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A SYSTEMATIC STUDY OF THE PWO HEAVY CRYSTAL CALORIMETER CELLS: THE SCINTILLATION DECAY CURVES

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Abstract

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Measurements of scintillation time characteristics are performed with a large lead tungstate (PWO) crystal sample which has been produced since 1993 at the Bogoroditsk plant, Russia, with different technologies of mass production, for the SAD-150 high-resolution PWO spectrometer. The measurement results show that with the recently improved technology high scintillation time parameters meeting the stringent requirements of the future collider and fixed-target experiments have been achieved.

Аннотация

Блик А.М. и др. Систематические исследования ячеек кристаллического PWO-калориметра: кривые высвечивания сцинтилляций: Препринт ИФВЭ 96-105. – Протвино, 1996. – 6 с., 4 рис., библиогр.: 7.

Проведены массовые измерения времен высвечивания тяжелых сцинтилляционных кристаллов вольфрамата свинца PWO, изготовленных в течение трех лет на Богородицком комбинате с использованием различных технологий массового производства ячеек фотонного калориметра для спектрометра ГАМС и других детекторов. Усовершенствование технологии позволило достичь высоких временных параметров сцинтилляционного сигнала, удовлетворяющих жестким требованиям будущих экспериментов на коллайдерах и на фиксированных мишенях.

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Introduction

In this paper we present the results of systematic tests of a large sample of PWO ($PbWO_4$) scintillation crystals produced at the Bogoroditsk Techno-Chemical Plant (Tula, Russia) [1-4] for the GAMS programme [5] during the 1994 spring to 1996 winter period. More than 200 PWO crystal cells have been tested and further used to build the SAD-150 calorimeter (Small Angle Detector), which is destined to detect photons in a heavily loaded region of the GAMS-4π spectrometer (more than 10^6 pions per second per PWO cell) in the experiment on exotic meson studies and glueball search (SERP-E-172), operating in π^- beam of the 70 GeV IHEP accelerator.

Along with new physics results, important for the development of the non-perturbative QCD theory, we expect from these studies that the experience gained during the SAD-150 exploitation under real conditions of a high-energy high-intensity particle physics experiment would provide unique information significant for the future collider and fixed-target projects (CMS, COMPASS, JHP, etc.), as it was the case with the microstrip gas chambers, used for the first time in our GAMS NA12/2 experiment at the SPS of CERN [6].

The SAD-150 is a 13 x 12 matrix composed of 22 X_o to 26 X_o long PWO crystal cells. The cells are hexagonal prisms 24 mm wide (distance between two parallel lateral faces), viewed from the rear end with FEU-147 or Philips XP1911 photomultiplier (PMT) detecting the scintillation light.

The beam test results of SAD-60, the SAD-150 prototype built of PWO cells based on the 1994–95 mass production technology using medium-purity raw materials, have been published [4]. Unlike the PWO crystals used in the early studies[1][2,3], the 1994–95 PWO sample showed a significant slow component in the scintillation decay curve.

[1]A small sample of the first calorimeter-size PWO crystals, produced at the Bogoroditsk plant during 1993 with an individual technology for our initial R&D studies and used in the first beam tests of the PWO calorimeter prototype at IHEP and CERN, showed a fast signal, that was practically free from the slow component.

The results on scintillation time characteristics obtained in the 1994–95 *PWO* sample, as well as those of the *PWO* cells which been produced during 1996, with an improved technology and purified raw materials, are presented below [7].

1. Measurement procedures

The measurements have been performed at the GAMS IHEP crystal test bench. Two methods of measuring the *PWO* scintillation decay curves are applied. In the former one (fig. 1a) the *PWO* cell is irradiated by electrons from ^{106}Ru decay (E_{max} = 3.5 MeV) which pass through a thin plastic scintillation counter, that provides a start signal for the time measurements. The stop signal is produced by the FEU-85 or Philips XP2020 PMT viewing the *PWO* cell through a diaphragm, that is used to strongly decrease the amount of scintillation light and to operate the PMT in one-photoelectron detection mode. The time interval between the start and stop signals after shaping with a zero-cross correction for the time-*versus*-amplitude dependence is measured by a standard TDC. The setup resolution is about 1 *ns*.

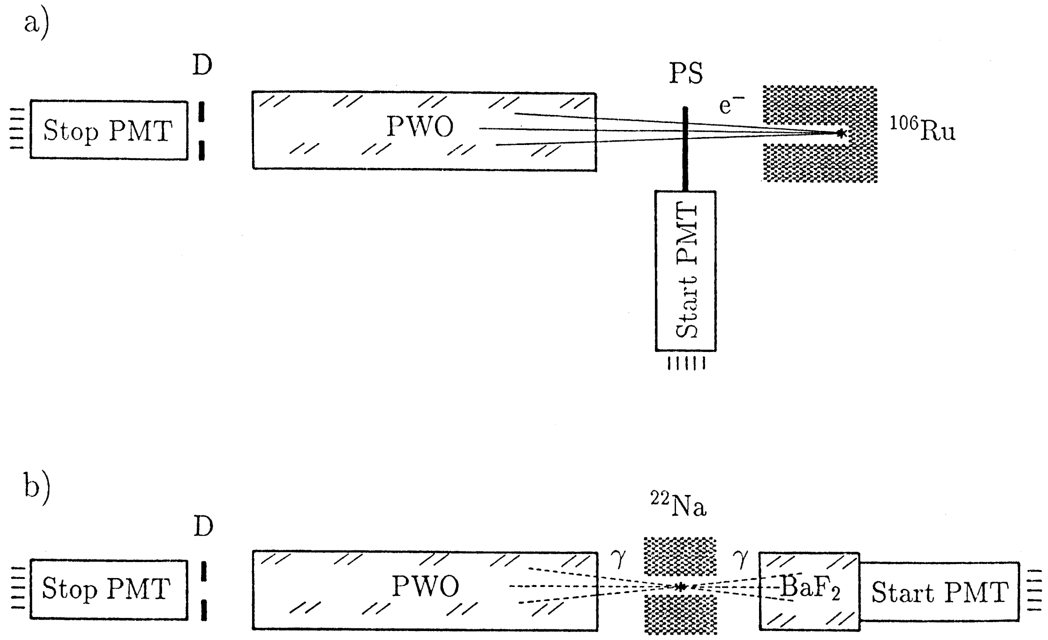

Fig. 1. *PWO* scintillation decay curve measurements at the GAMS test bench: a) with electrons from the ^{106}Ru source, b) using the annihilation $\gamma\gamma$ method with ^{22}Na source. *D* is a diaphragm, *PS* is a 1 *mm* plastic scintillator, for details see the text.

In the latter method a more traditional $\gamma\gamma$ technique is used (fig. 1b). In this case the start signal is produced by one of the ^{22}Na annihilation photons in the BaF_2 crystal viewed by the UV-sensitive XP2020-Q PMT, the other annihilation photon being detected by the *PWO* cell.

Both methods gave similar results, the background being lower with the ^{106}Ru source (fig. 1a).

The scintillation decay curves have been measured in two steps: first in the 0 – 200 ns interval, with 0.5 ns step (for fast components), and then in the 0 – 15 μs interval, with 10 ns step (to measure slow components). The two curves are then fitted simultaneously by the exponential dependencies e^{-t/τ_i}, taking into account the setup time resolution and the histogram binning. A sum of four such dependencies turned out to be enough for a good description of the decay curves: with $\tau_1 \approx 5$ ns (absorbing two main fast components with $\tau \approx 2$ ns and $\tau \approx 8$ ns [3]), $\tau_2 \approx 20$ ns, $\tau_3 \approx 200$ ns and $\tau_4 \approx 2$ μs. The measurements take 3 hours per cell providing $3 \cdot 10^6$ statistics.

2. Measurement results

The typical PWO scintillation decay curves, measured for "old" (1994–95 technology) and "new" (1996) PWO crystal cells, are shown in fig. 2. Their difference is evident: an order of magnitude more pronounced "tail" in the "old" crystals.

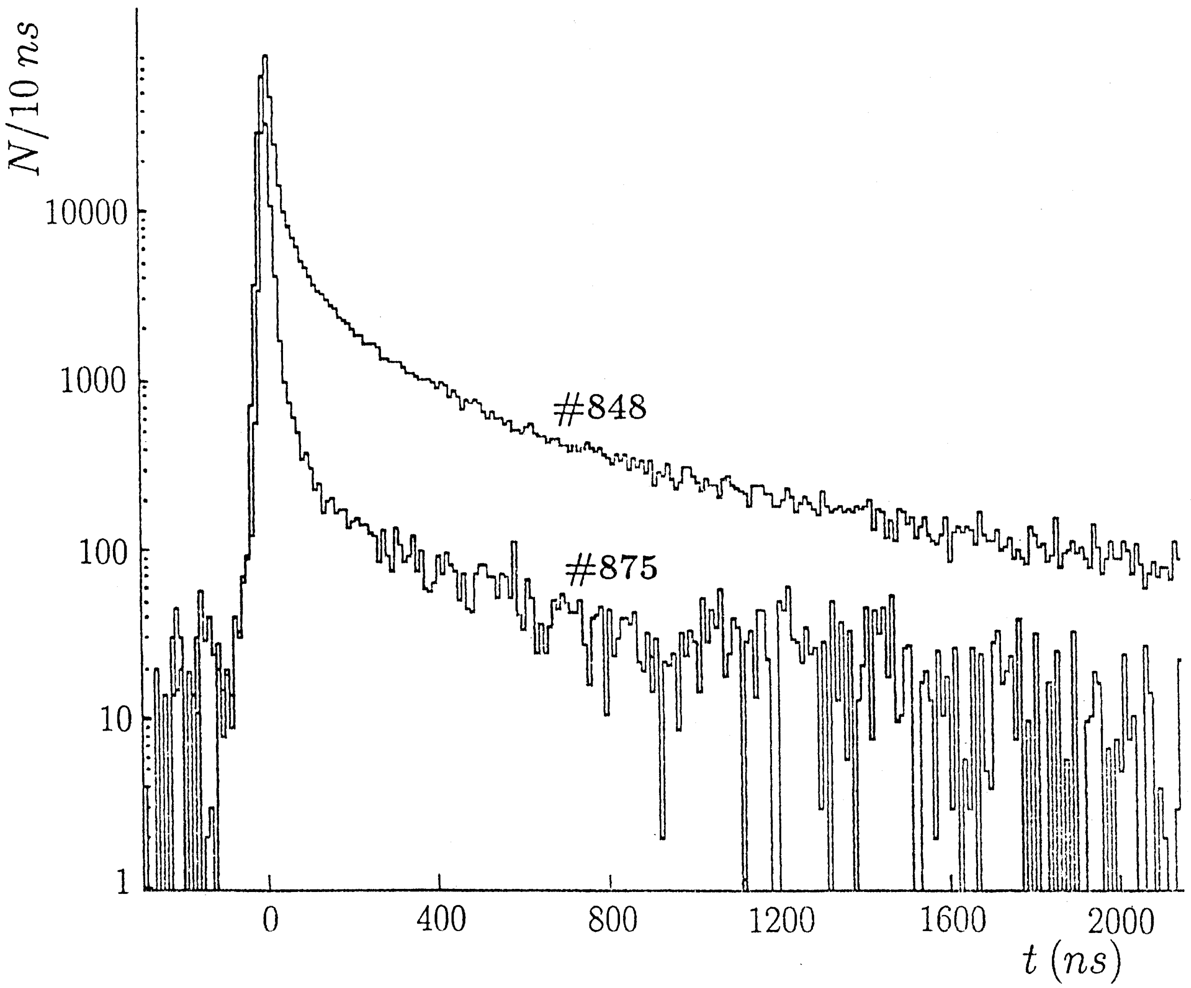

Fig. 2. Typical PWO scintillation decay curves measured with ^{106}Ru source for one of the "fast" crystals (cell #875, 1996 technology) and for one of the "slow" crystals (cell #848, 1994–95 technology).

The contribution of randoms to the measured decay curves is negligible, the plato of randoms has a zero time slope. The decrease of the ^{106}Ru electron flux by more than an order of magnitude, from $10^4/s$ to $500/s$, does not change the shapes of measured decay curves; the background-to-signal ratio shows a linear increase with intensity, as expected.

As a check, similar time measurements have been performed with the fast plastic scintillator. The decay curve in this case does not show any long "tail" above the sensitivity level of the present measurements which we estimate to be 2% for the slow (some microseconds) component contribution. Such a "tail" may be attributed both to real scintillations and to secondary ionization processes in the PMT.

The contribution of slow components to the total PWO signal is characterized by two values: Q_3 for the τ_3 fraction (the integral under e^{-t/τ_3}, in % of the total signal), and Q_4 for that with τ_4. These values for the 1994–95 and 1996 PWO samples are presented in fig. 3.

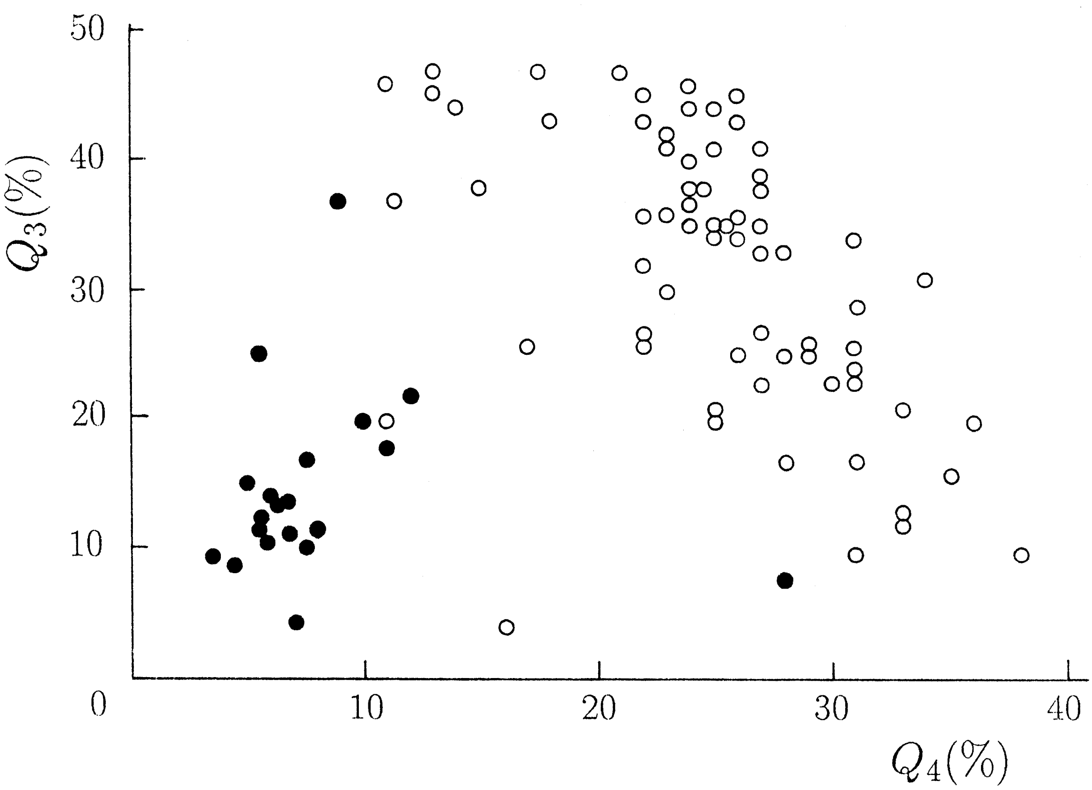

Fig. 3. Contributions of two slow exponential components to the total PWO signal: Q_3 vs Q_4 biplot. 1996 cells are shown in black, white is for the 1994–95 sample.

The slow component of the signal, its "tail", can also be numerically characterized by a signal fraction contained within the 0–100 ns interval, $R(100\ ns/1\mu s)$. The cell distribution over this parameter is given in fig. 4 [2]

[2]In the 1993 PWO sample, used in the initial studies [2,3], $R(100\ ns/1\mu s) \approx 0.9$.

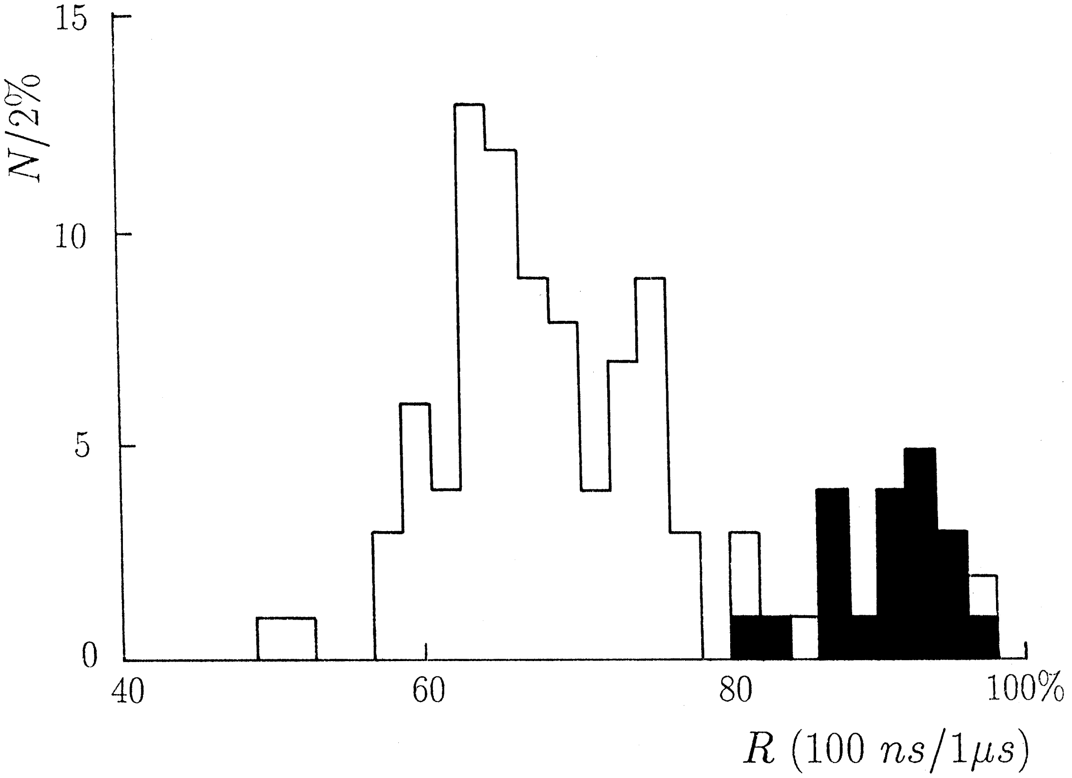

Fig. 4. "Tail" contribution to the *PWO* signal: $R(100\, ns/1\ \mu s)$ values for the 1996 cells (black) and the 1994–95 cells (white).

Conclusion

The last figure, which summarizes our observations, demonstrates that the *PWO* crystal cells produced at BTCP during 1996 with the new technology are fast, with R value of 0.92 ± 0.04[3], satisfying the stringent specifications of such high luminosity experiments as CMS and COMPASS, while the 1994–95 *PWO* sample has a pronounced slow scintillation decay component resulting in a much lower R value of 0.66 ± 0.08. Such *PWO* crystals may be well used in the projects of lower luminosity (ALICE, etc.).

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[3]The error shows a spread over the sample.

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