Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 567 (2006) 12–16
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A
www.elsevier.com/locate/nima

Photoelectron backscattering in vacuum phototubes

B.K. Lubsandorzhiev*, R.V. Vasiliev, Y.E. Vyatchin, B.A.J. Shaibonov

Institute for Nuclear Research of RAS, pr-t 60-letiya, Oktyabrya 7A, 117312 Moscow, Russia

Available online 12 June 2006

Abstract

In this article we describe results of studies of a photoelectron backscattering effect in vacuum phototubes: classical photomultipliers (PMT) and hybrid phototubes (PH). Late pulses occurring in PMTs are attributed to the photoelectron backscattering and distinguished from pulses due to an anode glow effect. The late pulses are measured in a number of PMTs and HPs with various photocathode sizes covering 1–50 cm range and different types of the first dynode materials and construction designs. It is shown that the late pulses are a generic feature of all vacuum photodetectors—PMTs and PHs—and they do not deteriorate dramatically amplitude and timing responses of vacuum phototubes.

PACS: 85.60. Ha

Keywords: Phototube; Photomultiplier; Photoelectron; Late pulse; Backscattering

1. Introduction

Vacuum phototubes are used widely in an overwhelming majority of experiments in astroparticle and high-energy physics. Precision timing of vacuum phototubes plays a crucial role in defining detectors angular and amplitude resolutions, background suppression etc. Phototube timing performance is of particular importance in case of experiments dealing with extremely low intensities of light fluxes, large-scale Cherenkov experiments in particular. One of the most strongly influencing effects on phototube timing is so-called "late" pulses and prepulses [1–4]. The late pulses are attributed to the photoelectron backscattering effect on the first dynodes of classical PMTs or the anode structures of HPDs [2,3]. This effect smears not only the timing response of vacuum phototubes but their amplitude resolution too [5].

2. Late pulses

It is still important to make distinction between the late pulses and afterpulses. Afterpulses stem from ionisation of the residual gas atoms and the atoms adsorbed by the first dynode surface, or luminescence of the dynodes and the residual gas [6–8]. Afterpulses are always correlated with the main pulses. The delay time of the ion-feedback afterpulses for classical PMTs stretches from hundred nanoseconds to dozens of microseconds. In our study, the afterpulses nearest to the main pulses are suppressed completely by the discriminator deadtime (~200 ns).

The late pulses are in fact a part of the main pulses of the phototube's response but they are only delayed by less than 10 ns in small phototubes and several dozens of nanoseconds in large phototubes. As it was mentioned above it is supposed that the late pulses arise from photoelectron backscattering (elastically or inelastically) on the first dynodes of classical PMTs or the anode structures of HPDs (silicon diodes or luminescent screens). A photoelectron hitting the first dynode may be backscattered even without liberating any secondary electrons. In turn, backscattered photoelectrons are decelerated by the electric field and then accelerated again towards the electron multiplying system producing finally the phototube's output signal. Thus the resulting delay time may be up to twice the photoelectron transit time between the photocathode and the electron multiplying system (the first dynode in case of PMT). We introduced in our previous work [3] the late

*Corresponding author. Tel.: +7 095 1353161; fax: +7 095 1352268.
E-mail address: lubsand@pcbai10.inr.ruhep.ru (B.K. Lubsandorzhiev).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.05.047

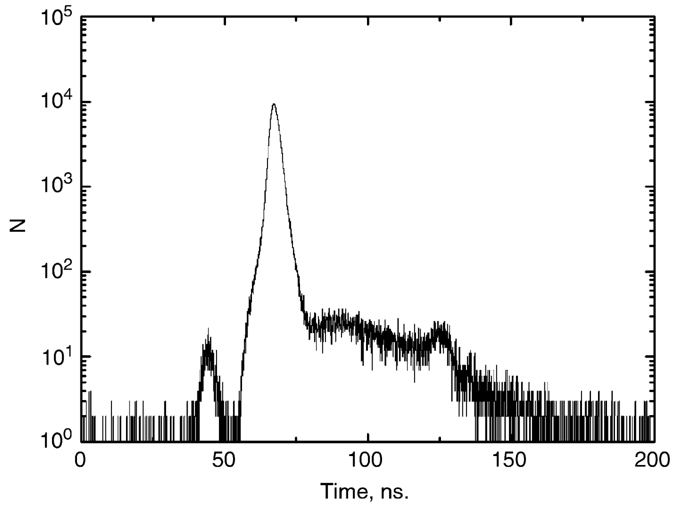

Fig. 1. Single photoelectron transit time distribution of EMI9350.

pulses probability coefficient $K_{\text{late}} = K_{\text{el}} + K_{\text{in}}$, where K_{el} and K_{in} are the elastic and inelastic backscattered late pulses probability coefficients, respectively.

The typical photoelectron transit time distribution of the 8″ EMI9350 phototube is shown in Fig. 1. The distribution was measured with the discriminator threshold of 0.01 p.e. The first peak of the distribution is due to prepulses [3]. The second "main" peak (between 50 and 70 ns) corresponds to the main pulses. The time interval between the prepulses peak and the main peak corresponds to the photoelectron transit time from the photocathode to the first dynode $t_{\text{c-1d}}$. The part of the distribution with time entries of more than 75 ns is explained largely by the late pulses. The broad peak around 110 ns with tail up to 140 ns is very likely due to the inelastically backscattered photoelectrons. The third rather sharp peak at 150 ns is attributed to the elastically backscattered photoelectrons. The time interval between the second and third peaks amounts roughly to twice the value of $t_{\text{c-1d}}$.

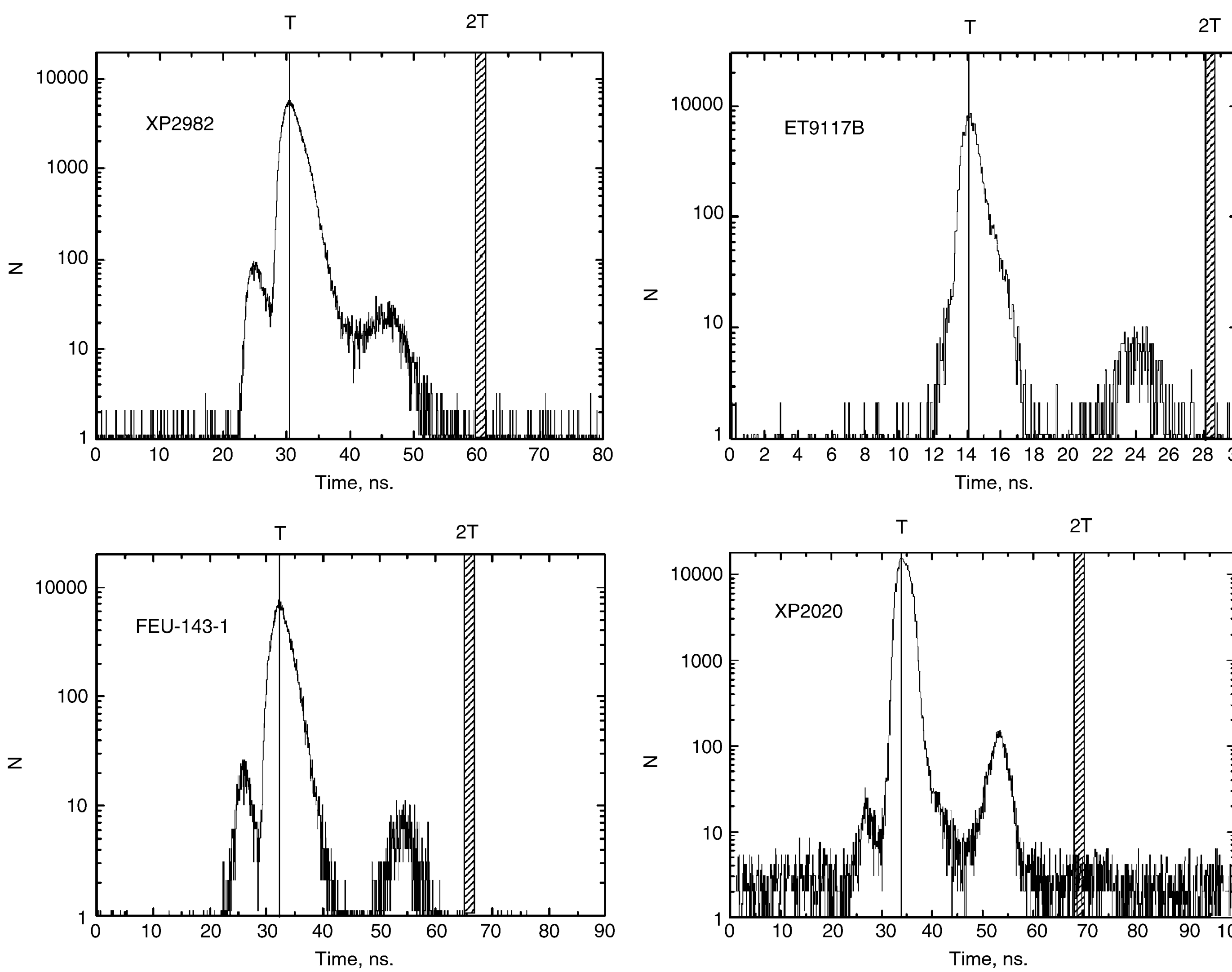

Fig. 2. Single phototelectron transit time distributions of a number of classical PMTs: clockwise from the upper left XP2982, ET9117B, FEU-143-1, XP2020.