PROCEEDINGS OF SCIENCE

Status of NICA project at JINR

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New scientific program is proposed at Joint Institute for Nuclear Research (JINR) in Dubna aimed a study of hot and dense baryonic matter in the wide energy region from 2 GeV/amu to $\sqrt{s_{NN}} = 11\ GeV$, and investigation of nucleon spin structure with polarized protons and deuterons maximum energy in the c.m. 27 GeV (for protons). To realize this program the development of JINR accelerator facility in high energy physics has started. This facility is based on the existing superconducting synchrotron - Nuclotron. The program foresees both experiments at the beams extracted from the Nuclotron, and construction of ion collider – the Nuclotron-based Ion Collider fAcility (NICA) which is designed to reach the required parameters with an average luminosity of $L = 10^{27} cm^{-2}s^{-1}$ for colliding Au (79^{+}), and more than $L = 10^{30} cm^{-2}s^{-1}$ for colliding protons.

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1. Introduction

The 7-years plan of Joint Institute for Nuclear Research (JINR) has been approved for 2010-2016 years. In accordance with this plan a project Nuclotron based Ion Collider fAcility (NICA) aimed to study of hot and dense baryonic matter and spin physics is realizing at JINR as a flagship project in high energy physics (HEP).

A study of hot and dense baryonic matter should shed light on: in-medium properties of hadrons and nuclear matter equation of state (EOS); onset of deconfinement (OD) and/or chiral symmetry restoration (CSR); phase transition (PT), mixed phase (see fig.1 *left*) and critical end-point (CEP); possible local parity violation in strong interactions (LPV) [1, 2, 3, 4]. It is indicated in series of theoretical works, in particular, in [3] that heavy ion collisions at $\sqrt{s_{NN}} \leq 11\ GeV$ allow to reach the highest possible baryon density in the lab (fig.1 *right*).

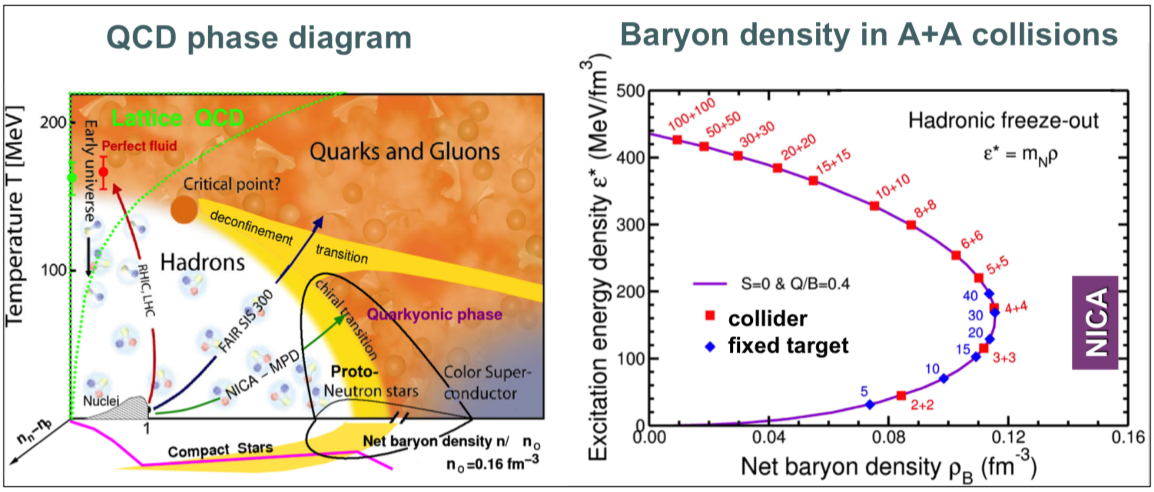

Figure 1: *left:* phase diagram for QCD matter (mixed phase is indicated by yellow); *right:* freezout diagrams for baryonic matter indicating baryon density reachable at different energies in collider and fixed target experiments [3] (the region covered by the NICA experiments is indicated).

The high intensity and high polarization (> 50%) of colliding beams could provide a unique possibility for spin physics research, which is of crucial importance for the solution of the nucleon spin problem ("spin puzzle") - one of the main tasks of the modern hadron physics.

The project NICA includes:

- an upgrade of the existing superconducting synchrotron Nuclotron to provide variety of ions up to Au^{79+} with maximum energy of 4.05 GeV/u;
- an experiment Baryonic Matter at Nuclotron (BM@N) in the ion beams extracted from the modernized Nuclotron;
- the construction of NICA collider providing collisions of variety of ions up to Au^{79+} at the energy region up to $\sqrt{s_{NN}} = 11\ GeV$ with the luminosity $L = 10^{27} cm^{-2}s^{-1}$, and polarized proton and deuteron beams up to the c.m.s. energy of 27 GeV for pp collisions with the luminosity higher than $L = 10^{30} cm^{-2}s^{-1}$;

- an experiment with the MultiPurpose Detector (MPD) at the first interaction point (IP) of NICA with a primary goal to study heavy ion collisions;
- an experiment at the second IP of NICA with a primary goal to study spin physics.

2. Accelerator Facility NICA

The Nuclotron - is an existing synchrotron located in the Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) of JINR, which has been put in operation in 1993. It is based on the unique technology of superconducting fast cycling magnets developed at VBLHEP. The upgraded Nuclotron will provide proton, polarized deuteron and multi charged ion beams. The magnetic field of dipole magnets $B = 1.8\ T$ corresponds to the ion beam energies: 5.2 GeV/u for d (A = 2, Z=1); 3.3 GeV/u for Xe (A=124, Z=42); and 4.05 GeV/u for Au (A=197, Z=79).

The new accelerator facility NCA includes (fig.2): an injector complex providing wide spectrum of ions up to the heaviest one $^{197}Au^{32+}$ at energy 3.5 MeV/u with an expected intensity $2 \cdot 10^9$; a booster accelerating ions up to 660 MeV/u; the source of polarize particles (protons and deuterons) SPP with the linac accelerating light ions up to 5 MeV/u; the Nuclotron continuing acceleration up to maximum energy (4.5 GeV/u) and two storage rings with two interaction points (IP). The ions are fully stripped before the injection to the Nuclotron. The major parameters of NICA collider are following: $B\rho_{max} = 45\ Tm$; vacuum in a beam camera - 10^{-11} Torr; maximum dipole field 2 T; kinetic energy from 1 GeV/u to 4.5 GeV/u for Au^{79+}; zero beam crossing angle at IP; 9 m space for detector allocations at IP's; maximum luminosity for ion collisions $L = 10^{30} cm^{-2} s^{-1}$. The required Nuclotron upgrade has started in 2008 and will be completed

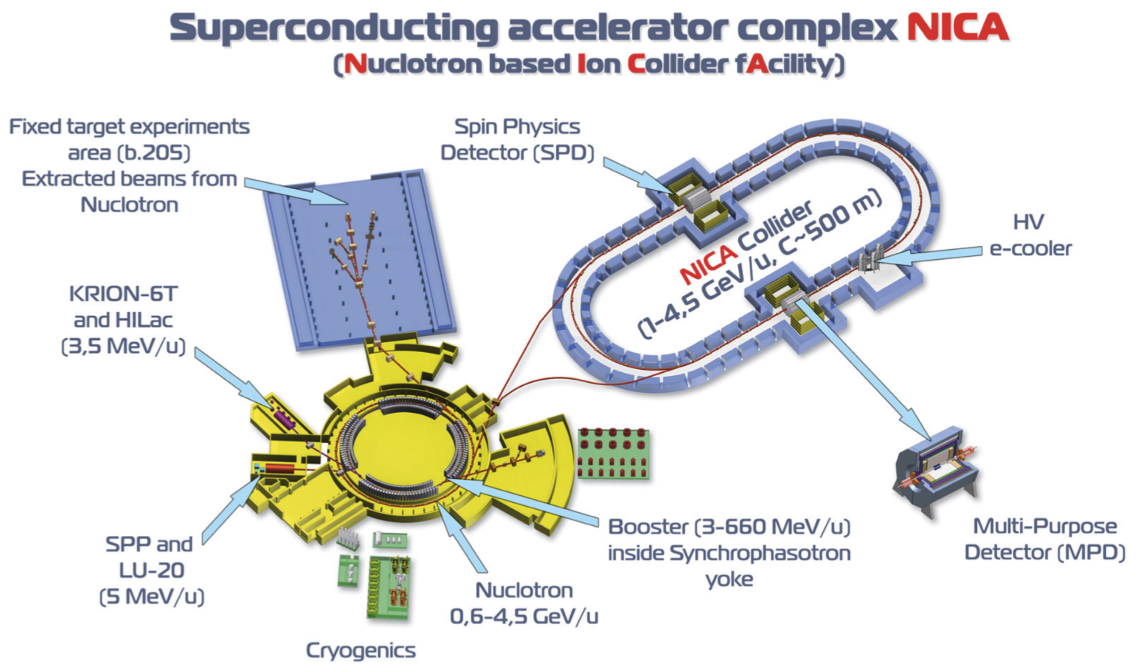

Figure 2: the new accelerator and experimental facility complex NICA at the VBLHEP.

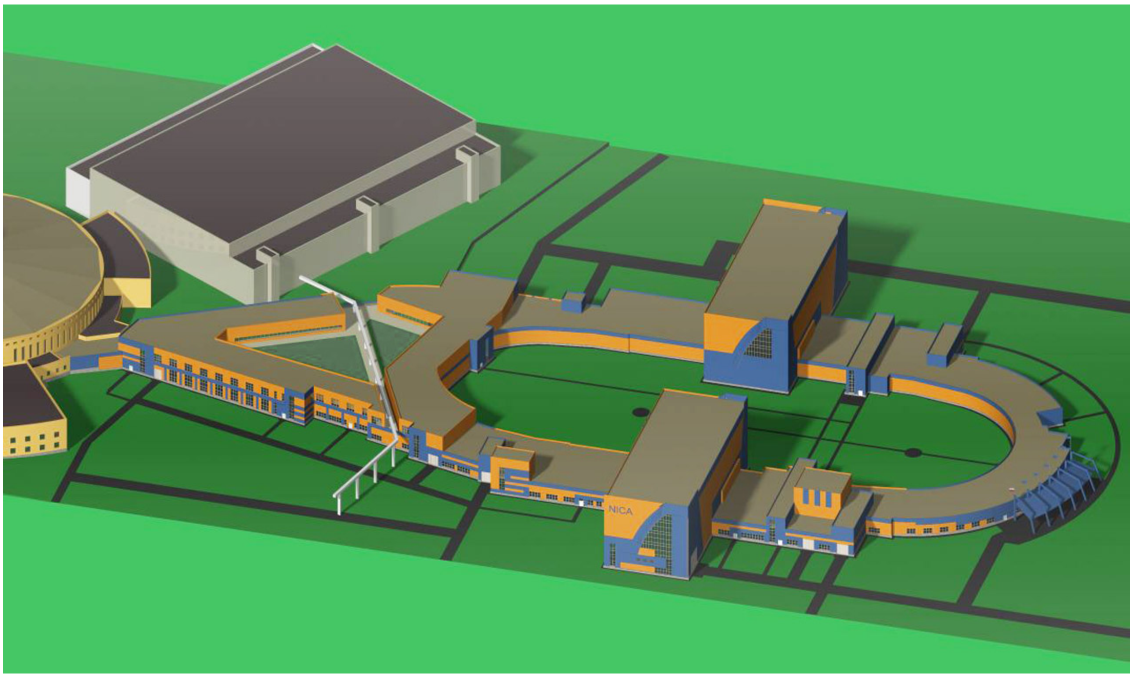

Figure 3: the architecture design of NICA collider and experimental buildings at two IP's

Table 1: The Nuclotron-NICA beams

beam	p	d	^{7}Li	^{12}C	^{24}Ar	^{56}Fe	^{84}Kr	^{124}Xe	^{197}Au
particles/pulse	$5\ 10^{12}$	$5\ 10^{12}$	$5\ 10^{11}$	$2\ 10^{11}$	$2\ 10^{11}$	$5\ 10^{10}$	10^{9}	10^{9}	10^{9}

by 2015 including a booster and new linac. The construction of the collider rings and IP's will be started in 2013. The corresponding design project is ready for the state expertise (fig.3). The overall construction schedule foresees that the collider storage ring and basic infrastructure facility should be available for the first ion collisions already in 2017 [5]. In the first IP the MultiPurpose Detector (MPD) will be installed, while a detector for the second IP is not yet designed. A call for the corresponding proposal is announced.

The comparison of the NICA accelerator complex with the existing heavy ion machines and ones being in preparation is indicated in fig.4 (the energy scale is recalculated to the c.m. system related to the Au + Au collision).

3. The BM@N Experiment

The energy of the extracted beams provided by upgraded Nuclotron-NICA finally will be reached 6 GeV/u for typical values of A/Z = 2. A typical variety of possible beams and their intensities provided by Nuclotron-NICA are presented in Table 1.

To realize the first stage of experiments at extracted beams with a fixed target a new set-up – BM@N (Baryonic Matter at Nuclotron) will be constructed using existing wide aperture dipole magnet, tracking chambers, time of flight (TOF) system, hadron calorimeter and fast counter

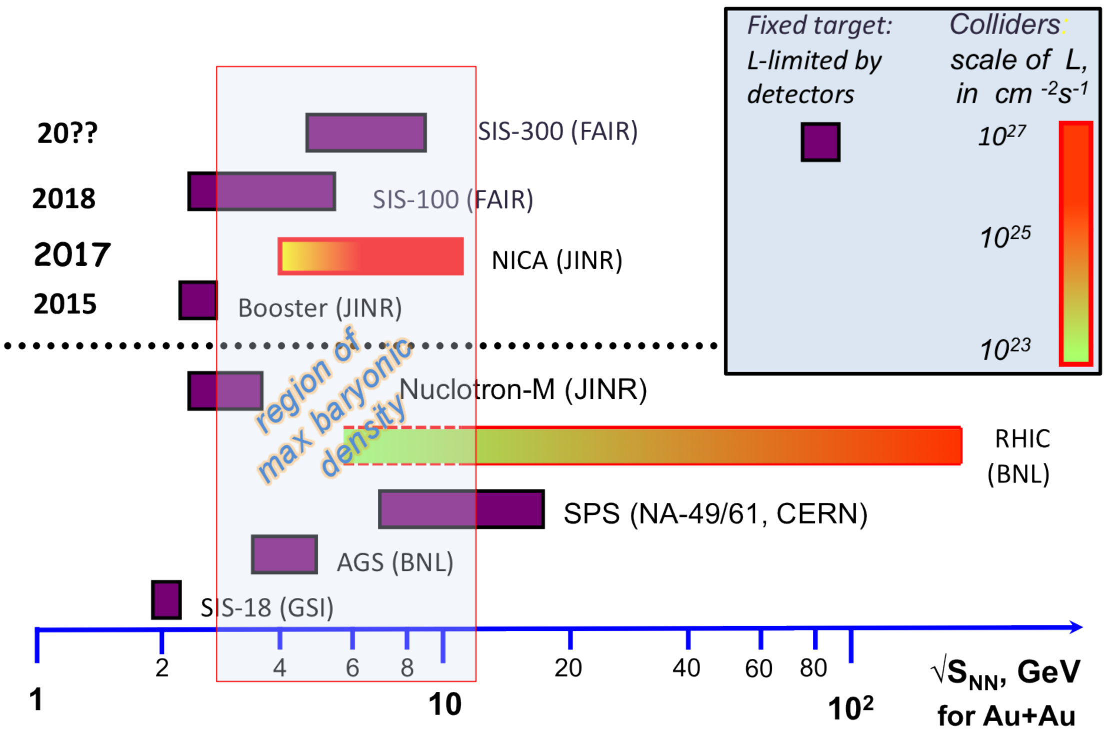

Figure 4: comparison of the running heavy on machines with ones being in construction (shadow in red frame indicates the region with maximum baryonic density)

detector providing trigger signal. At the second stage an upgrade is foreseen to accomplish the set-up with a silicon vertex detector (in cooperation with the partners from GSI, Darmstadt), with the electromagnetic calorimeter, and with the neutron detector (optional).

4. The MPD Experiment

The MPD experimental program is aimed to investigate both: the hot and dense baryonic matter, and the nuclon spin structure and polarization phenomena. A list of the first priority physics tasks to be performed in the experiment includes:

- in heavy ion program:
  measurement of a large variety of signals at systematically changing conditions of collision (energy, centrality, system size) using as bulk observables the following:
  - 4π geometry particle yields (OD, EOS); - multi-strange hyperon yields and spectra (OD, EOS); - electromagnetic probes (CSR, OD); - azimuthal charged-particle correlations (LPV); - event-by-event fluctuation in hadron productions (CEP); - correlations involving π, K, p, Λ (OD); - directed and elliptic flows for identified hadron species (EOS,OD);
  reference data (i.e. $p+p$) will be taken at the same experimental conditions;

- in spin physics:
  a study of hyperon polarization and other polarization phenomena; at the second stage after

the MPD upgrade it will be possible to study nuclon spin structure via the Drell-Yan (DY) processes.

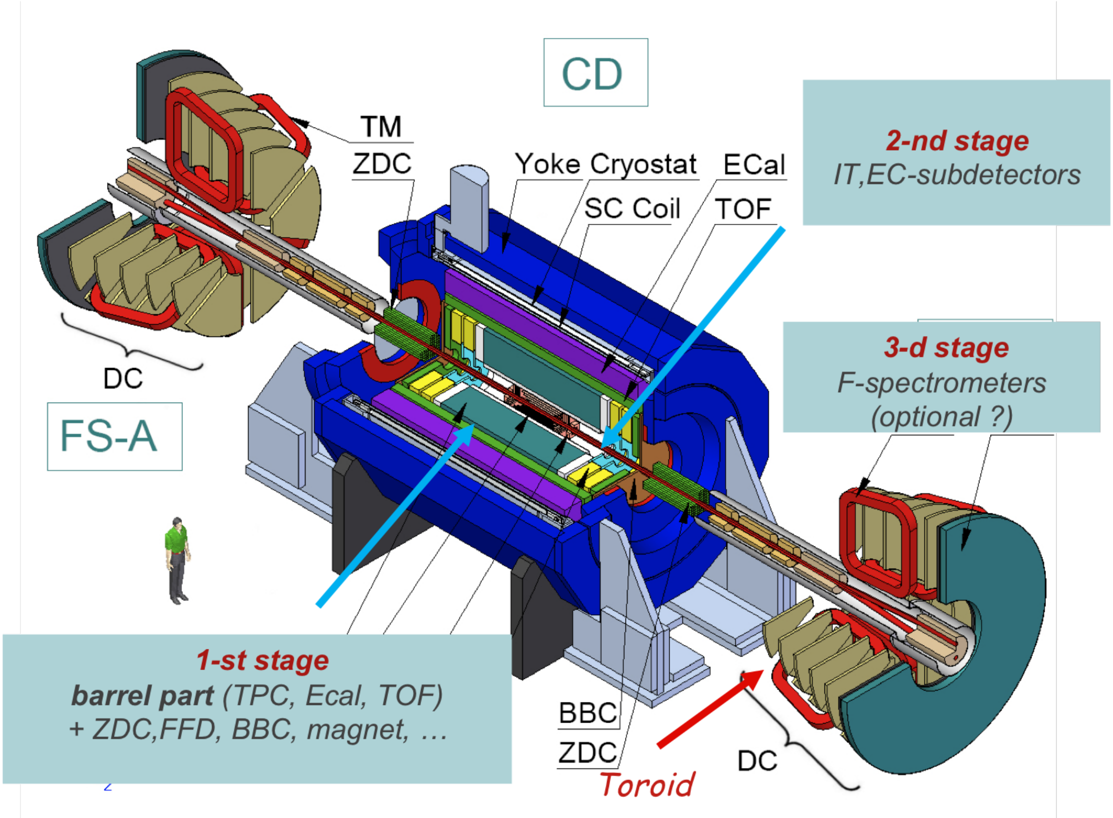

Figure 5: general view of the MPD, and sets of sub-detectors to be put in operation at different stages.

The MPD is a typical collider detector based on the solenoidal superconducting magnet. It will be installed in the first IP of NICA. The major sub-detectors of the MPD are (fig. 5): solenoidal superconducting magnet with a magnetic field of 0.5 T ($\sim 5\ m$ in diameter and $\sim 8\ m$ in length); time projection chamber (TPC); inner tracker (IT); time-of-flight (TOF) system; electromagnetic calorimeter (ECal); end cap tracker (ECT); two forward spectrometers based on toroid magnets (optional). There are foreseen three stages of putting MPD into operation. The first stage of operation involves magnet, TPC, TOF, ECal (partially) and IT (partially), and should be ready for the first collision beams in 2017. At the second stage the end caps of MPD will be fully equipped and some readout system modernized. The third stage is related to possible requirement for forward spectrometers and is optional. The MPD experiment should be competitive and at the same time supplementary to ones operated at RHIC [6], and constructed in the framework of FAIR [7] project.

The processes studied with MPD were simulated using the dedicated software framework (MpdRoot). This software is based on the object- oriented framework FairRoot [8] and provides a powerful tool for detector performance studies, development of algorithms for reconstruction and physics analysis of the data. Evaluated rate in Au + Au collisions at $\sqrt{s_{NN}} = 7.1\ GeV$ (10% central interactions) taking into account the luminosity of $L = 10^{27} cm^{-2} s^{-1}$ is 7 kHz. The corresponding particle yield are presented in Table 2.

Table 2: The particle yields in Au + Au collision (central) at $\sqrt{s_{NN}} = 7.1 GeV$.

particle	yield in 4π geometry	yield at y=0	decay mode	$\varepsilon, \%$	Yield in 10 weeks
$\pi^\pm$	290	100	–	61	$2.6 \cdot 10^{11}$
$K^\pm$	60	20	–	60	$4.3 \cdot 10^{10}$
p	140	40	–	60	$1.2 \cdot 10^{11}$
ρ	30	17	e^+e^-	35	$7.3 \cdot 10^5$
ω	20	10	e^+e^-	35	$7.2 \cdot 10^5$
ϕ	2.6	1.2	e^+e^-	35	$1.7 \cdot 10^5$
Ω^-	0.14	0.1	ΛK^-	0.7	$2.7 \cdot 10^6$

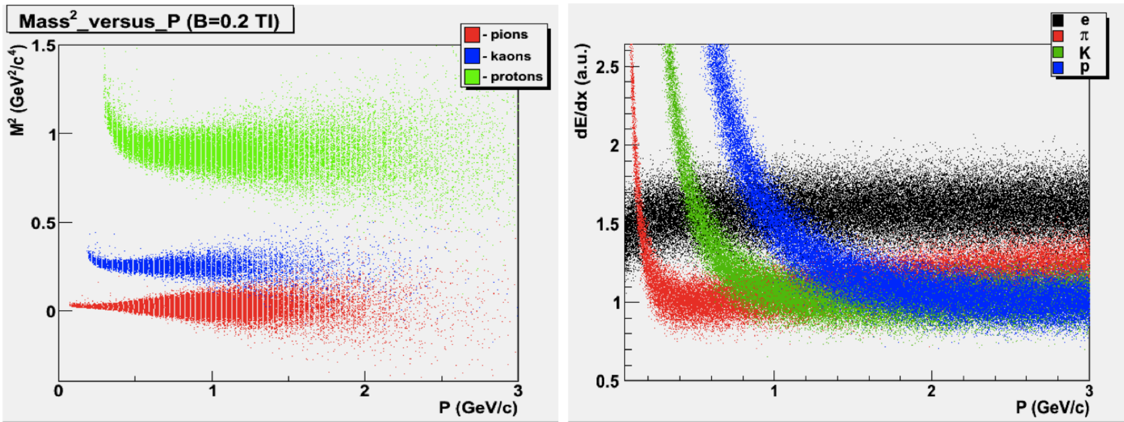

Figure 6: *left:* particle id using TOF system: *right:* particle id in the TPC by measuring the losses due to the ionization.

More than ten working groups from 12 institutions are intensively working on sub-detector R&D and on prototyping of all detector elements. More detailed information could be found in the corresponding conceptual design report [9].

It was shown that MPD is well optimized for study in-medium effects caused by high baryon densities, such as: changing particle properties in hot and dense medium (broadening of spectral functions etc.), event-by-event dynamical fluctuations of strange to non-strange particle ratios, and others. These studies could be done with better precision than ones performed at present experiments. The simulations of MPD experiment shows that high statistics of studied events could be accumulated (10^9 minimum bias events and 10^8 central events per week) which provide the best precision for femtoscopy study with respect to RP correlation of multistrange particles. In ten weeks of running more than $\sim 10^6$ of Ω-hyperon decays will be recorded.

Charged particles are reliably identified using both techniques: measuring dE/dx of tracks in TPC, and by TOF system (see fig.6). It was obtained sufficiently high resolution of vertices reconstruction illustrated in fig.7 *(left)*. This figure *(right)* shows as well an example of $\Omega \rightarrow \Lambda K^-$ decay reconstruction implementing full chain of simulation: central Au+Au collision generation at $\sqrt{s_{NN}} = 7.1 GeV$; hyperon productions and decays; decay product detection and their reconstruction using necessary MPD subdetectors.

The MPD performance in general satisfies the required parameters for proposed experimental program. The further optimization of MPD element design is continued. The corresponding infrastructure is developed as well at the site in the Veksler and Baldin Laboratory of High Energy Physics (JINR, Dubna).

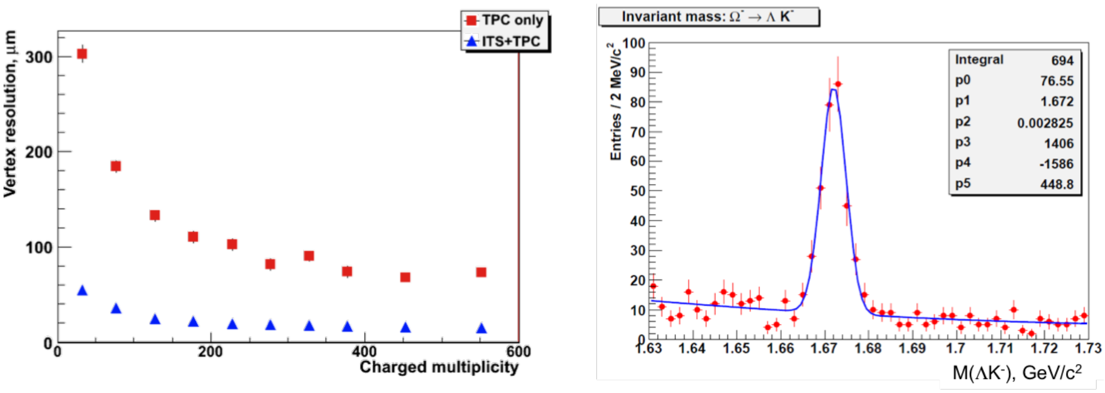

Figure 7: *left:* vertex resolutions versus multiplicity for events reconstructed with TPC only (squares), and for events reconstructed using both sub-detectors - TPC and IT (triangles); *right:* reconstructed invariant mass of Ω decay products (vertex reconstruction with TPC and IT, and particle ID with TPC and RPC).

For the reliable electron / positron identification both methods were implemented: TOF and energy losses in the TPC. The resulting plot with well defined region for electron/positron identification is presented in fig. 8 *left*. The reconstructed of e^+e^- invariant mass spectrum obtained with the corresponding electron / positron selection is presented in fig.8 *right*. Two signals of vector mesons are seen indicating their reliable selection.

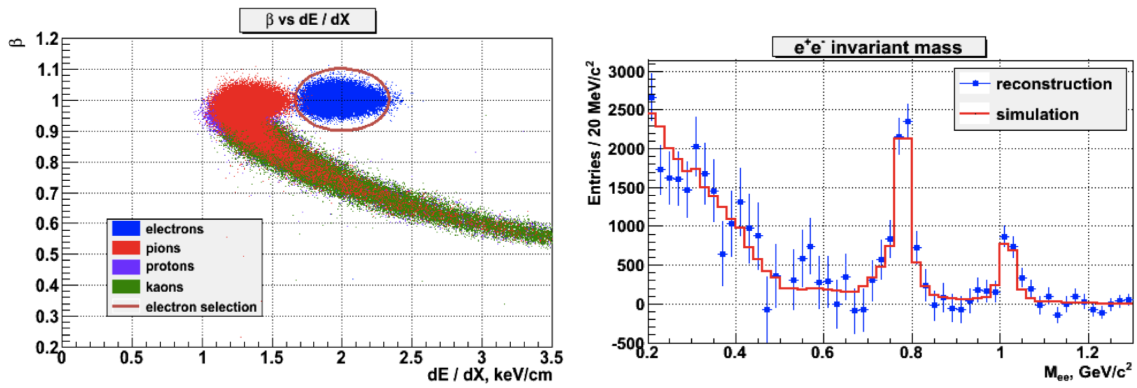

Figure 8: *left:* the plot of charged particles identification via TOF vs ionization losses in the TPC; *right:* simulated and reconstructed invariant mass of e^+e^- (electron/positron identification with TPC and TOF).

5. Detector for the second IP

The NICA program foresees that a detector will be designed and installed in the second IP. The physics program of the related experiment should be dedicated, first of all, to the spin physics.

One of the interesting process to be studied with the NICA is the Drell-Yan (DY) processes, not requiring the input from the poorly known fragmentation functions, that can be done in the kinematic region not available in other experiments.

The creation of motivated collaboration has started. The proposal could be prepared and presented to the JINR scientific committees. The time scale of this experiment will be defined after the consideration of the corresponding proposal.

6. Conclusion

The acceleration and experimental complex NICA to be constructed at VBLHEP JINR, and the related physics program, will provide relevant researches on one hand competitive, and on the other hand complementary to the ones being carried out and developing in other centers: RHIC at BNL, SPS and LHC at CERN, SIS18, SIS100 and SIS300 at GSI.

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