Photon Flux Monitor for Photonuclear Research

ABSTRACT

Nuclear photodisintegration (a nuclear reaction initiated by a photon) is a useful tool for the study of nuclear structure as well as understanding and modeling the strong nuclear force. Central to photonuclear research is the measurement of the photonuclear cross section, which is related to the probability of interaction between an atom's nucleus, and an incident photon. A photon flux monitor is therefore crucial to an experimental setup as it allows for the measurement of the number of incident photons. The intention of this poster is to describe the design, construction, testing and use of the device.

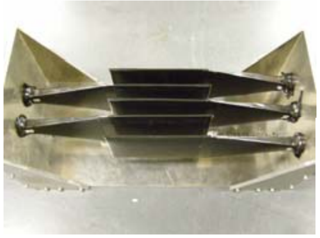
INTRODUCTION

The strong nuclear force is one of the fundamental forces of nature and is known to be responsible for the binding of subatomic particles to form nuclei. When bombarded by gamma rays, the nucleus may absorb a photon and undergo a nuclear reaction, fracturing into many pieces. By measuring the probability of a photonuclear event as well as the directional distribution and energy of the emitted fragments, it is possible to further refine theoretical models of the strong nuclear force, while also attaining a better understanding of nuclear structure. The number of photonuclear reactions that occur in an experiment is proportional to the number of incident gamma rays and the reaction probability. Therefore, in order to measure the reaction probability, it is essential to acquire a measurement of the experiment's photon flux.

COMPONENTS OF THE PHOTON FLUX MONITOR:

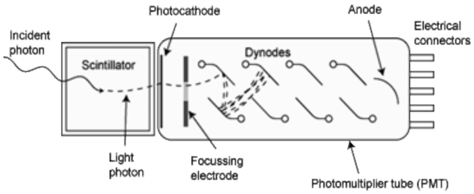
Scintillators and light guides:

The role of a scintillator is to convert the energy of an incident electron or positron into a light signal. The flux monitor arrays five organic scintillators in series, with an aluminum converter separating the second and third scintillator. Although a gamma ray could potentially interact with any matter it happens to pass through, the aluminum converter facilitates interactions to occur between scintillators 2 and 3. Any electrons or positrons emitted by the collisions may then pass through the scintillators, exciting and ionizing atoms along the way, which then return to their ground state and fluoresce. The emitted light passes through the transparent scintillator and enters a light guide, which funnels the light into the head of a photomultiplier tube.



Photomultiplier tubes:

The role of a photomultiplier tube (PMT) is to convert a light pulse into an electrical signal. This process starts when a number of photons strike the PMT's photocathode, causing a number of photoelectrons to be released. These electrons are accelerated through an electric potential and strike a series of dynodes, releasing a new shower of electrons with each collision. This resulting pulse in current can then be relayed to the electronics crate to be processed.



Electronics:

Processing of the detector signals occur primarily within the electronics crate. A pulse is first passed to a discriminator which converts any signal above a pre-set threshold into a logic pulse. The combined logic pulses of each detector are then wired into a logic gate where the monitor's signal is filtered according to coincidence and veto. These signals are counted to provide a number proportional to the number of incident gamma rays. Finally, the filtered signal is used to gate an analog-to-digital (ADC) converter, which allows the signal from each detector to be measured. The ADC communicates the data to a desktop computer. There, the data can be graphed with programs such as Lucid.

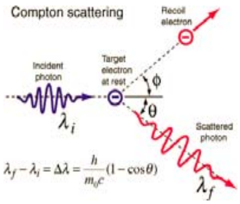
THEORY:

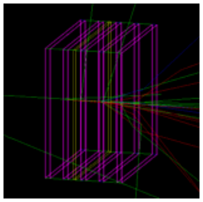
Gamma ray interaction:

High energy photons such as gamma rays are capable of passing through thick layers of matter with a small chance of interaction. However, when an interaction takes place, energetic electrons or electron/positron pairs are produced. This can happen in one of three ways:

- Compton scattering – a gamma ray scatters off an electron weakly bound to an atom, causing the electron to recoil at varying energies depending on the scattering angle.
- The Photoelectric effect – an atom fully absorbs a gamma ray and emits a photoelectron at the gamma ray's energy minus the electron's binding energy.
- Pair Production – a gamma ray is absorbed by an atomic nucleus, and its energy is converted into creating an electron and positron pair.

Because electrons and positrons have charge, they readily interact electromagnetically with any surrounding matter. They deposit their energy in the material by ionizing or exiting atoms. When these atoms return to their ground state they emit light which provides an indirect method of detecting the gamma ray that initiated the event.



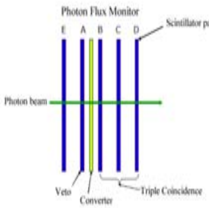


Simulation:

Only a small fixed fraction of the incident gamma rays will be detected by the photon flux monitor, the rest will pass through without interaction. While this information is useful for distinguishing the relative photon flux between two separate experiments, it is often necessary to know the absolute photon flux. If the detection efficiency of the flux monitor can be determined, it is possible to calculate the total number of incident photons from the number of those detected. Through the use of computer simulations, the efficiency may be estimated, and thus the total photon flux through the monitor can be calculated. Simulations also inform the user about the flux monitor's sensitivity to different parameters, as well as providing general information about the expected outcome of an experiment.

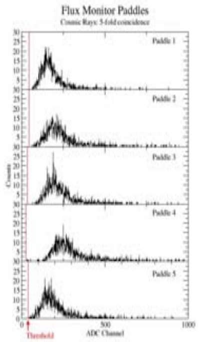
Coincidence and veto:

Upstream interactions between the gamma ray beam and its surrounding material is an experimental reality and unavoidable. Unwanted particles will be produced upstream, and pass through the flux monitor, artificially increasing the count rate. Likewise, background radiation contributes undesirable detection events. To address these problems, the flux monitor's 2nd upstream detector is designated as a "veto". A signal from the veto detector instructs a logic gate to momentarily ignore any detection events, and thus, any particles produced upstream are not counted. The logic gate further filters the detection signal by requiring coincident detection events in detectors 3, 4 and 5. This way, the flux monitor only detects particles that are moving in line with the photon beam. Particles that are incident from the sides are ignored. With these restrictions in place, the flux monitor is intended to register only those interactions taking place between scintillators 2 and 3 and are caused by photons creating fast recoil electrons or positrons. The monitor will thus be less sensitive to the upstream geometry of the experiment.



Testing:

After assembly, the monitor's detectors were tested for required function. Detector signals were scrutinized for signs of electronic noise, and for holes in the light-tight wrapping of the scintillator. Testing also includes the assignment of each detector's threshold, which is the voltage below which the discriminator will not relay the photomultiplier tube's signal. Proper assignment of a detector's threshold sets it high enough to filter out electronic noise, yet low enough to avoid interference with the detector's signal produced by recoiling electrons. Testing of the detector thresholds was accomplished by detecting cosmic rays, and observing changes in a detector's signal according to changes in the detector's threshold.



CONCLUSION:

The photon flux monitor has been assembled and appears to be in good working order. The device currently resides at Duke University in Durham, North Carolina, where it is hoped to be applied in subatomic physics experiments in the coming year.