Top Search in the Dimuon Channel at the CMS Experiment

Dirk Dammann

Deutsches Elektronen Synchrotron, Hamburg

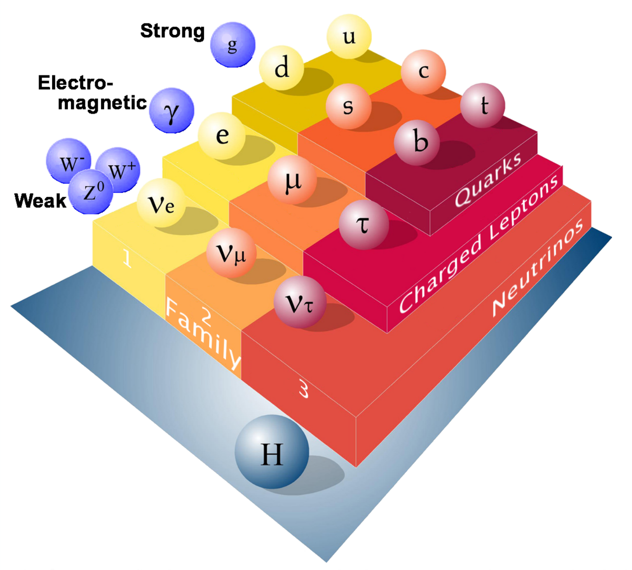
dirk.dammann@desy.de

Introduction

The top quark is until today the heaviest observed particle in the standard model of particle physics. As yet it was only produced at the Tevatron in the USA in proton-antiproton collisions since earlier accelerators didn't have enough energy.
At the Large Hadron Collider LHC top quarks will be produced in a 1000 times higher rate then at the Tevatron. One reason is that the LHC has a much higher luminosity which means that there are much more collisions per second. The other reason is that the proton beams at the LHC have a higher energy which increases the probability of top pair production in each collision. This probability to create a certain particle in a single collision at a given energy is called the particle's production cross section. The production rate is nothing else than just the product of the luminosity times the cross section. This higher top production allows to measure the top's properties in a much more precise way.
The first aim of my work is the rediscovery of the top quark at the LHC after the begin of the data taking next winter. If there will be enough data available after the first run period also a first measurement of the production cross section will be possible.

The Standard Model

All experimental knowledge of particles and their interactions is condensed in the standard model. These interactions are the strong, the electromagnetic and the weak interaction which are described by the exchange of so called gauge bosons. The fourth known interaction – the gravity – cannot be described in the current standard model but this doesn't matter since it is to weak to play an important role in particle physics. All forces (in physical sense) that we can observe in nature can be derived from one of these four interactions.

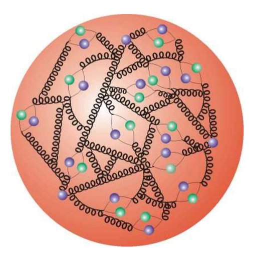


Particle physics can be illustrated in a very ordered way. The twelve matter building particles which are shown on the tiers can be separated into three families. The first family which is shown here in shades of yellow contains the electron neutrino ν_e, the electron e and two Quarks u and d. The particles of the second (orange) and third (red) family have exactly the same properties with the exception that their mass is higher. To each of these twelve elementary particles exists an oppositely charged antiparticle but these antiparticles are not shown here to keep the drawing simple.

In each family we find four particles: one neutrino, one charged lepton and two quarks. They are classified by the forces they underlie. The three neutrinos (ν_e, ν_μ, ν_τ) are here displayed on the lowest tier which means that they only underlie the weak interaction which is mediated by the charged $W^\pm$ and the uncharged Z^0-Boson. These two bosons are also very massive and have a mass about half as large as the top mass. All other particles are much lighter. On the next higher tier we find the charged leptons (e, μ, τ) which additionally interact electromagnetically via photon (γ) exchange. On the highest tier there are two quarks in each family so overall six quarks (d, u, s, c, b, t) which interact with all forces and are bounded to hadrons by gluon g exchange.
The Higgs-Boson H that is drawn in the foreground is the only standard model particle which is not discovered yet. But theoretical physicist expect its existence to explain how the other particles get their mass by coupling to the Higgs. Hopefully the Higgs will be discovered at the LHC.

Hadrons

The strong interaction effects that no free quarks can be observed. They are always combined to hadrons. One example for a hadron is the proton which consists in first order of two u and one d-quark.



On a closer view these three quarks exchange gluons between each other which glue them together. These gluons can again split up to quark-antiquark pairs so that even a particle like a proton has a very complex structure. The German Electron Synchrotron (DESY) has played a vital role in revealing the proton structure with the HERA-Accelerator between 1990 and 2007. These conclusions are important to understand later accelerator physics as at the LHC.

Detectable Particles

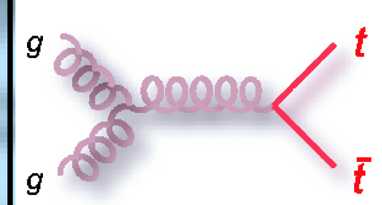
By far the most particles which are known decay almost immediately. Qarks and charged leptons of the second and third family decay to particles of the first one. So all than can be observed in an high energy experiments are their decay products. The most important particles which can directly be seen in a detector experiment are

- electrons,
- muons which live long enough to leave a track,
- charged hadrons like protons, pions or kaons,
- uncharged hadrons like neutrons and kaons.

Hadrons originating from one quark or gluon are often collimated into jets since their direction is determined from the original particle's direction of flight.

The Top Quark

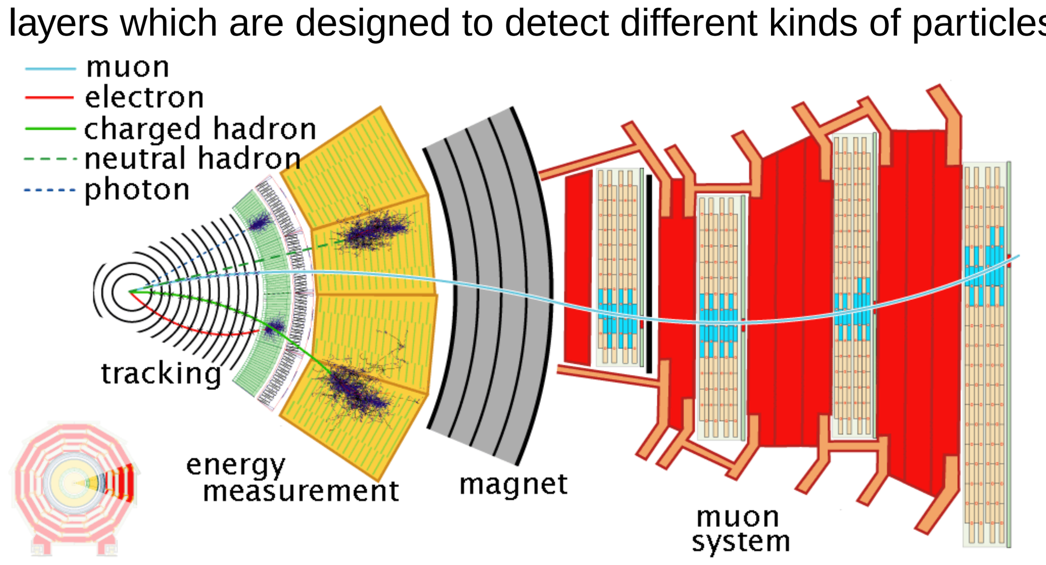
The top quark is by far the heaviest elementary particle in the standard model. Its mass is about 180 times higher than the proton mass and comparable with the mass of a whole gold atom. At the LHC the top will mostly be produced in top-antitop pairs ($t\bar{t}$) from two fusing gluons form the two colliding protons.



A further characteristic of the top is that it is the only quark which doesn't build hadrons because it decays so fast (within 10^{-25} seconds) after its production that no hadronization can take place.
A top almost always decays into a b-quark that makes a b-jet and a W-boson. This W instantly makes a further decay either into two hadronic jets or into a charged lepton and a corresponding neutrino of the same family. So for example a top can decay into a b-jet plus a muon μ plus a muon neutrino ν_μ.
A rediscovery and exact measurement of the top quark's properties is also important since events with top quarks are also background for the Higgs-Boson or processes in other exotic theories like supersymmetry.

The CMS experiment

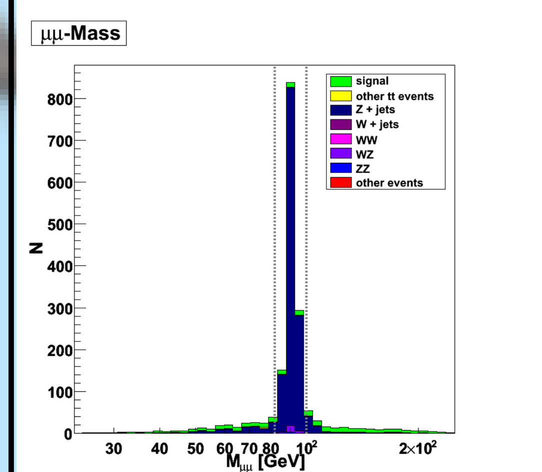
The CMS detector is one of the experiments at the LHC. It is a multipurpose detector which is build around one of the LHC collision points in order to detect as many emerging particles as possible. Beginning from the collision point it is built of different layers which are designed to detect different kinds of particles.



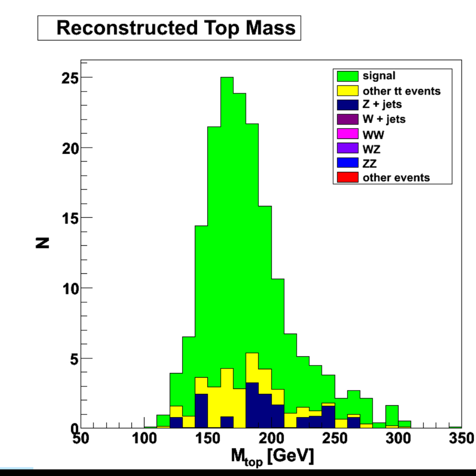
The picture shows a slice through the CMS detector going through all layers. Closest to the interaction point we have a silicon tracker which can reconstruct the way of all particles with electric charge. Since the tracker is embedded into a magnetic field all tracks of charged particles are bended. From the curve the particle's momenta can be calculated.
The next two layers are the electromagnetic and the hadronic calorimeter where most particles are stopped and their energy is measured.
Muons can pass the calorimeters and even the magnet and are detected in the muon system.

My Analysis

My own analysis concentrates on the dimuon decay channel of $t\bar{t}$-pairs. This means the top decays into a b and a W^+ which further decays into a positively charged muon μ^+ and a muon neutrino ν_μ while the anti-top $\bar{t}$ decays into a anti-b-quark $\bar{b}$, a negative muon μ^- and a anti-neutrino $\bar{\nu}_\mu$. So all together the event signature consists of two oppositely charged muons, two b-jets and two neutrinos which are not directly observable since they do not interact with the detector. Only one out of 100 $t\bar{t}$-pairs decays in this channel but this disadvantage compensated by the clear signature.
The challenge in every analysis is to separate ones signal from similar looking background events. Only one of ten thousands of recorded collisions produces a $t\bar{t}$-pair in my signal channel. Most important background events to be considered are events which contain other very massive particles i. e. one or two W or Z-bosons. When such particles decay most of there mass is directly transformed into kinetic energy of their daughter particles according to Einstein's famous formula $E = m \cdot c^2$. Because of these energy kick muons from Z and W-decays (and therefore also in my signal channel) are mostly found outside of jets so one get can rid of most of the background events by looking only at events containing two of such isolated muons.



Further events with one Z^0 decaying into two muons can be suppressed. Under the assumption that in one event both muons come from one particle this particle's mass can be reconstructed from the muon's momenta. The histogram shows this on the basis of a computer simulation. The different event types have different colors. The blue Z^0-events give a clear peak around the Z^0-mass of 91GeV while the green signal events are smooth distributed. Most Z^0-events are excluded by omitting events with a muon-muon mass between the two dashed lines.
A further selection can be done on the jets. Most events have more than two jets but most of them are not from b-quarks. Since hadrons containing b-quarks live long enough to decay some millimeters from the collision point they can be distinguished from other jets. Most tracks in an event come directly from the collision point which is called the primary vertex. If the tracks in one jet can be attached to a secondary vertex this jet is tagged as a b-jet. To apply this b-tagging a good understanding of the tracking detector's configuration is very crucial.



After this selection a very clean sample remains. The right histogram shows the reconstructed top mass for all events. From the number of this reconstructed $t\bar{t}$-events and an understanding how efficient these reconstruction is the cross section can be calculated.

SUSSP 2009, 65th Scottish Universities Summer School in Physics, 17-29 August 2009, St Andrews