Please Read the Abstract

By

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Abstract

The diffractive dijet photoproduction can probe the nuclear parton distribution at low Bjorken-x.

Acknowledgements

Thanks to my family and friends.

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Chapter 1

Studying the Nuclear PDFs in HI Collisions

1.1 The Standard Model

The Standard Model describes the fundamental particles of the universe in terms of fermions and bosons. Fermions are particles with half-integer spin, while bosons have integer-spin. This difference in spin has far reaching consequences. Fermions must obey the Pauli Exclusion Principle: only one fermion at a time can occupy a given state. However, multiple bosons can simultaneously occupy a specific state.

1.1.1 Quantum Electrodynamics

Quantum electrodynamics (QED) is a theory of electromagnetic interaction in terms of relativistic quantum field theory. QED addresses three specific processes: photon motion, electron motion, and the emission, or absorption, of a photon by an electron.

The QED coupling decreases with distance, as manifest the Coulomb force being proportional to an inverse-square law.

1.1.2 Quantum Chromodynamics

The quarks are a family of fermions that compose the baryons and the mesons. Baryons consist of three quarks in a color neutral state, while mesons consist two quarks in a color neutral state. "Color" in this context refers to the six kinds of strongly-interacting charge available to quarks: red and anti-red, blue and anti-blue, and green and anti-green. Color charge has no relation to optical phenomena, but provides a useful analogy for the stable combinations of quarks. The net color-charge of a baryon or meson is "white".

Unlike QED, the QCD coupling increases with distance. This has the practical consequence of the strong-interactions being stronger in high momentum transfer collisions. The direct results of the running QCD coupling are the dual phenomena of asymptotic freedom and color confinement.

1.1.2.1 Asymptotic Freedom

Within the nucleus, a proton can be thought of as a bubble in a vacuum. Debrye screening exerts a pressure on the proton. This pressure is responsible for the size of the proton.

1.1.2.2 Color Confinement

At large distances, string tension describes the binding force of the quarks. At short distances, however, Coulomb-like interactions dominate.

1.2 QCD Experiments

Scattering experiments are the basic tool for exploring the nucleus. The Large Hadron Collider (LHC) is capable of reaching heavy-ion collision energies of up to 7 TeV per nucleon-nucleon. The higher the energy, the more experiments can probe the nuclear phase-space diagram.

At the turn of the century, Ernst Rutherford probed the gold atom by bombarding a gold sheet with alpha-particles (helium nuclei). The angular distribution of the scattered alpha-particles demonstrates that the mass of the atom is concentrated in a small volume, i.e, the atom is mostly empty space.

Momentum transferred, expressed as Q^2, is an important quantity for characterizing QCD measurements.

In addition to Q^2, Bjorken-x, also known as Bjorken-scaling is necessary to describe the nuclear phase space. Bjorken-x represents the momentum fraction of partons.

1.2.1 Hard Processes

Hard processes involve scattering particles off partons in the manner of point-like charges.

1.2.1.1 Deep Inelastic Scattering

Deep inelastic scattering commonly refers to the scattering of a leptons off hadrons. These experiments provided the first evidence of Bjorken-scaling in the nucleus, a direct interpretation of which is the existence of quarks as point-like particles at high energies.

1.2.2 Soft Processes

Soft processes compose the low momentum transfer, typically gluon-gluon interactions during a collision.

1.2.3 Heavy-Ion Collisions

Similar to the Rutherford experiment, in heavy-ion collisions the scattered particles carry information about the internal structure of the nucleus.

The Rutherford experiment has the three components that still characterize high-energy nuclear experiments: a probe, a medium, and a signal. Alpha particles probe the medium of the gold atom, and the angular distribution of scattered alpha particles signals the internal structure of the atom.

1.2.3.1 Ultra-peripheral Collisions

Ultra-peripheral collisions occur at impact parameters greater than the sum of the heavy-ion radii. In these collisions, hadronic interactions are strongly suppressed while photonuclear activity is enhanced proportional to the square of the nuclear charge. The electromagnetic field of an incoming heavy-ion, from the perspective of a target, is equivalent to a flux of virtual photons.

1.3 Jet Production

Gluons are the particle exchanged in strong interactions. However, gluons themselves carry color charge. By analogy, photons transmit the electromagnetic force, but do not themselves have an electric charge.

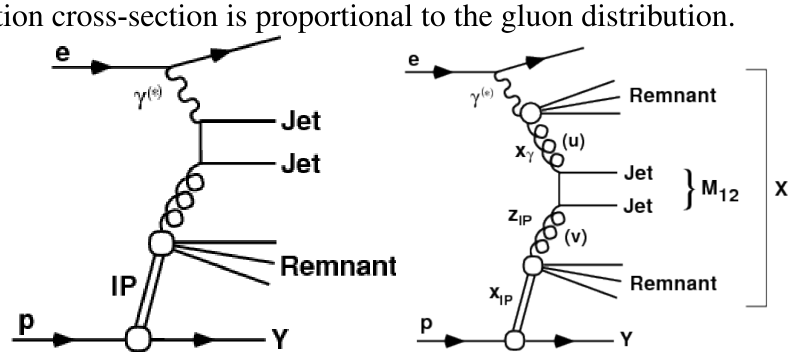
When a quark is scattered from a nucleus, the strong interaction gathers potential energy until the threshold for quark production is passed, at which point an anti-quark is generated to screen the ejected quark.

1.3.1 Diffraction

QCD factorisation describes the diffractive-photoproduction dijet cross-section as the convolution of the partonic cross-section with the diffractive parton distributions. However, factorisation only describes H1 data if the resolved-photon contribution is suppressed.

1.3.2 Photoproduction

The photoproduction cross-section is proportional to the gluon distribution.



1.3.2.1 Direct Photon Processes

At low momentum transfer, photons interact electromagnetically, i.e. directly, with partons.

1.3.2.2 Resolved Photon Processes

High energy photons possess a hadronic structure.

Chapter 2

Diffractive Dijet Photoproduction

Diffractive dijet photoproduction is a powerful constraint on the relationship between next-to-leading order (NLO) and non-perturbative (NP) QCD.

2.1 Diffraction in Photon-Hadron Collisions

The DESY collaboration is responsible for measuring the structure functions of the proton via diffraction.

2.1.1 Exclusivity

2.2 Next to Leading Order QCD + NPDF

2.3 Perturbative QCD

At low Bjorken-x, gluon interactions dominate the nucleus. As such, NLO-QCD no longer describes the PDF.

2.4 Factorisation Breaking

Chapter 3

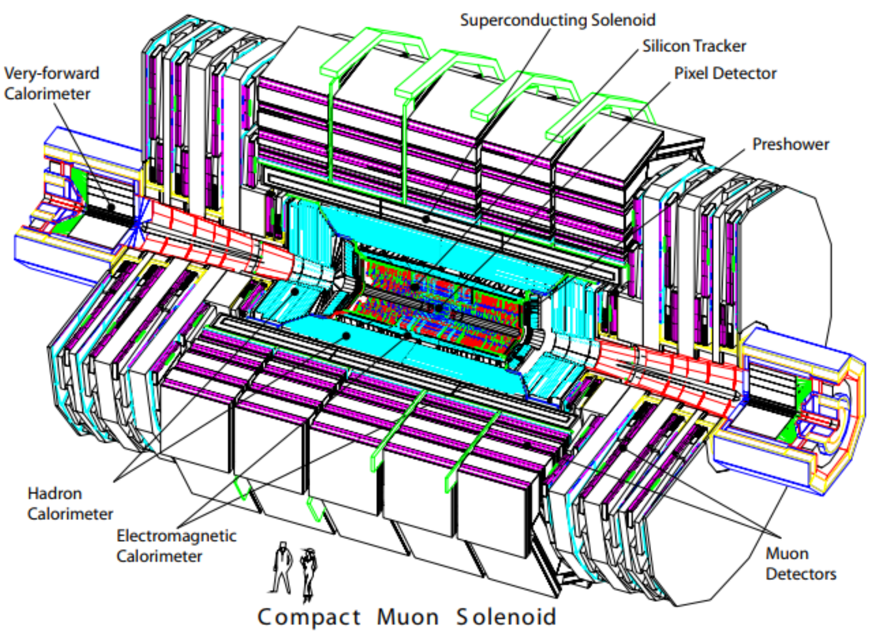
The Experiment

3.1 Large Hadron Collider

The Large Hadron Collider (LHC) has a radius of approximately 27 kilometers. As of this writing, it is the largest machine ever constructed. The initial purpose of the LHC was to discover the Higgs boson, but it is capable of investigating a variety of other physics phenomena, such as dark matter, extra-dimensions, and heavy-ion physics.

3.2 Compact Muon Solenoid

The Compact Muon Solenoid (CMS) is a general-purpose particle detector located at Point-5 of the LHC. CMS was designed to precisely measure the momentum of muons. The titular superconducting solenoid magnet generates a 4 Tesla field. This field is homogeneous and parallel to the beam line close to the interaction point. The momentum of a muon is measured from how it deflects when moving through the magnetic field.



3.2.1 Inner Tracker

The tracker measures the momentum of charged particles via their trajectory through a homogenous magnetic field. The tracker consists of two units, the pixel tracker and the strip tracker, both of which are made of silicon. A charged particle causes an electrical signal when passing through a silicon pixel or silicon microstrip. CMS reconstructs these electrical signals, taken at specific points of position and time, into tracks. These tracks are accurate to the 10 micrometers.

3.2.1.1 Pixel Tracker

Every silicon-pixel has a corresponding readout chip. The readout chips are soldered through the bump-bonding method. The readout chip amplifies signals from the pixel.

The pixel tracker is precise enough to distinguish the vertices of tracks originating from short-lived particles, such as bottomonia.

3.2.1.2 Strip Tracker

3.2.2 Electromagnetic Calorimeter

The Electromagnetic Calorimeter (ECAL) is the dedicated CMS calorimeter for detecting electrons and photons. The calorimeter is comprised of lead tungstate ($PbWO_4$) crystals arranged in cylinder about the beam, including two endcaps. The granularity of these crystals gives the ECAL excellent energy resolution, angular resolution, and spatial resolution. The ECAL is hermetic and homogenous. The data readout is fast enough that CMS can trigger off signals in the ECAL.

3.2.3 Hadronic Calorimeter

The Hadronic Calorimeter (HCAL) has such a large acceptance that it can indirectly observe non-interacting particles such as neutrinos.

3.2.3.1 Hadronic Forward Calorimeters

The Hadronic Forward Calorimeters (HF) absorbs the greatest portion of energy from collisions. As such it is designed for maximum radiative resistance.

3.2.4 Muon Detector

3.2.5 Zero Degree Calorimeter

3.2.6 Luminosity

One of the most important quantities measured by CMS is luminosity. Luminosity is necessary to convert the number of events detected, for a given channel, into a collision cross-section. Collision cross-sections are among the primary observables predicted by theoretical physics, specifically quantum field theory.

3.2.6.1 van de Meer Scanning

3.2.7 Triggering

CMS reconstruct events faster than they can be stored on hard-drives. To account for this phenomena – pile-up – CMS uses a two tiered triggering system. L1 triggers are always online, and for those events that pass the L1 triggers, the High Level Triggers (HLTs) will select which events are stored as data.

Chapter 4

Detecting Photoproduction in Ultra-Peripheral HI Collisions

4.1 Selection on Hadronic Forward Calorimeter

4.2 Selection on Zero Degree Calorimeter

4.3 Selection on Pixel Tracker

Chapter 5

DDPP at DESY

5.1 H1

The H1 Collaboration is an experiment hosted by the HERA electron-proton collider at DESY in Hamburg, Germany.

5.1.1 Diffractive Jets in ep

Diffractive jet analyses at H1 demonstrate factorization breaking in the nuclear parton distribution. In comparison to H1 data, next-to-leading order QCD calculations of the diffractive-photoproduction dijet cross-section are a factor of two larger than measured.

5.2 RAPGAP

RAPGAP is a Monte Carlo generator created for H1 analyses, specifically diffractive studies. By default, RAPGAP models electron-proton and proton-proton collisions. However, ultra-peripheral heavy-ion collisions are distinct from electron-proton collisions only in the photon spectrum. Re-weighing RAPGAP events by the heavy-ion photon spectrum can thus model heavy-ion UPC.

Chapter 6

DDPP measurement in CMS forward region

6.1 Rapidity Gap

6.2 Forward Tagging

6.3 Jet Reconstruction

6.4 PYTHIA and STARLIGHT

Chapter 7

Probing low-x nuclear PDFs with diffractive photoproduction at CMS

7.1 The Probe

Chapter 8

Conclusions

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Appendix A

My Appendix, Next to my Spleen

There could be lots of stuff here