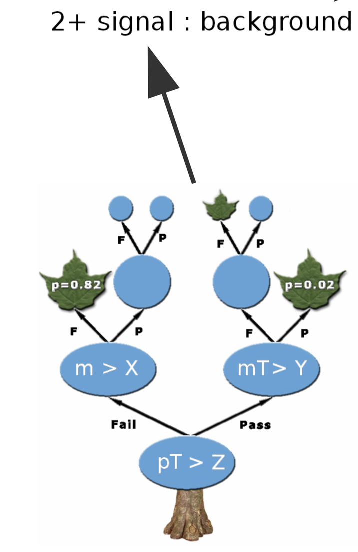


Figure: *A decision tree is trained for each spin & CP hypothesis to optimally separate from background processes.*

BDT's are trained for each of the spin & CP hypotheses. For each test, a 2D discriminant is formed from the SM spin-0 BDT as well as the BDT specific to the alternate hypothesis. This method allows each BDT to focus on separating possible Higgs' from the high-rate background processes, so that the spin determination can be done in a region of the 2D plane that has good signal-to-background ratios.



Investigate ATLAS Data, Result: Spin-0 Preferred

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The BDT's are trained using simulated samples of signal and background processes. By combining quantities into a single discriminant, the sensitivity is improved, as is the dependency on simulations.

The modeling of the various background processes is tested in control samples. In all cases, the detailed Monte Carlo simulations are in very good agreement with the observed data.

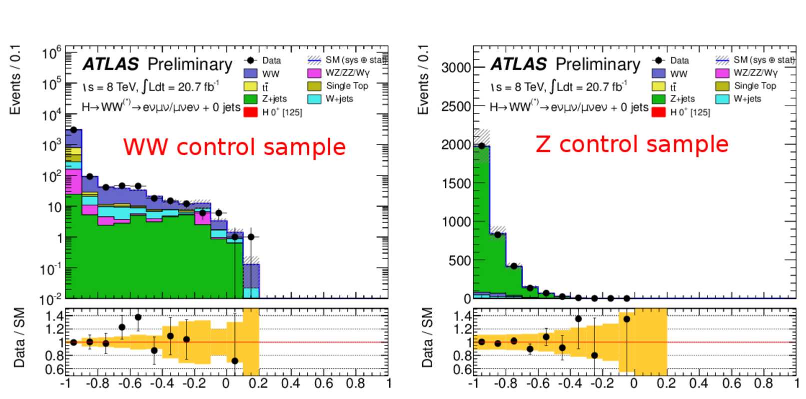
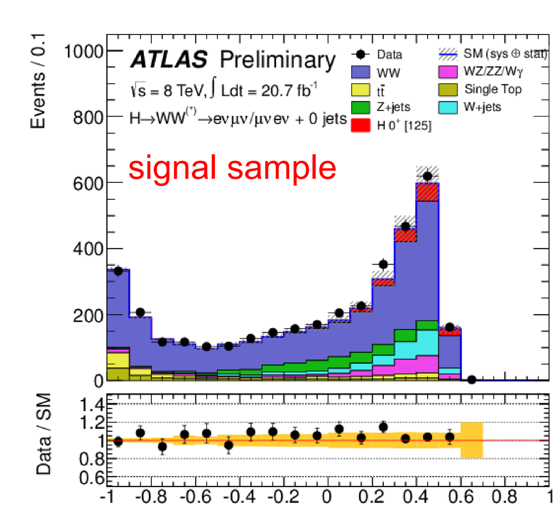
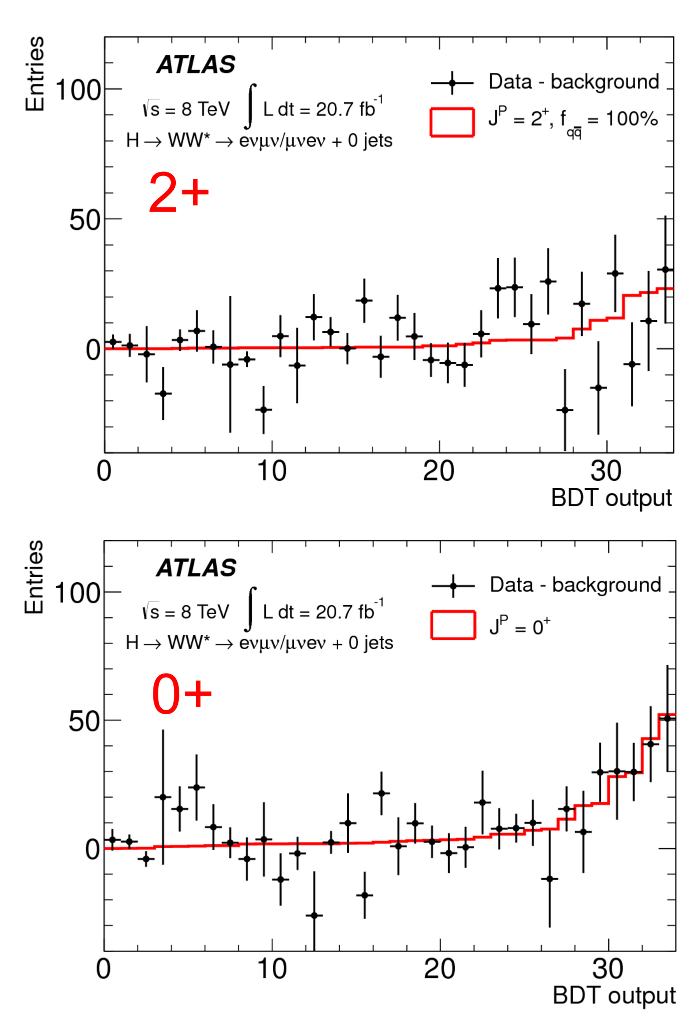


Figure: *BDT distributions in the WW and Z control samples. The yellow band represents the statistical and systematic uncertainty on the ratio.*



The low-BDT region is populated by background events, which provides an additional handle on the modeling of the backgrounds.

There is a clear excess at high BDT that is consistent with the presence of signal. In order to test the spin & CP hypotheses without reference to a particular model, the signal rate is fit directly in the data as a free parameter.



Upon determining the best-fit signal strength, and profiling all the systematic uncertainties, we found that the data favors a SM spin-0 hypothesis (bottom left) over the spin-2 hypothesis (top left). One can see by eye that the agreement with data is significantly better for the spin-0 hypothesis.

The likelihood-based test is performed at five working points of the qq-production fraction. The combined result from the three gauge boson decay channels is shown on the right, as a function of this fraction. One can see that the spin-2 hypothesis is disfavored at more than 2σ for all fractions.

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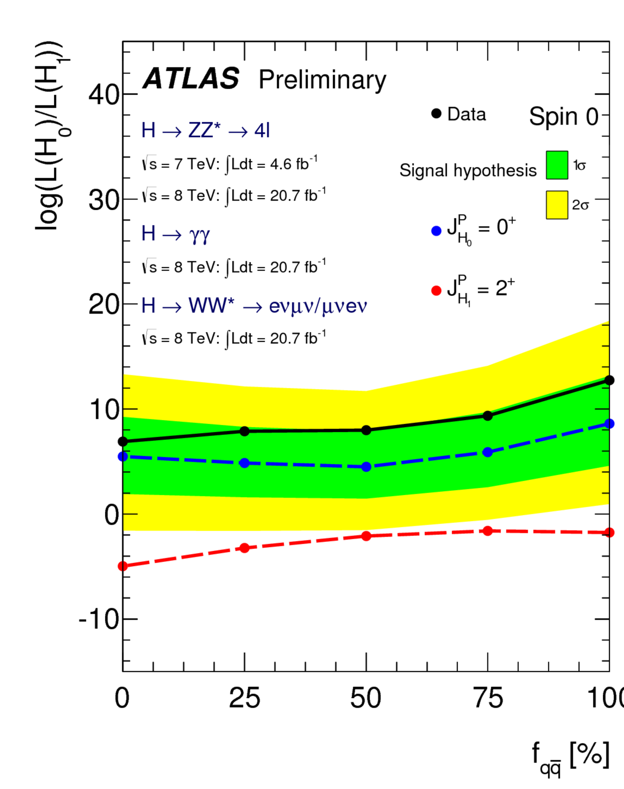
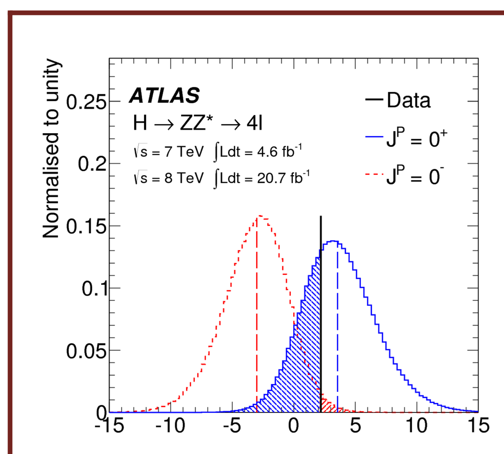
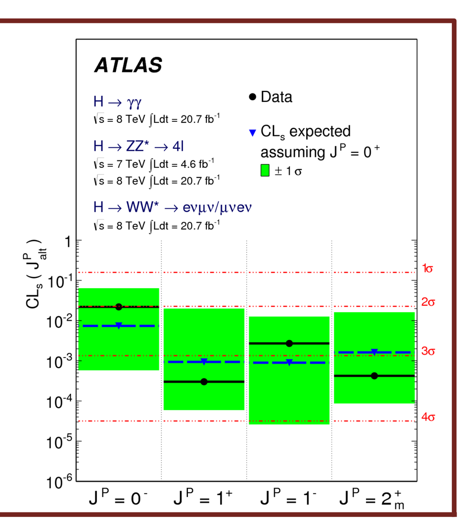


References:

ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Physics Letters B, Volume 716, Issue 1, Pages 1-29



ATLAS is also able to experimentally test alternative spin & CP hypotheses: 0-, 1+ and 1- (although the latter two are strongly disfavored by γγ already), especially in the ZZ "golden channel" decay mode. The SM model JP = 0+ hypothesis is strongly favored by the data, as shown in the figures on the left and right. Alternate hypotheses are excluded at > 95% confidence level, providing strong evidence that the new particle really is a Higgs boson.



2013 Nobel Prize

The experimental verification of the quantum properties of the Higgs boson was an important ingredient in the decision to award the 2013 Nobel Prize to Higgs and Englert. The results from the ATLAS collaboration were cited in the Nobel prize scientific backgrounder.

Upcoming

Currently we are working on finalizing and documenting our comprehensive properties measurements from Run I of the LHC. In addition, we are performing searches for mixed CP states. Evidence for CP mixtures would be a strong indication for a Higgs doublet, such as in supersymmetric models.

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