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ОБЪЕДИНЕННОГО
ИНСТИТУТА
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ИССЛЕДОВАНИЙ

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EXPRESSION OF INTEREST IN THE DUBNA NUCLEON-ELECTRON ACCELERATOR COMPLEX

1997

This is the first expression of interest in building the new JINR's basic facility (Dubna Nucleon-Electron Accelerator Complex) on the basis of the accelerator SATURNE II (Saclay, France) which is to be closed and dismounted in 1998. The basic idea is that this machine not only could be used with very limited effort and investment, as a good proton accelerator, but also opens up new opportunities for nuclear physics with heavy ions, condensed matter investigations and particle physics with electron-positron colliding beams.

I. SATURNE accelerator complex. The general parameters and options. Physics at SATURNE

The Dubna Nucleon- Electron Accelerator Complex (DUBNEAC) is proposed to be built on the basis of the SATURNE II synchrotron and the MIMAS booster [1], whose parameters are given in Table 1. The new complex will consist of 2 rings (Fig.1), 2 injector linacs and include, as a possible option, the existing synchrocyclotron "Phasotron" as the ion injector (after its modification). The straight sections of both rings are to be lengthened and the lattice is to be modified in accordance with the new functions of the DUBNEAC described below. A great advantage of both rings is the large aperture (acceptance), which is planned to be used in the new complex design. All these options need more attentive and detailed studies. The very tentative consideration and numerical application presented here show that the new complex can be designed and constructed as a multifunction experimental facility providing a great variety of experiments at different set-ups.

Table 1. Parameters of the SATURNE II synchrotron and MIMAS booster.
The extracted beam mode

Parameters	SATURNE II	MIMAS
Circumference, m	105.55	36.78
Bending radius, m	6.5	1.1
Weight, t	640	42
Straight section length, m	8	2.034
Magnetic rigidity, T×m	12.5	1.0
Aperture, mm×mm	200 *100	200*150
Number of dipoles	16	8
Number of quads	24	16
Energy range, GeV		
protons	0.1-2.95	45 MeV/u
deuterons	0.1-2.3	12 MeV/u
light ions	0.05-1.15	12 MeV/u
Beam intensity,		
particle number/cycle		
unpolarized protons	$6.1*10^{11}$	$6.1*10^{11}$
polarized protons	$2.1*10^{11}$	$2.1*10^{11}$
polarized deuterons	$3.1*10^{11}$	$3.1*10^{11}$
Power consumption, MW	3	0.5
Peak current in dipoles, kA	4.5	2
Cycle duration, s	1-7	depends on Saturne
Flat top duration, s	1	0.5
Vacuum, Torr	10^{-9}	10^{-11}
Baking temperature, deg, C	100	300

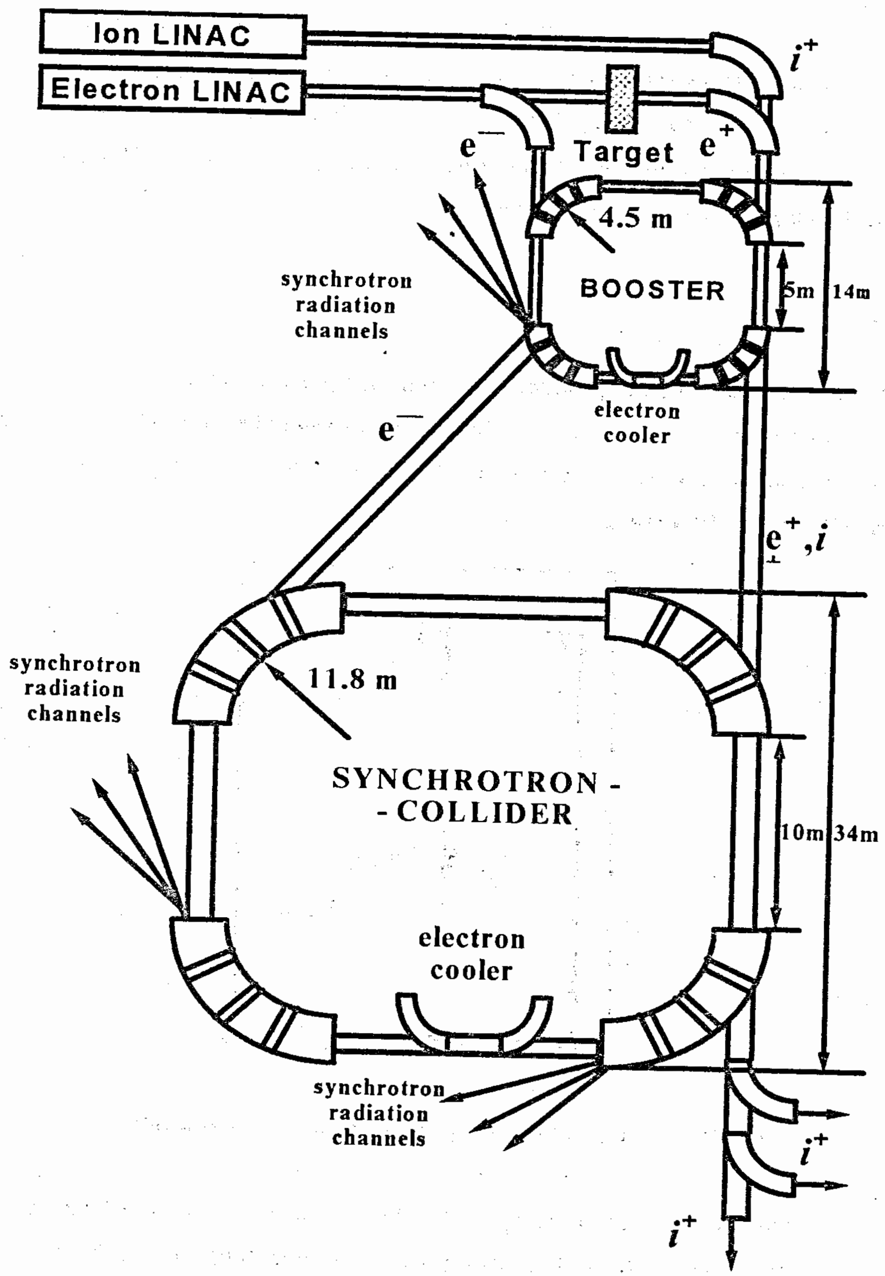

Fig. 1. Dubna Nucleon- Electron Accelerator Complex

As is seen from Table 1, SATURNE II provides a lot of possibilities for experiments with extracted beams. It is very obvious that the potential of this accelerator is far from being exhausted. As an impressive example one could mention the possible use of this machine as a factory of η-mesons [2]. It means that tagging of ^{3}He from the reaction

$$p\,d \rightarrow {}^{3}He\ \eta \qquad (1)$$

near the threshold one can produce a very pure sample of η-mesons.

An extremely small level of the background to signal ratio (~1% as it is seen from Fig.2) is due to a very monochromatic external proton beam from SATURNE ($\Delta E/E = 4\times10^{-4}$).

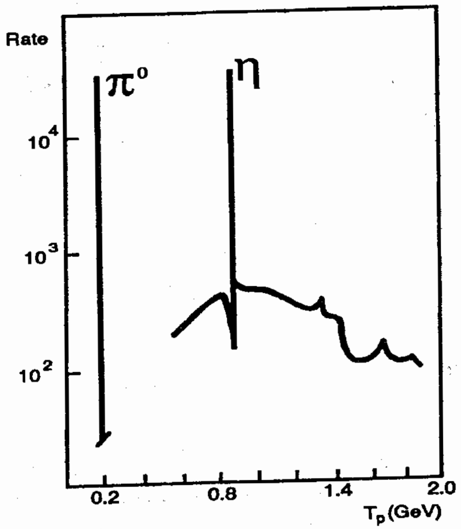

Fig.2. Events rate versus the beam kinetic energy in reaction (1)

Systematic study of η-decays not only can improve our knowledge in the field of low-energy QCD, but also provides a possibility of probing "non-standard" physics by searching for decays suppressed or forbidden in the Standard Model (e.g. $\eta \rightarrow e^+e^- / \mu^+\mu^-$, $\eta \rightarrow e\mu$, etc.). It must be mentioned that the experiment on the study of η-decays has been proposed at SATURNE with the participation of JINR, but this challenging task has not been performed mainly because too short time till the closure of SATURNE.

One more interesting physical issue is connected with the recent understanding of the intrinsic strangeness of the nucleon. As was motivated in several papers (see, e.g., [3] and [4]) the nucleon not only contains a considerable part of $s\bar{s}$ pairs, but this "strange component" of the nucleon is polarised.

This assumption leads to very interesting consequences in the strangeonium (ϕ-meson) production cross-section, namely the very different yields of ϕ-mesons in parallel or opposite spin orientations of colliding nucleons [5].

We know that the η-meson contains a considerable fraction of the $s\bar{s}$-state. As the probabilities of its formation as $q\bar{q}$- and $s\bar{s}$-pairs in hadron interactions are of the same order [6], one can expect that the cross section of reaction (1) will depend on the mutual polarisation of the incident proton and the target deuteron. Then measuring the yields of η with the polarised beam on polarised target can serve as a probe for the strange polarised component of the nucleon.

These are only few examples to show a very interesting physics programme which can be implemented at SATURNE as it is now, i.e. as high quality proton accelerator.

II. Ion storage ring mode

In this project heavy ions are supposed to be generated and accelerated by a linac up to an energy of 5 MeV/u (β=0.1). Then they are injected in the Booster ring (MIMAS) and after cooling and storing are injected in the Synchrotron - Collider ring (SATURNE). In the ion storage ring mode DUBNEAC can resolve many of the problems proposed for the K4- K10 project [7]. One can hope to have light ions in the Synchrotron ring at energy 1.2 GeV/u and the heaviest ones, like $^{238}U^{92+}$, at energy 0.8 GeV/u.

The number of ions stored in both rings is strictly limited by the development of the longitudinal instability and the resonances of the betatron oscillations, when the beam space charge becomes large. The thresholds of all these instabilities depend on the beam emittance and momentum spread, which are determined by the competition between the damping influence of electron cooling and the heating effect of intrabeam scattering. The equilibrium between all these phenomena gives us the magnitudes of the stable beam parameters (Table 2). Electron cooling permits one to obtain circulating particle beams with small emittance and low momentum spread (Table 2). At other hand, it substantially restricts the beam intensities. If necessary, one can increase intensity at the sacrifice of the beam quality. In this case the full acceptance of both rings can be used (Table 3).

Table 2. Monochromatic ion beams

Parameter	Booster			Synchrotron collider		
	Protons	Light ions A/Z=2, Z=8	$^{238}U^{92+}$	Protons	Light ions A/Z=2, Z=8	$^{238}U^{92+}$
Energy, GeV/u	0.045	0.011	0.006	2.95	1.2	0.8
Emittance, π mm mrad	0.1	0.1	0.1	0.1	0.1	0.1
Momentum spread, 10^{-4}	2	2	2	1	1	1
Intensity	10^{10}	$4*10^{8}$	$3*10^{7}$	10^{12}	$5*10^{10}$	$3*10^{9}$

Table 3. Intense ion beams with large emittance

Parameter	Booster			Synchrotron collider		
	Protons	Light ions A/Z=2, Z=8	$^{238}U^{92+}$	Protons	Light ions A/Z=2, Z=8	$^{238}U^{92+}$
Energy,GeV/u	0.045	0.011	0.006	2.95	1.2	0.8
Emittance, π mm mrad	500	500	500	500	500	500
Momentum spread, 10^{-2}	1	1	1	1	1	1
Intensity	$6*10^{11}$	$3*10^{10}$	$5*10^{9}$	10^{12}	10^{11}	$8*10^{9}$

The luminosity of the ion storage ring with a circulating beam in the presence of electron cooling and an internal target is determined by the beam intensity and the target thickness (Table 4).

Table 4. Luminosity of the ion beam interacting with the internal target of thickness 10^{14} atoms/cm^2 in the Synchrotron ring

Particles	Emittance, 0.1 π mm mrad
Number of protons Luminosity, cm^{-2} s^{-1}	$6*10^{11}$ $1.5*10^{32}$
Number of light ions (A/Z=2, Z=8) Luminosity, cm^{-2} s^{-1}	$5*10^{10}$ 10^{31}
Number of heavy ions ($^{238}U^{92+}$) Luminosity, cm^{-2} s^{-1}	$3*10^{9}$ $6*10^{29}$

III. The electron- positron collider

The project of building an electron-positron collider in Dubna is well known under the name of JINR's c-tau factory. A lot of investigations have been performed last years on physics to be covered, a machine conceptual design and a universal detector for this facility [8].

Our first estimation shows that the MIMAS+SATURNE complex with an electron linac could provide the electron-positron collider mode with parameters very close to those of the c-tau factory. The research programme for the c-tau factory includes τ-lepton and τ-neutrino physics, charmonium, charmed baryon physics and meson spectroscopy [8]. To remind you of the physics reach of the machine in Table 5 we list rates for production of various particles per second and per year. These rates are consistent with the luminosity of 10^{33} cm^{-2}c^{-1}.

Table 5. Production rates for various particles

Type of particle	E_{cm}, GeV	Production frequency	Events per year (10^7 s)
J/Ψ	3.10	1000	10^{10}
Ψ'	3.69	600	6×10^9
$\tau^+\tau^-$	3.57	0.4	4×10^6
$\tau^+\tau^-$	4.25	4	4×10^7
$D^+D^-(D^+\overline{D^0})$	Ψ''(3.77)	2	2×10^7
$D_s^+D_s^-(D_sD_s^*)$	4.03	0.7	7×10^6

The general layout of the electron-positron collider is the following.

Electrons are to be injected from an electron linac with an energy of 40 MeV. Positrons are to be generated in a target by the electron beam from the linac at an energy of 15 MeV, collected by a wide aperture lens, and accelerated in the other sections of the linac up to 40 MeV. Multicycle storing in the Booster permits one to reach the positron beam intensity of the order of

5*10^{10} particles/bunch at this energy. The maximal electron and positron energy after acceleration in the Booster is equal to 300 MeV (γ=600) and 3.8 GeV in the Synchrotron (γ=7560) in accordance with the magnetic rigidity of the Booster and Synchrotron- Collider rings (Table 1).

The particle oscillation damping provided by the synchrotron radiation helps to keep the beam stability at a very high intensity, which opens up a possibility of storing positrons in the Booster and in the Synchrotron- collider at the corresponding injection energy. The lattice of the electron Booster ring has to allow a high increase in the electron beam emittance. In this case an arc with FODO optics can be used. The lattice of the Synchrotron electron ring has to allow an essentially reduced electron beam emittance to reach high luminosity.

Lifetime due to intrabeam scattering (Touschek lifetime) is estimated to be 3h. for the electron beam of initial size $a_e \approx 3$mm, $\Delta p/p = 5\cdot10^{-3}$ and γ=600. For IBS compensation one can use the superconducting wiggler (B=5 T) in the electron Booster ring. The number of electrons per bunch in the Synchrotron-collider is determined by the beam-beam effects and limited by development of single bunch instability or turbulent bunch lengthening. The first one can be significantly reduced when the beam separation is used inside the large ring aperture (Table 6). The results of the estimations show, that possible luminosities are of great practical interest.

Table 6. Parameters of the electron- positron collider

Ring	Booster	Synchrotron-Collider	
Energy, GeV	0.3	1.5	3
Number of e^- and e^+ per bunch	3*10^{10}	2*10^{11}	
Number of e^- and e^+ in ring	2.4*10^{11}	8*10^{11}	
Number of bunches in ring	8	4	
Beam current, mA	320	350	
Luminosity, cm^{-2} s^{-1}		5*10^{32}	10^{33}
β_{coll}, cm		2,5	

IV. Electron-ion collider

Electron scattering is a powerful tool in nuclear physics. With the possibility storing of radioactive nuclei in one storage ring and electrons in another and performing colliding beam experiments, elastic electron scattering from a variety of unstable nuclei becomes possible. However, as compared with hadronic cross sections, the corresponding electron scattering cross sections are roughly two orders of magnitude smaller and therefore high luminosities are necessary.

An electron-ion collider project [9] is considered for studying of the radioactive nucleus charge distribution, nuclear momentum distribution and nuclear spectroscopy. A similar application is possible for DUBNEAC in the asymmetric electron- ion collider mode. One electron bunch, stored in the electron ring Booster, collides with a few ion bunches (Fig.3), stored in the Synchrotron-Collider ring.

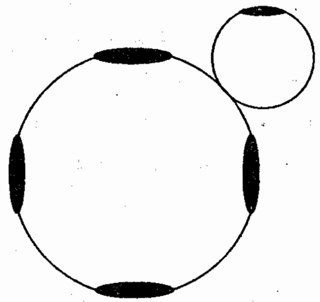

Fig. 3. Asymmetric electron - heavy ion collider

To satisfy the synchronisation conditions for the ion and electron beams, the number of ion bunches is to be equal to n= 4 at the circumferences $C_i \approx 115$ m, and $Ce \approx 40$m, when E/A=0.75 GeV/ u for $^{238}U^{92+}$.

The luminosity is restricted by the number of electrons per bunch N_e and the ion number. These values are determined mainly by the beam-beam effects (Table 7a,b).

The number of ions in the coasting beams can be increased by several times (Table 7b). The luminosity of the coasting ion beams (Z=8) is of the order of $L=10^{29}$ cm^{-2} s^{-1} for copropagating beams and $L= 10^{28}$ cm^{-2} s^{-1} for counterpropagating beams.

Table 7a. Parameters of the electron beam in the Booster ring

Energy, MeV	300
Emittance, π mm mrad	0.5
Intensity	$2*10^{11}$
β_{coll}, cm	50

Table 7b. Parameters of the ion beams in the Synchrotron collider

Parameter	Bunched beam		Coasting beam	
Particles	Light ions A/Z=2, Z=8	$^{238}U^{92+}$	Light ions A/Z=2, Z=8	$^{238}U^{92+}$
Energy, MeV/u	1250	750	1250	750
Emittance, π mm mrad	1		1	
Intensity	10^{10}	$7*10^{8}$	$5*10^{10}$	$3*10^{9}$
Luminosity, $cm^{-2}s^{-1}$	10^{29}	$5*10^{27}$	10^{29}	$4*10^{27}$
β_{coll}, cm	50		50	

V. Synchrotron radiation mode

Both rings of DUBNEAC can be used as generators of synchrotron radiation (SR). At different values of the electron energies available with the rings the maximum of the SR intensity lies in a wide range of the wavelength (Table 8).

The power of SR varies from hundred of watts (Booster maximal energy) up to 220 kW (Synchrotron- collider the energy 3 GeV). An application of wigglers is certainly possible, which will enrich the conditions of the experimental studies with SR use.

Table 8. Parameters of the synchrotron radiation available with the DUBNEAC rings

Parameter	Booster	Synchrotron collider	
Electron energy, MeV	300	300	3000
Electron number	$1.5*10^{11}$	$5*10^{11}$	$5*10^{11}$
Electron beam current, A	0.2	0.2	0.2
Emittance, nm	40	40	400
SR wave length at spectrum maximum, nm	30	180	0.18
SR energy, keV	$4*10^{-2}$	$6.6*10^{-3}$	6.6
SR power, kW	0.13	0.015	220
Energy loss /turn, keV	0.65	0.1	1000
Brilliance, $\frac{photons\ per\ sec}{(mrad)^2(mm)^2 0.1\%\ bandwidth}$	$5*10^{16}$	$3*10^{16}$	$5*10^{17}$

VI. Superslow extraction

Electron cooling gives some new possibility of superslow extraction of particles via recombination of ions with the cooling electrons. As a result, one can obtain, for instance, a flow of neutral hydrogen of energy 2.95 GeV and intensity $5*10^6$-10^7 H^0/sec. In this case 10^{12} protons cooled and stored in the Synchrotron ring will be extracted during 30-60 hours. The density of the electron cooling beam is about $5*10^7$-10^8 cm^{-3} for theses experiments. The electron temperature is comparable with 0.1 eV. One can develop special electron target with very high

(up to 10^{10} cm^{-3}) electron density and small electron beam diameter (keeping total beam current very modest). This will enhance the H^0 generation rate up to $5*10^8$ H^0/sec.

Conclusion

The proposed DUBNEAC complex will permit one to generate various particle beams in the following energy ranges (Table 1, 9).

Table 9. Parameters of particles in DUBNEAC

Particles	Energy
Protons	45 MeV - 2.95 GeV
Light ions, A/Z=2	11 MeV/u - 1.2 GeV/u
Heavy ions, $^{238}U^{92+}$	6.6 MeV/u - 0.8 GeV/u
Electrons, positrons	0.3- 3.8 GeV

The luminosity for different modes of the Dubna Nucleon-Electron Accelerator Complex are summarised in Table 10.

Table 10. Luminosity of Dubna Nucleon- Electron Accelerator Complex

Collision mode	Luminosity cm^{-2} s^{-1}
1) Ion collisions with internal target	
Protons	10^{32}
Light ions	10^{31}
Heavy ions ($^{238}U^{92+}$)	$5*10^{29}$
2)Electron- positron collider	10^{33}
3) Electron - heavy ion collider ($^{238}U^{92+}$)	$5*10^{27}$
(A/Z=2, Z=8)	10^{29}

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Мешков И.Н., Русакович Н.А., Сыресин Е.М. E9-97-132
О возможности создания
дубненского накопительно-ядерного комплекса

Представлено первое предложение о сооружении в ОИЯИ нового комплекса ускорителей. Схема комплекса позволяет использовать его в нескольких вариантах — как ускоритель с выведенными пучками, ионный накопитель, электрон-позитронный и электрон-ионный коллайдеры в области энергий заряженных частиц 1 — 3 ГэВ. Новый комплекс предполагается создать на основе синхротрона SATURNE II и бустера МИМАС (Сакле, Франция), которые будут закрыты в 1998 году. Проект комплекса включает два кольца и два инжектора на основе линейных ускорителей.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Expression of Interest
in the Dubna Nucleon-Electron Accelerator Complex

The first proposal of the Dubna Nucleon-Electron Accelerator Complex is presented. The complex scheme proposed here permits one to realize several operation modes: with extracted beams, as a nucleon storage ring complex, the electron-positron and electron-heavy ion collider modes in the particle energy range of 1 — 3 GeV. The new complex is proposed to be built on the base of the SATURNE II synchrotron and the MIMAS booster (Saclay, France), which is to be closed and dismounted in 1998. It will consist of 2 rings and 2 injector linacs.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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