JOINT INSTITUTE FOR NUCLEAR RESEARCH
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Alignment of the right panel of the time-of-flight 400 detector (TOF400) for Monte Carlo simulation.

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Contents:

Abstract:

The Baryonic Matter at Nuclotron (BM@N) is a new experiment conducted in the NICA complex (JINR) and designed to investigate properties of dense nuclear matter in nucleus-nucleus collisions with a fixed target (Hyperons at the BM@N experiment). The experiment includes high-precision measurements of particle trajectories and Time-Of-Flight (TOF) measurements that allow particle identification. For this study we used the experimental run which was performed on spring 2018 with Ar and Kr beams [1].

This report mainly discusses the geometry modification of the TOF400 right panel for the simulated Monte Carlo (MC) in the Ar/C 7th run after comparing the TOF400 data hits with the reconstructed MC hits without proper alignment.

1. Introduction:

The BM@N experiment that stands for Baryonic Matter at Nuclotron is the first experiment in operation conducted in the NICA complex (JINR) and aims at studying the properties of relativistic heavy-ion beam collisions with a fixed target at energies ranging at 2 ~ 3.8 GeV per nucleon which provides the unique opportunity to study nuclear matter under extreme density and temperature, as well as providing a better understanding of Quantum Chromodynamics (QCD) matter at densities similar to those predicted to exist in compact stellar objects, and shedding the light on the role of hyperons in neutron stars. [2]

The schematic view of the NICA-Nuclotron complex and the position of the BM@N setup are presented in figure 1. The sources of light and heavy ions, the beam Booster, Nuclotron accelerator and NICA collider are illustrated.

Figure 1: Schematic view of the NICA-Nuclotron complex and the position of the BM@N setup.

Technical runs with the BM@N detector were performed with deuteron and carbon beams with kinetic energy of 4 GeV per nucleon for the deuteron beam in December 2016, and kinetic energy that varied from 3.5 to 4.5 GeV per nucleon for the carbon beam in March 2017 [3]. An extended configuration of the BM@N setup was realized in the next run where the research program included the measurement of inelastic reactions with Ar and Kr beams performed in March 2018 with five fixed targets [4].

2. Experimental Set-Up

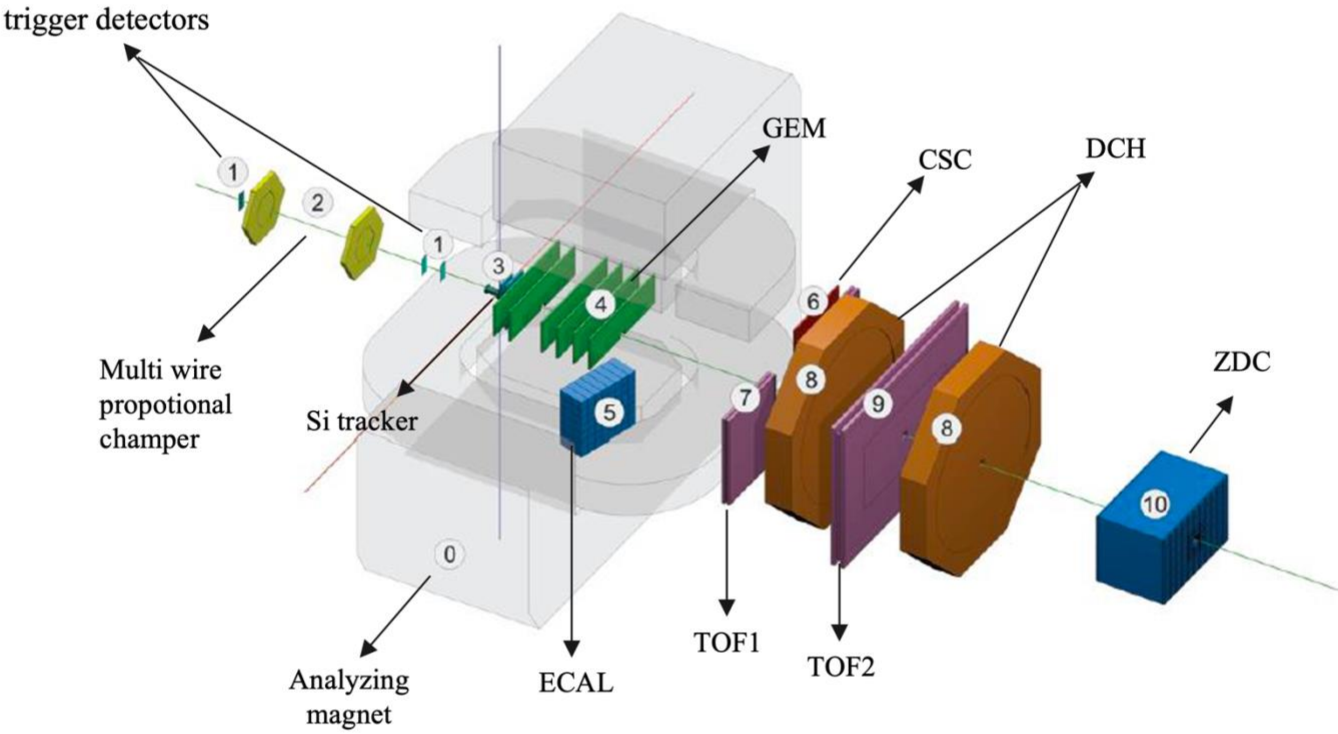


Figure 2: A schematic view of the BM@N set-up used in the run with argon and krypton beams.

A schematic view of the BM@N set-up is shown in Fig. 2, It was used in the experimental run of March 2018 using the Ar/Kr beam with the targets of C, Al, Cu, Pb, and Sn. The set-up consisted of an inner tracker mounted inside the SP41 analyzing magnet composed of six 2-coordinate planes of GEM detectors with a size of 163 Å~ 45 cm2, three forward silicon strip (Si) planes, an outer tracker based on two drift chambers (DCH), a cathode strip chamber (CSC), a full time-of-flight system consisting of ToF-400 and ToF-700 detectors, an extended trigger system T0T, a hadron zero degree calorimeter (ZDC) and an electromagnetic calorimeter (ECAL), and a read-out electronics and data acquisition (DAQ) system.

The main advantage of the setup is a large aperture analyzing magnet with 1 m gap between the poles. The magnet aperture is filled with coordinate detectors which sustain high multiplicities of particles and are operational in the strong magnetic field. Two walls of time-of- flight detectors placed “near to magnet” and “far from magnet” serve to identify particles with a low and high momentum. The link between the central tracker and time-of-flight detectors is done by the outer tracker. Overall, providing a high precision track measurement. [3]

2.1 Inner tracker

The inner tracker of the BM@N experiment is based on two-coordinate triple Gas Electron Multipliers (GEM), the inner tracker was extended with two-coordinate planes of a forward silicon detector designed to improve the primary vertex reconstruction and to improve the tracking efficiency. One silicon plane was operated in the carbon run (March 2017), two extra silicon planes were installed in the latest run with the argon and krypton beams in March 2018.

The GEM tracker was upgraded to six large area detectors, it has the basic requirements for a tracking system such as having high momentum and spatial resolution and having efficiencies better than 95% and possessing the maximum possible geometrical acceptance in terms of the BM@N experiment dimension. [2]

Therefore, the inner tracker configurations in the recent runs consists of 6 planes of GEM detector and 3 planes of FwdSi detector. [4]

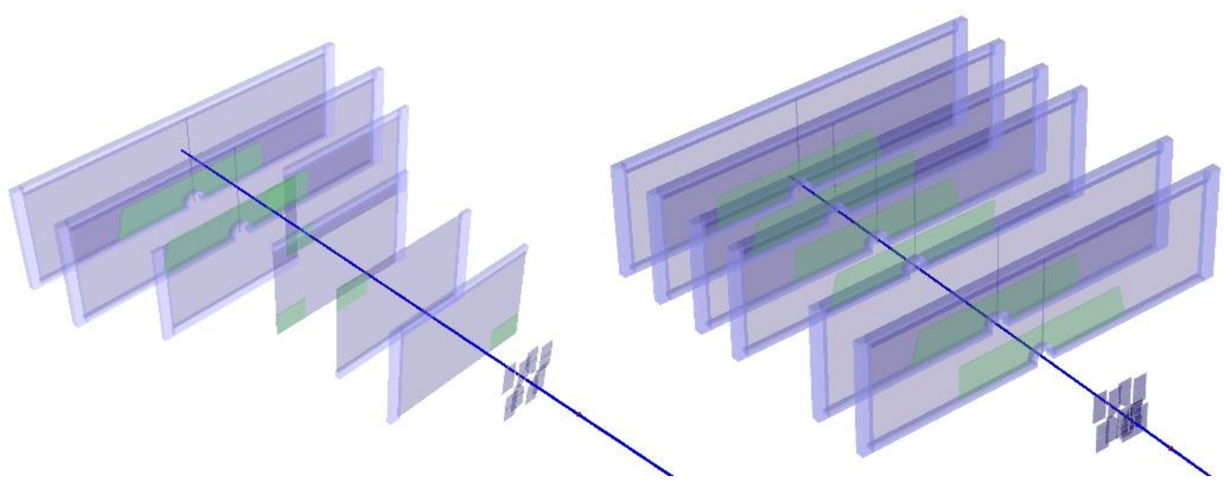


Figure 3

Left plot: Central tracker configuration in the carbon run. Right plot: the configuration used in the Ar/Kr run.

At the second stage of the BM@N experiment after 2023, the tracker will be based on 7 GEM planes and four two-coordinate planes of the Silicon Tracking System (STS) detectors will be installed in front of the GEM detectors to improve track reconstruction in heavy ion collisions. [2]

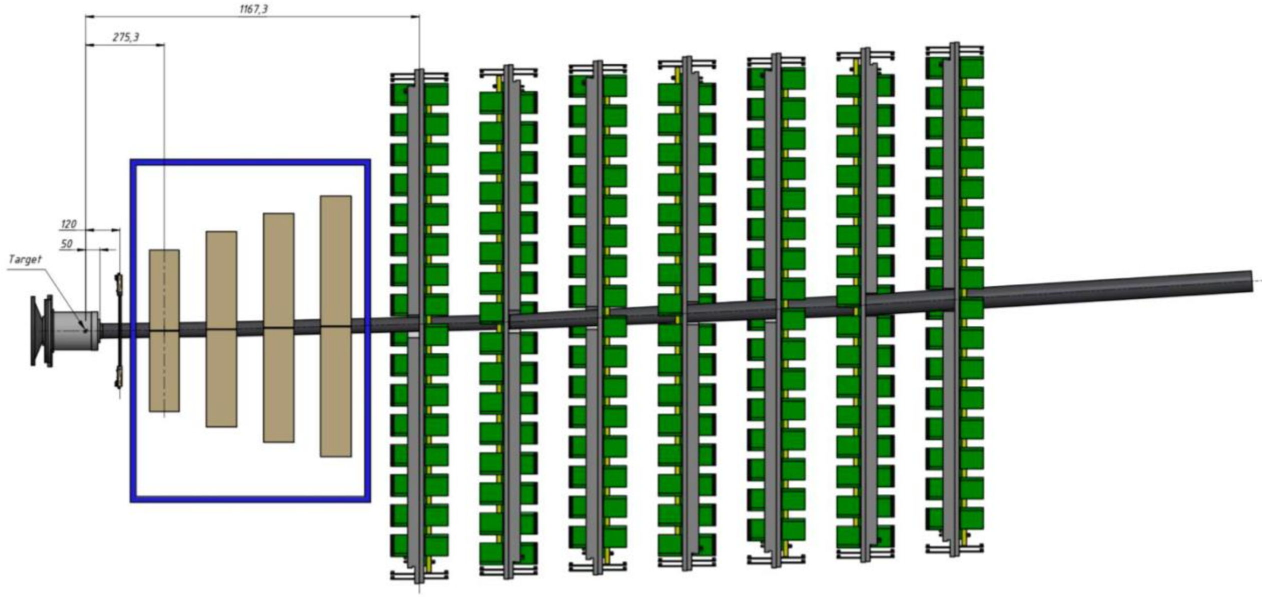


Figure 4: Schematic view of the final hybrid tracker based on 4 large aperture planes of silicon tracking system and 7 GEM planes. The carbon vacuum beam pipe follows the trajectory of the beam.

Year	2016-2017 spring	2018 spring	2022 spring	2023	after 2023
Beam	d, C	Ar,Kr, C(SRC)	Kr,Xe	up to Au	up to Au
Beam intensity, Hz	0.5 M	0.5 M	0.5 M	0.5 M	2 M
Data rate, Hz	5 k	10 k	10 k	20 k	50 k
Central tracker configuration	6 GEM half-planes	6 GEM half-planes + 3 small FwdSi planes	6 GEM full planes + 3 FwdSi full planes	7 GEM planes + 4 FwdSi planes + 2 STS planes	7 GEM planes + + 4 STS planes
Status of the experiment	Technical run	Technical run	Physics run, first stage	Physics run	High rate physics run, second stage

Table 1: Configuration of the BM@N central tracker, beam parameters and event rates in BM@N experimental runs.

2.2 Outer Tracker

The purpose of the outer tracker is to provide link between tracks measured in the inner tracker and hits in the ToF-400 and ToF-700 detectors as well as with clusters in the electro-magnetic ECAL calorimeter. [5]

It consists of two drift chambers (DCH) and a cathode strip chamber (CSC), The DCH and the CSC are installed outside the magnetic field. The CSC is a two-coordinate detector with the cathode readout, it’s used for the first time in this dataset session as a filter for bad tracks to compensate the low efficiency of the DCH. As for the DCH, it consists of four double coordinate planes and also used as a filter for bad tracks and measuring the angular distribution and momentum of the beam. [6]

2.3 Time-of-flight system

The time-of-flight (TOF) system for charged particles identification is based on the start time T_0 detector installed near to the target to provide the system with the start signal. The TOF system consists of two walls of Multi-gap Resistive-Plate Chambers (mRPC) with time resolution of 80-100 ps, allowing the discrimination between charged hadrons (π, K, p) and the separation between light nuclei with momenta reaching to few GeV/c. [5, 6]

The first wall of the multi-gap resistive Plate Chamber will be positioned at 4 meters from the target (TOF-400), and the second one at the distance of 6 meters (TOF-700) for Ar run. The TOF-400 wall will cover about 3 m^2. [7]

2.3.1 ToF-400 mRPC detector

The TOF-400 detector consists of two panels (left and right) placed symmetrical to the beam. Every panel consists of two gas boxes (modules) which contains 5 mRPCs each. The active area of the mRPCs overlap on 50 mm inside the box. Gas box made from aluminum frame covered by aluminum honeycomb for reduction of radiation length. Overlap of gas boxes ensures crossing of active area of detectors 50 mm. [7]

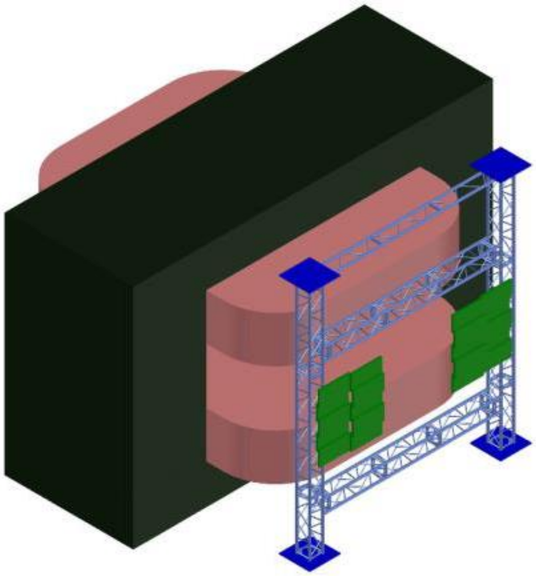


Figure 5: Schematic layout of the ToF-400 mRPC wall and its position behind the analyzing magnet.

Figure 6: Real view of a half part of the TOF400 system

2.3.2 ToF-700 mRPC detector

Time-of-flight detector ToF-700 placed at about 7m from the target provides BM@N with the pion/kaon separation up to 3 GeV/c and proton/kaon separation up to 5 GeV/c. ToF-700 system consist of 58 glass multigap Timing Resistive Plate Chambers (mRPC). The wall size of 3.2x1.6 m2 is defined to satisfy the geometrical acceptance of the tracking detectors. High resolution of ~60 ps was achieved with an efficiency above 97%. [2]

2.4 Trigger System

The trigger system consists of a trigger, T0, and beam detectors. The system is included in the BM@Nconfiguration to trigger the nucleus-nucleus collisions in the target effectively, and to provide the start signal for the ToF detectors with time resolution of picoseconds. Moreover, the trigger system monitors the beam characteristics and background. [5]

2.5 Read-Out Electronics and DAQ System

The DAQ system is responsible for the realization of data transfer from the read-out electronics in the detector to the storage system. The DAQ system consists of electronic modules, network infrastructure, and a software. The experimental data stored in the

DAQ storage is in a binary format and then it is digitized and converted into a ROOT format to be integrated into the BmnRoot framework. [2]

3. BmnRoot Framework

The BmnRoot is implemented in C++ programming language. It's based on the ROOT environment and the FairRoot framework.
The BmnRoot is used to:

- studying the detector performance and define the experimental setup.
- providing simulations of events
- Doing reconstruction of tracks.
- analyzing the experimental and simulated data and comparing between them. [8]

4. Monte carlo event generators and simulations.

4.1 Monte Carlo event generators

The MC generates the collision of events of heavy ions, MC allow to include theoretical models, phase space integration in multiple dimensions, inclusion of detector effects, and efficiency and acceptance determination for new physics processes. As a result, MC produce the final-state particles during the collision, which feed into the detector simulation.

We have an extended set of event generators for particle collisions such as Ultrarelativistic Quantum Molecular Dynamics (UrQMD), Quark Gluon String Model (QGSM, LAQGSM), Hybrid UrQMD, Dubna Cascade—Statistical Multifragmentation Model (DCMSMM), etc... [8]

4.2 Simulation of the BM@N experiment

The MC simulations are used in comparing the experimental results with theoretical predictions and to make predictions and preparations for future experiments as they include interactions and particles of interest, geometry of the system, materials used, generation of test events of particles, interactions of particles with matter and electromagnetic fields, response to detectors, records of energies and tracks, analysis of the full simulation at different detail and visualization of the detector system and collision events.

Simulation in high energy physics experiments uses transport packages Geant3/Geant4 integrated in BmnRoot framework to move the particles produced by event generators through experimental setup, the Geant3 geometrical model describes the detector geometries and forms the detector hits during tracking of all particles which are used in reconstruction task. [8]

5. Alignment of the right panel of the TOF400

Our task is to modify the geometry of the TOF400 right panel for the simulated Monte Carlo (MC) in the Ar/C 7th run using the geometry macro file
create_rootgeom_TOF400_plot.C
obtained from Vasilii, located in the directory
/nica/mpd20/vp_r7_v2/mc1/bmnroot_MC7/macro/geometry/
to match the reonstructed data hits obtained from Anastasia from the directory
/scratch1/huhaeva/Alignment_Dx_p/Files/BmnGemCscTof400IdentifiableTracks{RUN_ID}.root
where {RUN_ID} is the run number which ranges from 3756-4152 and from 4306-4704.

At first, to get MC points and tracks for 1 run, using the event generator model DCM-SMM, we did a MC simulation for the collision by executing the simulation macro file
run_sim_DCMSMM_std_osho.C
located in the directory:
/nica/mpd20/sherihan/TOF400_original_geo/
which is the modified version of simulation macro file
run_sim_DCMSMM_std.C
obtained from Lalyo. The simulation was done for 10000 events using the input file *DCMSMM_ArC_3.2AGeV_mb_10k_318.r12*
located in the directory
/eos/nica/bmn/users/kovachev/efficiency/DCMSMM/,
obtaining an output root file of generated points
run_sim_osho_C.root
located at
/nica/mpd20/sherihan/TOF400_original_geo/ .

After that, we reconstruct the the TOF400 MC points, The reconstruction of MC points is done using the
mainMcQsub.sh
script that is found in
/nica/mpd20/Sherihan/ ,
the process starts with obtaining
run_sim_osho_C.root

file as it contains the generated hits. And then, the latter file is used as an input file to obtain
bmndst_osho_C.root
file which contain TOF400 reconstructed hits.
executing the macro for reconstruction
"run_reco_bmn_osho.C"
located in the directory
/nica/mpd20/sherihan/TOF400_original_geo/
which is the modified version of reconstruction macro file
"run_reco_bmn.C"
obtained from Vasilli, then we get the reconstructed hits for the MC as an output root file
"bmndst_osho_C.root"
without any modification in the geometry in the specified directory of
/nica/mpd20/sherihan/TOF400_original_geo/ ,
which we compared with the reconstructed data hits .

For the comparison part, we overlay the 2 histograms obtained for the TOF400 hits position of xy-axis and z-axis for the 11th to 20th plane and the reconstucted TOF400 MC hits for the same planes without any alignment modifications.

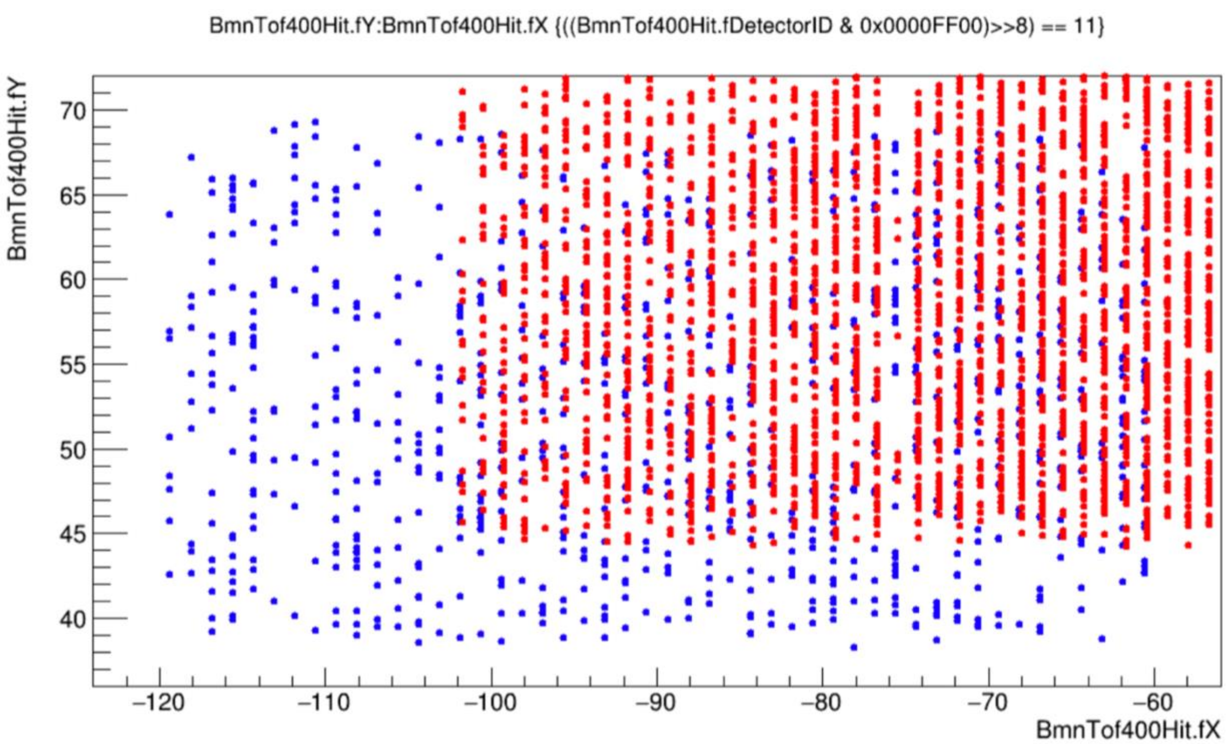


Figure 3: 2-D histogram that illustrates TOF400 data hits position for the 11th plane in red and the reconstructed TOF400 MC hits in blue for the same plane for overlayed xy-axis without alignment.

As we can see from the previous figure, the position of the 1st strip for the x-axis for the TOF400 data hits is around -102 cm, while the position of the first strip of the x-axis for the TOF400 MC hits is about -119 cm, so there's a difference in the position of the first strip for both MC and data hits about 17 cm and the acceptable difference shouldn't be more then 1mm.

The same goes for the position of the 1st strip for the y-axis for the TOF400 data hits being around 44 cm, while the position of the first strip of the y-axis for the TOF400MC hits is about 38cm, so there's a difference in the position of the first strip for both MC and data hits about 6 cm and the acceptable diff shouldn't be more then 1 mm.

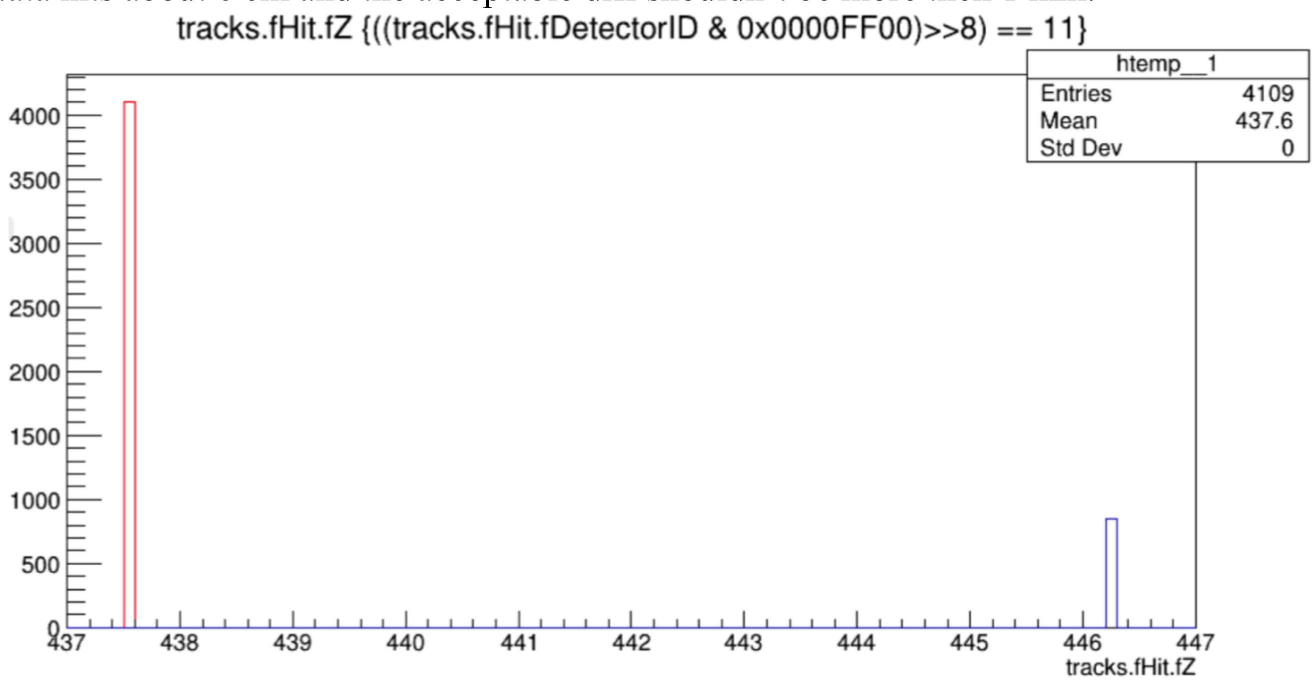


Figure 4: 2-D histogram that illustrates the TOF400 data hits position in red for the 11th plane and the reconstructed TOF400 MC hits in blue for overlayed z-axis. This is our reconstructed MC without alignment.

It's also very clear that there isn't a good matching in the overlayed histograms for the 11th plane between the position of TOF400 data hits for the z-axis in red and the position of the TOF400 MC hits for the z-axis in blue, the position difference is about 9 cm.

Therefore, from the previous results, it was clear that we need to change the geometry of the TOF400 layers of the reconstructed MC hits to match with the TOF400 data hits and then repeat the simulation process and reconstruction for comparison and more precise fitting.

For the comparison part, we overlay the 2 histograms obtained for the TOF400 hits position of xy-axis and z-axis for the 11th to 20th plane and the reconstucted TOF400 MC hits for the same planes without any alignment modifications.

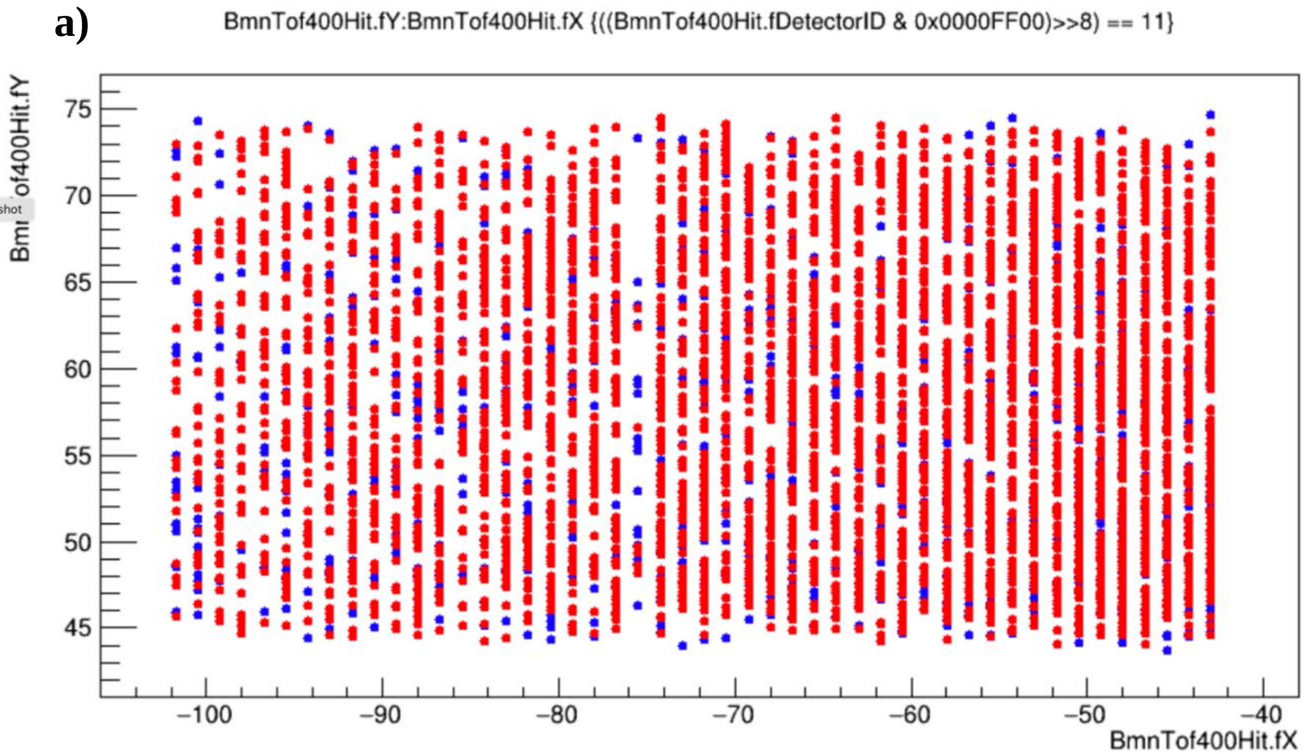
As stated before, editing the geometry macro file
" *create_rootgeom_TOF400_plot.C*"
obtained from Vasilii, located in the directory:
/nica/mpd20/vp_r7_v2/mc1/bmnroot_MC7/macro/geometry/,

and then executing this geometry macro would result in an output geometry root file *"TOF400_RUN7_plot.root"*
located in the directory:
/nica/mpd20/MC_GEM_r7/20190825_fromgit_bmnroot/geometry/,
then using the output root geometry file in the simulation macro
"run_sim_DCMSMM_std_osho.C"
and repeating the simulation and reconstruction processes for 10000 events with modified geometry.

6. Results of the alignment modification.

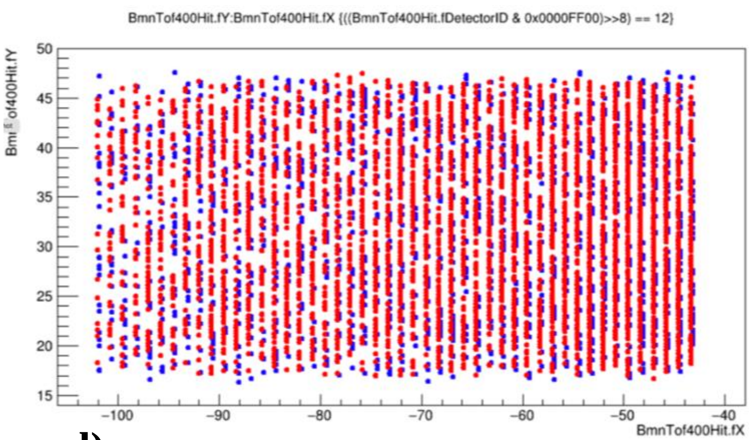
A better matching histogram for the position of the MC TOF400 reconstructed hits and data hits for xy&z axes from p11: p20 with difference in position less than 1mm.

a)



As we can see from figure **(a)**, the position of the 1st strip for the x-axis for the TOF400 data hits is around -101.7249 cm, and the position of the first strip of the x-axis for the TOF400 MC hits is about -101.7249 cm, so there's no difference in the position of the first strip for both MC and data hits which shows the good matching in alignment.

b)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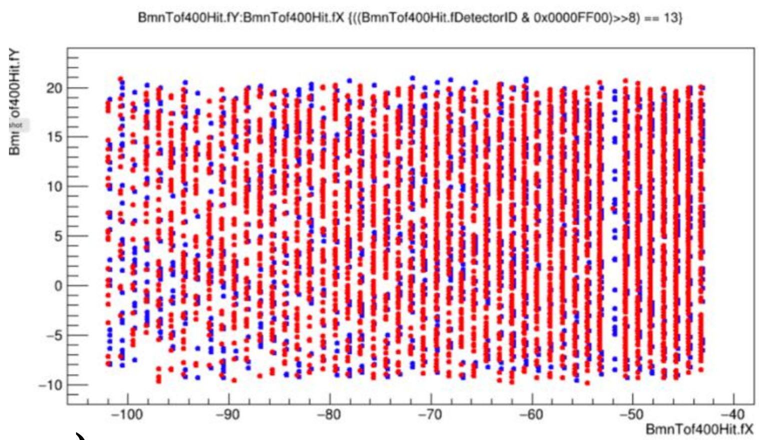
BmnTof400Hit.fX

c)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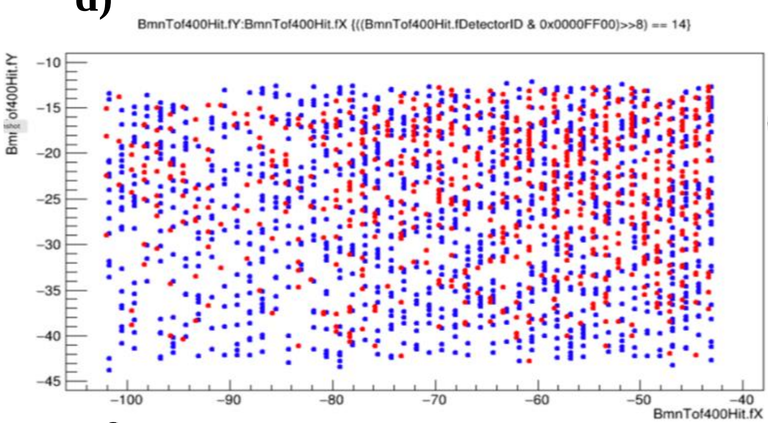
d)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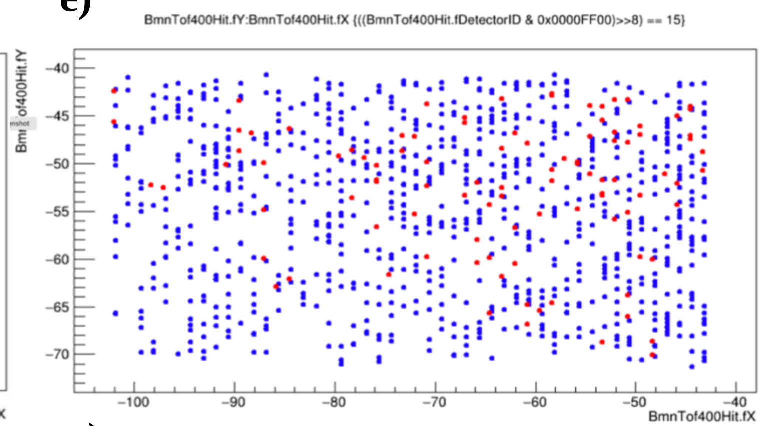
BmnTof400Hit.fX

e)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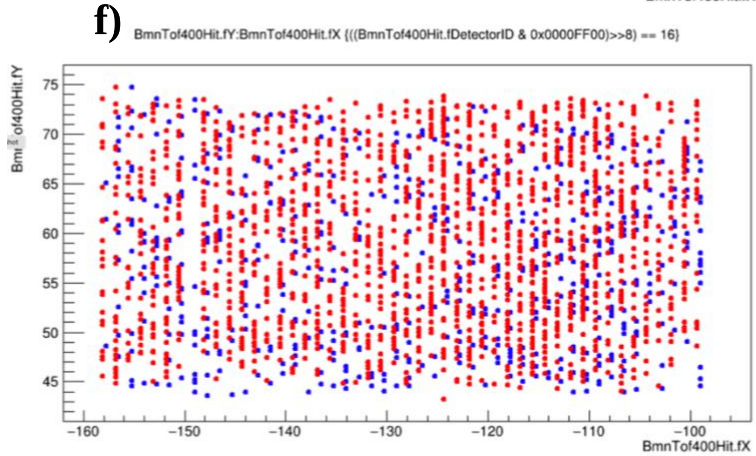
BmnTof400Hit.fX

f)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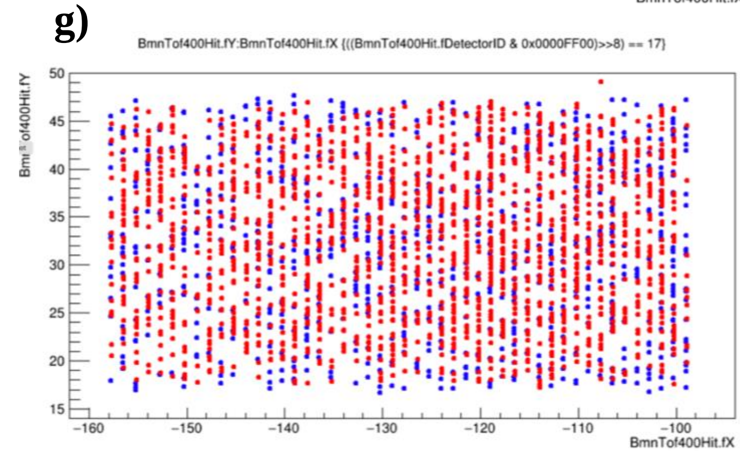
BmnTof400Hit.fX

g)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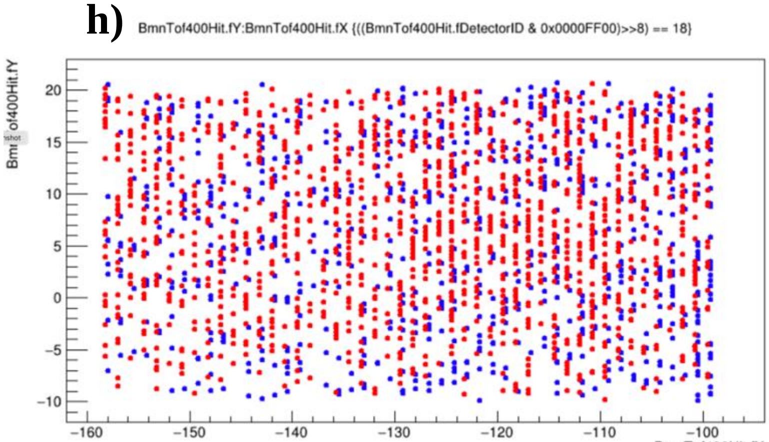
h)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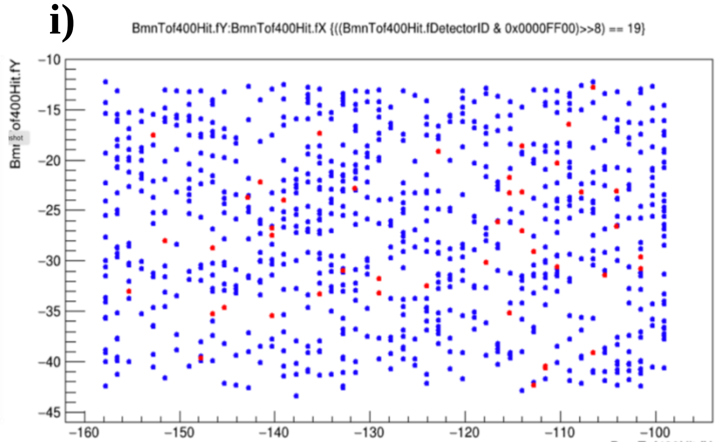
i)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BmnTof400Hit.fX

j)

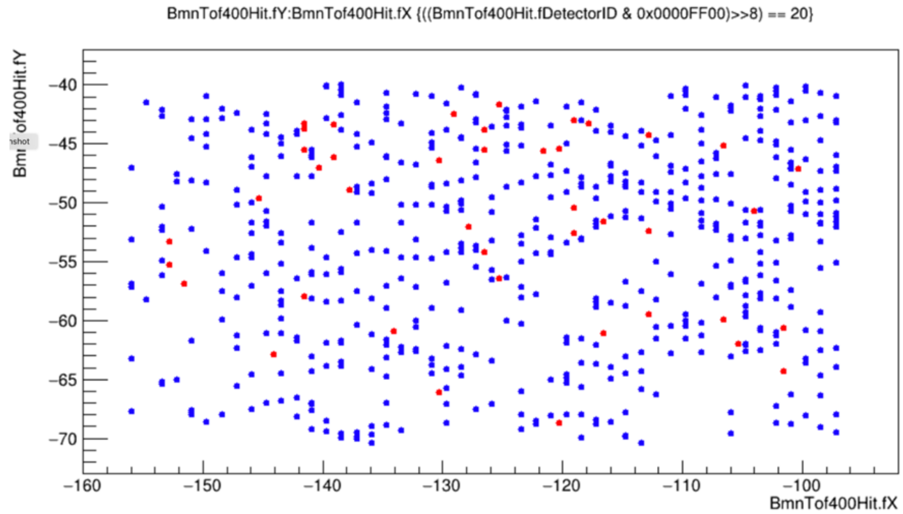
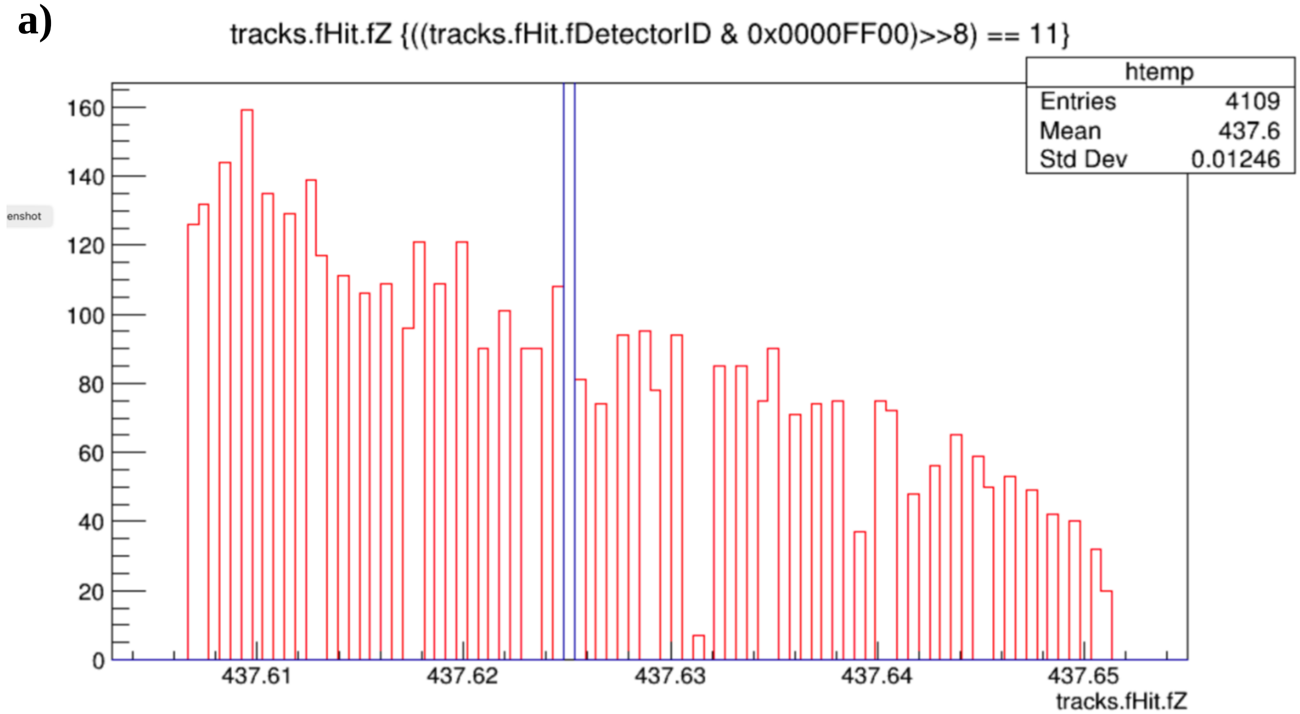


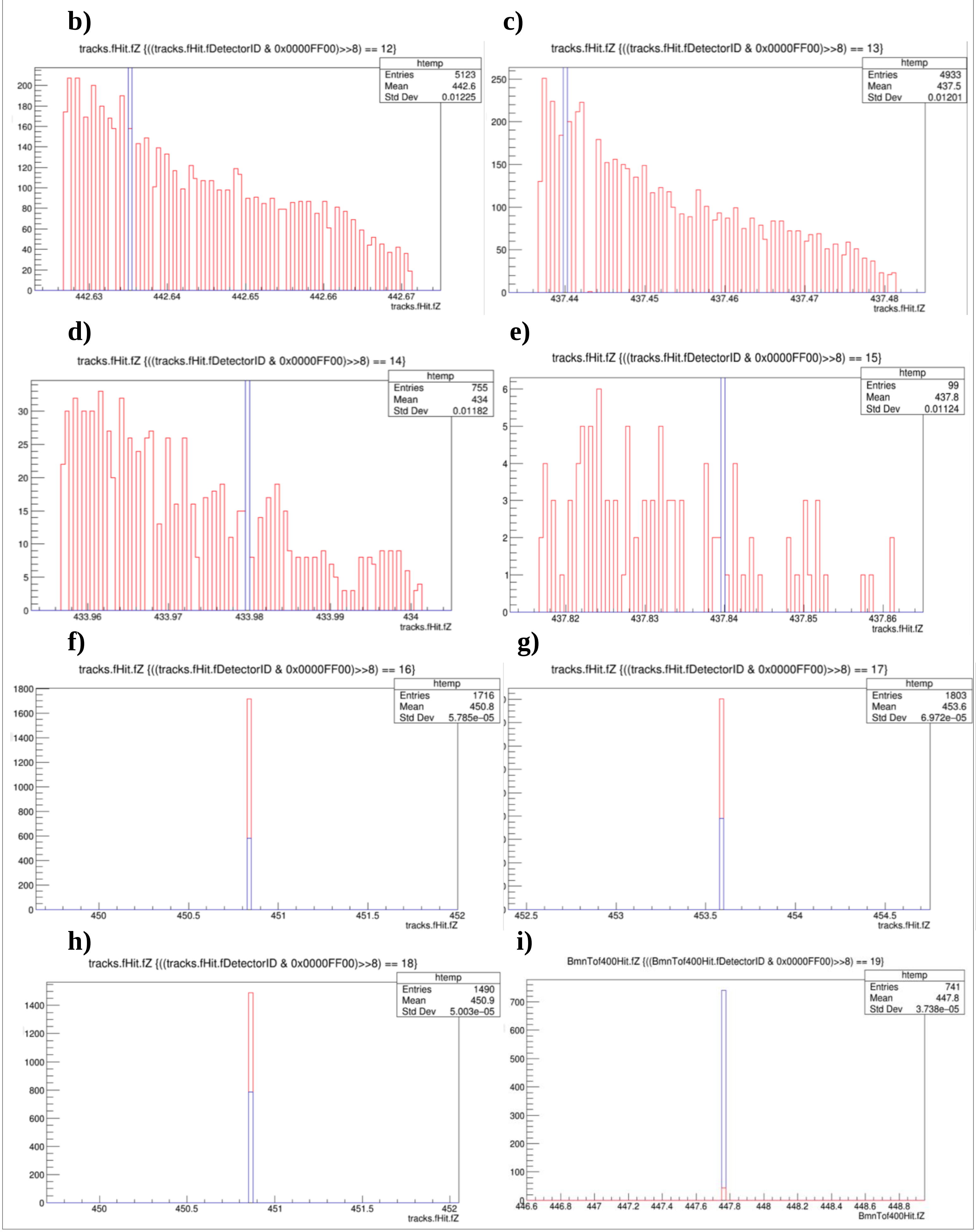
Fig 9 that contains a collection of 2-Dimensional histogram images from (a to j) plotted between the TOF400 data hits position in red and the realigned reconstructed TOF400 MC hits in blue for overlayed xy-axis, for the 11^{th}: 20^{th} planes of the TOF400 right panel. The histograms illustrate a good matching between the position of the MC TOF400 reconstructed hits after adjusting the alignment and data hits for xy-axes with an error less than 1mm.

The following graphs from (a-j) of fig 10 are 2-Dimensional histogram images plotted between the TOF400 data hits position in red and the realigned reconstructed TOF400 MC hits in blue for overlayed z-axis for the 11^{th}: 20^{th} planes of the TOF400 right panel. The histograms illustrate a good matching between the position of the MC TOF400 reconstructed hits after adjusting the alignment and data hits for z-axes with an error less than 1mm.

the average for the z-axis for the TOF400 data hits is around -101.7249 cm, and the position of the first strip of the x-axis for the TOF400 MC hits is about -101.7249 cm, so there's no difference in the position of the first strip for both MC and data hits

a)




b)
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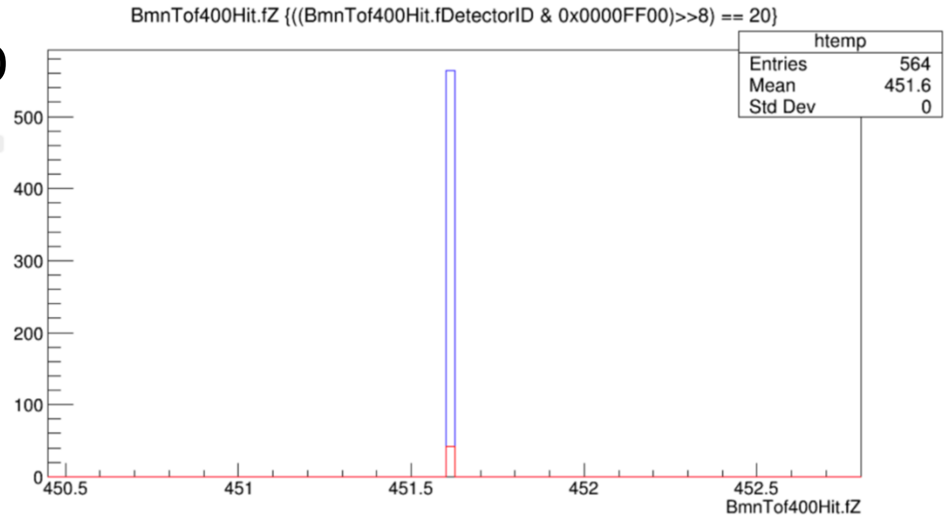
htemp
Entries 5123
Mean 442.6
Std Dev 0.01225
tracks.fHit.fZ
c)
tracks.fHit.fZ {(((tracks.fHit.fDetectorID & 0x0000FF00)>>8) == 13}
htemp
Entries 4933
Mean 437.5
Std Dev 0.01201
tracks.fHit.fZ
d)
tracks.fHit.fZ {(((tracks.fHit.fDetectorID & 0x0000FF00)>>8) == 14}
htemp
Entries 755
Mean 434
Std Dev 0.01182
tracks.fHit.fZ
e)
tracks.fHit.fZ {(((tracks.fHit.fDetectorID & 0x0000FF00)>>8) == 15}
htemp
Entries 99
Mean 437.8
Std Dev 0.01124
tracks.fHit.fZ
f)
tracks.fHit.fZ {(((tracks.fHit.fDetectorID & 0x0000FF00)>>8) == 16}
htemp
Entries 1716
Mean 450.8
Std Dev 5.785e-05
tracks.fHit.fZ
g)
tracks.fHit.fZ {(((tracks.fHit.fDetectorID & 0x0000FF00)>>8) == 17}
htemp
Entries 1803
Mean 453.6
Std Dev 6.972e-05
tracks.fHit.fZ
h)
tracks.fHit.fZ {(((tracks.fHit.fDetectorID & 0x0000FF00)>>8) == 18}
htemp
Entries 1490
Mean 450.9
Std Dev 5.003e-05
tracks.fHit.fZ
i)
BmnTof400Hit.fZ {((BmnTof400Hit.fDetectorID & 0x0000FF00)>>8) == 19}
htemp
Entries 741
Mean 447.8
Std Dev 3.738e-05
BmnTof400Hit.fZ

j)



7. Conclusion

The BM@N experiment provides the unique opportunity to study nuclear matter under extreme density and temperature, in addition to understanding the QCD matter at densities similar to those predicted to exist in compact stellar objects and sheds the light on the role of hyperons in neutron stars, yet our results for adjusting the alignment for the right panel of TOF400 detector for simulated MC to match with the experimental data showed a promising agreement in the position of the TOF400 reconstructed hits and data hits for xy&z axes from plane 11 to 20 with difference in position less than 1mm for the majority of the planes.

The obtained results could be used for further research points such as obtaining the GEM-DCH reconstructed tracks with the reconstructed tracks of TOF400 right shoulder for MC simulation with the new geometry and compare them with the obtained experimental data, as well as getting the efficiency for the MC TOF400 hits and tracks which at the end leads us to the process of particle identifications.

8. Acknowledgments

I would like to acknowledge and give deep and sincere gratitude to my research supervisor, Dr. Nelli Pukhaeva, for giving me the opportunity to do research and providing invaluable guidance throughout this session. Her dynamism, vision, sincerity, and motivation have deeply inspired me. Her guidance and advice carried me through all the stages of writing my report and understanding the experiment. I would also like to express my deepest appreciations to Mr. Vasilii Plotnikov, he has taught me the methodology to carry out the experiment and tasks, to present the report as clearly as possible. It was a great privilege and honor to work and study under Dr. Nelli and Mr. Vasilii guidance. I am extremely grateful for what they have offered me.

I would also like to give special thanks Mr. Lalyo Kovachev and Ms. Anastasia Khukhaeva for their continuous support and always being available to answer any questions that I had and provided me with assistance whenever I needed it.

Finally, I would like to extend my sincere thanks to the START program coordinators, Ms. Elena Karpova for her warm welcome and support, and the Joint Institute for Nuclear Research (JINR) for providing me with the opportunity to participate in this program. My experience at JINR has been truly rewarding and I am very grateful for everything that I have learned during my stay here.

9. References

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