Muons in early ATLAS data: from first collisions to W+ W- production

Ottersbach, J.P.

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
Summary & Outlook

The Long Awaited Collision Data

In March 2010, the ATLAS experiment at the Large Hadron Collider LHC at CERN started its long anticipated and very successful data taking stage. After almost 3 decades, from the first conceptual studies over the development and construction, the largest particle collider experiment ever built finally became operational, recording proton-proton collisions at a center of mass energy of 7 TeV. The additional time the LHC construction and commissioning required before starting the 2010 run was well used by the ATLAS collaboration. Based on simulated Monte Carlo samples and recorded cosmic muons, the detector alignment was improved and the software to reconstruct and identify the physics objects in data was studied, refined and updated. Detector as well as reconstruction software were consequently in a good shape the moment the first data arrived in 2010. Nevertheless, thorough studies of the performance of all sub-detector systems as well as all parts of the software on the recorded data are a crucial necessity before any complex physics analysis.

Besides investigating the performance of the $B$-field sensors that monitor the toroidal magnetic field in ATLAS which is necessary to measure the momenta of traversing muons, we used the early ATLAS data to scrutinize an important muon identification algorithm, the muon segment tagger MuTagIMO.

Muons in First ATLAS Data

At the very beginning of the data taking phase of ATLAS, muon segment taggers used to be neglected for very most physics analyses involving muons with sufficiently high transverse momentum to use combined algorithms for their identification ($p_T \gtrsim 8$ GeV). The mis-tag rate was simply too high so that, despite its high efficiency, the tagged muon collection was not sufficiently pure. Through detailed studies on first data as well as Monte
Carlo simulations, we were able to improve the performance of MuTagIMO considerably by lowering the mis-tag rate by about a factor 2 while maintaining the high efficiency of the algorithm. In our physics analysis detailed in the last chapter we demonstrated that the improved MuTagIMO segment tagger is a valuable addition to the established combined algorithms even for the identification of high momentum muons.

Besides MuTagIMO, there are five additional, independent algorithms to identify muons in ATLAS. In addition, the 'or' of combinations of algorithms is commonly used to increase the identification efficiency. In order to get an overview and detailed understanding on the performances of the individual algorithms and their commonly used combinations, we measured their efficiencies on data. A Tag-and-Probe method on $J/\psi$ particles was used which allowed us to measure not only the flat plateau region of the algorithm efficiencies but also the threshold curve, where they become operational. We hence obtained a complete picture of the individual identification efficiencies. Through the selection of calorimeter tagged muons instead of Inner Detector tracks as probes in the method, the measurement is the most precise of its kind in ATLAS. The results on first data were compared to the corresponding efficiencies on simulated Monte Carlo samples and scale factors depending on the transverse muon momentum and the pseudorapidity were determined. We concluded that the Muid algorithm family shows an overall higher identification efficiency with MuTagIMO being the most efficient muon identification algorithm in ATLAS.

**Measuring the $W^+W^-$ Cross Section Using Muons**

The excellent performance in 2010 and 2011 of both, the LHC and the ATLAS detector exceeded the most optimistic prediction by far. The amount and quality of data that has been recorded in 2011 by ATLAS allowed us to present an important measurement that does not only provide a crucial test of the Standard Model but is also essential to accomplish one of the major goals of the experiment, the discovery or exclusion of the Standard Model Higgs boson.

The production of $W^+W^-$ events includes triple gauge couplings, which arise from the non-abelian structure of the weak force. A precise measurement of the $W^+W^-$ production cross section is hence sensitive to an elementary feature of the Standard Model. Additionally, SM $W^+W^-$ events represent the largest and irreducible background contribution to Higgs boson searches in the $H \rightarrow W^+W^-$ channel, which is the dominant decay channel for Higgs masses larger than 135 GeV [66]. A search for the Higgs in this important channel requires hence a detailed understanding and therefore a precise measurement of the Standard Model $W^+W^-$ production.

We measured the Standard Model $W^+W^-$ production cross section in the di-muon final state, i.e. $W^+W^- \rightarrow \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$, taking advantage of our experiences with muons. At this point we profited from our work on the improved muon segment tagger MuTagIMO, which allowed us to increase our selection efficiency. Following our results on the measured muon identification efficiencies, we chose to select one Muid Combined muon and one muon that was either found by MuTagIMO or Muid Combined to select $W^+W^-$ can-
Figure 7.1: Event display of a $W^+W^-$ candidate in ATLAS (side-view). The track of the combined muon is depicted in red, the one of the segment tagged muon is depicted in green. The black arrow illustrates $E_T^{\text{miss}}$. Inner Detector tracks with $p_T > 1$ GeV are shown in orange and segments in the muon system are shown in purple. The visualization is based on ATLAS event 14817677 in run 187811.

didates. Figure 7.1 illustrates the abilities of MuTagIMO, showing an additional event display of a $W^+W^-$ event in which one muon ($p_T = 55.6$ GeV, $\eta = -0.06$) is missed by the combined algorithms since it falls within the feet region of the detector in the $\eta = 0$ acceptance hole of the ATLAS muon system. MuTagIMO successfully recovers this muon with only a single MDT segment present. Together with the three station combined muon in the event ($p_T = 23.5$ GeV, $\eta = 0.5$), all requirements on $W^+W^-$ events are passed. The two muon transverse mass is $m_T = 121.4$ GeV.

We measured the Standard Model $W^+W^-$ production cross section at a center of mass energy of 7 TeV to be

$$\sigma_{pp\rightarrow WW} (\sqrt{s}=7 \text{ TeV}) = (58.0 \pm 7.5 \text{ (stat.)} \pm 1.9 \text{ (theo.)} \pm 4.3 \text{ (exp.)}) \text{ pb} \quad (7.1)$$

which represents the most precise measurement of this cross section in the di-muon final state to date. Our result is in agreement with the SM prediction of $(47.0 \pm 2.0)$ pb, though the observed discrepancy in the central value sparked a discussion about the Higgs boson.

Is There a Higgs?

In our $W^+W^-$ cross section measurement we did not take the existence of a possible Higgs boson into account. It is hence reasonable to check the impact a Standard Model Higgs
Summary & Outlook

boson would have on our measurement. In order to do so, we assumed a low mass Higgs boson, as favored by the theory. We set the mass of the Higgs to \( m_H = 130 \text{ GeV} \) and added it to our backgrounds. The presence of the Higgs in the backgrounds lowers the central value of the measured \( W^+W^- \) cross section to \((53.2 \pm 7.5 \text{ (stat.)} \pm 4.7 \text{ (sys.)}) \) pb and hence the measurement agrees within statistical uncertainties with the prediction.

In addition, we estimated the Higgs boson cross section, assuming that the observed discrepancy between our measurement and the prediction is caused by the presence of the Higgs. The result, \( \sigma_{pp \rightarrow H \rightarrow WW} = (11.0 \pm 9.1) \) pb is well in agreement with the Standard Model predictions \( \sigma_{\text{predicted}}^{pp \rightarrow H \rightarrow WW} = 4.9^{+0.9}_{-0.7} \) pb, but the uncertainties are too large for any conclusive statement.

We would have loved to give a definitive answer to the question that titles this section. However, we could not present any proof for the presence of a Standard Model Higgs boson in the analyzed dataset. While some might already see a hint or even a glance of the Higgs in the presented measurement, more luminosity is needed to end the guesswork. Luckily, the successful run of the LHC and the ATLAS detector continues at full speed.

Supplement: DISCOVERY

On the 4th of July 2012 the two LHC experiments ATLAS and CMS presented the latest results on their Higgs searches to the global community of scientists as well as to the public media. Both experiments observe an excess of events at a mass of around 126 GeV with a significance of 5 \( \sigma \) (ATLAS), and 4.9 \( \sigma \) (CMS) respectively. A new particle has been discovered that resembles a Standard Model Higgs boson. ATLAS presented the analysis of a di-photon decay channel, as well as the channel with two \( Z \)-bosons in their leptonic decays (\( e, \mu \)). The analysis of the \( W^+W^- \) channel was not ready for publication at this date but also seems to confirm the observation in the other channels as has been discussed in internal ATLAS presentations. The extracted production cross section of the discovered particle agrees well with the Standard Model predictions for a Higgs boson with \( m_H = 126 \text{ GeV} \). However, more data is needed to measure additional properties of the discovered particle before definite conclusions on the Standard Model Higgs boson can be drawn.

This discovery also supports our findings in the last chapter. The shown event displays in Figure 6.6 and 7.1 might hence also show a Higgs boson in its \( W^+W^- \) decay.