Dependence of the Energy Resolution of a Scintillating Crystal on the Read-Out Integration Time

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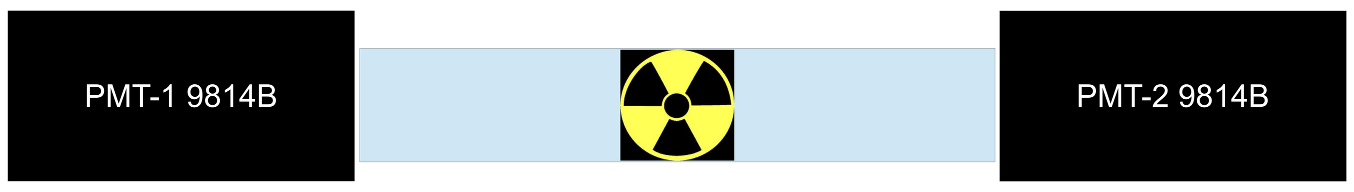
Abstract

When using detectors made of crystals and photo-detectors in high rate applications it is not always possible to integrate the whole signal. This is the case when the decay time of the scintillator is too long compared to the maximum permitted integration time to avoid the pile-up due to low energy particle background. An experimental test with a BGO crystal, readout by a photomultiplier and a Monte Carlo simulation demonstrates that, when the number of photoelectrons is large, the energy resolution obtained by a peak-sensitive acquisition scales as $1/\sqrt{N_{int}}$, where N_{int} is the average number of emitted photoelectrons which contribute to the formation of the integrated signal up to its maximum.

We also show that when the integration constant and N_{int} are small, the energy resolution is even better than the one expected by the Poisson fluctuations. Our measurements show that BGO is an attractive possibility for equipping calorimeters also in very high rate experiments and can be considered as an option for the forward calorimeter of the SuperB experiment. In this case the integration time should be as small as 100 ns (one third of the scintillation decay time) resulting in an important reduction of the signal pile-up and in a loss of energy resolution absolutely tolerable.

Experimental Set-Up

Photons with an energy of 662 keV from a ^{137}Cs radioactive source are detected by a 2 × 2 × 18 cm³ BGO crystal



The BGO crystal is read at both ends by two EMI-9814B PMTs. One of the two photomultipliers (PMT-1) is used to trigger the oscilloscope which records the pulses from the other (PMT-2)

In order to get rid of the noise, the trigger-signal from PMT-1 was amplified and shaped with an Ortec-444 having an integration time of 250 ns.

The signal from PMT-2 was processed by an Ortec-474 module that has a variable gain and an integration time (τ_{int}) that can be set to five different values.

Ortec-444

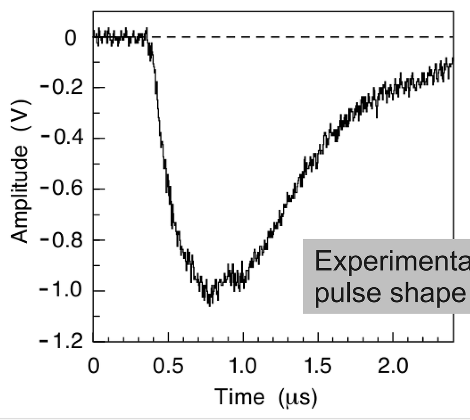
Ortec-474

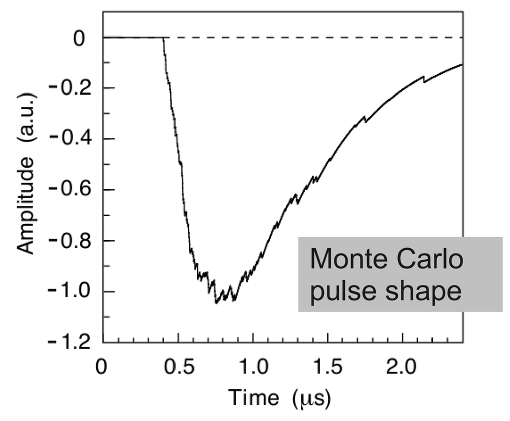
A Lecroy WavePro 7300A digital oscilloscope, having a bandwidth of 300 MHz and a sampling rate of 250 MS/s was used to record the signal waveforms.

Monte Carlo Simulation

To take into account the statistical fluctuations due to the discrete feature of the input current a MC simulation is needed. The input current I(t) is described as a series of delta functions, each one corresponding to an incoming photo-electron.

The amplitude at a time t of an integrated pulse turns out to be the sum of the contribution from each photo-electron emitted before that time:

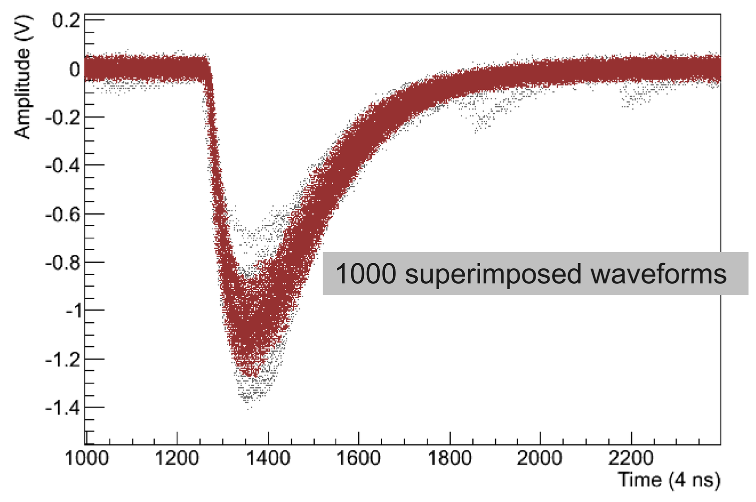


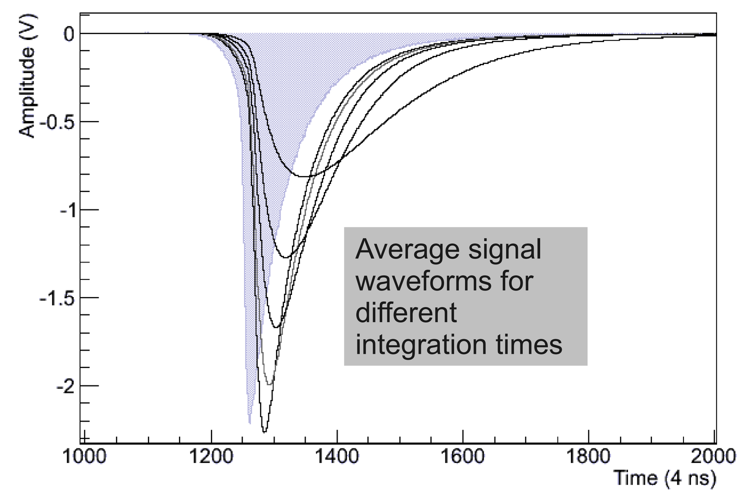


$$V(t) = G\,R_{in}\left(\frac{q}{\tau_{int}}\right)\sum_{i=1}^{n(t)} g_i\, e^{-(t-t_i)/\tau_{int}}$$

Signal Waveforms

For each of the five values of the integration time (τ_{int} =20, 50, 100, 200 and 500 ns) 15,000 waveforms are acquired, sampled every 4 ns for a total of 10 µs.



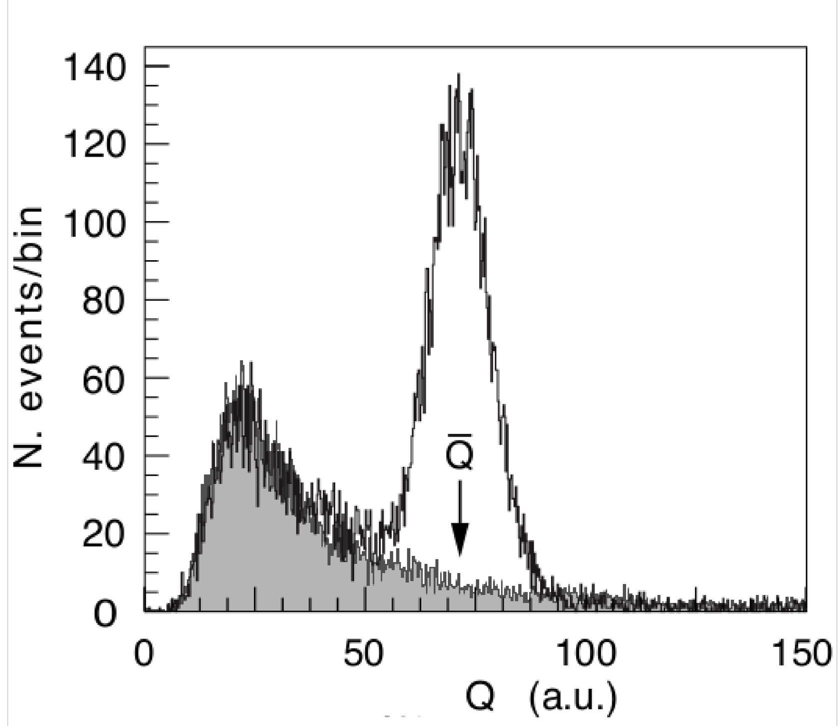


Q: The Total Charge

An off-line analysis allows to determine the total charge Q from the integral of the signal. Its fluctuations are mainly determined by the statistical fluctuations of the total number (Npe) of the photoelectrons and by the PM gain fluctuations which are due in large part to the fluctuations of the gain (g) of the first dynode according to the formula:

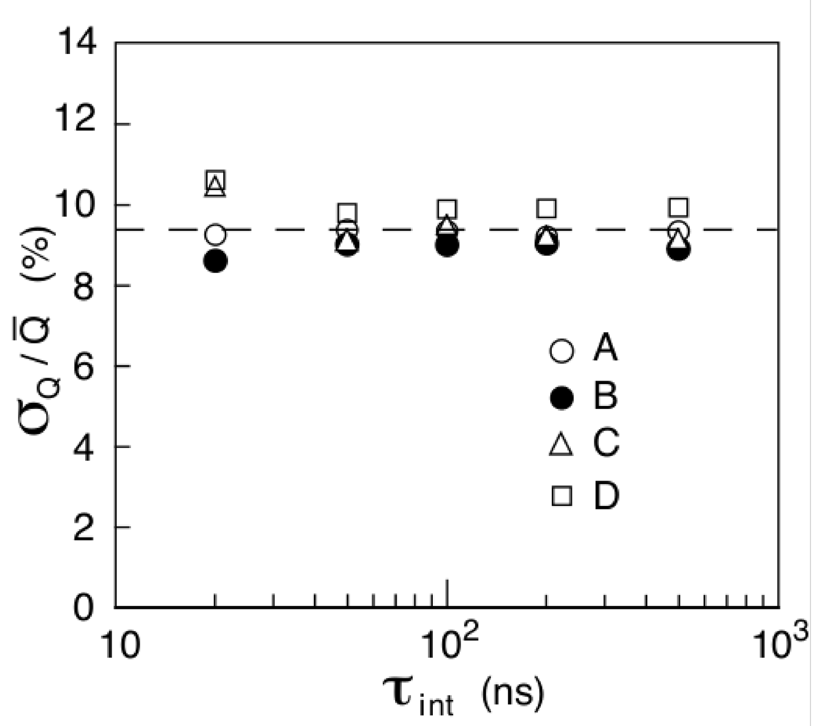
$$\frac{\sigma_E}{E} = \frac{\sigma_Q}{Q} = \frac{1}{\sqrt{N_{pe}}}\sqrt{\frac{1+\bar{g}}{\bar{g}}}$$

Spectrum of the total pulse charge



The peak from 662 keV photons is superimposed to a background (grey area) which was measured without the ^{137}Cs source.

Relative Q resolution as a function of τ_{int}



The dashed line represents the behavior expected from the MC for 130 photo-electrons.

A: The Signal Amplitude

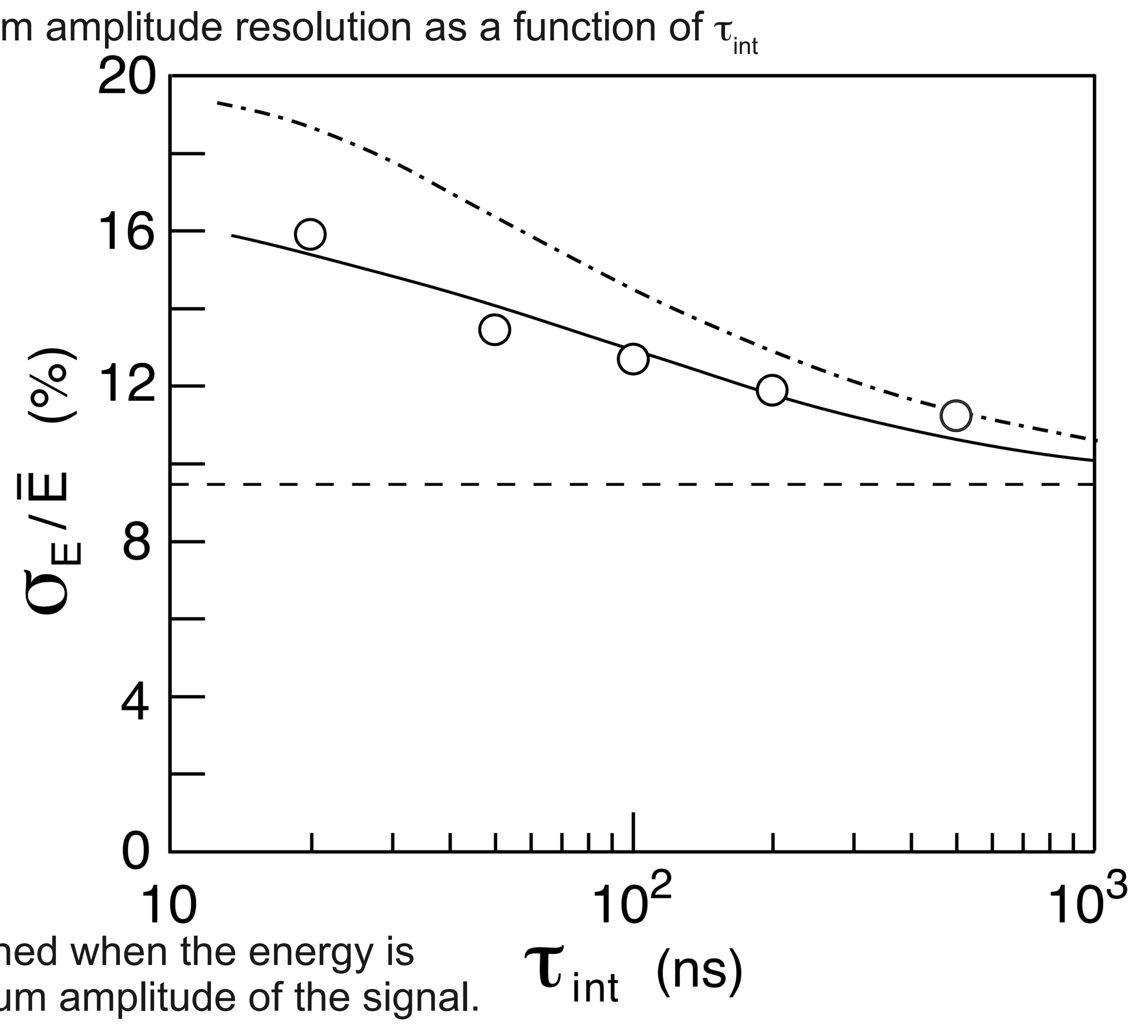
In high-rate experiment the measure of the total charge Q takes too long, so the energy deposited in the crystal is often inferred from the maximum amplitude A of the signal integrated with a time constant $\tau_{int} \leq \tau_{BGO}$.
This procedure, leads to a faster response at the cost of a worse resolution.
To determine how this effect depends on τ_{int}, the average values and the widths of the maximum amplitude distributions were evaluated by means of a gaussian fit.

Maximum amplitude resolution as a function of τ_{int}

The curve is the prediction of the MC calculation for 130 photo-electrons.

The dashed line is the asymptotic limit of the curve for $\tau_{int} >> \tau_{BGO}$.

The dashed-dotted line represents the behavior of the statistical fluctuations of the number of the photo-electrons integrated before the maximum amplitude.



A better resolution is obtained when the energy is evaluated from the maximum amplitude of the signal.

Conclusion

The possibility of using a scintillating crystal with a slow decay time (like BGO) for an electromagnetic calorimeter in a high-rate experiment was investigated. In these experimental conditions a fast measurement of the energy deposited in the crystal is needed. This can be obtained, at the cost of a lower energy resolution, by integrating the output signal of the photomultiplier over a time shorter than the scintillator decay time and by acquiring the peak amplitude of the integrated signal.
Our studies show that the energy resolution obtained with this method is of the order of the statistical fluctuations of the number of photoelectrons integrated before the peak and even better when this number is relatively small as in the present case.