Analyzing Momenta of Particles from UrQMD f13 output file

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What’s Happening?

- The UrQMD program is capable of simulating collisions between atomic nuclei. F13 output files provide data pertaining to the collision event and the particles emerging from the region in which the nuclei have collided. Figure 1 shows a stylized representation of this process in which nucleons are colored grey and particles are colored red, green, and blue.
- In this scenario, two output files were provided, each containing data for 250 collision events. Figures 2 and 3 show the first event headers of the first and second output files, respectively. The header of each event in the output file specifies the mass number and electric charge of the projectile and target nuclei along with other parameters.
- In all the events, the projectile and target nuclei had an equal mass number of 197 and electric charge of +79. Given these parameters, one can conclude that the nuclei simulated were that of gold atoms.

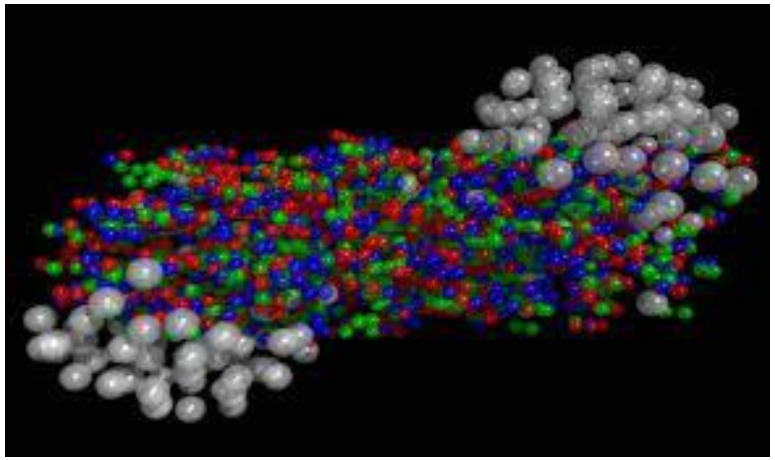

Figure 1

```
UQMD   version:       30400   1000  30400  output_file  13
projectile:  (mass, char)  197  79   target:  (mass, char)  197  79
transformation betas (NN,lab,pro)      0.0000000  0.9954088 -0.9954088
impact_parameter_real/min/max(fm):     2.83  0.00  3.40  total_cross_section(mbarn):      363.17
equation_of_state:    0  E_lab(GeV/u): 0.2029E+03  sqrt(s)(GeV): 0.1960E+02  p_lab(GeV/u): 0.2038E+03
event#          1 random seed:    10972519 (fixed)  total_time(fm/c):       200 Delta(t)_O(fm/c):       200.000
op  0    0    0    0    1    0    0    0    0    0    0    0    0    0    0
op  0    0    0    0    0    0    1    0    1    0    0    0 *  0    2    1
op  0    0    0    1    1    0    0    0    0    0    0    0    0    1    0
op  0    5    0    0    0    0    0    0    0    0    0    1    0    1    0
pa 0.1000E+01   0.5200E+00   0.2000E+01   0.3000E+00   0.0000E+00   0.3700E+00   0.0000E+00   0.9300E-01   0.3500E+00   0.2500E+00   0.0000E+00   0.5000E+00
pa 0.2700E+00   0.4900E+00   0.2700E+00   0.1000E+01   0.1600E+01   0.8500E+00   0.1550E+01   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
pa 0.9000E+00   0.5000E+02   0.1000E+01   0.1000E+01   0.1000E+01   0.1500E+01   0.1600E+01   0.0000E+00   0.2500E+01   0.1000E+00   0.3000E+01   0.2750E+00
pa 0.4200E+00   0.1080E+01   0.8000E+00   0.5000E+00   0.0000E+00   0.5500E+00   0.5000E+01   0.8000E+00   0.5000E+00   0.8000E+06   0.1000E+01   0.2000E+01
pa 0.5000E+00   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.7000E+00   0.3000E+01
pa 0.2000E+00   0.2000E+03   0.1000E+01   0.5000E+01   0.1000E+01   0.1000E+11   0.1000E+01   0.1000E+01   0.0000E+00   0.1000E+11   0.2000E+01   0.5500E+00
pvec: r0             rx             ry             rz             p0             px             py             pz             m          ityp 2i3 chg lcl#  ncl or
```

Figure 2

```
UQMD   version:       30400   1000  30400  output_file  13
projectile:  (mass, char)  197  79   target:  (mass, char)  197  79
transformation betas (NN,lab,pro)      0.0000000  0.9954088 -0.9954088
impact_parameter_real/min/max(fm):     2.64  0.00  3.40  total_cross_section(mbarn):      363.17
equation_of_state:    0  E_lab(GeV/u): 0.2029E+03  sqrt(s)(GeV): 0.1960E+02  p_lab(GeV/u): 0.2038E+03
event#          1 random seed:      113528 (fixed)  total_time(fm/c):       200 Delta(t)_O(fm/c):       200.000
op  0    0    0    0    1    0    0    0    0    0    0    0    0    0    0
op  0    0    0    0    0    0    1    0    1    0    0    0 *  0    2    1
op  0    0    0    1    1    0    0    0    0    0    0    0    0    1    0
op  0    5    0    0    0    0    0    0    0    0    0    1    0    1    0
pa 0.1000E+01   0.5200E+00   0.2000E+01   0.3000E+00   0.0000E+00   0.3700E+00   0.0000E+00   0.9300E-01   0.3500E+00   0.2500E+00   0.0000E+00   0.5000E+00
pa 0.2700E+00   0.4900E+00   0.2700E+00   0.1000E+01   0.1600E+01   0.8500E+00   0.1550E+01   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
pa 0.9000E+00   0.5000E+02   0.1000E+01   0.1000E+01   0.1000E+01   0.1500E+01   0.1600E+01   0.0000E+00   0.2500E+01   0.1000E+00   0.3000E+01   0.2750E+00
pa 0.4200E+00   0.1080E+01   0.8000E+00   0.5000E+00   0.0000E+00   0.5500E+00   0.5000E+01   0.8000E+00   0.5000E+00   0.8000E+06   0.1000E+01   0.2000E+01
pa 0.5000E+00   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.7000E+00   0.3000E+01
pa 0.2000E+00   0.2000E+03   0.1000E+01   0.5000E+01   0.1000E+01   0.1000E+11   0.1000E+01   0.1000E+01   0.0000E+00   0.1000E+11   0.2000E+01   0.5500E+00
pvec: r0             rx             ry             rz             p0             px             py             pz             m          ityp 2i3 chg lcl#  ncl or
```

Figure 3

Momentum Conservation

- The last line of the event header names the measured quantities of each of the particles involved in the interaction. The problem to be solved was determining whether momentum was conserved during these collisions. Each particle has an initial momentum and a freeze-out momentum; the freeze-out momentum being the momentum the particle has when it exits the collision region.
- If momentum is conserved, then one would expect the sum of all initial momentum XYZ-components to be equal to that of the freeze-out momentum components for the entire event in order to satisfy conservation of linear momentum. This is expressed in equation 1.

$$\sum_{k=1}^{N} \vec{p}_{xi_k} + \vec{p}_{yi_k} + \vec{p}_{zi_k} = \sum_{k=1}^{N} \vec{p}_{xf_k} + \vec{p}_{yf_k} + \vec{p}_{zf_k} \qquad (1)$$

Momentum Distributions

- Figures 4 – 9 show histograms of momentum distributions for initial and freeze-out components of all events for the first output file. Histograms with red borders correspond to initial momentum and blue to freeze-out momentum.

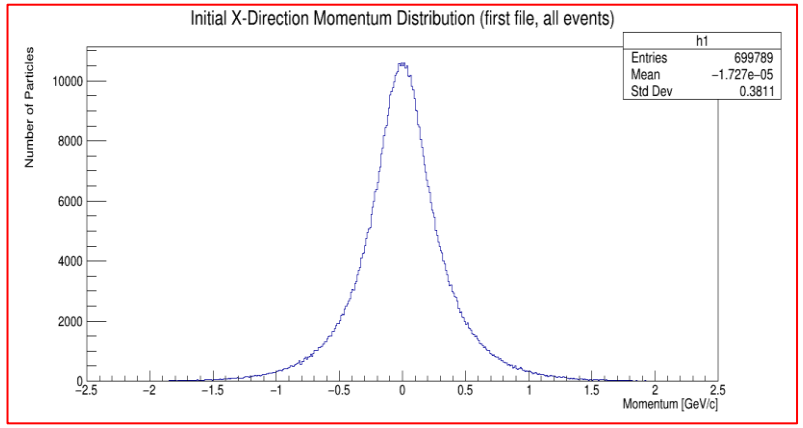

Figure 4

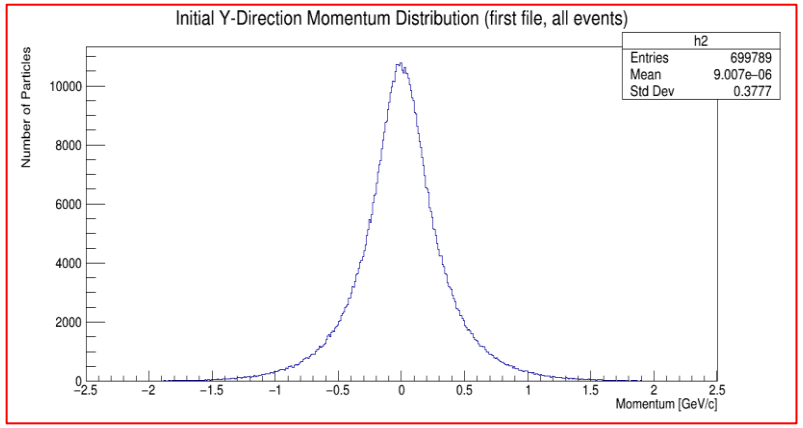

Figure 5

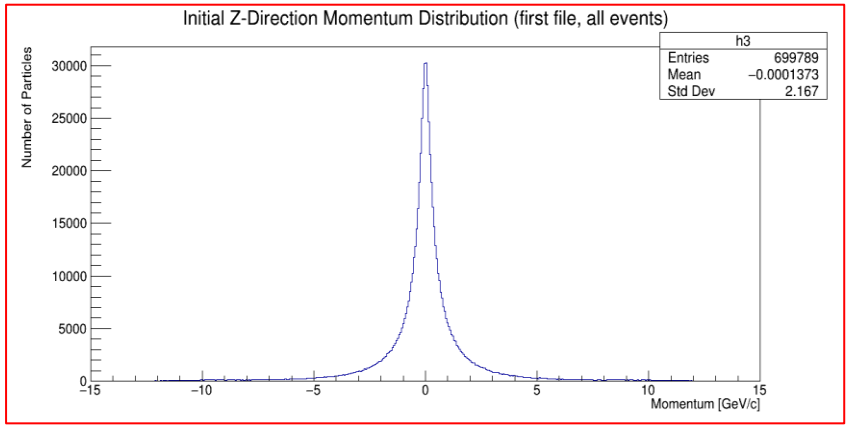

Figure 6

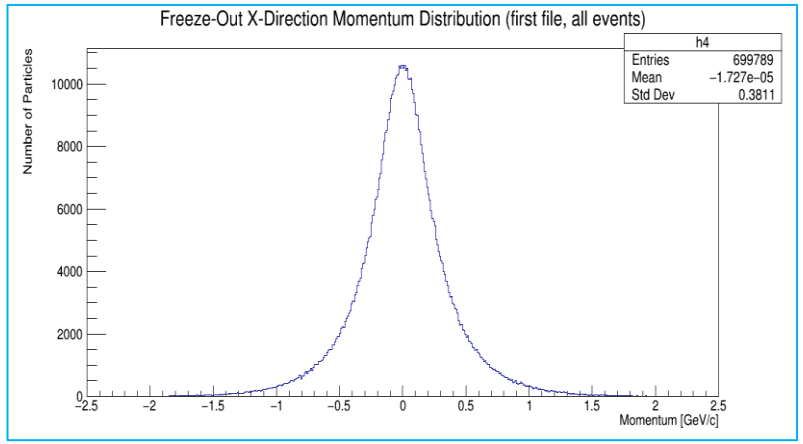

Figure 7

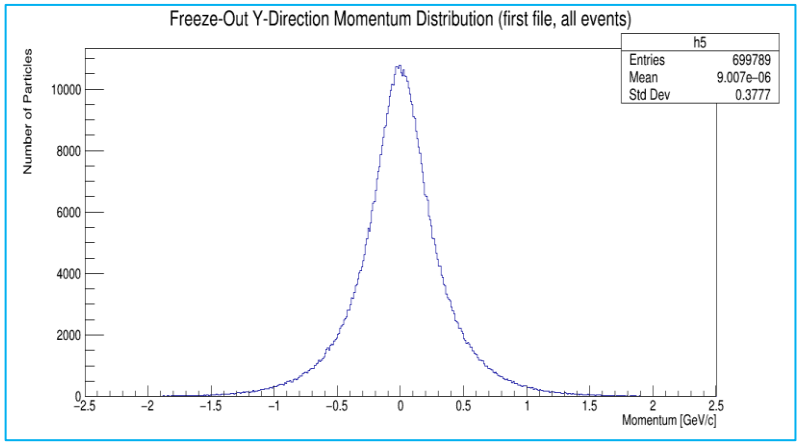

Figure 8

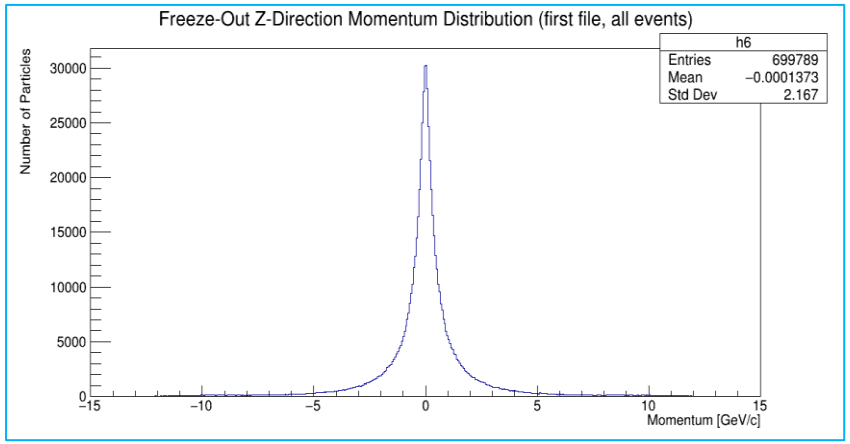

Figure 9

Momentum Distributions (continued)

- Figures 10 – 15 show histograms of momentum distributions for initial and freeze-out components of all events for the second output file.

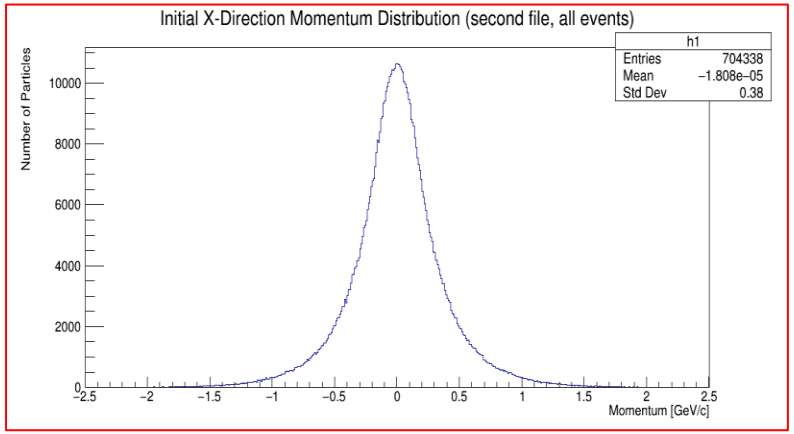

Figure 10

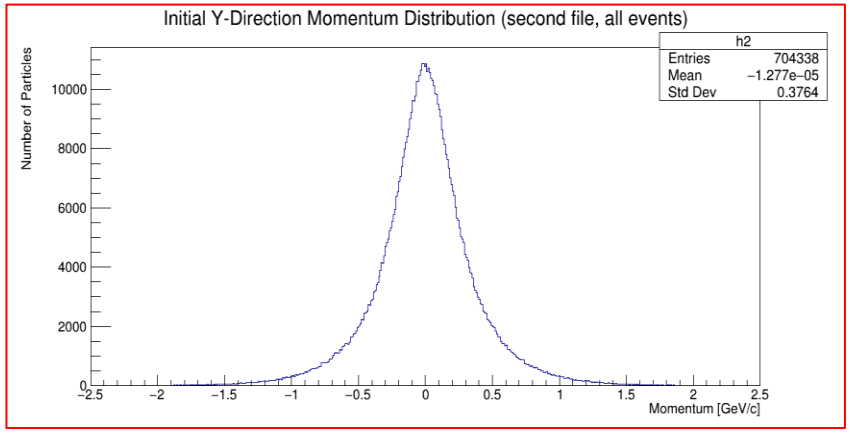

Figure 11

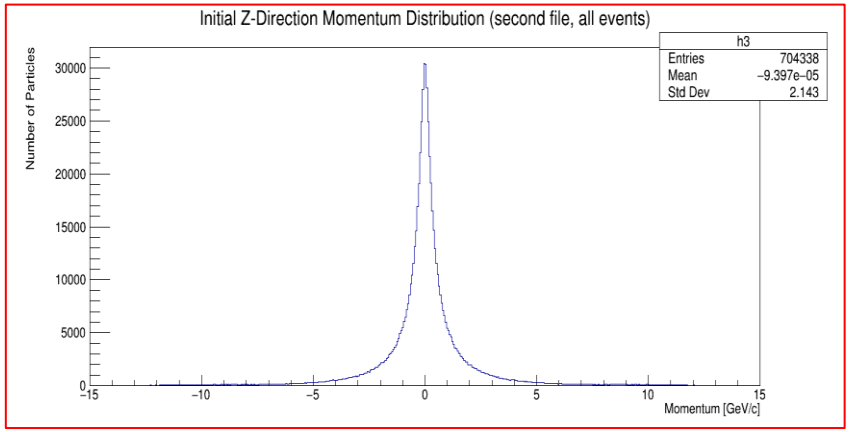

Figure 12

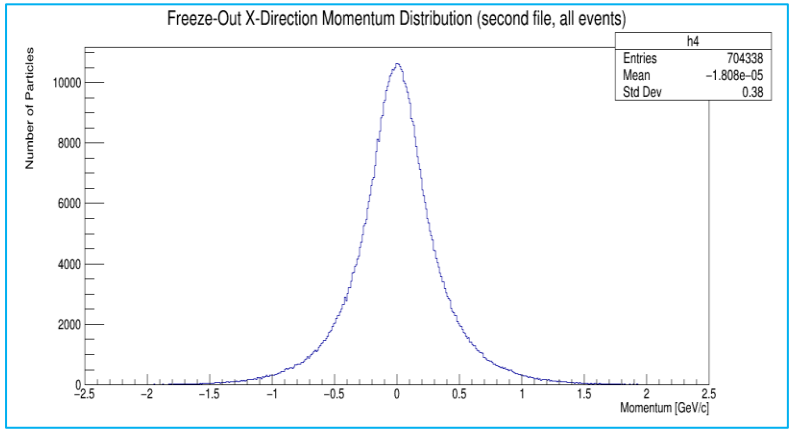

Figure 13

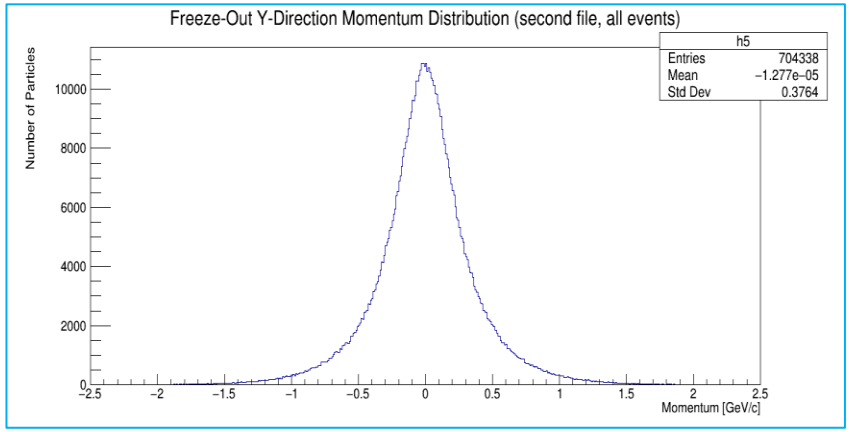

Figure 14

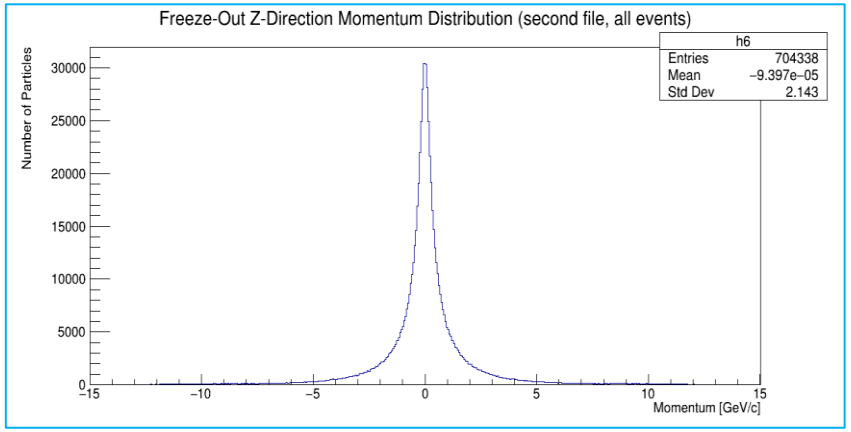

Figure 15

Was Momentum Conserved?

- As shown in figures 4-15, in both files, each direction has equal initial and freeze-out averages. For example, the first output file has an initial X-direction momentum average of -1.727e-05 GeV/c and a freeze-out X-direction average of -1.727e-05 GeV/c. The second output file has an initial X-direction momentum average of -1.808e-05 GeV/c and a freeze-out X-direction average of -1.808e-05 GeV/c.
- In order to determine whether momentum was conserved, two programs (one for each output file) written in C++ following the algorithm represented in Figure 16 were executed.
- Under the assumption that the program results are correct, momentum was in fact conserved. Figures 17 and 18 show screenshots of the program results.

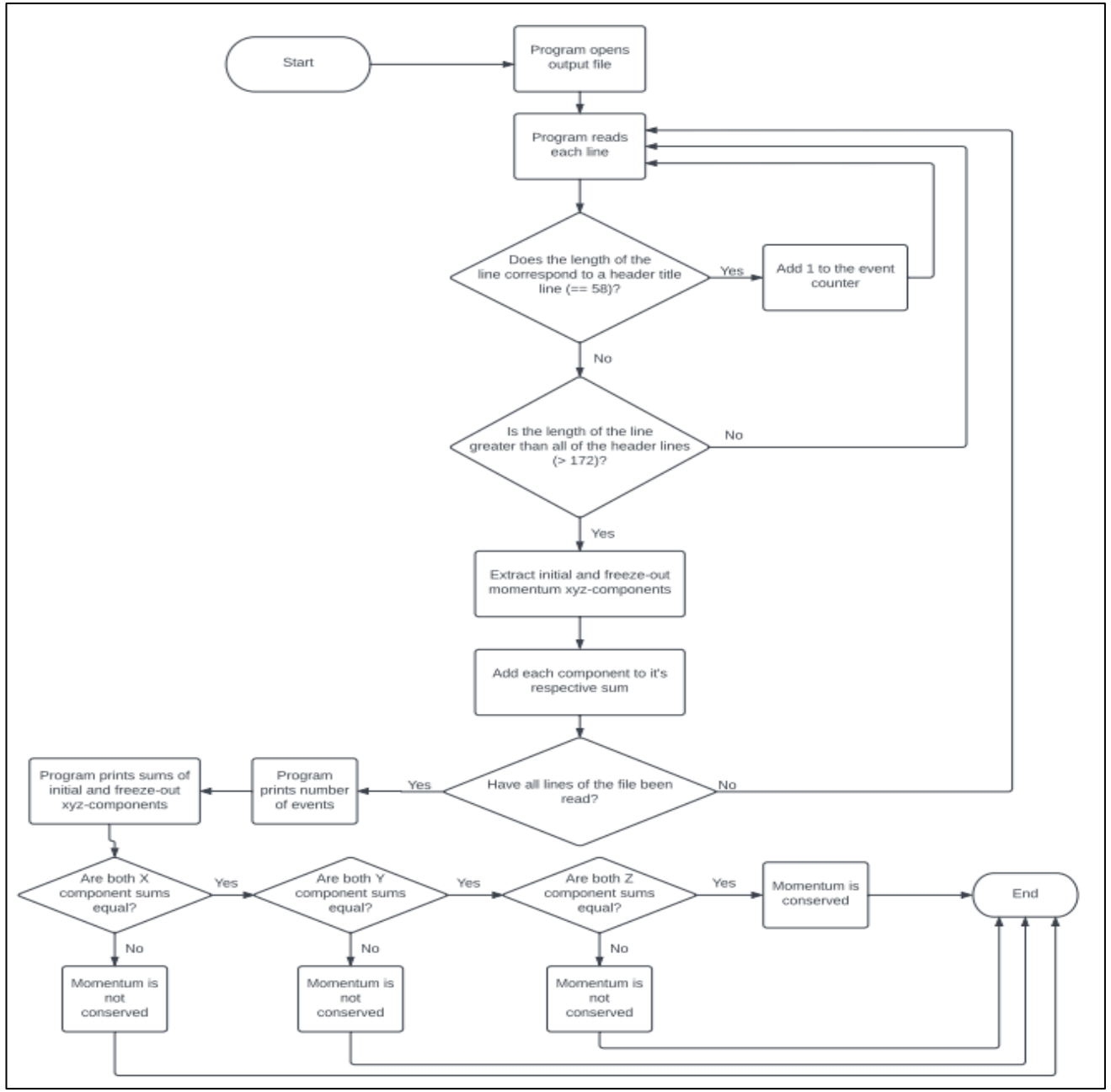

Figure 16: Program Algorithm Flowchart

Program Results

```
PS C:\Users\Ryan Mendoza\Desktop\research> root Conservation.cpp
   ------------------------------------------------------------------
  | Welcome to ROOT 6.26/10                        https://root.cern |
  | (c) 1995-2021, The ROOT Team; conception: R. Brun, F. Rademakers |
  | Built for win64 on Nov 16 2022, 10:42:54                         |
  | From tags/v6-26-10@v6-26-10                                      |
  | With MSVC 19.32.31332.0                                          |
  | Try '.help', '.demo', '.license', '.credits', '.quit'/'.q'       |
   ------------------------------------------------------------------

root [0]
Processing Conservation.cpp...
Number of events: 250

Sum of Initial X-components: 6.18064e-006
Sum of Initial Y-components: 3.18451e-006
Sum of Initial Z-components: -136.176
Sum of Freeze-out X-components: 6.18064e-006
Sum of Freeze-out Y-components: 3.18451e-006
Sum of Freeze-out Z-components: -136.176
Momentum is conserved in the X-direction
Momentum is conserved in the Y-direction
Momentum is conserved in the Z-direction
Momentum of all events is conserved
(int) 0
root [1]
```

Figure 17

```
PS C:\Users\Ryan Mendoza\Desktop\research> root Conservation2.cpp
   ------------------------------------------------------------------
  | Welcome to ROOT 6.26/10                        https://root.cern |
  | (c) 1995-2021, The ROOT Team; conception: R. Brun, F. Rademakers |
  | Built for win64 on Nov 16 2022, 10:42:54                         |
  | From tags/v6-26-10@v6-26-10                                      |
  | With MSVC 19.32.31332.0                                          |
  | Try '.help', '.demo', '.license', '.credits', '.quit'/'.q'       |
   ------------------------------------------------------------------

root [0]
Processing Conservation2.cpp...
Number of events: 250

Sum of Initial X-components: 2.92659e-006
Sum of Initial Y-components: 2.88095e-006
Sum of Initial Z-components: 171.938
Sum of Freeze-out X-components: 2.92659e-006
Sum of Freeze-out Y-components: 2.88095e-006
Sum of Freeze-out Z-components: 171.938
Momentum is conserved in the X-direction
Momentum is conserved in the Y-direction
Momentum is conserved in the Z-direction
Momentum of all events is conserved
(int) 0
root [1]
```

Figure 18