# CHAPTER 1

# INTRODUCTION

## 1.1 **Photoproduction in Diffractive Scattering**

Photoproduction refers to particle production that originates from photon. The word photoproduction itself is rephrased from the word '*photon*' and '*production*'. The signature of exclusive photoproduction in electron-proton collision events strictly consists of only the decay products of the searched particle, with no other significant activity in other detector components, since the scattered electron and proton escape undetected down the beampipe at small angles portraying a diffractive scattering. Diffractive scattering is a process where the colliding particles scatter at a very small angles and have no connecting color flux in the final state. This involves a propagator carrying the vacuum quantum numbers, called the Pomeron [1] and described, in the soft regime, within the Regge theory . Figure 1.1 shows a schematic diagram of a photon emission in electron proton collision which subsequently produces a $\psi(2S)$ particle that decays to a $J/\psi$ and a pion pair.

Since the first operation period in 1992, ZEUS and H1, the two experiments dedicated to the deep inelastic scattering (DIS) physics at Hadron Electron Ring Accelerator (HERA), observed that approximately about 10% of lepton-proton DIS events had a diffractive origin. It opens a new area of studies in particle production mechanism including the photoproduction events , providing a hard scale which can be varied over a wide range and therefore it is an ideal testing ground for Quantum Chromodynamics (QCD) models. Diffractive production of Vector Mesons (VMs) and real photons, γ, allows studies on the transition from the soft to the hard regime in strong interactions. The hard regime (high energy and low Bjorken-x, $x_{Bj}$) is sensitive to the gluon content and well described by perturbative-QCD, while in the soft regime (low-x) the interaction is well described within the Regge phenomenology. The diffractive production of real photons, a process known as Deeply Virtual Compton Scattering (DVCS), leads to the extraction of the Generalized Parton Distribution functions (GPDs), containing combined information about the longitudinal momentum distribution of partons and their position on the transfer plane. The GPD-based calculations will be very helpful in the description of the Higgs boson diffractive production mechanism, which will be experimentally studied with the Large Hadron Collider (LHC) accelerator.

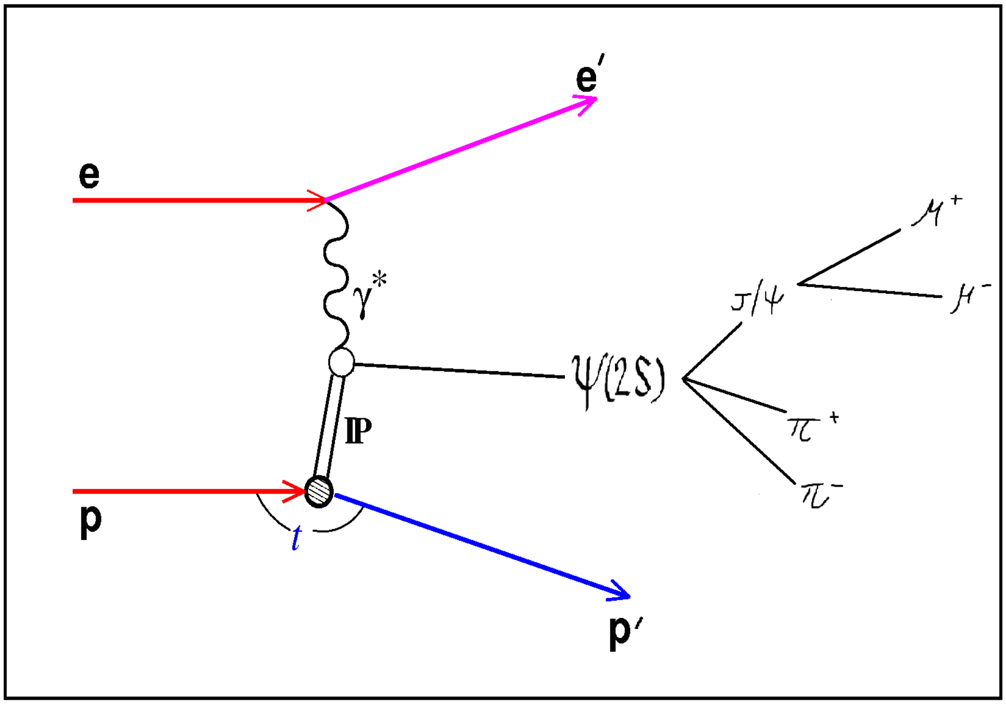


**Figure 1.1:** The picture shows the schematic diagram of $\psi(2S)$ photoproduction in electron-proton collision where the scattered electron and proton escape undetected in the beampipe.

## 1.2 The Standard Model

For many years, the development of particle physics research has been of huge interest for the physicists in exploring the quantum field theory. Beginning with the establishment of the basic particle foundation in the Standard Model (SM) as illustrated in Figure 1.2, the journey of particle search had changed rapidly through the subsequent years. Although it was strongly suggested that there are only three generations of fundamental particles according to SM, the latest and highest energy of collider, LHC is giving hope for the discovery of the new neutral current (NC) which has yet to be discovered, Higgs boson.

The history of the SM begins in early 1964, when the idea and discovery of quarks had extended the major believe of basic theory of structures of atoms and nuclei. In the era when scientists had put the quark as just a mathematical concept, the thinking had grown to the higher level of determining the real existence of these invisible partons or quarks. Rapidly developing research since then proved that their hard work was rewardable as they constantly managed to put on more facts of the quarks. In 1967, Weinberg and Salam had came out with the idea of unifying electromagnetic and weak interaction into electroweak interaction which required the existence of a neutral boson $Z^0$. Until three years later, Glashow, Ilioponlos and Maiani had recognized that the critical importance of the charm quark had allowed the theory of $Z^0$-mediated in weak interaction. This research of $Z^0$ weak force boson had continuously done until it was observed in 1973 by Andre Lagarrigue and his collaboration as the neutral manifestation of the weak force which had been predicted by electroweak theory [2]. Along with the $Z^0$-exchange observation in late 1973, a quantum field theory of the strong interaction was formulated. It was similar in structure to quantum electrodynamic (QED) but involved colour charges, and named in quantum chromodynamics (QCD). The quark was determined to be a real particle with colour charge and the gluon as the massless quantum of the strong interaction field. Also in the same year, Politzer, Gross and  Wilczek, predefined the colour theory of the strong force which then introduced a new property called the asymptotic freedom.

In 1974, it was the first time $J/\psi$ was discovered by two separate research groups, led respectively by Ting from the Brookhaven National Laboratory (BNL) and Richter from the Stanford Linear Accelerator Center (SLAC) [3]. This discovery had widened the understanding of the charmonium particles or charm-anticharm bound-state quarks which were singularly discovered earlier. Not long after the first discovery, the Richter's group again discovered the first excited state of the $J/\psi$ which was known as $\psi'$ or $\psi(2S)$, or occasionally $\psi(3686)$, indicating its quatum state or mass in MeV/c$^2$. The $J/\psi$ family production was identified as one of the most popular particle research done in high energy physics experiments. The popularity is attributable to the high efficiency of this particle to be seen in the experiment. Figure 1.3 shows the journey of the SM history together with the initial particle discoveries.

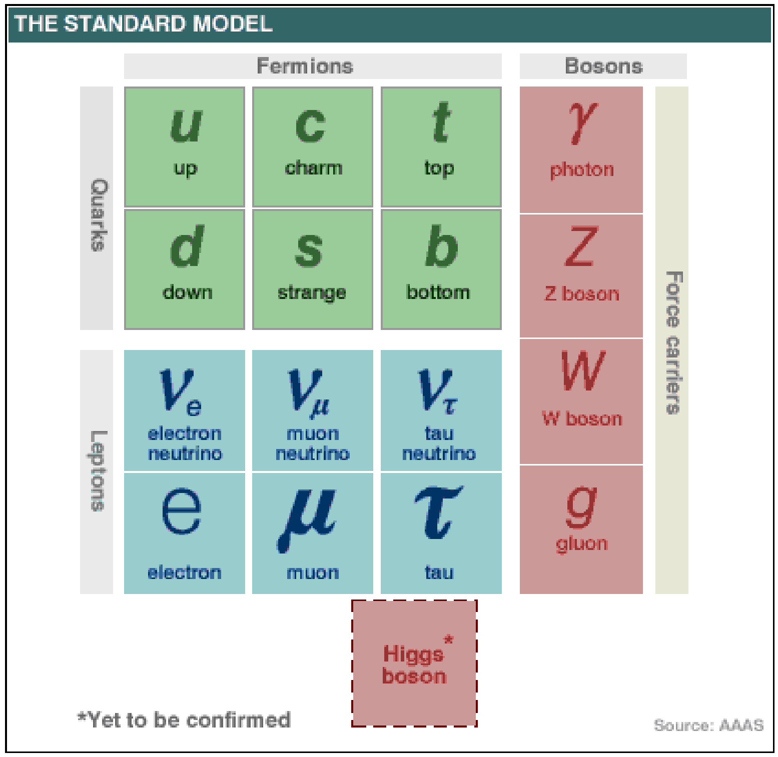


**Figure 1.2:** The diagram of the Standard Model (SM) of elementary particles

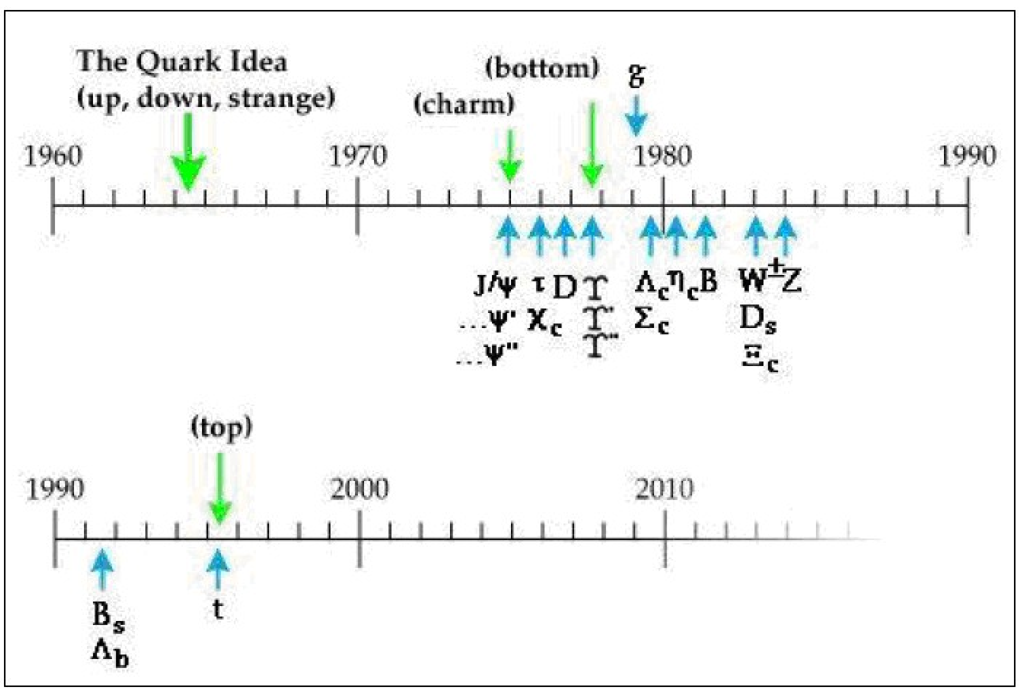


**Figure 1.3**: The Standard Model development in historical perspective. The idea of quarks as the constituents of matter and their subsequent experimental confirmation are shown.

### 1.3 Thesis Overview

In this thesis, we are going to study the exclusive photoproduction (PHP) of the first exited state of $J/\psi$, $\psi'$ or $\psi(2S)$ with the rest-mass frame of $3686.093 \pm 0.034$ MeV/c$^2$ at the electron-proton collider, HERA located at Deutch Elektronen Syncrothron (DESY), Hamburg, Germany. At HERA, a proton beam of energy 920 GeV collides with an electron or positron beam of energy 27.52 GeV. The interaction between proton and electron will produce the exchange of specific gauge bosons depending on the interaction force whether it be electromagnetic, weak or strong. For weak interaction, the exchange gauge boson is either a charged current (CC), $W^{\pm}$ or neutral current (NC), $Z^0$. While for the strong and electromagnetie (EM) forces, the exchange boson will be a gluon (g) and a photon ($\gamma$) respectively. The significant and interesting features of learning this heavy vector meson (VM) production is one unique characteristics of the daughter products, which is the the combination of hadronic particles, in diffractive interaction. In the search for $\psi(2S)$, we are combining $J/\psi$ (which decays to a muon pair) and a pion pair which are exclusively produced at the primary vertex of the electron-proton collisions. Muons, are prevalently known as minimum ionizing particles (MIP), will behave consistently stable through the detector's inner components such as the calorimeter, giving a special signature in the form of free isolated trajectory tracks. This muon will be subsequently

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[1] In the following, for simplicity we will denote the charged lepton as electron, independently wether it is an $e^+$ or an $e^-$, unless otherwise stated

detected at the specific surface component called the Muon Detector. In contrast, pions will be detected rapidly near the interaction area in the Central Tracking Detector (CTD). The particle properties of these muons of $J/\psi$ and pion pair will be useful for the study of the production cross-section of $\psi(2S)$. Moreover, the soft to hard transition of forces can be seen by studying the kinematics variables of the proton-photon interaction or typically known as W dependence of the cross-section for exclusive VM photoproduction.

The following is a brief preview of to upcoming chapters.

In Chapter 2, we shall go on to the kinematics of the electron-proton collision. Generally, the explanation in this chapter will focus on the process of exclusive photoproduction (PHP) at HERA which is the main subject matter in this thesis. In Chapter 3, there will be reviews of the experimental setup, the ZEUS Detector and HERA Accelerator. Meanwhile for Chapters 4, 5 and 6, the main discussion will focus on the tracking efficiency, $\psi(2S)$ production and results, and the conclusion, respectively. For the analytical method, in this study, we shall use open source software in the Linux Operating System, Physics Analysis Workstation or PAW which will be discussed further in Chapter 5.