JOINT INSTITUTE FOR NUCLEAR RESEARCH

Veksler and Baldin laboratory of High Energy Physics

Final Report of INTEREST program

MPD detector performance study at the NICA collider

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Contents

Abstract

The MPD experiment at the Nuclotron-based Ion Collider Facility (NICA) explores heavy ion collisions, crucial for understanding hadron dynamics and particle production in baryon-rich environments. Distinguishing between primary and secondary particles using generators like PHQMD and BOX is vital for dissecting collision events and optimizing data analysis. The project "MPD detector performance study at the NICA collider" focuses on evaluating the MPD detector's performance, particularly in estimating secondary particle contributions to (anti)proton and deuteron yields. Primary particles directly originate from collisions, while secondary particles result from interactions with detector materials or decay processes. This distinction aids in refining collision models, enhancing event reconstruction algorithms, and suppressing background noise. By accurately discerning between primary and secondary particles, researchers contribute to advancing particle physics research, deepening our understanding of fundamental particle interactions in heavy ion collisions.

Introduction

The study of heavy ion collisions in the MPD experiment (Multi-Purpose Detector) represents a significant effort in the field of particle physics, situated as a spectrometer within the Nuclotron-Based Ion Collider Facility (NICA) at the Joint Nuclear Research Institute (JINR). Focusing on the study of heavy ion collisions within a specific energy range, ranging from $4\text{GeV} \leq \sqrt{s_{NN}} \leq 11\text{GeV}$, the MPD explores the high density region of baryons, an area yet to be fully investigated. This experimental program aims to fill a gap in the energy scale, providing a deeper understanding of hadron dynamics and the production of multiple particles in a baryon-rich environment.

The importance of distinguishing between primary and secondary particles lies in the need to understand the underlying physics of collision processes and extract significant information about the particles involved. This distinction is crucial for several reasons: first, it allows us to understand the dynamics of collisions when analyzing initial conditions and fundamental interactions at high energies. Second, it facilitates event reconstruction by tracking primary particles, which improves the accuracy of event reconstruction algorithms. Third, it helps suppress background noise by distinguishing between primary particles that arise from the collision process and secondary particles that may interfere with signals of interest.

In the context of the MPD experiment, event generators such as BOX and PHQMD are used to simulate nuclear collisions and provide data for analysis. These generators allow us to investigate a variety of phenomena, from the phase transition from ordinary nuclear matter to quark-gluon matter to the production of exotic particles. Specifically, the PHQMD generator is used to simulate heavy ion collisions and explore the characteristics of quark-gluon matter produced in such events. On the other hand, the BOX generator is used to simulate basic nuclear collisions and generate statistical samples of generic collisions.

The analysis of the contribution of secondary particles in proton and deuteron yields is essential for understanding nuclear interactions and the formation of quark-gluon plasma in heavy ion collisions. This analysis provides crucial information about the underlying nuclear processes and plasma properties of quark-gluons under extreme temperature and density conditions. By studying the distribution of primary and secondary particles in collisions, regions with lower secondary particle contamination can be identified, which allows a more precise interpretation of the experimental data and a validation of the theoretical models in particle physics.

In this report, we will focus on estimating the contribution of secondary particles in proton and deuteron yields from data generated by BOX and PHQMD generators. We will explore the methods of analysis and the results obtained to better understand the physics of nuclear collisions and the nature of the particles produced in such events.

1 MPD Experiment

The MPD (Multi-Purpose Detector) experiment represents a significant endeavor in the realm of particle physics, situated as a spectrometer within the Nuclotron-based Ion Collider Facility (NICA) at the Joint Institute for Nuclear Research (JINR). Focused on studying heavy ion collisions within a specific energy range, ranging from $4\,\mathrm{GeV} \leq \sqrt{s_{NN}} \leq 11\,\mathrm{GeV}$, the MPD explores the high-density region of baryons, an area yet to be fully investigated. This experimental program aims to fill a gap in the energy scale, providing a deeper understanding of hadron dynamics and the production of multiple particles in a baryon-rich environment.

To achieve its objectives, the MPD relies on cutting-edge technology, including several key detector subsystems. The central barrel components exhibit an approximate cylindrical symmetry within $|\eta| < 1.5$, comprising the Time Projection Chamber (TPC), the Time of Flight Detector (TOF), and the Electromagnetic Calorimeter (ECal). The TPC serves as the main tracker, providing precise momentum measurements and particle identification, while the TOF identifies charged hadrons and offers precise time and coordinate measurements. The ECal, placed between the TOF and the MPD magnet, is crucial for detecting electromagnetic showers and plays a central role in photon and electron measurements. Additionally, the Fast Forward Detector (FFD) within the TPC barrel acts as a wake-up trigger, and the Forward Hadronic Calorimeter (FHCal) near the magnet end-caps helps determine collision centrality and the orientation of the reaction plane for collective flow studies.

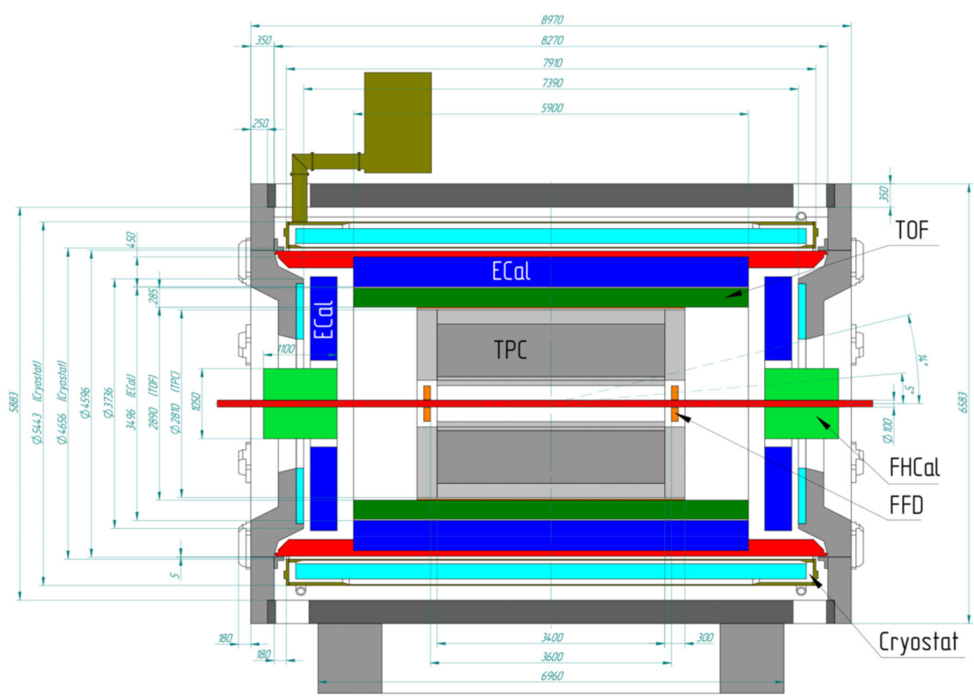


Figure 1: The overall schematic of the MPD subsystems in the first stage of operation (Stage 1) – cross-section by the vertical plane

This comprehensive setup, coupled with advanced software tools like MPDRoot specifically designed for this experiment, enables detailed event-by-event studies, providing crucial information about trajectories, particle identification, and collision centrality. With its installation planned in two phases and the development of state-of-the-art detector subsystems, the MPD is poised to drive new discoveries and significantly contribute to advancing knowledge in this fascinating and ever-evolving field.

2 Project "MPD detector performance study at the NICA collider"

This project consists of four tasks, which are:

1. Phase-space, spectra and yields from central Au+Au collisions;
2. MPD PID performance by means of ionization loss dE/dx;
3. Estimation of secondary particles contribution in the yields of (anti)protons and deuterons;
4. MPD PID performance by TOF measurements

In this report, I will focus to explain and make the tasks number 3.

2.1 Task 3 : Estimation of secondary particles contribution in the yields of (anti)protons and deuterons

Task 3 Objectives

- Born in $A + A$ collision primary particles interact inside MPD detector material producing secondaries.
- Some of the can be rejected by track selection criteria, some - cannot!
- One must estimate contribution of the secondaries in selected samples of (anti)protons and deuterons.

3 Approach to the task of analysis

Before we start doing the task, we need to understand the theory behind it. Not only the concepts of the technicians to be able to develop the entire experimental part, but also understand the concepts of the theorists

3.1 Understand the theory

Important concepts to understand what we are doing.

Primary particles

Primary particles are fundamental entities that emerge directly from the collision or interaction of high-energy particles, such as protons or heavy ions, in particle physics experiments. These collisions can occur in accelerators or in natural cosmic ray interactions with the Earth's atmosphere.

In the context of particle physics simulations, primary particles encompass not only the directly produced particles resulting from the collision but also any particles generated by the event generator software. Event generators simulate the entire collision process, from the initial collision to the final-state particles produced in the interaction.

Secondary particles

Secondary particles can be generate in both from within the primary particles themselves and from interactions with detector materials.

Decay Products of Primary Particles: Inside primary particles like Lambdas and Kaons, which possess properties such as strangeness, decay processes can occur even before the particles reach a detector. These decays result in the production of secondary particles such as protons and pions (only pions). This process contributes to the formation of secondary particles without the need for external interactions with the detector.

Interaction with Detector Material: Charged particles, including muons and protons, interact with the materials comprising the particle detector. These interactions lead to the generation of additional secondary particles.

Why do we want to detect the primary and secondary particles of collisions and make this distinction?

Detecting primary and secondary particles in collisions and distinguishing between them is crucial for understanding the underlying physics of the collision processes and extracting meaningful information about the particles involved. Here are several reasons why this distinction is important:

1. **Understanding Collision Dynamics:** Primary particles are those produced directly in the collision process, while secondary particles arise from interactions with detectors or subsequent decays of primary particles. By identifying the primary particles, we can analyze the initial conditions of the collision and obtain information about the fundamental interactions that occur at high energies. Studying secondary particles provides information on decay modes and interaction channels of primary particles, contributing to an integral understanding of collision dynamics.

2. **Event Reconstruction:** Primary particle tracking allows reconstruction of collision events and determination of their characteristics, such as collision centrality, moment distributions and energy deposition patterns. Secondary particles provide additional information on the evolution of the collision event and the interactions of underlying particles. Integrating primary and secondary particle information allows for more complete analysis of collision events and improves the accuracy of event reconstruction algorithms.

3. **Background Suppression:** Distinguishing between primary and secondary particles helps to mitigate background noise and pollution in experimental data. Secondary particles, which originate from sources other than the collision process of interest, can obscure signals of interest and introduce systematic uncertainties into data analysis.

Generator PHQMD

The PHQMD (Parton-Hadron-String Dynamics) generator is a theoretical model used to simulate heavy ion collisions and explore the characteristics of quark-gluon (QGP) matter produced in such events. This model combines the dynamics of partons, hadrons and strings, allowing research into a variety of phenomena, including the phase transition from ordinary nuclear matter to QGP and the production of exotic particles.

In the context of the MPD experiment, data generated with the PHQMD generator were used to analyze the moments of the event-by-event multiplicity distributions and to evaluate the sensitivity of the experiment to critical signals. In addition, specific mention was made of a request for data on Hypernuclei in Bi+Bi collisions with a mass center energy of $\sqrt{s} = 9.2AGeV$. This indicates that the PHQMD generator was used to simulate these collisions and study the characteristics of hypercores in that context.

Generator BOX

The "BOX" generator is a tool used in particle physics to simulate basic nuclear collisions. It is known for its simplicity and ability to generate statistical samples of generic nuclear collisions. Although it does not allow the specification of types of atomic nuclei that will interact, it offers the possibility to select some characteristics of the collision.

In the context of collision analysis using software such as MpdRoot, the BOX generator is an essential part of generating the information needed for the study. Simulated collisions with BOX provide data that is then processed through a chain of simulations and data analysis. This allows us to study the response of detectors and evaluate event reconstruction algorithms, which is crucial to understand the experimental results and validate theoretical models in particle physics.

What do we want to obtain from this type of collision?

The BOX generator does not produce a collision as such, but generates a specific particle (which? which we want). So, there is no real collision in this generator. However, this process helps us to visualize the trajectory and interaction of the particle, and also provides us with information on how to reconstruct them.

The aim of studying collisions involving Hypernuclei, particularly those requested for Bi+Bi collisions with a center-of-mass energy of $\sqrt{s} = 9.2$ AGeV, and utilizing data obtained from the PHQMD generator, is to gain insights into the behavior and properties of hypernuclei under extreme conditions. By simulating these collisions and analyzing the resulting data, we seek to understand how hypernuclei behave within the context of heavy ion collisions, shedding light on their formation, stability, and decay processes. Additionally, studying hypernuclei in such collisions can provide valuable information about the dynamics of nuclear matter at high densities and temperatures, contributing to our broader understanding of the fundamental forces and interactions governing the universe.

3.2 Elements to indentify primary and secondary particles

MotheID

In the FairRoot framework, crucial for high-energy physics experiments, the "FairRoot Mother ID" serves as a vital identifier within Monte Carlo simulations. It primarily distinguishes primary particles, facilitating comprehensive tracking of their interactions within detector setups.

This concept entails discerning the originating primary particle of a given particle. Primary particles are identified by a mother ID of -1, while any different value from this value designates the particle as secondary.

In specific contexts, like those involving generators such as UrQMD, primary particles receive a default Mother ID of -1 upon generation. Conversely, secondary particles resulting from the decay of primaries are assigned unique IDs distinct from -1.

This approach streamlines the differentiation between primary and secondary particles, enabling efficient tracking of particle lineage and comprehensive understanding of their origins within the simulation.

Code PDG

The Monte Carlo particle numbering scheme outlined in the text provides a structured approach to encode information about particles used in particle physics simulations. This scheme facilitates the interface between event generators, detector simulators, and analysis packages. The scheme assigns a 7-digit number to each particle, encoding details about its spin, flavor content, and internal quantum numbers.

The PDG code, maintained by the Particle Data Group, is a standardized numbering system for particles used in particle physics. It assigns unique numerical codes to particles, facilitating data exchange and comparison across different experiments and analyses. The PDG code includes a wide range of particles, from fundamental quarks and leptons to composite hadrons and exotic particles. PDG's for:

$$p = 2212 \tag{1}$$

$$d = 1000010020 \tag{2}$$

Why do we want to know only the number of protons and deuterons, both primary and secondary?

The analysis of the number of protons and deuterons, both primary and secondary, plays a crucial role in understanding nuclear interactions and the formation of quark-gluon plasma (QGP) in heavy-ion collisions. These particles provide crucial insights into underlying nuclear processes and the properties of QGP under extreme conditions of temperature and density. Given that protons are less massive than deuterons, we are likely to observe a higher abundance of protons compared to deuterons in the collected data, reflecting differences in particle production and fragmentation in the context of heavy-ion collisions.

The asymmetry between the abundance of protons and deuterons results from the combination of nuclear properties and collision dynamics. This discrepancy serves as a probe to investigate the structure and evolution of QGP, as well as to validate theoretical models of particle physics under extreme conditions. Altogether, the detailed analysis of protons and deuterons in experimental data provides a more comprehensive understanding of nuclear phenomena and the behavior of matter in a high-energy, high-density regime, such as that encountered in heavy-ion collisions.

3.3 How to do it (Methodology)

Things to remember before to start

- **runMC.C:** This file give us the interaction with the detectors that depends on the $geometry_stage1.C$ file.

- **runReco.C:** Make the reconstructs the traces, that is, the interaction with the detectors, it gives us points in different positions, or times, or voltages, etc.

  The reconstruction is taking that information to determine the moment and trajectory of a particle, on the mpddst.root file.

- **MC Tracks:** Verify that particle identification is good, this is known to be deficient.

- **Reconstructed Tracks:** Is what we see in the experiment.

Also, we can estimated that so many particles are produced by the interation with the detectors.

Step by step

In this part, I will to describe in general all steps to follow to obtain the Task 3 Objectives:

1. We already mentioned that we use BOX and PHQMD generators, for both cases we will use *100,000 events*. For PHQMD the data was provided to us. However, for the data generated by BOX we modified the "runMC files. C" and "runReco. C".

2. To get started we are going to edit our macro, the file "readDST. C" to be able to separate the primary and secondary functions using the MotherID. Once this is obtained we go to only the primary and secondary particles for protons and deuterons. Using pdg codes, that is, the codes described in 1 and 2[1].

3. Explore the *MpdTrack Class* [2]. We will look for the functions that help us in locating the particles that are at a Distance from the Closest Approach perpendicular and along the Z axis.

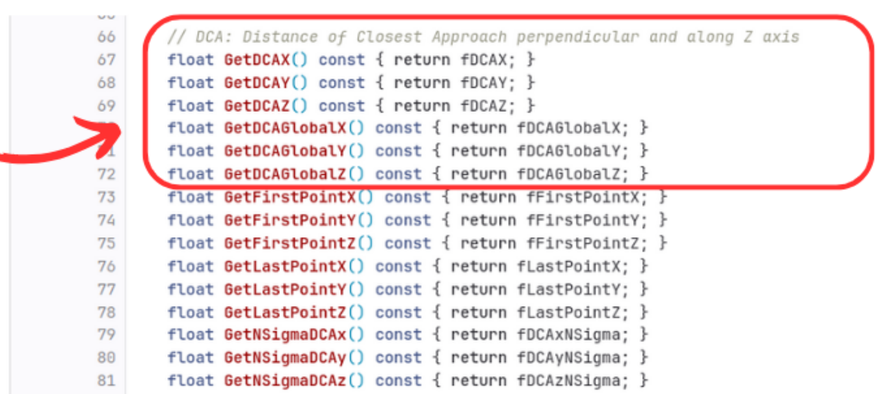


Figure 2: DCA: Distance of Closest Approach perpendicular and along Z axis

   For this case, We will use the functions DCA and DCAGlobal, like show in the figure 2.

4. Now that we know the functions we are going to use. Let's edit our macro, which is the "readDST. C" file. We will modify several aspects to obtain histograms for the three directions of position (x, y, z), Z vs radius and Z vs radius minus the main vertex. This will be done for data sets generated by BOX and PHQMD. Since we have two functions, we will get all these histograms for the DCA and DCAGlobal function. And

[1] Details of how they were modified the macros will be described in the next section.
[2] https://git.jinr.ru/nica/mpdroot/-/blob/dev/core/mpdBase/MpdTrack.h?ref_type=heads

for each histogram we'll separate the main particles from the secondary ones. All this for protons and deuterons

5. Once we get all the histograms, we're going to get the ratio between the position of the primary and secondary particles for protons and deuterons. This will allow us to see where we can make a cut so we can remove the secondary particles as much as possible.

6. Now, we only obtain all the histograms for every case with the cut.

4 Description of mpdroot working macro

4.1 Modify the BOX generators

In the figure 3, we can see how we modify the macro runMC. C to make it run over several particulates (more than needed were included if used). We also changed the number of events from 2 to 100.

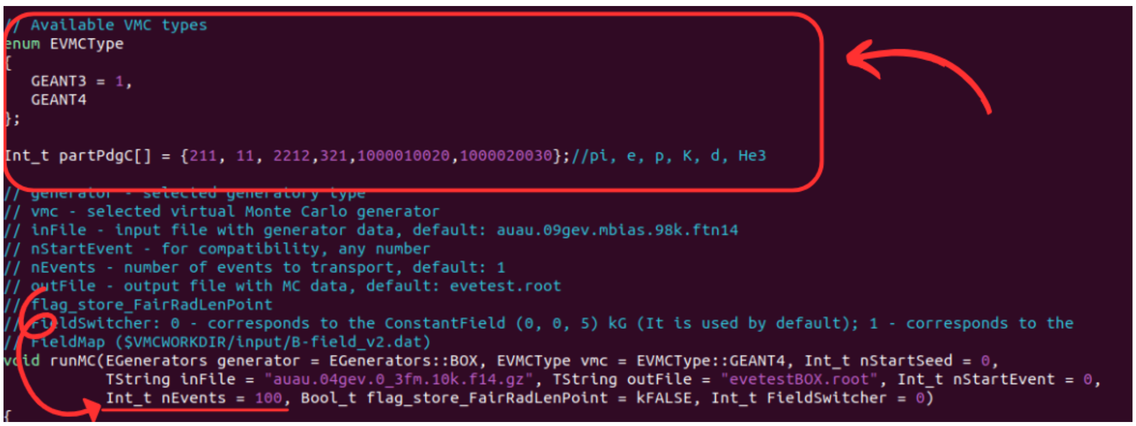


Figure 3: Part 1 of the macro modification *runMC.C*

In the figure 3, we change the centrality o the point (0.0), we change the centrality of events, which affects several aspects. The spatial distribution of particles can vary, along with parameters such as energy density and system symmetry. In addition, Fermi's time, which indicates the longitudinal energy fraction of the particles, can be influenced.

We also changed the multiplicity to 100, that is, with this change we will have a totality of 10,000 events[3].

[3] This same change was made for the macro *runReco.C*

```
// smearing of beam interaction point
primGen->SetBeam(0.0, 0.0, 0.1, 0.1); // for fix-target set all to 0.0
primGen->SetTarget(0.0, 0.0); // for fix-target set (-115.0, 0.0)
primGen->SmearGausVertexZ(kTRUE); // for fix-target set kFALSE
primGen->SmearVertexXY(kTRUE); // for fix-target set kFALSE

// Use user defined decays https://fairroot.gsi.de/?q=node/57
fRun->SetUserDecay(kTRUE);
// Use external decayer
// fRun->SetPythiaDecayer(TString("$VMCWORKDIR/gconfig/LambdaDecayConfig.C"));

for (Int_t i = 0; i < 6; i++)
   {
   switch (generator)
   {
   case EGenerators::BOX: // Box generator
   {
   //for (Int_t i = 0; i < 6; i++)
   //{
      gRandom->SetSeed(0);
      FairBoxGenerator *boxGen = new FairBoxGenerator(partPdgC[i], 100);
      //FairBoxGenerator *boxGen = new FairBoxGenerator(partPdgC[4], 100);
      //FairBoxGenerator *boxGen = new FairBoxGenerator(13, 100); // 13 = muon; 1 = multipl.
      boxGen->SetPRange(0.0, 5.0);                           // GeV/c, setPRange vs setPtRange
      boxGen->SetPhiRange(0, 360);                            // Azimuth angle range [degree]
      boxGen->SetThetaRange(0, 180);                          // Polar angle in lab system range [degree]
      boxGen->SetXYZ(0., 0., 0.);                             // mm o cm ??
      primGen->AddGenerator(boxGen);
      break;
     //}
   }
```

Figure 4: Part 2 of the macro modification *runMC.C*

In the figure 5, we make a script that iterates 10 times, generating unique files for each iteration of the loop. This allows us to get 10 times the runMC files. C and runReco.C. Which now gives us a total of 100,000 events. This makes it easy to run the files in the cluster, as it runs different files and generating the same amount of events in less time, if we only did it with a single file

```
#!/bin/sh
#SBATCH --ntasks-per-node=1
#SBATCH --mem-per-cpu=8192M # that much memory for simulation and reconstructrion jobs only
#SBATCH --time=24:00:00
#SBATCH -p mpd

for ((INDEX = 0; INDEX < 10; INDEX++))
do
sed -e "s/runMC/runMC${INDEX}/;         s/test.f14/test.f14${INDEX}/;                  s/evetestBOX.root/evetestBOX${INDEX}.root/" runMC.C > runMC${INDEX}.C
sed -e "s/runReco/runReco${INDEX}/;     s/evetestBOX.root/evetestBOX${INDEX}.root/;    s/mpddst.root/mpddst${INDEX}.root/" runReco.C > runReco${INDEX}.C
done
~
~
~
```

Figure 5: Iterative configuration file generation script

We must also modify the macro "readDST. C" to be able to run on several files. This change allows us to run over many files and apart from that, if there were to exist the case that there is no file, jump it and continue with the rest [4].

[4]We also need to add to the beginning of the macro the following lines:

char name[900];
Int_t initialfile = 9000;// initial counter to read files
Int_t finalfile = 9999;// final counter to read files

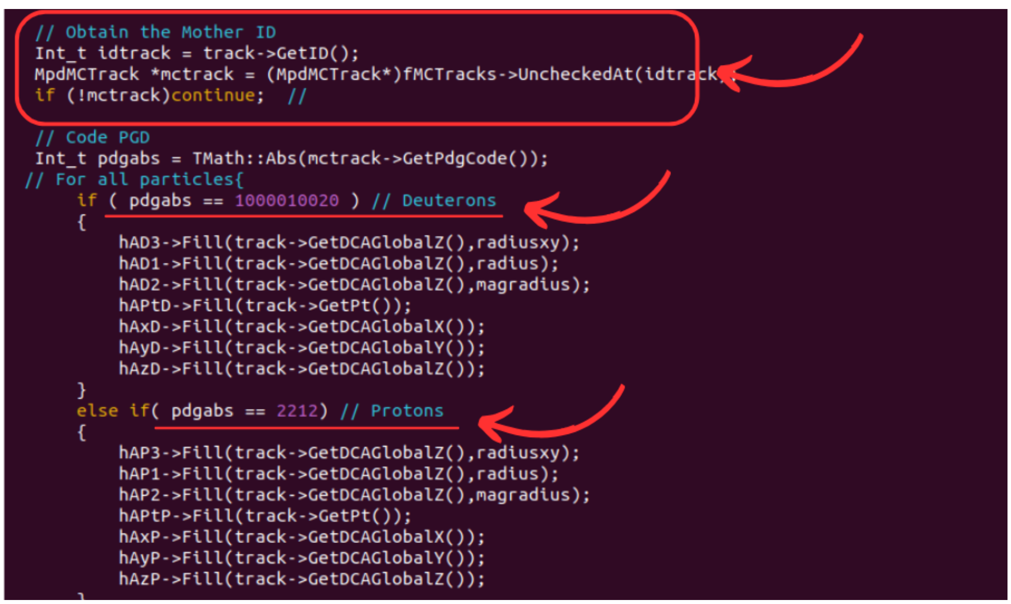
```
  for(Int_t nf=initialfile; nf<finalfile; nf++){

    sprintf(name,"/storage/mexnica/datosNICA/eos/eosnica.jinr.ru/nica/mpd/sim/data/exp/dst-BiBi-09.2GeV-m
00-%d.reco.root",nf);

  //sprintf(name,"/storage/mexnica/TallerMPD/CarlosMarquez/mpdroot-v23.12.23/build/mpddst%d.root",nf);

  TString inputFile = name;

  TFile fileInput(inputFile.Data());
 if (fileInput.IsZombie()) continue;

  TChain *dstTree = new TChain("mpdsim");
  dstTree->Add(inputFile.Data());

  printf("Procesando archivo: %s\n", name);
```

Figure 6: Modification in the macro "readDST. C" to run on several files

4.2 MotheID and Code PDG

As already mentioned, for a particulate to be considered as primary, its MotherID must be equal to -1 and if it is different from -1, it is considered as secondary particulate.

To obtain the primary and secondary particles of protons and deuterons we use the pdg code, i.e., 1 and 2.



```
  // Obtain the Mother ID
  Int_t idtrack = track->GetID();
  MpdMCTrack *mctrack = (MpdMCTrack*)fMCTracks->UncheckedAt(idtrack);
  if (!mctrack)continue;  //

  // Code PGD
  Int_t pdgabs = TMath::Abs(mctrack->GetPdgCode());
 // For all particles{
      if ( pdgabs == 1000010020 ) // Deuterons
      {
          hAD3->Fill(track->GetDCAGlobalZ(),radiusxy);
          hAD1->Fill(track->GetDCAGlobalZ(),radius);
          hAD2->Fill(track->GetDCAGlobalZ(),magradius);
          hAPtD->Fill(track->GetPt());
          hAxD->Fill(track->GetDCAGlobalX());
          hAyD->Fill(track->GetDCAGlobalY());
          hAzD->Fill(track->GetDCAGlobalZ());
      }
      else if( pdgabs == 2212) // Protons
      {
          hAP3->Fill(track->GetDCAGlobalZ(),radiusxy);
          hAP1->Fill(track->GetDCAGlobalZ(),radius);
          hAP2->Fill(track->GetDCAGlobalZ(),magradius);
          hAPtP->Fill(track->GetPt());
          hAxP->Fill(track->GetDCAGlobalX());
          hAyP->Fill(track->GetDCAGlobalY());
          hAzP->Fill(track->GetDCAGlobalZ());
```

Figure 7: Modification in the macro "readDST. C" to obtain the MotherID and the splitting between protons and deuterons.

4.3 Modify readDST.C to obtain all the histograms

Note that in the cases of the positions we occupy obtain histograms in 1D to obtain the primary example reasons among all the particles.

```
   // Mother ID
TH1F *hMID = new TH1F("MotherID","ID distribition; Mothe

   // Deuterons
TH2F *hAD3 = new TH2F("All Deuterns 3","z vs #sqrt{x^{2}+
TH2F *hPD3 = new TH2F("Primary Deuterons 3","z vs #sqrt{x
TH2F *hSD3 = new TH2F("Secondary Deuterons 3","z vs #sqrt
  // Other distribution
TH2F *hAD1 = new TH2F("All Deuterns","z vs #sqrt{x^{2}+y
TH2F *hPD1 = new TH2F("Primary Deuterons","z vs #sqrt{x^
TH2F *hSD1 = new TH2F("Secondary Deuterons","z vs #sqrt{x
  // Other distribution
TH2F *hAD2 = new TH2F("All Deuterns 2","z vs #sqrt{x^{2}+
TH2F *hPD2 = new TH2F("Primary Deuterons 2","z vs #sqrt{x
TH2F *hSD2 = new TH2F("Secondary Deuterons 2","z vs #sqrt
   // Deuterons Transversal Momentum
TH1F *hAPtD = new TH1F("p_{T} All Deuterons","p_{T} distr
TH1F *hPPtD = new TH1F("p_{T} Primary Deuterons","p_{T} d
TH1F *hSPtD = new TH1F("p_{T} Secondary Deuterons","p_{T}
  // Deuterons Position
TH1F *hAxD = new TH1F("All x: Deuterons","All x distribit
TH1F *hPxD = new TH1F("Primary x: Deuterons","Primary  x
TH1F *hSxD = new TH1F("Secondary x: Deuterons","Secondary
TH1F *hAyD = new TH1F("All y: Deuterons","All y distribit
TH1F *hPyD = new TH1F("Prmary y: Deuterons","Primary  y d
TH1F *hSyD = new TH1F("Secondary y: Deuterons","Secondary
TH1F *hAzD = new TH1F("All z: Deuterons","All z distribit
TH1F *hPzD = new TH1F("Prmary z: Deuterons","Primary  z d
TH1F *hSzD = new TH1F("Secondary z: Deuterons","Secondary
```

```
  // Protons
TH2F *hAP3 = new TH2F("All Protons 3","z
TH2F *hPP3 = new TH2F("Primary Protons 3"
TH2F *hSP3 = new TH2F("Secondary Protons
   // Other distribution
TH2F *hAP1 = new TH2F("All Protons","z vs
TH2F *hPP1 = new TH2F("Primary Protons","
TH2F *hSP1 = new TH2F("Secondary Protons"
   // Other distribution
TH2F *hAP2 = new TH2F("All Protons 2","z
TH2F *hPP2 = new TH2F("Primary Protons 2"
TH2F *hSP2 = new TH2F("Secondary Protons
   // Protons Transversal momentum
TH1F *hAPtP = new TH1F("p_{T} All Protons
TH1F *hPPtP = new TH1F("p_{T} Primary Pro
TH1F *hSPtP = new TH1F("p_{T} Secondary P
   // Protons Position
TH1F *hAxP = new TH1F("All x: Protons","A

TH1F *hSxP = new TH1F("Secondary x: Proto
TH1F *hAyP = new TH1F("All y: Protons","A
TH1F *hPyP = new TH1F("Prmary y: Protons"
TH1F *hSyP = new TH1F("Secondary y: Proto
TH1F *hAzP = new TH1F("All z: Protons","A
TH1F *hPzP = new TH1F("Prmary z: Protons"
TH1F *hSzP = new TH1F("Secondary z: Proto
```

Figure 8: Modification in the macro "readDST. C" to obtain all histograms that we need.

We also, need to obtain the primary vertex point 9 and radius 10.

```
for (Int_t i = 0; i < events; i++) {
    dstTree->GetEntry(i);

     //PrimaryVtx point
    Int_t nVert = vtxs->GetEntriesFast();
    MpdVertex *vtx = (MpdVertex*) vtxs->First();

    Double_t posVtxX = vtx->GetX();
    Double_t posVtxY = vtx->GetY();
    Double_t posVtxZ = vtx->GetZ();

    if(TMath::Abs(posVtxZ) > 5) continue;

    Int_t Ntracks = event->GetGlobalTracks()->GetEntriesFast();

    cout << " Number of tracks = " << Ntracks << endl;
    for (Int_t iTrack = 0; iTrack < Ntracks; iTrack++) {
        MpdTrack* track = (MpdTrack*) event->GetGlobalTracks()->UncheckedAt(iTrack);
```

Figure 9: Modification in the macro "readDST. C" to obtain the primary vertex.

```
//Obtain the radius
Double_t radiusxy=TMath::Sqrt( track->GetDCAGlobalX()*track->GetDCAX() + track->GetDCAY()*track->GetDCAY() );
Double_t radius=TMath::Sqrt( track->GetDCAGlobalX()*track->GetDCAX() + track->GetDCAY()*track->GetDCAY() + track->GetDCAZ()*track->GetDCAZ() );
Double_t magradius=TMath::Sqrt( track->GetDCAGlobalX()*track->GetDCAX() + track->GetDCAY()*track->GetDCAY() + track->GetDCAZ()*track->GetDCAZ() - posVtxZ );
```

Figure 10: Modification in the macro "readDST. C" to radius, etc.

To obtain all the histograms we use the same patron that we can see in the figure 7. For every case, to obtain primary and secondary particles[5].

4.4 Ratios between the position

Now that we have the histograms of position, we obtain the ratios of primary particles between all particles of the three directions. Also, the secondary particles between all particles. For

[5] All the histograms we can see in the section of Results.

every case we have.

```
void salidaPHQMD(){

        TFile *fA = TFile::Open("salidaPHQMD.root");

        // Histrograms form Deuterons
        // For x
        TH1F *hd1x=(TH1F*)fA->Get("Primary x: Deuterons");
        TH1F *hd2x=(TH1F*)fA->Get("Secondary x: Deuterons");
        TH1F *hdAx=(TH1F*)fA->Get("All x: Deuterons");
        // For y
        TH1F *hd1y=(TH1F*)fA->Get("Prmary y: Deuterons");
        TH1F *hd2y=(TH1F*)fA->Get("Secondary y: Deuterons");
        TH1F *hdAy=(TH1F*)fA->Get("All y: Deuterons");
        // For z
        TH1F *hd1z=(TH1F*)fA->Get("Prmary z: Deuterons");
        TH1F *hd2z=(TH1F*)fA->Get("Secondary z: Deuterons");
        TH1F *hdAz=(TH1F*)fA->Get("All z: Deuterons");

        // Histrograms form Protons
        // For x
        TH1F *hp1x=(TH1F*)fA->Get("Primary x: Protons");
        TH1F *hp2x=(TH1F*)fA->Get("Secondary x: Protons");
        TH1F *hpAx=(TH1F*)fA->Get("All x: Protons");
        // For y
        TH1F *hp1y=(TH1F*)fA->Get("Prmary y: Protons");
        TH1F *hp2y=(TH1F*)fA->Get("Secondary y: Protons");
        TH1F *hpAy=(TH1F*)fA->Get("All y: Protons");
        // For z
        TH1F *hp1z=(TH1F*)fA->Get("Prmary z: Protons");
        TH1F *hp2z=(TH1F*)fA->Get("Secondary z: Protons");
        TH1F *hpAz=(TH1F*)fA->Get("All z: Protons");

         // Divide histograms form Deuterons
         // For x
         hd1x->Divide(hdAx);
         hd2x->Divide(hdAx);
         // For y
         hd1y->Divide(hdAy);
         hd2y->Divide(hdAy);
         // For z
         hd1z->Divide(hdAz);
         hd2z->Divide(hdAz);

         // Dividir histogramas de Protones
         // Para x
         hp1x->Divide(hpAx);
         hp2x->Divide(hpAx);
         // Para y
         hp1y->Divide(hpAy);
         hp2y->Divide(hpAy);
         // Para z
         hp1z->Divide(hpAz);
         hp2z->Divide(hpAz);
```

Figure 11: Part 1 of the macro to obtain the ratios.

```
// Create a canvas para Deuterones
TCanvas *c1 = new TCanvas("c1", "Histograms: Deuterons", 800, 600);

// Crear canvas para Protones
TCanvas *c2 = new TCanvas("c2", "Histograms: Protons", 800, 600);
c2->Divide(3, 2);

// Divide the canvas into multiple pads
c1->Divide(3, 2); // Divide into 2 columns, 2 row

// Draw histograms
c1->cd(1); // Activate the first pad
hd1x->Draw();
c1->cd(2); // Activate the second pad
hd1y->Draw();
c1->cd(3); // Activate the third pad
hd1z->Draw();
c1->cd(4); // Activate the fourth pad
hd2x->Draw();
c1->cd(5);
hd2y->Draw();
c1->cd(6);
hd2z->Draw();

// Dibujar histogramas para Protones
c2->cd(1);
hp1x->Draw();
c2->cd(2);
hp1y->Draw();
c2->cd(3);
hp1z->Draw();
c2->cd(4);
hp2x->Draw();
c2->cd(5);
hp2y->Draw();
c2->cd(6);
hp2z->Draw();
```

Figure 12: Part 2 of the macro to obtain the ratios.

4.5 Code for cutting in histograms

That we see in the past section, we make the cut in ± 5, but we have to clarify that it is only a first approximation, it is important that we can still repeat this process and find a better cut to find the regions where you have more particle contamination of some kind.

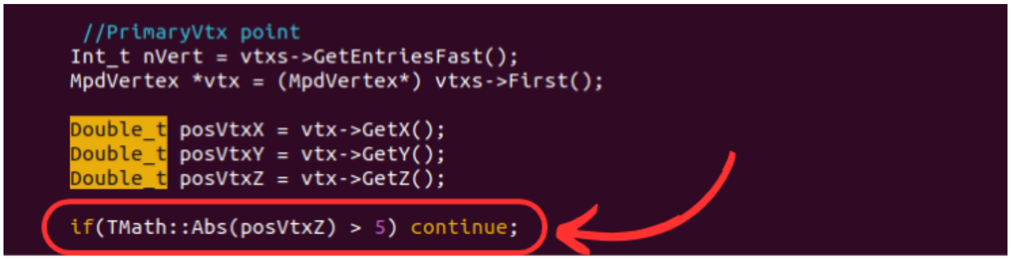


Figure 13: Modification in the macro "readDST. C" to make the cut to find the regions where we have more contamination.

5 Results

As mentioned we will perform task analysis with both functions, namely DCA and DCA-Global for two data sets obtained with BOX and PHQMD generators. However, we will only place and discuss in detail the analysis of tasks for **the DCA function and for the data with the generator PHQMD, the Hypernuclei data in the request Bi+Bi $\sqrt{s} = 9.2$AGeV**.

The main reason is because we have too much information for all cases, but at the end of will discuss a little what was obtained from the excluded cases

5.1 Histograms of x Position (No Cuts)

In this part, we only showed the position histograms in x, we also obtained all the histograms in the other directions. However, we do not place them here as they do not show information very similar to those of x, and the number of primary and secondary particles are the same.

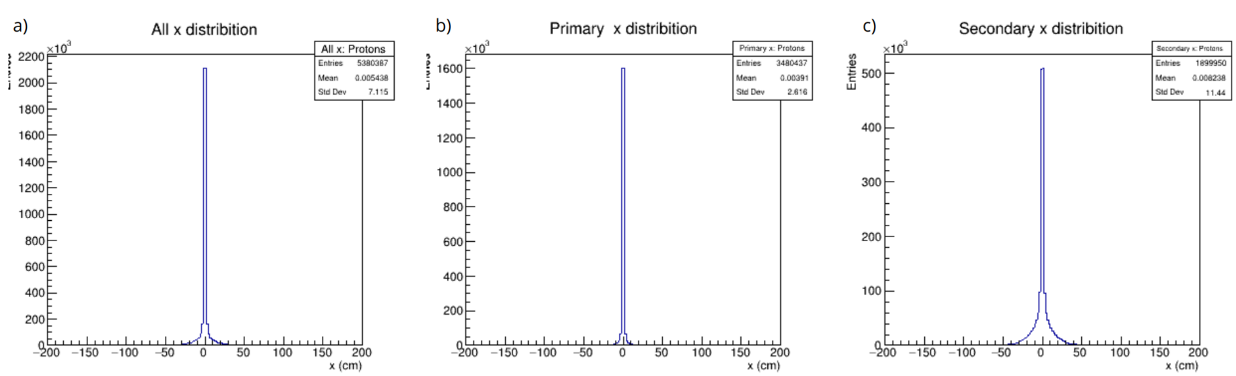


Figure 14: Position in direction x. a) All protons, b) Primary protons, c) Secondary protons.

As mentioned above, we will have two types of particles, protons and deuterons. To the naked eye, we did not observe differences between the histograms of both particles. However, by looking at the number of inputs, we realize that we have a significantly higher number of protons or deuterons. This was to be expected, as protons are less massive than deuterons.

Therefore, protons, being less massive than deuterons, are more likely to form because it is easier for the available energy to produce smaller particles.

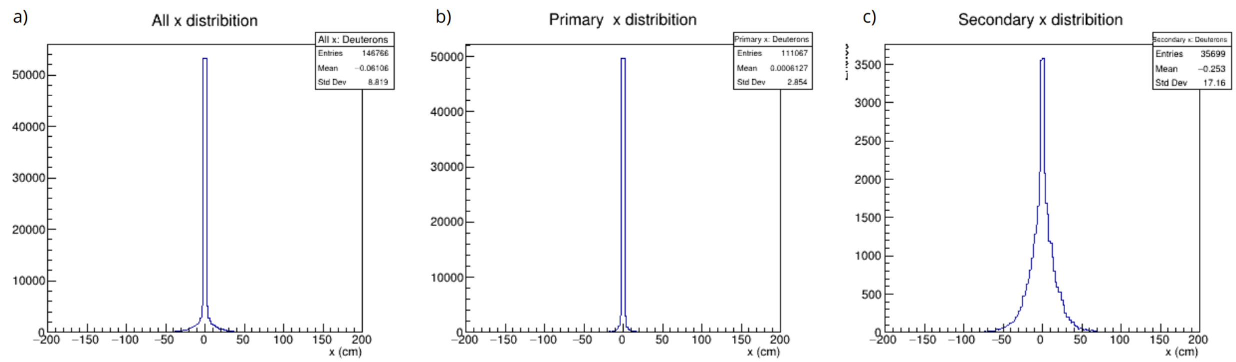


Figure 15: Position in direction x. a) All deuterons, b) Primary deuterons, c) Secondary deuterons.

It is also important to note that all histograms are between ±200 and are of one dimension (as shown in the figure 8) this will allow us to perform the next step, which is to find the ratios.

5.2 Primary and Secondary Ratios Across Three Directions (No Cuts)

Now that we have all the histograms of the positions, let's get the ratio between the position of the primary and secondary particles for protons and deuterons. As already mentioned this is going to help us see where we can make a cut to remove secondary particles. We are going to estimate that percentage are secondary and that both we can remove the regions where there is more contamination of the secondary particles for both protons and deuterons

Ratios of primary particles between all particles

We will start by looking at the reasons of the primary particles among all the particulates since it is the information that we want to obtain.

For the protons (figure 16) we observe that in the three directions we obtain the highest concentration of primary particles between the range of ±50. That is, we can stay in this interval as a first approximation to make. However, we could decrease this interval to make the cut seeing the contribution we will have from the secondary particles. As mentioned, we want to remove the highest percentage of pollution (secondary particles).

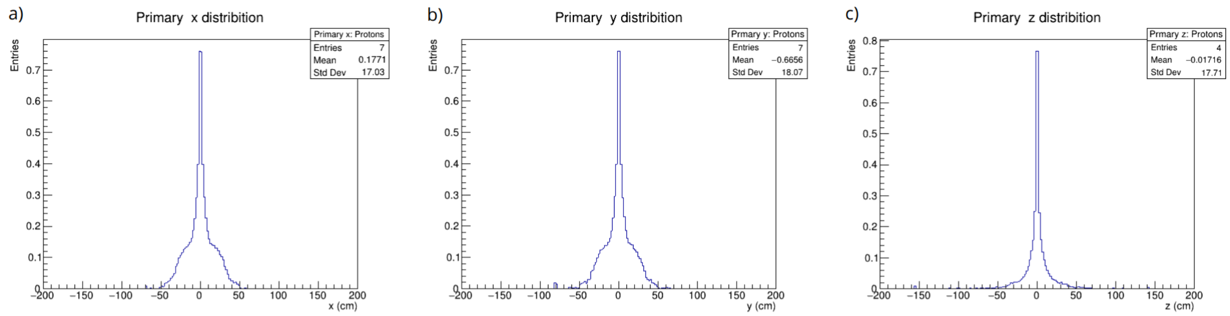


Figure 16: Ratios of primary protons between all protons. a) All protons, b) Primary protons, c) Secondary protons.

For the case of primary deuterons (Figure 17), we will have the same case, the highest concentration is in the range of ± 50. However, looking at the z-direction, we could still narrow the interval of this first approximation.

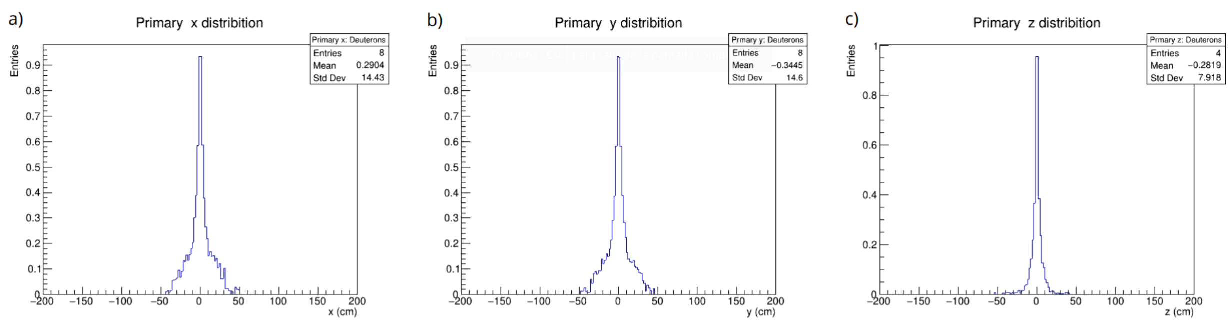


Figure 17: Ratios of primary deuterons between all deuterons. a) All deuterons, b) Primary deuterons, c) Secondary deuterons.

By looking only at the ratio of the primary particles between all the particles we can conclude that our highest concentration of primary particles for both protons and deuterons could be limited in the range of ± 50. *However, the important thing here is to remove the secondary particles. So before we make a cut, we must check the reason for the secondary particles between all particles.*

Ratios of secondary particles between all particles

Now we look at the reasons for the secondary particles among all the particles, both for protons (figure 18) and deuterons (figure 19). At first we observe that these graphs complement the graphs of the primary particulate ratios among all particulates.

Previously mentioned that we could have a cut at ± 50. However, looking at these histograms we realize that this interval does not serve for a first approximation. Since this interval there is still a good contribution of secondary particles. Therefore, a cut at ± 5 , we will still have a high percentage of contamination

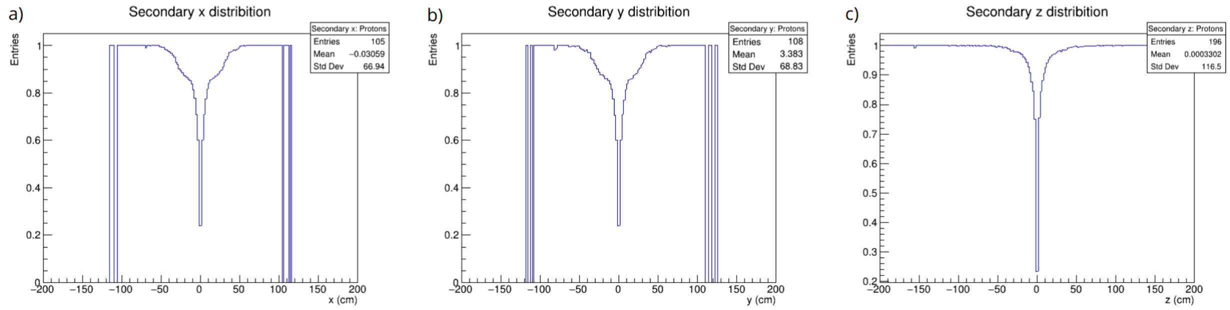


Figure 18: Ratios of secondary protons between all protons. a) All protons, b) Primary protons, c) Secondary protons.

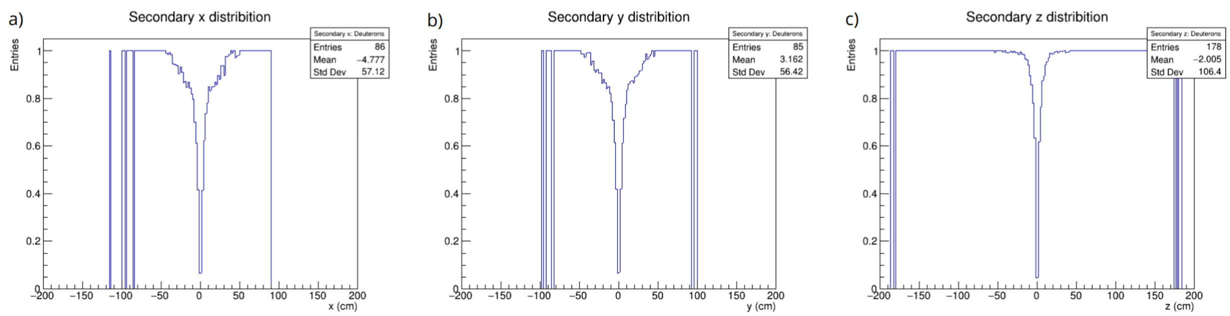


Figure 19: Ratios of secondary deuterons between all deuterons. a) All deuterons, b) Primary deuterons, c) Secondary deuterons.

Looking at the figure and the figure, we realize that a better interval for a good first approximation would be ± 5. Because by making a ± 5 cut we would be removing just under 80% of secondary particulates. This cut would be valid for both protons and deuterons.

Let's clarify that this is only a first approximation, since we could repeat the whole process, but now with the cut proposed in this first approximation, ie a cut in ± 5. By re-obtaining all histograms we can propose another approach. This will be discussed in more detail below.

5.3 Distribution of Z vs. Radius

When we graph "Z vs Radio" with the radius measured from the center of the detector, we are visualizing the radial distribution of the particles with respect to the center of the detector in the direction of the beam. This allows us to study how particles are distributed radially in the detector based on their position in the direction of the beam.

It is also important to note that you have particulate information at the origin. It does not necessarily tell us that we will be in the center of the dectector, but that we are in the first instant from which a particle is detected. Well, you have 200 Fermis as the parameter for the evolution of the system. This is something that we would see in a graph in centimeters in 0.

Distribution when we don't have a cut

For the uncut part, we can see that we have plenty of particulates. Both for protons and deuterons, as we saw in the histograms of the primary particulate ratios among all. We see an abundance of primaries in the ±5 range. Only now we have a whole area in blue. Which tells us we actually have very few particulates in these areas. On the other hand, near the origin we see that there is a greater abundance of particles. This is true for both protons and deuterons.

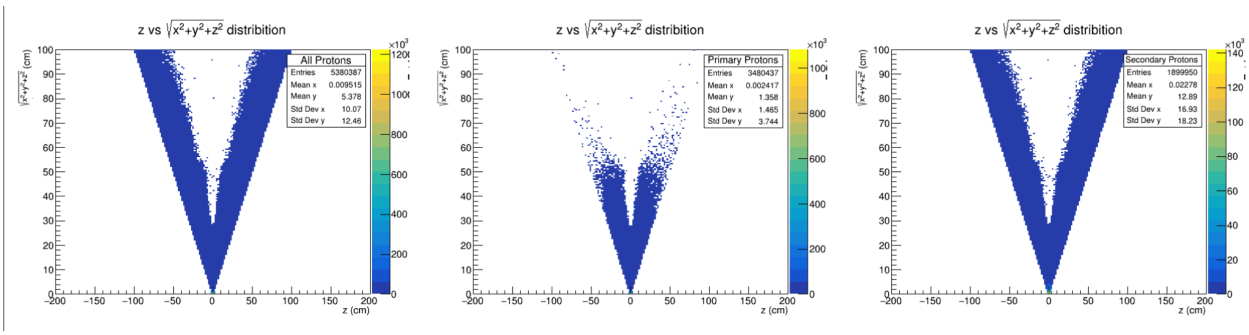


Figure 20: Distribution of protons en z vs radius without cut in -5 to +5 a) All protons, b) Primary protons, c)Secondary protons.

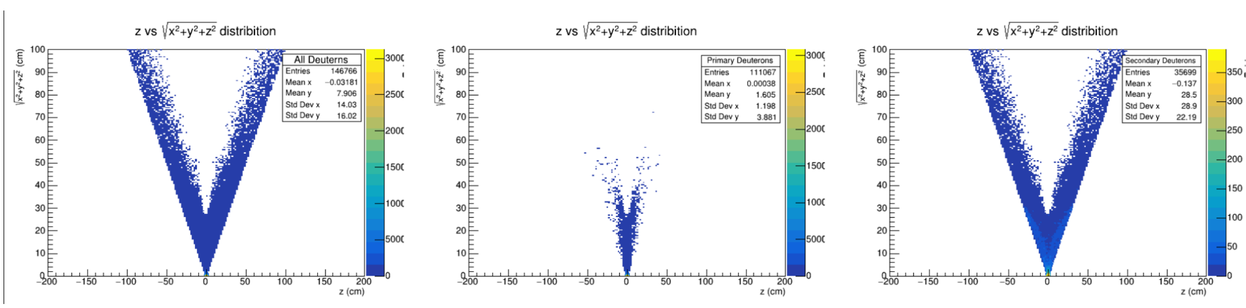


Figure 21: Distribution of deuterons en z vs radius without cut in -5 to +5 a) All deuterons, b) Primary deuterons, c)Secondary deuterons.

In the table 1

Distribution when we have a cut in ±5

Now that we made the cut in ±5 we observed how all the blue areas shown in the figures decreased significantly. This tells us that we lost a relative number of primary and secondary particles. However, it was to be expected as it has been mentioned that we will not be able to completely clean our signal. However, one thing he would tell us without having been a good cut or not is to look at the percentages.

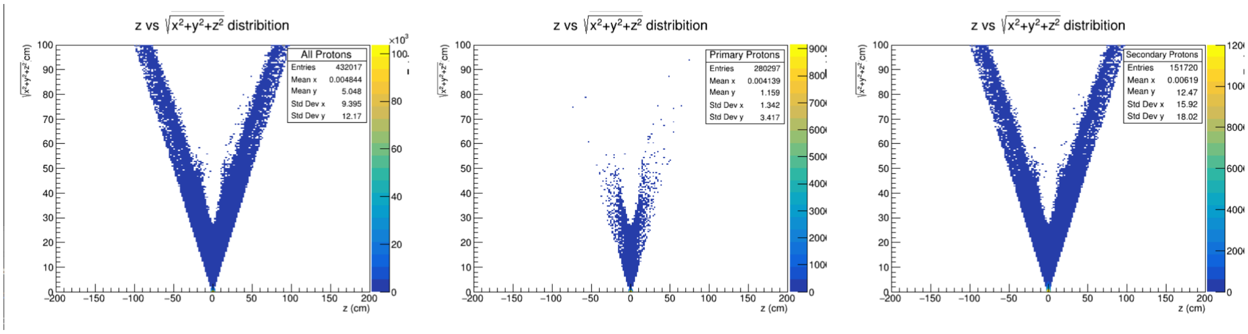


Figure 22: Distribution of protons en z vs radius minus principal vertex with cut in -5 to +5 a) All protons, b) Primary protons, c)Secondary protons.

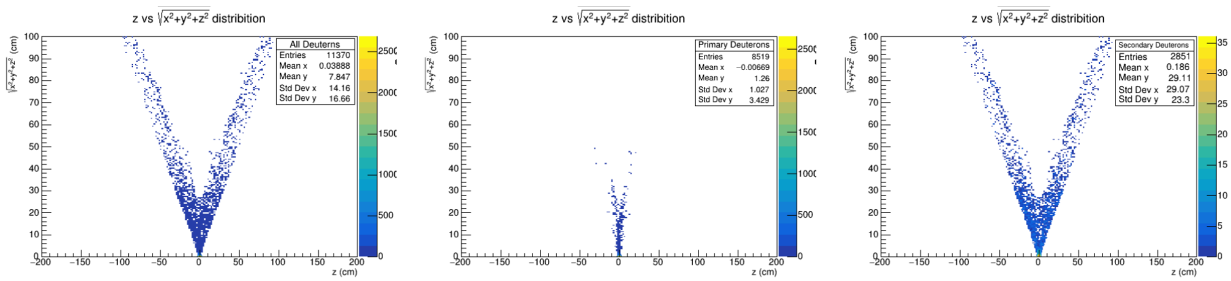


Figure 23: Distribution of deuterons en z vs radius minus principal vertex with cut in -5 to +5 a) All deuterons, b) Primary deuterons, c)Secondary deuterons.

Before proceeding, we should note that this has only been a first approximation. We could continue with the task of analysis to find a better approach. At the moment we only make a cut in the horizontal exercise, however, we can propose and perform the task of analysis in a horizontal cut. With this first approach we can propose a cut in the vertical exercise in 40. since here looking at the primary figures for both protons (figure 22) and deuterons (figure 23). There is no significant value in this area of primary particulates, but there is for secondary particulates. This cut can help us clean up the contamination in the information we want in the analysis.

Percentages of particles

Now let's look at the percentages of the number of primary and secondary particles for each case. Let's look at the table 1. Where the number of protons is 64.69% compared to the total number of particles we have. Now our cut despite we see a significant decrease in primary particles. The percentage is 68.88%, that is, we have an increase of 0.19%.

This is something that was expected to be obtained with the cut in this first approximation. As we expected the contribution of primary particles for protons to increase and the secondary protons decrease.

Percentage of Protons					
Without Cut			With Cut in ± 5		
Kind of particle	Entries	Percentage	Kind of particle	Entries	Percentage
All	5,380,387	100%	All	432,017	100%
Primary	3,480,437	64.69%	Primary	280,297	64.88%
Secondary	1,899,950	35.31%	Secondary	151,720	35.12%

Table 1: Comparison of the percentage of protons before and after cutting.

However, looking at our table 2, we realize that we have a case backwards. That is, the percentage of primary deuterons decreased and that of secondary deuterons increased by 0.75%. This is something, totally unexpected, as it must have been the same as the case of protons. However, remember that protons are less massive, so we will have a greater abundance of them. So in the first instance, we can conclude that our court was not effective for the deuterons. This leads us to check the intervals at which we could make a cut for deuterons.

As already mentioned, we can make another cut on both the horizontal and vertical axis. This would lead us to perform an analysis similar to the one described in this report, but separately from the protons.

Percentage of Deuterons					
Without Cut			With Cut in ± 5		
Kind of particle	Entries	Percentage	Kind of particle	Entries	Percentage
All	146,766	100%	All	11,370	100%
Primary	111,067	75.58%	Primary	8,519	74.07%
Secondary	35,699	24.32%	Secondary	2,851	25.07%

Table 2: Comparison of the percentage of deuterons before and after cutting.

5.4 Distribution of z vs. Radius Minus to Primary Vertex

The difference between graphing "Z vs. Radius" and "Z vs Radius Minus to Primary Vertex of the Z axis" lies in the source reference used for the radius. In the first case, the radius is calculated from the center of the detector, while in the second case it is calculated from the main vertex of the z-axis, which is a specific point within the detector.

When plotting "z vs radius minus the main vertex of the z axis", we are considering the relative position of the particles with respect to a specific point within the detector, which is the main vertex of the z axis. This allows us to analyze how particles are radially distributed with respect to this particular reference point, which can provide additional information about the geometry and internal structure of the detector.

Distribution when we don't have a cut

As mentioned earlier, this type of distribution provides us with additional information about the geometry and internal structure of the detector. We observe Figure 24 and 25 compare it with the previous distribution (Figure). In this case, it is more evident that a cut on the vertical axis above 30 or 40 could help obtain a better approximation than a single cut on the horizontal axis.

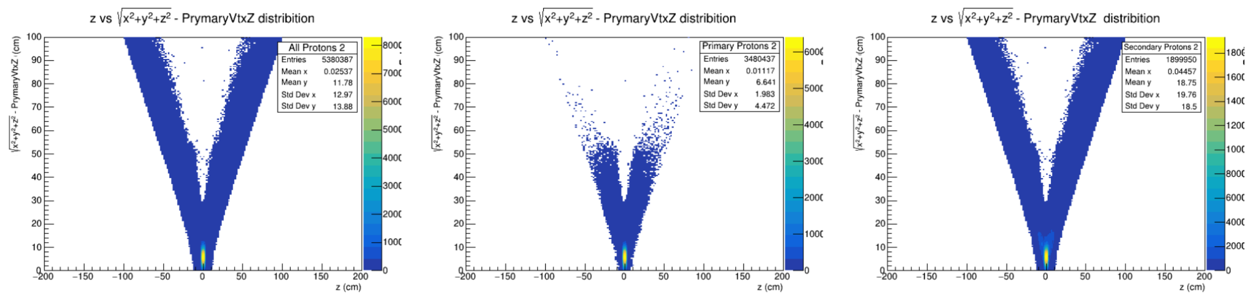


Figure 24: Distribution of protons en z vs radius minus principal vertex without cut in -5 to +5 a) All protons, b) Primary protons, c)Secondary protons.

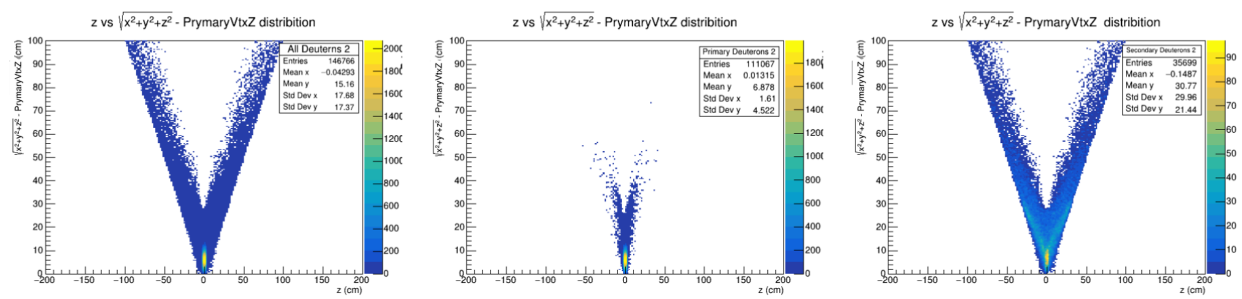


Figure 25: Distribution of deuterons en z vs radius minus principal vertex without cut in -5 to +5 a) All deuterons, b) Primary deuterons, c)Secondary deuterons.

Distribution when we have a cut in ±5

In the same vein as the distribution without a cut, in Figures 26 and 27, we observe more clearly that a cut can help achieve better removal of secondary particles.

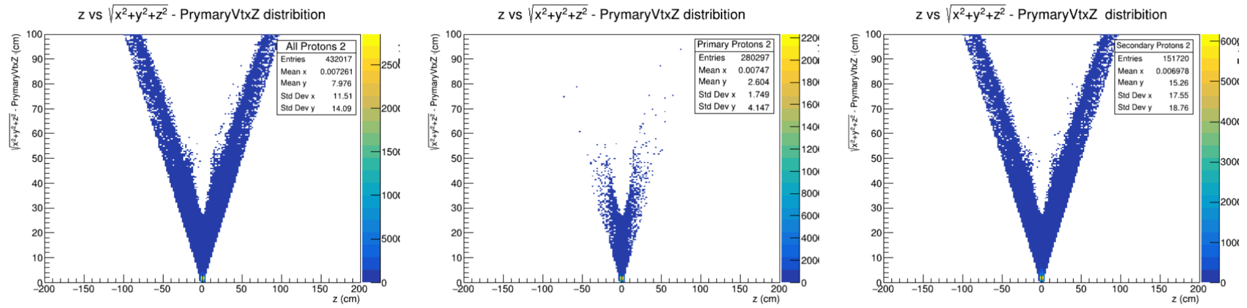


Figure 26: Distribution of protons en z vs radius minus principal vertex with cut in -5 to +5 a) All protons, b) Primary protons, c)Secondary protons.

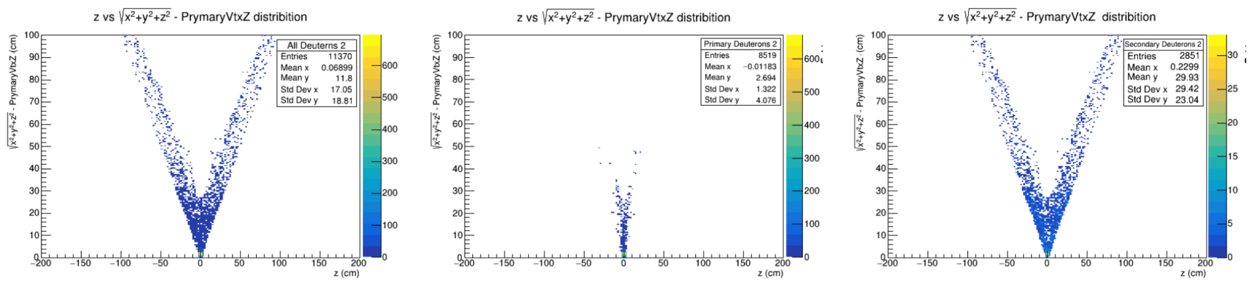


Figure 27: Distribution of deuterons en z vs radius minus principal vertex with cut in -5 to +5 a) All deuterons, b) Primary deuterons, c)Secondary deuterons.

Percentages of particles

This distribution only provides us with additional information about the geometry. However, it did not yield a better percentage ratio for primary particles. If we compare Tables 3 with Table 1, and Table 4 with Table 2, we observe that we have exactly the same percentages for each case. We observe the same behavior for both protons and deuterons.

Percentage of Protons					
Without Cut			With Cut in ±5		
Kind of particle	Entries	Percentage	Kind of particle	Entries	Percentage
All	5,380,387	100%	All	432,017	100%
Primary	3,480,437	64.69%	Primary	280,297	68.88%
Secondary	1,899,950	35.31%	Secondary	151,720	35.11%

Table 3: Comparison of the percentage of protons before and after cutting.

Percentage of Deuterons					
Without Cut			With Cut in ±5		
Kind of particle	Entries	Percentage	Kind of particle	Entries	Percentage
All	146,766	100%	All	11,370	100%
Primary	111,067	75.58%	Primary	8,519	74.07%
Secondary	35,699	24.32%	Secondary	2,851	25.07%

Table 4: Comparison of the percentage of deuterons before and after cutting.

However, this distribution provides redundant information. As mentioned earlier, we obtained the same results as the previous distribution, namely "ZvxRadius." Therefore, we could skip the analysis with this distribution and proceed directly to our analysis and propose our next approximations using this distribution. It provides the same information about the particle percentages along with additional insights into the geometry and internal structure of the detector.

6 Conclusions

Our first approach yielded satisfactory results for the protons, indicating that the approach used was effective in terms of detection and analysis. However, an individualized analysis for the deuterons remains pending, as they may behave differently and require specific treatment to obtain precise results.

The significant impact of implementing the vertical cut in our analysis is worth highlighting. This cut allowed us to gain a better understanding of the distribution of particles, both primary and secondary, by providing additional information about the geometry and internal structure of the detector. This practice proved to be fundamental in improving the quality of our results.

To further advance our study, we propose repeating the same process using a tighter cut interval, for example, ±5, in all our position histograms and primary-to-secondary ratios among all particles. This will enable us to refine our approximations further and gain a more precise insight into the behavior of particles in the detector.

Furthermore, we observed the possibility of a second approach by implementing a ±2 horizontal axis cut and conducting a more thorough analysis of the vertical axis for a cut in this axis. Although this approach was not implemented on this occasion, we believe exploring this option in future research could provide an even deeper understanding of the data.

It is important to note that, due to time limitations, we were unable to carry out additional cuts on the vertical axis as discussed during our analysis. However, we consider this to be a promising line of research worth exploring in subsequent studies.

Additionally, during the analysis of the vertical axis, we observed the possibility of a second approach using a narrower cut interval, such as ±2. Although this approach was not implemented on this occasion, we believe that exploring this option in future research could provide an even deeper understanding of the data.

It is important to note that, due to time limitations, we were unable to carry out additional cuts on the vertical axis as discussed during our analysis. However, we consider this to be a promising line of research worth exploring in subsequent studies.

As for the BOX generator, despite specifically requesting protons and deuterons, as mentioned in the report, this generator does not provide information on collisions. Therefore, when making the cut, we did not observe any significant changes worth reporting.

Acknowledgments

I thank Dr. Ivonne Maldonado for her advice, support and patience for teaching me to use the MPD software, also for meetings and discussions outside the established schedules. We also thank Dr Vadim Kolesnikov for his contributions and advice. In addition to Dr. Luis Alberto Hernández for providing advice and discussions on what was being done in the INTEREST Wave 10 program.

Bibliography

[1] Abgaryan, V. et al. (MPD Collaboration) *Status and initial physics performance studies of the MPD experiment at NICA.* Eur. Phys. J. A (2022) 58, 140.

[2] Iamaldonado. (s.f.). *CoreCoronaTask/classes/MpdV0AnalysisTask.cxx at main · iamaldonado/CoreCoronaTask. GitHub.* Retrieved April 17th, 2024 https://github.com/iamaldonado/CoreCoronaTask/blob/main/classes/MpdV0AnalysisTask.cxx

[3] Iamaldonado. (s.f.). *CoreCoronaTask.* GitHub. Retrieved April 17th, 2024, from https://github.com/iamaldonado/CoreCoronaTask

[4] Iamaldonado. (s.f.). *Macros ANA.* GitHub. Retrieved April 17th, 2024, from https://github.com/iamaldonado/Macros_ANA/blob/main/README.md

[5] Kekelidze V.D. et al. *Three stages of the NICA accelerator complex.* Eur. Phys. J. A (2016) 52, 211.

[6] Lechner, A. *Particle Interations with Matter.* CERN Document Server. Retrieved April 17th, 2024, from https://cds.cern.ch/record/2674116/files/660.pdf

[7] MPD experiment – another step forward. (s.f.). *Joint Institute For Nuclear Research.* Retrieved April 17, 2024, from https://www.jinr.ru/posts/mpd-experiment-another-step-forward/

[8] MPDROOT Developers. (s.f.). *MpdTrack.h.* MPDROOT. Retrieved April 14th, 2024, from https://git.jinr.ru/nica/mpdroot/-/blob/dev/core/mpdBase/MpdTrack.h?ref_type=heads

[9] MPDROOT Developers. (s.f.). *MPDROOT Repository.* MPDROOT. Retrieved 17 April 2024, from https://git.jinr.ru/nica/mpdroot/-/tree/v23.12.23?ref_type=tags

[10] Multi purpose detector: the Mega-Science Project «NICA». (2024). Retrieved April 17th, 2024, from https://mpd.jinr.ru/

[11] Raghunath Sahoo. *Relativistic Kinematics.* E-print: 1604.02651 [nucl-ex] https://arxiv.org/pdf/1604.02651.pdf