THE PROJECT OF VEPP-4 INTERACTION REGION WITH A NEW TAGGING SYSTEM FOR $\gamma\gamma$ -PHYSICS

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Abstract

The project of the tagging system for the electron with an axial magnetic field at the VEPP-4 collider is described. The specific feature of the project is the use of the interaction region optical structure as a high resolution strong focusing spectrometer. This allows a considerable improvement by relatively simple means in the $\gamma\gamma$ -invariant mass reconstruction accuracy for the two-photon processes.

Introduction

The central task of experiments at electron-positron colliding beams is the investigation of e^+e^- annihilation with the creation of a new lepton or hadron system X . Another production mechanism is the two-photon process $e^+e^- \to eeX$. The cross-section of this process is small at low energies and increases with energy. The annihilation cross-section in contrast decreases with energy. This fact and the possibility of direct production of the system with the set of quantum numbers different from the single photon one is the reason of the increasing interest to the investigation of the two-photon processes[1]

The detection of a two-photon event by the detector is much more difficult than that of e^+e^- annihilation. That results from the specific kinematics of $\gamma\gamma$ processes in which electron and positron scatter one at another each emitting a photon. Following the tradition, these particles will further be referred to, as tagging electrons (TE). The spectrum of photon emission has a typical bremsstrahlung behaviour $\sim 1/E_\gamma$. Small momentum transfer is characteristic for the main part of the $\gamma\gamma$ events. As a result TEs come from the interaction point at very small angles - more than a half of the particles are scattered less than by 10 mrad[2]. The invariant mass of the $\gamma\gamma$ system $W_{\gamma\gamma}$ is approximately equal to $2\sqrt{E_{\gamma_1} E_{\gamma_2}}$ and is also very small. Due to the longitudinal motion of the produced system its decay products emerge mainly inside the narrow cone around the beam axis, i.e. in that part of a solid angle where all detectors have the insensitive region. Therefore the determination of the $\gamma\gamma$-system invariant mass by its decay products is difficult and inefficient.

The installation of the special systems for the detection of TE, so called "tagging systems" (TS), complementary to the main detector led to the considerable improvement in the detection of $\gamma\gamma$ processes. Such a system must have good efficiency and maximum attainable accuracy in the measurement of TE's energies. A brief description of tagging systems created for different detectors may be found in the review [1].

Some design and exploitation experience for TS exists also in the Institute of Nuclear Physics at Novosibirsk. The detector MD-1 specially aimed at the study of $\gamma\gamma$ processes[3,4] was created in the Institute. The transverse magnetic field of MD-1 allowed to detect TE's and to measure their energies. The parameters of this detector TS were among the best presently achieved. Its accuracy in TE energy measurement $\sigma_{E/E} \simeq$ 1.5% allowed the reconstruction of $\gamma\gamma$ invariant mass with an accuracy about 100 MeV. A double tagging efficiency for $W_{\gamma\gamma}$ between 1.5 and 3.5 GeV was 10÷20%.

In accordance with the program of modernization of the VEPP-4 collider it was decided to build a new general purpose detector with an axial magnetic field, i.e. without transverse magnetic field that allowed good parameters with the TS of MD-1. The desire to continue the investigation of $\gamma\gamma$ processes with a new detector stimulated search for an optimal version of TS for it. As a result a new approach to the design of TS for the detector with an axial magnetic field has been found. The parameters of this TS are not worse than those for MD-1 and about 10 times better in accuracy of $\gamma\gamma$ invariant mass reconstruction. Another advantage of this approach is that TS is naturally included in the experimental region optics optimized for achievement of high luminosity.

1. TS for the detector with an axial field

As mentioned before the TS must have a good detection efficiency for TE and high accuracy in the measurement of its energy. Due to the specific kinematics of $\gamma\gamma$ processes the high efficiency can be achieved only when TS is able to detect TE with zero transverse momentum. This may be done only with the help of the bending magnet extracting outside the beam aperture TE that lost part of its initial energy. The energy of TE may be measured by different methods. All calorimetric methods, however, have accuracy worse, than that which may be achieved by magnetic spectrometer. Moreover, the magnetic spectrometer allows to detect TE coming out from the interaction point at a zero angle. Therefore, first of all we wanted to understand the applicability in our case of the extensive experience in the design of the magnetic spectrometers for the experiments with the beams extracted from the accelerator. It was found that the basic principles used in the so-called "focusing spectrometer"[5] may be used with some insignificant changes for the TS.

One possible version of such TS is shown in fig.1. The TE coming out from the interaction point passes first of all two quadrupole lenses L1 and L2 and then two magnets M1, M2. In the magnetic field particles with different energies are separated. TE are detected by four detecting systems TS1-TS4. Their positions are not accidental. They correspond to the places where the image of the interaction point is focused by the quadrupole lenses for TEs with energies 0.56E , 0.66E 0.77E , 0.91E respectively. For TS2-TS4 this corresponds to the middle of energy region of the TEs detected by the given system. For the first system TEs with the central energy of its energy interval are focused inside the magnet M1. Therefore the position of TS1 is not optimal. But it is impossible to more it closer to the quadrupole lenses because only at the end of the magnet horizontal displacement of TEs with this energy reaches the aperture limit.

For the particles coming out from the interaction point at a zero angle the coordinate in TS is unambigously related to energy. Angular distribution of TE though strongly peaked destroys this unambiguite. That means that a nonzero angle of TE leads to the error in TE energy. The lest energy accuracy will be achieved for TE for which the interaction point image is situated in one of the detection systems. Then for all emission angles θ_x TE with such energy comes to the same point of TS. The TEs with other energies do not behave in such a way. More is the difference between TE's energy and the optimal one, more is the error. Therefore TS is divided into four detecting systems that

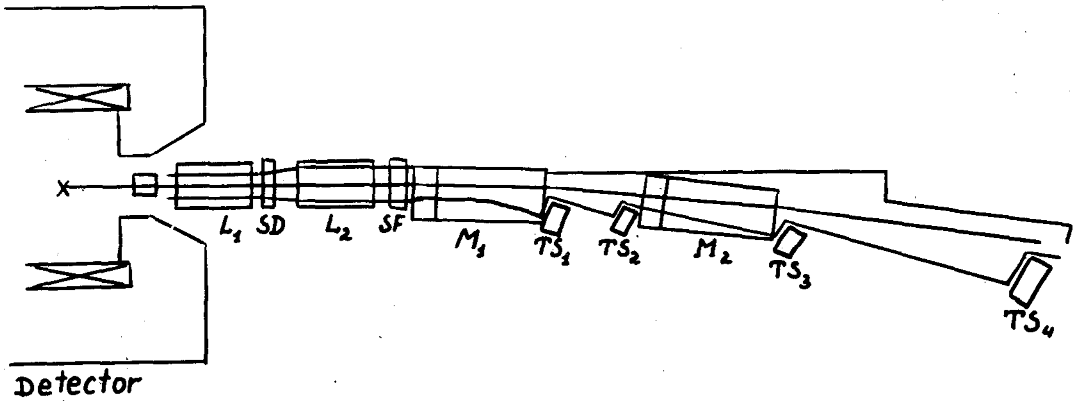


Fig. 1. Experimental region with TS
L1, L2 – quadrupole lenses,
SD, SF – sextupole lenses,
M1, M2 – bending magnets,
TS1-TS4 – detection systems of TE.

gives small error for TEs in a wide energy interval. The energy measurement accuracy σ_E/E versus TE energy is shown in fig. 2. The dashed line corresponds to ideal situation when measurement accuracy is defined by the spread in emission angle only.

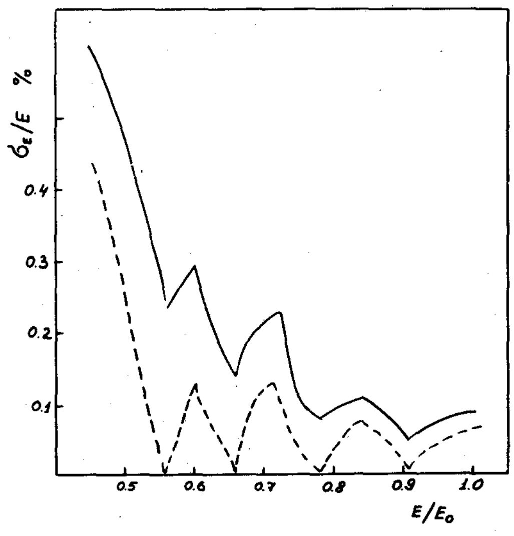


Fig. 2. The energy resolution of TS versus the ratio E/E . The dashed line shows the contribution from angular spread of TEs.

The solid line shows total energy resolution with contributions from a) the interaction region size in a transverse ($\sigma_x \simeq 0.5\,mm$) and longitudinal (σ_z = 3.5 cm) directions and b) – coordinate measurement accuracy ($\sigma \simeq 0.65\,mm$) of TS taken into account. The energy resolution was obtained by Monte-Carlo simulation with an account of the real angular distribution of TEs in $\gamma\gamma$ processes and beam angular spread at the interaction point. The resolution for the invariant mass of $\gamma\gamma$ system obtained simultaneaously is shown in fig. 3. At the interval from 0.5 up to 4 GeV σ_W changes from 10 to 20 MeV.

There is one more reason for segmentation of TS into four systems. Electrons with large energy loss have greater vertical and horizontal deflections, therefore it is desirable to detect them as soon as possible. With restricted size of beam pipe aperture it allows to avoid the great losses of TEs and to obtain good detection efficiency. The acceptance of TS is shown at fig. 4.

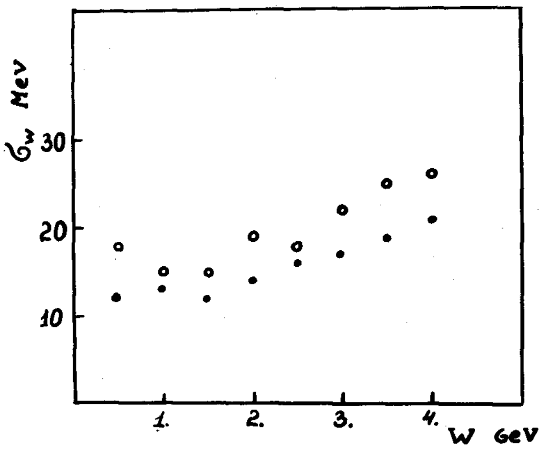


Fig. 3. The resolution for the invariant mass of $\gamma\gamma$ system
for all events
for TE with $\theta_z > 2\cdot10^{-4}$ radian

The quadrupole lenses besides being the part of the strong focusing spectrometer serve simultaneously for their usual purposes: beam focusing and achievement of the small values of β -functions at the interaction point. The behaviour of the vertical (β_z) and horizontal (β_x) β -functions at the half of the experimental section is shown in fig. 5. The positions of detector, quadrupole lenses, magnets and detecting systems are also shown. Note that in the most remote detecting system an image of the interaction point for the energy 0.91 E_0 is situated that is close to the beam energy. That means that the point where half wave of horizontal betatron oscillation ends also has to be close to TS4. In fact the minimum of β_x -function is situated immediately behind this system that indicates at the presence of the half wave of horizontal betatron oscillations from the interaction point to this minimum.

The installation of detecting system near the minimum is very useful. The small β -function means the small size of beam aperture. Therefore at this place it is possible to extract TE with an energy very close to E_0. The presence of a long straight section between the second magnet and the last detection system is very important because here the beam decomposition versus energy increases. As a result TE with energies up to $0.97_0 E$ may be reliably detected.

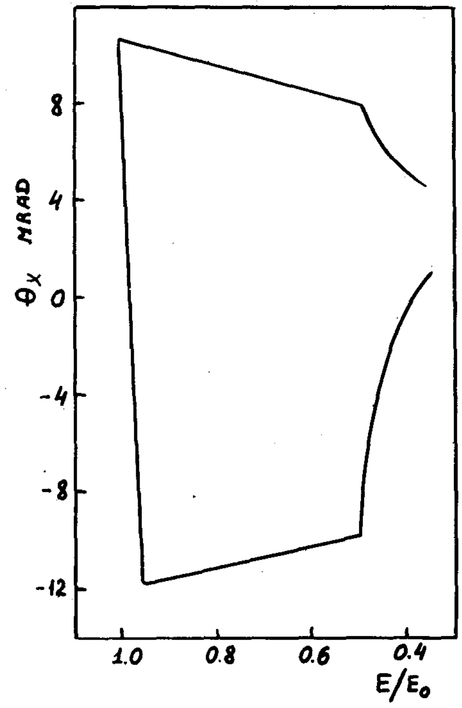
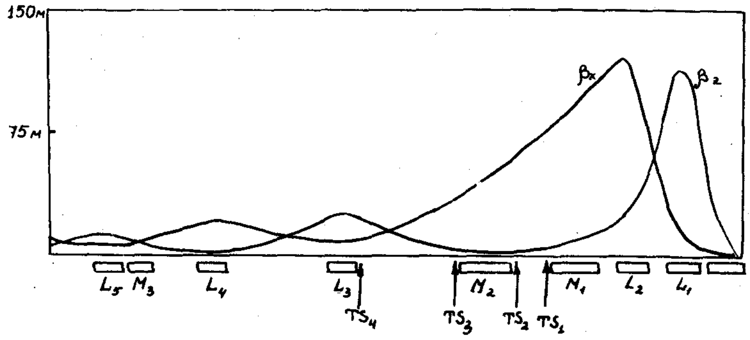


Fig. 1. TS acceptance.



The behaviour of β_x and β_z -functions at the experimental region.

Due to the ability to detect and to measure the energy of TEs with the small energy loss and zero emission angle the present TS has high enough detection efficiency. The probability to detect both TEs by this system vs invariant mass of $\gamma\gamma$ system is shown at fig. 6. The low threshold for detectable masses is very important for many experimental tasks. The detection of TEs with zero transverse momentum is complicated by the specific background conditions at TS which are discussed below.

2. Background at TS

The main source of background particles at the TS is the single bremsstrahlung process (SB). The large cross-section of this process makes the probability of accidental concidence between the electron from SB at TS with any multihadron event ~ 1 even at the luminosity $\sim 10^{31}$ cm^{-2} sec^{-1}. Therefore the suppression of this background becomes very important. One of the possible ways is the separation from background using the emission angle of TE relatively to the orbit plane θ_z. Due to the fact that angular distributuin of SB electrons is peaked much more strongly than that for ones from $\gamma\gamma$ processes the effect to background ratio may be increased by a factor about 10. This, however, leads to the loss in detection efficiency (see fig. 6) and to some degradation of invariant mass resolution.

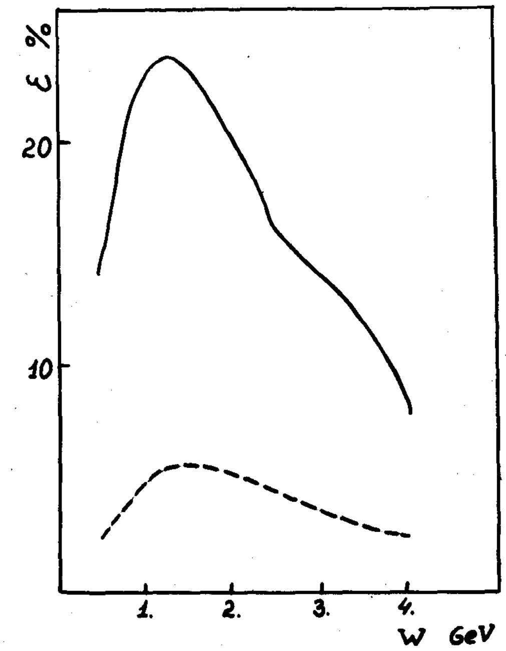


Fig. 6. The efficiency for the detection of both TEs from $\gamma\gamma$ processes vs $W_{\gamma\gamma}$. Dashed line - the same for $\theta_z > 2\cdot 10^{-4}$ radian.

We are considering several ways of background suppression without the loss in detection efficiency. These are the determination of the point of interaction with the help of moment of arrival of TE, independent measurement of energy deposition, the value and the direction of total momentum of the system by the decay products detected at the central detector.

The presence of bending magnets with a strong field close to the detector requires the special precautions against the synchrotron radiation (SR) background at the coordinate system of the main detector. For this purpose the system of SR absorbers and screens is planned to be installed in such a way that a SR photon has to scatter at least two times to penetrate into the coordinate system. Moreover the edge part of the bending magnet will be made with a field diminished by several times. These measures should allow to decrease the background of SR down to the acceptable level.

Conclusion

The presented TS for the detector with an axial field will be able to detect TE from $\gamma\gamma$ processes with high efficiency. The expected reconstruction accuracy for the invariant mass of $\gamma\gamma$ system $\sigma_W \approx$ 15 MeV in the interval 0.5-4 GeV. This system is to be created at the experimental straight section of VEPP-4. The detection system is naturally included into the experimental region optics optimized for achievement of high luminosity.

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