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Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

Study of identified Kaons in BM@N Experiment at Nuclotron

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Abstract. The BM@N (Baryonic Matter at Nuclotron) is a fixed target experiment and first experiment undertaken at Nuclotron of NICA accelerator complex. The BM@N scientific program comprises studies of dense nuclear matter in heavy ion beams of the intermediate energy range between the SIS-18 and NICA/FAIR facilities. The goal of BM@N is to study nuclear matter in relativistic heavy ion collisions. The experimental run was performed in the argon beam of the 3.2 AGeV kinetic energy with fixed targets. First physics results are presented on K^+ meson production in argon-nucleus interactions. Transverse momentum, rapidity spectra and yields of K^+ mesons are measured. We will describe and study of the production K^+ mesons in interactions of the argon beam with kinetic energy of 3.2 AGeV with *C, Al, Cu, Sn, Pb* targets at BM@N detector.

1. Introduction

Collisions of relativistic heavy ions provide a unique opportunity to study nuclear matter at extreme densities and temperatures. At the Nuclotron, the experimental research is focused on studies of hadrons with strangeness produced in the collision and not present in the initial state of two colliding nuclei. The energy range of ion beams at the Nuclotron corresponds to $\sqrt{S_{NN}}$ = 2.3 − 3.5 GeV. At the Nuclotron energies the nucleon density in a fireball created by two colliding heavy nuclei is 3 - 4 times higher than the saturation density. In addition, these energies are high enough to study strange mesons and (multi)strange hyperons produced in nucleus-nucleus collisions close to the kinematic threshold [1][2].

The purpose of the BM@N experiment is to study relativistic heavy ion beam interactions with fixed targets in the energy range of maximal baryon densities. The primary goal is to constrain parameters of the Equation of State of high-density nuclear matter. Studies of the excitation function of strange particle production below and close to the kinematical threshold provide the means to differentiate hard from soft behavior of EoS.

BM@N collected first experimental data in beams of carbon, argon, and krypton ions. We are presenting the first results on K^+ meson production in argon-nucleus interactions. Transverse momentum, rapidity spectra and yields of K^+ mesons are shown.

2. NICA accelerator complex

Nuclotron-based Ion Collider fAcility (NICA) is an accelerator complex which is created at the Joint Institute for Nuclear Research (Dubna, Russia). NICA ambitious goals cover many domains including reasearch of hot and baryon rich QCD matter in heavy ion collisions in the energy range $\sqrt{S_{NN}} = 4 - 11$ GeV and create a special state of matter in which our Universe stayed shortly after the Big Bang – the Quark-Gluon Plasma (QGP). NICA will provide different beams ranged from protons (protons will be accelerated up to kinetic energy of 12 GeV) and polarized deuterons to gold ions (heavy ions will be accelerated up to kinetic energy of 4.5 GeV) [1][3]. The project NICA includes study of collective effect, production of hyperon and hypernuclei, in-medium modification of meson propraties and evennt-by-event fluctuations [4].

2.1. Design of NICA collider

Elements of NICA facility are expected to include (see Figure 1):

1. Injection complex,
2. Superconducting Booster synchrotron,
3. Superconducting heavy ion synchrotron Nuclotron
4. Collider having two new superconducting storage rings,
5. New beam transfer channels.

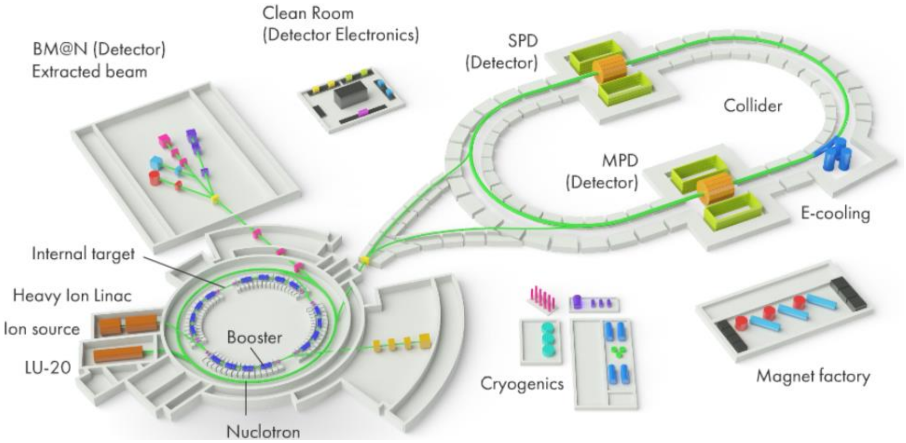

Figure 1. *The NICA collider; Nuclotron, Booster, Collider; experiments BM@N, MPD, and SPD.*

2.1.1. Booster

The NICA booster is a 211m circumference superconducting synchrotron. It will accelerate beams to 500 MeV and use 2.2 m-long dipole and quadrupole magnets [1].

The tasks of the Booster are:

1. Accumulation of $2{\cdot}10^9$ Au^{31+} ions; acceleration of the heavy ions up to energy required for effective stripping;
2. Forming of the required beam emittance with electron cooling system;
3. Providing a fast extraction of the accelerated beam for its injection into the Nuclotron.

2.1.2. Nuclotron

The Nuclotron SC proton synchrotron has three operation modes:

1. Acceleration of heavy ions for storage in the collider
2. Acceleration of polarized protons and deuteron for the collider
3. Acceleration of polarized and unpolarized protons and deuterons and heavy ions for internal target experiments or slow extraction to fixed target experiments.

2.1.3. Collider

The Collider will operate at a fixed energy without acceleration of an injected beam. It will be placed in a tunnel with buildings for two detectors and the electron cooler.

Maximum bending field will be 1.8 T. Two collider rings are placed one above the other and distance between the them is chosen to be 32 cm (what is achieved thanks to dipole and quadrupole magnets having two holes in one yoke).

3. Experiments of NICA collider

3.1. The MultiPurpose Detector (MPD)

The MultiPurpose Detector (MPD) is designed to study heavy-ion collisions at NICA complex (Figure 2). Its main components of MPD are time-of-flight system for particle identification, barrel electromagnetic calorimeter and a tracking system composed of a silicon microstrip vertex detector. The MPD has been designed as a 4π spectrometer which is able to detect charged hadrons, electrons and photons in heavy-ion collisions at high luminosity. Detector will contain a precise 3-D tracking system and high-performance particle identification (PID) system.

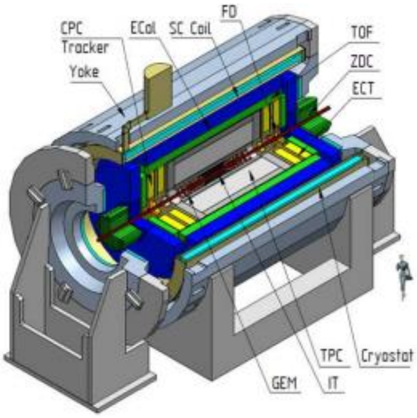

Figure 2. *A view of the MPD detector at NICA.*

Sub-detectors are located in a superconducting solenoid magnet. The magnet generates the magnetic field up to 0.5 T. The Time-Projection Chamber (TPC) is the main tracking device of the MPD detector which will provide trajectory reconstruction within the pseudorapidity range $|\eta| < 2$.

The TOF system contains a barrel and two endcap systems equipped with Multigap Resistive Plate Chambers (MRPC). It provides an extra PID power for charged tracks. The TOF system, having the intrinsic time resolution better than 70 ps, will provide hadron discrimination up to several GeV/c momenta.

Two arrays of quartz counters (FD) are placed at a distance of 140 cm at each side from the MPD center. They will allow fast timing and triggering for the experiment.

The MPD detector will operate in two stages. At the first stage MPD will be equipped with the TPC and barrel parts of the TOF and ECAL systems. At the second stage MPD will be equipped with the IT system and the endcap sub-detectors.

The MPD two-arm hadron calorimeter FHCALwill be used for event plane reconstruction and definition of the reaction centrality. The FHCAL is made of 44 modules with transverse dimensions of 15x15 cm^2 and cover the pseudorapidity range $2.0 < |\eta| < 4.8$.

3.1.1. Electromagnetic calorimeter

The Electromagnetic Calorimeter (ECAL) for electron and gamma measurements located behind the TOF detector. ECAL contains about 43000 modules of 18 radiation length thickness and of about 3 cm^2 cross section forming a barrel shape with projective geometry directing to the IP.

The primary role of the ECAL is to measure the spatial position and energy of electrons and photons which are produced in heavy ion collisions. It also will play a major role in particle identification due to high time resolution.

The electromagnetic calorimeter module contains of 16 towers that are glued together. Each tower is a lead-scintillator sandwich that consist of 220 tiles of Pb (0.3 mm thick each). The total thickness of the tower is about 42 cm. The scintillation light is collected via 16 Wave Length Shifting (WLS) fibers that are passing through the holes in the scintillator and lead tiles.
The information about the energy deposit from the ECAL calorimeter provide decreasing contamination of hadrons in the electron sample to the level of 10^{-5}. That could provide the reliable vector meson reconstruction though their dilepton decays in heavy-ion collisions at MPD [3].
To detect scintillation light (that is transported via the WLS fibers to the end plate of the module) special detecting heads (electronic boards) have been designed and produced.

3.2. Spin Physics Detector (SPD)

The Spin Physics Detector (SPD) will function have of a universal facility for study of the unpolarized and polarized gluon content of the nucleon at large Bjorken-x, using charmonia, open charm and prompt photon production processes. It will provide the measurements of asymmetries in the lepton pair (Drell-Yan) production in collisions of unpolarized, longitudinally and transversally polarized protons and deuterons beams. These measurements will enable an access to all leading twist collinear and Transverse-Momentum Dependent ditsribution functions of quarks and anti-quarks in nucleons.

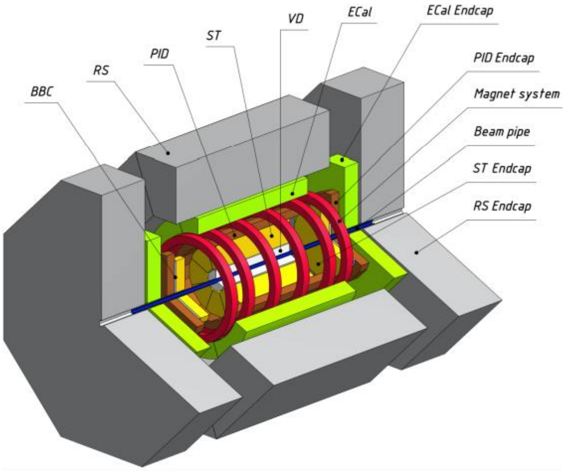

Figure 3. General layout of the SPD setup.

The SPD experimental setup is being designed as a universal 4π detector with advanced tracking and particle identification capabilities based on modern technologies. A scheme of the BM@N experimental setup is shown in Figure 3.
The experiment is planned to provide approach to the gluon helicity, gluon Sivers and Boer-Mulders PDFs in the nucleon, and gluon transversity distribution tensor PDFs in the deuteron. The obtained results that will have an important role in the comperhension of the nucleon content and will be used as a complementary input to the ongoing studies at RHIC, future measurements at the EIC (BNL) and fixed-target facilities at the LHC (CERN).

The minimisation of possible systematic effects will be achieved by simultaneous measurement of the same quantities (using various processes at the same experimental setup) [5].

Using dedicated triggers and Drell-Yan data, the measurement of asymmetries in production of J/Ψ and direct photons (which give complimentary information on the nucleon structure) will be possible.

4. Baryonic matter at Nuclotron (BM@N)

Baryonic matter at Nuclotron (BM@N) is a fixed target experiment at the Nica accelerator complex. The main goal of BM@N is to study nuclear matter in relativistic heavy ion collisions and measure yields of light hyper-nuclei, which are expected to be produced in coalescence of Λ-hyperons with nucleons. Experimental interest is focused on hadrons with strangeness, which are produces in collisions and do not exist in the initial state of two colliding nuclei [6][7][8].

A scheme of the BM@N experimental setup is shown in Figure 4.

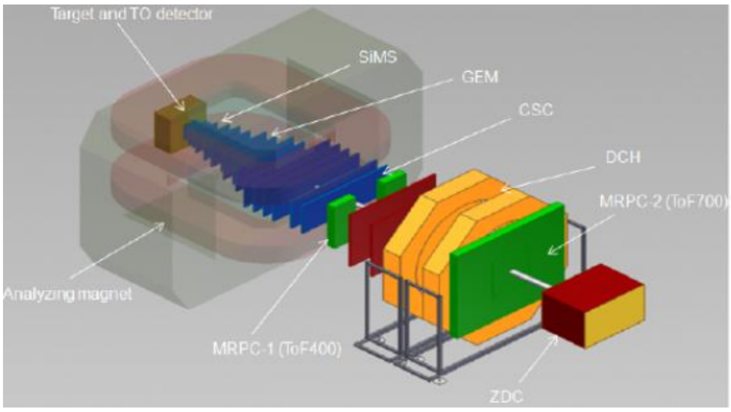

Figure 4. *Schematic view of the BM@N experimental setup: SiMS – Silicon Micro-strip Sensors, GEM – Gas Electron Multipliers, CSC – Cathode Strip Chamber, mRPC -Multi-gap Resistive Plate Chambers, DCH – Drift Chambers, ZDC – Zero Degree Calorimete*

There is opportunity of studying strange mesons and multi-strange hyperons close to the kinematic threshold, using collisions of Nuclotron heavy ion beams with fixed targets.

The magnetic field of the magnet can be up to 1 T to get the optimal detector acceptance and momentum resolution for different reactions and beam energies.

The Gas Electron Multipliers (GEM) is used to measure charged particle momentum and multiplicity and located inside the analyzing magnet and by Drift chambers (DCH) placed out of the magnetic field.

Double-sided silicon strip-detectors (SiMS) are places between the GEM tracker and the target to improve the track and vertex reconstruction in heavy-ion collisions.
A Cathode Strip Chamber (CSC) is places outside the magnet between GEM detectors and ToF400.

Two sizes of detectors are predicted to cover maximum geometrical acceptance within the experiment dimensions. Their dimensions are 163×45 cm^2 and 163×39 cm^2 and they are produced at CERN PH Detector Technologies (DT) and Micro-Pattern Technologies (MPT) workshop. Detectors contain three GEM multipliers, with the gaps between the electrodes: the drift gap (3 mm), the first transfer gap (2.5 mm), the second transfer gap (2 mm) and the induction gap (1.5 mm).

To install a vacuum beam pipe for heavy ion beam particles, there is a hole (80 mm) in the central region of the detectors.

The Cathode Strip Chambers (CSCs) constitute the primary muon tracking device in the CMS endcaps. CSCs are used to precise parameters of tracks obtained in GEM detectors inside the analyzing magnet.

The inner tracker (IT) system which maximize the MPD performance for vertex reconstruction will be based on MAPS technology developed by the ALICE experiment.

5. Data and the analysis

The experimental run of the BM@N detector was performed with the argon beam in 2018.
The track reconstruction method was based on the "cellular automaton" approach [CBM1]. "KF-particle" formalism [CBM2] is used to reconstruct primary and secondary vertices. K+ were identified using the time of flight from ToF detectors. Momentum and length of the trajectory were reconstructed in the central tracekr. K+ candidates should originate from the primary event vertex, correlate with hits in the CSC / DCH detectors and match hits in the ToF-400 / ToF-700 detectors (Figure 5) [9].

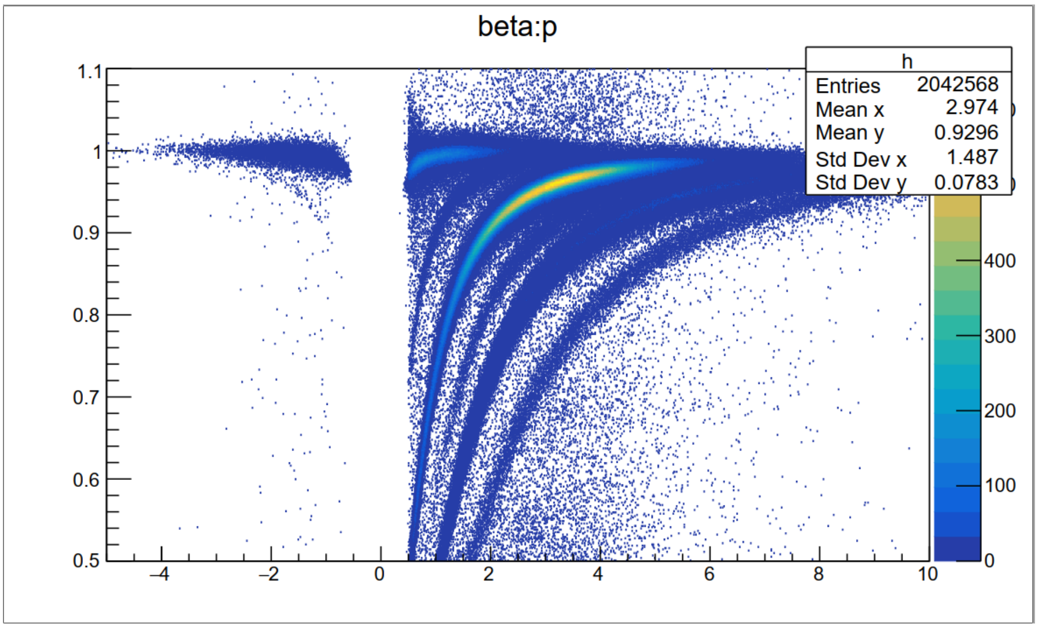

Figure 5. The distributions for different identified particles and clusters.

Events were recorded on the multiplicity silicon FD trigger detectors and minimum number of fired channels in the barrel BD.

The statistics of triggered events, beam fluxes and integrated luminosities collected in interactions of the argon beam of 3.2 AGeV with different target (ToF-400 data sample) are presented in Table 1.

Table 1. Number of triggered events, beam fluxes and integrated luminosities collected in interactions of the argon beam of 3.2 AGeV with different target (ToF-400 data sample).

Interactions, target Thickness	Number of triggers / 10^6	Integrated beam flux / 10^7	Integrated luminosity / 10^{30} cm^{-2}
Ar+C (2 mm)	11.7	10.9	2.06
Ar+Al (3.33 mm)	30.6	15.4	2.30
Ar+Cu (1.67 mm)	30.9	15.9	1.79
Ar+Sn (2.57 mm)	30.0	15.1	1.11
Ar+Pb (2.5 mm)	13.7	7.0	0.50

The statistics of triggered events, beam fluxes and integrated luminosities collected in interactions of the argon beam of 3.2 AGeV with different target (ToF-700 data sample) are presented in Table 2.

Table 2. Number of triggered events, beam fluxes and integrated luminosities collected in interactions of the argon beam of 3.2 AGeV with different target (ToF-700 data sample).

Interactions, target Thickness	Number of triggers / 10^6	Integrated beam flux / 10^7	Integrated luminosity / 10^{30} cm^{-2}
Ar+C (2 mm)	11.3	8.7	1.97
Ar+Al (3.33 mm)	29.2	10.2	2.05
Ar+Cu (1.67 mm)	28.7	11.3	1.60
Ar+Sn (2.57 mm)	25.9	9.5	0.91
Ar+Pb (2.5 mm)	13.7	4.9	0.40

K^+ selection criteria:

- Each track has at least 4 hits in GEM detectors (6 detectors in total), where hit is a combination of two strip clusters on both readout sides (X and X' views) on each detector [GEMTDR]
- Tracks are originated from the primary event vertex, the deviation of the reconstructed vertex from the position of the target along the beam direction $-3.4<|Z_{vertex} - Z_0|<1.7$ cm.
- A harder upper limit is aimed to remove background due to interactions in a scintillator counter behind the target
- Distance of the closest approach of tracks from the vertex in the direction perpendicular to the beam at Z_{vertex}: dca < 1 cm
- $\chi 2$ / ndf for tracks from the primary vertex < 3.52
- Momentum range of positive tracks: ppos > 0.5, 0.7 GeV/c for analysis of the ToF-400 and ToF-700 data, respectively
- Correlation of extrapolated tracks with the CSC / DCH hits as well as with the ToF-400 /ToF-700 hits should be within $\pm 2.5\sigma$ of the residual distributions.

The Figure 6 shows the distribution of the number of tracks of identified pions and Kaons for triggered and selected events for full the statistics of this run which we are using on this analysis.

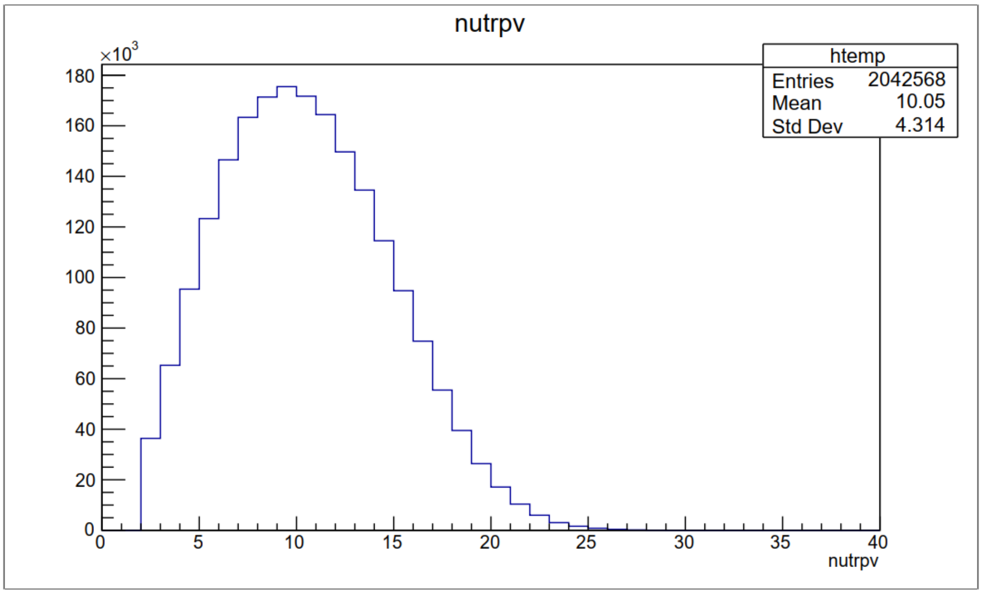

Figure 6. Number on indentified tracks.

The Figure 7 shows the distribution of transfers momentum with rapidity of reconstructed pions in mass square in the window from - 0.2 up to 0.14 GeV with momentum less of 2 GeV/c for triggered and selected events for full the statistics

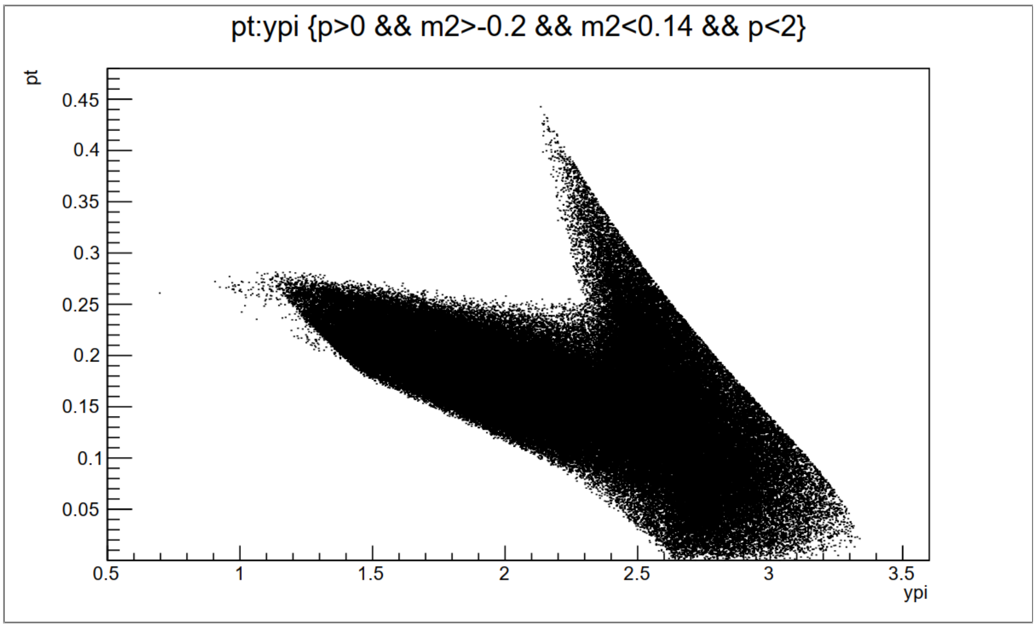

Figure 7. Distribution of the p_t / y for reconstructed pions

The Figure 8 shows the distribution of transfers momentum with rapidity of reconstructed Kaons in mass square in the window from 0.14 up to 0.34 GeV with momentum less of 2 GeV/c for triggered and selected events for full the statistics.

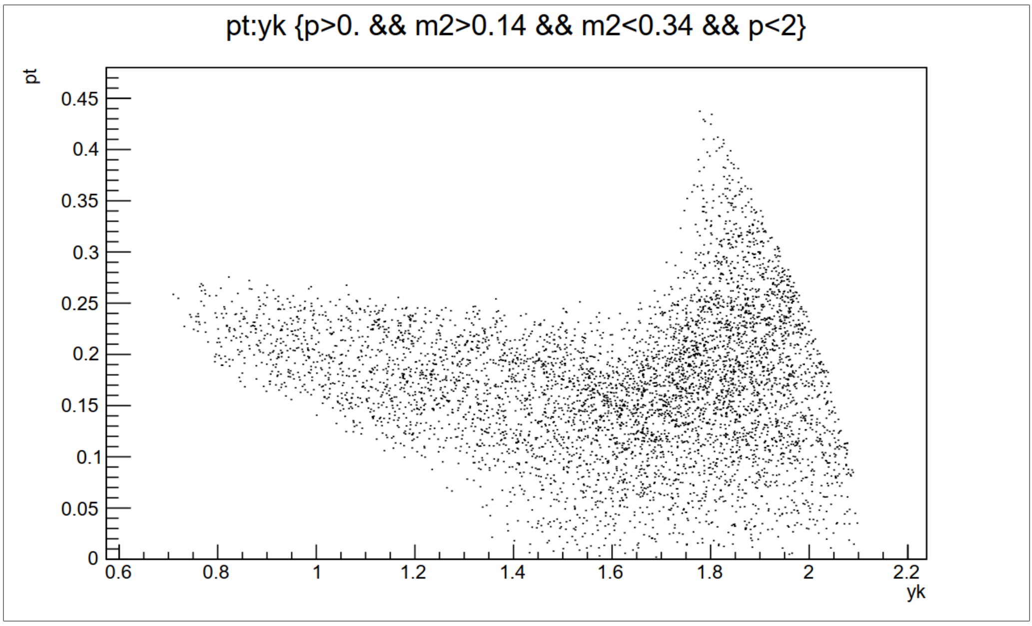

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Figure 8. p_t with y for identified Kaons.

The Figure 9 shows dx distribution for the reconstructed Kaons in the window from 0.14 up to 0.34 GeV with momentum less of 5 GeV/c for triggered and selected events.

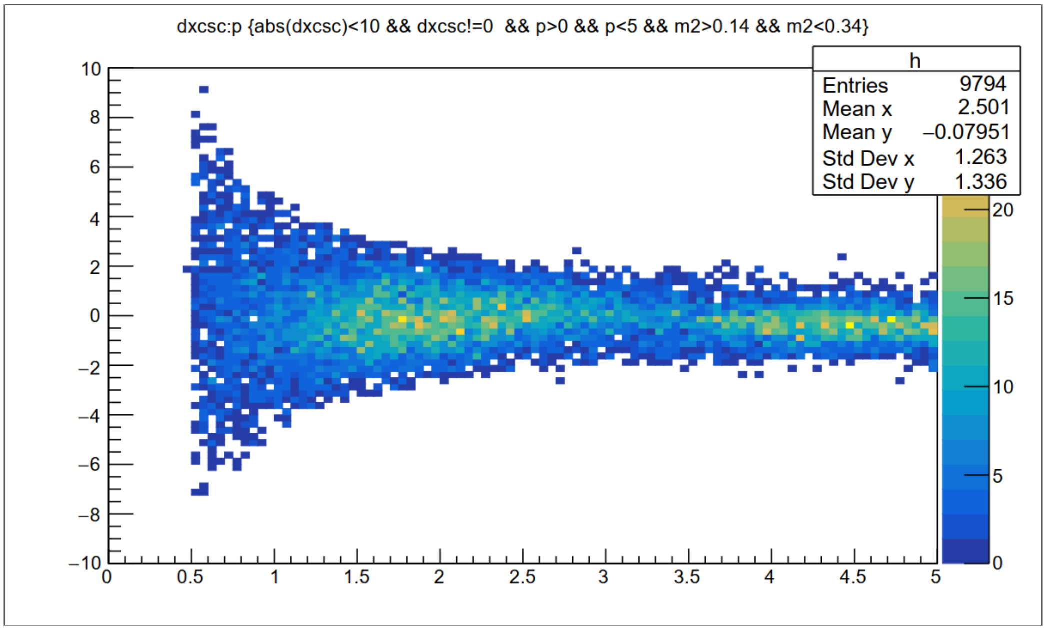

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Figure 9. dx for selected Kaons.

On the mass window of the Kaons (0.1 > m_2 < 0.5) for selected tracks we see clear peak of Kaons for the triggered events which is shown of the Figure 10.

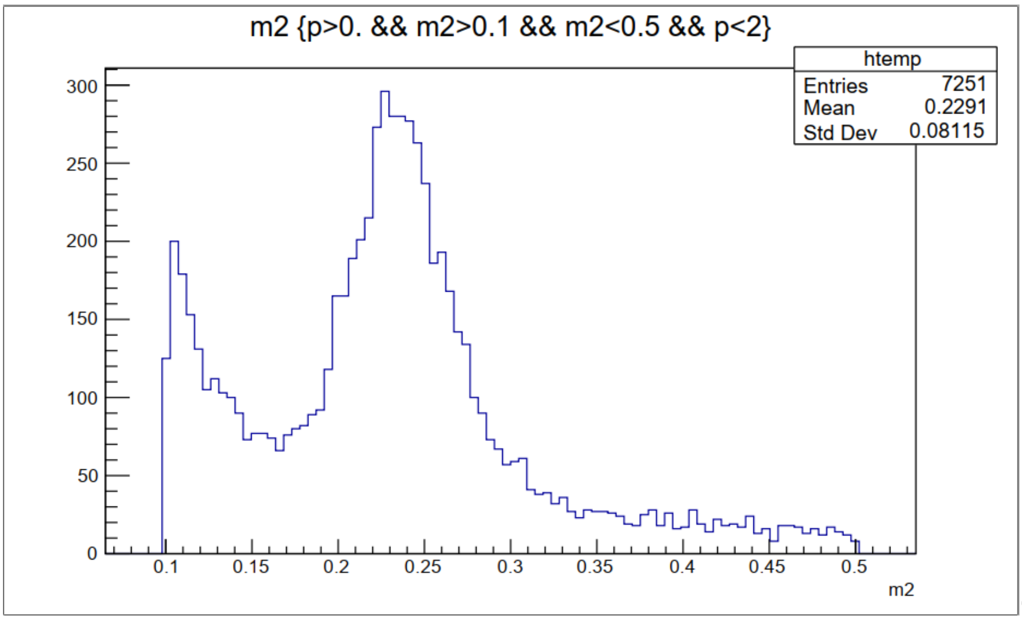

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Figure 10. mass distribution for Kain window.

Transfer momentum distribution for this (mass window of the Kaons ($0.1 > m_2 < 0.5$)) selected tracks we see clear peak of Kaons for the triggered events are shown in the Figure 11.

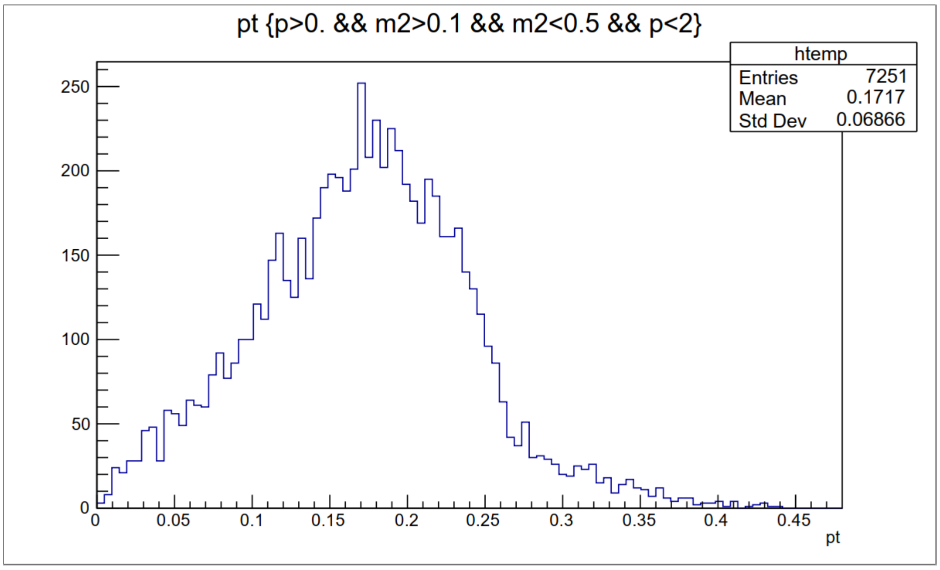

Figure 11. p_t distribution for Kaons.

The identification of particles we detectors of BM@N are working fine. We are going to continue the analysis of this sample for study the production of Kaons, cross section of this particles.

6. Summary

The experimental run of the BM@N detector was performed with the argon beam in 2018. The track reconstruction method was based on the “cellular automaton” approach [CBM1]. “KF-particle” formalism [CBM2] is used to reconstruct primary and secondary vertices. K+ were identified using the time of flight from ToF detectors. Momentum and length of the trajectory were reconstructed in the central tracekr. K+ candidates should originate from the primary event vertex, correlate with hits in the CSC / DCH detectors and match hits in the ToF-400 / ToF-700 detectors. Events were recorded on the multiplicity silicon FD trigger detectors and minimum number of fired channels in the barrel BD.

Main distributions are study for identified Kaons. Works will continue.

7. Reference

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