CONSTRUCTION AND COMMISSIONING OF GAS ELECTRON MULTIPLIER (GEM) DETECTORS IN ADVANCED ASSEMBLY DESIGN FOR LOW-ENERGY APPLICATIONS AT HIGH RATES AND ANALYSIS OF GEM DATA FROM THE MUSE EXPERIMENT AT PSI

A Dissertation

by

SAHARA JESMIN MOHAMMED PREM NAZEER

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This dissertation submitted by Sahara Jesmin Mohammed Prem Nazeer in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Hampton University, Hampton, Virginia is hereby approved by the committee under whom the work has been completed.

Michael Kohl, Ph.D.
Committee Chair

José L. Goity, Ph.D.

Paul Guèye, Ph.D.

Al Amin Kabir, Ph.D.

Jerald Dumas, Ph.D.
Dean, The Graduate College

Date

ABSTRACT

Construction and commissioning of Gas Electron Multiplier detectors in advanced assembly design and analysis of scattering data from the MUSE experiment at PSI
(August 2023)

Sahara Jesmin Mohammed Prem Nazeer, B.Sc., University of Peradeniya;
Ph.D. Hampton University
Chair of Advisory Committee: Dr. Michael Kohl

The search beyond the Standard Model explores dark matter and a potential fifth force. DarkLight@ARIEL investigates the dark photon as a mediator between ordinary and dark matter. The experiment aims to measure the process $e^{-}Ta \rightarrow e^{-}TaX \rightarrow e^{-}Ta(e^{-}e^{+})$, by detecting a charged lepton pair in the final state. The spectrometers will be instrumented with Gas Electron Multiplier (GEM) detectors with minimal material budget for tracking.

A novel GEM construction technique is employed for fabricating 25 cm x 40 cm GEM detectors, where all layers are mechanically stretched and assembled within a double frame. The dissertation outlines physics motivation, methods, experimental setup, and the role of GEM detectors in DarkLight. A comprehensive discussion on GEM detectors, focusing on the "NS2" technique, including design, parts, assembly, testing, and performance evaluation will be discussed.

The proton has garnered attention due to discrepancies in measuring its charge radius using muonic hydrogen and electron-based methods. The 2010 muonic hydrogen measurement of the proton charge radius $R_p = 0.84184(67)$ fm, showed a significant 7σ discrepancy compared to the previously known value of $R_p = 0.8775(51)$ fm, giving rise to the proton radius puzzle. Through simultaneous measurements of $e - p$ and $\mu - p$ elastic scattering, MUSE facilitates a precise and direct comparison of the

proton radius. The physics background of the proton radius puzzle, measurement techniques, the approach adopted by the MUSE experiment, its significance and the experimental setup will be discussed. Furthermore, the role of GEM detectors, along with an in-depth analysis of their data and efficiency will be discussed and evaluated.

Dedicated to my beloved parents, husband and children.

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CHAPTER 1
INTRODUCTION

1.1 GEM Detector Construction for DarkLight@ARIEL Experiment

The Standard Model explains subatomic particles and interactions, but not all mysteries. Dark matter constitutes 27% of the universe, yet remains invisible. A mediator, the dark photon or A', could interact with ordinary and dark matter. DarkLight@ARIEL experiment investigates a hypothetical particle using an electron beam at ARIEL facility, TRIUMF, Canada to understand the fifth force and dark matter.

The X17 particle, a hypothetical mediator of the fifth force, has gained significant attention due to various unexplained phenomena observed in recent experiments. Anomalous results in the decay of excited ^{8}Be and ^{4}He atoms have hinted at the presence of a new particle with a mass of around 17 MeV/c^2. These experimental findings, coupled with the deviation in the muon's magnetic moment (g_μ-2) from the predicted value, have piqued the interest of physicists in the existence of a new force carrier. The DarkLight experiment aims to explore this possibility further by utilizing the ARIEL e-linac's high-energy electron beam to investigate the interaction between the proposed protophobic boson and ordinary matter. By colliding the electron beam with a tantalum target, DarkLight seeks to shed light on the nature of dark matter and potentially discover evidence of the fifth force.

The projected scope of DarkLight@ARIEL encompasses a comprehensive investigation of the proposed fifth force parameter space. The experiment's sensitivity is