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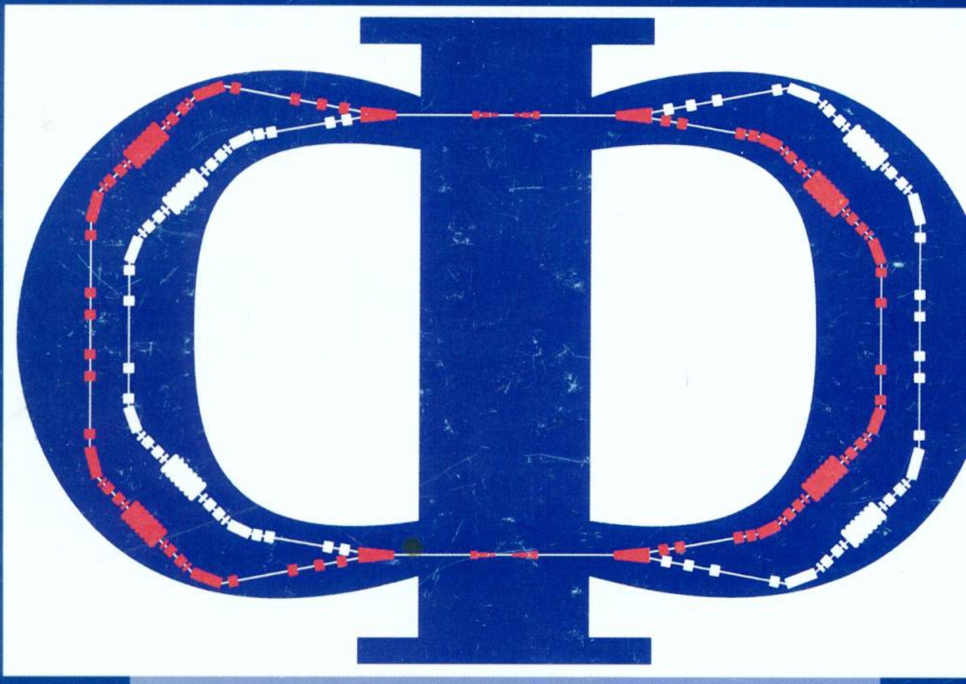

WORKSHOP ON PHYSICS AND DETECTORS FOR DAΦNE '95

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VEPP–2M STATUS AND PROSPECTS AND Φ–FACTORY PROJECT AT NOVOSIBIRSK

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1 VEPP-2M collider

Electron-positron collider VEPP-2M is the world first pre-Factory, constructed to rise sharply luminosity in already explored energy domain, and the only e^+e^- machine for last 20 years operating in the energy range 2E from 0.4 to 1.4 GeV, covering the energy of resonance production of lightest quarkonia ρ, ω, ϕ. Collider complex VEPP-2M (Fig. 1) consists of an injector part with 3 MeV linear accelerator ILU and 250 MeV electron synchrotron B-3M, 900 MeV synchrotron BEP for accumulation of electrons and positrons and 700 MeV collider VEPP-2M [1]. The maximum luminosity of VEPP-2M depends on its energy in accordance with E^4 law, and at the energy of 2E = 1000 MeV it is equal to $5 \cdot 10^{30}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. Several different type detectors have operated at the VEPP-2M starting from 1974.

It is worth to mention the best intensity results at VEPP-2M and BEP in a single beam single bunch mode: 0.2 A ($0.8 \cdot 10^{11}$ per bunch) and 0.6 A ($3 \cdot 10^{11}$ per bunch) at the collider and the booster, correspondingly.

The previous longest experimental run was performed at VEPP-2M with a Neutral Detector (ND) [2]. The physics results obtained with ND were based on 19 inverse picobarns of integrated luminosity [3]. In 1992 experiments with CMD-2 detector [4] started, and in early 1995 a new nonmagnetic Spherical Neutral Detector [5] began data acquisition as well. Now both CMD-2 and SND detectors, located in opposite straight sections of VEPP-2M, take data in parallel.

2 CMD-2 detector

The CMD-2 detector has been described in more detail in other presentations [6, 7]. The cross section of the detector is shown in Figure 2. The CsI barrel calorimeter

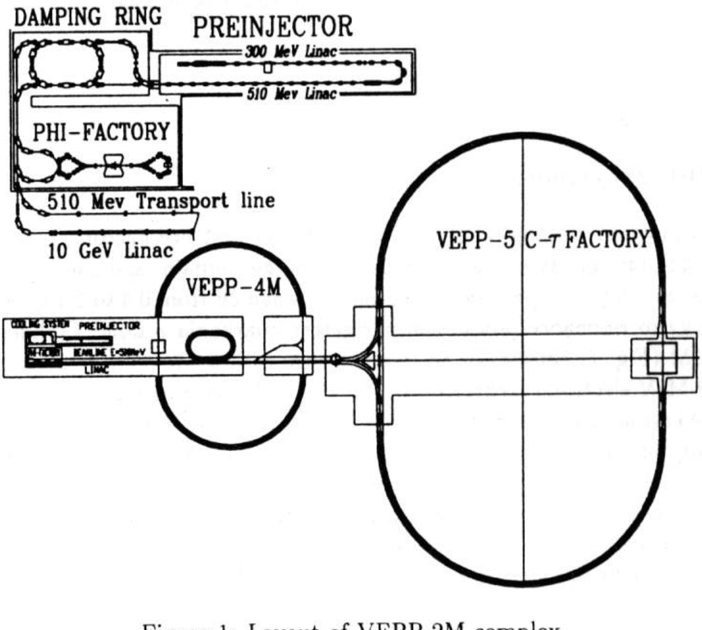

Figure 1: Layout of VEPP-2M complex

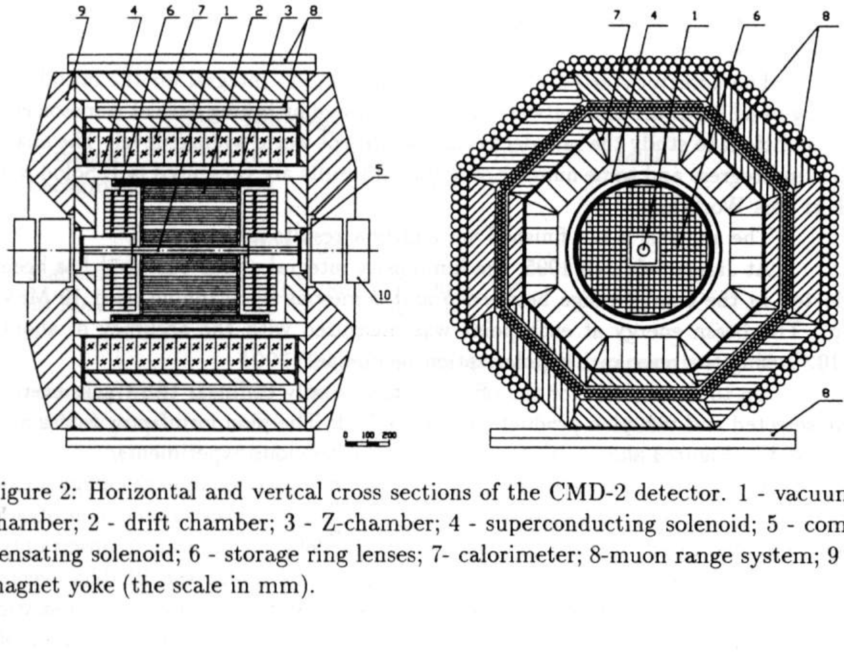

Figure 2: Horizontal and vertcal cross sections of the CMD-2 detector. 1 - vacuum chamber; 2 - drift chamber; 3 - Z-chamber; 4 - superconducting solenoid; 5 - compensating solenoid; 6 - storage ring lenses; 7- calorimeter; 8-muon range system; 9 - magnet yoke (the scale in mm).

with 6x6x15 cm crystal size is placed outside a superconducting solenoid with a 1 Tesla azimuthally symmetric magnetic field (coil thickness 0.4 r.l.). The endcap calorimeter is made of 2.5 x 2.5 x 15 cm BGO crystals and was not installed for the data presented here. The drift chamber inside the solenoid with 30 cm outer radius and 44 cm length has about 200 μ resolution transverse to the beam and 0.5-0.6 cm longitudinally. The vertex reconstruction resolution in case of neutral kaon decays into charged particles is about 0.2 cm radially. After reconstruction a momentum uncertainty of 4-5%/p for 250 MeV/c charged particles, and energy resolution of 10% for photons in the CsI calorimeter have been obtained.

A vacuum beam tube is made of Be with 0.077 cm wall thickness and has 3.4 cm outer diameter and may be considered as a target for the kaon interaction study.

The collected luminosity integral in different energy ranges of VEPP-2M collider is presented in Table 1.

The detector started with moderate luminosity integral for the initial debugging of all hardware and software systems, followed by taking data at ϕ-meson energy, sufficient to study the rare decays at the present world average level. The analisys is in progress and some number of obtained results are presented in E.Solodov's talk at this Workshop.

The analysis is not finished yet and new results are expected.

At January-March 1995, the luminosity integral about 300 nb^{-1} has been collected in the energy range between ρ and ϕ-mesons by scanning with 10 MeV step. The beam energy at each point was measured with the accuracy of about $1 \cdot 10^{-4}$ using the resonance depolarization technique.

Up to April 1995, for the off-line analysis only collinear two tracks events were selected and two pion production was studied. The pion formfactor values are presented in Figure3 along with the results of the previous experiments.

The statistical error of the $e^+e^- \to \pi^+\pi^-$ cross section at each energy point is better than 3%. The total systematic error at the moment is estimated to be about 1.5%. The main part of this error comes from the detector solid angle unsertainty (1%) and from the calculation of the radiative corrections for the Bhabha events (1%), which are using for the normalization. We hope to decrease the systematic error to the level of 0.5%. This level of accuraccy is nesesery for the calculation of the hadrinic vacuume polarization to g-2 of muons, to be able to interpret the result of the E821 experiment now in preparation at BNL. In this experiment the g-2 of muon is planned to be measured with extremely high accuracy of 0.35 ppm.

	c.m. energy range MeV	Triggers	Integrated Luminosity nb^{-1}
$\rho - \omega$–mesons	390 – 900	$5.5 \cdot 10^6$	20
ϕ–meson	1009 – 1028	$12.8 \cdot 10^6$	310
background	994	$0.45 \cdot 10^6$	20
	1993 runs		
ϕ–meson	1013 – 1040	$52.7 \cdot 10^6$	1400
background	994	$6.6 \cdot 10^6$	120
	1994 runs		
scanning with 10 MeV step	1000 – 786	$20.0 \cdot 10^6$	290
	1995/96 runs (before round beams at VEPP-2M)		
scanning with	780 – 360		300
10 MeV step	1000 – 1400		10000
ϕ–meson	1013 – 1040		10000

Table 1: List of the CMD-2 runs.

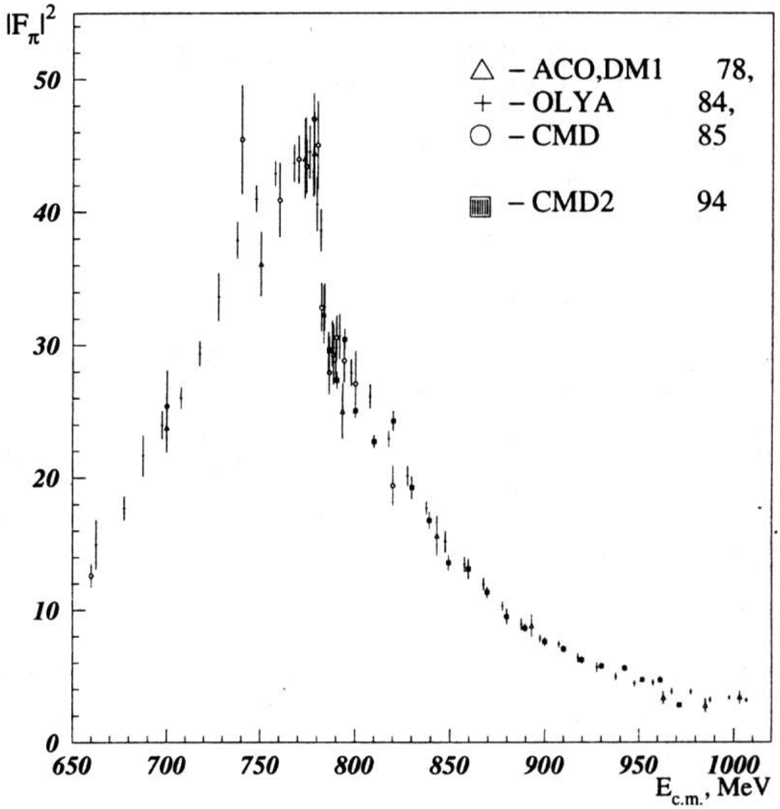

Figure 3: The experimental data for $|F_\pi|^2$.

3 SND detector

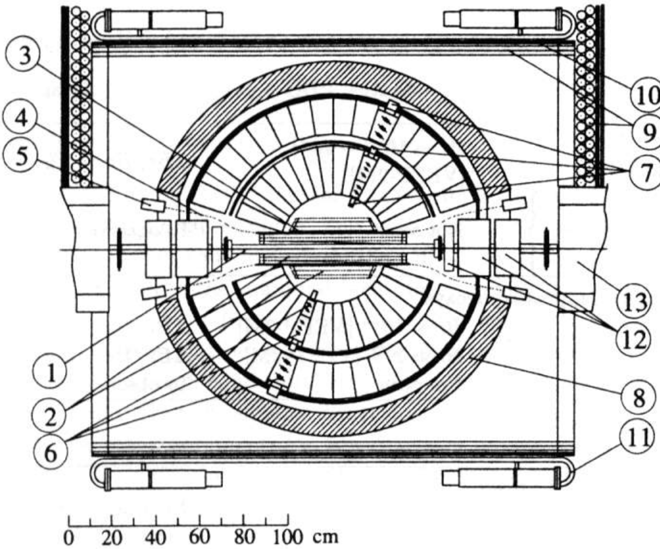

Figure 4: Detector SND — view transverse to the beam; 1 — beam pipe, 2 — drift chambers, 3 — scintillation counters, 4 — fiber lightguides, 5 — PMTs, 6 — NaI(Tl) counters, 7 — vacuum phototriodes, 8 — iron absorber, 9 — streamer tubes, 10 — 1 cm iron plates, 11 — scintillation counters, 12 — magnetic lenses, 13 bending magnets

In February 1995 experiments have been started with Spherical Neutral Detector (SND). SND (Fig. 4) is nonmagnetic wide purpose detector, intended to study e^+e^- annihilation at VEPP-2M. The main part of the SND is a three layer spherical NaI(Tl) calorimeter, consisted of 1680 individual crystals. The calorimeter thickness is 14 radiation lengths and its total mass is 3.6 tons. The energy resolution, expected for photons in the range of 50-500 MeV, is 4-6(rms), the angular resolution is 1.5 degrees. Inner part of the detector is a cylindrical drift chamber system for charge particles tracking with the accuracy of about 0.4 degrees in azimuthal and polar direction. Outside the calorimeter 11 cm iron absorber and muon/veto detector are installed, which consists of streamer tubes and scintillation counters. The last system is used as cosmic veto counter in events with neutral particles.

The parameters of SND detector allow to study wide range of physical processes, in spite of absence of magnetic field. The important part of the program is study of radiative decays of vector mesons, including both already measured magnetic dipole decays and still not observed electric dipole decays. The careful measurement of e^+e^- annihilation cross section into hadrons is another important point of the program. This cross section significantly contributes into hadronic vacuum polarization for muon (g-2) factor. The Table 2 shows full physics program for CMD-2 and SND detectors at VEPP-2M.

Table 2: Full experimental program with CMD-2 and SND at VEPP-2M

	Status, PDG	Goal
Radiative decays $\rho, \omega, \phi \to \pi^0\gamma, \eta\gamma$	Br $\sim 10^{-4} \div 10^{-1}$ [VEPP-2M]	$\Delta Br/Br \sim 1\%$
$\phi \to \eta'\gamma$ $\phi \to a_0\gamma, f_0\gamma, \pi\pi\gamma, \eta\pi\gamma$ $\rho, \omega \to \pi\pi\gamma$	Not seen	To observe
OZI and G-parity suppressed decays		
$\phi \to \pi\pi$	$Br \sim 10^{-4}$ [VEPP-2M]	$\Delta Br/Br \sim 5$ %
$\omega \to \pi\pi$	$Br \approx 2$ % [VEPP-2M]	$\Delta Br/Br \sim 5$ %
$\phi \to \omega\pi, \eta\pi\pi; \rho \to 3\pi$	Not seen	To observe
Electromagnetic decays $\rho, \omega, \phi \to \eta e^+e^-, \pi^0 e^+e^-$	Only $\phi \to \eta ee$ seen	To observe
e^+e^- annihilation into hadrons $e^+e^- \to 2\pi, 3\pi, 4\pi, 5\pi$ $e^+e^- \to \omega\pi, \eta\pi\pi, \phi\pi$ $e^+e^- \to K^+K^-, K_SK_L, KK\pi$		To measure total cross section with 1% accuracy and partial cross sections
Test of QED $e^+e^- \to 3\gamma, e^+e^-\gamma$ $(2 \to 3)$ $e^+e^- \to 4\gamma, e^+e^-\gamma\gamma, 4e$ $(2 \to 4)$		To study with accuracy $\sim 1\%$
$e^+e^- \to 5\gamma, 3\gamma e^+e^-, 4e\gamma$ $(2 \to 5)$		To observe
Search for rare K_S decays		
$K_S \to 2\gamma$	$Br \sim 10^{-6}$	$\Delta Br/Br \sim 20$ %
$K_S \to 3\pi^0, 2\pi^0\gamma, \pi^0\gamma\gamma, \pi^0 e^+e^-$	Not seen	$Br \le 10^{-5}$
Search for rare η decays $\eta \to 3\gamma, e^+e^-, 4e$	Not seen	$Br \le 10^{-4}$
Search for C-even reactions $e^+e^- \to \eta', a_0, f_0, a_2, f_2$	Not seen	To lower limit to $\sigma \le 10^{-36} cm^2$

4 Round beams and VEPP-2M

In the recent years electron–positron colliders with luminosities $L \sim 10^{33} cm^{-2}s^{-1}$ at the energy of 510 MeV, so called Φ-factories, are in consideration at different laboratories and under construction at Frascati and at Novosibirsk. In the Novosibirsk project the high luminosity level will be achieved with round colliding beams [8, 9]. What does mean "round beams"?

1. The equal and small $\beta_0 = \beta_x, \beta_z$ values.

2. The equal emittances ϵ_x, ϵ_z excited by quantum fluctuations independently.

3. The equal betatron tunes ν_x, ν_z and "zero" coupling.

4. The small positive non-integer tune fractions.

5. The small tunable synchrotron frequency ν_s.

As a result of items 1, 2 and 3, the angular momentum is conserved, thus converting transversal motion to "one-dimensional" one, with less beam-beam resonances which cause beam-beam blow-up and/or degrade their life-time. Items 4 and 5 proved to be important also in rising the maximal beam-beam tune shift $\xi_m ax$, which does not damage luminosity. We hope to rise its value, at least, up to 0.1, in comparing with 0.05 achieved now for flat beams. The additional useful effect arises due to the simple fact, that beam-beam tune shift for given counting bunch density is 2 times lower for round beams than for smaller dimension of flat beams.

There are many arguments for advantages of the round beam option. The best way to prove all significant arguments *pro* and *contra* round beam concept is an *experimentum crucis*. We have found a unique possibility to test them experimentally at VEPP-2M storage ring [12].

The present magnetic lattice of VEPP-2M has four symmetric periods with low β^*-functions (β_z = 5cm; β_x= 40cm) at interaction regions (IR), which are provided by two quadrupole doublets. Two opposite IRs are occupied by the detectors CMD-2 and SND detectors. Two remaining low-β straights are occupied by RF-cavity and SC wiggler. The superconducting wiggler has 5 poles with magnetic field up to 80 kG. The correction coils system can compensate the optics distortion from the wiggler and the solenoids of CMD-2 detector.

The main idea of VEPP-2M lattice modification to round beam mode is to replace the quadrupole doublets by SC solenoids accomodated inside the detectors (Fig. 5). The solenoids will provide the equal β^*-functions in the beam collision points, and besides rotate by $\pi/2$ the planes of the betatron oscillations. This will result in alternation of vertical and horizontal orientations of the planar betatron eigen-modes over each half-turn, similarly to the Novosibirsk ϕ-factory design. Weakening by ca.10 per cent the remaining 8 quadrupoles will transform the half-turn bends into achromats to provide for zero dispersion in the both IRs at the expense of enhanced dispersion in the bends (maximum of 140 cm vs. 70 cm at present) (Fig. 6). The momentum compaction factor will be left practically unchanged.

The chromaticity correction is performed by sextupoles placed on either side of the remaining quadrupole doublets. The natural chromaticity of betatron tunes with solenoids is:

$$\gamma \cdot \frac{\partial \nu_x}{\partial \gamma} = -12,\ \gamma \cdot \frac{\partial \nu_z}{\partial \gamma} = -13.$$

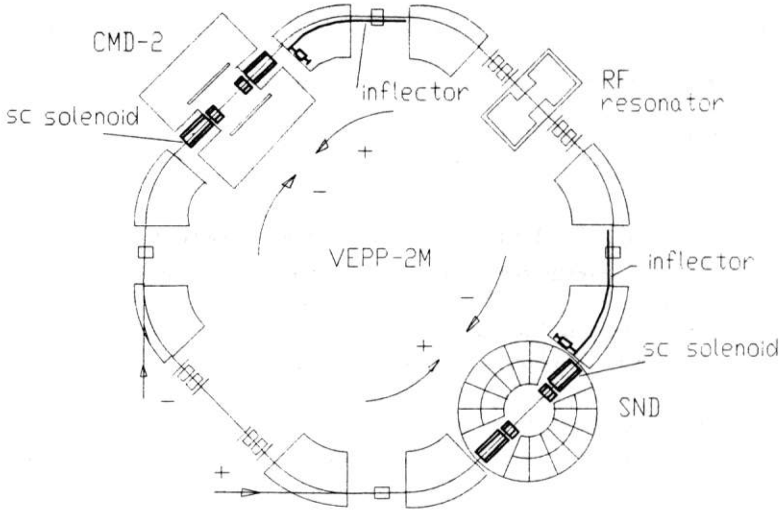

Figure 5: The VEPP-2M modification for round beam operation. The SC solenoids will be installed on both sides of existing detectors.

As far as the dispersion is zero over the IR, the compensation of the betatron tune chromaticities is possible only in the arcs by the appropriate sextupoles correction families S_x and S_z. The VEPP-2M round beam lattice was optimized to compensate the betatron tune chromaticity by minimizing the possible effect of sextupole correctors on the dynamic aperture. To determine the dynamic aperture limitation the particle motion was tracked in the lattice with averaging over initial betatron phases.

The computer simulations of the beam-beam interaction inherent in the dynamics of round beam collision encourage for the design goal of $\xi \sim 0.1$ ($N \sim 6.7 \cdot 10^{10}$) for the attainable beam-beam parameter. With the beam emittances of $\epsilon_x = \epsilon_z = 1.5 \cdot 10^{-5} cm \cdot rad$ this will hopefully come to luminosities of $L \sim 10^{32} cm^{-2} s^{-1}$ at the energy of 510 MeV.

The existing and proposed beam and optics parameters are summarized in the Table 3.

4.1 Specific Goals

This move will let us learn - just now! - such a non-traditional storage ring optics and study its tolerances, reach real gain in ξ_{max} and in luminosity, rising it from current $5 \cdot 10^{30} \mathrm{cm}^{-2}\mathrm{sec}^{-1}$ to $1 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{sec}^{-1}$. This improvement will give also a possibility to operate detectors at already very high fluxes of useful events, and, consequently, to collect many important experimental data.

VEPP-2M: BEAM AND OPTICS PARAMETERS			
Parameters		**flat beam**	**round beam**
Circumference, m	C	17.88	17.88
RF frequence, MHz	f_0	200	200
Momentum compaction	α	0.167	0.18
Emittances, $cm \cdot rad$	ε_x	$4.6 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$
	ε_z	$5.5 \cdot 10^{-7}$	$1.5 \cdot 10^{-5}$
Energy loss/turn, keV	ΔE_0	9.1	5.0
Dimensionless damping decrements	δ_z	$9.8 \cdot 10^{-6}$	$4.8 \cdot 10^{-6}$
	δ_x	$8.5 \cdot 10^{-6}$	$4.8 \cdot 10^{-6}$
	δ_s	$2.1 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$
Energy spread	σ_ε	$6 \cdot 10^{-4}$	$3.5 \cdot 10^{-4}$
β_x at IP, cm	β_x	48	5
β_z at IP, cm	β_z	4.5	5
Betatron tunes	ν_x, ν_z	3.05,3.1	3.1,3.1
Particles/bunch	e^-, e^+	$2 \cdot 10^{10}$	$6.7 \cdot 10^{10}$
Tune shifts	ξ_x, ξ_z	0.02,0.05	0.1,0.1
Luminosity, $cm^{-2} \cdot s^{-1}$	L_{max}	$\sim 5 \cdot 10^{30}$	$\sim 1 \cdot 10^{32}$

Table 3: Comparative parameters of VEPP-2M beams for flat beams option ("wiggler-on") and round beams option.

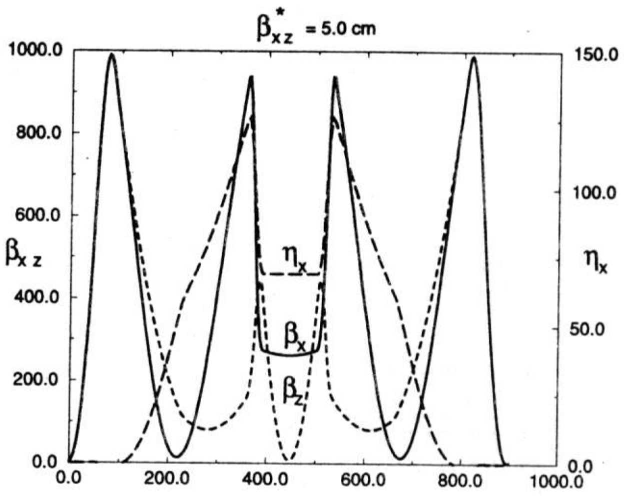

Figure 6: Optical functions for VEPP-2M round beam mode.

5 Four-wing ϕ-factory

Firstly, we summarize the status of the injection part of VEPP-5 complex envisaged for use by ϕ-factory, VEPP-4M and Charm/Tau Factory.

The civil engineering progress is rather fast: by now the halls of the injection linac and of the damping ring are constructed, as well as the rooms for all electric equipment and the control room, the klystron gallery and the main VEPP-5 linac tunnel. The ϕ-factory hall construction is about its finish. The equipment for the injection linac and transfer lines is partly installed. The SLAC klystron is tested for its nominal power. The major part of the damping ring magnetic system is machined. However, the pace of the project on the whole is apparently rather slow due to insufficient dedicated budgeting.

The concept of round colliding beams is still the highlight of the Novosibirsk approach to the ultra-high luminosities [8)]. Meanwhile, the last year resulted in a serious revision of the ϕ-factory project: we switched to the double-ring machine with the electrostatic orbit separation. The 50 kV/cm electrostatic separator plates are 2 meters in length and provide ± 2 cm aperture. Similarly to the previous "Siberian Butterfly" scheme, the interaction region is a common straight section with the axi-symmetric solenoidal focusing, envisaged for direct and reversed passages of colliding bunches (*i.e.* the bunches are in two-way head-on collision, see Fig. 7).

With the design RF harmonic number $h = 110$ ($\lambda = 42.8$ cm) two modes are possible for head-on collision of N bunches:

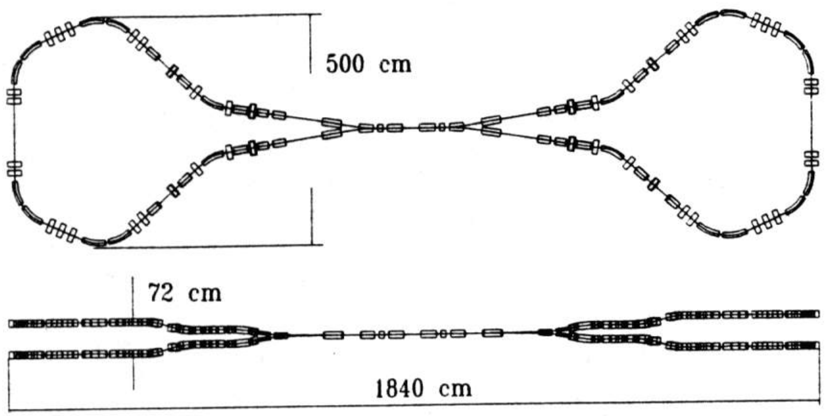

Figure 7: The ϕ-factory design.

• At $N = 11$ (*i.e.* the bunches are spaced by 9 empty RF buckets) we will collide only electrons with positrons. The closest parasitic collision of e^+e^+, e^-e^- occurs at a distance of 2.5 λ from the *I*nteraction *P*oint (IP), and the orbits are horizontally separated with magnetic field. The parasitic e^+e^- collision is 5 λ apart from the IP, it is electrostatically separated in the vertical plane.

At emittances about $1.25 \cdot 10^{-5} cm \cdot rad$ the luminosity should reach $2.5 \cdot 10^{33} cm^{-2} s^{-1}$.

• At $N = 10$ (10 empty RF buckets between the bunches) the e^+e^- collisions at the IP (half of luminosity) are simultaneous with the e^+e^+ and e^-e^- collisions (another half). In this collision mode all the parasitic collisions take place 5.5 λ apart from the IP. Here we have certain hopes for attaining a higher effective beam-beam parameter ξ as a result of overlapping of uni-directional e^+e^- bunches prior collisions and of consequent space charge compensation at collision.

At reduced emittances and/or higher bunch intensity, this option should give several times higher useful luminosity than the previous one.

Tunable optics of the rings is designed for controlling both the beam emittance values in the range of $(0.5 \rightarrow 2) \cdot 10^{-5}$ $cm \cdot rad$ and the momentum compaction in the range of $-0.02 \rightarrow 0.06$. The latter option may be important in taming coherent longitudinal instabilities and longitudinal beam-beam effects [13].

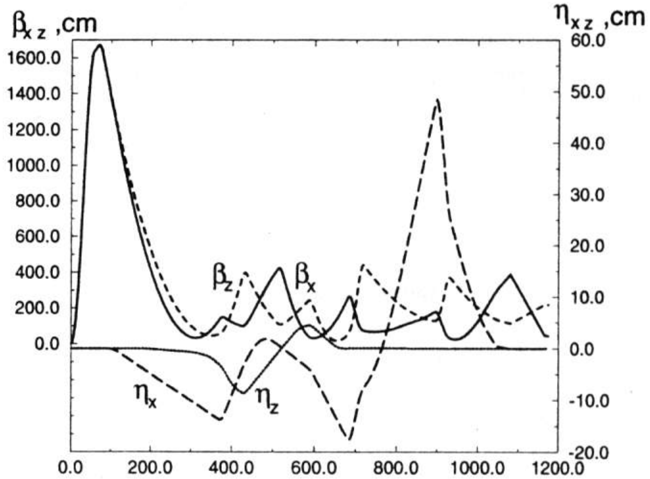

Figure 8: Optical functions of ϕ-factory.

The optical functions of the ring(s) are shown in Fig. 8. Note that the negative contribution to the momentum compaction comes from the vertical bends. Their purpose is to compensate for the (unwanted) vertical dispersion which originates from the electrostatic separator. The main parameters of the ϕ-factory are

Main parametrs of Phi—factory		
Circumference, m	C	47.08
RF frequence, MHz	f_0	700.4
RF voltage, kV	V	100
RF harmonic number	q	110
Momentum compaction	α	-0.02...0.06
Synchrotron tune	ν_s	0.012 ($\alpha = 0.04$)
Emittances, $cm \cdot rad$	ε_x ε_z	$1.25 \cdot 10^{-5}$ $1.25 \cdot 10^{-5}$
Energy loss/turn, keV	ΔE_0	13.5
Dimensionless damping decrements	δ_z δ_x δ_s	$1.25 \cdot 10^{-5}$ $1.25 \cdot 10^{-5}$ $2.92 \cdot 10^{-5}$
Energy spread	σ_ε	$4.3 \cdot 10^{-4}$
β_x at IP, cm β_z at IP, cm	β_x β_z	1.0 1.0
Betatron tunes	ν_x, ν_z	8.1,6.1
Particles/bunch	e^-, e^+	$5.0 \cdot 10^{10}$
Bunches/beam		11
Tune shifts	ξ_x, ξ_z	0.1,0.1
Luminosity, $cm^{-2} \cdot s^{-1}$	L_{max}	$2.5 \cdot 10^{33}$

Table 4: The main parameters of ϕ-factory.

presented in Table 4 .

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