Phenomenology and Experiment of Particle Physics

Higgs detection from beginning to end

1 PBL cycle – 1.5 ECTS

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1. The PBL-scenario

“Evidence for Higgs Boson Production in pp Collisions at sqrt(*s*)=14 TeV”

ATLAS Collaboration
CERN-PH-EP/2009-045
31 November 2009

Abstract
We have searched for a Higgs Boson with the ATLAS Detector at the Large Hadron Collider (LHC) in a sample of pp collisions at sqrt(s)=14 TeV with an integrated luminosity of 29.4 fb^{-1}. We found 106 events consistent with a Higgs boson production and decay through the channel qqH→ qqWW*. The estimated background in the sample was 60.3 events. The significance of the signal is 5.9σ using Poisson statistics. The Higgs boson was also searched for in the four lepton decay mode. 19 events consistent with a Higgs boson decaying into ZZ* → 4l were found, with an estimated background of 2.8 events. The statistical significance of the signal is 6.7σ. Fits to individual events in the four muon sample yield a Higgs mass of 138.6 +- 1.6(stat) +- 1.3(syst) GeV. No statistically significant signals were found in the decay modes H→γγ or H→bbbar. The statistics are too limited to firmly establish the existence of a Higgs boson by measuring its’ quantum numbers, or to prove whether the observed signal is a Standard Model Higgs or not. Nevertheless the observed signal is consistent with the Standard Model predictions.

2. Literature list

ATLAS Detector and Physics Performance Technical Design Report Vol I, ATLAS TDR 14, CERN/LHCC 99-14 (1999).

ATLAS Detector and Physics Performance Technical Design Report Vol II, ATLAS TDR 15, CERN/LHCC 99-15 (1999).

S. Asai *et al.*, ` Prospects for the search for a standard model Higgs boson in ATLAS using vector boson fusion´, Eur. Phys. J. C32 s02 (2003) 19.

V. Buescher and K. Jakobs, `Higgs Boson Searches at Hadron Colliders´, Int. J. Mod. Phys. Lett. A Vol 20 (2005), hep-ph/0504099v1 (2005).

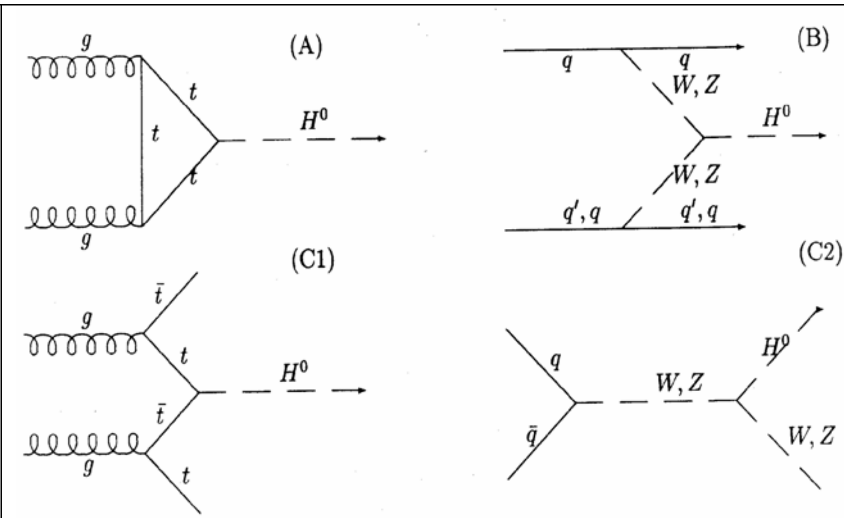
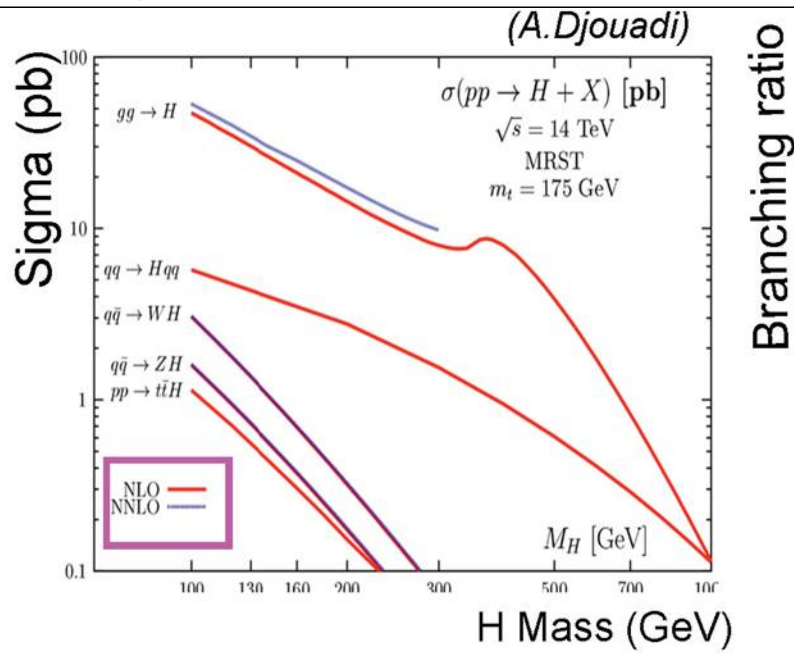
D. Rainwater, `Searching for the Higgs boson´, hep-ph/0702124v2 (2007).

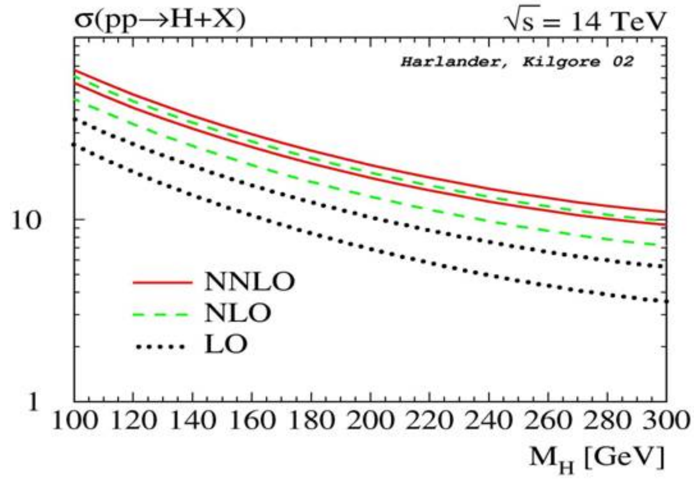
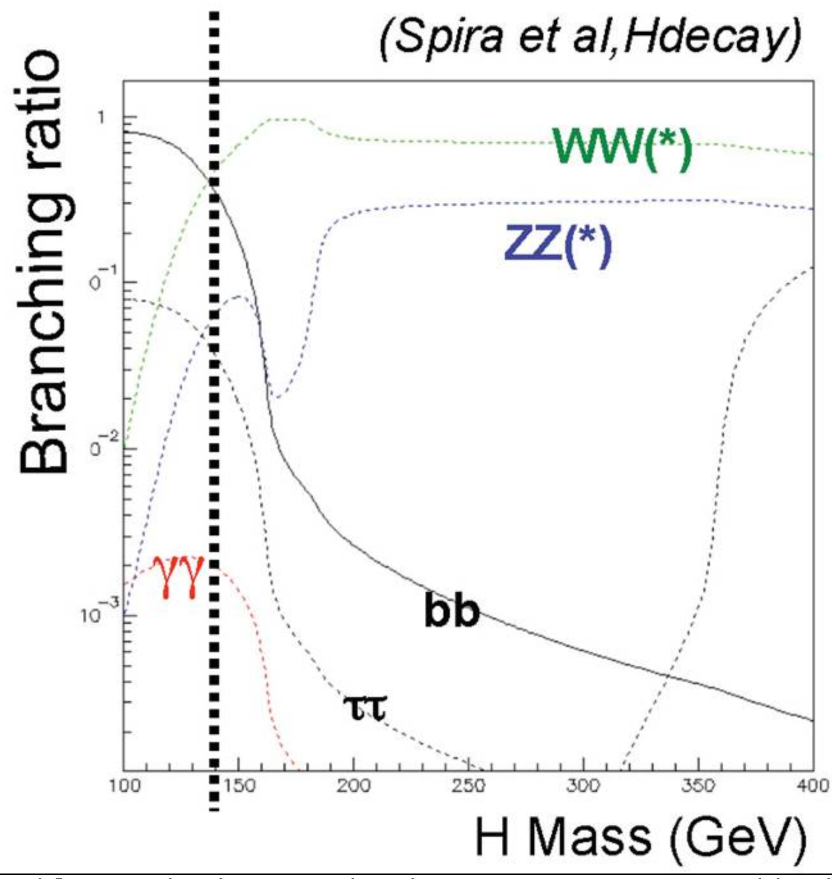
ATLAS Trigger Menus:
http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/HIGGS/trigger.html

W.-M. Yao *et al.*, The Review of Particle Physics, Journal of Physics G33 (2006) 1, http://pdg.lbl.gov/

3. Goals

- Higgs production at LHC: list production mechanisms, find out production cross-sections and decay branching fractions as a function of the Higgs mass, see Table 1.

a)	
b)	

c)		
d)		
	Table 1. a) Higgs production processes at LHC, b) Higgs production cross-section at LHC as a function of the Higgs mass, c) contributions from higher order corrections to the production cross-section, d) branching ratios of Higgs decays as a function of the Higgs mass.	

- Which are the production mechanisms and final states for the observed signals qqH→ qqWW* and H→ ZZ* → 4l?

- Estimate the number of produced signal events in the different production and decay channels for sqrt(*s*)=14 TeV and an integrated luminosity of 30 fb^{-1}.
- Why are the observed rates so much smaller than the produced rates? Answer: 1) Events have to be triggered, and the trigger selections have to be quite stringent in order to reject background as much as possible already at the trigger level. 2) Many selections have to be made in the analysis in order to reject the background further. 3) ATLAS fiducial coverage: events with very small angles with respect to the beam line cannot be observed.
- Discuss the consequences of the fact that one of the Z's/W's is off-shell.
- Consider which are the most important background processes. Try to estimate roughly their order of magnitude.
- How can the events be triggered in ATLAS? Which are the trigger signatures?
- Which are the most important analysis selections to reject the background?
- Statistical significance of a signal, Poisson statistics and Gaussian approximation.
- Measured width of the mass peak: which decay modes can be used to measure the width? Which decay modes have the best resolution? Is the measured width due to detection resolution, natural width, or both?
- Discuss how one could prove that the signal is really a Higgs, and whether it is a Standard Model Higgs or something else. A Higgs boson: quantum numbers should be measured. Quantum numbers: electric charge (neutral), colour charge (neutral), mass (free parameter), spin (0), CP (even), gauge coupling, Yukawa couplings. Decay mode $\gamma\gamma$ is important for proving that it cannot be a spin-1 and C=1 particle. Production cross-section and branching ratios give indication about whether the observed Higgs is consistent with the Standard Model or not. If one observes more than one Higgs-like particles with different masses, this would be a strong indication about an extended Standard Model.

4. Assignment: Higgs detection in ATLAS

- write an event generator for Higgs production by using PYTHIA. Assume Higgs decay mode H→ ZZ* → 4 leptons.
- write a simple parametrization to describe the ATLAS detector:
- remove decayed particles and neutrinos from the particle list.
- remove particles with p_T<0.5 GeV and |η|<2.5.
- make a separate list of muons and smear the p_T of the muons with a Gaussian with a mean equal to the true p_T, and standard deviation from the resolution given in Figure 1. Remove muons with |η|<2.4. Assume a muon identification efficiency of 90%, *i.e*. remove randomly 10% of the muons.
- make a separate list of electrons and photons and smear the energy of the electrons/photons with a Gaussian with a mean equal to the true *E*, and standard deviation obtained from the following formula for the energy resolution: $(\sigma/E)^2=(10\%/\mathrm{sqrt}(E))^2 + (1\%)^2$ (*E* given in GeV). Assume an electron identification efficiency of 70%, *i.e.* remove randomly 30% of the electrons.
- For the remaining charged particles (charged pions, protons), assume that each one of them can be misidentified as a muon with a probability of 0.2%. If a hadron is misidentified as a muon, apply the same transverse momentum resolution as for the real muons.
- For the remaining particles (charged pions, protons, neutrons), group them into jets by using a jet reconstruction algorithm. Assume that a jet can be misidentified as an electron with a probability of $P=7\mathrm{x}10^{-6}$. If you find any jets misidentified as an electron, apply the electron energy resolution to the jet energy.
- search for H→ ZZ* → 4 leptons signal, measure mass resolution.
- discuss trigger and backgrounds for these signals.

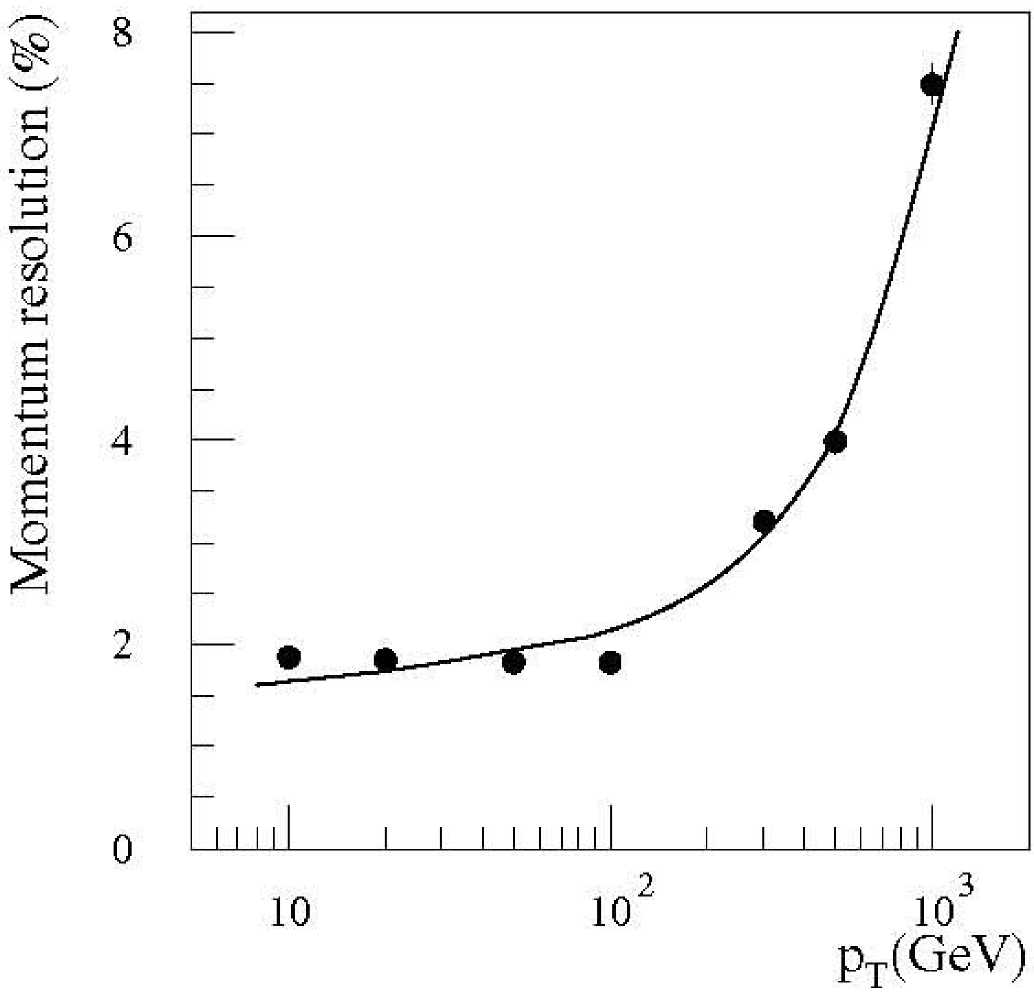


Figure 6-11 Simulated (points) and calculated (line) p_T dependence of the muon momentum resolution, ignoring energy loss fluctuations and for $|\eta| < 1.5$.

Figure 1. Muon momentum resolution in ATLAS as a function of the muon transverse momentum p_T.