Simulation of ALICE Project

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1 Introduction

ALICE_Simulation is a computer program that simulates the ALICE experiment that has been conducted at CERN since 1993, which consists of analyzing the collisions occurring between particles at very high energies[(1)]. Those particles would create different particles following a probability distribution (Table1).

Particle Type	Probability
π^+	40%
π^-	40%
k^+	5%
k^-	5%
P^+	4.5%
P^-	4.5%
k^*	1%

Table 1: *The table shows the probability of obtaining a specific particle from a collision of high energy particles*

In the simulation, we generated a finite amount of particles resulting from the collision of the flux in the particle accelerator, each with a proper momentum, mass, and resulting energy to maintain the conservation of those properties.The goal of the experiment is to detect the existence of the Kaon 0 (k^*), a very rare particle that decays into either a Positive Pion (π^+) and Negative Kaon (k^-) or a Negative Pion (π^-) and Positive Kaon (k^+), after only $5.2 \times 10^{-8} s$. We therefore stored the data of momentum, energy, charge, and invariant mass of all the particles to detect the presence of differences that could indicate the existence of the Kaon.

The program we implemented stores the information about the particles and generates histograms from which we studied the system.

2 Code Structure

The code's division into different files and folders has the background idea of making it more orderly. There are eight files for the simulation program (one main file:

mainE.cpp, one libraries file: library.hpp, three header files: ParticleType.hpp, ResonanceType.hpp, Particle.hpp, and three source files: ParticleType.cpp, ResonanceType.cpp, Particle.cpp) and one for the data analysis (analysis.C). The header files contain the classes implemented for the proper functioning of the simulation. Meanwhile, the source files contain the implementation of the methods defined in the headers.

ParticleType Class

The class ParticleType creates a homonymous type that contains the name, the mass, and the charge of a particular particle, respectively as a std::string, a double, and an integer. This class has five methods, two of which are virtual.

ResonanceType Class

The ResonanceType class is a derived class from ParticleType and, in addition to the base class items, it contains the information about the width of the particle as a double. The type defined with the name of this class creates a particle with a width. Contrarily to what happens for a ParticleType object, in which the width of the particle is always zero. This class has two methods, both of them are the override of the already existing virtual methods in the base class.

Particle Class

The class Particle is the one that allows creating a particle giving it a random momentum and making it decay into other particles if necessary. It also creates a set of particles type, each with a proper index as an identifier. The variables in the class are three momentum components (fPx, fPy, fPz), an array of ParticleType and its dimension (fParticleType, fMaxNumParticleType), an index of particle type (fNParticleType), and a numeric code proper of each particle type fIndex). This class has, also, several methods, including some static, which means they are accessible from the main without defining an object.

3 Generation

In the simulation, there had been 10000 collision events, each using a set of 100 particles. The particles resulting from the collisions were Positive Pions (π^+), Negative Pions (π^-), Positive Kaons (k^+), Negative Kaons (k^-), Protons (p^+), Antiprotons (p^-), and Resonance Kaons (k^*), generated randomly using a uniform distribution and the probability shown in Table 1. The module of the momentum of the particles comes from an exponential distribution with a mean of 1. While its direction drives from the cartesian components:

$$\begin{cases} p_x = |p| \cdot \cos\theta \cdot \cos\phi \\ p_y = |p| \cdot \cos\theta \cdot \sin\phi \\ p_z = |p| \cdot \sin\theta \end{cases} \tag{1}$$

Where the azimuthal angle theta (θ) and the polar angle phi (ϕ) are generated using a uniform random distribution respectively from 0 to π and the second from 0 to 2π. In the case that a Resonance Kaon is created from the collision of particles, it deacis into eather a Positive Pion and a Negative Kaon or a Negative Pion and a Positive Kaon with the same probability. The momentum of this new two particles comes from a normal distribution.

4 Analysis

The generation of particles types is compatible with the theoretical calculation as shown in Table. 2

Particle Type	Entries	Error	Theo. Ent.
π^+	3997740	1999	$4 \cdot 10^6$
π^-	4002160	2001	$4 \cdot 10^6$
k^+	500290	707	$5 \cdot 10^5$
k^-	499781	707	$5 \cdot 10^5$
P^+	449544	671	$4.5 \cdot 10^5$
P^-	450121	671	$4.5 \cdot 10^5$
k^*	100366	317	$1 \cdot 10^5$

Table 2: *The table shows the entries got from the simulation with the respective error calculated using root, and the theoretical entries calculated taking the percentage of each particle type from the total amount of particles.*

As well as the angles and the momentum distributios are fitting the relative uniform and exponential distribution as shown in the images 1 and 2.

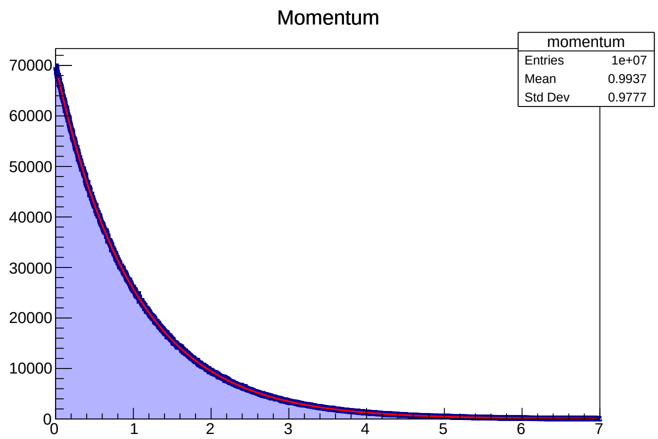

Figure 1: *The image shows the fit between the exponential distribution compared with the momentum histogram with occurrences randomly generated. The Chi-square divided by the number of degrees of freedom is very close to one, meaning that the histogram very well approximates an exponential distribution with a mean of 1.*

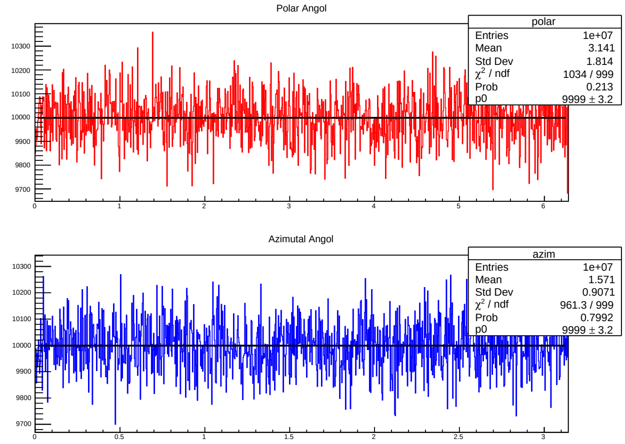

Figure 2: *The image shows the fit between the uniform distribution compared with the histogram of the angles randomly generated. The Chi-square divided by the number of degrees of freedom is very close to one, meanning that the histograms very well approximate an uniform distribution.*

It is possible to analyze these phenomena by looking at the histograms of the invariant mass. Because its definition contains both the momentum and the energy of the particles, we, therefore, assume it is conserved in the collision. Counting the number of particles per mass invariant value it is possible to construct the histogram of the invariant mass. The detection of the resonance Kaon consists of generating the histogram for only Pion and Kaon with different charges and comparing it with the histogram for the Pion and Kaon with the same charges. Because the resonance Kaon decays very quickly into those two particles with opposite charges, there should be a little "bump" in the first of those two histograms.

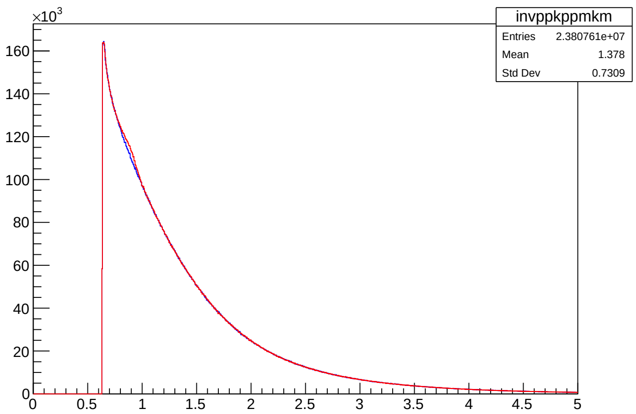

Figure 3: *The figure shows the histograms of the invariant mass in red and blue, respectively, of positive Pions & negative kaons or negative Pions & positive Kaons and positive Pions & positive Kaons or negative Pions & negative Kaons.*

A second approach consists of comparing the two histograms of the invariant mass of all the particles with the same charge and opposite charges.

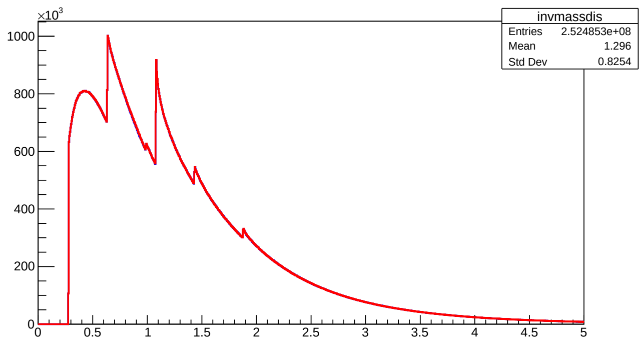

Figure 4: *The figure shows the two histograms of the invariant mass in red (thinnes) and blue (wider), respectively, of all the particles with same charges and all the particles with opposite charges.*

Subtracting the two pairs of histograms gives in both cases a bell shape, fitting a normal distribution with mean the mass of the resonance Kaon and sigma its error. Comparing the results with the testing histogram of the decay, filled during the simulation gives a very close value that stands inside the error.

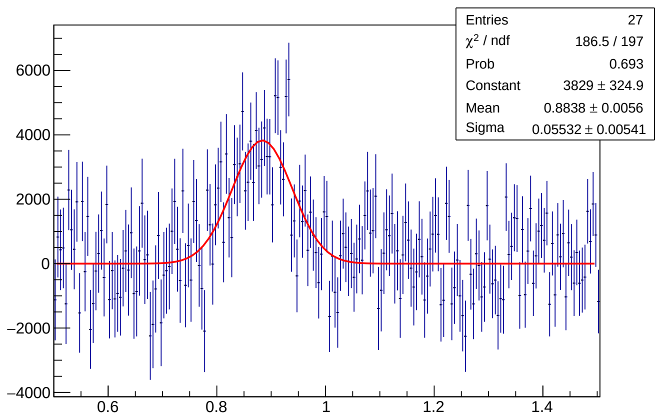

Figure 5: *The image shows the result of the subtraction between the histogram of the invariant mass of all the particles with the same charges and opposite charges. The red line represents the fitting normal distribution and the box shows the stats.*

In conclusion, the analysis of the first fit gives an experimental mass of 0.8838 ± 0.0553 Kg, while the second an experimental mass of 0.8884 ± 0.0531 Kg, both compatible with the supposed theoretical value of 0.89166 Kg.

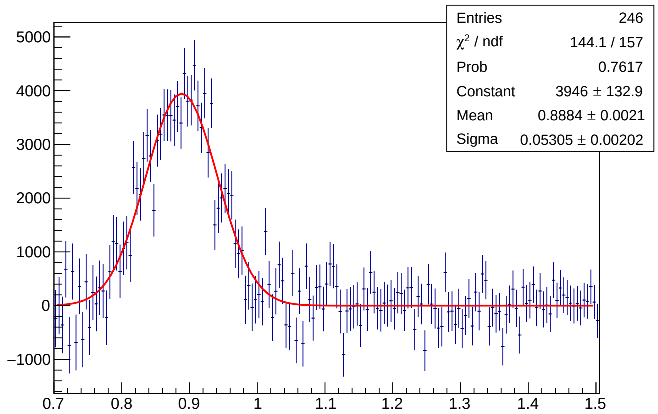

Figure 6: *This image show the result of the subtraction between the histogram of invariant mass of positive Pions & negative kaons or negative Pions & positive Kaon and the histogram of positive Pions & positive Kaon or negative Pions & negative Kaons. The red line represent the fitting normal distribution and the box shows its statts.*

Word Citacion

1. Alice Experiment. CERN. `https://home.cern/science/experiments/alice` . November 29^{th}, 2021.