Project:

Analysis & Dark Matter Physics Simulation for the Dark Photon

Team Members:

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Faculty Advisor:

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Clients:

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

Dates of Meeting(s):

- 8/27, 8/31

Goal and Motivation:

- Originally, we were tasked with automating the EIC pipeline simulating a photon collision producing a dark particle. Our first semester we managed to automate all the steps until background subtraction which was comparing a dark matter simulation to a regular collision.
- Moving forward our task has evolved into understanding and replicating a research python notebook detailing Constraining Long-Lived Gauge Bosons at the EIC and a Muon Beam Dump. The code within this notebook generates generator level cross sections using the Weizsacker-Williams approximation. We want to understand and replicate the findings of the original code.

Approach:

- **Constraining Long-Lived Gauge Bosons at the EIC and a Muon Beam Dump**
  - Reading the summary of results from the given notebook we want to understand the methods described and the code structure used.

        - Downloading the scripts and building structures resembling the code given in the notebook we want to mimic the techniques used by the authors.
        - Analyzing the results from running the code, we want to replicate the results from the paper.
    - **EIC Pipeline**
        - Visualize the decay products of the dark matter interaction in the EIC Geometry. Focuses on forming a clear picture of how particles created in a dark matter interaction move through the Electron–Ion Collider detector. By tracking where these particles travel and which detector regions they pass through, researchers can understand what the event should look like in the experiment. This helps ensure that the detector is being used effectively to observe possible dark matter-related signals.
        - Find the most probable dark matter signal (invariant mass, pseudorapidity (eta), location). The goal is to identify the key features that make a dark matter event most likely. This includes calculating the invariant mass of the detected particles, measuring their pseudorapidity (η) to understand how forward or central they are, and determining where in the detector they appear. These properties help narrow down the phase space where a true dark matter signal is expected to stand out.
        - Correctly perform background subtraction for competing processes (i.e., pions). This step is about removing signals from known Standard Model processes that can mimic dark matter events. Particles like pions are produced frequently and can look similar to the desired signal. By estimating how often these background processes occur and subtracting their contribution, researchers can isolate what remains and reduce false positives
        - Correct signal matching for the dark matter e+ e-. The final step ensures that the detected electron and positron are correctly paired as coming from the same dark matter interaction. This involves matching their tracks and energies so they form a consistent event. Proper signal matching prevents misidentifying unrelated particles as a dark matter decay and improves the reliability of the final results

Algorithms and Tools:

    - GitHub - Host for our website and version control for scripts and other files
    - MadGraph - 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 MadGraph
- 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

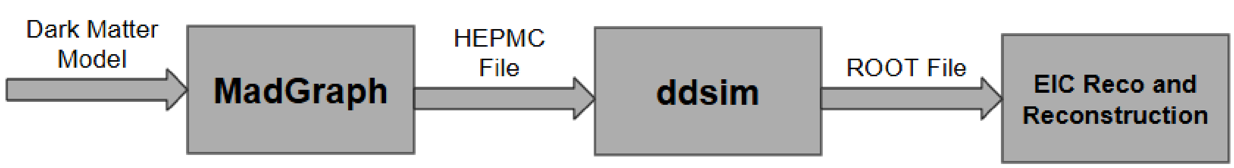
Novel Features:

- 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.

Technical Challenges:

- 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 MadGraph, HepMC, and EIC, and the processes between them to create diagrams of particles, but we will need to learn completely from scratch how to use these
- Also necessary to use ROOT and identify the 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

Design:



Evaluation:

- Speed - How fast we can get through the pipeline
- Accuracy - How accurate the predictions are compared to a possible real result
- Reliability - How many times we get the same result given the same data
- User Survey - How easy it is to download and run a simulation then test the replicated results and get through the pipeline

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 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

Task Matrix Plan for Milestone 4:

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

Discussion of each planned task for Milestone 4:

- Task 1: We will read through the documentation we’ve been provided to understand what exactly the W-W approximation is and how we will be using it
- Task 2: If the W-W approximation is something we will want to use, we will run and test it
- Task 3: If it is working, we will try to replicate the given results in the documentation
- Task 4: Start writing the user manual

Faculty Advisor Approval:

- "I have discussed with the team and approve this project plan. I will evaluate the progress and assign a grade for each of the three milestones."

Signature: ______________________________ Date: ________