Fortgeschrittenen Praktikum
Summer term 2019

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Studying the Z Boson with the ATLAS Detector at the LHC

Aarin Mielke & Thomas Ackermann

Abstract

Data from CERN in Geneva was analyzed in order to calculate the invariant mass of the Z Boson

Contents

1 Introduction

The main goal of the lab course is to analyze data from the ATLAS experiment and to calculate the invariant mass of the Z Boson.

1.1 The Standard Model of Particle Physics

The Standard Model of Particle Physics (fig. 1.1) is the summarization of the known structure of matter. It implies, that matter is composed of the twelve elementary fermions with spin $\frac{1}{2}$, which are the quarks and leptons. Each of these particles has a corresponding anti-particles, which are equal, except that they have opposite charge.

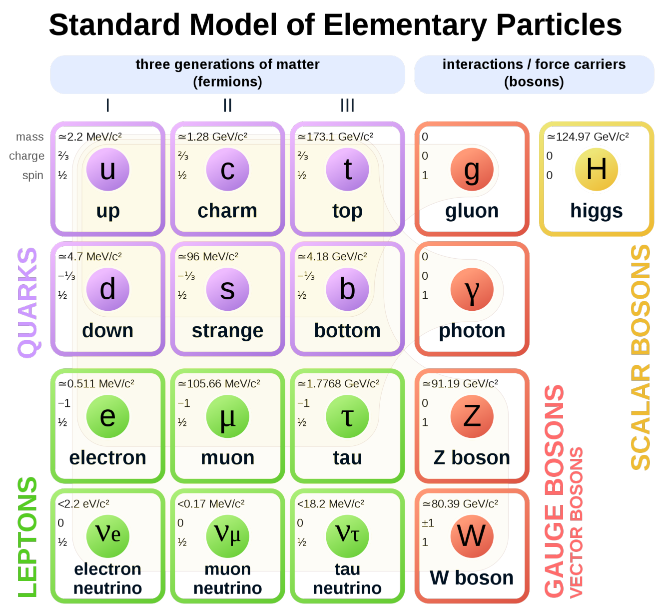

Figure 1.1: standard model of particle physics

There are three different interactions which are mediated by bosons carrying spin 1. The weak force exchange particles are the massiv Z and $W^{\pm}$ bosons, the massless photons for the electromagnetic force and eight massless gluons are mediating the strong force.

1.2 Drell-Yan Process

A Z Boson can be created during the so called "Drell-Yan" Process (fig. **??**).

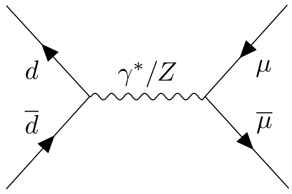

Figure 1.2: Drell-Yan process

This process happens predominatly in proton-proton collisions. When a quark and an anti-quark collide either a virtual photon γ^* or a Z Boson can be produced. The γ^* or the Z can then split into a lepton and its anti-particle partner like electron-positron or muon and anti-muon. The sum of the lepton and anti-particle partner momenta will then add up to the former boson momentum. A peak around 90 GeV will be observed corresponding to the Z boson.

1.3 ATLAS Detector

The Detector consists of three main components: inner detector, calorimeters and the muon spectrometer. They are onion-like constructed. The inner detector, the innermost layer, is mainly used to reconstruct the trajectories of electrically charged particles and to determine their momentum. With three aswell onion-like ordered tracking detectors, the pixel detector, the semi-conductor tracker and the transition radiation tracker, the inner detector can measure charged particles in a range of $|\eta| < 2.5$ and a $p_T > 400$ MeV.

The electromagnetic and the hadronic calorimeter allow to reconstruct the shower shapes of the showers from electromagnetically and strongly interacting particles. They are designed to contain the whole shower and cover a range up to $|\eta| < 4.9$. A precise energy measurement is possible.

The outermost layer is the muon spectrometer. Muons would espace the ATLAS detector without it and can now be tracked.

2 Experimental procedure

2.1 Getting familiar with the data

Before starting with the computation of the mass of the Z bosons one has to make oneself familiar with the provided data of the ATLAS detector. The given data is preselected. One only has data from events where a primary vertex was found and at least one lepton has a minimal transverse momentum of $p_T = 25$ GeV.

2.1.1 Particle entrance

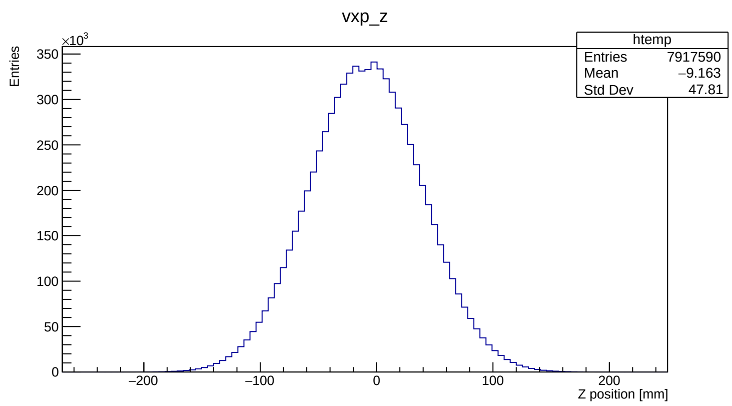

Figure 2.1: z-postion distribution, particle entrence in ATLAS detector

To check where the particle enter the detector, one can evaluate the given date for the vxp_z variable. The results are shown in fig. 2.1. The mean is shifted for -9 mm. This confirms, that the given data is from 2012 because collisions of bunches were not calibrated to the 0.0 position back then. Left and right to the mean are two maxima, which can also be explained with the assumption above. A momentum change of 90 degrees is impossible and most of the collisions take place at the place of the first intersection.

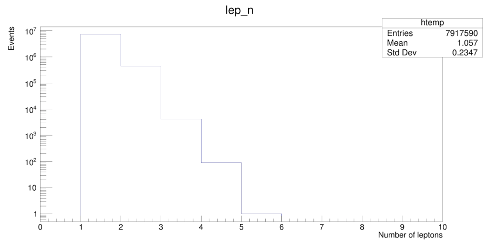

Figure 2.2: leptons recorded per event

2.1.2 leptons per event

To figure out, if one found an Z decay, one analysis the leptons per event value of the data (fig. 2.2). Around the wanted 2 leptons, one gets many events with 1 and 3 leptons. For this events to happen, one needs a $W^{\pm}$ decay involved.
Feynmann diagramms ?

2.1.3 data of the leptons

The stored data about transvers impuls, the ϕ degree and η varible provide information about all the leptons recorded by the ATLAS detector and accordinlgy has more entries than the former analyzed data variables.

2.2 Calculation of the invariant mass of the Z boson

According to the structure of the ATLAS detector, one can calculate the invariant mass in the following way:

$$M_\mu = \sqrt{p_\mu p^\mu} = \sqrt{E_1 E_2 - \vec{p_1}\vec{p_2}} \tag{2.1}$$
$$= \sqrt{E_1 E_2 - p_{T_1} p_{T_2} (\cos(\varphi_1)\cos(\varphi_2) + \sin(\varphi_1)\sin(\varphi_2) + \sinh(\eta_1)\sinh(\eta_2))} \tag{2.2}$$

An attempt to calculate it with the above given formula and the build-in function `TLorenz` in `ROOT` provided the exact same result. The calculated results will therefore be based on the `ROOT` method.
The first attempt to measure the mass was done by limiting the data to 2-lepton events. Further one ignored the events where $M_\mu^2 < 0$.
In 2.3, one can identify four peaks. The one on the right, at approximatly 91 GeV, is the subject of this investigation and the goal is to characterize it better in the course of this paper.
The two on the left are respectable by the virtue of the J/Ψ and the Υ decay.

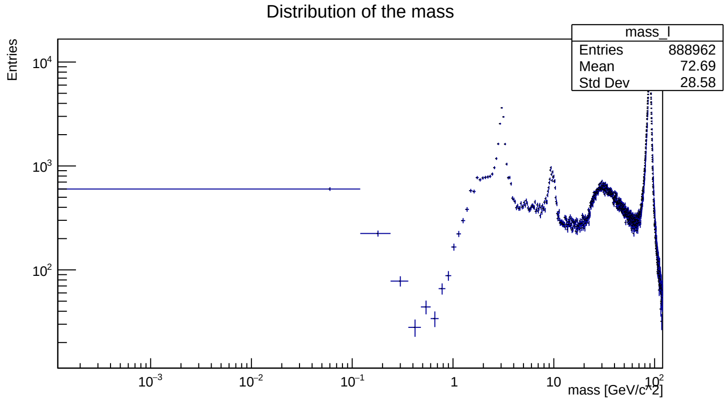

Figure 2.3: invariant Mass distribution of 2 lepton events

2.3 Selecting

The next step was to assert restictions to the dataset in order to ensure that a Z decay was meassured. The impact of each of the restrictions can be seen in fig.2.4. The eventbased

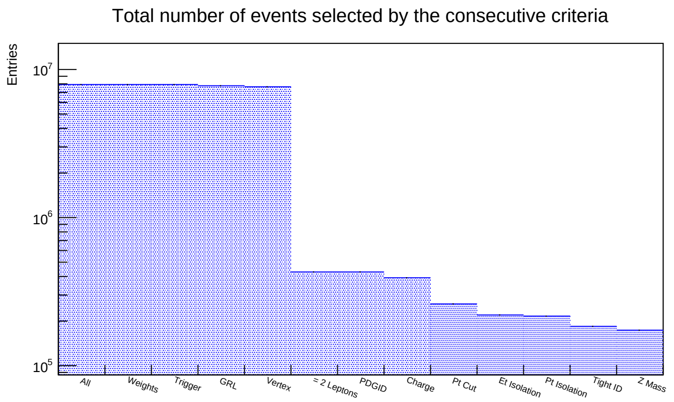

Figure 2.4: cutflow histogramm

cuts (in fig.2.4 the first four columns) have close to no impact on the selection because the given raw data from ATLAS is preselected on event and physics object level. As seen, the highest cut impact provides the 2 lepton cut, which is necessary for a Z decay. ATLAS only required one well measured primary vertex to save it as an event. The cut with the second highest impact is the p_T Cut. Due to the high mass of the Z Boson, one can restrict oneself to leptons with at least 25 GeV. The distribution of the transvers momenta from the two decay leptons peaks around half the Z mass.

2.4 Comparing Data and MC Simulation

One can now ask how well the meassured data matches with the theory. In order to do this one can do MC Simulations and then compare with the data (fig. 2.5). Three MC simulations for the possible leptons after the Z decay are analysed in the same way as in section 2.3 explained. One has to scale the results according to the luminosity of the ATLAS detector ($1fb^{-1}$). The comparison yields matching results.

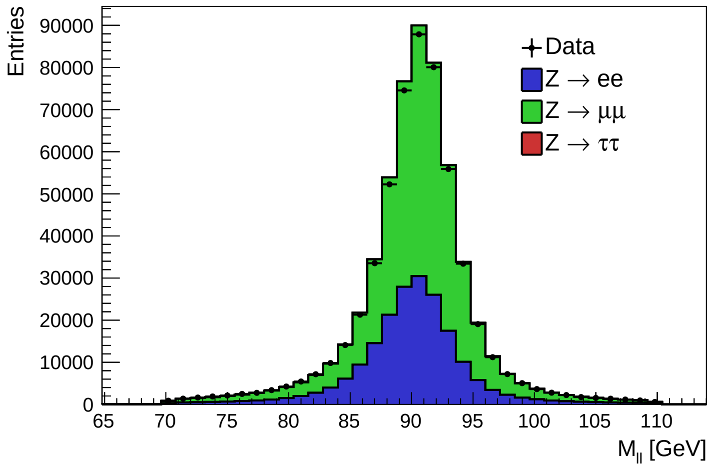

Figure 2.5: Comparison of meassured data and MC simulation

2.5 Fitting the Z mass

The best fit can be achieved by computing a convolution of a Gauss and a Breit-Wigner Curve. The reason is the Doppler effect (?)

2.6 Determining efficiencies

2.7 Systematic errors

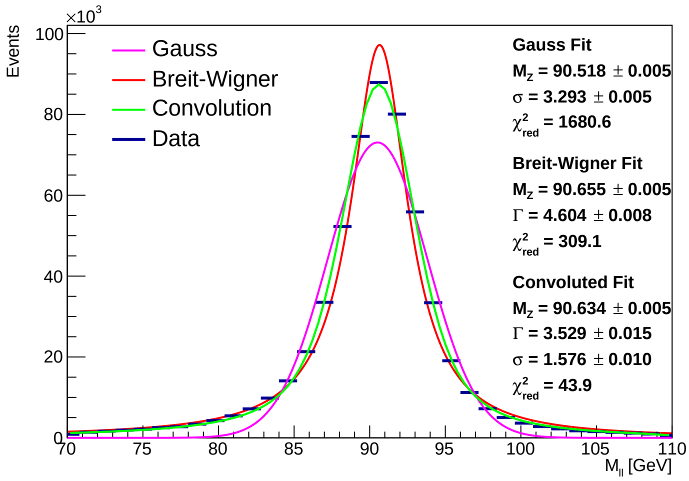

Figure 2.6: Comparison of meassured data and MC simulation