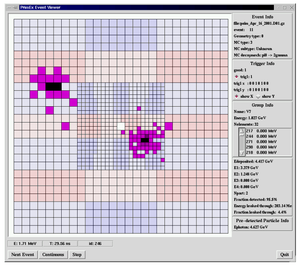
PRIMEX

Measurement of the π^0 lifetime

Introduction

The *strong* interaction is the dominant force acting between nucleons. It has profound significance for our understanding of nature and the structure of the matter of which we and our universe are composed. Our collaboration has proposed a test of the most fundamental properties of the strong interaction at low energy in terms of the underlying theory, *Quantum Chromodynamics* or "QCD".

PrimEx is an experiment that will perform a high precision measurement of the neutral pion lifetime. This will be done using the small angle coherent photoproduction of the π^0 in the Coulomb field of a nucleus.



Caption

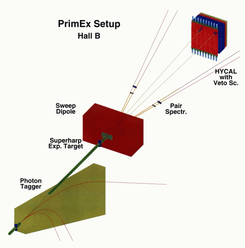
Why is this Important?

There are four fundamental interactions in the nature. The most powerful is the *strong* interaction. This holds the quarks together in the proton and neutron, as well as holding the protons and neutrons together in the nucleus of an atom. Understanding the strong force is vital to our understanding of the universe.

The strong force interacts with the *color* charged particles such as quarks and gluons. This behavior is modeled by the theory of *Quantum Chromodynamics* (QCD). By testing the predictions of QCD, we are testing our understanding of the strong force.

The strong force has a remarkable property called *confinement*. Confinement says particles must always bind together into combinations that have no color. This means quarks can not exist by themselves. Quarks **must** be attached to other quarks. In experiments, only particles with no net color can be seen (such as protons, neutrons, pions, ….). As a result, the most basic tests of QCD we can do involve the simplest quark combinations, such as pions.

At the lowest possible energies, the π^0 is the only *strongly* interacting particle. It plays a special role as a tool for investigating the most fundamental predictions of QCD in the very low energy limit. A high precision measurement of the π^0 lifetime will directly test the QCD prediction, helping us to test our understanding of the strong force. The lifetime of the π^0 is dominanted by the chiral anomaly and contains information about the number of colors inherent in the strong force. Understanding the π^0 lifetime provides a crucial step towards constructing a systematic link between quarks/gluons in QCD and the observable particles in the *hadronic* (strong) world. This lies at the heart of contemporary nuclear science and has a deep impact on particle physics, astrophysics and cosmology.



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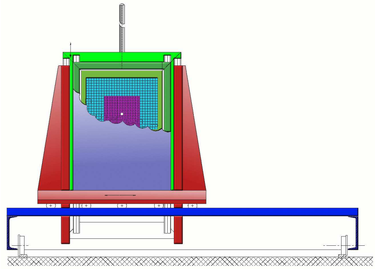
What is a π^0?

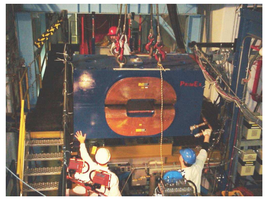
A π^0 is a particle made of two quarks much like a proton is made of three quarks. There are three types of pions. They the π^+, the π^-, and the π^0. The +, −, o symbols are used to indicate the electric charge of the pion. The π^0 has zero electric charge.

Pions are not stable particles. They can *decay* into several smaller particles. The mean lifetime of the charged pions (π^+ and π^-) is about 26 nanoseconds (or 0.000000026 seconds). The mean lifetime of the π^0 is much smaller and is only about 1/10th of a femtosecond (or 0.0000000000000001 seconds!). Even with today's fastest electronics, it is impossible to measure such a short time directly. We, therefore, must use indirect ways to measure the lifetime of the π^0.



Caption

Picture taken at a recent meeting of the PrimEx collaboration



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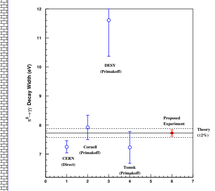

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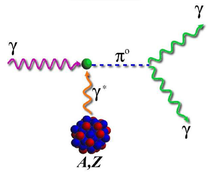
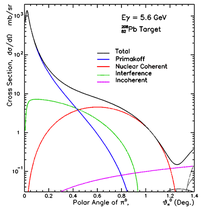
Primakoff Effect



$$\frac{d^3\sigma}{d\Omega^3} = \Gamma(\pi^0 \to \gamma\gamma)\frac{8\alpha Z^2}{m_\pi^3}\frac{\beta_\pi^3 E_\gamma^4}{Q^4}\left|F_{e.m.}(Q)\right|^2 \sin^2\vartheta_\pi$$

Caption



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Experimental Technique

The π^0 lifetime is very short (10^{-16} seconds). This is too short to measure directly so we must use an alternative method. The *PrimEx* experiment will use a physical process known as the *Primakoff effect*. In fact, the name PrimEx comes from **Prim**akoff **Ex**periment. To put it formally, the Primakoff effect is: *meson production in the Coulomb field of a nucleus*.

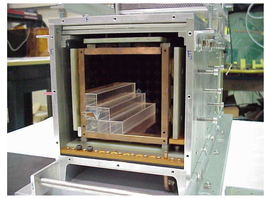
What's really happening is this: Every nucleus has an electric charge. This electric charge has an electric field. One way of thinking of the electric field is to picture it as a bunch of (virtual) photons flying in and out of the nucleus. (These virtual photons are how one electric charge talks to another electric charge.) If a real photon (from the JLab beam) runs into a virtual photon (from the nucleus), they can create a π^0. This is essentially the reverse of the process by which the π^0 decays. By measuring how easy it is to create a π^0 in this way, we are also measuring how easy it is for the π^0 to decay. This is known as the *decay width* and is just 1 divided by the π^0 lifetime!

Experimental Setup

In order to use the *Primakoff* technique to measure the π^0 lifetime, we need a beam of photons. The Jefferson Lab accelerator, however, produces a beam of energetic electrons. The electrons can be used to make a beam of photons using the *Photon Tagger* in Hall−B. The tagger is used to convert much of the electron's energy into an energetic photon.

The photon beam is then sent through a lead target (^{208}Pb). A few of the photons will interact with a nucleus in the lead target to create a π^0. The π^0 decays almost instantly into two photons. These two photons will strike the HyCAL detector which will measure the energy and position of each.

Some of the photons in the incident photon beam will create e^+/e^- pairs. These are swept away by a powerful dipole magnet so they can not enter the HyCAL detector. The pairs are detected by another set of detectors and used to monitor how many photons were sent through the lead target.



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