Wayne State REU Program

Simulations of Temperature Fluctuations in Heavy-ion Collisions

By:

Nathan Fisher

Mentor:

Prof. Claude Pruneau

Abstract

This report covers two separate projects with project 1 being abandoned and the project 2 introduced to fill in for the time left in the program. Project 1 was a study on radon detection and developing an application for smart phones with the goal of making a simple product that could be operated by anyone with a smart phone. Project 2 involved the study of temperature fluctuations in heavy-ion collisions and determining if it is possible to measure these fluctuations.

Project 1: Radon detection with a cell phone

The initial goal of project 1, the radon detection research, was to investigate the possibility of making a portable detector and application for smart phones. Would it be possible to make a simple device using scintillators that could be operated by anyone who wanted to test their home for radon gas? This idea was found to not be plausible given one specific factor. In order to detect radon gas a detector must be able to register alpha particles produced by radon decays. Alpha particles are difficult to detect due to the fact that they are easily blocked by most materials. Using scintillators to detect alpha particles produced by decays has been proven a viable method for detecting these particles. However, when operating a scintillator, it needs to be wrapped in enough opaque material in order to block out ambient light or the photomultiplier tube (PMT) used to read the scintillators light output will be rendered useless when placed under voltage. This conclusion was reached after using a program called "The Stopping and Range of Ions in Matter" also known as SRIM(The program can be downloaded from the following website www.srim.org).The program would take two or more types of particles and collide them within a simulation, generating a table containing a projected range that the particle would travel along with how much ion energy that would need to be generated in order to obtain a specific range. Alpha particles of 5 MeV have a range of 2.15 micro meters(μm) in plastic. They then would not pass through 1 mm of opaque material needed to shield plastic and PMT against ambient light. Therefore, it is not practical to block ambient light while still allowing alpha particles to enter the scintillators.Following this realization, it has been concluded that the project could not be continued with available resources andit was thus abandoned.

Project 2:Temperatures and Heavy-Ion Collisions

Introduction:

Project 2 focused on studying the feasibility of measurements of temperature fluctuations in heavy-ion collisions. The ultimate goal of such measurements is the determination of the Heat Capacity (C) of the quark gluon plasma formed in heavy ion collisions. One can show that C is related to the ratio of the fluctuations of temperature by the mean temperature of the matter produced.

Heavy-ion (HI) collisions produce large numbers of elementary particles with characteristic temperatures. These collisions will produce a momentum spectrum that resembles a Maxwell-Boltzmann distribution (MB).The temperature of the material will determine the specific shape of the distributions.The MB distribution of pions produced in HI collisions at high collision energies are characterized by a temperature of the order of 170 MeV. An exponential distribution can be used to approximate the shape of the MB distribution. An estimate of the temperature produced by thesecollisions can then be obtained by measuring the "slope" T of the exponential distribution.

$$\boldsymbol{f(p) \propto \exp\left(-\frac{p}{T}\right)},$$

In effect, T represents the effective temperature of the particles. In practice, an estimate of T is obtained by measuring the average transverse momentum of the particles produced by collisions. With a very large number of collisions, the determination of this average is quite precise and one thus estimatesthe temperature with reasonably high accuracy. The goal of this study was to discover whether or not the temperature can be measured collision by collision, based on the average of the transverse momentum of particles detected in each collision. Monte Carlo simulations of the production of pions were carried out in order to determine the feasibility of this statement.

Goal of the project: Determine how the precision on the temperature measurements varies, quantitatively, with the number of measured particles per event.

Method/Procedure:

The key question was to examine how many particles are needed, per collision, in order to obtain a relatively precise measure of the event temperature based on the average momentum of the particles detected in a given event. I thus carried out computer simulations with different numbers of produced particles and with and without actual temperature fluctuations.

First, in order to establish a baseline, I ran simulations each consisting of 1000 events with no generated fluctuations, that is, each event having a fixed pT average of 0.4 GeV/c. I then generated events with 10, 50, 100, 500, and 1000 particles to determine the resolution of the average pT of measured particles that can be achieved with finitely many particles.

The average pt of produced particles was calculated according to

$$< pT > = \sum_{k=1}^{n} p_{T,k}$$

and is plotted event by event in Figure 1 (left panel) for events generated with m=10, 50, 100, 500, and 1000 particles. The distribution of average pT of small multiplicity events is much broader, as expected, thereby indicating that the average pT resolution achievable with a small multiplicity is intrinsically limited.

The other panels of Figure 1 display similar simulations ran with finite temperature fluctuations. The temperature fluctuations were generated according

$\boldsymbol{f(p) \propto \exp\left(-\frac{p}{T'}\right)}$,

with T' = 0.4 GeV/c + R

where R is a random number selected event-by-event according to a Gaussian distribution with standard deviations of 0.005, 0.02, and 0.1 GeV/c. In theabsence of fluctuations, one finds that the width of the distribution (which represents the probability of observing a certain value of average pt) narrows substantially as the event multiplicity increases. In contrast, in the case of a variance of 0.1 GeV, one finds that the distributions are essentially independent of the multiplicity considered (10, 50, 100, 500, and 1000).

In order to determine the deviation between each of the generated histograms, a separate graph (Figure 2) was created with the standard deviation of each histogram plotted as a function of the number of particles used in each specific case. These curves, shown in figure 2, are used to determine if it is possible to measure the fluctuations with different numbers of particles and if there is a limit to the minimum number of particles needed for an accurate measurement. Each graph represents a set of histograms from figure 1 with identical color coding in order to match the correct data from each figure. As the number of particles increased it became more noticeable the temperature difference between each curve. This separation of curves from each other as the number of particles increased indicates the temperature fluctuations between the different sets of HB distributions. These exponential distributions that are shown in figure 2 can be measured in order to obtain an estimate of the temperature created by these collisions.

Simulation Code:

The simulation code uses multiple ‘for loops’ with all of its variables defined before the loop. A total of 20 histograms were generated with five displayed on each of the four graphs. All histograms were defined with two ‘for loops’, one inside of the other. After defining the histograms all variables were defined with the number of events run called nEvent. The number of particles used for each event (mvalues), standard deviation set as a 4 by 5 array and labeled std, and four different resolutions that are defined for the graphs in canvas 2. For the core of the simulation, four different ‘for loops’ were created with one loop inside of the other. The first for loop contained the four different resolutions labeled as iRes, followed by a ‘for loop’ containing mCases that were defined by m and were dependent on the mvalues. Another loop labeled as iEvents contained the nEvents defined earlier in the code. This loop contains a Gaussian random number generator used to apply the different resolutions to the simulation. The final ‘for loop’ was labeled iPart and contained the calculation for the sum of the mean transverse momentum defined by the exponential of the average momentum (evtAvgP); henceforth, this sum was taken and divided by m as defined earlier.Two separate canvases were created for displaying all recorded histograms and graphs from the simulation for visual observation of all calculations. This is to ensure that results are accurate and that there are no errors in the code. Basic knowledge allows for an approximation of what the data should present; therefore, it is possible to confirm the data presented by the calculations is correct.

Analysis and Results:

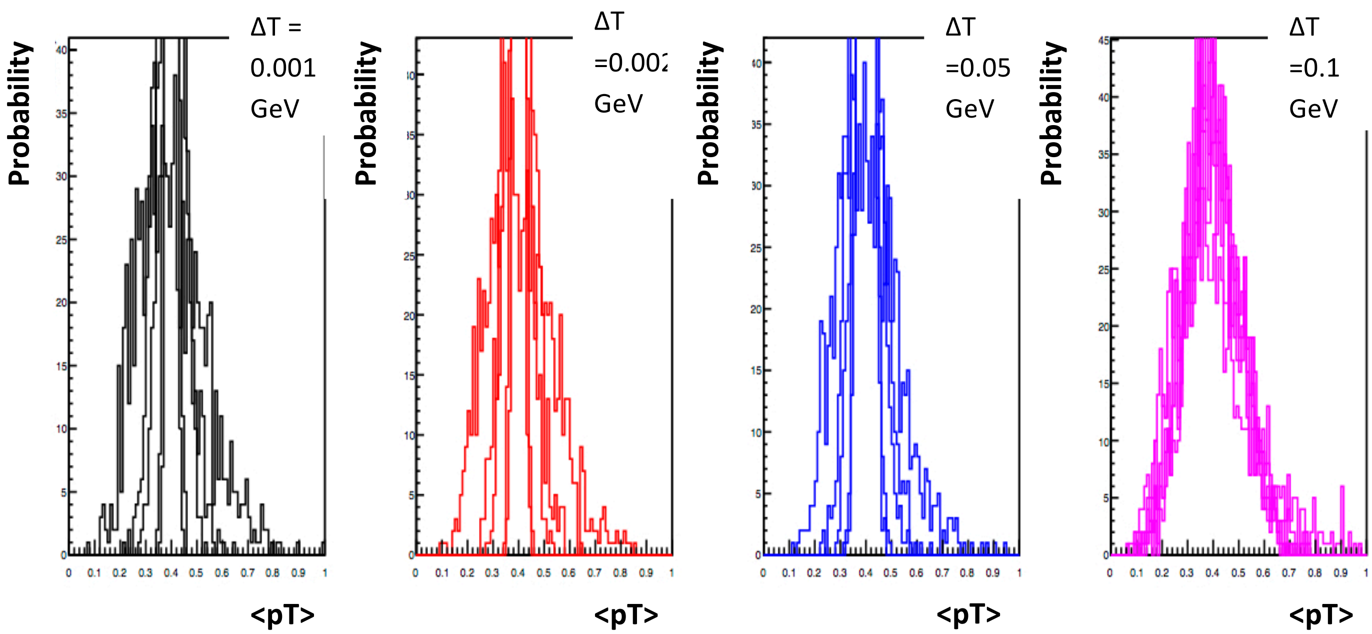

Figure 1: These histograms represent four sets of distributions generated with temperature fluctuation variances of 0.005, 0.001, 0.02, 0.1GeV, and in case for five distinct values of multiplicity (10, 50, 100, 500, 1000).

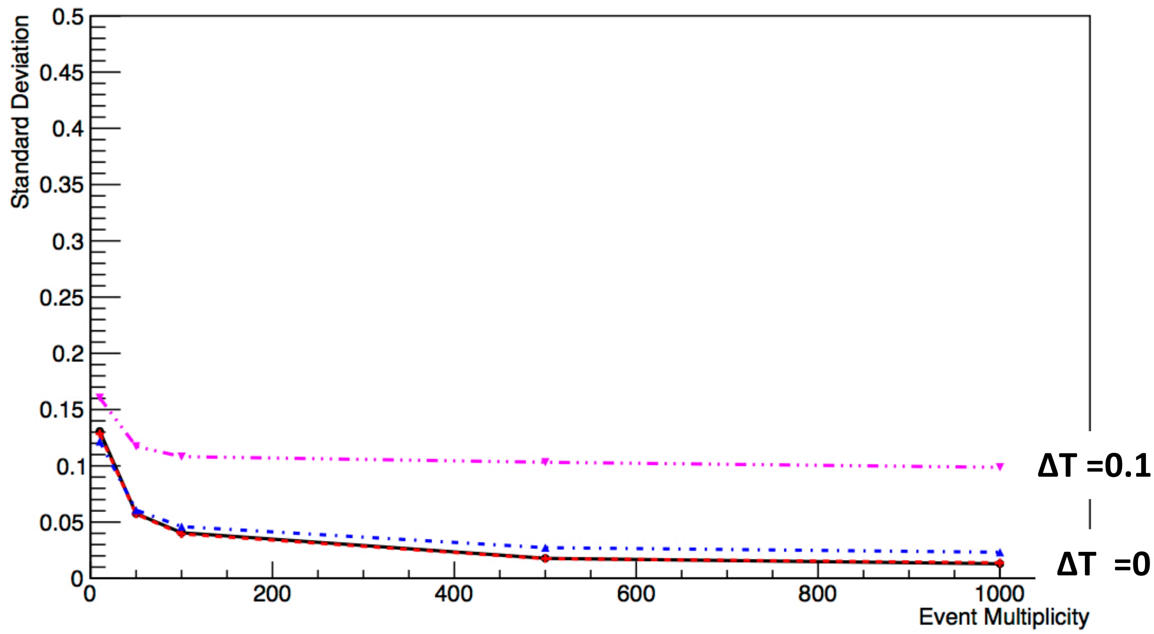

Figure 2: Variances of the curves shown in Fig 1 for the four sets of simulation parameters, plotted as function of the generated event multiplicity. Legend: black: 0.001 GeV, red: 0.005GeV, blue:0.02 GeV, and purple: 0.1 GeV.

Discussion

To identify variations in temperature, figure 1 showed four different sets of histograms with five histograms in each set showing varying fluctuations. Each fluctuation, measured in GeV, was taken and used to calculate the standard deviation in order to determine the temperature fluctuations of each. While fluctuations with a standard deviation of 0.001 to 0.005GeV could not be measured with less than 50 particles,it was possible to measure the temperature fluctuations with a standard deviation of 0.05 to 0.1 GeV. After observing figure 2, it can be stated that it is possible to measure collision temperatures that have a fluctuation of 0.1 GeV with as few as 10 particles.

Conclusion

In conclusion, after studying these temperature fluctuations through simulations, it can be stated that it is possible to measure the fluctuations in temperature of heavy-ion collisions.

References

Basu S, Chatterjee R, Nandi B K., Nayak T K. 2015. "Characterization of relativistic heavy-ion collisions at the Large Hadron Collider through temperature fluctuations".