STATUS OF VEPP-4M COLLIDER

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Abstract

At present the VEPP-4 storage ring facility provides varied experimental programs including HEP, nuclear physics, synchrotron radiation, polarized electron/positron beam research, etc. Until now, the studies were mainly performed at the beam energy below 2 GeV but a strong interest of experimentalists encourages us to increase the beam energy up to 5 GeV. Reliable and high-performance operation at high energy is a challenge for the machine. Here we discuss the recent experimental results at the low energy, and prospects and constraints of the energy ramp.

INTRODUCTION

Since 2000, the VEPP-4M collider [1] has been operating with the KEDR detector [2] providing HEP experiments at the τ lepton and J/ψ charmonium energies (beam energy ≤ 2 GeV). By now, the study is almost completed [3] and the next run envisages the beam energy increase up to 5 GeV with the goal of Υ meson physics.

Besides HEP, there are other experimental programs at the VEPP-4 storage ring facility including electron and photon test beam bench, photo-nuclear study, accelerator physics, and technology and experiments with synchrotron radiation (SR). The latter program also welcomes the beam energy enhancement to extend the SR spectrum into a harder X-ray region.

The beam intensity increase is another direction of the VEPP-4 upgrade. For the SR experiments it gives higher photon flux while for the HEP program large beam current is needed to reach the designed luminosity because the critical bunch intensity due to the beam-beam interaction increases with energy as $I_b \sim E^3$.

The energy and the beam current gain sets high requirements to the VEPP-4 performance and reliability, to the energy calibration accuracy and to the obtainment of the design luminosity. Presently we have a routine operation at the beam energy of 4 GeV with maximum current of 30 mA in two bunches and 4.7 GeV with 2 mA during the short test run. The main limitation comes from old RF generators which need some upgrade.

VEPP-4 FACILITY

VEPP-4 is shown schematically in Fig. 1. It includes two storage rings VEPP-3 and VEPP-4M and common injection complex consisting of a high current linac, booster synchrotron, beam transfer lines and other systems. The main parameters of the storage rings are listed in Table 1. VEPP-4M storage ring operation priority is the e^+e^- collider mode with 2×2 bunches. The maximum peak luminosity at low energy (~1.8÷2 GeV) is $2\cdot10^{30}$ cm^{-2}s^{-1}. The maximum design luminosity at high energy (~4÷5 GeV) is ~$0.5\cdot10^{32}$ cm^{-2}s^{-1}.

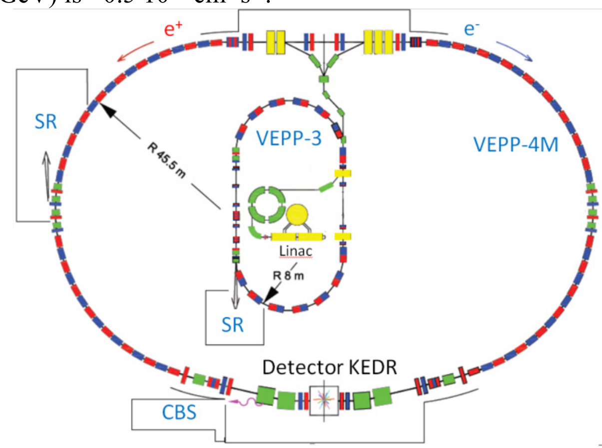

Figure 1: The VEPP-4 layout with the KEDR detector, Compton backscattering (CBS) system and SR experimental halls.

Table 1: Parameters of VEPP-4M at 1.8 GeV and VEPP-3 at 2 GeV

PARAMETER	VEPP-4M	VEPP-3
Circumference (m)	366	74.4
Max.energy (GeV)	5.3	2
Nat. chromaticity x/y	-14/-20	-3/-2
Damping times x/y/s (ms)	35/70/70	4/4/2
Hor. emittance (nm)	20	250
Energy spread ×10^{-4}	4	7
Bunch length (cm)	6	9
Energy loss/turn (keV)	16	250

STATUS OF EXPERIMENTS

High Energy Physics

To make the HEP program interesting and attractive despite a quite modest luminosity, we focused our efforts on the experiments requiring precise beam energy calibration.

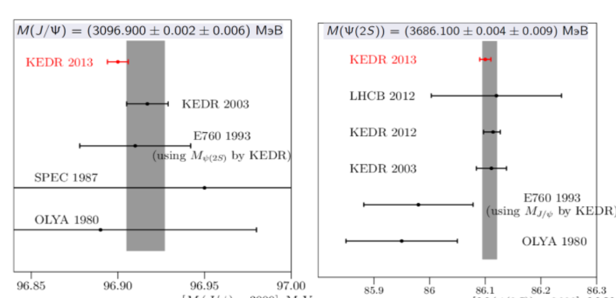

Figure 2: J/ψ (left plot) and ψ(2s) mass measurement at VEPP-4M with the KEDR detector.

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We employ two methods of the energy calibration: resonant depolarization providing the record energy accuracy of 10^{-6} [4] and Compton back scattering of laser photons with $\lambda \approx 10$ μm which gives the relative energy accuracy $\approx 3\cdot10^{-5}$ and the energy spread ≈7% (important for narrow resonances study) in 10 min [5]. The recent results include a record mass measurement of J/ψ and $\psi(2s)$ mesons (Fig. 2), precise measurement of the η_c meson mass and leptonic width, $J/\psi \to \gamma\eta_c$ branching fraction determination, $\psi(2s) \to \mu^+\mu^-$ decay study, etc.

Synchrotron Radiation

We have two SR experimental halls, one belongs to VEPP-3 (9 experimental hutches) and the other - to VEPP-4M (3 hutches). VEPP-4M experimental stations are intended for high energy (up to 5 GeV) and hard X-ray spectrum operation. Fig. 3 demonstrates the results from LIGA experiment at VEPP-3 and phase-contrast microtomography at VEPP-4M.

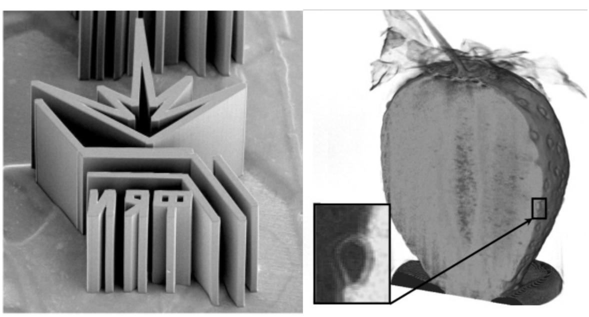

Figure 3: LIGA-produced BINP emblem is on the left. The aspect ratio is 30×300 μm^2. Phase-contrast microtomography of a strawberry is on the right.

Nuclear Physics

For many years electro- and photo-nuclear reactions are investigated with an internal gas target based on the open-ended storage cell inserted in the VEPP-3 vacuum pipe [6]. We can use different high-purity gas targets (including polarized ones) with a thickness of $\approx 10^{15}$ atom/cm^2 and different lepton beams circulating in VEPP-3 (e^+/e^-, polarized/unpolarized). The recent research program is focused on the pion photo-production at the polarized deuteron $\gamma + \vec{d} \to \pi^0 + d$. We expect that the measurement of the tensor polarization asymmetry in this reaction will allow us to clarify the nuclear meson model, to study a contribution of nuclear resonances in the meson production process, etc. A preliminary result of the tensor analysing power asymmetry is given in Fig. 4.

Test Beam Facility

In 2010 a new test beam facility was commissioned at VEPP-4 [7]. An intense bremsstrahlung radiation is either directly extracted from the VEPP-4M vacuum pipe to the experimental hall or converted to the electron beam with the parameters listed in Table 2.

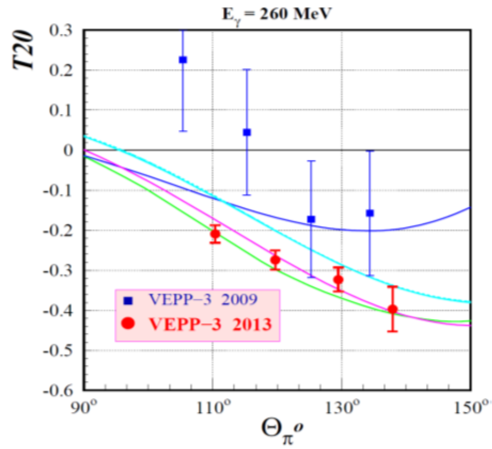

Figure 4: Tensor polarization asymmetry in the reaction $\gamma + \vec{d} \to \pi^0 + d$. Blue and red dots correspond to the results of 2009 and 2013, respectively. The curves relate to different theoretical models.

Table 2: VEPP-4M test beam parameters

Parameter	e^-	γ
Energy range (GeV)	0.1÷3.0	0.05÷1.5
σ_E / E (%)	0.5÷1.5	≈0.5
Intensity (Hz)	10÷100	≈1000

The test beam facility is used for study and calibration of various HEP detector systems. Here we can mention calorimeter prototype for COMET experiment (KEK), Cherenkov light detector for PANDA (Germany), MCP detectors for CMS (CERN), etc. Two results from the VEPP-4M test beam facility are shown in Fig. 5.

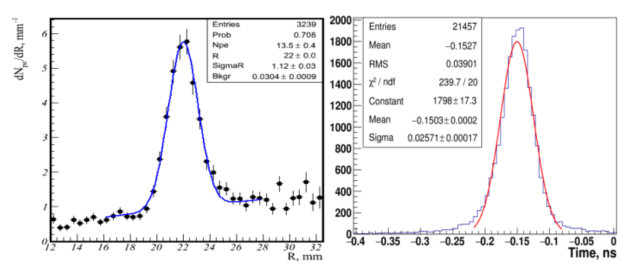

Figure 5: Cherenkov ring width after the 4-layer focusing aerogel is on the left. MCP time resolution measurement (30 ps/e$^-$ was obtained) is on the right.

VEPP-4 PROSPECTS

Progress with the VEPP-4M research in HEP and SR strongly depends on the beam energy ramp up to 5 GeV. The planned experiments in particle physics include cross-section study for $e^+e^- \to hadrons$, precise measurement of the Υ meson mass and two-photon physics when the reaction of $e^+e^- \to e^+e^- X$ goes through the channel with two virtual photons $\gamma\gamma \to X$. In this case, study of the

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C-even final states is available as contrasted with the single-photon annihilation. Specifically for this program, we have developed a unique e^+e^- tagging system consisting of a focusing magnetic spectrometer placed symmetrically around the IP. Electrons and positrons, which lose the energy in the two-photon process, change the trajectory (see Fig. 6) and are detected by 8 counters consisting of two-coordinate GEM-detector and drift-tube hodoscope. A calibration system based on the *Nd:YAG* laser provides the relative energy resolution of $\approx 2\cdot 10^{-4}$; we hope to improve this value twice in the near future [8].

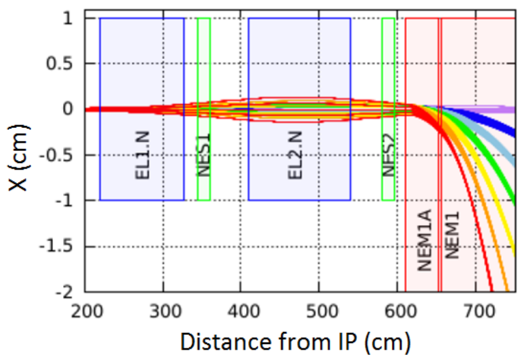

Figure 6: Horizontal displacement in focusing magnetic spectrometer for the particles, which lost the energy in the two-photon process.

The VEPP-4M energy enhancement up to ~4÷5 GeV extends substantially the SR spectrum in the hard X-ray region and boosts the research including fast processes study with ns- and ps-resolution, small angle diffraction, microtomography, experiments with focusing refraction optics, etc.

At present, from VEPP-3 (at 2 GeV), we have the radiation with critical energy of $\varepsilon_c \le 10$ keV. From VEPP-4M at 4 GeV, the SR energy is in the range of $10 < \varepsilon_c < 30$ keV. We expect that with the new 7-pole 2.1-T hybrid wiggler, which is under production now, the VEPP-4M photon flux with the critical energy of $\varepsilon_c \le 40$ keV will be increased by factor 50.

In the field of nuclear physics research at VEPP-3, we plan to concentrate mainly on two experiments. The first one relates to the measurement of the tensor analysing power asymmetry for two-particle photo-disintegration process $\gamma + \vec{d} \to p + n$ in the photon energy range of $E_\gamma \approx 0.4 \div 1.5$ GeV. This reaction, we believe, can improve the details of the nucleon-meson exchange models and form factors. The second planned experiment is a search of the dark (heavy) photon in the annihilation reaction $e^- + e^+ \to \gamma + A'$. A massive hypothetical dark photon (gauge vector $U(1)$ boson) was proposed as an extension of the Standard Model allowing to explain a dark matter particles interaction [9]. Estimation shows that if it exists, its mass has the range of $m_{A'} \sim 1$ MeV ÷ 1 GeV. Our experiment is planned to employ an intense positron beam from the new BINP Injection Facility [10] at the energy of $E_{e+} \approx 500$ MeV circulating in the VEPP-3 storage ring and interacting with internal hydrogen target. The massive photon search scenario based on the annihilation process with single γ detected: a peak in the missing mass spectrum should indicate production of A'. Simulation has shown that for the half-year run we can scan a not-yet studied region of the heavy photon mass of $m_{A'} < 15 \div 20$ MeV.

For all major experimental programs at the VEPP-4 facility, use of the BINP new Injection Facility is essential. The new Injection Facility, which is now under commissioning [10], will provide a much higher injection rate for both electron and positron beams in comparison with the existing injection complex. The main relevant parameters for both are given in Table 3.

Table 3: Main parameters of the new and old injection complex of VEPP-4

Parameter	Old	New
Energy [MeV]	355	450
Repetition rate [Hz]	1	1
No.of e^- per shot/current [mA]	$3\cdot 10^9$/2	10^{10}/6.5
No.of e^+ per shot/current [µA]	10^8/65	$2\cdot 10^9$/1300
80 mA e^+ storing in VEPP-3 [min]	~60	1
Injecting bunch length [cm]	150	1

CONCLUSION

In spite of the advanced age of VEPP-4, it is still able to provide experiments in HEP, nuclear physics, synchrotron radiation research, etc. Our mainstream focuses on the VEPP-4M beam energy boost up to 5 GeV together with the beam current increase.

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