THE INTERACTION REGION OF THE VEPP-4 STORAGE RING FOR THE DETECTOR WITH THE TRANSVERSE FIELD MD-1

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Summary

Analysis is performed of the main features of the magnetic detector MD-1 with the field perpendicular to the orbit plane of the storage ring. Principles of the organization of the interaction region for such detectors are considered as well as their realization at the VEPP-4 collider. The values of detection efficiencies of two-photon processes are given, background conditions and plans of future development of the detector are discussed.

Introduction

The electron-positron storage ring VEPP-4 [1] of the Novosibirsk Institute of Nuclear Physics is equiped with the magnetic detector MD-1 with a vertical magnetic field [2]. Unlike the magnetic detectors with a longitudinal magnetic field, this detector makes it possible to detect charged particles and to analyse their momenta in the entire range of angles θ, including $\theta \simeq 0$, as well as to analyse the γ-quanta emitted at zero angles. This advantages of the detector most strictly manifest themselves in the detection of the two-photon processes $e^+e^- \to e^+e^- + \gamma^*\gamma^* \to e^+e^- + X$ in which scattered electrons and positrons as well as particle decay products are emitted mainly forward in the direction of the beams. For these processes the magnetic field, perpendicular to the orbit plane, allows a substantial increase of a detection efficiency.

Detection efficiency of two-photon processes

In studying two-photon processes, of particular importance is the detection of the scattered electron and positron as well as the measurement of their energy. These particles are emitted, as a rule, together with the particles of the main beam and differ from the latter only in an energy. In view of this, in order to have an opportunity to detect the electrons and positrons with low energy losses, the length of the magnetic field, perpendicular to the orbit plane, needs to be long enough in the vicinity of the interaction point. It is the circumstance that determines an approach to the organization of the interaction point at the VEPP-4.

Fig. 1 demonstrates a lay-out of the experimental straight section. The magnetic field, perpendicular to the orbit plane, is generated by the detector MD-1 itself and by two additional magnets DM-1 and DM-2. The latter are symmetrycally spaced with respect to the MD-1. Detection system is placed just behind the additional magnets. The system described above enables one to detect the scattered electrons and positrons, the energy losses of which per interaction constitute $(0.1-0.5)E_0$ where E_0 is the beam energy in the storage ring. The angular acceptance ranged 0 to 20 mrad in the vertical direction and from 0 to 100 mrad over the horizontal. The momentum resolution is $\Delta p/p \simeq 1\%$.

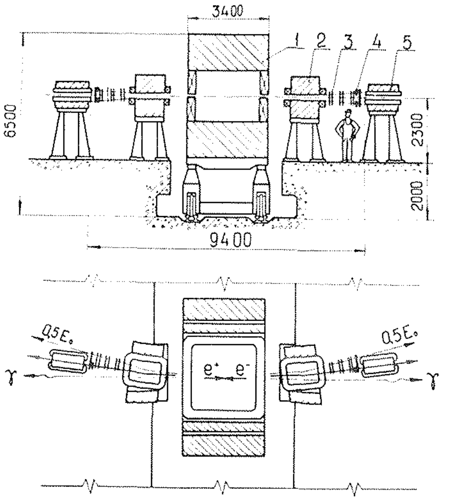

Fig. 1. The central interaction region: 1 - detector MD-1; 2 - additional bending magnet; 3,4 - electron tagging and luminosity monitoring system; 5 - lens.

The detection efficiency of two-photons processes ε depends on the invariant mass

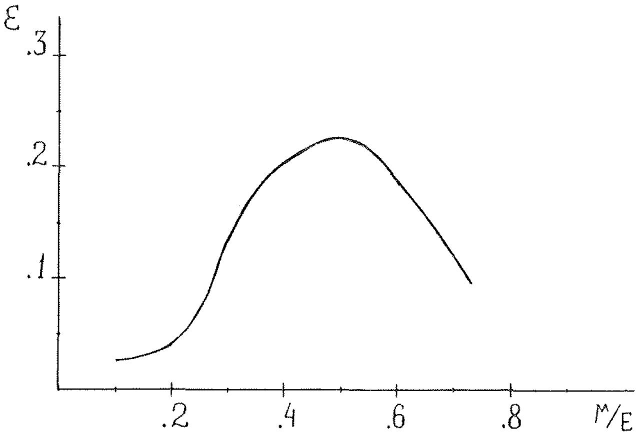

Fig. 2. Dependence of the detection efficiency of two-photon processes on M/E. M is an invariant mass of produced particles, E is

a beam energy (E = 5 GeV).

μ of produced particles. The calculated value of ε for various μ is presented in Fig. 2. It is seen that the maximum value of is equal to about 25%. This is one order of magnitude larger than the detection efficiency of similar processes in a conventional approach without a transverse magnetic field.

Luminosity

The characteristic peculiarity inherent in the organization of the interaction point in the detector with a vertical magnetic field is the need to place quadrupole lenses (determining small values of beta-functions) far from the collision point. As a result, in an attempt to obtain very small values of the beta-functions in the interaction region, the beta-functions in the lenses become very large and serious difficulties immediately arise: it is necessary a) to have a large aperture in lenses, b) to eliminate, in the operating region of the aperture, the nonlinearities of a magnetic field up to the nonlinearities of higher orders, and c) to compensate a large chromatism of the lenses. For these reasons, in the initial version of the organization of the interaction point at the VEPP-4 the beta-functions in it are fairly large: β_z = 43 cm and β_x = 300 cm. It is circumstance which determines a comparatively low level of luminosity 10^{30} $cm^{-1}s^{-1}$ in the first experiments. Further methods of increasing the luminosity are connected with a decrease of the beta-functions at the interaction point. This can be made as follows: in the period of storing the beams and of increasing the energy, use is made of the storage ring optics corresponding to large beta-functions, and in the period of data acquisition, the optics is readjusted so that the vertical beta-function is decreased down to 19 cm at the interaction point. Such a change of the beta-function in the course of the experiments enables, in principle, to avoid first difficulties indicated above. The last problem needs to be carefully approached. In our case, since the dispersion function ψ_x becomes zero in the interaction point due to the magnetic field of the detector MD-1 (see Fig. 3), it turns out to be possible to employ sextupole lenses in order to compensate the chromatism. These lenses are placed beside the quadrupole lenses, the contribution of which to the total chromatism increases with increasing the beta-functions. The sextupole lenses permit the chromatism to be compensated directly at the point of its appearance. Because these lenses are symmetrically spaced relative to the interaction point and are distant from each other by a half-wave of vertical and horizontal betatron oscillations, their switching on does not lead, in practice, to gaining the third-order resonances in magnitude.

The regime of changing the beta-function at the interaction point at the VEPP-4 has made it possible to raise the luminosity up to $3 \cdot 10^{30}$ $cm^{-2}s^{-1}$. The diagrams illustrating the horizontal and vertical beta-functions and the dispersion function in the initial regime of the storage ring optics (figure I) and in its new regime (when the optics is readjusted) (figure 2) are depicted in Fig. 3. This Figure demonstrates a half of the beam interaction region. One can see the locations of the detector MD-1, additional magnet DM-1, tagging system of scattered electrons (positrons) and the locations of sextupole and quadrupole lenses.

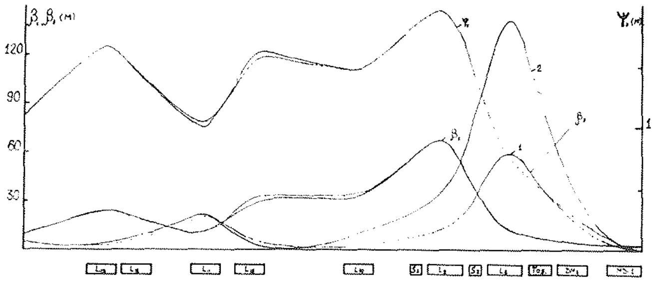

Fig. 3. Behaviour of functions β_x , β_z , ψ_x in the optical system of the experimental interaction region of the storage ring VEPP-4. 1 - β_z = 43 cm, 2 - β_z = 19 cm in the interaction region.

At present, the transition to a mode of operation with β_z = 12 cm at the interaction point is being prepared.

Background conditions in the detector

As has already been mentioned, the transverse field of the detector allows a substantial increase of the detection efficiency of $\gamma\gamma$ -processes. However, the presence of the transverse field complicates the background situation in the detector. In particular, this field has much influence on the background of synchrotron radiation.

The paper [4] considers the background problem, associated with synchrotron radiation, in the MD-1. The main idea of the solution of this problem is to create a special vacuum chamber which enables the synchrotron radiation to be passed through the detector without its contact with the chamber walls (Fig. 4). The radiation detectors are placed at a fairly long distance from the detector centre so that only the backward scattered photons arrive at the detector. This substantially reduces the SR flux, arriving at the detector, especially in a hard part of the spectrum. The radiation receivers are made of copper and are cooled with water. To decrease the reflection factor, copper is covered with silver of about 1-mm thickness (this halved the reflection factor). Such a construction of the vacuum chamber decreases the flux of photons at the central part of the detector approximately by a factor of 10^6. Additional attenuation is achieved due to the foils located on a thin cylindrical part of the vacuum chamber and in the window in front of the tagging system. At the present time, there is 1/30 X_0 Al, 1/40 X_0Sn and

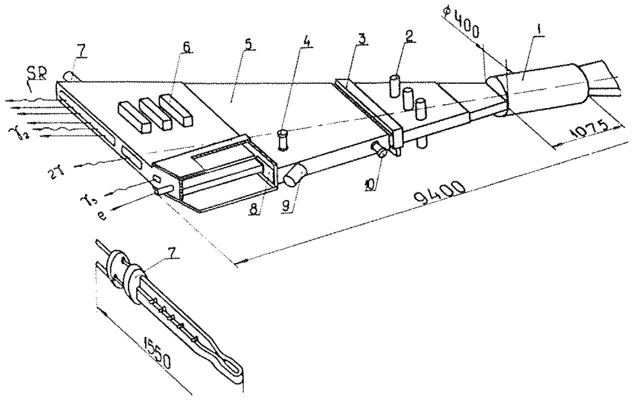

Fig. 4. The layout of the vacuum chamber in the central interaction region:
1 - cylindrical part, 2 - movable collimator, 3 - latch, 4 - vertical probe, 5 - chamber for SR escape, 6 - vacuum pumps, 7 - SR receivers, 8 - entrance window of the electron tagging system, 9 - electron escape for γ-quanta monochromatization, 10 - radial probe.

1/40 X_0 Pb in the cylindrical part. In addition to the vacuum chamber foil (1/100 X_0 Fe), the tagging system is protected by 1/40 X_0 Sn.

The synchrotron radiation background is significant only for the coordinate chambers and for the chambers of the tagging system. The remaining elements of the detector are protected with a thick layer of material. With the aim of analysing the events in the detector, it is desirable that only one wire in the chamber operate upon one passage of the beam through the interaction point. At the energy of a Υ-meson, the number of operated wires during one passage of the beams constitutes 1.5 for the coordinate chamber, the nearest to the beam, and 0.1 for the most distant one at currents 10 x 10 mA^2. For the chambers detecting the scattered electrons the corresponding quantity is about 0.1.

The experimental data dealing on the background load due to synchrotron photons are in agreement with the calculational results to an accuracy of up to the factor of about 2.

The background, which is due to the loss of particles in the beams, proves to be significant as well. Our measurements have shown the following nature of this background in the detector. First, in the storage ring there are particles which leave the equilibrium orbit and make a lot of turns prior to their loss. The spatial density distribution of these particles (halo) is quite broad and has sharp limits. The cut-off of the halo occurs at the point where the aperture of the storage ring is minimum. If such a point is near the detector, this results in a background counting rate. Aiming at the reduction of such a background, we specially limit the aperture in the injection section of the storage ring by means of a movable probe. Second, the beam electrons, losing their energy because of the bremsstrahlung on residual gas in the straight section of the storage ring in front of the detector, are deflected by a magnetic field and come into the vacuum chamber in the vicinity of the detector. To reduce this background, we detect the bremsstrahlung γ-quanta by means of the scintillation sandwiches. The counting rate of these counters is 3÷7 kHz/mA. The counters operate in the trigger in the regime of anticoincidences. This decreases the number of detector triggerings by a factor of 3-7. The largest contribution to the counting rate of the tagging system comes from the electrons and positrons losing their energy at the interaction point because of the single bremsstrahlung. With a luminosity of $3\cdot10^{30}$, the counting rate of such events is 200 kHz and the probability of random coincidence of effect and background events becomes significant, about 25%. To increase the luminosity of the storage ring and to reduce the background caused by random coincidences in the tagging system, we are currently studying the possibility of operation in the multibunch mode with 3 x 3 or 9 x 9 bunches.

In addition, the ways of a possible modernization of the detector MD-1 are considered in order to raise the detection efficiency of the MD-1, including its detection of the $\gamma\gamma$-events. It is assumed to replace the set of coordinate proportional chambers by the drift ones. This will enable the solid angle of the detector to be increased and the momentum resolution to be improved. Furthermore, the size of the tagging system is suggested to be increased. This would make it possible to improve the detection efficiency of the $\gamma\gamma$-events by a factor of 1.5÷3.

References

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