Instrumentation development for measuring background radiation in the MTA Hall

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Abstract

This study presents the results that comprehensively understand background radiation measurements in the MTA Hall utilizing a tungsten target. The discernible increase in neutron counts, alongside the differential response of the photomultiplier tube, accentuates the significance of accurate and tailored detection methodologies for distinct radiation species. This research contributes to advancing radiation measurement techniques, particularly in complex operational settings, with implications for accelerator operations, radiation safety, and nuclear research endeavors.

1. INTRODUCTION

Background radiation is critical in accelerator facilities, especially regarding electronic radiation hardness and muon-catalyzed fusion studies. This research aims to better understand the radiation environment in the MTA Hall by measuring background radiation both with and without the presence of a tungsten target.

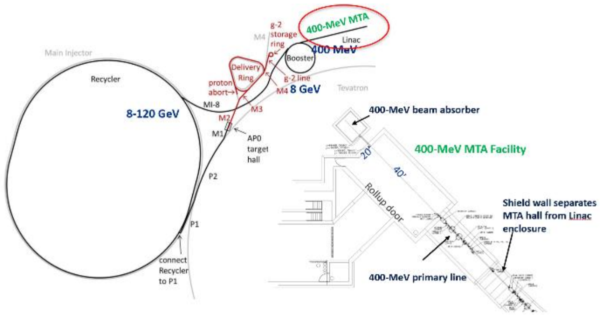

Figure 1: Current MTA facility at the end of the 400MeV LINAC

The results from this study are vital for the future design and construction of accelerator facilities, like PIP-II, where the impact of radiation on electronic components needs to be considered.

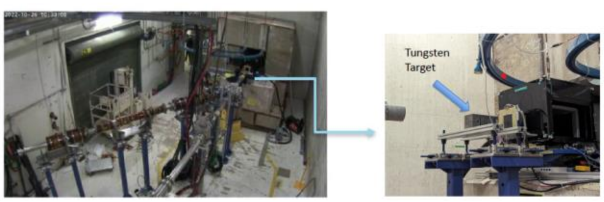

Figure 2: MTA Hall with Tungsten as target

2. EXPERIMENTAL SETUP

The experimental setup consisted of a 400 MeV proton beam line that transported H- ions from the Fermilab LINAC to the MTA beam alcove(Figure 2). In this setup, the tungsten target was positioned near the end of the 40' MTA Hall. To observe variations in the number of neutrons recorded by the detectors, part of the experiment involved relocating the detector rack from across the tungsten target to a position 12 meters back and upstream. The intense 400 MeV proton beam struck the tungsten target, producing many secondary subatomic particles that subsequently struck the detectors. The detectors used in the experiment included an 8-channel CAEN high-voltage power supply to power the detectors. Signals from the particle detectors, a neutron detector, a photomultiplier tube (which detects gammas), and an ion chamber were connected to a fast oscilloscope for data acquisition(Figure 3).

Figure 3: Power supply, Oscilloscope, Neutron detector, Ion chamber PMT, MTA Hall pinpointing to the original and new location of the detectors

It's worth noting that the ion chamber directly measures the electrical current induced by the ionization process and does not amplify the signal from particles. Therefore, it effectively provides an overall charge or current measurement rather than detecting specific particles.

2.1 TUNGSTEN TARGET

Tungsten is chosen as the target material due to its exceptional properties. It boasts a high melting point of 3410 °C, making it capable of withstanding the high heat and energy produced during particle beam experiments. Additionally, its high thermal conductivity of 170 W/m·K helps dissipate the generated heat effectively. Tungsten's 19.3 g/cm^3 density also makes it an excellent spallation source, resulting in large amounts of radiation when bombarded with a high-energy proton beam(Figure 4).

Spallation is a nuclear reaction process occurring in particle accelerators, where high-energy particles like protons collide with a target nucleus, breaking it into smaller fragments and releasing substantial energy. Tungsten is commonly used as a target material for spallation reactions, particularly in neutron sources. However, this process has significant effects on tungsten. The spallation process generates heat, neutron flux, and radiation. To manage these challenges, specialized target designs, cooling systems, and materials are needed to enhance the target's performance and longevity in generating neutrons for scientific research.

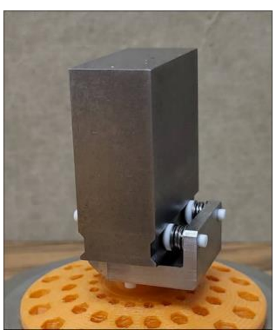

Figure 4: Tungsten Target

2.2 NEUTRON DETECTOR

A neutron detector is a specialized device designed to detect and measure neutrons, which are neutral subatomic particles. Neutrons are challenging to detect directly due to their lack of electric charge, but certain interactions with matter can produce detectable signals.

The heart of the neutron detector comprises a blend of lithium and a scintillator. Neutrons are absorbed by lithium, resulting in the emission of an alpha particle. This alpha particle promptly strikes a scintillating substance, transforming into visible light – a photon. The subsequent detector component is a photomultiplier tube (PMT). Positioned at the PMT's entrance is a responsive material, where photons induce the release of electrons. Operating within a vacuum, the released electron interacts with a series of electrodes, each exhibiting a property of emitting more electrons than they receive upon impact. This multiplication occurs progressively with each electrode collision due to an electric field. The amplified signal grows, eventually becoming observable on an oscilloscope. The amplified signal is collected and measured, providing information about the number of detected neutrons and their energy levels.

2.3 ION CHAMBER

An ion chamber is a type of radiation detector that measures the electrical current generated by the ionization process. When ionizing radiation, such as alpha and beta particles, X-rays, or gamma rays, interacts with the gas-filled chamber, it creates ion pairs by removing electrons from gas atoms or molecules. The ion pairs consist of positively charged ions and free electrons.

The chamber typically consists of a gas-filled volume between two electrodes maintained at a high voltage difference. The positively charged ions are attracted to the negatively charged electrode (cathode), and the free electrons are attracted to the positively charged electrode (anode). This movement of charged particles creates an electrical current proportional to the incident radiation's intensity.

Ion chambers are commonly used for measuring gamma radiation in the environment, as they offer good sensitivity and wide dynamic range. However, they are unsuitable for detecting neutrons directly since neutrons are uncharged particles and do not produce ionization within the gas-filled chamber. Instead, they are used to measure the total radiation field, including secondary particles produced by the interaction of neutrons with other materials.

2.4 PHOTOMULTIPLIER TUBE(PMT)

The PMT is particularly suitable for detecting low-intensity light signals. When the scintillation light reaches the PMT, it strikes a photocathode, liberating photoelectrons. These photoelectrons are then accelerated and focused by a series of electrodes called dynodes, resulting in an exponential multiplication of electrons.

Essentially, the PMT magnifies one photon into multiple electrons. This multiplication is rooted in the interaction of electrons within the material, whereby a charged particle like an electron striking the surface initiates a cascade effect photomultiplier tube (PMT) is a highly sensitive device that detects and amplifies low-level light signals, such as those generated in scintillation detectors. It is based on the photoelectric effect, where photons strike a photocathode, liberating photoelectrons.

The PMT consists of several stages of dynodes, which are electrodes with increasing positive potentials. When the photoelectrons are emitted from the photocathode, they are accelerated towards the first dynode, where each electron can generate several secondary electrons due to a process called secondary emission. These secondary electrons are then accelerated towards the next dynode, where the multiplication process repeats. This cascade of electron multiplication results in an exponential amplification of the original signal.

The amplified signal from the last dynode is collected and measured as an output signal, providing information about the intensity of the incident light. PMTs are highly sensitive and widely used in various applications, including particle physics experiments, medical imaging, and astronomical observations.

In the experimental setup, the PMT was utilized to detect gamma rays, as it can efficiently convert scintillation light into electrical signals. However, since neutrons are uncharged particles and do not interact directly with the PMT, it does not detect the neutrons themselves but rather measures the secondary particles (e.g., gamma rays) produced by neutron interactions with other materials.

3. OBJECTIVES

The primary objective of this research was to characterize the radiation levels in the MTA Hall, with a specific focus on the neutron radiation component. By comparing the radiation levels with and without the tungsten target, in addition to moving the detectors have provided information in regards to the impact of the target on background radiation. This information is essential for designing and constructing future accelerator facilities, where radiation can affect the performance and lifespan of electronic components.

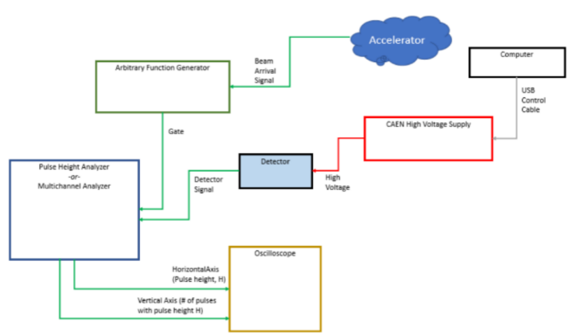

Figure 5: Sequence of events c/o Randy Thurman-Keup

4. DATA COLLECTION AND ANALYSIS

Throughout the data collection process, we accounted for various crucial parameters. These encompassed factors such as detector voltages, the presence or absence of tungsten, and variations in the positioning of the detector rack. Comprehensive details of these parameters have been thoughtfully documented in Appendix B.

Our analysis of the accumulated data has compellingly substantiated the notion that introducing tungsten yields a diverse spectrum of subatomic particles. This stands in distinct contrast to data collected in the absence of tungsten.

Python was the chosen tool for data analysis, offering the advantage of efficient handling of large datasets and effective data visualization techniques. This allowed us to comprehensively understand the neutron radiation levels and their correlation with the relative position of the detectors concerning the tungsten target. This strategic decision greatly facilitated the exploration of neutron radiation levels and their intricate correlation with the relative positions of the detectors in relation to the tungsten target. The Python scripts used for data analysis and visualization are provided in Appendix A, offering transparency and reproducibility in the methodology employed. This analytical approach expedited the data processing and contributed significantly to the project's success by enabling a thorough exploration of the phenomena under study. Data collection for this study was meticulously executed, considering a range of crucial parameters. Variations in the voltage settings of the PMT (Photomultiplier Tube) and neutron detector

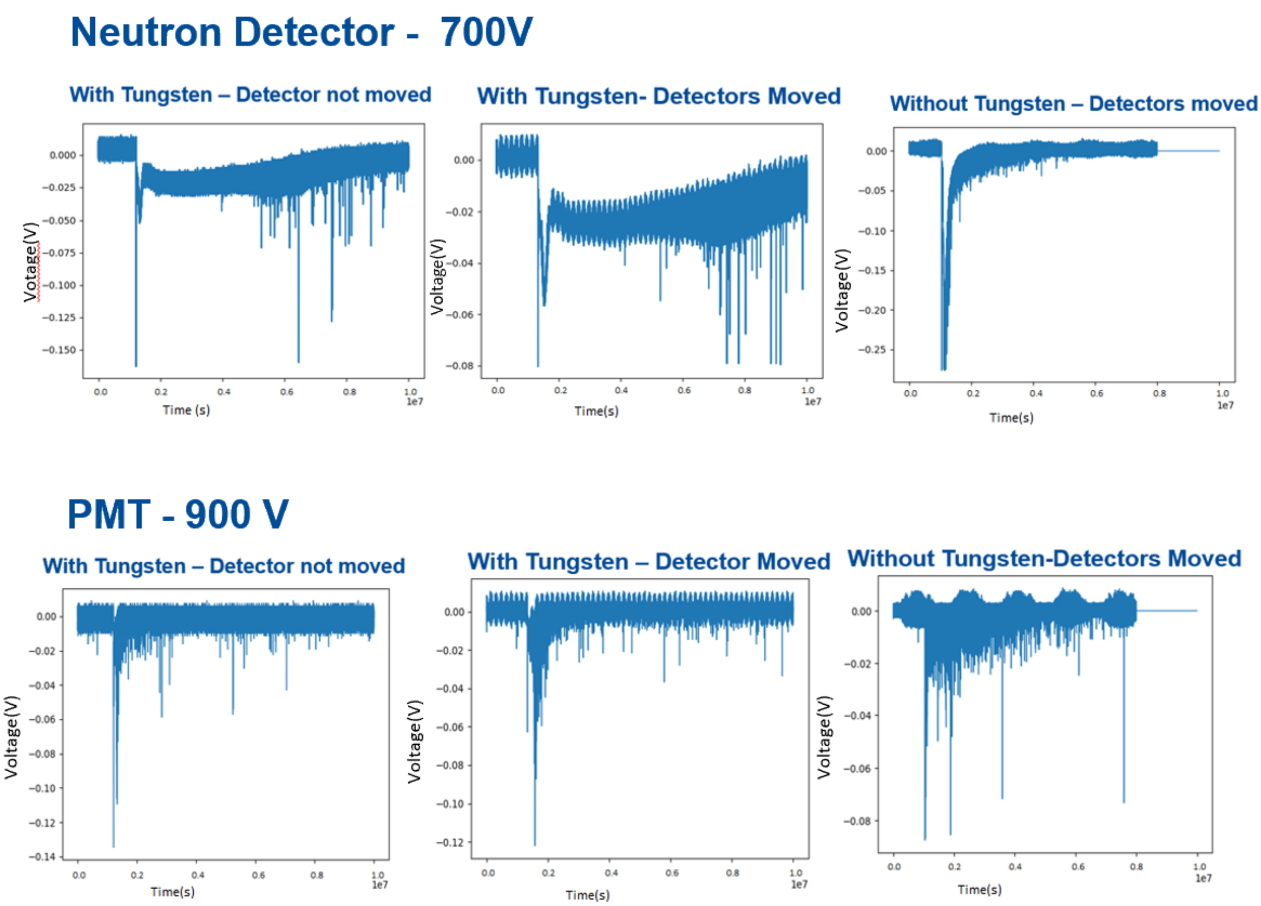

Figure 6: Data analysis results using Python shows a significant contrast in results when observing neutron production with the introduction of tungsten

were systematically explored to analyze their effects on radiation measurements comprehensively. The experimental setup encompassed scenarios involving the presence of tungsten and its absence, allowing for a comprehensive investigation of radiation interactions in differing conditions. Moreover, data was acquired with detectors both in static positions and with deliberate movement, enabling the assessment of radiation patterns across diverse spatial
configurations. The collected data underwent rigorous analysis utilizing Python scripts, as detailed in Section 4, and the results of this analysis are presented graphically in Figure 6.

5. RESULTS

The experimental results provided significant insights into the generation of neutrons using a tungsten target within an operational accelerator environment. The data showed a considerable increase in the number of neutrons measured by the neutron detector when the tungsten target was present (Figure6). Conversely, the photomultiplier tube (PMT) did not exhibit a similar increase since it detects only charged particles.

Additionally, the relocation of the detectors provided crucial insights into how the presence of the tungsten target influenced neutron trajectories and interactions compared to the original setup.

6.ACKNOWLEDGEMENTS

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8.APPENDIX A

Python code used in data analysis :

```
import matplotlib.pyplot as matplot
import csv
import numpy
data = numpy.empty(50000000)
print("Starting...")
with open(r"C:\CSV DATA\tres.csv") as csv_file:
    iter = csv.reader(csv_file)
    ind = 0
    for row in iter:
        data[ind] = float(row[1])
        ind += 1
print("Done.")

matplot.figure()
matplot.plot(data, linewidth = 1)
matplot.show()
```

APPENDIX B

During the data collection phase, we've developed a convenient spreadsheet to streamline the task of deciphering the voltage information stored within the .csv files. Below, you'll find a list of the file names associated with the collected data:

.csv files data for MTA Beam Study Summer 2023

MTA Hall Beam Study 7/6/2023 - TUNGSTEN IN/ Detectors not moved

	Measurement #1	Measurement #2	Measurement #3	Measurement #4	Measurement #5
Channel 0	2000	2000	2000	2000	2000
Channel 4	500	300	250	700	200
Channel 5	800	600	500	900	400
File#	...31111.csv	...32037.csv	...32802.csv	...33955.csv	...34954.csv

All measurements are in cronological order
The Oscilloscope saved everything for 7/7/2023 (I think)

Oscilloscope Inputs	
Channel 1	Neutron Detector
Channel 2	PMT Detector
Channel 3	Ion Chamber

Oscilloscope to Supply connection	
Channel 0	Ion Chamber
Channel 4	Neutron Detector
Channel 5	PMT

MTA Hall Beam Study 7/12/2023 Detectors moved / Without Tungsten

	Measurement #1	Measurement #2	Measurement #3	Measurement #4	Measurement #5	Measurement #6
Channel 0	2000	2000	2000	2000	2000	2000
Channel 4	500	300	700	800	600	1000
Channel 5	800	600	900	1000	1000	1100
File #	..722.csv	..735.csv	..434.csv	...142.csv	..930.csv	..3931.csv

Measurements have been attempted at previous values from 7/6/2023, #3 and #5, but less activity was noticed.

MTA Hall Beam Study 7/14/2023 Detectors moved/ With W

	Measurement #1	Measurement #2	Measurement #3	Measurement #4	Measurement #5	Measurement #6	Measurement #7	Measurement #7	Measurement #7
Channel 0	2000	2000	2000	2000	2000	2000	2000	2000	2000
Channel 4	500	300	250	700	600	800	800	800	200
Channel 5	800	600	500	900	1000	1000	1000	1000	400
File #	...006.csv	..754.csv	..501.csv	..311.csv	..100.csv	..140000.csv	..700.csv	..459.csv	..901.csv
						First part of the reading . Stopped at 518ms	Second part of the reading	Just neutron detector	