ELECTRON-POSITRON STORAGE RING VEPP-4. STATUS AND PROSPECTS

The VEPP-4 staff

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The work at the storage ring VEPP-4 has been carried out on the following lines:

- Upgrading of the efficiency of the storage ring. At the energy of 5 GeV the luminosity obtained was $3\cdot 10^{30}\,cm^{-2}sec^{-1}$. At the present time, the maximum energy is 5.8 GeV.

- Production of polarized beams and development of the polarization measurement methods.

- Running of the physical experiments. The precise measurements of the masses of the psi- and upsilon-meson families have been carried out. A study of the two-photon processes on the installed detector MD-1 has been started.

The time share scheduled for experiments achieved 60% of the calender time.

1. Beam Production at the VEPP-4

The linear accelerator, which is supplied by a pulsed gyrokon serves as a source of electrons. The electron beam of about 40 A is accelerated to 50 MeV. The positrons with an energy of 7 MeV from the tungsten target of the conversion system are injected into the synchrotron B-4.

To produce the electrons, the energy of the electron accelerator is lowered to 7 MeV, the converter is mechanically removed and the magnetic field of the synchrotron and of the other elements is changed in sign.

The electrons (or positrons), accelerated by the synchrotron to 350 MeV, are stored in the storage ring VEPP-3. Particle injection is performed on the first harmonic of the revolution frequency with a phase shifted from the equilibrium one. A 0.4-second radiation damping time enables to inject the particles at 1 Hz repetition rate.

Acceleration in the VEPP-3 is made on the 19th harmonic of the revolution frequency up to an energy of 2 GeV. The maximum accelerated current is 80 mA. An 80-90% of the particles are transferred into VEPP-4. This makes it possible to have the currents of 10 to 12 mA in the VEPP-4. There is no need in the higher currents in one bunch at the energy of the ipsilon-mesons since the beam-beam effects appear at these currents.

During the injection, the electron and positron orbits are separated by means of electrostatic electrodes. They are brought together at the required place in the course of the experiments.

The operating rate of storing of the positrons in the VEPP-4 is about 0.5 mA per minute. The rate of electron injection is higher by a factor of 10. In practice, the positrons are stored in the VEPP-3 ring for a many-hour run time of the experiment. In view of this, the rate of positron collection has little influence on the storage ring performance.

With the 2 x 10 mA currents in the VEPP-4 the lifetime of the beams is about 5 hours.

2. The Storage Ring VEPP-4

The MD-1 detector is installed at the central interaction point of the storage ring at the end of 1980[3]. The distinctive feature of the detector is that its magnetic field is perpendicular to the plane of the storage ring orbit.

Such a detector has the following advantages over the longitudinal-field detectors:

1. There is the possibility of detecting the particles and analysing their momentum over the whole angular range, including zero angle. This is essential in the two-photon processes $e^-+e^+ \to e^-+e^++x$, in which the scattered electrons and the reaction products fly, mainly, forward.

2. It is convenient to detect the γ-quanta escaping at zero angles: the location of the collision point in the transverse magnetic field provides a low level of background and a large aperture for their detection. The use of this possibility has been made in the single bremsstrahlung measurement experiments where a considerable distortion of the bremsstrahlung spectrum in the e^+e^- scattering occurs due to of the large impact parameters[4] cut off.

The lay-out of the MD-1 is shown in Fig. 1. There are additional bending magnets on each side of the main magnet, which enable a magnetic field in the detector to be varied. In order to detect the scattered electrons in two-photon processes, a system of proportional chambers is placed between the bending magnet and the quadrupole lens next to the collision point. The design accuracy of the energy measurement of the scattered electrons is 1%. The system detects the electrons which escape at the zero angle with a 10-50% energy loss. The total-energy electrons are detected in an angular range of 12-100 mrad.

The main magnet of the detector is a closed-type rectangular solenoid. The volume of the magnetic field with a strength of up to 16 kG is 9.5 m^3. Inside the magnet there are a system of coordinate proportional chambers, scintillation counters, Čerenkov gas counters, and the shower-range proportional chambers. In addition, the muon chambers are installed behind the magnet winding and the iron yoke and inside this yoke.

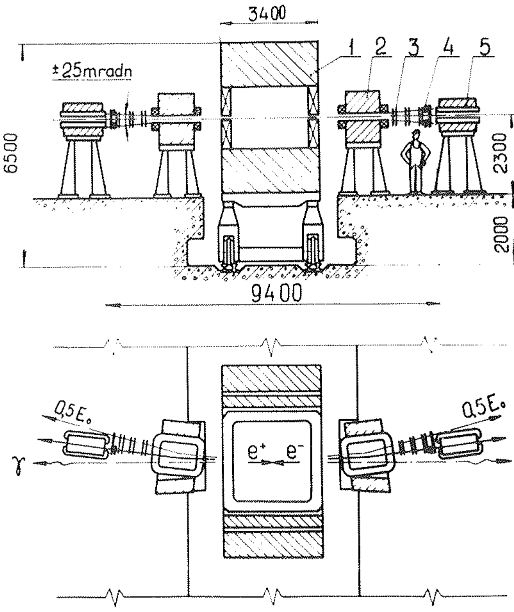

Fig. 1. The central interaction region: 1 - detector MD-1, 2 - additional bending magnets, 3,4 - electron tagging and luminosity monitoring system, 5 - lenses.

The total number of the electronics channels in the proportional chambers is equal to 16 000.

So far the transversefield detectors has never been installed on electron-positron storage rings. One of the basic reasons for this is a more complicated solution of the background problem in such a detector due to the loss of particles from the storage ring and due to the synchrotron radiation produced in the detector[5]. The experimental investigation on the storage ring VEPP-4 has demonstrated[6] that the background conditions at the detector MD-1 are reasonably good. In ipsilon-meson mass measurement runs, which will be discussed below, there have been no significant difficulties with the background.

In order to obtain a high efficiency of the detector, it has been necessary that simultaneously with the installation of the detector MD-1, the bending magnets and the electron registration system be placed on both sides of the detector. For this reason, in VEPP-4, the distance between the lenses, adjacent to the collision point is very long, about 9 meters.

This distance has determined the minimum value of the β -function at the collision point: 45 cm. In further decreasing the β - function at the collision point, the vertical aperture of the storage ring in the adjacent quadrupole lenses has been limited mechanically. Since the size of the aperture is of particular importance when storing the beams and when building the energy up, the optics of the straight section needs to be re-tuned at the energy of the experiments, by decreasing the β -function down to 19 cm at the collision point. A similar operation has been proposed and tested on the storage ring VEPP-3 for the first time[7]. Ten lenses have been involved in the re-tuning of the optics. With the same beam currents the VEPP-4 luminosity has been doubled.

The psi-meson mass measurement[8] has been made at the detector 'OLYA' located in the side collision point. Upon installation of the magnetic detector MD-1 a new version of the straight section optics has been used. This has been easy to do owing to an independent power supply for the elements of the straight section. In this version three collision points with low β -functions at a time have been dropped and only the central collision point has been retained. For this purpose, the point with $Q_x = 8.54$ and $Q_z = 9.60$ has been chosen as an operating one, since in this case the linear synchrotron resonances are absent and the energy dispersion at the collision point is equal to zero.

In addition, the new version of the straight section optics has allowed the smaller number of points with large values of the β -function. This has resulted in an effective increase of the aperture and in a reduction of the chromatism, which has permitted one, in turn, to weaken the sextupole corrections.

Operating the new optics in the experimental runs has given positive results. The linear beam-beam tune shift has been achieved as high as 0.1 at the Υ -meson energy. The luminosity obtained equals $3 \cdot 10^{30}$ $cm^{-2}s^{-1}$.

The luminosity of the storage ring with the detector MD-1 installed on it can be further increased by making the vertical β - function 2-3 times lower and by using the multi-bunch mode of operation. These experiments are under way.

3. Control

Six computers 'ODRA' (ICL) with 32 or 64 K of core memory words control the operation of all the systems of the storage ring. The utilities for a fast program preparation and the multiprogram mode in each computer offer convenience in control. All the programs are written by the machine people themselves. About ten microprocessors are employed at the lower level. All the computers are united by a computer library. There is a special computer intended for simulation.

At present, about 20% of the control units are made in CAMAC. Further improvement of the system is connected with use of the whole set of units and microprocessors made in the CAMAC standard.

4. Polarized Beams

The electrons travelling in a magnetic field are subject to the radiative polarization. The time of polarization is proportional to E^{-5} and at the energy of upsilon-meson it is equal to 50 minutes.

In practice, the degree of polarization can prove to be small, particularly for spin precession frequencies in the vicinity of integer multiples of the revolution frequency of the frequency of betatron oscillations. The strength of resonances depends on perturbations in the storage ring and is connected, first of all, with radial magnetic fields.

The initial experiments have given vague results on account of a low degree of polarization. The analysis has been made, which has enabled the most probable reasons for this situation to be elucidated. A degree of polarization of over 50% has been achieved by means of a distributed system for suppressing the coupling of radial and vertical betatron oscillations instead of the previously used system of lumped correctors in the straight sections. It is probable that in this case the coupling is compensated at the place of its origin.

With the help of correctors with a radial magnetic field the degree of polarization has been demonstrated to be a function of the amplitude and the phase of a spin perturbation harmonic.

To measure the degree of polarization, we have made use of various methods. Previously, at low energies (1.5-2.0 GeV), the measurement has been based on the dependence of the elastic scattering of particles inside a bunch (Touchek effect) on the polarization. At high energies, this method becomes ineffective and we have used the dependence of the Compton scattering cross section of circularly polarized photons on the transverse polarization of electrons. At alternate light polarizations the difference in the vertical distributions of Compton quanta is proportional to the degree of transverse polarization of electrons.

Two versions of measuring the polarization have been realized. In the first version a solid-state laser of 1 W power (the LAP method-laser polarimeter) serves as a source of circularly polarized light[9]. In the second, the synchrotron radiation emitted by the opposite-rotating beam, which has a considerable degree of circular polarization with opposite sign above and below the plane of equilibrium orbit, is utilized as a source. For this purpose, the colliding beams have been separated vertically by electric fields over $3\sigma_z$ (i.e. 0.1 mM) (the CSIP method)[10]. As has been noticed, at the beam currents close to the beam-beam effects, the polarization of the beams has been destroyed.

Fig. 2 presents the energy dependence of the beam polarization measured by the LAP method. One can clearly see the absence of the polarization at the energies when the spin precession frequency is integer multiple of the revolution frequency and of the betatron frequencies. The maximum degree of polarization has constituted about 80%.

Additionally, the polarimeter using spin correction to SR intensity was realized successfully.

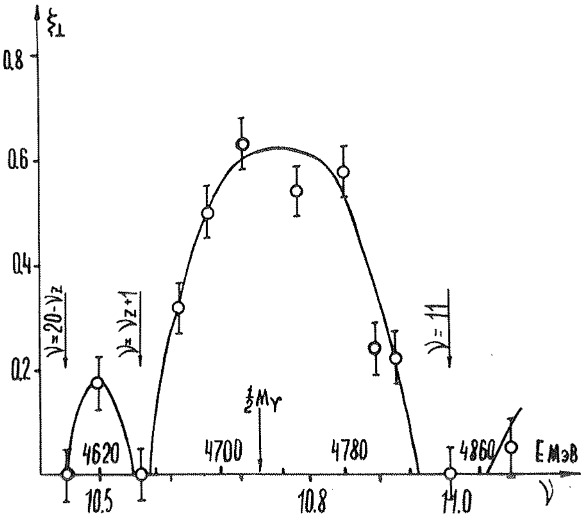

Fig. 2.

5. Experiments

The development of the methods of obtaining the polarization in the VEPP-4 and the methods of measuring its degree as well as the use of the conventional technique of beam depolarization by a slow scanning of the frequency, perturbing the spin motion, has enabled the energy calibration of the storage ring with respect to the frequency of beam depolarization to be performed and the mass of the psi- and ipsilon-mesons to be measured.

Three frequencies on which the beam depolarization has occured have been found in the course of energy calibration. The side frequencies have been separated from the central one by the frequency of synchrotron oscillations. The side bands has been identified by the smaller strength of the depolarizing resonances and by variation of the synchrotron frequency with tuning the accelerating rf voltage.

We have carried out about 600 energy calibrations. When processing the measurement results we have taken into account the effects which are likely to cause an erroneous estimation of the mass. In particular, among these effects there are the change of the β -function and, hence, of the counting rate of events upon deviations of the particle momentum from the equilibrium value. It is the effect mentioned above, the most significant from those taken into account which has resulted in a correction to the mass of about 0.05 MeV.

The masses

$M(\psi) = 3096.9 \pm 0.1$ MeV
$M(\psi') = 3686.0$ MeV± 0.1 MeV
$M(\Upsilon) = 9460.6 \pm 0.4$ MeV
$M(\Upsilon') = 10023.8 \pm 0.7$ MeV
$M(\Upsilon'') = 10355.5 \pm 0.6$ MeV

have been found to a high accuracy.

The two-photon physics experiments have been started.

The storage ring is equipped with five extraction channels for SR beams. The work concerning with high-energy physics is being made simultaneously with the studies on these beams by a variety of research groups.

6. Prospects

The basic program of the experiments, which is scheduled for the nearest years is a study of the two-photon processes. For these experiments the detector MD-1 and the general lay-out of the collision point on the VEPP-4 offer some advantages. As to the energy, the work will be made in the range of upsilon resonances. This will make it possible to investigate the properties of this family of resonances as well.

The development of the methods of obtaining the longitudinally-polarized beams at the storage ring is carried[11] on and the problems associated with the monochromatization of an interaction energy are being treated[12].

References

1. The VEPP-4 Group, Proc. 11th Intern. Conf. High-Energy Accel., Geneva, 1980, p. 38.
2. I.Ya. Protopopov, Proc. 10th Intern. Conf. High-Energy Accel., Protvino (Serpukhov), 1977, Vol. 1, p. 421.
3. S.E.Baru et al., preprint INP 77-75, Novosibirsk (1977).
4. A.F.Blinov et al., Phys. Lett., 1982, 113B, 423.
5. A.P.Onuchin, Ya.A.Tikhonov, Preprint INP 77-77, Novosibirsk (1977).
6. S.E.Baru et al., Intern. Conf. on Instrumentation for Colliding Beam Physics, SLAC, 1982.
7. Status report on VEPP-3, Proc. 8th Intern. Conf. High-Energy Accel., CERN, 1971, p. 138.
8. A.A.Zholentz et al., Phys. Lett. 1980, 96B, 214.
9. A.E.Blinov et al., Proc. 8th National Conf. Accel., Dubna, 1982.
10. P.V.Vorobyev et al., Proc. 8th National Conf. Accel., Dubna, 1982.
11. Ya.S.Derbenev et al., Project of obtaining longitudinally polarized colliding beams. In these Proc.
12. A.A.Avdienko et al., High monochromaticity ee-colliding beams. In these Proc.