THE ANGULAR RESOLUTION OF TIMING CHERENKOV DETECTORS
OF TIEN-SHAN GAMMA-TELESCOPE

R.A. Antonov, V.I. Gaikin, R.M. Golynskaja, I.P. Ivanenko,
L.A. Kuzmichev, T.M. Roganova

Institute of Nuclear Physics, Moscow State University,
119 899 Moscow, USSR

and

S. Karakula, I.V. Moskalenko†, W. Tkaczyk

Institute of Physics, University of Lodz,
ul. Pomorska 149/153, 90-236 Lodz, Poland

† Permanent address: Institute of Nuclear Physics,
Moscow State University, 119 899 Moscow, USSR

Abstract. In connection with construction of Tien-Shan
γ-rays telescope for research of point sources in TeV/PeV
energy range, the angular resolution of seven timing CHERENKOV detectors is calculated. Monte-Carlo simulations
shown that ≈0.10÷0.15 degree angular resolution should be
obtained for γ-quanta 10 TeV which coming inside the area
of circle of radius r≤100 m from the center of telescope,
≈0.15 degree for r≤200 m and ≈0.20 degree for r≤300 m. The
precision of determination of shower core position using
the lateral Cherenkov light distribution is better than
when the curvature of showers surface is used.

1. Introduction. In the previous papers [1-3] we have ana-
lyzed by Monte-Carlo simulations the accuracy of determi-
nation of primary γ-quantum direction. The value ≈0.2
degree have been obtained for γ-quanta which coming inside
the area of circle of a radius r≤200 m from the center of
the telescope. This calculations have been made using the
timing information from three detectors only (the scheme
of detectors location is shown on the Fig.1).

In this paper we have analyzed accuracy of primary
γ-quanta direction determinations using timing information
from all seven detectors. Various methods of data analy-
zizing have been compared.

2. Analysis and Results. The bank of 50 artificial vertical
showers which were initiated by primary γ-quanta with
energy 10^{13} eV have been used. For each individual shower
the information on shape of Cherenkov pulse have been done
for three values of distances to shower core: 30 m, 100 m
and 300 m. The mean time delay τ_{1/2} (where τ_{1/2} is the time
of increasing of Cherenkov pulse up to 1/2 of maximum
value) of pulse arriving versus distance r have been obta-
inied. The values τ_{1/2} and mean square deviation of one
σ_{1/2} against r are shown on the Fig.2 and 3 respectively.
For calculation of the core location of \(\gamma\)-shower we have used the lateral distribution of Cherenkov light curve \(Q(r)\) which is shown on the Fig.4 and Poisson’s fluctuations of one were taken into account.

In order to obtain real conditions of shower detection the following procedure have been used. For each of bank’s shower 100 simulations of the core position \((x,y)\) within radius \(R_m (R_m=100m, 200m \text{ and } 300m)\) and arriving direction have been taken. The zenith angle of these showers have been taken 0.4 rad for all events. To obtain \(t_{1/2}\) for a given position two variants of the procedure have been used [2]: i) the square interpolation of the \(t_{1/2}\) from three values of bank’s data; ii) the mean value of \(t_{1/2}\) (see Fig.2) was used and fluctuation of one have been simulated using Gauss distribution with parameter \(\sigma_{1/2}\) (see Fig.3). In this way we obtained 5000 shower events (input array of showers), which have been analyzed to obtain the telescope’s parameters.

The shower core position \((x,y)\) of these events was found by the least squares method with help of known functions \(t_{1/2}(r)\) and \(Q(r)\) (Fig.2 and 4).

The calculated errors \(\sigma^t_{x,y}, \sigma^0_{x,y}\) of these methods have been done in the Table 1. From the Table it is seen that \(Q(r)\) method is more accurate than \(t_{1/2}(r)\) method and we use it for following calculations.

The shower direction for known core position \((x,y)\) was found by the ways:

\(\text{a) using information of various combinations and number of detectors with correction on } \vec{r}_{1/2} \text{-dependence (Fig.2);} \)
\(\text{b) using least squares procedure for all seven detectors.} \)

The mean values of the angles between primary shower direction and calculated ones (\(\vec{\xi}_0 - \vec{\xi}\)) have done in the Table 2, where accuracy of the values are approximately \(0.01^\circ\).

From the Table 2 it is seen that using of previous \((x,y)\) core position in the calculations of shower direction gives more accurate definition of one (see rows 1 and 2,3). In the case of full correlated fluctuations of \(t_{1/2}\) (row 3) the precision of calculations is better than in the case of independent ones (row 2). The precision increase also in the case when the number of used detectors increase. When we have used of 6 triangles combinations of the detectors (row 6) the precision not increase in compare with the case of two triangles (row 5) combination \((1,3,5)\) and \((2,4,6)\), because some triangles have a little area (see Fig.1). The best precision have been obtained in the case when the least square method is used for seven detectors (row 7).

<table>
<thead>
<tr>
<th>(R_m, m)</th>
<th>(\sigma^t_{x,y}, m)</th>
<th>(\sigma^0_{x,y}, m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>300</td>
<td>80</td>
<td>12</td>
</tr>
</tbody>
</table>
Fig. 1. The Cherenkov detectors location.

Fig. 2. The mean time delay of Cherenkov pulse.

Fig. 3. The absolute (solid) and relative (dotted) time delay deviations.

Fig. 4. The Cherenkov light lateral distribution.
The parameters of electronics and photomultipliers gives errors on the angle position less than 0.1 degree.

TABLE 2.

<table>
<thead>
<tr>
<th>$\sigma_{x,y}$</th>
<th>The procedure to obtain ($\xi_0 - \xi$)</th>
<th>$\xi_0 - \xi$, degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x,y$-position not used</td>
<td>on the base of (1,3,5) detectors (see Fig.1), using procedure (i) *</td>
<td>0.62 1.10 1.36</td>
</tr>
<tr>
<td>0</td>
<td>(1,3,5), (i)</td>
<td>0.05 0.14 0.29</td>
</tr>
<tr>
<td>0</td>
<td>(1,3,5), (ii)</td>
<td>0.04 0.03 0.07</td>
</tr>
<tr>
<td>using $\sigma^0_{x,y}$ from Tab.1</td>
<td>(1,3,5), (i)</td>
<td>0.12 0.19 0.33</td>
</tr>
<tr>
<td>The mean of values on the bases (1,3,5) and (2,4,6), (i)</td>
<td></td>
<td>0.11 0.17 0.25</td>
</tr>
<tr>
<td>Also for (1,3,5), (2,4,6),(1,2,3),(2,3,4), (3,4,5),(4,5,6), (i)</td>
<td></td>
<td>0.12 0.18 0.31</td>
</tr>
<tr>
<td>On the base of (1,2,3, 4,5,6,7) by the least squares method, (i)</td>
<td></td>
<td>0.14 0.15 0.21</td>
</tr>
</tbody>
</table>

*) Without correction on the shower front curvature. All of following values are calculated with this correction.

3. Conclusions. The main results of our Monte-Carlo simulations are:
1) The precision of determination of shower core position using the lateral Cherenkov light distribution is better than when the curvature of showers surface is used.
2) The value of shower direction precision are: $\approx 0.1 \pm 0.15$ degree for $R_m = 100m$, $\approx 0.15$ degree for $R_m = 200m$ and $\approx 0.2$ degree for $R_m = 300m$ if the fluctuations of arrival time are independent.
3) The precision of shower direction estimation is better as above if the fluctuations of arrival time are partly correlated.

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References

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