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IJS Report
IJS - DP - 7673
March 1997

Beam test of a RICH with C_4F_{10} gas as radiator and an array of MA-PMTs for photon detection

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Abstract

A test has been carried out with 32 Hamamatsu M16 PMTs read out by OTR ASD8 boards. During the test the radiator gas mixture changed from pure Argon to a 80:20 C_4F_{10} - Argon mixture. The figure of merit of the counter stayed constant (roughly equal to 65/cm) throughout the experiment.

1 Apparatus

In the present beam test we have used the same RICH set-up which was in previous years employed to test the three sorts of photon detectors for the HERA-B RICH. To equip it with MA PMTs, a mechanical support for nine base boards, each housing 4 PMTs, was designed in such a way that it can easily plug in the detector panel (lower, "CsI" hole) of the radiator vessel in the test beam area T24 at DESY as well as in the test light source in Ljubljana (Fig. 1). The black painted module support consists of holes for 9 modules of the base boards shown in our previous report [2]. The material for the 10 mm thick support is transformer steel with a high value of μ.

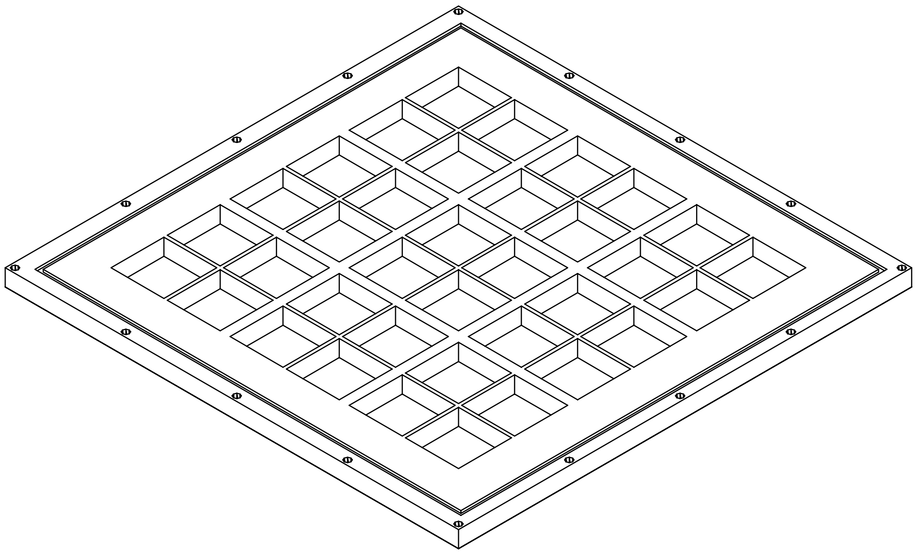

Figure 1: *The mechanical support for 9 base boards, 36 PMTs, to fit on the test beam vessel.*

The digital signals from ASD8 chips were led to the amplifier/TDC chain of the ARGUS μ-vertex chamber, the same read-out that was employed in the TMAE-CsI beam tests. The data were recorded by the usual beam test DAQ and on-line program, which runs on the micro-Vax (estrip.desy.de).

2 Scans: HV and threshold

Note that the set of MA PMTs that was used in the test, was not subjected to a quality assesment test prior to the measurement. Also note that a single HV channel was used for all 32 tubes. To determine the working HV value we therefore had to measure the number of Čerenkov photons per ring as a function of voltage value while the vessel was still filled by Argon (Fig. 2). In a separate measurement, the threshold voltage of the ASD8 chip was varied as well. From the two sets of measurements (Fig. 3) we chose the

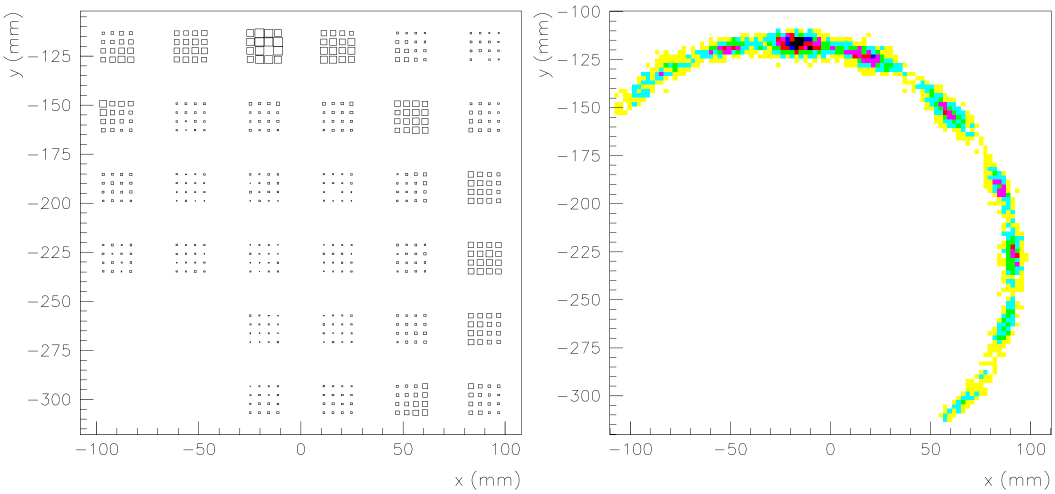

Figure 2: *Accumulated Čerenkov ring on the photon detector, with argon gas as radiator: raw data (left), using tracking information (right).*

HV value of 750 V, and the threshold value of 0.6 V.

3 Filling the vessel with freon

The radiator vessel volume (2 m^3) was filled with C_4F_{10} at a rate of approximately 100 l/h. After 10 hours the first bottle (i.e. the same that was used in the scintillation measurements last year) was empty, and was substituted by the second bottle, with a somewhat reduced gas flow.

The gas was led from the bottle via a sequence of two cleaning cartridges into the vessel through two thin copper tubes which enter the vessel in the mid-plane. As a result the two gases, Argon and C_4F_{10}, got very well mixed[1], and as we shall see later on, we can infer from the measurements that the mixing was perfect. At the time the two bottles

[1] It takes about 0.3 s of free fall to reach the bottom of the vessel, and by solving the diffusion equation for an idealized case (e.g. neglecting the interaction with the cylinder wall) it becomes clear that the flux pipe of freon is even in this short time diluted with about 20% of argon in the middle, and much more at the edges.

available were empty (after roughly 33 hours), the concentration of C_4F_{10} amounted to about 80% (Fig. 4).

During the filling about 40 measurements were performed, each collecting several tens of thousands of events. For each measurement, the raw data were analyzed by first correcting the hit coordinates with tracker information on an event by event basis. Some of the resulting accumulated rings are shown in Fig. 5. The Čerenkov ring radius and the number of hits (Fig. 7) were determined from the distribution of detected Čerenkov photons over ring radius Fig. 6. The number of observed hits was normalized to the full ring and full detector coverage.

Note that in order to allow for a good ring coverage at the end of the test, the initial position of the ring section was in one of the corners. As a consequence, in the initial part of the measurement the individual PMTs, as well as a precise evaluation of detector acceptance play an important role, and cause a considerable variation in the evalution of number of photons per ring.

4 Number of detected photons

The refractive index of the radiator gas can be extracted from two measured quantities, the radius of the Čerenkov ring,

$$R_c = f\sqrt{2(n-1)},$$

and the number of detected Čerenkov photons,

$$N_c = LN_0\theta_c^2 = fN_0 2(n-1).$$

Here we have introduced the so-called figure of merit[2] of a RICH counter N_0. In Fig. 8 the two values for $(n-1)$ are compared with the value derived under the assumption of perfect mixing of gases and a constant flux. There is clearly a very good correlation between the three.

We can also extract the value of N_0 from each measurement by combining the two results, R_c and N_c,

$$N_0 = \frac{N_c f}{R_c^2}.$$

The resulting plot is shown in Fig. 9. Again, we can observe the rather strong initial variation due to a limited number of PMTs covered by the ring.

The value of N_0 (69 cm^{-1}) can then be used to determine the number of photons we would expect if the 5 m long radiator vessel were filled with freon only. In this case $n-1$ would be 1.410^{-3} (instead of roughly 1.10^{-3} at the end of the measurement), and the number of detected hits would equal to $N_c = 97$. In the case of HERA-B the radiator is shorter, and a fully efficient light collection system would enable a detection of 54 hits

[2]The figure of merit N_0 enables at least some comparison of RICH counters, and is often encountered in the literature [4]

(for a track length of 2.7 m in the radiator gas). This, in turn, would yield 38 detected hits if a light collection system had an efficiency of 70%.

Of course, the number of hits is, due to cross-talk, not equal to the number of detected photons. To find a lower limit on the later, we have determined the same figure of merit by looking for clusters (a group of adjacent hits), and counting them as a single hit. The resulting N_0 is shown in Fig. 9, and amounts to roughly 62.5/cm, yielding 34 detected photons in HERA-B. Note, however, that this is a lower limit, as it neglects that there is a finite probability for two real photons to produce adjacent hits. A more refined analysis is under way to determine this probability for each run.

5 Scintillation background

The scintillation in freon is a potential worry. Although a measurement was made with a small container nearly a year ago [3] indicating that this type of background is not expected to be important, it was felt that the present beam test should be used to cross check the result. To do so, we plot the time of arrival as recorded by the TDC (Fig. 10).

The photons from scintillation are emitted isotropically, and are therefore expected to originate mainly directly from the region in the gas radiator closest to the photon detector. If scintillation were an important contribution to the background, they would therefore show up as a distribution starting about 30ns (10 m divided by the velocity of light) before the main peak, at about 90 ns in Fig. 10. From our previous measurement, as well as from the measurements by Friese et al. [5], we would expect about 0.015 detected scintillation photons per track. If the peak at 90 ns is identified with scintillation in the gas, it results in a yield which roughly agrees with the expectation. A more refined analysis is still underway, which would take also into account the specific 1/r distribution of scintillation background, and would also investigate the structures at later times.

6 Acknowledgements

The test would not be able to take place at such a short notice if it were not Mario Pohl of Zeuthen, who lent us the necessary amount of OTR ASD8 boards, together with some small but essential bits and pieces, as well as D. Škrk and J. Eržen, who manufactured in a record time the base boards, interface boards and PMT pin stiffeners.

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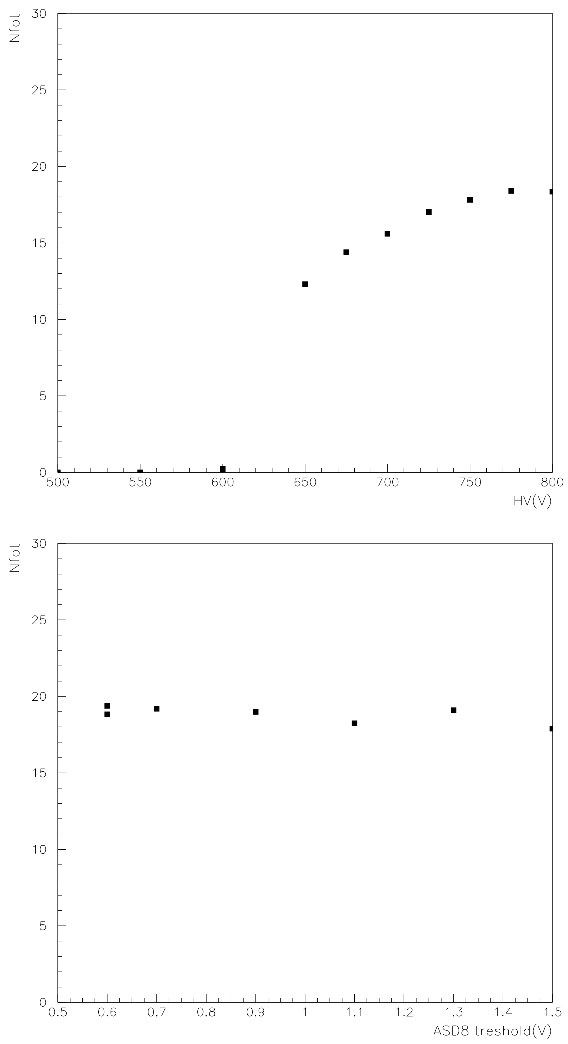

Figure 3: *Number of Čerenkov photons per ring as a function of high voltage (top), and as a function of ASD8 threshold voltage (bottom).*

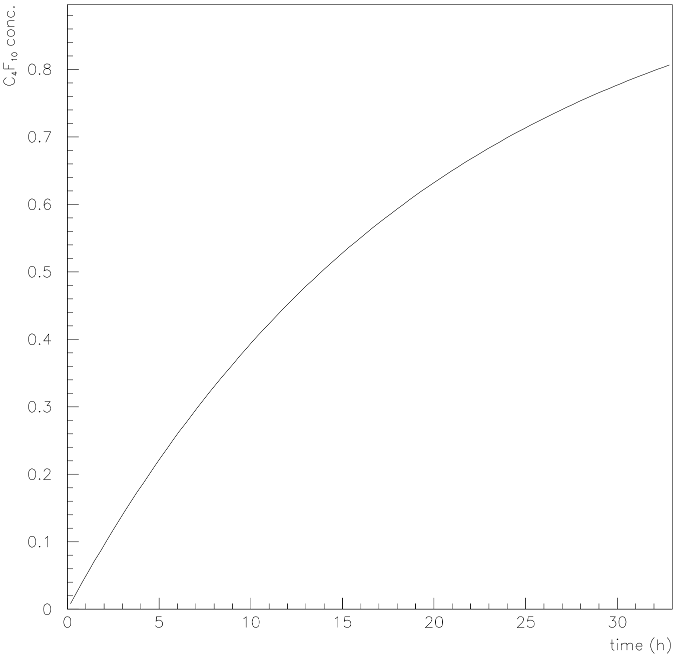

Figure 4: *The concentration of* C_4F_{10} *as a function of time under the assumption of perfect mixing of gases, and a constant gas flux.*

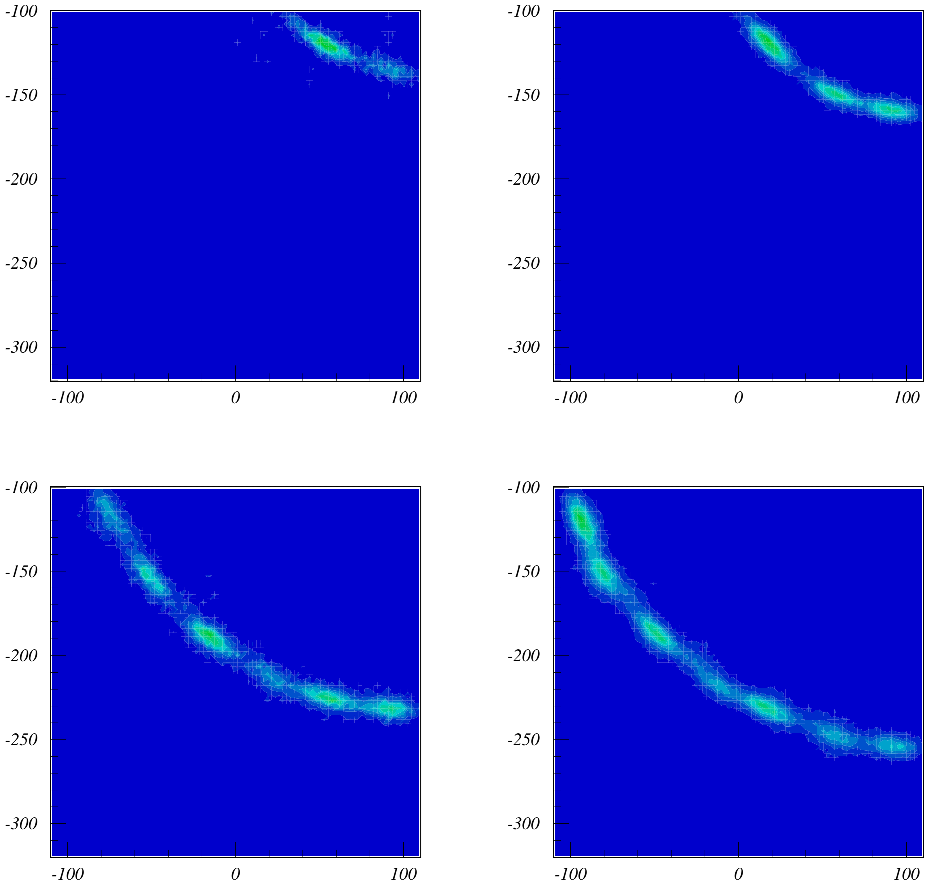

Figure 5: *Čerenkov rings on the photon detector, with argon as gas radiator (top left) and after flushing the vessel with* C_4F_{10} *for 1.5 hours (top right), 16 hours (bottom left), 28 hours (bottom right). The rings were corrected by using the tracker information on an event by event basis.*

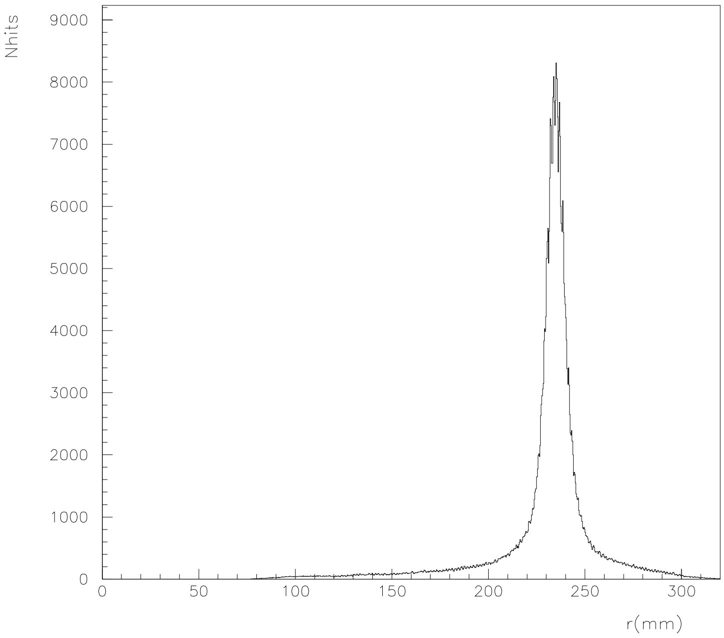

Figure 6: *Distribution of hits over the ring radius corrected by using the tracker information, during the last measurement, 10 hours after the flushing was stopped.*

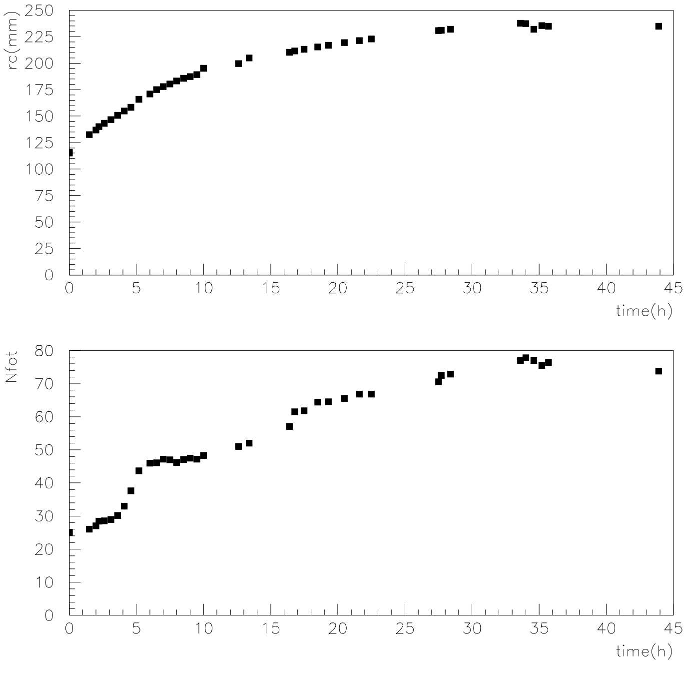

Figure 7: *Ring radius and the number of detected Čerenkov hits per a fully equipped ring, both as a function of flushing time. The flushing was stopped at around 33 hours.*

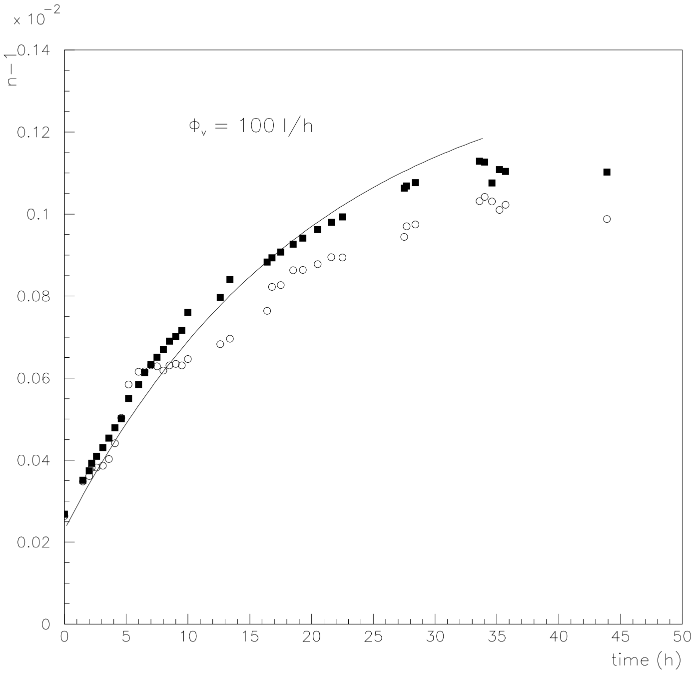

Figure 8: *The refractive index as extracted from the measured radius of the Čerenkov ring (squares) and from the number of detected Čerenkov photons (circles), compared with the calculated one in case of a perfect mixing of gases, shown as a function of time.*

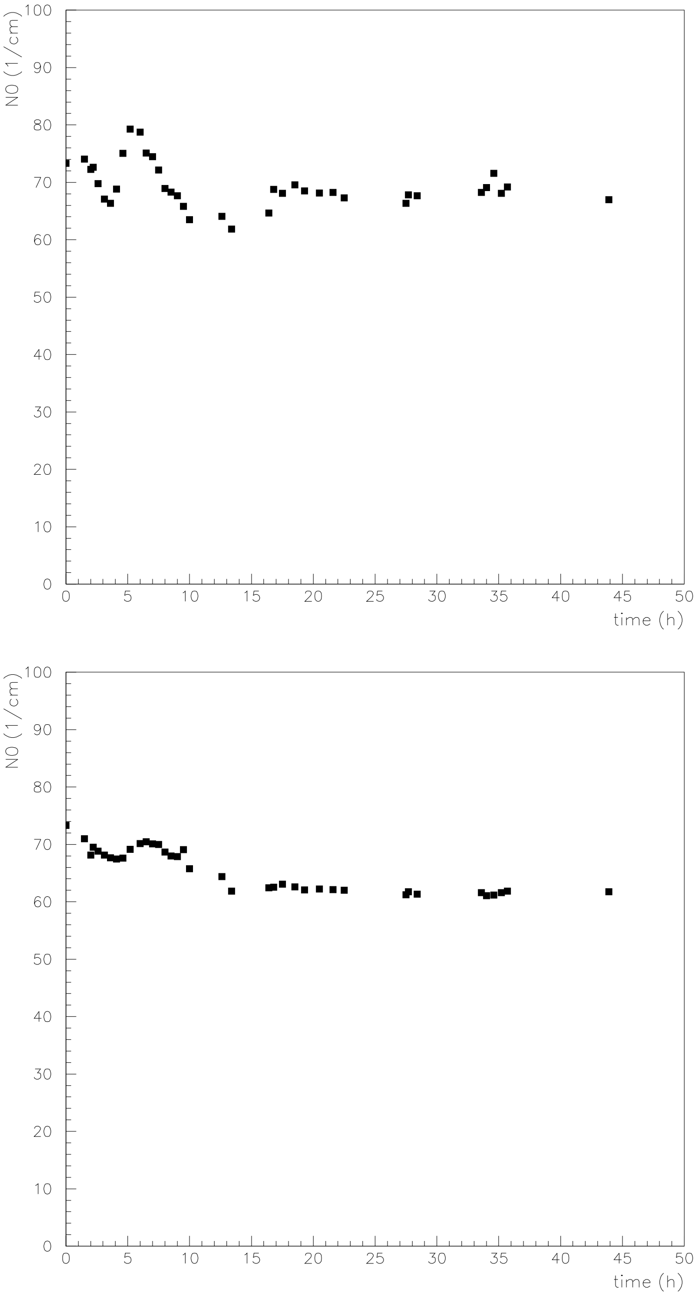

Figure 9: *The figure of merit N_0 as a function of time, as deduced from the number of hits (above) and the number of clusters (below).*

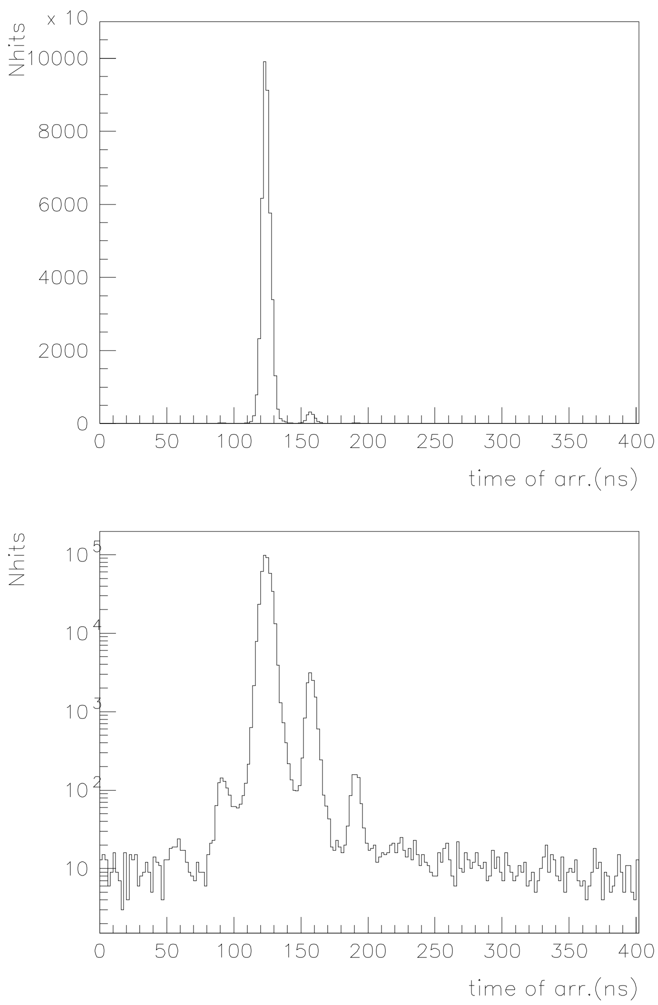

Figure 10: *The time of arrival of signals on the photon detector: linear scale (top), logarithmic (bottom).*