ELECTRON-POSITRON COLLIDERS AT NOVOSIBIRSK

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Abstract

INP has been developing colliders for over 30 years. The ®rst experiments on scattering electrons on electrons at large angles were started at the ®rst electron-electron collider at an energy of 2 x 130 MeV already in 1964. A year later the ®rst in the world electron-positron collider VEPP-2 was put into operation, and in 1966 the ®rst results of the phi-meson decays was published. Since then INP created VEPP-3 and VEPP-4 which were later modernized into VEPP-2M and VEPP-4M. The energy in the centre-of-mass system of these machines ranged from 400 MeV up to 12 GeV. Starting from the ®rst experiments on electron-positron colliding beams we have gone through the luminosity range of $10^{24} cm^{-2} sec^{-3}$ to $310^{31} cm^{-2} sec^{-1}$. A big amount of information and experimental results obtained on these machines have been published in Particle Data.

In 1986 we have started to develop colliders of a new class, i.e. electron-positron colliders, like B- and Phi-factories (VEPP-5). Unfortunately, the beginning of this work coincided with the launch of Perestrojka in Russia, and the rate of ®nancing, and whence, the construction rate of these machines was slowed down.

In 1993 following the recommendation of the International Program Committee for high energy physics of the Russian Ministry of Science the construction of the B-factory was cancelled and it was recommended to develop a C-tau-factory. The present report shows the status of the VEPP-2M, VEPP-4M and VEPP-5 facilities.

I. VEPP-2M

In 1989 due to the modernization of VEPP-2 there appeared a BEP cooling storage ring in the complex and a new VEPP-2M hard focus collider at a maximum enegy of the beam of 2×670 MeV. Since then this collider has the luminosity best recorded in the world in this energy range $310^{31} cm^{-2} sec^{-1}$. During the run time of this collider it accumulated an integrated luminosity of 20 reverse picobarn. At present the experiments are carried out at two detectors, KMD-2 and SND. The nearest two years will be devoted to the experiments on the precision measurement of hadron cross sections for estimating the contribution of the hadron polarization to the g-2 muon, as well as the study of rare decay modes of light vector mesons and the preparation for the experiments on the study of CP-violation at the Phi-factory.

A. ROUND BEAMS IN THE VEPP-2M COLLIDER

The Novosibirsk project of the Phi-factory is based on the idea of round beams [1]. There are many agruments in favor of this method of attaining high luminosity. Nevertheless, the ®nal conclusion on the validity of this idea can be made only on the basis of experimental tests. Such a validity test is planned to be carried out at the VEPP-2M facility after its modernization. The necessary changes in the lattice provide for a substitution of superconducting solenoids for quadrupole dublets in the experimental sections (Fig. 1). Like in the Novosibirsk project of the Phi-factory, here the solenoids also perform two functions. First, they allow for obtaining equal betta-functions at the interaction points, second, they turn the betatron oscillation planes by $\pi/2$, which is required for the non-resonant formation of the phase space in both directions. In the case of the round beam optics as compared to the current optics the dispersion function in the experimental sections is equal to zero. In this case it does not only improve the conditions for the beam-beam effects, but also reduces the number of the background particles reaching the detectors. After the modernization the anticipated luminosity at an energy of a phi-meson is $0.5 - 1.0 \times 10^{32} cm^{-2} sec^{-1}$ [2].

Peremeters	¯at beam	round beam
Circumference, m	17.88	17.88
RF frequence, MHz	200	200
Momentum compaction	0.167	0.18
Emittances, cm/rad	4.6×10^{-5} 5.5×10^{-7}	1.5×10^{-5} 1.5×10^{-5}
Energy loss/turn, keV	9.1	5
Dimensionless damping decrements	4.4×10^{-6} 3.8×10^{-6} 9.4×10^{-6}	8.2×10^{-6} 8.2×10^{-6} 2×10^{-5}
Energy spread	6×10^{-4}	3.5×10^{-4}
bx at IP, cm bz at IP, cm	48 4.5	4.5 4.5
Betatron tunes	3.05, 3.1	3.1, 3.1
Particles/bunch	2×10^{10}	6.7×10^{10}
Tune shifts	0.02, 0.05	0.1, 0.1
Luminosity, $cm^{-2} s^{-1}$	$\sim 5 \times 10^{30}$ *	$\sim 1 \times 10^{32}$

* Wiggier ºonº

In the original project of the VEPP-2M modernization it was supposed to use superconducting solenoids with NbTi windings with a maximum ®led at the axis of 10.6 T. In order to obtain such a ®eld in the solenoid it is required to cool its winding from 4.2 K down to 1.8 K. There has been recently found such a version of the solenoid design in which the necessary integral of the magnetic ®eld at an energy of 510 MeV is obtained at a ®eld of 8.7 T. With such a ®eld no additional cooling of the winding is required.

The design and manufacture of the facility is planned for the nearest two years.

II. THE VEPP-4M

The accelerator complex consists of an electron-positron collider at an energy of up to 2 x 6 GeV, a VEPP-3 cooling storage ring at an energy of up to 2 GeV, and an injection complex, see Fig.2 . Since put into operation, the complex was twice modernized. The last modernization was made after ®re of 1987. The

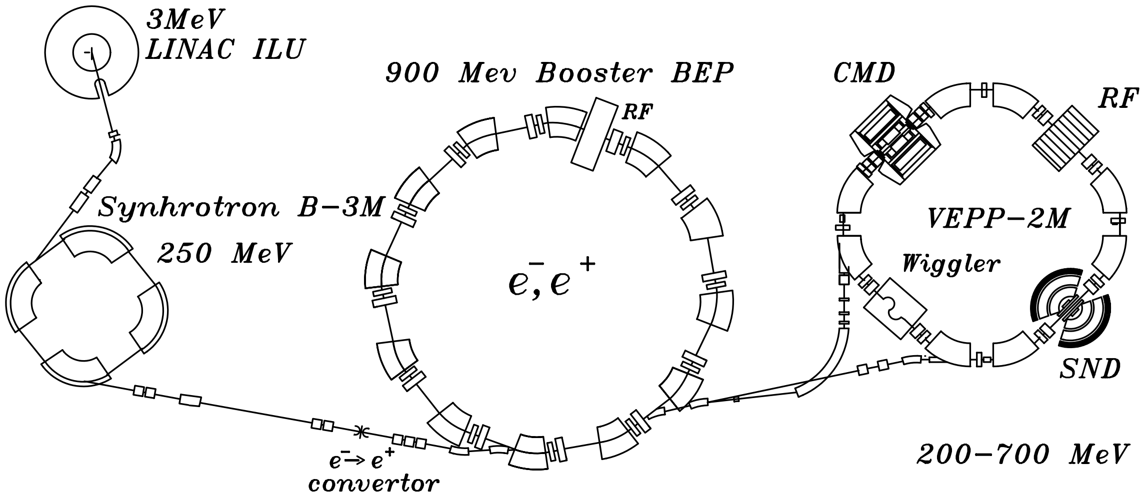

Figure 1. Layout of VEPP-2M complex

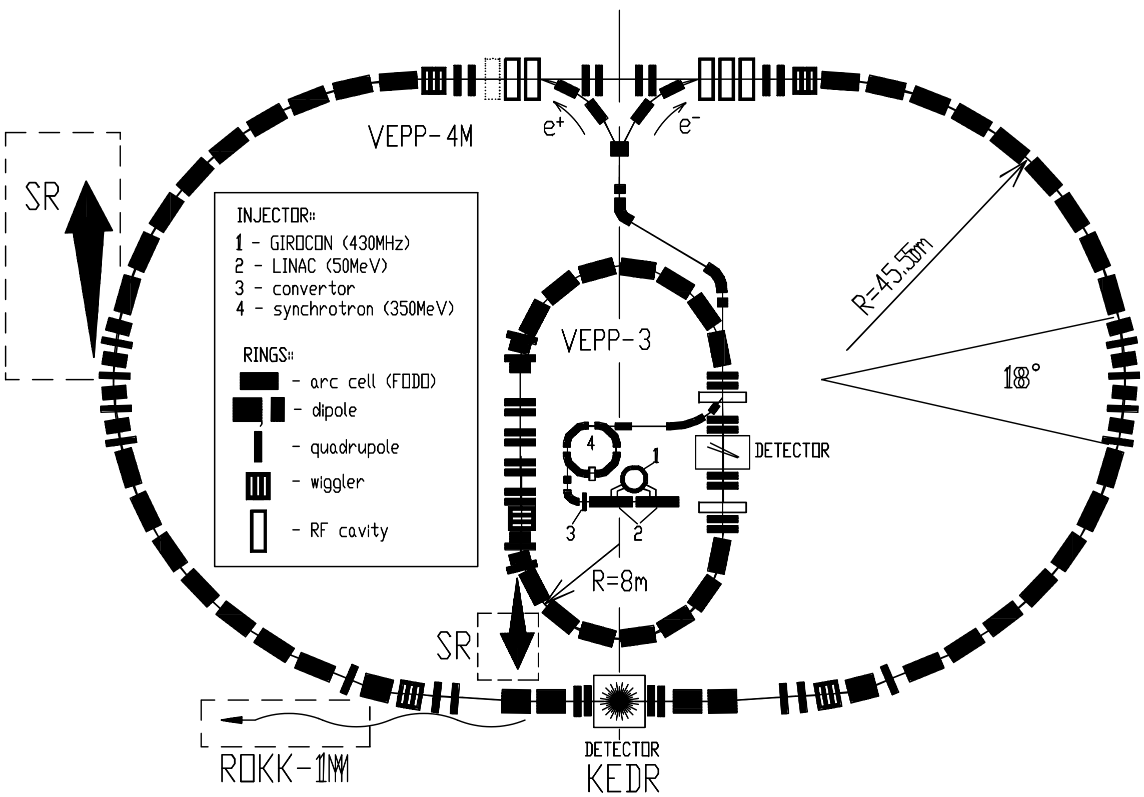

Figure 2. Layout of VEPP-4M complex

design parameters of VEPP-4M are listed in Table 2.

The VEPP-4M collider is mainly designed for carrying out investigations in the epsilon physics on the KEDR detector, and in the two-photon physics on the distributed spectrometer, formed by the collider lattice. Besides, VEPP-4M is equipped with SR beam extraction lines into a $1200m^2$ experimental room with a high-intensity gamma-quantum ROKK-1M setup at an energy range from 50 to 1600 MeV. The gamma-quantum beam is produced by the method of back Compton scattering of a laser light by the electron beam of VEPP-4M.

For increasing the luminosity of the VEPP-4M facility the following modi®cations are envisaged:
a) reduction of the beta-function down to 5 cm and an operation mode of two electron and two positron colliding bunches;
b) installation of superconducting wigglers in the insertions for increasing the bunch phase space, and correspodingly, the maximum currents with respect to the beam-beam effects;
c) installation of a superconducting cavity for reducing the bunch length, and respectively, the bunch size at the interaction point.

Along with the problem of fabricating the superconducting wigglers and cavity, the problem of positron lack, which were discussed above, there arises the problem of the threshold current in the bunch at VEPP-4M. During 1994 the threshold current was increased from 5 up to 20 mA. Provided 35 mA is obtained in every of the four bunches, the luminosity of $1.4 \cdot 10^{31} cm^{-2} sec^{-1}$ can be attained.

Energy, GeV	6
Circumference, m	366
Average arc radius, m	45.6
Horizontal aperture, cm	6
Vertical aperture, cm	2.7
Bending radius, m	34.5
Betatron frequencies ν_x, ν_z	8.53, 7.57
Compaction factor	0.017
Horizontal emittance, mm*mrad	0.4
Vertical emittance, mm*mrad	0.001
Energy spread, SR loss, MV/turn	4
Synchr. oscill. damping time, msec	2
RF wave length, m	1.65
Harmonic number	222
Accelerating voltage, MV	9
Bunch length, cm	4
RF power for by SR, kW	400
Heat losses in cavities, kW	800
Horizontal beta-function, cm	75
Vertical beta-function, cm	5
Dispersion function, cm	80
Beam sizes X and Z, micron	1000, 7
Space charge parameters X, Z	0.005, 0.05
Number of particles per bunch	2×10^{11}
Number of bunches per beam	2
Beam current, mA	50
Luminosity	7×10^{31}

Table.2

Before modernization VEPP-4 was run in a single bunch mode at currents $I \times I = 8 \times 8$ mA at a luminosity L = 5×10^{30}. The threshold current with respect to the beam-beam effects were of an order of magnitude of 10 mA and were easily obtained by means of a single injection from the VEPP-3 booster storage ring. The possibility of obtaining currents I = 17 mA in one separatrix was limited by the development of the instability appearing due to the interaction of the bunch with the ®elds induced by the bunch on the vacuum chamber inhomogeneities.

Some steps were taken in the new con®guration of VEPP-4M to smoothen the vacuum chamber, in particular there were shut the bellows connections near the electrostatic pick-ups. But at the same time, due to the transit to the two-bunch operation mode, the insertions were additionally equipped with 8 pairs of separation plates, which drastically affected the electro-dynamic properties of the vacuum chamber.

III. EXPERIMENTAL RESULTS OBTAINED AT VEPP-4M BY 1994

By the present time the following results have been obtained at the VEPP-4M collider at an energy of 1.8 GeV: the rated luminosity has been attained, the electrons at currents of up to 15 mA and two bunches at currents of about 1 mA have been raised to an energy of up to 5.1 GeV (the energy is determined by the power of the 1st stage of the RF system), the backgrounds from the SR around the KEDR detector have been studied at this energy.

The magnetic system of the experimental section of VEPP-4M forms a distributing spectrometer for determining the energy loss of electrons and positrons in the two-photon physics experiments. Simultaneously, the ROKK-1M setup (obtaining of a gamma-quantum bunch by the back Compton method) was created and put into operation at the VEPP-4M facility.

These systems complement each other: the sharp edge of the back Compton spectrum provides for the calibration of the scattered electrons detection system. The scattered electrons detection system was calibrated and it showed a high resolution (matching the calculation) with respect to determing the energy. On the other hand, the scattered electrons detection system makes it possible in the experiments with a Compton bunch to mark Compton quanta with reference to energy, which offers outstanding possibilities for the experiments with a bunch of gamma-quanta at an energy range from 50 MeV up to 1.6 GeV.

The ®rst experiments on the photo-nuclear split of heavy elements were performed on ROKK-1M together with teams from Italy and France. It was also on this setup that the experiments on measuring the energy and space resolution of the krypton prototype calorimeter for the KEDR detector were performed.

There were studied the background conditions and demonstrated the feasibility of the following experiments: a) splitting a photon in a strong Coulomb ®eld; b) the Delbrouk scattering of a photon in a strong Coulomb ®eld. These experiments are planned for 1995.

The elements of the ROKK-1M setup make it possible to transform it into a laser palarimeter for VEPP-4M.

A number of systems have been assembled and initially tested at the KEDR detector: the vertex detector, parts of the drift chamber, the end calorimeter, muon chambers.

In full swing is the work for obtaining the luminosity at a high energy and tuning the luminosity monitor.

IV. THE VEPP-5

The VEPP-5 complex consists of an electron and a positron linacs, a cooling storage ring, a Phi-factory and a C-tau-factory (Fig.3-5).

The task of the electron linac is to create an 300 MeV intensive electron bunch for the production of positrons. The electron linac accelerates positorns after conversion and electrons generated by the photo-gun up to an operation energy of the cooling storage ring and the Phi-factory, i.e. up to 510 MeV.

The main parameters of the preinjector are listed in Table 3.

Beam energy	510 MeV
Number of electrons per pulse	10^{11}
Number of positrons per pulse	10^9
Pulse repetition frequency	50 Hz
Energy spread:	
of the electron bunch	$\pm 1\%$
of the positron bunch	$\pm 3\%$
Operation frequency	2856 MHz
Pulse power of the klystron	~ 63 MW
Number of klystrons	$4 + 1$
Total consumed power	~ 1 MW

The design of the main elements of the preinjector has been currently completed. There have been manufacture the prototypes of accelerator section, of the subharmonic cavity, and SLED cavities. A number of RF elements have been subjected

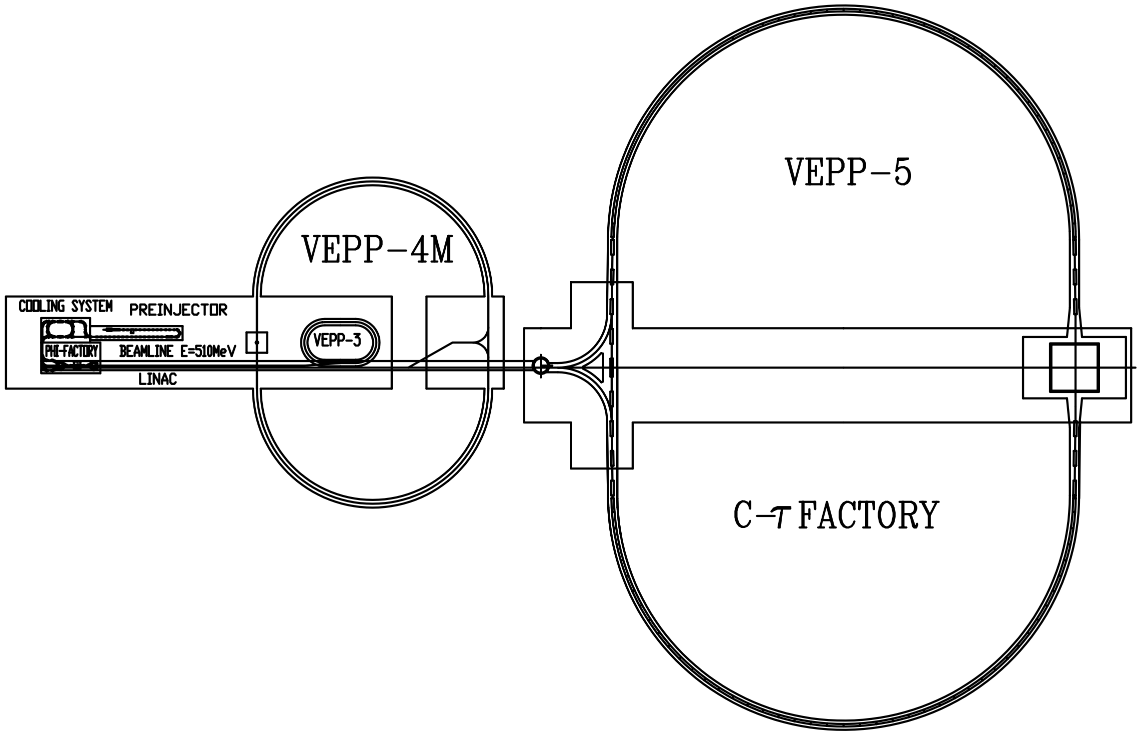

Figure 3. Layout of VEPP-5 complex

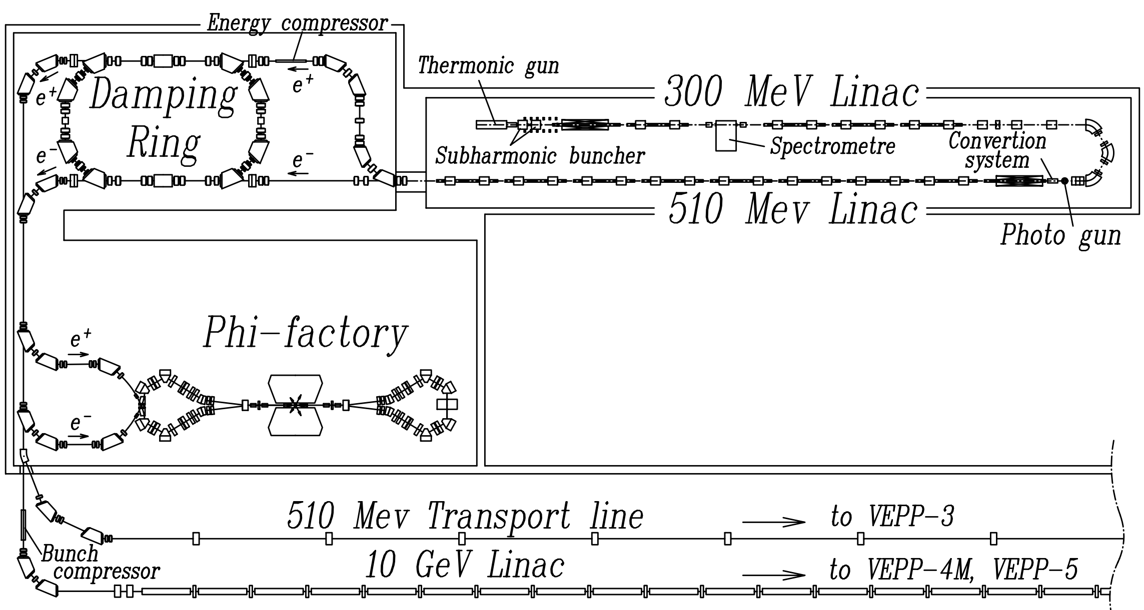

Figure 4. Layout of Injecor complex

to ºcoldº tests. The ®rst 5045 klystron (product of SLAC) is delivered to Novosibirsk.

The ®rst modulator for the 5045 klystron designed and fabricated at INP has successfully undergone the tests. The tests were performed on a resistive load. After the test run the ®rst 5045 klystron was connected to the modulator and the required parameters, i.e. 60 mW at an RF pulse duration of 4.5 microseconds, were attained. The solution was made to manufacture the rest modulators.

V. COOLING STORAGE RING

The key elements of the ring, that is the pulse generators for injection-ejection are complete, have successfully undergon the tests, and are ready to be installed in the ring; the RF generator and the cavity are 70% complete and will be tested in autumn; the prototypes of dipoles and quadrupoles are manufactured and have been successfully tested; the magnetic system was put into production in December 1994. The yokes for the cooling storage ring and for the beam lines are 90% ready, the manufacture of the coils is delayed by December 1995 due to overlapping with contractual orders. The production of the dipoles and quadrupoles for the injection complex is planned for the end of 1996.

VI. PHI-FACTORY

The Phi-factory project is currently under revision. The main principles remain the same, but in order to expedite the operation in the multi-bunch mode it is decided to separate the rings for electrons and positrons. Besides, we succeeded to reduce the ®eld in the focusing solenoids from 11 T to 9.5 T. The present-day main parameters of the four-wing Phi-factory are listed in the below table 4:

Circumference	47.08 m
Revolution frequency	6368 MHz
Number of rings	2
Number of bunches per beam	11
Number of particles per bunch	$5 \cdot 10^{10}$
Betta-function value at IP	1.0 cm
Bending ®eld B_0	1.79 T
Solenoidal ®eld B_s	9.5 T
Separation ®eld E_y	50 kV/cm
RMS bunch length	0.8 cm
Emittances, ($\epsilon_x = \epsilon_y$)	1.25 10^{-5} cm rad
Betatron tunes ν_x; ν_y	8.1; 6.1
Compaction factor alpha	-0.02...0.06
Energy loss per turn	13.5 keV
Decrements $\delta_x, \delta_y \delta_s$	1.25, 1.25. 2.92 10^{-5}
RMS Momentum Spread	4.310^{-4}
RF harmonic Number q	110
RF frequency	700.4 MHz
RF voltage V	100. kV
Synchrotron tune ν_s ($\alpha = 0.04$)	0.012
Tune shift parameter $\xi_x = \xi_y$	0.1
Beam-beam lifetime	11 min
Design Luminosity	2.510^{33}

Table.4

Schematically the four-wing Phi-factory is shown in Fig.5.

A further optimization of the storage ring parameters is presently under way.

VII. C-TAU-FACTORY

The parameters of the beam for the C-TAU-Factory are determined by the requirement of obtaining a maximum high luminosity of $1.010^{34} cm^{-2} sec^{-1}$ [3] . Along with such a maximum luminosity mode the possibility of obtaining modes of monochromatization of colliding beams is considered as well as of polarized colliding beams. For the operation in these modes it is necessary to have a beam emittance control system. Thus, for obtaining monochromatic colliding beams it is necessary, that the main contribution to the vertical size at the IP is made by the energy spread, while the vertical betatron betatron size is considerably less. For the purpose of control and in order to preserve the polarization one should have rather long solenoids with a magnetic ®eld longitudinal with respect to the beam. As a matter of fact, one can hardly provide all these modes simultaneously, and the transition from one mode to another will be made by replacing magnetic elements in the straight sections. The contribution of arcs (half-rings) to emittances in this case should be as low as possible. In the assumption, that the RF system is used at a frequency of 700 MHz and the distance between the bunches is divisible by the length of the RF wave, one can write down the beam parameters for the ultimate luminosity in the form of Table 5:

Energy (Gev)	2.1
Circumference (m)	773.036
Ring radius (m)	89.63
Interbunch distance (m)	8.14
Straight section lenght (m)	100
Beam radius at IP (μ m)	33
Number of rings	2
Number of bunches per beam	95
Number of particle per bunch	2×10^{11}
b-function at IP (cm)	1
Beams emittance ($\epsilon_x = \epsilon_y$) (cm/rad)	10^{-5}
RMS bunch length (cm)	0.8
Compaction factor	$0.001 \div 0.0017$
Betatron tune ν_x	29.077
Betatron tune ν_y	31.077
Vertical damping time (s)	0.11
RF voltage (kV)	1000
RF frequency (MHz)	700
Energy loss per turn (keV)	100
Energy spread	5×10^{-4}
Harmonic Number	1805
Tune shift parameter $\xi_x = \xi_y$	0.1
Design Luminosity ($cm^{-2}s^{-1}$)	10^{34}

From the point of view of its geometry the C-TAU-factory is located in a tunnel, $3 \times 3m^2$ in cross section, with tunnel ¯oor located at a level of 163 m, and the ceiling at a level of 166 m over the sea. The underground part consists of two arcs, 98.58 m in radius, and interconnected 100 m long straight sections. Here the length of an ideal orbit makes 773.036 m, which corresponds to 1805 RF wave lengths. With the same geometry, each 19th separatrix contains a bunch of particles; altogether the ring will have 95 bunches. The technical section is enlarged up to $3 \times 5m^2$ for housing the injection equipment and the magnetic systems for the emittance control. The tunnel should be enlarged towards the injection beam lines leaving a distance of 1.5 m to the internal wall, and 3.5 m to the external one. The nearest to the surface point in the tunnel is situated at a depth of 10 m, and one of the nearest and in principle accessible points is the bottom of the auxiliary channel, located 168.6 m over the sea, which corresponds to the ground thickness of 2.6 m above the ceiling of the C-TAU-Factory tunnel.

At the present moment the tunnel from the injection complex to the well from where the injection beam line of the C-TAU-Factory starts is complete. The beam line is 200 m long. The construction of these beam lines transporting the electron and the positron bunches into the injection section will be started in the nearest future. The construction is performed by the ºGornyakº company. The construction rate is mainly determined by the ®nancial funds available. Provided the construction rate is preserved at the present level, it will take about 5 years to complete the underground part of the complex.

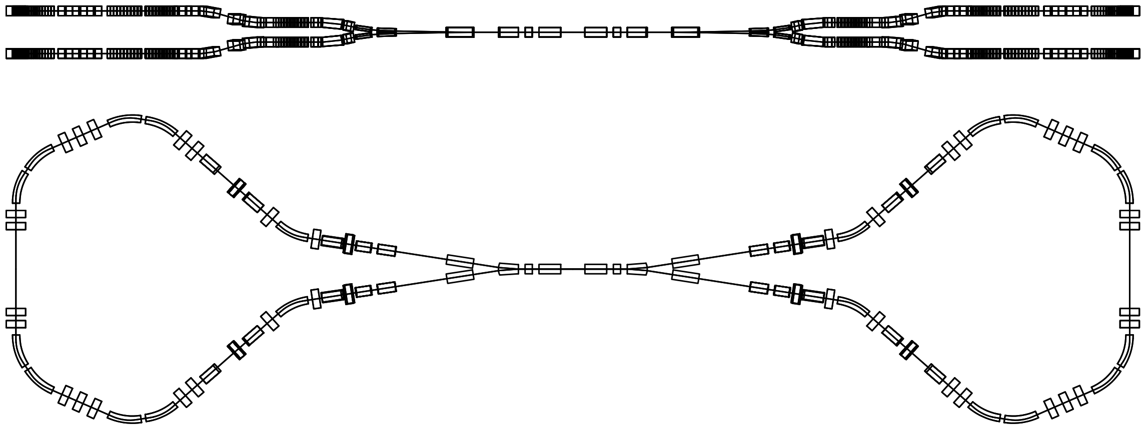

Figure 5. Layout of Phi-factory

Dedicated sections of the magnetic system should be used for the emittance control, where one can change the magnetic ®eld. A well-known element used for this purpose is a wiggler which allows a considerable increase in the synchrotron radiation energy loss. As a rule, the psi-function in the wiggler is low, and as a result, when a strong damping is induced, the magnet does not increase the emittance too high. The magnetic system of the C-TAU-Factory consists of two storage rings, located one over the other and overlapping at the interaction point. For arranging the collision of longitudinal-polarized beams it is proposed to install spin rotators in the arcs. As an example of a particular lattice let us consider a simple system consisting of a dipole magnet, 1.5 m long, with a ®eld of 1042 G and quadrupole lenses, each 0.4 m long, with the parameters listed in Table 6:

	Length (cm)	Field (kG)	Gradient (kG/cm)
Quad	40		1.0631
Gap	30		
Dipole	150	1.042	
Gap	30		
Quad	40		-1.0631
Gap	30		
Dipole	150	1.042	
Gap	30		

For obtaining the ultimate luminosity of the most interest is the arrangement of the interaction point with a small beta-function produced with the help of a strong longitudinal ®eld (9.6 T and a length of 2.18 m). Having a symmetrical focusing in both directions, such a system well corresponds to the idea of operation with round beams and provides for obtaining the space charge parameter $\xi > 0.1$. The main problem in arranging the IP is the necessity of electrostatical beam separation. The total length of the plates with a ®eld of 100 kV/cm is 2 m, and they are located in a place where the value of the beta-function is high, which incurs the problem with providing for the coherent beam stability. A stable strong electrical ®eld under the condition of the plates exposure to the synchrotron radiation also presents a serious problem.

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