Verification of a novel calorimeter concept for studies of charmonium states
Guliyev, Elmaddin

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2011

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
1. Introduction

The Standard Model (SM) of elementary particles and fields has been very successful in describing the fundamental constituents of matter and their interactions. According to the theory, the particles and force carriers are divided into three families as shown in Figure 1.1 [1].

The Standard Model has been extensively tested by various experiments at high energies and it has shown a remarkable predictive power which helped to observe yet undiscovered particles. However, it leaves us with many unsolved questions [2].

Recently the Large Hadron Collider (LHC) has started to run and it accelerates two beams of particles of the same kind (protons or ions up to Pb ions). The collision energy for protons will go up to 14 TeV.

LHC experiments at these high energies may help to understand some of the yet unsolved questions of the SM. In the Standard Model the origin of mass of the fundamental constituents of matter is explained by the Higgs mechanism: the whole space is filled with a ‘Higgs field’ and by interacting with this field, particles like leptons and quarks can acquire mass. The Higgs field is mediated by the Higgs boson [2, 3]. If such a particle exists, experiments at the LHC should be able to detect it and determine its properties. However, the Higgs mechanism does not explain, why some particles are heavy and others are light or extremely light, like the neutrinos. Nor does the Higgs mechanism explain how particles composed of light quarks can acquire a large mass.

According to the current theories, the Universe born from the Big Bang went through a stage during which matter existed as a sort of extremely hot, dense soup, called quark-gluon plasma (QGP) composed of the elementary building blocks of matter [3]. As the Universe cooled, the quarks became trapped into composite particles such as protons and neutrons. This phenomenon is called the confinement of quarks. The LHC is able to reproduce the QGP by colliding two beams of heavy ions (Pb ions). In the collisions, the temperature will exceed 100 000 times that of the center of the Sun.

Quantum chromodynamics (QCD) is a main component of the SM together with the electroweak theory [1, 2] and plays a key role in describing the strong interaction between quark and gluon constituents of matter.

In the past decades QCD has been extensively tested at high energies, where the strong coupling constant becomes small and perturbation theory applies. However, in the low-energy regime QCD starts to become non-perturbative. This situation requires the development of approximate theoretical models based on effective field theories which are rooted on the symmetries of QCD and are formulated in terms of the more relevant low-energy (i.e. hadronic) degrees of freedom. The exact formulation of an effective field theory depends on the energy range of interest.

In a more direct approach, based on first principles, the problem of solving non-perturbative QCD is treated by numerical calculations on a space-time lattice. However, computational limitations may lead to systematic errors that may require a comparison to results of an effective field theory. Such approaches need to be scrutinized by confrontation with precise experimental data e.g. on hadron masses, hadron decay rates and information.
on the structure of hadrons. The Fermilab Lattice Collaboration [4] calculated the mass value of the hadrons and was able to reduce the uncertainty in the mass value from the 10% level to about 2% [5].

Figure 1.1: Elementary particles and the gauge bosons carrying the forces in the Standard Model.

The PANDA (antiProton ANnihilation at DAArmstadt) experiment at the recently founded Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany, will address the yet unresolved questions of nonperturbative QCD [6] with antiproton beams in the 1.5 – 15 GeV/c momentum range. The realization of this experiment to study QCD in the nonperturbative regime can therefore be considered as one of the most important events in recent years for hadron physics. One of the main purposes is to study hadrons containing a charm quark or consisting of a charm c and anti-charm \( \bar{c} \) quark. Such systems are particularly suited for comparisons with theory since the charm quark allows a nonrelativistic approximation due to its large mass. The rich spectrum of charmonium (\( c\bar{c} \)) states and the transitions between these states can be accessed directly in proton – antiproton annihilations. This is a great advantage over electron-positron annihilation experiments where only states with the photon quantum numbers can be accessed directly.

PANDA will be a unique experiment providing precise data for the understanding of hadronic bound states and resonances, the generation of exotic quark-gluon structures, and the importance of QCD symmetries. The physics program of the PANDA experiment focuses on charmonium spectroscopy and the search for hybrid states (i.e. mesons with an explicit gluon component) and glueballs (i.e. states consisting merely of gluons). Moreover, a large variety of other physics topics such as the study of hypernuclei, in particular those with two \( \Lambda \) hyperons, and measurements of the timelike form factor of the proton [6] will be addressed.

The study of the spectrum of charmonium states is an important research topic and a powerful tool for the understanding of the strong interaction [6]. Precision measurements of mass, width and decay branches of all charmonium states will provide information on the quark-confining potential and its spin dependence. Such a broad physics program of the PANDA experiment requires a multi-purpose detector with the important component of a high-resolution Electromagnetic Calorimeter (EMC) [7].

For high precision charmonium spectroscopy a low photon energy threshold is required.
One of the crucial issues is to optimize the energy resolution for studying narrow resonances with high precision. Another important requirement is the minimization of the time resolution to less than 1 ns for a clean event correlation and background suppression. These above-mentioned requirements demand a state-of-the-art development of the PANDA EMC front-end electronics and extensive performance studies.

This thesis will focus on research and development of the front-end electronics for the PANDA Electromagnetic Calorimeter.

- Chapter 2 gives a brief introduction to charmonium and exotic hadronic states. The physics program of the PANDA experiment is described.

- Chapter 3 provides an overview of the PANDA detector. The most important detector components are briefly discussed.

- The working principle and technical details of the PANDA EMC are explained in Chapter 4.

- Chapter 5 provides a description of the readout electronics for the PANDA EMC. It gives an overview of the employed preamplifiers, digitizer modules and the developed data acquisition and analysis scheme.

- In Chapter 6 the three different test measurements with LED light pulser, high-energy ion and photon beam and their analysis results are described.

- Chapter 7 assesses the implementation details of the online-analysis algorithm into a commercial XILINX Spartan FPGA development-board and SIS3302 Sampling ADC.

- Chapter 8 provides a simulation study for the PANDA EMC. Results will be discussed for single photons hitting a $3\times3$ crystal array and for the decay of the $h_c$ charmonium into $7\gamma$ detected with the PANDA EMC.