Dark Matter Physics Simulation & Analysis for the Dark Photon Semester 2 Test Plan

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Faculty Advisor and Client

- Dr. Marcus Hohlmann - Physics Professor
- Pietro Iapozzuto - Graduate Student with Dr. Hohlmann

Goal and Motivation - EIC Pipeline

- Originally we were tasked with automating the EIC pipeline simulating a proton collision producing a dark particle. Our first semester we managed to automate all the steps up until background subtraction which was comparing a dark matter simulation to a regular proton collision.

Goal and Motivation - Research Notebook “Long-Lived Dark Gauge Boson”

- Our task has evolved into understanding and replicating a codebase from a Python notebook that computes how a hypothetical long-lived dark gauge boson would be produced in lepton-nucleus collisions at the EIC and a muon beam dump. The code computes the differential production cross-section using the Weizsäcker-Williams approximation. We want to understand and justify the use of the W-W approximation in computing these production cross-sections, and validate the branching-fraction calculations built on top of it.
- Alongside this new task we also want to finalize what we have accomplished in the first semester.

Approach - EIC Pipeline

1. Visualize the decay products of the dark matter interaction in the EIC Geometry (Create HepMC files).
2. Find the most probable dark matter signal (invariant mass, pseudorapidity (eta), location).
3. Correctly perform background subtraction for competing processes (ie Pions).
4. Correct signal matching for the dark matter e+ e-.

Approach - Research Notebook “Long-Lived Dark Gauge Boson”

1. Read and understand what the Weizsacker-Williams approximation is doing fundamentally.
2. Interpret why this specific approach was chosen.
3. Replicate the code used within the python notebook.
4. Compare results with original notebook, and explain the key similarities and differences.

Novel Features

- Visualization of the dark matter tracks that is able to be shown and explained to a customer or nontechnical person.
- Background subtraction of user specific dark matter process allowing for matching of dark matter between simulation and real data.
- A verification that using Weizsacker-Williams approximation produces consistent results when computing cross sections.

Algorithms and Tools

- GitHub - Host for our website and version control for scripts and other files
- Mad Graph - CLI Modeling Software
- HepMC - Object-oriented C++ event record in High Energy physics
- ROOT - Data analysis framework to create histograms, can work as a python library
- EIC Shell - Containerized software environment for the Electron-Ion Collider
- Python - Primary programming language we will be working with
- Fortran Compiler - To run the specific command “launch” while inside of Mad Graph
- Discord and Google Chat - For group communication
- Weizsacker-Williams Approximation - Approximation scheme used in particle physics to simplify and analyze complex high-energy electromagnetic and electroweak interactions

Technical Challenges - EIC Pipeline

- We will use a lot of commands through the CLI and will have to manage them so we use the right commands with the software we are working with at that time
- It will be necessary to use Mad Graph, HepMC, and EIC and the processes between them to create diagrams of particles, but we will need to learn completely from scratch on how to use these
- Also necessary to use ROOT and identify Dark photon and decay products, will need to understand how to use this software
- Producing visualizations at the generator level with correct colors and data shown and have a reasonable fps to show.

Technical Challenges - Research Notebook “Long Lived Gauge Bosons”

- We will need to download and understand the use of the libraries used in the original code.
- The Weizsacker-Williams approximation contains many physics assumptions that we will be responsible for learning and understanding.
  - Alongside these assumptions the approximation is made up of different physics equations that we will also be responsible for understanding the concepts these equations are solving.

System / EIC Pipeline Design

Progress Summary

Task	Completion %	To do
Ran MadGraph and produce an automation script	100%	-
Analyze HepMC files	100%	-
Convert HepMC files to root files using ddsim scripts	100%	-
Analyzing the reconstructed particles from the root file	100%	-
Compare reconstructed root particles between a dark matter collision and a regular collision	75%	We understand how to examine a run of this step; we now have to automate this task in an easy and intuitive way
Optimizing pipeline	75%	We still need to automate background subtraction into correcting signal matching for dark matter. This is the last step within our EIC pipeline.
Visualization	65%	Visualization of tracks from the provided HepMC files. Essentially finding points in which a positron and an electron collide at a single point.

Milestone 4

- Task 1: Understanding the Weizsacker-Williams approximation code base
- Task 2: Testing Weizsacker-Williams approximation code base
- Task 3: Replicating results from the Weizsacker-Williams approximation code base
- Task 4: Write the user manual

Milestone 4 Task Matrix

Task	Nikhil	Sam	Jacob
Understanding the Weizsacker-Williams approximation code base	1/3	1/3	1/3
Testing Weizsacker-Williams approximation code base	1/3	1/3	1/3
Replicating results from the Weizsacker-Williams approximation code base.	1/3	1/3	1/3
Write the user manual	1/3	1/3	1/3

Milestone 5

- Task 1: Optimise background subtraction and path flow
- Task 2: Find a location where physicists should put another detector, aka a vertex
- Task 3: Continue streamlining and cross-section validation

Milestone 6

- Task 1: Complete optimization of pipeline
- Task 2: Run and evaluate through the whole pipeline and ensure the pipeline runs smoothly to the right specifications given by the client
- Task 3: Complete user manual

Thank You