STATUS OF THE ELECTRON-POSITRON COLLIDER VEPP-4

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Abstract

The near future of the e+e– collider VEPP-4M (Budker INP, Novosibirsk) is focused on experiments in the energy range from 4 GeV to 10 GeV (c.m.). To overcome the lack of positrons at high energy we have switched over to a new injection facility. The paper discusses the VEPP-4M performance with the new injector and other aspects of experimental study at high energy including laser polarimeter for precise energy calibration.

INTRODUCTION

VEPP-4 is a multipurpose storage ring facility [1,2] with several research programs including high energy physics (HEP) on colliding beams, nuclear physics, synchrotron radiation, accelerator physics study, etc.

Since 2000, the VEPP-4M collider has been operating with the KEDR detector [3], providing HEP experiments at 1 GeV to 1.9 GeV beam energy, and the program was almost completed by the end of 2016. The next run assumes gradual energy increase from 2 GeV to 5 GeV for Y-meson study and $\gamma\gamma$-physics as the main goal. To reach maximum luminosity at the high energy we decided to switch from the old injection complex to the new one with a 10-fold positron production rate [4]. In October 2016 the first beam from the new injector was injected in the storage ring, and in February 2017 the luminosity run at $\psi(3770)$ was started on VEPP-4M with KEDR detector.

VEPP-4 FACILITY

The VEPP-4 facility, which is shown schematically in Fig. 1, includes the new e^+e^- injector (Fig. 2), the long (150 m) beam transfer line K-500, the VEPP-3 booster storage ring, the pulse-magnet beam transfer line from VEPP-3 to VEPP-4M and the VEPP-4M storage ring. Main parameters of the storage rings are listed in Table 1.

The new e^+e^- injector [4] delivers the beams to VEPP-4 since 2016. It provides particles for the VEPP-2000 collider [5] as well. The injector consists of the electron gun, 270-MeV electron linac, positron target with pulse magnetic concentrator, 400-MeV positron linac and damping ring for collecting and cooling electron and positron beams with a repetition rate of 12.5 Hz. The injector provides $2\cdot10^9$ e^+/s and 10^{10} e^-/s with a repetition rate of 1 Hz.

VEPP-3 is a storage ring with combine-function bending magnets, which affords a very compact lattice. It has two accelerating RF systems allowing injection into the longitudinal phase space of the 8-MHz RF bucket with transition to 72 MHz at 600 MeV and further acceleration of 2 possible bunches up to a maximum energy of 2 GeV.

VEPP-4M is a single ring e^+e^- collider with the operation beam energy range from 925 MeV to 5.2 GeV.

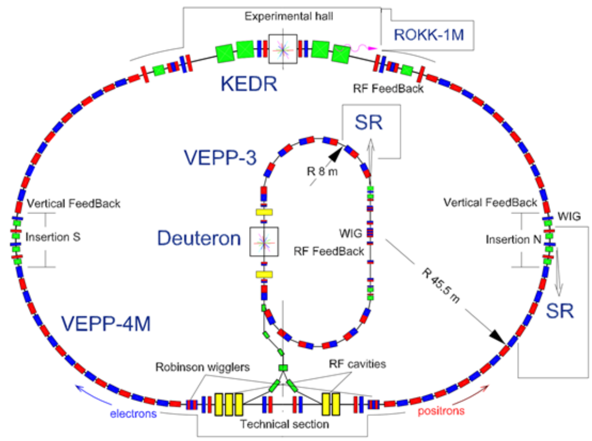

Figure 1: VEPP-4 layout.

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

Parameter	VEPP-3	VEPP-4M
Circumference	74.4 m	366 m
Energy range	0.4-2 GeV	1÷5.2 GeV
Betatron tunes	5.12/5.18	8.54/7.58
Nat. chroms	-3/-2	-14/-20
Hor. emittance	250 nm·rad	20 nm·rad
Energy spread	$7\cdot10^{-4}$	$4\cdot10^{-4}$
Bunch length	9 cm	6 cm

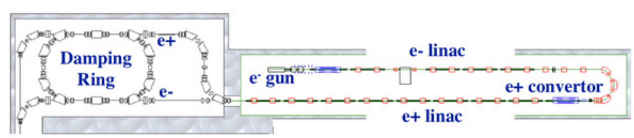

Figure 2: The new e^+e^- injector layout.

The present maximum energy of 4.75 GeV is limited by the dipole magnet power supply. Two electron and two positron bunches are used for the collider mode. Up to 16 bunches are available for SR experiments.

The efficiency of the old injector was so low that we never reached the beam-beam limit at 1.9 GeV and higher. With the new injector, we definitely observed the beam-beam effects, especially while converging e^+ and e^- beams at the IP (during the injection, the beams at the IP are separated vertically). To eliminate the particle loss due to the beams overlapping, a transverse 2×2 feedback system [6] was implemented. It increased the peak luminosity from $2\cdot10^{30}$ cm^{-2}s^{-1} to $3.3\cdot10^{30}$ cm^{-2}s^{-1}.

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STATUS OF EXPERIMENTS

High Energy Physics

The HEP experiments with e^+e^- colliding beams on VEPP-4M are performed with KEDR detector [3], which is a versatile magnet detector with a 6-kG longitudinal field and unique electron and positron tagging system for γγ-physics. To provide competitive study with the VEPP-4M moderate luminosity we implemented extremely precise energy calibration techniques including the resonant depolarization (~10^{-6} relative accuracy) [7] and Compton backward scattering (~3×10^{6}) [8]. Among recent results we can mention the measurement of the ratio R of the hadronic cross section in the energy range from c.m. 3.12 GeV to 3.72 GeV [9] with a total systematic uncertainty of about 2.1%. In the fall of 2017 we plan to spend some time for luminosity collecting at a VEPP-4M extremely low energy of c.m. 1.85 GeV and 1.95 GeV, which is important to overlap the R measurement with VEPP-2000 results, and then the energy increase to the maximum possible value will start.

Synchrotron Radiation

The synchrotron radiation (SR) experiments are carried out on both the VEPP-3 and VEPP-4M storage rings [10]. Ten user stations on VEPP-3 employ the radiation from a wavelength shifter. Taking into account the relatively high maximum energy of VEPP-4M, the SR experiments mainly concentrate in the hard X-ray region up to a critical energy of 100 keV. Currently we have on VEPP-4M a 5+2 electromagnetic wiggler with a field amplitude of 1.3 T as a photon source, but to extend the flux in the harder X-ray region a new hybrid-magnet wiggler was developed and is ready for installation (see the wiggler description below). There are five experimental stations on the VEPP-4M storage ring and three more will be launched in the future.

Test Beam Facility

Another experimental facility of VEPP-4M uses bremsstrahlung γ-rays from the movable beam scraper inserted in the halo of the circulating electron beam for test experiments with HEP detector components [11]. High energy gammas are converted into e^+e^- pairs at the lead target in the experimental hall. The dipole magnet separator selects particles with a specified energy. The momentum of selected particles is measured by its deflection in a known magnetic field using a coordinate system. The electron beam energy is 100 MeV to 3 GeV; the intensity is 100 Hz.

Since 2011 the test facility was used for the following experiments:

- FARICH development, calibration and study;
- Calibration and study of GEM coordinate detectors;
- Time resolution and detection efficiency investigation for microchannel plate detectors for the CMS upgrade.

LASER POLARIMETER

The main advantage of VEPP-4M in the HEP experiments is the high-precision (~ 10^{-6}) beam energy measurement by resonant depolarization [7]. To define the beam polarization at low energy (E ≈ 1.5÷2 GeV) we use the Touschek scattering. However, at high energies the method becomes inefficient at high energies. We developed a laser polarimeter based on the Compton scattering. Circularly polarized laser photons scatter on vertically polarized electrons, and the up-down asymmetry is defined as [12]

$$A=\frac{N_{up}-N_{down}}{N_{up}+N_{down}}\approx-\frac{3}{4}\frac{\omega_0 E}{m_e^2}V\cdot P,$$

where N_{up} and N_{down} are the number of photons scattered into the top and the bottom hemispheres, respectively; P is the vertical polarization degree of the electron beam; V is the Stokes parameter of the laser photon circular polarization; ω_0 is the initial energy of laser photon; E is the beam energy. With our parameters A ~ 1% at E = 5 GeV, which is quite enough for registration. Circularly polarized (with the help of the Pockels cell and the λ/4 phase plate) photons from the 527-nm Nd:YLF laser are scattered at the polarized electron beam with a 2-kHz repetition rate and detected through the 12 mm thick lead converter by the GEM two-coordinate detector. The first observation of the Sokolov-Ternov radiative polarization in VEPP-4M by the laser polarimeter is shown in Fig. 3. The beam polarization degree is calculated from the asymmetry comparison for the left and right photon polarizations (L-R mode) in order to suppress the systematic bias that is not connected with the beam polarization. The effect disappears for the same photon polarization (L-L mode), as expected.

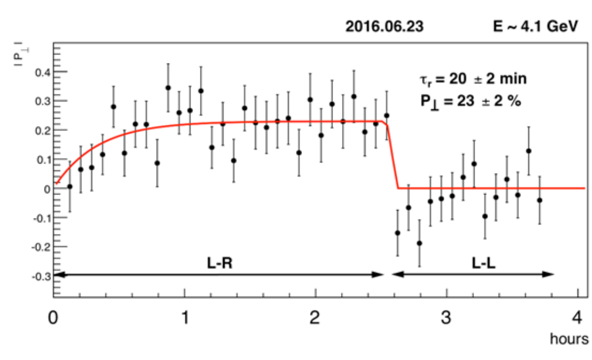

Figure 3: Observation of radiative polarization at 4.1 GeV.

HYBRID WIGGLER

A compact hybrid magnet wiggler is being developed for the VEPP-4M SR research program [13]. This device will replace the old 1.3-T wiggler of the same length. The pole gap is decreased from 40 to 30 mm. The NbFeB permanent magnet concentrators redistribute the magnetic flux to increase the field from 1.8 T to 2 T. With such a

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peak field and 7 poles instead of the old 5 ones, the photon flux at 100 keV increases by a factor of 30-40 for a beam energy of 4 GeV. Fig.4 shows the hybrid magnet wiggler.

The new wiggler significantly expands the SR research program, especially for study of fast processes, massive sample analysis, micro-beam cancer therapy and dynamic study of materials of thermo-fusion reactors.

The new wiggler is planned to be installed during the fall of 2017.

Figure 4: The hybrid wiggler view.

BPM SYSTEM UPGRADE

There are 20 BPMs on the VEPP-3 storage ring and 54 BPMs on the VEPP-4M storage ring. The old BPM electronics, developed about 30 years ago, are now being replaced by new electronics developed at BINP recently [14]. Each BPM has an adjacent processor, which is connected to the computer via 100-Mb/s Ethernet. The BPM control system applies EPICS.

The VEPP-4M operates with two electron bunches and two positron bunches. Beam position measurement close to the IP requires BPMs with high time resolution. The wide bandwidth (25, 105, and 210 MHz) allows one to resolve the bunch position with a time interval between bunches of 18 ns. To reduce the error caused by overlapping of the e^+e^- signals at the pick-up electrodes around the IP, a special tail compensation code was developed and implemented in the BPM processor.

The new BPM system operates in three modes: slow closed-orbit measurements (resolution of ≈3÷6 μm), turn-by-turn measurements (≈15÷30 μm) and "post mortem" mode, in which the turn-by-turn memory is filled continuously. A special trigger signal (for instance, a beam current decay) stops the memory filling, and beam behaviour can be studied to find the cause of the current loss.

In VEPP-3 either electrons or positrons circulate at a time, and the switches connect a pick-up electrode to the single signal processor. This approach reduces the error induced by the different gains of the analogue channels and provides a BPM resolution of 1 μm.

CONCLUSION

The HEP study on the VEPP-4M collider in the low energy range (1÷2 GeV) is almost completed, and the next luminosity run is planned with the energy scan from 2 GeV up to 5 GeV. This challenging perspective necessitates some upgrade of the old collider, including injection efficiency increase, equipment modernization (new PS, RF system upgrade, etc.), lattice tuning for the luminosity enhancement, etc. In spite of the low luminosity, we believe that we still are able to find some interesting (however, niche) experiments using unique accelerator technologies like resonant depolarization, laser polarimeter or precise electron and positron tagging system for γγ-physics.

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