Form №24

The development of the facility for measurements with test electron beams at LNP

LINAC-200

04-2-1126-2015/2020

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PROJECT APPROVAL LIST

The development of the facility for measurements with test electron beams at LNP

LINAC-200

04-2-1126-2015/2020

Valery Vasilievich Kobets

APPROVED BY THE JINR DIRECTOR

AGREED

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Contents

Abstract

Detector and instrumentation R&D is a necessary condition for the continuous progress of experimental nuclear physics and particle physics. Preparation of new accelerator experiments requires the development of new types of detectors, capable of working under high load and at the same time providing the required accuracy and reliability of particles registration. The design of new types of particle detectors is equally important for other fields like biology, medicine and materials science, which widely use in their studies the synchrotron radiation and intense X-rays sources. The beginning of studies at XFEL complex alongside with the launch of new synchrotron sources and ELI centers in the JINR member states require the design of experimental stations, based on image detectors with high spacial and energy resolution.

The possibility to test the detectors at the test beams in the clean experimental conditions has a decisive role for the success of any detector and instrumentation R&D. The lack of electron test beams at JINR slows down the progress of this kind of research aimed at construction of precise electron calorimeters, photon imaging detectors and radiation hard devices for future collider experiments. The proposed project has a goal to upgrade the electron accelerator Linac-200 up to 800 MeV and to create a research infrastructure for studies at its test beams. This facility can also be used in applied research in other fields of science (like radiation modification of materials, radiogenetics etc.) The facility also has a large educational potential, it will be used for the laboratory and practical trainings of students and PhD students - future engineers from JINR member states.

The project budget is 805 kUSD for 2019-2021.

Introduction

R&D of new types of detectors is a necessary condition for the continuous progress of experimental nuclear physics and particle physics. In particular, preparation of new accelerator experiments (ILC, CLIC, CEPC, HL-LHC) requires the development of new types of detectors, capable to work under high load and at the same time to provide the required accuracy and reliability of particles registration [1-4]. In contrast to the experiments at LEP, Tevatron and LHC, the main requirement often is radiation resistance, which is due to the long working time of the future facilities as well as much higher loading in comparison with the existing accelerator complexes as a result of the higher beam energy and luminosity of the future accelerators.

It is obvious, that the development of new detectors is not limited only by the future collider experiments. Examples are experiments on search of neutrinoless muon conversion into electron, which require the allocation of extremely weak signal from electrons with a certain energy [5, 6], as well as neutrino experiments of the new generation, for which detectors with high temporal resolution are developed, able to significantly suppress the background events by allocating the direction of neutrino movement by dividing the Cherenkov radiation and photons from scintillation [7].

The development of the detectors of a new type is important not only for higher energy physics. The future of such branches of science as biology, materials science and medicine is closely related to investigations using sources of synchrotron X-rays and other nuclear physics methods. In the next decade, not only the growth of experiments at the XFEL but also the launch of new synchrotron sources and high intensity ultra-short pulse lasers that are under development in the JINR Member States.

During the study of the characteristics of prototype detectors in the course of scientific and methodological research, as well as during the quality control during small-scale production, sources of elementary particles are invariably used. The most accessible and widespread are cosmic rays and radionuclide sources, but the use of beams of charged particles at the accelerator has a number of invaluable advantages, such as high energy and intensity, possibility of their reliable identification, possibility of particle energy control, precise timing and coordinate information. Some detector characteristics are simply impossible to be identified without using particle beams from accelerators. By the way, at present the opportunities of particle test beams at LNP and at JINR in general are extremely limited. It is possible to acquire particles with the energy of 100 MeV and higher only at Nuclotron and Fasotron and only proton and heavy ions beams are available. There is no source of higher energy electrons at JINR. Geographically, the nearest source of electrons of this kind is the S-25P "Pakhra" synchrotron at the Lebedev Physical Institute of the 1 GeV energy, launched in 1974, which does not have any equipped test beams.

Technical characteristics of the LINAC-200 accelerator, which is under development at JINR, allow creating on its basis the advanced system of test beams for scientific methodical researches of detectors in interests of LNP and also other laboratories as well as JINR Member States, and thus turn it into a new basic facility of JINR.

Available test electron beams

Currently, there are about a dozen of accelerating centers in the world, where measurements with electron test beams are possible (see Table). By the way, the work at test beams at international centers entails the costs of transportation and maintenance of equipment, as well as delays, as shifts at test beams are usually allocated over the several months ahead.

Science Center	Year of construction of accelerator/beams	Particle type	Energy range [MeV]	dP/P [%]	The number of equipped lines
BTF (Frascati, Italy)	1997/2003	$e^{\pm}$	25-750	1	1
ELPH (Tohoku, Japan)	1997/2006	$e^{\pm}$	< 850	1	1
Верс-II (IHEP, China, Beijing)	2008	e^{-} $e^{\pm}$ (secondary)	1100 - 1500 400 - 1200	1	3
FTBL (KEK, Япония)	1998/2007	e^{-}	500-3400	0.4	1
DESY-II (Germany)		e^{-}	1000-6000	1	3
CERN PS (Switzerland)	1960	e, hadrons, μ	$(1\text{-}15)*10^3$		4
CERN SPS (Switzerland)	1976	e, hadrons, μ	$(10\text{-}400)*10^3$		4
FTBF (FNAL, США)	1999	e^{-}, π^{-}, μ	$(1\text{-}66)*10^3$		1
SLAC (USA)	1999	e^{-} e, hadrons (secondary)	$13{,}6*10^3$ $(0{,}1\text{-}13{,}6)*10^3$	0,1-1,3	1
IHEP (Protvino, RF)	1967	e, hadrons, μ	$(1\text{-}45)*10^3$		4
BINP (Novosibirsk, RF)	1994/2012	e^{-}	100-3500	1,8-2	1
LPI (Troitsk, RF)	1974	e^{-}	300-1300		0
Yerevan Physics Institute (Armenia)	1967	e^{-}	75 6000		0
LINAC-200 (JINR)	*1975/2020*	e^{-}	*20 - 800*	*1*	*6*

Historical overview and current state of the LINAC-200.

Linear electron accelerator LINAC-200 is developed on the basis of the MEA accelerator, transported into JINR from NIKHEF (the Netherlands) in 1999-2000. The Medium Energy Accelerator with the design energy of 800 MeV was produced by the Haimson Research Coporation (USA) in 1975 as a part of the future NIKHEF accelerator complex. In 1980, the MEA accelerator was put into operation with the electron energy of 700 MeV and was used for nuclear physics researches until 1990. In 1990 after the upgrade, the MEA accelerator was used for the filling of the AmPS storage ring. In the end of 1998, the accelerator complex was taken out of operation. The equipment of the MEA accelerator MEA and the AmPS ring was transferred to JINR, to develop on its basis the DELSY setup - a source of synchrotron radiation of the third generation. The installation of the first line of the MEA accelerator in the building 118 of FLNP was started in 2003 as a part of the DELSY project. However, due to the lack of funding, the DELSY project was stopped in 2005, and the linear electron accelerator was proposed to be used to create on its basis a FEL (LINAC-800 facility). In 2007, an electron gun was assembled and the electron current of 30 mA at the operating voltage 50 kV was obtained. A year later a high-voltage electron gun power supply of 400 kV was launched. In 2011, the accelerator station № 1 was assembled and a beam was carried through the first accelerating section. In 2015, the accelerator station №2 was assembled and the electron energy of 60 MeV was obtained. In 2016, the accelerator stations №3 and №4 were assembled, and in August, 2017 the first physical start-up of the LINAC-200 facility (the first stage of the LINAC-800 facility) was carried out with the electron energy of 220 MeV.

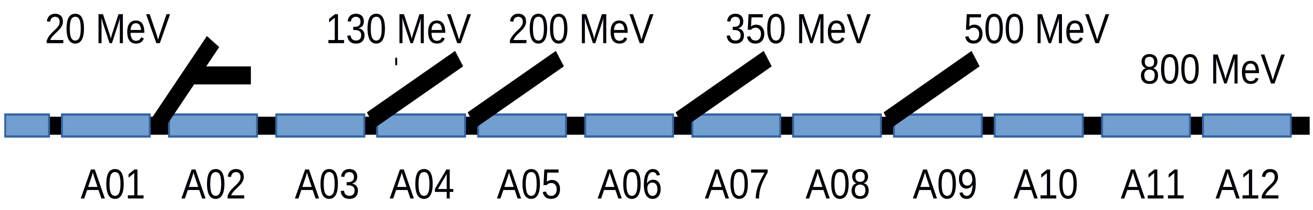

Figure. 1: LINAC-200 accelerator scheme

Simultaneously with the commissioning works at the LINAC-200 facility since 2014 the scientific methodical works on research of prototypes of detectors have been conducted by the groups of Mu2e, Medipix and TRITON (LNP). In addition, the scientific and engineering group of University Centre created the "training" electron beam in 2014-2015 and now educational programs with its use are prepared for the training of students and advanced training of specialists from JINR and JINR Member States.

Characteristics of the LINAC-200 accelerator

The linear accelerator with its engineering systems is located in the LNP building 118 on the site of the outdated electron accelerator LIU-30. The LINAC-200 accelerating structures are placed on the ground floor of the building in a 200 m long tunnel behind the concrete shielding. Modulators and RF systems are placed on the first floor of the accelerator building. The injector part of the accelerator is located on the side of the IBR-2 reactor. The length of the linac is 180 meters.

The linear electron accelerator LINAC-200 consists of an injector, a buncher and 12 accelerating stations. With 12 accelerating stations, LINAC-200 is able to accelerate electrons up to the 800 MeV energy. Currently, the injector, the buncher and 4 accelerating stations (A01-A04) have been assembled, capable of accelerating electrons up to the energy of 220 MeV. The installation of additional resonators of the RF pulse compression system (SLED) allows achieving the energy of 2 GeV at the cost of the beam current reduction. The structure of the beam is pulsed, with pulse length of 0.1-3 μs. The current in the pulse can be set in a wide range of values, from 40 mA to almost zero values. The frequency of pulses is set in the range from 1 to 100 Hz, which corresponds to the electron intensity from 1 to 10^{13} e^-/s. The possibility to change electron intensity in such a wide range is one of the main advantages of the LINAC-200 accelerator, allowing to carry out investigations of detectors with extremely small loading (for example, detectors of electronic neutrino or calorimeters for experiments on search of neutrinoless muon conversion into electron), as well as detectors, the important requirement of which is high radiation resistance (e.g. detectors for experiments on future electron-positron colliders).

Having achieved the beam energy of 800 MeV and higher it is possible to create a source of synchrotron and transient radiation in a soft X-ray range to study the characteristics of image detectors and conduct applied research.

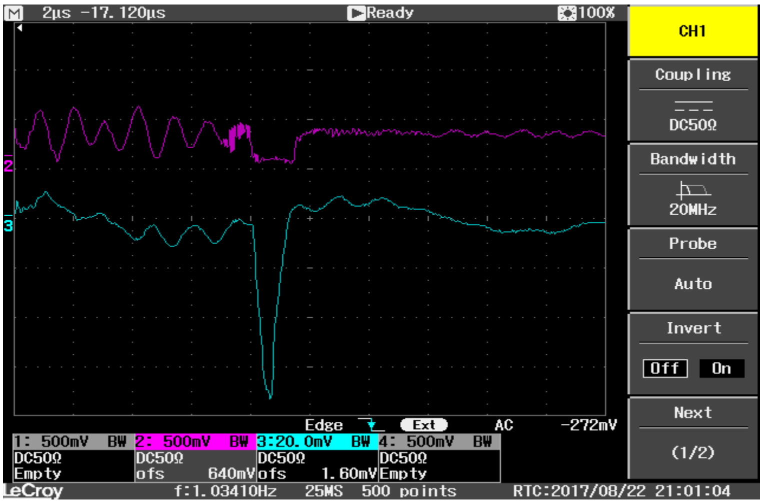

Figure. 2: Physical star-up of A04 station (upper line - current of electron beam after the 1st accelerator station, the energy of 20 MeV, lower line – the current after the 4th accelerator station, the energy of 220 MeV.)

Purpose and objectives of the project

The purpose of the project is to create on the basis of the linear accelerator LINAC-200 a facility for measurements with electron testbeams with the energy up to 800 MeV and to increase the time available for experiments up to 500 hours in 2021.

To achieve this purpose, the following objectives must be accomplished:

1. Assembling, commissioning and launch of 8 accelerator stations (A05-A12).
2. Upgrade of accelerator engineering systems to achieve the required characteristics of electron testbeams.
3. Construction of 4 testbeams, equipped with necessary tools of beam instrumentation, fastenings and protective shielding.

<u>Assembling, commissioning and launch of 8 accelerator stations (A05-A12).</u>

The main elements of the A05-A12 accelerator stations were also transferred to JINR from NIKHEF and are stored in the building 118. To launch the accelator stations the equipment the thermal stabilization system for accelerating sections and control electronics for the modulators should be obtained. Moreover, the existing timing and synchronization system should be extended. Directly for the installation of the remaining sections of the accelerator, it is necessary to prepare holes for wave guides and pipes of the stabilization system in the concrete ceiling between the accelerator and modulator halls. Installation, commissioning and physical start-up of A05-A12 stations can be performed within two years.

<u>Upgrade of accelerator systems to achieve the required characteristics of test electron beams.</u>

The following are obsolete and requiring modernization:

(a) vacuum system;

(b) accelerator control system (ACS);
(c) beam diagnostics tools.

Vacuum system of the LINAC-200 accelerator is modular: each module of the system pumps one accelerator station out. In addition, the electron gun, the drift tubes and the beam tuning setup are equipped with additional pumping units.

Getter-ion vacuum pumps are used in the vacuum system. Except for three pumps of General Electric 22TR 250, 100 L/sec, installed at the electron gun, the first drift tube and at the buncher input, all other units are the pumps of the VARIAN company: of the 911-5032 type with the capacity of 30 L/sec (wave guides, drifting tubes), of the 911-5043 type with the capacity of 60 L/sec (accelerating cavities) and 100 L/sec (beam tuning setup). Vacuum pumps are outraged and are the main reason of failure in the accelerator operation now. In the course of the project it is assumed to gradually replace all vacuum pumps and to install vacuum gauges capable of automated data collection.

The main tasks of the accelerator control system of the LINAC-200 accelerator are: control of operating parameters of accelerator equipment and testbeams, monitoring of beam parameters (position, profile, emittance, current, energy spread, etc.), radiation control, as well as protection of accelerator elements and staff in case of accelerator breakdown. The LINAC-200 ACS will be based on Tango-Controls SCADA [8]. Control of the main equipment of accelerating stations will be carried out with the help of Weltek Programmable Logic Controllers (PLC). Each accelerator station is operated by one PLC. It is planned to acquire information from RF gauges, vacuum gauges, diagnostic sensors and automated control of power supplies of bending magnets, quadrupole lenses, solenoids and corrective coils.

The beam diagnostics is carried out by means of set of detectors installed in drift tubes. The diagnostic system includes beam pickups to measure horizontal and vertical beam position, Compton beam loss detectors, inductive beam current monitor. Additionally, the focal spot monitor and beam profile measurement system can be used. To collect information from diagnostics sensors it is necessary to design the DAQ board capable to connect to ACS.

Testbeam construction

Currently, there are two testbeams to extract beam from the drift area after the accelerator station A01. One of these beam channels is intended for educational programs. The second testbeam allows carrying out studies with the electron energy of 20 MeV.

IConstruction of another testbeams is foreseen in scope of the project: from the drift area after the A03 accelerator station (electron energy of 130 MeV), A04 (energy of 200 MeV), A06 (energy of 350 MeV) and A08 (energy of 500 MeV). The energy spread of the beam should not exceed 1%. It should be possible to focus the beam with the size of the focal spot less than 1 mm, as well as the possibility of defocusing to ensure the uniform illumination in the area of 20 cm x 20 cm. The beam intensity should vary from the range from 1 to 10^{13} e^{-}/s and change in time by no more than 5% when carrying out measurements.

Each testbeam includes a bending magnet, quadrupole lenses to focus the beam, a horizontal and vertical collimators and a vacuum pipe with window for beam transportation and its output into the air. Each test beam must be equipped with the devices to measure and monitor the beam characteristics (energy, coordinates and direction, intensity). Calorimeters based on BGO, coordinate hodoscopes and detectors of beam profile measurement, Faraday cap and beam current monitors will be used for this purpose. Test beams should have the necessary set of supporting structures and positioning system for irradiation of detectors and local shielding for reduction of radiation loading and improvement of background conditions during the experiments.

A systematic study of beam characteristics and simulation to optimize measurement conditions is an important task in construction and tuning the testbeam channels.

Work plan

2018 (for reference) – Preparation of technical design report for upgrade of LINAC-200 facility and test beam construction

In 2019 the following tasks are planned to be accomplished:

- The upgrade of the vacuum system at A01-A04 stations
- The development and deployment of the ACS
- Equipping the two existing testbeams with the standard set of detectors
- Delivery of 200 hours of beam time for detector R&D
- Start of practice at the "training" beam

In 2020 the following tasks are planned to be accomplished:

- Installation and commissioning works at A05-A08 accelerating stations
- Construction of the testbeams after A03 and A05 stations
- Delivery of 300 hours of beam time for detector R&D

In 2021 the following tasks are planned to be accomplished:

- Installation and commissioning works at A09-A12 accelerating stations
- Construction of the testbeams after A08 and A11 stations
- Delivery of 500 hours of beam time for detector R&D

It is the renovation of the accelerator hall and the ventilation in building 118 which is crucial for the commissioning of the accelerator. These works are possible to do in parallel with the machine development, however the renovation may delay the project schedule a 3-4 months or longer, depending on the renovation funding and planning.

Educational program

The following practical activities can be performed at the "training" beam of the LINAC-200 facility: Installation and dismantling of vacuum equipment; study of magnetic optics (bending magnet, quadrupole lenses, sextupole); beam diagnostics, emittance measurement.

Moreover, at the LINAC-200 facility it is possible to carry out trainings to study the response of various particle detectors. In future, laboratory classes to measure electron scattering on nuclei, research of giant resonances, etc. are planned.

Human resources

All works in scope of the project will be carried out by the staff of the 4th sector of the Department of Colliding-Beam Physics. The project team is 18 FTE. The sector comprises two groups: Modulators and RF-systems group and technology group. In the course of the project it is foreseen to involve more young specialists in the field of accelerator, vacuum and RF-technics, electronics and automation.

Implementation of the educational program using the LINAC-200 facility will be carried out by the scientific and engineering group of the University Centre.

Short SWOT[1] analysis

Strengths of the project

1 SWOT – strengths and weaknesses, opportunities, threats

1. The LINAC-200 facility is the only source of test beams of high energy electrons at JINR. The project will completely meet the needs of scientific groups of the Institute (first of all, from LNP and LHEP) in electron beams for R&D of particle detectors developed at JINR.

2. The LINAC-200 is developed based on the MEA accelerator, which has a well-tried design and extensive operational experience. The first stage of the facility has already been mounted and the physical start-up of 220 MeV has been carried out. The project team has wide experience of installation and commissioning of elements of the accelerator, knows in detail with the design and characteristics of its individual units.

3. The facility can be used for educational purposes for training of personnel from JINR and Member States of the Institute.

Weaknesses of the project

1. The facility is based on the MEA accelerator, which was produced more than 40 years ago. Despite a number of upgrades made in NIKHEF, some units of the accelerator equipment are obsolete and need to be replaced. Some systems, in particular the accelerator control system, should be developed from scratch.

2. The team, carrying out the installation, commissioning and in future the operation of accelerators, needs the influx of young specialists in the field of accelerator technology, vacuum and RF-technology, electronics and automation.

Opportunities

1. It is possible to give access to test beams for scientific groups from JINR Member States.

2. The facility can be used for training of personnel in the field of accelerators, vacuum and RF-technology, readout electronics and automation, including training of students and improvement of skills of engineers and scientific employees.

3. It is technically possible to develop the synchrotron light source on the basis of the LINAC-200 facility and also increase the electron energy up to 2.0 GeV

Threats

1. Limitation of financing which will not allow completing commissioning works and manufacture of the equipment necessary for construction of electron testbeams.

2. Commissioning of the machine depends on the renovation of the accelerator hall and ventilation system in the building 118.

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Form №26

Proposed Time-Schedule and Necessary Resources
for implementation of Project
ELECTRON TESTBEAM FACILITY FOR DETECTOR R&D (LINAC-200)

Parts and systems of set-up, resources and sources of financial support.	**Cost of parts of set-up. Required financial support.**	**Profile proposed by Laboratory.**		
Main parts and equipment (kUSD)				
		2019	**2020**	**2021**
Materials	**75**	**25**	**25**	**25**
Equipment	**720**	**240**	**240**	**240**
A05-A12 station commissioning	240	80	80	80
clystron coils recovery	*60*	*20*	*20*	*20*
cooling and heat setting system	*180*	*60*	*60*	*60*
Accelerator upgrade	330	110	110	110
Vacuum pumps replacement	*240*	*80*	*80*	*80*
Monitoring and control	*60*	*20*	*20*	*20*
Beam diagnostics	*30*	*10*	*10*	*10*
Testbeam construction (4 beams)	150	50	50	50
Magnets and collimators	*54*	*18*	*18*	*18*
Detectors	*36*	*12*	*12*	*12*
Vacuum pipes, valves and windows	*60*	*20*	*20*	*20*
Travel costs	**10**	**2**	**4**	**4**
Necessary manpower support (man-hours)				
JINR Central workshop:	–-	–	–	–
LNP: - workshop; - design bureau	3000	1000	1000	1000
Accelerator, Reactor	–-	–	–	–
Computer	–-	–	–	–
Maintenance & Operational	–-	–	–	–
Sources of financial support (kUSD)				
JINR budget	805	267	269	269
Extra – budgetary (grants, agreements, sponsors etc.)	–-	–	–	–

Project Leader V.Kobets

Deputy Project Leader M.Gostkin

Form №29

1. Financial Resources Needed for Project realization

ELECTRON TESTBEAM FACILITY FOR DETECTOR R&D (LINAC-200)

No	TASKS	Total value	2019	2020	2021
	Direct costs of the Project				
1	Accelerator, reactor	–	–	–	–
2	Computer	–	–	–	–
3	Materials	75	25	25	25
4	Equipment	720	240	240	240
5	R&D	–	–	–	–
7	Travel resources				
	a) in non-ruble area	5	1	2	2
	b) in ruble area	5	1	2	2
	Total direct cost:	**805**	**267**	**269**	**269**

Project Leader V. Kobets

Deputy Project Leader M. Gostkin

Director of the Laboratory V.Bednyakov

Main planning engineer of the Laboratory G.Usova