ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-TUA01

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, I. B. Nikolaev, O. N. Okunev, E. A. Simonov, A. G. Shamov, S. V. Sinyatkin, E. V. Starostina, C. Yu. Todyshev, V. N. Zhilich, A. A. Zhukov, A. N. Zhuravlev,
Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia

Abstract

From 2018 HEP experiments at the VEPP-4M collider with the KEDR detector were carried out in the high energy range (higher than 2 GeV). VEPP-4M is an electron positron collider in the beam energy range from 1 to 6 GeV. KEDR is the universal magnetic detector with 6 kGs longitudinal field and the particle tagging system for selection of gamma-gamma interaction. The paper discusses recent experimental activity of the VEPP-4M: the hadron cross section measurement from 2.3 to 3.5 GeV, ϒ(1S) meson searching, gamma-gamma physics luminosity run, synchrotron radiation, etc. Also the beam energy measurement by the resonance depolarization method using the laser polarimeter has been presented.

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], nuclear physics experiments at Deuteron facility [4], experiments with extracted hard gamma beams (~ 0.1÷3 GeV) at Test Beam Facility for detector physics [5] and accelerator physics researches. The VEPP-4 facility is shown schematically on Fig. 1. On the figure SR is experimental halls for synchrotron radiation researches and ROKK-1M is an experimental hall for the Test Beam Facility and the laser polarimeter.

The VEPP-3 is storage ring with 74 m length and beam energy from 400 MeV to 2 GeV. It has its own experimental program and is used also for the particle acceleration and the particle polarization for VEPP-4M. The transport channel from VEPP-3 to VEPP-4M is pulse with 1.9 GeV maximum energy.

The VEPP-4M ring is a racetrack of 366 m length with single magnetic turn for electron and positron beams. The beam energy range is from 0.9 to 6.0 GeV. Four vertical bumps by 4 electrostatic plates in each allow circulating of 2 electron and 2 positron bunches. The beams are collided in main interaction point after the injection and the acceleration. For radiation beam control 2 Robinson gradient wigglers two dipole 3-pole wigglers at 2 T are used. The vertical digital feedback suppresses single-bunch instability and the analog RF feedback suppresses the multibunch longitudinal instability. All this allows increasing the beam currents and the beam lifetime at low energies and obtaining threshold currents for the beam-beam.

† piminov@inp.nsk.su

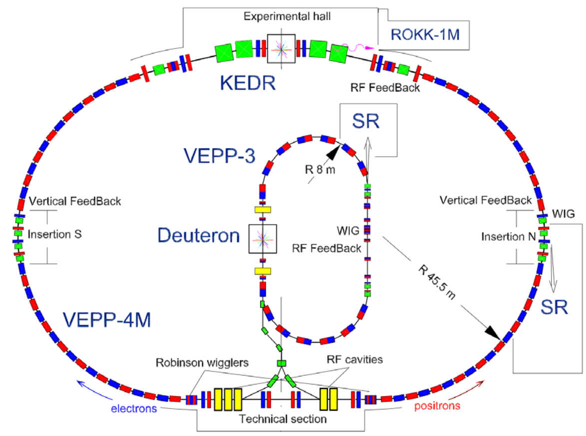

Figure 1: VEPP-4 layout.

The maximum acceleration rate is 20 MeV/s. RF system has 5 cavities and operates at 180 MHz frequency (222 harmonic number) and 4.5 MV maximal voltage.

Parameters of VEPP-4M for different energies are given in Table 1. The red colour marks out nearest goals.

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
Beam	2x2	2x2	1x1→2x2	
Bunch current	6	9→12	9→12	mA
Luminosity	0.5	1.2→2.0	0.5→1.4	$\cdot 10^{31}$ cm^{-2} s^{-1}

HIGH ENERGY PHYSICS EXPERIMENT

Since 2018 KEDR experimental program in the high energy range of VEPP-4M was started. It requires the beam acceleration in the collider. The beam injection and the acceleration take during 30 minutes and the luminosity time is 2 hours.

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 (R-scan) from 2.3 to 3.5 GeV in 17 points. The total luminosity integral is 13.7 pb^{-1}. The beam energy measurement is not required. The beam energy stability in each point is 5 MeV.

The R values are critical in various precision tests of the Standard Model. The energy region 4.6÷7 GeV, where KEDR data has been collected, gives small contribution

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-TUA01

to the anomalous magnetic moment of the muon, it is of about 1%. At the same time this energy range provides 10% into the hadronic contribution to the running the electromagnetic coupling constant $\alpha(M_Z^2)$ and the corresponding contribution of the uncertainty is about 15%. In addition, when considering the energy region above 5.2 GeV and up to upsilon resonances, theoretical calculations based on pQCD are usually used. New measurements of KEDR will allow the use of experimental data up to 7 GeV.

Gamma-Gamma Physics

In 2021 the luminosity run for gamma-gamma physics [2] was started. For the experiment the particle tagging system (TS) of the KEDR is used. It allows registration of the scattered electron positron pair after two photons interaction. The final focus 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.

For the first stage we plan to collect 50÷100 pb^{-1} at the energy range 3.5÷4.7 GeV. It provides (a) the measurement of the total cross section for the process gamma-gamma → hadrons within the invariant mass range 1÷4 GeV and study physical characteristics of events (multiplicity, spectra, etc) and (b) study exclusive gamma-gamma processes at low invariant masses (≤1 GeV) which are approachless for B-factories due to the trigger conditions. Based on the results of the first stage we will evaluate the possibility for the larger luminosity integral and further gamma-gamma investigations. In particular, the study of charmed resonances η_c, $\chi_{0,2}$, η_c (2S), etc.

At present time the luminosity is collected at 3.5 GeV where we hope will be achieved the maximum luminosity of VEPP-4M (higher that $2\cdot10^{31}$ $\text{cm}^{-2}\cdot\text{s}^{-1}$). Now the maximum peak luminosity is $1.2\cdot10^{31}$ $\text{cm}^{-2}\cdot\text{s}^{-1}$, the integral luminosity is 177 nb^{-1} per 12 hours and 1.4 pb^{-1} per a week. The total recorded luminosity integral is 10 pb^{-1}.

ϒ(1S)-Meson

In June 2021 the luminosity run at 4.75 GeV for searching ϒ(1S) meson has been made. Unfortunately the beam energy calibration in this range was unsuccessful due to the spin resonance. Using the main dipole field control using NMR technique ϒ(1S) meson was founded in during 12 hours with 42 nb^{-1} luminosity integral in 8 points in 10 MeV energy range. After the position of the peak has been determined 190 nb^{-1} in 10 points has been collected. The final results is shown on Fig. 2 where E_{set} is the collider magnetic system energy or magnetic rigidity which is calculated by the control system. Knowing the rest mass of ϒ(1S) from PDG, the energy offset was fitted.

The main goal of the experiment is to demonstrate the possibility of operation of the collider and detector at this energy. Also background conditions have been inspected. The beam energy spread was checked in this experiment. The energy position of Y(1S) meson is marker for the laser polarimeter tuning and the radiation polarization obtaining at this energy.

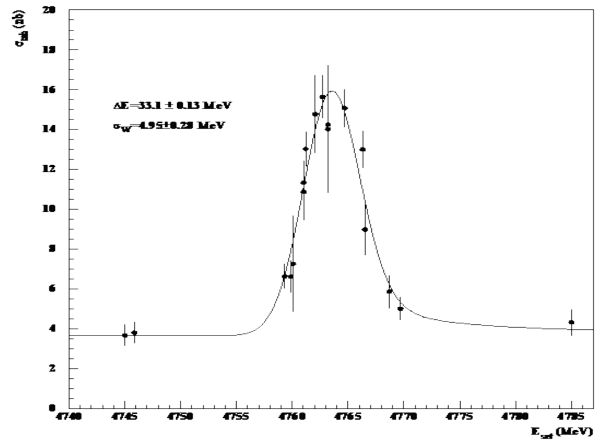

Figure 2: The Y(1S) scan.

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 or 2.0 GeV) and VEPP-4M (1.9 2.5 and 4.5 GeV). For experiments with hard X-rays [6] on VEPP-4M at 4.5 GeV 9-pole 1.9 T hybrid wiggler is used [7]. 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 (up to 23 bunches separated by 50 ns).

LASER POLARIMETER

An experiment on Upsilon-meson mass measurement requires beam energy calibration by resonance depolarization method with beam polarization determination. We developed a laser polarimeter based on the Compton scattering [8]. 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. Pockels cell toggles left-right laser beam polarization for each laser pulse. In order to deterine electron beam polarization we apply join fit to the left and right two-dimentional distributions of registered photons using Compton differential cross section convoluted with angular spread of electron momentum (Fig. 3).

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-TUA01

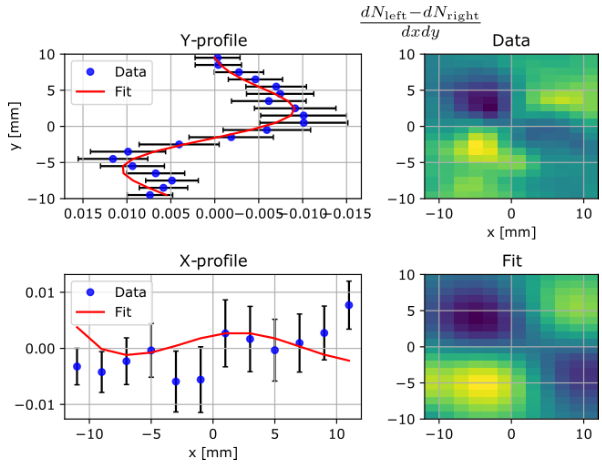

Figure 3: The result of the two-dimentional join fit to the left and right distributions of the scattered photons. The vertical (Y) projection shows Compton back scattering asymmetry due to vertical polarization of electron beam appearance

The energy calibration by resonance depolarization method at the energy 4.1 GeV (Fig. 4) shows highest possible electron beam polarization (93%) according to Sokolov-Ternov theory. Obtaining polarization at the 4.7 GeV (ϒ(1S)-meson energy) which is our main goal is difficult due to depolarizing spin-betatron resonances. In order to increase accuracy of polarization/energy measurement we are developing new water-cooling copper mirror. This mirror will result in better laser focusing on electron bunch thus Compton scattering rate will increase.

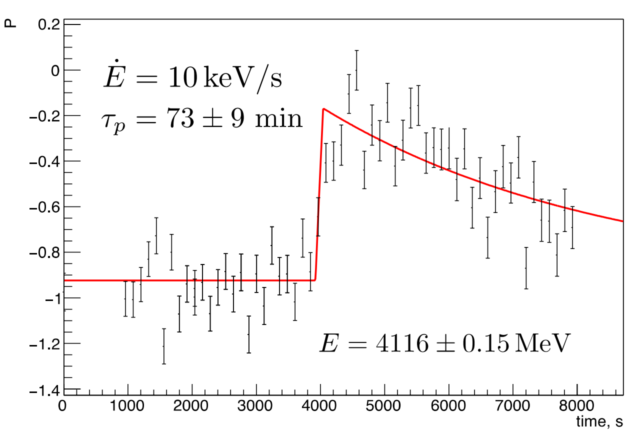

Figure 4: The beam energy calibration at 4.1 GeV.

UPGRADE

For operation at high energy main subsystems has been upgraded (RF system, beam and optical diagnostics, control and protection system, engineering infrastructure, etc).

Currently, the maximum operation energy is 4.75 GeV. It is limited by the arc elements power supply (PS) system. 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.

One of troubles limiting the beam current is low power of the high voltage generators of the electrostatic system. There is a photocurrent from electrostatic plates due to synchrotron radiation. The photocurrent and the voltage between electrostatic plates increase with increasing the beam energy. At energies above 3 GeV the power of the generators isn't enough and the voltage drops down and the beam is lost. Three years ago four new generators (30 kV 10 mA) were installed in Insertion N (see Fig. 1). Now others generator has been made and now they are commissioning.

CONCLUSION

HEP experiments at VEPP-4V collider with KEDR detector at energy high range are continued. The hadron cross section from 2.3 to 3.5 GeV beam energy has been finished. The luminosity run for gamma-gamma physics at 3.5 GeV using the particle tagging system is continuing. Preliminary searching of ϒ(1S) meson at 4.75 GeV has been finished successfully. It demonstrates a possibility of the collider and the detector performance at high energy. Development of resonant depolarization technique using laser polarimeter system for absolute energy calibration at energies higher than 3 GeV is continued. Radiate polarization and depolarization of electron beam at 4.1 GeV has been obtained. Synchrotron radiation runs have been performed periodically. Various subsystems are being upgraded to allow experiments at maximum energy.

REFERENCES

[1] P. A. Piminov *et al,* "Current Status of the VEPP-4 Accelerator Facility", *Phys. Part. Nucl. Lett.* 17(7), 2020, pp.938-850.

[2] V. V. Anashin *et al,* "The KEDR detector", *Phys. Part. Nucl.* vol. 44 no. 4, 657-702, 2013. DOI:10.1134/S1063779613040035.

[3] P. A. Piminov *et al,* "Synchrotron radiation research and application at VEPP-4", *Physics Procedia* 84, 19 26, 2016. DOI:10.1016/j.phpro.2016.11.005.

[4] D. M. Nikolenko, "Experiments with internal targets at the VEPP-3 electron storage ring", *Physics of Atomic Nuclei,* 73, 8, 2010, p. 1322-1338, DOI:10.1134/S1063778810080065

[5] V. S. Bobrovnikov *et al.,* "Extracted electron and gamma beams in BINP", *JINST* 9 C08022, 2014. DOI: 10.1088/1748-0221/9/08/C08022.

[6] G.Baranov *et al,* "Experiments with Synchrotron Radiation at the VEPP-4M", *Journal of Surface Investigation,* 14, 1, pp. 150-154, 2020. DOI:10.1134/S1027451020020032.

[7] G. N. Baranov *et al,* "Hybrid Nine-Pole Wiggler as a Source of Hard X-ray Radiation at the VEPP-4 Accelerator Complex", *Journal of Surface Investigation,* 2020, 14(6), 1290-1293, DOI: 10.1134/S1027451020060269.

[8] V. E. Blinov *et al,* "Status of laser polarimeter at VEPP-4M", *JINST* 15 (2020) C08024, DOI: 10.1088/1748-0221/15/08/C08024.