JOINT INSTITUTE FOR NUCLEAR RESEARCH

Laboratory of Information Technologies

**FINAL REPORT ON THE SUMMER STUDENT PROGRAM**

# Simulation of nucleon-nucleon interactions in wide energy rang


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# Contents



## Abstract

The aim of the presented work is a realistic simulation of nucleon-nucleon interactions for the new Spin Physics Detector SPD[1] planned at the future accelerator facility NICA [2] in JINR, Dubna, Russia.

Our calculation shows that FTF model of GEANT4 [3] toolkit gives a good agreement with existing experimental data published by the NA61/SHINE collaboration on various hadron production in a wide incident momentum range – from 20 GeV/c up to 158 GeV/c.

For SPD experiment, we present estimations of proton, neutron, $\pi\pm$ and $K\pm$ meson's production in proton-proton interactions at Ecms=12 GeV using FTF model of Geant4.

## Introduction

A new accelerator facility will start to operate in the nearest future – the Nuclotron based Ion Collider fAcility (NICA) at JINR (Dubna, Russia). NICA is creating near the old JINR accelerator–Synchrophasotron.It will be an intersecting storage ring, where two beams will be circulated in opposite directions.
Two experiments are foreseen at the accelerator NICA. The first experiment is aimed to study of nucleus-nucleus interactions in the energy range Ecms = 5-10 GeV per nucleon-nucleon collision – the Multi-Purpose Detector (MPD). The main

scientific goal of the NICA/MPD is to explore the mixed phase of quarks, gluons and hadrons in the nucleus-nucleus interactions.

The second experiment at the NICA is Spin PhysicsDetector (SPD) with polarized proton and deuteron beams at the energies Ecms = 10-25 GeV. The SPD experiment is aimed to measure asymmetries in production of lepton pair (Drell-Yan), direct photons, J/Ψ which can provide information on the nucleon structure, the Transverse-Momentum Dependent distribution functions of quarks and anti-quarks in nucleons.

For achievement of the goals of the experiments−MPD and SPD, it is needed to have realistic simulation models. In this project, we have performed simulation of proton-proton interactions in the wide energy range using Phase Space (PhSp) generator from ROOT package [4] and Geant4 FTF generator installed now in the computation framework of SPD experiment – SPDRoot [5] .
Using the PhSp generator [6], we have simulated pp-reactions with 3,4,6 particles in final states and studied momentum, rapidity, energy distributions of produced hadrons.
In the frame of SpdRoot, we have calculated with the FTF model proton-proton interactions in the center of mass system at energy 12 GeV. We obtained Root-Tree file and studied properties of produced hadrons – protons, neutrons, K+, K-, pi+, pi-.

## Computing framework of SPD experiment - SPDRoot

SPDRoot is a simulation and analysis software package for a future SPD experiment. SPDRootis based on the FairRoot package. SPDRoot is created and developed similar to frameworks of other future experiments − MPDRoot, PandaRoot, CBMRoot.

To perform simulations in the frame of SpdRoot, it is needed to know:

1) how to work in Linux operation system;
2) programming languages C/C++ ;
3) how to operate with the known data analysis framework – ROOT.

Therefore, the first part of our program was study of the Linux system, C/C++ languages and ROOT package classes – TGraph, TArray, TH1F, TH2F,TParticle, TTree and others. All these tasks were carried out at the HybriLIT cluster at JINR on our local account opened by system programmers of the HybriLIT cluster.

After this, we installed SPDRoot at the HybriLIT cluster. For the installation we used last versions of FairROOT and FairSoft installed by system programmers of the HybriLIT. Then, we investigate how to run Macro-files for events simulations in SPDRoot. We have performed simulations of proton-proton interactions using the FTF generator in SPDRoot. For SPD experiments, it is needed to perform simulations in the center of mass system. Therefore, we implemented in the FTF generator the special option for a possibility of simulations as in Center of mass system, as in Laboratory system. Then, we obtained our simulation results.

## Results of proton-proton simulations

The Phase Space generator of Root package is implemented in TGenPhaseSpace Class. The generator randomly generates n-body event with constant cross-section (default) or with Fermi energy dependence. The events are generated in the center-of-mass frame, but the decay products are finally boosted using the betas of the original particle. In the frame of the PhSp, we simulated proton-proton reactions:
PP-> $PP\pi^+\pi^-$, PP->$PP\pi^0$, PP->$PPK^+K^-$, PP-> $PN2\pi^+\pi^-\pi^0$.
In the Fig.1, we present kinematical properties of particles produced in the reaction PP->$PN2\pi^+\pi^-\pi^0$at initial energy 6 GeV.

We illustrate energy, squared momentum and identificator one-dimensional distributions, and px-pz 2-dimensional distributions of produced hadrons. Of course, the PhSp generator cannot simulate physical realistic events. However, calculations with this generator can be used for simulations of signal reactions and simulation of detector responses.

For simulations of realistic nucleon-nucleon events, we used the FTF generator of Geant4 toolkit. Geant4 is a huge package aimed to simulate elementary particles interactions with matter. It is applied in many branches of science and technology.

The Geant4 FTF model is based on the Fritiof model [6], [7] of the LUND university. Main assumptions of the Fritiof model are quite simple. It is assumed, that hadrons turn into excited states due to inelastic interactions.

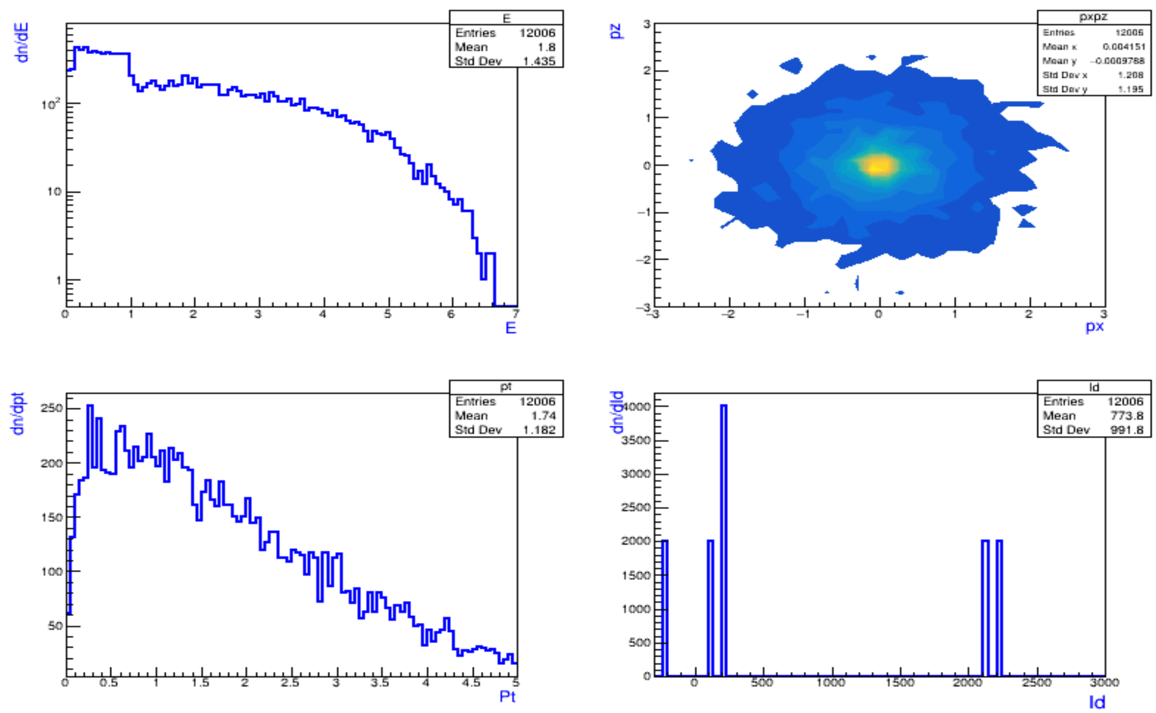


Fig.1.

If only one hadron is excited, the process is called diffraction dissociation. Excited states of hadrons are characterized by masses. Usually, masses are increased at excitations. The excited states are considered as quark-gluon strings. For decay and fragmentation of quark-gluon strings  Lund fragmentation model is used.

For verification of the Geant4 FTF model, we used  experimental data of the NA61/SHINE collaboration. Very interesting and useful experimental data were published last time by NA61/Shine collaboration. In 2017, the NA61/Shine collaboration published detailed experimental data on π±, K±, protons and antiprotons produced in P-P interactions in the wide energy range from 20 GeV/c up to 158 GeV/c.

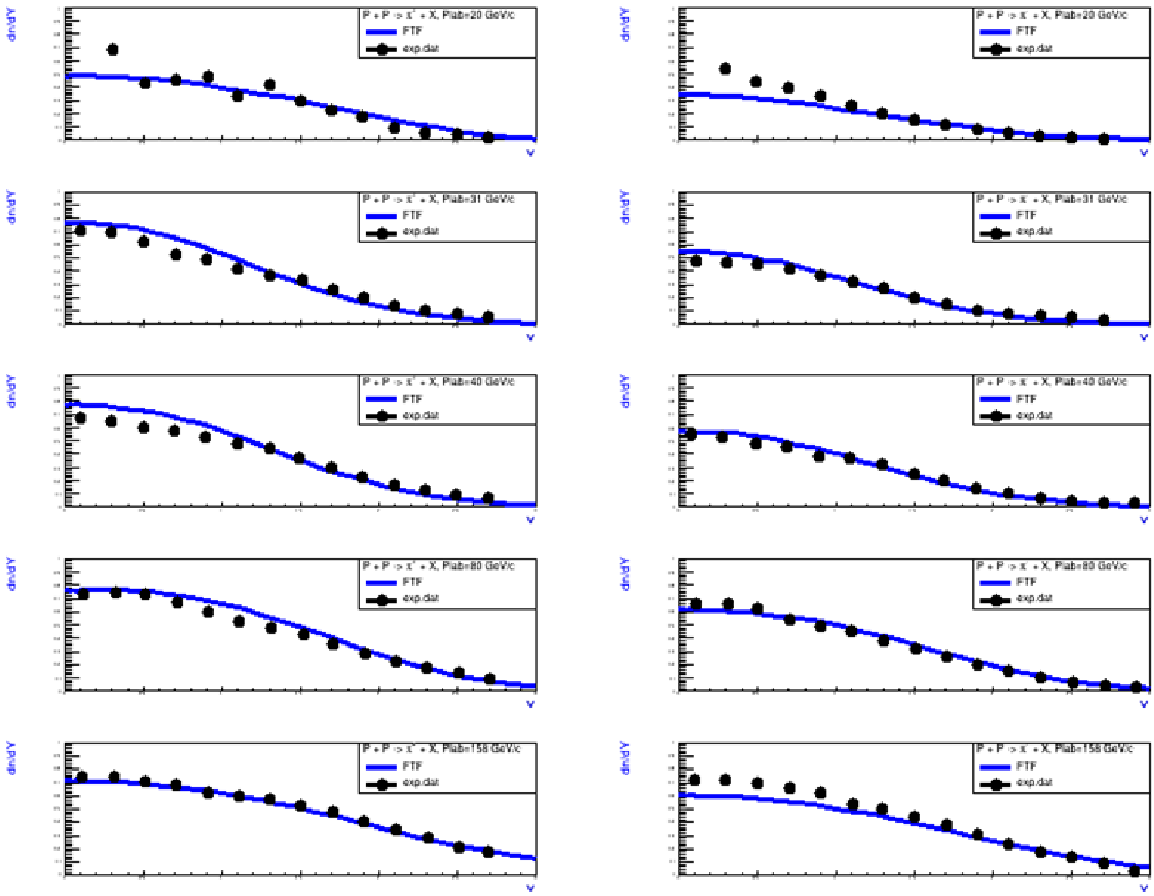


Fig.2.

In Fig.2, we presented experimental data of on rapiditiy distributions of π+, π- mesons (left and right columns, correspondingly) produced in PP-interactions at 20, 31, 40, 80, 158 GeV/c. Experimental data are given by black points. We performed corresponding calculations by the FTF model. Our calculations for π+, π- mesons are given blue lines. As seen in Fig.2, there is a very good agreement between the FTF model calculations and experimental data.

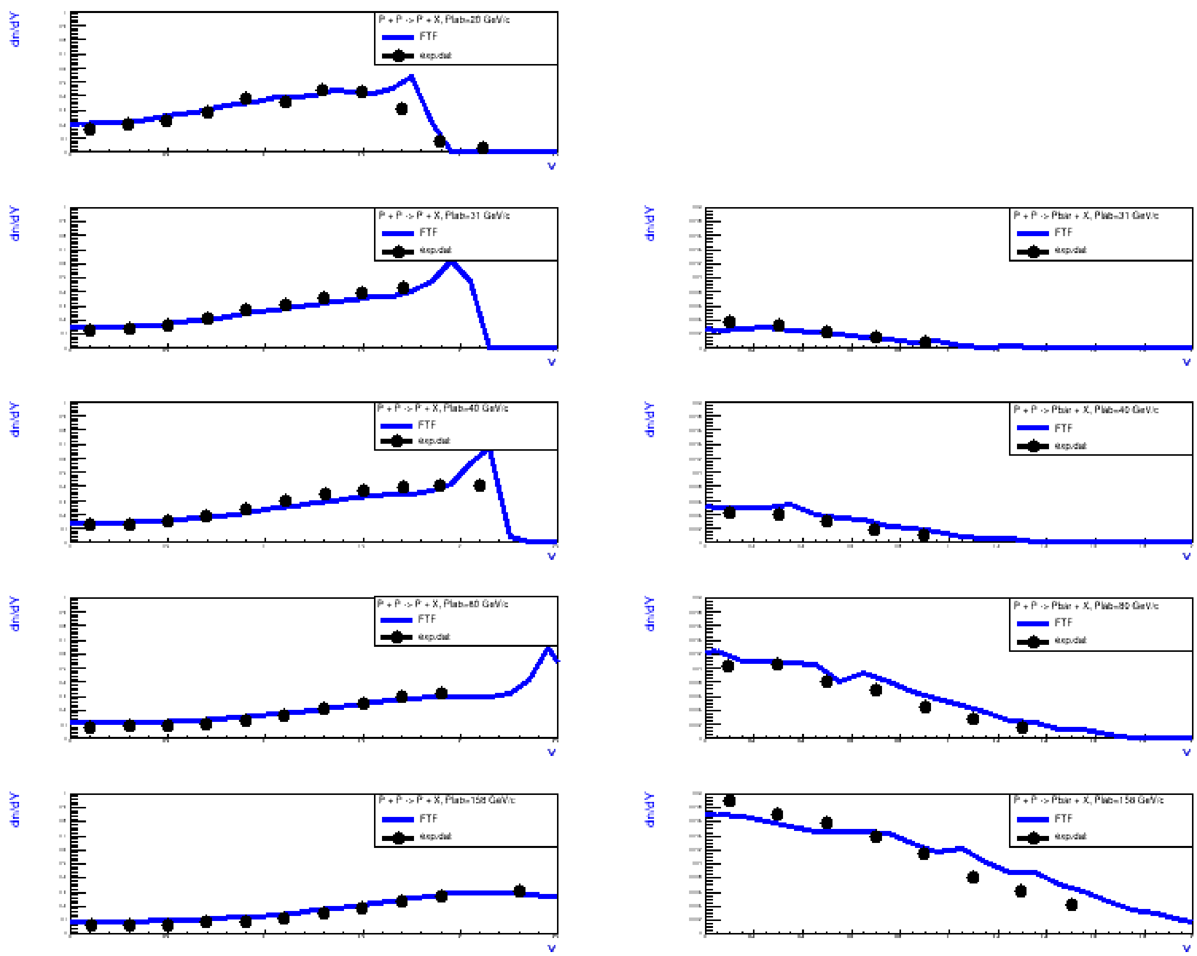

Fig.3

Let us considered baryon production in PP-interactions. In Fig.3, we present rapidity spectra of proton and antiprotons produced in PP-interactions. In left column of Fig.3 , we show experimental data (points) and the FTF model calculations (lines) for rapidity distributions of protons produced in PP-interactions at initial momenta from 20 GeV/c to 158 GeV/c. The FTF model describes well proton distributions. However, FTF model overestimates the experimental data on protons in the beam diffraction dissociation region. It is need to understand, this overestimation is connected with experimental conditions or there is a model problem. In the right column of Fig.3, we presented experimental data and the FTF model calculations for rapidity distributions of antiprotons at momenta 31, 40, 80 and 158 GeV/c. On the whole, the FTF model calculations are in a good agreement with the experimental data. Let us turn to production of strange particles in proton-proton interactions. In the Fig. 4, K+ and K- rapidity distributions are presented for proton-proton interactions at initial momenta 20, 31, 40, 80, 158 GeV/c.

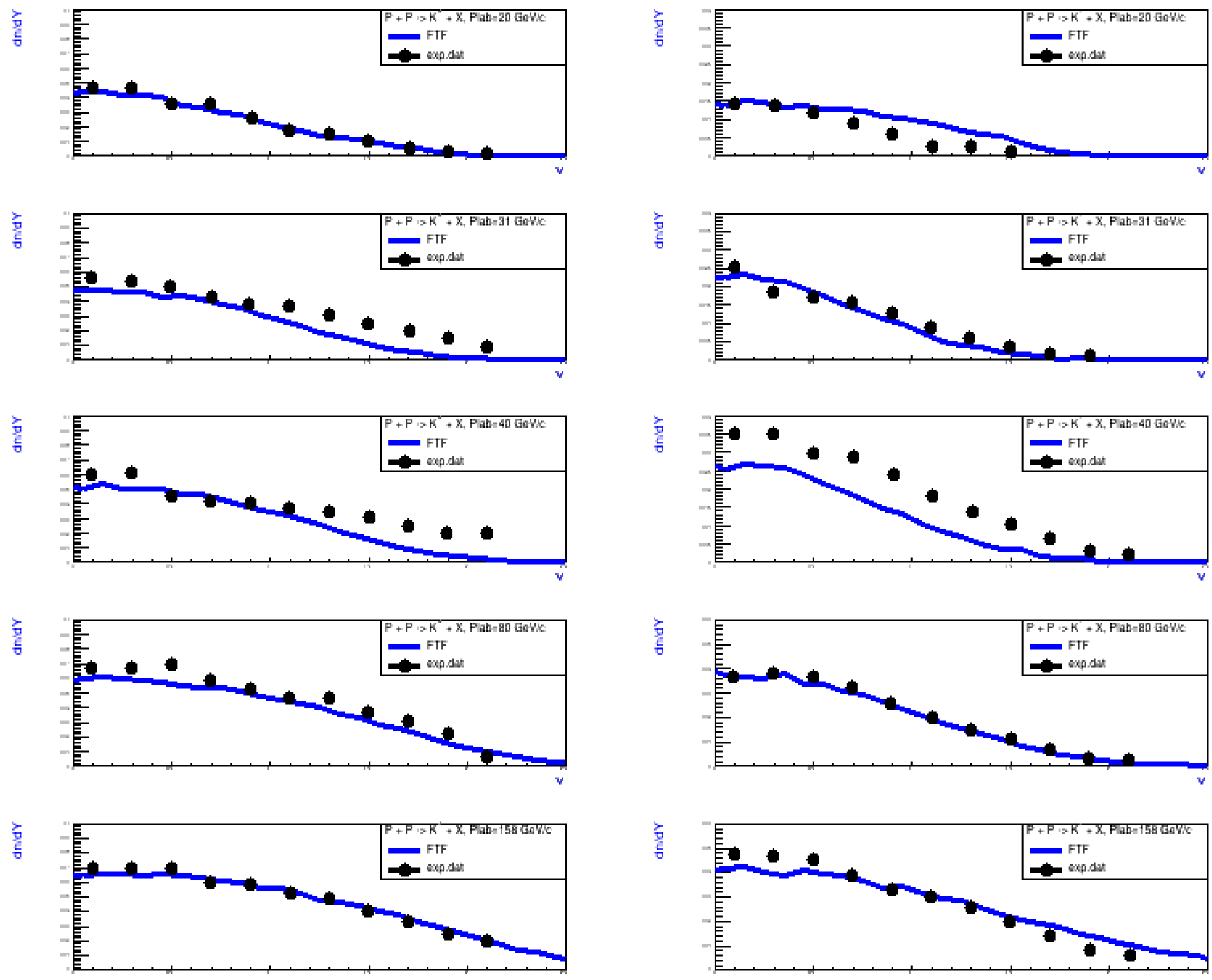


Fig.4.

As seen, the FTF model describes well K ± meson spectra at projectile momenta 20, 31, 80 and 158 GeV/c. Only at 40 GeV/c, we cannot describe $K^-$ -meson spectra. We have to note, this experimental data at 40 GeV/c fall out of common regularity of all experimental data. Summing up, we can conclude that the Geant4 FTF model gives quite good description of kinematical properties of hadrons produced in nucleon-nucleon interactions in the wide energy range. Due to this, the FTF model can be used for a realistic simulation for NICA/SPD experiment.

For SPD, we have performed simulations of 100000 PP-events in center of mass system at Ecms=12 GeV by the FTF model, installed in SPDRoot. In Fig.5, we show rapidity distributions of protons, neutrons, $\pi\pm$ -mesons, $K\pm$ mesons produced in PP- interactions at Ecms=12 GeV. Two peaks in proton and neutron spectra are

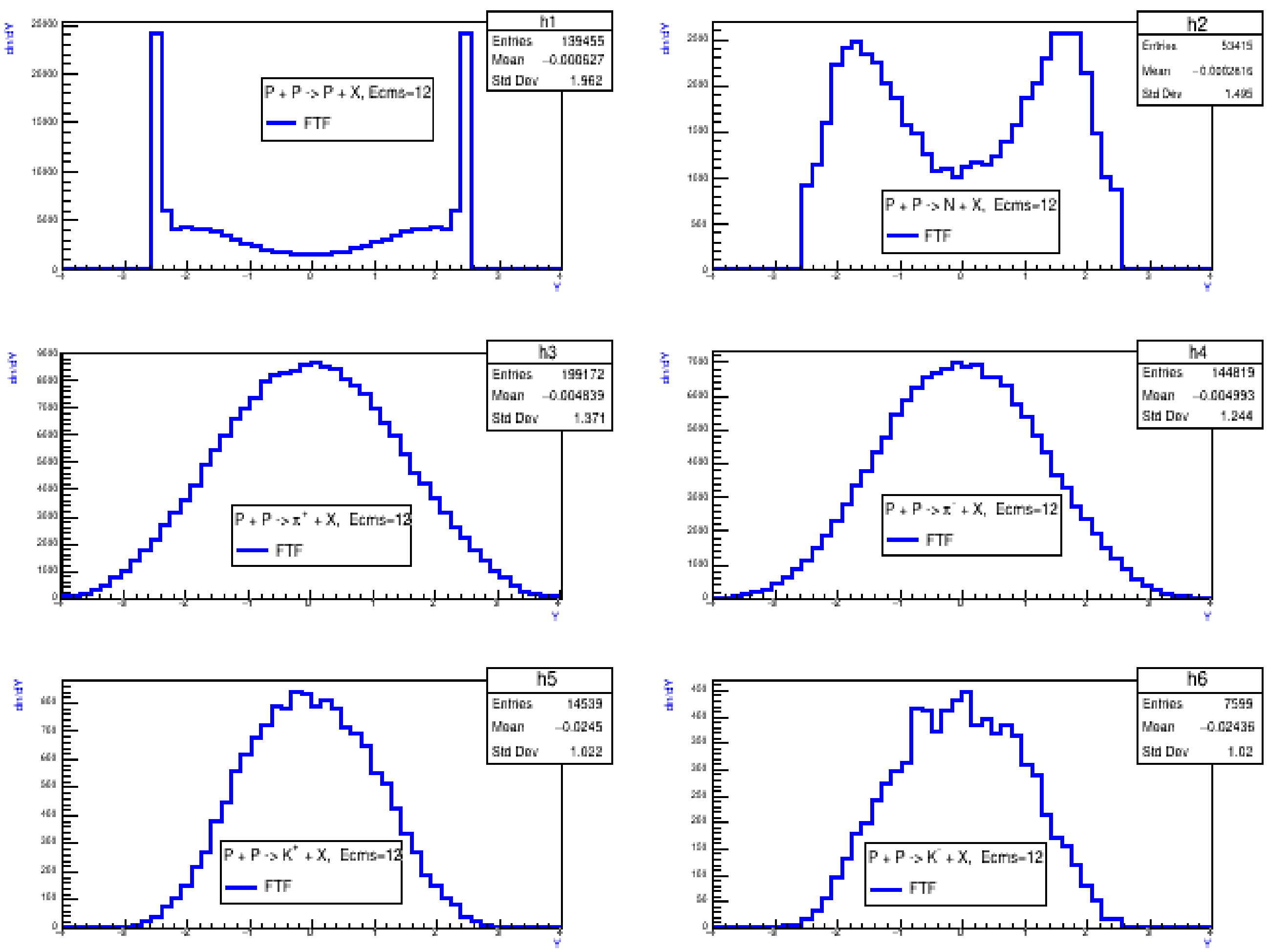


Fig.5

correspond to diffraction dissociation. The FTF model calculations can be used for realistic background estimations of the NICA/SPD experiment.

## Conclusion

1. During Summer Student program, Linux operation system, C/C++ and ROOT were studied.
2. Using the Phase Space generator of ROOT, calculations of nucleon-nucleon interactions at various energies were performed.
3. SPDRoot was installed in local account of HybriLIT JINR cluster. In the frame of SPDRoot, simulations of proton-proton interactions at initial projectile momenta 20, 31, 40, 80, 158 GeV/c by the FTF generator have been done. It is shown that calculation results are in good agreement with corresponding experimental data by the NA61/SHINE collaboration.
4. Using the FTF model in SPDRoot, we give predictions for various hadron production in proton-proton collisions at SPD energies.

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