TUGAS AKHIR

RECONSTRUCTION OF D^0 MESON USING THE ALICE DETECTOR IN P-P COLLISION AT CENTER-OF-MASS ENERGY OF 13 TEV

MEUTIA WULANSATITI NURSANTO

NPM: 2013720011

PROGRAM STUDI FISIKA
FAKULTAS TEKNOLOGI INFORMASI DAN SAINS
UNIVERSITAS KATOLIK PARAHYANGAN
2017

LEMBAR PENGESAHAN

RECONSTRUCTION OF D^0 MESON USING THE ALICE DETECTOR IN P-P COLLISION AT CENTER-OF-MASS ENERGY OF 13 TEV

MEUTIA WULANSATITI NURSANTO

NPM: 2013720011

Bandung, 2 Juni 2017

Menyetujui,

Pembimbing Utama	Pembimbing Serta
Sylvia Hastuti Sutanto, Ph.D	**Suharyo Sumowidagdo**

Penguji 1

Reinard Primulando, Ph.D

Mengetahui,

Ketua Program Studi Fisika

Philips N. Gunawidjaja, Ph.D

PERNYATAAN

Dengan ini saya yang bertandatangan di bawah ini menyatakan bahwa tugas akhir dengan judul:

RECONSTRUCTION OF D^0 MESON USING THE ALICE DETECTOR IN P-P COLLISION AT CENTER-OF-MASS ENERGY OF 13 TEV

adalah benar-benar karya saya sendiri, dan saya tidak melakukan penjiplakan atau pengutipan dengan cara-cara yang tidak sesuai dengan etika keilmuan yang berlaku dalam masyarakat keilmuan.

Atas pernyataan ini, saya siap menanggung segala risiko dan sanksi yang dijatuhkan kepada saya, apabila di kemudian hari ditemukan adanya pelanggaran terhadap etika keilmuan dalam karya saya, atau jika ada tuntutan formal atau non-formal dari pihak lain berkaitan dengan keaslian karya saya ini.

Dinyatakan di Bandung,
Tanggal

Meutia Wulansatiti Nursanto
NPM: 2013720011

Rekonstruksi meson D^0 dilakukan dari mode peluruhan $D^0 \rightarrow K^- \pi^+$. Deteksi produk peluruhan dari D-meson dilakukan dengan menggunakan detektor ALICE. Rekonstruksi dilakukan dengan 55 juta *minimum bias event* dalam tumbukan proton-proton di energi-pusat-massa ($\sqrt{s}$) 13 TeV. Terdapat sekitar 1417 ± 87 meson D^0 setelah seleksi di selang p_T $1 < p_T < 24$ GeV/c. Perbandingan dengan rekonstruksi D^0 pada $\sqrt{s} = 7$ TeV dari Run 1 juga dilakukan. Penjelasan mengenai Model Standar, terutama pada bagian interaksi kuat disediakan. Karakteristik khas dari teori interaksi kuat, *Quantum Chromodynamics*, diuraikan bersama dengan perannya dalam menjelaskan produksi meson D. Selain latar belakan teoritis, deskripsi detektor ALICE juga disediakan.

Kata Kunci: Meson D, *Quantum Chromodynamics, Large Hadron Collider*, ALICE

Abstract

Reconstruction of D^0 meson was done in the decay mode of $D^0 \rightarrow K^-\pi^+$. The detection of the D^0 meson's decay products was done using the ALICE detector. The reconstruction was done with a data sample of 55 million minimum bias events in proton-proton collisions at centre-of-mass energy ($\sqrt{s}$) of 13 TeV. About 1,417 ± 87 D^0 meson was counted after selection cuts at $1 < p_T < 24$ GeV/c. Comparisons with D^0 reconstruction at $\sqrt{s} = 7$ TeV from Run 1 was done. A description of the Standard Model, especially the realm of the strong interaction is provided. Peculiar characteristics of the theory of the strong interaction, Quantum Chromodynamics, is outlined along with their roles in explaining the production of the D meson. Aside from the theoretical background, a description of the ALICE detector is provided.

Keywords: D^0 meson, Quantum Chromodynamics, Large Hadron Collider, ALICE

PREFACE

Many thanks are due to everyone who has supported me in writing this final project titled Reconstruction of D^0 Meson Using the ALICE Detector in p-p Collision at Centre-of-mass Energy of 13 TeV. The writing of this final project is done as a requirement to earn the degree of Bachelor of Science (Sarjana Sains) from the Faculty of Information Technology and Science of Parahyangan Catholic University. During the process of writing this final project I have received advice, help, and support from many people that benefited to the writing of this final project. As such, it is only appropriate to express the utmost gratitude to everyone, but not limited to, mentioned in the following.

Firstly, many thanks to Dr. Suharyo Sumowidagdo who has supervised me throughout the writing of this final project. I am immensely grateful for your patience in teaching and guiding me into the realm of experimental particle physics, which I had almost no knowledge of previously. I am also grateful for your faith in me on completing this final project, in regard of my complete inexperience on the topic. Also I am forever grateful for the opportunities you have opened up for me, CERN Summer Student Programme is just an example of many.

Thank you also to Dr. Sylvia Hastuti, for agreeing to be my main supervisor and for always being available whenever I was ready to talk about my final project. Although our chats more often than not ended up on a tangent from the final project, I have always enjoyed chatting with you about many things from processes on getting scholarships to what food to eat in Switzerland.

Thank you to Dr. Reinard Primulando, my examiner, who has supported and encouraged me on delving into experimental particle physics since that faithful day of me recognizing a laser cut piece of art that was ATLAS in a rectangular prism. Thank you for your willingness to have many random conversations with me every time I decided to come by your office. Many of those conversations have served to add a broad spectrum of insight, from what it is like to be a researcher to how guillotines are still used until recently. Thank you also for your concern about my future, as demonstrated by your daily question on what I am going to do after summer school, which I almost always answered with ”I have no idea”. Although recently we have seem to figure that one out.

Thank you to everyone in High Performance Computing Lab at LIPI: Pak Rifki, Mas Adit, Mba Inna, Mba Nida, Mas Abka, and Mas Uje. Although I had no business on the lab itself, everyone have been welcoming and supportive on my working on this final project. Special thank you to Mas Nizar, for your support and help on figuring out the workings of the complicated codes required to run for this final project.

Thank you to all lecturers at Department of Physics of UNPAR, Prof. Benedictus Suprapto Brotosiswojo, Dr. Aloysius Rusli, Dr. Paulus Cahyono Tjiang, Dr. Haryanto Mangaratua Siahaan, Dr. Philips Gunawidjaja, Elok Fidiani, M.Sc., Kian Ming, M.Si, Risti Suryantari, M.Si., Flaviana, M.T., Drs. Janto Sulungbudi, for your time and effort to teach me physics throughout the years. In particular thank you to Dr. Paulus and Dr. Philips for your effort on sorting out my certificate of education from high school. Without your efforts, I would not be here studying physics. Also special thanks to Drs. Janto Sulungbudi, who has guided me throughout the years, and also for your efforts to, and I quote, "reprogram me into thinking like you", which I have enjoyed very much.

I am grateful to all of my friends at department of physics for the support and encouragements. In particular I am grateful to everyone from the year of 2013: Sovia, Shierly, Felipa, Michael, Sovy, Fahmi, Santo, and Harry, for the support and encouragements, especially near the day of defence. Special thanks to Sovia, for your willingness to let me stay over at your place every time I was too tired to go home. Also thank you to Konita, whom I learned a great deal from in term of patience. You will always be in my heart.

I am also grateful to my very special friend, Surya, for the continuous support and encouragements whenever it was needed and more. Also to my friends Frieda and Jessica, for never failing to become a source of entertainment and support.

Finally, a big thank you to my family and relatives (both human, feline, and canine) for their love and support. Especially warmest thanks to my Mom for her love and support through the good and the bad throughout my life. You have been a bedrock and an inspiration for everything I have done, and no matter how far away I went, and no matter how long, I know there will be a home I could come back to. Without you, none of this would have been possible.

Bandung, Juni 2017

Writer

Contents

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1.1 Motivation

Since as early as 6th century B.C.E., the idea that all matter were comprised of elementary particles was already familiar. It was Democritus of ancient Greece who proposed that all matter was composed of small, invisible particles called atoms [11]. This idea later developed into natural philosophy called atomism, from Greek *atomos*, meaning "uncuttable". The idea prevailed in Europe until 2nd century C.E., when after Galen had presented his extensive discussion on atomism [12]. Since then no serious work was done on the subject. It was in the 17th century that the idea of atomism was resurrected by French philosopher Rene Descartes.

The advancement of engineering and technology in the 18th century pushed scientists to re-question the idea of the composition of matter. In the 19th century, John Dalton concluded that elements were constituted of a single unique particle, which he named atoms, after the term "atom" that was used in atomism philosophy. Not long after that in the 20th century, it was found through Rutherford's experiment that atom was not the smallest constituent of matter, but instead composed of smaller particles, a positively charged nucleus with negatively charged electrons orbiting around it. In the 1930s, it was found that the nucleus was comprised of two particles, a positively charged proton and a neutral particle named neutron.

Also in the 1930s, the idea of an "electrically neutral particle with a spin of $\frac{1}{2}$ and obey the exclusion principle" was put forth by Wolfgang Pauli in a letter to his colleagues at a physicist workshop in Tubingen. Pauli came across the idea of this particle in order to explain the continuous β spectra in β-decays. In 1934, Enrico Fermi built the first theory of the β-decay of nuclei based on Pauli's idea and named it neutrino [13].

In the later half of the 20th century, with the development of particle accelerator and particle detectors, experimental particle physics at high energy became feasible. The experiment created many particles, all of which seemed to be elementary.

The abundance of elementary particles led to the proposal of up, down, and strange quarks by Murray Gell-Mann and George Zweig in 1964. These quarks were proposed to be the constituent of mesons and baryons. They have a spin of $\frac{1}{2}$ and carry charge of $\frac{2}{3}$, $-\frac{1}{3}$, $-\frac{1}{3}$, respectively. As these charges could not be observed, quarks were treated as mathematical objects rather that physical ones. In the same year, Sheldon Glashow and James Bjorken proposed the existence of a fourth quark, coined the charm quark, to mimic the pattern found in leptons. A few years later in 1967, Steven Weinberg and Abdus Salam proposed the theory of electroweak interaction. In this theory, a neutral boson was required (now known as the Z boson). Continuing from the proposal of quarks, in 1968 electrons were observed bouncing off small hard cores inside proton in a scattering experiment at the Stanford Linear Accelerator (SLAC). This experiment gave evidence to the existence of quarks. Since then, many theories have been proposed to explain the fundamental interaction of matter such as the Quantum Electrodynamics (QED), Quantum Chromodynamics (QCD), and the electroweak theory. In 1974, a summary talk given by John Iliopoulos presented a view of physics in a single report, now called the Standard Model. In the same year, experiments at SLAC and Brookhaven discovered a charm-anticharm meson, now called the J/Ψ meson [14][15]. This discovery provided support to the existence of the charm quark, further validating the success of the Standard Model. In 1976, the tau lepton was discovered at SLAC [16]. This lepton was the first third generation particle. A year later in 1977, Leon Lederman discovered another quark called the bottom quark. As it was well known by physicists that quarks come in pairs, the quest of finding the sixth quark began. In 1979, evidence for gluon radiated by quarks was discovered in DESY laboratory. In 1983, the intermediate bosons of the weak interaction was discovered at CERN in proton-antiproton collision, confirming the prediction of the Standard Model. In 1995 after 18 years since the quest of finding the final quark began, experiments at Fermilab discovered the top quark. Finally in 2012, Higgs boson was discovered at CERN by ATLAS and CMS experiments [17].

The discoveries of fundamental particles by various experiments to improve the Standard Model demonstrates the intertwine of theoretical and experimental physics. In particle physics, the fundamental building blocks of matter are studied along with their interactions. The Standard Model of particle physics describes these fundamental particles and the force particles exchanged between them. Among these forces are electromagnetic, weak, and strong interaction. Although the Standard Model has been immensely successful, it is not without its flaws. It contains arbitrary parameters such as coupling strengths that still cannot be predicted. There are also many features that cannot be explained, such as the existence of three generations of matter particles [17]. The world's most powerful particle accelerator at the moment, the Large

Hadron Collider (LHC), located at the France-Switzerland border is colliding protons and lead ions in order to take a deeper look into matter and its constituent particles and is an effort to look deeper into the Standard Model and even beyond.

One of the major experiments at CERN, A Large Ion Collider Experiment (ALICE) studies the physics of strongly interacting matter. The strong interaction is described in a theory called Quantum Chromodynamic (QCD). Quarks and gluons are the only fundamental particles subject to the strong force. The unique properties of QCD give rise to the possibility of a phase of matter called Quark Gluon Plasma, which is believed to permeate the universe during its early times [18]. During proton-proton collision at the Large Hadron Collider, heavy quarks can be created. One such quark that can be created is the charm quark. After its creation, it immediately form a hadron due to a phenomenon called confinement. One type of hadron that the charm quark can hadronize into is the D-meson. Understanding the D-meson production in proton-proton collision provides an opportunity to assess perturbative Quantum Chromodynamic (pQCD) calculations at highest available energy [19].

1.2 Objectives and Benefits

The objective of this final project is to reconstruct D^0 meson from data sample of proton-proton collisions at centre-of-mass energy of 13 TeV, recorded by the ALICE detector. This final project will be a part of an international scientific collaboration, ALICE, where the results of this final project will contribute to the study of D meson production in respect to charge multiplicity. Hopefully the audience of this final project can learn in general about the basic overview of particle physics and its importance in the scientific field. Specifically in experimental particle physics and an example of what analysis is done in an experiment. As for myself, by doing this final project, I will gain experience with analysing experimental data, which is a valuable experience as a kick start getting into the field of experimental particle physics.

1.3 Outline of the Thesis

The final project write up is organized as follow. Chapter 2 includes introduction to the theories relevant to this final project. An overview to the standard model is given in Section 2.1, followed by a brief explanation to the quark and strong force in Section 2.2. An overview to quark gluon plasma and the D meson encompass the rest of the chapter in Section 2.3 and Section 2.4. In Chapter 3, an overview of the Large Hadron Collider and the ALICE detector is given along with an overview of data collection in ALICE. An overview of the Large Hadron Collider in laid out in Section 3.1. Section 3.2 gives an introduction to the ALICE Detector as well as detailing the sub-detectors within ALICE relevant to this final project. Following after, Chapter 4 describes reconstruction. Section 4.1 describes track and vertex in general followed by tracking and vertex determination in ALICE detector. Section 4.2 describes reconstruction of D^0 meson decay and the topological and kinematic criteria used to filter in the D^0. Following that, the resulting reconstruction is presented in Section 5, along with comparison to reconstruction done with Run 1 data of centre-of-mass energy of 7 TeV. The last section is conclusion and outlook.