Snowmass'2021 : Letter of Interest

Beam Cooling development in Russia and potential international collaboration. Synchrotrons for nuclear physics and hadron therapy. Digital educational environment for accelerator science.

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Summary: fields of interest

- Design and construction of new types of superconducting magnets including HTSC technologies;
- Development of synchrotron power supply systems using HTSC energy storage elements;
- Development of ESIS type ion sources with superconducting solenoid;
- SC resonators for pulsed and cw hadron linear injectors;
- Room-temperature high current cw-RFQ and cw-DTL;
- Development of beam cooling methods: electron and stochastic, combination of both cooling method for beam accumulation with RF barrier bucket system and cascade of RF bunching systems;
- Technologies for high intensity polarized ion source;
- Precise laser metrology for colliders and ultra-small emittance machines;
- Development of modern automatic control systems with elements of machine learning technologies;
- Development of education programs on the basis of modern technologies.

Summary: enabling R&D

• Beam accumulation with bunching and cooling, maintaining a high luminosity level of the experiment at a record low energy and high intensity bunches;
• Optimization of nonlinear dynamics, dynamic aperture and energy acceptance, collective instabilities, accumulation of electron clouds in a positron beam, etc;
• HV electron and stochastic beam cooling by fast 3D cooling;
• Stochastic beam cooling for ultra-high vacuum collider storage rings, using optic cables and RF antennas;
• Usage of superferric fast-cycling SC magnets in intense RI beam facilities including e-RI colliders looks promising. Usage of such magnets is useful for hadron therapy synchrotrons and gantry due to their compactness and energy efficiency.
• R&D of compact high gradient (up to 100 T/m) superconducting quadrupole lenses and other final focus magnets.
• R&D of resonators for RFQ and DTL structures designed for operation with high-intensity low β ion beams from low-duty cycle up to cw mode;
• R&D of compact cryo-elements of crab-waist systems placed inside the detector in close proximity to the interaction point;
• Electron String Ion Source (ESIS) for operation at injector for synchrotron due to large pulse intensity and high quality of the beam;
• Technologies of methods for ultra-high precision positioning and monitoring of various ring elements (magnets, lenses, beam position sensors, etc.);
• Technologies related to the development of magnetic structures with ultra-low emittance;
• Investigation of the photo sorption properties of vacuum surfaces and coatings (NEG)

Accelerator facilities for the next (or next next) decade in Russia

In the field of relativistic heavy ion nuclear physics and dense baryonic matter – heavy ion collider NICA (an international project) is being constructed at Dubna (JINR) [1]. It is planned to start its operation in 2023. The facility uses the unique three-stage of beam accumulation and formation cascade, utilizes three beam cooling systems. The possibility to carry out the precision experiments with polarized p/d beams opens an additional research field of NICA, namely the spin physics.

In the field of HEP/Particle Physics the Super Charm-Tau Factory is designed and steadily constructed at Novosibirsk (Budker INP) [2]: an electron-positron collider with a circumference of 478m, at energy $\sqrt{S}$= 3-7 GeV, with luminosity not lower than 10^{35} $cm^{-2}s^{-1}$. The main experimental program is to study processes with c-quarks and tau-leptons, also operation with a longitudinally polarized electron beam is foreseen.

In the field of low-energy nuclear physics - the CDR of the DERICA (Dubna Electron – Rare Isotope Collider fAcility) project at JINR is under consideration. RIB facility DERICA concept covers broad range of modern nuclear physics with intense secondary RIB (new isotope synthesis and production, its masses, lifetimes and decay modes, nuclear reactions and spectroscopy). The emphasis of the project is storage ring physics with ultimate aim of electron-RIB scattering studies in collider experiments enabling to determine the fundamental properties of nuclear matter - electromagnetic form factors of exotic nuclei.

The design of a new accelerator for energies up to 1-5.5 GeV with a beam power of 1.5-2.0 MW and a neutron flux density of 10^{16}n/cm2s is underway at INR RAS (Troitsk).

Design and construction (after 2025-2030) of MWatt neutron spallation source at IHEP NRC KI (Protvino) is in progress.

At Budker INP (Novosibirsk) the construction of the Siberian Ring Photon Source (SKIF) has been started in 2019 [3]. It is a 4+ generation synchrotron radiation source (476 m ring), 3 GeV beam energy and emittance of up to ~ 50-60 pm. Commissioning of the source is scheduled for 2023. SKIF is intended for research with bright, intense and coherent radiation beams in a wide range of wavelengths from vacuum UV up to hard X-ray.

Possibilities for R&D and technology development; education [4]

The ESIS-type ion source invented at JINR VBLHEP. JINR has more than 20 years experience in their development and operation, including specialized test benches.

The superferric fast-cycling superconducting magnets (so-called “Nuclotron-type magnets”) are the key elements of two modern accelerator based projects: NICA at JINR and FAIR in Darmstadt. SC related activities are supported by largest in Russia cryogenic facility providing cooling power of 8 kW@4.5K. NICA automatic control system based on TANGO technologies is under development since 2013.

Development of superconducting accelerating cavities coaxial half-wave resonator and QWR is actively going on in collaboration of JINR, ITEP, MEPhI, Rosatom and industry of JINR member states.

Stochastic cooling test chain at the Nuclotron [5] and electron cooling system of the NICA Booster (constructed by BINP) are operational for investigations of the beam cooling process. Presently stochastic and electron cooling systems for the NICA collider are under construction.

Corad LLC in cooperation with NRNU MEPhI are producing new family of S-band linacs with energy of 2-10 MeV and average beam power up to 15 kW for medical equipment sterilization, radiation detectors calibration, activation analysis and beam modification of polymers. These linacs have narrow beam energy spectrum and very high total electrical efficiency ~21 % for the averaged power 12 kW / 10 MeV linac.

Experiments using beam cooling methods open wide opportunities for research into the nuclear physics and nuclear matter structure. Large number of unexplored fundamental problems remains in the low-energy and GeV-energy ranges for accelerator complexes capable of operation with both protons and various ions as well as in ion-electron collision mode. The most advanced of them are the NICA (Russia), FAIR (Germany), HIAF (China) and EIC (USA) projects. They are being built in order to obtain intense beams of primary and radioactive ions for experiments in physics of exotic nuclei, nuclear spectroscopy, precision mass measurement, high energy density physics etc.

The construction of the NICA collider with electron cooling systems for the booster up to 60 keV and for the main ring with electron energy of up to 2.5 MeV is nearing completion at JINR. Both electron cooling systems are constructed in Budker INP SB RAS. Cooperation with the University of Mainz (Germany) is developing in the framework of the development of an electron cooler for energies up to 8 MeV (FAIR). Budker INP is also developing technology for high-energy cooling based on ERL.

Development of the high intensity ion linac (HIIL) operating in high duty cycle up cw mode is one of the most important tasks for accelerator physics and technology. Since SC resonators are efficient starting from the beam energy about 3-5 MeV/nucleon the initial part of cw-HIIL (so called the front-end) is based on the room temperature resonators. Mainly the front-end includes the DC ion source and either single RFQ or RFQ plus DTL sections. It is considered that the front end for the facility will include the room-temperature RFQ and several room-temperature DTL with high duty factor. The NRC “Kurchatov institute” (including IHEP Protvino and ITEP Moscow) is now developing such a project.

Compact neutron sources based on the high intensity protons/deuterons cw-linac enable neutron beam generation with intensity of 10^{14}n/s and more. They can substitute the middle class research reactors and be installed at the research centers and Universities. At the moment the cw-RFQ for beam of U^{34+} ions with current up to 20 pμA is under development. The RFQ is a front-end part of 100 MeV heavy ion linac-driver for rare isotope production.

References:

[1] A N Sissakian *et al* 2009 *J. Phys. G: Nucl. Part. Phys.* 36 064069

[2] S. Gurov, et al Ring Source of Photons. *J. Synch. Investig.* **14,** 651–654 (2020).

[3] Piminov, P. Project for a Super Charm–Tau Factory at BINP. *Phys. Part. Nuclei Lett.* **15,** 732–736 (2018).

[4] Joint International Accelerator School https://cas.web.cern.ch/about/joint-international-accelerator-schools

[5] A Sidorin *et al* 2016 *Phys.-Usp.* **59** 264