RECOMMISSIONING AND PERSPECTIVES OF VEPP-2000 COMPLEX

Yu. Rogovsky[#1], V. Anashin, D. Berkaev, A. Kasaev, I. Koop[1], A. Kenzhebulatov, A. Krasnov, G. Kurkin, A. Kyrpotin, A. Lysenko, S. Motygin, E. Perevedentsev[1], V. Prosvetov, A. Semenov, A. Senchenko[1], Yu. Shatunov, P. Shatunov, D. Shwartz[1], A. Skrinsky, I. Zemlyansky, Y. Zharinov,
Budker Institute of Nuclear Physics, Novosibirsk, Russia
[1]also at Novosibirsk State University, Novosibirsk, Russia

Abstract

VEPP-2000 is electron-positron collider exploiting the novel concept of round colliding beams. After three seasons of data taking in the whole energy range of 160-1000 MeV per beam it was stopped in 2013 for injection chain upgrade. The linking to the new BINP source of intensive beams together with booster synchrotron modernization provides the drastic luminosity gain at top energy of VEPP-2000. Recommissioning status, fist results and perspectives of the VEPP-2000 complex will be presented.

VEPP-2000 OVERVIEW

The VEPP-2000 collider [1] exploits the round beam concept (RBC) [2]. The idea of round-beam collisions was proposed more than 25 years ago for the Novosibirsk Phi-factory design [3]. This approach, in addition to the geometrical factor gain, should yield the beam-beam limit enhancement. An axial symmetry of the counter-beam force together with the *X*–*Y* symmetry of the transfer matrix between the two IPs provide an additional integral of motion, namely, the longitudinal component of angular momentum $M_z = x'y - xy'$. Although the particles' dynamics remain strongly nonlinear due to beam–beam interaction, it becomes effectively one-dimensional. The reduction of degrees of freedom thins out the resonance grid and suppress the diffusion rate resulting finally in a beam-beam limit enhancement [4].

The layout of the VEPP-2000 complex as it worked before shutdown for upgrade in 2013 is presented in Fig. 1.

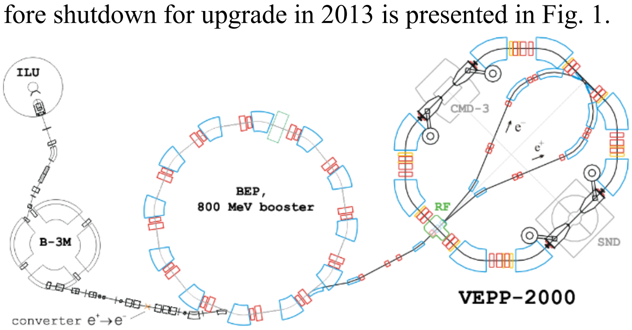

Figure 1: VEPP-2000 complex layout.

VEPP-2000 collider used the injection chain of it's predecessor VEPP-2M [5]. It consisted of the old beam production system and Booster of Electrons and Positrons (BEP) with an energy limit of 800 MeV. Collider itself hosts two particle detectors [6], Spherical Neutral Detector (SND) and Cryogenic Magnetic Detector (CMD-3), placed into dispersion-free low-beta straights. The final focusing (FF) is realized using superconducting 13 T solenoids. The main design collider parameters are listed in Table 1. In Fig. 2 one can find a photo of the collider ring.

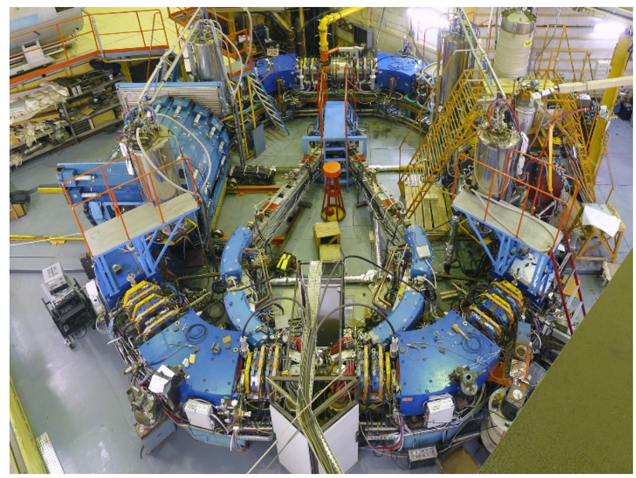

Figure 2: VEPP-2000 collider photo.

The density of magnet system and detectors components is so high that it is impossible to arrange a beam separation in the arcs. As a result, only a one-by-one bunch collision mode is allowed at VEPP-2000.

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

Parameter	Value
Circumference, C	24.39 m
Energy range, E	150–1000 MeV
Number of bunches	1 × 1
Number of particles per bunch, N	1×10^{11}
Betatron functions at IP, $\beta^*_{x,y}$	8.5 cm
Betatron tunes, $\nu_{x,y}$	4.1, 2.1
Beam emittance, $\varepsilon_{x,y}$	1.4×10^{-7} m rad
Beam–beam parameters, $\xi_{x,z}$	0.1
Luminosity, L	1×10^{32} cm^{-2} s^{-1}

EXPERIMENTAL RUNS

VEPP-2000 started data-taking with both detectors installed in 2009 [7]. The first runs were dedicated to experiments in the high-energy range [8, 9], while during the last 2012 to 2013 experimental run the scan to the lowest energy limit [10, 11] was done (see Fig. 3). Apart from partial integrability in beam-beam interaction, the RBC gives a

#rogovsky@inp.nsk.su

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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.

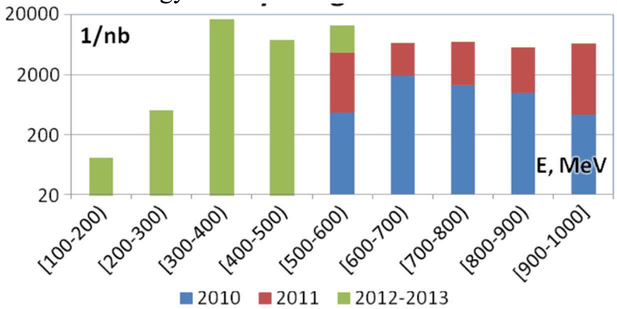

Figure 3: Delivered luminosity in 2010 – 2013.

The averaged over 10% of best runs luminosity obtained by CMD-3 detector during the last three seasons is shown in Fig. 4 with red points. The red lines overestimate the hypothetically achievable peak luminosity with jumps corresponding to possible shortening of FF solenoids by feeding only half of coils. 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.

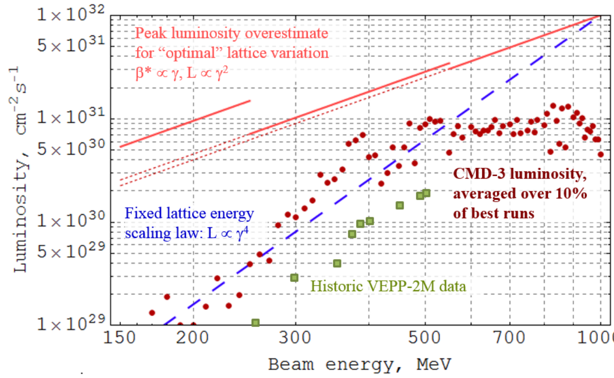

Figure 4: Achieved VEPP-2000 luminosity.

At high energies (> 500 MeV) luminosity was limited mostly by an insufficient positron production rate. At energies over 800 MeV the necessity of energy ramping in the collider storage ring additionally restricts the luminosity. Only for middle energy range 300÷500 MeV the luminosity is really limited by the beam–beam effects, especially by the flip-flop effect. At the lowest energies the main limiting factors are the small DA, IBS, weak radiation damping, and low beam lifetime as a result.

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 [12,19].

Figure 5: VEPP-2000 linked to the new Injection Complex.

VEPP-2000 COMPLEX UPGRADE

During first phase of operation, the luminosity of VEPP-2000 at top energies (see Fig. 3, left) was limited by: 1) insufficient e+ production rate and 2) necessity of acceleration at VEPP-2000 ring. 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 to the new BINP Injection Complex (IC) providing e$^+$/e$^-$ beams at energy of 400 MeV (see Fig. 5). In addition, BEP was upgraded to provide top-up injection up to 1 GeV.

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 (see Fig. 6). Damping ring stores and cools down both electron and positron beams for the next extraction to K-500 beam transfer line [13].

The K-500 beam transfer line was turned into operation in the end of 2015 [14]. 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. The fragment of the K-500 is shown in Fig. 7 (left).

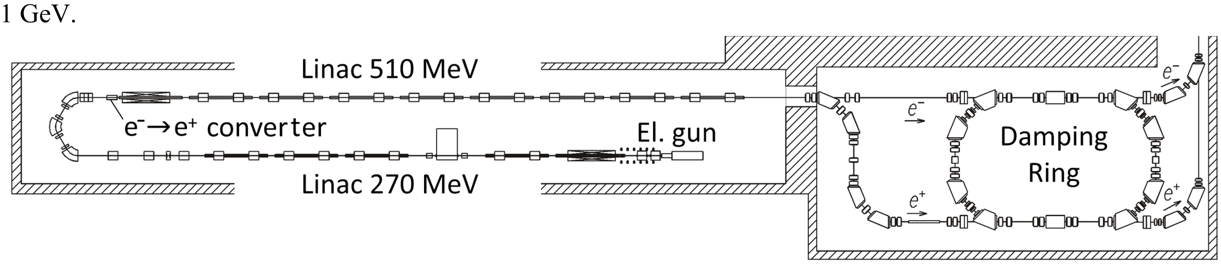

Figure 6: VEPP-5 Injection Complex Layout.

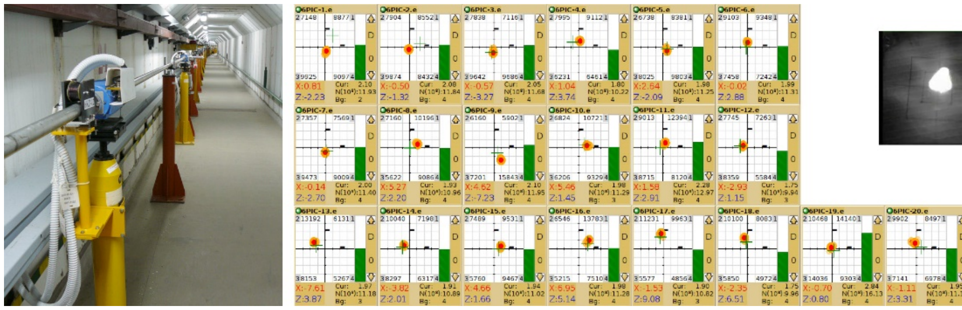

Figure 7: K-500 tunnel (left). Beam at BPMs along K-500 (center) and at scintillator screen (up-right).

Booster BEP Upgrade

Booster BEP dedicated to capture, cooling and stacking of hot 125 MeV positrons from old conversion system operated 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 and vacuum pumping (see Fig. 8). Booster layout is presented in Fig. 2, main parameters are listed in Table 2.

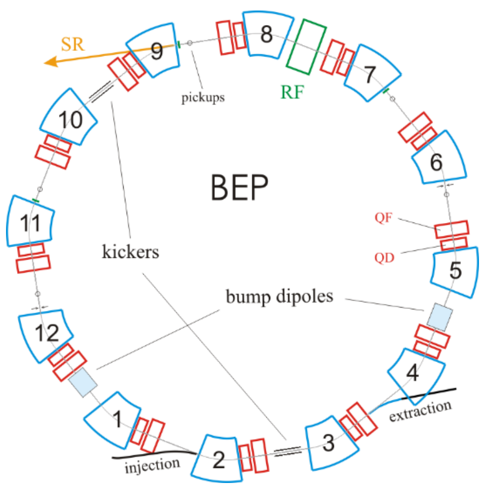

Figure 8: Booster synchrotron BEP layout.

Table 2: Modified BEP Main Parameters @ 1 GeV

Parameter	**Value**
Perimeter, Π	22.35 m
Revolution frequency, f_0	13.414 MHz
Bending radius, r_0	128 cm
RF harmonic, q	13
Synchrotron radiation loss	70 KeV/turn
Emittances, ε_x, ε_y	$8.6{\cdot}10^{-6}$, 10^{-8} cm
Betatron tunes, ν_x, ν_y	3.4, 2.4
Momentum compaction, α_p	0.06

To achieve the 1 GeV all magnetic elements were strengthened during upgrade. The field of 2.6 T was achieved in the normal conducting dipole magnets [15] 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 (see Fig. 9, left). The poles of quadrupoles also were remachined to increase the sextupole component needed for chromaticity compensation. (see Fig. 9).

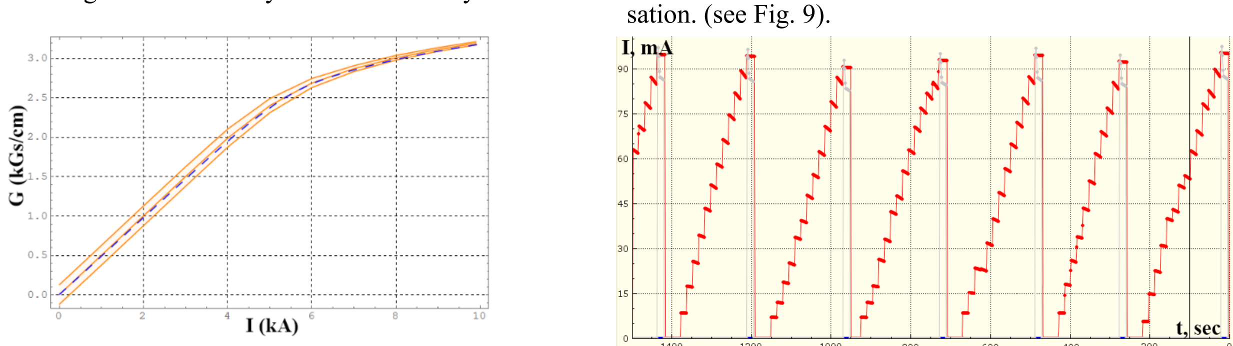

Figure 9: F-quad excitation curve compared to dipole's one (left). e+ stacking @ BEP (right).

The aluminum vacuum chamber was deformed locally inside the dipoles and D-quads due to aperture reduction. In order to increase RF voltage up to 110 kV new 174.376 MHz cavity was installed (see Fig. 10, left). Beam diagnostic system based on six CCD-cameras and old-fashioned BPMs was improved with 2 new sensitive calibrated electrostatic pickups (see Fig. 11).

The upgrade was finished in the beginning of 2016. VEPP-2000 injection chain was successfully recommissioned [16]. The achieved positron stacking rate at BEP amounts to $2{\times}10^8$ e+/sec that exceeds corresponding value before upgrade in one order of magnitude (see Fig. 9, right).

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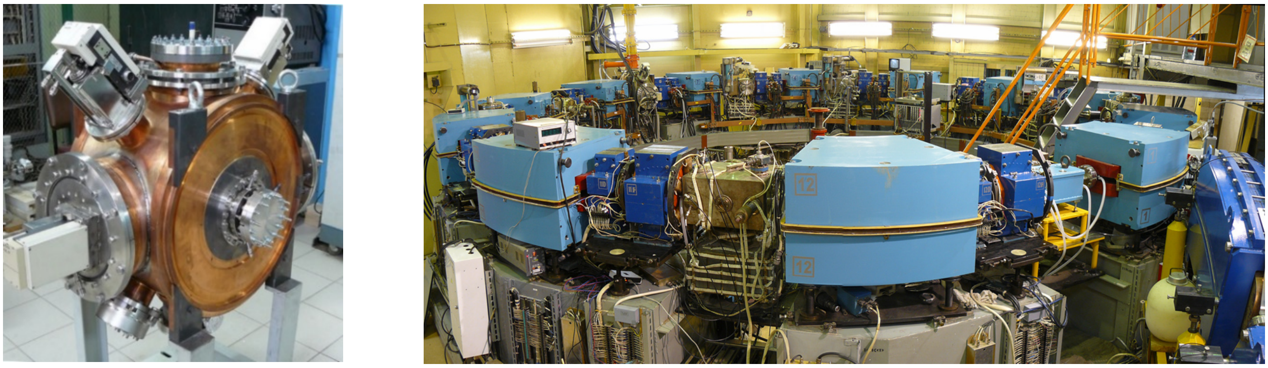

Figure 10: BEP new RF-cavity (left). BEP after assembly (right).

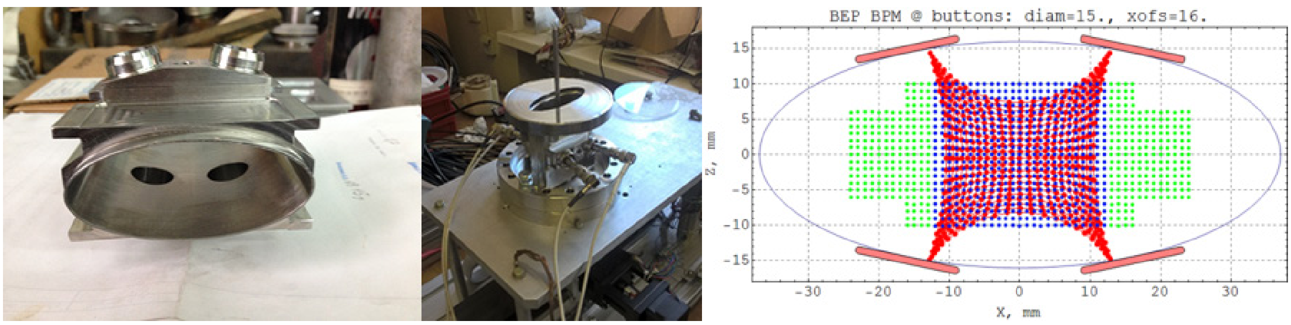

Figure 11: BEP new electrostatic BPM: production (left), test stand (middle), nonlinear calibration (right).

VEPP-2000 Collider Upgrade

Relatively small modifications were done in VEPP-2000 storage ring. Two additional kickers were installed to provide 1 GeV beam injection. All 8 two-sided copper mirrors used to extract the synchrotron light to CCD cameras were replaced. In 2016 the collider passed through the beam scrubbing procedure (see Fig. 12, right) working with switched-off SC solenoids. In addition, in this regime two beams e^+/e^- with low intensity were obtained to carry out the beam diagnostics alignment and tuning.

In 2016 the collider passed through the beam scrubbing procedure working in so called "warm mode" with switched off FF solenoids. In this regime two beams e^+/e^- with infinitesimal intensity were obtained to carry out the beam diagnostics alignment and tuning.

During upcoming new run (end of 2016, beginning 2017) we intend to achieve target luminosity and start it's delivery to detectors SND/CMD-3 with ultimate goal to deliver at least 1 fb^{-1} [17] with luminosity close to project value $L = 1 \times 10^{32}$ cm^{-2} s^{-1}.

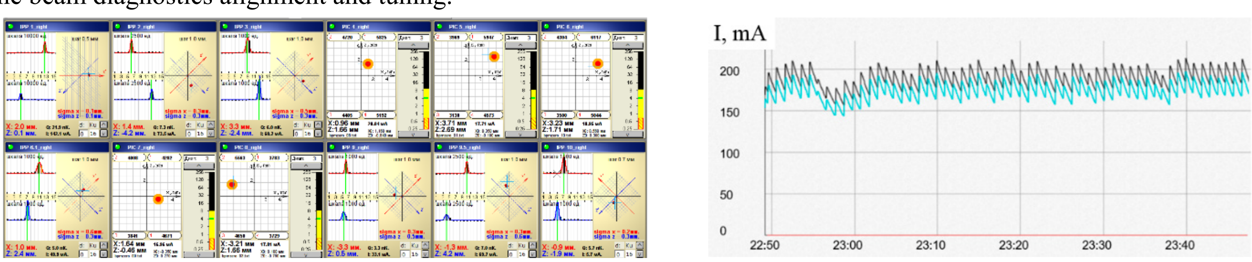

Figure 12: BEP-VEPP beam transfer (left). Beam scrubbing at VEPP-2000 (right).

CONCLUSION

Round beams give a serious luminosity enhancement. The achieved beam-beam parameter value at middle energies amounts to $\xi \sim 0.1$–0.12. VEPP-2000 was successfully taking data with two detectors across the whole designed energy range of 160–1000 MeV with a luminosity value five times higher than that achieved by its predecessor, VEPP-2M [18]. To reach the target luminosity, injection chain upgrade was done. Upgraded complex is now at the finish of the commissioning phase and ready to deliver luminosity at the design level for the next 5-10 years.

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REFERENCES

[1] Yu.M. Shatunov *et al*., "Project of a New Electron-Positron Collider VEPP-2000", in *Proc. EPAC'00*, Vienna, Austria, 2000, pp. 439-441.

[2] V.V. Danilov *et al*., "The Concept of Round Colliding Beams", in *Proc. EPAC'96*, Sitges, Spain, 1996, pp. 1149-1151.

[3] L.M. Barkov *et al.*, "Phi-Factory Project in Novosibirsk", in *Proc. 14th HEACC'89*, Tsukuba, Japan, 1989, p. 1385.

[4] K. Ohmi, K. Oide and E.A. Perevedentsev, "The beam-beam limit and the degree of freedom", in *Proc. EPAC'06*, Edinburgh, Scotland, 2006, pp.616-618.

[5] G.M. Tumaikin *et al.*, in *Proc. HEACC'1977*, Serpukhov, USSR, 1977, p.443.

[6] T.V. Dimova *et al.*, "Recent Results on $e^+e^-\to$hadrons Cross Sections from SND and CMD-3 Detectors at VEPP-2000 collider", *Nucl. Part. Phys. Proc*., vol. 273-275, pp. 1991-1996, 2016.

[7] M.N. Achasov *et al.*, "First Experience with SND Calorimeter at VEPP-2000 Collider," *Nucl. Instrum. Meth. A* vol. 598, pp. 31–32, 2009.

[8] D.N. Shemyakin *et al.*, "Measurement of the $e^+e^- \to K^+K^-\pi^-$ cross section with the CMD-3 detector at the VEPP-2000 collider", *Phys. Let. B,* vol. 756, pp. 153-160, 2016.

[9] M.N. Achasov *et al.*, "Study of the process $e^+e^- \to \omega\eta\pi^0$ in the energy range $\sqrt{s} < 2$ GeV with the SND detector", *Phys. Rev. D,* 94, 032010, 2016.

[10] M.N. Achasov *et al.*, "Search for the $\eta' \to e^+e^-$ decay with the SND detector", *Phys. Rev. D,* 91, 092010, 2015.

[11] V.E. Shebalin *et al.*, " Calorimetry of the CMD-3 detector", *J NIM 824, DOI: 10.1016/j.nima.2015.11.128*, 2016.

[12] D. Shwartz et al., Recent Beam-Beam Effects at VEPP-2000 and VEPP-4M, Proc. ICFA Mini-Workshop BB2013, CERN-2014-004, pp. 43-49.

[13] F.A. Emanov *et al.*, "Feeding BINP Colliders by the New VEPP-5 Injection Complex", in proc. RuPAC-2016, paper id WEXMH01.

[14] P.Yu. Shatunov *et al.*, "Commissioning of e+/e- Transfer Line from BINP Injection Complex to VEPP-2000 Facility", in proc. RuPAC-2016, paper id TUPSA001.

[15] D. Shwartz *et al.*, "Booster of Electrons and Positrons (BEP) Upgrade to 1 GeV", in *Proc. IPAC'14*, Dresden, Germany, pp. 102-104.

[16] D. Berkaev *et al.*, "Comissioning of Upgraded VEPP-2000 Injection Chain", in *Proc. IPAC'16*, Busan, Korea, pp. 3811-3813.

[17] I. Logashenko *et al.*, "Measurement of hadronic cross-sections with CMD-3 at VEPP-2000", in *Proc. ICHEP'16*, 2016, to be published.

[18] P.M. Ivanov *et al.*, "Luminosity and the Beam-Beam Effects on the Electron-Positron Storage Ring VEPP-2M with Superconducting Wiggler Magnet", in *Proc. 3rd Advanced ICFA Beam Dynamics Workshop on Beam–Beam Effects in Circular Colliders*, Novosibirsk, USSR, 1989, pp. 26-33.

[19] P.Yu. Shatunov *et al.,* "Status and perspectives of the VEPP-2000", *at. Phys. Part. Nuclei Lett. (2016) 13: 995. doi:10.1134/S154747711607044X.*

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