Light extraction from compact water Cherenkov counter

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Abstract

The light formation and collection in the water Cherenkov counter utilized at the work with the system of the luminosity measurement on the H1 setup in the HERA electron-proton collider is considered. In the instrument the directional effect of the Cherenkov radiation is clearly used. The counter is thin. Its thickness along the beam is considerably lower than the radiation length of water ($L \sim 0.14X_0$). Internal rear side of the counter is made specularly reflecting. On the front wall of the counter the photons of Cherenkov radiation are contained in the limits of a ring. The readout of light signal is performed with the aid of two PMTs, which are arranged in the back hemisphere relative to the direction of the motion of detected particles. The basic parameters of the counter are given. The fundamental characteristics of the counter are investigated by the method of mathematical simulation. The dependence of its output signal on the parameters of the recorded beam is studied.

1 Introduction

- In the first P.A.Cherenkov experiments on a study of the directivity of the emission of faster-than-light particles reflecting surfaces were used (1937).
- Cylindrical mirrors were used in the first experiments on the antiprotons observation Chamberlain O., Segre E., Wiegand C., Ypsilantis T. (1955).
- Compact water Cherenkov counter was integrated into the luminosity measuring system of the H1 installation of the collider HERA.
- The high energy photons going through the beryllium absorber create in it electromagnetic shower. A response of the counter to the falling on it electrons and positrons of this electromagnetic shower is investigated.
- A water Cherenkov (veto) counter was established from the very beginning of the measurement of the luminosity on the H1 installation in 1992 and successfully worked (Andreev et al. (1993)).

2 The operating principle of the counter

- The counter occupies the intermediate position between the threshold Cherenkov counters and the Cherenkov counters of the total absorption.
- The directional effect of the Cherenkov radiation is clearly used.
- Water is used as the radiator since it is substance with the high radiation resistance.
- Control of the motion (focusing) of the Cherenkov photons is accomplished with the aid of a coating of the internal side of the counter with the specularly reflecting layers.
- The detection of the particles of the shower is achieved on the light, which appears in the water.
- The photons of the Cherenkov radiation are reflected by the internal mirror surface of rear side of the counter and are transported to the photoreceivers.

3 The quantitative characteristics.

- The Cherenkov angle θ is counted off relative to the direction of a particle motion and is determined by
$$\cos\theta = \frac{c}{n(\omega)v}. \tag{1}$$
- The threshold energy $\mathcal{E}_{th} = mc^2\gamma_{th}$ is determined by simple expression $\gamma_{th} = n/(n^2 - 1)^{1/2}$.
- For the water the refractive index $n_{wt} = 1.33$, $v_{th} = 0.75 \quad c$, $\gamma_{th} = 1.516$. Ultra-relativistic electrons and positrons in the water emit Cherenkov light at angle near $\theta_{ur} = 41.2^o$.
- The number of the Cherenkov photons with the energy of E, radiated by particle per unit length of its path
$$d^2N/dEdx \sim 370 sin^2\theta_c(E) eV^{-1}cm^{-1}. \tag{2}$$
It is possible to write down for the number of photoelectrons in FEU
$$N_{p.e} \sim LN_0 < sin^2\theta_c(E) >, \tag{3}$$
where N_0 – the quality coefficient of Cherenkov detector.

4 The extraction of the light signal

- Electrons fall normally to the face plate of the counter.
- The radiation is formed on the total length L of an electron trajectory in the water.
- On the rear side of the counter the Cherenkov photons are distributed inside the circle with a radius of $R_{ch} = L \times \mathrm{tg}\,\theta_c$. This distribution has a maximum on the counter axis. In Fig. 1 a) it is shown the resulting distribution of the Cherenkov photons, which is formed on as a result of the intersection of the counter by one electron.
- On the front wall the Cherenkov photons reflected from the rear side of the counter are concluded inside the ring with the short radius $R_{sm} = R_{ch}$ and the long radius of $R_{bg} = 2R_{ch}$.
- In Fig. 1 b) the distribution of the Cherenkov photons on the front side of the counter with the use of light reflection from its rear wall is shown.
- Even number of photoreceivers with the small sizes of the input windows, placed axially symmetrically relative to the axis of a counter can be used in such a way that their windows partially overlap this region. The planes of their input windows must be oriented normal to the direction of propagation of the flow of Cherenkov photons. An optimum radius of window composes the value of the order of $R_{phd} \sim (R_{bg} - R_{sm})/2 = R_{ch}/2$.
- In Fig. 2 the distribution of Cherenkov photons on the phase plane $(x_{sb}, \mathbf{r}_{\perp,x})$ is shown. Also the distribution on the $(\mathbf{r}_{\perp,x}, \mathbf{r}_{\perp,y})$ plane is shown. The photons evenly fill the circle of the radius $r_\perp = \mathrm{tg}\,\theta_c$.

5 The schematic design of the counter

- Fig. 3 shows the cross-section of the counter by the median plane.
- The counter is symmetrical relative to the vertical plane, passing through its horizontal axis.
- Electrons and positrons fall on the front side of a counter. Moving along the axis of counter in the water, they at the entire length of their trajectory emit Cerenkov radiation. The internal rear side of the counter is made specularly reflecting. Reflection coefficient is about 95 %.
- The Cerenkov light incident on the back surface of the counter experiences a reflection and as a result falls on front surface.
- The light emitted under a given angle, penetrates the system of openings and it is directed to one of two photomultipliers.

- The counter has the advantage that for its production it is not required the expensive materials, and its mechanical design is characterized by simplicity.

6 The simulation of the counter performance

The numerical simulation of the generation and propagation of the Cherenkov light in the counter was performed by the Monte Carlo method.

6.1 The simulation procedure

- In the program depending on the energy of the falling particle and the index of refraction of the medium the angle Cherenkov radiation is calculated.
- In the course of simulation is determined complete, emitted at the entire length of counter, the number of photons.
- Assuming that the photons evenly are emitted on this length, the longitudinal coordinate of the point of the photon emission is developed.
- Then azimuthal angle is generated.
- The geometric tracking of the motion of photons is carried out
- The influence of the multiple scattering of electrons in the radiator can be taken into account by means of the introduction of some smearing of the Cherenkov angle.
- The calculation is produced the with allowance for the transverse sizes the incident beam. The beam particle distribution of in the transverse plane is assumed to be Gaussian.
- The acceptance of photoreceivers is considered at the completing stage of the simulation.

6.2 Basic parameters

- energy of electrons $\mathcal{E}$,
- the index refraction of the medium n
- and the length of the counter L.

6.3 The simulation restrictions

- Water is assumed to be transparent.
- For the electrons of sufficiently high energy it is possible to disregard by ionizing losses.

7 The results of the simulation

- The distribution of the Cherenkov photons for the real photon (electron) beam elongated in the horizontal plane and having $\sigma_x = 2.0$ cm and $\sigma_y = 0.5$ cm is shown in Fig. 4.
- The form of the photon distribution on the rear plane of the counter is close to the distribution of the electron beam.
- The distribution of the reflected photons on the faceplate takes the specific form. In this distribution the second azimuthal harmonic with the maxima which lie at the vertical plane is clearly visible.
- In the HERA II operation mode distribution of the electron (positron) beam in the ring of accelerator was characterized by more symmetrical form.

8 The construction of the counter

8.1 General view

- The light-insulating rigid metal housing of the counter is executed in the form of a parallelepiped with the sizes of the lateral faces of 24 cm, 12 cm and 6 cm Fig. 5.
- To one of the wide faces of this housing two identical cylindrical branch pipes are connected. The diameter of the branch pipe is 6 cm. The axis of the branch pipes are displaced relative to the center of the lateral face by 7.5 cm along the wide edge. The axes of these branch pipes form with the normal to the wide face angle near 45^o.
- In each branch pipe a PM is placed on.
- The housing is filled with water. The thickness of water along the beam composes 50 mm.
- The area of the active region in the transverse plane is equal to 10.0×10.0 cm^2.
- Water approaches closely the PM's input window.

8.2 The signal readout

- As the photodetector the PHILIPS PM with the size of the photoelectric cathode of 32 mm have been selected. The maximum of the spectral sensitivity of this PM is fallen to the blue light.
- Two PMs are used. There are two channels of the readout of information about the light output in the counter.
- In the real experimental conditions the signals from two PMs are summarized.

8.3 The arrangement of the compact water Cherenkov counter in the operating position in the tunnel of the collider HERA

- The photon beam moves to the right Fig. 5. The counter is placed between the attenuator-absorber of the synchrotron radiation, which plays the role of the active material, and the luminosity monitor, which is arranged to the left (it is located beyond the framework of this figure).
- The counter geometry and sizes are determined the place accessible both along the direction of the beam motion and in the transverse plane.
- Its wide input face is oriented perpendicularly to the direction of a drop of the recorded particles.

9 Conclusion

- At the work of the H1 installation of the electron-proton collider HERA signal from the compact water Cherenkov counter was considered at the processing of the complete signal from the luminosity monitor.
- Its sensitivity to the photon beam position was used for fine tuning of the luminosity system.

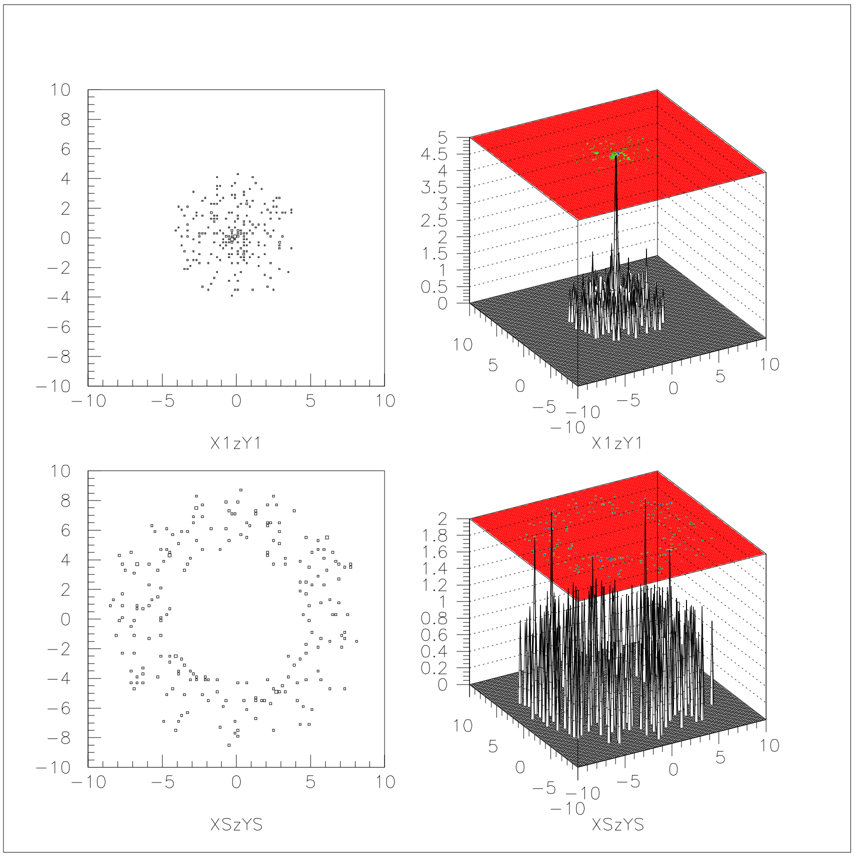

Figure 1: The distribution of the Cherenkov photons on the rear and front sides of the counter for one radiating electron.

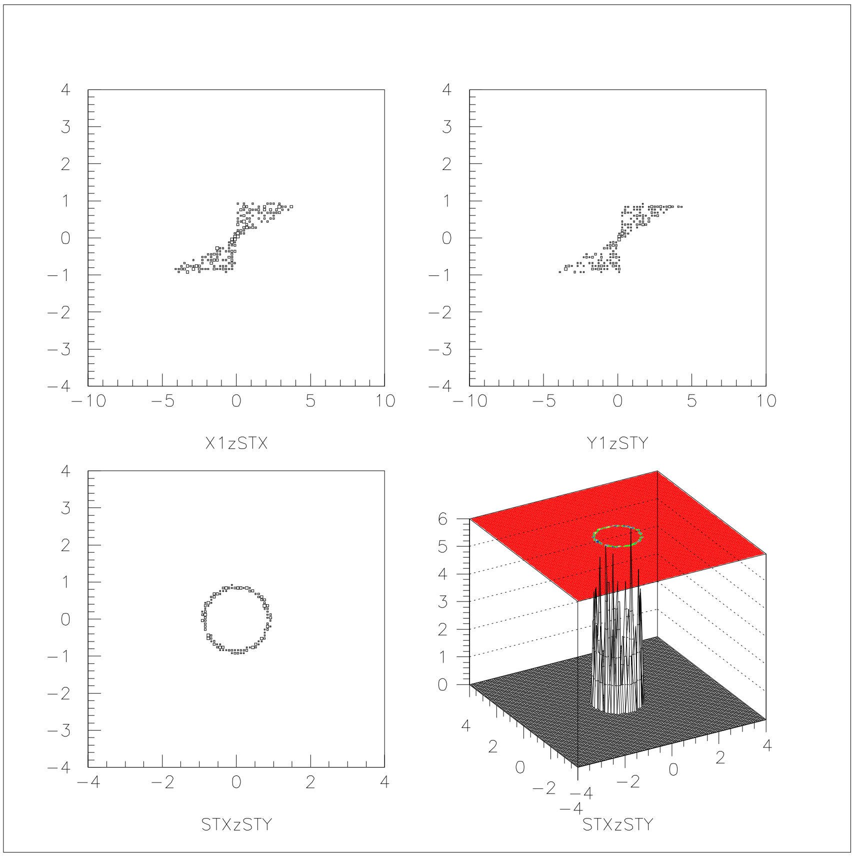

Figure 2: The distribution of the Cherenkov photons on the phase plane.

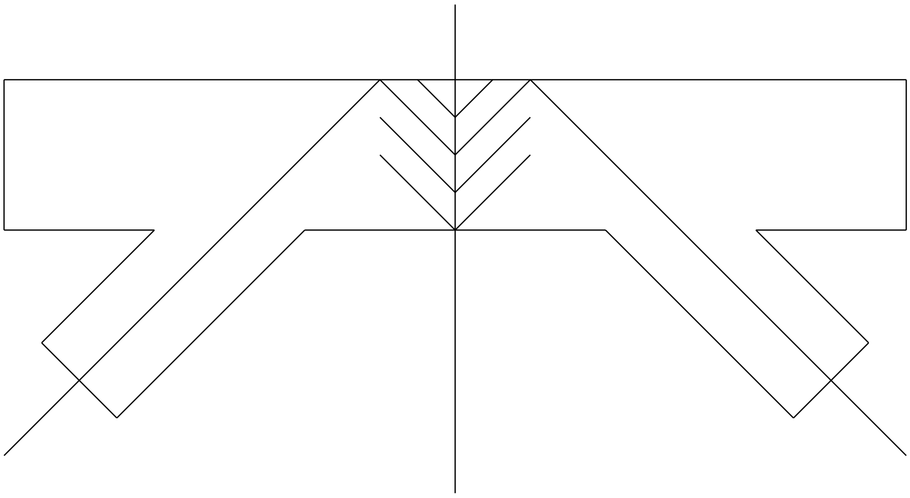

Figure 3: Schematic view of the water Cherenkov counter.

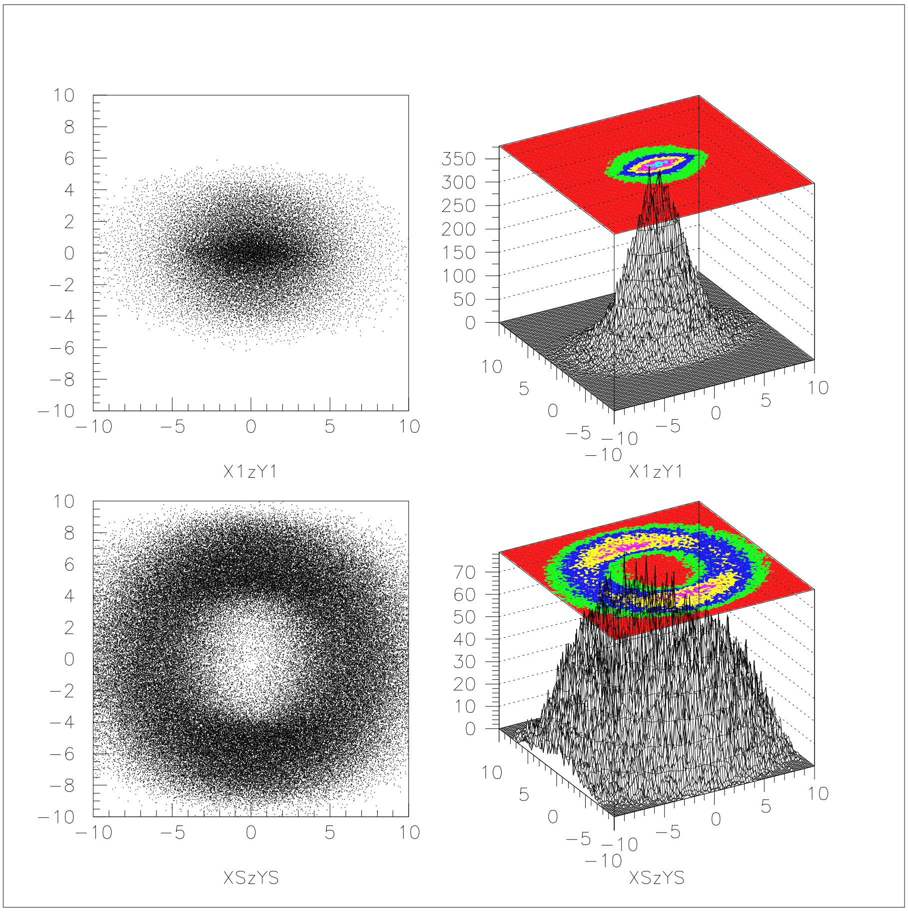

Figure 4: The distributions of Cherenkov photons on the rear and front sides of the counter for the elongated in the horizontal plane incident photon beam.

Figure 5: The compact water Cherenkov counter in the operating position in the tunnel of the HERA collider. The left relative to the beam arm of the counter with entering it PM is seen.