Nuclear Instruments and Methods in Physics Research A 3[illegible] (1996) 30–34

ELSEVIER

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Light response and particle identification with large CsI(Tl) crystals coupled to photodiodes

S. Aiello[a,*], A. Anzalone[b], G. Cardella[a], Sl. Cavallaro[b,c], E. De Filippo[a,c], A. Di Pietro[b,c], S. Femminò[d], M. Geraci[a,c], P. Guazzoni[e], M. Iacono-Manno[b], G. Lanzanò[a], S. Lo Nigro[a,c], A. Musumarra[b,c], A. Pagano[a], M. Papa[a], S. Pirrone[a], G. Politi[a,c], F. Porto[b,c], F. Rizzo[b,c], S. Sambataro[a,c], M.L. Sperduto[b,c], C. Sutera[a], L. Zetta[e]

[a] Istituto Nazionale di Fisica Nucleare-Sezione di Catania, Corso Italia 57, I-95129 Catania, Italy
[b] Istituto Nazionale di Fisica Nucleare-LNS, Via S.Sofia 44, I-95123 Catania, Italy
[c] Dipartimento di Fisica dell'Università, Corso Italia 57, I-95129 Catania, Italy
[d] Istituto Nazionale di Fisica Nucleare-Gruppo collegato di Messina and Dipartimento di Fisica dell'Università, Messina, Italy
[e] Dipartimento di Fisica dell'Università and Istituto Nazionale di Fisica Nucleare-Sezione di Milano, Milano, Italy

Received 23 March 1995; revised form received 17 July 1995

Abstract

The light response of large CsI(Tl) crystals supplied by various companies and coupled to photodiodes has been investigated. Energy resolution measurements and $Z = 1$ isotopic identification using the two gates method have been performed with in-beam experiments.

1. Introduction

The great number of detection modules used in the most sophisticated experiments in heavy ion physics at energies around 100 MeV/nucleon require the use of large area and low cost detectors. Considerable thickness is also necessary to stop light charged particles (LCP) emitted with energy up to several hundred MeV.

The relatively simple handling and the light output performances of CsI(Tl) crystals make them very suitable for a 4π detector assembly to duly satisfy all the above requirements.

Such crystals can be coupled both to photomultipliers [1–4] or to photodiodes [5–11] with different merits. Coupling to photomultipliers gives a better energy resolution, especially at low energies and usually an easier LCP identification, whereas the coupling to photodiodes has a better stability, a low operating voltage, low power dissipation and allows a very compact assembly. However, LCP identification is more difficult and has only been achieved with small crystals and at relatively high energy, to date.

In this work, the light response and the LCP identification capability of large CsI(Tl) crystals manufactured by different companies and coupled to photodiodes have been investigated. We found that identification tests seem to be an appropriate method to gain insight into the global characteristics of crystals. The tests have been performed at low bombarding energies where LCP identification is expected to be a critical parameter.

The detectors used in this work are prototypes of the 1200 ΔE–E telescopes for the 4π detector CHIMERA [12]. Each telescope consists of a 300 μm thick ΔE silicon detector with an active area of about 25 cm^2, followed by a CsI(Tl) crystal with photodiode readout as a stop detector. The crystal lengths range from 3 to 12 cm according to the expected proton energies at various detection angles.

Section 2 describes the detector assembly, Section 3 illustrates some results of tests performed with α and γ sources concerning light output homogeneity, and finally in Section 4 in-beam experiment results are reported.

2. Detector assembly

The CsI(Tl) scintillators had entrance surface areas of 50×50 mm^2 and lengths of 120 and 60 mm. The two smaller faces were polished while the sides were matted. The front surface was covered with a 1.5 μm reflecting film of aluminized mylar. The crystals were then wrapped in a

* Corresponding author.

0168-9002/96/$15.00 © 1996 Elsevier Science B.V. All rights reserved.
SSDI 0168-9002(95)00783-6

white layer 150 μm thick and then coated with 30 μm thick aluminium foil. For in-beam experiments, photodiodes manufactured by Hamamatsu Photonics were coupled to the back surfaces by means of a thin silicone grease layer. The photodiodes, type S-3204, were 300 μm thick with an active sensitive area of 18 × 18 mm². The leakage currents were about 2 nA under vacuum operation with a bias voltage of 80 V. The diode capacitance was 130 pF at full bias. Photodiode signal readout was achieved by a low cost charge preamplifier designed by the Saclay CEA Electronic Laboratory. The low power dissipation of these preamplifiers allows them to operate in vacuum without cooling. Their electronic noise was ≤10 keV (silicon equivalent) for an input capacitance of 130 pF.

Preamplifier signals were amplified and shaped by means of a standard spectroscopy amplifier (Ortec 572) with 2 μs shaping time. The energy resolutions of these electronic assemblies for 5.486 MeV α particles are reported in Fig. 1 (filled circles) together with the measurements of Boutet et al. [5] (open circles) who have performed energy resolution studies as a function of crystal size. For large crystals and especially in α-ray energy measurements, where the light collection is poor, the electronic noise is the limiting factor [13]. This depends essentially on the photodiode dimensions and on the preamplifier noise. The latter is the dominating factor according to the "Ortec handbook" [14]. Therefore the comparison of Fig. 1 is not rightly correct as our photodiode dimensions and electronics were different from those used in Ref. [5]. Nevertheless, we notice that the energy resolution is strictly connected to the detector size in the homogeneous data. In the same figure we also show the resolution obtained with a 2 in. photomultiplier readout (Hamamatsu R2059-01), shaping the output signals with a 1 μs Ortec 572 amplifier (filled squares). Due to a better light collection and to a lower electronic noise, the resolution improves by more than a factor 2. This kind of readout is a good means to test light performances by using source measurements as described in the next section.

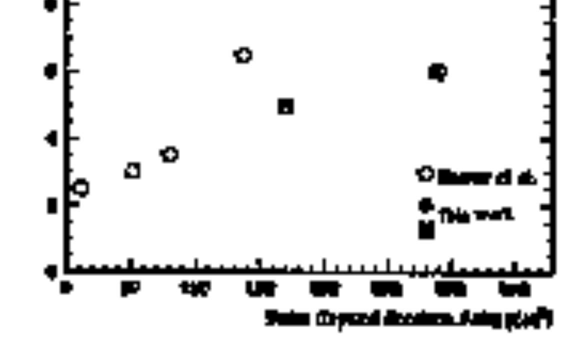

Fig. 1. Energy resolution for 5.486 MeV α particles as a function of the total surface area of the CsI(Tl). Circles refer to data obtained with photodiode readout, whereas the squares correspond to photomultiplier readout.

3. Light output characteristics

We studied the nonuniformities of the scintillation efficiency by scanning 15 different crystals delivered from 4 different companies (Crismatec, Merck-Clevenot S.A., Hilger Analytical, Scionix Holland BV). We used a 662 keV ^{137}Cs collimated γ source to scan the crystals along their lengths as shown in Fig. 2a, whereas a 5.48 MeV ^{241}Am collimated α source was used to scan the back face (Fig. 2b). The α particle scanning provides a better sensitivity due to the much smaller volume changed compared to the γ-ray scan [15]. The values reported in Fig. 2 are the peak positions for various source locations for one of the tested crystals. For all crystals we obtained light yield nonuniformities up to 4% for γ measurements and up to 6% for α measurements. The best crystals gave values of about 1% for both tests. For instance, for the crystal presented in Fig. 2, we had variations of 1.9% and 3.7% for α and γ scanning, respectively.

The γ photopeak energy resolution obtained with a full

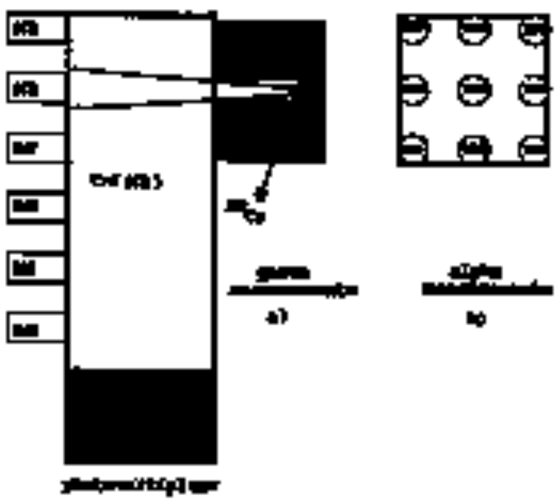

Fig. 2. Experimental assembly and results of one of the light response nonuniformity tests: (a) γ-ray response obtained moving the source along the crystal length; (b) α measurements at various positions on the front face of the crystal.

irradiation of the entrance faces ranged from 3 to 14% with variations in the absolute light yield of about 20%.

These variations in scintillation efficiency are most probably due to differences in thallium concentration and distribution, related to various crystal growth techniques and to the cut directions used to obtain the requested shapes.

4. In-beam measurements

For these tests we used two CsI(Tl) crystals ($50 \times 50 \times 120\ mm^3$), thereafter named crystal #1 and crystal #2, coupled to photodiodes as described in Section 1.

γ scanning resulted in a nonuniformity of 1% for both crystals, whereas α scanning yielded 1 and 3.5% nonuniformity for crystal #1 and crystal #2, respectively. The light output of crystal #2 was 20% lower than that of crystal #1.

The in-beam measurements were performed with oxygen beams delivered by the Tandem accelerator of the INFN Laboratorio Nazionale del Sud (LNS) at Catania. Beam energies were varied from 60 to 104 MeV. A LiH target 70 μg/cm² thick was used in order to have high LCP yield and to allow proton energy calibrations using the elastic recoil proton peak at various energies. The target was made at the LNS target laboratory using LiH powder in pellet form evaporated on 20 μg/cm² thick carbon foils. The target thickness was measured with an accuracy of 3% by particle energy-loss measurements.

The two CsI(Tl) crystals were placed at 40 cm from the target, symmetric around the beam axis. In order to obtain an unambiguous identification of the LCP, energy loss information was obtained via a 350 μm thick silicon detector with an active area of $50 \times 50\ mm^2$ manufactured by Micron LTD, placed in front of the CsI(Tl) during some runs. Standard electronics were used for this detector. No collimator was used, so that the total active area of the crystals was irradiated. The data were processed by a SILENA ADC and a CAEN TDC using the software package acquisition system of the LNS.

4.1. Light response

In Fig. 3, we show the light output for crystal #1 as a function of the energy of protons and of oxygen ions, at various beam energies. In the insert, we report the proton data in detail. Our data are compared with some CsI(Tl) response data reported in the literature [16–18]. The nonlinear and well-known response observed for these particles is reflected in the different trends of the measured data. We describe the experimental data by means of the simple expression $L(Z,E) = aZ^bE^c$ using the same coefficients $b = 0.5$, $c = 1.3$ reported in Ref. [18] while a is a scaling factor; Z and E are the charge and energy, respectively. The results of this parameterization, shown as

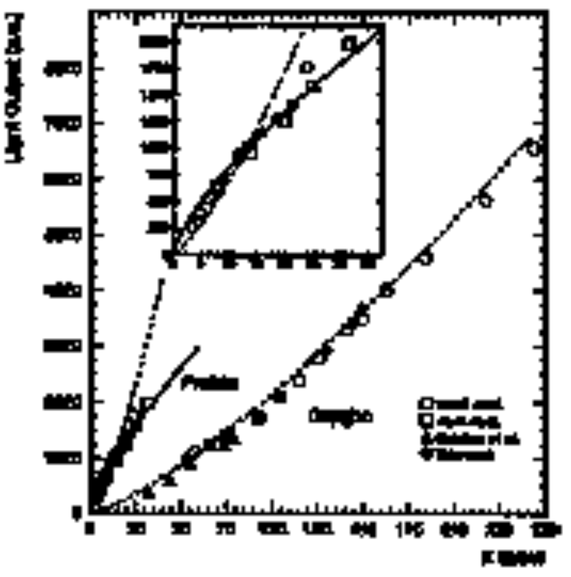

Fig. 3. CsI(Tl) light response for protons and oxygen ions compared to the data of Refs. [16–18].

dashed lines of Fig. 3, reproduce the experimental data only for oxygen ions. In the proton case, indeed, a saturation effect has already been observed experimentally and predicted to occur at around 6 MeV [19]. We have then fitted the proton data with a power function of energy $L(E) = aE^{\gamma}$ obtaining $\gamma = 0.75$ (solid line of Fig. 3). The good reproducibility in the light response of our crystals is very important for energy calibrations, specially if we have to work with a multidetector array like CHIMERA. In fact, by using elastically scattered particles from hydrogenated targets at various beam energies it is possible to obtain the relative calibrations for all different particles.

In Fig. 4, we report the results of intrinsic energy resolution measurements from the peaks of elastic recoil protons and elastically scattered oxygen ions for crystal #1. It is important to remark, as already reported, that we did not use collimators, sampling in this way the global crystal response. For this reason, it is very important to accurately correct the peak widths by considering their kinematic broadening. We performed this correction by means of a Monte Carlo calculation that takes into account the angular and energy distributions from Rutherford scattering and straggling effects in the 1.5 μm thick entrance foil of the crystal. The squares in Fig. 4 represent the data without corrections, obtained directly from the FWHM of the peaks, while the circles represent the data after the above kinematic corrections. These corrected data have been fit with a power function of the light response, L^{β}, that gives a value of -0.22 for β (continuous line in Fig. 4). From the statistical considerations given in Ref. [13] we notice that in our energy region, the resolution is nearly completely dominated by electronic

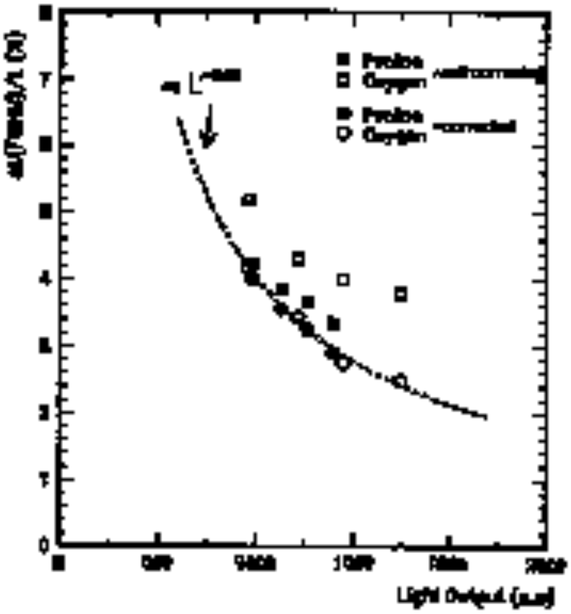

Fig. 4. Light response resolution for proton and oxygen ions. Circles represent values corrected for kinematic broadening.

noise ($\beta = -1$) rather than by scintillation statistics ($\beta = -0.5$) taking into account also local luminescence fluctuations and inhomogeneities in light transmission and collection. Moreover, in our case, it seems that for equal light response the resolution is almost independent of the

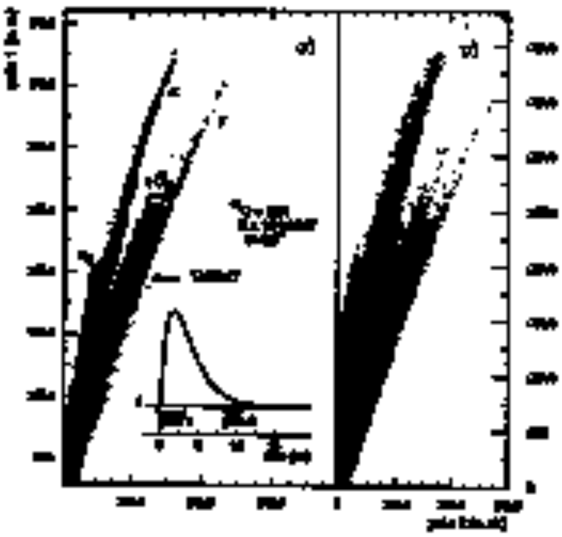

Fig. 5. Particle identification with the two gates method for (a) crystal #1 and (b) crystal #2. In the lower part of (a) the time characteristics of the signals and gates used are shown.

detected particle type, even if with very different ionization density and therefore penetrating power.

4.2. Two gates method

As is well known, the light output of CsI(Tl) is characterized by a combination of two exponential functions with different time constants

$$L(t) = L_f \exp\left(-\frac{t}{\tau_1}\right) + L_s \exp\left(-\frac{t}{\tau_2}\right), \qquad (1)$$

where $L(t)$ is the light pulse amplitude at time t and L_f and L_s are the light amplitudes for the fast and slow components, their decay time constants $0.4 \le \tau_1 \le 0.7$ μs and $\tau_2 \sim 3.2$ μs, respectively [10].

The fast component increases with decreasing ionization density and therefore depends on the mass, charge and energy of the detected particle, while the slow component varies very slowly with particle type and energy. This dependence is the essential feature that permits particle discrimination by pulse shape analysis. The discrimination technique used in this work is the two gates method of Ref. [1] adapted for photodiode readout [4].

The LCP identification of crystal #1 is shown in Fig. 5a where a typical scatter plot of the two integration gates is reported. In the lower part of this figure, the time characteristics of the signal and the gates used for the charge analysis are illustrated. The high energy γ yield is mainly due to cosmic rays as deduced from background measurements. In a recent paper [11], a good discrimination between $Z = 1$ and $Z = 2$ particles was obtained at around 2 MeV, whereas in our case identification thresholds are much higher. The high quality of the results of Ref. [11] is probably due to the small size of the crystal used providing a much better energy resolution (see Fig. 1), and also to the absence of deuterons, tritons and specially heavy ions that in our case fill the low light output region of the scatter plot. Fig. 5b shows the scatter plot for crystal #2 in the same experimental conditions. The poor quality of the discrimination efficiency confirms the results obtained with the source tests.

In our case, particle discrimination is not sufficient to simultaneously identify $Z = 1$ isotopes at low energies. However a substantial improvement of particle identification is observed for increasing energy. To show the evolution of this $Z = 1$ isotope identification as a function of the energy, the two gates scatter plot has been linearized by using the empirical function (gate 1)$^{\gamma}$/(gate 2) and integrated starting from three different proton energies thresholds, 10, 15 and 20 MeV respectively. Fig. 6 shows the results obtained for crystal #1. The γ coefficient used in the above expression is the same found in the fit of the proton light response (see Fig. 2), probably reflecting the fact that the saturation effect in the light response is present mainly in the fast component.

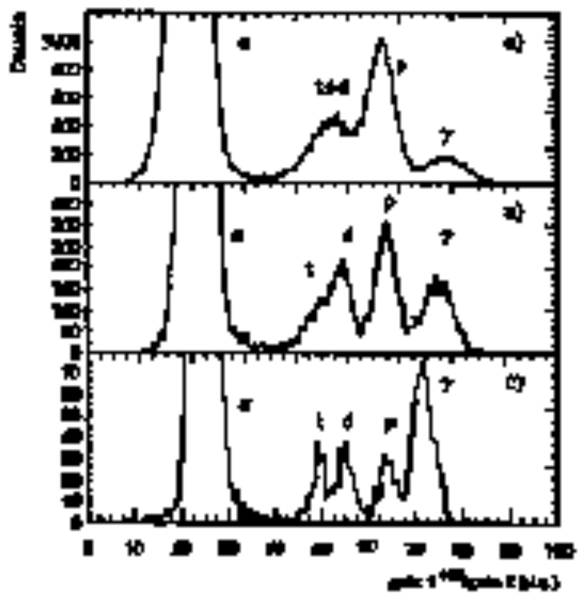

Fig. 6. Particle identification spectra obtained with the two gates method for crystal #1. The spectra are integrated with three low cut proton energies: (a) 10 MeV, (b) 15 MeV and (c) 20 MeV.

4. Conclusions

We have measured the light response characteristics of various CsI(Tl) crystals supplied by different companies. We found some differences in uniformity and the absolute value of scintillation efficiency. These facts are strongly reflected in the $Z = 1$ isotope discrimination capability using the two gates method.

For crystals with good light response, the energy resolution is quite good (2.3% for protons of 20 MeV) regardless of the large size, at least for particles with high light response. $Z = 1$ isotopic identification is possible but with a relatively high energy threshold (between 15–20 MeV).

The CHIMERA Si–CsI(Tl) telescope standard ΔE–E technique ensures LCP identification for low energies, but it would be affected at higher energies by a threshold due to electronic noise and straggling effects in large silicon detectors; the two gates method overcomes this limitation and so completes the performance of this kind of telescope.

Acknowledgements

We wish to thank S. Urso and N. Giudice for their able assistance in the course of this work and C. Marchetta for target preparation. We are grateful to J.P. Passerieux and B. Cahan of CEA-DAPNIA/SED (Saclay) for their invaluable collaboration. Our grateful thanks are also due to Laboratorio Nazionale del Sud (Catania) accelerator staff for their assistance in providing the beam used in the experiment. Finally we are grateful to Miss A. Fusiano and Dr. R. Bassini for their careful reading of the manuscript.

References

[1] X. Alarja et al., Nucl. Instr. and Meth. A 242 (1986) 352.
[2] P. Boccaccio et al., Nucl. Instr. and Meth. A 281 (1989) 197.
[3] C.E. Chanel et al., Nucl. Instr. and Meth. 145 (1976) 253.
[4] T. Masuda et al., Nucl. Instr. and Meth. A 322 (1992) 135.
[5] P. Kreutz et al., Nucl. Instr. and Meth. A 260 (1987) 120.
[6] R.E. Meijer et al., Nucl. Instr. and Meth. A 260 (1987) 253.
[7] W.G. Gong et al., Nucl. Instr. and Meth. A 268 (1988) 190.
[8] D. Drain et al., Nucl. Instr. and Meth. A 270 (1988) 614.
[9] J.C.C. Van Melle et al., Nucl. Instr. and Meth. A 277 (1989) 395.
[10] X. Rangel et al., Nucl. Instr. and Meth. A 220 (1987) 582.
[11] M. Moszynski et al., Nucl. Instr. and Meth. A 326 (1993) 582.
[12] S. Aiello et al., Nucl. Phys. A 583 (1995) 461c.
[13] U. Kilgus et al., Nucl. Instr. and Meth. A 297 (1990) 425.
[14] D. Guinet et al., Nucl. Instr. and Meth. A 239 (1984) 141.
[15] R.T. de Souza et al., Nucl. Instr. and Meth. A 295 (1990) 109.
[16] G. Viesti et al., Nucl. Instr. and Meth. A 252 (1986) 75.
[17] A.R. Quinton et al., Phys. Rev. 115 (1959) 886.
[18] D. Horn et al., Nucl. Instr. and Meth. A 320 (1992) 273.
[19] E.J.W. Tweddell et al., Nucl. Instr. and Meth. B 51 (1990) 58.
[20] J.D. Valentine et al., Nucl. Instr. and Meth. A 325 (1993) 147.