Analysis & Dark Matter Physics Simulation for the Dark Photon Milestone 1

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Creating HepMC files - MadGraph

MadGraph is a software capable of producing simulated data of particle collisions with multiple styles of constraints to vary the results produced.

```
load MG5 configuration from ../input/mg5_configuration.txt
set fastjet to fastjet-config
eMELA-config does not seem to correspond to a valid eMELA-config executable.
 Please set the 'fastjet'variable to the full (absolute) /PATH/TO/eMELA-config (including eMELA-config).
 MG5_aMC> set eMELA /PATH/TO/eMELA-config

set lhapdf to lhapdf-config
set lhapdf to /home/jacob2236/seniordesign/MG5_aMC_v3_5_13/HEPTools/lhapdf6_py3/bin/lhapdf-config
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
Loading default model: sm
INFO: Restrict model sm with file ../models/sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+ t b t~ b~ z w+ h w- ta- ta+
MG5_aMC>generate p e- > p e-
```

The Process - MadGraph

Our specific restraints:

P e- > P e+

```
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying process: g e- > g e- WEIGHTED<=4 @1
INFO: Trying process: u e- > u e- WEIGHTED<=4 @1
INFO: Process has 2 diagrams
INFO: Trying process: u e- > c e- WEIGHTED<=4 @1
INFO: Trying process: c e- > u e- WEIGHTED<=4 @1
INFO: Trying process: c e- > c e- WEIGHTED<=4 @1
INFO: Process has 2 diagrams
INFO: Trying process: d e- > d e- WEIGHTED<=4 @1
INFO: Process has 2 diagrams
INFO: Trying process: d e- > s e- WEIGHTED<=4 @1
INFO: Trying process: s e- > d e- WEIGHTED<=4 @1
INFO: Trying process: s e- > s e- WEIGHTED<=4 @1
INFO: Process has 2 diagrams
INFO: Crossed process found for u~ e- > u~ e-, reuse diagrams.
INFO: Crossed process found for c~ e- > c~ e-, reuse diagrams.
INFO: Crossed process found for d~ e- > d~ e-, reuse diagrams.
INFO: Crossed process found for s~ e- > s~ e-, reuse diagrams.
8 processes with 16 diagrams generated in 0.032 s
Total: 8 processes with 16 diagrams
MG5_aMC>
```

Pythia8 - MadGraph

Pythia8 is a software included with Madgraph. Using this software we can include all the sub-collisions after the main event including quarks and particle decay.

```
Either type the switch number (1 to 5) to change its setting,
Set any switch explicitly (e.g. type 'shower=Pythia8' at the prompt)
Type 'help' for the list of all valid option
Type '0', 'auto', 'done' or just press enter when you are done.[60s to answer]
>1
The following switches determine which programs are run:
/================== Description ==================|============ values ==============|======== other options ========\
| 1. Choose the shower/hadronization program       |        shower = Pythia8           |     OFF                        |
| 2. Choose the detector simulation program        |      detector = Not Avail.        |     Please install module      |
| 3. Choose an analysis package (plot/convert)     |      analysis = Not Avail.        |     Please install module      |
| 4. Decay onshell particles                       |       madspin = OFF               |     ON|onshell|full            |
| 5. Add weights to events for new hypp.           |      reweight = OFF               |     ON                         |
\=================================================================================================================/
Either type the switch number (1 to 5) to change its setting,
Set any switch explicitly (e.g. type 'shower=OFF' at the prompt)
Type 'help' for the list of all valid option
Type '0', 'auto', 'done' or just press enter when you are done.
>
```

Simulation Finished - MadGraph

Example of a completed simulation

```
INFO: Update the dependent parameter of the param_card.dat
WARNING: update the strong coupling value (alpha_s) to the value from the pdf selected: 0.13
Generating 10000 events with run name run_01
survey  run_01
INFO: compile directory
Not able to open file /home/jacob2236/seniordesign/MG5_aMC_v3_5_13/bin/PROC_sm_2/crossx.html since no program configured.Please set one in ./input/mg5_configuration.txt
compile Source Directory
Using random number seed offset = 21
INFO: Running Survey
Creating Jobs
Working on SubProcesses
INFO: Compiling for process 1/1.
INFO:     P1_ql_ql
100%|                                                                                | 720/720 [00:00<00:00, 65838.90it/s]
100%|                                                                                | 719/719 [00:00<00:00, 75475.64it/s]
100%|                                                                                | 719/719 [00:00<00:00, 63802.83it/s]
100%|                                                                                | 720/720 [00:00<00:00, 87869.50it/s]
INFO:     P1_ql_ql
INFO:  Idle: 1,  Running: 0,  Completed: 0 [ current time: 13h29 ]
INFO:  Idle: 0,  Running: 0,  Completed: 1 [  0.81s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 1 [  0.81s  ]
INFO: End survey
refine 10000
Creating Jobs
INFO: Refine results to 10000
INFO: Generating 10000.0 unweighted events.
sum of cpu time of last step: 0 second
INFO: Effective Luminosity 119.61722488038278 pb^-1
INFO: need to improve 1 channels
- Current estimate of cross-section: 100.32 +- 1.9497
    P1_ql_ql
INFO:  Idle: 1,  Running: 11,  Completed: 0 [ current time: 13h29 ]
INFO:  Idle: 0,  Running: 11,  Completed: 1 [  2.8s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 12 [  3.2s  ]
INFO: Combining runs
sum of cpu time of last step: 51 seconds
INFO: finish refine
refine 10000 --treshold=0.9
No need for second refine due to stability of cross-section
INFO: Combining Events
combination of events done in 17.623574495315555 s
  === Results Summary for run: run_01 tag: tag_1 ===

     Cross-section :   100.2 +- 0.2701 pb
     Nb of events :  10000

INFO: Running Systematics computation
INFO:  Idle: 1,  Running: 3,  Completed: 0 [ current time: 13h30 ]
```

Analyzing HepMC files

Each line contains information about the collision.

P = Particle

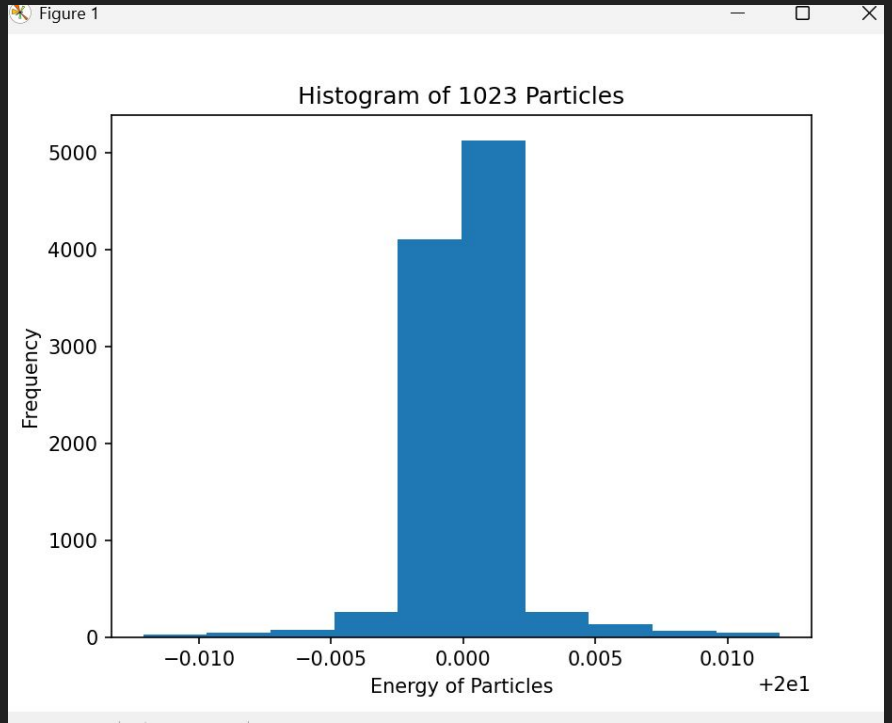
E = Event

V = Vertex

```
V -18 0 0 0 0 0 1 2 0
P 1 2212 4.440892098500626e-15 0 1.200244459514792e+02 1.200611259183611e+02 9.382700000000005e-01 4 0 0 -18 0
P 26 2 8.6870333775089925e-01 -1.4598932807472362e+00 9.9676198853595423e+01 9.9690674347110757e+01 0 61 0 0 -10 1 1 501
P 33 2101 -8.9736599758049018e-01 1.4178167727737963e+00 2.0082165447961589e+01 2.0160467813594373e+01 5.7933000000000001e-01 63 0 0 -30 1 2
501
V -19 0 0 0 0 0 0 1 0
P 27 1023 1.6965861233642048e+01 -3.0249858653823671e+00 3.7846930509556245e+00 2.6671139426941313e+01 2.0000869730000002e+01 62 0 0 -25 0
V -20 0 0 0 0 0 0 1 0
P 28 2 -2.0719693736881425e+01 -9.1347016953524900e+00 4.1979373865708766e+01 4.7697131085319910e+01 0 62 0 0 -28 1 1 502
```

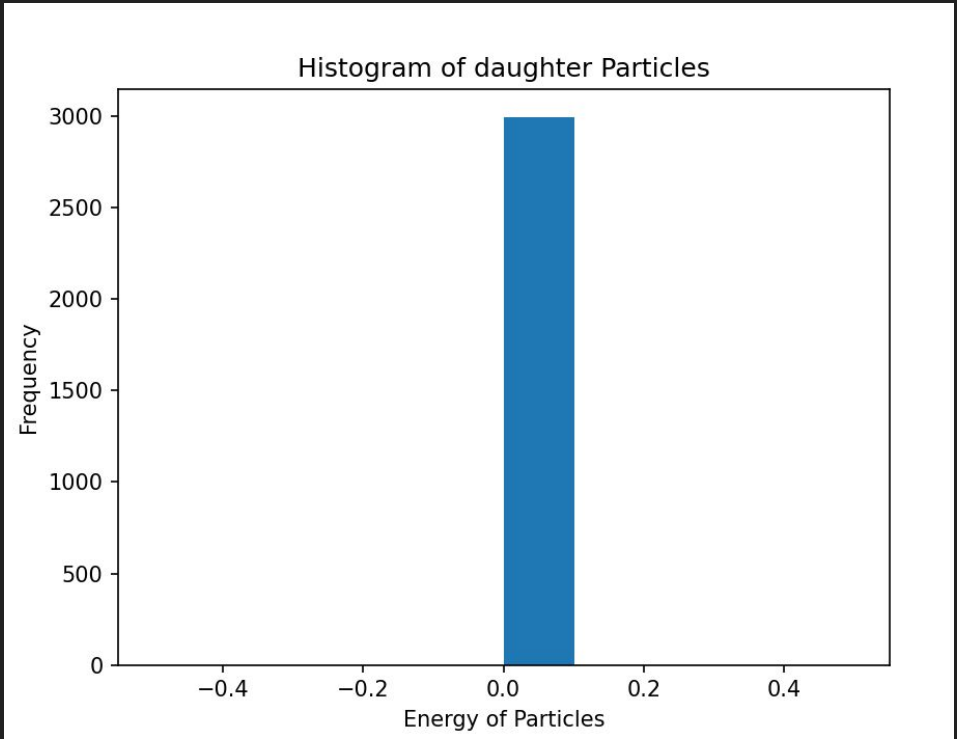
Graphing the dark particles

From the HepMC file



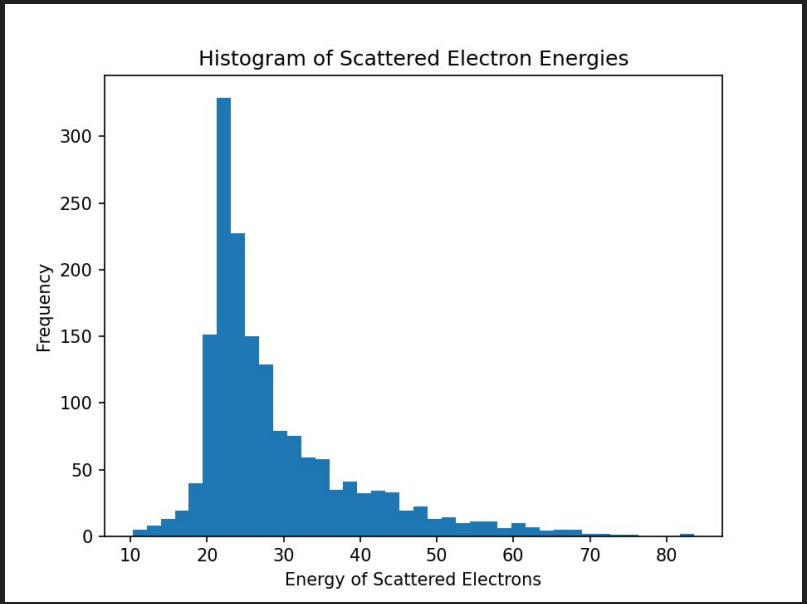
Graphing the daughter particles

From HepMC file using dark particles

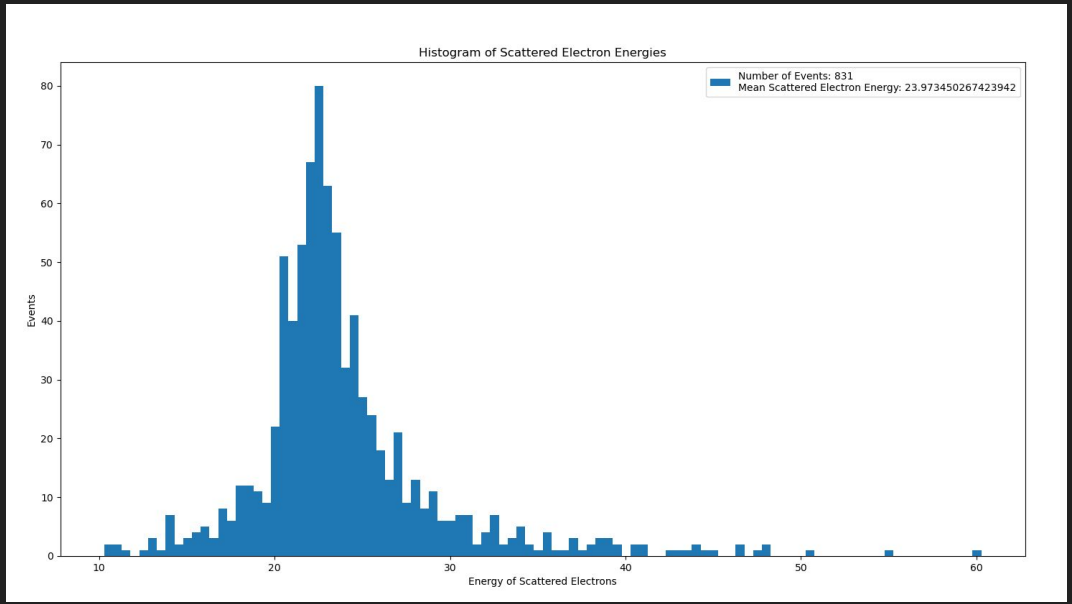


Plotting Scattered Electrons Energies

With quarks included, but not wanted:



Without quarks, and just scattered electrons:



Creating Root Files

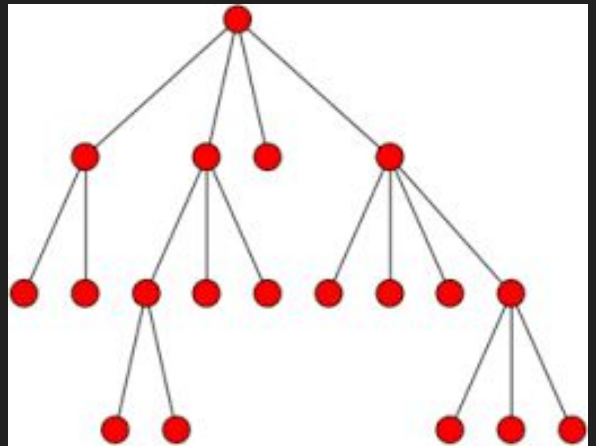
Using GEANT4 a reconstructed root file is produced by propagating HepMC truth-level events through detector simulation, digitization, and reconstruction algorithms to produce analysis-ready physics objects stored in ROOT format.

Root files

How are they organized?

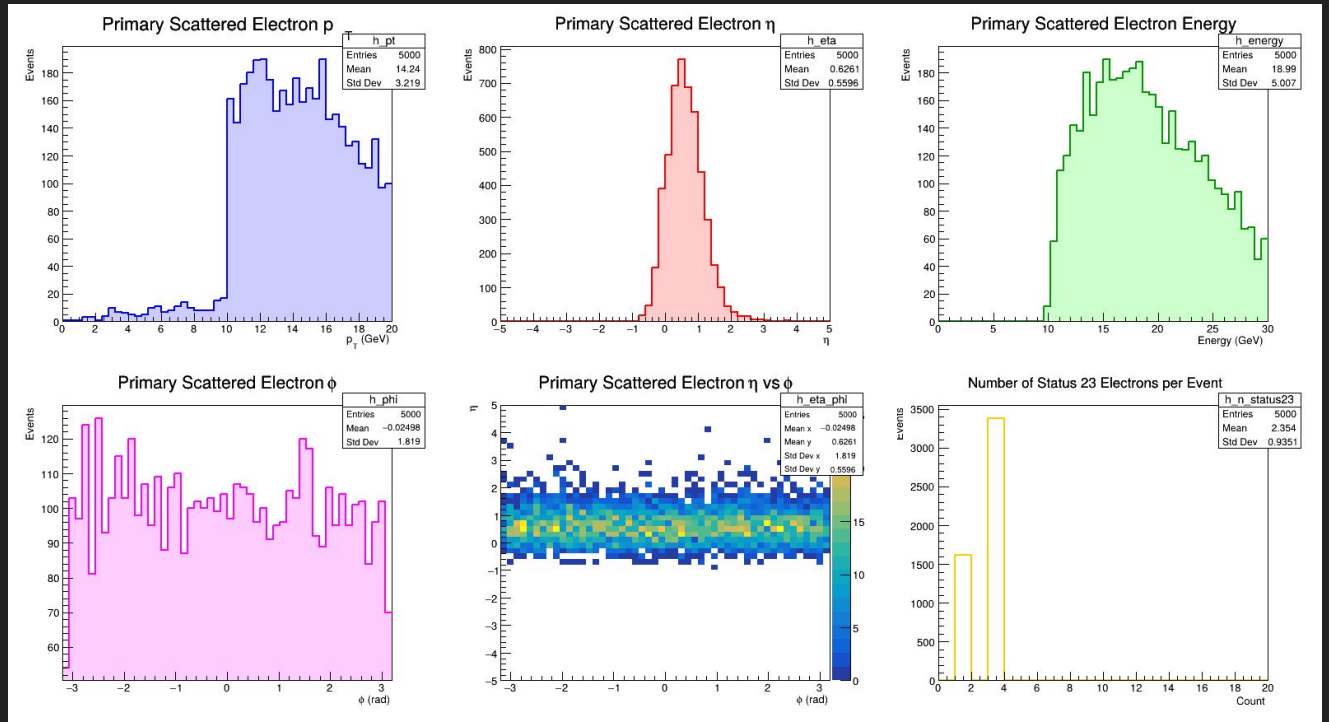
Contains a tree of branches, each branch containing relevant information on the particle collision.

We want the reconstructed particle branch and the MCparticle branch.



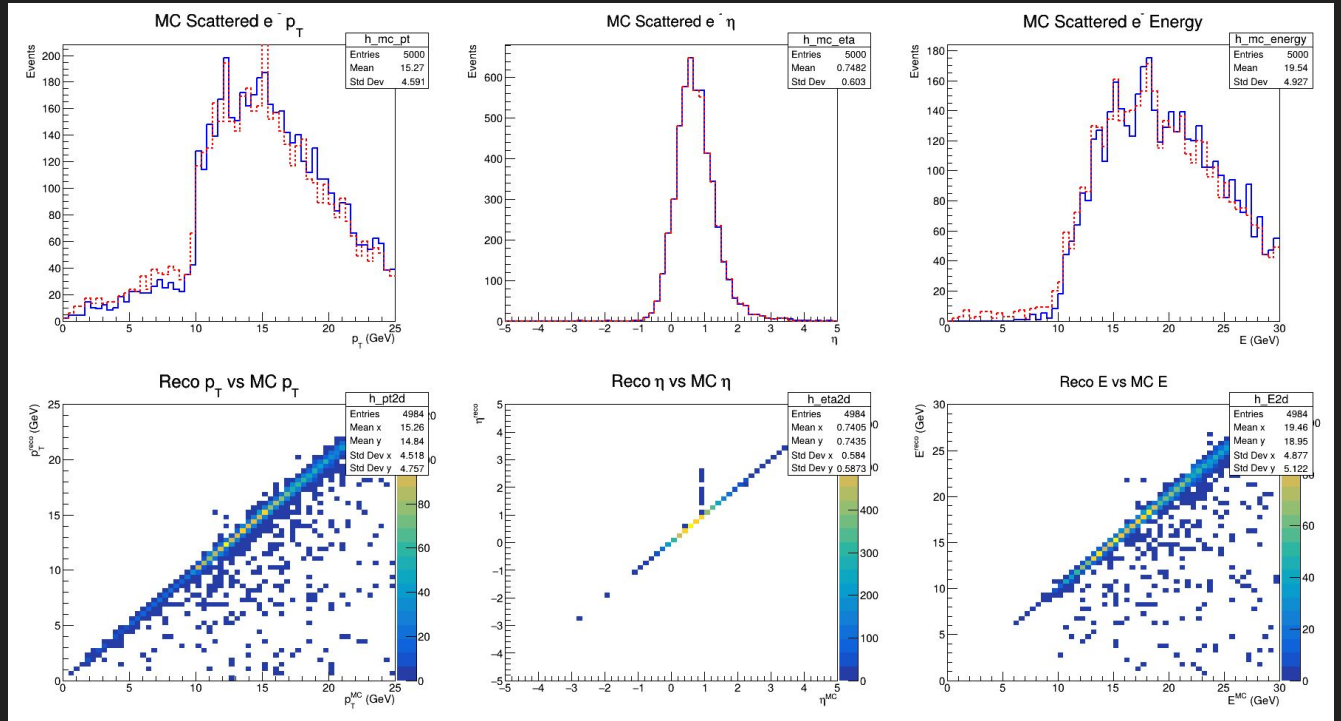
Graphing reconstructed scattered electrons

Using C scripts to find data in a reconstructed.root file in the MC particle branch



Matching scattered electrons

At this phase we are comparing particles in the two branches we specified earlier

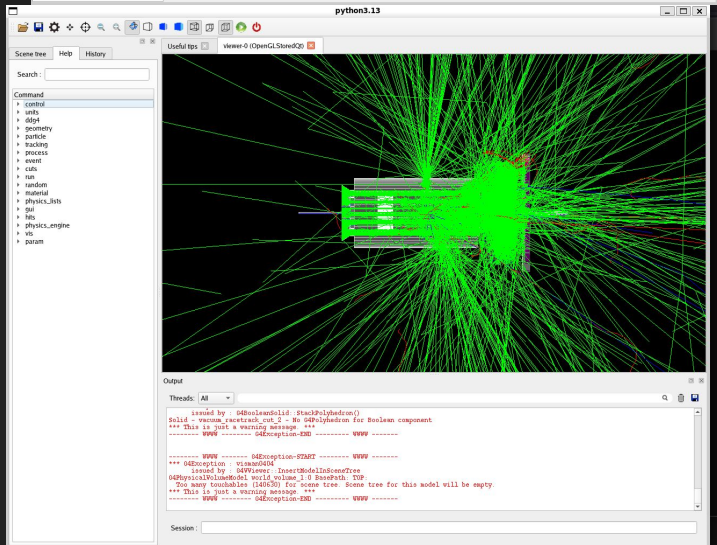


Visualization

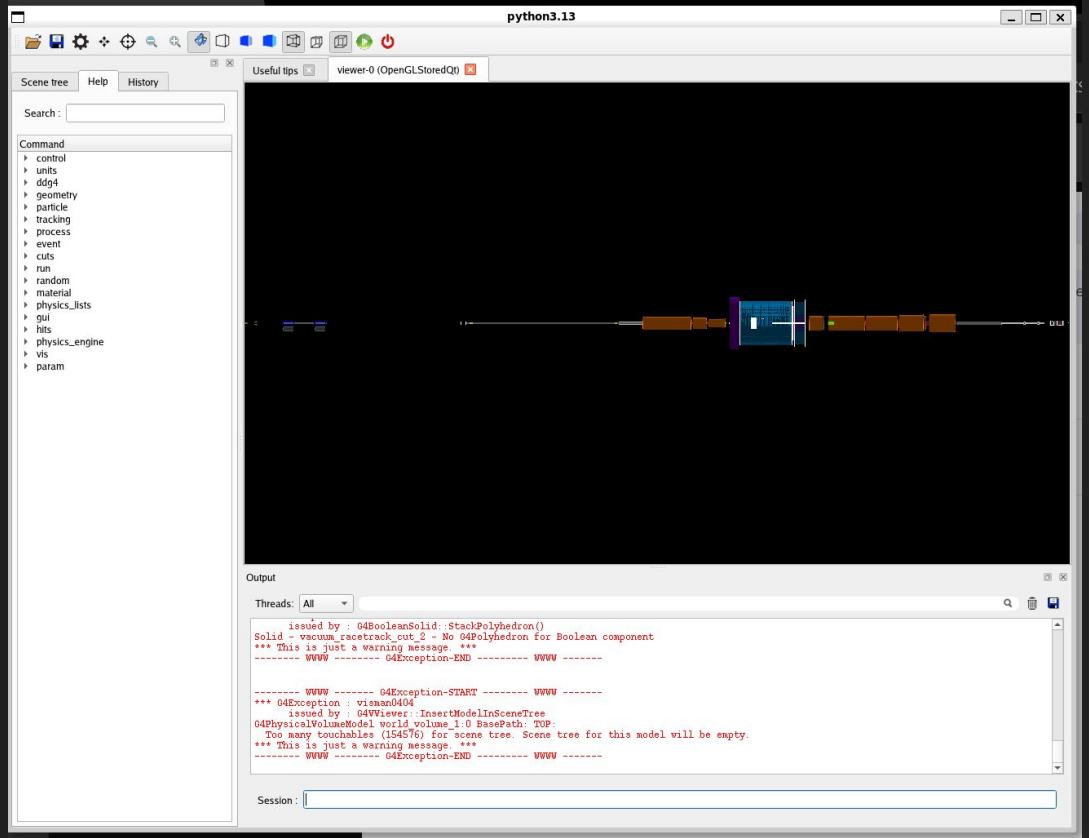
Green - Gamma Ray

Blue - Negative

Red - Positive



Visualization cont.



Requirements

User Interface

File Interface

Software Interface

Data Generation and Input

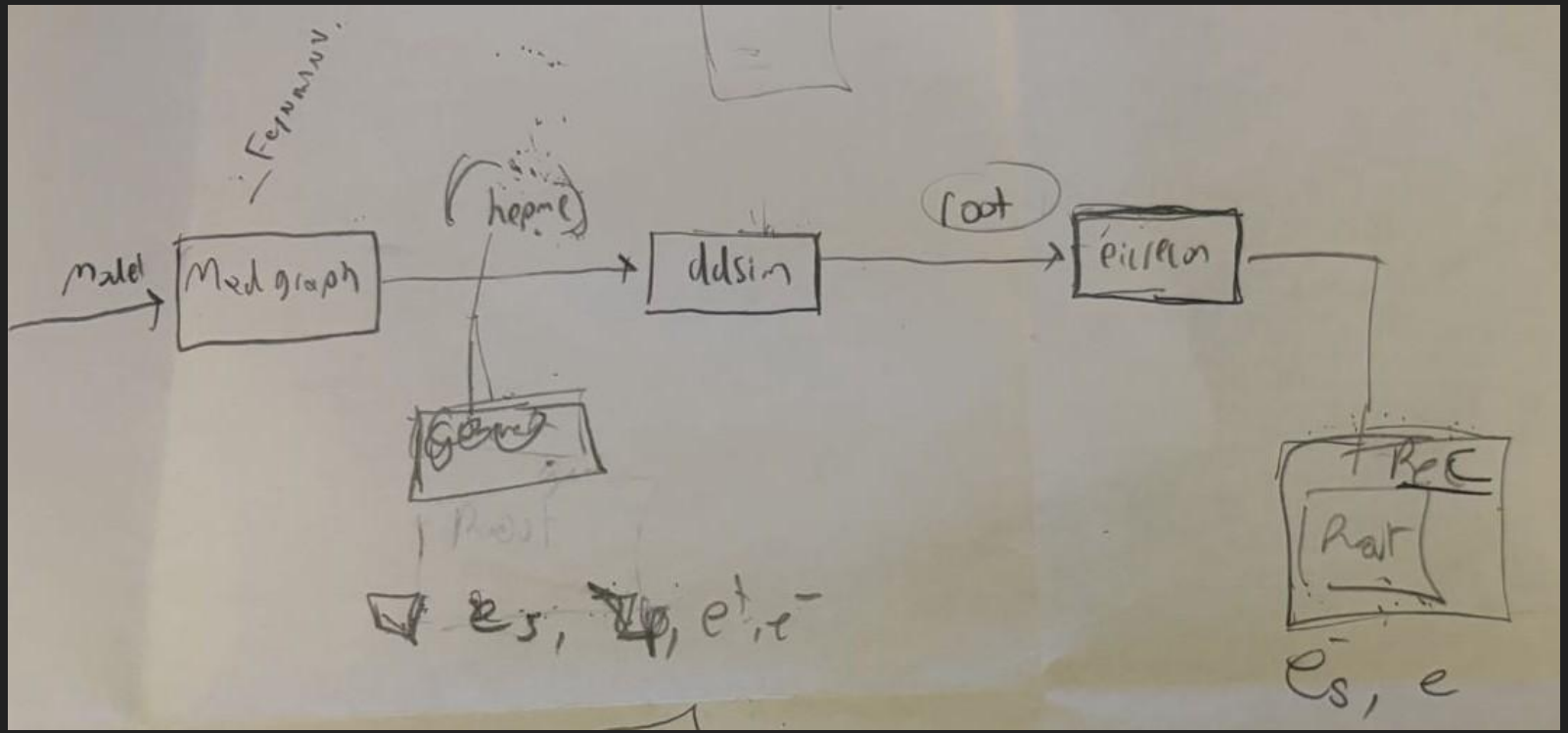
Detector Simulation and Reconstruction

Physics Object Identification and Extraction

Visualization and reporting

File Creation and Analyzation

Design



Test Plan

Data Organization - Test how accurately we are gathering data from the files we are generating.

Data Comparison - Test by comparing file data we are producing to existing research data.

Data Reproduction - Test how easily we can reproduce the correct data given different constraints on the creation of the initial particle collision.

Milestone 1 Task Matrix

Task	Completion %	Nikhil	Sam	Jacob
Learn and understand how to use Mad Graph, HepMC, and ROOT	100%	1/3	1/3	1/3
Start reading HEPMC files	100%	1/3	1/3	1/3
Use ROOT to identify particle id numbers ie 1023 is dark photon candidate as a parent particle and its decays (children) and graph physics related quantities ie Momentum of scattered particle	100%	-	-	100%
Install EiC RECO and Use EIC Geometry, NPSIM to output reconstruction root file	100%	100%	-	-
Use ROOT to graph signals of initial proton and electron, the scattered electron and decay products at the madgraph generator level, and compare it to the EIC reconstruction level	50%	-	-	50%
Produce EIC visualization using inner detector obtaining dark matter decay product e- e+ tracks	100%	100%	-	-
Using HepMC file data, produce a Python script that works along with ROOT to produce histograms of scattered electron energy	100%	-	75%	25%
Requirement Document	100%	100%	-	-
Design Document	100%	-	100%	-
Test Plan	100%	-	-	100%

Milestone 2

- Complete graph of background subtracted signal of dark matter at the end of the EIC pipeline.
- Explore 10-20 different invariant masses and have them get run through the simulation pipeline
- Visualize the invariant masses to identify most probable dark matter invariant mass and incorporate the background subtracted

Milestone 2 Task Matrix

Task	Nikhil	Sam	Jacob
Complete graph of background subtracted signal of dark matter at end of EIC pipeline	-	50%	50%
Explore 10-20 different invariant masses and have them get run through the simulation pipeline	-	50%	50%
Visualize the invariant masses to identify most probable dark matter invariant mass, and incorporate the background subtracted	100%	-	-

Thank you, Questions?