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VEPP-4M COLLIDER OPERATION AT HIGH ENERGY

P. A. Piminov†, G. N. Baranov, A. V. Bogomyagkov, V. M. Borin, V. L. Dorokhov, S. E. Karnaev, K. Yu. Karyukina, V. A. Kiselev, E. B. Levichev, O. I. Meshkov, S. I. Mishnev, I. A. Morozov, O. N. Okunev, E. A. Simonov, S. V. Sinyatkin, E. V. Starostina, A. N. Zhuravlev
Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia

Abstract

VEPP-4M is an electron positron collider equipped with the universal KEDR detector for HEP experiments in the beam energy range from 1 GeV to 6 GeV. A unique feature of VEPP-4M is the high precision beam energy calibration by resonant polarization technique which allows conducting of interesting experiments despite the low luminosity of the collider. Recently we have started new luminosity acquisition run above 2 GeV. The hadron cross section was measured from 2.3 GeV to 3.5 GeV has been done. The luminosity run for gamma-gamma physics has been started. The luminosity at ϒ(1S)-meson has been obtained. For the beam energy calibration the laser polarimeter is used. The paper discusses recent results from VEPP-4M collider.

INTRODUCTION

The multipurpose accelerator complex VEPP-4 [1] is used for high energy physics (HEP) experiments at electron positron collider VEPP-4M with KEDR detector [2], experiments with synchrotron radiation (SR) at VEPP-3 and VEPP-4M [3, 4], nuclear physics experiments at Deuteron facility [5], experiments with extracted hard gamma beams (~ 0.1÷3 GeV) at Test Beam Facility for detector physics [6] and for general R&D in accelerator. The layout of VEPP-4 facility is shown on Fig. 1.

The electron and positron beams with energies of 430 MeV are injected into the VEPP-3 storage ring from the Injection complex [7] (not shown on Fig. 1). The injector provides $2{\cdot}10^9$ e^+/s and 10^{10} e^-/s at 1 Hz repetition rate. Beams are accelerated up to 1.9 GeV in the VEPP-3 ring and extracted to the VEPP-4M ring via the VEPP-3 – VEPP-4 pulse transport channel.

The VEPP-4M collider is designed to work in the beam energy range from 0.9 to 6.0 GeV. Currently, the maximum operation energy is 4.75 GeV. It is limited by the arc elements power supply system. The VEPP-4M ring has a racetrack shape with 366 m circumference. Two Robinson gradient wigglers and two dipole 3-pole wigglers at 2 T are used to control the damping decrement, the beam emittance and the energy spread. The electrostatic separation system installed at four symmetrical locations allows storage of two electron and two positron beams in the ring. The injection and the acceleration of the beams is performed in uncolliding mode. The maximum acceleration rate in the VEPP-4M collider is 20 MeV/s.

†piminov@inp.nsk.su

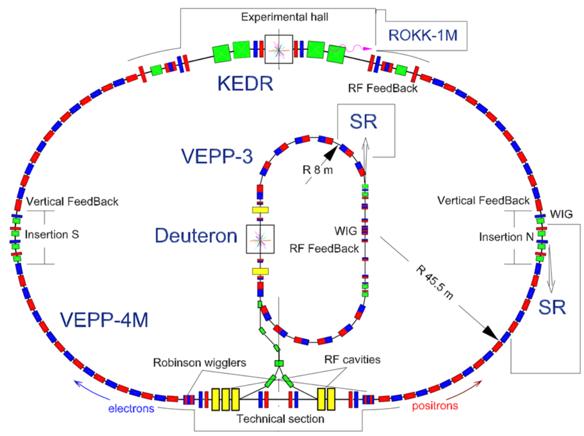

Figure 1: VEPP-4 layout.

RF system operates at the 222nd harmonic of the revolution frequency (180 MHz). The maximal RF voltage in 5 cavities is 4.5 MV. VEPP4-M collider operates with two feedback systems for longitudinal and vertical planes. VEPP-3 has only longitudinal feedback system.

High precision absolute energy calibration system based on resonant depolarization [8] is a unique feature of the VEPP-4M collider. At beam energies below 3 GeV polarization is monitored by Touschek polarimeter. For higher energies laser polarimeter is being installed [9].

Parameters of VEPP-4M for different energies are given in Table 1. The red colour is the goal.

Table 1: Parameters of VEPP-4M for Different Energies

Energy	2.3	3.5	4.75	GeV
Betatron Tunes		8.54/7.57		
Nat. Chroms		–14/–20		
Comp. Factor		0.0168		
Hor. Emit.	42	100	180	nm·rad
Energy Spread	3.7	6.5	7.5	$\cdot 10^{-4}$
Bunch Length		4		cm
Bunch Current	6	9/15	15	mA
Luminosity	0.5	1.2/2.0	$0.6{\cdot}10^{31}$	$\cdot 10^{31}$ cm^{-2} s^{-1}

HIGH ENERGY PHYSICS EXPERIMENT

From 2000 to 2018 HEP experiments at the VEPP-4M electron positron collider with the KEDR detector were carried out in the lower energy range from 0.9 to 1.9 GeV. During this time, the rest masses of the main states of the ψ-meson and τ-lepton [10], the lepton widths of ψ-mesons, the hadron cross section from 920 MeV to 1.9 GeV [11] were measured, the search for narrow resonances was performed.

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After 2018, the next cycle of experiments has begun above the injection energy (1.9 GeV), which requires acceleration of the beams directly in VEPP-4M. In order to calibrate the beam energy, an extra time is given for beams polarization in VEPP-4M.

Hadron Cross Section Scan from 2.3 to 3.5 GeV

The first goal of the KEDR physical program was measurement of the hadron cross section from 2.3 to 3.5 GeV. In this experiment 14 pb^{-1} in 17 energy points were collected. All energy points were divided into two sets (even and odd points). The beam energy was determined through field measurements using NMR probe, which was calibrated by absolute beam energy measurements based on the resonant depolarization technique. For low energy the beam energy calibration has been done using a resonant depolarization technique with Touschek polarimeter [8] in three points: at the injection 1.89 GeV and at 1.93 and 1.98 GeV with acceleration of polarized beam in VEPP-4M. During acceleration several the beam crossed several spin-betatron resonances [1]. For high energy (4.06 GeV) a laser polarimeter was used [9]. The beam energy stability in each energy point is 0.5 MeV.

Figure 2 shows maximum peak luminosity versus the beam energy. It can be seen that above 3.3 GeV, the luminosity decreases due to the limitation of the beam currents.

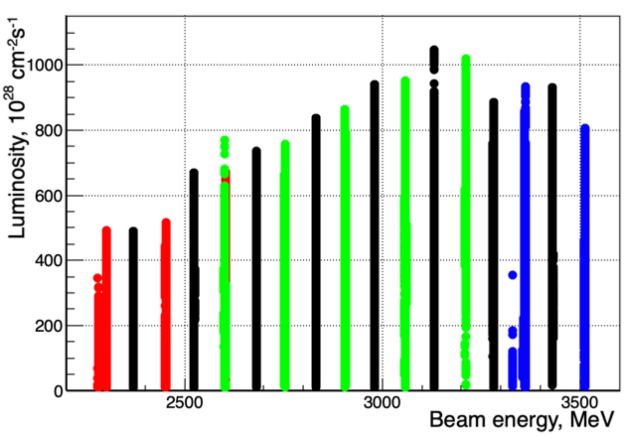

Figure 2: The luminosity in R-scan 2.3÷3.5 GeV.

Gamma-Gamma Physics

In 2021 the luminosity run for gamma-gamma physics [2] was started. The main goal is the measurement of the cross section of gamma-gamma to hadrons.

The specific feature of the KEDR is the particle tagging system (TS). It allows registration of the scattered electron positron pair after two photons interaction. The first two quadrupoles and two special bending magnets of the collider form the focusing magnetic spectrometer. The scattered electrons or positrons with the energy loss from 0.02 to 0.6 of the beam energy are registered by one of the four modules of the TS. The module consists of six double layers of the drift tubes and the two-coordinate GEM detector in front of them.

The required luminosity integral for gamma-gamma is 200 pb^{-1}. The beam energy for this luminosity run is 3.5 GeV. We hope to achieve the maximum luminosity of VEPP-4M at this energy ($\sim 2\cdot10^{31}$ $cm^{-2}\cdot s^{-1}$). The beam energy measurement and the beam energy stability are not required. Now the maximum peak luminosity is $1\cdot10^{31}$ $cm^{-2}\cdot s^{-1}$, the integral luminosity is 180 nb^{-1} per 12 hours and 1.2 pb^{-1} per a week.

ϒ(1S)-Meson

The next goal of the KEDR program is the measurement of ϒ-mesons parameters (the rest mass, the lepton width, etc). Now only ϒ(1S)-meson on 4.73 GeV is available due to the limitation of the arc bend power supply. New power supply (7.5 kA 70 V), which already has been built, allows to reach of 6 GeV beam energy.

For the measurement of ϒ(1S)-meson the required luminosity integral is 6÷10 pb^{-1}. It depends on the beam energy spread (see below). The beam energy measurement is required for the experiment. For this purpose resonance depolarization method using a laser polarimeter is chosen [9]. The radiation polarization of electron beam and its depolarization was already observed.

In 2019 the test luminosity run has been performed. The luminosity of $0.5\cdot10^{31}$ $cm^{-2}\cdot s^{-1}$ for low level bunch current (~ 8x6 mA) has been obtained. The synchrotron radiation background in the KEDR was suppressed by moveable SR power absorber. The next luminosity run on 4.73 GeV is scheduled for summer 2021.

SYNCHROTRON RADIATION

For SR experiments special runs are organized [3]. Normally, 25% of complex operation time is dedicated for SR and 75% for HEP. During SR runs experiments are performed simultaneously at VEPP-3 (1.2 GeV or 2.0 GeV) and VEPP-4M (1.9 GeV or 4.5 GeV).

Currently, nine SR extraction channels are used at VEPP-3 for nine experimental stations. One station is used for electron beam position stabilization. SR is extracted from dipole and from a 3-pole 2 T wiggler (shifter magnet). The maximum beam current is 200 mA in two bunches separated by half of the turn or 250 ns.

Five SR stations are operational at VEPP-4M with SR extracted from two channels. Experiments with soft X-rays and vacuum ultraviolet radiation are performed at "Kosmos" meteorological station using SR from 0.4 T dipole magnet at 1.9 GeV. For experiments with hard X-rays SR from 9-pole 1.9 T wiggler at 4.5 GeV is used [4]. In standard operation mode, two 10 mA electron bunches separated by half of the turn or 610 ns are used. Multi-bunch operation mode is available with full loading (23 bunches separated by 50 ns).

ENERGY SPREAD MEASUREMENT

In the near future, the collider VEPP-4M will operate at 4.75 GeV beam energy to refine the mass of the ϒ(1S)-meson. When planning experiments, information about the energy spread of the beam is required since the

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time of collecting statistics for given collider luminosity *L* and the accuracy of mass measurement *ΔM* is proportional to the cube of the energy spread σ_W [12].

We have measured the energy spread of the beam over almost the complete energy range available to VEPP-4M, and compared the results obtained using two different techniques. The energy spread of the beam was determined by the parameters of the envelope of vertical betatron oscillations [13] and by the beam length measurements by the streak camera. The obtained results are shown in Fig. 3.

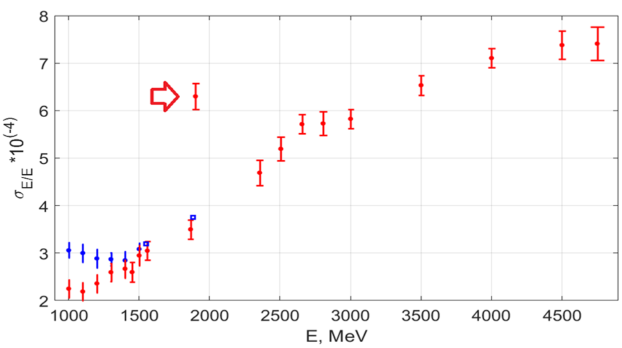

Figure 3: VEPP-4M beam energy spread in energy range 1000 – 4750 MeV.

The red and blue dots in the energy range of 1000-1500 MeV correspond to operation with two values of synchrotron tune ν_s = 0.0076 and ν_s = 0.0147 respectively. In the latter case, the energy spread increases due to intra-beam scattering. The red arrow indicates the value obtained when the 3-pole wiggler was turned on at the injection energy, which increased the energy spread almost twice. The blue squares correspond to the values obtained by scanning of the J/ψ, ψ' resonances. At energies above 3.5 GeV, the growth of the energy spread slows down, and this is due to the saturation of the Robinson wigglers used in the magnetic structure of the collider to compensate the influence of the gradient dipole magnets on the damping numbers. Due to saturation, it is impossible to maintaine the value of this parameter at a constant level, which results in a redistribution of the decrements and decrease of the energy spread.

UPGRADE

Power Supply

To increase maximum energy of the VEPP-4M collider up to 6 GeV a new 10 kA, 70 V thyristor PS is installed to feed 66 main magnets connected in series. PS has output current stability of better than 0.01% at the maximum current. Now this PS is in commissioning stage.

Electrostatic Separation

With two electron and two positron bunches circulating simultaneously in the VEPP-4M collider in the same vacuum chamber separation of beam trajectories in interaction points is required. There are four such points in the collider ring. Each point is equipped with four pairs of electrostatic plates with voltage up to 30 kV applied. If the bunch current exceeds 5÷10 mA the discharging of the separation plates appears because of synchrotron radiation hitting the plates. This requires more powerful PSs of the plates. A new 30 kV, 10 mA PS with voltage stability of better than 0.1% is developed in BINP for this purpose. Now new PSs are in preparation stage to be installed on the collider.

RF System

To achieve 5.3 GeV beam energy VEPP-4M RF system was modified with goal to provide up to 4.5 MV of total voltage in five 180 MHz acceleration cavities. This will allow acceleration of four bunches with total beam current of 80÷100 mA. We installed a new transistor preamplifier in the RF-system, and modified the 6th cascade with four powerful RF-lamps switching in parallel.

Beam Diagnostics

New BPM-receivers are installed on VEPP-3 and VEPP-4M. That allows to achieve resolution of transverse beam position measurement of 1÷2 μm for VEPP-3 in averaging mode and 10÷20 μm for VEPP-4M with bunch-to-bunch resolution [14].

In addition the new BPM-receivers are installed in a 40-m long transport channel between VEPP-3 and VEPP-4M [15]. The channel consists of compact pulsed magnetic elements. Use of precise beam transverse position measurements allowed more accurate tuning of the magnet elements from shot to shot. The channel luminescent screens are equipped with digital cameras to provide more precise observation of the beam transverse shape and position.

Also new FCT and DCCT from Bergoz are installed on VEPP-4M to provide more precise beam current and bunch distribution measurements.

Control System

A new PS controller is in development stage for the VEPP-4 accelerator complex. The new controller will provide a synchronous continues monitoring of all parameters of the devices in accordance with beam behaviour, and help to immediately indicate faulty device.

CONCLUSION

HEP experiments are continued at VEPP-4M with energies higher than 2.0 GeV, and SR at VEPP-3 (1.2 GeV and 2.0 GeV) and VEPP-4M (1.9 GeV and 4.5 GeV). Deuteron photodisintegration experiments are planned to be continued in 2021 at VEPP-3 with Deuteron facility (a thin polarized target). Development of resonant depolarization technique using laser polarimeter system for absolute energy calibration at energies higher than 3 GeV is continued. The beam energy spread was measured in the almost entire available range of VEPP-4M operation energies. Various subsystems are being upgraded to allow experiments at maximum energy.

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