Generation and analysis of events for Au-Au collisions using the Monte Carlo generator - THERMINATOR 2

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Abstract

It was proposed that up to a few milliseconds after the Big Bang, the Universe was in a state called Quark-Gluon Plasma (QGP) in which quarks and gluons reach to very high energies and high net barion densities, and they behave as free particles. QGP is also believed to be present in the core of neutron stars. Femtoscopic correlation function is used to measure extremely small and short-lived systems. Using THERMINATOR 2, we can generate particles in relativistic high ion collisions. In this report, collisions were generated for Au-Au at 200 GeV and femtoscopic correlation function was carried out for particles at 30-40% centrality for π^+-π^+ and π^--π^- pairs.

1. **Introduction**

High energy physics is a very vast and vigorous field of research and it deals with the collisions of particles at high energies. The extraordinary work of Landau [7] and Fermi [8] have shown the vibrant nature of high energy physics. It allows us to study the universe just after the Big Bang using heavy ion collisions at energies higher than 12 TeV in Large Hadron Collider (LHC) at CERN and densities ten times greater than found in atomic nuclei. Heavy nuclei are collided resulting in heavy ion acceleration at Large Hadron Collider (LHC) and at Relativistic Heavy Ion Collider (RHIC) for the study of Quark-Gluon Plasma (QGP), a new state of matter. It also led to the formulation of a theory of the strong interactions - Quantum Chromodynamics (QCD). The high energies involved in heavy ion collisions cause the particle beams to undergo Lorentz force and contract until they become disk-shaped. After the collision, QGP forms in the central region after which it starts to expand and cool down. With the energy dramatically decreasing, hadrons are formed in a process called hadronization. [2,3] All mutual interactions cease when freeze-out temperature is reached. To get a grasp of the timescales and parameters involved in these collisions it is useful to look at figures 1, 2 and 3.

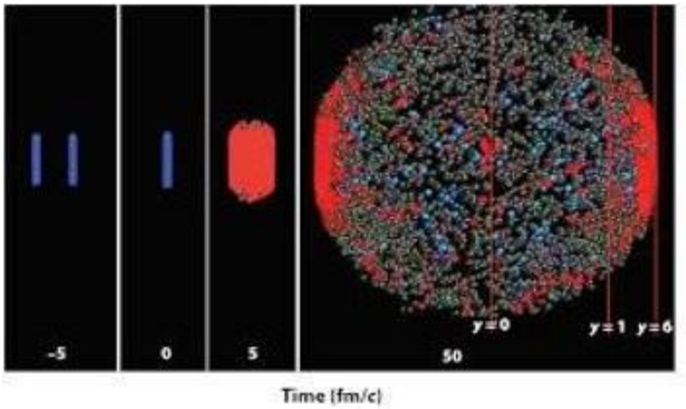


Figure 1: Evolution of a central collision of Pb-Pb nuclei at 2.76TeV in time (fm/c). The red dots represent the QGP and the blue and grey dots represent hadrons, the hottest regions being correlated with high rapidity y [1]

In figure 2 collision evolution is time-scaled, starting from initial state before collision, then second stage is called pre-equilibrium where collision is transferred. After that hydrodynamic evolution takes place and at the last, freezeout state. [1,5]

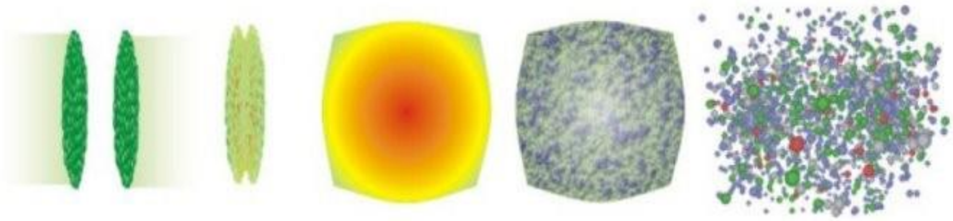


Figure 2: Various stages of ultra-relativistic heavy-ion collisions.

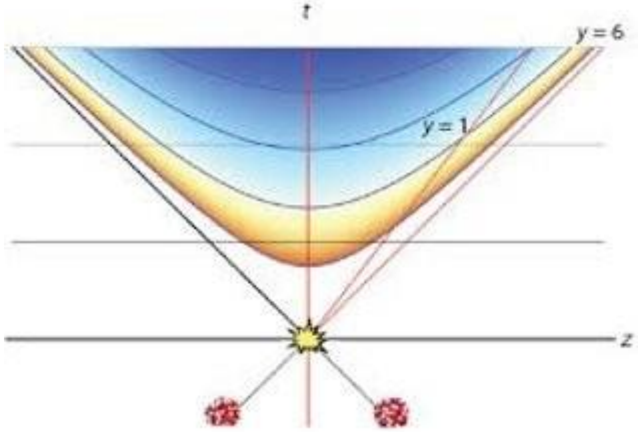


Figure 3: The space-time evolution can also be illustrated with a light-cone diagram. The two colliding beams move along the light cone and collide at t = 0. The emerging fragments travel along the light cone, while matter between the fragmentation zone remains in the central region. This matter is in the state of QGP and its evolution is described by relativistic hydrodynamics [4,6].

2. Femtoscopic analysis and the correlation function

To understand how the universe was created 14 billion years ago and to study QGP, analyzing the particles is one way. Hadron femtoscopy is used for analysis of particle correlations and it measures the space-time characteristic of particle production and thus we use it for studying QGP. Also, correlations of identical bosons and identical fermions are underpinned by different physics and such we will only concern ourselves with the bosons. The simplest description is offered by the participant-spectator picture (PSP). PSP assumes that the colliding nuclei move along the same line and the only interacting nuclei are those who overlap, while the others are considered “spectators” [4]. The “centrality” of the collision is also an important factor and it is characterized by the impact parameter, b. Impact parameter is the distance between the centers of two colliding nuclei it basically tells the centrality of the collision, how close or off their centers the ions are colliding. It can be measured either by counting the non-interacting nucleons (as lower centralities lead to fewer interactions) or by appealing to characteristics of produced particles, like multiplicity. The Glauber model [12] allows the calculation of the number of nucleons involved in the collision for a given centrality and its premises are that nucleons can be treated as hard spheres whose distribution follows a Woods-Saxon potential and that one should neglect any internal motion and correlation between nuclei [4].

The correlation function of a pair of particles is defined as:

$$C\,(p_{1},\,p_{2}) = P\,(p_{1},\,p_{2}) / P(p_{1})\,P(p_{2})$$

in which the numerator is the measured distribution difference, i.e., **q** = $p_1 - p_2$ of the three-dimensional momenta of the two particles form the same event and the denominator is the distribution of the two particles being taken from different events. These values are normalized so that the correlation function will tend to 1 when there is no correlation between the particles.

3. THERMINATOR 2

The ”THERMal heavy IoN generATOR 2” or THERMINATOR 2 is a Monte Carlo event generator. It is used to study the statistical production of subatomic particles in relativistic heavy ion collision. For Au-Au, Pb-Pb and pPb at RHIC and LHC, the library of standard hypersurfaces and velocity profiles are used. For the analysis of femtoscopic correlations, and for obtaining information about the spatial evolution of system, a second code, FEMTO-THERMINATOR, is provided. The description of the tasks performed, from the installation of the program to the analysis of the results, is given in the following subsections. For the purpose of this paper, only main operations were taken into account, for further information regarding this, please see the THERMINATOR manual [9].

3.1 Installing the THERMINATOR 2 environment

This project was done on Ubuntu 18.04 which was installed on a virtual machine due to the incompatibility of Ubuntu 20.04 with THERMINATOR 2. This was followed by the installation of ROOT CERN package and gcc C++ compiler, both required to run THERMINATOR 2. Complete information on installing root can be found on the official website [10].

The documentation necessary for the installation of THERMINATOR 2, as well as the latest version, can be found at the official website [11]. The main steps regarding the installation of the program are outlined on the website too, but one must be aware that the last version of THERMINATOR 2 is from 2011 and the installation requires some modifications to the code. The line "using namespace std;" is added to the downloaded documentation in the build/src/therm2 event.cxx file. Line 119,123,127 of Makefile in the main directory were brought to the form `$ (LD) $ˆ −o $@ $ (LFLAGS)`, otherwise the linking would not have been done correctly. hindering the installation process.

3.2 Generation of events for Au-Au collisions

Events run by using commands ./runall.sh or ./therm2_events and the generated events are created in the therminator2/events/lhyquid2dbi-RHICAuAu200c2030Ti429ti025Tf145 subdirectory by default with the main parameters being found in the name of the file. Other types of events can be generated by picking the file with wanted parameters from the therminator2/fomodel/lhyquid2dbi folder. Changing the name of the file in line 42 of fomodel/lhyquid2dbi.ini file and running the event will produce the desired events. A new folder with the filename will be created. It is advices to increase the number of events by modifying line 55 of events.ini or to run the same event multiple times to obtain good statistics.

3.3 Analysis of the generated data

The command:

```
./therm2_femto <KTBIN> <EVENT_DIR><EVENT_FILES>
```

was used to implement femtoscopic formalism and generate the histogram showing the numerator and denominator correlation function as shown in the figure below.

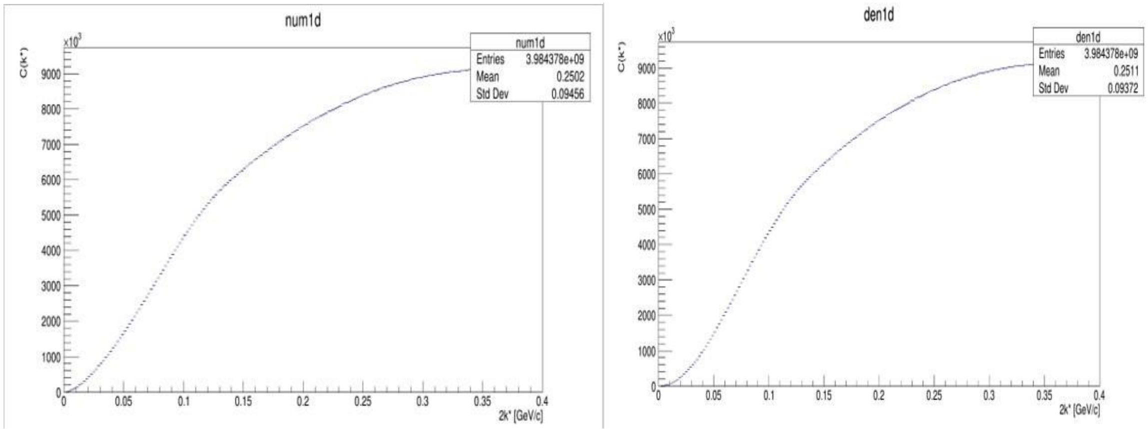


Figure 5: Generated Histograms

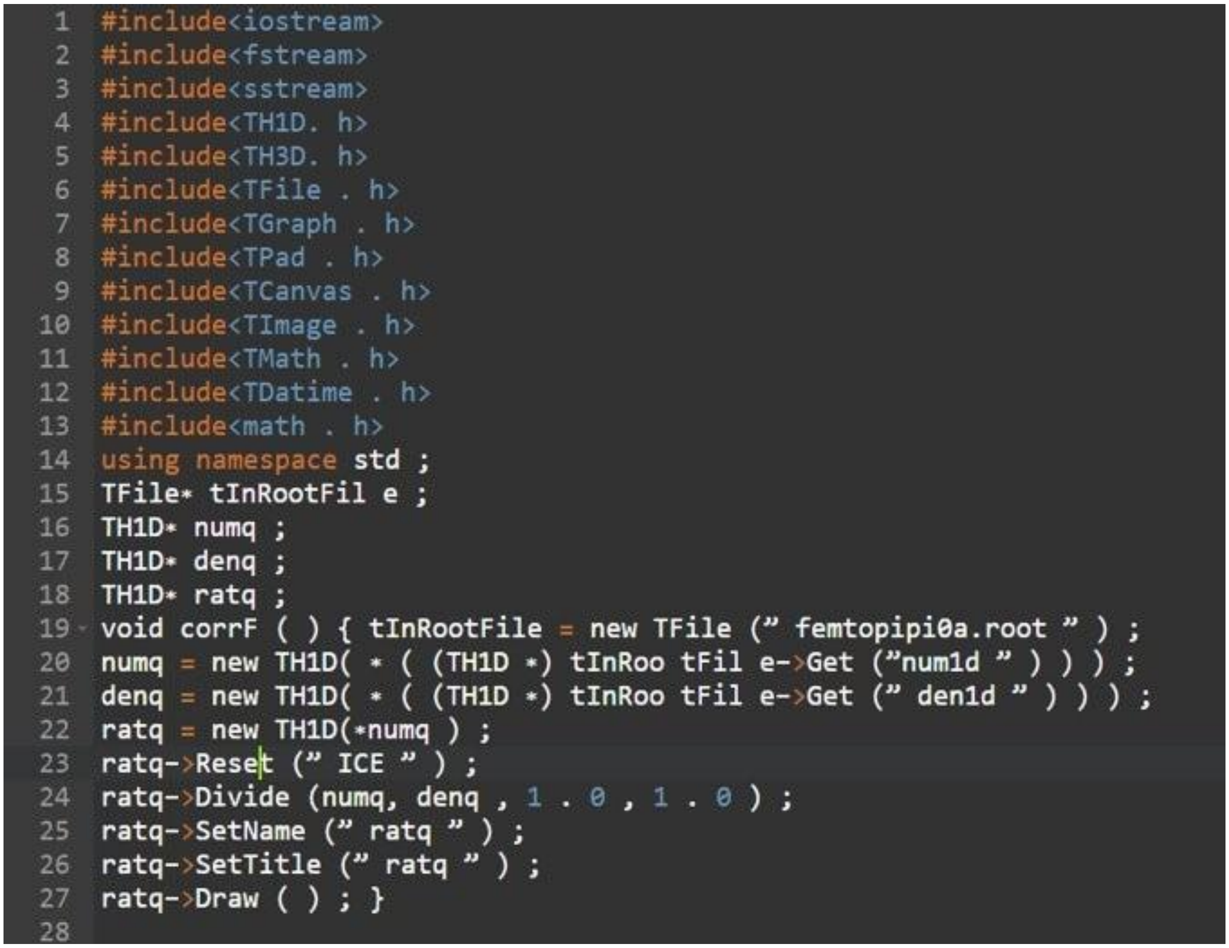
The first parameter was given the value 1 while the second and the third parameters specifies the path of the event and the number of files in the directory respectively. The event mix was set to 50 and the coulombs corrections were eliminated.

To open the histograms, the following steps are followed:

1. Run command root followed by name of file containing the histograms.
2. Run command TBrowser to navigate files using file explorer.

3.3 Correlation function

The correlation function is obtained by dividing the numerator and denominator. For this, a new compiler that contains a function that takes the ratio of histograms.



```
#include<iostream>
#include<fstream>
#include<sstream>
#include<TH1D. h>
#include<TH3D. h>
#include<TFile . h>
#include<TGraph . h>
#include<TPad . h>
#include<TCanvas . h>
#include<TImage . h>
#include<TMath . h>
#include<TDatime . h>
#include<math . h>
using namespace std ;
TFile* tInRootFil e ;
TH1D* numq ;
TH1D* denq ;
TH1D* ratq ;
void corrF ( ) { tInRootFile = new TFile (” femtopipi0a.root ” ) ;
numq = new TH1D( * ( (TH1D *) tInRoo tFil e->Get (”num1d ” ) ) ) ;
denq = new TH1D( * ( (TH1D *) tInRoo tFil e->Get (” den1d ” ) ) ) ;
ratq = new TH1D(*numq ) ;
ratq->Reset (” ICE ” ) ;
ratq->Divide (numq, denq , 1 . 0 , 1 . 0 ) ;
ratq->SetName (” ratq ” ) ;
ratq->SetTitle (” ratq ” ) ;
ratq->Draw ( ) ; }
```

Figure 6: Code for dividing Numerator and Denominator

3.4 Calculation for Bohr’s radius for K+K- pair type

The pair radii are calculated by $a_c = \hbar/(\mu * c * \alpha)$ ----------- [eq 1]

For Pair Radii calculation, we need to take into consideration that all terms must be in GeV. Then we need to use the developed Pair Radii relation:

a_c=1/μ*alpha as (h=c=1)

α=fine structure constant = 1/137

Therefore a_c=137/μ ------------------[eq 2]

μ= reduced mass= (m_1*m_2)/(m_1+m_2)

mass of K^+ and K^- = 493.67 * 10^{-3} GeV

Therefore, reduced mass, μ= 246.83 * 10^{-3} GeV= 0.2468 GeV

Putting the values in eq 2, a_c = 555.10 GeV (radius of K^+ K^- pair)

4. Conclusion

This report was made to describe the steps required to obtain the correlation function for pion-pion pair and then obtain the Bohr's radius for K^+K^- pair type. The first step was to install THERMINATOR 2 software followed by the generation of events in step 2. Then histograms for numerator and denominator were produced, which were used in step 4 to obtain the correlation function by running the aforementioned compiler. In 5th step, the Bohr's radius was found for K^+-K^- pair type.

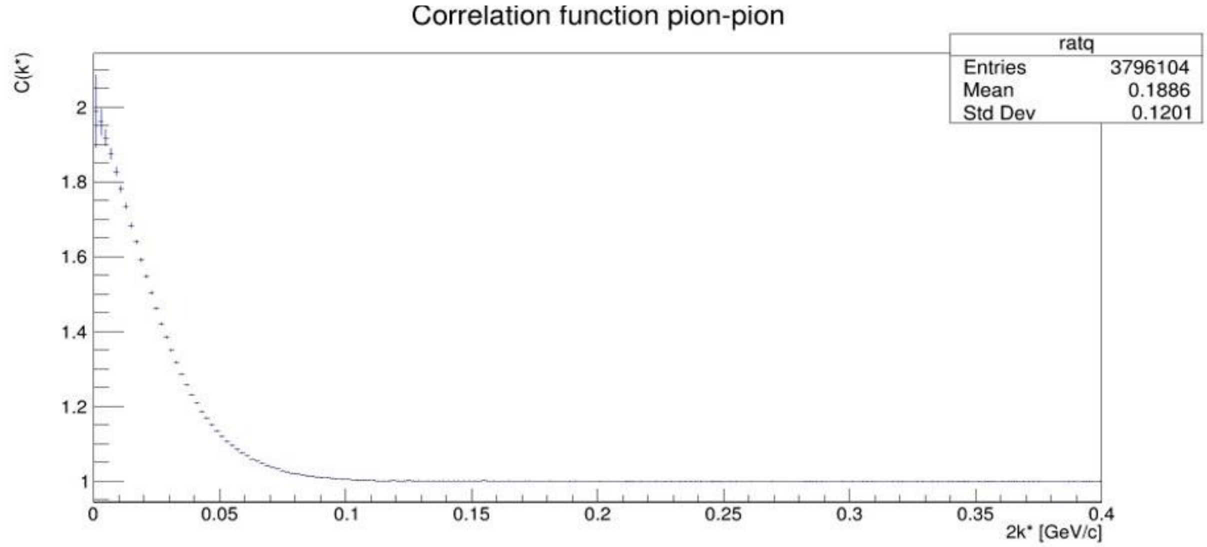


Figure 5: Correlation function of a ππ pair, generated in an Au-Au collision at 30%-40% centrality.One can see how the correlation function almost reaches 2

5. Acknowledgement

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