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VEPP-2000 Project

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The status of the VEPP-2M collider is presented. Implementation of the Round Colliding Beams (RCB) concept in the new collider VEPP-2000 is outlined, and potential advantages of RCB over the flat colliding beams are discussed. The main design parameters and features of this VEPP-2000 collider are reported.

1. MOTIVATIONS

Since the end of 1992, the e^+e^- collider VEPP-2M in Novosibirsk has been successfully running in the c.m. energy range from the threshold of hadron production up to 1.4 GeV. Since 1984, VEPP-2M has been operating with the five poles superconducting wiggler with the maximum field $B = 8$ T, which increases the beam emittance by a factor of $\simeq 3$. The integrated luminosity of about 50 pb^{-1} was collected with two modern detectors SND [1] and CMD-2 [2] allowing precise measurements of most of the hadronic channels of e^+e^- annihilation. Together with 24 pb^{-1} collected at VEPP-2M in the previous generation of experiments from 1974–1987, this integrated luminosity is more than one order of magnitude higher than about 6 pb^{-1} accumulated by various experimental groups in Frascati and Orsay in the c.m. energy range from 1.4 to 2 GeV. Thus, there is a serious energy gap between the maximum energy attainable at VEPP-2M and 2 GeV in which existing data on e^+e^- annihilation into hadrons are rather imprecise. Accurate measurements of hadronic cross sections in this energy range are crucial for a better understanding of many phenomena in high energy physics.

A recent decision to upgrade the VEPP-2M complex by replacing the existing collider with a new one, in order to improve the luminosity and at the same time increase the maximum attainable energy up to 2 GeV, will significantly broaden the potential of experiments performed at the collider. Following modern trends, the new project was named VEPP-2000.

2. LUMINOSITY OF COLLIDERS AND ROUND COLLIDING BEAMS CONCEPT

The basic parameter of a collider is its luminosity L which in the case of short bunches is determined by the formula:

$$L = \frac{\pi\gamma^2\xi_z\xi_x\epsilon_x f}{r_e^2\beta_z}\cdot\left(1+\frac{\sigma_z}{\sigma_x}\right)^2,$$

where ξ_z, ξ_x are the space charge parameters whose maximum values are limited by the beam-beam effects; ϵ_x is the horizontal emittance of the beams, σ_z, σ_x are their r.m.s. sizes at the interaction point (IP), and β_z is the vertical β-function at the IP; f is the frequency of collisions at this IP, r_e is the classical electron radius, γ is the relativistic factor.

The space charge parameter per interaction is:

$$\xi_{x,z} = \frac{N r_e}{2\pi\gamma}\frac{\beta_{x,z}}{(\sigma_x+\sigma_z)\sigma_{x,z}},$$

where N is the number of particles in the opposite bunch. Colliding bunches with maximum values of $\xi_z \simeq 0.05$ and $\xi_x \simeq 0.02$ are experimentally obtained on the VEPP-2M collider [3].

Aiming at a very high luminosity due to raising the ξ limits in the Novosibirsk Φ-Factory project [4, 5], colliding beams with round transverse cross-sections were proposed (just “round beams” in what follows). During the last decade at BINP, this approach evolved into the concept of Round Colliding Beams (RCB) [6].

In the RCB case, the luminosity formula has the form

$$L = \frac{4\pi\gamma^2\xi^2\varepsilon f}{r_e^2\beta}$$

and the space charge parameters are now the same in the two directions, so the horizontal parameter can be strongly enhanced.

The evident advantage of round colliding beams is that with the fixed particle density, the tune shift from the opposite bunch becomes twice as small as the tune shift in the case of flat colliding beams. Besides, the linear beam–beam tuneshift in the round beams becomes independent of the longitudinal position in the bunch, thereby weakening the action of synchro-betatron resonances.

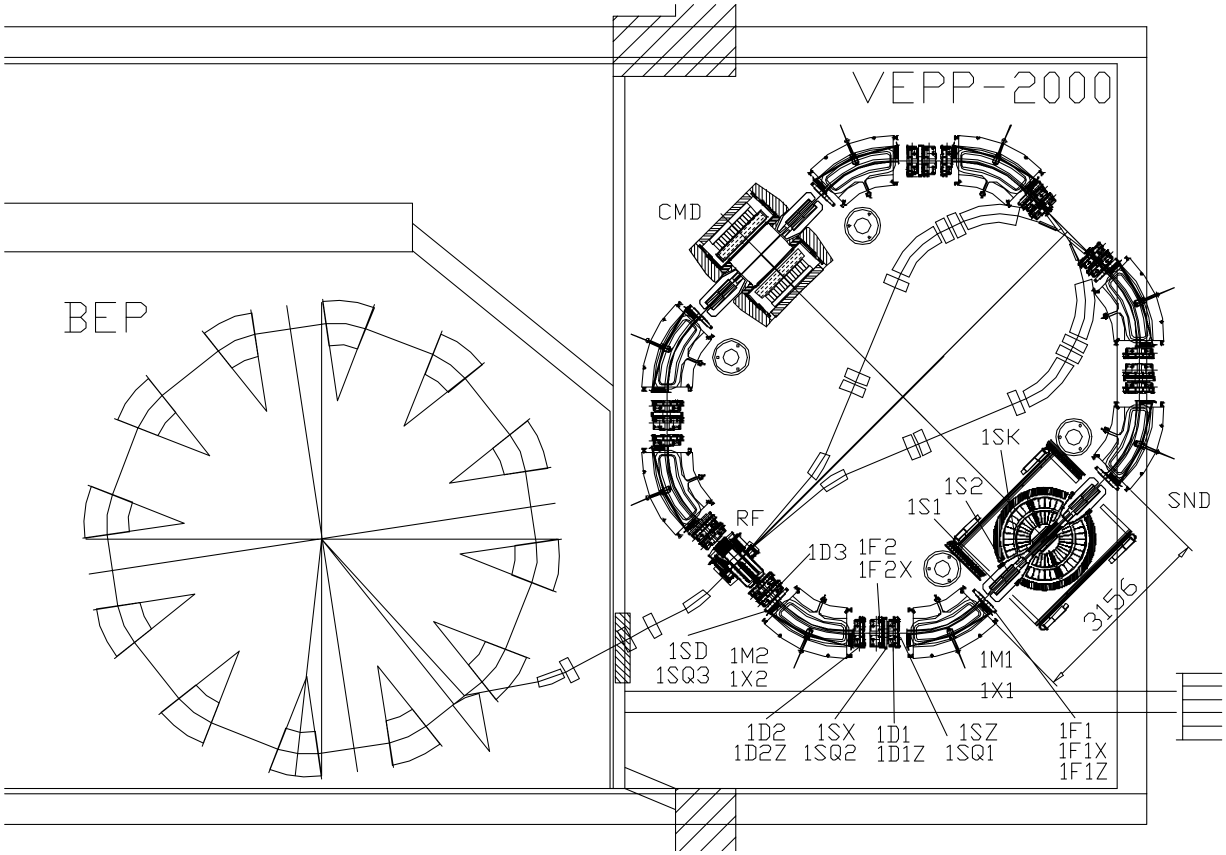

Figure 1: The VEPP-2000 collider layout

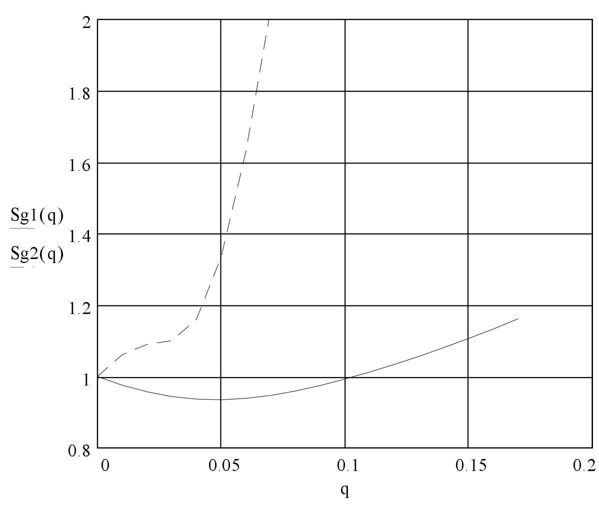

Figure 2: Variation of the weak beam size versus the the space charge parameter ξ: solid curve for the round colliding beams, dashed curve for the flat beam option.

The main feature of the RCB is rotational symmetry of the kick from the round opposite beam; complemented with the X–Z symmetry of the betatron transfer matrix between the collisions, it results in an additional integral of motion $M = xz' - zx'$, that is, the longitudinal component of the particle's angular momentum is conserved. Thus, the transverse motion becomes equivalent to a one-dimensional (1D) motion. Resulting elimination of all betatron coupling resonances is of crucial importance, since they are believed to cause the beam lifetime degradation and blow-up.

The above arguments in favour of RCB have been checked out by the computer simulations of the beam-beam effects in the VEPP-2M collider lattice, modified to the RCB option [7]. The main results of the simulations [8] are presented in Figure 2, where the beam sizes are plotted versus the space charge parameter ξ. One can see that the beam blow-up for the round beam option is much weaker than what is simulated by the same code for flat colliding beams (dashed line). The simulations have also demonstrated stability of RCB against the "flip-flop" effect, similarly to conclusions from simple flip-flop models [9].

3. DESIGN OF VEPP-2000

3.1. Magnets

The lack of space for placing the new machine lead to the demand of using strong dipole magnets. For the energy of particles in the beam to be 1 GeV, the field of a magnitude 2.3 T is needed. For this purpose it is planned to use the construction of magnets of booster BEP [10] that works at the level of the magnetic field needed. The parameters of magnets are shown in Table I.

Table I The main parameters of the bending magnets

Gap	40 mm
Bending angle	45°
Bending radius	1.40 m
Maximal field	2.3 T
Number of coil turns	10
Current in coil	9 kA
Power consumption	900 kW
Accuracy	0.001%
Range of reconstruction with a beam	1.2
Time of reconstruction	100 s

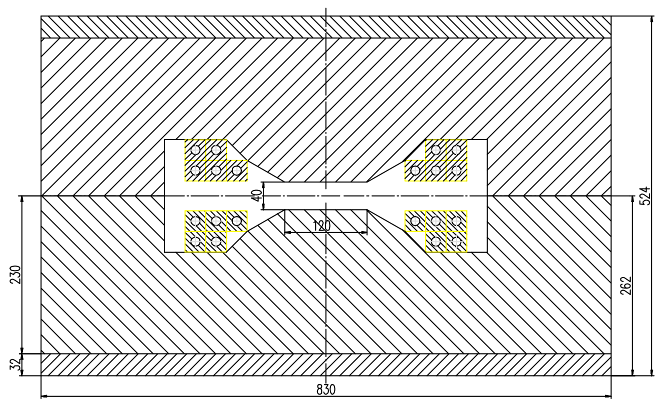

Figure 3: The dipole magnet of the VEPP-2000

Construction of magnets with such a big field requires the optimization of coils placement, a form of a pole and magnet yoke for decreasing the effect of iron saturation, power consumption and obtaining a sufficient region of uniform field. The field nonuniformity at the edges of a dipole magnet was also accounted for. Figure 4 shows the guide field distribution versus longitudinal coordinate s that was obtained by simulation of the dipole magnet VEPP-2000 model with *MERMAID* code.

3.2. Solenoids

Focusing in the two interaction regions is performed by SC solenoids, installed symmetrically with respect to the IPs. Each solenoidal block consists of a main solenoid which is longitudinally divided into two parts, and a compensating solenoid with reverse field to adjust longitudinal field integral and focussing. Such a scheme gives an additional possibility to control the β^* value by feeding only one half of the main solenoid at lower energies.

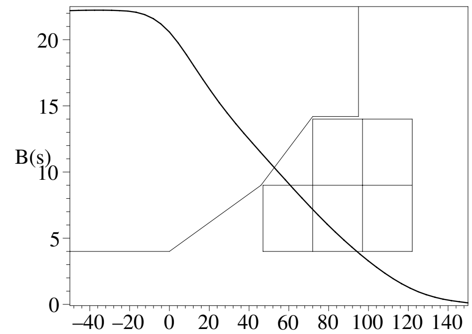

Figure 4: The dependence of the guide field of dipole magnet on the longitudinal coordinate (*MERMAID*). The edge of a magnet and its coil are shown schematically.

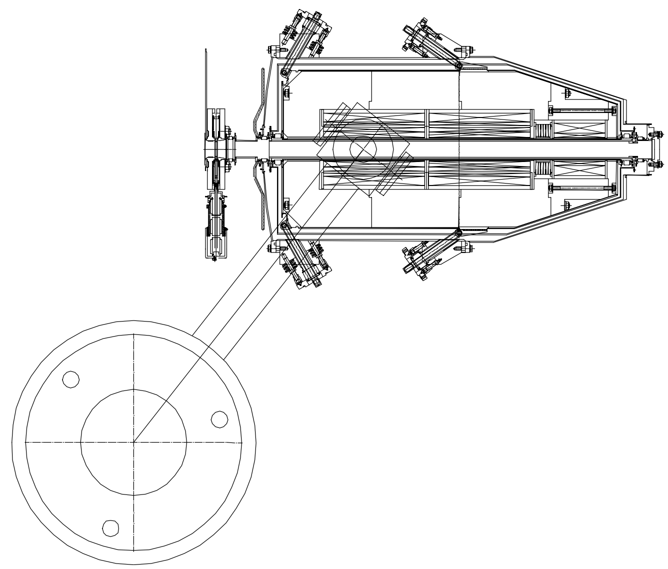

Figure 5: The superconducting solenoid of VEPP-2000

The solenoid coil is divided into three sections: the inner section has a thickness of 30 mm and is made of Nb_3Sn wire 1.23 mm in diameter (50% Cu + 50% Nb_3Sn); the middle section has a thickness 20 mm and is wound with a NbTi wire 1.2 mm in diameter (48% Cu + 52% NbTi) and the outer layer has a thickness of 10 mm, made of NbTi wire 0.85 mm in diameter (48% Cu + 52% NbTi). To feed this three-section coil we plan to use two power supply units. The connection scheme implies that the current in the outer section is the sum of currents in the inner ones. The distribution of currents in the sections is: inner section – 145 A, intermediate section – 167 A, outer section – 312 A. The peak magnetic field is 12.1 T.

Magnetic flux is closed by the iron return yoke located together with all the coils in a common LHe cryostat. The aperture of the coil is 50.0 mm. The inner tube of the helium vessel is a part of the collider vacuum cham-

Table II The main parameters of solenoids

Solenoid	Main	Compensative
Magnetic field, T	12.7	9.0
Coil length, m	0.526	0.128
Inductance, H	14.3	1.2
Number of turns	26080	4940
Stored energy, J	346	27

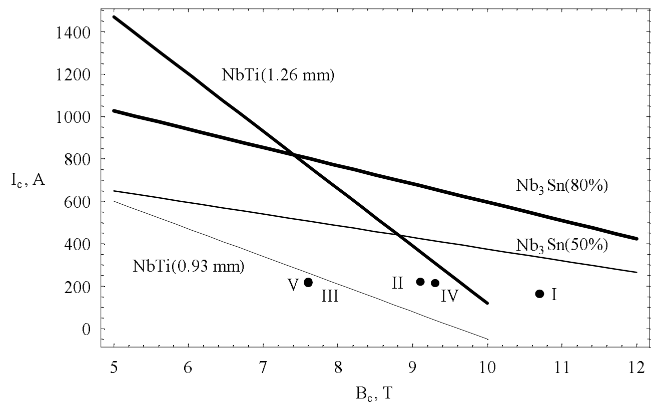

Figure 6: The critical parameters of the superconducting wires used. I — (10.7 T, 165 A), II — (9.1 T, 220 A), III — (7.6 T, 220 A), IV — (9.3 T, 214 A), V — (7.6 T, 214 A)

ber. A nitrogen vapour cooled liner is envisaged to protect the surface of the helium cryostat from heating by synchrotron radiation.

3.3. RF System

Beam revolution frequency is 12.292 MHz. The accelerating RF frequency was chosen at 14-th revolution frequency harmonic, that is, 172 MHz. With accelerating voltage of 100 kV the bunch length is about $\sigma = 3$ cm at the energy of 1 GeV. Energy loss per turn is 64 keV, and with colliding beam currents of 2×0.1 A the power delivered to the beams is 12.8 kW. The so-called single-mode cavity is proposed to be used to ease suppression of coherent instabilities (see Figure 7). Two coaxial damping loads are foreseen to absorb the energy from high-order modes excitation. The fundamental mode is isolated from the upper load by the tunable choke.

The RF field distribution of the accelerating mode on the axis of the RF cavity is shown in Figure 8.

3.4. Vacuum System

The high-vacuum system consists of 16 ports with ion-getter pumps PVIG-100, which are located at the edges of bending magnets vacuum chambers; of ion-getter

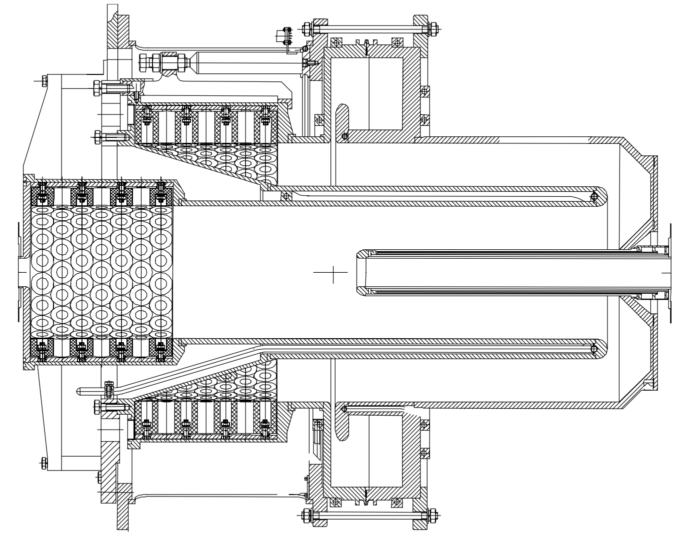

Figure 7: Cross-section of the cavity

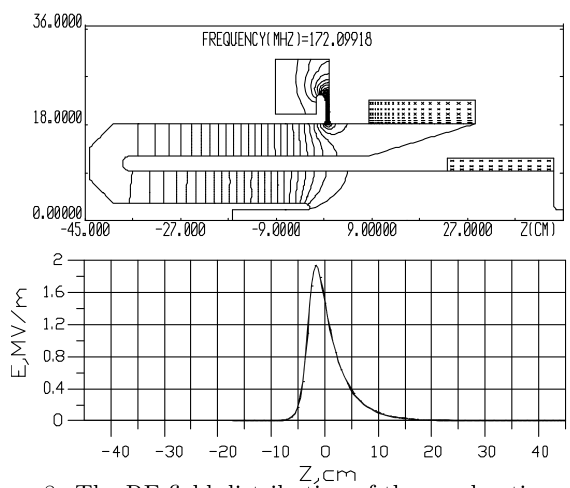

Figure 8: The RF field distribution of the accelerating mode of RF cavity (upper picture). The field distribution on the cavity axis (lower picture)

pump PVIG-250 connected to the RF cavity; of 4 cryopumps formed of cool solenoid surface. To prevent heating cryosurface, which is under 4.2 K, by SR there is a plan to use a perforated liner cooled with the liquid nitrogen. The liners ports should provide a linear pumping rate of 5 l/s/cm for the nitrogen. The cool surface under 4.2 K is an ideal pumping for all the residual gases but the hydrogen, because after accumulation of more than one cryosrpted hydrogen monolayer, the saturated vapor pressure of the hydrogen reaches the value of 5×10^{-7} Torr under the given temperature. In spite of this circumstance our calculations showed that in general the beam life time will depend on residual CO pressure. Numerical simulation of the pressure over the ring was performed under the following conditions:

- $I_p = I_e = 200$ mA — electron and positron beam currents

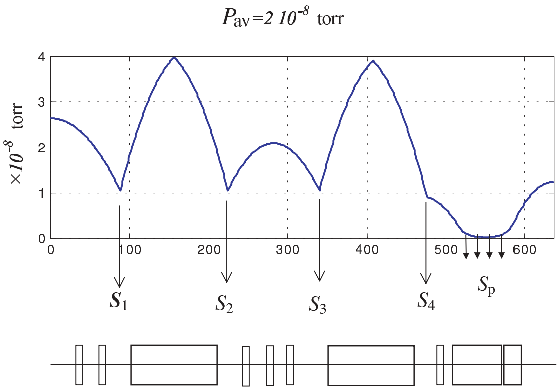

Figure 9: Graph of CO pressure distribution for one quoter the VEPP-2000 circumference.

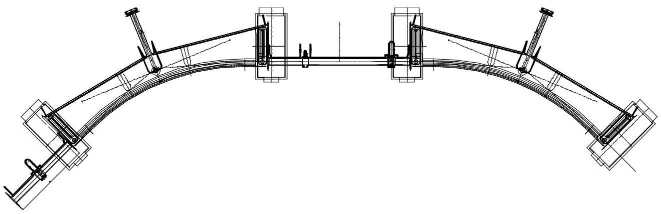

Figure 10: The vacuum chamber of one quadrant of the VEPP-2000

- $S1, S2, \ldots, S16$ — lumped ports with the pumping rate of 150 l/s, $Sp = 5$ l/s/cm — distributed cryopumping
- Photon flux is 2.2×10^{19} photon/s/rad
- Coefficient of photostimulated disorption (for after more than 100 Ah):
  - for non-heated chamber sections — 3×10^{-5} molecule/photon
  - for heated chamber sections — 3×10^{-6} molecule/photon

The graph of CO pressure distribution for one quarter of the VEPP-2000 circumference is presented in Figure 9.

The vacuum chamber of the VEPP-2000 is shown in Figure 10.

4. BEAM INJECTION

The injection of beams into the storage ring is planned to be done in the horizontal plane into the long drift opposite to the RF cavity (see Fig. 1). The inflector plates will be placed on the inner side of the vacuum chamber in the bending magnets at the ends of the drift. The advantage of such a scheme is independence of the injected beam trajectory on the solenoids field. This gives us an opportunity to test different options of optics: usual round beams, "Möbius", and flat beams with zero rotation of the betatron oscillation plane.

In Table III the main parameters of generators are collected.

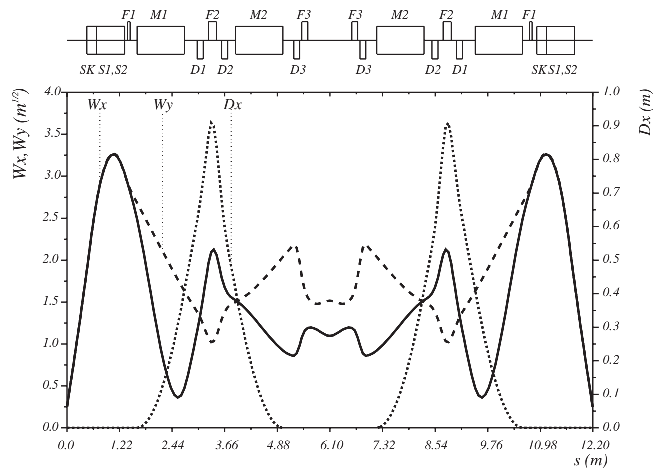

Figure 11: Half period lattice functions. $S = 0$ corresponds to IP

Table III The main parameters of kickers feed generators

Parameter	Value
charging voltage	up to 40 kV
Polarity of charging voltage	positive
Amplitude of the output pulse	up to 30 kV
Half-height pulse duration	80 ns
Pulse leading/trailing edge duration	60 ns
Output pulse polarity	negative
Output impedance	12,5 Ohm
Each circuite of DSC impedance	6,25 Ohm
Thyratron current amplitude	up to 4,8 kA
Repetition frequency	1 Hz

The BEP booster is capable of production beams with the energy of up to 900 MeV. Thus, operation at lower energies will be continuous, with injection of the beam at the experiment energy. In the region from 900 MeV to 1 GeV, the energy ramping from 900 MeV to the experiment energy is required.

5. VEPP-2000 PARAMETERS

The optical functions of the round beam lattice of VEPP-2000 are presented in the Figure 11.

An essential advantage of the found optics is zero dispersion in the IRs, RF cavity, and injection straight sections.

The chosen optics has another very useful feature. Variation of the focusing strength of the solenoids changes β^* and the beam emittance in inverse proportion, at fixed energy. Changing energy, we can squeeze β^*, conserving the maximum beam size at the solenoids, thus giving a possibility to tune optics for better performance. Apparently, this feature provides the luminosity

Table IV Main parameters of the collider at E=900 MeV

Circumference, m	C	24.388
RF frequency, MHz	f_0	172.0
RF voltage, kV	V	100
RF harmonic number	q	14
Momentum compaction	α	0.036
Synchrotron tune	ν_s	0.003 ($\alpha = 0.04$)
Emittances, cm·rad	ε_x ε_z	$2.2 \cdot 10^{-5}$ $2.2 \cdot 10^{-5}$
Energy loss/turn, keV	ΔE_0	41.5
Dimensionless damping decrements	δ_z δ_x δ_s	$2.3 \cdot 10^{-5}$ $2.3 \cdot 10^{-5}$ $4.6 \cdot 10^{-5}$
Energy spread	σ_ε	$6.4 \cdot 10^{-4}$
β_x at IP, cm β_z at IP, cm	β_x β_z	6.3 6.3
Betatron tunes	ν_x, ν_z	4.1, 2.1
Particles/bunch	e^-, e^+	$1.0 \cdot 10^{11}$
Bunches/beam		1
Tune shifts	ξ_x, ξ_z	0.075, 0.075
Luminosity/IP, $cm^{-2} \cdot s^{-1}$	$L_{\max}$	$1.0 \cdot 10^{32}$

scaling at lower energies approximately as γ^2 (instead of γ^4 for the option with fixed β^*).

The main parameters of the new collider are given in Table IV.

6. STATUS OF THE PROJECT

The designing of the main part of all the collider systems is finished. Manufacturing dipole magnets and quads is in progress and planned to be finished this year. Manufacturing and testing solenoids as the longest operation is planned to start this year and will continue the next year. The commissioning of the VEPP-2000 collider will start in the end of 2002.

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