

Understanding double Higgs boson production with vector boson fusion with the ATLAS detector at the LHC

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Introduction

- The discovery of the Higgs boson on the 4 July 2012, was one of the most monumental discoveries in particle physics.
- The discovery of a scalar Higgs boson in nature confirmed the existence of the Higgs field, which permeates throughout space
- The existence of the Higgs boson is predicted by the Standard Model. The Higgs boson is the manifestation of spontaneous symmetry breaking and is responsible for the masses of the known gauge bosons.
- Vector boson fusion has interesting kinematics, which makes it one of the most sensitive production channels for the Higgs boson
- The Higgs is produced at the centre of the detector and the two quarks from which the vector bosons radiated, shower and manifest themselves as transverse momentum jets in the forward region of the detector.

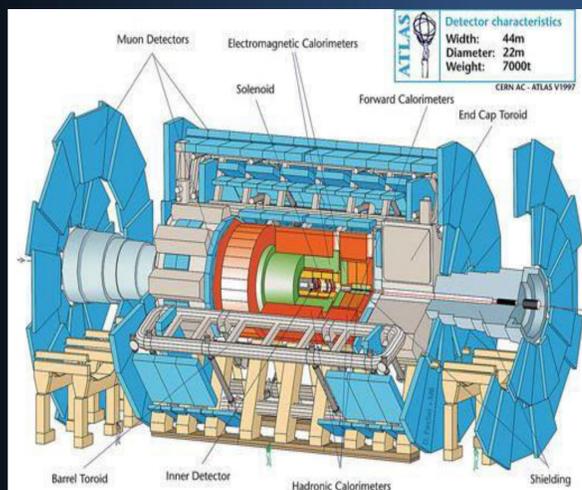


Figure 1. Atlas Detector (<http://scienceinschool.org/2008/issue10/lhchow>)

Spontaneous Breaking of Symmetry

- Symmetry is spontaneously broken by giving a non-vanishing vacuum an expectation value to some field. There is a connection between particle masses and symmetries. Symmetry does not allow the introduction of a mass term, the breaking of symmetry generates the mass term

Higgs potential : $V(\phi) = \frac{\lambda}{4} \phi^4 - \frac{\mu^2}{2} \phi^2$

- The potential $V(\phi)$ does not have mass term.
- $V(\phi)$ is Invariant under the transformation $\phi \rightarrow -\phi$
- The minimum of the potential if found at
- $\phi = \pm \sqrt{\frac{\mu^2}{\lambda}} = \pm v$
- We select one of the minima as the ground states and look at the solution in the neighbourhood of v by making the substitution $\phi = v + \phi'$

The new potential becomes :

$V(\phi) = \frac{\lambda}{4} \phi'^4 + \lambda v \phi'^3 + \frac{3}{2} \lambda v^2 \phi'^2 + \lambda v^3 \phi' + \frac{\lambda k^4}{4} - \frac{\mu^2}{2} (v^2 + 2v\phi' + \phi'^2)$

- The cubic and linear terms break the original symmetry of the original potential
- The new potential is not invariant under the transformation $\phi \rightarrow -\phi$
- Hence symmetry is broken.

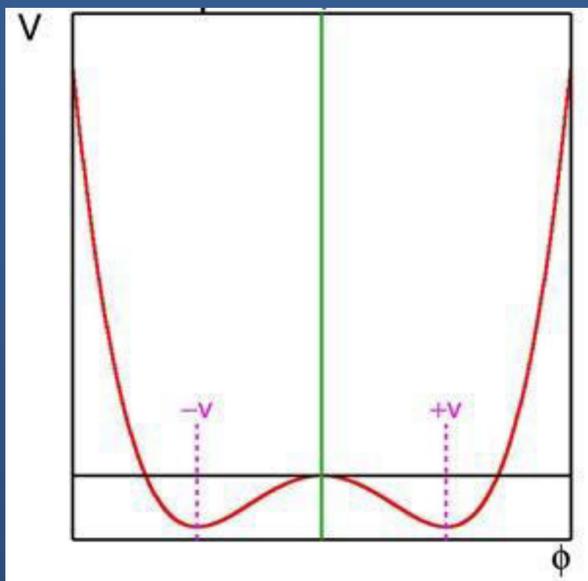


Figure 2. Higgs potential, with two minima.

Feynman Diagram of Double Higgs:

- The Standard Model Lagrangian contains a Higgs self-coupling term, which leads to double Higgs Production
- The Higgs boson is produced in proton-proton collisions at the Large Hadron collider at CERN
- Vector boson in one of the production mechanism in which the Higgs boson can be produced
- Vector boson fusion happens when quarks from each one of the two colliding protons radiate W or Z bosons that subsequently interact or fuse to produce a Higgs boson

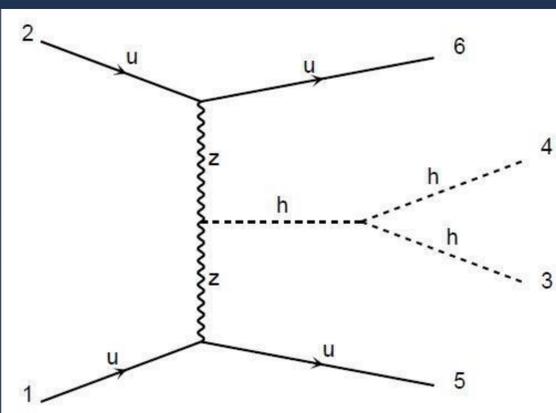


Figure 3. Feynman Diagram for double Higgs boson production

Results

- The result were produced by Madgraph (The MadGraph5 aMC@NLO); an Event generator that generate simulated high energy particle physics events
- It randomly generates events as those produced in the LHC.
- We studied the Kinematics of the double Higgs production ($pp \rightarrow hhjj$) and compared it to that of the single Higgs production ($pp \rightarrow hjj$) at beam energies 6500 GeV and 50000 GeV for 50000 events.

Total cross section (6500 GeV):

- Double Higgs:= 0.001712 pb
- Single Higgs := 4.522 pb

	Transverse Momentum (GeV/c)				Invariant Mass (GeV)
	Jet 1	Jet2	h1	h2	
Double Higgs	9.7*10	4.4*10	1.4*10 ²	8.8*10	5.6 * 10 ²
Single Higgs	8.6*10	3.9 *10	8.8*10	-	4.2 * 10 ²

Table 1. Kinematics for double and single Higgs production at 6500 GeV.

Total cross section (50000 GeV):

- Double Higgs:= 0.07735 pb
- Single Higgs:= 90.57 pb

	Transverse Momentum (GeV/c)				Invariant Mass (GeV)
	Jet 1	Jet2	h1	h2	
Double Higgs	1.1*10 ²	4.8 *10	1.5*10 ²	9.4*10	5.6 * 10 ²
Single Higgs	9.8 *10	4.4*10	1.0*10 ²	-	5.0* 10 ²

Table 2. Kinematics for double and single Higgs production at 50000 GeV.

Conclusion

- In studying the kinematics of the double Higgs production ($pp \rightarrow hhjj$) and the single Higgs production ($pp \rightarrow hjj$), we see that the total cross section increases with higher proton energy
- Thus increasing the accuracy of the probability of Higgs boson production
- The total cross section for the single Higgs production is significantly higher than that of double Higgs production for both 6500 GeV and 50000 GeV beam energies
- The Higgs boson has higher likelihood of being produced via single production than in double Higgs production
- The transverse momentum of the collision products and the invariant mass of the jets for double Higgs production is higher than that of the single Higgs production

References

- Cottingham W N and Greenwood D A 1998 *An introduction to the standard model of particle physics*, 2nd ed (Cambridge:Cambridge University Press)
- Bettini A 2008 *Introduction to elementary particle physics* (Cambridge, Cambridge University Press)
- Paschos E A 2007 *Electroweak theory* (New York: Cambridge University Press)
- Barger V 1987 *Collider physics* (Redwood City, California: Addison-Wesley)
- The MadGraphy5 aMC@NLO, <http://madgraph.hep.uiuc.edu>