BEAMS OF THE DUBNA SYNCHROPHASOTRON AND NUCLOTRON*

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In the March'93 the first commissioning run of the Nuclotron, a novel superconducting accelerator of nuclei, has been carried out at the Laboratory of High Energies of the Joint Institute for Nuclear Research. The first experiment on its internal target has been performed already in July. Thus, two accelerators, Synchrophasotron and Nuclotron, having a common injector and a common set of external beam lines, can further provide physics experiments with various beams. Both a brief description of the accelerator facility and of the beams parameters are given in this paper. The main beam lines are also shown.

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1.

The phenomena of relativistic nuclear physics are the main subject of research at the Laboratory of High Energies (LHE). These investigations dated from 1970 when relativistic deuterons (10 GeV) were first obtained at the Dubna Synchrophasotron. Although next light nuclei were also accelerated later on, the Laboratory saw its perspective in the construction of a new superconducting accelerator of nuclei named the Nuclotron. The construction of the Nuclotron was performed during 1987–1992, after a wide program of research and design in various relevant fields. In the March'93, the first commissioning run of the novel machine has been successfully carried out [1, 2]. Experiments on the Nuclotron internal target are planned

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to begin this year using a specially prepared setup [3]. The test run with 200 MeV/nucleon deuterons has been already done in July. Thus, the two laboratory accelerators can further work for physics.

2.

A general plan of the LHE accelerator centre is shown in Fig. 1. The Nuclotron is placed in the Synchrophasotron building in the existing ground floor tunnel (the distance between the middleplanes is 3.7 m). Contrary to the Synchrophasotron, it is a strong focusing separated function machine. The Nuclotron lattice consists of 96 dipoles, 64 quadruples and a set of auxiliary elements grouped in 8 superperiods [4].

The superconducting elements are cooled by two helium liquefiers KGU–1600 with a capacity of 1.6 kW each [2]. The main parameters of both accelerators are given in Table I. At the first stage the Nuclotron will operate with the Synchrophasotron injector–linac LU-20 and four types of alternatively used ion sources: a duoplasmotron (p, d, α), a laser, electron-beam (nuclei) and polarized deuteron sources. The intensities of the beams, at a maximum energy, currently available and those to be obtained from the nuclotron in the nearest future, are listed in the first and second columns of Table II [5]. The last line in the column "Synchrophasotron" — sulphur nuclei — is quite the recent result which is a next sequent step in the development of the injector base [6].

TABLE I

Parameter	Units	Synchro-phasotron	Nuclotron
Energy (max)	A GeV	4	6
Repetition rate	p.p.s.	0.12	0.5 - 1
Extraction time (max)	s	0.5	10
Vacuum	Torr	10^{-6}-(10^{-7})	10^{-10}-10^{-11}
Magnetic field (max)	T	1.1	2.1
Circumference	m	208	252
Chamber size	cm	120	12
Extracted beam emittence	mm mr		
ε_{hor}		35π	2.5π
ε_{ver}		40π	2.0π

TABLE II

Beam	Intensity, particles per cycle		
	Synchrophasotron (now)	Nuclotron (plan)	Nuclotron+Booster (plan)
p	$4 \cdot 10^{12}$	$1 \cdot 10^{11}$	$1 \cdot 10^{13}$
d	$1 \cdot 10^{12}$	$5 \cdot 10^{10}$	$1 \cdot 10^{13}$
d↑	$1 \cdot 10^{9}$	$3 \cdot 10^{8}$	$1 \cdot 10^{11}$
^{3}He	$2 \cdot 10^{10}$		
^{4}He	$5 \cdot 10^{10}$	$5 \cdot 10^{9}$	$2 \cdot 10^{12}$
^{7}Li	$2 \cdot 10^{9}$	$2 \cdot 10^{10}$	$5 \cdot 10^{12}$
^{12}C	$1 \cdot 10^{9}$	$7 \cdot 10^{9}$	$2 \cdot 10^{12}$
^{16}O	$5 \cdot 10^{7}$		
^{20}Ne	$1 \cdot 10^{4}$	$1 \cdot 10^{8}$	$5 \cdot 10^{9}$
^{24}Mg	$5 \cdot 10^{6}$	$3 \cdot 10^{8}$	$5 \cdot 10^{11}$
^{28}Si	$3 \cdot 10^{4}$		
^{32}S	$3 \cdot 10^{3}$		
^{40}Ar		$3 \cdot 10^{7}$	$2 \cdot 10^{9}$
^{56}Fe			$1 \cdot 10^{11}$
^{84}Kr		$2 \cdot 10^{7}$	$5 \cdot 10^{8}$
^{96}Mo			$1 \cdot 10^{10}$
^{131}Xe		$1 \cdot 10^{7}$	$2 \cdot 10^{8}$
^{181}Ta			$1 \cdot 10^{8}$
^{238}U		$3 \cdot 10^{6}$	$1 \cdot 10^{8}$

3.

The great advantage of the LHE accelerator facility is the presence of the extraction systems and a broad net of external beam lines. There are two directions (labelled MV-1 and MV-2 in Fig. 1) of beam extraction from the Synchrophasotron. Along the first direction the beams are slowly extracted and transported to the experimental area in hall 205. Extraction can be done up to a maximum energy with a duration of 0.5s and an efficiency of 95%. Along the second direction, either fast ($T_{\text{extr}} < 10^{-3}s$) or slow ($T_{\text{extr}} = 0.35s$) extraction can be done. The physics setups in experimental hall 1B are supplied with the beams of this direction. Both extractions can operate simultaneously in the same accelerator cycle. At the first stage, the beams from the Nuclotron will be only ejected to experimental hall 205.

A layout of the beam lines in this hall is shown in Fig. 2. Eight beam lines, namely the main beam line VP-1 and seven lateral 1V–7V, provide ten physics setups with beams. The VP-1 beam line transfers particles from the crossover F3 (the final point of slow extraction MV-1) through the

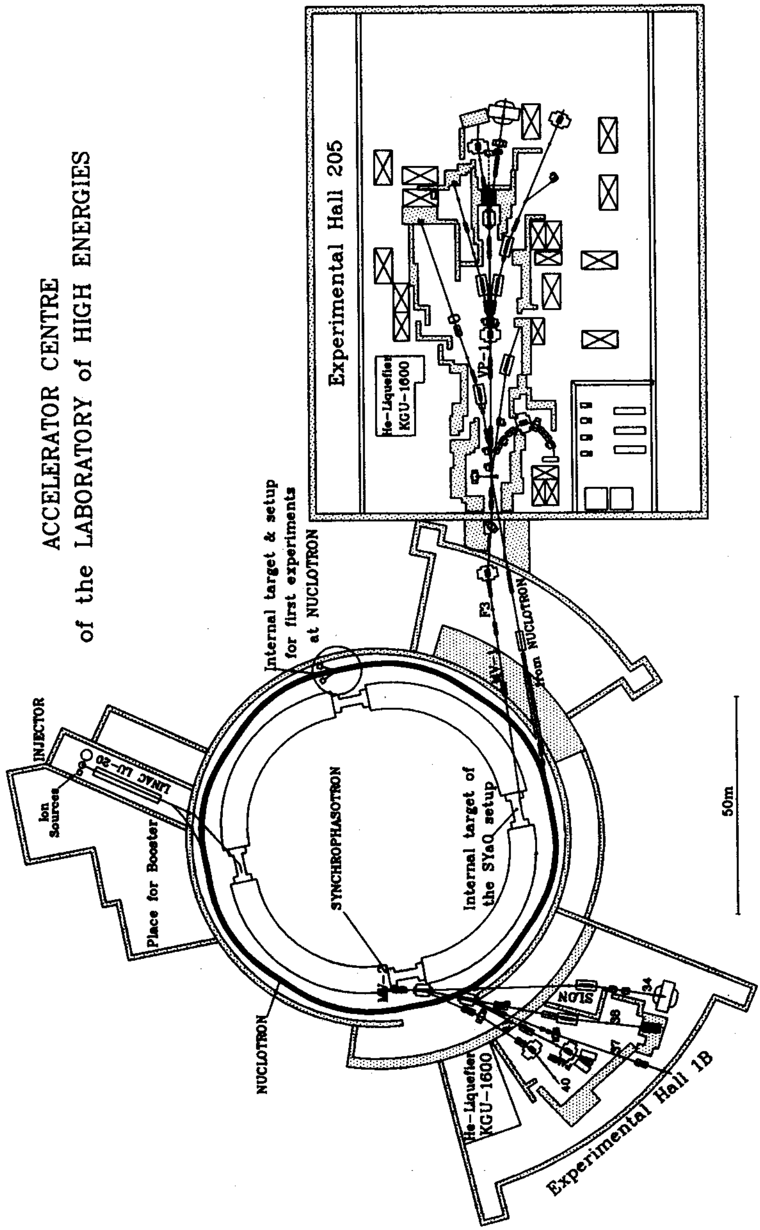
ACCELERATOR CENTRE
of the LABORATORY of HIGH ENERGIES
Experimental Hall 205
He-Liquefier
KGU-1600
VP-1
Internal target & setup
for first experiments
at NUCLOTRON
F3
from NUCLOTRON
INJECTOR
Ion
Sources
LINAC LU-20
Place for Booster
SYNCHROPHASOTRON
Internal target of
the SYaO setup
50m
NUCLOTRON
He-Liquefier
KGU-1600
SIDN
Experimental Hall 1B

Fig. 1

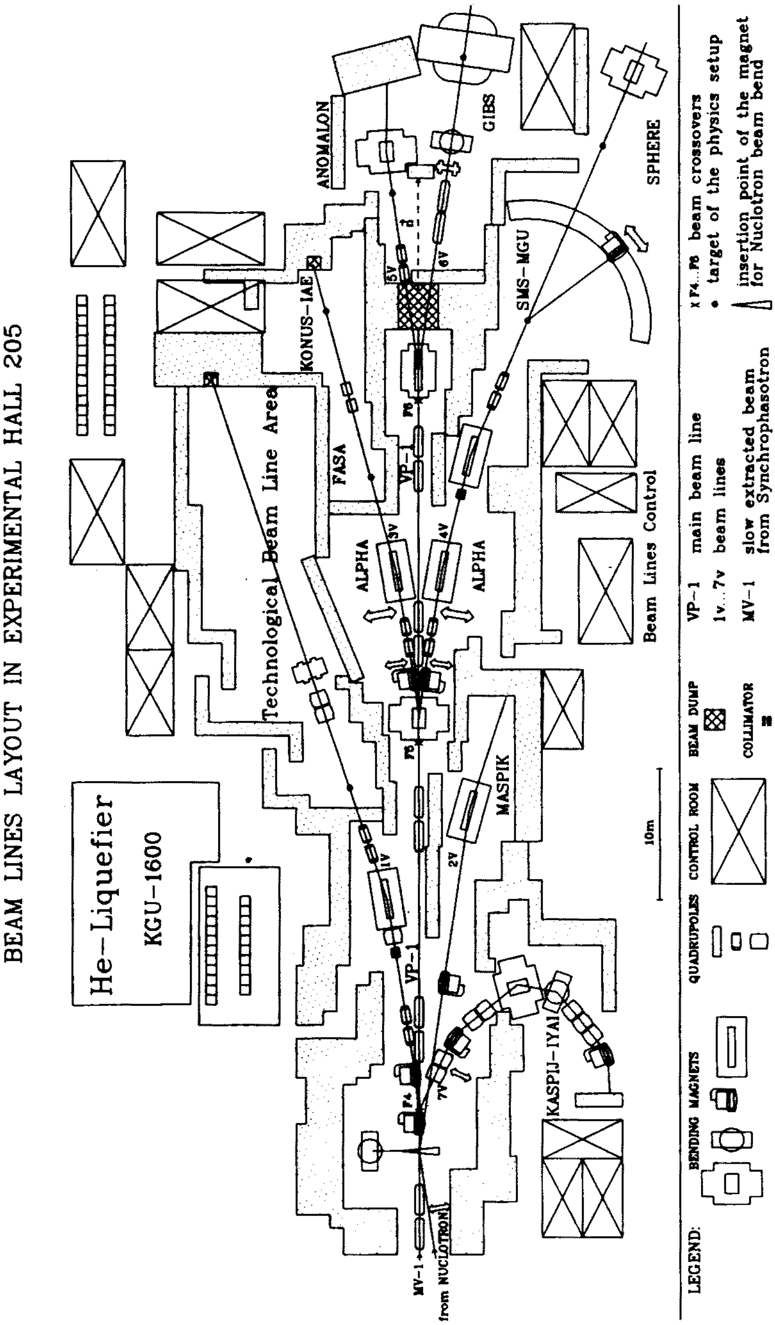
BEAM LINES LAYOUT IN EXPERIMENTAL HALL 205
He-Liquefier
KGU-1600
Technological Beam Line Area
KONUS-IAE
FASA
ALPHA
ALPHA
ANOMALON
GIBS
SPHERE
SMS-MGU
MASPIK
KASPIJ-IYAI
Beam Lines Control
MV-1
from NUCLOTRON
VP-1
10m
LEGEND:
BENDING MAGNETS
QUADRUPOLES
CONTROL ROOM
BEAM DUMP
COLLIMATOR
VP-1 main beam line
1v...7v beam lines
MV-1 slow extracted beam from Synchrophasotron
x F4...F6 beam crossovers
• target of the physics setup
insertion point of the magnet for Nuclotron beam bend

Fig. 2

experimental hall to the beam dump, and other three crossovers (F4, F5, F6) are formed. Some VP-1 parameters are the following:

- total length — 90 m,
- number of magnet elements — 17,
- aperture — 200 mm,
- full beam sizes at the crossovers at a maximum energy
  — 15 mm×30 mm — Synchrophasotron,
  — 3 mm×6 mm — Nuclotron (expected).

A powerful concrete shield allows one to work on the VP-1 at any available intensities and with any targets. Primary nuclei are usually used in most physics experiments, and the beams are simply transferred from points F4 – F6 to the setup targets through the lateral beam lines. But traditional secondary beams (pions *etc.*) can be also created. The 1V, 4V and 7V beam lines, having the corresponding optics, are most suitable for these purposes.

The configuration of the VP-1 line makes it possible to form beams of nuclei fragments at a 0 degree: the target is at the F3 point, the channel is adjusted to the corresponding momentum. As an example, we give the tritium beam data:

- incident beam — 10^9 of 3 GeV/c/nucleon α-particles,
- target — 10 g/cm^2 of polyethylene,
- flux of 3 GeV/c/nucleon tritium at the GIBS setup (beam line 6V) — $5 \cdot 10^5$.

The same scheme is used in some polarization experiments. In this case incident particles are polarized deuterons and fragments are protons polarization of which is measured [7, 8].

In the frame of the LHE polarization program, a polarized neutron beam is being prepared. The neutron production target is placed at the F6 point. Charged particles, including noninteracting primary deuterons, are bent to a solid part of the VP-1 beam dump by the following magnet. Neutrons fly through the collimator hole 3.5 m long and 3 cm in diameter in the same dump [9]. The conditions and the result of the last test run are the following:

- incident beam — 10^9 of 4.5 GeV/c/nucleon deuterons,
- target — $(CH)^k$ 20 cm long,
- neutron flux — 10^6 through a 2.5 cm diameter spot at a 15 m distance from the target,
- charged impurity — 5% from the neutron flux.

One of the beam lines, technological beam line (1V), is specially prepared for the applied purposes. It has a large area for experimental equipment. Any available beam can be used here.

There are five beam lines in experimental hall 1B. This area is intended for fundamental and applied investigations at intermediate energies of the Synchrophasotron.

4.

The next step of development of the LHE accelerator facility will be the modernization of the injector system [10]. The construction of a booster-accumulator with an energy of $200 \cdot A$ MeV must be an essential part of this program [11]. The values in the last column of Table II are beam intensities which will be obtained after this work. The emittence and momentum spread of the beams will decrease by a factor of 10–100 by electron cooling. The booster can be used as an independent high-quality accelerator at intermediate energies.

More far future of the LHE is connected with the Supernuclotron project [10]. The $60 \cdot A$ GeV superconducting synchrotron, and then the $2 \times 60 \cdot A$ GeV nuclear collider are to be constructed according to this project. The complement of a 4–10 GeV electron accelerator to the Supernuclotron is also discussed [12].

In conclusion, the main features of the LHE accelerator facility should be emphasized:

- wide set of nuclei and secondary particles,
- operation at relativistic and intermediate energies,
- internal target operation at high luminosities in 4π–geometry,
- flexibility in external beam experiments,
- large experimental area,
- well-developed cryogenic and production facilities,
- moderate cost of accelerator time.

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