HIGH LUMINOSITY AT VEPP-2000 COLLIDER WITH NEW INJECTOR

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Abstract

VEPP-2000 e+e- collider at BINP was commissioned and started data taking with two detectors in 2010 with old injection chain. In the middle energy range, where the luminosity was limited by beam-beam effects, the world record values of beam-beam parameter were achieved, ξ=0.12/IP. At the same time the design luminosity value of $L = 10^{32}$ $cm^{-2}s^{-1}$ at top energy (E = 1 GeV per beam) remained unreachable due to limited e+ production rate. The injection chain was significantly upgraded in 2013-2016. The experience of upgraded VEPP-2000 complex operation at top energies with Round Colliding Beams will be presented.

INTRODUCTION

The electron-positron collider VEPP-2M at Budker Institute of Nuclear Physics (BINP) was decommissioned in 2000 after 25 years of successful operation with several generations of particle detectors [1]. It was operating in the energy range of 180 ÷ 700 MeV per beam with maximal peak luminosity of $3{\times}10^{30}$ $cm^{-2}s^{-1}$. The total integrated luminosity of about 100 pb^{-1} was collected that 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. The decision to replace the existing collider with a new one, VEPP-2000 [2], was made in order to improve the luminosity and at the same time to increase the maximum attainable energy up to 1 GeV per beam. The luminosity increase comes from the implementation of novel concept of Round Beams [3] that allows to gain values of beam-beam parameters as large as $\xi \sim 0.15$ without any significant blow-up of the beam emittances. Also the energy range extension highly enriches the experimental program.

VEPP-2000 OVERVIEW

During commissioning and first phase of operation VEPP-2000 collider used the injection chain of it's predecessor VEPP-2M. It consisted of the old beam production system with limited rate of $2{\times}10^7$ e^+/sec, and Booster of Electrons and Positrons (BEP) with an energy limit of 800 MeV. Collider itself hosts two particle detectors, Spherical Neutral Detector (SND) and Cryogenic Magnetic Detector (CMD-3), placed into dispersion-free low-beta straights. The main design collider parameters are listed in Table 1. In Fig. 1 the collider layout can be found.

The RBC at VEPP-2000 was implemented by placing two pairs of 13 T superconducting final focusing solenoids into two interaction regions (IR) symmetrically with respect to collision points. Several combinations of solenoid polarities satisfy the RBC requirements, with different type of eigenmodes of betatron oscillations. Finally it was found that only 'flat' combinations (+− +− or +− −+) provide dynamic aperture (DA) sufficient for stable operation. This optics satisfies the RBC approach if the betatron tunes lie on the coupling resonance $\nu_x - \nu_y = 2$ to provide equal emittances via X-Y coupling.

Table 1: VEPP-2000 Main Parameters (at E = 1 GeV)

Circumference, C	24.39 m
Number of bunches	1 × 1
Betatron functions at IP, $\beta^*_{x,y}$	8.5 cm
Beam–beam parameters, $\xi_{x,z}$	0.1
Energy range, E	150÷1000 MeV
Number of particles per bunch, N	1×10^{11}
Betatron tunes, $\nu_{x,y}$	4.1, 2.1
Luminosity, L	1×10^{32} cm^{-2} s^{-1}

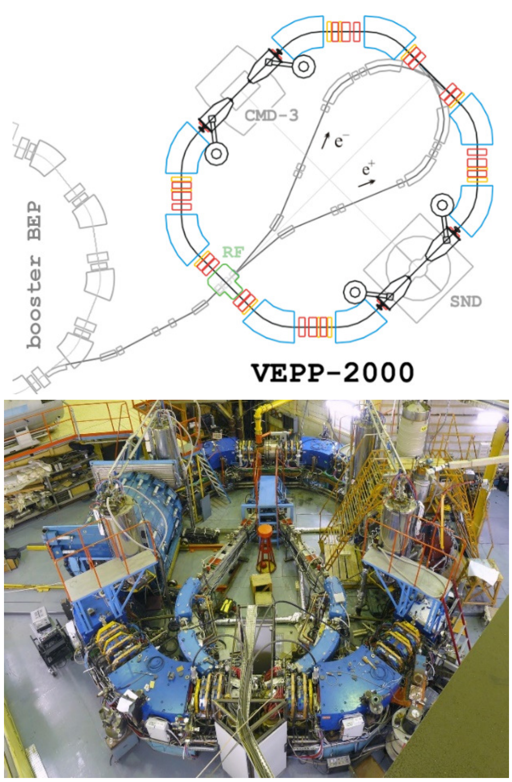

Figure 1: VEPP-2000 layout (up) and photo (down).

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DATA TAKING DURING PHASE 1

VEPP-2000 started data-taking with both detectors installed in 2009. The first runs were dedicated to experiments in the high-energy range, 500 ÷ 1000 MeV [4, 5], while during the last 2012/2013 run the scan to the lowest energy limit was done (see Fig. 2). Apart from partial integrability in beam-beam interaction the RBC gives a significant benefit in the Touschek lifetime when compared to traditional flat beams. This results in the ability of VEPP-2000 to operate at an energy as low as 160 MeV — the lowest energy ever obtained in e^+e^- colliders.

The averaged over 10% of best runs luminosity logged by CMD-3 detector during the last three seasons is shown in Fig. 2 (bottom) with red points. The blue dashed line shows the beam-beam limited luminosity for a fixed machine lattice (energy scaling law $L \propto \gamma^4$). It was successfully exceeded due to β^* reduction to 4÷5 cm available at low energies. At middle energies after thorough machine tuning the beam-beam parameter achieved the maximal value of $\xi \sim 0.12$ per one IP during regular work breaking a world record [6].

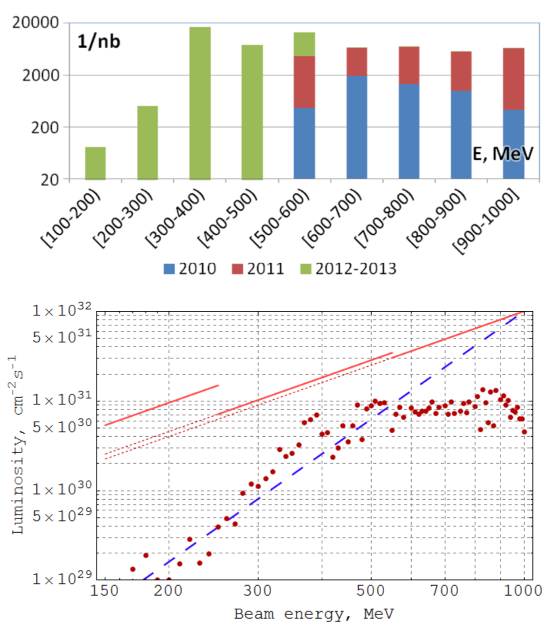

Figure 2: Integrated luminosity (top) and achieved luminosity at CMD-3 (bottom) over the energy range.

COMPLEX UPGRADE AND RECOMMISSIONING

During first phase of operation, the luminosity of VEPP-2000 at top energies (see Fig. 2, bottom) was limited by: 1) insufficient e^+ production rate and 2) necessity of acceleration at VEPP-2000 ring [7]. In order to achieve the design luminosity the machine was stopped in 2013 for upgrade of the whole injection chain. Firstly, the complex was linked up via a 250 m beamline K-500 [8] to the new BINP Injection Complex (IC) providing e^+,e^- beams at energy of 400 MeV (see Fig. 3). In addition, BEP was upgraded to provide top-up injection up to 1 GeV [9]. The transfer channels to VEPP-2000 ring were also reconstructed in order to cope with 1 GeV beam.

IC consists of electron gun, 270 MeV driving electron linac, 510 MeV positron linac and damping ring. Damping ring stores and cools down both electron and positron beams for the next extraction to K-500 beam transfer line. This 250 m beamline consists of three parts: descent from DR to K-500 tunnel, regular FODO structure in the tunnel and ascent to the BEP hall.

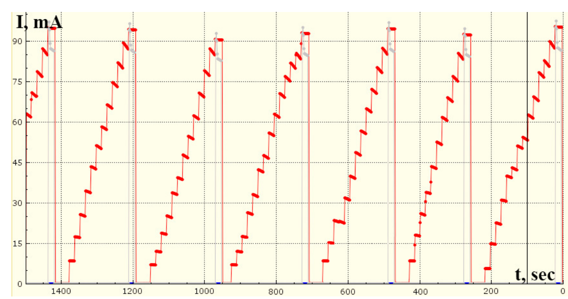

Figure 4: e^+ stacking @ BEP.

Booster BEP was dedicated to capture, cooling and stacking of hot 125 MeV positrons coming from old conversion system and was in operatio since 1991. It consists of 12 FODO cells. Each cell houses 30° sector dipole, two quads and straight, used for RF-cavity, kickers, injection/extraction septum, diagnostics, vacuum pumping.

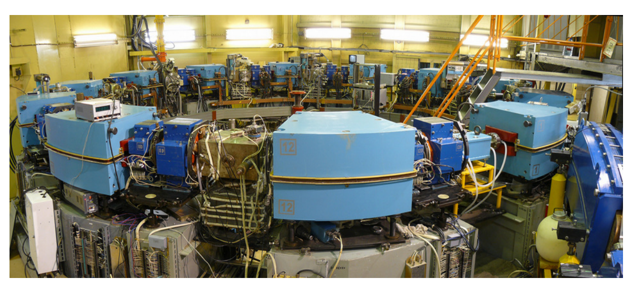

Figure 5: BEP – Booster of Electrons and Positrons.

To achieve the 1 GeV all magnetic elements were strengthened during upgrade. In order to increase RF voltage up to 110 kV new 174.376 MHz cavity was installed.

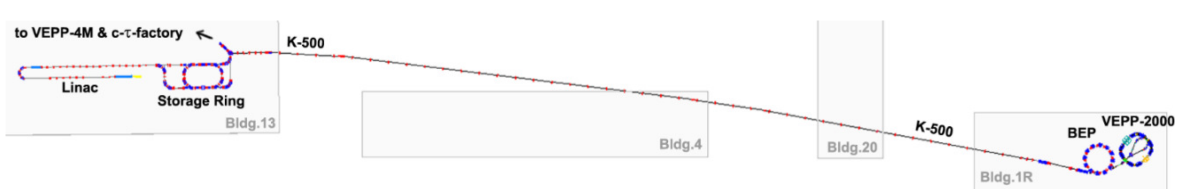

Figure 3: VEPP-2000 linked to the new Injection Complex.

The field of 2.6 T was achieved in the normal conducting dipole magnets both by 20% reduction of gap and feeding current increase up to 10 kA. Due to feeding in series with dipoles by accurate return yoke profiling quads' excitation curve was fitted to the dipoles' one in whole energy range. The poles of quadrupoles also were remachined to increase the sextupole component needed for chromaticity compensation.

The upgrade was finished in the beginning of 2016. VEPP-2000 injection chain was successfully recommissioned [10]. The achieved positron stacking rate at BEP amounts to 2×10^8 e^+/sec that exceeds corresponding value before upgrade in one order of magnitude [11].

EXPERIMENTAL SEASON 2016-2017

It was decided to dedicate first experimental season after the upgrade to a new scan at high energy range, starting from 850 MeV where the lack of positrons vastly effected the achievable luminosity during last seasons. From December of 2016 to May 2017 the range was scanned with the step of 10 MeV up to the energy of 1003.5 MeV. At each point the integrated luminosity of 1 pb^{-1} was collected. For the energy 1003.5 MeV which corresponds to the D^{*0} meson and probably maximum achievable energy at VEPP2000 the integral luminosity of 4 pb^{-1} was collected. With the given rate of the luminosity the 1 pb^{-1} integral is collected with less than 2 days of work including the liquid helium tanks refueling, change of the lattice due to the energy change, orbit and lattice function correction and the equipment maintenance both of the collider and detectors.

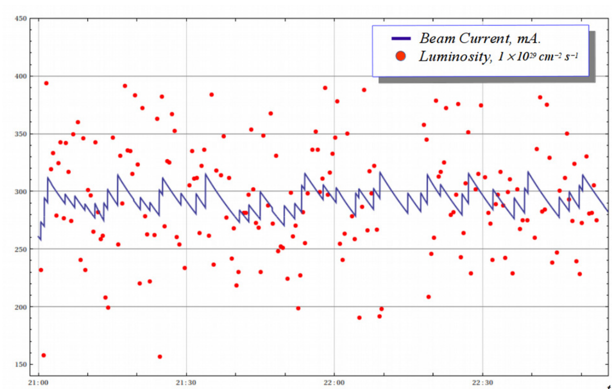

Figure 6: Sum current of two beams (blue line, mA) and luminosity measured by CMD-3 detector during the 2 hours of the collider work at energy of 939.6 MeV.

The injection is possible at the energy of the experiment for all points. The particle production rate allows to achieve the sum currents of up to 330mA (see Fig.6). It corresponds to the instant luminosity of up to 4×10^{31} cm^{-2} s^{-1}. Further increase of the beam currents and therefore the luminosity is prevented by the flip-flop effect that significantly reduces the beam lifetime.

In the Fig.7 the averaged luminosity among 10% of best runs of CMD-3 detector at each energy point is shown for the 2012 season (before upgrade) and for 2017 season. It is obviously seen that increase of averaged luminosity is up to 6 times (980MeV).

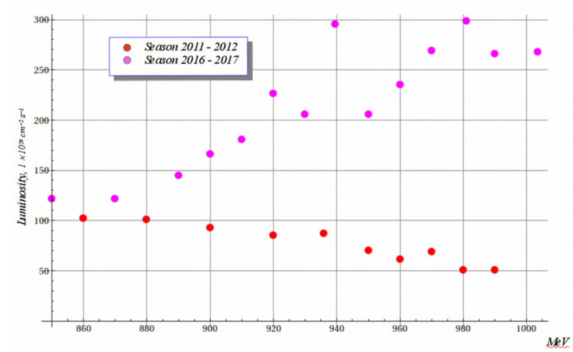

Figure 7: Luminosity over the energy at 2012 and 2017.

CONCLUSION

After the upgrade VEPP2000 has started experiments with the ability to work at full energy range with high luminosity. Further machine tuning is foreseen to achieve the design parameters. This work will be done together with delivery of the luminosity to detectors. The ultimate goal is to deliver at least 1 fb^{-1}.

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